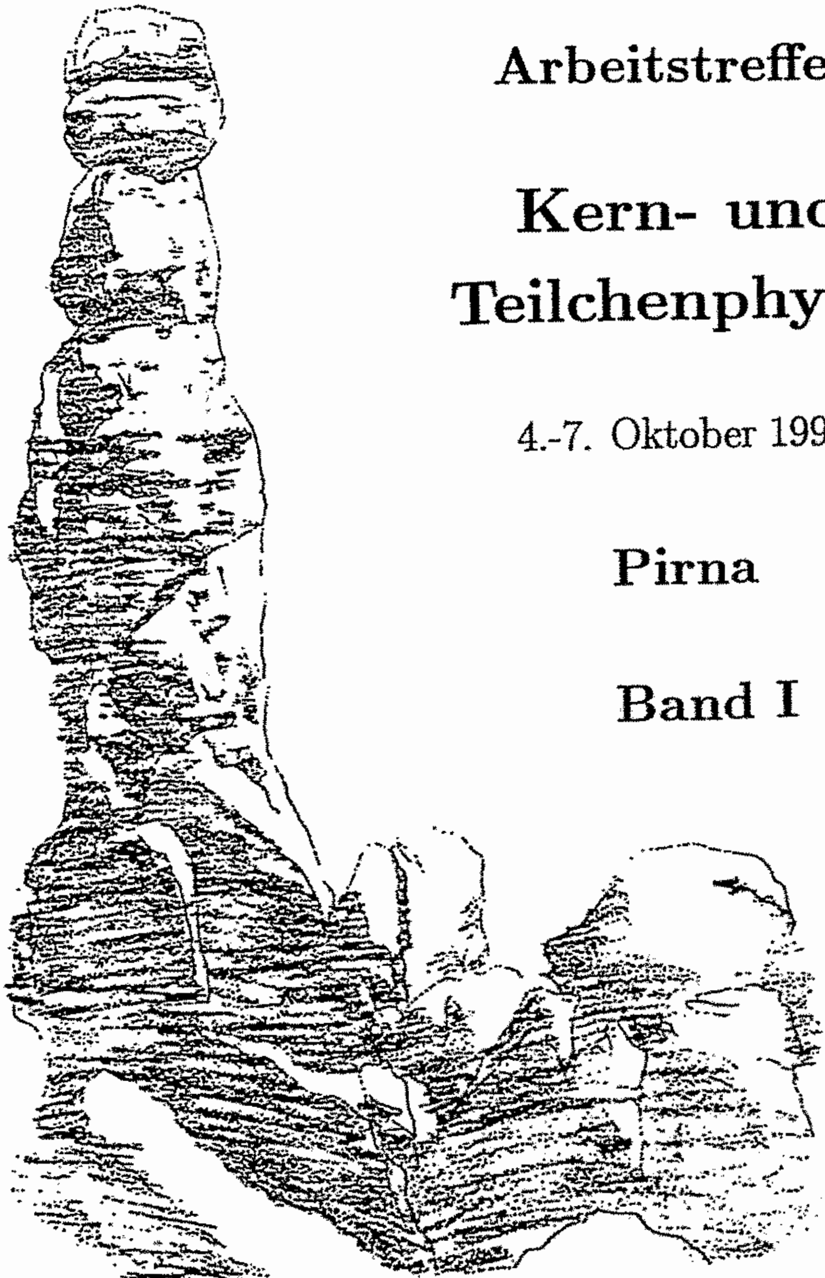
FORSCHUNGSZENTRUM
ROSSENDORF e.V.

FZR

FZR-63
November 1994



Arbeitstreffen

Kern- und Teilchenphysik

4.-7. Oktober 1994

Pirna

Band I

" Barbarine " - Elbsandsteingebirge

Forschungszentrum Rossendorf e.V.
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Tannen-Säle

Finanzielle Unterstützung für das Arbeitstreffen
"Kern- und Teilchenphysik 1994"
Pirna, 4.-7.10.1994, haben geleistet:

Bundesministerium für Forschung und Technologie, Bonn

Sächsisches Staatsministerium für Wissenschaft und Kunst, Dresden

Forschungszentrum Rossendorf e.V.

und folgende Firmen:

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MÜNCHEN

G.E. Körner

Arbeitstreffen "Kern- und Teilchenphysik 1994"
PIRNA (Tannensäle), 4.-7.10. 1994

Zeitplan

DIENSTAG	MITTWOCH	DONNERSTAG	FREITAG
8:30 Begrüßung	8:30 E.Offermann	8:30 G.Mallot	8:30 E.Grosse
8:45 W.Weise	9:10 R.Beck	9:10 A.Brüll	9:10 K.Kilian
9:25 B.Schoch	9:50 H.Schmieden	9:50 P.Blüm	9:50 J.Kleinfeller
10:05 W.Schwille	10:30 Pause	10:15 C.Strassburger	10:30 Pause
10:45 Pause	11:00 H.Schmitt	10:40 Pause	11:00 H.D.Gräf
11:15 W.Meyer	11:40 S. Paul	11:10 M.Faessler	11:40 P.v Neumann-Cosel
11:55 H.Clement	12:20 Mittagspause	11:35 U.Wiedner	12:20 Mittagspause
12:45 Mittagspause		12:00 K.Beuchert	
		12:25 Mittagspause	
14:30 THEORIE-WORKSHOP (1. Teil)	13:30 Vortrag über d. WISMUTproblematik	14:30 DETEKTOREN UND DATENERFASSUNG (1.Teil)	14:30 EXPERIMENTE AN e-BESCHLEUNIGERN
16:00 Pause	15:00 Exkursion (WISMUT/ Sächsische Schweiz)	16:00 Pause	16:00 Pause
16:30 THEORIE-WORKSHOP (2.Teil)		16:30 DETEKTOREN... (2.Teil)	16:30 CERN/LEAR-AKTIVITÄTEN
18:00 PHYSIK AN MESONENFABRIKEN	18:00 Gemeinsames Abendessen	17:15 NEUE PROJEKTE	18:00 Ende

Programm des Arbeitstreffens "Kern- und Teilchenphysik 1994" in Pirna

Band I Dienstag, 4. Oktober 1994

Band II Mittwoch, 5. Oktober 1994

Band III Donnerstag, 6. Oktober 1994

Band IV Freitag, 7. Oktober 1994

Entwicklungen in der Theorie der Hadronen
– Aspekte der Niederenergie-QCD –

W. Weise
Regensburg

4.Oktober 1994

W. Weise

Pirna '94

ENTWICKLUNGEN
in der

THEORIE der HADRONEN

— ASPEKTE der NIEDERENERGIE-QCD —

1. CHIRALE STÖRUNGSTHEORIE

- Überblick
- Anwendungen (Physik bei MAMI, ELSA, PSI) ...

2. KONSTITUENTEN-QUARKS als QUASI-TEILCHEN

- Konzepte
- Spin- und Flavourstruktur
- Anwendungen (Bsp.: Strukturfunktionen)

3. HADRONEN in MATERIE (ρ, T)

- Kondensate und Massen
- Chirale Thermodynamik
  (incl. Gitter-QCD)
- Perspektiven (Physik bei GSI-SIS, CERN, ...)

INTRODUCTORY REMARKS:

● Experiments determine:

$$\langle H'(p')\,|\,J^a(x)\,|\,H(p)\rangle$$

(FORM FACTORS; exclusive measurements)

$$\langle H(p)\,|\,J^a(x)\,J^b(y)\,|\,H(p)\rangle$$

(CURRENT-CURRENT CORRELATION fcts.; inclusive measurements)

here: $|H\rangle$: composite hadrons (incl. nuclei)
(also: $|0\rangle$ "vacuum")

● BASIC CURRENTS subject to observation:
⇨ QUARK FLAVOUR CURRENTS

$$J^a(x) = \bar{q}(x)\,\Gamma^a\,q(x)$$

$$\Gamma^a : \begin{cases} \text{DIRAC structure } 1, \gamma_\mu, \gamma_\mu\gamma_5, \dots \\ \text{FLAVOUR structure } 1, \lambda^a \end{cases}$$

flavour singlet

SU(3) flavour matrices

1.

CHIRALE DYNAMIK
und
CHIRALE STÖRUNGSTHEORIE

QCD and CHIRAL SYMMETRY

- LAGRANGIAN:

$$\mathcal{L}_{QCD} = \mathcal{L}^{(0)}_{QCD} - \underbrace{\bar{q}\, m\, q}_{\text{QUARK MASS TERM}}$$

$$q = \begin{pmatrix} u \\ d \\ s \\ c \\ b \\ t \end{pmatrix}$$

LIGHT: $m \to 0$: CHIRAL SYMMETRY

HEAVY: $m \to \infty$: Heavy Fermion Effective Theory

- Light Quarks: $N_f = 3$ massless quarks as starting point!

$q_L = \frac{1}{2}(1-\gamma_5)q$ $\quad \overset{\vec{S}}{\Longleftarrow}\!\!\Longrightarrow \vec{p}$ LEFT-handed

$q_R = \frac{1}{2}(1+\gamma_5)q$ $\quad \overset{\vec{S}}{\Longrightarrow}\!\!\Longrightarrow \vec{p}$ RIGHT-handed

- $\mathcal{L}^{(0)}_{QCD}$ invariant under:

$$q_{L,R} \Rightarrow \exp\left[i\,\theta^a_{L,R} \frac{\lambda^a}{2}\right] q_{L,R}$$

CHIRAL $SU(3)_L \otimes SU(3)_R$

- CONSERVED CURRENTS: $V^a_\mu = \bar{q}\gamma_\mu \frac{\lambda^a}{2} q$; $A^a_\mu = \bar{q}\gamma_\mu\gamma_5 \frac{\lambda^a}{2} q$

EXPLICIT CHIRAL SYMMETRY BREAKING

$$\Delta \mathcal{L}_{mass} = - m_u \bar{u}u - m_d \bar{d}d - m_s \bar{s}s$$

- SCALAR $\bar{q}q = \bar{q}_L q_R + \bar{q}_R q_L$

  breaks CHIRAL SYMMETRY

- CURRENT QUARK MASSES:

$$\boxed{\begin{aligned} m_u &= (\mathbf{5} \pm 2)\ MeV \\ m_d &= (\mathbf{9} \pm 3)\ MeV \\ m_s &= (\mathbf{175} \pm 55)\ MeV \end{aligned}}$$

(at renormalization scale $\Lambda \sim 1$ GeV)
(Gasser, Leutwyler)

- note:

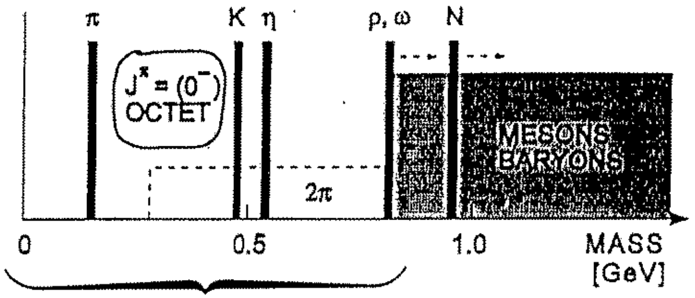
  $m_{u,d} \ll M_N \sim 1 GeV$

  $m_s < M_N$

  (typical hadronic mass scale)

→ CHIRAL PERTURBATION THEORY

HADRON SPECTRUM
(schematic)



GAP

$$\Delta \sim 1 GeV \quad (\sim 2 M_{CONSTITUENT})$$

⇨ NO parity doublets

(no degenerate states with $J^\pi = 0^\pm,\ 1/2^\pm,\ 1^\pm$ etc.)

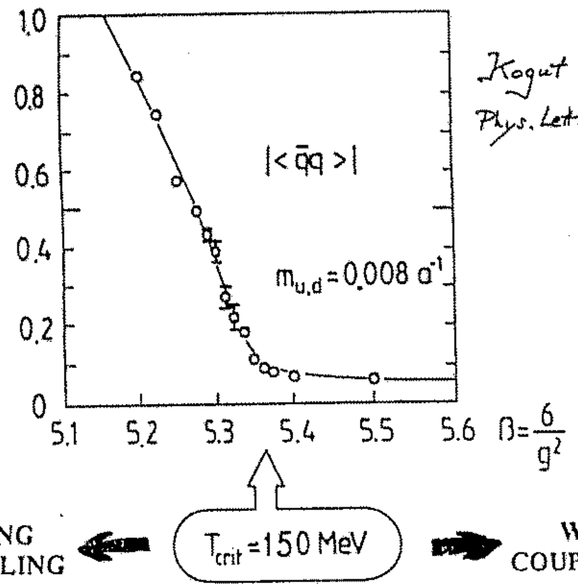
⇨ CHIRAL SYMMETRY
realized in (spontaneously broken)
NAMBU - GOLDSTONE mode

(rather than "unbroken" WIGNER - WEYL mode)

CHIRAL CONDENSATE

QCD on the LATTICE:

- **Spontaneous Chiral Symmetry Breaking**



Kogut et al., Phys. Lett. B263 ('91) 101

- "EMPIRICAL" VALUE (at T=0):

$$\langle\bar{u}u\rangle \simeq \langle\bar{d}d\rangle = -(230 \pm 25\ \mathrm{MeV})^3 \simeq -1.6\ \mathrm{fm}^{-3}$$

RECALL: $\rho_N = \langle N^+N\rangle_{\text{nuclear matter}} = 0.17\ \mathrm{fm}^{-3}$

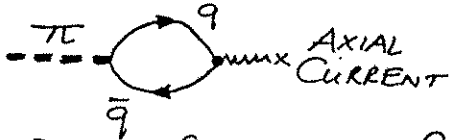
SPONTANEOUS SU(3)$_L$ ⊗ SU(3)$_R$ SYMMETRY BREAKING

⇨ OCTET OF PSEUDOSCALAR ($J^\pi=0^-$) GOLDSTONE BOSONS

e.g. **PIONS**:

$$m_\pi^2 f_\pi^2 = -\frac{1}{2}(m_u+m_d)\langle\bar{u}u+\bar{d}d\rangle + \mathcal{O}(m_\pi^4)$$

(Gell-Mann, Oakes, Renner)



- PION DECAY CONSTANT $f_\pi = 93.3$ MeV

KAONS:

$$m_K^2 f_K^2 = -\frac{1}{2}(m_u+m_s)\langle\bar{u}u+\bar{s}s\rangle + \mathcal{O}(m_K^4)$$

CHIRAL EFFECTIVE LAGRANGIAN

- **Low Energy Approximation to QCD with $N_f = 3$ Quark Flavours**

  CHIRAL $SU(3)_L \otimes SU(3)_R$ spontaneously broken down to $SU(3)_V$ ("eightfold way")

- **Pseudoscalar Goldstone Boson fields** $\phi_a(x)$ $(a = 1, \dots, 8)$ **as collective variables**

$$\lambda^a \phi_a = \sqrt{2} \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & K^0 \\ K^- & \overline{K}^0 & -\frac{2\eta_8}{\sqrt{6}} \end{pmatrix}$$

- **Chiral Fields:**

$$\mathbf{U}(x) \equiv u^2(x) = \exp\left[i \lambda^a \phi_a / f\right]$$

$$\mathbf{U}^+\mathbf{U} = 1, \quad \det \mathbf{U} = 1$$

- **Chiral Transformations:**

$$\mathbf{L} \in SU(3)_L, \quad \mathbf{R} \in SU(3)_R$$

$$\mathbf{U} \to \mathbf{R}\mathbf{U}\mathbf{L}^+$$

- **Construct Effective Lagrangian**

$$\mathcal{L}_{eff}(\mathbf{U}, \partial_\mu \mathbf{U})$$

organize low - energy, low - momentum limit as power series in $\partial_\mu U$

... leading term:

NON-LINEAR SIGMA MODEL

- $$\mathcal{L}_{eff} = \frac{f^2}{4} \operatorname{tr} \partial_\mu \mathbf{U} \partial^\mu \mathbf{U}^+ + \frac{f^2}{2} b \operatorname{tr} \mathcal{M} (\mathbf{U} + \mathbf{U}^+)$$

  Symmetry breaking mass term:

$$\mathcal{M} = \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_d & 0 \\ 0 & 0 & m_s \end{pmatrix}$$

- LOW ENERGY QCD (in the absence of baryons:)

  ➡ WEAKLY interacting GOLDSTONE BOSONS

  ➡ PREDICTIONS for $\pi\pi$, πK, ... scattering (Weinberg, Gasser & Leutwyler)

4th ORDER TERMS :

$$
\begin{aligned}
\mathcal{L}_4 = \; & L_1\, \mathrm{tr}\,(D_\mu U D^\mu U^+)^2 + L_2\, \mathrm{tr}\,(D_\mu U D_\nu U^+)\, \mathrm{tr}\,(D^\mu U D^\nu U^+) \\
+ \; & L_3\, \mathrm{tr}\,(D_\mu U D^\mu U^+ D_\nu U D^\nu U^+) \\
+ \; & L_4\, \mathrm{tr}\,(D_\mu U D^\mu U^+)\, \mathrm{tr}\,(\chi U^+ + \chi^+ U^+) \\
+ \; & L_5\, \mathrm{tr}\,[D_\mu U D^\mu U^+ (\chi U + \chi^+ U^+)] \\
+ \; & L_6\, [\mathrm{tr}\,(\chi U^+ + \chi^+ U^+)]^2 + L_7\, [\mathrm{tr}\,(\chi U^+ - \chi^+ U^+)]^2 \\
+ \; & L_8\, \mathrm{tr}\,(\chi^+ U \chi^+ U + \chi U^+ \chi U^+) \\
+ \; & L_9\, [\mathrm{tr}\,(-i F^R_{\mu\nu} D^\mu U D^\nu U^+) + \mathrm{tr}\,(-i F^L_{\mu\nu} D^\mu U^+ D^\nu U)] \\
+ \; & L_{10}\, \mathrm{tr}\,(U^+ F^R_{\mu\nu} U F_L^{\mu\nu});
\end{aligned}
$$

$(F_{\mu\nu} = \partial_\mu F_\nu - \partial_\nu F_\mu - i[F_\mu, F_\nu],\;\; F_\mu^{R,L} = v_\mu \pm a_\mu)$

Coefficient L_i^{ren} ($\mu = m_\eta$)	Value $[10^{-3}]$	Source	NJL model *)
L_1	0.65 ± 0.28	ππ Scatt.	0.96
L_2	1.89 ± 0.26	K_{l4}	1.95
L_3	-3.06 ± 0.92	decay	-5.21
L_4	~ 0		0
L_5	2.3 ± 0.2	F_K / F_π	1.23
L_6	~ 0		0
L_7 ☆)	-0.4 ± 0.2	meson masses	-0.40
L_8 ☆)	0.9 ± 0.3		0.62
$2L_7 + L_8$	0.4 ± 0.1		
L_9	7.1 ± 0.3	rare pion decays	6.27
L_{10}	-5.6 ± 0.3	$(\pi \to e\nu\gamma)$	-5.42

from: Donoghue, Golowich, Holstein
"Dynamics of the Standard Model"
Cambridge Univ. Press (1992)

see also: ☆) Gasser, Leutwyler: Nucl. Phys. B250 (1985) 465
*) Ruiz - Arriola, PL B253 (1991) 430

CHIRAL LAGRANGIAN
with inclusion of
BARYONS

$$
\mathcal{B} = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -\frac{2\Lambda}{\sqrt{6}} \end{pmatrix}
$$

$SU(3)_F$
OCTET

$$D_\mu \mathcal{B} = \partial_\mu \mathcal{B} + [\Gamma_\mu, \mathcal{B}]$$

external fields
(vector & axial)

$$\Gamma_\mu = \frac{1}{2}\left\{u^+[\partial_\mu - i(v_\mu + a_\mu)]u + u[\partial_\mu - i(v_\mu - a_\mu)]u^+\right\}$$

$$U = u^2 = \exp[i\lambda^a \phi_a / f]$$

$$\mathcal{L}_{eff} = \mathcal{L}_{MESONS}(U, \partial_\mu U) + \mathcal{L}_{MESON-BARYON}$$

$$\mathcal{L}_{MESON-BARYON} = tr\left[i\bar{\mathcal{B}}\gamma_\mu D^\mu \mathcal{B} - M^{(0)}\bar{\mathcal{B}}\mathcal{B} + \frac{D}{2}\bar{\mathcal{B}}\gamma_\mu\{u^\mu, \mathcal{B}\} + \frac{F}{2}\bar{\mathcal{B}}\gamma_\mu\gamma_5[u^\mu, \mathcal{B}]\right]$$

$$u^\mu = i(u^+ D^\mu u - u D^\mu u^+)$$

- Constraints : $D + F = g_A = 1.26$ (β-decay)
  $D/_{D+F} \simeq 0.6$ (hyperon decays)

⇨ example :

ELECTRO MAGNETIC INTERACTIONS of πN SYSTEMS

$$\mathcal{L}_{\pi N\gamma} = \bar{N}\left[i\gamma_\mu \mathcal{D}^\mu - M + \frac{g_A}{2}\gamma_\mu\gamma_5 u^\mu\right]N$$

$$\mathcal{D}^\mu = \partial^\mu - ie\underset{\gamma NN}{\mathbf{A}^\mu} + \underset{\text{TOMOZAWA - WEINBERG}}{\frac{1}{f_\pi^2}[\pi, \partial^\mu \pi]} + \dots$$

$$u^\mu = -\frac{1}{f_\pi}\partial^\mu \pi + \underset{\text{KROLL - RUDERMAN}}{\frac{ie}{f_\pi}[\mathbf{A}^\mu, \pi]} + \dots$$

$$\left(\pi \equiv \vec{\tau}\cdot\vec{\pi} \; ; \; A^\mu \equiv \tfrac{1}{2}(1+\tau_3)\mathcal{A}^\mu\right)$$

➡ recent applications:

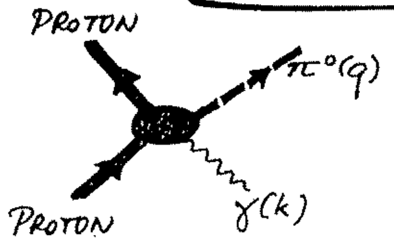
NUCLEON E.M. POLARIZABILITIES

π° ELECTRO & PHOTOPRODUCTION

(Bernard, Kaiser, Meißner)

➡ PROBLEM: inclusion of Δ(1232)

example : π° – PHOTOPRODUCTION at THRESHOLD



$$\left.\frac{d\sigma}{d\Omega}\right|_{\vec{q}\to 0} = \frac{|\vec{q}|}{|\vec{k}|}\,|E_{0+}|^2$$

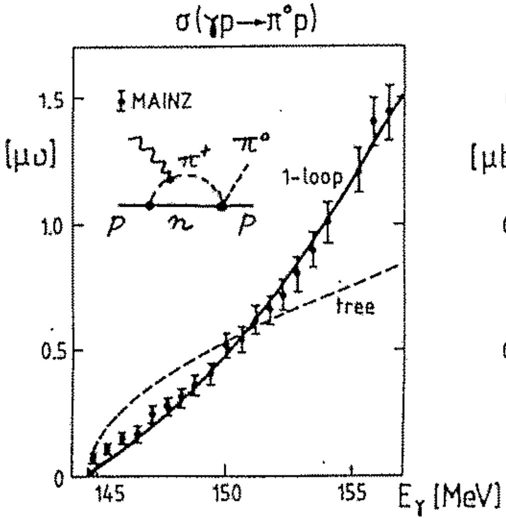
S-WAVE PRODUCTION

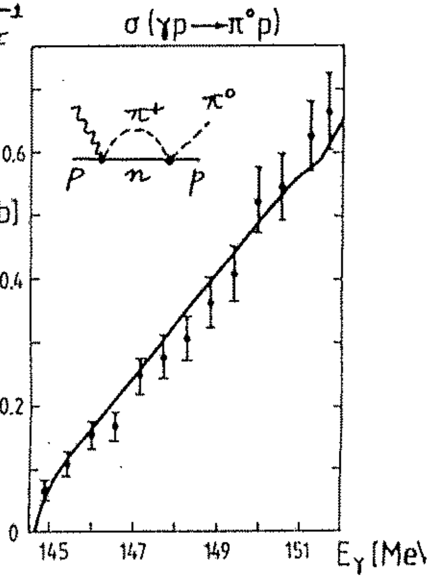
$$E_{0+} = \frac{e g_A}{8\pi f_\pi}\left[-\mu + \left(\frac{3+\kappa_p}{2} + \frac{M_N^2}{16 f_\pi^2}\right)\mu^2 + \mathcal{O}(\mu^3)\right]$$

$$= (\underset{\mu}{-3.5} \underset{\mu^2}{+4.4} \underset{\mu^3\,(\text{prel.})}{-(2.4)}) \cdot 10^{-3} m_\pi^{-1} \qquad \left(\mu = \frac{m_\pi}{M_N}\right)$$

● SLOW CONVERGENCE !

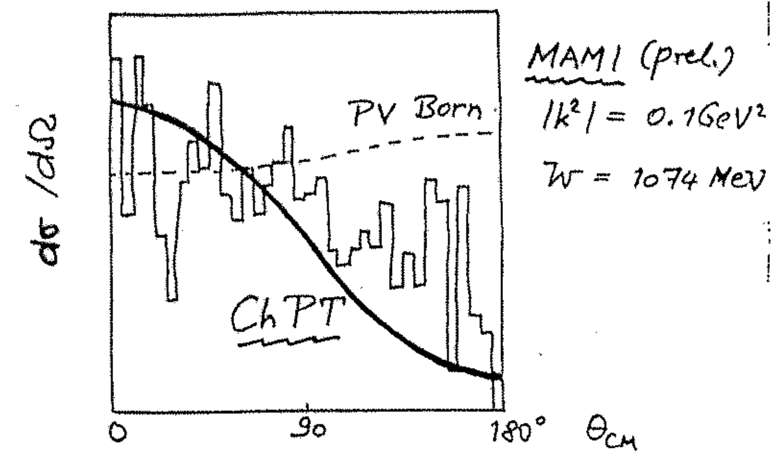
$$E_{0+}(\text{exp.}) = (-2.0 \pm 0.2)\cdot 10^{-3} m_\pi^{-1}$$





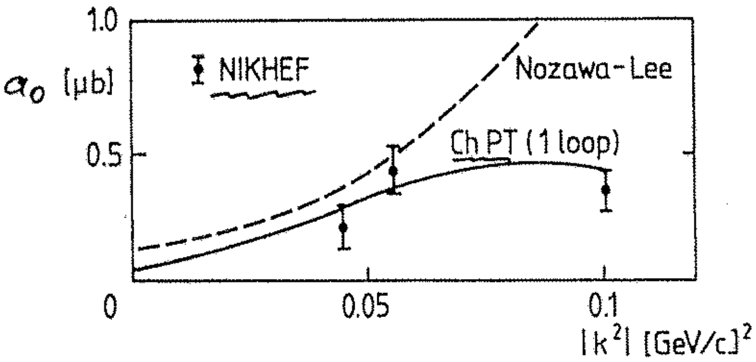
V. Bernard, N. Kaiser, U.-G. Meißner

π° ELECTROPRODUCTION $ep \to e'p\pi^0$

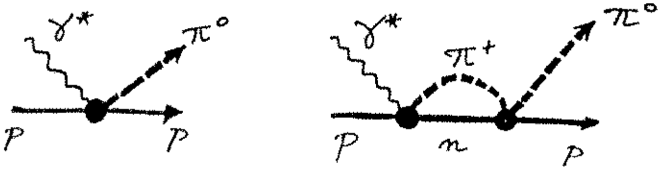


MAMI (prel.)
$|k^2| = 0.1\,GeV^2$
$W = 1074$ MeV

S-WAVE CROSS SECTION



Bernard, Kaiser, Lee, Meißner,
PRL 70 (1993) 387



KN SCATTERING LENGTH (in fm) from CHIRAL PERTURBATION THEORY

(Lee, Jung, Min, Rho; Phys. Lett. B (1994))

	σ(Q) WEINBERG -TOMOZAWA	σ(Q²)	σ(Q³)	Λ (1405)	empirical Re a
a_{K^-p}	+ 0.59	0.32	– 0.14	– 1.43	– 0.67
a_{K^-n}	+ 0.29	0.28	– 0.20	–	0.37
a_{K^+p}	– 0.59	0.32	– 0.11	0.08	– 0.33
a_{K^+n}	– 0.29	0.28	– 0.18	–	– 0.18

$$\frac{C}{4\pi(1+\frac{m_K}{M})}\;\frac{m_K}{f_K^2}$$

$$C = \begin{cases} \pm 1 \;\ldots\; K^\pm p \\ \pm\frac{1}{2} \;\ldots\; K^\pm n \end{cases}$$

$f_K = 90$ MeV

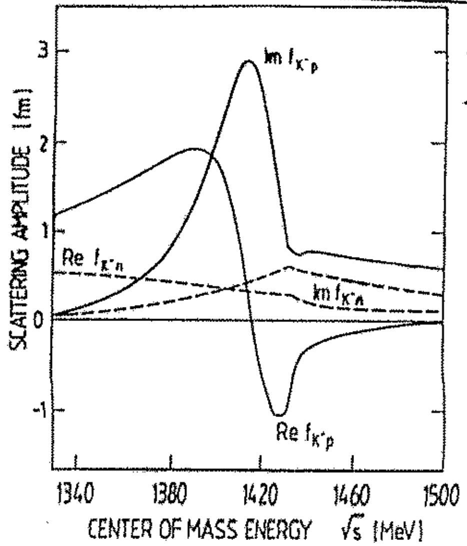
Σ_{KN}-term plus corrections

NOTE:

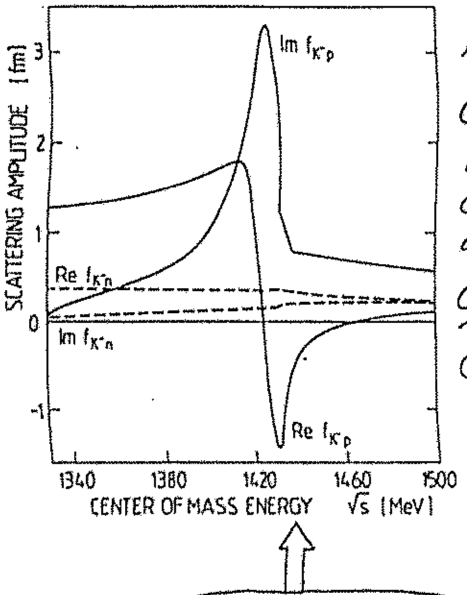
dominance of **Λ** (1405) in **K^-p** channel

Λ(1405)

K⁻N SCATTERING AMPLITUDES and extrapolation below threshold



A. D. Martin
NP B (1981)
empirical
K-matrix
analysis



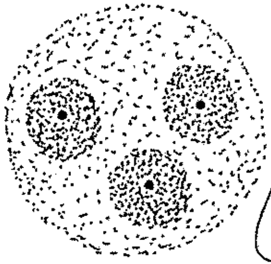
K^-p THRESHOLD

A. Steiner, W.W.
Coupled Channels
K-matrix
calculation
using
Chiral input
(ATTRACTION
from
TOMOZAWA-
WEINBERG
term)

2. KONSTITUENTEN-QUARKS als QUASI-TEILCHEN

Hinweise: ⇨ magnetische Momente: $\vec{\mu}_q = \frac{e}{2M_q}\vec{\sigma}_q$

⇨ RADIEN aus $d\sigma/dt$
(Povh, Hüfner, PL B245 ('90) 653)

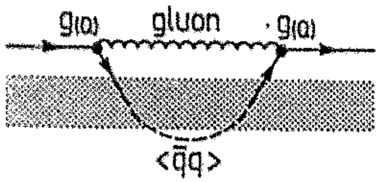


$$\langle r^2\rangle_q \simeq \frac{const}{M_q^2}$$
$$\langle r^2\rangle_{u,d} \simeq 0.36\ fm^2$$
$$\langle r^2\rangle_s \simeq 0.16\ fm^2$$

"KONSTITUENTEN-QUARKS" $\hat{=}$
VALENZ-QUARKS umgeben von Polarisationswolken aus $q\bar{q}$-PAAREN (MESONEN) und Gluonen

Running Quark Mass

... in the presence of a $\langle\bar{q}q\rangle$ condensate



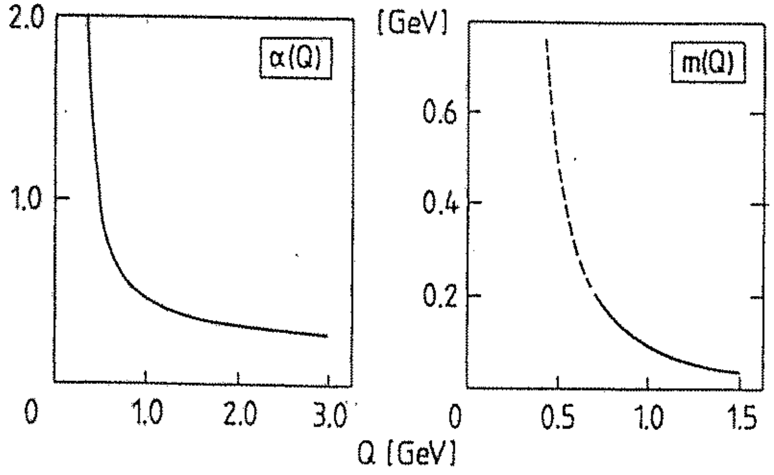
$$\left(\alpha = \frac{12}{33-2N_f} \right)$$

$$M(Q) = - \frac{g^2(Q)}{Q^2} \langle \bar{q}q \rangle \Big|_{Q_0} \left(\frac{g^2(Q^2)}{g^2(Q_0^2)} \right)^{-\alpha}$$

$$\alpha(Q) = \frac{g^2(Q)}{4\pi} = \frac{12\pi}{(33-2N_f)\ln(Q^2/\Lambda^2_{QCD})}$$

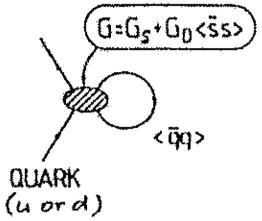
$$(\Lambda_{QCD} \simeq 0.23\,GeV \;,\; Q_0 \simeq 1\,GeV)$$

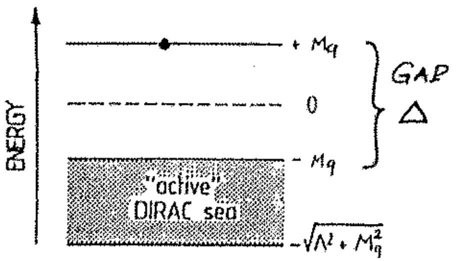
$$\langle \bar{q}q \rangle \Big|_{1GeV} \simeq -(0.25\,GeV)^3$$



... a SCHEMATIC MODEL : NAMBU & JONA-LASINIO

- **NJL:** *MEAN FIELD approx. (Hartree-Fock)*

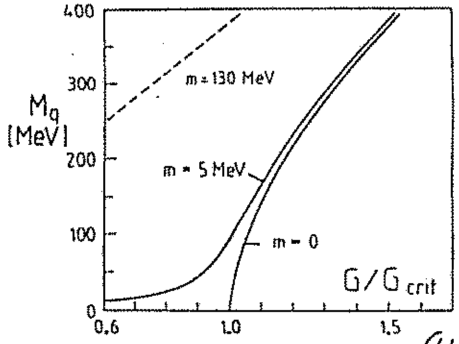


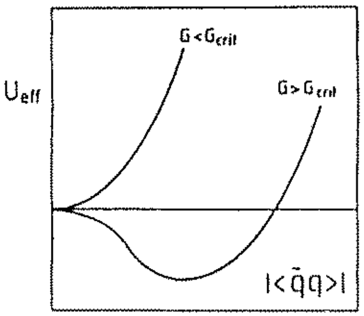


GAP eqn.:

$$\mathcal{M}_q = m - G \langle \bar{q}q \rangle$$

$$\langle \bar{q}q \rangle = -2N_c \int_{|\vec{p}| \le \Lambda} \frac{d^3p}{(2\pi)^3} \frac{\mathcal{M}_q}{\sqrt{\vec{p}^{\,2} + \mathcal{M}_q^2}}$$





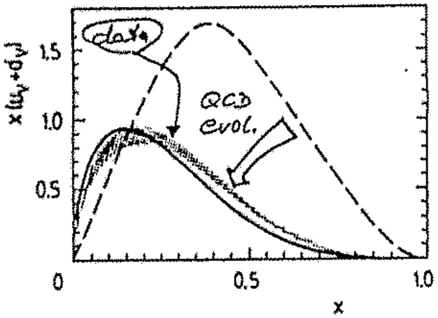
(U. Vogl, W.W., Prog. Part. N. Ph. 27 (91))

DYNAMICAL QUARK MASS GENERATION ⟺ SPONTANEOUS CHIRAL SYMMETRY BREAKING

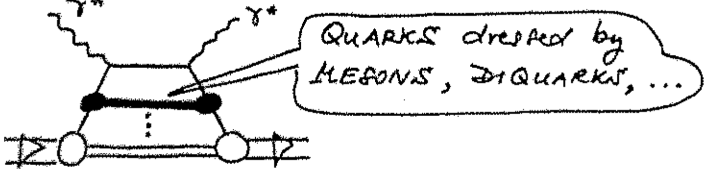
$$G = \frac{g^2}{\Lambda^2} \;,\; \Lambda \simeq 1\,GeV \;,\; \frac{g^2_{crit}}{4\pi} = \frac{\pi}{3} \sim 1$$

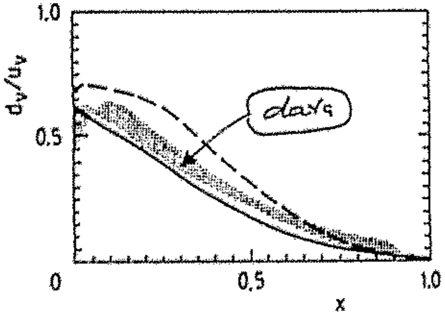
NUCLEON STRUCTURE FCTS. from RELATIVISTIC CONSTITUENT QUARKS

(W. Melnitchouk, W. W., PLB 334 ('94) 275)



VALENCE QUARK DISTRIBUTIONS (evolved to $Q^2 = 5\,GeV^2$)





RATIO of VALENCE d- and u-QUARK distributions

SPIN STRUCTURE OF THE NUCLEON

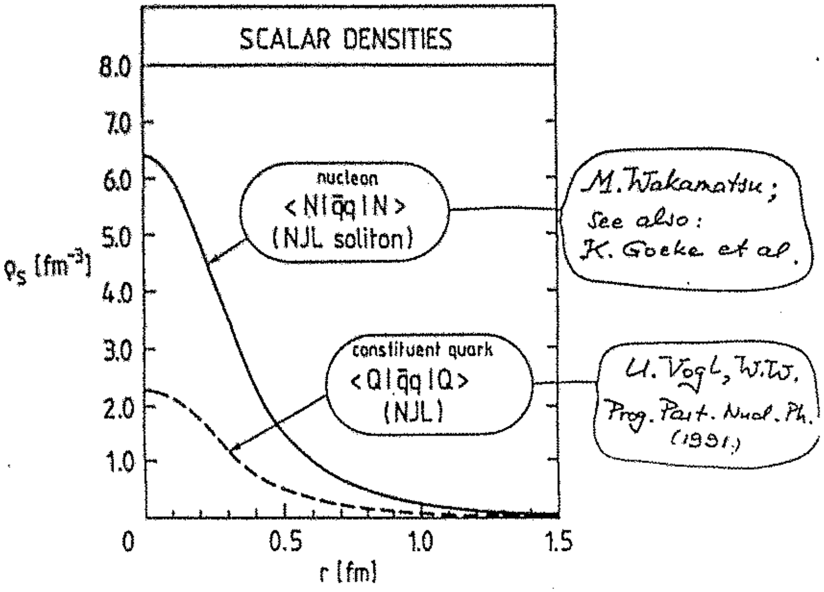
★ FACTS: $S_\mu \Delta q = \langle N | \bar{q} \gamma_\mu \gamma_5 q | N \rangle$

interpretation: $\Delta q = (q^\uparrow + \bar{q}^\uparrow)(x) - (q^\downarrow + \bar{q}^\downarrow)(x)$

AXIAL CONSTANTS:

	NAIVE Q.M.	EMPIRICAL
$\boxed{g_A \equiv g_A^{(3)} = \Delta u - \Delta d}$	5/3	1.26 (neutron β decay)
$\boxed{g_A^{(8)} = \Delta u + \Delta d - 2\Delta s}$	1	0.6 ± 0.1 (hyperon decays)
$\boxed{\Delta\Sigma \equiv g_A^{(0)} = \Delta u + \Delta d + \Delta s}$	1	$\boxed{0.30 \pm 0.11}$ (combined analysis of EMC, SMC, SLAC data)
$\boxed{\Delta s}$	0	$\boxed{-0.10 \pm 0.04}$

SCALAR DENSITIES
OF
CONSTITUENT QUARKS AND NUCLEONS:
SIGMA TERMS



M. Wakamatsu;
See also:
K. Goeke et al.

U. Vogl, W.W.
Prog. Part. Nucl. Ph.
(1991)

- πN SIGMA term:

$$\Sigma_N = \frac{1}{2}(m_u + m_d) \langle N | \bar{u}u + \bar{d}d | N \rangle$$

$$= \frac{1}{2}(m_u + m_d) \int d^3r \, \rho_S^N(r) = (45 \pm 8) \, \text{MeV}$$

(Gasser, Leutwyler, Sainio)

- note: $\boxed{\Sigma_N \simeq 3 * \Sigma_Q}$

⇨ LOW ENERGY (S-WAVE) πN Scattering in terms of π - QUARK scattering

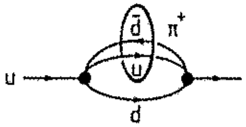
FLAVOUR STRUCTURE
OF CONSTITUENT QUARKS

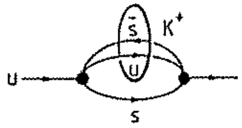
★ GOTTFRIED SUM:

$$S_G = \int_0^1 \frac{dx}{x} \left(F_2^p(x) - F_2^n(x) \right) \qquad \left(x = \frac{Q^2}{2M\nu} \right)$$

Charge symmetry, but not $\bar{u}(x) = \bar{d}(x)$:

$$S_G = \frac{1}{3} + \frac{2}{3} \int_0^1 dx \left[\bar{u}(x) - \bar{d}(x) \right]$$





★ NMC: $\boxed{S_G = 0.240 \pm 0.016}$ (at $Q^2 = 5 \, \text{GeV}^2$)

Constituent quarks dressed by pion cloud:

$$|N\rangle = \sqrt{Z} \, |QQQ\rangle + \sqrt{n_\pi} \, |QQQ\pi\rangle + \ldots$$

$$S_G = \frac{Z}{3} - \frac{n_\pi}{9} + \ldots$$

★ STRANGE QUARKS in the NUCLEON:

from analysis of πN Σ-term: $\frac{\langle P | \bar{s}s | P \rangle}{\langle P | \bar{u}u + \bar{d}d | P \rangle} = 0.1 \pm 0.1$

CONSTITUENT QUARKS dressed by $\bar{s}s$ CLOUD:

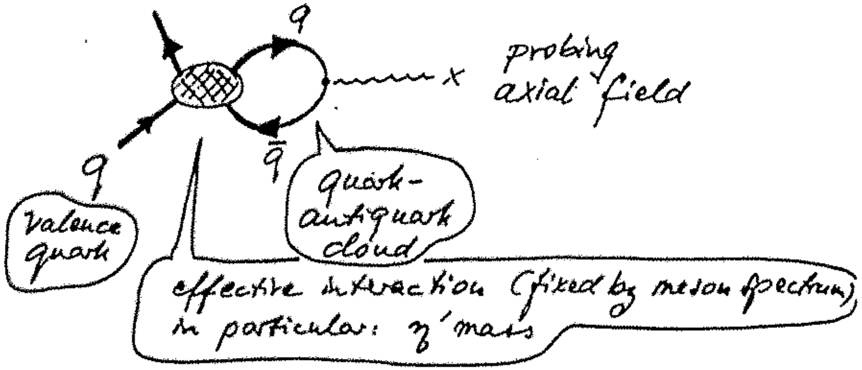
$\langle \bar{s}s \rangle_N / \langle \bar{u}u + \bar{d}d \rangle_N \lesssim 5\,\%$ (K. Steininger, W.W., PLB 329 ('94) 169)

$\langle N | \bar{s} \gamma_\mu s | N \rangle \sim -0.1$ (roughly)

SPIN STRUCTURE OF CONSTITUENT QUARKS

from CHIRAL (e.g. NJL) EFFECTIVE THEORIES

- ingredients:
  - ★ Spontaneously broken CHIRAL $SU(3)_L \otimes SU(3)_R$
  - ★ AXIAL ANOMALY in QCD: $\underbrace{U(1)_A \text{ breaking}}$ $\partial^\mu \underbrace{\mathbf{A}^{(0)}_\mu}_{\text{singlet axial current}} \sim \underbrace{\mathbf{E}\cdot\mathbf{B}}_{\text{gluons}}$



effective interaction (fixed by meson spectrum) in particular: η' mass

⇨ ANGULAR MOMENTUM :

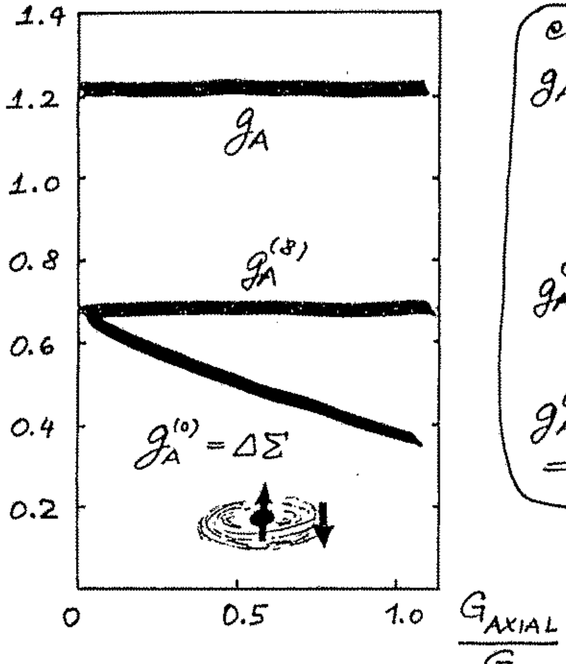
$$\vec{\mathbf{J}}\begin{pmatrix}\text{CONSTITUENT}\\ \text{QUARK}\end{pmatrix} = \vec{\mathbf{S}}\begin{pmatrix}\text{VALENCE}\\ \text{QUARK}\end{pmatrix} + \vec{\mathbf{j}}\begin{pmatrix}\text{POLARIZATION}\\ \text{CLOUD}\end{pmatrix}$$

RESULTS:

(K. Steininger, W.W., Phys. Rev. D48 (1993) 1433; H. Yabu, M. Takizawa, W.W., Z. Phys. A345 (1993) 193)

$$\left(g_A^{(i)}\right)_{\text{NUCLEON}} = \underbrace{\left(g_A^{(i)}\right)_{\substack{\text{CONST.}\\ \text{QUARK}}}}_{\text{constituent quark structure}} \cdot \underbrace{F_A^{(i)}}_{\text{relativ. nucleon wave fct.}}$$

AXIAL CONSTANTS



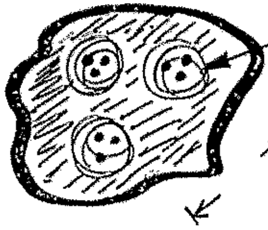
empirical:
$g_A = 1.26$
$g_A^{(8)} = 0.6 \pm 0.1$
$g_A^{(0)} \equiv \Delta\Sigma = 0.3 \pm 0.1$

rel. strength of axial singlet effective interaction

★ NOTE :
constraint from η-η' system: $\frac{G_{AXIAL}}{G} \lesssim 1$
$|\Theta(\eta-\eta')| \lesssim 20°$

3.

HADRONEN IN DICHTER/HEIßER MATERIE



$\langle r_N^2\rangle^{1/2} \sim 1\text{ fm}$

$$d = \begin{cases} 1.8\text{ fm} \;\dots\; \rho=\rho_0=0.17\text{ fm}^{-3} \\ <1.3\text{ fm} \;\dots\; \rho=3\rho_0 \end{cases}$$

⇨ KEINE "SAUBERE" TRENNUNG ZWISCHEN HADRONISCHEN SKALEN UND KERN-DIMENSIONEN

★ STICHWORTE:

- ÄNDERUNG des $\langle\bar{q}q\rangle$-KONDENSATS IN MATERIE
- ÄNDERUNG VON HADRON-EIGENSCHAFTEN (MASSEN etc.) MIT WACHSENDER DICHTE UND TEMPERATUR

(CHIRALE THERMODYNAMIK)

VACUUM STRUCTURE

- How does $\langle\bar{q}q\rangle$ condensate change with increasing BARYON DENSITY

$$\rho = \langle N^+ N\rangle \quad ?$$

- at $\rho = 0$:

$$m\,\langle\bar{q}q\rangle_{\rho=0} = -\,m_\pi^2 f_\pi^2 \qquad \text{(Gell-Mann, Oakes, Renner)}$$

$$m = \tfrac{1}{2}(m_u+m_d)\,,\quad \langle\bar{q}q\rangle = \langle 0|\bar{u}u+\bar{d}d|0\rangle$$

- at finite nuclear density $\rho > 0$:

$$\boxed{\langle\bar{q}q\rangle_\rho = \langle\bar{q}q\rangle_{\rho=0} + \langle N|\bar{q}q|N\rangle\cdot\rho}$$

+ higher orders in density

... more precisely: $\langle\bar{q}q\rangle_\rho = \langle\bar{q}q\rangle_0 + \frac{\partial}{\partial m}\mathcal{E}(\rho)$

energy density $\mathcal{E}(\rho) = M_N\,\rho + \mathcal{E}_{kin}(\rho) + \mathcal{E}_{int}(\rho)$

- PION-NUCLEON SIGMA-TERM:

$$\boxed{\begin{aligned}\Sigma_N &= \tfrac{1}{2}(m_u+m_d)\,\langle N|\bar{u}u+\bar{d}d|N\rangle \\ &= m\,\langle N|\bar{q}q|N\rangle = m\,\frac{\partial M_N}{\partial m} \\ &= (45\pm 8)\text{ MeV}\end{aligned}}$$

(Gasser, Leutwyler, Sainio; Phys. Lett. B253 (1991) 252)

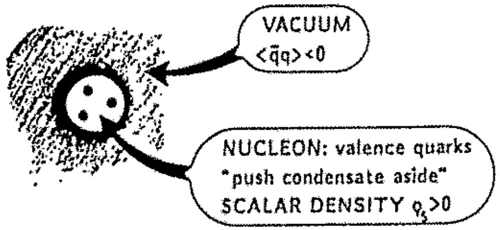
MODEL INDEPENDENT RESULT
(to leading order in ρ):

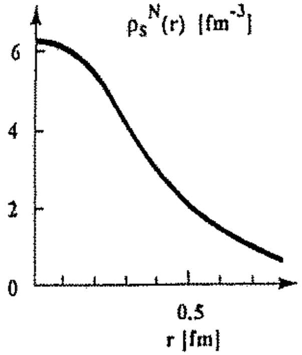
$$\boxed{\frac{\langle\bar{q}q\rangle_\rho}{\langle\bar{q}q\rangle_0} = 1 - \frac{\Sigma_N}{m_\pi^2 f_\pi^2}\,\rho + \dots}$$

Drukarev, Levin, NPA (1990, 91)
Cohen, Furnstahl, Griegel, PRC (1992)
Lutz, Klimt, W.W., NPA (1992)

→ NOTE: ~ **30 %** CHANGE of CONDENSATE at $\rho = \rho_0 = 0.17\,fm^{-3}$

- **Interpretation:**





- **πN SIGMA-term:**

$$\Sigma_N = m \int d^3r\, \rho_S^N(r)$$

example: CAVITY $\rho_S^N(r) = -\langle\bar{q}q\rangle_0\, \theta(R-r)$

$$\Sigma_N = 45\ MeV \Longleftrightarrow R = \left[\frac{3\Sigma_N}{4\pi m_\pi^2 f_\pi^2}\right]^{1/3} \simeq 0.8\,fm$$

$$\boxed{v_N = \frac{4\pi}{3}R^3 \simeq 2\,fm^3 \simeq \frac{1}{3}\rho_0^{-1}}$$

CORRECTIONS of higher order in ρ
(R. Brockmann, W.W.)

- RESULTS: (preliminary)

EFFECTIVE πN SIGMA TERM in MATTER:

$$\boxed{\tilde{\Sigma}_N(\rho) = \Sigma_N\left(1 + \frac{m_\pi^2}{A\Sigma_N}\frac{\partial E(\rho)}{\partial m_\pi^2}\right)}$$

- at $\rho = \rho_0 = 0.17\,fm^{-3}$:

$$\frac{\tilde{\Sigma}_N(\rho_0)}{\Sigma_N} = 1 + 0.4 - 0.25 - 0.01 - 0.04$$

from SCALAR exchange

from VECTOR exchange

from π exch.

from FERMI motion

hence:

$$\boxed{\begin{array}{l}\dfrac{\langle\bar{q}q\rangle_{\rho=\rho_0}}{\langle\bar{q}q\rangle_0} = 1 - \dfrac{\tilde{\Sigma}_N(\rho_0)}{m_\pi^2 f_\pi^2}\rho_0 \\ \tilde{\Sigma}_N(\rho_0) \simeq 1.1\,\Sigma_N\end{array}}$$

but: ⇨ subtle cancellations !

⇨ significant corrections to be expected at higher density ρ

SCALAR MEAN FIELD
in nuclei from a QCD point of view

- assume : $M_N \propto \langle\bar{q}q\rangle$

  (QCD Sum Rules ; NJL model)

- then : $\frac{M_N^*(\rho)}{M_N} = \frac{\langle\bar{q}q\rangle_\rho}{\langle\bar{q}q\rangle_{\rho=0}}$

  $$= 1 - \frac{\Sigma_N}{m_\pi^2 f_\pi^2}\rho + \dots$$

- SCALAR MEAN FIELD ($\rho_0 = 0.17\ \mathrm{fm}^{-3}$)

$$\boxed{\begin{aligned} U_S &= M_N^*(\rho) - M_N \\ &= -\frac{M_N \Sigma_N}{m_\pi^2 f_\pi^2}\rho \\ &\simeq \mathbf{-7.2}\,\Sigma_N\left(\frac{\rho}{\rho_0}\right)\end{aligned}}$$

- for $\Sigma_N = 45\ \mathrm{MeV}$,

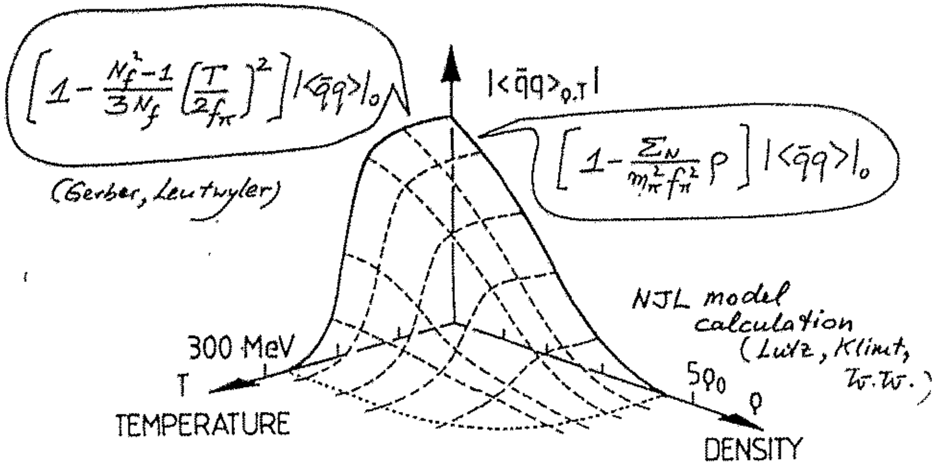
  $U_S \simeq -325\ \mathrm{MeV}\left(\frac{\rho}{\rho_0}\right)$

- compare with nuclear Dirac phenomenology

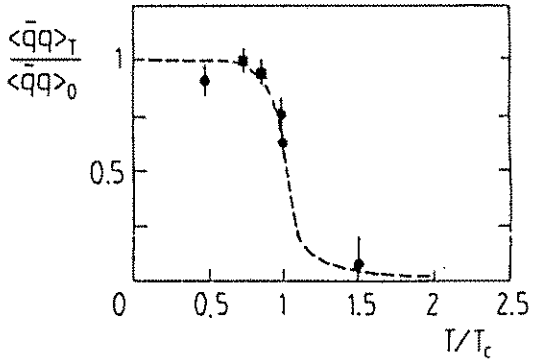
$$U_S(\rho = \rho_0) = -(300 \div 400)\ \mathrm{MeV}$$

(see : Relativistic Brueckner- Hartree-Fock calculations)

CHIRAL THERMODYNAMICS
RESTORATION OF CHIRAL SYMMETRY



- CHIRAL CONDENSATE in LATTICE QCD (G. Boyd et al.)



$T_c \simeq 150\ \mathrm{MeV}$

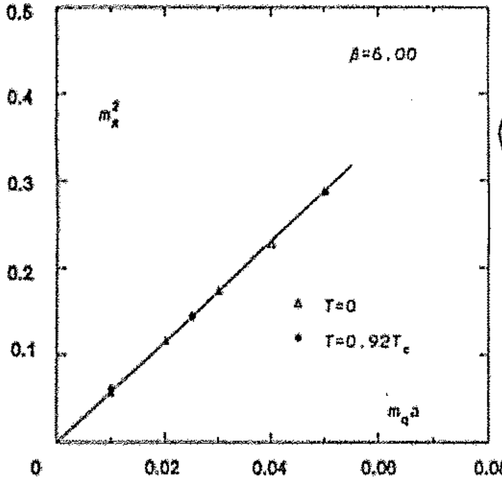
PION MASS (ρ, T)

- ★ GELL-MANN, OAKES, RENNER:

$$m_\pi^2 f_\pi^2 = -\frac{1}{2}(m_u + m_d)\langle \bar{u}u + \bar{d}d \rangle$$

VALID at FINITE ρ and T (Lutz, Steiner, W.W.)

- ★ **T** - dependence from LATTICE QCD:



(Karsch et al.)

$$\boxed{m_\pi(T) = \text{constant}}$$

for $T \lesssim T_c$

$T_c \simeq 150$ MeV

- ★ **ρ** - dependence from CHIRAL DYNAMICS:

(Lutz, Klimt, W.W., Nucl. Phys. A (1992)):

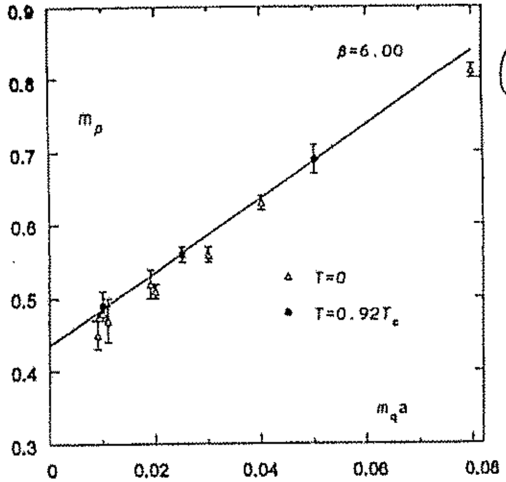
$$\boxed{m_\pi(\rho) \simeq \text{constant}}$$

for $\rho \lesssim \rho_0$

- ★ PION PROTECTED by its GOLDSTONE BOSON CHARACTER

VECTOR MESON MASS (ρ, T)

- ★ **T** - dependence from LATTICE QCD:



(Karsch et al.)

$m_\rho(T) \simeq$ Constant

$T \lesssim T_c$

- ★ **ρ** - dependence: yet unclear

⇨ chiral models: $m_\rho(\rho) \simeq$ const.

Γ_ρ increases

⇨ QCD sum rules: $m_\rho(\rho) \searrow$

$$m_\rho^* \sim f_\pi^* \sim \langle \bar{q}q \rangle_\rho^{1/2}$$

Zusammenfassung:

NIEDERENERGIE - QCD ⟺ CHIRALE DYNAMIK

a) CHIRALE STÖRUNGSTHEORIE

Quantitative Beschreibung von Niederenergie-prozessen (insbesondere elektroschwache WW von πN-, KN-Systemen)

abor: nicht geeignet im RESONANZ - Bereich

b) CHIRALE KONSTITUENTEN - QUARKS

Weniger gut fundiert, aber möglicherweise nützlich zur Interpolation zwischen Niederenergie und tief-inelastischer Streuung

c) CHIRALE THERMODYNAMIK

Modell-unabhängige Aussagen (z. B. $\langle\bar{q}q\rangle_{\rho,T}$, $m_\pi^*(\rho,T)$)

in führender Ordnung $T \lesssim 100\ \text{MeV}$

$\rho \lesssim \rho_0 = 0.17\ \text{fm}^{-3}$

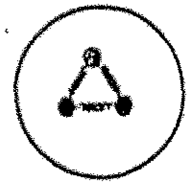
Offene Fragen ($\rho > \rho_0$; $m_{\rho,\omega}(\rho,T)$; ...)

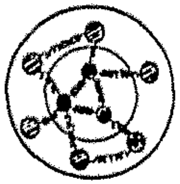
Experimente zur Struktur des Nukleons
(ELSA)

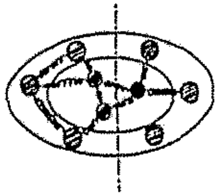
B. Schoch
Bonn

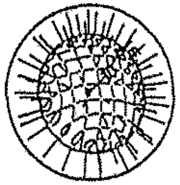
4.Oktober 1994

Modelle:


MIT-
bag model


Chiral
"bag"-model


Deformed
„bags"


Soliton

$$|N\rangle = \alpha\,|N_0\rangle + \beta\,|N_0+\pi\rangle + \gamma\,|\Lambda+K^+\rangle + \ldots$$

Static properties

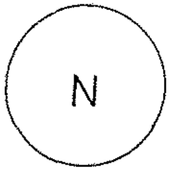
Distribution of charge
and current
Formfactors

$G_M^n(q^2)$

Relativistic
effects
$d(e,e'p)$

Particle production
Excitation
Resonances

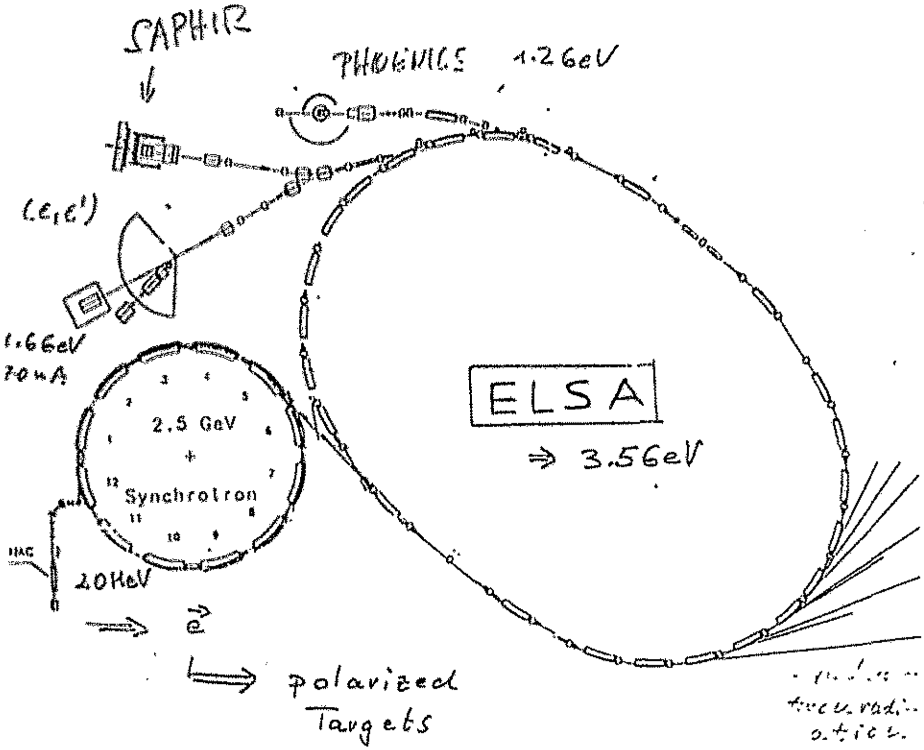
$C2/M1$



$p(e,e'\eta)$

The constituents
Quarks,Gluons

Spinstructure



Large acceptance detectors
Moderate (few MeV) missing
mass resolution
⟹ Studies on
the nucleon

ELSA (Status 4.94)

ACCELERATOR PhD-student, Undergraduate

D.Husmann,W.V.Drachenfels,C.Nietzel,H.Bongartz,T.Götz,
S.Nakamura,M.Picard,S.Voigt,J.Wenzel,J.Keil

ELAN (e,e'x)

T.Reichelt,B.Schoch,F.Frommberger,G.Gothe,W.Hillert,
G.Kranefeld,H.Reike,D.Durek,D.Doll,H.Hainer,D.Jakob,C.Kunz,
G.Pfeiffer,H.Putsch,D.Wacker,G.Schantz,M.Westermann,
H.Brunhöber,D.Kluxen,M.Tramm

PHÖNIX (Tagged Photons,Pol.Target)

G.Anton,W.Meyer,M.Rigney,H.Dutz,W.Beulertz,K.Helbing,J.Hey,
B.Zucht,R.Gehring,S.Goertz,G.Reicherz,A.Thomas,M.Pullmann,
C.Bradke,M-Blückthun,K.Runkel

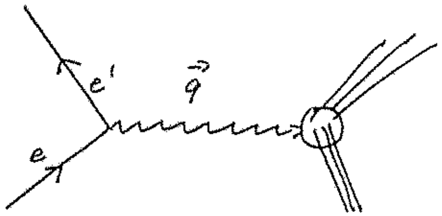
SAPHIR (Taged Photons)

W.Schwille,K.Heinloth,E.Paul,R.Wedemeyer,N.Jakob,D.Menze,
H.Bockhorst,H.Jüngst,U.Kirch,M.Tran,R.Burgwinkel,
J.Hannappel,J.Scholmann,F.Wehnes,F.Klein,H.van Pee,J.Link
S.Schmidt,J.Wisskirchen

SYNCHROTRON LIGHT

J.Hormes,F.v.Busch,R.Chauvistre,R.Franke,M.Höfer,G.Küper,
S.Steil,G.Akhtar,U.Alkemper,U.Ankerhold,J.Doppelfeld,B.Esser,
A.Breest,A.Pantelouris,J.Pollmann,F.Palm,A.Rashid,J.Rothe,
W.Schmitt,I.Winter,O.Wollersheim,H.Zumaque-Diaz,D.Reich
R.becker,S.bender,P.Drotbohm,J.Schramm,J.Zanghellini

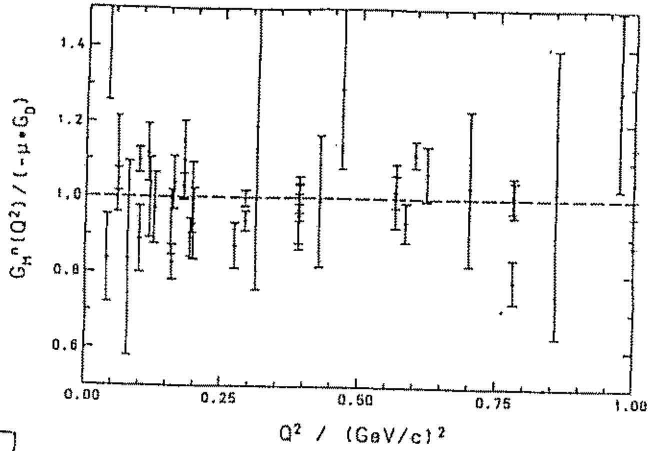
Messung des magnetischen Formfaktors



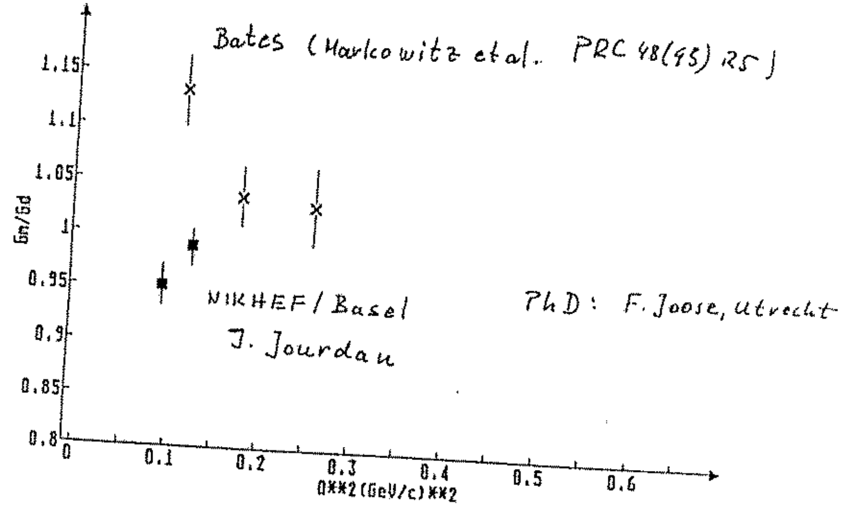
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_M \left[\frac{G_E^2 + \frac{Q^2}{4M^2}\boxed{G_M^2}}{1+\frac{Q^2}{4M^2}} + \frac{Q^2}{2M^2}\boxed{G_M^2}\tan^2\left(\frac{\theta}{2}\right)\right]$$

Relativ gute Beschreibung (qualitativ)

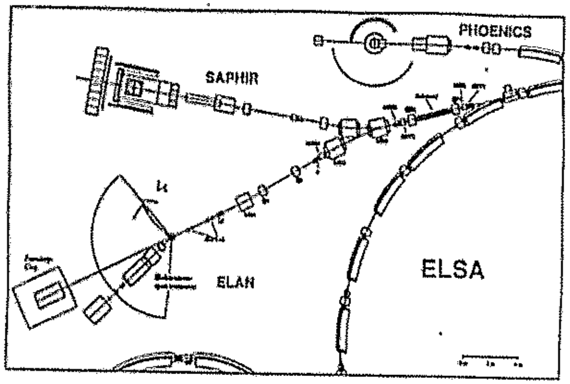
Dipol - FF: $G_D = \frac{1}{\left(1+\frac{Q^2}{\Lambda^2}\right)^2}$ mit $\Lambda = 0.71\,\mathrm{GeV}^2$



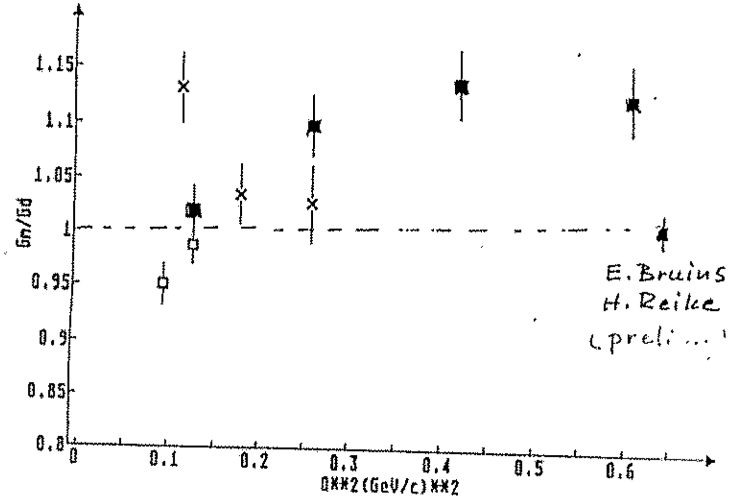
$\boxed{G_m^n}$



e^-
1.2
1.6 GeV

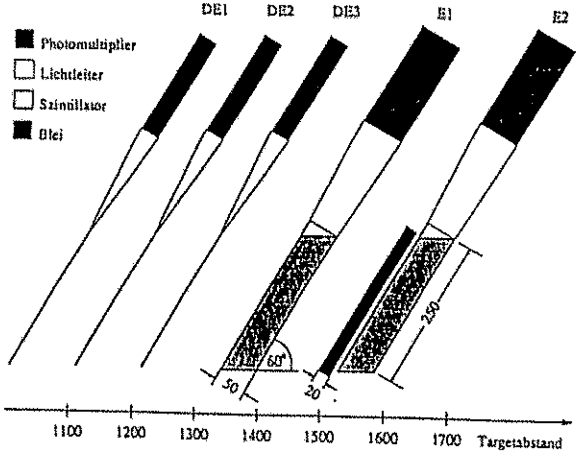


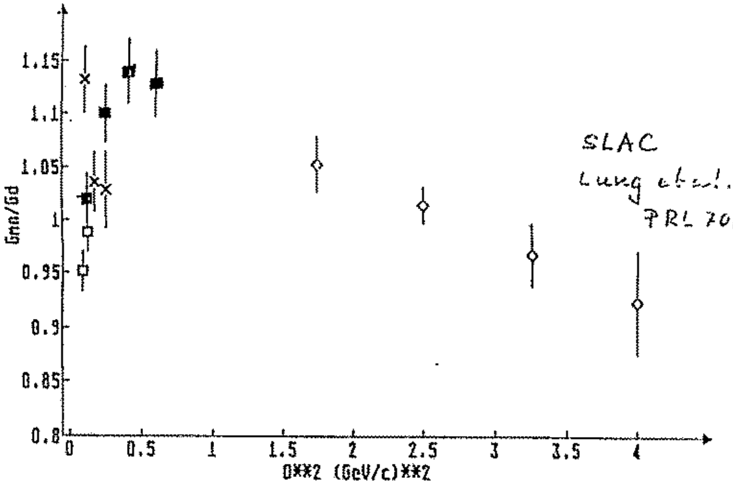
NIKHEF/Utrecht/Bonn



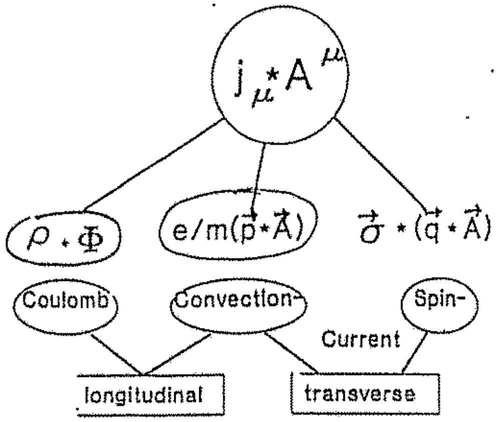
E. Bruins
H. Reike
(preli...)

v.f. >





SLAC
Lung et al.
PRL 70(93)718



Multipoles: Coulomb Electric Magnetic

EXPERIMENT:Linear/circular polarisation of the virtual/real photon

linear pol. γ^*
(x-dir.)

$$\Rightarrow \left(\varepsilon_z \cdot \underset{\overset{\nearrow}{P_0\cdot\cos\vartheta}}{p_z} + \varepsilon_x \underset{\overset{\nwarrow}{P_0\cdot\sin\vartheta\cdot\cos\varphi}}{p_x}\right)$$

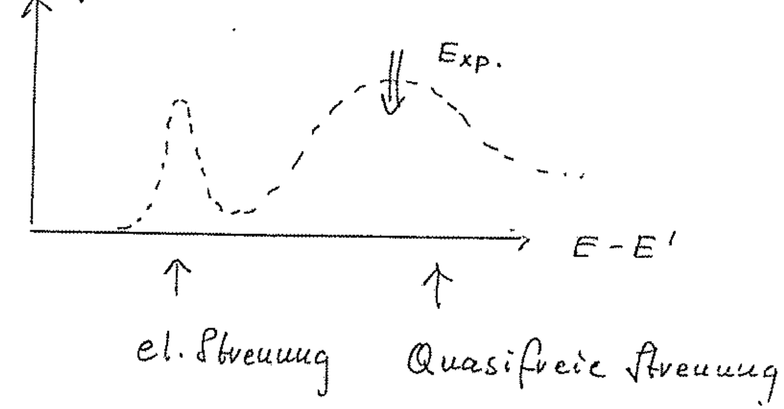
$$\Rightarrow P_0^2\left(\underset{\overset{\uparrow}{\sigma_L}}{1} - \tfrac{1}{2}\underset{\overset{\uparrow}{\sigma_T}}{\sin^2\vartheta} + \tfrac{1}{2}\underset{\overset{\uparrow}{\sigma_{TT}}}{\sin^2\vartheta\cdot\cos 2\varphi} + \underset{\overset{\uparrow}{\sigma_{TL}}}{\sin 2\vartheta\cos\varphi}\right)$$

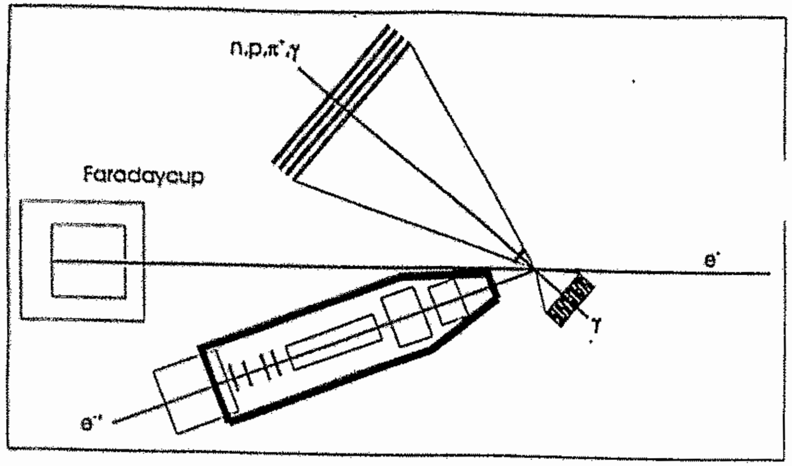
$\delta\sigma \sim$

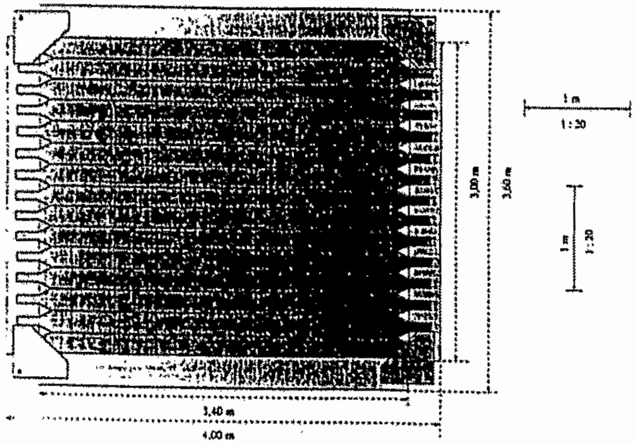
Separation:
Rosenbluth-Plot

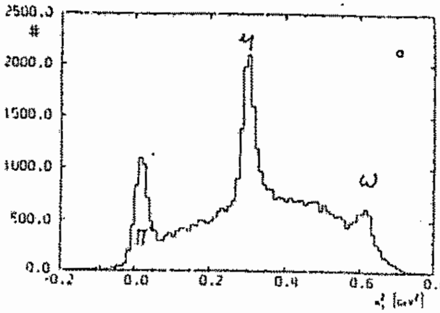
out of plane
detection of hadrons

Relativistische Effekte
in $d(e,e'p)$





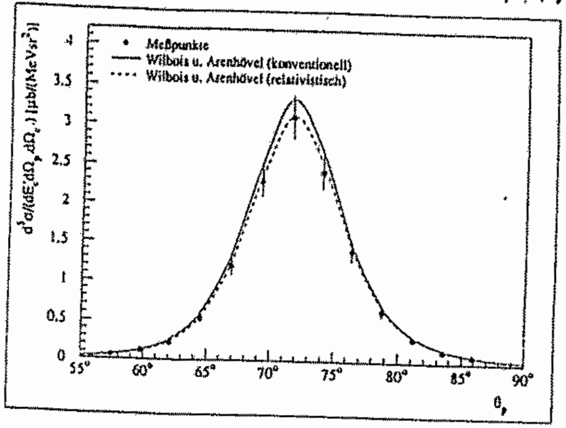




← DESY

$p(e,e'p)X$

F. Frommberger



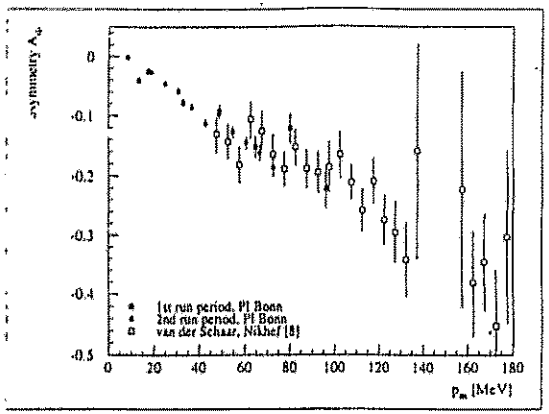
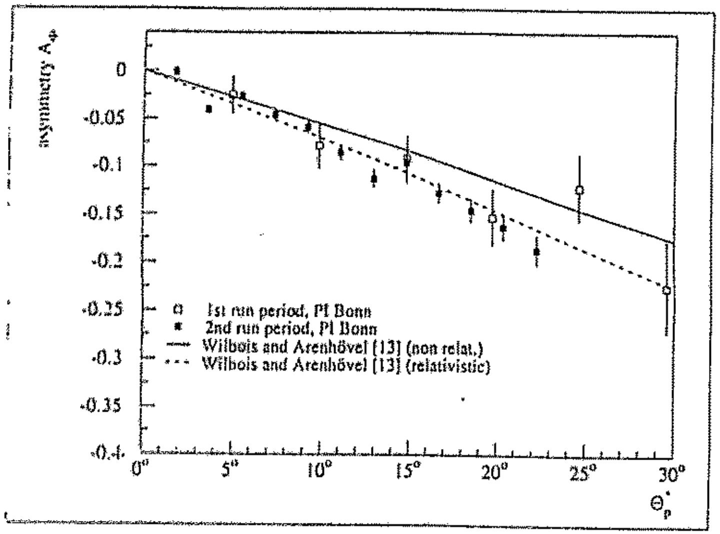
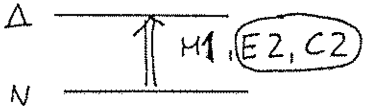


Figure 3. Measured asymmetries

□ NIKHEF
v. d. Schaar
et al.

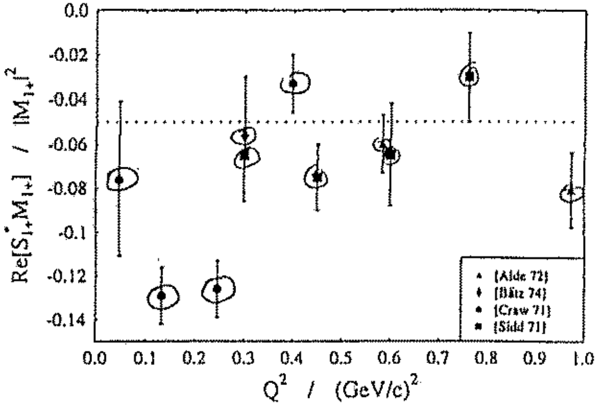


<u>Exploration:</u> N-Δ -transition



sensitive to N/Δ -Deformation

Measurement: S_{1+}/M_{1+} -ratio



○ CEA !??
○ DESY
○ NINA

L	elektromagnetische Multipole	πN-System J	l	Pionproduktions-Multipole
0	C0	1/2	1	L_{1-}
1	E1/C1	1/2	0	E_{0+}/L_{0+}
		3/2	2	E_{2-}/L_{2-}
	M1	1/2	1	M_{1-}
		3/2	1	M_{1+}
2	$\boxed{E2/C2}$	3/2	1	$\boxed{E_{1+}/L_{1+}}$
		5/2	3	E_{3-}/L_{3-}
	M2	3/2	2	M_{2-}
		5/2	2	M_{2+}

M_{1+}-Domination

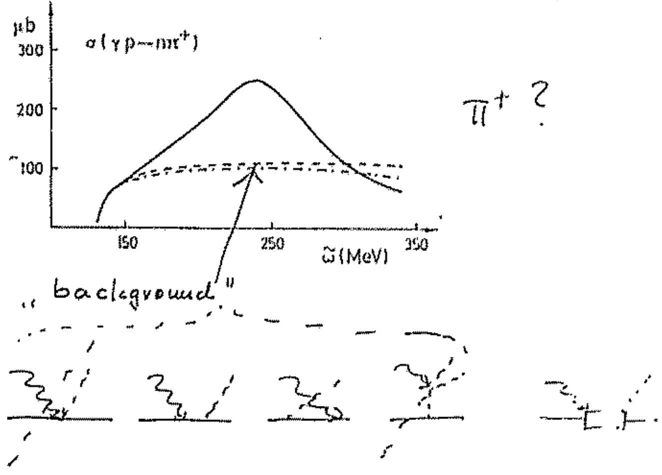
$$\sigma_T \sim \left(2.5 - 1.5 \cdot \cos^2 \vartheta_\pi^*\right) \cdot |M_{1+}|^2 + \cos \vartheta_\pi^* \cdot 2 \operatorname{Re}\left[E_{0+}^* M_{1+}\right]$$

$$\sigma_{TT} \sim -1.5 \cdot \sin^2 \vartheta_\pi^* \, |M_{1+}|^2$$

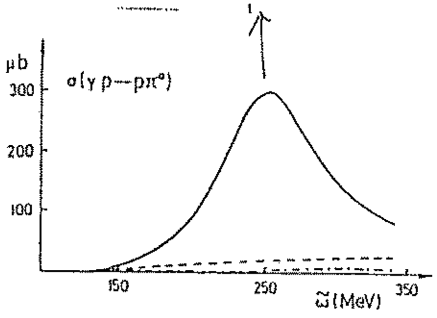
$$\sigma_{TL} \sim 6 \cdot \cos \vartheta_\pi^* \cdot \sin \vartheta_\pi^* \cdot \operatorname{Re}\left[L_{1+}^* M_{1+}\right]$$

$\Rightarrow$ Ratio: $\frac{\sigma_{TL}}{\sigma_{TT}}$, $\frac{\sigma_{TL}}{\sigma_T}$

Which channel?

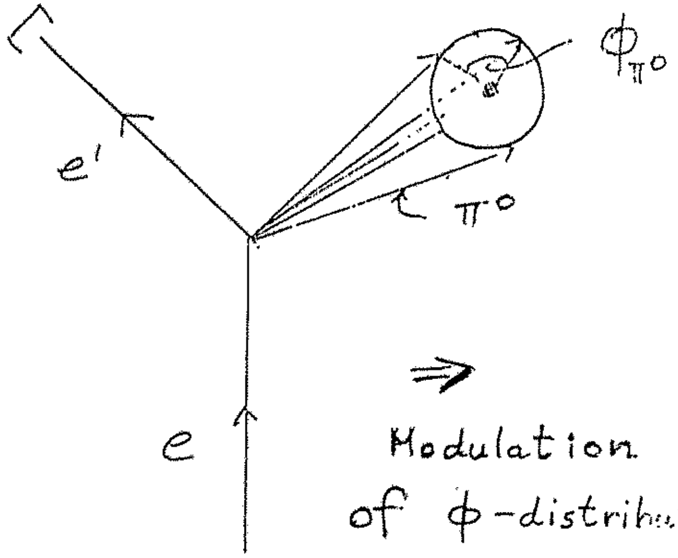


π^+ ?



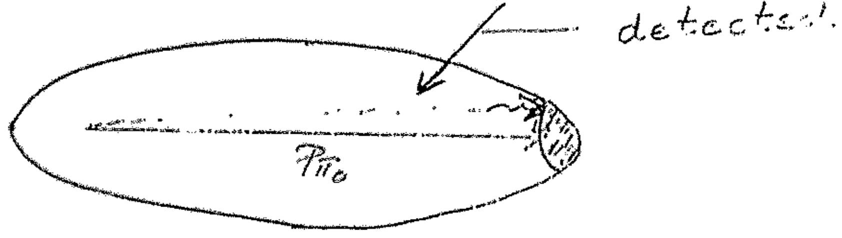
π^0 !

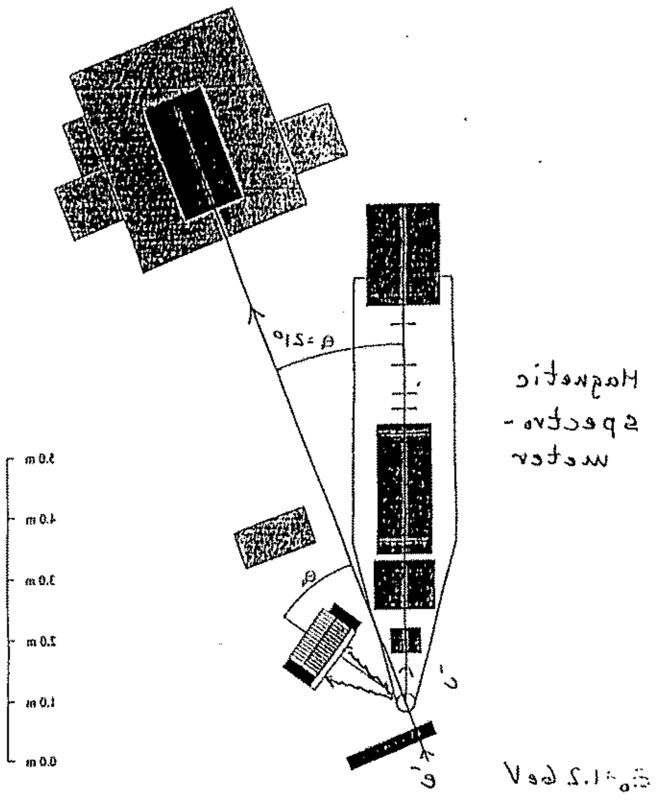
Method :

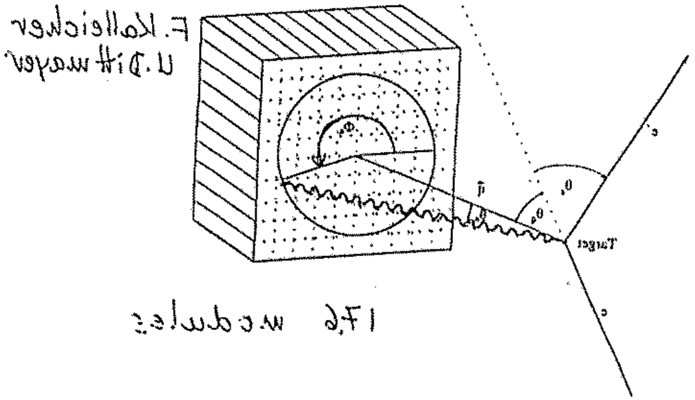


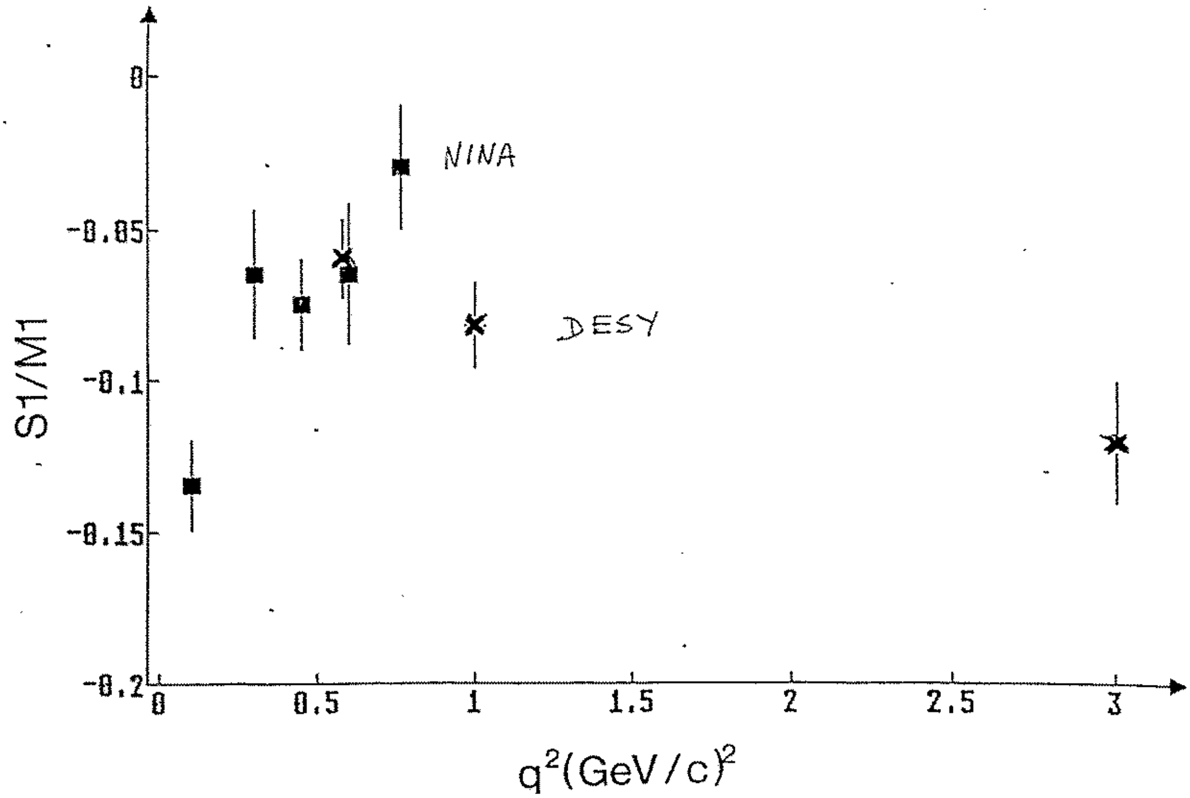
$\Rightarrow$ Modulation of ϕ-distribution

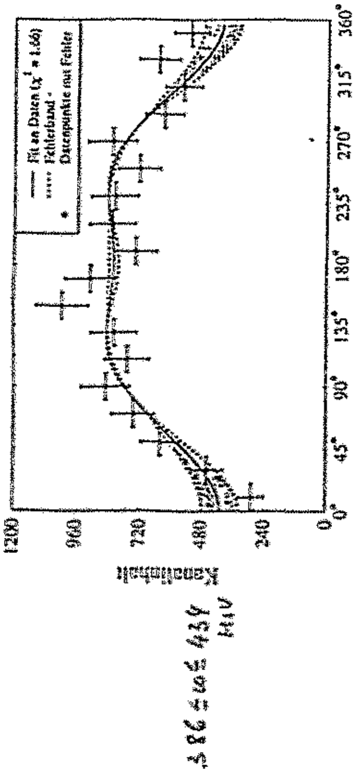
Reaction : $p(e,e'\pi^0)$
but Experiment : $p(e,e'\gamma)$

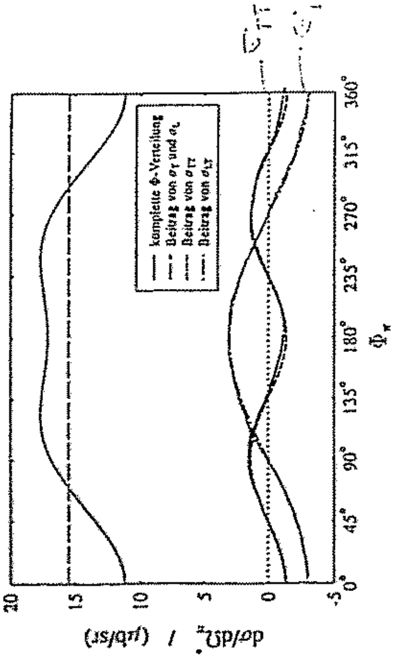












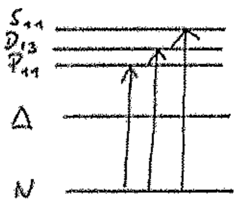
Our parametrisation:

$$\frac{d\sigma}{d\Omega_\pi^\circ} = A(1 + B\cdot\cos 2\phi_\pi + C\cdot\cos\phi_\pi)$$

$$\hookrightarrow \frac{C}{B}, \frac{C}{A}$$

η - Production

H. Wilhelm
H. Putsch

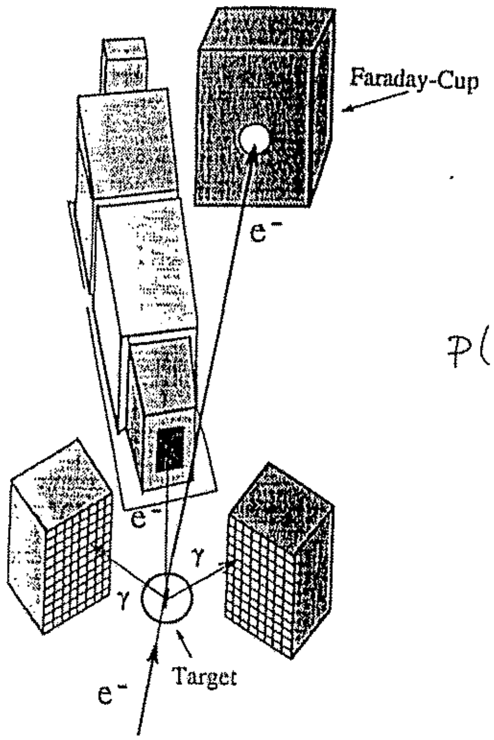


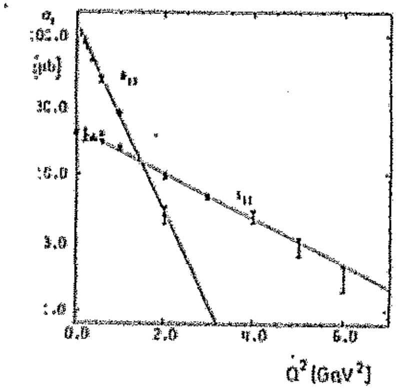
Electric Dipole

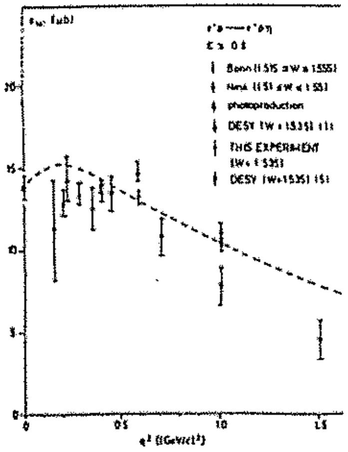
Magnetic Dipole.

Questions: Roper $\leftrightarrow \eta$ - coupling
η - N - coupling constant

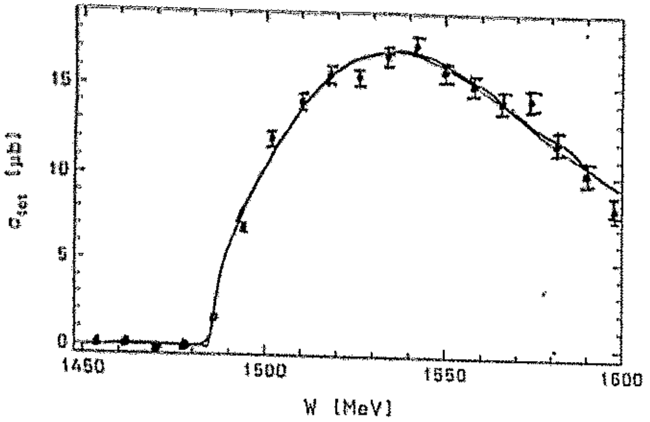
$p(e, e'\eta)p$
$\hookrightarrow 2\gamma$







η - production   p(e,e'η)



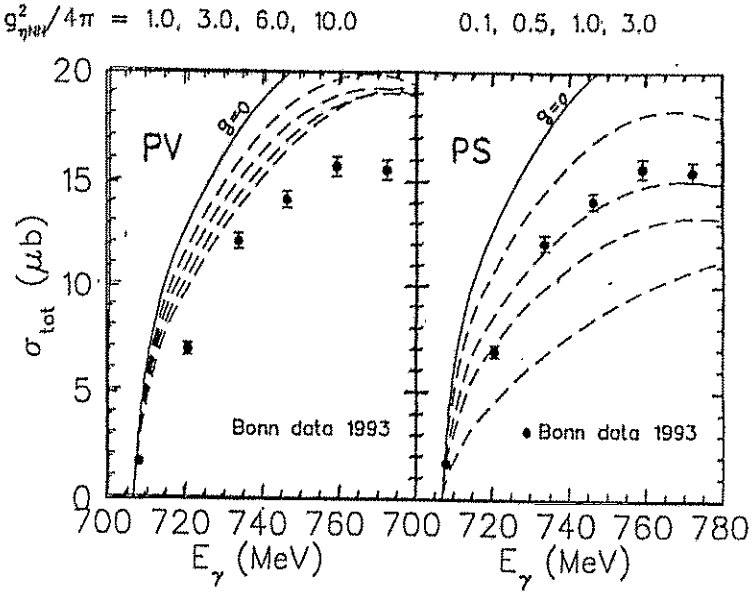
Bonn 93

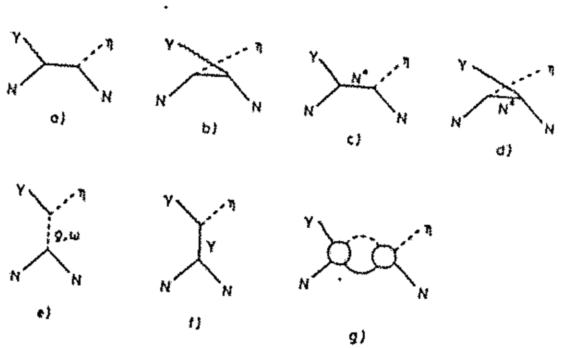
S_{11} - Breit-Wigner-Fit

$W_R = 1540.1 \pm 1.1$ MeV

$\Gamma_R = 134.6 \pm 5.6$ MeV

$\boxed{\gamma + p \rightarrow \eta + p}$ L. Tiator



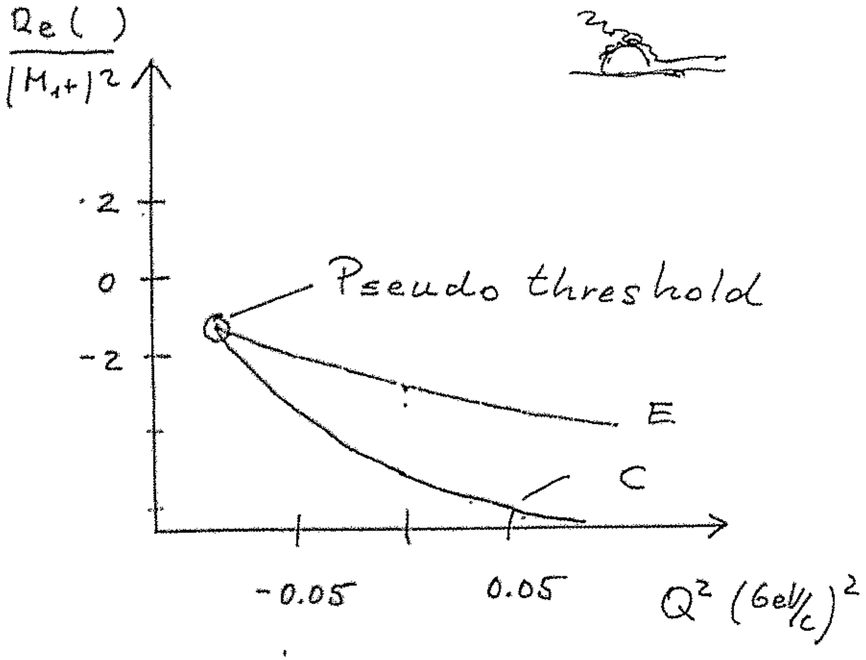


Connection $S_{1+} \rightarrow E_{1+}$

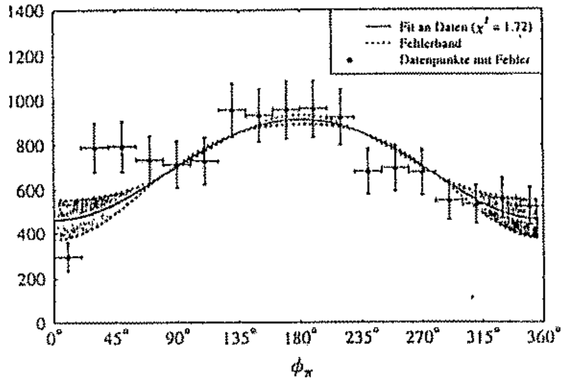
$$\boxed{\omega^* S_{1+} = |\vec{q}| L_{1+}}$$

Factor : 2

$L_{1+} \longrightarrow E_{1+}$

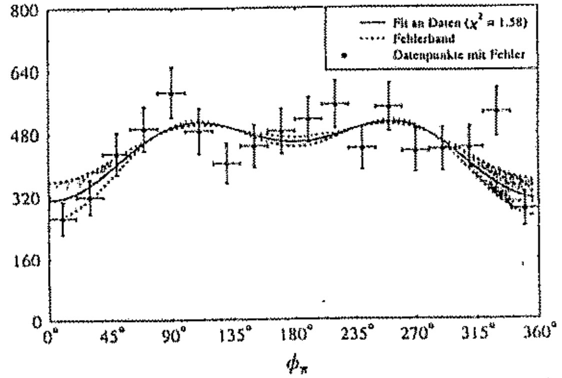


338 MeV ≤ ω ≤ 386



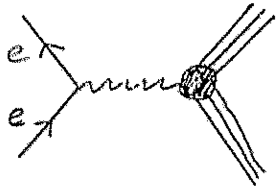
$$\frac{Re[S_{1+}^* M_{1+}]}{|M_{1+}|^2} = (-13.0 \pm 1.9)\,\%$$

434 ≤ ω ≤ 482 MeV



$= (-7.7 \pm 1.8)\,\%$

Formfaktoren: ① Elastische e⁻-Streuung



$$\langle N | V^\mu_\gamma | N \rangle =$$

$$\bar u_N \left(F_1 \gamma^\mu + \frac{i}{2m} F_2 \sigma^{\mu\nu} q_\nu \right) u$$

$$\boxed{V^\mu_\gamma = \frac{2}{3} \bar u \gamma^\mu u - \frac{1}{3} \bar d \gamma^\mu d - \frac{1}{3} \bar s \gamma^\mu s}$$

Wichtig! Isospinzerlegung

$$V^\mu_\gamma (T=1) = \frac{1}{2} \left(\bar u \gamma^\mu u - \bar d \gamma^\mu d \right)$$

$$V^\mu_\gamma (T=0) = \frac{1}{6} \left(\bar u \gamma^\mu u + \bar d \gamma^\mu d \right) - \frac{1}{3} \bar s \gamma^\mu s$$

$\Rightarrow F_1, F_2$ bzw. G_E, G_M von Proton <u>und</u> Neutron

Photon-Nukleon-Experimente im GeV-Bereich (Experimente mit dem SAPHIR-Detektor)

W. Schwille
Bonn

4.Oktober 1994

Photon - Nucleon Experiments

in the GeV Region

Experiments with the SAPHIR Detector

M. Bockhorst, R.Burgwinkel, J.Hannappel, K.Heinloth, H.-P. Jakob, N.Jöpen, H.Jüngst,
U.Kirch, F.-J. Klein, L.Lindemann, J.Link, D.Menze, H.Merkel, W.Neuerburg, E.Paul,
H. van Pee, R.Plötzke, S.Schmidt, J. Scholmann, W. J. Schwille, M. Q. Tran,
R. J. Wedemeyer, F.Wehnes, J.Wißkirchen, A.Wolf
Physikalisches Institut der Universität Bonn

J.Ernst, H. Kalinowsky, E.Klempt, R.Maschuw, C. Strassburger
ISKP Bonn

Ch. Poech, F. Smend, M.Schumacher
II. Physikalisches Institut Universität Göttingen

Photon - Proton Reactions:

$\gamma + p$ -> $K^+ \Lambda$, $K^+ \Sigma^0$ **
$K^+ \Sigma^+$
ωp *
ρp
Φp
$p \pi^+ \pi^-$

Photon - Deuteron Reactions:

$\gamma + D$ -> $p n \pi^+ \pi^-$ $(p \pi^+ \pi^-)$ *
$p p \pi^- \pi^0$
$d \pi^+ \pi^-$
$p p \pi^-$

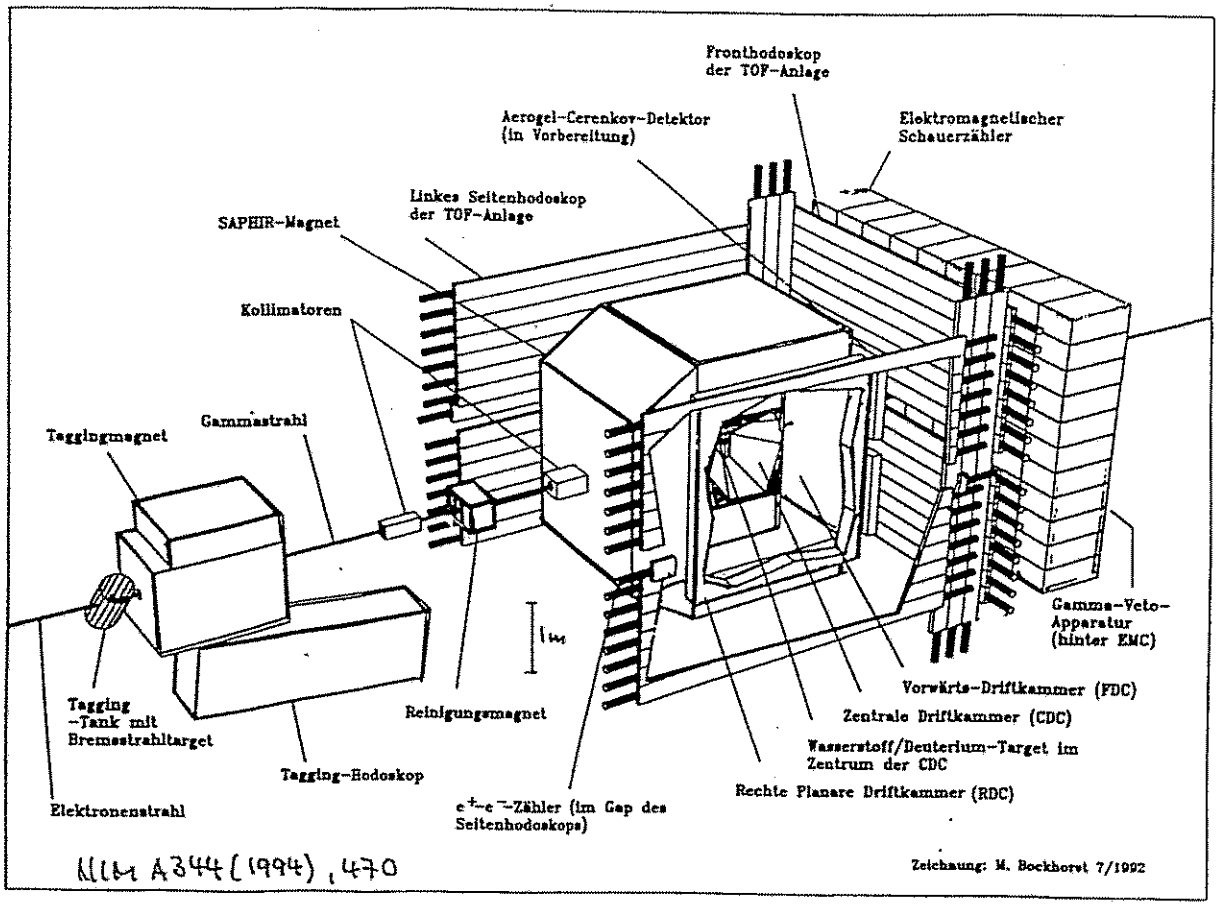
Motivation - a short survey

"Non strange" reactions:

γd -> $p p \pi^-$	resonance contributions at higher ernergies, FSI separation eventually B_1 (2014) verification
γd -> $p n \pi^+ \pi^-$ $p p \pi^- \pi^0$ $d \pi^+ \pi^-$	dominant production mechanism, $\Delta\Delta$ part of the deuteron wave function, existence of a $\Delta\Delta$ (2380) bound state
γp -> $p \pi^+ \pi^-$	resonance contributions beyond the Δ^{++} region, Δ^{++} polarization
γp -> ωp ρp	new resonances with weak πN coupling, determination of the non diffractive part

Reactions involving strange quarks:

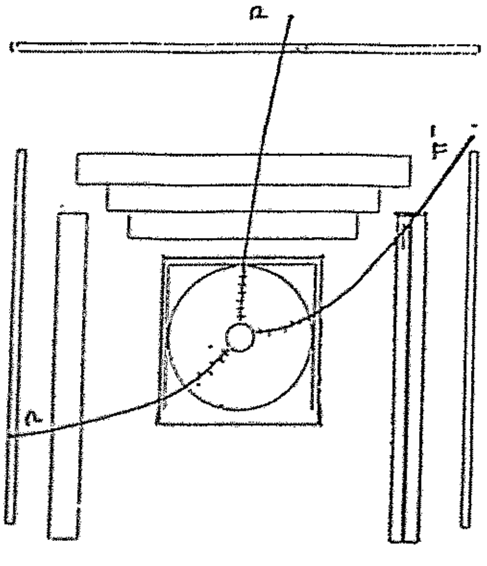
γp -> $K^+ \Lambda$, $K^+ \Sigma^0$ $K^+ \Sigma^+$	dominant production mechanism for $s\bar{s}$ - generation in these processes, spin transfer photon -> s - quark
γp -> Φp	deviations from the diffractive behaviour at large - t values: interference between s- and p- wave contributions, besides the dominant diffractive p - waves could a s - wave contribution result from a $s\bar{s}$ - preformation in the nucleon.



NIM A344 (1994), 470

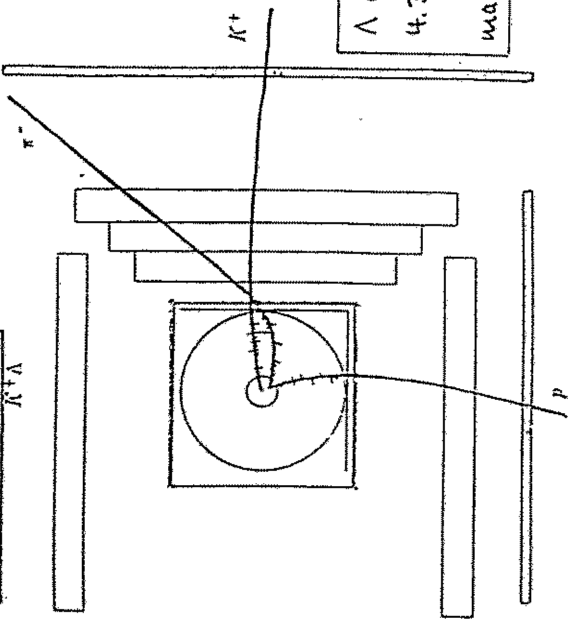
Zeichnung: M. Bockhorst 7/1992

$\gamma d \to p p \pi^-$



$\gamma + p \to K^+ \Lambda$

$K^+\Lambda$

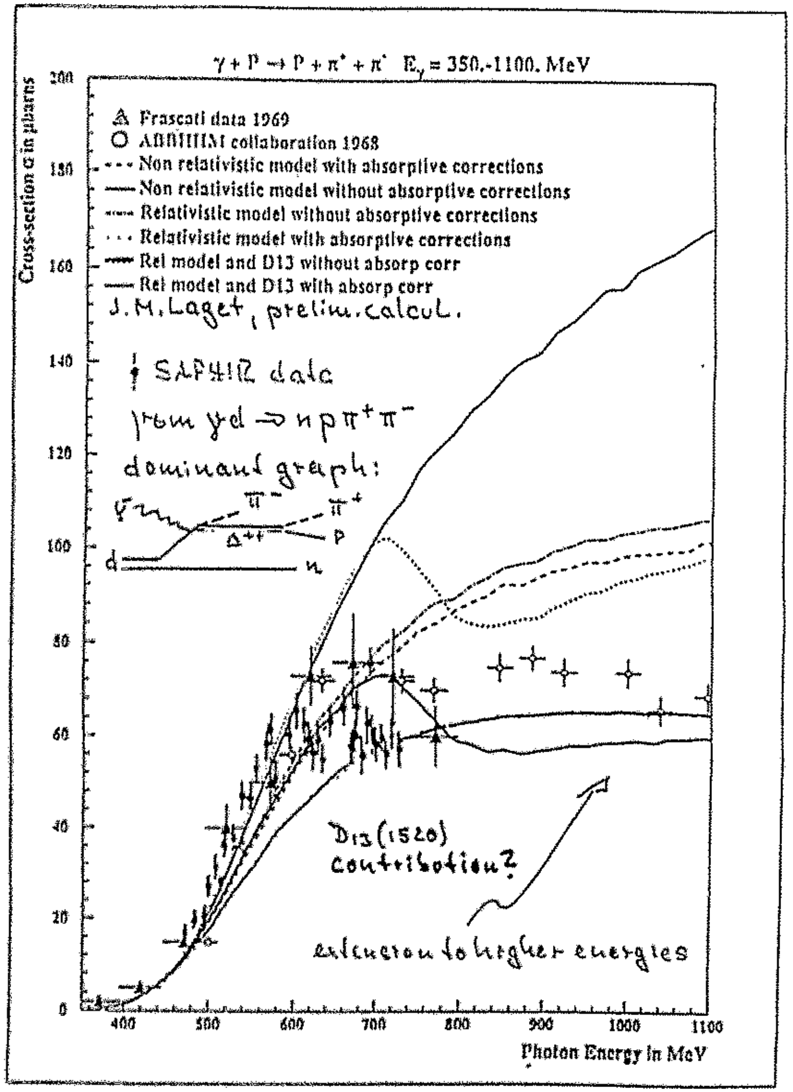


Λ decay length: 4.3 ± .3 cm

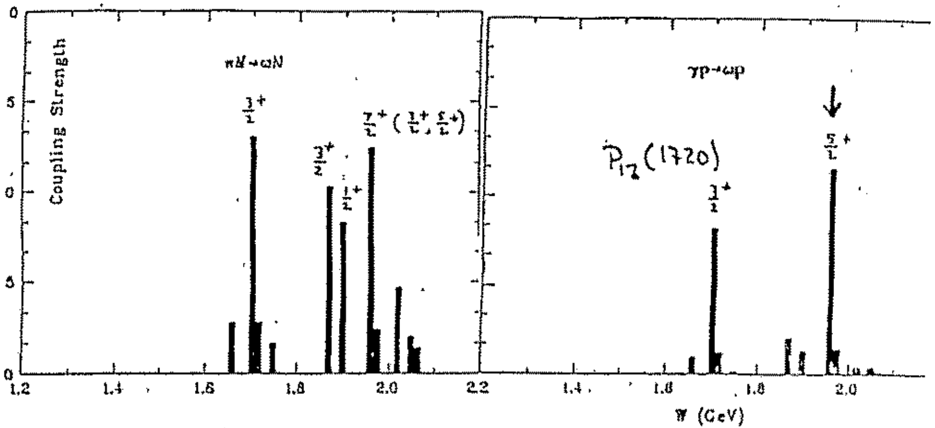
mass: 1.117 ± .001

$\gamma p \to p \pi^+ \pi^-$

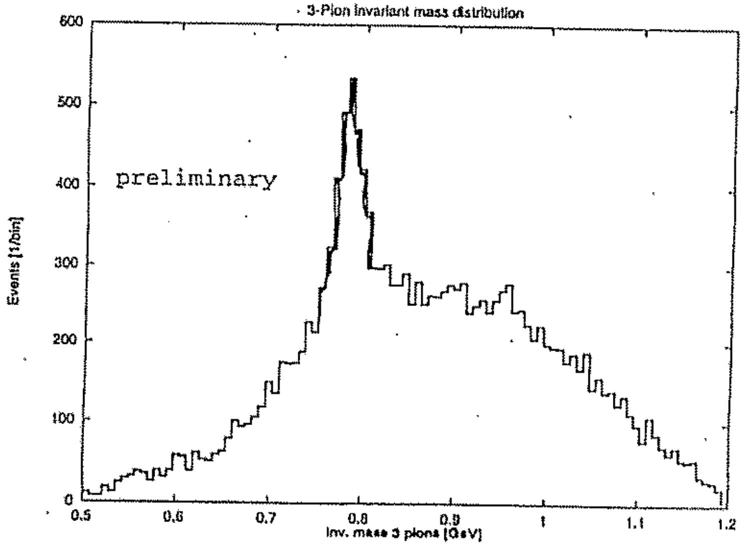
comparison: data off free proton – off deuteron
resonance contributions at higher E_γ
Δ^{++} - polarization



$\gamma p \to \omega p$

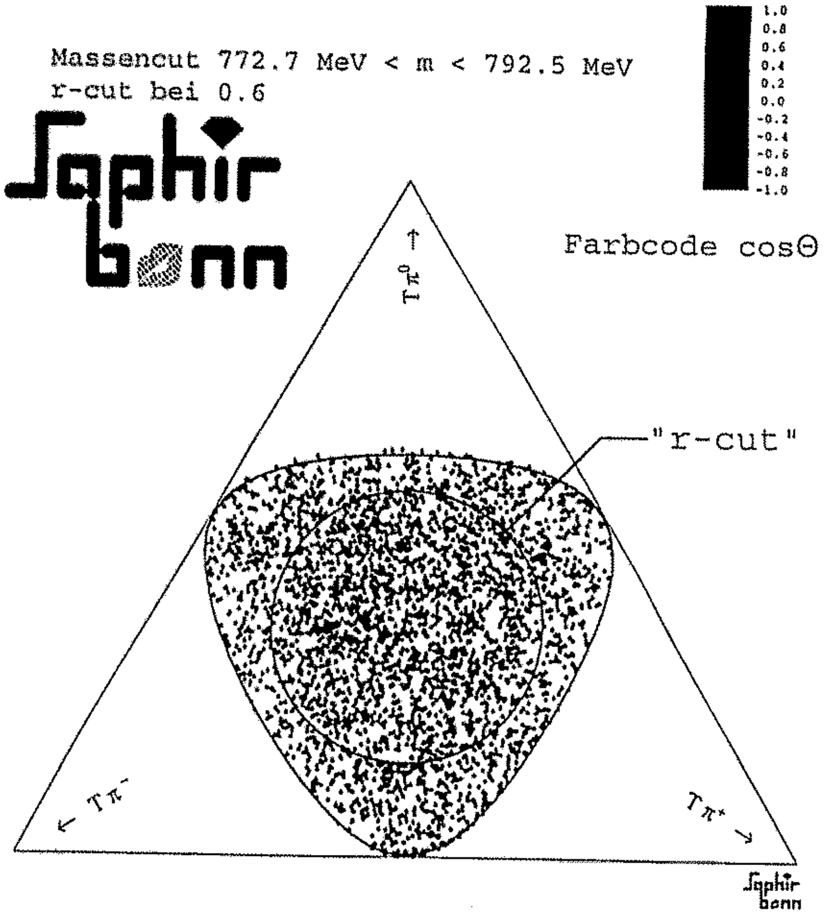


search for N^* with weak πN - coupling <u>but</u>
stronger γN, ωN couplings
N. Isgur et al. → $F_{15}(2000)$ → ωp dominant

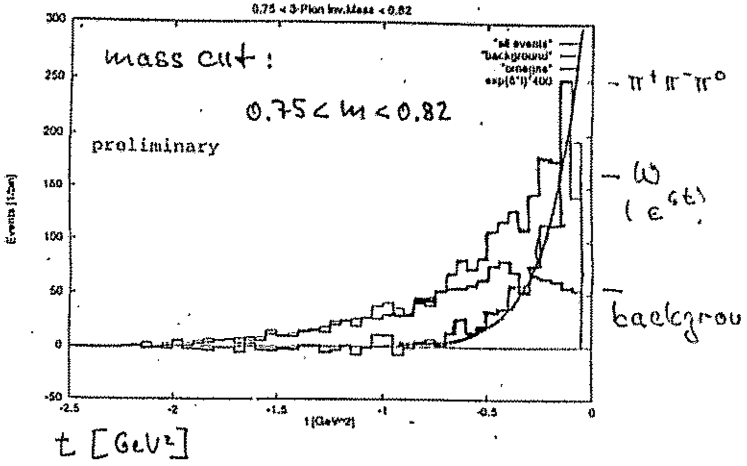


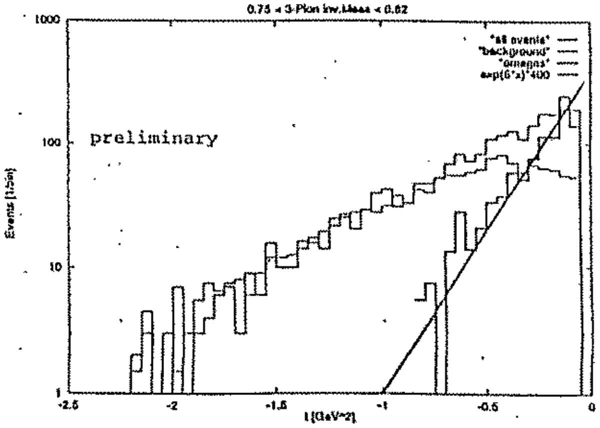
Dalitzplot $\omega \rightarrow \pi^+\pi^-\pi^0$

Massencut 772.7 MeV < m < 792.5 MeV
r-cut bei 0.6



t-dependence for $\gamma p \to \omega p$





<u>experimental difficulty:</u> search for a resonance at large $-t$, outside the diffractive region

evaluated data: 8.5k $\pi^+\pi^-\pi^0$ → 500 ω
on tape : 67 k → 4000 ω
→ long term task

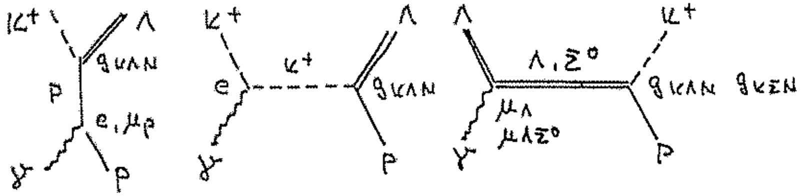
$\gamma + p \rightarrow K^+\Lambda$, $K^+\Sigma^0$

lowest lying heavy quark

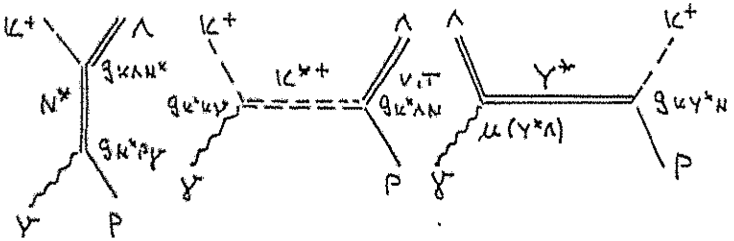
what is known about production mechanism?

Isobaric models

Born terms: $(K^+\Lambda)$



resonance contributions:



used diagrams: Born terms + K^*
+ examples

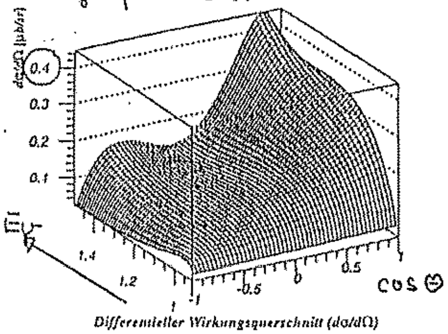
Adelseck - Saghai AS-1 $P_{11}(1440)$; $\Lambda^*(1670)$, $K_1(1280)$
AS-2 $P_{11}(1440)$, $\Lambda^*(1405)$, $K_1(1280)$

Meyer zu Hörste $\underline{S_{11}(1656)}$ or $P_{11}(1650)$

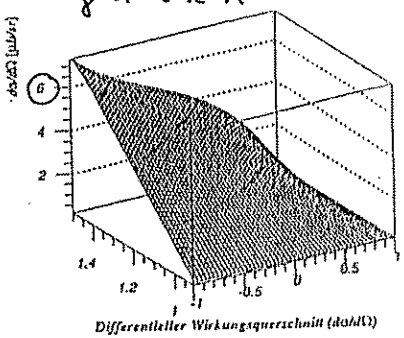
s-resonance contributions small & ambiguous!
problems!

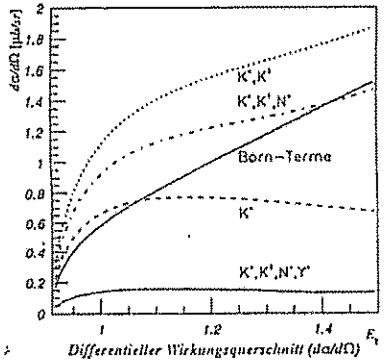
"Isobaric Problems"

$\gamma + p \rightarrow K^+\Lambda$



$\gamma n \rightarrow K^0\Lambda$



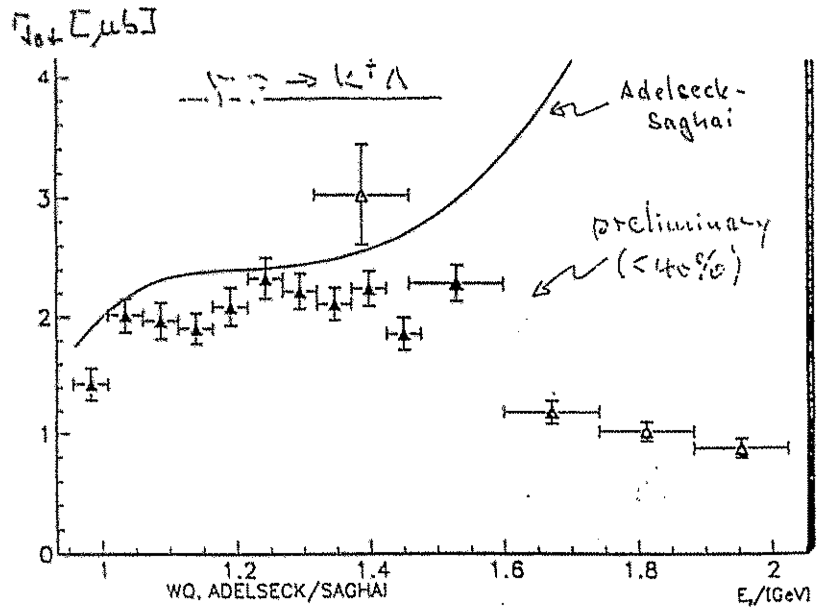


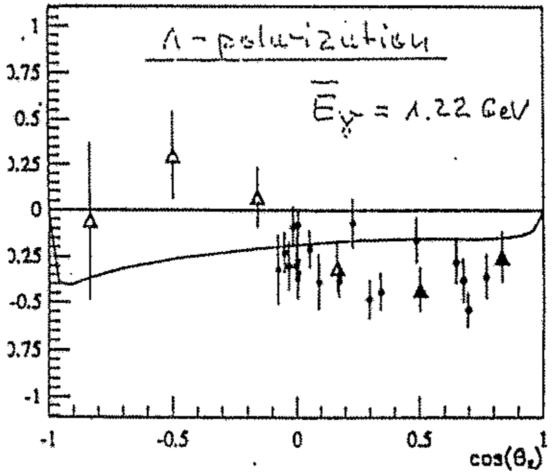
calculations with
graphs and couplings
from Adelseck - Saghai
but similar with
other isobaric models

isospin invariance:
strong couplings $(K^+\Lambda) \rightarrow (K^0\Lambda)$

steep increase of the Born terms with E_γ
from magnetic parts of Born amplitudes
→ cancelling leads to unrealistic
resonance amplitudes

Comparison with our data





$\gamma + p \rightarrow K^+ \Sigma^0$

isobaric models: diagram contributions

Bornterms + K^{*+}

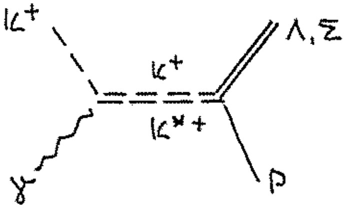
C. Bennhold	D_{33} (1700)
T. Mart et al.	$S_{11}(1650)$, $P_{11}(1710)$, $S_{31}(1900)$, $P_{31}(1910)$
R.A. Williams et al.	$S_{11}(1650)$, $P_{11}(1710)$, $S_{31}(1620)$, $P_{31}(1910)$, $\Lambda^*(1405)$, $K_1(1280)$
U. Meyer zu Hörste	F_{37} (1950)

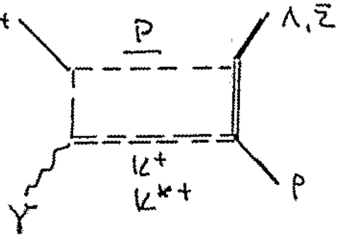
→ model inherent problems (Bornterms)
for the reviewed fit: no polarization observables
since: first Σ^0 polarz. data from SAPHIR

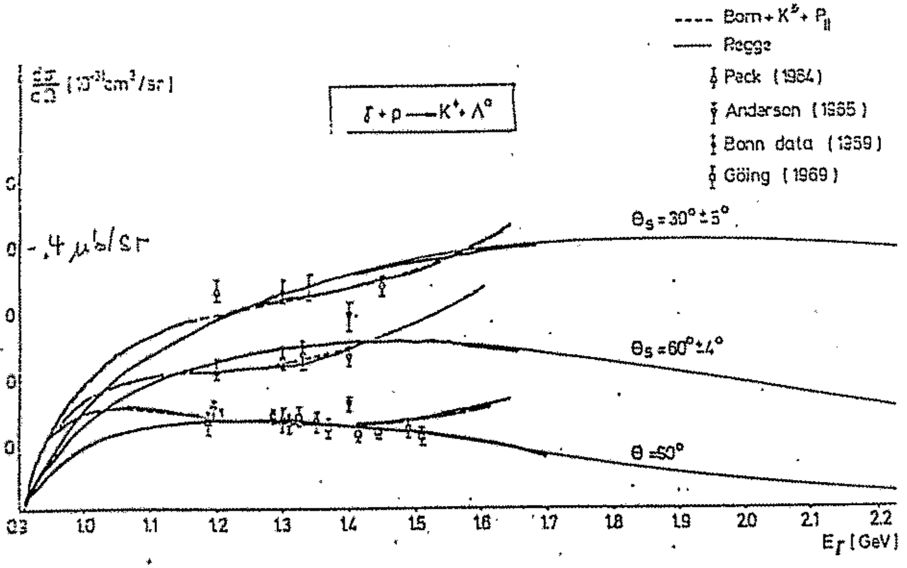
Regge fit model (U. Meyer zu Hörste)

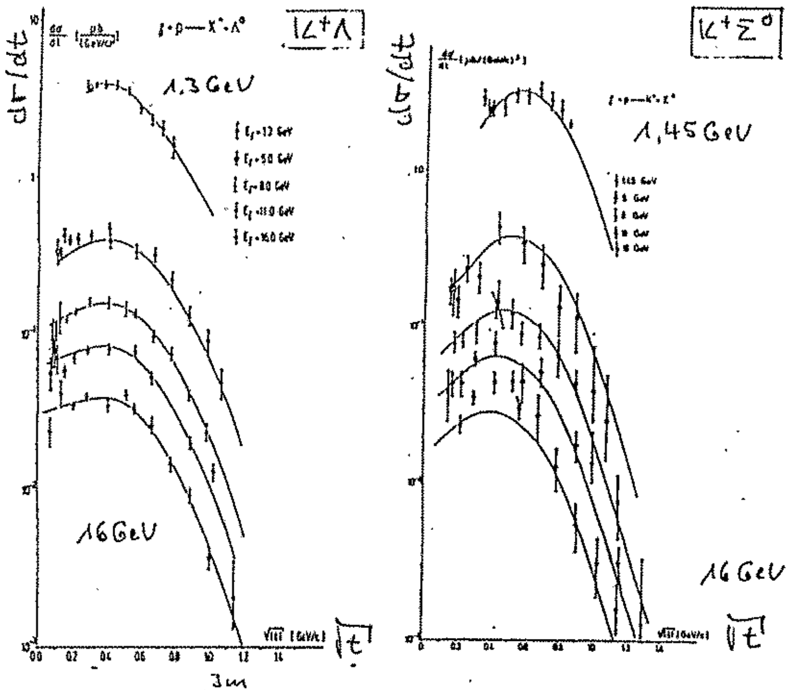
fit for data 1.3 (1.45) – 16 GeV for $\gamma p \rightarrow K^+\Lambda, \Sigma^0$

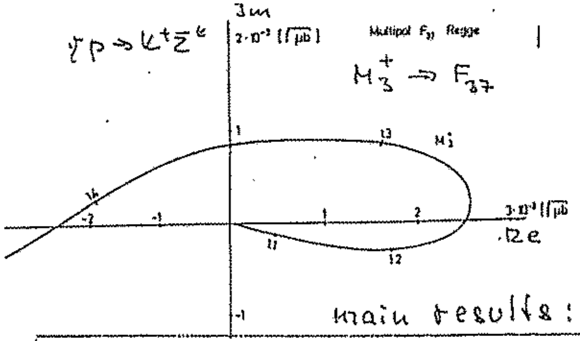
Regge Pole contributions: Regge cut contributions











main results:

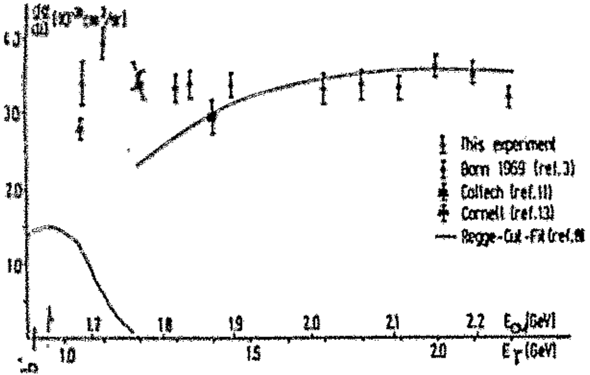
K⁺Λ : $K^*\underline{P}$ cut dominant $\xrightarrow{\text{Deden, Horn, Schmid}}$ none or small resonance contributi

K⁺Σ⁰ : K^* - Pole + $K^*\underline{P}$ cut have same order of ma

$\xrightarrow{\text{DHS}}$ s-channel resonance contributions

M^+ loop in the Argand diagram

$\gamma p \to K^+\Lambda$ $d\sigma/d\Omega$ at $t = -0{,}147$

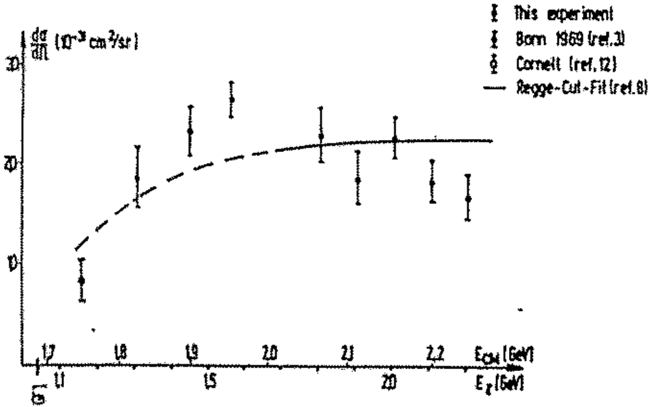


$K^+\Lambda^0$ photoproduction at $t = -0.147$ [GeV²]. ($23° < \theta_{C.M.} < 30°$).

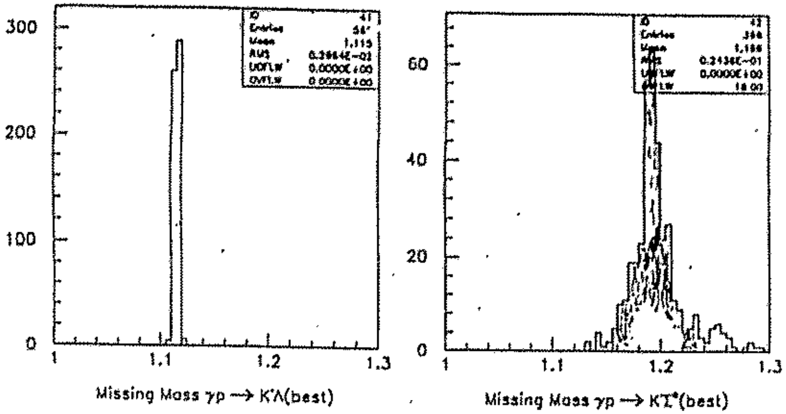
$S_{11}'(1650)$? similar role as the $S_{11}(1520)$ for η?

P_{13}?

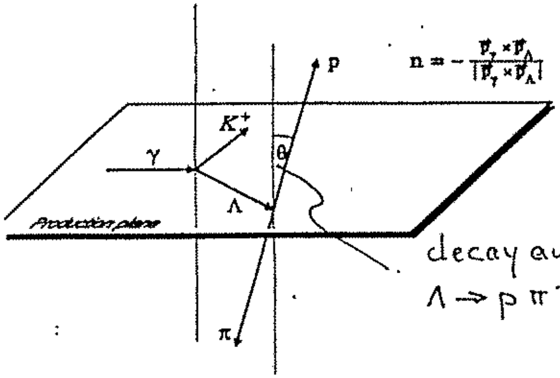
$\gamma p \to K^+\Sigma^0$ $d\sigma/d\Omega$ at $t = -0.17$



$K^+\Sigma^0$ photoproduction at $t \approx -0.17$ [GeV²] ($25° < \theta_{C.M.} < 32°$).



$\Lambda - \Sigma^0$ separation below 1.6 GeV



$$\boxed{\begin{aligned}&W(\Theta)\,d\Omega = \\ &\tfrac{1}{2}(1+\alpha P(\Lambda)\cos\Theta)\,d\Omega\end{aligned}}$$

$\alpha = 0.642 \pm 0.013$

decay angle of the p from $\Lambda \to p\pi^-$ in the Λ rest system

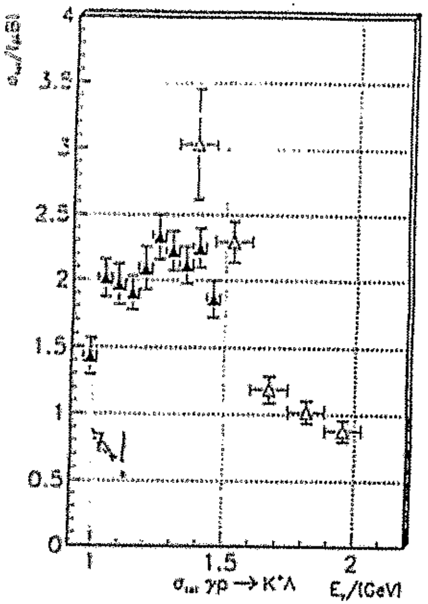
Σ^0 polarization: $\Sigma^0 \to \Lambda\gamma$ (100%)

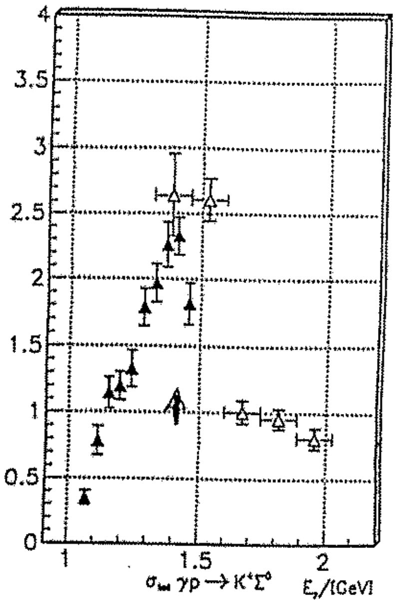
$$\vec{P}_\Lambda = -(\vec{P}_{\Sigma^0}\cdot\vec{u}_\Lambda)\,\vec{u}_\Lambda$$

averaging over all Λ directions ⤳

$$P_\Sigma = -3\,\overline{P_\Lambda}$$

new SAPHIR data!



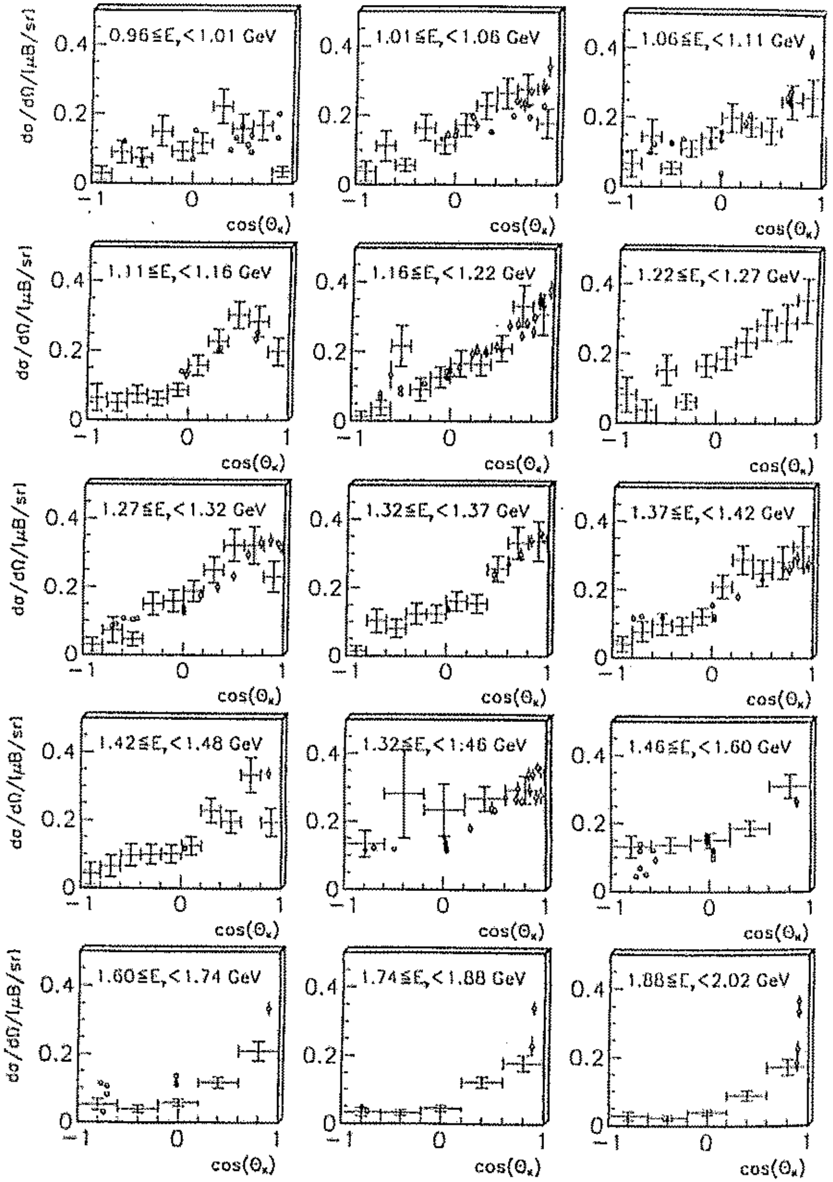


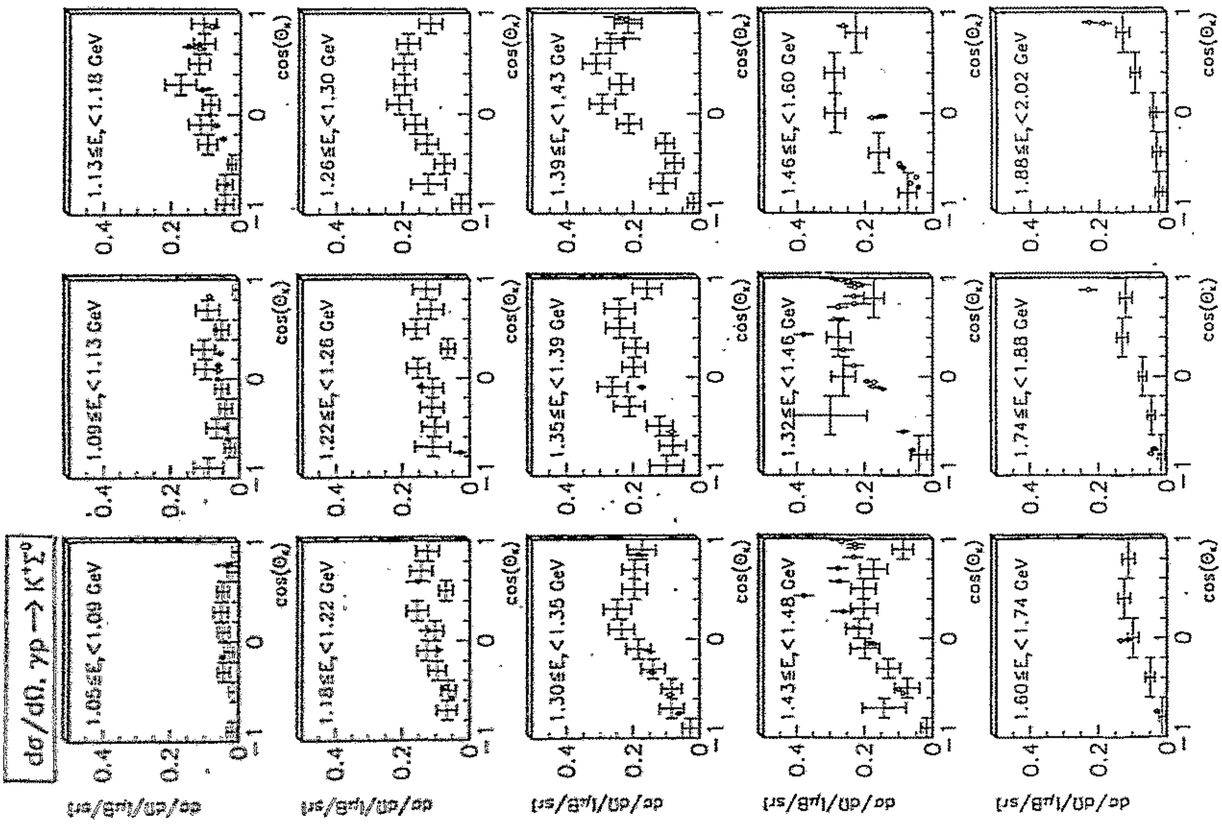
σ_{tot} v.s. E_γ

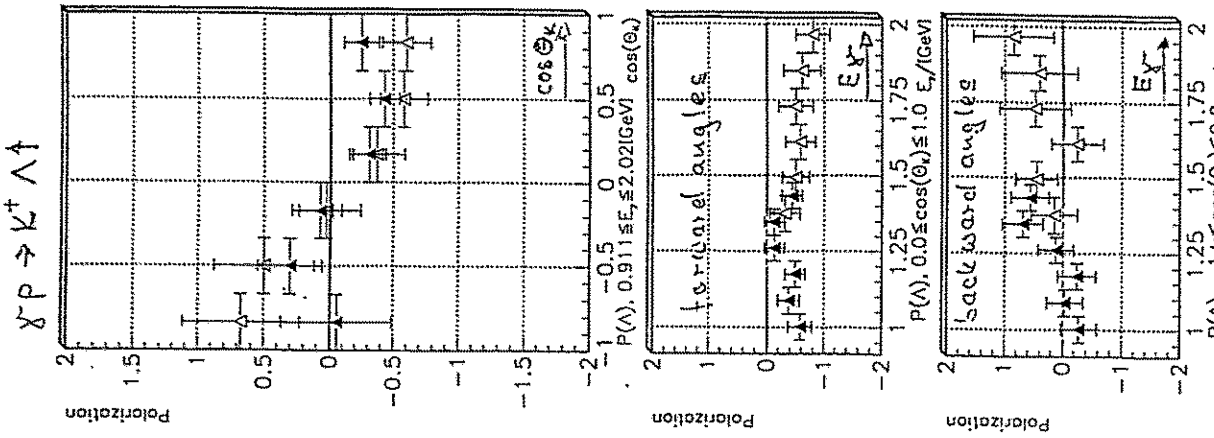
$\gamma p \to K^+\Lambda$

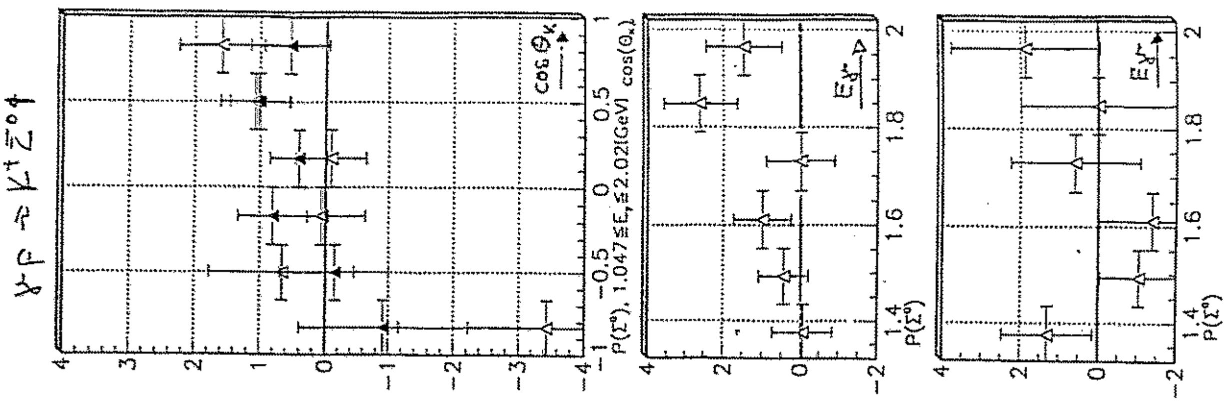
$\gamma p \to K^+\Sigma^0$

$d\sigma/d\Omega,\ \gamma p \to K^+\Lambda$

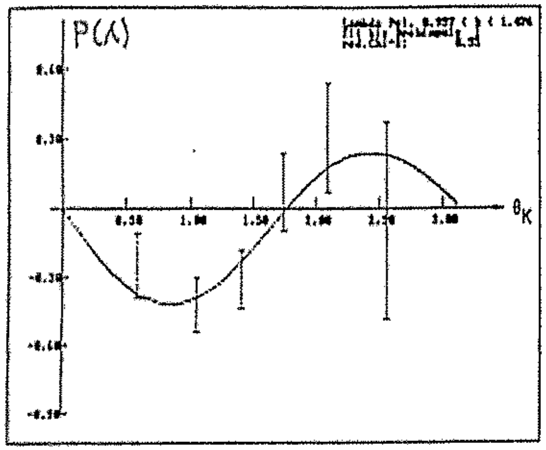



dσ/dΩ, γp → K⁺Σ⁰
1.05≤E_γ<1.09 GeV
1.09≤E_γ<1.13 GeV
1.13≤E_γ<1.18 GeV
1.18≤E_γ<1.22 GeV
1.22≤E_γ<1.26 GeV
1.26≤E_γ<1.30 GeV
1.30≤E_γ<1.35 GeV
1.35≤E_γ<1.39 GeV
1.39≤E_γ<1.43 GeV
1.43≤E_γ<1.48 GeV
1.32≤E_γ<1.46 GeV
1.46≤E_γ<1.60 GeV
1.60≤E_γ<1.74 GeV
1.74≤E_γ<1.88 GeV
1.88≤E_γ<2.02 GeV
dσ/dΩ/μB/sr
cos(Θ_K)
0.4
0.2
0
-1
0
1


γp → K⁺Λ↑
Polarization
P(Λ), 0.911≤E_γ≤2.02[GeV] cos(Θ_K)
cos Θ_K
forward angles
P(Λ), 0.0≤cos(Θ_K)≤1.0 E_γ/[GeV]
E_γ
backward angles
P(Λ), -1.0≤cos(Θ_K)≤0.0 E_γ/[GeV]
E_γ
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1
1.25
1.5
1.75
2


γp → K⁺Σ⁰↑
P(Σ⁰), 1.047≤E_γ≤2.02[GeV] cos(Θ_K)
cos Θ_K
P(Σ⁰)
E_γ
4
3
2
1
0
-1
-2
-3
-4
-0.5
0
0.5
1.4
1.6
1.8
2

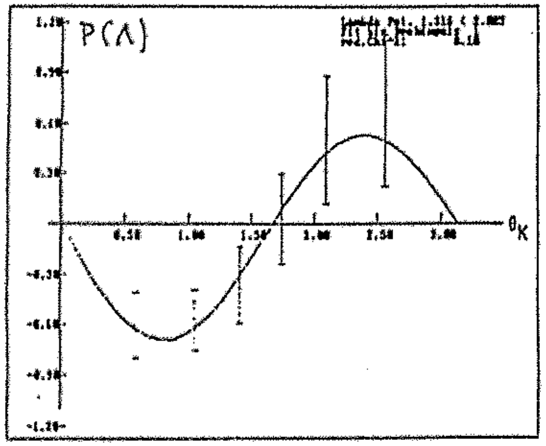
Λ polarization v.s. Θ_{K^+}



$\bar{E}_\gamma$ = 1.2 GeV

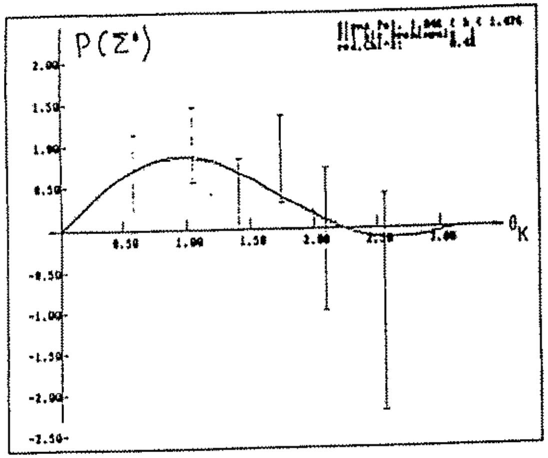
⇒ sign change close to $\Theta_K = 90°$

⇒ no strong energy dependence



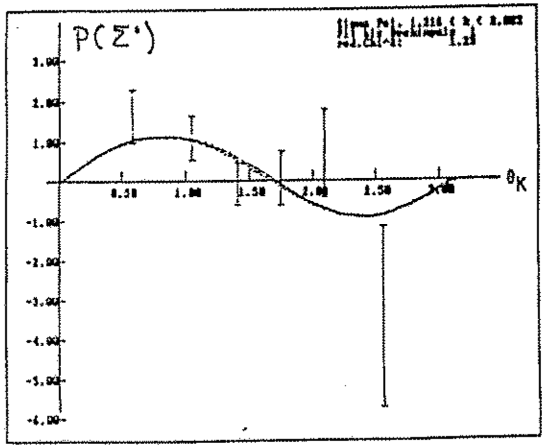
$\bar{E}_\gamma$ = 1.67 GeV

Σ^0 polarization v.s. Θ_{K^+}



$\bar{E}_\gamma$ = 1.26 GeV

⇒ opposite sign compared with P(Λ



$\bar{E}_\gamma$ = 1.67 GeV

Discussion and outlook

* quark model $\Rightarrow \boxed{\Lambda\downarrow = \begin{matrix}u\\d\\s\downarrow\end{matrix}\!\!\left.\begin{matrix}\\ \\ \end{matrix}\right\}J=0 \quad \Sigma^0\uparrow = \begin{matrix}u\\d\\s\downarrow\end{matrix}\!\!\left.\begin{matrix}\\ \\ \end{matrix}\right\}J=1}$

$\mu_\Lambda = \mu_s \qquad \mu_{\Sigma^0} = \frac{2}{3}(\mu_u + \mu_d) - \frac{1}{3}\mu_s$

our Λ, Σ^0 polarisation data →

$P(\Lambda), P(\Sigma^0)$ opposite sign

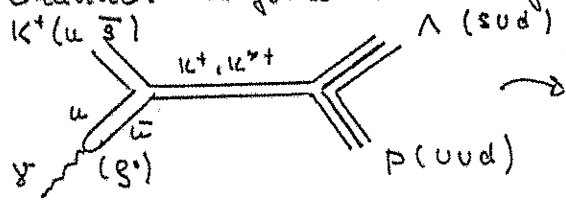
→ essentially the same production mechanism

* possible (?) extent to quark-production, -recombinati

e.g. DeGrand, Miettinen [inclusive hadronic react.]

- accel. sea quark → $s\downarrow$
- retard. beam quark → $s\uparrow$

t-channel = forward K^+ angles:



→ $\boxed{S\downarrow = \Lambda\downarrow}$

same sign as in our measurements

necessary conclusions from *, **:

- extension to measurement of heavier kaons and hyperons
  $K^*(892), \Sigma(1385), \ldots\ldots$
- extension to $\gamma p \to K^0\Lambda^0$ e.g. with small t-channel contribution e.t.c.

→ find selection rules for consistent picture

— - — - — - —

Isobaric & Regge models

our Λ, Σ^0 polarization measurements over the full angular range already introduce new and essential limits.

Isobaric models should try fits with the lowest possible number of s-channel resonces.*

Measurements of the other isospin channels and other polarization observables (under preparation) will improve the situation.

Model independent phase analysis ?

The Regge fit activities seem promising and should be continued.

* very interesting: $K^+\Lambda$ threshold

Pion- und Eta-Produktion an polarisierten Protonen
(ELSA)

W. Meyer
Bonn

4.Oktober 1994

- Einleitende Bemerkungen
- Pion photoproduktion mit PHOENICS

  Pol. messung : Targetasymmetrie
- Eta photoproduktion mit PHOENICS
- Weitere Pol. messungen und Ausblick

ELSA - PHOENICS Exp.

- $\gamma p \rightarrow \pi^+ n$

BONN-PT : K.H. Althoff, H. Dutz, R. Gehring,
S. Goertz, D. Krämer, W. Meyer, R. Paulsen
G. Reicherz, A. Thomas

Bonn-Phoenics : G. Anton, J. Arends, W. Beulertz,
A. Bock, M. Breuer, K. Büchler,
T. Dyroff, M. Gerander, K. Helbing,
J. Hey, G. Nöldeke, S. Wartenberg,
B. Zucht

- $\gamma p \rightarrow \eta p$

Bonn-Phoenics: G. Anton, M. Breuer, A. Bock,
W. Beulertz, K. Helbing, J. Hey
M. Pullmann, M. Rigney

Orsay : J.P. Didelez, P. Hoffmann-Rothe,
E. Hourani, L. Rossier

Göttingen : M. Bruns, M. Schumacher,
F. Smend, G. von Edel

Phys. Fragestellungen bei mittleren Energien

① Interne Freiheitsgrade von Hadronen ?
- → Quark-Gluon Dynamik im Confinement Bereich
- → Anregungsspektren von Baryonen und Mesonen; Hadronzerfälle

② Nukleon - Nukleon Wechselwirkung
- → Einfluß der Freiheitsgrade der Hadronen

ELEKTROMAGNETISCHE WECHSELWIRKUNGEN:

"One powerful way of experimentally investigating the strongly interacting particles (HADRONS) is to look on them, to probe them with a known particle, in particular the photon (no other is known as well)" Feynman

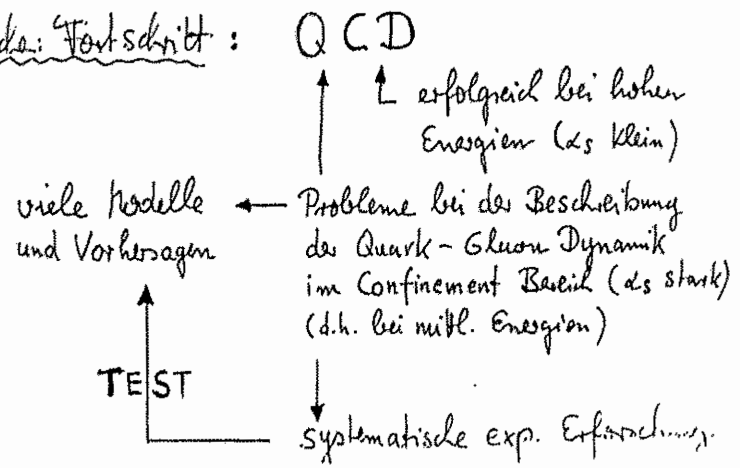
---

Neuerliches Interesse

Experimenteller Fortschritt: Neue Generation von Elektron Gleichstrombeschleunigern bei mittleren Energien

AMPS	(0.9 GeV)
CEBAF	(4.0 GeV)
ELSA	(3.5 GeV)
MAMI	(0.855 GeV)

Theoretischer Fortschritt : QCD



1. Schritt: Wirkungsquerschnittsmessungen

Aber: Mittelung über einzelne
SPINZUSTÄNDE

SPIN als 'INTRINSISCHE EIGENSCHAFT'

Historisch: SPIN war eine wesentliche Komplikation bei der Beschreibung von Naturgesetzen

1609 : Kepler-Gesetze ...... Drehimpulserhaltung

1920's: Fehlschlag der Klass. Gesetze atomare Systeme zu beschreiben

1925 : Pauli Prinzip .... Spin/Statistik Gesetze

1925 : Hypothese vom 'intrinsischen' SPIN .... Uhlenbeck + Goudsmit

1926 : Thomas Präzession .... Korekte relativ. Berechnung

1928 : Dirac Gleichung .... elegante Formulierung

$(i\hbar\not{\partial} - mc)\psi = 0$ freies Spin $\frac{1}{2}$ Teilchen

Hinzunahme des elektromagn. Feldes ⇒

Basis für QED

$\left.\begin{array}{l}\text{renormierbar} \\ \alpha \text{ klein}\end{array}\right\}$ berechenbare THEORIE

Unübertroffene Erfolge von THEORIE + EXPERIMENT

$(g-2)_{e,\mu}$ "

Heute ... STANDARD MODELL

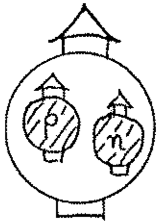
1970's : 3 Familien von Quarks u. Leptonen

1980's : + 5 Vektorbosonen

$$\underbrace{\begin{bmatrix} u \\ d \\ e \\ \nu \end{bmatrix} \begin{bmatrix} c \\ s \\ \mu \\ \nu \end{bmatrix} \begin{bmatrix} (t) \\ b \\ \tau \\ \nu \end{bmatrix}}_{\text{SPIN } 1/2\text{-Fermionen}} \qquad \underbrace{(\gamma;\ g;\ W^{\pm};\ Z^{0})}_{\text{SPIN } 1}$$

zusammengesetzter SPIN

Kerne



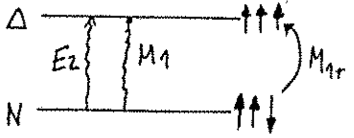
- Wechselwirkungsstärke ist spinabhängig

z.B. Neutron - Proton Kopplung zu $S = 1$ (Deuteron)

kein Di-Proton ; Di-Neutron

Nukleon (Mittelenergie)

z.B. Baryonresonanz Δ ←



Nukleon (Hochenergie)

$$S_z^{(N)} = \frac{1}{2} = \frac{1}{2}\sum_i (q_i\uparrow - q_i\downarrow) + (g\uparrow - g\downarrow) + L_z$$

(Drehimpulserhaltung)

q_i - Impuls vert.!

→ Schlüsselexp. am CERN und SLAC:

Tiefinelastische polarisierte LEPTON-NUKLEON Streuung

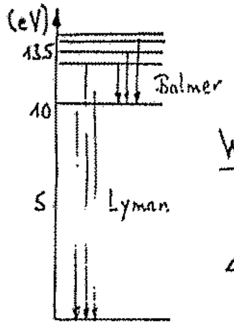
Untersuchung von Spineffekte ⇒

Zukunft: Polarisationsexperimente

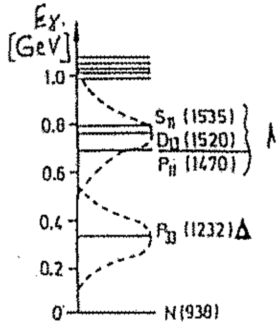
d.h. mit verbesserten Polarisationstechniken verbesserte und neue Experimente an den neuen und alten Beschleunigern

Interne Freiheitsgrade der HADRONEN

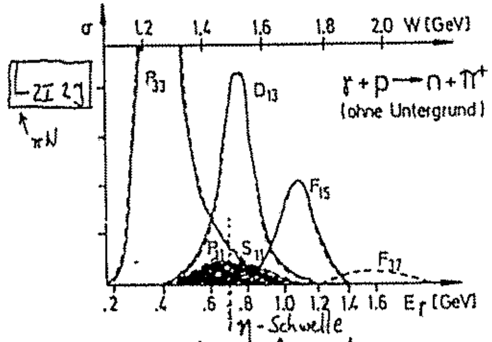
möglicher Lösungsweg : Untersuchung von angeregten resonanten Zustände



Wasserstoff	Nukleon
$\tau \sim 10^{-8}s$	$\tau \sim 10^{-23}s$
$\Delta E \sim 10^{-6}eV$	$\Delta E \sim 200\,MeV$

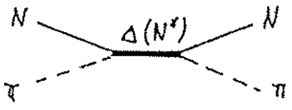


Problem : viele überlappende Resonanzen bzw.
viele verschiedene Multipolbeiträge



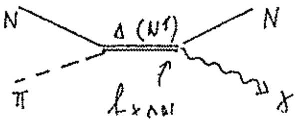
qualitatives Bild für die
relative Stärke der ersten
angeregten Zustände

Großteil der Informationen :
(Masse, Breite, Quantenzahlen)

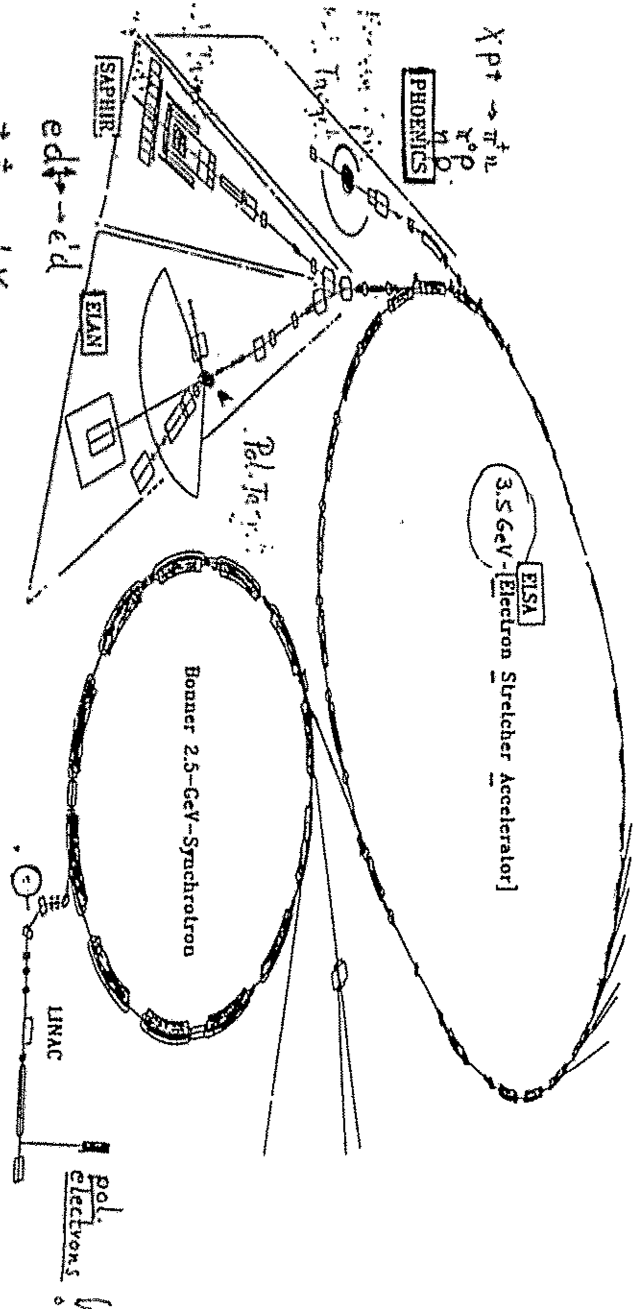


Elektromagnetische Eigenschaften der NUKLEON Resonanze
('Radiation Decay')

Experimentell : π- PHOTOPRODUKTION



ELSA (Bonn Univ.) – One topic – Polarizationexp



$\vec{\gamma}\vec{p} \to \pi^+ n$
$\pi^0 p$
ηp

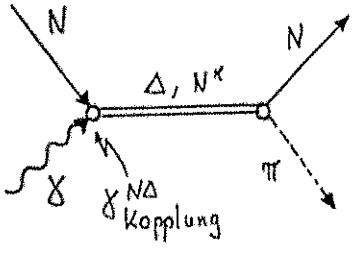
$e\vec{d} \to e'd$

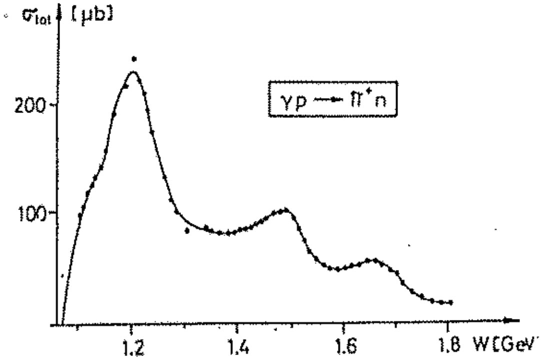
$\vec{e}\vec{p} \to e'X$

(DHG-exp. in preparation)

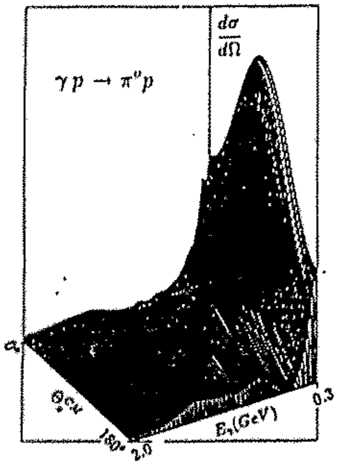
(→ CERN 1985, 19
SLAC 1993/94

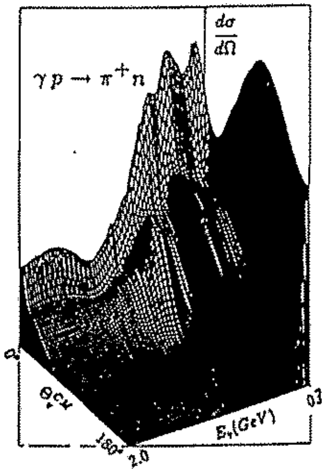
RESONANZ ANREGUNG des NUKLEONS





$\gamma p \to \pi^0 p$
$\gamma p \to \pi^+ n$
$\gamma n \to \pi^- p$
$\gamma n \to \pi^0 n$





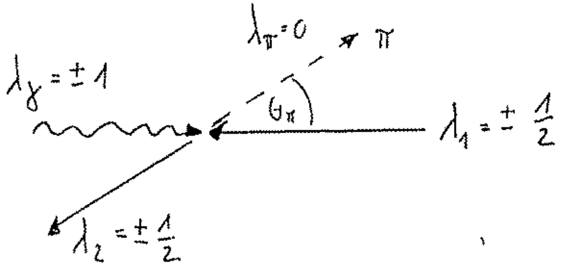
Res. deutlich sichtbar

Aber: unmöglich, schwach angeregte Resonanzen, kleine Multipolamplituden aus $\frac{d\sigma}{d\Omega}$ zu isolieren.

Strategie: Polarisationsobservable
verschiedene Reaktionskanäle

SPINABHÄNGIGKEIT des WW:

Theoretische Beschreibung im Helizitätsformalismus $[\lambda = \frac{\vec{\sigma}\cdot\vec{p}}{|\vec{p}|}]$



Helizitäts - Amplituden: $A(\underbrace{\lambda_\gamma, \lambda_1, \lambda_2}; K, \theta_\pi)$

$= H_i(K, \theta)$

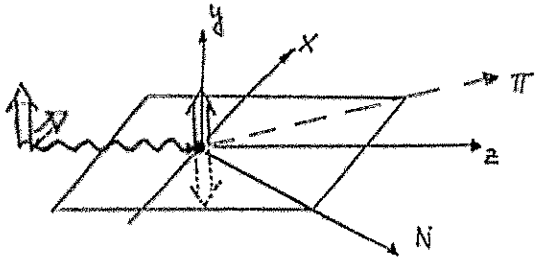
PHOTOPRODUKTION: 4 unabh., kompl. $\underline{H_1 \dots H_4}$

→ 7 unabh. Messungen

→ $\frac{d\sigma}{d\Omega}$ + 6 Pol. Observable

Daten → Partialwellenanalyse → γ - Koppl. konstanten

MESSGRÖSSEN



$$\frac{d\sigma}{d\Omega} \sim |H_1|^2 + |H_2|^2 + |H_3|^2 + |H_4|^2$$

$$\Sigma \sim \mathrm{Re}\,(H_1 H_4^* - H_2 H_3^*)$$

$$T \sim \mathrm{Im}\,(H_1 H_2^* + H_3 H_4^*)$$

Doppelpolarisation, z.B.

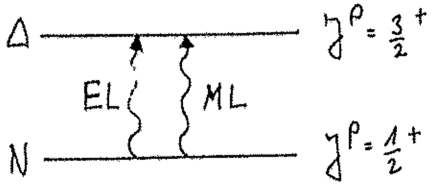
$$G \sim -\,\mathrm{Im}\,(H_1 H_4^* + H_2 H_3^*) \quad \left\{ \begin{array}{l} \text{Strahl } 45^\circ \\ \text{Target } P_z \end{array} \right.$$

Multipolentw.: $(\ell \leq 1)$

z.B.: $H_1 = -\frac{1}{\sqrt{2}} \cos\theta \left[2E_{0+} - 2M_{1-} - 3E_{1+} - M_{1+} + 3\cos\theta\,(3E_{1+} + M_{1+}) \right]$

Polarisationsgrößen: Höhere Sensitivität auf kleine Multipolamplituden durch Interferenzterme

UBERGANG N → Δ



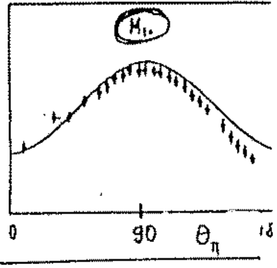
Parität- und Drehimpulssatz.

→ $\boxed{E2,\ M1}$

M_{1+}, E_{1+} mögliche Multipolamplituden

M1+ dominiert: $\frac{d\sigma}{d\Omega} \sim |M_{1+}|^2 (5 - 3\cos^2\theta)$

$\gamma N \to \pi N;\ k_\gamma = 340$ MeV



$$\mathrm{EMR} = \frac{E_{1+}}{M_{1+}} = ?$$

Theoretisches Interesse:

- SU(6)-sym. Quarkmodell:

$$\uparrow\uparrow\downarrow \xrightarrow[\gamma N\Delta]{} \uparrow\uparrow\uparrow \quad L^q = 0$$

N(938) $S_q = \frac{1}{2}$ Δ(1232) $S_q = \frac{3}{2}$

QUARK SPIN FLIP ≙ magnetischer Dipolübergang M_{1+}

EMR = 0 ; sphär. Lad. verteilung

QCD-inspirierte Modelle: (z.B. Isgur, Karl + Konjuk)

- Deformation von N, Δ durch qq-Tensorkräfte
- d-Wellen-Beimischung ($L^q = 2$) in der Quarkwellenfunktion

⟹ EMR ≠ 0 ; $E_{1+} \neq 0$

Kleine Effekte < 1.5% ⟹ Polarisationsobservable

$\frac{d\sigma}{d\Omega}$ nicht sensitiv genug

Datenbasis muß verbessert werden:

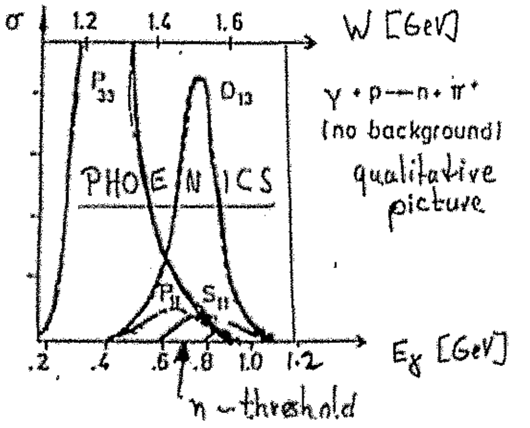
PHOENICS, [illegible]

PHOENICS

(PHOton Experiments on Nuclei In
Counter Set-up)

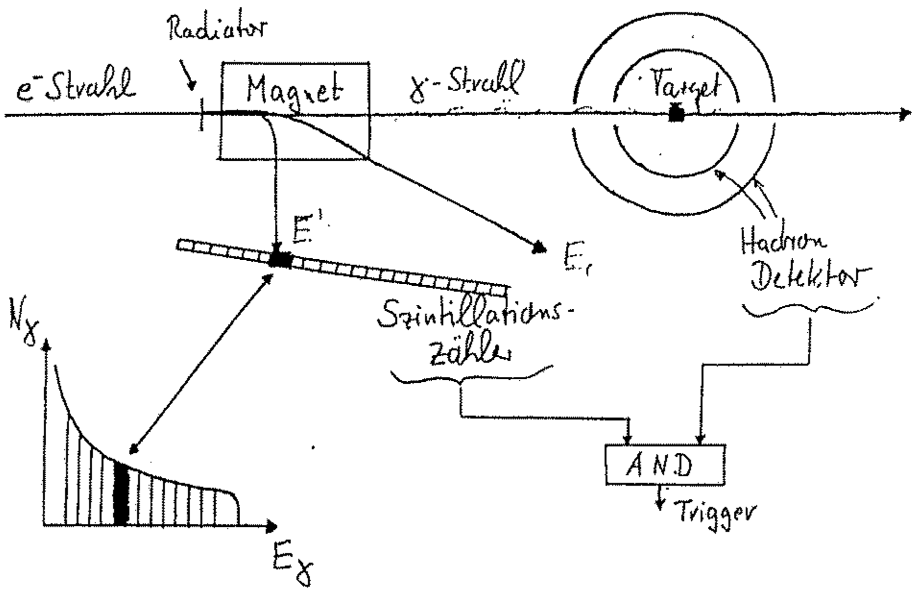
≙ tagged Photon facility with $0.2\,\text{GeV} \le E_\gamma \le 1.15\,\text{GeV}$

• $\gamma p \to \pi^+ n$	$d\sigma/d\Omega$	
∘ $\gamma p \to \pi^+ n$	Targetasy.	← new data
⋮		
$\gamma p \to \eta p$	$d\sigma/d\Omega$	} data in evaluation (some publ.)
$\gamma n \to \eta n$	$d\sigma/d\Omega$	
* $\gamma p \to \eta p$	Targetasy.	in preparation



Photoreaktionsexperimente mit energiemarkierten Photonen

Bremsstrahlung : $e A \to e' A \gamma$

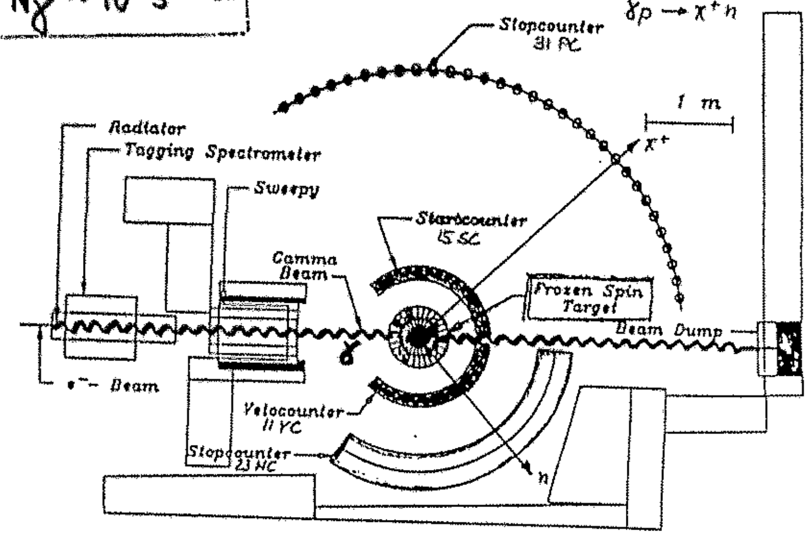


Vorteile :

- genaue Photonenergiebestimmung
  $E_\gamma = E_0 - E'$; $\Delta E_\gamma = 2 - 10\,\text{MeV}$
  $E_\gamma \sim (0.2 - 1.15)\, E_0$
- definierter Photonenfluß
  $\dot{N}_\gamma \sim 10^7 \cdot d \cdot \text{sec}^{-1}$
  ← Duty-Faktor des e^--Strahls
- ideale Kombination mit einem FROZEN SPIN TARGET

PHOENICS – Aufbau für PION – PHOTOPRODUKTION

$\boxed{\dot{N}_\gamma \sim 10^7 s^{-1} \cdot d.}$



- überdeckt einen großen Kin. Bereich gleichzeitig ($E_\gamma ; \theta_\pi$)
- 2 Teilchen Nachweis im Endzustand

→ Kinematische Überbestimmung

notwendig : E_γ , θ_π

gemessen wird zusätzlich : $\phi_\pi ; \phi_n$
β_π
β_n
θ_n

ERGEBNISSE : $\gamma p \rightarrow \pi^+ n$

Nucl. Phys. A570 (1994) 541

$d\sigma / d\Omega$

Kinematischer Bereich : $E_\gamma = 200 - 950$ MeV
$\theta_\pi^{cm} = 35° - 135°$

Bins : $\left.\begin{array}{l}\Delta E_\gamma = 30 \text{ MeV} \\ \Delta \theta_\pi^{cm} = 10°\end{array}\right\}$ 290 Datenpunkte

Leertargetbeitrag : ≤ 1%
Untergrundbeitrag : 1 – 4%
Fehler von ε_n : 2.5 – 6.5%

Totaler systematischer Fehler : 4 – 8%
Typischer statistischer Fehler : 3 – 5%
Max. stat. Fehler : 35%

1. Schritt

POLARIZED TARGET BONN

since 1969 (K.H. Althoff, H. Herr, W.M.)

$$P_{(\frac{1}{2})} = \tanh \frac{\mu B}{kT}$$ ← high magn. field ← low temperature

today : 3 operating systems

magn. fields : 2.5; 3.5; 5.0 Tesla

temperatures : 1.0; 0.5; 0.2; 0.05 Kelvin
↑ ^{4}He-refr. ↑ ^{3}He-refr. ↑ ^{3}He-^{4}He dil. refr.

target materials : alcohols ; NH_3 ; ND_3 ; ^{7}LiH ; ^{6}LiH ; ^{6}LD, HD
↓ BONN ↓ CERN (SLAC) ↓ PSI (SLAC) BONN ↓ Studies started and planned

P_p = 80 - 100%
P_D = 30 - 50%

Experiments:

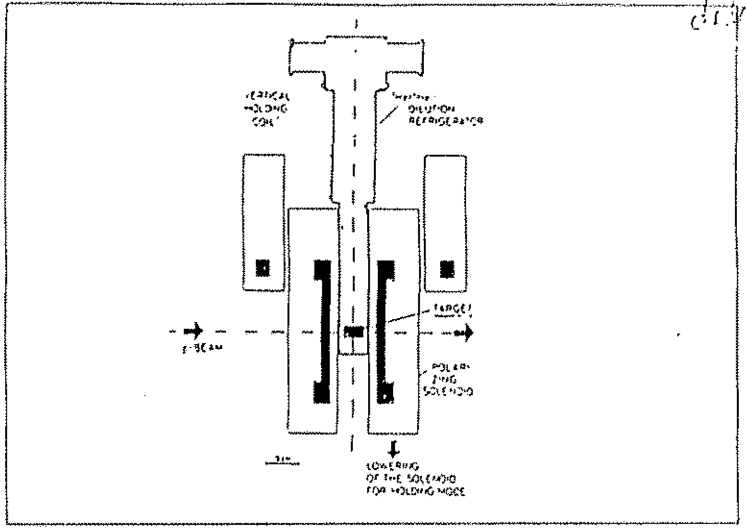
$\gamma p \rightarrow \pi^+ n$
$\gamma n \rightarrow \pi^- p$
$\gamma d \rightarrow p n$
$e d \rightarrow e' d$
} Bonn (2.3 GeV synchrotron

→ $\gamma p \rightarrow \pi^+ n$
$\gamma p \rightarrow \pi^0 p$
} Phoenics - ELSA

in progress $\gamma p \rightarrow \eta p$ Phoenics - ELSA
$\gamma p \rightarrow X$ DHG - Mainz/Bonn

planned $\gamma p \rightarrow K^+ \Lambda$
$\gamma p \rightarrow K^+ \Sigma$
} Saphir - ELSA

BONN-FROZEN-SPIN TARGET at PHOENICS
↖ decisive for large angle [illegible]



Polarizing field	5 tesla
Holding field	0.35 tesla
Target temperature	≤ 60 mK
Target material	butanol (C_4H_9OH)
maximum polarization $P_{max.\pm}$	~ 92%
relaxation time τ_n ($T_{/\!\!,} \approx 60mK$)	120 h
averaged polarization (24 hour cycle)	84%

Table 2: Characteristics of the Bonn Frozen Spin Target

POLARIZATION OBSERV.

TARGETASYMMETRY : $T = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow}$

EXPERIMENT : counting rate asymmetry ε

$$\varepsilon = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow} = \frac{N_{pol}\uparrow - N_{pol}\downarrow}{N_{pol}\uparrow + N_{pol}\downarrow + 2N_B}$$

$$\Rightarrow \boxed{T = \frac{1}{P} \cdot \frac{1}{K} \cdot \varepsilon}$$

$$\frac{1}{K} = \frac{N_{total}}{N_{pol}\uparrow + N_{pol}\downarrow} \quad C_4H_{10}O + H_2 \ldots$$

P = Nucleon Pol.

in the past : $N_{pol}\uparrow + N_{pol}\downarrow = 2N_{unpol.} = N(CH_2) - N(C)$

$$\frac{1}{K}(E_\gamma, \theta) \approx 3 \ldots 5$$

PHOENICS now : Kinematical overdetermination $\frac{1}{K}(E_\gamma, \theta) \approx 1$

OUR EXPERIMENT $\frac{1}{K}(E_\gamma, \theta) \approx 1.1 \ldots 1.2$

$\Delta T \approx \frac{1}{P^2} \cdot \frac{1}{K^2} \cdot \frac{1}{\sqrt{N\uparrow + N\downarrow}}$ $\Rightarrow$ with 2500 Events

$\Delta T \approx 3\%$ (statistical error)

$$\boxed{T = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow} = \frac{1}{P} \cdot \frac{1}{K} \cdot \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}}$$

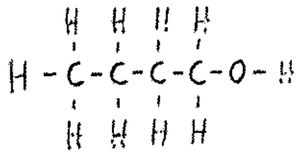
P = proton pol. = 0.85

K = dilution factor = 0.9

$N\uparrow\downarrow$ = counting rate

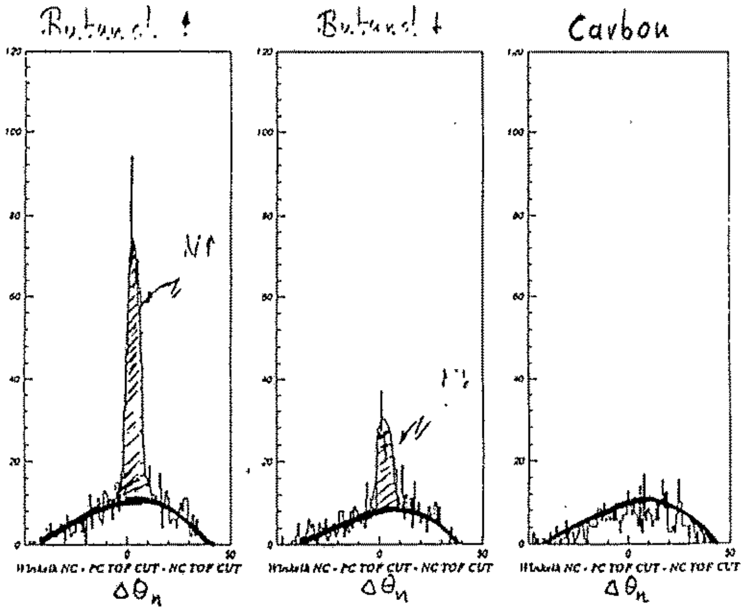
for fixed ΔT → measuring time $\sim \frac{1}{P^2} \cdot \frac{1}{K^2}$

Target material : BUTANOL



$$H-CH_2-CH_2-CH_2-CH_2-O-H$$

On line example : $E_\gamma = 300\,MeV$, $t = 20\,min$ each



Doktorarbeiten:
H. Dutz
D. Krämer
B. Zucht

ERGEBNISSE: $\gamma p^{\uparrow} \rightarrow \pi^{+} n$

Targetasymmetrie $T = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow}$

Kinematischer Bereich: $E_\gamma = 215 - 850$ MeV
$\theta_\pi^{cm} = 35° - 135°$

Bins: $\left.\begin{array}{l}\Delta E_\gamma = \pm 20\,\text{MeV} \\ \Delta \theta_\pi^{cm} = \pm 5\%\end{array}\right\}$ 216 Datenpunkte

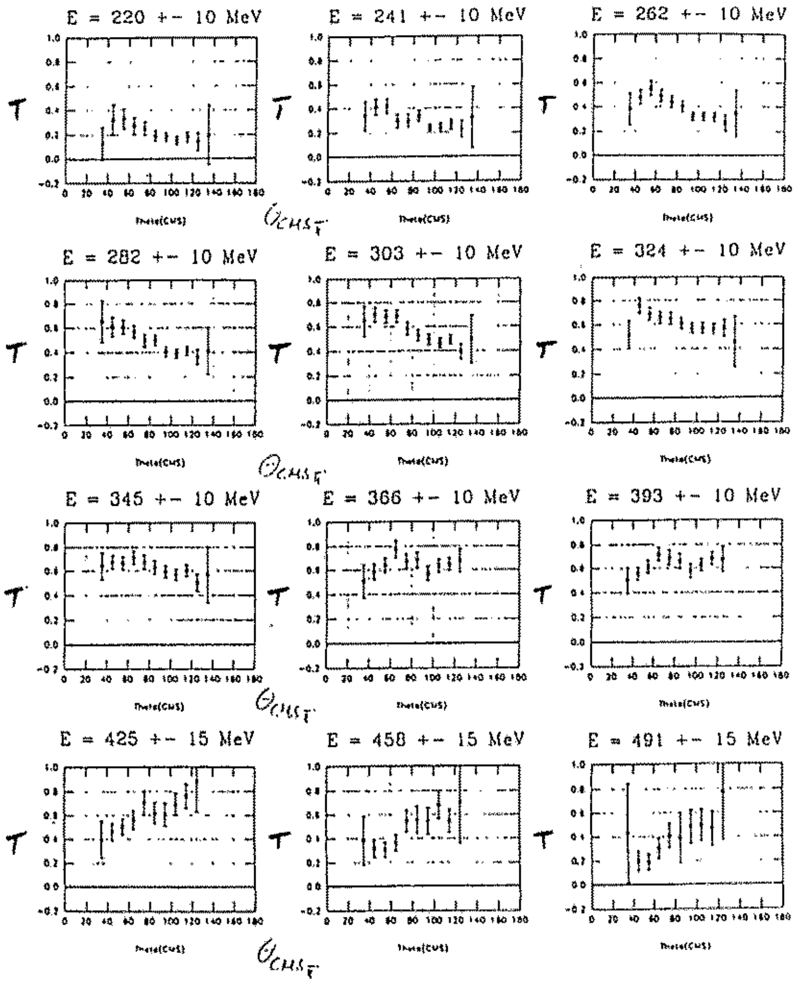
Syst. Fehler: 3%

Syst. + stat.: 4% - 15%
Fehler
(Datenpunkte)

2. Schritt

Results: angular distribution π^{+} - production

$220 \le E_\gamma \le 491$ MeV



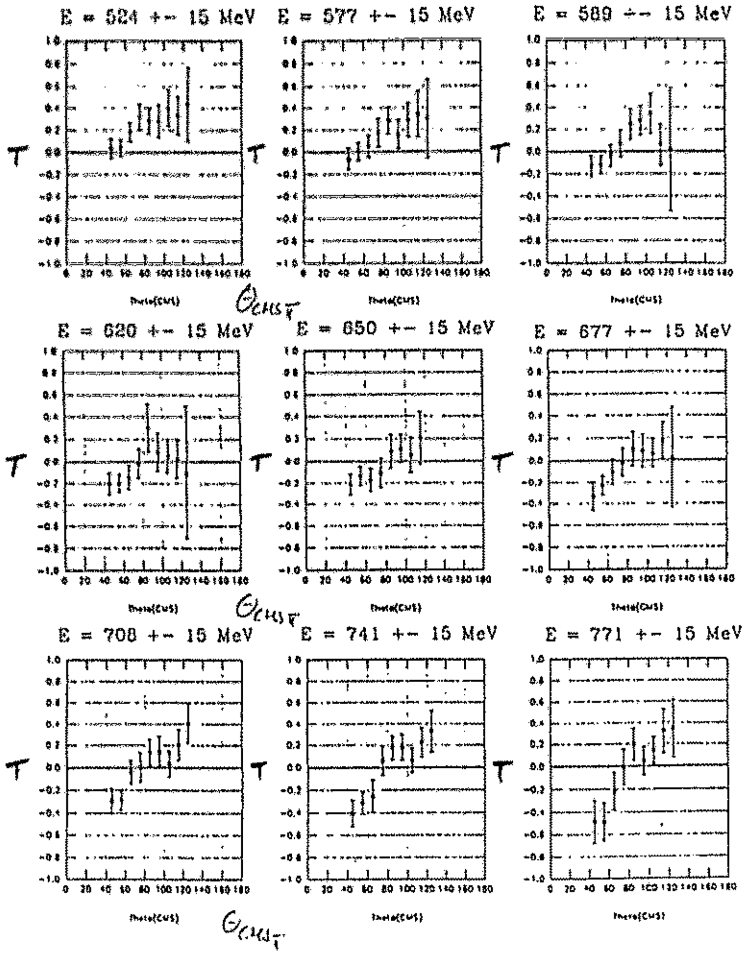
all data: $\Sigma = 3150$ data points

error bars included statistic and systematic error

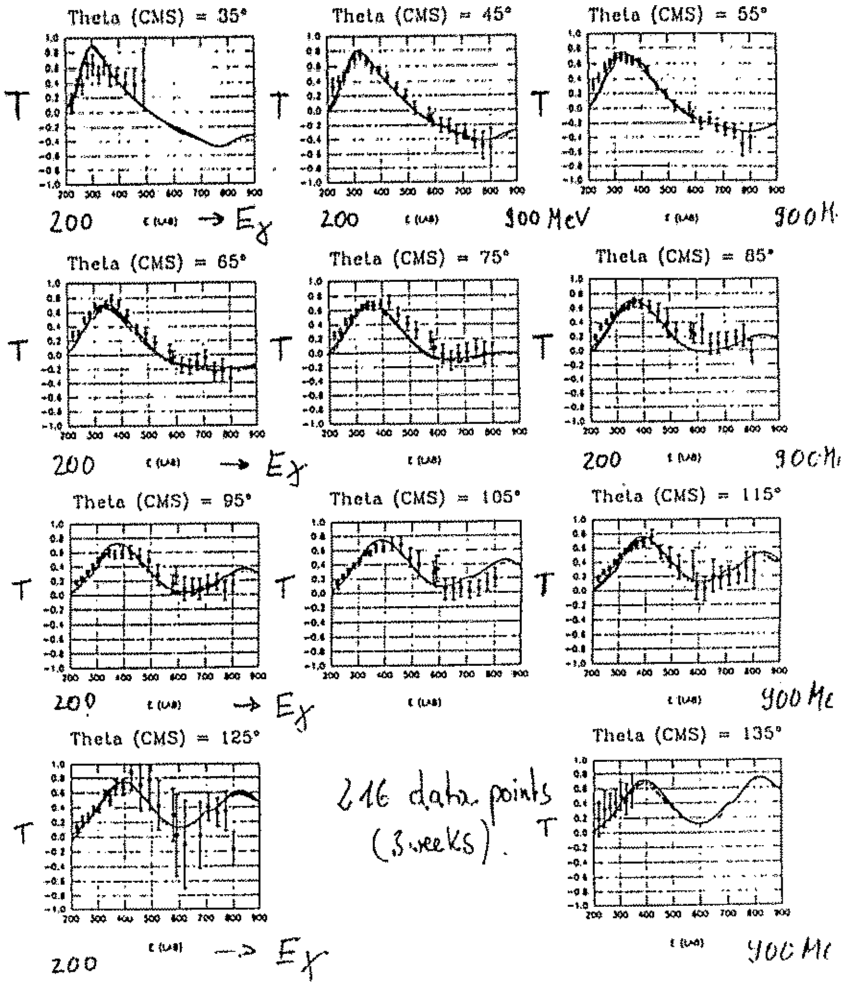
systematic error => only $\Delta P = 3\%$

Results : angular distribution π^+ - production

$524 \leq E_\gamma \leq 800$ MeV



I⁻ $\sigma\uparrow + \sigma\downarrow$ UI

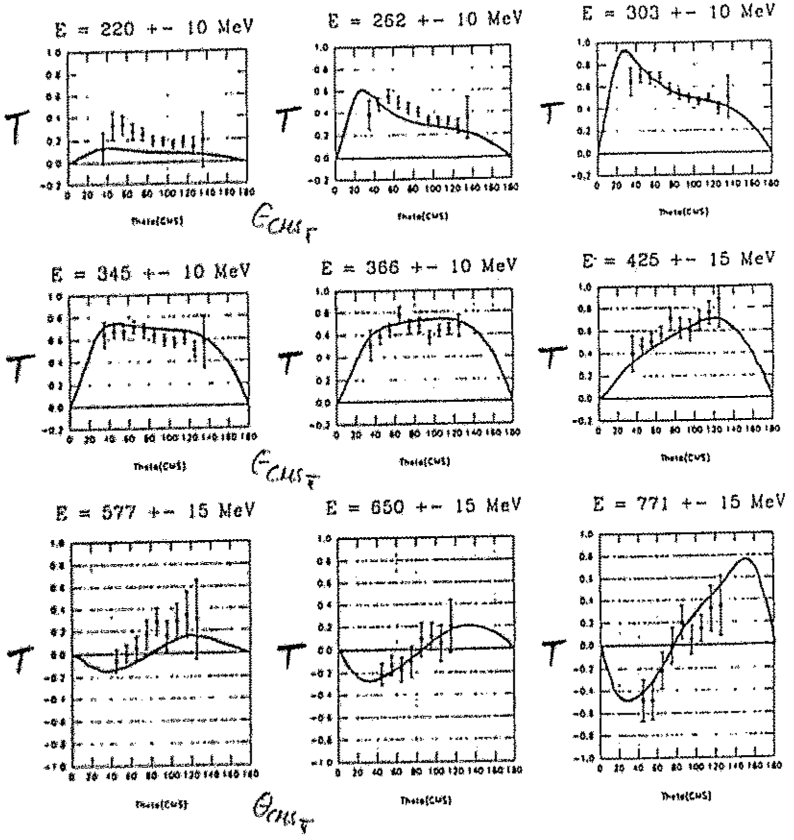


216 data points (3 weeks).

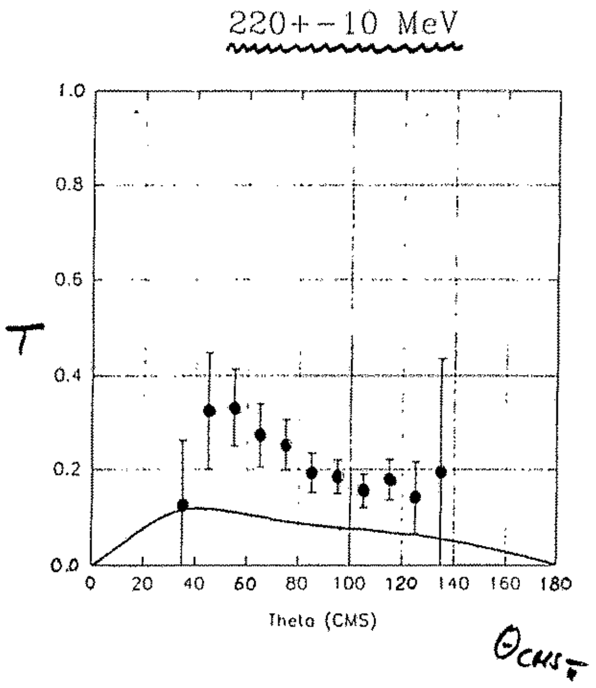
Abbildung 6.11: Vergleich der Targetasymmetriedaten mit theoretischen Analysen. T in Abhängigkeit von E_γ im CM-System. o: unsere Messung. Durchgezogene Linie: [8]

Arndt et al. PWA 59 (1996)

angular distribution π^+-production



— : Arndt et al., Phys. Rev. C42 (1990) 1853
I. Strakowsky, (1994)



$$T(\Theta) = \frac{|\vec{q}|}{|\vec{k}|} \frac{1}{d\sigma/d\Omega} \sin\Theta \, (a + b\cos\Theta)$$

$$a = \mathrm{Im}\left(\underline{E_{0+}}\, 3\, (\underline{M_{1+}^*} - E_{1+}^*)\right)$$

$$b = 3\,\mathrm{Im}\left(-(M_{1+}^* - E_{1+}^*)M_{1-} + 4M_{1+}^* E_{1+}\right)$$

Ausblick : Weitere Messungen

		Strahl	Target
Beamasymmetrie	Σ (Mainz)	$L(\frac{\pi}{2};0)$	–
Doppelpolarisation ↳	$\Sigma;T;P$	$L(\frac{\pi}{2};0)$	y
	$G;H$	$L(\pm\frac{\pi}{4})$	$z;x$
MVU-MAINZ GDH-coll. →	$E;F$	C	$z;x$

Strategie 2 :
verschiedene
Reaktionskanäle

→ $S_{11}(1535)$

$\gamma p \to \eta p$

$\gamma d \to \eta \, (p)(n)$

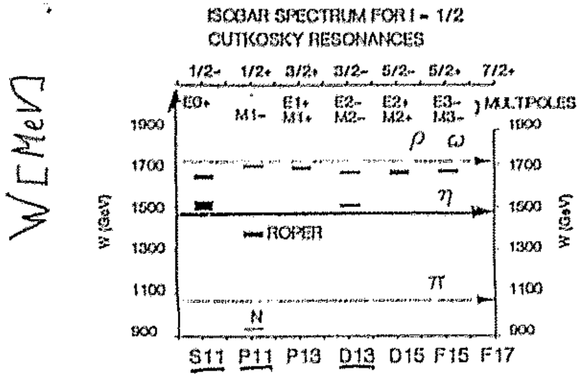
$\gamma\, {}^{14}N \to \eta \, (p)(n)$

$\gamma d \to \eta d$

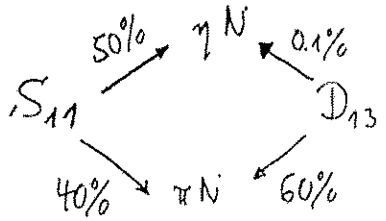
Targetasymmetrie $\gamma p^{\uparrow} \to \eta p$
Bonn 1994.

η – Photoproduction : why :

- selective · $\eta : I=0 \Rightarrow$ only $I=\frac{1}{2}$ - resonances



$P_{11}(1440)$
$D_{13}(1520)$
$S_{11}(1535)$

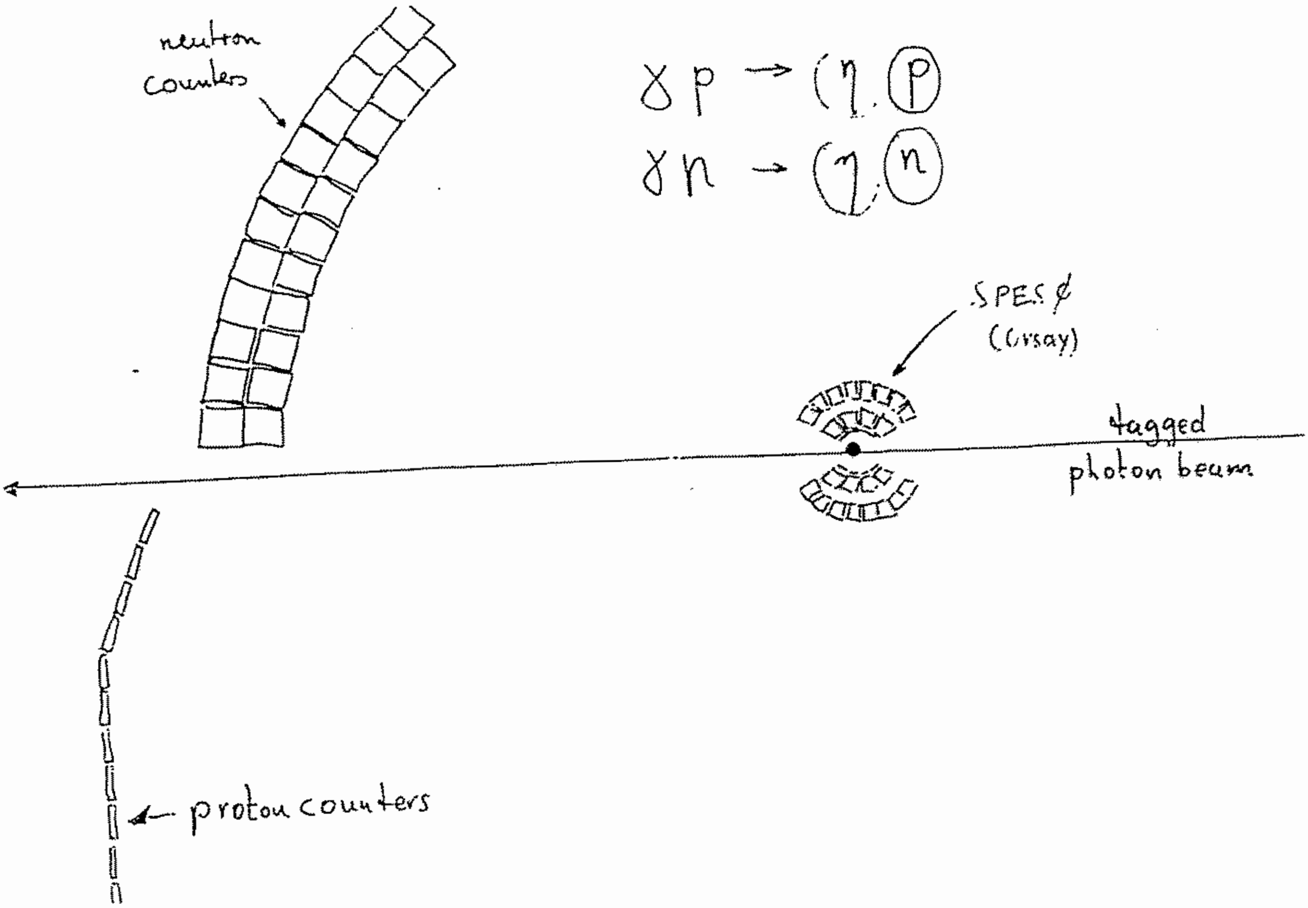


- study of 'small' resonances
  → S_{11} dominant at the threshold

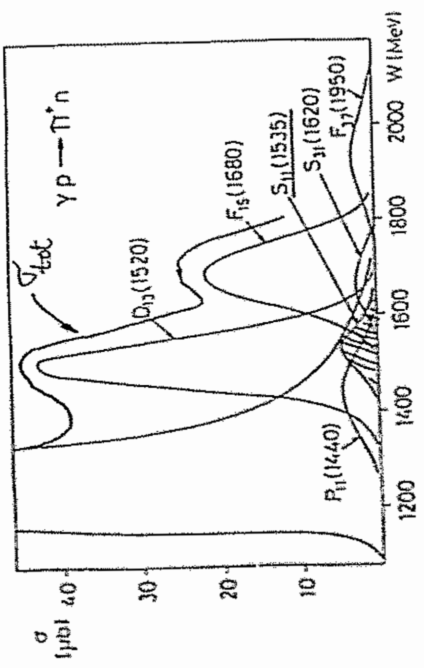
- tests of quark model

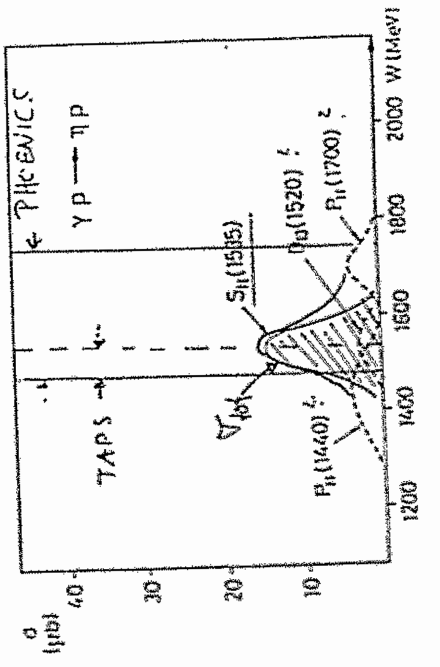
$\gamma p \rightarrow (\eta\, \text{ⓟ})$

$\gamma n \rightarrow (\eta\, \text{ⓝ})$



Resonance excitation at $\left\{ \begin{array}{l} \gamma N \rightarrow \pi N \\ \gamma N \rightarrow \eta N \end{array} \right.$

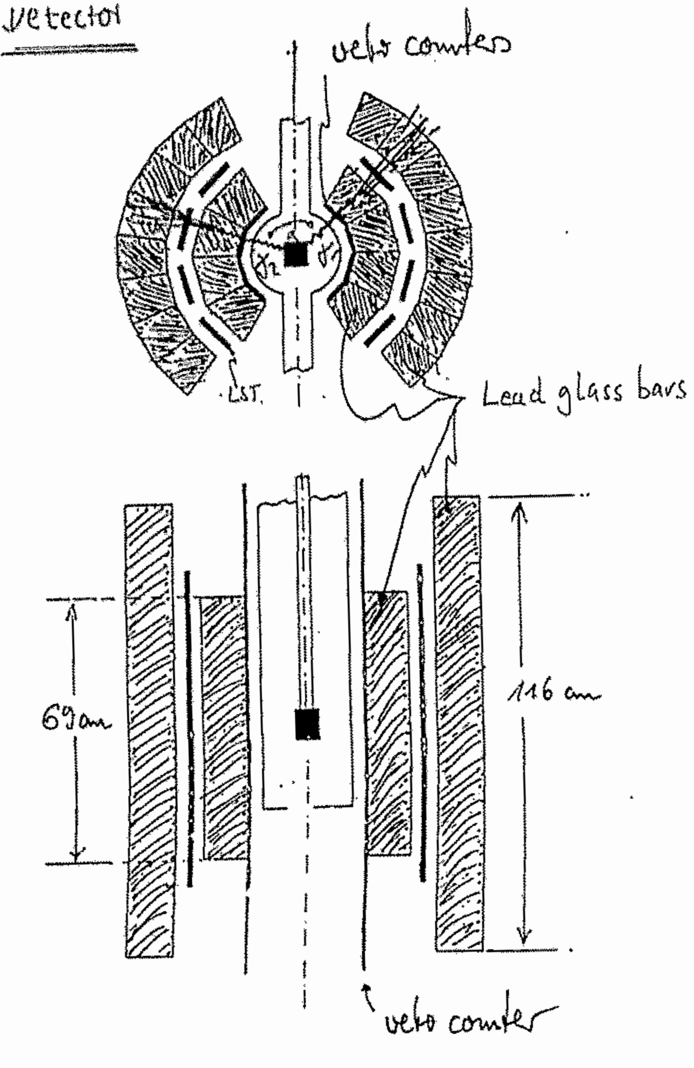




$\gamma N \rightarrow \eta N$: strong selectivity for S_{11} (153

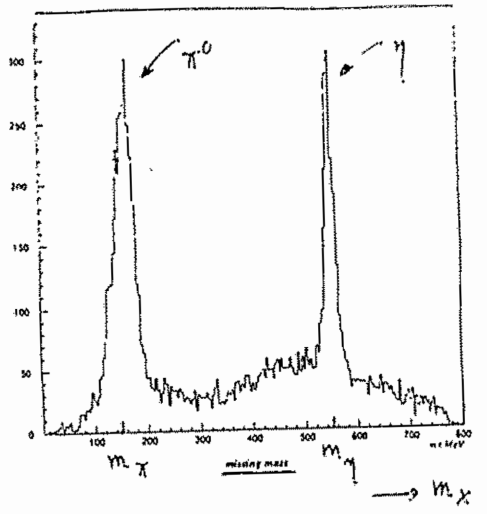
SPESP - Detector

acceptance
$\Delta\Omega = 2\pi$ sr

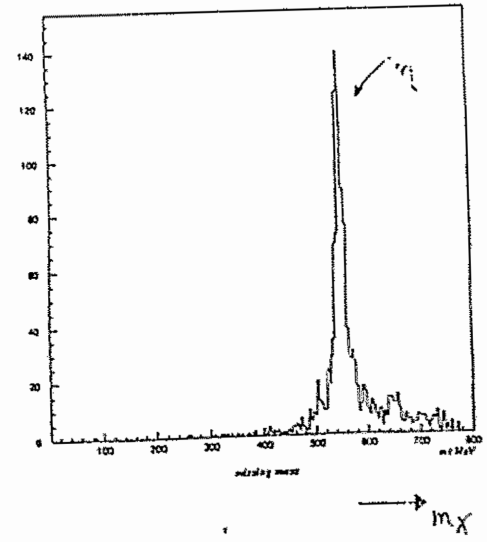


Missing distribution

PHOENICS



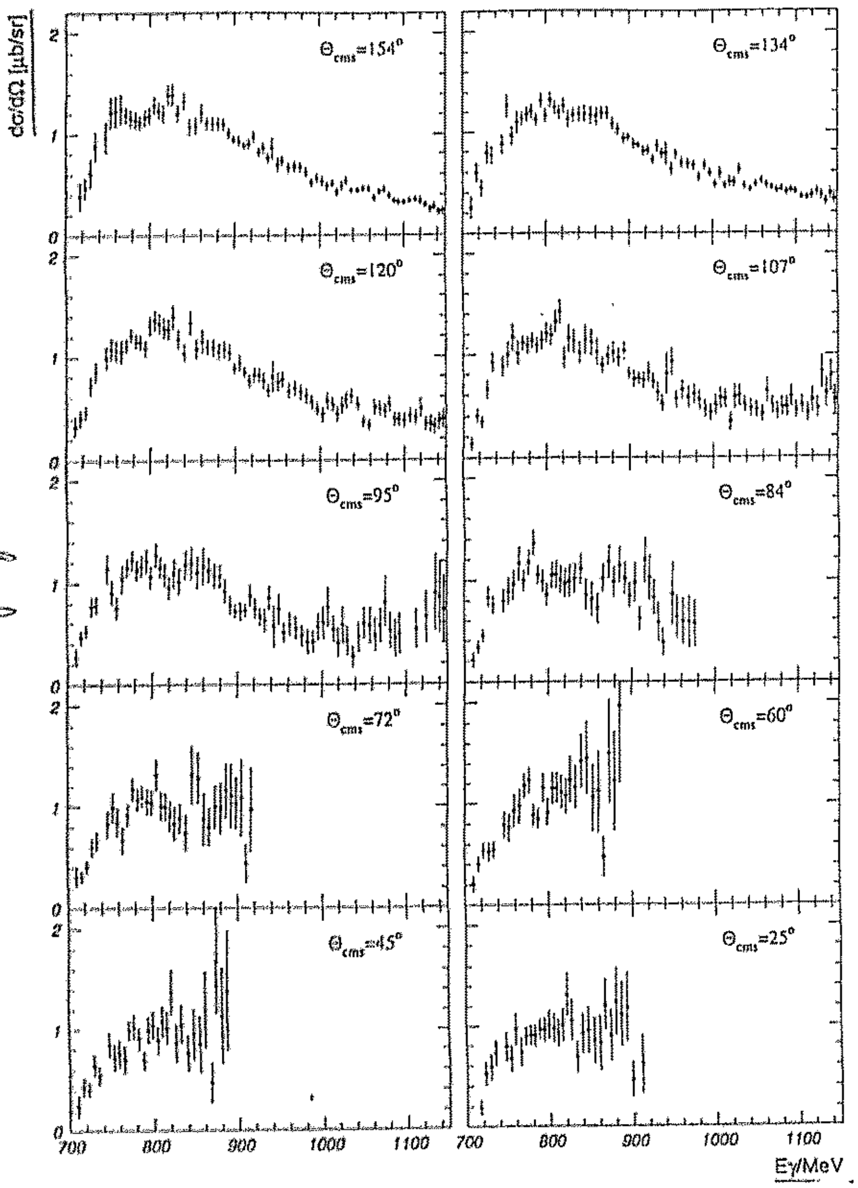
$\gamma p \rightarrow pX$
X reconstructed



after cut
on $\eta \rightarrow \gamma\gamma$
in SPESP

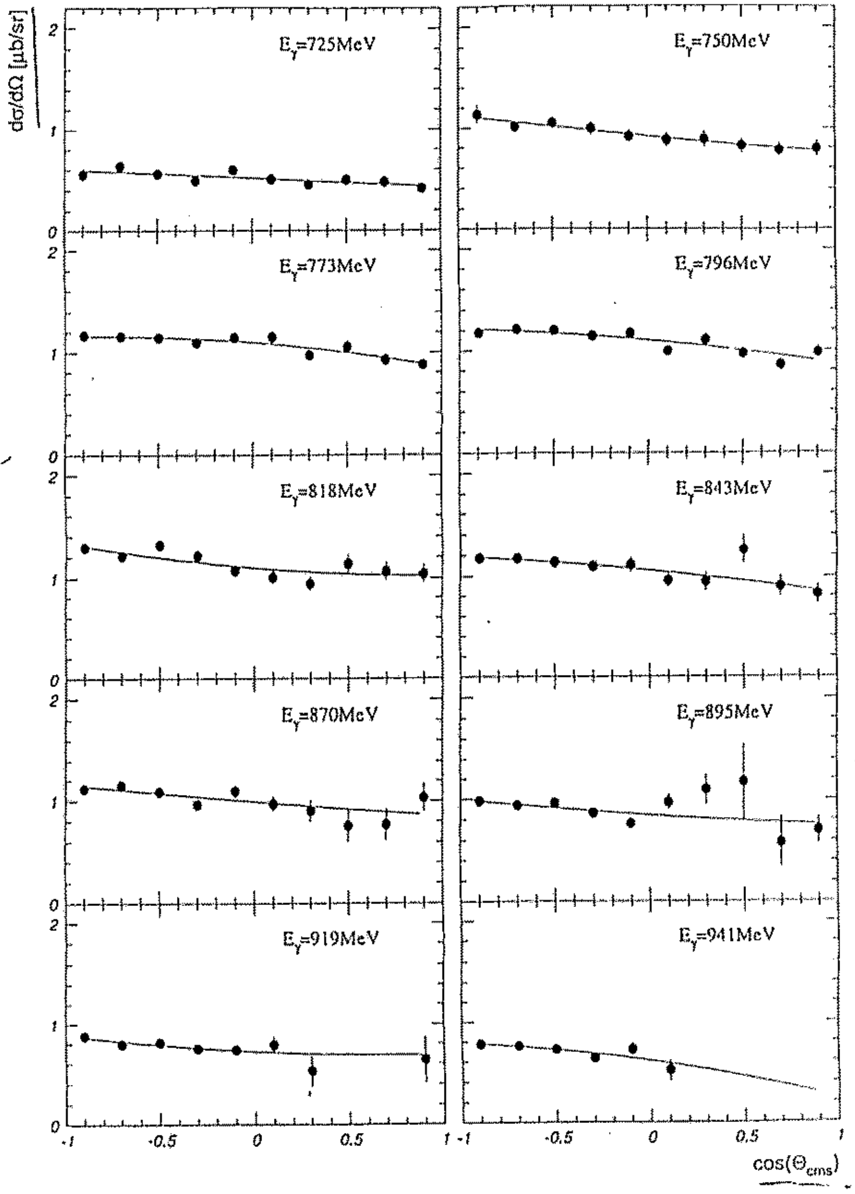
γp → ηp (vorläufig 30% aller Daten) [Bonn · Göttingen Orsay]

Anregungskurven

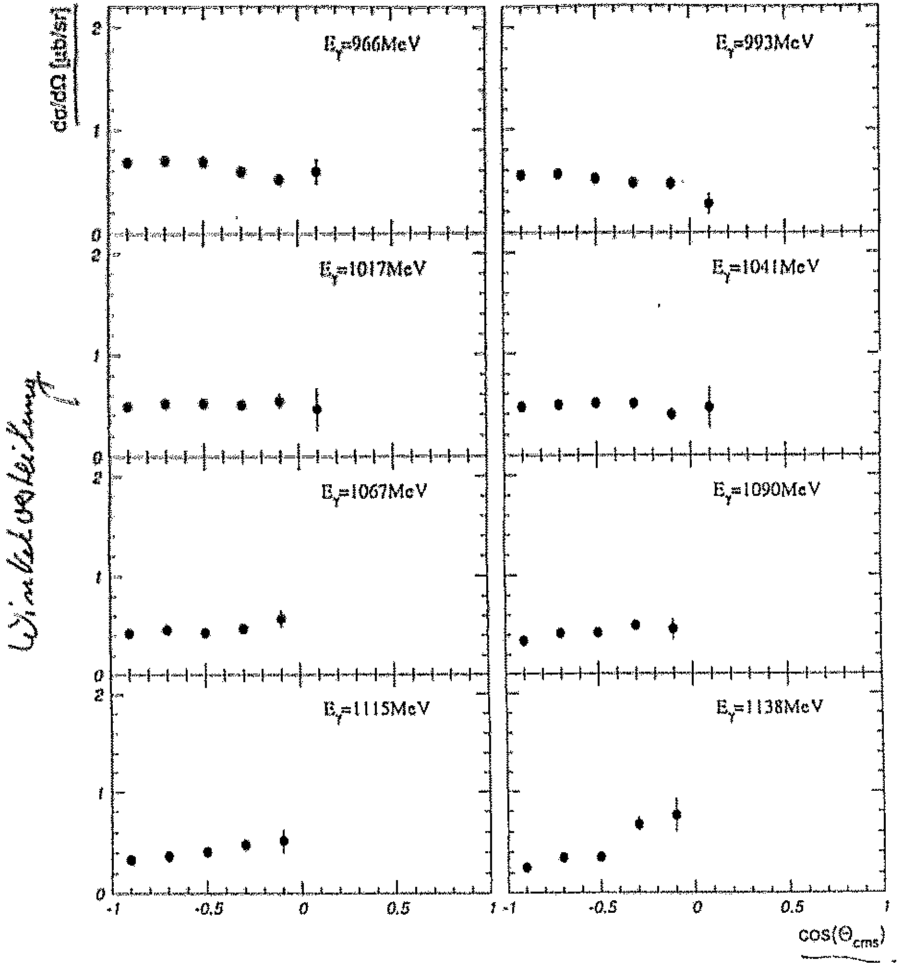


γp → ηp (preliminary 30% aller Daten) [Bonn Orsay]

Winkelverteilung



$\gamma p \to \eta p$ (vorläufig 30% aller Daten) [Bonn - Göttingen Orsay]



What ISOSPIN $I = \frac{1}{2}$ Resonances are involved?

S_{11} decays mainly in η N with angular momentum $\ell = 0$

↳ excited by an electrical dipol E_{0+}.

P_{11} ← excited by an magnetic dipol M_{1-} $(\ell = 1)$

$$\frac{d\sigma}{d\Omega} = \frac{q}{k} \left(a + b \cos\theta + c \cos^2\theta \dots \right)$$

$$a = \frac{1}{2} |2M_{1+} + M_{1-}|^2 + \frac{1}{2} |3E_{1+} - M_{1+} + M_{1-}|^2 + |E_{0+}|^2$$

$$b = 2 \mathrm{Re} \left(E_{0+} (3E_{1+} + M_{1+} - M_{1-})^* \right)$$

$$c = |3E_{1+} + M_{1+} - M_{1-}|^2 - \frac{1}{2} |2M_{1+} + M_{1-}|^2 - \frac{1}{2} |3E_{1+} - M_{1+} + M_{1-}$$

If only S_{11} → isotropic angular distribution

" " P_{11} → " " "

S_{11} and P_{11} → interference term with $\cos\theta$ depends.

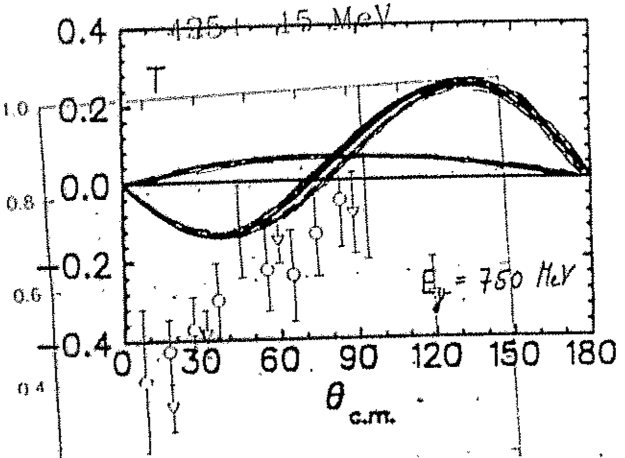
D_{13} contribution? → Prof. [illegible]:
e.g. TAPS [illegible]

$T = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$

Model calculation $\gamma p \to \eta p$

L. Tiator et al.

coupled channel $\gamma N - \pi N - \eta N$: S_{11} (1535)
D_{13} (1520)
P_{11} (1440)
+ born terms + vector meson exchange



— full calculation

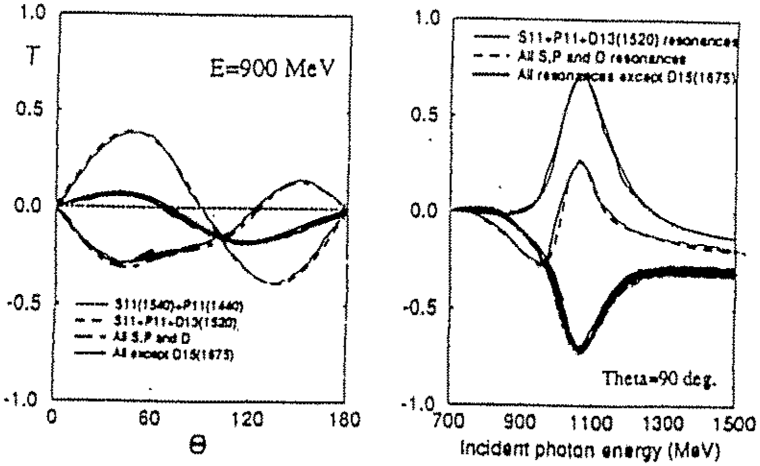
— without D_{13} (1520)

— without P_{11} (1440)

Model calculation $\gamma p \to \eta p$

B. Saghai et al.

amplitude = background + $\sum_{res}$ 'Breit Wigner'

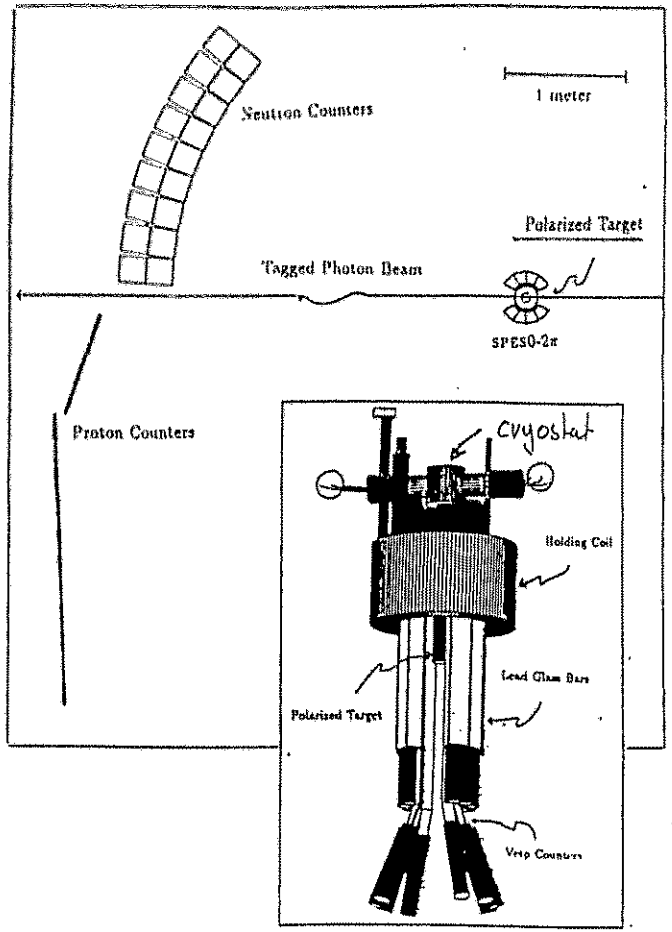


— full calculation

— without D_{15} (1675)

— $S_{11}(1535) + P_{11}(1440) + D_{13}(1520)$

Exp. Setup for $\gamma p\uparrow \rightarrow \eta p$



III FROZEN SPIN TARGET

Physics Principle: based on long Nuclear Relaxation Time T_{1n} at low temperature and moderate field

Procedure

(I)	Polarize by DNP at high field	2.5 … 5 Tesla
(II)	Switch off μ-waves → add. lowering of the temperature	T ≃ 50 mK
(III)	Change ~~to~~ Holding field → mechanical + elect. manipulations	0.3 – 0.5 Tesla
(IV)	DATA TAKING	
(V)	Reverse Polarization → starting at (I)	

⊕ : Open Geometry → Simultaneous Measurement of the Physical Observables over a large Kinematical region

⊖ : Online Measurement of the Pol. not possible

Fast and frequent Pol. Reversal not "

FROZEN SPIN TARGET for Experiments at INTERMEDIATE Energies with PROTONS; γ; NEUTRONS ($I_{BEAM} \leq 10^8$ part/sec)

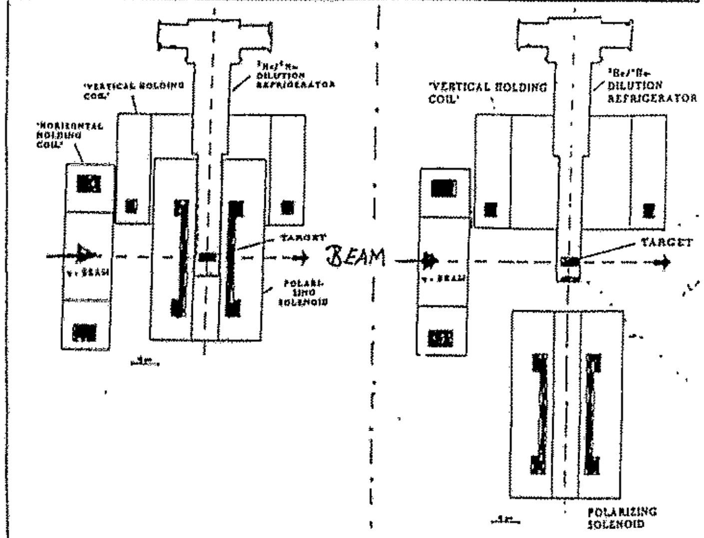
SACLAY

$pp \to pp$
$np \to np$

BONN

$\gamma p \to \pi^+ n$
$\qquad \pi^0 p$

$\gamma p \to \eta p$

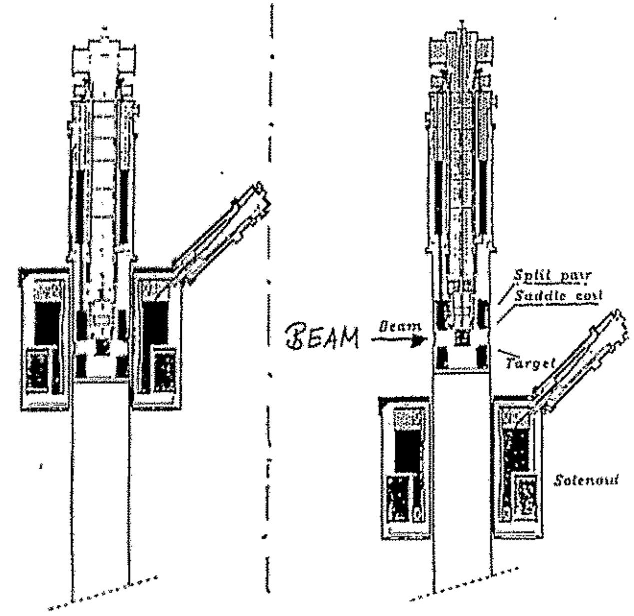


POLARIZING MODE | 'HOLDING' MODE

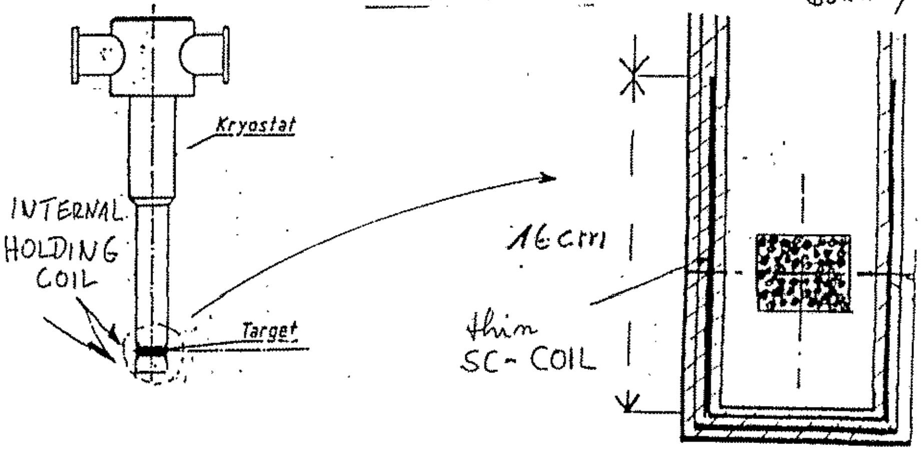
TRIUMF
CHAOS-Exp.

PSI

$np \to np$

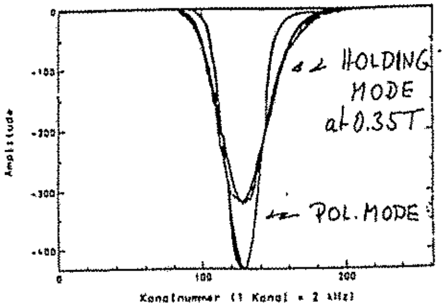


VERY THIN INTEGRATED SUPERCONDUCTING HOLDING COIL ([illegible] H. DUTZ BONN)



2 Layers of 100 μ thick SC-wire on 300 μ copper (radiation shield) in ISOLATION VACUUM

ON-LINE Pol. Measurement in the 'HOLDING MODE'



Coil data

Length	10 cm
Inside diameter	6.6 cm
Total thickness	500 μm
Diameter of wire	100 μm
Windings	2500 in 2 layers
Inductance	0.168 H
max. center field	0.35 T=3500 Gauss
Current	19.7 A
Current density	1550 $\frac{A}{mm^2}$
stored Energy	21 J

→ New EXPERIMENTS

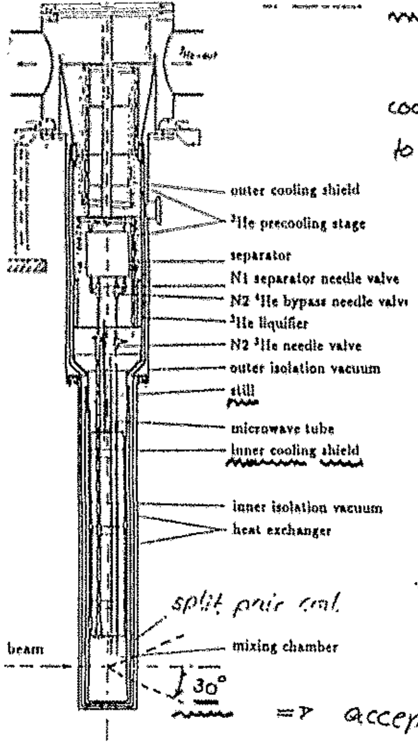
$\gamma p^{\uparrow} \to \eta p$ (BONN)

$\vec{\gamma}\vec{p} \to X$ GDH: $\int_0^\infty d\nu \frac{\sigma_{1/2} - \sigma_{3/2}}{\nu} = \frac{2\pi\alpha}{m^2}\kappa^2$ (MAINZ-BONN)

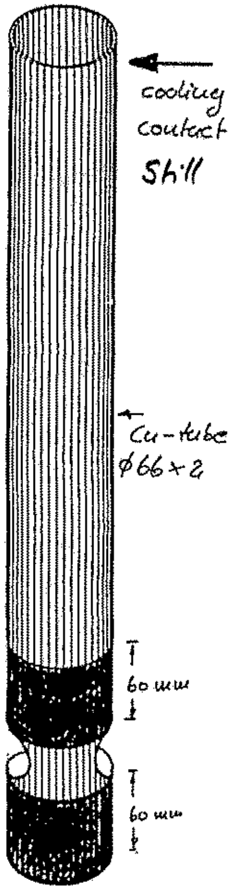
~ Internal superconducting holding magnets

principle: at a given field
decrease dimensions ⇒ decrease current

⇒ Internal magnet as a part of the refrigerator



spec: inner cooling shield
⇓
cooled by heat transfer to the still



wire:
100 μ NiTi

N = 2 × 5000

$B_{max} = 0.385\,T$

⇒ acceptance: ± 30° (cone)

⇒ coil successfully tested

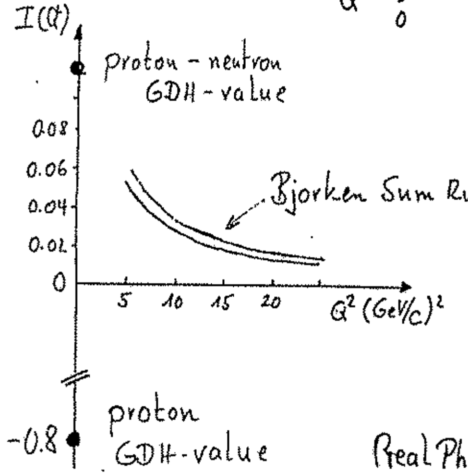
⇒ new class of pol. experiment can be performed

Gerasimov - Drell - Hearn Sum Rule

$$\int_0^\infty d\nu \, \frac{\sigma_{\frac{3}{2}} - \sigma_{\frac{1}{2}}}{\nu} = \frac{2\pi\alpha}{m^2} \, K^2$$

$$\sigma_{\frac{1}{2}} - \sigma_{\frac{3}{2}} = \frac{8\pi^2\alpha}{\nu - \frac{Q^2}{2m}} \left(m\nu \, G_1(\nu,Q^2) - Q^2 \, G_2(\nu,Q^2) \right)$$

$$I(Q^2) = \frac{2m^2}{Q^2} \int_0^1 dx \, g_1(x,Q^2)$$



Experimental verification needed!

Real Photons : $Q^2 = 0$

$$I(0) = \frac{m^2}{8\pi\alpha^2} \int_0^\infty \frac{\sigma_{\frac{1}{2}} - \sigma_{\frac{3}{2}}}{\nu} \, d\nu$$

required:

- circularly pol. real tagged photons
- long. pol. nucleon target
- 4π - detector
- 3 GeV or more

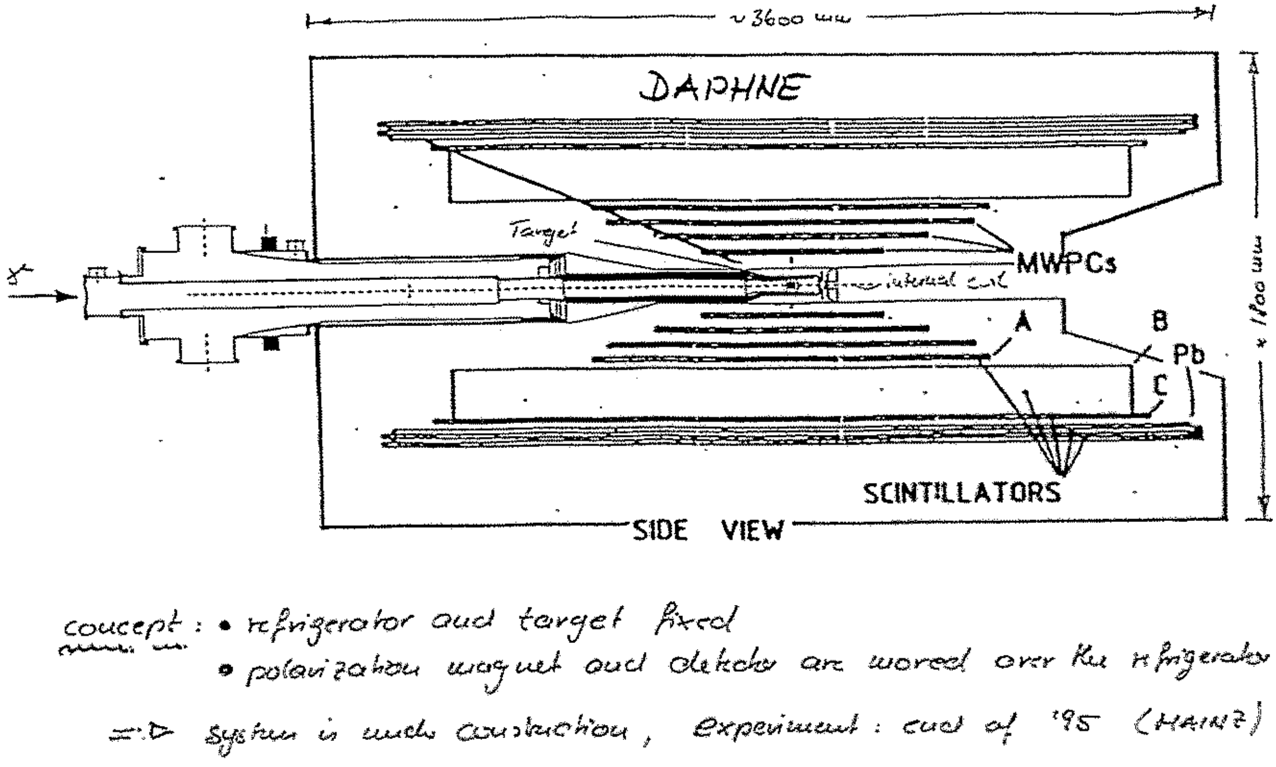
$\Big\}\ \sigma_{tot} (\vec{\gamma}\vec{p} \to X)$

Collaboration at MAMI (MAINZ) and ELSA (BONN)

Zusammenfassung

- Spin ist ein sensitives Instrument zur Untersuchung des Nukleons
- Erste Pol. messungen mit Pol. Target (PT) + Phoenics Detektor an ELSA
- Weiterer technischer Fortschritt am PT
  ↳ verbesserte + neue Pol. experimente (η- Produktion; GDH; …)

experimental mode / frozen spin mode



concept:
- refrigerator and target fixed
- polarization magnet and detector are moved over the refrigerator

⟹ system is under construction, experiment: end of '95 (MAINZ)

Experimente mit Pionen am PSI

H. Clement
Tübingen

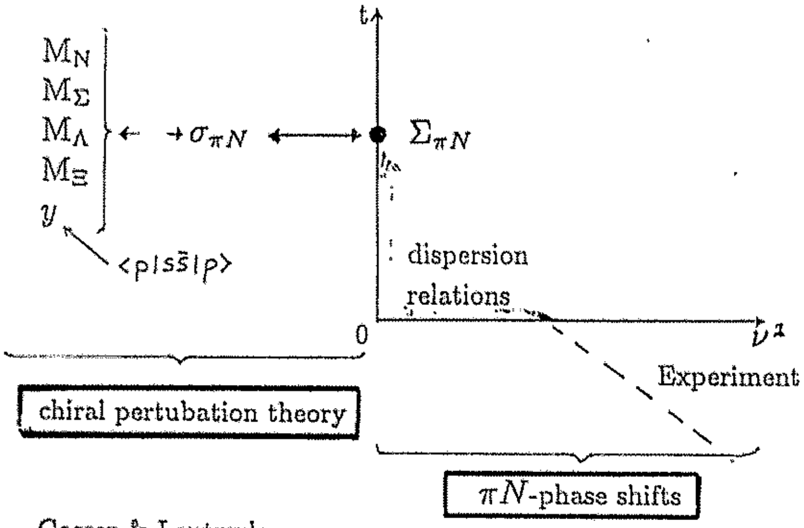
4.Oktober 1994

Experimente mit Pionen am PSI

- πN - System — LEPS
- Spin-Effekte in πA - Streuung — Boschitz et al.
- π - Absorption in Kernen — LADS
- Doppelter Ladungsaustausch und πNN - Resonanz (d') — LEPS

πp-Scattering at Low Energies

- reliable πN-phase shifts
- $\sigma_{\pi N} \sim \langle p|\bar{u}u + \bar{d}d|p\rangle$ quark mass term
  measure of explicit chiral symmetry breaking of QCD



Gasser & Leutwyler

$$\sigma_{\pi N} = \frac{(35 \pm 5)\mathrm{MeV}}{1 - y}$$

$$\Sigma_{\pi N} = \sigma_{\pi N} + \underset{⑮}{\uparrow}5\mathrm{MeV}$$

$\to y = 0.2 \pm 0.2$

Karlsruhe-Helsinki analysis (KH80)

$$\Sigma_{\pi N} = \begin{cases} (64 \pm 8)\mathrm{MeV} & \text{Koch, Höhler} \\ (56 \pm 2)\mathrm{MeV} & \text{Gasser et al.} \\ 60 \pm 2 & (1991) \end{cases}$$

3. Experimental data (after 1990)

Low energy data are crucial for the extrapolation to the C.D. point

large efforts in recent years at LAMPF, PSI/SIN, TRIUMF to improve quality and quantity of the data

meanwhile converging results

- $\pi^- p$ S-wave scattering length *(PSI/SIN)*
- 'integral' cross-sections *(LAMPF, TRIUMF)*
- angular distributions *(PSI/SIN, TRIUMF)*
- polarisation measurements *(PSI/SIN, TRIUMF)*

3.1. *π^-p S-wave scattering length*

is determined from the energy shift ε of the 3P-1S X-ray transition (due to the strong interaction) in pionic hydrogen

$$\varepsilon = -4\frac{E_{1S}}{r_B}\,\mathrm{Re}\,a_{\pi^-p} = -4\frac{E_{1S}}{r_B}\left[\tfrac{1}{3}(2a_1 + a_3)\right] \approx -5\,\mathrm{eV}$$

with $E_{1S} = 3246$ eV, $r_B = 222.56$ fm

ETH Zürich, PSI, Neuchâtel 1990-1994

high resolution double focusing Si-crystal spectrometer attached to a cyclotron trap, detection with CCD

1990: $a^{\mathrm{exp}}_{\pi^-p} = (0.087 \pm 0.004)\ \mu^{-1}$

1994: $a^{\mathrm{exp}}_{\pi^-p} = (0.0873 \pm 0.0007)\ \mu^{-1}$

$a^{\mathrm{KH80}}_{\pi^-p} = (0.082 \pm 0.004)\ \mu^{-1}$

$$a^+_{0^+} = a^{\mathrm{exp}}_{\pi^-p} - \underbrace{a^-_{0^+}(\mathrm{KH80})}_{0.091\,\mu^{-1}} = (-0.004 \pm 0.004)\ \mu^{-1}$$

3.2. 'Integral' cross-sections

Jerusalem-TRIUMF-Tübingen-UBC 1989-1993

Elastic scattering $\pi^+ p \rightarrow \pi^+ p$: *60-200 MeV* ($\theta_{lab} > 20°, 30°$)

Elastic + SCX: $\pi^- p \rightarrow \pi^- p$: *125-200 MeV* ($\theta_{lab} > 20°$)

$\pi^- p \rightarrow \pi^0 n$: *125-200 MeV (total)*

Measurements of the attenuation of $\pi^{\pm}$ in matched pairs of CH_2 and C, integrated over the solid angle Ω complementary to the solid angle of the detector resulting in the integral cross sections for elastic scattering $\pi^+ p \rightarrow \pi^+ p$ and in the sum of elastic scattering $\pi^- p \rightarrow \pi^- p$ and charge exchange $\pi^- p \rightarrow \pi^0 n$. The total cross section for charge exchange is obtained by means of a 4π detector in anticoincidence (no particles coming out) with the incoming pion flux. The integral cross section $\pi^- p \rightarrow \pi^- p$ is obtained from the difference of both.

$$\sigma_{attenuation} = \int_{\Omega}^{4\pi} \frac{d\sigma_{\pi^{\pm}p}}{d\omega} d\omega$$

Good agreement of $\pi^{\pm} p \rightarrow \pi^{\pm} p$ with KH80 or KA85, charge exchange $\pi^- p \rightarrow \pi^0 n$ below KH80.

Colorado-LAMPF-UBC 1991-1994

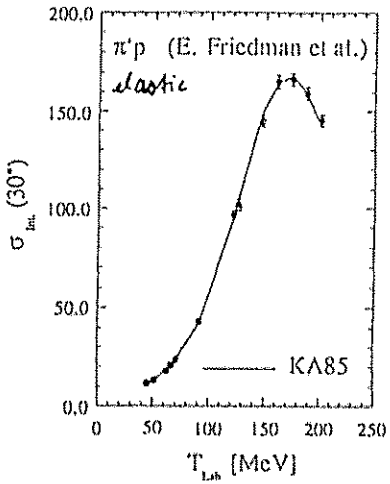
Elastic scattering $\pi^+ p \rightarrow \pi^+ p$: *40-500 MeV* ($\theta_{lab} > 30°$)

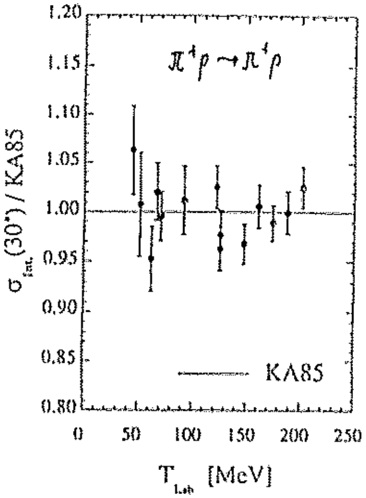
Elastic +SCX : $\pi^- p \rightarrow \pi^- p$: *40-300 MeV* ($\theta_{lab} > 30°$)

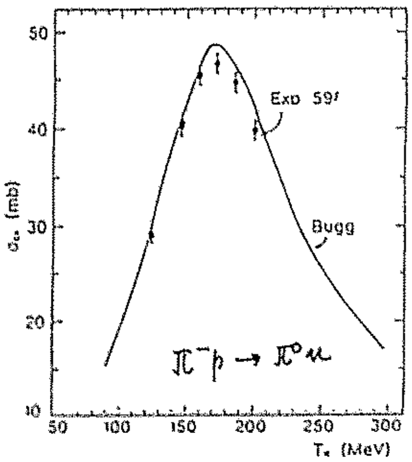
$\pi^- p \rightarrow \pi^0 n$: *40-300 MeV* ($\theta_{lab} > 30°$)

LH_2 target, P^3W channel at LAMPF

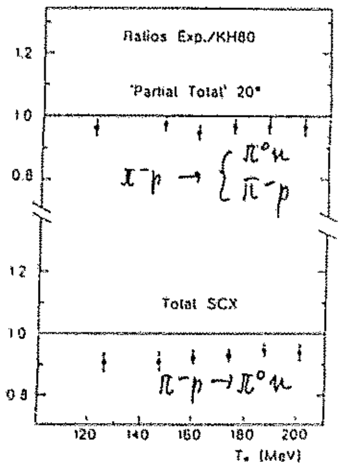
No general agreement with KH80, in particular data below KH80 at energies below 100 MeV for $\pi^+ p \rightarrow \pi^+ p$ and slightly below KH80 at almost all energies for the sum of $\pi^- p \rightarrow \pi^- p$ and $\pi^- p \rightarrow \pi^0 n$.

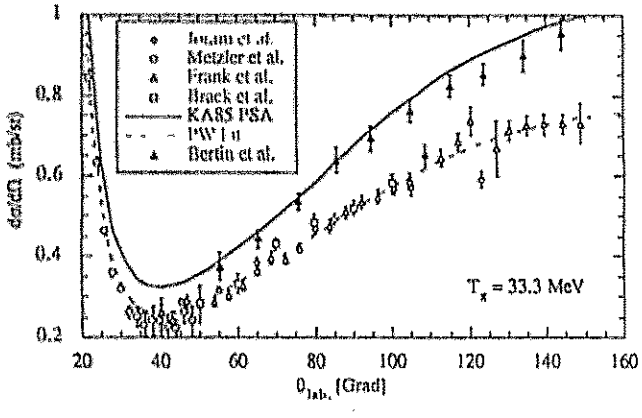


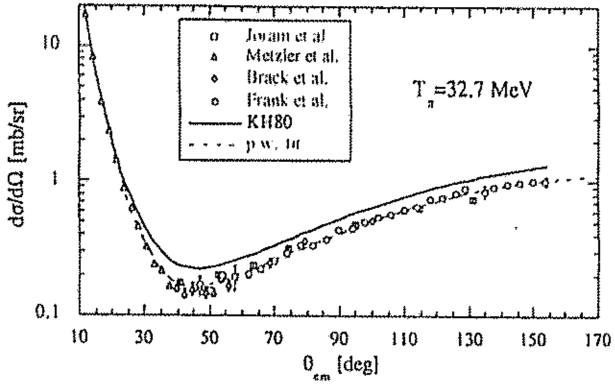


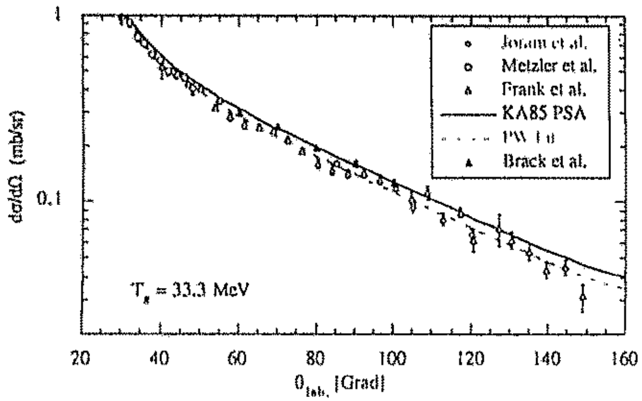


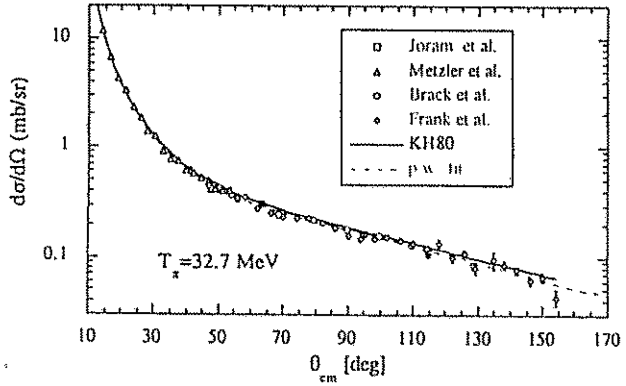
Friedman et al. 1993
(TRIUMF)




dσ/dΩ (mb/sr)
1
0.8
0.6
0.4
0.2
20
40
60
80
100
120
140
160
$\theta_{lab.}$ [Grad]
Joram et al.
Metzler et al.
Frank et al.
Brack et al.
KA85 PSA
PW fit
Bertin et al.
T_π = 33.3 MeV


dσ/dΩ [mb/sr]
10
1
0.1
10
30
50
70
90
110
130
150
170
θ_{cm} [deg]
Joram et al
Metzler et al.
Brack et al.
Frank et al.
KH80
p.w. fit
T_π=32.7 MeV


dσ/dΩ (mb/sr)
1
0.1
20
40
60
80
100
120
140
160
$\theta_{lab.}$ [Grad]
Joram et al.
Metzler et al.
Frank et al.
KA85 PSA
PW fit
Brack et al.
T_π = 33.3 MeV


dσ/dΩ (mb/sr)
10
1
0.1
10
30
50
70
90
110
130
150
170
θ_{cm} [deg]
Joram et al.
Metzler et al.
Brack et al.
Frank et al.
KH80
p.w. fit
T_π=32.7 MeV

$\pi^+ p$ $\pi^- p$

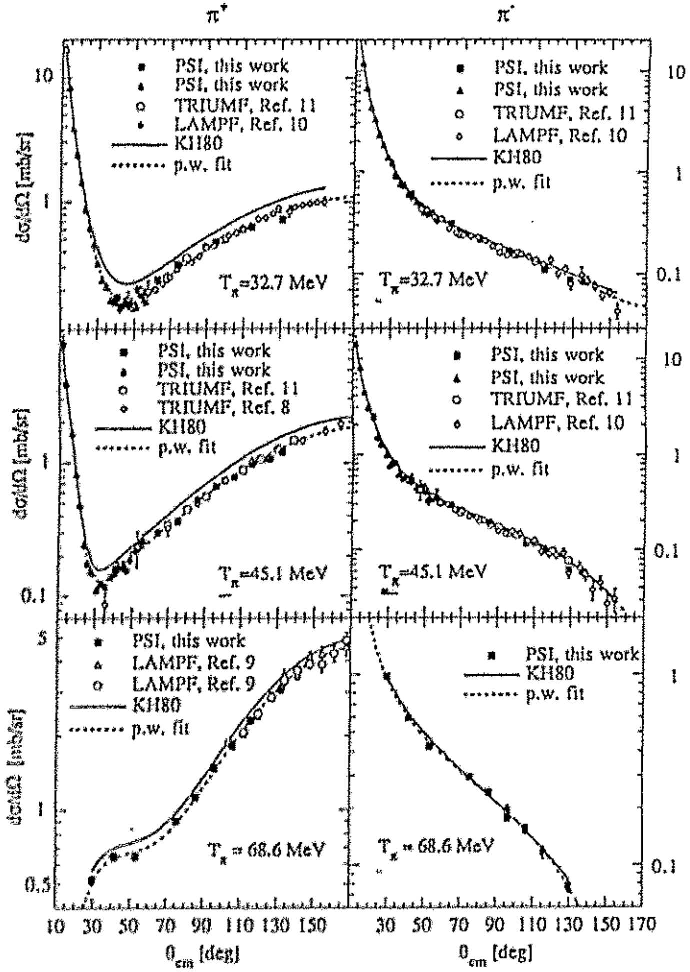
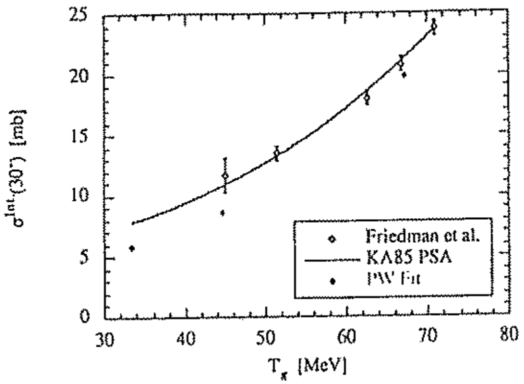
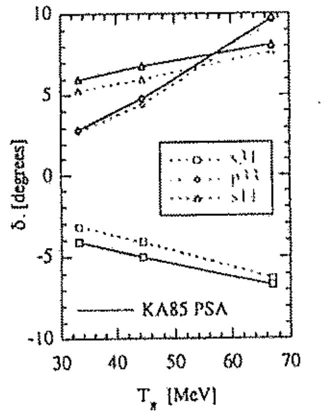


Fig. 6: Comparison with the results of other experiments available at energies around 30, 45 and 70 MeV. The various data sets have been renormalised (compare Table 3) within bounds given by their respective systematic uncertainties.

Ch. Joram et al.,
to be published

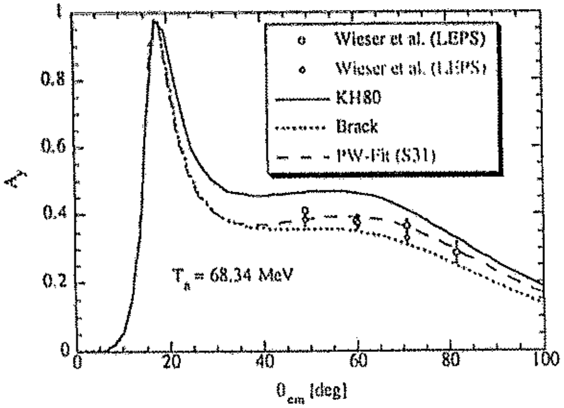




3.4. Polarisation

UBC-TRIUMF-Colorado-Saskatchewan-Sacramento-Regina-VPI 1989
$\pi^+\vec{p} \rightarrow \pi^+\vec{p}$ at energies in the Δ-resonance region (98, 139, 166, 215, 263 MeV), agree with KH80

Karlsruhe-PSI-Tübingen -St. Petersburg 1992-1994
$\pi^+\vec{p} \rightarrow \pi^+\vec{p}$ analysing power at 68.3 MeV



Least square fit of the S_{31}-wave:

	S_{31}	P_{31}	P_{33}
KH80	-6.96	-1.23	10.13
Fit to the A_y-data	-6.07	dito	dito
Fit with Joram	-6.25	-1.26	9.72

Zusammenfassung (πN-System)

Experimente:

- schwierig, insbesondere bei tiefen Energien (hoher Untergrund von π-Zerfall, etc.)
- Magnetspektrometer-Daten (LEPS) sehr zuverlässig (anderen Methoden überlegen)
- allg. Problem: angegebene Fehler oft kleiner als die Unterschiede zwischen verschiedenen Gruppen
  → i.a. systematische Fehler unterschätzt!
- Klärung durch Polarisationsexperimente
- insgesamt: Ergebnisse der letzten Jahre konvergieren!

Analyse:

- S_{11} und S_{31}-Streuphasen kleiner als in KH80
- Dispersionsanalyse mit neuen Daten erforderlich
- Konsequenz für σ-Term?

Spin-Effekte in πA-Streuung

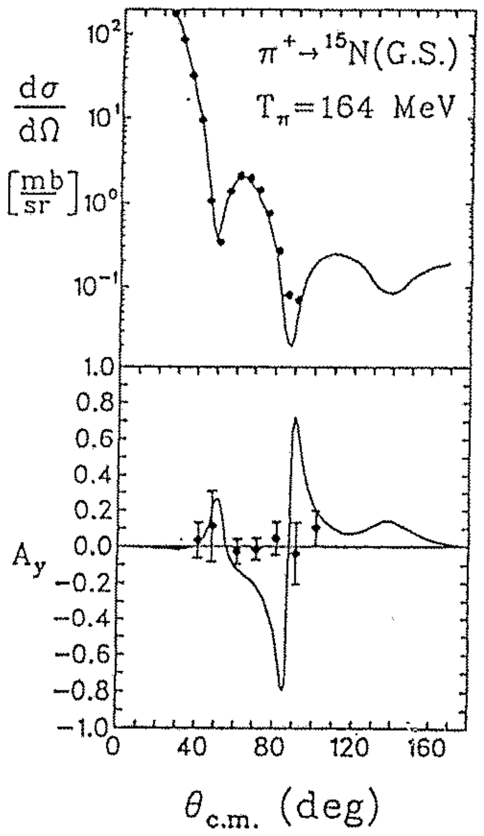
(Boschitz, Brinkmöller et al.)

Kernstruktur

$\vec{\ell}_\pi \cdot \vec{S}_N$ - Wechselwirkung

$\vec{S}_\Delta \cdot \vec{S}_N$ - " -

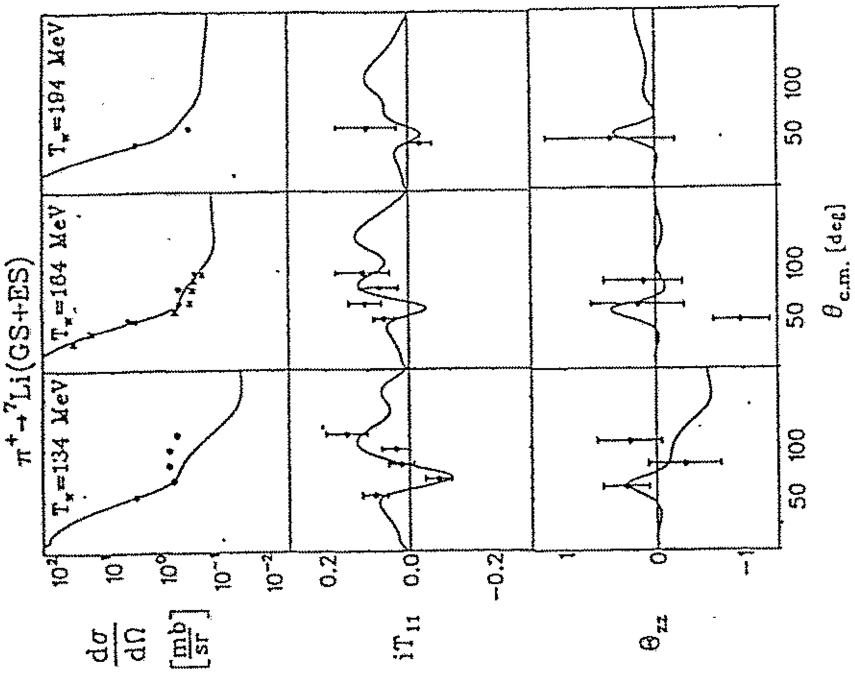
πA	Vektor-Pol.	Tensor-Pol.	Spin-Transfer	T_π (MeV)	
$\pi^+ d$	●	●	(●)	50 – 325	PSI TRIUMF LAMPF
$\pi^\pm\,{}^3He$	●	—		100, 180	TRIUMF LAMPF
$\pi^+\,{}^6Li$	●	●		100 - 219	PSI
$\pi^+\,{}^7Li$	●	●		134 - 194	
$\pi^\pm\,{}^{13}C$	●	—		132, 230	LAMPF
${}^{13}C(\pi^+,\pi^0)$	●	—		163	
$\pi^+\,{}^{15}N$	●	—		164	PSI



PSI

R. Meier et al., PRC 42 (1990) 2222

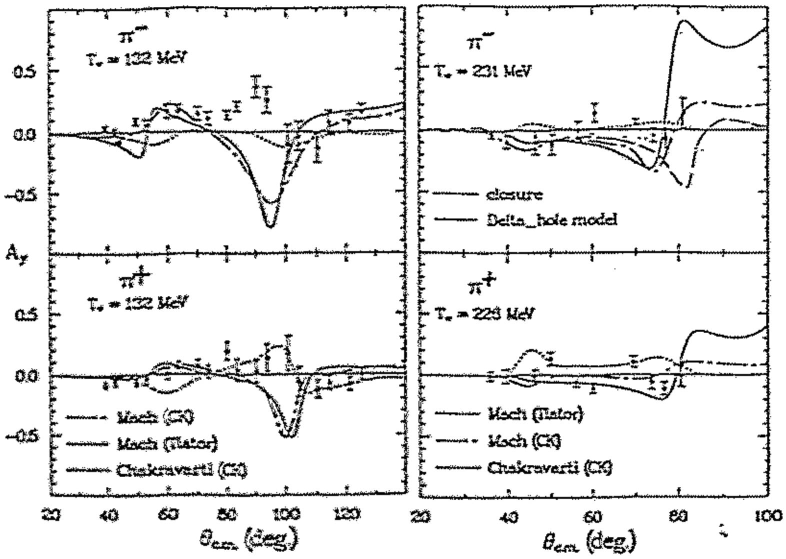
PSI



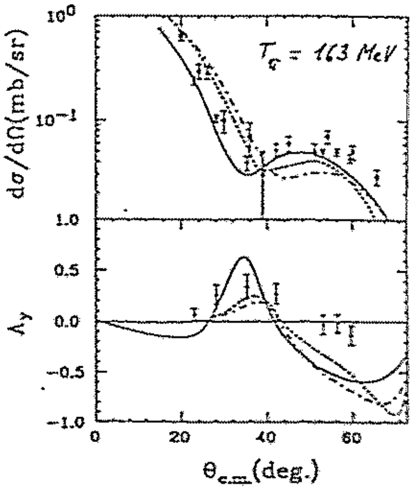
π ¹³C

LAMPF

elastic scattering

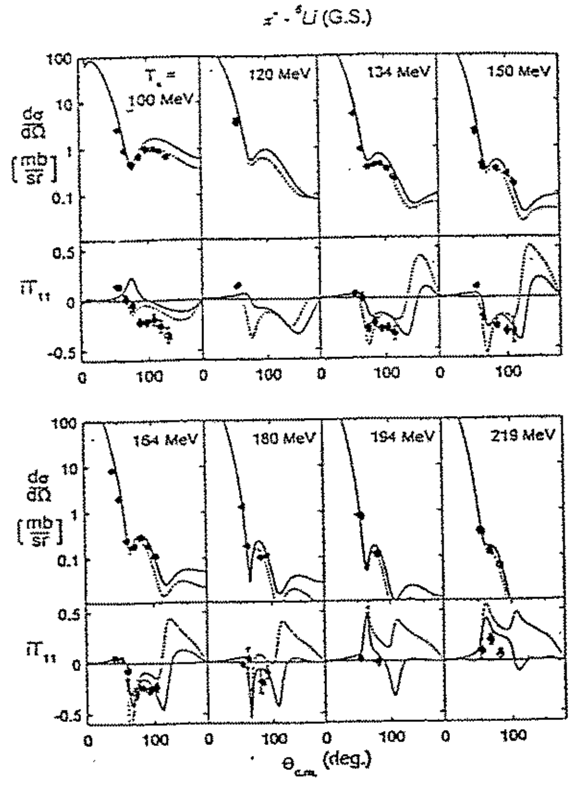


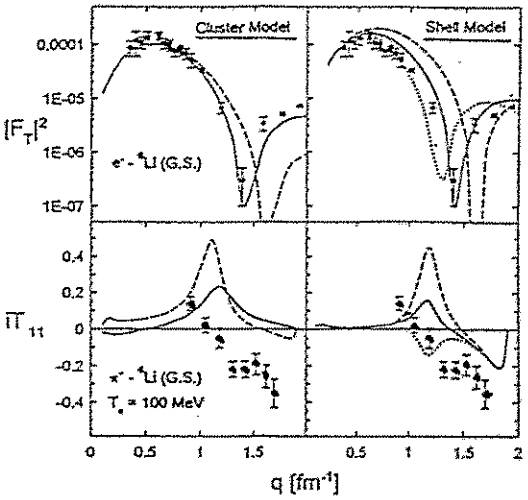
SCX (π⁺, π⁰)



π ^6Li

PSI



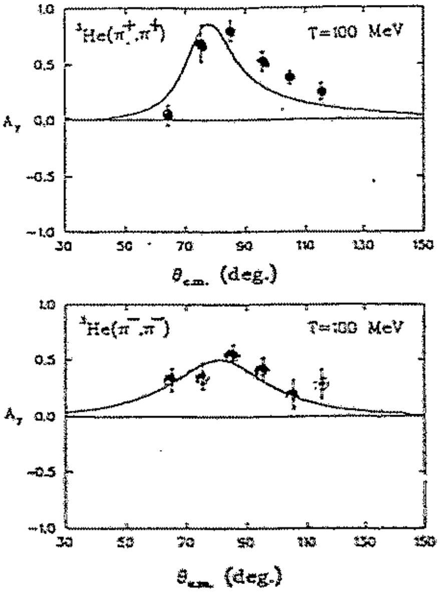


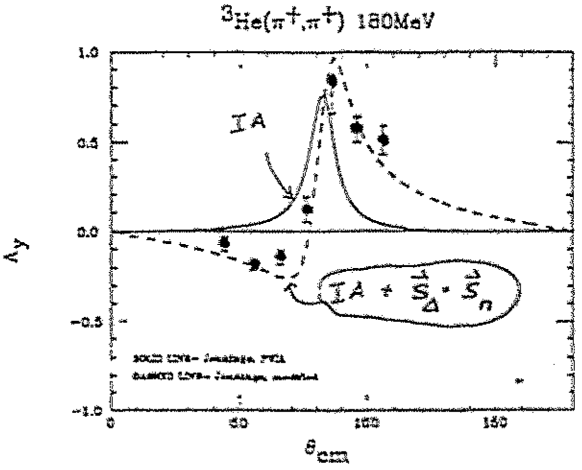
S. Ritt et al., PR C 49 (1994) 3117

π ^3He

TRIUMF

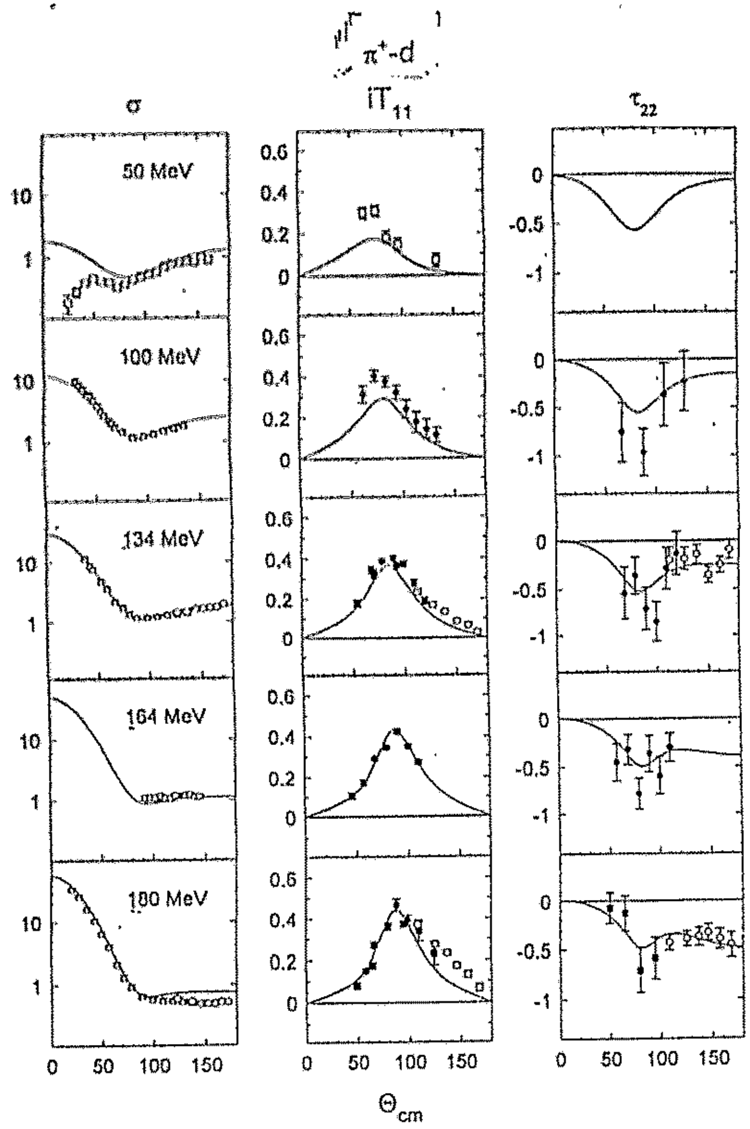
LAMPF



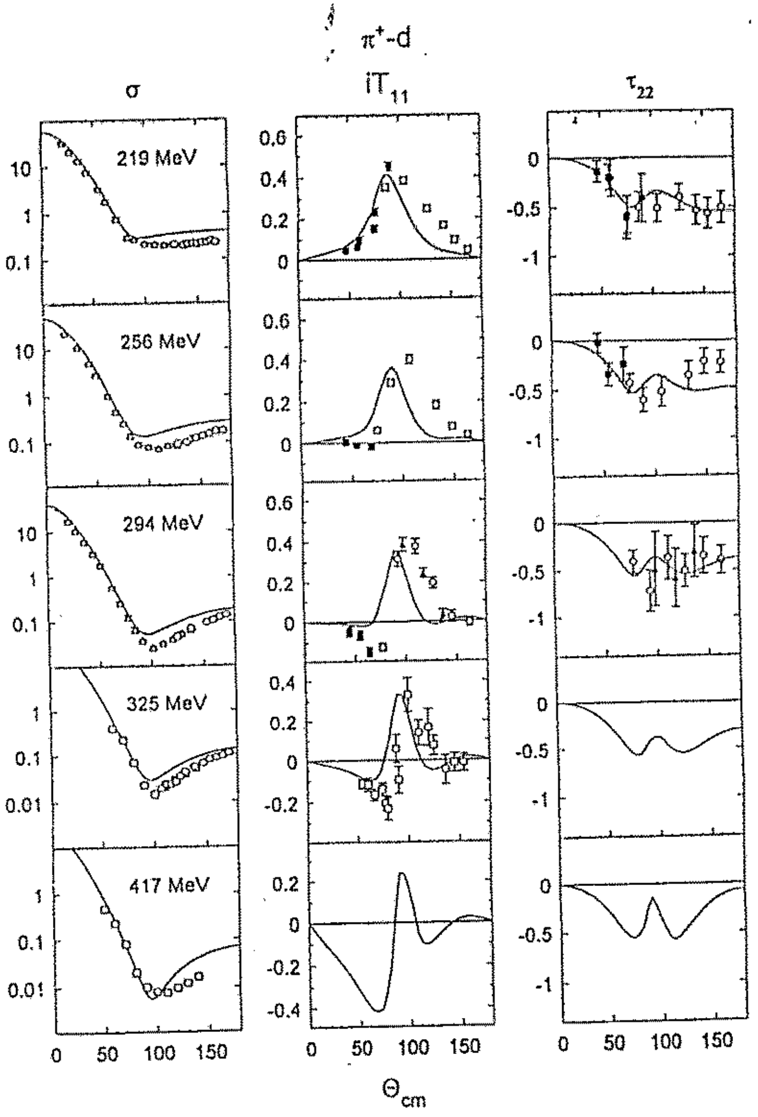


B. Larson et al., PRL 67 (1991) 3356

M. Espy et al., SPIN 94 Conf.



M. Wessler et al., subm. PRC



M. Wessler et al., subm. PRC

Zusammenfassung (Spin-Effekte)

- Größe der Spin-Effekte in elastischer πA-Streuung nimmt mit zunehmendem A ab

- Kernstruktureffekte spielen große Rolle, in erster Linie jedoch der Spinformfaktor $F_s(q) (\approx F_t(q))$

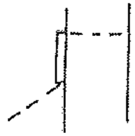
- $\left.\begin{matrix}\pi d\\ \pi\,{}^3He\end{matrix}\right\}$ $T_\pi \lesssim 160$ MeV: A_y gut verstanden
  höhere Energien: theor. Beschreibung
  systematisch
  falsch für A_y
  ⤢
  ΔN Spin-Spin-Wechselwirkung ?
  N.B.: Theor. Behandlung des πNN-Systems bisher nur approximativ möglich !
  $\not{K}$ π-Absorption, Δ, ...

