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2^{nd} Workshop on Kaon Production

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2nd Workshop on Kaon Production

Transparencies of the Kaon Workshop

Forschungszentrum Rossendorf, December 10-11, 1998

Editors:

Eckart Grosse, Burkhard Kämpfer

2^{nd} Workshop on Kaon Production

During the fall of 1996 an internal mini-workshop on kaon production was organized at Rossendorf (cf. FZR-150 [September 1996]). The aim of this first workshop was to give a survey on the experimental and theoretical status of kaon production in elementary hadron reactions and in heavy-ion collisions. Since then the Department of Hadron Physics in the Institute of Nuclear and Hadron Physics of the FZR focused in its research activities on near-threshold strangeness production in colliding hadron systems and on activities devoted to studies with electromagnetic probes.

Since 1996 a considerable progress has been achieved in the field. New results from COSY (COSY-11, ToF, COSY-13 and first runs at ANKE) as well as SIS (KaoS and FOPI) allow to determine various elementary cross sections in hadron reactions and kaon yields from heavy-ion collisions. These new results led us to organize a second workshop bringing together the experts of these experiments and various theoreticians. An important purpose of the workshop was to enforce the mutual information and to demonstrate the close interrelation of COSY physics and the heavy-ion programme at SIS.

Highlights in the field are (i) the consolidation of the need of strong in-medium modifications to describe the K^- production in heavy-ion reactions and (ii) refined measurements of various elementary strangeness channels near threshold. For the latter the role of final state interactions must be clarified to arrive at a unique input to transport-model calculations for heavy-ion reactions.

Many experimental aspects included in the programme have been proposed by P. Senger (GSI), whereas the composition of its theoretical part benefitted a lot from the support by J. Aichelin (Nantes).

E. Grosse, B. Kämpfer
(local organizers)

Kaon Workshop

Forschungszentrum Rossendorf near Dresden

December 10-11, 1998

The workshop is devoted to kaon production near threshold, with emphasis put on heavy-ion collisions. Embedded in the workshop is a meeting of the KaoS collaboration. In parallel the representants of theory groups are going to compare in detail the results of their transport codes relevant for the experiments.

Programme

December 9: Arrival
December 10 (Tandemseminarraum):

9.00 - 9.30	E. Grosse: Opening W. Cassing/E. Bratkovskaya (Giessen): RBUU approach, the implemented kaon production and optical potentials, Discussion of my benchmark tests	(chairman: E. Grosse)
9.30 - 9.50	Gy. Wolf (Budapest): Differences between RBUU of Giessen and my approach, Discussion of my benchmark tests	
9:50 - 10.20	C.-H. Lee (Stony Brook): Differences between RBUU of Giessen and my approach, Discussion of my benchmark tests	
10.20 - 10.50	**Coffee break**	
10.50 - 11.20	J. Aichelin (Nantes): QMD: What is important for the kaon production, discussion of my benchmark tests for HQMD	(chairman: W. Cassing)
11.20 - 11.40	C. Hartnack (Nantes): IQMD - Differences to HQMD as far as of importance for the kaon production, discussion of my benchmark tests for IQMD	
11.40 - 12.05	C. Fuchs (Tübingen): Differences as compared to HQMD, discussion of my benchmark tests with Tübingen kaon production	
12:05 - 12.35	S. Soff (Frankfurt): Kaon production around 1 GeV/N in URQMD - Differences to QMD, discussion of my benchmark tests for UrQMD	
12.35 - 13.00	A. Sibirtsev (Giessen): News from elementary kaon production reactions	
13.00 - 14.00	**Break**	
14.00 - 14.20	F. Laue (GSI): Recent results from KaoS (1): K^+/K^- ratios	(chairman: W. Oelert)
14.20 - 14.40	Y. Shin (Frankfurt): Results from Kaos (2): azimuthal anisotropy of K^+	
14.40 - 15.00	C. Sturm (Darmstadt): Recent results from KaoS (3): K production and nuclear EoS	
15.00 - 15.30	P. Crochet (C-Ferrand): Results from FOPI (1)	
15.30 - 16.00	C. Plettner (Rossendorf): Results from FOPI (2)	
16.00 - 16.30	**Coffee break**	
16.30 - 17.00	A. Metzger (Erlangen): Results from COSY-TOF	(chairman: N. Herrmann)
17.00 - 17.30	T. Lister / S. Sewerin:	

	Results from COSY-11	
17.30 - 18.00	M. Debowski (Rossendorf): Prospects of ANKE	
18.00 - 18.20	A. Gillitzer (München): Strangeness programme at FRS	
18.20 - 18.40	P. Kulessa (Crakow): Λ nuclei	
18.40 - 18.55	W. Scheinast (Rossendorf): pA runs at KaoS	
19.00 - ∞	**Buffet**	

December 11:

Parallel sessions 9.00 - 12.00:

1. KaoS collaboration meeting (Seminarraum Flachbau, organizer: P. Senger)
2. Theory session (Tandemseminarraum, organizer: J. Aichelin)

Afternoon session (Auditorium):

13.00 - 13.20	K. Schubert (Dresden): Recent results on symmetry breaking in K systems	(chairman: B. Kamys)
13.20 - 13.45	E. Kolomeitsev (GSI): In-medium kaonic excitations	
13.45 - 14.10	J. Knoll (GSI): Transport kinetics of broad resonances	
14.10 - 14.40	B. Kämpfer (Rossendorf): Comparison of the benchmark tests	
14.40 - 15.00	**Coffee break**	
15.00 - 16.00	Round table discussion about the different models Conclusions & perspectives for our kaon physics	(chairman: P. Senger)

Departure
(e.g. 17.27 p.m. Dresden-Neustadt --> Frankfurt/Main)

Kaon Workshop Participants

Who	From	Where	When
Aichelin, J.	Nantes	Gästehaus	9. - 12.
Böttcher, I.	Uni Marburg	Zu d.Linden	9. - 13.
Bratkovskaya, E.	Giessen	Schänkhübel	9. - 11.
Büscher, M.	Jülich	Zu den Linden	9. - 11.
Cassing, W.	Giessen	Schänkhübel	9. - 11.
Crochet, P.	C-Ferrand	Arcade	9. - 11.
Förster, A.	TU Darmsdtadt	Arcade	9. - 13.
Fuchs, C.	Tübingen	Arcade	9. - 13.
Gillitzer, A.	München	Arcade	9. - 11.
Nantes	Arcade	10. - 11.	
Khoukaz	Münster	Arcade	9. - 11.
Herrmann, N.	GSI	Gästehaus	9. - 11.
Kamys, B.	Krakau	Gästehaus	10. - 11.
Knoll, J.	GSI	Gästehaus	9. - 11.
Koczon, P.	GSI	Arcade	9. - 12.
Kohlmeyer, B.	Uni Marburg	Gästehaus	9. - 11.
Kolomeitsev, E.	GSI	privat	
Krusche, R.		Arcade	9. - 11.
Laue, F.	GSI	Arcade	9. - 11.
Lee, C.-H.	Stony Brook	Arcade	9. - 13.
Lister, Th.	Münster	Arcade	9. - 11.
Menzel, M.	Marburg	Arcade	9. - 11.
Metzger, A.	Erlangen	Gästehaus	9. - 11.
Moscal, P.	Crakow	Arcade	9. - 11.
Oelert, W.	Jülich	Zu d. Linden	9. - 12.
Oeschler, H.	TU Darmstadt	Zu d. Linden	9. - 11.
Quentmeier, Ch.	Münster	Arcade	9. - 11.
Reisdorf, W.	GSI	Zu d.Linden	9. - 11.
Scheinast, W.	FZR	Arcade	9. - 11.
Schepers, G.	Jülich	Arcade	9. - 12.
Senger, P.	GSI	privat	
Sewerin, S.	Jülich	Arcade	9. - 12.
Shin, Y.	Uni Frankfurt	Arcade	9. - 13.
Sibirtsev, A.	Giessen	Schänkhübel	9. - 11.
Sistemich, K.	Jülich	Zu d. Linden	9. - 11.
Soff, S.	Frankfurt	Arcade	9. - 11.
Sturm, C.	TU Darmstadt	Arcade	9. - 11.
Uhlig, F.	TU Darmstadt	Arcade	9. - 11.
Walus, W.	Cracow	Zu d. Linden	9. - 11.
Wolf, Gy.	Budapest	Wohnunterk.	
Wisniewski, C.	GSI	Gästehaus	9. - 11.
Grosse, E.	FZR		9. - 11.
Kämpfer, B.	FZR		9. - 11.
Müller, H.	FZR		9. - 11.
Debowski, M.	FZR		9. - 11.
Schneider, C.	FZR		9. - 11.
Naumann, L.	FZR		9. - 11.
Barz, H.W.	FZR		9. - 11.
Kotte, R.	FZR		9. - 11.
Plettner, C.	FZR		9. - 11.
Wohlfarth, D.	FZR		9. - 11.
Dohrmann, F.	FZR		9. - 11.

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Transparencies of the Kaon Workshop

1. Experimental Part

T. Lister:
$pp \to ppK^+X$ near the $f_0(980)$

A. Metzger:
Strangeness production – results from COSY-TOF

M. Debowski:
Prospects of ANKE

P. Kulessa:
Determination of Λ lifetime in heavy hypernuclei

A. Gillitzer:
K^- production at the GSI fragment separator

P. Crochet:
Results from FOPI (1)

C. Plettner:
Results from FOPI (2):
Investigation of charged K mesons at low $p_\perp$ and around midrapidity

Y. Shin:
Azimuthally anisotropic emission of K^+ mesons in Au + Au collisions at 2 AGeV

F. Laue:
Kaons and anti-kaons in hot and dense nuclear matter

C. Sturm:
K^+ production in heavy-ion reactions as a probe for the nuclear equation of state

K.R. Schubert:
Recent results on symmetry breaking in the K^0 system

2. Theoretical part

W. Cassing & E. Bratkovskaya:
The RBUU (HSD) approach to strangeness production

C.-H. Lee:
Bechmark test of the RVUU model

J. Aichelin:
QMD

S. Soff:
Kaon production at SIS energies in the UrQMD approach

Gy. Wolf:
Kaon production – benchmark test

C. Fuchs:
K^+ production with Tübingen QMD

B. Kämpfer:
Comparison of benchmark tests

E.E. Kolomeitsev:
Kaonic excitation in HICs

A. Sibirtsev:
Theoretical news on strangeness production in p + p collisions

J. Knoll:
Transport kinetics of broad resonances

Experimental Part

T. Lister:

$pp \to ppK^+X$ near the $f_0(980)$

I. Lister

$pp \to ppK^+X$ near the $f_0(980)$

inner structure of the $f_0(980)$???

$\Downarrow$

- modified $q\bar{q}$ - meson
- glueball
- $qq\bar{q}\bar{q}$ - state
- $K\bar{K}$ - molecule?

$\searrow$ $pp \to pp(K^+K^-)$

other channels in $pp \to pK^+(pX)$:

$\Lambda(1405) \xrightarrow{\sim 100\%} \Sigma\pi$

$\uparrow$

?(pK^-)?