- kompletter Satz von Spinobservablen in πd-Streuung ein wichtiger Testfall

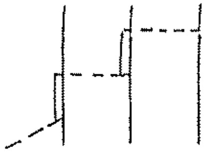
Pion - Absorption

(LADS - Kollaboration)

2N - Absorption



3N - Absorption



⋮

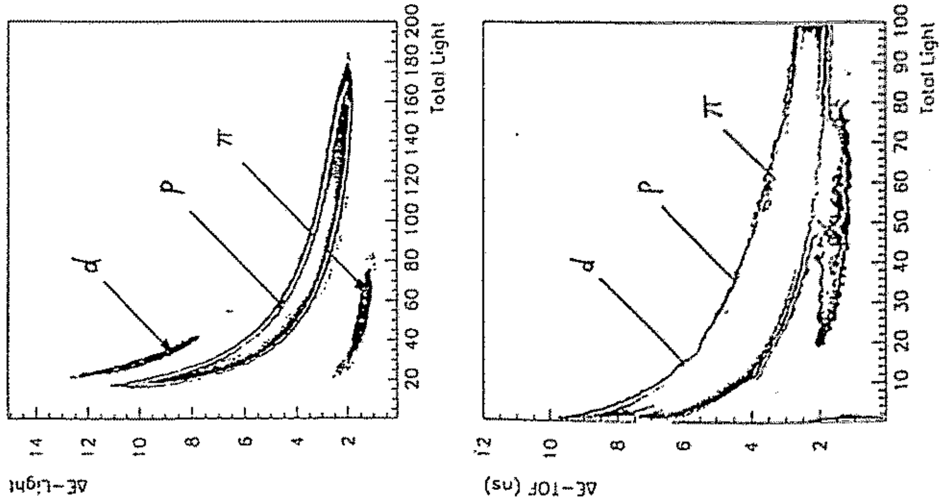
Erste Ergebnisse von LADS

^3He, ^4He

erstmals über vollen Raumwinkel vermessen

Particle Identification

Target: ^{4}He $\qquad T_{\pi^+} = 118$ MeV



$E \leftrightarrow \frac{dE}{dx}$

$E_p \gtrsim 40$ MeV

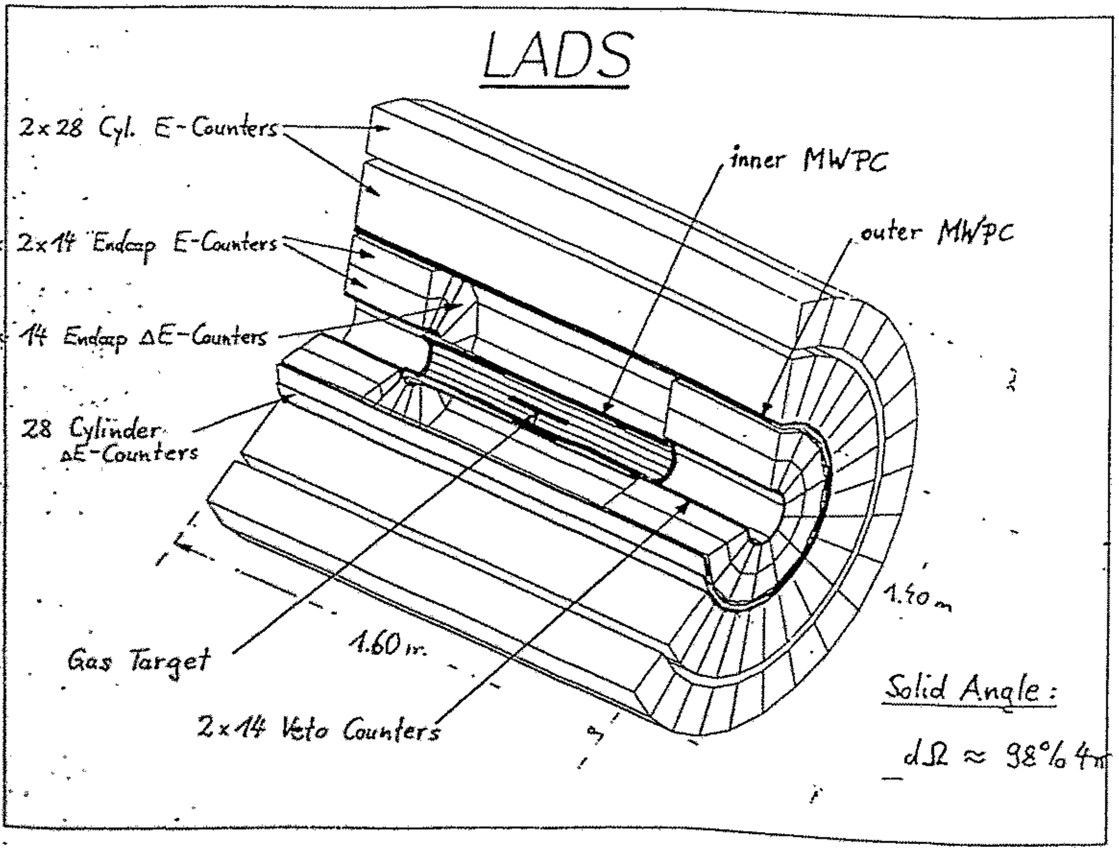
$E \leftrightarrow$ TOF

$15\,\mathrm{MeV} \le E_p \le 40$ Me

(stopped in ΔE-Counter

$\Delta t \approx 750$ ps

LADS



Solid Angle:

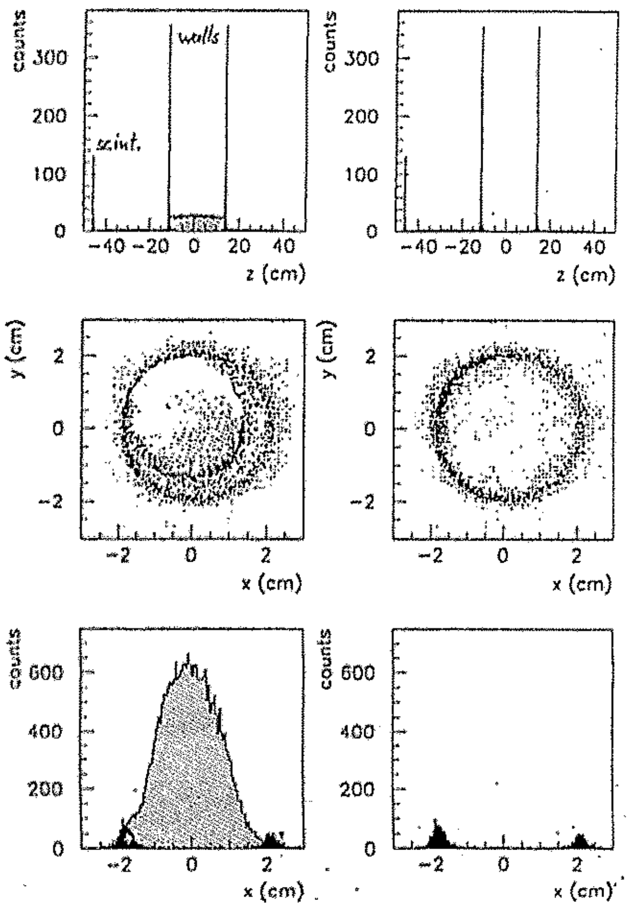
$d\Omega \approx 98\%\, 4\pi$

MAR 1993 11:02 AM BY IKP307

Vertex Reconstruction

Target : 26 x 4 cm ϕ (C-Fibre)

Full Target (^4He, 95 bar)   Empty Target



Radial Cut:

$0 < r < 1.7$ cm

z - Cut:

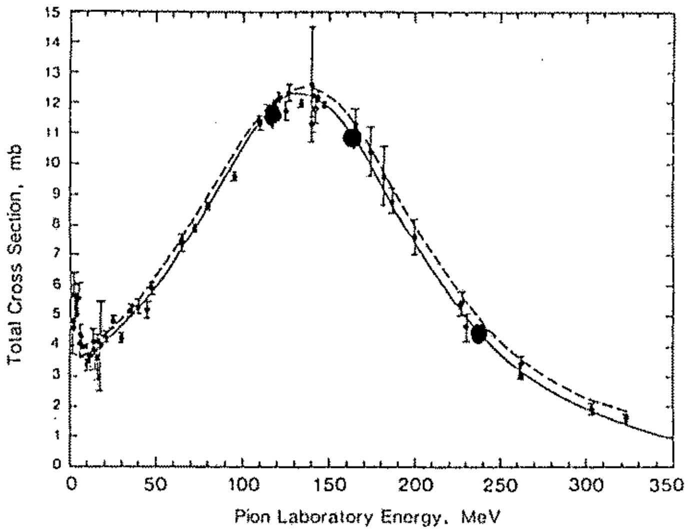
$-9 < z < 11$ cm

z - and y - Cut:

$-9 < z < 11$ cm

$-0.2 < y < 0.2$ cm

Total Cross Section of $\pi^+ d \rightarrow pp$



- World Data until 1983 (from H.J. Weyer, Phys. Rep. 1990)

Lines, Phenomenological Fits:

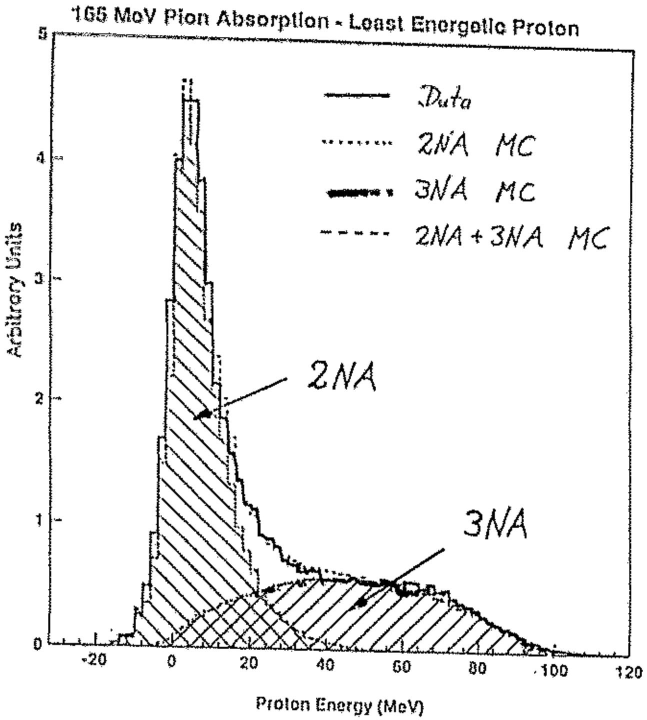
—— Ritchie, Phys. Rev. C28 (1983)

– – – Spuller and Measday, Phys. Rev. D12 (1975)

● LADS results $\pi d \rightarrow pp$

Determination of Integral Cross Sections

$^3He(\pi^+,pp)p$; $^3He(\pi^+,ppp)$



σ^{tot}_{Abs} No pion in final state (98 % 4π)

σ^{2N}_{Abs} Monte Carlo weighted with p_{Spec} Fermi momentum and QFA angular distribution (Ritchie)

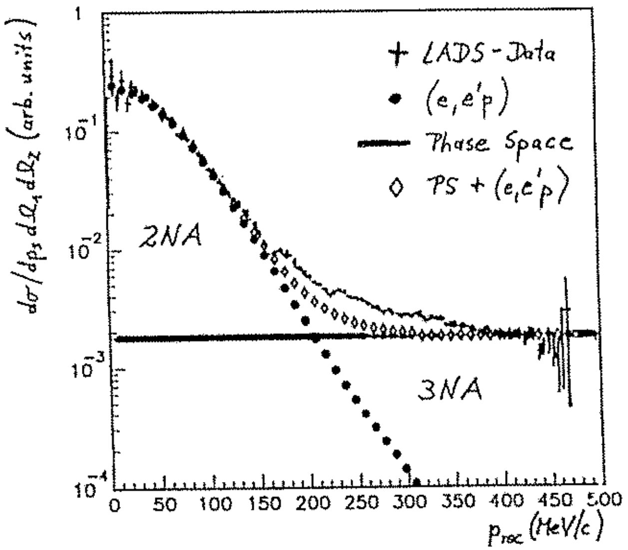
σ^{3N}_{Abs} Monte Carlo pure phase space

Recoil Momentum Distribution

$^3He(\pi^+,pp)p$ + $^3He(\pi^+,ppp)$

T_π = 118 MeV

> 90 % solid angle

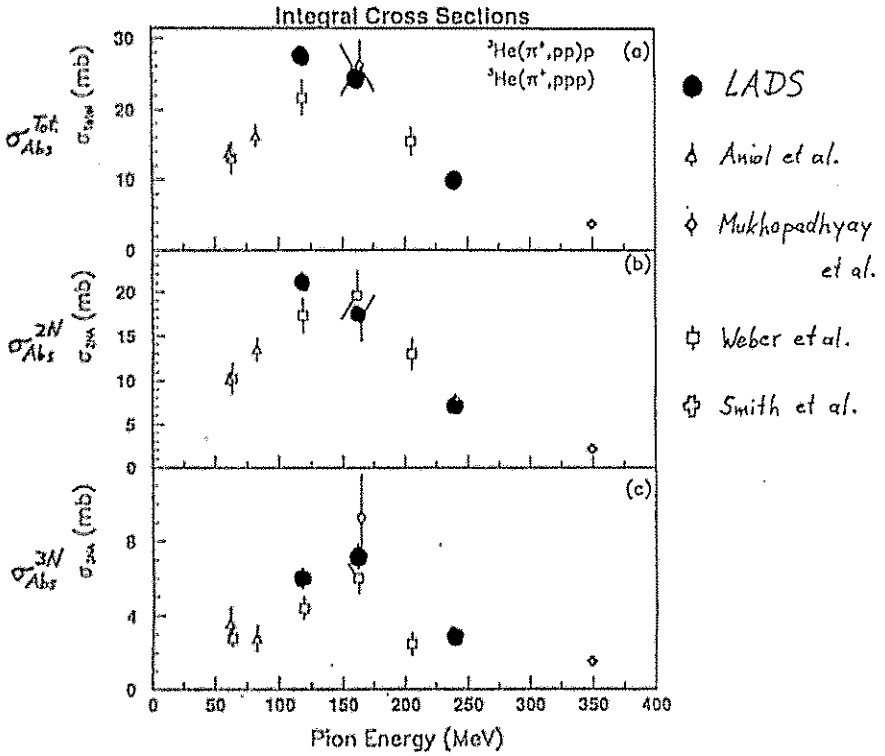


2NA: spectator nucleon shows Fermi momentum distribution

3NA: flat distribution ⇒ phase space

But small deviations !

$\pi^+ - {}^3He$ Absorption



LADS: First direct measurement σ^{Tot}_{Abs}, σ^{3N}_{Abs}

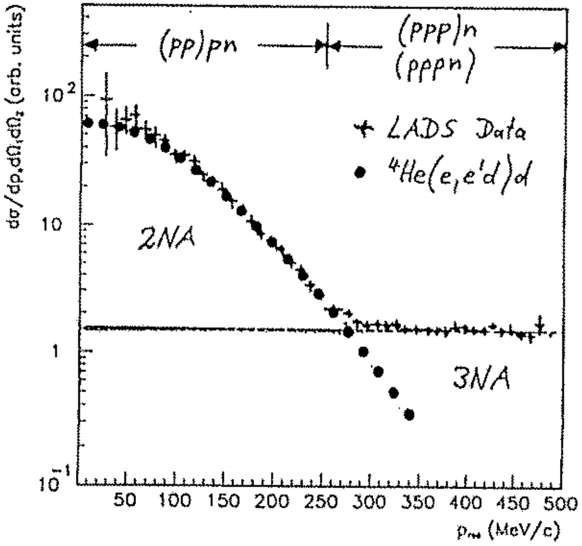
$\approx$ "No" extrapolation

4He Momentum Distribution

${}^4He(\pi^+,pp)pn$ + ${}^4He(\pi^+,ppp)n$ + ${}^4He(\pi^+,pppn)$

$T_\pi = 240$ MeV

$\approx 80\%$ solid angle



very
preliminary

2NA: spectator nucleus (pn, d) shows Fermi momentum distribution

3NA: flat distribution -> phase space

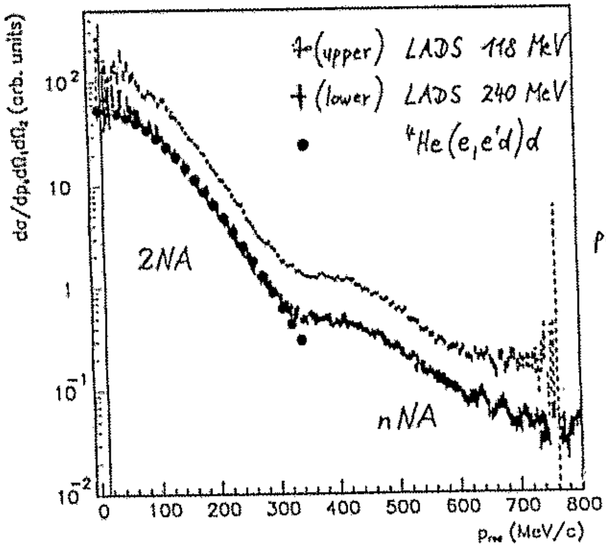
-> ppp similar in ${}^3He$ and ${}^4He$!

Recoil Momentum Distribution

$^4He(\pi^+, pp)d$ + $^4He(\pi^+, pd)p$ + $^4He(\pi^+, ppd)$

T_π = 118 MeV + 240 MeV

> 90% solid angle



2NA: rest nucleus shows Fermi momentum distribution

nNA: not pure phase space!

Tick-up pppn → ppd ?

Zusammenfassung (π-Absorption)

LADS hervorragend geeignet zum Studium der Multinukleon-Absorption:

Raumwinkel ≈ 98% von 4π

gute Energie- und Impulsauflösung

Absorptions-Querschnitte erstmals ohne Extrapolation bestimmt

---

3N-Absorption in ^3He zeigt Phasenraum-Verteilung

$\sigma_{3N} \approx 20-30\%$ von σ_{abs}

ISI- und FSI-Effekte können kinematisch isoliert werden

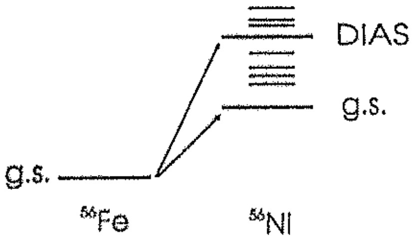
π-Absorption in schweren Kernen:

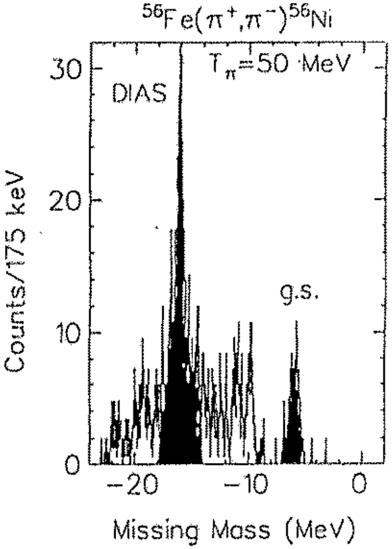
^{14}N, ^{40}Ar, Xe

gemessen, aber noch nicht ausgewertet

Double Charge Exchange (DCX)

$^{A}Z(\pi^{+},\pi^{-})^{A}(Z+2)$





Wirkungsquerschnitte: nb - µb/sr

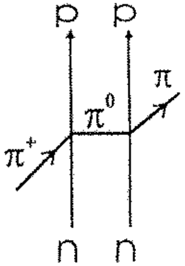
- ●Untergrund-Unterdrückung
- ●Meßempfindlichkeit
- ●Energieauflösung

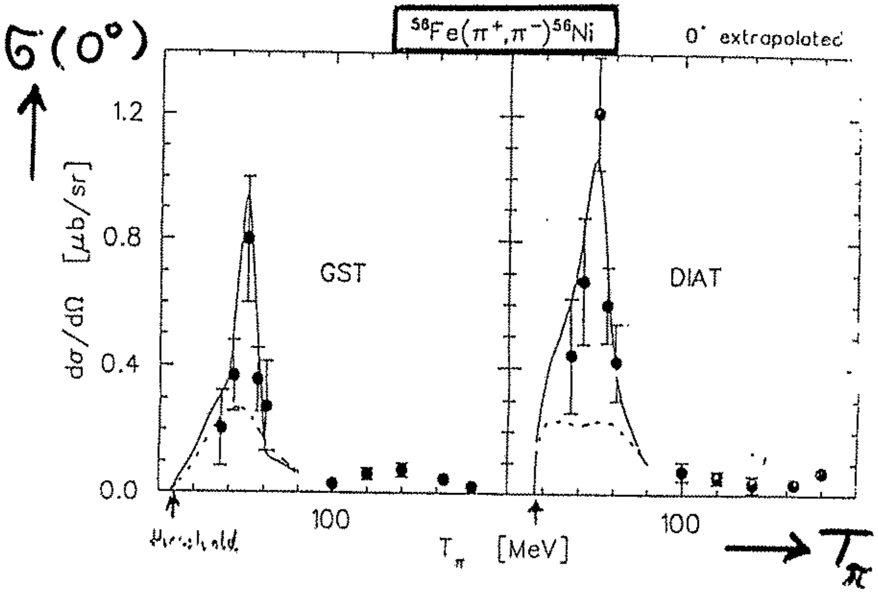
LEPS

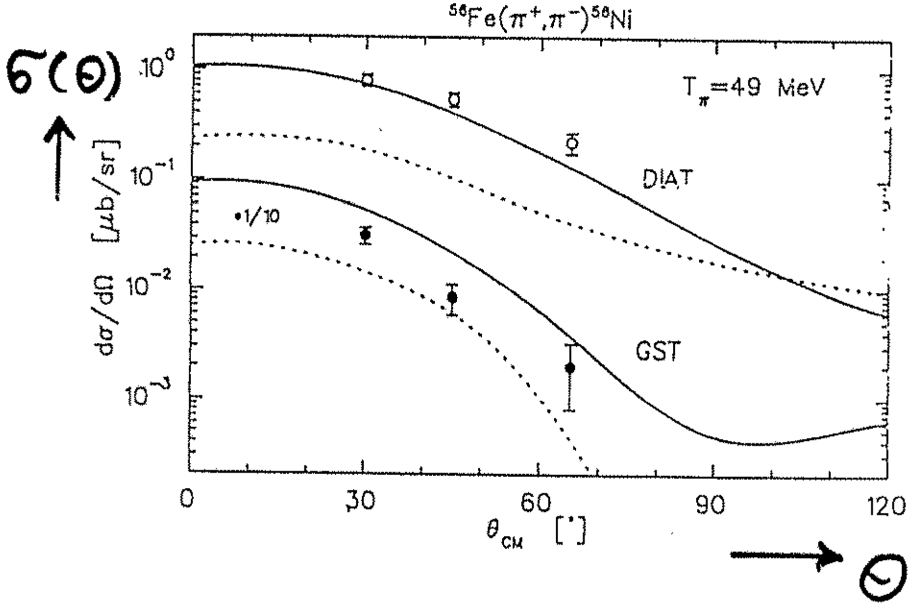
bei *niedrigen Energien* (deutlich unterhalb Δ-Resonanz)

- ●stark reduzierte Absorption
- ●hohe Empfindlichkeit auf kurzreichweitige NN-Korrelationen (< 1 - 2 fm)

N.B.: 2N-Prozeß
πNN-System







Gemeinsamkeiten der DCX-Daten

(i) *Energieabhängigkeit:*
universelle, resonanzartige Struktur
bei $T_\pi = 50$ MeV
(ii) *Winkelabhängigkeit:*
kein außergewöhnliches
Verhalten bei niedrigen Energien

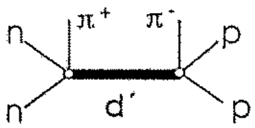
(i) ⇒ Resonanz mit J^P

(a) falls im π–Kern-System, dann:

$$\sigma(\theta) = P_J^2(\cos\theta)$$

in Widerspruch zu (ii)!

(b) falls im πNN Subsystem, dann:

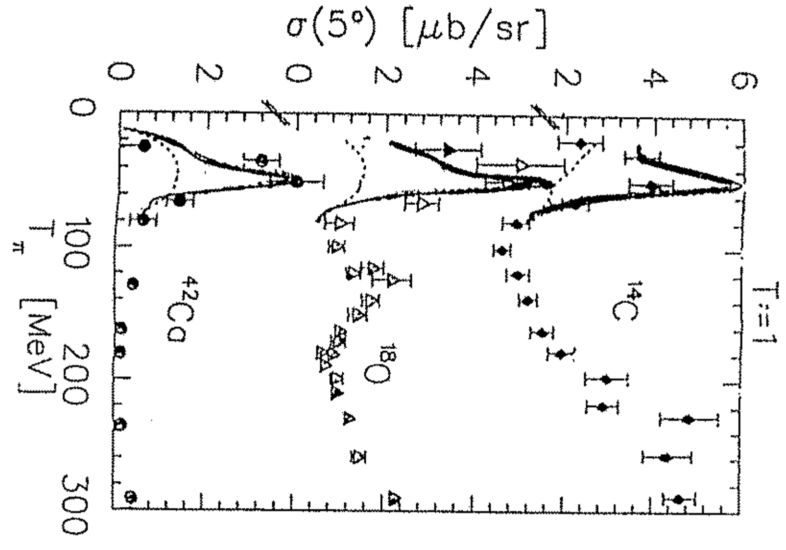


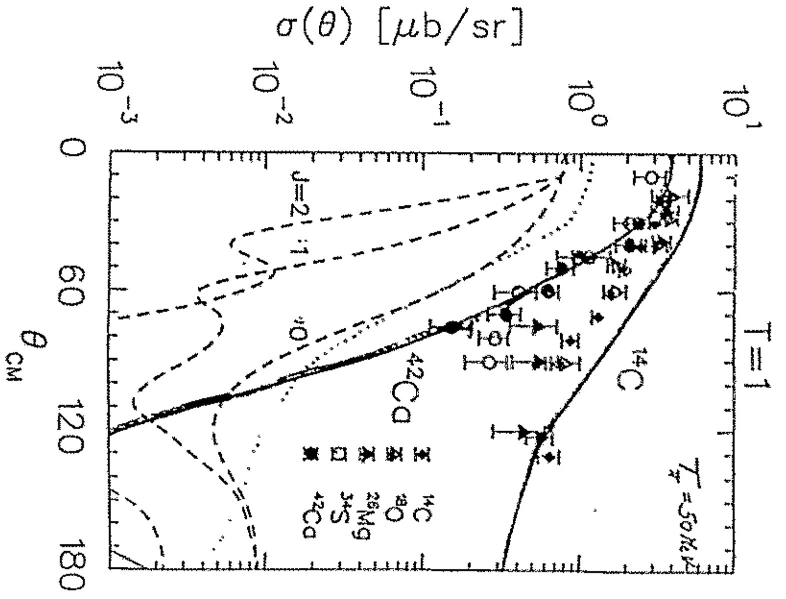
$$T_{DCX} \propto \int \frac{\sqrt{\Gamma_+ \cdot \Gamma_-}}{T_\pi - E_R + \frac{Q \cdot k}{2m_N} + i\,\Gamma/2}\, P_J(\cos\gamma)\cdot\Psi_i(Q)\cdot\Psi_f^*(Q')\,d^3Q$$

Phys. Rev. Lett. 71, 42 (1993)

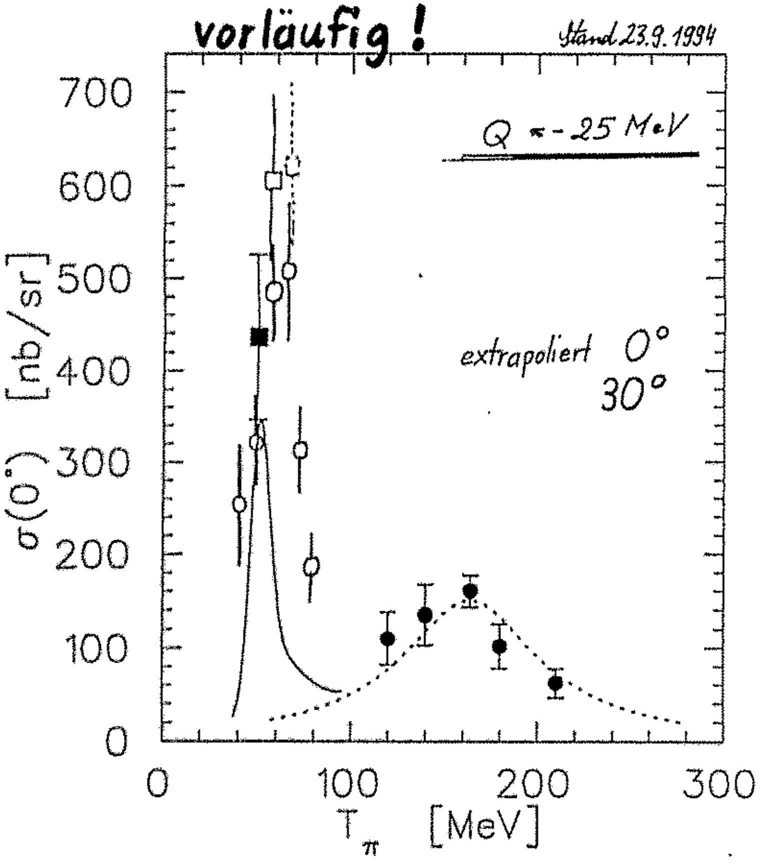
d': $J^\pi = 0^-$

PRL 71(1993)4





$^{40}Ca(\pi^+,\pi^-)\,^{40}Ti_{g.s.}$



Bland et. al., phys lett 128 B 157

Resumee der bisherigen DCX-Messungen:

$$NN \nleftrightarrow d' \begin{cases} \to pp\pi^- \\ \to pn\pi^0 \\ \to nn\pi^+ \end{cases}$$

$I(J^P)$=gerade(0^-)
M=2.06 GeV, $\Gamma_{NN\pi}$=0.5MeV

bisher beobachtet in allen DCX-Daten ($12 \le A \le 56$)

Kernmediumseffekte ??

Reaktionen, bei denen Kernmediumseffekte keine (oder geringe) Rolle spielen:

(i) DCX an He: $^3He(\pi^-,\pi^+)nnn$ TRIUMF
$^4He(\pi^\pm,\pi^\mp)NNNN$

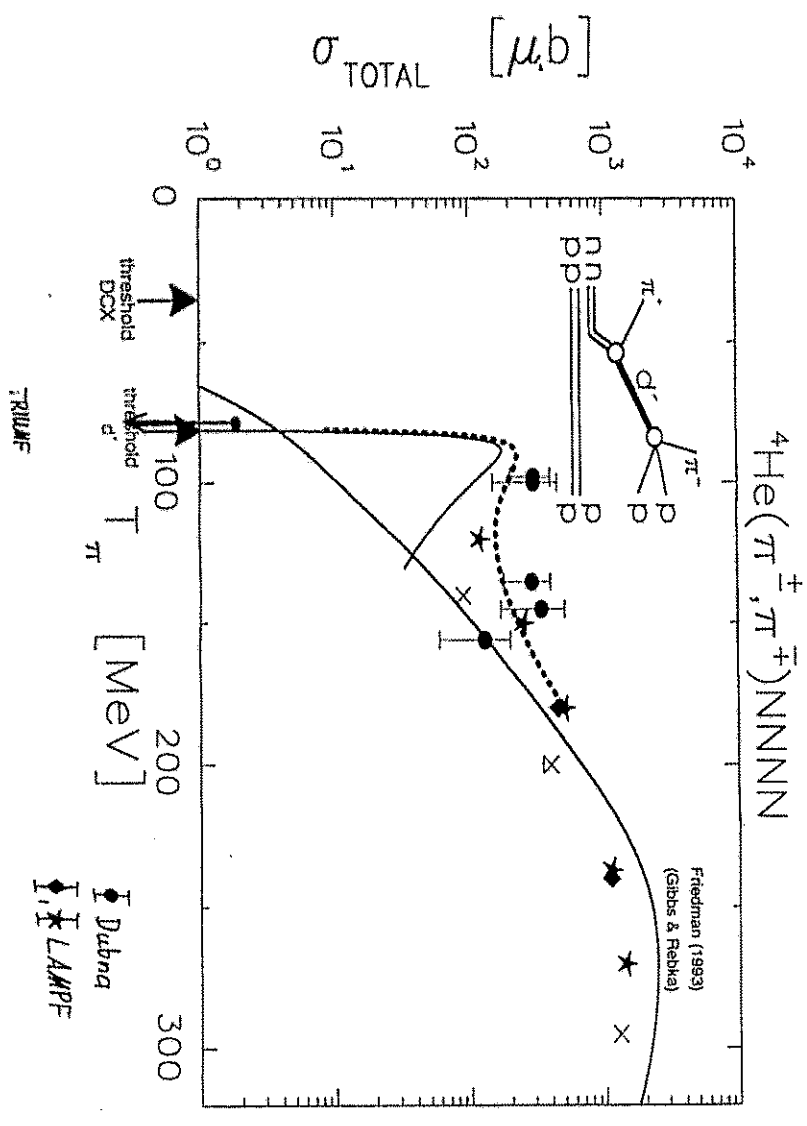
(ii) $\gamma + d \to d' \to \pi + N + N$ MAMI-B

oder mit virtuellen γ´s (e,e') CEBAF, (DESY)

(iii)

$$p + p \to d' + \pi^+ \to \rlap{$\underbrace{}_{M_{pp\pi^-}}$}\pi^- + \overbrace{p + p + \pi^+}^{M_{pp\pi^+}}$$

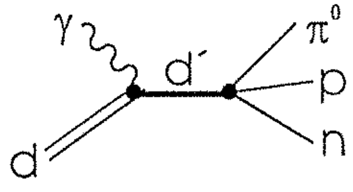
COSY
CELSIUS
ITEP



Elektromagnetische Produktion von d´

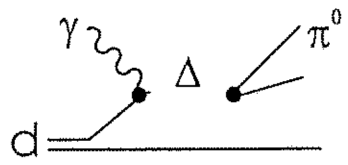
(i) am Deuteron: $d(\gamma,\pi^0)pn$

$\boxed{\sigma \le 1-10\mu b}$



$E_\gamma \approx 200$ MeV

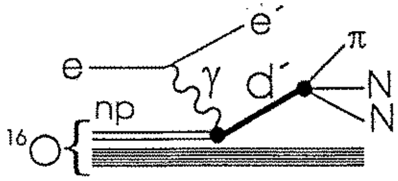
$\boxed{\sigma \approx 30\mu b}$

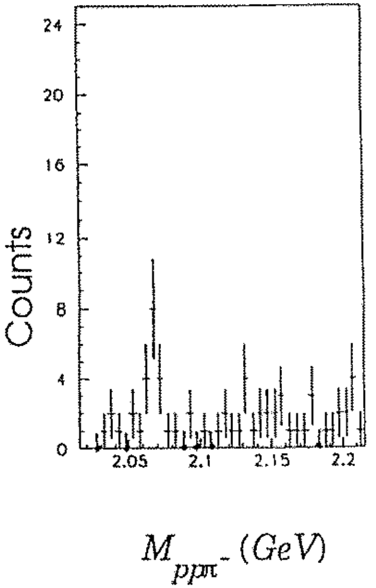


(ii) an ^{16}O

(ARGUS "beam gas data"):
Doroshkevich et al., ITEP, priv. comm.

$e + {}^{16}O \rightarrow p + p + \pi^{\pm} + X$

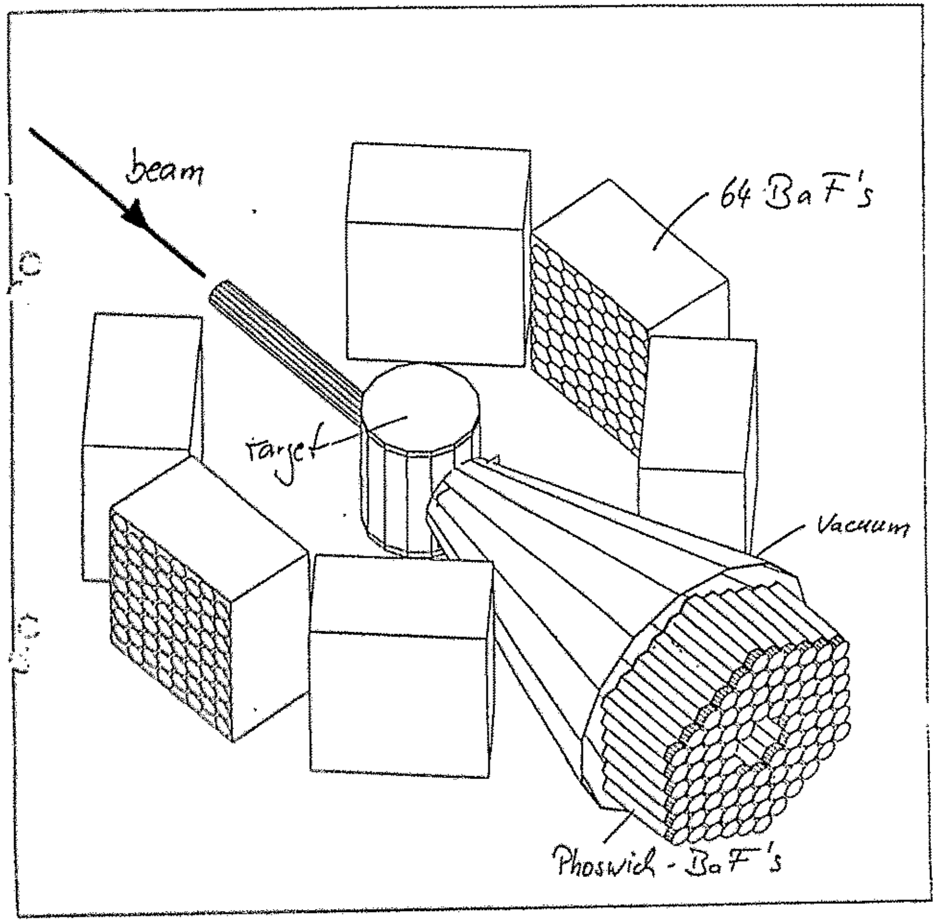




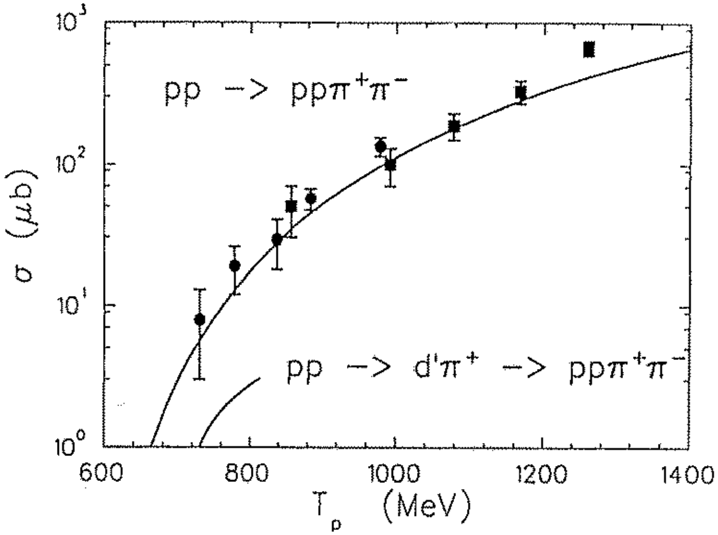
planned TAPS-Setup for 1995

6 TAPS-blocks

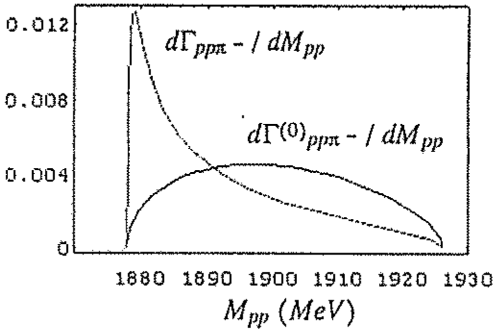
forward-detector covers: $\Theta_{Lab,max} = \pm 20°$



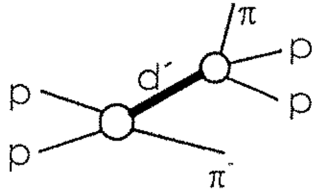
d´-Produktion im pp-Stoß



Z. Phys. A345, 407 (1993)

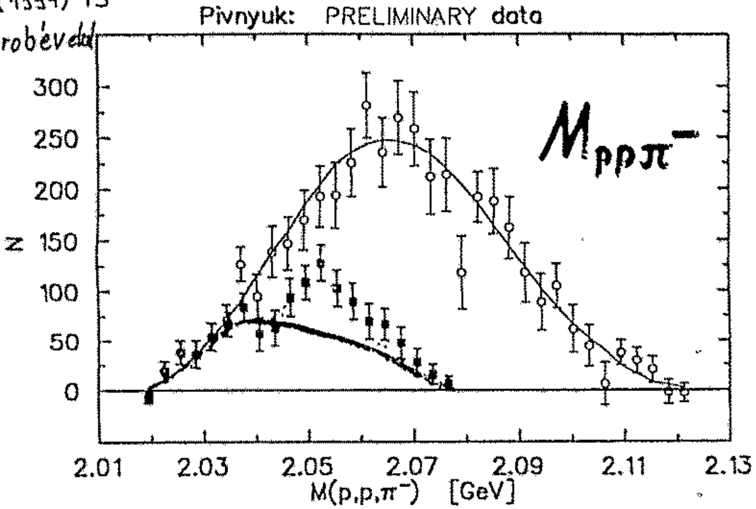


d`-Zerfalls-
charakteristik

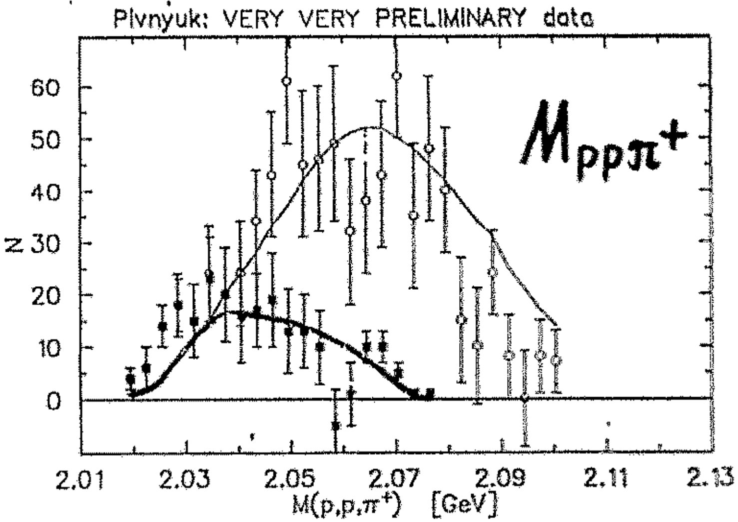


ITEP $pp \rightarrow pp\pi^-\pi^+$ $T_p = 900 MeV$

JETP Lett.
59 (1994) 75
L.S. Vorob'ev et al.



$M_{pp} - 2M_p < 18 MeV$



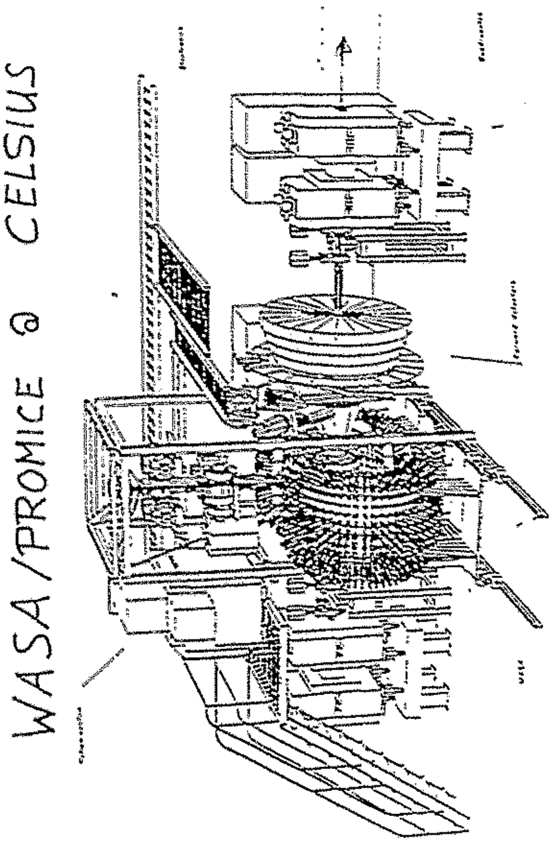
Vorgeschlagene Präzisionsexperimente

$p + p \rightarrow p + p + \pi^+ + \pi^-$

für d′: $T_p > 713$ MeV

CELSIUS: (Uppsala)	Protonenstrahl (gekühlt nur bis 500 MeV)
WASA:	internes Target, 4π-Detektor, Vorwärtsdetektor bereits im Einsatz,
COSY:	gekühlter Protonen-Strahl
COSY-11:	internes Target, Suche nach d′ direkt an der Schwelle
COSY-TOF:	externes Target, 4π-Detektor, Suche nach d′ oberhalb der Schwelle

WASA/PROMICE @ CELSIUS



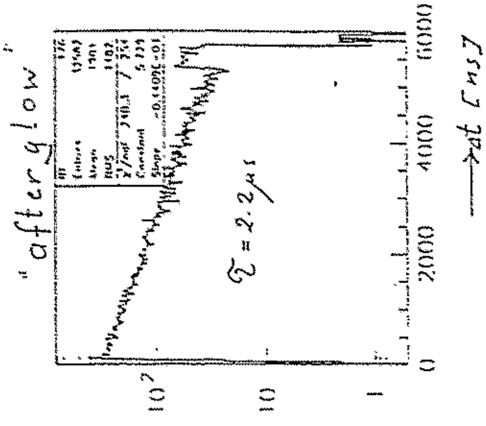
π^+ identification: delayed pulse technique

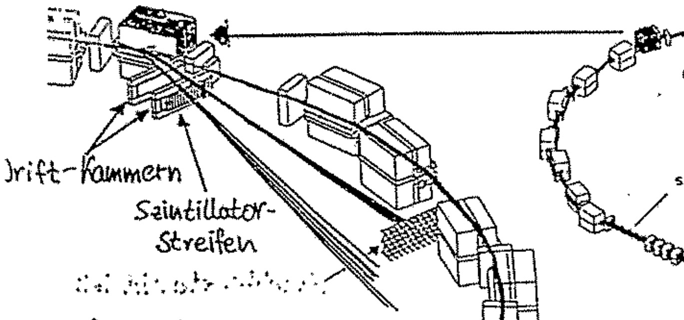
in medium:

26ns

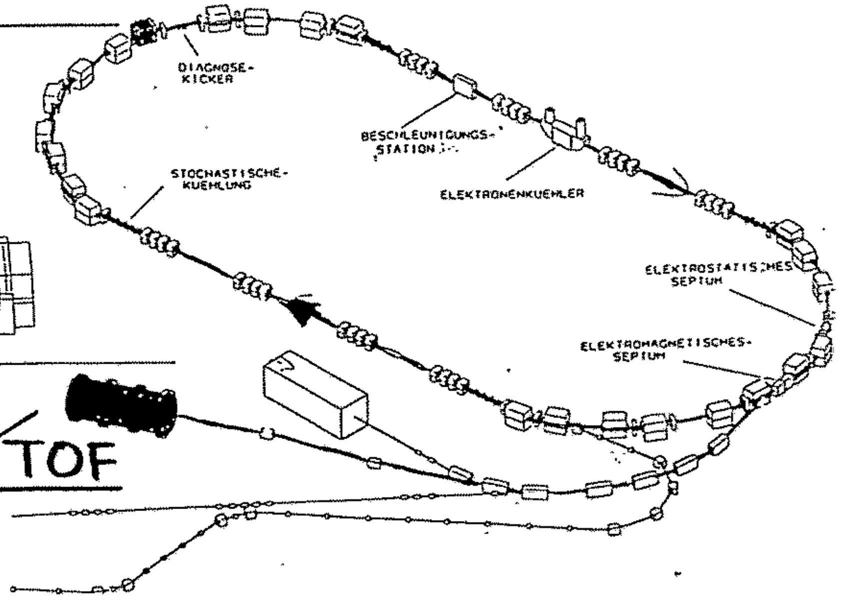
2.2μs

$\nu_e \bar{\nu}_\mu$

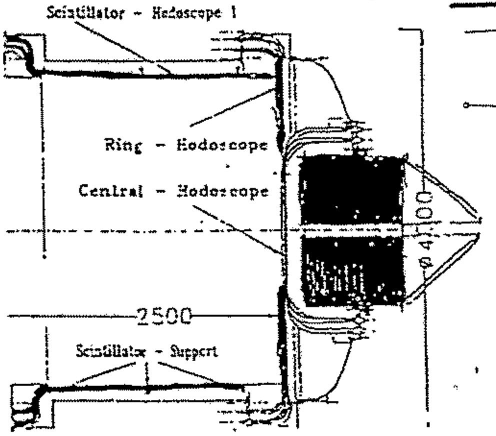


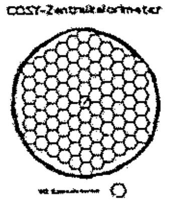


GOSY-11



TOF





COSY

Zusammenfassung

Universelle Struktur der niederenergetischen DCX-Energieanregungsfunktion findet natürliche Erklärung durch eine <u>schmale Resonanz im πNN-Subsystem</u>

$\boxed{d'}$ $\boxed{\begin{array}{l} I(J^P)=\text{gerade}(0^-) \\ M=2.06\ \text{GeV},\ \Gamma_{NN\pi}=0.5\,\text{MeV} \end{array}}$ $\not\rightarrow$ $\boxed{NN}$

freier Zerfall: $d' \Rightarrow \pi^- pp,\ \pi^0 pn,\ \pi^+ nn$

$\searrow \gamma np$

Kernmediumseffekte ???

$\boxed{\begin{array}{l} \text{ARGUS Messungen} \\ c+{}^{16}O \Rightarrow p+p+\pi+X \end{array}}$ $\boxed{\begin{array}{l} \text{ITEP Messungen} \\ p+p \Rightarrow p+p+\pi^+ + \pi^- \end{array}}$ unterstützen d´-Hypothese

Problem: geringe Statistik!

geplante Experimente
an einfachen Systemen:

DCX an He,

2π-Produktion im pp-Stoß an
COSY und CELSIUS,

d´- Photo / Elektro -Produktion

Theorie-Workshop

(*Koordinator:* **H. J. Pirner**)

1. **D. Pirjol** (Mainz)
   Heavy Baryons
2. **R. Fleischer** (München)
   CP-Verletzung im B-System
3. **R. Jakob** (Wuppertal)
   E.m. Formfactors in the modified Hard Scattering Approach
4. **W. Melnitchouk** (Regensburg)
   Deep inelastic Scattering from Relativistic Constituent Quarks
5. **M. Beinker** (Dresden)
   $q^2\bar{q}^2$ im Konstituenten–Quarkmodell
6. **E. Kolomeitsev** (Rossendorf)
   Kaon-Polarisation in Kernmaterie

HEAVY BARYONS

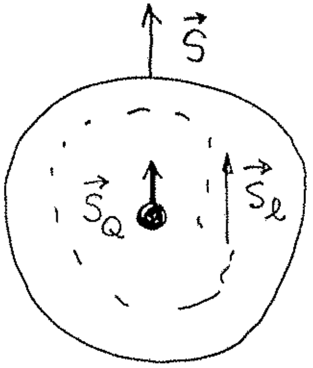
(SELECTED TOPICS)

D. PiRJOL , MAiNZ

J. LANDGRAF
J. KÖRNER
K. SCHiLCHER

1. HEAVY QUARK SYMMETRY
2. HEAVY BARYONS
3. STRONG & ELECTROMAGNETiC DECAYS
4. SEMiLEPTONiC DECAYS $b \to c$

HEAVY - QUARK SYMMETRY



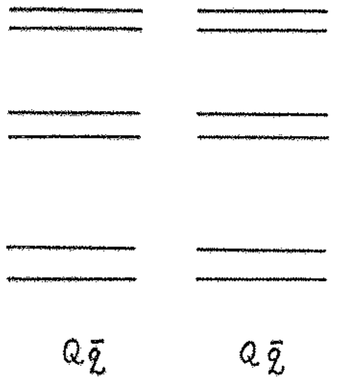
$$\vec{S} = \vec{S}_Q + \vec{S}_\ell$$

- SPiN SYMMETRY : $\vec{S}_Q$, $\vec{S}_\ell$ ARE SEPARATEL CONSERVED

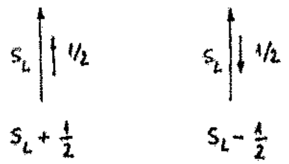
- FLAVOR SYMMETRY : THE TYPE OF HEAVY QUARK iS iRRELEVANT

Voloshin, Shifman 1989
Isgur, Wise 1990

Implications for the hadron spectrum (mesons + baryons)



Good quantum numbers for labeling the levels are the angular momentum and parity of the light d.o.f. $s_\ell^{\pi_\ell}$.

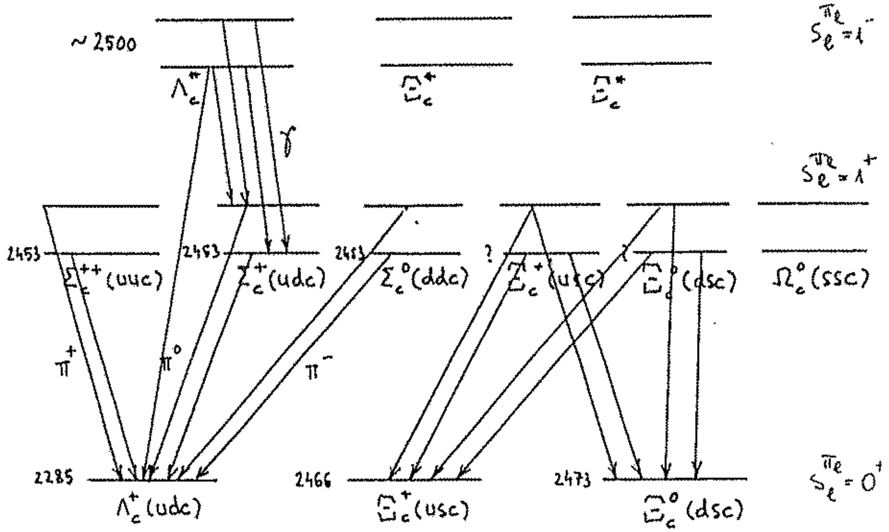


(possibly singlets if $s_L = 0$ → Λ - baryons)

E.g. (D, D^*), (D_1', D_2^*), (Σ, Σ^*), (Ω, Ω^*)

HEAVY BARYONS' MASS SPECTRUM

$$3 \otimes 3 = \bar{3} \oplus 6$$

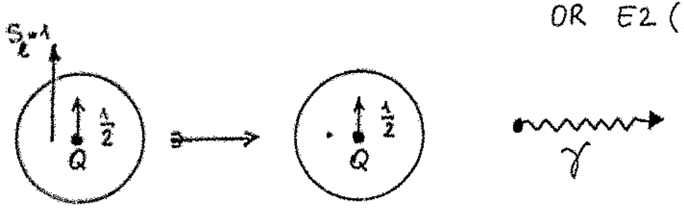


TYPICAL HEAVY QUARK SYMMETRY PREDICTIONS FOR STRONG AND ELECTROMAGNETIC DECAYS OF HEAVY HADRONS

- SELECTION RULES

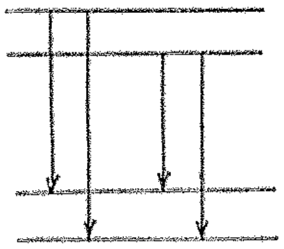
e.g. $\Sigma_c^* \longrightarrow \Lambda_c + \gamma \qquad \left(\frac{3}{2}^+ \to \frac{1}{2}^+ \gamma\right)$

IN PRINCIPLE, THE PHOTON COULD BE $M1(1^+)$ OR $E2(2^+)$



LIGHT DEGREES OF FREEDOM : $1^+ \to 0^+ + 1^+ \qquad M1(1^+)$ $\cancel{E2(2^+)}$

- AMPLITUDE RATIOS



THE AMPLITUDES OF THE 4 TRANSITIONS ARE RELATED.

Isgur, Wise 1990

FORMAL DESCRIPTION OF THE HEAVY-QUARK SYMMETRY

THE HEAVY-QUARK PROPAGATOR

$$S_F(p) = i\,\frac{\not{p}+m}{p^2-m^2}$$

BECOMES NEAR ON-SHELL, WITH $P = mv + K$

$$S_F(K) = \frac{1+\not{v}}{2}\cdot\frac{i}{v\cdot K} + \mathcal{O}(1/m)$$

ANY MASS-DEPENDENCE HAS DISAPPEARED!

THE ANALOG OF THIS IN POSITION SPACE IS THE FIELD TRANSFORMATION

$$Q(x) = \frac{1+\not{v}}{2}\, e^{-imv\cdot x}\, h(x)$$

IN THE QCD LAGRANGIAN

$$\mathcal{L} = \bar{Q}\,(i\gamma_\mu D^\mu - m)\,Q$$

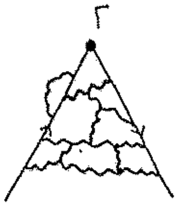
IT BECOMES

$$\mathcal{L}_{HQET} = \bar{h}\, iv\cdot D h + \mathcal{O}(1/m)$$

SEMILEPTONIC DECAYS

- HEAVY-TO-HEAVY $\Lambda_b \rightarrow \Lambda_c e\bar{\nu}$ $\quad b \rightarrow c$
  $\Omega_b \rightarrow \Omega_c^{(*)} e\bar{\nu}$
- HEAVY-TO-LIGHT $\Lambda_c \rightarrow \Lambda e\bar{\nu}$ $\quad c \rightarrow s$

THE MOST PREDICTIVE POWER IS OBTAINED FOR HEAVY-TO-HEAVY TRANSITIONS.



$$\sim \bar{u}(v')\,\Gamma\, u(v)\ \underset{\text{ISGUR-WISE FUNCTION}}{\underset{\downarrow}{\xi(v\cdot v')}}$$

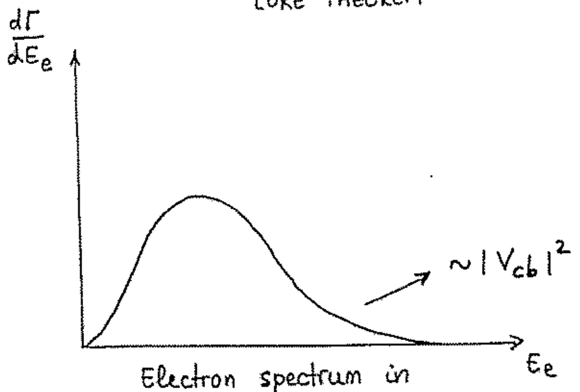
FOR $\Gamma = \gamma_\mu \quad \rightarrow \quad \xi(1) = 1.$ NORMALIZATION CONDITION

- FOR $\Lambda_b \rightarrow \Lambda_c$, 3 FORM-FACTORS NEEDED IN GENERAL
  $\xrightarrow{m_b, m_c \to \infty}$ 1 FORM-FACTOR (IW-FUNCTION)
- A SIMILAR (BUT LESS EFFECTIVE) SIMPLIFICATION OCCURS ALSO FOR HEAVY-TO-LIGHT TRANSITIONS

MASS CORRECTIONS AND THE LUKE THEOREM

$$\langle \Lambda_c(v') | \bar{c}\gamma_\mu\gamma_5 b | \Lambda_b(v) \rangle = \bar{u}(v')\left[f_1^A(v\cdot v')\gamma_\mu + f_2^A v_\mu + f_3^A v'_\mu\right]\gamma_5 u(v)$$
$$= \bar{u}(v')\gamma_\mu\gamma_5 u(v)\,\xi(v\cdot v') + \mathcal{O}\left(\frac{1}{m_{b,c}}\right)$$

$$f_1^A(v\cdot v'=1) = \underset{\text{HQET prediction}}{1} + \underset{\text{LUKE THEOREM}}{\cancel{\frac{C_1}{m_{b,c}}}} + \frac{C_2}{m_{b,c}^2} + \dots \rightarrow ?$$



Electron spectrum in $\Lambda_b \rightarrow \Lambda_c e \bar{\nu}_e$

THE KNOWLEDGE OF THE $1/m^2$ - CORRECTIONS IS ESSENTIAL FOR A PRECISE V_{cb} DETERMINATION.

MODEL - INDEPENDENT DETERMINATION OF THE $1/m^2$ CORRECTIONS

- CONSIDER THE HADRONIC TENSOR

$$W^{i}_{\mu\nu} = (2\pi)^3 \sum_X \delta(p_b - q - p_X) \langle H_b | J^{\dagger}_{\mu} | X \rangle \langle X | J_{\nu} | H_b \rangle$$

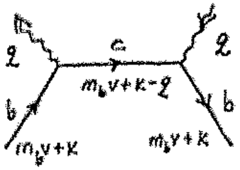
AS FUNCTION OF $v \cdot k$ AT FIXED $v \cdot v'$

- IT CAN BE RELATED TO

$$T_{\mu\nu} = -i \int d^4x \, e^{-iq\cdot x} \langle H_b | T \, J^{\dagger}_{\mu}(x) \, J_{\nu}(0) | H_b \rangle$$

AS $W_{\mu\nu} = -\frac{1}{\pi} \, \mathrm{Im} \, T_{\mu\nu}$

- IN THE $m \to \infty$ LIMIT, THE T-PRODUCT CAN BE EXPANDED INTO AN OPERATOR PRODUCT EXPANSION.



$$\xrightarrow[\substack{q \to \infty \\ m \to \infty}]{} c_1 \bar{b} \gamma_\mu (\gamma_5) b + c_2 \frac{1}{m_b} \bar{b} \gamma_\mu (\gamma_5) D_\nu b + \frac{c_3}{m_b^2} \bar{b} \gamma_\mu (\gamma_5) D_\alpha D_\beta b + \dots$$

- THE MATRIX ELEMENTS OF THE OPERATORS ON THE RIGHT-HAND SIDE CAN BE PARAMETRIZED IN TERMS OF 2 NUMBERS (TO ORDER $1/m^2$).

- DIMENSION - 3 OPERATORS $\bar{b} \gamma_\mu (\gamma_5) b$

  $\longrightarrow$ FREE-QUARK DECAY

- DIMENSION - 4 OPERATORS $\bar{b} \gamma_\mu (\gamma_5) \, iD_\nu \, b$

  $\longrightarrow$ CAN BE RELATED BY THE EQ. OF MOTION TO DIM. - 5 OPERATORS

- DIMENSION - 5 OPERATORS $\bar{b} \gamma_\mu (\gamma_5) \, iD_\alpha \, iD_\beta \, b$

THEIR MATRIX ELEMENTS CAN BE REDUCED TO TWO NUMBERS :

$$\langle \Lambda_b | \bar{b} (iD)^2 b | \Lambda_b \rangle \simeq -0.5 \text{ GeV}^2$$ (from QCD sum rules)

= the average kinetic energy of the b-quark within the hadron Λ_b.

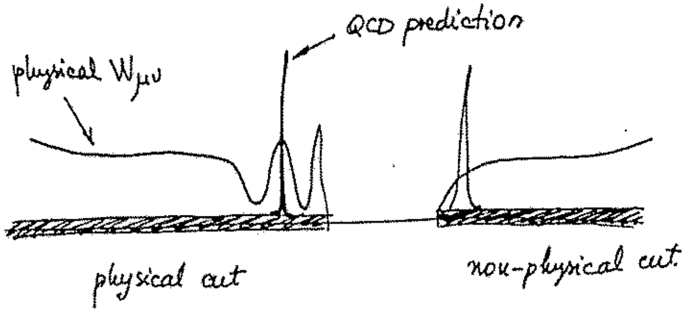
$$\langle \Lambda_b | \bar{b} \gamma_\mu \gamma_5 b | \Lambda_b \rangle = \left(1 + \frac{\mu_s^2}{m_b^2} + \dots\right) s_\mu$$

$$\mu_s^2 \simeq -0.33 \text{ GeV}^2$$ (from quark models

OPE SUM RULES

Uraltsev, Shifman, Vainshtein
Körner, Pirjol
Bigi, Uraltsev, Shifman,
Vainshtein

BASIC IDEA : EQUATE THE THEORETICAL EXPRESSION FOR $W_{\mu\nu}$ WITH ITS REPRESENTATION AS A SUM OVER INTERMEDIATE STATES. (SIMILAR TO QCD SUM RULES)



ASSUME DUALITY :

$$\int_{\substack{\text{physical}\\ \text{cut}}} W_{\mu\nu}^{QCD}(q_0)\, dq_0 = \int_{\substack{\text{physical}\\ \text{cut}}} W_{\mu\nu}^{\text{hadronic}}(q_0)\, dq_0 \, ,$$

$$\rightarrow \quad f_1^A(1) \leq 1 - \frac{\mu_\pi^2}{8}\left(\frac{1}{m_c^2} + \frac{1}{m_b^2} + \frac{2}{3 m_c m_b}\right) + \mathcal{O}\left(\frac{1}{m^3}\right) \sim 2.5\%$$

CP-Verletzung im B-System

Vortrag für das Arbeitstreffen
Kern- und Teilchenphysik des BMFT
Pirna, 4.–7. Oktober 1994

R. F.
Physik Department
Institut für Theoretische Physik
TU München

① Einführung zur CP-Verletzung
② CP-Verletzung im Standardmodell
③ CP-Asymmetrien in B^0- und $B^\pm$-Zerfällen
④ Neue Entwicklungen
⑤ Zusammenfassung

CP-Verletzung im B-System

$\cancel{CP}$ ist eines der zentralen Phänomene der Elementarteilchenphysik

* direkter experimenteller Nachweis der $\cancel{CP}$ bisher nur im System der neutralen K-Mesonen:
(Christensen et al. ('64))

$$\boxed{K_L \to \pi\pi}$$

$$BR(K_L \to \pi\pi) \approx 2 \cdot 10^{-3}$$

$\Rightarrow$ $\cancel{CP}$ ist kleiner Effekt!

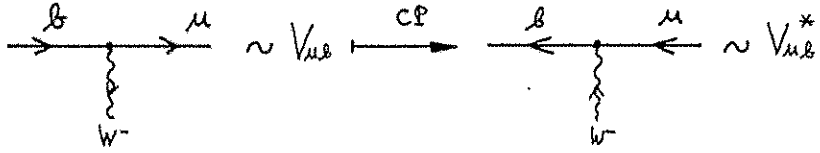
* System der B-Mesonen für zukünftiges experimentelles Studium der $\cancel{CP}$ sehr vielversprechend!

Beschreibung der $\cancel{CP}$ im Rahmen des Standardmodells der elektroschwachen WW

$*$ Cabibbo-Kobayashi-Maskawa-Matrix (CKM-Matrix):

$$\boxed{V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}$$

CKM-Elemente ⇝ "CC-Kopplungen":



Kobayashi und Maskawa ('73):

$\boxed{\cancel{CP}\text{, falls es mindestens 3 Generationen gibt!}}$

⇝ komplexe Phase in der CKM-Matrix

Wolfenstein ('83): $\lambda, A, \varrho, \eta$

$$\boxed{V = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3\sqrt{\varrho^2+\eta^2}\,e^{-i\gamma} \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3\sqrt{(1-\varrho)^2+\eta^2}\,e^{-i\beta} & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)}$$

(Buras Lautenbacher Ostermaier ('94))

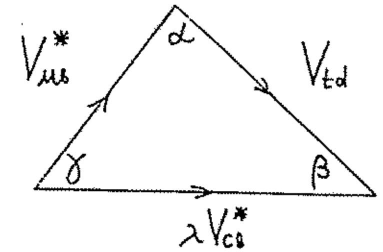
$\lambda = 0.22$; $A = 0.83 \pm 0.10$; $\frac{1}{\lambda}\frac{|V_{ub}|}{|V_{cb}|} = \sqrt{\varrho^2+\eta^2} = 0.36 \pm 0.09$

$\boxed{\beta = \beta(\varrho,\eta)\ ,\ \gamma = \gamma(\varrho,\eta)}$ ⇝ Winkel des Unitaritätsdreiecks:

$\boxed{V^\dagger V = 1} \Rightarrow V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0 \Rightarrow$

$|V_{ud}|e^{i\gamma} - \lambda V_{cb}^* + |V_{td}|e^{-i\beta} = 0$

$\Rightarrow$



$$\left.\begin{array}{l}\text{CP-verletzende}\\ \text{Asymmetrien}\\ \quad\text{in}\\ \text{B-Zerfällen}\end{array}\right\}\rightsquigarrow\left\{\begin{array}{l}\text{Winkel}\\ \quad\text{des}\\ \text{Unitaritäts-}\\ \quad\text{dreiecks}\end{array}\right.$$

$\Rightarrow$ großes Interesse an "B-Physik":

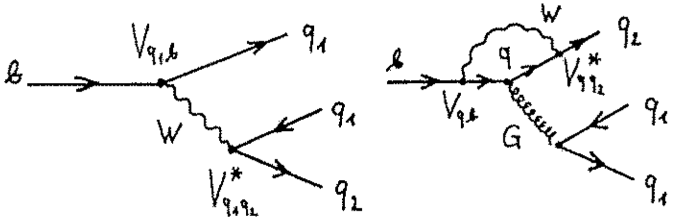
* geplante Projekte:

- DESY (HERA-B)
- SLAC
- FermiLab
- CERN
- KEK

Elektroschwache B-Meson-Zerfälle

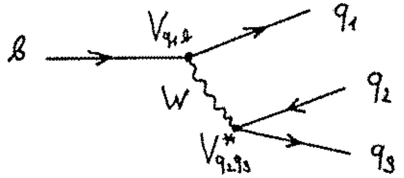
$\rightsquigarrow$ drei Zerfallsklassen:

- Zerfälle mit Tree- und Pinguin-Beiträgen:



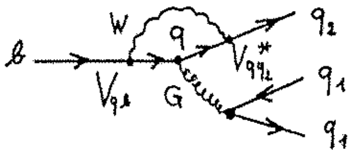
$q_1 \in \{u,c\}$, $q_2 \in \{d,s\}$, $q \in \{u,c,t\}$

- reine Tree-Zerfälle:



$q_1 \neq q_2 \in \{u,c\}$, $q_3 \in \{d,s\}$

- reine Pinguin-Zerfälle:



$q_1, q_2 \in \{d,s\}$, $q \in \{u,c,t\}$

CP-Asymmetrien in B^0 – Zerfällen

* charakteristische Eigenschaft der B^0_q – Mesonen $(q \in \{d, s\})$:

$$\boxed{B^0_q - \bar{B}^0_q - \text{Mischung}}$$

⇝ interessante Effekte, u.a.

$$\boxed{\text{mischungsinduzierte } \cancel{CP}}$$

* besonders vielversprechend (th. & exp.):

Zerfälle $B_q \to f$ mit $CP|f\rangle = \pm|f\rangle$:

$$\begin{tikzcd}
B^0_q \arrow[dr] \arrow[dd, leftrightarrow, "\text{Mischung}"'] & \\
& f \\
\bar{B}^0_q \arrow[ur] &
\end{tikzcd}$$

Falls Dominanz einer CKM-Amplitude (i.a. Tree-Beiträge) in $\overset{(-)}{B}{}^0_q \to f$ ⟹ $\nexists$ hadronische Unsicherheiten in den CP-Asymmetrien!

⇝ zeitabhängige CP-Asymmetrie

$$\boxed{\begin{aligned} a_{CP}(t) &\equiv \frac{\Gamma(B^0_q(t) \to f) - \Gamma(\bar{B}^0_q(t) \to f)}{\Gamma(B^0_q(t) \to f) + \Gamma(\bar{B}^0_q(t) \to f)} = \\ &= \mathcal{A}_{CP}(B_q \to f)\, \sin(\Delta M_q t) \end{aligned}}$$

$$\boxed{\mathcal{A}_{CP}(B_q \to f) = \pm \sin\left[2\{\theta_M^{(q)} - \theta_D^{(f)}\}\right]}$$

$$\theta_M^{(q)} = \begin{cases} \beta & \text{für } q = d \\ \sigma & \text{für } q = s \end{cases} \quad \text{charakteristische schwache Phase der } B^0_q - \bar{B}^0_q - \text{Mischung}$$

$$\theta_D^{(f)} = \begin{cases} -\gamma : & \text{dominante } b \to u \text{ Tree-Beiträge in } B_q \to f \\ \sigma : & \text{dominante } b \to c \text{ Tree-Beiträge in } B_q \to f \end{cases}$$

ΔM_q : Massendifferenz der physikalischen Mischungseigenzustände

"Mischungsparameter":

$$\boxed{x_q \equiv \tau_{B_q} \Delta M_q = \begin{cases} 0.76 \pm 0.06 & q = d \\ \mathcal{O}(10) \quad \text{für} & q = s \end{cases}}$$

$\tau_{B_q} \approx 1.5$ ps : Lebensdauer

– wichtige Beispiele und Anwendungen:

$\boxed{B_d \to \psi K_S:}$

$CP|\psi K_S\rangle = -|\psi K_S\rangle$

$\Theta_M^{(d)} = \beta$

$b \to c$ Tree-Amplitude dominant $\Rightarrow$

$\Theta_D = 0$ (in sehr guter Näherung!)

$$\boxed{\mathcal{A}_{CP}(B_d \to \psi K_S) = -\sin[2\{\beta + 0\}]}$$

$\boxed{B_d \to \pi^+\pi^-:}$

$CP|\pi^+\pi^-\rangle = +|\pi^+\pi^-\rangle$

$\Theta_M^{(d)} = \beta$; $\Theta_D = -\gamma$ ($b \to u$ Tree dominant)

$$\boxed{\mathcal{A}_{CP}(B_d \to \pi^+\pi^-) = \sin[2\{\beta+\gamma\}] = -\sin 2\alpha}$$

– hadronische Unsicherheiten (Pinguine) können durch Isospin-Relationen zwischen $B_d^0 \to \pi^+\pi^-$, $B_d^0 \to \pi^0\pi^0$ und $B^+ \to \pi^+\pi^0$ eliminiert werden (Gronau & London ('90))

$\boxed{B_s \to \rho^0 K_S:}$

$CP|\rho^0 K_S\rangle = -|\rho^0 K_S\rangle$

$\Theta_M^{(s)} = 0$ $\quad \Theta_D = -\gamma$ ($b \to u$ Tree dominant)

$$\boxed{\mathcal{A}_{CP}(B_s \to \rho^0 K_S) = -\sin[2\{0+\gamma\}] = -\sin 2\gamma}$$

– hadronische Unsicherheiten (Pinguine)

CP – Asymmetrien in $B^\pm$ – Zerfällen

* charakteristische Eigenschaft der $B^\pm$ – Mesonen:

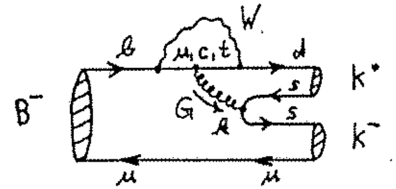
$$\boxed{\nexists \text{ Mischung}} \Rrightarrow \boxed{a_{CP} \equiv \frac{\Gamma(B^+\to f) - \Gamma(B^-\to \bar{f})}{\Gamma(B^+\to f) + \Gamma(B^-\to \bar{f})}} \rightsquigarrow \left\{ \begin{array}{l} \text{direkte} \\ \not{CP} \end{array} \right.$$

– theoretische Analysen von a_{CP} problematisch und i.a. mit großen Unsicherheiten behaftet!

* interessante Prozesse:

- pinguininduzierte $b \to d$ Zerfälle $\rightsquigarrow$ große direkte $\not{CP}$
  (Gérard & Hou ('89), Simma & Wyler ('91), R.F. ('93–'94))

z.B.: $\boxed{B^- \to K^- K^0:}$



$\rightsquigarrow a_{CP} \neq 0$ durch Interferenz der Pinguine mit internen u-, c- und t- Quarks

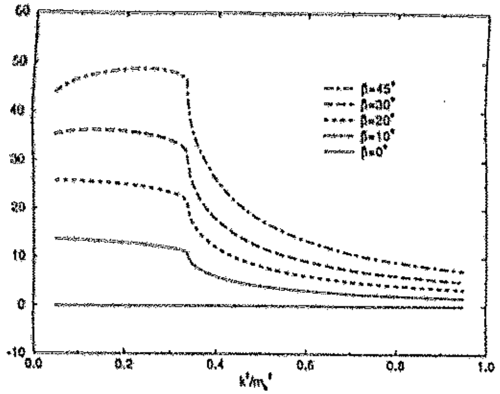
- Zerfälle des Typs $B^\pm \to D K^\pm$
  (Gronau & Wyler ('91))

$$\boxed{B^\pm \to D^0 K^\pm, \quad B^\pm \to \bar{D}^0 K^\pm, \quad B^\pm \to D_{CP} K^\pm}$$

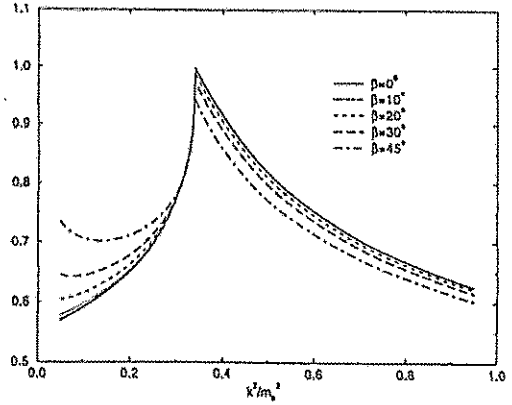
$\underbrace{\phantom{B^\pm \to D^0 K^\pm, \quad B^\pm \to \bar{D}^0 K^\pm}}_{\text{reine "Tree-Zerfälle", keine } \not{CP}}$

erlauben "saubere" Bestimmung von γ mit Hilfe von Dreiecksrelationen

• R.F. ('94)



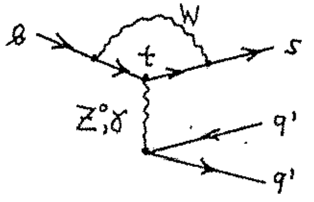
$a_{CP}(B^- \to K^- K^0)$ [%]

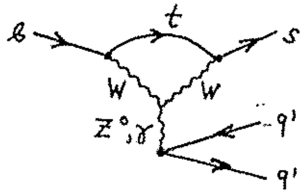


$BR(B^\pm \to K^\pm K^0)/10^{-6}$

Neue Entwicklungen

* Beiträge elektroschwacher Pinguine:
(R.F. ('93–'94), Deshpande & He ('94))





- werden für große Top-Quark-Massen ($m_t = O(170\,GeV)$) wichtig (Analogie zu ε'/ε im K-System)

- Signifikante Effekte im $B^- \to K^- \phi$:
  (R.F. ('93), Deshpande & He ('94))

  $BR(B^- \to K^- \phi) = O(10^{-5})$ wird durch
  EWP – Beiträge um ~30% reduziert!

- elektroschwache Pinguine dominant in
  $B \to M\phi$ ($M \in \{\pi, \rho, ...\}$) (R.F. ('94))

  ⇝ starke m_t-Abhängigkeit vom
  $BR(B^- \to \pi^- \phi) = O(10^{-8})$ und $a_{CP}(B^- \to \pi^- \phi) = O(10^{-2})$

- elektroschwache Pinguine dominant im
  $B_s \to \pi^0 \phi$ (R.F. ('94))

* SU(3) – Relationen zwischen B-Meson Zerfallsamplituden
(Gronau, Hernández, London, Rosner ('94))

$$\left\{\begin{array}{c}\text{SU(3) – Flavour – Symmetrie der starken WW}\\ \oplus \\ \text{plausible dynamische Annahmen}\end{array}\right\} \rightsquigarrow$$

$\rightsquigarrow$ Dreiecksrelationen zwischen $B \to \{\pi\pi, \pi k, k\bar{k}\}$

> Bestimmung sowohl der schwachen Phasen der CKM-Matrix als auch starker Endzustands-Wechselwirkungsphasen durch Messung der entsprechenden Verzweigungsverhältnisse! (keine Zeitabh. $\not{CP}$)

- Probleme der Methode durch:
  - nichtfaktorisierbare SU(3) – Brechung
  - elektroschwache Pinguin-Beiträge (Buras & R.F., Deshpande & He ('94))
  - QCD-Pinguine mit internen up- und Charm-Quarks (Buras & R.F. ('94):
    - können durch Messung der B^0_d–$\bar{B}^0_d$ / B^0_s–$\bar{B}^0_s$-Mischung eliminiert werden
- weitere Anwendung der Methode zur Vorhersage der CP-Asymmetrie $\mathcal{A}^{\text{mix-ind}}_{CP}(B_d \to K^0\bar{K}^0)$

(R.F. ('94)) $\boxed{\mathcal{A}^{\text{mix-ind}}_{CP}(B_d \to K^0\bar{K}^0) = \mathcal{O}(30\%)}$ ← QCD-Pinguine mit internen u- und c-Quarks

$\neq 0$ im SM!

Zusammenfassung

- $\not{CP}$ zentrales Phänomen der ETP
- B-System sehr vielversprechend für experimentelles Studium der $\not{CP}$:
- CP-Asymmetrien in neutralen B-Zerfällen

$B_d \to \psi K_S$:	$\sin 2\beta$
$B_d \to \pi^+\pi^-$:	$\sin 2\alpha$
$B_s \to \rho^0 K_S$:	$\sin 2\gamma$

- CP-Asymmetrien in geladenen B-Zerfällen:
  - Rechnungen i.a. problematisch und unsicher!
  - pinguininduzierte $b \to d$ Zerfälle $\rightsquigarrow$ große direkte $\not{CP}$
  - $B^\pm \to D K^\pm$ $\rightsquigarrow$ "saubere" Bestimmung von γ
- Neue Entwicklungen:
  - Elektroschwache Pinguine können für $m_t = \mathcal{O}(170\,\text{GeV})$ wichtig werden ($B \to K\phi$, $B \to M\phi$ (M ∈ {π, ρ…}), $B_s \to \pi^0\phi$)
  - Anwendungen der SU(3) – Flavour – Symmetrie der starken Wechselwirkung

Rainer Jakob Pirna, 4.10.94

ELECTROMAGNETIC FORM FACTORS

in the **modified** Hard Scattering Approach

$F_\pi(Q^2)$, $G_M^p(Q^2)$, $G_M^n(Q^2)$

<u>outline</u>

- HSA, mHSA
- pion form factor
- magn. form factor of nucleons

R.J., P. Kroll, PLB 315('93)463,
B 319 ('93) 545 (E)

J. Bolz, R.J., P. Kroll, M. Bergmann, N.G. Stefan
WU-B-94-06, WU-B-94-17

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form factors

information about deviations from point-like structure of charge and magnetic moment distributions

non-relativistic charge form factor =
F.T of spatial charge distribution

relativistic case: possible to go to frame where q^μ has no time-like component
(e.g. brick wall)

$\Rightarrow$ charge (magnetic) distributions =
F.T. of F_π, G_E (G_M)

distributions are <u>not</u> Lorentz invariant modulus squared of

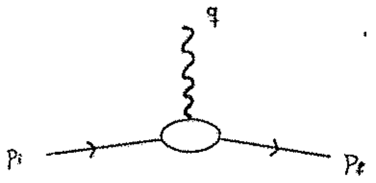
form factors

describe probability of a hadron to stay intact when it is hit by a photon.

probability decreases with increasing momentum transfer

'dimensional counting rules': $F(Q^2) \sim Q^{-n+2}$

n = min. # of ext. partons



define:
pion form factor

$\gamma^* \pi \to \pi$ vertex in the amplitude for $e\pi \to e\pi$

$$\Gamma_\mu = -ie \; F_\pi(Q^2) \; (p_i + p_f)_\mu$$

G.P. Lepage, S.J. Brodsky, PRD 22 (1980) 2157

Hard Scattering Approach

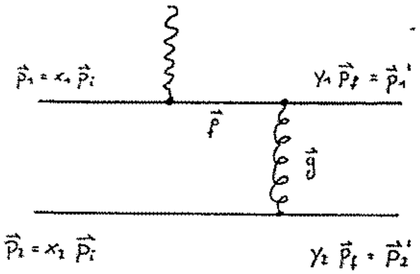
Drell - Yan - West

$$F_\pi(Q^2) = \int \frac{dx \, d^2k_\perp}{16\pi^3} \; \Psi^*(x, (1-x)\vec{q} + \vec{k}_\perp) \; \Psi(x, \vec{k}_\perp)$$

large $|\vec{q}|$: perturbative tail → OGE Kernel

$$F_\pi(Q^2) = \int \frac{dx \, d^2k_\perp}{16\pi^3} \int \frac{dy \, d^2\ell_\perp}{16\pi^3} \; \Psi_0^*(y, \vec{\ell}_\perp) \; T_H(x, y, \underset{\sim}{k_\perp, \ell_\perp}, Q, \mu) \; \Psi_0(x, \vec{k}_\perp)$$

$\Psi_0(x, k_\perp)$ soft part of (valence Fock state) wave function



collinear approx.

$g^2 = -x_2 y_2 Q^2$

$f^2 = -x_2 Q^2$

Light cone variables.

$p_2^+ = x_2 \, Q/\sqrt{2}$ $\quad p_2'^- = y_2 \, Q/\sqrt{2}$

$$F_\pi(Q^2) = \frac{f_\pi^2}{24} \int_0^1 dx\,dy\ \phi(y,\mu_F)\ T_H(x,y,Q,\mu)\ \phi(x,\mu_F)$$

with

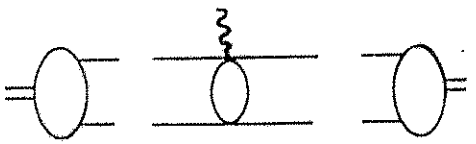
$$T_H \approx \frac{16\pi\,\alpha_s(\mu)\,C_F}{x_2\,y_2\,Q^2}$$

and

$$\frac{f_\pi}{2\sqrt{6}}\ \phi(x,\mu_F) = \int_{|\vec{k}_\perp| \le \mu_F} \frac{d^2k_\perp}{16\pi^3}\ \Psi(x,k_\perp) \qquad \mathrm{DA}$$

factorization:

$$\phi^* \otimes T_H \otimes \phi$$



Long-distance non-perturbative ⊗ short dist. perturbative ⊗ Long-dist. non-perturb.

problems in HSA

1.) scale μ in $T_H(x,y,Q,\mu)$:

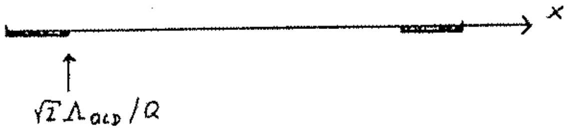
$\mu^2 = Q^2$ leads to large higher order corrections

$$\ln(\mu^2/x_2 y_2 Q^2)$$

$\mu^2 = x_2 y_2 Q^2$ leads to singularities of $\alpha_s(x_2 y_2 Q^2)$ for $x_2 ; y_2 \to 0$

2.) large end-point contributions

e.g. $Q^2 = 5\ \mathrm{GeV}^2$ IR - cutoff in α_s



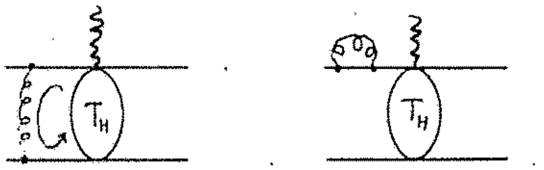
define 'end-point regions' by $x_i < \sqrt{2}\,\Lambda_{QCD}/Q$
, i.e., Large components p_i^+, p_i^- smaller than Λ_{QCD}!

DA	'endpoint contributions'
C.Z.	83 %
asy.	46 %

J. Botts, G. Sterman, Nucl. Phys. B 325 (1989) 62
H.-n. Li, G. Sterman, Nucl. Phys. B 381 (1992) 129
H.-n. Li, Phys. Rev. D48 (1993) 4243

modified Hard Scattering Approach

coincides with HSA for $Q \to \infty$; x fixed
retains more information for $x \to 0$:
Q fixed



in axial gauge: double logs

in axial gauge: single logs

transverse momentum flow through hard amplitude T_H

in transverse configuration space:

$$F_\pi(Q^2) = \int \frac{dx\,dy}{(4\pi)^2} \int d^2b_1\, d^2b_2 \quad \hat{\Psi}_0(y,b_2)\, \hat{T}_H(x,y,b_1,b_2,Q,\mu)\, \hat{\Psi}_0(x,b_1$$

$$\times \quad \exp\left\{-S'(x,y,b_1,b_2,Q,\mu)\right\}$$

$\hat{T}_H$ = Fourier transform of

$$\frac{x_2 Q^2}{x_2 Q^2 + k_\perp^2} \; \frac{16\pi \alpha_s(\mu)\, C_F}{x_2 y_2 Q^2 + (k_\perp + \ell_\perp)^2}$$

note:

$$\frac{k_\perp^2}{Q^2} \ll 1 \quad \text{but} \quad \frac{k_\perp^2}{x_2 y_2 Q^2} \not\ll 1$$

for $x_2 y_2 \to 0$

in transverse configuration space

m HSA

$$F_\pi(Q^2) = \int \frac{dx\,dy}{(4\pi)^2} \int d^2b_1\, d^2b_2 \quad \hat{\Psi}_0(y,b_2)\; \hat{T}_H(x,y,b_1,b_2,Q,\mu)\; \Psi(x,b_1)$$

$$\times \quad \exp\left\{-\,S(x,y,b_1,b_2,Q,\mu)\right\}$$

with

$$S(x,y,b_1,b_2,Q,\mu) = \sum_{i=1}^{2} \left[\, s(x_i,b_1,Q) + s(y_i,b_2,Q) \,\right]$$

(LL & NLL)

$$-\frac{1}{\beta_1}\, \ln\left(\frac{\ln t/\Lambda}{\ln 1/b_1\Lambda}\right) - \frac{1}{\beta_1}\, \ln\left(\frac{\ln t/\Lambda}{\ln 1/b_2\Lambda}\right)$$

and

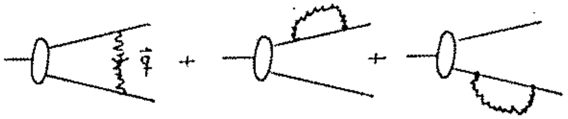
$$\hat{T}_H(x,y,b_1,b_2,Q,\mu) = \frac{4\,\alpha_s(t)\,C_F}{\pi}\;\; K_0(\sqrt{x_2 y_2}\,Q b_2)\, K_0(\sqrt{x_2}\,Q\,|\vec{b}_1+\vec{b}_2|)$$

with the choice $\mu = t := \max\left(\sqrt{x_2 y_2}\,Q,\ 1/b_1,\ 1/b_2\right)$

i.e., the largest mass scale in $\hat{T}_H$

Sudakov corrections

in axial gauge: leading double-log corrections may be factored into the wave functions



exponentiation of leading logs:

$$\exp\left[-\,S(x,b,Q)\right] = \exp\left[-\,s(x,b,Q) - s(1-x,b,Q)\right]$$

$$s(x,b,Q) = \frac{C_F}{2\beta_1}\left\{ \ln(x\sqrt{2}\,Q/\Lambda_{QCD})\; \ln\left[\frac{\ln(x\sqrt{2}\,Q/\Lambda_{QCD})}{-\ln(b\Lambda_{QCD})}\right] \right.$$

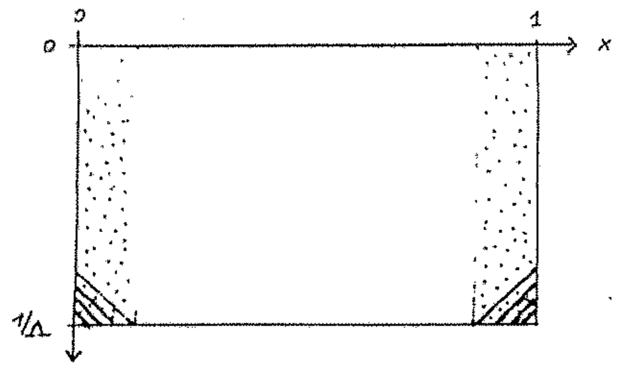
$$\left. -\ln(x\sqrt{2}\,Q/\Lambda_{QCD}) - \ln(b\Lambda_{QCD}) \right\}$$

$C_F = 4/3 \qquad \beta_1 = (11 - 2/3\, n_f)/4 \qquad n_f = \#$ flavors

b = transverse distance of the constituents
(conj. var. of transverse momentum)

acts as infrared-regulator
(in analogy to QED: charge dipol)

vay cut $\qquad x_2 y_2 Q^2 + \underline{\underline{(k_\perp + \ell_\perp)^2}}$



b = 'impact parameter' (can. conj. of $k_\perp$)

◌ 'soft' in HSP ▨ 'soft' in modified HSP

gluon is 'soft' if both

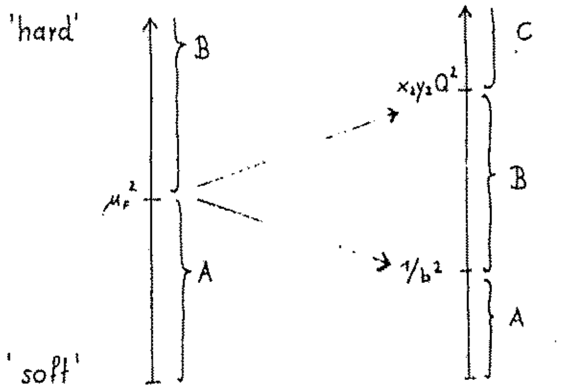
$x_2 y_2 Q^2$ and $(k_\perp + \ell_\perp)^2$ are small
(i.e. b is large)

suppose a mechanism which suppresses

the dangerous soft regions

⇒ no 'cuts' are necessary

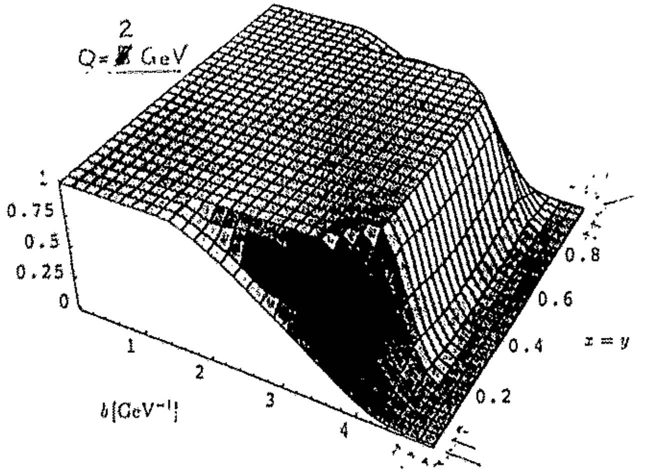
Scales



HSP	modified HSP
A: soft → evolution of DAs	A: very soft → evolution
B: hard → higher order corrections of T_H (K - factor)	B: intermediate soft → explicitly in Sudakov factor
	C: hard → h.o. in T_H

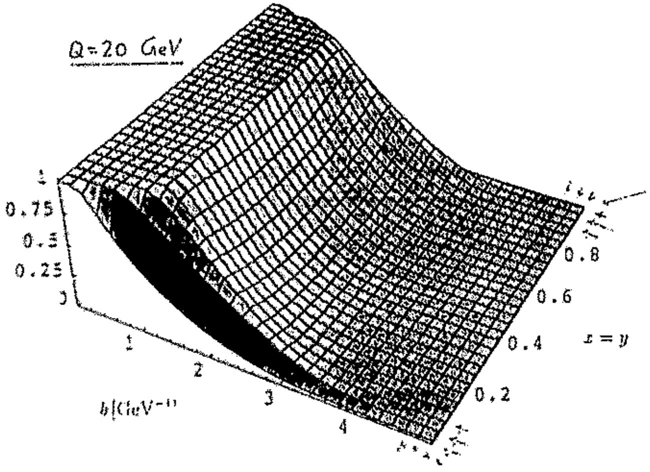
scales $x_2 y_2 Q^2$ and $1/b^2$ are allowed to interchange !

What happens with the Sudakov factor ?



Q = ~~[illegible]~~ 2 GeV

Sudakov factor in F_π
at x = y



Q = 20 GeV

intrinsic transverse momentum

respective b-dependence in $\hat{\Psi}_0(x,b)$

ansatz:

$$\hat{\Psi}_0(x,b) = \frac{f_\pi}{2\sqrt{6}} \; \varnothing(x) \; 4\pi \exp\left(-\frac{x(1-x)\,b^2}{4\,a^2}\right)$$

with $\int_0^1 dx \; \varnothing(x) = 1$

two parameters: f_π, a

two constraints: $\pi \to \mu\nu \;\Rightarrow f_\pi = 130.7$ MeV

$\pi^0 \to \gamma\gamma \;\Rightarrow a$

DA s

$\varnothing(x) = 6x(1-x)$ asymptotic DA

$\varnothing(x) = 30x(1-x)(2x-1)^2$ C.Z. DA

V.L. Chernyak, A.R. Zhitnitsky,
Nucl. Phys. B 201 (1982) 492

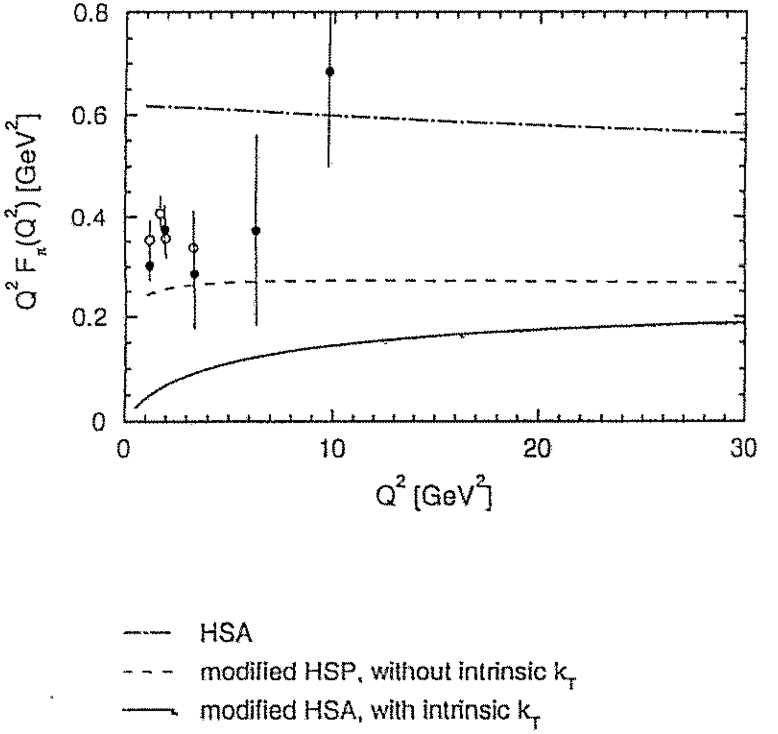
interpretation

$\exp[-s(x,b,Q)-s(1-x,b,Q)]$	$\exp[-x(1-x)\,b^2/4a^2]$
perturbative	non-perturbative
Sudakov corrections	phenomenological input model assumptions
taken literally even in IR-region (i.e. b large)	'weight fct.' for probability to find configurations with quark-antiquark distance b

. relative importance of both factors (Q dependent) ?

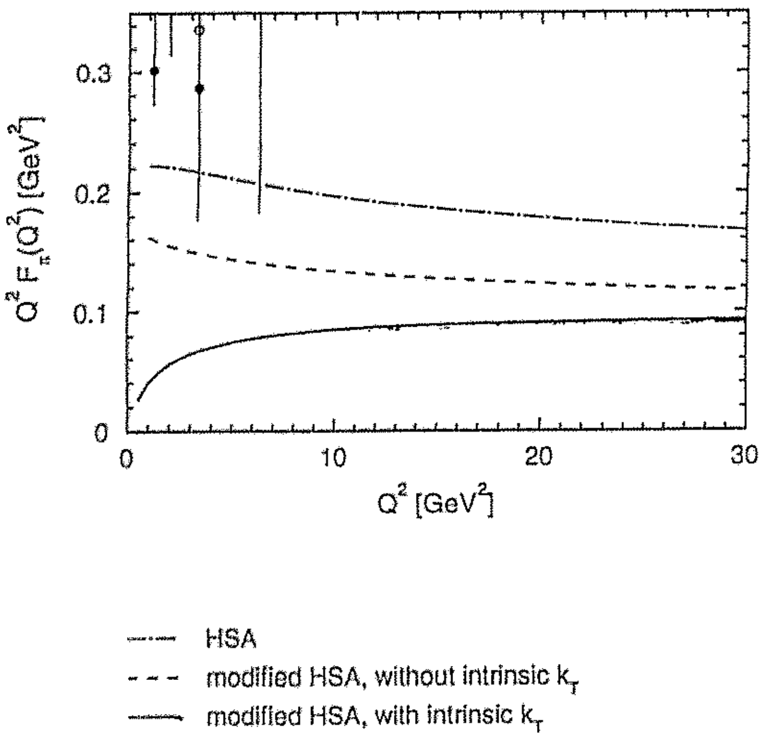
PION FORM FACTOR $F_\pi(Q^2)$

$$\hat{\Psi}_0(x,b) = \frac{f_\pi}{2\sqrt{6}} 30\, x(1-x)\,(2x-1)^2\, 4\pi\ \exp\left[-x(1-x)\,b^2/4a^2\right]$$



PION FORM FACTOR $F_\pi(Q^2)$

$$\tilde{\Psi}_0(x,b) = \frac{f_\pi}{2\sqrt{6}} 6\,x(1-x)\,4\pi\ \exp\left[-x(1-x)\,b^2/4a^2\right]$$



self - consistency

self - consistency of the perturbative results

→ contributions obtained with $\alpha_s \leq 0.7$

DA	$Q^2 = 1\ GeV^2$	$Q^2 = 2\ GeV^2$	$Q^2 = 5\ GeV^2$
asymptotic	61 %	73 %	86 %
C. Z.	53 %	60 %	71 %

Nucleon form factors

$\gamma^* N \to N$ vertex in the amplitude for $eN \longrightarrow eN$

$$\Gamma_\mu^N = \gamma_\mu F_1^N(Q^2) + \frac{\kappa}{2M_N} F_2^N(Q^2)\ i\,\sigma_{\mu\nu} q^\nu$$

Dirac - f.f. Pauli - f.f.

$F_1(0) = F_2(0) = 1$ proton $\kappa = 1.79$

$F_1(0) = 0$ $F_2(0) = 1$ neutron $\kappa = -1.91$

charge and magnetic distributions ?

static charge : $e F_1(0)$ static magn. moment: $F_1(0) + \kappa F_2(0)$

$$\Longrightarrow \qquad G_E = F_1 - \frac{\kappa Q^2}{4 M_N^2} F_2 \qquad G_M = F_1 + \kappa F_2$$

$$\sigma(\theta) = \sigma_{Mott}(\theta)\ \frac{E}{E'} \left[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau\, G_M^2 \tan^2\left(\frac{\theta}{2}\right) \right]$$

$$\tau = Q^2/4M_N^2$$

magnetic form factor of the proton in modified HSA

$$G_M^p(Q^2) = \frac{16}{3} \int_0^1 [dx][dx'] \int \frac{d^2 b_1}{(4\pi)^2} \int \frac{d^2 b_2}{(4\pi)^2} \sum_{j=1}^{2} \hat{T}_j(x, x', \vec{b}, Q, \mu)\, \hat{Y}_j(x, x', \vec{b}, \mu_F)\ e^{-S_j}$$

$$\hat{Y}_1 = \frac{1}{(1-x_1)(1-x_1')} \Big\{ 4\, \hat{\Psi}^{*\prime}_{123} \hat{\Psi}_{123} + 4\, \hat{\Psi}^{*\prime}_{132} \hat{\Psi}_{132} + \hat{\Psi}^{*\prime}_{231} \hat{\Psi}_{231} + \hat{\Psi}^{*\prime}_{321} \hat{\Psi}_{321}$$
$$+ 2\, \hat{\Psi}^{*\prime}_{231} \hat{\Psi}_{132} + 2\, \hat{\Psi}^{*\prime}_{132} \hat{\Psi}_{231} + 2\, \hat{\Psi}^{*\prime}_{321} \hat{\Psi}_{123} + 2\, \hat{\Psi}^{*\prime}_{123} \hat{\Psi}_{321} \Big\}$$

$$\hat{Y}_2 = \frac{1}{2(1-x_2)(1-x_1')} \Big\{ 3\, \hat{\Psi}^{*\prime}_{132} \hat{\Psi}_{132} + \ \ldots \Big\}$$

with

$$\hat{T}_1 = \frac{8}{3} C_F\, \alpha_s(t_{11})\, \alpha_s(t_{12})\ K_0\left(\sqrt{(1-x_1)(1-x_1')}\, Q b_{13}\right) K_0\left(\sqrt{x_2 x_2'}\, Q b_{23}\right)$$

$$\hat{T}_2 = \frac{8}{3} C_F\, \alpha_s(t_{21})\, \alpha_s(t_{22})\ K_0\left(\sqrt{x_1 x_1'}\, Q b_{13}\right) K_0\left(\sqrt{x_2 x_2'}\, Q b_{23}\right)$$

and

$$t_{11} = \max\left(\sqrt{(1-x)(1-x')}\, Q,\ 1/b_{13}\right) \qquad t_{21} = \max\left(\sqrt{x_1 x_1'}\, Q, b_{13}\right.$$

$$t_{12} = t_{22} = \max\left(\sqrt{x_2 x_2'}\, Q,\ 1/b_{23}\right)$$

magnetic form factor of the proton

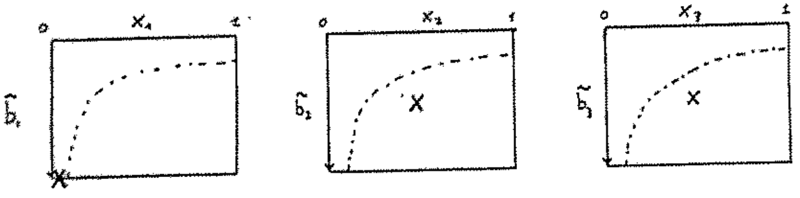
in the modified HSA   H.-n. Li, PRD 48 (93) 4243

Li's (numerical) analysis seriously flawed !

uncancelled singularities

of the form $\sim \ln^{-\kappa}(1/\tilde{b}_p \Lambda_{QCD})$

$\kappa = 7/9$ w.o. evolution , $\kappa \geq 123/81$ with evolution



$e^{-S} = 1$ e^{-S} nonzero e^{-S} nonzero

way out : common $\tilde{b}$ scale in all Sudakov fcts.

$$\tilde{b}_1 = \tilde{b}_2 = \tilde{b}_3 = \max\{b_{13}, b_{23}, b_{12}\}$$

quarks in proton are <u>not</u> pairwise color neutral !

ansatz for wave functions

$$\hat{\Psi}_{123}(x, \vec{b}, \mu_F) = \frac{1}{8\sqrt{N_c!}} f_N(\mu_F)\ \Phi_{123}(x, \mu_F)\, \hat{\Omega}_{123}(x, b)$$

Gaussian

$$\hat{\Omega}_{123}(x, b) = (4\pi)^2 \exp\left[-\frac{1}{4a^2}\left(x_1 x_3 b_{13}^2 + x_2 x_3 b_{23}^2 + x_1 x_2 b_{12}^2\right)\right]$$

two parameters : f_N , a

$f_N = 5.0 \cdot 10^{-3}\ \mathrm{GeV}^2$ QCD sum rules

a = ?   different values have been tested corresponding to $\langle k_\perp^2 \rangle^{1/2} = 270 - 600$ Me

! a constrained by $P_{3q} \leq 1$

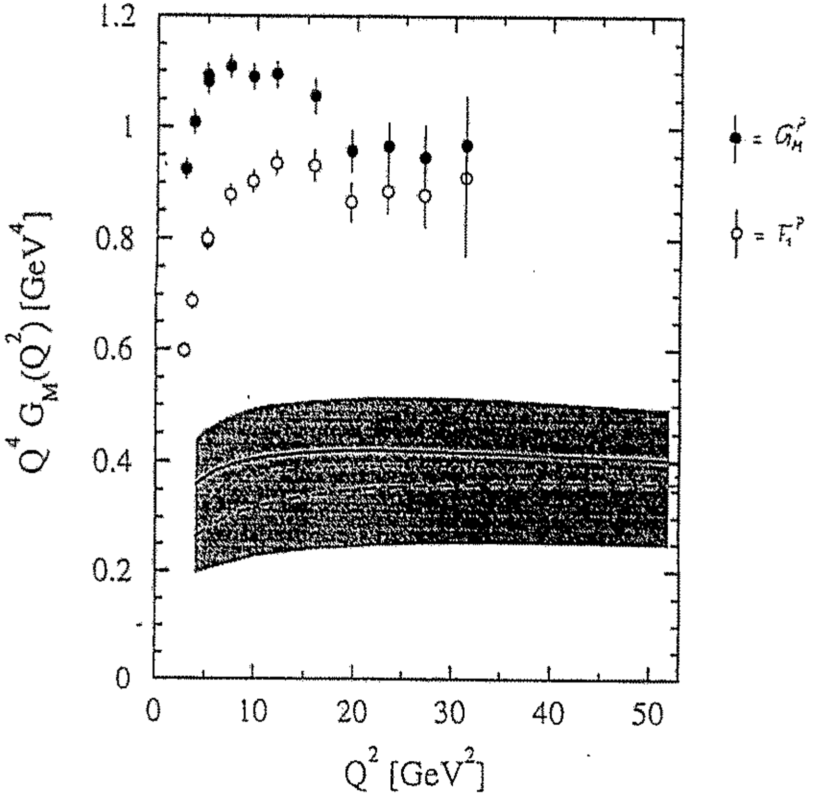
$\Longrightarrow$ upper limit for perturbative

contributions to G_M^p obtained

with a set of 45 DAs (QCD sum rules)

note : G_M^p with asymptotic DA = 0 !

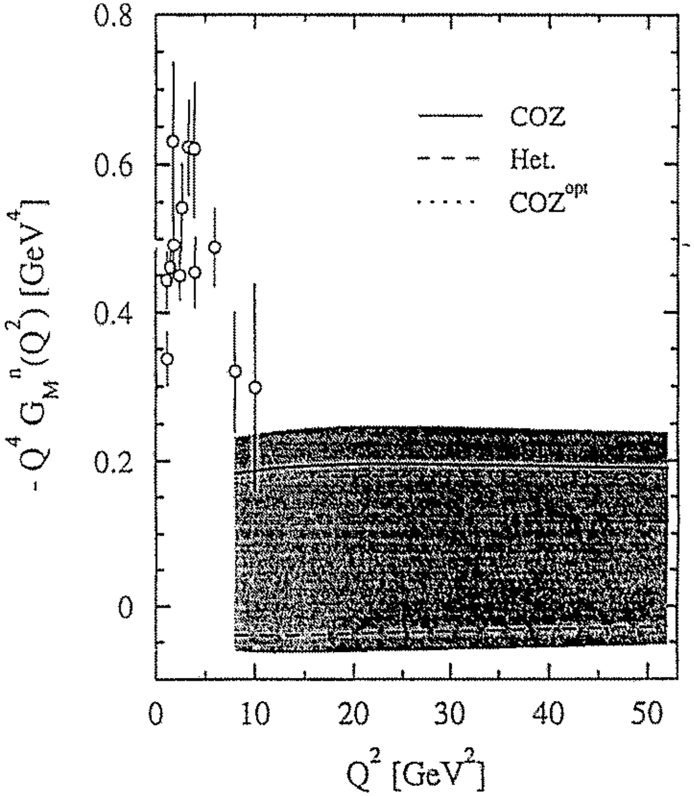
[illegible] the proton



data: [illegible]

[illegible]

[illegible] the neutron



data: [illegible]

[illegible]

Summary:

electromagnetic (elastic) form factors F_π, G_M^p, G_M^n

in the modified HSA:

- Sudakov corrections
- transverse momentum flow through T_H
- intrinsic transverse momentum / size

$\Longrightarrow$ perturbative results (alone) fall short to describe the experimental data

$\Longrightarrow$ calculations are 'self-consistent'

F_π : $Q^2 \gtrsim 1\text{-}2\ \mathrm{GeV}^2$.

G_M^p, G_M^n : $Q^2 \gtrsim 6-10\ \mathrm{GeV}^2$ –

$\Longrightarrow$ α_s singularities are avoided without introducing external parameters

PIRNA 4.10.94

D.I.S. FROM RELATIVISTIC CONSTITUENT QUARKS

W.M., W. WEISE, S. KULAGIN
(REGENSBURG)

1. LARGE x (DIQUARK SPECTATOR)
   → **QDN** VERTEX

HIGHER ORDER CORRECTIONS

SMALL x (MASSIVE SPECTATORS)
→ REGGE MODEL

PREVIOUS CALCULATIONS:

- BAG MODELS (MIT, CHIRAL, ...)
- NON-RELATIVISTIC QUARK MODEL
- QCD SUM RULES

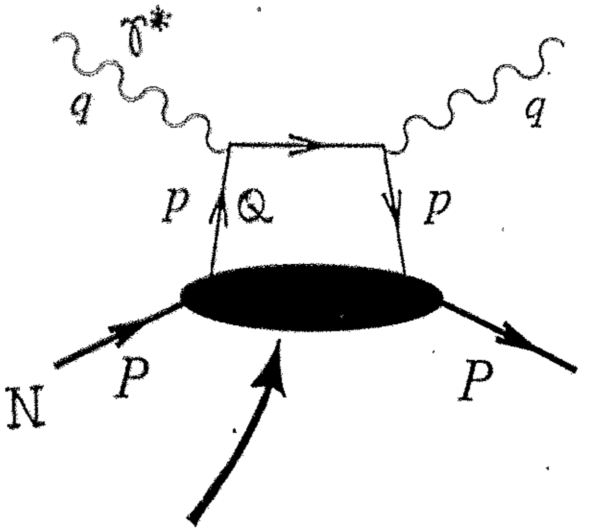
MORE RECENTLY:

- RELATIVISTIC QUARK-NUCLEON VERTEX FUNCTIONS

"FIELD-THEORETIC" APPROACH BASED ON FEYNMAN DIAGS.

-3-

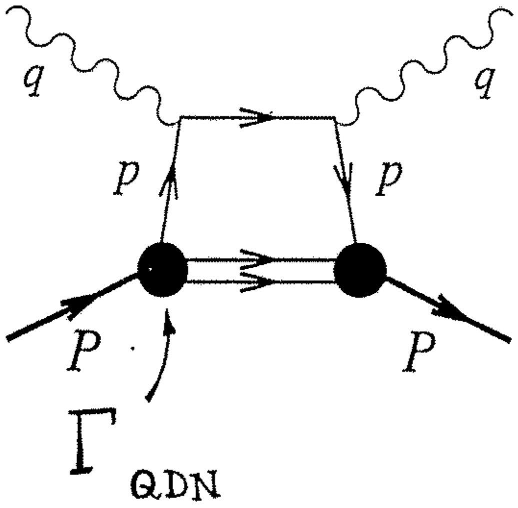
LEADING TWIST PART OF N STRUCTURE FUNCTION



SOFT (CONSTITUENT ?)
QUARK PHYSICS

-4-

STRUCTURE FUNCTION FROM RELATIVISTIC Q-D-N VERTEX FUNCTION



➡ MODEL OF HANDBAG DIAGRAM

GENERAL STRUCTURE OF Γ_{QDN}

$$\Gamma_{QDN} \rightarrow I\,\Phi_1^S + \not{p}\,\Phi_2^S + \cdots$$

SCALAR VERTEX

$$\gamma_5\gamma_\alpha\,\Phi_1^A + \gamma_5 p_\alpha\,\Phi_2^A + \cdots$$

AXIAL-VECTOR VERTEX

MOMENTUM DEPENDENCE OF $\Phi_i^{S,A}$ CALCULATED BY SOLVING COVARIANT BETHE-SALPETER EQN.

EG. NJL MODEL

[ISHII, BENTZ, YAZAKI ; HUANG, TJON ; MEYER]

FOR BOUND STATE, VERTEX FUNCTION SHOULD HAVE FORM:

$$\Phi^{S,A}(p^2) = \mathbf{N}\,\frac{(p^2 - m_Q^2)}{(p^2 - \Lambda_{S,A}^2)^{n_{S,A}}}$$

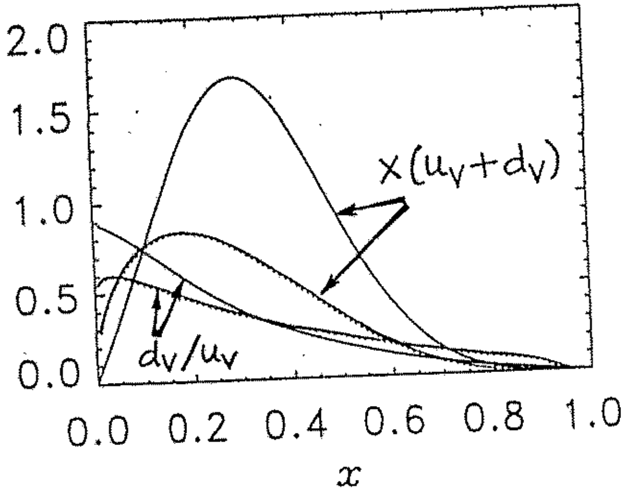
$n_{S,A} \rightarrow$ LARGE-x BEHAVIOR OF $u(x)$, $d(x)$

$\Lambda_{S,A} \rightarrow$ "RADIUS" OF QUARK SPECTATORS

$\mathbf{N} \rightarrow$ NORMALIZATION

$m_A - m_S \sim 200$ MeV

VALENCE QUARK DIST. FROM HANDBAG DIAGRAM

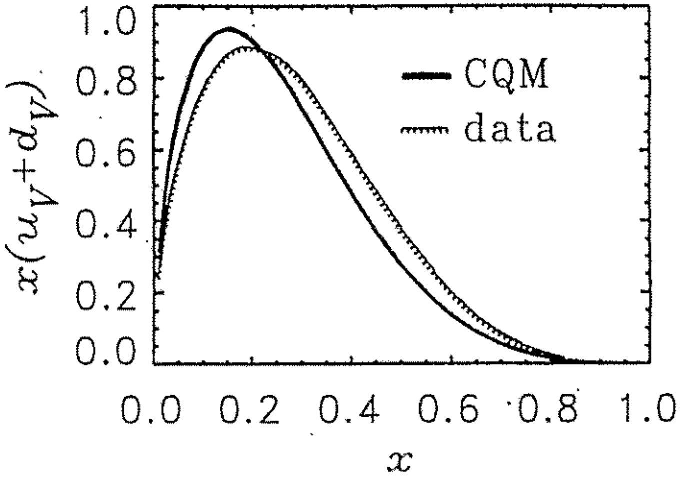


— CALCULATED
— DATA

SCALAR VERTEX $I\,\Phi^S$
PSEUDOVECTOR VERTEX $\gamma_\alpha\gamma_5\,\Phi^A$

- $m_Q = 400$ MeV
- $n_S = 1$, $n_A = 2.5$
- $\Lambda_S = 0.9$ GeV, $\Lambda_A = 1.1$ GeV

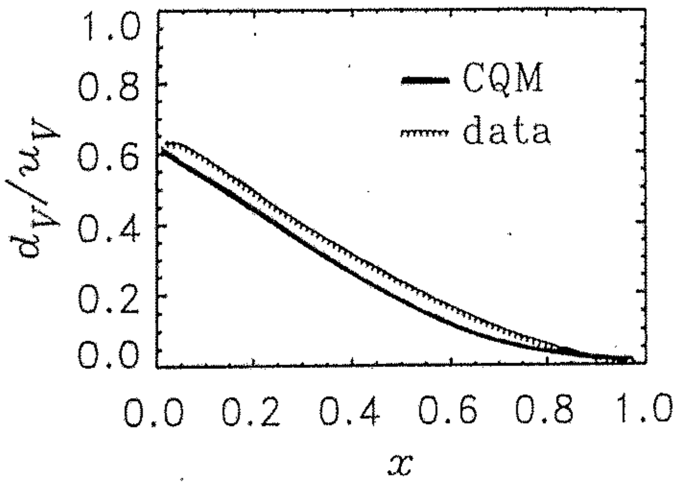
VALENCE QUARK DISTRIB.



EVOLVED FROM $Q_0^2 \sim 0.2$ GeV
TO $Q^2 = 5$ GeV^2

BUT $\alpha_S = \mathcal{O}(1)$

VALENCE d/u RATIO



BASIC PROBLEM :

MODELS WITH FINITE SPECTATOR MASS CANNOT GIVE CORRECT (SINGULAR) $x \to 0$ BEHAVIOR

$q_V(x) \longrightarrow x^{\alpha-1}$, $\alpha \sim 1/2$
REGGE

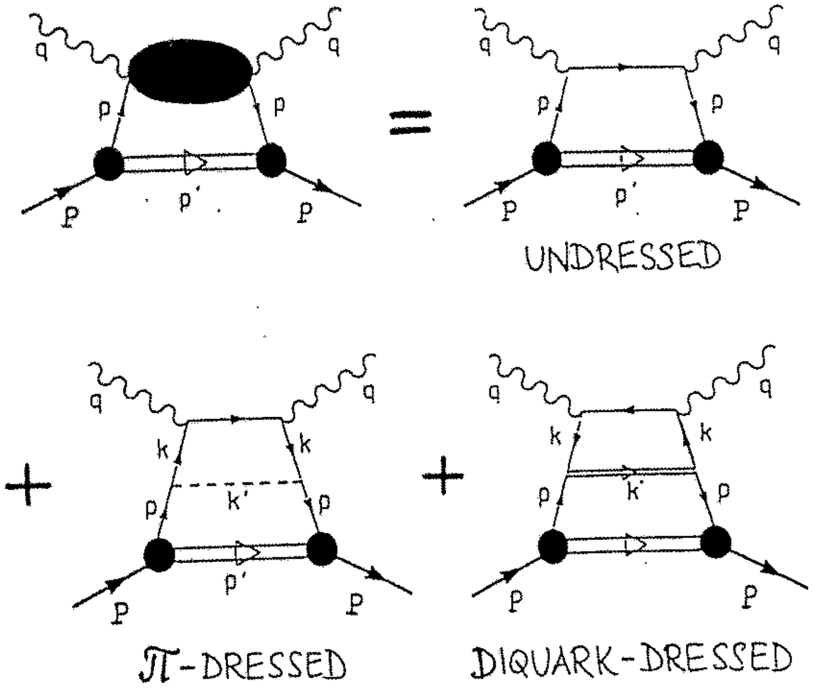
$q_V(x) \longrightarrow$ CONSTANT
MODELS WITH FINITE m_D

→ NEED TO CONSIDER HIGHER MASS SPECTRUM

★

W.M., W.WEISE PHYS. LETT. B334 (94) 275

DRESSING OF CONSTITUENT QUARK BY MESON & DIQUARK "CLOUDS"



+ . . .

- FORMULATE AS CONVOLUTIONS IN I.M.F.

TIME-ORDERED PERT. TH.

➔ ON-MASS-SHELL PARTICLES

$$q_N(x) = \int_x^1 dy\, f_{Q/N}(y)\; q_Q\left(\frac{x}{y}\right)$$

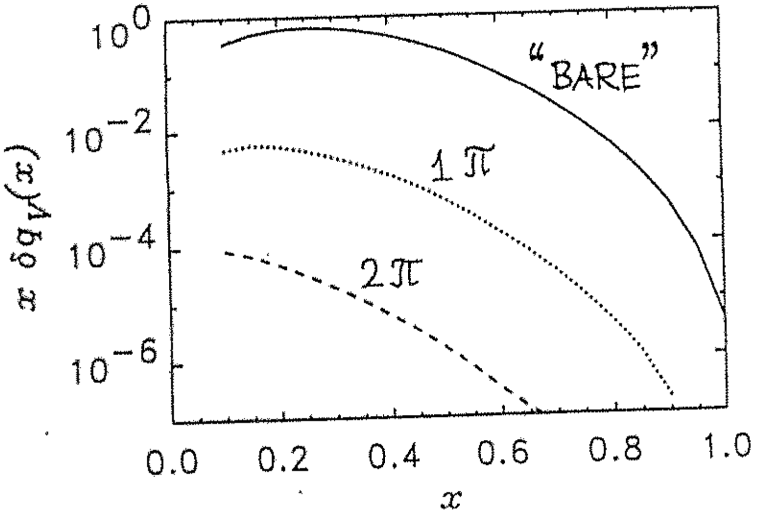
↑ CONSTITUENT QUARK DISTRIBUTION IN NUCLEON

↑ STRUCTURE FUNCTIO OF CONSTITUENT QUAR

- COVARIANT CONVOLUTIO FAILS FOR PARTICLES WITH SUBSTRUCTURE

-13-

π-DRESSING CORRECTIONS



DRESSING OF CONSTITUENT QUARKS DOES NOT SOLVE SMALL-X PROBLEM ★

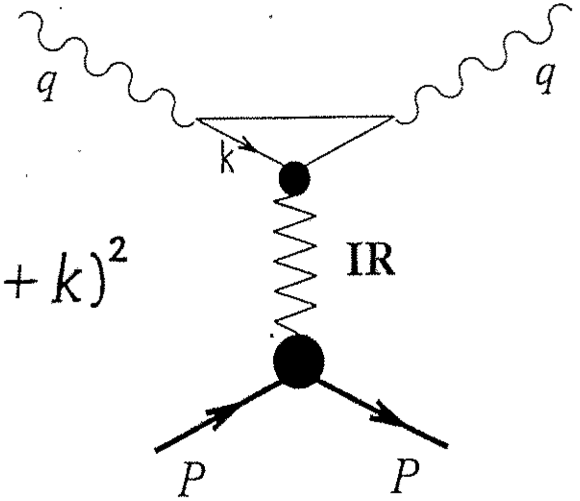
-14-

SUMMATION OF LADDERS

➡ REGGE ASYMPTOTICS

MODEL HIGH-MASS SPECTRUM VIA REGGEON EXCHANGE

$$s = (P + k)^2$$



$$q^{IR}(x) \sim \int ds\, dk^2\, \mathrm{Tr}\left[(\not{P}+M)\, \hat{T}_{qN}\, (\not{k}+m_q)\, \not{q}\, (\not{k}+m_q)\right]$$

$$\boxed{\hat{T}_{qN} \sim \Gamma^{(q)}_{qR} \cdot \Gamma^{(N)}_{NR} \longrightarrow \gamma^{(q)}_{\mu}\, \gamma^{\mu\,(N)}}$$

[KULAGIN PILLER. WEISE PRC 50 (94) 1154]

$$\Im m\, T_{qN} = g_{\mathbb{R}}(k^2) \cdot \Im m\, T_{NN}(s)$$

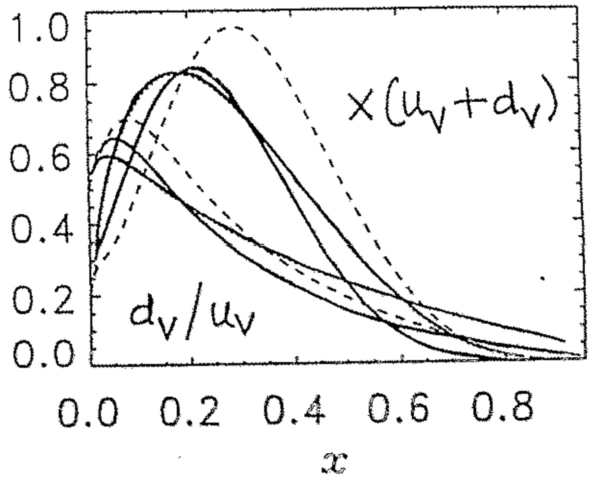
$$\propto \left(1 - k^2/\Lambda^2_{\mathbb{R}}\right)^{-1} \cdot s^{\alpha_{\mathbb{R}}}$$

$$\alpha_{\mathbb{R}} \sim 1/2 \quad \Rightarrow \quad q^{\mathbb{R}}(x) \sim x^{-1/2}$$

$$\Lambda^2_{\mathbb{R}} \approx 1.7 \text{ GeV}^2$$

$$\Rightarrow \int_0^1 dx\, q^{\mathbb{R}}(x) \approx 43\,\%$$

HANDBAG + REGGE CONTRIBUTION



--- CALCULATED

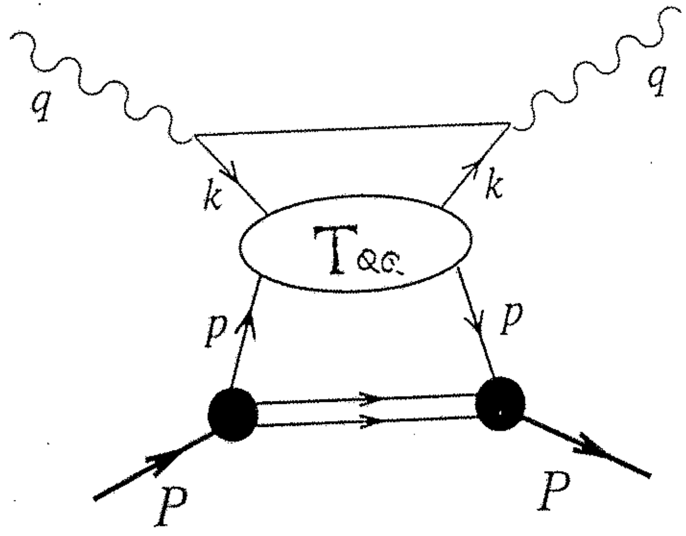
— EVOLVED $Q_0^2 \approx 0.7$ GeV TO 10 GeV^2 (NLO)

— DATA

$$\langle x \rangle_{u_V+d_V} \sim 40\,\% \quad @ \quad Q^2 = 0.7 \text{ GeV}^2$$

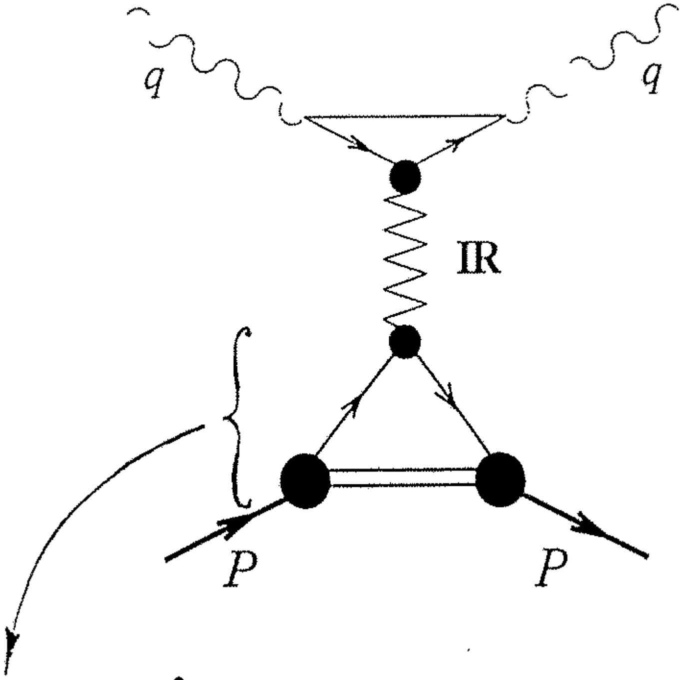
MORE MICROSCOPIC PICTURE

HIGH ENERGY
Q-Q SCATTERING



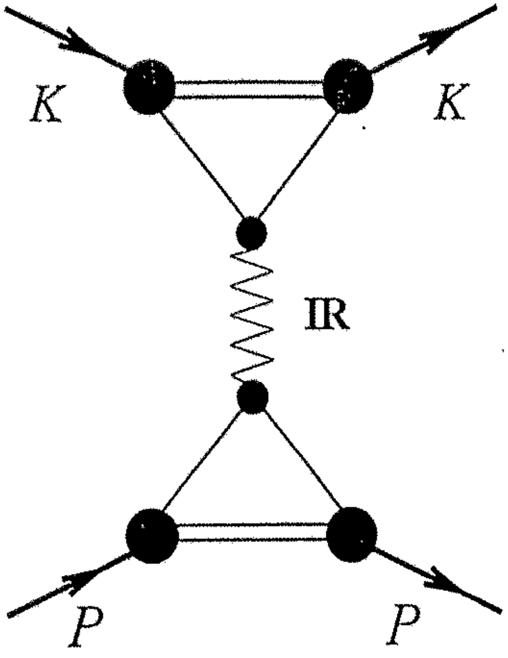
LARGE $s = (p+k)^2$ $\Longrightarrow$

REGGE EXCHANGE BETWEEN QUARKS



$$\Gamma_{N\mathbb{R}} = \int d^4p \; \bar{\Gamma}_{QDN} (\not{p}+m_Q) \underset{\propto\, \gamma_\mu}{\Gamma_{Q\mathbb{R}}} (\not{p}+m_Q) \, \Gamma_{QDN}$$

CONSTRAIN Q-$\mathbb{R}$ "VERTEX"
BY **NN** SCATTERING DATA



$$= T_{NN}$$

SUMMARY

- ◉ VALENCE STRUCTURE FUNCTIO
  - → CONSTITUENT QUARKS
- ◉ LOW MASS SPECTRUM.
  - → RELATIVISTIC **QDN** VERTEX
- ◉ π, D, ... DRESSING SMALL
  - → I.M.F. – NO COVARIANT CONVOLUTIO
- ◉ HIGH MASS SPECTRUM
  - → SMALL X
  - → REGGE EXCHANGE
- ◉ MICROSCOPIC MODEL LINKING **QDN** VERTEX & REGGE MODEL

$q^2\bar{q}^2$ im Konstituenten-Quarkmodell

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1 Einleitung

Exotische Mesonen:

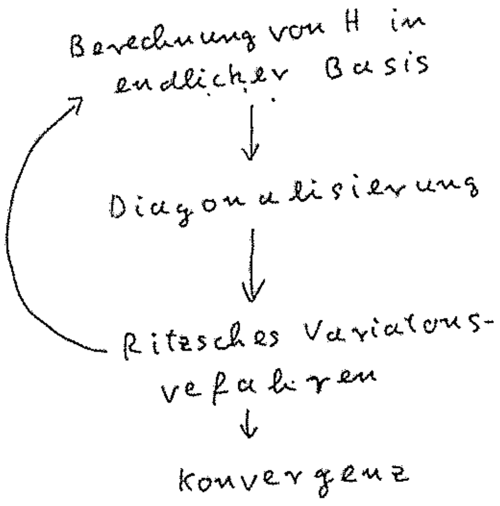
g^n $(n>1)$: GlueBalls
$q\bar{q}g$, $q\bar{q}gg, \ldots$: Hybridzustände
$q^2\bar{q}^2$, $q^6, \ldots$: Multiquarkzustände

Hier: $q^2\bar{q}^2$ im nichtrelativischen Konstituenten-Quarkmodel

Methode

Lösen von

$$H\Psi_n = E_n\Psi_n$$



Berechnung von H in endlicher Basis

Diagonalisierung

Ritzsches Variationsvefahren

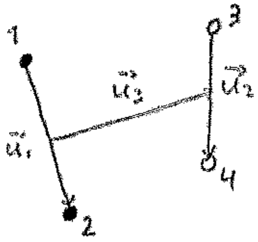
Konvergenz

2 Der Hamiltonoperator

$$H = M + K + V_{conf} + H_{eff}$$

$M = \sum_{i=1}^{4} m_i$: Summe der Quarkmassen

$K = \frac{\vec{p}_{u_1}^{\,2}}{2\mu_{u_1}} + \frac{\vec{p}_{u_2}^{\,2}}{2\mu_{u_2}} + \frac{\vec{p}_{u_3}^{\,2}}{2\mu_{u_3}}$: kinet. Energie



μ_{u_i} : reduzierte Massen

$\vec{p}_{u_i}$: Relativimpulse

● : Quark, Index 1, 2

○ : Antiquark, Index 3, 4

$$V_{conf} = \sum_{i<j} F_{ij}^{c} (a_{ij} + b_{ij} r_{ij})$$

r_{ij} : Abstand von Quark i und j

a_{ij}, b_{ij} : Konstanten, wobei $a_{q\bar q}$ und $b_{q\bar q}$ frei gewählt werden

F_{ij}^{c} : 2 verschiedene Ansätze:

$P_{ij}^{c_1}$: Projektor auf Coloursinglett

$F_i \cdot F_j$ mit $F_i = \begin{cases} \frac{\lambda_i}{2} & \text{für Quarks} \\ -\frac{\lambda_i^*}{2} & \text{für Antiquarks} \end{cases}$

$$H_{eff} = H_{q_1 q_2} + H_{\bar q_3 \bar q_4} + H_{q_1 \bar q_3} + H_{q_2 \bar q_4} + H_{q_1 \bar q_4} + H_{q_2 \bar q_3}$$

$$H_{qq} = -\tilde{g} \left(P^{s=1} P_6^c + 2 P^{s=0} P_{\bar 3}^c \right) \delta^3(\vec{r})$$

P^s : Spinprojektor

P^c : Colourprojektor

$\tilde{g} =$

	ud	du	us	ds	sd	su	uu	dd	ss
ud	g	-g	0				0		
du	-g	g							
us	0		g'	0	0	-g'	0		
ds			0	g'	-g'	0			
sd			0	-g'	g'	0			
su			-g'	0	0	g'			
uu	0		0				0		
dd									
ss									

$$H_{q\bar q} = \hat{g} \left(\frac{1}{2} P^{s=1} P_8^c + P^{s=0} \left(\frac{1}{2} P_8^c + 8 P_1^c \right) \right) \delta^3(\vec{r})$$

$\hat{g} =$

	$u\bar d$	$d\bar u$	$u\bar s$	$d\bar s$	$s\bar d$	$s\bar u$	$u\bar u$	$d\bar d$	$s\bar s$
$u\bar d$	-g	0	0				0		
$d\bar u$	0	-g							
$u\bar s$	0		-g'		0		0		
$d\bar s$				-g'					
$s\bar d$			0		-g'				
$s\bar u$						-g'			
$u\bar u$	0		0				0	g	g'
$d\bar d$							g	0	g'
$s\bar s$							g'	g'	0

Freie Parameter

Parameter	Wert
m_u	300 MeV
m_s	540 MeV
$a_{q\bar{q}}$	-852 MeV
$b_{q\bar{q}}$	850 MeV fm^{-1}
g	122 MeV fm^3
g'	82 MeV fm^3
Λ	0,27 fm

Die Parameter stammen aus einer Arbeit von W. Blask, U. Bohn, M.G. Huber, B.C. Metsch, H.R. Petry, „Hadron spectroscopy with instanton induced quark forces" und sind an Meson- und Baryon-Spektren angepaßt.

β = Oszillatorlänge → Variationsparameter

N_{max} = maximale Zahl der Oszillatoranregungen des Ortsteil eines Basiszustandes

→ Maß für die Genauigkeit der Näherung

3 Die Basis

Der Ortsanteil ist eine Lösung des 4×2 dimensionalen harmonischen Oszillators:

$$\psi^{Ort}_{NLM}(\vec{u}_1,\vec{u}_2,\vec{u}_3) = \left[\left[\phi^{\beta_1}_{n_1 l_1}(\vec{u}_1) \otimes \phi^{\beta_2}_{n_2 l_2}(\vec{u}_2)\right]^{l} \otimes \phi^{\beta_3}_{n_3 l_3}(\vec{u}_3)\right]^{L}_{M}$$

$$N = 2n_1 + l_1 + 2n_2 + l_2 + 2n_3 + l_3$$

$\beta_i^2 = \frac{\hbar}{\mu_i \omega}$

ω = Oszillatorfrequenz

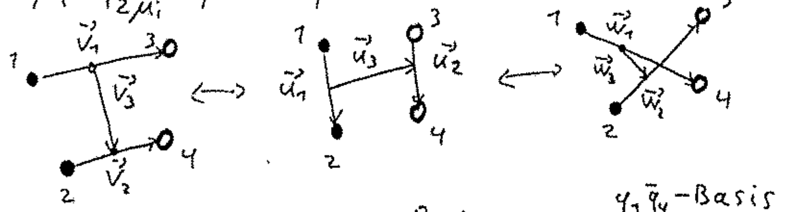
μ_i = reduzierte Massen

n_i = Hauptquantenzahl

l_i = Bahndrehimpulsquantenzahl

$\beta_i = \sqrt{\frac{m_u}{2\mu_i}}\,\beta$

β = Variationsparameter



$q_1\bar{q}_3$-Basis $\quad$ q_1q_2-Basis $\quad$ $q_1\bar{q}_4$-Basis

Spin-Wellenfunktion:

$$\chi^S = \left[\left[\tfrac{1}{2} \otimes \tfrac{1}{2}\right]^{S_{12}} \otimes \left[\tfrac{1}{2} \otimes \tfrac{1}{2}\right]^{S_{34}}\right]^{S}$$

Flavour-Wellenfunktion

$$\chi^T_F = \left[\left[t_1 \otimes t_2\right]^{t_{12}} \otimes \left[t_3 \otimes t_4\right]^{t_{34}}\right]^{t}$$
$$= \left[\chi^{t_{12}} \otimes \chi^{t_{34}}\right]^{T}_{S^f_{12}, S^f_{34}}$$

Colour-Wellenfunktion:

In $q^2\bar{q}^2$-Systemen gibt es 2 Coloursinguletts:

$$3\otimes 3\otimes\bar{3}\otimes\bar{3} = (6\oplus\bar{3})\otimes(\bar{6}\oplus 3)$$
$$= 1_{6\otimes\bar{6}}\oplus 1_{\bar{3}\otimes 3}\oplus 8\oplus 8\oplus 8\oplus 8\oplus 10\oplus\overline{10}\oplus 27 \qquad qq\text{-Basis}$$

oder

$$3\otimes\bar{3}\otimes 3\otimes\bar{3} = (1\oplus 8)\otimes(1\oplus 8)$$
$$= 1_{1\otimes 1}\oplus 1_{8\otimes 8}\oplus 8\oplus 8\oplus 8\oplus 8\oplus 10\oplus\overline{10}\oplus 27 \qquad q\bar{q}\text{-Basis}$$

$$\chi^c = c_1\,|1_{6\otimes\bar{6}}\rangle + c_2\,|1_{\bar{3}\otimes 3}\rangle = \tilde{c}_1\,|1_{1\otimes 1}\rangle + \tilde{c}_2\,|1_{8\otimes 8}\rangle$$

$|1_{6\otimes\bar{6}}\rangle$ symmetrisch bzgl. Vertauschens von $q_1\leftrightarrow q_2$, $\bar{q}_3\leftrightarrow\bar{q}_4$

$|1_{\bar{3}\otimes 3}\rangle$ antisymmetrisch ———

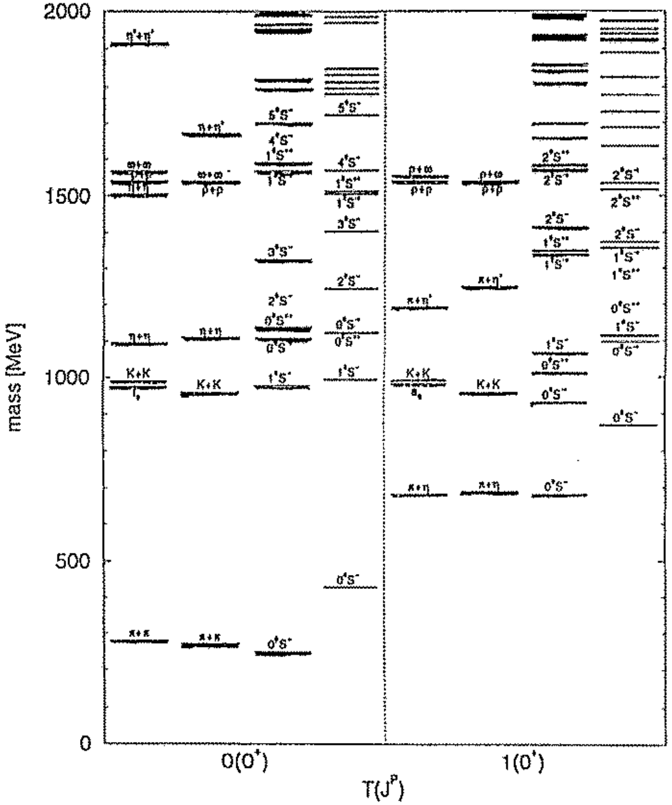
$|1_{1\otimes 1}\rangle$ $q\bar{q}$ im Coloursinglett

$$\Psi_{q_1 q_2} = \Big[\big[[\phi^{\beta_1}_{n_1 l_1}(\vec{u}_1)\otimes\phi^{\beta_2}_{n_2 l_2}(\vec{u}_2)]^{l}\otimes\phi^{\beta_3}_{n_3 l_3}(\vec{u}_3)\big]^{L}\otimes$$
$$\otimes\big[[\tfrac{1}{2}\otimes\tfrac{1}{2}]^{s_{12}}\otimes[\tfrac{1}{2}\otimes\tfrac{1}{2}]^{s_{34}}\big]^{S}\Big]^{J}_{M}\cdot$$
$$\cdot\,[\chi_f^{t_{12}}\otimes\chi_f^{t_{34}}]^{T}_{s^f_{12}\,s^f_{34}}\;\chi_c^{c_{12}}$$

Pauliprinzip:

$$(-1)^{l_1+s_{12}+t_{12}+\delta_{c_{12}=1_{3\otimes\bar{3}}}} = -1 \qquad \text{falls } s^f_{12}=0,2$$
$$(-1)^{l_2+s_{34}+t_{34}+\delta_{c_{12}=1_{3\otimes\bar{3}}}} = -1 \qquad \text{falls } s^f_{34}=0,2$$

Spektren



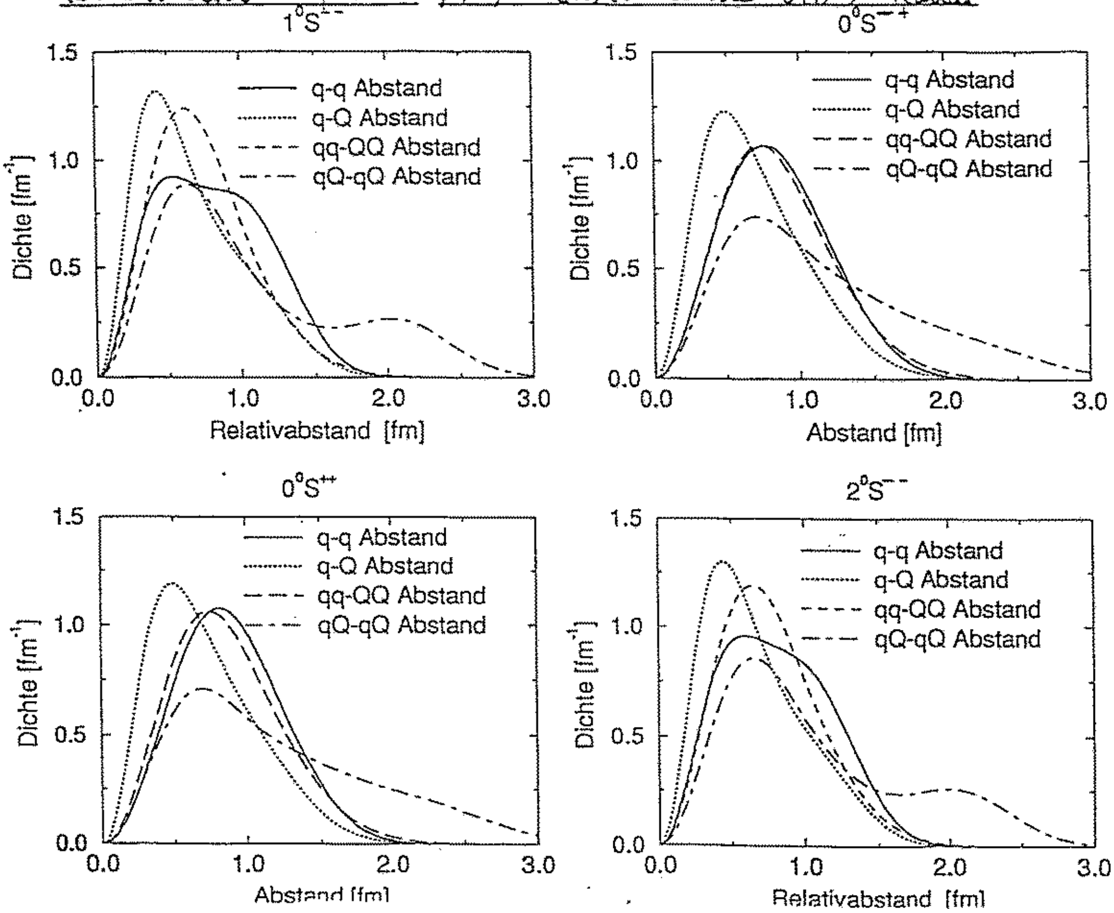
— Summe von 2 Mesonmassen, exp.

— Summe von 2 Mesonmassen, theor.

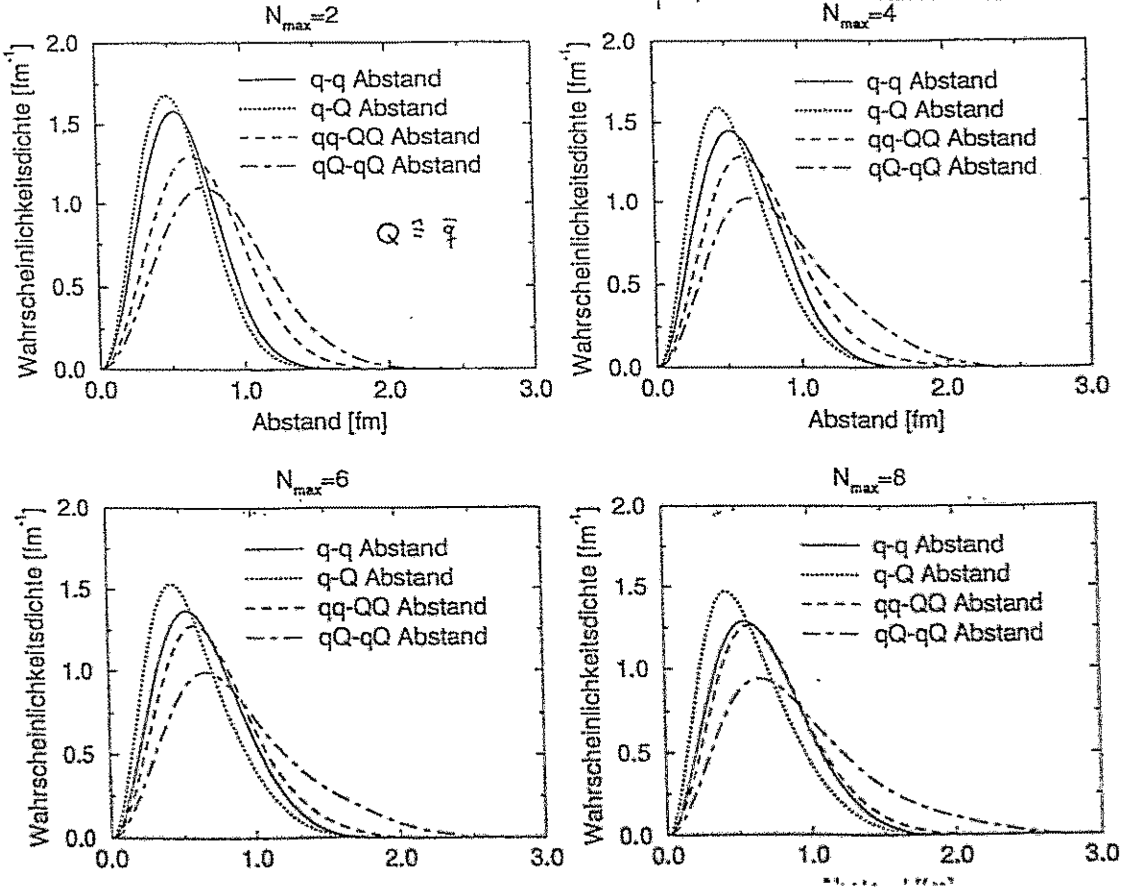
— $q^2\bar{q}^2$-Spektren, ρ^{c+}_{ii}-Confinement

— $q^2\bar{q}^2$-Spektren, $T_i\cdot T_j$-Confinement

Radialdichten für angeregte Zustände im $O(0^+)$-Kanal



Relativabstände bei verschiedenen Nmax für den Grundzustand im $O(0^+)$-Kanal



Dichten

Radiale Dichten:

z. B. für den q-$\bar{q}$-Abstand:

$$\rho_{q\text{-}\bar{q}}(r) = \int d^3v_1\, d^3v_2\, d^3v_3\, \Psi^\dagger(\vec{v}_1, \vec{v}_2, \vec{v}_3)\, \Psi(\vec{v}_1, \vec{v}_2, \vec{v}_3)\, \delta(|\vec{v}_1|-r$$

$\rho_{q\text{-}\bar{q}}(r)$ ist die radiale Dichte für den q-$\bar{q}$-Abstand

$\vec{v}_i$ Koordinaten in der $q_1\bar{q}_3$-Basis

$\Psi(\vec{v}_1, \vec{v}_2, \vec{v}_3)$ Eigenzustand von Hausgedrücht in der $q_1\,\bar{q}_3$-Basis

Quarkaufenthaltswahrscheinlichkeit:

$$\rho(z) = \int d^3x_1\, d^3x_2\, d^3x_3\, d^3x_4\, \Psi^\dagger(\vec{x}_1, \vec{x}_2, \vec{x}_3, \vec{x}_4) \cdot$$
$$\cdot\, \Psi(\vec{x}_1, \vec{x}_2, \vec{x}_3, \vec{x}_4) \cdot \delta\Big(\frac{1}{M}\sum_{i=1}^{4} m_i \vec{x}_i\Big)\, \delta(\vec{x}_1 - \vec{X})$$

$\vec{X} = \begin{pmatrix} 0 \\ 0 \\ z \end{pmatrix}$ $\quad \vec{x}_i$: Absolutkoordinaten der Quarks

Es gilt: $\rho(z) = \sum_i a_i(z)\, e^{-\frac{z^2}{b_i^2}}$ Es treten 6 nach Flavours zu unterschiedliche Breiten auf.

Nützliche Beziehungen:

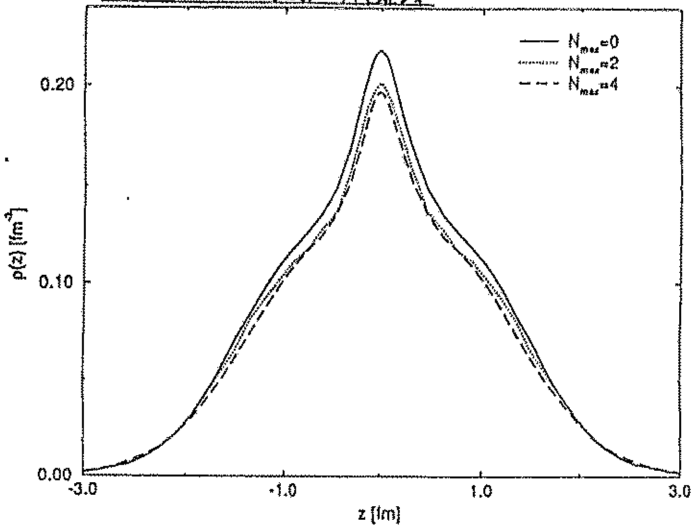
$$e^{-(x+a)^2} + e^{-(x-a)^2} = 2\, e^{-(x^2+a^2)} \cosh(2ax)$$

Für $z \to \infty$ folgt:

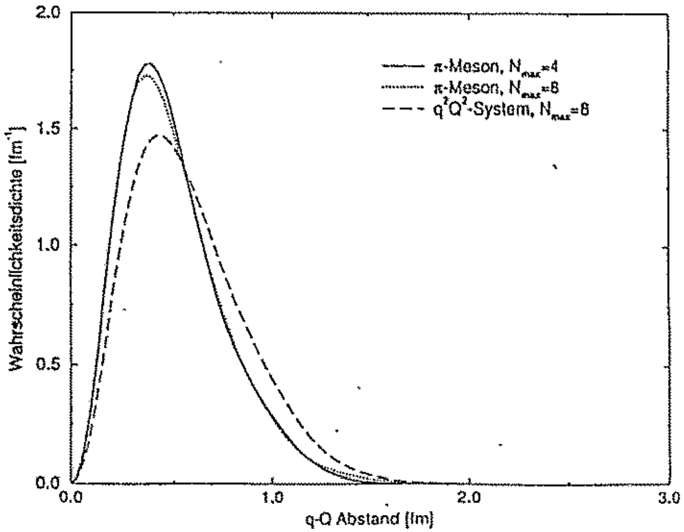
$$\ln\big(P(z)\cosh(2az)\big) \to \pm 2az + O(\ln(z))$$

$P(z)$: Polynom in z

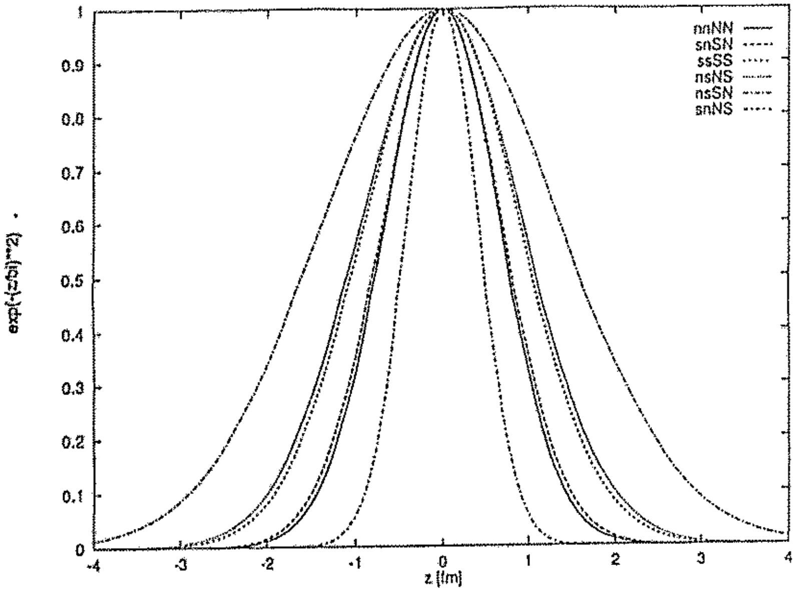
Quarkverteilung entlang einer willkürlichen Achse



Vergleich der q-$\bar{q}$-Radialdichte zwischen π-Meson und $q^2\bar{q}^2$ $(T(\delta^P) = O(0^+))$



Die Gauß anteile



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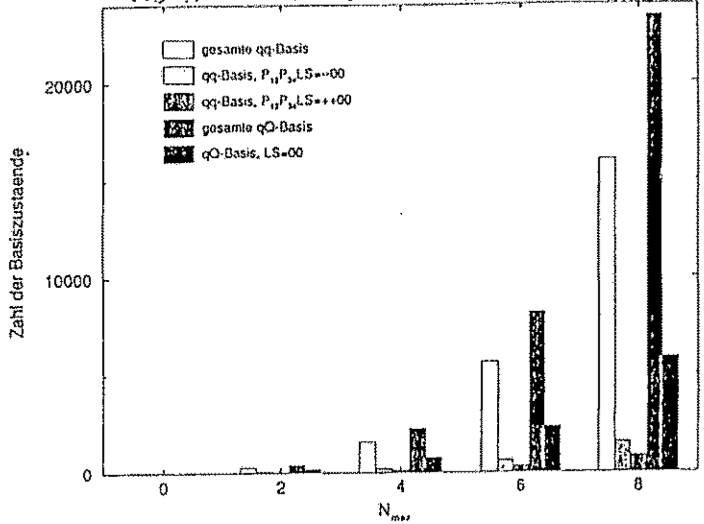
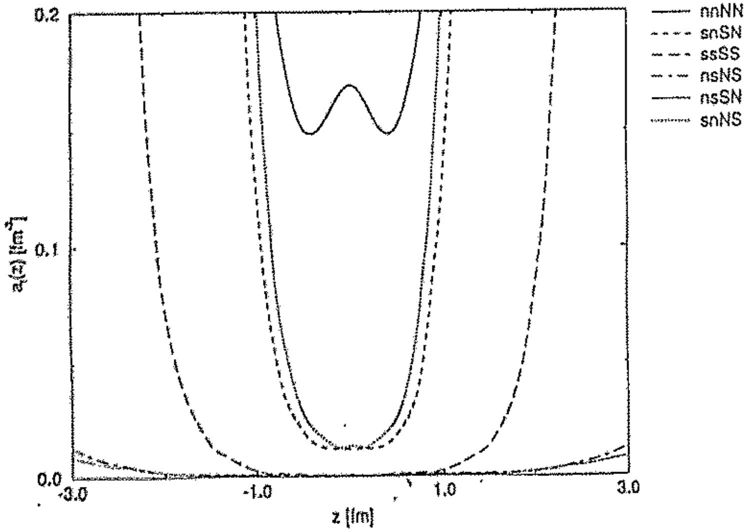


Die Koeffizienten $a_i(z)$



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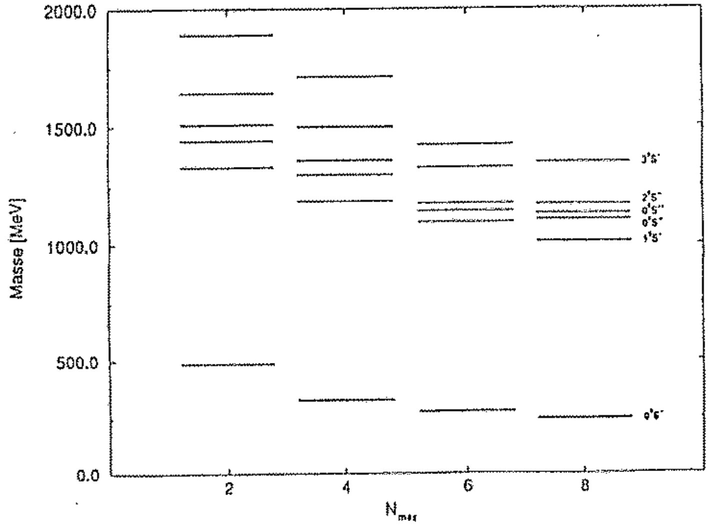

8 Zusammenfassung

- keine prinzipiellen Schwierigkeiten bei der Behandlung von $q^2\bar{q}^2$ im Konstituenten – Quarkmodell.
- der große Rechenaufwand läßt nur ungenaue Näherungen zu.
- Problem der Unterscheidung quasifreier und gebundener Mesonen konnte durch Betrachtung der Quarkdichte gelöst werden.
- Bisher keine Anzeichen auf die Existenz echt gebundener $q^2\bar{q}^2$-Zustände
  ↳ Vermutung: Gluon-Anteil wichtig

- Für ein eindeutiges Votum ist genauere Analyse der Zustände nötig.

KAON POLARIZATION IN NUCLEAR MATTER

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PREVIOUS RESULTS:

$\star$ **1986** Kaplan, Nelson (PL B175, p. 57)

$\chi\mathcal{L} \Longrightarrow$ kaon condensation $K^{\pm}$ at $\rho \sim (3-4)\rho_o$

$\{$Brown, Kubodera, Rho '87$\}$ $\{$Politzer, Wise '91$\}$

The origin of the condensation is the contact KN interaction

$$\mathcal{L} = \frac{\Sigma_{KN}}{f^2}(\bar{K}K)(\bar{N}N) \quad \Longrightarrow \quad m_K^{*2}(\rho) = m_K^2\left(1 - \frac{\rho}{\rho_c}\right)$$

$$\rho_c = \frac{m_K^2 f^2}{\Sigma_{KN}}$$

Σ_{KN} is the parameter of χ-symm. breaking.

$\star\star$ $\{$Brown, Kubodera, Rho, Thorsson '92$\}$

A novel mechanism of K^--condensation caused by instability with respect to reaction

$$n \longrightarrow p + K^-$$

$$\star\star\star \left\{ \begin{array}{l} \text{Brown, Lee, Rho, Thorsson '94} \\ \text{Lee, Brown, Rho '94} \\ \text{Lee, Brown, Min, Rho '94} \end{array} \right\}$$

The s-wave K^--polarization operator was calculated via χ-expansion based on Weinberg's counting rule (NLO, N^{2}LO).

(parameters $\Longleftarrow$ exp. data on KN-scattering)

$$\star\star\star\star \left\{ \begin{array}{l} \text{Yabu, Nakamura, Myhrer, Kubodera '93} \\ \text{Yabu, Myhrer, Kubodera '94} \end{array} \right\} \text{off-shell puzzle}$$

Taking into account the Adler consistency condition, which implies some restriction on KN-scattering amplitude off-shell, shifts the K^--condensation up to $\rho_c \sim 10\rho_o$

OUR APPROACH:

Instead of chiral expansion $\left(\begin{array}{c}\text{How many graphs should} \\ \text{be taken into account?}\end{array}\right)$

we follow the phenomenological approach

{as done for πN-interaction Migdal et. al. (1990) Phys. Rep 192}.

We will calculate explicitely graphs, which vary rather sharply with ω and k at $\omega, k \lesssim m_K$ taking into acount:

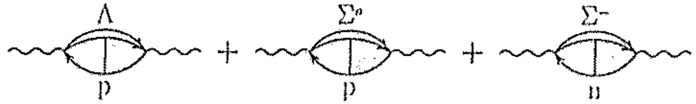
- the lightest strange particles $\Lambda(1116)$ and $\Sigma(1200)$
- the part of regular interaction calculated by Brown et. al. (extended to the case $k \neq 0$)
- contribution of pionic intermediate states (pion mode softening in nuclear matter)
- kaon fluctuation
- residual interaction (restored by Adler's relation).

K⁻N-P-WAVE INTERACTION IN COLD NUCLEAR MATTER

$$\mathcal{L}_{KN\Lambda} = f_{KN\Lambda}\bar{\Lambda}\gamma^{\mu}\gamma_5(\partial_{\mu}K^{+})N \quad \mathcal{L}_{KN\Sigma} = f_{KN\Sigma}\bar{\Sigma}^{a}\gamma^{\mu}\gamma_5(\partial_{\mu}K^{+})\tau_a N$$

$$\left.\begin{array}{l} f_{KN\Lambda} \simeq -1.17/m_{\pi} \\ f_{KN\Sigma} \simeq 0.22/m_{\pi} \end{array}\right] \begin{array}{c}\text{Jülich} \\ \text{model}\end{array} \quad \left.\begin{array}{l} \simeq -0.88/m_{\pi} \\ \simeq 0.26/m_{\pi} \end{array}\right] SU(3)\times SU(3)$$

$\Pi^{-,p} =$



$$\Pi^{-,p}_{\Lambda,\Sigma} \propto \Phi_{\Lambda,\Sigma}(\omega, k) \text{ - Lindhard's function.}$$

in simplified form

$$\Pi^{-,p}_{\Lambda} \simeq \frac{\rho}{\rho_o}\left\{\frac{1.1m_{\pi}(k^2-\omega^2)+1.1\omega\tilde{\omega}_{\Lambda}(t)}{\omega-\tilde{\omega}_{\Lambda}(t)}+0.7m_{\pi}\omega\right\}$$

$$\Pi^{-,p}_{\Sigma} \simeq \frac{2\rho_n+\rho_p}{\rho_o}\left\{\frac{0.1m_{\pi}(k^2-\omega^2)+0.4\omega\tilde{\omega}_{\Sigma}(t)}{\omega-\tilde{\omega}_{\Sigma}(t)}+0.3m_{\pi}\omega\right\}$$

$$\tilde{\omega}_{\Lambda,\Sigma} = \omega_{\Lambda,\Sigma} + \frac{k^2-\omega^2}{2m_N}, \quad \omega_{\Lambda,\Sigma} = m_{\Lambda,\Sigma} - m_N$$

$\rho_{p(n)}$ is the proton (nucleon) density.

$$\Pi^{-,p}_{\Lambda} \gg \Pi^{-,p}_{\Sigma}$$

THE REGULAR PART OF THE POLARIZATION OPERATOR

[Brown et. al. NPh A576 (1994) 937]

Expansion of $\chi\mathcal{L}$ + Weinberg's counting rules

Next-to-leading order terms are considered

$$\mathcal{L}_{\nu=1} = -\frac{i}{8f^2}\left[3(\bar{N}\gamma^\mu N)(\bar{K}\overset{\leftrightarrow}{\partial_\mu} K) + (\bar{N}\vec{\tau}\gamma^\mu N)(\bar{K}\vec{\tau}\overset{\leftrightarrow}{\partial_\mu} K)\right],$$

$$\mathcal{L}_{\nu=2} = \frac{\Sigma_{KN}}{f^2}(\bar{N}N)(\bar{K}K) + \frac{C}{f^2}(\bar{N}\vec{\tau}N)(\bar{K}\vec{\tau}K) + \frac{\tilde{\mathcal{D}}}{f^2}(\bar{N}N)(\partial_\mu\bar{K}\partial^\mu K) + \frac{\tilde{\mathcal{D}}'}{f^2}(\bar{N}\vec{\tau}N)(\partial_\mu\bar{K}\vec{\tau}\partial^\mu K),$$

$$\bar{K}\overset{\leftrightarrow}{\partial_\mu} K \equiv \bar{K}\overset{\leftarrow}{\partial_\mu} K + \bar{K}\overset{\rightarrow}{\partial_\mu} K.$$

Corresponding terms of the polarization operator are equal to

$$\Pi^{-,reg}(\ell = 0) = -\left[\frac{\tilde{\mathcal{D}} - \tilde{\mathcal{D}}'}{f^2} + 2\nu\frac{\tilde{\mathcal{D}}'}{f^2}\right]\rho(\omega^2 - \vec{k}\vec{k}) - \frac{1+\nu}{2f^2}\rho\omega - \frac{\Sigma_{KN}}{f^2}\rho.$$

parameters $\tilde{\mathcal{D}}$, $\tilde{\mathcal{D}}'$ ⟵ experiment on KN-scattering

$$\Pi^{-,reg}(\text{no loops}) \simeq -2.3m_\pi^2\frac{\rho}{\rho_o} - 0.57m_\pi(1+\nu)\omega\frac{\rho}{\rho_o} - (0.15\nu - 0.15)(\omega^2 - \vec{k}\vec{k})\frac{\rho}{\rho_o}$$

EXTRA CONTRIBUTION TO THE REGULAR PART OF Π^-

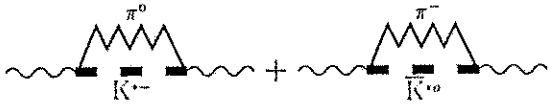
- contribution of $\Lambda\bar{p}$, $\Sigma^o\bar{p}$, $\Sigma^-\bar{n}$-loops

(which survives at $k \neq 0$)

To satisfy the data with $\Pi^{-,reg}(Brown)$ in adding $\Pi^{-,p}(\omega, k)$, we should substract it on-shell ($\omega = m_K$, $k = 0$) $\Longrightarrow$

$\Longrightarrow$ $\delta\Pi^{-,reg} = -\Pi^{-,p}(\omega = m_K, k = 0) \simeq (1.4\rho_p + 0.2\rho)m_\pi^2/\rho_o$

- contribution of pionic intermediate states



where "〰" is the exact pion Green function in nuclear matter [Migdal et. al. PRep 192]

At $\rho > \rho_c \sim (0.6-0.7)\rho_o$ the pion mode is softened, the effective pionic gap $\tilde{\omega}_\pi < m_\pi$. In approximation of rather strong pion softening $\tilde{\omega}_\pi^2 \ll m_\pi^2$ [Dygaev; Voskresensky, Mishustin]

$$\Pi_{\pi K} \propto < \varphi_\pi^*(0)\varphi_\pi(0) >_T \propto \begin{cases} \tilde{\omega}_\pi & T = 0 \\ \frac{T}{\tilde{\omega}_\pi} & T \neq 0,\ T/\tilde{\omega}_\pi \gg 1(!) \end{cases}.$$

Pion softening promotes the kaon condensation at $T \neq 0$

- **kaon fluctuation**

this contribution is important at $T \neq 0$ and in the vicinity of the critical point of the phase transition.

- **off-shell interaction**

To restore the possible residual interaction we use the consistensy condition of Adler for the KN-scattering amplitude.

Current algebra + PCAC$\Longrightarrow$

$\Longrightarrow A^{KN}_{reg}(\omega = \omega' = 0, \vec{k}^2 = 0, \vec{k}'^2 = -m_K^2) = 0$

In order to satisfy Adler's relation:

[Troitsky, Chekunaev '81; Migdal et. al. PRep 192]

$$A = A^{theor}_{reg} - \lambda \underbrace{\left(\omega^2 - m_K^2 - \frac{\vec{k}^2 + \vec{k}'^2}{2}\right)}_{\text{on-shell } = 0}$$

λ corresponds to some residual interaction off-shell.

TOTAL POLARIZATION OPERATOR OF K^-

$$\begin{aligned}\Pi^-(\omega, k, \rho) \quad = & - \, d\rho - \alpha(1+\nu)\rho\omega - (\beta + \beta'\nu)\rho(\omega^2 - k^2) + \delta\Pi^{-s}(\rho, \nu) \\ & + \left\{\frac{A_0(k^2 - \omega^2) + A_1\omega\tilde{\omega}_\Lambda(l)}{\omega - \tilde{\omega}_\Lambda(l)} + A_2\omega\right\} \nu\frac{\rho}{\rho_o} \\ & + \left\{\frac{B_o(k^2 - \omega^2) + B_1\omega\tilde{\omega}_\Sigma(l)}{\omega - \tilde{\omega}_\Sigma(l)} + B_2\omega\right\} (2 - \nu)\frac{\rho}{\rho_o} \\ & + \, g(\omega^2 - k^2 - k_0^2) + \lambda_+\rho\left(\omega^2 - m_K^2 - k^2\right),\end{aligned}$$

with

$$d = \frac{\Sigma_{KN}}{f^2}, \quad \alpha = \frac{1}{2f^2}, \quad \beta = \frac{\tilde{\mathcal{D}} - \tilde{\mathcal{D}}'}{f^2}, \quad \beta' = 2\frac{\tilde{\mathcal{D}}'}{f^2}, \quad g = 3\frac{g^2_{KK^*\pi}}{m^2_{K^*}}A_\pi$$

SPECTRUM OF $K^{\pm}$ IN NUCLEAR MATTER

There are two branches in the spectrum of K^-

The new low-lying branch consists mainly of the mixed states of Λ particles and p-holes with the quantum numbers of the K^- meson.

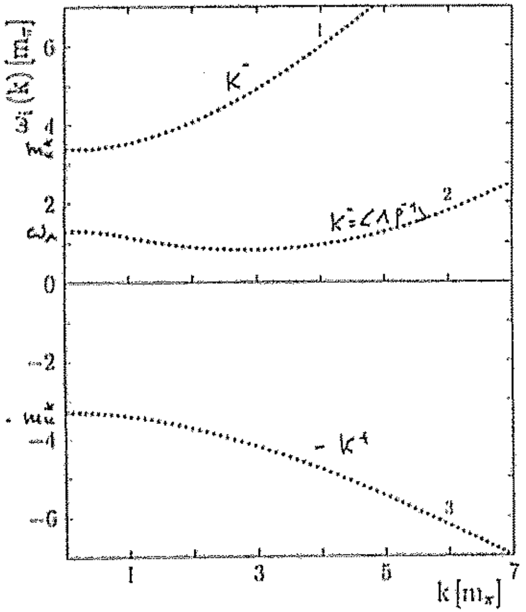
effective mass $\quad m_K^{*2}(\rho) = m_K^2 \dfrac{1-\lambda\rho/2}{1-\lambda\rho}$

at low density

$m_K^{*2}(\rho) \simeq m_K^2(1-\rho/\tilde{\rho}_c)$, $\tilde{\rho}_c = -2/\lambda$ [mass slightly decreases]

at high density

$m_K^{*2}(\rho) \simeq m_K^2/2$ [constant]

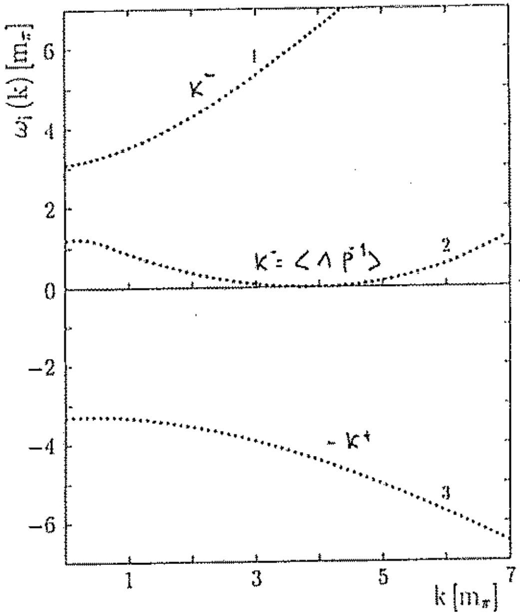


$\nu = 1$

proton matter

$\rho = 3\rho_o$

SPECTRUM OF KAONS...



$\nu = 1$

$\rho = \rho_c^-$

$\rho_c^- = 4\rho_o\ (\Sigma_{KN} = 1.4m_\pi)$

$\rho_c^- = 5.8\rho_o\ (\Sigma_{KN} = 2m_\pi)$

in the vicinity of the minimum $\rho \sim \rho_c^-$

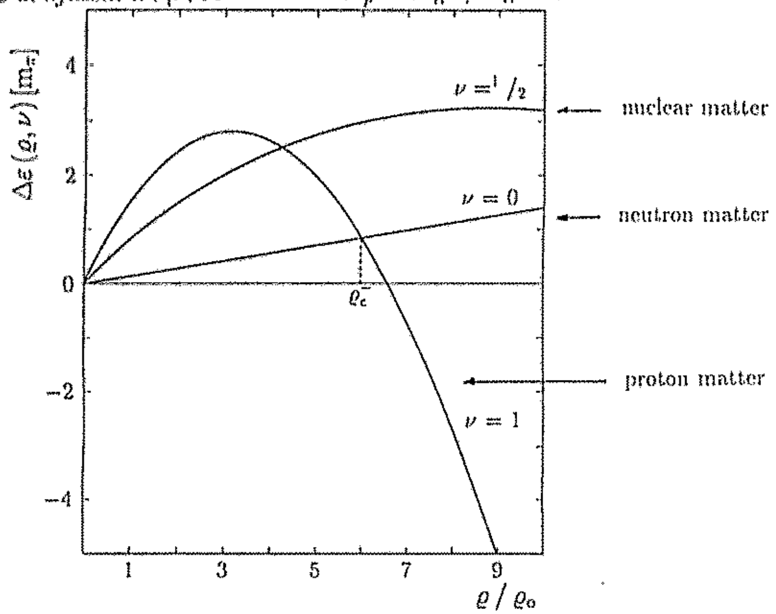
$$\omega_2(k) \simeq \omega_c + \gamma\left(1 - \frac{k^2}{k_0^2}\right)$$

$$\omega_c = \dot{\omega}_\Lambda - \left\{ \sqrt{\frac{1.1\rho_p/\rho_o}{1-\lambda\rho}} - \sqrt{\frac{m_K^{*2}(\rho)}{2m_N}} \right\} \longleftarrow \text{effective kaon gap}$$

$\omega_c \leq 0 \Longrightarrow K^-$-condensation sets in!

NUCLEAR MATTER WITH KAONS AT HIGH DENSITY

EOS of system n+p+K^- $\qquad N_p = N_{K^-},\ \Lambda_K = 0$



$\Delta\varepsilon(\rho,\nu) = \varepsilon_{tot} - \varepsilon_B^0(\rho) = \varepsilon_{sym}(\rho,\nu) + \omega_c(\rho,\nu)\rho_p$

$\varepsilon_B^0(\rho)$ is the isotopic independent part of the baryon energy.

At $\rho \geq \rho_c^-$ $(\omega_c(\rho_c^-,\nu = 1) = 0)$ the isotopic phase transition

$$\nu = 0 \quad \Longrightarrow \quad \nu = 1$$

becomes energeticaly favorable

$$\text{NEUTRON STAR} \quad \underset{\text{p.t}}{\overset{\text{1st order}}{\Longrightarrow\!\!\Longrightarrow}} \quad \text{PROTON STAR}$$

$\bar{K}^o$ - CONDENSATION

$\bar{K}^o$ in neutron matter = K^- in proton matter

$\bar{K}^o$ has the second branch in the spectrum with roton like minimum.

The vanishing of the effective gap $\omega_c^{\bar{K}^o}(\rho_c^-,\nu = 0) = 0$ leads to instability with respect to reaction

$$n \longrightarrow n + \bar{K}^o.$$

<u>Second order</u> phase transition

$\bar{K}^o$- condensate becomes stable only due to $\Lambda \neq 0$ repulsion, whereas

K^--condensate is stabilized by electric interaction.

$\Longrightarrow$ *for static system $\bar{K}^o$-condensate is preferable!*

$$\text{NEUTRON STAR} \left[\begin{array}{l} \longrightarrow \text{PROTON STAR} + K_c^- \\ \\ \longrightarrow \text{NEUTRON STAR} + \bar{K}_c^o \end{array} \right.$$

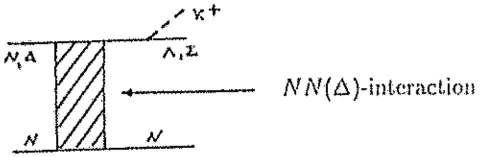
K^+ yields in heavy ion reactions

$\star K^+$ **yield**

$\lambda_{K^+} > D_{fireball} \Longrightarrow K^+$ spectrum is approximately free

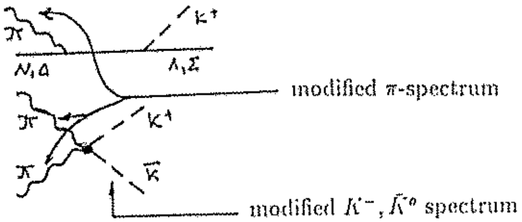
K^+ production is determined by the rate of direct reastions, which are modified in medium.

$NN(\Delta) \longrightarrow N\Lambda(\Sigma)K^+$



$N(\Delta)\pi \longrightarrow \Lambda(\Sigma)K^+$

$\pi\pi \longrightarrow K\bar{K}$



$\star\star K^-$ **yield**

$\lambda_{K^-} < D_{fireball} \Longrightarrow K^-$ confined inside the fireball till breakup

$\Longrightarrow$ manifestation of two branches

In sudden breakup model

$$\frac{dN_{K^-}}{V_b d^3k/(2\pi)^3} = \sum_{i=1}^{2} \frac{2\sqrt{m_K^2 + k^2}}{2\omega_i(k) - \frac{\partial\Pi}{\partial\omega}|_{\omega_i(k)}} \frac{1}{exp\left(\frac{\omega_i(k) - \mu}{T_b}\right) - 1}$$

T_b, V_b are temperature and volume of fireball at breakup.

$\mu = 0$, if K^- are in equilibrium at $t < t_b$.

Physik an Mesonenfabriken

(*Koordinator:* **G. Wagner**)

1. **J. Arnold** (Freiburg)
   Experimente mit polarisierten Neutronen am PSI
2. **K. P. Jungmann** (Heidelberg)
   Präzisionsmessung am Myoniumatom ($\mu^+ e^-$)
3. **C. Dohmen** (Aachen)
   Suche nach der μ-e Konversion an Kernen im SINDRUM II-Spektrometer
4. **J. Hartmann** (München)
   Neues von μCF und langsamen Myonen

Experimente mit polarisierten Neutronen am PSI

Jürgen Arnold, Universität Freiburg
Pirna 4.10.1994

Beteiligte Institute:

Universität Freiburg
Universität Genf
Paul Scherrer Institut
DAPNIA CEN-Saclay
Universität Prag

Übersicht:

1. Motivation

Darstellung bezüglich Isospin als Ket:

Nukleon = $|T,T_3\rangle$

Neutron = $|\frac{1}{2},-\frac{1}{2}\rangle$

Proton = $|\frac{1}{2},\frac{1}{2}\rangle$

Proton + Proton = $|\frac{1}{2},\frac{1}{2}\rangle + |\frac{1}{2},\frac{1}{2}\rangle = |\underline{1},1\rangle$

Neutron + Proton = $|\frac{1}{2},-\frac{1}{2}, + |\frac{1}{2},\frac{1}{2}\rangle = \frac{1}{\sqrt{2}}(|\underline{1},0\rangle + |\underline{0},0\rangle)$

→ Isospin-0-Kanal nur in Neutron-Proton Streuung

Aber:

wenig Daten (vor allem mehr-spin-Parameter)

→ Unsicherheit in der Streuphasenanalyse

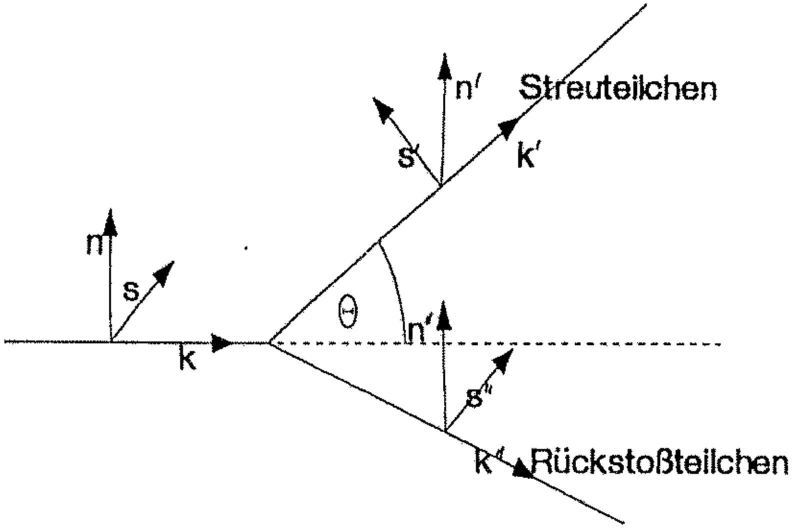
→ Neue Messungen nötig

2. Theoretische Grundlagen:

Koordinatensysteme:

$\hat{n},\hat{k},\hat{s}$ mit der Streuung verbunden
$\hat{k}$ = Strahlachse
$\hat{n}$ = Streunormale $k_{in} \times k_{fin} / |..|$
$\hat{s}$ ergänzt zu rechtshändigem System

entsprechende Systeme für gestreutes- und Rückstoßteilchen.
$\hat{k}$ = jeweils Impulsrichtung,
$\hat{n}$ = Streunormale
$\hat{s}$ ergänzt



Streumatrix M:

$\Psi_{fin} = M \Psi_{in} M^{\dagger}$ $M = M(E,\theta)$

Erhaltungssätze → Darstellung durch 5 unabhängige Größen

Koeffizienten sind komplexwertige Funktionen: Streuamplituden:
→ $M = M(E,\theta,a,b,c,d,e)$

Observable:

"Saclay"-Konvention:
X_{srbt}

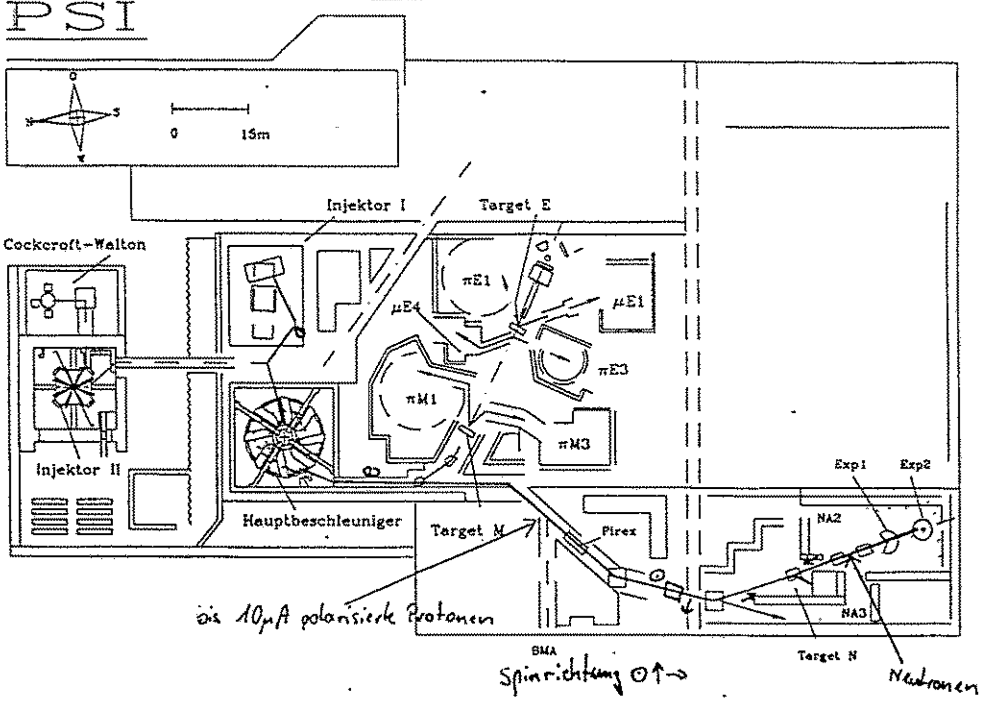
s = streu-, r = rückstoß-, b = beam-, t = target-Teilchen   jeweils k, s, n, 0

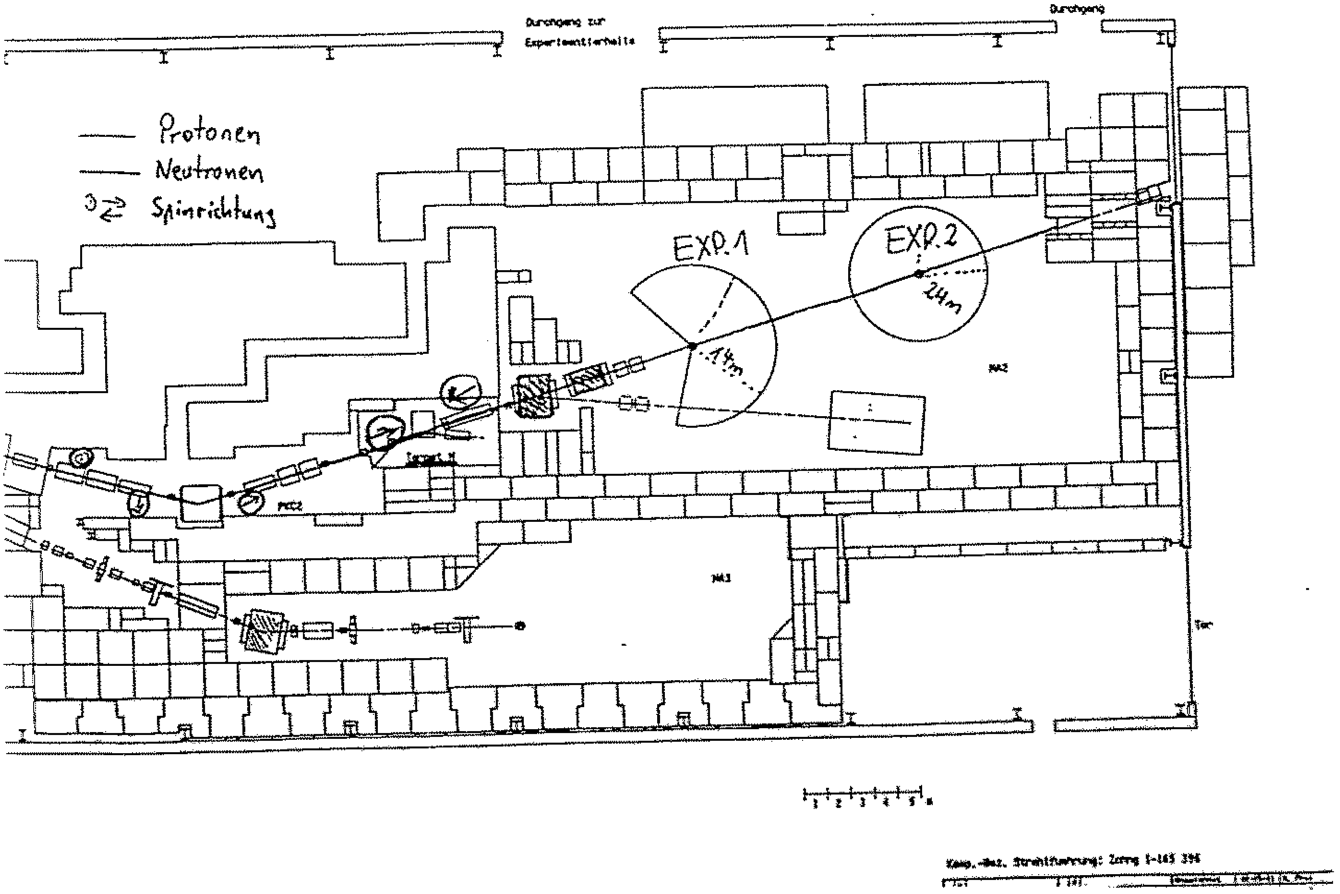
Erhaltungssätze: 25 unabhängige $\neq 0$

z.B. $A_{ooon} = A_{oono} = P_{onoo} = P_{nooo}$ Analysierstärke
A_{oonn} Spinkorrelation

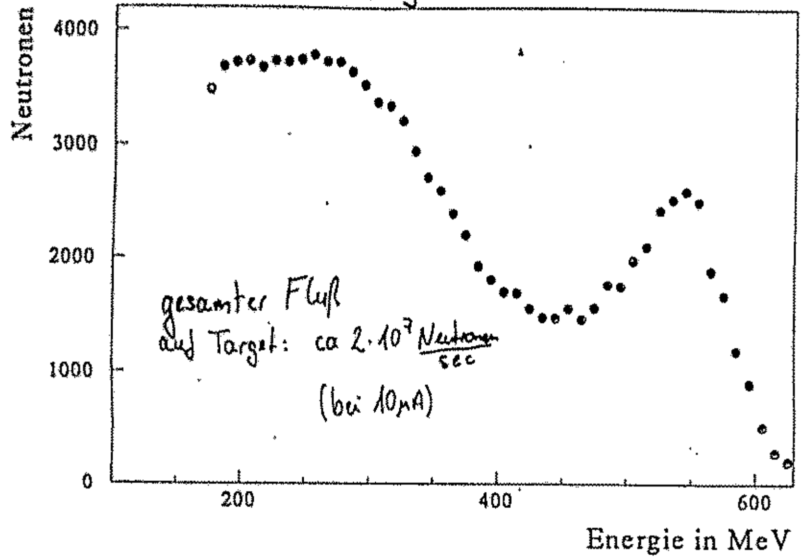
Messung genügend vieler Observabler (> 9)
→ Rekonstruktion aller 5 Streuamplituden:
= "vollständiges Experiment"

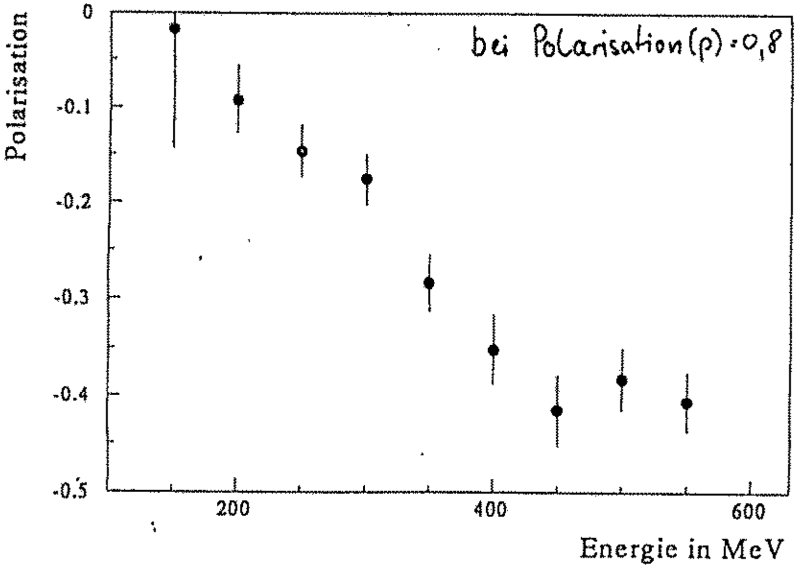
3. Polarisierter Neutronenstrahl





Strahleigenschaften





EXP. 1

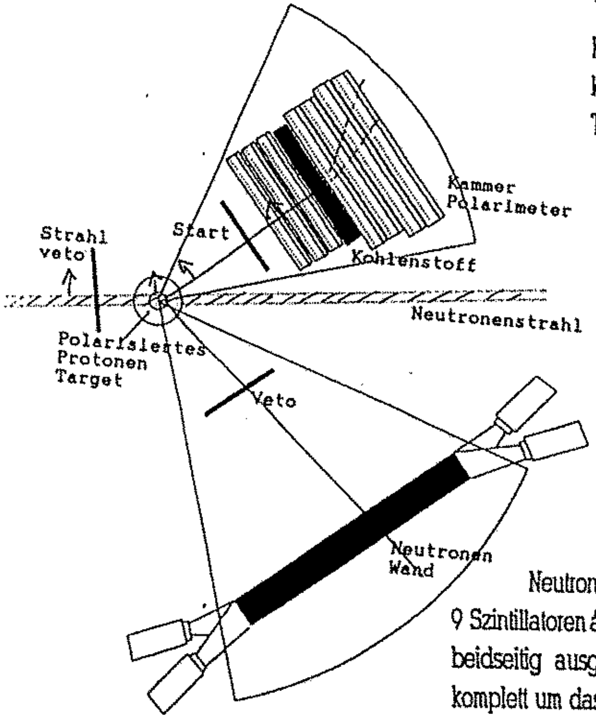
Lafette I:

Target: $4 \times 4 \times 4$ cm^3 frozen spin Target

Polarisation bei T kleiner 100 mK größer 0.8

Protonpolarimeter:

7 Proportionalkammern
Kohlenstoffstreuer
komplett um das
Targetzentrum drehbar,



Neutronseite:

9 Szintillatoren á $160 \times 20 \times 8$ cm^3,
beidseitig ausgelesen,
komplett um das
Targetzentrum drehbar,

Geplante Messungen: alle Dreispinkorrelationsparameter
Neutron 60-160 Grad cms

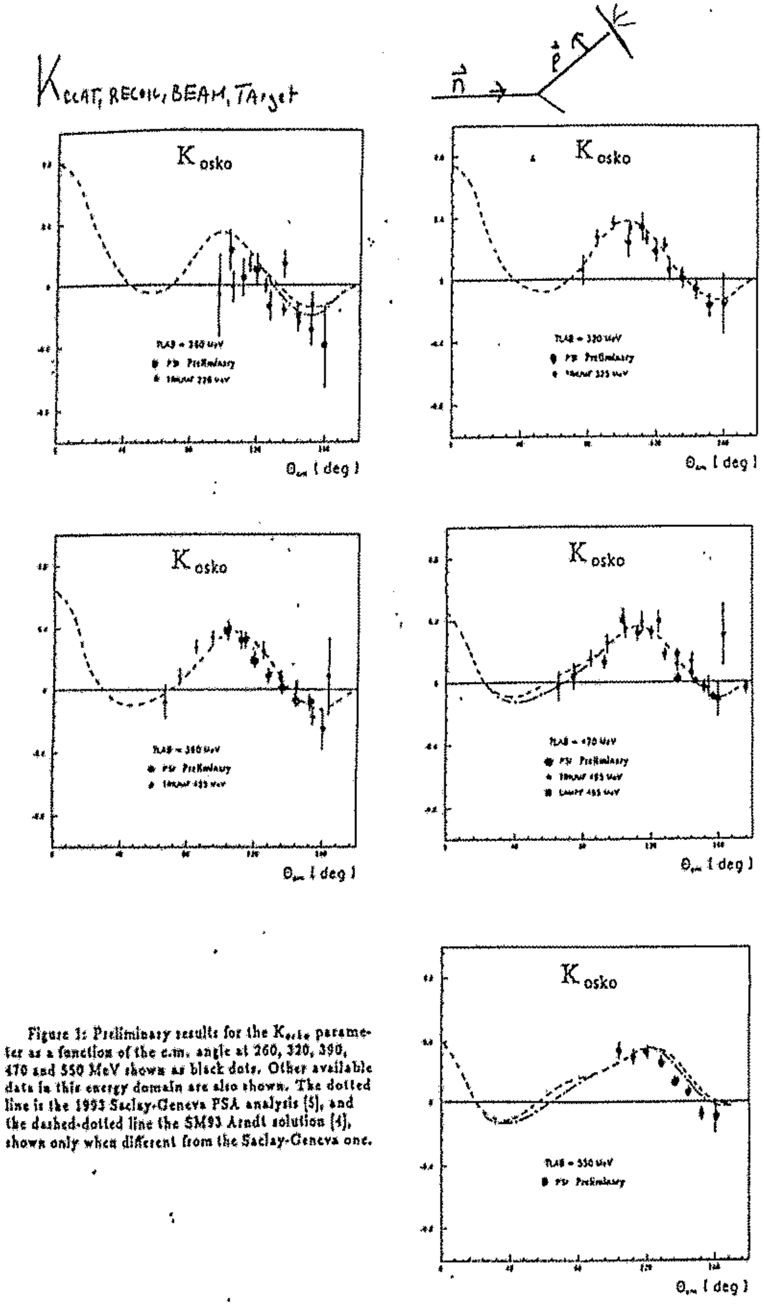


Figure 1: Preliminary results for the K_{osko} parameter as a function of the c.m. angle at 260, 320, 390, 470 and 550 MeV shown as black dots. Other available data in this energy domain are also shown. The dotted line is the 1993 Saclay-Geneva PSA analysis [5], and the dashed-dotted line the SM93 Arndt solution [4], shown only when different from the Saclay-Geneva one.

EXP. 2

Lafette 2 :

Target: Flüssigwasserstoff-Target

Protonpolarimeter:

Driftkammern

Kohlenstoffstreuer

am Spektrometermagnet montiert

Spektrometermagnet:

(Impulsbestimmung, Spindrehung)

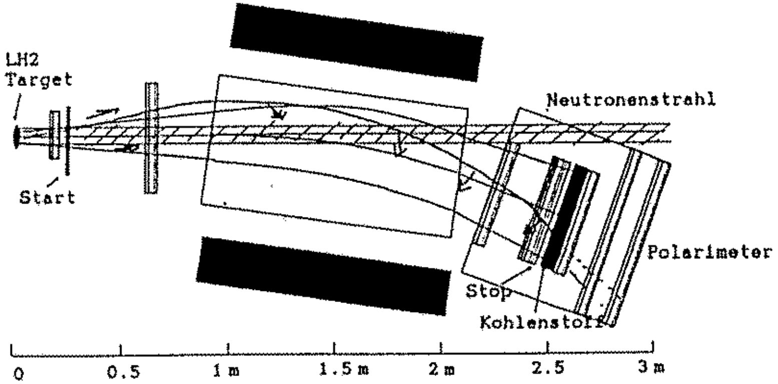
um das Targetzentrum drehbar

Neutronendetektoren: (bei Messungen > 0 Grad)

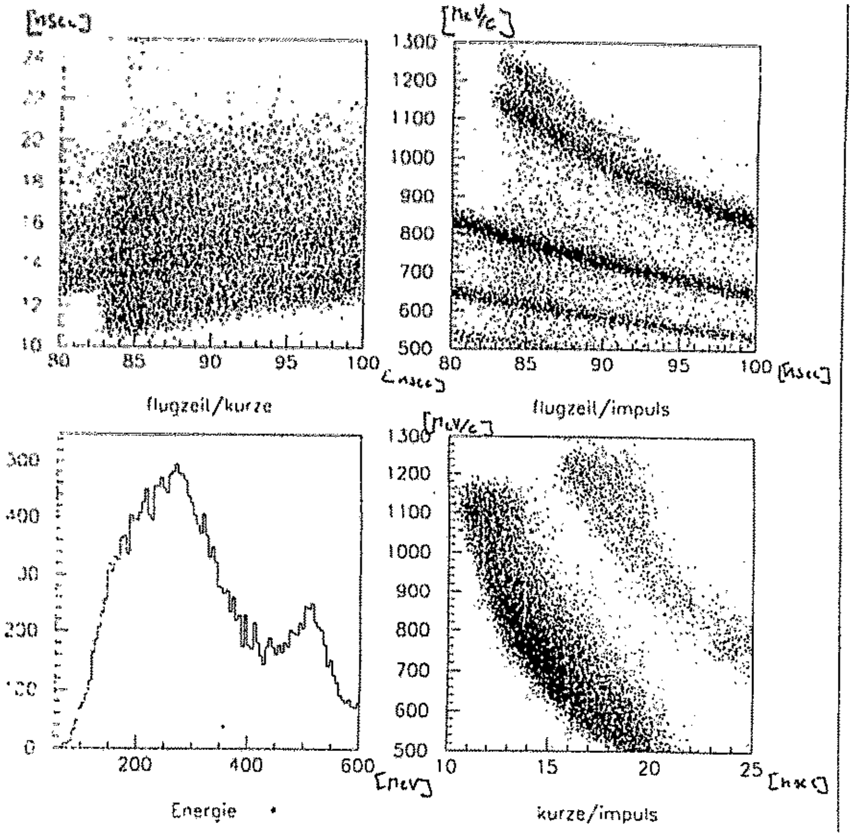
gegebenenfalls 100x10x10 cm^3 Szintillatoren

geplante Messungen: Spintransfer n-p , am Anfang unter 0 Grad

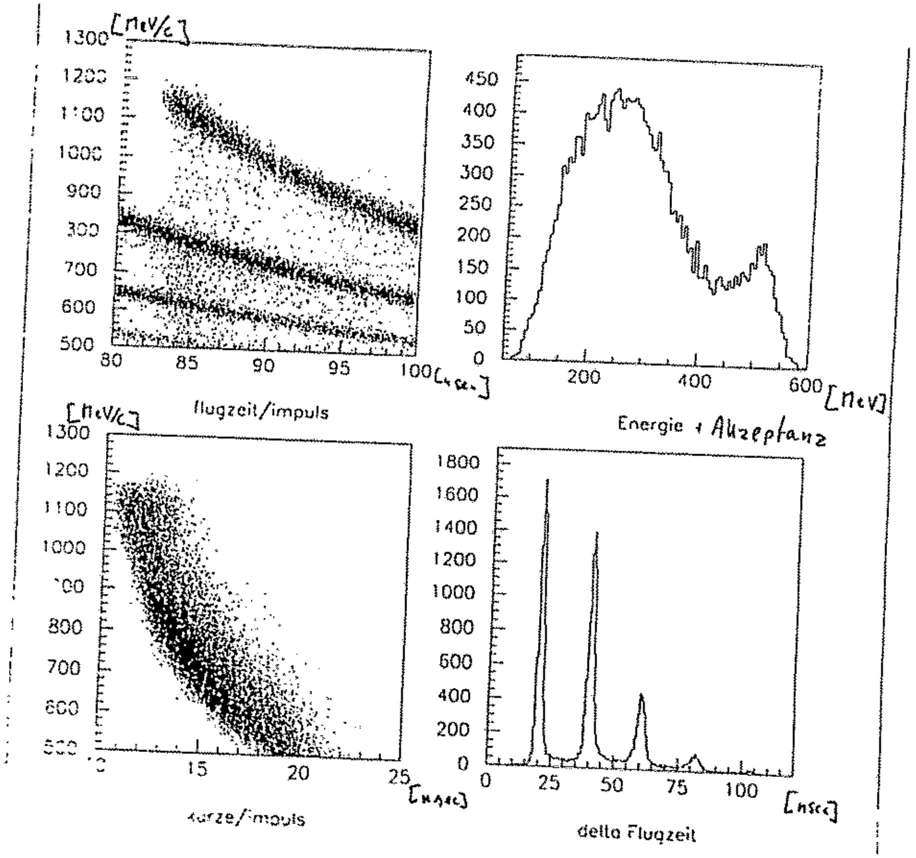
K_{onno}, K_{okko}, K_{okso}, K_{osso} (ohne Magnet)



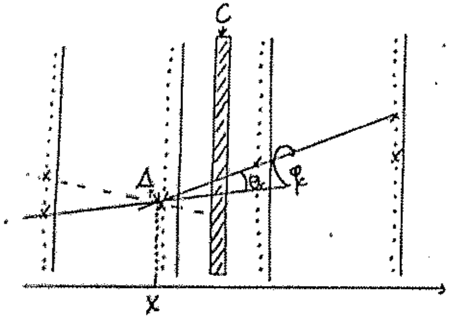
Rohdatenverteilung

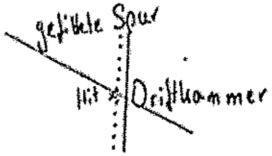


Mit Deuteron-cut.



Analysestreuung im Kohlenstoff

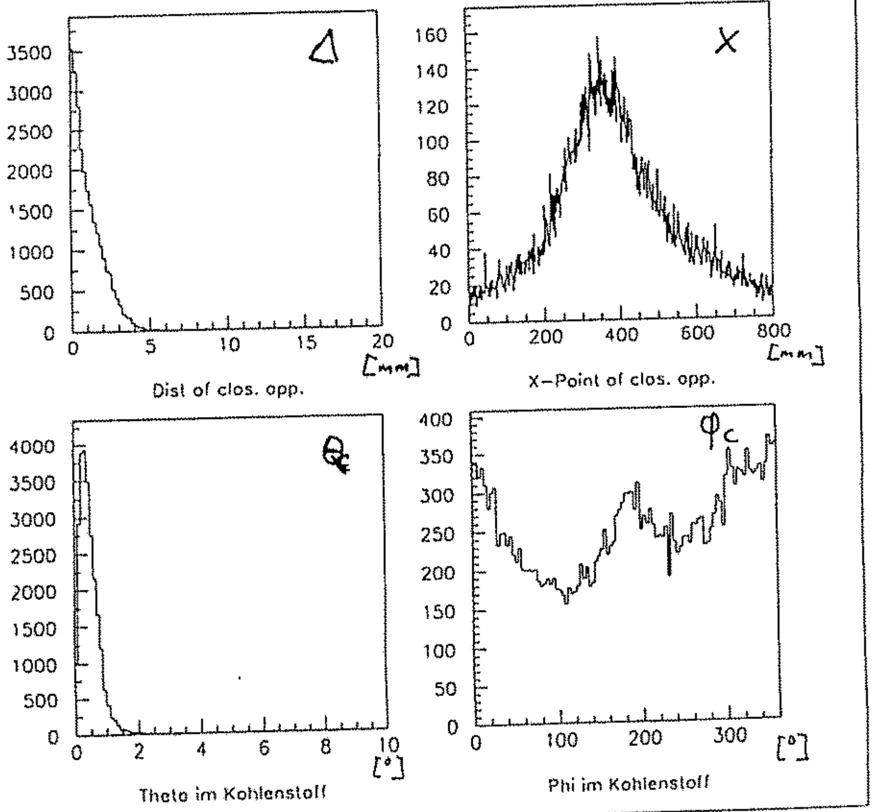




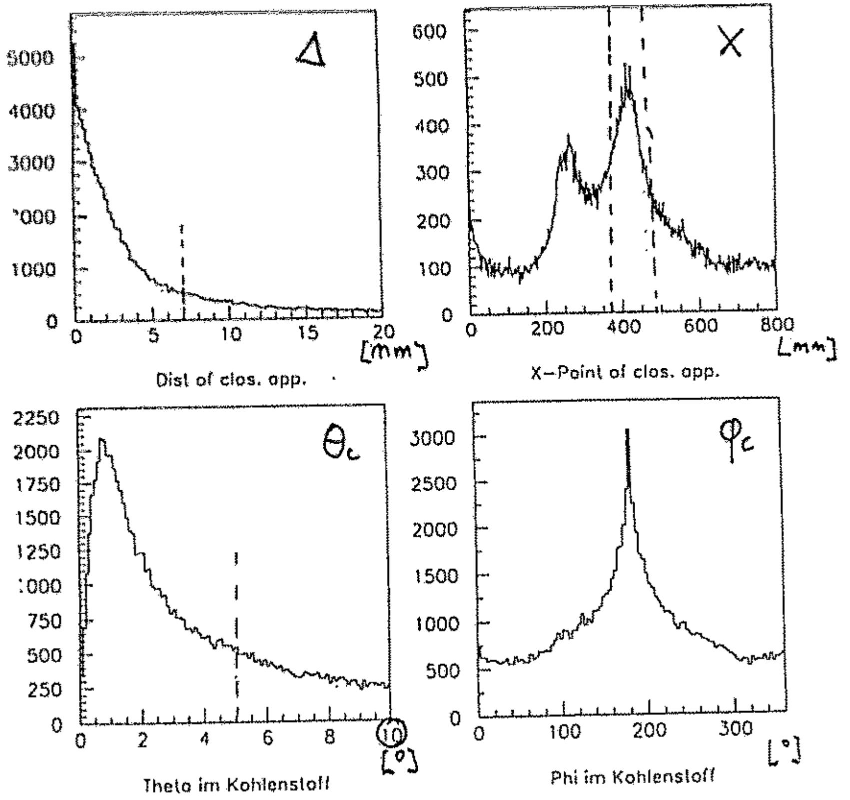
Kenngrößen der Streuung

Δ = "Distance of closest approach"
X = X-Koordinate des "point of closest approach"
Θ_c: Streuwinkel im Kohlenstoff
φ_c: Azimutwinkel im Kohlenstoff

Kein Kohlenstoff im Polarimeter

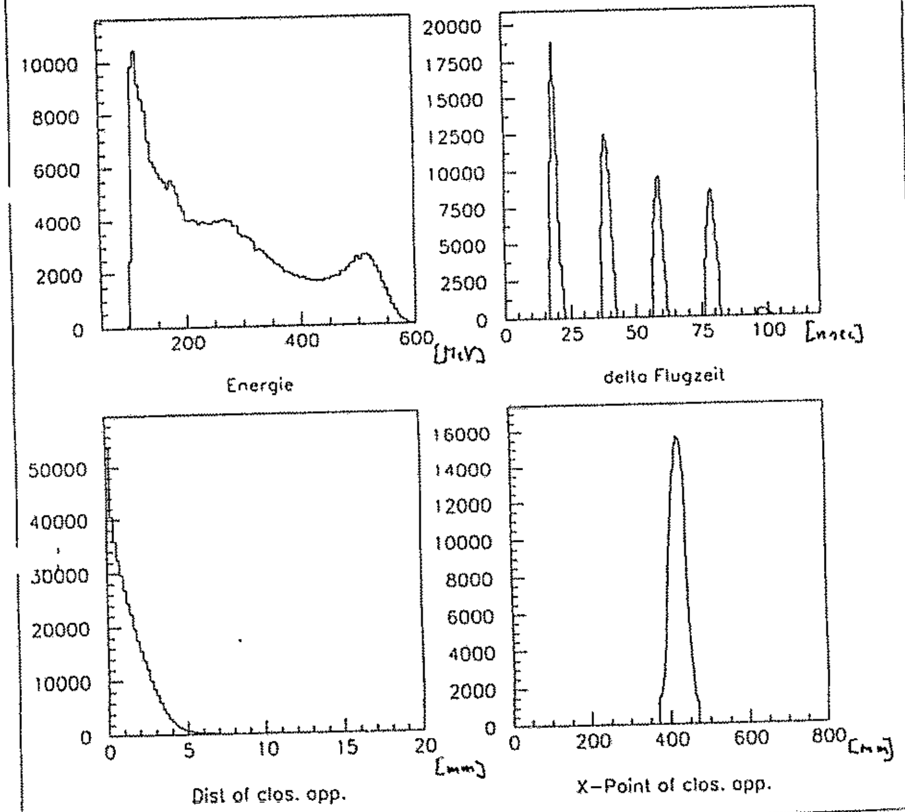


Streuung im Polarimeter

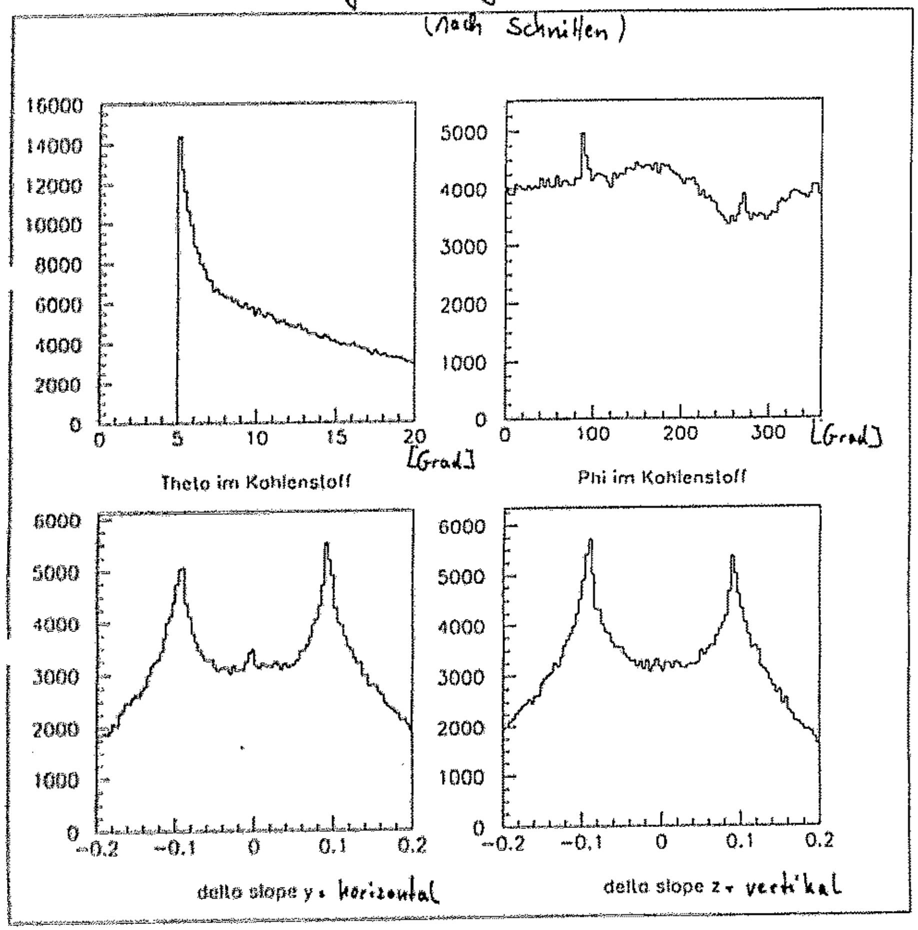


alle Kombinationen einsortiert

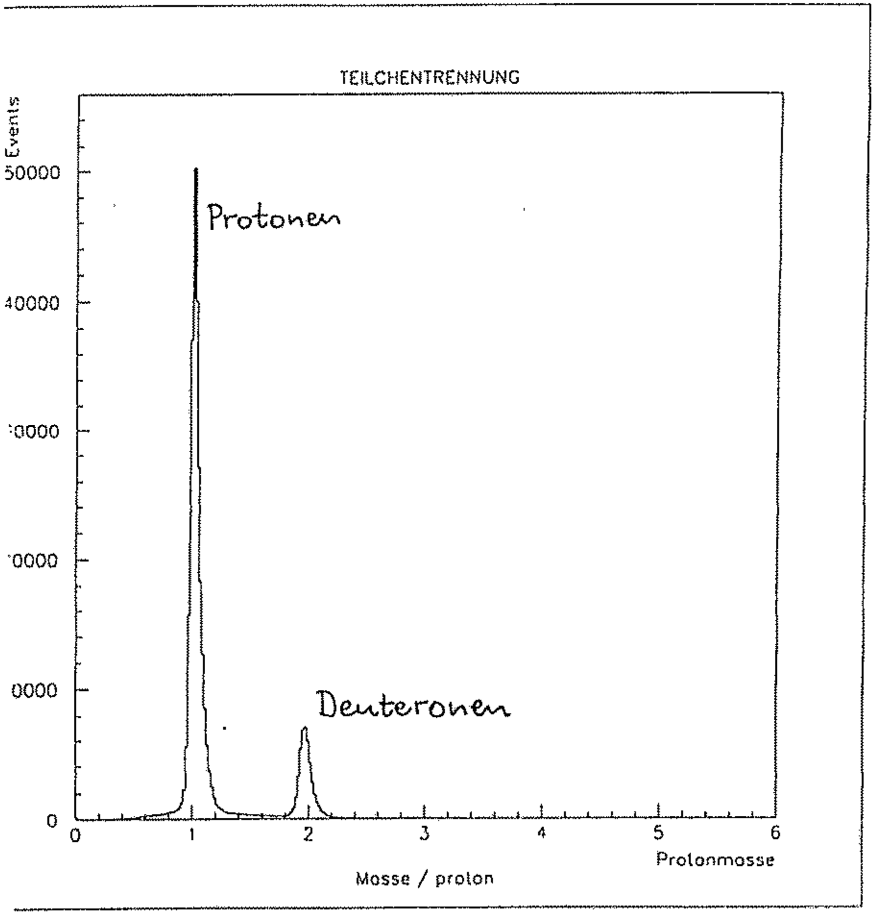
Teilchen nach der Analysierstreuung im Kohlenstoff
(mit Schnitten)



Analysestreuung im Kohlenstoff

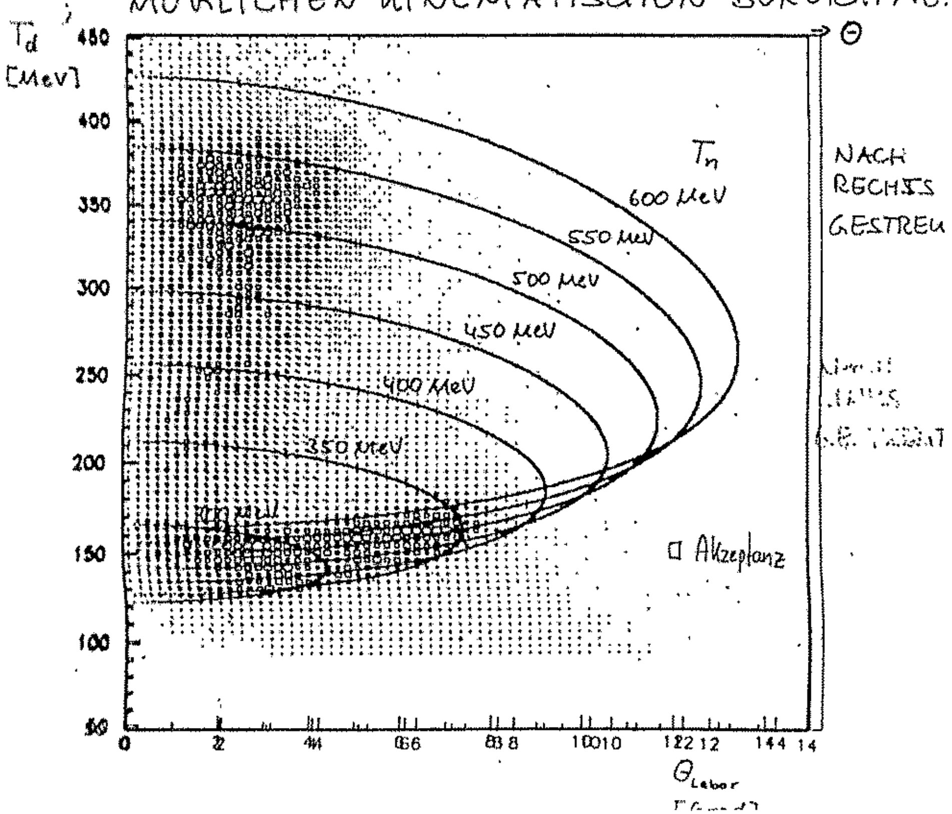

(nach Schnitten)

$\frac{m}{z} = \frac{p}{z \cdot \beta \cdot \gamma}$ Rohdaten



KINEMATIK + AKZEPTANZ

- Schwelle $np \to d\pi^0$: 275 MeV
- Doppeldeutigkeit:
  Zu fester Neutronenenergie T_n gibt es zu einem Streuwinkel Θ_{Labor} zwei mögliche Deuteronenergien T_d
- Dieses Problem taucht bei der Bestimmung von T_n in anderer Form wieder auf → Ambiguitäten und bei der Festlegung der Kinematik
- DAS EXPERIMENT DECKT NICHT DEN MÖGLICHEN KINEMATISCHEN BEREICH AB.



BERÜCKSICHTIGUNG DES TARGETUNTERGRUNDS

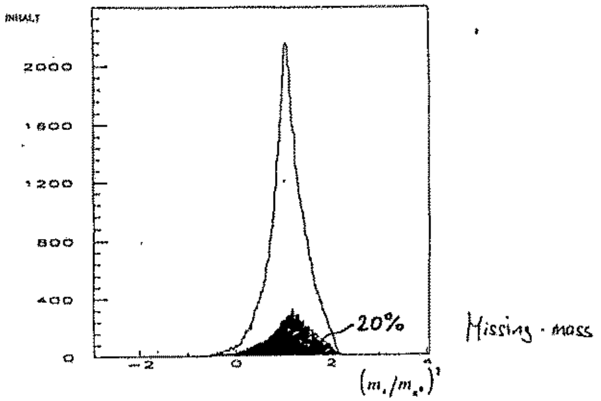


Abb. 50: Anteil des Targetuntergrunds an der Hauptmessung nach den Schnitten auf die Impulsdifferenzverteilungen.

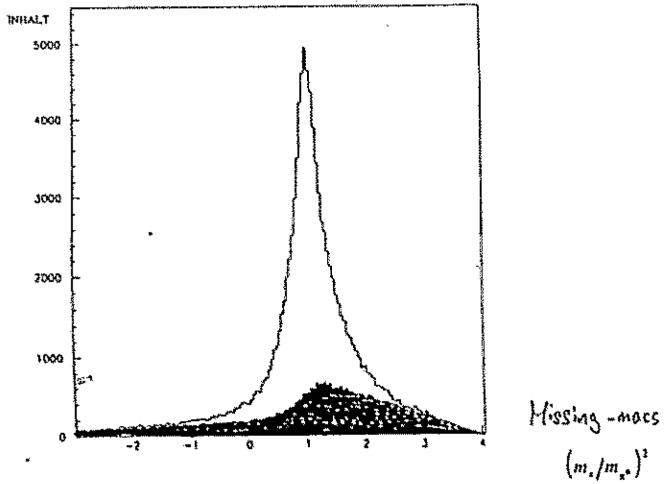
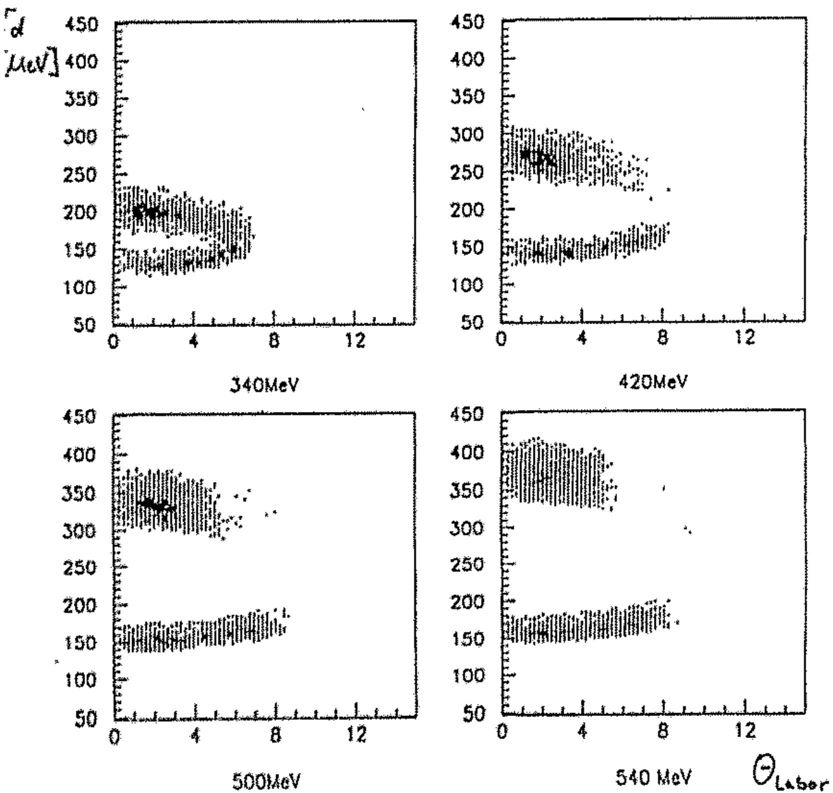


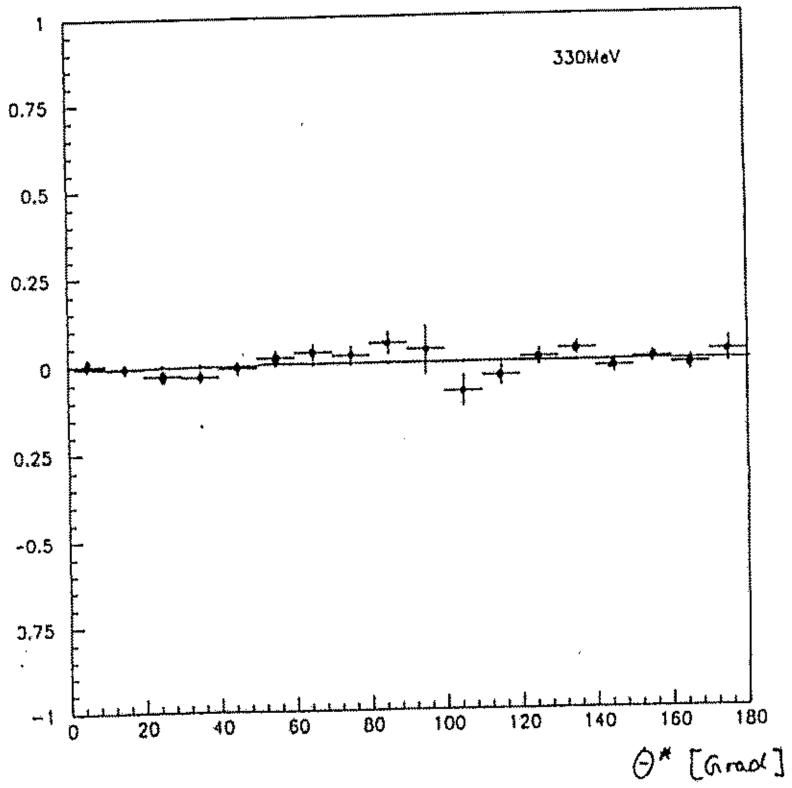
Abb. 51: Anteil der Target-Leermessung an der Hauptmessung vor den kinematischen Schnitten.

Kinematische Kurven nach den Schnitten

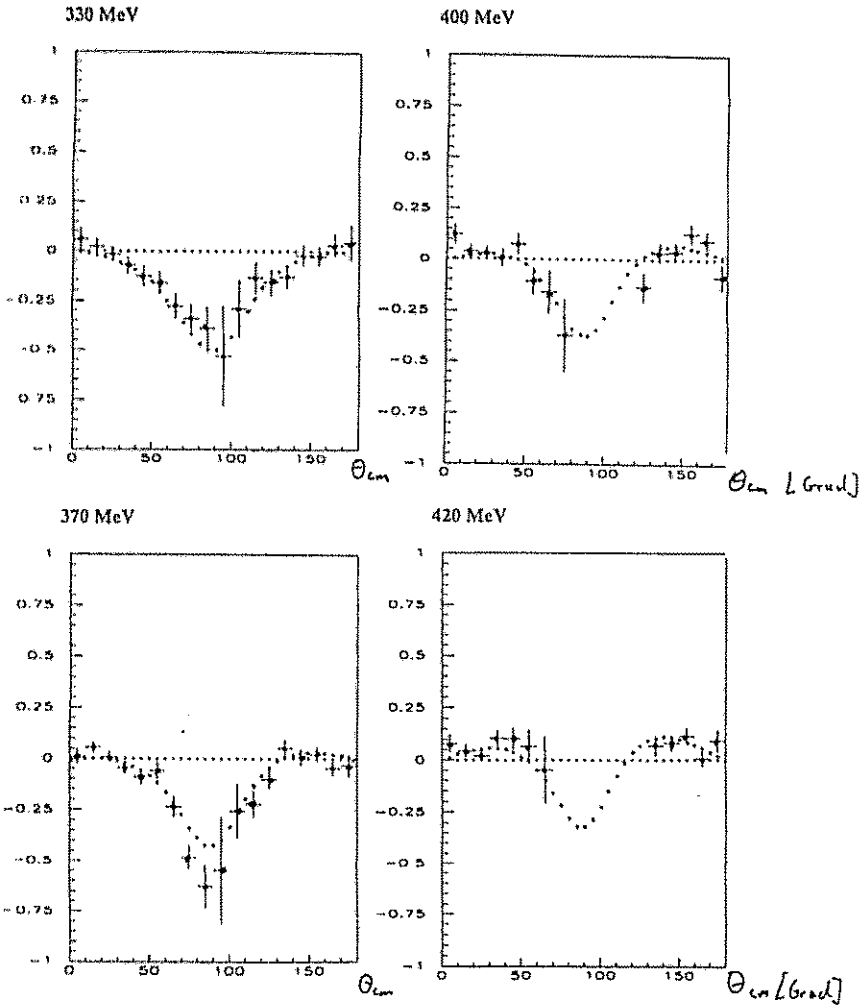
Binbreite T_n: 20 MeV



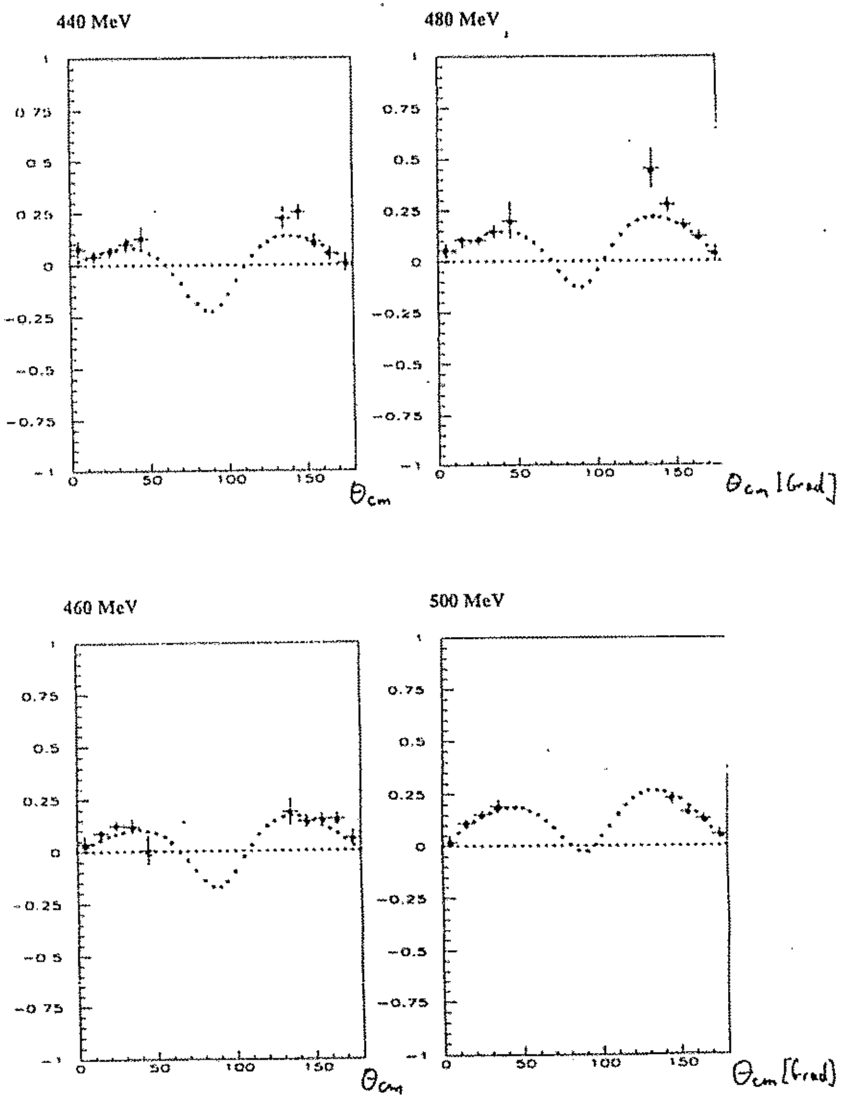
ASYMMETRIE BEI K-POLARISATION



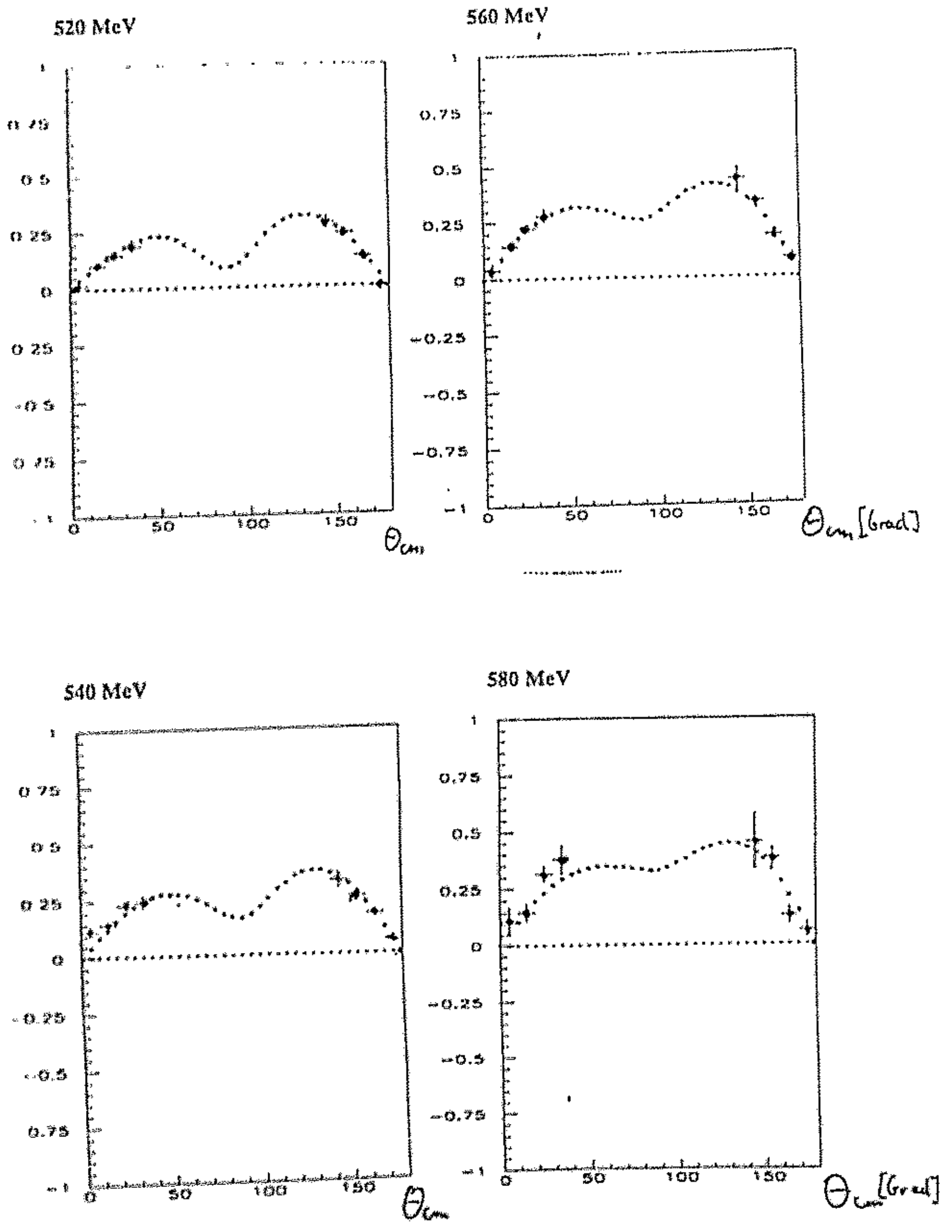
Analysierstärke $\vec{n}p \to d\pi^0$



Analysierstärke $\vec{n}p \to d\pi^0$



Analysierstärke $\vec{n}p \to d\pi^0$



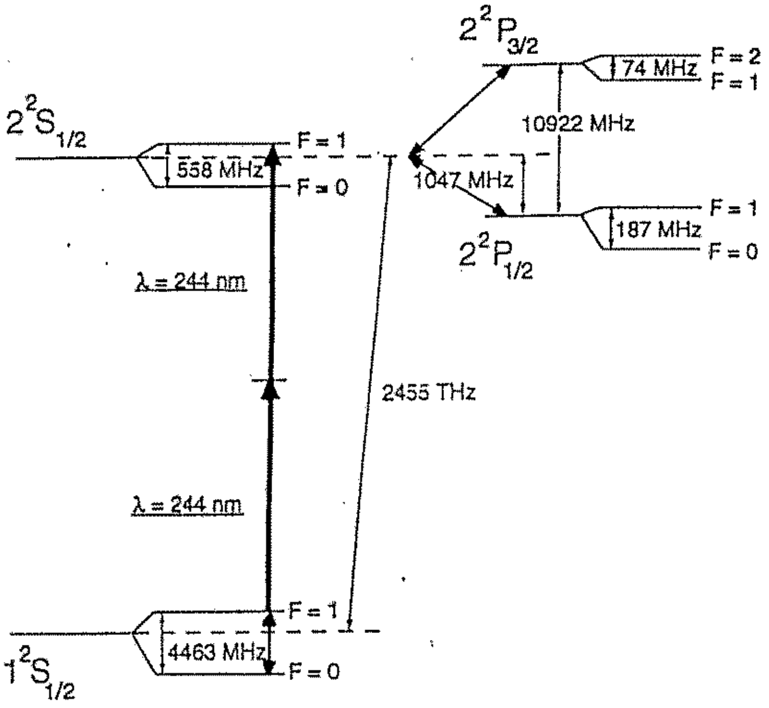
Präzisionsmessungen am Myoniumatom

$(\mu^+ e^-)$

K. Jungmann
Universität Heidelberg
Physikalisches Institut
69120 Heidelberg

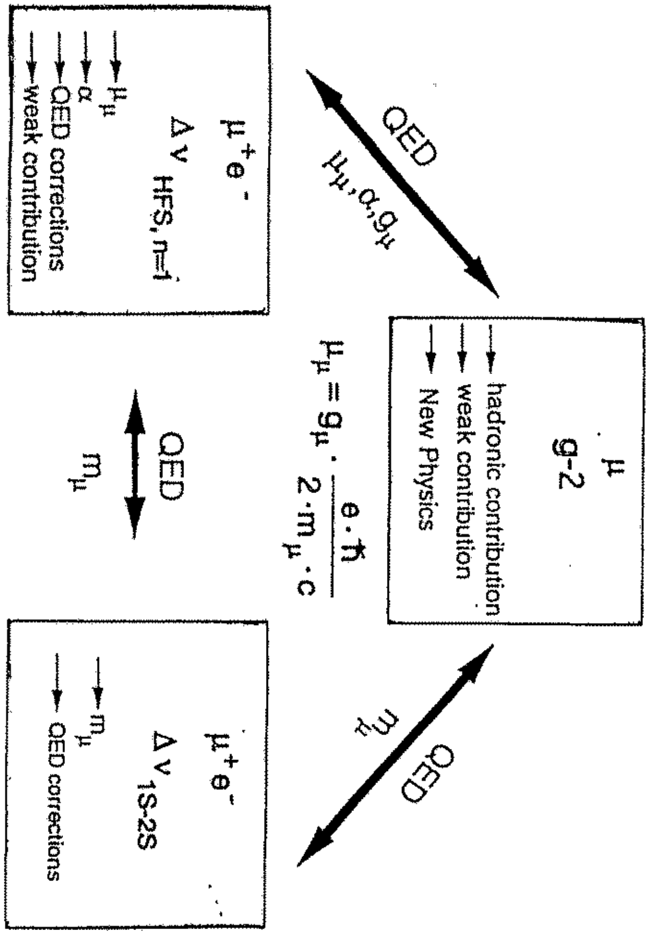
Arbeitstreffen
"Kern- und Teilchenphysik 1994"
PIRNA, 4.-10.07.1994

Muonium Energy Levels
$n = 1$ and $n = 2$



Muonium: $(\mu^+ e^-)$

not to scale



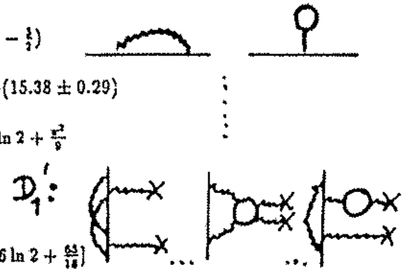
$$\mu_\mu = g_\mu \cdot \frac{e\cdot\hbar}{2\cdot m_\mu \cdot c}$$

Muonium Hyperfine Structure - Theory

$$\Delta\nu_{HFS} = E_F\,(1+\varepsilon_{QED}) + \Delta\nu_{weak} + \Delta\nu_{exotic}$$

- $E_F = \frac{16}{3}(Z\alpha)^2 R_\infty \frac{\mu_\mu}{\mu_B}[1+\frac{m_e}{m_\mu}]^{-3} = 4\,459\,033.4\ (0.6)\ kHz$
- $\varepsilon_{QED} = \varepsilon_{rad} + \varepsilon_{rec} + \varepsilon_{rad-rec}$

$$\begin{aligned}\varepsilon_{rad} &= (1+a_\mu)(1+\tfrac{3}{2}(Z\alpha)^2 + a_e + \alpha(Z\alpha)(\ln 2 - \tfrac{5}{2})\\ &-\tfrac{8\alpha(Z\alpha)^2}{3\pi}\ln(Z\alpha)(\ln(Z\alpha/4) + \tfrac{281}{480}) + \tfrac{\alpha(Z\alpha)^2}{\pi}(15.38 \pm 0.29)\\ &+\tfrac{\alpha^2(Z\alpha)}{\pi}[-\tfrac{4}{3}\ln^2\tfrac{1+\sqrt{5}}{2} - \tfrac{20\sqrt{5}}{9}\ln\tfrac{1+\sqrt{5}}{2} + \tfrac{608}{45}\ln 2 + \tfrac{\pi^2}{9}\\ &-\tfrac{38\pi}{15} + \tfrac{91639}{37800} - 0.310742\ldots + D_1'])\end{aligned}$$



$$\varepsilon_{rec} = -\tfrac{3Z\alpha}{\pi}\tfrac{m_e m_\mu}{m_\mu^2 - m_e^2}\ln\tfrac{m_\mu}{m_e} + \tfrac{(m_e Z\alpha)^2}{m_e m_\mu}[2\ln\tfrac{1}{2Z\alpha} - 6\ln 2 + \tfrac{65}{18}]$$

$$\begin{aligned}\varepsilon_{rad-rec} &= \tfrac{\alpha(Z\alpha)m_e}{\pi^2 m_\mu}(-2\ln^2\tfrac{m_\mu}{m_e} + \tfrac{13}{12}\ln\tfrac{m_\mu}{m_e}\tfrac{21}{2} + \zeta(3) + \zeta(2) + \tfrac{35}{9} + (2.15 \pm 0.14)\\ &+\tfrac{\alpha}{\pi}[-\tfrac{4}{3}\ln^3\tfrac{m_\mu}{m_e} + \tfrac{4}{3}\ln^2\tfrac{m_\mu}{m_e} + O(\ln\tfrac{m_\mu}{m_e})])\end{aligned}$$

- $\Delta\nu_{weak} = 130 \cdot C_{AA}^{e\mu}\ Hz = 65\ Hz$ (axial – axial vector via Z)
- $\Delta\nu_{M\overline{M}} = 519 \cdot (G_{M\overline{M}}/G_F)\ Hz \leq 83\ Hz$ (M – $\overline{\mathrm{M}}$ oscillation)

$\Delta\nu_{HFS}(exp) = 4\,463\,302.88\ (16)\ kHz\ (36\ ppb)$

$\Delta\nu_{HFS}(theory) = 4\,463\,302.63\ (1.34)(0.21)(0.17)\ kHz\ (300\ ppb)$

June-1994 ; T. Kinoshita and H. Nio, Phys. Rev. Lett. 72, 3803; errors: (δm_μ)($\delta\alpha$)(δ[illegible]

EXPERIMENT 1054

Ultra-High Precision Measurement on Muonium Ground State:

Hyperfine Structure and Muon Magnetic Moment

Yale - Heidelberg - Syracuse - Los Alamos - Brookhaven

Spokespersons: V.W. Hughes (Yale),
G. zu Putlitz (Heidelberg),
P.A. Souder (Syracuse)

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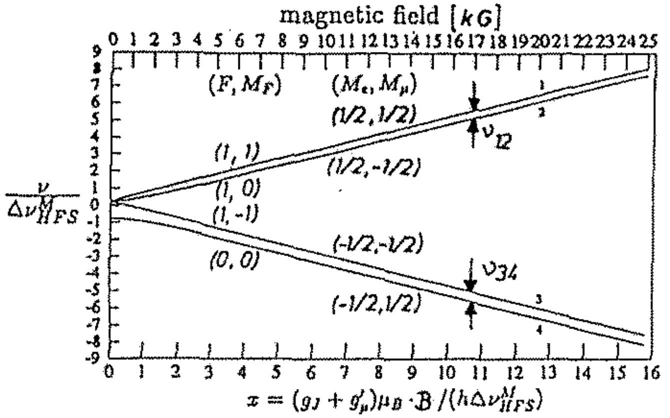
Jan-1994

Muonium $1^2S_{1/2}$ State in an External Magnetic Field



$$\boxed{\nu_{12} + \nu_{34}} = \boxed{\Delta\nu_{HFS}}$$

$$\boxed{\nu_{12} - \nu_{34}} = \frac{2\boxed{\mu_\mu} g_\mu' B}{h} + \boxed{\Delta\nu_{HFS}}[(1 + x^2)^{1/2} - x]$$

$$\nu_{12} = \frac{\mu_\mu g_\mu'}{h} + \frac{1}{2}\Delta\nu_{HFS}[(1+x) - (1+x^2)^{1/2}]$$

$$\nu_{34} = -\frac{\mu_\mu g_\mu' H}{h} + \frac{1}{2}\Delta\nu_{HFS}[(1-x) + (1+x^2)^{1/2}]$$

with $g_\mu' = g_\mu[1 - \frac{\alpha^2}{3} + \frac{m_e}{m_\mu}\frac{\alpha^2}{2}]$

Old Muonium Signal

statistical figure of merit:

$F = \sqrt{N_{e^+}} \left(\frac{S}{B}\right) \frac{1}{L}$

N_{e^+} : number of decay e^+

S/B : Signal to Background rat

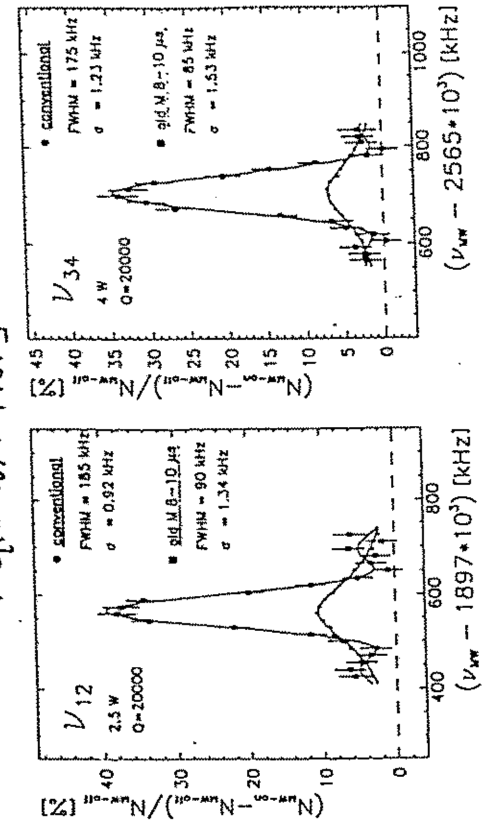
L : Linewidth

Lineshape:

$$S \propto \frac{2|b|^2}{\Gamma^2}\left[1+\frac{\gamma(\Gamma\sin(\Gamma T)-\gamma\cos(\Gamma T))}{\Gamma^2+\gamma^2}\right]$$

$|b|^2 \propto$ microwave power; T: waiting time; $\gamma = \tau_\mu^{-1}$

$\Gamma = [(\omega-\omega_0)^2 + 4|b|^2]^{1/2}$



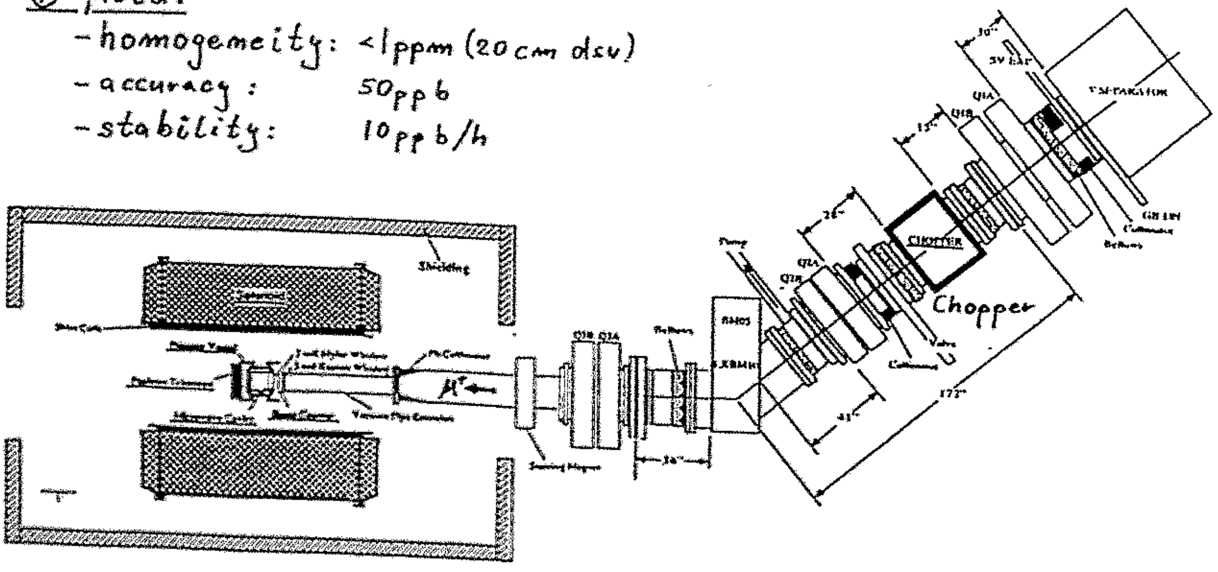
preliminary: $\Delta\nu^{M}_{HFS} = 4463\,302.72\,(12)(30)$ kHz

muonium "age" [μs]	0 – ∞	4 - 6	6 - 8	8 - 10
uncertainty of $\delta\nu_{12}$ [kHz]	0.9	0.8	0.8	1.3
Line center $\delta\nu_{34}$ [kHz]	1.2	1.0	1.1	1.5

LAMPF Experiment 1054 Yale - Heidelberg - Syracuse - LAMP

E1054 Setup

B-field:
- homogeneity: <1ppm (20 cm dsv)
- accuracy : 50 ppb
- stability: 10 ppb/h

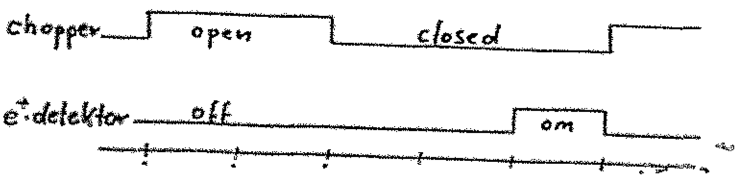


$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$

Yale - Heidelberg - Syracuse

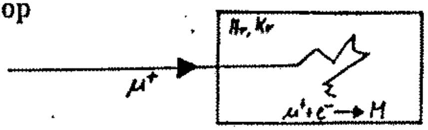
V.W. Hughes, G. zu Putlitz, P. Souder et al.

Old Muonium:



Methods of Muonium Production

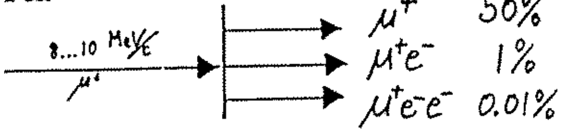
- Gas Stop



Yields up to 100% foreign gas effects

Polarization up to 50% (B = 0)
100% (B>>.15T)

- Beam Foil

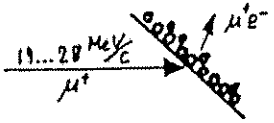


Muonium in Vacuum

n=2 state populated (~10%) keV kinetic energy

fast muonium

- SiO_2 Powder

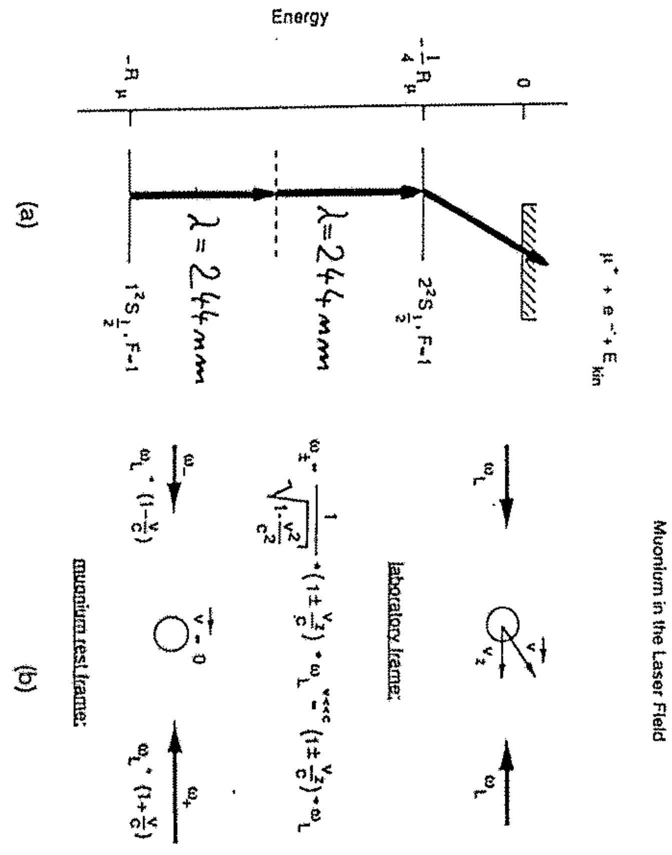


Thermal Muonium in Vacuum

Polarization 39(9)% $\frac{M(n=2)}{M(n=1)} \leq 10^{-4}$

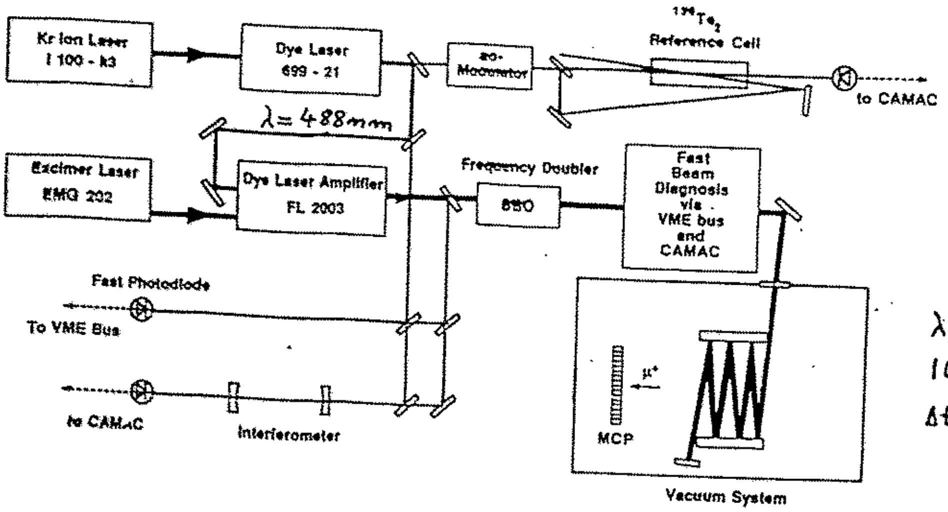
yields up to 12(2) % *for* μ^+ *at 20 MeV/c*

Silica Aerogels yield 1.9(4) % *for* μ^+ *at 26 MeV/c*



(a) (b)

accurate to 0.8 ppb ≙ 0.5 MHz



λ = 244 nm
10 mJ per pulse
Δt = 28 n sec

RAL Experiment 709

Heidelberg - Oxford - RAL - Southampton - Strathclyde - Yale
K. Jungmann et al.

Experiment 709 at Rutherford Appleton Laboratory

High Resolution Two Photon Spectroscopy of the Muonium
1S - 2S Transitions

B. Braun, K. Jungmann, F. Maas, B.E. Matthias, G. zu Putlitz, I. Reinhard, W. Schwarz,
L. Willmann, L. Zhang

Physikalisches Institut der Universität Heidelberg,
Philosophenweg 12, D-6900 Heidelberg 1

D. Berkeland, M.G. Boshier, V.W. Hughes

Physics Department, Yale University, New Haven Ct. 06520

P.E.G. Baird, P.G.H. Sandars, G. Woodman

Clarendon Laboratory, Oxford, OX1 3PU

G. Eaton, W.T. Toner, M. Towrie

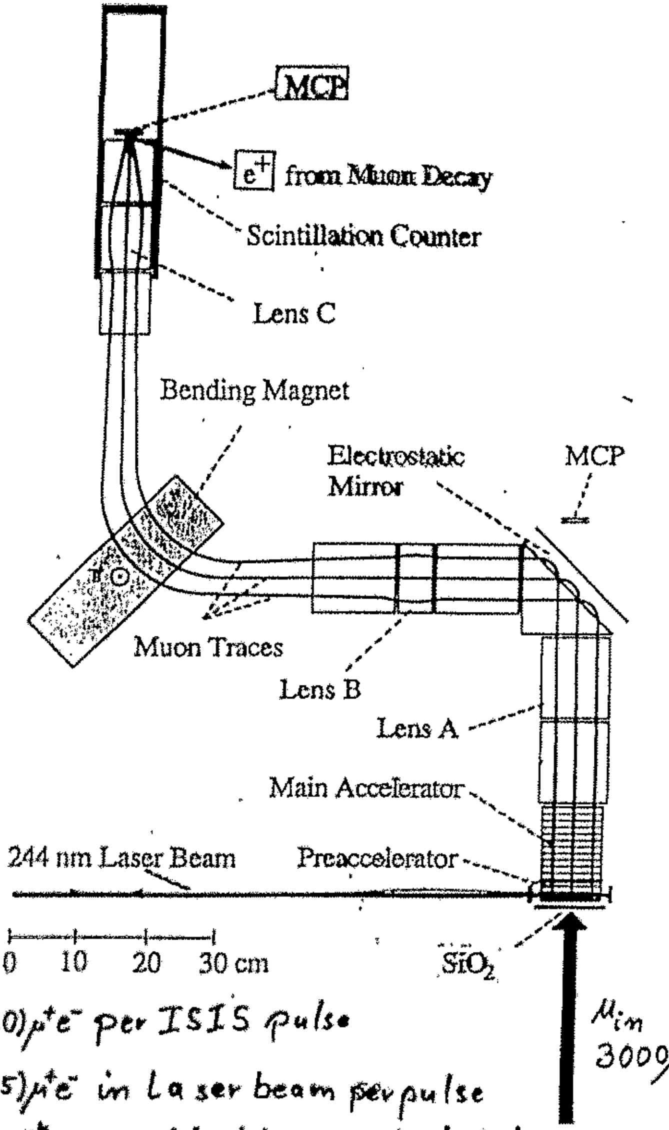
Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX

J.R.M. Barr

Department of Physics, University of Southampton, Southampton S09 5NH

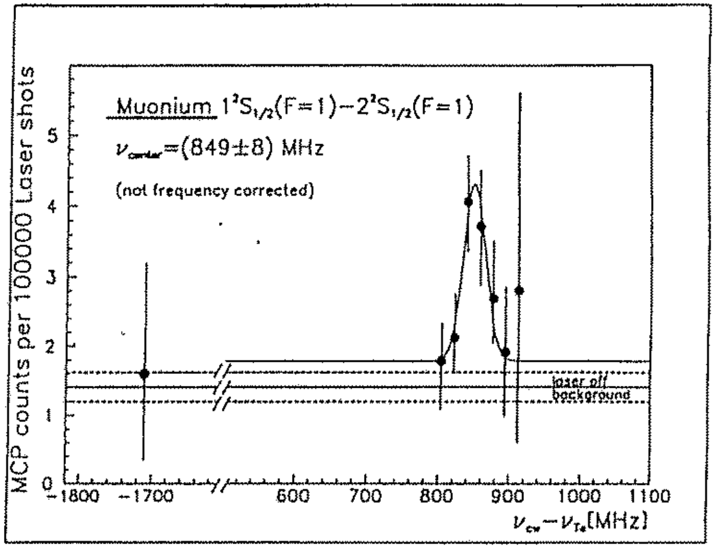
P. Curly, A.I. Ferguson, M. Persaud

Department of Physics and Applied Physics, University of Strathclyde, Glasgow G4 0NG



μ_{in} 3000/pulse

- 80(20) μ^+e^- per ISIS pulse
- 1.5(5) μ^+e^- in Laser beam per pulse
- $2\cdot10^{-4}$ excitation probability
- 10(5)% μ^+ detection efficiency



	Frequency [MHz]	stat. uncert.	system. uncert.
values at λ=488 nm			
$\nu_{cw}-\nu_{Te}$	849	8	0
$+\nu_{Te}(d_4)$	613 881 149	0	0.5
$=\frac{1}{4}\cdot\Delta\nu^{raw}$(1S,F=1-2S,F=1)	613 881 998	8	0.5
values at λ=122 nm			
$\Delta\nu^{raw}$(1S,F=1-2S,F=1)	2 455 527 993	33	9.0
$+\Delta\nu_{1st.Doppler}$	0	0	8.4
$+\Delta\nu_{2nd.Doppler}$	1	0	0
$+\Delta\nu_{ac-Stark}$	-52	0	20
$+\Delta\nu_{chirp}$	84	0	40
$+\Delta\nu_{hfs}$(F=1-F=1)	976	0	0
$=\Delta\nu^{exp}$(1S-2S)	2 455 529 002	33	46
$\Delta\nu^{theory}$(1S-2S)	2 455 528 934		3.6

F.E.Maas et al., Phys.Lett.A 187, 247 (

agreement with KEK Experiment – Chu et al. 198

Results from Muonium 1S-2S Laser Excitation

- **1S-2S transition frequency:**

$\Delta\nu_{1S-2S}$ (exp) = 2 455 529 002(33) (46) MHz
$\Delta\nu_{1S-2S}$ (theory) = 2 455 528 934.3 (3.6) MHz

- **Lamb shift contribution to 1S-2S:**

$\Delta\nu_{LS}$ (exp) = 6 988 (33) (46) MHz
$\Delta\nu_{LS}$ (theory) = 7 056.1 (1.0) MHz

- **Isotope shifts:**

Hydrogen:
$\Delta\nu_{M-H}$ (exp) = 10 532 414 (33) (46) MHz
$\Delta\nu_{M-H}$ (theory) = 10 532 478.8 (3.6) MHz

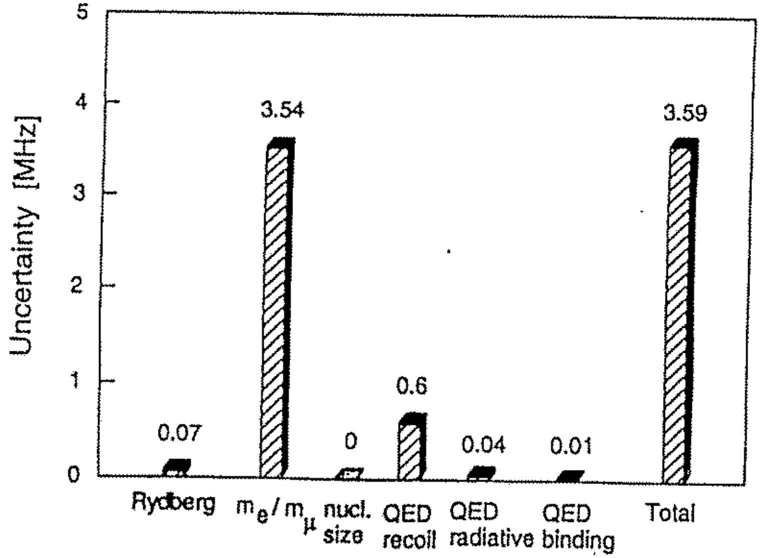
Deuterium:
$\Delta\nu_{M-D}$ (exp) = 11 203 447 (37) (46) MHz
$\Delta\nu_{M-D}$ (theory) = 11 203 473.1 (3.6) MHz

- **Muon Mass:**

m_{μ^+} ($\Delta\nu_{M-H}$, $\Delta\nu_{M-D}$) = 105.658 80 (29) (43) MeV/c^2
m_{μ^+} ($\mu\mu$) = 105.658 386 (44) MeV/c^2
m_{μ^-} (μ^- atoms) = 105.658 41 (33) MeV/c^2

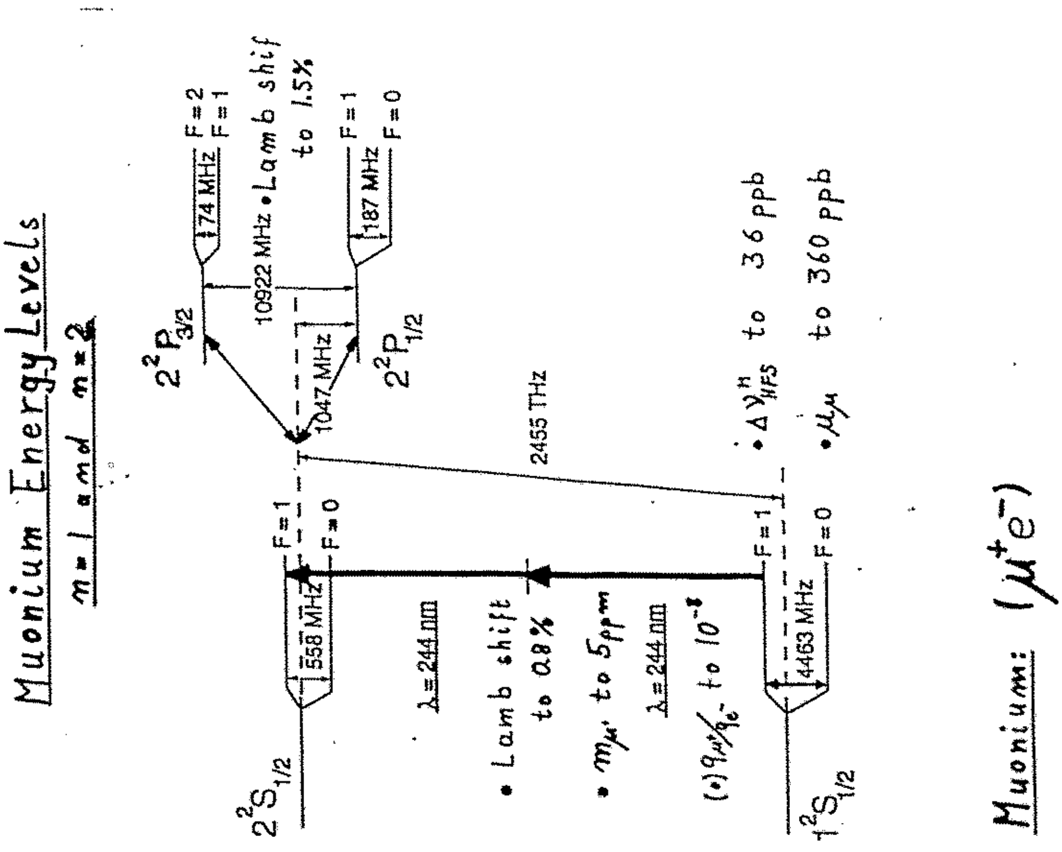
Contribution [MHz]	M(1S-2S)
Dirac energy	2 467 411 581.53
Dirac reduced mass	-11 875 786.78
Relativistic two-body	195.73
QED corrections	
one-loop	-7 037.21
two-loop	-0.88
relativistic recoil	-18.14
radiative recoil	0.05
total QED corrections	-7 056.18
Finite nuclear size	0.00
Lamb shift	-7 056.18
Total:	2 455 528 934.30

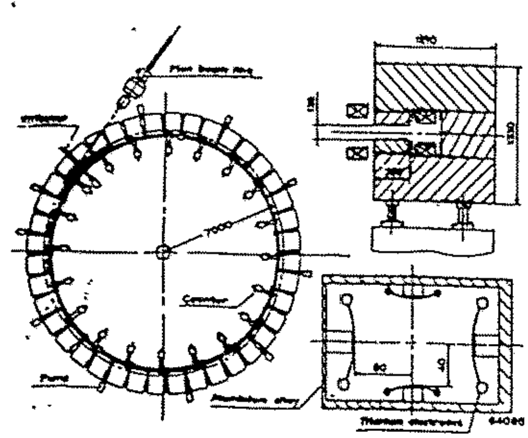
Uncertainties in the 1S-2S energy difference in Muonium

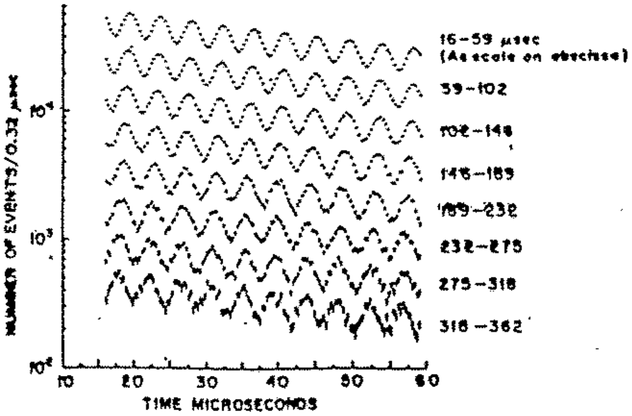


Muon g - 2

$$\mu_\mu = g_\mu \cdot \frac{e\hbar}{2 \cdot m_\mu \cdot c} = 2 \cdot (1 + a_\mu) \cdot \frac{e\hbar}{2 \cdot m_\mu \cdot c}$$







Anomaly Frequency:†
$$\boxed{\omega_a = \boxed{\omega_s} - \boxed{\omega_c} = \frac{e}{m_\mu c} a_\mu B}$$
$$a_\mu^{CERN} = 1165\,922.9(8.5)\cdot 10^{-9}$$
$$(\pm 7.2\,\text{ppm})$$

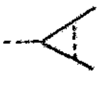
Spin Precession Frequency:
$$\boxed{\omega_s} = \frac{e}{m_\mu \gamma c}\cdot B + \frac{e}{m_\mu c} a_\mu \cdot B \quad ; \quad \gamma = \left(1 - \frac{v^2}{c^2}\right)^{-1/2}$$

Cyclotron Frequency:
$$\boxed{\omega_c} = \frac{e}{m_\mu \gamma c}\cdot B$$

† also valid in external electric fields, if $\frac{1}{\gamma^2-1} - a_\mu = 0$ $\boxed{\Rightarrow \quad p_\mu = 3.1\ GeV/c}$

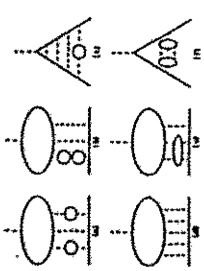
Contributions to the Muon Magnetic Anomaly a_μ

- $a_\mu = \frac{1}{2}(g_\mu - 2) = a_\mu^{QED} + a_\mu^{Hadr} + a_\mu^{Weak} + a_\mu^{exotic}$



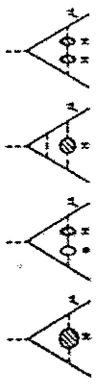
$$= \frac{\alpha}{2\pi} + \ldots$$

- $a_\mu^{QED} = 1\,165\,846\,955\,(46)(28)\cdot 10^{-12}$ z.B.:



$a_\mu^{QED} \approx 99.33\%$

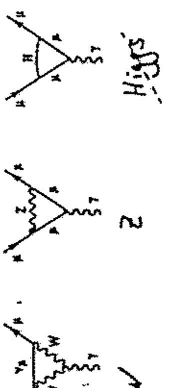
- $a_\mu^{hadr} = 7027(175)\cdot 10^{-11}$ z.B.:



$a_\mu^{Hadr} = 60.3\,ppm$

from: $\frac{\sigma(e^+e^- \longrightarrow \text{hadrons})}{\sigma(e^+e^- \longrightarrow \mu^+\mu^-)}$ (measurable to .5%!)

$a_\mu^{weak} = 195(10)\cdot 10^{-11}$



$a_\mu^{Weak} = 1.7\,ppm$

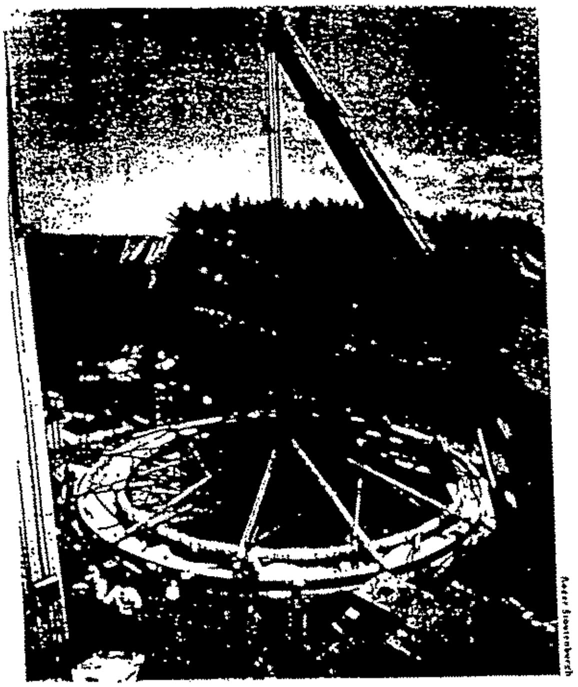
⟶ Test renormalizability in weak interaction

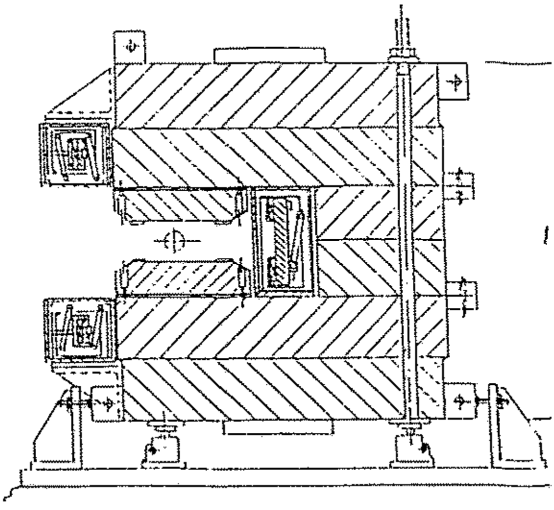
⟶ Compare to $M_W^2 = \frac{\pi\alpha}{\sqrt{2}\,G_F\left(1 - \frac{M_W^2}{M_Z^2}\right)(1-\Delta r)}$; $\Delta r \approx 7;$ $\overset{\uparrow}{m_t ?}$

AGS Experiment E821: Muon g-2
V.W. Hughes, B.L. Roberts, V. Morse et g-2 coll

Got the Coil on a String!

(See "World's Largest Superconducting Coil Completed" on page 2.)





MUON G-2 MAGNET CROSS SECTION

Radius of ring: ~ 7 m

AGS EXPERIMENT 821

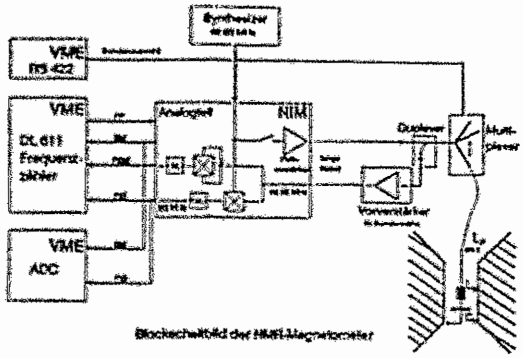
TITLE: A NEW PRECISION MEASUREMENT OF THE MUON G-2 VALUE AT THE LEVEL OF 0.35 PPM.

Boston	R. Carey E. Hazen F. Krienen J.P. Miller B.L. Roberts * L.R. Sulak W. Worstell	Heidelberg	K. Jungmann G. zu Putlitz
		MPI-Heidelberg	U. Haeberlen
BNL	H.N. Brown G. Bunce G.T. Danby J.W. Jackson Y.Y. Lee S. Mane W.M. Morse * A. Prodell R. Shutt K. Woodle	KEK	K. Endo H. Hirabayashi S. Ichii S. Kurokawa Y. Mizumachi T. Sato A. Yamamoto
		Riken Tokyo	L. Ishida M. Iwasaki K. Nagamine
Cornell	T. Kinoshita Y. Orlov	Novosibirsk	L.M. Barkov B.I. Kazin D.N. Grigorev E.A. Kuraev S.I. Redin Ya.M. Shatunov E. Solodov
Fairfield	D. Winn		
LANL	W.P. Lysenko		
Yale	P. Cushman S.K. Dhawan F.J.M. Farley X. Fei S. Hou N. Janousch V.W. Hughes *		

Goal: better than 0.35 ppm

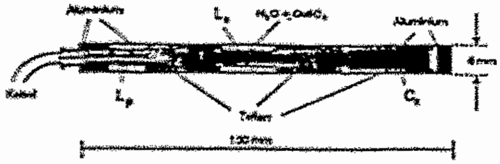
g-2 Magnetometer

- gepulste Kernspinresonanz (H_2O)
- Zählen von Nulldurchgängen des FID-Signals

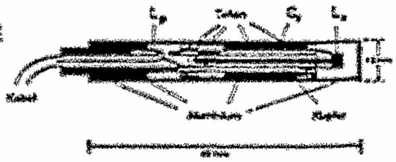


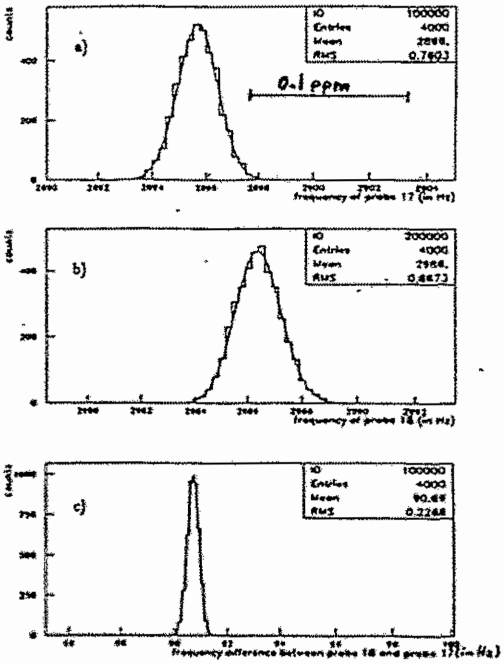
Blockschaltbild der NMR-Magnetometer

- **feste Probe**

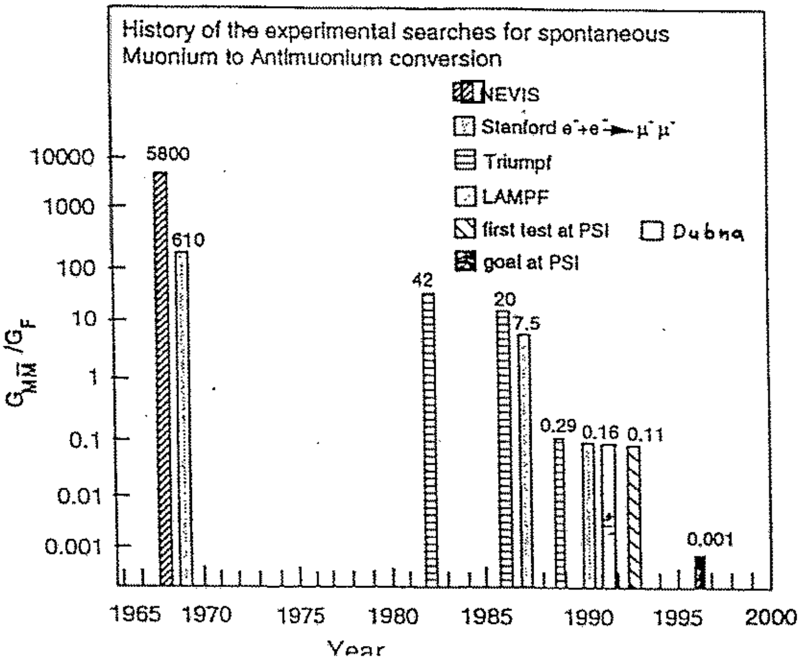


- **bewegliche Probe**

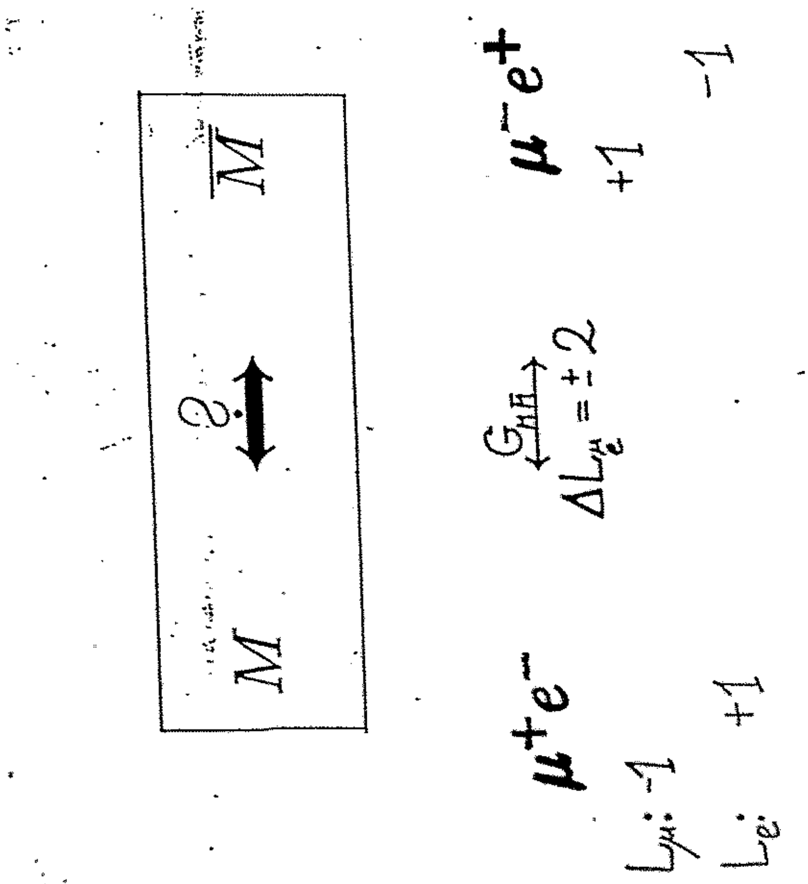


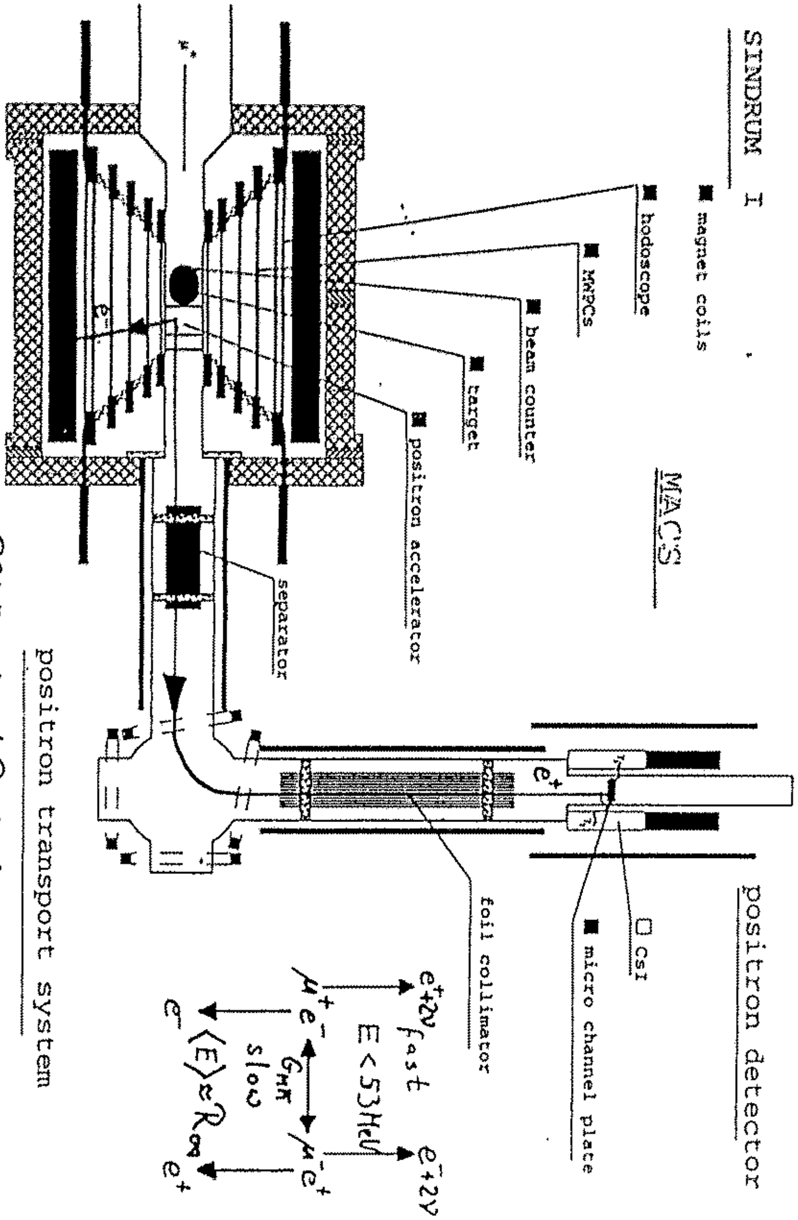


4000 Einzelmessungen in MRI Magnet



History of the experimental searches for spontaneous Muonium to Antimuonium conversion





PSI Experiment R-89-06

Aachen-Dubna-Heidelberg-PSI-Tbilisi-Yale-Zürich

Experiment R-89-06 at PSI

Search for Spontaneous Conversion of Muonium to Antimuonium[1]

B. Fischer von Weikersthal, K. Jungmann, F. Maas, B.E. Matthias,
T. Prokscha, G. zu Putlitz, I. Reinhard, P. Schmidt, L. Willmann, L. Zhang,
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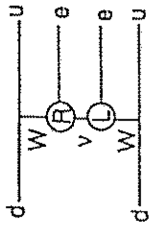
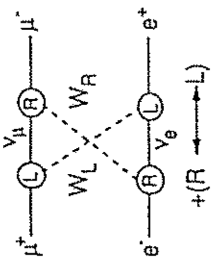
V.W. Hughes, W. Schwarz
Yale University, New Haven Ct., USA

1stalüs. Jul-94

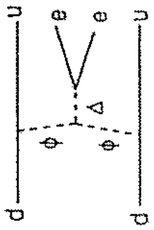
Majorana Neutrino Exchange Mechanism

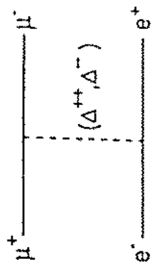




$G_{M\bar{M}}=\lambda(G_F m_1^2/2\pi^2)\ln(\lambda^{-1})\leq 10^{-5}\,G_F$

Higgs Mechanism

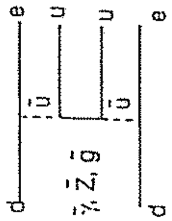


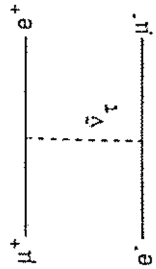


$G_{M\bar{M}}\sim h^2/m_\Delta^2\,G_F \lesssim 10G_F$

$\gtrsim 7\cdot 10^{-5}\,G_F$

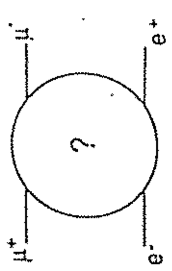
R-Parity violating SUSY

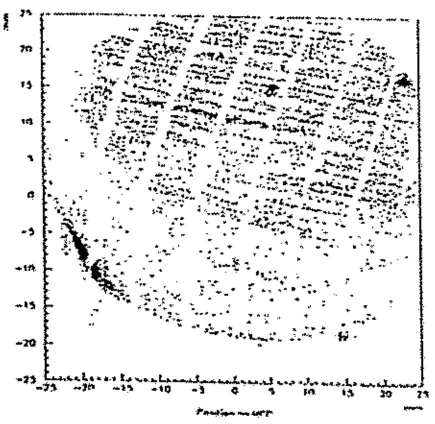


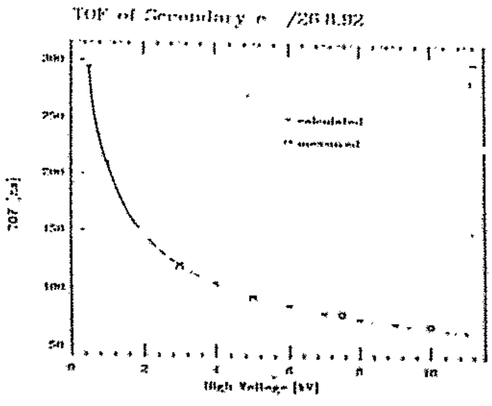


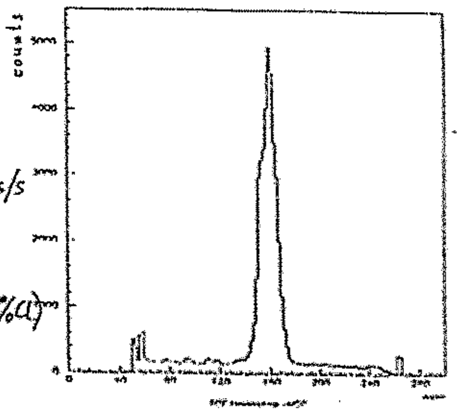
$G_{M\bar{M}}\sim\left(\frac{\lambda_{312}\,\lambda'_{321}}{m^2_{\tilde{\nu}_\tau}}\right)\lesssim 2\cdot 10^{-2}\,G_F$

more general

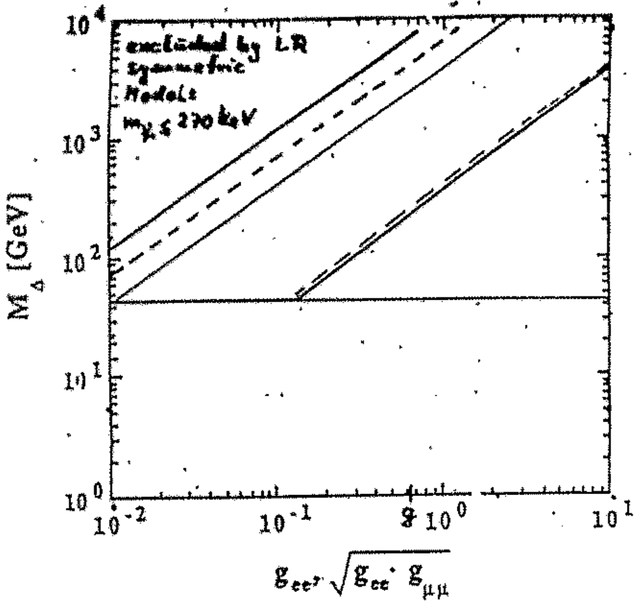








- accidental background $\lesssim 10^{-9}$ events/s
  @ $\mu^+_{in} = 5\cdot 10^5\,\mu^+/s$
- Warmup run 1992:
  1day of data taking ⇒ $G_{M\bar{M}} \leq 0.11\,G_F$ (90%CL)
- 1st step: data run 1993:
  400h data taking ⇒ sensitive to
  $G_{M\bar{M}} \sim 2\cdot 10^{-7}\,G_F$



$$G_{M\bar{M}} = \frac{g_{ee} \cdot g_{\mu\mu}}{g^2} \left[\frac{M_W}{M_\Delta}\right]^2 G_F$$

M.L. Swartz
Phys. Rev. D46,1521 (1989)

- - - - $M\bar{M}$ LAMPF

——— $e^+e^- \longrightarrow$ 4 Leptons

——— $e^+e^- \longrightarrow e^+e^-$ PEP & PETRA

——— $M\bar{M}$ proposed PSI

——— minimal LR Theory
- - - - with reasonable assumptions

P. Herczeg and R. Mohapatra,
Phys. Rev. Lett. 17, 2475 (1992)

Arbeitstreffen Kern- und Teilchenphysik 1994
PIRNA

SUCHE NACH DER μ–e–KONVERSION AN KERNEN IM SINDUM II – SPEKTROMETER

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SINDRUM II – Kollaboration
Aachen / PSI / Zürich (ETH + U)

<u>SIN</u> <u>D</u>etector for <u>R</u>are and <u>U</u>nexpected <u>M</u>odes

(SIN – Schweizer Institut für Nuklearforschung, *heute im* PSI – Paul Scherrer Institut)

- gefördert vom BMFT -

Leptonflavour = Generationsnummer

	$e^-\nu_e$	$e^+\bar{\nu}_e$	$\mu^-\nu_\mu$	$\mu^+\bar{\nu}_\mu$	$\tau^-\nu_\tau$	$\tau^+\bar{\nu}_\tau$
L_e	1	-1				
L_μ			1	-1		
L_τ					1	-1

Hadronen wird die Leptonflavour 0 zugeordnet.

Alle bisher beobachteten Prozesse:

$$\Delta L_e = \Delta L_\mu = \Delta L_\tau = 0$$

„Leptonflavourerhaltung"

Beispiel: Myon–Zerfall

$$\begin{array}{lccccccl} & \mu^- & \rightarrow & e^- & \nu_\mu & \bar{\nu}_e & & \\ L_e & 0 & & 1 & 0 & -1 & & \Sigma L_e = 0 \\ L_\mu & 1 & & 0 & 1 & 0 & & \Sigma L_\mu = 0 \end{array}$$

Standard – Modell: (SM)

Die Leptonflavour ist keine fundamentale Erhaltungsgröße, d.h. ist nicht mit einer Symmetrie verknüpft (wie z.B. die Ladung).

⇒ Prinzipiell ist *Leptonflavourverletzung* (LFV) möglich.

Mechanismus: Mischung der Generationen bei (unterschiedlichen) nicht verschwindenden Neutrinomassen

Experimentelle Massengrenzen für die Neutrinos und Neutrino – Oszillations – Experimente

⇒

Grenzen für die Verzweigungsverhältnisse von LFV–Reaktionen

z.B. $BR(\mu \rightarrow e\gamma) \quad < 10^{-20} \quad (\text{exp. } \mathcal{O}(10^{-11}))$

$BR(\mu^- A \rightarrow e^- A) \quad < 10^{-16} \quad (\text{exp. } \mathcal{O}(10^{-12}))$

Innerhalb des Standardmodells sind die Limits für LFV–Reaktionen aus der Neutrinomassenbestimmung auf absehbare Zeit besser als die Ergebnisse direkter μ–Zerfallsexperimente.

Weitergehende Theorien, die LFV zulassen:

- Rechts–Links–Symmetrie
- Rechtshändige Majorana–Neutrinos
- Nicht–minimaler Higgs–Sektor
- Neue Eich–WW
- Leptoquarks
- SUSY
- Stringtheorien

⇒ *Motivation für LFV-Experimente*

LFV wäre der erste direkte experimentelle Hinweis auf Physik hinter dem Standardmodell.

⊗ Phys. Lett. B 317 (1993) 631

Prozess	Verzweigungsverhältnis (90% C.L.)		
	aktuelle Grenze		angestrebte Sensitivität
$\mu^- Ti \to e^- Ti$	$\leq 4.6 \times 10^{-12}$ TRIUMF TPC	4.3×10^{-12} ⊗ SINDRUM II ('93)	3×10^{-14} SINDRUM II
$\mu^- Pb \to e^- Pb$	$\leq 4.9 \times 10^{-10}$ TRIUMF TPC	4.4×10^{-11} SINDRUM II ('92)	10^{-11} SINDRUM II
$\mu^- Ti \to e^+ Ca$	$\leq 1.7 \times 10^{-10}$ TRIUMF TPC	4.3×10^{-12} ⊗ SINDRUM II ('93)	10^{-12} SINDRUM II
$\mu^+ \to e^+ \gamma$	$\leq 4.9 \times 10^{-11}$ Crystal Box		6×10^{-13} MEGA
$\mu^+ \to e^+ e^+ e^-$	$\leq 1.0 \times 10^{-12}$ SINDRUM I		
$\mu^+ e^- \to \mu^- e^+$	$P_{M\bar{M}} \leq 3.4 \times 10^{-7}$ $G_{M\bar{M}} \leq 0.12\, G_F$ $M\bar{M}$		10^{-11} $M\bar{M}$
……			
$K^+ \to \pi^+ \mu e$	$\leq 2.1 \times 10^{-10}$ Lee *et al.*		5×10^{-12} BNL
$K_L^0 \to \mu e$	$\leq 3.3 \times 10^{-11}$ Kettell		
……			
$Z^0 \to \mu\tau$	$\leq 2.9 \times 10^{-5}$ (95% C.L.) L3		$\approx 10^{-6}$ alle LEP Experimente
$Z^0 \to e\tau$	$\leq 3.0 \times 10^{-5}$ (95% C.L.) L3		
$Z^0 \to e\mu$	$\leq 1.5 \times 10^{-6}$ (95% C.L.) L3		$\approx 10^{-6}$ alle LEP Experimente

SINDRUM II : Myon – Elektron – Konversion

$$\boxed{\mu^- + (A,Z) \to e^- + (A,Z)}$$

Signatur: Monoenergetisches Elektron

$$E_{e^-} = m_\mu c^2 - B_\mu - R_{Kern}$$

B_μ — μ^--Bindungsenergie im 1s-Zustand
R_{Kern} — Rückstoßenergie des Kerns

Titan : $E_{e^-} = 104$ MeV
Blei : $E_{e^-} = 95$ MeV

Ergebnis: Verzweigungsverhältnis

$$B_{\mu e} = \frac{\Gamma\left(\mu^- + (A,Z) \to e^- + (A,Z)\right)}{\Gamma\left(\mu^- + (A,Z) \to \nu_\mu + (A,Z-1)^*\right)}$$

$$= \frac{\Gamma\left((\mu,e)\text{–Konversion}\right)}{\Gamma\left(\mu\text{–Einfang}\right)}$$

Parametrisierung des Verzweigungsverhältnis (modellunabhängig)

Hamiltonfunktion für vektorielle Kopplung:
(skalar analog)

$$H = \frac{G_F}{\sqrt{2}} \sum_{i=0,1} g^i \underbrace{(\bar{e}\gamma^\lambda(1-\alpha^i\gamma^5)\mu)}_{\text{Leptonstrom}} \quad \underbrace{Q^i_\lambda}_{\text{Quarkstrom}}$$

$$i = \begin{cases} 0 & \text{isoskalarer Quarkstrom} \\ 1 & \text{isovektorieller Quarkstrom} \end{cases}$$

g^i phänomenologische Kopplungskonstante
$\alpha^i = \pm 1$ für rein rechts– bzw. linkshändige e^-

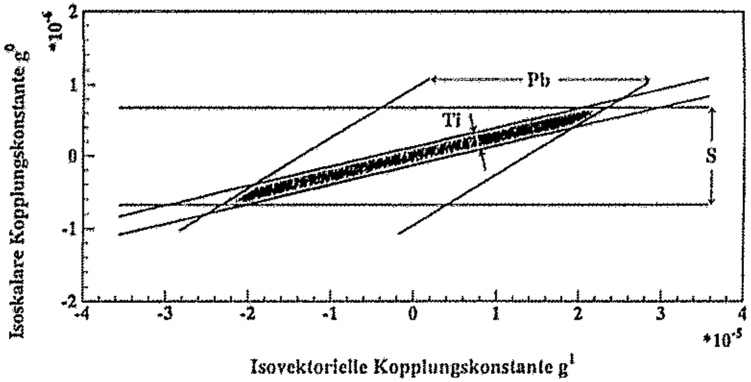
$\Rightarrow$ Verzweigungsverhältnis:

$$B_{\mu e} = \left[g^0 + g^1 \frac{Z-N}{3A} \right]^2 \frac{\Gamma(Z,A)}{\Gamma(\mu\text{–Einfang})}$$

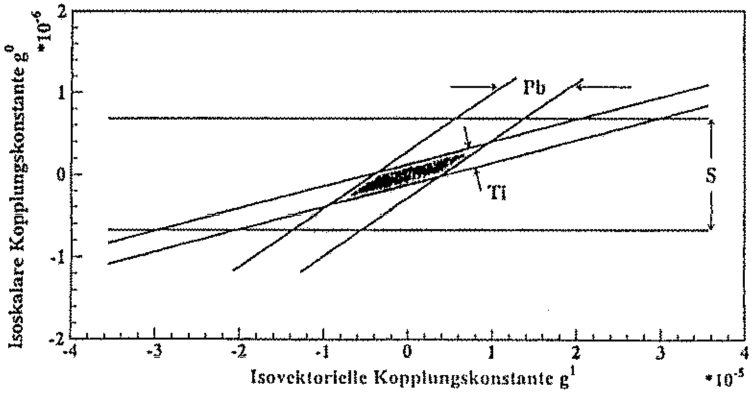
Z, N, A — Proton-, Neutron-, Massenzahl
$\Gamma(Z,A)$ — Kernphysik
- ▷ μ/e – Wellenfunktionen
- ▷ Nukleonformfaktoren

Grenzen für die vektoriellen Kopplungskonstanten

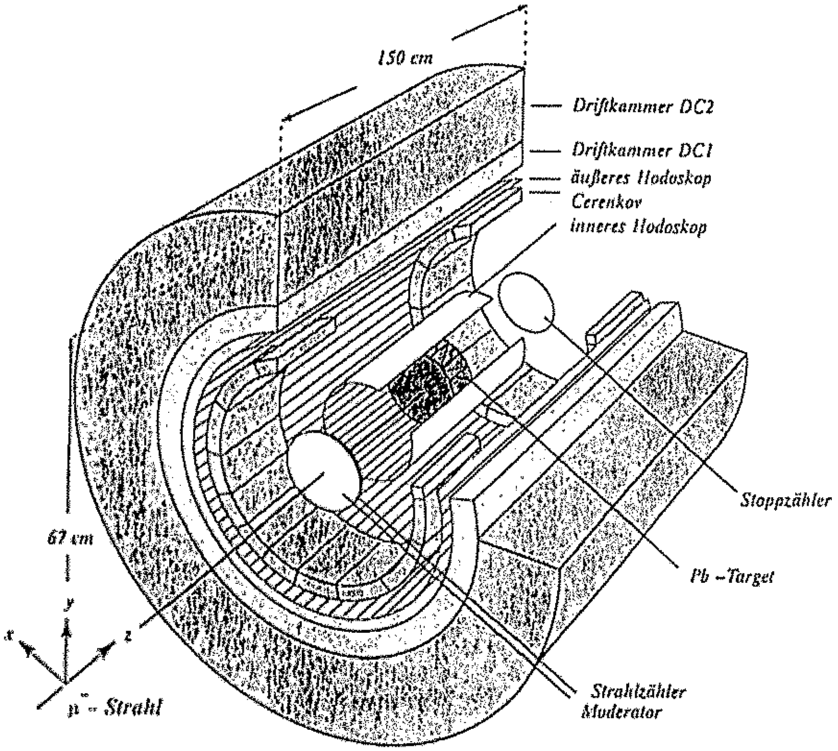
Ti: $B_{\mu e} < 4.3 \cdot 10^{-12}$ SINDRUM II ('89)
Pb: $B_{\mu e} < 4.9 \cdot 10^{-10}$ TRIUMF TPC
S: $B_{\mu e} < 7.0 \cdot 10^{-11}$ (Badertscher *et. al.* 82)



Ti: $B_{\mu e} < 4.3 \cdot 10^{-12}$ SINDRUM II ('89)
Pb: $B_{\mu e} < 4.4 \cdot 10^{-11}$ SINDRUM II ('92)

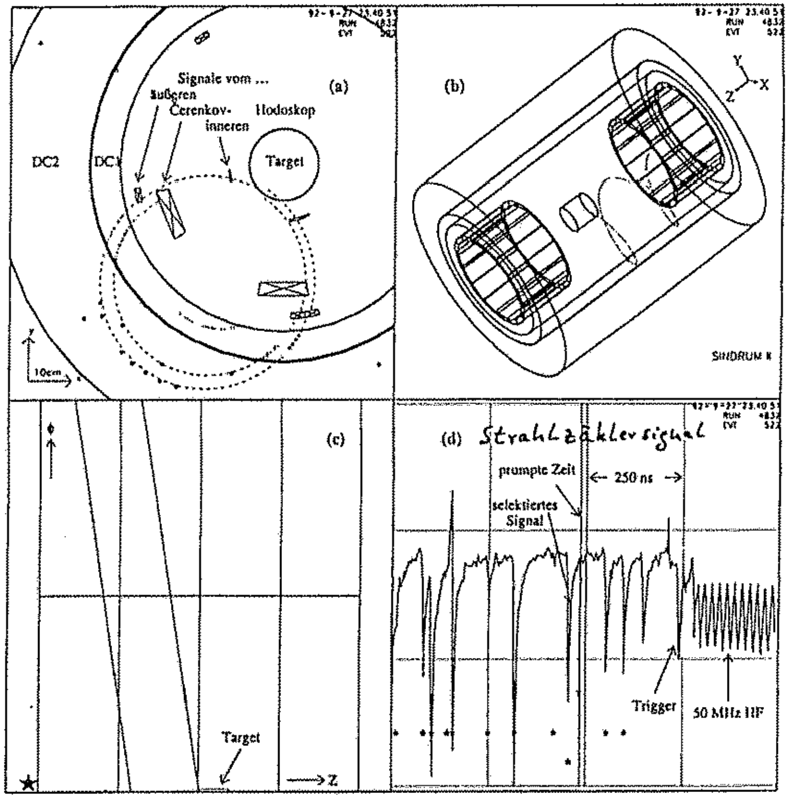


SINDRUM II – Detektor



$B_z = 1.2$ T

Rekonstruiertes Event in verschiedenen Ansichten

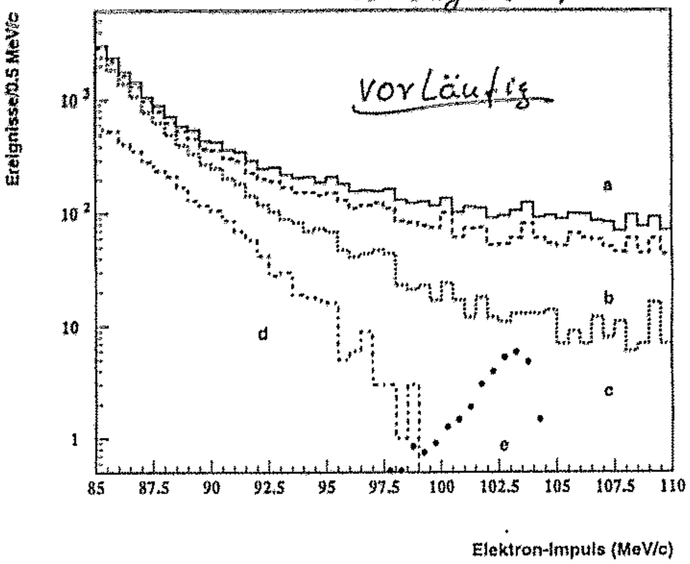


Detektorkomponenten in der Analyse

- Strahlzähler
  - Phasenlage zur Zyklotronfrequenz
  - Eintrittszeitpunkt des Strahlteilchens relativ zum Hodoskop-Signal
- Szintillatorhodoskope
  - Ereigniszeit (≡ Zerfallszeit)
  - Drehsinn ≡ Ladung über relative Zeiten mehrerer Durchgänge
  - Hinweis auf Zusatzspuren (kosm. Strahlung)
- Driftkammer DC1
  - 3D-Spurpunkte (Anodendrähte und Kathoden–streifen) $\sigma_{r\phi} = 200\mu m$, $\sigma_z = 1.4mm$
  - Basis der Spurrekonstuktion und des Impulsfits
- Driftkammer DC2
  - 2D-Spurpunkte in $r\phi$ (Anodendrähte)
  - Erkennung der Ereignistopologie
  - Hinweis auf Zusatzspuren von außen (kosm. Strahlung)
- Čerenkovhodoskope
  - e^- –Identifikation
  - weitere Zeitinformation
  - grobe z–Information

Selektionsschnitte und Impulsspektrum

Ti – Target (1333)



(a) alle Ereignisse vom Target

(b) mit Schnitten auf Elektronen

(c) mit Schnitten zur Cosmic-Unterdrückung

(d) mit Schnitten zur Unterdrückung promter Ereignisse (mittels Strahlzähler)

(e) erwartetes Signal bei $B_{\mu e} = 1 \cdot 10^{-11}$

π^+-Messung

$$\boxed{\pi^+ \longrightarrow e^+ + \nu_e} \qquad E_{e^+} = 69.7\ \mathrm{MeV}$$

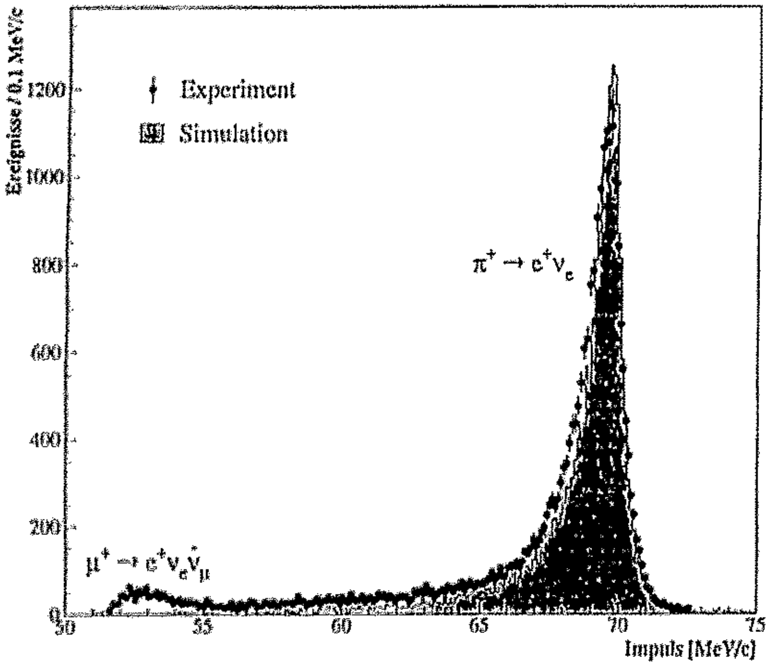
Magnetfeld: umgepolt und reskaliert

$\Rightarrow$

e^+ – Eventtopologie entspricht Konversionselektronen

- ▷ Absoluteichung des Detektors
- ▷ Test der Monte-Carlo-Simulation

e^+-Impulsverteilung



Messungen und Status

1989
- Titan: 4×10^{12} μ^--Stopps
  $B_{\mu e}^{\mathrm{Ti}} < 4.3 \times 10^{-12}$ (90% C.L.)

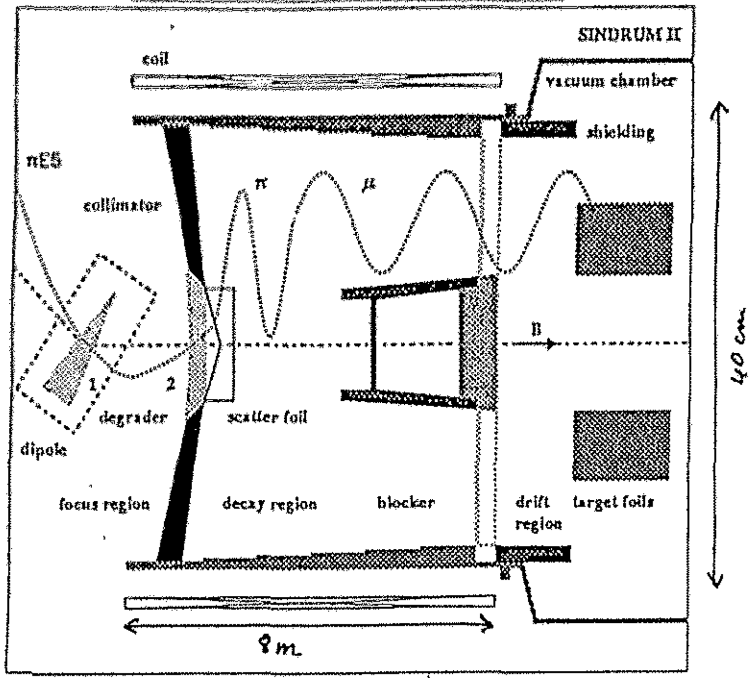
1990/91: Strahl-Shutdown

1992
- Blei: 1.7×10^{12} μ^--Stopps
  $B_{\mu e}^{\mathrm{Pb}} < 4.4 \times 10^{-11}$ (90% C.L.)

1993
- Titan: $\sim 3 \times 10^{13}$ μ^--Stopps
  (in der Auswertung $\rightarrow B_{\mu e}^{\mathrm{Ti}} \lesssim 8 \times 10^{-13}$) (vorläufig)

$\geq$ 1994: Pion-Myon-Converter (PMC)
angestrebte Sensitivität: $\mathcal{O}(10^{-14})$

PMC – Pion Muon Converter



	1993	PMC	
Protonstrom	400 – 850 μA	1 mA	
Stopprate	$10^7\ \mu/s$ (65 %)	$10^8\ \mu/s$ (85 %)	
π–Kontamination	$\sim 10^{-7}$	$< 10^{-9}$	(RPC)
BR	$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-14})$	

PMC ist bestellt / in Fertigung
→ Lieferung und Inbetriebnahme bis Frühjahr 1995
→ erneute Messungen 1995 + 96

Zusammenfassung

- Leptonflavourverletzung auf dem derzeitigen experimentellen Niveau wäre ein direkter Hinweis auf Physik hinter dem Standardmodell.
- SINDRUM II sucht nach der μe-Konversion.
  Zur Eingrenzung der isoskalaren und isovektoriellen Kopplungskonstante werden verschiedene Targetmaterialien verwendet.
- Messung mit einem Bleitarget im Herbst 1992.
  Ergebnis (Verbesserung um Faktor 11):

  $$B_{\mu e}^{\mathrm{Pb}} < 4.4 \cdot 10^{-11} \text{ (90\% C.L.)}$$

  (Likelihoodanalyse)

- Messung mit einem Titantarget 1993.
  vorläufiges Ergebnis:

  $$B_{\mu e}^{\mathrm{Ti}} < 8 \cdot 10^{-13} \text{ (90\% C.L.)}$$

  (Cutanalyse, Likelihood folgt)

Neues von μCF und langsamen Myonen

F.J. Hartmann
Physik-Department, E18, TU München,
D-85747 Garching, Germany

μCF: Berkeley – Fribourg – Gatchina – München – Neuchatel – PSI – Wien

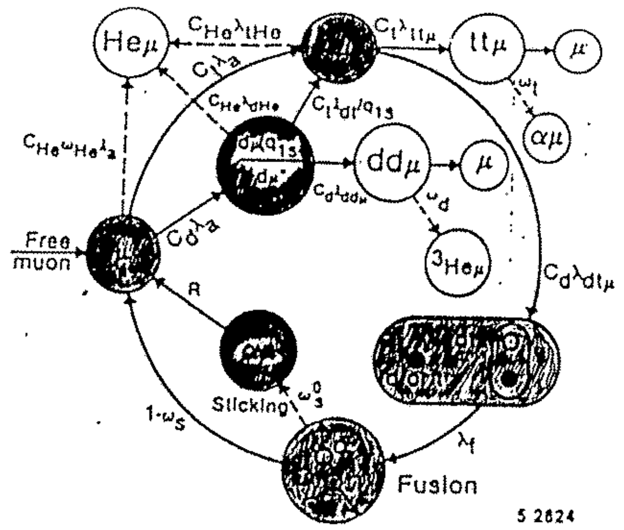
Langsame Myonen: München – PSI – Zürich

Myonenkatalysierte Kernfusion

- Der Zyklus der myonenkatalysierten Fusion
- Das q_{1s}–Problem
- Molekülbildung und Fusion
- Sticking

Langsame Myonen

- Bremsvermögen für langsame Myonen (Barkas-Effekt)
- Reibungskühlung langsamer Myonen
- Eine Myonenfalle – einmal anders



$$T = \lambda_c^{-1} = \phi^{-1}\{q_{1s} \cdot c_d \cdot (c_t\lambda_{dt})^{-1} + (c_d\lambda_{dt\mu})^{-1} + 3/4 \cdot (c_t\lambda_{t\mu}^{10})^{-1}\}$$

$$dN/dt = \lambda_c \cdot \exp(-\lambda_n t), \text{ with } \lambda_n = \lambda_0 + \omega_s\lambda_c$$

$$Y_n^{-1} = \lambda_0/\lambda_c + \omega_s$$

$\lambda_c/\lambda_0 \lesssim 350 \rightarrow Y_n \lesssim 120$

$\boxed{\omega_s} \approx 0.5\,\% \nearrow$

- q_{1s} klein,
- $\lambda_{d\mu}$ groß,
- ω_s klein.

$\lambda_0 = 0.455/\mu s$

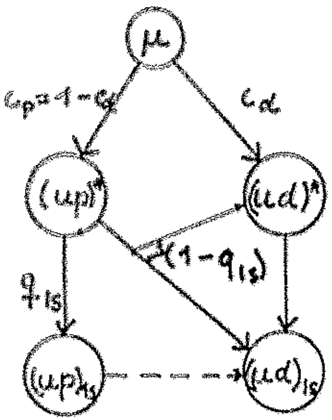
$\lambda_{dt} = 280/\mu s$

$\lambda_{dt\mu} = 300/\mu s$

$\lambda_{t\mu}^{10} = 900/\mu s$

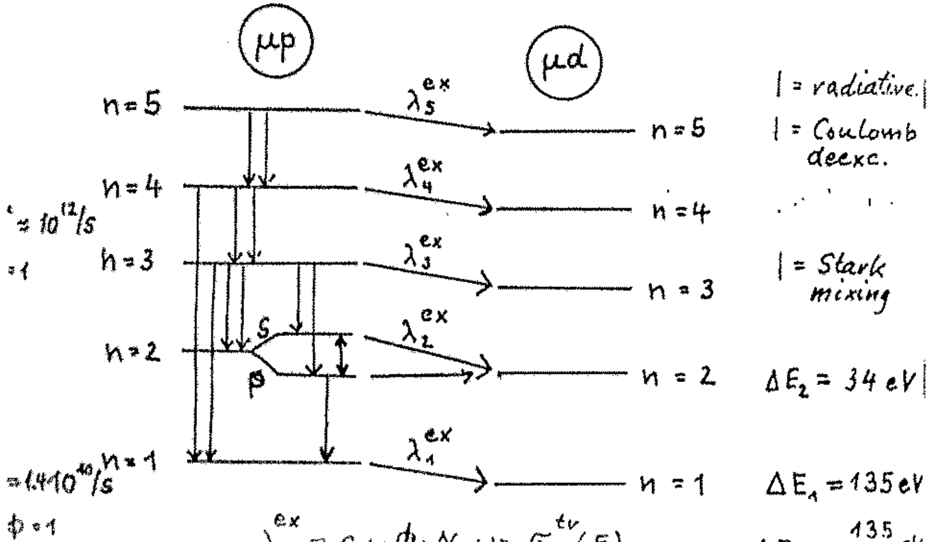
Raten für $\phi_0 = 4.25 \cdot 10^{22}$ Atome/cm^3.

Muon transfer during the muonic cascade (the q_{1s} problem)

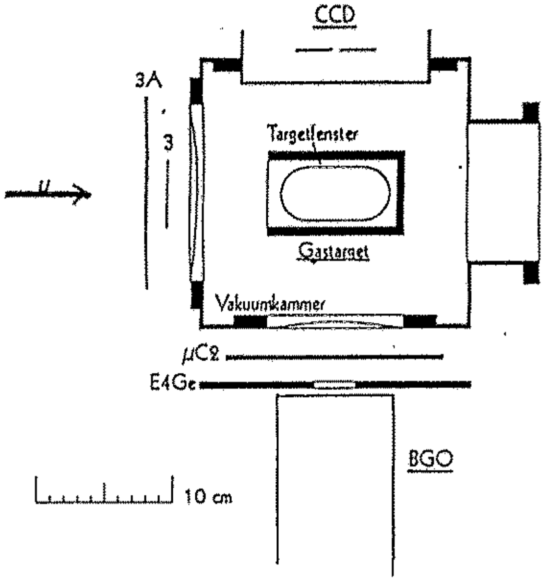


$$q_{1s} = q_{1s}(\phi, c_d, \varepsilon_{p\mu})$$

q_{1s} small ⇔ transfer fast (dt!)

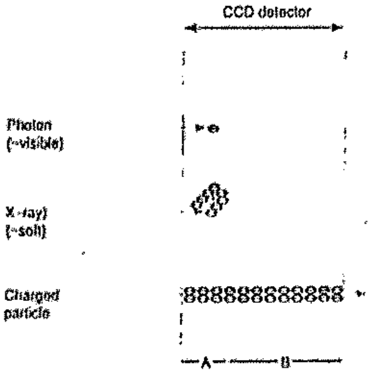


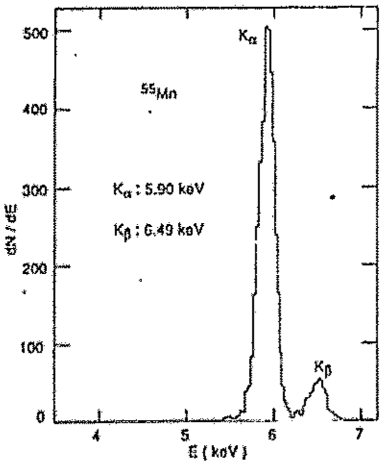
$$\lambda_n^{ex} = c_d \cdot \phi \cdot N_0 \cdot v \cdot \sigma_{1s}^{tr}(E) \qquad \Delta E_n = \frac{135}{n^2}\text{ eV}$$



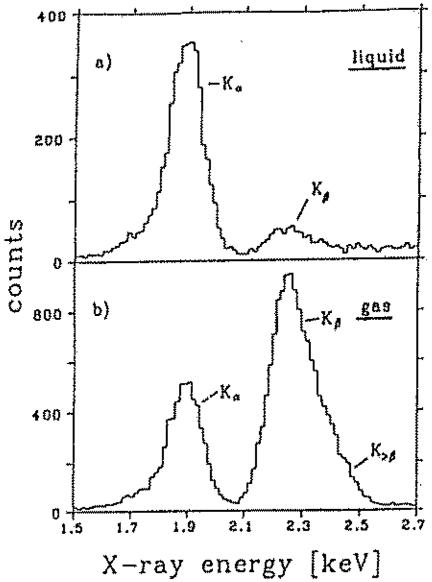
Der CCD-Detektor

- **2** mal [770 × 1152 Pixel (je 22 μ × 22 μ)]
- ΔE(FWHM) = 150 eV bei 2 keV
- Auslesezeit ca. 50 μs pro Pixel



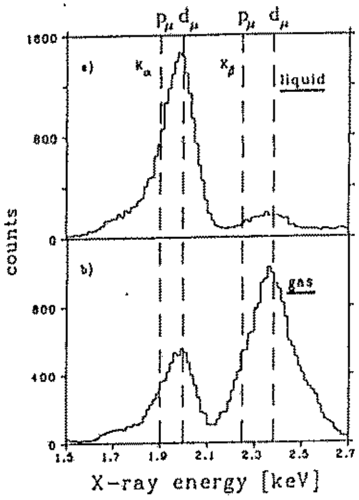


H₂ pur

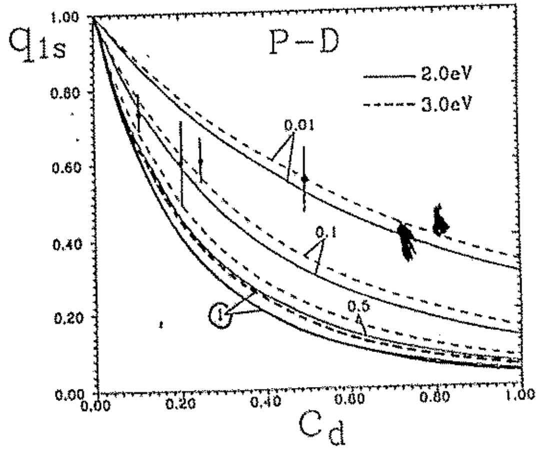


ΔE (fwhm) = 140 eV @ 1.9 keV.

Protium 50%
Deuterium 50%



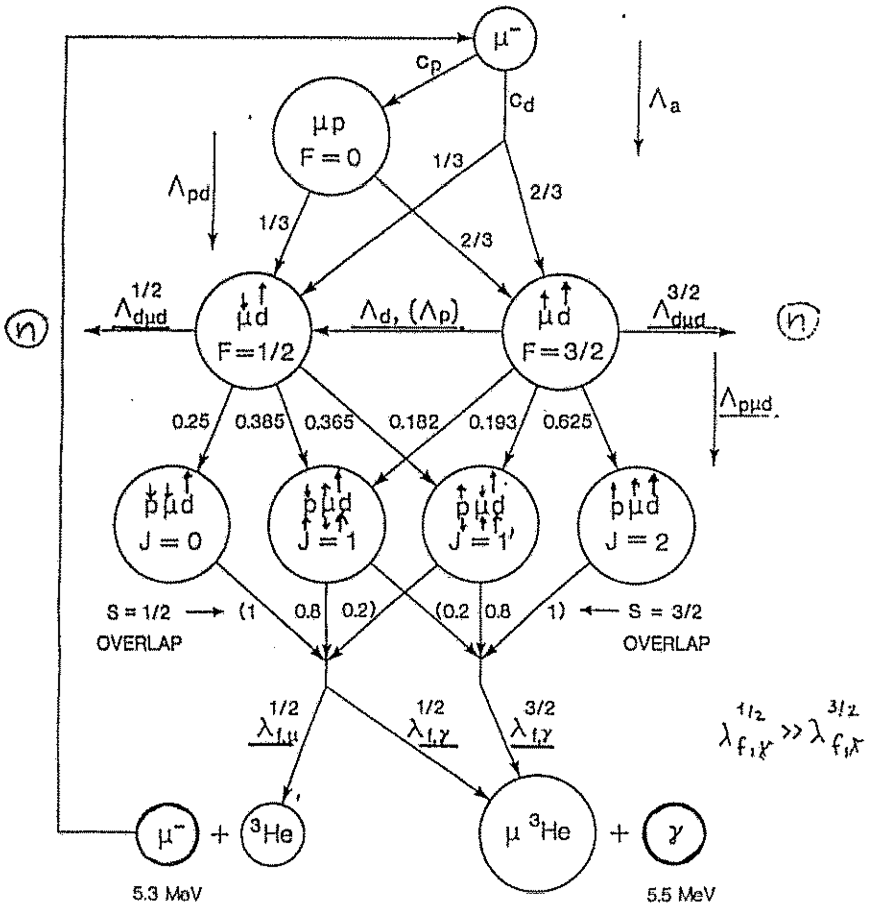
liquide

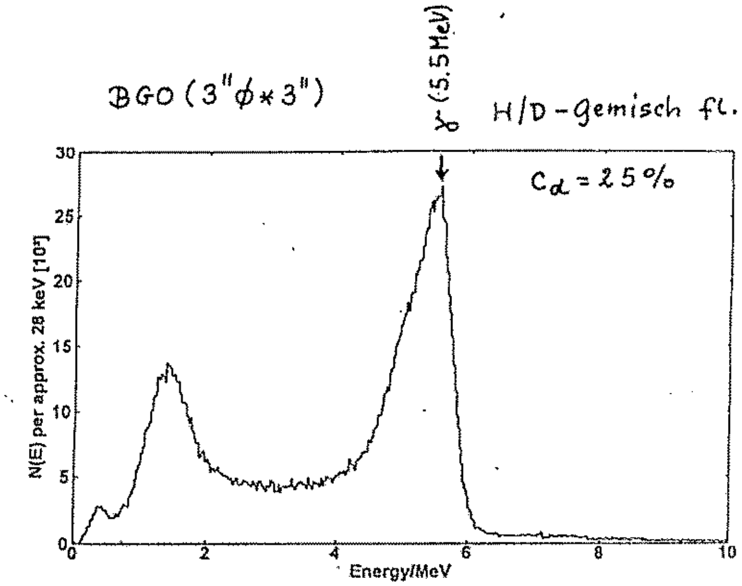


Theorie:
Czapliński et
PRA 50, 525
(1994)

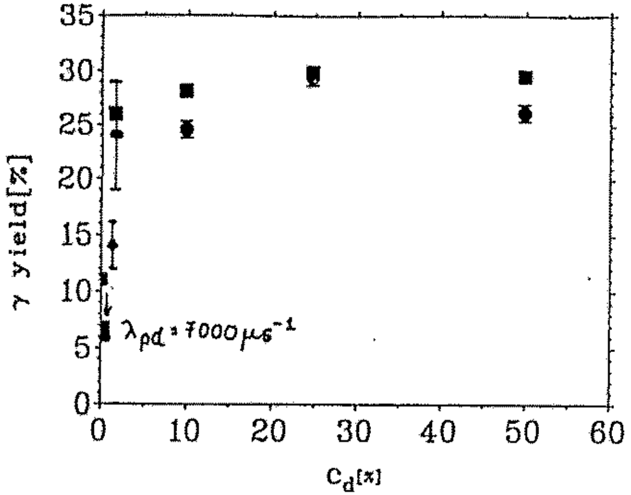
μCF kinetics in H/D mixtures

Wolfenstein-
Gerhtein-
Effekt





Liquid H/D mixtures



- ● Kosak et al., diese Messung
- ◊ I Bleser et al. (1963)
- ♦ Petitjean et al. (1990)
- ■ Rechnungen, $\lambda_{pd} = 14300 \mu s^{-1}$

$\lambda_{d\mu}(3/2 \rightarrow 1/2) = 37 \mu s^{-1}$

$\lambda^{1/2}_{f,\gamma} = 0.35 \mu s^{-1}$

$\lambda^{3/2}_{f,\gamma} = 0.11 \mu s^{-1}$

$\lambda^{1/2}_{f,\mu} = 0.06 \mu s^{-1}$

"Sticking" bei dt-Fusion

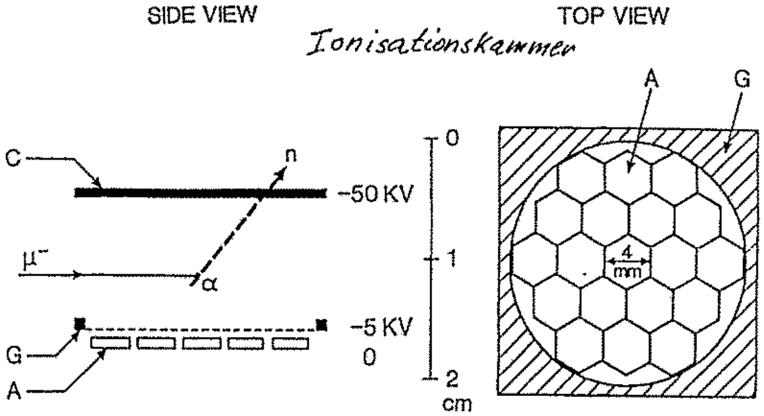


Figure 1(a)

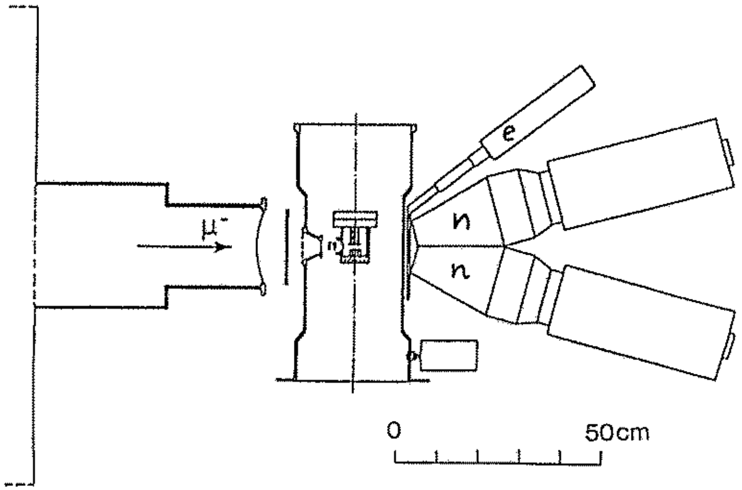
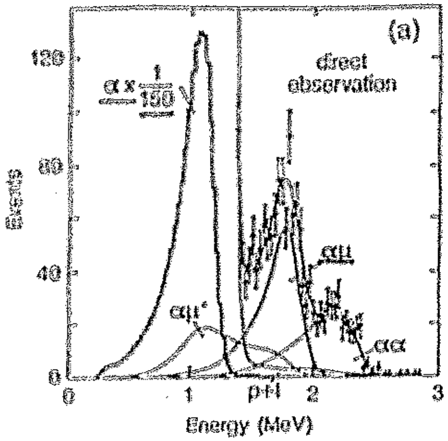


Figure 1(b)

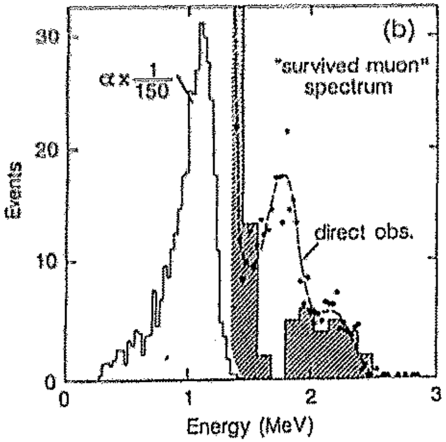


stat. syst.

$\omega_S = (0.57 \pm 0.03 \pm 0.03)\%$

$\mathcal{R} = 0.31$ (fixed)

$\omega_S^0 = (0.83 \pm 0.06)\ \%$



$\omega_S = (0.57 \pm 0.07 \pm 0.02)\%$

Stopping power

$$S = -dE/dx = \frac{4\pi e^4}{mv^2} Z z_1^2 \cdot (\mathrm{L}_0 + \mathrm{L}_1 z_1 + \mathrm{L}_2 z_1^2)$$

Bethe term L_0:

$$\underline{\mathrm{L}_0 = \ln(2mv^2/I) - \beta^2 - \mathrm{C}(v,Z)/Z}$$

with

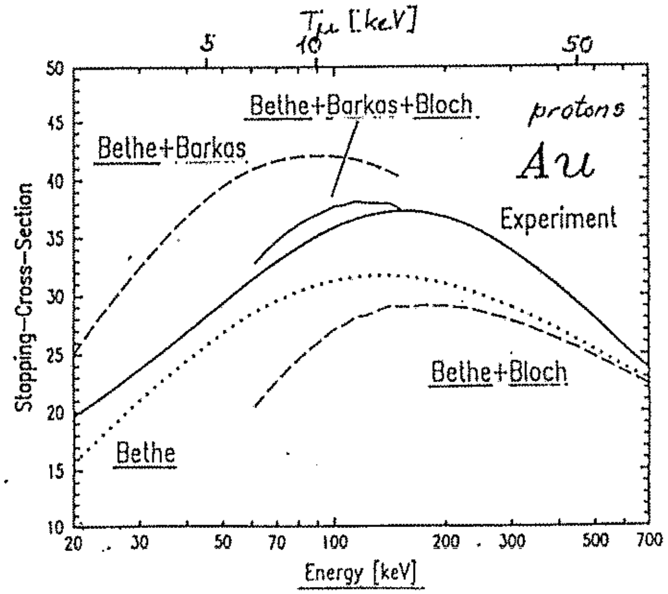
$$Z \cdot \ln I = \sum_k f_k \ln I_k.$$

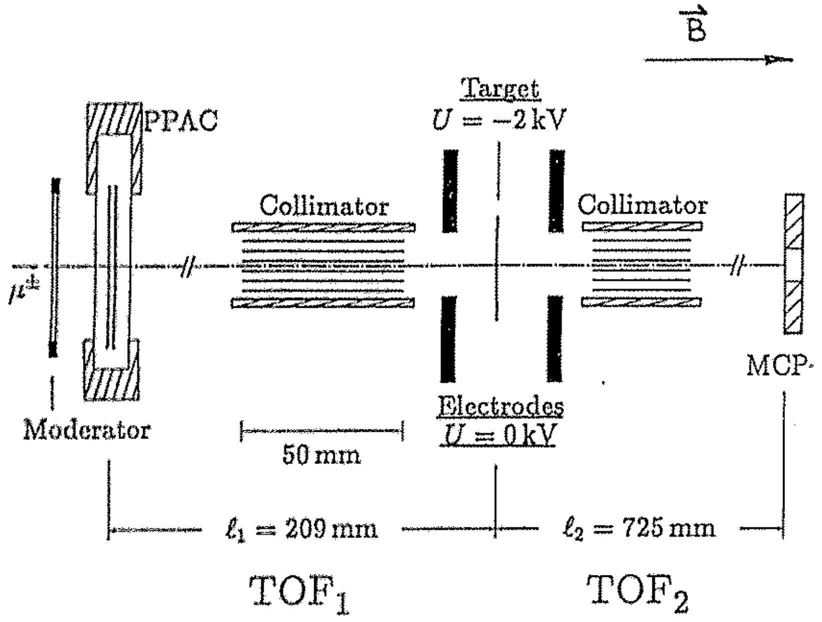
Barkas term L_1: Polarization of the electrons by the projectile.

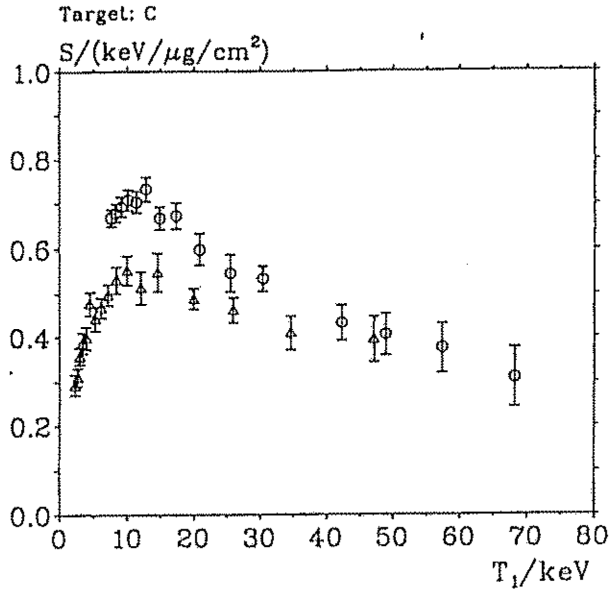
Bloch term L_2: Higher order terms in the polarization:

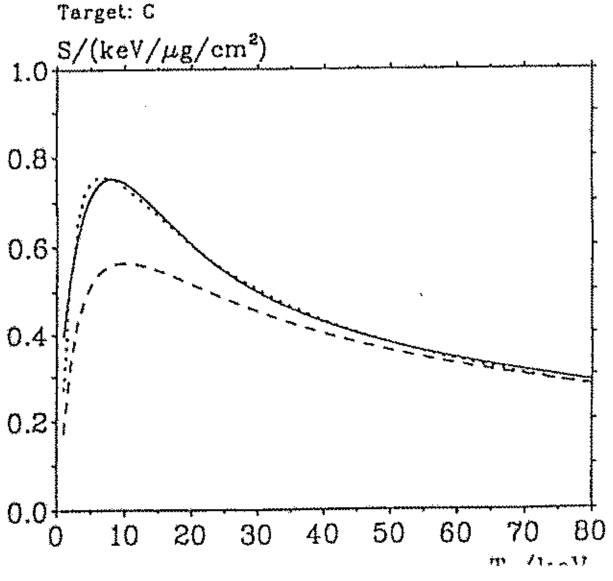
$$\underline{\mathrm{L}_2 = \psi(1) - \Re[\psi(1 + i \cdot z_1 v/v_0)] = -1.2...1.6 \cdot (v_0/v)^2}$$

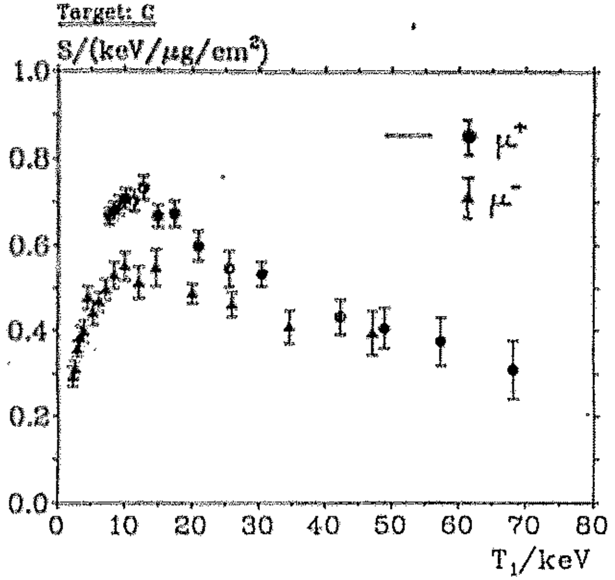
with $\Re$ = real part, $\psi = d\ln(\Gamma)/dx$ = Digamma function

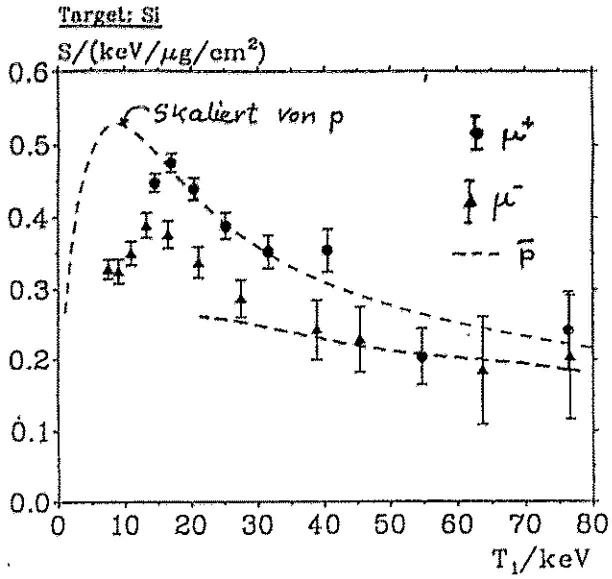



B
Target
U = −2 kV
PPAC
Collimator
Collimator
$\mu^{\pm}$
MCP
Moderator
50 mm
Electrodes
U = 0 kV
ℓ_1 = 209 mm
ℓ_2 = 725 mm
TOF₁
TOF₂

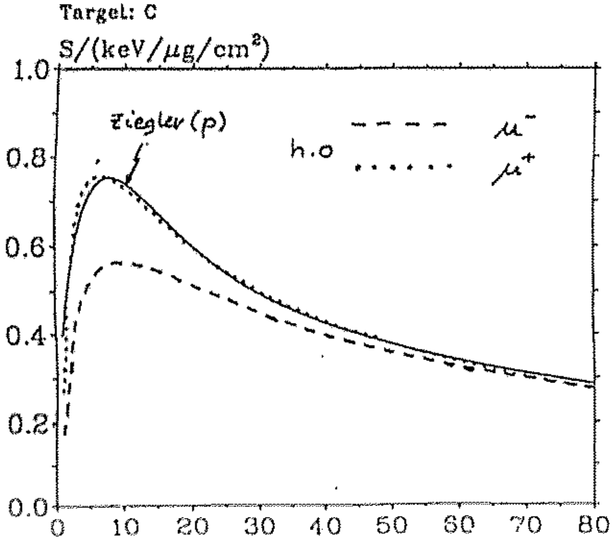

Target: C
S/(keV/μg/cm²)
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
T₁/keV


Target: C
S/(keV/μg/cm²)
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80

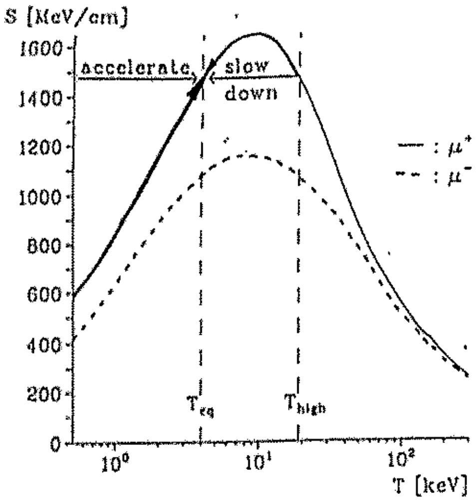




$\bar{p}$: *Medenwaldt et al., LEAR*



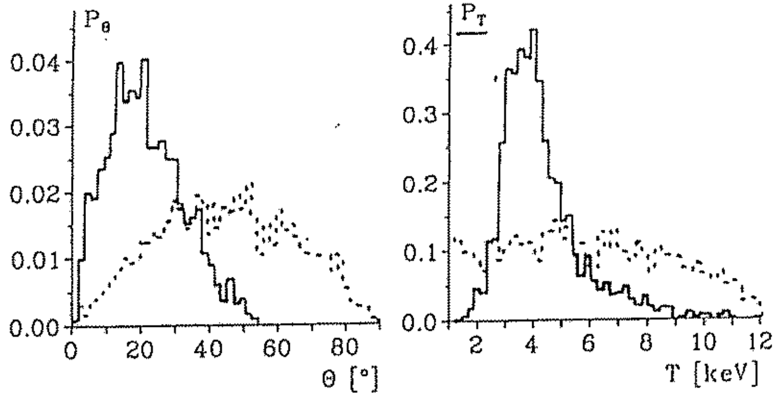
Principle of frictional cooling



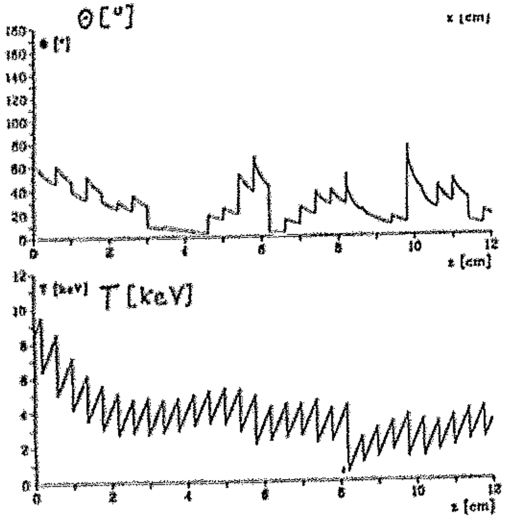
Average stopping power $S(T)$ of carbon for μ^+ and μ^-.

$$S = -\frac{dT}{ds}$$

$$S(T_{eq}) = q \cdot E$$



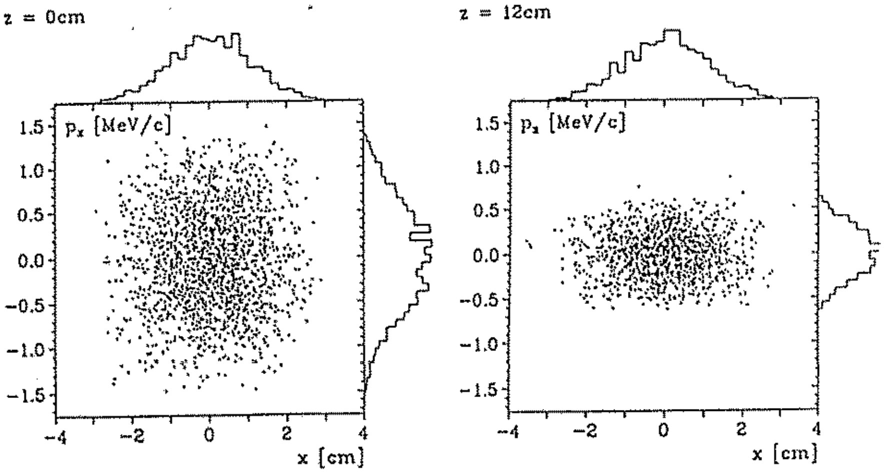
Angular and energy distribution P_Θ and P_T, respectively, of incoming (- - -) and outgoing (—) muons; carbon moderator; $T_{eq} = 4$ keV; angular distribution of the incident muons according to Lambert's law.



- Transverse energy dissipated
- $S(T \gtrsim T_{eq}) \gtrsim |qE|$

$\rho d_{foil} = 5\,\mu g/cm^2$

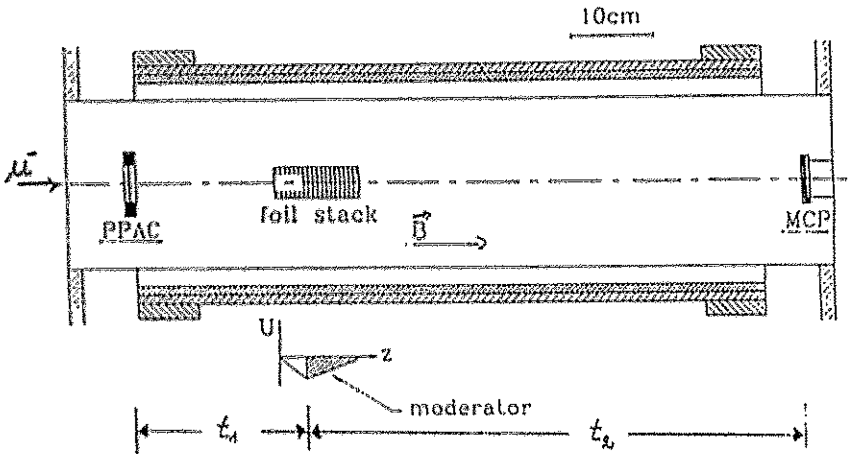
$U/\ell = 2.2\,kV/0.4\,cm$



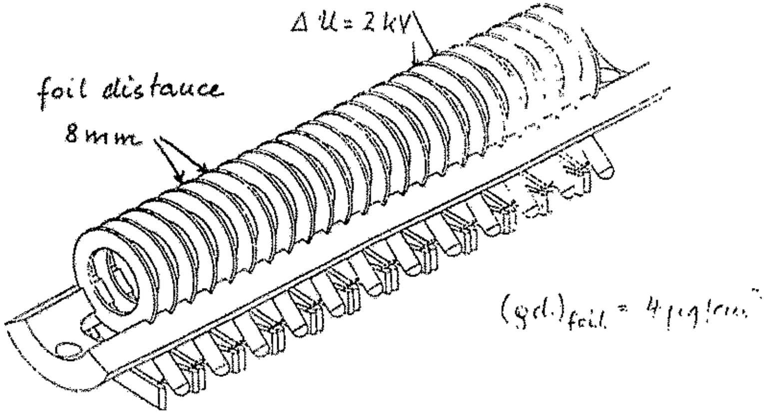
Phase space diagram (plane (x, P_x))) of incoming (left) and outgoing (right) muons; carbon moderator; $T_{eq} = 4$ keV; angular distribution of the incident muons according to Lambert's law.

Increase phase-space density by a factor of 6/2.5

Experimental setup

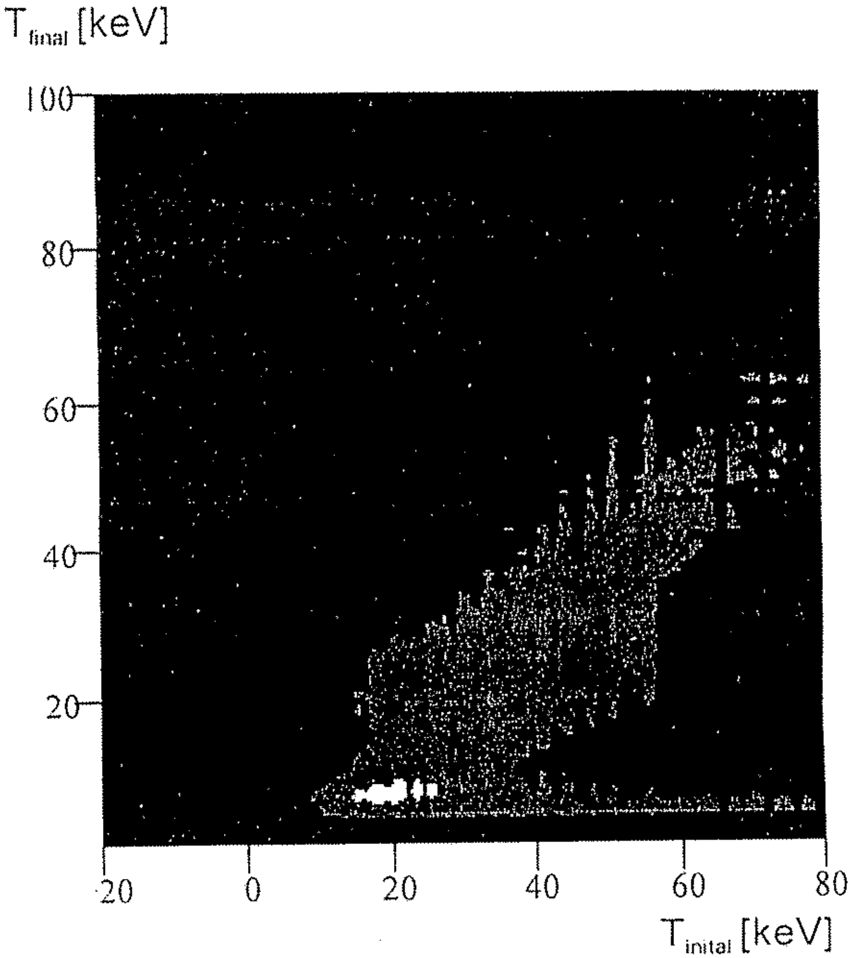


Experimental setup for the frictional cooling experiment.

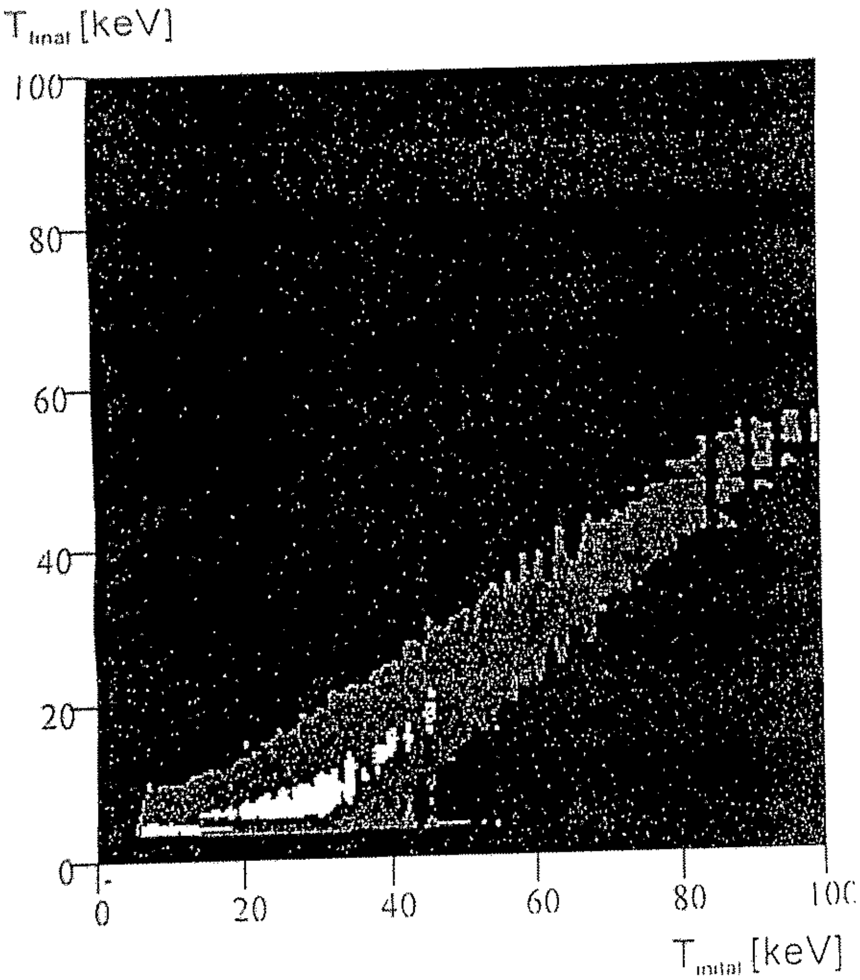


Isometric view of the foil arrangement to be used.

Experiment summer 94



With Cooling (10 Foils, ΔU=2kV)

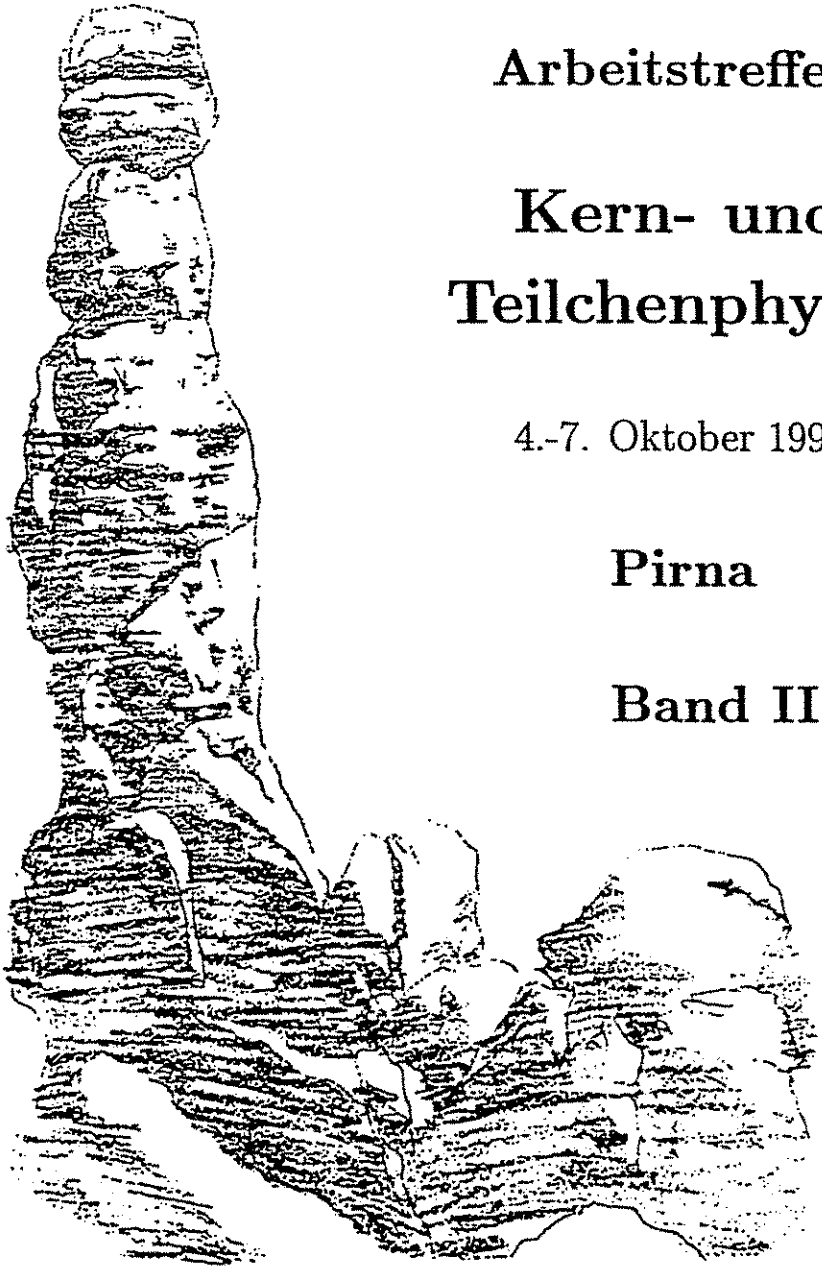


Without Cooling

FORSCHUNGSZENTRUM
ROSSENDORF e.V.

FZR

FZR-63
November 1994



" Barbarine " - Elbsandsteingebirge

Arbeitstreffen

Kern- und Teilchenphysik

4.-7. Oktober 1994

Pirna

Band II

Forschungszentrum Rossendorf e.V.
Postfach 51 01 19 · D-01314 Dresden
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Programm des Arbeitstreffens "Kern- und Teilchenphysik 1994" in Pirna

Band I Dienstag, 4. Oktober 1994

Band II Mittwoch, 5. Oktober 1994

Band III Donnerstag, 6. Oktober 1994

Band IV Freitag, 7. Oktober 1994

Recent Results of the Collaboration A1

E. Offermann
Mainz

5.Oktober 1994

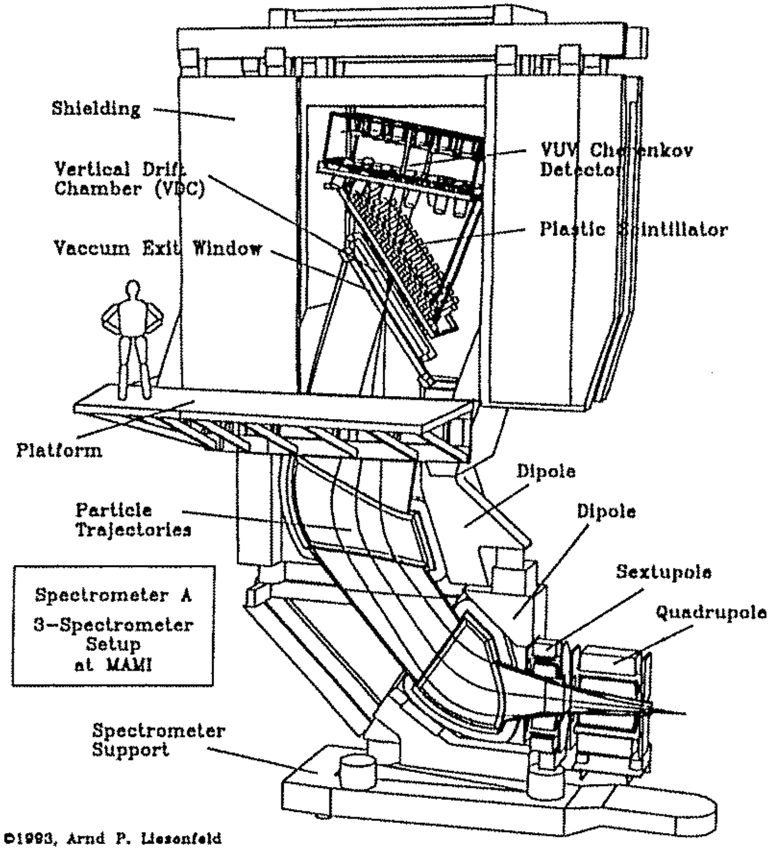
Recent Results of the Collaboration A1

Eddy Offermann

Institut für Kernphysik, Mainz

- Experimental Set up
- Overview of Physics Topics
- $^{16}O(e,e'p) \rightarrow$ NN correlations
- Summary and Outlook

Instrumentation



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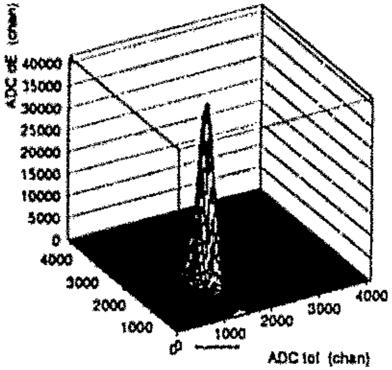
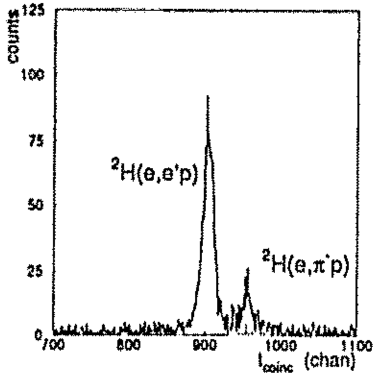
Particle Discrimination

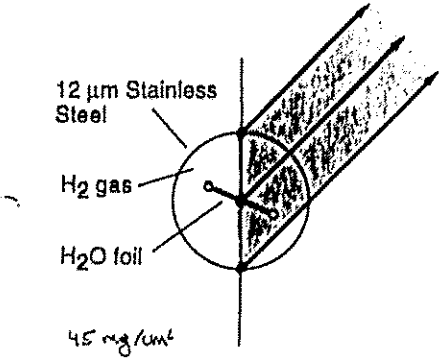


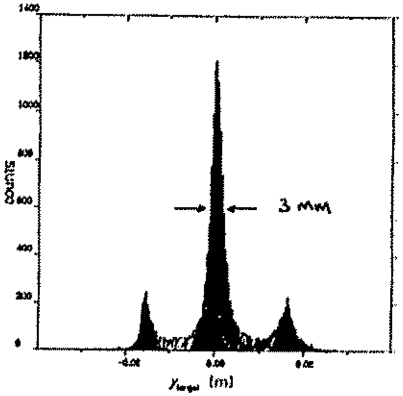
Plastic Scintillator



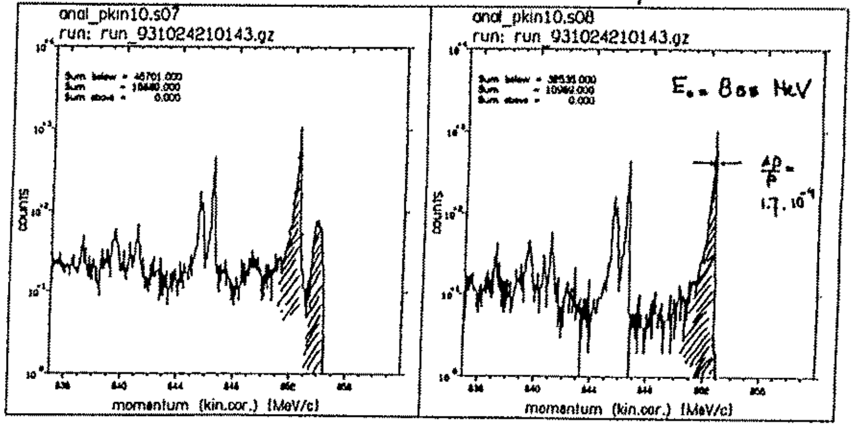
Čerenkov

Vertex / Time Resolution



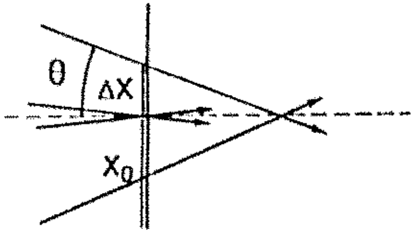


−0.075 < y < 0.075 m



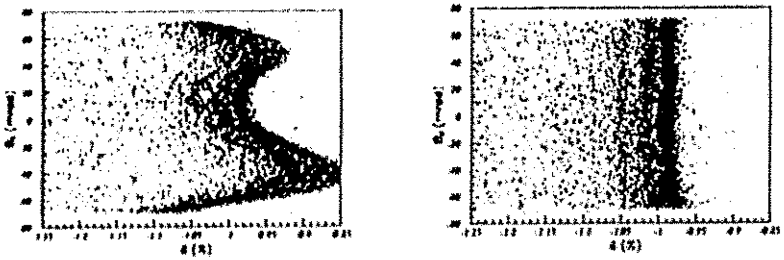
Spectrometer aberration corrections

Spherical aberrations



$$p = f(x_0)$$
$$x = x_0 + \Delta x$$
$$\Delta x = \langle x \mid \theta \rangle \tan(\theta)$$

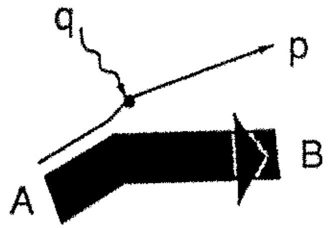
focal plane



Experimental Program Collaboration A1

Topics	Reaction	Physics
Few-Body Systems	^{2}H(e,e'p)	high-momentum components long./transv. separation ⇒ non-nucleonic degrees of freedom
	^{3}He,^{4}He(e,e'p)	high-momentum components
Nucleon Form Factors	^{2}H(e,e'p)	measurement of $G_{M,n}$
	^{1}H(e,e'π^+)	structure functions R_L, R_T, R_{LT} ⇒ different form factors tune-up for pion detection
	^{1}H(e,e'π^0)	test of Chiral Perturbation Theory
	^{1}H($\vec{e}$,e'$\vec{p}$)π^0	C2/M1, E2/M1 in p→Δ excitation ⇒ deformation of the nucleon
Δ-physics	^{12}C(e,e'x_1x_2)	multi-hadron final states Δ-propagation
	^{3}He(e,e'$\pi^\pm$)	$\frac{\sigma_{tot}(\pi^+)}{\sigma_{tot}(\pi^-)}$ in long. channel ⇒ Δ content in nucleus
NN correlations	A(e,e'p) A=^{12}C, ^{16}O	high-momentum components separation of structure functions
	A(e,e'$\vec{p}$) A=^{16}O, ^{40}Ca	optical-model test

A(e,e'p)B



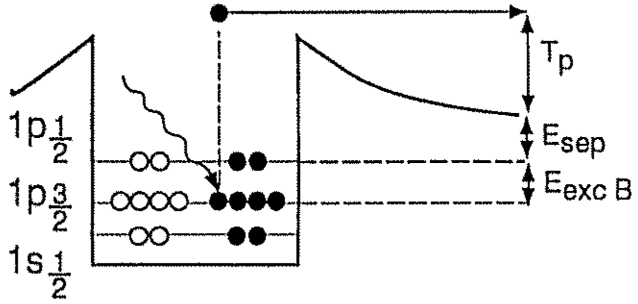
PWIA

$\vec{p}_m = \vec{q} - \vec{p}$

$E_m = \omega - T_p - T_B$

$\vec{p}_m = \vec{p}_B = -\vec{p}_i$

$E_m = E_{sep} + E_{exc\,B}$



Spectral function:

$$\frac{d^6\sigma}{d\Omega_e\, d\omega\, d\Omega_p\, dT_p} = K \left.\frac{d\sigma}{d\Omega}\right|_{ep} S(E_m, p_m)$$

Amplitude ~$j_\mu A^\mu$

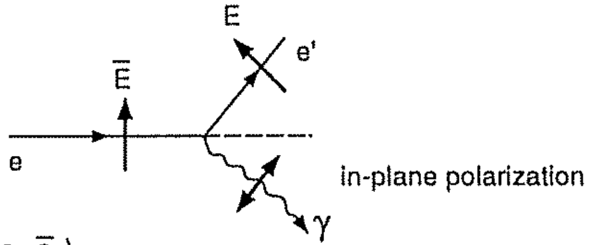
$\rho \cdot \phi$ Coulomb

$\frac{e}{m}\,\bar{p}\cdot\bar{A}$ Convection

$\frac{\mu}{2m}\,\bar{\sigma}\cdot(\bar{q}\times\bar{A})$ Spin

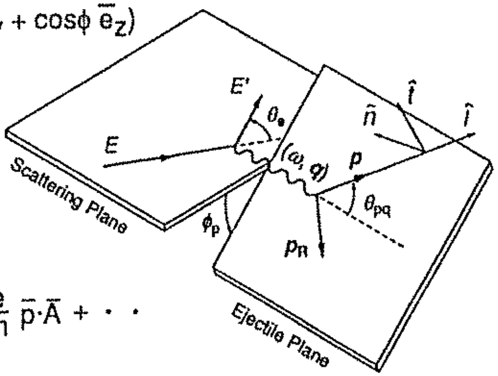
Current

Linear polarization



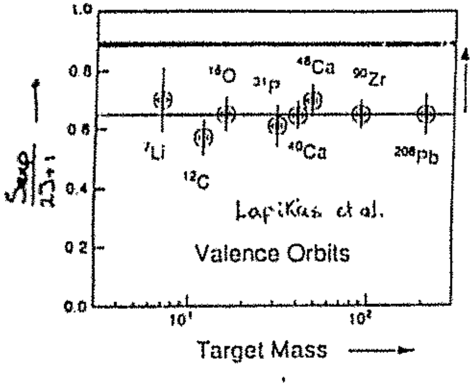
$\bar{A} \sim (a_x\,\bar{e}_x + a_z\,\bar{e}_z)$

$\bar{p} = p_0(\sin\theta\cos\phi\,\bar{e}_x +$
$\sin\theta\cos\phi\,\bar{e}_y + \cos\phi\,\bar{e}_z)$

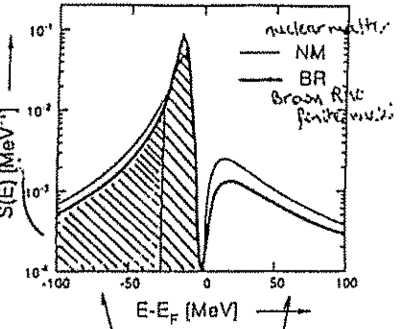


Amplitude ~ $\cdot\ \cdot + \frac{e}{m}\,\bar{p}\cdot\bar{A} + \cdot\ \cdot$

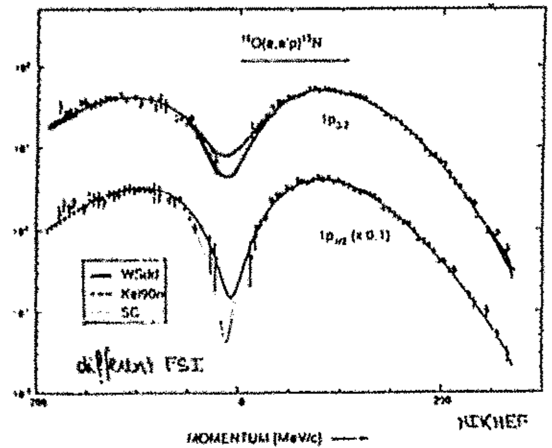
(e,e'p) results

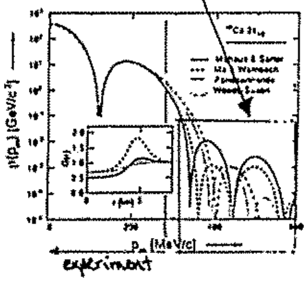


$$S_{exp} = \int_{E_{peak}-2\Gamma}^{E_F} S(E)\,dE$$



short-range and tensor correlations





$x_1 \cdot Y_1$, E_x, 6.32 MeV

S_{α} {WSdd 1.98±(16) ; Kelgon 2.348(19)}

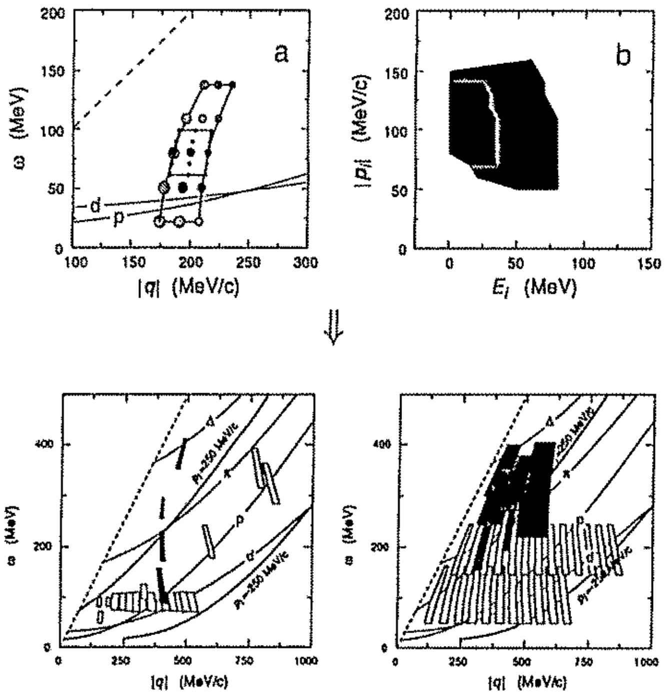
$\Delta S_{\alpha} \approx 20\%$

Experimental Improvements

1 Duty Factor 1% $\Longrightarrow$ 100%

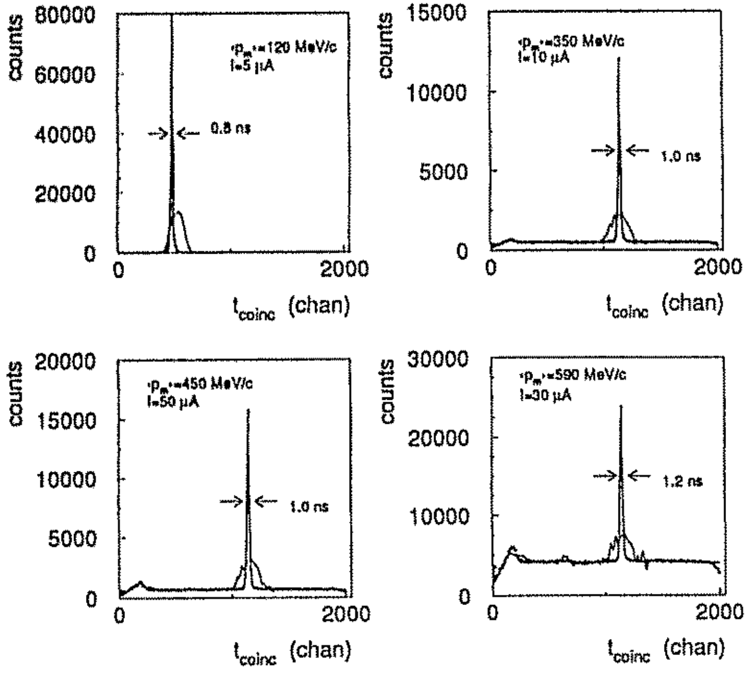
2 Phase Space Coverage

NIKHEF - MAMI ^{12}C(e,e'p)



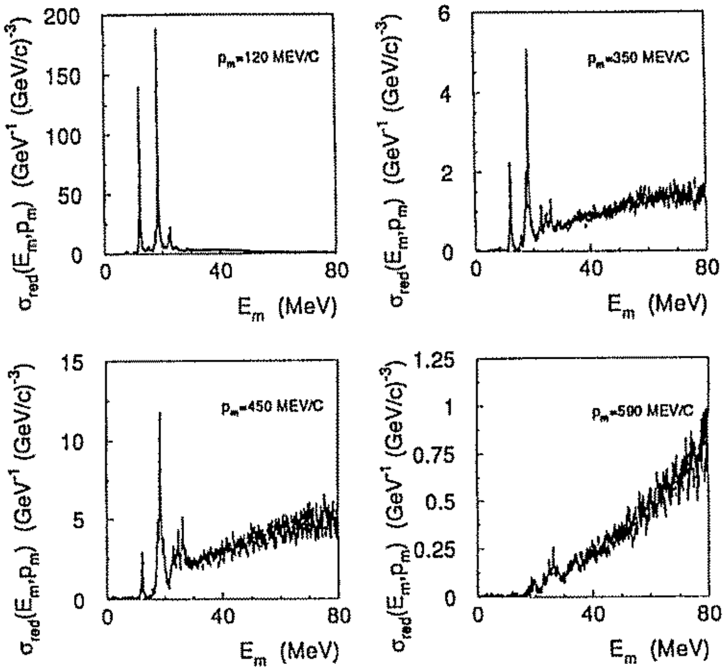
coincidence time

d_{H2O}=40 mg/cm^2

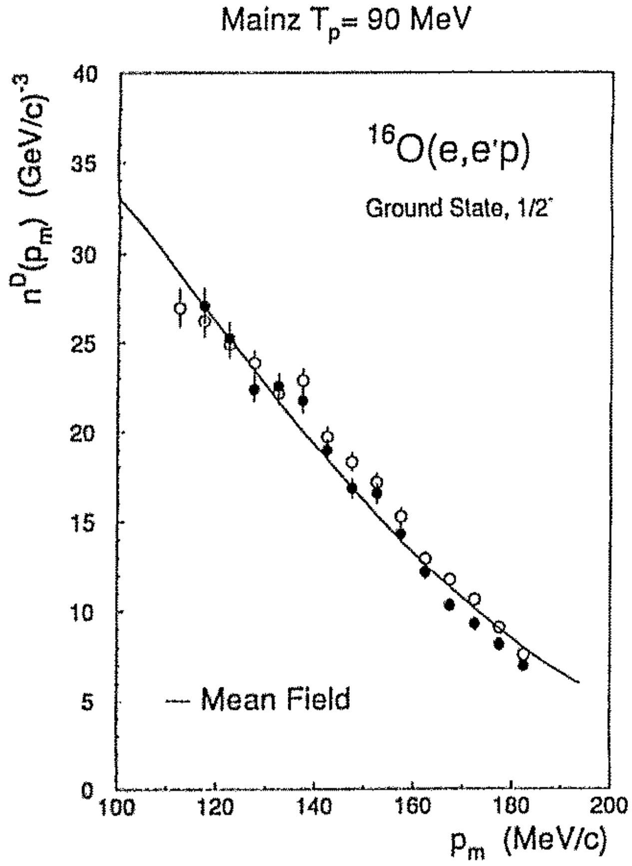


^{16}O(e,e'p)

NO radiative corrections applied



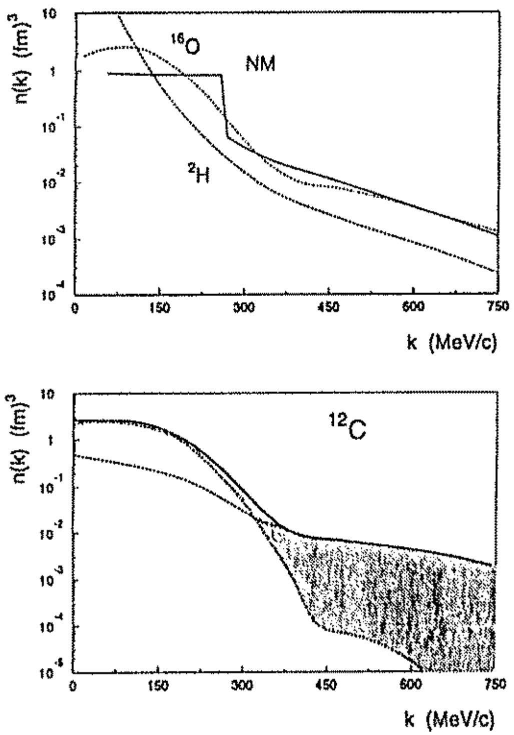
Normalization



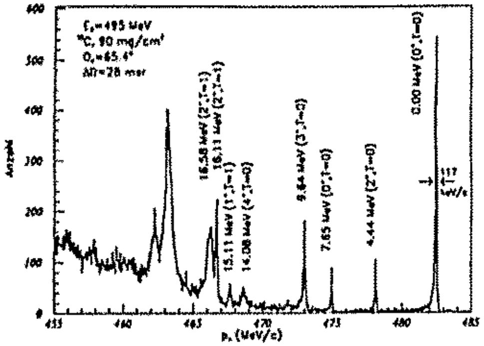
Spectr. Factor	NIKHEF	Mainz	
g.s. $\frac{1}{2}^-$	1.124(61)	1.165(10)	1.107(10)

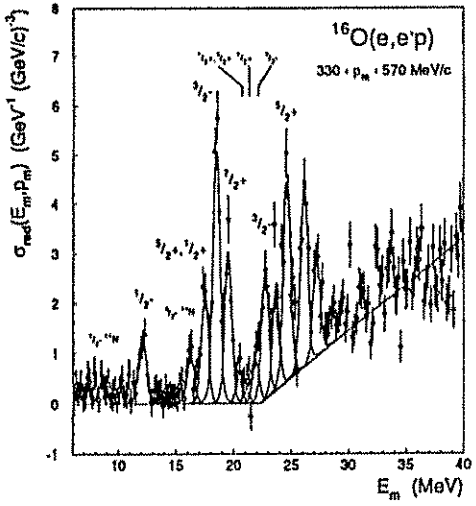
Predictions of Momentum Distributions

$$\begin{aligned} n(\vec{k}) &= \int_0^\infty d\epsilon S(\vec{k},\epsilon) \\ &= \int_0^\infty d\epsilon \left[\Sigma_\alpha n_\alpha(\vec{k})\delta(\epsilon-\epsilon_\alpha) + n_c(\vec{k}) f(\epsilon)\right] \end{aligned}$$

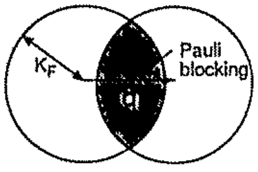


Benhar et al.

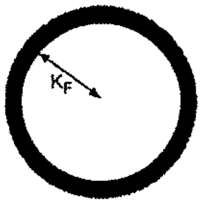




Fermi Model

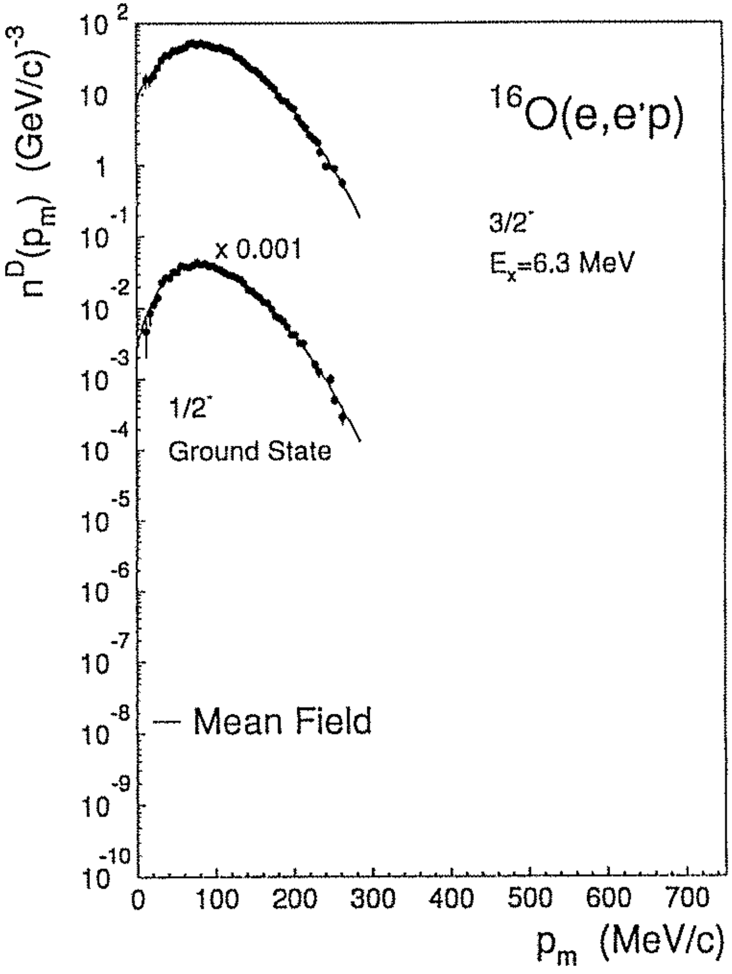


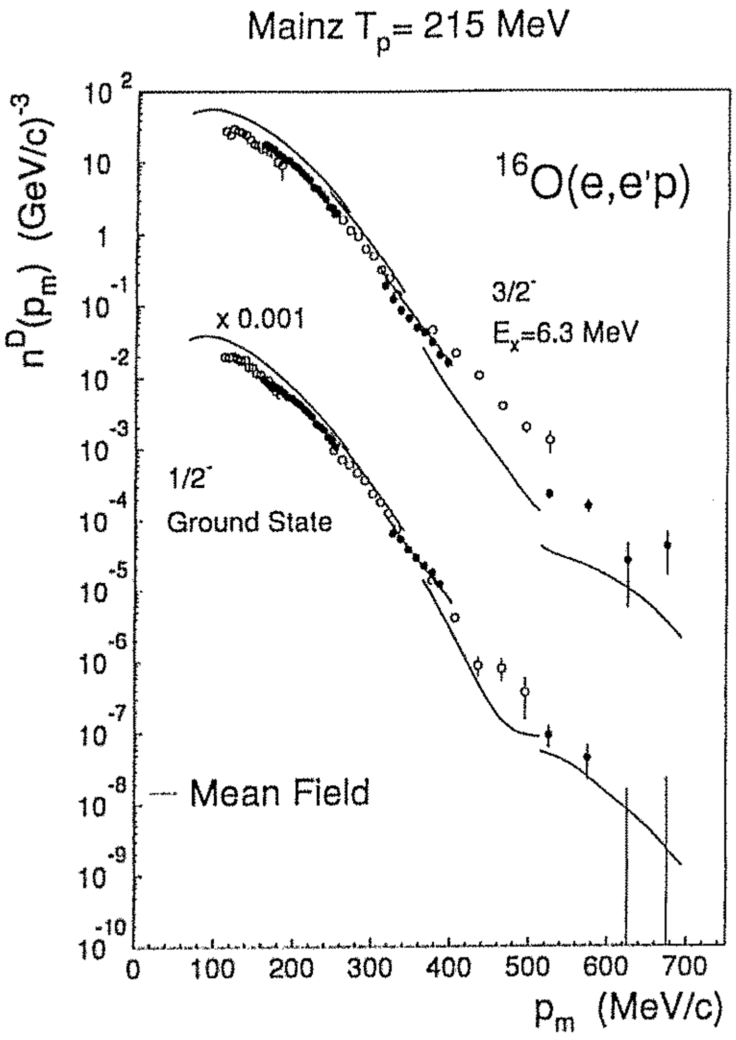
q > $2K_F$ $\sigma_{elastic}$ = 0

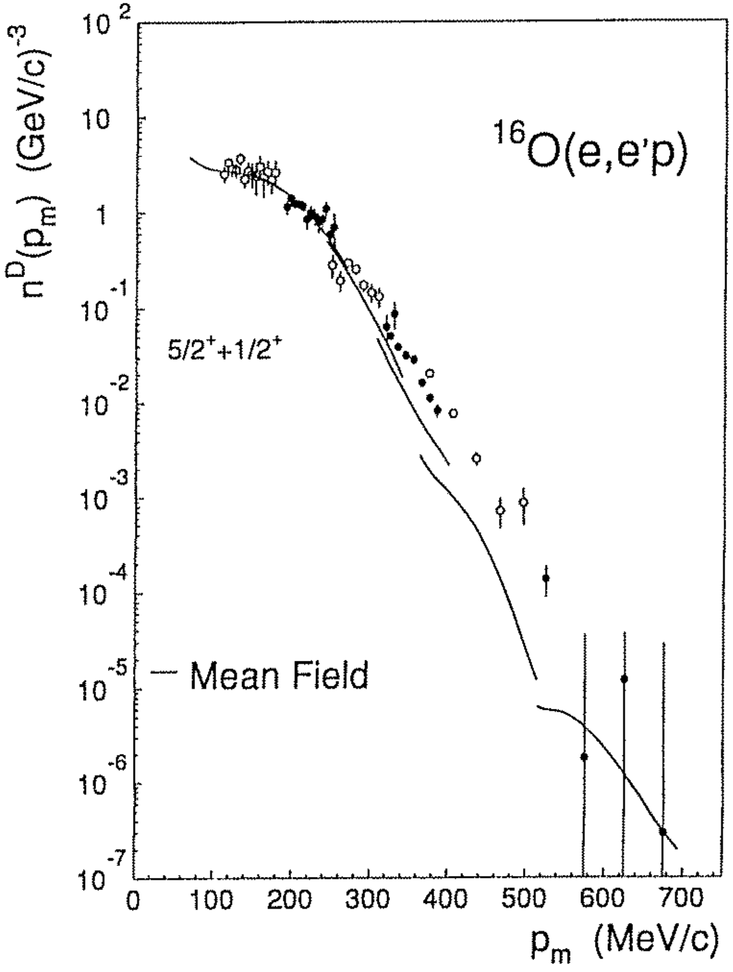


p_m > K_F $\sigma_{ee'p}$ = 0

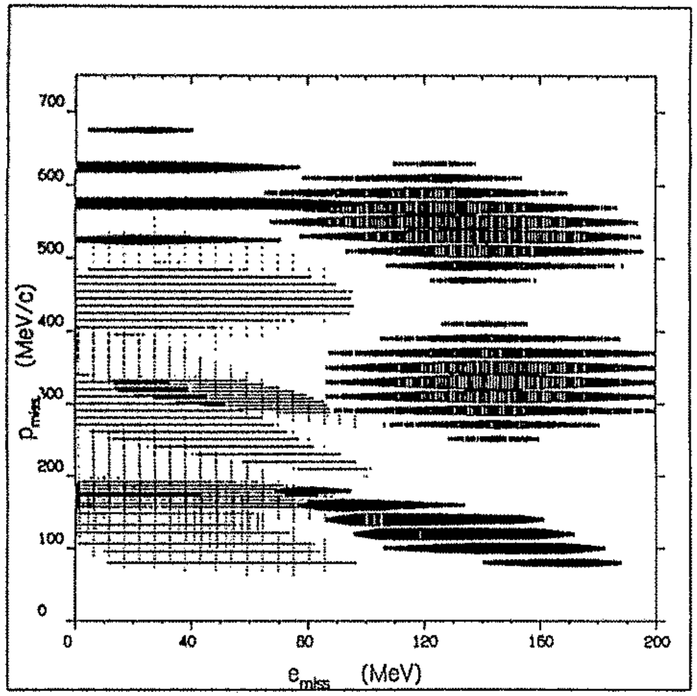
NIKHEF T_p = 90 MeV

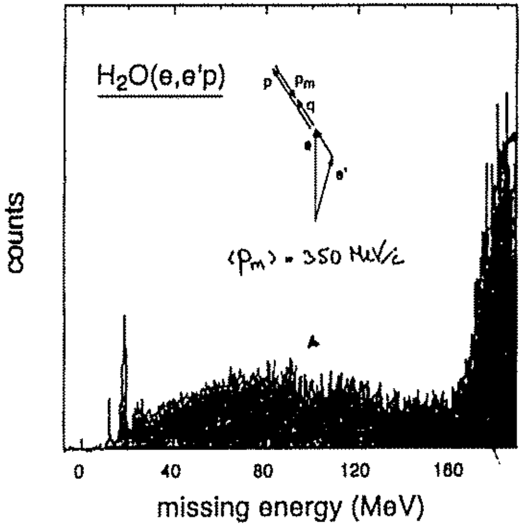



Mainz T_p= 215 MeV
^{16}O(e,e'p)
$n^D(p_m)$ (GeV/c)$^{-3}$
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
3/2$^-$
E_x=6.3 MeV
x 0.001
1/2$^-$
Ground State
— Mean Field
0
100
200
300
400
500
600
700
p_m (MeV/c)


^{16}O(e,e'p)
$n^D(p_m)$ (GeV/c)$^{-3}$
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
5/2$^+$+1/2$^+$
— Mean Field
0
100
200
300
400
500
600
700
p_m (MeV/c)

Phase Space 16O(e,e'p) covered in Mainz



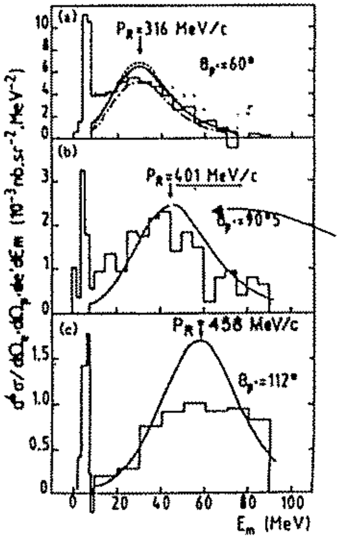


- H(e,e'p)π°

A=16

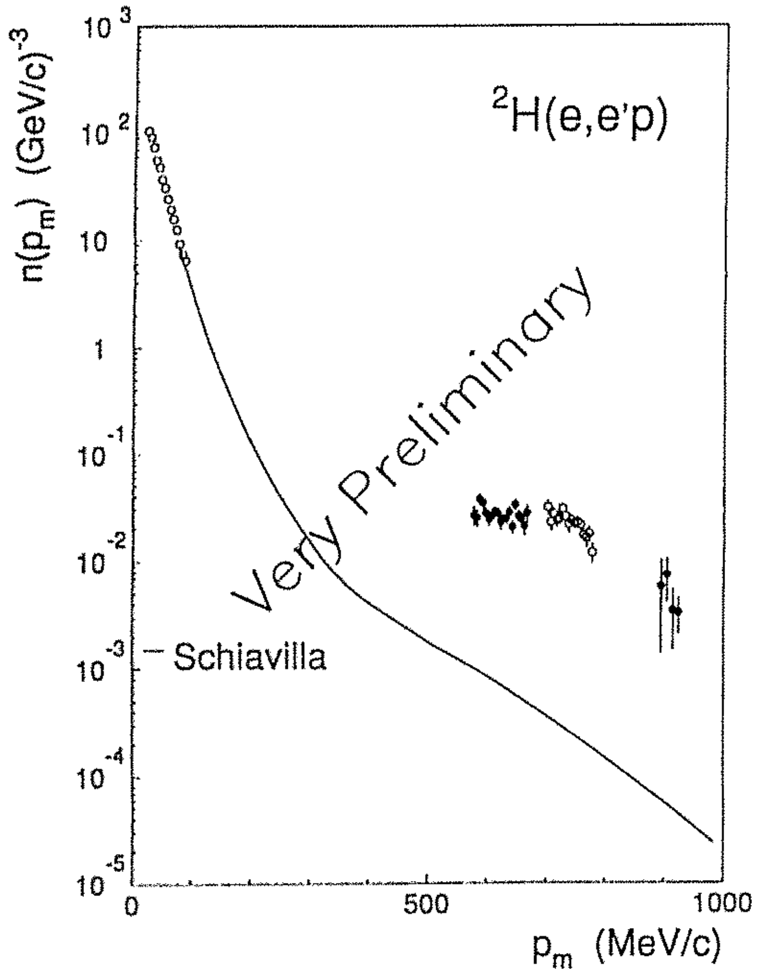
$^3He(e,e'p)$

(Marchand et al.)



$$E_m = E_r^{pN} + \frac{(A-2)}{2(A-1)}\,\frac{P_m^2}{M_N}$$

A=2



Summary & Outlook

- Two-Spectrometer Set up fully operational

spec	$\Delta p/p$ (%)	$\delta p/p$ (%)	$\Delta\theta_{tg}$ (mrad)	$\delta\theta_{tg}$ (mrad)	δy_{tg} (mm)	$\Delta\phi_{tg}$ (mrad)	$\delta\phi_{tg}$ (mrad)
A	-5/+15	0.02	±70	2.0	6.0	±100	2.0
B	±7.5	0.01	±70	2.3	2.0	±20	2.6

- Momentum distributions measured over **7** (!) orders of magn., ^{16}O: $|p_m| < 700$ MeV/c, ^{2}H: $|p_m| < 1$ GeV/c
- Feasibility demonstrated for π-detection

- End of this year first TRIPLE-coincidence measurements (e,e'pp), (e,e'pπ$^-$)
- Spring 1996 spin degrees of freedom: ($\vec{e}$,e'$\vec{p}$)

Experimente mit reellen Photonen

Erste Ergebnisse von den Experimenten am Mainzer Mikrotron (A2-Kollaboration)

R. Beck
Mainz

5.Oktober 1994

Experimente mit reellen Photonen

Erste Ergebnisse von den Experimenten am Mainzer Mikrotron

R. Beck für die

A2 - Kollaboration

Institut für Kernphysik, Mainz
INFN, Sezione di Pavia, Pavia
Department of Physics and Astronomy, University of Glasgow
Physikalisches Institut, Bonn
CEN Saclay, DAPNIA/SPN, Paris
Department of Physics, Edinburgh
INFN, Laborati di Frascati, Frascati
Institute for Nuclear Research, Moskau
INFN, Sezione di Genova, Genova
Institut für Kernphysik, Gießen
II. Physikalisches Institut, Gießen
Physikalisches Institut, Tübingen
II. Physikalisches Institut, Göttingen
Institut für Strahlungsphysik, Stuttgart

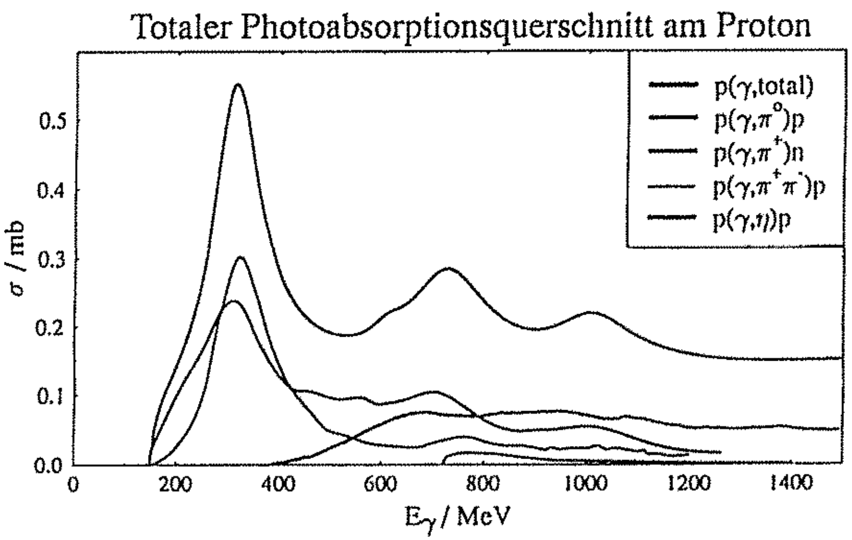
Übersicht:

1. Einführung und Motivation
2. Photonmarkierungsanlage
3. Compton Streuung
4. Totalabsorptionsquerschnitte
5. 2π - Produktion
6. E2/M1 - Verhältnis im N → Δ Übergang
7. Zusammenfassung und Ausblick

experimentelles Programm in A2

Untersuchung des freien und gebundenen Nukleons mit reellen Photonen

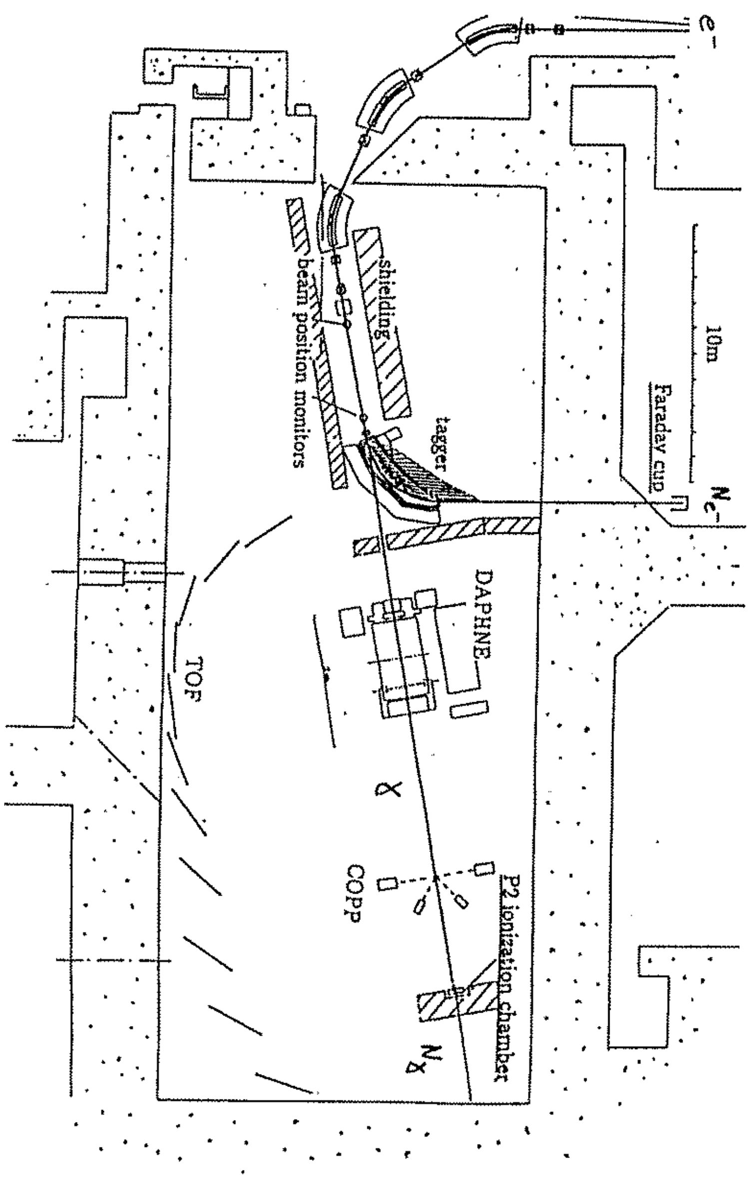
- Photonabsorptions Mechanismus
- Photoproduktion von π- und η- Mesonen
- Compton Streuung



㉑

A2 Mainz

MaMi: $E_0 = 855\,MeV$



Gruppen in A2

- Comptonstreuung

  $\gamma + p \rightarrow \gamma + p$

  $\gamma + k \rightarrow \gamma + k$

  Detektor : CATS ; COPP (Genua, Göttingen, Mainz, Moskau)

- Absorptionsquerschnitte , 2π - Produktion

  H, D, ^3He, ^4He

  $\gamma + p \rightarrow p + \pi^+ + \pi^-$

  $\gamma + p \rightarrow n + \pi^+ + \pi^0$

  $\gamma + p \rightarrow p + \pi^0 + \pi^0$

  Detektor: DAPHNE (Saclay, Pavia, Mainz)

- π- und η- Produktion

  $\gamma + p \rightarrow p + \pi^0$ $\quad$ $\gamma + k \rightarrow k + \pi^0$

  $\gamma + p \rightarrow p + \eta$ $\quad$ $\gamma + k \rightarrow k + \eta$

  Detektor: TAPS (Gießen, GSI, ...)

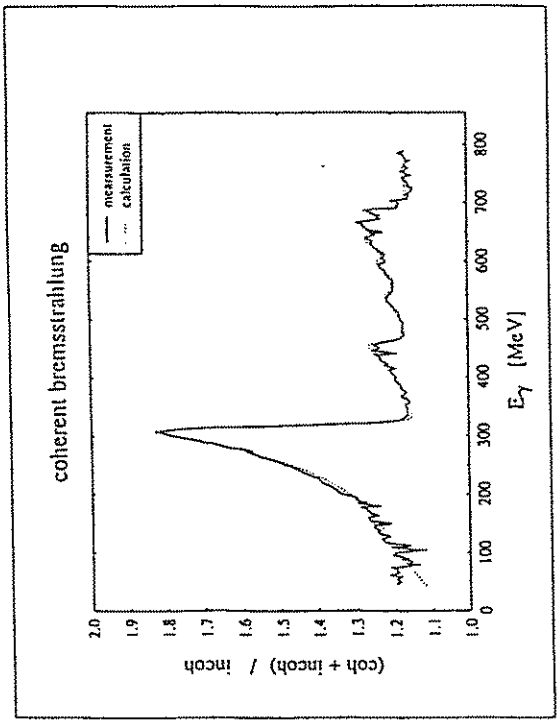
  H. Ströher Fr. 14:30

- γ,p- und γ,np - Reaktionen

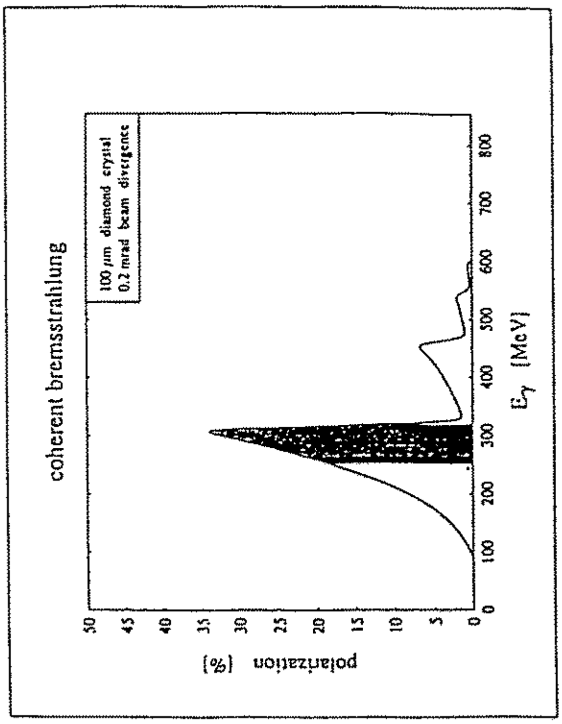
  Detektor: PiP-TOF (Edinburgh, Glasgow, Tübingen)

  P. Grabmayer Fr 14:30

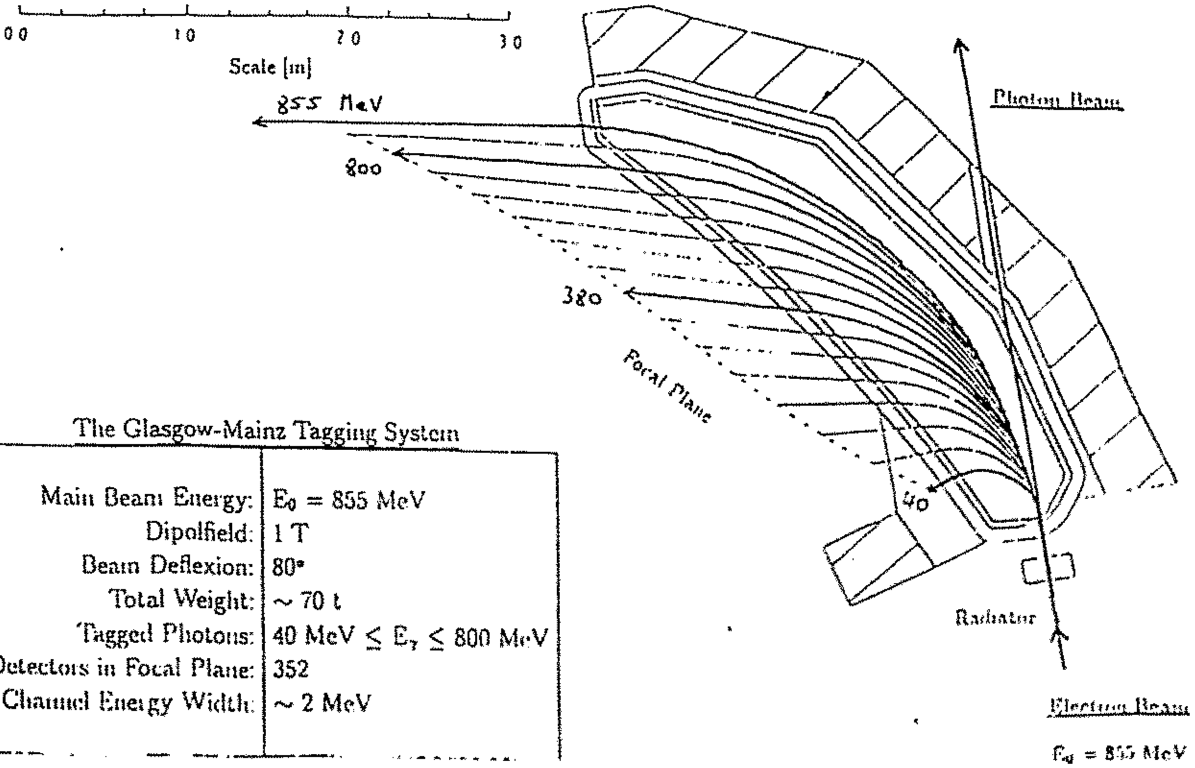
Linear polarisierte Photonen



Polarisation : $E_\gamma = 30-60\%$ $E_\gamma^t = 450 - 100$ MeV



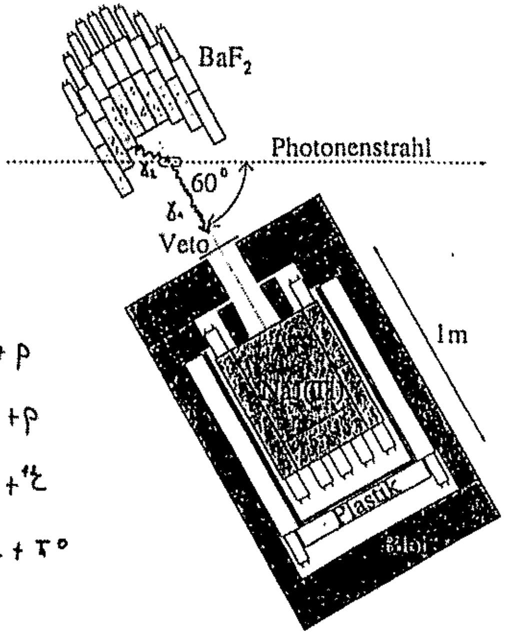
Glasgow - Mainz Tagger (Glasgow)



The Glasgow-Mainz Tagging System

Main Beam Energy:	$E_0 = 855$ MeV
Dipolfield:	1 T
Beam Deflexion:	80°
Total Weight:	~ 70 t
Tagged Photons:	40 MeV $\leq E_\gamma \leq$ 800 MeV
Detectors in Focal Plane:	352
Channel Energy Width:	~ 2 MeV

CATS (Mainz, Göttingen, Genua)



$\Delta E_\gamma = 1.5\%$

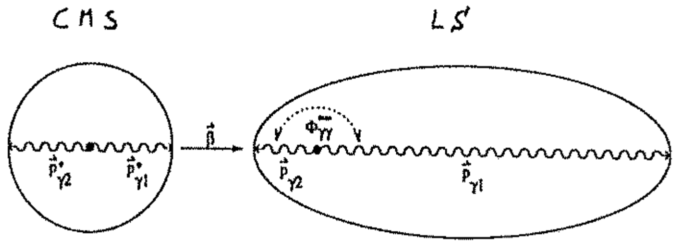
$\gamma + p \to \gamma + p$

$\gamma + p \to \pi^0 + p$

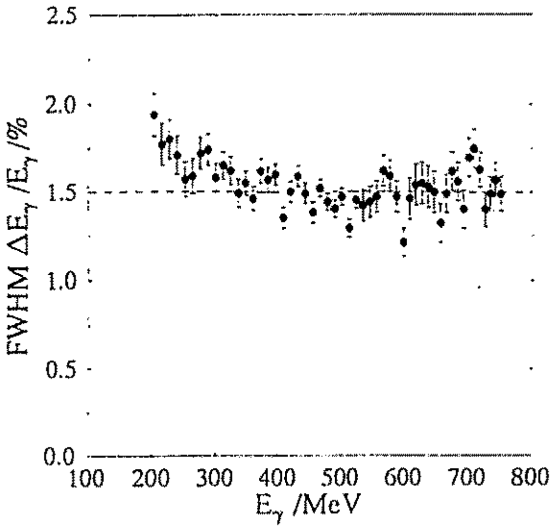
$\gamma + {}^{12}C \to \gamma + {}^{12}C$

$\gamma + {}^{12}C \to {}^{12}C + \pi^0$

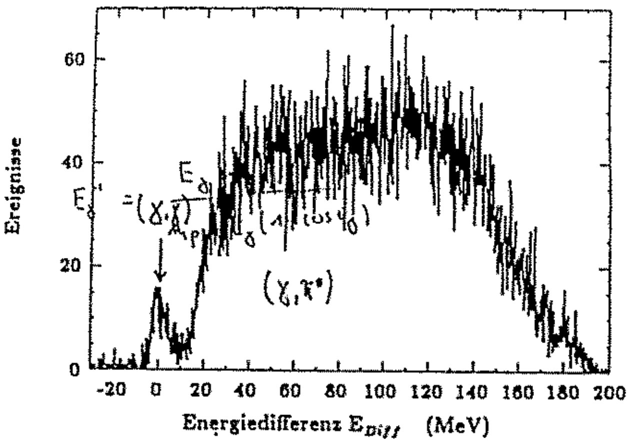
π^0- Zerfall



Energieauflösung



Energiedifferenz

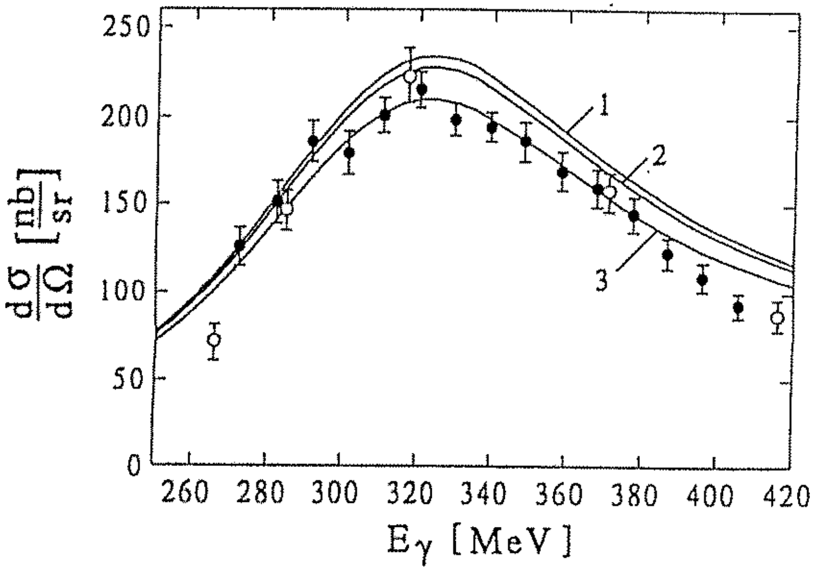


$E_\gamma^H - E_\gamma^{S'}$

$$E_\gamma^S = \frac{E_\gamma \, m_p}{m_p + E_\gamma (1 - \cos\vartheta_\gamma)}$$

A. Hünger
J. Peise 1994

$\gamma + p \rightarrow p + \gamma$ $\quad \Theta^{LS} = 60°$



Multipol Analyse Arndt et al.

1 : $E2/M1 = -1.4\,\%$

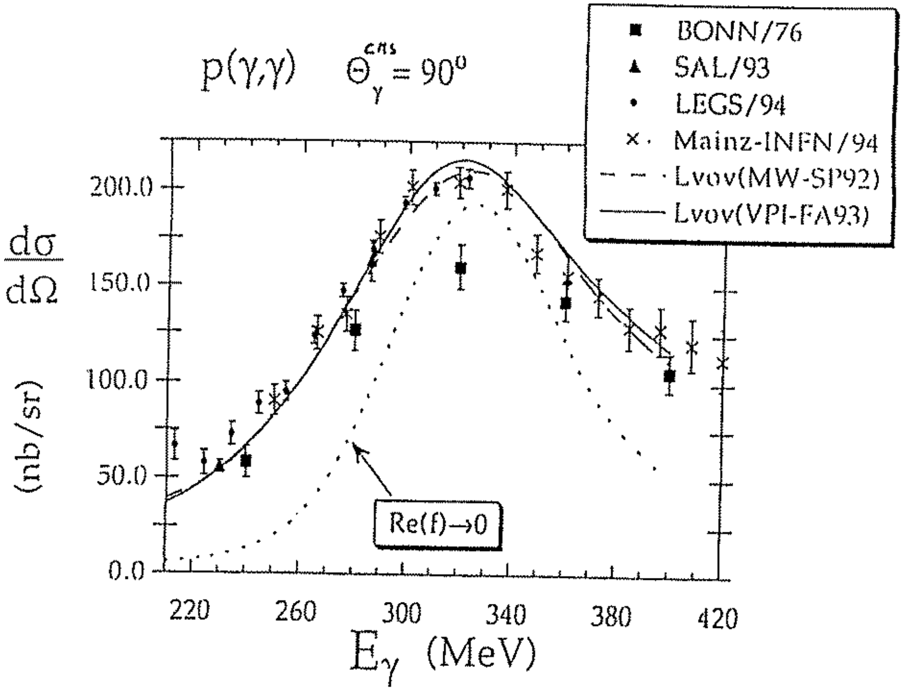
2 : $E2/M1 = -5\,\%$

3 : $M1 = 0.97 \cdot M1$

COPP (Genua, Göttingen, Mainz)

$\gamma + p \rightarrow p + \gamma$

R. Kordsmeier 1994

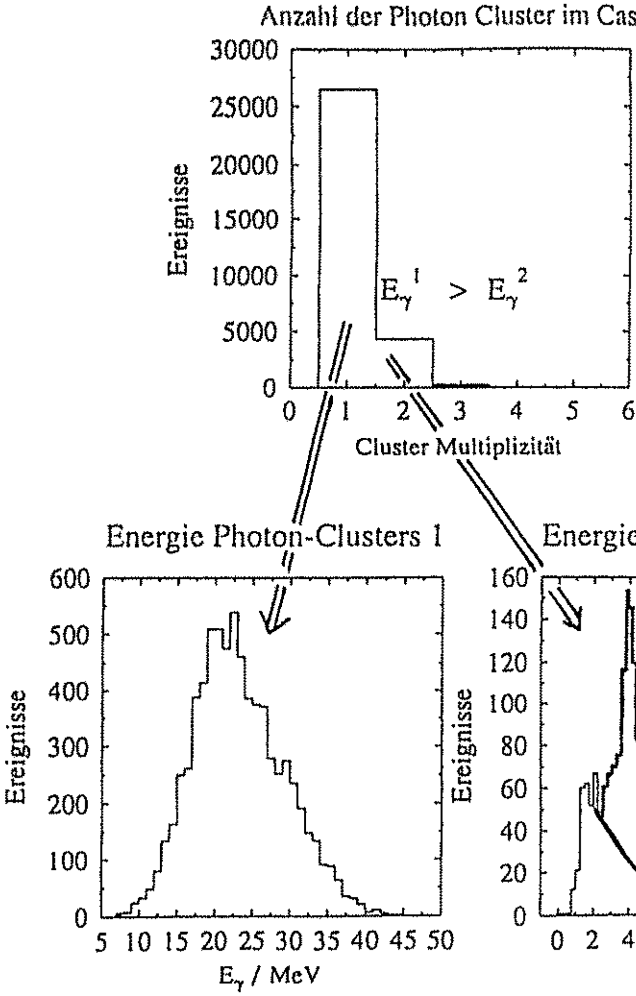


Unitarität : $\operatorname{Im} f(E_\gamma) = \frac{E_\gamma}{4\pi} \sigma_{tot}$ $\quad$ opt. Theorem

Identifikation der $^{12}C(\gamma,\pi^0)^{12}C^*$ (4.4 MeV) Ereignisse

$\gamma_1 + \gamma_2$ γ_3

M. Schnitz 1994


Anzahl der Photon Cluster im Castle

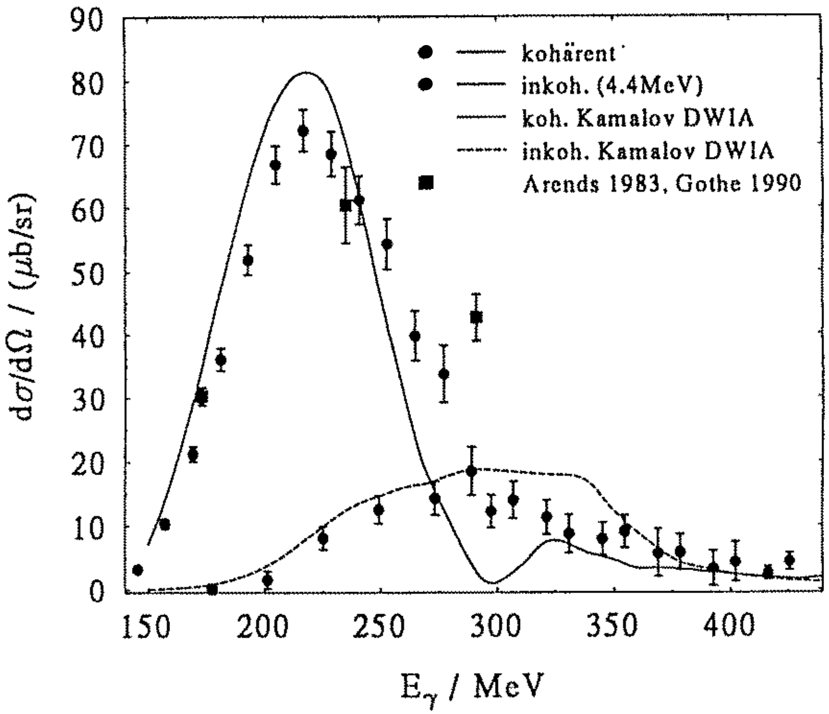
136 < E_γ^{tag} < 790 MeV

Energie Photon-Clusters 1

Energie Photon-Clusters 2

250 < E_γ^{tag} < 450 MeV

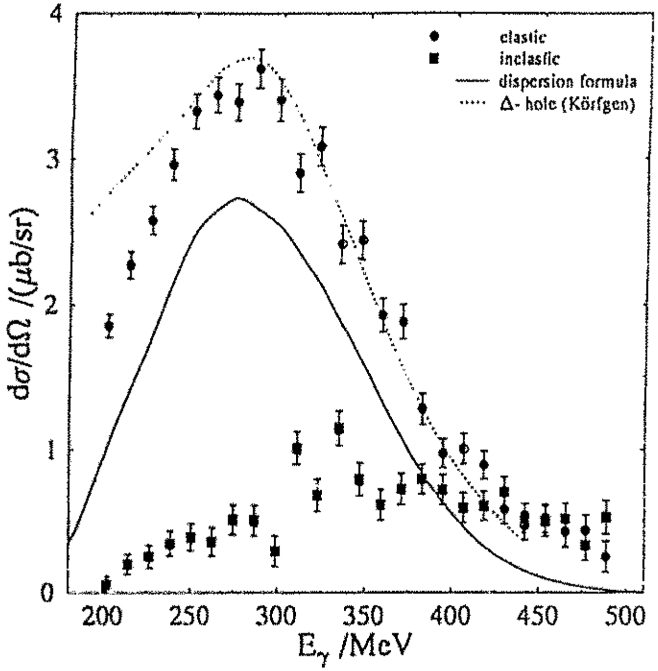
$^{12}C(\gamma,\pi^0)^{12}C$ $\vartheta_{ls} = 60 \pm 10$ °



$\Theta_\gamma^{LS} = 40°$

$\gamma + {}^{12}C \rightarrow {}^{12}C^* + \gamma$

F. Wissmann 1993



DAPHNE (Soclay, Pavia, Mainz)

Nukleon:

- totaler Absorptionswirkungsquerschnitt
- 2π -Photoproduktion

  $\gamma + p \rightarrow p + \pi^+ + \pi^-$

  $\gamma + p \rightarrow n + \pi^+ + \pi^0$ empfindlich auf D_{13} (P_{11}?)

  $\gamma + p \rightarrow p + \pi^0 + \pi^0$
- Photonen asymmetrie

  $\vec{\gamma} + p \rightarrow p + \pi^0$ E2/M1

  $\vec{\gamma} + p \rightarrow n + \pi^+$

Kern :

- totaler Absorptionswirkungsquerschnitt D, ^3He und ^4He
- Photospaltung

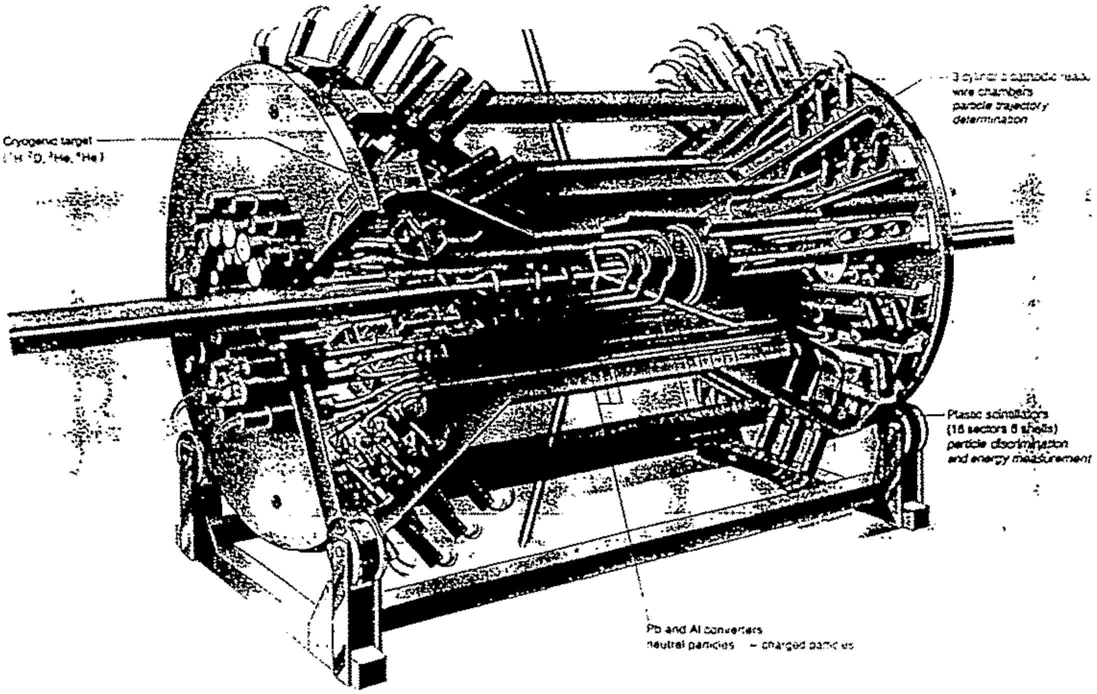
  $\gamma + d \rightarrow p + n$

  $\gamma + d \rightarrow p + p + \pi^-$ NN, NΔ Kanäle

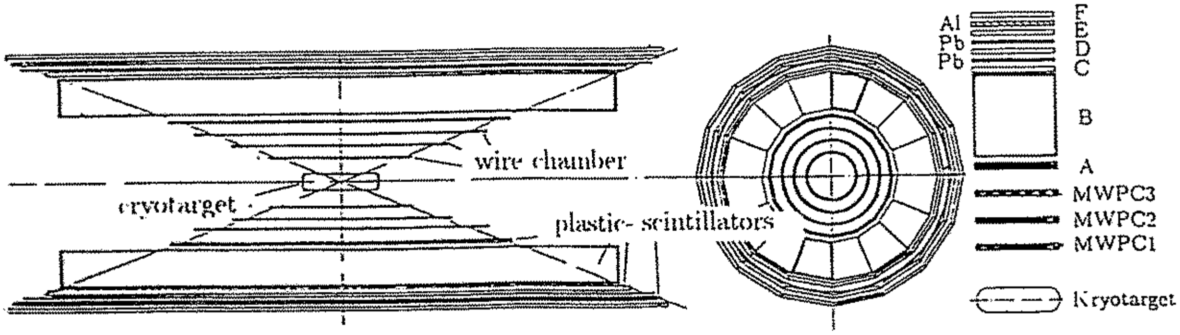
  $\vec{\gamma} + d \rightarrow p + n$

DAPHNE

Détecteur à grande Acceptance pour la Physique photo Nucléaire Expérimentale



DAPHNE (Saclay, Pavia)



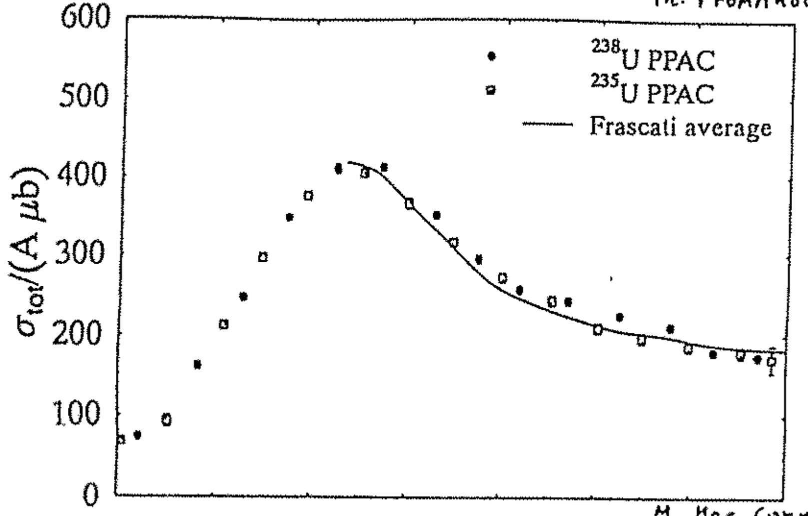
$20° < \theta < 160°$ $\Delta\theta = 1°$

$0° < \varphi < 2\pi$ $\Delta\varphi = 2°$

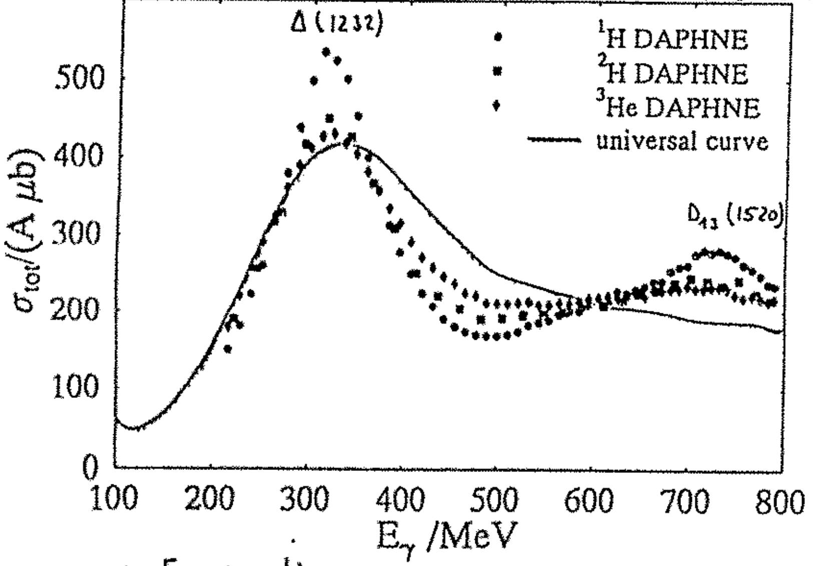
$\Delta\Omega = 0.94 * 4\pi$

Totale Absorptionsquerschnitte ..

Th. Frommhold 1994



M. Mac Cormick 1994

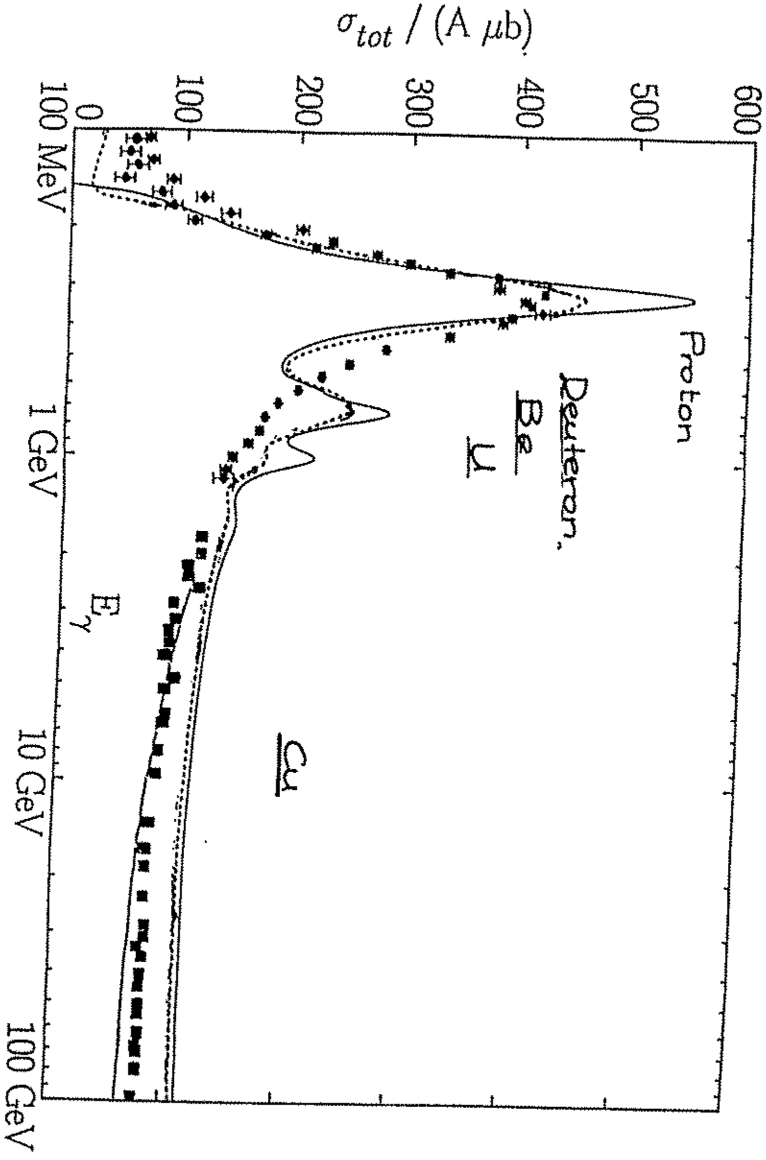


- Fermi motion
- Pauli blocking
- ΔN → NN

ξ

stat. Fehler < 1%

syst. Fehler < 4%



2π - Photoproduktion

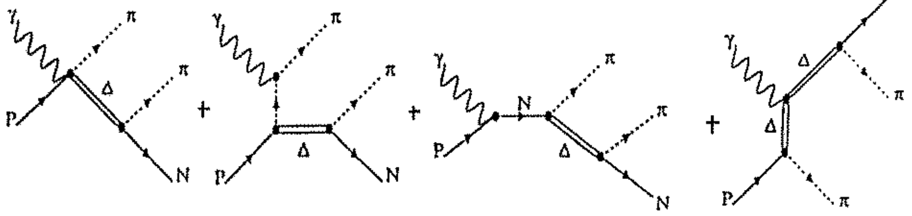
$\gamma + p \rightarrow p + \pi^+ + \pi^-$

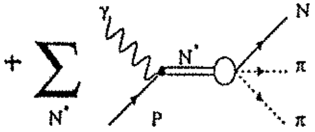
$\gamma + p \rightarrow n + \pi^+ + \pi^0$

$\gamma + p \rightarrow p + \pi^0 + \pi^0$

Isobaren Modell   Lüke und Söding 71
Laget und Murphy 94

$\gamma + N \rightarrow \pi\Delta \rightarrow N\pi\pi$



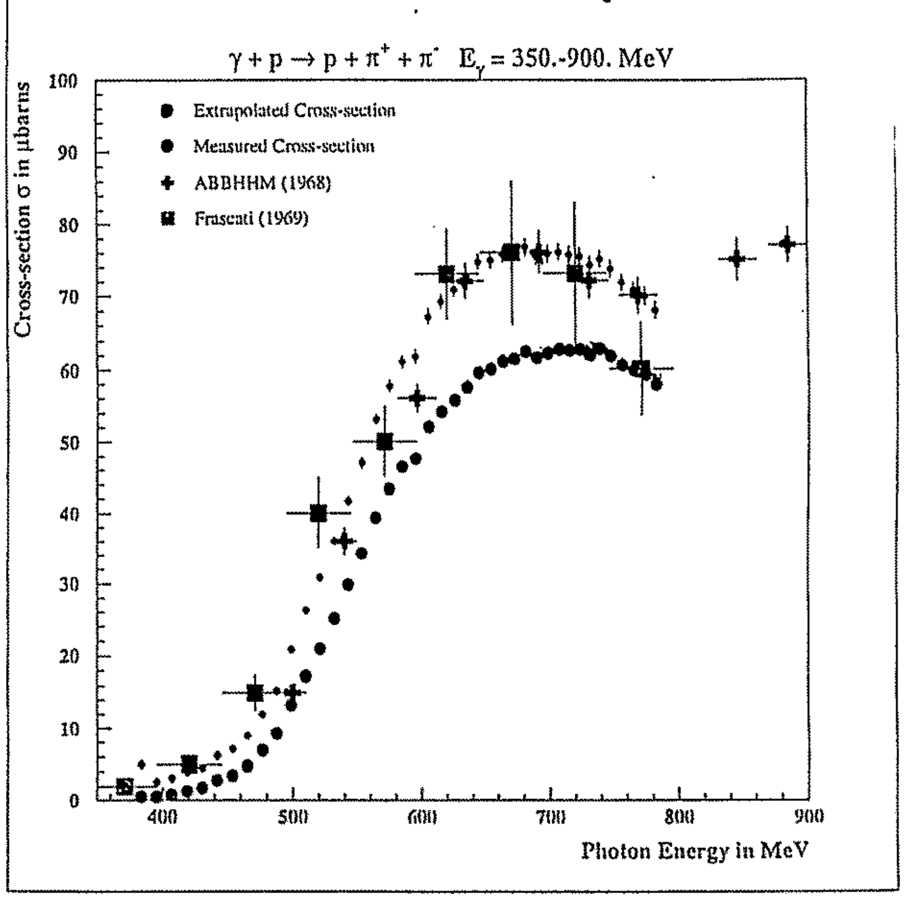


$P_{11}(1440) \longrightarrow N\pi\pi$ 30 - 40%
$\Delta\pi$ 20 - 30%

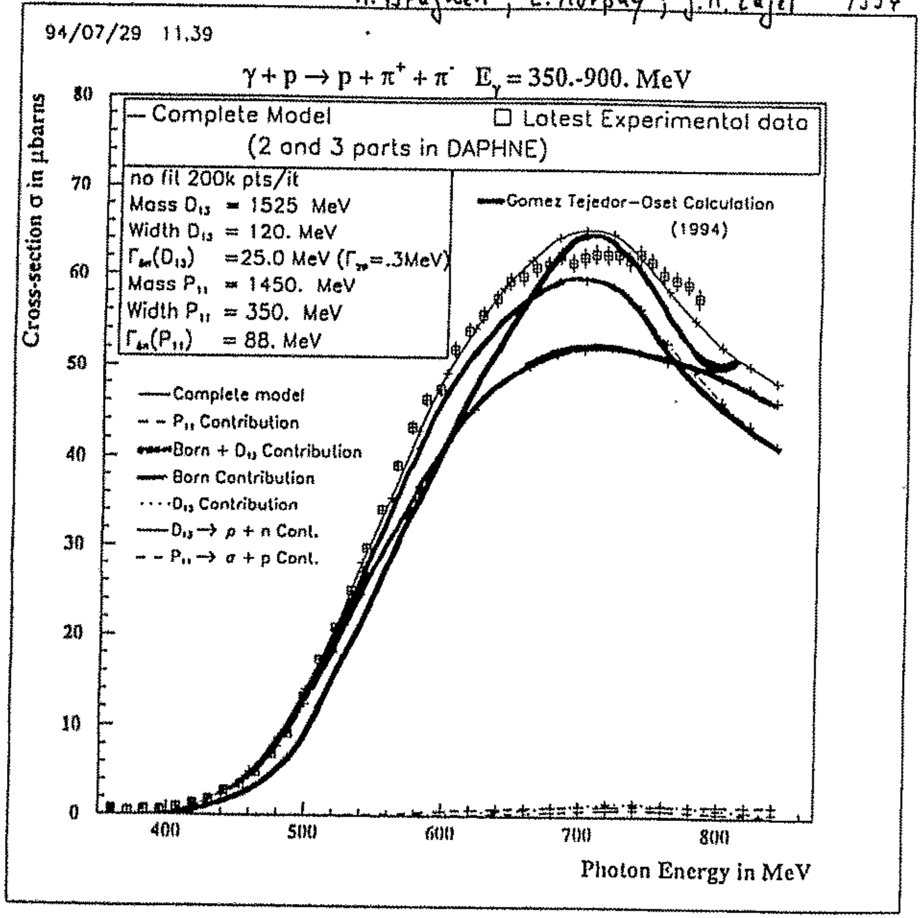
$D_{13}(1520) \longrightarrow N\pi\pi$ 40 - 50%
$\Delta\pi$ 15 - 30%

$S_{11}(1535) \longrightarrow N\pi\pi$ 5 - 20%
$\Delta\pi$ < 10%

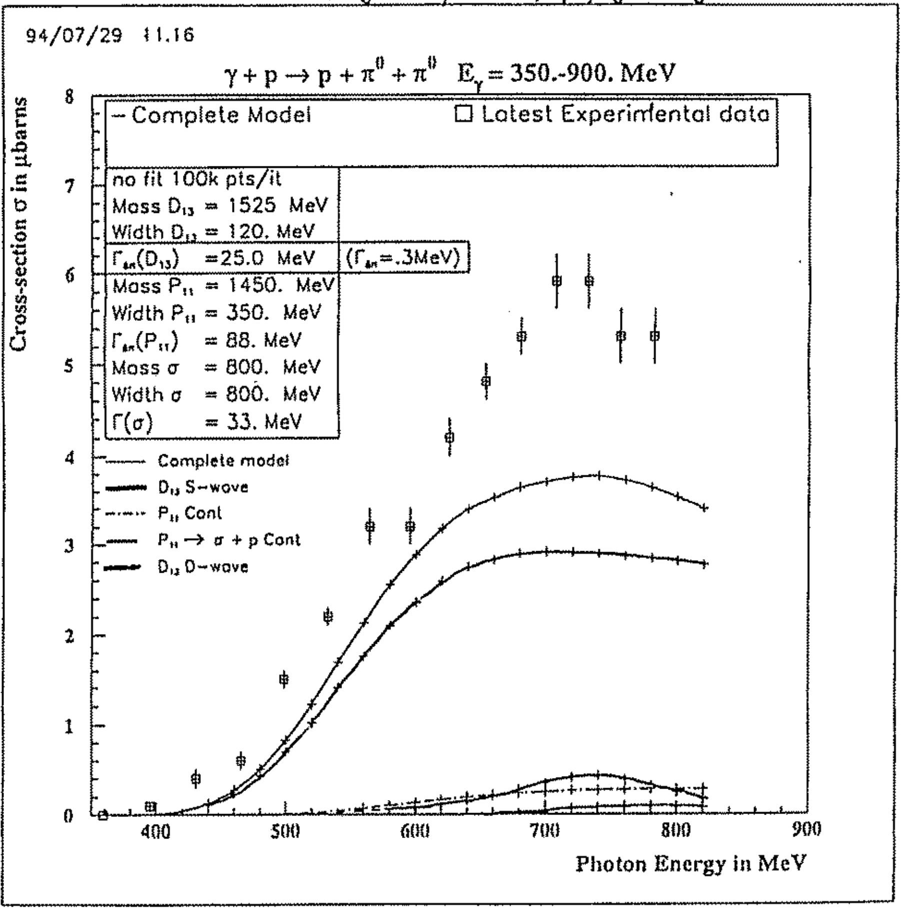
A. Braghieri ; L. Murphy



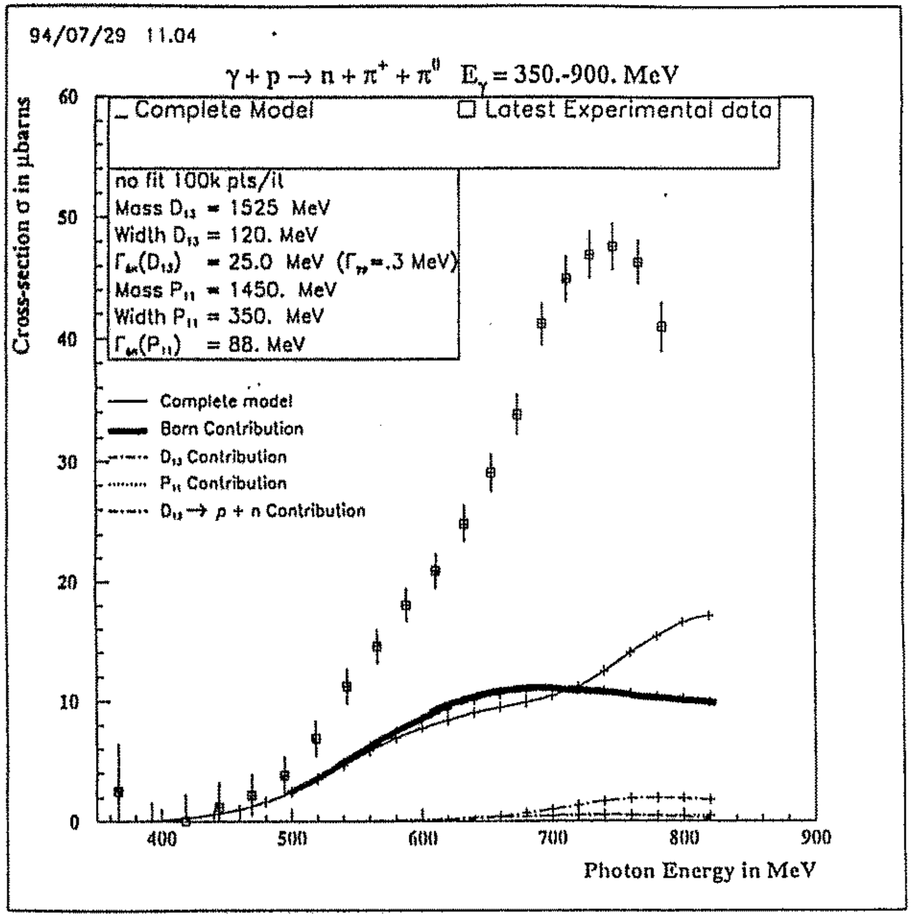
A. Braghieri ; L. Murphy ; J.M. Laget 1994



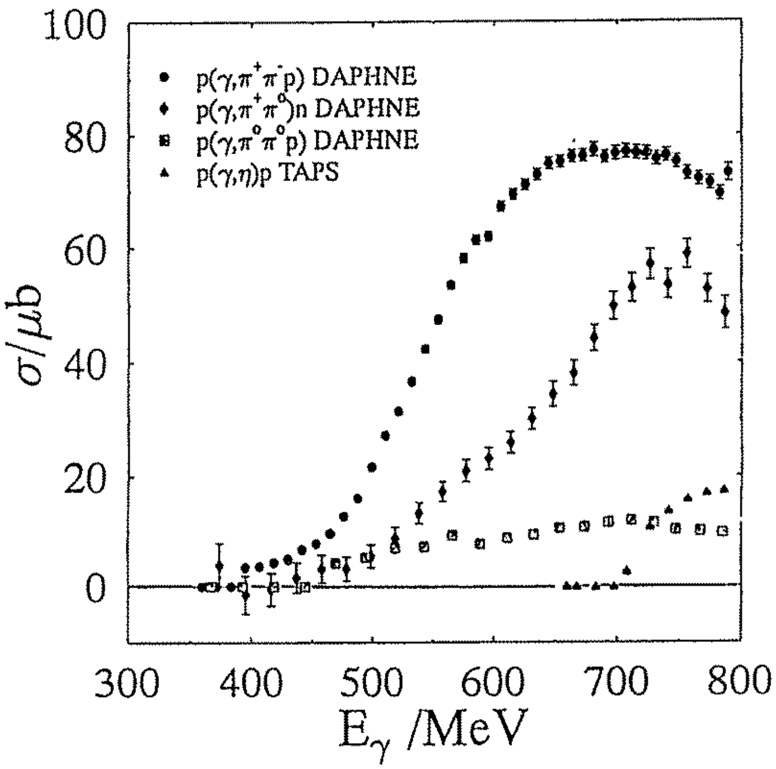
A. Braghieri ; L. Murphy ; J.M. Laget 1994



A. Braghieri ; L. Murphy ; J. M. Laget 1994



DAPHNE A. Braghieri ; L. Murphy
TAPS B. Krusche



E2/M1 - Verhältnis in $N \to \Delta$ - Übergang

$J = \frac{1}{2}$ $I = \frac{1}{2}$

$J = 3/2$ $I = 3/2$

analog: 1π - Austausch ⟶ Tensor Anteil ⟶ D - Beimischung, Deuteron wellenfkt, Quadrupolmoment

1 Gluon-Austausch ⟶ Tensor Anteil ⟶ D-Beimischung, Nukleon wellenfkt, Delta wellenfkt ⟶

E2 - Übergang

Daten und Analysen: $E2/M1 = \frac{E_{1+}^{3/2}}{M_{1+}^{3/2}} = -2\%$ bis $+2\%$

Neue Messungen: Photon asymmetrie

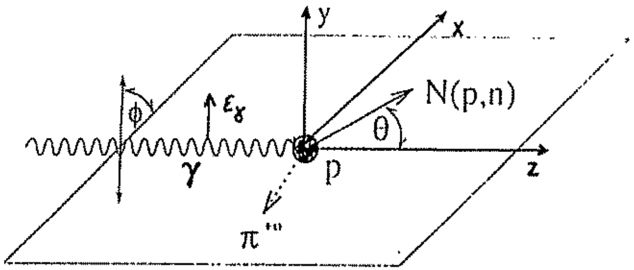
$$\left.\begin{array}{l} \vec{\gamma} + p \to \Delta^+ \to n + \pi^+ \\ \vec{\gamma} + p \to \Delta^+ \to p + \pi^0 \end{array}\right\} E_{1+}(p\pi^0) \,;\, E_{1+}(n\pi^+)$$

$$E_{1+}^{3/2} = E_{1+}(p\pi^0) - \frac{1}{\sqrt{2}} E_{1+}(n\pi^+)$$

Photon asymmetrie

Linear polarisierte Photonen

$$\vec{\gamma} + p \to p + \pi^0$$
$$\vec{\gamma} + p \to n + \pi^+$$



WQ: $\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta) \left\{ 1 - \varepsilon_\gamma \Sigma \cos 2\phi \right\}$

Asymmetrie:

$$\Sigma = \frac{1}{\varepsilon_\gamma} \frac{d\sigma^\perp - d\sigma^\parallel}{d\sigma^\perp + d\sigma^\parallel}$$

$$\frac{d\sigma^\parallel}{d\Omega} = (1 - \Sigma) \frac{d\sigma}{d\Omega} \qquad \frac{d\sigma^\perp}{d\Omega} = (1 + \Sigma) \frac{d\sigma}{d\Omega}$$

$$\frac{d\sigma}{d\Omega} = \frac{q}{k}\left\{ A + B\cos\theta + C\cos^2\theta \right\}$$

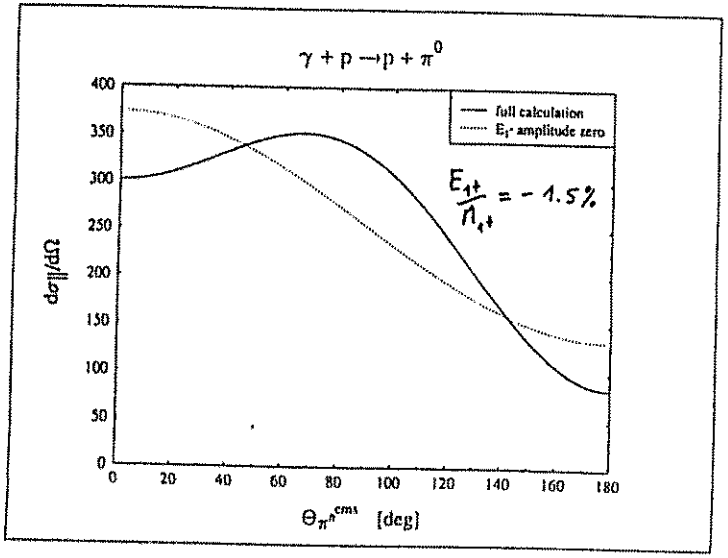
$$\frac{d\sigma^{\perp}}{d\Omega} = \frac{q}{k}\left\{ A_{\perp} + B_{\perp}\cos\theta + C_{\perp}\cos^2\theta \right\}$$

$$\frac{d\sigma^{\parallel}}{d\Omega} = \frac{q}{k}\left\{ A_{\parallel} + B_{\parallel}\cos\theta + C_{\parallel}\cos^2\theta \right\}$$

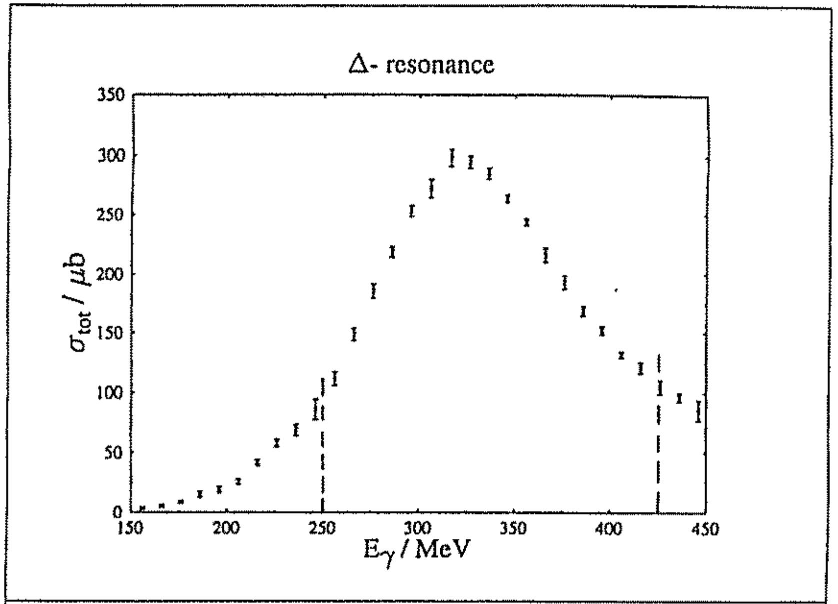
$$C_{\parallel} = 12\,\mathrm{Re}\left\{ E_{1+}\,(M_{1+} - M_{1-})^{*} \right\}$$

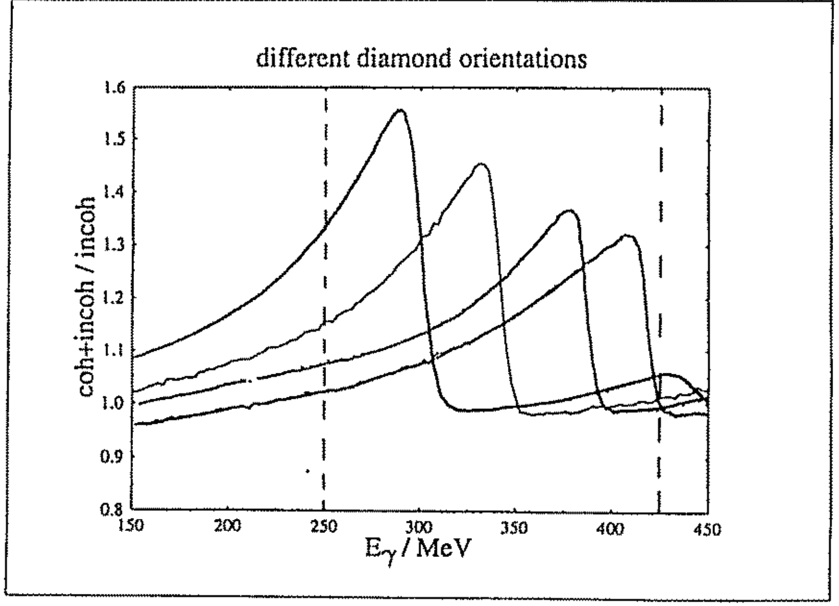
$$\frac{C_{\parallel}}{A_{\parallel}} = \frac{12\,\mathrm{Re}\left\{ E_{1+}\,(M_{1+} - M_{1-})^{*} \right\}}{|M_{1+} - M_{1-}|^{2}}$$

Empfindlichkeit



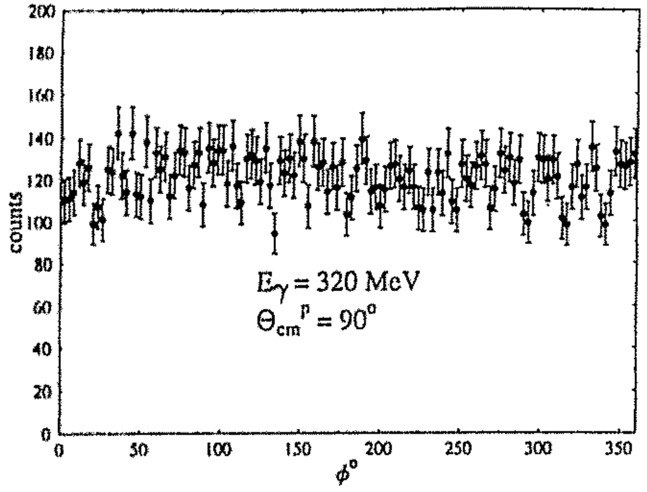
Linear polarisierte Photonen


Δ- resonance

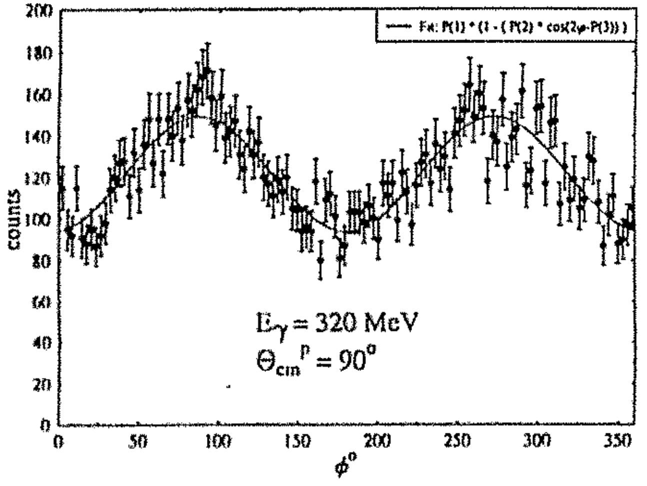

different diamond orientations

Asymmetrie

Asymmetrie unpolarisiert



Asymmetrie polarisiert

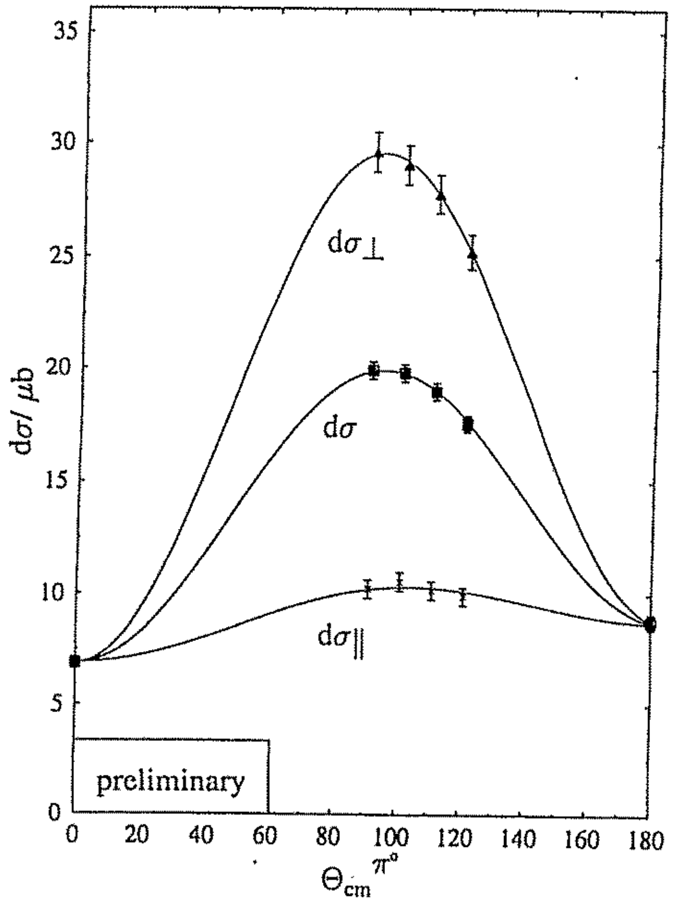


Wirkungsquerschnitt

$\vec{\gamma} + p \rightarrow p + \pi^0$

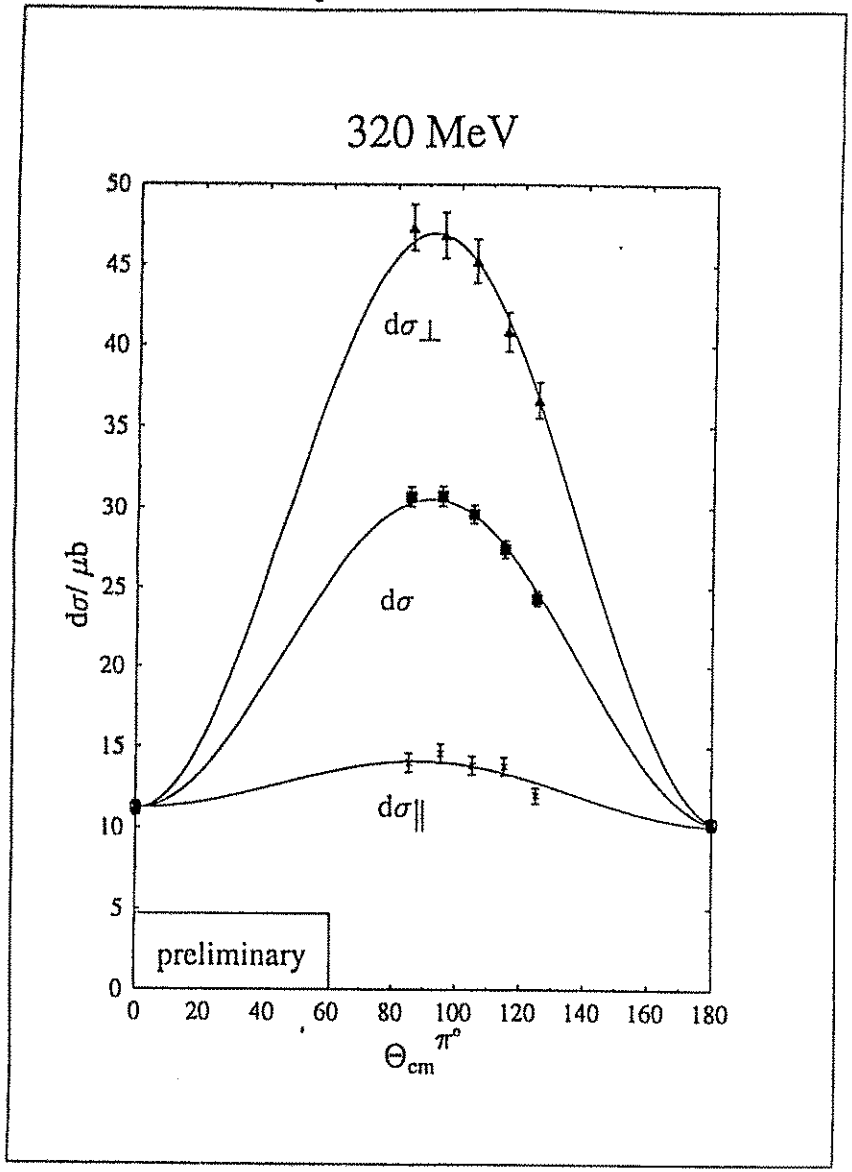
Kurve: $\frac{d\sigma}{d\Omega} = \frac{q}{k} \{ A + B \cos\Theta + C \cos^2\theta \}$

280 MeV



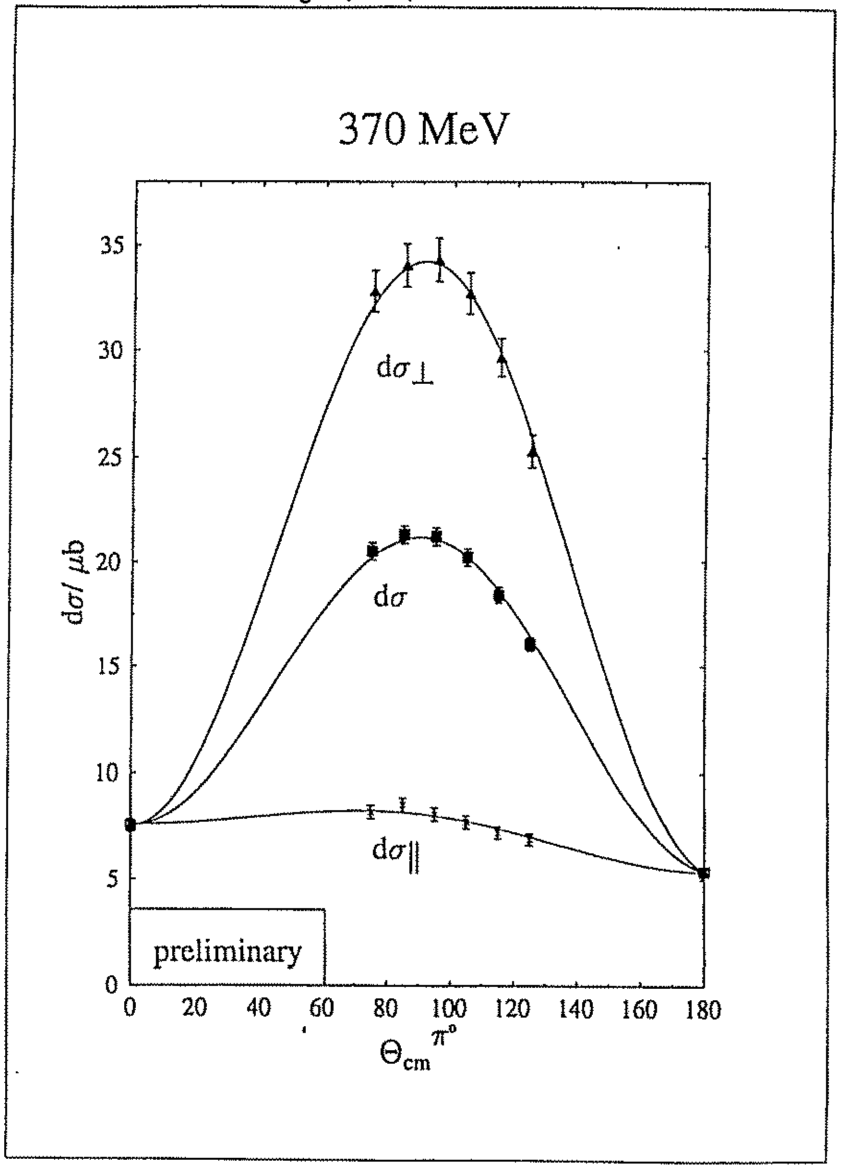
Wirkungsquerschnitt

$\vec{\gamma} + p \rightarrow p + \pi^0$

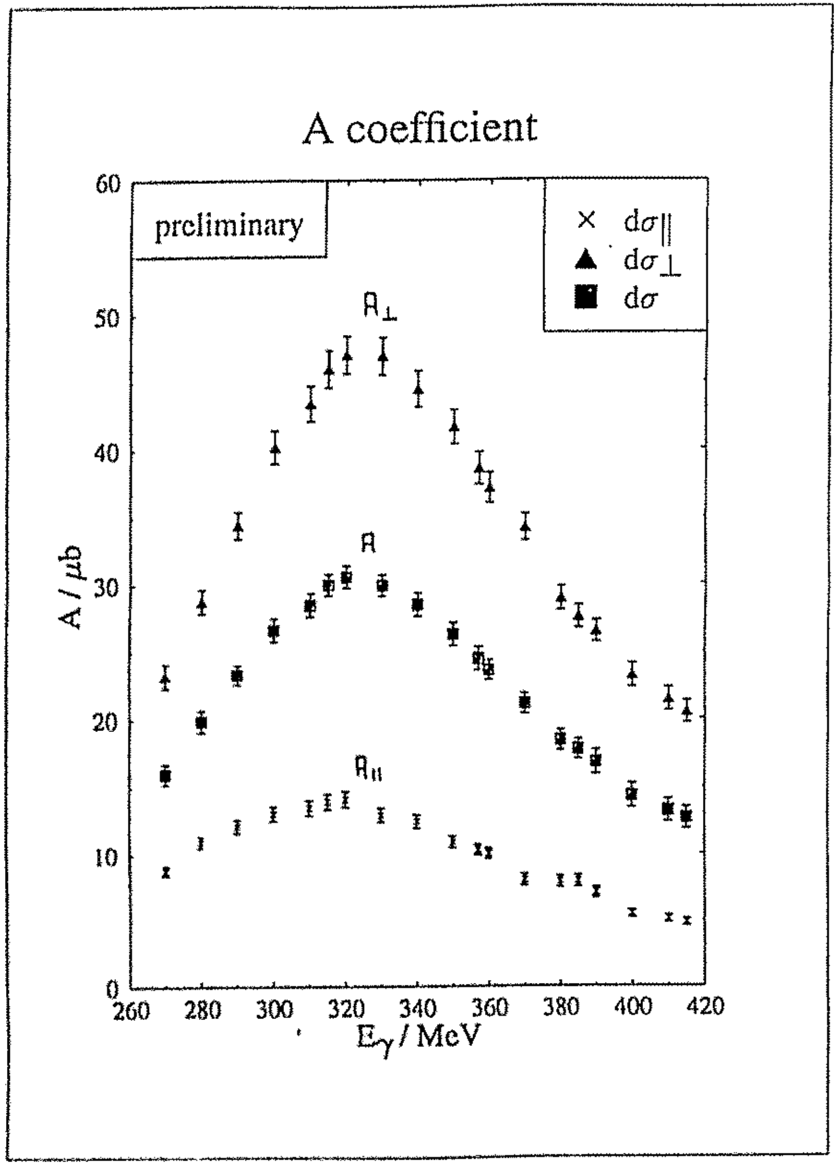


Wirkungsquerschnitt

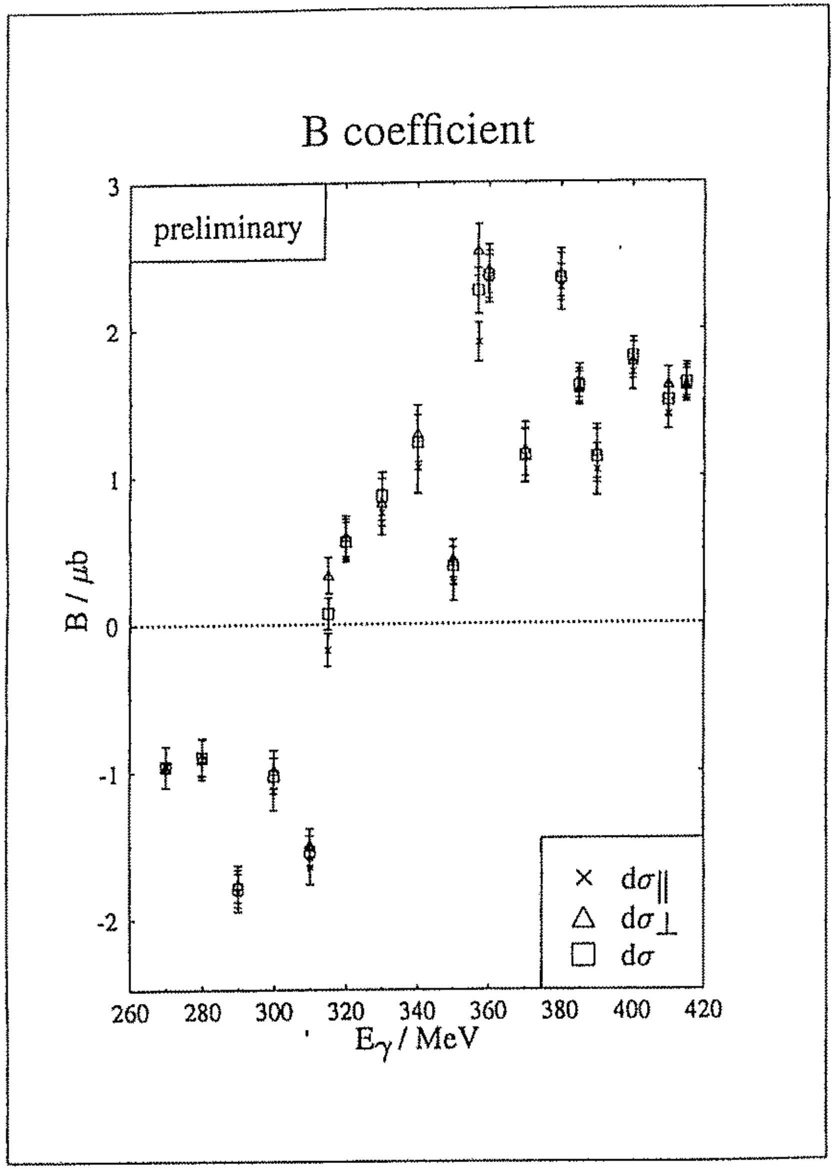
$\vec{\gamma} + p \rightarrow p + \pi^0$



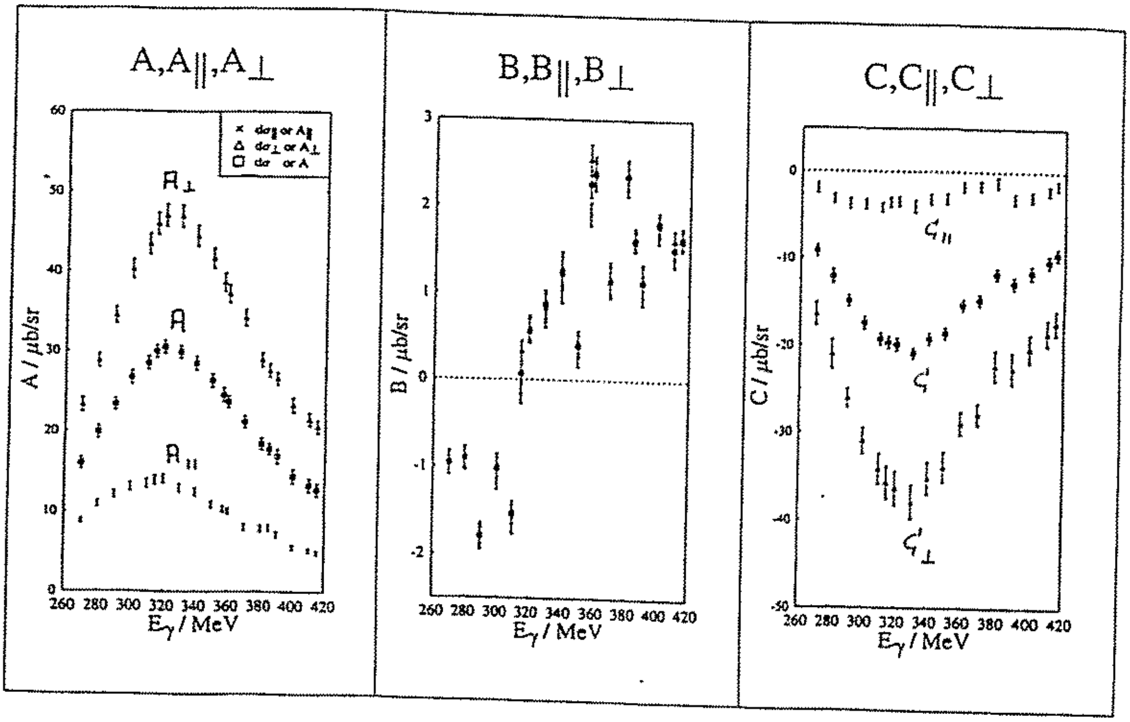
$$\frac{d\sigma}{d\Omega} = \frac{q}{k}\left\{ A + B\cos\theta + C' \cos^2\theta \right\}$$



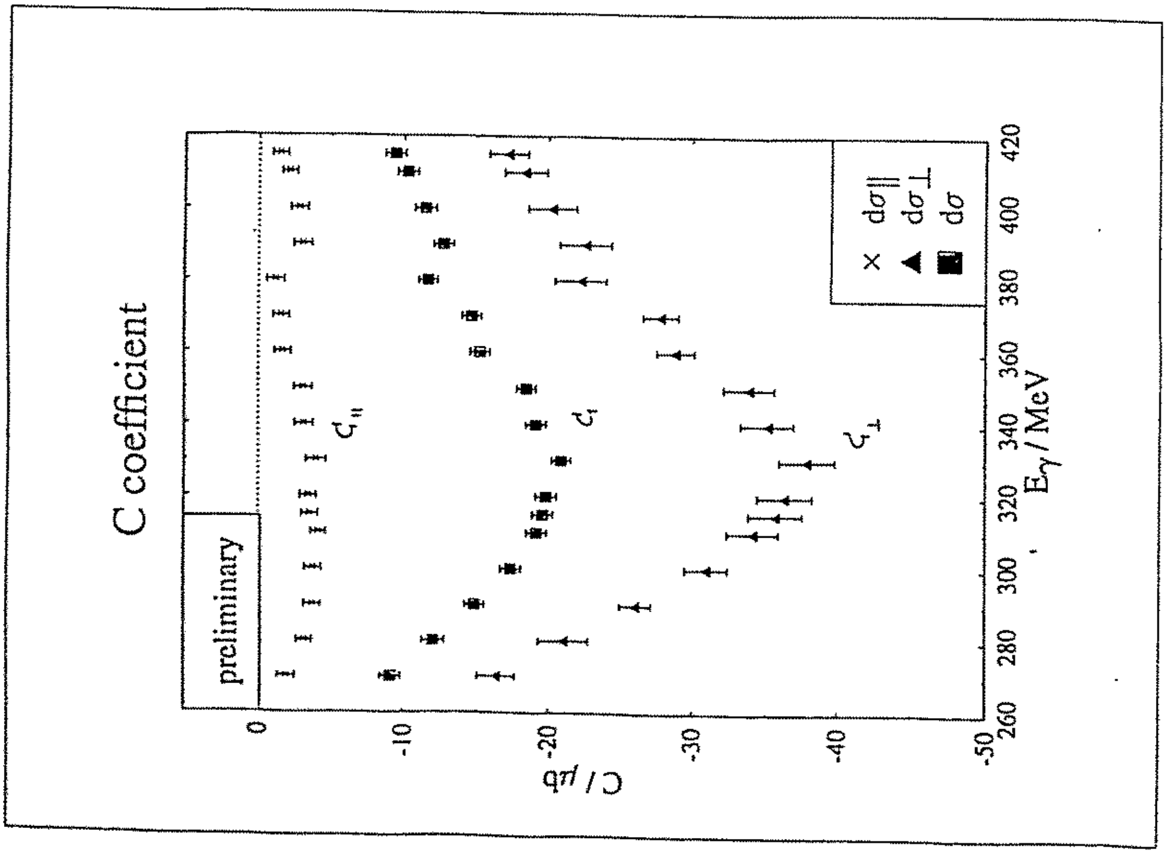
$$\frac{d\sigma}{d\Omega} = \frac{q}{k}\left\{ A + B\cos\theta + C' \cos^2\theta \right\}$$



$$\frac{d\sigma}{d\Omega} = \frac{q}{k}\left\{ A + B\cos\theta + C\cos^2\theta \right\}$$

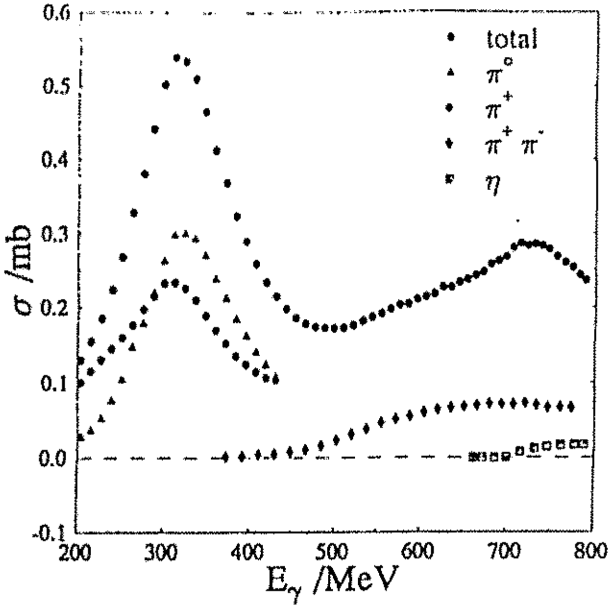


$$\frac{d\sigma}{d\Omega} = \frac{q}{k}\left\{ A + B\cos\theta + C\cos^2\theta \right\}$$



Zusammenfassung und Ausblick

in A2 gemessene totale WQ's am Proton



- Compton Spektrometer mit großer Akzeptanz
  $20° < \theta_\gamma < 160°$
- zirkular und linear polarisierte Photonen
- polarisierte Targets (Bonn)
- Doppelpolarisationsexperimente

  z.B. : DHG - Summenregel

Messung des elektrischen Formfaktors des Neutrons
(MAMI)
Erste Ergebnisse von den Experimenten am Mainzer Mikrotron
(A3-Kollaboration)

H. Schmieden
Mainz

5.Oktober 1994

Messung des elektrischen Formfaktors des Neutrons

Erste Ergebnisse von den Experimenten am Mainzer Mikrotron

MAMI

H. Schmieden für die

A3 - Kollaboration

Institut für Kernphysik, Universität Mainz
Institut für Physik, Universität Mainz
Physikalisches Institut, Universität Tübingen
Department of Physics and Astronomy, University of Glasgow
Ecole Normale Supérieure, Paris

Übersicht:

1. Einführung und Motivation
2. Experimentelle Methoden
    - 2.1 quasifrei an Deuterium
    - 2.2 elastisch an Deuterium
    - 2.3 Polarisationsexperimente
3. A3 - Experimente, erste Ergebnisse
    - 3.1 $^2D(\vec{e},e'\vec{n})$
    - 3.2 $^3\vec{He}(\vec{e},e'n)$
4. Zusammenfassung und Ausblick

Neutron → $Z = 0$ Ladung

Neutron → $\mu = -1{,}91\,\mu_K$ mag. Moment

⇓

kein Punktteilchen

⇓

4 - Stromdichte enthält i.a. 2 Formfaktoren

[illegible] Dirac

[illegible] Pauli

$$G_M(Q^2) = [illegible](Q^2) + \kappa\,[illegible](Q^2)$$
$$G_E(Q^2) = [illegible](Q^2) - \tau\kappa\,[illegible](Q^2);\ \tau = Q^2/4M^2$$

} Sachs-FF

$$\left.\begin{array}{l} \mu_N \xleftarrow{\quad} G_M \\ \quad Q^2\to 0 \\ Z_N \xleftarrow{\quad} G_E \end{array}\right\} \xleftrightarrow{\text{F.T.}} \left\{\begin{array}{l} \rho_M(r) \\ \rho_E(r) \end{array}\right.$$

Breit-System
↓
$Q^2 \rightarrow |\vec{q}|^2$

$$G_{E,p} = \left(1+\frac{Q^2}{0{,}71\,GeV^2}\right)^{-2} = G_D$$ Dipolverlauf

$$G_{M,p} = \mu_p G_D \qquad G_{M,n} = \mu_n G_D \qquad G_{E,n} = -\tau\,G_{M,n}$$

$$\frac{-a\tau G_{M,n}}{1+b\tau}$$

Ausdehnung $\xrightarrow{Q^2 \to 0}$ endlicher Ladungsradius

$$\left.\frac{dG_E}{dQ^2}\right|_{Q^2=0} = 0 - \frac{1}{6}\langle r^2\rangle + \cdots = \left.\frac{dF_1}{dQ^2}\right|_{Q^2=0} - \frac{\varkappa}{4M^2} F_2(0)$$

$$\langle r^2\rangle = -6 \left.\frac{dG_E}{dQ^2}\right|_{Q^2=0} = -6 \left\{ \left.\frac{dF_1}{dQ^2}\right|_{Q^2=0} - \frac{\varkappa}{4M^2} \right\}$$

$$= \frac{3\hbar c}{\alpha M_n c^2} \cdot b_{ne} = \frac{3\hbar c}{\alpha M_n c^2} \left\{ a_D + \underset{\substack{\uparrow \\ -1{,}468\ \mathrm{mfm}}}{a_F} \right\}$$

Kohärente n-Atom Streuung

- kein magnetisches Moment
- E_n < 150 eV

$\sigma_{abs}(E) = (f_{kern} + f_{res} + f_{ne} + f_{pol})^2$ + Korrekturen

Interferenzterm

$\propto Z\, b_{ne}\, [1 - F_A(E)]$

atomarer Formfaktor

→ 1 - 0,01 (E = 0 - 150 eV)

⇒ Separation des Terms $\propto b_{ne}$ über Energieabhängigkeit

H. Leeb & G. Teichtmeister PR C48(1993)1719

TABLE I. List of the best experimental values of the neutron-electron scattering length b_{ne}.

Authors	Reference	Year	b_{ne} (fm)	a_D [mfm]
Hughes *et al.*	[1]	1953	$(-1.39 \pm 0.13) \times 10^{-3}$	
Melkonian *et al.*	[2]	1959	$(-1.56 \pm 0.05) \times 10^{-3}$	
Krohn and Ringo	[3]	1973	$(-1.30 \pm 0.03) \times 10^{-3}$	+ 0,17
Koester *et al.*	[4-6]	1973-1988	$(-1.32 \pm 0.04) \times 10^{-3}$	+ 0,15
Alexandrov *et al.*	[7,8]	1975-1985	$(-1.60 \pm 0.05) \times 10^{-3}$	− 0,13
Alexandrov *et al.*	[9-11]	1983-1989	$(-1.55 \pm 0.11) \times 10^{-3}$	− 0,08
Kopecky *et al.*	[25]	1992	$(-1.39 \pm 0.04) \times 10^{-3}$	+ 0,08

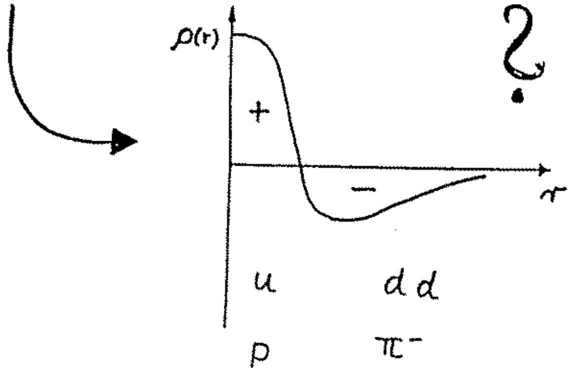
① a_F bestimmt praktisch b_{ne}

$\boxed{a_D \approx 0 \Rightarrow F_1 \approx 0}$ Q^2 klein

② Vorzeichen des intrinsischen $\langle r_n^2\rangle$

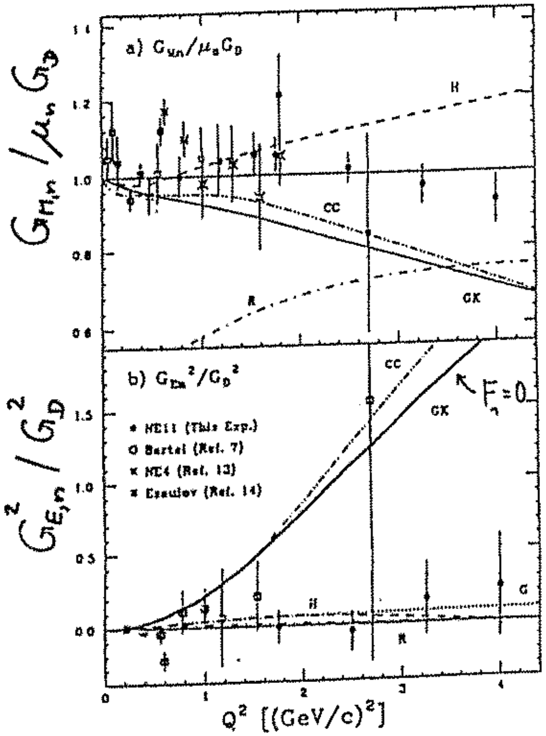
¿

statisches Neutronmodell:



hoher Impulsübertrag $\boxed{Q^2 \leq 4\ \mathrm{GeV}^2}$: SLAC - Daten $^2\mathcal{D}(e,e')$

A. Lung et al., Phys.Rev.Lett. 70 (1993) 718 L / T Sep.



- $G_{E,n} = F_1 - \tau\kappa F_2 \approx 0 \quad \Rightarrow \quad \boxed{\tau\kappa F_2 \approx F_1 \neq 0}$
  - FF - Modelle ausgeschieden
  - Mittlere Impulsüberträge ?

    $F_1 \approx 0$ bei $Q^2 = 0 \longrightarrow F_1 \approx F_2$

2. Experimentelle Methoden zur Bestimmung von $G_{E,n}$

(mittlere Q^2)

- kein freies n - Target $\Rightarrow$ Deuterium

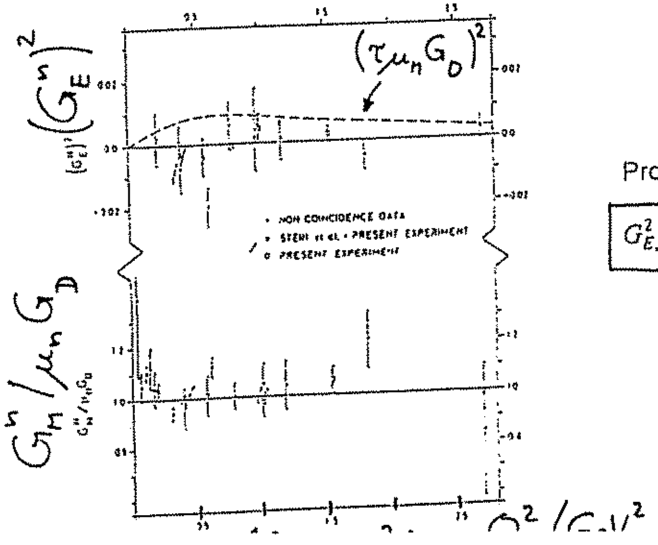
2.1 Quasifreie Streuung an Deuterium

Wirkungsquerschnitt für elastische Elektronstreuung am ausgedehnten Spin ½ - Objekt :

$$\boxed{\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \cdot \left[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2\left(\frac{\vartheta}{2}\right)\right]} \quad \text{Rosenbluth}$$

$\Rightarrow$ Separation von $G_E{}^2$ und $G_M{}^2$ über Winkelabhgängigkeit

Bartel et al., Nucl. Phys. B58 (1973) 429 D (e,e´n)



Problem:

$\boxed{G_{E,n}^2 << G_{M,n}^2}$

2.2 Elastische Streuung an Deuterium

Wirkungsquerschnitt für elastische Elektronstreuung an einem Spin 1 - Objekt :

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \cdot \left[A + B \cdot \tan^2\left(\frac{\vartheta_e}{2}\right)\right]$$

A(Q^2) und B(Q^2) enthalten Deuteron-Formfaktoren

$$A(Q^2) = G_{0,Deut}^2 + \tfrac{8}{9}\tau^2 G_{2,Deut}^2 + \tfrac{2}{3}\tau G_{1,Deut}^2$$

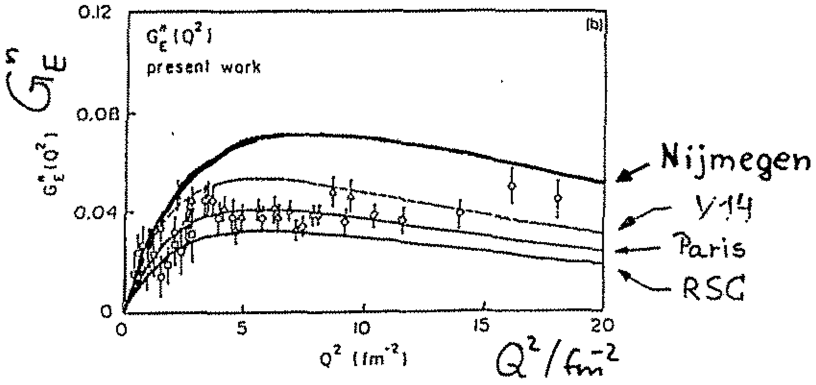
$$G_{0,Deut} \propto (G_{E,p} + G_{E,n}) \cdot C_E$$

$$G_{2,Deut} \propto (G_{E,p} + G_{E,n}) \cdot C_Q$$

Modell !

Entfaltung der Wellenfunktion

$G_{E,p} \cdot G_{E,n}$ Interferenzterm



S. Platchkov et al.
Nucl. Phys. A510 (1990) 740

2.3 Polarisationsexperimente

Streuung polarisierter Elektronen am freien Neutron : $n(\vec{e}, e')\vec{n}$

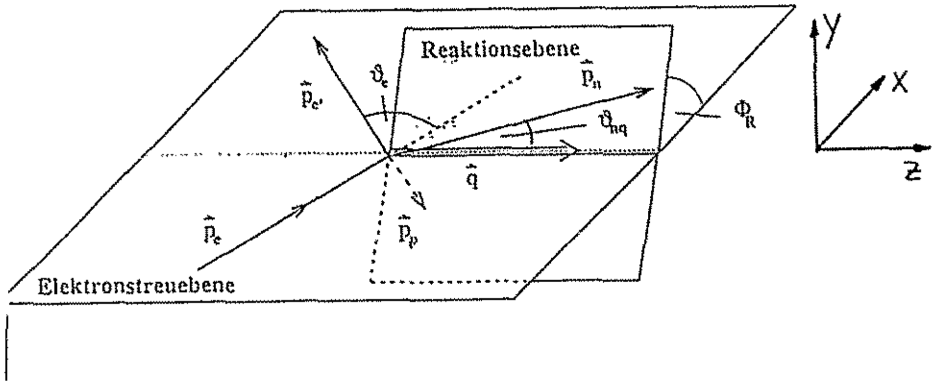
$$p_x = -p_e \frac{2\sqrt{\tau(1+\tau)} \cdot \tan\frac{\vartheta_e}{2} \cdot G_{M,n} \cdot G_{E,n}}{G_{E,n}^2 + \tau G_{M,n}^2\left[1 + 2(1+\tau)\tan^2\frac{\vartheta_e}{2}\right]} = \frac{a \cdot G_{M,n} \cdot G_{E,n}}{G_{E,n}^2 + c G_{M,n}^2} \sim \frac{G_E^n}{G_M^n}$$

$$p_y = 0$$

$$p_z = p_e \frac{2\tau\sqrt{1 + \tau + (1+\tau)^2 \tan^2\frac{\vartheta_e}{2}} \tan\frac{\vartheta_e}{2} \cdot G_{M,n}^2}{G_{E,n}^2 + \tau G_{M,n}^2\left[1 + 2(1+\tau)\tan^2\frac{\vartheta_e}{2}\right]} = \frac{b \cdot G_{M,n}^2}{G_{E,n}^2 + c G_{M,n}^2} \sim \text{konst.}$$

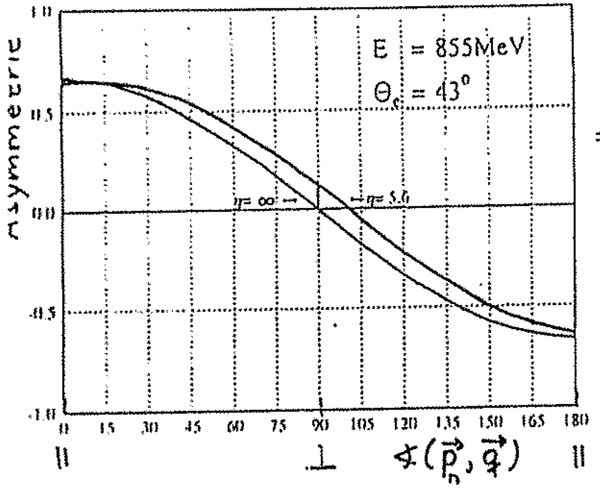
Komponenten der n - Polarisation

Arnold, Carlson und Gross; Phys. Rev. C23 (1981) 363



äquivalent : $\vec{n}(\vec{e},e')$ ⇒ WQ - Asymmetrie

allgemein : $\varepsilon = -p_e \frac{a \cdot G_{E,n} \cdot G_{M,n} \cdot p_x + b \cdot G_{M,n}^2 \cdot p_z}{G_{E,n}^2 + c \cdot G_{M,n}^2}$



⇒ Empfindlichkeit auf $G_{E,n}$

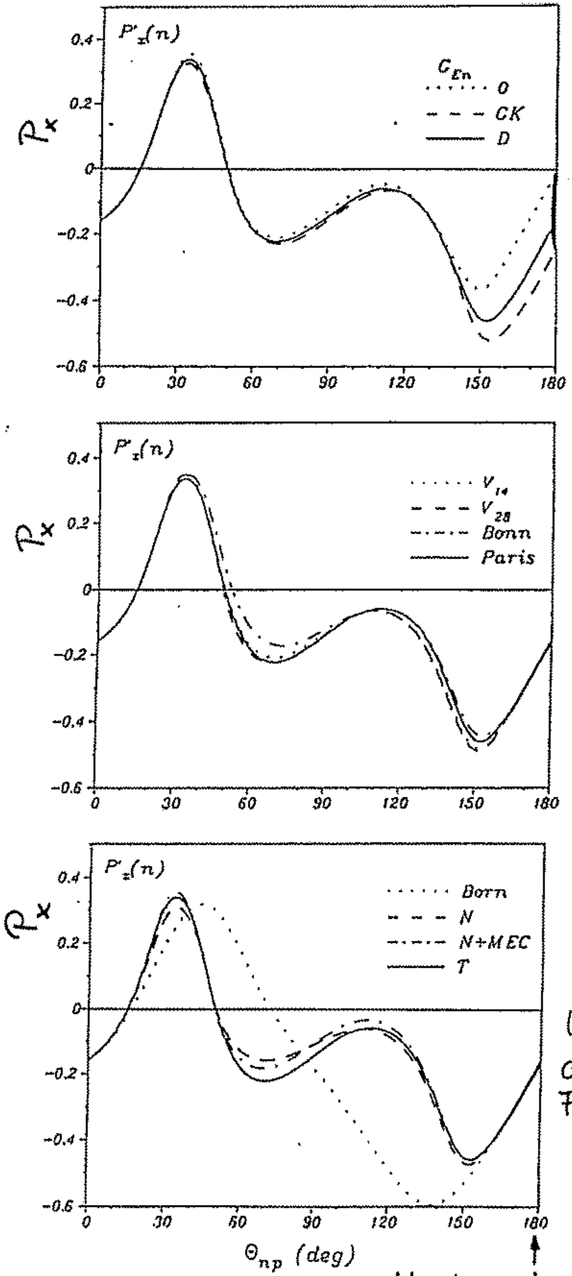
$$G_{E_n} = -\frac{\mu_n \cdot \tau}{1 + 5{,}6 \cdot \tau} G_D$$

$$G_{E_n} \equiv 0$$

H. Arenhövel, Leidemann, Tomusiak, Z. Phys. A 331 (1988) 123

H. Arenhövel, Phys. Lett. B199 (1987) 13

$Q^2 = 12 \text{ fm}^{-2}$



Empfindlich auf G_E^n

Unempf. auf Potential

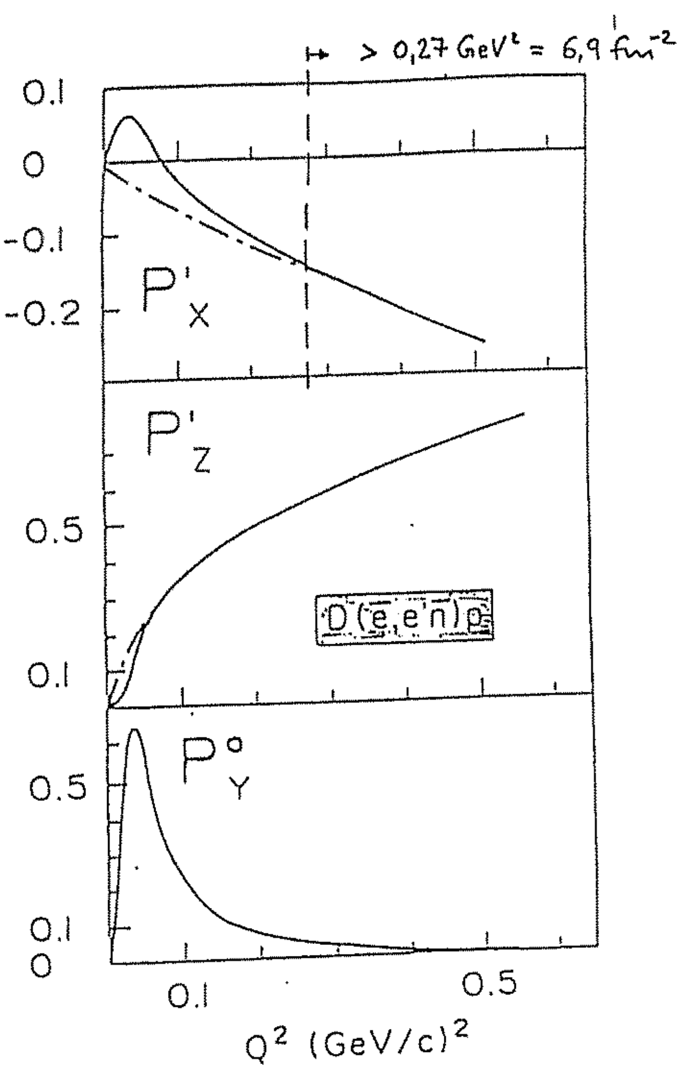
Unempf. auf subnukl. Freiheitsgrad

Neutron in $\vec{q}$-Richtung

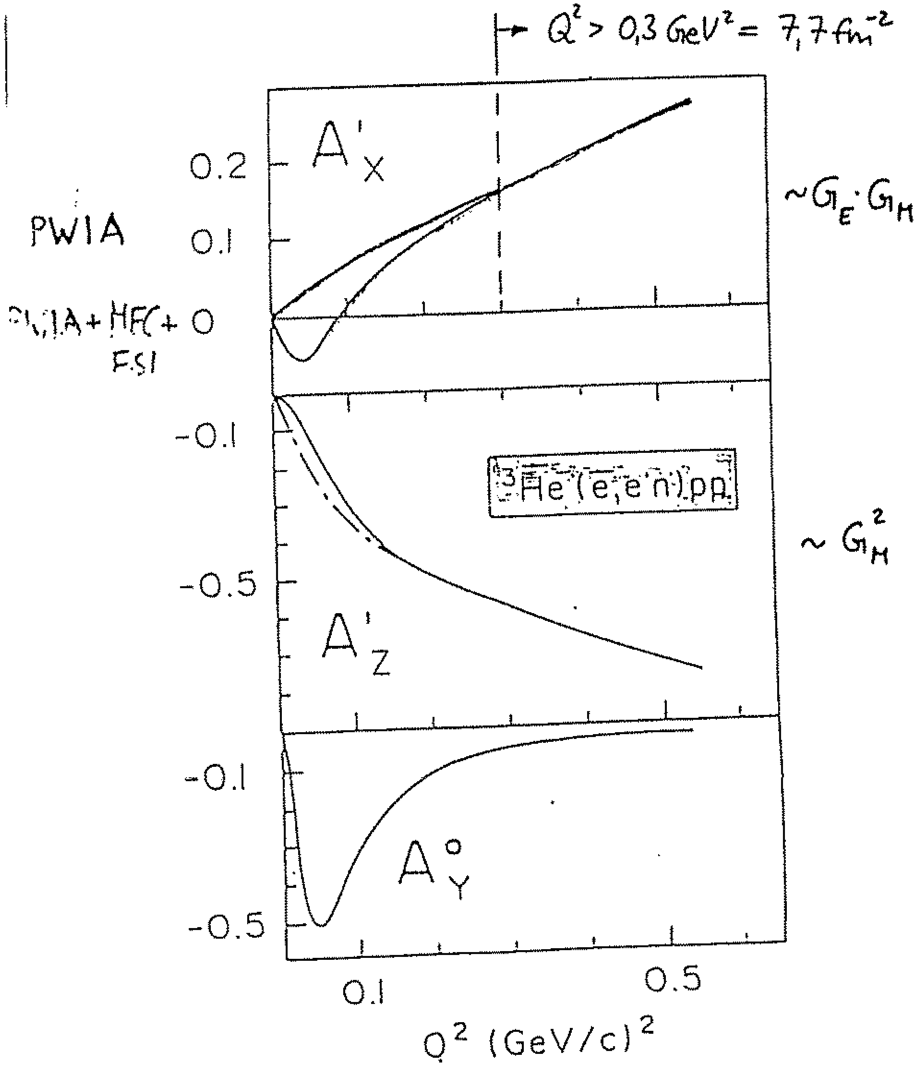
freies durch gebundenes n ersetzen ⇒ $\boxed{\text{quasifreie Streuung}}$

- $^2D(\vec{e},e'\vec{n})$ und $^3\vec{He}(\vec{e},e'n)$
- Vorsicht bei $^3\vec{He}(\vec{e},e')$ quasifrei *inklusiv* :

  Schulze und Sauer, Phys. Rev. C48 (1993) 38
- möglicher Einfluß von Kernbindungseffekten



J.M. Laget, Phys. Lett. B273 (1991) 367



J.M. Laget, Phys. Lett. B273 (1991) 367

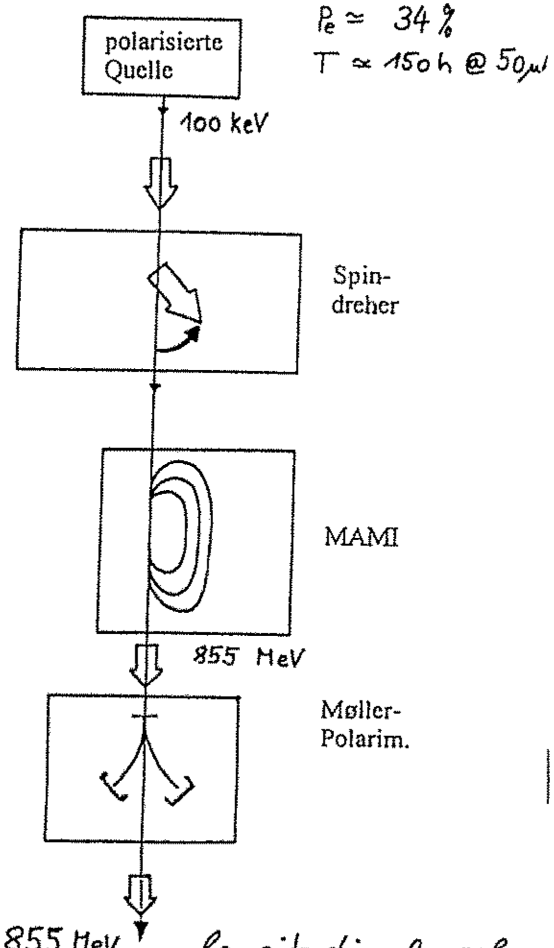
3. A3 - Experimente

- Komponenten für polarisierten Strahl

Dr.-Arbeit
K. Aulenbacher

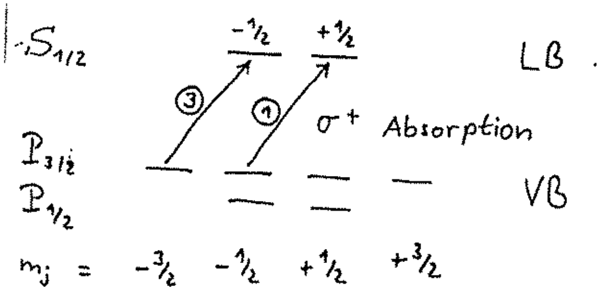
Dr.-Arbeit
K.-H. Steffens
NIM A325 (1993) 378

Dr.-Arbeit
J. Blume-Werry

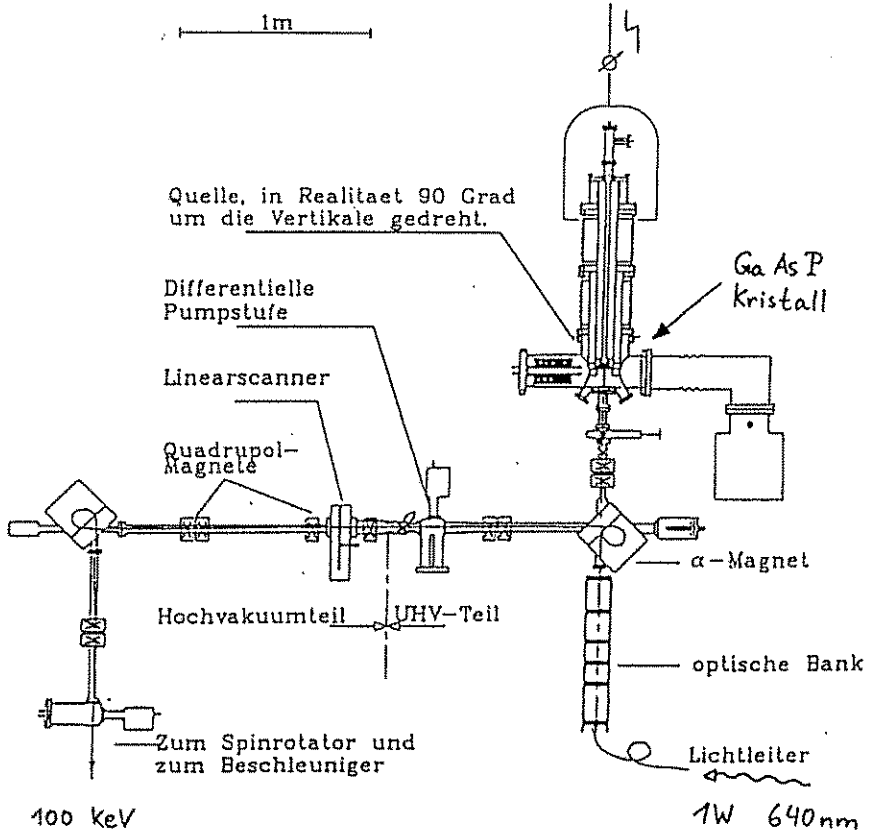


$P_e \simeq 34\,\%$
$T \approx 150\,h$ @ $50\,\mu A$

$i = 5 \ldots 10\,\mu A$ 855 MeV longitudinal pol.



$$P = \frac{N(\frac{1}{2}) - N(-\frac{1}{2})}{N(\frac{1}{2}) + N(-\frac{1}{2})} = \frac{1-3}{1+3} = 50\,\%$$

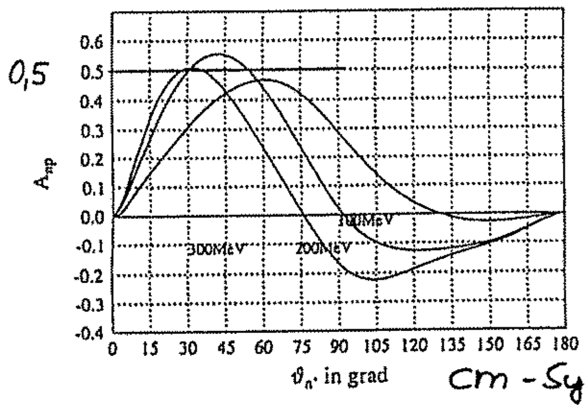


100 KeV
$\simeq 50\,\mu A$

3.1 $^2D(\vec{e}, e'\vec{n})$

$\rightarrow p(\vec{n}, n)$ - Streuung

$\Rightarrow$ Nachweis der n-Polarisation p_x
⊥ zum Impulsübertrag



Analysierstärke am Proton

cm - System

Asymmetrie : $\varepsilon = \frac{n_o - n_u}{n_o + n_u} = p_x \cdot A(\vartheta_{n'}, E_n) \cdot \sin\varphi_{n'}$

- nutze Protonen C_nH_n - Plastikszintillator

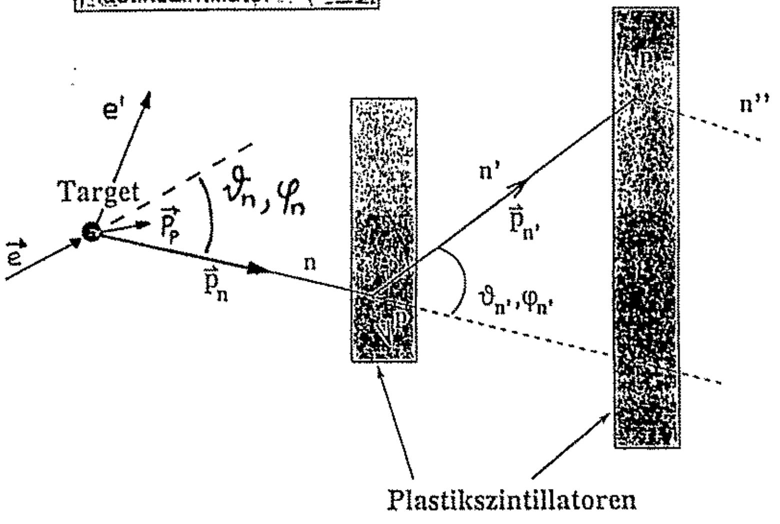
(T. N. Taddeucci et al., NIM A241 (1985) 448)

Vorteil : einfache Vertexbestimmung

Nachteil : "Verdünnung" der Analysierstärke $A \rightarrow A_{eff}$

$\Rightarrow$ Eichung des Polarimeters erforderlich

Polarisationsnachweis im Plastikszintillator



brauche :

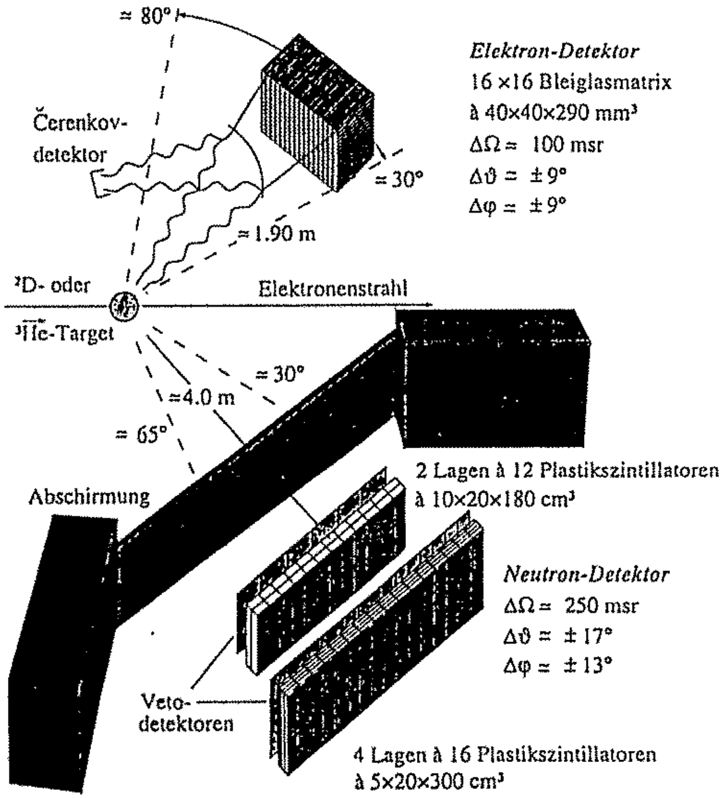
- Vertex 1. Wand } $(\vartheta_{n'}, \varphi_{n'}); (\vartheta_n, \varphi_n)$
- Vertex 2. Wand
- Flugzeit zur 1. Wand → E_n
- E_{recoil} → Anreicherung der n-p-Streuung

$$\begin{array}{rl} 9 & \text{Impulskomponenten} \\ - \; 4 & (E, \vec{p})\text{-Erhaltung} \\ \hline 5 & \end{array}$$

$\Rightarrow$ kinematisch vollständig

wähle : $\boxed{\vartheta_n, \varphi_n, E_n, \vartheta_e, \varphi_e}$ $\curvearrowright$ e^- Kalorimeter

A3 - Detektoraufbau

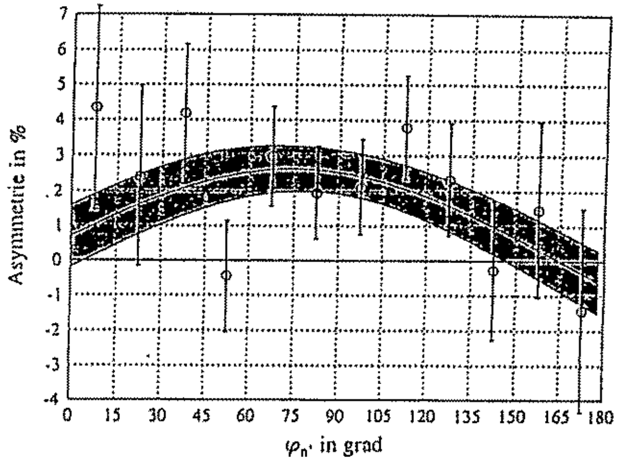


Asymmetrie $\varepsilon = \dfrac{N_o - N_u}{N_o + N_u} = \dfrac{N_o^+ - N_o^-}{N_o^+ + N_o^-} = \dfrac{N_u^- - N_u^+}{N_u^- + N_u^+}$

Redundanz in oben/unten (φ',φ'+π) und Helizität (+,-)

$$\Rightarrow \quad \Re = \sqrt{\frac{N^+(\varphi')\cdot N^-(\varphi'+\pi)}{N^-(\varphi')\cdot N^+(\varphi'+\pi)}} \quad \Rightarrow \quad \varepsilon(\varphi') = \frac{\Re - 1}{\Re + 1}$$

Asymmetrie in $^2D(\vec{e}, e'\vec{n})$:



140 h

15 % Vollausbau

$\varepsilon(\varphi') = \varepsilon_x \sin(\varphi') + \varepsilon_y \cos(\varphi')$

Fit : $\varepsilon_y = (0{,}70 \pm 0{,}89)\%$

$\varepsilon_x = (2{,}53 \pm 0{,}61)\%$ ⟶ nach Anreicherung n-p Streuung

$P_x = \dfrac{1}{A_{eff}} \varepsilon_x$

⇒ ($G_{E,n}$) nach [redacted]

3.2 ${}^{3}\vec{He}(\vec{e},e'\vec{n})$

- Polarimeter im reinen Flugzeitmodus
- fokussierender Luft Cerenkov-Detektor

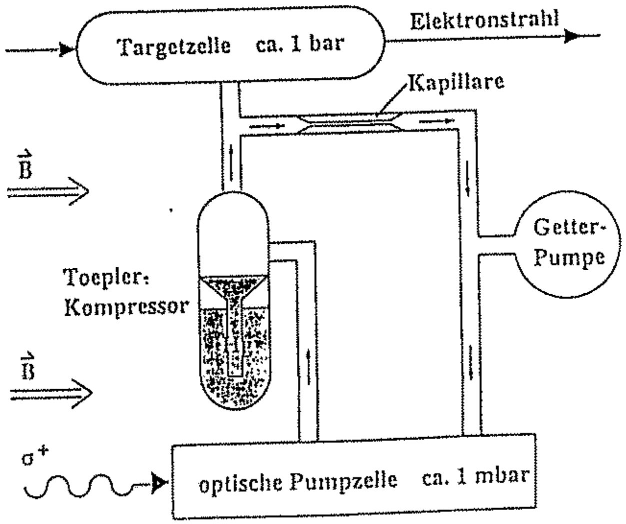
  $\Rightarrow$ L_{Target} = 10 cm eff. → 2,4 · 10^{20} cm^{-2}

- Verhältnismessung $\frac{\varepsilon_{\perp}}{\varepsilon_{\parallel}} \propto \frac{G_{E,n}}{G_{M,n}}$ $\Rightarrow$ Wegfall syst. Fehler !

Polarisiertes ${}^{3}He$-Target

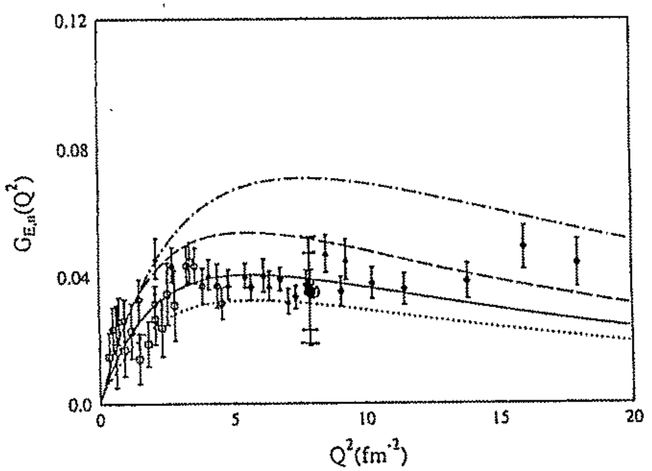
$\bar{P} = 38\%$ @ I = 10 μA

G. Eckert et al.
NIM A320 (1992) 53



Erste Ergebnisse

140 h
~ 15 % Vollausbau Detektor



H. Meyerhoff et al. Phys. Lett. B327 (1994) 2

- $G_{E,n}(Q^2 = 0,31\ GeV^2)$ = 0,035 ± 0,012 stat ± 0,005 syst
- 140 h Strahlzeit @ 10 μA (He) / 4 μA (D)
- $\bar{p}_e$ = 34 %
- ${}^{2}D(\vec{e},e'\vec{n})$ mit Annahme A[illegible] = 50 [illegible]

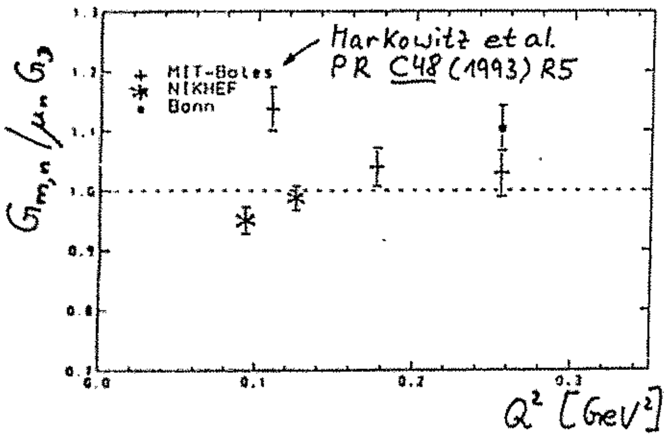
  $\Rightarrow$ $G_{E,n}(Q^2 = 0,3\ GeV^2)$ = 0,066 ± 0,0[illegible]

Dr.-Arbeit A. Frey

Stand des magnetischen Formfaktors $G_{M,n}$

Präzise $G_{M,n}$ - Daten ⇒

- Verhältnismessung $\frac{G_{E,n}}{G_{M,n}}$
- Bestimmung von $F_1^n = \frac{G_{E,n} + \tau G_{M,n}}{1+\tau}$



aus
H. Reike,
Dr.-Arbeit
BN, 1993

neue Daten : J. Jourdan et al., Phys. Lett. (accepted)

J. Jourdan et al. Proposal Kollaboration A1 MAMI (1991)

D(e,e'n) mit
-- genauer Kontrolle der n-Ansprechwahrscheinlichkeit
-- Verhältnismessung $R = \frac{D(e,e'n)}{D(e,e'p)}$

⇒ $G_{M,n}$ mit ≅ 2% Fehler im Bereich $Q^2 = 5 \ldots 20\ \mathrm{fm}^{-2}$

Zusammenfassung & Ausblick

- $G_{E,n}$ bis dato unzulänglich bekannt
- mittlere Q^2 : $G_{E,n}$ aus elastischer D(e,e') Streuung
  - ⇒ stat. Fehler besser als syst.
- Erste A3 - Ergebnisse von MAMI
  - ⇒ kleine systematische Unsicherheit
  - ⇒ noch schwache Statistik
- Vollausbau Detektor abgeschlossen
- Verbesserung der Statistik in D(e,e'n). ab Oktober '94
  - ⇒ $\delta G_{E,n}/G_E$ < 10 %
- Installation eines Magneten zur Drehung der p_z - Komponente
  - ⇒ p_x/p_z - Verhältnismessung in D(e,e'n)
- Beginn Datennahme Anfang 1995

Strangeness-Produktion am LEAR

H. Schmitt
Freiburg

5.Oktober 1994

Strangeness–Produktion am LEAR

Experiment PS185

$$\bar{p}\, p \longrightarrow \bar{Y}\, Y$$

$Y =: \Lambda, \Sigma^0, \Sigma^\pm$

von der Schwelle bis 2 GeV/c

$$\bar{p}\, p \longrightarrow K_S\, K_S$$

von 1,3 bis 1,8 GeV/c

* * *

Experiment PS202 (*JETSET*)

$$\bar{p}\, p \longrightarrow \Phi\, \Phi$$

zwischen 1 und 2 GeV/c

Motivation der Experimente

QCD: *Quarks* mit Farbladungen $\bar{q}$, q

Gluonen g

Hadronen: farbneutrale Zustände

qqq $\bar{q}q$

Aber auch andere ("*exotische*") Zustände:

gg ggg $\bar{q}qg$ $\bar{q}q\bar{q}q$ $\bar{q}qqqq$ etc.

QCD bei kleinem 4-Impulsübertrag nichtperturbativ

-> schwierige mathematische Behandlung (Gitterrechnungen)

Konstituenten Quarkmodell (statisch)

einfach, recht erfolgreich bei Hadronenspektrum

(Massenverhältnisse, magnetische Momente, ...)

Boson-Austauschmodelle (Bonn, Paris, ...)

Gute Beschreibung der N-N-Wechselwirkung (< 300 MeV)

Untersuchung geeigneter Prozesse bei mittleren Energien

PS 185

Beispiel: $\bar{p}\,p \longrightarrow \bar{\Lambda}\,\Lambda$

- "flavour" - Erzeugung $\bar{s}\,s$ – Paar
- kleiner Wirkungsquerschnitt
  $\sigma_{\bar{p}p \to \bar{\Lambda}\Lambda} \leq 10^{-3} \times \sigma_{\bar{p}p\text{-elast; ann}}$
- in Schwellennähe wenige Partialwellen
- hoher Impulstransfer, selbst an der Schwelle ≈ 600 MeV/c ($\approx 3\ \mathrm{fm}^{-1}$)

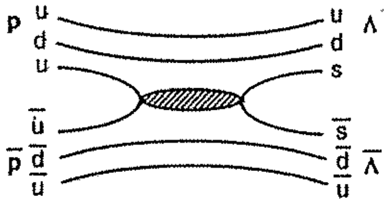
——> sind perturbative Näherungen möglich?

——> wie gut beschreiben die Modelle diesen Prozess?

Zwei komplementäre Beschreibungen

Quark-Bild	**Meson-Austausch Bild**
+ fundamental	- wenig fundamental
- sehr schwierig	+ bewährt bei N-N-Pot. (Bonn, Paris, Nijmegen...)

Quark-Bild

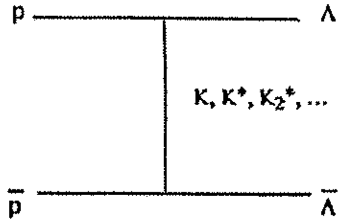


Strangeness - Produktion

(s - Kanal)

Wie sieht das Übergangspotential V_{trans} für den Prozess $u\,u \longrightarrow s\,s$ aus?

Meson-Austausch Bild

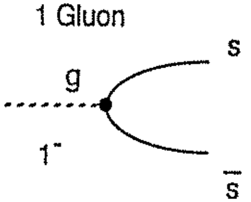


Meson - Austausch

(t - Kanal)

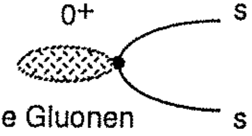
Welche Mesonen sind wichtig? Wie sehen die Kopplungen aus?

"Hochenergie"-Näherung



$^3S_1$-Modell

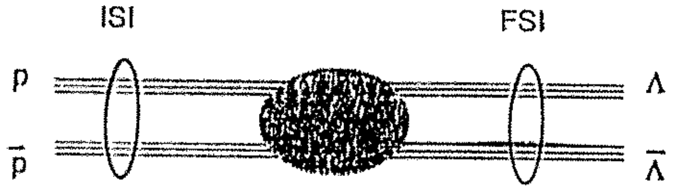
"Niederenergie" - Näherung?



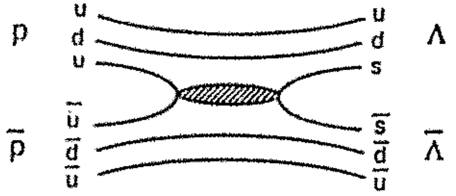
$^3P_0$+ Modell "Vakuum"

Bei allen Modellen

Anfangs- und Endzustands-Wechselwirkung



Spectator - Diquark



I = S = 0

Spinstruktur der Hyperonen ——>

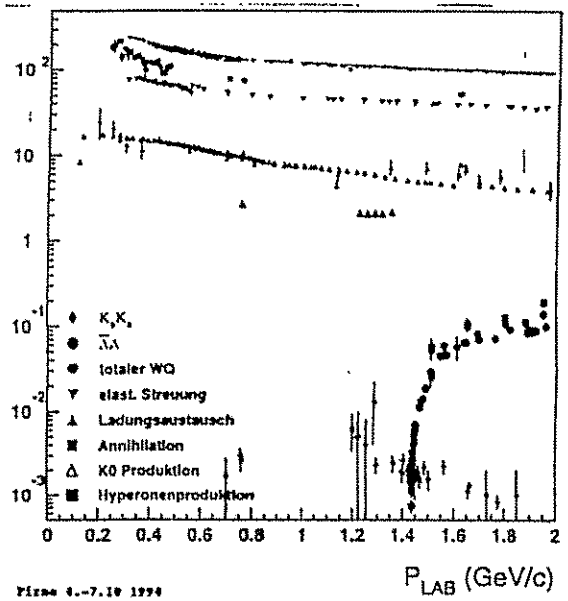
Spinstruktur der **Quarkpaare**

Von PS185 untersuchte Reaktionen

Reaktion	Masse (GeV)	Schwelle (GeV/c)	ct (cm)	Zerfall	%
$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	1,115	1,435	7,89	$p\pi^-$	64,1
				$n\pi^0$	35,7
$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0 +$ cc	1,189	1,653	2,40	$p\pi^0$	51,6
				$n\pi^+$	48,3
$\bar{p}p \rightarrow \overline{\Sigma^+}\Sigma^+$	1,192	1,853	2.10^{-9}	$\Lambda\gamma$	100
$\bar{p}p \rightarrow \overline{\Sigma^-}\Sigma^-$	1,197	1,898	4,43	$n\pi^-$	99,8

Wirkungsquerschnitte ≈ 10^{-3} — 10^{-5}

des totalen $\bar{p}p$ WQ.



PS 185 - Kollaboration

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Experimenteller Aufbau

Zerfalls-Baryonen

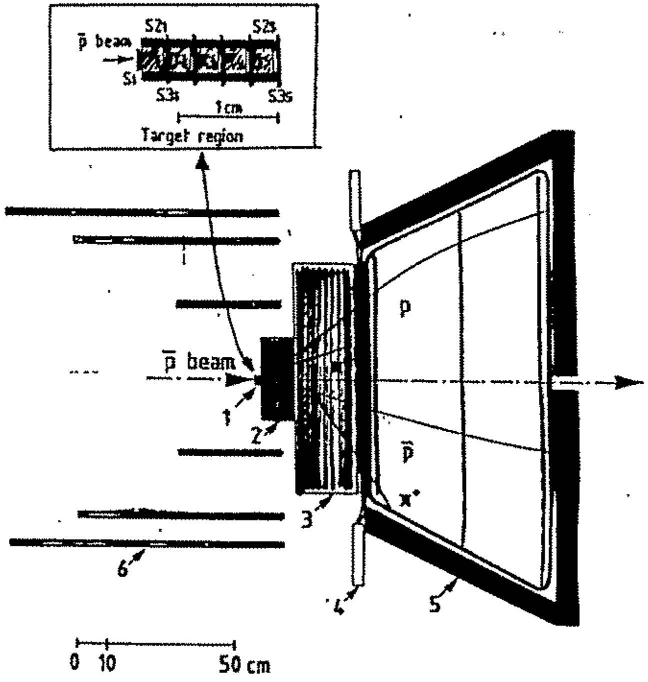
-> Vorwärtskonus

$p\,p \to \bar{\Lambda}\,\Lambda$

$\hookrightarrow p\,\pi^-$

$\longrightarrow n\,\pi^+$

} 42 %

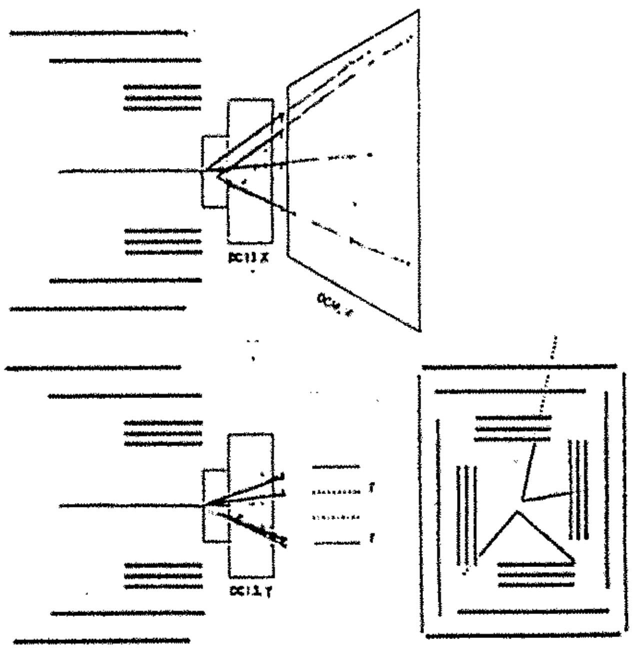


Experimental set-up with : 1 = target, 2 = multiwire proportional chambers, 3 = drift chambers, 4 = scintillator hodoscope, 5 = magnetic solenoid with drift chambers, and 6 = limited streamer tubes.
A "perfect event" $\bar{p}p \to \bar{\Lambda}\Lambda \to \bar{p}\pi^+ p\pi^-$ is indicated.
The target region is given in a magnified view with : T = target cells, and S1, S2, S3 = scintillation counters.

Trigger "Strahl" . "neutral" . "geladen" ($\Lambda\,\Lambda$, $K_S\,K_S$)

"Strahl" . "geladen" . "dE/dx" ($\Sigma\,\Sigma$)

Ein typisches $\bar{\Lambda}\ \Lambda$ – Ereignis



Meßgrößen

$\bar{\Lambda}\ \Lambda$:

differentielle W.Q.	$d\sigma/d\Omega$
integrierte W.Q.	$\sigma = \int d\sigma/d\Omega$
Polarisation	P
Spinkorrelationen	C_{ij}

Hyperonen sind selbstanalysierend durch Paritätsverletzung beim schwachen Zerfall:

$$I(\beta) = I_o\,(1 - \alpha\,\mathbf{P}_\Lambda\,\mathbf{cos}(\beta))$$

$$\alpha = 0{,}64$$

$(\bar{\Lambda}\ \Sigma^o + \overline{\Sigma^o}\ \Lambda)\quad \Sigma^o \;\text{—>}\; \Lambda\,\gamma$:

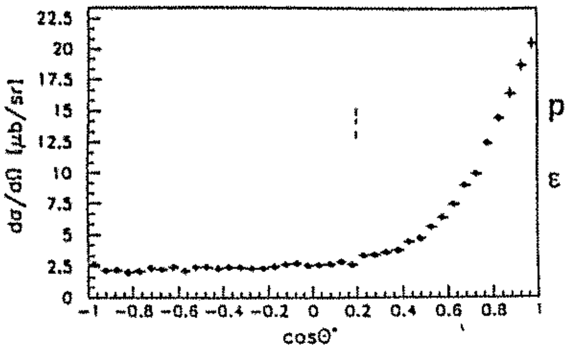
gemessen: $d\sigma/d\Omega$, $\sigma = \int d\sigma/d\Omega$, P

$$\mathbf{P}_\Sigma = \mathbf{3\ P}_\Lambda$$

$\overline{\Sigma^+}\,\Sigma^+ \quad \overline{\Sigma^-}\,\Sigma^-$

$d\sigma/d\Omega$, $\sigma = \int d\sigma/d\Omega$, $\sigma_{\Sigma^+} / \sigma_{\Sigma^-}$

$d\sigma/d\Omega$ ($\bar{\Lambda}\Lambda$)



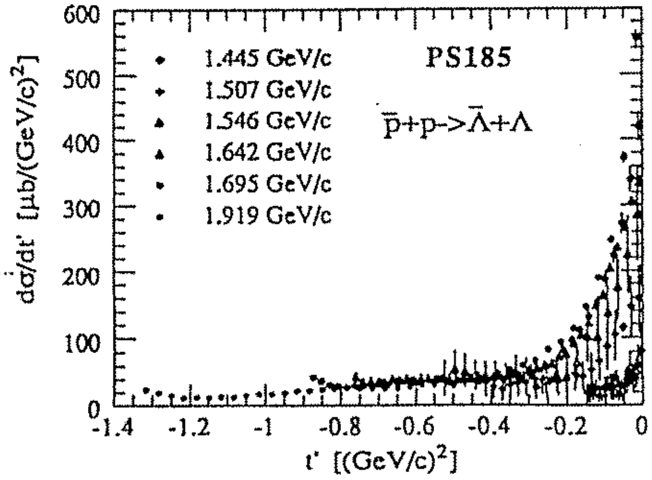
$p_{lab} = 1{,}642$ GeV/c

$\varepsilon = 72{,}9$ MeV

$\varepsilon = \sqrt{s} - 2 \cdot m_\Lambda$ Relativenergie im $\bar{\Lambda}\Lambda$ cm-System

$t' = t - t_0 = 1/2 \cdot \sqrt{(s - 4 \cdot m_p^2)(s - 4 \cdot m_\Lambda^2)}\,(1 - \cos\theta)$

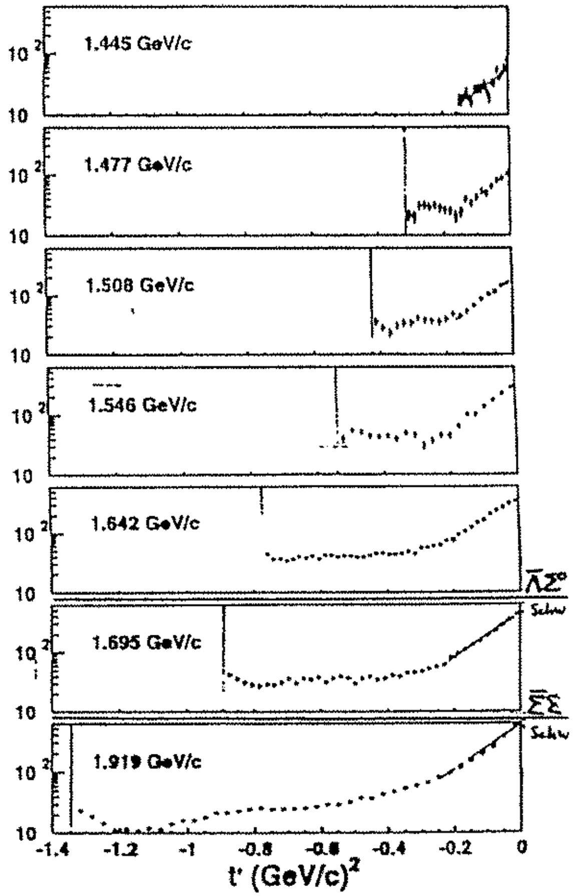
4 - Impulsübertrag



Diff. Wirkungsquerschnitte $\bar{\Lambda}\Lambda$

$d\sigma/dt$

$[\mu b \cdot (GeV/c)^{-2}]$



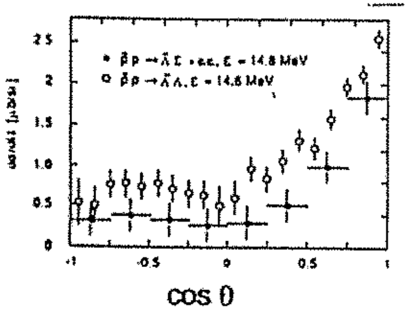
$t' = t - t_{min} \propto \cos\theta$

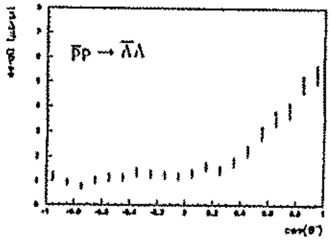
Für $|t'| < 0{,}15\ (GeV/c)^{-2}$: $d\sigma/d\Omega \propto e^{-b\,t'}$,

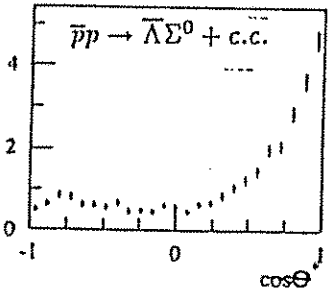
mit $b = 8{,}85\ (GeV/c)^{-2}$

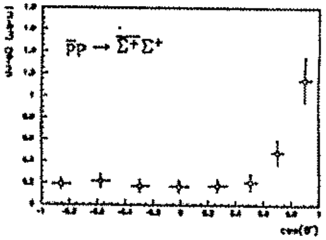
Vergleich der Wirkungsquerschnitte

$\overline{\Lambda}\,\Sigma^o + \ldots$ $\Sigma^+\,\Sigma^+$







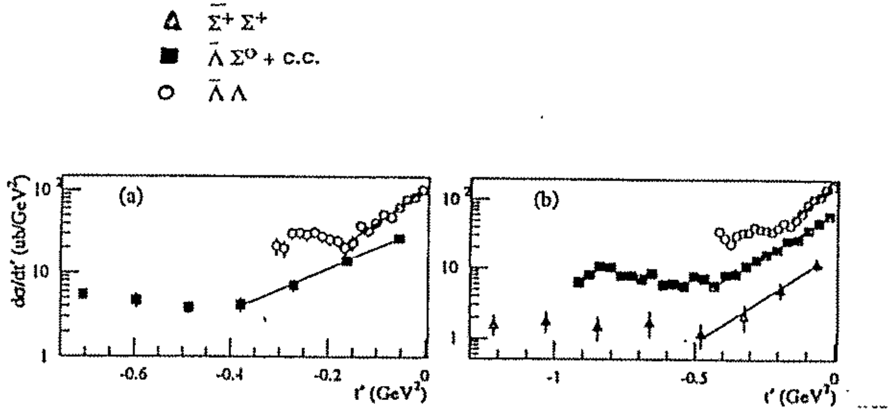


ε = 14,8 MeV

ε = 25 MeV

$\sigma(\overline{\Sigma^+}\,\Sigma^+)/\sigma(\overline{\Sigma^-}\,\Sigma^-) = 2{,}5 \pm 1{,}3$

Vergleich Vorwärtsanstieg



ε = 14,5 MeV   ε = 24,5 MeV

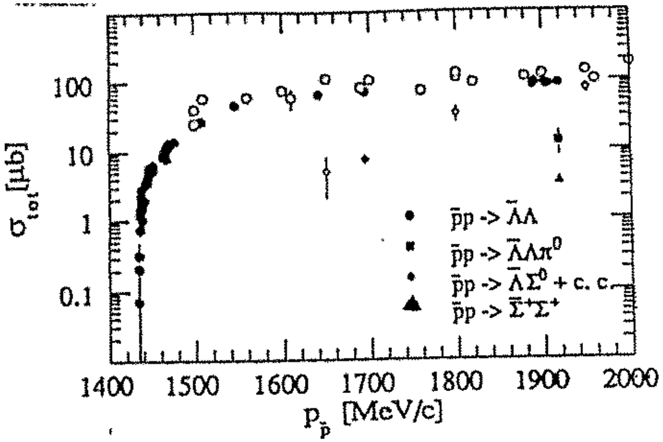
"Streuung an **schwarzer** Scheibe"

$d\sigma/d\Omega \propto e^{-b\,t'} \quad \Rightarrow \quad R = \sqrt{4b}$

$b(\bar{\Lambda}\Lambda) \approx 9\ \text{GeV/c}^{-2} \qquad R_{\bar{\Lambda}\Lambda} \approx 1{,}2\ \text{fm}$

$b(\bar{\Lambda}\Sigma, \bar{\Sigma}\,\Sigma) \approx 6\ \text{GeV/c}^{-2} \qquad R_{\bar{\Lambda}\Sigma, \bar{\Sigma}\Sigma} \approx 1{,}0\ \text{fm}$

Integrierte Wirkungsquerschnitte



Vorhersagen verschiedener Modellrechnungen über Verhältnisse integrierter W.Q.

$\sigma(\bar{\Lambda}\Sigma^0)/\sigma(\bar{\Lambda}\Lambda)$

	Theorie	Experiment
Rubinstein	0,238	0,29 ± 0,02 (ε = 14,8 MeV)
Genz/Tatur	0,259	0,27 ± 0,01 (ε = 25,0 MeV)
Kohno/Weise		
Holinde		

$\sigma(\overline{\Sigma^+}\Sigma^+)/\sigma(\bar{\Lambda}\Lambda)$

Rubinstein	0,18	$0{,}12 \pm 0{,}02\,^{+0{,}06}_{-0{,}02}$
Genz/Tatur	0,33	
Kroll	0,17	(ε = 25,0 MeV)
Holinde	0,13	

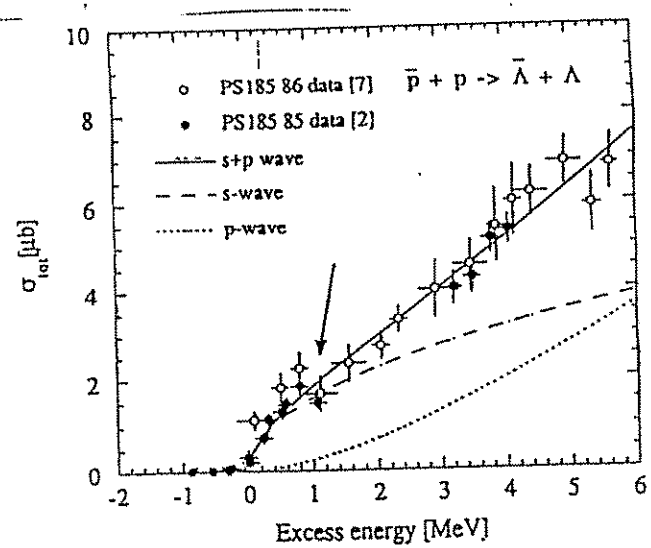
Integrierte $\bar{\Lambda}\Lambda$ Wirkungsquerschnitte an der Schwelle

$$\boxed{\sigma = a_S \cdot \varepsilon^{1/2} + a_P \cdot \varepsilon^{3/2}}$$

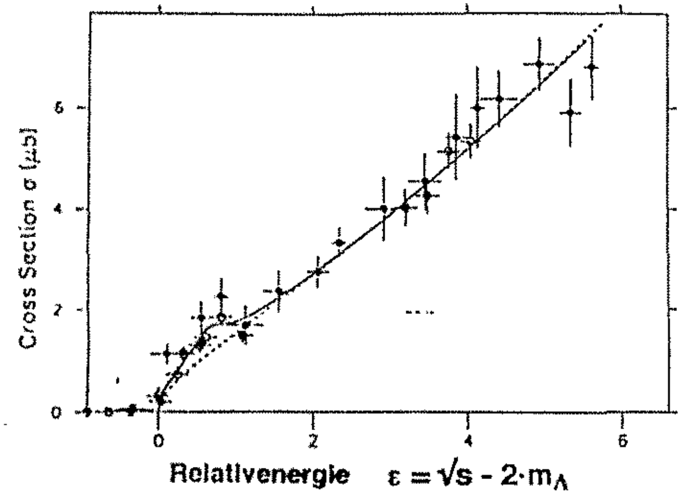
$$a_S = 1{,}18 \pm 0{,}15 \ \text{mb/(MeV)}^{1/2}$$
$$a_P = 0{,}35 \pm 0{,}04 \ \text{mb/(MeV)}^{3/2}$$

p–Welle bereits nahe der Schwelle wichtig

siehe auch Winkelverteilungen



Verhalten von $\sigma(\bar{p}\,p \rightarrow \bar{\Lambda}\,\Lambda)$ in Schwellennähe



- Struktur zwischen ε = 0,5 ... 1,0 **MeV**
- ε_{Res} = **0,64 ± 0,12 MeV**
- Γ_{Res} = **0,59 ± 0,25 MeV**
- **Invariante Masse: 2232 MeV**

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- Stärke : **0,5 μb**

exotischer Zustand? (Glueball, Hybrid, ...)

?

Shapiro et al.: p-Wellen-enhancement

-> **starke, attraktive FSI**

Carbonell + Protasov: schmaler quasi-nuklearer $\bar{\Lambda}\,\Lambda$ - subthreshold Zustand

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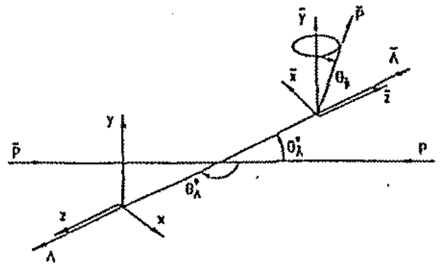
Polarisation der Hyperonen



$$I(\beta) = I_o\,(1 - \alpha\, P_\Lambda \cos(\beta_p))$$

Asymmetrieparameter (Λ) : $\alpha = 0{,}642 \pm 0{,}013$

Zerfallswinkelverteilung der Baryonen
—>Polarisation

Methode der gewichteten Summen:

$$P = \frac{1}{\alpha}\,\frac{\Sigma \cos \Theta y_{(k)}}{\Sigma \cos^2 \Theta y_{(k)}}$$

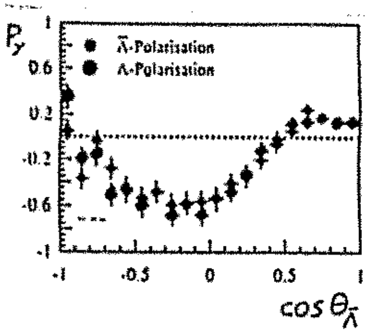
Ebenso Spinkorrelation:

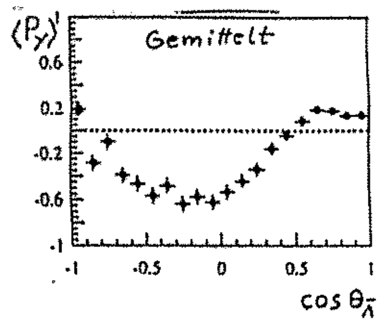
$$C_{ij} = \frac{1}{\alpha\,\alpha} \cdot \frac{1}{N}\;\Sigma \cos \Theta_{i(k)} \cdot \cos \Theta_{j(k)}$$

Summe über alle Ereignisse: K = 1 ... N

Polarisation $\overline{\Lambda}\,\Lambda$

p_{lab} = 1,653 MeV/c

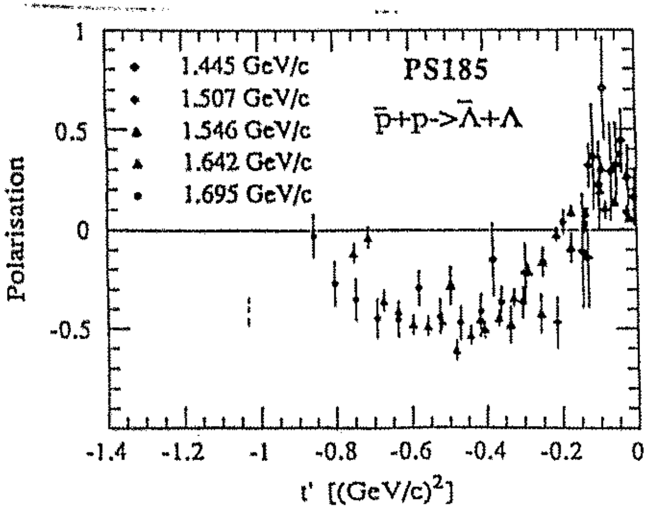




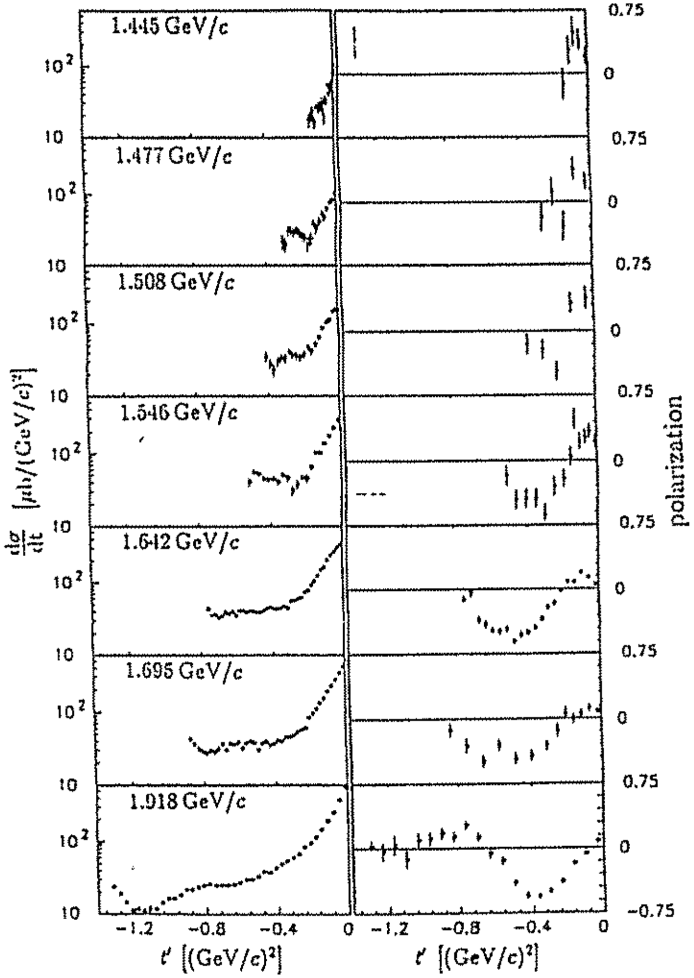
C – Invarianz bei $\overline{\Lambda}\,\Lambda$ – Produktion —> $P_y(\overline{\Lambda}) = P_y(\Lambda)$

CP – Invarianz bei Λ (Λ) Zerfall —> $\overline{\alpha} = -\alpha$

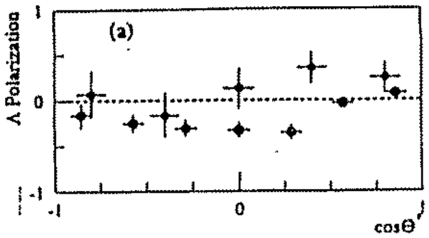
—> Mittelung von $P_y(\overline{\Lambda})$ und $P_y(\Lambda)$



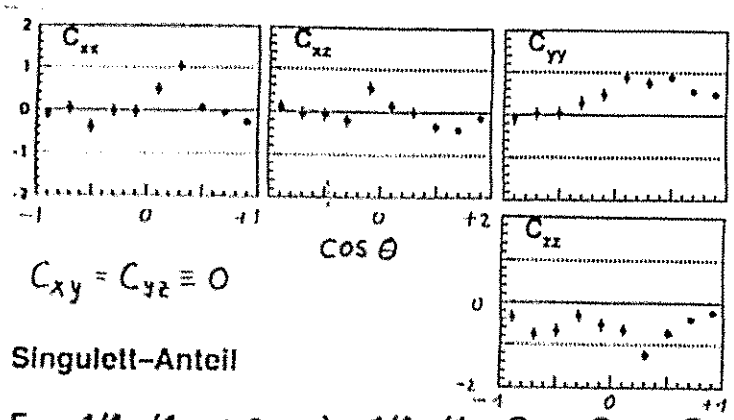
Polarisation $\overline{\Lambda}\,\Lambda$



- $\overline{\Lambda}\,\Sigma^0$ + c.c. 1,726 GeV/c
- $\overline{\Lambda}\,\Lambda$ 1,726 GeV/c



Spinkorrelationen
1,642 MeV/c



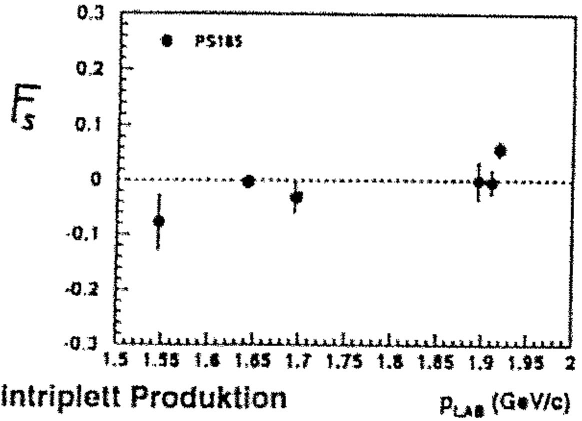
$C_{xy} = C_{yz} \equiv 0$

Singulett-Anteil

$F_S = 1/4 \cdot (1 - \langle \sigma_{\bar{\Lambda}}\, \sigma_{\Lambda} \rangle) = 1/4 \cdot (1 + C_{xx} - C_{yy} + C_{zz})$

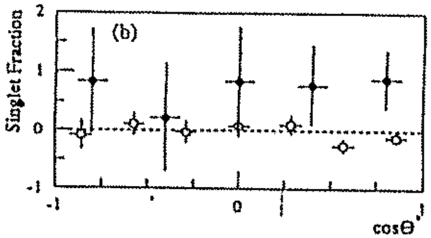
$F_S = 1$ für Singulett Zustand
$F_S = 0$ für Triplett Zustand

Keine Korrelation: —> $F_S = 1/4$



Daten zeigen: Spintriplett Produktion

Spinkorrelationen $\bar{\Lambda}\,\Sigma^0$



1,726 GeV/c

○ $\bar{\Lambda}\,\Lambda$

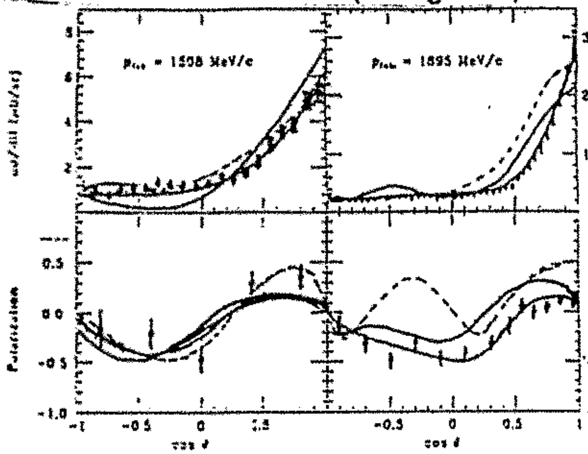
● $\bar{\Lambda}\,\Sigma^0$ + c.c.

Für $\bar{\Lambda}\,\Sigma^0$ + c.c. —> $F_S \neq 0$ (≈ 1)

—> Singulett - Produktion

Vergleiche mit Rechnungen

(Alberg et al.)

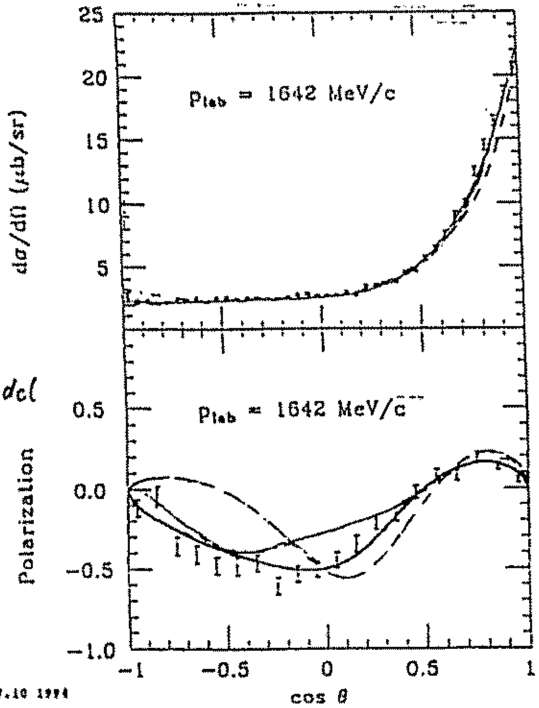


— Alberg…

— Haidenbauer…

— La France…

— Timmermans…



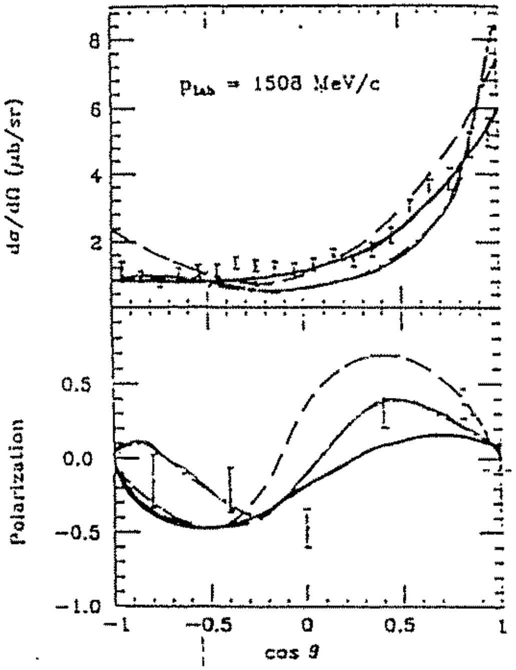
Alberg et. al.