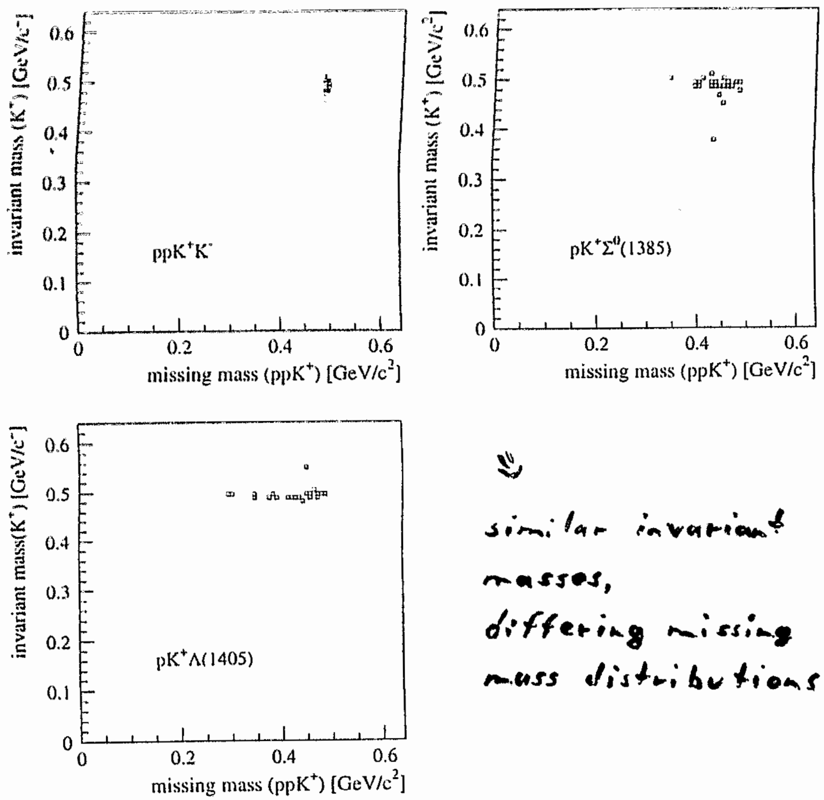
- $\Sigma^- \to n\pi^-$ (99.8%)
- $\Sigma^+ \to p\pi^0$ (51.6%), $n\pi^+$ (48.3%)
- $\Sigma^0 \to \Lambda\gamma$ (100%)
  - $\Lambda \to p\pi^-$ (63.9%), $n\pi^0$ (35.8%)

$\Sigma^0(1385) \longrightarrow \Lambda\pi$ (88%), $\Sigma\pi$ (12%)

$\Downarrow$

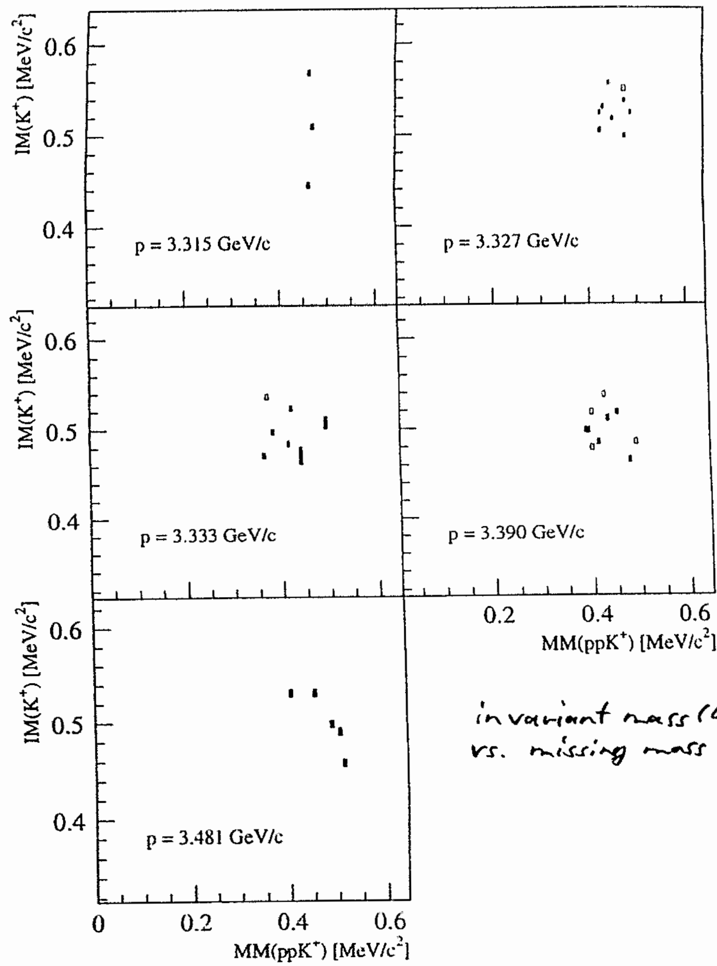
$(pK^+p) + X$

MC - simulations



⇒ similar invariant masses, differing missing mass distributions

experimental data



invariant mass (K^+) vs. missing mass (ppK^+)

detection efficiencies

beam momentum	$\varepsilon_{ppK^+K^-}$	$\varepsilon_{pK^+\Sigma^0(1385)}$	$\varepsilon_{pK^+\Lambda(1405)}$
3.315 GeV/c	$3.44 \cdot 10^{-2} \cdot (1^{+43.8\%}_{-16.8\%})$	$7.5 \cdot 10^{-5} \cdot (1 \pm 11.5\%)$	$1.3 \cdot 10^{-4} \cdot (1 \pm 6.7\%)$
3.327 GeV/c	$1.65 \cdot 10^{-2} \cdot (1^{+20.7\%}_{-16.8\%})$	$7.5 \cdot 10^{-5} \cdot (1 \pm 11.5\%)$	$2.2 \cdot 10^{-4} \cdot (1 \pm 6.8\%)$
3.333 GeV/c	$1.26 \cdot 10^{-2} \cdot (1^{+16.7\%}_{-11.9\%})$	$6.1 \cdot 10^{-5} \cdot (1 \pm 12.8\%)$	$1.2 \cdot 10^{-4} \cdot (1 \pm 9.2\%)$
3.390 GeV/c	$2.54 \cdot 10^{-3} \cdot (1^{+8.1\%}_{-6.9\%})$	$6.0 \cdot 10^{-5} \cdot (1 \pm 12.9\%)$	$6.6 \cdot 10^{-5} \cdot (1 \pm 12.3\%)$
3.481 GeV/c	$1.07 \cdot 10^{-4} \cdot (1^{+12.2\%}_{-12.0\%})$	$1.8 \cdot 10^{-6} \cdot (1 \pm 23.6\%)$	$6.3 \cdot 10^{-6} \cdot (1 \pm 20.0\%)$

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number of events

beam momentum	no. N of (ppK$^+$)-events	no. n of possible (ppK$^+$K$^-$)-events	CL=95% n_0 (K$^+$K$^-$)	CL=95% N_0 (Σ^0(1385) ∨ Λ(1405))
3.315 GeV/c	3	0	3.00	7.75
3.321 GeV/c	2	0	3.00	6.30
3.327 GeV/c	10	0	3.00	16.96
3.333 GeV/c	10	2	6.30	16.96
3.390 GeV/c	10	1	4.74	16.96
3.481 GeV/c	5	1	4.74	10.51

↑ allowed deviation in missing mass: 6 MeV/c^2

beam momentum	n_0	ε_{ppK^+}	integrated luminosity	cross section
3.315 GeV/c	3.00	$3.44 \cdot 10^{-2}$	$5.17 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 260 pb,
		$\cdot(1^{+43.8\%}_{-16.8\%})$	$\cdot(1 \pm 10.78\%)$	CL = 95%
3.321 GeV/c	3.00	$5.15 \cdot 10^{-2}$	$7.90 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 1.1 nb,
		$\cdot(1^{+10.6\%}_{-27.2\%})$	$\cdot(1 \pm 3.3\%)$	CL = 95%
3.327 GeV/c	3.00	$1.65 \cdot 10^{-2}$	$3.52 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 680 pb,
		$\cdot(1^{+20.7\%}_{-16.8\%})$	$\cdot(1 \pm 11.25\%)$	CL = 95%
3.333 GeV/c	6.30	$1.26 \cdot 10^{-2}$	$4.64 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 1.4 nb,
		$\cdot(1^{+16.7\%}_{-11.9\%})$	$\cdot(1 \pm 11.55\%)$	CL = 95%
3.390 GeV/c	4.74	$2.54 \cdot 10^{-3}$	$7.52 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 3.0 nb,
		$\cdot(1^{+8.1\%}_{-6.9\%})$	$\cdot(1 \pm 11.62\%)$	CL = 95%
3.481 GeV/c	4.74	$1.07 \cdot 10^{-4}$	$1.38 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 400 nb,
		$\cdot(1^{+12.2\%}_{-12.0\%})$	$\cdot(1 \pm 12.63\%)$	CL = 95%

upper limits of

$pp \to ppK^+K^-$

upper limits

beam momentum	N_0	$\mathcal{E}_{ppK^+}$	integrated luminosity	cross section
3.315 GeV/c	7.75	$7.5 \cdot 10^{-5}$.	$5.17 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 245 nb,
		$(1 \pm 11.5\%)$	$(1 \pm 10.78\%)$	CL = 95%
3.327 GeV/c	16.69	$7.5 \cdot 10^{-5}$.	$3.52 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 775 nb,
		$(1 \pm 11.5\%)$	$(1 \pm 11.25\%)$	CL = 95%
3.333 GeV/c	16.69	$6.1 \cdot 10^{-5}$.	$4.64 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 735 nb,
		$(1 \pm 12.8\%)$	$(1 \pm 11.55\%)$	CL = 95%
3.390 GeV/c	16.69	$6.0 \cdot 10^{-5}$.	$7.52 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 460 nb,
		$(1 \pm 12.9\%)$	$(1 \pm 11.62\%)$	CL = 95%
3.481 GeV/c	10.51	$1.8 \cdot 10^{-6}$.	$1.38 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 57.6 μb,
		$(1 \pm 23.6\%)$	$(1 \pm 12.63\%)$	CL = 95%

$pp \rightarrow pK^+ \Sigma^0(1385)$

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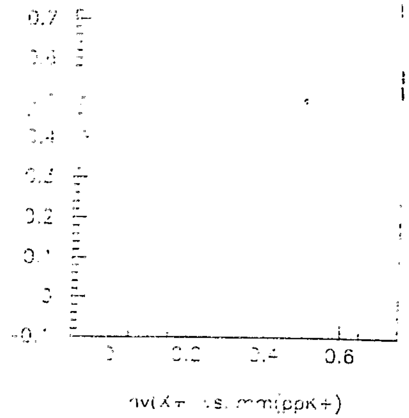
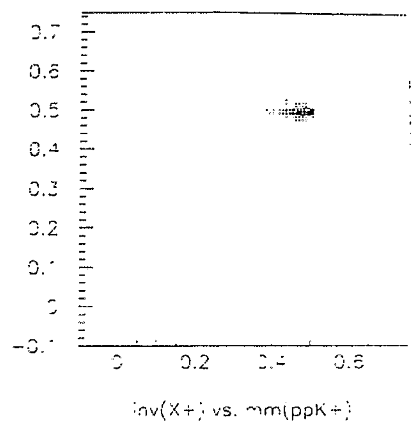
upper limits

beam momentum	N_0	$\mathcal{E}_{ppK^+}$	integrated luminosity	cross section
3.315 GeV/c	7.75	$1.31 \cdot 10^{-4}$	$5.17 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 135 nb,
		$\cdot(1 \pm 6.7\%)$	$\cdot(1 \pm 10.78\%)$	Cl = 95%
3.327 GeV/c	16.69	$2.19 \cdot 10^{-4}$	$3.52 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 255 nb,
		$\cdot(1 \pm 6.8\%)$	$\cdot(1 \pm 11.25\%)$	Cl = 95%
3.333 GeV/c	16.69	$1.17 \cdot 10^{-4}$	$4.64 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 370 nb,
		$\cdot(1 \pm 9.2\%)$	$\cdot(1 \pm 11.55\%)$	Cl = 95%
3.390 GeV/c	16.69	$6.60 \cdot 10^{-5}$	$7.52 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 420 nb,
		$\cdot(1 \pm 12.3\%)$	$\cdot(1 \pm 11.62\%)$	Cl = 95%
3.481 GeV/c	10.51	$6.25 \cdot 10^{-6}$	$1.38 \cdot 10^{35} \cdot \frac{1}{cm^2}$	< 1.6 μb,
		$\cdot(1 \pm 20.0\%)$	$\cdot(1 \pm 12.63\%)$	Cl = 95%

$pp \rightarrow pK^+ \Lambda(1405)$

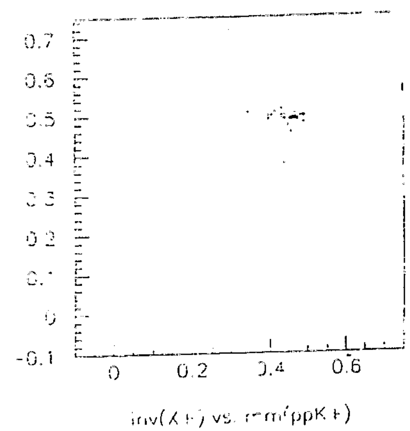
$pp K^+ K^- \Rightarrow$





$\Leftarrow pK^+ \Lambda(1405)$

$pK^+ \Sigma(1385) \Rightarrow$



conclusions.

- $pp \to ppK^+X$ -events are seen

- upper limits of the cross sections of

$$pp \longrightarrow ppK^+K^-$$
$$pK^+\Sigma^0(1385)$$
$$pK^+\Lambda(1405)$$

are calculated

- further data, especially below K^+K^--threshold and with higher statistics have to be taken

A. Metzger:

Strangeness production – results from COSY-TOF

Armin Metzger, Erlangen
Rossendorf, 10.12.1998

Strangeness Production

Results from COSY-TOF

$pp \to \overset{\bar{s}}{K}\overset{s}{Y}N$

- **Motivation**
- **Experiment**
- **Results**
- **Outlook**

Strangeness ($\bar{s}s$) Production close to Threshold:

$pp \to KYN$ (KKpp)

Information: dynamics: degrees of freedom
structure: strange content (?)

Experiment: *COSY-TOF*

- exclusive observables
  polarization: Λ-polarization
  polarized beam/target
- full phase-space
- threshold region → only few partial waves
- different reaction channels : $Y = \Lambda, \Sigma^0, \Sigma^+, (\Sigma^-)$

Comparison:

- different hadronic surroundings
  ⇒ data from $\gamma p \to K^+\Lambda$ ***ELSA***
  $\pi^- p \to K^0\Lambda$
  $\bar{p}p \to \bar{\Lambda}\Lambda$ ***LEAR***
- high energy data

Search for exotics: e.g. $Z^+(uud d\bar{s})$ - resonance

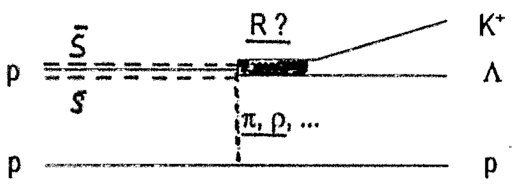
Medium effects:

- nucleon-nucleus : $pA \to KX$ ***COSY-ANKE***
- nucleus-nucleus : $AA \to KX$ ***GSI, CERN***

Meson Exchange Model

One boson exchange

strange content



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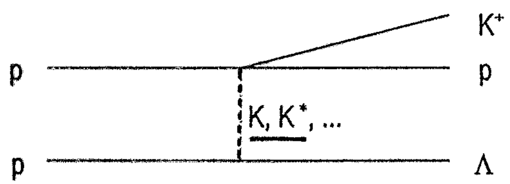

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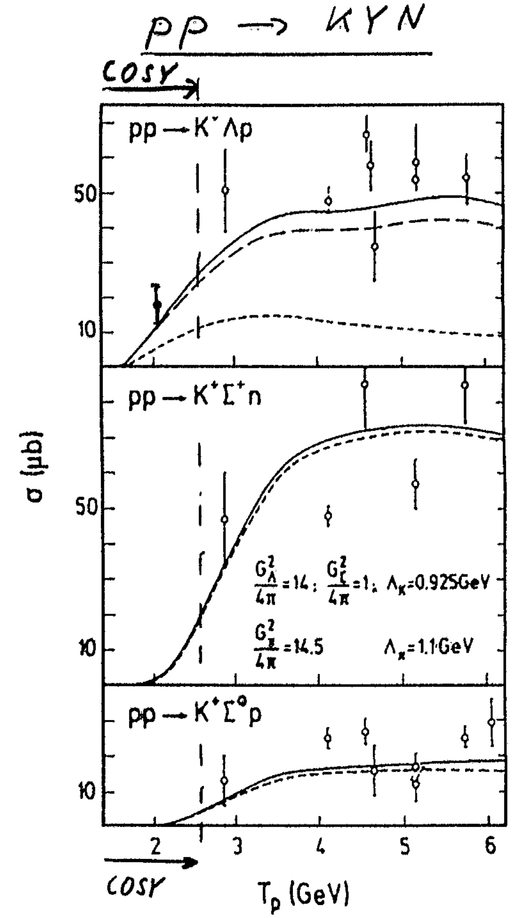
initial + final state interaction

coupled channels effects

Cassing, Sibirtsev et al.
Dillig, Kleefeld
Fäldt, Wilkin
Haidenbauer, Hanhart et al.
Laget
Li, Ko et al.   and others



calculations:

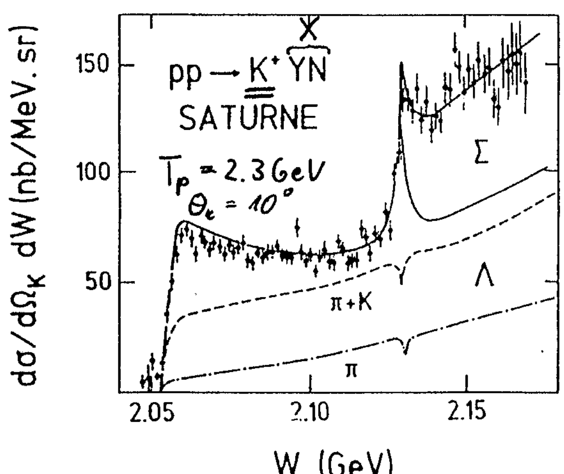
Laget et al.

— π + K

--- π

data:

CERN-HERA Comp. (1975)



+ FSI

data

Siebert et al.

N.P. A 567 (1994)

Experimental Constraints

Threshold momenta :

Reaction	$\sqrt{s}$ GeV	Momentum GeV/c	kin. Energy GeV
$pp \longrightarrow K^+\Lambda p$	2.548	2.339	1.582
$pp \longrightarrow K^+\Sigma^+ n$	2.622	2.560	1.789
$pp \longrightarrow K^+\Sigma^0 p$	2.624	2.566	1.793
$pp \longrightarrow K^0\Sigma^+ p$	2.625	2.569	1.796
$pp \longrightarrow K_s K_s pp$	2.875	3.327	2.518
$pd \longrightarrow K^+\Lambda d$	3.485	1.839	1.127
$p^4He \longrightarrow K^+\Lambda^4 He$	5.338	1.581	0.900
$p^{12}C \longrightarrow K^+\Lambda X$		1.400	0.747

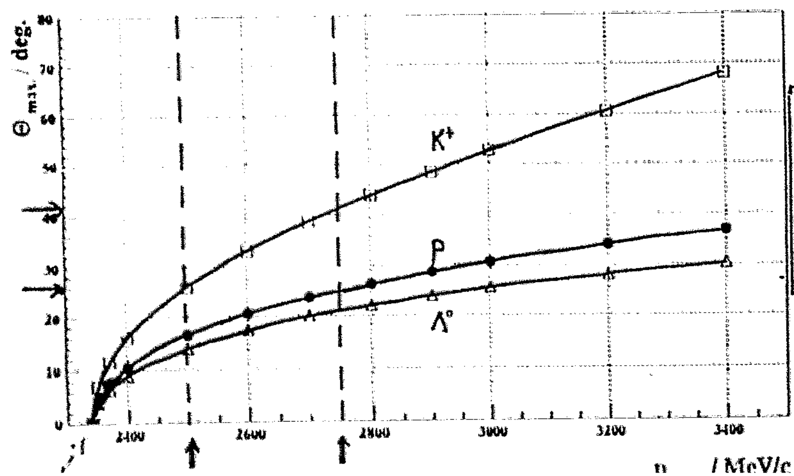
$pp \longrightarrow K^+\Lambda p$

Signature :

delayed decay $\Lambda \longrightarrow \pi^- p$ $(c\tau_\Lambda = 7.9\,cm)$ 64%

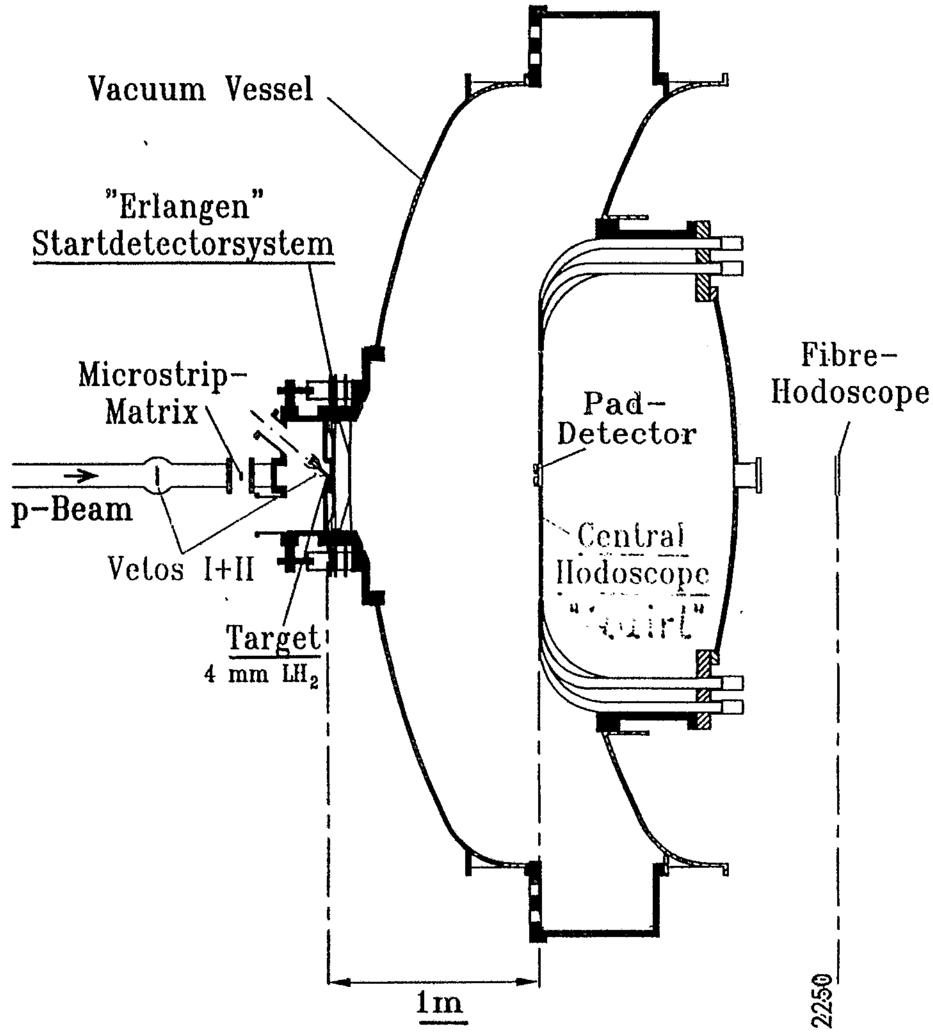
increase of charged multiplicity $2 \longrightarrow 4$: Trigger!

Reaction angles :



forward detector ≙ 4π

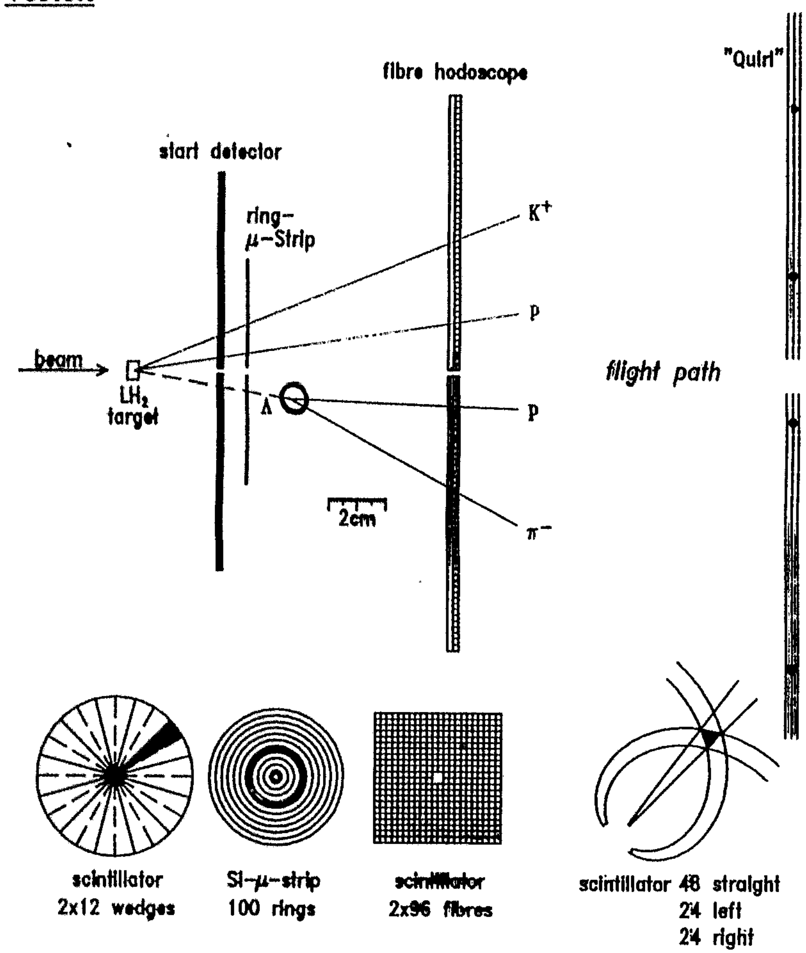
TOF-Setup '95/'96



inner detector

$pp \to K^+ \Lambda p \to K^+ p \pi^- p$

"4π"-detector
vertex "