— Vektor

— Skalar

— SV-quark model

Vergleiche mit Rechnungen



— Alberg et al.

— $^3S_1$ - Modell Kohno + Weise

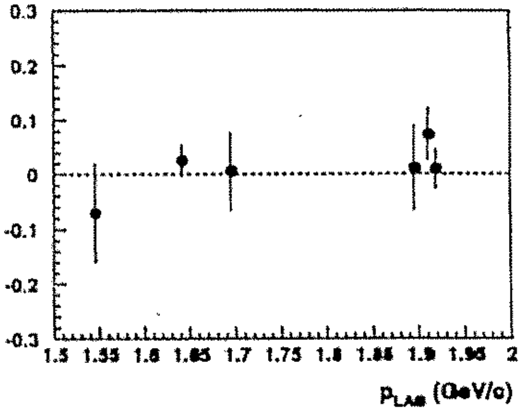
— $^3P_0$ - Modell Furui + Faessler

Weitere Resultate (Nebenprodukte)

CP–Symmetrie

$\alpha_\Lambda = \alpha_{\bar{\Lambda}}$

$$A = \frac{\alpha P_\Lambda + \bar{\alpha} P_{\bar{\Lambda}}}{\alpha P_\Lambda - \bar{\alpha} P_{\bar{\Lambda}}}$$



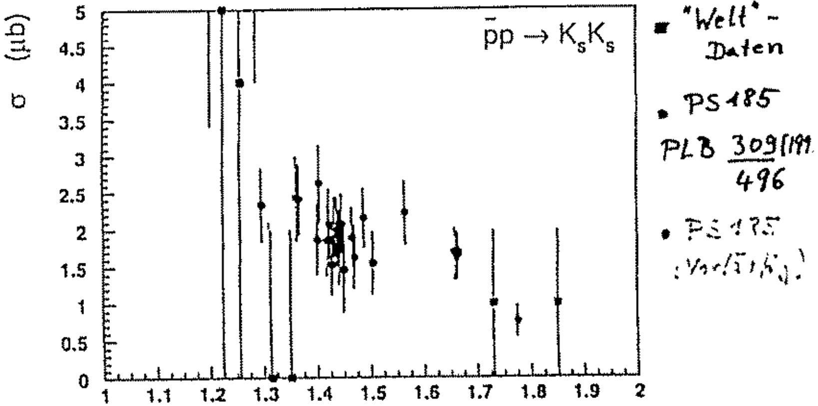
$$\boxed{A = 0{,}022 \pm 0{,}019}$$

Lebensdauern von $\bar{\Lambda}$ und Λ aus Verteilung der Zerfallslängen

$$\boxed{\mathbf{R} = 2\cdot(\tau - \bar{\tau})/(\tau + \bar{\tau}) = (-1{,}8 \pm 6{,}6 \pm 5{,}6)\cdot 10^{-3}}$$

→ CPT – Test

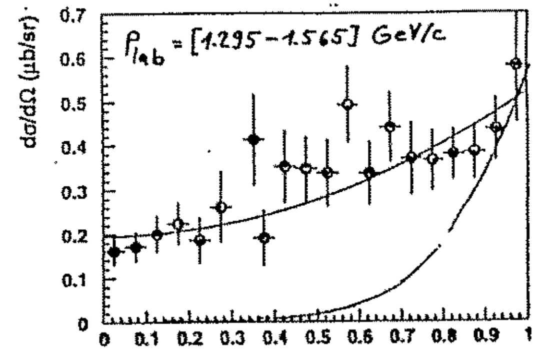
$\bar{p}\,p \longrightarrow$ Ks Ks



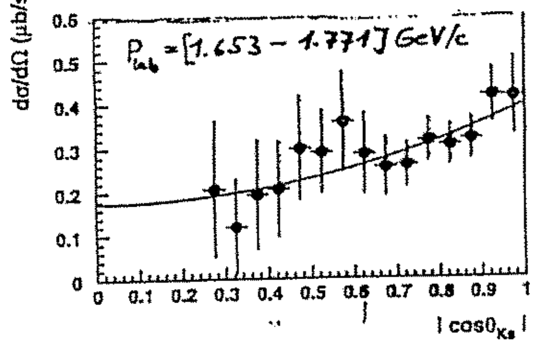
P_{LAB} (GeV/c)

Kein Hinweis auf Resonanz $\bar{p}p \to \xi(2230)/f_4 \to K_sK_s$

B.R. $(\bar{p}p \to \xi) < 0.1\%$



— Girija + Tabakin P.R.C



PS202 (JETSET)

Reaktion ist OZI unterdrückt

→ hoher Gluonen-Anteil im Zwischenzustand (allerdings: auch andere Mechanismen möglich)

→ $\bar{p}\,p \rightarrow \Phi\,\Phi \rightarrow K^+ K^- K^+ K^-$

geeigneter Prozess zur Suche nach exotischen Zuständen

Bisherige Messungen von $\bar{p}\,p \rightarrow \Phi\,\Phi$

1974	Blasenkammer, 6 Ereignisse $\bar{p}\,p \rightarrow 4\,K$ davon eines $\Phi\,\Phi$ (1,6 - 2,2 GeV/c 600 nb)
1989	ISR bei 3,7 GeV/c $\sigma(\bar{p}\,p \rightarrow \Phi\,\Phi) \sim 25$ nb
1986 ff	Glueball - Kandidaten und Resonanzen im Bereich $2{,}04 < m_X > 2{,}43$ GeV von verschiedenen Experimenten:

→ teilweise widersprüchlich, oder schlechte Statistik

$J^{PC} = 2^{++}$ (BNL, WA67)
$J^{P} = 0^{-}$ (MarkIII, DM2)

PS 202 Kollaboration

L. Bertolotto [5], A. Buzzo [5], P. Debevec [6], D. Drijard [2], S. Easo [5], R.A. Eisenstein [6], W. Eyrich [3], T. Fearnley [2], M. Ferro-Luzzi [2], H. Fischer [4], J. Franz [4], R. Geyer [3], N.H. Hamann [2†], P.G. Harris [6], D.W. Hertzog [6], S.A. Hughes [6], A. Johansson [9], T. Johansson [9], R.T. Jones [2], K. Kilian [7], K. Kirsebom [5], A. Klett [4], H. Korsmo [8], M. Lo Vetere [5], M. Macri [5], M. Marinelli [5], M. Moosburger [3], B. Mouëllic [2], W. Oelert [7], S. Ohlsson [2], A. Palano [1], S. Passaggio [5], J.-M.†Perreau [2], M.G. Pia [5], S. Pomp [4], M. Price [2], P.E. Reimer [6], J. Ritter [6], E. Robutti [5], K. Röhrich [7], M. Rook [7], E. Rössle [4], A. Santroni [5], H. Schmitt [4], T. Sefzick [7], O. Steinkamp [7], F. Stinzing [3], B. Stugu [7], R. Tayloe [6], M. Tscheulin [4], H.J. Urban [4], H. Wirth [4] and H. Zipse [4]

1) University of Bari and INFN, Bari, Italy
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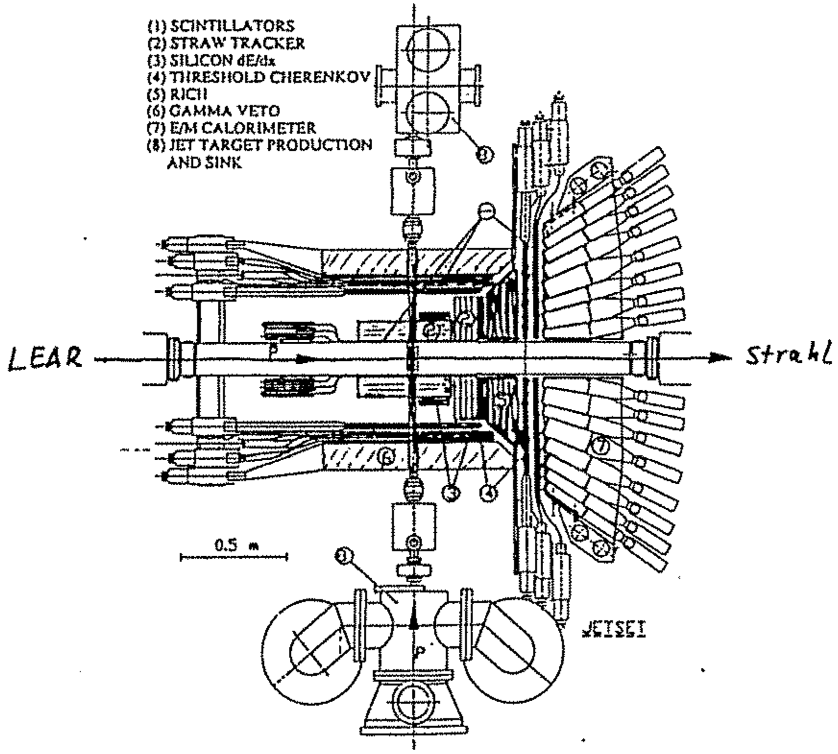
7) *Institut für Kernphysik, Forschungszentrum Jülich, Jülich, Germany*
8) University of Oslo, Oslo, Norway
9) Uppsala University, Uppsala, Sweden
† deceased

Das Experiment



Messungen

Impulsbereich: Schwelle (867 MeV/c) — 2 GeV/c

Nachweis der Φ - Mesonen durch Zerfall $\Phi \rightarrow K^+ K^-$

Kinematik: alle 4 K - Mesonen in Vorwärtsrichtung,
mindestens drei davon mit $\theta_K < 45°$

Trigger:
Plastik-Szint. um Strahlrohr,
Schwellen - Cherenkovzähler
Vorwärts-Plastik-Szint. Hodoskope
E.M. Kalorimeter für γ - Veto

Spurbestimmung durch "straw chambers", zylindrisch um Strahlrohr und in Vorwärtsrichtung

Teilchen - ID mit dE/dx von Silizium-Pads und Cherenkov Zählern

Massenauflösung ≈ 1 MeV in Anregungskurve geg. durch Auflösung des gekühlten LEAR - Strahls

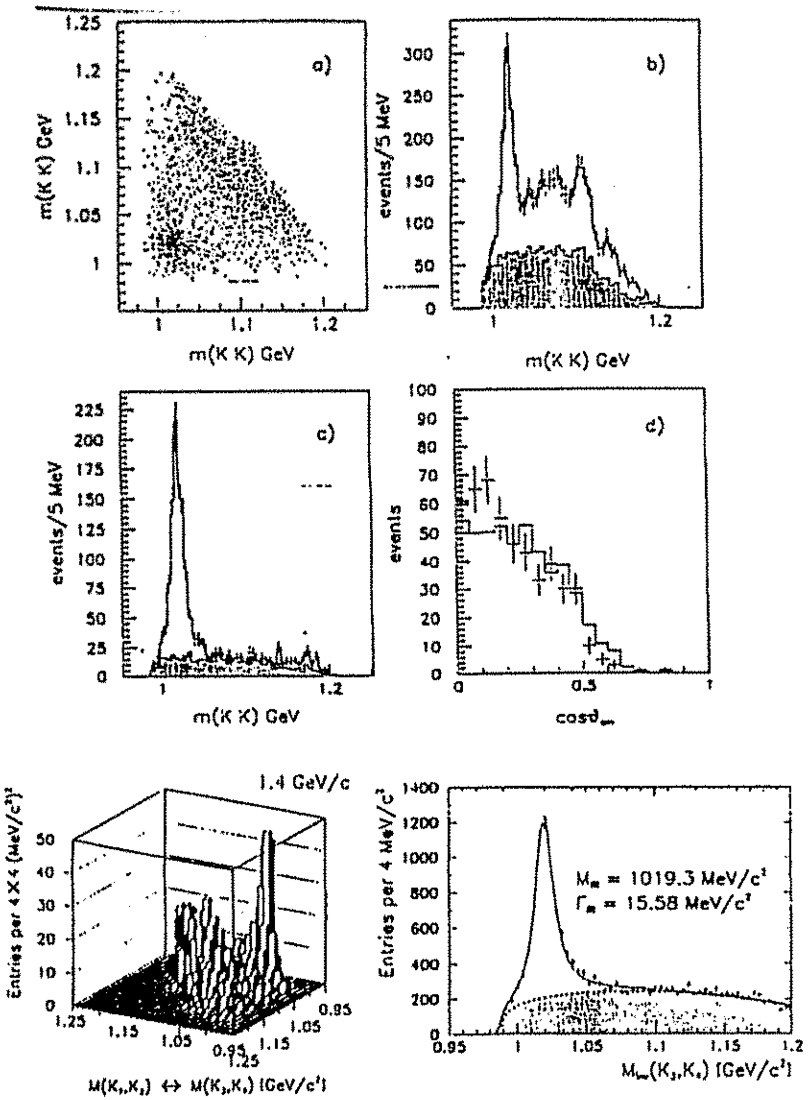
Luminosität Messung der elastischen p p - Streuung

Resultat bei 1.4 GeV/c

$$\boxed{\sigma(\bar{p}\,p \rightarrow \Phi\,\Phi) = 3{,}65 \pm 0{,}27 \pm 0{,}18\ \mu b}$$

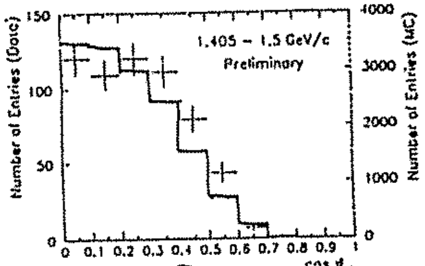
$$\boxed{\sigma(\bar{p}\,p \rightarrow 4\,K^{\pm})/\sigma(\bar{p}\,p \rightarrow \Phi\,\Phi) = 3{,}65 \pm 0{,}27 \pm 0{,}18\ \mu b}$$

ϕ ϕ – Identifizierung

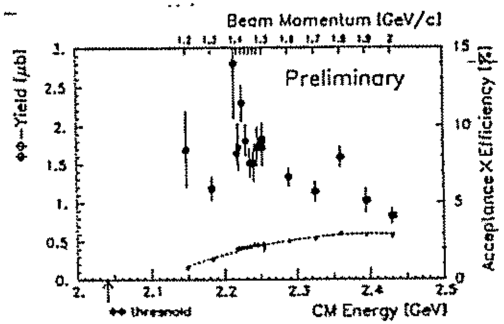


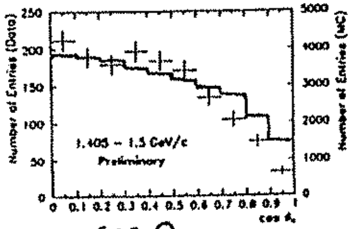
Erste Resultate

(vorläufig!)

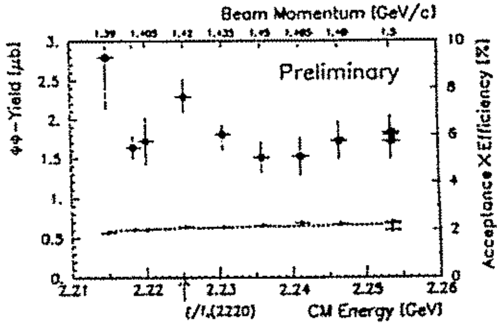


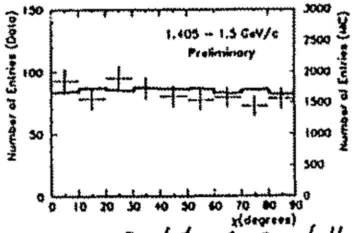
cos Θ





cos Θ$_K$



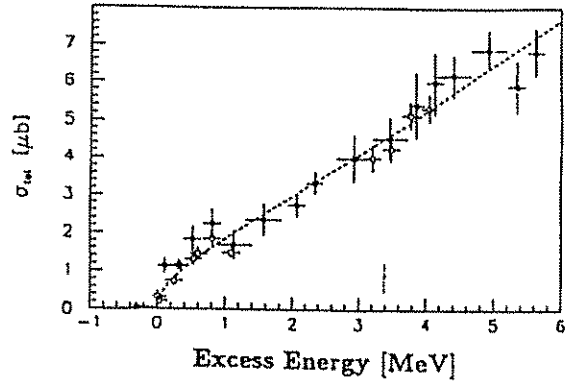


χ (φ$_1$-φ$_2$-Zerfalls-Ebene)

Zusammenfassung

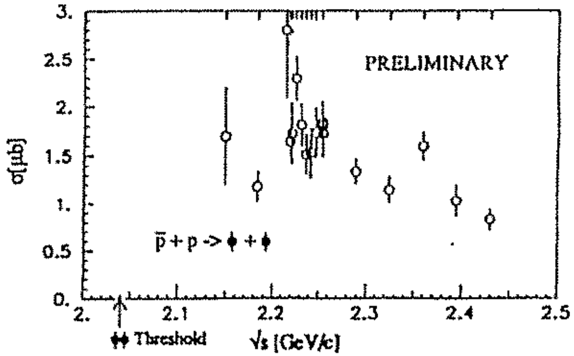
- Strangeness - Produktionsprozesse helfen zum Verständnis der hadronischen Wechselwirkung
  - → Einsichten in Reaktionsmechanismen (Quark, Gluon, Meson, ...)
  - → Fakten für theoretische Entwicklungen
- Konsistentes Bild der $\bar{Y}Y$ - Produktion
  - → p - Welle schon an der Schwelle bei $\bar{\Lambda}\Lambda$
  - → $d\sigma/dt$ zeigt starken Vorwärts-Anstieg ($|t'| < 0{,}15$)
  - → Polarisation positiv für kleine t, dann negativ
  - → $\sigma(\bar{Y}Y)/\sigma(\bar{\Lambda}\Lambda)$-Verhältnis stimmt gut mit Theorie überein
  - → Triplett - Produktion bei $\bar{\Lambda}\Lambda$, Singulett bei $\bar{\Lambda}\Sigma^0$
  - → Zahlreiche theoretische Arbeiten
- Strangeness - Produktionsprozesse geeignet zur Suche nach exotischen Zuständen
  - → "Bump" in $\sigma_{\bar{\Lambda}\Lambda}$?
  - → Kein Signal in $\bar{p}p \rightarrow K_s K_s$
  - → Insbesondere OZI - verbotene Prozesse wie $\bar{p}p \rightarrow \Phi\Phi$ (gluonreicher Zwischenzustand) bieten gute Chancen zur Suche nach Exoten
  - → PS 202 hat Fülle von Daten; Auswertung ist weit fortgeschritten

Ausblick



Neue Messung mit hoher Statistik in Schwellen-Region
→ Juli 1994

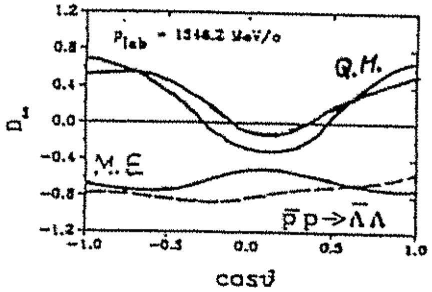
Daten-Analyse in Arbeit



$\bar{p}p \rightarrow \Phi\Phi$

in kleinen Energie - Schritten gemessen

Analyse weit fortgeschritten



Q.H. Quark - Modell

M.E. Meson - Austausch - Modell

Messung von Spintransfer-Parametern mit pol. Target am PS185 - Apparat möglich !

→ 1995 ... 1996

Physik mit Hyperonen
Neues von WA 89

S. Paul
CERN / MPI-Heidelberg

5.Oktober 1994

Physik mit Hyperonen

Neues von WA89*

Stephan PAUL
(MPI-Heidelberg)

* eine Kollaboration

Bristol, CERN, Genua, Grenoble
HD-MPI, HD-Univ, Mainz Uni,
Moskau Lebedev Inst. Rutgers^{94}
Iowa^{93}

physikalische Spielwiese des:
Hyperonstrahlexperimentes WA89:

→ • charmant seltsame Baryonen

- Spektroskopie
- Produktion
- Lebensdauern
- Verzweigungsverhältnisse
- Semileptonische Zerfälle

• Seltsame Exoten

$U: \Lambda\bar{p}\,(+n\pi)$ $M \sim 3.1\ \mathrm{GeV}/c^2$ $sq\bar{q}\bar{q}$

$H: \left.\begin{matrix}\Xi^- p \\ \Lambda\Lambda\end{matrix}\right\}$ Ergebnisse auf Konferenzen vorgestellt $ssuudd$

$\Sigma^+\Sigma^-$
$\Sigma^- p$
$\Lambda p \pi^-$
Λn

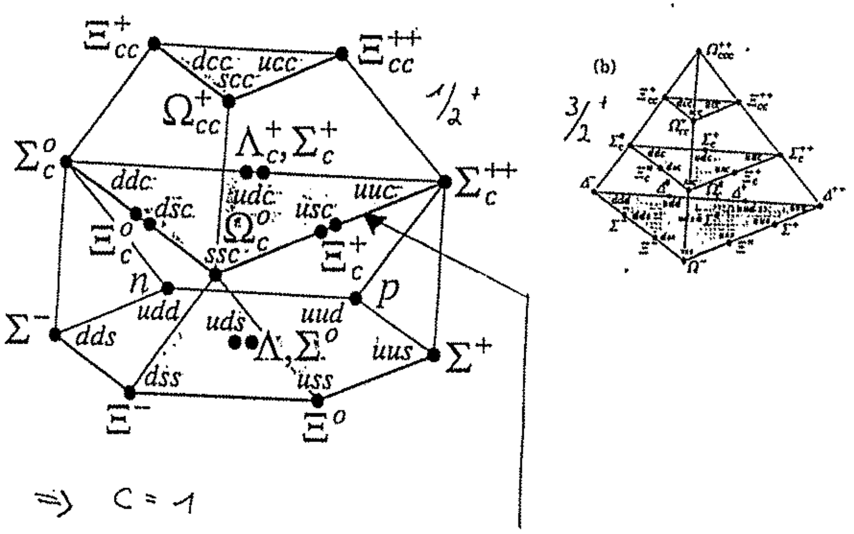
Pentaquark $c\bar{q}\,qqq$

• Hyperon Polarisation (Zeitschr. f. Physik A)

• Hyperon Resonanzen

- Einleitung
- Experimenteller Aufbau
  Datenanalyse
- Produktionsphenomene für
  charmante Baryonen
- Zerfallseigenschaften
  charmanter seltsamer Baryonen
- Spektroskopie
- Ausblick

Nomenklatur SU(4)



$\Rightarrow$ C = 1

Notation

$\underbrace{q-q}_{}-c$
a-symmetrisch
Λ_c^+

$\underbrace{q-q}_{}-c$
symmetrisch
Σ_c Triplett

$\underbrace{q-s}_{}-c$
a-symmetrisch
Ξ_c^A

$\underbrace{q-s}_{}-c$
symmetrisch
Ξ_c^s Dublett

$\underbrace{s-s}_{}-c.$
symmetrisch
Ω_c

Physik mit Charm

- 20 Jahre nach Entdeckung weiter attraktiv

$m_c \sim 1.5\ GeV/c^2$

- ↳ naiv: Einfluß leichter Freiheitsgrade in hadronischer Umgebung klein

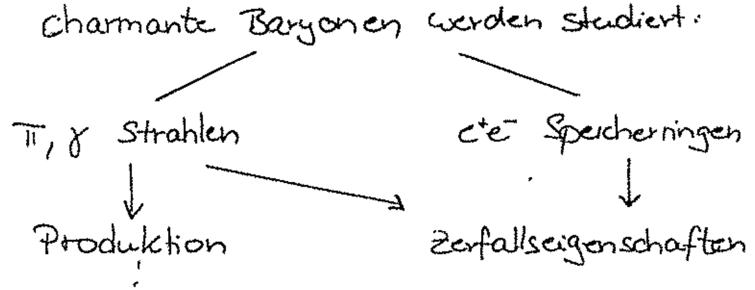
Produktion	Zerfall
⇒ Verteilung der kinematischen Variablen unabhängig von Projektil und Endzustand	Zerfall des hadron charakterisiert durch "freien" Zerfall v. c-Quark: $\tau_{hadron} \sim \tau_c$

- ABER

aus Mesonstrahlen: Projektileffekt existiert bei großen Sekundärimpulsen	$\tau_{D^+}/\tau_{D^0} \sim 2$ $\tau_{D}/\tau_{\Lambda_c} \sim 6$

- Vielfältigste Studienobjekte: charmante Baryonen

Produktion


charmante Baryonen werden studiert:

π, γ Strahlen

e^+e^- Speicherringen

Produktion

Zerfallseigenschaften

- c-Produktion scheinbar verstanden (frühe Resultate m. Baryonstrahlen störend)

γ-Prod.: NLO QCD beschreibt Daten "gut"

π-Prod: Modell notwendig (LUND) für 'langreichweitige' Effekte wie 'leading particle' Effekt.

- 'langreichweitige' Effekte in Baryonstrahlen stärker:

↳ $\Sigma^-(dds)$

Zerfälle

↳ Verständnis der starken W.W. in schwachen Zerfällen

- Bestimmung der Lebensdauern

	s	c	b	
$\frac{\Delta\tau}{\tau}$:	100	10	1	Variation in Familie

↑ Effekt der starken W.W.

τ_i Vorhersage: $\Omega_c^0 \le \underbrace{\Xi_c^0 \le \Lambda_c^+ \le \Xi_c^+ < D, D_s}_{\text{Messungen existieren}}$

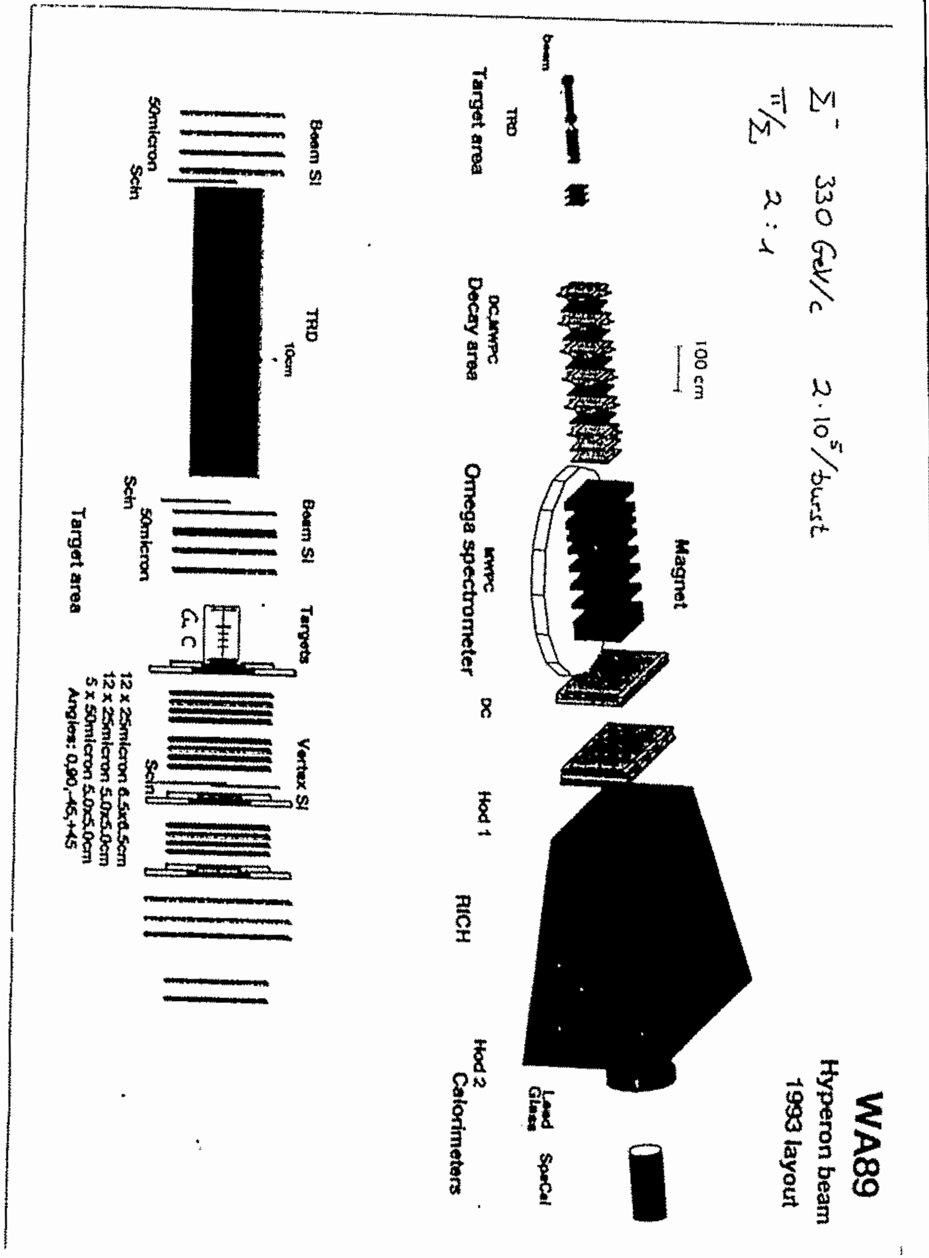
- Verzweigungsverhältnisse vieler Endzustände

  verschiedene Quark Diagramme für verschiedene charmante Baryonen in unterschiedlichen Endzuständen

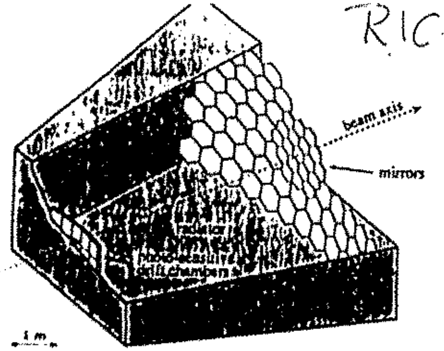
  Problem: keine absoluten Zerfallsraten

- Semileptonische Zerfälle stellen Bindeglied dar

  theoretisch recht verläßlich bestimmbar



RICH



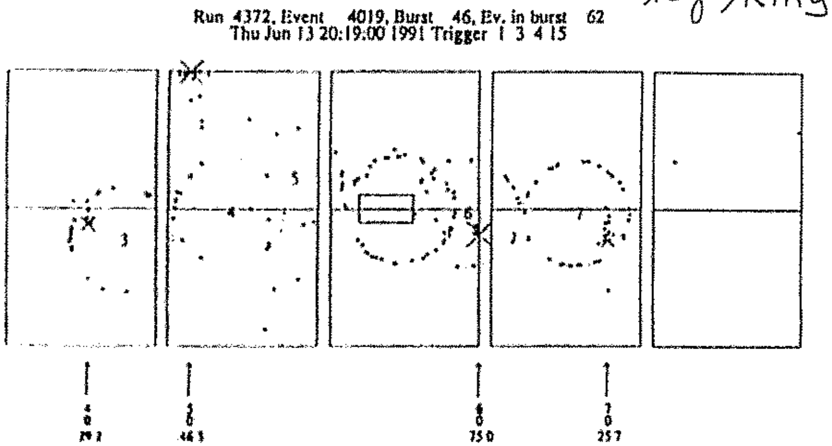
threshold $\gamma \approx 41$

$P_\pi \sim 6$ GeV/c

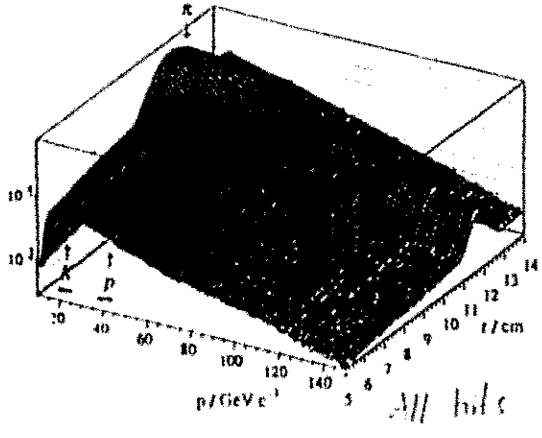
$K \sim 20$ GeV/c

$p \sim 40$ GeV/c

15 γ/Ring



Ringzentren über Spurparameter vorhergesagt



All hits

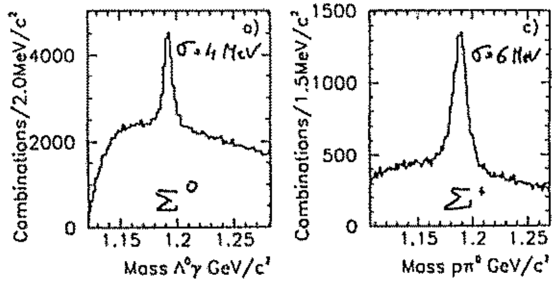
Trennung:

$K/\pi \leq 100$ GeV/c

$P/\pi \leq 150$ GeV/c

E. M. Bleiglas

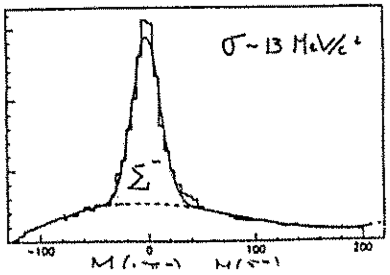
γ
- acceptance ≤ 30 mrad
- Energieauflösung $\frac{\sigma_E}{E} \sim \frac{5\%}{\sqrt{E}} + 2\%$
- Winkelauflösung 0.3 mrad



$\Lambda\gamma$ $\quad$ $p\pi^0$

Hadron Kalorimeter (Spaghetti TYP)

n
- acceptance ≤ 1.5 mrad
- Energieauflösung (hadr.) $\frac{\sigma_E}{E} \sim \frac{31\%}{\sqrt{E}} + 1\%$
- Winkelauflösung ≈ 1 mrad



Analyse

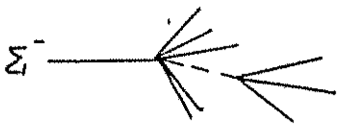
- 3 Strahlzeiten 1991 ~ 10^8 Ereignisse rekonstr.

  verbesserter Aufbau 1993 ~ $2\cdot 10^8$

  → vorläufige Resultate von 15% - 80% der Daten

  1994 ~ $3\cdot 10^8$ Ereignisse auf Band

- charm :
  - Teilchenidentifikation Λ, Ξ, Ω via Zerfall
  - p $K^\pm$ via RICH (wenn in Akzeptanz)
  - topologische Schnitte



- prim sekundär vtx . $\Delta x > n\sigma$
  σ [300 - 700 μm]
  n abhängig von Zerfall
- Impakt . < 100 - 200 μm
- Isolierter Vtx (vor allem für '91 Daten)

Produktion

Nicht pertubativ	pertubativ	Nicht pertubativ
Quarks, Gluonen in Hadronen	gg-Fusion $q\bar{q}$-Annihilation	Hadronisierung
Strukturfunktionen	$\sqrt{x_1 x_2 s}$	langreichweitige Korrelationen

$$\begin{array}{ccccccccccccc}
\Sigma_c^{++} & & \overset{\Sigma_c^{+}}{\Lambda_c^{+}} & & \Sigma_c^{0} & & \Sigma & & \Xi_c^{0} & & \Xi_c^{+} & & \Omega_c^{0} \\
u & & u & & d & - & d & & c & & c & & c \\
u & & d & - & d & - & d & + & d & & u & & s \\
c & & c & & c & & s & + & s & - & s & - & s
\end{array}$$

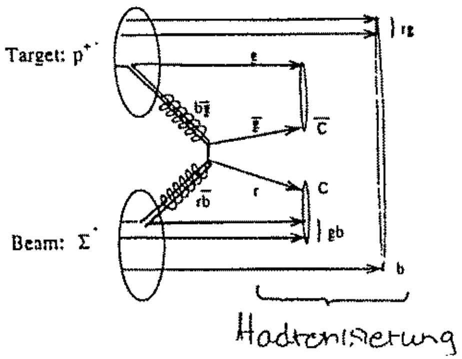
QCD : Vorhersage von σ für Elementarprozess

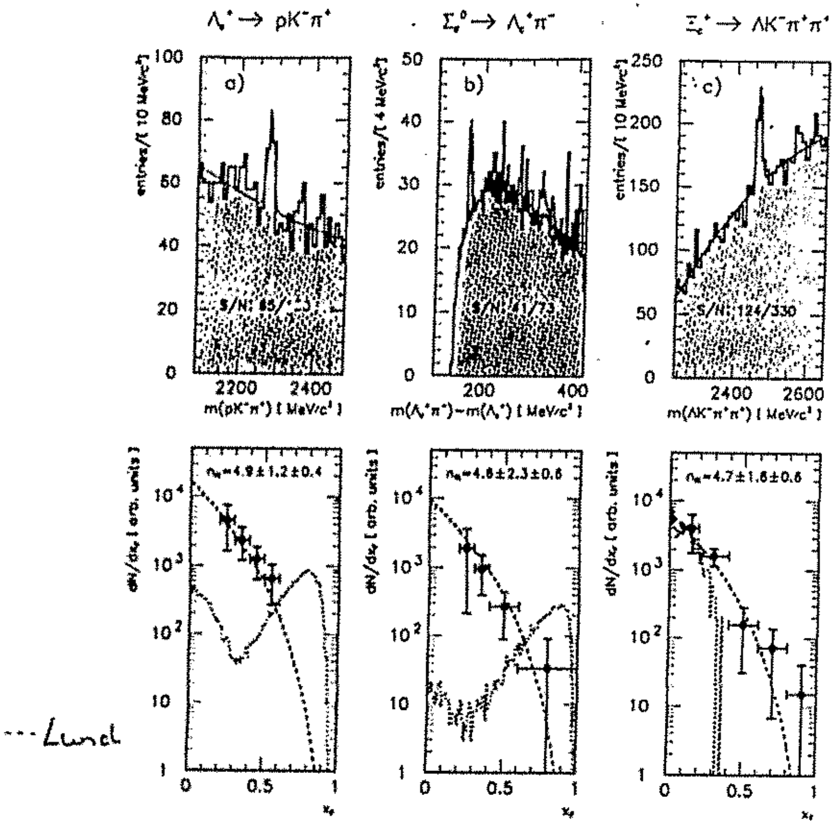
LUND :

Hadronisierung

'leading' Effekt via

Farb-Korrelationen





$$\frac{d\sigma}{dx_f} = A \cdot (1-x_f)^n \qquad x_f \quad \frac{2P_{\parallel}^{cm}}{\sqrt{s}}$$

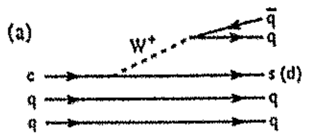
- n: erwartet
  - groß für "non leading"
  - klein für " leading "
- gemessen:
  - Keine Abhängigkeit

- differentielle Verteilungen noch nicht schlüssig
- integrierte Produktionsraten $x_f \geq 0.2$

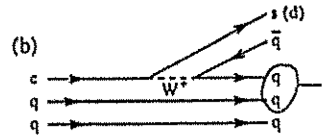
	WA89	Lund Modell
• Σ_c^0/Σ^{++}	> 1.9 (90% C.L.)	33
• $\Sigma_c^0/\Lambda^+_{c\,(\text{primär})}$	1.64 ± 60%	.95
• D^-/D^+	2.1 ± .9	1.2
π^- Strahl	1.1	
• Λ_c^+/D^-	11.3 ± 7	0.58
π^- Strahl	umgedreht	

Zerfälle

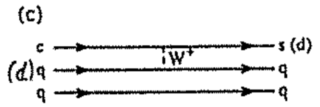
Verzweigungsverhältnisse & Lebensdauern



freier Quarkzerfall
(S.L. Zerfall)



interner Zerfall
— Interferenz



W - Austausch
(nur mit d-Quark)
Λ_c^+, Ξ_c^0

Amplituden a-c → Lebensdauern

Amplituden a-c → Hadronisierung → Verzweigungsverhältnisse

Daten 1991:

Beispiel für zwei analoge Zerfälle
von $\Xi_c^+ - \Xi_c^0$

Lebensdauermessung
↓

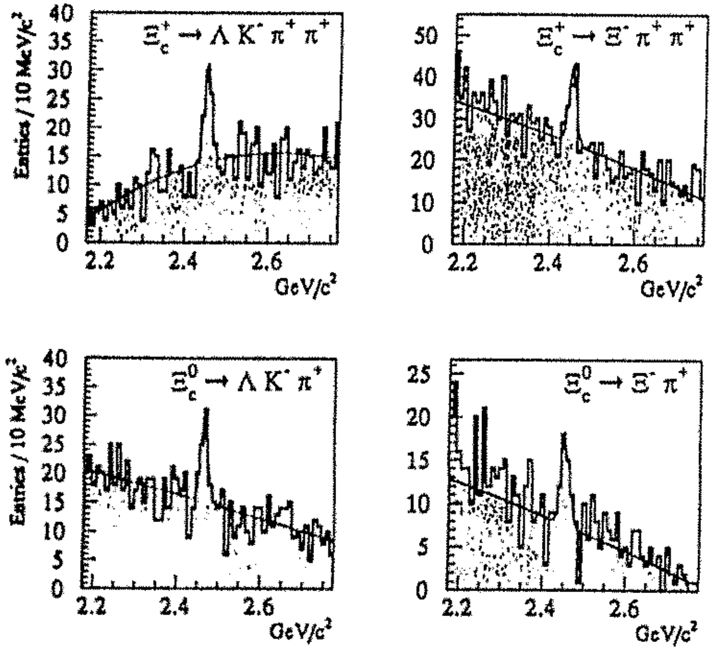
↗ erste Beobachtung

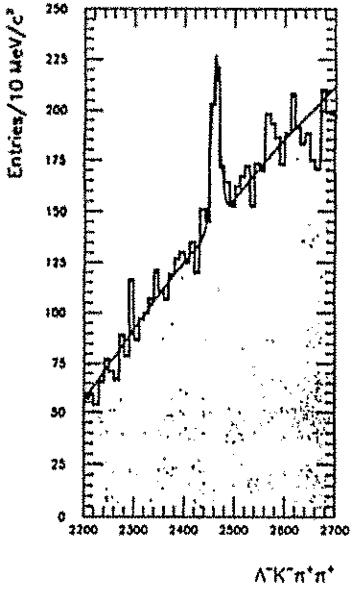
! verschiedene Schnitte für alle Signale aus 1993:

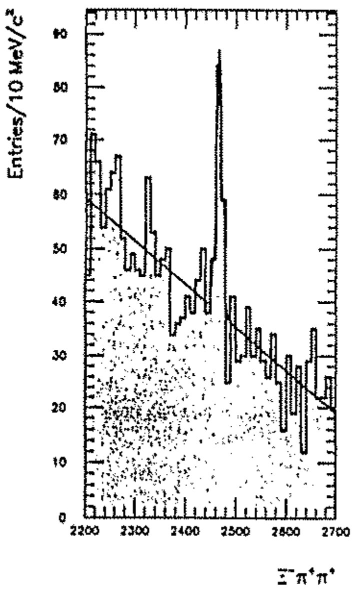
Ξ_c^+

ca 15% der Daten

ca 60% der Daten







Bestimmung einiger Verzweigungsverhältnisse:

nur Ξ_c^+ (1993)

- W-Austausch abwesend

  ↳ Y^* im Endzustand unterdrückt da kein Spinflip via W

- Messung: $\Xi_c^+ \to \underbrace{\Lambda \pi^+}_{\Sigma^*_{1385}} \underbrace{K^- \pi^+}_{K^{0*}_{892}}$

  a) b)

  a) $\frac{\Sigma^* K^- \pi^+}{\Lambda K^- \pi^+ \pi^+} \leq 0.33$ (90% C.L.) $0^{+.7}_{-0}$

  b) $\frac{\Lambda K^{0*} \pi^+}{\Lambda K^- \pi^+ \pi^+} \leq 0.9$ (90% C.L.) $.38 \pm .38 \pm .15$

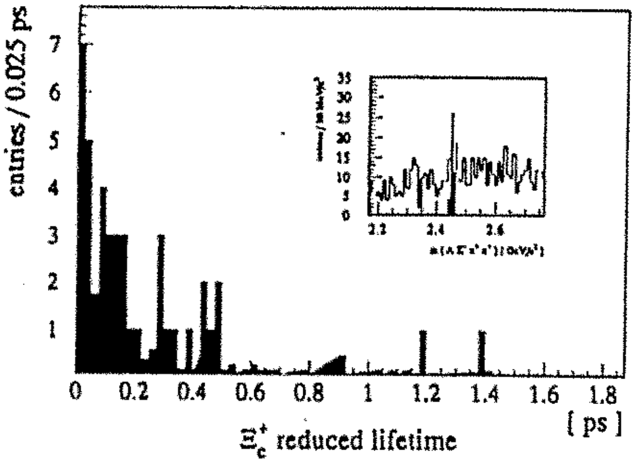
- Messung: Ξ_c^+ $\frac{\Lambda K^- \pi^+ \pi^+}{\Xi^- \pi^+ \pi^+} \sim 4 \pm ?$

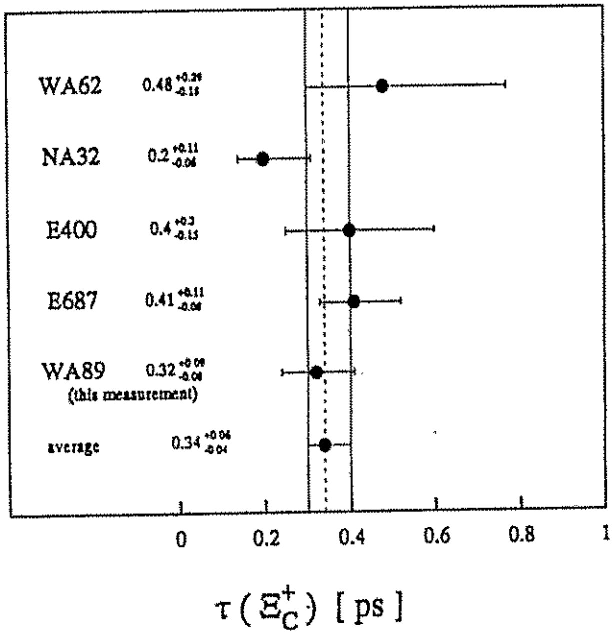
  $c \to s$ großer Rückstoß auf s

  ↳ Kleine Bindungseffizienz in Baryon

  ↳ s-Quark zieht K vor

- Methode: "binned likelihood fit"
- Schnitte: nur absolute Separation
  $X_{Zerfall} - X_{target}$ > gut simulierbar
- Fitparameter: n_{Signal}, τ_{Signal}, $n_{Untergrund}$
  Lebensdauerverti. des Untergrundes
  aus Seitenbändern

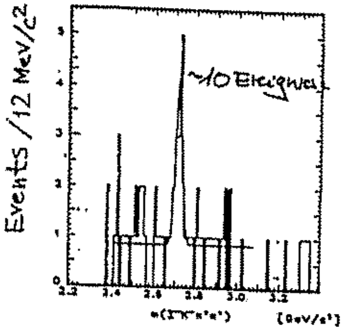




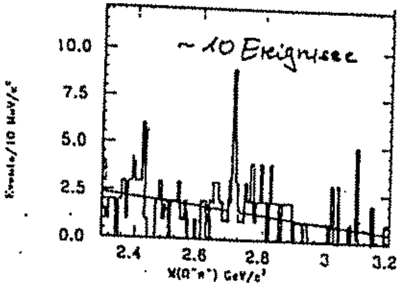
- $\tau_{\Xi_c^+} = 0.32^{+.09}_{-.08} \pm 0.05$ ps (noch vorläufig)
  Effekt der M.C. Korrektur ~ 10%
- für $\tau_{\Lambda_c^+} = 0.18$
  Effekt der M.C. Korrektur ~ 15-20%

Ω_c^0 (SSC)

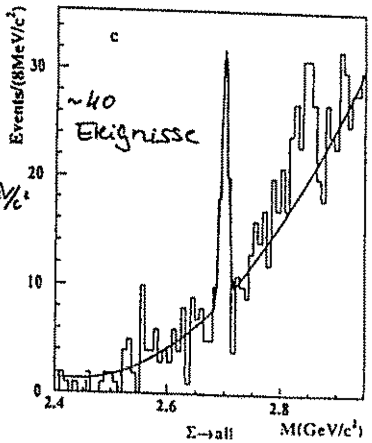
- 1985 WA62 Σ^--Strahl
  $\Xi^- K^- \pi^+ \pi^+$ ~ 3 Ereignisse
  2740 ± 20 MeV/c^2



- 1992 Argus e^+e^-
  $\Xi^- K^- \pi^+ \pi^+$
  $2719 \pm 7.0 \pm 2.5$ MeV/c^2
  ~~CLEO~~

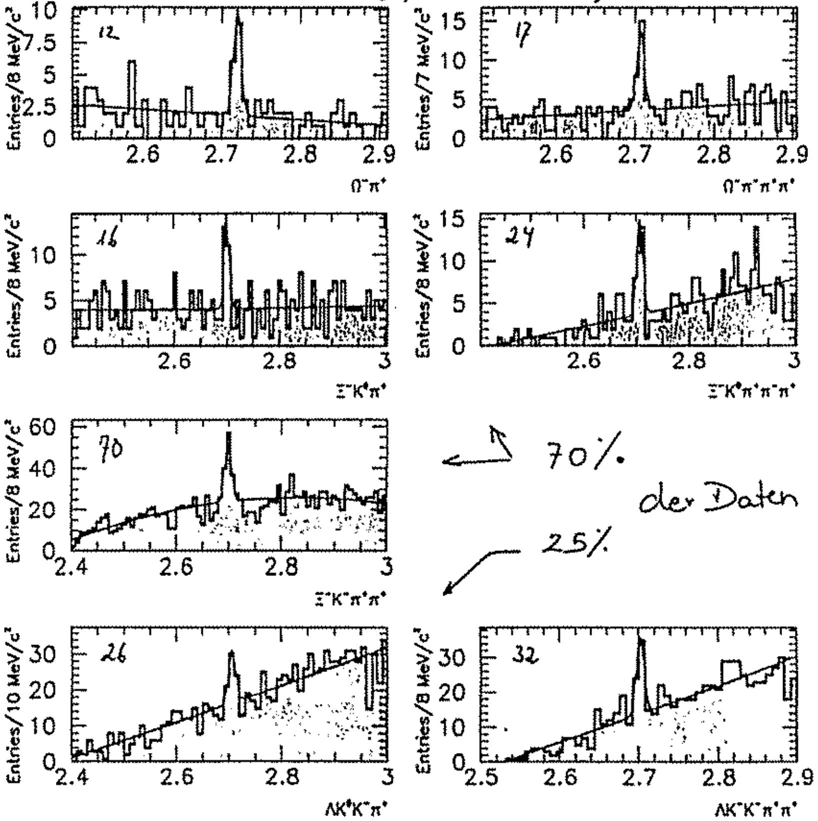


- 1993 E687 γ-Strahl
  $\Omega^- \pi^+$
  $2705.9 \pm 3.3 \pm 2$



Neu
- 1994 E687 γ-Strahl
  $\Sigma^+ K^- K^- \pi^+$
  $2699.9 \pm 1.5 \pm 2.5$ MeV/c^2

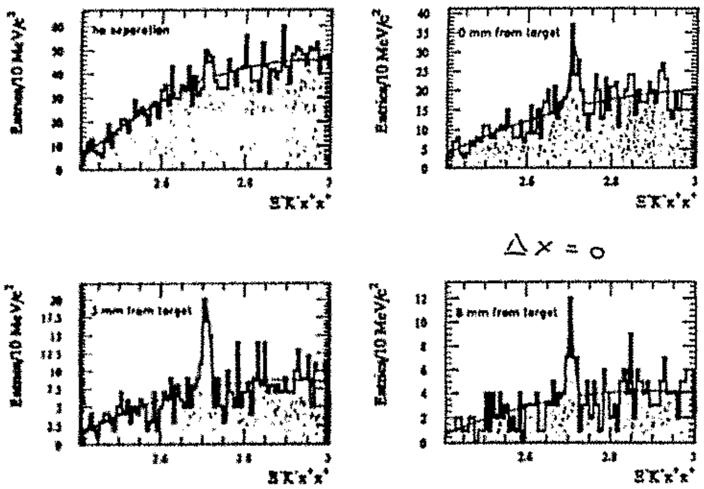
WA89 Ω_c preliminary



Total ~ 190 Kandidaten
M ~ 2704 MeV/c^2

K. mm Ξ τ

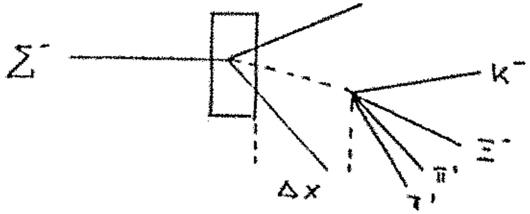
WA89 Ω_c lifetime studies from Cu-target



$\Delta x = 0$

$\Delta x = 3mm$

$\Delta x = 8$ mm

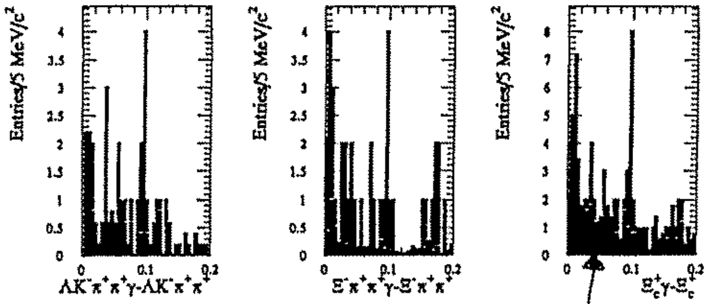


$\Delta x = 8mm$
$\hat{=} \bar{\tau} \cdot 4ps$

Spektroskopie:

- Ξ_c Wellenfunktion $q{\uparrow}s{\downarrow}c$
  multiplett Partner $q{\uparrow}s{\uparrow}c$ + Mischung

  $\Delta m(\Xi_c' - \Xi_c) = \Delta m(\uparrow\uparrow - \uparrow\downarrow) \sim 80\text{-}140 MeV/c^2$



1991

Ξ_c Seitenband

- Wie : $\Xi_c^+ \longrightarrow \Lambda K^- \pi^+ \pi^+$ $+ \gamma$
  $\longrightarrow \Xi^- \pi^+ \pi^+$

Diskriminierung des niederenergetischen
γ- Untergrundes durch
Schnitte auf Zerfallswinkel

Erster Hinweis auf $\Xi_c^{+\prime}$
noch nichts für $\Xi_c^{0\prime}$

Ausblick

93. 94 Daten:

Produktion : Vergleiche D, D_s

Λ_c^+ $\Sigma_c^{0,+,++}$

$\Xi_c^{+,0}$, Ξ_c'

Ω_c

Zerfall : viele 100 Ereignisse in dominanten Zerfallskanälen

Lebensdauer : Λ_c^+, Ξ_c^+, Ξ_c^0, Ω_c^0 limitiert durch Systematik

Spektroskopie : Anzeichen für Σ_c^* bereits jetzt.
Keine Grenzen ...

Exotika Antwort auf die Jackpot frage
u oder K

Zukunft : . Neues Experiment am CERN
1997 - 2000
> 50 × Intensität

?

FORSCHUNGSZENTRUM
ROSSENDORF e.V.

FZR

FZR-63
November 1994

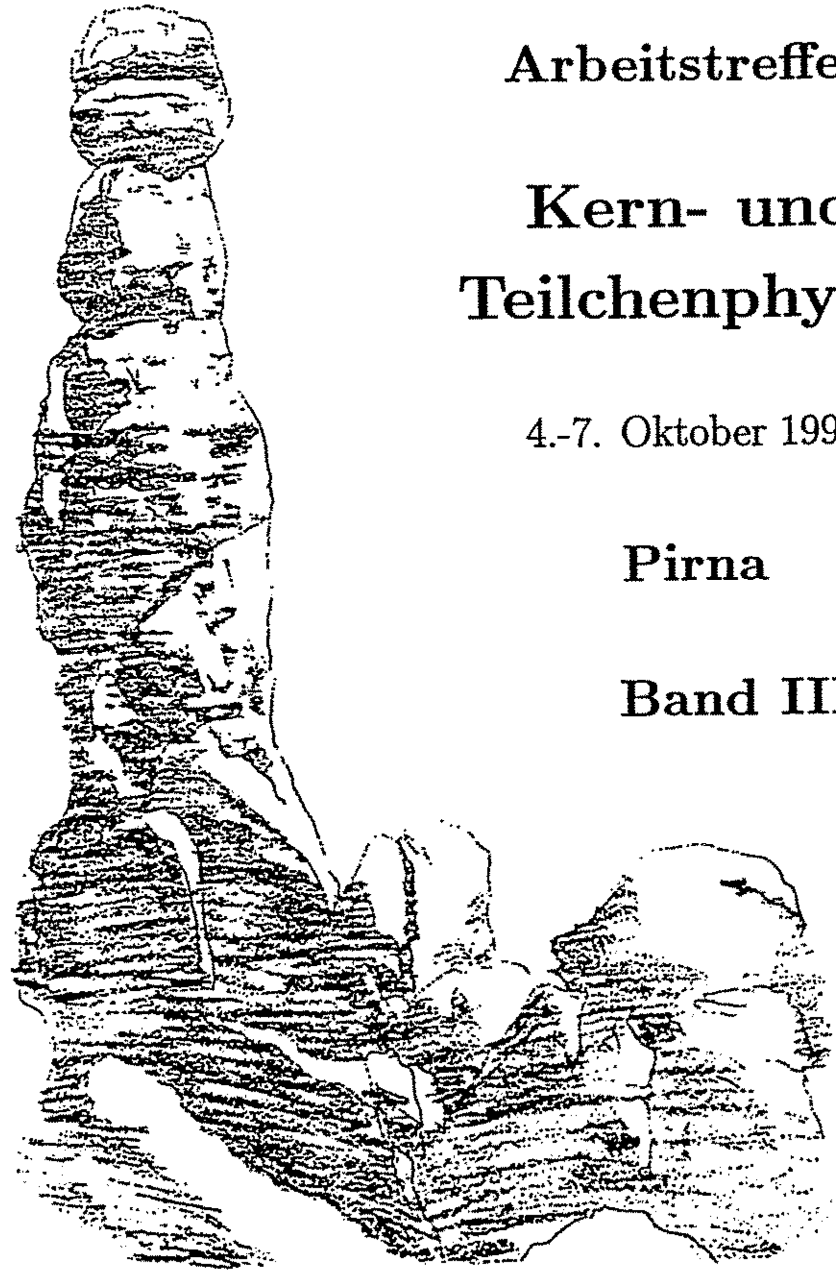
Arbeitstreffen

Kern- und Teilchenphysik

4.-7. Oktober 1994

Pirna

Band III



" Barbarine " - Elbsandsteingebirge

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Telefax (0351) 591 3700
E-Mail pirna@fz-rossendorf.de

Programm des Arbeitstreffens "Kern- und Teilchenphysik 1994" in Pirna

Band I Dienstag, 4. Oktober 1994

Band II Mittwoch, 5. Oktober 1994

Band III Donnerstag, 6. Oktober 1994

Band IV Freitag, 7. Oktober 1994

Spinstruktur des Nukleons
Ergebnisse der Spin Myon Collaboration am CERN

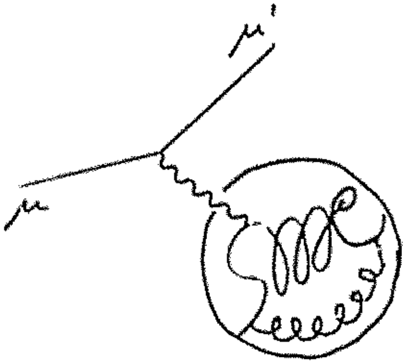
G. Mallot
CERN / Uni Mainz

6.Oktober 1994

SPINSTRUKTUR DES NUKLEONS

ERGEBNISSE DER

SPIN MUON COLLABORATION
AM CERN



G.K. MALLOT
UNIV. MAINZ
PIRNA, 6.10. '94

THE NUCLEON SPIN PUZZLE

- THE NUCLEON SPIN IS BUILT-UP BY
  - $\Delta\Sigma$ THE SPINS OF QUARKS & ANTIQUARKS
  - Δg THE GLUON SPINS AND
  - L_z ANGULAR MOMENTUM

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma_1 + \Delta g + L_z$$

- NAÏVE QUARK PARTON MODEL

  LARGE CONTRIBUTION FROM QUARK SPINS

  $\Delta\Sigma_1 \sim 0.6$ (SEA QUARKS UNPOLARISED)

- EMC MEASUREMENT 1985 pub. 1988/89 PLB 328 (1989) 1

  proton: $\Delta\Sigma_1 = 0.12 \pm 0.17$

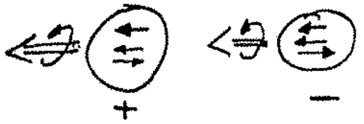
  QUARK SPINS CONTRIBUTE LITTLE TO NUCLEON SPIN.

  STRANGE QUARKS ARE POLARIZED OPPOSITELY TO PROTON

  $$\Delta s = -0.19 \pm 0.06$$

QUARK POLARIZATION ΔΣ

- $\Delta\Sigma = \Delta u + \Delta d + \Delta s$
  with
  $\Delta q = q^+ + \bar{q}^+ - q^- - \bar{q}^-$



- $m s^\mu \Delta q = \langle ps|\bar{\psi}_R \gamma^\mu \psi_R|ps\rangle - \langle ps|\bar{\psi}_L \gamma^\mu \psi_L|ps\rangle$
  WITH $\gamma_5 = (1+\frac{\gamma_5}{2}) - (1-\frac{\gamma_5}{2})$
  $= \langle ps|\bar{\psi}\gamma^\mu\gamma_5\psi|ps\rangle$

  MATRIX ELEMENT OF AXIAL VECTOR CURRENT

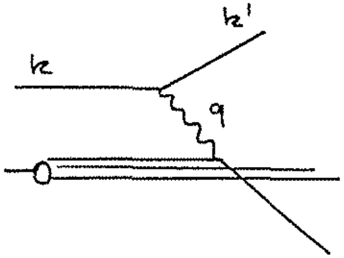
  $\Delta\Sigma$ AXIAL CHARGE (FLAVOUR SINGLET)

- AXIAL ANOMALY CAN MODIFY ΔΣ

$$\Delta q' = \Delta q - \frac{\alpha_s}{2\pi}\underbrace{\Delta g}_{\text{GLUON POLARIZATION}}$$

NEED LARGE $\Delta g \sim 4$ TO RECONCILE EMC & $\Delta\Sigma \sim 0.6$.
DIRECT MEASUREMENT VERY DIFFICULT

DEEP INELASTIC CHARGED LEPTON SCATTERING



$x_{Bj} \overset{lab}{=} \frac{Q^2}{2m\nu}$; $Q^2 = -q^2$
$\nu = E - E'$

x_{Bj}: momentum fraction carried by struck q

- CAN MEASURE g_1 STRUCTURE FUNCTION
  QPM: $g_1(x) = \frac{1}{2}\sum_{i=1}^{N_f} e_i^2 \left(q_i^+(x) - q_i^-(x)\right)$
  POLARIZED TARGET & BEAM NEEDED
  C.F. UNPOLARIZED
  $F_1(x) = \frac{1}{2}\sum_i e_i^2 \left(q_i^+(x) + q_i^-(x)\right)$

- FIRST MOMENT OF g_1

$$\Gamma_1 := \int_0^1 g_1(x)\,dx$$

- TO GET ΔΣ NEED TO INTEGRATE
  (EXTRAPOLATE TO $x=0$, $x=1$)
  AND MORE INPUT TO DEAL WITH FACTOR e_i^2

SUM RULES FOR $\Gamma_1 = \int g_1(x)\,dx$

Bjorken Sum Rule 1966

proton – neutron $\Delta u^n = \Delta d^p$, etc.

FUNDAMENTAL SR; CONSEQUENCE OF QCD & ISOSPIN SYM.

$$\Gamma_1^p - \Gamma_1^n = \frac{1}{18}\left\{ \begin{array}{l} 4\Delta u + \Delta d + \Delta s \\ - \Delta u - 4\Delta d - \Delta s \end{array} \right\}$$

$$= \frac{1}{6}\underbrace{(\Delta u - \Delta d)}_{|g_A^{n\to p}| = 1.257 \pm 0.003}$$

QCD CORRECTIONS $\mathcal{O}(\alpha_s^3)$, estimates $\mathcal{O}(\alpha_s^4)$

LARIN, VERMASEREN PLB 259 (1991) 345; KATAEV CERN-TH 7190/94

Ellis-Jaffe Sum Rule 1974

$$\Gamma_1^{p,n} = \pm\frac{1}{12}(\Delta u - \Delta d) + \frac{1}{36}(\Delta u + \Delta d - 2\Delta s) + \frac{1}{9}(\Delta u + \Delta d + \Delta s)$$

$$= \pm\frac{1}{12}|g_A| + \frac{1}{36}a_8 + \frac{1}{9}\Delta\Sigma$$

SU(3) sym in weak decays in Baryon Octet $n\to p,\ \Sigma\to n$; $\Lambda\to p,\ \Xi\to\Lambda$

$\rightarrow a_8 = 3F - D \sim 0.579 \pm 0.025$

QCD CORRECTIONS $\mathcal{O}(\alpha_s^2)$, estimates $\mathcal{O}(\alpha_s^3)$

LARIN, PLB 334 (1994) 192, KATAEV CERN-TH 7333/94

ORIGINAL FORMULATION: ASSUME $\Delta s \equiv 0$

$a_0 = a_8 \approx 0.6$

EXPERIMENTAL METHOD

- MEASURE CROSS SECTION ASYMMETRIES

PARALLEL TRANSVERSE

$$A_\parallel(x,Q^2) = \frac{d\sigma^{\uparrow\downarrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\uparrow\downarrow} + d\sigma^{\uparrow\uparrow}} \qquad A_\perp(x,Q^2) = \frac{d\sigma^{\downarrow\rightarrow} - d\sigma^{\uparrow\rightarrow}}{d\sigma^{\downarrow\rightarrow}\ d\sigma^{\downarrow\rightarrow}}$$

Polarization beam target

- VIRTUAL PHOTONS ARE LESS POLARIZED THAN LEPTON.

VIRTUAL PHOTON ASYMMETRIES A_1, A_2

$$A_1(x,Q^2) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \qquad A_2(x,Q^2) = \frac{2\sigma_{LT}}{\sigma_{1/2} + \sigma_{3/2}}$$

$$A_\parallel = D(A_1 + \eta A_2) \qquad A_\perp = D'(A_2 - \eta' A_1)$$

- LIMITS $|A_1| < 1$ $\quad |A_2| < \sqrt{R}$

$R = \frac{\sigma_L}{\sigma_T}$ small

$$A_1 = \frac{1}{F_1}(g_1 - \gamma^2 g_2) \qquad A_2 = \frac{\gamma}{F_1}(g_1 + g_2)$$

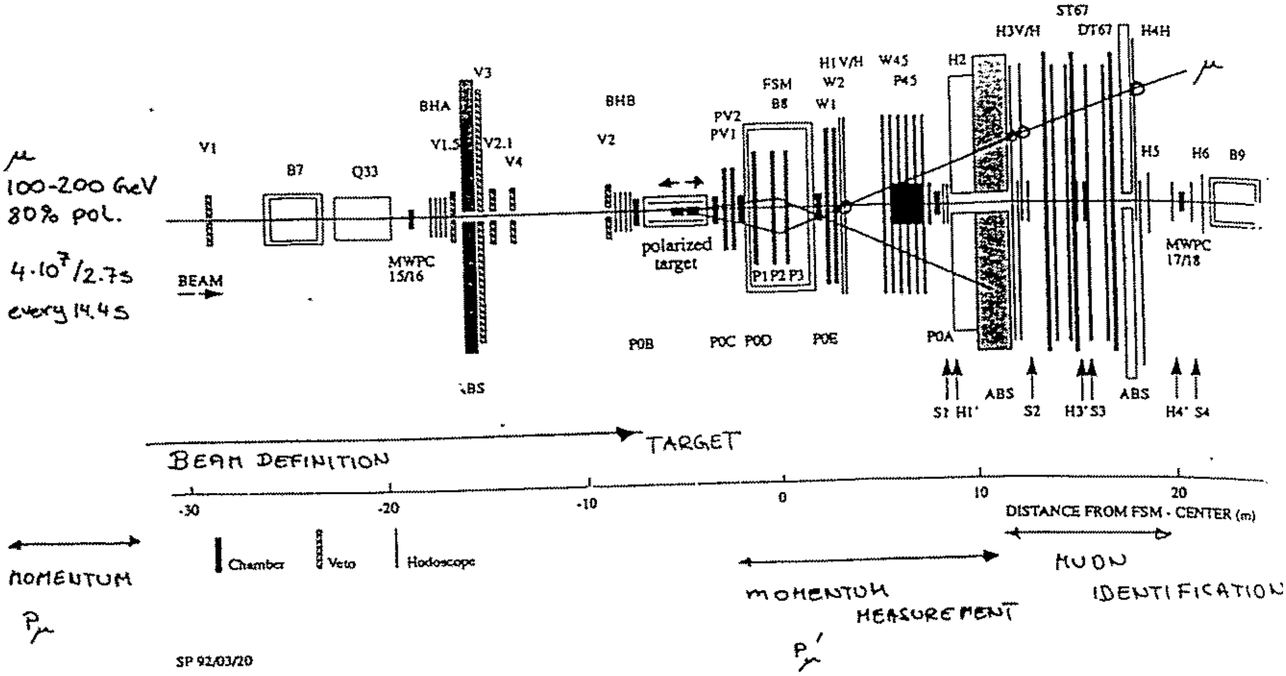
$\gamma = \frac{2Mx}{\sqrt{Q^2}}$ small

- BOTTOM LINE

$$\boxed{g_1 \approx A_1 F_1 \approx \frac{1}{D} A_\parallel \frac{F_2}{2x(1+R)}}$$

FROM UNPOLARIZED DIS

SMC EXPERIMENT - SPECTROMETER (SCHEMATIC)



SPIN MUON COLLABORATION

AT CERN

NA47

27 INSTITUTES

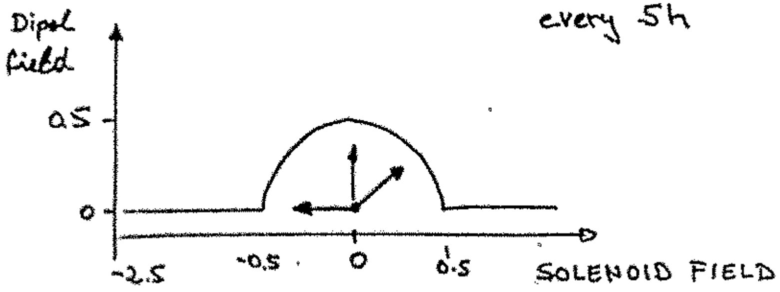
~160 PHYSISISTS
(26 PhD students)

University of Bielefeld, Germany
Boğaziçi University, Çekmece Research Center, Istanbul University
and Istanbul Technical University, Istanbul, Turkey
University of California, Los Angeles, CA, USA
University of California, Santa Cruz, CA, USA
CERN, Geneva, Switzerland
University of Freiburg, Germany
GKSS, Geesthacht, Germany
Helsinki University of Technology, Finland
University of Houston, TX, USA
JINR, Dubna, Russia
University of Mainz, Germany
University of Mons, Belgium
University of Munich, Germany
Nagoya University, Japan
NIKHEF, FOM and Free University, Amsterdam, The Netherlands
Northeastern University, Boston, MA, USA
Northwestern University, Evanston, IL, USA
Rice University, Houston, TX, USA
DAPNIA, CE Saclay, Gif-sur-Yvette, France
University of Santiago, Santiago de Compostela, Spain
Tel Aviv University, Israel
INFN Trieste and University of Trieste, Italy
Uppsala University, Sweden
University of Virginia, Charlottesville, VA, USA
Soltan Institute for Nuclear Studies and Warsaw University, Warsaw, Poland
Yale University, New Haven, CT, USA

Spokesman: V. W. Hughes   Contactman: G. K. Mallot

SMC POLARISED TARGET

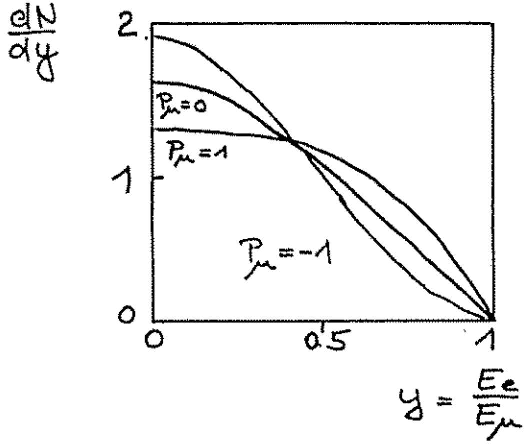
- MATERIAL: BUTANOL & DEUTERATED But.
- SOLENOID FIELD: 2.5T
- DIPOL FIELD: 0.5T
- TEMPERATURE 40mk frozen Mode
- AVERAGE POL.: 86% (p) >45%(d 1994)
- TWO TARGET HALVES; 60long, Ø5cm POLARISED IN OPPOSITE SENSE by DNP.
- POLARISATION MEASURED BY 10 embedded NMR coils
- INVERSION OF SPIN DIRECTIONS BY Rotation OF MAGNETIC FIELD every 5h



BEAM POLARIMETER

$\mu^+ \longrightarrow e^+ \nu_e \bar{\nu}_\mu$ MUON DECAY IN FLIGHT

PARITY VIOLATION CAUSES DEPENDENCE OF SHAPE OF e^+ ENERGY SPECTRUM ON μ POLARISATION.



RESULT (190 GeV μ^+)

$P_\mu = -0.80 \pm 0.03\,(\text{stat}) \pm 0.02\,(\text{sys})$

- agrees WITH MC OF BEAM TRANSPORT
- 1994 μ-e SCATTERING FROM MAGN. IRON FOIL

SMC DATA SAMPLES

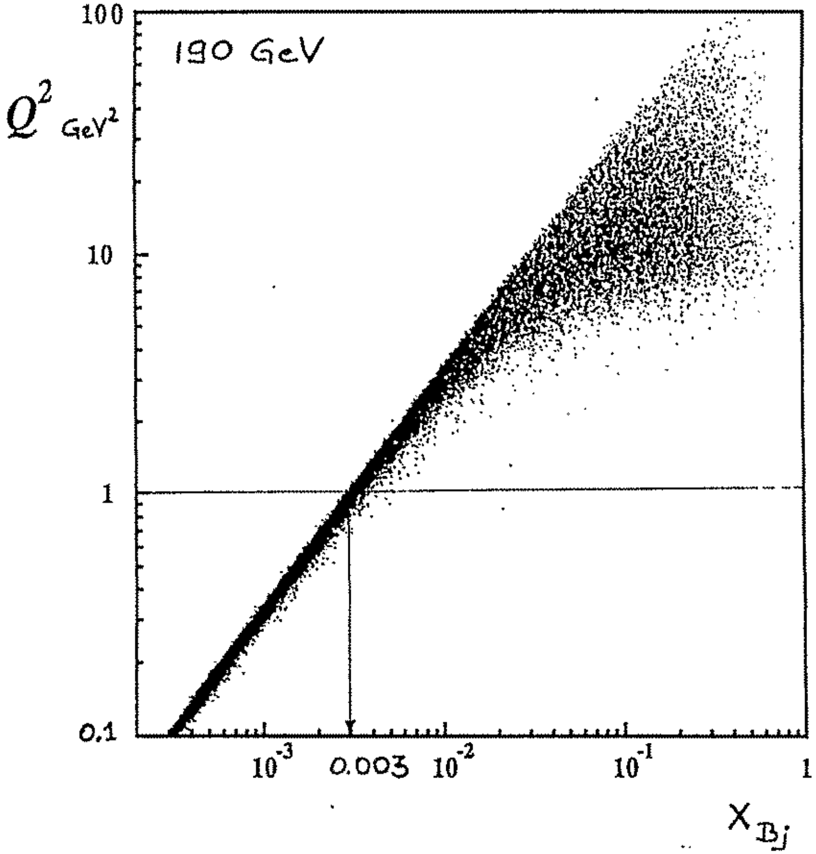
	PROTON	DEUTERON
year	1993	1992
E_μ	190 GeV	100 GeV
x	0.003 – 0.7	0.006 – 0.6
Q^2	1 – 60 GeV^2	1 – 30 GeV^2
$\langle P_t \rangle$	0.86	0.35 ; max 0.43
P_μ	−0.80	−0.82
# ev after cuts	4.4 10^6	$3.2 \cdot 10^6$
	PLB 329 (1994) 399	PLB 302 (1993) 533

- TRANSVERSE POLARISATION OF TARGET

  $0.8 \cdot 10^6$ evnts 100 GeV 1993 ; PLB 336 (1994) 125

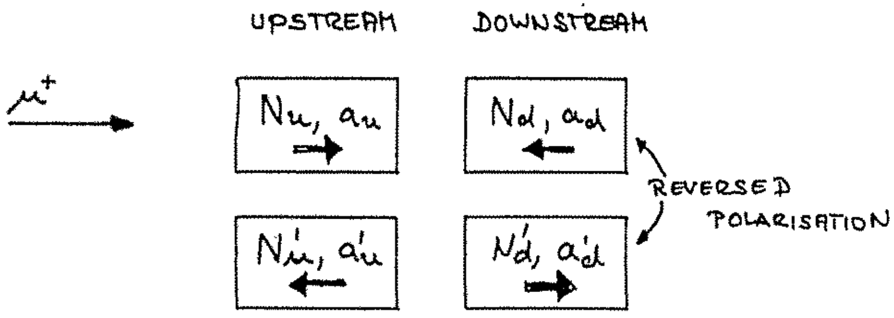
- SEMI INCLUSIVE DATA
- DATA AT SMALL x WITH $Q^2 < 1$ GeV^2

KINEMATICS x vs Q^2



EXTRACTION OF THE ASYMMETRY A_1

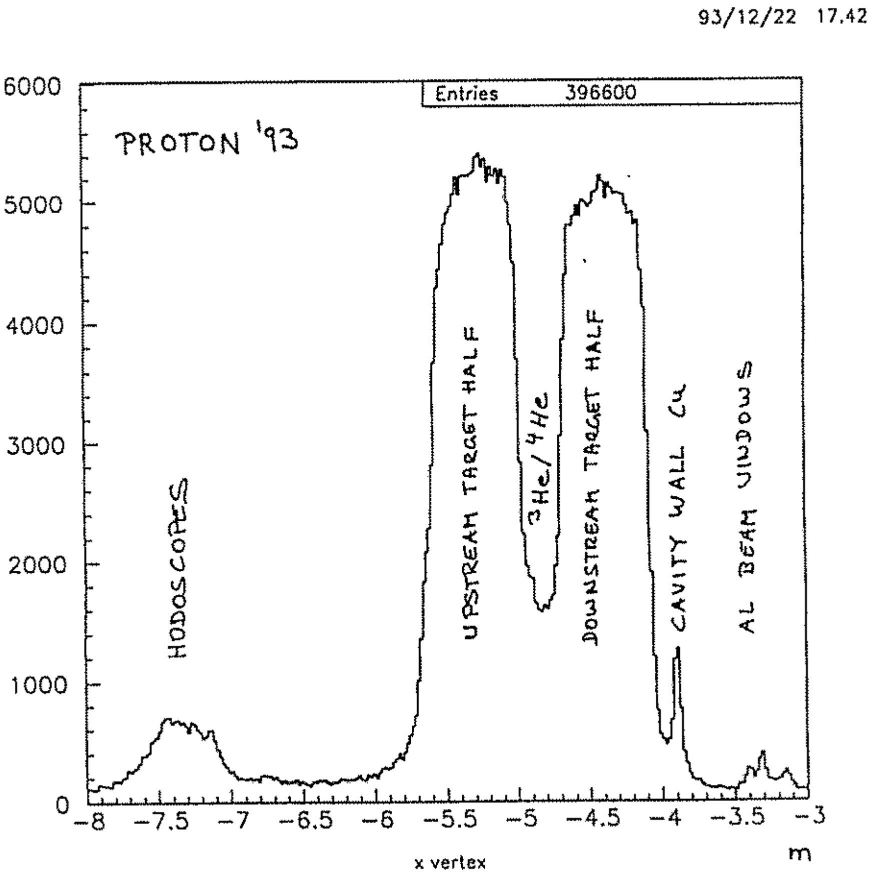
$$N = n a \phi \bar{\sigma} [1 - f P_\mu P_t \underbrace{D(A_1 + \overbrace{\eta A_2}^{\text{small}})}_{A = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}}}]$$



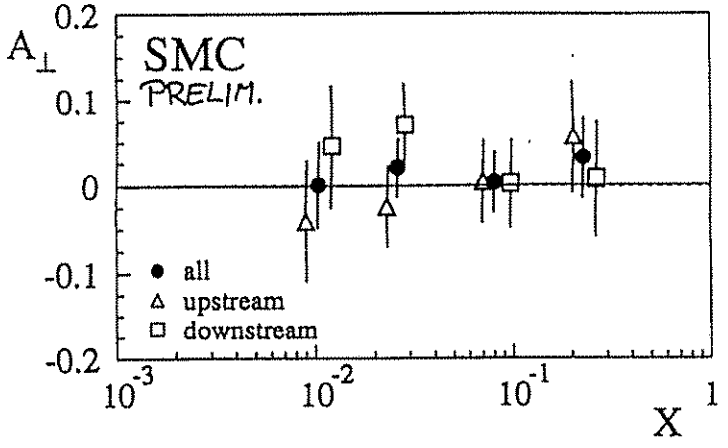
$$\frac{N'_u N_d}{N_u N'_d} = \frac{a'_u / a'_d}{a_u / a_d} \left(1 + 4 \underbrace{f P_\mu P_t D A_1}_{\text{"RAW ASYMMETRY"} \sim 0.01} + \dots\right)$$

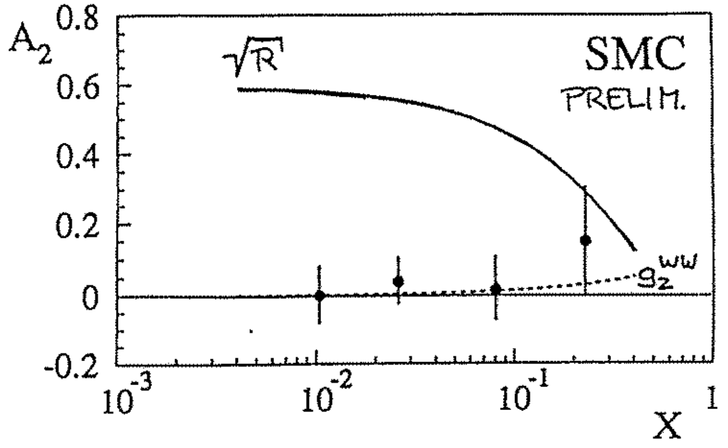
n, ϕ, σ_0 CANCEL
ONLY ACCEPTANCE RATIO MUST
BE CONTROLLED

INTERACTION VERTICES



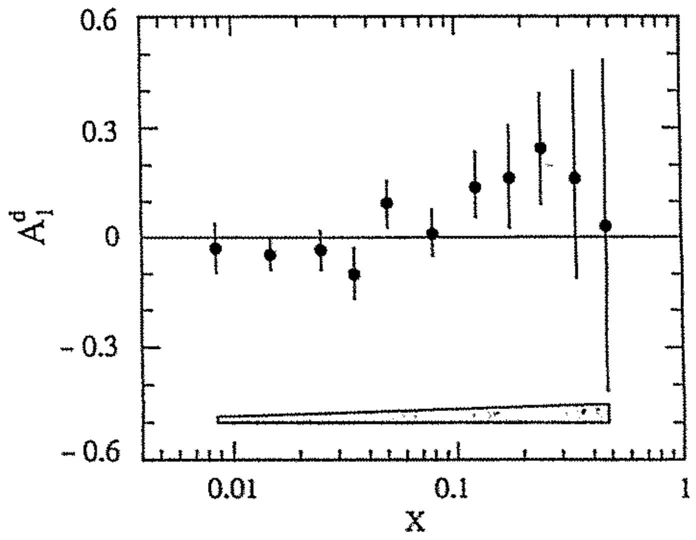
$A_\perp$ AND A_2 PROTON



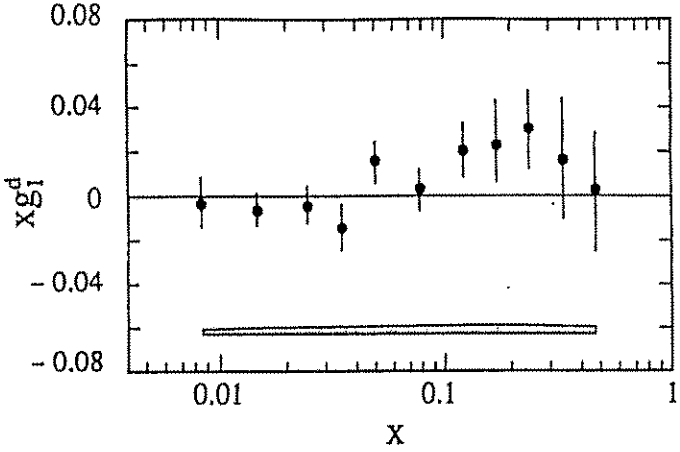


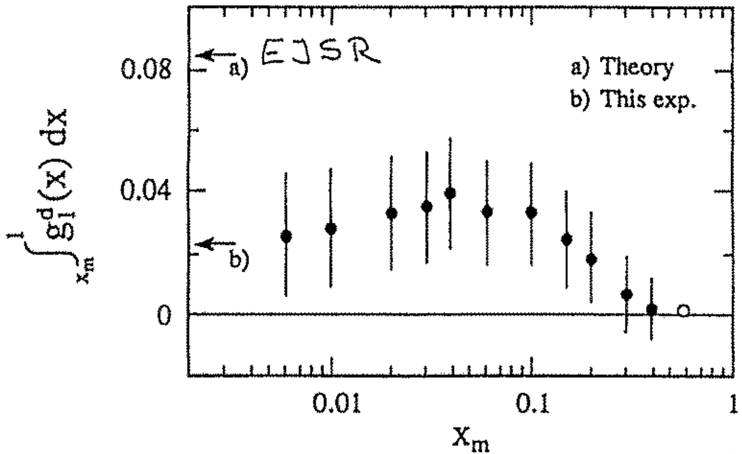
ASYMMETRY A_1^d

$$A_1 = \frac{1}{D} \cdot A_{\parallel} \underbrace{- \eta A_2}_{\text{small}} = \frac{g_1}{F_1} - \underbrace{\frac{\gamma^2}{F_1} g_2}_{\text{small}}$$



DEUTERON g_1^d Γ_1^d

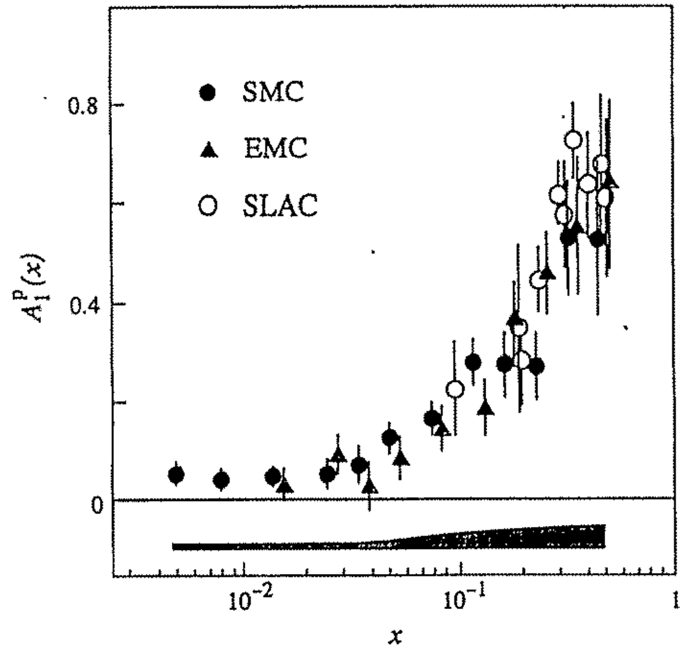




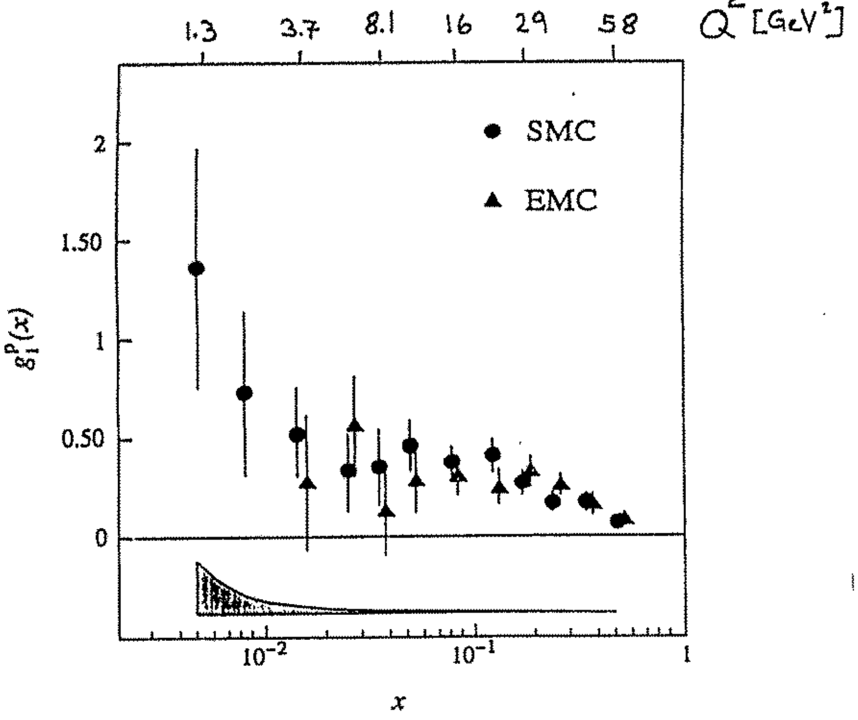
EJSR: ELLIS-JAFFE SUM RULE FOR $\Gamma_1^n + \Gamma_1^p$
multiplied by $(1 - \frac{3}{2}\omega_D)$
$\omega_D = 5.8\%$ DEUTERON D-state

ASYMMETRY A_1^p

SMC, PLB 329 (1994) 399



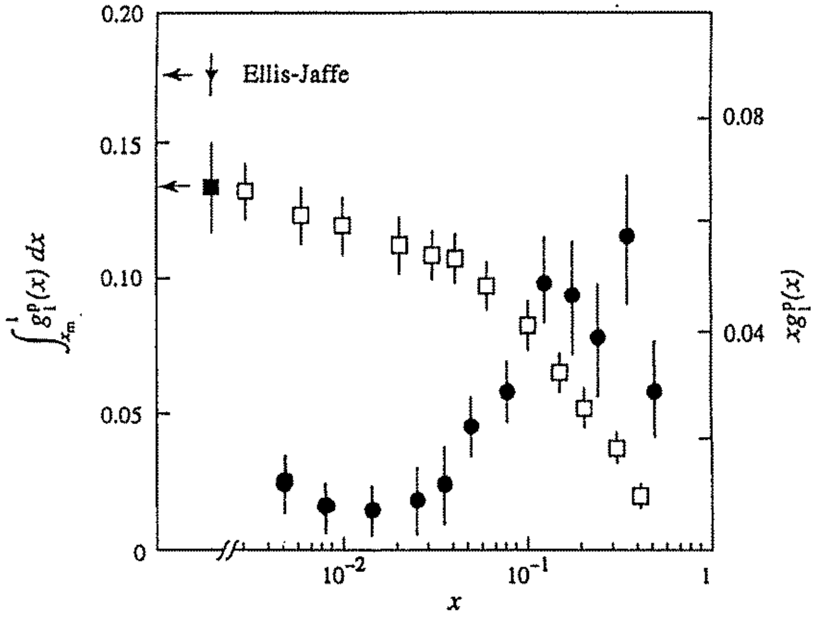
$g_1^p(x, \langle Q_x^2 \rangle)$



Γ_1^p (10 GeV^2) SMC

$$\boxed{\Gamma_1^p = 0.136 \pm 0.011 \pm 0.011}$$

$$\Gamma_{1\,EJ}^{p} = 0.176 \pm 0.006 \quad (n_f = 4, \alpha_s = 0.23)$$



For $0.01 < x < 0.7$

EMC $\Gamma_1^p = 0.124 \pm 0.013 \pm 0.019$

SMC $0.118 \pm 0.010 \pm 0.009$

Exeellent agreement

SMC RESULTS

	10 GeV² PROTON	4.6 GeV² DEUTERON
Γ_1^{SMC}	$0.136 \pm 0.11 \pm 0.11$	$0.049 \pm 0.044 \pm 0.032$ $(\Gamma_1^p + \Gamma_1^n)$
Γ_1^{EJSR}	0.176 ± 0.006	0.187 ± 0.010
$\Delta\Sigma$	$0.22 \pm 0.10 \pm 0.10$	$0.06 \pm 0.20 \pm 0.15$
Δs	$-0.12 \pm 0.04 \pm 0.04$	$-0.21 \pm 0.07 \pm 0.05$

- QUARKS CARRY LITTLE OF NUCLEON SPIN $\Delta\Sigma < 0.6$
- STRANGE SEA NEGATIVELY POLARIZED $\Delta s < 0$

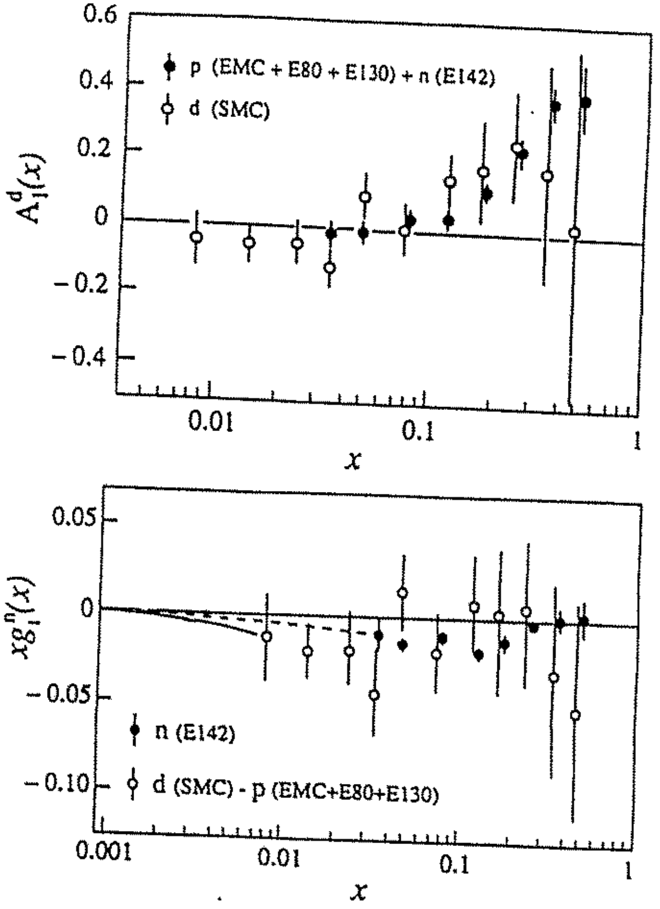
PROTON: SMC & EMC & SLAC E80 E130

$$\boxed{\begin{aligned} \Gamma_1^p &= 0.142 \pm 0.008 \pm 0.011 \\ \Delta\Sigma &= 0.27 \pm 0.08 \pm 0.010 \\ \Delta s &= -0.10 \pm 0.03 \pm 0.04 \end{aligned}}$$

$\Gamma_1^{EMC} = 0.126 \pm 0.010 \pm 0.015$

COMPARISON w E-142 ^{3}He

PRL 71 (1993) 959
PLB 320 (1994) 400



PRELIMINARY RESULTS FROM SLAC E-143

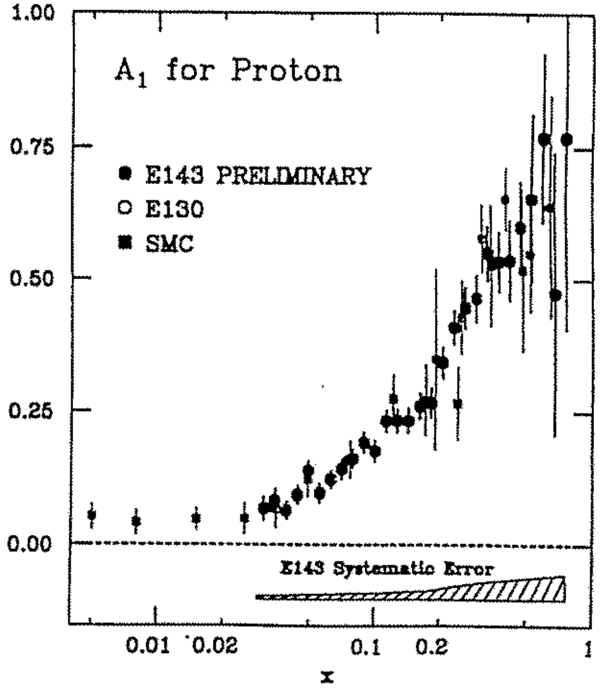
SLAC-PUB 6508 1994.

$$\boxed{\Gamma_1^p = 0.129 \pm 0.004 \pm 0.009 \quad \text{at } Q^2 = 3\ \text{GeV}^2}$$

$\Gamma^p_{1\,\text{EJ}} = 0.160 \pm 0.006$ $Q^2 = 3\ \text{GeV}^2$

$\Delta\Sigma = 0.29 \pm 0.10$

$\Delta s = -0.10 \pm 0.04$

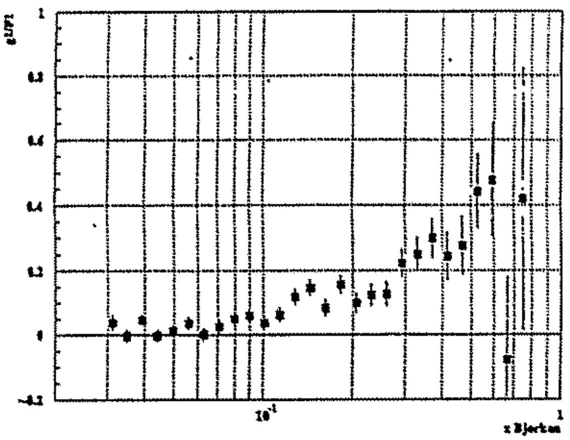


SLAC E-143 DEUTERON

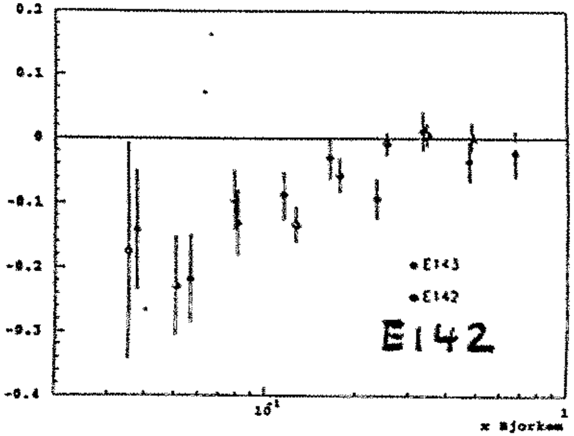
PRELIMINARY

$\frac{g_1}{F_1} \approx A_1$

Deuteron - E143



Neutron g1



DATA SUMMARY

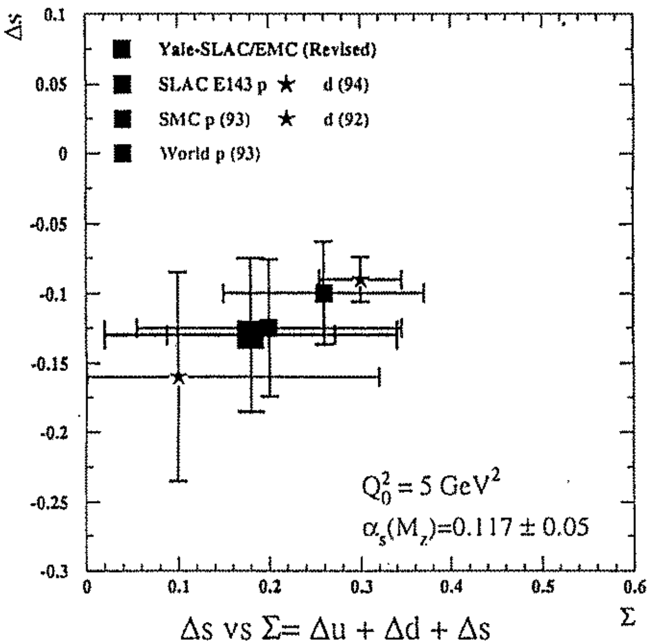
$\Delta\Sigma$, Δs are recalculated using the same values for $\alpha_s(m_Z)$, n_f, g_a, F/D for all experimental results

Summary of all data on the first moments of g_1 of the nucleon
$g_a = 1.257$, $F/D = 0.575$, $\alpha_s(m_Z) = 0.116$
The calculation was performed for 4 flavours and $O(\alpha_s^2)$

Experiment	Γ_1	year	Γ_1	$\langle Q^2 \rangle$	α_s	$\Delta\Sigma$	Δs
SMC	p+n (d)	1993	0.049±0.054	4.6	0.27	0.09±0.25	−0.16±0.14
SMC	p	1994	0.136±0.016	10	0.24	0.24±0.14	−0.11±0.06
SMC&earlier	p		0.142±0.014	10	0.24	0.29±0.13	−0.10±0.05
E-142	n (^3He)	1993	−0.022±0.011	2	0.34	0.48±0.11	−0.03±0.06
E-143	p	1994	0.129±0.010	3	0.31	0.21±0.10	−0.12±0.04
E-143	p+n (d)	1994?	0.094±0.006	3	0.31	0.30±0.07	−0.09±0.03

$\Delta\Sigma \sim 0.30$
$\Delta s \sim -0.10$

Total and Strange Spin Contents in the Nucleon



Δs vs $\Sigma = \Delta u + \Delta d + \Delta s$

BJORKEN SUM RULE

CONSEQUENCE OF QCD :

$$\int g_1^p - g_1^n \, dx = \Gamma_1^p - \Gamma_1^n$$

SMC p + E142 n + SMC d

$\Gamma_1^p - \Gamma_1^n = 0.163 \pm 0.017$ (5 GeV^2)

DISCARDING E-142 n EXTRAPOLATION TO $x \to 0$

$\Gamma_1^p - \Gamma_1^n = 0.204 \pm 0.029$

THEORY 0.185 ± 0.004 @ 5 GeV^2

E 143 p & E142 n

0.151 ± 0.014 3 GeV^2

THEORY 0.171 ± 0.008 3 GeV^2

E143 p + d

0.164 ± ? 3 GeV^2

BORKEN SR VALID
AND TESTED TO ~10%

USED TO EXTRACT $\alpha_s(2.5\,\mathrm{GeV}^2) = 0.375^{+0.062}_{-0.081}$

$\alpha_s(m_Z) = 0.122^{+0.005}_{+0.009}$ ELLIS, KARLINER
CERNTH 7324/94

QCD CORRECTIONS

$N_f = 3$

$$\Gamma_1^{p(n)} = \Big[1 - \frac{\alpha_s}{\pi} - 3.58\frac{\alpha_s^2}{\pi^2} - 20.2\left(\frac{\alpha_s}{\pi}\right)^3 - 130\left(\frac{\alpha_s}{\pi}\right)^4\Big] \times \left(\pm\frac{|g_a|}{12} + \frac{a_8}{36}\right)$$

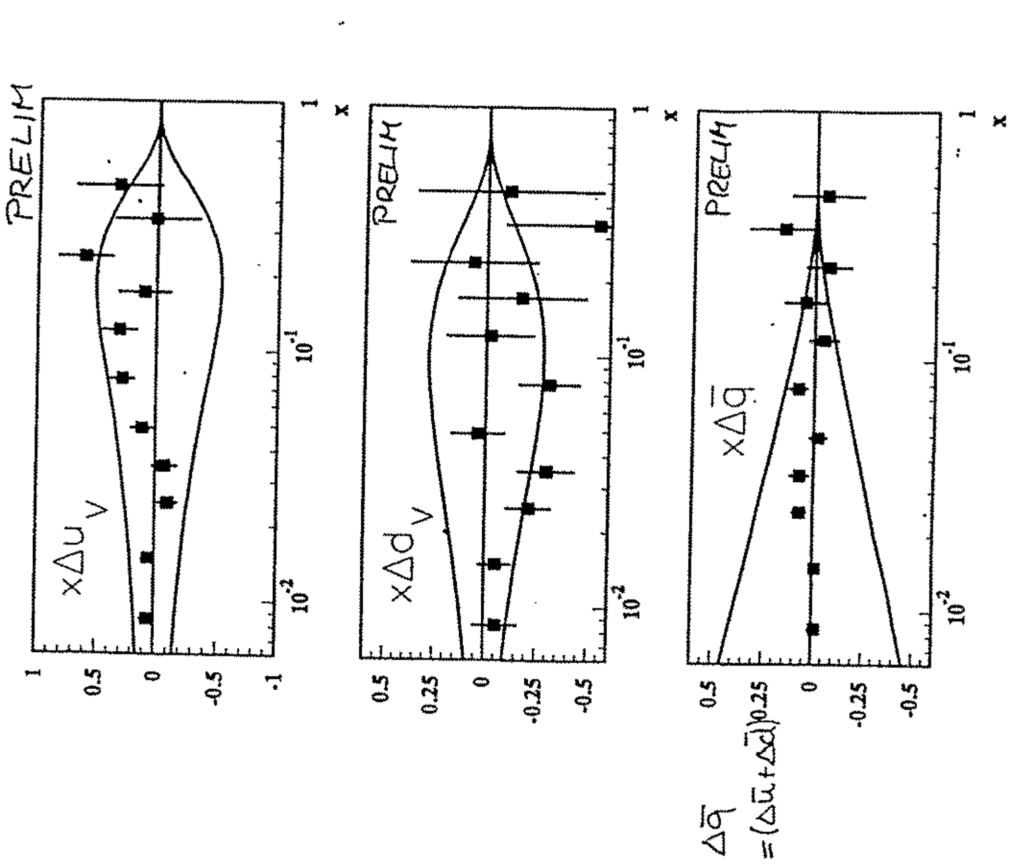
$$+ \Big[1 - 0.33\frac{\alpha_s}{\pi} - 0.55\frac{\alpha_s^2}{\pi^2} - 2\left(\frac{\alpha_s}{\pi}\right)^3\Big] \times \frac{1}{9}\Delta\Sigma$$

estimates

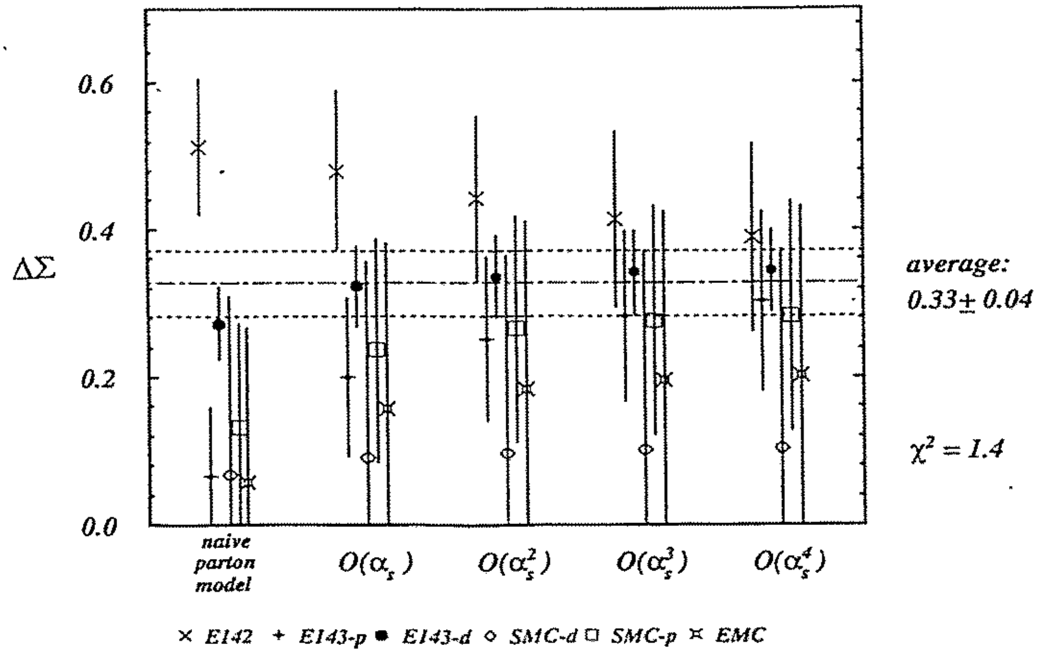
LARIN, VERMASEREN
LARIN
KATAEV

SEMI INCLUSIVE RESULTS

J. PRETZ
FREITAG NACHM.



Proton spin fraction carried by quarks vs. order of QCD pert. theory



all $\Delta\Sigma$ values evolved to $Q^2=10$ GeV^2

ELLIS &
KARLINER

DIFFICULTIES

- Assumed in ANALYSES of $\Gamma_1^p(Q_0^2)$

  $$A_1(x, Q^2) = A_1(x)$$

  - EXPERIMENTALLY NO HINT, BUT ERROR TO LARGE
  - CALCULATIONS SHOW VERY SMALL Q^2 DEPENDENCE OF A_1
  - DEPENDS ON ASSUMED POLARISED GLUON DISTRIBUTION

  $$g_1(x, Q_0^2) = \frac{A_1(x)\ F_2(x, Q_0^2)}{2x\,(1 + R(x, Q_0^2))}$$

  - GEHRMANN & STIRLING

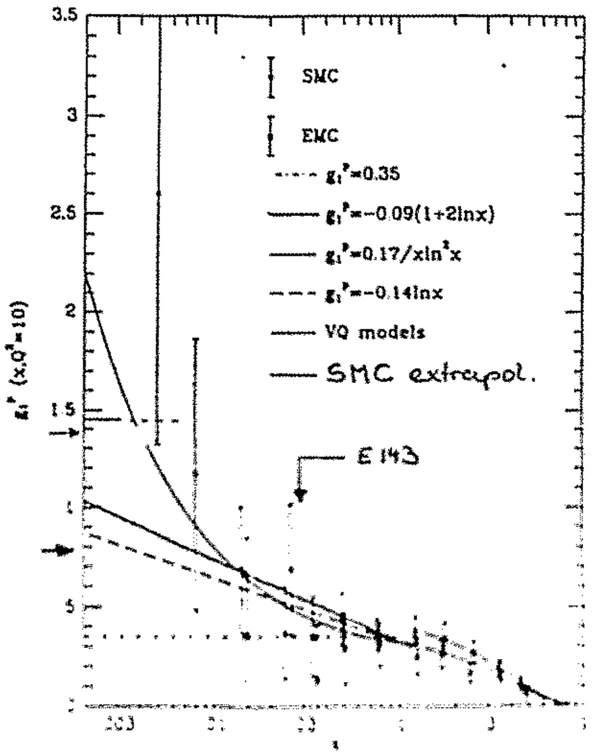
- Extrapolation to $x = 0$.

  - REGGE THEORY $g_1(x) \sim x^{-\alpha}$, $-0.5 < \alpha < 0$
  - NORMALLY ASSUMED $\alpha = 0$
  - SMC PROTON DATA INDICATE RISE AT SMALL X
  - Bass & Landshoff 2 gluon exchange may go like

    $$g_1 \sim 2 \ln\frac{1}{x} - 1$$

  - WOULD change E-143 result by <u>0.012</u>

    SMC unchanged



F Close & R G Roberts RAL 94-071

— S Bass & P V Landshoff HEP 94/9 Cavendish

OUTLOOK

1994	SMC	d	ca 5fache Stat.
1995	SMC	d or p	
	E-154	^3He	50 GeV
	HERMES	^3He ?	
1996	"	?	
	E-155	p, d	50 GeV

199? CERN

NEUES MUON EXPERIMENT DISKUTIERT

: SEMI INKLUSIVE STUDIEN

POL / un polarisiert

Vorteil: Hohe ENERGIE, KLARE TRENNUNG VON QUARK UND TARGET FRAGMENTATION.

Ziel: Flavour struktur des Nucleons STRANGENESS CONTENT

ZUSAMMENFASSUNG

- NEUE DATEN SMC p, d
  E-142 n
  E-143 p, d
- ALLE DATEN KONSISTENT ..
- $\Delta\Sigma \sim 0.3$ klein $\quad \Delta s \sim -0.1$ negativ

SPIN PUZZLE BESTEHT WEITER

- Björken SUMMEN REGEL O.K.

Neue NMC-Resultate aus der tiefinelastischen Myon-Streuung

A. Brüll
Heidelberg

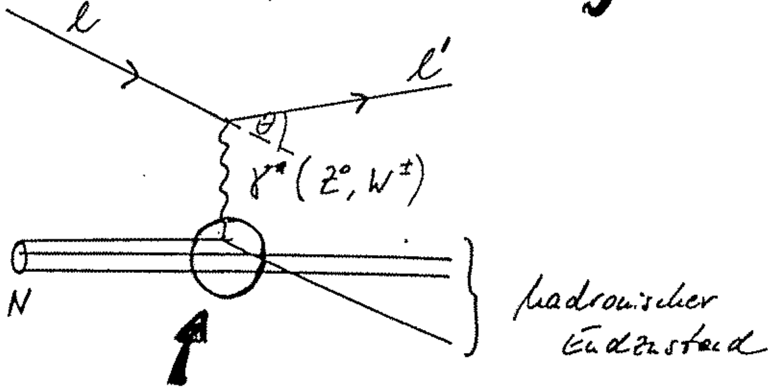
6.Oktober 1994

Neue NMC-Resultate aus der tiefinelastischen Myon-Streuung

Pirna, 6.10.94
A. Brüll, Heidelberg

- Die Strukturfunktionen des Nukleons
- Die Gottfried-Summenregel
- Kerneffekte
  - F_2^A/F_2^D für $x \to 0$
  - Q^2-Abhängigkeit von F_2^{Sn}/F_2^C
- Ausblick

Tiefinelastische l-N Streuung



$$\boxed{F_2, R, (F_3)}$$

Strukturfunktionen

$Q^2 \approx 4EE' \sin \theta/2$

$\nu = E - E'$

$x = Q^2/2M\nu$

$y = \nu/E$

$$\frac{d^2\sigma^{l^\pm N}}{dQ^2\,dx} = \frac{4\pi\alpha^2}{Q^4}\,\frac{F_2(x,Q^2)}{x}\left(1 - y - \frac{Mxy}{2E} + \frac{y^2}{2}\,\frac{1+\frac{4M^2x^2}{Q^2}}{1+R(x,Q^2)}\right)$$

l-N Streuung

QPM: $F_2 = F_2(x)$

$= x \sum_i e_i^2 \left(q_i(x) + \bar{q}_i(x) \right)$

· Bjorken scaling

$R \equiv 0$ falls $S_q = \frac{1}{2}$

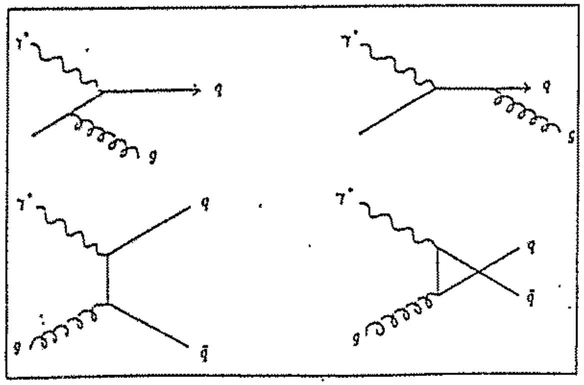
$(\infty$ falls $S_q = 1)$

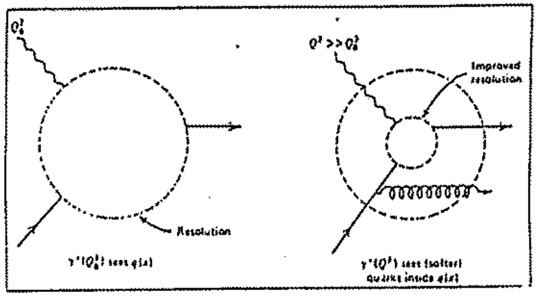
QCD: $F_2(x) \rightarrow F_2(x, Q^2)$

$R(x, Q^2) \neq 0$

· scaling violation

· $\propto \alpha_S$



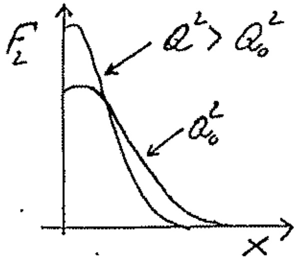


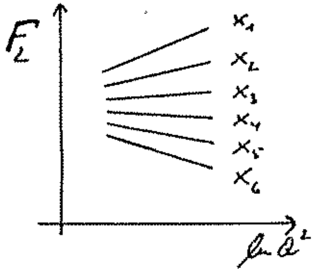
$Q_0^2 \ll Q^2$

Gribov - Lipatov - Altarelli - Parisi

➘ Q^2- Entwicklung der Strukturfunktionen

logarithmische Q^2 Abhängigkeit

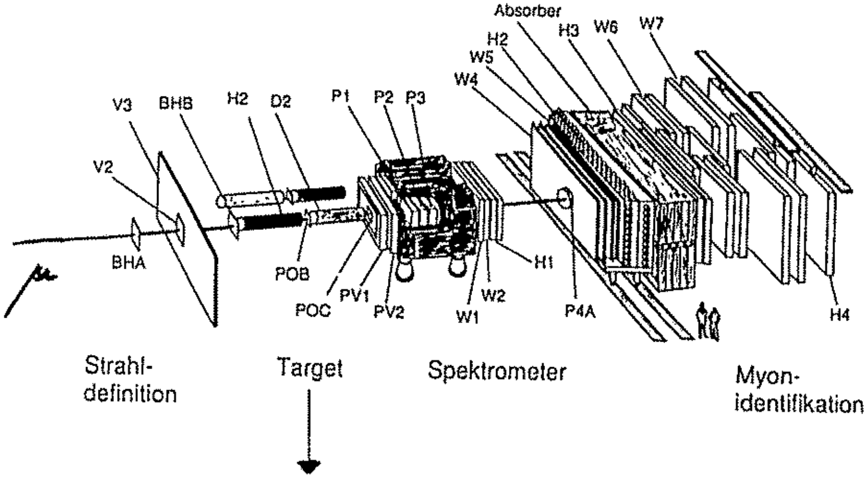




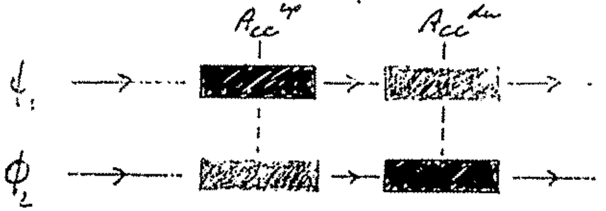
Das NMC-Experiment

- CERN Myon-Strahl 90 – 280 GeV
- Datennahme 1986 – 89
- Experiment der 2. Generation ↔ Präzisionsexp.
- <u>Wesentliche Ziele</u>
    - Bestimmung der Strukturfunktionen des Nukleons F_2^p und F_2^n sowie $R = \sigma_L/\sigma_T$
        - Auflösung des EMC/BCDMS-Problems
        - Erweiterung des kinematischen Bereichs
        - Vergleich mit QCD → Gluonverteilung
    - Präzisionsmessung von F_2^n/F_2^p
    - Genaue Untersuchung des EMC-Effektes
        - Q^2-Abhängigkeit
        - A-Abhängigkeit
    - Myoproduktion von J/ψ, ϕ, ρ Mesonen

The NMC spectrometer



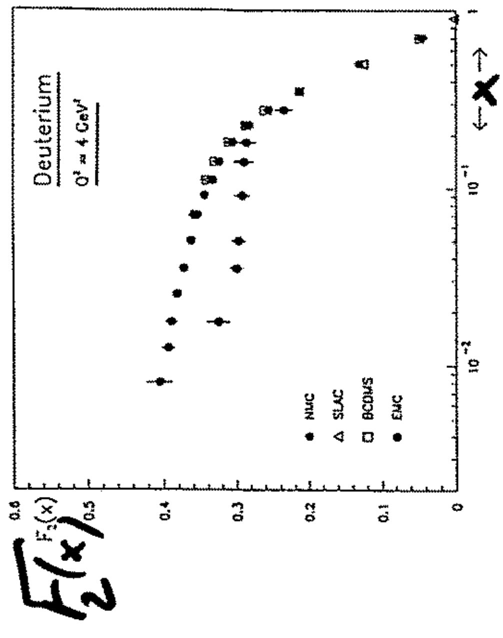
The complementary target setup

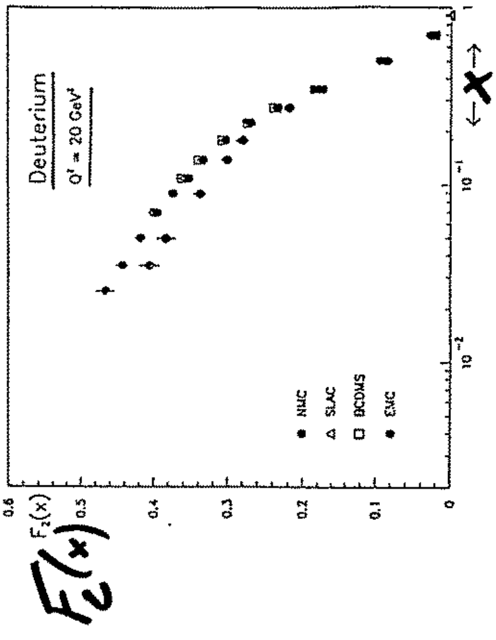


■ material A

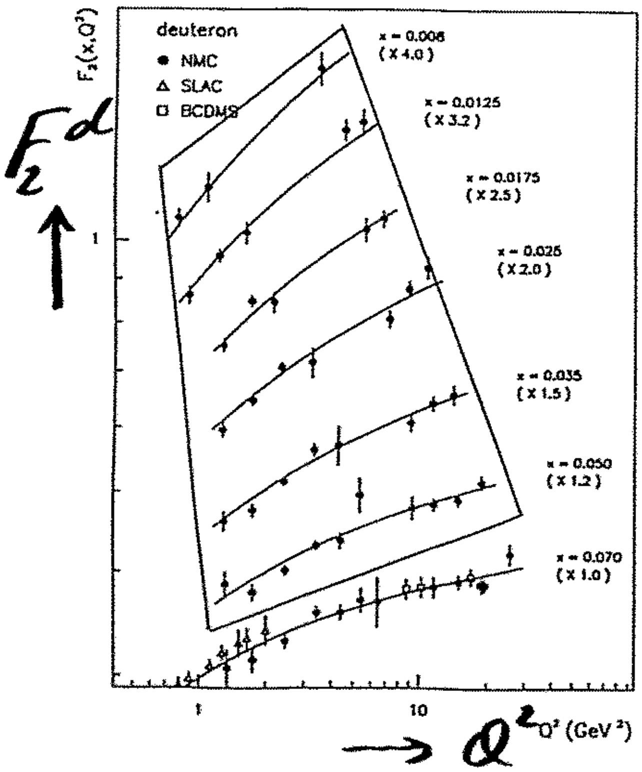
$$\frac{\sigma^A}{\sigma^B} \propto \sqrt{\frac{N^A_{up}\cdot N^A_{dn}}{N \cdot N}}$$

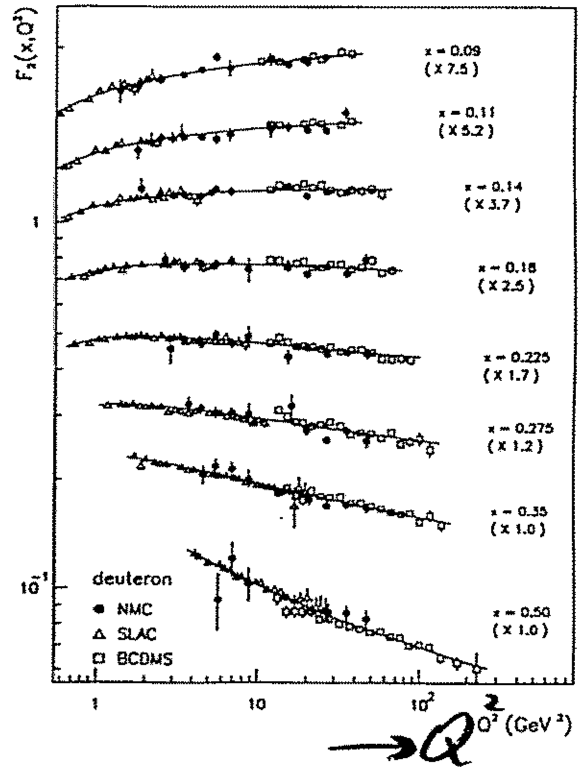
NMC-SLAC-BCDMS-EMC





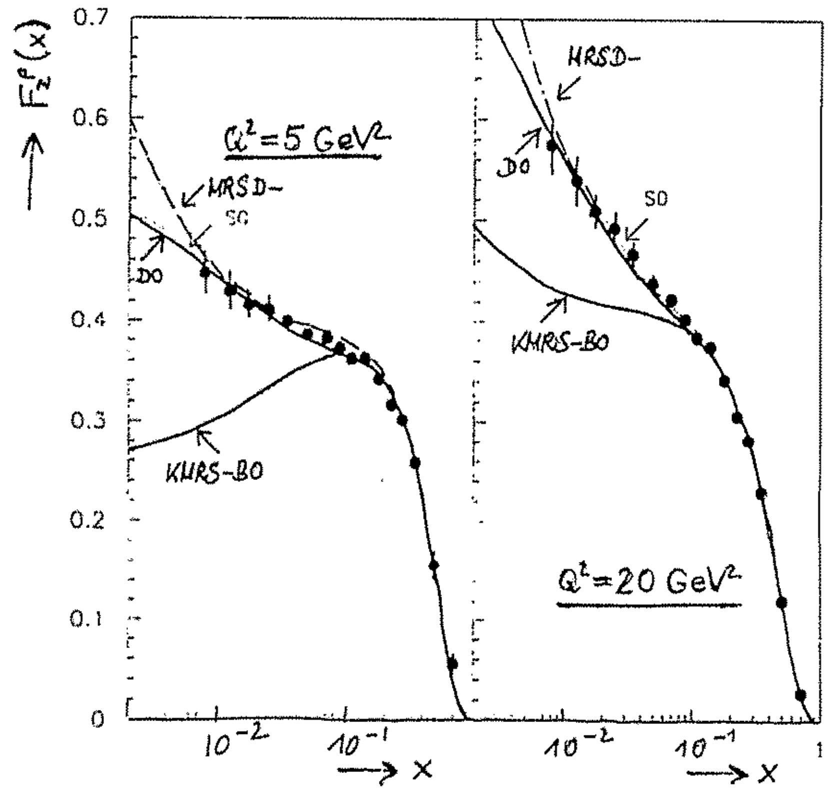
published (PL B295, 159 (1992))





Consequences for parametrisations of parton distributions

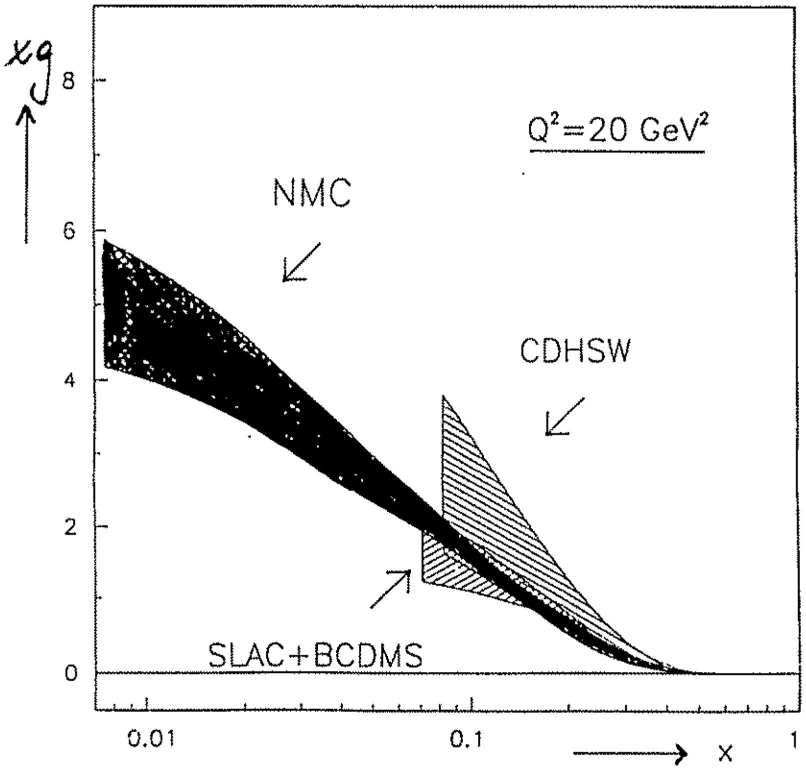
- old parametrisations (e.g. KHRS, MT-S,B) don't describe the NMC data for $x < 0.07$
- new parametrisations available



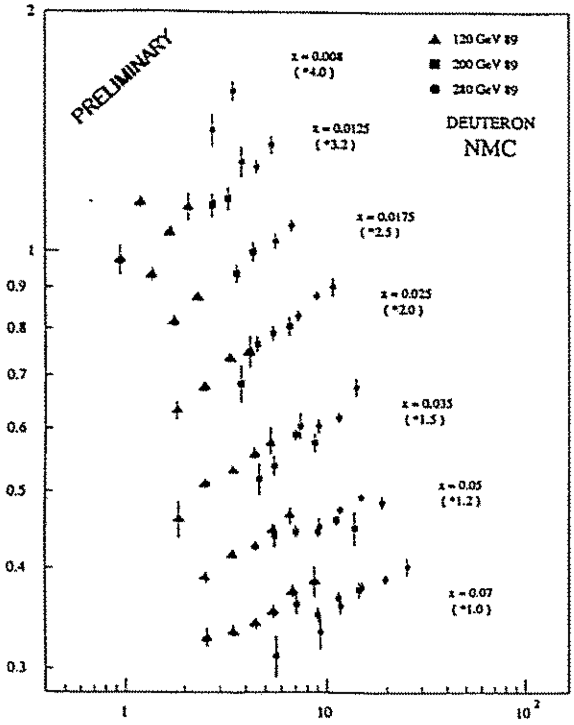
Comparison of $xg(x)$

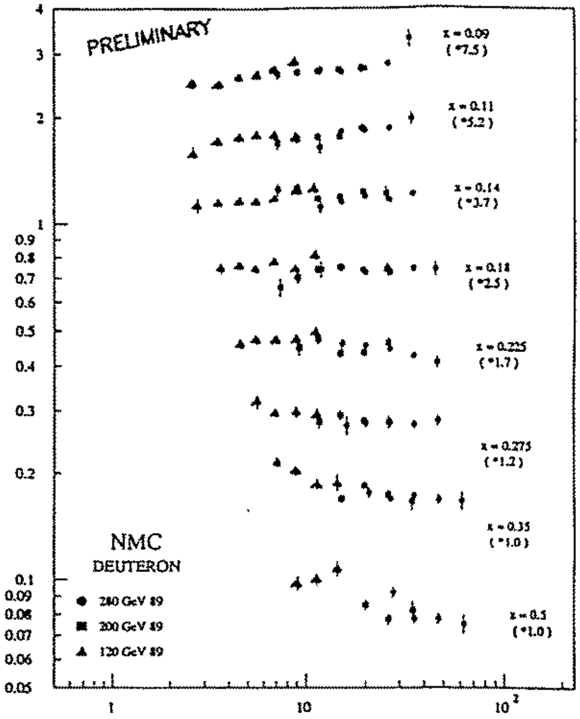
- deep inelastic scattering

↳ agreement
extension to low x
accuracy

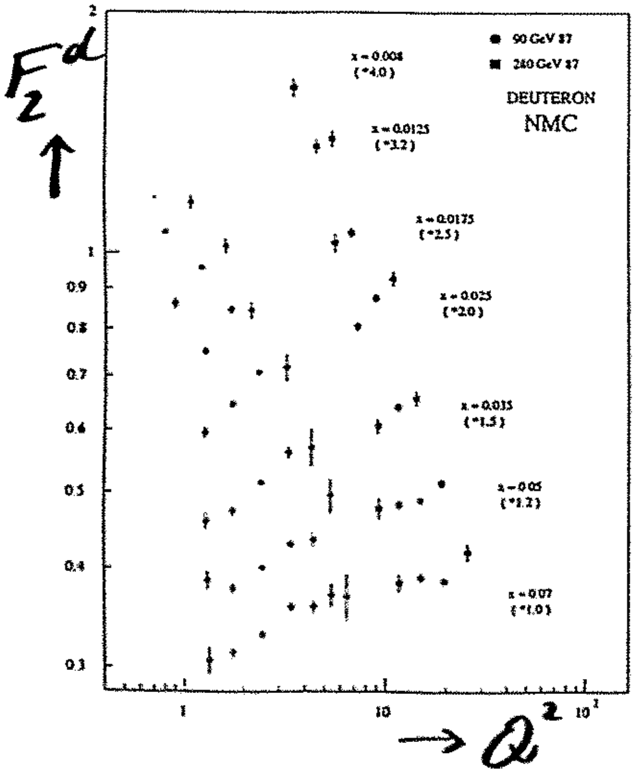


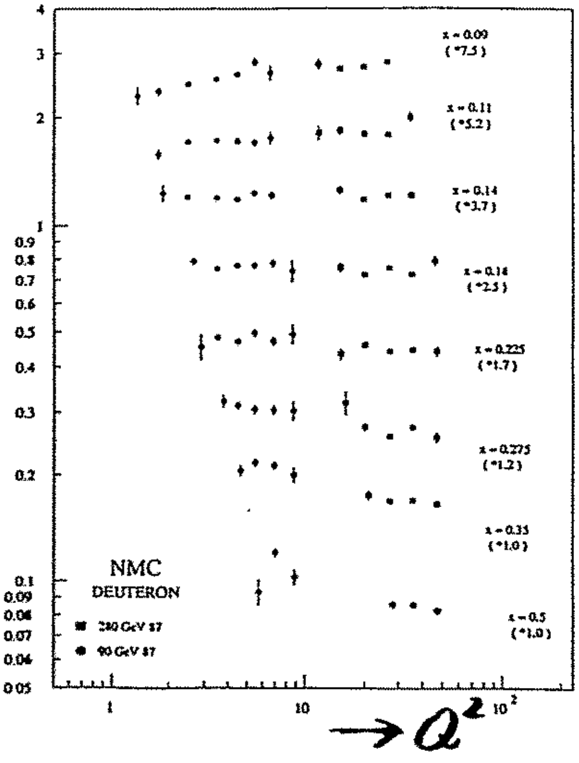
new NMC data





published data





NMC-Daten zu F_2^p & F_2^d

1992: Veröffentl. der 90 + 280 GeV Daten

- **kein** Überlapp in x, Q^2
- rel. große Unsicherheit in der Akzeptanzkorrektur

↓ dominante Unsicherheit

1993: Partonverteilungen und α_S

1994: vorl. Resultate für die 120, 200 + teilw. 280 GeV Daten

- deutlich höhere stat. und syst. Genauigkeit
- mögl. Bestimmung von $R = \sigma_L/\sigma_T$

Die Gottfried-Summenregel

$$S_G = \int \frac{dx}{x}\left(F_2^p - F_2^n\right)$$

$$= 1/3 + \frac{2}{3}\int dx\,(\bar{u} - \bar{d})$$

NMC (1991, PRL 66, 2712): $S_G = 0.240 \pm 0.016$

mit $F_2^p - F_2^n = 2F_2^d \dfrac{1 - F_2^n/F_2^p}{1 + F_2^n/F_2^p}$

Parametrisierung der SLAC', BCDMS und EMC'-NMC Daten

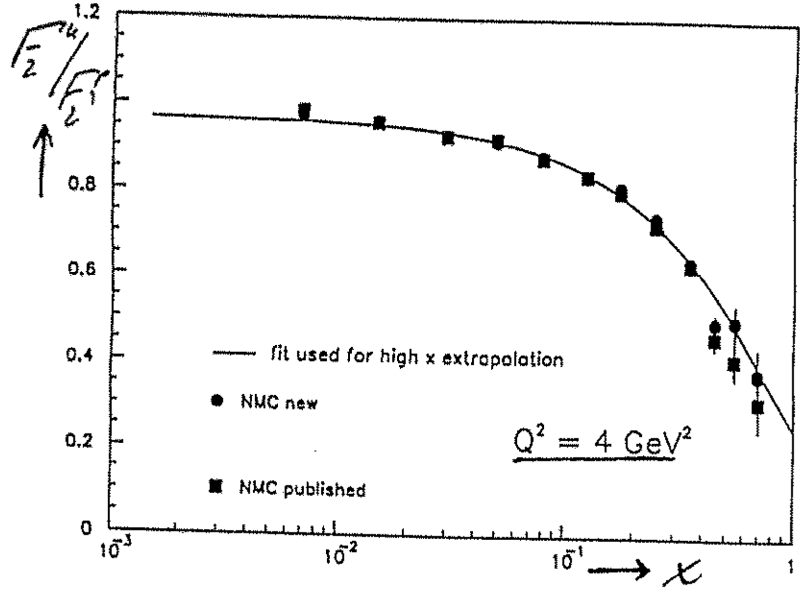
1992: NMC Resultate für F_2^d

→ neue Parametrisierung (NMC + SLAC' + BCDMS) mit Unterschieden bis zu 15%

→ neue Energiekalibration der 90 GeV Daten

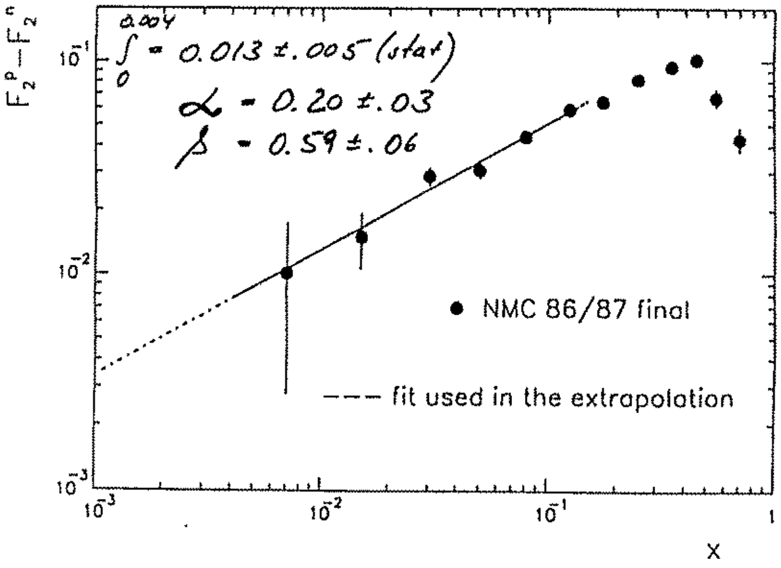
→ neuer Wert für S_G

Changes in F_2^n / F_2^p



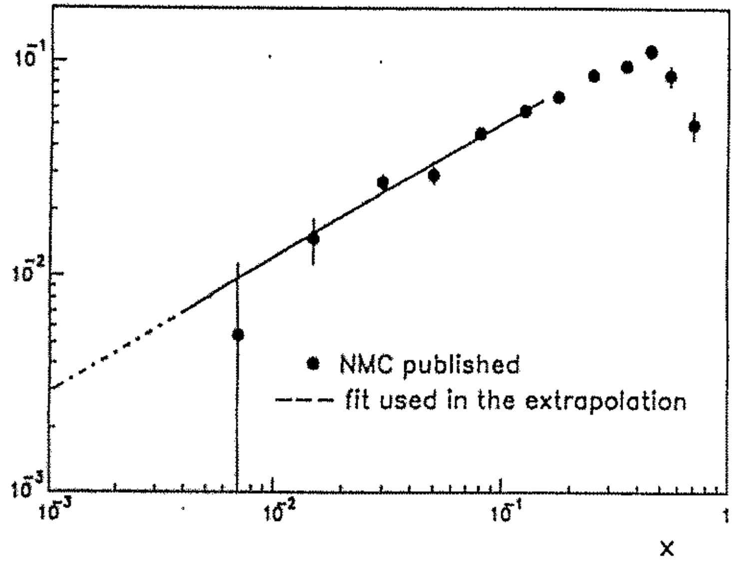
- at high x (compared to the published values)
  ↑ energy calibration 90 GeV
- at low x (radiative corrections)

Changes in $F_2^p - F_2^n$ and the extrapolation to $x = 0$



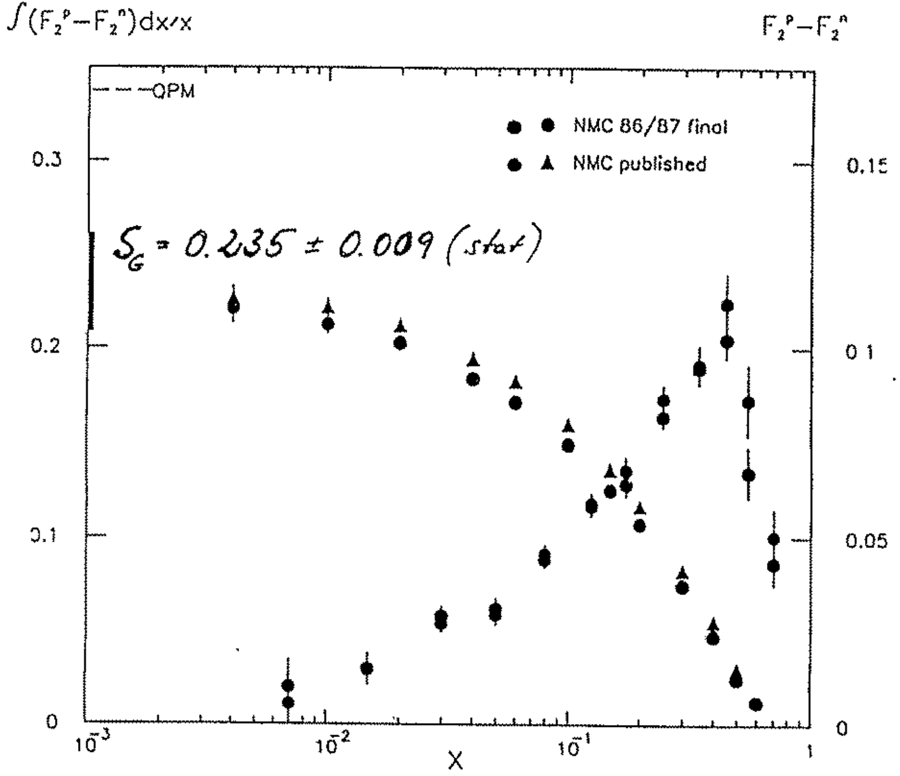
published : $G(0 - 0.004) = 0.011 \pm .003$ (stat)

Changes in S_G

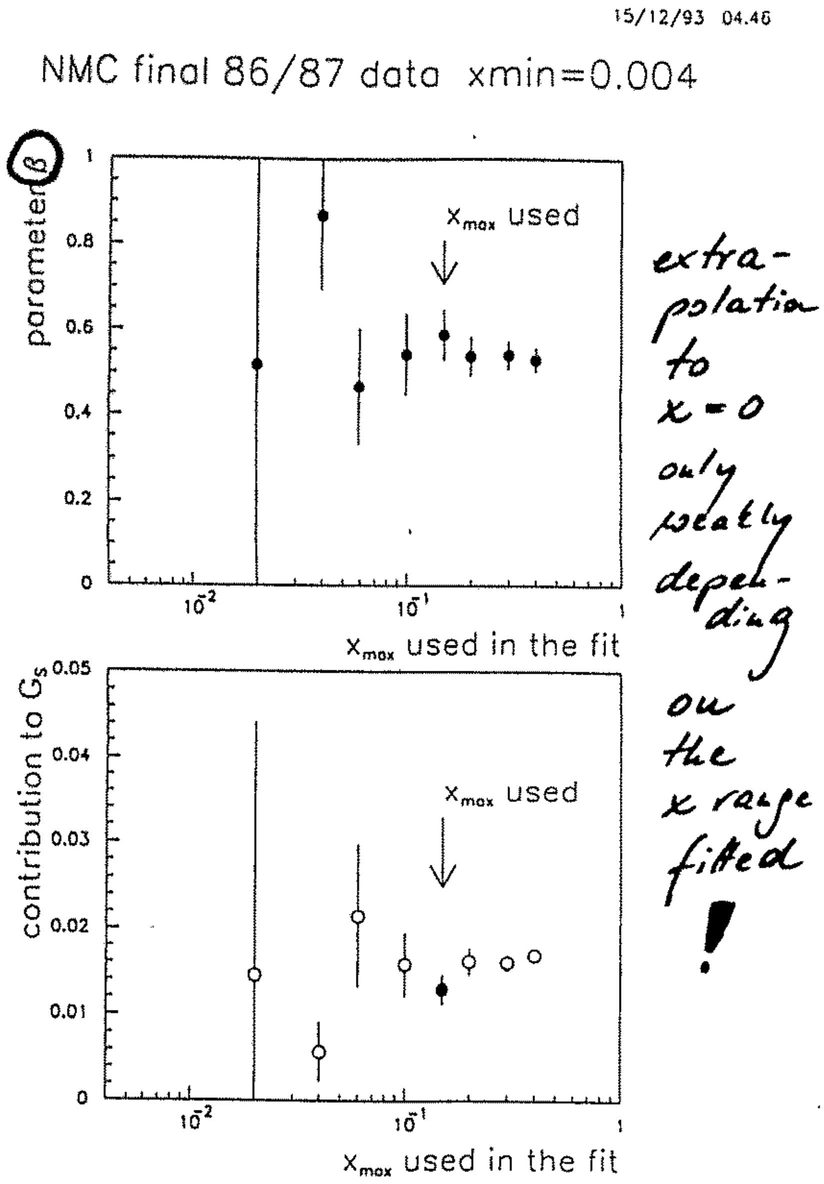


measured range $(0.004 < x < 0.8)$

$S_G = 0.221 \pm 0.008$



published : $S_G = 0.240 \pm 0.008$ (stat)



$$F_2^p - F_2^n = \alpha \cdot x^\beta$$

extrapolation to $x = 0$ only weakly depending on the x range fitted !

Systematic error

on F_2^n/F_2^p and S_G

- vertex smearing — unchanged.
- momentum uncertainties — recalculated (reduced)
- radiative corrections
  - sets of maximal / minimal radiative corrections
  - $\xrightarrow{!}$ choosen such that $\Delta F_2^n/F_2^p$ is maximal
  - → different F_2 parametrisations at low x, low Q^2 compared
  - $\xrightarrow{!}$ F_2^p fixed instead of F_2^d
- uncertainty in F_2^d (F_2^p)
  - $\xrightarrow{!}$ 5% $\forall x, Q^2$
  - $\xrightarrow{!}$ changed in the same way in the calculation of S_G and rad. corrections

- systematic uncertainty of the extrapolation to $x \to 0$ treated together with the measured range

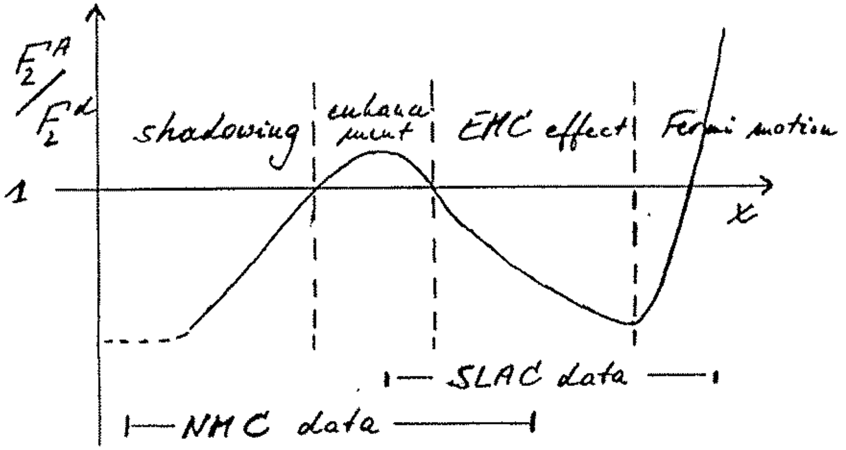
no shadowing corr.
no higher twist corr.

$$\int \frac{dx}{x}\left(F_2^p - F_2^n\right) = \underline{0.235 \pm 0.026}$$

Conclusions unchanged

Nuclear effects

observation: $F_2^A \neq F_2^d$



- saturation of shadowing for $x \to 0$?
- A dependence of shadowing, enhancement & EMC effect
- Q^2 dependence ?

Neuberechnung der nuklearen Strukturfunktionsverhältnisse

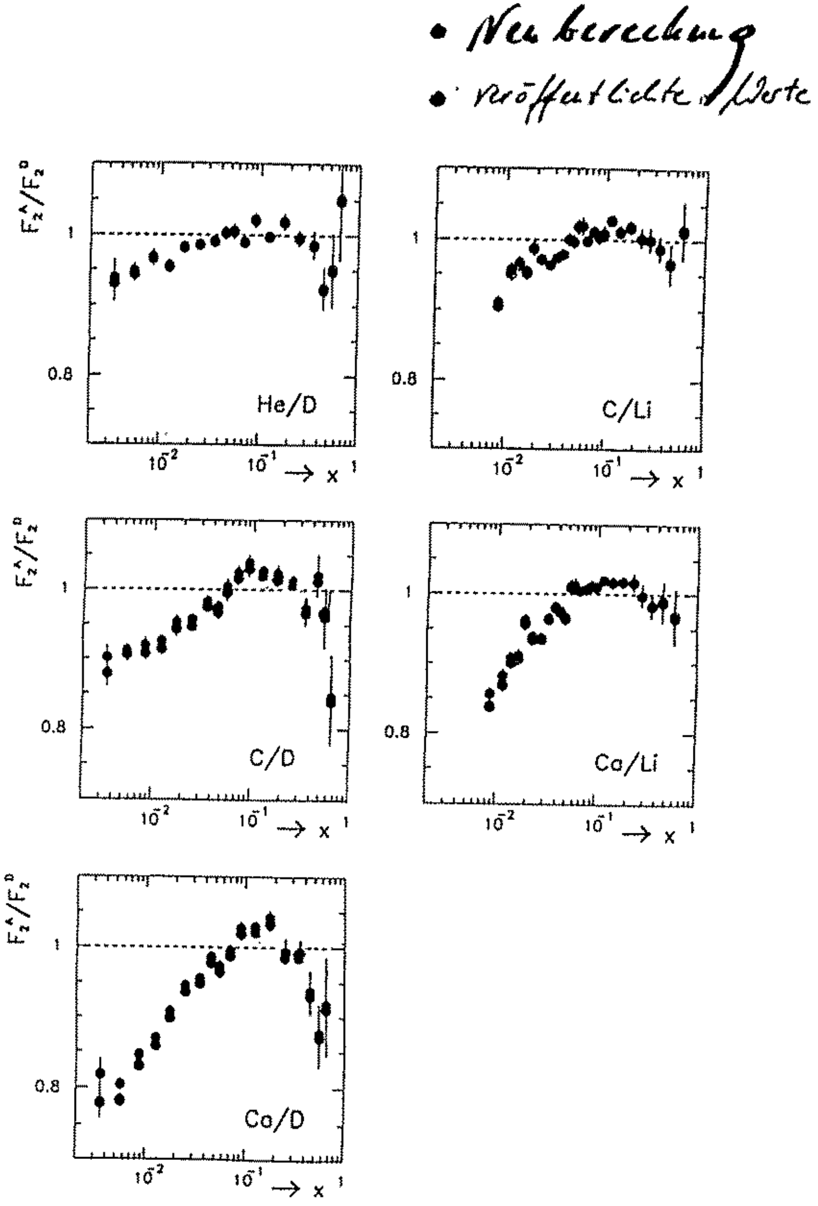
Gründe:

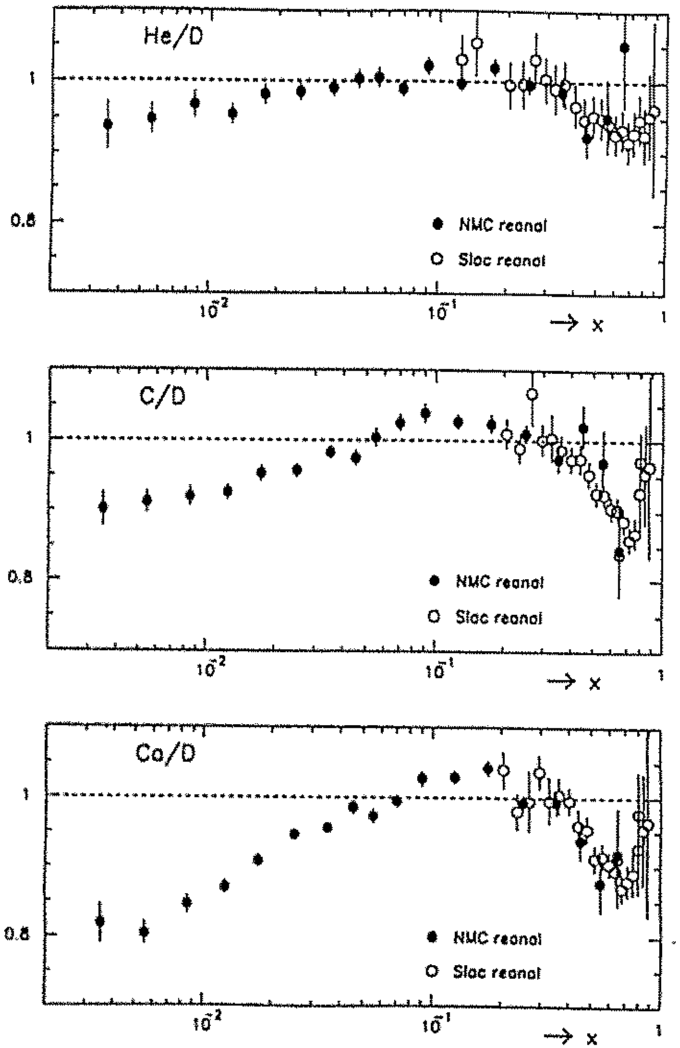
1) Änderung von F_2^d
   → neue Strahlungskorrektur

2) Fehler in der Massenberechnung der Deuteriumtargets in den C/D- und Ca/D-Daten

3) Verbesserte Methode zur Berechnung der Strahlungskorr.

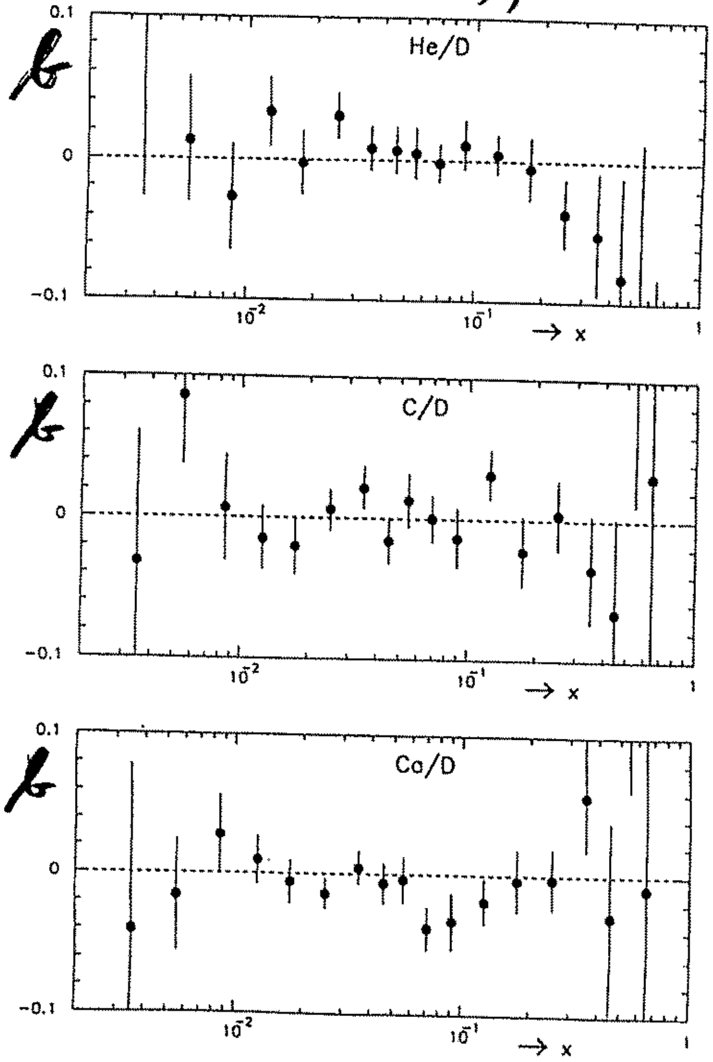
→ neue Werte für
He/D, C/D, Ca/D
C/Li, Ca/Li





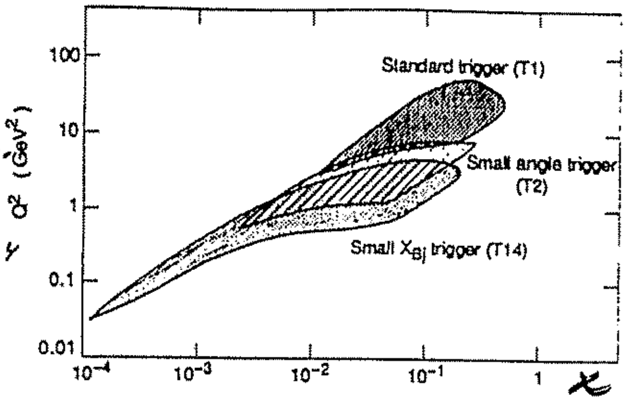
Q^2 - Abhängigkeit

$$b := d\left(F_2^A/F_2^d\right)/d\ln Q^2$$

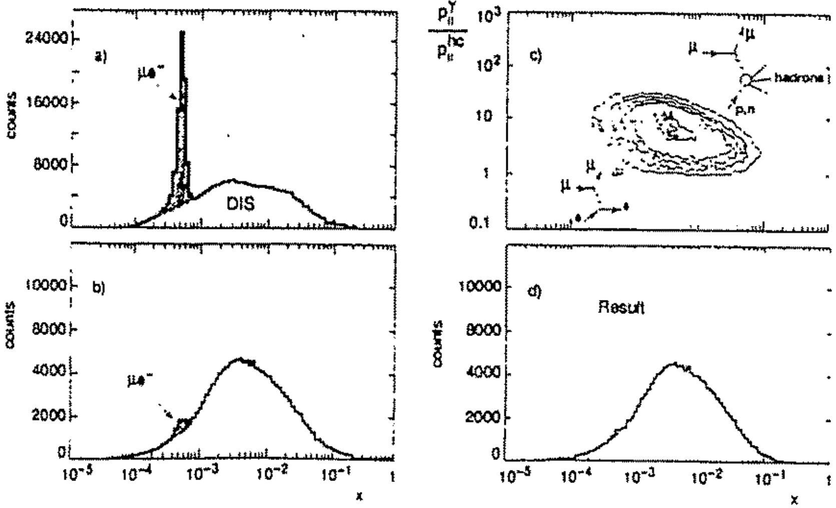


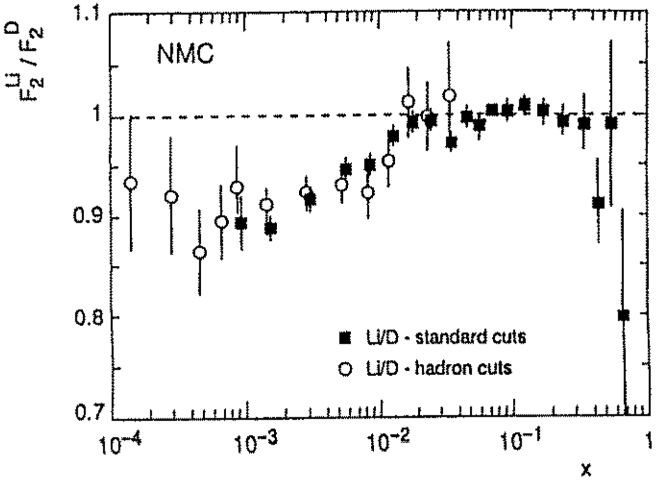
F_2^A / F_2^D bei kleinen x

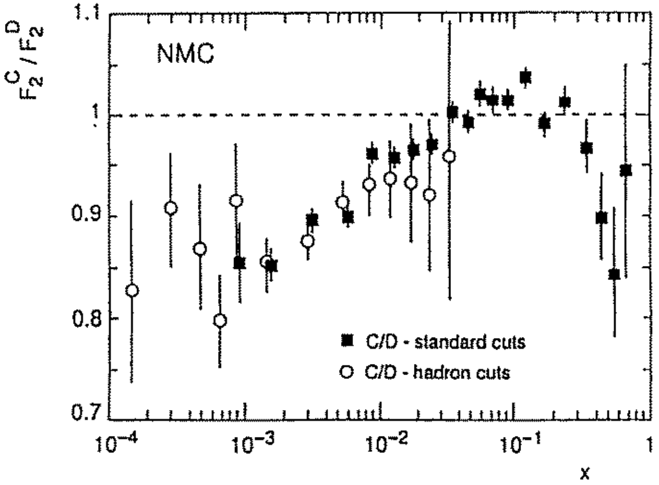
1989
zusätzlicher
Trigger
→ $x > 10^{-4}$



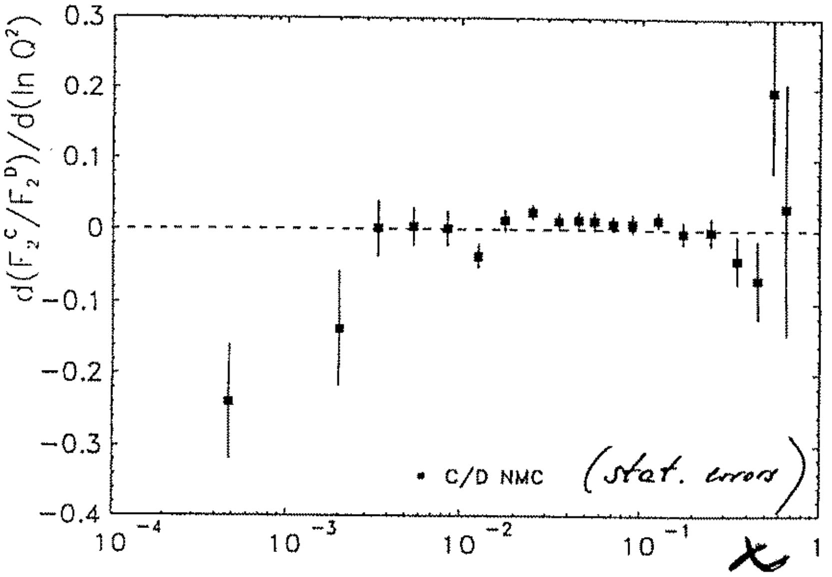
<u>Problem</u>: Separation der tiefinelastischen Ereignisse (elastische μ-e-Streuung bei $x = \frac{m_e}{m_\mu}$!)



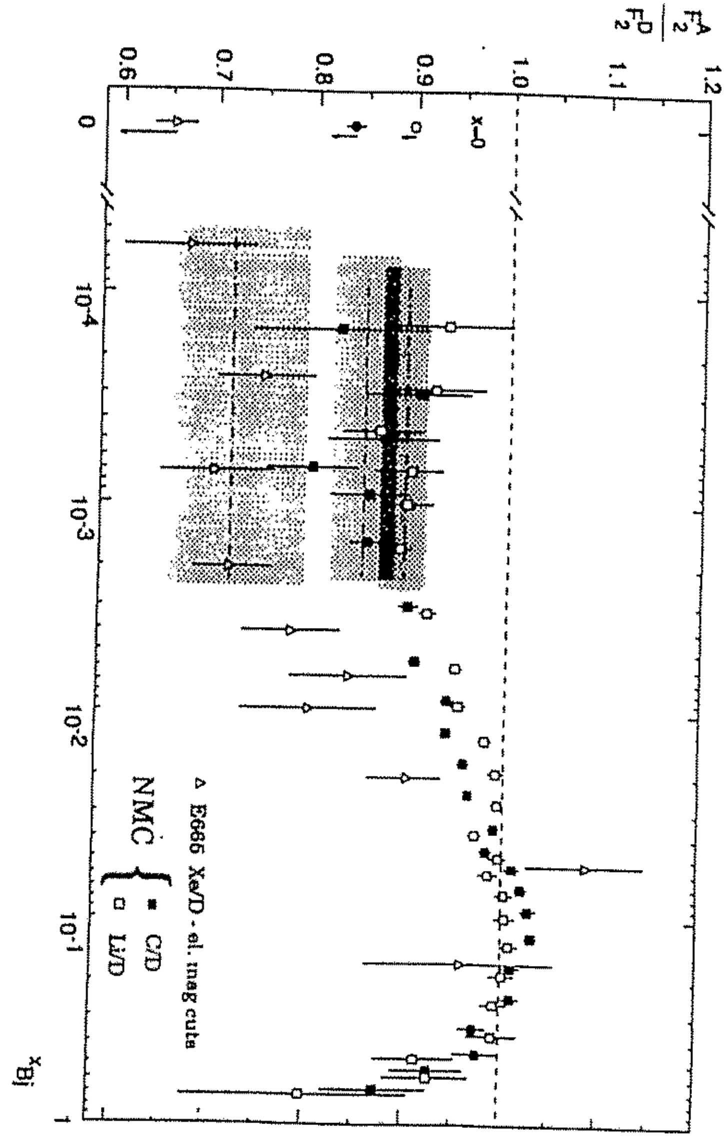




Q^2 - Abhängigkeit

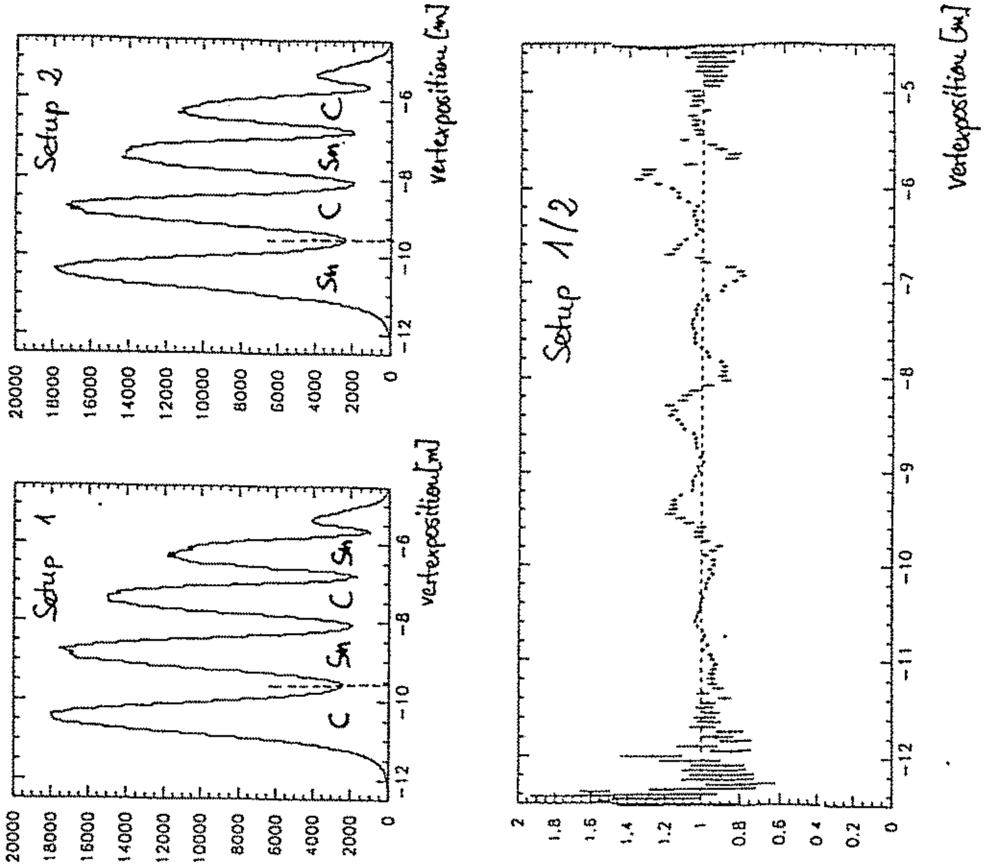


- Erweiterung des Q^2-Bereichs durch zusätzlichen Trigger
- Anzeichen für sehr schwache Q^2-Abh. im Bereich $0.01 < x < 0.1$

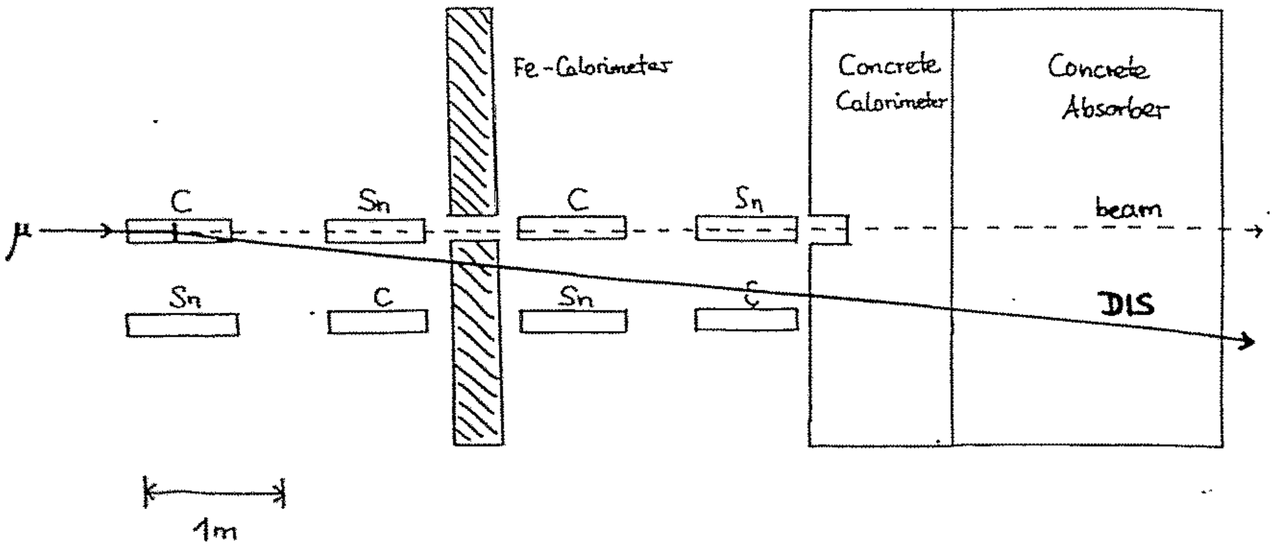


Vertex distributions (Data)

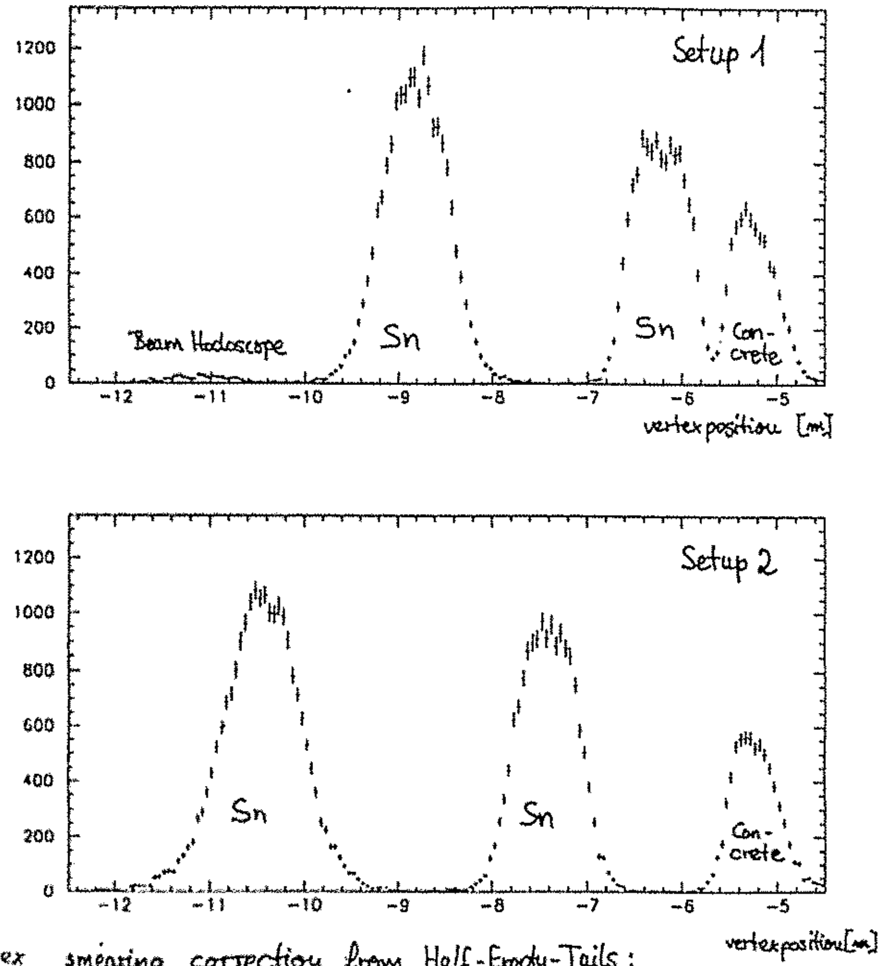
120 GeV



Sn / C Target Setup
+ Target Calorimeter



Vertexdistributions of Half-Empty-Target Setup
(Data) 120 GeV



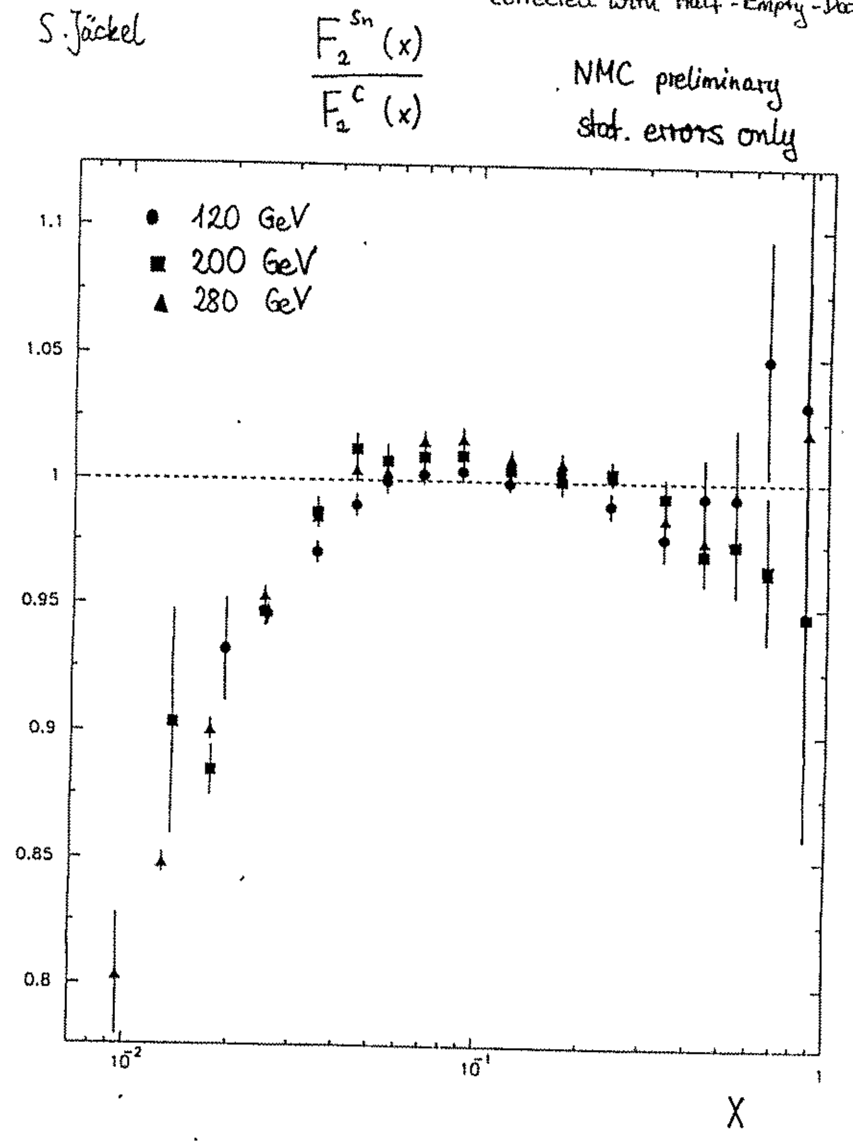
ertex smearing correction from Half-Empty-Tails:

only Sn, 1/2 material, time of data taking, statistics,
no kinematic smearing

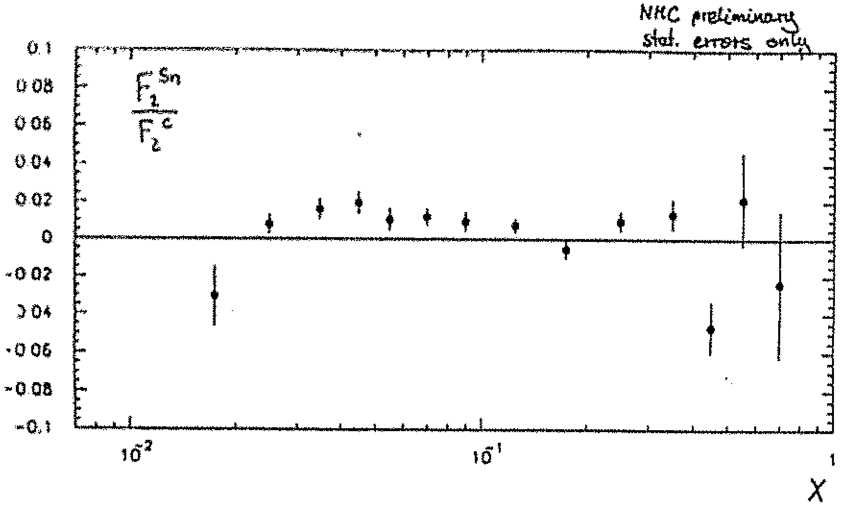
S. Jäckel

corrected with Half-Empty-Data

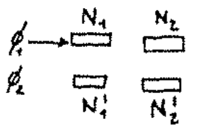
NMC preliminary
stat. errors only



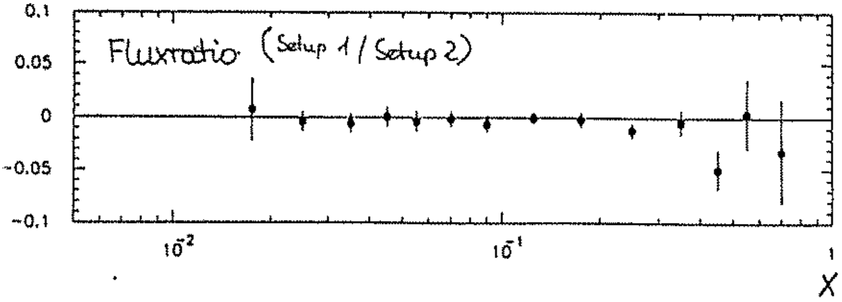
Slopes of Fits in log q^2 (corrected with Half-Empty-Data)



Fluxratio: cross check, no x- or q^2-dependence should be there!



$$\frac{\phi_1}{\phi_2} = \sqrt{\frac{N_1 N_2}{N_1' N_2'} \cdot \frac{H_1' H_2'}{H_1 H_2}}$$



Ausblick

- Abschluß der Analyse Ende 94
- Verbesserte Werte für F_2^p & F_2^d

  → Bestimmung von $R = \sigma_L/\sigma_T$
- Extrem genaue Bestimmung von F_2^d/F_2^p

  → $R^p - R^d$, $C^p - C^d$
- Q^2- und A-Abhängigkeit der Kerneffekte

  → Test verschiedener Modelle
- QCD-Analyse aller fixed target Experimente → α_s

Das CRYSTAL BARREL Experiment am LEAR

P. Blüm
Uni Karlsruhe

6.Oktober 1994

STAND OKTOBER 1994

Pirna, den 6. Oktober 1994

Das Crystal Barrel Experiment am LEAR

Peter Blüm
Institut für Experimentelle Kernphysik,
Universität Karlsruhe

- Was sind die physikalischen Ziele von **CBAR**?
- Wie sind diese Ziele zu erreichen?
- Was sind die Eigenschaften des Detektors?
- Was sind die zukünftigen Pläne von **CBAR**?

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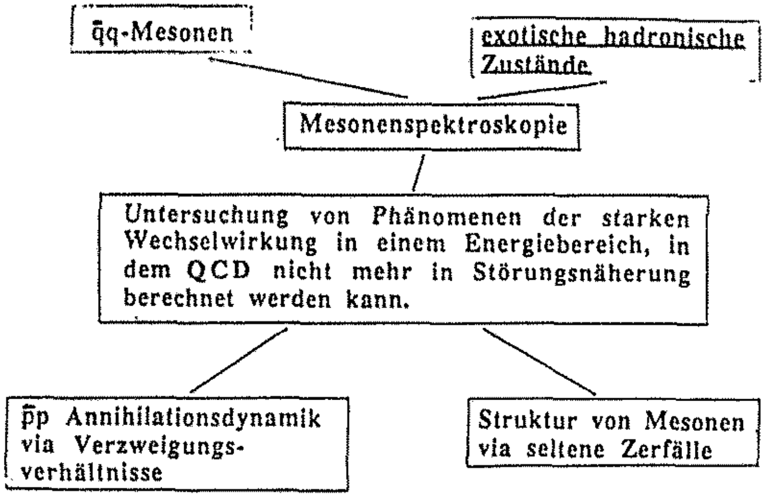
o) PHD student (22)

Was sind die physikalischen Ziele von CBAR?



q̄q-Mesonen

exotische hadronische Zustände

Mesonenspektroskopie

Untersuchung von Phänomenen der starken Wechselwirkung in einem Energiebereich, in dem QCD nicht mehr in Störungsnäherung berechnet werden kann.

p̄p Annihilationsdynamik via Verzweigungsverhältnisse

Struktur von Mesonen via seltene Zerfälle

Proposal: 1986 → DATENANALYSE: DEZEMBER 89

- *Search for glueballs and hybrids (meson spectroscopy)*

  p̄p -> π° X with X -> π°π°, ηη, or KK̄

  p̄p -> π°π° X → CH. STRASSBURGER, H. FRESSLER

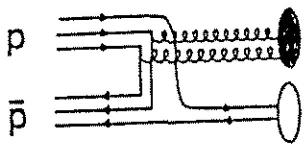
- Study of radiative and rare decays → U. WIEDNER
- Study of the p̄p - annihilation dynamics → K. BEUCKERT, J. BROSE
- Search for p̄p - bound states at rest
- *There are strong motivations of scanning the p̄ momentum in reasonable steps*

Wie sind diese Ziele zu erreichen?

Beispiel: Suche nach exotischen, d.h. nicht q̄q Zuständen.

Präzise Messung von p̄p - Annihilationsreaktionen in kinematisch vollständig bestimmten Endzuständen

Eindeutige Zuordnung der beobachteten Teilchen in die SU(3)-Nonets; zusätzliche Zustände sind Kandidaten für exotische Teilchen; Untersuchung der Produktions- und Zerfallseigenschaften.

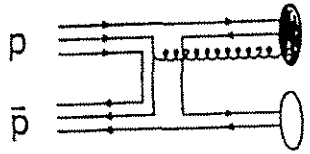


Glueball

expected below 2GeV

$0^{++}, 2^{++}, 0^{-+}$

$m(0^{++}) \sim 1500$ MeV $\qquad \frac{m(0^{++})}{m(2^{++})} \sim \frac{1}{1.5}$

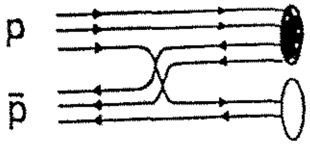


Hybrid

expected above 1GeV

exotic J^{PC} possible

0^{+-} 0^{--} 1^{-+} 2^{+-}



4-Quark State

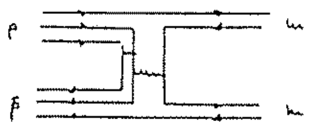
exotic quantum numbers

|Q|>1, |S|>1 or I>1

Experimentelle Ausrüstung:

- Hochintensiver p̄ Strahl mit hohen strahloptischen Qualitäten

  ⇒ LEAR



- Variabler Produktionsprozess

  ▲Änderung der Quantenzahlen des Anfangszustands
  - flüssiger Wasserstoff ≈88% annihilieren aus L = 0
    ≈12% annihilieren aus L = 1
  - gasförmiger Wasserstoff ≈48% annihilieren aus L = 0
    ≈52% annihilieren aus L = 1
  - Experimente bei höheren p̄ Impulsen L ≥ 0
  - Experimente mit Deuterium I = 1

  ▲ Änderung des Quarkinhalts des Anfangszustands

$\bar{p}p$:	$(\bar{u}\bar{u}\bar{d})(uud)$	Wasserstofftarget
$\bar{p}n$:	$(\bar{u}\bar{u}\bar{d})(udd)$	Deuteriumtarget

- Detektor der eine vollständige kinematische Rekonstruktion der Reaktion erlaubt.

  (i) großer Raumwinkel (≈ 4π)

  (ii) gute Energie- und Ortsauflösung für Photonen

  (iii) gute Orts- und Impulsauflösung für geladene Teilchen

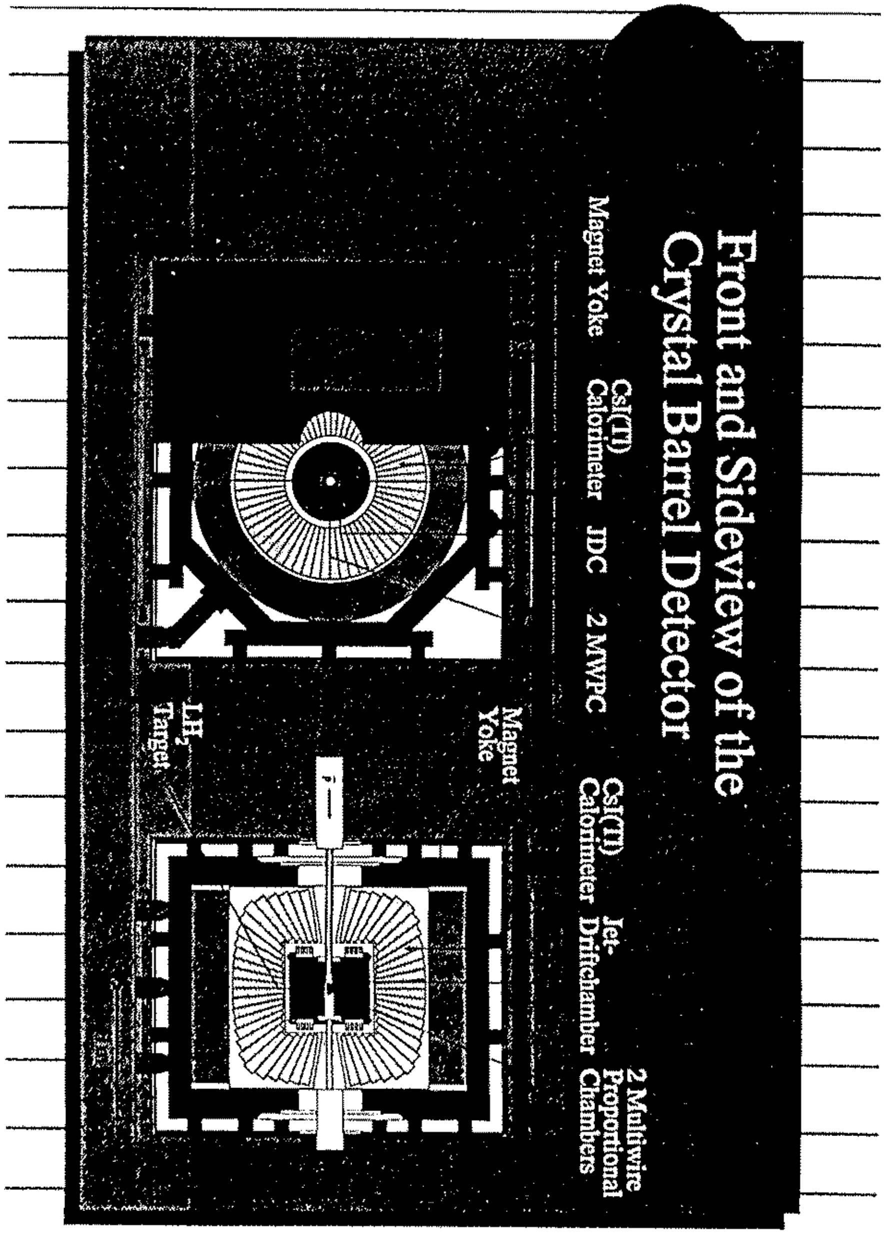
  (iv) effektive Pion/Kaon Trennung

  (v) hohe Datenerfassungsrate

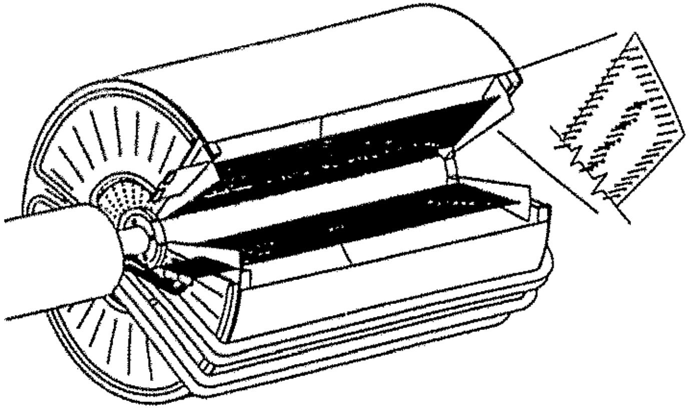
  (vi) selektives elektronisches Filter (multi-level trigger)

  ⇒ Crystal Barrel

V·N A321 (1992) 61-108

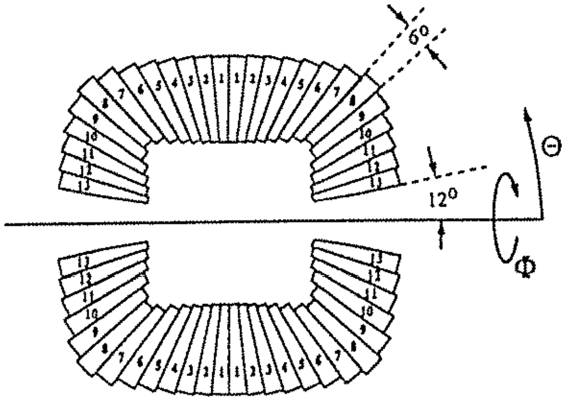

Front and Sideview of the Crystal Barrel Detector

Specifications of the Crystal Barrel tracking system

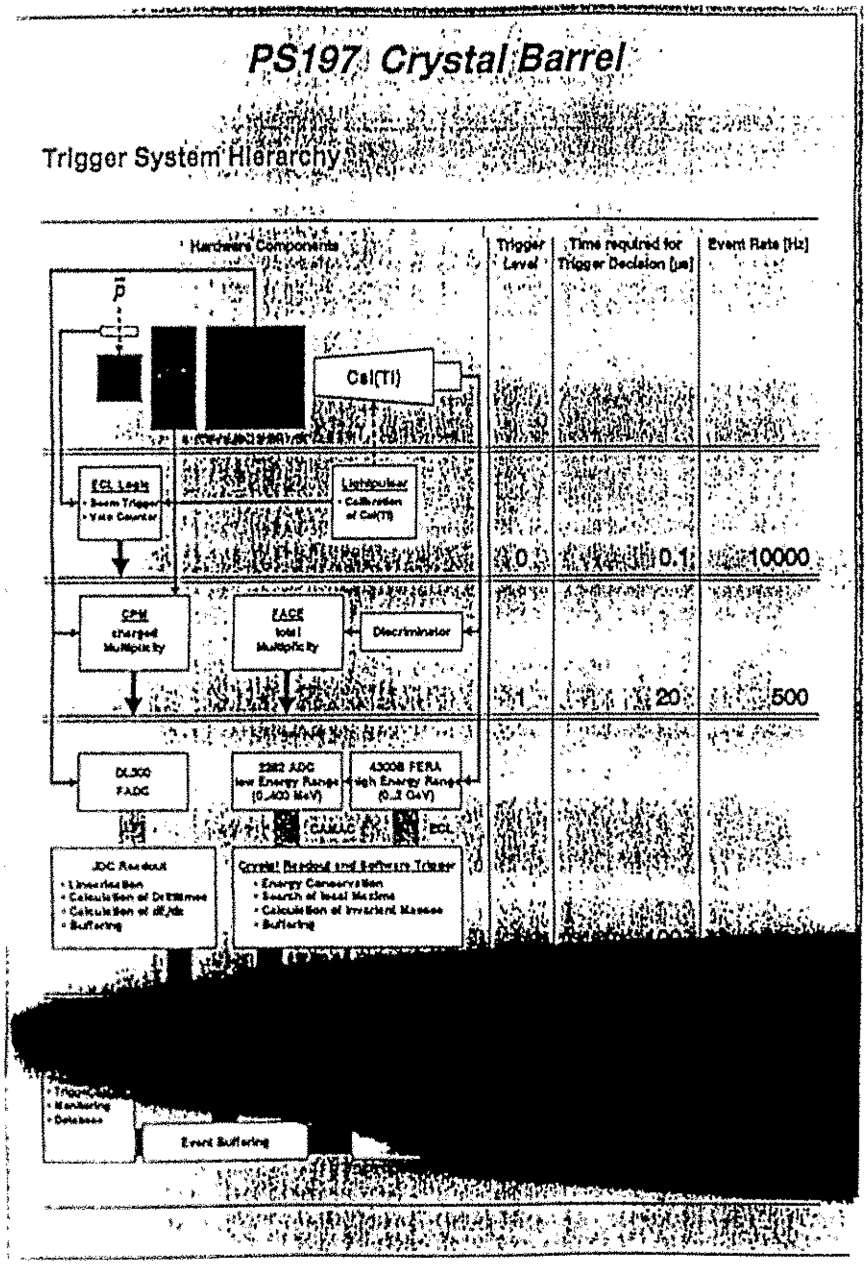


Proportional wire chamber	
solid angle	97% of 4π
number of layers	2 at r= 25.5 mm and r=43 mm
wires/layer	90 in inner and 150 in outer
wire spacing	1.8 mm
wire length	350 mm
Jet drift chamber	
solid angle	83% of 4π (at layer 10)
overall dimensions	
length	400 mm
inner radius	50 mm
outer radius	257 mm
segmentation	30 sectors à 23 layers
layer gap	8 mm
sense wires	690 (stainless steel 29,7 Ω/cm)
diameter	20 μm
field wires	2430 (gold-plated aluminium)
diameter	152 μm
gas	CO_2:isobutane (90:10)
drift field	1.1 kV/cm
drift velocity	8.4 mm/μsec
Lorentz angle	7.2°

Specifications of the Crystal Barrel calorimeter



general layout	barrel configuration
polar angle range	12° - 168°
solid angle	95% of 4π
scintillator	CsI(Tl) (1380 Module)
radiation length	1.86 cm
Molière radius	3.8 cm
light output	0.85 relative to NaI
maximum emission	at 550 nm
photon yield/MeV	4.5×10⁴
decay times	0.9 μsec and 7 μsec
active length	300 mm (16.1 X_0)
granularity	6° (12° near beam axis)
readout	WLS and photodiode



PS197 Crystal Barrel

Trigger System Hierarchy

Was sind die Eigenschaften des Detektors?

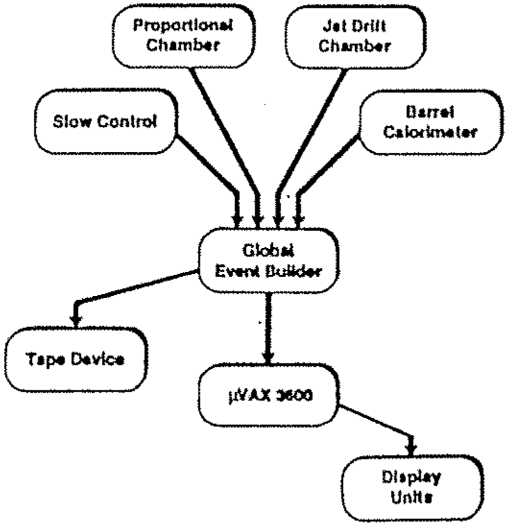
Data flow:

average amount of data per event: 15 kByte (zero suppressed)

typical trigger rate: 60 Hz

$\Rightarrow$ 900 kByte/sec to tape

parallel readout of digitized data; VME-based lokal system; OS9-system software; fast intercrate connectionvia VICbus



$5 \cdot 10^7$ Ereignisse auf Band!

Calorimeter performance:

noise performance: 250 keV (incoherent)
60 keV (coherent)

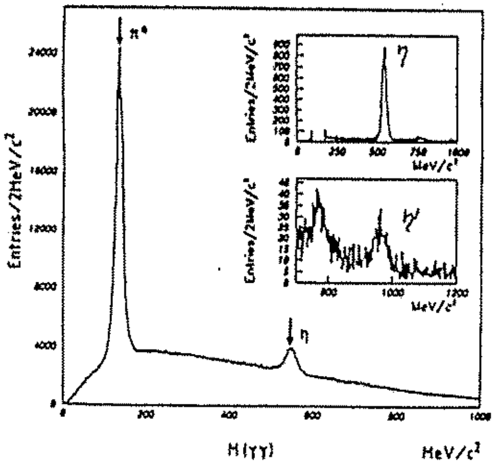
failure occurence: 660 y MTBF for photodiode
140 y MTBF for preamplifier

energy resolution: $\boxed{\sigma_E/E = 2.5\% / \sqrt[4]{E}}$ E in [GeV]

angular resolution: <u>< 25 mrad</u> for one-PED-cluster
with energy E > 50 MeV

K_L - WW.-WAHRSCHEINLICHKEIT: ~58% für p_{K_L} ~ 800 MeV/c
~42% für 200 MeV/c < p_{K_L} < 700 MeV/c

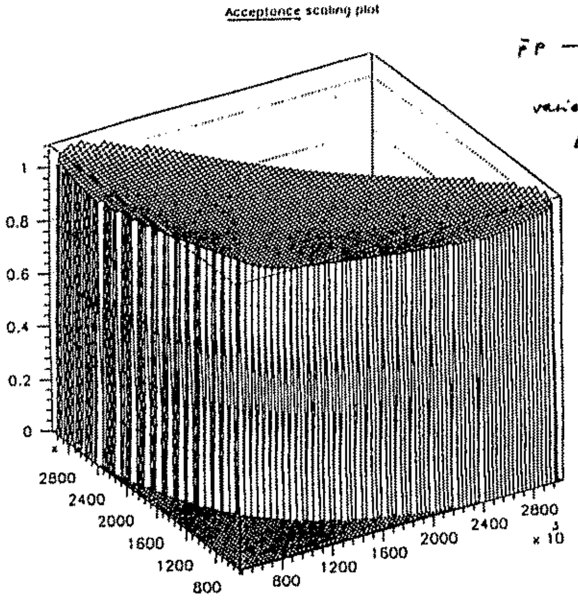
mass resolution:



e.g.
$\underline{\bar{p}p \to 6\gamma}$

$E_\gamma = 2.5\% / \sqrt[4]{E\,[GeV]}$

$\sigma(\pi^0 \to \gamma\gamma) = 7.5$ MeV
$\sigma(\eta \to \gamma\gamma) = 14.5$ MeV
$\sigma(\eta' \to \gamma\gamma) = 16.9$ MeV

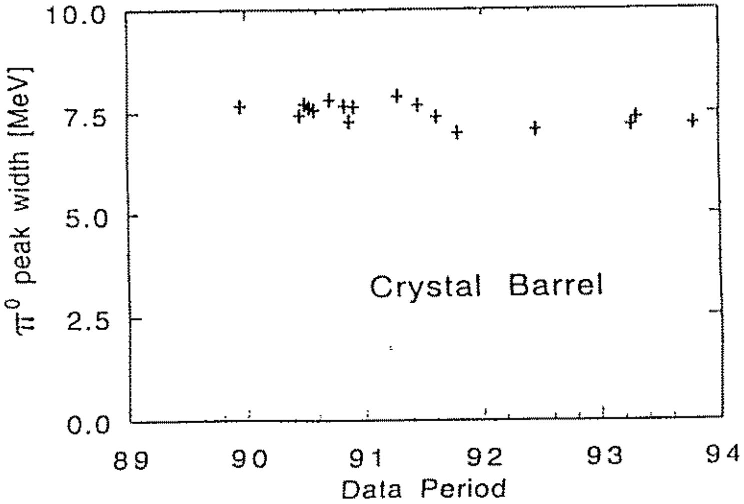


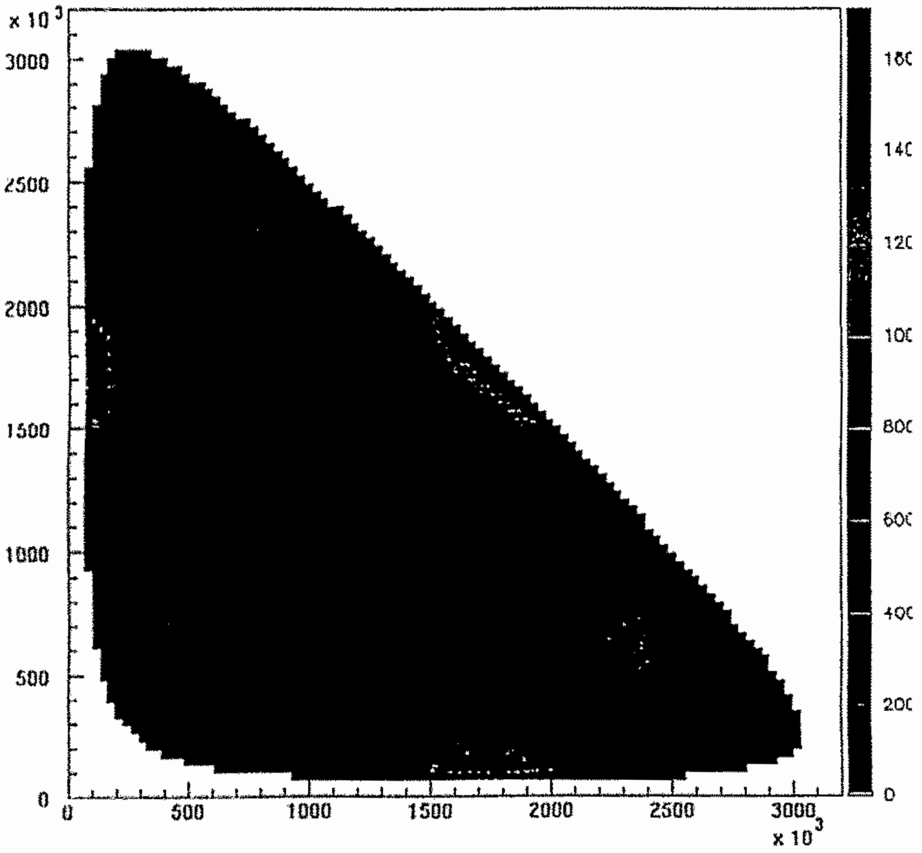
$\bar{p}p \to \pi^0\pi^0\eta \to 6\gamma$

variation: 2.5%

ϵ_{rec}: ~ 30%

im FLUGE:
variation: ~ 15-20%



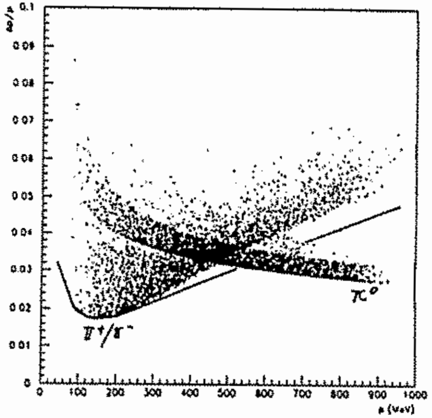


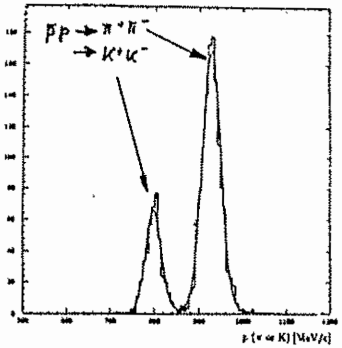
Jet drift chamber performance:

spatial resolution: r,φ resolution 130 μm
z-resolution 7mm

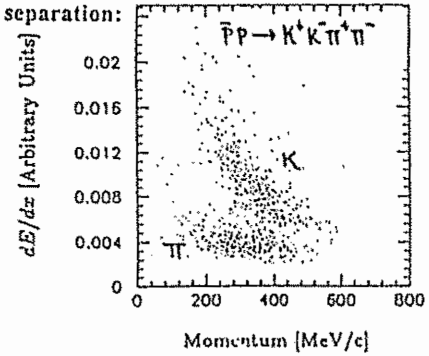
momentum resolution: (R.L. Gluckstern, NIM 24 (1963) 381

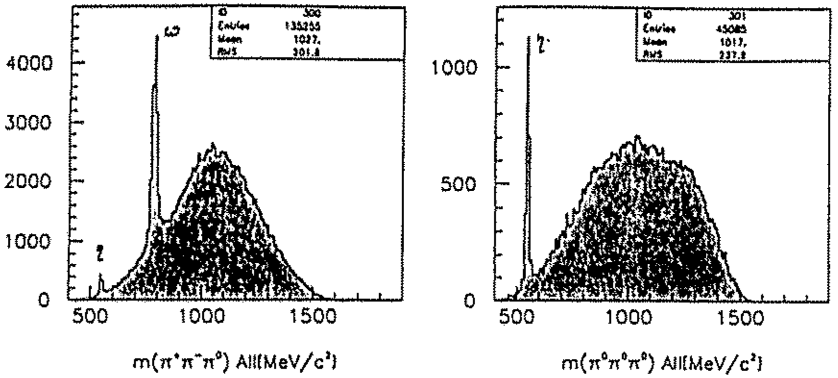
$$\frac{\sigma_{p_t}}{p_t} = \underbrace{\frac{\sigma_{r\phi}\, p_t}{0.3\ BL^2}\sqrt{\frac{720}{N+5}}}_{\text{spatial resolution}} + \underbrace{\frac{0.05}{LB\beta}\sqrt{\frac{1.43L}{X_0}}}_{\text{multiple scattering}}$$

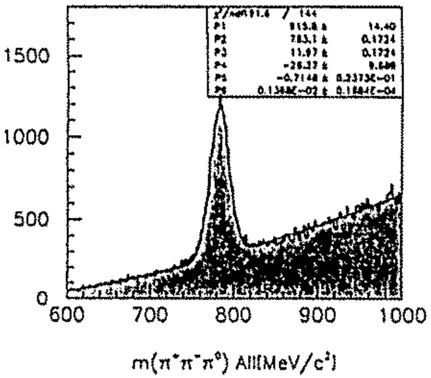




Pion/Kaon separation:





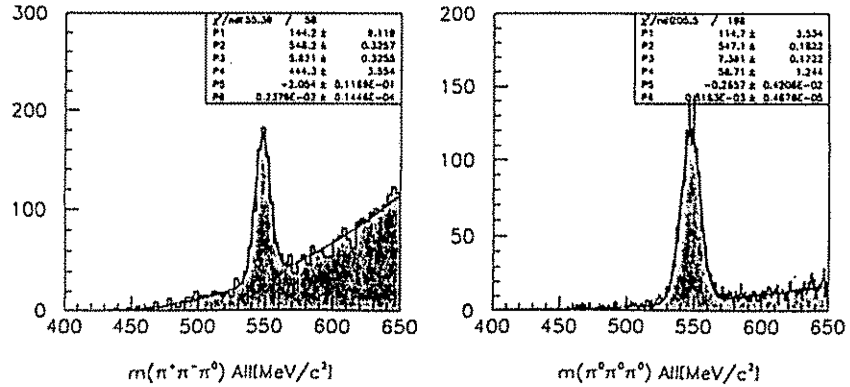


$$\boxed{\bar{p}p \longrightarrow \pi^+\pi^- 3\pi^0}$$

$\sigma(\omega) = 12\ \mathrm{MeV}/c^2$

$\sigma(\eta)_{CB} = 5.8\ \mathrm{MeV}/c^2$

$\sigma(\eta)_{N} = 7.4\ \mathrm{MeV}/c^2$



Was sind die zukünftigen Pläne für CBAR?

1995 - 1996

Messungen mit speziellen Triggern insbesondere kaonischer Endzustände im flüssigen und gasförmigen Wasserstoff
(spezieller* Silicon Vertex Detektor im Aufbau)

* MICRO-DETEKTOR;

Fortsetzung der Messungen zur Suche nach Hybridzuständen.
(20 Millionen 2-prong Trigger bei 1940 MeV/c)

Vervollständigung unseres Datensatzes mit Annihilationen am Deuterium.

Beginn eines Impulscans: Δp = 150 MeV/c
"GLUEBALL IN FORMATION" (≈50 MeV/c^2)

1997

Fortsetzung

$\bar{p}p \rightarrow G \rightarrow \bar{m}m$

ωX zusätzliche Information aus der Zerfallsverteilung des ω

$\pi^0\pi^0$ gut für 0^{++} / 2^{++} Studien

>1998

Vorschlag zur Einführung des mini-collider Modus am LEAR

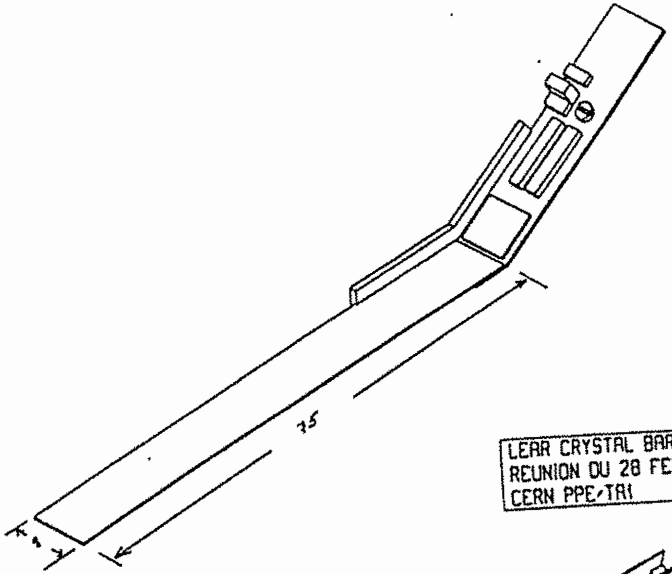
Fortsetzung der Mesonspektroskopie und der Suche nach Glueballs im Massenbereich 2 bis 3.5 GeV

(0^{++} (1500) ⇒ 2^{++} (≈2300) ⇒ 4^{++}(?))

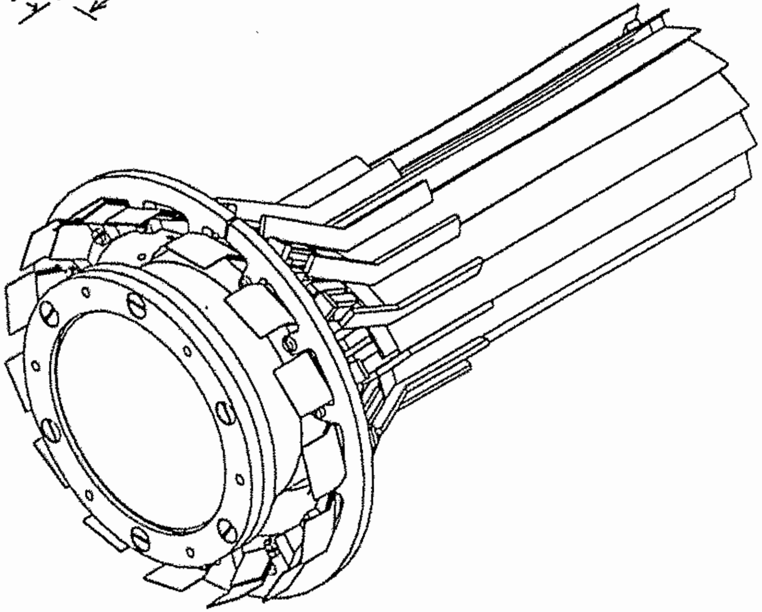
((ggg)-Gluballs sind ebenfalls in diesem Bereich zu erwarten. Suche nach (ggg) → (gg) + m)

z.B. $\{1^{++}\} \rightarrow f_0(1500) + \eta$

andere Optionen sind auch in Diskussion



LEAR CRYSTAL BARREL
REUNION DU 28 FEVRIER 1994
CERN PPE/TA1



Der Mini-Collider am LEAR:

Anzahl Protonen		$2 \cdot 10^{11}$
Anzahl Antiprotonen		10^{11}
Zahl der Bunche		58
Strahldimensionen am Detektor	horz.	0.9 mm
	vert.	1.3 mm
Strahlfläche		0.15 cm^2
Bunchlänge		10 cm
Impulsverschmierung		$2.1 \cdot 10^{-3}$
Luminosität		$0.9 \cdot 10^{28}$ cm^{-2} sec^{-1}
Wechselwirkungsrate im Detektor (100 mbar)		1000

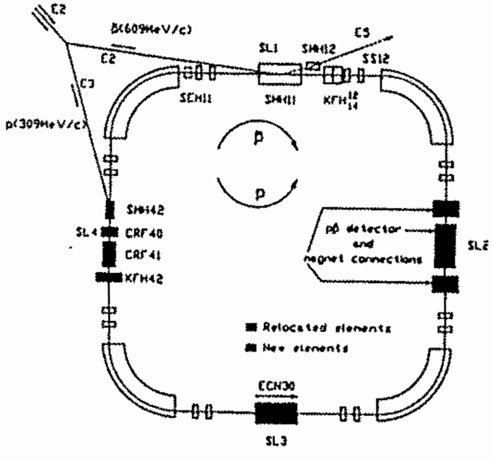


Fig. 2 : LEAR layout for pp̄ collisions

Wurde im CRYSTAL BARREL Experiment der skalare Glueball entdeckt?

C. Straßburger
Uni Bonn

6.Oktober 1994

Wurde im Crystal Barrel Experiment der skalare Glueball entdeckt ?

Christoph Straßburger
Institut für Strahlen- und Kernphysik
Universität Bonn
für die Crystal Barrel Kollaboration

Pirna, Oktober 1994

Übersicht :

Datensätze $\pi^0\pi^0\pi^0$, $\pi^0\pi^0\eta$, $\pi^0\eta\eta$, $\pi^0\eta\eta'$

Partialwellenanalyse

Interpretation der Partialwellenanalyseergebnisse

Zusammenfassung

Die Datenselektion

Datensatz : 17.0 Millionen Ereignisse mit
0-Prong-Trigger $\equiv$ 500$\cdot 10^6$ $\bar{p}p$-Annihilationen

Gemeinsame Selektionskriterien für alle Datensätze :

keine Spur in der Driftkammer

$18^0 \leq \Theta_{Photon} \leq 162^0$

Unterdrückung von e.-magn. Schauerfluktuationen

6 Photonen mit $E_{Photon} \geq 20 MeV$

Kinematische Anpassung an einzelne Hypothesen

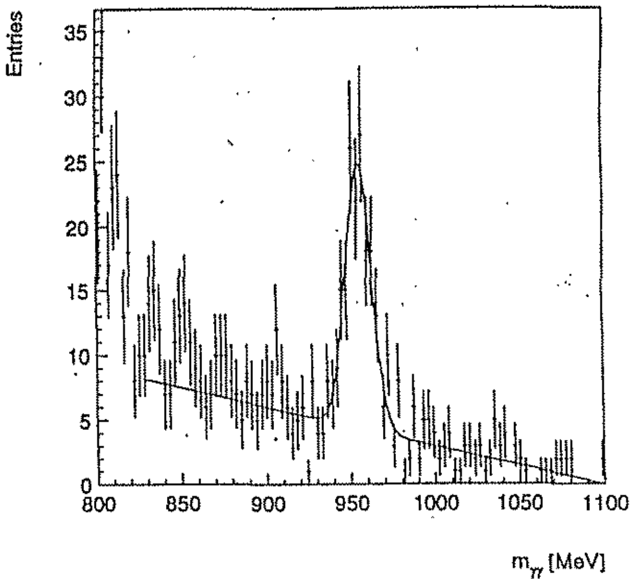
712.000	$\pi^0\pi^0\pi^0$-Ereignisse	BR=$(6.3\pm1.0)\cdot10^{-3}$
280.000	$\pi^0\pi^0\eta$-Ereignisse	BR=$(6.7\pm1.2)\cdot10^{-3}$
31.000	$\pi^0\eta\eta$-Ereignisse	BR=$(2.1\pm0.4)\cdot10^{-3}$
130	$\pi^0\eta\eta'$-Ereignisse	BR=$(2.5\pm0.5)\cdot10^{-4}$

Trigger Anreicherung der Endzustände $\pi^0\eta\eta$ auf
180.000 Ereignisse und $\pi^0\eta\eta'$ auf 819 Ereignisse

Akzeptanz Nahezu flache Akzeptanz für alle
Endzustände, auch für die getriggerten Daten

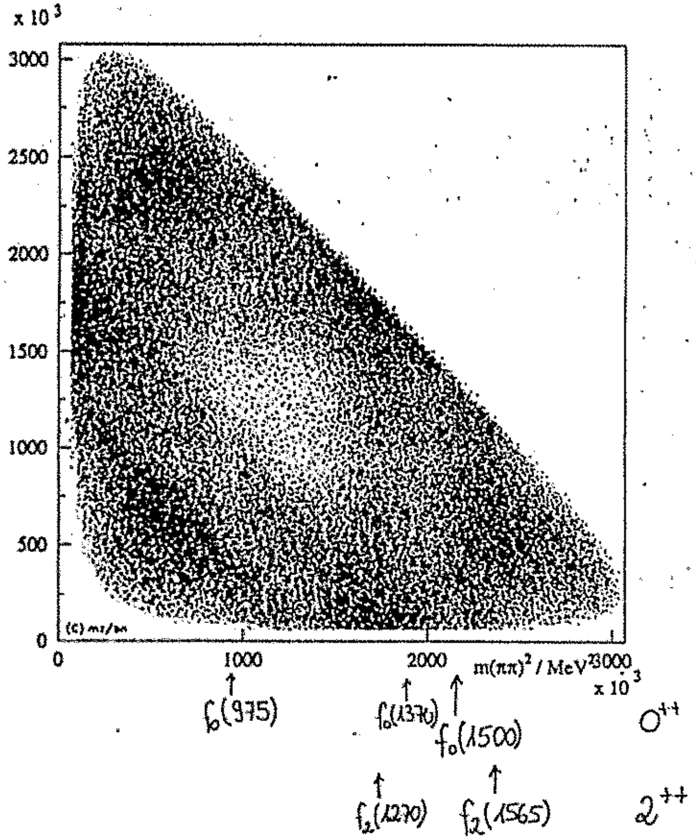
Crystal Barrel

$\gamma\gamma$-inv. Masse für $\pi^0\eta\gamma\gamma$



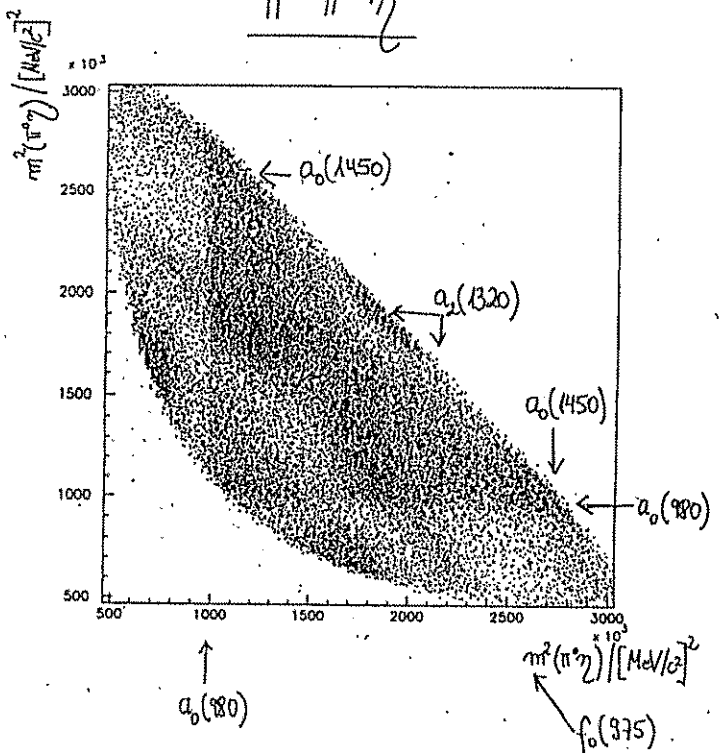
Crystal Barrel

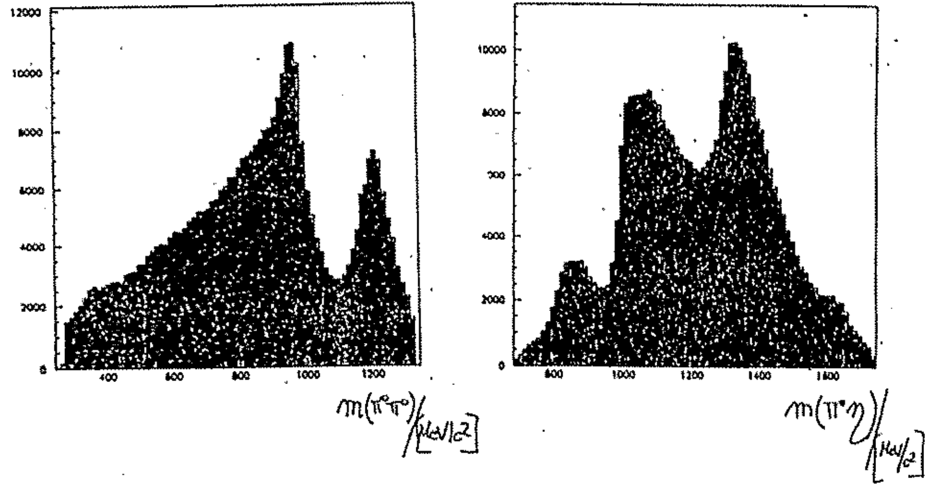
$\pi^0\pi^0\pi^0$ Dalitzplot



Crystal Barrel

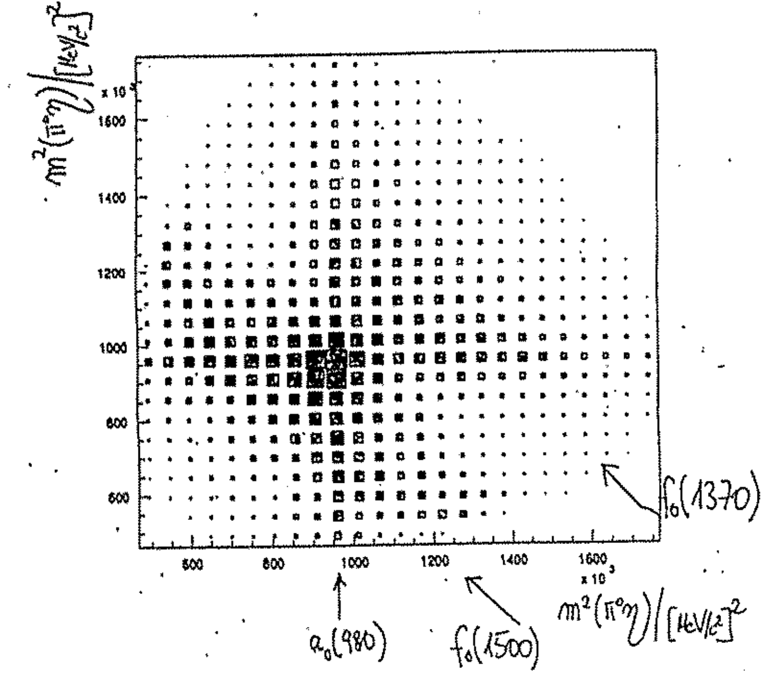
$\pi^0 \pi^0 \eta$

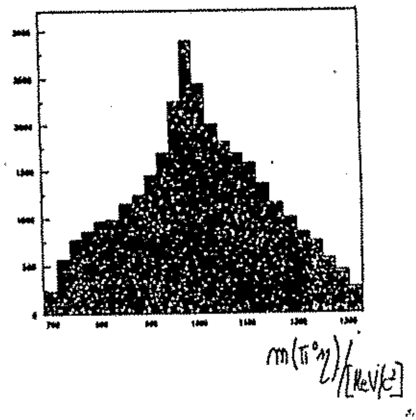


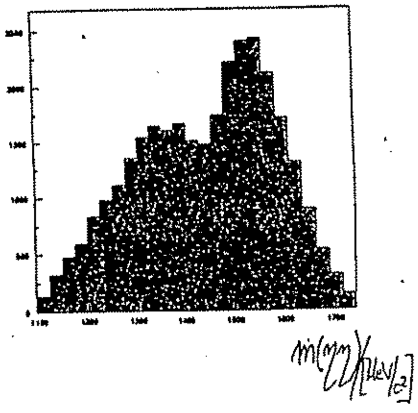


5 c)

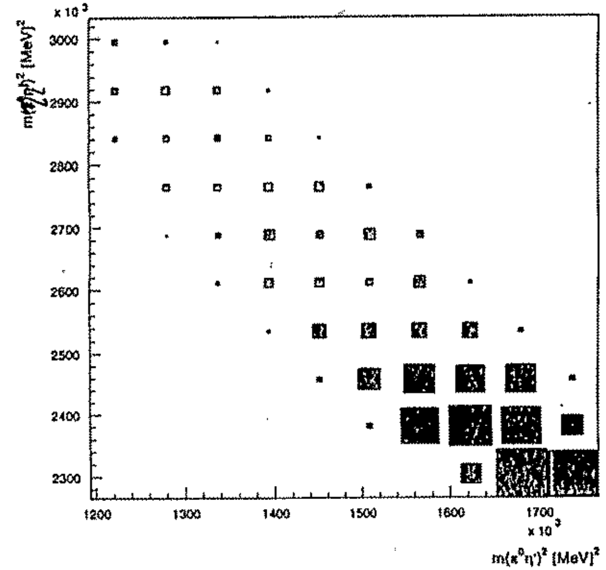
$\pi^0 \eta \eta$







$\pi^0\eta\eta'$ Dalitzplot (Trigger)



Crystal Barrel

6. Oktober 1994

Der Dalitz Plot

Ein Zerfall

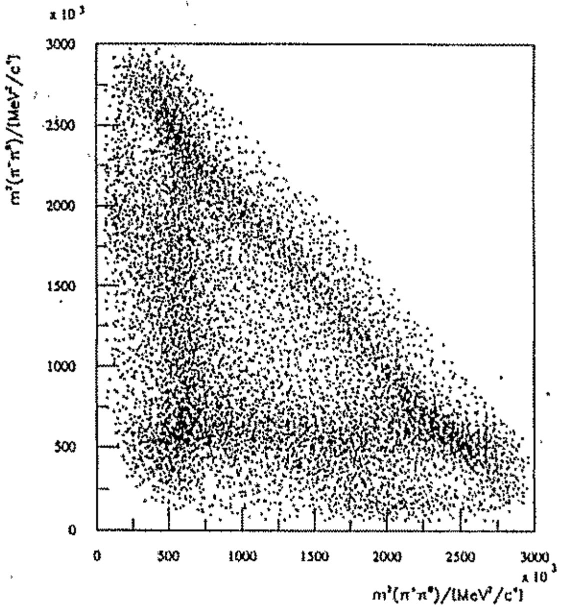
$$\bar{p}p \rightarrow M_1\ M_2\ M_3$$

wird durch 12 Variablen beschrieben (3 Vierervektoren). Folgende Nebenbedingungen reduzieren die freien Variablen

- Die 3 Mesonmassen $\longrightarrow$ 9 Variablen
- Impulserhaltung $\longrightarrow$ 6 Variablen
- Energieerhaltung $\longrightarrow$ 5 Variablen
- 3 Eulerwinkel

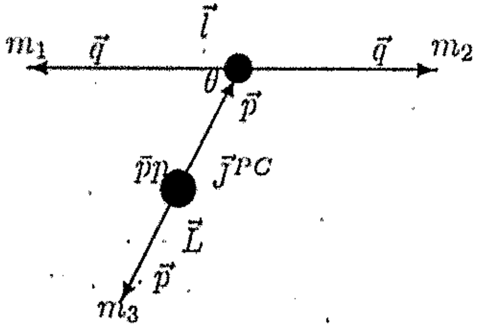
$\longrightarrow$ 2 Variablen

2 Variablen beschreiben die vollständige Dynamik.



$\pi^+\pi^-\pi^0$–Dalitzplot

Partialwellenanalyse im K-Matrixformalismus



Die Produktionsamplitude ist dann wie folgt definiert :

$$\mathcal{A}_{J^{PC},L,l}(\vec{p},\vec{q}) = \sum_{permutations} Z_{J^{PC},L,l}(\vec{p},\vec{q}) \cdot F^l(\vec{p},\vec{q})$$

- $Z_{J^{PC},L,l}$ beschreibt die Winkelverteilung
- F^l beschreibt die 2-Meson Endzustandswechselwirkung

$$\begin{aligned} S &= I + 2i\rho T \\ T &= (I - iK\rho)^{-1} K \\ T_{11} &= \frac{K_{11} - i\rho_2(K_{11}K_{22} - K_{12}K_{21})}{D} \\ D &= 1 - i\rho_1 K_{11} - i\rho_2 K_{22} - \\ & \quad \rho_1\rho_2(K_{11}K_{22} - K_{12}K_{21}) \end{aligned}$$

Crystal Barrel

Im P-Vektoransatz nach Aitchinson ergibt sich für die dynamische Amplitude:

$$F = (I - iK\rho)^{-1} P \,,\; T = (I - iK\rho)^{-1}$$

Im Fall einer einzigen Polstelle, besitzt F die bekannte Breit-Wigner-Form :

$$K = \frac{g^2}{m_0^2 - m^2} \qquad P = \frac{\beta g}{m_0^2 - m^2}$$

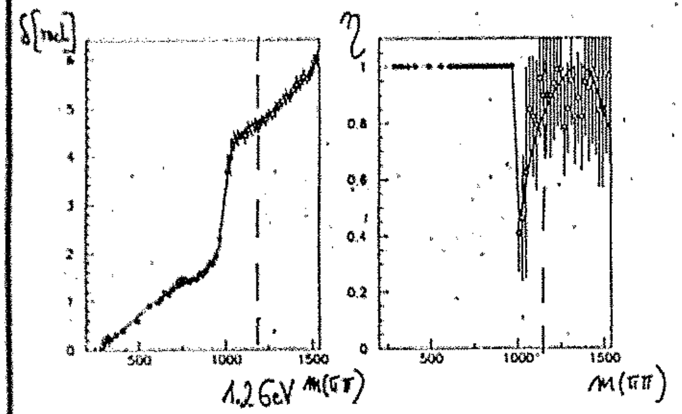
$$F = \frac{\beta g}{m_0^2 - m^2 - i\rho g^2}$$

Die Analyse umfaßte die Crystal Barrel Daten und für die $\pi\pi$ S–Welle zusätzlich die Streudaten der CERN-München-Kollaboration:*

$$T = (I - iK\rho)^{-1} K$$

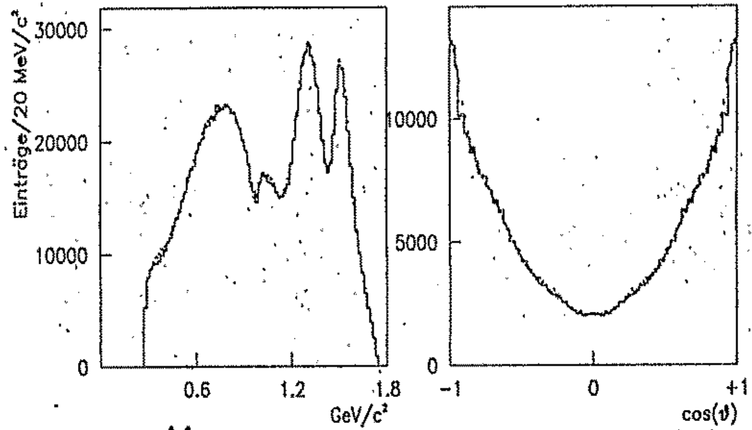
* G. Grayer et al., Nucl. Phys. B75(1974)189

Crystal Barrel



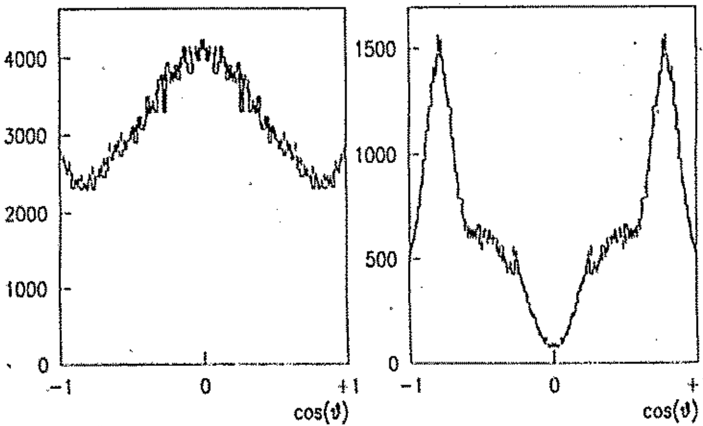
⟹ gemeinsame Anpassung der Dalitzplots
und der ππ- Streudaten

Anpassung an $3\pi^0$



$\pi^0\pi^0$ invariante Masse

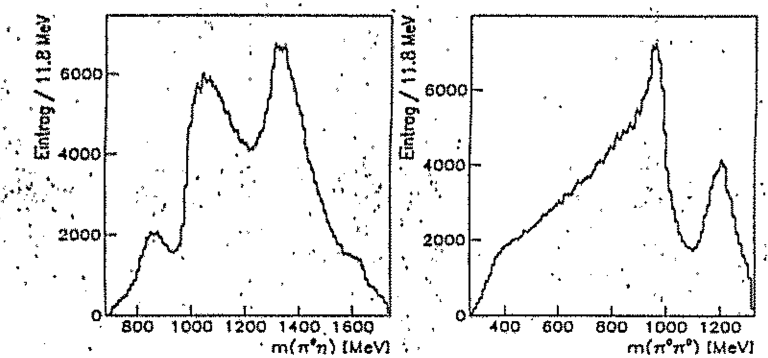
Winkelverteilung im Bereich A



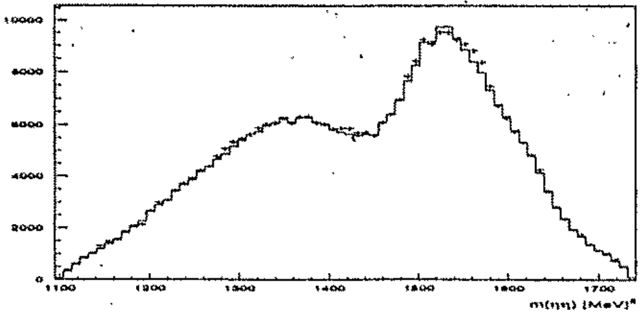
Winkelverteilung im Bereich C+D

Winkelverteilung im Bereich E

Ergebnis für $\pi^0\pi^0\eta$



Fit an $\pi^0\eta\eta$



Ergebnisse der Partialwellenanalyse

a) Die isoskalaren S-Wellen-Resonanzen

$f_0(975)$:	$M = (980\pm20) MeV$	$\pi\pi$
	$\Gamma = (100\pm20) MeV$	
$f_0(1370)$:	$M = (1365\pm50) MeV$	$\pi\pi$ $\eta\eta$ 4π
	$\Gamma = (270\pm80) MeV$	
$f_0(1500)$:	$M = (1500\pm15) MeV$	$\pi\pi$ $\eta\eta$ $\eta\eta'$
	$\Gamma = (150\pm20) MeV$	

b) Die isovektoriellen S-Wellen-Resonanzen

$a_0(980)$:	$M = (985 \pm 5) MeV$	$\pi\eta$ $K\bar{K}$
	$\Gamma = (54 \pm 5) MeV$	
$a_0(1450)$:	$M = (1450 \pm 40) MeV$	$\pi\eta$ $K\bar{K}(?)$
	$\Gamma = (270 \pm 40) MeV$	

c) Die isoskalaren D-Wellenresonanzen

$f_2(1270)$:	$M = (1265 \pm 10) MeV$	$\pi\pi$
	$\Gamma = (195 \pm 20) MeV$	
$f_2(1565)$:	$M = (1540 \pm 20) MeV$	$\pi\pi$
	$\Gamma = (160 \pm 30) MeV$	

d) Die isovektoriellen D-Wellenresonanzen

$a_2(1320)$:	$M = (1316 \pm 5) MeV$	$\pi\eta$	$K\bar{K}$
	$\Gamma = (113 \pm 4) MeV$		
$a_2(1650)$	$M = (1650 \pm 50) MeV$	$\pi\eta$	
	$\Gamma = (220 \pm 50) MeV$		

e) keine Evidenz für $\hat{S}(1405) \rightarrow \pi\eta$

Crystal Barrel

Einordnung des $a_0(1450)$ und das Nonett der Skalaren Mesonen

$f_0(975)$ ~~und $a_0(980)$ $K\bar{K}$-~~Moleküle ?

$f_0(1525)$ ~~schwaches Signal unter dominanter D-Welle~~

$K_0^*(\bar{K}_0^*)(1430)$ etablierter I=$\frac{1}{2}$ Grundzustand

$f_0(1370)$ in mehreren unabhängigen Analysen bestätigt

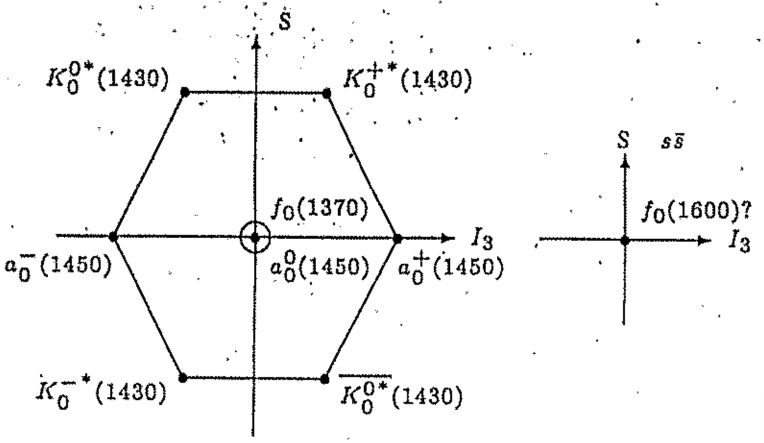
$a_0(1450)$ ⇒ **Isovektor zu $f_0(1370)$**

$f_0(1600)$?

$K\bar{K}$-Daten dringend erforderlich !

Crystal Barrel

Das mögliche Nonett der Skalaren Mesonen



Crystal Barrel

Was ist das $f_0(1500)$

⇒**Skalares Nonett** komplett

⇒**$s\bar{s}$-Zustand** im Skalaren Nonett unwahrscheinlich

⇒**$\bar{N}$N-Bindungszustand** unwahrscheinlich

⇒**Masse** für Hybrid zu niedrig

⇒**Massenvorhersagen** für den skalaren Glueball liegen in diesem Bereich

Kopplung an die Zerfallskanäle nach Phasenraumkorrektur :

2π	$\eta\eta$	$\eta\eta'$	$K\bar{K}$
3 :	(0.72 ±0.37) :	(1.05 ±0.44) :	≤ 0.4

⇒ Diese Kopplungen sind nicht kompatibel mit der Einordnung in ein Nonett, **unabhängig** vom Mischungswinkel !

Crystal Barrel

Frage : Zerfällt ein Glueball "flavourblind" ?

a) Flavoursymmetrie

2π	$\eta\eta$	$\eta\eta'$	$K\bar{K}$
3 :	1 :	0 :	4

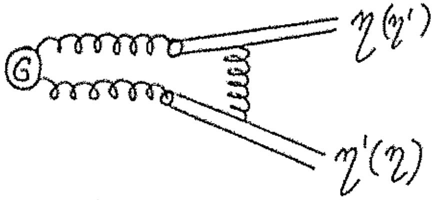
b) Flavoursymmetrie gebrochen (nach F. Close)

$K\bar{K}\downarrow$ $\eta\eta'\uparrow$

⟶ untersuche $K\bar{K}$-Daten !!

c) "Decolorization" (nach S. Gershtein)

- Flavoursymmetrie nur bei Zerfall in 2 Colorsingletts
- Zerfall in 2 Flavoursingletts mit anschliessendem Glueaustausch möglich



Zusammenfassung

Crystal Barrel Experiment liefert neutrale Endzustände mit 3 pseudoskalaren Mesonen mit bisher unerreichter Statistik und Präzision

Akzeptanz für diese Endzustände flach im Rahmen weniger Prozent Abweichungen, selbst bei getriggerten Datensätzen

Partialwellenanalysen zeigen eindeutige Evidenz für zwei neue skalare Resonanzen

$$\Longrightarrow a_0(1450)\ und\ f_0(1500)$$

$a_0(1450)$ I=1-Zustand im Nonett der Skalaren Mesonen

$f_0(1500)$ Eigenschaften sprechen für die Interpretation als Skalarer Glueball

Suche nach Mesonen II
(CRYSTAL BARREL)

M. Faessler
München

6.Oktober 1994

SUCHE NACH MESONEN II

$\bar{p}p \to K\bar{K}X$ ($\bar{p}$ IN RUHE, LH_2-TARGET)

CRYSTAL-DARREL-EXPERIMENT

M. FAESSLER, UNIV. MÜNCHEN
PIRNA, 6. 10. 94

UNTERSUCHTE ENDZUSTÄNDE:

VIEDNER ← ($X = \gamma$: $K_L K_S \gamma$, $K^+K^-\gamma$)

⟹ $X = \pi$: $K_L K_S \pi^0$, $K_L K_L \pi^0$, $K_S K_S \pi^0$, $K_L K^\pm \pi^\mp$, $K^+K^-\pi^0$

($X = \eta$: $K_L K_S \eta$, $K_S K_S \eta$)

⟹ $X = 2\pi$: $K_L K_S 2\pi^0$, $K_L K^\pm \pi^\mp \pi^0$

···⇝ $X = 3\pi$: $K_L K^\pm \pi^\mp 2\pi^0$

WICHTIGSTE GEGENWÄRTIGE NAHZIELE:

- DIE KONSTITUENTEN DER VON CRYSTAL-DARREL GEFUNDENEN

  f_0 - MESONEN

  $\boxed{f_0(1525) \text{ UND } f_0(1365)}$

  ZU IDENTIFIZIEREN

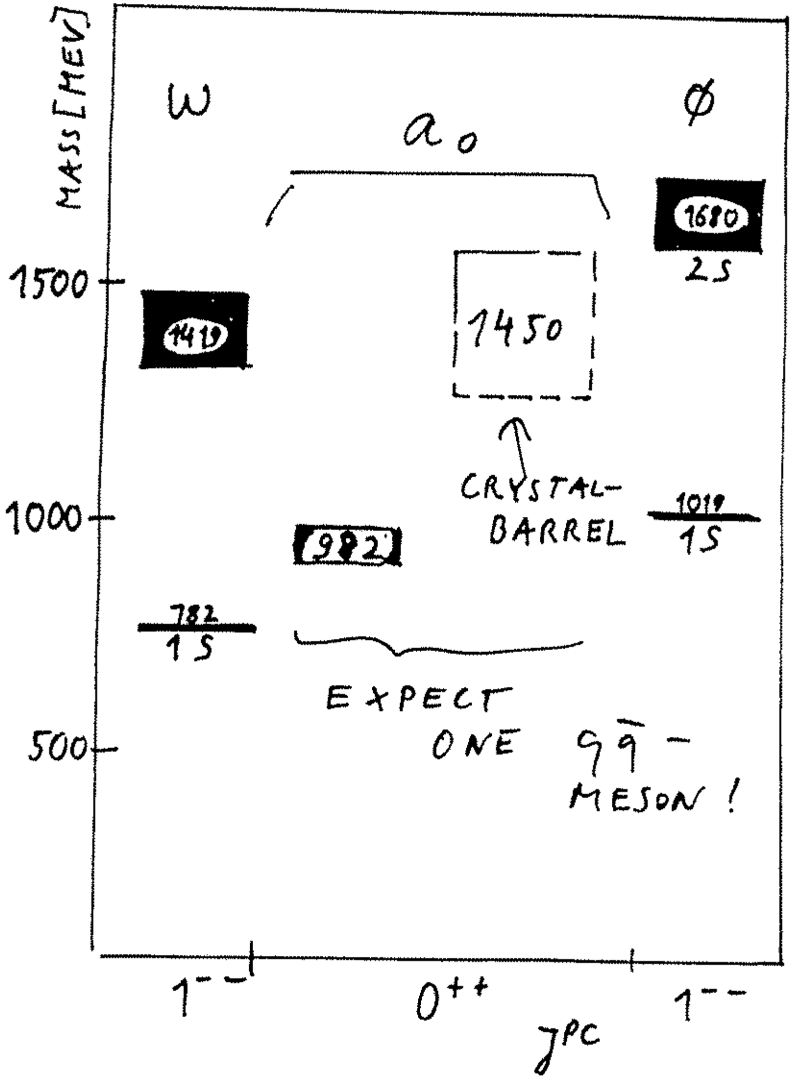
- DIE EXISTENZ DES (EDENFALLS VON CB GEFUNDENEN)

  a_0 - MESONS

  $\boxed{a_0(1450)}$

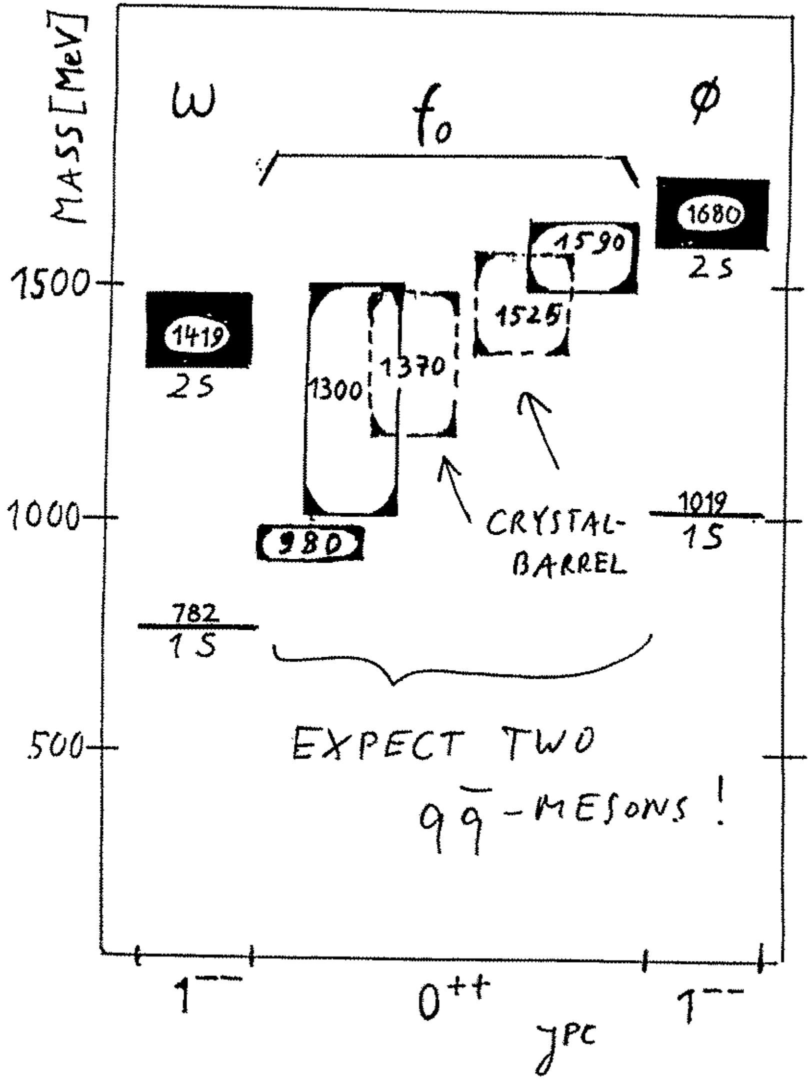
  DURCH NACHWEIS IN ANDEREN ZERFALLSMODEN ZU VERI- ODER FALSIFIZIEREN

THE ISOVECTOR SCALAR MESONS BETWEEN $\omega(1S)$ AND $\phi(2S)$



[PDG 94]

THE ISOSCALAR SCALAR MESONS BETWEEN $\omega(1S)$ AND $\phi(2S)$



[PDG 94]

ROLLE VON $K, \bar{K}$:

1) INDIKATOREN VON K-RESONANZEN

➡ **2)** $(K\bar{K})$-PAAR UNTER DEN ZERFALLSPRODUKTEN VON ([illegible] $S=0$) – RESONANZEN
↝ SONDE DER KONSTITUENTEN

VIER BEISPIELE:

a) $f_0 = \frac{u\bar{u} + d\bar{d}}{\sqrt{2}} \overset{SU(3)}{\curvearrowright} \frac{BR(f_0 \rightarrow K\bar{K})}{BR(f_0 \rightarrow \pi\pi)} = \frac{1}{6}$

b) $f_0' = s\bar{s} \curvearrowright \frac{BR(f_0' \rightarrow K\bar{K})}{BR(f_0' \rightarrow \pi\pi)} = \frac{1}{0}$

c) $f_0 =$ glueball $\overset{SU(3)}{\curvearrowright} \frac{BR(f_0 \rightarrow K\bar{K})}{BR(f_0 \rightarrow \pi\pi)} = \frac{4}{3}$
(FLAVOUR-SINGULETT)
$\pi\pi : K\bar{K} : \eta\eta : \eta\eta' = 3 : 4 : 1 : 0$ FLAVOUR-DEMOKRATIE

d) $f_0 = M\bar{M}$-MOLEKÜL ↝ $f_0 \rightarrow M\bar{M}$ dominant

NACHWEIS VON $K^{\pm}, K_L, K_S$
IM CRYSTAL-BARREL-DETEKTOR

ERSTES BEISPIEL (K_L, K_S):

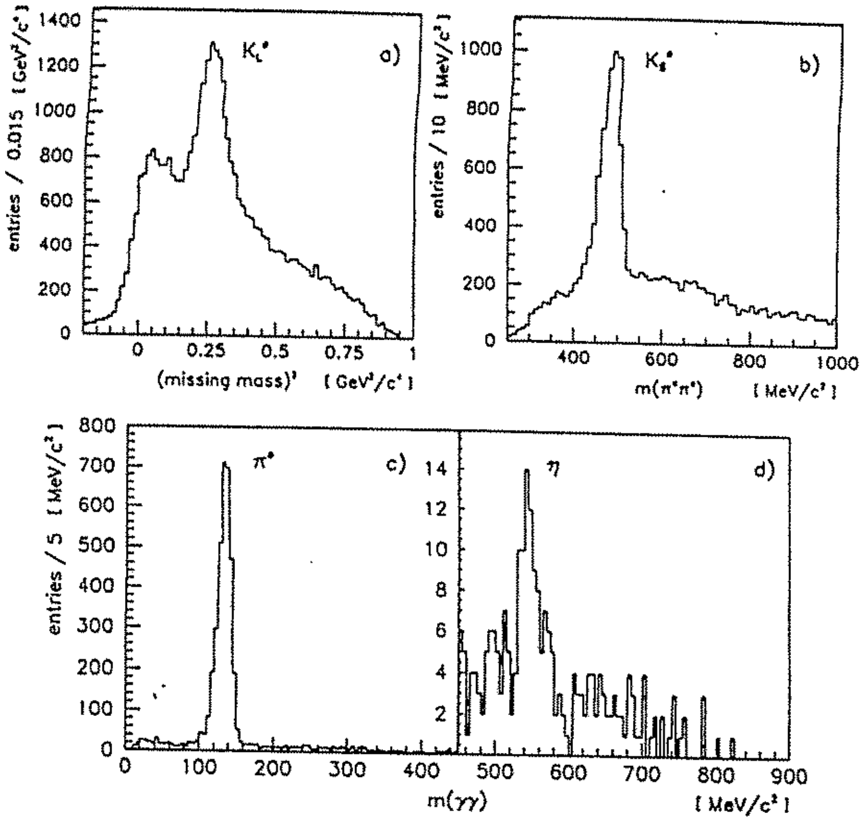
$$\boxed{\bar{p}p \rightarrow K_L K_S \pi^0}$$

$\pi^0 \rightarrow 2\gamma$
$K_S \rightarrow \pi^0\pi^0 \rightarrow 4\gamma$
$K_L \rightarrow$ "MISSING"

SCHNITTE:

$4.5 \cdot 10^6$ ZERO-PRONG TRIGGERS
↓
$8 \cdot 10^5$ 6 elektromagn. Schauer
↓
BILD a) 58 000 $900 < E_{tot} < 1400$ MeV UND ANDERE SCHNITTE
↓
" b) 10 300 NACH KIN. FIT $K_L + 6\gamma$
↓
" c, d) 4400 NACH KIN. FIT $K_L K_S 2\gamma$

$(\bar{p}p \rightarrow K_L K_S \pi^0)$



WICHTIG:

WINKEL- UND ENERGIEAUFLÖSUNG
+ HERMETIZITÄT (≈ 4π AKZ.)

ZWEITES BEISPIEL (K^+, K^-, K_L)

$$\boxed{\bar{p}p \rightarrow K_L K^{\pm} \pi^{\mp} + 2\text{-}4\ \gamma\text{'s}}$$

SCHNITTE:

TWO-PRONG-TRIGGERS + MIN. BIAS

↓

ZWEI LANGE SPUREN IN JDC

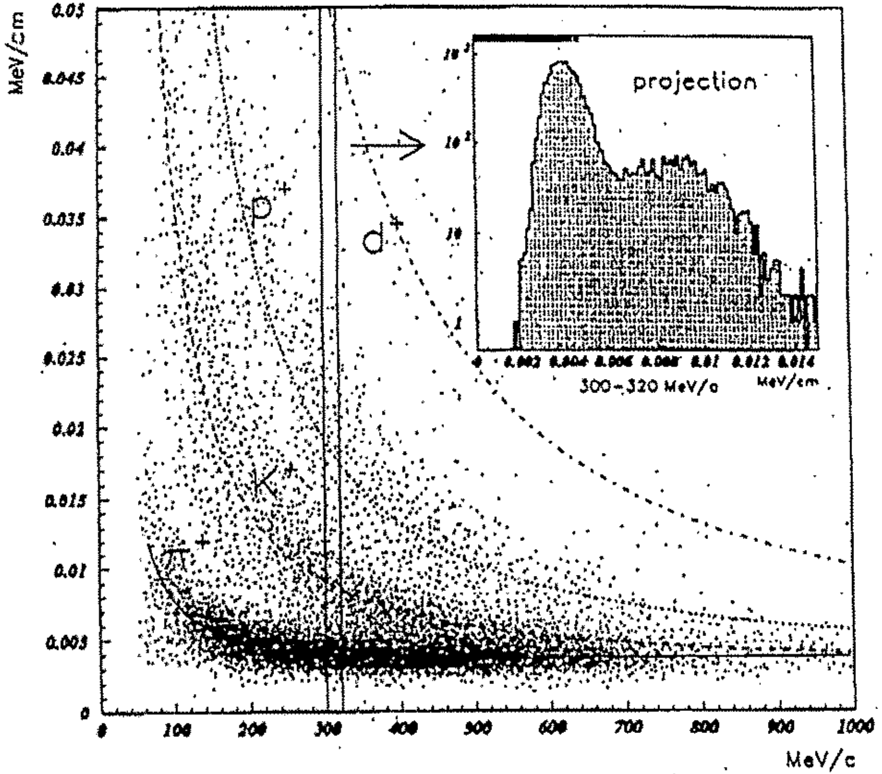
$E_{tot} < 1600$ MeV, 2-5 "UNMATCHED PEDS"

BILD

dE/dx vs p

$\bar{p}p \rightarrow$ 2 PRONGS + 2–5 γ's

$E_{tot} < 1600$ MeV



dE/dx vs. Particle Momentum

WICHTIG:

4π, Impulsauflösung, dE/dx

$\bar{p}p \rightarrow K\bar{K}\pi^{\cancel{0}}$

5 verschiedene Kanäle untersucht:

$K_L K_S \pi^0$

$K_L K_L \pi^0$, $K_S K_S \pi^0$

$K_L K^\pm \pi^\mp$

$K^+ K^- \pi^0$

↓

$K\pi$ UND $\boxed{K\bar{K}}$ RESONANZEN

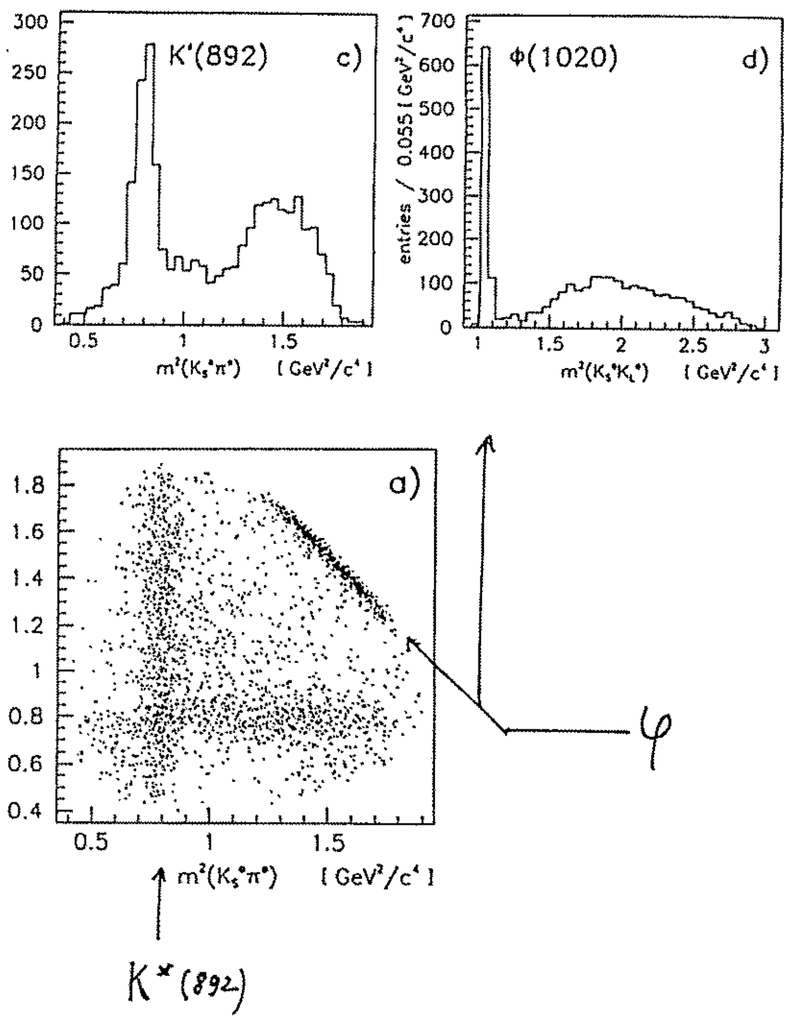
$(K\bar{K})$ – QUANTENZAHLEN

PARITÄT VON $K\bar{K}$: $P = (-1)^J$

C-PARITÄT: K_S : $C = +1$
K_L : $C = -1$

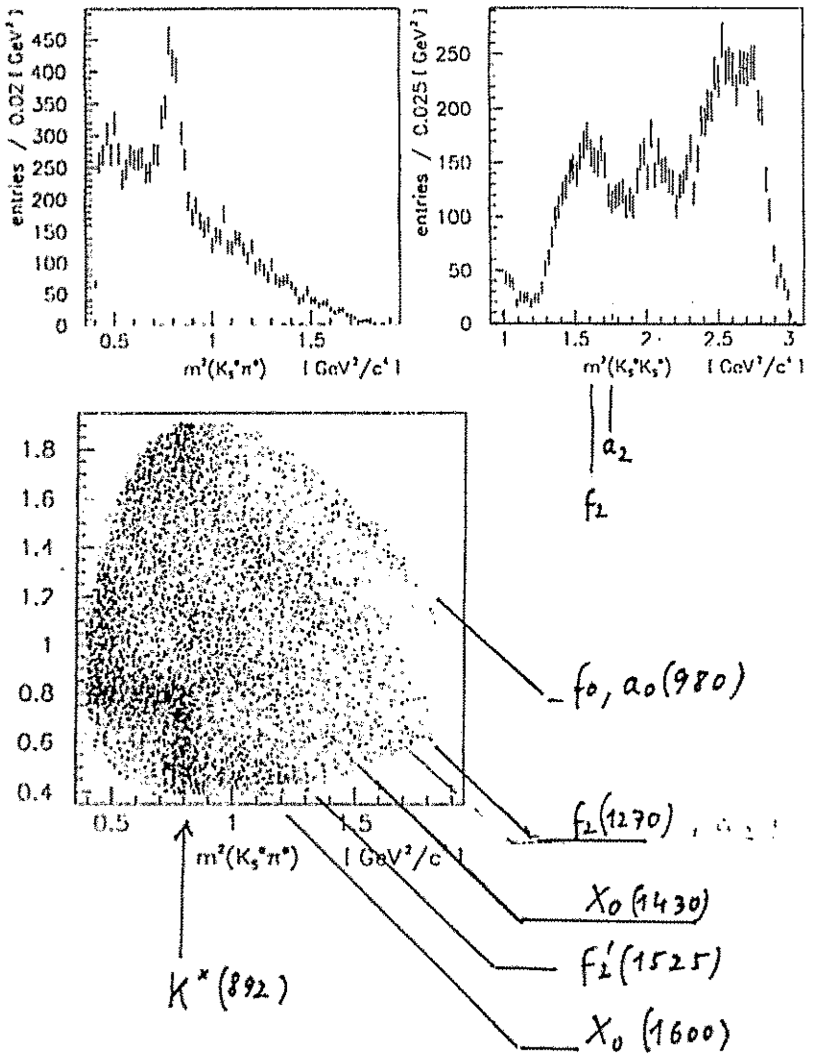
	C	I	J^{PC}	MÖGLICHE RESONANZEN
$K_L K_S$	-1	$0,1$	$1^{--}, \ldots$	$\varphi, \ldots$
$K_L K_L, K_S K_S$	$+1$	$0,1$	$0^{++}, 2^{++}, \ldots$	$a_0, f_0, a_2, f_2, \ldots$
$K_{L,S} K^{\pm}$	✗	1		$a_0, a_2, \ldots$
$K^+ K^-$	$0,1$	$0,1$		$\varphi, a_0, f_0, a_2, f_2, \ldots$

$\bar{p}p \to K_L K_S \pi^0$ at rest



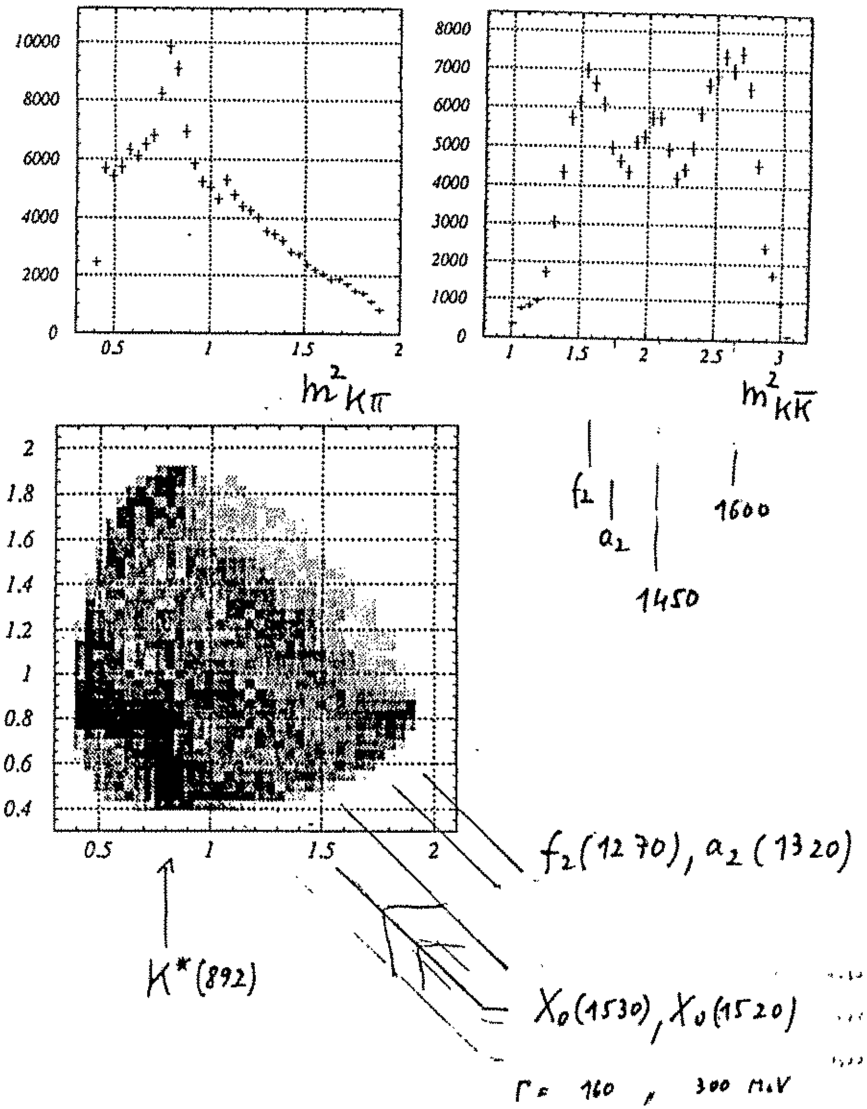
2830 EVENTS [Dietz, PLB319,373]

$\bar{p}p \to K_S K_S \pi^0$ at rest



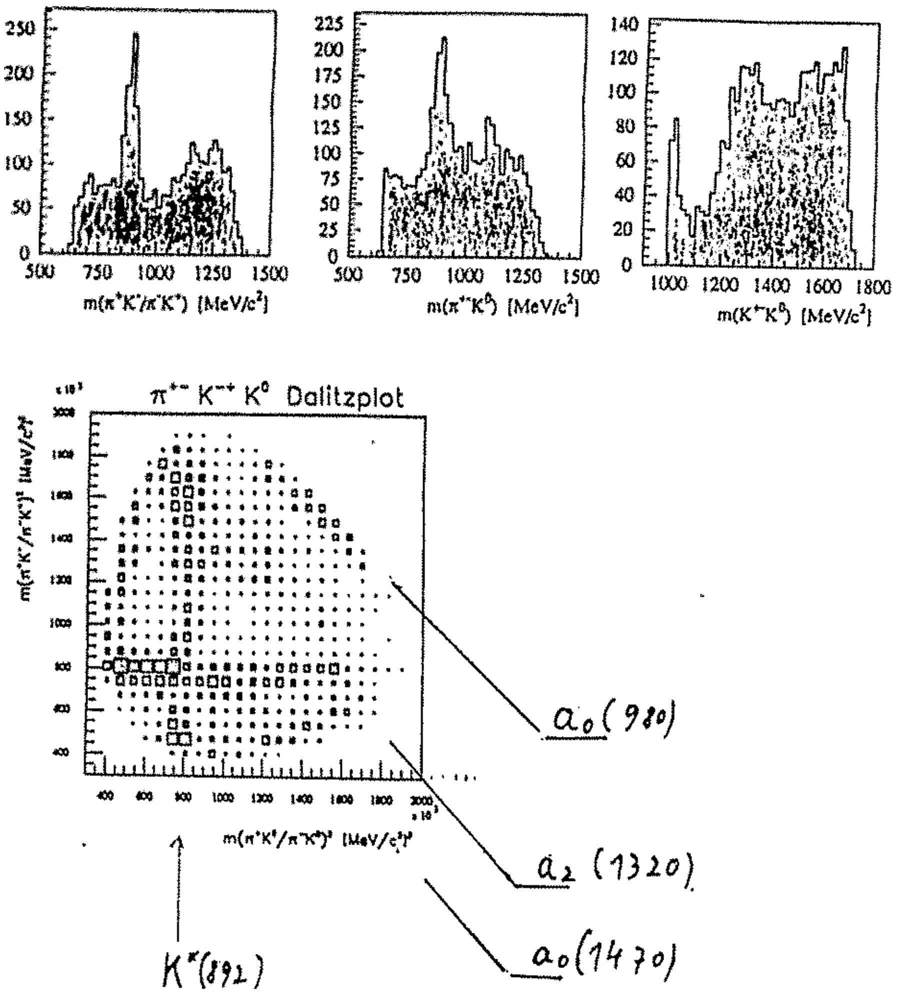
10 k EVENTS [Dietz]

$\bar{p}p \to K_L K_L \pi^0$ at rest



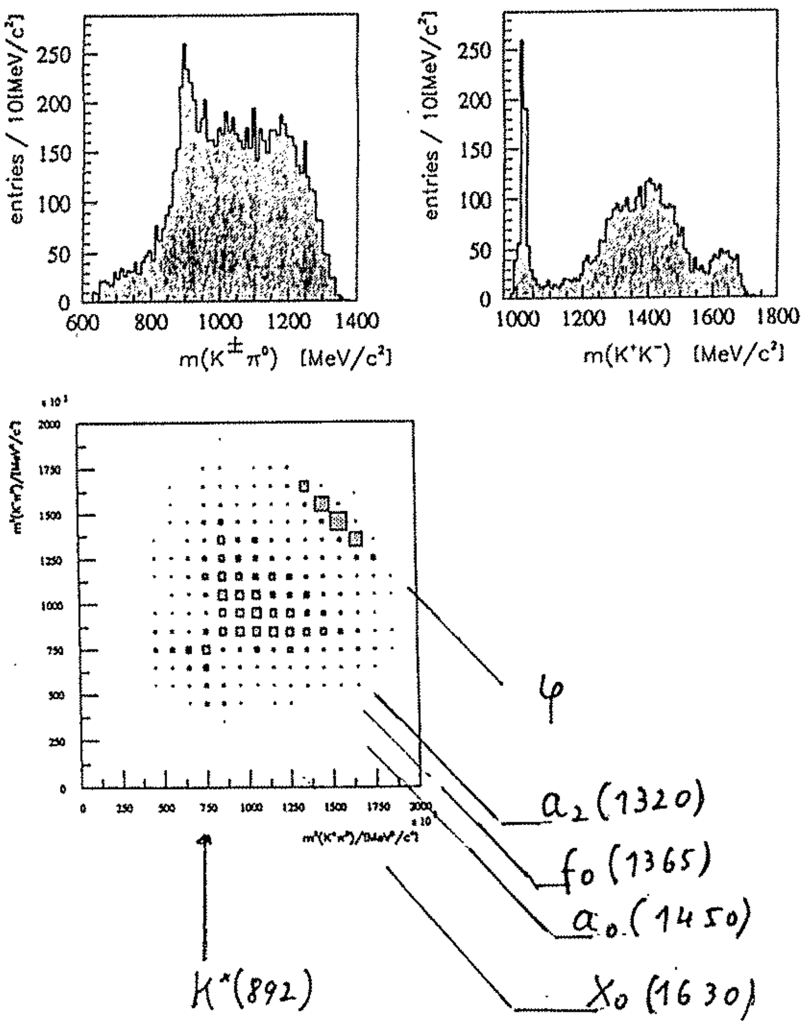
100 k EVTS [Dombrowski]

$\bar{p}p \rightarrow K_L K^{\pm} \pi^{\mp}$ at rest



3400 EVTS [Kaltever]

$\bar{p}p \rightarrow K^+K^-\pi^0$ at rest



4100 EVTS [Straßburger]

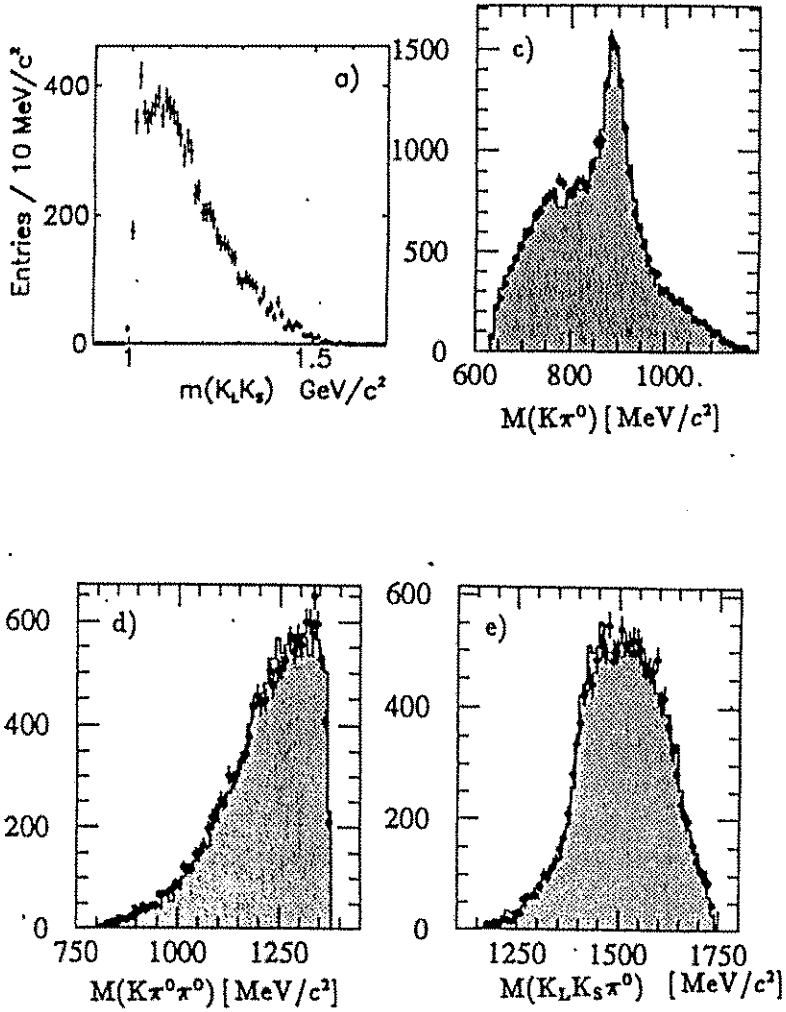
$$\boxed{\bar{p}p \rightarrow K_L K_S \pi^0 \pi^0}$$

$$\Downarrow$$

$K\pi$-, $K\bar{K}$-, $K\pi\pi$- UND $\underline{\underline{K\bar{K}\pi}}$ $(C=-1)$-

RESONANZEN

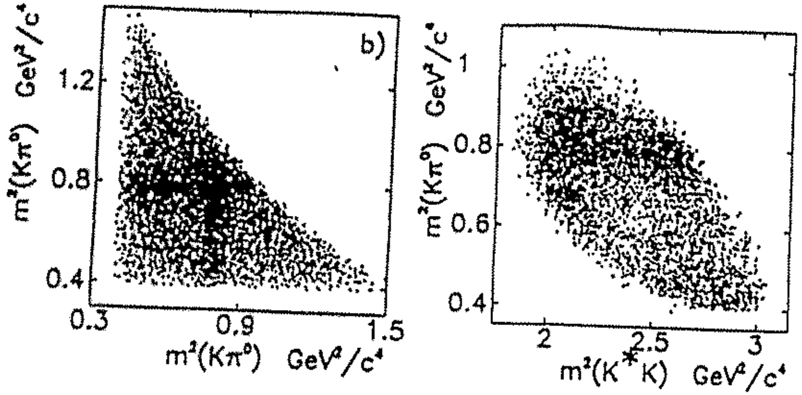
$\bar{p}p \rightarrow K_L K_S \pi^0 \pi^0$



7430 EVTS

[Felix]

$\bar{p}p \rightarrow K_L K^{\pm}\pi^{\mp}\pi^0$

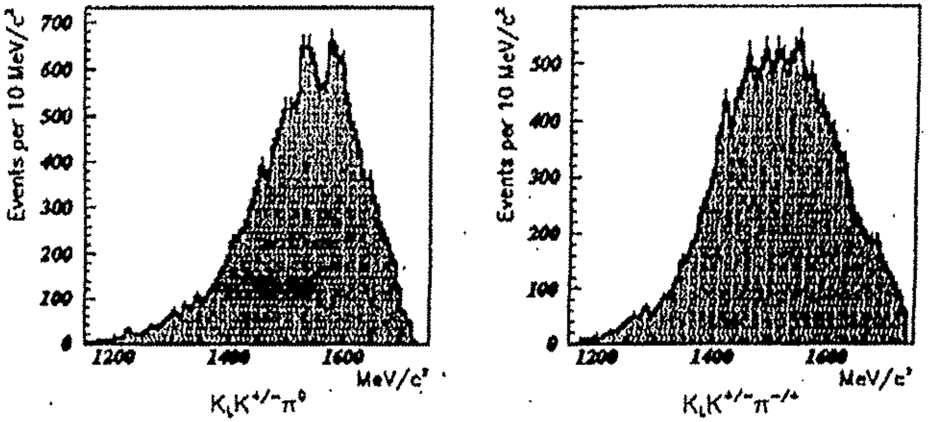


The $K^*K\pi^0$ Dalitz plot.

Amplitude	Intensity [%]	Phase [deg]
K^*K^* S-wave	6.0 ± 2.0	0 (fixed)
K^*K^* D-wave	3.2 ± 1.5	214 ± 12
$K_1(1270)K$ S-wave $K_1(1270)\rightarrow K^*\pi^0$ S-wave	5.7 ± 2.0	1 ± 8
$K_1(1270)K$ S-wave $K_1(1270)\rightarrow K(\pi\pi)_S$ P-wave	1.3 ± 1.0	25 ± 13
$K_1(1400)K$ S-wave $K_1(1400)\rightarrow K^*\pi^0$ S-wave	42. ± 15.	301 ± 7
$K_1(1400)K$ S-wave $K_1(1400)\rightarrow K^*\pi^0$ D-wave	8.6 ± 2.0	240 ± 10
$K_1(1400)K$ S-wave $K_1(1400)\rightarrow K_0^*(1430)\pi^0$ P-wave	4.0 ± 2.0	286 ± 11
$K_1(1400)K$ S-wave $K_1(1400)\rightarrow K(\pi\pi)_S$ P-wave	1.0 ± 1.0	285 ± 16
$\phi(\pi\pi)_S$ S-wave $\phi\rightarrow K_L K_S$ P-wave	3.6 ± 1.5	215 ± 17
$X(1^{+-})\pi^0$, S-wave $X(1^{+-})\rightarrow K^*K$ S-wave	3.3 ± 1.2	86 ± 8

M = 1370 MeV
h_1' ?

KKπ Invariant Mass Spectra



14200 EVTS [Kolo]

ZUSAMMENFASSUNG

$\boxed{K\bar{K}\pi}$ — f_0-AKTIVITÄT IN $(K\bar{K})^0$ ZWISCHEN 1500–1600 MeV

— a_0-ANZEICHEN UM 1450 MeV

$\boxed{K_L K_S \pi^0 \pi^0}$ (IN $K\bar{K}\pi$):

— (K^*K) $J^{PC} = 1^{+-}$ $\left[\begin{array}{l} m = 1385 \text{ MeV} \\ \Gamma = 200 \text{ ''} \end{array}\right]$

preliminary $(h_1' \; ?)$

— $(\varphi\pi)$ $J^{PC} = 1^{+-}$ $\left[\begin{array}{l} m = 1420 \text{ MeV} \\ \Gamma = 34 \text{ ''} \end{array}\right]$

$I = 1$

$\boxed{K_L K^{\pm} \pi^{\mp} \pi^0}$ ANZEICHEN VON SCHMALEN RESONANZEN

preliminary → K^*K, 1535 UND 1585 MeV

$I = 1$, $(J^P = 1^-$, $G = +1$?$)$

Seltene Zerfälle und die Verletzung der OZI-Regel (CRYSTAL BARREL)

U. Wiedner
Uni Hamburg

6.Oktober 1994

Seltene Zerfälle und die Verletzung der OZI-Regel

Ulrich Wiedner

(Universität Hamburg)

Pirna, den 5.10.1994

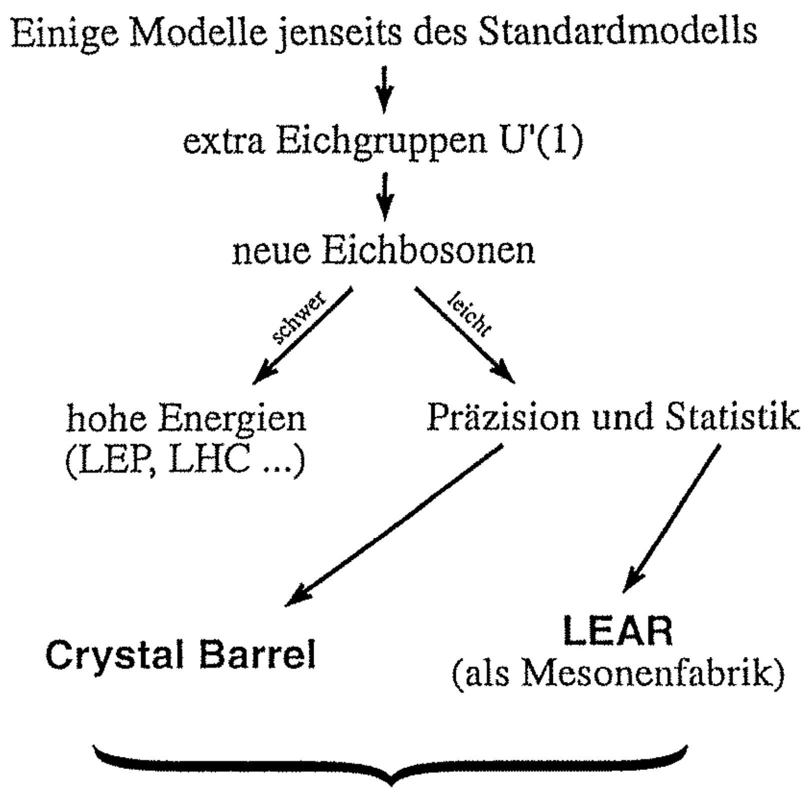
~~niche~~

nice

physics

Inhaltsübersicht

1. Die Suche nach leichten Eichbososen
2. η-Zerfälle als Test chiraler Störungsrechnung
3. Die Gültigkeit der OZI-Regel
   und ein möglicher strange-Quarkinhalt des Protons



Einige Modelle jenseits des Standardmodells

extra Eichgruppen U'(1)

neue Eichbosonen

hohe Energien
(LEP, LHC ...)

Präzision und Statistik

Crystal Barrel

LEAR
(als Mesonenfabrik)

Untersuchte Kanäle:

$$\pi^o \longrightarrow \gamma X$$
$$\eta \longrightarrow \gamma X$$
$$\eta' \longrightarrow \gamma X$$

Massenbereich: $m_X \leq m_{Meson}$

Mögliche Zerfälle von X:

abhängig von der Art der Wechselwirkung
(M. I. Dobroliubov)

$X \longrightarrow \nu\bar{\nu}$
$X \longrightarrow e^+e^-$

ungeeignet wegen
$\pi^\circ \longrightarrow \gamma\, e^+e^-$ (1%)

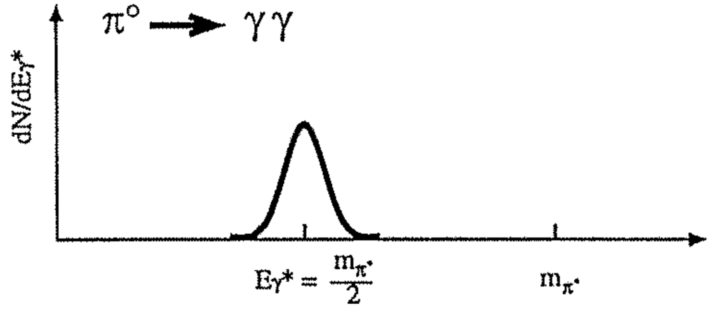
$X \longrightarrow \gamma$ + "nichts"
(X zerfällt nicht im Detektor)

Erwartete Verzweigungsverhältnisse

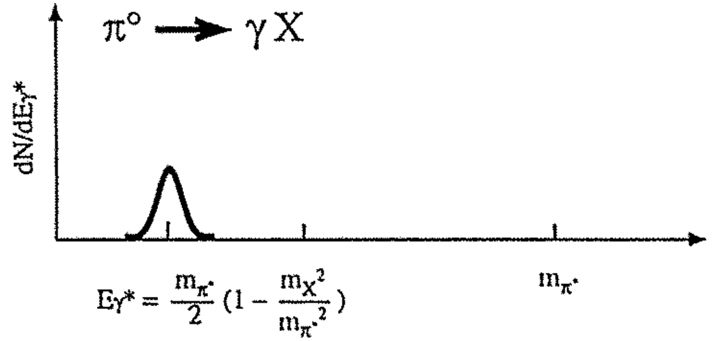
$\le 6.2 \times 10^{-6}$	$\pi^\circ \longrightarrow \gamma X$	$\le 2.7 \times 10^{-3}$
$\le (1.6 - 3.8) \times 10^{-4}$	$\eta \longrightarrow \gamma X$	$\le (2.0 - 4.7) \times 10^{-4}$
$\le (0.7 - 5.7) \times 10^{-6}$	$\eta' \longrightarrow \gamma X$	$\le (0.3 - 2.3) \times 10^{-6}$

Signaturen im Detektor:

$\pi^\circ \longrightarrow \gamma\gamma$



$\pi^\circ \longrightarrow \gamma X$



Benötigt:
wohldefinierte Kinematik = Annihilation in Ruhe

$$E_g = 2\, m_p \qquad \vec{p}_g = 0$$

Analysierter Datensatz:

15×10^6 Ereignisse mit einem "all neutral" Trigger

$\triangleq 3.75 \times 10^8$ Annihilationsereignissen

Analysemethode:

Suche nach 5 γ Ereignissen in:

$\bar{p}p \longrightarrow \pi^\circ\pi^\circ\pi^\circ \qquad (6.3\pm1.0) \times 10^{-3}$

$\bar{p}p \longrightarrow \pi^\circ\pi^\circ\eta \qquad (6.5\pm0.7) \times 10^{-3}$

$\bar{p}p \longrightarrow \pi^\circ\pi^\circ\eta' \qquad (4.0\pm0.7) \times 10^{-3}$

CB preliminary

Hauptsächlicher Untergrund:

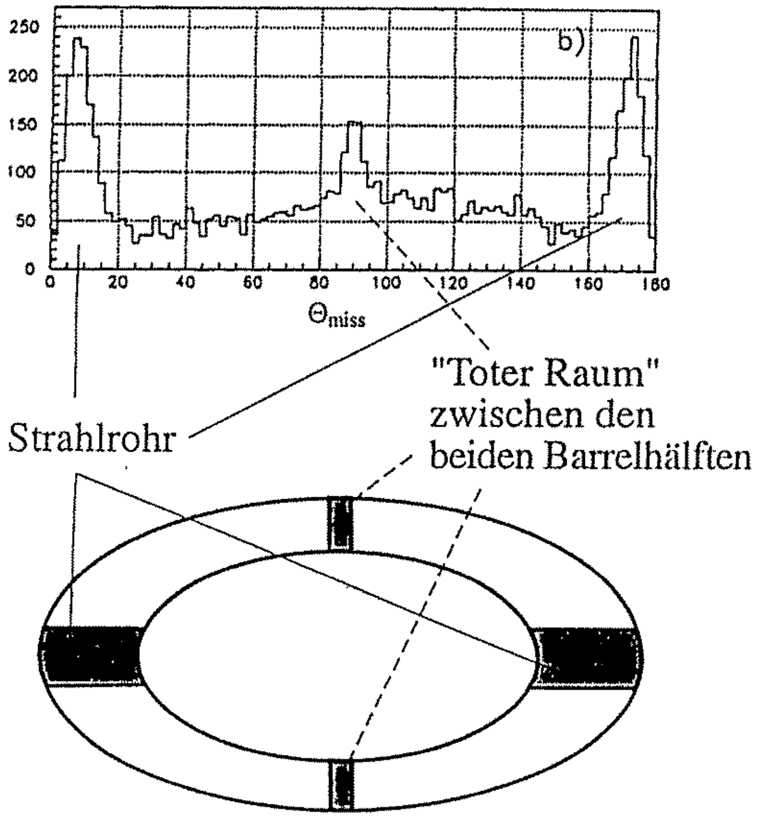
nicht detektierte γ

Detektorgeometrie

Energieschwellen

endliche Auflösung des Detektors

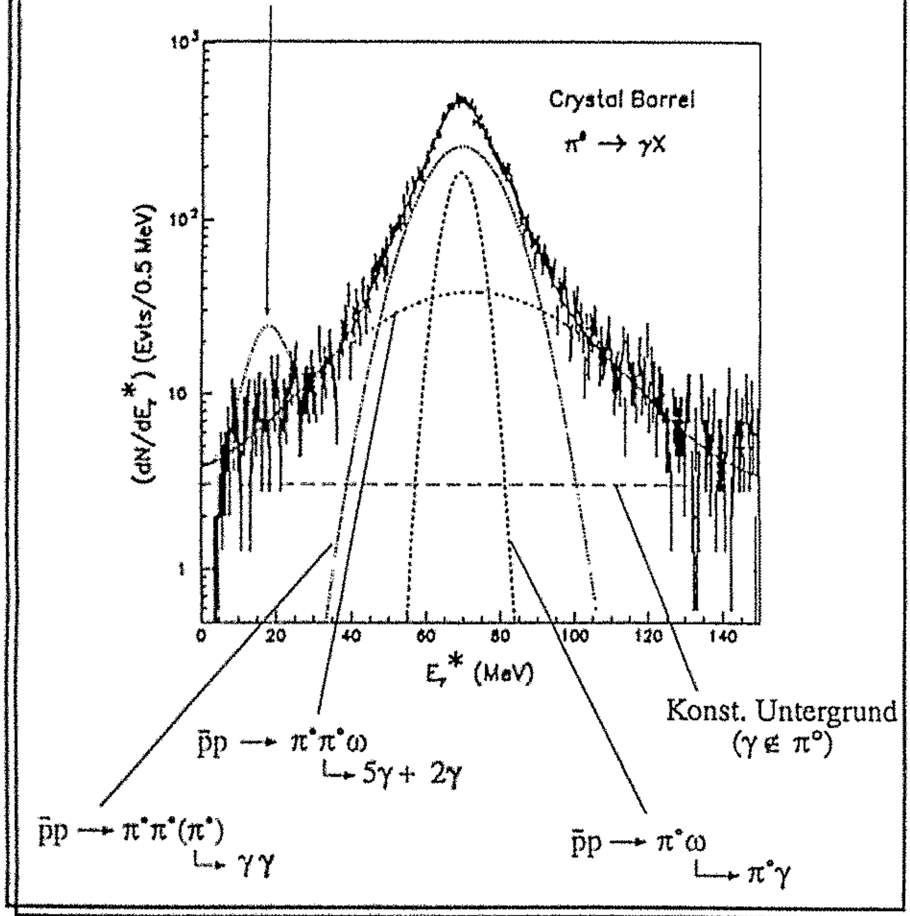
Winkelverteilung der fehlenden γ



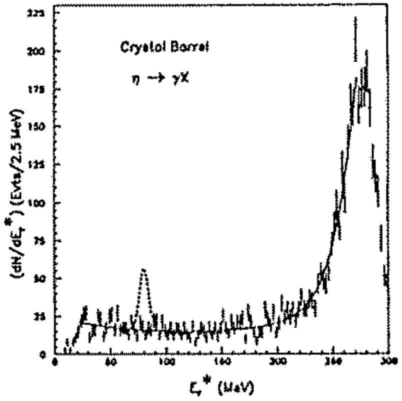
$\pi^\circ \longrightarrow \gamma X$

$BR(\pi^\circ \longrightarrow \gamma X) = 5 \times 10^{-4}$

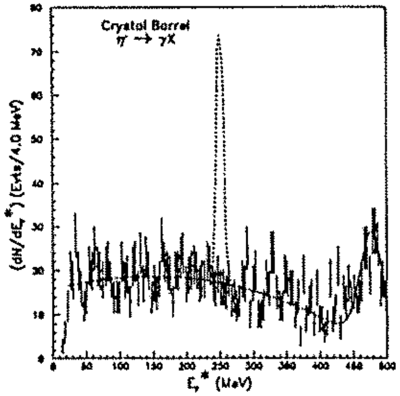
F. Ould-Saada, Zürich



$\eta \longrightarrow \gamma X$



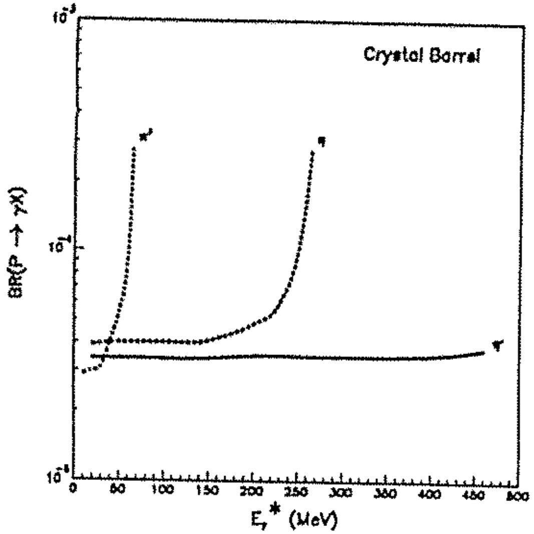
$\eta' \longrightarrow \gamma X$



F. Ould-Saada, Zürich

Ergebnisse

BR $(P \longrightarrow \gamma X)$ @ 90% C.L.



π°: 6×10^{-5} für $65 < M_X < 125$ MeV/c^2
2.8×10^{-5} für $M_X \sim 0$

η: 6×10^{-5} für $200 < M_X < 525$ MeV/c^2
3×10^{-4} für $50 < M_X < 200$ MeV/c^2

η': 4×10^{-5} für $0 < M_X < 925$ MeV/c^2 preliminary

F. Ould-Saada, Zürich

$\eta \rightarrow 3\pi$ Zerfälle

Annahmen:

- keine elektromagnetische Wechselwirkung
- Quarkmassendifferenz $(m_u - m_d) = 0$

$\Downarrow$

$\eta \rightarrow 3\pi$ aus Symmetriegründen verboten

Der Zerfall wird aber beobachtet, d.h.

- die elektromagnetische Wechselwirkung trägt bei
- es gibt Beiträge der starken Wechselwirkung

Der Beitrag der starken Wechselwirkung ~ $(m_u - m_d)$

$\Downarrow$

Das Studium der η-Zerfälle erlaubt eine Überprüfung der Theorie, welche die leichten Quarkmassen bestimmt

Dashens Theorem:

"Der Beitrag der elektrischen Ladung
zur Masse der Teilchen ist gleich groß
für Mesonen des selben Oktetts"

$$(m^2_{K^o} - m^2_{K^+})_{QED} - (m^2_{\pi^o} - m^2_{\pi^+})_{QED} = 0$$

Chirale Störungsrechnung besagt:

$$(m_d - m_u) \sim (m^2_{K^o} - m^2_{K^+}) - (m^2_{\pi^o} - m^2_{\pi^+})$$

$$\Downarrow$$

$$\boxed{\Gamma_{\eta \to \pi^o \pi^+ \pi^-} = 160 \pm 50 \ \text{eV}}$$ (Gasser, Leutwyler)

Annahmen:

- Dashens Theorem gültig
- die Massendifferenz $(m(\pi^0) - m(\pi^+))$ ist nur durch die elektromagntische Wechselwirkung bedingt

Die experimentellen Werte:

$\Gamma_{\eta \to \pi^o \pi^+ \pi^-} = 197 \pm 29 \ \text{eV}$ (Particle Data Group 1982)

$\Gamma_{\eta \to \pi^o \pi^+ \pi^-} = 283 \pm 28 \ \text{eV}$ (Particle Data Group 1992)

Neuere Berechnungen bezweifeln die Gültigkeit von Dashens Theorem:

$$\boxed{\Gamma_{\eta \to \pi^0 \pi^+ \pi^-} = 225 \text{ eV}}$$

Donogue, Holstein, Wyler 1992

$$\boxed{\Gamma_{\eta \to \pi^0 \pi^+ \pi^-} = 240 \text{ eV}}$$

Bijnens 1992

Folgendes Verhältnis ist hiervon unabhängiger:

$$\boxed{r = \frac{\Gamma_{\eta \to 3\pi^0}}{\Gamma_{\eta \to \pi^0 \pi^+ \pi^-}}}$$

Der QCD-Wert (Chirale Störungsrechnung):

$$\boxed{r = 1.44 \pm 0.02}$$

Die experimentelle Situation

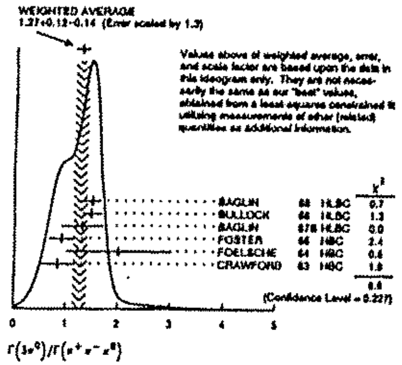
Ergebnisse bisheriger Experimente:

$$r = 1.27 \begin{matrix} +0.12 \\ -0.14 \end{matrix} \quad \text{(PDG-Mittelwert)}$$

$$r = 1.35 \pm 0.05 \quad \text{(PDG-Fit)}$$

$\Gamma(3\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$

VALUE	EVTS	DOCUMENT ID		TECN
1.35 ± 0.05 OUR FIT	Error includes scale factor of 1.2.			
$1.27^{+0.12}_{-0.14}$ OUR AVERAGE	Error includes scale factor of 1.3.			
$1.50^{+0.15}_{-0.29}$	199	BAGLIN	69	HLBC
$1.47^{+0.20}_{-0.17}$		BULLOCK	68	HLBC
1.3 ± 0.4		BAGLIN	67B	HLBC
0.90 ± 0.24		FOSTER	65	HBC
2.0 ± 1.0		FOELSCHE	64	HBC
0.83 ± 0.32		CRAWFORD	63	HBC

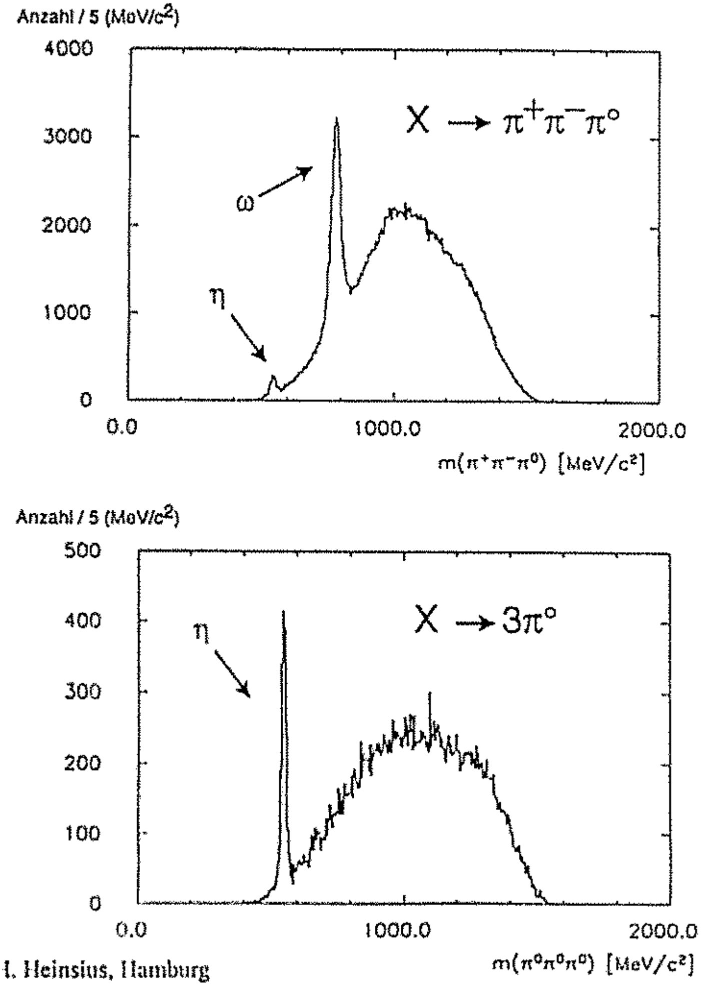


Values above of weighted average, error, and scale factor are based upon the data in this ideogram only. They are not necessarily the same as our "best" values, obtained from a least-squares constrained fit utilizing measurements of other (related) quantities as additional information.

→ *Genauestes Ergebnis auf der Basis von 199 Ereignissen*

Aber 10^7 $\bar{p}p$-Annihilationen enthalten *300,000* η η-Zerfälle: Daten

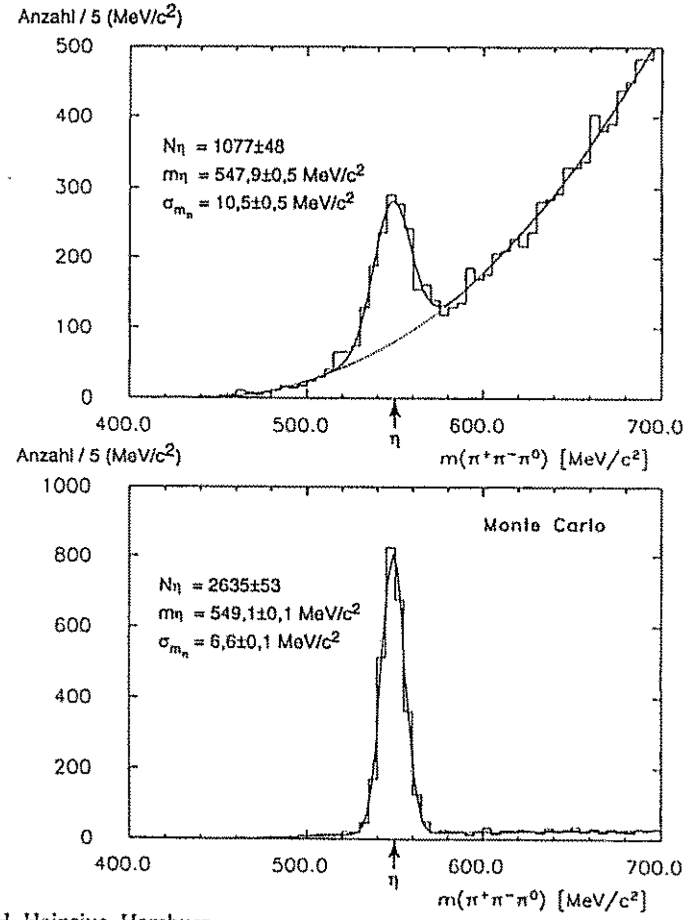
$\bar{p}p \longrightarrow \pi^+\pi^-X$



F. H. Heinsius, Hamburg

η-Zerfälle: Daten

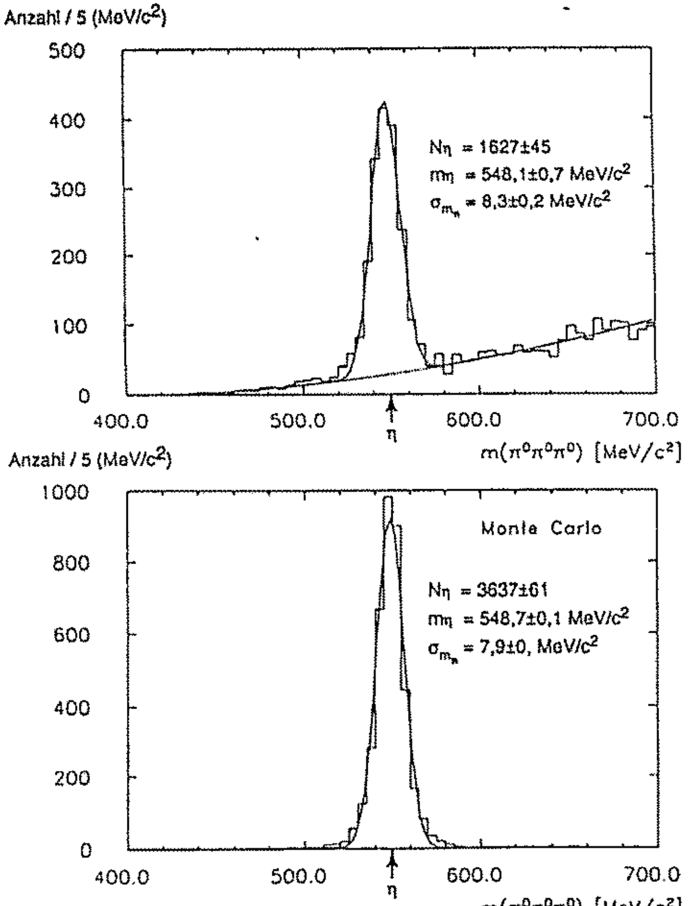
$\bar{p}p \longrightarrow \pi^+\pi^-\pi^+\pi^-\pi^\circ$



F. H. Heinsius, Hamburg

η-Zerfälle: Daten

$\bar{p}p \longrightarrow \pi^+\pi^-\pi^\circ\pi^\circ\pi^\circ$



F. H. Heinsius, Hamburg

Ergebnisse

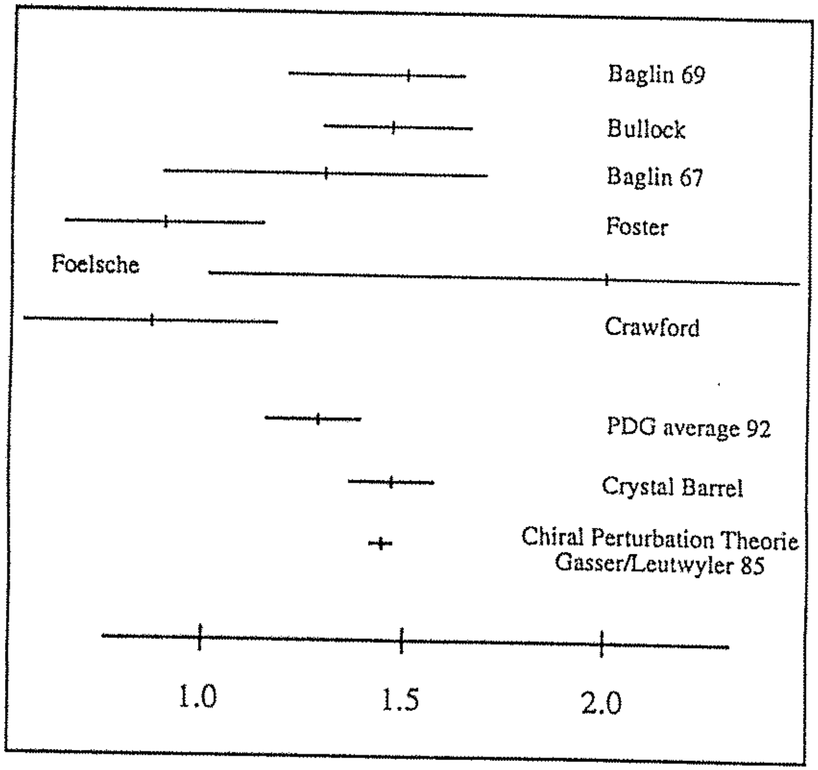
$$\Gamma_{\eta \rightarrow \pi^+\pi^-\pi^\circ}$$

Crystal Barrel:
$\Gamma = 240 \pm 30\ \mathrm{eV}$

$$r = \frac{BR\,(\eta \longrightarrow 3\pi)}{BR\,(\eta \longrightarrow \pi^+\pi^-\pi^\circ)}$$

Crystal Barrel:
$r = 1.47 \pm 0.09 \pm 0.07$

$$\frac{\Gamma_{\eta \to \pi^+\pi^-\pi^\circ}}{\Gamma_{\eta \to 3\pi^\circ}}$$



(strange?) Quarkinhalt des Protons

$$\text{QCD} \xrightarrow[\text{gültig}]{} \text{chirale Symmetrie}$$

Die Art und Weise der SU(3) Symmetriebrechung scheint nicht in das Bild

$$p = uud$$

zu passen.

Ausweg: Selbst bei Energien vergleichbar mit der Ruheenergie des Nukleons enthält das Proton $\bar{s}s$-Quarkpaare

Experimentelle Hinweise:

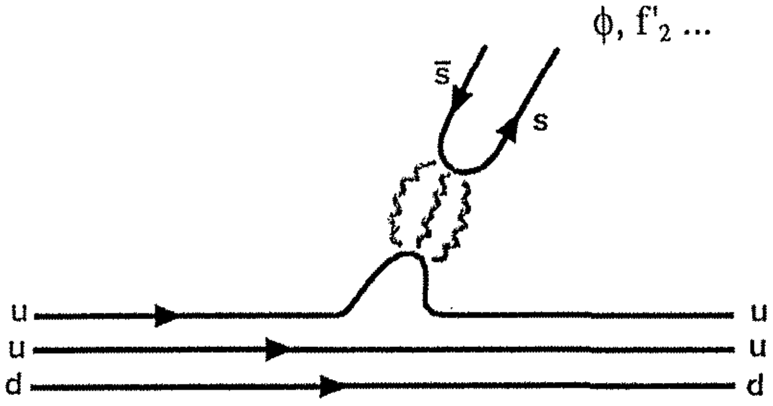
1) π-N-σ Term
   Analyse der experimentellen Daten mit Standardmethoden ergibt einen zu kleinen Wert der Nukleonenmasse, wenn man die strange-Quarkmasse im Nukleon gleich 0 setzt.

2) Tief inelastische polarisierte Lepton-Proton-Streuung
   "Spinkrise des Protons"

3) Verletzungen der Okubo-Zweig-Iizuka-Regel

Wir wissen nicht, warum das Konstituenten Quark Modell und die OZI-Regel in einigen Fällen so gut funktionieren und in anderen nicht.

In $\bar{p}p$-Annihilationsprozessen kann man die Gültigkeit der OZI-Regel testen.

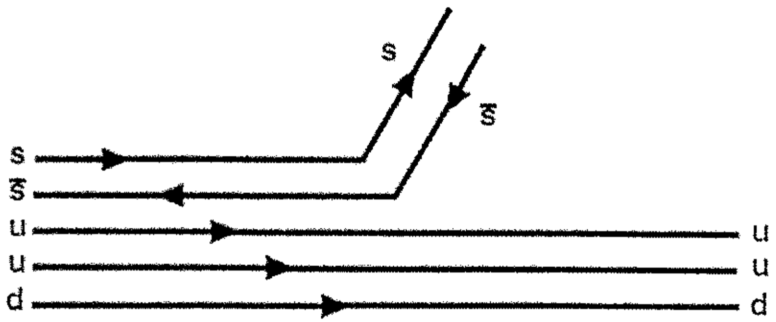


Kopplung eines $\bar{s}s$-Mesons
an ein Baryon ohne Strangeness
nur mit unterbrochenen Quarklinien

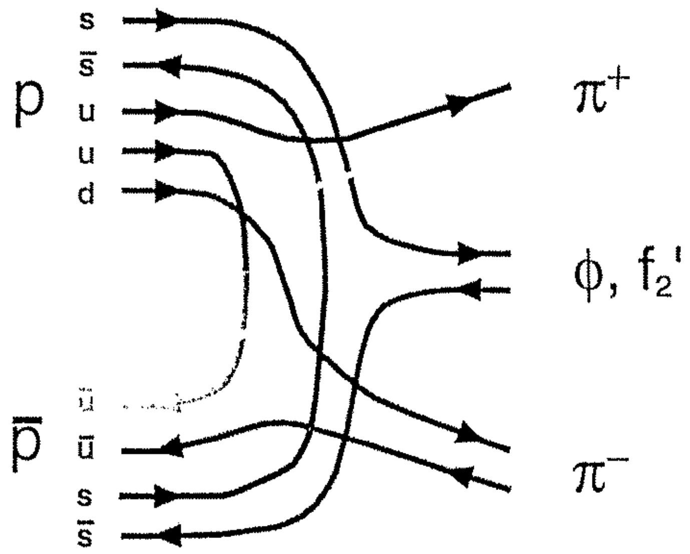
OZI-verboten

Umgehung der OZI-Regel

durch vorhandene $\bar{s}s$-Quarks



Falls es $\bar{s}s$-Quarks im Proton gibt ...

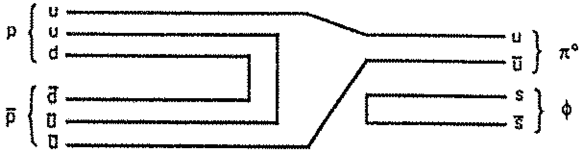


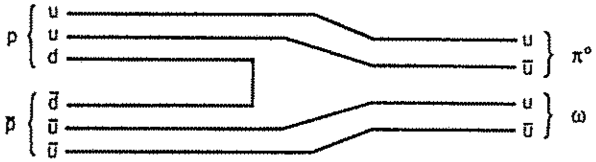
$$\bar{p}p \longrightarrow (\phi \text{ or } f_2')\, \pi^+\pi^-$$

Vektormeson-Produktion

in der p̄p-Annihilation

Meson	Quarkinhalt	OZI-Regel
ϕ-Meson	(fast nur) $\bar{s}s$	**verboten**
ω-Meson	*(fast nur) $\bar{u}u+\bar{d}d$*	***erlaubt***





"Fast nur" bei der Quarkzusammensetzung bedeutet:

Das ϕ-Meson enthält einen kleinen Anteil von up- und down-Quarks

⇓

Produktion von ϕ-Mesonen in der p̄p-Annihilation nicht komplett verboten, sondern nur unterdrückt

Berechnetes Unterdrückungsverhältnis

$$\frac{\bar{p}p \longrightarrow \phi X}{\bar{p}p \longrightarrow \omega X} = \frac{1}{240}$$

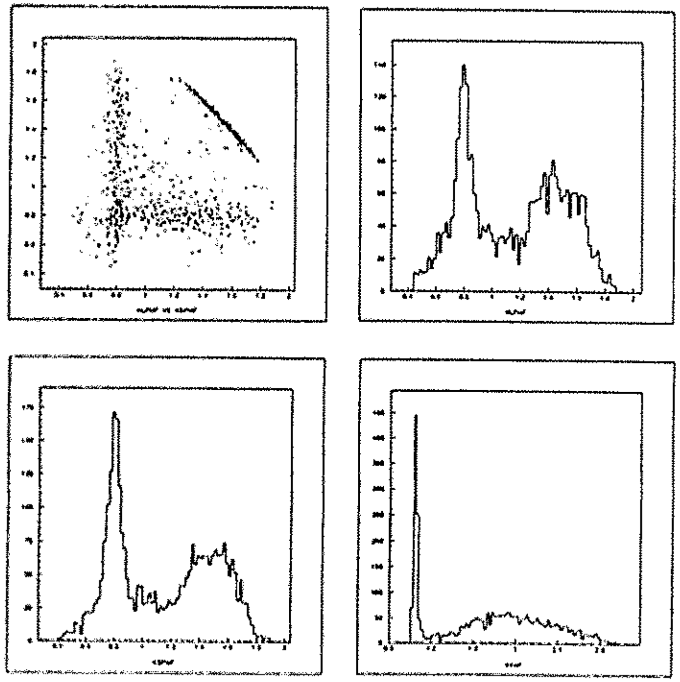
Abweichung von diesem Wert heißt:

- OZI-Regel versagt, oder
- Quarkzusammensetzung des Protons ist anders

$\bar{p}p \longrightarrow K_L K_S \pi^0$

K_S → $\pi^0\pi^0$

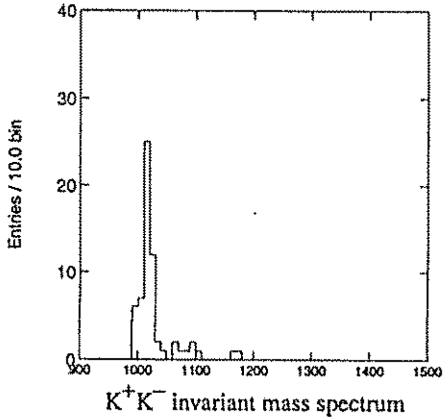
K_L → missing mass (tag)



H. P. Dietz, München

$\bar{p}p \longrightarrow K^+K^-\gamma$

Erwartetes Branching Ratio: 10^{-7}!



Branching Ratio

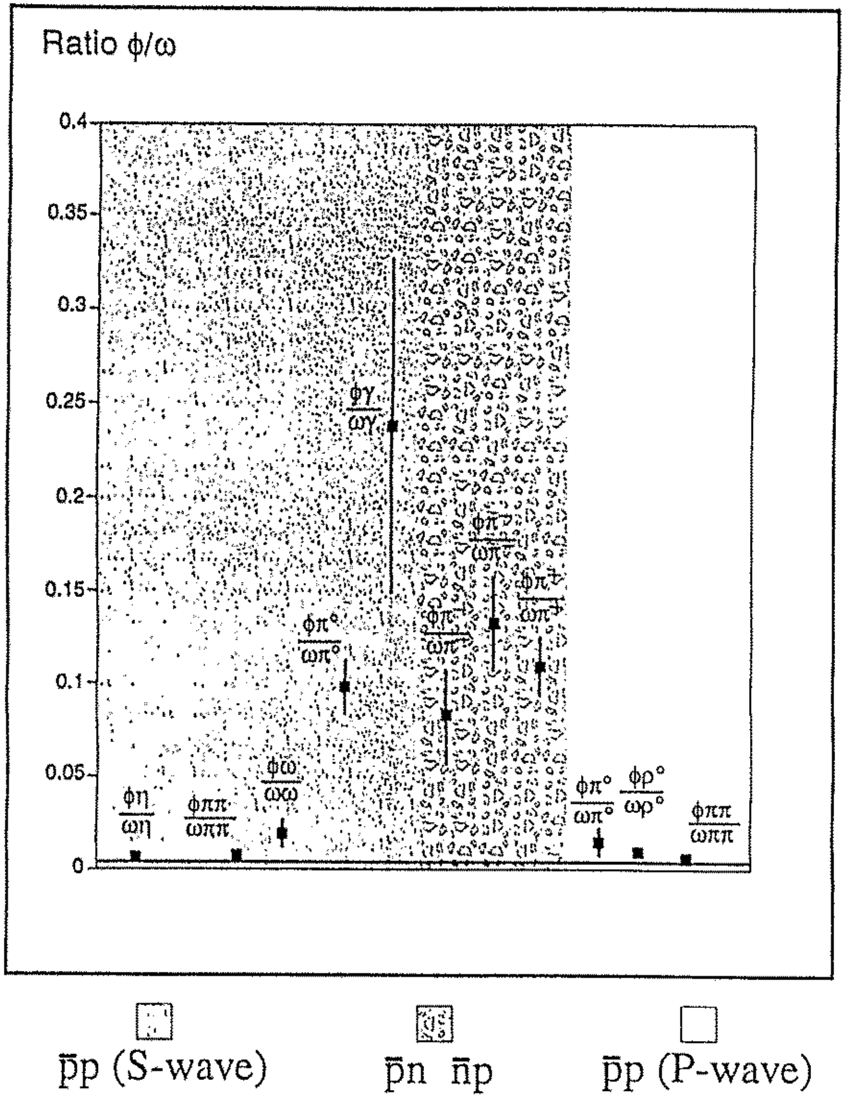
$\bar{p}p \longrightarrow \phi\gamma$

$1.7 \pm 0.4 \times 10^{-5}$

OZI relevantes Verhältnis

$$\frac{\phi\gamma}{\omega\gamma} = \frac{1.7 \times 10^{-5}}{6{,}8 \times 10^{-5}} = 0.24 \pm 0.09$$

ϕ/ω Production Ratios



▬ OZI

© Ulrich Wiedner

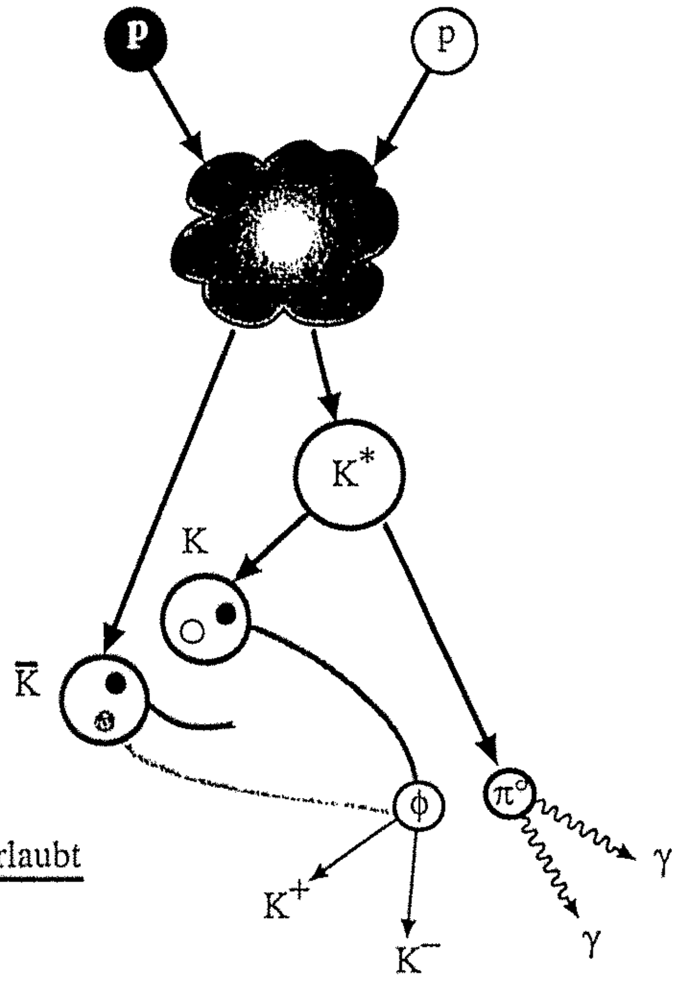
Wie kann die starke Verletzung
der OZI-Regel bei Annihilation
aus der S-Welle erklärt werden?

Hängt die Verletzung der OZI-Regel
vom Impuls des ϕ-Mesons ab?

"Rückstreuung vs. Direkte Produktion"

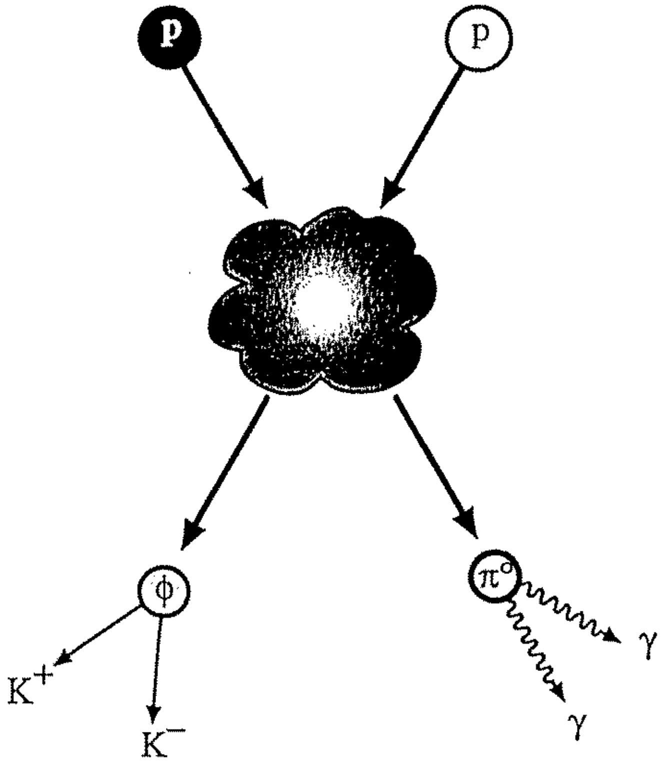
© Ulrich Wiedner

Final State Interaction



OZI-erlaubt

Direkte Produktion



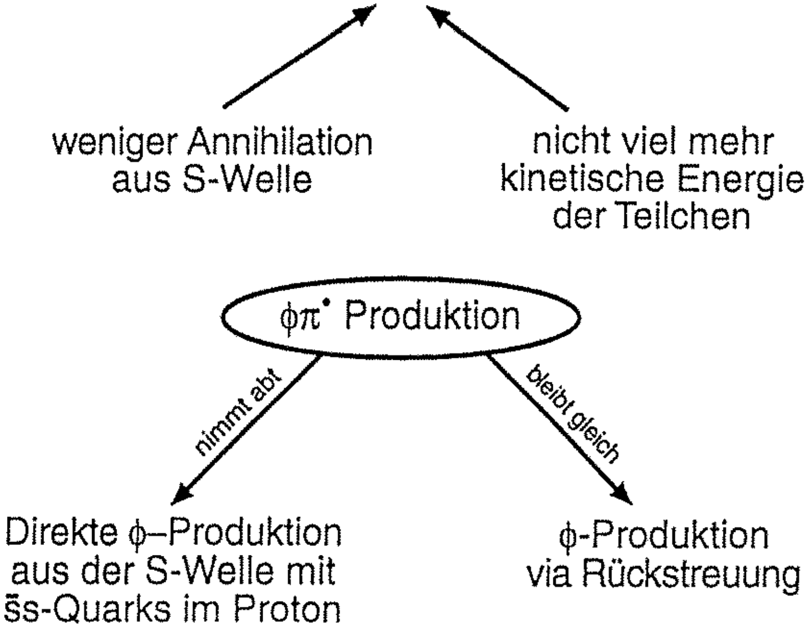
OZI-verbotener Prozeß

Strategie zur Unterscheidung
zwischen den beiden Modellen:

Reduktion des S-Wellen Anteils ohne den Überlapp der beiden Kaonen zu reduzieren

Lösung:

Bestimmung des $\phi\pi^0$ Produktionsverhältnisses
in $\bar{p}p$-Annihilationen bei 600 MeV/c $\bar{p}$-Impuls



weniger Annihilation
aus S-Welle

nicht viel mehr
kinetische Energie
der Teilchen

$\phi\pi^0$ Produktion

nimmt ab

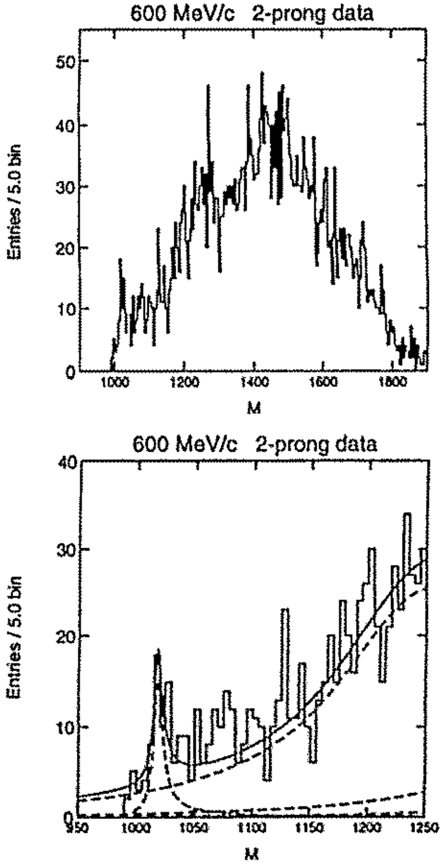
bleibt gleich

Direkte ϕ–Produktion
aus der S-Welle mit
$\bar{s}s$-Quarks im Proton

ϕ-Produktion
via Rückstreuung

K^+K^- Invariantes Massenspektrum

600 MeV/c



41 Ereignisse im ϕ-Peak

600 MeV/c $\bar{p}$-Impuls

Produktionsverhältnis $\bar{p}p \rightarrow \phi\pi^0$:

$1.18 \pm 0.3\,(\text{syst.}) \pm 0.14\,(\text{stat.}) \times 10^{-4}$

preliminary

Deutlich niedriger als bei Annihilationen in Ruhe:

$5.5 \pm 0.7 \times 10^{-4}$

$K^*\bar{K}$ Produktionsverhältnisse $\times 10^4$

In Ruhe	700 MeV/c
(21 ± 3) 36 ± 5	18 ± 1.56

Zusammenfassung und Ausblick

Crystal Barrel sieht Verletzungen der OZI-Regel in mehreren Endzuständen.

Das Produktionsverhältnis für die ϕ-Produktion bei 600 MeV/c $\bar{p}$-Impuls macht es schwierig, diese OZI-Regel-Verletzungen durch einfache Rückstreumodelle zu erklären.

Zukünftige experimentelle Untersuchungen:

a) Untersuchungen zur ϕ-Produktion in Abhängigkeit vom Drehimpuls des Anfangszustandes.

b) Studium der OZI-Regel in anderen Endzuständen, z.B. $f_2'(1525)$ / $f_2(1270)$ Produktion.

Experimente mit Antiprotonen im Fluge (CRYSTAL BARREL)

K. Beuchert
Bochum

6.Oktober 1994

Experimente
mit
Antiprotonen
im Fluge
(mit Crystal Barrel)

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representing
Crystal Barrel (PS 197)

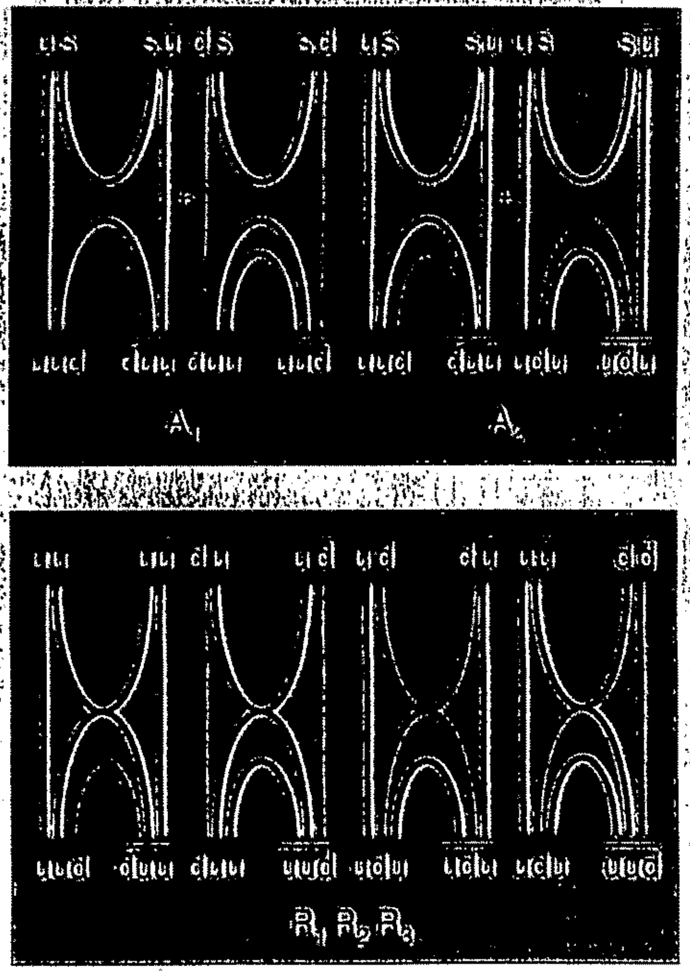
Warum im Fluge?

→ mögliche Anregung
schwererer Resonanzen

→ in Produktionsprozessen
bessere Kenntnis
von Resonanzen am
Phasenraumende
(z. B. „AX")

→ mögliche Anregung
von Resonanzen mit
höherem Spin

Annihilations- und Rearrangement-Diagramme



Klaus Peters, RUB (LEAP '94)

Karsten Beuchert
Pirna 1994

Warum im Fluge?

→ weitere Effekte:
Veränderung relativer Verzweigungsverhältnisse

z. B. $\pi\omega \longleftrightarrow \eta\omega$

$\omega\eta' \longrightarrow 0$

für $p > 1200$ MeV/c

↓

Resonanzformation?

↑

Impuls-Scanning mit
Crystal Barrel
als Formationsexperiment
(später Mini-Collider am LEAR?)

(CB)

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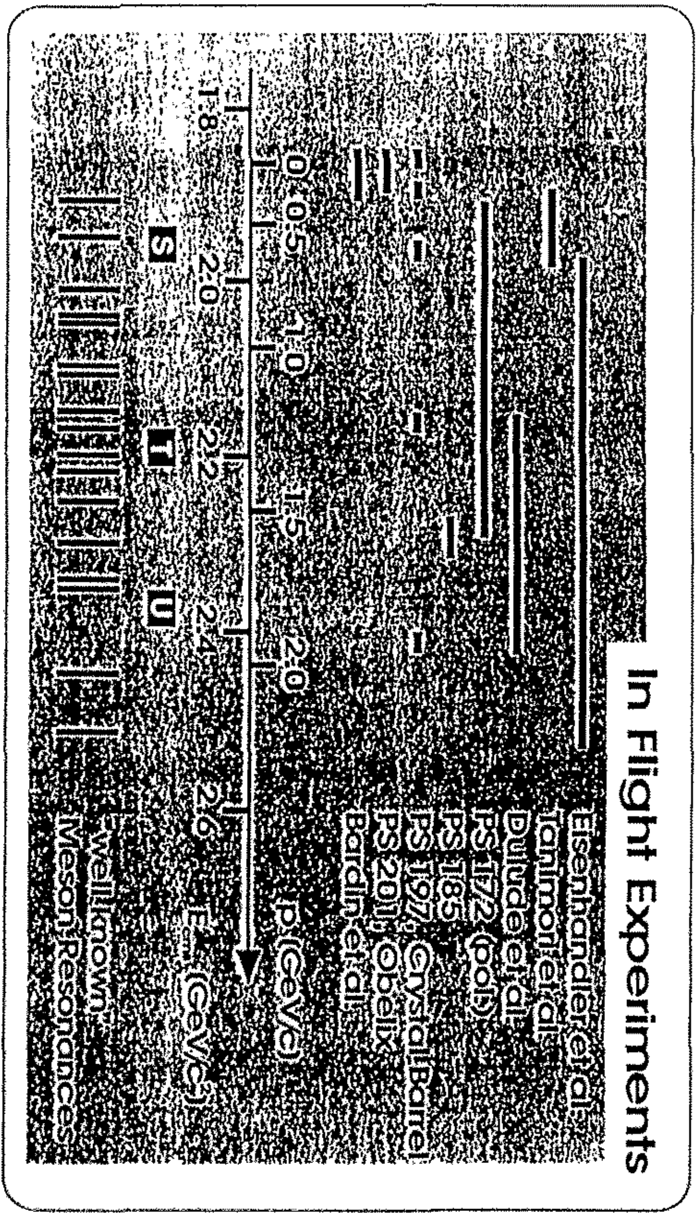

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Analysen im Fluge bei CB

Detektorverständnis:
- → hochenergetische Pionen
- → hadronische Split-Offs

Physikalisches Verständnis (Annihilation):
- → $p\bar{p}$ Anfangszustände

Physikalisches Verständnis (Struktur der Nukleonen):
- → Strangeness im Proton
  (→ Ulrich Wiedner)

Physikalisches Verständnis (starke Wechselwirkung):
- → Exotica
  (Glueballs, Hybride, etc.)

CB

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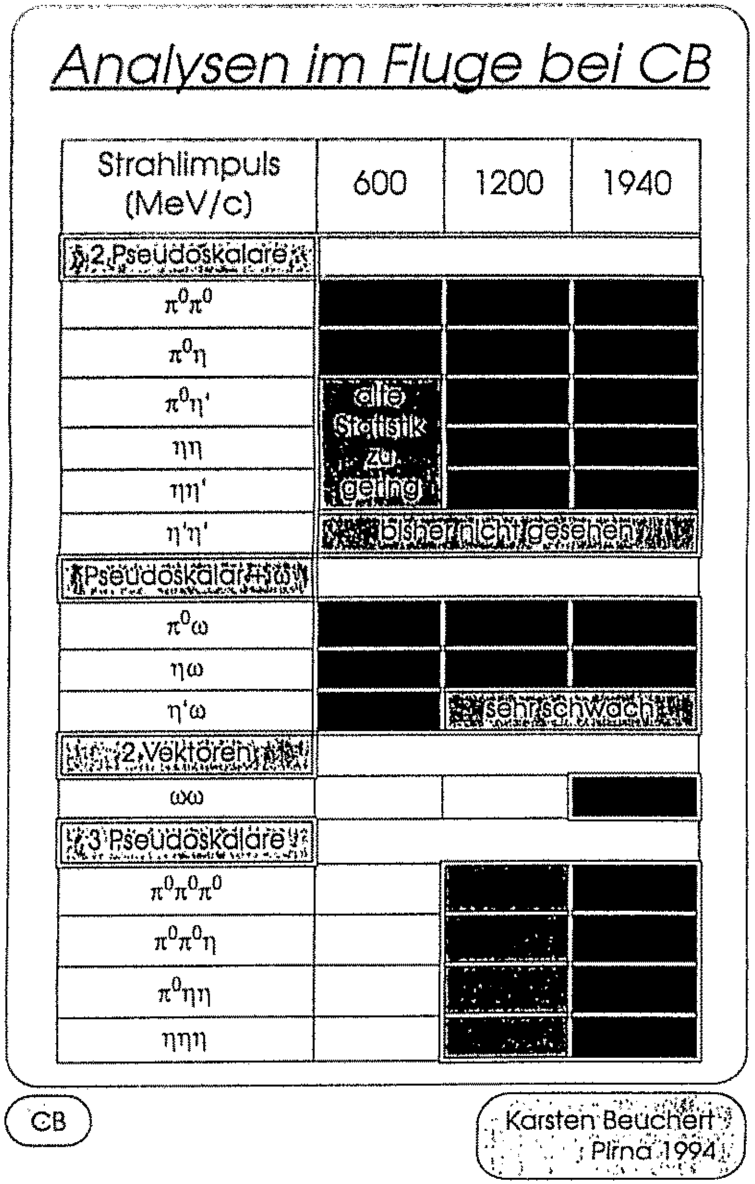

Analysen im Fluge bei CB

Strahlimpuls (MeV/c)	600	1200	1940
2 Pseudoskalare			
$\pi^0\pi^0$	■	■	■
$\pi^0\eta$	■	■	■
$\pi^0\eta'$	alte Statistik zu gering	■	■
$\eta\eta$		■	■
$\eta\eta'$		■	■
$\eta'\eta'$	bisher nicht gesehen		
Pseudoskalar+ω			
$\pi^0\omega$	■	■	■
$\eta\omega$	■	■	■
$\eta'\omega$	■	sehr schwach	
2 Vektoren			
$\omega\omega$			■
3 Pseudoskalare			
$\pi^0\pi^0\pi^0$		▨	■
$\pi^0\pi^0\eta$		▨	■
$\pi^0\eta\eta$		▨	■
$\eta\eta\eta$		▨	■

CB

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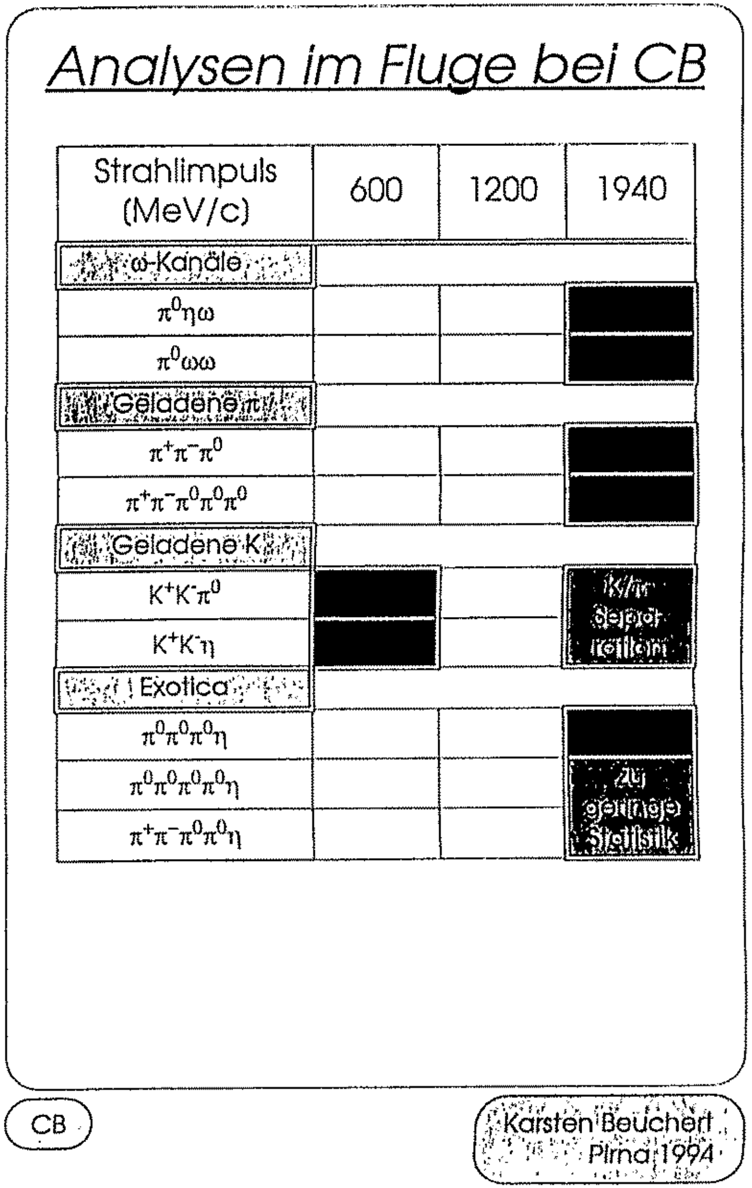

Analysen im Fluge bei CB

Strahlimpuls (MeV/c)	600	1200	1940
ω-Kanäle			
$\pi^0\eta\omega$			■
$\pi^0\omega\omega$			■
Geladene π			
$\pi^+\pi^-\pi^0$			■
$\pi^+\pi^-\pi^0\pi^0\pi^0$			■
Geladene K			
$K^+K^-\pi^0$	■		K/π Separation
$K^+K^-\eta$	■		
Exotica			
$\pi^0\pi^0\pi^0\eta$			■
$\pi^0\pi^0\pi^0\pi^0\eta$			zu geringe Statistik
$\pi^+\pi^-\pi^0\pi^0\eta$			

CB

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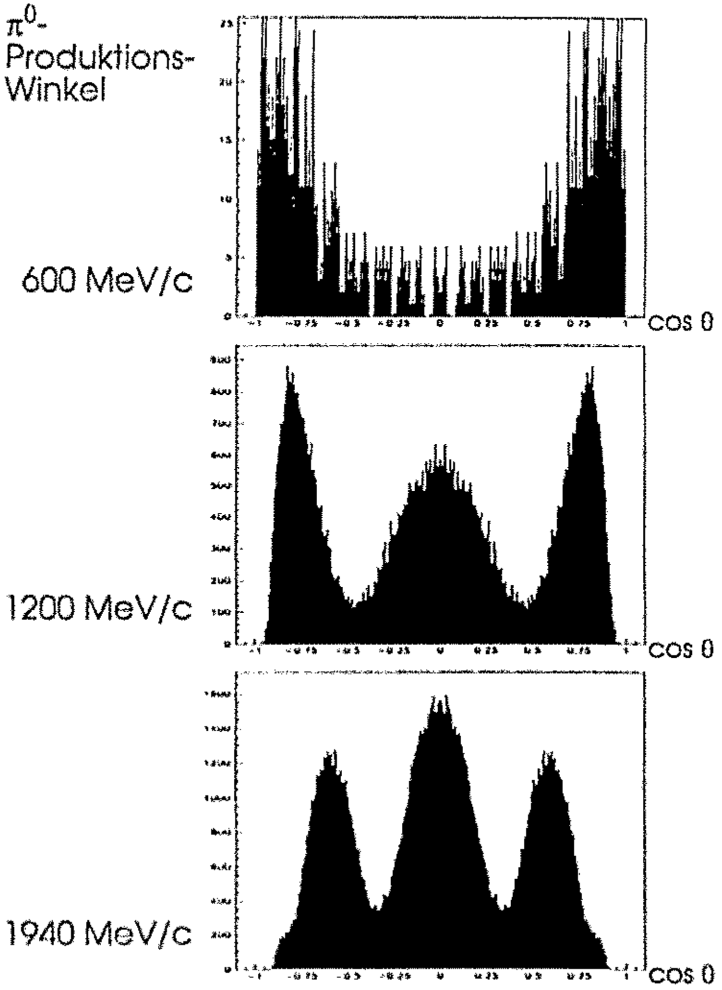
$p\bar{p} \longrightarrow \pi^0\pi^0$

π^0-Produktions-Winkel



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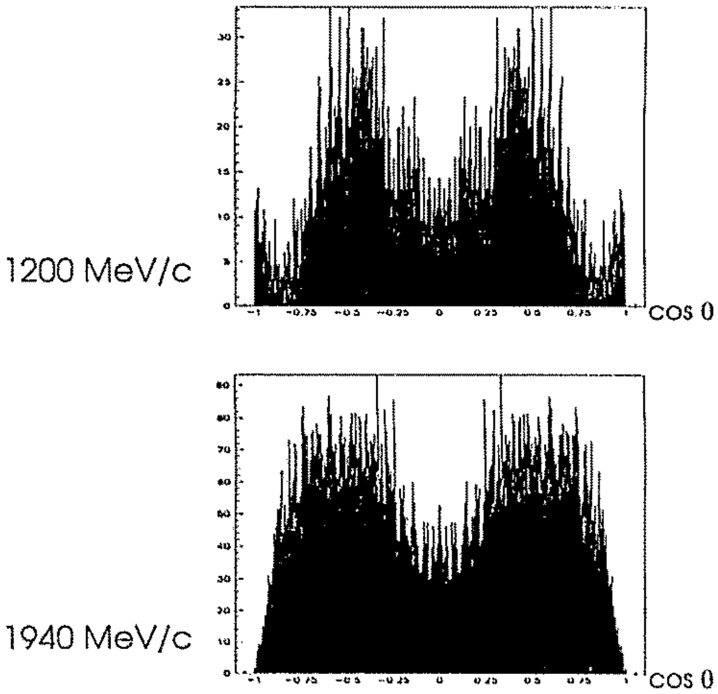
$p\bar{p} \longrightarrow \eta\eta$

η-Produktions-Winkel



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$p\bar{p} \longrightarrow$
2 Pseudoskalare

Winkelverteilung:

[illegible]

$\longrightarrow$ Uneindeutigkeiten

Fitfunktion:

$$I(\Omega) = \sum_l a_l P_l(\cos(\theta))$$

$p\bar{p} \longrightarrow$
2 Pseudoskalare

l_{max} wird bestimmt durch:
- keine weitere Änderung in χ^2
- kleine Koeffizienten für höhere Polynome
- Stabilität des Fits

	600	1200	1940
$\pi^0\pi^0$	4	6	8
$\pi^0\eta$	?	6	8
$\eta\eta$	?	6	~8

l_{max} steigt kanalunabhängig mit Impuls,
im Gegensatz zu Dulude et al.
(preliminary)

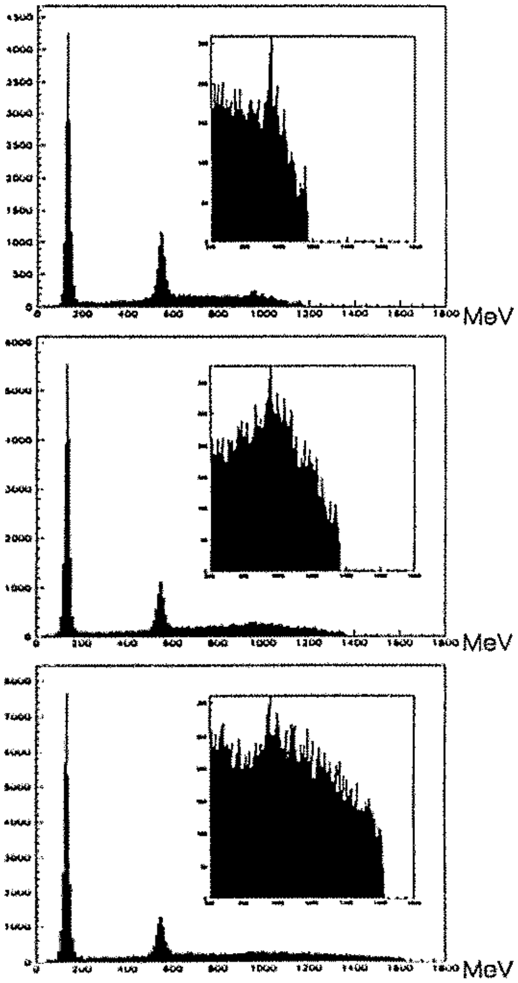
$p\bar{p} \longrightarrow \omega\gamma\gamma$

Invariantes
γγ-Massen-
Spektrum

600 MeV/c

1200 MeV/c

1940 MeV/c



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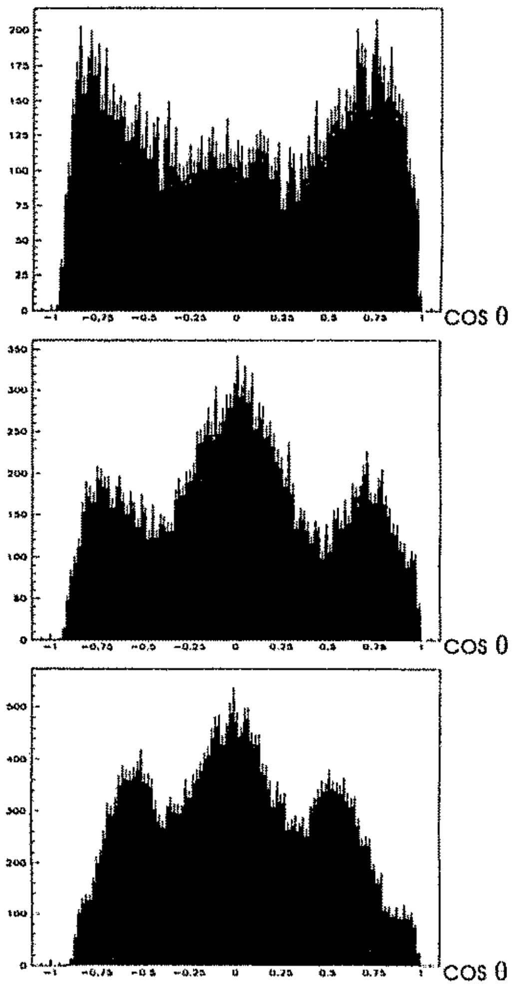
$p\bar{p} \longrightarrow \pi^0\omega$

ω-
Produktions-
Winkel

600 MeV/c

1200 MeV/c

1940 MeV/c



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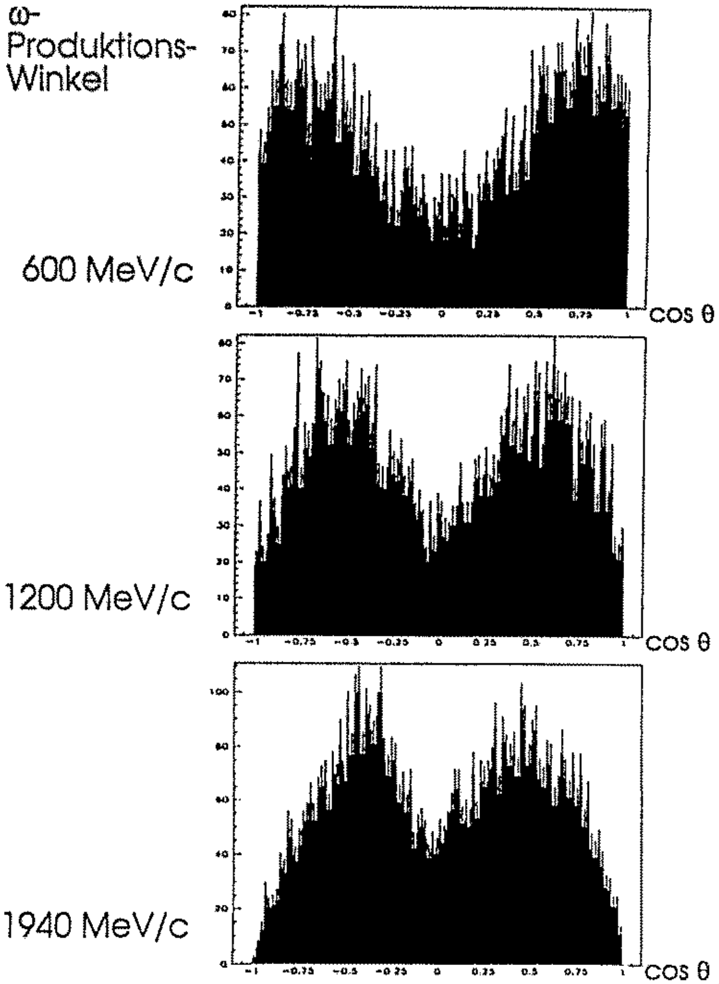
$p\bar{p} \longrightarrow \eta\omega$



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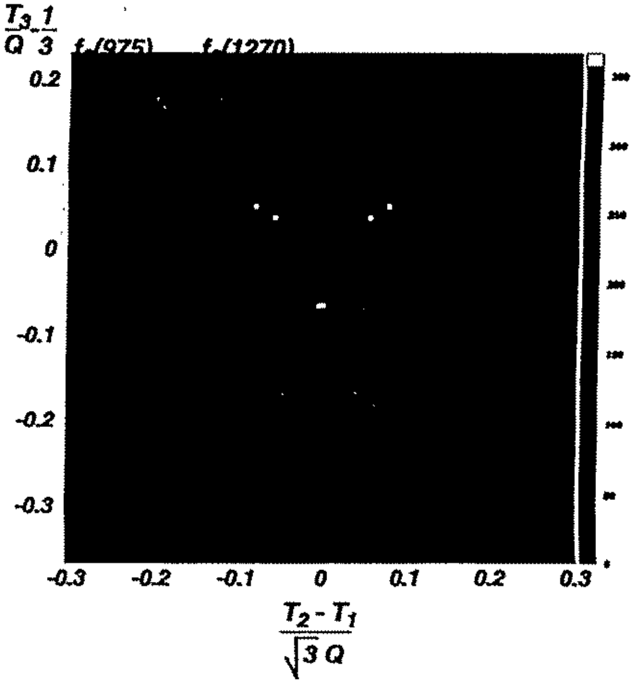
$p\bar{p}(1940\ MeV/c) \longrightarrow 3\pi^0$



162 k events

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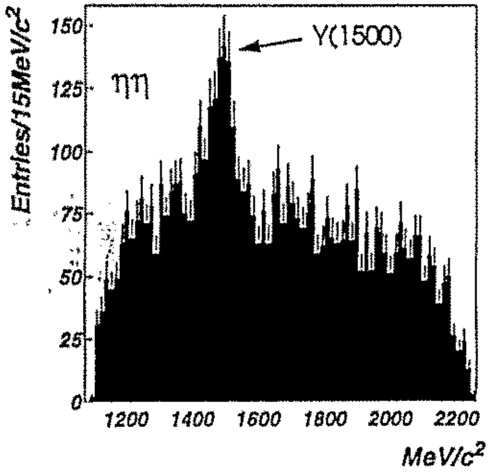
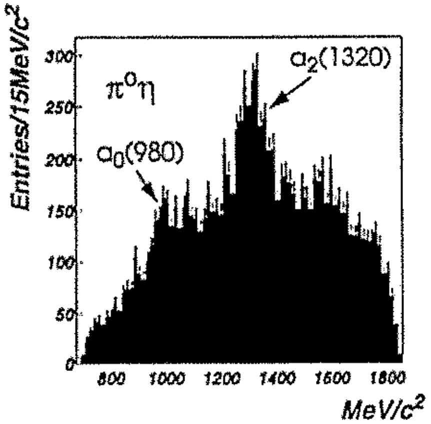
$p\bar{p}(1940\ MeV/c) \longrightarrow 2\eta\pi^0$





Jörg Lüdemann, RUB

Karsten Beuchert
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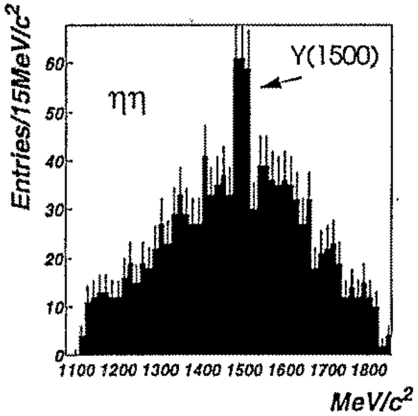
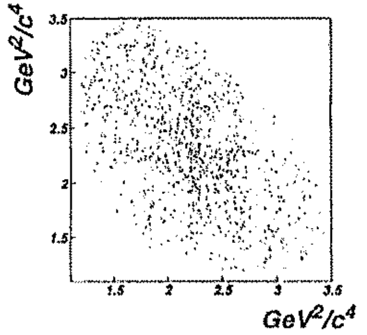
$p\bar{p}(1940\ MeV/c) \longrightarrow 3\eta$



422 events



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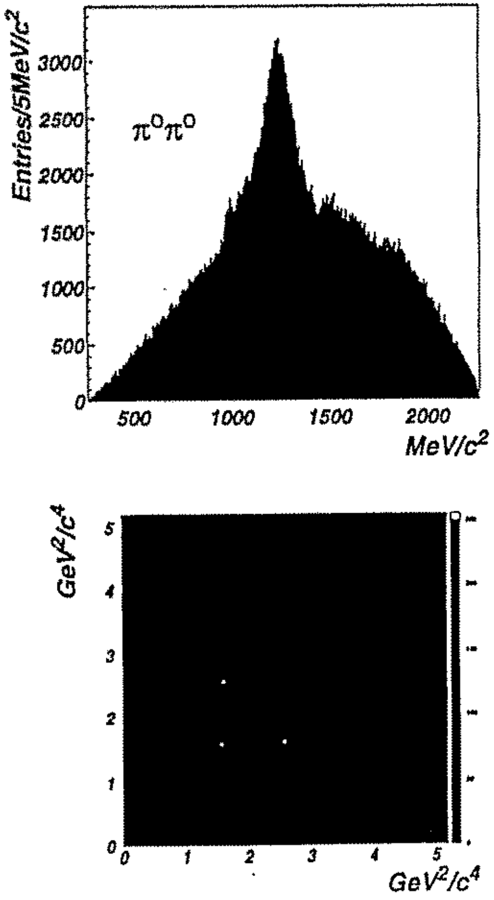
$p\bar{p}$(1940 MeV/c) ⟶ $3\pi^0$



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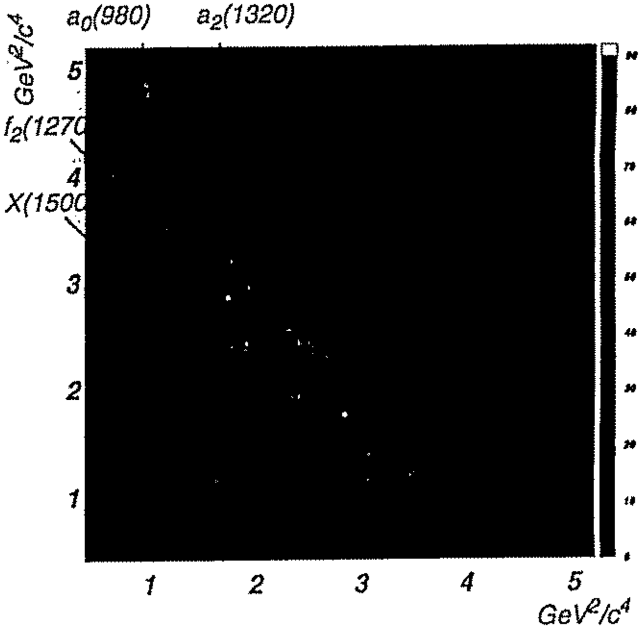
$p\bar{p}$(1940 MeV/c) ⟶ $2\pi^0\eta$



80 k events

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Amplitude

Resonance i with spin J and helicity λ
observed in a decay
with angles θ, ϕ
and invariant mass s_{12}

$$\boxed{A^i_\lambda = F^i_\lambda \cdot D^{J\,*}_{\lambda 0}(\phi,\theta,0) \cdot BW(s_{12})}$$

Intensity

$$I = \left| \sum_{i,\lambda,c} A^i_\lambda \right|^2$$

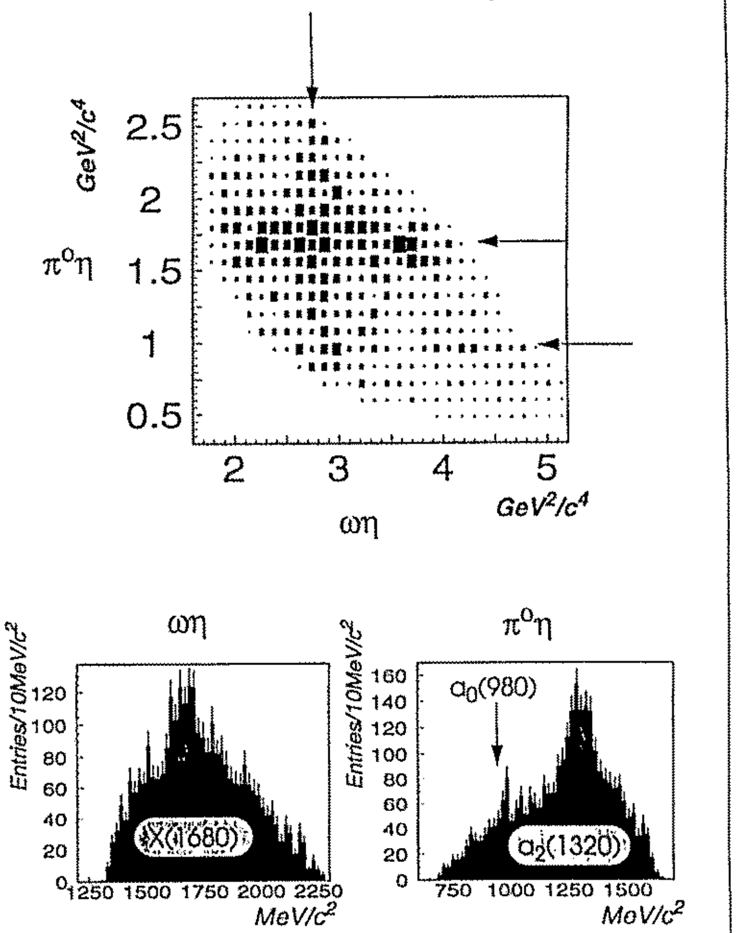
Likelihood

$$L = \frac{n!\,\Pi\, I}{(\Sigma\, I_{MC})^n}$$

Jörg Lüdemann, RUB

Karsten Beuchert
Pirna 1994

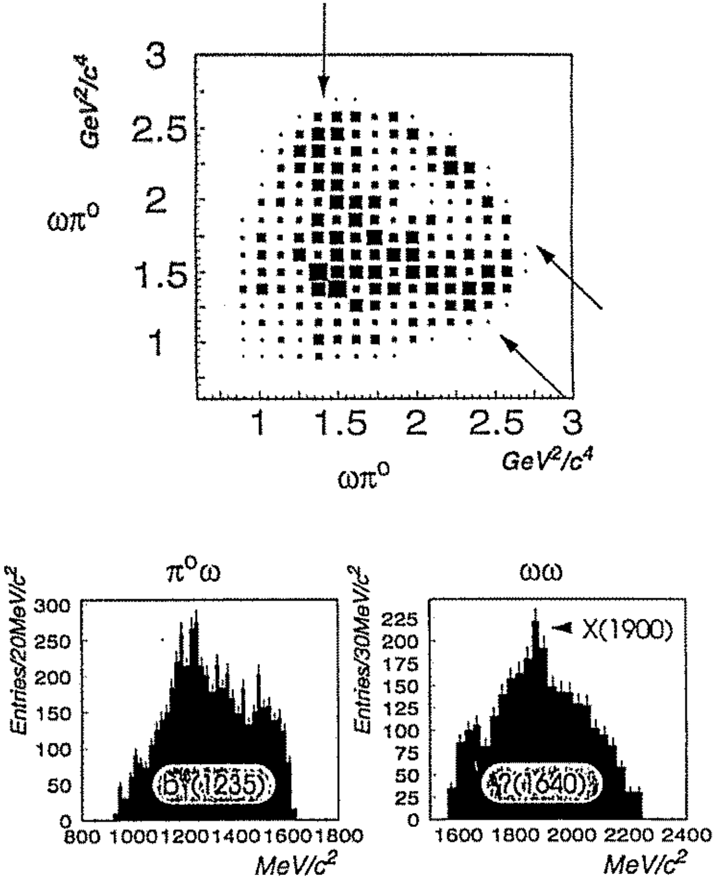
$p\bar{p}(1940\ MeV/c) \longrightarrow \omega\eta\pi^0 \longrightarrow 7\gamma$



Sven Ravndal, RUB

Karsten Beuchert
Pirna 1994

$p\bar{p}(1940\ MeV/c) \longrightarrow \omega\omega\pi^0 \longrightarrow 8\gamma$



Jürgen Salk/Basil Moshous, RUB

Karsten Beuchert
Pirna 1994

Detektoren und Datenerfassung

(*Koordinator:* **S. Paul / M. Godbersen**

1. **M. Heidrich** (Heidelberg)
   Gasmikrostreifendetektoren
2. **K. Zeitelhack** (TU München)
   Entwicklung eines schnellen RICH-Detektors für HADES
3. **H. Kraus** (TU München)
   Status und Perspektiven von Tieftemperatur-Kalorimetern
4. **P. Michel** (Rossendorf)
   Entwicklung eines schnellen TDC mit Konvertierungszeiten im Bereich weniger Nanosekunden
5. **S. Lange** (TU Dresden)
   Extraktion der pp-Bremsstrahlung mit künstlichen neuronalen Netzen

Gasmikrostreifendetektoren

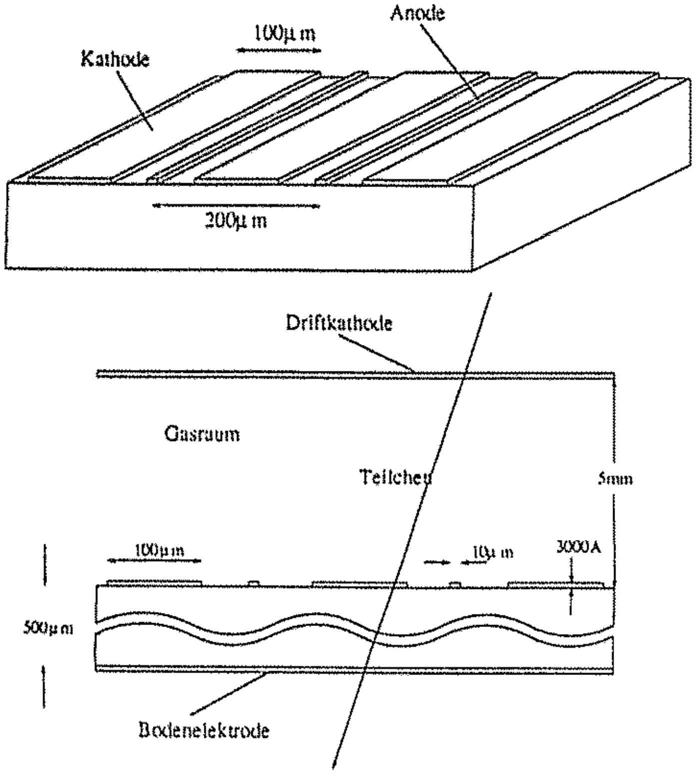
Matthias Heidrich

Max-Planck-Institut für Kernphysik
Heidelberg

Überblick

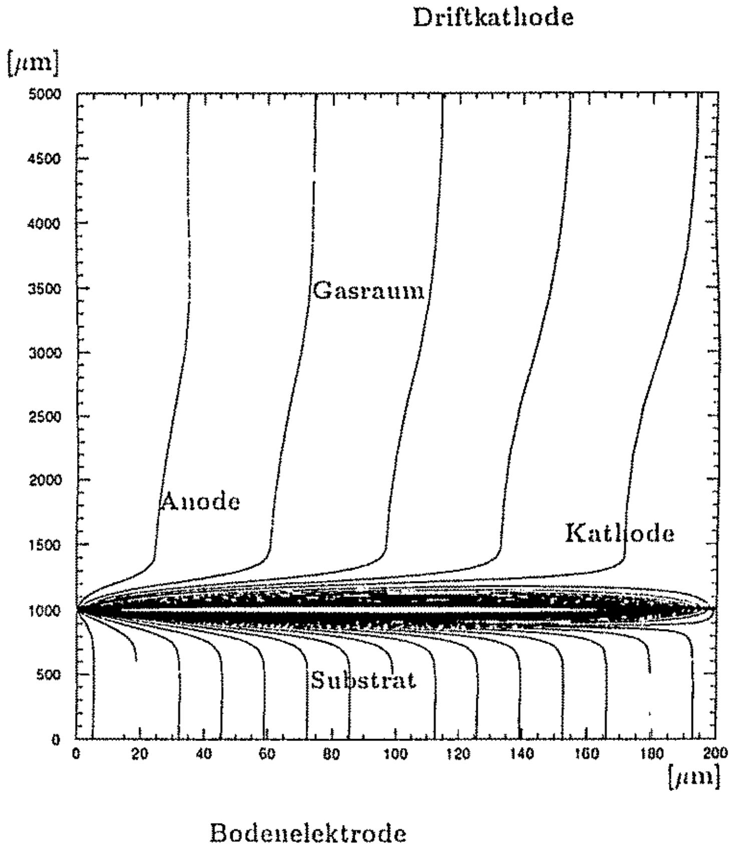
1. Aufbau und Funktionsweise eines GMSD
2. Vergleich mit MWPC
3. Vergleich mit SMD
4. Verstärkungsinstabilitäten aufgrund von
    - Polarisation
    - Aufladung
5. Entwicklung von GMSD auf
    - Glas
    - Plastik
6. Die Micrgap-Chamber
7. Zusammenfassung

Aufbau eines GMSD

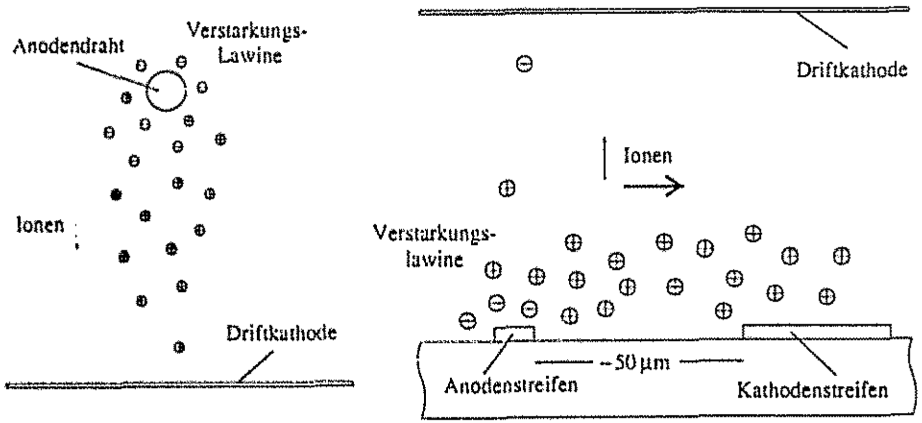


- Erster Prototyp 1988 (Oed, ILL, Grenoble)
- Substrat: Glas, Silizium oder Plastik
- Mikrostreifen: Al, Cr oder Au
- typische Spannungen: Driftspannung D=-2000V, Kathodenspannung K=-500V, Bodenspannung B=-100V

Der Feldlinienverlauf im Gasmikrostreifendetektor



Ionendrift



Drahtkammer:

- Driftweg: einige Millimeter
- Driftzeit: einige 10μs

Gasmikrostreifendetektor:

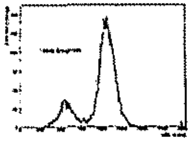
- Driftweg: ~50μm
- Driftzeit: einige 100ns

⟹

- GMSD ist wesentlich schneller
- hat viel höhere Ratenverträglichkeit

Vergleich mit der Vieldrahtproportionalkammer:

1. Ratenverträglichkeit:
   Beim GMSD um zwei Größenordnungen besser
2. Ortsauflösung:
   (100μm pitch ↔ 1mm Drahtabstand)
   ⟹ Beim GMSD um eine Größenordnung besser
3. Energieauflösung:
   10–20% (GMSD) ↔ 20–30% (MWPC)



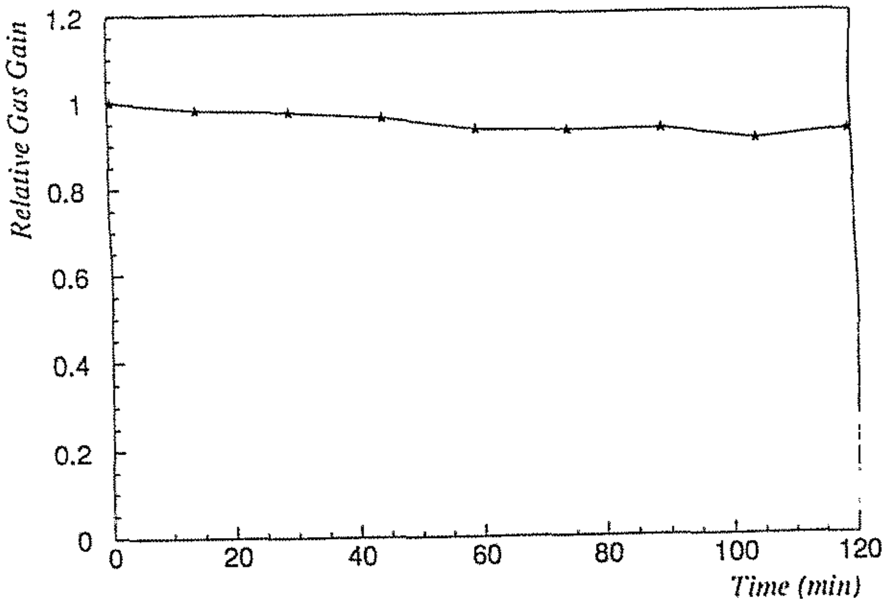
4. Gasverstärkung:
   10^3–10^4 (GMSD) ↔ ~10^6 (MWPC)
   ⟹ i.a. schlechtes Signal-Rausch-Verhältnis
   ⟹ Verwendung von 'low noise'-Chips (wie in Siliziumdetektoren)
5. Größe:
   - GMSD gegenwärtig ≤ 20x20cm^2, begrenzt durch die Möglichkeiten der Photolithographie
   - MWPC können viele Quadratmeter groß sein.

Vergleich mit dem Siliziummikrostreifendetektor:

1. Ratenverträglichkeit:
   - Siliziumdetektoren sind nicht strahlungshart
   - GMSD funktionieren auch bei hohen Teilchenflüssen
2. Ortsauflösung:
   (100μm pitch ↔ 25μm pitch)
   ⟹ Die des *GMSD* ist schlechter
3. Größe:
   Siliziumdetektoren üblicherweise 6x6cm^2 groß
   (limitiert durch die Methoden der Siliziumtechnologie)

Grundlegendes Problem:

Abfall der Gasverstärkung

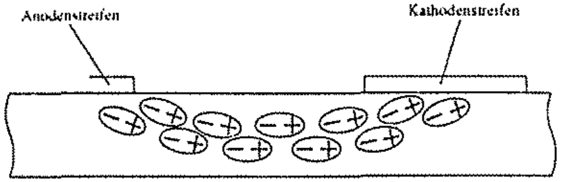


Verstärkungsabfall unmittelbar nach Anlegen der Kathodenspannung

- global (auf dem gesamten Detektor)
- unabhängig von der Einstrahlungsrate

Ursache: Polarisation des Substratmaterials

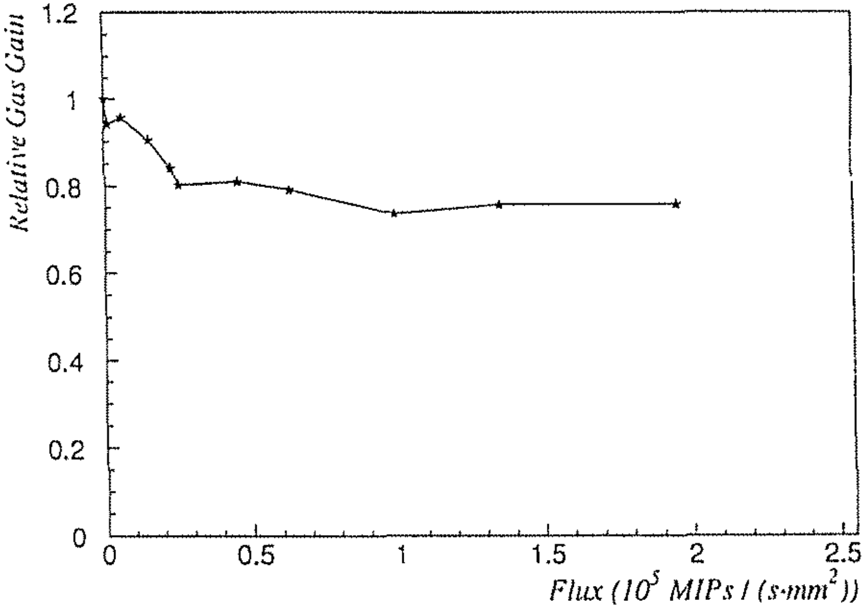
Polarisation des Substratmaterials



Anlegen der Kathodenspannung
⇓
Polarisation des Substratmaterials
⇓
Resultierende Ladungen an der Oberfläche verursachen entgegengesetztes Feld
⇓
Abnahme der Feldstärke auch im Gasraum
⇓
Abfall der Gasverstärkung

Grundlegendes Problem:

Abfall der Gasverstärkung

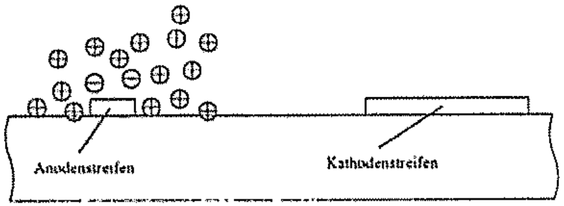


Verstärkungsabfall bei starker Einstrahlung

- lokal (im Bereich der Einstrahlung)
- stark abhängig von der Einstrahlungsrate

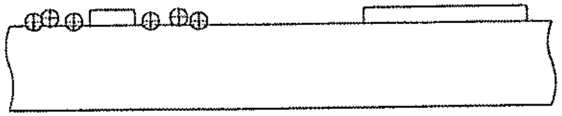
Ursache: Aufladung des Substrates durch Ionen aus den Verstärkungslawinen

Aufladung des Substrates

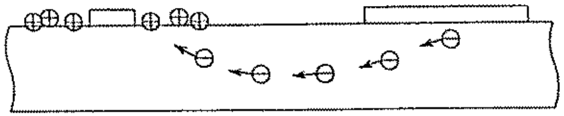


Aufladung durch Ionen aus der Verstärkungslawine
⇓
Veränderung des elektrischen Feldes im Gasraum
⇓
Abfall der Gasverstärkung

Einfluß des Substratwiderstandes



Isolierendes Substrat ($R \sim 10^{15} \Omega cm$)
⇓
Ionen haften auf der Oberfläche
⇓
Verstärkung sinkt bei sehr hohem Teilchenfluß
($\gg$ 1000 MIPs/s/mm^2) merklich ab.
⇓
Problem insbesondere für Einsatz in CMS und Atlas:
Fluß hier ist $5 \cdot 10^4$MIPs/s/mm^2



Schwach leitfähiges Substrat ($R \approx 10^9 .. 10^{12} \Omega cm$):
⇓
Kathoden liefern Elektronen
⇓
Neutralisation der Ionen
⇓
stabile Verstärkung

Anforderungen an ein geeignetes Substratmaterial:

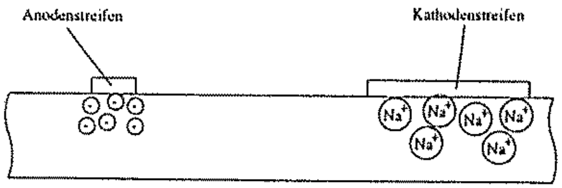
1. Einsatz bei hohem Teilchenfluß :
   $R \sim 10^9 .. 10^{12} \Omega cm$ (Untergrenze durch Leckstrom)
2. gute Oberflächenqualität:
   - gute Haftung des Metalls für die Mikrostreifen auf der Oberfläche
   - geringe Oberflächenrauheit (⇒ hohe Qualität der Mikrostruktur
3. mechanische Stabilität

⇒ diverse Glas- und Plastikmaterialien?

Jedoch:

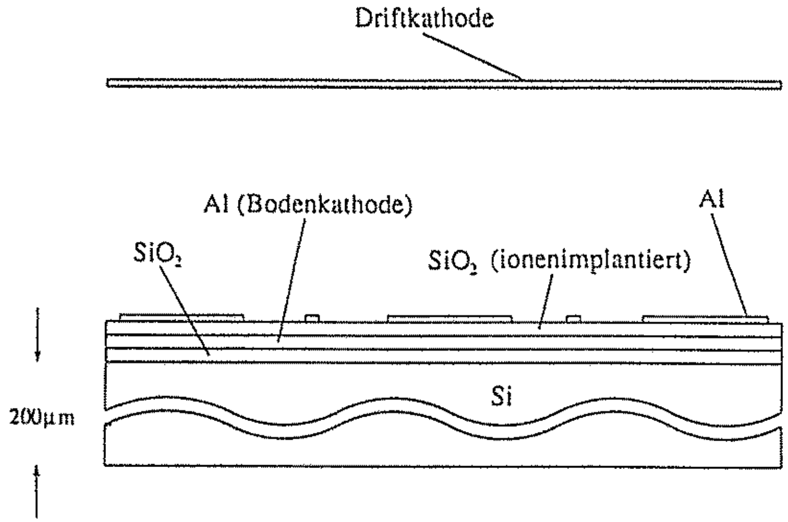
- Der Widerstand von Plastikmaterialien ist zu hoch ($\geq 10^{15} \Omega cm$)
- Gläser mit so niedrigen Widerstand sind im allgemeinen ionisch leitfähig.

Wanderung von Na-Ionen im ionisch leitfähigen Glas



Anlegen der Kathodenspannung
⇓
Wanderung der Natriumionen des Substratmaterials zu den Kathodenstreifen hin.
⇓
Ladungen an der Oberfläche verursachen Abnahme der Feldstärke im Gasraum
⇓
Abfall der Gasverstärkung
UND: Natriumionen können das Kathodenmaterial angreifen!

Silizium als Substrat

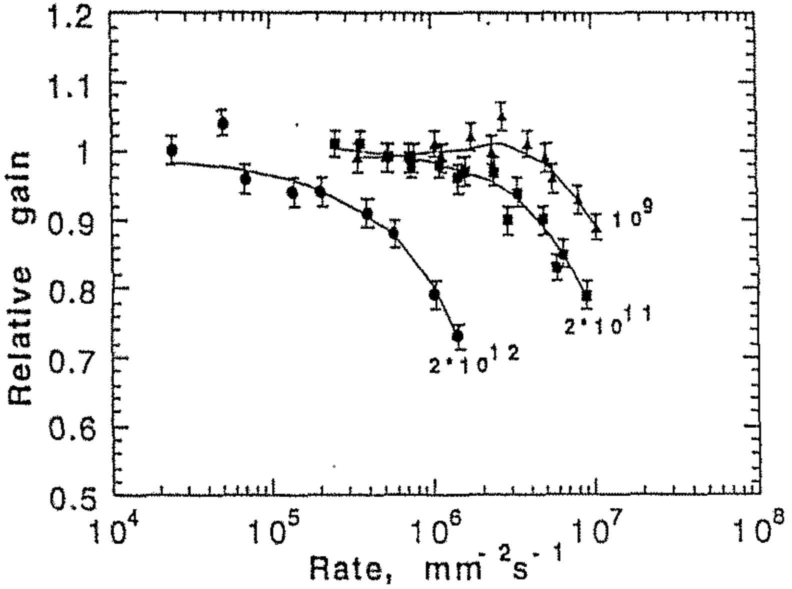


- Bellazini et al., INFN, Pisa
- Bodenkathode ist in Streifen senkrecht zu den Anoden unterteilt ⇒ zweidimensionale Auslese
- stabile Gasverstärkung auch bei hohen Teilchenflüssen
- Siliziumtechnologie erforderlich ⇒
  - stark größenlimitiert
  - teuer in der Herstellung

Glas als Substratmaterial:

1. Ionenimplantation in Quarz (Bellazini et al., INFN, Pisa) ⟶ 8 GMSD-Ebenen in NA12 (erster Einsatz von GMSD in HEP-Experiment)
2. Ionenimplantation in andere Gläser ebenfalls erfolgreich, wenn auch Langzeitstabilität des Widerstandes problematisch
3. Entwicklung von elektronisch leitfähigen Gläsern (Ropelewski et al., CERN):
   - $FeOFe_2O_3(20-25\%)SiO_2(30-40\%)$+andere Oxyde
   - 4.3cm Strahlungslänge (SiO_2: 12.3 cm)
   - bis zu 200μm Dicke herstellbar (Institut of Vacuum Glasses, Moskau)
   - Schott S8900:
     - elektronisch leitfähig
     - 10cmx10cm kosten 1000 DM
     - $\geq$ 500μm dick

GMSD auf elektronisch leitfähigen Gläsern



- niedriger Widerstand ⇒ Stabilität bei hohen Teilchenraten
- stabile Verstärkung bis zu $3 \cdot 10^6$ MIPs/s/mm^2

Plastik als Substratmaterial:

- Vorteil:
  - Strahlungslänge größer als die von Gläsern
  - sehr dünn erhältlich ($\geq 7\mu m$)
- Grundsätzliche Probleme:
  - Haftung von Metallen auf Polymeren grundsätzlich schlecht.
  - Weiche Oberfläche wird leicht beschädigt (⇒ Defekte)
  - Sehr hoher Widerstand von Polymeren ($\geq 10^{15}\Omega cm$)

Verbesserung der (Oberflächen-)

Leitfähigkeit von Plastikmaterialien

1. Ionenimplantation (He, Ar, Kr) in Plastik (Kapton, Upilex) (Armitage et al., Carleton University, Ottawa) :
   - führt zu stabilem, gewünscht niedrigem Widerstand
   - jedoch sehr schlechte Haftung eines Metalls auf implantiertem Plastik
   - Säuren der Ätzprozesse verändern den Widerstand der implantierten Schicht

2. Industrielle Herstellung von leitfähigem Kunststoff (Kapton) durch Beimischung großer Anteile von Kohlenstoff (DuPont):
   - Widerstand wird zu niedrig
   - oder inhomogen

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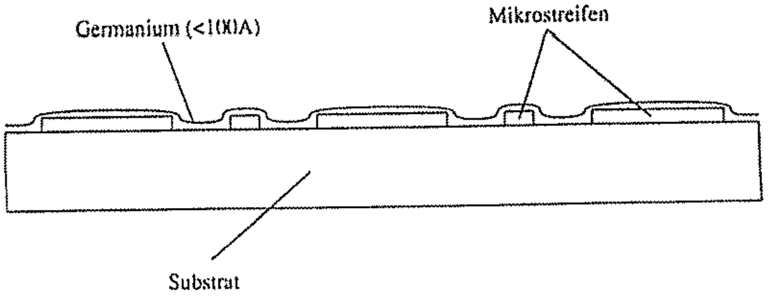
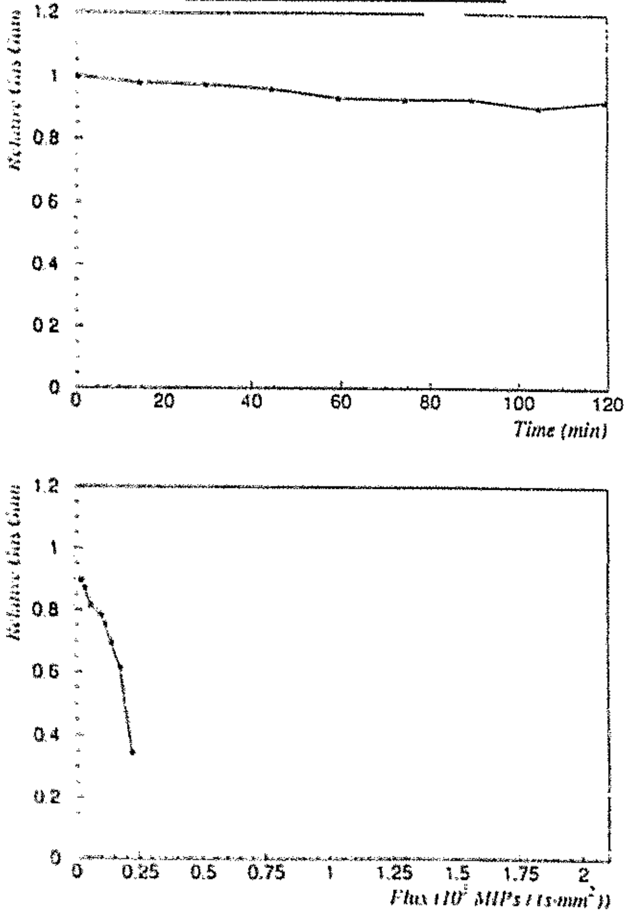
3. Aufbringen einer sehr dünnen schwach leitfähigen Schicht (MPI Heidelberg):



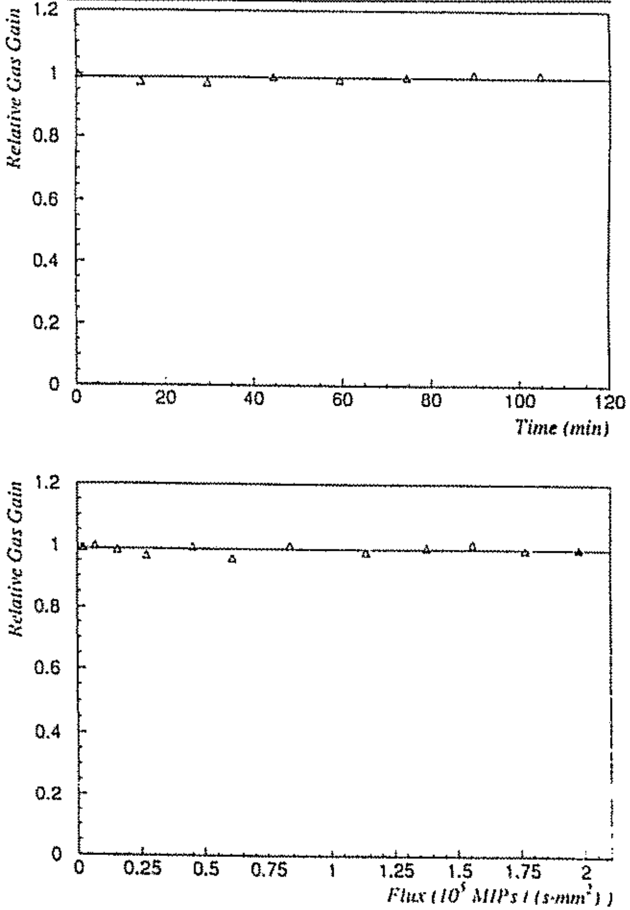
- Anfängliche Versuche mit Kupfer:
  - Leitfähigkeit zu hoch
  - bzw. notwendige Schichtdicke ≤ 10 Å
- Erfolg mit Germanium:
  - Verstärkungsabfall aufgrund von Polarisation verschwindet
  - stabile Gasverstärkung bis hin zu sehr hohen Teilchenflüssen
  - funktioniert ebenso mit Glassubstraten

Verhalten der Gasverstärkung (Upilex-Substrat)



- oben: Verstärkungsabfall unmittelbar nach Anlegen der Kathodenspannung (Polarisation)
- unten: Verstärkungsabfall abhängig von der Einstrahlungsrate (Aufladung)

Gasverstärkung (Upilex- Substrat mit 28Å-Germanium-Schicht)



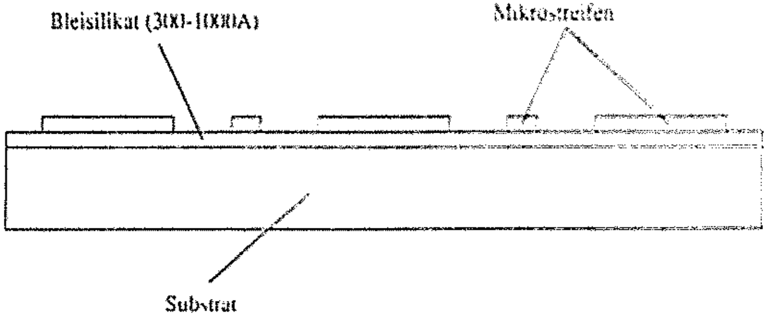
- oben: Stabile Gasverstärkung unmittelbar nach Anlegen der Kathodenspannung
- unten: Stabile Verstärkung bis zu sehr hohen Teilchenflüssen

Passivation:

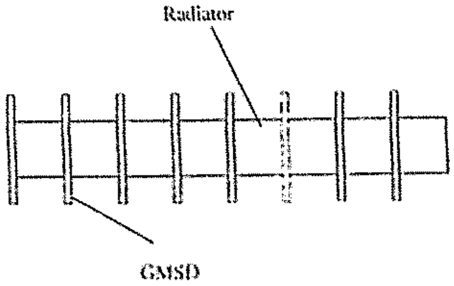
Andere Arten der Passivation von GMSD, die inzwischen versucht wurden:

- Armitage et al., Carleton University, Ottawa:
  Ni oder Cr (1μm dick) auf Tedlar-Substrat
- Oed et al., ILL, Grenoble und Sann et al., GSI, Darmstadt: AlO auf Glas- und Plastiksubstraten
- Sauli et al. Cern, Genf:
  Bleisilikat (300–1000 Å) auf verschiedenen Gläsern

Ebenso gelungen: Realisation der Mikrostruktur auf einer dünnen Bleisilikatschicht:

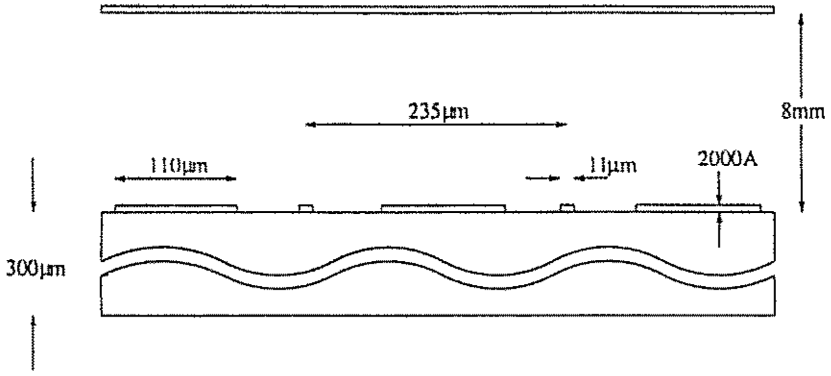


Ein Übergangsstrahlungsdetektor basierend auf GMSD für das WA89-Experiment



- Detektor zur e^+/e^--Identifikation
- 8 Radiator-GMSD-Paare

Aufbau einer der TRD-Kammern:



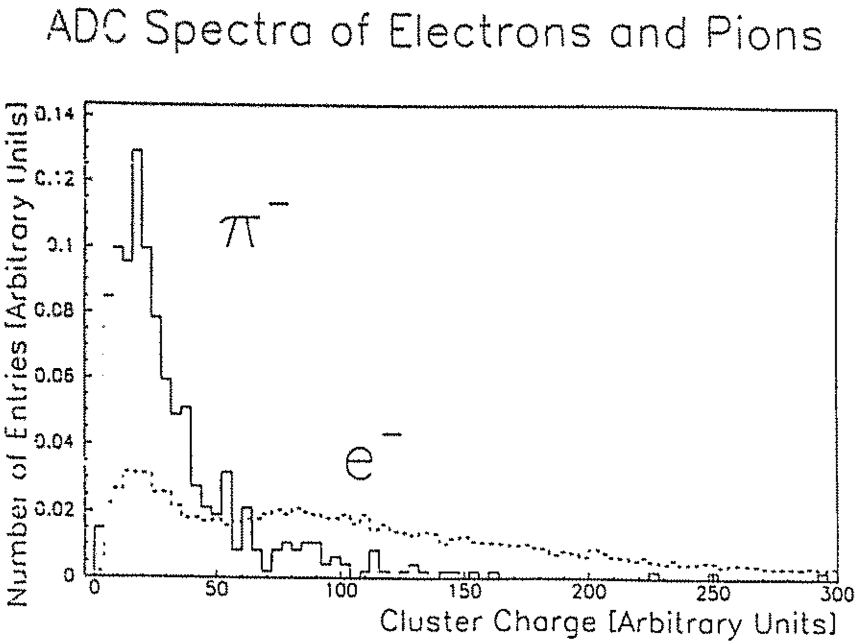
- Glassubstrat: Desag D263
  - sehr gute Oberflächenqualität
  - sehr geringer Na-Gehalt
  - Widerstand ~$10^{15}\Omega$cm
  - nur wenige % Verstärkungsverlust beim WA89–Teilchenfluß von 1000 MIPs/s/mm^2
  - 300μm dick, 20x20cm^2 groß
- Mikrostreifen aus Chrom
  - läßt sich sehr genau ätzen
  - keine Oxydation der Streifen
- 15cmx16cm große aktive Fläche
- Gasfüllung: Xe-CH$_4$

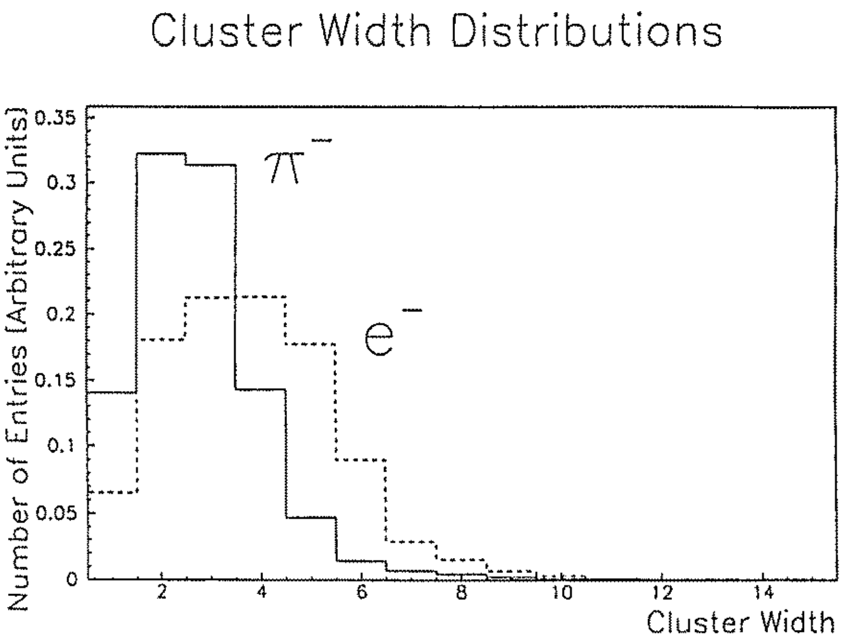
Der Radiator:

- 150 Polypropylen-Folien (20μm dick)
- Folienabstand: 470μm

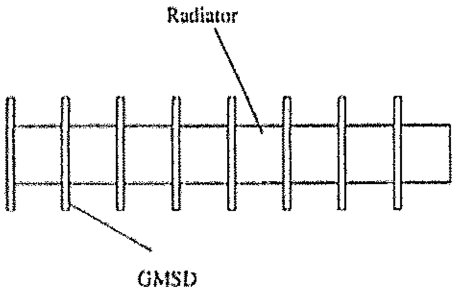
Die Auslese-Elektronik: Der SVX-Chip

- für Siliziumdetektoren entwickelt
- Nullunterdrückung auf dem Chip
- Analoginformation steht zur Verfügung


ADC Spectra of Electrons and Pions

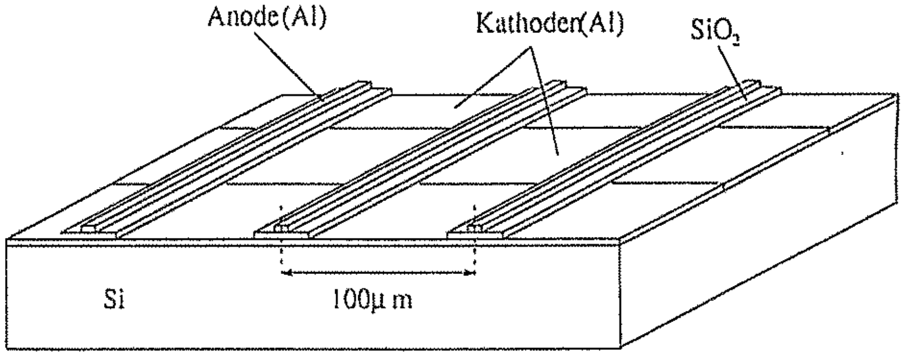

Cluster Width Distributions

Stand der Dinge:



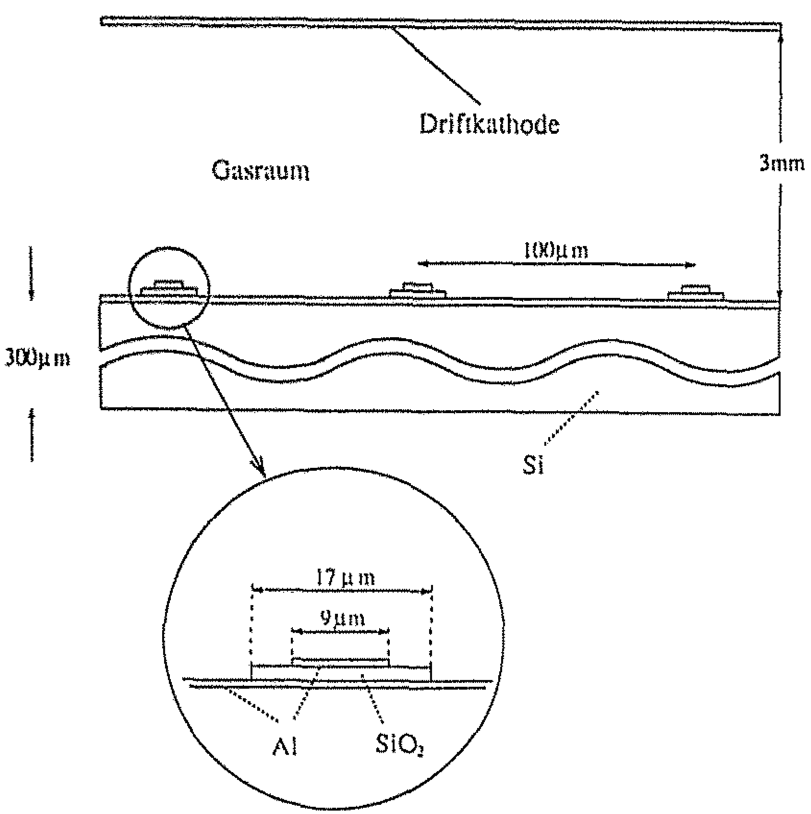
- In einem Teststrahl wurden verschiedene Parameter der Kammern optimiert und die Elektronik getestet
- Im WA89-Run 1994 kamen 2 TRD-Kammern zum Einsatz
- Bis zum Run 1996 werden die restlichen 6 Kammern fertiggestellt werden

Die Microgap-Chamber

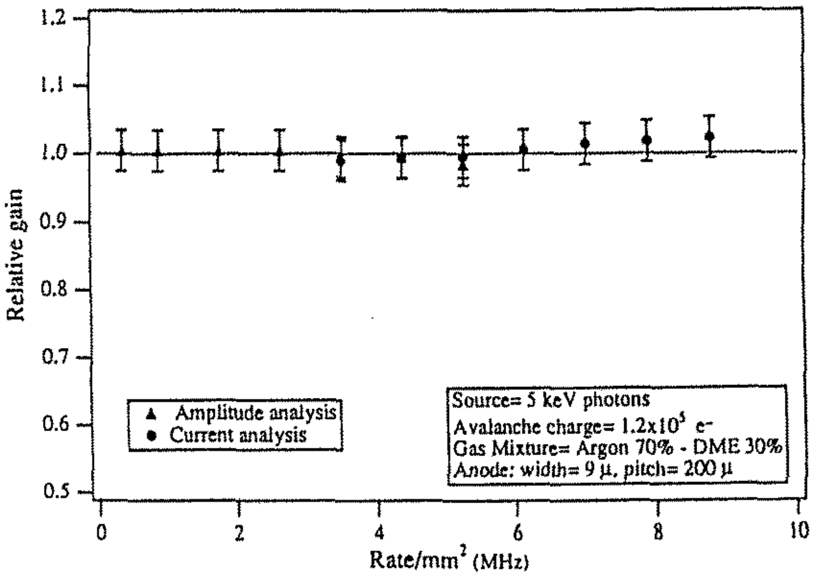


- Bellazini et al., INFN, Pisa
- Substrat: Silizium
- Kathoden: Metallschicht, in Streifen unterteilt
- Anoden: senkrecht zu den Kathoden, durch SiO_2-Streifen von diesen getrennt

Die Microgap-Chamber im Querschnitt



Stabilität der Gasverstärkung:



Abstand zwischen Anode und Kathode nur wenige Mikrometer

⇓

Enorme Ratenverträglichkeit ($\gg 10^7$MIPs/s/mm^2)

Bisher nur mit Siliziumtechnologie herstellbar ⇒

- *Limitiert in der Größe*
- Teuer in der Herstellung

Doch einiges ist im Gange...

Zusammenfassung und Ausblick

- Eigenschaften des GMSD:
  - hohe Ratenverträglichkeit
  - hohe Ortsauflösung
  - hohe Energieauflösung
  - bis 20x20 cm^2 groß
  - geringe Gasverstärkung

- GMSD lassen sich fertigen auf Silizium, Glas- und Plastiksubstraten

- Bisher existieren GMSD in nur wenigen HEP-Experimenten (NA12, SMC, WA89,...?)

- Einsatz bei hohen Teilchenflüssen erfordert niedrigen (Oberflächen-) widerstand des Substrates. Möglichkeiten sind
  - Ionenimplantiertes SiO_2
  - Ionenimplantierte Gläser
  - eigens hierfür entwickelte elektronisch leitende Gläser
  - passivierte (Ge, Ni, Cr, Bleisilikat, AlO,...) Plastik- und Glassubstrate

Zusammenfassung und Ausblick

- Die Microgap-Chamber vereinigt alle Vorzüge des GMSD in sich, ist
  - sogar noch schneller
  - Ratenverträglichkeit ist noch höher

- Sie ist jedoch bislang nur mit den Methoden der Siliziumindustrie herstellbar, daher
  - teuer
  - stark limitiert in der Größe

- Bestrebungen sind im Gange, MGC einfacher zu fertigen...

Entwicklung eines schnellen RICH-Detektors für HADES

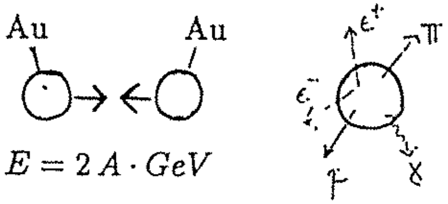
J. Friese, R. Gernhäuser, J. Homolka, W. Karle, A. Kastenmüller, P. Kienlé, H.-J. Körner, P. Maier-Komor, M. Münch, R. Schneider, A. Stolz, K. Zeitelhack

Physik-Department E 12, TU München

- Physikalische Motivation
- Konzept eines "schnellen" RICH-Detektors
  - Der Radiator
  - Der Photonendetektor
  - Auslese und Ringerkennung
- Fazit und Ausblick

Studium heißer dichter Kernmaterie

- "in medium" Effekte

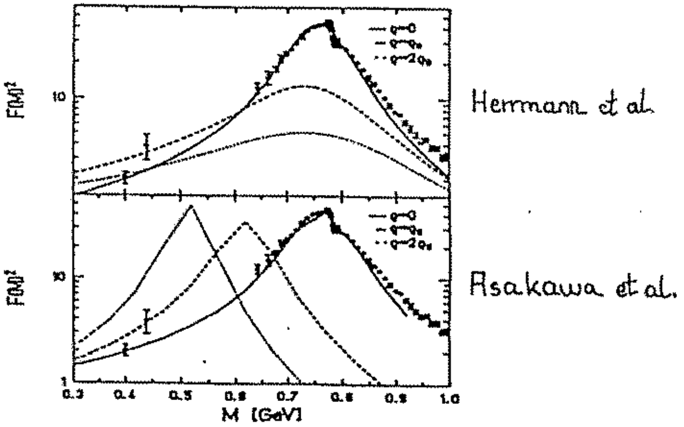


$E = 2\,A \cdot GeV$

T ≃ 100 MeV
$\rho \simeq 2 - 3\,\rho_0$

Meson	[MeV/c^2]	$c \cdot \tau$ [fm]	dom. Zerfall	e^+e^- BR
ρ	768	1.3	$\pi\,\pi$	$4.4 \cdot 10^{-5}$ ←
ω	782	23.4	$\pi\,\pi\,\pi$	$7.2 \cdot 10^{-5}$ ←

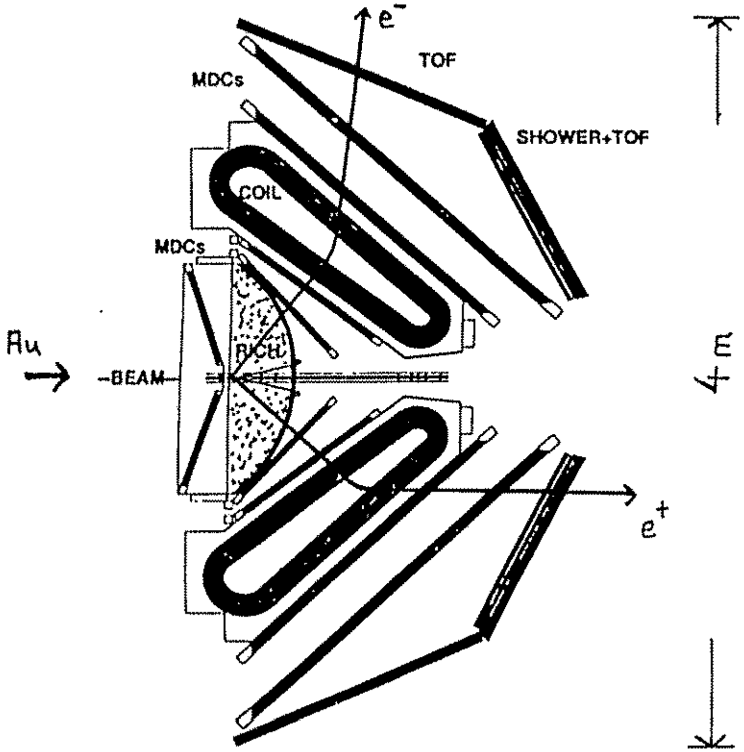
Formfaktor des ρ-Mesons



Das HADES - Dileptonspektrometer

1 $A\cdot GeV$ Au : $10^{8}\,s^{-1}$
zentr. Stöße : $10^{5}\,s^{-1}$
gelad. Teilch. : $10^{7}\,s^{-1}$ ←

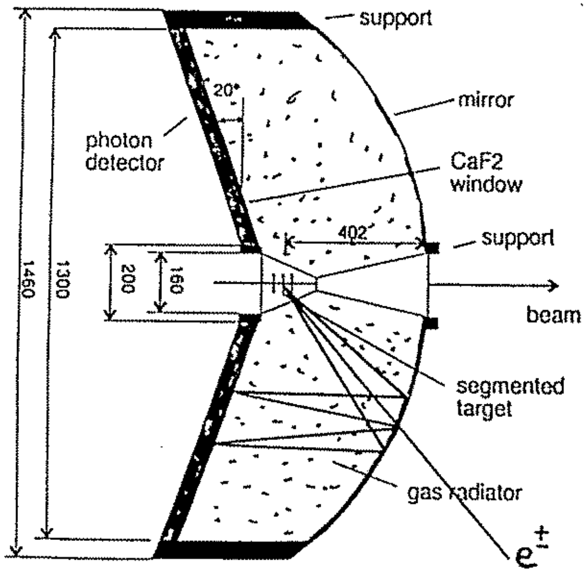
Dileptonen: $\rho \to e^{+}e^{-}$: $10^{-1}\,s^{-1}$ ←
aber Untergrund: π^{0} : $10^{6}\,s^{-1}$
↳ $\gamma e^{+}e^{-}$: $10^{4}\,s^{-1}$ ←



Das HADES - RICH Konzept

- "Blind" für Hadronen ⇒ Gasradiator
- Rückwärtsgeometrie mit dünnem Kugelspiegel ($2\,mm$ CFK + Al + MgF_2)
- 2-D ortsaufl. Photonenzähler ($A \simeq 1.5\,m^2$), Einzelphotonnachweis, hohe Zählrate ($R \simeq 10^5\,s^{-1}$), schnelle Ringerkennung ($\tau < 10\,\mu s$)

⇒ MWPC mit reflekt. CsI - Photokathode und schneller Kathodenpad - Auslese



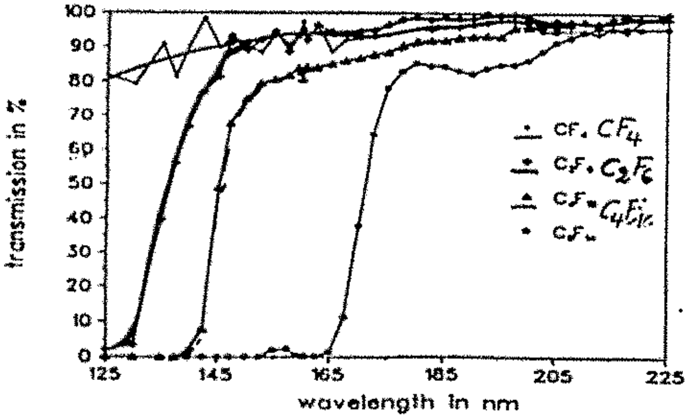
Der HADES-Gasradiator

- Hohe Lichtausbeute ($n\text{-}1 \simeq 10^{-3}$)
- Hohe VUV - Transparenz
- Geringe Massenbelegung (→ externe Konversion)
- Keine Szintillation

Fluor-Kohlenstoff Verbindungen

Gas	$n-1$ $[10^{-3}]$	$\Delta n/\Delta E$ $[10^{-6}/eV]$	γ_{thr} at 177 nm	λ_{cut} [nm]	L [m]
CF_4	0.49	10	32.0	< 120	
C_2F_6	0.79	23	25.1	136	5.52
C_4F_{10}	1.51	53	18.2	145	3.22

VUV - Transmission

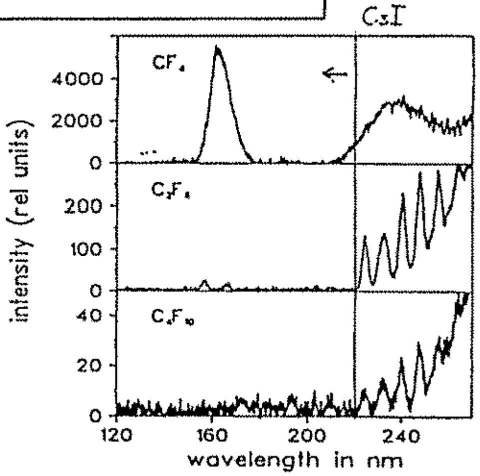


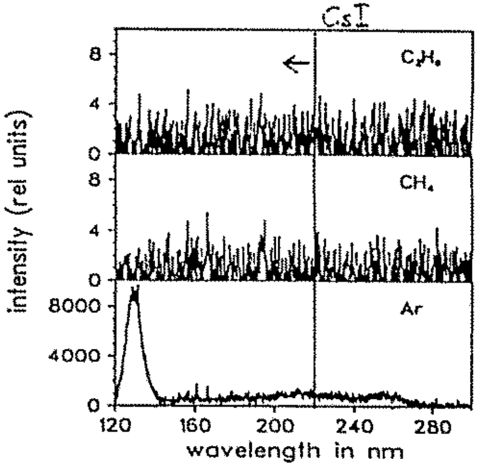
VUV - Szintillation

$E = 80\,\text{MeV}\ {}^{16}O$

$E = 22\,\text{MeV}\ p$

:

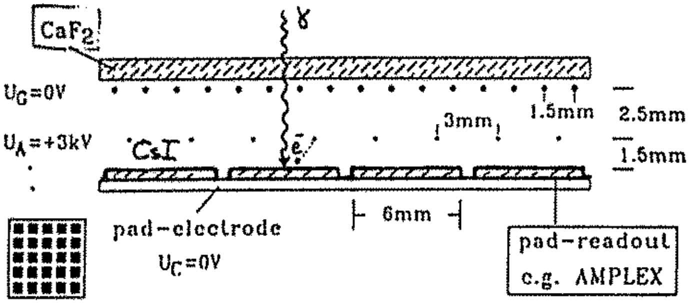


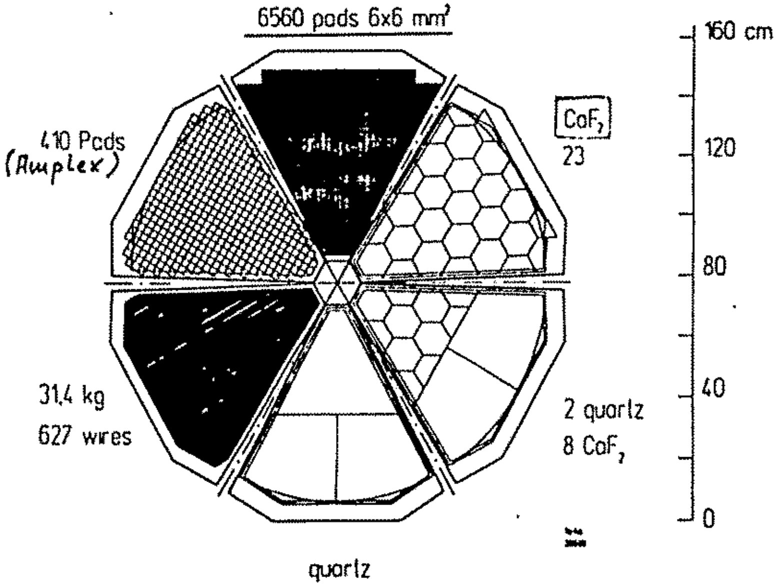


Gas	Ar	CF_4	C_2F_6	C_4F_{10}	CH_4	C_2H_6
N_γ / MeV	420	56	0.52	0.28	0.06	0.01
		−	+	+		

HADES : $\Delta E_{c.p.} \simeq 350\,\text{MeV}$ pro zentr. Stoß

Der HADES - Photonendetektor



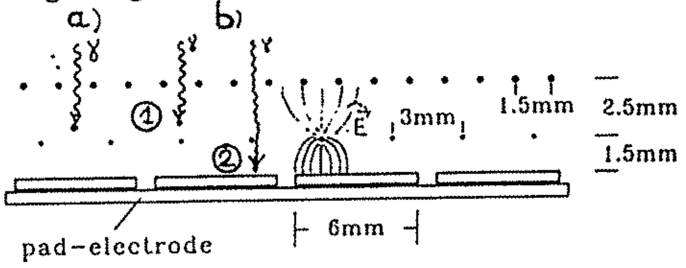


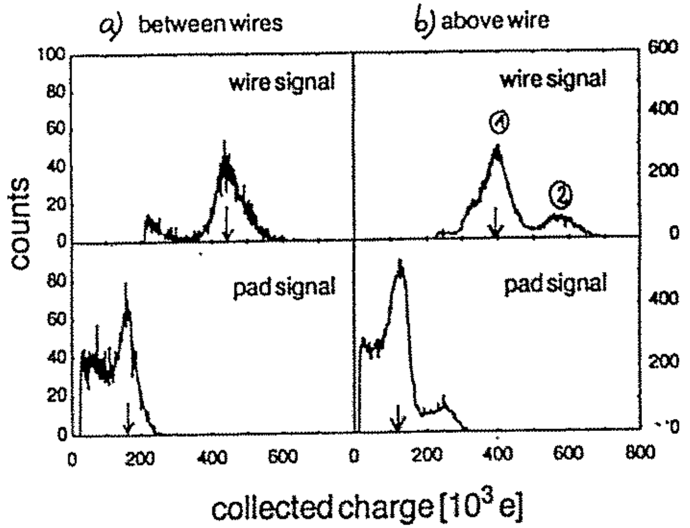
Messungen mit dem Prototyp

Kollimierte ^{55}Fe - Quelle ($E_{x-ray} = 5.9\,\mathrm{keV}$)

Ar-CH$_4$ 90/10, p = 1atm, $g \simeq 10^4$

Ladungsinteg. Auslese von Anodendraht bzw. Pad



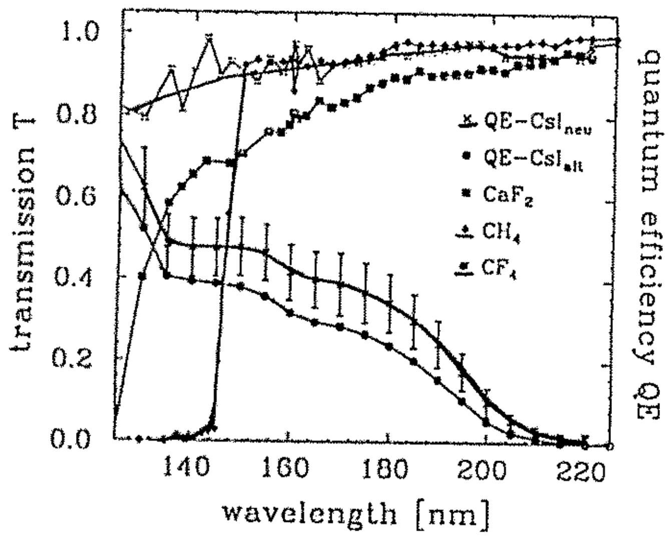


$$Q_{Pad} \,/\, Q_{Anode} \simeq 0.38$$

Nachweis von VUV - Licht

Photokonverter

	Name	Zustand T = 300 K	$E_{thr.}$ [eV]	$l_{abs.}$ [mm]
→	CsI	fest	5.9	-
	TMAE	flüssig	5.3	13.7 ← +
	TEA	flüssig	7.5	0.6



Alterung durch H_2O und UV-Bestrahlung

10^{13} Photoelektronen / cm^2 ⇒ 10 a HADES

Photoelektronen pro Ring

$$N \;=\; N_0 \cdot l_{Rad} \,/\, \gamma_{th}^2 \qquad\qquad (\beta = 1)$$

$$N_0 \;=\; \frac{370}{eV \cdot cm} \cdot \int_{E1}^{E2} R \cdot T \cdot QE \cdot \varepsilon_{pe} \cdot dE$$

$R = 0.85$: Reflektivität Spiegel

T: Transmission Rad., Fenster, Det.

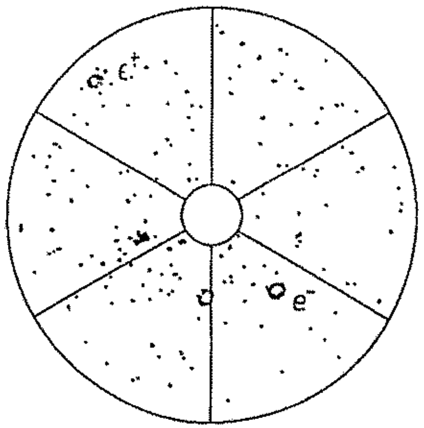
QE: Quanteneffzienz. CsI

$\varepsilon_{pe} = 0.95$: Nachweiseffizienz. e^-

	Rad.	Fenster	Det.-Gas	N_{min}	N_{max}
→	C_4F_{10}	CaF_2	CH_4	22	38
→	C_2F_6	CaF_2	CH_4	13	23
	C_2F_6	CaF_2	CF_4	16	28
	CF_4	-	CF_4	21	37

Simulation

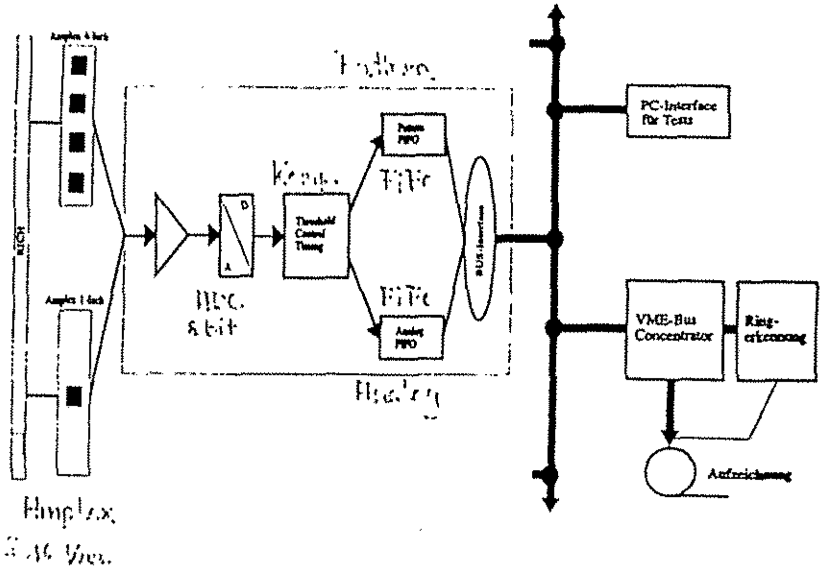
1 A·GeV Au + Au



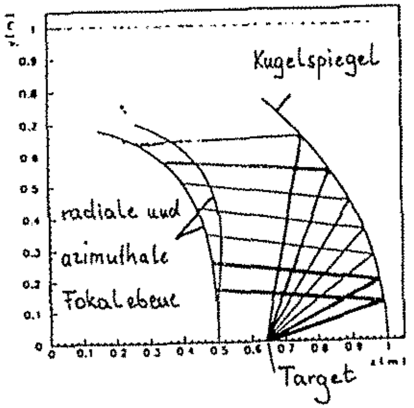
Das RICH - Auslesekonzept

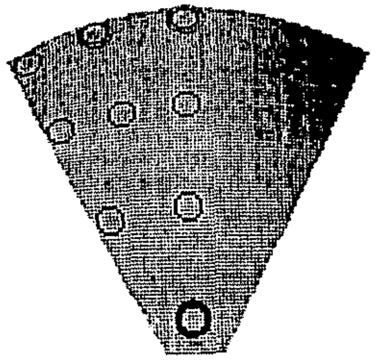
! Auslese von 40000 Kanälen in $t < 10\,\mu s$

- Frontend-Modul mit AMPLEX / GASPLEX Analogchip, 8 Bit ADC, individueller Schwelle für jeden Kanal, Multi event buffer, Pattern und Analog-Information
- Frontend-Module verbunden mit digitalem Bus
- Parallele Auslese mehrerer Ketten durch "Konzentratormodule"
- Übergabe der Patterninformation an Triggermodul
- Speichern der Analoginformation in VME-memory



Optik





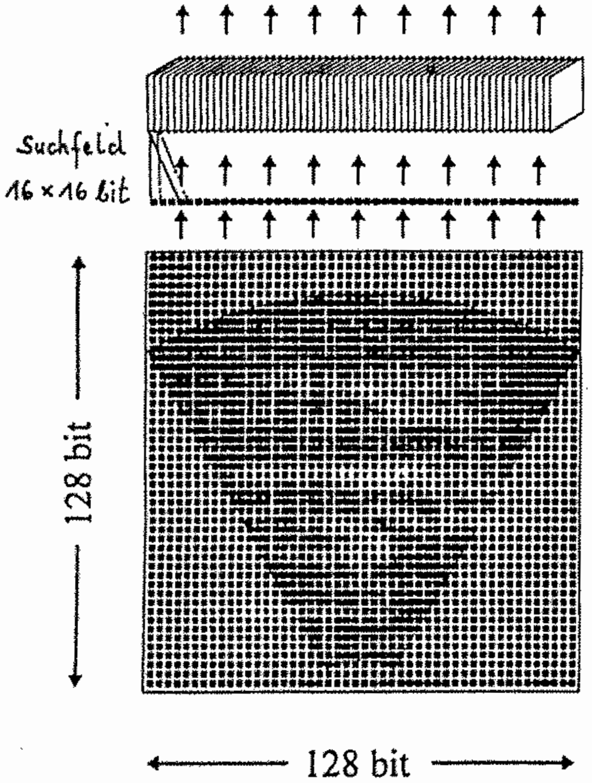
"Ringe" für verschied. Polar- und Azimuthwinkel

Variation der Pad-Größe mit Θ und Φ

⇓

Konstantes Ring-Pattern

Schnelle Ringerkennung



Prozessor-Farm

Suchfeld 16 × 16 bit

Eine Reihe pro Zyklus (25 ns)

3.2 μs pro Event

128 bit

128 bit

Konstanter Ringradius

⇓

Vergleich mit Ringmaske

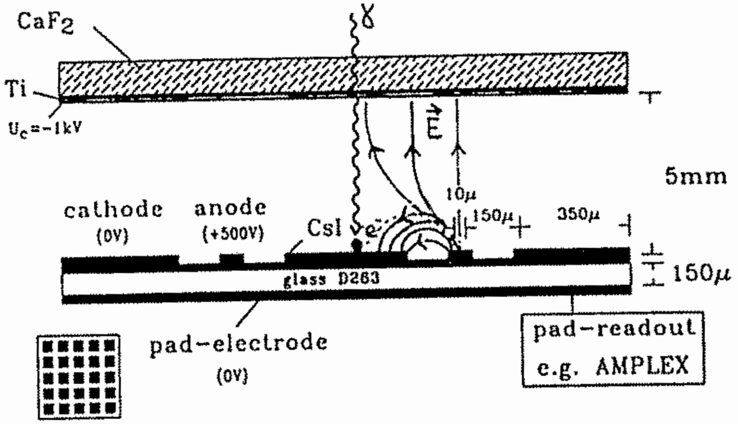
Fazit

Konzept mit C_2F_6 / C_4F_{10}-Radiator, CaF_2-Fenster und CH_4 als Detektorgas ⇒ 15 - 25 e^- pro Ring

Auslese (Analog + Pattern-Information) und Ringerkennung in $\tau < 10\,\mu s$

Ausblick

2D - Pixel-Detektor für VUV-Photonen

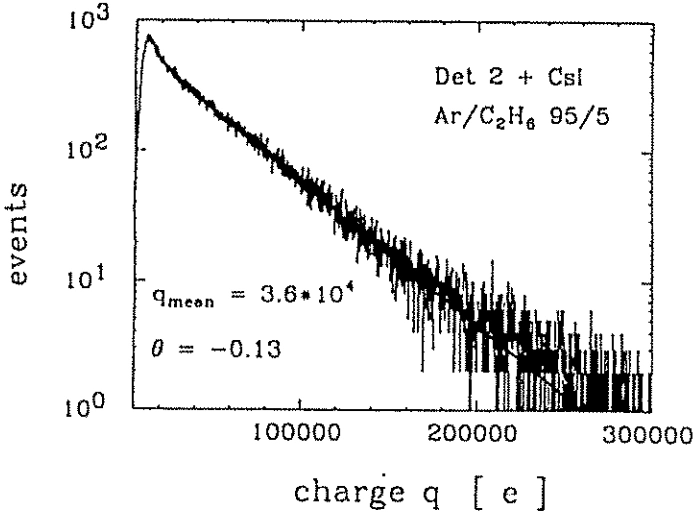


- kurze Ionendriftzeiten
- geringe UV-Rückkopplung
- einfache Mechanik (drahtlos)

Einzelphotonen - Nachweis

Polyia-function:

$$P(q) \propto \left[(1+\Theta)\cdot\frac{q}{q_{mean}}\right]^{\Theta}\cdot e^{-(1+\Theta)\cdot\frac{q}{q_{mean}}}$$



- Bestrahlung mit VUV-Photonen ($\lambda = 170 \pm 0.2$ nm) mit Rate $r \simeq 10$ kHz
- Ladungs-integrierende Anodenauslese
- $\varepsilon_{tot\,(\lambda=170\,nm)} = QE_{CsI}\cdot\varepsilon_{PE}\cdot\varepsilon_A\cdot T_{tot} \simeq 2-3\,\%$

Status und Perspektiven von Tieftemperatur-Kalorimetern

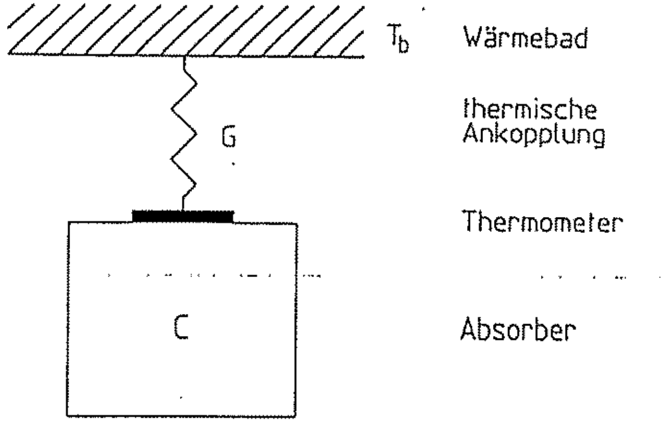
H. Kraus

Technische Universität München
Physik-Department E15
Garching

- Tieftemperaturkalorimeter
- Thermometer
- Anwendungen
- Status bei verschiedenen Gruppen

Das Tieftemperaturkalorimeter

Prinzip:



Energiedeponierung ⟶ Temperaturerhöhung

$$\Delta T(t) \approx \frac{\Delta E}{C(T)} \cdot \exp\left(-\frac{t}{\tau}\right) \; ; \qquad \tau = \frac{C}{G}$$

für $T \to 0$; $C(T) \to 0$

$\Rightarrow$ große, massive Absorber
hohe Sensitivität

Wichtig: ΔT möglichst genau messen

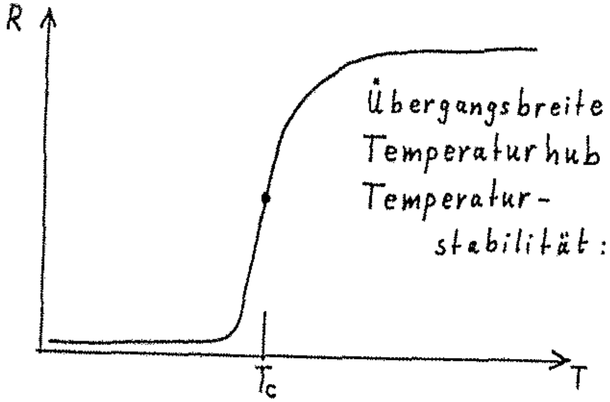
Thermometer: hohes $\frac{\partial V}{\partial T}$ bzw.
hohes $\alpha := \frac{1}{R} \frac{\partial R}{\partial T}$

Thermometer

Halbleiterthermistoren

Ge, Si, smallgap, NTD-Ge

Supraleitende Phasenübergangsthermometer



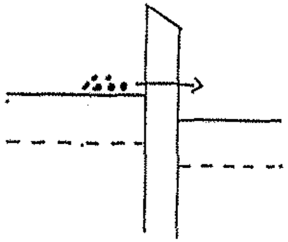
Übergangsbreite: ~ mK
Temperaturhub: ~ 10 μK
Temperaturstabilität: < 1 μK

Ir, Ir/Au, W Thermometer

Induktive / kapazitive Thermometer

kin. Inductance, KTN

Supraleitende Tunneldioden
SIS, SIN, SNS



Limitierung der Energieauflösung

Thermodynamische Fluktuationen

$$\Delta E \approx \sqrt{kT \cdot CT} \qquad \lesssim \text{eV}$$

Strahlungsaustausch mit der Umgebung

$$\Delta E \approx \sqrt{8\sigma\varepsilon k T^5 \cdot A \cdot \Omega \frac{C}{G}} \lesssim \text{meV}$$

Johnson Noise von Thermometer / Widerständen

$$\Delta E = \sqrt{4kTR} \cdot \frac{\sqrt{C \cdot G}}{i \cdot \frac{\partial R}{\partial T}} \approx \text{eV}$$

Vorverstärkerrauschen

$$\Delta E = \sqrt{\frac{e_n^2 + (i_n R)^2}{|S|^2} \tau} \approx ?$$

Zusätzliche Rauschquellen

Einstrahlung
Mikrophonie
Temperaturschwankung ....

Ortsabhängigkeit der Detektorantwort
Langlebige Zustände im Absorber

Experimente mit Kryodetektoren

Suche nach Dark Matter Kandidaten
TUM, MPI München, UC Berkeley

ββ - Zerfall
INFN Milano

Nachweis geringer Kontaminationen mit α, β Strahlern
INFN Milano, TUM

ν - Masse (β - Endpunktspektroskopie)
Princeton, Oxford

Schwerionenphysik
GSI

17keV Neutrino
Princeton, Oxford

Röntgenspektroskopie an EBIT
LLNL

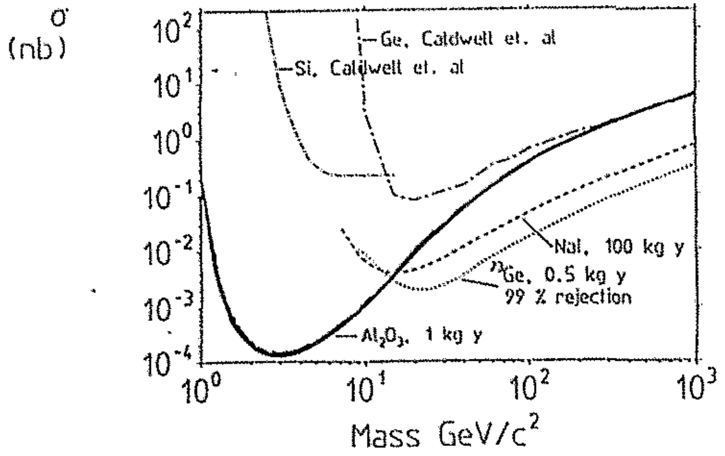
Röntgenastronomie, Plasmadiagnose
NASA, UW Madison, TUM, Oxford, SRON, ESA, PSI

In Diskussion:
Lamb - Shift - Messung (GSI)
Röntgenspektroskopie in der Festkörperphysik

Kryodetektoren für Suche nach Dark Matter

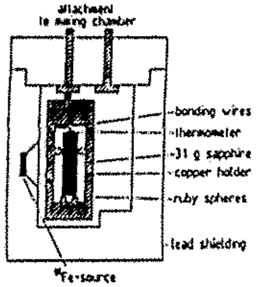
- ▶ Gute Energieauflösung (≈ 100eV)
- ▶ Sehr niedrige Energieschwelle (≈ 500eV)
- ▶ Volle Nachweiseffizienz für Kernrückstöße
- ▶ Hohe Flexibilität bei der Wahl des Absorbers
  z. B. Al_2O_3, GaAs, MgF_2, Supraleiter
- ▶ Große Absorbermassen möglich (≈ 1kg / Kanal)
- ▶ Wenig Probleme mit radioaktivem Untergrund

Sensitivität:
Ausschließungsplot (3σ)
Flacher Untergrund: 1 cnt/(keV·kg·day)
für 0.5keV < E < 8keV

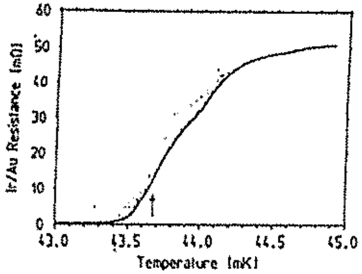


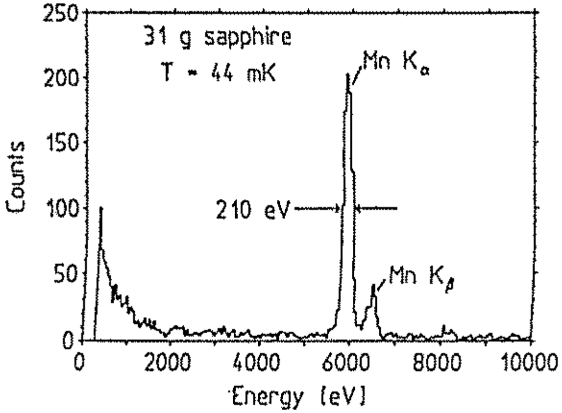
Massive Kryodetektoren mit guter Energieauflösung (MPI München)

Geometrie:

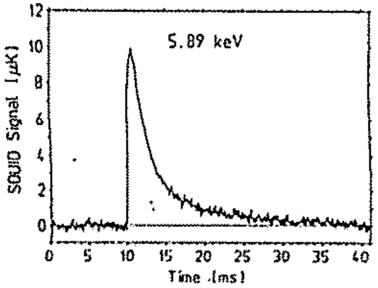


Ir/Au Thermometer:





Meßzeit: 9 Std.



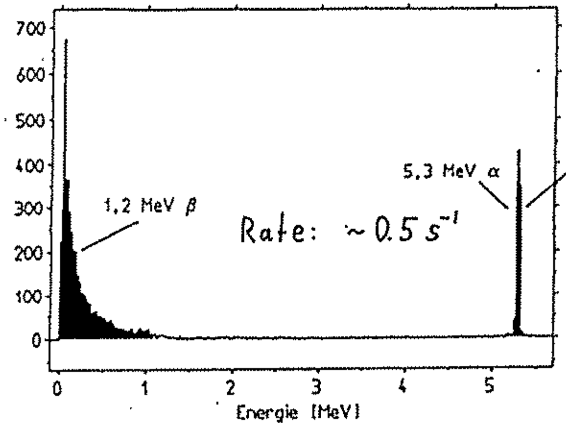
Schnelle Komponente:

$\tau_D \approx 2\ ms$

Langsame Komponente:

$\tau_D \approx 10\ ms$

1.6 g Bleiabsorber mit Au/Ir Thermometer



Rate: ~ 0.5 s^{-1}

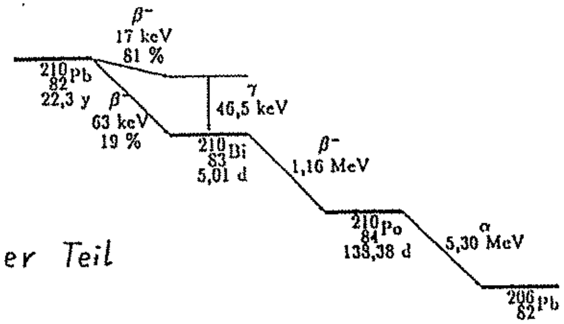
$\frac{\Delta E}{E} \approx 0.5\ \%$

~ 27 keV

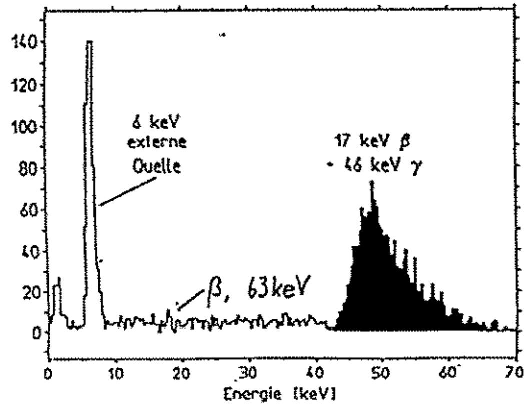
=> ~ 300 Bq/kg

≙ 10^{-13} g/g

Zerfall-Schema von ^{210}Pb:



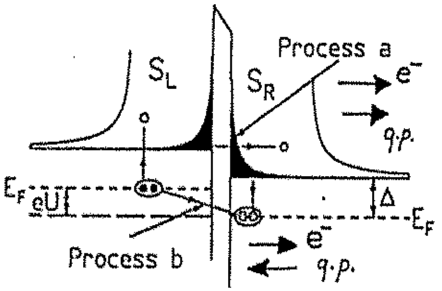
Niederenergetischer Teil des Spektrums:



$\frac{\Delta E}{E} \approx 16\%$ @ 6keV

~ 1 keV

Superconducting Tunnel Junctions



Tunnel Processes

Retunneling

γ_T , γ_V

Charge amplification

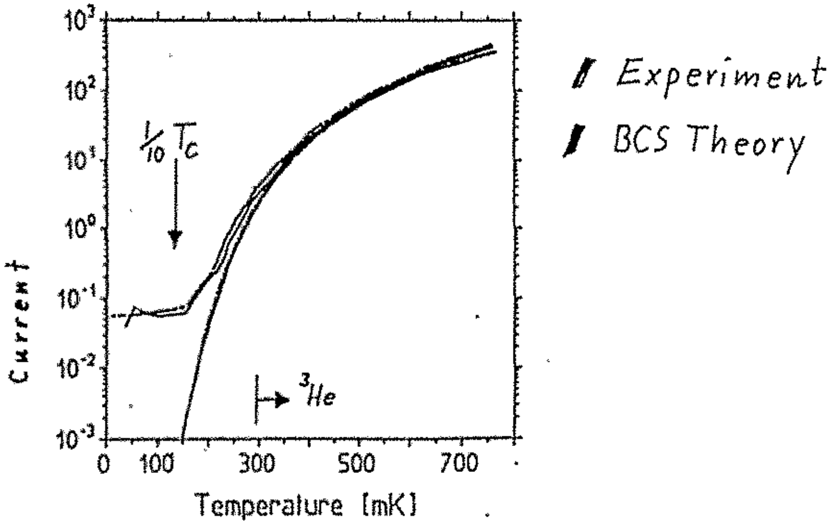
Thermally excited quasiparticles: $n_{Th} \propto \sqrt{T}\, e^{-\frac{\Delta}{kT}}$

Magnetic field for d.c. Josephson current suppression

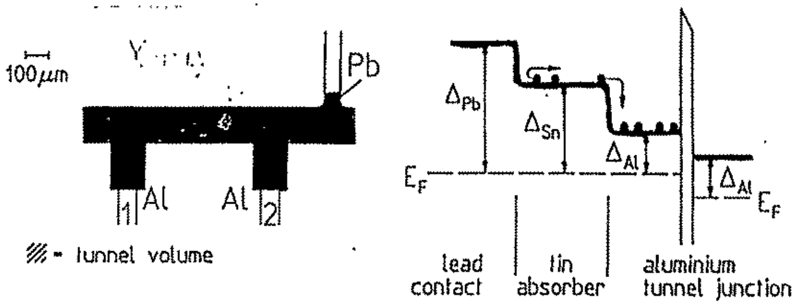
Optimal Signal to Noise ratio: high γ_T , $\mathcal{Q} = \frac{R_D}{R_{NN}}$

low γ_V , Area

Thermal Current vs. Temperature



Thin film absorbers in STJ detectors



Diffusion of quasiparticles along the absorber

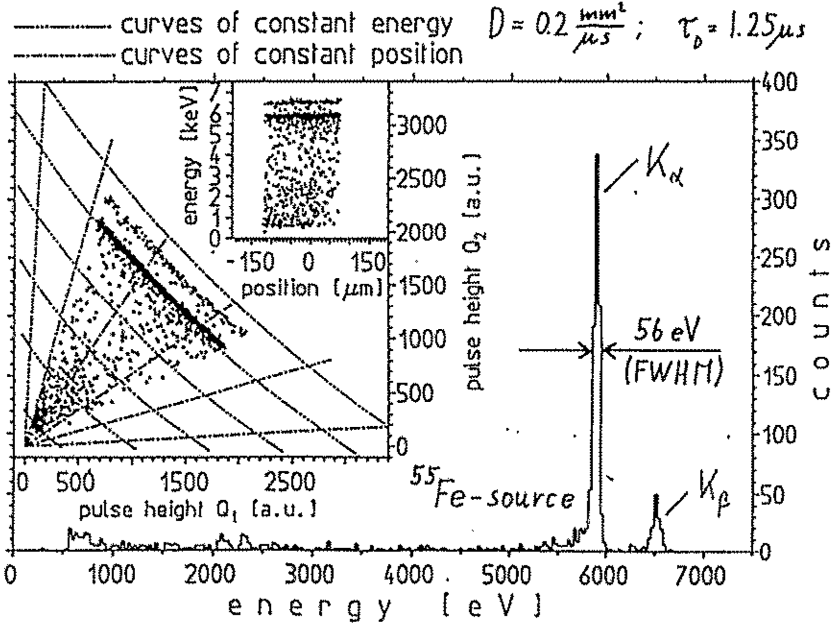
Loss of single quasiparticles (e.g. in traps)

$$\dot{n}(x,t) = D \cdot \Delta n(x,t) - \gamma_D \cdot n(x,t)$$

$$Q_{1,2} = E_0 \cdot \frac{K}{\omega} \cdot \frac{\sinh \alpha \left(\frac{1}{2} \pm \frac{x_0}{\ell}\right)}{\sinh \alpha} \quad \Longrightarrow \quad \alpha = \frac{\ell}{\sqrt{D \tau_D}}$$

↳ Inversion: ⇒ E_0 , x_0

$D = 0.2 \frac{mm^2}{\mu s}$; $\tau_D = 1.25 \mu s$



Status bei verschiedenen Gruppen

INFN Milano	334g TeO_2 Kristall im LNGS	
	internes ^{238}U, ^{232}Th $\sim \cdot 10^{-13}$ g/g	
	0ν-$\beta\beta$ Zerfall $T_{1/2} \sim 10^{22}$ y (68% C.L.)	
TUM MPI	31g Al_2O_3 / Ir-Au Thermometer	220eV @ 6keV
	4g Al_2O_3 / W-Thermometer	78eV @ 1.5keV
	1.1g Sn / Ir-Au Thermometer	370eV @ 6keV
	Ir-Au Thermometer, W; Ir-Th.	
	Supraleitende Tunneldioden	54eV @ 6keV + Ortsauflösung
NASA UW Madison	Mikro-Kalorimeter spot: 7.3 eV @ 6keV 1/4 mm² 12 eV -> 36 Elemente à 1mm²	
GSI	$\sim 1 \cdots 4 \cdot 10^{-3}$ $\frac{\Delta E}{E}$, Al-Mäander	
Princeton	Sn-Absorber / NTD-Germanium	
	$^{107}Pd \rightarrow {}^{107}Ag + e^- + \overline{\nu}_e$ (37.5 ± 0.1 keV)	
	-> Null-Resultat für 17keV Neutrino	
Berkeley	60g Ge Kristall / NTD Ge Thermistor	
	gleichzeitige Messung von Jonisation und Wärme	

Entwicklung eines schnellen TDC mit Konvertierungszeiten im Bereich weniger Nanosekunden

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** *Institut für Kern- und Hadronenphysik*

1. Motivation - triggerintegrierbare Zeitmessung
2. Hardware
3. Limits
4. Anwendungen

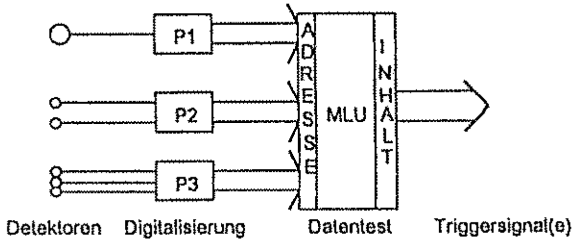
---

1. Motivation


Präzisions-experimente → Statistik → interessante Events / Background → intelligente Trigger

kombinierte Triggerparameter

- Digitalisierung einzelner Triggerparameter (Zählermuster, Zeiten, Impulshöhen, Ladungen)
- Kombination zu Worten (8,16..bit)
- Test der kombinierten Informationen auf die Triggerbedingung(en)



Integrierbarkeit von Zeitinformationen in Hardwaretrigger ?

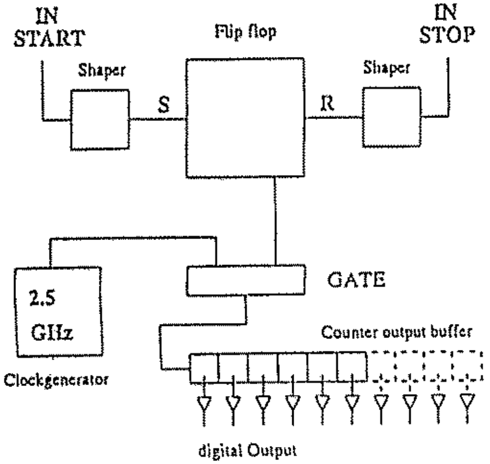
	$t_{conv.}$	$\sigma_{tel.}$
Zeitmessung m. konv. TDC's (Le Croy TFC/FERA,Philips 10C6 ...)	> 5 µs	50 ps
triggerintegrierbare Zeitmessung	< 50 ns	100-300 ps

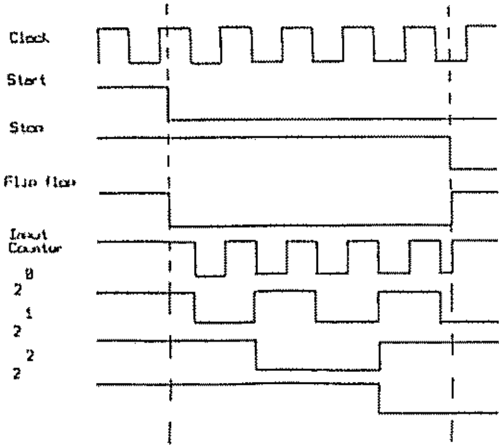
Zeitskala:

Flugzeiten	> 3ns/m
Impulslängen (Szintillatoren,HL...)	> 10ns
Lichtlaufzeiten(Szint.)	> 5 ns/m
Elektronendriftzeiten in Gasdetektoren	> 20ns/mm

2. Hardware

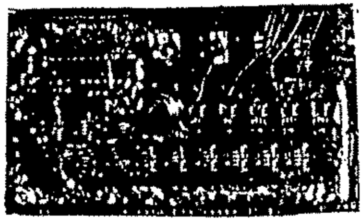
Aufbau des Real Time to Digital Converters (RTDC)





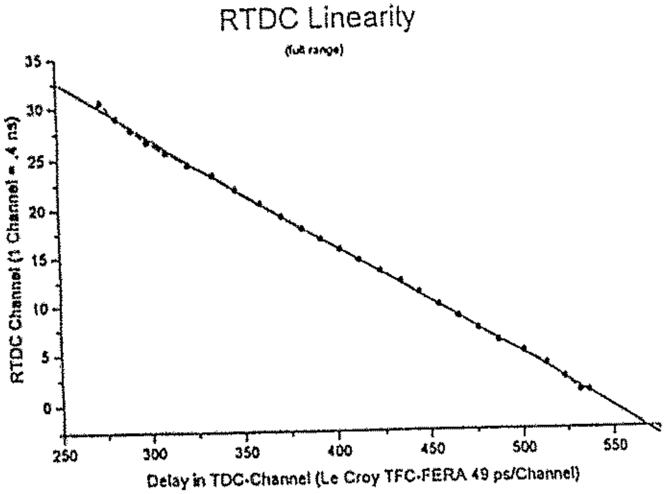
Elektronik im GHz-Bereich

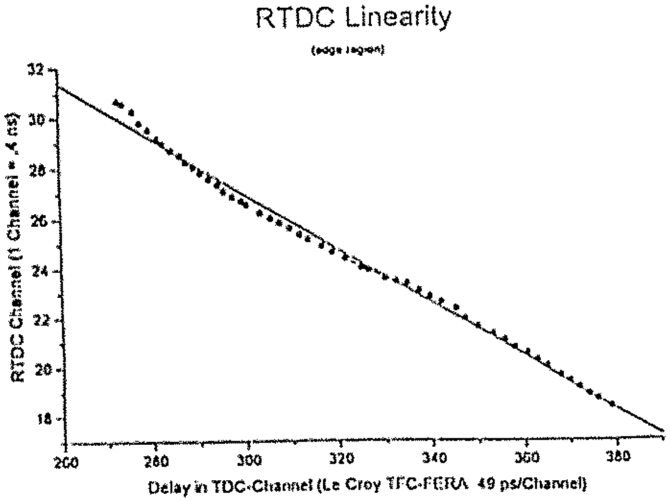
- **extrem kurze (angepasste) Leitungsführung**
- **Trennung von Signalverarbeitung und Versorgungsspannungen auf verschiedenen Leiterplattenseiten**
- **Abblockkapazitäten**
- **extrem kleine parasitäre Kapazitäten und Induktivitäten**
- **Bauelementewahl (Bandbreite,Pinbelegung..)**
(z.B. Motorolla MC100EL....ultra high speed ECL)



3. Limits

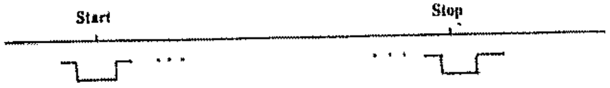
Linearität





Zeitauflösung

unbekanntes Meßzeitintervall



$\sigma_t(\text{Start}) = \frac{1}{\sqrt{12}} * \text{LSB}$

$\sigma_t(\text{Stop}) = \frac{1}{\sqrt{12}} * \text{LSB}$

$\sigma_t^2 = \sigma_t^2(\text{Start}) + \sigma_t^2(\text{Stop})$

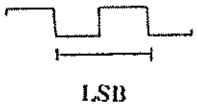
$\sigma_t = \frac{1}{\sqrt{6}} \text{LSB} = 0.41 * \text{LSB}$ (mittlerer Fehler)

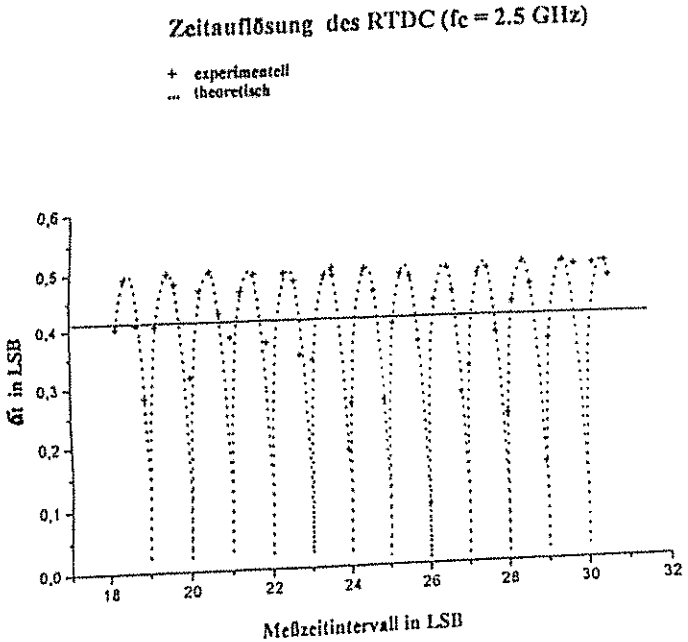
bekanntes Meßzeitintervall

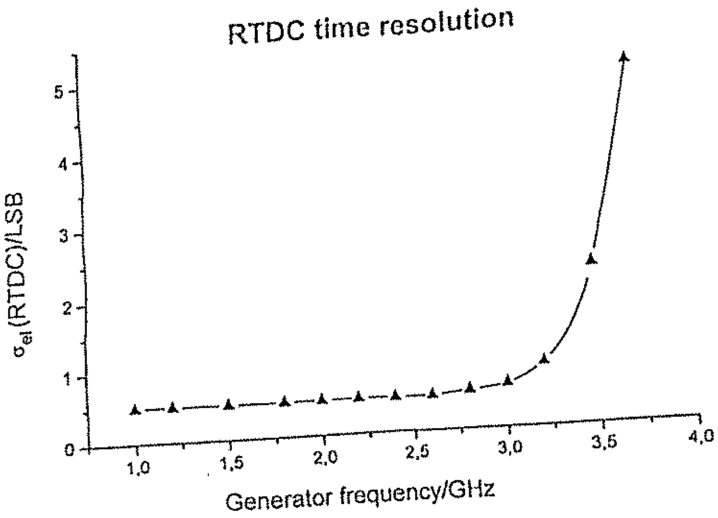
σ_t min : $t = N * \text{LSB} \Rightarrow \sigma_t = 0$
σ_t max: $t = N/2 * \text{LSB} \Rightarrow \sigma_t = 0{,}5 * \text{LSB}$

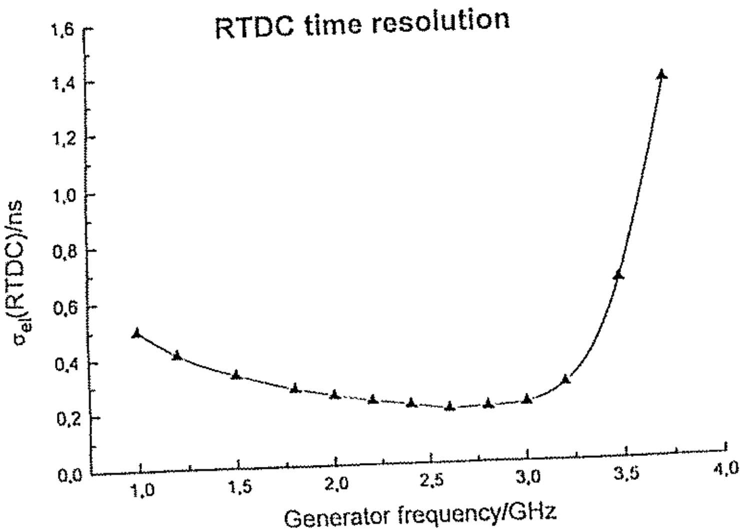
$\sigma_t = \sqrt{\chi - \chi^2} * \text{LSB}$ mit $\chi = t / \text{LSB} - \text{INT}(t / \text{LSB})$

LSB: Low Significant Bit

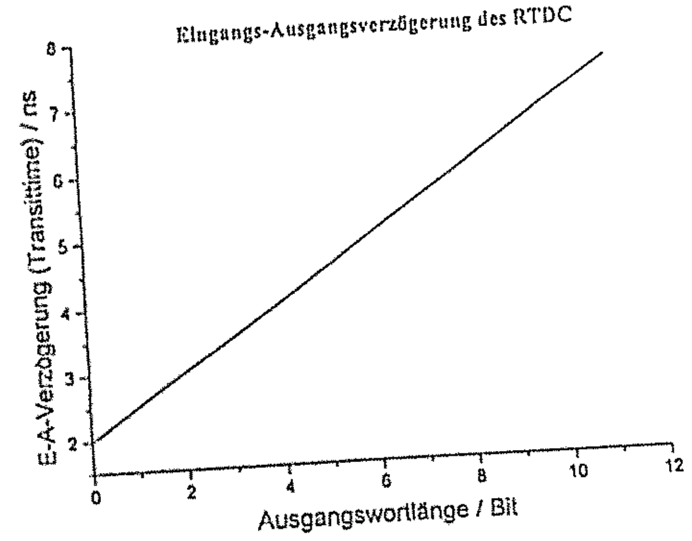



Zeitauflösung des RTDC (fc = 2.5 GHz)
+ experimentell
... theoretisch
δt in LSB
0,6
0,5
0,4
0,3
0,2
0,1
0,0
18
20
22
24
26
28
30
32
Meßzeitintervall in LSB


RTDC time resolution
σ_{el}(RTDC)/LSB
5
4
3
2
1
0
1,0
1,5
2,0
2,5
3,0
3,5
4,0
Generator frequency/GHz

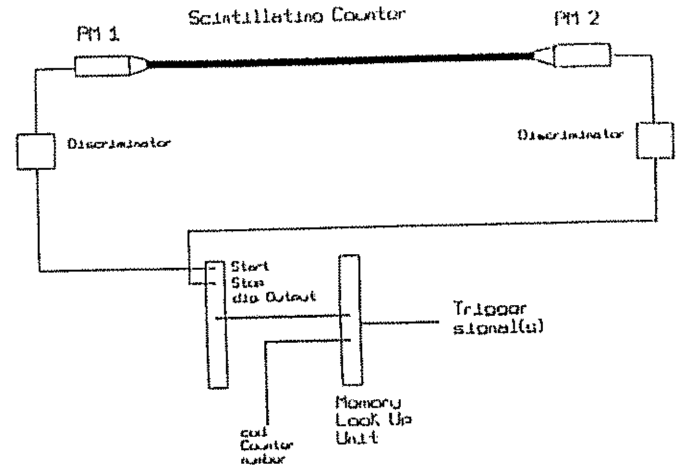

RTDC time resolution
σ_{el}(RTDC)/ns
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
1,0
1,5
2,0
2,5
3,0
3,5
4,0
Generator frequency/GHz

Eingangs-Ausgangsverzögerung

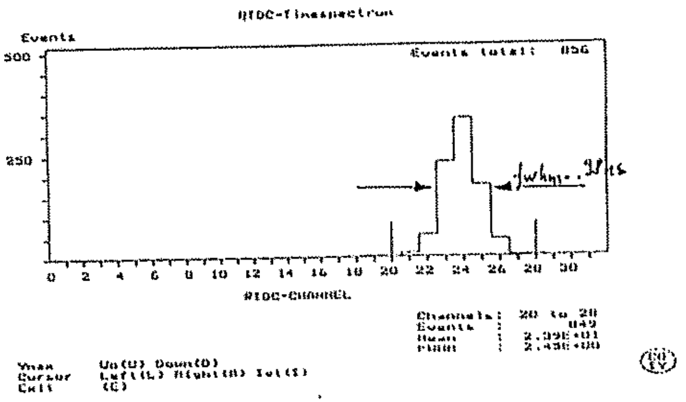


4. Anwendungen

triggerintegrierbare Positionsbestimmung in Szintillatoren

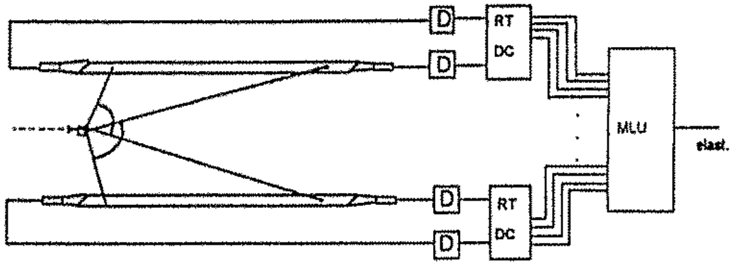


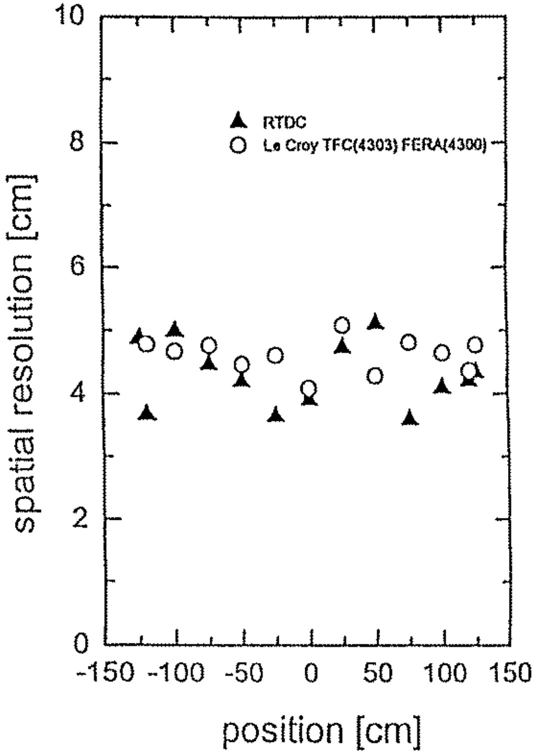
Erzeugung eines ortsabhängigen Triggersignals durch beidseitige Auslese eines Szintillatorstreifens und Digitalisierung mittels RTDC



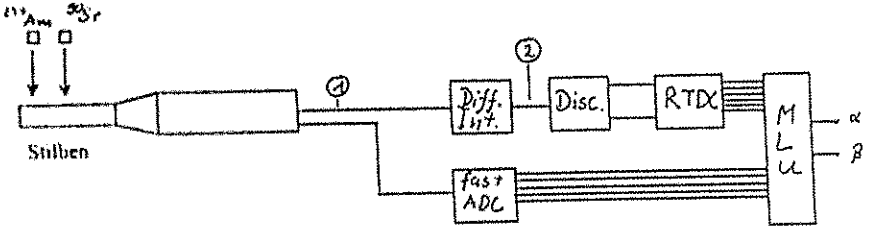
RTDC - Spektrum der Lichtlaufzeitdifferenz eines zweiseitig ausgelesenen Szintillatorstreifens. Mittels Masterszintillator wurde der 1 GeV/c Pionenstrahl auf 3 cm begrenzt.

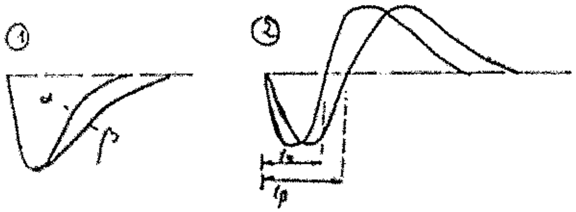
Vetotrigger für elastische Streuung an COSY-TOF



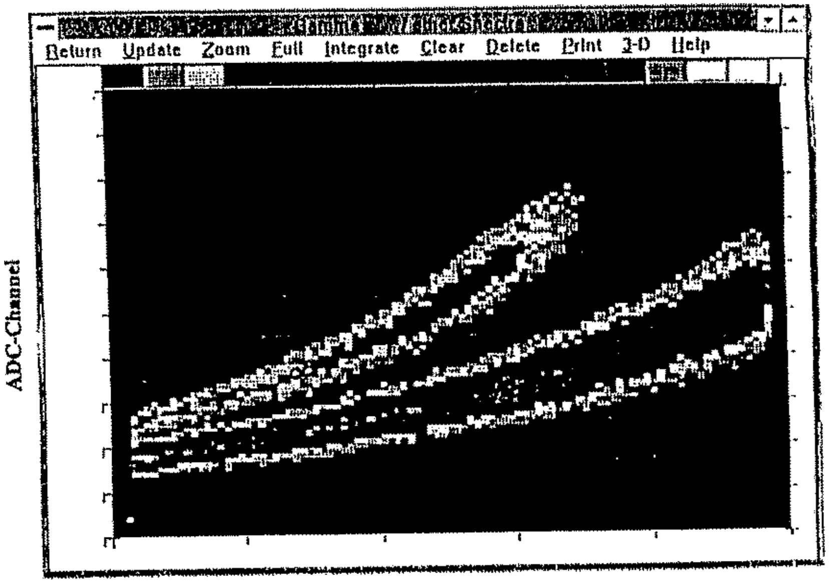


Auflösung der Koordinatenmessung am langen Szintillator mit RTDC und konventioneller TDC triggerintegrierbare Teilchenunterscheidung



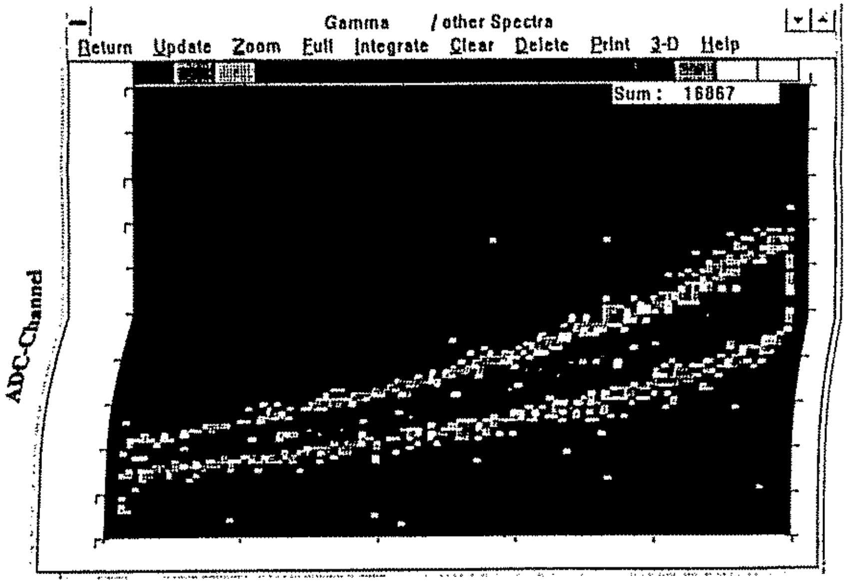


Trigger: α + β



RTDC-Channel

Trigger: β



RTDC-Channel

Zusammenfassung

- RTDC liefert triggerintegrierbare Zeitinformationen - Transittime ca. 5 ns
- Nichtlinearitätsfehler sind vernachlässigbar
- verwendete Hardware liefert optimale Zeitauflösung bei ca. 2.5 - 3 GHz - σ_t ca. 200 ps
- Anwendungen:
  - Echtzeit-Ortsbestimmung in Szintillatoren
  - Echtzeit-Teilchenunterscheidung
  - ....

Extraktion der pp–Bremsstrahlung mit künstlichen neuronalen Netzen

J. S. Lange

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TU Dresden

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http://tau.ep1.ruhr–uni–bochum.de/~soeren

- Missing–Mass–Analyse
- Neuronale Netze des Feed–Forward Typs

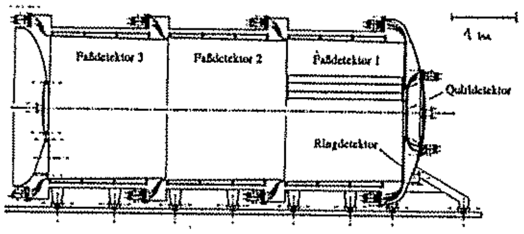
  Überwachtes Lernen
- Selbstorganisierende neuronale Netze

  Unüberwachtes Lernen
  - Simulierte Daten COSY T_{Strahl}=400 MeV
  - Experimentelle Daten SATURNE T_{Strahl}=1000 MeV

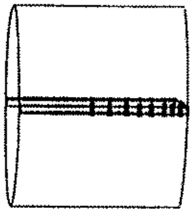
Arbeitstreffen für Mittelenergiephysik / Pirna
6.10.1994

Der Detektor: *TOF–Spektrometer an COSY*

- *Nur Nachweis geladener Teilchen*
- *Rekonstruktion höchstens eines ungeladenen Teilchens über Viererimpulserhaltung*



(Bochum, Dresden, Erlangen, Jülich, Tübingen)

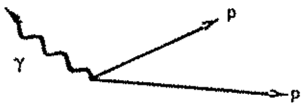


Testexperiment SATURNE
(Bochum)

Das Problem:

- Extraktion der

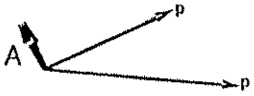
  Proton–Proton–Bremsstrahlung



$pp \rightarrow pp\gamma$

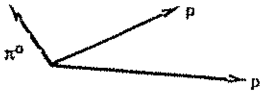
- Untergrundreaktionen
  - *Nukleare Reaktionen in Targetfolien*

    $d = 2 \cdot 2\ \mu m$



$pA_1 \rightarrow ppA_2$

  - *Pionenproduktion*



$pp \rightarrow pp\pi^0$

  - $pp \rightarrow d\pi^+$
  - $pp \rightarrow pn\pi^+$
  - $pp \rightarrow pp\pi^+\pi^-$

Protonen passieren den Trigger

▷ Erkennung in Offline-Analyse

Missing-Mass-Analyse

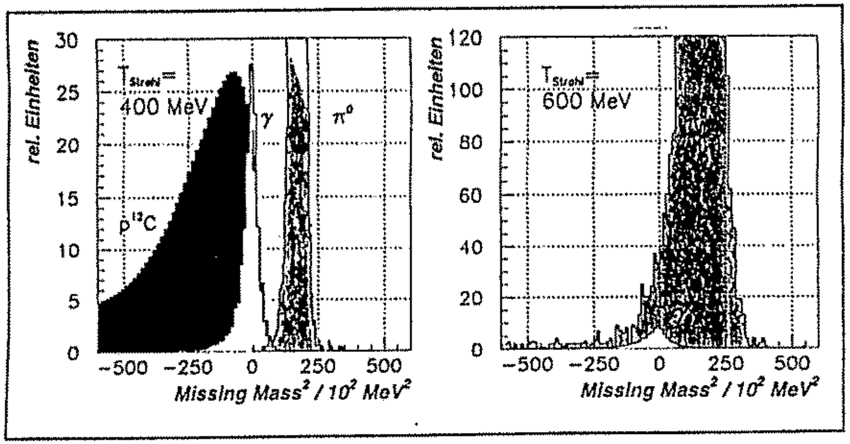
Simulierte Daten COSY

$T_{Strahl} = 400$ MeV

$\vec{p}_3$

↓ Verlust an Information

$$m_3^2 = E_3^2 - p_3^2$$

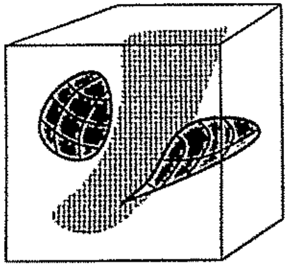


Erweiterung der Missing-Mass-Analyse

- *Zusätzliche kinematische Parameter* $E_3, p_3, \vartheta_3, \vartheta_1+\vartheta_2, \Delta\Phi_{12}$
- *Suche nach Clustern im höherdimensionalen Parameterraum*
  - o *herkömmliche Methode:*
    Reihe 2-dim. Schnitte

  - o *Alternativmethode:*
    Schnitte direkt im höherdimensionalen Parameterraum

    z.B. mit neuronalen Netzen



Neuronales Netz
Feed-Forward Typ

S. Lange et al.
New Computing Techniques
in Physics Research III
S. 369
World Scientific, 1994

Großer Nachteil:

Training mit simulierten
Daten notwendig

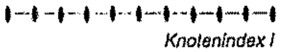
Problem:
Simulation hadronischer Wechselwirkung im COSY-Energiebereich

Selbstorganisierende neuronale Netze

- Unüberwachtes Lernen
- „Training" mit exp. Daten
- Algorithmus: Topologie erhaltende Abbildung (T. Kohonen, 1987)

Cluster im Eingaberaum ⟶ Cluster im Knotenraum
keine Projektion !

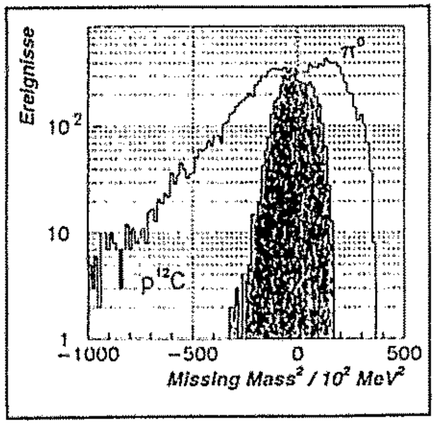
- Besonderheiten:
  - *Erstmalig*
    1–dimensionale Knotenanordnung
  - *Erstmalig*
    Clustergravitation



Gravitative Wechselwirkung im Eingaberaum

⟶ *Allgemeine Relativitätstheorie*

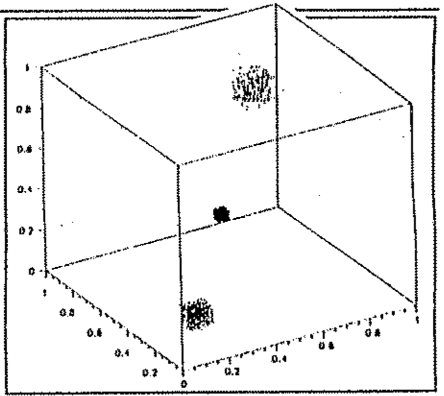
⟶ *Veränderung der Metrik im Knotenraum*



Simulierte Daten COSY T_{Strahl} =400 MeV

Modell: 3 Cluster in 3–dim Eingaberaum

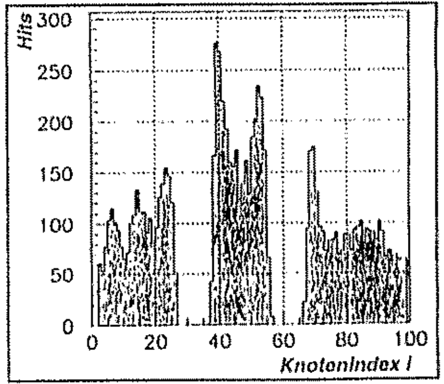
- jeweils 3333 Ereignisse
  gewürfelt innerhalb Quadervolumina



- Zuordnung eines Clusters

Hitspektrum:

Bestimmter Knotenbereich „feuert"



Extraktion der pp–Bremsstrahlung

SATURNE

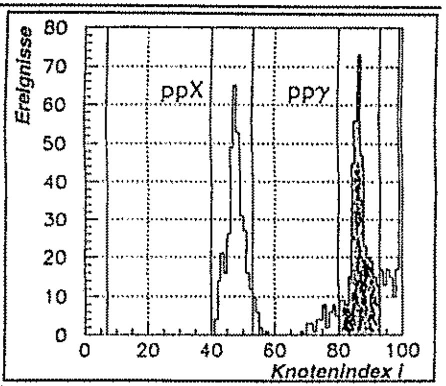
T_{Strahl}=1000 MeV

mit dem selbstorganisierenden neuronalen Netz inkl. Clustergravitation

Hitspektrum

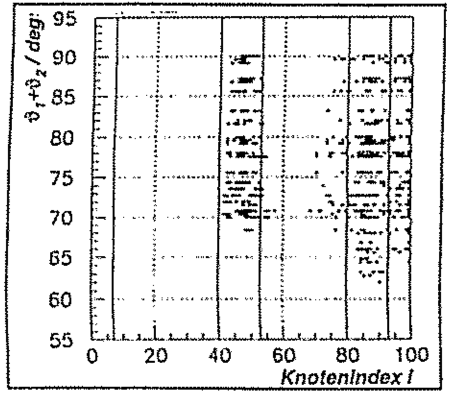
Anreicherung über „herkömmlichen" Cut

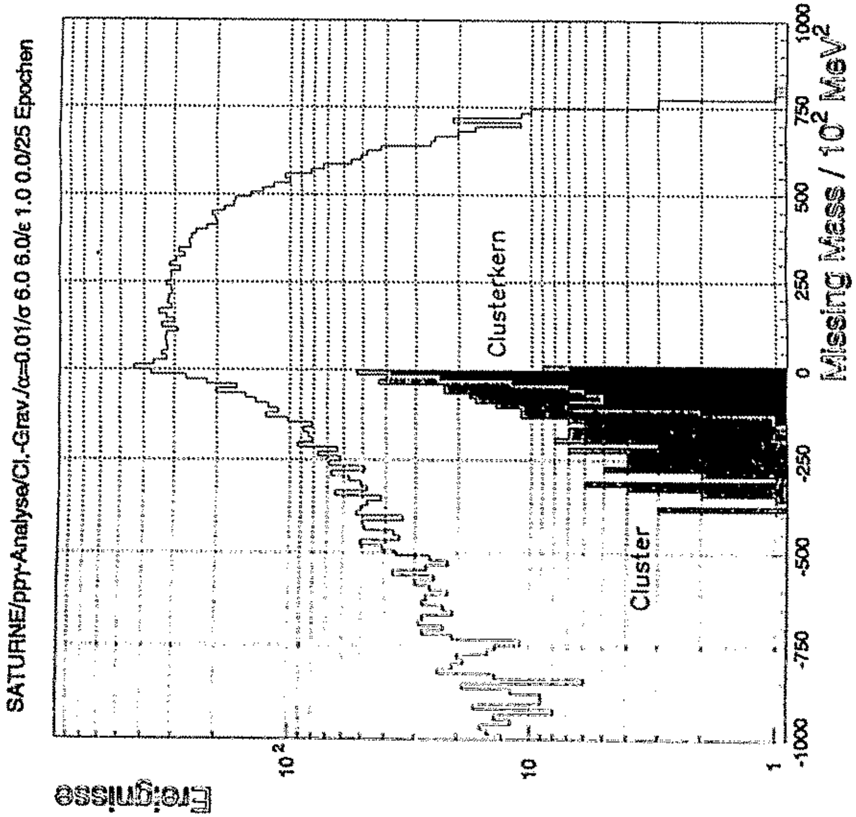
$\vartheta_1 + \vartheta_2$ und ϑ_3



Möglichkeiten

- pp → pp elastisch
  $\vartheta_1+\vartheta_2 \approx 78^o$
- pp → ppγ
  $0^o \leq \vartheta_1+\vartheta_2 \leq 90^o$





Fazit

Was bringt ein selbstorganisierendes neuronales Netz ?

- SATURNE

  Erstmals Nachweis von Ereignissen $pp \rightarrow pp\gamma$
  bei $T_{Strahl} = 1000\ MeV$

- COSY
  - Faktor 2 mehr korrekt identifizierte Ereignisse $pp \rightarrow pp\gamma$ zu erwarten als mit Missing–Mass–Analyse
  - Korrekt identifizierte Ereignisse in Randbereichen von Missing–Mass–Peaks (3–4%)

Dank

TOF–Koll. / Uni Bochum

V. Fischer
M. Stunk

Crystal Barrel–Koll. / Uni Bochum

M. Kunze
J. Lüdemann
Th. Degener
R. Berlich

TOF–Koll. / Uni Tübingen

R. Bilger

AG Kernreaktionen / Uni Bochum

W. Potthast

H1–Koll. / Uni Dortmund

H. Kolanoski
Th. Krämerkämper
D. Goldner

Seminar über künstliche Intellignez
in der Kern– und Teilchenphysik
(SS 1994, Uni Bochum, Uni Dortmund)

Publikation zu Anwendung neuronaler Netze des Feed–Forward–Typs:

WWW::http://www.ep1.ruhr–uni–bochum.de/~soeren

Neue Projekte

(*Koordinator:* **H. Koch**)

1. **V. Burkert** (CEBAF)
   Geplante Experimente bei CEBAF
2. **H. Marsiske** (SLAC)
   PEP-II: The SLAC - based asymmetric B-Factory
3. **T. Lohse** (Berlin)
   B-Physics at HERA-B and LHC
4. **U. von Hagel** (Karlsruhe)
   Das DAPHNE-Projekt

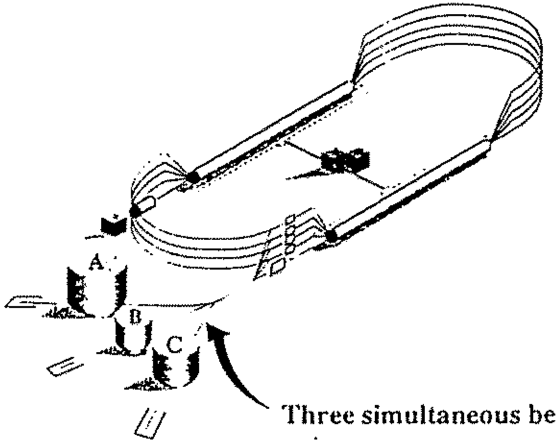
CEBAF

The Continuous Electron Beam Accelerator Facility

SCIENTIFIC MISSION

Investigate strongly interacting matter at the quark-gluon level.

- Nature of quark and gluon confinement
- Quark-gluon picture of the nucleus



MACHINE CHARACTERISTICS	
Energy	4 GeV
Current	200 μA
Duty Factor	cw
Emittance	$\epsilon \approx 2 \times 10^{-9}$ m·rad
Energy Spread	$\frac{\sigma E}{E} \approx 2.5 \times 10^{-5}$

PHYSICS START 3Q FY94

Three simultaneous beams into three experimental areas

- Independent energy and intensity
- Major equipment components procured in all halls

[illegible]

GEPLANTE EXPERIMENTE BEI CEBAF

Volker D. Burkert

- Der Beschleuniger,
- Die experimentelle Instrumentierung,
- Das physikalische Programm
  - Experimente an Nukleonen
  - Experimente an leichten Kernen
- Zusammenfassung

Arbeitstreffen "Kern - und Teilchenphysik 1994", Pirna, Oktober 4 - 7, 1994

Totals for PACs 4 -8

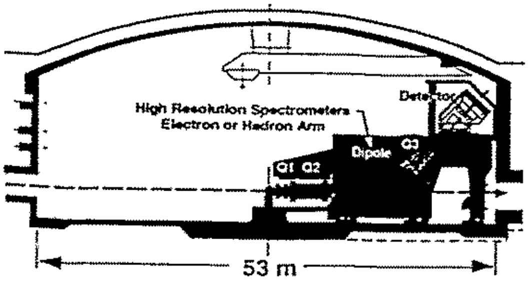
	Experiments Recommended for Approval	Additional Experiments Recommended for Conditional Approval	Total
Experiments	69	10	79
Authors	503	37	540
Institutions	112	5	117
Countries	18		18

Totals of Approved Experiments by Physics Topic for PACs 4-8

Topic	Number	Hall A	Hall B	Hall C
Nucleon and Meson Form Factors and Sum Rules	10	3	3	4
Few Body Nuclear Properties	13	7	3	3
Properties of Nuclei	14	3	8	3
N^* and Meson Properties	21	3	16	2
Strange Quarks	11	2	6	3
Total	69	18	36	15

SIMULTANEOUS COMPLEMENTARY EXPERIMENTS

CEBAF

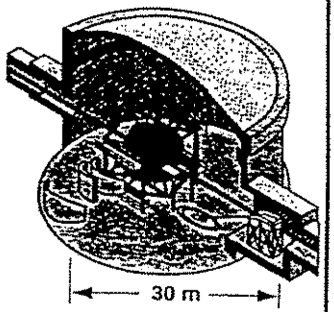


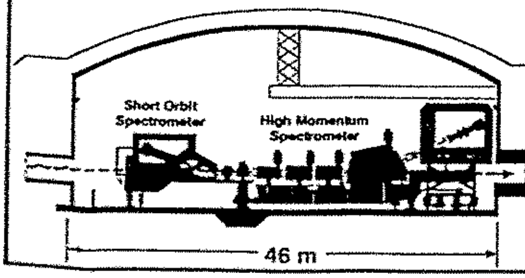
HALL A *(Start of physics: 4Q FY95)*

Pair of Identical High Resolution Spectrometers (HRS^2)

HALL B *(Start of physics: 4Q FY96)*

CEBAF's Large Acceptance Spectrometer (CLAS) and Bremsstrahlung Photon Tagger





HALL C *(Start of physics: 3Q FY94)*

High Momentum Spectrometer (HMS) and Short Orbit Spectrometer (SOS)

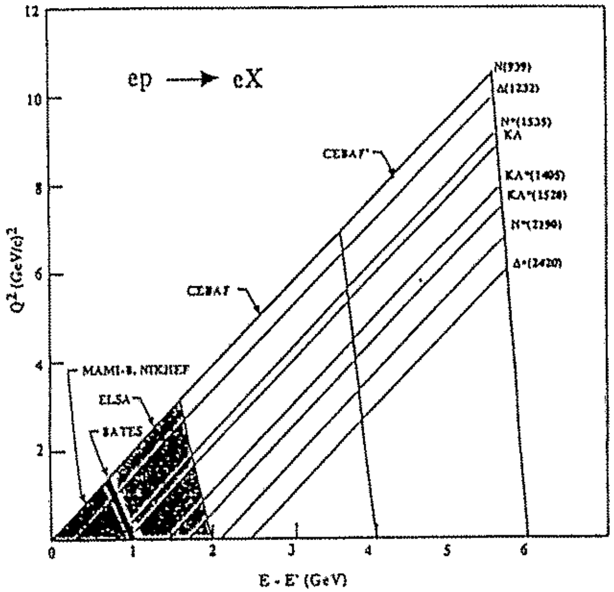
EndStations/SimComExp/Short::mbs

Ziel des Experimentellen Programmes bei CEBAF

- Beiträge für ein quantitativen Verständnis der hadronischen Struktur der Materie im Bereich mittlerer und kurzer Abstände.
  - QCD ist die korrekte Theorie der starken Wechselwirkung: Wie sind die leichten Hadronen aus Quarks und Gluonen (Glue) aufgebaut?
- Struktur des Nukleons
  - Elektromagnetische und schwache Formfaktoren im Grundzustand des Nukleons
  - Anregungsspektrum des Nukleons
  - Übergangsformfaktoren vom Grundzustand in die angeregten Zustände
  - Spinstruktur der Nukleonenübergänge
- Grenzen von Modellen die eine "effektive" Beschreibung liefern wie z.B. das Konstituenten Quarkmodell, etc.
- Studium von leichten Kernen bei hohen Impulsüberträgen
  - Grenzen der Mesonentheorie?
  - Wo spielen Effekte der Quarks und Gluonen eine Rolle?

Die Struktur Leichter Baryonen

$Q^2 - \nu$ Kinematik für $ep \rightarrow e'X$



→ Elastische Formfaktoren

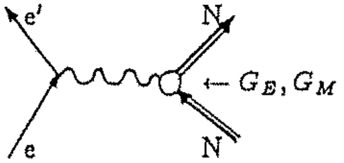
→ Anregung von Baryonen mit leichten Quarks (u, d)

→ Erzeugung leichter Hyperonen

→ Grosser Q^2 Bereich erlaubt Untersuchungen von Strukturen mit $r < 0.1$ fm

EM Struktur des Nukleons im Grundzustand

o Ladungs - und Stromverteilung im Nukleon
  → Mikroskopische Modelle, QCD SR, QCD Lattice
  → Interpretation von Elektron-Kern Streuexperimenten



$$G_E = F_1 - \tau F_2$$
$$G_M = F_1 + F_2$$
$$\tau = Q^2/4M^2$$

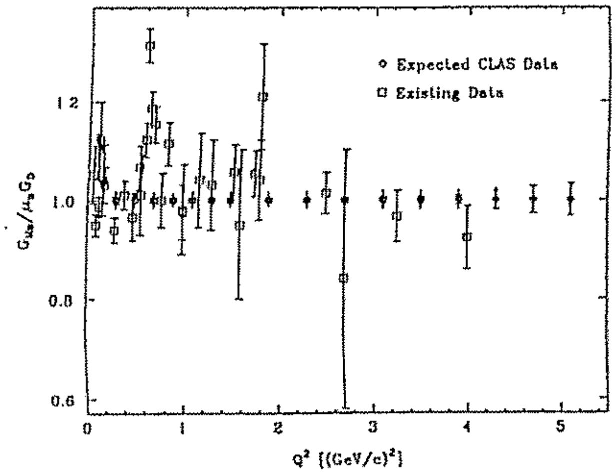
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_M \frac{E'}{E}[(G_E^2 + \tau G_M^2) + 2\tau(1+\tau)G_M^2 \tan\frac{\theta}{2}]$$

Rosenbluth Trennung

o G_{Mn}^2: Gemessen mit grossen systematische Fehler

→ $ed \to e'np$ (quasi elastisch) (e' unter Rückwärtswinkeln)

→ $ed \to enp_s$ / $ep \to ep$, und $ep \to e\pi^+ n$

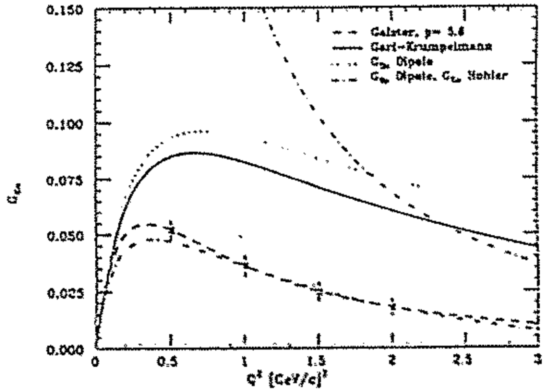


Polarisationsmethode:

o $\vec{N}(\vec{e}, e'N)$, $N(\vec{e}, e'\vec{N})$, (quasi-elastisch)

$$A_{en} = \frac{2\tau\cos\theta v_T' + 2\sqrt{2\tau(1+\tau)}\frac{G_E}{G_M}\sin\theta v_{TL}'}{v_L(1+\tau)\frac{G_E^2}{G_M^2} + 2\tau v_T}$$

→ In q.e. Kinematik $A_{eD} \sim G_{En}$



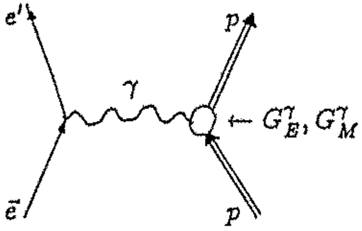
o $D(\vec{e}, e'\vec{n})$ HRS/Neutronpolarimeter

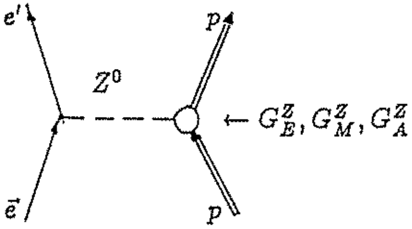
o $N\vec{D}_3(\vec{e}, e'n)$ HMS/Neutrondetektor

o $p(\vec{e}, e'\vec{p})$ $\to \delta G_{Ep}/G_{Ep} \simeq 0.05$ für $Q^2 \leq 4.5 GeV^2$, HRS^2 mit Protonpolarimeter)

Hidden Strangeness im Proton?

o Paritätsverletzung in $\vec{e} + p \rightarrow e + p$ ist empfindlich auf strangeness Vektorströme $\bar{s}\gamma_\mu s$





$$A_{\vec{e}p} = \frac{G_F Q^2}{\pi\alpha\sqrt{2}} \frac{\epsilon G_E^\gamma G_E^Z + \tau G_M^\gamma G_M^Z - \frac{1}{2}(1 - 4\sin^2\theta_W) K G_M^\gamma G_A^Z}{\epsilon (G_E^\gamma)^2 + \tau (G_M^\gamma)^2}$$

$$G_E^Z = (\frac{1}{2} - \sin^2\theta_W) G_{Ep}^\gamma - \frac{1}{4}(G_{En}^\gamma + G_E^s)$$

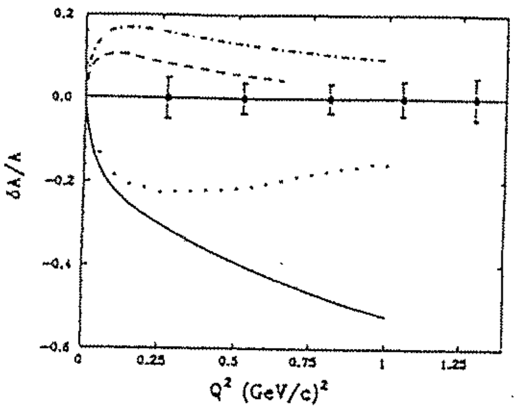
$$G_M^Z = (\frac{1}{2} - \sin^2\theta_W) G_{Mp}^\gamma - \frac{1}{4}(G_{Mn}^\gamma + G_M^s)$$

G_E^Z, G_M^Z kann durch Variation der Elektronenkinematik abgetrennt werden .

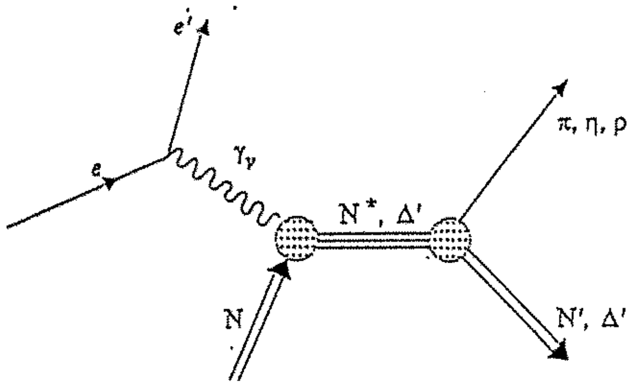
Bates/MIT: $p(e,e')p \quad \rightarrow \quad G_M^s$

CEBAF: $p(\vec{e},e')p$, $p(\vec{e},p)e'$, $^4He(\vec{e},e')^4He \quad \rightarrow \quad G_E^s$

$p(\vec{e},e')p$ (HRS^2)



Elektromagnetische Anregung von Baryonresonanzen



- QCD Struktur des Nukleons
  - Räumliche Struktur des angeregten Zustandes und die Spin-struktur des Resonanzübergangs
  - Symmetrie Eigenschaften der Resonanzanregung: Symmetrisches Quarkmodell versus Quark Cluster Modell

versus

  - Rolle von gluonischen Freiheitsgraden in der Nukleonanregung (q^3G)
  - Anteil des Drehimpulses der angeregten Nukleonen der von Gluonen getragen wird?

N* EXPERIMENTS AT CEBAF

$ep \longrightarrow ep\pi^0$ $ep \longrightarrow en\pi^+$ $ed \longrightarrow e\pi^- pp_s$ - - - - - - - - $\vec{e}p \longrightarrow ep\pi^0$ $\vec{e}p \longrightarrow ep\pi^+$ - - - - - - - - $\vec{e}p \longrightarrow e\vec{p}\,\pi^0$	Δ(1232), Model independent determinations of E_{1+}, S_{1+}, M_{1+}
$ep \longrightarrow ep\pi^0$ $ep \longrightarrow ep\pi^+$ $ed \longrightarrow e\pi^- pp_s$ $\vec{e}\vec{p} \longrightarrow ep\pi^0$ $\vec{e}\vec{p} \longrightarrow ep\pi^+$	P_{11} (1440), D_{13} (1520), F_{15} (1680) Transition amplitudes in large Q^2 range, gluonic excitations
$ep \longrightarrow eN\pi\pi$ (Δπ, Nρ)	S_{31} (1620), D_{33} (1700), D_{15} (1700) Precise tests of the SQTM Missing q^3 states, $I = 1/2, 3/2$
$ep \longrightarrow ep\omega$	Missing q^3 states, $I = 1/2$
$ep \longrightarrow ep\eta$	S_{11} (1535), P_{11} (1710) Transition form factors
$\gamma p \longrightarrow \eta p$ $\gamma p \longrightarrow \eta' p$	S_{11} (1535), P_{11} (1700) Photocoupling amplitudes, gluonic contributions
$\gamma p \longrightarrow p\pi^+\pi^-$	Missing q^3 states, $I = 1/2, 3/2$
$ep \longrightarrow e\Delta^{++}\pi^-_{soft}$ (proposed)	Δ(1232), $G_A^{N\Delta}(Q^2)$ Axial transition form factor

Elektroproduktion der $\Delta(1232)$

$\gamma N \to \Delta(1232)$ $M_{1+},\ E_{1+},\ S_{1+}$ multipoles contribute.

o $SU(6) \otimes O(3)$: $\{56, 0^+\}_{N=0} \to \{56, 0^+\}_{N=0}$

$$\updownarrow \updownarrow \updownarrow \ \to\ \updownarrow \updownarrow \updownarrow \qquad L_{3Q} = 0$$

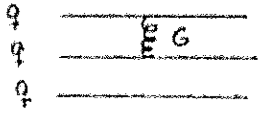
Reiner M_{1+} Übergang $\to E_{1+} = 0,\ S_{1+} = 0$

o Restaurierung der chiralen Invarianz bei hohen Q^2 fordert:

$$\frac{E_{1+}}{M_{1+}} \to 1, \quad \frac{A_{3/2}}{A_{1/2}} \to 0, \quad Q^2 \to \infty$$

o Mehr realistische Modelle:

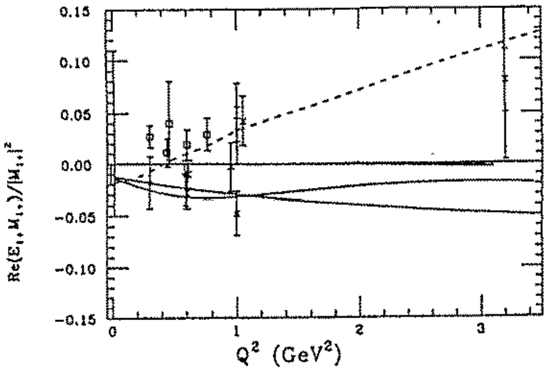
- $\Delta(1232)$ ist deformiert aufgrund des 1-gluon Austausch

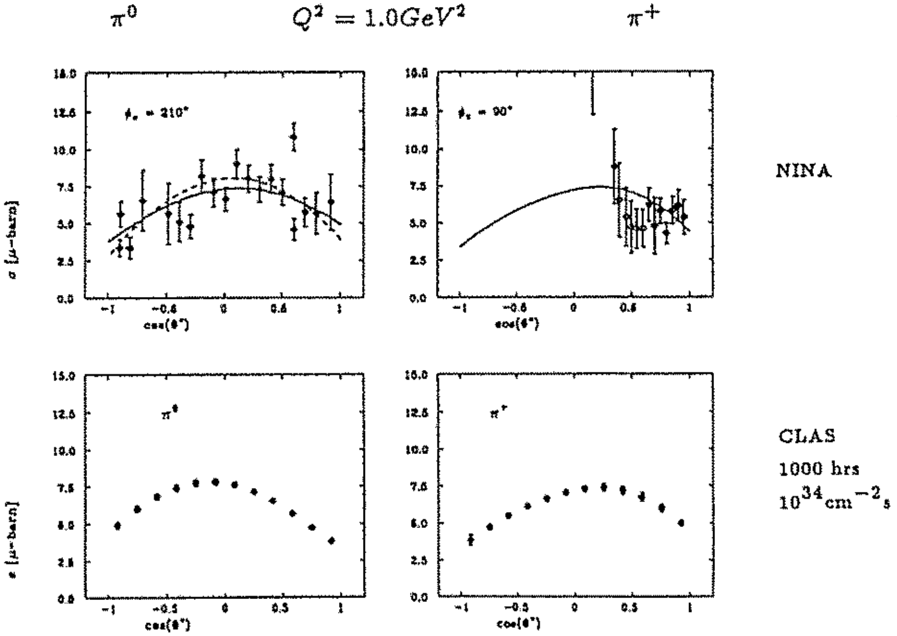


Color magnetische Spin-Spin W.W.
erkärt $N - \Delta$ Massenaufspaltung

- $L_{3Q} = 2 \to |E_{1+}/M_{1+}| \leq 0.05$
- Lattice QCD: $E_{1+}/M_{1+} = 0.03 \pm 0.08, \quad Q^2 = 0.$

$e + p \to e + p + \pi^0$





2 bins von 1000 im Massenbereich der $\Delta(1232)$.

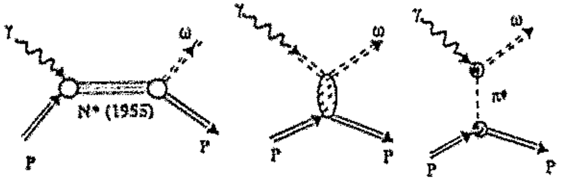
Suche nach "fehlenden" Quarkmodell Zuständen

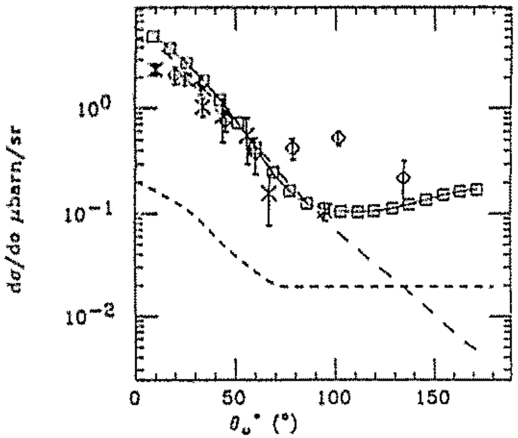
- Viele vom QCD motiviertem Quarkmodell vorhergesagten Baryonenzustände wurden in $\pi N \rightarrow \pi N$ nicht beobachtet. Diese Zustände koppeln möglicherweise nicht an πN, sondern an $\pi\Delta$, $\rho N, \omega N$.

e.g.

$$\gamma p \rightarrow F_{15}(1955) \rightarrow p\omega \rightarrow p\pi^+\pi^-\pi^0$$

- Geringe Zerfallsbreite des ω → Missing Mass Methode.
- Selektiert I = 1/2 Zustände





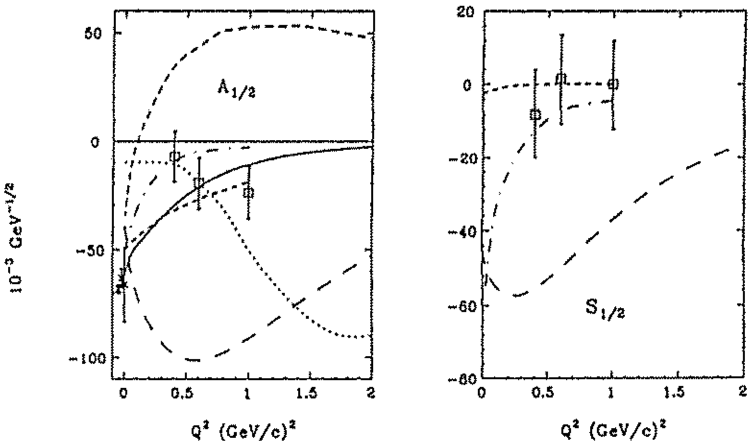
- Messung der ω Polarisation erhöht die Sensitivität auf resonante Erzeugung.

Gluonische Anregung von leichten Baryonen

- QCD erlaubt (wahrscheinlich) die Existenz gluonischer Anregungen der Baryonen.
- Gegenwärtige Vorhersagen bezüglich Anregungsspektrum sind modellabhängig. Bag Modell sowie QCD SR ergeben als leichteste gluonische Baryonen:

$$P_{11}^G\,, \quad M^G \simeq 1500\ MeV$$

- Hat die $P_{11}(1440)$ "Roper" Resonanz eine signifikante gluonische Komponente?
- Die Annahme $P_{11}(1440) = P_{11}^G$ erlaubt eine verbesserte Beschreibung der Helizitätsamplituden $A_{1/2}(Q^2)$, $S_{1/2}(Q^2)$ für die Roper:



Sollte $P_{11}(1440)$ die erste gluonische Anregung des Nukleons sein → weitere Zustände mit $(I)(J^P) = (\frac{1}{2})(\frac{1}{2})^+, (\frac{3}{2})^+$

Nicht-perturbative Spinstruktur des Nukleons

$$\Gamma_1(Q^2) = \int_0^1 g_1(x, Q^2)dx$$

Für $Q^2 = 0$ ist die Steigung von Γ_1 durch die Gerasimov-Drell-Hearn Summenregel festgelegt:

$$I'(Q^2) = \frac{2M^2}{Q^2}\Gamma_1(Q^2) \longrightarrow -\frac{1}{4}\chi^2$$

CEBAF Experimente: $W < 2.2$ GeV, $Q^2 = 0.2 - 2$ GeV^2.

$$\vec{e}\vec{p} \to eX,\ \vec{e}\vec{D} \to eX,\ \vec{e}^3\vec{H}e \to eX$$

$$\frac{d\sigma}{d\Omega dE'} = \Gamma_T\{\sigma_T + \sigma_L \pm \sqrt{1-\epsilon^2}\cos\psi\sigma_T A_1 \pm \sqrt{2\epsilon(1-\epsilon)}\sin\psi\sigma_T A_2\}$$

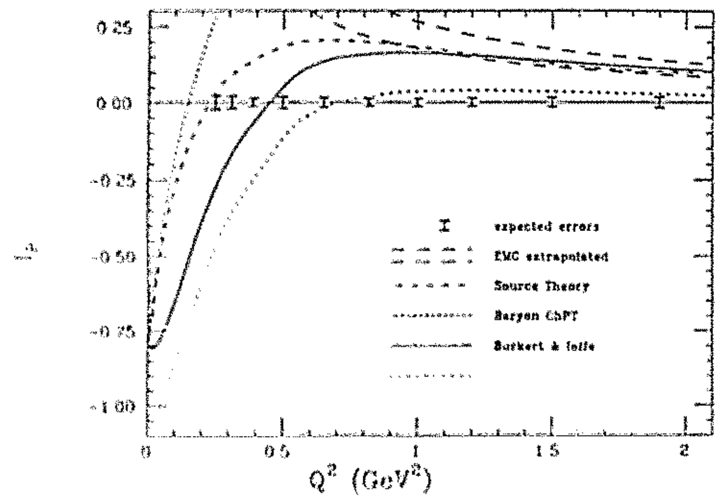
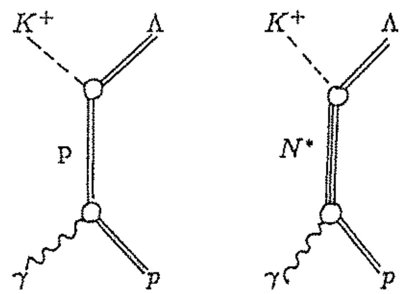
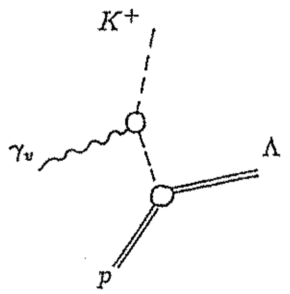


Photo- and Electroproduktion von Hyperonen

$$\gamma_v p \to KY, \quad Y = \Lambda,\ \Sigma,\ \Lambda^*,\ \Sigma^*$$



KYN Kopplungstärken
(CLAS)



K⁺ Formfaktor
σ_L/σ_T (HMS/SOS)

Λ Polarisation ist auf den Produktionsmechanismus empfindlich

- o Quarkstruktur des $f^o(975)$:

  $q\bar{q}$ - unwahrscheinlich

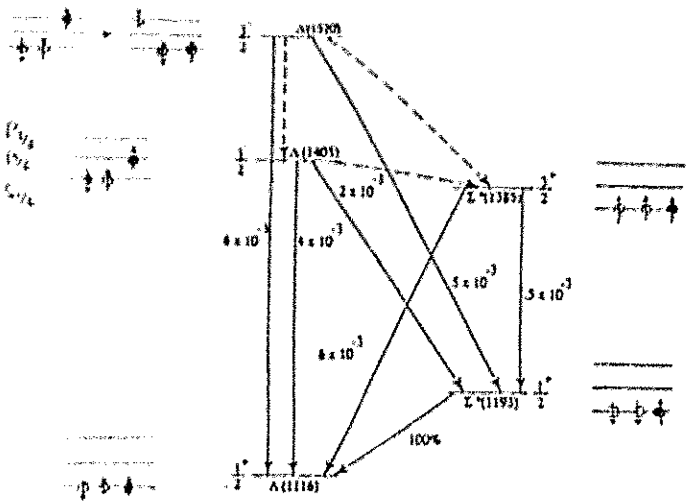
  $qq\bar{q}\bar{q}$ - exotisch ?

  $(q\bar{q}) - (q\bar{q})$ Molekül ?

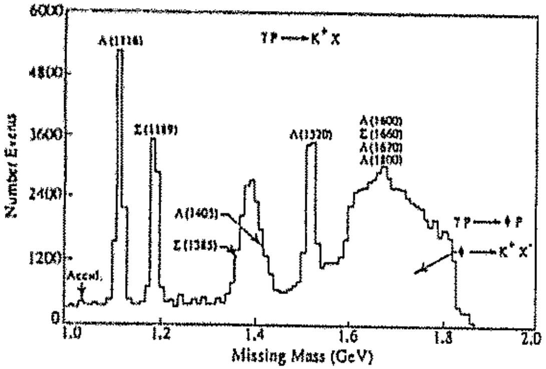
CEBAF Experiment: $ep \to epK^+K^- \longrightarrow 10^4\ f^o(975)$ pro Tag.

Strahlungsübergänge von leichten Hyperonen.

$$\gamma p \to K^+ Y^* \to K^+ \Lambda\gamma \to K^+ p\pi^-\gamma \quad \text{(CLAS)}$$



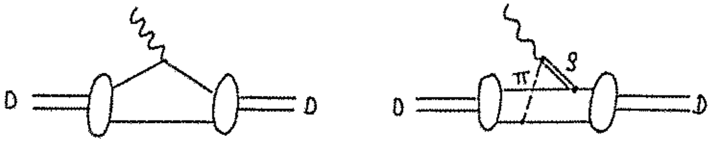
→ Test der Wellenfunktion leichter Hyperonen



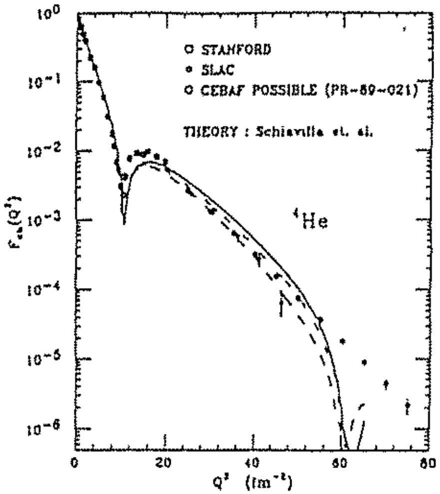
Elektromagnetische Formfaktoren von leichten Kernen

- Evidenz für nicht-nukleonische Freiheitsgrade in Kernen (Mesonische Austauschströme) von

$$eD \to eD, \quad e^3He \to e^3He, \quad e^4He \to e^4He$$



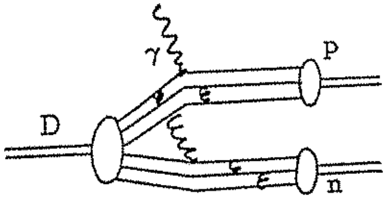
- Erweiterung zu kürzeren Abständen (hohes Q^2):
  - Kurzreichweitige Korrelationen in NN Wechselwirkung
  - Beiträge zu 3-Körperkräften
  - Bedeutung der Quark-Gluon Wechselwirkung?



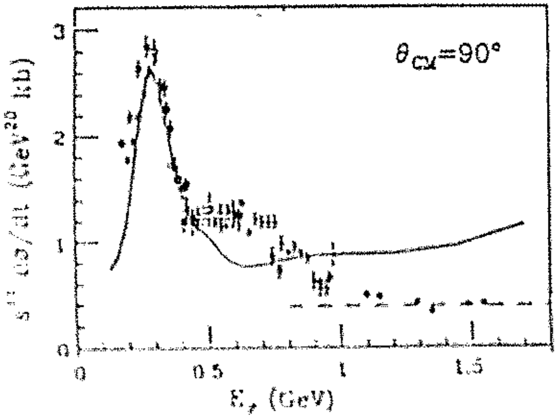
Photospaltung des Deuterons.

- Die Energieabhängigkeit des $D(\gamma, p)n$ Wirkungsquerschnitts für $E_\gamma \geq 1 GeV$ folgt der Quark "counting rule" :

$d\sigma/dt \sim (1/s)^{11}$

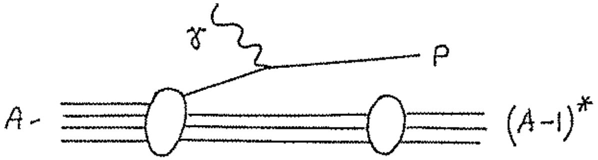


$D(\gamma, p)n$ (SLAC)



- Resultate bei kleineren Winkeln deuten unterschiedliches Verhalten an
- Erweiterung des Energiebereiches bis zu $4GeV$ (HMS), Winkelverteilung (CLAS)
- Messung der Rückstosspolarisation des Protons (HRS)

Einfach Nukleonen Knockout Prozesse $A(e, e'p)A^*$

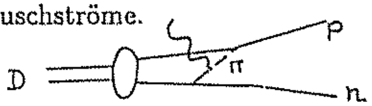


Experimente bei niedrigen energien → erlaubten die Bestimmung von Nukleonen Dichten für Impulse bis zu

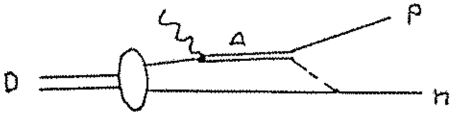
$\sim 600 MeV/c$ für D, ^3He, ^4He

$\sim 300 MeV/c$ für schwerere Kerne

- o Grenzen der einfachsten Modelle (PWIA)
- o $D(e, e')pn$ nahe der Schwelle → Signaturen für isovektorielle mesonische Austauschströme.

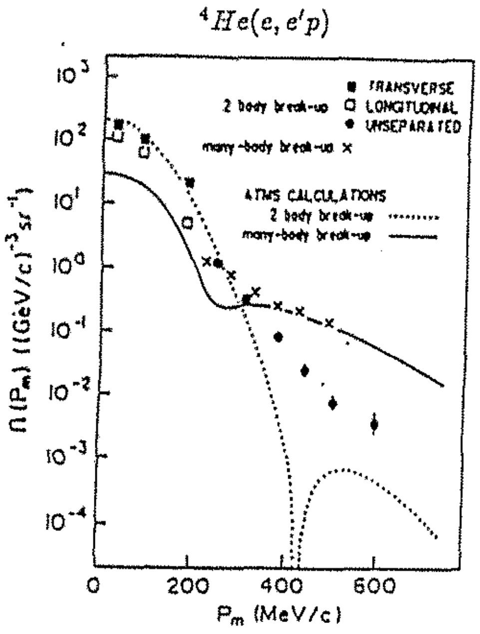


- o $D(e, e'p)n$ bei höheren Energien → Bedeutung von $\Delta(1232)$ Beiträgen



Bei höheren Energien:

- o Höhere Impulskomponeneten in der Wellenfunktion
- o Kurzreichweitige Korrelationen
- o Colortransparenz → reduzierte Endzustandswechselwirkung bei hohen Impulsüberträgen



→ Impulse ≥ 350 MeV/c treten hauptsächlich in Mehrkörper Aufbruchreaktionen auf.

CEBAF:

HRS²: Erweiterung des kinematischen Bereiches für die Trennung von 3 Response Funktionen im Wirkungsquerschnitt für $Q^2 \leq 1$ GeV² bei Rückstossimpulsen bis 1 GeV/c.

CLAS: Erweiterung zu $(e, e'NN)$, $(e, e'NN^*)$, $(e, e'\Delta\Delta)$ an verschiedenen Kernen

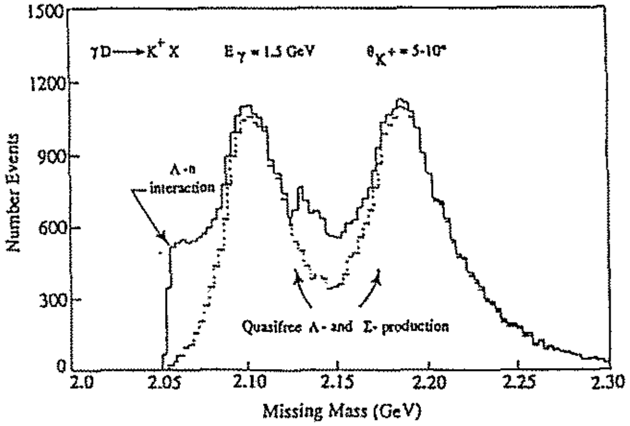
Photo- and Electroproduktion von Hyperonen an Kernen

Λ, Σ Hyperonen

- o wirken im Kern als kontrollierte Verunreiningung deren Verhalten nicht vom Pauli Prinzip eingeschränkt ist
- o leben lange genug um als Sonde für das Kerninnere zu wirken
- o Elektromagnetische Wechselwirkung:
  - erlaubt es Hyperonen im Kerninnern zu erzeugen
  - besetzt Zustände mit unnatürlicher Parität wenn man von einem 0^+ Kern ausgeht

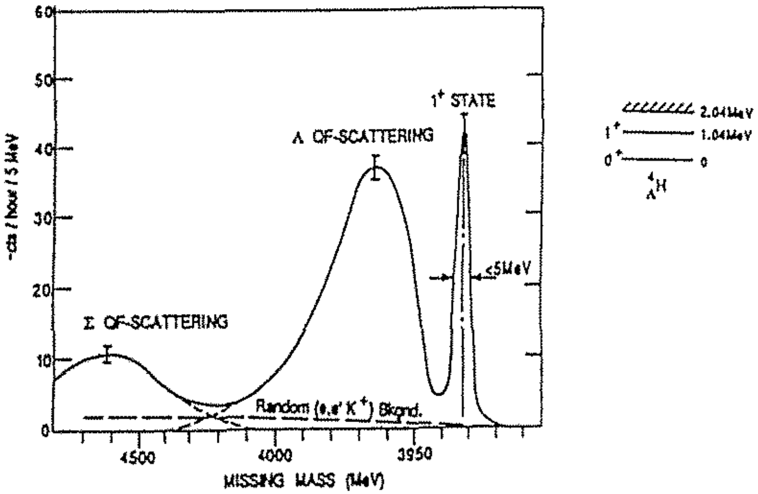
Quasi-freie $K\Lambda$ Erzeugung (verschiedenene Kerne) mit CLAS:

- o $\gamma d \to K^+(\Lambda n)$, $K^+(\Sigma n)$ → Endzustandswechselwirkung
- o Interferenzstruktur aufgrund $\Lambda N \to \Sigma N$ (cusp).
- o S = -1 Dibaryonen D_o and D_1, nahe Σ cusp



Der leichteste stabile Hyperkern kann erzeugt werden:

$$^4He(e,e'K^+)^4_\Lambda H \text{ (HMS/SOS)}$$



Vorschlag für ein spezialisiertes Spektrometer mit hoher Auflösung für Hyperkernphysik (HNSS).

Ausblick

- Die elektromagnetische Wechselwirkung ist ein ausgezeichnetes Mittel zum Studium der Struktur von Baryonen und leichten Kernen.

- Der CEBAF Beschleuniger und das experimentelle Equipment ermöglichen es diese Strukturen mit bislang nicht möglicher Genauigkeit und in einem grossen kinematischen Bereich zu untersuchen.

- Bereits das anfängliche experimentelle Programm sollte Antworten auf Fragen bezüglich der Manifestierung der starken Wechselwirkung im Bereich des Confinement sowie im Übergangsbereich zur tief inelastischen Streuung geben.

- Vom Studium leichter Kerne lässt sich das Verhalten der Kernwellenfunktion bei kurzen Abständen untersuchen, in einem Bereich wo Quarks und Gluonen möglicherweise eine wichtige Rolle spielen.

PEP-II: THE SLAC-BASED ASYMMETRIC B FACTORY

HELMUT MARSISKE

Stanford Linear Accelerator Center

Presented at

Arbeitstreffen Kern- und Teilchenphysik 1994

1) PHYSICS
2) PEP-II MACHINE
3) BABAR DETECTOR

PHYSICS MOTIVATION

- TWO CRUCIAL BUT LARGELY UNTESTED AREAS IN THE STANDARD MODEL:
  - ORIGIN OF MASS (HIGGS)
  - — " — CP VIOLATION (CKM)
- SM CAN ACCOMODATE $\not{CP}$ VIA COMPLEX PHASE IN CKM, BUT IS THIS REALY THE ORIGIN OF $\not{CP}$, OR e.g. SUPERWEAK
- $\not{CP}$ SOFAR ONLY OBSERVED IN K SYSTEM:
  - $\not{CP}$ IN MIXING $|\varepsilon| = (2.258 \pm 0.018)\,10^{-3}$
  - $\not{CP}$ IN DECAY ("DIRECT $\not{CP}$") STILL NOT ESTABLISHED

BOTH RESULTS CONSISTENT WITH SM, BUT NOT A CONCLUSIVE TEST BECAUSE OF LARGE HADRONIC UNCERTAINTIES IN THEORY AND LARGE EXP. UNCERTAINTIES IN ε'/ε

- IF CKM PHASE RESPONSIBLE FOR $\not{CP}$ IN K DECAY
  → PREDICT LARGE $\not{CP}$ EFFECTS – $\mathcal{O}(10^{-1})$ – IN B DECAY (ALMOST NONE IN D DECAY)

- B SYSTEM ALLOWS COMPREHENSIVE STUDY OF $\not{CP}$ BECAUSE OF RICH B DECAY SPECTRUM
  - ESTABLISH ORIGIN OF $\not{CP}$ WITHIN SM

  OR

  - ESTABLISH NEED TO GO BEYOND SM AND POINT DIRECTION WHERE TO GO

⇒ 1) FIND $\not{CP}$ IN B SYSTEM

2) PROOF/DISPROOF UNDERLYING SM FRAMEWORK (CKM PICTURE);

DISTINGUISH BETWEEN COMPETING MODELS THROUGH A BROAD PROGRAM OF MEASUREMENTS

- CABIBBO-KOBAYASHI-MASKAWA (CKM) MATRIX
  - UNITARY 3×3 MATRIX DESCRIBING MIXING BETWEEN MASS AND WEAK EIGENSTATES

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$\not{CP}$ IN SM

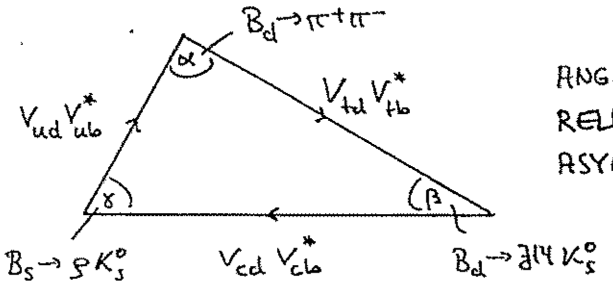
⇓

  - PARAMETRIZED BY 3 ANGLES, 1 PHASE

- UNITARITY CONDITION

$$\boxed{V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0}$$

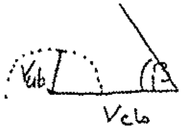
CAN BE REPRESENTED IN THE COMPLEX PLANE BY THE SO-CALLED UNITARITY TRIANGLE (UT)



ANGLES α, β, γ RELATED TO $\not{CP}$ ASYMMETRIES

- GOAL IS TO MAKE ENOUGH MEASUREMENTS TO OVERCONSTRAIN THE UT

  i.e., ≥ 2 SIDES$_{V_{cb}, V_{ub}}$ & ≥ 2 ANGLES$_{\beta, \alpha}$



  - INCONSISTENCIES → ~~SM~~

  - ∃ ALREADY SOME CONSTRAINTS FROM

    V_{ub}/V_{cb} , B^0-$\bar{B}^0$ MIXING , ε

- NON-ZERO ANGLES IN UT SIGNAL ~~CP~~ ;
  CAN BE MEASURED THROUGH CP ASYMMETRIES a_{CP}

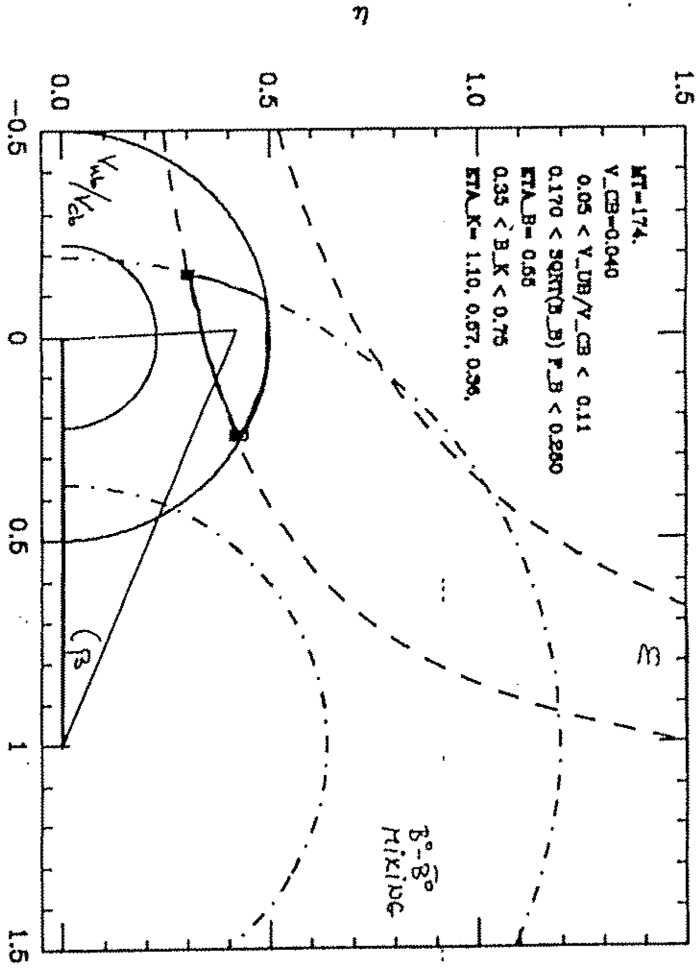
  - IN CASE OF B DECAYS TO CP EIGENSTATES AND ONE AMPLITUDE DOMINATING THE DECAY:

    DIRECT RELATION $\phi \leftrightarrow a_{CP}$ WITH MINIMAL THEORETICAL UNCERTAINTIES

- ASYMMETRIES MEASURED IN DIFFERENT REACTIONS CAN MEASURE THE SAME UT ANGLE

  → CONSISTENCY CHECK + INCREASED SENSITIVITY

  IF INCONSISTENT, ∃ CLEAR PREDICTIONS WHICH ASPECT OF SM IS FAILING



MAX ALPHA = 91.7 MAX BETA = 29.9 MAX GAMMA = 116.4

MIN ALPHA = 46.9 MIN BETA = 14.7 MIN GAMMA = 59.2

$0.49 \leq \sin 2\beta \leq 0.86$

TYPES OF $\cancel{CP}$

1.) $\cancel{CP}$ IN MIXING : $\Gamma(B^0 \to \bar{B}^0) \neq \Gamma(\bar{B}^0 \to B^0)$

RESULTS FROM MASS EIGENSTATES BEING DIFFERENT FROM WEAK EIGENSTATES

FOR EXAMPLE, IN SEMILEPTONIC B DECAY

$$e^+e^- \to B^0\bar{B}^0 \quad , \quad \begin{array}{l} B^0 \to \ell^+\nu_\ell X \\ \bar{B}^0 \to \ell^-\bar{\nu}_\ell X \end{array}$$

LOOK FOR ASYMMETRY

$$\boxed{a_{CP}^{s\ell} = \frac{N(\ell^+\ell^+) - N(\ell^-\ell^-)}{N(\ell^+\ell^+) + N(\ell^-\ell^-)}}$$

EXPECTED TO BE 10^{-3} (10^{-4}) FOR B_d (B_s) → TOO SMALL

2.) $\cancel{CP}$ IN DECAY : $\Gamma(B \to f) \neq \Gamma(\bar{B} \to \bar{f})$

FOR EXAMPLE, IN CHARGED B DECAY

$$\boxed{a_{CP}^{direct} = \frac{N(B^+ \to f) - N(B^- \to \bar{f})}{N(B^+ \to f) + N(B^- \to \bar{f})}}$$

WHERE $\overset{(-)}{f}$ TAGS FLAVOR OF $\overset{(-)}{B}$, LIKE $B^- \to K^-\pi^0$

$\pi^- K^0_s$

NEED AT LEAST TWO INTERFERING AMPLITUDES WITH DIFFERENT PHASES, e.g., TREE + PENGUIN

$$A = A_1 e^{i\varphi_1} e^{i\delta_1} + A_2 e^{i\varphi_2} e^{i\delta_2}$$
$$\bar{A} = A_1 e^{-i\varphi_1} e^{i\delta_1} + A_2 e^{-i\varphi_2} e^{i\delta_2}$$

A_i REAL

φ_i WEAK PHASE

δ_i STRONG – – –

$$\rightarrow \boxed{a_{CP}^{direct} \sim \sin(\varphi_1 - \varphi_2)\sin(\delta_1 - \delta_2)}$$

FOR $a_{CP} \neq 0$, BOTH $\Delta\varphi$ & $\Delta\delta \neq 0$

→ WEAK PHASE CAN'T BE EXTRACTED BECAUSE STRONG PHASE UNKNOWN

⇒ UNAMBIGOUS OBSERVATION OF DIRECT $\cancel{CP}$ BUT UNKNOWN RELATION TO SM PARAMETERS

3.) $\cancel{CP}$ IN THE INTERFERENCE OF MIXING & DECAY

$$\begin{tikzcd} B^0 \arrow[rr, "\text{DECAY}"] \arrow[dr, "\text{MIXING}"'] & & f \\ & \bar{B}^0 \arrow[ur, "\text{DECAY}"'] & \end{tikzcd}$$

FINAL STATE f ACCESSIBLE TO BOTH B^0 & $\bar{B}^0$, e.g., CP EIGENSTATE f_{CP}

- TWO INTERFERING AMPLITUDES ARE MIXING & DECAY

→ BOTH DECAY PATHS HAVE OPPOSITE WEAK PHASE AND SAME STRONG PHASE, BUT WEAK PHASE FROM MIXING AMPLITUDE TAKES THAT ROLE

⇒ NO HADRONIC UNCERTAINTY; THEORETICALLY CLEAN CONNECTION TO SM PARAMETERS !

$$\boxed{a_{f_{CP}} = \frac{N(B^0 \to f_{CP}) - N(\bar{B}^0 \to f_{CP})}{N(B^0 \to f_{CP}) + N(\bar{B}^0 \to f_{CP})}}$$

NOTE : NEED TO TAG FLAVOR OF $\overset{(-)}{B}{}^0$ SINCE f_{CP} DOESN'T TELL ASYMMETRY VANISHES WITHOUT FLAVOR TAGGING

BEST PLACE FOR A COMPREHENSIVE MEASUREMENT PROGRAM IS AN e^+e^- COLLIDER RUNNING AT THE $\Upsilon(4S)$ RESONANCE i.e., $\sqrt{s} = 10.58$ Ge

- LARGE $B\bar{B}$ CROSS SECTION

  $\sigma(e^+e^- \to \Upsilon(4S) \to B\bar{B}) = 1\,nb$

- EXCELLENT SIGNAL : NOISE

  $\sigma(e^+e^- \to hadrons) = 2.6\,nb$ @ $\sqrt{s} \lesssim 10.58$ GeV

- $\Upsilon(4S)$ DECAYS EXCLUSIVELY INTO $B\bar{B}$
  - → NO EXTRA FRAGMENTATION PARTICLES
    - ⇒ B's MONOENERGETIC IN $\Upsilon(4S)$ REST FRAME
      - ⇒ EXCELLENT NON-B BACKGROUND REJECTION CLEAN & EFFICIENT B FLAVOR TAGGING

- MANY RECONSTRUCTABLE B DECAY MODES DUE TO THE CLEAN e^+e^- ENVIRONMENT
  - ⇒ COMPREHENSIVE STUDY OF THE PHENOMENON OF $\cancel{CP}$, WITHIN AND POSSIBLY BEYOND THE SM

- $\cancel{CP}$ ASYMMETRIES EXPECTED TO BE LARGE $\mathcal{O}(10^{-1})$, BUT CP RELEVANT B DECAY BF's SMALL ($\leq 10^{-3}$)
  - → NEED IN EXCESS OF 10^7 NEUTRAL B's
    - ⇒ NEED HIGH-LUMINOSITY e^+e^- COLLIDER

      INITIAL GOAL IS $30\,fb^{-1}$ / year
      - → REQUIRE $3 \cdot 10^{33} cm^{-2} s^{-1}$ ASSUMING SNOWMASS YEAR OF $10^7 s$ ⇒ B, τ/CHARM FACTORY
        - ⇒ $\boxed{3 \times 10^7 \; B\bar{B} \text{ EVENTS / year}}$

QUANTUM MECHANICAL PECULIARITY ON THE $\Upsilon(4S)$:

BECAUSE OF $C(\Upsilon(4S)) = -1 = P(\Upsilon(4S))$ AND BOSE-EINSTEIN STATISTICS, B^0 & $\bar{B}^0$ ARE PRODUCED IN A COHERENT (ANTISYMMETRIC) STATE $\frac{1}{\sqrt{2}}(B^0\bar{B}^0 - \bar{B}^0B^0)$

REMAIN IN THIS STATE UNTIL SUCH TIME AS ONE OF THEM DECAYS.

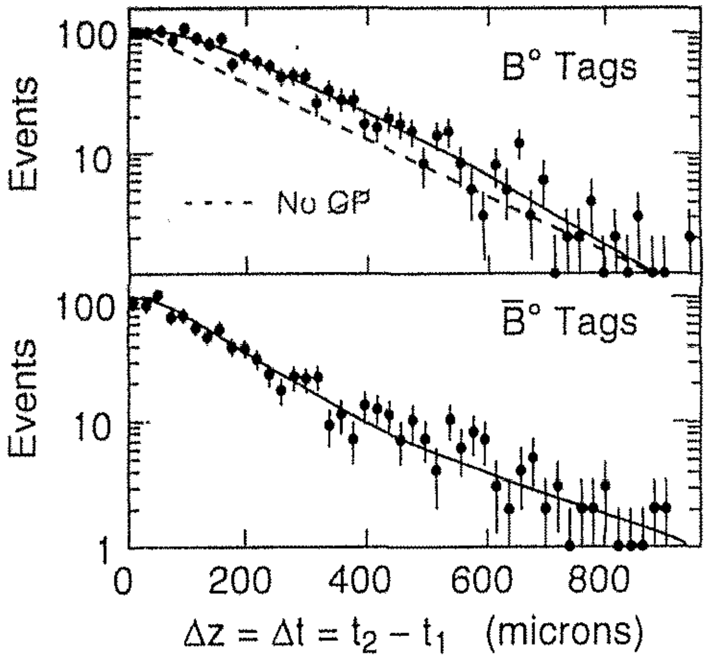
IF AT TIME t_{tag} ONE B DECAYS TO A FINAL STATE f_{tag} THAT TAGS ITS FLAVOR, THEN THE OTHER B IS PROJECTED INTO THE ORTHOGONAL STATE AND ITS FLAVOR AT t_{tag} IS UNAMBIGOUSLY DETERMINED

IT WILL UNDERGO B^0-$\bar{B}^0$ OSCILLATIONS UNTIL IT DECAYS INTO f_{CP} AT TIME t_{CP} ; ITS TIME EVOLUTION DEPENDS ONLY ON $\underline{t_{CP} - t_{tag} = \Delta t}$

$$\boxed{\Gamma(B^0\bar{B}^0 \to f_{CP} f_{tag}) \sim e^{-\Gamma|\Delta t|}\left[1 \pm \underset{\substack{\uparrow \\ \text{UT ANGLE}}}{\sin 2\phi} \sin(\Delta m \Delta t)\right]}$$

⇒ $\cancel{CP}$ MODULATES THE NORMAL DECAY EXPONENTIALS BY A SINUSOIDAL OSCILLATION WITH AMPLITUDE $\sin 2\phi$ AND FREQUENCY $\sin(\Delta m \Delta t)$

Measurement of sin2β Using $B^0 \to J/\psi K_S$



Number of Events $\propto e^{-\Gamma \Delta t}\{1 \pm \sin 2\beta \sin(\Delta m \Delta t)\}$

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HOW TO MEASURE Δt ON THE $\Upsilon(4S)$

- SOLUTION IS TO BOOST THE $\Upsilon(4S)$ TO ACHIEVE A SEPARATION OF THE B DECAY VERTICES (ALONG THE BOOST DIRECTION) WHICH CAN BE MEASURED WITH A VERTEX DETECTOR
- SINCE THE B MOMENTUM IN THE $\Upsilon(4S)$ REST FRAME IS ONLY ~300 MeV, THE SPATIAL SEPARATION Δz TRANSLATES INTO THE REQUIRED DIFFERENCE IN DECAY TIME Δt TO A VERY GOOD APPROXIMATION

⇒ REQUIRES ENERGY-ASYMMETRIC STORAGE RING

PEP-II : 9 GeV ELECTRONS ON 3.1 GeV POSITRONS

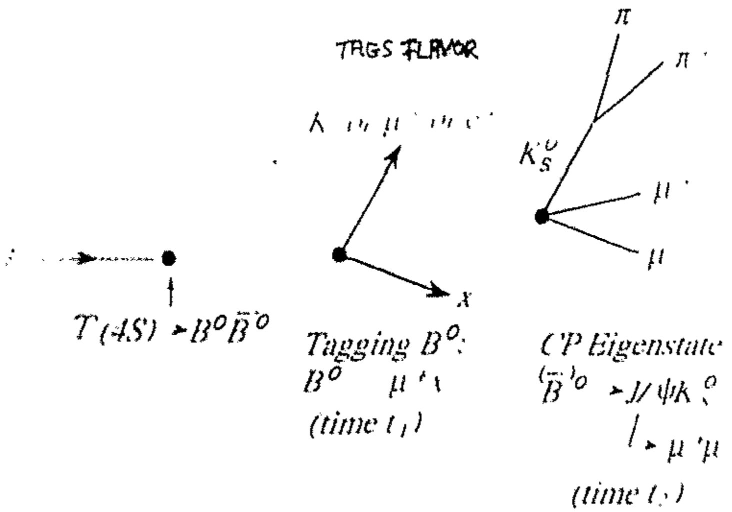
$\rightarrow \beta\gamma\,(CM) = 0.56$

$\Rightarrow \beta\gamma c\tau\,(B) \approx 250\,\mu m$

COMPARED TO $30\,\mu m$ FOR B's AT REST

- EASY TO MEASURE DISTANCE FOR MODERN SILICON VERTEX DETECTORS

Strategy: Use Moving $\Upsilon(4S)$; Require One B to Decay to CP Eigenstate, the Other is Used as a Tag of $B^0\bar{B}^0$



One must measure 4 distinct configurations $n(t_1 - t_2)$ depending on whether the tag or CP eigenstate decays first:

- n_2: $f_B(t_1) f_{CP}(t_2)$
- n_1: $f_{CP}(t_1) f_B(t_2)$
- $\bar{n}_2$: $f_{\bar{B}}(t_1) f_{CP}(t_2)$
- $\bar{n}_1$: $f_{CP}(t_1) f_{\bar{B}}(t_2)$

CP violation produces a $t_2 - t_1$ distribution which is different for n_1 & $\bar{n}_2$ from that of $\bar{n}_1$ & n_2.

- $t_2 - t_1$ is not Measured – Distance Between the Decay Points of Two B^0s is Faithful Adjunct
  - ☐ Requires Sufficient Separation of Decay Vertices
    - ☐ Achieved by Lorentz Boost from Asymmetric Beams Energies $\gamma\beta$ $\to \gamma\beta c\tau \approx 230\mu$....

THE TIME-EVOLUTION MEASUREMENTS TURN OUT TO BE MUCH RICHER; THE MEASUREMENTS ARE NOT RESTRICTED TO CP SELF-CONJUGATE FINAL STATES. MANY MORE B DECAY MODES ARE USABLE AS LONG AS THE FINAL STATE IS ACCESSIBLE TO BOTH B^0 AND $\bar{B}^0$

THE MENU LOOKS MORE LIKE:

1) f=SELF-CONJUGATE FINAL STATES

$B \to \Psi K_S$, $B \to D^+D^-$, $B \to \pi^+\pi^-$, $B \to \rho K_S^0$, ...

2) f=STATES WITH CP+ AND CP- ADMIXTURES

$B \to \Psi K^*$, $B \to D^{*+}D^{*-}$, ...

DECAY ANGULAR DISTRIBUTIONS VARY AS FUNCTION OF $t_1 - t_2$. WITH AN APPROPRIATE CHOICE OF "PROJECTION OPERATORS", ONE CAN EXTRACT THE APPROPRIATE UNITARITY TRIANGLE ANGLES.

3) STATES WITH NO INTRINSIC CP (SELF-CONJUGATE SET OF QUARKS)

$B \to \rho\pi$, $B \to a_1\pi$, ...

THERE ARE ENOUGH CONSTRAINTS TO EXTRACT: ISOSPI ANALY

$SIN2\alpha$, STRONG PHASE AND STRONG AMP.

The measurement strategy will evolve as the experiment matures:

- ✳ Initially *CP* asymmetries from a variety of channels will be combined for greatest sensitivity on the angles α and β of the unitarity triangle
- ✳ When more data is accumulated, further tests of the underlying assumptions of the Standard Model become possible, as *CP* asymmetries in different channels purporting to measure the same unitarity angle are compared

$$\delta(\sin 2\phi)=\frac{1}{(1-2w)d}\left(\sqrt{2\varepsilon_f\varepsilon_{tag}B(B^0\to f)f_{B^0}\sigma(b\bar{b})\int L dt}\right)^{-1}$$

(w = wrong tag fraction; d = dilution factor)

Mode	Branching Fraction (* = assumed)	Reconstructable Fraction	Reconstruction Efficiency	Tagging Efficiency	$\sigma(\sin 2\phi)$ 30 fb^{-1} ← ONE YEAR @ 3 [illegible]
$J/\psi K^0_S$ [3]	5×10^{-4}	0.12	0.51 [6]	0.45	0.09
$J/\psi K^0_L$ [4]	5×10^{-4}	0.12	0.34	0.42	0.12
$J/\psi \bar{K}^{*0}$ [5]	12.5×10^{-4}	0.04	0.30	0.45	0.13
D^+D^{-*} [3]	6×10^{-4}	0.017	0.38	0.45	0.28
$D^{*+}D^{*-*}$	16×10^{-4}	0.017	0.21	0.45	0.21
→ combined ■ $\delta(\sin 2\beta)$					0.059 ←
$\pi^+\pi^-$ [1]	$2\times10^{-5*}$	1.0	0.35	0.45	0.20
$\rho^\pm\pi^\pm$ [7]	$6\times10^{-5*}$	1.0	0.48	0.45	0.12
$a_1^\pm\pi^\pm$ [7]	$6\times10^{-5*}$	0.5	0.42	0.45	0.15
→ combined ■ $\delta(\sin 2\alpha)$					0.083 ←

EXPECT $\sin 2\beta > 0.4$

ALSO CHECK CHANNELS
WITH ZERO ASYMMETRY PREDICTED, e.g., $B_d \to \phi\pi^0, K^0_S K^0_S$

Physics Program

The physics program of PEP-II is keyed to, but extends far beyond, the measurements of *CP*-violating asymmetries:

- ■ measurement of all three angles of the unitarity triangle, with experimental handles on sources of systematic errors and on theoretical assumptions
- ☐ measurements of x_d and x_s separately

In addition, the large data set obtained will allow a variety of other kinds of measurements, such as

- ■ precise determination of V_{cb}
- ■ determination of V_{ub} from exclusive semileptonic decay modes such as $B^0_d \to \pi l \nu_l, \rho l \nu_l$
- ■ direct measurement of f_B in $B \to \tau\nu_\tau$ decay,

that require tagged *B* samples,

and provide large samples of *B* mesons, charmed particles and τ leptons for other interesting investigations

- ■ rare *B* and *D* decay branching ratios
- ■ $D^0\bar{D}^0$ mixing
- ■ precisely measured lifetimes of $\Lambda_c, \Xi^0_c, \Xi^+_c, \Omega_c$
- ■ τ lepton measurements:
  - ○ precise lifetime using 3 prong *vs* 3 prong events
  - ○ very precise determination of $B(\tau \to e\nu\bar{\nu})$
  - ○ rare τ decays

Detector design must balance the needs of these different types of physics

THE PEP-II MACHINE

- PEP-II CONSTITUTES A COST-EFFECTIVE UPGRADE OF THE SLAC SITE TO PRODUCE AN ELECTRON-POSITRON COLLIDER CAPABLE OF PRODUCING VERY LARGE SAMPLES OF B QUARKS.

- MAJOR REWORK -- PEP WILL BE CONVERTED FROM A ONE-RING MACHINE TO A TWO-RING MACHINE

- CONCEPTUAL DESIGN TAKES ADVANTAGE OF 85% OF EXISTING PEP CONVENTIONAL FACILITIES, HARDWARE, INFRA-STRUCTURE ETC

  NO CONVENTIONAL CONSTRUCTION IS NEEDED

- *NO UPGRADE OF THE UTILITIES IS REQUIRED*

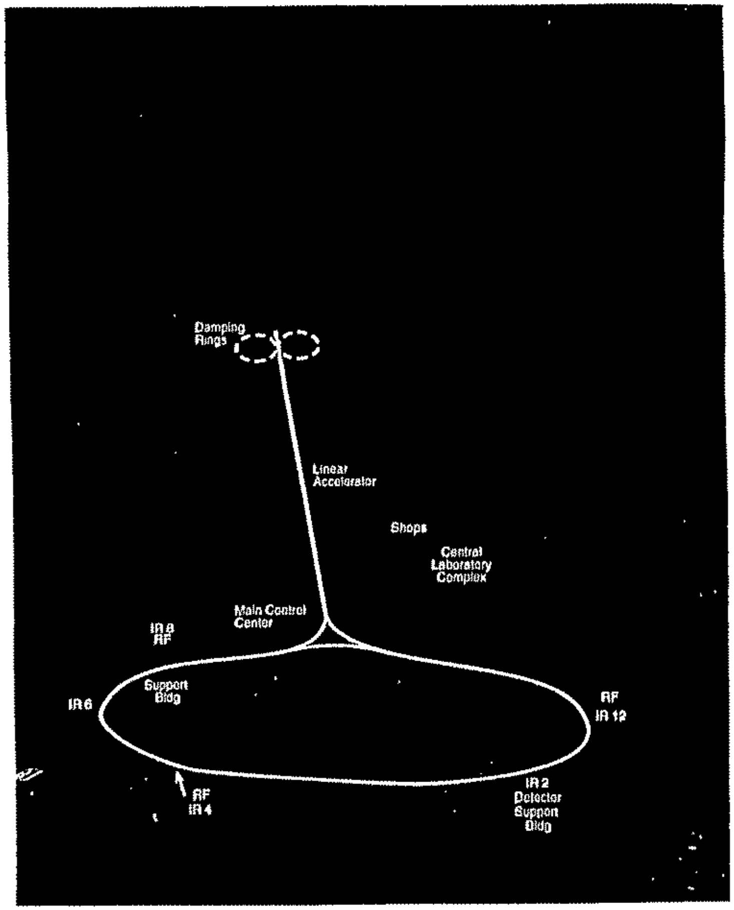
- THE PROJECT WILL BE ACCOMPLISHED AS A COLLABORATION OF SLAC, LBL AND LLNL

- *THE AVAILABILITY OF:*

  ☐ *LINAC*

  ☐ *PEP STORAGE RING COMPLEX*

AVES CONSIDERABLE MONEY AND SEVERAL YEARS OF
ONSTRUCTION TIME



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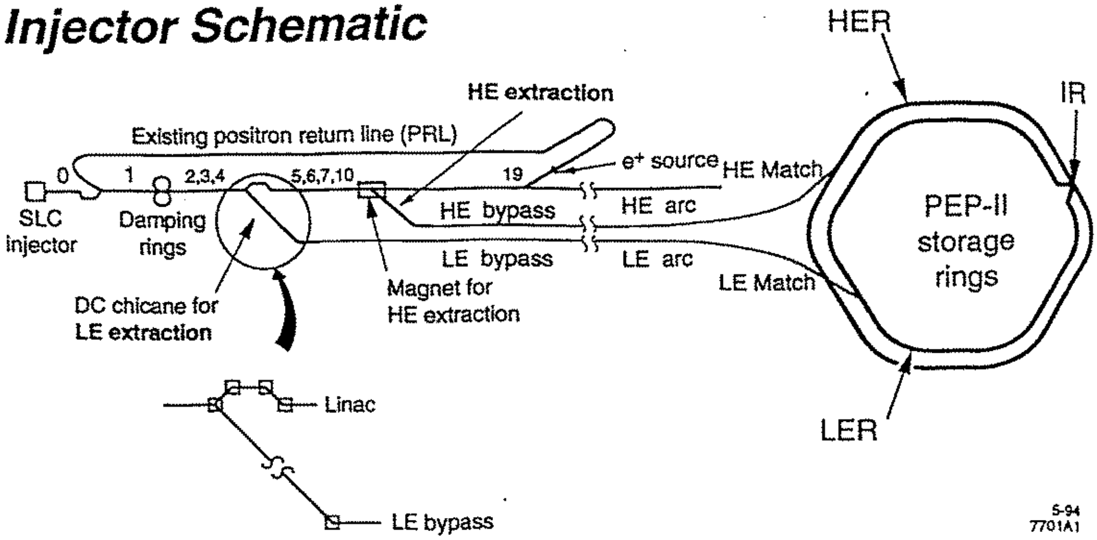
Injector Schematic



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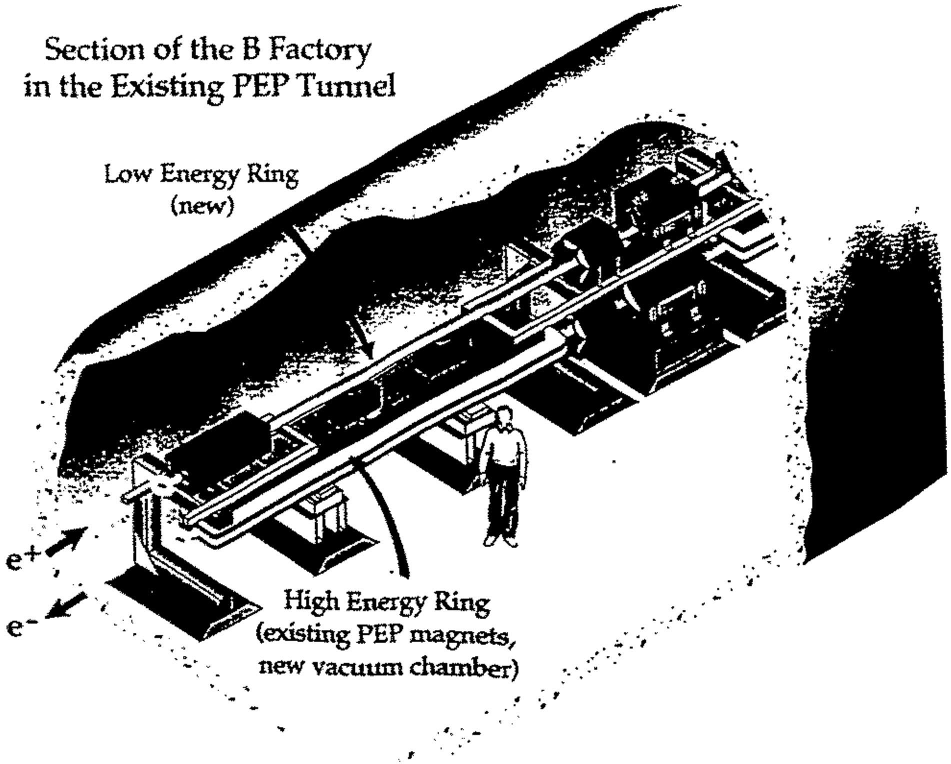
Section of the B Factory
in the Existing PEP Tunnel



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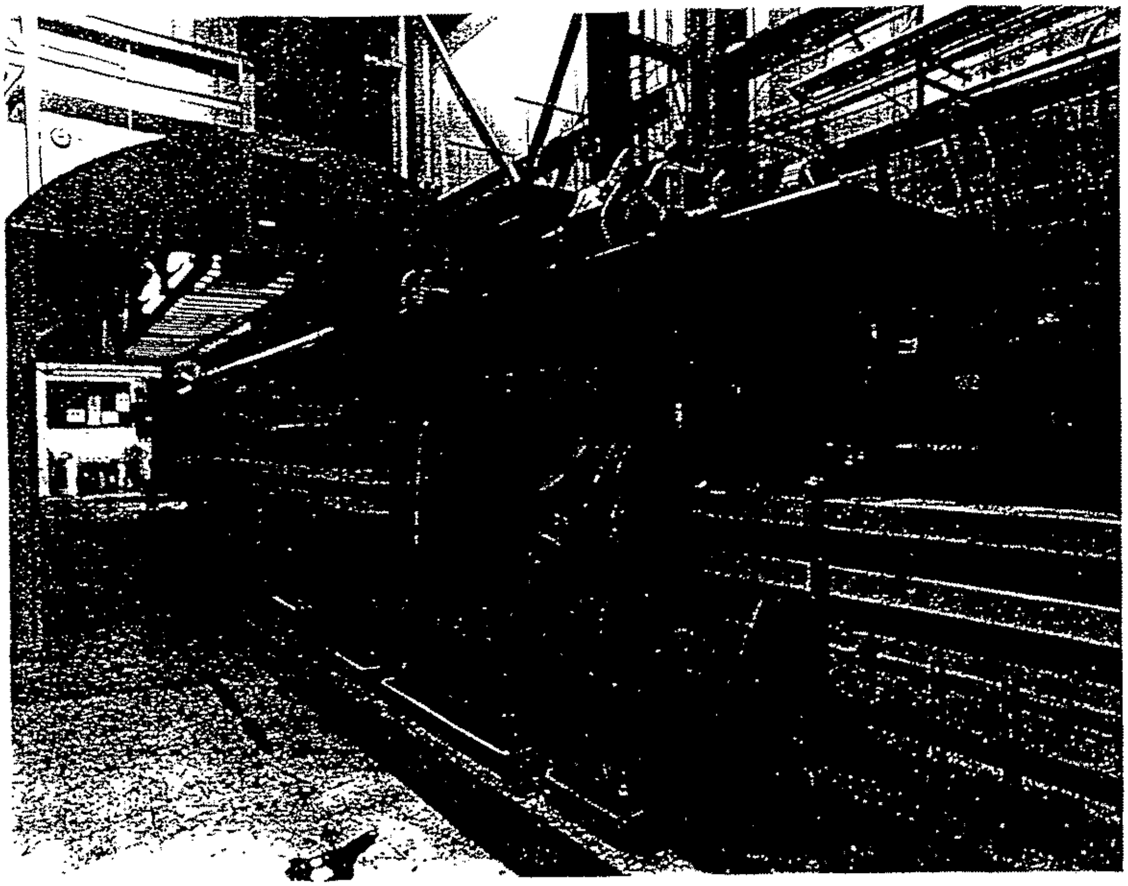

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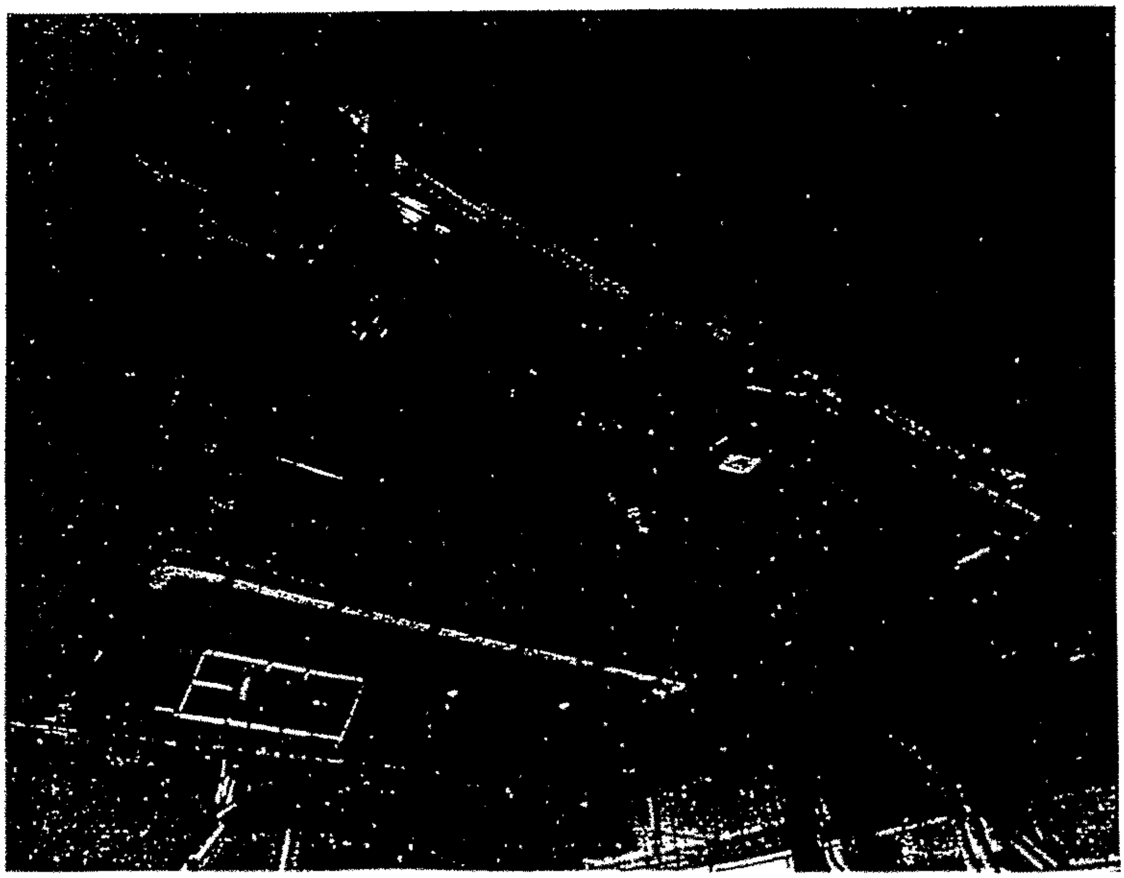
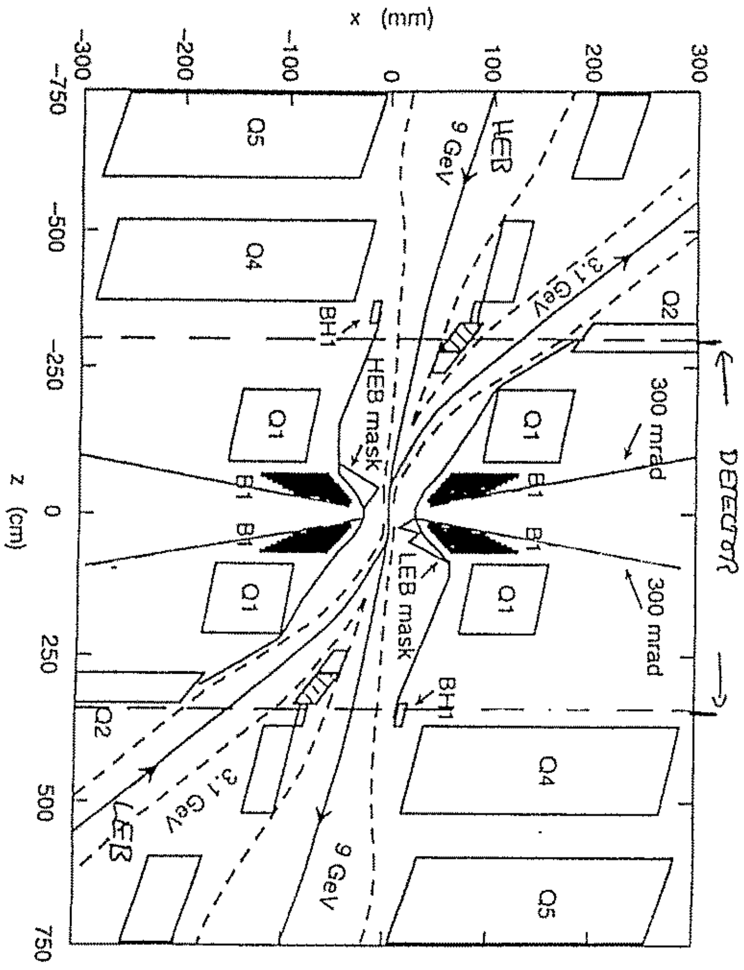




HEAD-ON COLLISION
MAGNETIC SEPARATION (B1)

<u>GOAL</u> $30\ fb^{-1}/year \Rightarrow 3\times10^{33}\ cm^{-2}s^{-1} \times 10^{7}s$

Choices for L Optimization are not Wide Ranging:

$$\boxed{L = 2.17\times10^{34}\,(1+r)\,\Delta\nu\left(\frac{E(\mathrm{GeV})\,I(\mathrm{amps})}{\beta_y^*\,(\mathrm{cm})}\right)^{+,-}}$$

- $E^{+,-}$ → Given by physics
- β_y^* → Limited to ≳ 1 cm by bunch length and practical considerations
- $\Delta\nu$ → Beam-beam sets this; Not really a parameter
- $0<r<1$ → r is aspect ratio of beams (flat/round). Practical considerations make round beams unmanageable

⇒ Route to HIGH luminosity is HIGH circulating currents

- Single-beam instabilities force you to large # bunches
  - Forces you to two separate rings; EVEN WITHOUT ENERGY ASYMMETR
    Must control Multi-Bunch Instabilities

Our design is charact~~y~~erized by Single-Bunch parameters (I_b, $\Delta\nu$, β_y^*, ε, ...) which are very similar to those used in present day machines. The major change is in the total current (# bunches). Machine is more an engineering challenge than accelerator physics ground breaker.