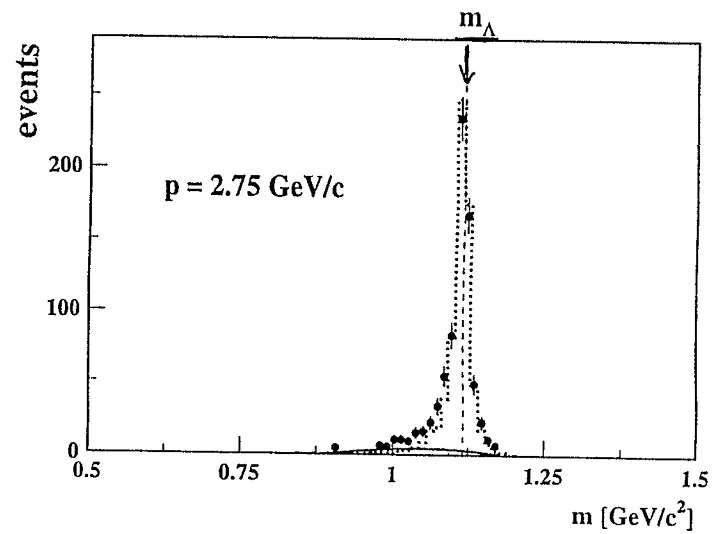
multiplicity trigger : 2 → 4

sufficient: start scint. $\geq [(1 \wedge 2) \vee (2 \wedge 1)]$
Quirl ≥ 3

TOF: run 96

mass reconstruction

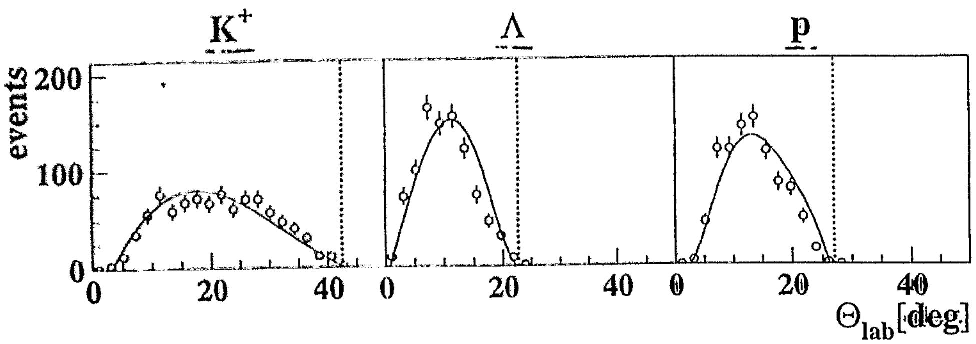
(geometrical with K⁺- p hypothesis)



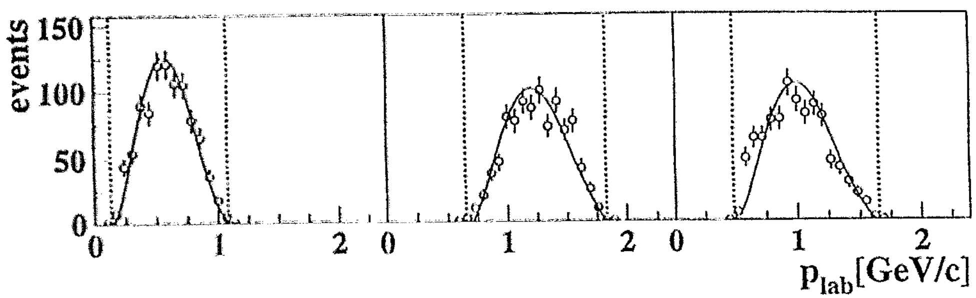
TOF

$pp \rightarrow K^+\Lambda p$ at $p_{beam} = 2.75 GeV/c$

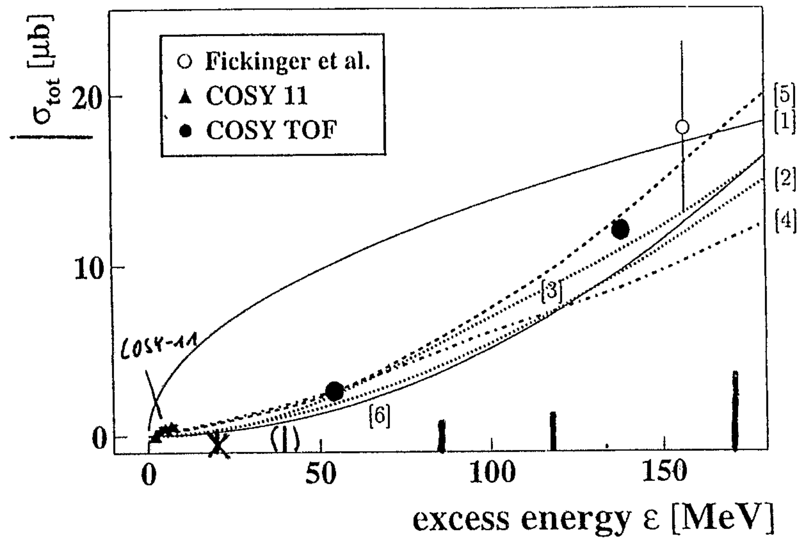
angular distributions



momentum distributions



$pp \longrightarrow K^+\Lambda p$



98

[1] J. Randrup and C.M. Ko, Nucl. Phys. A343 (1980) 519

[2] A. Sibirtsev, Phys. Rev. Lett. B359 (1995) 29;

[3] K. Tsushima, A. Sibirtsev, A.W. Thomas, Internal Rep. ADP-96-29/T228 (1996)

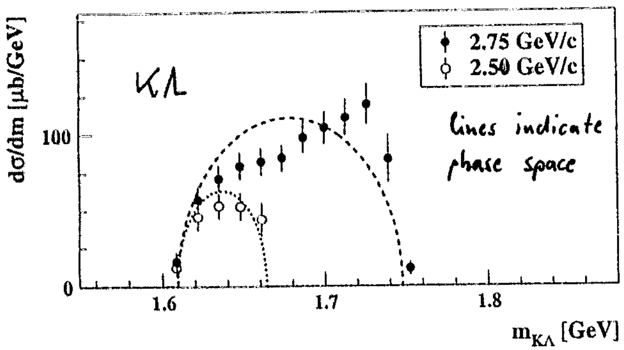
[4] J.M. Laget, Phys. Lett. B259 (1991) 24

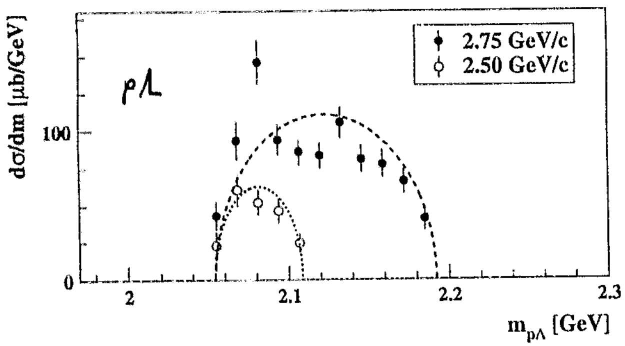
[5] F. Kleefeld, M. Dillig, F. Pilotto, Acta Phys. Pol. B27 (1996)

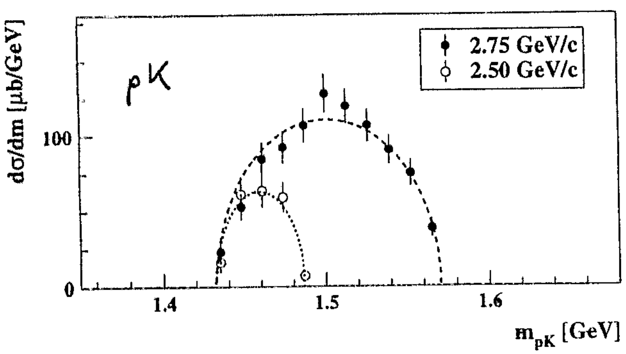
[6] B. Schürmann and W. Zwermann, Mod. Phys. Lett. A3 (1988) 251

Differential X-Sections

invariant masses





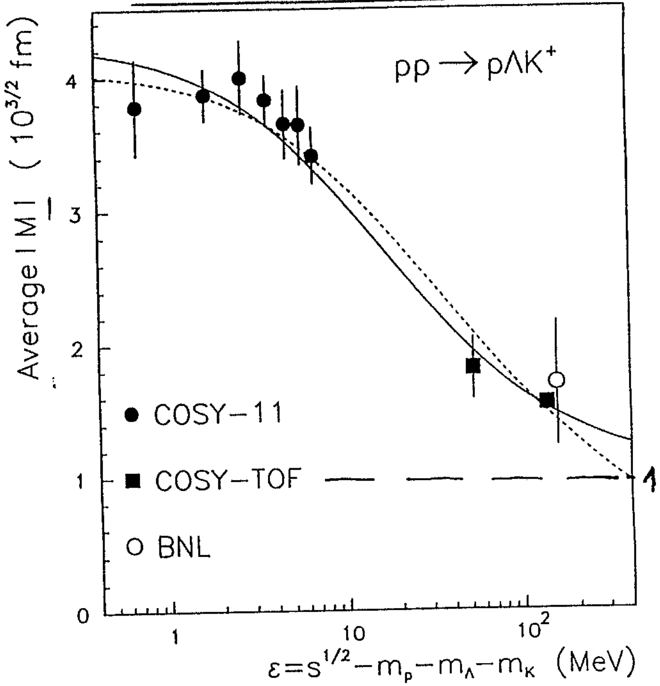


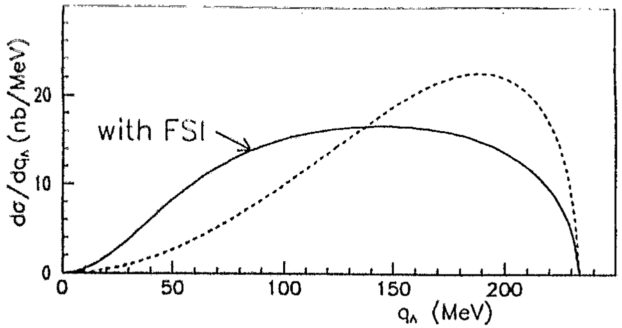
Influence of final-state-interaction (Λp)

$$\overline{|M|}^2 = \frac{\sigma_{tot}}{\text{phase space}}$$

reaction amplitude

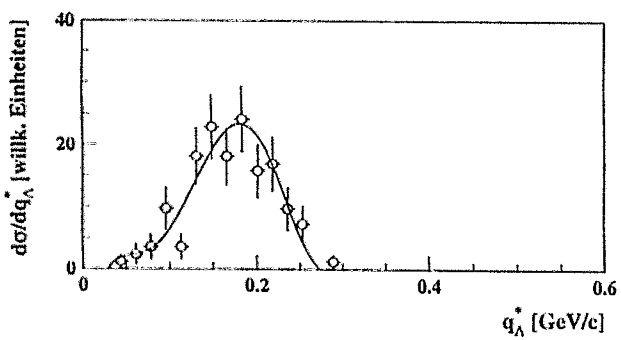
Sibirtsev + Cassing (nucl-th 9802025)

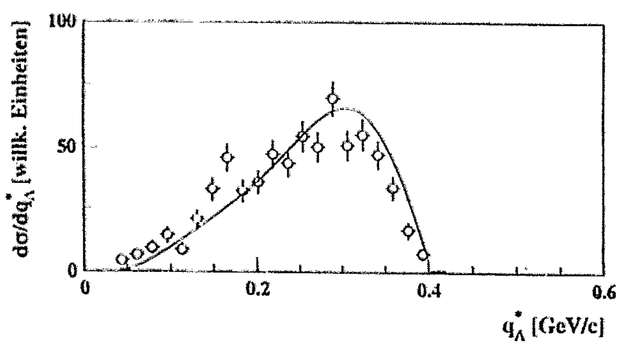




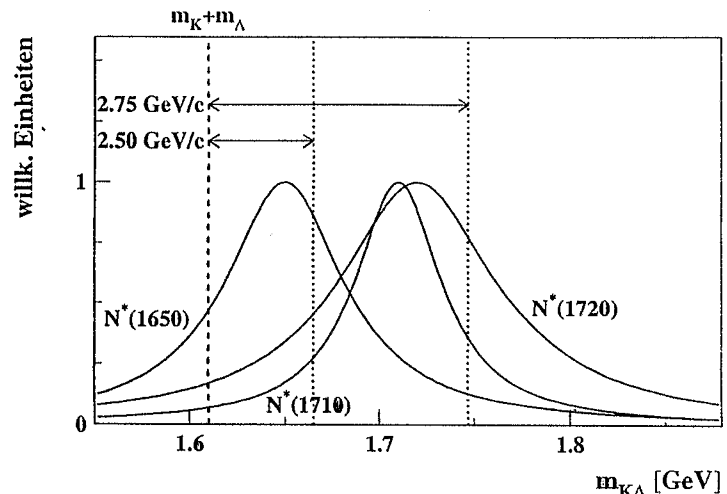
A. Sibirtsev und W. Cassing, Preprint nucl-th/9802025 (1998).