PEP-II

Asymmetric B Factory
Main Collider Parameters

	LER	HER
Energy, E [GeV]	3.1	9
Circumference, C [m]	2199.32	2199.32
$\varepsilon_y/\varepsilon_x$ [nm·rad]	2.6/64	1.9/48
β_y^*/β_x^* [cm]	1.5/37.5	2.0/50.0
$\xi_{0x,0y}$	0.03	0.03
f_{RF} [MHz]	476	476
V_{RF} [MV]	5.9	18.5
Bunch length, σ_ℓ [cm]	1	1
Number of bunches, k_B	1658†	1658†
Bunch separation, s_B	1.26	1.26
Damping time, τ_E/τ_x [ms]	19.8/40.3	18.4/37.2
Total current, I [A]	2.14	0.99
U_0 [MeV/turn]	1.14	3.58
Luminosity, $\mathcal{L}$ [cm^{-2}s^{-1}]	3×10^{33}	

→ 4 n' SPACII

†allows for gap of ≈5% for ion clearing

WHAT ARE THE TECHNICAL CHALLENGES OF ASYMMETRIC B FACTORY??

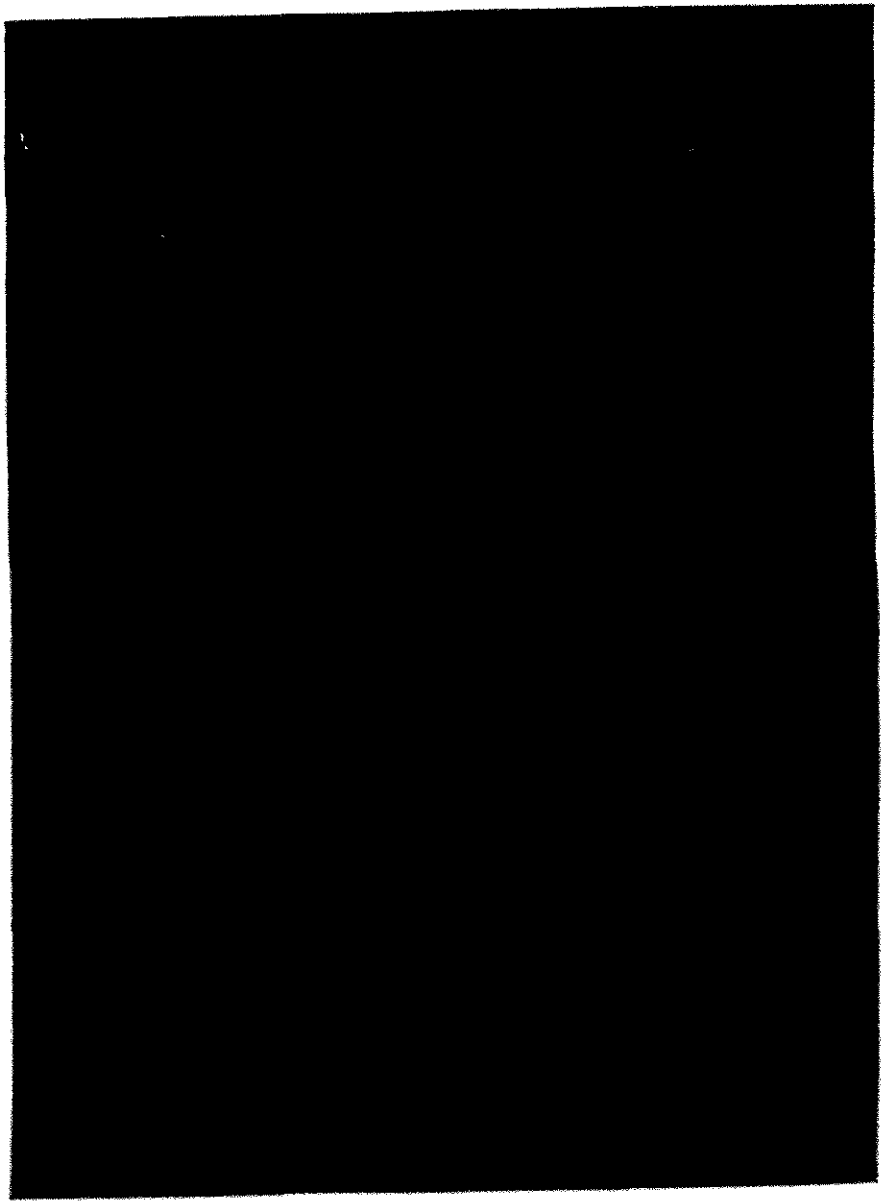
OUR DESIGN PHILOSOPHY HAS BEEN TO ADOP SINGLE-BUNCH PARAMETERS CONSISTENT WIT COMMON STORAGE–RING PRACTICE. HIG LUMINOSITY IS OBTAINED BY ADOPTING LARGE BEA CURRENTS, AND THUS MANY BUNCHES. HENCE:

- NEED A POWERFUL INJECTOR; CURRENTS AR HIGH AND BEAM LIFETIMES ARE RELATIVELY SHORT
- LARGE SYNCHROTRON RADIATION LOAD
  (→ VACUUM SYSTEM)
- MUST CONTROL MULTIBUNCH INSTABILITIES
  (→ RF SYSTEM, FEEDBACK, VACUUM SYSTEM)
- MUST SEPARATE HETERO-ENERGETIC BEAMS IN THE IR AND CONTROL THE BACKGROUNDS

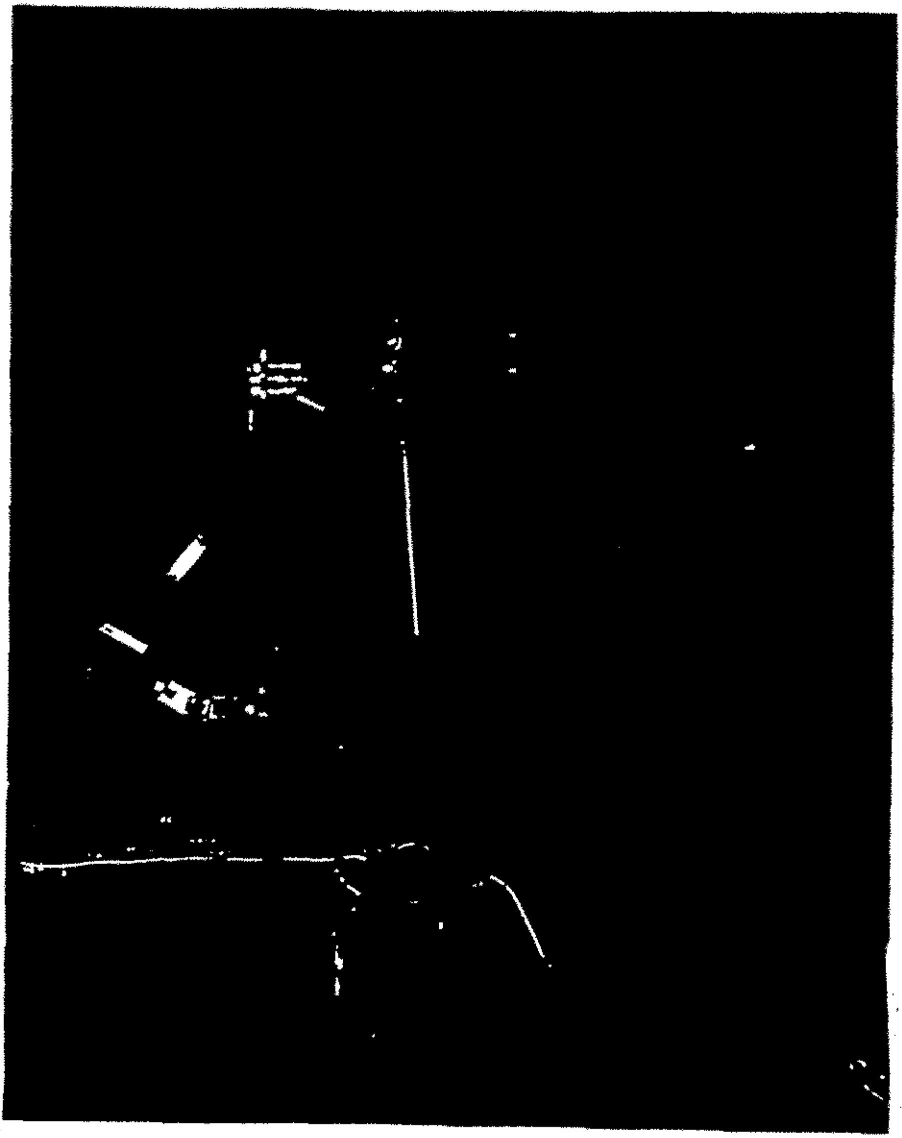
THE MACHINE IS THUS MUCH MORE OF A *ENGINEERING* CHALLENGE THAN AN *ACCELERATO PHYSICS GROUND BREAKER*

OUR RESPONSE TO THIS CHALLENGE HAS BEEN THE INVESTMENT IN DETAILED, QUALITY ENGINEERING AN A·FOCUSED R&D PROGRAM

- Vacuum system
  - — materials choice made based on LLNL photodesorption tests at NSLS
    - OF-Cu (C10100) for beam chamber, Cu-P (C10300) for cooling bar
  - — design simplified to facilitate Cu extrusion
    - RF screen for shielding beam from pumps to be slid into chamber after extrusion
  - — fabrication optimization
    - technique to bend chambers to desired radius without buckling ("stretch forming") demonstrated
    - e-beam welding of cooling bar to beam chamber demonstrated
- First sample extrusions (7-m length) arrived at SLAC in March, 1993
  - — photodesorption tests of actual chamber section scheduled at BNL in May, 1993



- RF system
  - — demonstrated adequate HOM damping on low-power prototype cavity
  - — measured *Q* values below design value of 70
    - measurements in agreement with calculated *Q* values
  - — design of high-power test cavity (with CRL) is well along
    - tests planned by end of '93
  - — RF test stand available now (476 MHz, 500 kW)
  - — R&D on high-power klystron well along (476 MHz, >1.2 MW)
    - design is power efficient and has head-room for RF feedback purposes
    - reduced group delay for improved feedback performance



- Feedback system
  - — beam tests performed at SPEAR of simple "1-bunch" version of longitudinal multibunch feedback system
    - system performed perfectly under "combat" conditions
  - — equivalent 1-bunch tests have now been repeated at ALS
  - — additional tests of enhanced prototype version ~~to be~~ done at ALS this summer
- PEP-II feedback group collaborating with ALS group to deliver actual ALS feedback systems in November '93
  - — full prototypes of the required PEP-II system
  - — SUCCESSFULL TEST IN SPRING '94

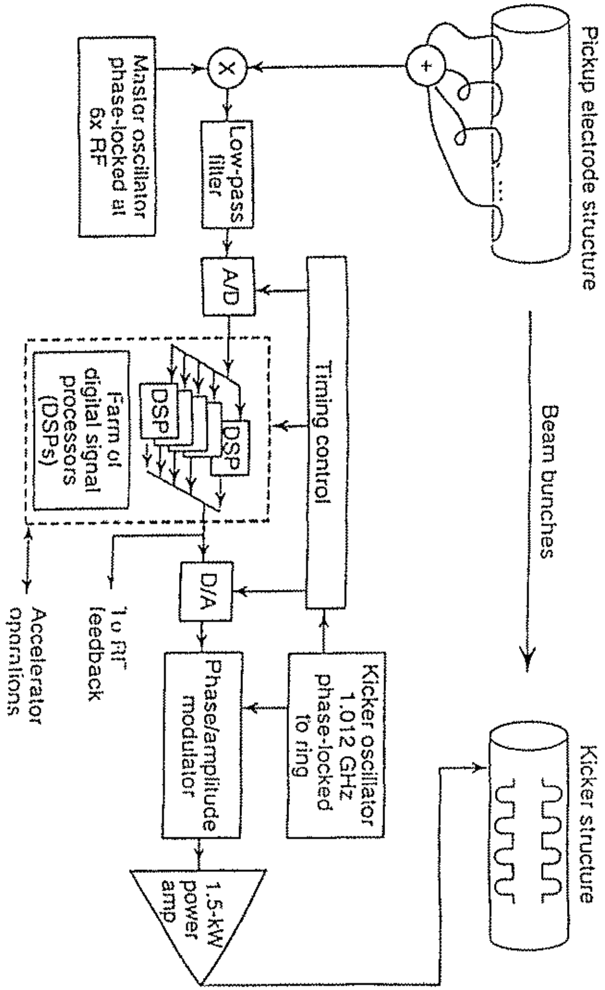
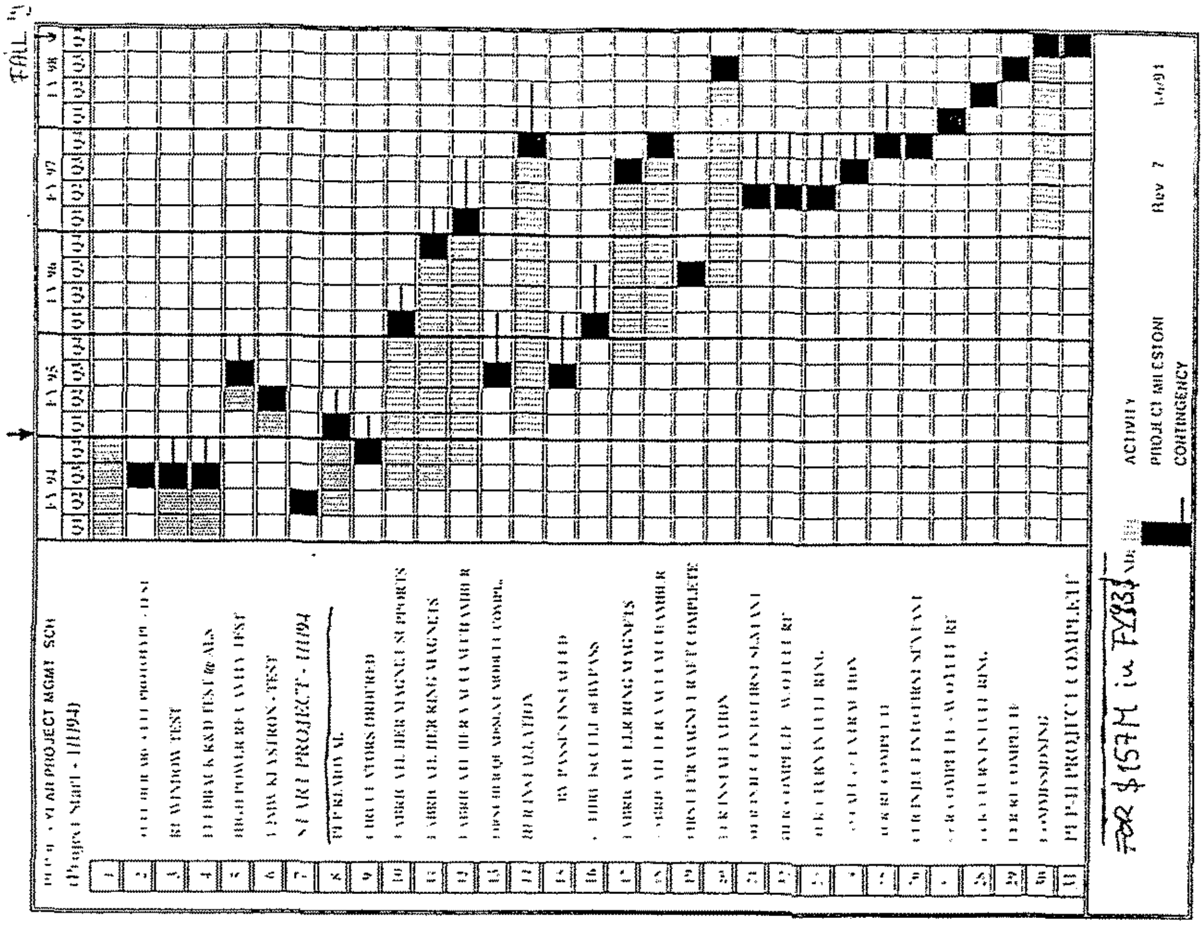


Fig. 5-114. Block diagram of the PEP-II longitudinal feedback system.



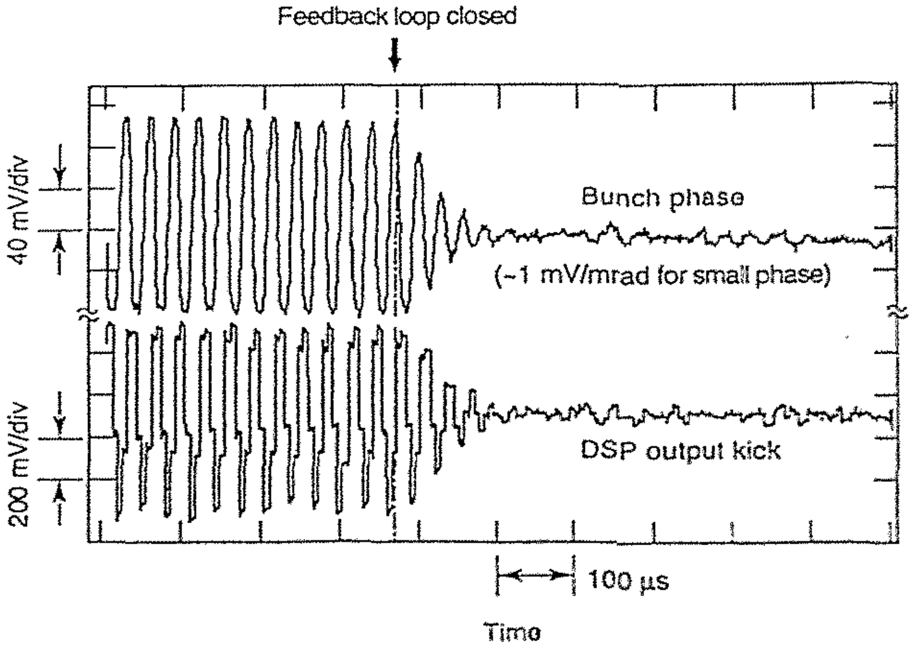
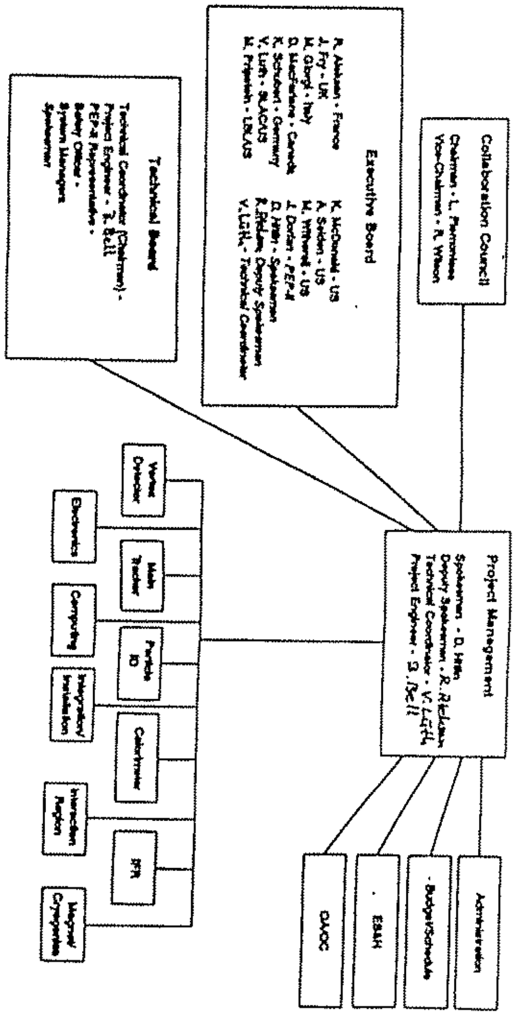


Figure 5-136. Time response of an excited bunch and the associated DSP filter output. The feedback loop is closed at the time of the dotted line in the figure.

BABAR Collaboration Organization
(preliminary)



~ 400 COLLABORATORS TOTAL
~ 200 US, ~ 170 EUROPEANS (32 INSTITUTIONS

Inst. Collab.

The BABAR Collaboration

LoI, JUNE '94
TDR, Dec. '94

US [29/206]
California Institute of Technology
UC, Davis
UC, IIRPA
UC, Irvine
UC, Los Angeles
UC, Santa Barbara
UC, Santa Cruz
U of Cincinnati
U of Colorado
Colorado State U
U of Houston
U of Iowa
Iowa State U
LBL
LLNL
U of Maryland
U of Massachusetts
MIT
U of Mississippi
Mount Holyoke College
U of Notre Dame
ORNL/Y-12
U of Pennsylvania
Princeton
Rutgers
SLAC
U of Texas at Dallas
Vanderbilt
U of Wisconsin

Canada [7/22]
U of British Columbia
Carleton U and CRPP
McGill U
U de Montréal
TRIUMF
U of Victoria
York U

China [4/19]
Beijing Glass Research Inst.
Inst. of High Energy Physics, Beijing
Shanghai Inst. of Ceramics (SICCAS)
Tsinghua U, Beijing

France [6/37]
LAPP, Annecy
LAL Orsay
Ecole Polytechnique
U Pierre et Marie Curie, Paris 6
Collége de France
CEA, DAPNIA, CE-Saclay

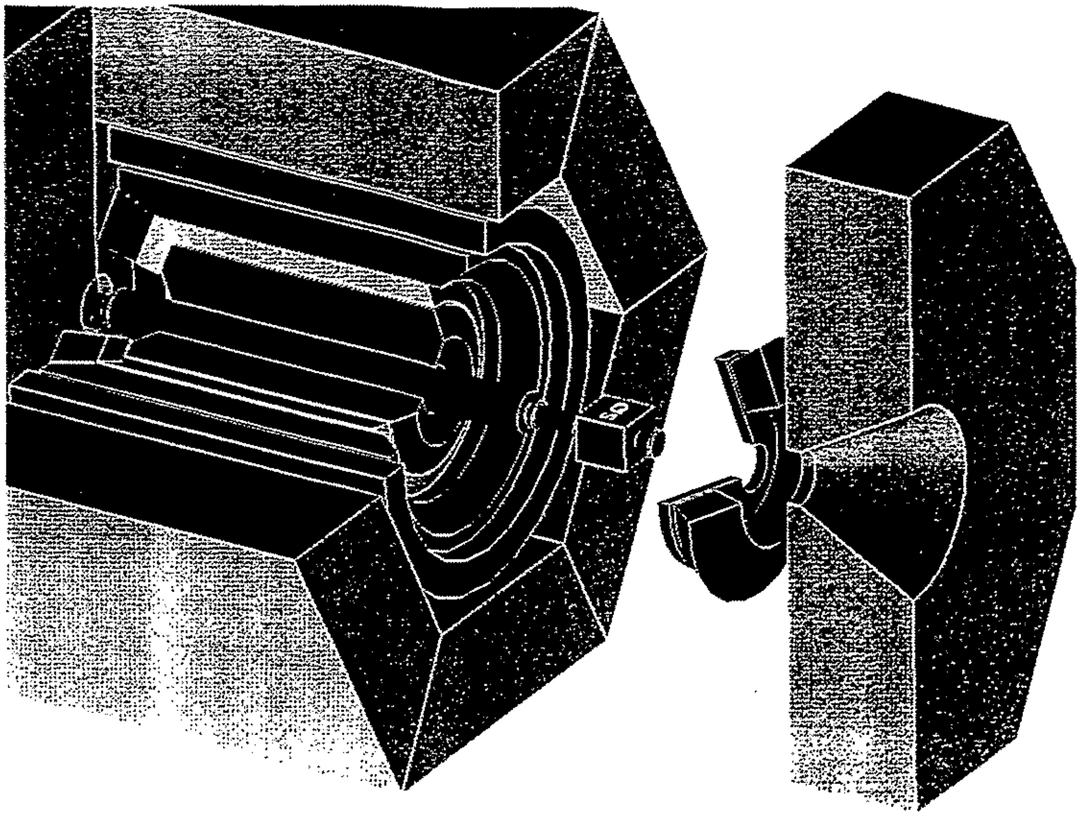
Germany [2/7]
Technische U Dresden
U Karlsruhe

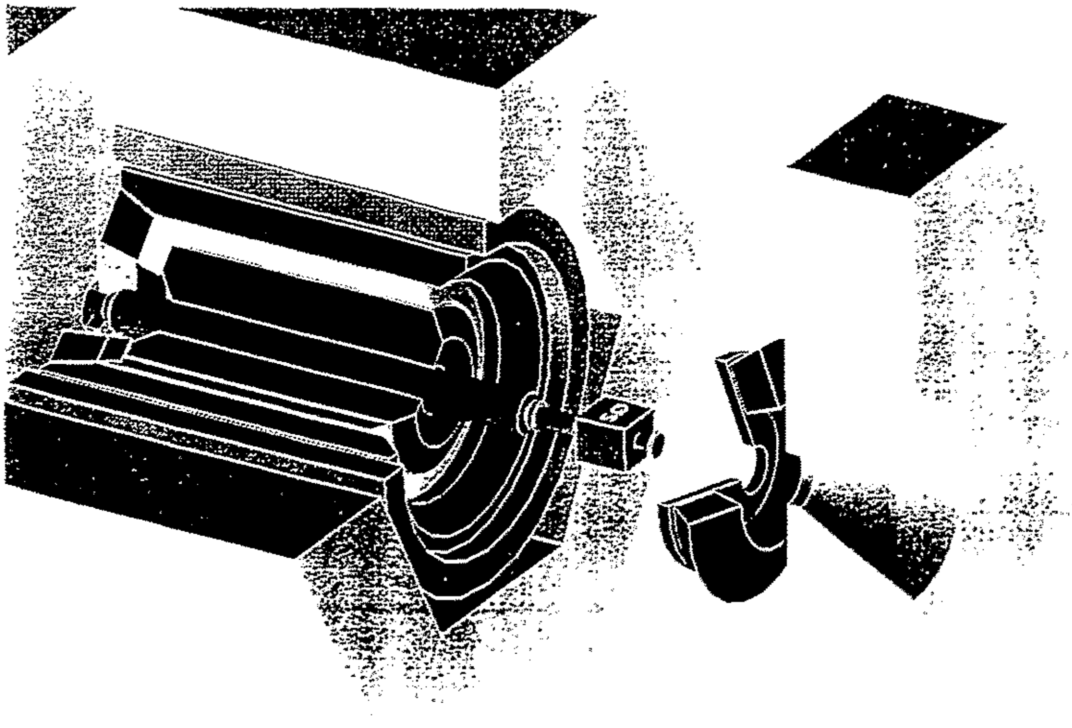
Italy [12/49]
INFN, Bari and U di Bari
INFN, Ferrara
Lab. Nazionali di Frascati dell' INFN
INFN, Genova and U di Genova
INFN, Milano and U di Milano
INFN, Napoli and U di Napoli
INFN, Padova
U di Pavia
INFN, Pisa, U di Pisa and Scuola Normale
INFN, Superiore di Sanita', Roma
INFN, Torino and U di Torino
INFN, Trieste and U di Trieste

Russia [2/40]
Budker Institute, Novosibirsk
JINR, Dubna

United Kingdom [10/30]
U of Bristol
Brunel University
U of Edinburgh
U of Lancaster
U of Liverpool
Imperial College
Queen Mary & Westfield College
Royal Holloway & Bedford New College
U of Manchester
Rutherford Appleton Laboratory

Taiwan [2/4]
Academia Sinica, Taiwan
National Taiwan U, Taiwan





ETTER OF INTENT JUNE 94 ✓
TECHNICAL DESIGN REPORT DECEMBER 94 ←

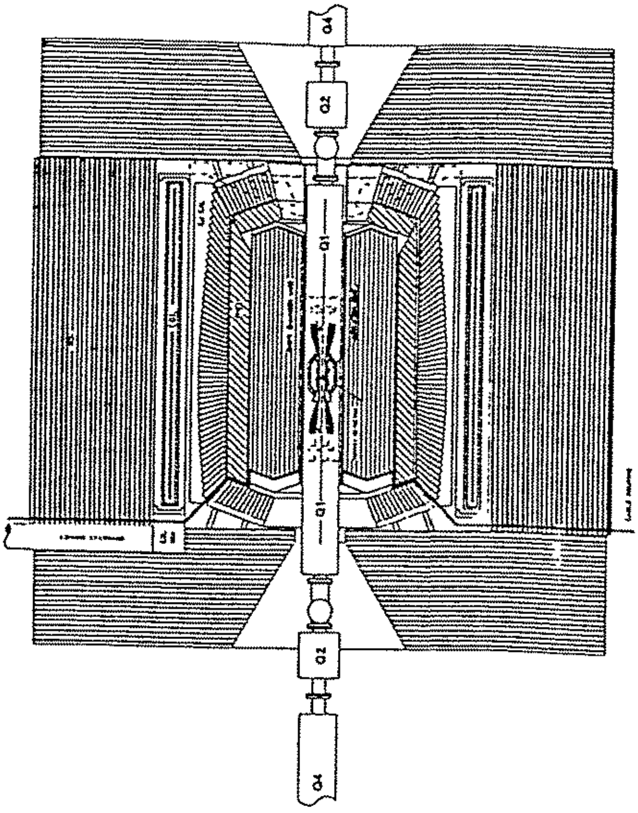
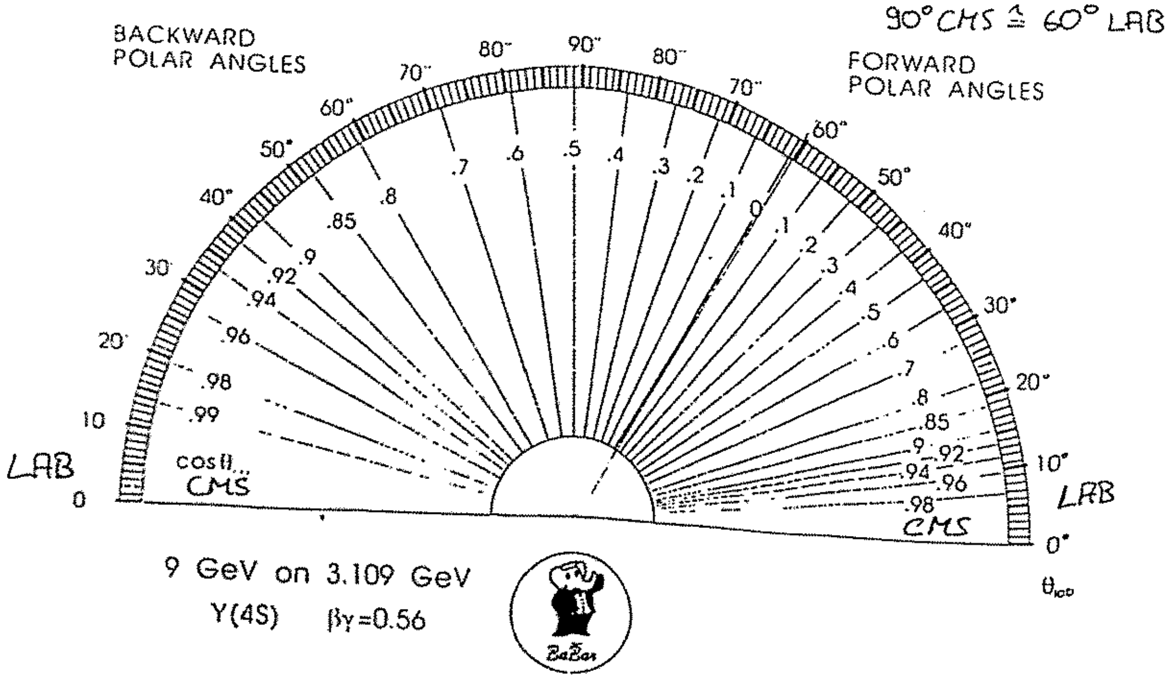


Figure 3-3. Cross-sectional view of the baseline detector showing from the beamline outward a silicon vertex detector, central tracking chamber, particle identification (PID) system, CsI calorimeter, superconducting coil, and instrumented flux return (IFR). The space allowed for the PID system can accommodate any of the three possible detector technologies: aerogel threshold counters, DIRC or Fast RICH. The detector is 6.687 m long and 3.196 m in radius at the back of the IFR, with the drift chamber displaced by 46 cm in the high-energy beam direction towards the right.

DETECTOR PROTRACTOR - γ's

90° CMS ≙ 60° LAB



Introduction

- ☐ An experiment to measure *CP*-violating asymmetries at PEP-II represents some novel experimental challenges
  - ○ The detector should be asymmetric to maximize solid angle coverage in the CMS
  - ○ There is a premium on vertex resolution along the beam (z direction) as well as in the more conventional transverse plane (r-ϕ direction)
  - ○ Reconstruction efficiency and invariant mass resolution must be optimized: exclusive state reconstruction is the heart of the matter. This requires the best possible charged particle momentum and photon energy and angular resolution over a wide dynamic range
  - ○ Particle identification (π, K, p, e, μ) over a wide range of momentum is required, as many interesting modes have small branching ratios and kinematic separation is insufficient
  - ○ Rates are high (for an e^+e^- experiment) and machine-related backgrounds may be formidable. Radiation damage is an issue
  - ○ Large amounts of experimental and Monte Carlo data must be handled, on-line, and particularly, offline

General Considerations

- ☐ The average charged particle multiplicity is ~10
- ☐ The average photon multiplicity is ~10
- ☐ The average charged particle momentum is less than 1 GeV/c
  - ○ Multiple coulomb scattering must be held to a minimum
    - ◆ Helium-based drift chamber gases have a radiation length 5 times longer than conventional argon-based gases
    - ◆ Aluminum wires can reduce mass
    - ◆ Low mass drift chamber end plates are important
- ☐ The average photon momentum is even lower : < 0.5 GeV/c
  - ○ High efficiency for photon energies down to a few tens of MeV is important for overall reconstruction and tagging efficiency
    - ◆ Low noise in the electromagnetic calorimeter is important
    - ◆ Material in front of the calorimeter, particularly in the particle ID system, must be held to a minimum
  - ○ Segmentation in the calorimeter is determined by the required angular resolution more than by overlap considerations

General Considerations (continued)

☐ The average distance between the B^0 decay vertices is 250 μm
  ○ Excellent vertex resolution, particularly in the *z* direction, is of paramount importance

☐ Continuum event background typically has a single vertex; tagged *CP* eigenstate events have 2 to 4 vertices

☐ Particle identification capability must extend up to ~4.5 GeV/c in the forward direction for *B* events, up to ~6 GeV/c for τ events

  ○ *dE*/*dx* and time-of-flight techniques may suffice in the barrel region; some Cerenkov-based technique is likely to be required in the forward direction

☐ Extending muon identification to the lowest practical momentum increases tagging efficiency and reconstruction efficiency for τ's and *B* semileptonic decays
  ○ Flux return should be segmented

☐ Calorimetrizing the flux return also allows detection of K_L^0. This improves reconstruction efficiency for several interesting *CP* modes, *e.g.* $B_d^0 \to J/\psi K_L^0$ as well as $B_d^0 \to J/\psi K_S^0$

General Considerations (continued)

☐ Radiation hardness of the vertex detector and end cap particle ID and calorimeter systems is an important question

☐ At a luminosity of 10^{34}, the physics rate is ~10 Hz/nanobarn

☐ At the initial design luminosity of 3×10^{33} the physics rate, including Bhabhas, exceeds 100 Hz

  ○ A pipelined data acquisition system with tiered trigger levels appears to be the approach of choice

☐ A computing capacity of the order of 10^4 MIPS is required

☐ A storage capacity of the order of 50 terabytes/year is required

CONCLUSIONS

- RICH AND EXITING PHYSICS PROGAM :

  $\not{CP}$ AND MUCH MORE

- MATURE AND CONSERVATIVE MACHINE DESIGN ;

  COMPLETED VERY EXTENSIVE R&D PROGRAM ON ALL CRITICAL COMPONENTS ;

  PROCUREMENT AND INSTALLATION PROCEEDING ON SCHEDULE

- VITAL AND ACTIVE DETECTOR COLLABORATION ;

  DETECTOR DESIGN WELL ADVANCED ;

  TECHNICAL DESIGN REPORT DUE IN DECEMBER

  CONSTRUCTION TO START SOON THEREAFTER ,

  TO BE COMPLETED FALL 1998

B-PHYSICS AT HERA-B AND LHC

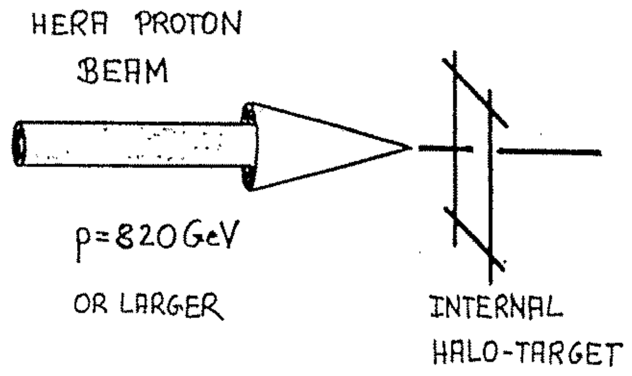
PRESENTED BY

THOMAS LOHSE

HUMBOLDT-UNIVERSITÄT

- HERA-B : DESIGN
  - CP REACH
  - OTHER B-PHYSICS
- CP VIOLATION IN THE LHC ERA

FROM HERA-B ...



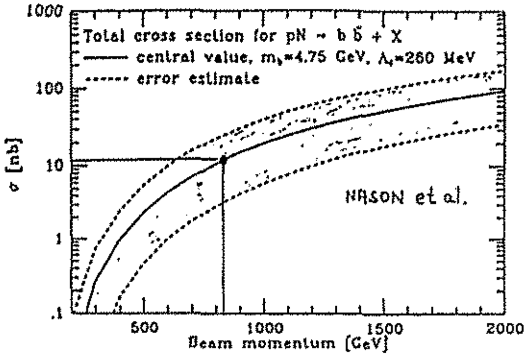
AN EXPERIMENT TO STUDY $\not{CP}$ IN THE B-SYSTEM USING AN INTERNAL TARGET AT THE HERA PROTON RING

PRESENT COLLABORATION

HUMBOLDT-UNIV. BERLIN
UNIV. DORTMUND
DESY
UNIV. HAMBURG
MPI HEIDELBERG
UNIV. HEIDELBERG
INR KIEV
UNIV. LJUBLJANA
U.C. LOS ANGELES
UNIV. MANNHEIM
UNIV. MASSACHUSETTS, AMHERST
ITEP MOSCOW
MPEI MOSCOW
UNIV. TEXAS, AUSTIN

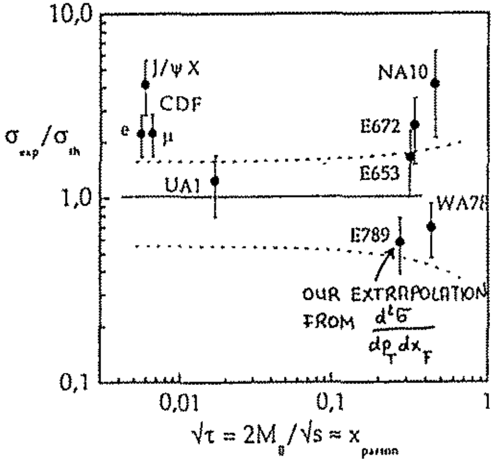
I.f.H. ZEUTHEN

$b\bar{b}$ cross section



● πN cross section dominated by quark fusion

● $p N$ cross section dominated by gluon fusion



CP Reach

Statistics

$a_{obs} = D_{Tag}\, D_{CP} \sin(2\beta)$ $\quad D_{CP} \approx 0.6$

$\Delta a_{obs} = (1/N)^{1/2}$ $\quad D_{Tag} \approx 0.4$

$\Delta\sin(2\beta) = 1/D_{Tag}\, D_{CP} \sqrt{N}$

for $\Delta\sin(2\beta) \approx 0.1$ need $\approx$1000 evts.

Event Rates

$\sigma_{bb}/\sigma_{inel}$	$\approx 5 \cdot 10^{-7}$
$2P_{b \to B^o}$	≈ 0.8
$Br(B^o \to J/\Psi\, K_S)$	$\approx 5 \cdot 10^{-4}$
$Br(J/\Psi \to e^+e^-/\mu^+\mu^-)$	≈ 0.12
$Br(K_S \to \pi^+\pi^-)$	≈ 0.69
	$\approx 10^{-11}$
trigger, reconstruction, tagging efficiency	$\approx 10^{-1}$
	$\approx 10^{-12}$

for 1000 tagged events,
need $\approx 10^{15}$ interactions,
or $3 \cdot 10^{7}$ sec. @ 30 MHz rate !

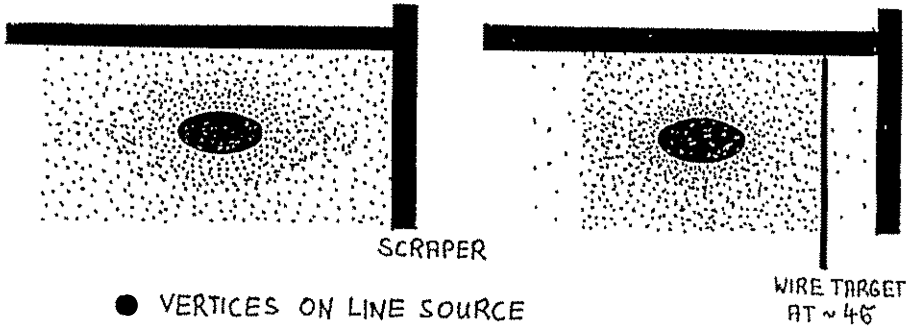
Machine

HERA BX $\approx$ 10 MHz
$\Rightarrow$ multiple interactions per BX !

Natural beam loss $\approx$ 100 MHz
$\Rightarrow$ rate ok with efficient target !

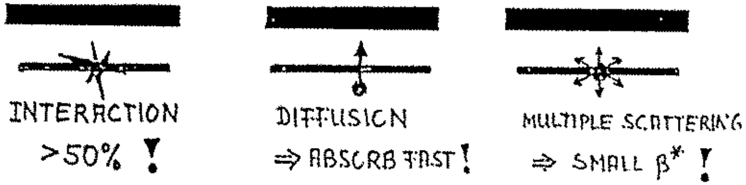
INTERNAL TARGET

- THIN WIRES (RIBBONS) IN BEAM HALO

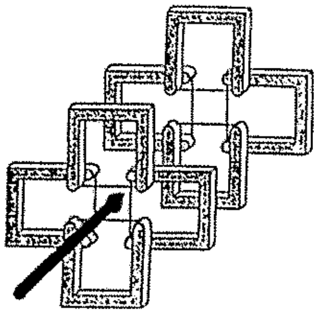


- VERTICES ON LINE SOURCE
- STABLE PROTONS ≈ UNTOUCHED ($\mathcal{L}_{ep}$ ✓)
- EFFICIENT COMPETITION WITH SCRAPERS NEEDED

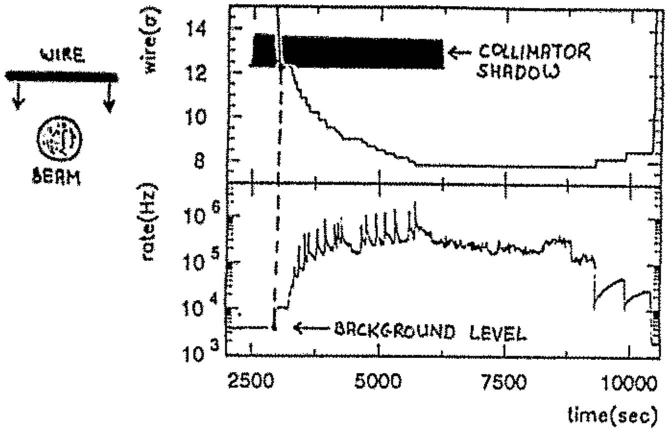
- LOSS MECHANISMS



- POSSIBLE DESIGN



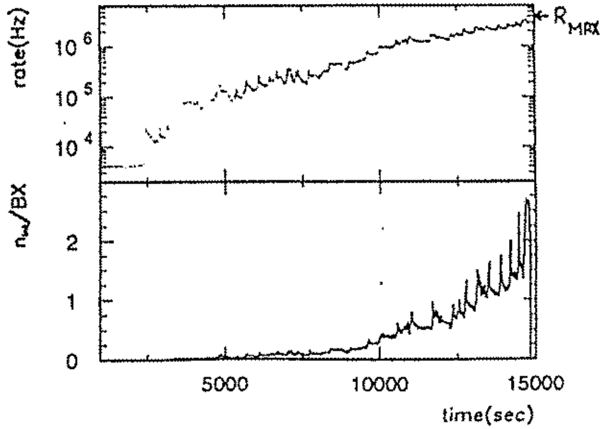
TARGET WIRE SCANS:



HIGH RATE SCAN:

$$R_{MAX} = \frac{1\ \text{TRIGGER}}{BX} \underset{\substack{\uparrow \\ 84\ \text{BUNCHES}}}{=} 4\,MHz$$

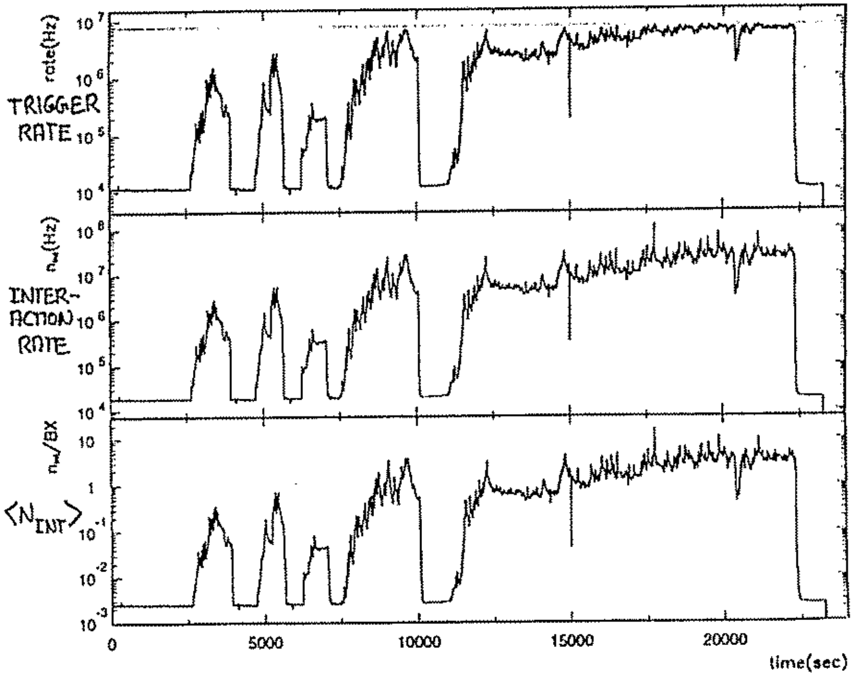
$$R_{TRIG} = R_{MAX} \cdot \left(1 - e^{-\epsilon \langle n_{Int} \rangle}\right)$$



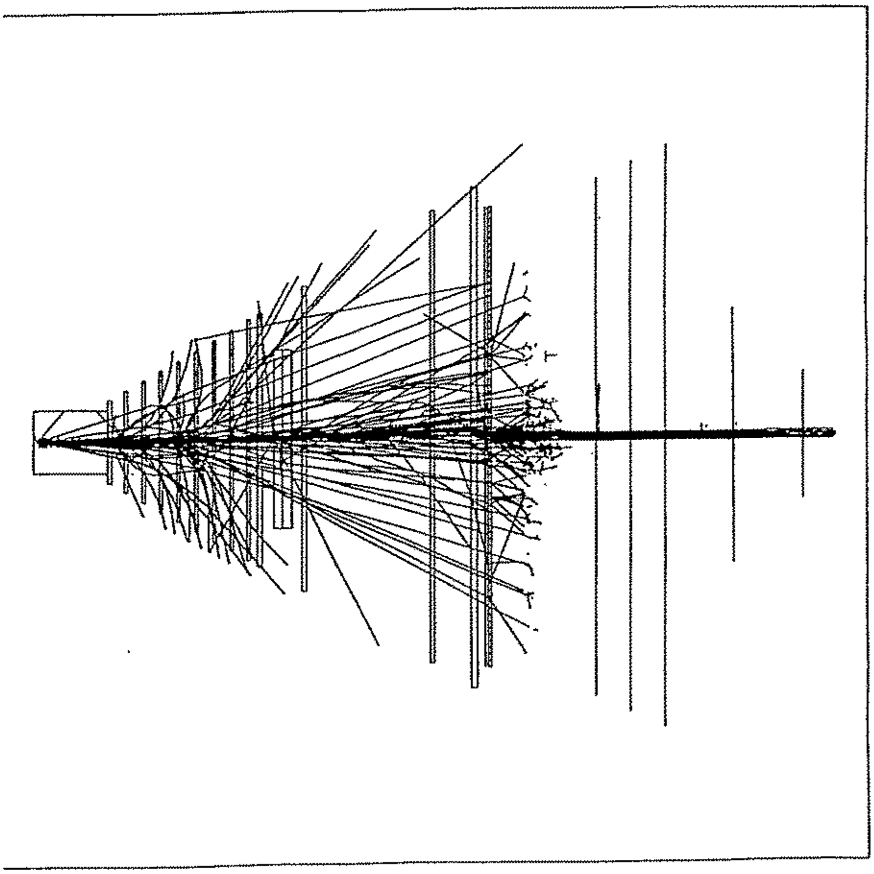
UP TO 2.5
INTERACTIONS
PER BX
ACHIEVED

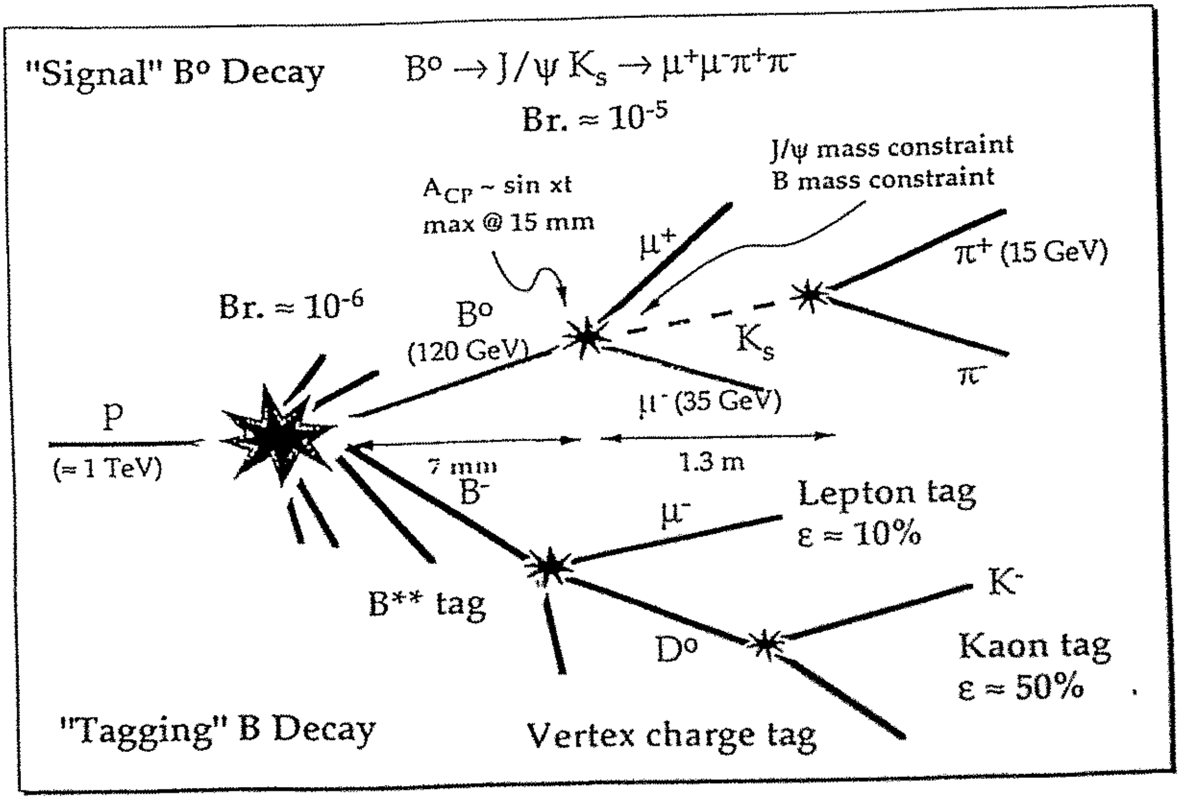
HIGH RATE SCAN 1994

170 BUNCHES
1/3 DESIGN-CURRENT



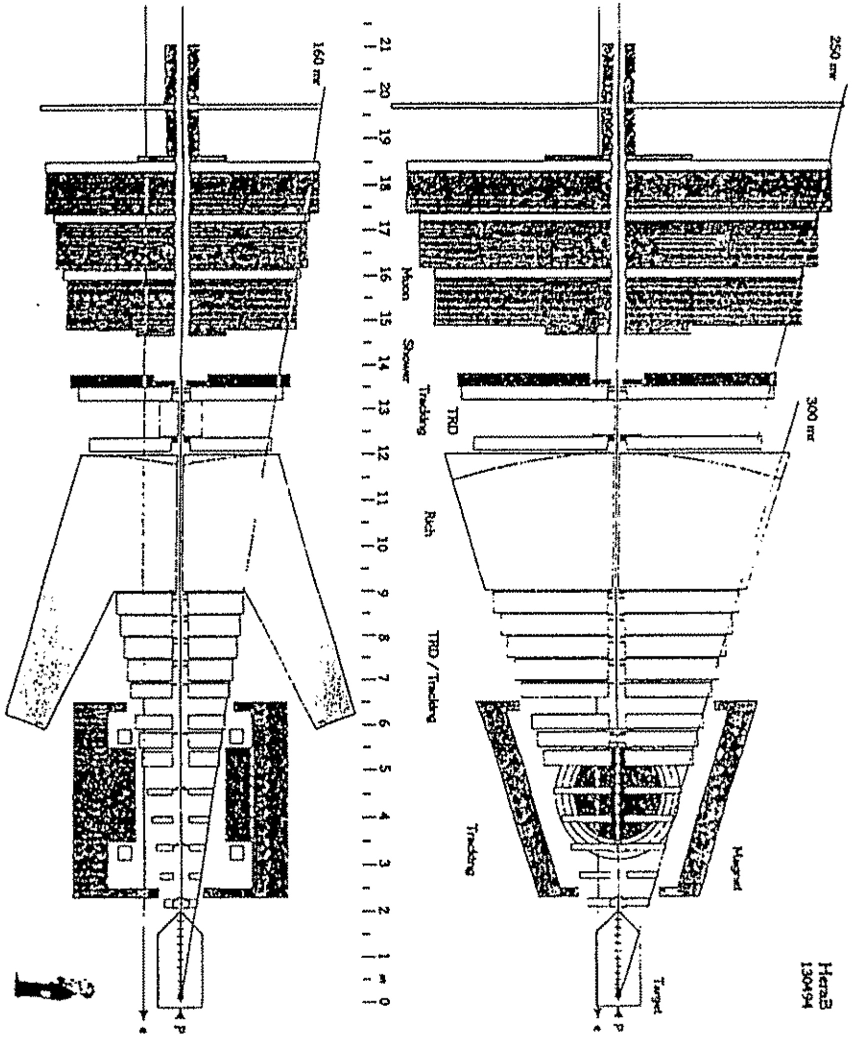
30 MHz INTERACTION RATE
4 INTERACTIONS PER BX



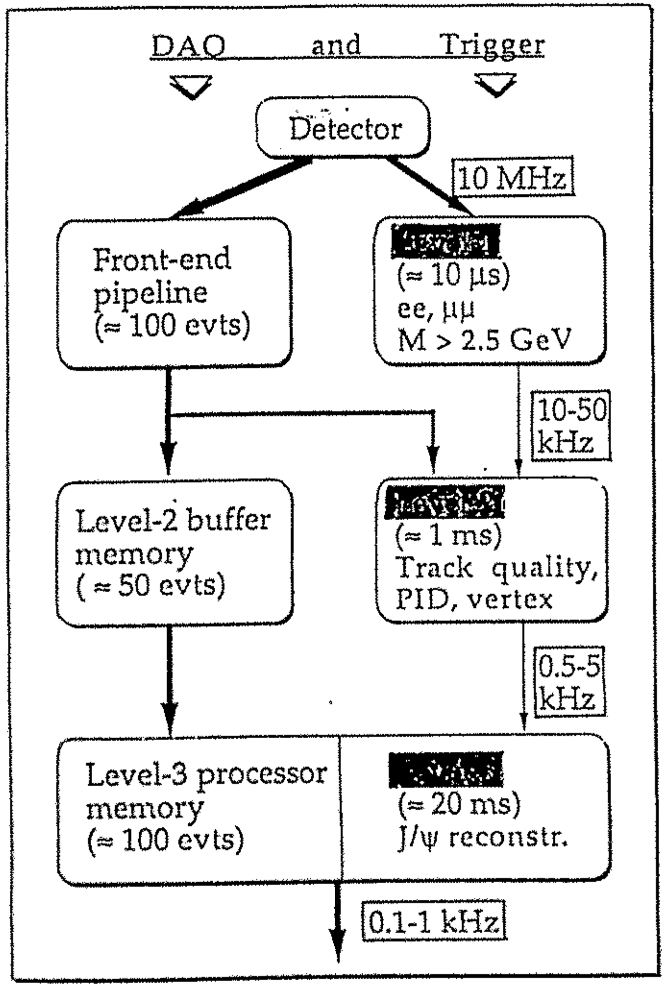

"Signal" B° Decay
$B^o \to J/\psi K_s \to \mu^+\mu^-\pi^+\pi^-$
Br. ≈ 10^{-5}
J/ψ mass constraint
B mass constraint
A_{CP} ~ sin xt
max @ 15 mm
μ^+
π^+ (15 GeV)
Br. ≈ 10^{-6}
B°
(120 GeV)
K_s
π^-
μ^- (35 GeV)
p
(≈ 1 TeV)
7 mm
1.3 m
B^-
μ^-
Lepton tag
ε ≈ 10%
B** tag
K^-
Kaon tag
ε ≈ 50%
D°
"Tagging" B Decay
Vertex charge tag

REQUIREMENTS FOR THE B-DETECTOR

- ► FORWARD SPECTROMETER, LARGE ACCEPTANCE
- ► HIGH-MULTIPLICITY CAPABILITY (~50 TRACKS/BX)
- ► FAST (EVENT RATE = ν_{BX} = 10 MHz)
- ► B-VERTEX RECONSTRUCTION
- ► e, μ IDENTIFICATION
- ► $K^{\pm}$ IDENTIFICATION
- ► RADIATION HARDNESS



Trigger Concept



DAQ and Trigger

Detector

10 MHz

Front-end pipeline (≈ 100 evts)

Level-1 (≈ 10 µs) ee, µµ M > 2.5 GeV

10-50 kHz

Level-2 buffer memory (≈ 50 evts)

Level-2 (≈ 1 ms) Track quality, PID, vertex

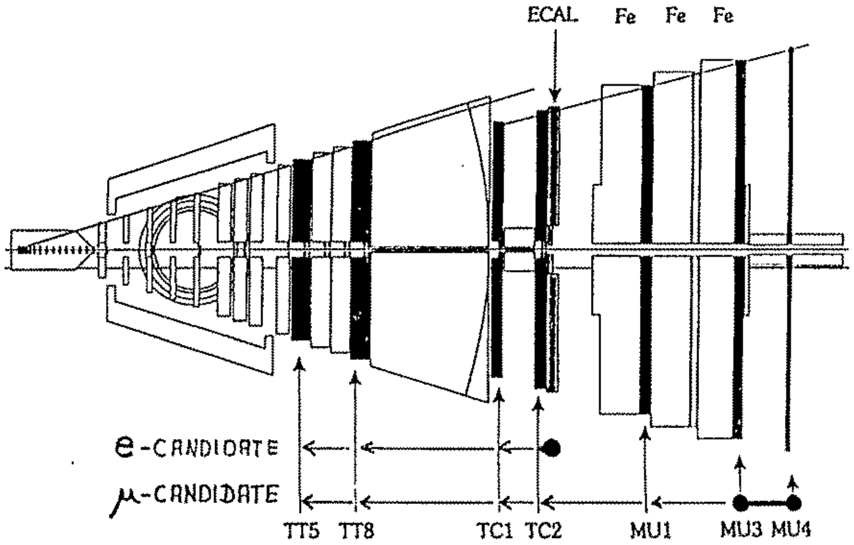
0.5-5 kHz

Level-3 processor memory (≈ 100 evts)

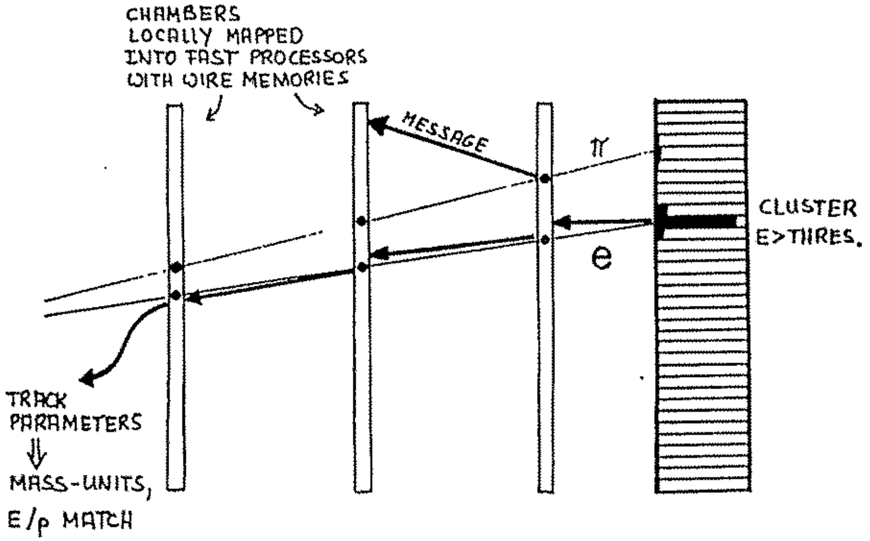
Level-3 (≈ 20 ms) J/ψ reconstr.

0.1-1 kHz

DESIGN OF THE LEVEL-1 TRIGGER

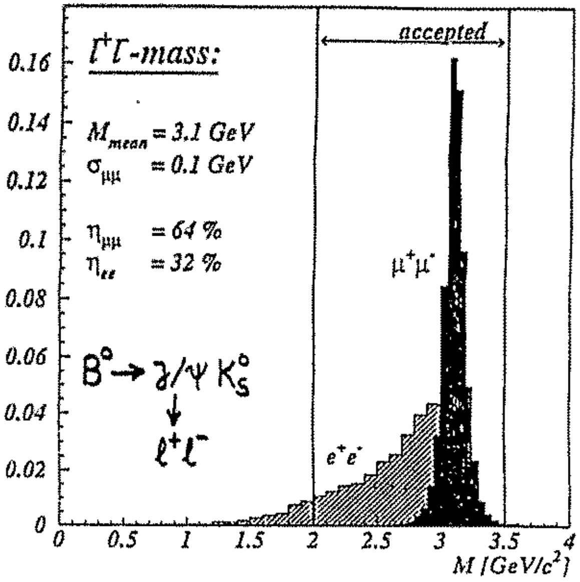


TRACK-TINDING PHILOSOPHY ("KALMAN TILTERING")

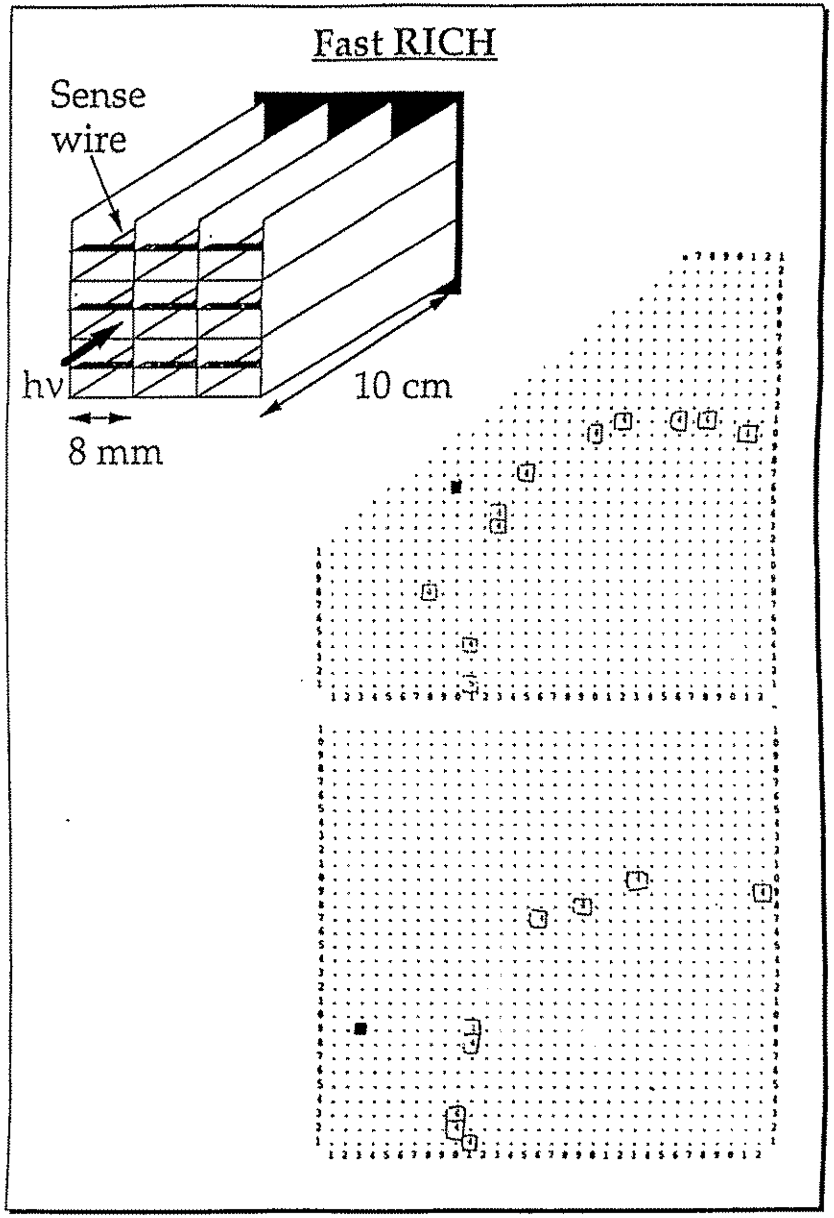


TRIGGER PERFORMANCE

A. ACCEPTING SIGNAL – EFFICIENCY

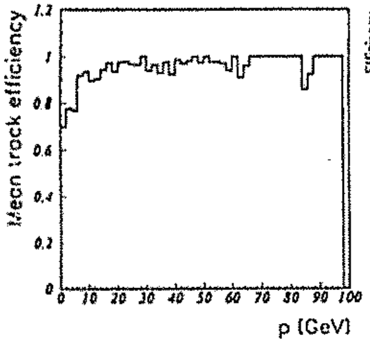


	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
GEOMETRY	71%	70%
P,E-CUTS	90%	50%
$M(l^+l^-)$ CUTS	>99%	91%
EFFICIENCY	63%	32%

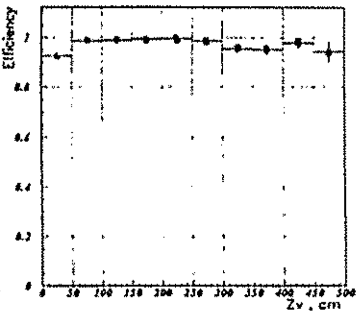


[Pattern Recognition]

Track efficiency:



K_S^0 vertex efficiency:



Combined multi-track efficiencies for $B - J/\psi K_S^0$ decay products	
TRD/Tracker+MSGC ($\ell^+\ell^-\pi^+\pi^-$)	$\epsilon = 90\%$
Silicon ($\ell^+\ell^-$)	$\epsilon = 98\%$
K_S^0 reconstruction	$\epsilon = 97\%$

CP REACH

[ASSUME $\sigma_{b\bar{b}}$ = 12nb/NUCLEON
σ_{pCu} = 13mb/NUCLEON]

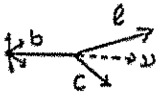
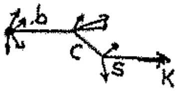
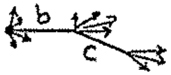
I. $B_d^0 \rightarrow J/\psi K_S^0$ STATISTICS

SUPPRESSION	$J/\psi \rightarrow \mu^+\mu^-$	$J/\psi \rightarrow e^+e^-$
$\sigma_{b\bar{b}} / \sigma_{tot}$	$9.2 \cdot 10^{-7}$	$9.2 \cdot 10^{-7}$
BR	$1.7 \cdot 10^{-5}$	$1.7 \cdot 10^{-5}$
TRIGGER	0.63	0.32
TRACKING	0.54	0.54
LEPTON ID	0.94	0.85
J/ψ, B_d^0 REC.	0.95	0.66
KINEMATICS CUTS	0.80	0.80
VERTEX CUT	0.69	0.69
TOTAL SUPPR.	$2.6 \cdot 10^{-12}$	$0.6 \cdot 10^{-12}$
10^7s (~1YEAR) @ 40MHz	1030 EVENTS	330 EVENTS

$\delta \sin(2\beta)$ WITH PERFECT TAG	0.041

TAGGING DILUTION

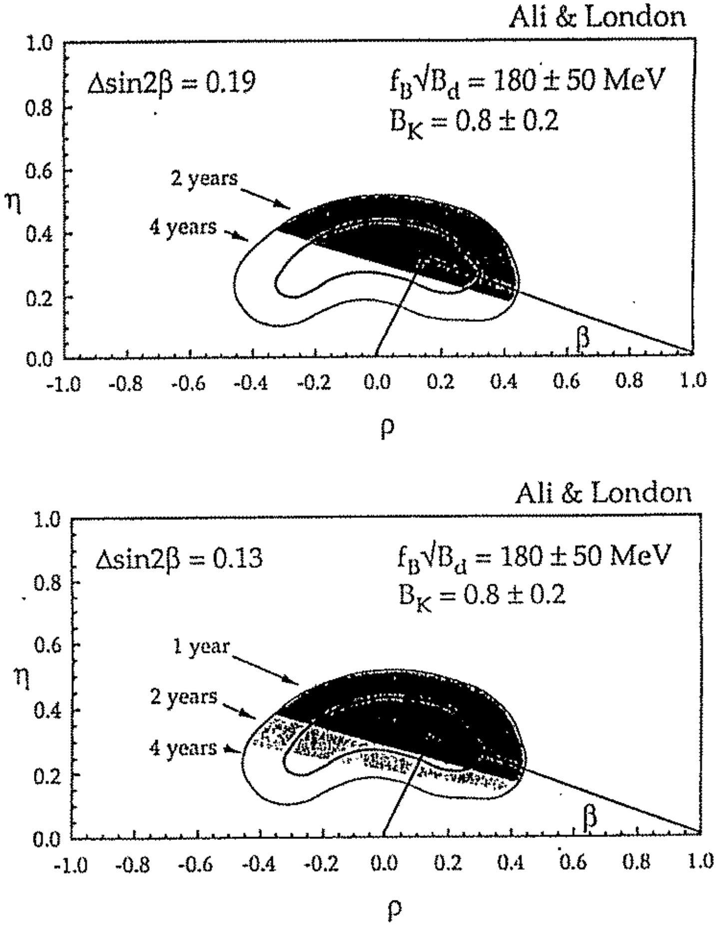
[CUTS ON p, p_t, VERTEX DISTANCES]

TAG	LEPTON	KAON	CHARGE
	 $\boxed{\mathrm{sign}(q_\ell)}$	 $\boxed{\mathrm{sign}(q_K)}$	 $\boxed{\mathrm{sign}(\sum_i q_i p_i)}$
ϵ	16.1%	46.0%	96.4%
CORRECT	11.5%	31.3%	56.0%
WRONG	4.6%	14.7%	40.4%
DILUTION $D=\frac{C-W}{C+W}$	0.43	0.36	0.16
TAGGING POWER $\mathcal{P}=D\cdot\sqrt{\epsilon}$	0.17	0.24	0.16
		0.31	

10^7s @ 40 MHz $\Longrightarrow$ $\boxed{\delta\sin(2\beta) = 0.13}$

CP Discovery Potential of HERA-B

(4-σ effect)



"Borrowed" from LHC R&D:

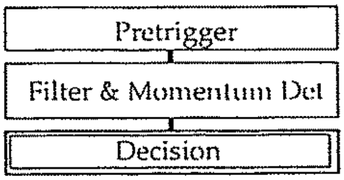
- Radiation-hard silicon detectors
- MSGC
- Straw chamber tracker/TRD
- Honeycomb wire chambers
- Shashlik calorimeter

- Si front-end electronics and pipelines
- DC front-end electronics
- Optical links
- DAQ architecture
- Fast data links (HIPPI, SCI...)
- Level-2 implementation

HERA-B will be the first field-test for many of these components and concepts!

... close collaboration with LHC R&D groups!

Other Physics Topics - Additional Triggers

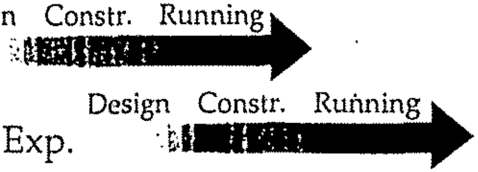


Trigger	$B \to J/\psi X \to l^+l^- X$ (CP Violation)	$B_1B_2 \to l_1l_2X$ (B Mixing, CKM...)	$B \to l_1CX \to l_1l_2X$ (Charm Mixing, CKM)	$B \to lX$ (Inclusive B)	$C_1C_2 \to l_1l_2X$ (Charm)
"J/ψ" (e^+e^-, $\mu^+\mu^-$, $M > 2.5$ GeV)	48%	9%	4%	–	0.05%
"Dilepton" ($\mu\mu$, $e\mu$, e^+e^-, $p_t > 1...1.2$ GeV)	25%	18%	2%	–	0.01%
"Single lepton" (e,μ, $p_t > 2.5...3$ GeV)	9%	7%	5%	4%	–
Total FLT Efficiency	50%	29%	9%	4%	0.06%
Events/year	260 k	1400 k	380 k	3200 k	>> M

Schedule

- Aggressive !
- October 94 Open Collab. Meeting
  Freeze detectors and resp.
- 95/96 Modify optics
  Install magnet
  Install prototype detectors
- 96/97 Install parts of inner detectors,
  First level trigger
- 97/98 Install remaining components
- 98 Commissioning

- 0? Continuation of B physics
  program at LHC



HERA-B: Design Constr. Running

LHC B Exp.: Design Constr. Running

... INTO THE LHC ERA

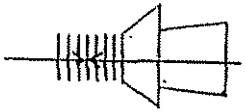
EXPERIMENT	E_{BEAM}	$\sqrt{s}$	$\sigma_{b\bar{b}}$	$\frac{\sigma_{b\bar{b}}}{\sigma_{tot}}$
HERA-B	820GeV	40GeV	10nb	10^{-6}
LHC FIXED TARGET	8 TeV	630GeV	15μb	$2\cdot10^{-5}$
LHC COLLIDER	8 TeV	16TeV	500μb	$7\cdot10^{-3}$

THE ACTORS:

1) "CENTRAL" COLLIDER (MULTI-PURPOSE)

ATLAS
CMS

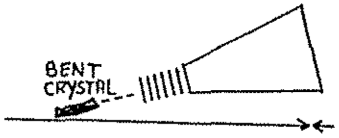
2) "FORWARD" COLLIDER (B-DEDICATED)



COBEX

3) FIXED TARGET (B-DEDICATED)

GAJET



LHB

SHOW-DOWN: LHCC COMMITTEE , 8.6.1994

► LHB:
- VERTEXING +++
- ACCEPTANCE +++
- EXTRACTION −

► GAJET:
- TRIGGER +++
- TECHNOLOGY +
- VERTEXING −

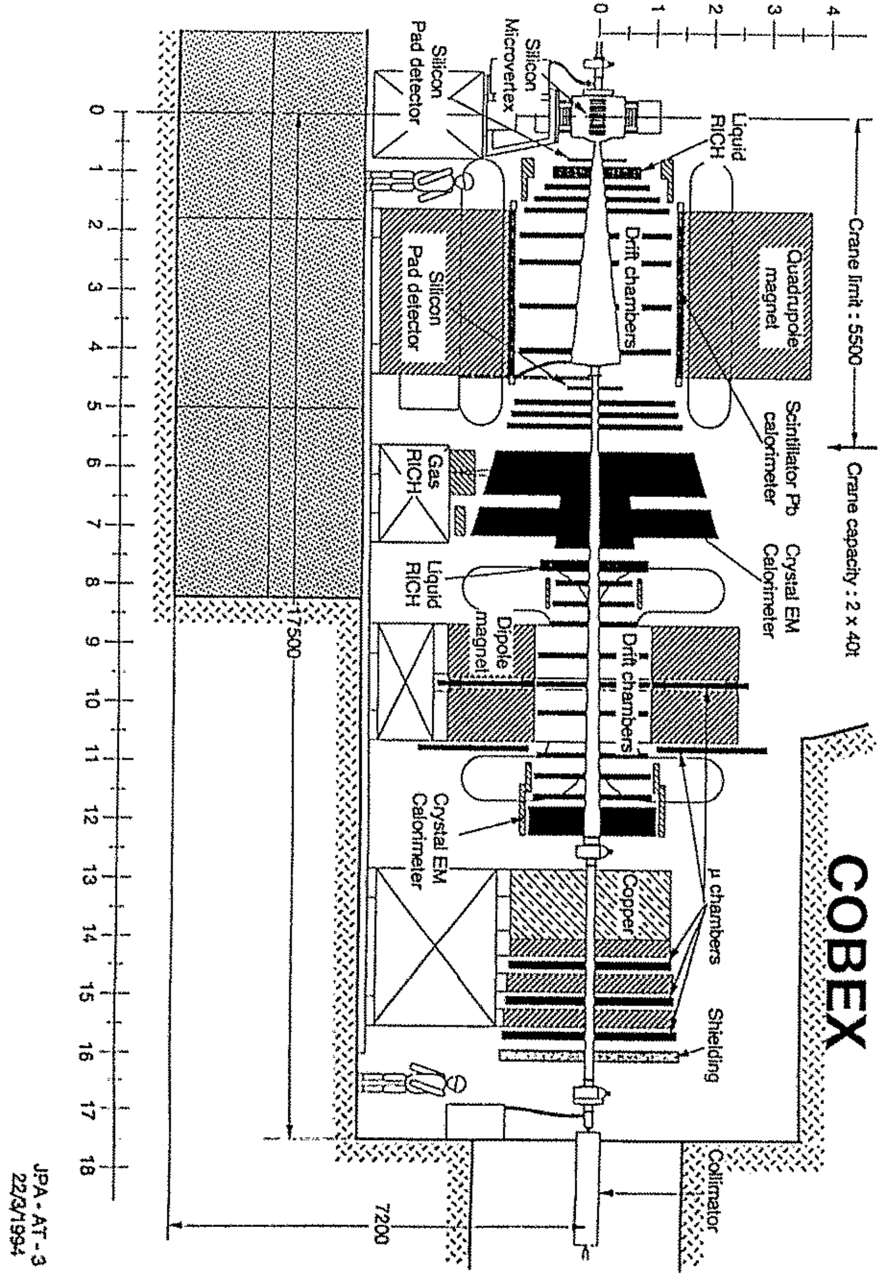
► COBEX:
- CROSS-SECTION +++
- VERTEXING ++
- FLEXIBILITY ++
- DETECTOR DESIGN −

COLLIDING BEAM RECOMMENDED

⇒ CERN WANTS COLLIDER B-DETECTOR ON DAY 0!

NEW DESIGN:

$$\text{LHC-B} = \begin{cases} \text{COBEX} \\ \text{GAJET} \\ \text{LHB} \\ \text{PARTS OF HERA-B} \\ \text{OTHERS} \end{cases}$$



JPA - AT - 3
22/3/1994

CP REACH AT LHC

RUN TIME : 10^7 s (= 1 YEAR)

LUMINOSITY: 10^{33} cm^{-2}s^{-1} (POSSIBLY DETUNED FOR LHC-B)

TYPE	$B^0 \rightarrow J/\psi K^0_S$ $\delta(\sin 2\beta)$	$B^0 \rightarrow \pi^+\pi^-$ $\delta(\sin 2\alpha)$
CENTRAL COLLIDER	~ 0.05	~ 0.12
FORWARD COLLIDER	~ 0.01	~ 0.03

$\mathcal{L} < 5 \cdot 10^{31}$ cm^{-2}s^{-1} $\Rightarrow$ "TOPOLOGY" (VERTEX) TRIGGER FEASIBLE (COBEX)

↓

GENERAL B-TRIGGER ; RICH $\not{CP}$ AND NON-$\not{CP}$ B-PHYSICS PROGRAM

CONCLUSIONS

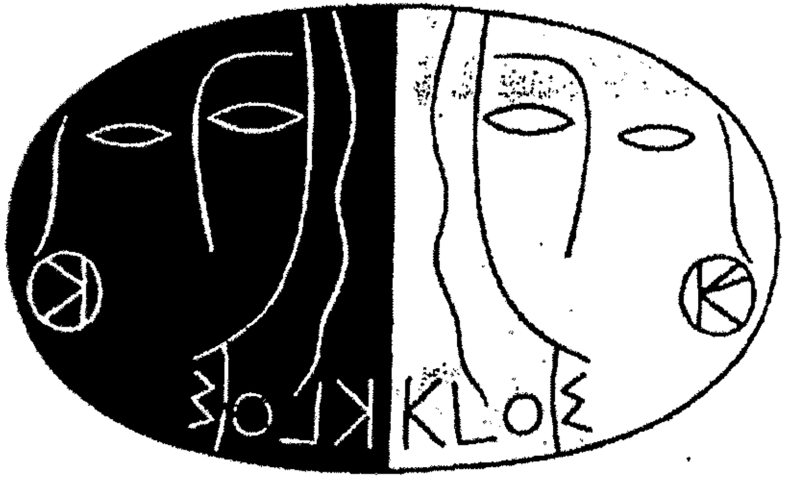
- HERA-B IS A PIONEERING EXPERIMENT
  - FIRST HADRONIC B-FACTORY
  - FIRST GENERATION $\not{CP}$ EXPERIMENT
  - RICH NON-$\not{CP}$ PHYSICS PROGRAM
  - FIRST APPLICATION OF LHC TECHNOLOGIES
  - NECESSARY PREPARATION FOR LHC-B
- LHC GENERAL PURPOSE EXPERIMENTS

  VERY GOOD $\not{CP}$ REACH BUT 2^{ND} GENERATION
- LHC-B: DEDICATED FORWARD COLLIDER DETECTOR READY AT START-UP
  - VERY RICH B-PHYSICS PROGRAM
  - BY FAR MOST POWERFUL $\not{CP}$-EXPERIMENT
  - WILL GOVERN $\not{CP}$-MARKET FOR MANY YEARS TO COM

L. FOA (RESEARCH DIRECTOR, CERN):

"HERA-B AND LHC-B REPRESENT THE SAME LINE OF RESEARCH, STARTING AT DESY AND CONTINUING AT CERN" (SUMMER 1994)

PIRNA, 6. OKTOBER '94



Das DAΦNE-Projekt

M. BILLICH, A. DENIG, U. VON HAGEL, M. IMHOF,
W. KLUGE, S. WESELER, R. WIESER, A. ZOTT

I. Der Teilchenbeschleuniger DAΦNE

II. Untersuchung diskreter Symmetrien/
CP-Verletzung

III. Übriges physikalisches Programm

IV. Detektoren (KLOE u. FINUDA)

V. Karlsruher Beiträge

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$\boxed{\text{DAΦNE*}}$

$$\text{*}\underbrace{\underline{D}\text{ouble }\underline{A}\text{nnular}}\ \underline{\Phi}\text{-factory for }\underline{N}\text{ice }\underline{E}\text{xperiments}$$

- 2 getrennte Speicherringe für Positronen und Elektronen

⇒ Große Anzahl von Bunches möglich (h_{max}=120)

⇒ Dadurch läßt sich eine hohe Gesamtluminosität von $\boxed{L \approx 1 \bullet 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}}$ erreichen, bei sonst durchaus konventionellen Designparametern:

- Der Umfang der Hauptspeicherringe beträgt 95 m.
- Maximale Teilchenzahl pro bunch: $\boxed{8{,}9 \bullet 10^{10}}$
- Horizontale Kollision unter 10 mrad in der WW-Zone
- Strahldimensionen in den Wechselwirkungszonen:

$$\boxed{\sigma_z : \sigma_y : \sigma_x = 30 : 2{,}11 : 0{,}021\,[\mathrm{mm}]}$$

(flacher Strahlquerschnitt)

⇒ Die Zeit zwischen den Bunch-Kollisionen ist mit ≈ 3 ns allerdings <u>außerordentlich kurz</u> !

⇒ Vorgeschalteter Akkumulatorring (Umfang 30 m) sammelt die vom LINAC kommenden Teilchen.

⇒ Beschleunigung von e^- auf 250 MeV mittels LINAC
Elektronen-Positronen-Konverter zur e^+-Erzeugung
Zweiter LINAC zur Beschleunigung auf die Endenergie von 510 MeV (±220 keV in den Hauptspeicherringen).

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- DAΦNE-Strahlenergie: $E(e^\pm) = 510 \pm 0{,}2$ MeV

Luminosität $L = 1 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$
zwei Wechselwirkungszonen
$\sigma_{tot}(e^+e^- \Rightarrow \phi(1020)) = 4{,}4\ \mu\text{b}$

⇒≈ 5000 φ -Mesonen/sec

⇒Das Φ ist ein Vektormeson ($J^{PC}=1^{--}$) und daher ein CP-Eigenzustand (EW +1) mit folgenden Zerfällen:

Zerfall (Φ⟶...)	Impuls MeV/c	Verzw.-verhältnis	Events/Jahr *) x 10^{10}	
K^+K^-	127,9	49,5%	2.50	$L_{rel.}=1$
$K_S K_L$	110	34,4%	1.70	$L_{rel.}=1$
ρπ	183	12,9%	0.70	
$\pi^+\pi^-\pi^0$	462	1,9%	0.10	OZI-unterdrückt
ηγ	362	1,3%	0.07	

⇒Wesentliche Eigenschaften der erzeugten Kaonen-Paare:

- Niederenergetisch und monochromatisch: (K^+K^- / $K^0\overline{K}^0$: 127,9±1,5 bzw. 110 MeV/c).

---

*) bei einer Luminosität von $1 \cdot 10^{33}$ cm^{-2} sec^{-1}

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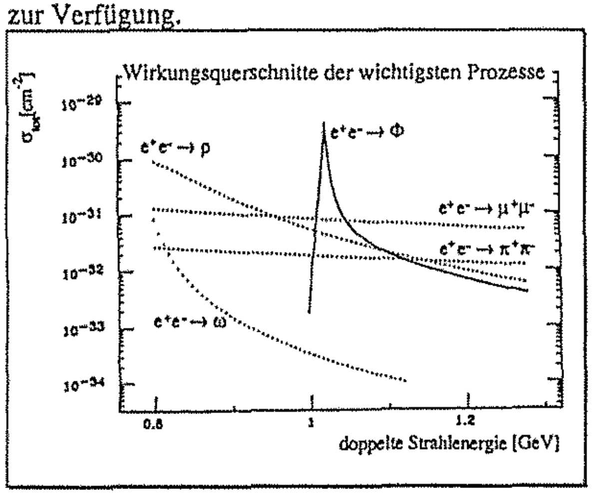
- Kohärente Erzeugung in einem 2-Teilchen-Zustand, aus dessen zeitlicher Entwicklung z.B. $\Re(\varepsilon'/\varepsilon)$ mit einer zusätzlichen Methode bestimmt werden kann.
- Durch die paarweise Erzeugung und die Ereignisstruktur stehen sowohl K_L's als auch erstmalig K_S's "getagged" zur Verfügung.



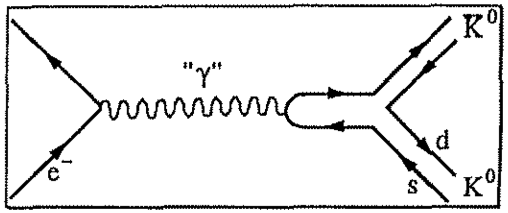
Wirkungsquerschnitte der Reaktionen $e^+e^- \to X$ bei Energien um 1020 MeV. Die Breite der Φ-Resonanz beträgt 4,43 MeV.

⇒"saubere physikalische Umgebung" bei der Φ-Resonanz:

- Der Wirkungsquerschnitt für die Reaktion $e^+e^- \to \mu^+\mu^-$ liegt bereits 2 Größenordnungen unter der Φ-Produktion.
- Untergrund durch Bhabha-Streuung (≈ 50 kHz) und kosmische Strahlung (≈ 5 kHz) kann und muß vom Trigger verworfen werden.

$K^0\overline{K}^0$-System

Das Φ-Meson wird durch elektroschwache Wechselwirkung in e^+/e^--Kollisionen erzeugt:



Der "starke" Zerfall in $K\overline{K}$-Paare ist wegen der OZI-Regel dominierend.

Das $K\overline{K}$-System*) wird durch den Hamilton-Operator

$$\boxed{H = \begin{pmatrix} h & l \\ m & n \end{pmatrix} = M + i\Gamma = \begin{pmatrix} M_{11} & M_{12} \\ M_{12}^* & M_{22} \end{pmatrix} + i\begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma_{22} \end{pmatrix}}$$

in der Basis der Strangeness-Eigenzustände $K^0 = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$ und $\overline{K}^0 = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$ beschrieben.

- Transformation der Matrizen M und Γ in dieser Basis:

  CP: $M \to \tau_1 M \tau_1$ und $\Gamma \to \tau_1 \Gamma \tau_1$ (τ_i=Pauli-Matizen), da $CP|K^0\rangle = |\overline{K}^0\rangle$ und $CP|\overline{K}^0\rangle = |K^0\rangle$.

  T: $M \to M^*$ und $\Gamma \to \Gamma^*$

- Entwicklung von M und Γ nach Pauli-Matrizen: $X \to c_0 1 + c_i \tau_i$

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*) Die Notation folgt der ausführlichen Darstellung von L. Maiani im "Daφne Physics Handbook".

Diskrete Symmetrien im K^0K^0-System

Transformationsverhalten der Entwicklungskoeffizienten:

	c_0	c_1	c_2	c_3
CP:	+	+	-	-
T:	+	+	-	+
CPT:	+	+	+	-

Daraus ergibt sich für die Matrixelemente:

- Aus CPT-Erhaltung folgt: $c_3=0 \Rightarrow c_0=M_{11}=M_{22}$ (für M). (gleiche Diagonalelemente bei CPT-Erhaltung)
- Bei CPT-Erhaltung wird CP-Verletzung nur durch den Imaginärteil der Nicht-Diagonalelemente beschrieben ! Durch die Phasentransformationen $|K^0\rangle \to e^{-i\alpha}|K^0\rangle$ bzw. $|\overline{K}^0\rangle \to e^{i\alpha}|\overline{K}^0\rangle$ ließen sich Γ_{12} und M_{12} reell machen, falls (Bedingung für CP-Invarianz:) $\boxed{\arg\left(\frac{\Gamma_{12}}{M_{12}}\right)=0}$.

Die 8 reellen Parameter von H können äquivalent durch die zwei komplexen Eigenwerte zu den Eigenzuständen von H

$$\boxed{\begin{aligned} |K_S\rangle &\approx \frac{1}{\sqrt{2}}\left[(1+(\varepsilon+\delta))\,|K^0\rangle+(1-(\varepsilon+\delta))\,|\overline{K}^0\rangle\right] \\ &\approx |K_1\rangle+(\varepsilon+\delta)\,|K_2\rangle \\ |K_L\rangle &\approx \frac{1}{\sqrt{2}}\left[(1+(\varepsilon-\delta))\,|K^0\rangle-(1-(\varepsilon-\delta))\,|\overline{K}^0\rangle\right] \\ &\approx |K_2\rangle+(\varepsilon-\delta)\,|K_1\rangle \end{aligned}}$$

$$(CP(K_2)=-1 \qquad CP(K_1)=+1)$$

Diskrete Symmetrien im K^0K^0-System

Eigenwerte: $\boxed{H|K_{L/S}\rangle=\left(M_{L/S}-\frac{i}{2}\Gamma_{L/S}\right)|K_{L/S}\rangle}$

und die komplexen Parameter ε und δ ersetzt werden.

$$\boxed{\varepsilon=\frac{-i\,\mathrm{Im}\,M_{12}+\mathrm{Im}\,\Gamma_{12}/2}{(M_S-i\,\Gamma_S/2)-(M_L-i\,\Gamma_L/2)}} \text{ bzw.}$$

$$\boxed{\delta=\frac{(M_{11}-M_{22})/2-i(\Gamma_{11}-\Gamma_{22})/4}{(M_S-i\,\Gamma_S/2)-(M_L-i\,\Gamma_L/2)}}$$

- $\delta \neq 0$ erfordert Verletzung der CPT-Invarianz in H.
- Im $M_{12} \neq 0$ beschreibt CP-Verletzung (bei gleichzeitiger T-Verletzung !) in den $\Delta S=2$-Übergängen $K^0 \Leftrightarrow \overline{K}^0$. (indirekte CP-Verletzung).
- Im $\Gamma_{12} \neq 0$ beschreibt CP-Verletzung in den ($\Delta S=1$-) Zerfallsamplituden reeller Zerfälle von K^0 und $\overline{K}^0$, z.B. für 2π-Zerfälle (direkte CP-Verletzung):

$$\boxed{\begin{aligned} A\left(K^0 \to 2\pi, I\right) &= \langle 2\pi, I|H_W|K^0\rangle \equiv A_I\, e^{i\delta_I} \\ A\left(\overline{K}^0 \to 2\pi, I\right) &= \langle 2\pi, I|H_W|\overline{K}^0\rangle \equiv A_I^*\, e^{i\delta_I} \end{aligned}}$$

(bei CPT-Invarianz; δ_I = Phasen der π-π-Streuung)

wobei sich CP-Verletzung ($A_I \neq A_I^*$) als Imaginärteil der Matrixelemente von Γ ausdrückt, da:

$$\Gamma_{ab}=\sum_n 2\pi\,\delta\left(M_K-E_n\right)\langle a|H_W|n\rangle\langle n|H_W|b\rangle$$

Diskrete Symmetrien im K^0K^0-System

- Da die Zustände $|K^0\rangle$ und $|\bar{K}^0\rangle$ bis auf eine Phase bestimmt sind, kann durch Neudefinition dieser Phase eine Amplitude reell gemacht werden:

$$\boxed{A_0 = \text{reell} \geq 0} \qquad \text{(Wu-Yang Konvention)}$$

Direkte CP-Verletzung ist dann gleichbedeutend mit einer von Null verschiedenen relativen Phase von A_0 und A_2:

$$\boxed{\varepsilon' = \frac{i e^{i(\delta_2-\delta_0)}}{\sqrt{2}} \frac{\operatorname{Im} A_2}{A_0}}$$

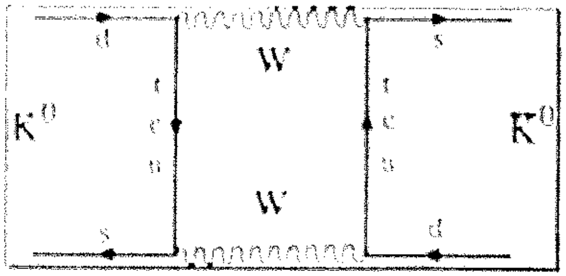
Beschreibung der CP-Verletzung im Standardmodell:

Die schwache Wechselwirkung zweier Quarks (ab → cd) wird im Standardmodell durch die Amplitude:

$$\boxed{\mathcal{M} \sim J^\mu_{ca} J^\dagger_{\mu db} = U_{ca} U^*_{db} \left(\bar{u}_c \gamma^\mu \left(1-\gamma^5\right) u_a\right) \left(\bar{u}_d \gamma_\mu \left(1-\gamma^5\right) u_b\right)}$$

beschrieben, die Elemente der CKM-Matrix U enthält.

Der Übergang $K^0 \leftrightarrow \bar{K}^0$ wird im Standardmodell durch sogenannte Box-Diagramme beschrieben, z.B.:



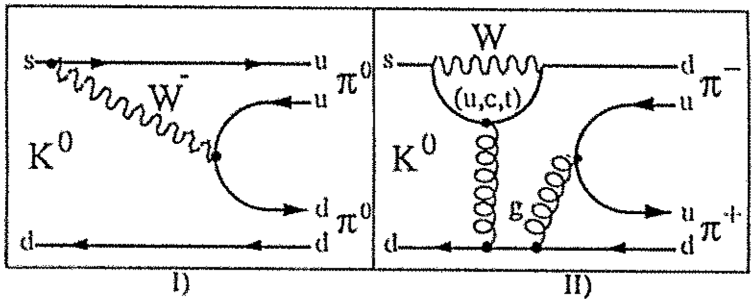
CP-Verletzung im Standardmodell

⇒Enthält die Amplitude für dieses Diagramm komplexe Elemente der CKM-Matrix, dann gilt:

$$\boxed{\mathcal{M}(\bar{K}^0 \to K^0) \neq \mathcal{M}^\dagger(K^0 \to \bar{K}^0)},$$

d.h. die CP-Symmetrie (und T-Symmetrie) ist verletzt.

Wird die CP-Verletzung durch komplexe Elemente der CKM-Matrix erzeugt, dann gibt es zwangsläufig auch Diagramme, die Beiträge zur direkten CP-Verletzung in den Zerfällen $K^0/\bar{K}^0 \to 2\pi$ liefern (Pinguin-Diagramme):



- Das Standardmodell ist "milliweak" ⇒ es läßt indirekte CP-Verletzung erwarten ($\varepsilon' \neq 0$).

- Diagramm I) liefert Beiträge zu den Amplituden A_0 und A_2, verletzt aber nicht die CP-Symmetrie.

  Diagramm II) jedoch verletzt die CP-Symmetrie (U_{td} der CKM-Matrix ist komplex) trägt aber nur zu A_0 bei !

⇒CP-Verletzung im Standardmodell nur in A_0.

CP-Verletzung im Standardmodell

- Die indirekte CP-Verletzung wird im Standardmodell durch die schwache Wechselwirkung in 2. Ordnung erzeugt.

- $$\boxed{\begin{array}{l} \varepsilon = 2{,}263 \pm 0{,}023 \bullet 10^{-3} \\ \mathrm{Arg}(\varepsilon) = (46{,}0 \pm 1{,}4)^\circ \end{array}}$$ [**]

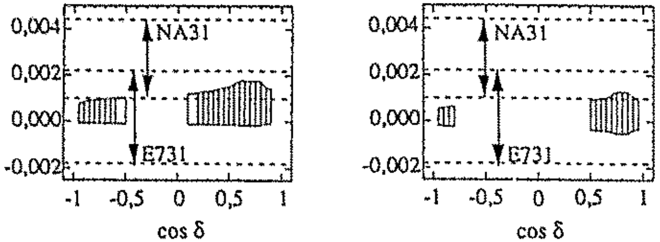
- Das Standardmodell ist milliweak, d.h. es gibt CP-Verletzung auch in 1. Ordnung der schwachen Ww.

⇒Falls es keine direkte CP-Verletzung gibt:

- Erklärung der indirekten CP-Verletzung durch neuartige, superschwache Wechselwirkung mit $\Delta S=2$, oder:

  $\varepsilon' = 0$ in Übereinstimmung mit dem Standardmodell bei einer Topmasse von ≈ 200 GeV:

$\Re(\varepsilon'/\varepsilon)$ für $m_{top} = 160$ GeV und $m_{top} = 200$ GeV:



M. Lusignoli, L. Maiani, G. Martinelli, L. Reina, Nucl. Phys. B369

Für die das $K^0\overline{K}^0$-System beschreibenden Parameter existieren aus bisherigen Experimenten folgende Werte:

- $$\boxed{\Re\frac{\varepsilon'}{\varepsilon} = \begin{cases} (23 \pm 7) \bullet 10^{-4} & \text{NA31} \\ (6 \pm 7) \bullet 10^{-4} & \text{E731} \end{cases}}$$

[**] R.Carosi et. al.,Phys. Lett.,B237 bzw. M.Karlsson et. al.,Phys.Rev.Lett.,64 (1990)

Messungen der CP-Verletzung

Die Erhaltung diskreter Symmetrien im $K^0\overline{K}^0$-System wird bei Daϕne mit unterschiedlichen Methoden untersucht werden, von denen einige schon bei bisherigen Experimenten verwendet wurden, andere jedoch erst durch die speziellen physikalischen Gegebenheiten an einer Φ-Fabrik ermöglicht werden.
Bisherige Experimente:

- Messung der indirekten CP-Verletzung in K_L-Zerfällen:

$$K_L \approx K_2 + \varepsilon K_1 \quad \text{mit} \quad CP(K_2) = -1 \quad CP(K_1) = +1$$

2π- und 3π-Endzustände ohne rel. Drehimpuls sind CP-Eigenzustände mit den Eigenwerten +1 bzw. -1.
⇒Der Zerfall $K_L \Rightarrow \pi\pi$ verletzt die CP-Symmetrie
(Christenson, Fitch et al. 1964)

- Beobachtung anfänglich reiner K_L-Strahlen nach Durchqueren eines Regenerators. Messung der Ladungsasymmetrie δ in semileptonischen Zerfällen:

$$K^0 \Rightarrow \ell^+ \nu_\ell \pi^- \quad \text{bzw.} \quad \overline{K}^0 \Rightarrow \ell^- \overline{\nu}_\ell \pi^+$$

Wegen der $\Delta S=\Delta Q$-Regel (keine flavour-ändernden neutralen Ströme) zerfallen die Strangeness-Eigenzustände in Leptonen unterschiedlicher Ladung
(Gjesdal et al. (1974)). Ladungsasymmetrie δ:

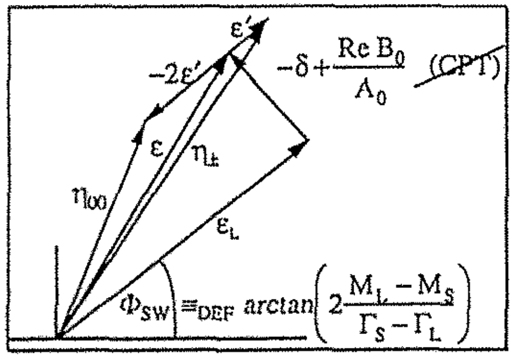
$$\delta(t) = \frac{N^+ - N^-}{N^+ + N^-} = 2\left[e^{-t(\Gamma_S - \Gamma_L)/2} \bullet \cos(\Delta m t) + \mathrm{Re}\,\varepsilon\right]$$

Messungen der CP-Verletzung bei DAΦNE

- Messung des Doppelverhältnisses $\mathcal{R}^{\pm}/\mathcal{R}^{0}$:

Relativer Anteil der CP-verletzenden Amplituden $K_L \Rightarrow 2\pi$:

$$\frac{A(K_L \Rightarrow \pi^+\pi^-)}{A(K_S \Rightarrow \pi^+\pi^-)} \equiv \eta_{\pm} = \varepsilon + \varepsilon' ; \qquad \frac{A(K_L \Rightarrow \pi^0\pi^0)}{A(K_S \Rightarrow \pi^0\pi^0)} \equiv \eta_{00} = \varepsilon - 2\varepsilon'$$



⇒Mit der Messung von $\mathcal{R}^{\pm}/\mathcal{R}^{0}$ läßt sich $\Re(\varepsilon'/\varepsilon)$ bestimmen:

$$\boxed{\mathcal{R}^{\pm}/\mathcal{R}^{0} \equiv \frac{N(K_L \Rightarrow \pi^+\pi^-)}{N(K_S \Rightarrow \pi^+\pi^-)} \div \frac{N(K_L \Rightarrow \pi^0\pi^0)}{N(K_S \Rightarrow \pi^0\pi^0)} = 1 + 6 \bullet \Re\left(\frac{\varepsilon'}{\varepsilon}\right)}$$

Statistischer Fehler der Messung von $\mathcal{R}^{\pm}/\mathcal{R}^{0}$:

$$\Delta\left(\mathcal{R}^{\pm}/\mathcal{R}^{0}\right) \approx \sqrt{\frac{3}{2} \bullet \frac{1}{N_{K_L \Rightarrow \pi^0\pi^0}}} \approx 6 \bullet \Delta\left(\Re \frac{\varepsilon'}{\varepsilon}\right)$$

⇒$\boxed{\Delta(\Re(\varepsilon'/\varepsilon)) \approx 5 \bullet 10^{-5}}$(per anno; bei $L \approx 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$;
Detektor- und "tagging"-Effizienz unberücksichtigt)

Messungen der CP-Verletzung bei DAΦNE

- Erkennung von K_L / K_S an Art und Ort des Zerfalls:

Identifizierung von K_S durch Zerfälle in $\pi^+\pi^-$ in der Nähe des Strahlrohres. ⇒ "Tagging" von K_L.

Identifizierung von K_L durch die Zerfälle in $\pi^+\pi^-\pi^0, \pi^{\pm}\mu^{\mp}\nu$ und $\pi^{\pm}e^{\mp}\nu$ in >30 cm Abstand von der Ww-Zone.

⇒Erster "getaggter" K_S-Strahl.

Beobachtung der CP-Verletzung in den Zerfällen $K_S \Rightarrow 3\pi$

- Messungen mit "Interferenz-Methoden"

Durch den Zerfall des Φ-Mesons wird der Zustand

$$\boxed{\begin{aligned} |i\rangle &\propto |K^0, \vec{p}\rangle|\overline{K}^0, -\vec{p}\rangle - |\overline{K}^0, \vec{p}\rangle|K^0, -\vec{p}\rangle \\ &\propto |K_S, \vec{p}\rangle|K_L, -\vec{p}\rangle - |K_L, \vec{p}\rangle|K_S, -\vec{p}\rangle \end{aligned}}$$

erzeugt.

Die Anzahl der Zerfälle dieses Zustandes in den Endzustand (des einen Kaons) f_1 zum Zeitpunkt t_1 bzw. f_2 (des anderen Kaons) zum Zeitpunkt t_2 ist damit gegeben durch:

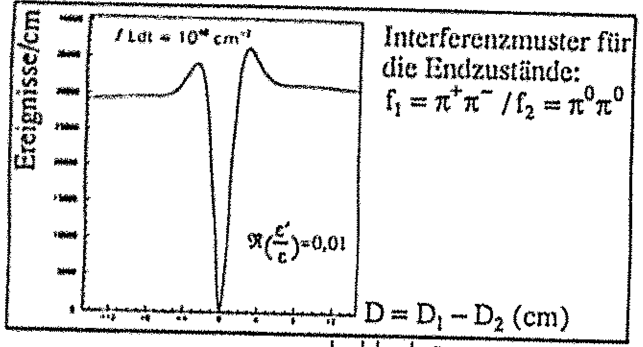
$$\boxed{\begin{aligned} I(f_1; f_2\, \Delta t) = \frac{1}{2(\Gamma_S + \Gamma_L)} \left|\langle f_1|K_S\rangle\langle f_2|K_S\rangle\right|^2 \Big(|\eta_1|^2 e^{-\Gamma_L \Delta t} + |\eta_2|^2 e^{-\Gamma_S \Delta t} \\ -2|\eta_1||\eta_2| e^{-(\Gamma_S+\Gamma_L)\Delta t/2} \cos(\Delta M\, \Delta t + \Phi_1 - \Phi_2)\Big) \end{aligned}}$$

wobei $\eta_i = \frac{\langle f_i|K_L\rangle}{\langle f_i|K_S\rangle} = |\eta_i|\, e^{i\Phi_i}$

- Gleiche Endzustände z.B. $f_1 = f_2 = \pi^+\pi^- \Rightarrow \Gamma_S, \Gamma_L, \Delta M$

Messungen der CP-Verletzung bei DAΦNE

- $f_1 \neq f_2$

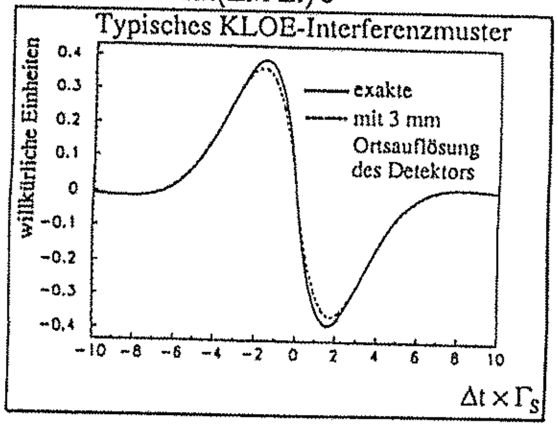


Interferenzmuster für die Endzustände: $f_1 = \pi^+\pi^- / f_2 = \pi^0\pi^0$

a) $f_1 = \pi^+\pi^-\,;\, f_2 = \pi^0\pi^0 \;\Rightarrow\; \underbrace{|\eta_1|, |\eta_2|, \Phi_1 - \Phi_2}_{\Re(\varepsilon'),\, \Im(\varepsilon')}$

- Die Interferenzmessungen erfordern eine gute Ortsauflösung des Detektors. Die Abbildung zeigt den Einfluß, den eine Genauigkeit der Rekonstuktion des Zerfallsvertex von 3 mm auf ein typisches Interferenzmuster hat:

$$\propto \sin(\Delta M\, \Delta t)\, e^{-|\Delta t|\Gamma_S/2}$$



Typisches KLOE-Interferenzmuster

Messungen der CP-Verletzung bei DAΦNE

b) Zerfall in Leptonen: $f_1 = \pi^-\ell^+\bar{\nu}_\ell\,;\, f_2 = \pi^+\ell^-\nu_\ell \;\Rightarrow$
Kabir-Test: T-Invarianz erfordert:

$$\boxed{M\left(K^0(t=0) \Rightarrow \overline{K}^0(t)\right) = M\left(\overline{K}^0(t=0) \Rightarrow K^0(t)\right)}$$

⇒Identifikation des zuerst zerfallenden Kaons durch semileptonischen Zerfall
⇒definierter Zustand des zweiten Kaons
⇒Rückschluß auf $K^0 \Leftrightarrow \overline{K}^0$-Umwandlung aus dem semileptonischen Zerfall dieses Kaons.

⇒Messung der T- bzw. CPT-verletzenden Antisymmetrien: (L^{++}/L^{+-}=Anzahl der entsprechenden Dileptonzerfälle)

$$\boxed{\begin{aligned} A_T(\Delta t) &= \frac{N(\overline{K}^0 \Rightarrow K^0;\Delta t) - N(K^0 \Rightarrow \overline{K}^0;\Delta t)}{N(\overline{K}^0 \Rightarrow K^0;\Delta t) + N(K^0 \Rightarrow \overline{K}^0;\Delta t)} \\ &= \frac{L^{++} - L^{--}}{L^{++} + L^{--}} = 4\,\Re(\varepsilon) \\ A_{CPT}(\Delta t) &= \frac{N(K^0 \Rightarrow K^0;\Delta t) - N(\overline{K}^0 \Rightarrow \overline{K}^0;\Delta t)}{N(K^0 \Rightarrow K^0;\Delta t) + N(\overline{K}^0 \Rightarrow \overline{K}^0;\Delta t)} \\ &= \frac{L^{-+} - L^{+-}}{L^{-+} + L^{+-}} \approx 4\,\Re(\delta) \end{aligned}}$$

c) Beobachtung der Zeitentwicklung der Zerfallsraten "getaggter" $K^0/\overline{K}^0$-Zustände (z.B. $K^0/\overline{K}^0 \Rightarrow \pi^+\pi^-$):

Andere Messungen bei DAΦNE

DAΦNE ermöglicht über die *Erforschung der CP-Verletzung* hinaus Experimente auf zahlreichen anderen Gebieten:

- Tests der chiralen Störungstheorie (χPT):
  - Effektive Feldtheorie zur Beschreibung der starken Wechselwirkung im Niederenergiebereich ($E \leq M_\rho$).
  - Die QCD-Lagrangefunktion ist invariant unter der globalen $SU(3)_L \times SU(3)_R$-Transformation bei verschwindenden Quark-Massen (u,d,s).
  - Spontane Symmetriebrechung reduziert die Symmetrie des Grundzustands ⇒ Identifikation des Nonetts der pseudo-skalaren ($J^{PC} = 0^{-+}$)-*Mesonen als Goldstone-Bosonen.*
  - Die Theorie enthält freie Parameter: Pion-Zerfallskonstante und eine Kombination der Meson-Massen als freie Parameter in niedrigster Ordnung ($O(p^2)$). 10 Parameter in 2. Ordnung ($L_1 - L_{10}$).

I) Bestimmung dieser Parameter durch wenige experimentelle Quellen. (z.B. $L_1 - L_3$ aus ππ-WW in K_{e4}-Zerfällen)

- Zerfall $K^+ \Rightarrow \pi^+\pi^-e^+\nu_e$:
  Bisher (letzte Messung 1977): ≈30.000 Ereignisse.
  Bei Daφne: 10^6 / Jahr + ladungskonjugierte Zerfälle.

II) Vorhersage einer Vielzahl von Parametern insbesondere für K-Zerfälle.

Andere Messungen bei DAΦNE

⇒Daφne als Kaon-Fabrik ermöglicht Messungen zahlreicher Zerfälle mit einer um Größenordnungen höheren Zahl von Ereignissen z.B.:

$$\boxed{K_{l3}-, K_{l2,\gamma}-, K_{l2,e^+e^-}-, K_{l3,\gamma} - \text{Zerfälle};\ K^\pm \Rightarrow \pi^\pm\gamma\gamma}$$

Außerdem:

- radiative Φ-Zerfälle ($\Phi \Rightarrow \eta'\gamma$, $\Phi \Rightarrow \eta\gamma$), $\eta' \Leftrightarrow \eta$
  Untersuchung der 0^{++}-Zustände a_0 / f_0 (Glueballs ?, $K\bar{K}$-Moleküle ?).
- Untersuchung der niederenergetischen ($E_{kin,K^\pm}$=16 MeV) KN-Streuung (elastisch, mit Ladungsaustausch) ⇒ Bestimmung des KN-σ-Terms.
  Regeneration ($K_L^0\, p \Rightarrow K_S^0\, p$), K-Streuung am Deuteron.
  Erzeugung von Hyperonen durch K^-:

  $$K^-p \Rightarrow \Lambda\pi^0, \quad K^-\,p \Rightarrow \Sigma^\pm\pi^\mp, \quad K^-p \Rightarrow \Sigma^0\pi^0$$

- Kernphysikalische Untersuchungen an Hyperkernen, die durch gestoppte K^- erzeugt werden:

  Spektroskopie an Λ-Hyperkernen, Produktion von Λ-Hyperkernen mit Neutronenüberschuß in dem 2-Stufen-Prozeß: $K^-p \Rightarrow \Lambda\pi^0$ gefolgt von $\pi^0 p \Rightarrow n\,\pi^+$, etc.

⇒Für diese Experimente wird ein eigener Detektor*) (FINUDA) um die zweite Wechselwirkungszone aufgebaut.

---

*) Fisica NUcleare a DAΦNE

Detektoren

⇒KLOE[*]:

Der KLOE-Detektor dient in erster Linie der Untersuchung der CP-Verletzung mit den oben beschriebenen Methoden. Daraus ergeben sich folgende Anforderungen an den Detektor:

- K_L-Zerfälle (Sekundärvertex) können wegen der großen Zerfallslänge im gesamten Detektor auftreten.

⇒Um bei K_L-Zerfällen möglichst hohe Raten zu erreichen, muß die Größe des Detektors ungefähr der K_L-Zerfallslänge von 350 cm entsprechen.

⇒Die Effizienz des Detektors für neutrale Zerfälle ($K_L \Rightarrow 2\pi^0/3\pi^0$, Photon-Nachweis) muß in einem definierten Volumen homogen hoch sein.
⇒möglichst geschlossenes Kalorimeter
⇒Photon-Nachweis bis hinunter zu ≈20 MeV

⇒Hohe Effizienz und Impulsauflösung auch für geladene Teilchen $K_L \Rightarrow \pi^+\pi^-/\pi^+\pi^-\pi^0$; $K_S \Rightarrow \pi^+\pi^-$.
⇒Driftkammer mit hoher Granularität in allen Bereichen.
⇒möglichst leichte Konstruktion der Driftkammer (wenig Material um Vielfachstreuung zu minimieren).

- Die Anwendung der Interferenz-Methoden erfordert eine präzise (Orts-)Bestimmung der Zerfallsvertices.

KLOE besteht im wesentlichen aus zwei Komponenten:

---

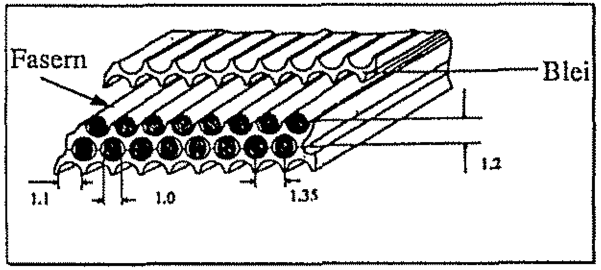
[*] K zero LOng Experiment

Der KLOE-Detektor

I) KALORIMETER

⇒Barrel-Kalorimeter:

- 24 Module (M=3,5 t) von 5,1 m Länge in z-Richtung in zylindrischer Anordnung (Innendurchmesser 4,5 m).
- Grundstruktur aus Szintillatorfasern in einer Bleimatrix:



- Auslese von 3,5 cm × 3,5 cm großen Bereichen durch Photomultiplier an beiden Enden.

- Energieauflösung : $\sigma_E / E \cong 4{,}5\% / \sqrt{E(\mathrm{GeV})}$
- Bestimmung des γ-Konversionspunktes auf 1 cm genau.
- Zeitauflösung : $\sigma_t \cong 100$ ps bei 250 MeV
  ⇒Messung des K_L-Vertex mit 6 mm Auflösung.
- Umschließt die Wechselwirkungszone zu 99%.

⇒Endkappen-Kalorimeter:

- Gleiche Grundstruktur (Spaghetti) wie Barrel. "C"-förmige Elemente versch. Länge mit Auslese an beiden Enden.

- Das Kalorimeter befindet sich im Magnetfeld (0,6 T).

- Verschiedene Prototypen (darunter ein vollständiges Barrel-Segment) wurden am Paul-Scherrer-Institut getestet.

Der KLOE-Detektor

II) DRIFTKAMMER

- Die zylindrische Driftkammer schließt sich nach innen an das Kalorimeter an (Innen-/Außenradius: 25 bzw. 194 cm)

- Um eine möglichst große Strahlungslänge zu erreichen, wird die Kammer ($\approx 40\ m^3$) mit einer Helium-Gasmischung (90% He / 10% $iC_4H_{10}, X_0 \approx 1,3$ km) gefüllt.

- Die Kammer wird ≈53000 in z-Richtung gespannte Drähte (Al, vergoldet) enthalten, die zu rd. 13000 Driftzellen in 62 koaxialen Schichten angeordnet sind.
  Diffizil: Alle Drähte werden als Stereodrähte gespannt.

⇒Querschnitt der Driftzellen ändert sich stark mit z.

⇒z. T. komplexe Ort-Driftzeit-Relation.

⇒Spurrekonstuktion und Patternrecognition schwierig.

Abbildung: Zellstruktur der Prototypen 0.1/0.2 im Querschnitt:

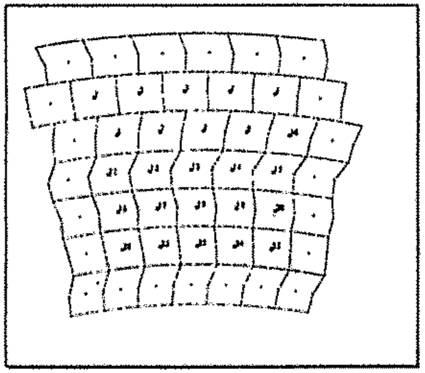


Abbildung: Lage der Stereodrähte beim Prototypen 1.0:

Der KLOE-Detektor

- Befestigung der Drähte an konischen Endplatten aus GFK. (Endplatten des Prototypen 1.0 von Fa. Stesalit hergestellt) Dicke der Endplatten 5 mm, Zugbelastung ≈4000 kg.

Prototyp 1.0:

- Zur Zeit wird in Lecce der Prototyp 1.0 fertiggestellt. Dieser realisiert einen Ausschnitt der KLOE-Driftkammer mit 500 Driftzellen und dient zum Test verschiedener Größen von Driftzellen, der für KLOE bisher entwickelten Elektronik (Vorverstärker, HV-Versorgung), zum Test der verwendeten Materialien und der Organisation von Arbeitsabläufen (Spannen der Drähte).

  Am Test dieses Prototypen am CERN wird unsere Gruppe beteiligt sein, wie schon an den Tests der vorherigen Prototypen 0.1/0.2 am PSI.
  Dafür wurde von uns ein Gassystem entworfen und gebaut, auf dessen Basis wir ein Gassystem für die KLOE-Driftkammer realisieren werden.

KLOE-Gassystem

- Gasmischung auf Heliumbasis mit einer (evtl. zwei) weiteren Komponenten (z.B. 90% He / 10% iC_4H_{10} oder 80% He / 20% CH_4).

- Auslegung als geschlossenes Gassystem (Gaszirkulation ≈30 L/min.), um eine gleichbleibende und genau bekannte Gaszusammensetzung zu gewährleisten.

Der KLOE-Detektor

- Permanente Überwachung der Gaszusammensetzung, Feststellung von Verunreinigungen und laufende Messung der für den Betrieb der Driftkammer relevanten Parameter:

⇒Messung von Driftgeschwindigkeit und Gasverstärkung mit einer Monitordriftkammer, in der Gasproben mittels eines Lasers ionisiert werden.

⇒Messung des Sauerstoffkonzentration mit Hilfe einer elektrochemischen Meßzelle (Panametrics).

⇒Bestimmung des Wassergehalts mittels Taupunktsensor.

⇒Messung des Methan/Isobutan-Anteils mit einem IR-Photometer (BINOS).

⇒Messung der Temperaturverteilung im Detektor.

- Vollständige Automatisierung des gesamten Systems: Steuerung der Ventile, Gasflußregler, Pumpen und Meßgeräte durch einen Rechner. Automatische Erfassung der Meßdaten und Weitergabe an die KLOE-DAQ.

Konstruktion:

⇒Verwendung von VCR-Verbindungen für hochreine Systeme, Metall-Faltenbalgventilen und -pumpen im gesamten Gassystem.

⇒Vermeidung von Schmierstoffen oder ausgasenden Materialien.

Der KLOE-Detektor

⇒Modulare Konstruktion des Systems:
- Getrennte Mischung für große und kleine Gasmengen.
- Modul zum Anschluß des Detektors.
- Analysegeräte und Gasreinigung.

weitere Aktivitäten:

- Systematische Messungen der Elektron-Driftparameter (Driftgeschwindigkeit, longitudinale und transversale Diffusion, Elektronenanlagerung, etc.) in Helium-Gasmischungen mit Hilfe der Monitorkammer des Gassystems.
- Untersuchung von "cluster counting" als neuartige Methode zur Teilchenidentifikation in Zusammenarbeit mit einer Gruppe der Universität Roma II.
- Mitarbeit bei der Entwicklung elektronischer Komponenten für KLOE, insbesondere Entwicklung und Bau des VME-Boards, das die speziell für KLOE entwickelten TDC-Bauteile aufnehmen wird.

Fertigstellung von DAΦNE: Ende 1995

Erster Einsatz des KLOE-Detektors: Juni 1996

***

(Gefördert vom BMFT unter 06 KA 564)

FORSCHUNGSZENTRUM
ROSSENDORF e.V.

FZR

FZR-63
November 1994

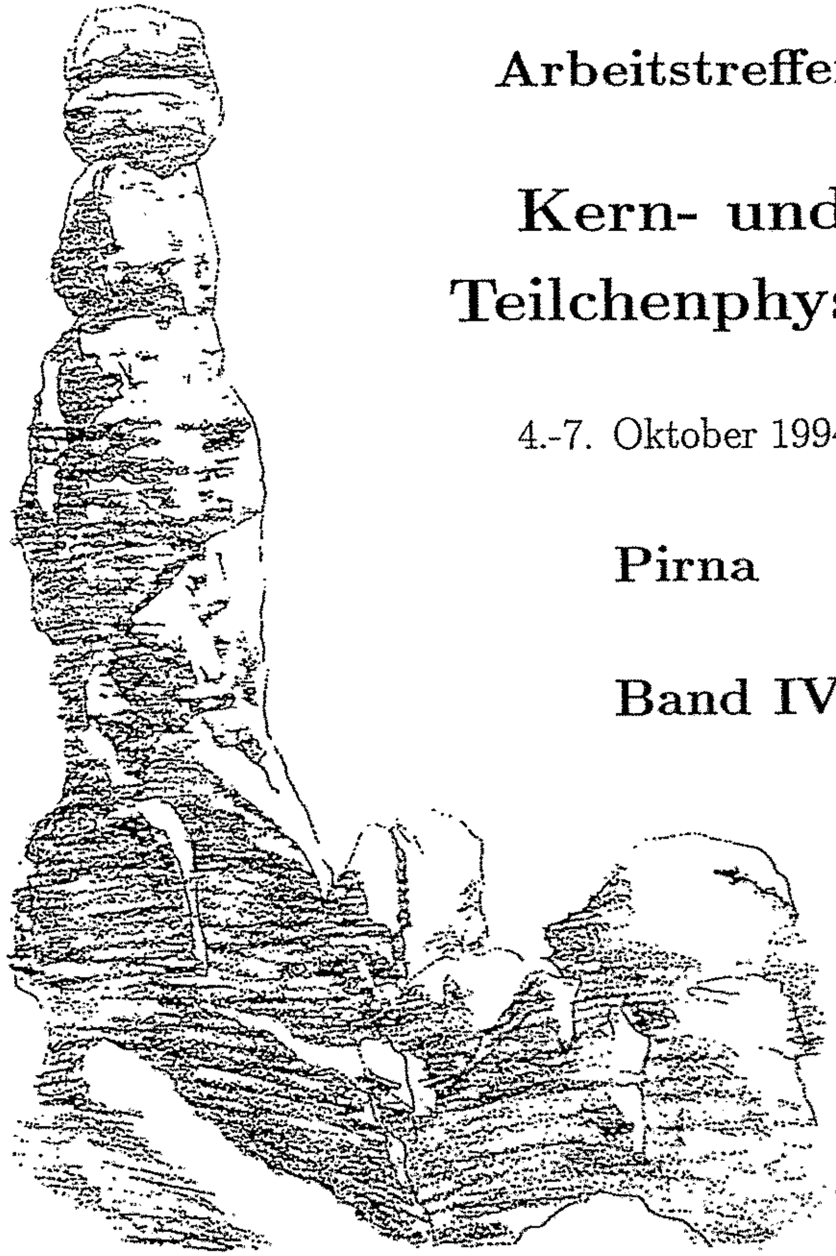
Arbeitstreffen

Kern- und Teilchenphysik

4.-7. Oktober 1994

Pirna

Band IV



" Barbarine " - Elbsandsteingebirge

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Programm des Arbeitstreffens "Kern- und Teilchenphysik 1994" in Pirna

Band I Dienstag, 4. Oktober 1994

Band II Mittwoch, 5. Oktober 1994

Band III Donnerstag, 6. Oktober 1994

Band IV Freitag, 7. Oktober 1994

Mesonenproduktion in Schwerionenkollisionen bei mittleren Energien ($\sim$ 1GeV/n)

E. Grosse
Darmstadt

7.Oktober 1994

Mesonenproduktion in Schwerionenkollisionen bei ~1 GeV/u

E. Grosse, GSI

Kern-Kern-Stöße bei mittleren Energien

Experimente am SIS in Darmstadt

K^+-Produktion in pp, p-^{12}C, p-Pb (SATURNE)

"K^+-enhancement" in A-A-Kollisionen

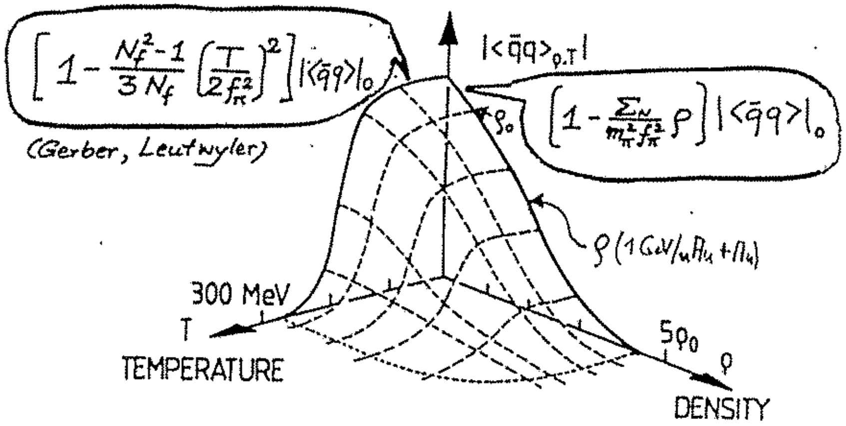
Strukturen in π-Winkelverteilungen

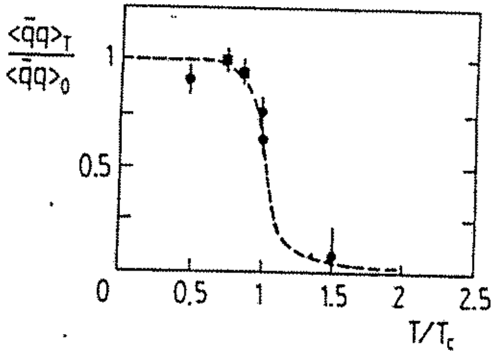
Ausblick

CHIRAL THERMODYNAMICS

- example: NJL model calculation (Lutz, Weise et al., 1992)

RESTORATION OF CHIRAL SYMMETRY

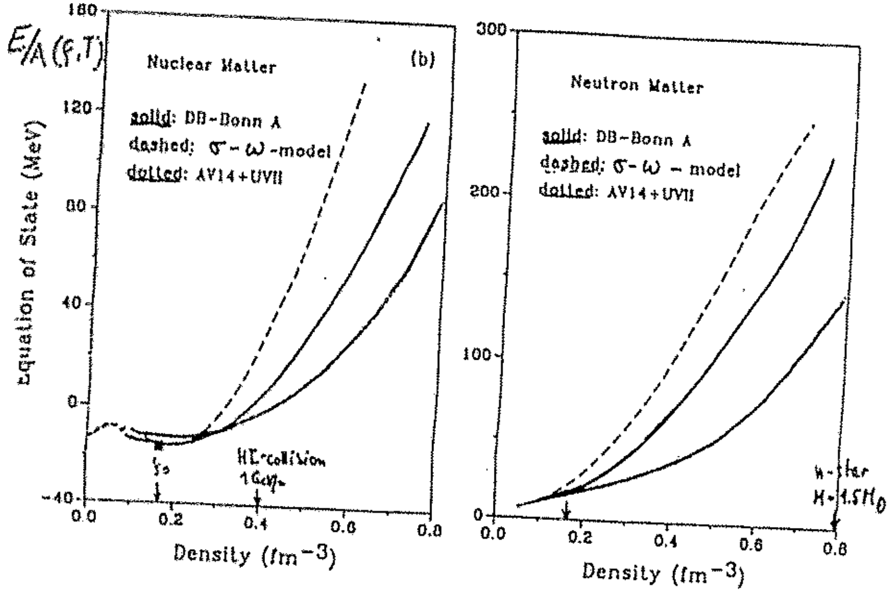




$T_c \simeq 150$ MeV

- CHIRAL CONDENSATE in LATTICE QCD

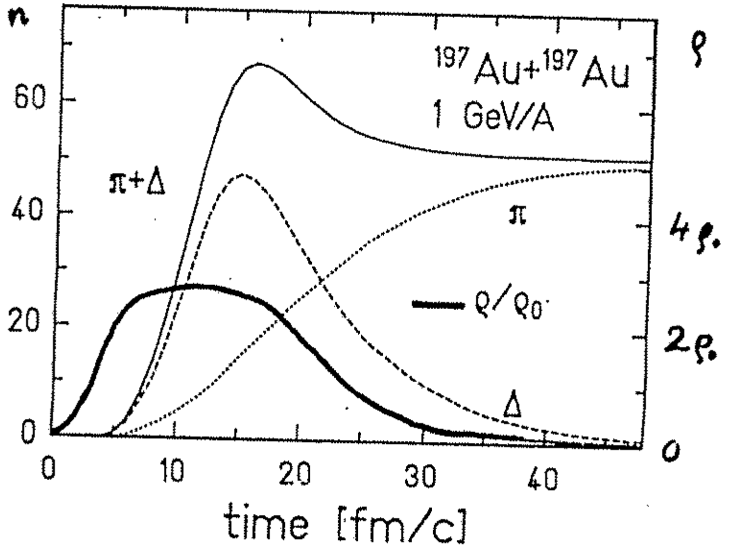
(G. Boyd et al.)



pressure : $P(\rho,T) = \rho^2 \cdot \dfrac{\partial\, E/A\,(\rho,T)}{\partial\rho}$

incompressibility : $K(\rho_0) = \rho_0 \dfrac{\partial P}{\partial\rho} = \rho_0^2 \dfrac{\partial^2 E/A}{\partial\rho^2}$ for $S = \text{const}$

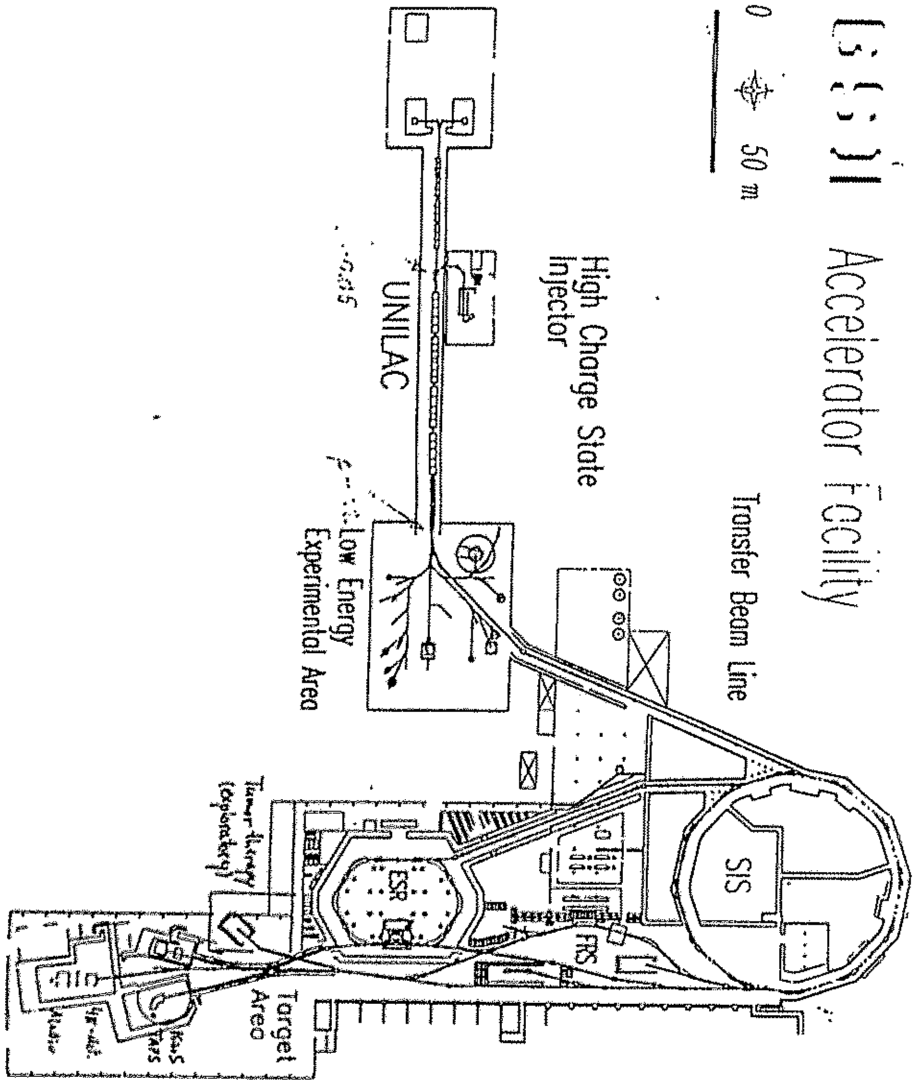
Li, Machleidt, Brockmann (1992)



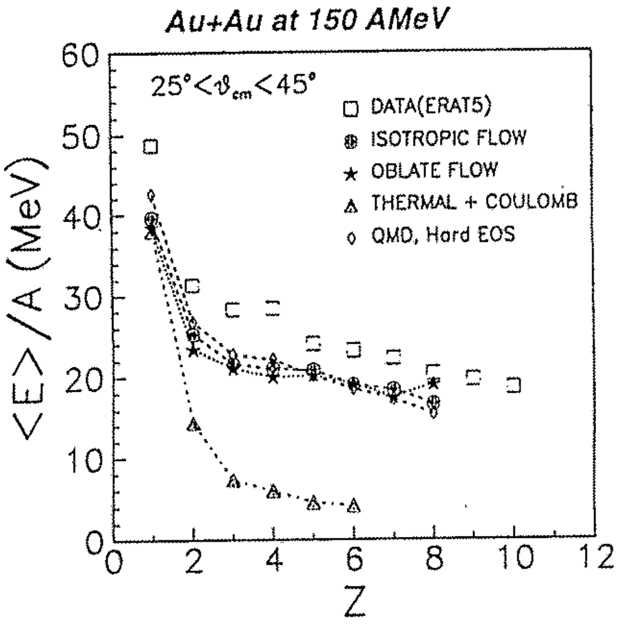
Transport model calculation (BUU) including $NN \to N\underset{\hookrightarrow \pi N}{\Delta}$; Gy. Wolf et al. '93

In central collisions the projectile energy it converted into :

- compression → expansion
- heat → thermal motion
- baryon excitation → meson production



Mean Kinetic Energies of IMFs

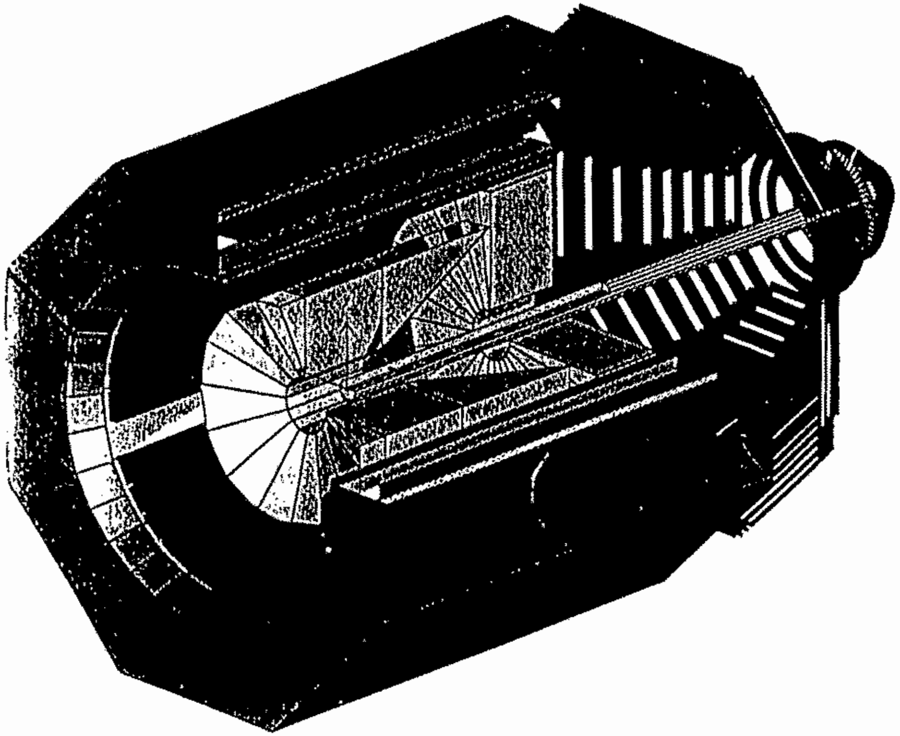


$$\left.\begin{array}{l} E_{thermal}(A) \sim T = const \\ E_{collective}(A) \sim A \cdot e_{coll} \end{array}\right\} \langle E\rangle/A \sim 1/A + e_{coll}$$

e_{coll} = 16 +/- 2 MeV

e_{av} = 37 MeV

FOPI Phase II

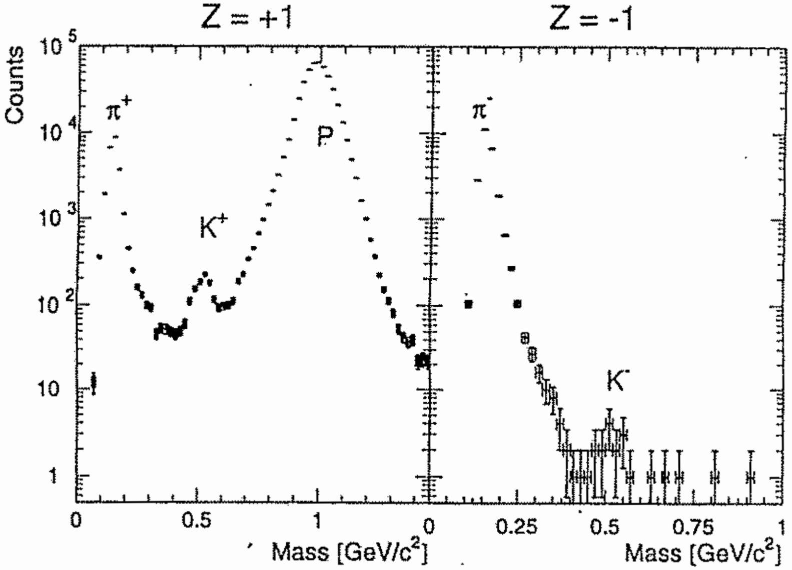


FOPI - Collaboration:

IPNE Bucharest + CRIP Budapest + LPC Clermont-Ferrand
GSI Darmstadt + Univ. Heidelberg + ITEP/KIAE Moscow
FZ Rossendorf + CRN Strasbourg + Univ. Warsaw + RBI Zagreb

FOPI

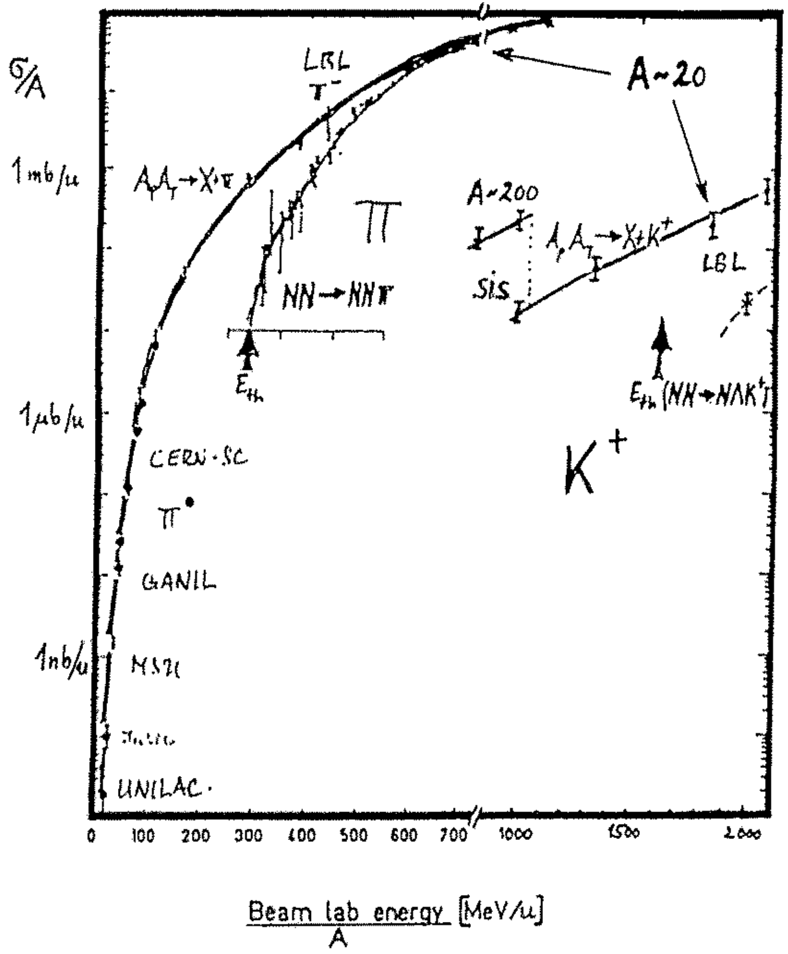
Ni (1.93 AGeV) + Ni



'elementary' process:

$NN \rightarrow NYK^+$ $Y = \Lambda, \Sigma$

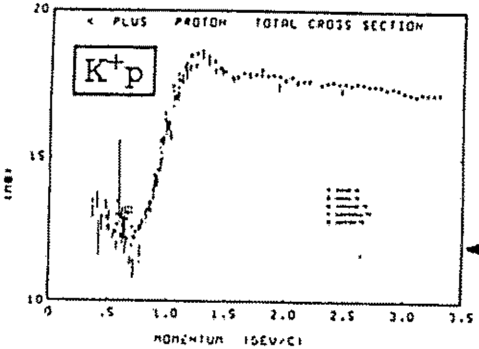
$NN \rightarrow NNK^+K^-$



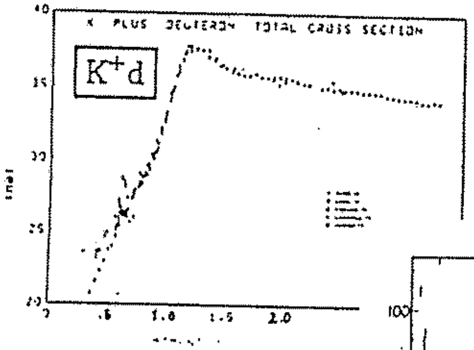
threshold: NN: $E_p^{lab}/A > 2 m_\pi c^2 + \Delta E_{relativ.}$

A_pA_T: $E_p/A_p > \frac{A_p+A_T}{A_pA_T} m_\pi c^2 + \Delta E_{relativ.}$

$\overset{!}{=} \frac{2 m_\pi c^2}{A} + \dots$ for $A_p = A_T$



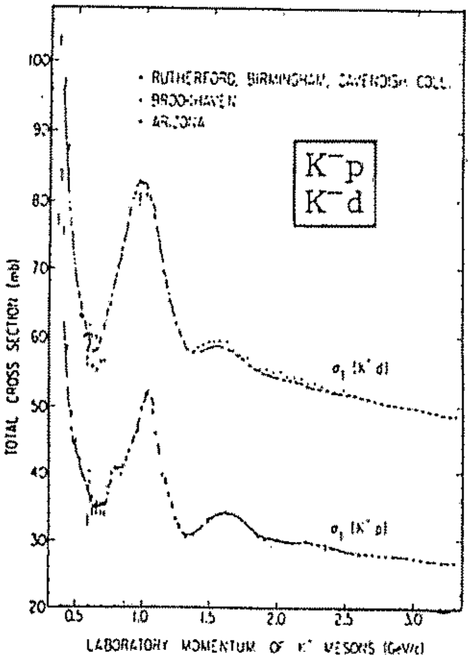
← $\lambda = \frac{1}{\sigma\rho} \sim 5\,fm$



K^+: Little rescattering

$\underline{no}$ absorption

→ good probe for the interior of collision zone



'elementary' process: $NN \rightarrow NYK^+$ $Y = \Lambda, \Sigma$

$pp \rightarrow K^+ X$
Hogan et al.

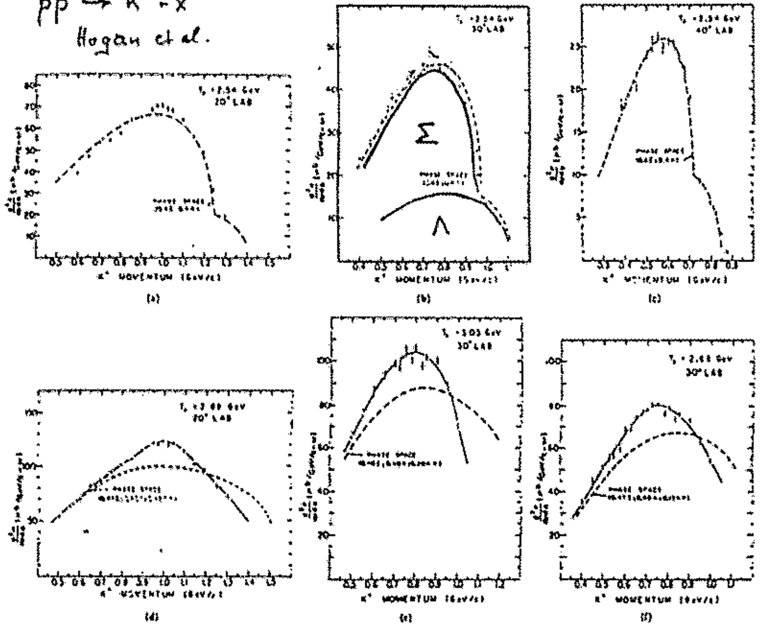
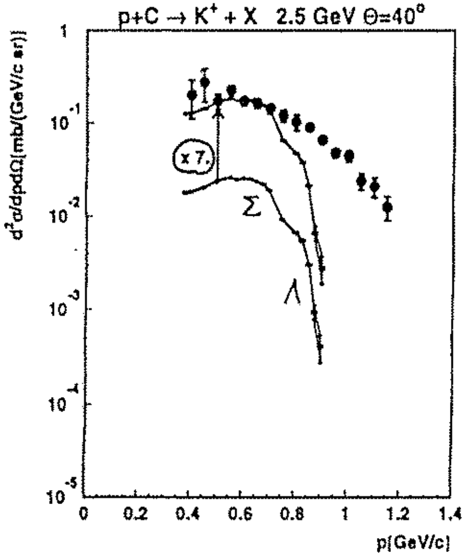


FIG. 4. Laboratory momentum spectra of K^+ mesons produced in hydrogen at the lab angles and incident proton kinetic energies indicated. Errors include statistical errors as well as uncertainties introduced through corrections, but do not include the ~16% uncertainty in the absolute calibration. Momentum resolution is ~2%. The dashed lines represent phase space (see text) normalized to the area under the data.

threshold:	$\sqrt{s}$	E_{lab}^{kin}	
$NN \rightarrow N\Lambda K^+$	2.548	1.582	
$N\Sigma K^+$	2.620	1.780	GeV
NNK^-K^+	2.864	2.494	



$p + {}^{12}C$
SATURNE - GSi collaboration

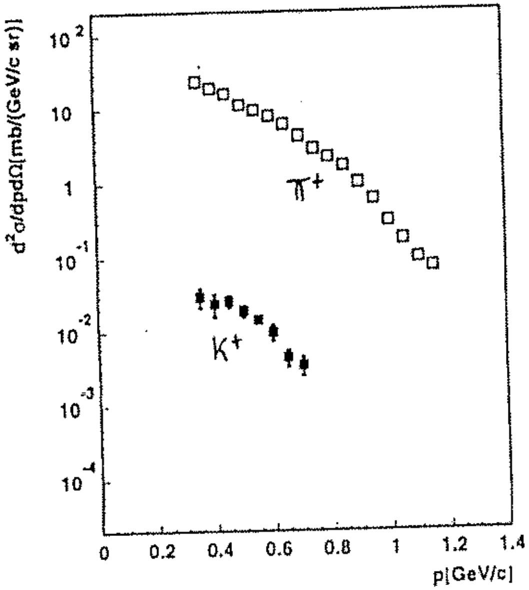
$p + p$
Hogan et al.

$\sigma_K(p\,{}^{12}C) = 7 \times \sigma_K(pp)$ + high momentum tail
due to fermi motion and
2-step processes:

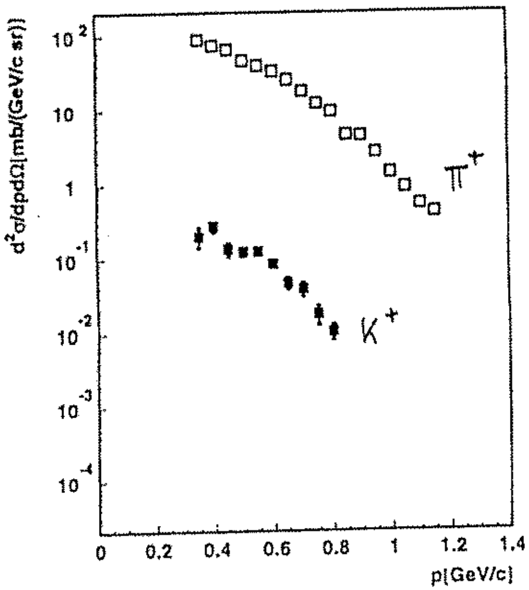
$NN \rightarrow N\Delta$
$\Delta N \rightarrow YNK^+$

or: NN [illegible]
[illegible] → YK

'Subthreshold' K^+ production at 1.5 GeV (SATURNE)



$p + {}^{12}C \rightarrow K^+ + X$



$p + Pb \rightarrow K^+ + x$

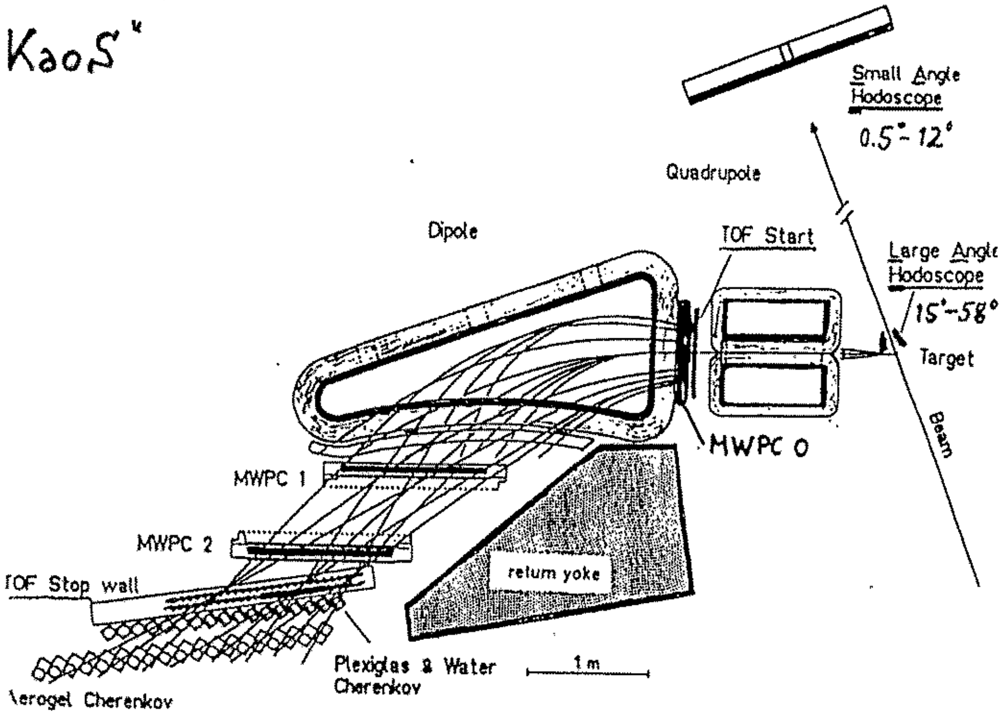
$\sigma_K(p{+}Pb) \simeq 7 \times \sigma_K(p{+}{}^{12}C)$

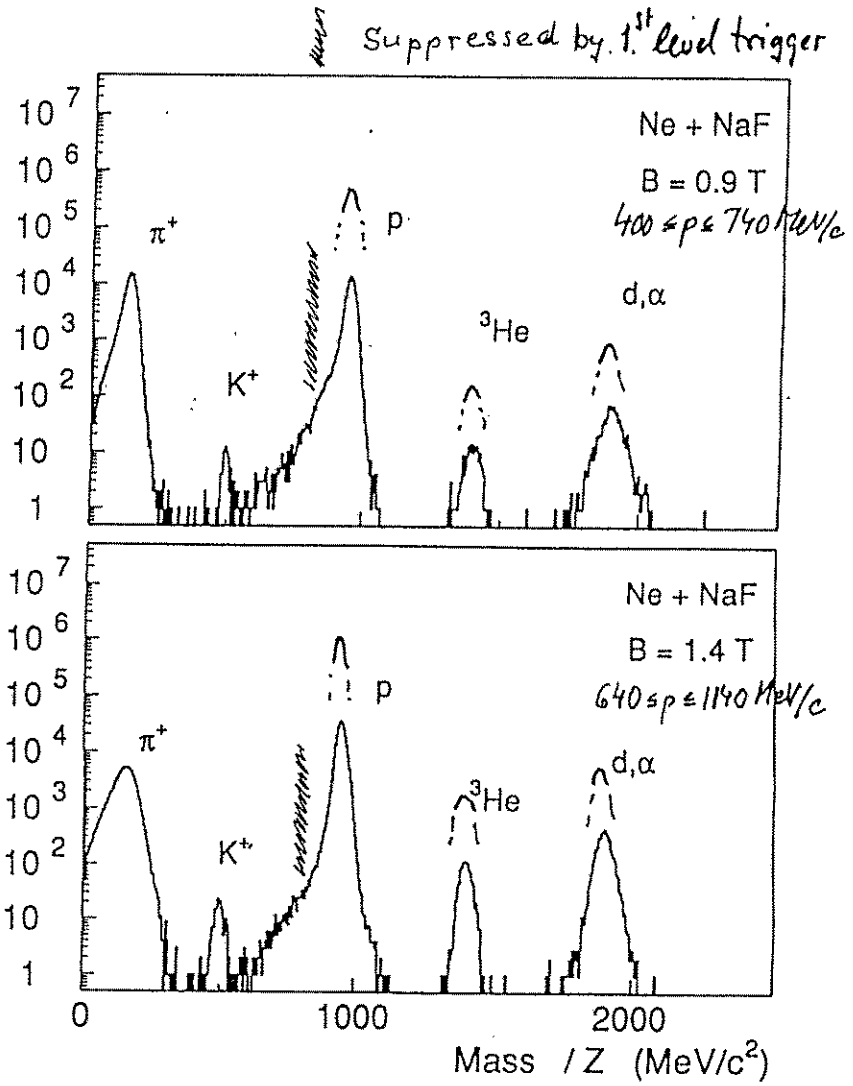
$\sigma_\pi(p{+}Pb) \simeq 4 \times \sigma_\pi(p{+}{}^{12}C)$

similar at 1.2 GeV

The kaon spectrometer at SIS

"KaoS"

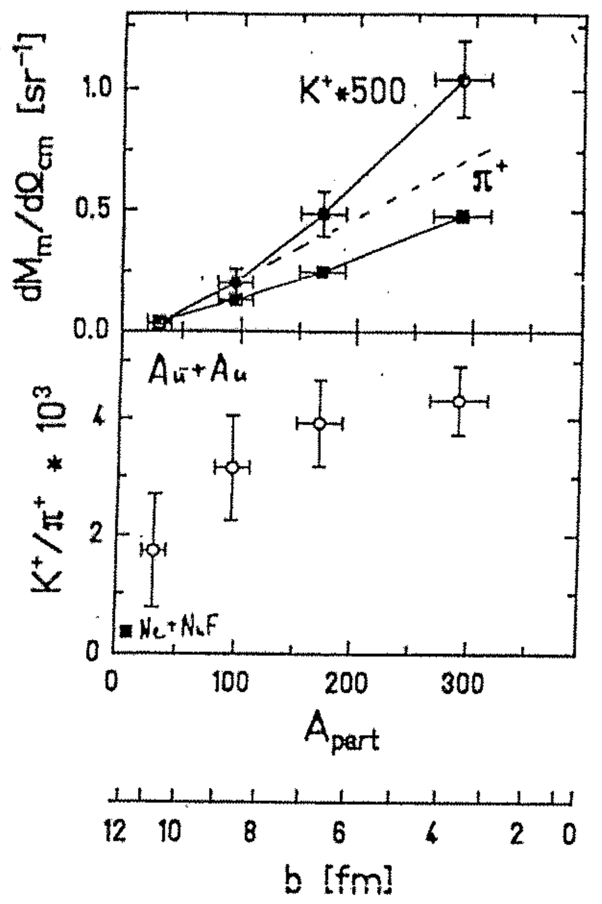




The KaoS Collaboration:

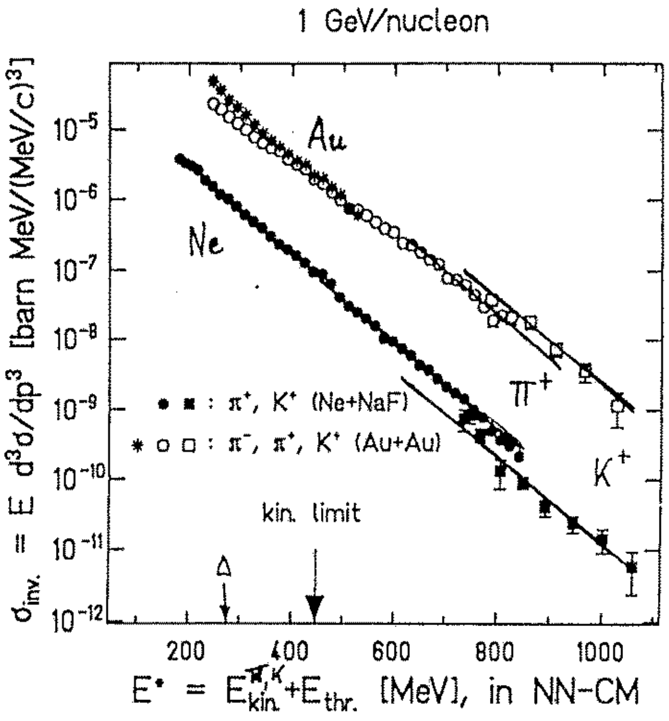
W. Ahner[a], P. Baltes[b], R. Barth[a], P. Beckerle[c], Ch. Bormann[c], D. Brill[c], M. Cieślak[a], M. Debowski[a], E. Grosse[a], W. Henning[a,*], P. Koczoń[a], B. Kohlmeyer[d], M. Mang[a], D. Miśkowiec[a], Ch. Müntz[b], H. Oeschler[b], H. Pöppl[d], F. Pühlhofer[d], R. Schicker[a], E. Schwab[a], P. Senger[a], Y. Shin[c], J. Speer[d], J. Stein[c], R. Stock[c], H. Ströbele[c], Ch. Sturm[b], K. Völkel[d], A. Wagner[b], W. Waluś[e]

[a] *GSI Darmstadt,* [b] *TH Darmstadt,* [c] *Univ. Frankfurt,* [d] *Univ. Marburg,* [e] *Univ. Kraków (Poland),* [*] *now at Argonne Nat. Lab. (USA)*



$\curvearrowright$ K^+ enhanced for large A_{part}

for large ρ



$$NN \rightarrow N \Lambda K^+$$

$$E_{thr} = m_K + m_\Lambda - m_N$$
$$= m_\pi$$

$\curvearrowright$ K^+ enhanced for large A

Strangeness suppression at high energies

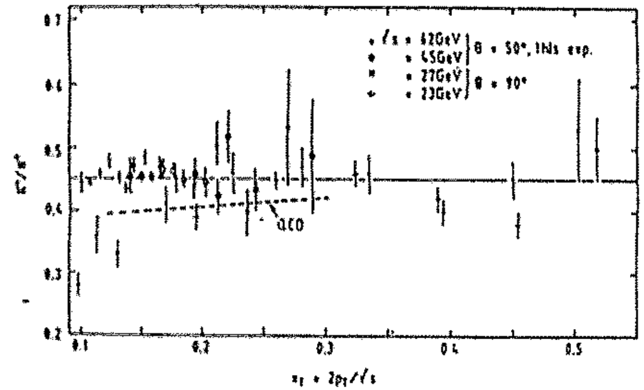


FIGURE 20
Experimental ratio of K^+ to π^+ production in proton-proton interactions at large $x_T = 2p_T/\sqrt{s}$. The dashed line shows a model prediction using $\lambda = 0.5$

λ: strangeness suppression factor   W. Hofmann NP (90)

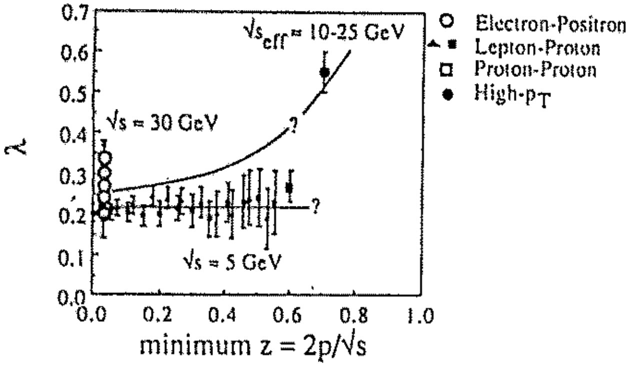
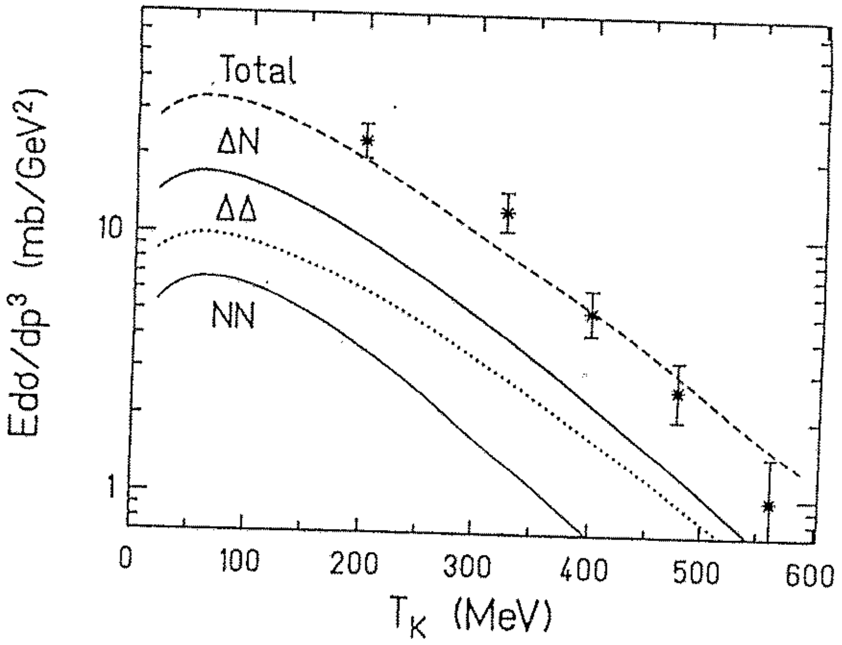


FIGURE 21
Values of λ as derived from K/π ratios, as a function of the minimum $z = P_{hadron}/P_{quark}$ above which hadrons are used in the analysis. Data are shown for e^+e^- annihilation (from several experiments), for neutrino-nucleon scattering, for low-p_T pp reactions and for high-p_T meson production in pp interactions.



Horiyama & Cassing 1993

$NN \to N\Delta$

$\Delta \to N\pi$

$\Delta N \to NN$ Δ acts as energy 'reservoir'

$\to NYK^+$ ~2%

$\Gamma_\Delta = 115$ MeV ↗ $c\tau_\Delta \approx 1.5$ fm

$\simeq d_{NN}(\rho_0)$

↑ ρ - dependence

Calculations based on transport equations

"hard" collisions $BB \to \overset{BB}{BB_M}$

with σ taken from systematics of $NN \to NN\pi$ resp. $\to NYK^+$

coupled to

baryon dynamics in mean field

<u>either</u>: potential of Skyrme type, density dep.

<u>or</u>: scalar field σ, attractive
+ vector field ω, repulsive, momentum dep.

$\rightsquigarrow$ effective mass $m_H^* = m_H - g_\sigma \langle\sigma\rangle$
momentum $p_x^* = p_x - g_\omega \langle\omega\rangle$

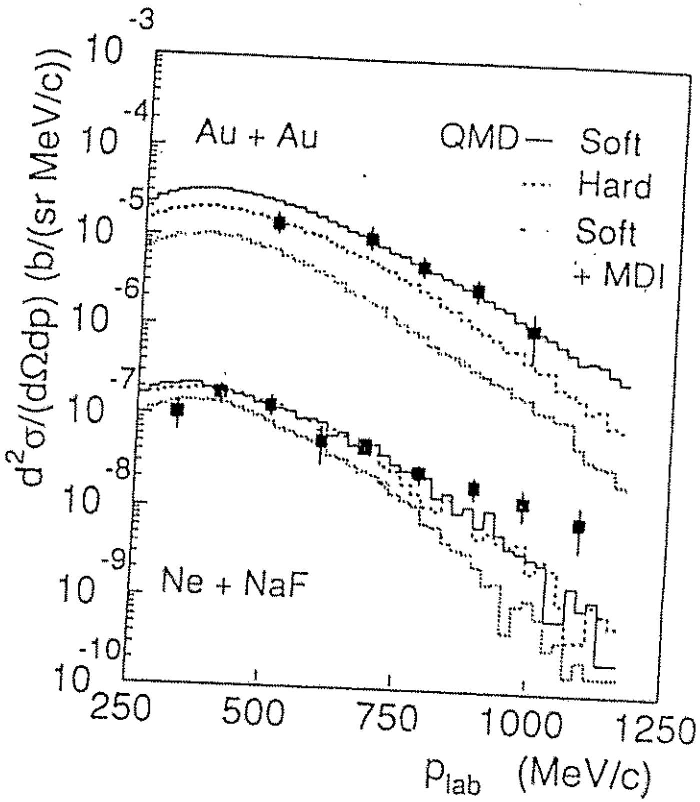
Multi-step-processes

1) $NN \to N\Delta$

2a) $\Delta N \to NN$

b) $\Delta \to N\pi$

c) $\Delta N \to YK^+N$ $Y = \Lambda, \Sigma$



KaoS data
Hartnack & Aichelin (193)

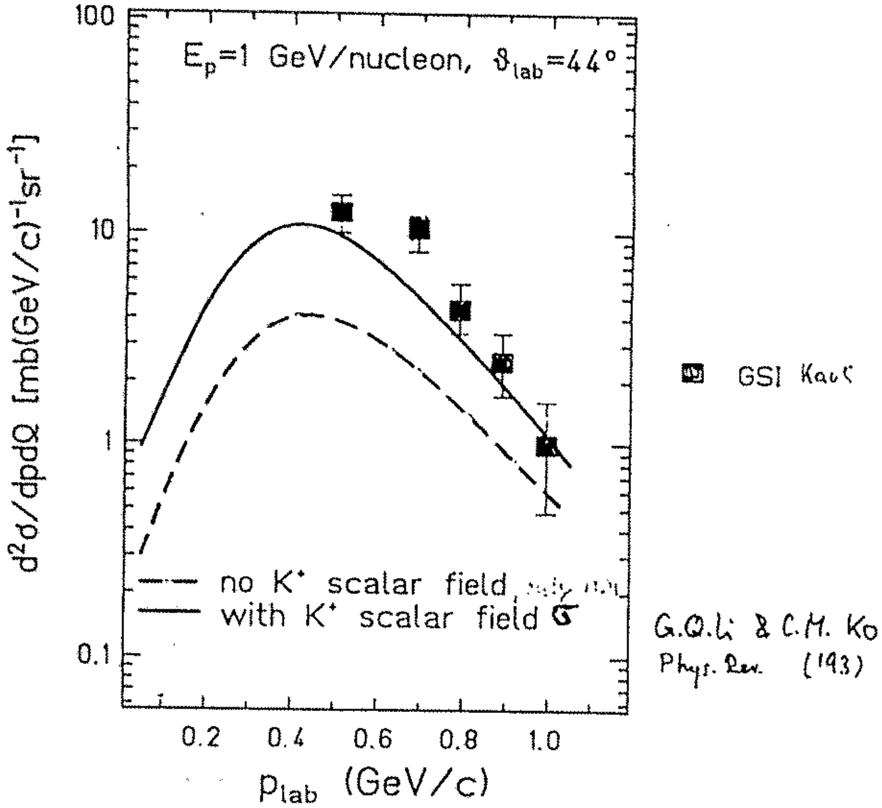
relativistic treatment using σ-ω-model:

medium effect: [illegible]

effective mass $m_K^*(\rho) \neq m_K(\text{free})$

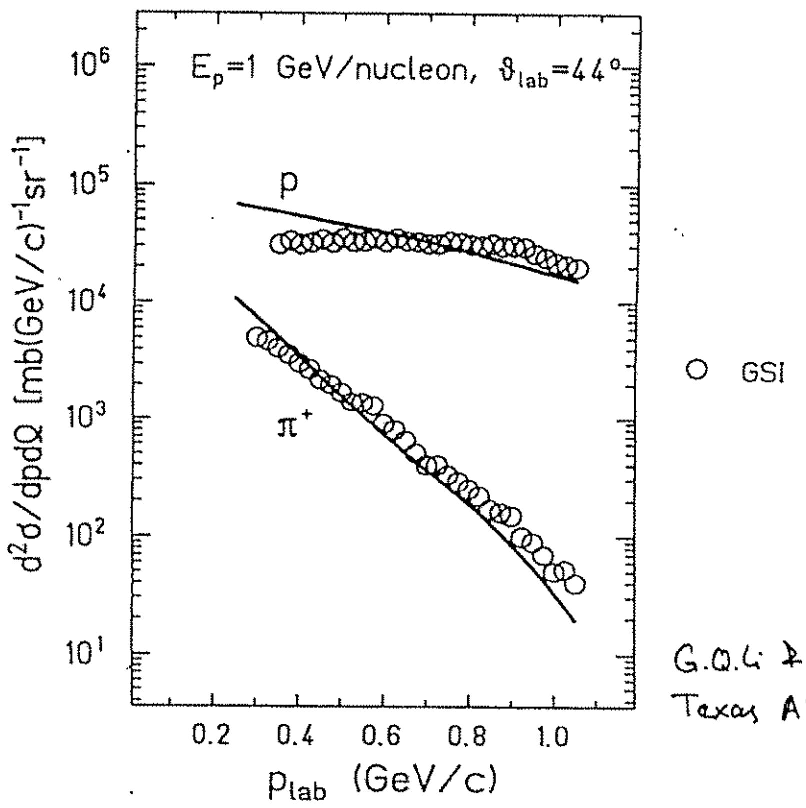
scalar field $\sigma(2\rho_0) < \sigma(\rho_0) < 0$

$^{197}\text{Au} + ^{197}\text{Au} \rightarrow K^+ + X$

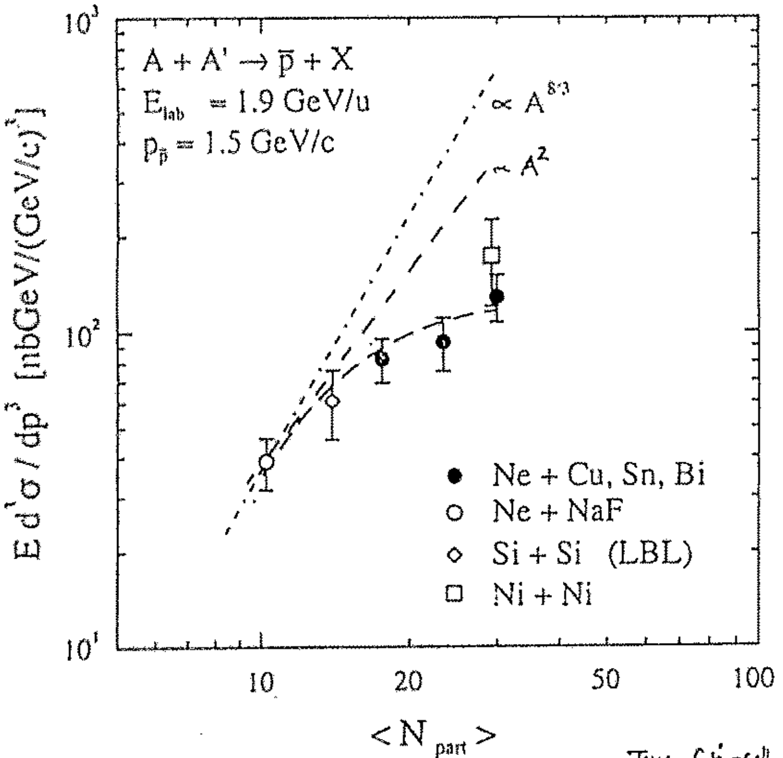


G.Q.Li & C.M. Ko
Phys. Rev. ('93)

$^{197}\text{Au} + ^{197}\text{Au}$



G.Q.Li & C.M. Ko
Texas A&M



TUM-GSI-coll.
A. Gillitzer et al.

$\bar{p}$ are strongly reabsorbed, but still $\sigma_{inel}(\bar{p})$ is rather large, suggesting the importance of medium effects.

Central collisions of high energy heavy ions $\rightsquigarrow$ fireball : $T \sim 50-100$ MeV, $\rho \sim 2-3\,\rho_0$

kinetic energy converted into heat and

compression & collective expansion $\sim 40\%$

internal baryonic excitation & meson production $\sim 20\%$

'weakly' interacting probes: K^+, γ, e^+e^-

$\uparrow$ enhanced for large ρ

Theoretical description (equation of state) should include: relativistic medium effects:

effective masses

momentum dependent potentials

first attempts using σ-ω-model for HI-collisions & n-star matter

High density matter enriched in heavy baryons (Δ, ...)

possible secondary $\pi^{\pm}$-beams from SIS

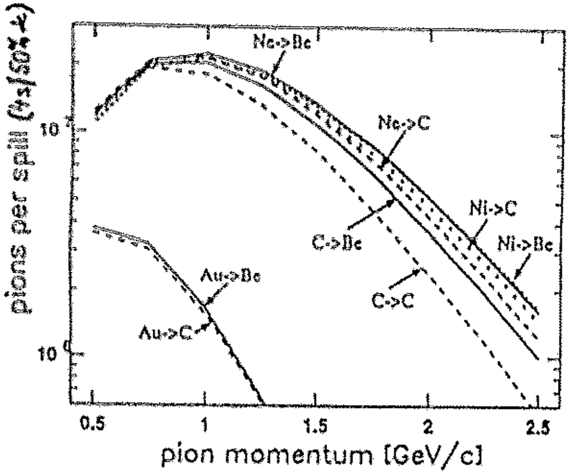


Figure 1: Expected $\pi^{\pm}$ - intensities for $\Delta\Omega\Delta p/p$ = 30 msr% and different target-projectile combinations , maximum SIS energies

may serve at experiments in target hall:

4π - detector & large gap dipole (Aladin)

QD - spectrometer (KaoS) & BaF_2-array (TAPS)

dilepton - spectrometer HADES & "test" area (>1995)

Ausblick:

Anregungsfunktion für π, K^+, K^-, η 1995: Au @ 1.4 GeV/u

Zerfall in Medium (ρ, ω, ϕ, Δ, ..) 1997: HADES
high acceptance di-lepton sp.

Vergleich mit Hadron-induzierter Produktion
1995: COSY: (p, K^+)
möglich: π-Strahl bei SIS
0.8 - 2 GeV/c , ~ 10^7/s

Physikalisches Programm an COSY

K. Kilian
Jülich

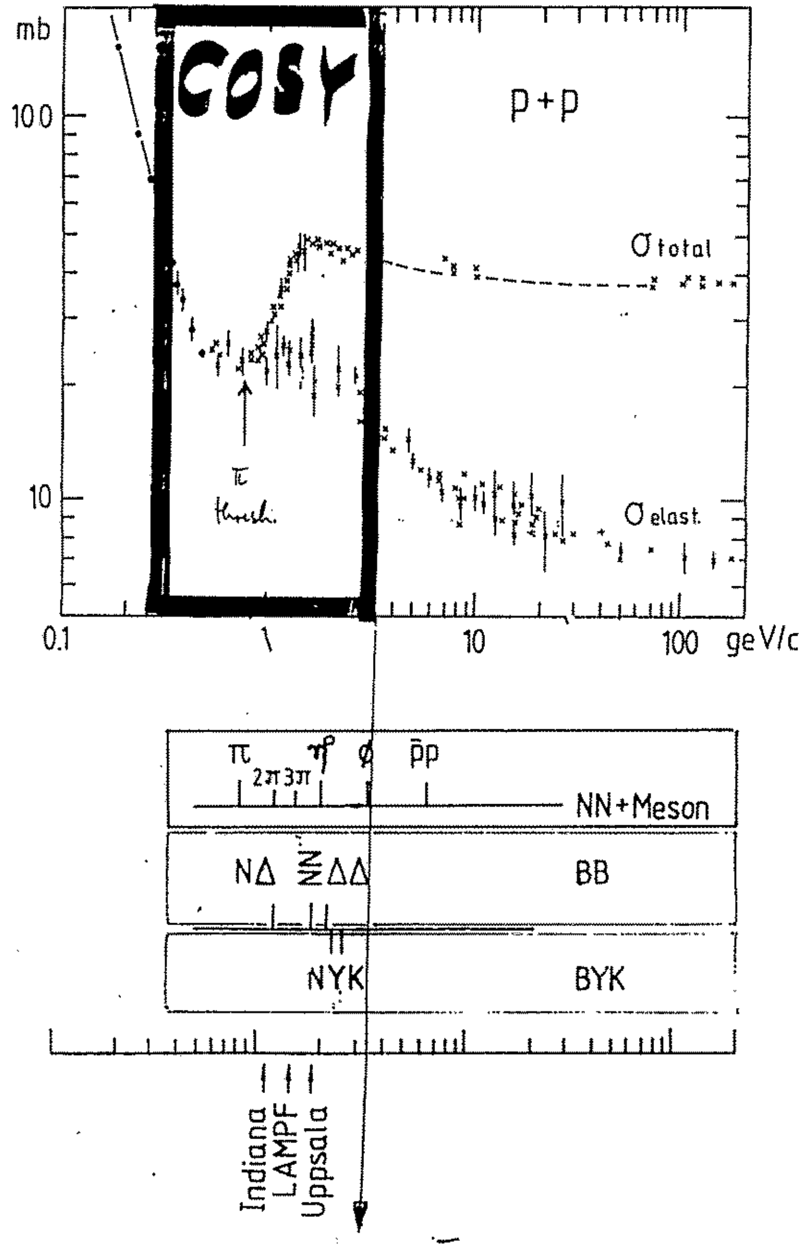
7.Oktober 1994

Physics Program at COSY

Physics → beam requirements

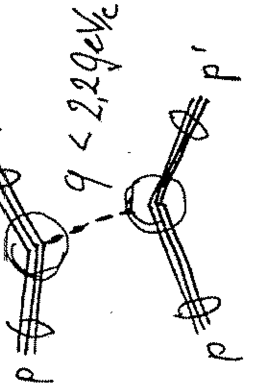
Accelerator (+ cooling)

Experiments



$\varepsilon = \sqrt{s} - 2m_p \sim 1.1\,GeV$

at COSY



$$k = \frac{q}{\hbar c} \lesssim 11\,\mathrm{fm}^{-1}$$

$$\boxed{\lambda = \frac{2\pi}{k} \gtrsim 0{,}6\ \mathrm{fm}}$$

No chance to resolve quarks (and gluons) with 2,2 GeV/c momentum transfer in proton-proton scattering.

momentum of quark $\approx \frac{1}{5}$ momentum of baryon

$\Rightarrow$ the quarks get much less q_γ

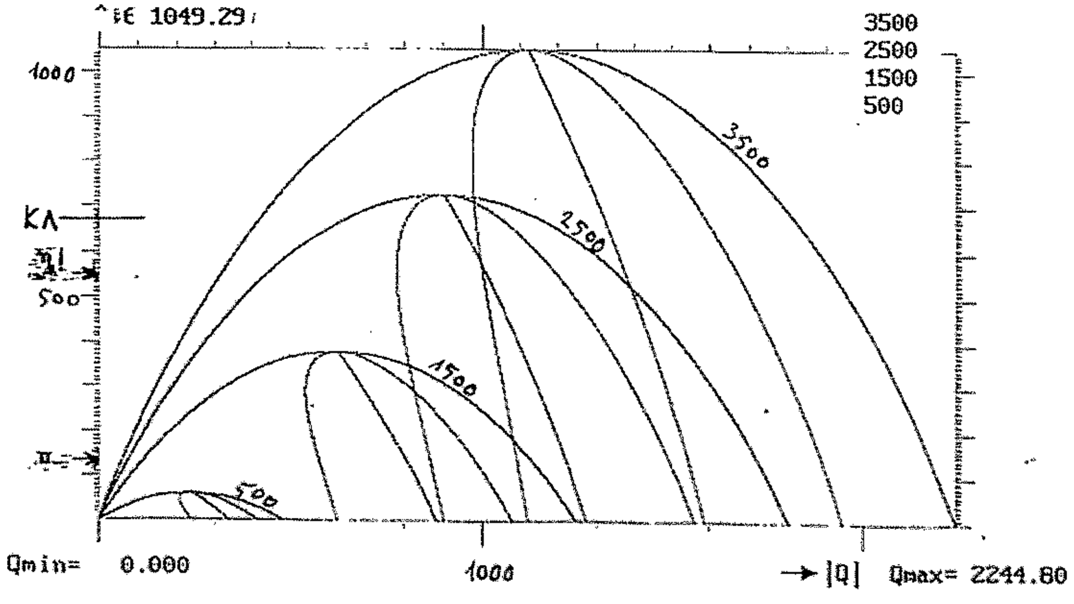
$\Rightarrow$ hadronic degrees of freedom $\nearrow$ baryons $\searrow$ mesons

(exotics ?)

* quark aspects in associated strangenes production

p + p → p + (p+ε)

```
P1  3500.00 |938.27 + 938.27 --> 938.27 + 938.27 +E| Emax= 1049.29  Th=0.00
       0.56 | 90.000  1122.40    Γ=1.559  |  90.000  1122.40    ß=0.767|
B1=0.9659   | -0.00   1750.00   3500.00   |  -0.00   1750.00   3500.00 |
Pcm1= 1122.4          0.000 < t <   0.000
```



(q,ε) range for responsefunction

COSY physics $\Rightarrow$ beam requirements

$\gtrsim 1$ GeV energy can be converted into new hadrons

$$p + p \rightarrow p + \underbrace{p + X}$$

→ all sorts of hadrons

- One or more mesons, thresh. product.
- $K\bar{K}$ pairs and ϕ
- KY associated production
- baryonic excitations, Δ, N^*

Studies of
- Production
- Decay
- Interaction

of • unstable hadrons

in p+p, p+d and p+A interactions

Unstable hadrons $\Rightarrow$ beam requirements

→ **production in threshold reactions**

c.m. distribution into small lab. angle range.

Needs very good $\Delta\theta$ and Δp

→ **multiparticle final states**

full acceptance detectors needed

small target vertex needed

→ **strange particle delayed decay**

perfect trigger and kinematic reconstruction

if beamsize $\ll L_{decay}$

COSY : $\Delta p/p < 10^{-4}$

$\varepsilon_{H,V} < 1\,\pi$ mm mr

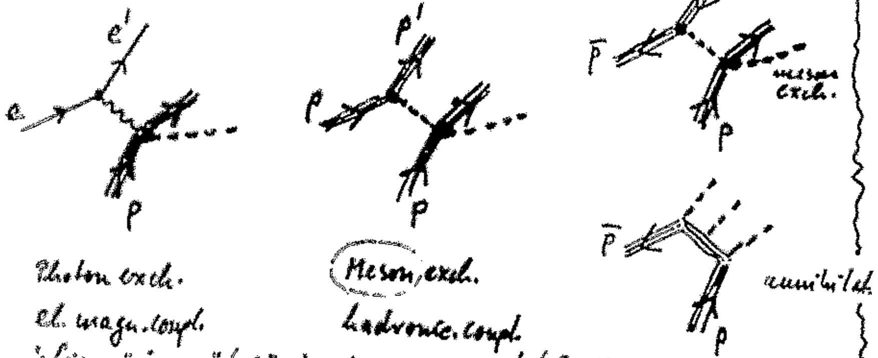
stochastic extraction

→ at 4/94 33 proposals + LoI from
36 research institutes
> 220 names

COSY and Some MEP accelerators

			MeV/c	MeV	
oling c+s	COSY Jülich	S	>3300	>2500	protons (polarized)
c	CELSIUS Upps.	S	2100	1360	
c	IUCF cooler	S	1090	500	
	SATURNE	S	3770	2950	
	PSI-SIN	C	1220	600	
	LAMPF	L	1460	800	
	TRIUMF	C	1090	500	
	ELSA	S	3500	3500	e, γ
	MAMI	M	850	850	
oling c+s	LEAR	S	2000	1270	$\bar{p}$

COMPLEMENTARY

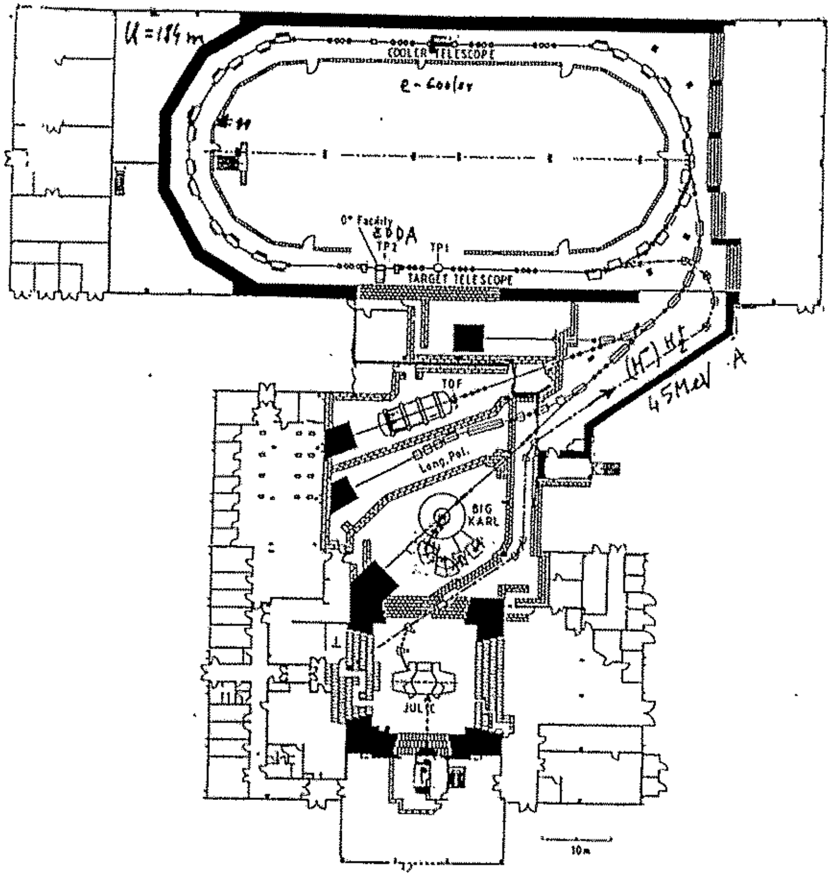


ELSA MAMI	COSY	LEAR
Photon exch.	Meson exch.	annihil.
el. magn. coupl.	hadronic coupl.	
"electron" "muon" (<0,5 ub)	Large cross sect. (>20 ub)	

	ELSA MAMI	COSY	LEAR
max mesonic mass	1,79 0,64	1,05	0,55 (inelast.) 2,4 (annihil)

COSY construction 1988-1993

IKP + AP + ZAT + ZEL Projectleader, U. Pfister)



pol. Source (Bonn Erlangen Köln)

Beam and Optical Properties of COSY

momentum range	270-3300 MeV/c	(50 – 2506 MeV)
max. no. of stored protons	$2 \cdot 10^{11}$	
horizontal/vertical tune	3.38/3.38	
transition momentum	1860 MeV/c	
geometrical acceptance	horizontal: 130 π mm mrad vertical: 35 π mm mrad Δp/p: ± 0.5%	
nat. chromaticity hor./vert.	- 5.2/- 4.5	

lattice function at

	β_{hor}	β_{vert}	dispersion
TP1:	5.6 m	5.9 m	0 m
TP2:	1.6 m	5.1 m	0 m
TP3:	6.0 m	22.2 m	10.1 m

radii and divergences for an extracted emittance of 2.5 π mm mrad and Δp/p of $1 \cdot 10^{-3}$ at

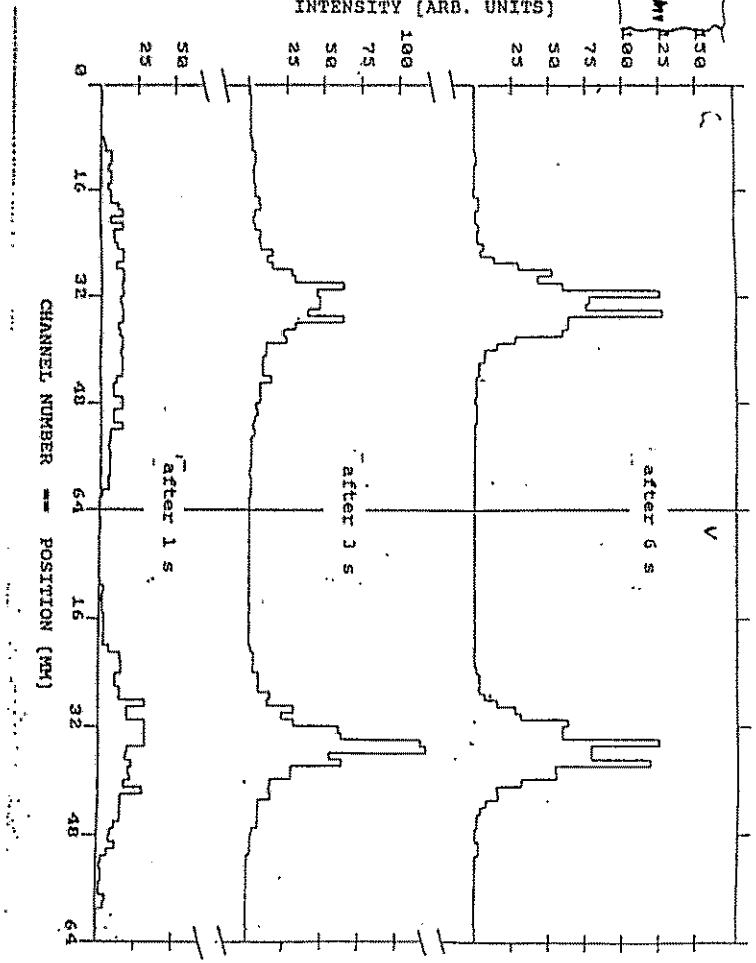
	x/mm	x'/mrad	z/mm	z'/mrad
medical therapy area	3.25	1.34	1.88	1.24
Time of Flight	0.56	4.90	0.72	3.47
BIG KARL	0.45	7.14	0.43	6.92

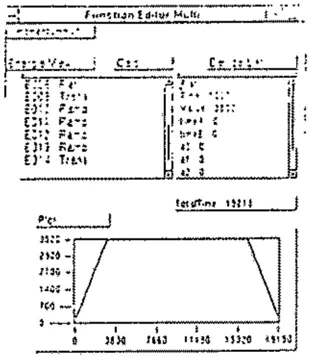
goal: $\varepsilon < 1\pi$ mm mr $\Delta p/p < 10^{-4}$

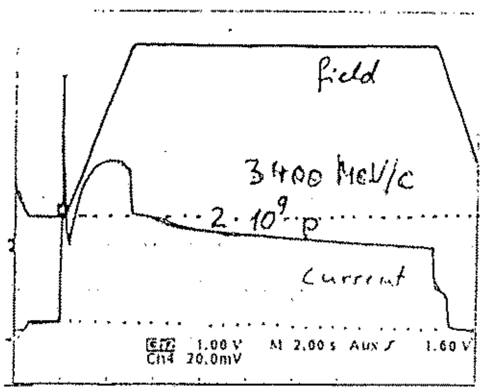
17.9.92 first turn of protons (270 MeV/c)
5.93 acceleration
9/94 >3,3 GeV/c internal (> 10^7/spill external at 1 GeV/c)

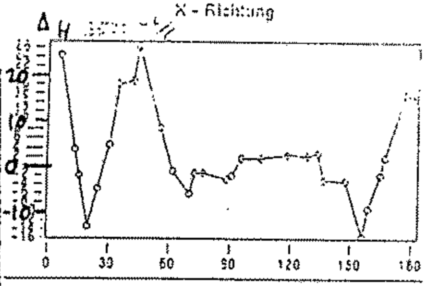
Size of H° beam out of e-cooler straight section

$\varepsilon_{h,v} \lesssim 0{,}5\pi$ mm mr









22. Sep. 1994 COSY erreicht gegen 17:30 einen Impuls von 3300 MeV/c + Maier. Maier 22.9.

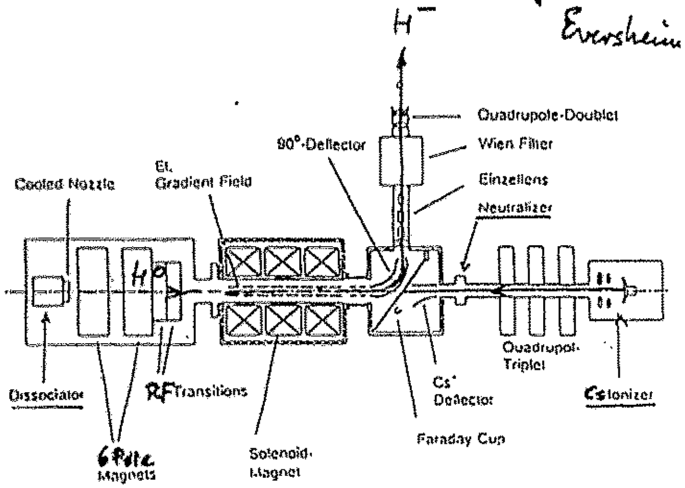
Dies stimmt genau

"find ich auch"

D.

Polarized source

(Bonn Erlangen Köln Univ)
Eversheim et al



- Beam development just started (4/94).
  $I \geq 1\ \mu A\ \vec{H}^-$; P ~ 75 % (goal 30 μA).
- To be done :
  - Injection to cyclotron.
  - Optimization of current and polarisation.
  - Acceleration of polarized beam.
  - Measurements of the polarization (polarimeter exists).
- Needs change of COSY injection from H_2^+ to H^-.
  New injection chamber ready for installation.

April 1994

COSY experiments

The Program Advisory Committee has reviewed so far 33 Proposals and Letters of Intent for research at COSY. In accordance with the PAC recommendations the following experimental installations are brought into operation:

- The magnetic spectrograph „BIG KARL" (for the MOMO and GEM collaboration)
- An internal experiment (EDDA) in a straight section
- A universal wide angle equipment (TOF)
- An internal cluster target experiment at a dipole (COSY-11)
- A polarized source
- An internal target setup for hypernucleus production

The PAC suggested furthermore that the development of a 0° Facility should be pursued as a natural extension of COSY-11.
The proposals recommended the PAC are listed with their new experiment number:

E1. A Study of p+p Excitation Functions and Search for Dibaryonic Resonances (Bisplinghoff, Hinterberger, Scobel; Proposal 5, EDDA)

E2. A Precision Study of Near Threshold Two Meson Production via the Reaction $p+d \rightarrow {}^3He+\pi^+\pi^-$ and $p+d \rightarrow {}^3He+K^+K^-$ (Jahn; Proposal 6, MOMO)

E3. Investigation of Proton-Proton Bremsstrahlung (Kuhlmann; Proposal 9, TOF)

E4. Experimental Investigaiton of Low-Lying States of Pionic Atoms (Machner; Proposal 10, GEM)

E5. Threshold Meson Production at the Internal COSY-Beam in the Range of Scalar Mesons involving Strangeness (Oelert; Proposal 11)

E6. Study of η and η' Production and Interaction (Roderburg; Proposal 12, TOF)

E7. Associated Strangeness Production in pp-Reactions (Turek; Proposal 15, TOF) ← (Eyrich)

E8. K⁺-Meson Spectroscopy with a 0° Facility at TP2 in COSY (Sistemich; Proposal 18)

E9. Deuteron Fragmentation Study with a 0° Facility at TP2 in COSY (Komarov; Proposal 20)

E10. Production of Very Heavy Λ-Hypernuclei (Ohm; Proposal 13)

most of the proposals since 9/89 → build detectors

No.	Proposal new 11.4.94	Installation	Additional components
16	Study of selective excitation of baryon-resonances H.P. Morsch	TOF	liquid ^{4}He target Si-μ-strip 'decay spectrometer' with 'quirl' structure
24	A study of $\vec{p}+^2H \rightarrow \eta + X$ reactions with 4 π detector geometries H. Machner	GEM BIG KARL TOF	
27	Search for narrow exotic six-quark states in the p-p bremsstrahlung at the energy below pionic threshold A.S. Khrykin		
28	The 2μ decay of the η E. Kuhlmann	TOF	forward calorimeter
29	Proton-deuteron pionic and radiative capture studied with the GEM Detector H. Machner, T. Kutsarova	GEM BIG KARL	
30	Search for a πNN rsonance in the reaction $pp \rightarrow pp\pi^-\pi^+$ at the COSY-11 installation H. Clement	COSY-11	
31	Pre-therapeutic biological experiments with proton beams at energies between 50 and 250 MeV K. Schwenke	COSY-MED	tissue equivalent detectors
32	Measurement of the lifetime of the hypertriton $^3_\Lambda H$ H. Nann	TOF	Si-μ-strip 'decay spectrometer' with 'quirl' structure hemispherical scintillator hodoscope
33	Weak production of lambda particles at COSY T. Sefzick	TOF	Si-μ-strip 'decay spectrometer' hemispherical scintillator hodoscope forward calorimeter

first installations and measurements

internal targets { EDDA $pp \rightarrow pp$ precise excit. fct. — szintill. hodoscopes

COSY-11 } $M \leftrightarrow \left\{ \begin{matrix} K^+K^- \\ \pi^+\pi^- \end{matrix} \right. \left\{ \begin{matrix} pp \rightarrow ppM / d'\pi^+ \\ pd \rightarrow {}^3He\, M \end{matrix} \right.$ — COSY dipole, cluster tg.

external targets { MOMO } — Scifi hodoscope.

GEM — π-nucleus at rest (RFK) — 'Big Karl' spectrometer, Ge μstrip + E detectors

TOF
pp Bremsstrahlung
pp+mesons (π η ρ ω η' ϕ..)
2step reactions on d target
η and η' scattering
KY production
} Universal Wide angle Equipment
3 layer scint. hodoscopes + start- and decay detect.

internal targets {
[illegible] 13 heavy hypernuclei lifetime — recoil distance of fission
0° Facilit. (p, K$^+$d) on nuclei, react. mech. — orbit bump spectrometer
p+d breakup

Pol. source

Proposals are welcome

OSY users at the experimental installations

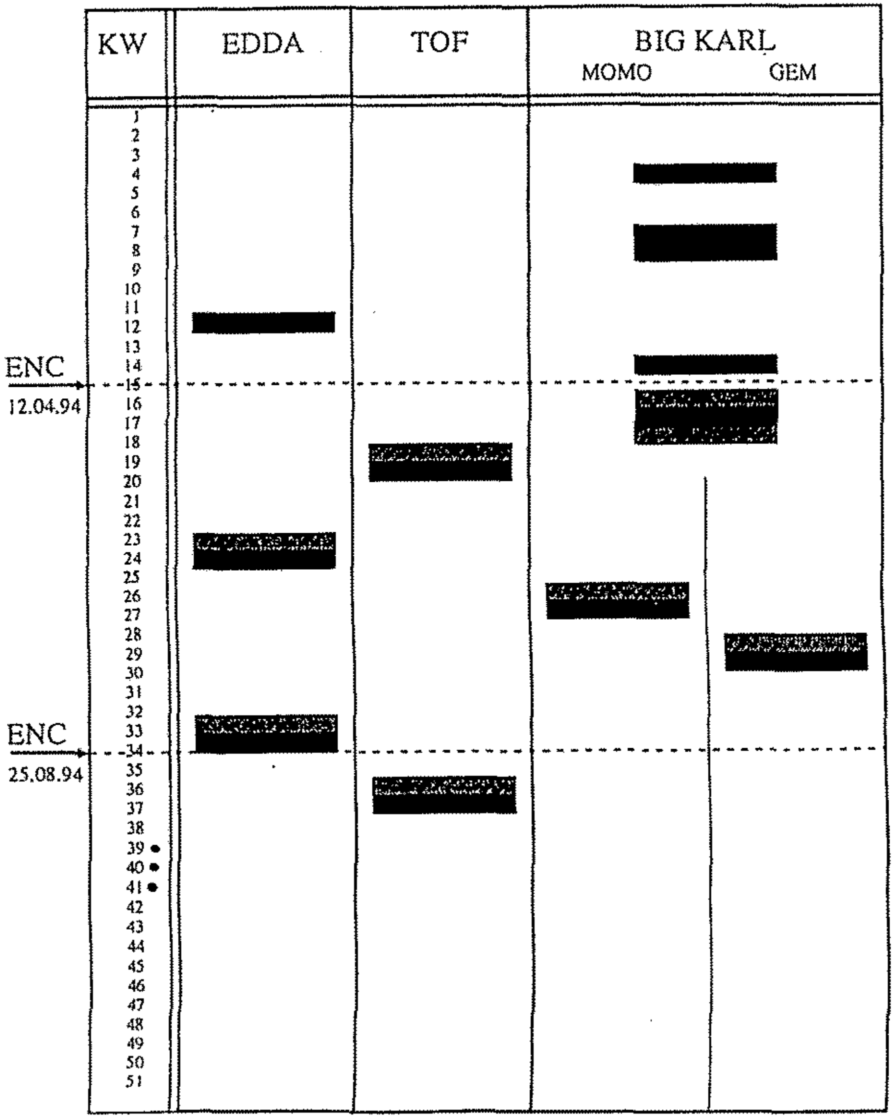
tatus : April 11. 1994

o. of proposals : 33
xperiment groups : 36 institutions, 225 scientists and students

Institution	EDDA ●	MOMO ●	GEM ●	TOF ●	COSY 11 ✗	0° facility	pol. source ●	COSY MED	total
IKP Uni Bochum				16					16
ISKP Uni Bonn	20	21	2	2		2	6		31
ITKP Uni Bonn	2	2							2
PI Uni Bonn				5					5
IKP TH Darmstadt		2							2
IKP TU Dresden			2	2					4
IG Uni Essen								1	1
PI Uni Erlangen				8			6	3	14
ITP Uni Gießen						1			1
IEP Uni Hamburg	10								10
IKP KFA Jülich	5	3	15	20	7	19		7	42
IME KFA Jülich								11	11
ZEL KFA Jülich			3		5	5			10
IKP Uni Köln	1						6		6
IKP Uni Münster			1		4	3			5
FZ Rossendorf				6		6			12
PI Uni Tübingen				3	5				5
FP Uni Wuppertal								1	1
INRNE Sofia Bulgaria			1						1
DAP Uni Sofia Bulgaria			2						2
EP D. CERN						1			1
IPN Orsay France		2							2
LNS France				2					2
NIKHEF Amsterdam			1						1
PI Cracow Poland		4	6		8	6			11
INP Cracow Poland			4		2				5
INS Warsaw Poland				3					3
JINR Dubna Russia						8			8
LNPI Gatchina Russia						2			2
ITEP Moscow Russia				2	2				2
Uni Stockholm Sweden				1					1
IUCF Indiana USA	1			1	1				3
FSU Florida USA			1						1
SCN Mass. USA				1					1
GMU Virginia USA			1						1
total	39	33	39	72	34	53	18	23	225

● start of tests

Experiment Strahlzeiten 1994



The

EDDA

Collaboration

A HIGH RESOLUTION STUDY OF p+p EXCITATION FUNCTIONS

Spokesmen: J. BISPLINGHOFF, F. HINTERBERGER, W. SCOBEL

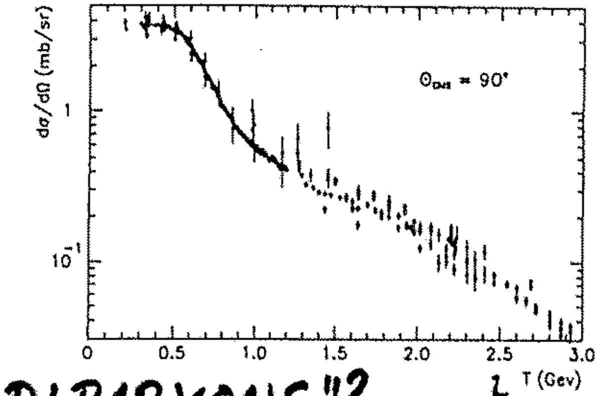
J. BISPLINGHOFF, R. BOLLMANN, P. CLOTH, O. DIEHL, F. DOHRMANN, V. DRÜKE, S. EISENHARDT, H.P. ENGELHARDT, J. ERNST, D. EVERSHEIM, D. FILGES, S. FRITZ, M. GASTHUBER, J. GREIFF, A. GROSS, R. GROSS-HARDT, A. HEINE, F. HINTERBERGER, R. JAHN, M. JESKE, U. LAHR, R. LANGKAU, R. MASCHUW, T. MAYER-KUCKUK, G. MERTLER, B. METSCH, F. MOSEL, M. MÜLLER, M. MÜNSTERMANN, H. PETRY, D. PRASUHN, B. v. PRZEWOSKI, M. RADTKE, H. ROHDJESS, D. ROSENDAAL, U. ROSS, P. von ROSSEN, H. SCHEID, H. PAETZ gen. SCHIECK, N. SCHIRM, M. SCHULZ-ROJAHN, F. SCHWANDT, W. SCOBEL, G. STERZENBACH, H.J. TRELLE, J. WEBER, A. WELLINGHAUSEN, W. WIEDMANN, K. WOLLER, R. ZIEGLER

Institut f. Strahlen- und Kernphysik, Universität Bonn
I. Institut f. Experimentalphysik, Universität Hamburg
Institut f. Kernphysik, Forschungszentrum Jülich
Institut f. Theoretische Kernphysik, Universität Bonn
Institut f. Kernphysik, Universität Köln
IUCF, Bloomington, Indiana

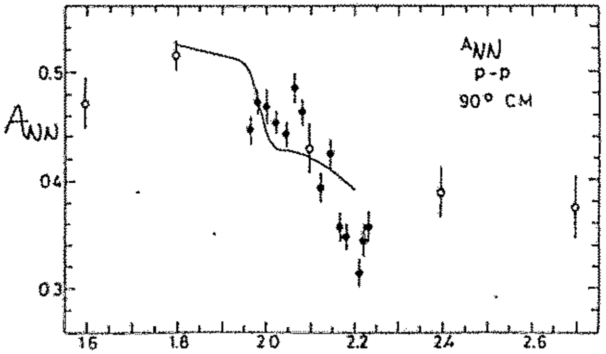
Aug '94

MOTIVATION

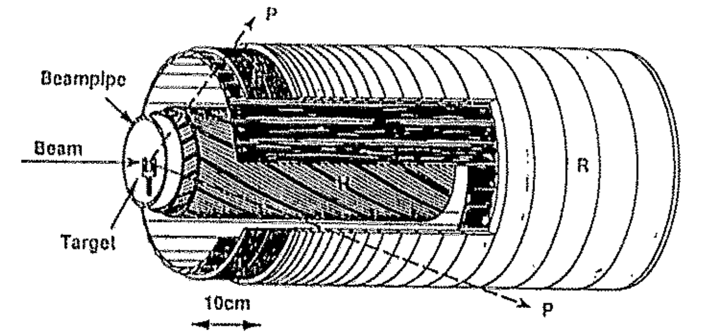
- $pp \rightarrow pp$ $\quad \frac{d\sigma}{d\Omega}$
  $\vec{p}\vec{p} \rightarrow pp$ $\quad A, A_{NN}, A_{LS}, A_{SS}$
  $T_p = 0.5 \ldots 2.5$ GeV
- PHASE SHIFT ANALYSIS !



- "DIBARYONS"? $pp \xrightarrow{?} B_2 \xrightarrow{?} pp$



J. Ball et. al
Phys Lett B320, 206 (1994)
(1994)

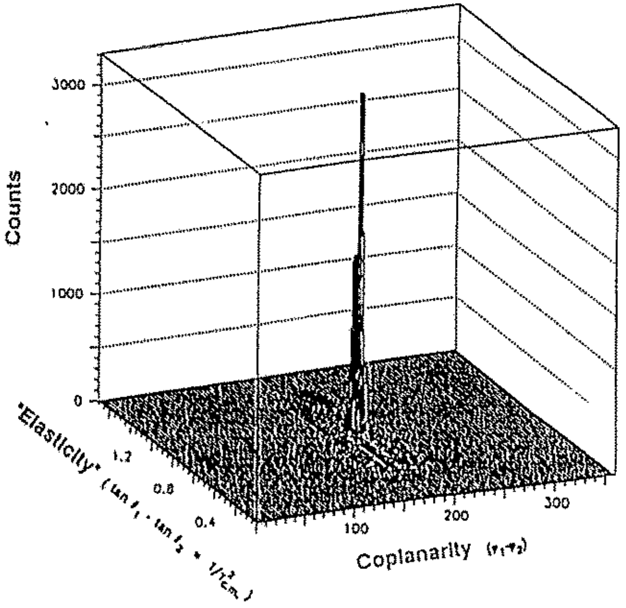


The EDDA Detector (not to scale): Target (CH_2 fiber suspended from fork, later polarized atomic beam), Beam pipe (2 mm Al in sensitive region), H Scintillating Fibers wound in opposing helicities, B Scintillator bars, F + R Scintillator rings

Elastic p-p Scattering , T = 0.25 - 2.5 GeV

$d\sigma/d\Omega(T)$, $A(T)$, $A_{NN}(T)$, $A_{SS}(T)$, $A_{SL}(T)$

→ Phase Shifts ! → Dibaryons ?

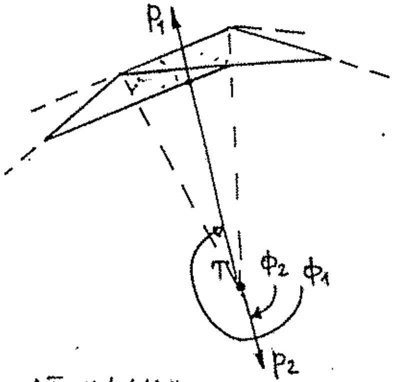


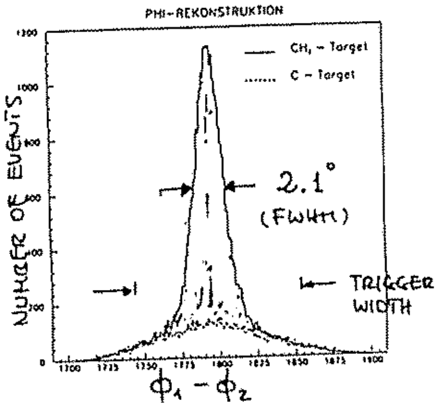
Identification of p-p elastic events

⑥

POSITION RESOLUTION OF OUTER SCINTILLATOR LAYERS:

SCINTILLATOR BARS FOR COPLANARITY.

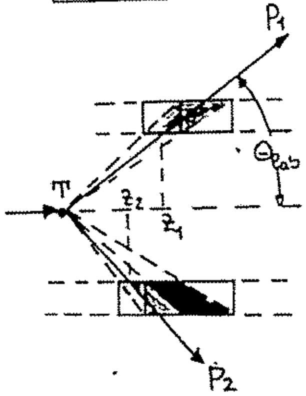




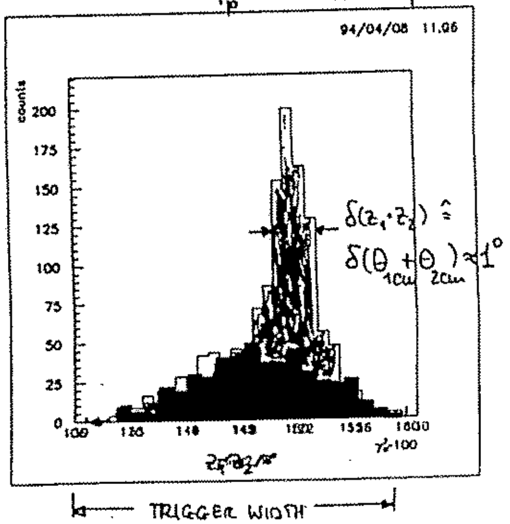
$\Delta T_p \approx 1.6$ MeV:
TIME RESOLUTION
$\delta(\Delta T_{12}) \approx 780$ ps => ADDITIONAL CUTS

- SCINTILLATOR SEMIRINGS FOR SCATTERING KINEMATICS

$\boxed{Z_1 \cdot Z_2 \sim \gamma^2(T_p)}$



T_p : 1500 MeV/c

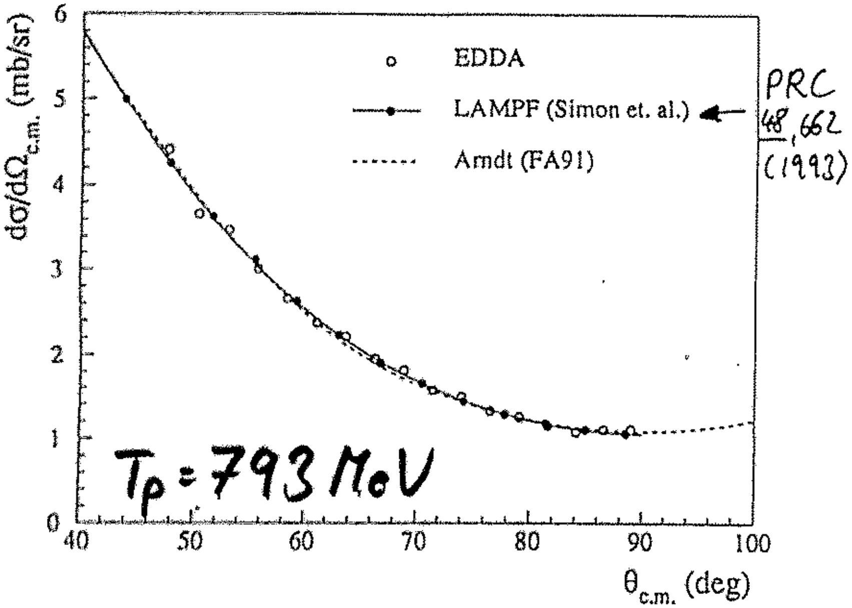


ANGULAR DISTRIBUTION:

- SUBTRACT QF-BACKGROUND

$$N_H(\theta) = N_{CH_2}(\theta) - N_c(\theta)$$

- NORMALIZE TO WORLD DATA SET



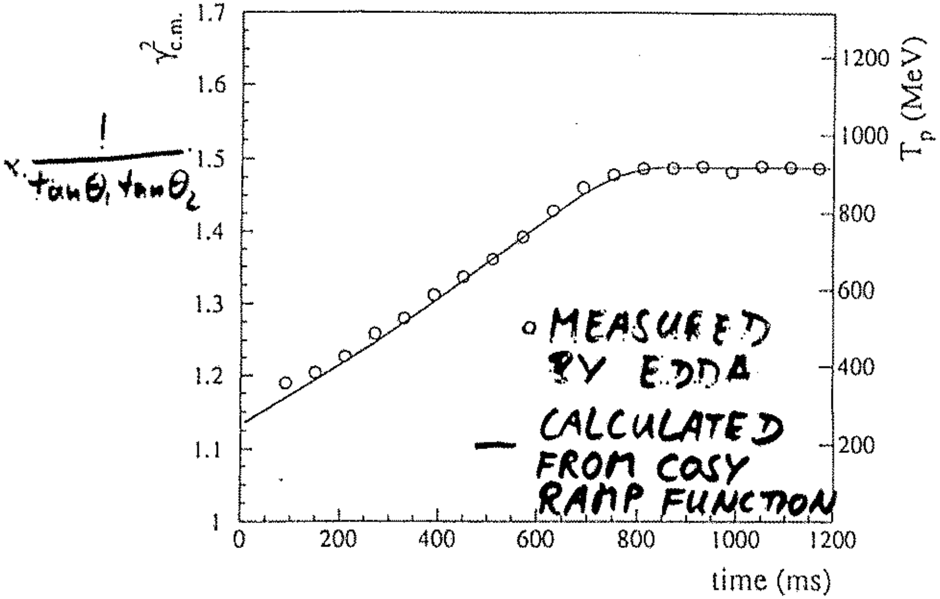
THE EDDA DETECTOR WORKS!

DATA ACQUISITION DURING THE RAMP

$$p = 800 \ldots 1600 \ \frac{MeV}{c}$$

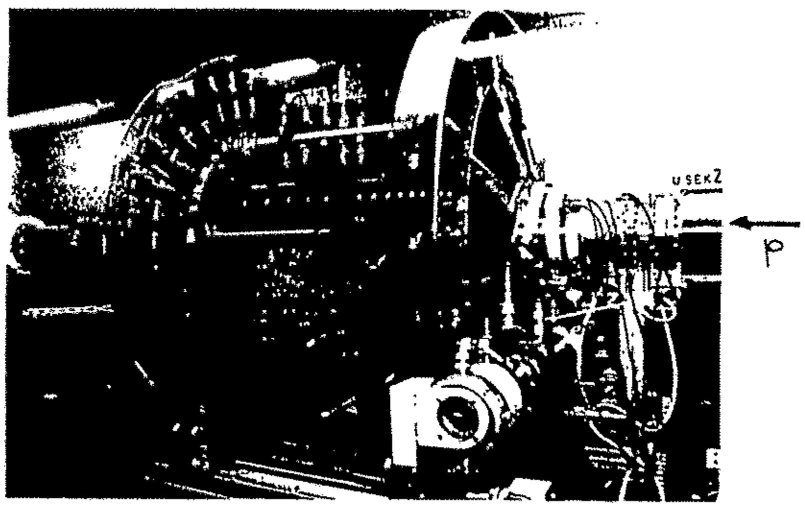
$$(T_p = 300 \ldots 900 \ MeV)$$

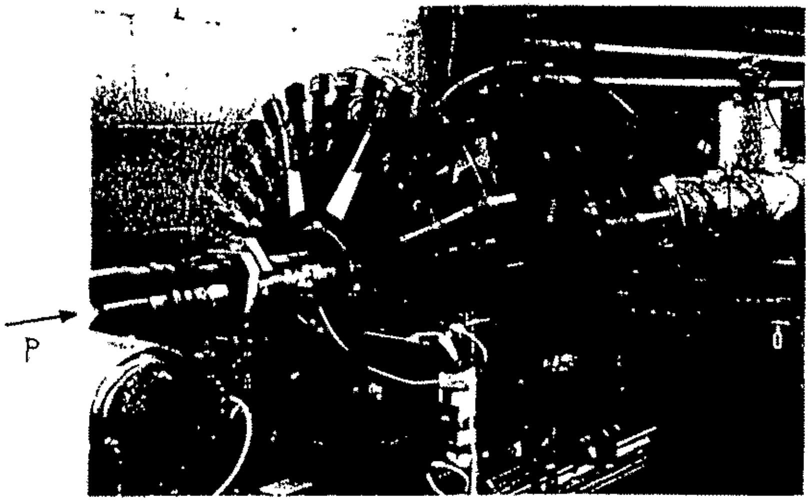
$$\frac{dp}{dt} = 1.15 \ \frac{GeV}{c\,s}$$



MEASUREMENTS WHILE RAMPING ARE FEASIBLE!

II. EDDA AT TP2 : PROGRESS SINCE PAC #7 ⑤

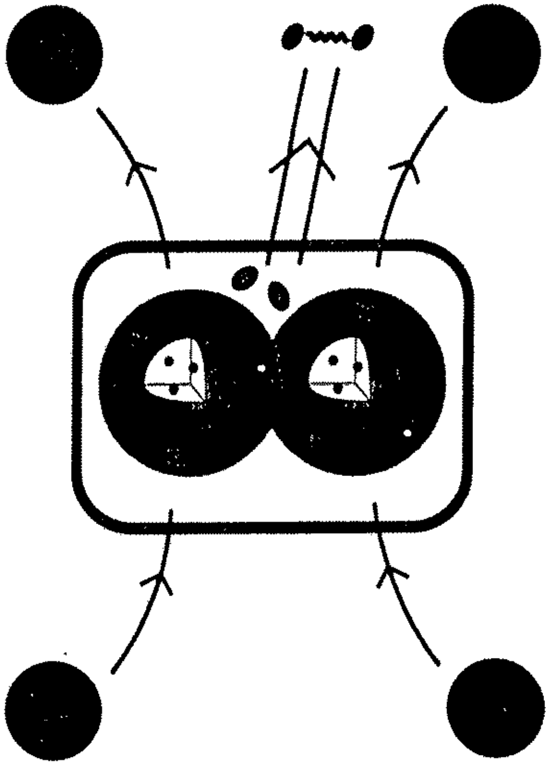




≥ 3/94

MARCH 21-26 : GOING INTO OPERATION, 1500 $\frac{MeV}{c}$

Meson - Meson Interaction



[redacted]

D. Lohse et al. P.L. B234(90)235

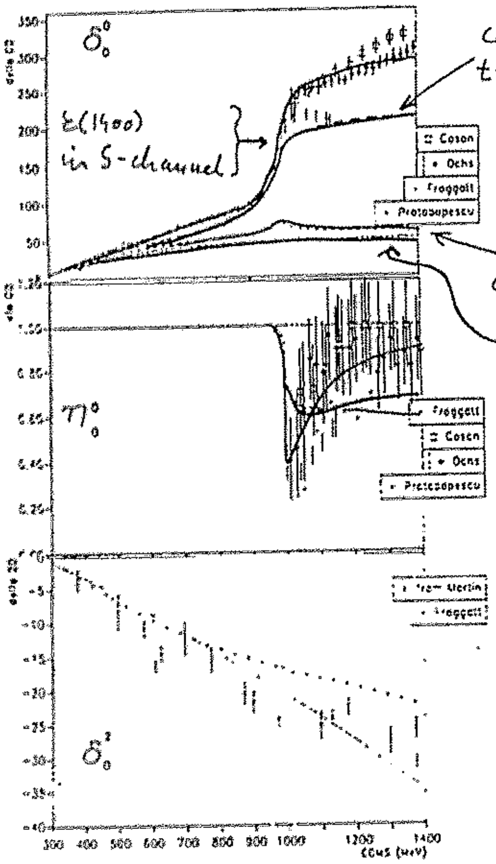
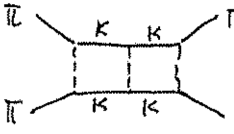


Fig. 1. The results of four different theoretical models for the I = 0, J = 0 ππ phase shift δ_0^0 and elasticity parameter η_0^0. The long-short dashed curve is the result for ρ exchange only. The short dashed curve includes the effect of coupling to the $K\bar{K}$ channel with no $K\bar{K}$ interaction. The long dashed curve includes t-channel exchange contributions in the $K\bar{K}$ channel, the solid curve adds the ε as an s-channel process. The experimental phase shifts are taken from refs. [7–10]. In the lower part we compare the I = 2, J = 0 ππ phase shift with the data of refs. [8,11]. The effect here is only due to the t-channel meson exchange.

ε(1400) in S-channel

coupling to $K\bar{K}$ with t-channel exchange



coupling to $K\bar{K}$

ρ exchange

S wave $\pi\pi$ scattering

I = 0 J = 0 phase shift and elasticity

→ quasibound $K\bar{K}$ pair

COSY 11
(Oelert)

Ⓔ5

$\boxed{pp \to pp \underbrace{K^+K^-}_{X^0}}$

$\pi^+ \ \pi^-$

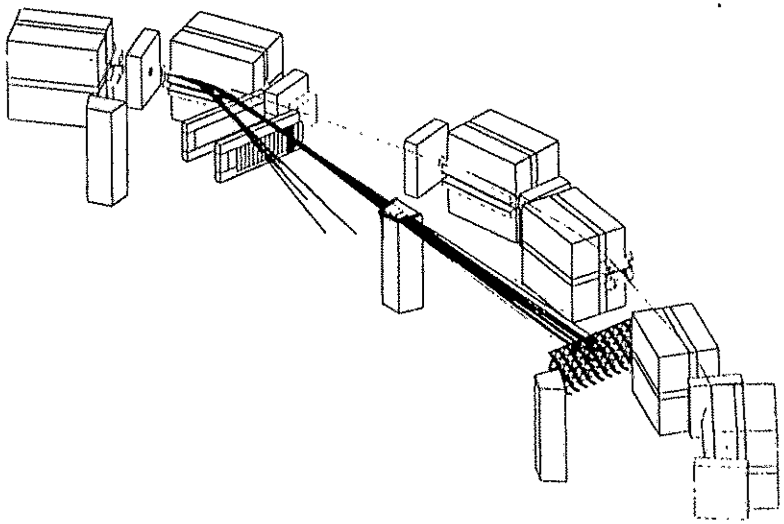
$\boxed{4C}$ event reconstr.

internal cluster target (Münster) $\sim 10^{-9}\ \mathrm{g/cm^2}$

COSY dipole as spectrometer

Driftchambers (Krakau)

Scintillators + Si-pads (Jül) + „Amadeus"

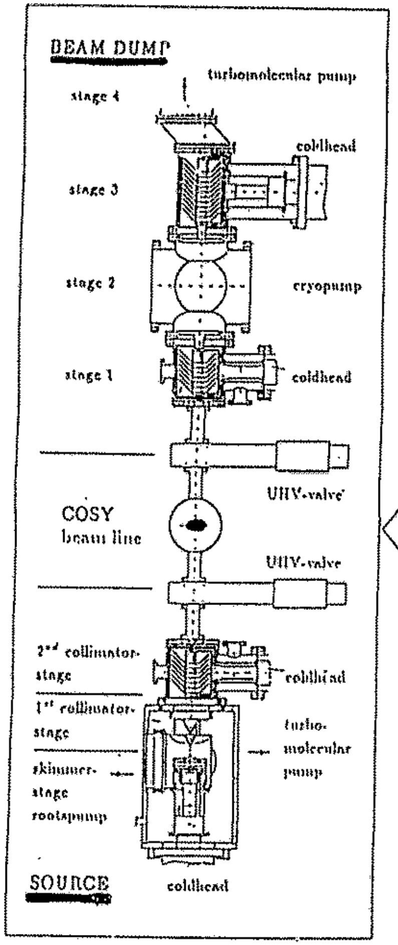


X^0 =

$f_0(975)$

$a_0(980)$

Grzonka



Aufbau

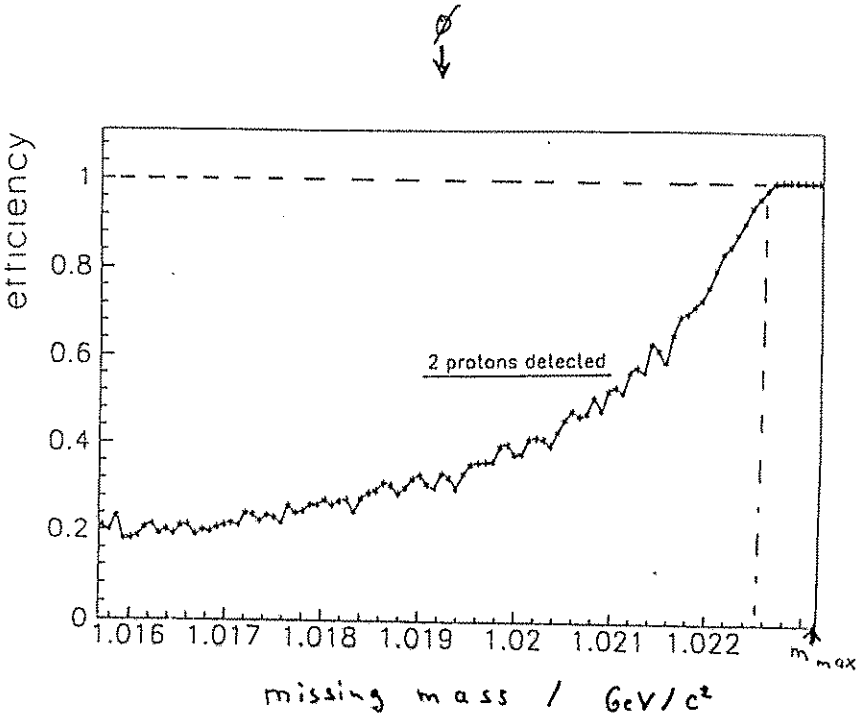
Betriebsparameter

$\rho \sim 10^{14}\ \frac{Atome}{cm^3}$

$\varnothing = 1 - 10$ mm

$\rho dx = 10^{12} - 10^{14}\ \frac{Atome}{cm^2}$

$L = 10^{28} - 10^{30}\ \frac{1}{cm^2 s}$



Monte Carlo events

$pp \rightarrow pp\,\phi$

$P_{beam} = 3.416$ GeV/c

(K^+K^-) or $(\pi^+\pi^-)$ $\qquad \mathcal{E}_{1s} \sim 6$ keV or $1{,}7$ keV

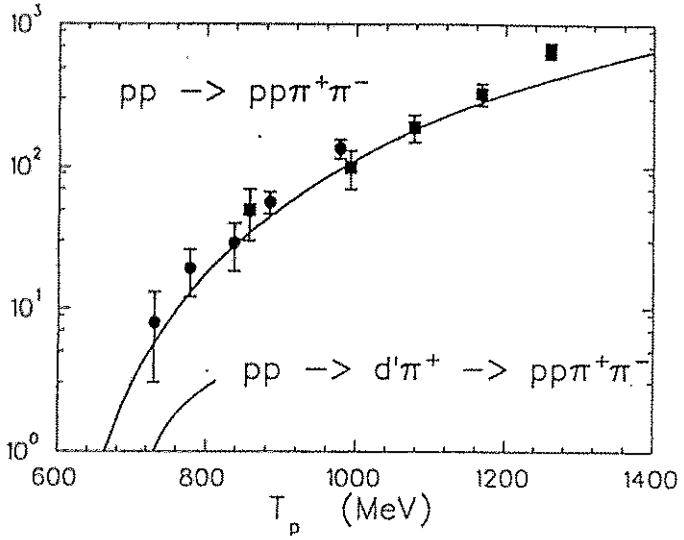
possibly studies of e.m. atoms? $\rightarrow \frac{\Delta p}{p} \lesssim 10^{-6}$!

comp. L. Nemenov

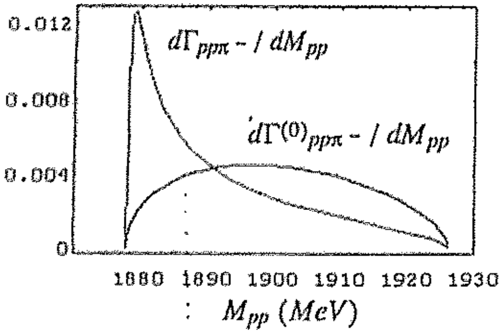
Clusterstrahltarget für COSY 11

Federführend R. Santo Münster

d´-Produktion im pp-Stoß



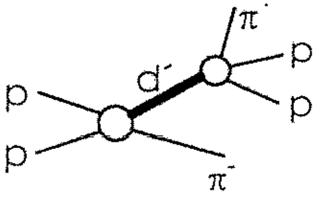
Z. Phys. A345, 407 (1993)



kleine Winkel- und
Impulsdifferenzen zwischen
den Protonen ⇒

d`-Zerfalls-charakteristik

$m_{d'} \approx 2060$
$\varepsilon_{\pi pp} = 44$ MeV



BIG KARL Spectrometer

- QQQDDQ on external target.
  1.05 GeV/c per unit charge; $\Delta p/p = 8\%$; $\Delta\Omega = 10$ msr.
  Drift chambers and szintillator hodoscopes in focal plane.

Two different acceptance extensions close to target.

MOMO

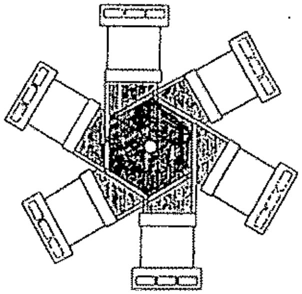
F. Jahn

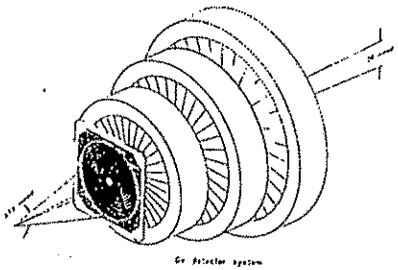
Vertex wall, a 3 layer
szintillating fiber hodoscope

GEM

H. Machner

Germanium detector stack
with Ge μstrip in front



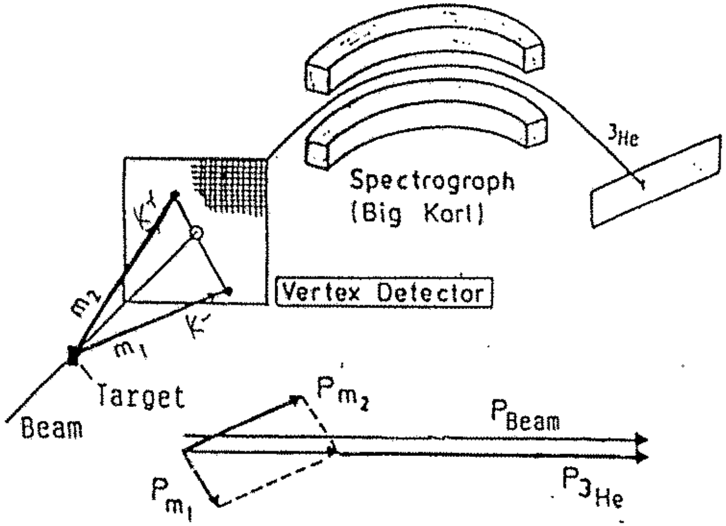


Tests with extracted, accelerated beam since 11/93.
Measurements of pp→dπ with LH2 target running.
MOMO vertex wall ready in 94
GEM Ge detectors ready in 95

COSY E2 (MOMO) R. Jahn (Bonn)

$$p + d \longrightarrow {}^3He + \pi^+\pi^- \qquad T_{thr.} = 432\ MeV$$

$$p + d \longrightarrow {}^3He + \underbrace{K^+K^-}_{X^0} \qquad T_{thr.} = 1.73\ GeV$$



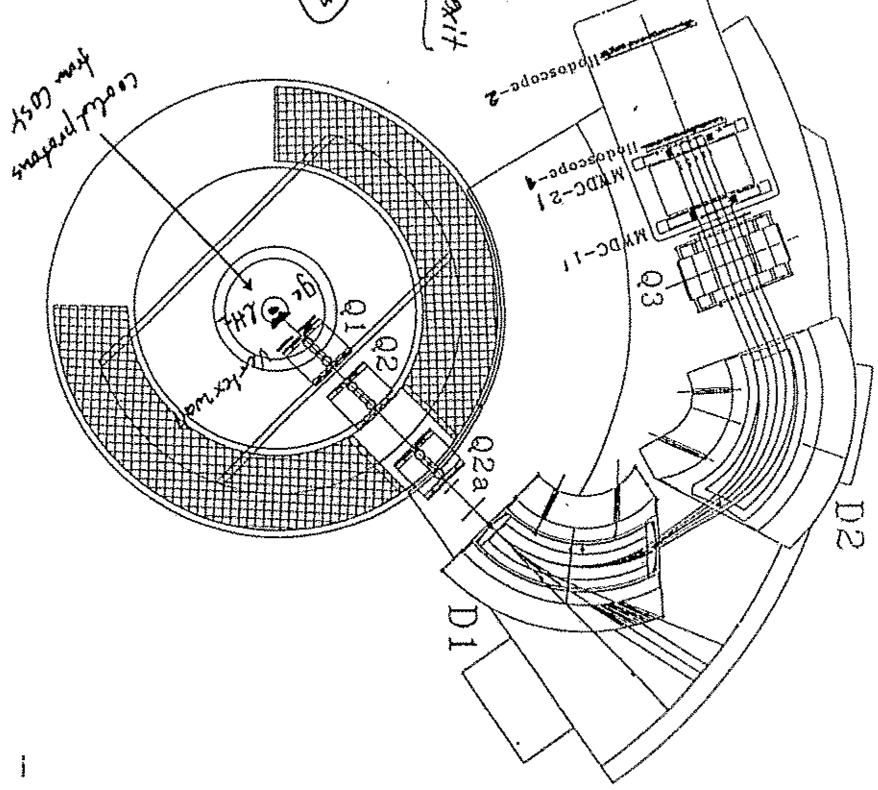
Particle tracks in exit

↓

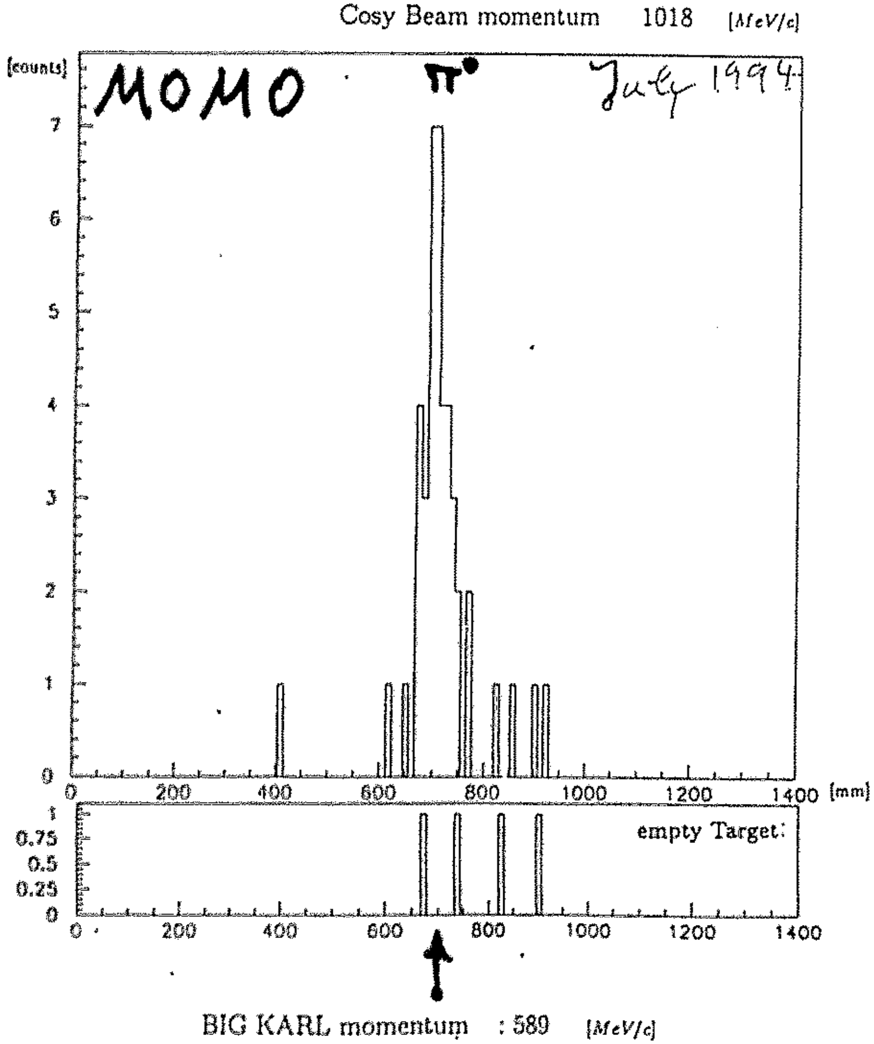
Big Karl Optics

↓

four-vectors out of target

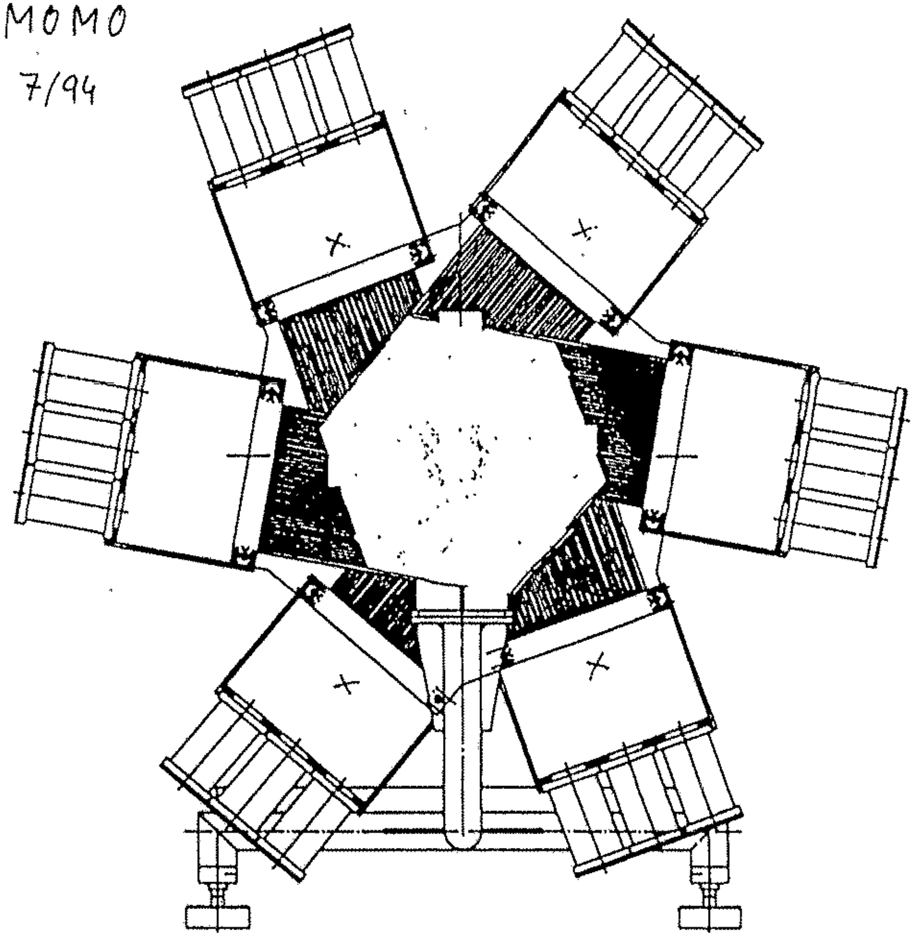


$p + d \rightarrow {}^3He + \pi_0$



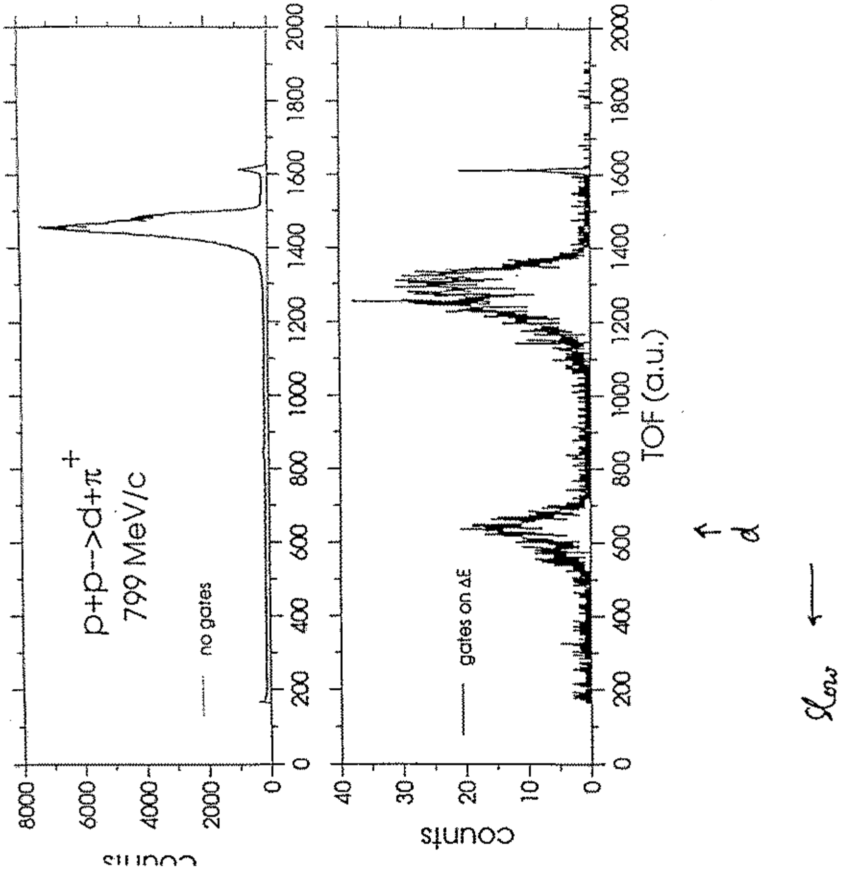
3He - focal plane spectrum

MOMO
7/94

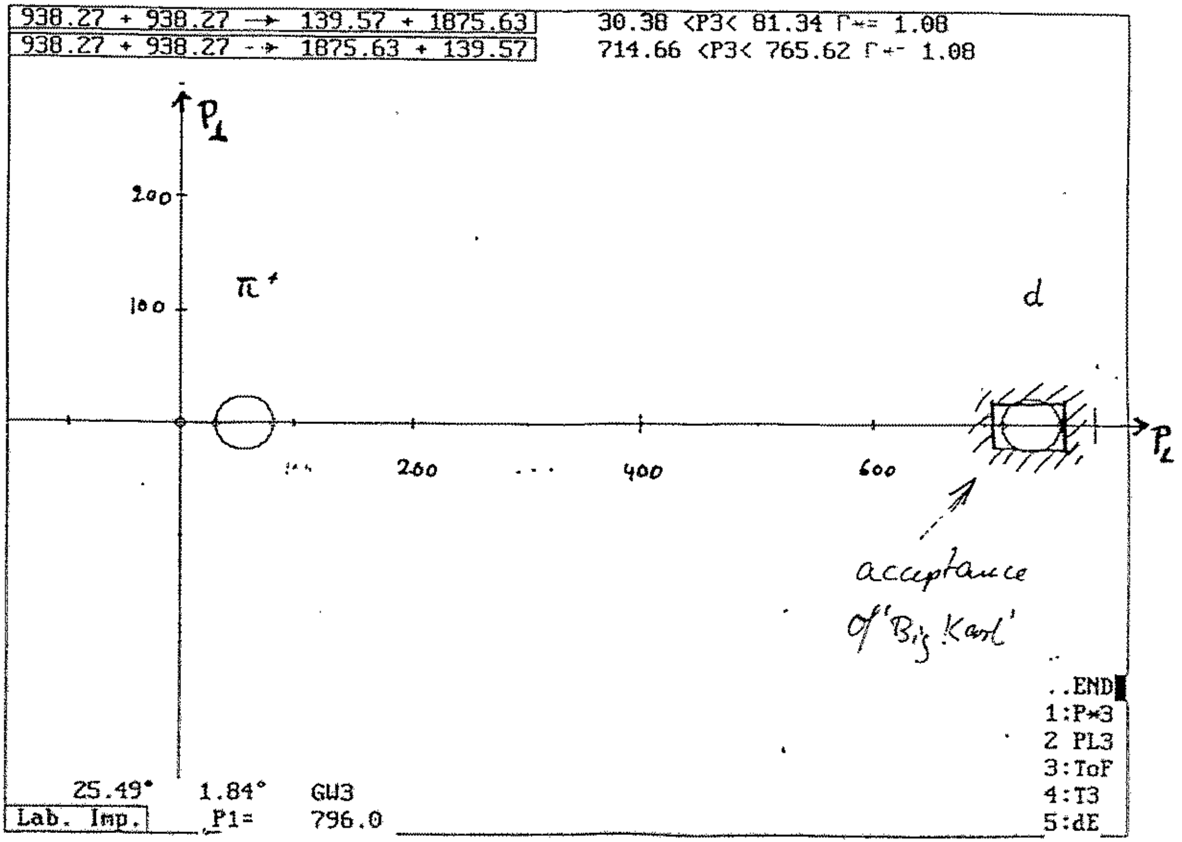


$p + d \rightarrow {}^3He + \pi^+ \pi^-$

first $\pi^+\pi^-$ events in the scintillating fibers vertex detector
(four modules operational, ready 10/94)



E gates { H1 H2 H3 high (→ no protons)
{ H4 nothing (d does not reach)



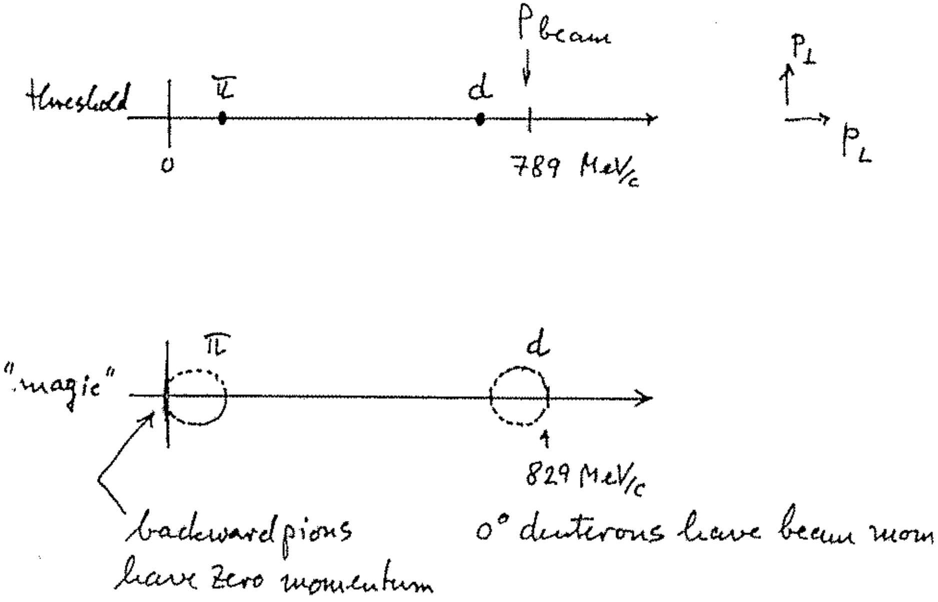
```
938.27 + 938.27 --> 139.57 + 1875.63     30.38 <P3< 81.34 Γ+= 1.08
938.27 + 938.27 --> 1875.63 + 139.57     714.66 <P3< 765.62 Γ+- 1.08
```

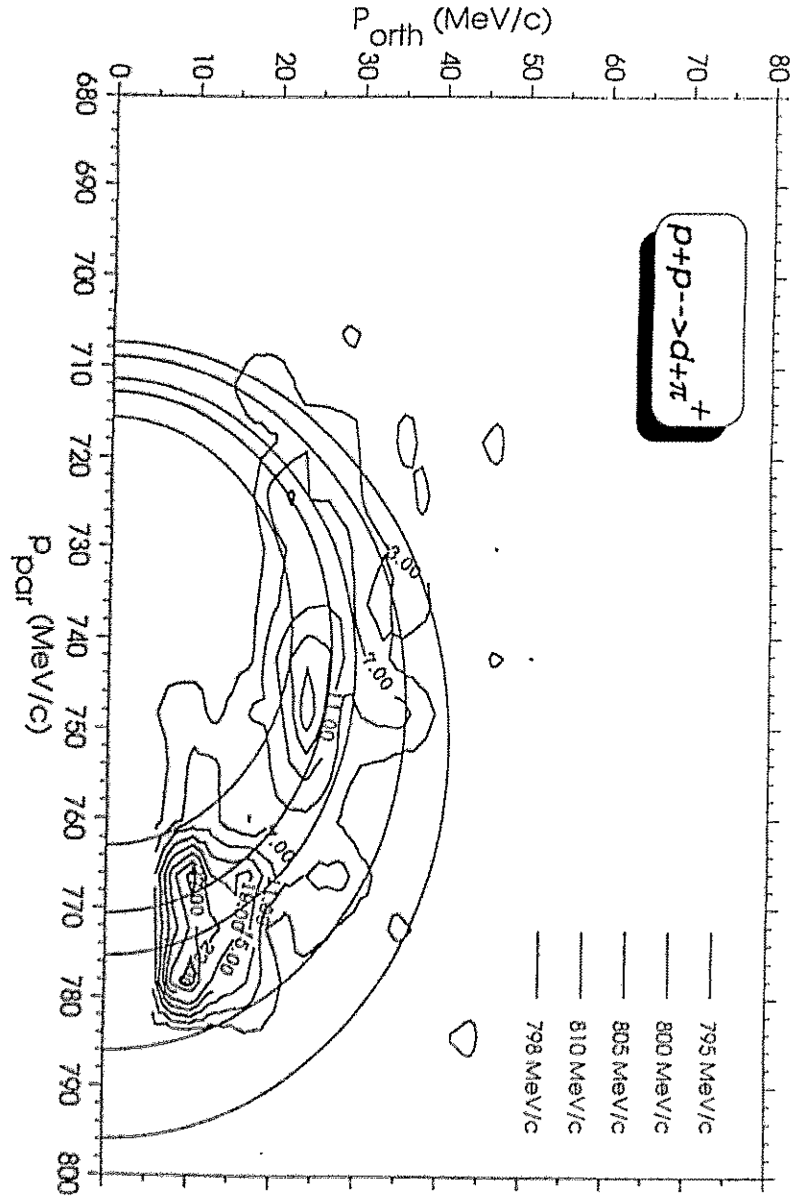
```
                                                        ..END
                                                        1:P*3
                                                        2 PL3
                                                        3:ToF
                                                        4:T3
     25.49°      1.84°    GW3                           5:dE
Lab. Imp.        P1=      796.0
```

$P_{H.} = 789$ MeV/c ; $\bar{E} = 2.15$ MeV

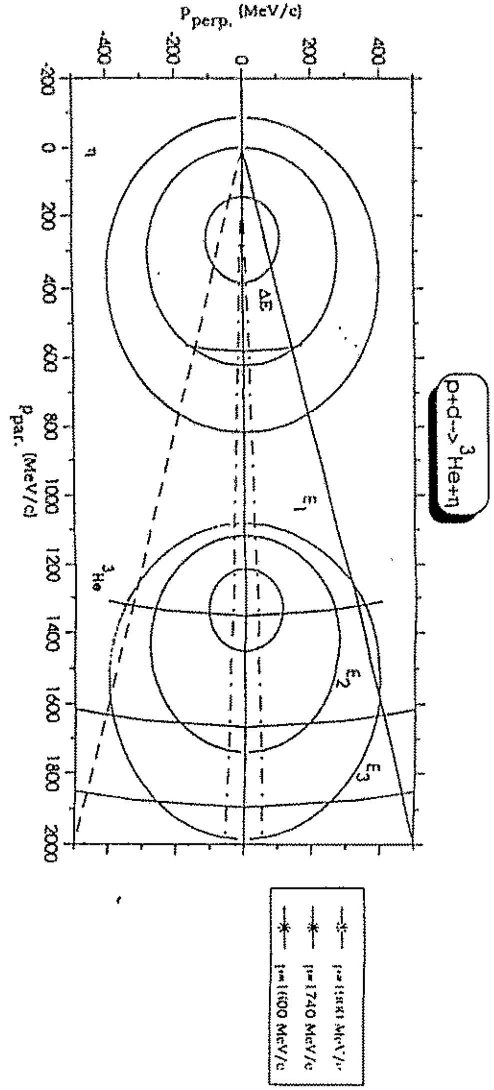
Example of "magic" momentum in $pp \to d\pi^+$

($\to$ π^+ at rest in the lab. system)





Energy acceptance of the Ge-telescope in GEM
ΔE: Quirl detector $E_{1..3}$: 17mm detectors



10) E4 Recoilless Production of π^- Atoms, $A\ell + p \to \pi^- + 2p$ ('86.
Amsterdam
Jülich (Machner) Krakau Tallahassee

π^--nucleus interaction at highest density

π^- capture in (atomic) bound state is proportional to:

$$\exp\left(-\frac{E_{recoil}}{E_{bind}}\right) = \exp\left(-\frac{q_\pi^2/2m_\pi}{E_{bind}}\right)$$

π^- at rest possible at "magic momentum" ~830 MeV/c in

$$p + \binom{^{39}Ca}{n} \longrightarrow \binom{^{39}Ca}{\pi^-}^* + \{p\,p\}_{\sim 0{,}5\,MeV} \qquad q_\pi \approx 0$$

2 protons coincident in magnetic spectrometer (+ Ge det. array)
⇒ missing mass reconstruction of $(^{39}Ca + \pi^-)^*$ states
gives shift E and width Γ of states with respect to QED!
decay of $(^{39}Ca + \pi^-)^*$ detected with BGO Ball

Compare IUCF: $p\,^{13}C \to \{^{14}B + \pi^-\} \to p\,^{13}C$ $q_\pi > 200$ MeV/c

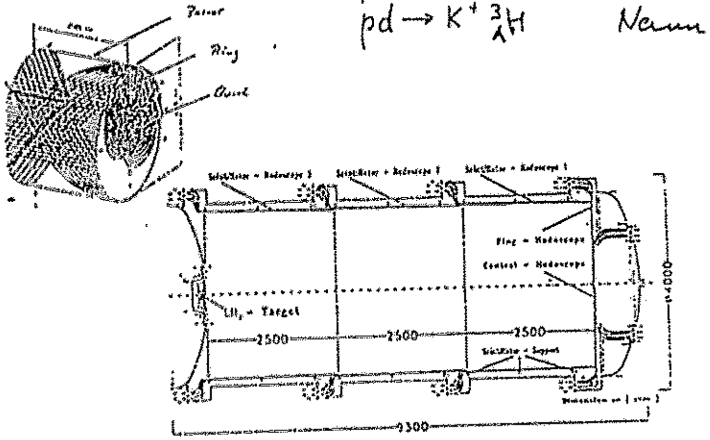
SATURNE: $d\,A_z \to \{A_{z+1} + \pi^-\} + 2p$ $q_\pi > 200$ MeV/c
↓
$T_\pi > 100$ MeV

N.B.: $p \binom{R}{n} \to \binom{R}{\eta}\,d.$ RFK at 3.04 GeV/c
$\underbrace{\qquad}_{\{\eta\text{-nuclei}\}}$

22

TOF

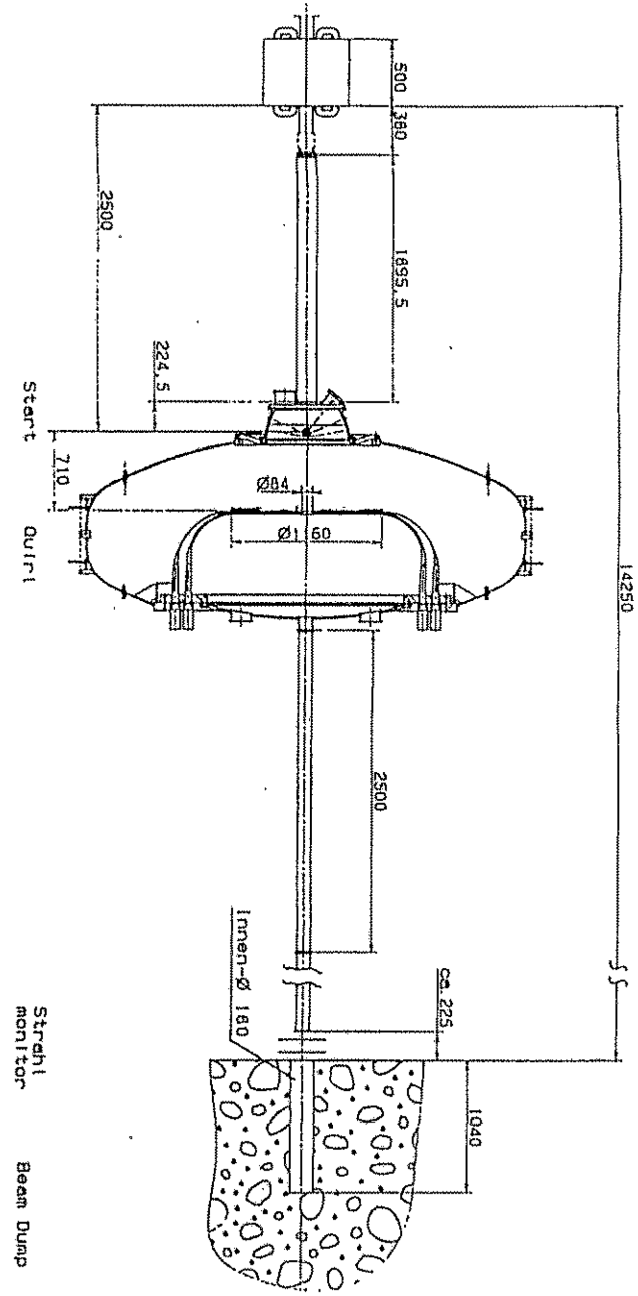
$pp \rightarrow pp\gamma$	Kuhlmann
$pd \rightarrow {}^3He\,\eta\ (\eta')$	Roderburg
$pp \rightarrow K^+\Lambda p$	Eyrich
$pp \rightarrow d'\pi^+$	Clement
$p\alpha \rightarrow N^*(1710)\alpha$	Morsch
$pd \rightarrow K^+\,{}^3_\Lambda H$	Nann



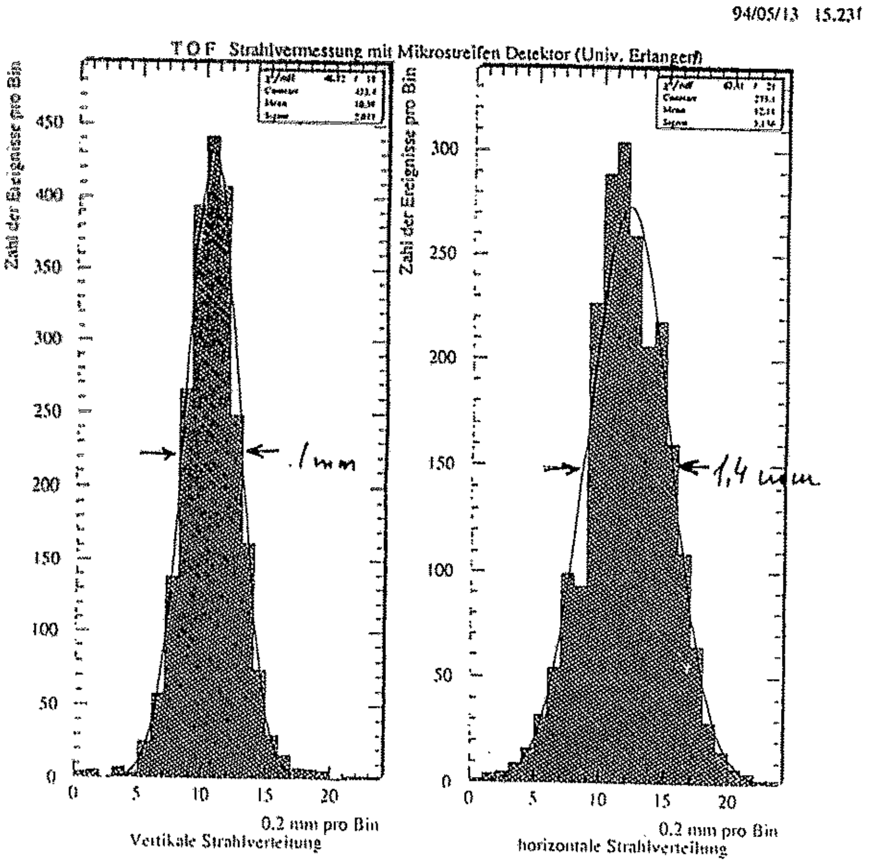
Time-of-Flight – Spectrometer (TOF)

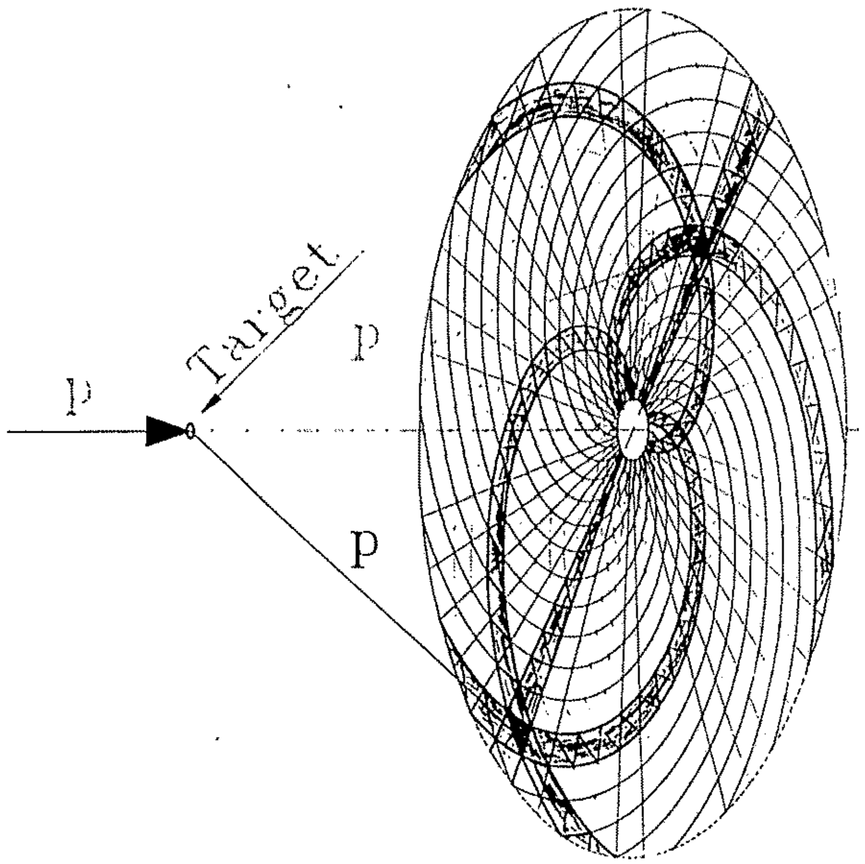
- A "massless, 100 % acceptance" time of flight spectrometer for charged particles.
  3 layer scintillator hodoscopes with axial symmetry.
  Precision comes from kinematical overconstraints.
  Additional precision for strange particle from decay pattern (needs cooled beam).

- LH_2 / LD_2 target and startdetectors for Bremsstrahlung and hyperon production ready.
  "Quirl" detector calibrated with cosmic rays.
  Start version ready for data taking in 5/94.