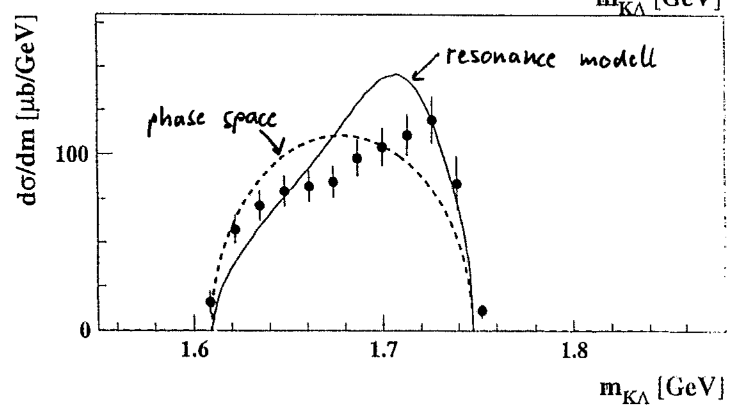
- Λ-momentum-distribution in the $p\Lambda$-cm-system
- FSI from elastic $p\Lambda$-scattering





Resonance-Modell



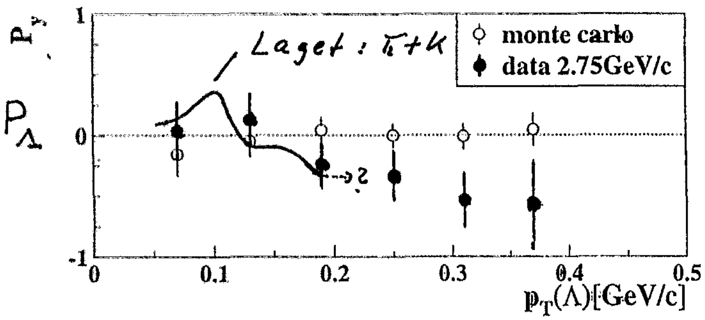


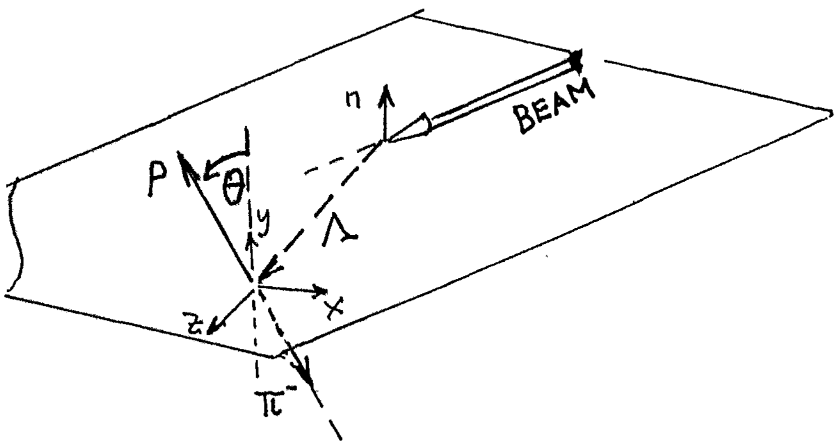
- K. Tsushima, S.W. Huang, A. Faessler, J. Phys. G21(1995) 33.
- K. Tsushima, A. Sibirtsev, A.W. Thomas, Internal Report ADP-96-29/T228(1996).

TOF

Λ-Polarisation

$pp \longrightarrow K^+\Lambda p$ @ 2.75GeV/c





$$dN/d\cos\theta = 1/2\,(1 + \alpha P_Y \cos\theta)$$

$\alpha = 0.64$

NEXT STEPS → FUTURE:

Detector upgrade:

- start detector system ✓
  double sided micro strip + additional fibre hodoscope
- stop detector
  barrel detector ✓ + ring detector (✓)
- neutron detector ✓
- energy detector

Run April 98: $pp \rightarrow K^+\Lambda p$ („high statistics")

$pp \rightarrow K^+\Sigma^+ n$, $K^0\Sigma^+ p$ (Search for Z^+)

$pd \rightarrow KY$... and $p\alpha \rightarrow KY$...

(✓)

Polarized beam + **Polarized target**

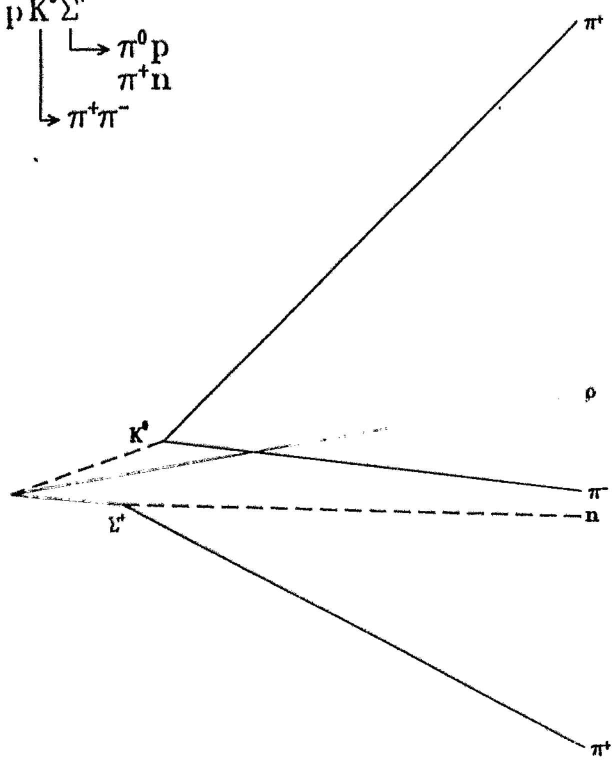
Large Angle μ-Strip Detector +

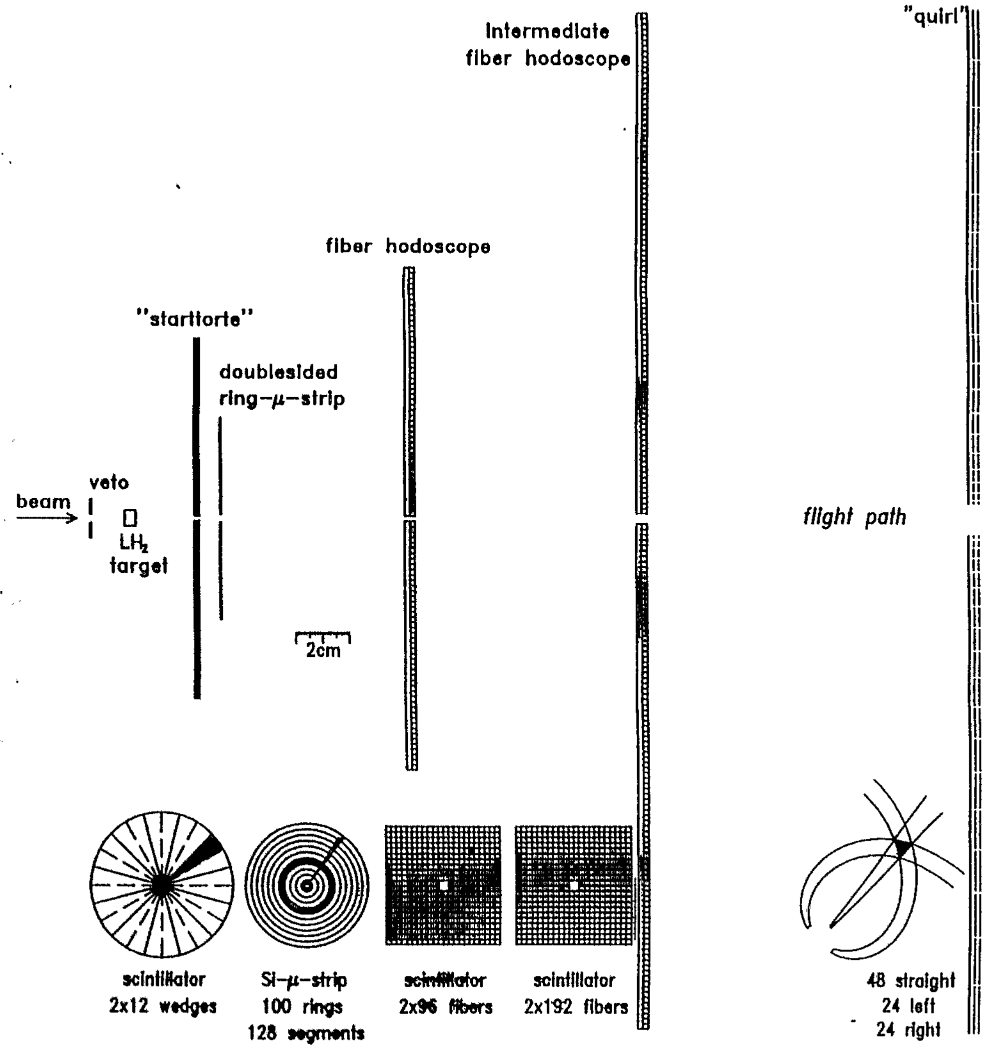
Magnetic field and intermediate tracker:

- $p\,^4He \rightarrow \alpha_{recoil}$ ($N^* \rightarrow K\Lambda$)
  scalar structure of the nucleon
- $pp \rightarrow ppKK$

Erlangen Startdetector '98

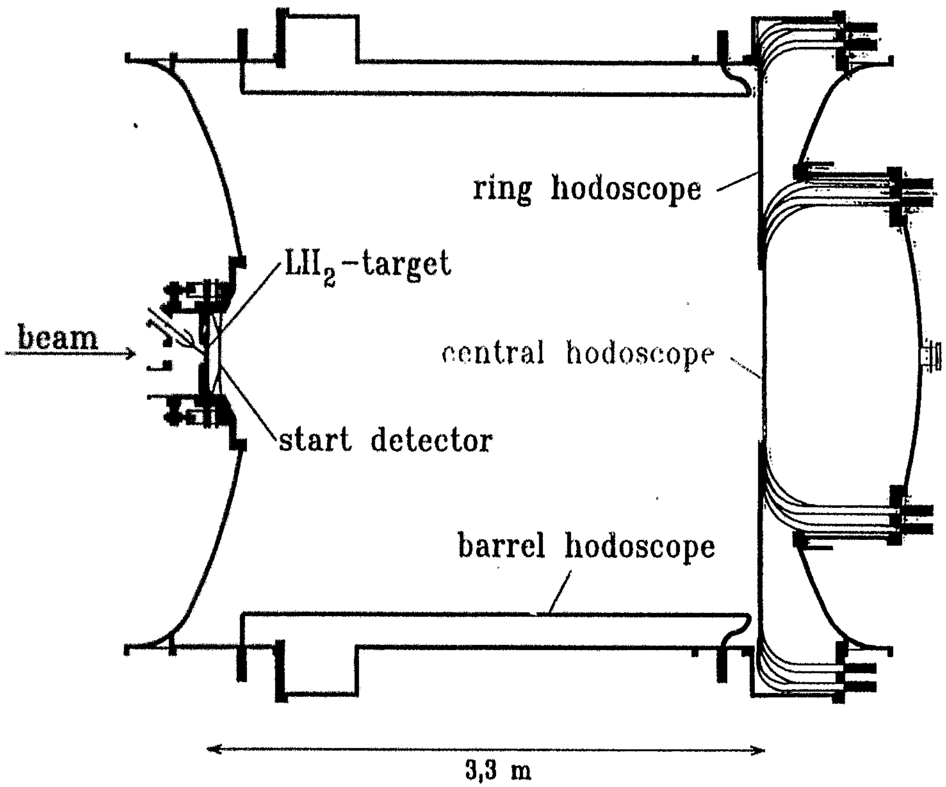
$$pp \longrightarrow p K^0 \Sigma^+ ; \quad \Sigma^+ \to \pi^0 p,\ \pi^+ n ; \quad K^0 \to \pi^+ \pi^-$$





COSY-TOF

Bochum - Bonn - Dresden - Erlangen - Indiana - Jülich - Rossendorf - Tübingen - Turin



large angle spectrometer
modular vacuum vessel
miniaturized target
startdetector system(s)
stopdetector system

COSY-TOF - Kollaboration

R. Bilger[7], A. Böhm[3], K.-Th. Brinkmann[3], H. Clement[7], H. Dennert[4], S. Dshemuchadse[6], H. Dutz[2], W. Eyrich[4], D. Filges[5], H. Freiesleben[3], M. Fritsch[4], R. Geyer[5], A. Hassan[9], J. Hauffe[4], P. Herrmann[1], D. Hesselbarth[5], B. Hübner[3], P. Jahn[5], K. Kilian[5], H. Koch[1], J. Kress[7], J. Krug[1], E. Kuhlmann[3], S. Marwinski[5], A. Metzger[4], W. Meyer[1], P. Michel[6], K. Möller[6], H.P. Morsch[5], H. Nann[8], B. Naumann[6], L. Naumann[6], K. Nünighoff[5], E. Roderburg[5], M. Rogge[5], A. Schamlott[6], P. Schönmeier[3], W. Schroeder[4], M. Schulte-Wissermann[3], M. Steinke[1], F. Stinzing[4], G.Y. Sun[3], J. Wächter[4], G.J. Wagner[7], M. Wagner[4], S. Wirth[4], and U. Zielinski[1]

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[2]Physikalisches Institut, Universität Bonn, D-53115 Bonn
[3]Institut für Kern und Teilchenphysik, Technische Universität Dresden, D-01062 Dresden
[4]Physikalisches Institut, Universität Erlangen-Nürnberg, D-91058 Erlangen
[5]Institut für Kernphysik, Forschungszentrum Jülich, D-52425 Jülich
[6]Institut für Kern- und Hadronenphysik, Forschungszentrum Rossendorf, D-01314 Dresden
[7]Physikalisches Institut, Universität Tübingen, D-72076 Tübingen
[8]IUCF Bloomington, Indiana 47408, USA
[9]Atomic Energy Authority NRC, Kairo, Egypt

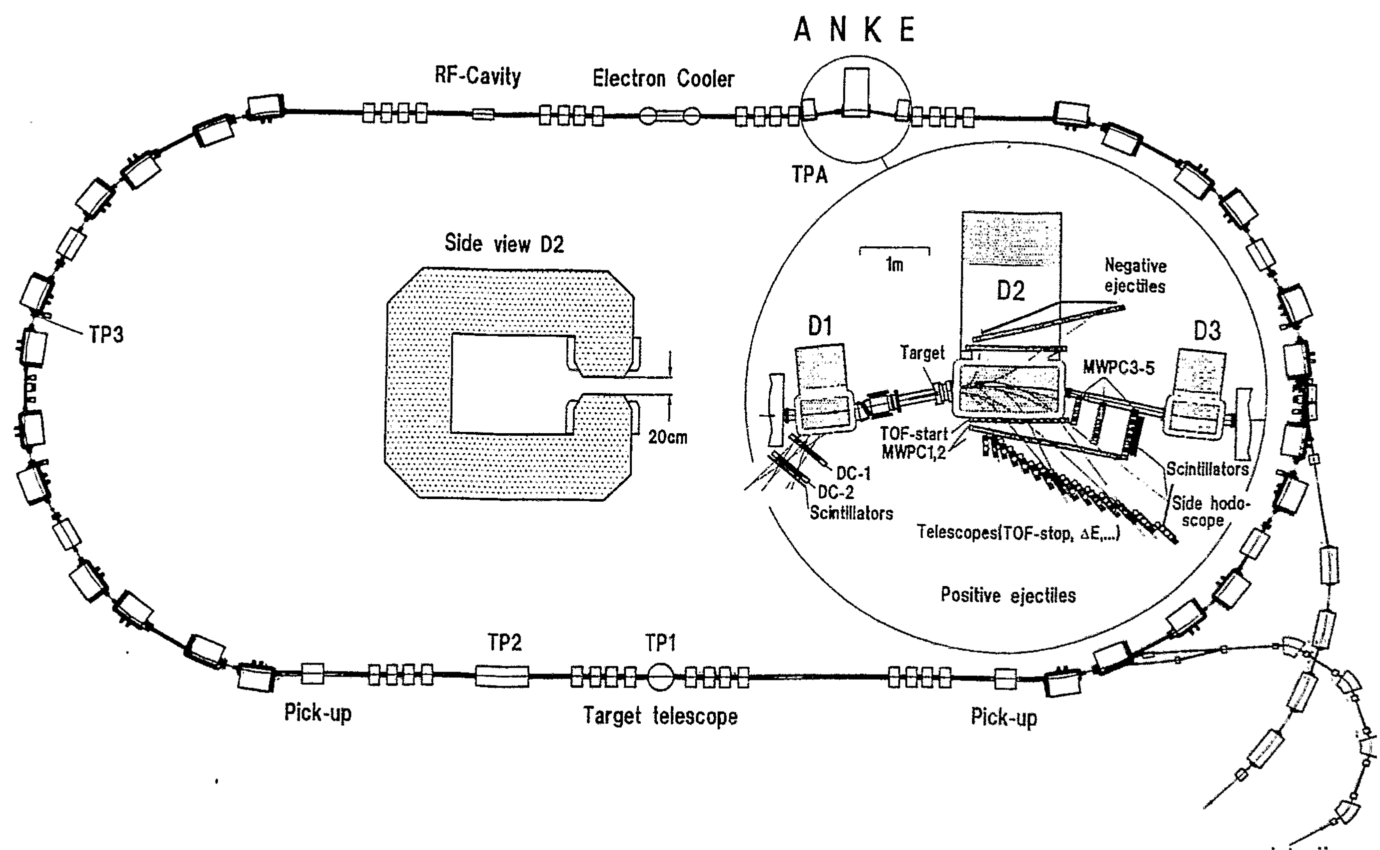
M. Debowski:

Prospects of ANKE

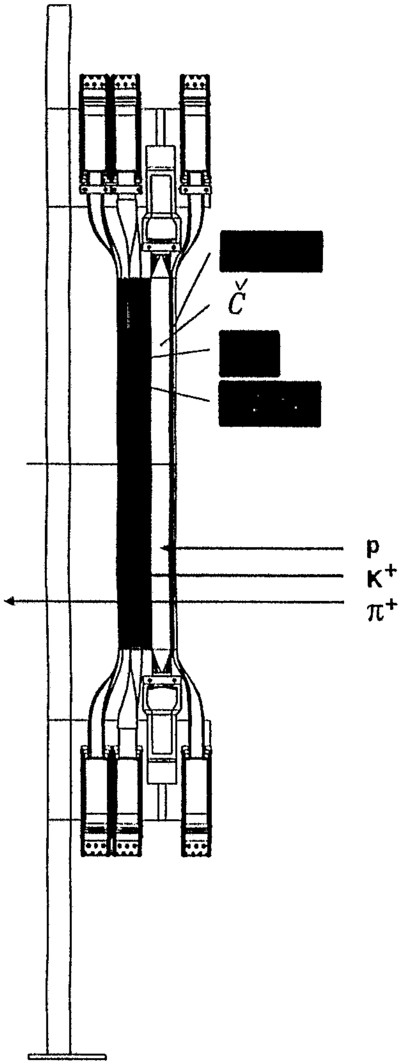
Prospects of Anke

M. Dębowski

FZ Rossendorf



Telescopes for K^+ Detection



- Width = 10 cm
  Height = 52 ... 100 cm
- 13 Telescopes @ 1.3 T
  15 Telescopes @ 1.6 T
- BC 408
  GS 233
  XP 2020

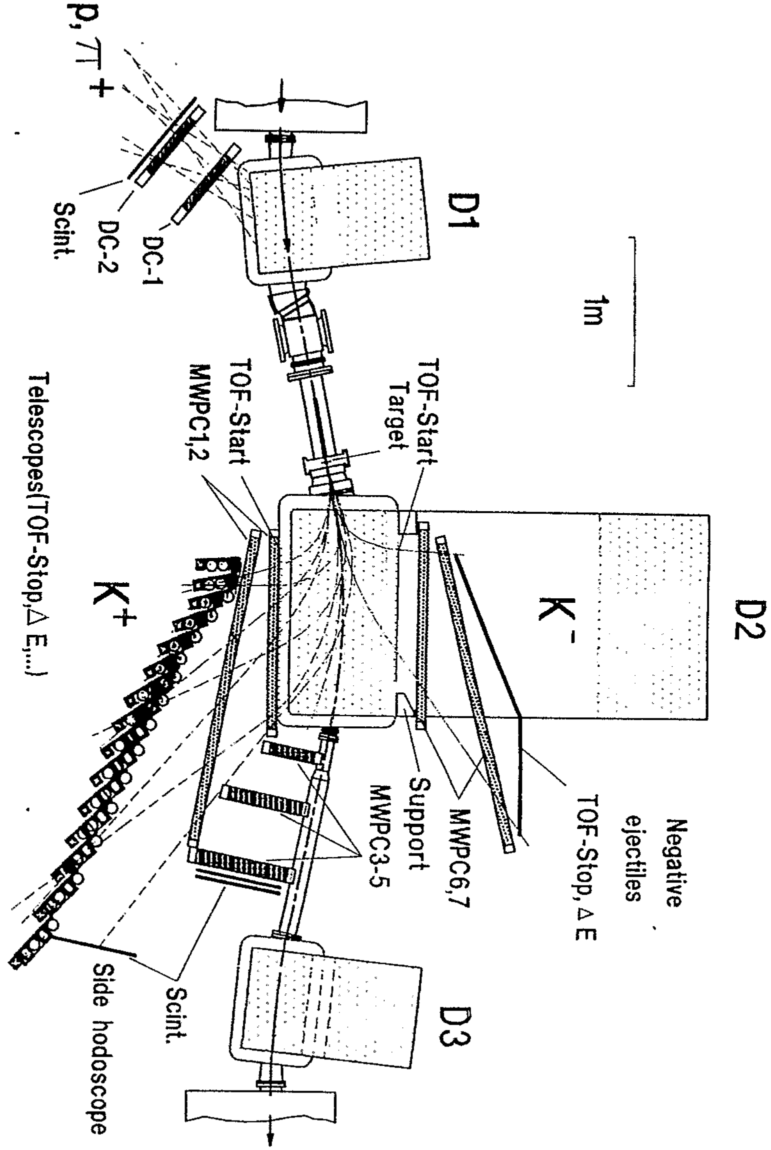
  GS 218
  XP2312

π^+ and p suppression

$\gtrsim 10^6$

(tested)

A N K E

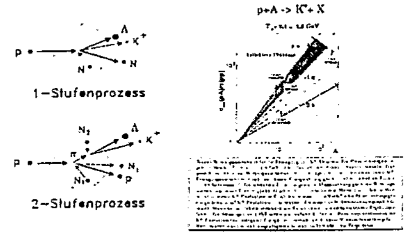


Geplante Experimente an ANKE

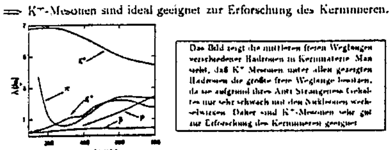
K^+-Mesonen-Produktion in Proton-Kern Stößen unterhalb der Nukleon-Nukleon-Schwelle

(COSY-Proposal #18; K.Sistemich)

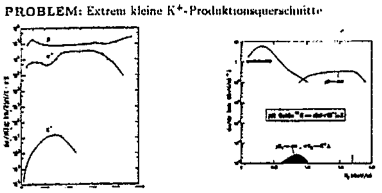
⟹ Information über den K^+-Produktionsmechanismus.



⟹ K^--Mesonen sind ideal geeignet zur Erforschung des Kerninneren.



PROBLEM: Extrem kleine K^+-Produktionsquerschnitte



K^+K^--Mesonen-Produktion in Proton-Kern-Stößen unterhalb der Nukleon-Nukleon-Schwelle

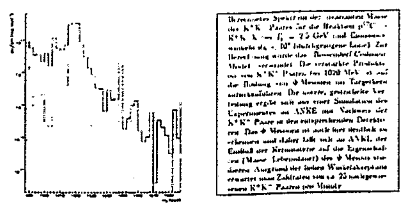
(COSY-LOI #21; H.Mueller, FZ Rossendorf)

⟹ Mögliche Reaktionsmechanismen

- Direkte Produktion. $pN \to NNK^+K^-$
- Produktion über mesonische Resonanzen. $pN \to NNM \to NNK^+K^-$
  - $\Phi(1020)$, $\Gamma = 4.2$ MeV
  - $a_0(980)$, $\Gamma = 175$ MeV
  - $f_0(980)$, $\Gamma = 220$ MeV
- Produktion über die D_{03} Resonanz ($\Gamma = 15.6$ MeV) $pN \to p\Lambda(1520)K^+ \to pNK^+K^-$

⟹ **ZIEL:** Erforschung der Kernstruktur und der Reaktionsmechanismen.