Testrun 5/94 with Quirl hodoscope in vacuum first beam at TOF





pp → pp

light from a hit in l- and r-"bananas" has identical timing -

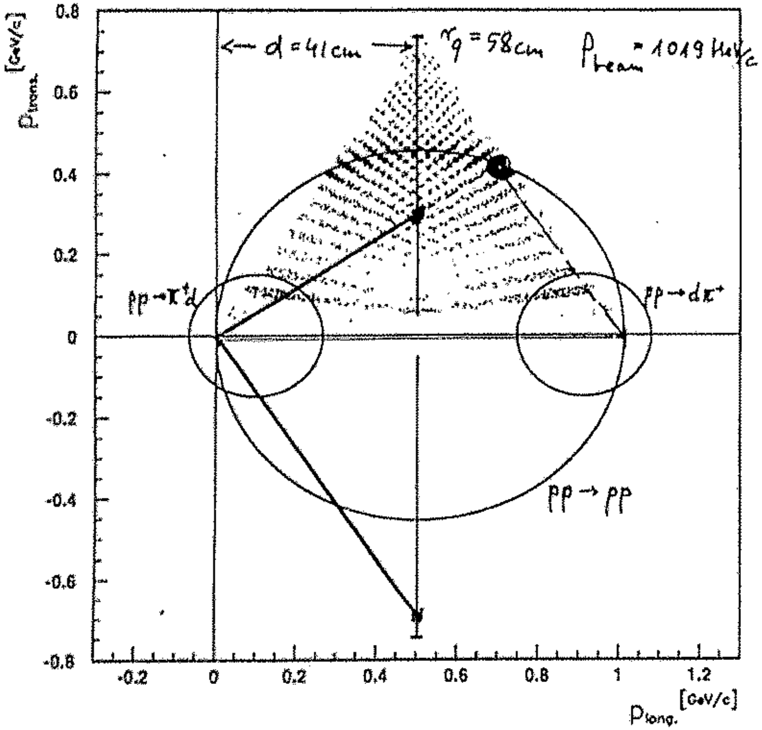
ONLY GEOMETRY

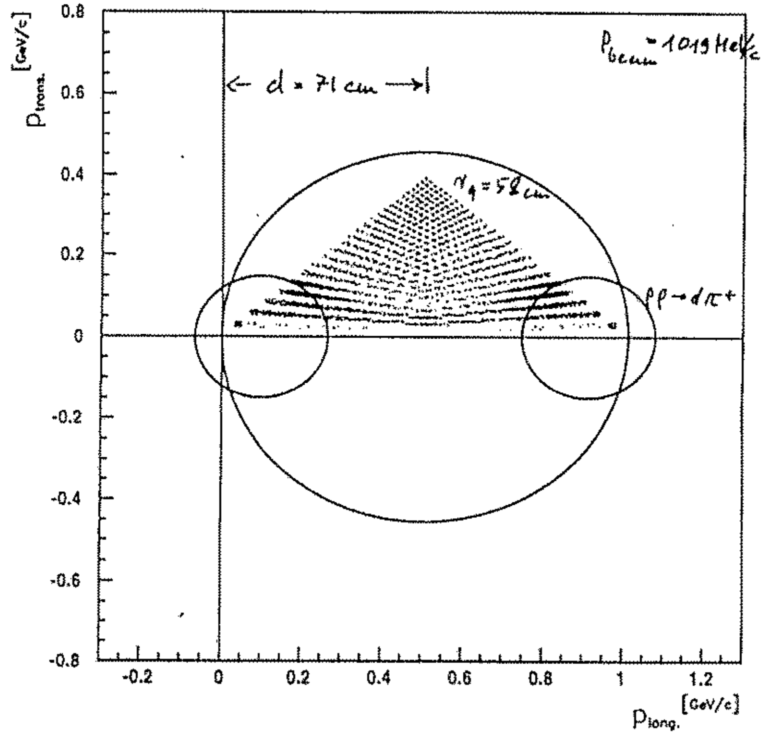
conditions

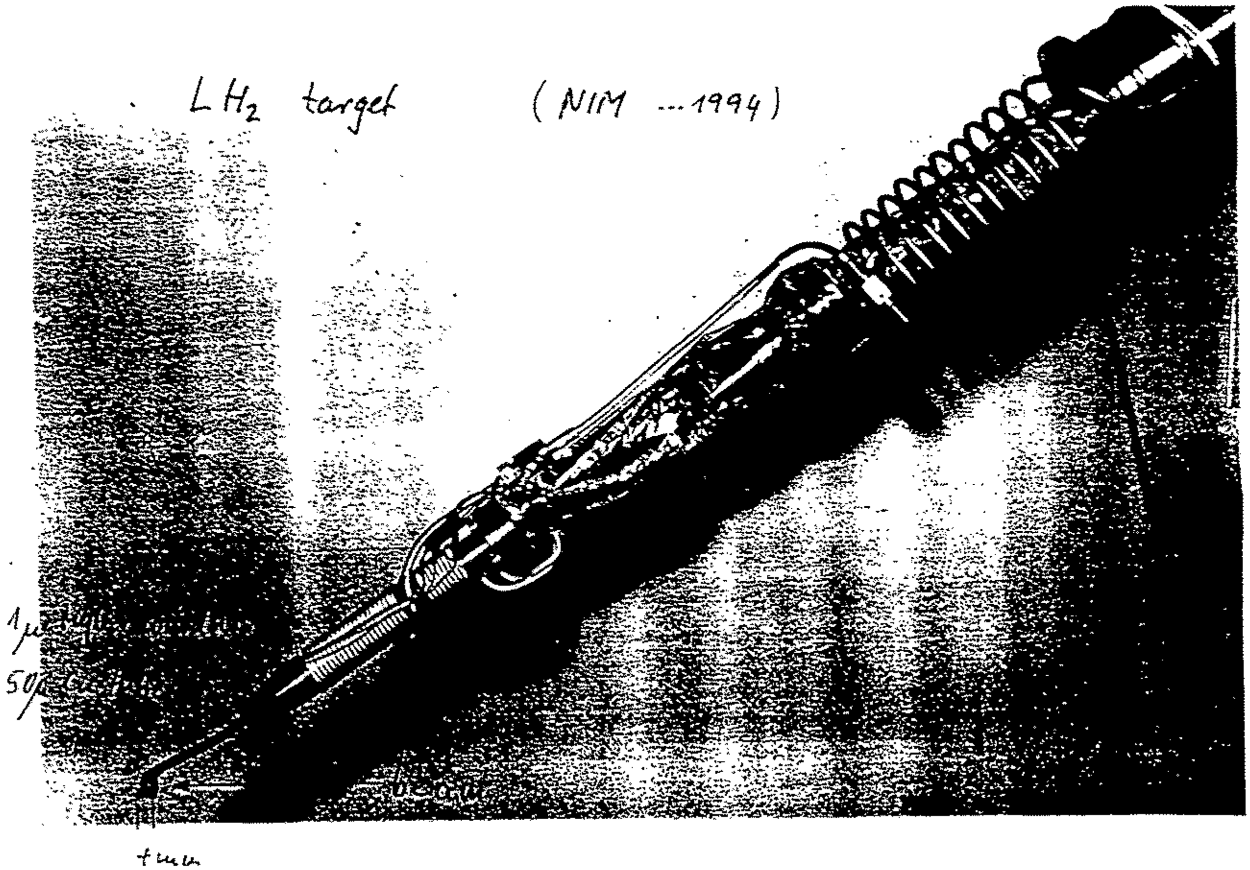
- * 2 hits in 3 planes each (on line)
- * coplanarity (off line)

$|\Delta t| \lesssim 0{,}5\,ns$ for pp elastic

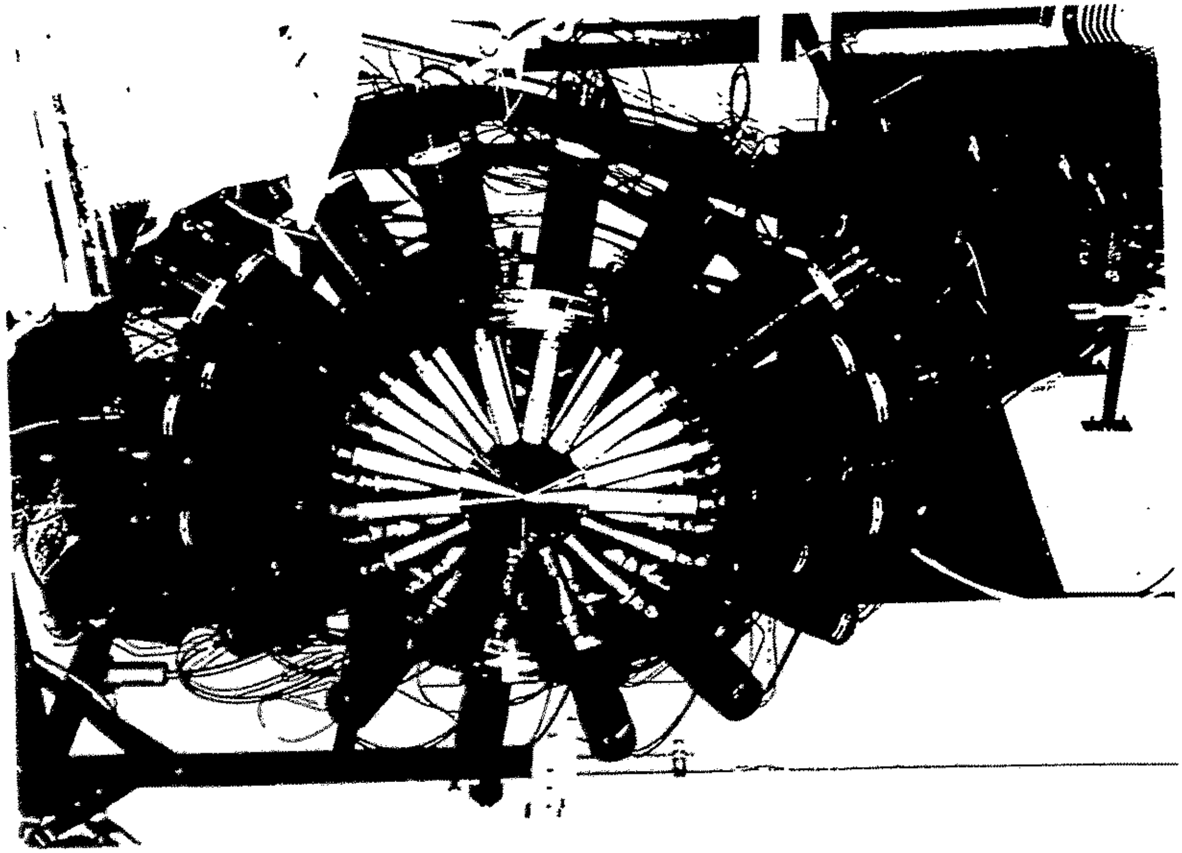
$|\Delta t| \gtrsim 2\,ns$ for $d\pi^+$







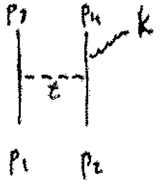
LH_2 target (NIM ...1994)



! Max. off shell in $pp\gamma$ never really seen

↓

Bremsstrahlung $pp \to pp\gamma$



External B.S
t-matrix from elast. scat. (off shell ..)
should change across π thresholds
since imaginary part comes into play

Intermediate Δ production
$\Delta\text{ decay} \nearrow 99.4\%\ N\pi$
$\searrow 0.6\%\ N\gamma \Leftarrow$ large contribution
(Dalitz plot)

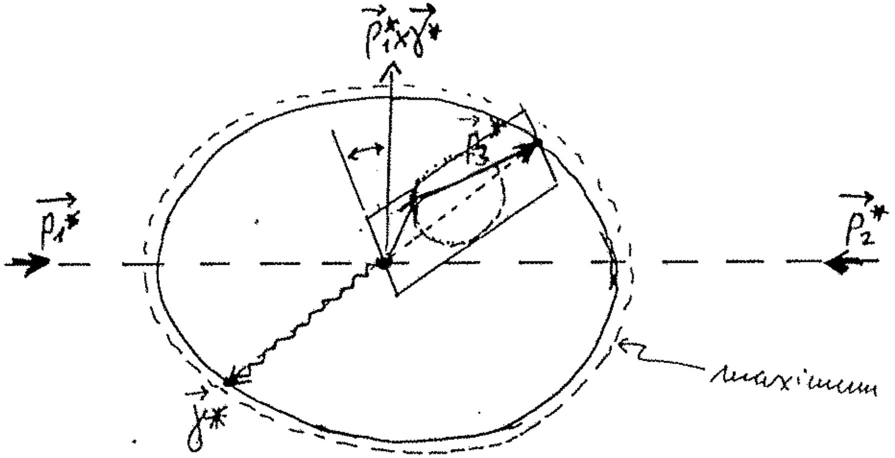
Internal radiation from ω decay
at 200 MeV negligible
at 400 MeV ~10% of σ

$$\boxed{p_1 p_2 \to p_3 p_4 X^0}$$ kinematically complete when two protons measured

$\mathbb{P}_X = \mathbb{P}_1 + \mathbb{P}_2 - \mathbb{P}_3 - \mathbb{P}_4 \Rightarrow$ including directional correlations

$\mathbb{P}_X^2 = m_X^2$; $\underline{\text{if } m_X^2 = 0 \text{ B.S}}$

maximum of shell bremsstrahlung and systematic correlations have never been measured in $pp \to pp\gamma$

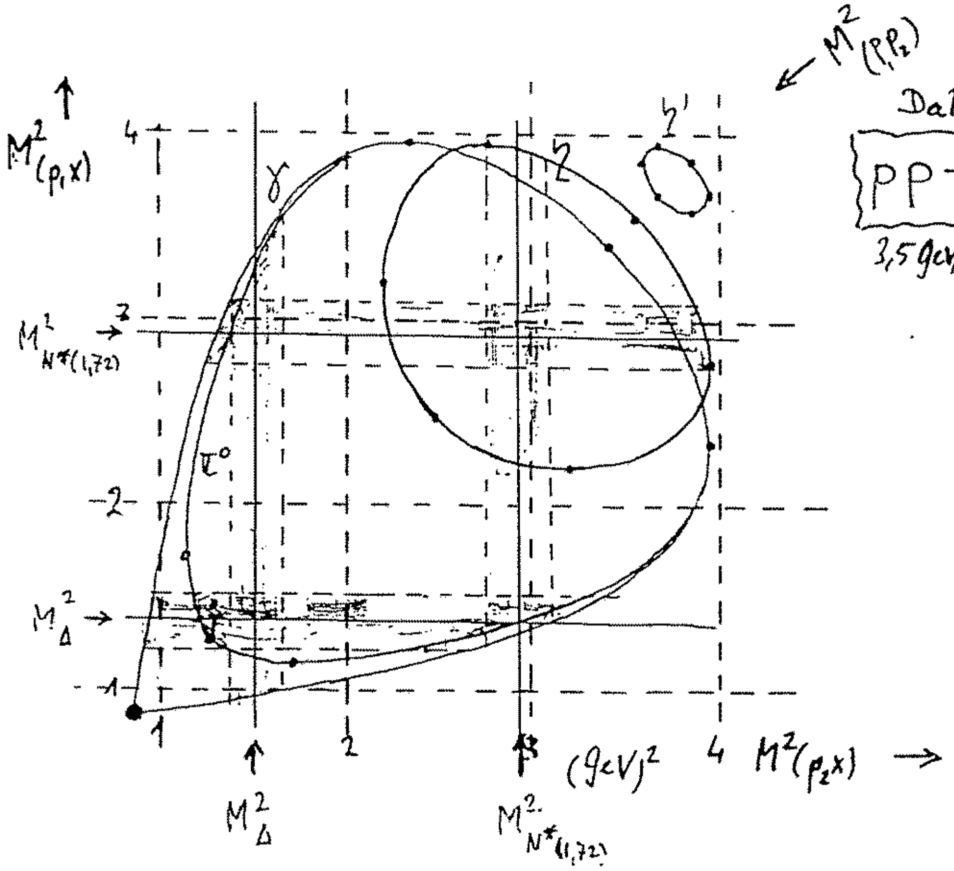


! Interferences between such diagrams might change drastically across pion thresholds

Quadrupole ↓ Comparison ! Dipole ↓

$$\text{COSY}\begin{cases} pp \to pp\gamma \\ pp \to pp\,\pi^0_{\hookrightarrow 2\gamma} \\ pp \to p\Delta_{\hookrightarrow p\gamma} \end{cases}$$

- SATURNE $np \to np\gamma$
- (LEAR) $-\bar{p}p \to \bar{p}p\gamma$



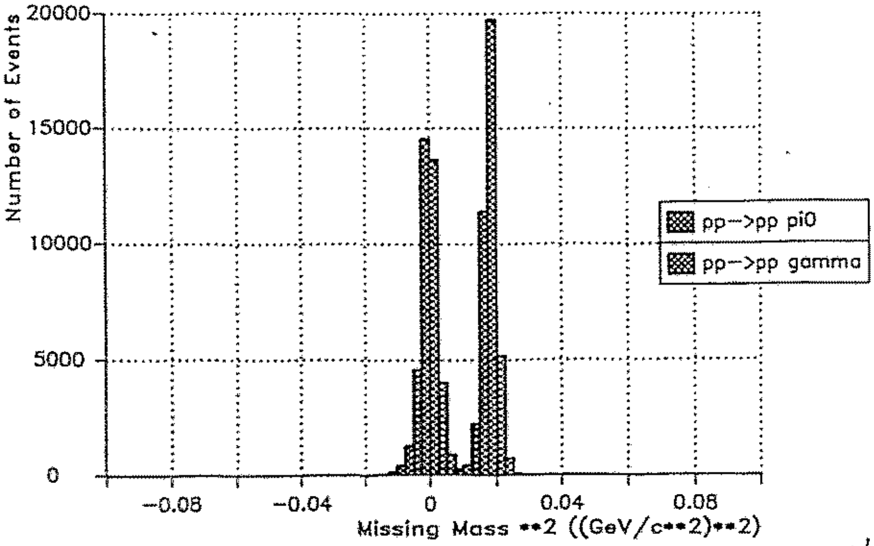
Dalitz plot

$\{pp \rightarrow p_1 p_2 X^0\}$

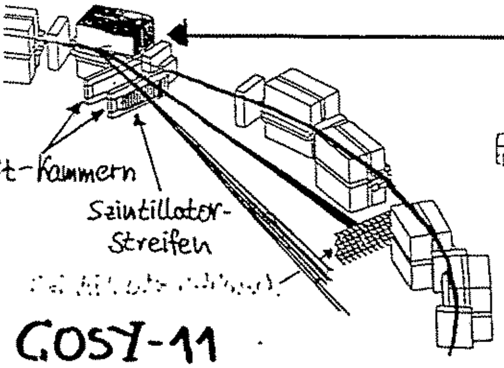
3,5 GeV/c E = 1049 MeV

(Monte Carlo)

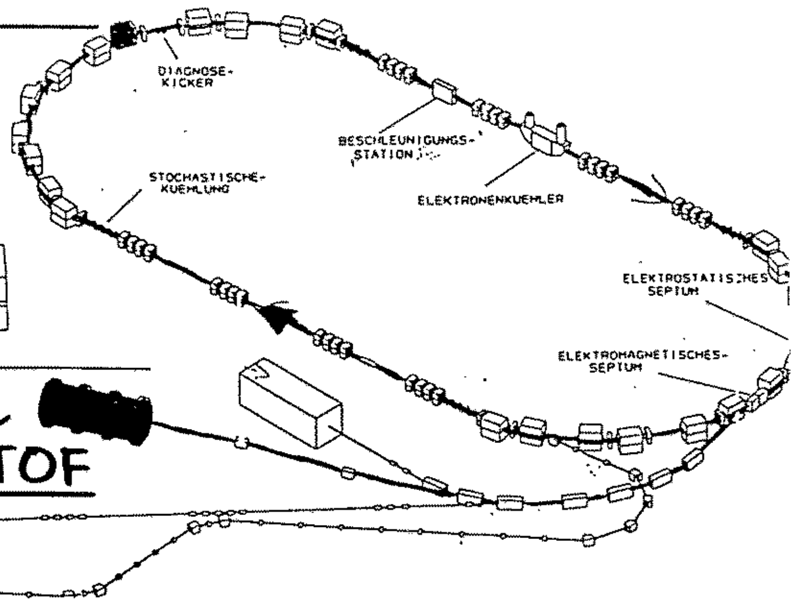
Proton Beam Momentum of 1.2 GeV/c



Δt: 0,7 ÷ 1,2 ns fwhm measured

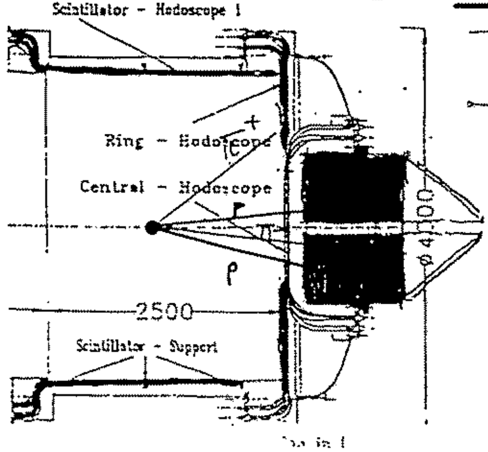


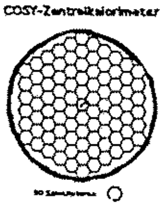
COSY-11



COSY

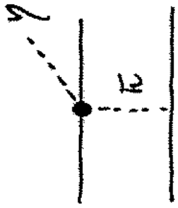
TOF



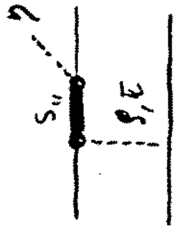


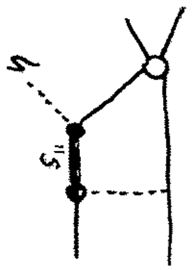
$$pp \to d' \pi^+$$
$$\hookrightarrow \{pp\}_{E \leq 40\,MeV} + \pi^-$$

$pp \to pp\eta$



Laget, Wellers, Lecolley
Ph. Lett B 257 (91) 254





Germond + Wilkin
Nucl. Phys. A 518 (90) 308

↑

'line' in
Dalitzplot
at $(P_p + P_\eta)^2 \sim M_{S_{11}}^2$

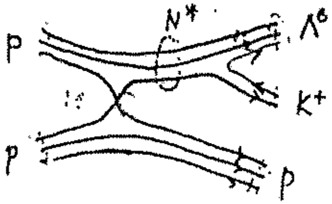
Saturne Experiment

Comparison of $\bar{s}s$ quarkpaircreation at low energy

$pp \to K^+\Lambda^0 p$

$\boxed{\text{COSY}}$ SATURNE R.Bertini

Kunsch. at 2,34 GeV/c

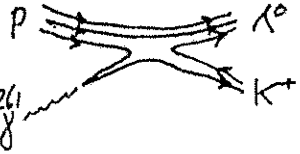


$p \begin{Bmatrix} d \\ {}^3He \\ {}^4He \end{Bmatrix} \to K^+\Lambda^0 \begin{Bmatrix} d \\ {}^3He \\ {}^4He \end{Bmatrix}$

$\boxed{\text{CELSIUS}}$

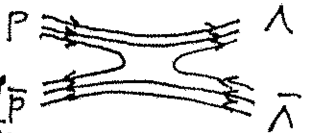
$\gamma p \to K^+\Lambda^0$

$\boxed{\text{ELSA}}$ Haas et al. N.P. B137 (78) 261



$\bar{p}p \to \bar{\Lambda}\Lambda^0$

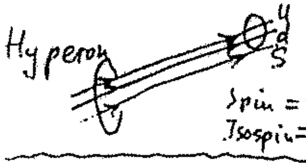
$\boxed{\text{LEAR}}$ PS185 Exp. P.L. B189 (87) 249



Λ polarization measurable by asymmetry of decay

$\Lambda^0 \to p\pi^-$

Spin of Λ is spin of s quark



Spin = $\frac{1}{2}$
Isospin = 0

$\Lambda^0 : (ud)_{I=0} \Rightarrow (ud)_{spin=0}$

$\Sigma^0 : (ud)_{I=1} \Rightarrow (ud)_{spin=1}$

1. $\bar{s}s$ paircreation with different probes
2. s-quark interaction with $I=S=0$ and $I=S=1$ diquarks can be compared
3. Polarization vector of quarks

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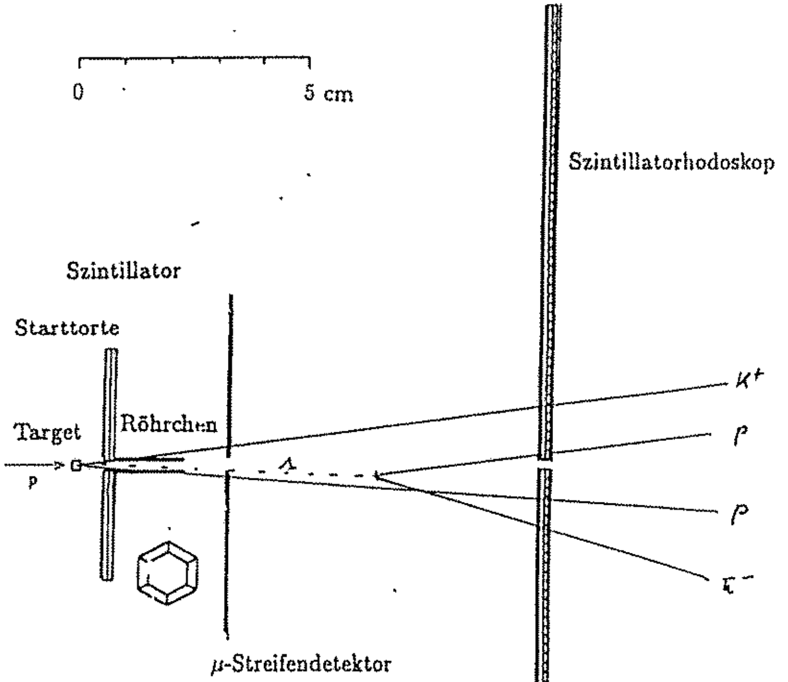
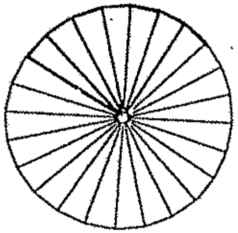
Innendetektor für COSY-Experiment 15 *Hyperonproduktion*

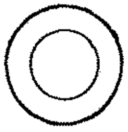
„Vorläufige Endversion"

$pp \to K^+\Lambda p \to K^+ p\pi^- p$

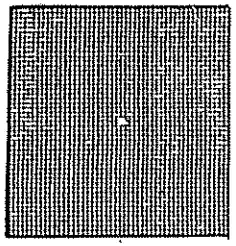




2 Lagen à 12 Segmente

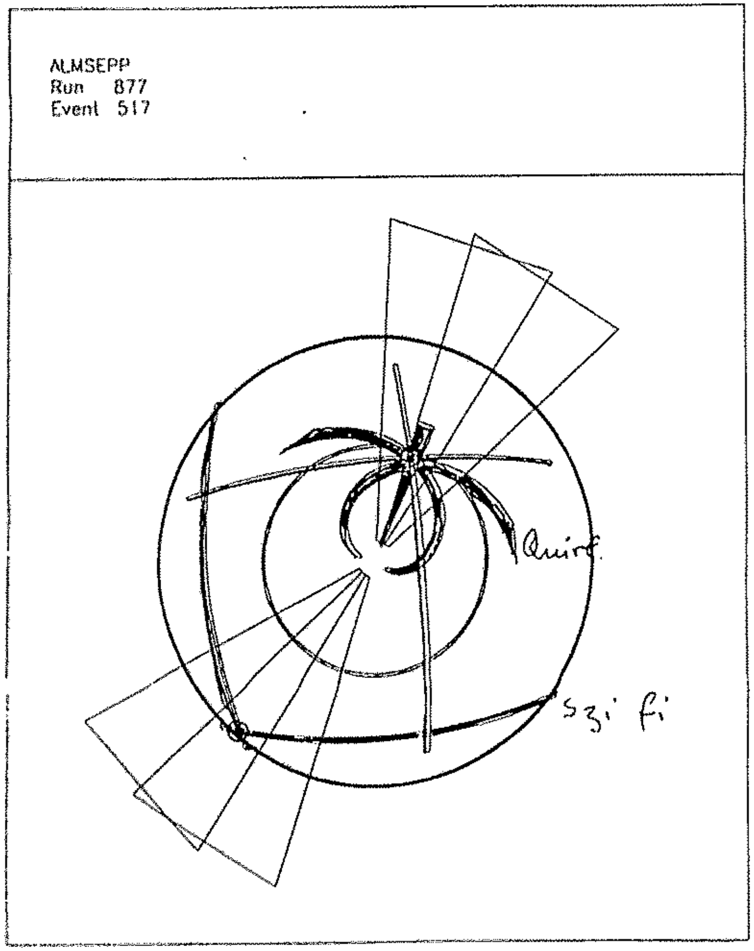


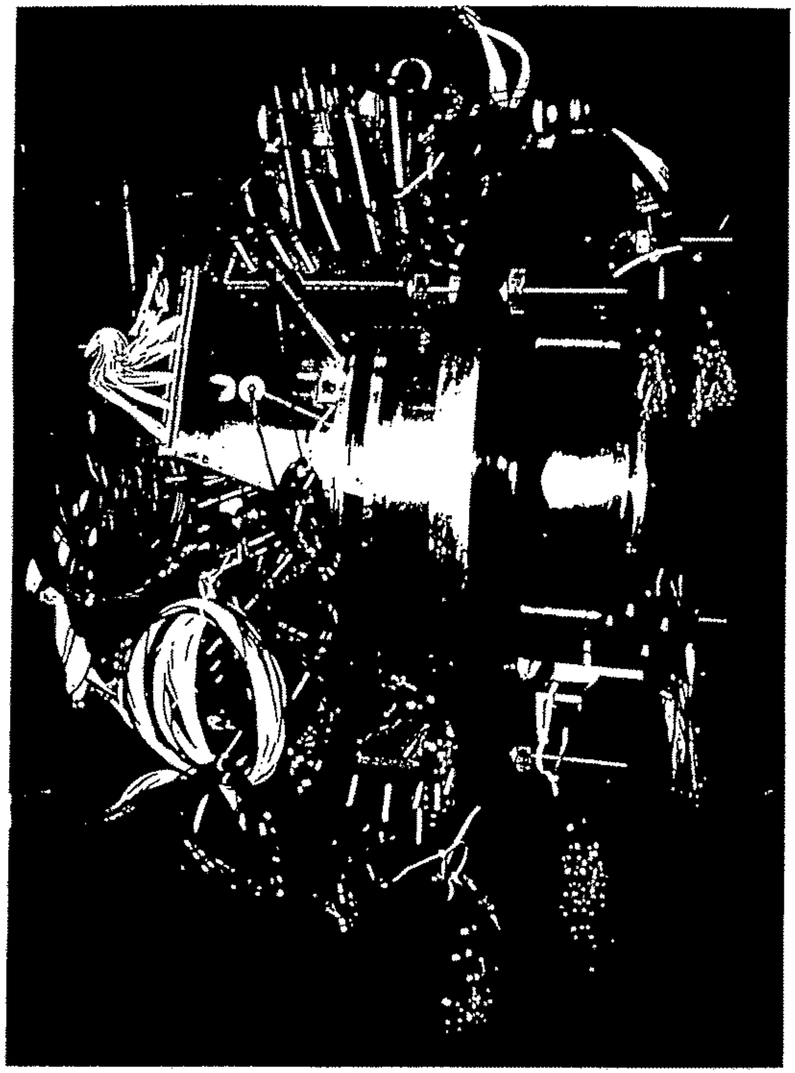
100 Ringe à 300 μm



2 × 100 Streifen
à 2 mm Breite

Testrun 5/94 Erlangen-decaycounter + Quirl





$$\boxed{pp \to pK\Lambda \atop \quad\quad\quad \hookrightarrow p\pi^-}$$

The Tof-spectrometer has ~100% acceptance

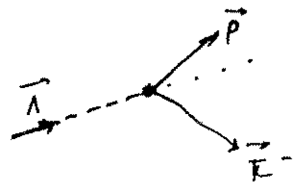
provides full 4-vector information.
(→ 4 constraints)

All subsystem spectra can be obtained

$$\left.\begin{array}{l} pp \to pN^* \\ \qquad\quad \hookrightarrow K^+\vec{\Lambda} \\ pp \to K^+ \{\text{strange dibaryons}\} \\ \qquad\qquad \hookrightarrow p\vec{\Lambda} \\ pp \to \vec{\Lambda}\,\{\text{exotics}\} \\ \qquad\qquad \hookrightarrow K^+p \end{array}\right\} \text{"two body" reactions}$$

All effects are visible at the same time in the Dalitz-plot

➔ Λ polarization always measured



+ pol. beam (soon)

+ pol target (from Bonn)

$\vec{p} + \vec{p} \to \vec{\Lambda}\ K^+ \ldots$

* Selective N^* production

$p\alpha \to N^*\alpha$ (Δ forbidden)
α selects spin = isospin = ½ transition

* Selective $N^*(1710)$ decay P_{11}
↳ $K^+\Lambda$ BR ~ 15% !

$$\underbrace{\qquad\qquad\qquad\qquad\qquad\qquad}$$

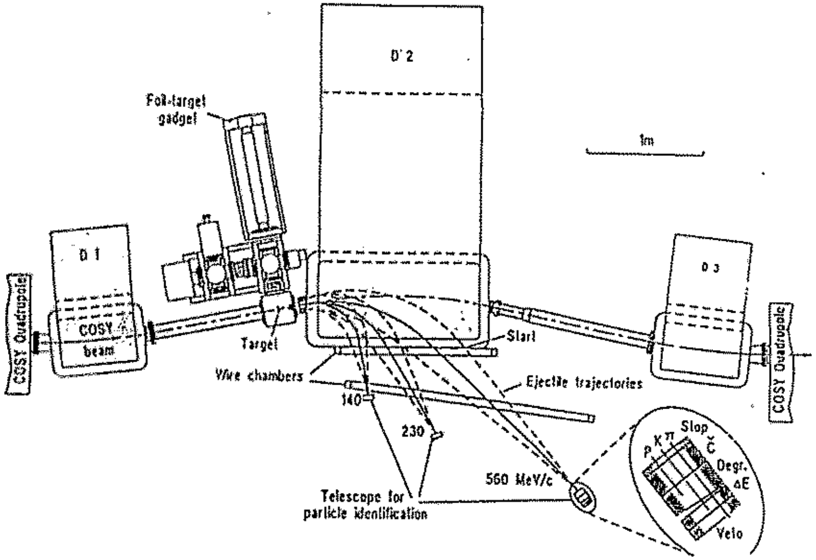
$p\alpha \to K^+\Lambda\,\alpha \iff \overset{\text{"two body"}}{\boxed{p\alpha \to N^*\alpha}}$

isolates $N^*(1710)$ resonance

⇒ easier partial wave analysis

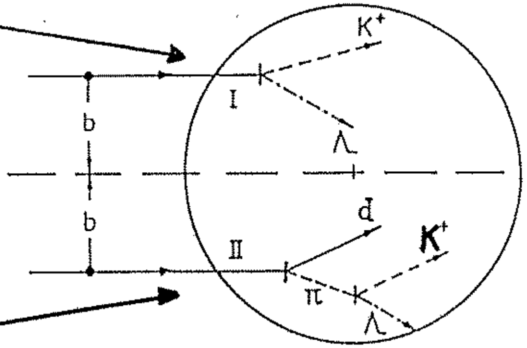
Detector: Cigar the target in TOF
+ Ge Quirl
⇒ perfect for [illegible]

0° facility



- Internal target in an orbit bump of COSY.
  Dipole used as high acceptance spectrometer for positive and negative particles.
  0° reaction products (even neutrals) measurable.
  " 100 % acceptance " close to thresholds.
- Ready to order dipoles (financing !).
  Many goals :
  - Medium effects on elementary K production.
  - " Subthreshold " production.
  - Reaction mechanisms.

Clearing up the Mechanism of Subthreshold K⁺ Production



One step mechanism

$p + N \rightarrow K^+ + \Lambda + N$

Two step mechanism

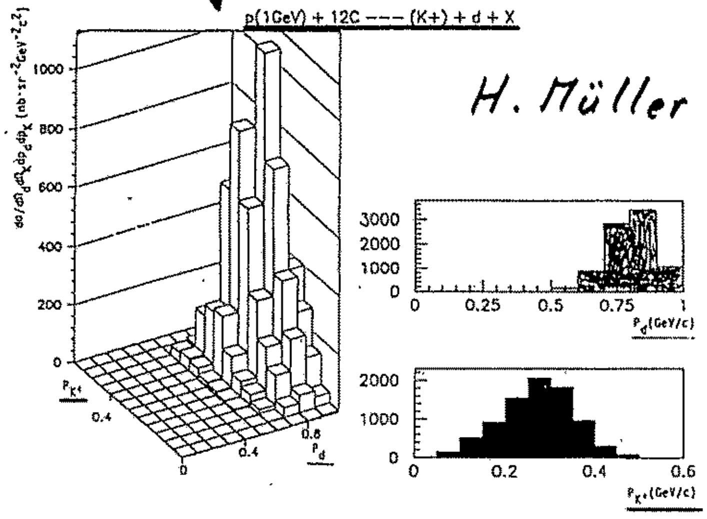
$p + N_1 \rightarrow N + N + \pi$

$\pi + N_2 \rightarrow \Lambda + K^+$

Particular channel

$p + N_1 \rightarrow d + \pi$

$\pi + N_2 \rightarrow \Lambda + K^+$



H. Müller

The COSY scientific Program and its Implementation

Running in phase
first interactions with accelerated protons
(internal: EDDA 9/93 external: BIG KARL 1/94 TOF 5/94)
debugging of new installations , no unexpected obstacles.
on a good track!

• General Features of COSY and Chances

(q , ω) range : about (2.2GeV/c , 1.05 GeV) in p+p interactions
production ,decay and interaction of hadrons ,including strangeness
phase space cooling , high brilliance beams
internal and external targets
effort in beam preparation gives advantages in detector performance
(low background , 100 % acceptance for. many body , kinematically complete)

• The present COSY Program

10 accepted proposals (since 9/89 with some recent addenda)
  NN interaction
  meson- meson interaction
  elementary meson production (especially at thresholds)
  strangeness production
  reaction mechanisms in p+d and in p+A interactions
  (meson production subthreshold , one and two step processes , role of kinematics)
  meson-nucleus interaction (rfk)
Detectors : EDDA , BIG KARL , TOF ready to go
    Cosy-11 and Cosy-13 wait for installation into the ring
    ZDF needs money to order magnets (ready to go on)
Polarized source works , polarimeter installation still 94

• Future Development

extend medium energy hadron physics
possibility to do weak interaction studies
extend detector equipment :
  external frozen spin target , internal pol. atomic beam , longitudinally pol. ext. beam
  a full acceptance shower counter (like ETA /Saclay or AMPIR / Moscow ...)
cooperation with other laboratories

KARMEN: Neutrino-Spektroskopie an der Spallationsquelle ISIS

J. Kleinfeller
Karlsruhe

7.Oktober 1994

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KARMEN

Neutrino-Spektroskopie
an der
Spallationsquelle ISIS

KARLSRUHE-RUTHERFORD
MEDIUM ENERGY
NEUTRINOEXPERIMENT

KFK KARLSRUHE

KARLSRUHE UNIVERSITY

ERLANGEN UNIVERSITY

QUEEN MARY & WESTFIELD
COLLEGE LONDON

OXFORD UNIVERSITY

RUTHERFORD APPLETON
LABORATORY

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E-mail: j.kleinfeller@rutherford.ac.uk   Arbeitstreffen Kern- und Teilchenphysik, Pirna 04.-07.10.1994

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KARMEN - COLLABORATION

KFK & KARLSRUHE UNIVERSITY

B.	Armbruster	T.	Jannakos
T.	Csabo	M.	Kleifges
G.	Drexlin	J.	Kleinfeller
V.	Eberhard	C	Oehler
C.	Eichner	P.	Plischke
K.	Eitel	J.	Rapp
H.	Gemmeke	J.	Weber
R.	Gumbsheimer	J.	Wochele
H.	Hucker	J.	Wolf
D.	Hunkel	B.	Zeitnitz
R.	Maschuw	(Bonn University)	

ERLANGEN UNIVERSITY

D.	Blaser	J.	Hößl
B.A.	Bodmann	P.	Jünger
M.	Ferstl	W.	Kretschmer
E.	Finckh	H.	Schmidt
T.	Hanika	O.	Stumm
M.	Hehle		

QM&W COLLEGE LONDON

I.	Blair	B.	Seligmann
J.A.	Edgington		

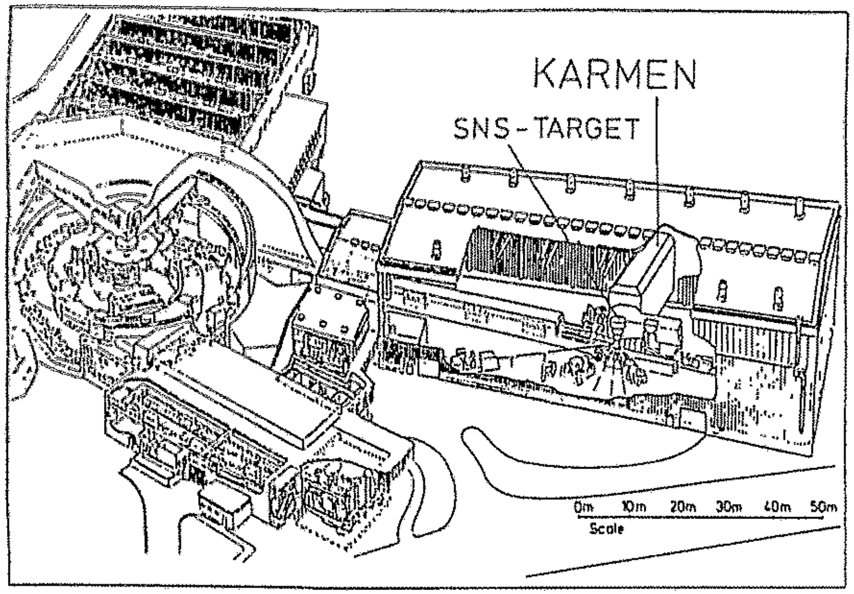
OXFORD UNIVERSITY

N.	Booth

RUTHERFORD APPLETON LAB.

28.09.1994

ISIS



SYNCHROTRON: p | 800 MeV | 200 μA

EXTRACTION : 50 Hz

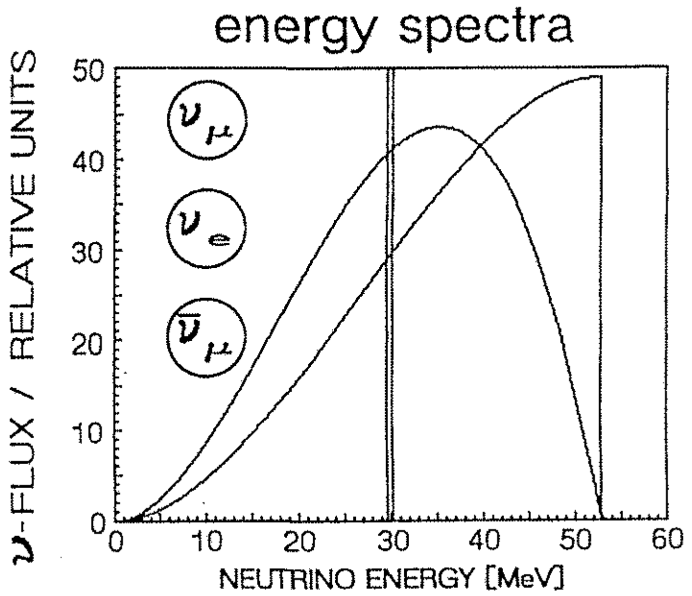
100ns PULSE - 330ns PAUSE - 100ns PULSE

TARGET: URANIUM (U-D_2O) BEAM DUMP

ISIS

$$\pi^+ \xrightarrow{\boxed{26\,ns}} \mu^+ + \nu_\mu$$

$$\mu^+ \xrightarrow{\boxed{2.2\,\mu s}} e^+ + \nu_e + \bar{\nu}_\mu$$



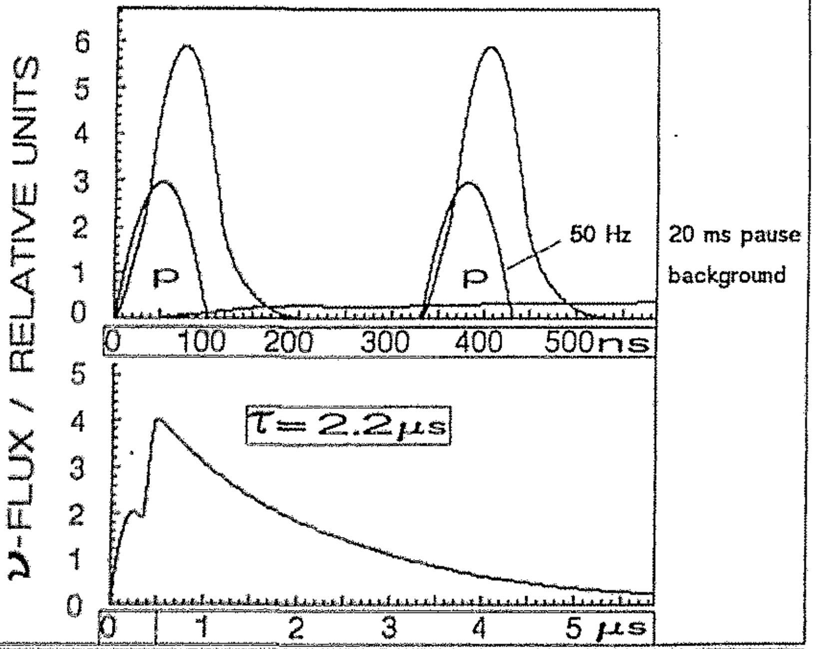
$$\Phi_{\nu_\mu} = \Phi_{\nu_e} = \Phi_{\bar{\nu}_\mu}$$

I S I S

$$\pi^+ \xrightarrow[\boxed{26\,ns}]{} \mu^+ + \textcircled{\nu_\mu}$$

$$\mu^+ \xrightarrow[\boxed{2.2\,\mu s}]{} e^+ + \textcircled{\nu_e} + \textcircled{\bar{\nu}_\mu}$$

time structure



duty factor: $\nu_\mu \sim 10^{-5} \,|\, \nu_e, \bar{\nu}_\mu \sim 10^{-4}$

20.01.1994

RESEARCH PROGRAMME

ν – nuclear excitation

$\boxed{\nu - \text{spectroscopy}}$

$\boxed{\nu_e}$-charged current reaction

$<\sigma>$; $\sigma(E_{\nu_e})$; $F_A(q^2)$; $\omega_L(\nu_e\text{-shape})$

$\boxed{\nu_\mu};\boxed{\nu_e};\boxed{\bar{\nu}_\mu}$-neutral current reaction

ν – oscillations

$\pi^+ \xrightarrow[\boxed{26ns}]{} \mu^+ + \boxed{\nu_\mu} \longrightarrow \boxed{\nu_e}$ appearance

$\mu^+ \xrightarrow[\boxed{2.2\mu s}]{} e^+ + \boxed{\nu_e} + \boxed{\bar{\nu}_\mu} \longrightarrow \boxed{\bar{\nu}_e}$ appearance

$\boxed{\nu_e} \longrightarrow X$ disappearance

l-violating decays

$\pi^+ \xrightarrow[\boxed{26ns}]{} \mu^+ + \boxed{\bar{\nu}_e}$

$\pi^+ \xrightarrow[\boxed{26ns}]{} e^+ + \boxed{\bar{\nu}_e}$

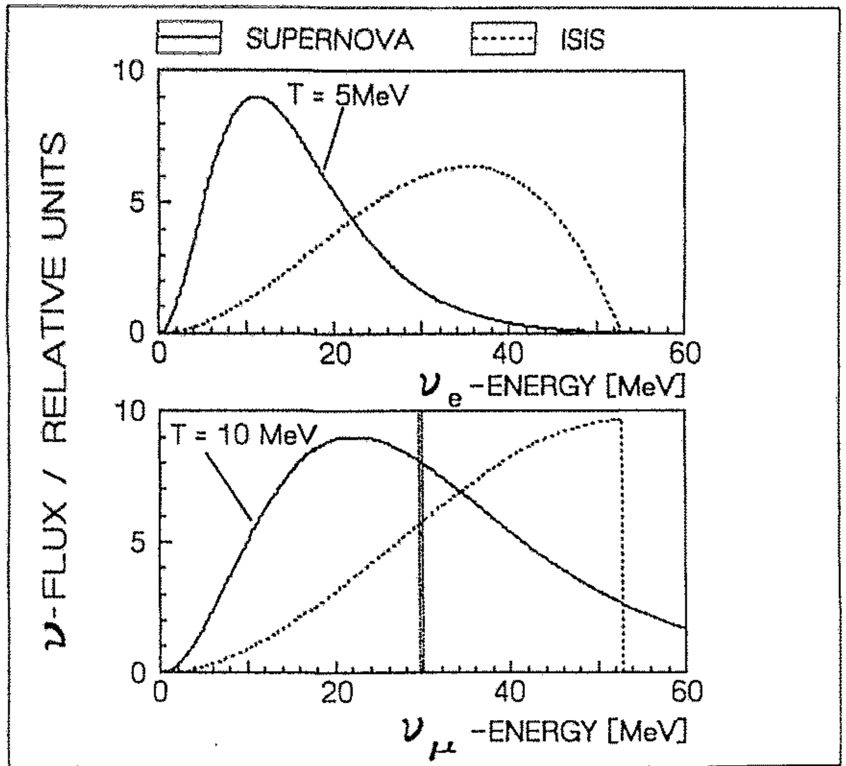
$\mu^+ \xrightarrow[\boxed{2.2\mu s}]{} e^+ + \boxed{\bar{\nu}_e} + \boxed{\nu_\mu}$ lf -violating

28.09.1994

ISIS - SUPERNOVA NEUTRINOS

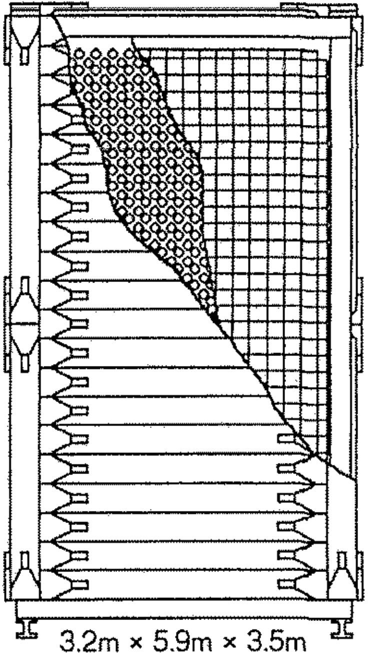
$$\pi^+ \xrightarrow{\boxed{26\,\mathrm{ns}}} \mu^+ + \textcircled{\nu_\mu}$$

$$\mu^+ \xrightarrow{\boxed{2.2\,\mu\mathrm{s}}} e^+ + \textcircled{\nu_e} + \textcircled{\bar{\nu}_\mu}$$



KARMEN DETECTOR

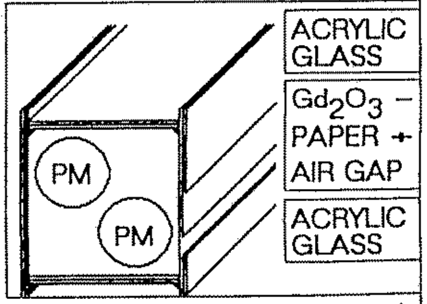
56 t LIQUID SCINTILLATOR CALORIMETER



NE110	OUTER SHIELD
20cm	PASSIVE SHIELD
96	INNER SHIELD
2240	3" PHOTOTUBES
16×32	CENTRAL DETECTOR

3.2m × 5.9m × 3.5m

SINGLE MODULE



18cm × 18cm × 350cm (1.5mm)

96 % ACTIVE VOLUME

MASSIVE SENSITIVE TARGET

^{12}C ^{1}H e^-

FOR ν — INTERACTIONS

KARMEN DETECTOR

56 t liquid scintillator
calorimeter

96 % active volume

massive sensitive target

^{12}C ^{1}H e^-

for ν – interactions

$$\frac{\sigma E}{E} = \frac{11.5\%}{\sqrt{E(\mathrm{MeV})}}$$

$$= 80\ \mathrm{p.e./MeV}$$

$$\sigma T = 0.4\ \mathrm{ns}$$

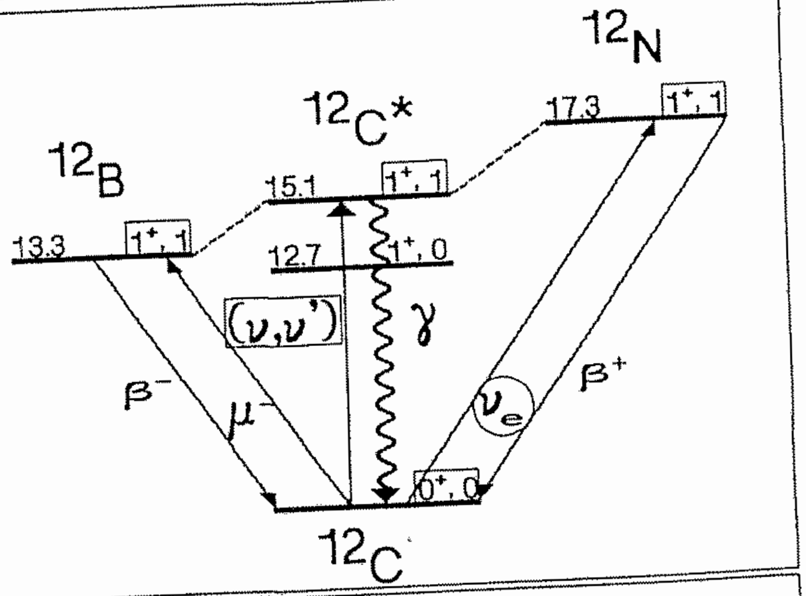
$$\sigma X = 6.0\ \mathrm{cm}$$

20.01.1994

CC + NC NUCLEAR EXCITATION

$\boxed{CC}$: $\nu_e + {}^{12}C \longrightarrow {}^{12}N + e^-$

$\boxed{NC}$: ${}^{12}C\,(\nu\,,\nu')\,{}^{12}C^*\ (^{1^+,1}_{15.1\ \mathrm{MeV}})$



$(J^{\pi}, T) : (0^+, 0) \longrightarrow (1^+, 1)$ $\Delta S = 1\,;\Delta T = 1$

isovector - axialvector coupling spin - isospin filter

flavour universality $\boxed{\nu_\mu}, \boxed{\nu_e}, \boxed{\bar{\nu}_\mu} - Z^0$

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EXCLUSIVE CC REACTION

$$\begin{tikzcd} \nu_e + {}^{12}C \arrow[r] & {}^{12}N_{gs} + e^- \; - \; 17\,MeV \arrow[d, "\tau = 16ms \quad \varepsilon_0 = 16MeV"] \\ & {}^{12}C + e^+ + \nu_e \end{tikzcd}$$

e^-, e^+ : spatially correlated
: delayed coincidence

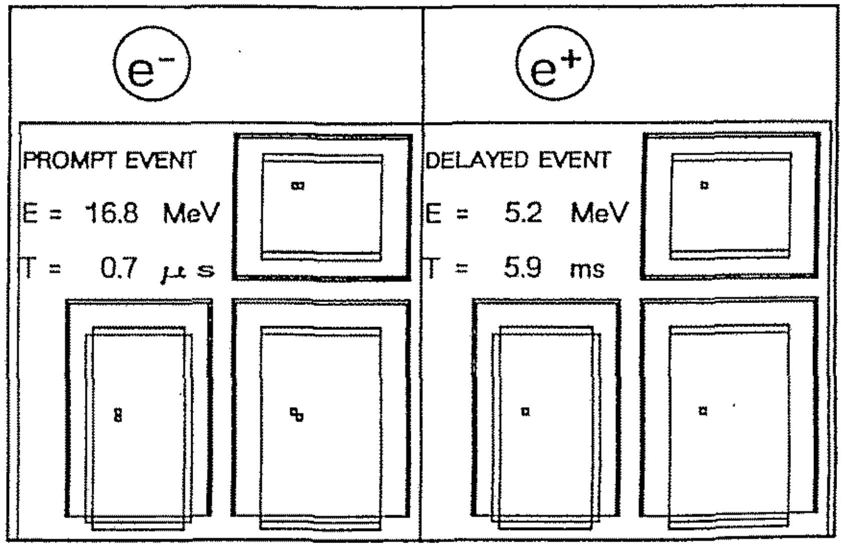
e^- : E = 10 - 36 MeV
: T = 0.6 - 9.6 μs
$\{\bar{\nu}_\mu, \nu_e\}$ - time window

e^+ : E = 3.5 - 16.5 MeV
: T = 0.5 - 36.5 ms
up to next beam period

EXCLUSIVE CC REACTION

$$\begin{tikzcd} \nu_e + {}^{12}C \arrow[r] & {}^{12}N_{gs} + e^- \; - \; 17\,MeV \arrow[d, "\tau = 16ms \quad \varepsilon_0 = 16MeV"] \\ & {}^{12}C + e^+ + \nu_e \end{tikzcd}$$

NEUTRINO EVENT SIGNATURE


e^-
PROMPT EVENT
E = 16.8 MeV
T = 0.7 μs

e^+
DELAYED EVENT
E = 5.2 MeV
T = 5.9 ms

EXCLUSIVE CC REACTION

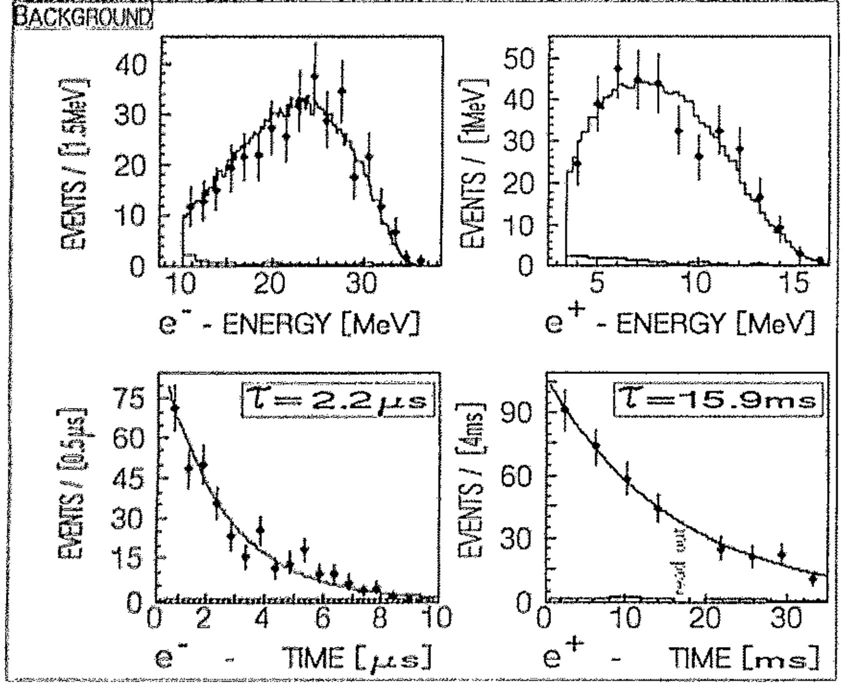
$$\nu_e + {}^{12}C \longrightarrow {}^{12}N_{gs} + \textcircled{e^-} - 17\,\mathrm{MeV}$$

$$\tau = 16\,\mathrm{ms}$$

$$\varepsilon_0 = 16\,\mathrm{MeV}$$

$$\downarrow$$

$${}^{12}C + \textcircled{e^+} + \nu_e$$



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EXCLUSIVE CC REACTION

$$\nu_e + {}^{12}C \longrightarrow {}^{12}N_{gs} + \textcircled{e^-} - 17\,\mathrm{MeV}$$

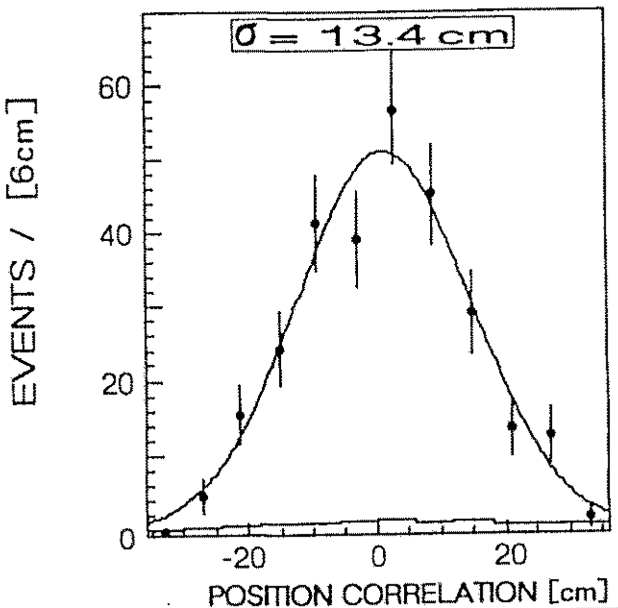
$$\tau = 16\,\mathrm{ms}$$

$$\varepsilon_0 = 16\,\mathrm{MeV}$$

$$\downarrow$$

$${}^{12}C + \textcircled{e^+} + \nu_e$$

SPATIAL CORRELATION



24.05.1994

EXCLUSIVE CC REACTION

JUL. 90 - JUN. 94 | 6261 Coulomb

$\varepsilon(T,E,X) = 0.34$ | $\Phi_\nu = 1.7\times10^{21}\ \nu$

sequential events : 359

background : $5.2_{(random)} + 4.7_{(seq.)}$

new signal / background = $\boxed{60/1}$

$^{12}C(\nu_e,e^-)^{12}N_{gs}$:	349

CC flux averaged cross section

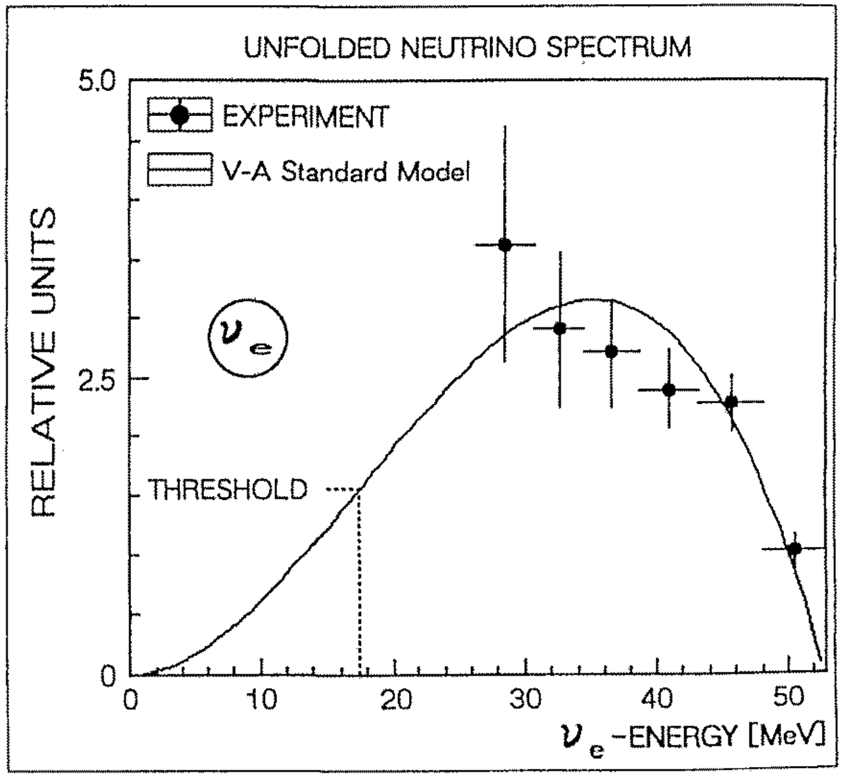
$$\langle\sigma(\nu_e)\rangle^{exp.}_{CC} = \boxed{9.3 \pm 0.5_{\,(stat)} \pm 0.8_{\,(syst)}} \times10^{-42}\,cm^2$$

$$\langle\sigma(\nu_e)\rangle^{theo.}_{CC} = \boxed{8.0 - 9.4} \times10^{-42}\,cm^2$$

Donnelly / Mintz et al. / Fukugita et al. / Kolbe et al.

EXCLUSIVE CC REACTION

$$E_{\nu_e} = E_{e^-} + 17.3\ MeV$$



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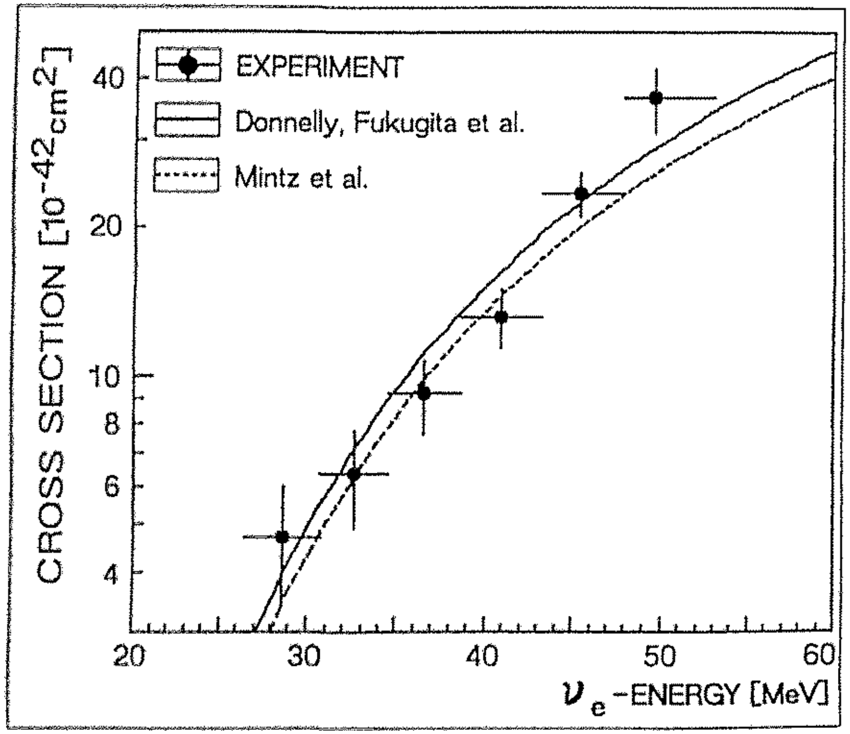
EXCLUSIVE CC REACTION

$$E_{\nu_e} = E_{e^-} + 17.3\ \mathrm{MeV}$$

$$\sigma \sim (E_{\nu_e} - 17.3)^2$$



24.06.1994

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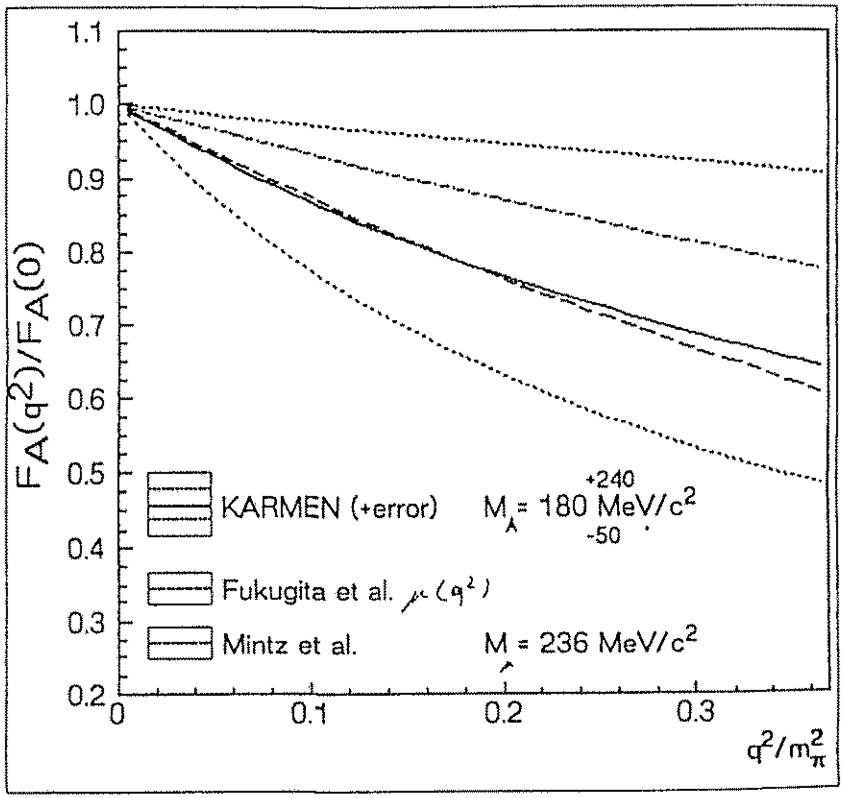
EXCLUSIVE CC REACTION

$$F_A(q^2) = g(q^2) \times [1+q^2/M^2]^{-2}$$



rms → weak axial charge $R_A = 3.8^{+1.4}_{-1.8}$ fm

→ el. - charge $R_\mu = 2.478$ fm

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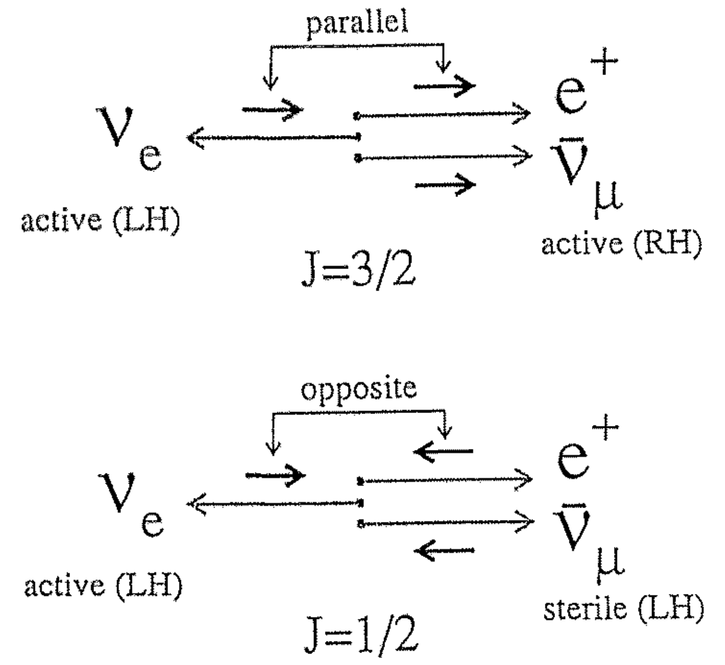
EXCLUSIVE CC REACTION

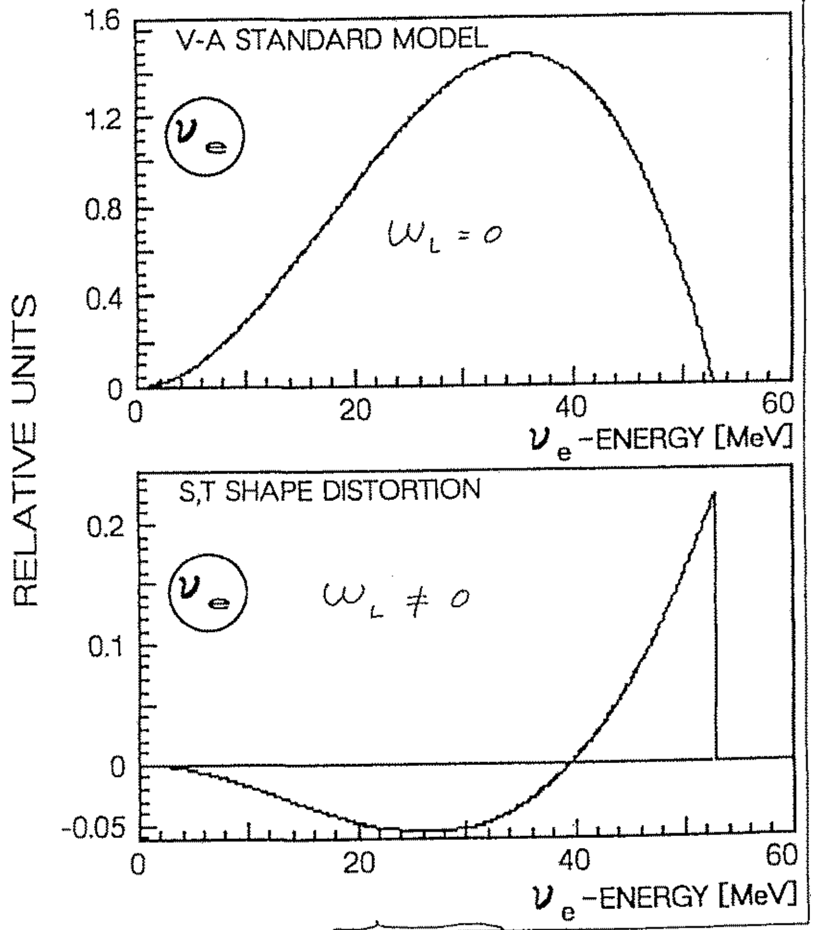
HELICITY DEPENDENCE OF ν_e-SHAPE



20.01.1994

EXCLUSIVE CC REACTION

HELICITY DEPENDENCE OF ν_e-SHAPE



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$$\omega_L = \frac{3}{4}\,\frac{\{|g^S_{RL}|^2 + |g^V_{LR}|^2 + \overbrace{|g^S_{RL} + 2g^T_{RL}|^2}\}}{\{|g^S_{RL}|^2 + |g^S_{RR}|^2 + 4|g^V_{LL}|^2 + 4|g^V_{LR}|^2 + 12|g^T_{RL}|^2\}}$$

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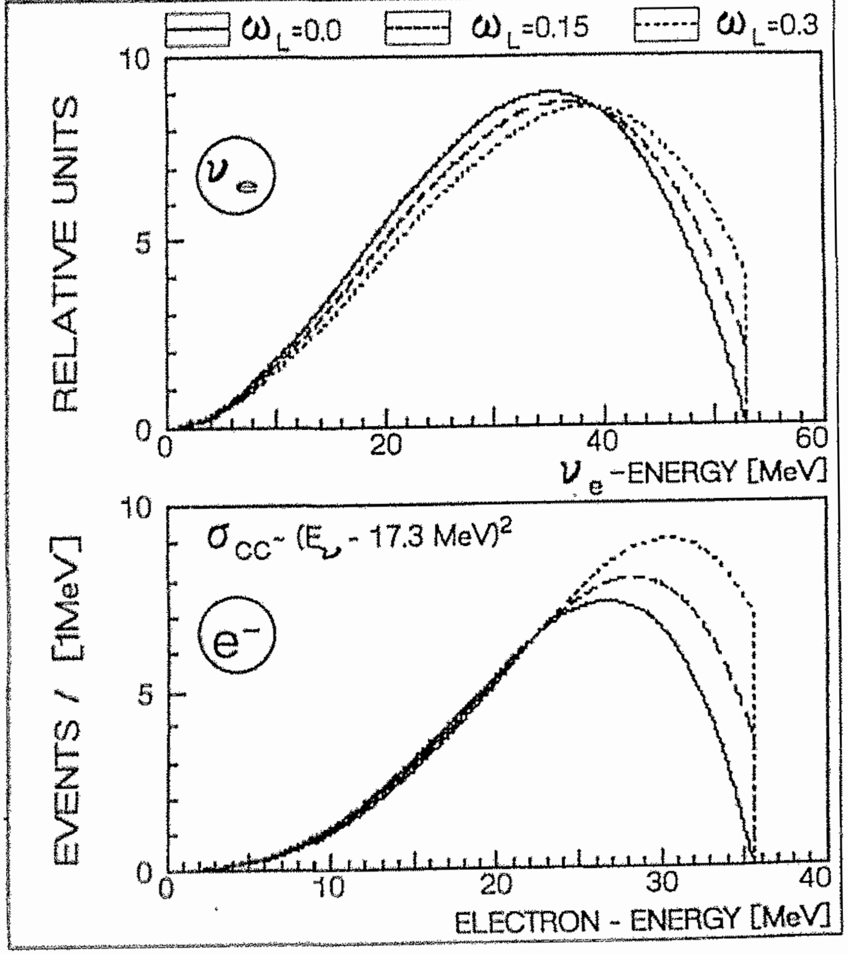
EXCLUSIVE CC REACTION

HELICITY DEPENDENCE OF ν_e-SHAPE



20.01.1994

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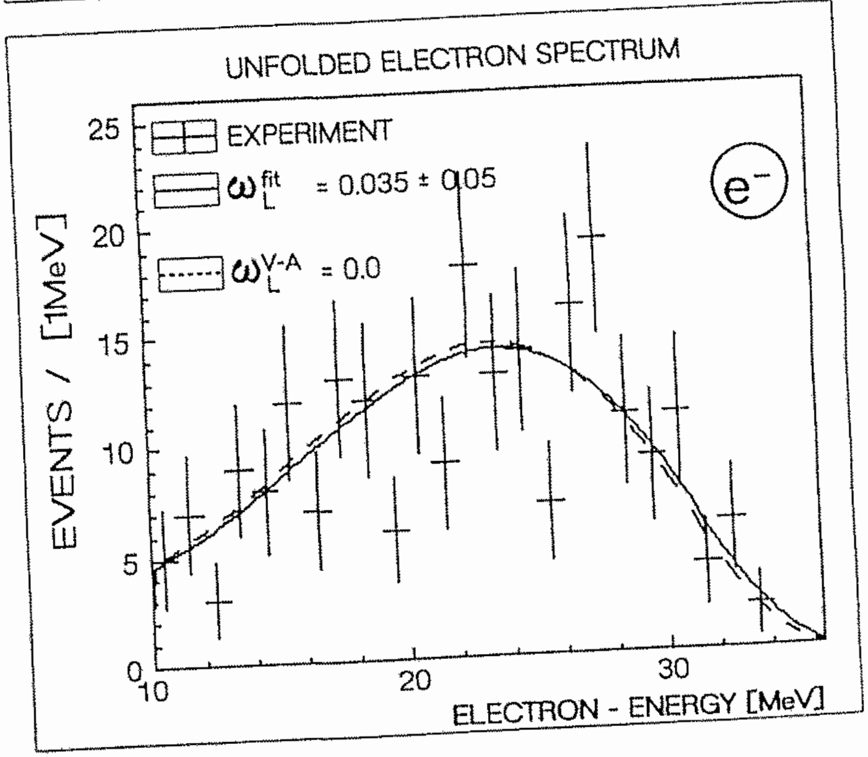
EXCLUSIVE CC REACTION

$$E_{\nu_e} = E_{e^-} + 17.3\ \mathrm{MeV}$$



$\Delta\omega$ < 0.122 (90 % cl) / $\Delta\omega$ < 0.076 (68 % cl)

$$| g^S_{RL} + 2 g^T_{RL} | \leq \sqrt{\tfrac{16}{3} \Delta\omega_L}$$

$$\Delta\omega_L = 0.65/\sqrt{N}$$

24.05.1994

NC NUCLEAR EXCITATION

$$\nu + {}^{12}C \longrightarrow {}^{12}C^{*}(1^{+},1) + \nu'$$

$$\downarrow \quad 95\%$$

$${}^{12}C + \gamma\text{'s} \; (15.1\,\text{MeV})$$

scintillation event of 15 MeV

γ's

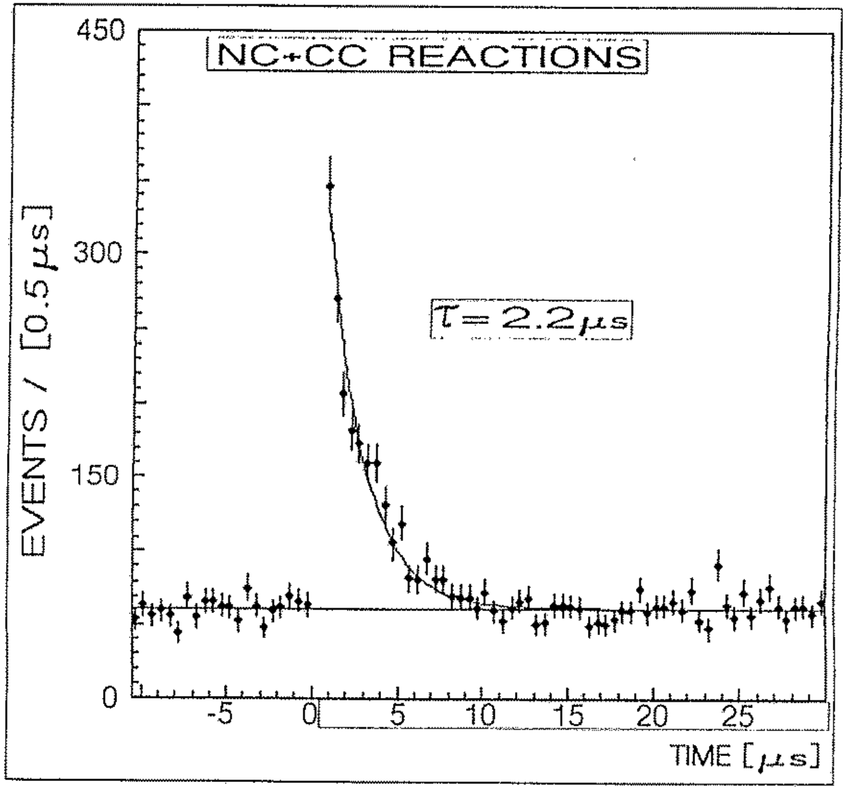
: T = 0.7 - 30 μs

$\{\bar{\nu}_{\mu}, \nu_e\}$ - time window

: E = 8 - 60 MeV

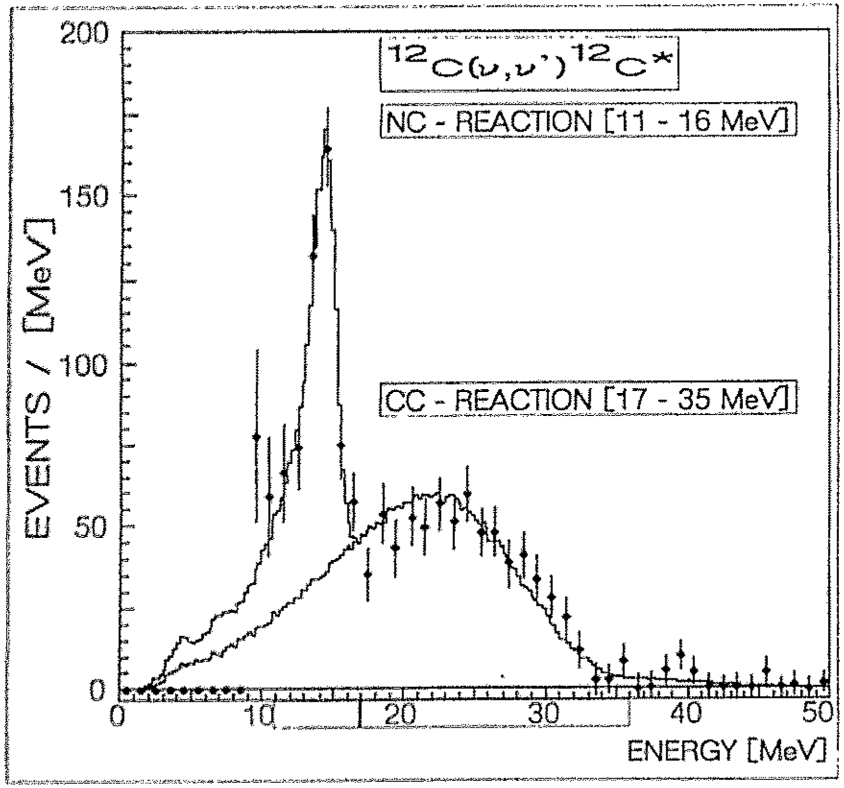
NC+CC NUCLEAR EXCITATION

time distribution [8 - 60 MeV]



NC NUCLEAR EXCITATION

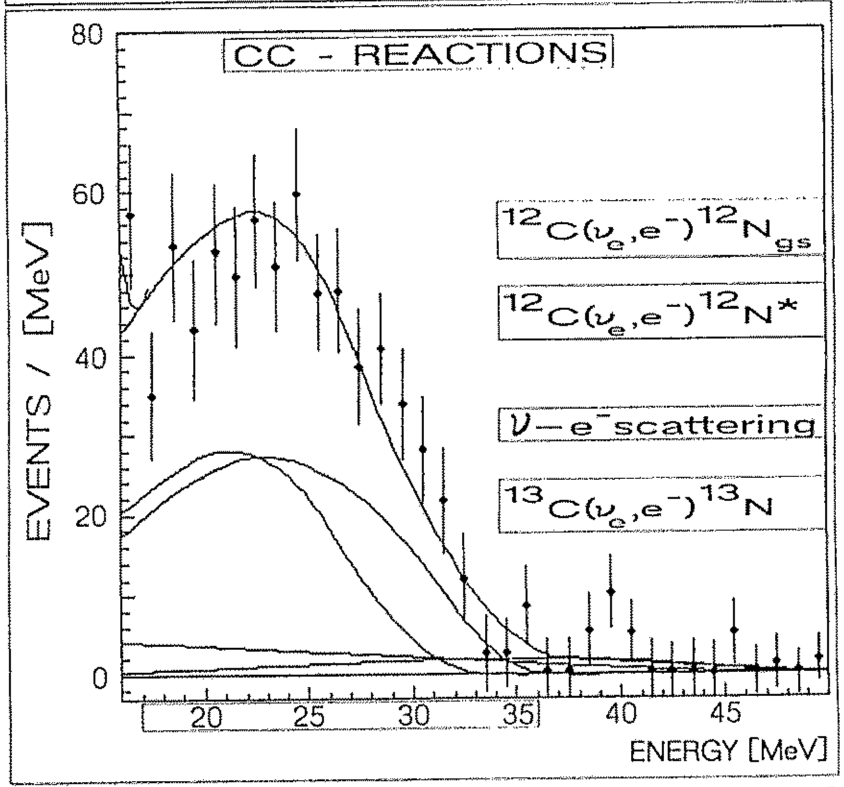
JULY 90 - JUNE 94 | 6231 C



28.09.1994

INCLUSIVE CC REACTION

$^{12}C\ (\nu_e\ ,\ e^-)\ ^{12}N^*$



GEANT3-SIMULATION SPECTRA

28.09.1994

NC NUCLEAR EXCITATION

ν – events [11-16MeV]	519
CC events [inclusive]	132

background: 616

$^{12}C(\nu,\nu')^{12}C^*$:	387

NC flux averaged cross section

$$\langle\sigma(\nu_e + \bar{\nu}_\mu)\rangle^{exp.}_{NC}$$

$$\boxed{10.7 \pm 1.1\ (stat) \pm 0.9\ (syst)} \times 10^{-42} cm^2$$

$$\langle\sigma(\nu_e + \bar{\nu}_\mu)\rangle^{theo.}_{NC}$$

$$\boxed{9.9 - 11.5} \times 10^{-42} cm^2$$

Mintz et al. / Fukugita et al. / Bernabéu et al. / Kolbe et al.

INCLUSIVE CC REACTION

ν – events [17-35MeV]	721

$^{12}C\ (\nu\ \ ,\nu\ )\ ^{12}C^*$:	1
$^{12}C\ (\nu_e\ , e^-)\ ^{12}N_{gs}$:	321
$^{13}C\ (\nu_e\ , e^-)\ ^{13}N$:	20
ν – e^--scattering :	47

background: 674

$^{12}C(\nu_e,e^-)^{12}N^*$:	332

CC* flux averaged cross section

$$\langle\sigma(\nu_e)\rangle^{exp.}_{CC^*} = \boxed{6.0 \pm 1.1\ (stat) \pm 0.5\ (syst)} \times 10^{-42} cm^2$$

Kolbe (CRPA):	$6.4 \times 10^{-42}\ cm^2$
Donnelly:	$3.7 \times 10^{-42}\ cm^2$
Los Alamos (exp.):	$3.6 \times 10^{-42}\ cm^2$

FLAVOUR UNIVERSALITY $\nu_e, \bar{\nu}_\mu - Z^\circ$

$$\langle \sigma(\nu_e + \bar{\nu}_\mu) \rangle_{NC}^{exp.} = 10.7 \times 10^{-42}\,cm^2$$

$$\langle \sigma(\nu_e) \rangle_{CC}^{exp.} = 9.3 \times 10^{-42}\,cm^2$$

$$\sigma_{NC}(\nu_e) \approx \tfrac{1}{2}\,\sigma_{CC}(\nu_e)$$

$$\boxed{R =} \frac{\sigma_{NC}(\nu_e + \bar{\nu}_\mu)}{\sigma_{CC}(\nu_e)} \boxed{\approx 1}$$

THEORY	Fukugita:	1.08 ± 0.02
	Kolbe:	$1.13 \,\&\, 1.20$
	Mintz:	1.22 ± 0.09
KARMEN		$R = 1.15 \pm 0.12 \pm 0.06$

neutrino flux - independent

$\nu_\mu \longrightarrow \nu_e$ appearance

$$\nu_e + {}^{12}C \longrightarrow {}^{12}N_{gs} + e^- \; - 17\,MeV$$

30 MeV
ν_μ-time

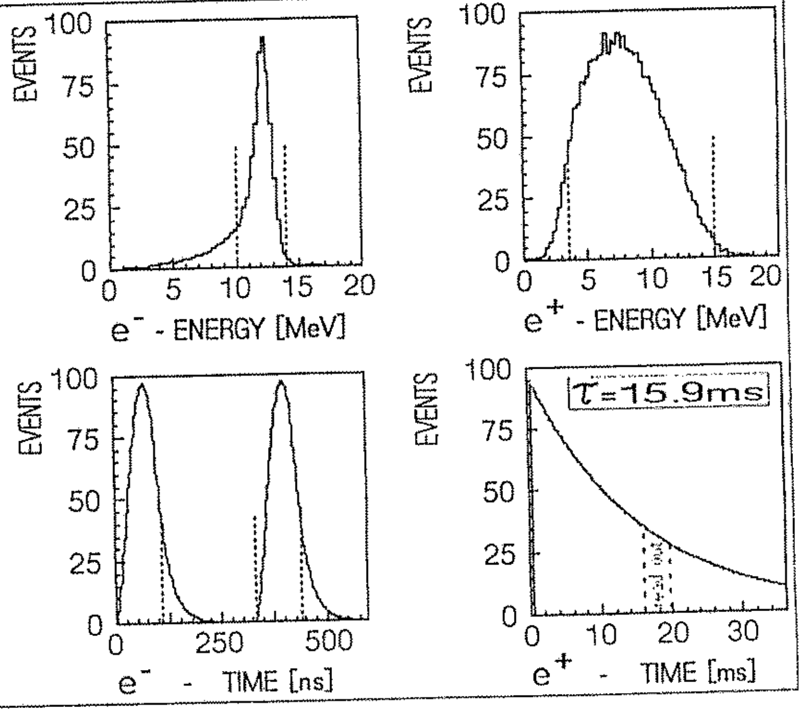
$\tau = 16ms$

$\varepsilon_0 = 16MeV$

P = 1MC

$$\downarrow$$

$${}^{12}C + e^+ + \nu_e$$



$\nu_\mu \longrightarrow \nu_e$ appearance

$$\pi^+ \xrightarrow{\boxed{26\,\mathrm{ns}}} \mu^+ + \boxed{\nu_\mu} \longrightarrow \boxed{\nu_e}$$

ν_μ - time window

$E_{\nu_\mu} = E_{\nu_e} \sim 30$ MeV

$$\nu_e + {}^{12}C \longrightarrow {}^{12}N_{gs} + \textcircled{e^-} \quad - 17\,\mathrm{MeV}$$

$E_{e^-} = 10-14$ MeV $\quad \tau = 16$ms

$E_{e^+} = 3.5-15$ MeV $\quad \varepsilon_0 = 16$MeV

$$\downarrow$$

$${}^{12}C + \textcircled{e^+} + \nu_e$$

found :	1.0
expected for P=1 :	134
background :	1.4
(sequential 0.07 / ν_e-contamination 1.37)	

excluded : > 3.1

$P(\nu_\mu \rightarrow \nu_e) < 2.4\times10^{-2}$ (90%CL)

29.09.1994

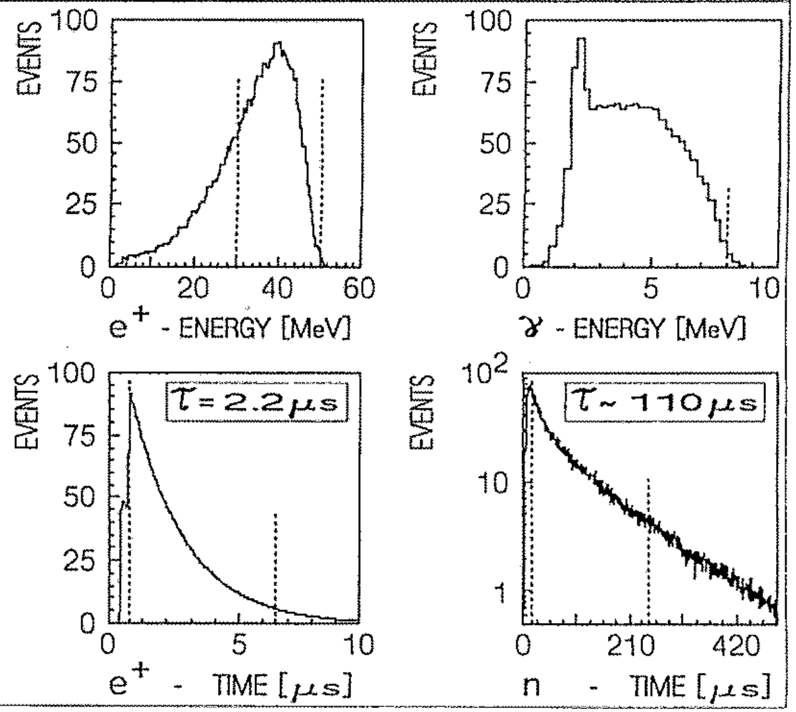
$\bar{\nu}_\mu \longrightarrow \bar{\nu}_e$ appearance

$$\bar{\nu}_e + {}^1H \longrightarrow n + \textcircled{e^+} \quad - 1.8\,\mathrm{MeV}$$

$$n \rightarrow n_{therm} \quad (\tau_{therm} \sim 110\,\mu s)$$

P = 1 MC

$$n_{therm} + Gd \longrightarrow Gd^* \longrightarrow Gd + \textcircled{\gamma's}$$



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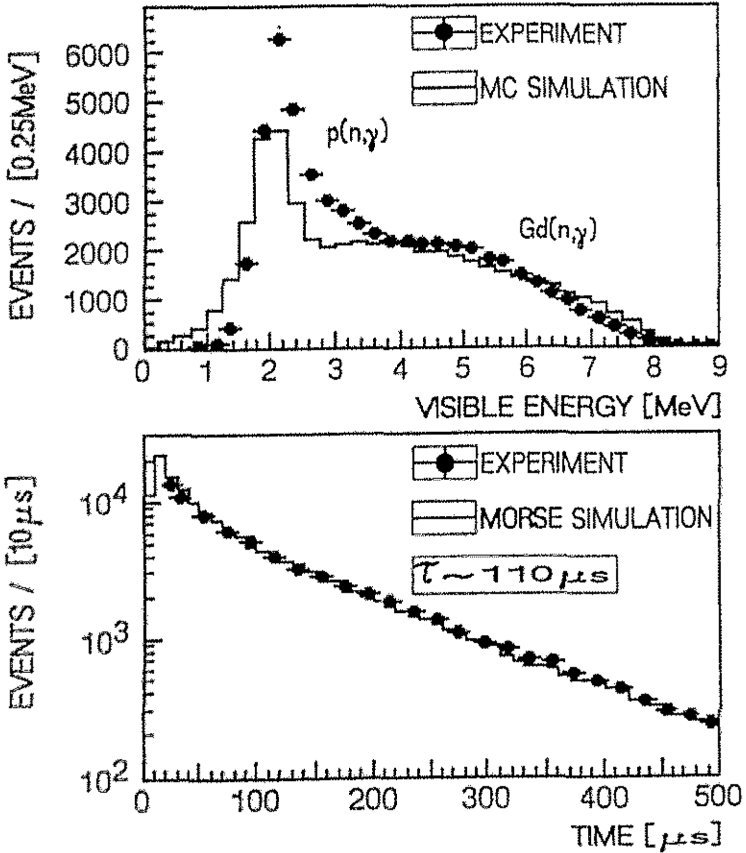
TEST OF NEUTRON DETECTION

$$\mu^- + {}^{12}C \longrightarrow {}^{11}B + \nu_\mu + n \longrightarrow Gd(n,\gamma)$$



20.01.1994

$\bar\nu_\mu \longrightarrow \bar\nu_e$ appearance

$$\mu^+ \xrightarrow[\boxed{2.2\,\mu s}]{} e^+ + \nu_e + \boxed{\bar\nu_\mu} \longrightarrow \boxed{\bar\nu_e}$$

$$\bar\nu_e + {}^1H \longrightarrow \underset{\substack{\downarrow \\ n_{therm}}}{n} + \enclose{circle}{e^+} \quad \sim 1.8\ MeV$$

$(\tau_{therm} \sim 110\ \mu s)$

$$n_{therm} + Gd \longrightarrow Gd^* \longrightarrow Gd + \enclose{circle}{\gamma's}$$

$E_{e^+} \in [30,50]$ MeV $\Sigma E_\gamma = 8$ MeV

found: 11
expected for P=1: 1591
background: 17
(16.2 sequential / 0.38 CC-contamination)

excluded: > 4.9

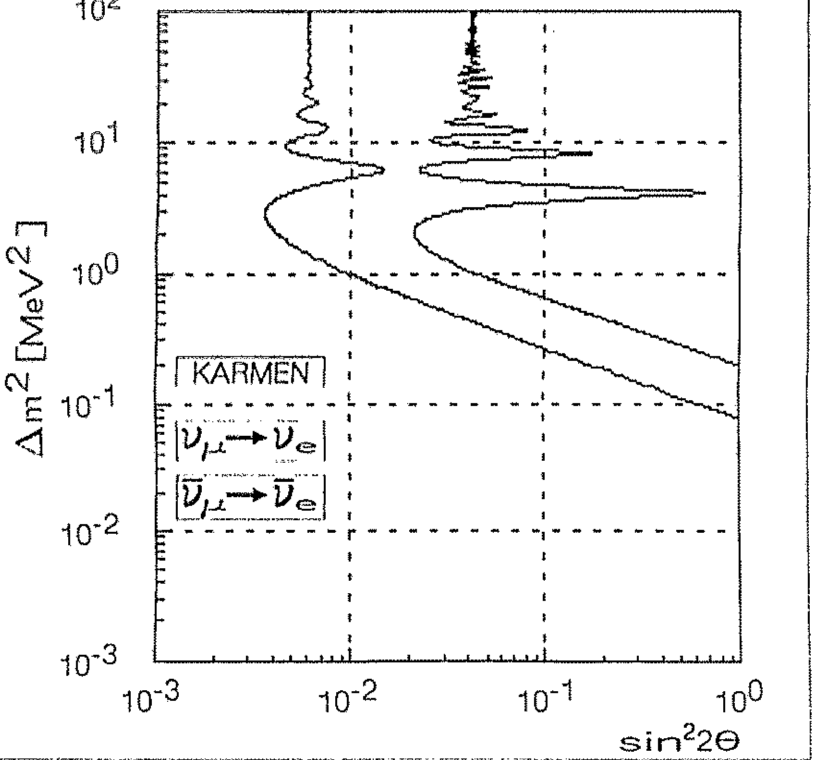
$P(\bar\nu_\mu \longrightarrow \bar\nu_e) < 3.1\times10^{-3}$ (90%CL)

29.09.1994

50

OSCILLATION LIMITS

$$P_{\nu_i \longrightarrow \nu_j} = \sin^2 2\theta \times \sin^2\left(1.27 \times \frac{\Delta m^2 L}{E_\nu}\right)$$

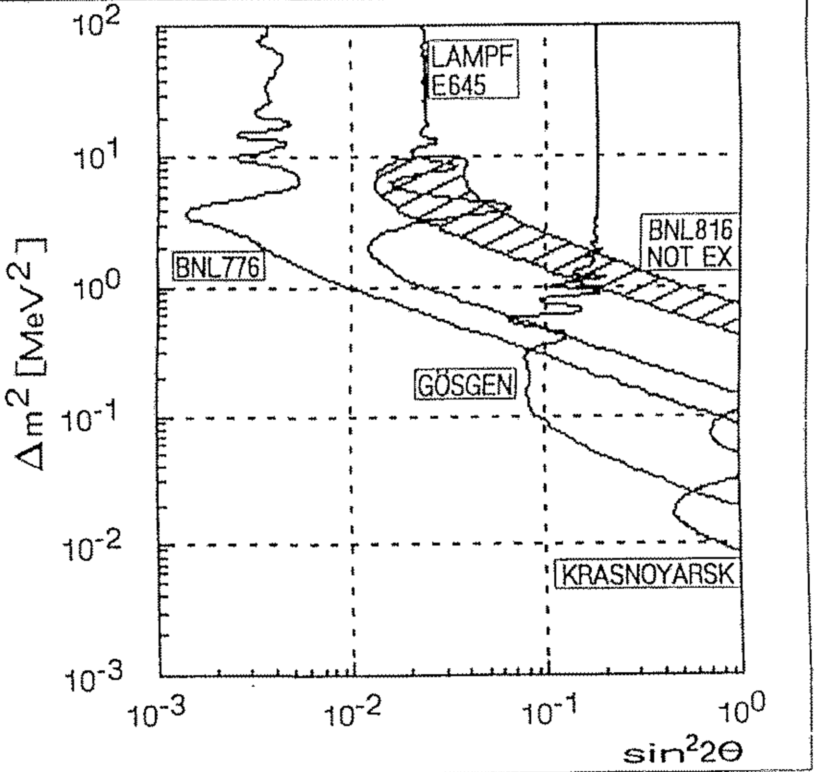


29.09.1994

47

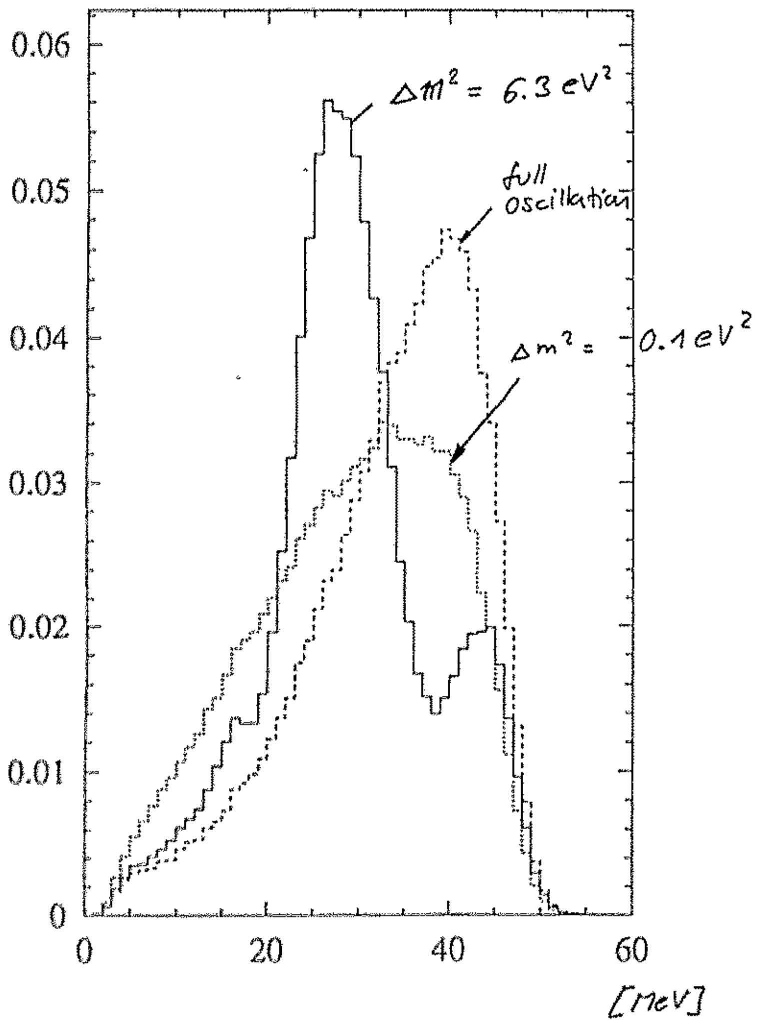
OSCILLATION LIMITS

$$P_{\nu_i \longrightarrow \nu_j} = \sin^2 2\theta \times \sin^2\left(1.27 \times \frac{\Delta m^2 L}{E_\nu}\right)$$



24.05.1994

Positron spectra for various Δm^2



LF - VIOLATING DECAYS

$\mu^+ \xrightarrow[\boxed{2.2\,\mu s}]{} e^+ + \boxed{\bar{\nu}_e} + \boxed{\nu_\mu}$

$\bar{\nu}_e + {}^1H \longrightarrow n + \textcircled{e^+}$ - 1.8 MeV

$E_{e^+} \in [30,50]$ MeV $\Sigma E_\gamma = 8$ MeV

found: 11
expected for $\Gamma_i / \Gamma_{tot} = 1$: 1591
background: 17

excluded: > 4.9

$\Gamma_i / \Gamma_{tot} < 3.1 \times 10^{-3}$ (90%CL)

E 225 : $\Gamma_i / \Gamma < 1.2 \cdot 10^{-2}$

LAMPF 1992

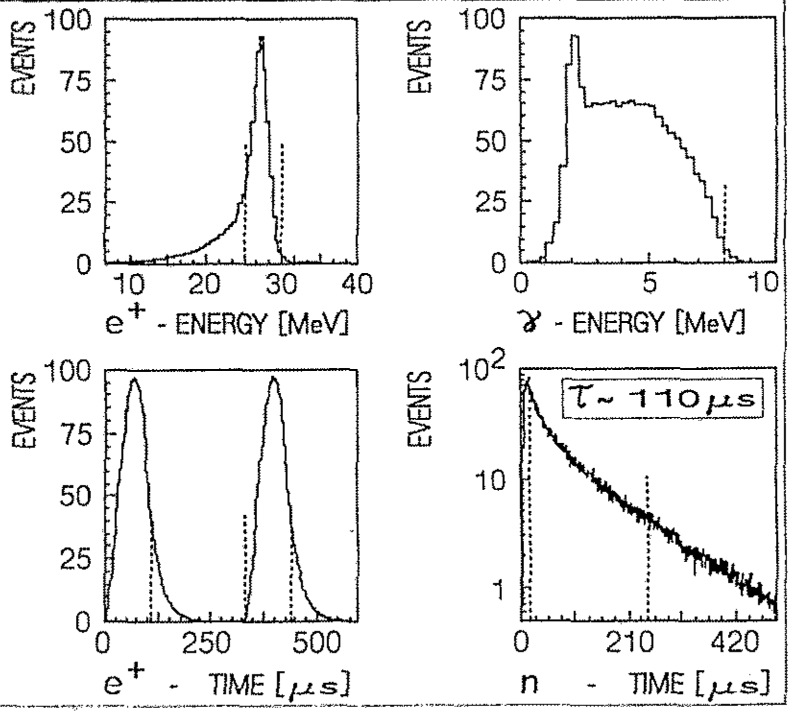
29.09.1994

L - VIOLATING DECAYS

$\bar{\nu}_e + {}^1\mathrm{H} \longrightarrow n + \enclose{circle}{e^+}$ $- 1.8$ MeV

$\boxed{\begin{array}{l}30\ \mathrm{MeV}\\ \nu_\mu\mathrm{-time}\end{array}}$ $\quad n \downarrow n_{\mathrm{therm}}$ $\quad (\tau_{\mathrm{therm}} \sim 110\ \mu s)$

$n_{\mathrm{therm}} + \mathrm{Gd} \longrightarrow \mathrm{Gd}^* \longrightarrow \mathrm{Gd} + \enclose{circle}{\gamma\text{'s}}$



29.09.1994

L - VIOLATING DECAYS

$\pi^+ \xrightarrow[\boxed{26\,\mathrm{ns}}]{} \mu^+ + \boxed{\bar{\nu}_e}$ $\quad E_{\bar{\nu}_e} \sim 30$ MeV

$\bar{\nu}_e + {}^1\mathrm{H} \longrightarrow n + \enclose{circle}{e^+}$ $- 1.8$ MeV

$E_{e^+} \in [22,35]$ MeV $\quad T_{e^+} \in [0,500]$ ns

MLA input events:	202
excluded e^+ :	> 9.7
expected for $\Gamma_i / \Gamma_{tot} = 1$:	3507

Γ_i / Γ_{tot} <	2.8×10^{-3}	(90%CL)

background included in analysis

cosmics
neutrons
CC reactions
$\nu - e^-$-scattering

PDG : $\Gamma_i/\Gamma < 1.5\cdot10^{-3}$

BEBC CERN SPS 1982 $\quad$ Wb - ν - beam
$E_\nu > 10$ GeV

29.09.1994

L - VIOLATING DECAYS

$\pi^+ \xrightarrow[\boxed{26\,\mathrm{ns}}]{} e^+ + \boxed{\bar{\nu}_e}$ $E_{\bar{\nu}_e} \sim 70\,\mathrm{MeV}$

$\bar{\nu}_e + {}^1H \longrightarrow n + ⓔ^+$ $-1.8\,\mathrm{MeV}$

$E_{e^+} \in [50,70]$ MeV $T_{e^+} \in [0,500]$ ns

MLA input events	:	289
excluded e^+	:	> 45
expected for $\Gamma_i / \Gamma_{tot} = 1$:		20752

Γ_i / Γ_{tot} <	2.1×10^{-3}	(90%CL)

background included in analysis
cosmics
neutrons

PDG : $\Gamma_i/\Gamma = (1.2 \pm 0.004)\cdot10^{-4}$

BGO PSI 1988

π^+, e^+ coincidence $\nu, \bar{\nu}$?

SUMMARY

excellent calorimetry; clear ν – signatures

$\boxed{CC}$: ${}^{12}C(\nu_e, e^-)\,{}^{12}N_{gs}$ (excl.)

$\boxed{\nu - \text{spectroscopy}}$

$\langle\sigma\rangle$; $\sigma(E_{\nu_e})$; $F_A(q^2)$; $\omega_L(\nu_e\text{-shape})$

$\boxed{NC}$: ${}^{12}C(\nu, \nu')\,{}^{12}C^*\,(1^+,1 \atop 15.1\,\mathrm{MeV})$

$\langle\sigma(\nu_e + \bar{\nu}_\mu)\rangle$ $\boxed{\text{first observation}}$

$(\nu_e ; \bar{\nu}_\mu)$ $\boxed{\text{flavour universality}}$

flavour independent ν – flux

$\boxed{CC}$: ${}^{12}C(\nu_e, e^-)\,{}^{12}N^*$ (incl.)

ν – oscillations: stringent limits

l, lf - violating $\pi^+ ; \mu^+$ decays: ν - ID limits

future: 3000 C p.a. / increased statistics
exploitation of time structure

Fünf Jahre Betrieb des S-DALINAC
– Ein Statusreport –

H. D. Gräf
Darmstadt

7.Oktober 1994

Fünf Jahre Betrieb des S-DALINAC

– Ein Statusbericht –

I. Beschreibung und Vorgeschichte

II. Betriebserfahrung

Technische Entwicklungen

Status

III. Momentane Aktivitäten

Ausblick

H.-D. Gräf
Pirna, 7. Okt. 94

Unterstutzt durch BMFT

Arbeitsgruppe

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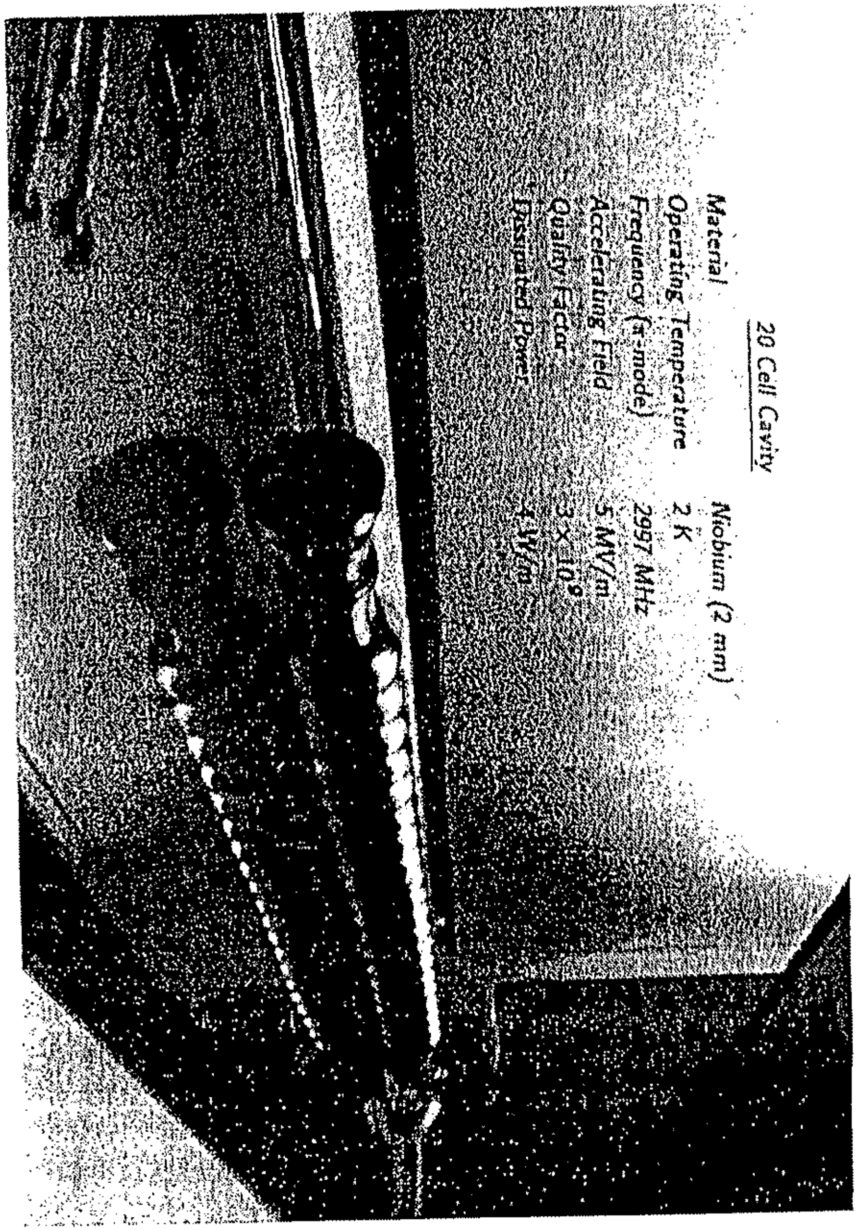
S. Döbert, R. Eichhorn, J. Freudenberger,
R. Galemann, H. Genz, H.-D. Gräf, L. Gröning,
R. Hahn, T. Hampel, R. Hofferbert,
P. Hoffmann - Stascheck, J. Horn, F. Humbert,
N. Huxel, M. Kohl, M. Kuss, H. Loos,
C. Lüttge, U. Nething, P. v. Neumann - Cosel,
F. Neumeyer, M. Rehfeld, A. Richter,
M. Reichenbach, K. Rühl, P. Schardt,
C. Schlegel, V. Schlott, G. Schrieder,
E. Spamer, A. Stascheck, A. Stiller, S. Strauch,
M. Thomas, O. Titze, T. Wesp, M. Wiencken.

K. Alrutz - Ziemssen, J. Auerhammer,
D. Flasche, G. Herbert, V. Huck,
K. D. Hummel, M. Knirsch, T. Rietdorf,
M. Schanz, S. Simrock, J. Töpper,
H. Weise, H. Wörtche, W. P. Ziegler.

ZEITLICHE ENTWICKLUNG DES S-DALINAC

OKT	1976	ERSTE ÜBERLEGUNGEN ZUR ERNEUERUNG DES ALTEN DARMSTÄDTER ELEKTRONENLINEARBESCHLEUNIGERS (DALINAC)
MAI	1977	DARMSTADT - WUPPERTAL KOOPERATION (H. PIEL)
OKT	1977	FB PHYSIK UNTERSTÜTZT DIE ERNEUERUNG
JUL	1978	ORGA - AUSSCHUSS DER THD UNTERSTÜTZT ERNEUERUNG
APR	1979	MEMORANDUM
OKT	1979	"AD - HOC - AUSSCHUSS KERNPHYSIK" DES BMFT EMPFIEHLT REALISIERUNG
MAI	1980	HAUSHALTSAUSSCHUSS DER THD BESCHLIESST LINAC ERSATZ
JUN	1980	1. HBFG - ANTRAG WIRD EINGEREICHT
SEP	1980	BEGINN DES PILOTPROJEKTES
JAN	1981	2. HBFG - ANTRAG WIRD EINGEREICHT
MAI	1981	DFG EMPFIEHLT REALISIERUNG DES PROJEKTES
SEP	1981	AUFNAHME IN DAS DRINGLICHKEITSPROGRAMM DER HOCHSCHULBAUFÖRDERUNG
AUG	1982	BAUGENEHMIGUNG WIRD ERTEILT
OKT	1982	BAUBEGINN
SEP	1983	RICHTFEST
JAN	1984	BEGINN DER INSTALLATIONEN
APR	1986	ERSTE INJEKTORTESTS

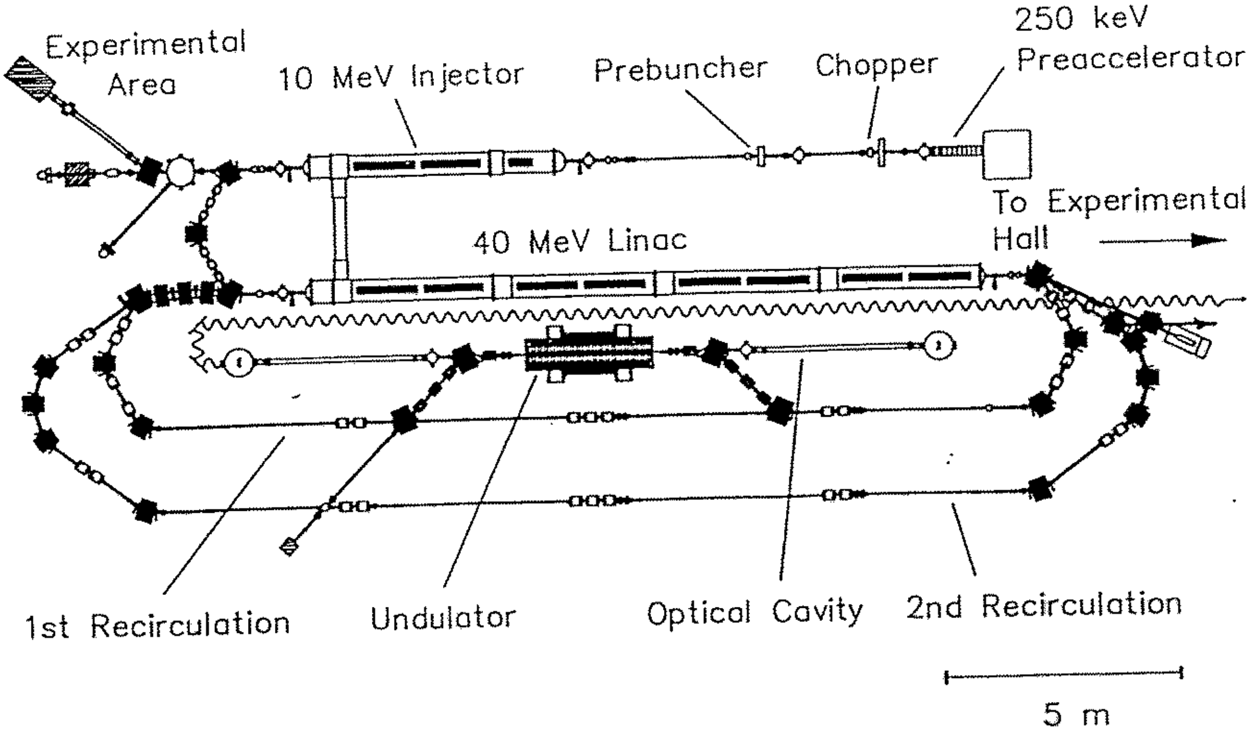
20 - zellige supraleitende Beschleunigungsstruktur



20 Cell Cavity

Material	Niobium (2 mm)
Operating Temperature	2 K
Frequency (π-mode)	2997 MHz
Accelerating Field	5 MV/m
Quality Factor	3×10^9
Dissipated Power	4 W/m

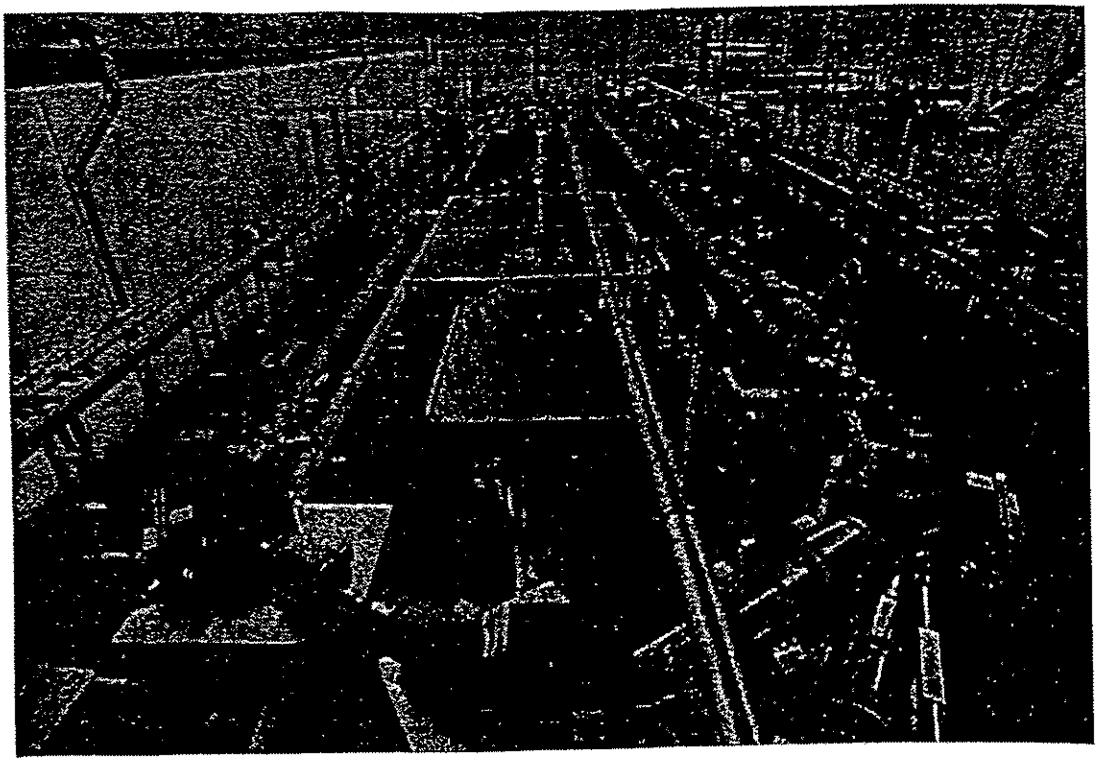
S – DALINAC



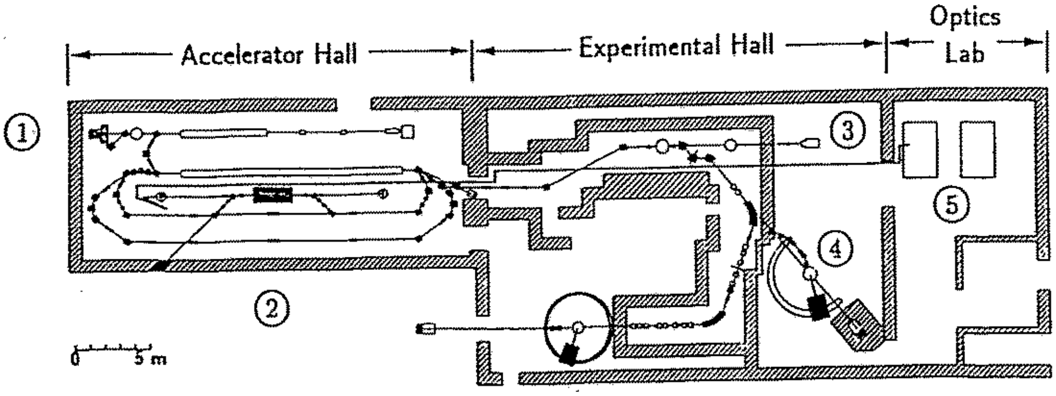
Parameter des S–DALINAC

Strahlenergie	E	<	130 MeV
Strahlstrom	i	≥	20 μA
Beschleunigungsstrukturen			10 x 1 m
Einfangstruktrur			0.25 m
Rezirkulationen			2

S – DALINAC



S-DALINAC and Experimental Facilities



① Channeling Radiation, PXR, and (γ,γ')

② Free Electron Laser

③ High Energy Channeling

④ $(e,e'x)$ - and (e,e') - Experiments

⑤ Optics Experiments

Technische Entwicklungen

HF - Kontroll - und Regelsystem

Tuner

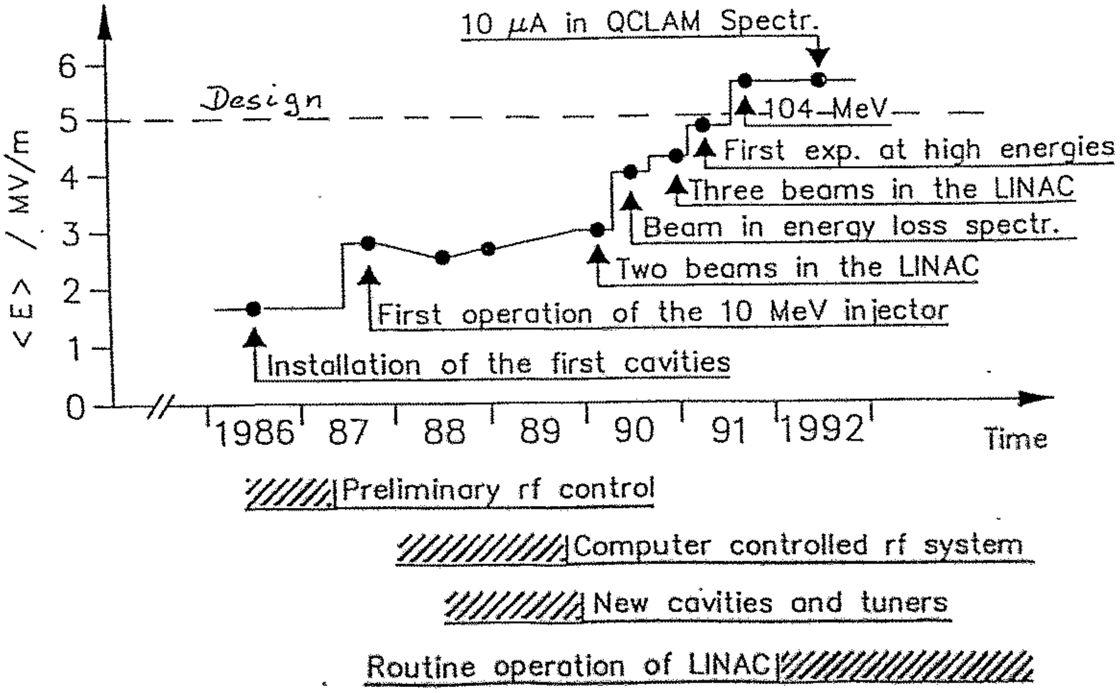
HF - Ein - und Auskoppler

Weglänge der Rezirkulationen

Hochstrominjektion (FEL)

Beschleunigersteuerung

Technische Entwicklung des S-DALINAC



Tuner

Nach Installation und Abkühlen muß die Eigenfrequenz der Beschleunigungsstrukturen auf die Betriebsfrequenz einstellbar sein.

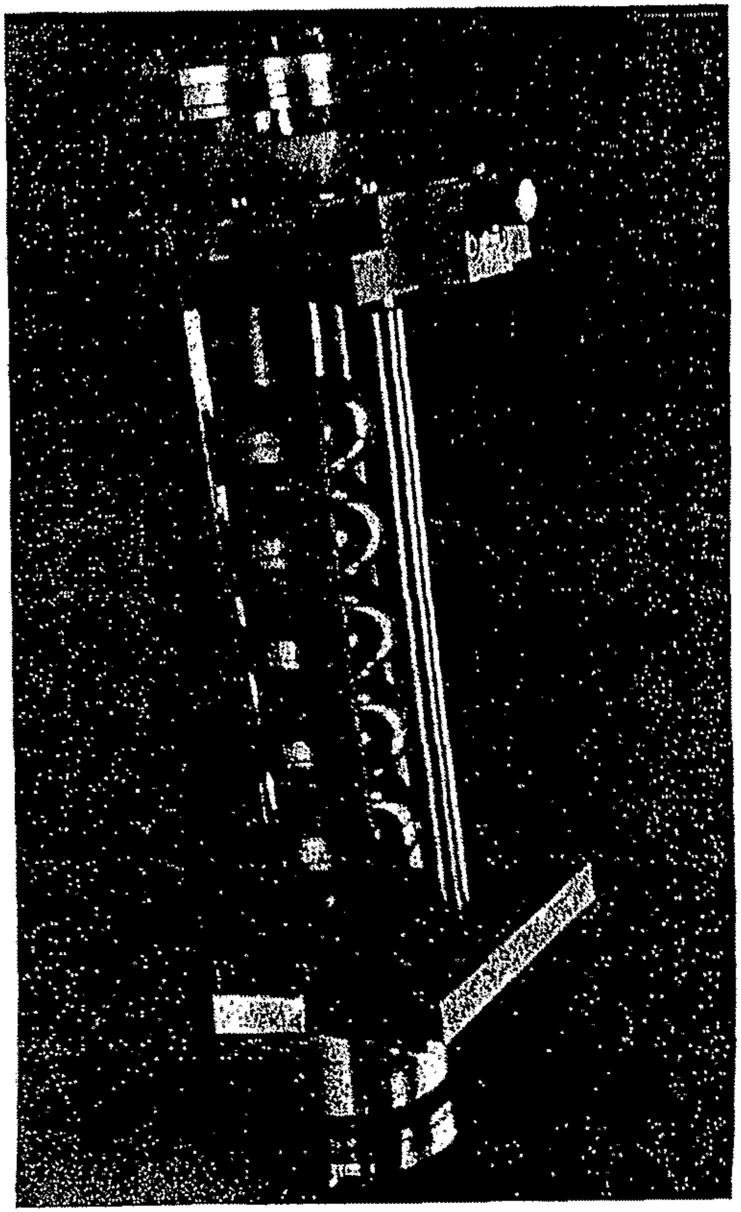
⟶ Reproduzierbarkeit der Installation und Vorhersagbarkeit der Eigenfrequenz der Strukturen bestimmen den Stellbereich des Tuners.

Korrektur langsamer Driften der Eigenfrequenzen. Stellgeschwindigkeit ist durch mechanische Resonanzen des Cavity-Tuner Systems begrenzt.

Korrektur von Verstimmung der Strukturen durch Lorentzkräfte.

⟶ Tuner müssen aktiver Teil des HF-Regelsystems sein.

Tuner müssen bei T = 2 K zuverlässig funktionieren.



5 - zellige Einfangstruktur mit Tuner

HF – Kontroll-und Regelsystem

Anforderungen

$$\Delta E \leq \pm 13 \text{ keV}$$

$$\Delta V / V \leq \pm 10^{-4}$$

$$\Delta \Phi \leq 1^0$$

Sensibilität

$$\Delta f / \Delta L \approx 500 \text{ kHz} / \text{mm} \qquad (L = 1 \text{ m})$$

$$\Delta \Phi / \Delta f = 90^0 \cdot \frac{Q}{f_0}$$

$\Delta \Phi / \Delta f \approx 10^0 / \text{nm}$	bei $Q = 3 \cdot 10^9$
$\Delta \Phi / \Delta f \approx 0.1^0 / \text{nm}$	bei $Q = 3 \cdot 10^7$

Konsequenz

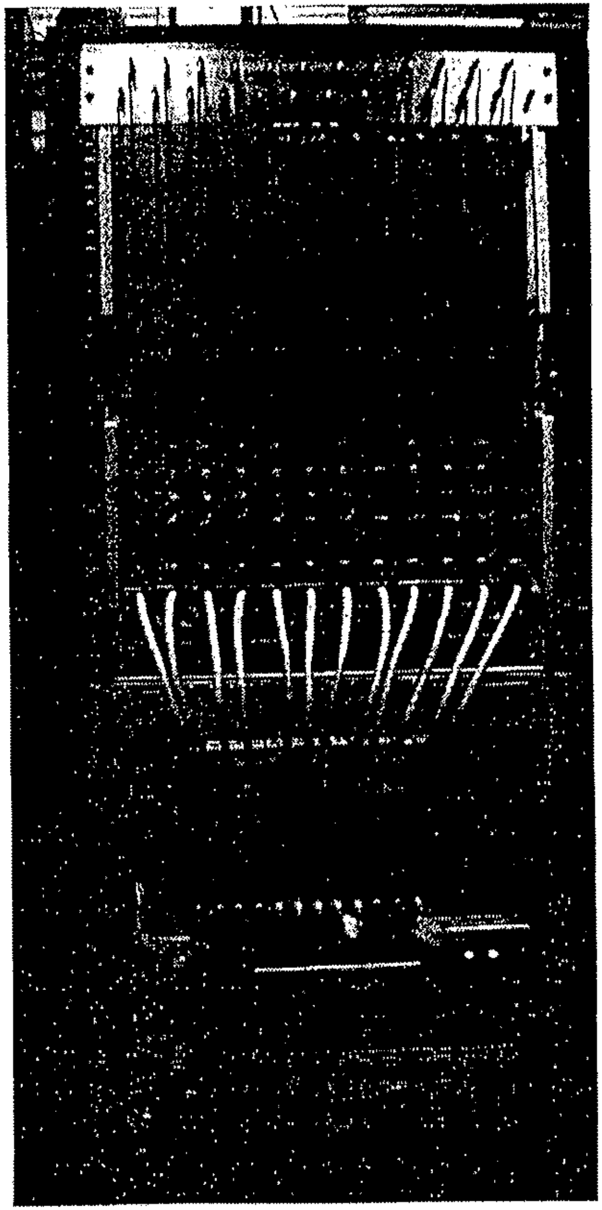
Präzise elektronische Stabilisierung von Amplitude und Phase des Beschleunigungsfeldes.

Eigenfrequenz der Strukturen muß aktiv nachgeregelt werden.

Status

$\Delta \Phi < 0.4^0$ $\qquad$ $\Delta V / V \leq \pm 4 \cdot 10^{-4}$

HF – Kontroll-und Regelsystem



RF Couplers

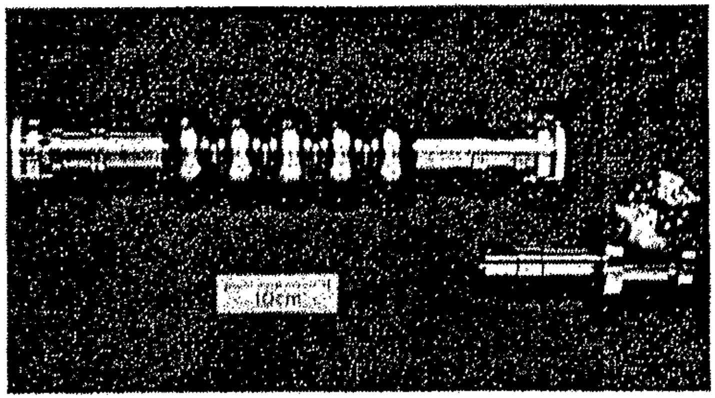
Input Couplers

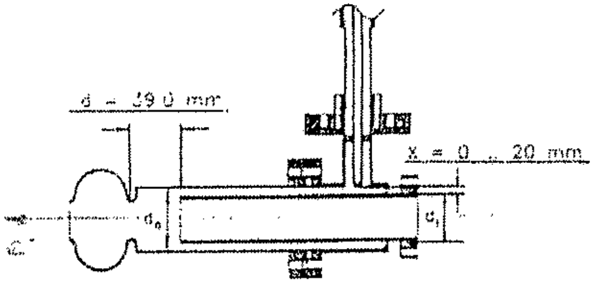
- Mechanical Rigidity
- Reproducibility and Predictability of Q_{ext}
- Variable Coupling, $10^7 \le Q_{ext} \le 10^9$
- No Transverse Electric Field on Axis
- Low Losses

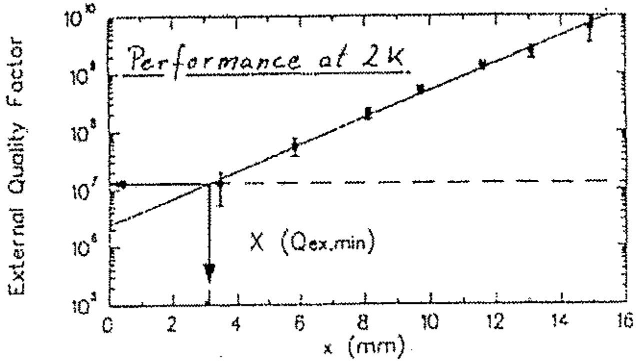
Probe Couplers

- Mechanical Rigidity
- Reproducibility and Predictability of Q_{ext}
- Fixed Coupling, $Q_{ext} = 1.5 \cdot 10^{10}$

Variable Input Coupler

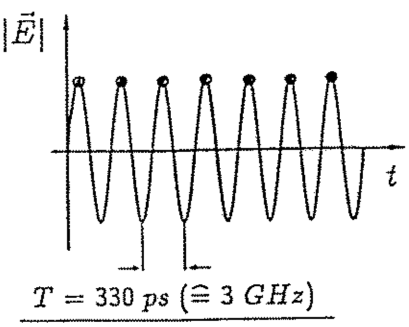




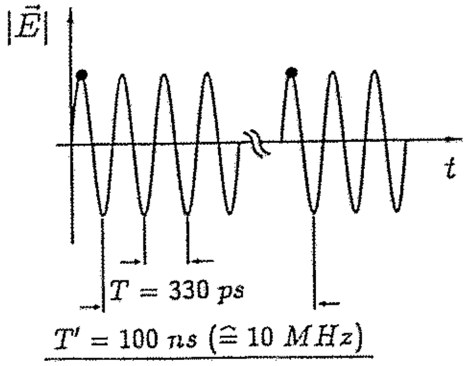


Time Structure

Nuclear Physics



Free Electron Laser



$$\boxed{\begin{aligned} P &= U \cdot \bar{I} \\ 300\ W &= 5\ MV/m \cdot \hat{I} \cdot \frac{2^\circ}{360^\circ} \end{aligned}}$$

$\rightsquigarrow \hat{I} \approx 10\ mA$

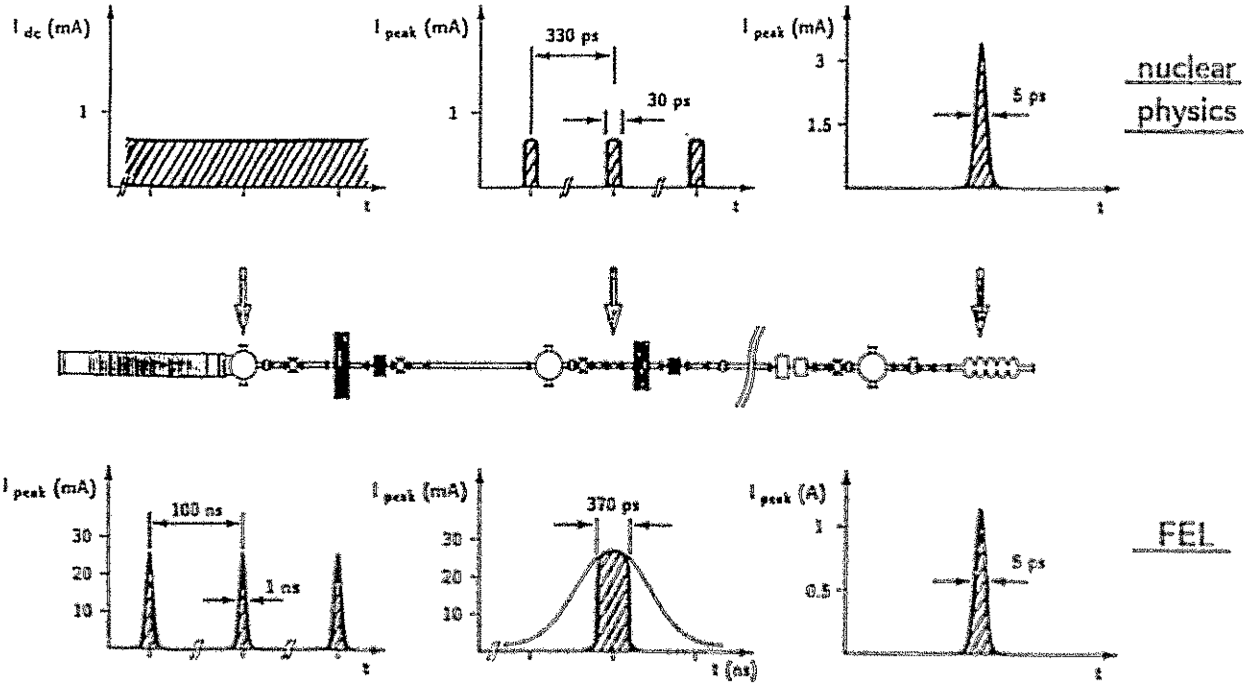
operation at 300th subharmonic

$\rightsquigarrow \hat{I} \approx 3\ A$ (FEL operation)

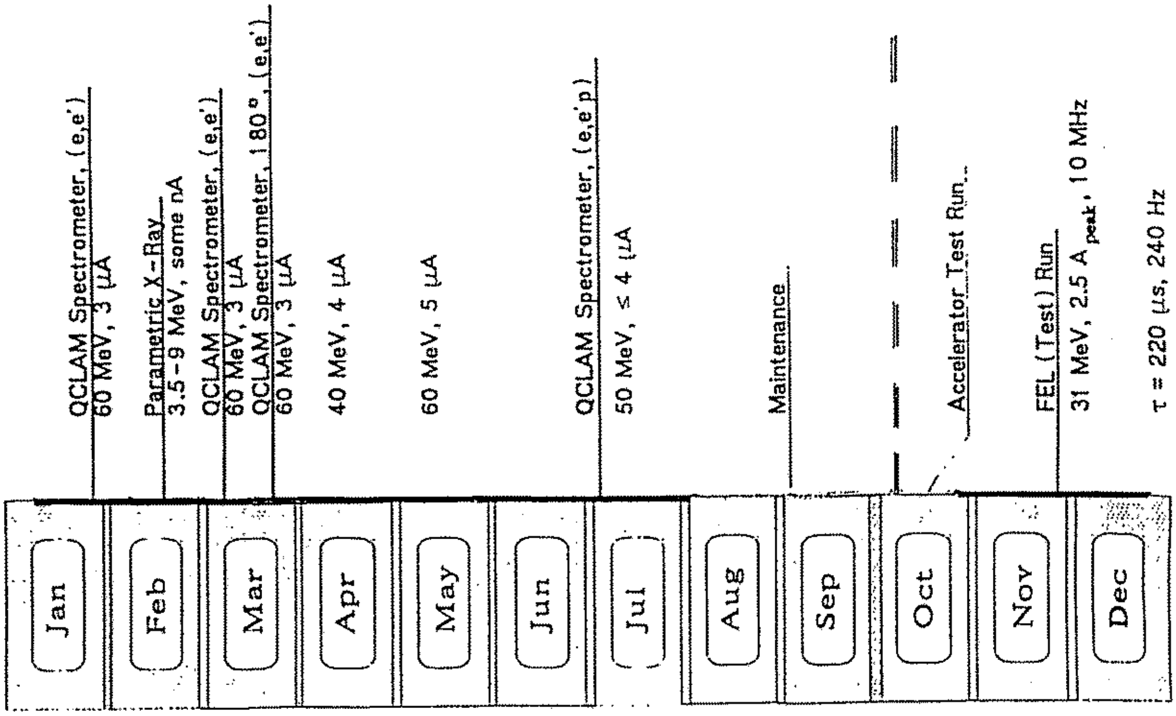
Generation of ps Bunches
with q_b = 5 pC at 10 MHz Rep. Rate
(synchronized to Accelerator RF)

15'

High Peak Current Generation



Operation in 1994



Beam Characteristics

Experiment	Energy/MeV	Current/µA	Mode
Nucl. Res. Fluorescence	2.5 - 10	40	3 GHz, cw
LE Channeling	3 - 10	0.01 - 10	3 GHz, cw
HE Channeling	75	1	3 GHz, cw
Electron Scattering	22 - 80	5	3 GHz, cw
FEL	32 - 38	2.7 A_{peak}	10 MHz, (cw)

Energy Spread: $\Delta E_{FWHM} = 50$ keV at $E_o = 80$ MeV

Emittance: $\varepsilon_n \approx 3 - 7\ \pi \cdot \mathrm{mm} \cdot \mathrm{mrad}$

Beam Time: > 8000 h (total)

Cavity Characteristics

Cavity Type	Number	Material	E_{acc} (MV/m)	Q_0
5 cells	1	RRR = (30)	7	
20 cells	2	RRR = 100	4.4 – 6	$< \approx 10^9 >$
20 cells	8	RRR = 280	5 – 10 $< 6 >$	

Cryogenics

Standby Losses	≈ 20 W
Cavities (RF)	≈ 125 W
Couplers, Input Lines	≈ 15 W
Aux. RF Cables	≈ 10 W
Total	≈ 170 W

⟹ Surface Chemistry ?

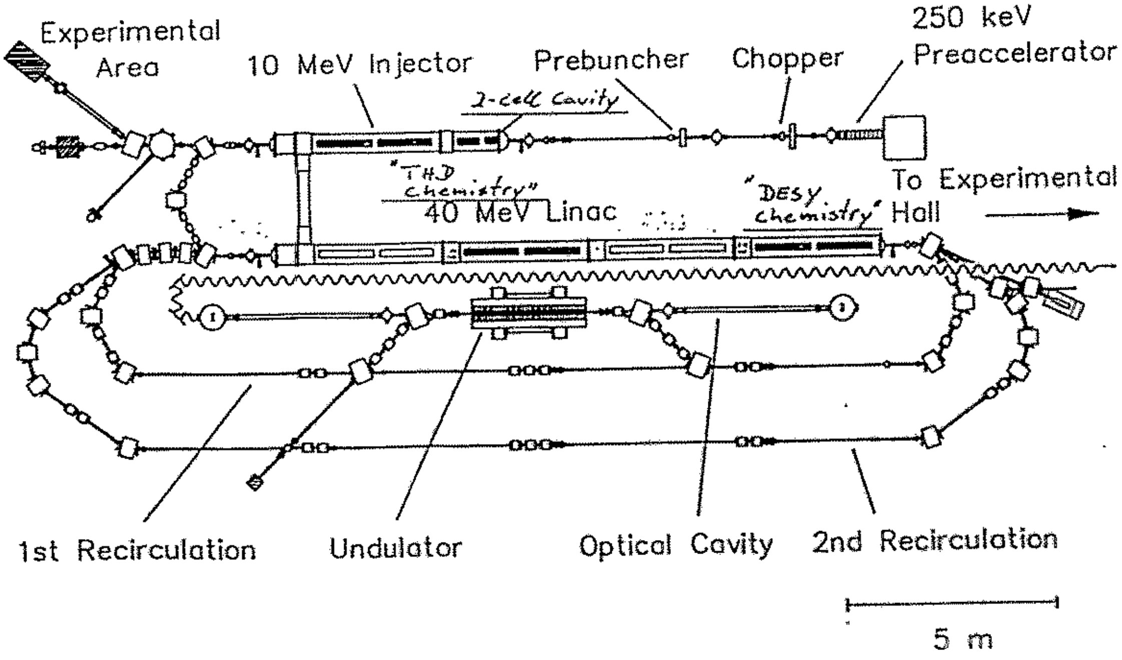
DESY, TTF

Refrigerator: 100 W

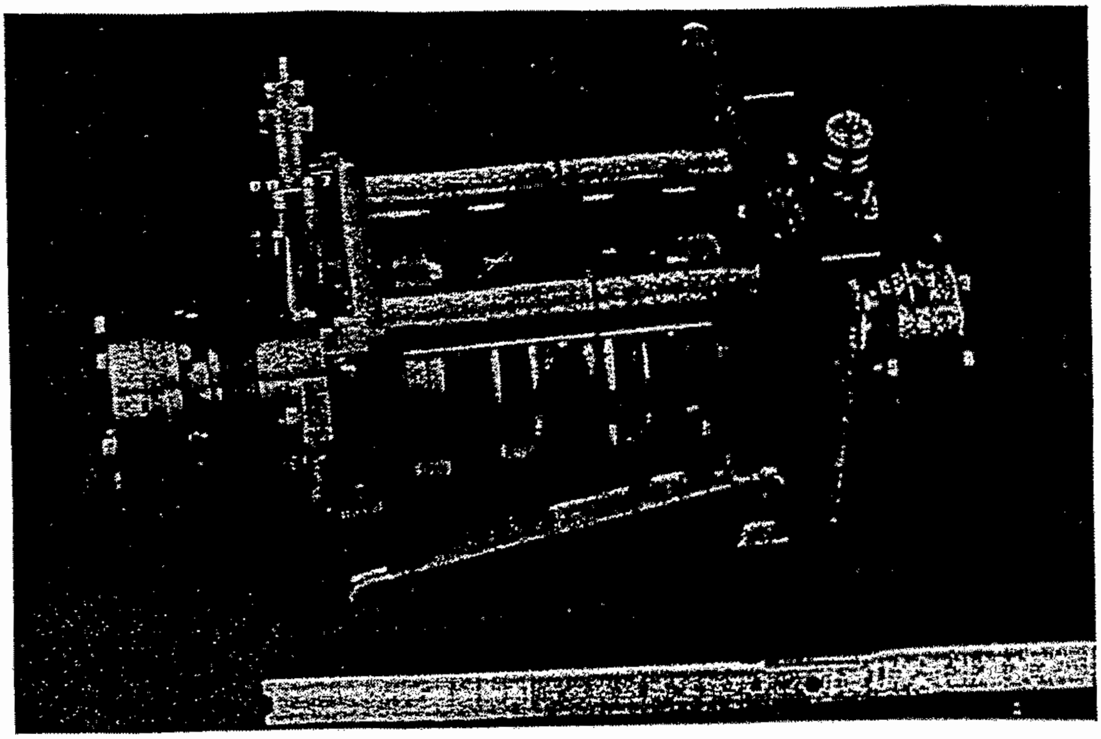
cw Limit: $E_0 \approx 80$ MeV

50 % Duty $E_0 = 104$ MeV

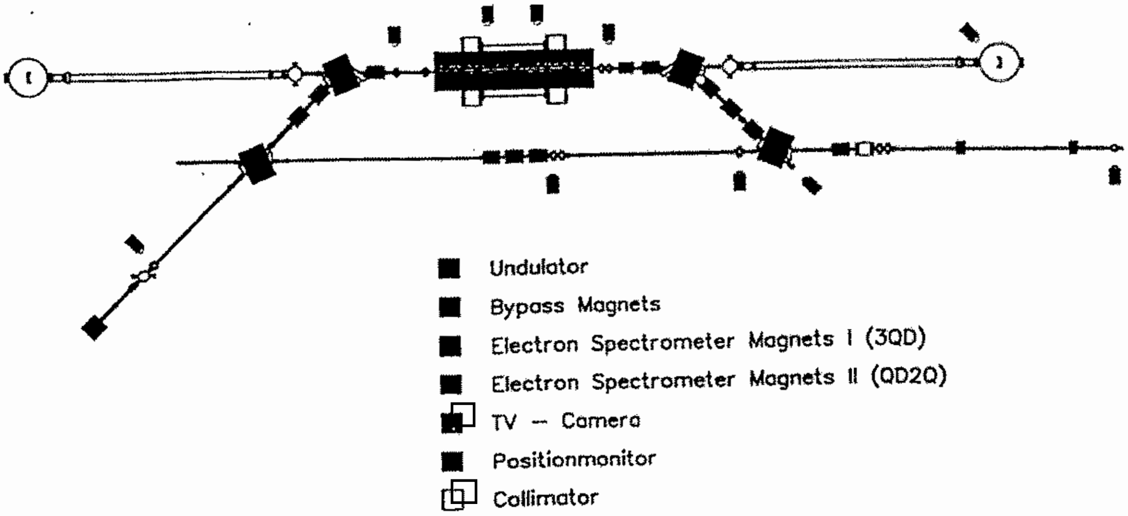
S – DALINAC



2 - zellige Vorbeschleunigungsstruktur ($\beta = 0.85$)



FEL Electron Beam Diagnostics



Ausblick

Verbesserung der Strukturgüten

Strahlenergie → 130 MeV

Verbesserung der Diagnostik

On - Line Strahlsimulation

Erstes Anschwingen des FEL

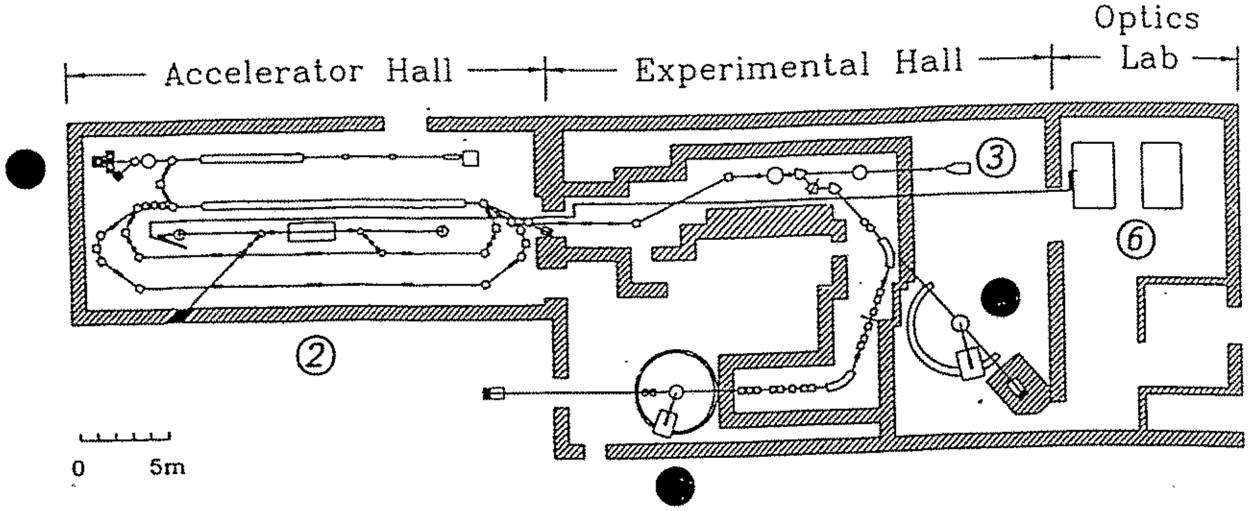
Weiterhin $T \geq 2000$ h Strahl pro Jahr

Stand der Experimente zum Studium elementarer Kernanregungen am S-DALINAC

P. von Neumann-Cosel
Darmstadt

7.Oktober 1994

Experiments at the S-DALINAC



● channeling radiation & (γ,γ') - experiments

② Free Electron Laser

③ high energy channeling

● (e,e'x) - experiments

● (e,e') - experiments

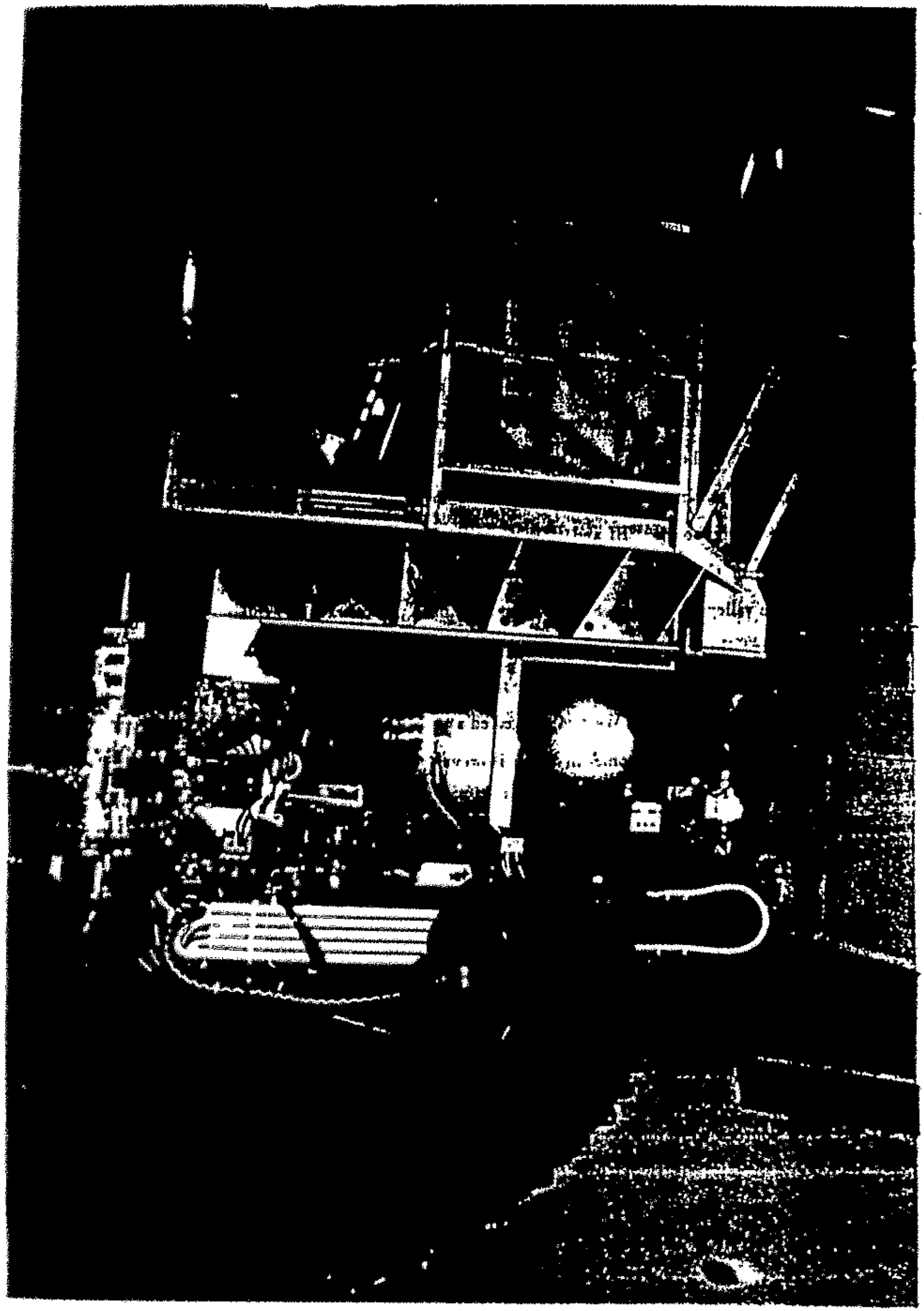
⑥ optics experiments

Stand der Experimente zur Untersuchung elementarer Kernanregungen am S-DALINAC

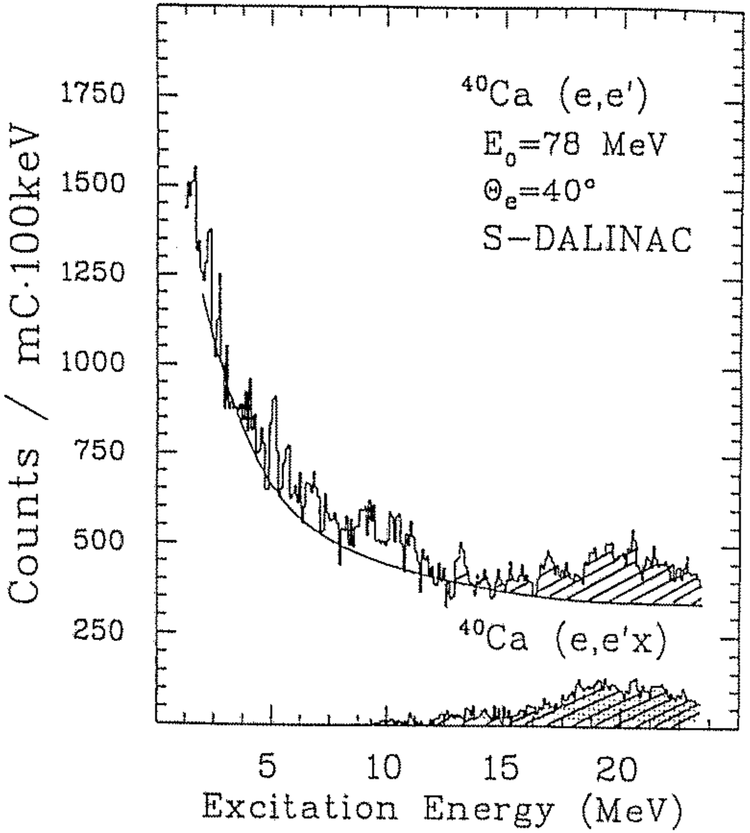
P. von Neumann-Cosel

Institut für Kernphysik, Technische Hochschule Darmstadt

- Elektronenstreu - Koinzidenzexperimente
  - Elektrische Riesenresonanzen in ^{40}Ca
  - IAR in ^{90}Zr
  - Aufbruch des Deutrons bei niedrigem Impulsübertrag
- M1 "Antwort" eines schweren deformierten Kerns
  - das Beispiel ^{154}Sm
- Ein System zur Elektronenstreuung unter 180° und erste Anwendungen

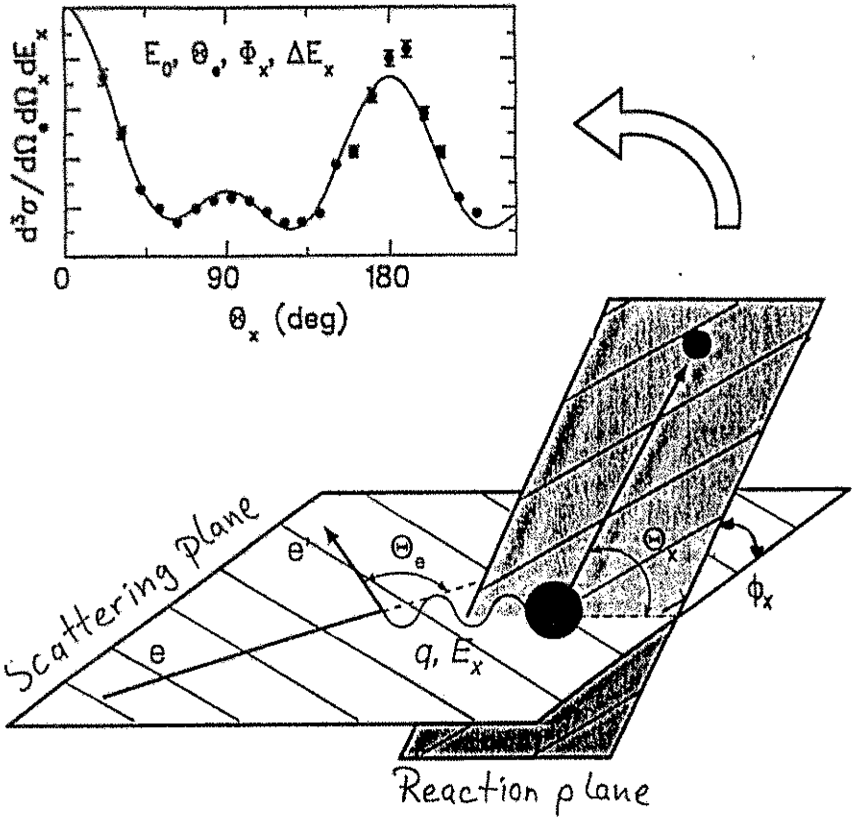


Inclusive vs. exclusive electron scattering



- Backgroundfree response!

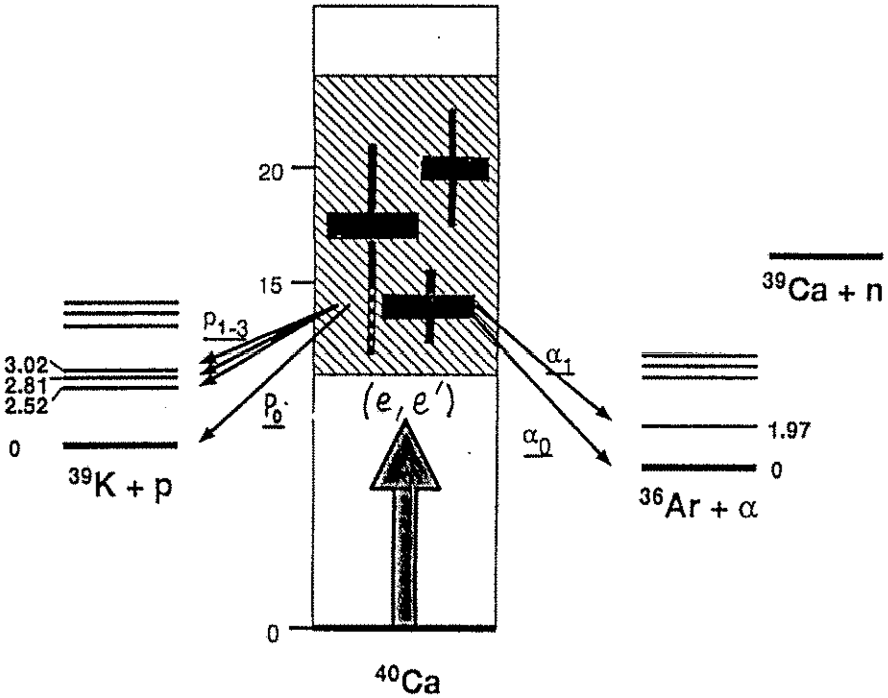
The Reaction A(e,e'x)B



$$\frac{d^3\sigma}{dE_x d\Omega_e d\Omega_x} = \frac{d^3}{dE_x d\Omega_e d\Omega_x}(\sigma_L + \sigma_T + \sigma_{LT}\cos\Phi_x + \sigma_{TT}\cos 2\Phi_x)$$

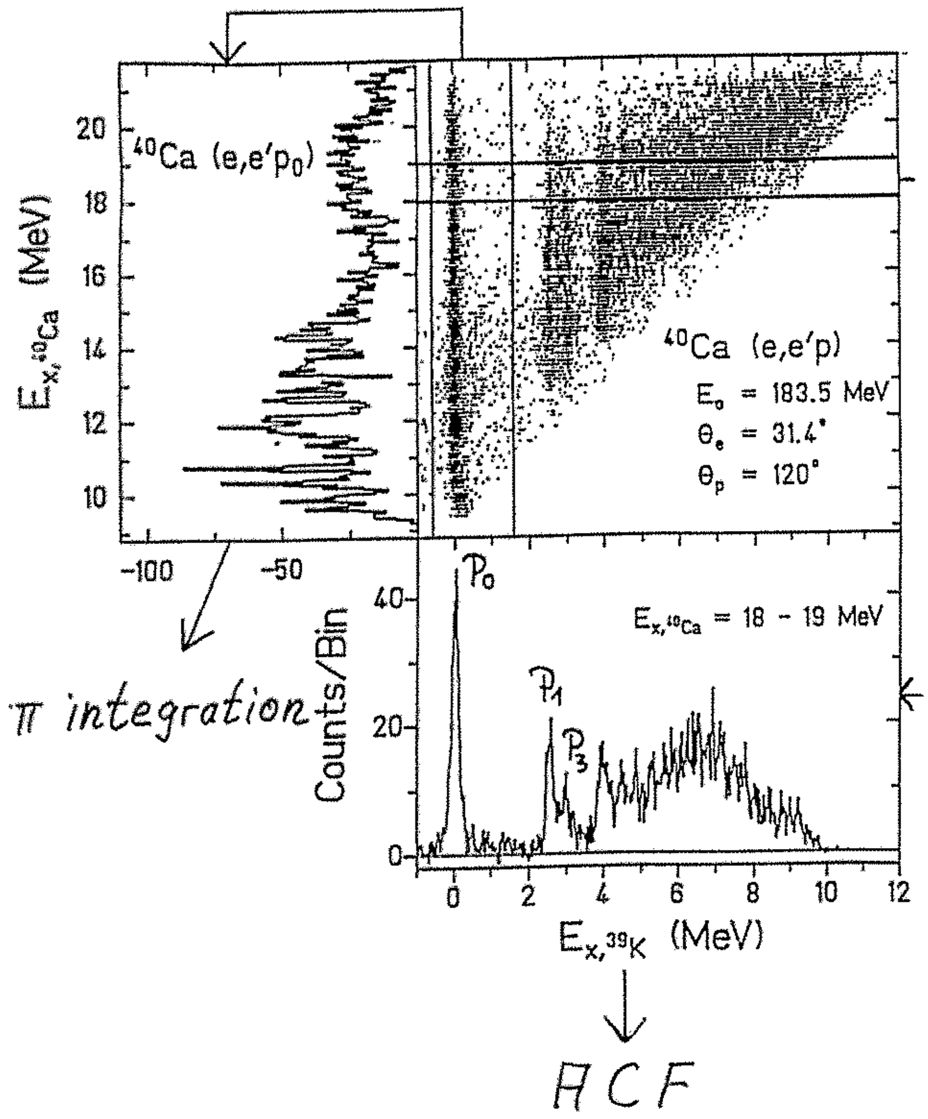
Structure functions

Excitation and Decay of ^{40}Ca

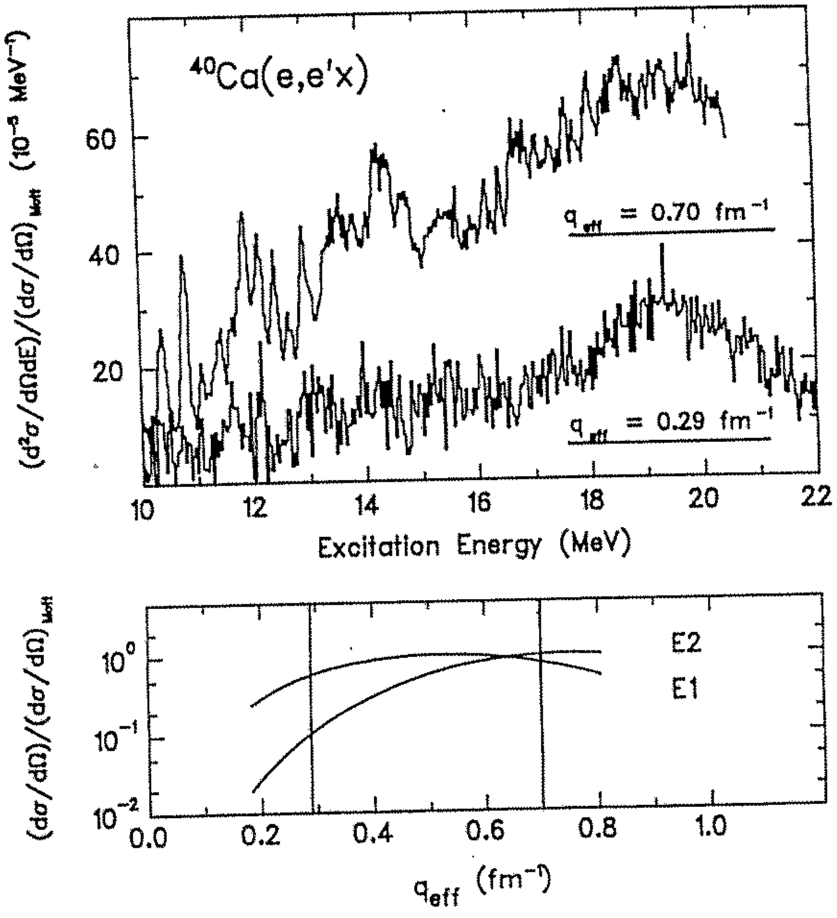


- Decomposition of mingled E0/E1/E2 strength
- Statistical vs. semidirect decay
- Fine structure

Dalitz plot



4π integrated Cross Sections



Multipole Analysis

Data

- Measurements at three momentum transfers in the excitation energy rage $E_x = 10 - 20.5$ MeV
- Photonuclear cross section

Cross section

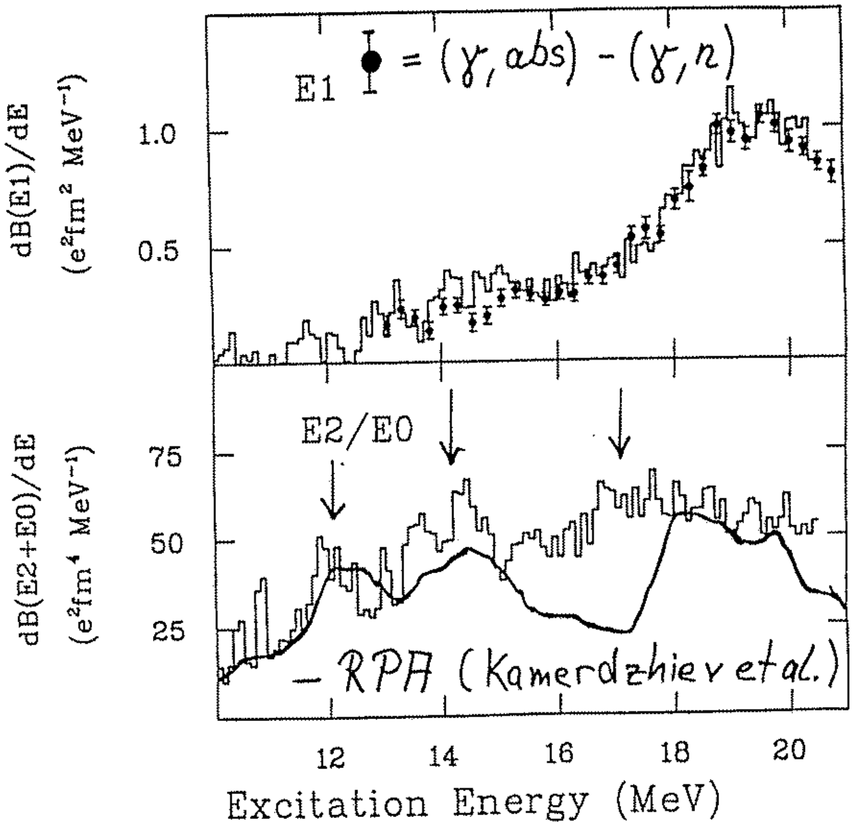
$$\frac{d^2\sigma}{dE_x d\Omega_e} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \cdot \sum_{\lambda=0}^{\Lambda} |F_\lambda(q, E_x)|^2$$

- only E0, E1 and E2 excitations
- indistinguishable E0 and E2 form factors
- shape of the form factors assumed constant as function of E_X

Fit

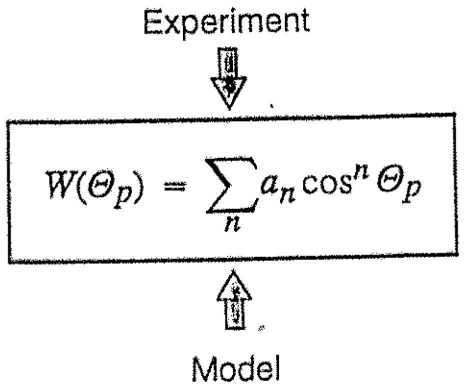
$$\frac{\sigma_{exp}}{\sigma_{Mott}}(q_i, E_{x_j}) = \underline{a_{E1}(E_{x_j})}\, \underline{|F_{E1}(q_i)|}^2 + \underline{a_{E2(E0)}(E_{x_j})}\, \underline{|F_{E2(E0)}(q_i)|}^2$$

Multipole analysis: results

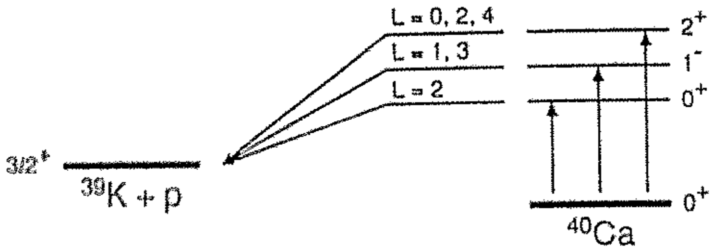


EWSR: E1 58(15) %
E2(E0) 80(16) %

Angular correlation functions (e,e′p)

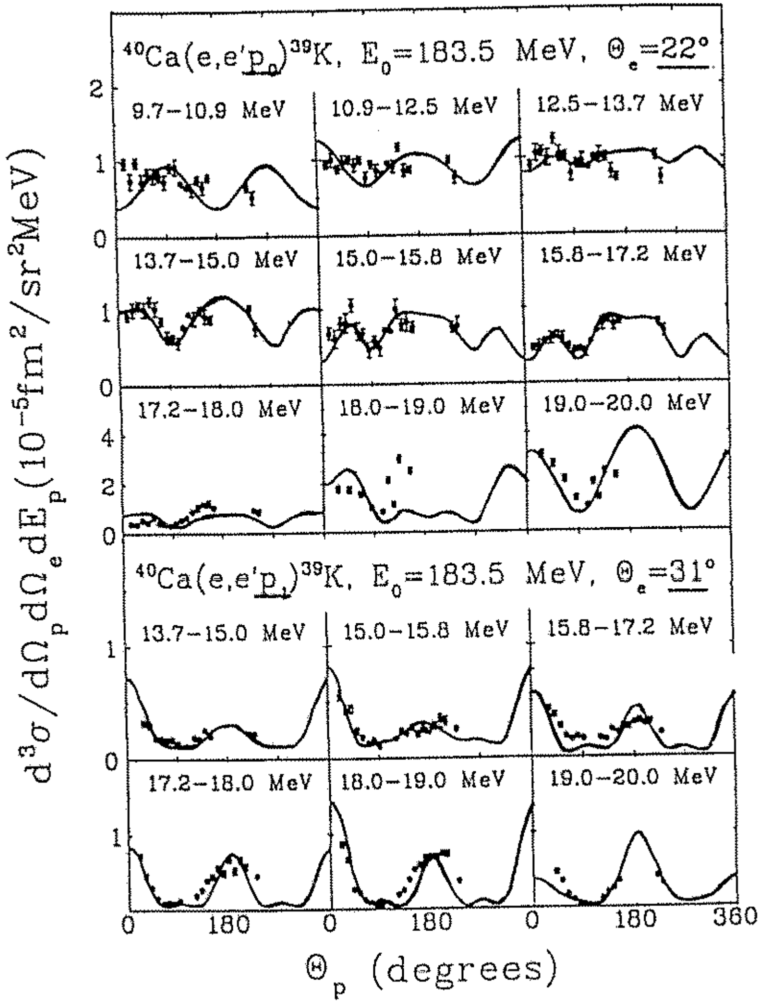


$$W(\Theta_p) = \sum_n a_n \cos^n \Theta_p$$



- Shell-model calculation (Kleppinger)
- selfconsistent RPA-calculation including multistep processes (Ryckebusch)

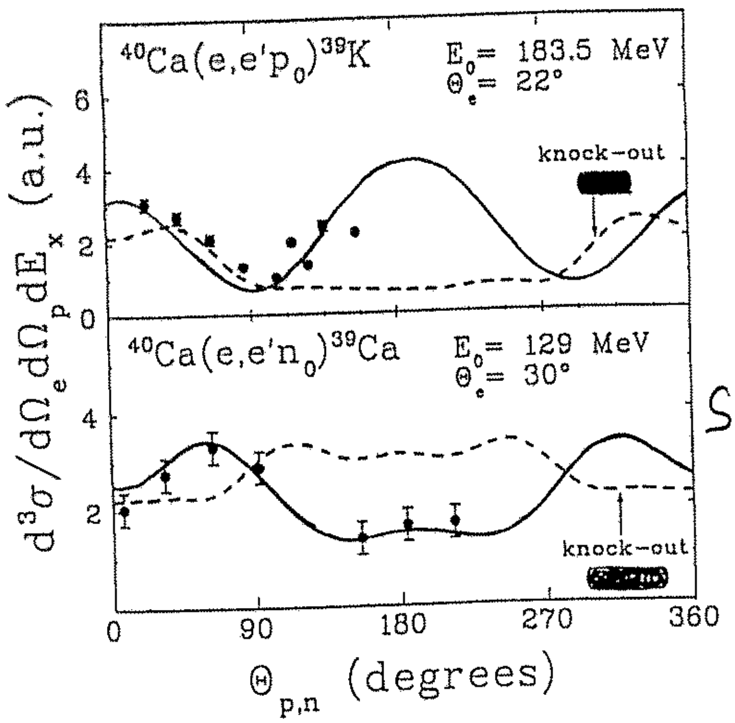
Angular correlation functions: p_0, p_1 channels



- Very encouraging!

Angular correlation functions: p_0 vs. n_0 channel

$E_x = 19 - 20$ MeV



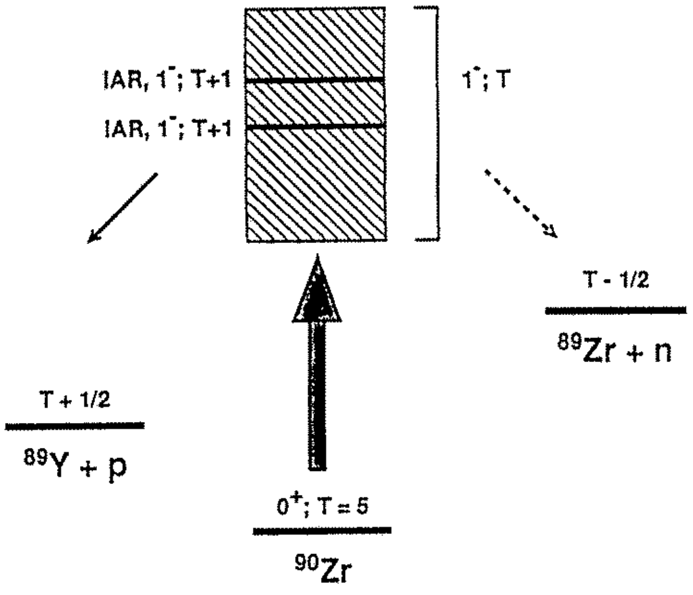
Sendai

knockout + charge exchange rescattering

- (e,e'p_0) + (e,e'n) (n,p_0)

(e,e'n_0) + (e,e'p) (p,n_0)

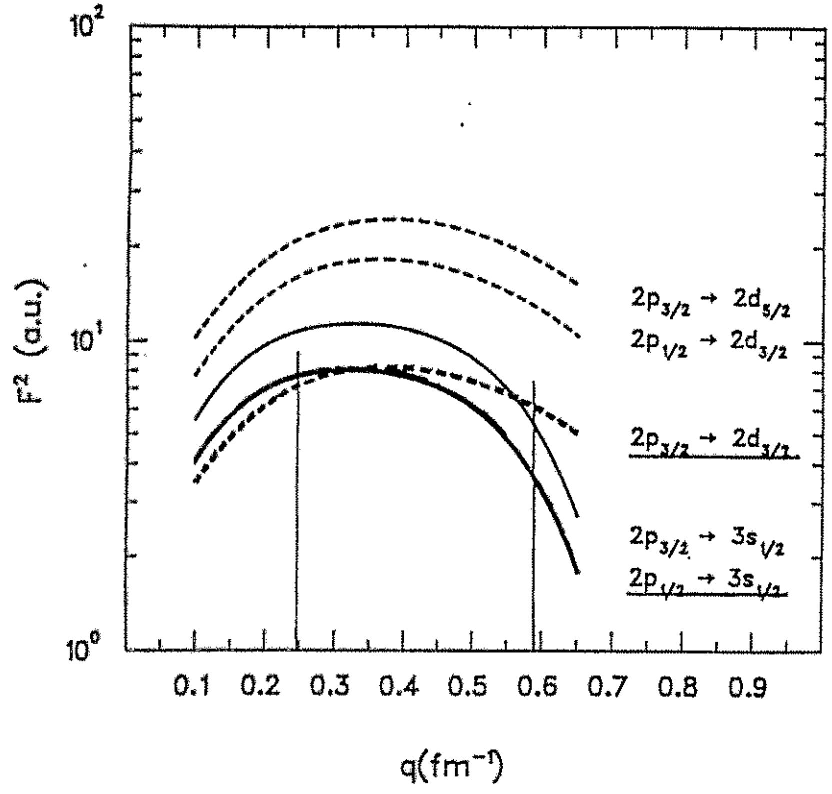
Isobaric Analog Resonances in ^{90}Zr(e,e'p)



- Microscopic particle - hole structure of 1^-, $T = T_{g.s} + 1$ IAR ?

$\rightarrow$ Look at form factors

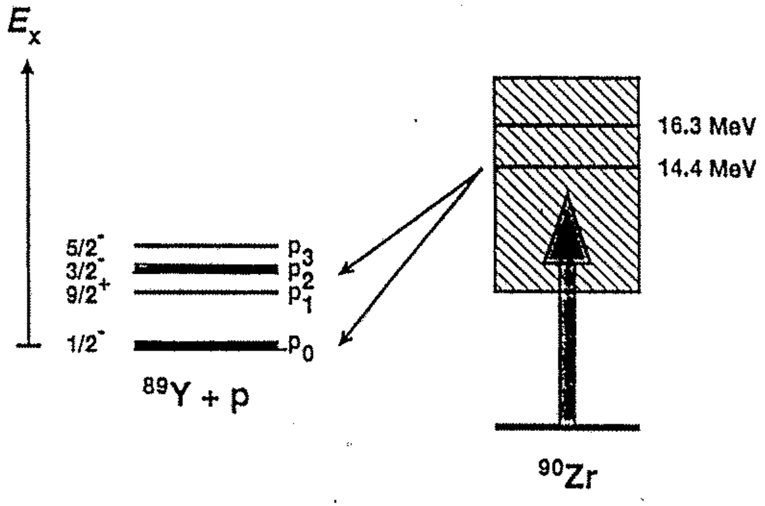
Form Factors for Different p-h Configurations

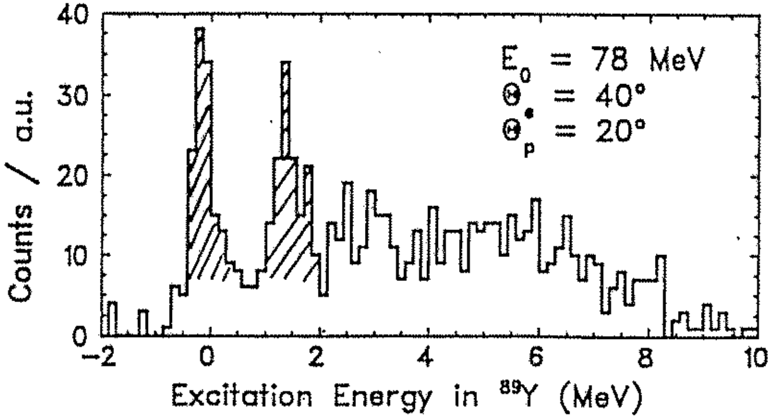


$$q = 0.25\,fm^{-1} \longrightarrow \frac{\sigma(p_{3/2} \to d_{3/2})}{\sigma(p_{1/2} \to s_{1/2})} \approx 0.8$$

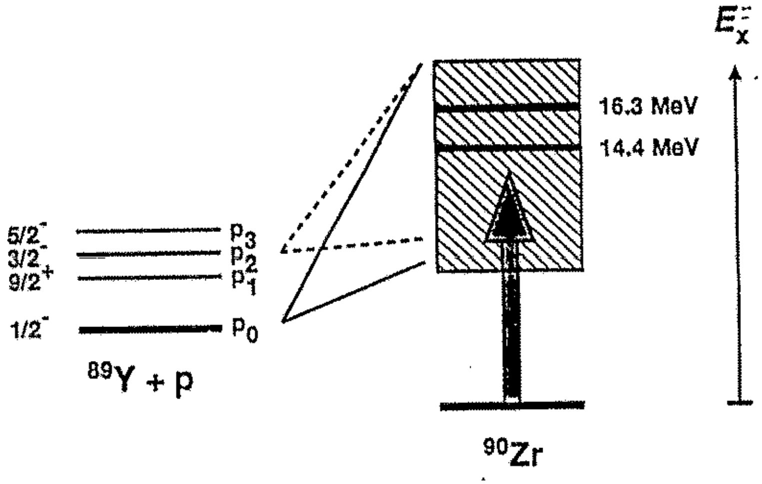
$$q = 0.60\,fm^{-1} \longrightarrow \frac{\sigma(p_{3/2} \to d_{3/2})}{\sigma(p_{1/2} \to s_{1/2})} \approx 1.7$$

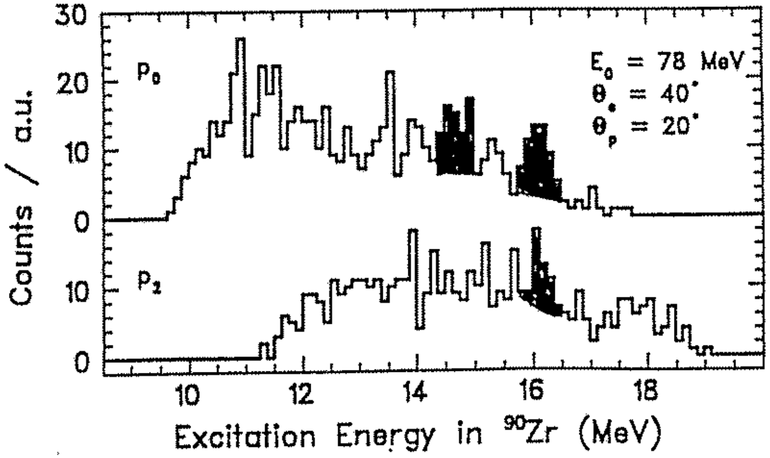
Residual ^{89}Y Spectrum





^{90}Zr Excitation Spectrum for Resolved Final States





Electro-Induced Deuteron Breakup at Low Momentum Transfer

Measured D(e,e'p)n

$E_0 = 50$ MeV $\quad \theta_e = 40°$

≈ 5 MeV above threshold

Separation of structure functions

$$\sigma = \sigma_L + \sigma_T + \sigma_{LT} \cos\phi + \sigma_{TT} \cos 2\phi$$

Measure at $\phi = 0°, 45°, 135°$

① $(\sigma_L + \sigma_T) = \sigma_{45} + \sigma_{135}$

② $\sigma_{LT} = \frac{1}{\sqrt{2}} (\sigma_{45} - \sigma_{135})$

③ $\sigma_{TT} = \sigma_0 - (1 + \frac{1}{\sqrt{2}}) \sigma_{45} - (1 - \frac{1}{\sqrt{2}}) \sigma_{135}$

M1 Response in Nuclei

Structure of the M1 operator

$$T(M1) = \sum_i \{ g_\ell(i)\, \vec{\ell}_i + g_s(i)\, \vec{s}_i \} \mu_N$$

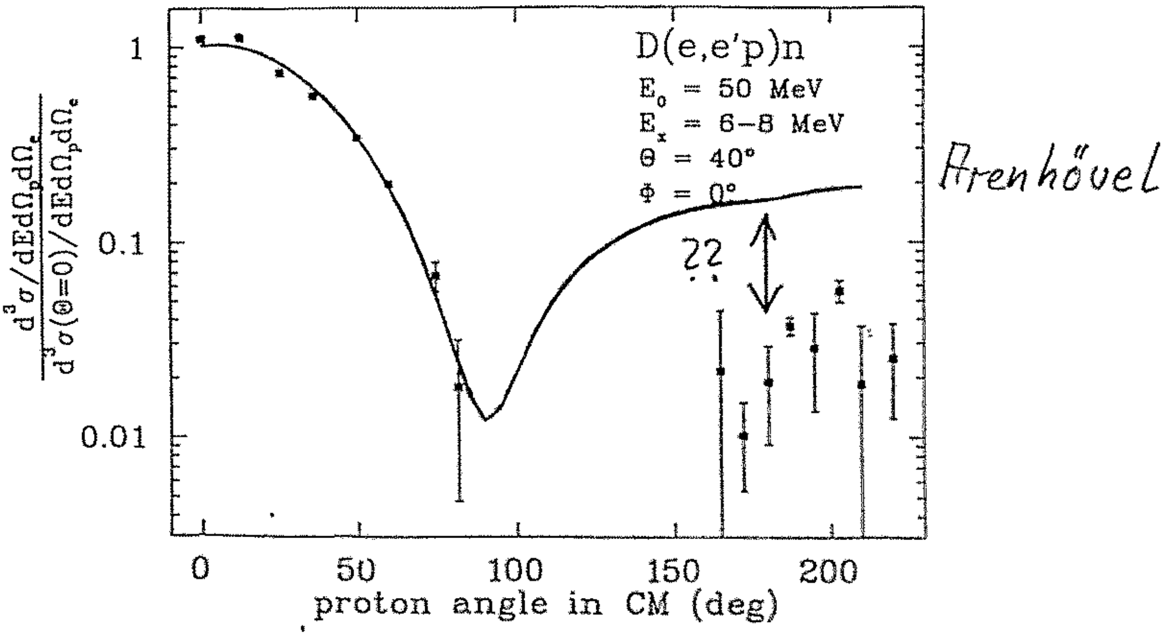
$$\rightarrow T(M1) \approx T(M1)_{IV} + \underset{\uparrow \text{ small}}{\cancel{T(M1)_{IS}}}$$

$$T(M1)_{IV} = \{ \sum_i t_z(i)\, \vec{\ell}_i + (g_p - g_n) \sum_i t_z(i)\, \vec{s}_i \} \mu_N$$

$$= \{ \underset{\uparrow \text{ rotation generator}}{\tfrac{1}{2}(\vec{L}_p - \vec{L}_n)} + \underset{\uparrow \text{ enhanced 'spin-flip' GT}}{4.71\, T(M1)_{\Delta T_z = 0}} \} \mu_N$$

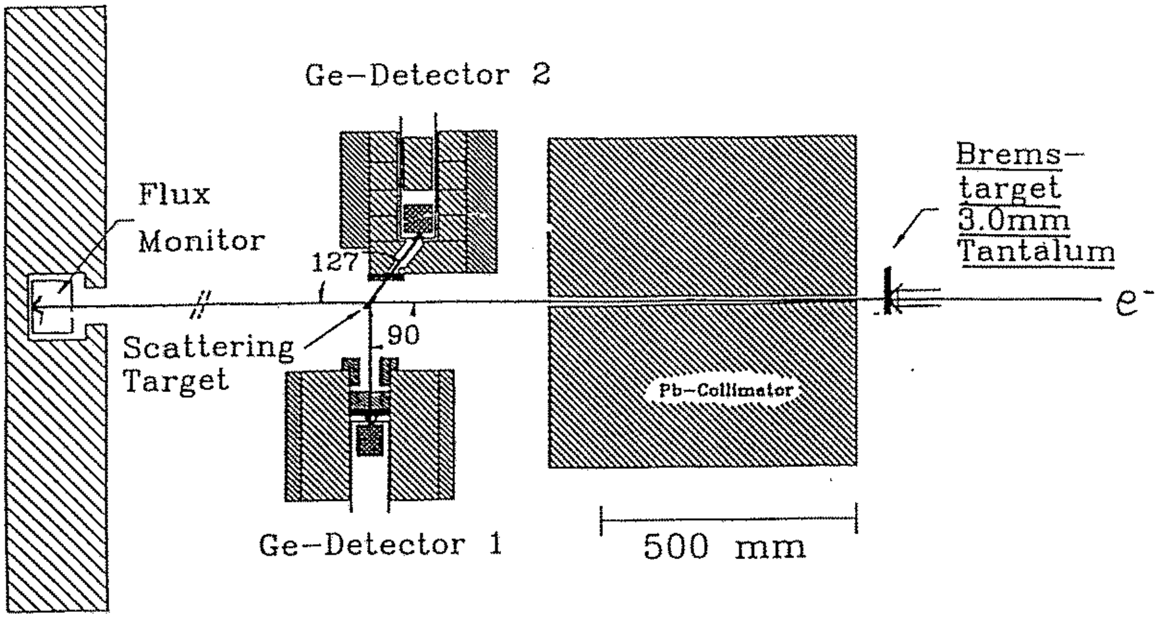
In-Plane Angular Correlation

(preliminary)

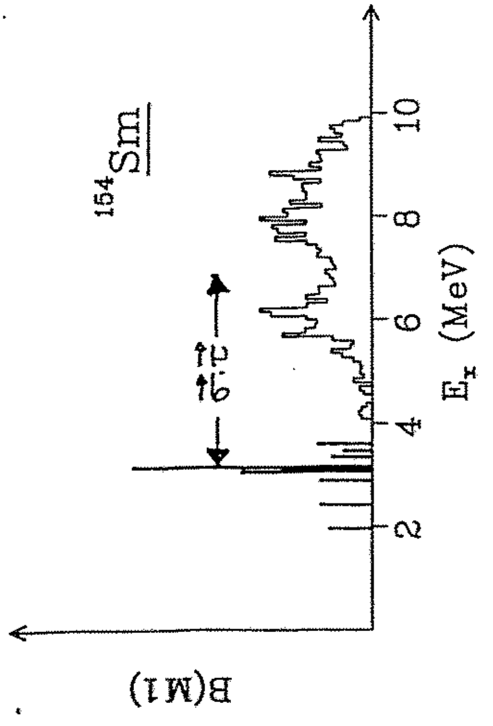


- No correction for p threshold emission, but that cannot explain the discrepancy!

Nuclear Resonance Fluorescence



M1-response in heavy deformed nuclei



$\bar{E}_x \approx 3$ MeV

$\Sigma B(M1) \approx 3\ \mu_N^2$

$B_\ell(M1) : B_\sigma(M1) \approx 10:1$

$\Sigma B(M1) \propto \delta^2$

"scissors mode"

↑

(e,e')
(γ,γ')
(p,p')

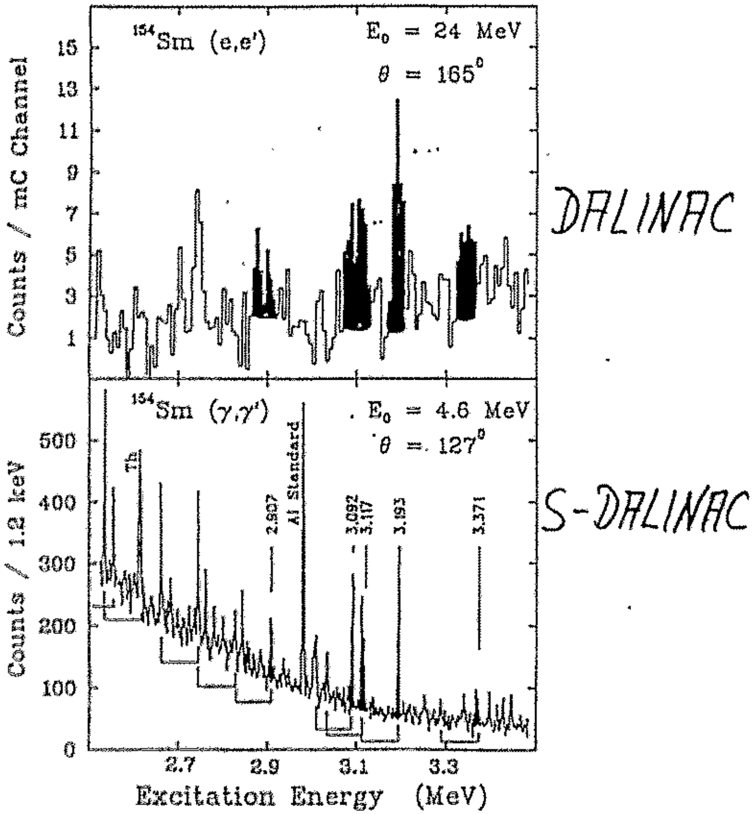
$\Sigma B(M1) \approx 11\ \mu_N^2$

"spin-flip resonance"

↑

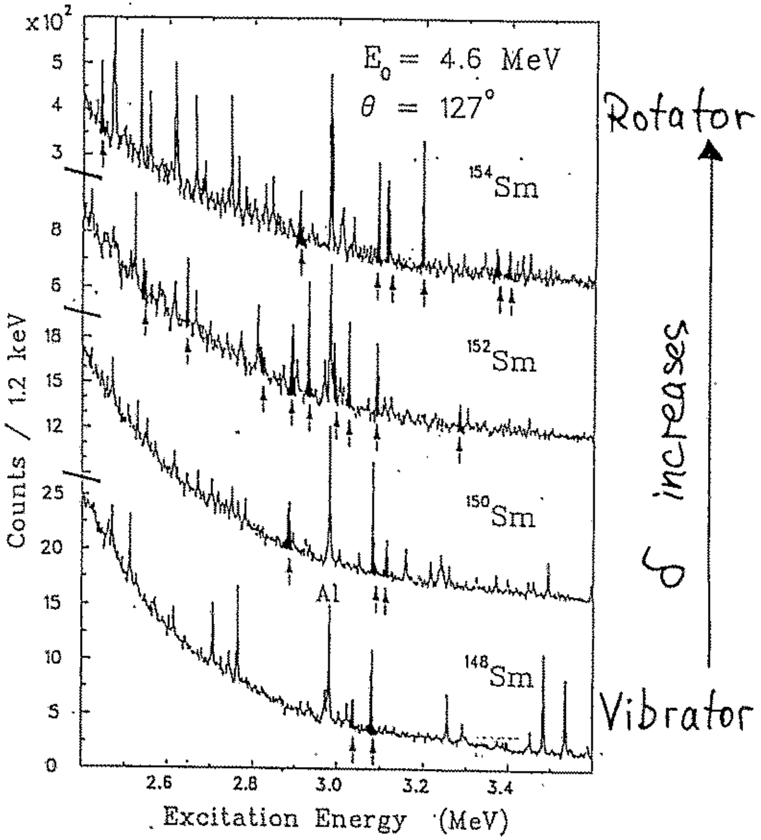
(p,p')

^{154}Sm(e,e') vs. ^{154}Sm(γ,γ')



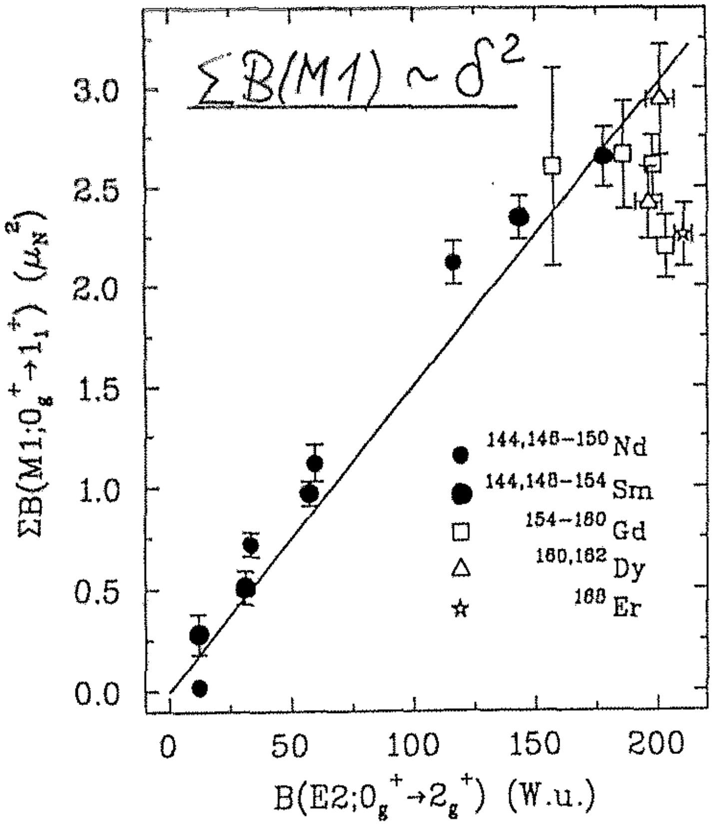
NRF experiments in the Sm isotopic chain

W. Ziegler et al., NPA 564 (1993) 366



- Fragmentation of the "scissors" mode

B(M1) – B(E2) correlation



- Confirmed for Nd-chain (Köln / Stuttgart)
- More or less reproduced by all models

M1 response in even-even nuclei :

spin

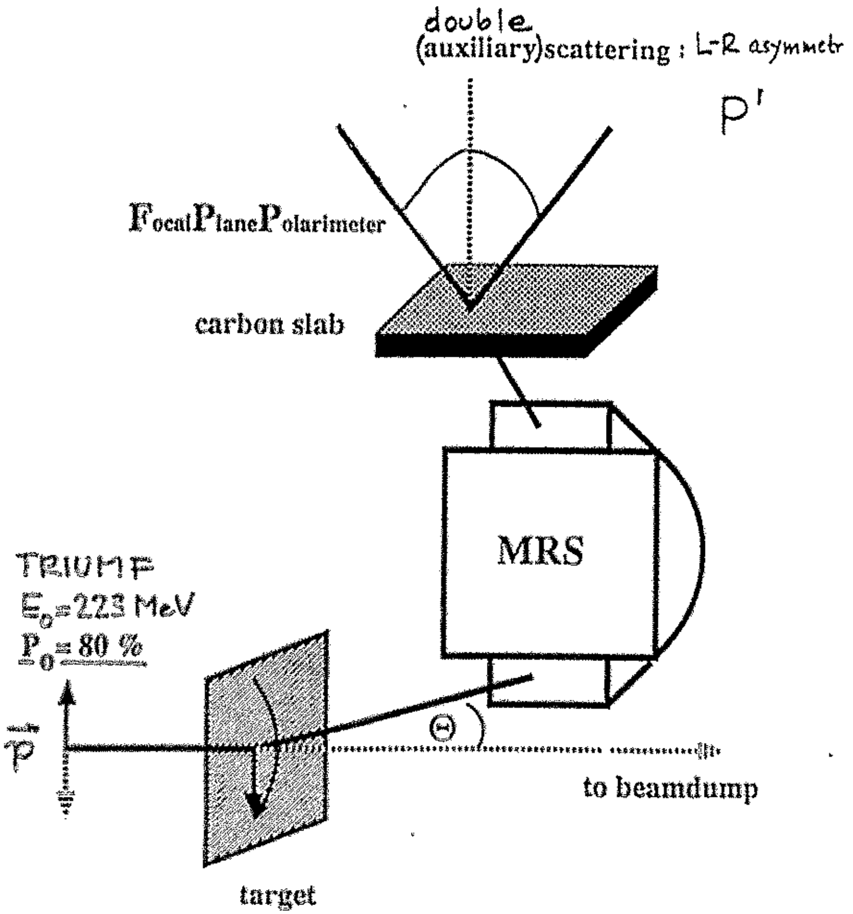
- direct detection of the spin-strength
- existence of a high lying ($E_x \cong 20$ MeV) *"scissors mode"* : $K^\pi = 1^+$ component of the Isovector Giant Quadrupole Resonance

→ $(\vec{p},\vec{p}')$ on ^{154}Sm
$E_0 = 223$ MeV ; $\Theta = 2.4^\circ$-5.9°

$$\frac{d^2\sigma}{d\Omega\, dE} \;;\; \underset{\uparrow}{S_{nn}} \quad \text{für } E_X = 4 - 32 \text{ MeV}$$

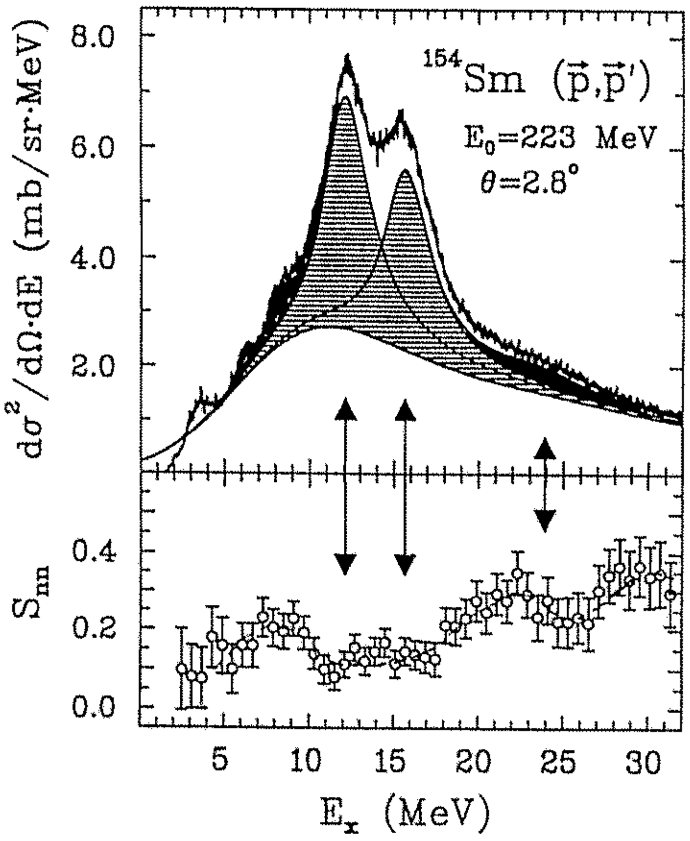
SPIN-FLIP PROBABILITY

Scheme of the FPP / MRS Setup



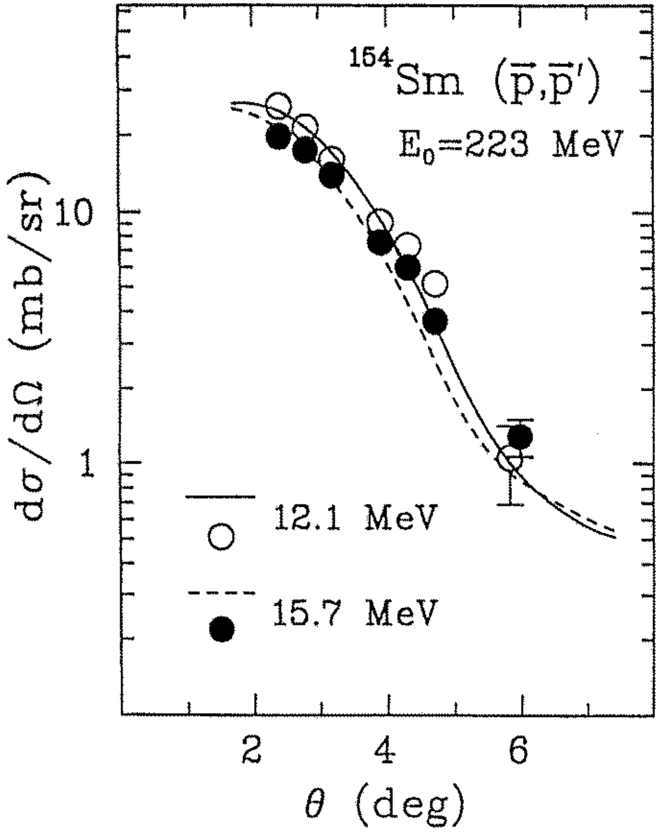
$$D_{nn'} \approx P'/P_0 \longrightarrow -1 \le D_{nn'} \le 1$$ WOLFENSTEIN PARAMETER

$$\longrightarrow \boxed{S_{nn'} = \frac{1}{2}(1 - D_{nn'})}$$ SPIN-FLIP PROB.



- background dominated by quasifree-contributions
- checked by the E1 - cross section

Giant Dipole Resonance

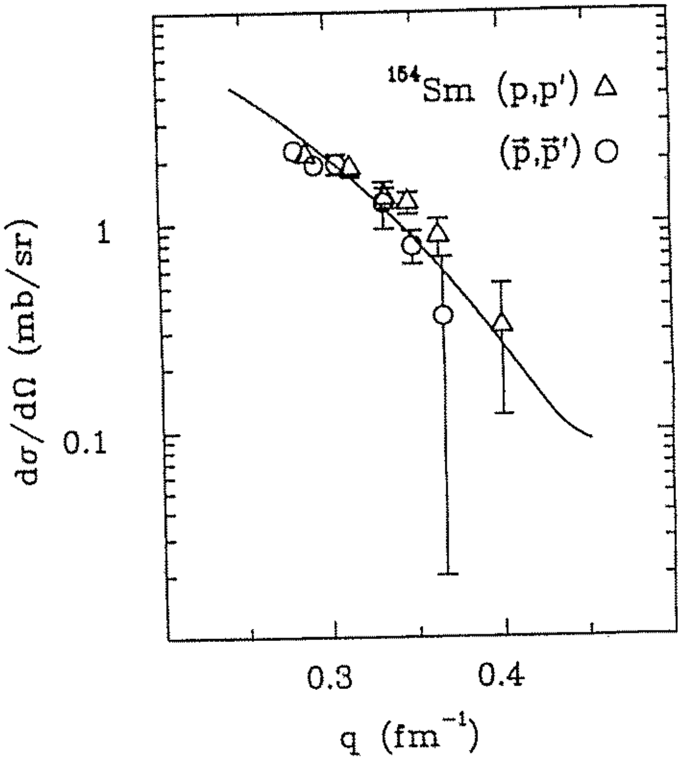


— - - - ΔL=1 DWBA Coulomb excitation cross section

- K=0 (12.2 MeV) : 47±5% EWSR ↔ 52%
- K=1 (15.7 MeV) : 64±6% EWSR ↔ 69%

} (γ,n) ; (γ , 2n)

Spin-Flip Resonance



— $(\nu i_{13/2} \rightarrow \nu i_{11/2})$ DWIA cross section

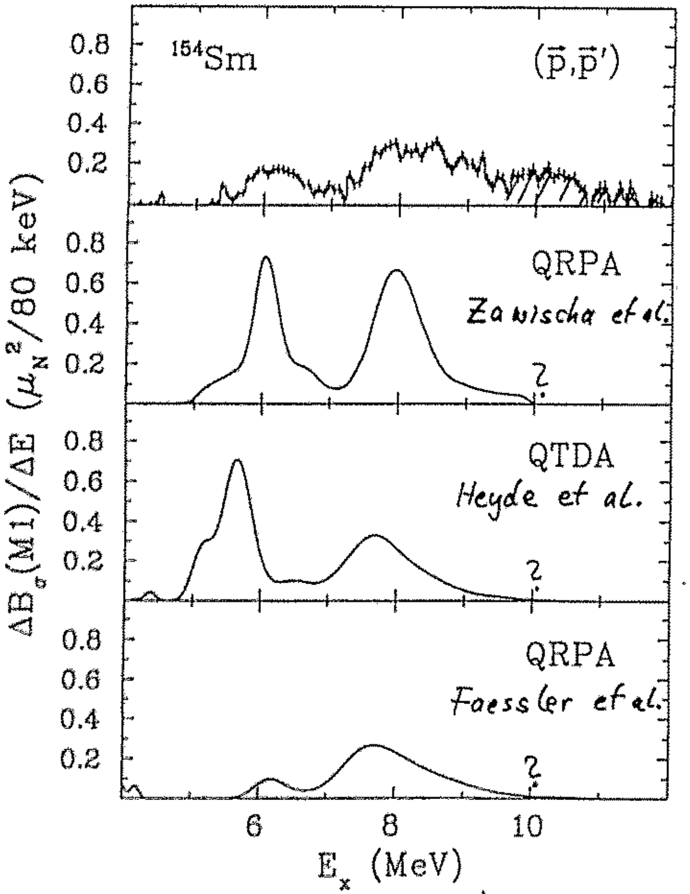
- resulting strength :

(p,p ') : $\boxed{B_\sigma(M1) = 11.0 \pm 2\ \mu_N^2}$

$(\vec{p},\vec{p}\,')$: $\boxed{B_\sigma(M1) = 10.5 \pm 2\ \mu_N^2}$

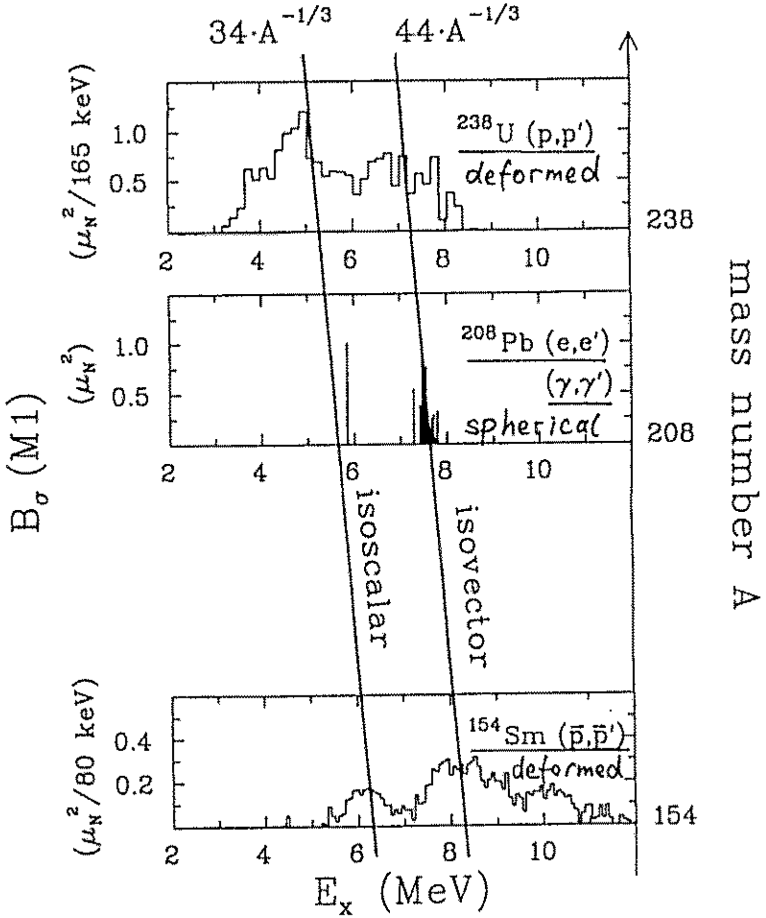
- within the errors independent of the structure of the transition

Comparision:
Experiment – Theories



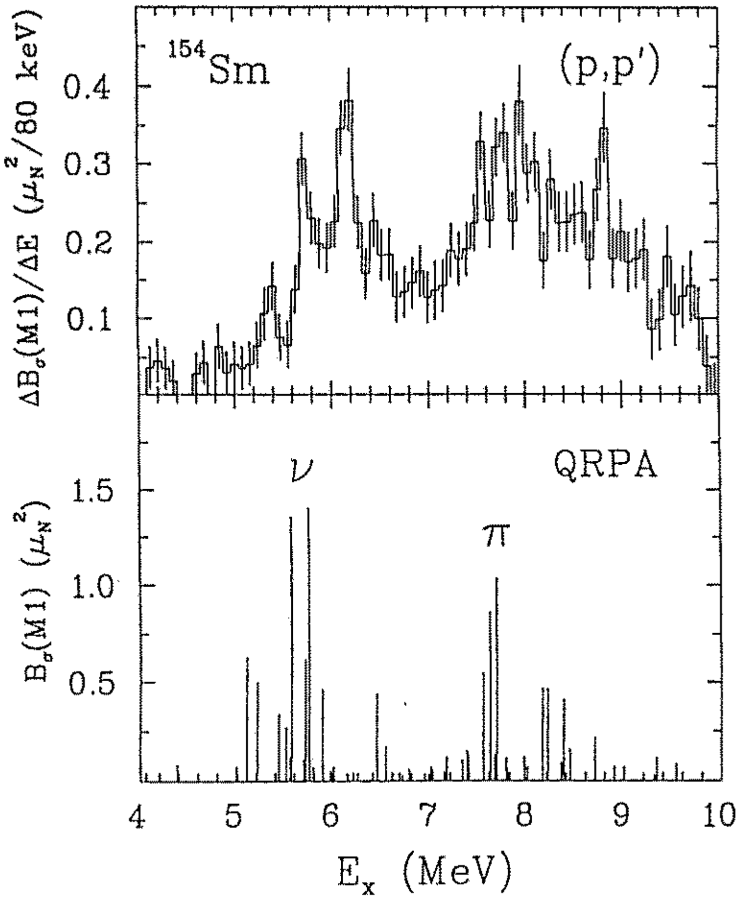
- only qualitative understanding of a most elementary M1 excitation

Mass dependence



- Mixing into underlying 2qp 1^+ States in deformed nuclei

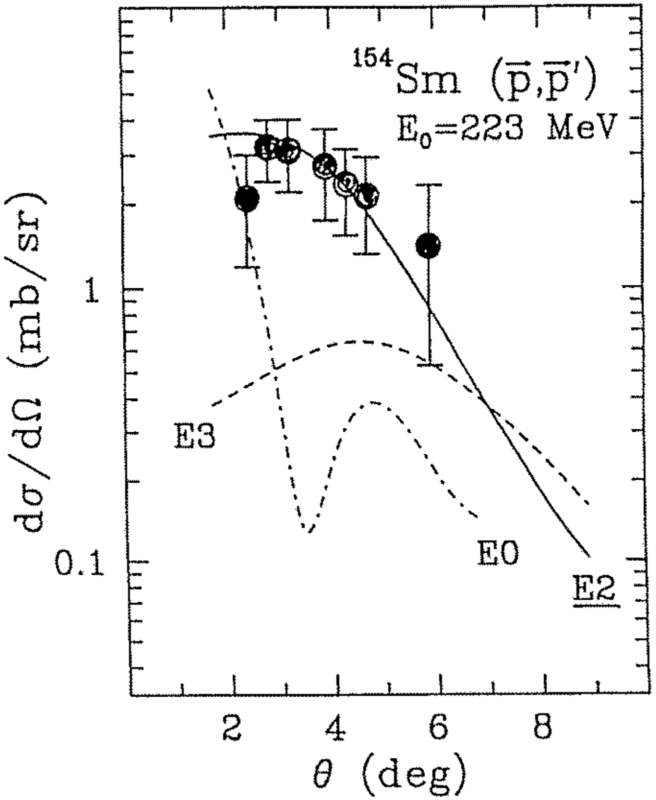
Microscopic picture of spin–flip M1 strength



- IS – IV picture too simple !

→ test with EUROBALL cluster (γ, γ')

Isovector Giant Quadrupole Resonance



— ΔL=2 DWBA Coulomb excitation cross section

- E_x=23.4±0.6 MeV ; Γ=6.8±0.6 MeV
- depletion of the EWSR (E2, ΔT=1) : 76±11%

Sum Rule

Zamick, Zheng, Moya de Guerra (1993)

$$\underbrace{\sum_n E_x B(\mathrm{M1})_{\mathrm{orbital}}}_{7.7 \pm 0.4\ \mathrm{MeV}\ \mu_N^2} = \frac{9\chi}{16\pi}\underbrace{\left[\sum_n B(\mathrm{E2}, \Delta T = 0) - \sum_n B(\mathrm{E2}, \Delta T = 1)\right]}_{9.3 \pm 0.3\ \mathrm{MeV}\ \mu_N^2}$$

$\sum_n E_x B(\mathrm{M1})_{\mathrm{orbital}}$ ↑ (e,e') (γ,γ')

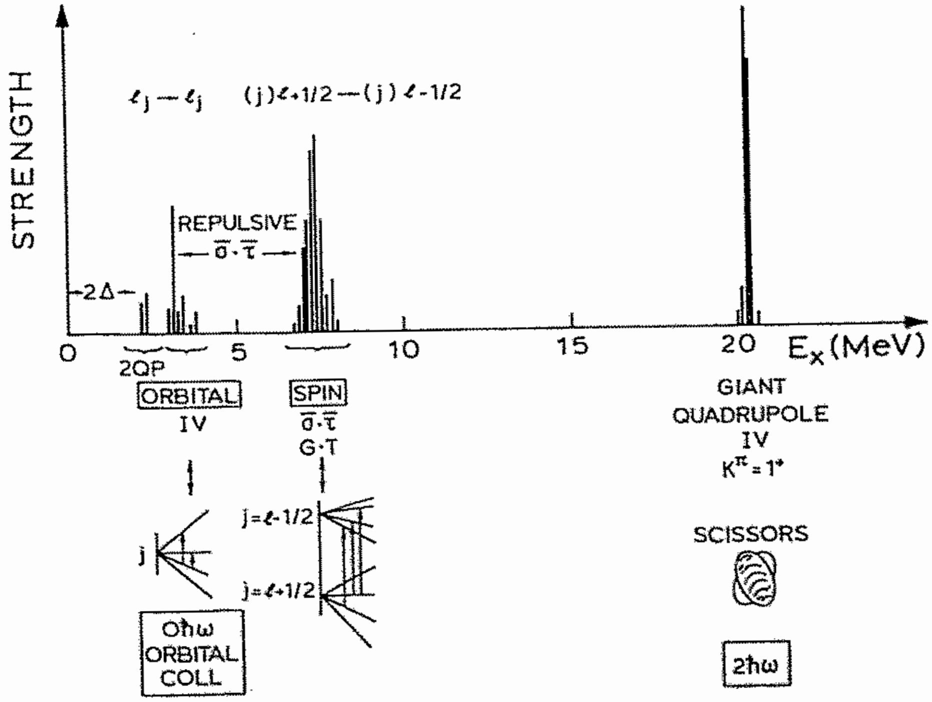
$\sum_n B(\mathrm{E2}, \Delta T = 0)$ ↑ (e,e') (α,α')

$\sum_n B(\mathrm{E2}, \Delta T = 1)$ ↑ (p,p')

83% for $E_x \leq 4$ MeV ⟶ *"low lying scissors mode"* strength in heavy deformed nuclei completely detected!

⟶ first complete picture of the M1-response in heavy deformed nuclei by comparing the results of electromagnetic and hadronic probes.

HEAVY NUCLEI

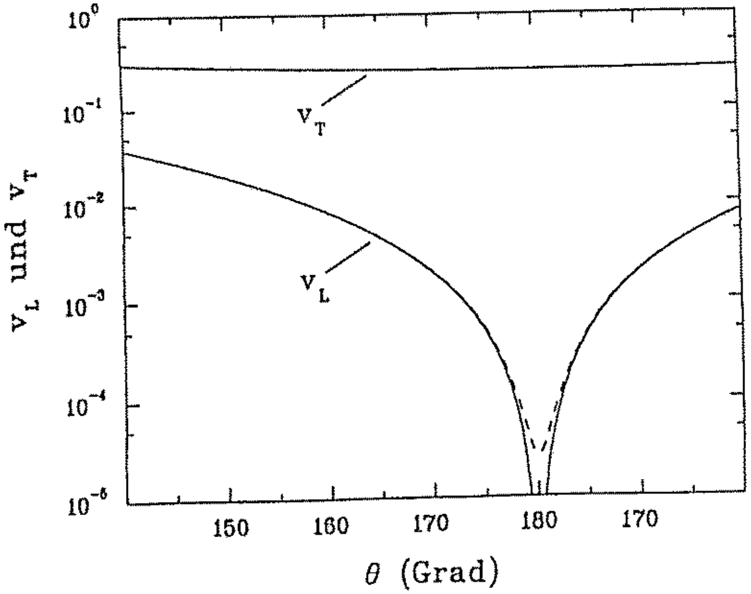


Inelastic Cross Section for Inclusive Electron Scattering

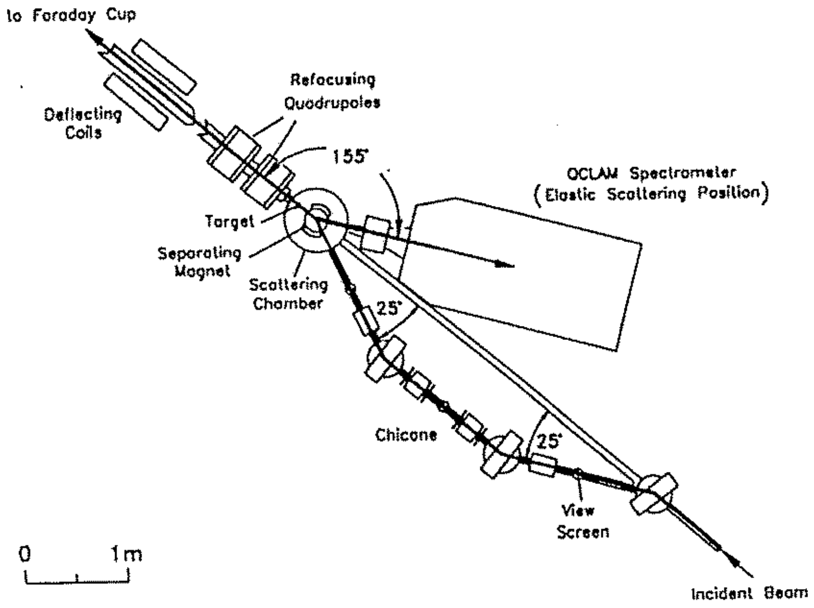
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_{\mathrm{Mott}}}\left[|F_C(q)|^2 + \left(\frac{1}{2} + \tan^2\frac{\Theta}{2}\right)\left(|F_E(q)|^2 + |F_M(q)|^2\right)\right]$$

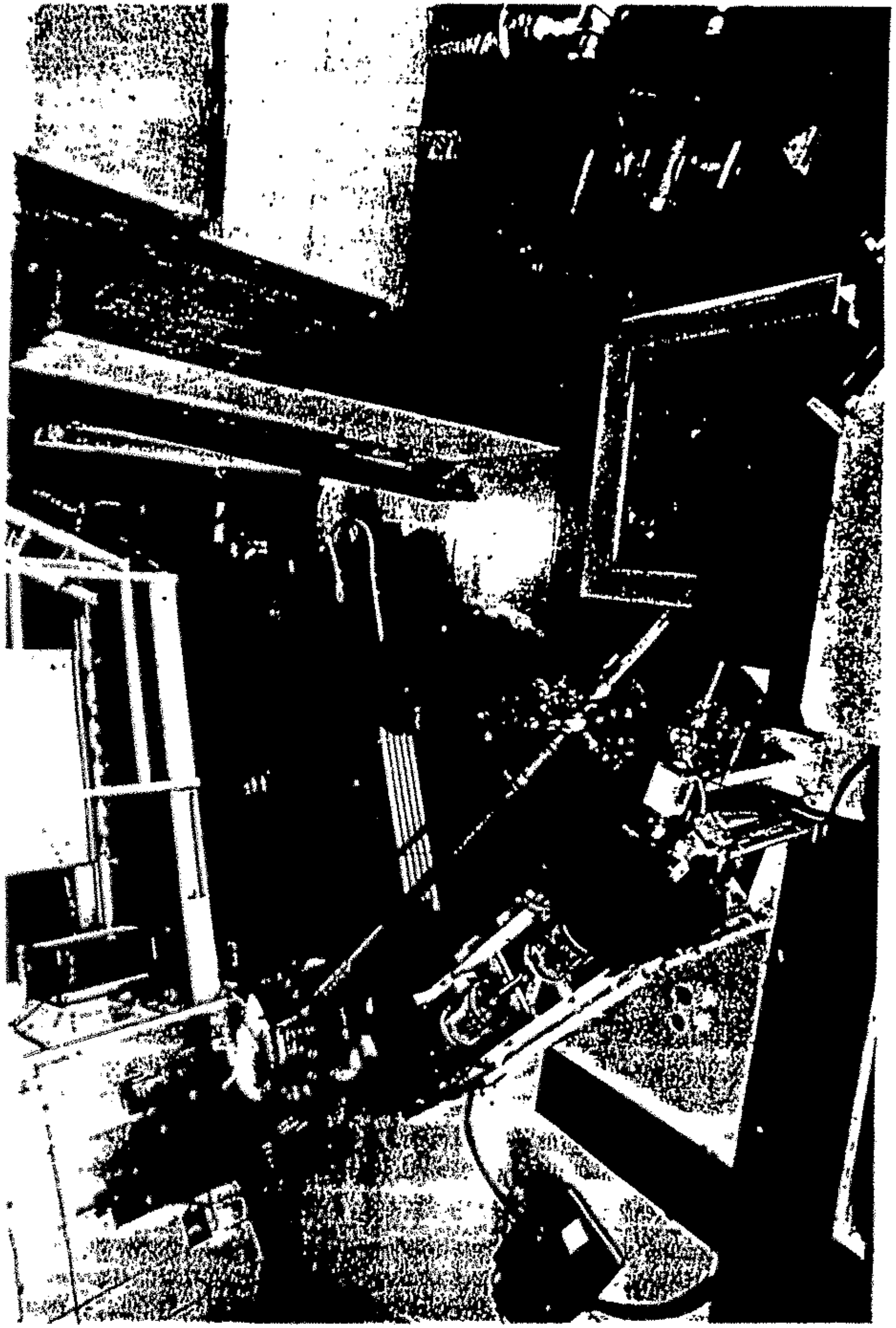
$$\frac{d\sigma}{d\Omega_L} = \left(\frac{Ze^2}{E_0}\right)^2 \frac{\cos^2(\Theta/2)}{4\sin^4(\Theta/2)}\,|F_C(q)|^2$$

$$\frac{d\sigma}{d\Omega_T} = \left(\frac{Ze^2}{E_0}\right)^2 \frac{1+\sin^2(\Theta/2)}{8\sin^4(\Theta/2)}\,\left(|F_E(q)|^2 + |F_M(q)|^2\right)$$



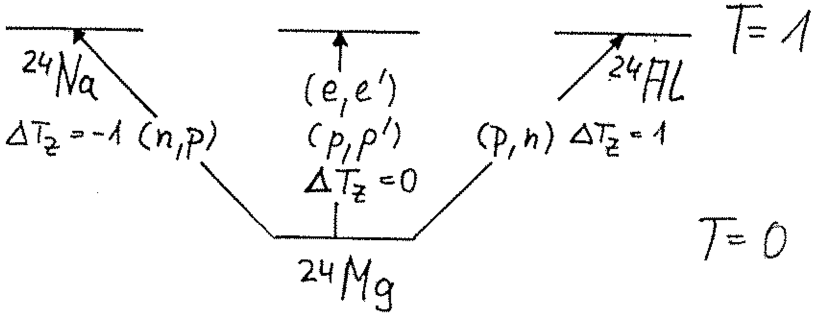
180°-System schematic Layout





Meson Exchange Current Enhancements of Isovector M1 Strength in Complex Nuclei

(A. Richter et al., PRL <u>65</u> (1990) 2519)

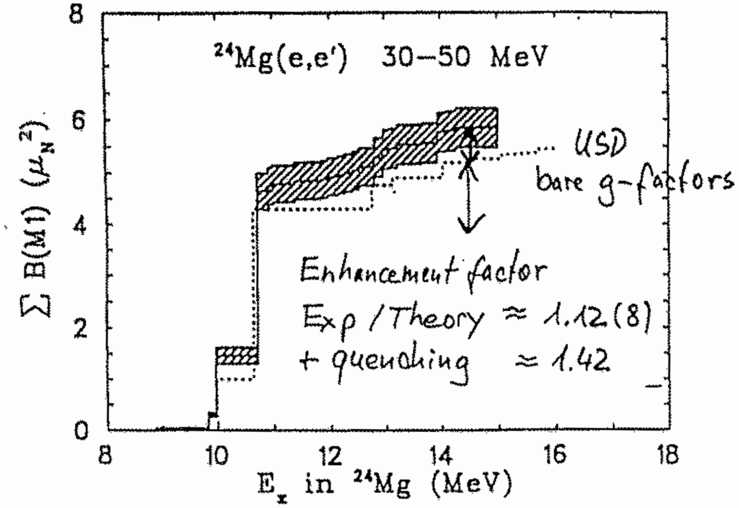


$$(e,e') \rightarrow B(M1) = [M(\sigma) + M(\ell) + M_\Delta + \underset{\substack{\uparrow \\ \text{Large}}}{M_V^{MEC}}]^2 \, \frac{3(\mu_p - \mu_n}{8\pi}$$

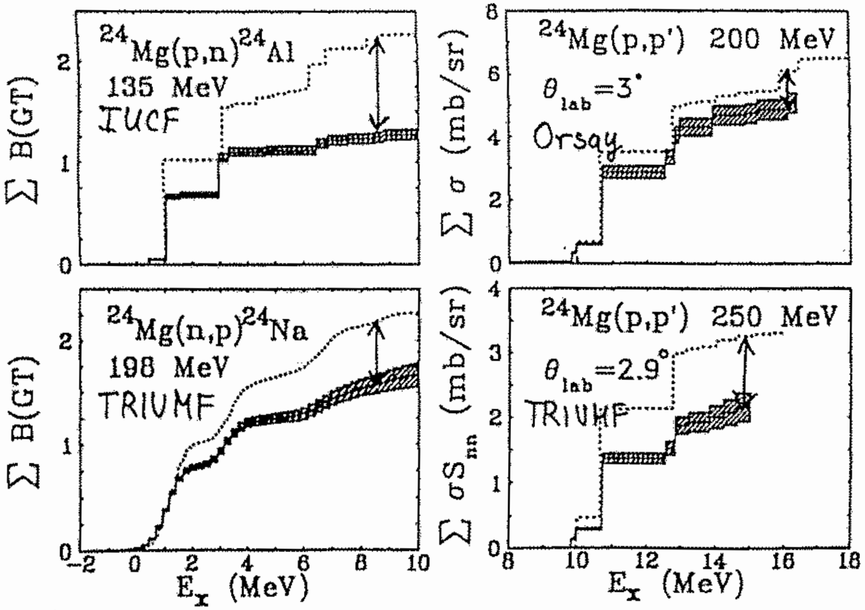
$$\left.\begin{matrix}(p,p')\\(p,n)\\(n,p)\end{matrix}\right\} \rightarrow B(GT) = [M(\sigma) \qquad + M_\Delta + \underset{\substack{\uparrow \\ \text{small}}}{M_A^{MEC}}]^2$$

$$\rightarrow \underline{R(M1/GT) \text{ measures } \underset{\substack{\uparrow \\ \text{predictable in sd-shell}}}{M(\ell)} \text{ and } M_V^{MEC}}$$

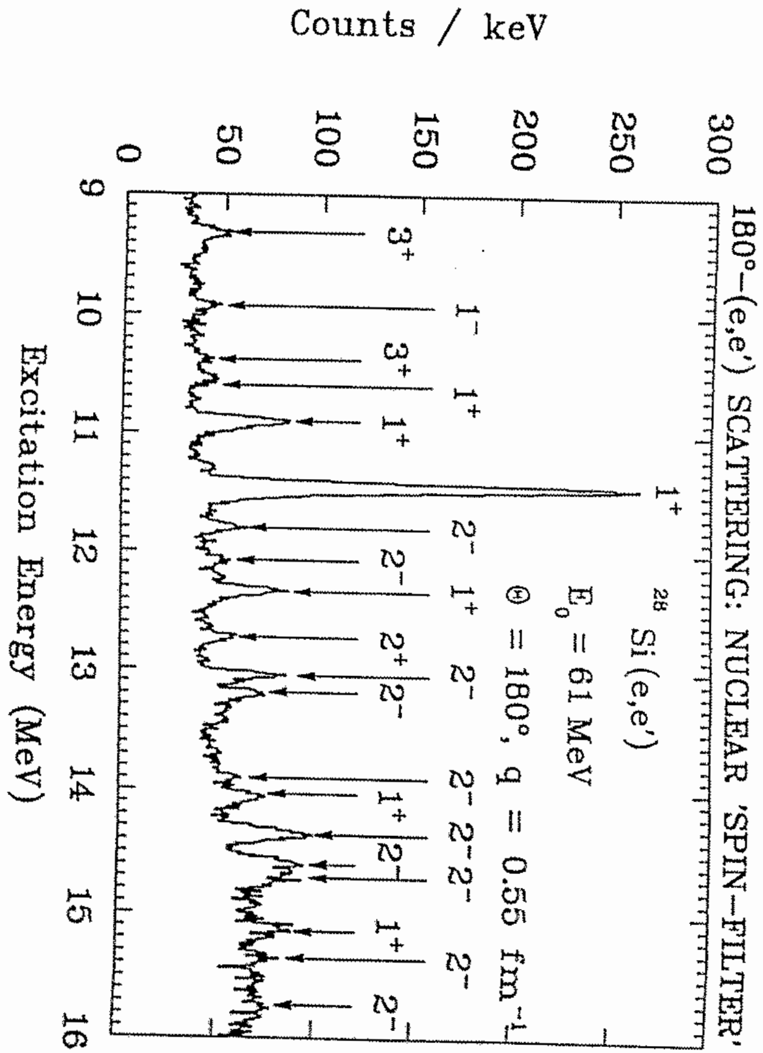
Running Sums of M1 and GT Strength in ^{24}Mg



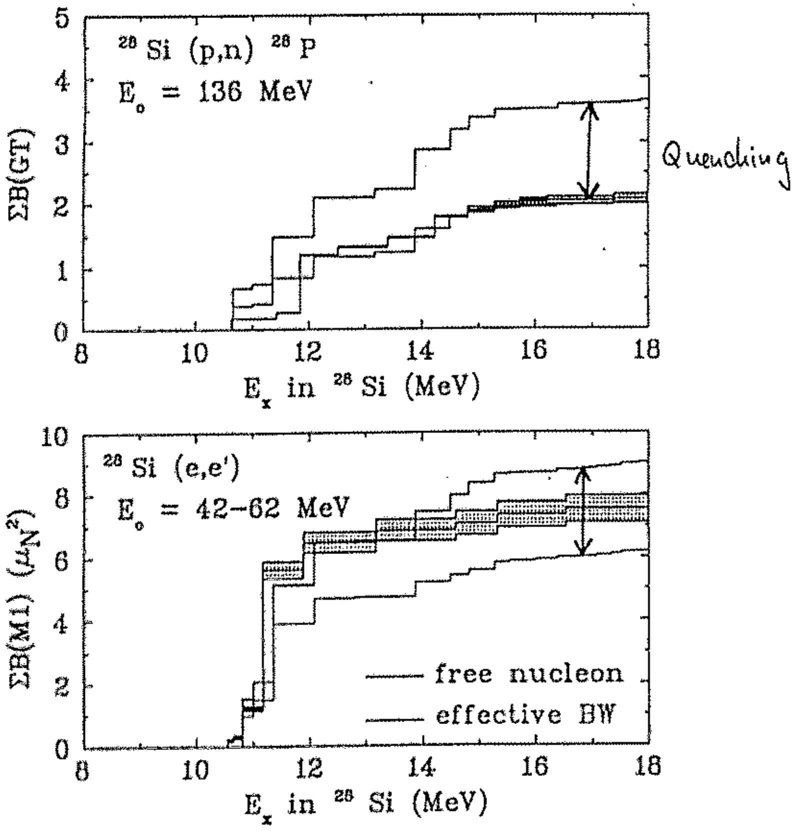
Enhancement factor
Exp / Theory ≈ 1.12(8)
+ quenching ≈ 1.42

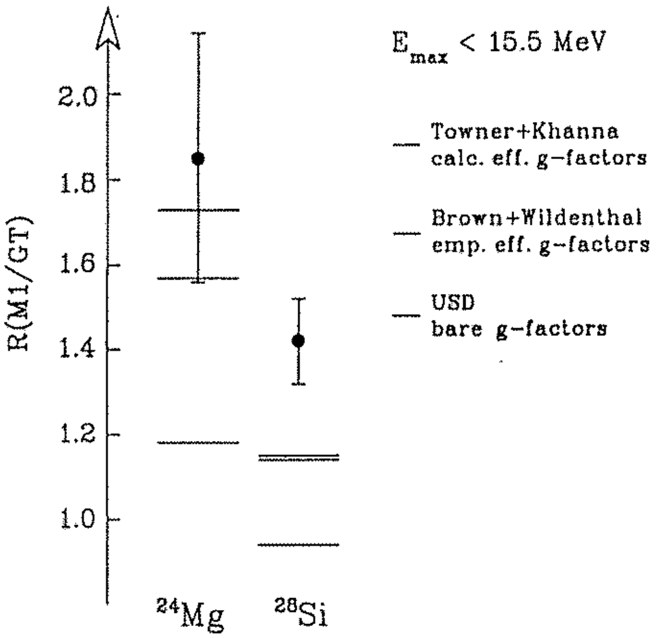


↑ Quenching factor Exp / Theory = 0.72(10)



Running Sums for GT- and M1-Transitions





$$M1_{eff} = g_s S + g_l L + g_s\left[\delta_s S + \delta_l L + \delta_p P\right]$$

$$GT_{eff} = (1+\delta_s)S + \delta_l L + \delta_p P$$

- Enhancement for effective g-factors
- ^{28}Si g.s. correlations ?

Ausblick

- Riesenresonanzen in ^{48}Ca(e,e'x)

- Ladungsradius, elektrische und magnetische Formfaktoren des Deuterons

- (e,x) Reaktionen (Astrophysik)

- Feinstruktur der Spin-Flip M1 Resonanz
  - ^{154}Sm(γ,γ') mit EUROBALL Cluster

- M1, M2, M3 Resonanzen in schweren Kernen

Experimente an e-Beschleunigern

(*Koordinator:* **J. Arends**)

1. **H. Ströher** (Giessen)
   Untersuchung von N* -Resonanzen mit η-Photoproduktion
2. **P. Grabmayr** (Tübingen)
   (γ,NN)- Experimente an leichten Kernen
3. **H. Genz** (Darmstadt)
   Nutzung des S-DALINAC für neuere Entwicklungen in der Strahlungsphysik
4. **H. Jüngst** (Bonn)
   Messung der Reaktionen $\gamma p \rightarrow K^+\Lambda$ und $\gamma p \rightarrow K^+\Sigma^\circ$ von der Schwelle bis 2.0 GeV mit SAPHIR an ELSA
5. **A. Richter** (Mainz)
   Elektropionproduktion H(e, e'π^+) an der Dreispektrometeranlage an MAMI

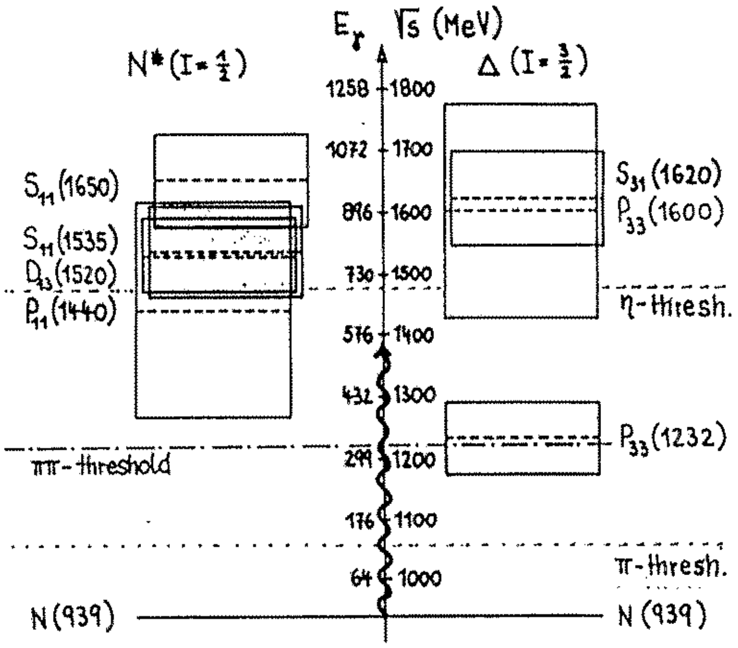
Untersuchung von N*-Resonanzen mit η-Photoproduktion

H. Ströher (für TAPS- und A2-Kollaboration)
Arbeitstreffen Mittelenergiephysik
Pirna, Okt. '94

1) Einführung
2) Experiment
3) Ergebnisse: Proton
   Deuteron
   kompl. Kerne
4) Zusammenfassung, Ausblick

Experimente - 3

- **Motivation:** Studium von Nukleonen-Resonanzen



η-Photoproduktion
Einführung

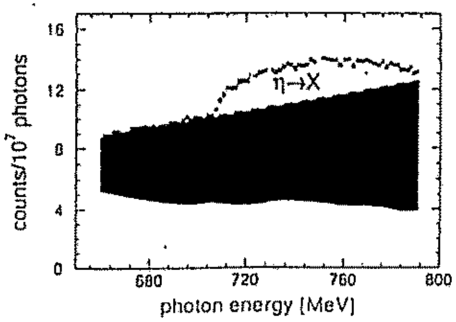
- $\gamma N \rightarrow \eta N$:

$\rightarrow \gamma\gamma$	39%
$\rightarrow 3\pi^0 \rightarrow 6\gamma$	32%
$\rightarrow \pi^+\pi^-\pi^0 \rightarrow 2\gamma \ldots$	29%

a) bekannte Einschußenergie:
MAMI ⊕ 6M-tagger

b) Photonenspektrometer:
TAPS

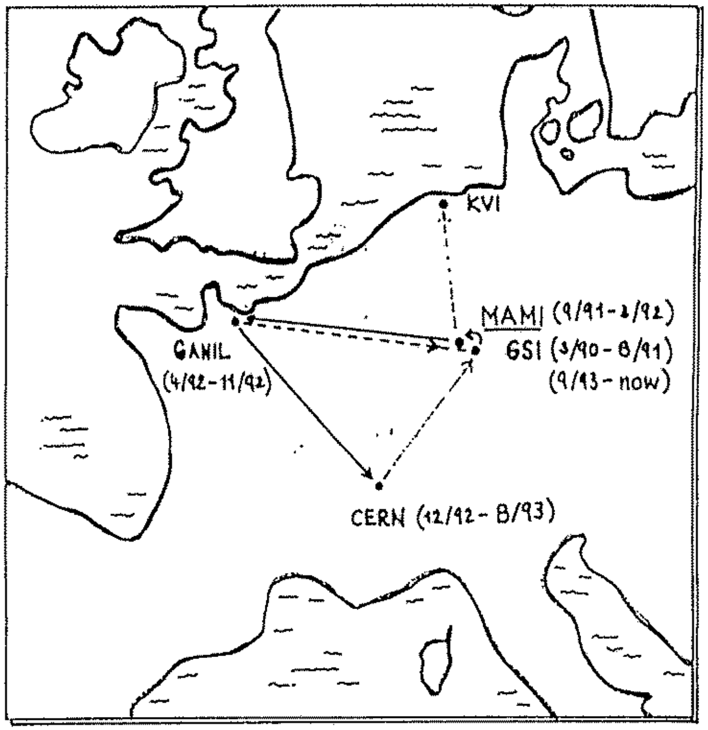
↳ excitation function of 2-γ-events



TAPS

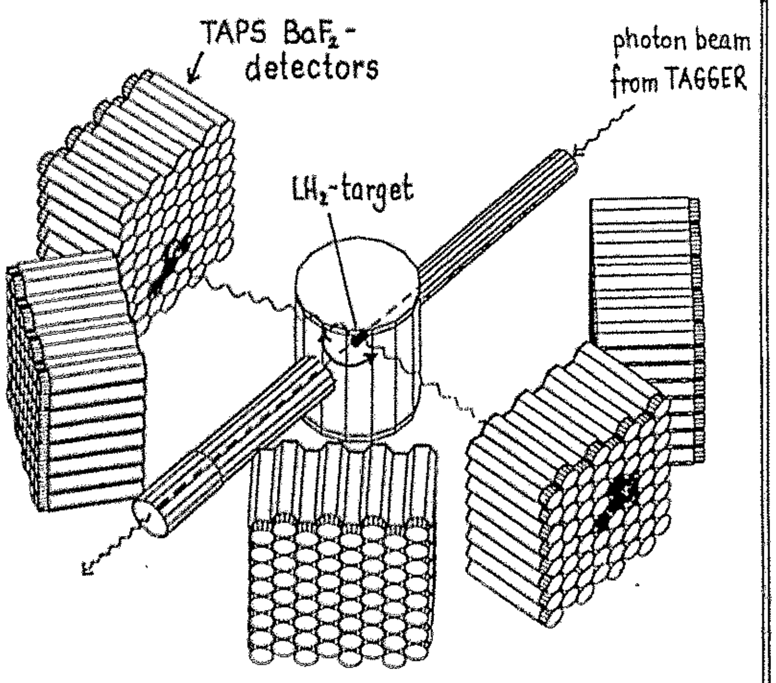
"portable"

↳ "TRAVEL AROUND PHOTON SPECTROMETER"

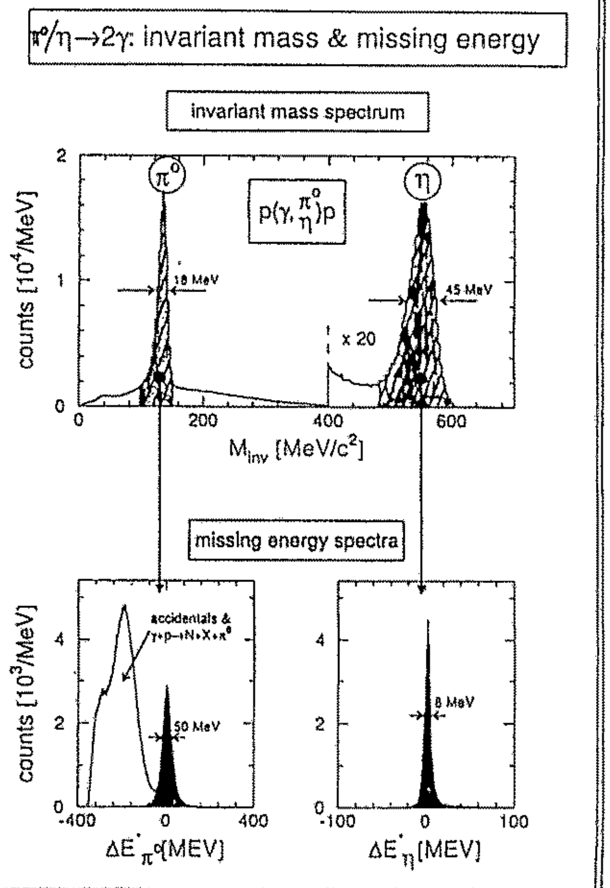


η - Photoproduktion
Experiment

- Nachweis und Spektroskopie der η's :

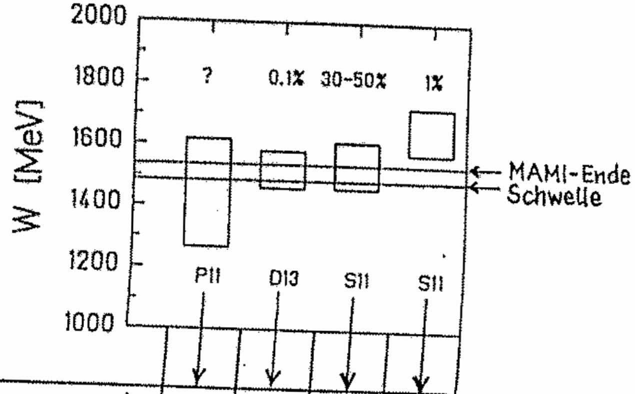


Eta - Photoproduction on Nucleon
Expt'l Results



η - Photoproduktion
Analyse

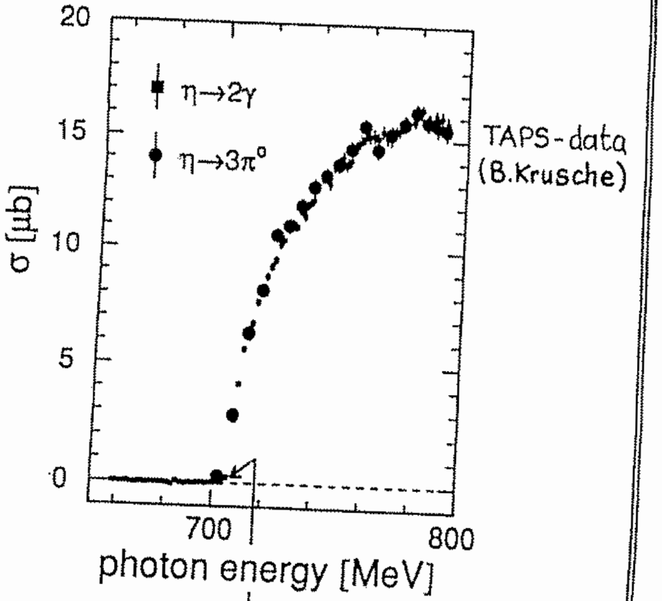
- Welche Resonanzen tragen bei ?



$\sigma \sim (E_\gamma - E^{thr})^{\ell+\frac{1}{2}}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
$\frac{d\sigma}{d\Omega} = A + Bx + Cx^2$ $x = \cos\theta$	A	A, C	A	A

Eta - Photoproduction on Nucleon
Results

- total cross section : $p(\gamma,\eta)p$

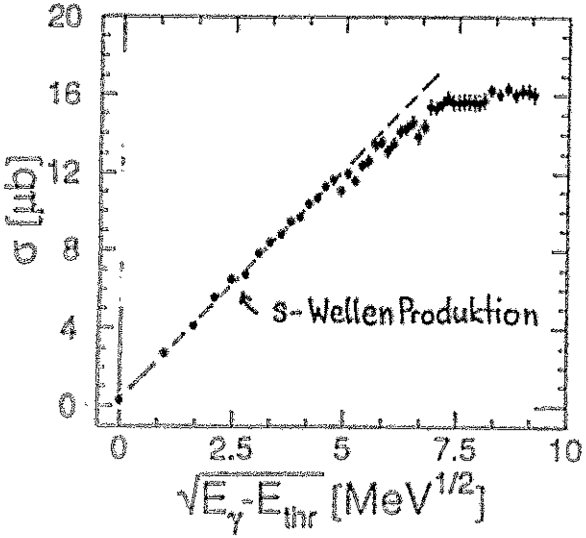


$m_\eta = (547.22 \pm 0.09 \pm 0.25)$ MeV

Experimente -3

- Analyse: Welche Resonanz ?

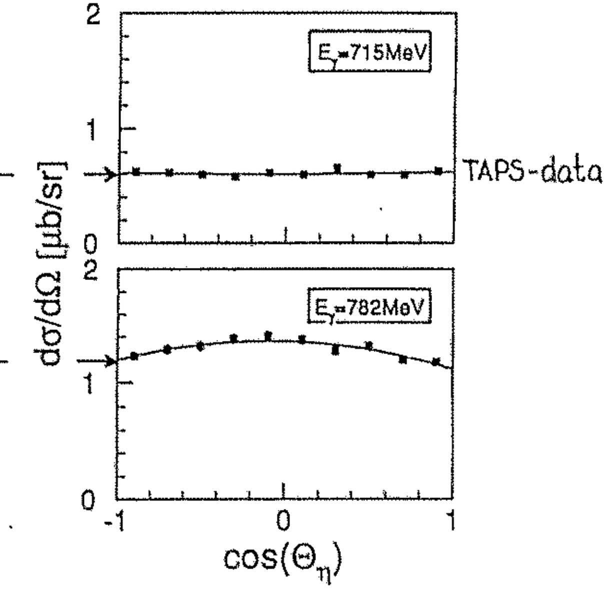
$$\boxed{\sigma \sim (E_\gamma - E_{thr})^{\ell+\frac{1}{2}}} \begin{cases} (E_\gamma - E_{thr})^{1/2} & \ell=0\,;\ S_{11} \\ (E_\gamma - E_{thr})^{3/2} & \ell=1\,;\ P_{11} \\ (E_\gamma - E_{thr})^{5/2} & \ell=2\,;\ D_{13} \end{cases}$$



⇒ $\gamma + p \rightarrow \boxed{S_{11}(1535)} \rightarrow \eta + p$

Eta-Photoproduction on Nucleon Results

- diff. cross sections: $p(\gamma,\eta)p$

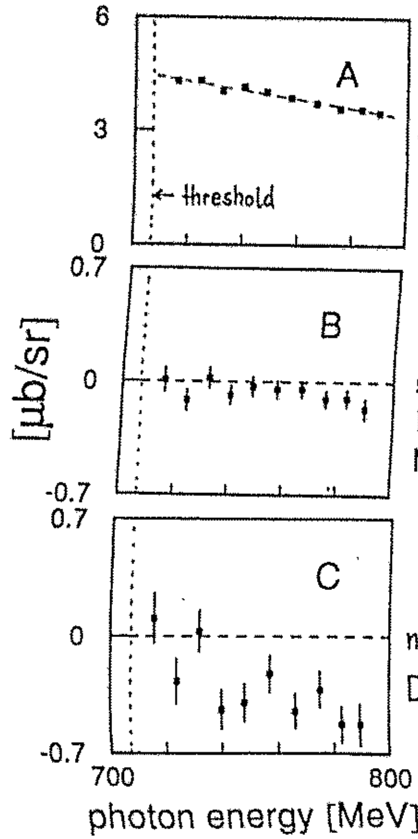


$$\boxed{\frac{k_\gamma}{q_\eta}\frac{d\sigma}{d\Omega} = \underset{\uparrow}{A} + \underset{\uparrow}{B}\cos(\Theta^*_\eta) + \underset{\uparrow}{C}\cos^2(\Theta^*_\eta)}$$

"physics"

Eta - Photoproduction on Nucleon
Results

- angular distribution coefficients:



$A(E_\gamma^{thr}) = |E_{0+}|^2$

$\hookrightarrow \boxed{|E_{0+}|^2 = 4.6 \frac{\mu b}{sr}}$

huge! (S_{11})

small; M_{1-} (P_{11}) or M_{2-}, E_{2-} (D_{13})

negative; D_{13} (N(1520))

η- Photoproduktion
Kerne

- Übergang freies Nukleon → gebundenes N.:

a) quasifreie Produktion:

$$\gamma A \longrightarrow (A-1)N^* \longrightarrow (A-1)N\eta$$

- Bindungsenergie
- Fermibewegung
- Pauli - Blocking $N^* \to N\eta$
- 2 Stufenprozesse $\gamma\pi$ & $\pi\eta$
- zusätzliche Zerfallskanäle $N^*N \to NN$
- Absorption $\eta N \to N^* \to N\pi$

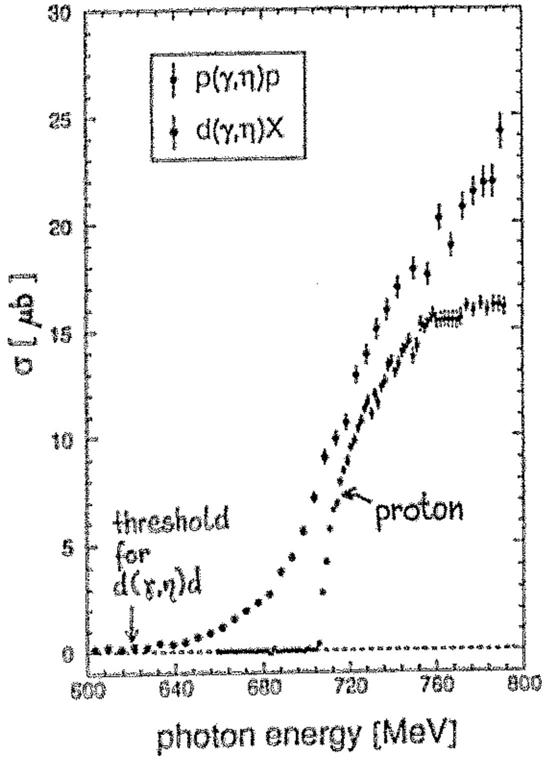
b) kohärente Produktion:

$$\gamma A \longrightarrow A\eta$$

↪ kompliziert !

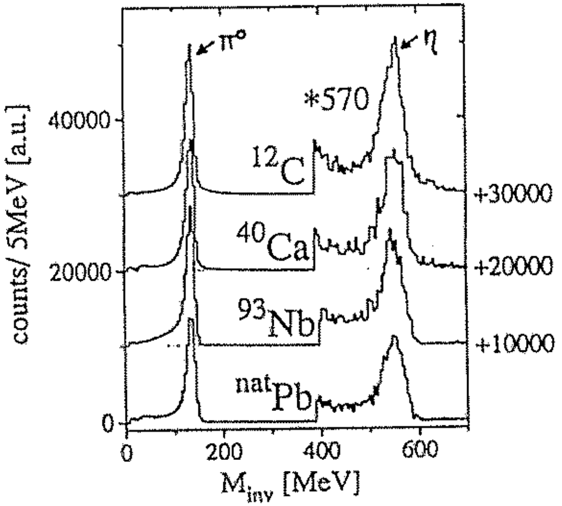
Eta-Photoproduction on Deuterium
Results

- total cross section: $d(\gamma,\eta)X$



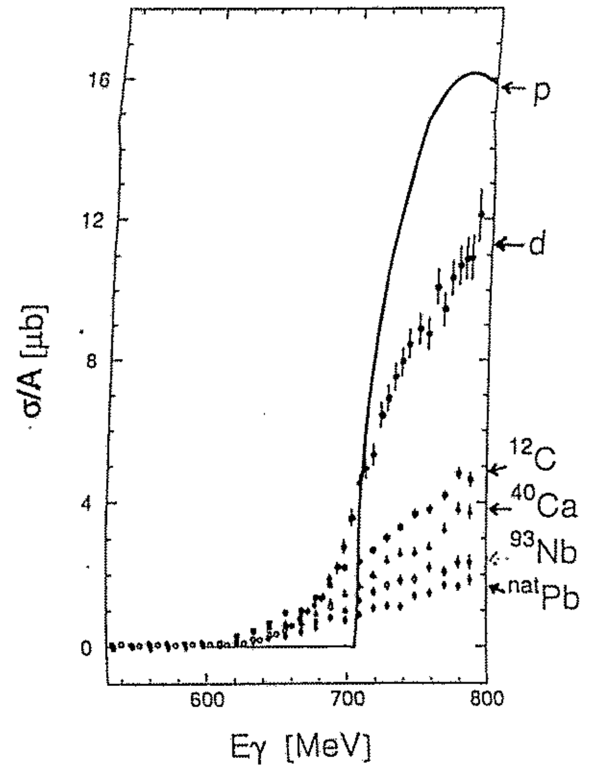
Eta-Photoproduction on Nuclei
Results

- invariant mass spectra:



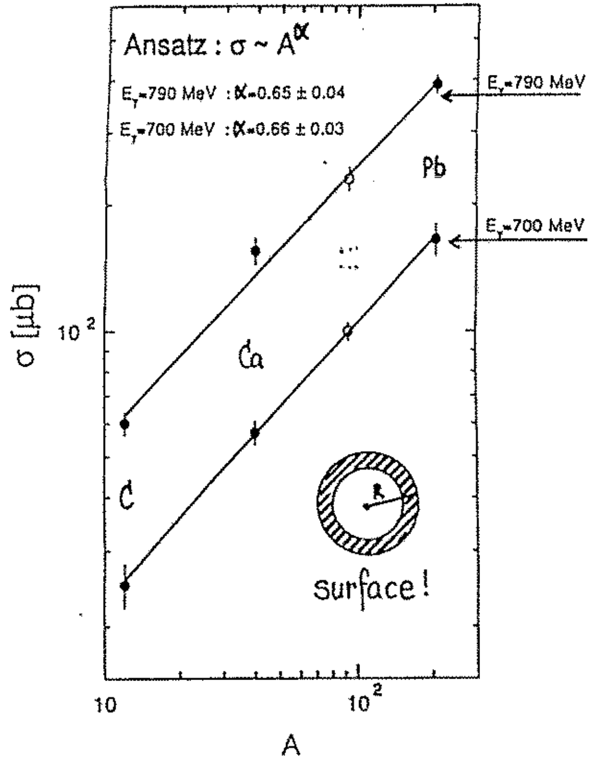
Meson Photoproduction Results

- total cross sections for $A(\gamma,\eta)X$:



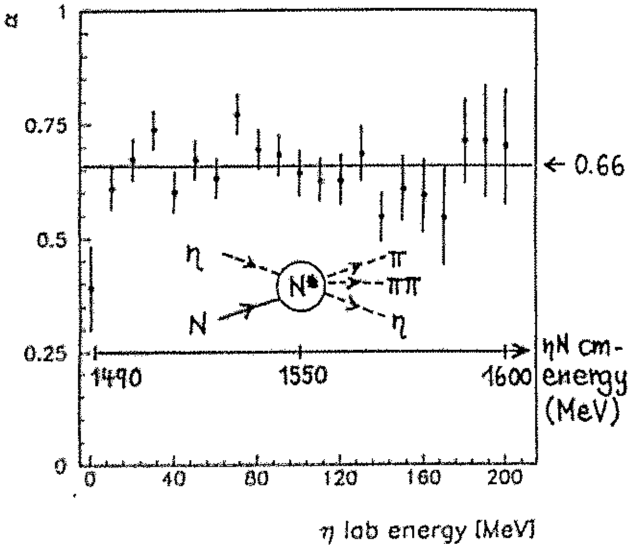
Meson Photoproduction Results

- A-dependence of η-production:



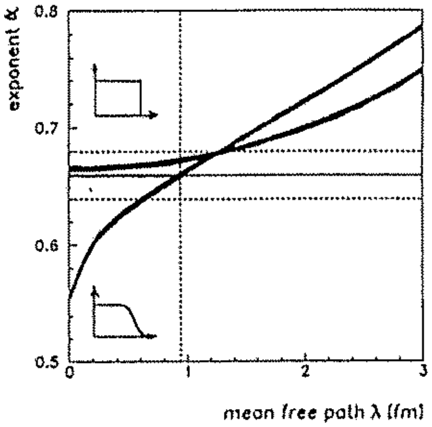
Eta - Photoproduction on Nuclei
Results

- energy dependence : $\sigma \sim A^{\alpha(E)}$



η- Photoproduktion
Analyse

- Mittlere freie Weglänge von η's:

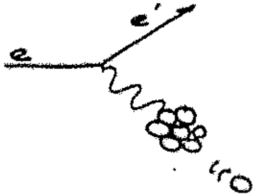


↪ $\boxed{\lambda^{\eta}_{mfp} \simeq 1 \text{ fm}}$

Photoproduction of η's ...
Summary, Outlook

- TAPS-experiments @ MAMI
  ($E_\gamma = E_\gamma^{thr}$ ... 790 MeV)
- nucleon:
  - $S_{11}(1535)$-dominance
  - small contributions from P_{11}, D_{13}
  - η-mass
- deuteron:
  - Fermi motion
- nuclei: (C, Ca, Nb, Pb)
  - absorption
  - surface production
- OUTLOOK:
  TAPS → MAMI in 1995

MOTIVATION

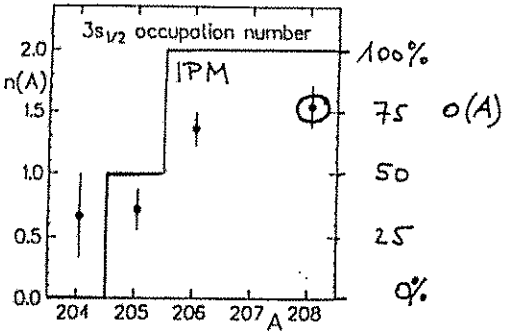


quasifrei $(e,e'p)$
EINTEILCHEN EIGENSCHAFT

CERES - METHODE

Besetzungs wahrsch.
$o(3s) \sim 75\%$

Prog. Part. Nucl. Phys 29 (92) 257
Phys. ReV C49 (94) 2971



- ABWEICHUNG VOM IPM
  ↦ KORRELATIONEN
- BINDUNGSENERGIE VON KERNEN
  [H. Müther et al. Phys. ReV. C49 (94) 633]

  OBEP aus NN Streuung + rel. K.
  + KORRELATIONEN

↦ REAKTIONSMECHANISMEN DER PHOTOABSORPTION

(γ,NN) EXPERIMENTE AN LEICHTEN KERNEN

P. GRABMAYR
UNIVERSITÄT TÜBINGEN

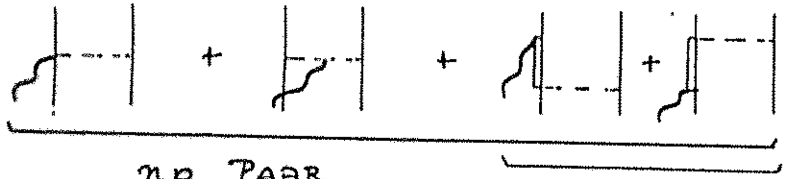
PIRNA, 7. OKT. 1994

VIELTEILCHENSYSTEM ATOMKERN
NN - KORRELATIONEN
PHOTOABSORPTION (MECHANISMEN)
(γ,NN) EXP. AN MAMI

PHOTOABSORPTION

QUASIDEUTERON PROZESS

2N - ABS.



np PAAR

nn, pp PAAR

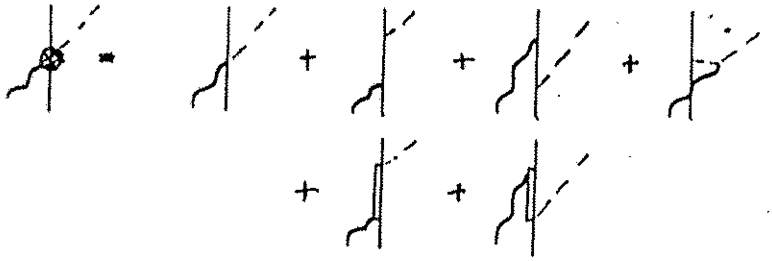
?KORRELATIONEN?

$$\frac{\sigma_{pp}}{\sigma_{np}} \approx \begin{cases} 0.05 & @\ E_\gamma \sim 100\,\mathrm{MeV} \\ 0.20 & @\ E_\gamma \sim 400\,\mathrm{MeV} \end{cases}$$

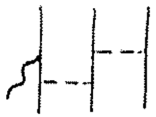
(GIUSTI, RYCKEBUSCH)

AUSSERDEM

1N - ABS:



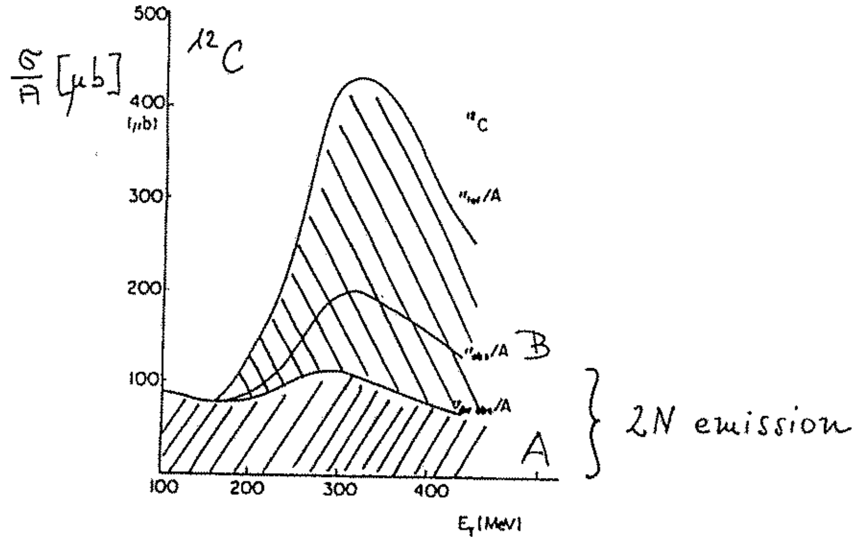
3N - ABS



(CARRASCO, OSET)

TOTAL CROSS SECTION

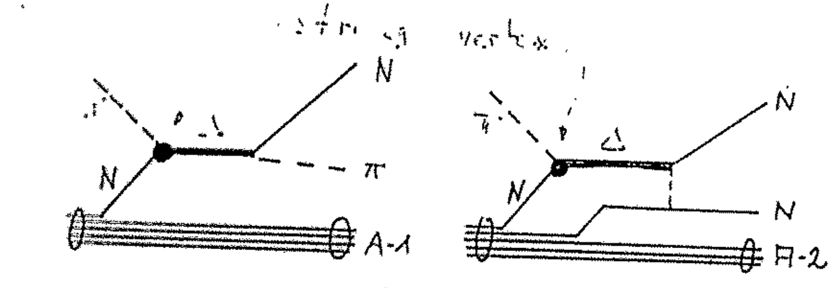
CARRASCO & OSET NPA536(92)445



A: genuine 2body absorption

B: quasifree π production (1body)

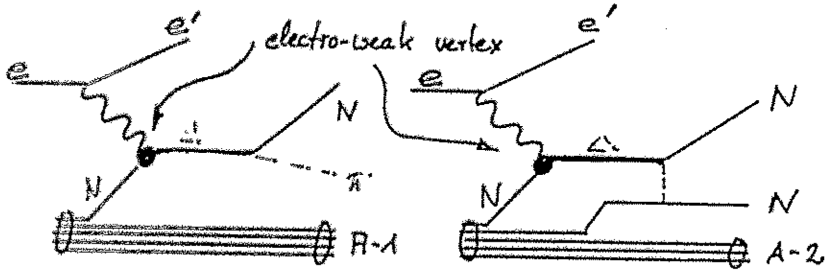
a) with π's:



↳ 3 particle final state ↲

---

b) with γ's & γ*'s:



↳ 4 particle final state ↲

(π,2N) much easier than (γ,2N) [illegible]

2 fold vs. 3 fold coinc.

strong vs. el-weak vertex

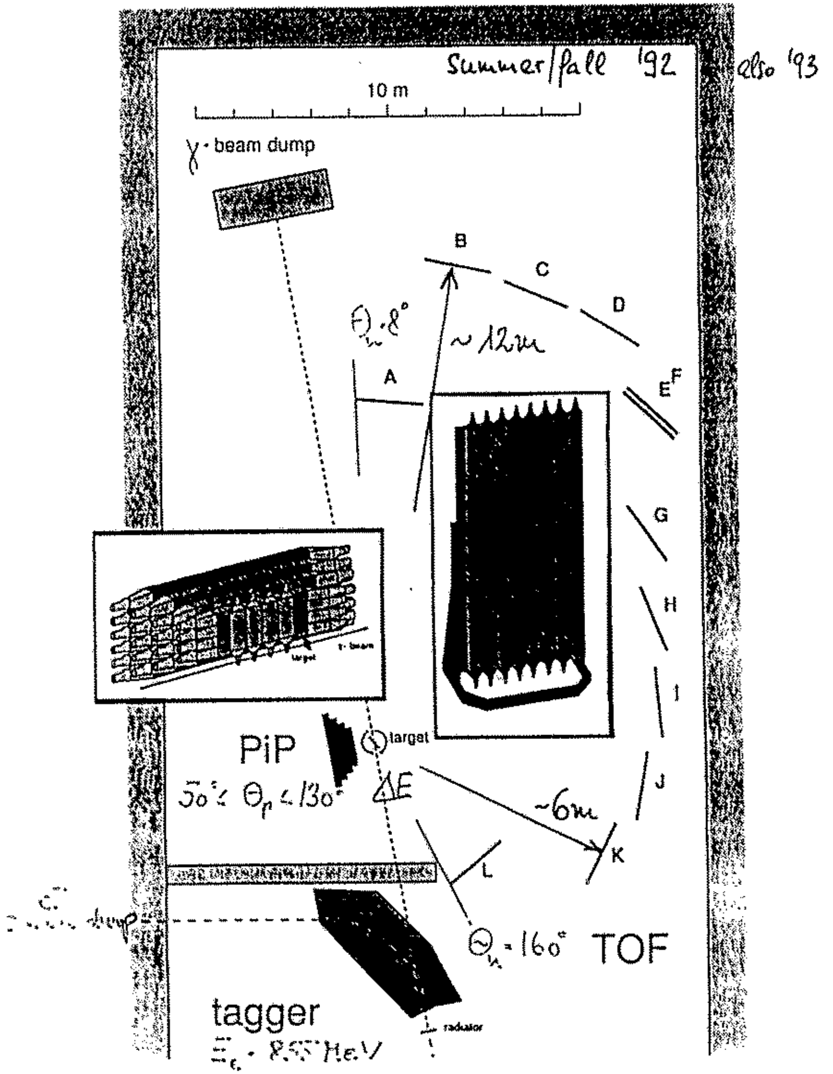
[illegible]

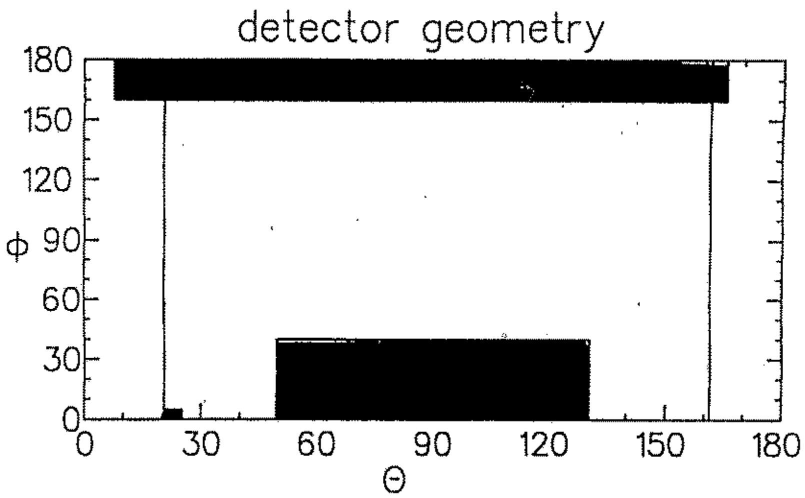
strong interaction not understood

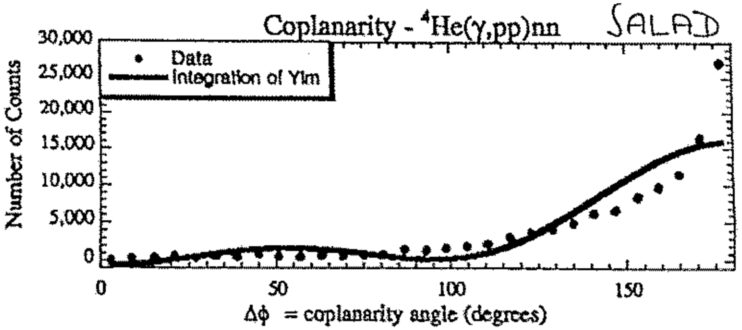
surface limited

[illegible] dominated

A2- HALL IN MAINZ

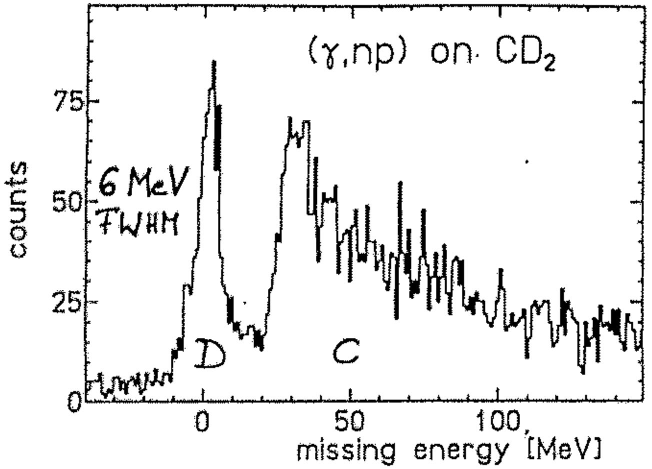


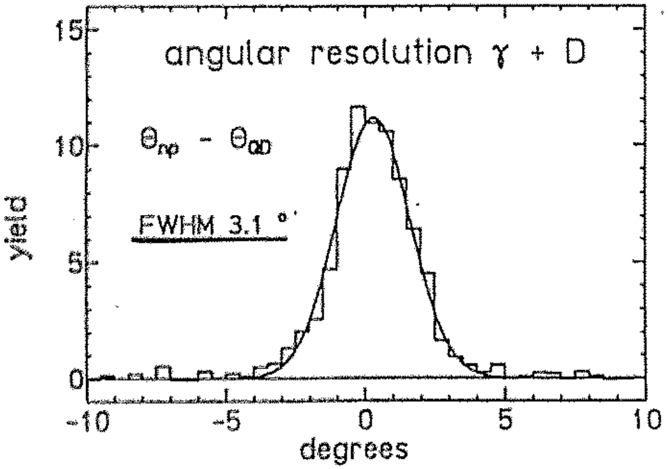

detector geometry


Coplanarity - $^4He(\gamma,pp)nn$ SALAD

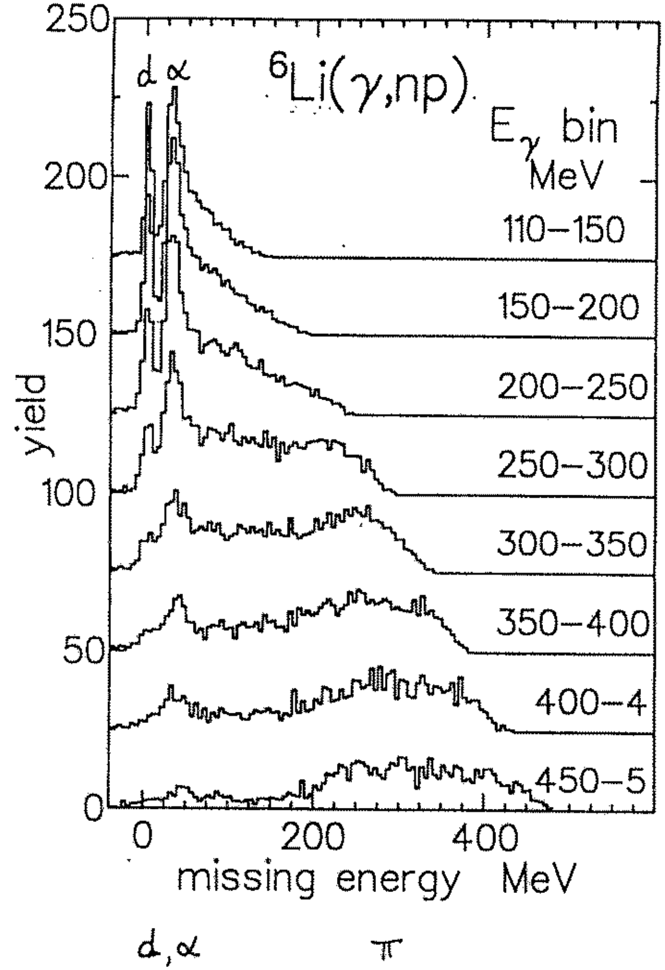
3-fold coincidence: e-n-p

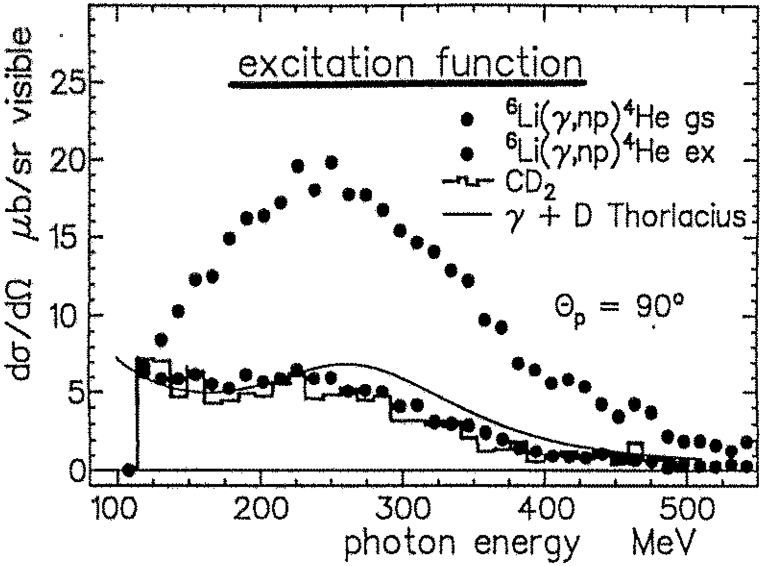
$$E_m = E_\gamma - T_n - T_p - T_R$$



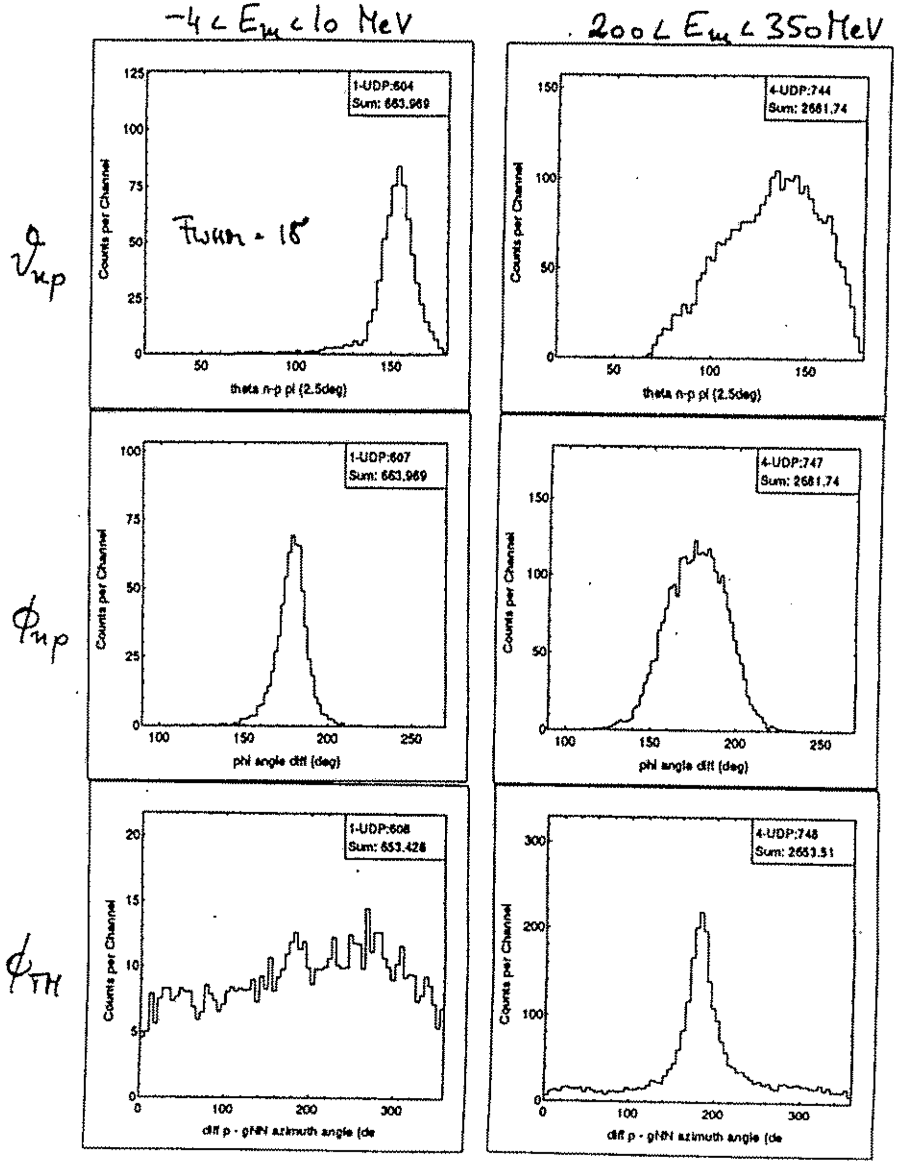


$\Delta p_m \sim 15\ MeV/c$

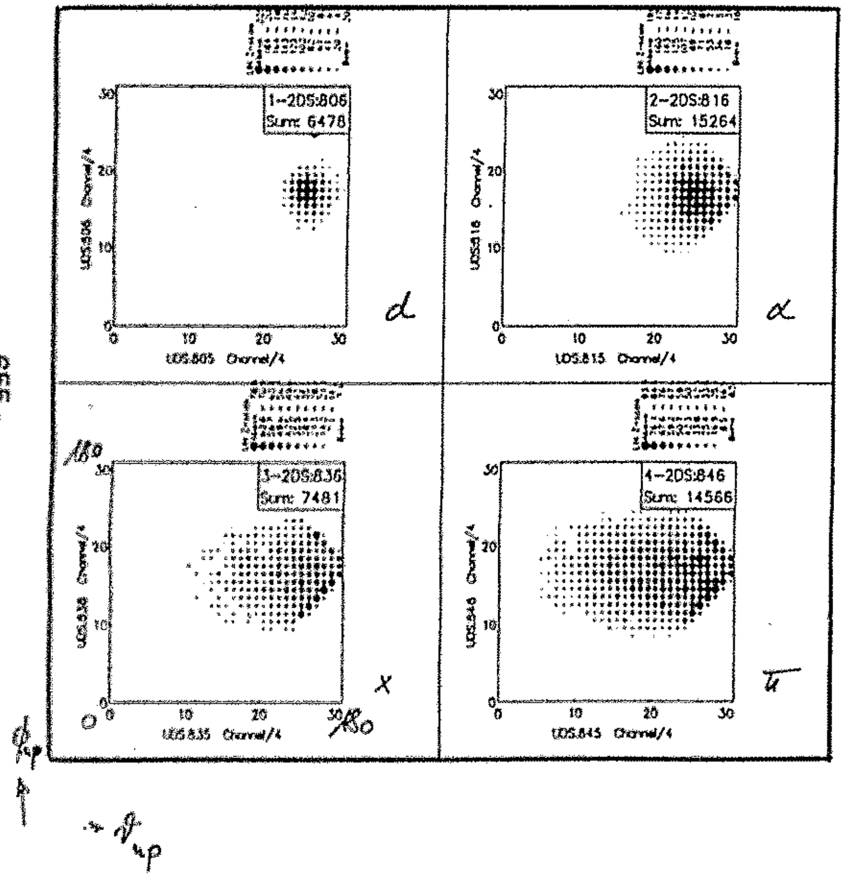


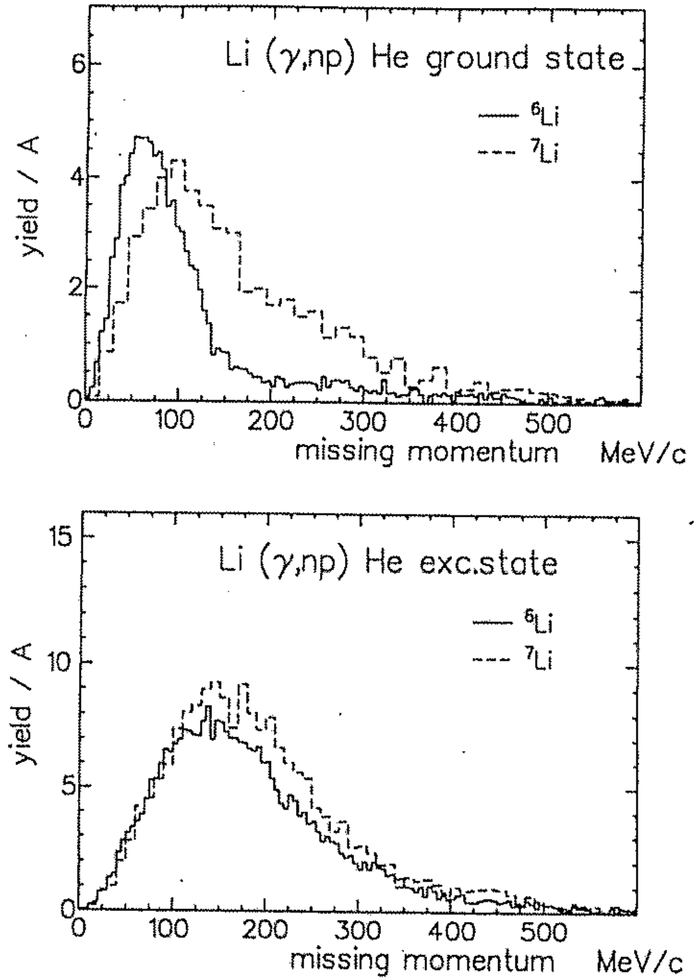

excitation function
● ^{6}Li(γ,np)^{4}He gs
● ^{6}Li(γ,np)^{4}He ex
CD$_2$
γ + D Thorlacius
Θ$_p$ = 90°
dσ/dΩ μb/sr visible
0
5
10
15
20
25
100
200
300
400
500
photon energy MeV

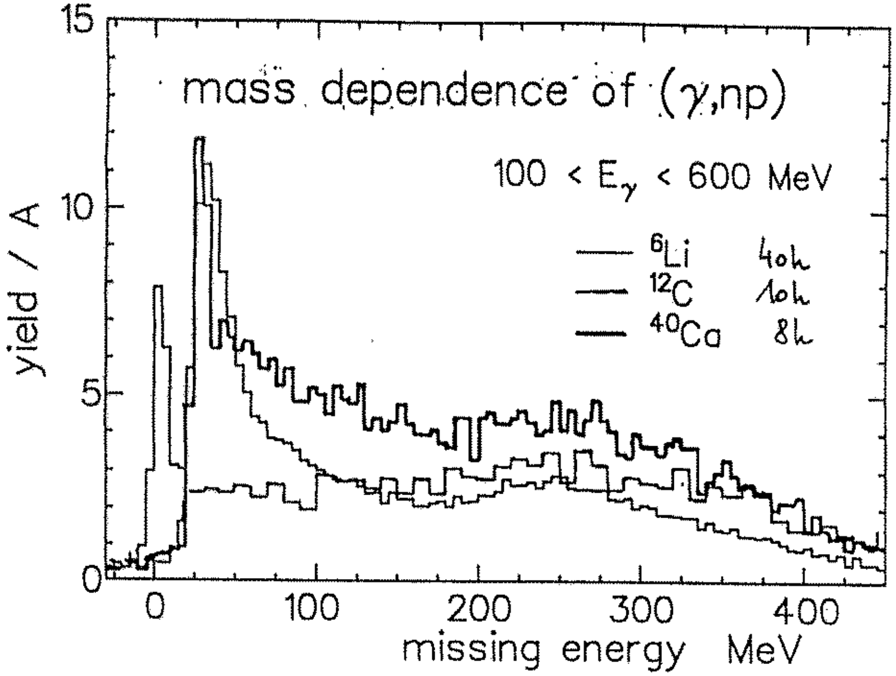
^{6}Li(γ,np)


−4 < E$_m$ < 10 MeV
200 < E$_m$ < 350 MeV
ϑ$_{np}$
φ$_{np}$
φ$_{TH}$
FWHM ≈ 18°
1-UDP:604
Sum: 663.969
4-UDP:744
Sum: 2681.74
1-UDP:607
Sum: 663.969
4-UDP:747
Sum: 2681.74
1-UDP:608
Sum: 653.428
4-UDP:748
Sum: 2653.51
Counts per Channel
theta n-p pl (2.5deg)
phi angle diff (deg)
diff p - gNN azimuth angle (de

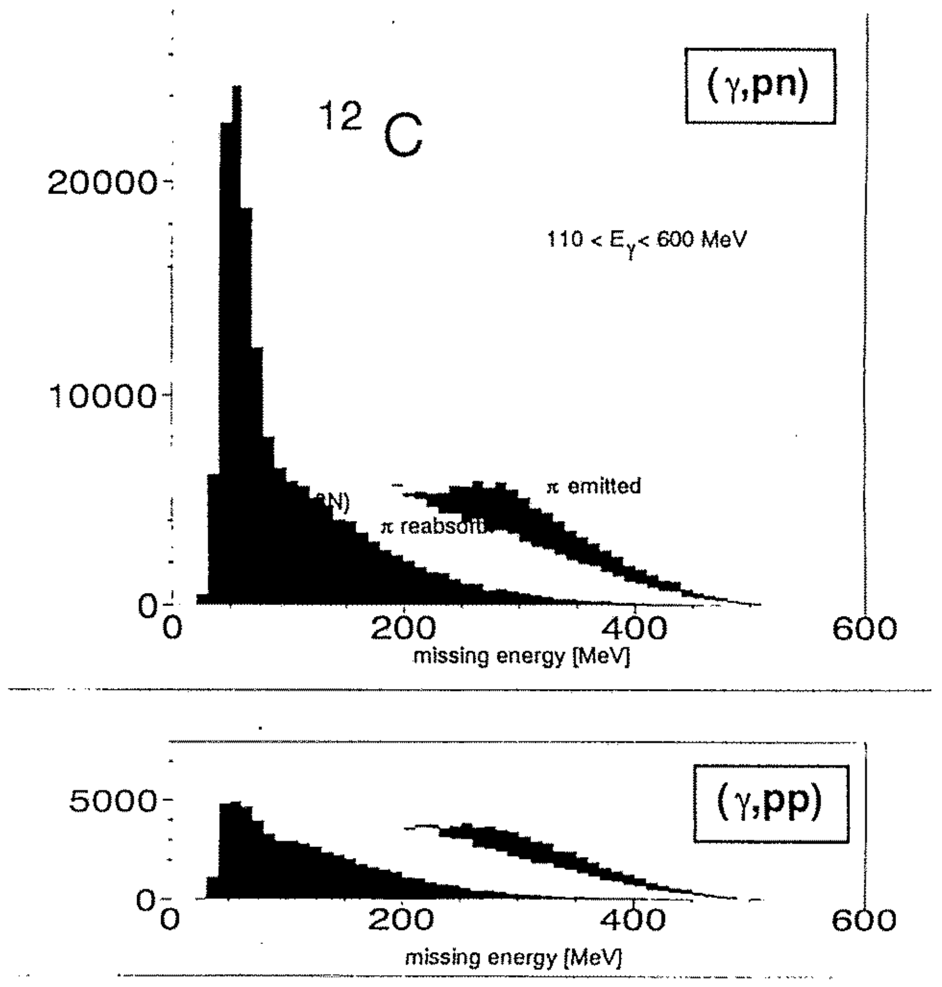
$^6Li(\gamma,np)$

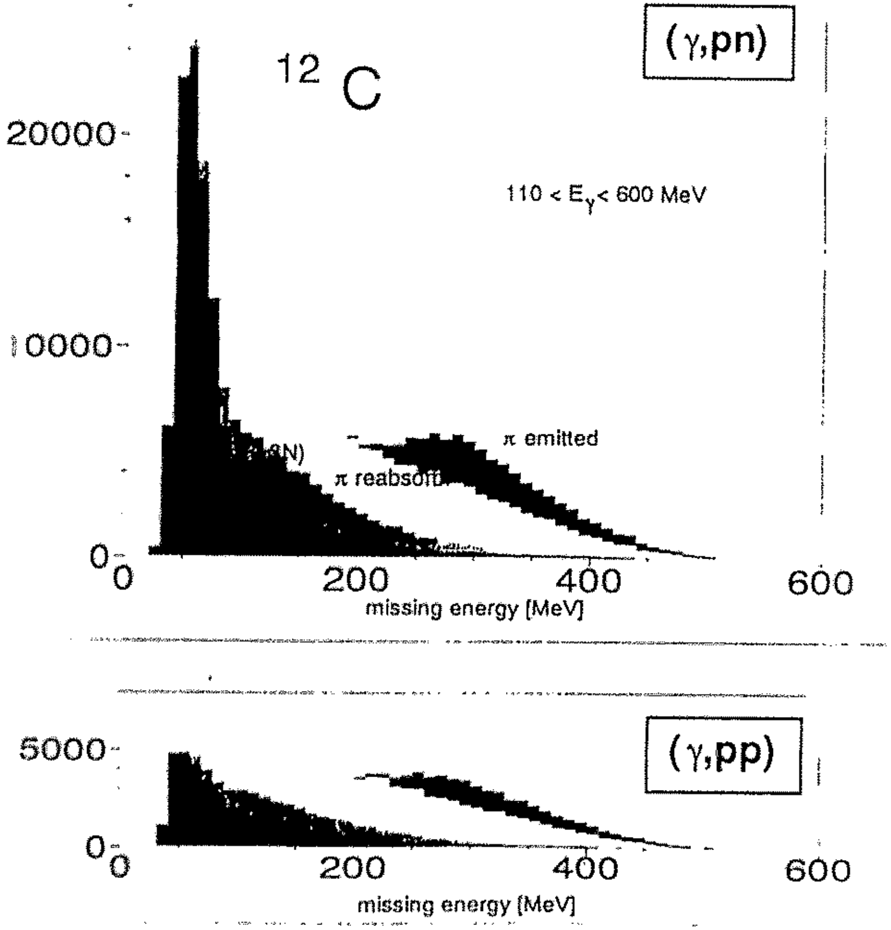

1→2DS:806
Sum: 6478
UDS:806 Channel/4
UDS:805 Channel/4
d
2→2DS:816
Sum: 15264
UDS:816 Channel/4
UDS:815 Channel/4
α
3→2DS:836
Sum: 7481
UDS:836 Channel/4
UDS:835 Channel/4
x
180
0
4→2DS:846
Sum: 14566
UDS:846 Channel/4
UDS:845 Channel/4
π
φ_np
ϑ_np

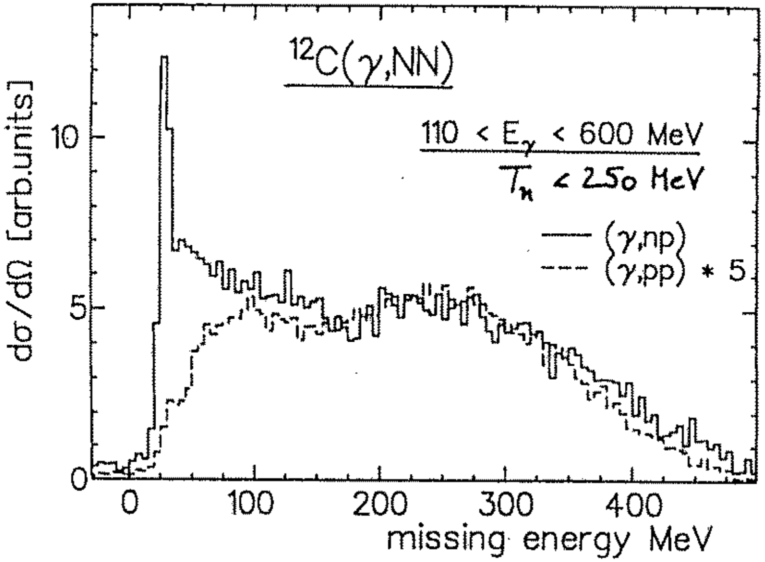

Li (γ,np) He ground state
— 6Li
--- 7Li
yield / A
0
2
4
6
0
100
200
300
400
500
missing momentum MeV/c
Li (γ,np) He exc.state
— 6Li
--- 7Li
yield / A
0
5
10
15
0
100
200
300
400
500
missing momentum MeV/c



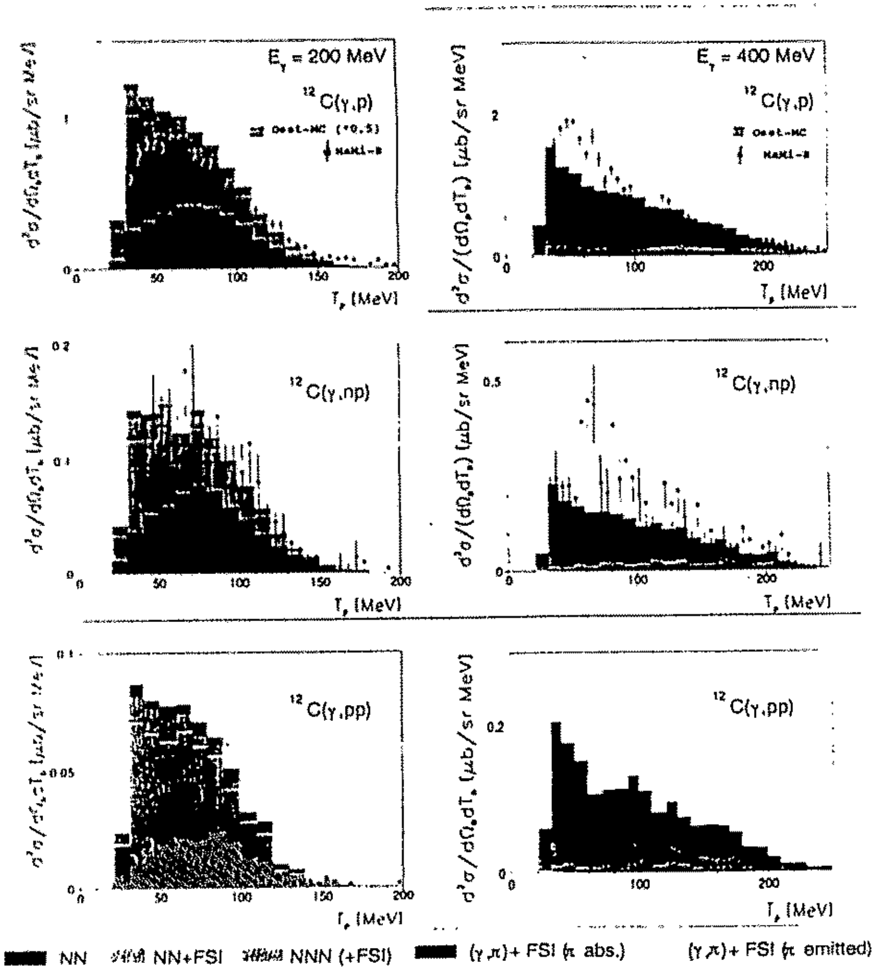
DETECTOR ACCEPTANCES



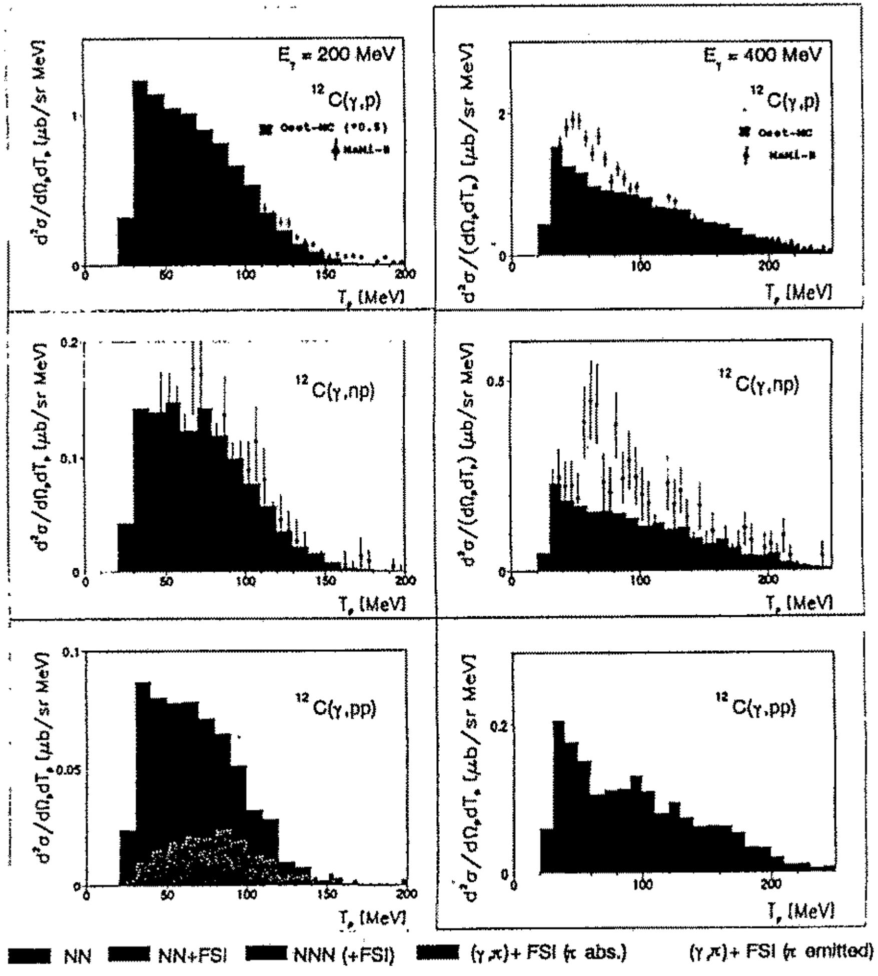

12 C
(γ,pn)
110 < E$_\gamma$ < 600 MeV
π emitted
π reabsorb
20000
10000
0
0
200
400
600
missing energy [MeV]
(γ,pp)
5000
0
0
200
400
600
missing energy [MeV]


$^{12}C(\gamma,NN)$
110 < E$_\gamma$ < 600 MeV
T$_\pi$ < 250 MeV
(γ,np)
(γ,pp) * 5
dσ/dΩ [arb.units]
10
5
0
0
100
200
300
400
missing energy MeV

T_p spectra at $\Theta_p = 80° \pm 10°$, compared to Oset code

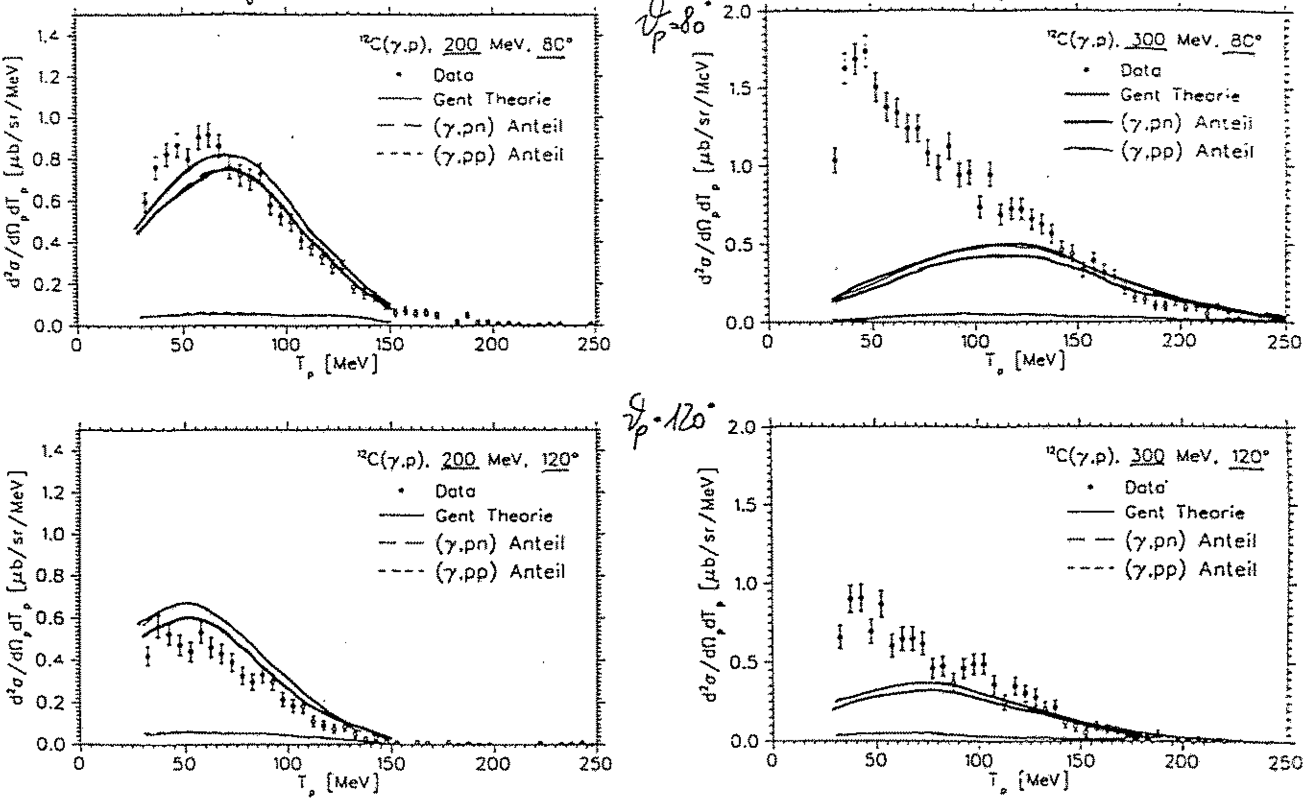


T_p spectra at $\Theta_p = 80° \pm 10°$, compared to Oset code



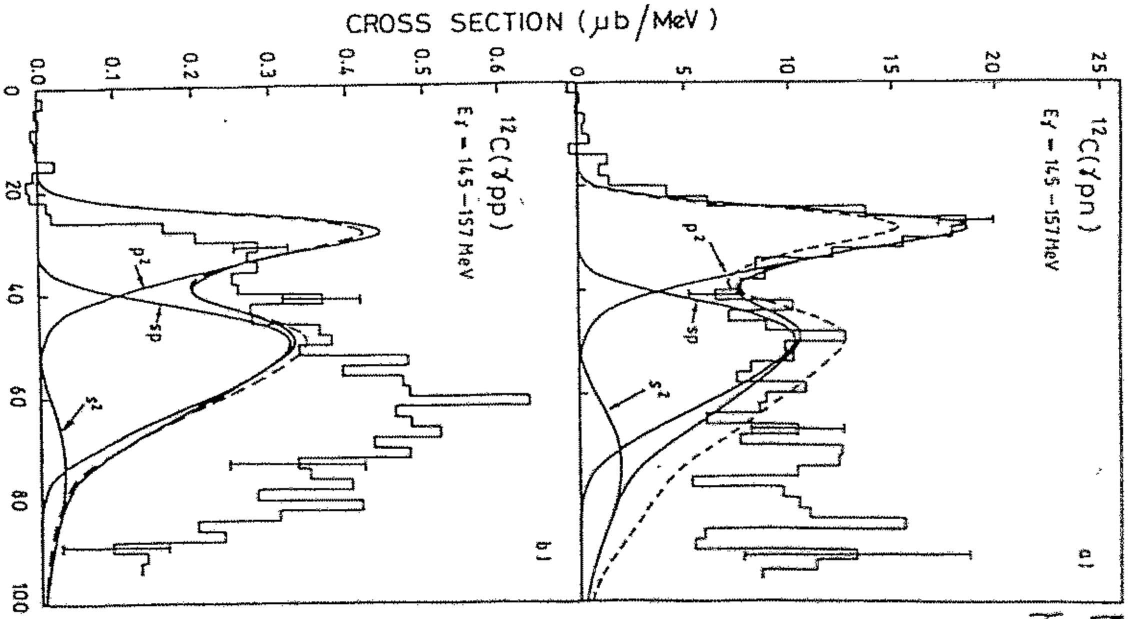
Eγ = 200 MeV

Eγ = 300 MeV



ϑp = 80°

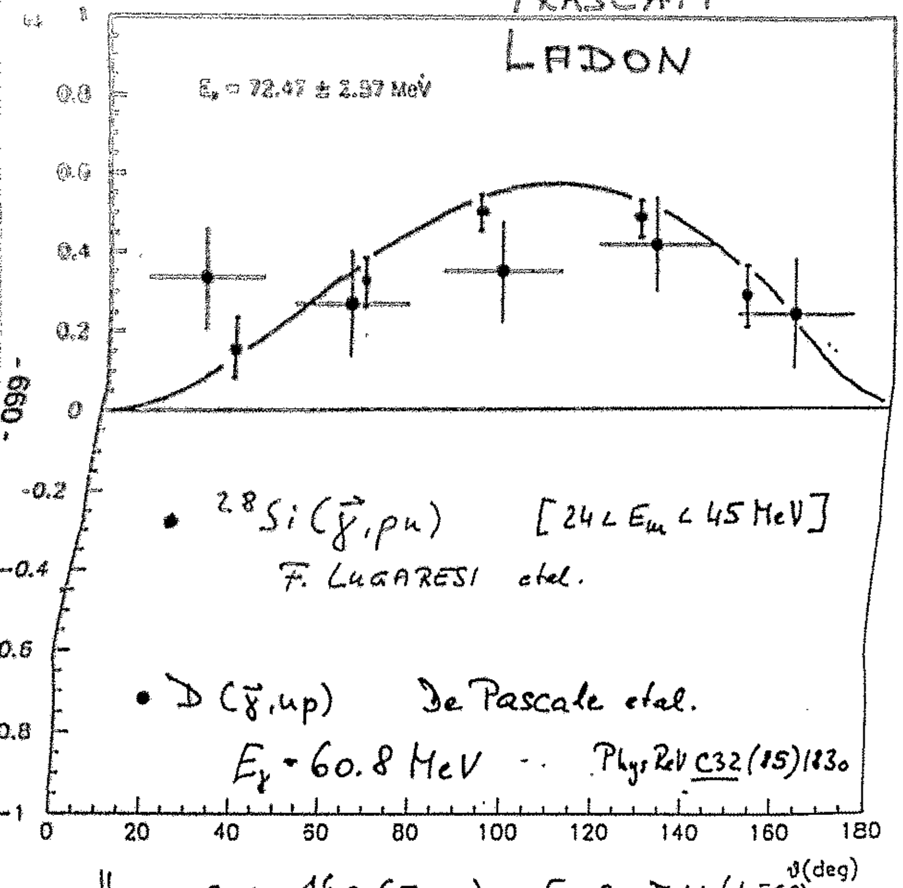
ϑp = 120°



MAMI A
McGeorge et al.