- Hochimpulskomponenten der nuklearen Wellenfunktion
- Clusterbildung von mehreren Nukleonen im Kern
- Einfluß der Kernmaterie auf Hadronen und deren Produktion
- Beimischung von ss-Komponenten zur Grundzustandswellenfunktion des Nukleons
- Endzustandswechselwirkung von K^--Mesonen im Kern



Exklusive Messung des Deuteronenaufbruc[h]s mit einem polarisierten Protonenstrahl und einem polarisierten Deuteronentarge[t]

(COSY-Proposal #20; V.Komarov, JINR Dubna)

- $\vec{p}\vec{d} \to p(0^\circ)p(180^\circ)n$, Nachweis der vorwärts und rückwärts emittierten Protonen
- Projektilenergie T_p = 1000 – 2500 MeV
- Exklusive Messung der Vektor- und Tensoranalysierstärken sowie der Spinkorrelatio[ns]-Asymmetrie

Messung der Φ-Mesonen-Produktion mit polarisierten Protonenstrahlen und -targets

(COSY-LOI #35; M.Sapozhnikov, Dubna)

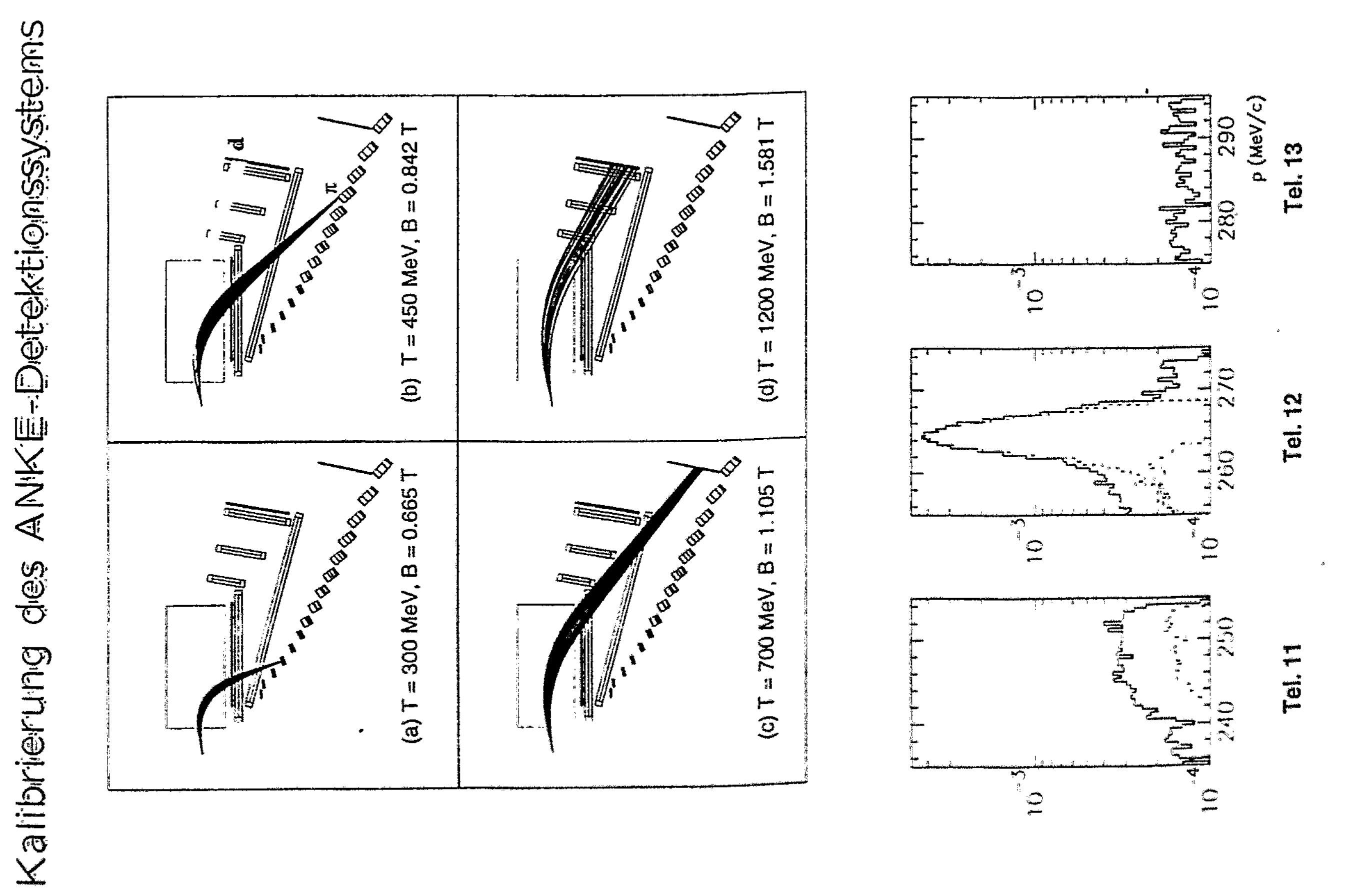
- $\vec{p}\vec{p} \to pp\Phi \to ppK^+K^-$
- Nachweis aller vier Teilchen im Ausgangskanal aufgrund der großen Winkelakzeptanz ANKE möglich
- Messung in Schwellennähe d.h. bei einer Projektilenergie von $T_p \approx 2600$ MeV
- Information über die Polarisation der intrinsischen Nukleonen-Strangeness

Untersuchung der η-Mesonen-Produktion in Proton-Kern-Stößen

(COSY-Proposal #23; H.Seyfarth)

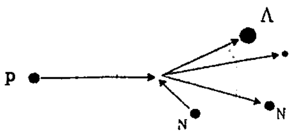
Weitere Experimentvorschläge:

- Messung der p-η Endzustandswechselwirkung in Reaktionen pp→ppη im Energiebereich T_p = 300 – 1300 MeV (V. Koptev, PNPI Gatchina).
- Messung der pp→π⁺ Anregungsfunktion bei kleinen Winkeln (F.Hinterberger, Uni Bonn)
- Studium der pp, pd und p³He Wechselwirkung in reinen Spinzuständen (S.L.Belostotski, PNPI Gatchina)
- Messung der π⁺ Produktion unter Vorwärtswinkeln in p¹²C Reaktionen bei $T_p \approx 1$ GeV (V. Koptev, PNPI Gatchina)
- Untersuchung der Produktion schneller Deuteronen in p¹²C-Reaktionen bei $T_p \approx 1$ GeV (A.Sibirtsev, JINR Dubna).
- Produktion leichter Hyperkerne und Suche nach gebundenen Hyperon-Nukleon-Zuständen (A. Chizugkov, ITEP Moskau).
- Untersuchung des Einflusses der Kernmaterie auf die Massen und Breiten hadronischer Resonanzen (A. Chizugkov, ITEP Moskau).
- Studium der "T odd Asymmetry" in elastischer $\vec{p}\vec{d}$ Rückwärtsstreuung (I.M.Sitnik, JINR Dubna).



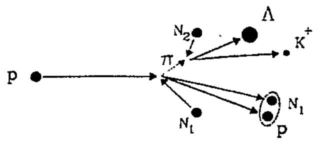
Reaction mechanism

1 step:



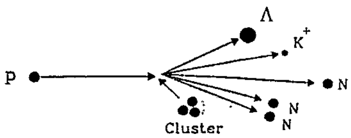
$$\sigma_{pA}^{K^+} = N_1 \int d^3q\rho(q)\sigma_{pN}^{K^+}(\sqrt{s})$$

2 step :



$$\sigma_{pA}^{K^+} = N_1 \int\int d^3qd^3p_\pi\rho(q)F(p_\pi)W(p_\pi, A)\sigma_{\pi N}^{K^+}(\sqrt{s})$$

clusters:

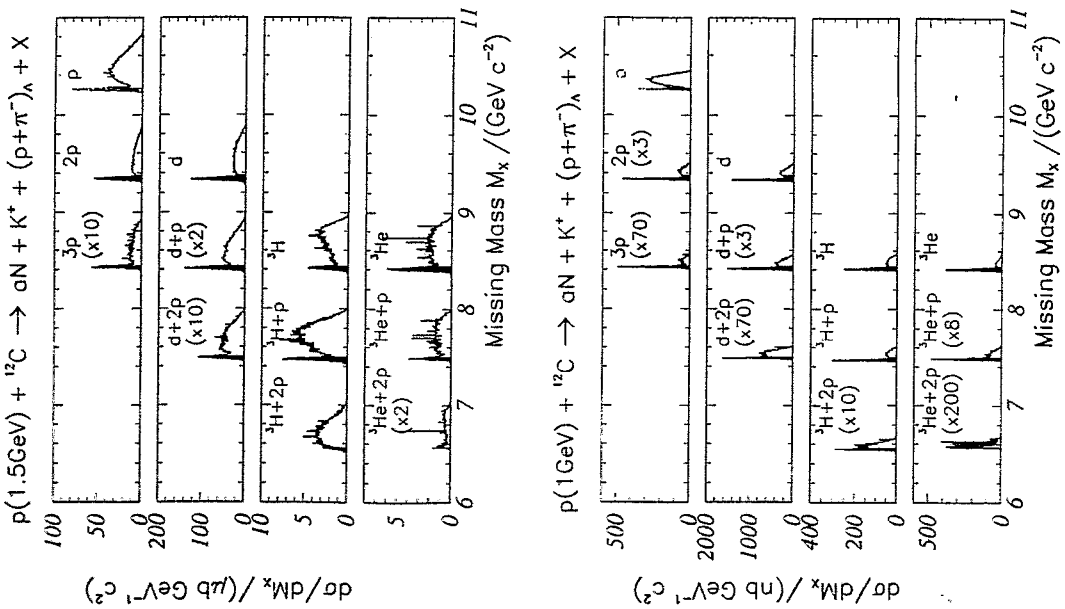


$$d\sigma(s) = \sum_a \sum_z \sigma_{az} \sum_{\alpha_{az}} dW_{az}(s, \alpha_{az})$$

Missing mass peaks

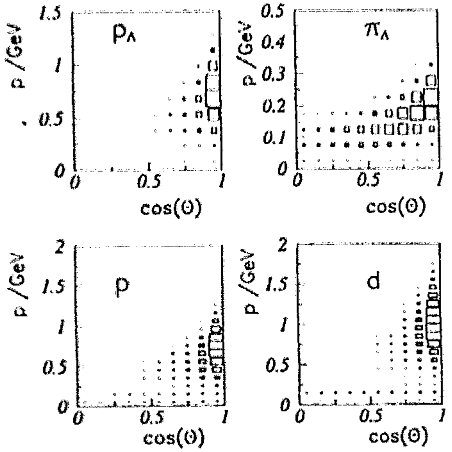
1.5 GeV

1.0 GeV

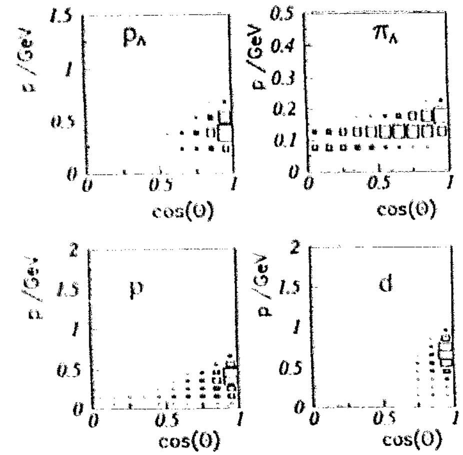


Winkel-Impuls-Korrelationen

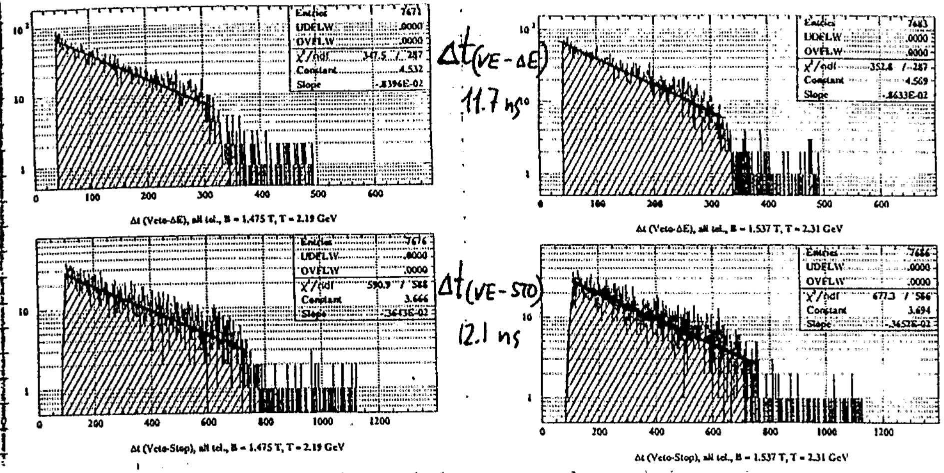
Projektilenergie 1,5 GeV



Projektilenergie 1,0 GeV



Resulting spectra:



PAW fits a function $f(t) = \exp(a+bt)$. From b one can calculate

T [GeV]	spectrum	b [Ch]	$\tau = -1/b$ [1/Ch]	τ [ns]
2.12	Veto-Stop	$-3.64\cdot10^{-3}$	274.7	[illegible]
	Veto-ΔE	$-8.40\cdot10^{-3}$	119.0	[illegible]
2.13	Veto-Stop	$-3.65\cdot10^{-3}$	274.0	[illegible]
	Veto-ΔE	$-8.63\cdot10^{-3}$	115.9	[illegible]

(0.044 ns/
(0.100 ns/c

The average value is $\tau_{K^+} = 11.9$ ns

Why not 12.4 ns ?

→ time calibration o.k. ?