FRASCATI

LADON



- $^{28}Si(\vec{\gamma},pn)$ [$24 < E_m < 45$ MeV]
  F. LUGARESI et al.

- $D(\vec{\gamma},np)$ De Pascale et al.
  $E_\gamma = 60.8$ MeV .. Phys Rev C32 (85) 1830

HOWEVER : $^{16}O(\vec{\gamma},pp)$; $E_\gamma = 300$ MeV (LEGS)

$\Sigma = 0$

SUMMARY

- (γ,2N) data of high quality low background

  large solid angle detectors (~ 1sr)

  large angular range
  (50< Θ_p <130° , 10< Θ_n <160°)

  high flux of tagged photons within
  $50 < E_\gamma < 800$ MeV

  good resolution for missing energy
  $\Delta E = 6 - 8$ MeV (FWHM)

- separation of knockout of $(1p)^2$ and $(1p1s)$, $(1s)^2$ pairs 'cold' residual
- separation of one- and two-body absorption
- 2N absorption seen up to $E_\gamma \sim 400$ MeV
  angular distributions

- up to $E_\gamma \sim 400$ MeV : PWIA valid

OUTLOOK

- study of ^{4}He as the densest nucleus
  - angular and energy dependence
- employ polarisation
  - Σ as signature of 2N-absorption
- detailed comparison between $(\gamma, \pi N)$ and (γ, NN)
- detailed comparison to (e,e'pp) and (e,e'np)
- high resolution $^{16}O(\gamma, np)^{14}N$
  - resolve g.state $(S = 1, T = 0)$ and 2.13 MeV $(S = 0, T = 1)$ states.
- mass dependence

MAMI

Edinburgh

D. Branford, M. Liang, T. Davinson,
J.A. Mackenzie, D. Johnstone, A. Shotter

Glasgow

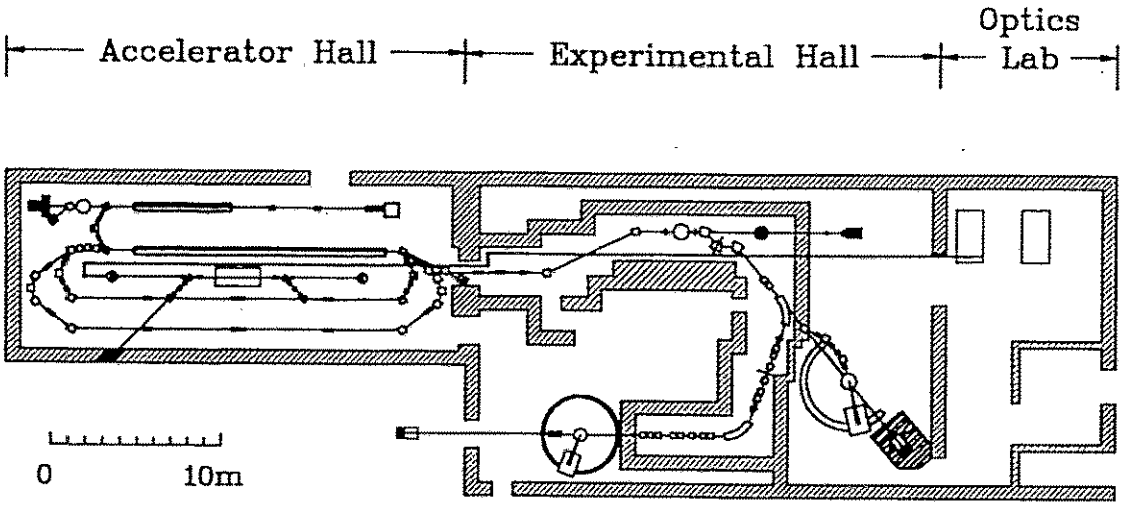
J.R.M. Annand, I. Anthony, G. Cross,
S. Hall, P. Harty, J. Kellie, I. MacGregor,
S. McAllister, J. McGeorge, G. Miller
R. Owens, R. Watson, D. Watts, T. Yau

Tübingen

P. Grabmayr, T. Hehl, Th. Lamparter,
J. Leypoldt, A. Mondry, G. Mauser,
M. Sauer, R. Schneider, K. Spaeth,
G.J. Wagner

Grants:
EC, NATO, DAAD,
SERC, BMFT, DFG

S–DALINAC Facility with Experiments



ARBEITSTREFFEN

Kern- und Teilchenphysik

Pirna 04.-07. Oktober 1994

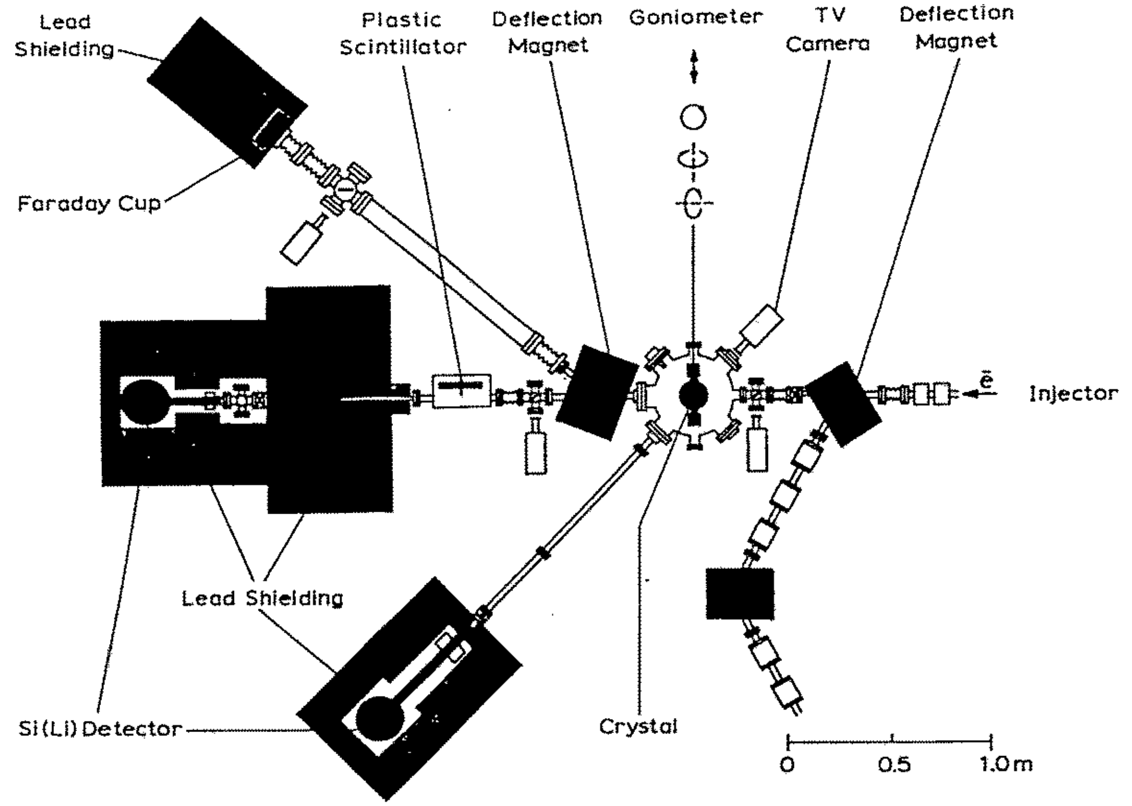
NUTZUNG DES S-DALINAC FÜR NEUERE ENTWICKLUNGEN IN DER STRAHLUNGSPHYSIK

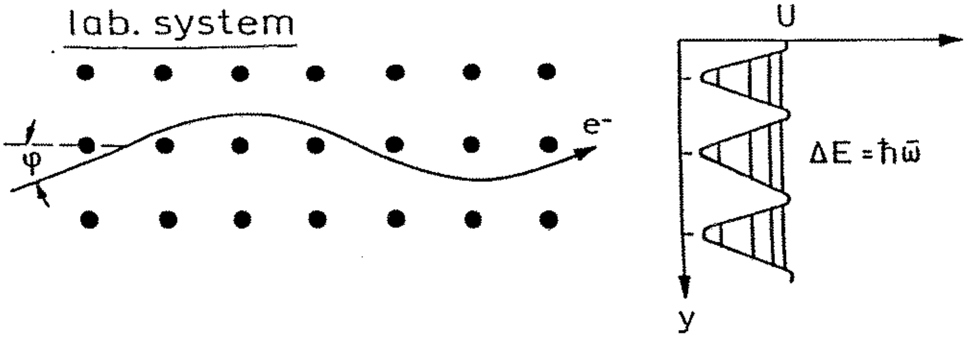
Harald Genz

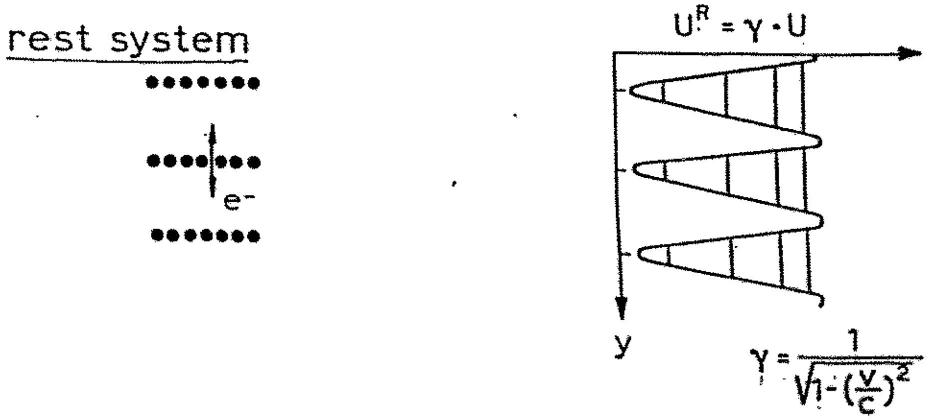
Technische Hochschule Darmstadt, Institut für Kernphysik

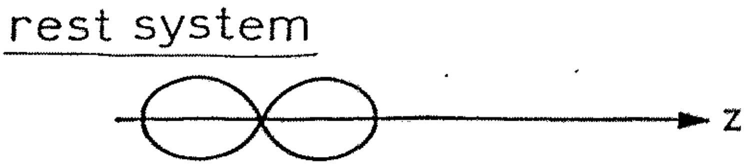
- * Channeling Strahlung
- * Parametrische Röntgenstrahlung
- * Freie-Elektronen-Laser

Unterstützt durch BMFT und DFG

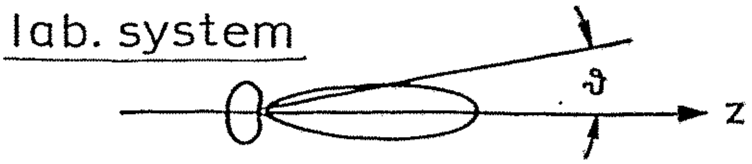

Lead Shielding
Faraday Cup
Plastic Scintillator
Deflection Magnet
Goniometer
TV Camera
Deflection Magnet
Injector
ē
Lead Shielding
Si(Li) Detector
Crystal
0
0.5
1.0m


lab. system
φ
e⁻
U
ΔE = ħω̄
y

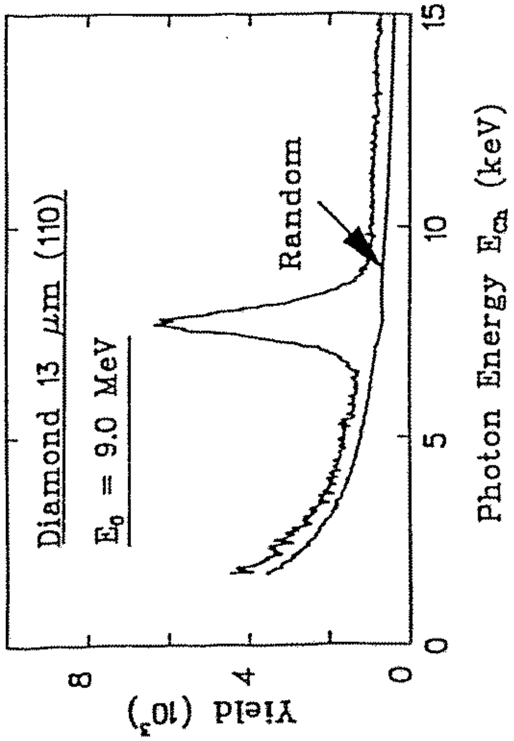

rest system
e⁻
$U^R = \gamma \cdot U$
y
$\gamma = \frac{1}{\sqrt{1-(\frac{v}{c})^2}}$

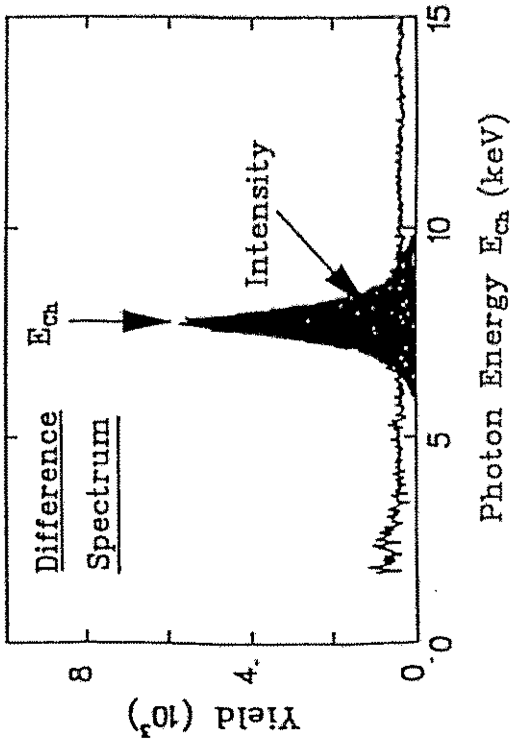


$\hbar\omega^R = \gamma\hbar\bar{\omega}$



$E_{Ch} = \hbar\omega = 2\gamma^2\hbar\bar{\omega}$





Experiment **Theorie**

$$\frac{d^2N(i \to f)}{d\Omega d\omega} = \frac{d^3N(i \to f)}{d\Omega d\omega dz} \int_0^d P_i(z)\, dz$$

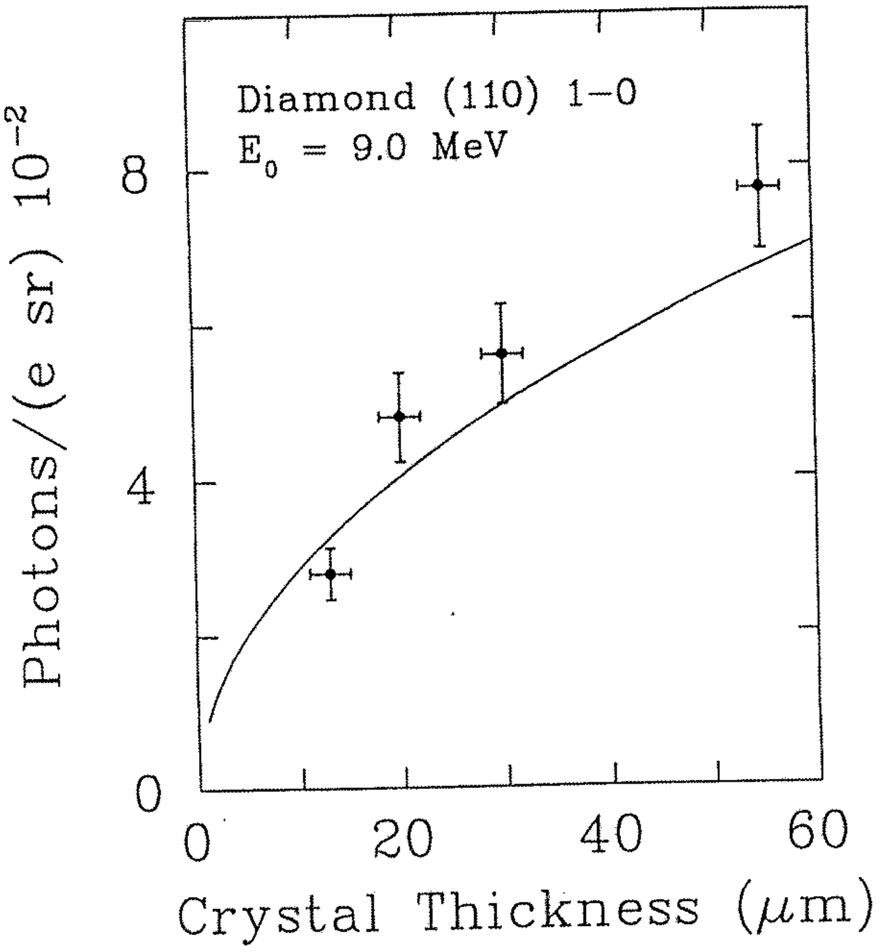
$$I \sim \int_0^d P_i(z)\, dz$$

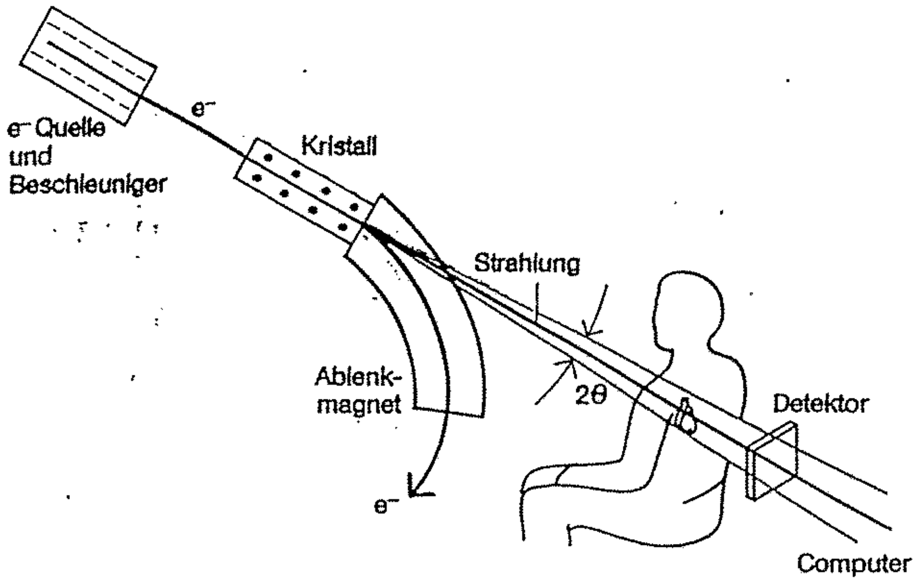
Dynamischer Lösungsansatz
(Mastergleichung)

$$\frac{dP_i}{dz} = \sum_j w_{ij}\,(P_j - P_i)$$

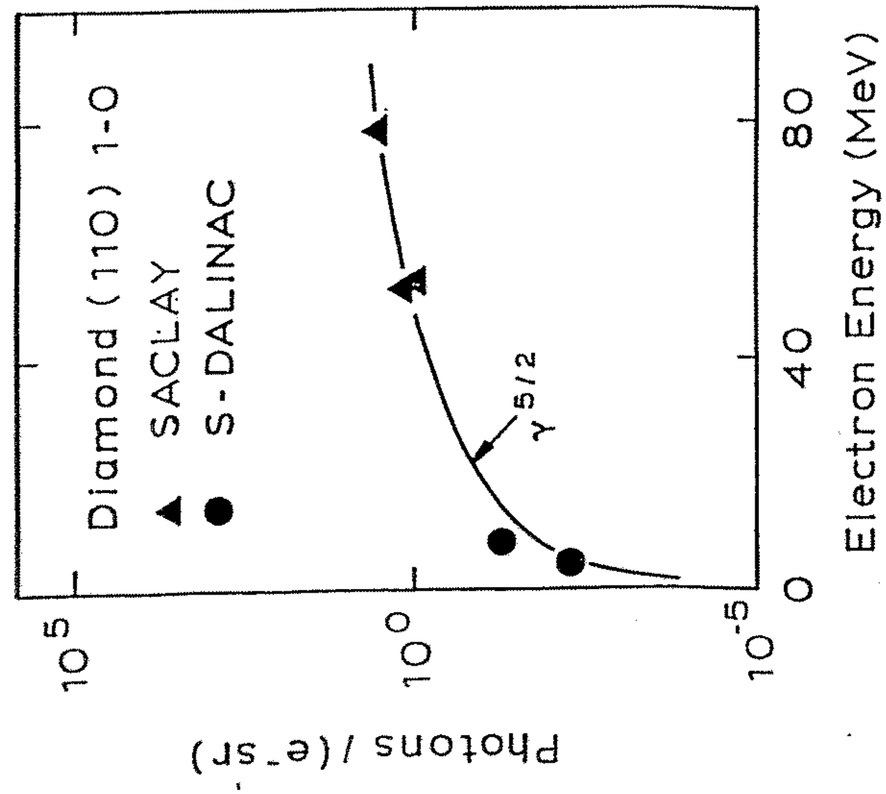
w_{ij} Übergangsrate pro Länge
P_i Population des i-ten Zustandes

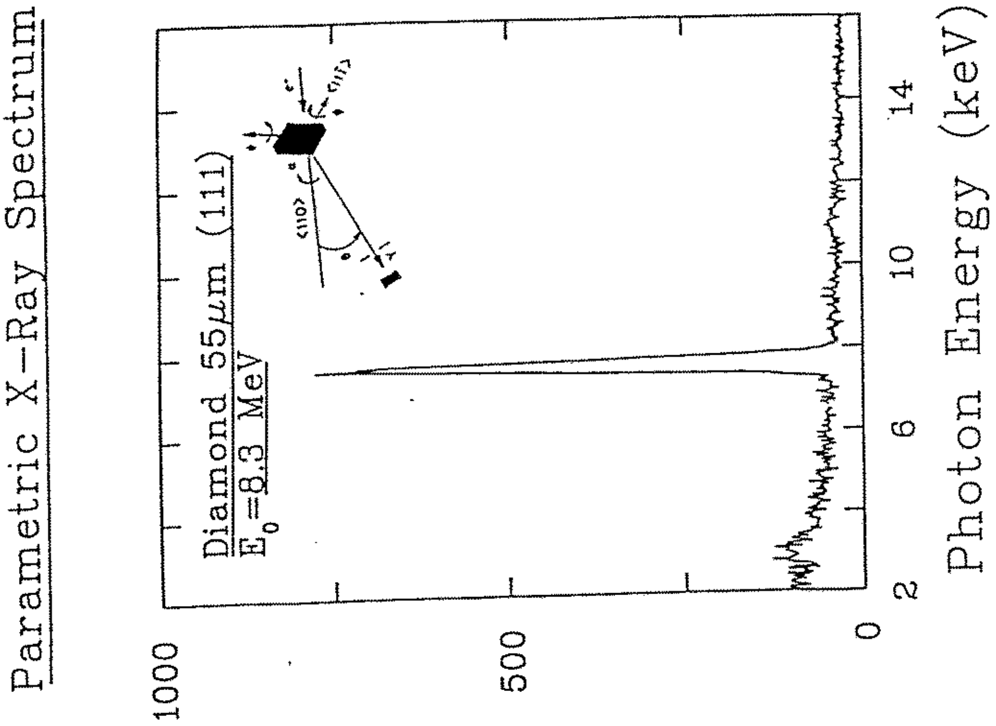
Thickness Dependence



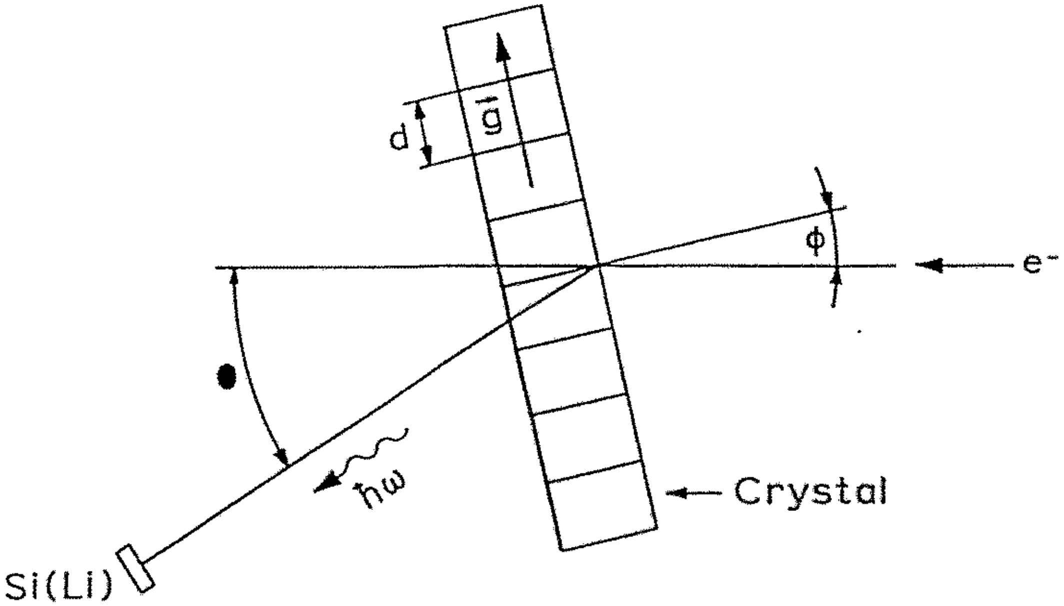


Angiographie mit Channelingstrahlung



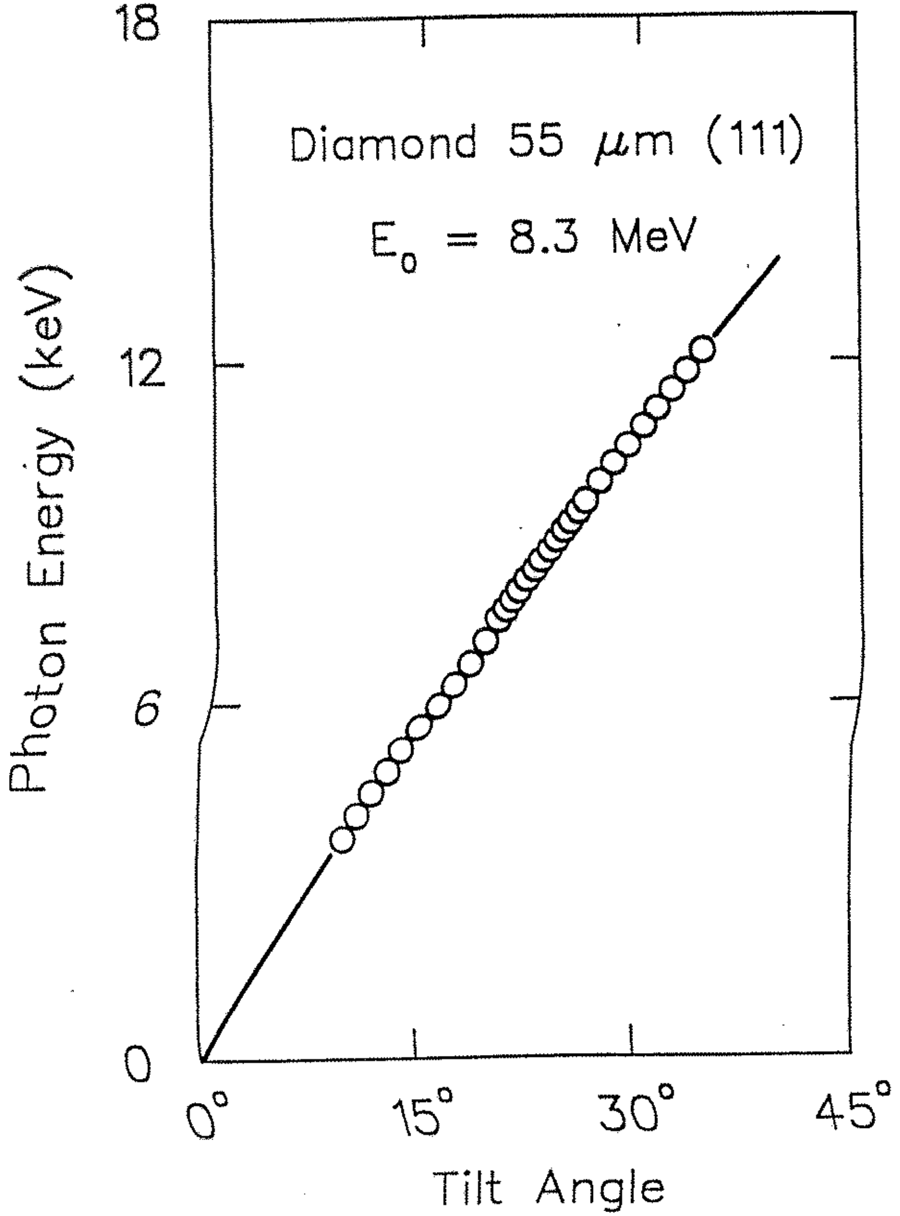


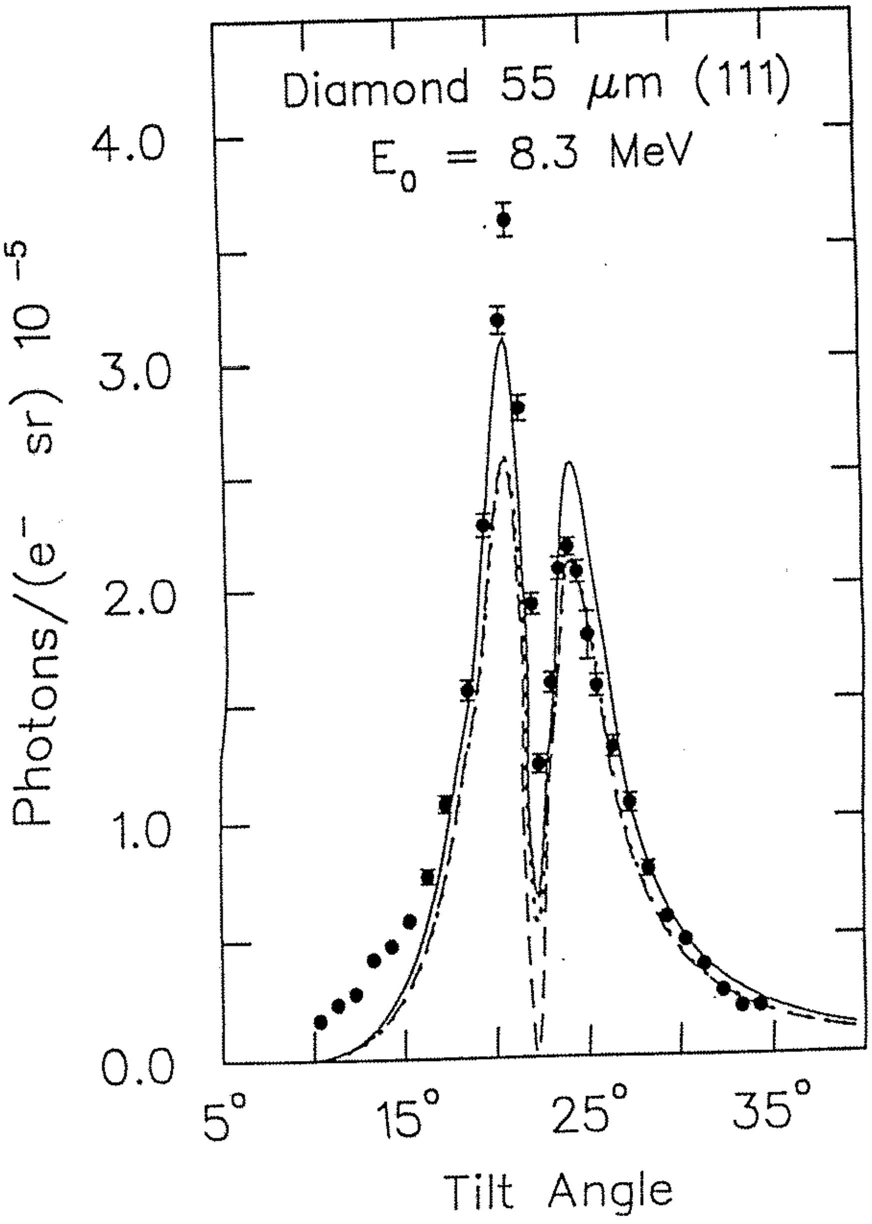
PARAMETRIC X-RAYS: DIFFRACTION OF VIRTUAL PHOTONS



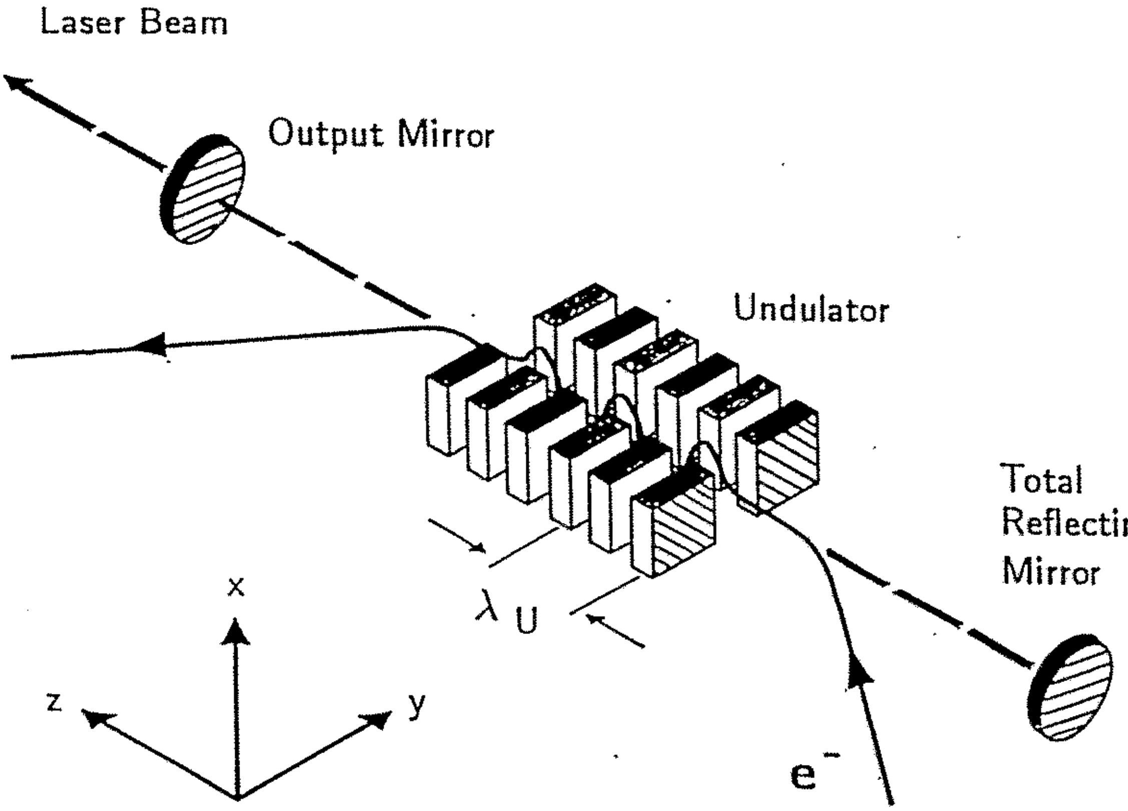
ENERGY DEPENDENCE OF THE PXR-PHOTONS: $\hbar\omega = \hbar c g \frac{\sin\Phi}{\frac{1}{\beta} - \cos\bullet}$

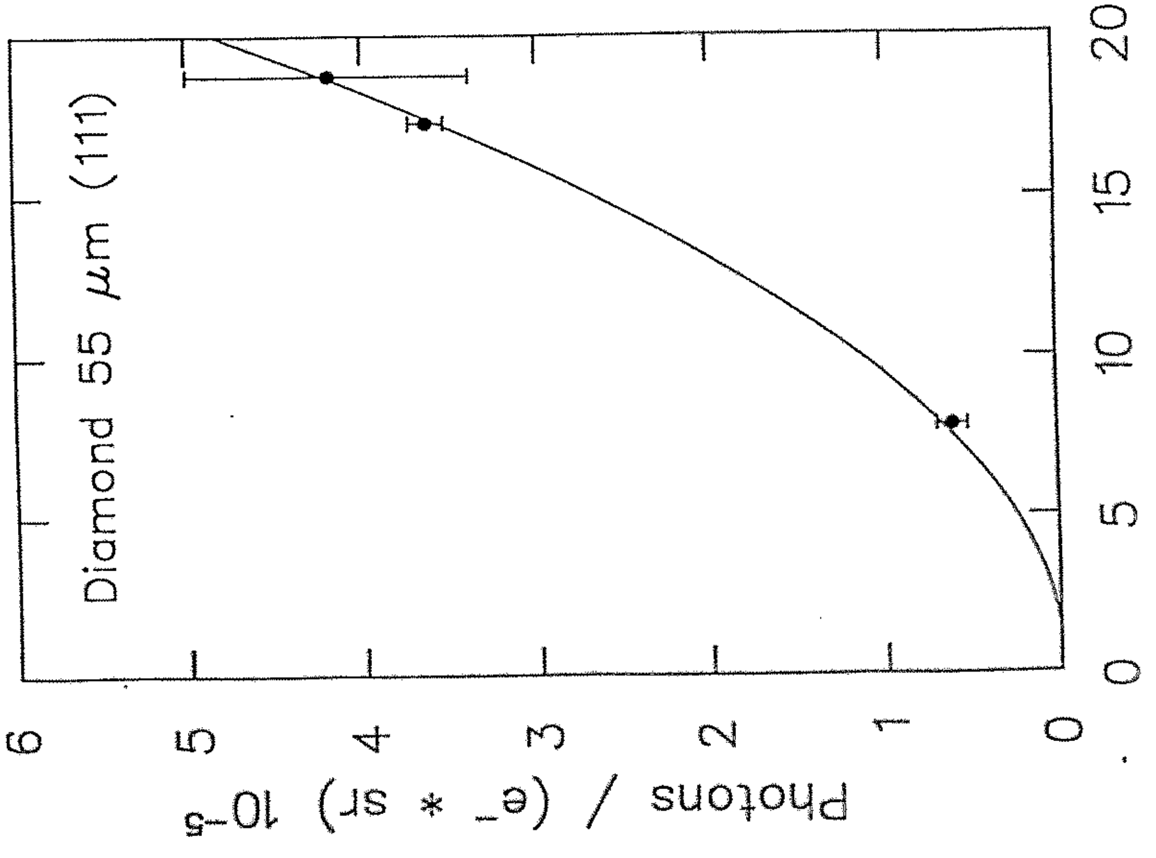
Yield

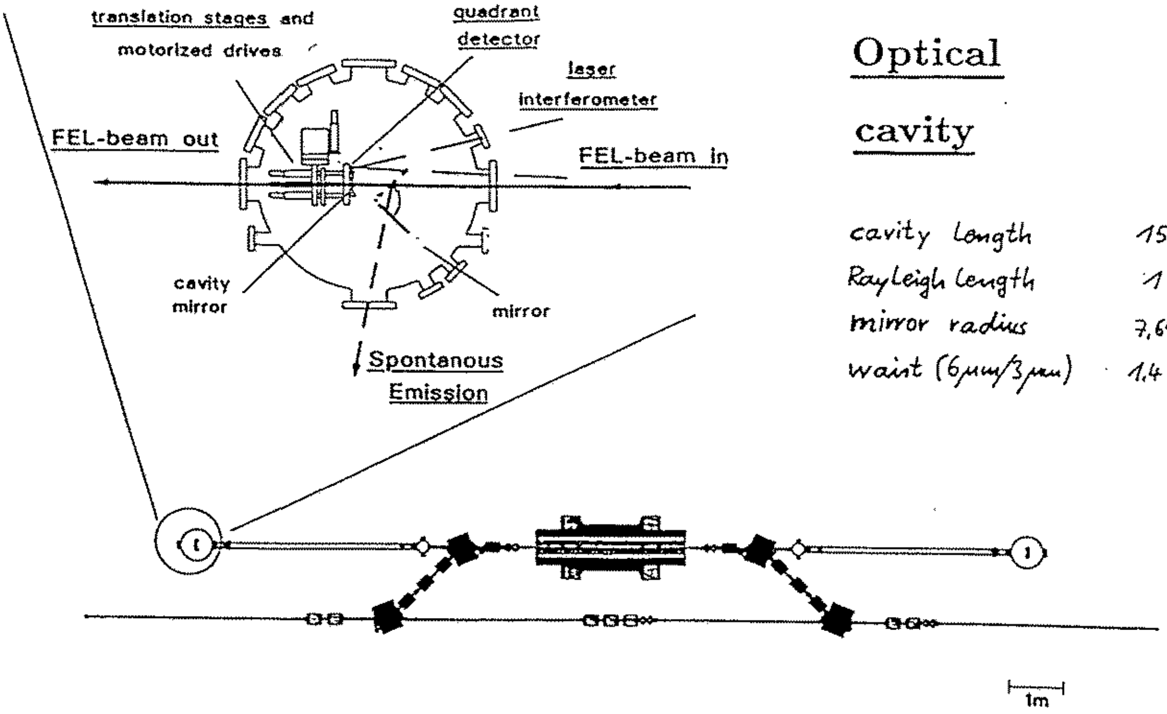

Diamond 55 μm (111)
E_0 = 8.3 MeV
Photon Energy (keV)
0
6
12
18
0°
15°
30°
45°
Tilt Angle


Diamond 55 μm (111)
E_0 = 8.3 MeV
Photons/(e^- sr) 10^{-5}
0.0
1.0
2.0
3.0
4.0
5°
15°
25°
35°
Tilt Angle

Free Electron Laser Principle







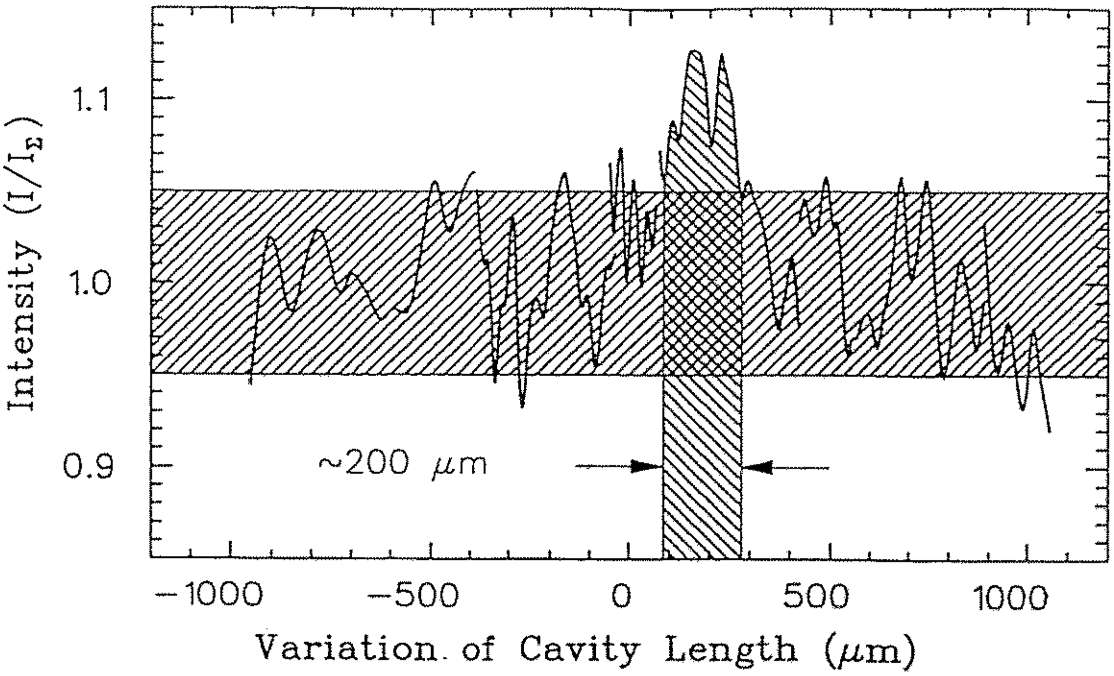
Optical cavity

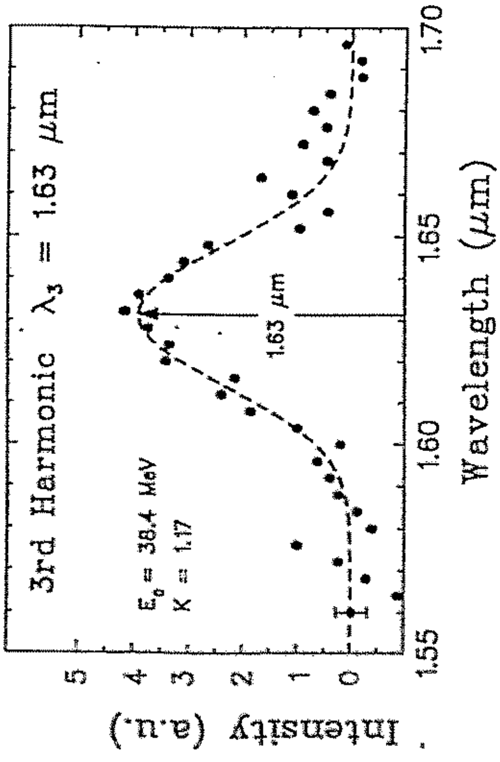
cavity Length	15 m
Rayleigh Length	1 m
mirror radius	7,64 m
waist (6µm/3µm)	1,4 mm/1,0 mm

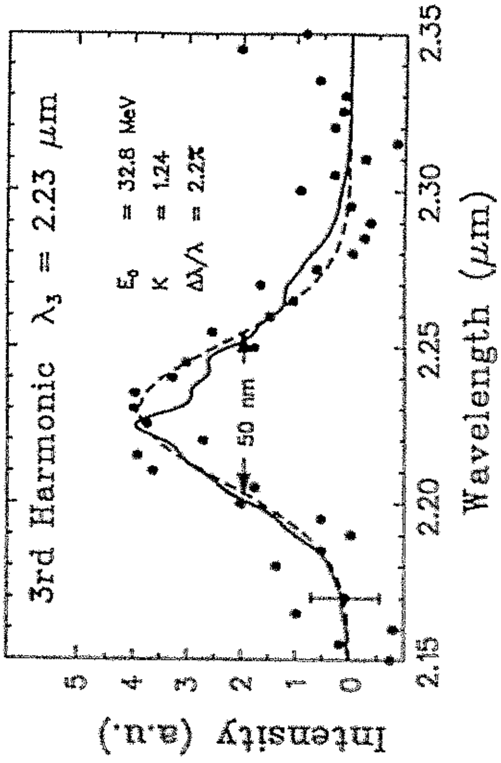
Parameters of Darmstadt IR–FEL

Electron Beam			
Pulse Length	τ	=	1.9 ps
Repetition Rate	ν	=	10 MHz
Energy	E	=	30 to 50 MeV
Peak Current	$\hat{I}$	=	2.7 A
Mode of Operation	cw		
Undulator			
Period Length	λ_u	=	3.2 cm
Number of Periods	N	=	80
Undulator Length	L_u	=	2.56 m
Undulator Parameter	K	=	0.5 to 1.3
Optical Cavity			
Q–Value	Q	≈	50
Length	L	=	15.00383 m
Rayleigh Length	$Z_0 = L_u/2.5$	=	1.024 m
Radiation Characteristics			
Wavelength	λ	=	2.5 to 7.0 µm
Peak Power	$\hat{P}$	≈	100 kW
Small Signal Gain	G	≈	9%

Amplification of Spontaneous Emission







THD - S-DALINAC - FEL

STATUS

I. Achievements

- All components mounted
- Observation of spontaneous emission '92
- Observation of amplification '93

II. Current Activities

- Improved beam transport system
- Improved beam diagnosis system
- Q-value determination of cavity

III. Planned Activities

- Next beam time November - December '94

AKTIVITÄTEN - STRAHLUNGSPHYSIK

S-DALINAC

Channelingstrahlung, Parametrische Röntgenstrahlung, Kohärente Bremsstrahlung

Elektron-Kristalle-Wechselwirkung	Darmstadt - Bonn
	MPI München - Johannesburg
Polarisation (CR, PXR)	Darmstadt - MPI München
Mamographie	Darmstadt - Siemens Erlangen
Tiefenlithographie	Darmstadt - Bonn
Röntgenlinse	Darmstadt - Moskau
PXR	Darmstadt - Kharkov
Kohärente Bremsstrahlung	Darmstadt - Washington

Freie-Elektronen-Laser

Bau und Test IR-FEL	Darmstadt
EUROFEL	Darmstadt - Nieuwegein
	Orsay - Frascati
Medizinische Anwendungen	Darmstadt - Tübingen
	Heidelberg
Dünne Schichten	Darmstadt - Berlin

MAMI

Transition Radiation, Smith-Purcell-Strahlung	Mainz - Monterey

GELINA

Transition Radiation, Smith-Purcell-Strahlung	Geel

S - DALINAC

Strahlungsphysik

J. Freudenberger
M. Galemann
H. Genz
H.-D. Gräf
L. Groening
R. Hahn
P. Hoffmann-Stascheck
H. Loos
U. Nething
A. Richter
V. Schlott
M. Thomas
M. Wiencken
T. Wesp

Measurement of the reactions
$\gamma p \rightarrow K^+\Lambda$
and
$\gamma p \rightarrow K^+\Sigma^0$
from the threshold up to 2.0 GeV with SAPHIR at ELSA, Bonn

Pirna 1994

M. Bockhorst, R. Burgwinkel, J. Hannappel, K. Heinloth, H.-P. Jakob, N. Jöpen, H. G. Jüngst, U. Kirch,
F.-J. Klein, L. Lindemann, J. Link, D. Menze, H. Merkel, W. Neuerburg, E. Paul, H. van Pee, R. Plötzke,
S. Schmidt, J. Scholmann, W.-J. Schwille, M. Q. Tran, R. Wedemeyer, F. Wehnes, J. Wißkirchen, A. Wolf
Physikalisches Institut der Universität Bonn, Germany

J. Ernst, H. Kalinowsky, E. Klempt, R. Maschuw, C. Strassburger
ISKP Bonn, Germany

F. Smend, M. Schuhmacher, Ch. Posch
II. Physikalisches Institut Göttingen, Germany

- The SAPHIR detector
- Measurements
- Event reconstruction
- Acceptance
- Separation of the reactions up to 2 GeV
- Data statistics, number of events
- Isobaric model and fit procedure
- Comparision of measurements and model
- Summary and Outlook

The SAPHIR detector

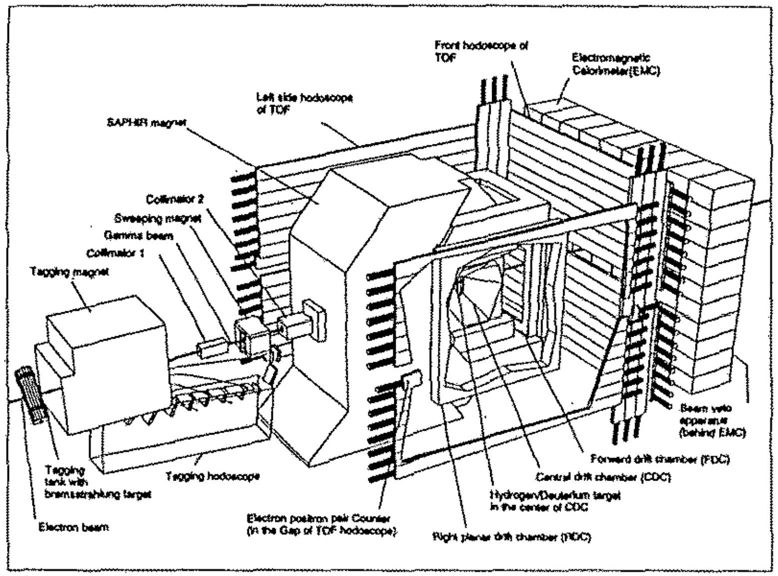


Abb. 1: Total view of the SAPHIR detector

- Tagging system
  - Trigger (photon)
  - Photon energy
- Central Drift Chamber
  - Measurement of charged particle tracks
- TOF counter
  - Trigger (charged particles)
  - Time of flight

Measurements

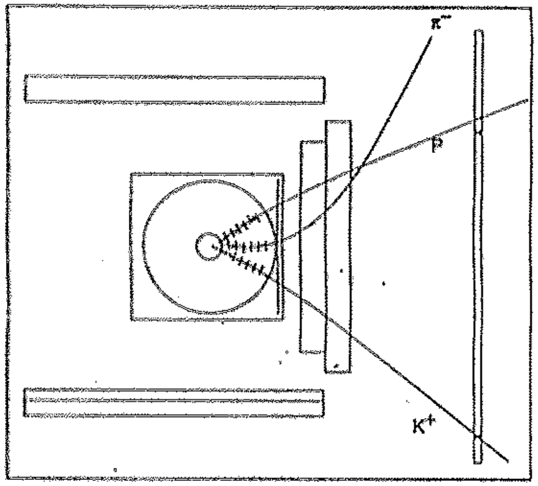


Abb. 2: Single event at SAPHIR, $\gamma p \to K^+\Lambda$

Measured data

- Photon energy $E_\gamma = E_e - E_{e'}$ with tagging system
- Tracks and momenta of charged particles ($\rightarrow$ vertices) with drift chambers
- Time of flight ($\rightarrow$ mass) with TOFs

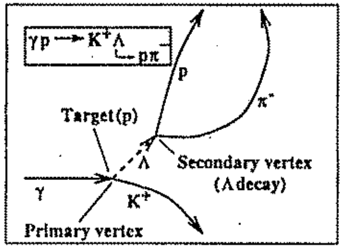
Reactions and decays

- $\gamma p \rightarrow K^+\Lambda$, $\Lambda \rightarrow p\pi^-$
- $\gamma p \rightarrow K^+\Sigma^0$, $\Sigma^0 \rightarrow \Lambda\gamma$, $\Lambda \rightarrow p\pi^-$

Event reconstruction

- 3 reconstructed tracks (K^+, p, π^-)
- Vertices ($K^+\Lambda$ or $K^+\Sigma^0$, $\Sigma^0 \rightarrow \Lambda\gamma$, $\Lambda \rightarrow p\pi^-$)
- Criterions
  - – Cuts in $P(\chi^2)$ of tracks and vertices
  - – Charge conservation (K^+, p, π^-)
  - – Kinematic fits
  - – Missing mass cut
  - – Cut around Λ mass (invariant mass of $p\pi^-$)

Kinematic fit:
probing energy–momentum conservation



- At the primary vertex:
- $E_\gamma + m_{target} - \sum_i \sqrt{p_i^2 + m_i^2} = 0$
- $\vec{p}_\gamma - \sum_i \vec{p}_i = \vec{0}$
- At decay vertex (e.g. $\Lambda \rightarrow p\pi^-$):
- $m_\Lambda^2 = (\sqrt{p_p^2 + m_p^2} + \sqrt{p_\pi^2 + m_\pi^2})^2 - (\vec{p}_p + \vec{p}_\pi)^2$

Missing mass:

- $m_\Lambda^2 = (E_\gamma + m_{target} - \sqrt{p_K^2 + m_K^2})^2 - (\vec{p}_\gamma + \vec{p}_K)^2$

Determination of polarization of Λ, Σ^0

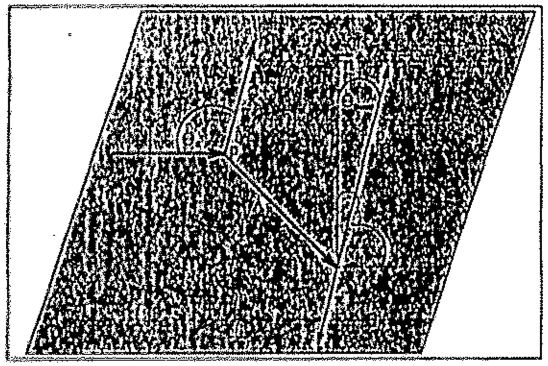


Abb. 3: Production plane, Polarization of the Λ, decay of the Λ in the Λ rest system and definition of all angles

$$W(\Theta_{decay})d\Omega = \frac{1}{2}(1 + \alpha P_\Lambda \cos\Theta_{decay})d\Omega \quad (1)$$

$$\alpha = 0.642 \pm 0.0.13 \text{ [PPDB92]}$$

$$P_\Lambda = \frac{2}{\alpha}\frac{N_1 - N_2}{N_1 + N_2} \quad (2)$$

$\Sigma^0 \to \Lambda\gamma(100\%)$, $\vec{\varepsilon} \cdot \vec{u}_\gamma = 0$

$$\vec{P}_\Lambda = -(\vec{P}_{\Sigma^0} \cdot \vec{u}_\Lambda)\vec{u}_\Lambda \quad (3)$$

$\vec{\varepsilon}$ ≡ Polarization vector of decay photon
$\vec{u}_\gamma$ ≡ Unit vector decay photon direction
$\vec{P}_\Lambda$ ≡ Polarization vector of Λ
$\vec{P}^0_\Sigma$ ≡ Polarization vector of Σ^0
$\vec{u}_\Lambda$ ≡ Unit vector in Λ direction

Averaging over all Λ directions $\vec{u}_\Lambda$: $\vec{P}_\Lambda = -\frac{1}{3}\vec{P}_{\Sigma^0}$ (4)

Acceptance

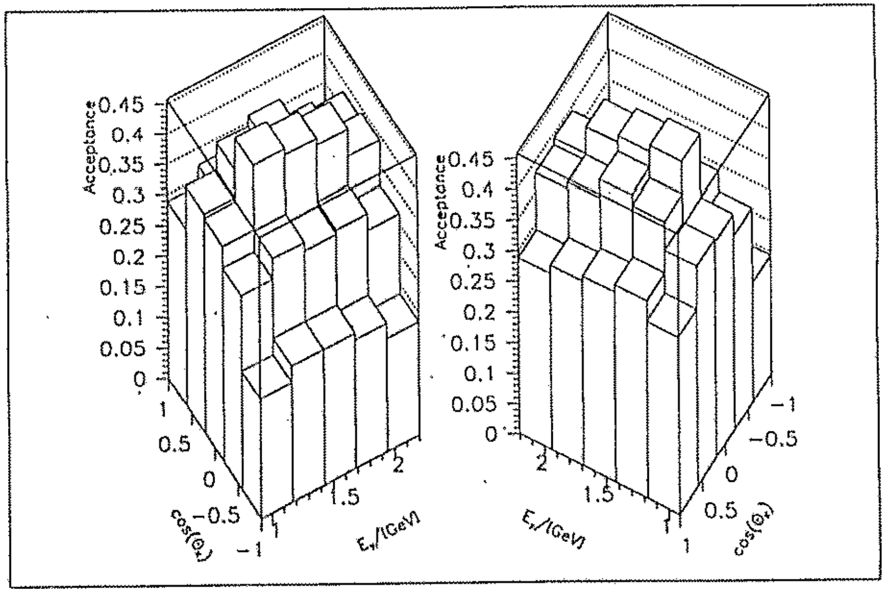


Abb. 4: Acceptance of the SAPHIR detector for the reaction $\gamma p \to K^+\Lambda$

- Simulated $\gamma p \to K^+\Lambda$ events
- Simulations in consideration of multiple scattering, energy loss, resolution
- Same reconstruction program for measured and simulated events
- Acceptance is everywhere > 0
- Acceptance for $\gamma p \to K^+\Sigma^0$ very similar

Separation of the reactions up to 2 GeV

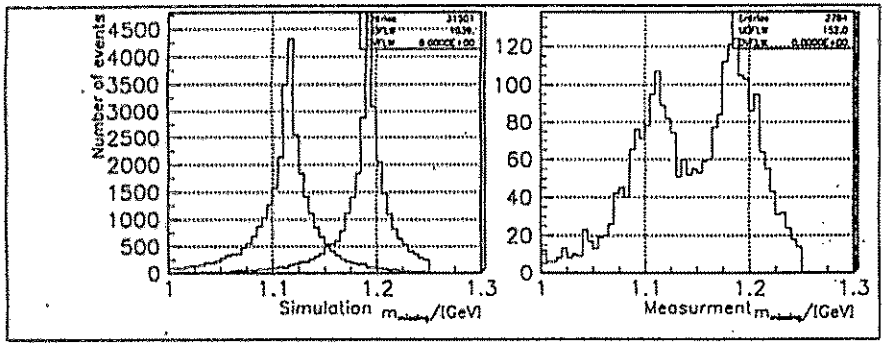


Abb. 5: Missing mass against K$^+$ for $\gamma p \to K^+\Lambda$ and $\gamma p \to K^+\Sigma^0$

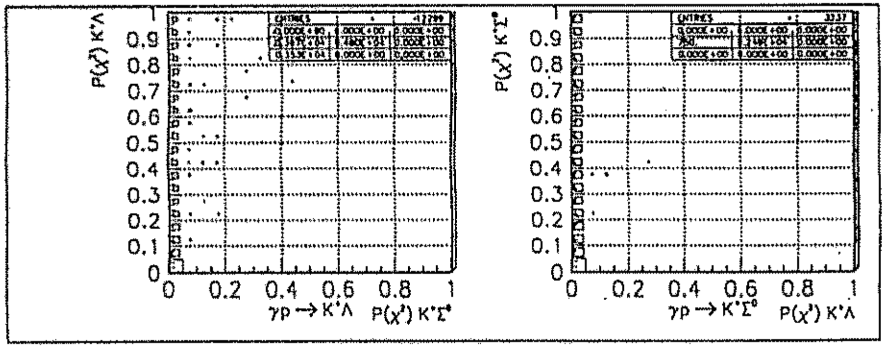


Abb. 6: χ^2 probabilities of kinematic fits for measured $\gamma p \to K^+\Lambda$ and $\gamma p \to K^+\Sigma^0$

- Separation of $\gamma p \to K^+\Lambda$ and $\gamma p \to K^+\Sigma^0$ with kinematic fit
- Separation of background and other reactions with missing mass and invariant mass cuts

Data statistics, number of events

Run #	E_γ [GeV]	Tr. TOF	Trigger Events	Run Time
06.92	0.96 . . . 1.48	$\geq$2	1,594,000	6d 2h
10.92	0.96 . . . 1.48	$\geq$2	2,034,000	4d
02.93	1.32 . . . 2.02	$\geq$1	2,639,000	3d 7h
05.93	1.32 . . . 2.02	$\geq$1	6,590,000	6d 6h
10.93	1.32 . . . 2.02	$\geq$1,2	11,925,000	10d 17h
01.94	1.03 . . . 1.54	$\geq$2	3,003,265	4d 15h
02.94	1.03 . . . 1.54	$\geq$2	2,693,880	6d 17h
05.94	1.32 . . . 2.02	$\geq$2	1,019,090	3d

Tabelle 1: Measurements at the SAPHIR detector with H_2 target

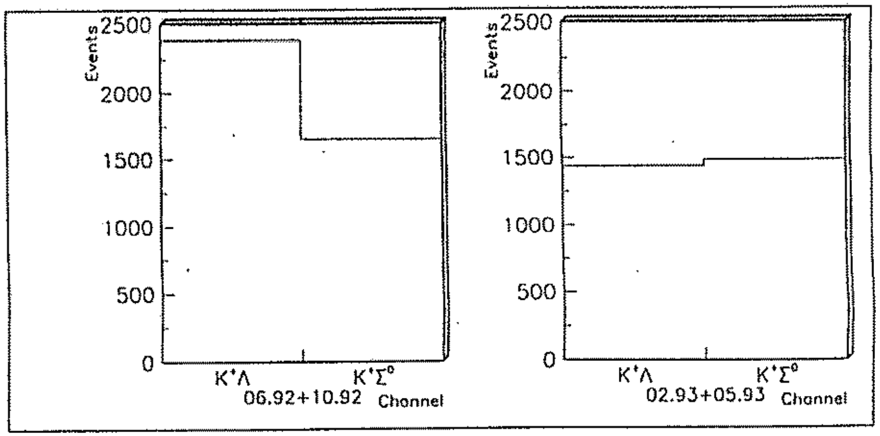


Abb. 7: $\gamma p \to K^+\Lambda$ and $\gamma p \to K^+\Sigma^0$ events found at SAPHIR

Isobaric model and fit procedure

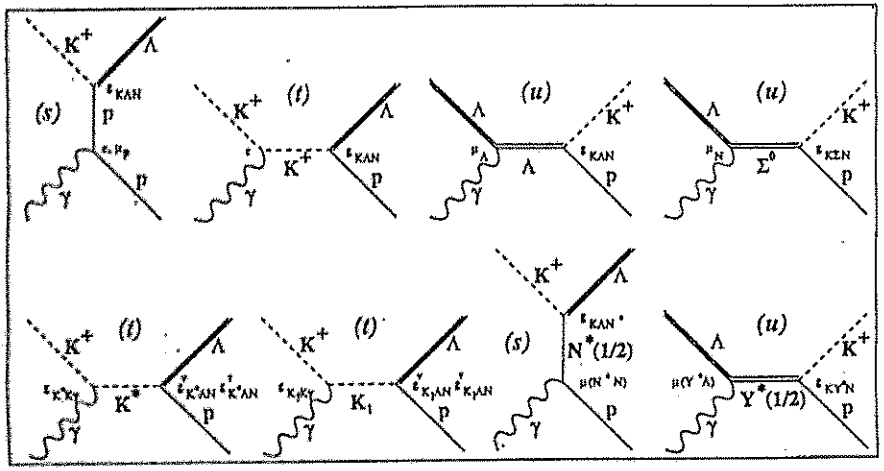


Abb. 8: Feynman diagrams for $\gamma p \to K^+\Lambda$

- Isobaric model
  - Feynman diagrams
    - ∗ Born terms
    - ∗ Resonances
  - Predictions for cross section and polarizations
- Fit of coupling constants
  - Cross section
  - Polarizations
    - ∗ Hyperon polarization
    - ∗ Target asymmetry [BONN78, Althoff et al.]
    - ∗ Photon polarizations (future)

Comparision of measurement and model
Total cross section

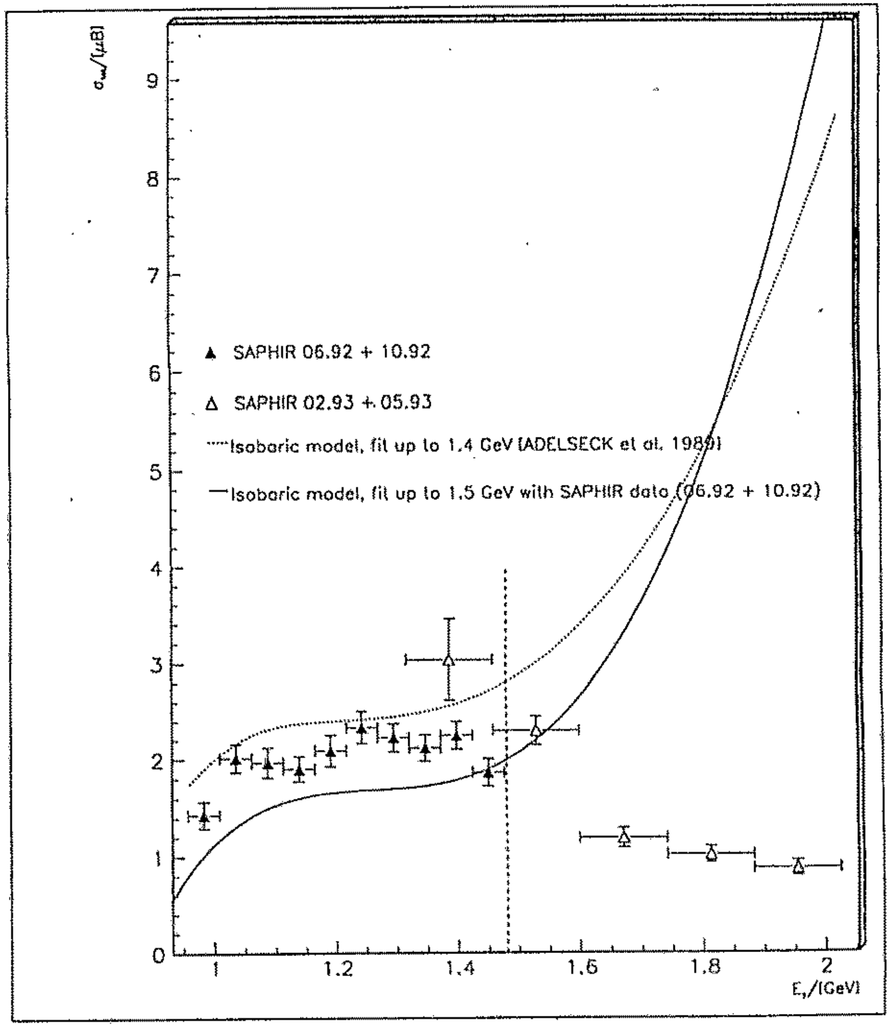


Abb. 9: Total cross section of $\gamma p \to K^+\Lambda$, fit with differential cross section

Comparision of measurement and model
Differential cross section

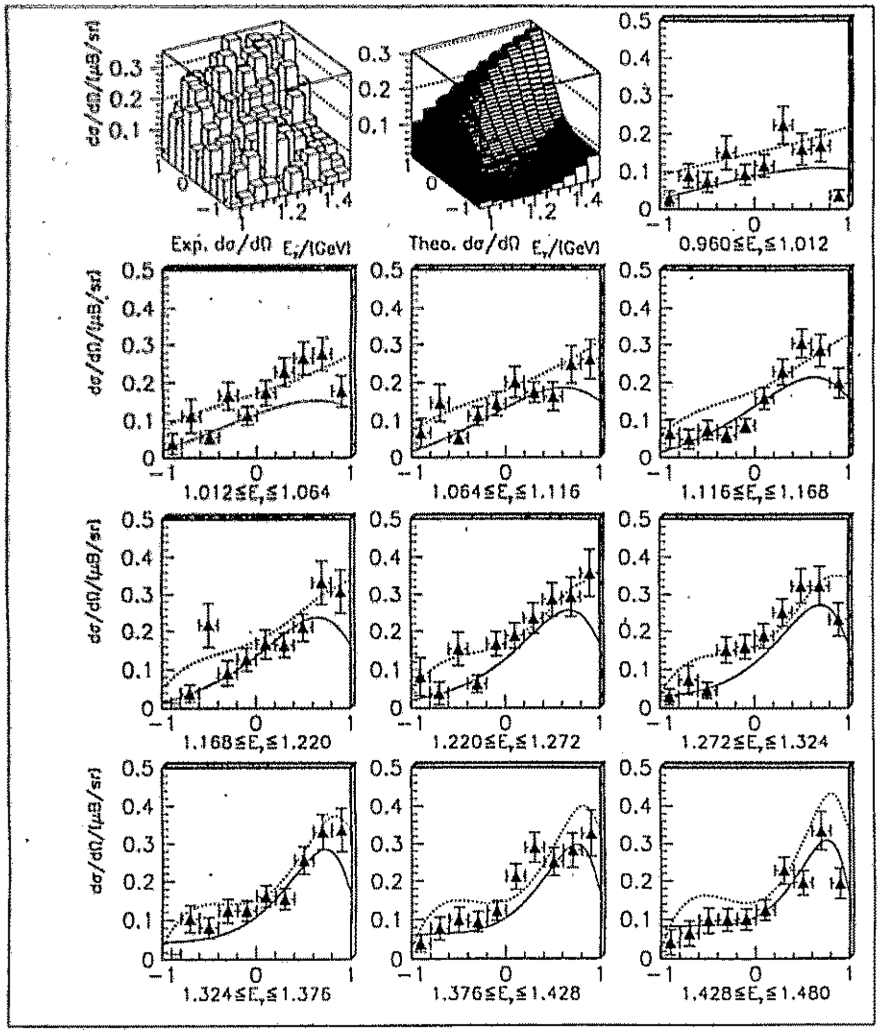


Abb. 10: Fit with $\frac{d\sigma}{d\Omega}$ of $\gamma p \to K^+\Lambda$

Comparision of measurement and model
Polarization

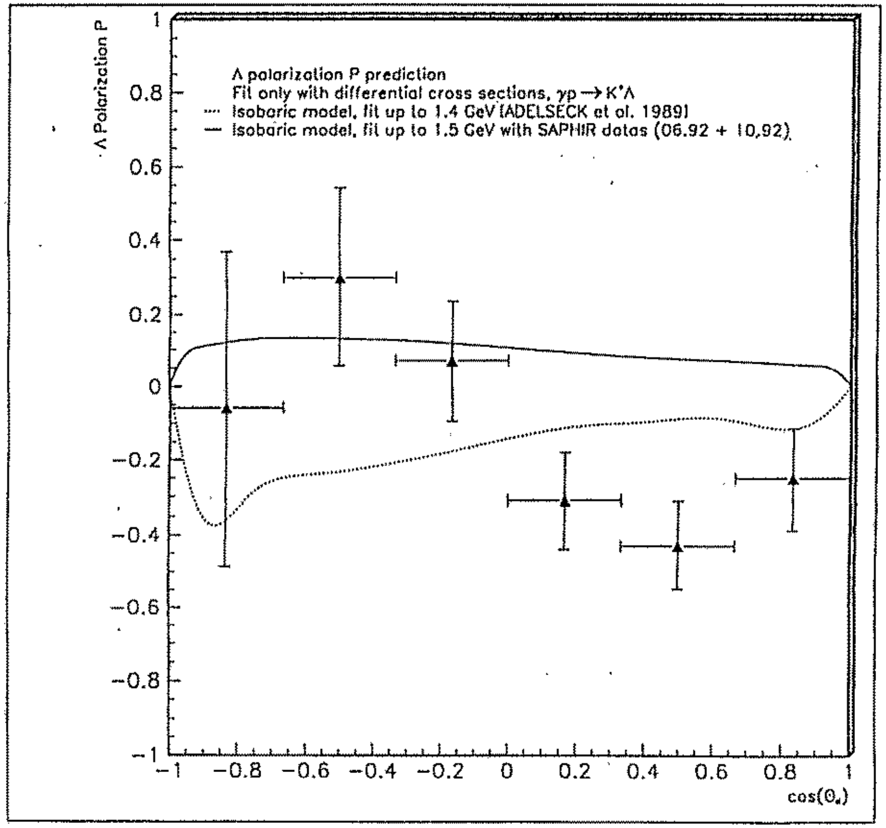


Abb. 11: Λ polarization for $\gamma p \to K^+\Lambda$

First fits including the Λ polarization and the target asymmetry were made yet, but they do not describe the measured polarization good enough.

Summary and Outlook

Summary

- Measured cross section and hyperon polarization of $\gamma p \rightarrow K^+\Lambda$ and $\gamma p \rightarrow K^+\Sigma^0$ with acceptance > 0 over full angle sphere from threshold up to 2 GeV at SAPHIR (4π detector)
- Good event identification
- Good background suppression
- Description of measured data with isobaric model including cross section and polarization

Outlook

- Analysis of further data
- Data taking with polarized photons and target
- Modification of isobaric model and study of new models

Elektropionproduktion
$H(e,e'\pi^+)$
an der Dreispektrometeranlage an MaMi

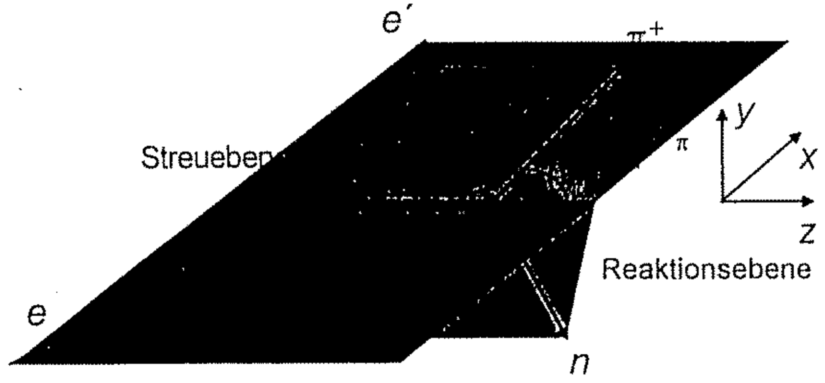
A1-Kollaboration
vorgetragen von Alfred Richter

Arbeitstreffen Kern- und Teilchenphysik
Pirna, 7. Oktober 1994

Inhalt

1. Einleitung / Motivation
2. Trennung der WQ-Anteile
3. Kinematische Verhältnisse
5. Datenanalyse
6. Resultate
7. Ausblick

Trennung der Anteile im Wirkungsquerschnitt



WQ in Ein-Photon-Näherung

Γ: Fluß der virtuellen Photonen

$$\boxed{\frac{d\sigma}{d\varepsilon_f d\Omega_f d\Omega_\pi} = \Gamma \frac{d\sigma_v}{d\Omega_\pi}}$$

für unpolarisierte Elektronen und unpolarisiertes Target:

Beachte: implizite $\sin\Theta_\pi$-Abhängigkeit in σ_{TL} *und* σ_{TT}

$$\frac{d\sigma_v}{d\Omega_\pi} = \boxed{\frac{d\sigma_T}{d\Omega_\pi} + \varepsilon_L \frac{d\sigma_L}{d\Omega_\pi}} + \left[2\varepsilon_L(1+\varepsilon)\right]^{\frac{1}{2}} \boxed{\frac{d\sigma_{TL}}{d\Omega_\pi}\cos\Phi_\pi} + \varepsilon \boxed{\frac{d\sigma_{TT}}{d\Omega_\pi}\cos 2\Phi_\pi}$$

Rosenbluth-Separation

Links/Rechts-Messung

Out-Of-Plane-Messung

Strukturfunktionen und Multipolamplituden

$$R_T = \left|E_{0+}\right|^2 + 0.5|2M_{1+} + M_{1-}|^2 + 0.5|3E_{1+} - M_{1+} + M_{1-}|^2$$
$$+2\cos\Theta Re\{E^*_{0+}(3E_{1+} + M_{1+} - M_{1-})\}$$
$$+\cos^2\Theta(|3E_{1+} + M_{1+} - M_{1-}|^2 - 0.5|2M_{1+} + M_{1-}|^2$$
$$-0.5|3E_{1+} - M_{1+} + M_{1-}|^2)$$
$$R_L = |L_{0+}|^2 + 4|L_{1+}|^2 + |L_{1-}|^2 - 4Re\{L^*_{1+}L_{1-}\}$$
$$+2\cos\Theta Re\{L^*_{0+}(4L_{1+} + L_{1-})\} + 12\cos^2\Theta(|L_{1+}|^2 + Re\{L^*_{1+}L_{1-}\})$$
$$R_{TL} = -\sin\Theta Re(L^*_{0+}(3E_{1+} - M_{1+} + M_{1-}) - (2L^*_{1+} - L^*_{1})E_{0+}$$
$$+6\cos\Theta(L^*_{1+}(E_{1+} - M_{1+} + M_{1-}) + L^*_{1-}E_{1+}))$$
$$R_{TT} = 3\sin^2\Theta(3/2|E_{1+}|^2 - 0.5|M_{1+}|^2 - Re\{E^*_{1+}(M_{1+} - M_{1-}) + M^*_{1+}M_{1-})$$

Multipol-Amplituden:

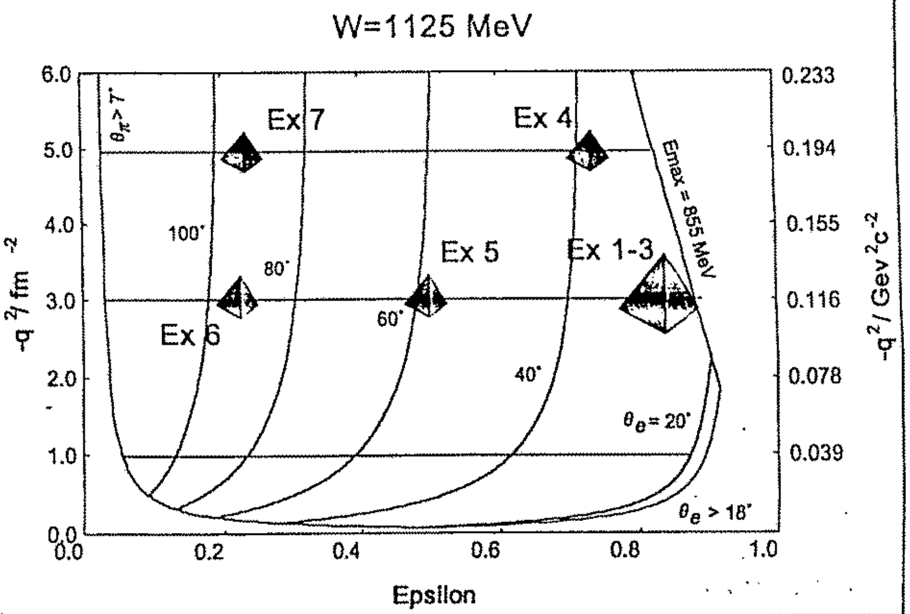
L	*elektromagn. Multipol*	$\pi N-System$ J	$\pi N-System$ I	*Pionprod. Multipol*
0	$C0$	1/2	1	L_{1-}
1	$E1/C1$	1/2	0	E_{0+}/L_{0+}
1	$M1$	1/2	1	M_{1-}
1	$M1$	3/2	1	M_{1+}
2	$E2/C2$	3/2	1	E_{1+}/L_{1+}

E_{0+}, M_{1+}, L_{0+} sind groß
$E_{1+}, M_{1-}, L_{1+}, L_{1-}$ sind klein

somit bspw: $\sigma_{LT} \sim R_{LT} \sim (A + B\cos\Theta_\pi)\sin\Theta_\pi$

Kinematischer Bereich

$W = 1125$ MeV							
Name	q^2	ε	E_i	E_f	Θ_e	Θ_π	$\|p_\pi\|$
	$(GeV/c)^2$		MeV	MeV			MeV/c
Ex 1	-0.117	0.834	855.11	587.35	27.93°	39.31°	188.84
Ex 2						46.31°	
Ex 3						32.31°	
Ex 4		0.500	510.11	242.35	58.22°	28.31°	
Ex 5		0.219	405.11	137.36	92.96°	18.41°	
Ex 6	-0.195	0.742	855.11	545.79	37.72°	38.27°	209.62
Ex 7		0.229	495.11	185.79	93.45°	20.12°	



Dreispektrometeranlage

3 Vielzweckspektrometer A,B,C für Koinzidenzexperimente
der Kollaboration "Virtuelle Photonen" (A1)
Auflösungen: dp/p < 5 x 10-5, Winkel: < 0.3 mrad

Spektrometer A

pmax = 735 MeV/c
Akzeptanzen:

Impuls Δp = 22 %
Winkel:
dispersiv +/- 70 mrad
n-disp. +/- 100 mrad
Raumwinkel: 28 msr

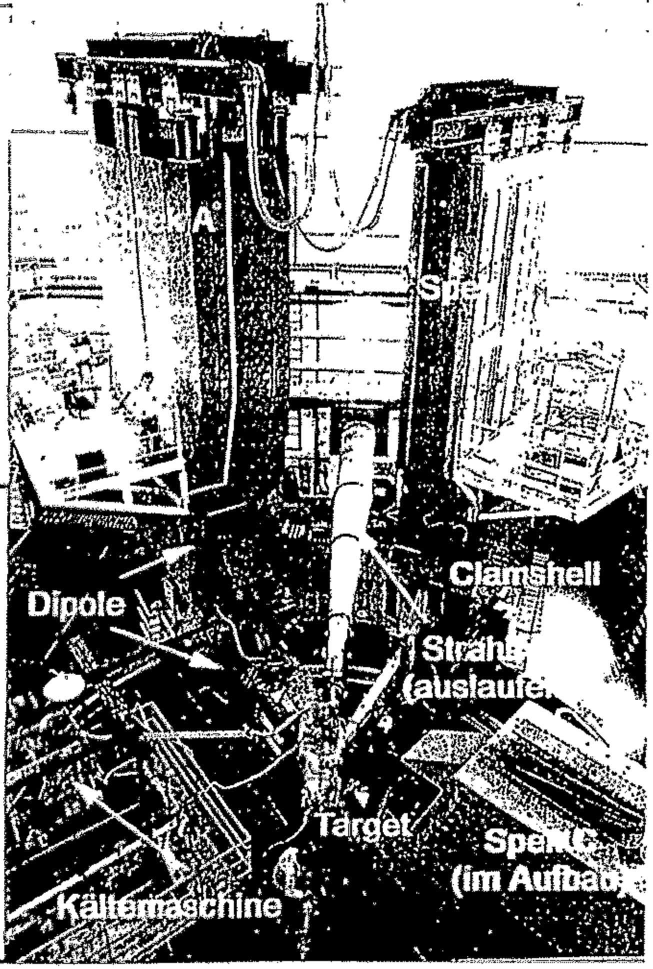
Länge Zentralstrahl:
10.75 m

Spektrometer B

pmax = 870 MeV/c
Akzeptanzen:

Impuls Δp = 15 %
Winkel:
dispersiv +/- 70 mrad
n-disp. +/- 20 mrad
Raumwinkel: 5.6 msr

Länge Zentralstrahl:
12.0 m



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Detektorsysteme

Vertexbestimmung: 4 vertikale Driftkammern (VDC)
Triggerdetektoren: 2 segmentierte Plastikszintillationsebenen
+ Gas-Tscherenkow-Detektor
Größe der Fokalebene (Spek A): 1950 x 450 mm

VDC

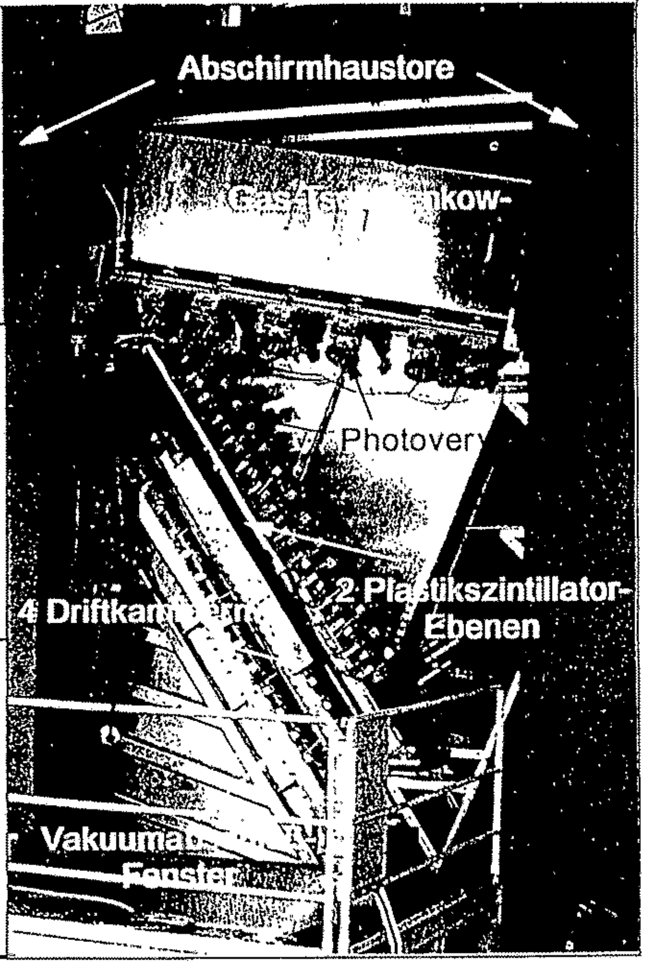
~ 2000 Kanäle
Einzeldrahtauslese
Ortsauflösung ~ 90 um
Winkelaufl. ~ 0.3 mrad
Nachweiswahrsch.
99.99 %

Szintillatoren

14/15 Segmente/Ebene
beidseitig ausgelesen
intr. Zeitaufl. σ ~ 300 ps
Koinz-Zeitauflösung
σ < 500 ps
Nachweiswahrsch.
> 99.5 %

Tscherenkow-Detektor

Radiator: Freon 114
12/6 sphär. Spiegel
mit PM XP 4500 B
Nachweiswahrsch.:
> 99.9 %



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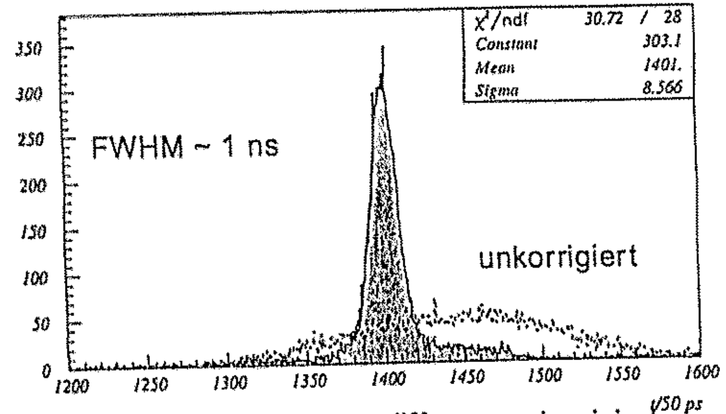
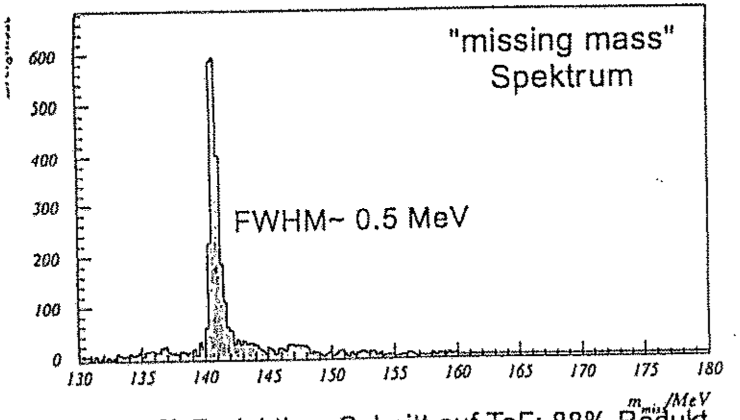
Teilchenidentifikation

Koinzidenzzeitspektrum

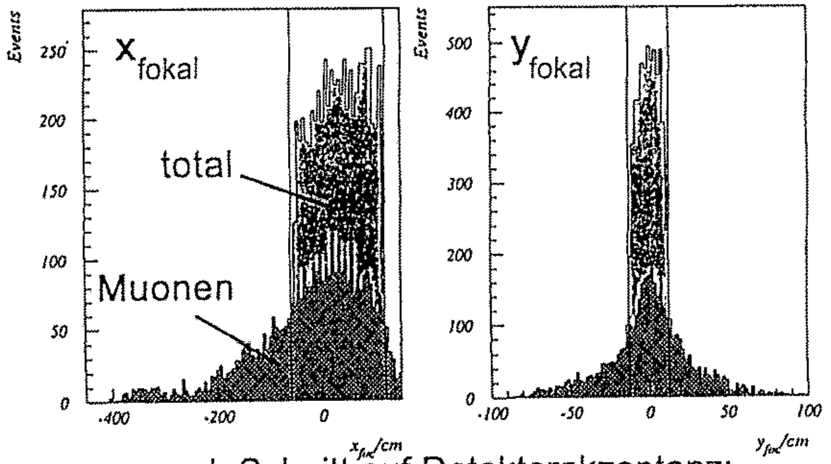


bezüglich Flugwegdifferenzen korrigiert

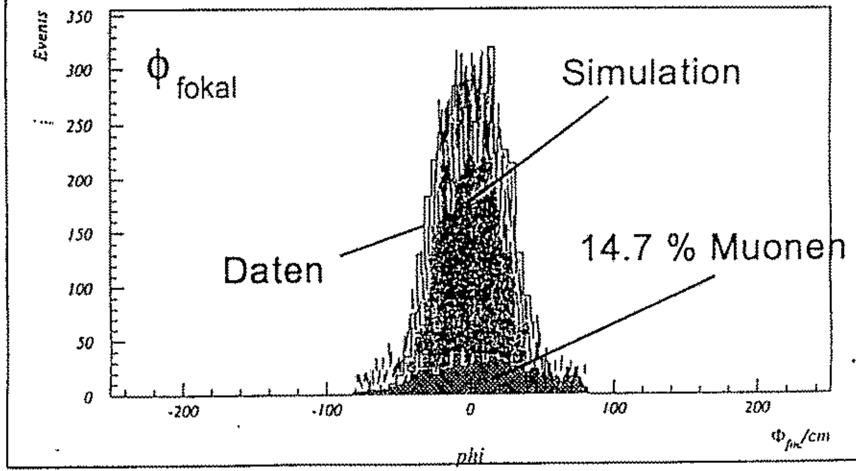


Tscher: 59% Reduktion, Schnitt auf ToF: 88% Redukt.

Pion-Zerfalls-Simulation

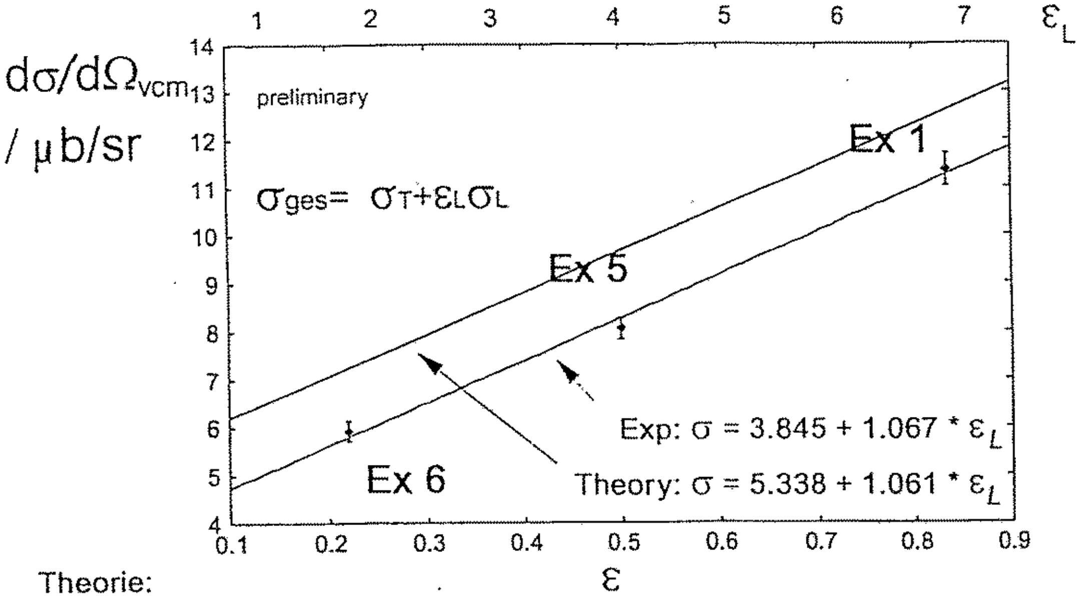


nach Schnitt auf Detektorakzeptanz:



L/T Separation

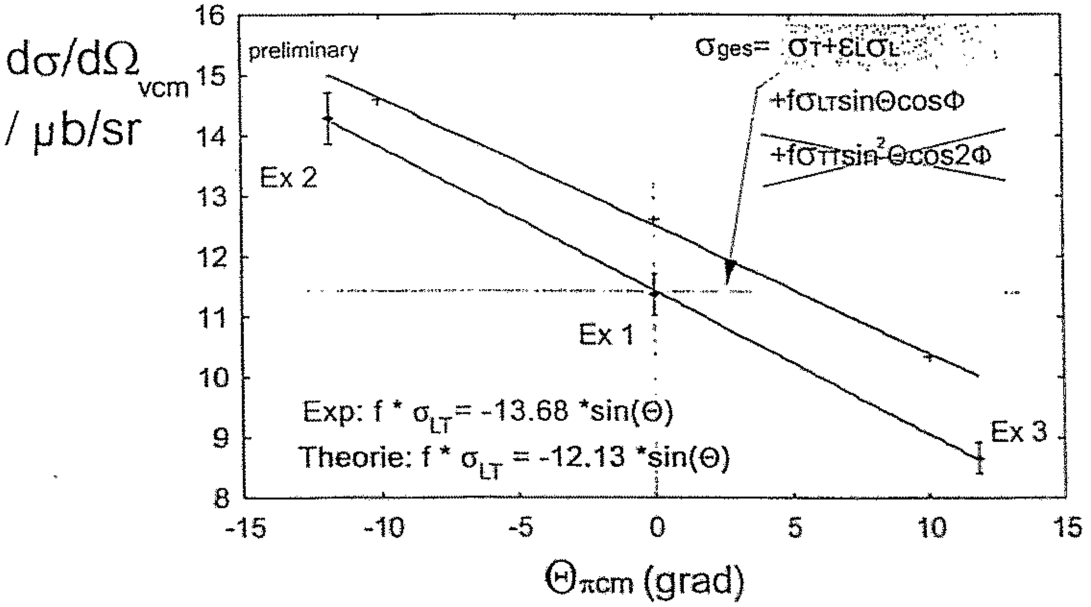
W=1125 MeV, q**2=-0.117 (GeV/c)**2



Theorie:
eff. Lagr. (Blömqvist/Laget, Tiator)

Interferenzterm LT

W=1125 MeV, q**2=-0.117 (GeV/c)**2, eps=0.834



Theorie: eff. Lagr. (Blomqvist/Laget, Tiator)

CERN/LEAR-Aktivitäten

(*Koordinator:* **U. Landgraf**)

1. **J. Pretz** (Mainz)
   Messung der Valenz- und Seequarkpolarisation im Nukleon
2. **J. Hartmann** (München)
   Laserspektroskopie langlebiger Zustände in antiprotonischem Helium
3. **T. v. Egidy** (München)
   Antiprotoninduzierte Spaltung und Kernaufheizung
4. **J. Brose** (Mainz)
   Untersuchung der Annihilation von Antiprotonen in Deuterium
5. **T. Degener** (Bochum)
   Anwendung neuronaler Netze in der Datenanalyse

Messung der Valenz- und Seequarkpolarisation im Nukleon

Spin **M**uon **C**ollaboratio

Jörg Pretz
Universität Mainz

Pirna
Okt. '94

Woher kommt der Spin des Nukleons?

- statisches SU(6) Quarkmodell:
  $|p\uparrow\rangle = \frac{1}{\sqrt{18}}(2u^\uparrow u^\uparrow d^\downarrow - u^\uparrow u^\downarrow d^\uparrow - u^\downarrow u^\uparrow d^\uparrow + \text{perm.})$

  $\curvearrowright \Delta u := u^\uparrow - u^\downarrow = \frac{4}{3} \; \frac{\hbar}{2}$

  $\Delta d := d^\uparrow - d^\downarrow = -\frac{1}{3} \; \frac{\hbar}{2}$

- inklusive tief inelast. ℓ-N Streuung
  $\vec{\ell} + \vec{N} \rightarrow \ell' + X$ & SU(3) Matrixelem. F, D

  $\curvearrowright \Delta U = \Delta u + \Delta\bar{u} = 0{,}83 \pm 0{,}03$

  $\Delta D = -0{,}43 \pm 0{,}03$

  $\Delta S = -0{,}10 \pm 0{,}03$

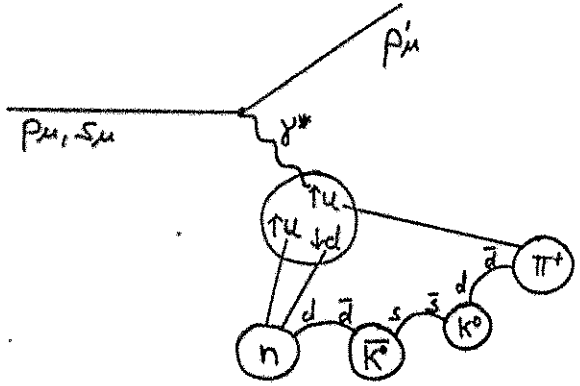
$\curvearrowright \Delta\Sigma = \Delta U + \Delta D + \Delta S = 0{,}31 \pm 0{,}07$

→ Keine Trennung von Δq_v und Δq_s möglich!

→ Keine Messung der x-Bjorken-Abhängigkeit $\Delta q(x)$ möglich!

Semi-inklusive ℓ-Nukleon Streuung: $\vec{\ell}+\vec{N} \rightarrow \ell' + \text{Hadron} + X$

3



$$\boxed{\begin{aligned} Q^2 &= -(p_\mu - p'_\mu)^2 \\ \nu &= E - E' \\ x &= \frac{Q^2}{2M_p \nu} \\ z &= \frac{E_{Had}}{\nu} \end{aligned}}$$

$$\boxed{\sigma_h^{\frac{1}{2}(\frac{3}{2})}(x,z) \underset{QPM}{\widetilde{}} \sum_{\substack{i=u,d,s,\\ \bar{u},\bar{d},\bar{s}}} e_i^2 \, q_i^{\uparrow(\downarrow)}(x) \cdot D_{q_i}^h(z)}$$

$$A^h_{(x,z)} = \frac{\sigma_h^{\frac{1}{2}}(x,z) - \sigma_h^{\frac{3}{2}}(x,z)}{\sigma_h^{\frac{1}{2}}(x,z) + \sigma_h^{\frac{3}{2}}(x,z)}$$

$$\boxed{A^h_{(x,z)} = \frac{\sum e_i^2 \, \Delta q_i(x) \, D_{q_i}^h(z)}{\sum e_i^2 \, q_i(x) \, D_{q_i}^h(z)}}$$

$$\Delta q = q^\uparrow - q^\downarrow$$
$$q = q^\uparrow + q^\downarrow$$

4

Allgemein gilt:

$$\boxed{A(x,z) = \sum_i c_i \, \Delta q_i(x)}$$

wobei $c_i = c_i(\, q(x), D(z))$

- $q(x)$: unpolarisierte Quarkverteilungen sind gemessen

- $D(z)$: Es tauchen 36 Fragmentationsfunktionen auf:

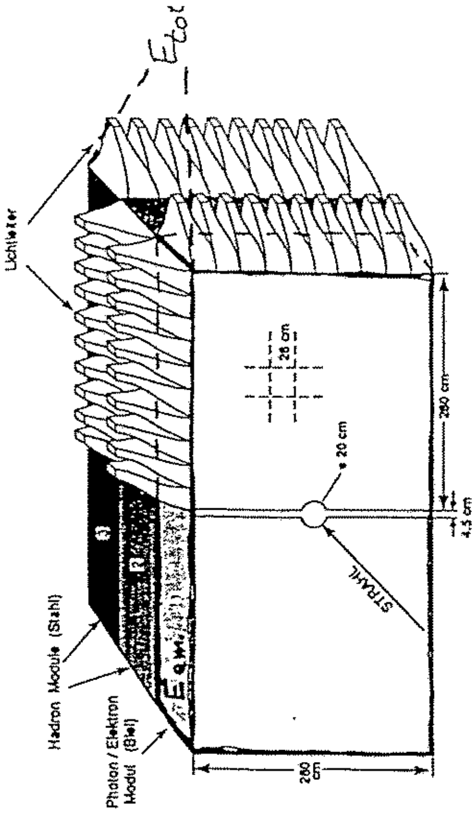
$$D_{u,\bar{u},d,\bar{d},s,\bar{s}}^{\pi^+,\pi^-,K^+,K^-,p,\bar{p}}$$

EMC hat unter Annahme von Isospin- und Ladungskonjugationssymmetrie die nonstrange FF bestimmt:

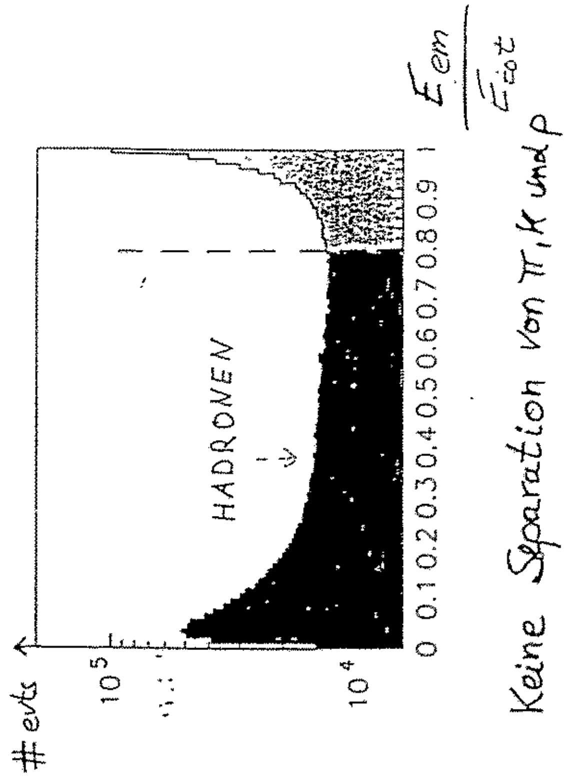
$$\begin{matrix} D_u^{\pi^+} & \underset{I}{\overset{\uparrow}{=}} & D_d^{\pi^-} & \underset{LK}{\overset{\uparrow}{=}} & D_{\bar{d}}^{\pi^+} & \underset{I}{\overset{\uparrow}{=}} & D_{\bar{u}}^{\pi^-} \\ \vdots & & & & & & \vdots \end{matrix}$$

Unter Annahme von SU(3)-Flavoursymmetrie können auch die $D_{s\bar{s}}^{\cdots\cdots}$ durch die EMC-FF ausgedrückt werden.

Kalorimeter



e.m. - Teil : 20 StrahlungsLängen
insgesamt : 5,5 hadr. WW-Längen

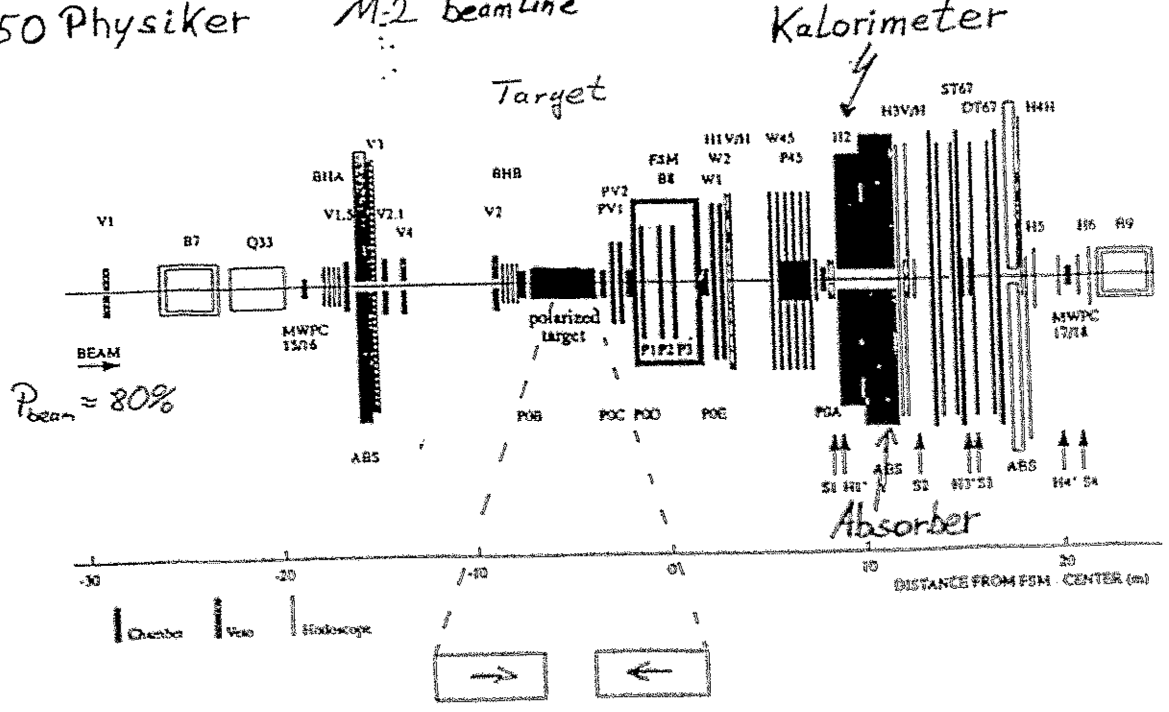


Keine Separation von π, K und p

SMC EXPERIMENT - SPECTROMETER

~25 Institute
~150 Physiker

CERN Na 47
M2 beamline

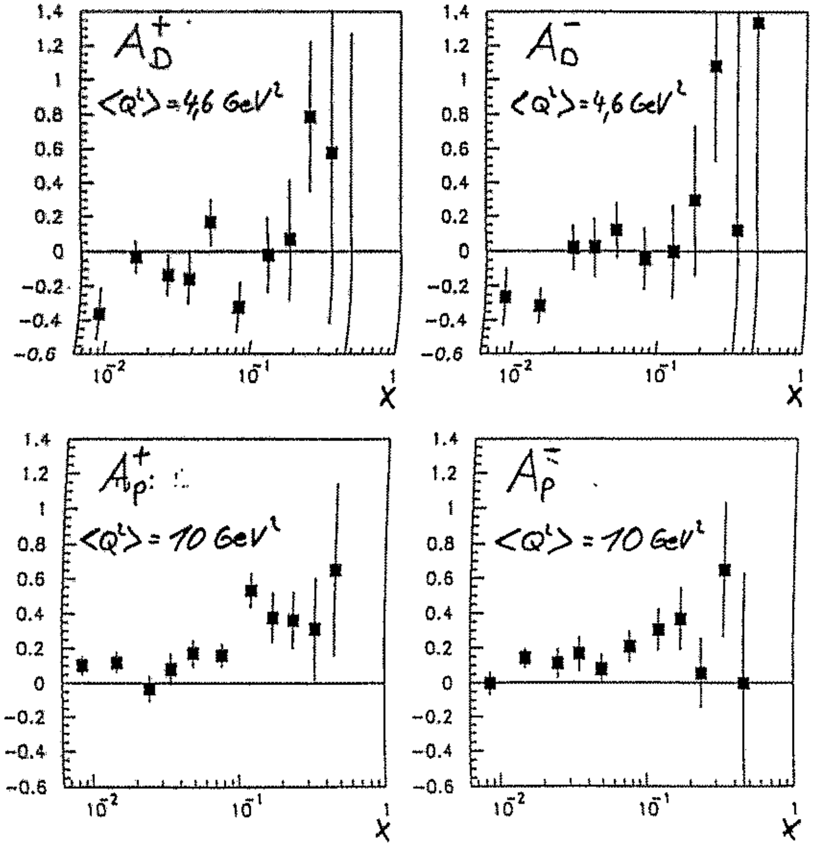


Semi-inklusive Asymmetrien

7

$$A = \frac{1}{\underset{\text{dilution-Factor}}{f} \cdot \underset{\text{Strahl-Targetpol.}}{P_B \cdot P_T} \cdot \underset{\text{Depolarisations-Faktor}}{D}} A^{raw}$$

da $A(x,z) = A(x)$ integriere über z mit $z_{min} = 0{,}2$



$0{,}006 < X < 0{,}6$

Methode

8

Mit Deuteron- und Protontarget können 6 Asymmetrien gemessen werden:

$$\begin{array}{r} \text{semi-inkl. Asymmetrien}\left\{\begin{pmatrix} A_D^+ \\ A_D^- \\ A_p^+ \\ A_p^- \end{pmatrix}\right. \\ \text{inkl. Asymmetrien}\left\{\begin{pmatrix} A_D^\mu \\ A_p^\mu \end{pmatrix}\right. \end{array} = \hat{C}(q,D) \begin{pmatrix} \Delta u \\ \Delta \bar{u} \\ \Delta d \\ \Delta \bar{d} \\ \Delta s \\ \Delta \bar{s} \end{pmatrix}$$

$$\Delta u = \Delta u_v + \Delta u_s$$
$$\Delta d = \Delta d_v + \Delta d_s$$

Annahme:

$$\Delta u_s = \Delta \bar{u} = \Delta d_s = \Delta \bar{d} =: \Delta \bar{q}$$

Sensitivität auf $\Delta \overset{(-)}{s}$ zu gering ($\delta(\Delta s) > s$)

$\rightarrow$ Annahme: $\Delta s + \Delta \bar{s} = \alpha S$, α so bestimmt, daß $\int dx\, (\Delta s + \Delta \bar{s}) = -0{,}12$

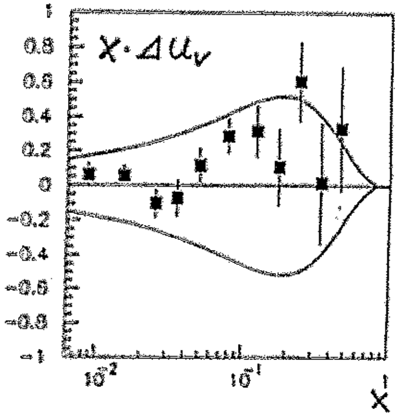
$\rightarrow$ Löse LGS für

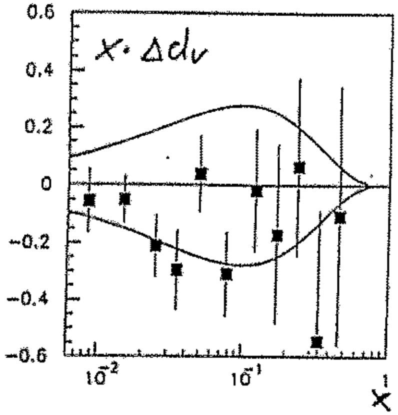
$$\boxed{\Delta u_v,\ \Delta d_v \text{ und } \Delta \bar{q}}$$

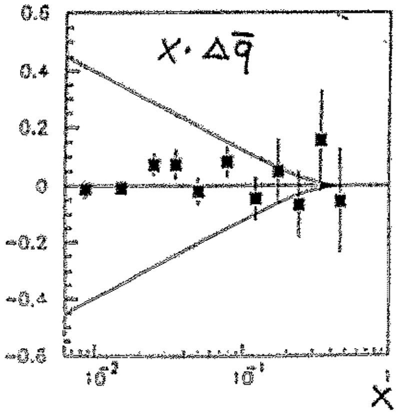
Δu_v, Δd_v und $\Delta\bar{q}$

Kurven: unpol. Quarkverteilungen $q_i(x)$

$$|\Delta q_i(x)| = |q_i^{\uparrow}(x) - q_i^{\downarrow}(x)| \leq q_i^{\uparrow}(x) + q_i^{\downarrow}(x) = q_i(x)$$







Ergebnisse

$$\int_0^1 dx\, \Delta u_v(x) = 0{,}83 \pm 0{,}26$$

$$\int_0^1 dx\, \Delta d_v(x) = -0{,}67 \pm 0{,}33$$

$$\int_0^1 dx\, \Delta\bar{q}(x) = 0{,}07 \pm 0{,}07$$

nur statistischer Fehler!

Zusammenfassung

- erste Messung von semi-inklusiven Spin-Asymmetrien bei

  $Q^2 = 4{,}6$ bzw. $10 \ \mathrm{GeV}^2$

  $0{,}006 < x < 0{,}6$

  dadurch möglich:
  - Trennung von Δq_v und Δq_s
  - Bestimmung der x-Bjorken Abhängigkeit von $\Delta q(x)$
- Ergebnis:

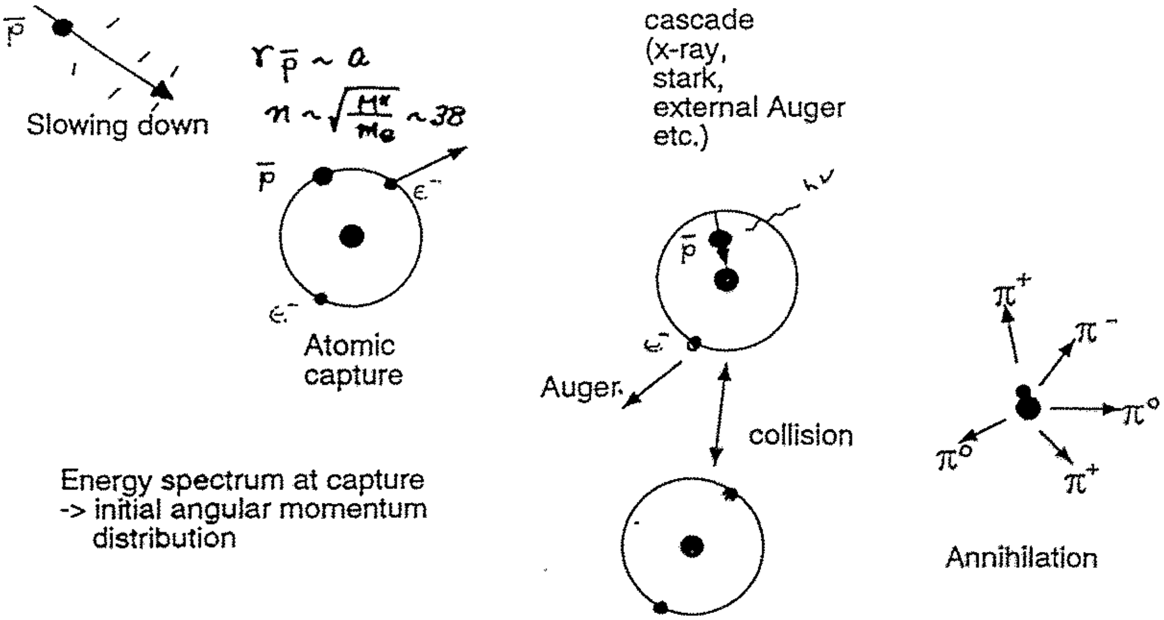
  $\Delta u_v > 0, \ \Delta d_v < 0, \ \Delta \bar{q} \approx 0$

  → Spin wird von Valenz- und nicht von den nonstrange Seequarks getragen

Ausblick

- '94-er Daten werden Deuteronstatistik vervierfachen
- geplant: '95 Messung mit Protontarget

Fate of $\bar{p}$ stopping in condensed matter



Energy spectrum at capture
-> initial angular momentum
distribution

Laserspektroskopie langlebiger Zustände in antiprotonischem Helium

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F. J. Hartmann, H. Daniel, T. von Egidy, B. Ketzer, W. Müller, A. Niestroj,
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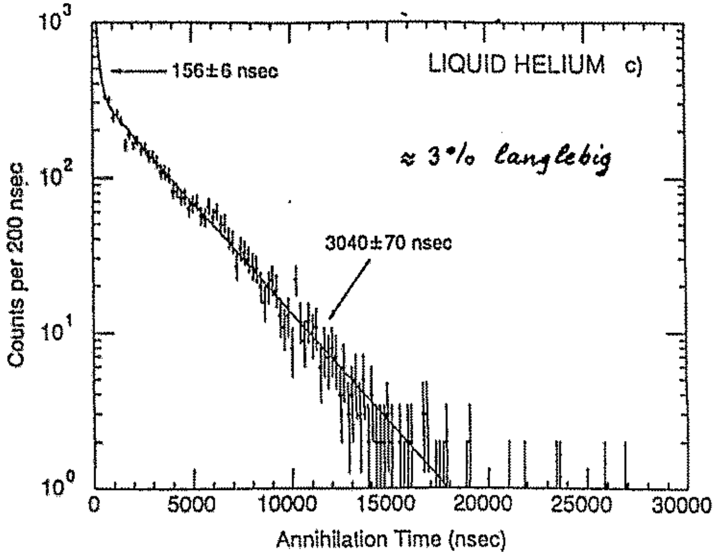
Laserspektroskopie langlebiger Zustände in antiprotonischem He

M. Iwasaki et al., PRL 67, 1246 (1991): KEK



≈ 3% langlebig

Fig. 2c)

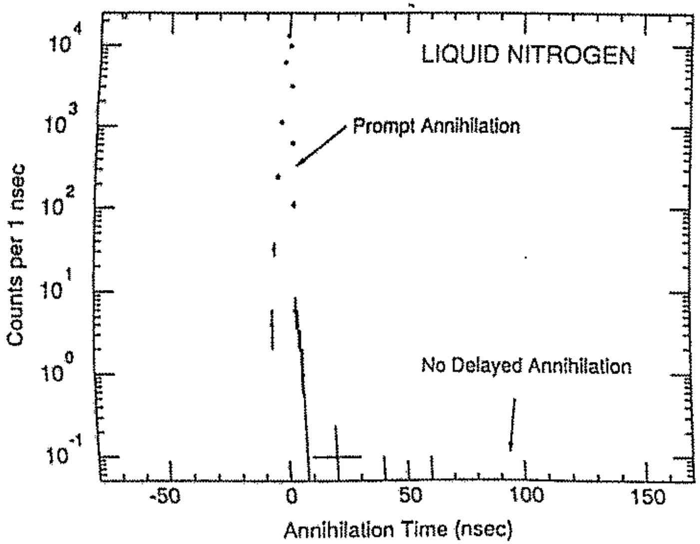
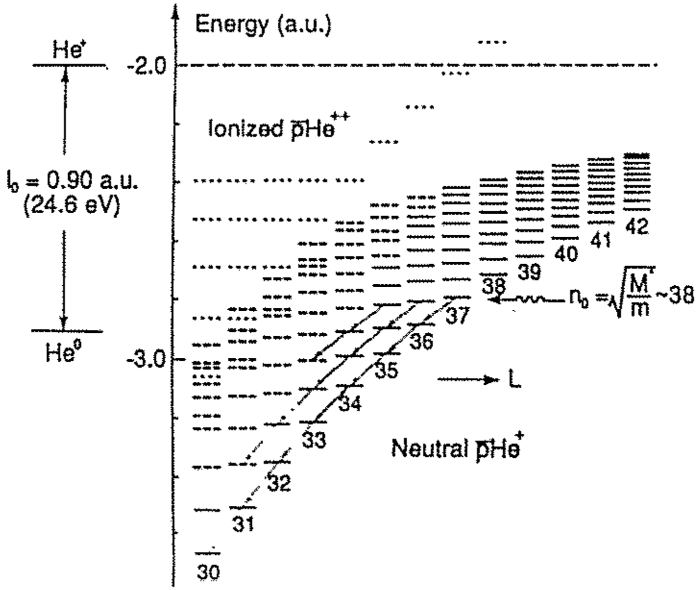
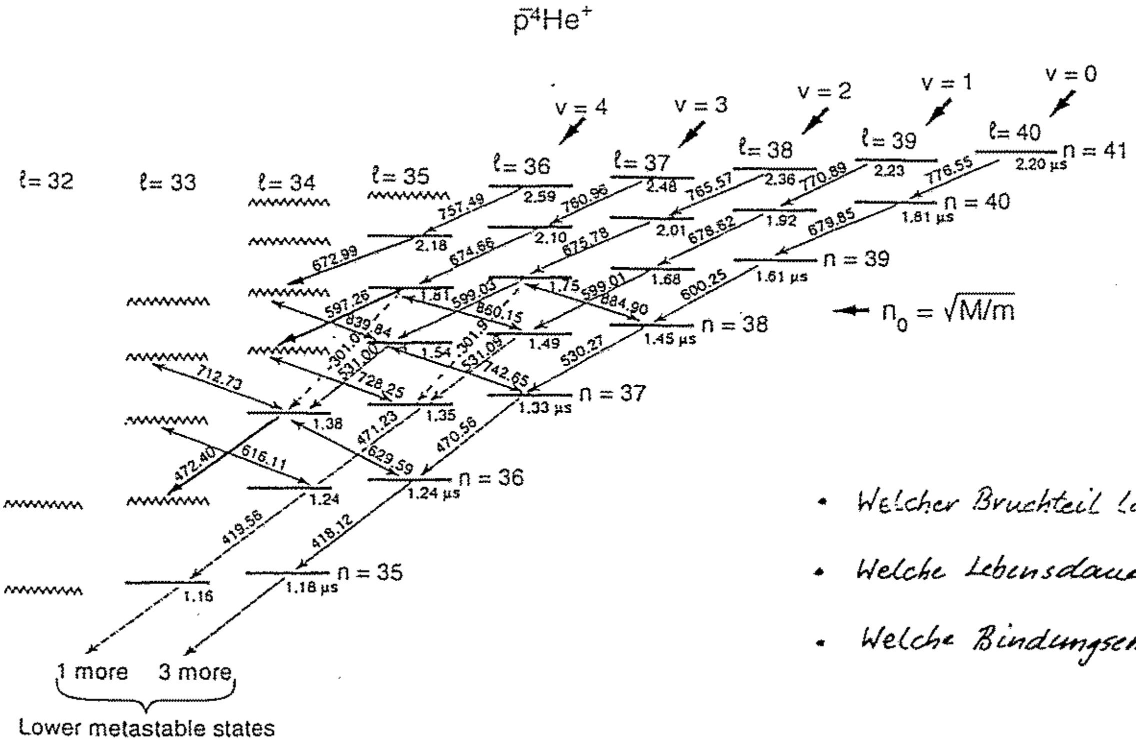
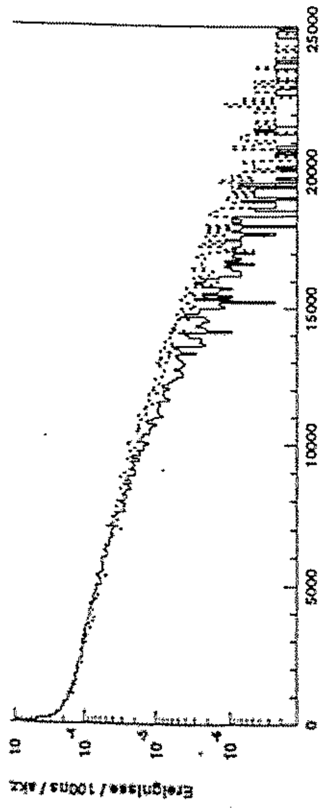


Fig. 3

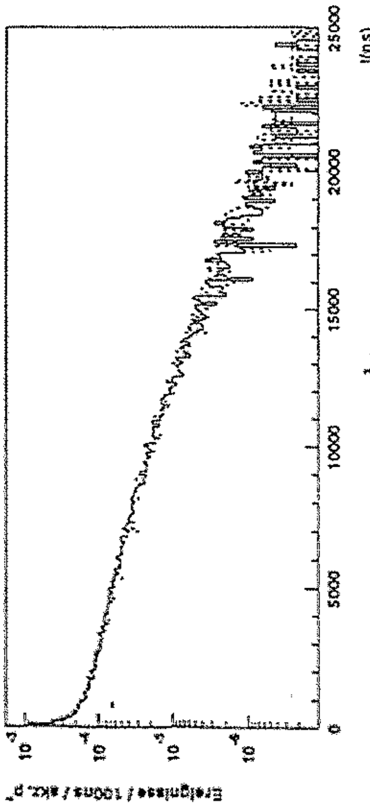




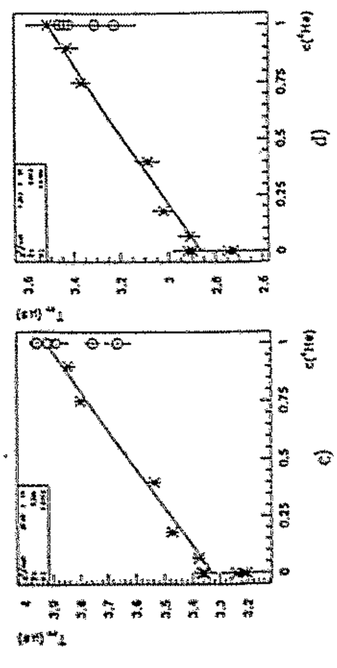
- Welcher Bruchteil langlebig?
- Welche Lebensdauern?
- Welche Bindungsenergien?



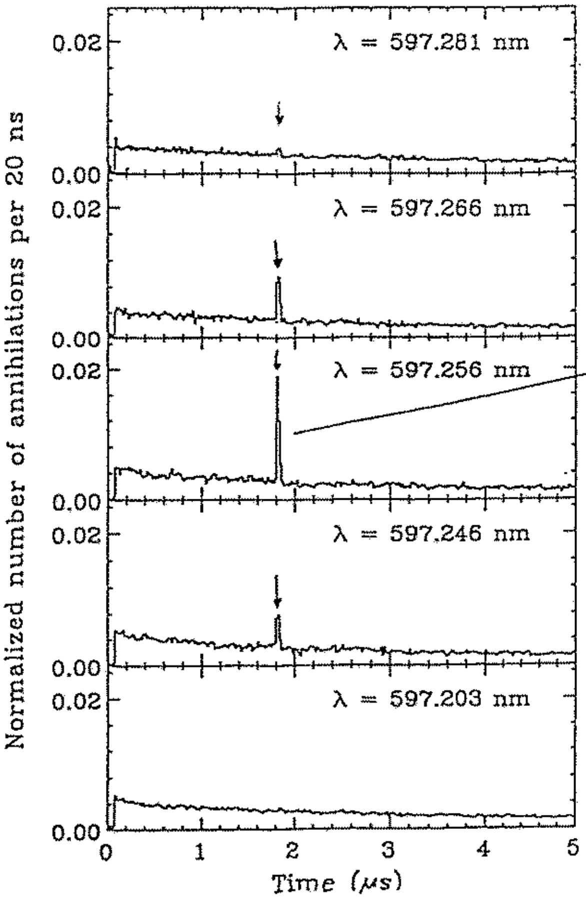
a) ³He, ⁴He

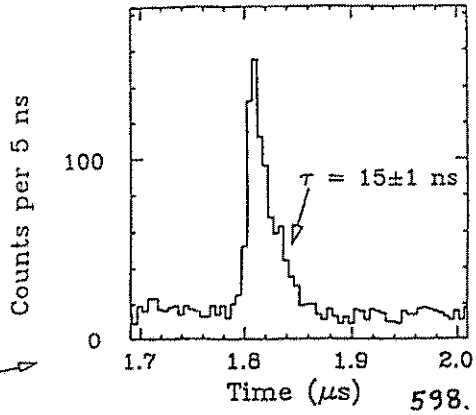


b) Zeitskala ³He gedehnt



c) d)



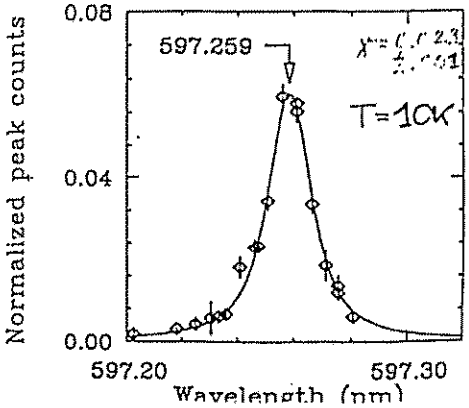


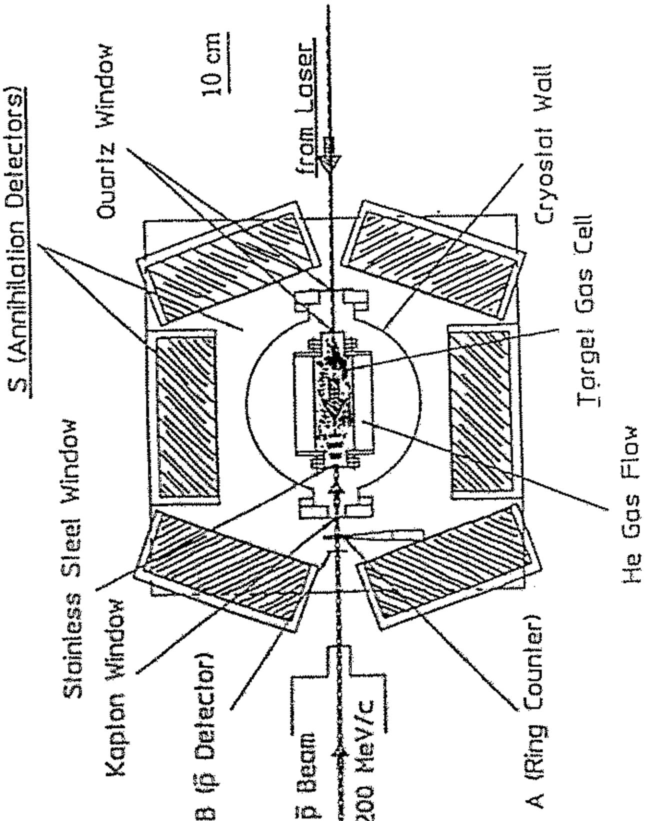
598.01 Shi

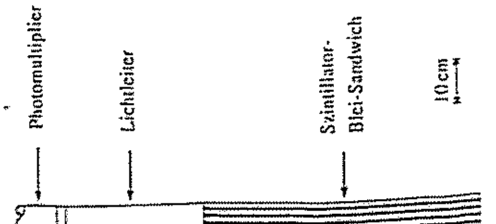
λ = 597.259(2):
(39,35 → 38,34)

598.10 Yre

597.14 [illegible]

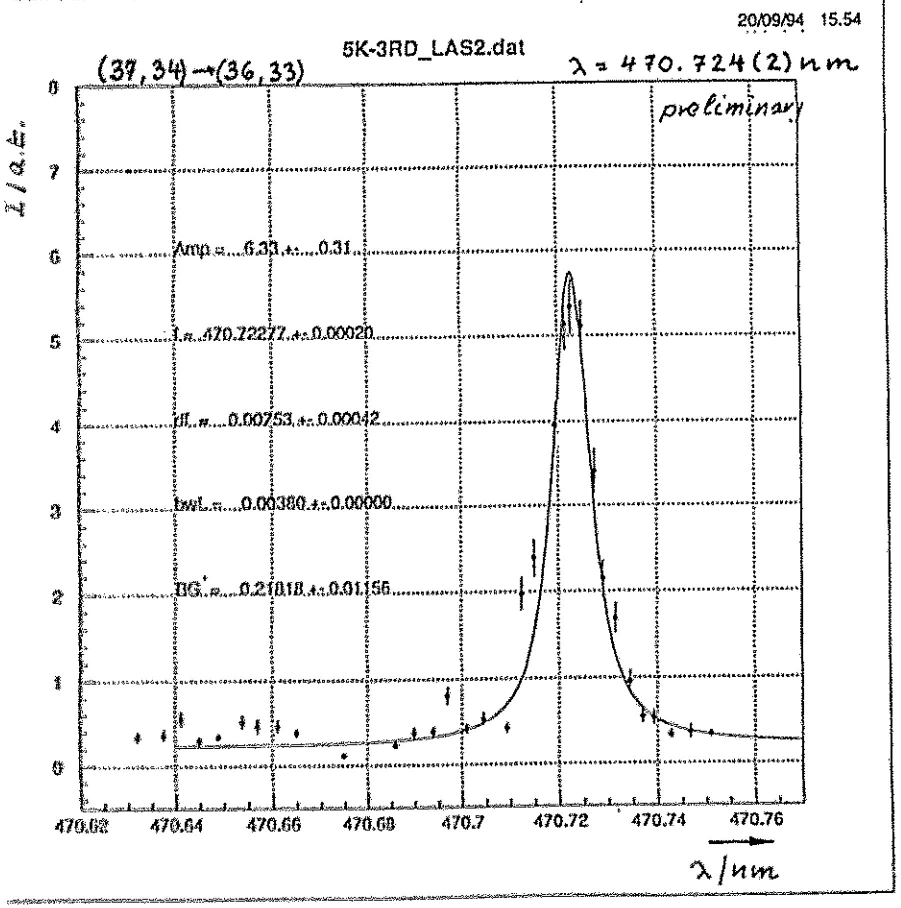


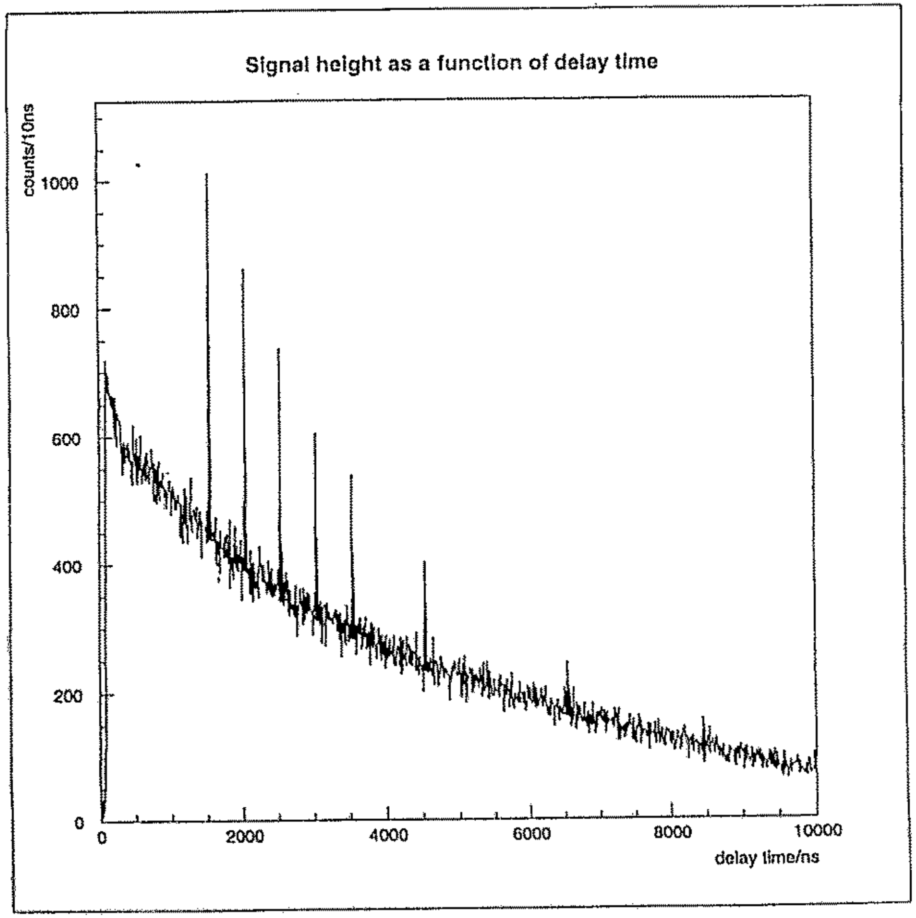




1994

neue Resonanz

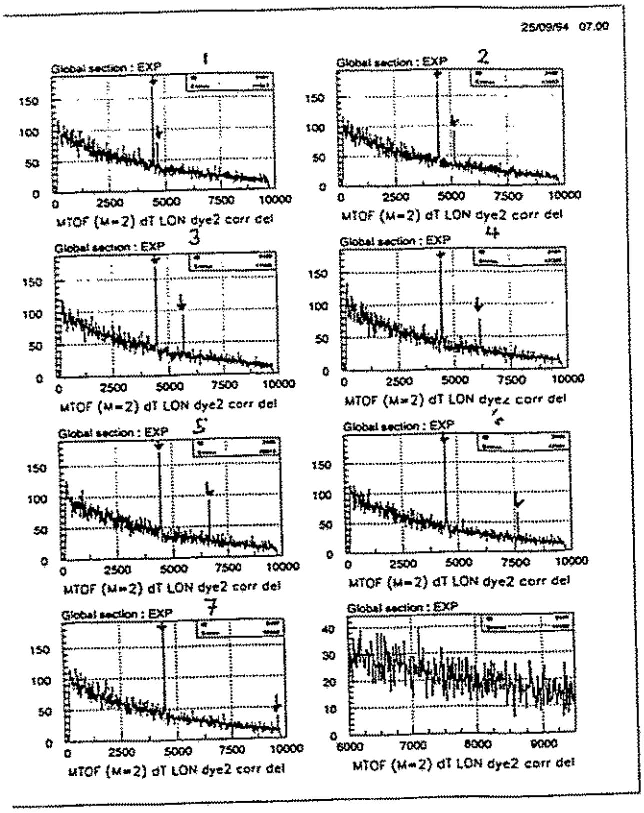


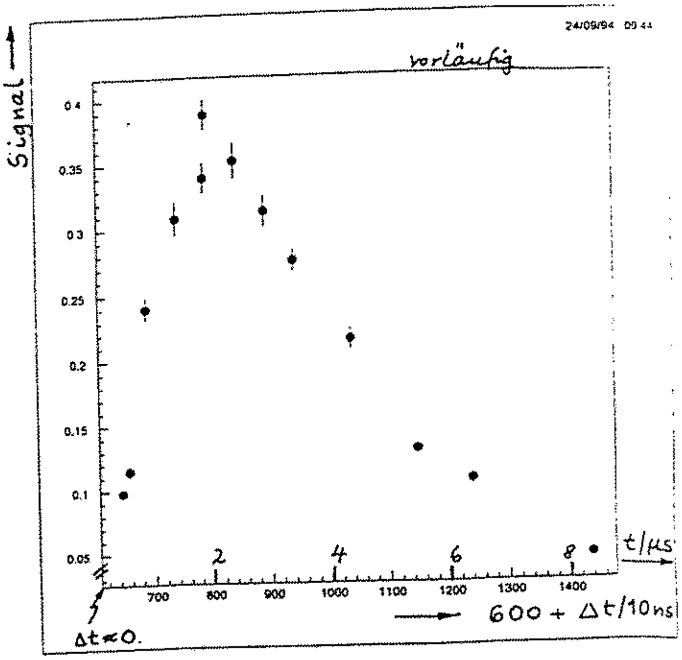


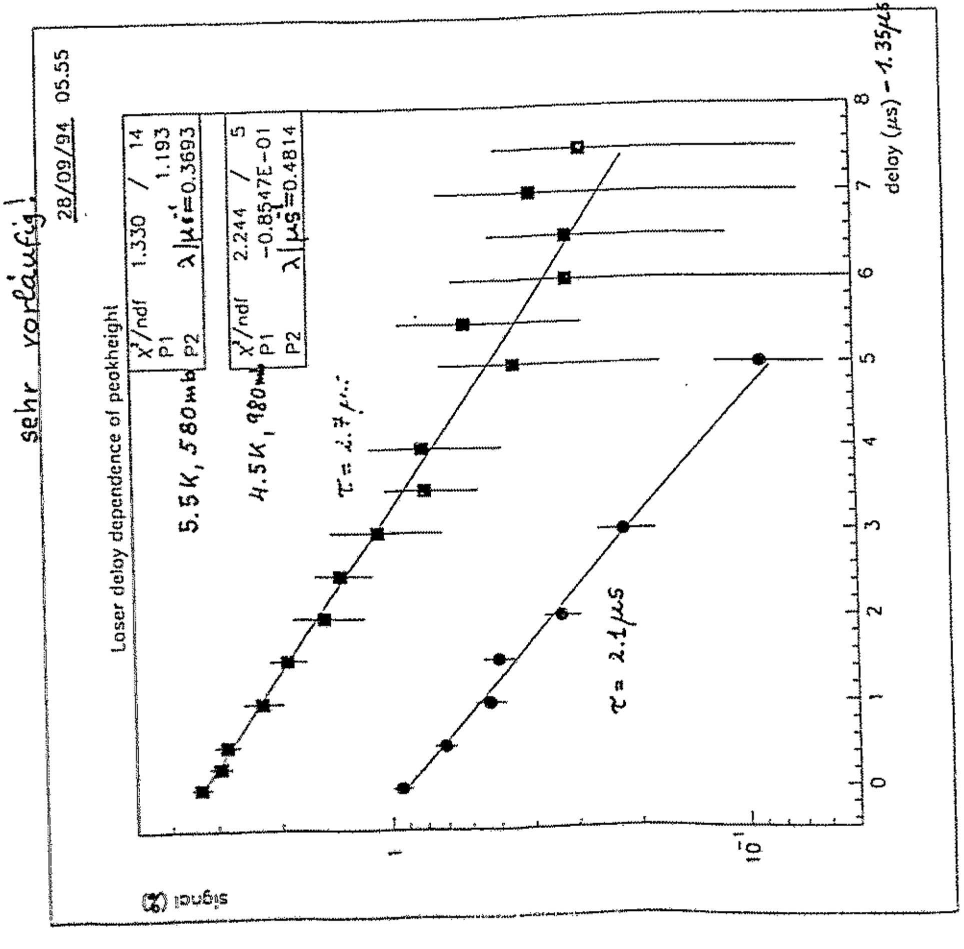
λ = 470.49 nm Ohtsuki

λ = 471.36 nm Shimamura

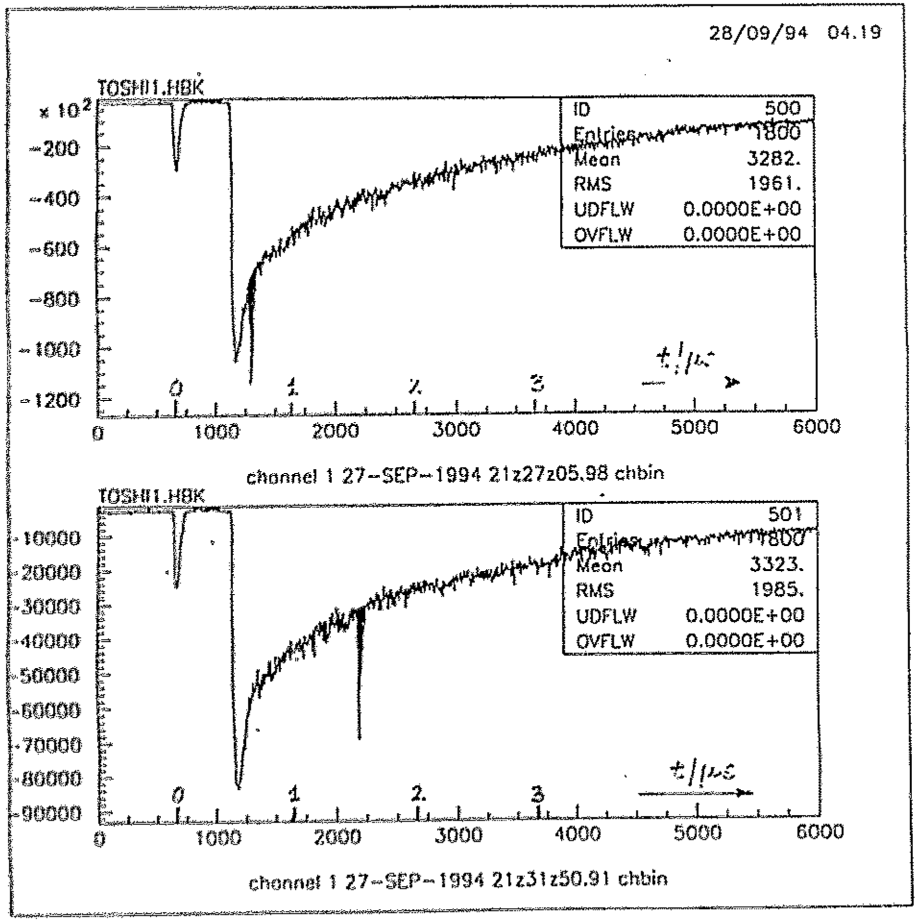
λ = 470.88 nm Kartavtsev


25/09/94 07.00
Global section : EXP
1
2
3
4
5
6
7
150
100
50
0
2500
5000
7500
10000
MTOF (M=2) dT LON dye2 corr del
40
30
20
10
6000
7000
8000
9000

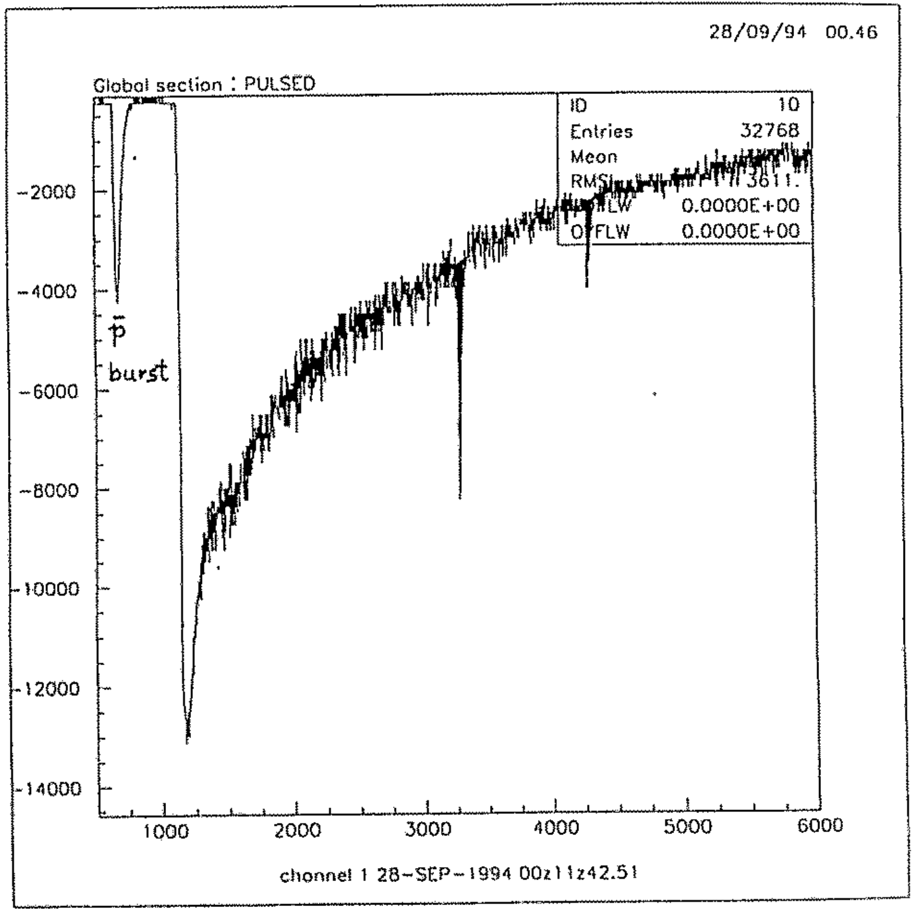

24/09/94 09.44
vorläufig
Signal →
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
700
800
900
1000
1100
1200
1300
1400
2
4
6
8
t/μs
Δt≈0.
600 + Δt/10ns


sehr vorläufig!
28/09/94 05.55
Laser delay dependence of peakheight
χ²/ndf 1.330 / 14
P1 1.193
P2 λ|μs⁻¹=0.3693
χ²/ndf 2.244 / 5
P1 −0.8547E−01
P2 λ|μs=0.4814
5.5K, 580mb
4.5K, 980mb
τ = 2.7μs
τ = 2.1μs
delay (μs) − 1.35μs!!
0
1
2
3
4
5
6
7
8
1
10⁻¹
signal (%)

"Pulsed extraction", ~ $6 \cdot 10^8 \, \bar{p}$ in ca. 200ns.
HV-PM gepulst.
PM-Signal auf Digitaloszill. - 2 Gs/s.



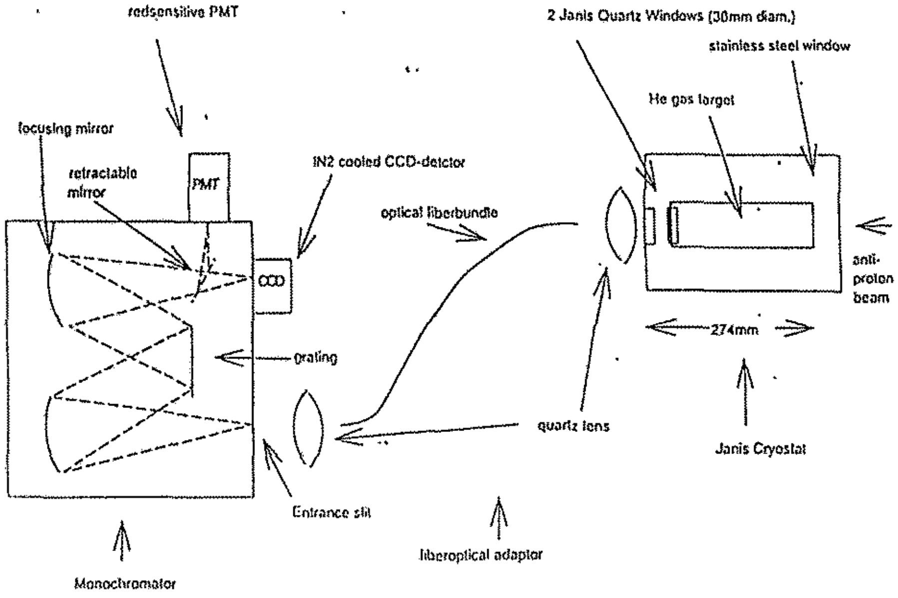
"Pulsed extraction", ~ $6 \cdot 10^8 \, \bar{p}$ in ca. 200 ns.
gepulster PM,
PM-Signal auf Digitaloszill.
2 Gs/s.



Monochromator

Zweck: Erster direkter Nachweis der Übergänge in hochangeregten exotischen Atomen (400 – 700 nm)

- Holographisches Beugungsgitter
- Auslese mit CCD-Detektor (500 × 500 Pixel) ~ 1 $e^-/px/h + 8 e^-/px$.
- Meßbereich bei einer Messung ca. 10 nm
- Auflösung bis zu $\Delta\lambda \approx 0.008$ nm (10 μm Spalt).
- Effizienz total ca. $6,4 \cdot 10^{-6}$ $(= 1.4 \cdot 10^{-5} \cdot 0.61 \cdot 0.75)$.
- Ankopplung an das Target durch Glasfaserlichtleiter
- Untergrund: Allgemeiner Strahlungsuntergrund, Photonen aus Abbremsung der Antiprotonen und aus Bremsung der Pionen, geladene Teilchen



T.v.Egidy, TU Mü

Antiprotoninduzierte Spaltung und Kernaufheizung

Experiment PS 203 at LEAR
PS 208

TU Munich: T.v.E., F.J. Hartmann, S. Schmid, W. Schmid

HMI Berlin: D. Hilscher, D. Polster, H. Rossner

INR Moscow: D.I. Ivanov, A.S. Iljinov, Y.S. Golubeva, M.V. Mebel, V.G. Nedorezov, A.S. Sudov, I.A. Pshenichnov

Warsaw University: A. Grabowska, J. Jastrzebski, W. Kurcewicz, P. Lubinski, A. Trzcinska

KFA Jülich: H. Machner

FSU Tallahassee: H.S. Plendl

CERN Geneva: J. Eades, S. Neumaier

Antiprotonen-Kern-Wechselwirkung

Experimentelle Methoden

Experimente am Low-Energy-Antiproton-Ring LEAR bei CERN

Bisher mit gestoppten Antiprotonen (100,200,300 MeV/c).
Ab 1994 auch mit 2 GeV/c Antiprotonen;
dadurch erwartet man eine wesentlich höhere Kernaufheizung.

Teilchenspektren gemessen mit Teleskopen und TOF.
Spaltfragmente: E, A, ϑ beider Fragmente.
Absolute Spaltwahrscheinlichkeit.
Restkernverteilung durch Messung der induzierten γ-Strahlung.

Neues Gerät (1994): Berliner Ball

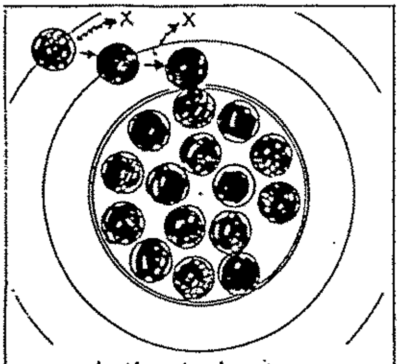
4π–Neutronen-Detektor (1.4m Durchmesser)
darin 4-π-Si-Detektor für geladene Teilchen und Fragmente.

Mißt die Reaktionen sehr heißer Kerne
(Teilchenemission, Fragmentenergien)
als Funktion der Anregungsenergie
(bis über 500 MeV, gemessen durch Neutronenmultiplizität).

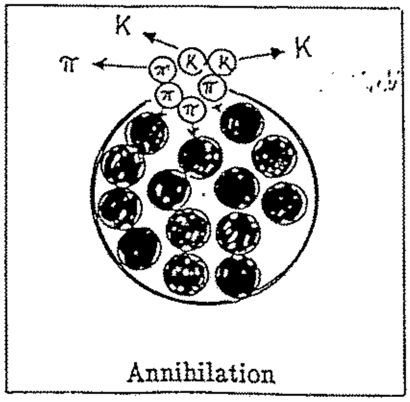
Neutronenhalo

nachgewiesen durch Messungen der γ-Strahlung der (A-1) Kerne

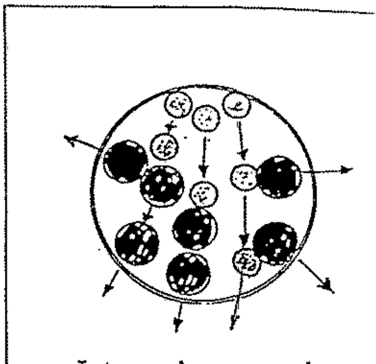
Reactions



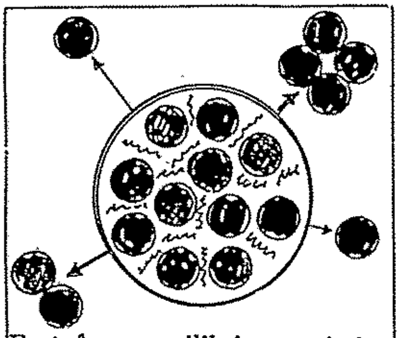
Antiprotonic atom



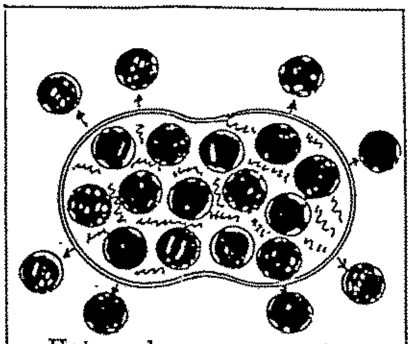
Annihilation



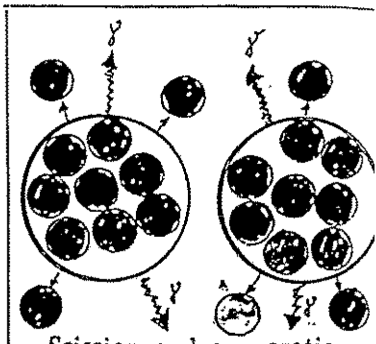
Intranuclear cascade



Fast & preequilibrium emission, coalescence production

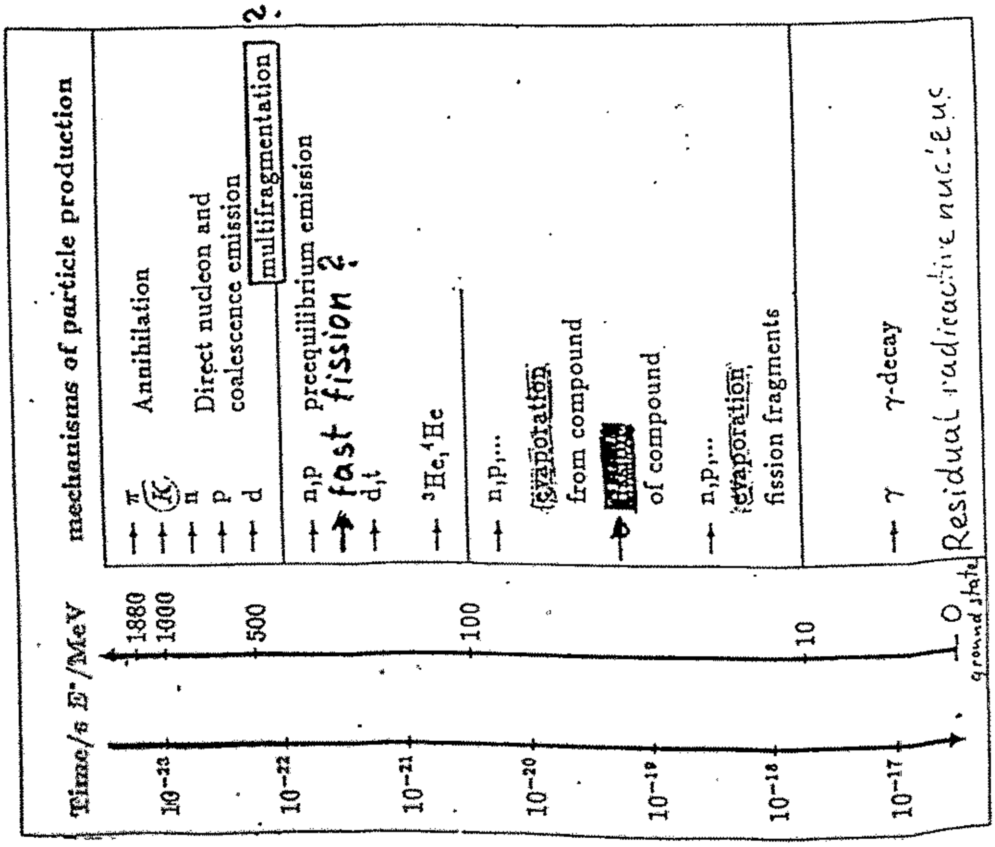


Hot nucleus, evaporation before scission



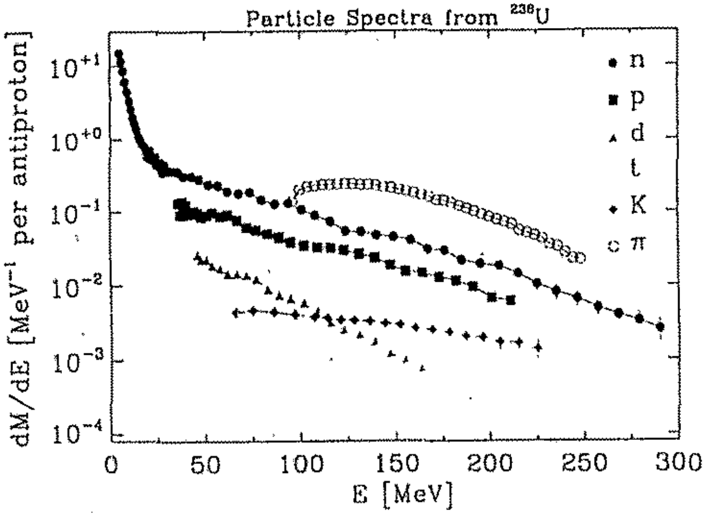
Scission and evaporation from fragments

Time Scale and Energy Scale after Antiproton-Nucleus Annihilation

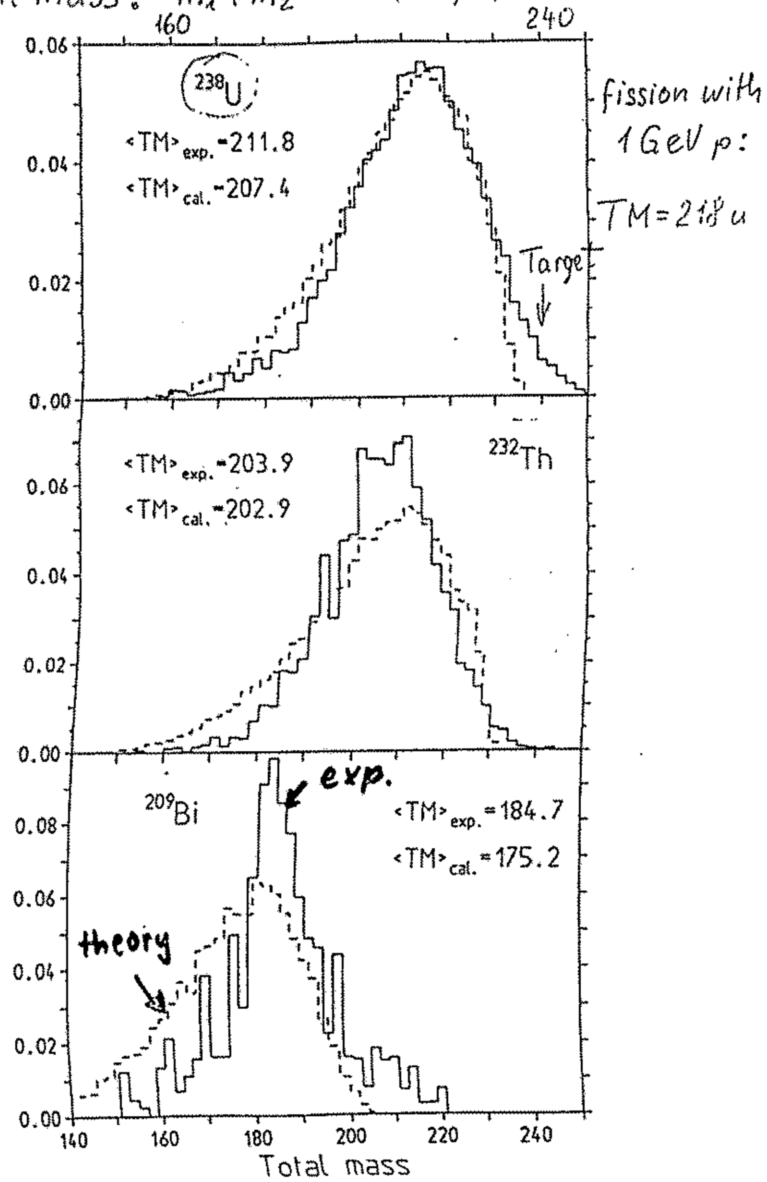


Warum studieren wir Antiproton-Kern-Wechselwirkung?

1) Antiprotonische Atome: Antiproton-Kern-Potential
2) **Einfluß der Kernmaterie auf Annihilation?**
3) Strangenessproduktion, Multipionreaktion
4) **Heiße Kerne, bis 1 GeV thermalisiert,**
5) **Kleiner Drehimpuls, ohne Kompression**
6) Teilchenemission kann gemessen werden.
7) Restkernverteilung gibt Energiedeposition.
8) **Spaltung: neue Moden?**
Viele Parameter zu messen: E_1, E_2, m_1, m_2, [illegible]
9) **Neutronen vor und nach Spaltung: ergibt Zeitskala: 10^{-16} - 10^{-23} s.**
10) **Vergleich mit intranuklearen Kaskadenrechnungen gibt Details der Prozesse in heißen Kernen:**
Schnelle Kaskade, Präequilibriumprozesse, Multifragmentation, Koaleszenz, Trawling-Effekt, Verdampfung, Thermalisierung, Spaltung, ...
11) **Komplementär zu Schwerionenreaktionen**
12) **n-Halo durch $\bar{p}$-Annihilation**



Total mass: $m_1 + m_2 = TM$ of fission fragments



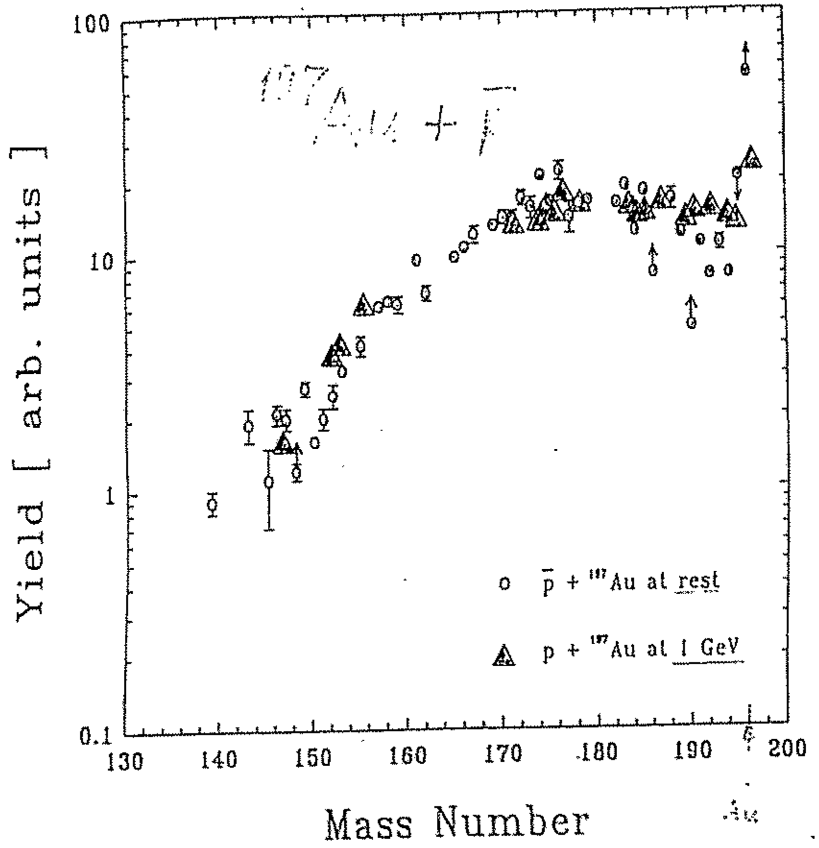
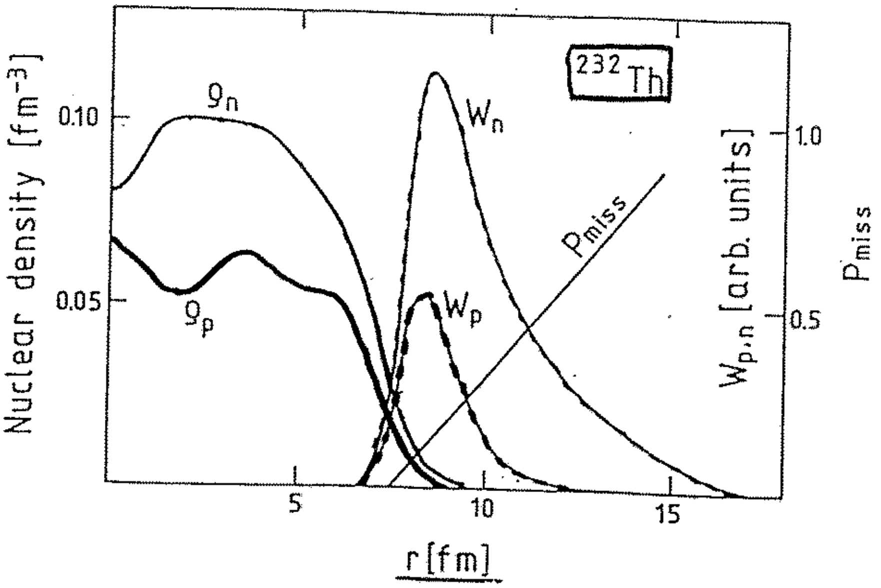


Figure 1. Comparison of the mass yield distributions in the spallation region for the ^{197}Au + $\overline{p}$ at rest and ^{197}Au + p at 1 GeV [2] reactions.

Proton and neutron density and absorption probability.

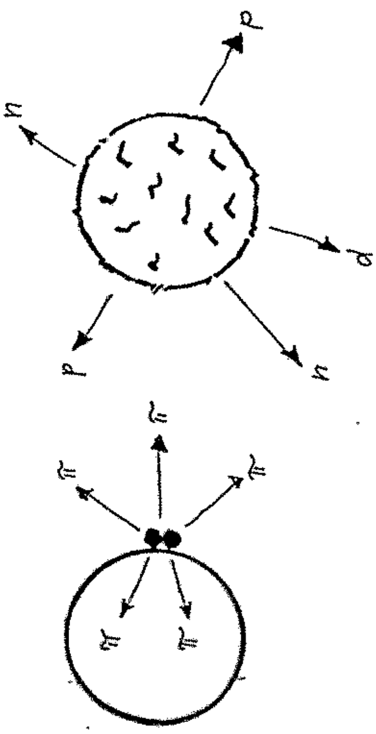


Neutronenhalo

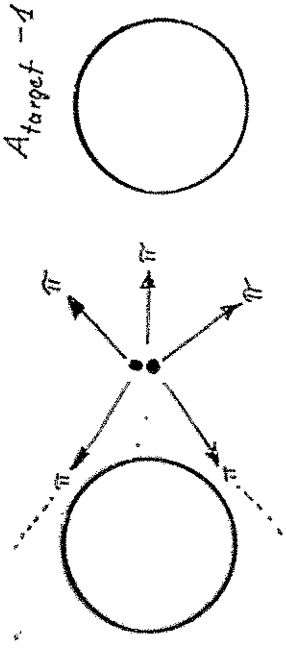
Annihilation ohne Kernanregung

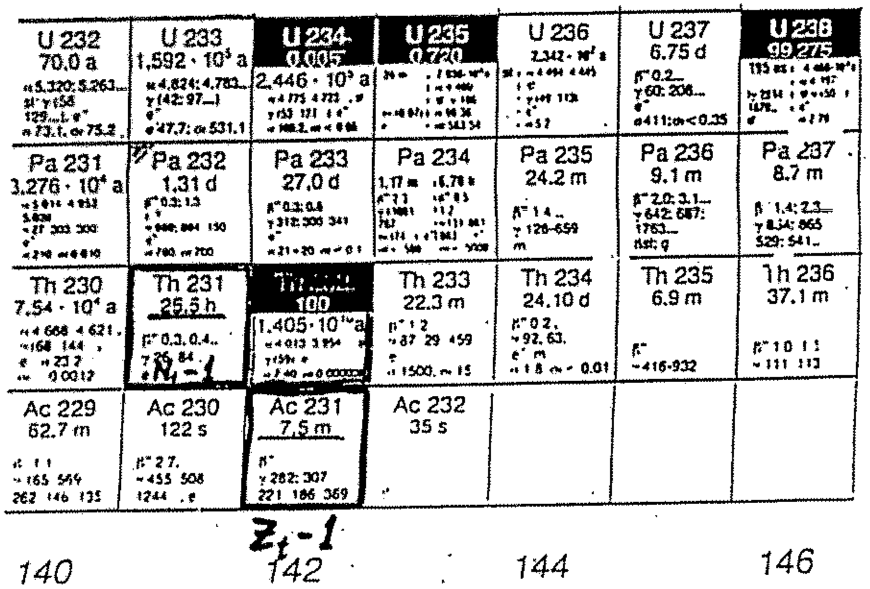
$(A_{target} - 1)$ - Kerne

Annihilation in Kernnähe → heiße Kerne



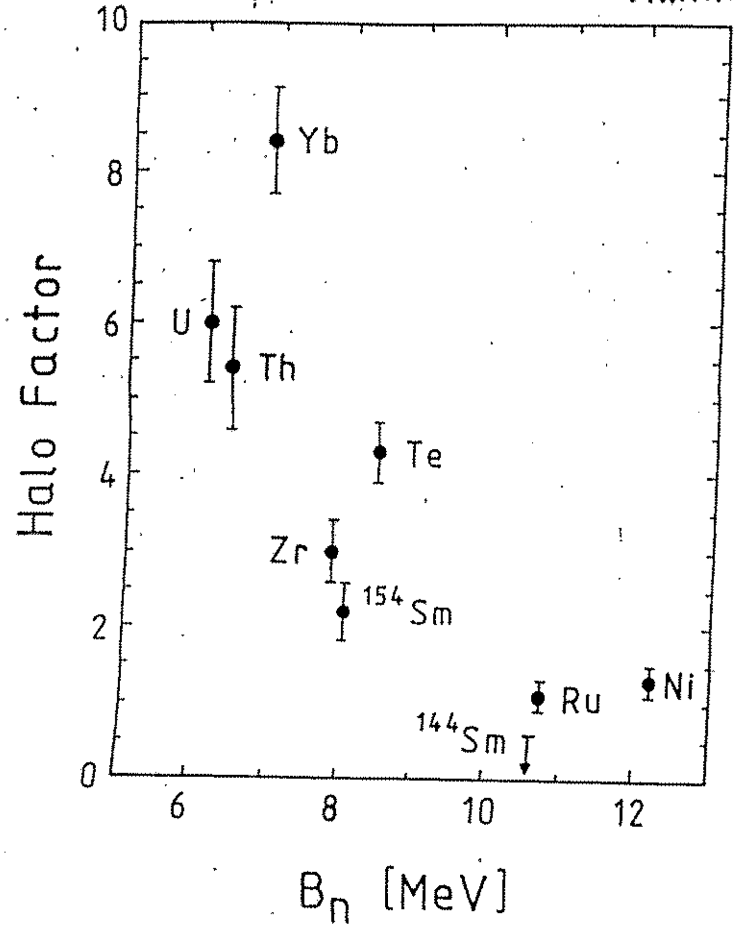
Annihilation in Kernferne → kalte Kerne





U 232 70.0 a	U 233 1.592 · 10⁵ a	U 234 0.005 2.446 · 10⁵ a	U 235 0.720	U 236 2.342 · 10⁷ a	U 237 6.75 d	U 238 99.275
Pa 231 3.276 · 10⁴ a	Pa 232 1.31 d	Pa 233 27.0 d	Pa 234 1.17 m 6.70 h	Pa 235 24.2 m	Pa 236 9.1 m	Pa 237 8.7 m
Th 230 7.54 · 10⁴ a	Th 231 25.5 h $N_t - 1$	Th [illegible] 100 1.405 · 10¹⁰ a	Th 233 22.3 m	Th 234 24.10 d	Th 235 6.9 m	Th 236 37.1 m
Ac 229 62.7 m	Ac 230 122 s	Ac 231 7.5 m	Ac 232 35 s			

Neutron Halo Measured with Antiproton Annihilation



$$f_{\text{halo}}^{\text{peripheral}} = \frac{N(\bar{p}n)}{N(\bar{p}p)} \, \frac{\mathrm{Im}\, a_p}{\mathrm{Im}\, a_n} \, \frac{Z_t}{N_t}$$

FIG. 1.

Absolute fission probabilities measured with a multiwire proportional chamber at LEAR

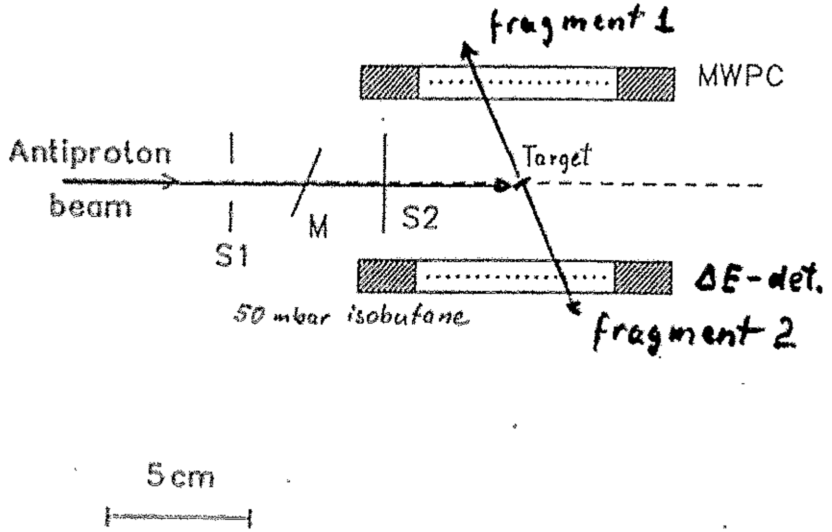
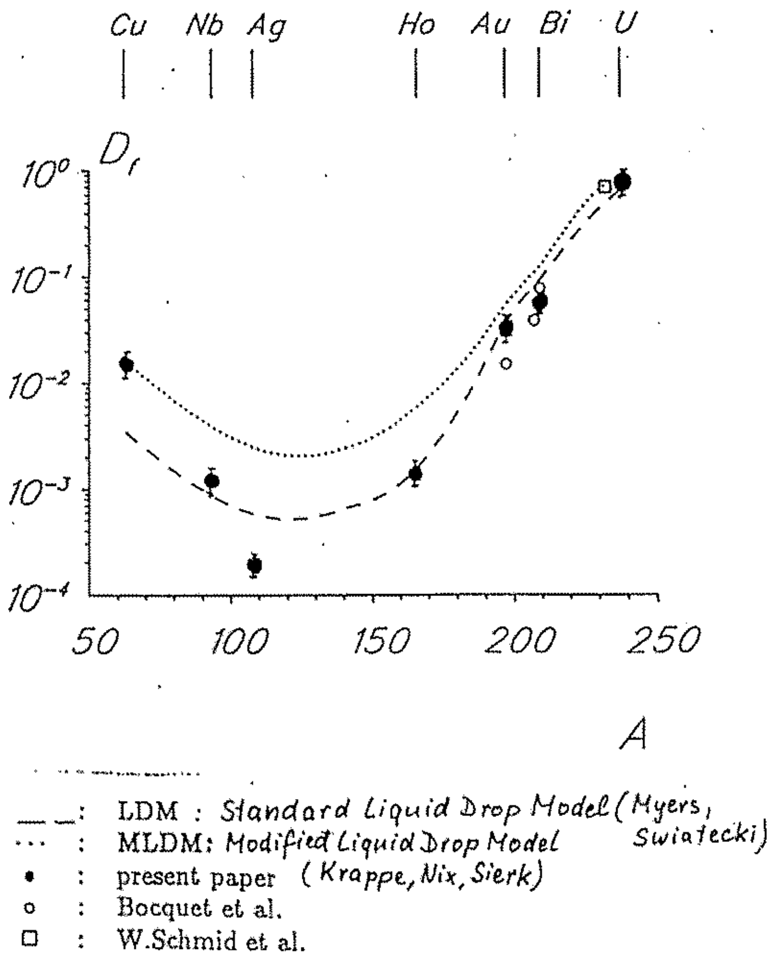
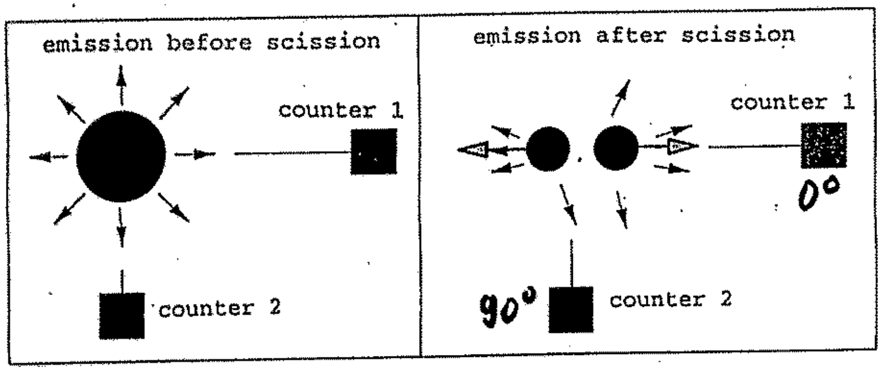


fig. 1

Absolute Probabilities of Antiproton Induced Fission

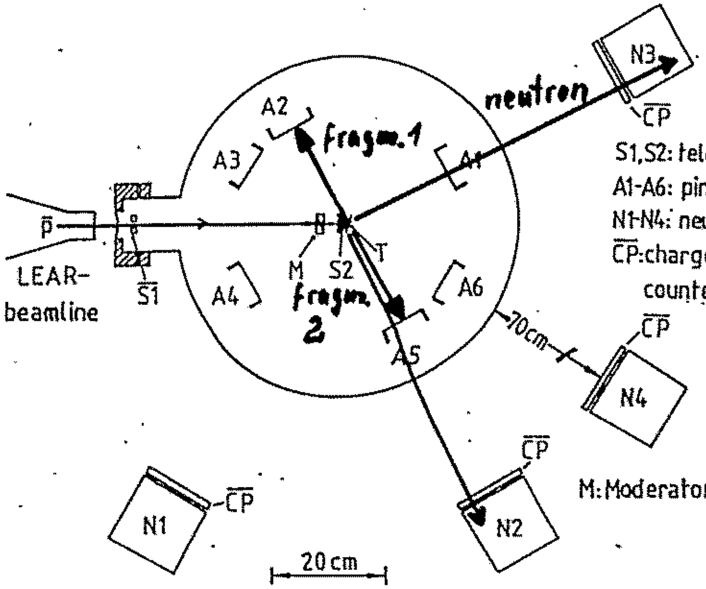


Measurement of neutron spectra in correlation with the fission axis



Neutron emission before and after scission is distinguished by kinematical focussing.

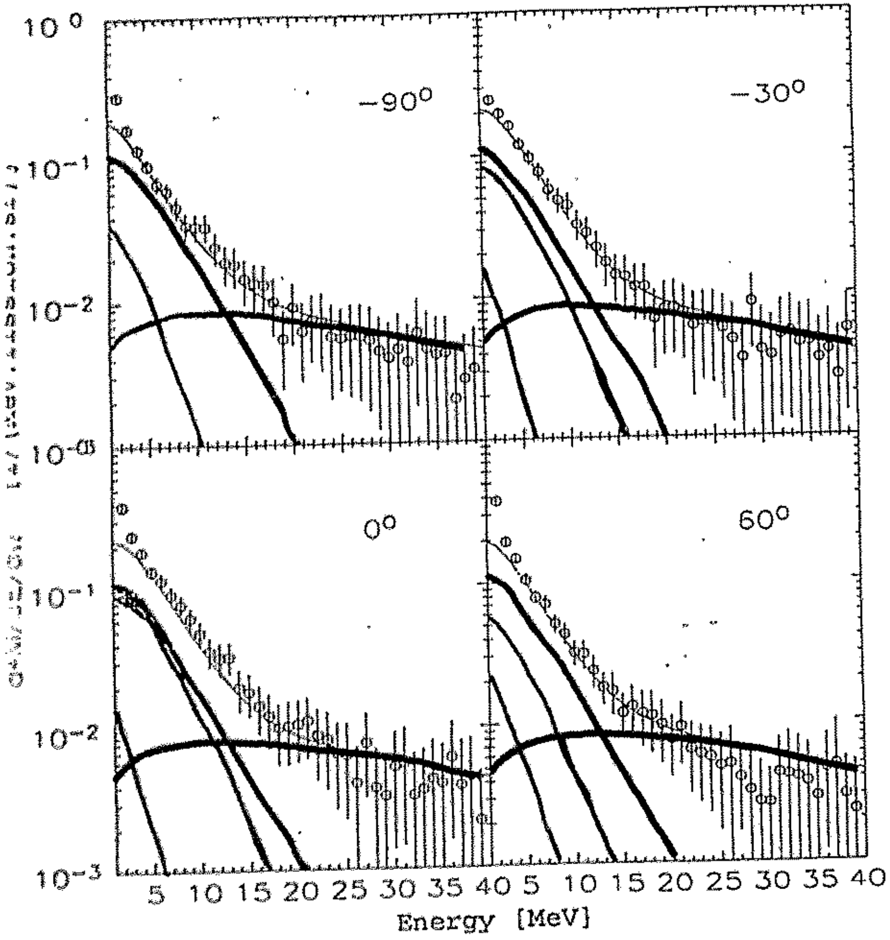
Measurement of fragments and neutrons in coincidence



S1,S2: telescope counters
A1-A6: pin diode arrays
N1-N4: neutron counters
$\overline{CP}$: charged particle veto counter

M: Moderator, T: Target

Neutron spectra at different angles to the fission axis.



Fit formula: $\frac{d^2M}{dE\,d\Omega} = \sum_{i=1}^{4} \frac{M_i}{2(\pi T_i)^{3/2}} \sqrt{E}\, \exp\left(-\frac{E - 2\sqrt{\varepsilon_i E}\cos\psi_i + \varepsilon_i}{T_i}\right)$

Emission before scission

Emission after scission: forward - backward

Multiplicity of neutrons emitted before and after scission for various reactions.

Reaction	$\overline{E^*}$ in MeV	Multiplicity per fission before scission	Multiplicity per fission after scission
stopped $\bar{p} + {}^{238}U$	220		
present exp.		15.3(11)	6.4(6)
previous exp. (multiplicity of nucleons)		10 (1)	15(1)
20 Ne + ^{209}Bi	120	5.7(4)	6.4(5) Hinde
16 O + ^{208}Pb	187	7.8(3)	6.8(3) Hinde
475 MeV p + ^{238}U	140	8.4(17)	8.6(17) Fraenkel
1 GeV p + ^{238}U	170	2.3(5)	16.8(24) Chestnov

The evaluation is not yet finished.

We shall evaluate the multiplicities as a function of $E^* \sim$ total mass loss.

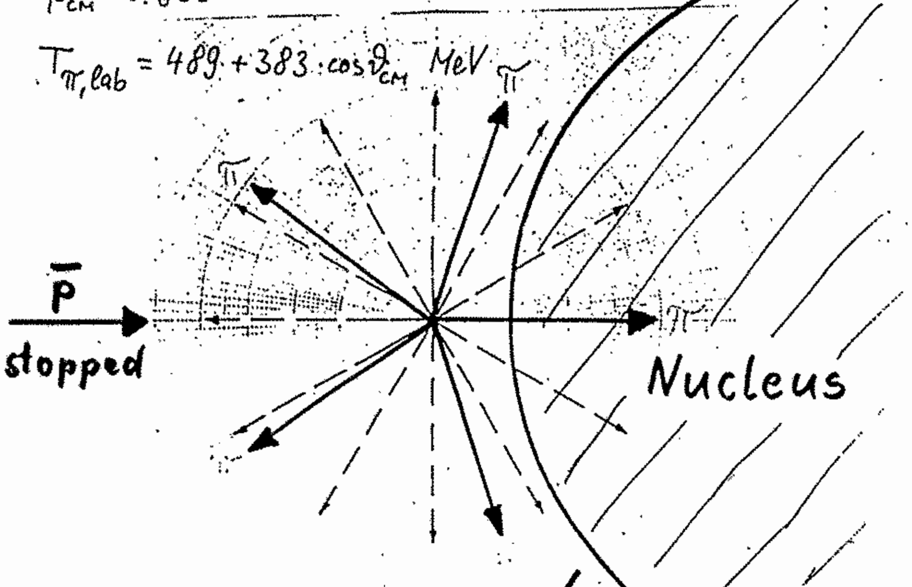
We measured also $\bar{p}$ + Bi.

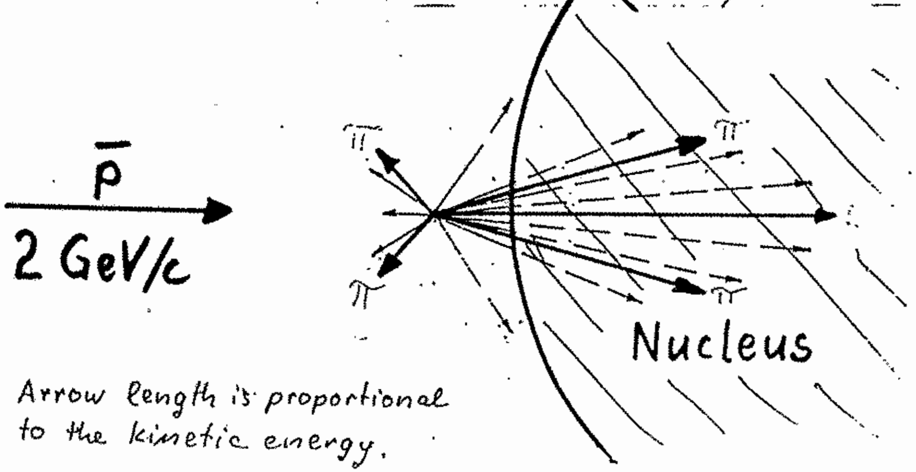
Annihilation of 2 GeV/c $\bar{p}$

$p_{\bar{p}} = 2$ GeV/c ; $T_{\bar{p}} = 1271$ MeV

$E_{CM} = 2430$ MeV; $p_{CM} = 782$ MeV/c for $\bar{p}p$-System
$\beta_{CM} = 0.635$

$T_{\pi,lab} = 489 + 383 \cdot \cos\vartheta_{CM}$ MeV





Arrow length is proportional to the kinetic energy.

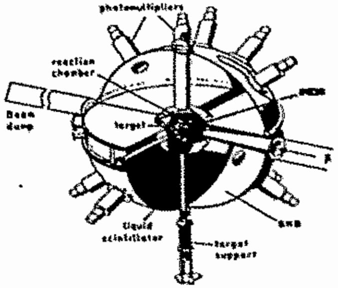
First Results on the decay of hot nuclei at low spin (PS208)

HMI-Berlin, TU-Munich, GANIL-Caen, U. Warsaw,
FZ-Rossendorf, IPN-Orsay, INR-Moscow

$\bar{p} + A \Rightarrow$ well defined hot nuclei at low spin
$E^* = 100 - 1000$ MeV, $I = 15\text{-}20\,\hbar$

- excitation energy distribution via neutron multiplicity
- decay of hot nuclei: multiplicity of evaporated neutrons (thermal excitation energy) and all charged nuclear particles (4π-Si-ball): evaporation, fission, multifragmentation
- Comparison with p-, ^{3}He- (0.5-2 GeV), HI-reactions

experiment: 4π-neutron sphere + 4π-silicon ball



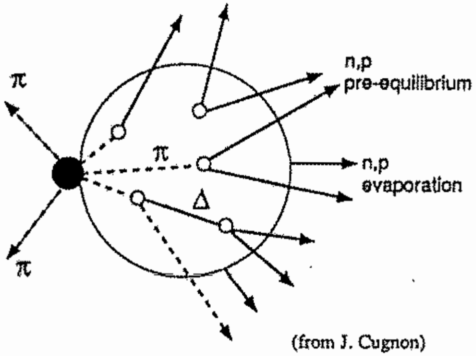
- preliminary (on-line) results of two runs at LEAR/CERN
  $\bar{p}$-annihilation at rest (200 MeV/c) June 1994
  $\bar{p}$-annihilations in flight (1940 MeV/c) August 1994

Mechanism of energy dissipation in $\overline{p}$+nucleus reactions:

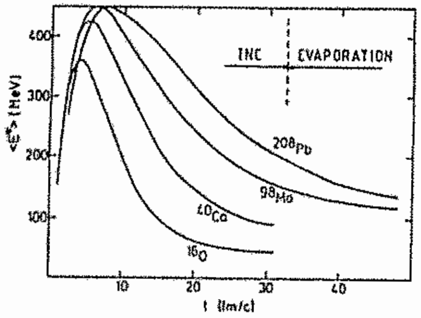
Antiproton annihilation at rest on a heavy nucleus:

$<M_{\pi}> = 5$

$<E_{\pi}> = 230$ MeV



(from J. Cugnon)

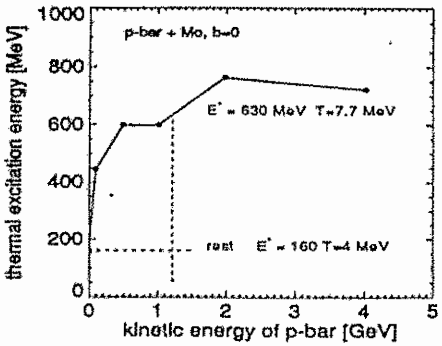


$E^*_{therm} \approx 200$ MeV

10% of $E_{transfer}$

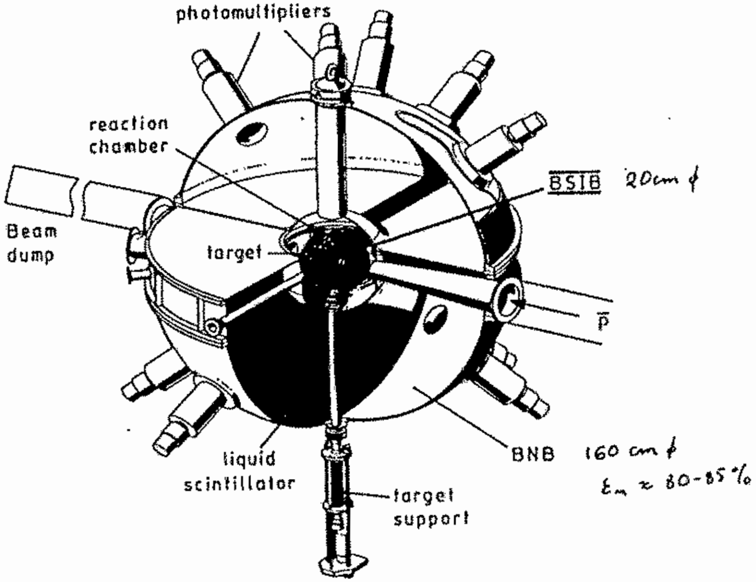
Antiproton annihilation in flight:

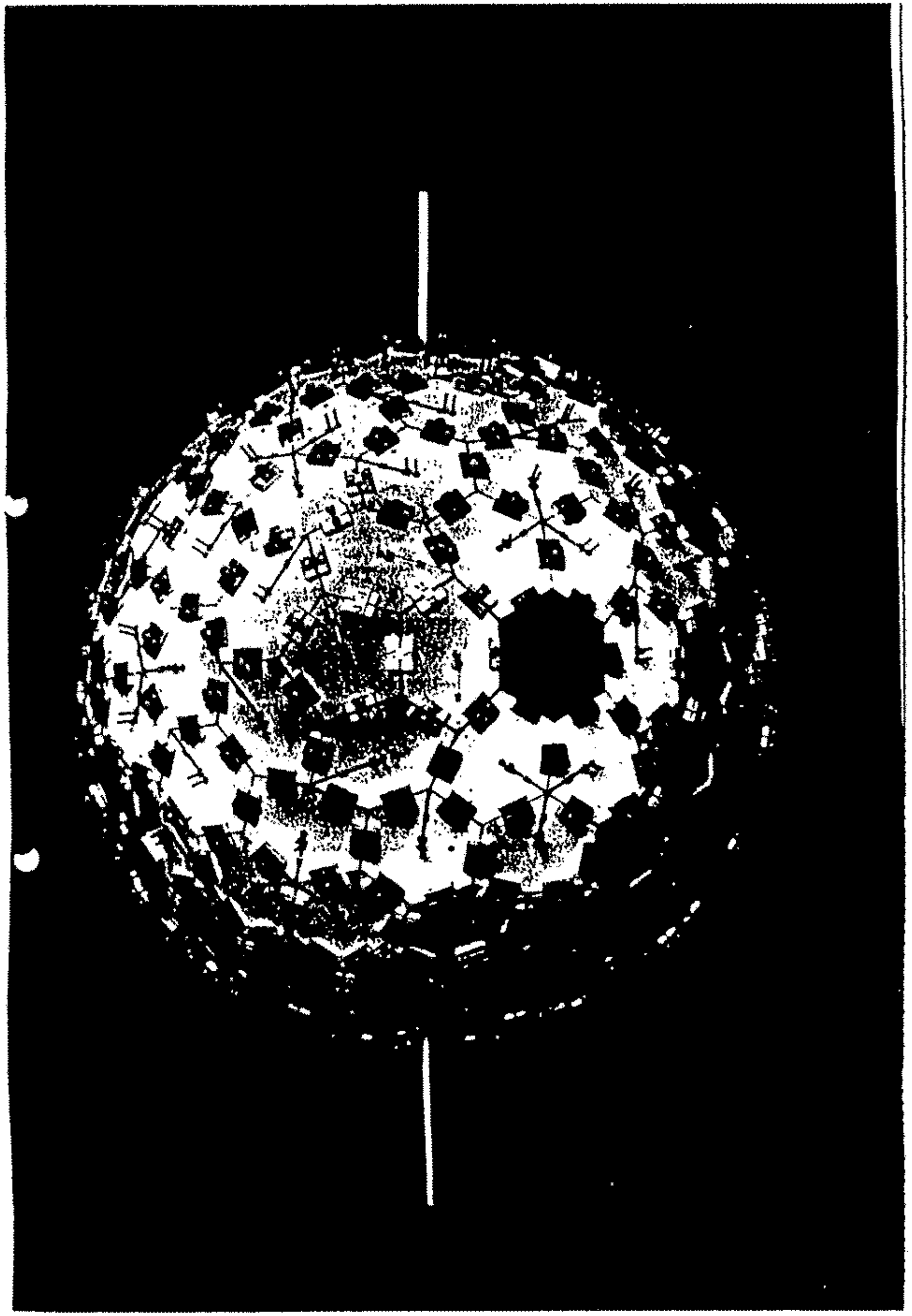
(from J. Cugnon)

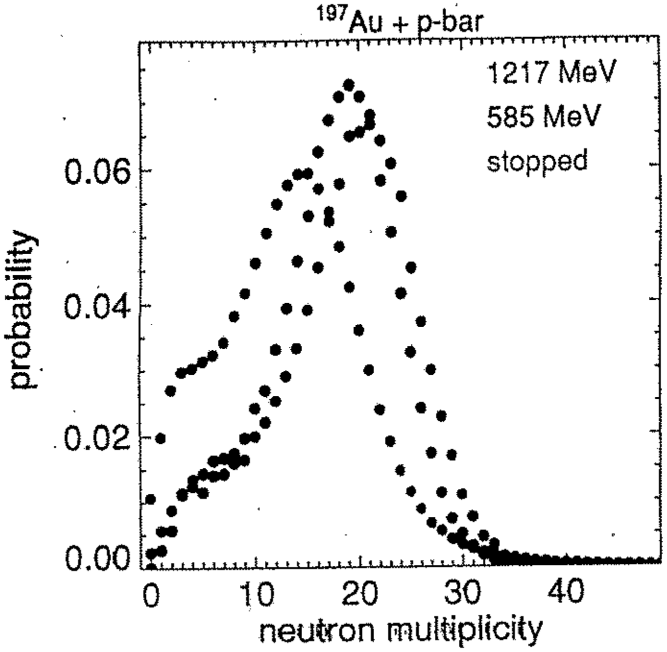


Berlin 4π-neutron (BNB) and 4π-silicon (BSIB) ball

- BNB: 1400 l Gd-loaded scintillator liquid, ➡ neutron multiplicity distributions M_n and correlated prompt light $L_{p\text{-recoils},\pi^{+/-},K^{+/-}}$
- BSIB: 160 Si-detectors 500 μ thick, ➡ nuclear (no π and K) charged particles p, d, α , ... IMF, FF: M_{cp}, E_{cp}, (Θ_{cp}, Φ_{cp})



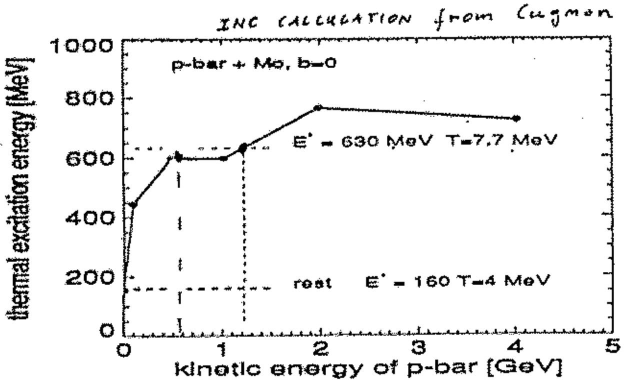


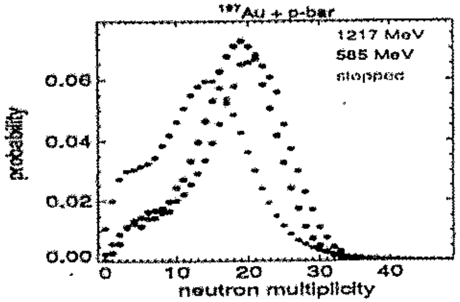


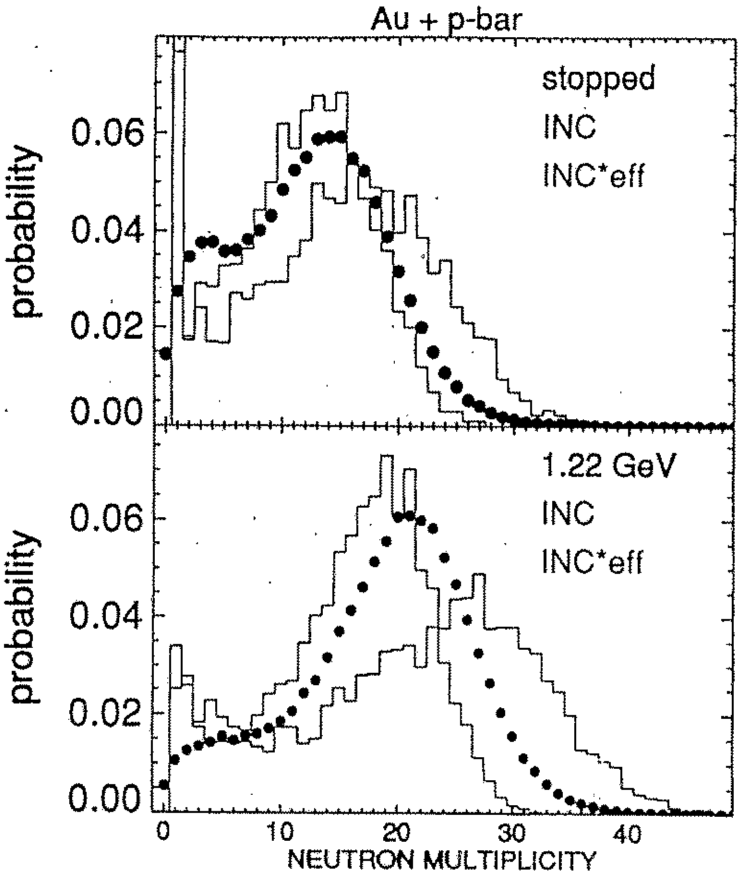
^{197}Au + p-bar
1217 MeV
585 MeV
stopped
probability
0.06
0.04
0.02
0.00
0
10
20
30
40
neutron multiplicity

Increase of E^* (M_n) with $E_{\bar{p}}$

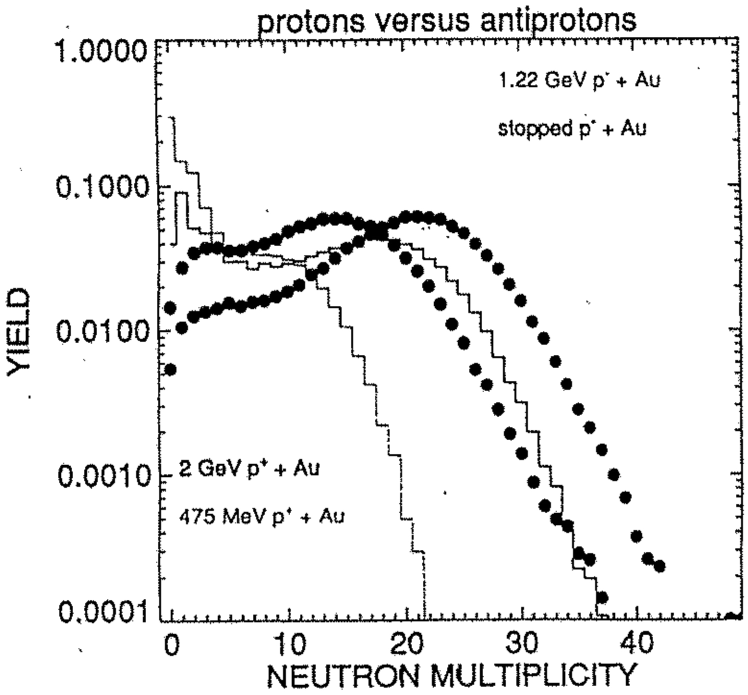
INC CALCULATION from Cugnon



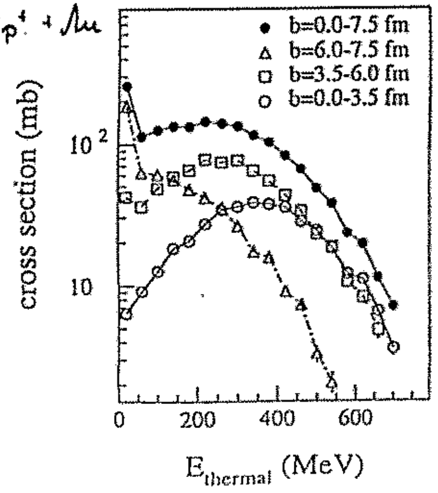




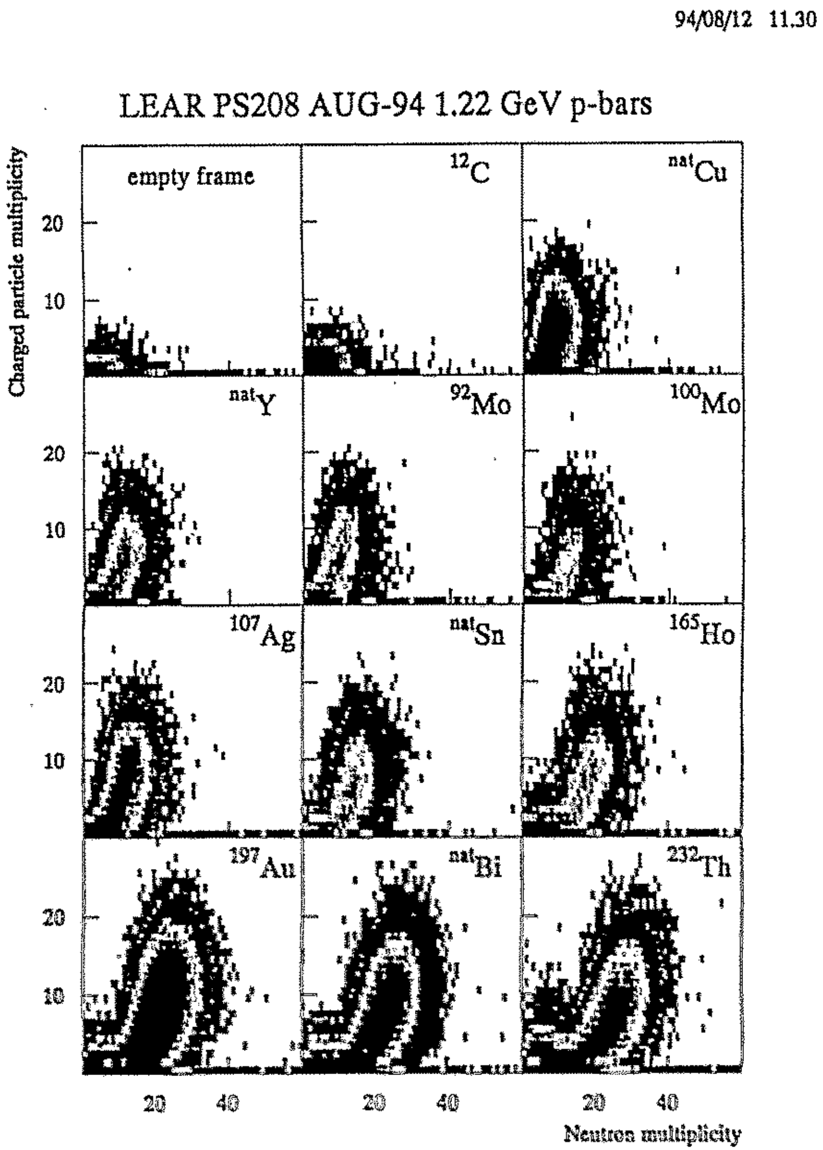
Golubeva



2 GeV p⁺ + Au



Pienkowski et al
PLB (94) ...


LEAR PS208 AUG-94 1.22 GeV p-bars

Results-Conclusions

- background problems with BNB solved
- first neutron multiplicity distributions for $\overline{p}$-annihilation at rest and in flight
- large increase of M_n from stopped to 585 MeV $\overline{p}$, small increase from 585 to 1217 MeV
- at 1217 MeV almost only annihilations
- high $E^*_{thermal}$ = 500 to 800 MeV obtained
- reasonable agreement with INC calculation
- Outlook: evaporation, binary fission probabilities, multifragmentation, fission dynamics at low spin as a function of excitation energy

---

First results on the decay of hot nuclei at low spins (PS208)

D.Hilscher[1], W. Bohne[1], J. Eades[8],
T. von Egidy[3], P. Figuera[1], H. Fuchs[1],
F.J. Hartmann[3], J. Galin[2], F. Goldenbaum[1],
Ye.S. Golubeva[7], K. Gulda[4], A.S. Iljinov[7],
D.I. Ivanov[7], U. Jahnke[1], J. Jastrzebski[4],
W. Kurcewicz[4], B. Lott[2], M. Morjean[2],
V.G. Nedorezov[7], S. Neumaier[8],
G. Pausch[5], A. Peghaire[2], L. Pienkowski[4],
D. Polster[1], S. Proschitzki[6],
I.A. Pshenichov[7], B. Quednau[2],
H. Rossner[1], S. Schmid[3], W. Schmid[3],
A.S. Sudov[7], P. Ziem[1]

1 HMI-Berlin
2 GANIL-Caen
3 TU-Munich
4 U.-Warsaw
5 FZ-Rossendorf
6 IPN-Orsay
7 INR-Moscow
8 CERN-Geneva

Zusammenfassung

1) Sehr heiße Kerne mit kleinem Drehimpuls ohne Kompression.
2) Teilchenemission: Mittlerer Impuls für alle Targets und Ejektile ähnlich
3) Teilchenspektren verglichen mit Theorie: Auskunft über Details der Prozesse.
4) Restkernverteilung: Energiedeposition Vergleich mit Theorie
5) Neutronenhalo aus $(A_{target}-1)$-Kernen
6) Spaltung: Asymmetrisch, symmetrisch, auch vor Thermalisierung.
7) Spaltung schneller bei heißen Kernen
8) Neutronen bei Spaltung: Zeitskala.
9) Vergleich mit intranuklearen Kaskadenrechn..

1994 mit Berliner Ball

1) Multifragmentation
2) Phasenübergang bei heißen Kernen
3) Strangeness-Produktion in Kernen
4) Messung der Neutronenmultiplizitäten → Uhr.

5) Annihilation von 2 GeV $\bar{p}$: im Kern

→ Produktion extrem heißer Kerne durch Multipionheizung.

Untersuchung der Annihilation von Antiprotonen in Deuterium

Jens Brose
Institut für Physik
Universität Mainz *

CRYSTAL BARREL Collaboration

Arbeitstreffen Kern- und Teilchenphysik
Pirna, 1994

* jetzt am
Institut für Kern- und Teilchenphysik
TU Dresden

- Vergleich der Antiproton–Vernichtung in Wasserstoff und Deuterium
  ⟶ Verzweigungsverhältnisse
- Reaktionsmechanismen
  Einfluß des (nicht) an der Reaktion beteiligten Nukleons

  $p_n < 200 MeV/c$:
  - Quasifreie Annihilation am Nukleon
    Spectator–Modell

  $p_n > 200 MeV/c$:
  - Meson–Rückstreuung oder –Absorption am Nukleon
    Nukleon–Resonanzanregung
  - $q\bar{q}$– Umordnung / Vernichtung / Erzeugung
    Pontecorvo–Reaktionen
- $\bar{p}d \rightarrow X\ p$
  reiner I = 1 Anfangszustand

Crystal Barrel Daten

- Rein neutrale Endzustände
  $4 \cdot 10^6$ Ereignisse
- Daten mit einer Spur geladener Teilchen
  $2 \cdot 10^6$ Ereignisse
- Minimal getriggerte Daten
  $3 \cdot 10^6$ Ereignisse

- Datenselektion und kinematische Anpassung an mesonische Endzustände

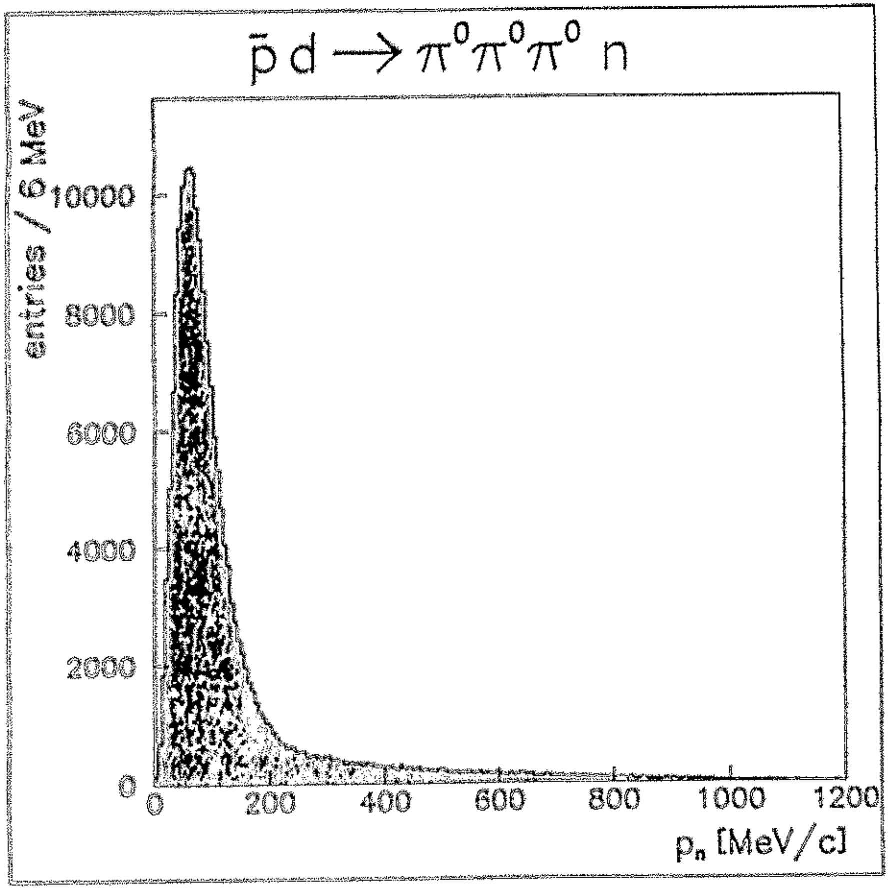
- Rekonstruktionswahrscheinlichkeit (MC)

Absolute Verzweigungsverhältnisse $\cdot 10^4$

	H_2: BR($\bar{p}p \longrightarrow$) *	D_2: 2·BR(($\bar{p}p$)n$\longrightarrow$)	D_2: BR(($\bar{p}n$)p$\longrightarrow$)
$\pi^0\pi^0\pi^0$	63.0±10.0	75.2±7.0	
$\pi^0\pi^0\eta$	67.0±12.0	52.8±5.0	
$\pi^0\eta\eta$	21.0±4.0	25.6±3.0	
$\eta\omega$	151.0±12.0	146.0±14.0	
$\pi^0\omega$	57.3±4.7	89.8±9.0	
$\pi^-\omega$			59.0±10.0
$\pi^0\eta$	2.12±0.12	5.36±0.50	
$\pi^-\eta$			3.9±0.6
$\pi^0\eta'$	1.23±0.13		
$\pi^-\eta'$			1.9±0.7
$\eta\eta$	1.64±0.10	3.38±0.40	
$\pi^0\pi^0$	6.93±0.43	13.5±1.3	
$\pi^+\pi^-$	30.7±1.3		
$(\pi^+\pi^-)_S$	16.8±1.6		
$\pi^-\pi^0$			40.0±5.0

* Crystal Barrel: Z. Phys. C58 (1993) 175

$$BR_S(\bar{p}p \longrightarrow \pi^+\pi^-) = BR(\bar{p}p \longrightarrow \pi^+\pi^-) - 2 \cdot BR(\bar{p}p \longrightarrow \pi^0\pi^0)$$



Pontecorvo–Reaktionen

Antiproton–Nukleon Annihilation
nur 1 Meson im Endzustand
hier:

$$\bar{\mathrm{p}}\mathrm{d} \rightarrow \text{Meson} + \text{Baryon}$$

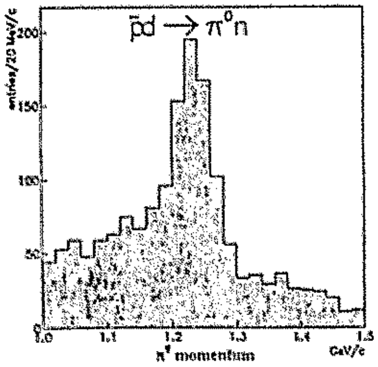
Sensitiv auf kleine Nukleonen–Abstände
⟶ Quark–Freiheitsgrade

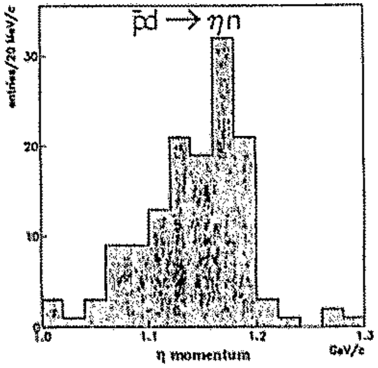
Bisher nur $\bar{\mathrm{p}}\mathrm{d} \rightarrow \pi^-\mathrm{p}$ gemessen:

$$BR(\bar{\mathrm{p}}\mathrm{d} \rightarrow \pi^-\mathrm{p}) = (1.20 \pm 0.27) \times 10^{-5}$$

OBELIX

Crystal Barrel: Pontecorvo–Reaktionen mit Neutronen im Endzustand





Verzweigungsverhältnisse:

$$
\begin{aligned}
BR(\bar{\mathrm{p}}\mathrm{d} \to \pi^0\mathrm{n}) &= (7.03 \pm 0.72) \times 10^{-6} \\
BR(\bar{\mathrm{p}}\mathrm{d} \to \eta\mathrm{n}) &= (3.19 \pm 0.48) \times 10^{-6} \\
BR(\bar{\mathrm{p}}\mathrm{d} \to \omega\mathrm{n}) &= (22.8 \pm 4.1) \times 10^{-6} \\
BR(\bar{\mathrm{p}}\mathrm{d} \to \eta'\mathrm{n}) &\leq 14 \times 10^{-6} \,@\, 95\% \text{ CL}
\end{aligned}
$$

Ladungsunabhängigkeit:

$$\frac{BR(\bar{\mathrm{p}}\mathrm{d} \to \pi^-\mathrm{p})}{BR(\bar{\mathrm{p}}\mathrm{d} \to \pi^0\mathrm{n})} = 2$$

Experiment:

$$\boxed{1.7 \pm 0.4}$$

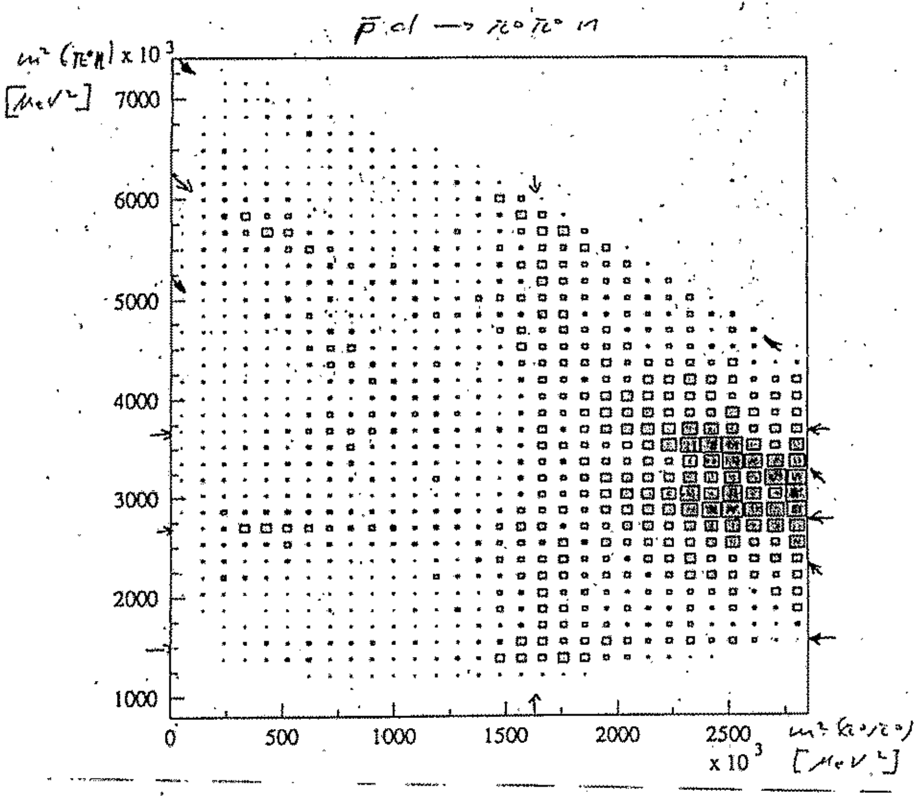
Meson– und Baryon–Resonanzen

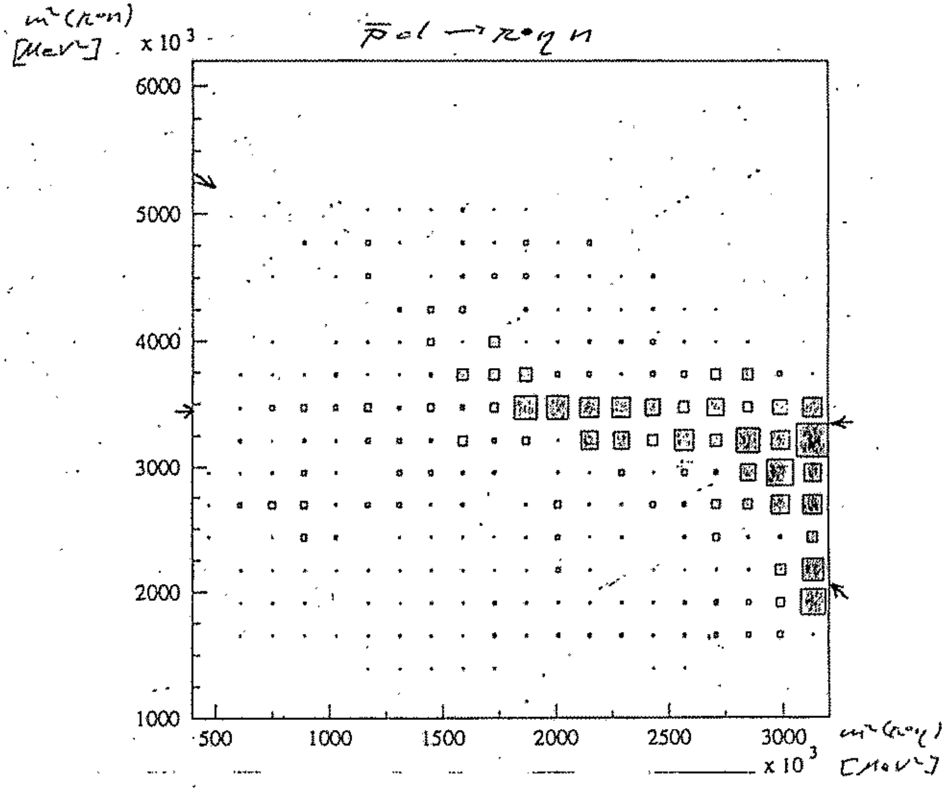
$$
\begin{aligned}
\bar{\mathrm{p}}\mathrm{d} &\to \pi^0\pi^0\mathrm{n} \\
\bar{\mathrm{p}}\mathrm{d} &\to \pi^0\eta\mathrm{n}
\end{aligned}
$$

Dalitz plots:

Interferenzen von $\pi^0\pi^0$ $(\pi^0\eta)$
und $\pi^0\mathrm{n}$ $(\pi^0\mathrm{n})$
$(\eta\mathrm{n})$

Strukturen


p̄d → π⁰π⁰n
m² (π⁰n) x 10³
[MeV²]
7000
6000
5000
4000
3000
2000
1000
0
500
1000
1500
2000
2500
x 10³
m² (π⁰π⁰)
[MeV²]


p̄d → π⁰ηn
m² (π⁰n)
[MeV²]
x 10³
6000
5000
4000
3000
2000
1000
500
1000
1500
2000
2500
3000
x 10³
m² (π⁰η)
[MeV²]

Anwendung neuronaler Netze in der Datenanalyse

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D-4630 Bochum
e-mail: thomas@tau.ep1.ruhr-uni-bochum.de

Inhalt

Einführung
(feed forward backpropagation, FFBP)

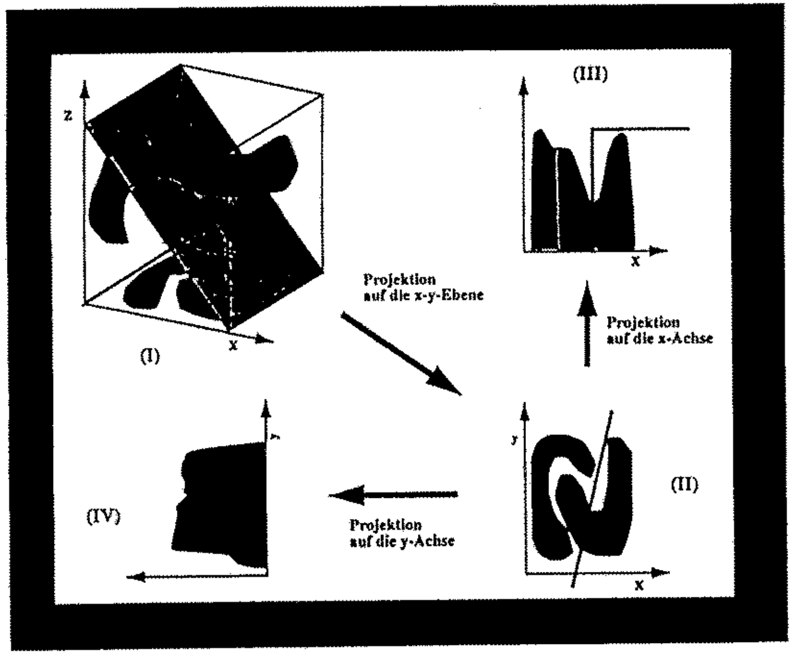
Unterdrückung von Schauerfluktuationen

Bewertung kinematischer Fits

Zusammenfassung

Einführung
(Standardmethode in der Datenanalyse)

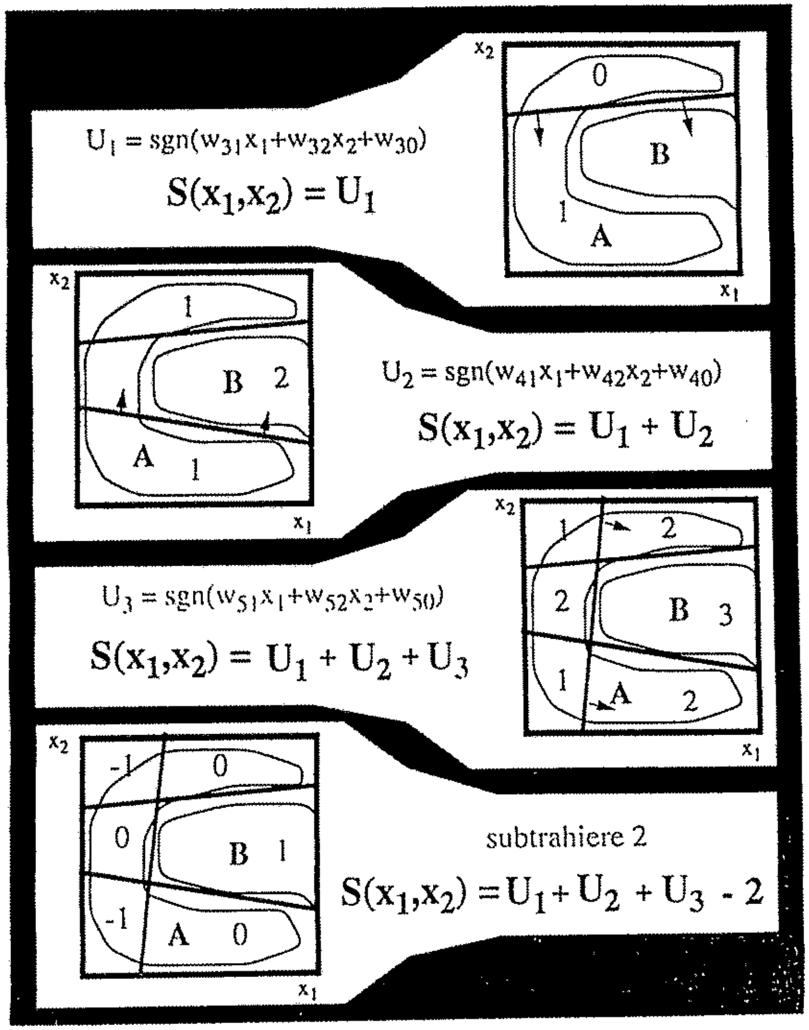
Eine sequentielle Folge von linearen Schnitten separiert zwei Klassen A und B.



- In jeder Projektion geht Information über die Klassen verloren. Der Parameter y, für sich allein betrachtet, trägt scheinbar keine zur Trennung der Klassen verwertbare Information.

Ersetze die ein- oder zwei-dimensionalen Schnitte durch Abgrenzungen im mehrdimensionalen Parameterraum
→ Künstliche neuronale Netze
(feed forward backpropagation, FFBP)

Einführung
(Standardmethode in der Datenanalyse)



$U_1 = \mathrm{sgn}(w_{31}x_1 + w_{32}x_2 + w_{30})$

$S(x_1,x_2) = U_1$

$U_2 = \mathrm{sgn}(w_{41}x_1 + w_{42}x_2 + w_{40})$

$S(x_1,x_2) = U_1 + U_2$

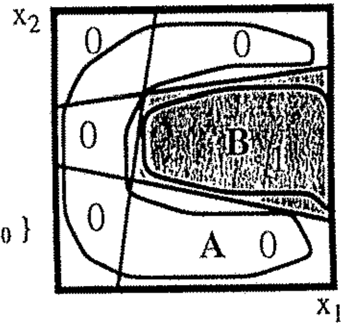
$U_3 = \mathrm{sgn}(w_{51}x_1 + w_{52}x_2 + w_{50})$

$S(x_1,x_2) = U_1 + U_2 + U_3$

subtrahiere 2

$S(x_1,x_2) = U_1 + U_2 + U_3 - 2$

Einführung
(Feed forward Backpropagation, FFBP)

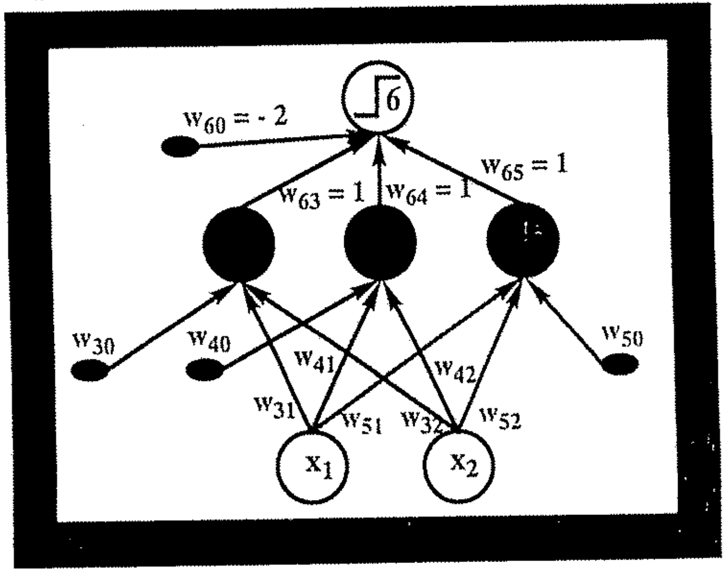


$S(x_1,x_2) = \mathrm{sgn}\{\, U_1 + U_2 + U_3 + w_{60} \,\}$

$= \mathrm{sgn}\{\mathrm{sgn}(w_{31}x_1 + w_{32}x_2 + w_{30}) +$
$\mathrm{sgn}(w_{41}x_1 + w_{42}x_2 + w_{40}) +$
$\mathrm{sgn}(w_{51}x_1 + w_{52}x_2 + w_{50}) + w_{60}\,\}$

$w_{60} = -2$

Eine graphische Darstellung des Ergebnisses ergibt ein „feed forward" Netz.



Die Bestimmung der Gewichte erfolgt durch den Error Backpropagation Algorithmus.

Neuronale Netze
(Pro und Contra)

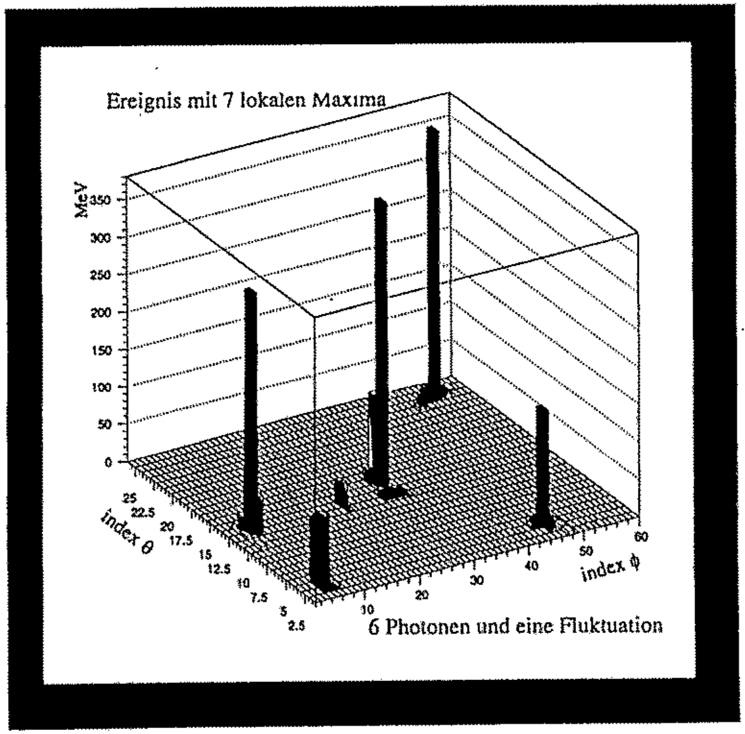
Vorteile

- **Selbstorganisation**
  „Lernen“ einer Lösung durch Lernbeispiele (Training)
- **Generalisierung**
  Fähigkeit auf „unbekannte“ Eingaben zu generalisieren
- **Modellunabhängigkeit**
- **Intrinsisch multi- dimensional**
- **Fehlertoleranz**
- **Parallelität**
  schnelle Lösung durch „parallele Hardware“ möglich
  „Neuro-Computer“ : CNAPS, Synapse

Nachteile

- schwer nachvollziehbarer Lösungsweg
- unvorhersehbares Verhalten (in der dynamischen Phase)
- Approximation statt exakter Lösungen

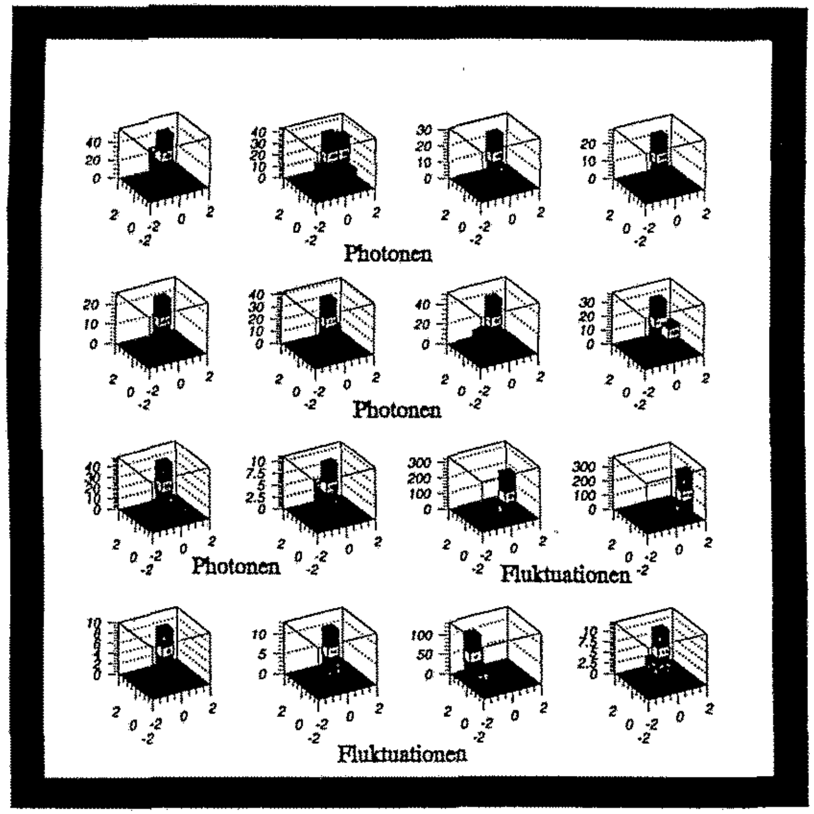
Unterdrückung von Schauerfluktuationen



Unterdrückung von Schauerfluktuationen (neuronales Netz - Eingaberaum)

5×5 Kristallmatrix

Die lokalen Maxima befinden sich bei (0,0)



Unterdrückung von Schauerfluktuationen

Zur Rekonstruktion von Photonen im Kalorimeter des Crystal Barrel Detektors werden benachbarte Kristalle mit einem Energieeintrag gruppiert (**cluster**).

- **lokales Maximum** in einem Cluster = Photon
- Monte Carlo: 5-6% der lokalen Maxima entstehen durch Schauerfluktuationen → zu viele Photonen
- 2 konventionelle Methoden wurden entwickelt („SMART“, „DOLBY C“)

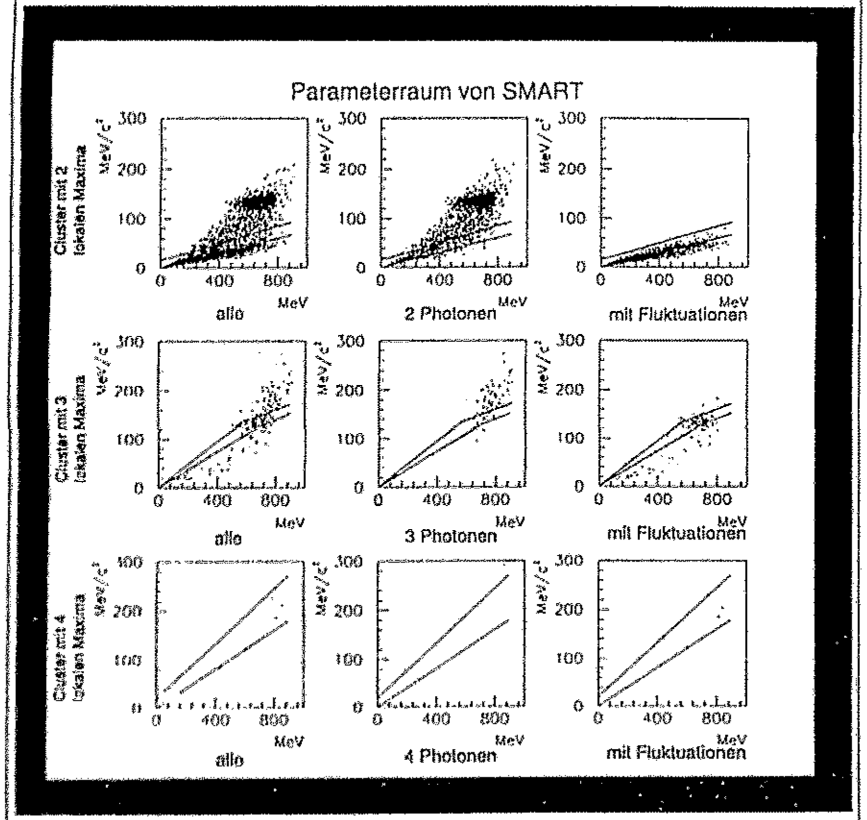
„invarianten Schauermasse“ Cluster-Energie

$$m_S = \sqrt{\left(\sum_{i=1}^{n} E_i\right)^2 - \left(\sum_{i=1}^{n} \vec{p}_i\right)^2} \qquad E_{Cl} = \sum_{i=1}^{n} E_i$$

- Schnitte im zwei-dimensionalen Parameterraum aus m_S und E_{CL} ermöglichen eine gute Separierung von Photonen und Fluktuationen.

Unterdrückung von Schauerfluktuationen (konventionelle Methode)

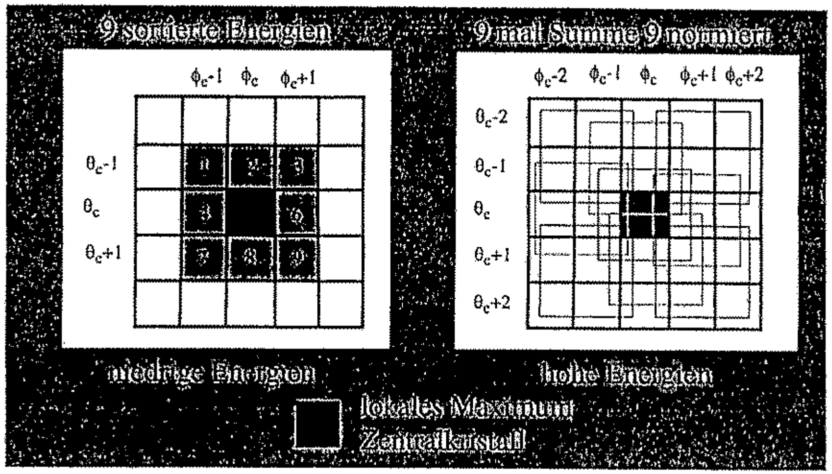
Invariante Schauermasse vs. Cluster-Energie



Unterdrückung von Schauerfluktuationen (neuronales Netz, FFBP)

Hierarchische Netzwerkstruktur (2 Unter-Netze, 1 Ober-Netz)

- Konfiguration der Unter-Netze: 9-8-1 und 9-7-1
- Eingabeparameter:
  3×3 - Kristallmatrix → 9 sortierte Energien
  5×5 - KristallMatrix → 9 mal Summe 9

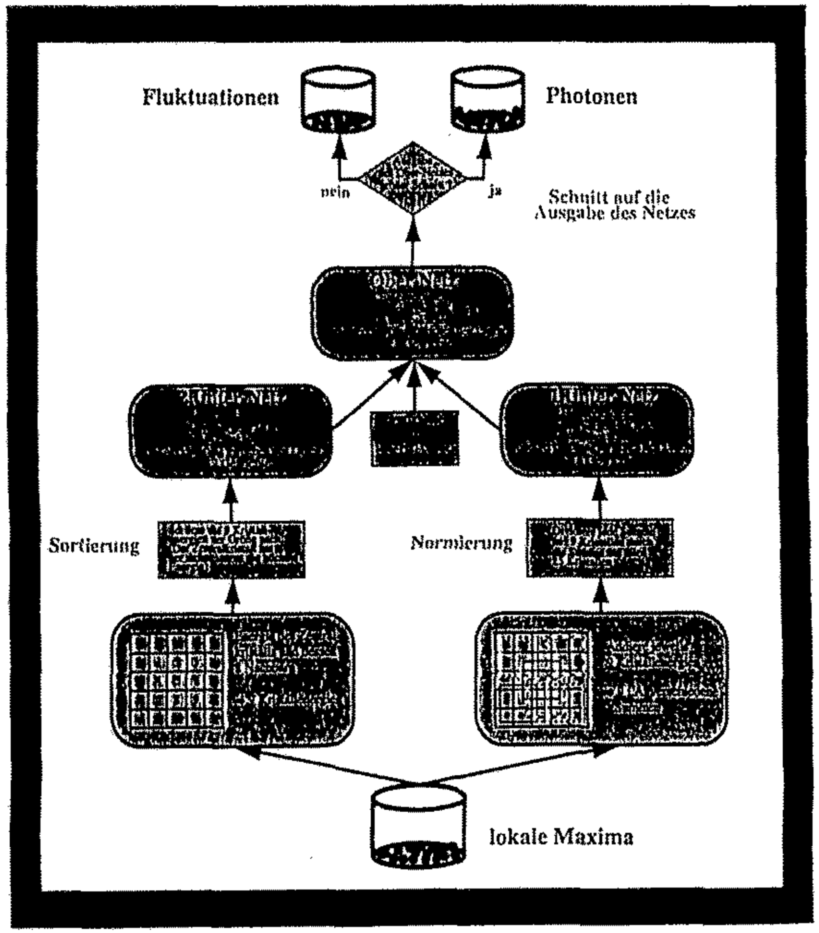


- Sortierung → Rotationsinvarianz (bzgl. Zentralkristall)
- Training beider Netze im **gesamten** Energiebereich mit Monte Carlo Daten
- jeweils 2000 Fluktuationen (Ausgabe: 0) und Photonen (Ausgabe: 1)

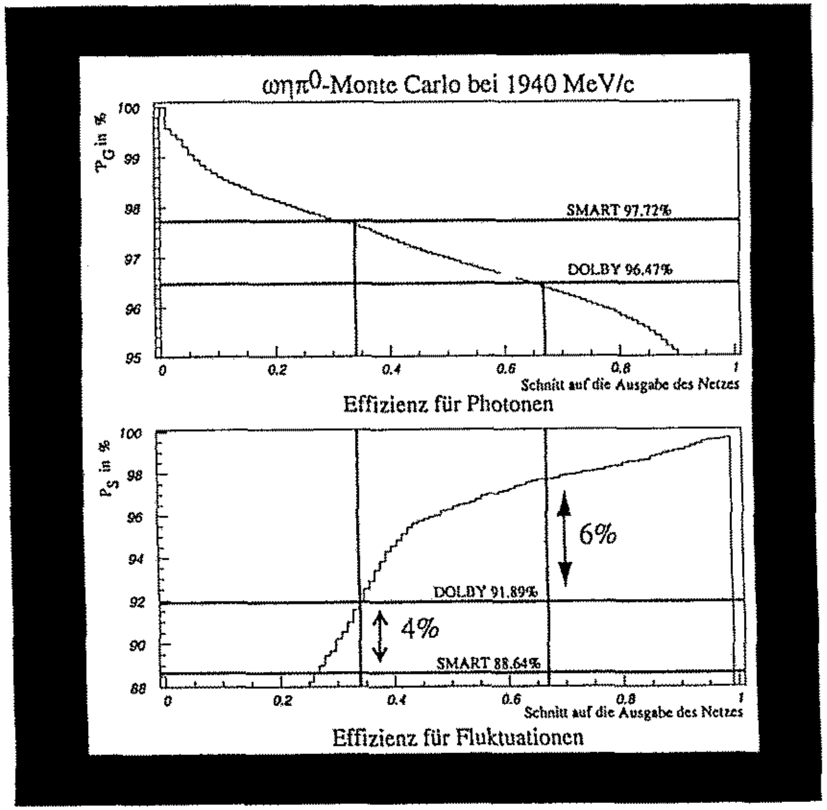
- 3-4-1 Ober-Netz wertet die Ausgaben der Unter-Netze aus
- Training des Ober-Netzes mit **festen** Gewichten in den Unter-Netzen

Unterdrückung von Schauerfluktuationen (neuronales Netz, FFBP)

Hierarchische Netzwerk Struktur



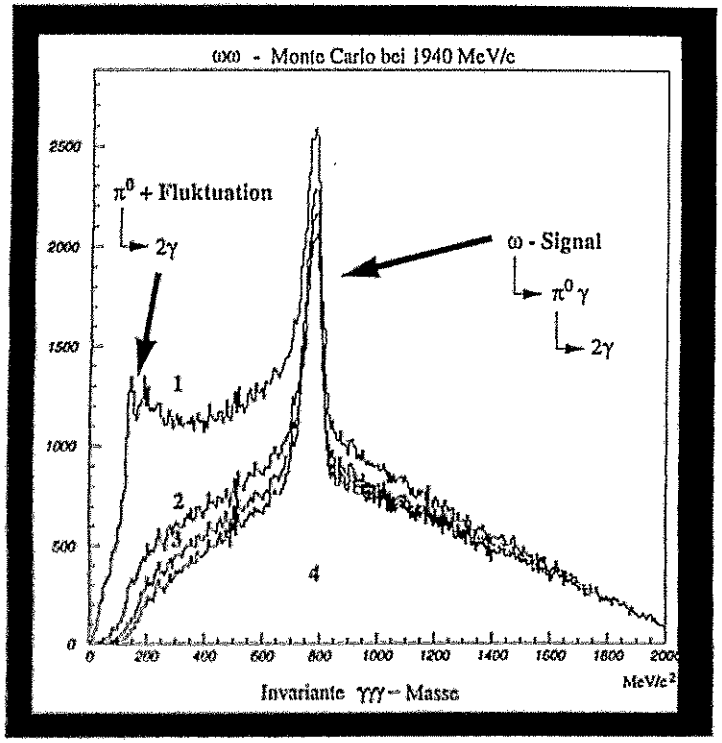
Unterdrückung von Schauerfluktuationen (Vergleich: neuronales Netz - konventionelle Methoden)



- Bei gleicher Effizienz für Photonen, eine um 4% (6%) höhere Effizienz Fluktuationen zu erkennen.
- Der Schnitt auf den Ausgabewert des Netzes wirkt wie ein kontinuierlich durchstimmbarer Filter.

Unterdrückung von Schauerfluktuationen (neuronales Netz, FFBP)

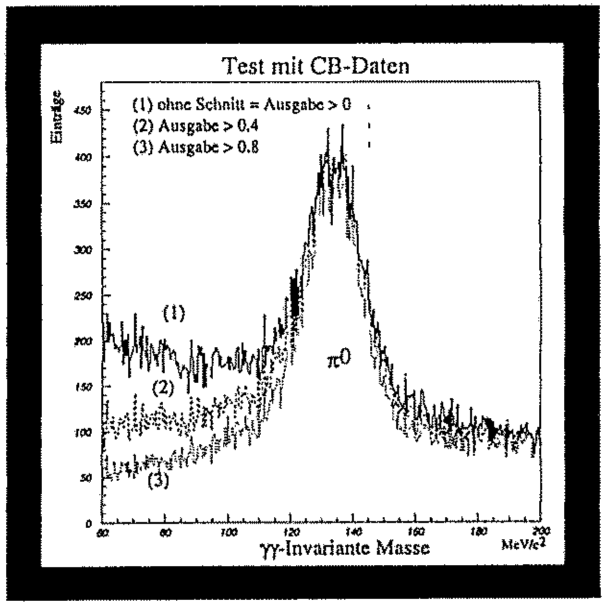
Test mit Monte Carlo Daten



1. ohne Schnitt = Augabe > 0
2. Ausgabe > 0.1
3. Ausgabe > 0.4
4. Ausgabe > 0.8

Unterdrückung von Schauerfluktuationen (neuronales Netz, FFBP)

Ergebnis



- Vergleichbare Effizienzen, bei 2 GeV/c Strahlimpuls bessere Effizienzen als die konventionellen Methoden.
- keine Abhängigkeit vom Strahlimpuls (200 MeV/c, 600 MeV/c, 1200 MeV/c, 1940 MeV/c)
- keine Abhängigkeit von der γ-Multiplizität oder dem Zerfallkanal
- robust gegenüber Energieauflösung, Kalibrierung und Rauschen
- flexibel einsetzbar, da kontinuierlich durchstimmbar

Bewertung kinematischer Fits (FFBP)

Selektion mesonischer Endzustände (Crystal Barrel Detektor)

Standardmethode

Selektion einer γ-Multiplizität z.B.: 6γ

Kinematische Fits zu folgenden Hypothesen:

H_P: 6γ -(Phasenraum)

H_1: $3\pi^0$ H_2: $2\pi^0\eta$ H_3: $2\eta\pi^0$ H_4: 3η

Entscheidung durch Schnitte auf die Wahrscheinlichkeiten (confidence level, CL):

CL(H_P) > 10% und CL(H_1) > 10% und CL(H_1) > CL(H_2-H_4)

Endzustand = $3\pi^0$

MC: Entscheidung ist in einigen Prozent der Fälle falsch
(stark abhängig vom selektierten Endzustand)

Verbesserung durch FFBP-Netz, trainiert mit MC-Datensätzen
→ fast alle Ereignisse (MC) richtig klassifiziert

Bestehende Anwendungen (verschiedene Netzwerk-Modelle)

Klassifizierung von Teilchen und Endzuständen

• $e^+e^- \to$ gg-jets, qq-jets	MC, C.Peterson, Lund
• $p\bar{p} \to$ W, QCD-jets	MC,P.Bhat et al., DESY
• $Z^0 \to$ qq-jets	ALEPH, J.Jousset, U BP, Aubiere
• $Z^0 \to$ b-Quarks	ALEPH, B.Brandl, U Heidelberg
• $Z^0 \to$ b-Quarks	ALEPH, B.Brandl, U Heidelberg
• $\tau\to\rho\nu, \tau\to\pi\nu, \tau\to e\nu\bar{\nu}$	L3,V.Innocente, INFN
• Schwere Neutrinos	LEP200, K.H.Becks, U Wuppertal
• top → multi-jets	CDF, B.Denby et al., FNAL
• gg $\to H^0 \to Z^0Z^0 \to \mu^+\mu^-\mu^+\mu^-$	CERN LAA, F.Block, U Wuppertal
• Photon-Gluon Fusion $\to c\bar{c}, b\bar{b}$	H1, P.Ribarics, MPI München
• $\tau^+\tau^- \to$ Leptonen	ARGUS, M. Joswig et al.

Spurrekonstruktion (Drift- und Proportionalkammern)

• Elastic tracking	MC, M.Gyulassy, LBL
• Elastic arms	MC, C.Peterson, Lund
• Online tracking (VLSI)	CDF, B.Denby, FNAL
• Secondary vertices	ALEPH, G.Stimpfl, U BP, Aubiere
• Online tracking	CP-LEAR, G.Athanasiu, CERN

Cluster Trigger (segmentierte Kalorimeter)

• Cluster trigger	MC, T.Altherr, L.A.P.P.
• Isolation trigger (VLSI)	CDF, B.Denby, FNAL
• Cluster trigger	LHC, G.Stimpfl, U BP, Aubiere
• Core trigger	CASCADE, H.Majer, KfK

Bestehende Anwendungen (verschiedene Netzwerk-Modelle)

Teilchen Identifizierung

- π, K, p - Separierung (RICH)MC, T.Altherr, L.A.P.P.
- e, π - Separierung (TRD)LHC, J.Renner, Kopenhagen
- e, π - Separierung (Si/W)WIZARD, P.G. Costa
- γ, π^0 - Separierung (TGT strip)ATLAS, M.Wunsch, U Heidelberg
- $\bar{p}$, μ, π, e-Separierung (RICH) CAPRICE, K.Jonsson, Stockholm

Rekonstruktion von invarianten Massen

- $\eta, \pi^0 \rightarrow \gamma\gamma$ MC, T.Awes, Oak Ridge NL
- $\eta, \pi^0 \rightarrow \gamma\gamma$ TAPS, F.Lefevre, GANIL
- $\bar{p}p \rightarrow W \rightarrow q\bar{q} \rightarrow$ Hadronen MC, C.Peterson, Lund
- $\bar{p}p \rightarrow X + \rho$, $K \rightarrow \pi\pi$ E735, T.Alexopoulos, FNAL

Offline Analyse

- γ-Impulse SPES2, P.Fuchs, SACLAY
- Schauerfluktuationen CB, T.Degner, RUB
- Histogramm Einteilung CB, J.Lüdemann, RUB
- Bewertung kin. Fits CB, J.Lüdemann, RUB
- pp-Bremsstrahlung TOF/COSY, S.Lange, RUB

Zusammenfassung

- **Neuronale Netze sind ein gutes Hilfsmittel in der Datenanalyse**
  - ⇒ Klassifikation
  - ⇒ Parametrisierung von nicht linearen Funktionen
- **In der Teilchenphysik wurden bisher hauptsächlich drei Netzwerktypen verwandt**
  - ⇒ Hopfield Netze
  - ⇒ Selbstorganisierende Karten
  - ⇒ Feed forward Backpropagation
- **Mit neuronalen Netzen lassen sich Lösungen gleicher Güte wie mit optimierten Standardmethoden finden**
- **Neuronale Netze eignen sich sehr gut für Parallelverarbeitung**
  - ⇒ Echtzeit-Anwendungen, Trigger

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