K^- production

1. **direct**

$$N + N \rightarrow N + N + u\bar{u} + s\bar{s}$$
$$\rightarrow N + N + K^+ + K^-$$

2. via mesonic **resonances**

$$N + N \rightarrow N + N + q\bar{q}$$
$$\rightarrow N + N + meson$$
$$\rightarrow N + N + K^+ + K^-$$

- well established:

  $\phi(1020)$ $\Gamma = 4.2$ MeV

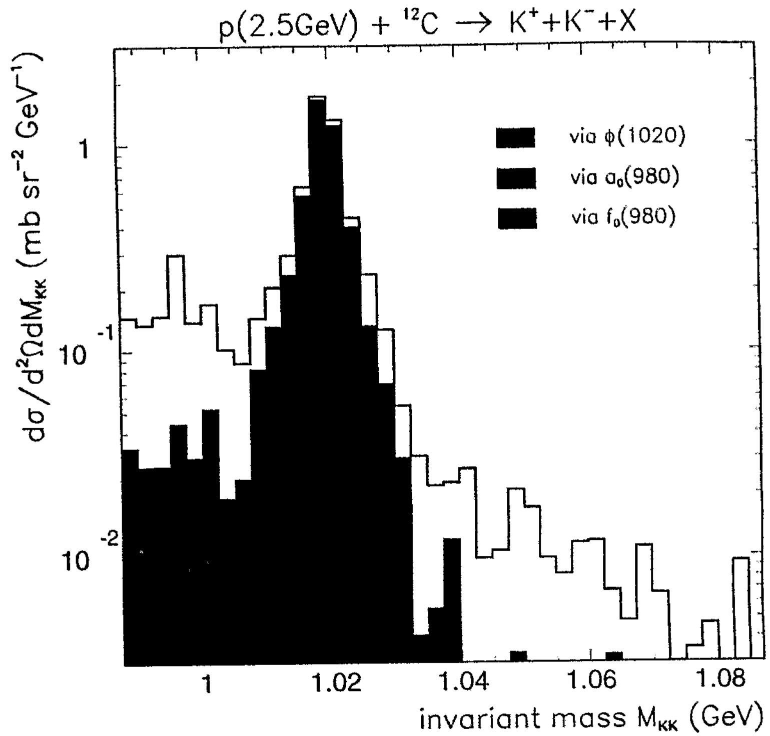
- structure under discussion:

  $a_0(980)$ $\Gamma = 50 \ldots 300$ MeV

  $f_0(980)$ $\Gamma = 40 \ldots 400$ MeV

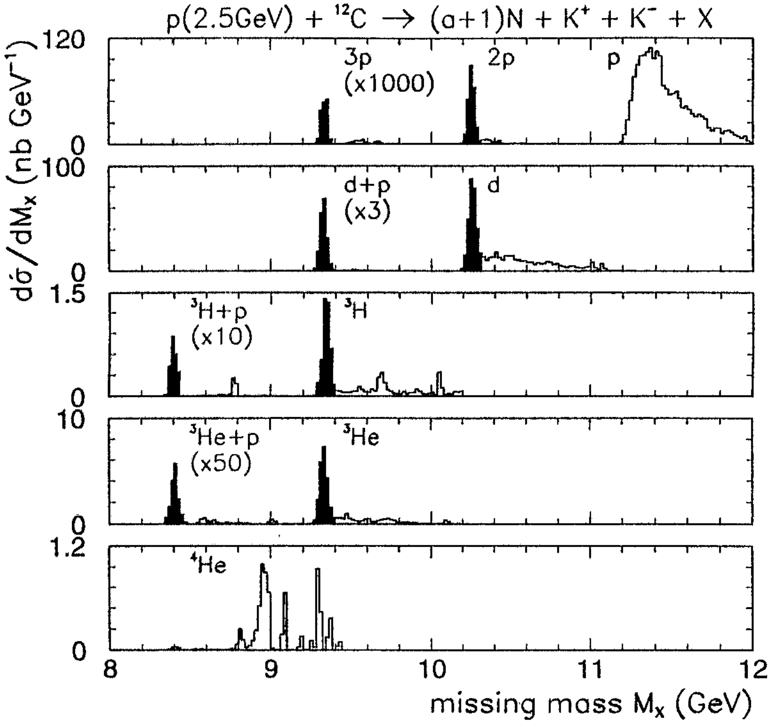
3. via baryonic $\Lambda(1520)$ **resonance**
   $\Gamma = 15.6$ MeV

$$p + N \rightarrow p + N + s\bar{s}$$
$$\rightarrow N + \Lambda(1520) + K^+$$
$$\rightarrow N + p + K^- + K^+$$



Calculated K^+K^- invariant-mass spectrum for emission angles $\theta \leq 10°$

- strength of $\phi(1020)$ production
- propagation of $\phi(1020)$, K^+ and K^- through nuclear matter



Calculated missing mass spectra from p^{12}C interactions at 2.5 GeV for the production of K^+/K^- pairs accompanied by $(a+1)$ nucleons with a being the number of participants according to

$$p + [aN] \rightarrow (a+1)N + K^+ + K^- \quad (a = 1 \ldots A)$$

– ANKE Zero Degree Facility

$K^+ K^-$ spectrometer
subthreshold particle production

- $|\theta| < 10°$
- momentum resolution < 1.5 %
- time resolution < 500 ps
- trigger TOF & "telescope"
- PID TOF, ΔE, Č

– K^+

- inclusive K^+ spectra
  different beam energies and targets
- "coincidence measurement"
  number of participating nucleons

– K^-

- inclusive spectra – enhancement ?
- low p_T K^-

– $K^+ K^-$ pairs

- K^- production mechanism
- ϕ production and propagation
  in the nuclear medium
- "coincidence measurement"

ANKE - Kollaboration

K. ABRAHAMS[12], V. ABAZOV[16], N. AMAGLOBELI[21], V. ARTEMOV[16], S. BARSOV[18], U. BECHSTEDT[1], S. BELOSTOTSKI[18], N. BONGERS[1], G. BORCHERT[1], W. BORGS[1], W. BRÄUTIGAM[1], M. BÜSCHER[1], W. CASSING[8], V. CHERNETSKY[19], B. CHILADZE[21], M. CHUMAKOV[19], J. DIETRICH[1], M. DROCHNER[2], S. DYMOV[16], J. ERNST[6], W. ERVEN[2], R. ESSER[9], A. GERASIMOV[19], YE.S. GOLUBEVA[20], O. GORCHAKOV[16], D. GOTTA[1], O. GREBENYUK[18], H. GRUPPELAAR[12], D. GRZONKA[1], M. HARTMANN[1], L. JARCZYK[14], H. JUNGHANS[1], A. KACHARAVA[16], N. KADAGIDZE[16], B. KAMYS[14], M. KARNADI[1], A. KHOUKAZ[10], ST. KISTRYN[14], F. KLEHR[3], W. KLEIN[4], H.R. KOCH[1], N. KOCH[7], M. KÖHLER[2], V.I. KOMAROV[16], L. KONDRATYUK[19], V. KOPTEV[18], P. KRAVCHENKO[18], V. KRUGLOV[16], P. KULESSA[14], A. KULIKOV[16], A. KURBATOV[16], H. LABUS[1], N. LANGENHAGEN[5], S. LEMAÎTRE[9], A. LEPGES[1], TH. LISTER[10], H. LOEVENICH[2], G. MACHARASHVILI[16], R. MAIER[1], S. MARTIN[1], Z. MENTESHASHVILI[21], S. MIKIRTICHYANTS[18], H. MÜLLER[5], R. NELLEN[1], V. NELYUBIN[18], M. NIORADZE[21], W. OELERT[1], H. OHM[1], A. PETRUS[16], H. POHL[2], D. PRASUHN[1], B. PRIETZSCHK[5], H.J. PROBST[1], C. QUENTMEIER[10], F. RATHMANN[7], B. RIMARZIG[5], K. RITH[7], Z. RUDY[14], R. SANTO[10], M. SAPOZHNIKOV[16], H. PAETZ GEN.SCHIECK[9], R. SCHLEICHERT[1], A. SCHNEIDER[1], CHR. SCHNEIDER[5], H. SCHNEIDER[1], CHR. SCHNEIDEREIT[5], G. SCHUG[1], O.W.B. SCHULT[1], U. SCHWARZ[11], H. SEYFARTH[1], A. SIBIRTSEV[8,19], U. SIELING[2], K. SISTEMICH[1], J. SMYRSKI[14], H. STECHEMESSER[3], E. STEFFENS[7], H.J. STEIN[1], J. STENGER[7], A. STEPANOV[19], H. STRÖHER[1], A. STRZALKOWSKI[14], V. TCHERNYSHEV[19], W. TENTEN[2], C. THOMAS[7], S. TRUSOV[17], YU. UZIKOV[16], A. VASSILIEV[18], A. VOLKOV[16], K.-H. WATZLAWIK[1], C. WILKIN[13], P. WÜSTNER[2], S. YASCHENKO[16], V. YAZKOV[17], B. ZALIKHANOV[16], N. ZHURAVLEV[16], K. ZWOLL[2] und I. ZYCHOR[15]

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P. Kulessa:

Determination of Λ lifetime in heavy hypernuclei

Determination of the Λ lifetime in heavy hypernuclei

COSY-13

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The Polish Committee for Scientific Research (Grant No.2 PO3B 065 12),
Internatiomnal Bureau of the BMBF, Bon DLR

Λ production

- Reactions
  - Strangeness exchange

$$K^- + n \to \Lambda + \pi^-$$

  - Associated production

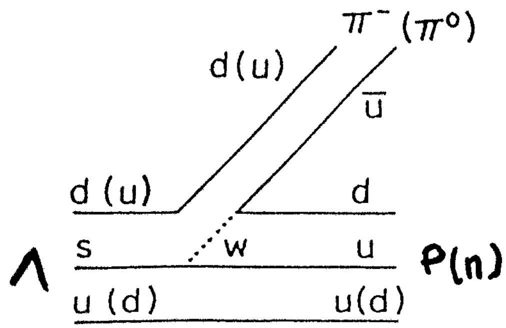
$$p + N \to \Lambda + K^+ + N$$
$$\pi^+ + n \to \Lambda + K^+$$

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

  - Antiproton annihilation

$$\overline{p} + p \to \Lambda, \Sigma, K^+, \pi, ..$$

The weak decay of the Λ particle

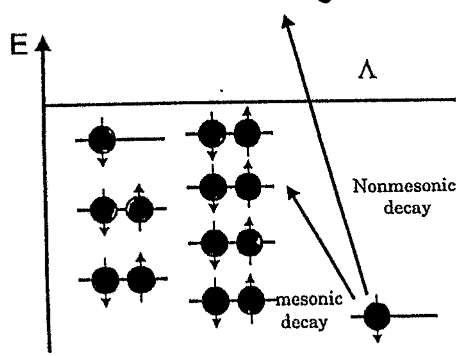


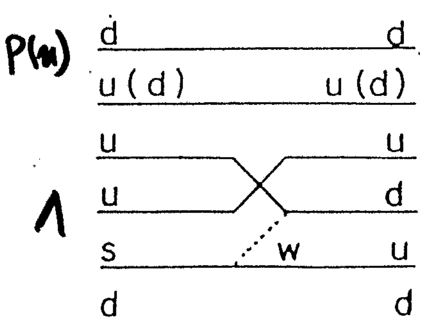
Mesonic decay

$\Lambda \to p + \pi^- + 37.8\ MeV$
$\quad\ \ n + \pi^0 + 41.1\ MeV$

$\tau_\Lambda = 263\ ps$

Pauli blocking of the mesonic decay





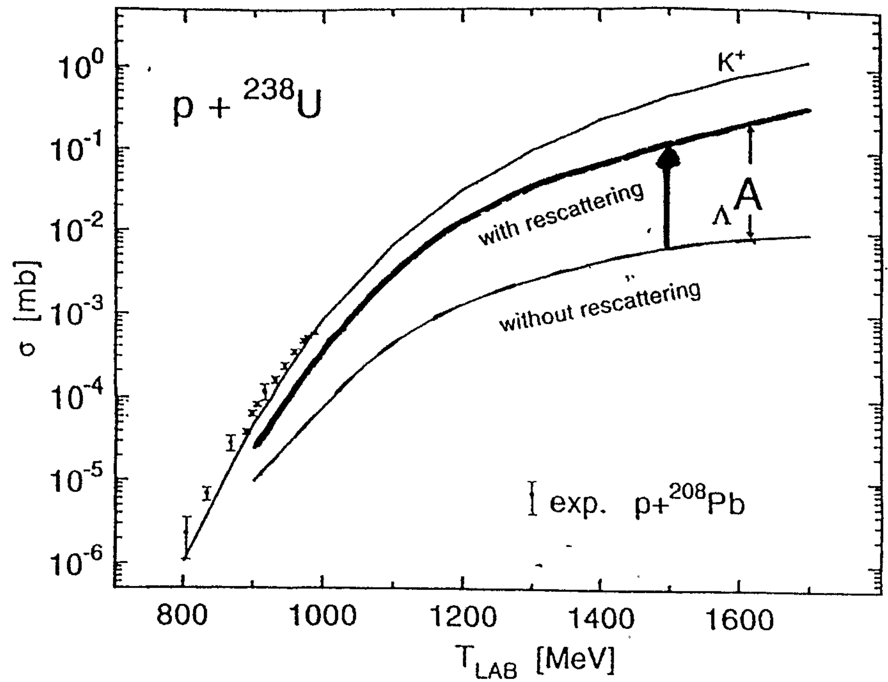
P(n) Nonmesonic decay

$\Lambda + N \to n + N + 176\ MeV$

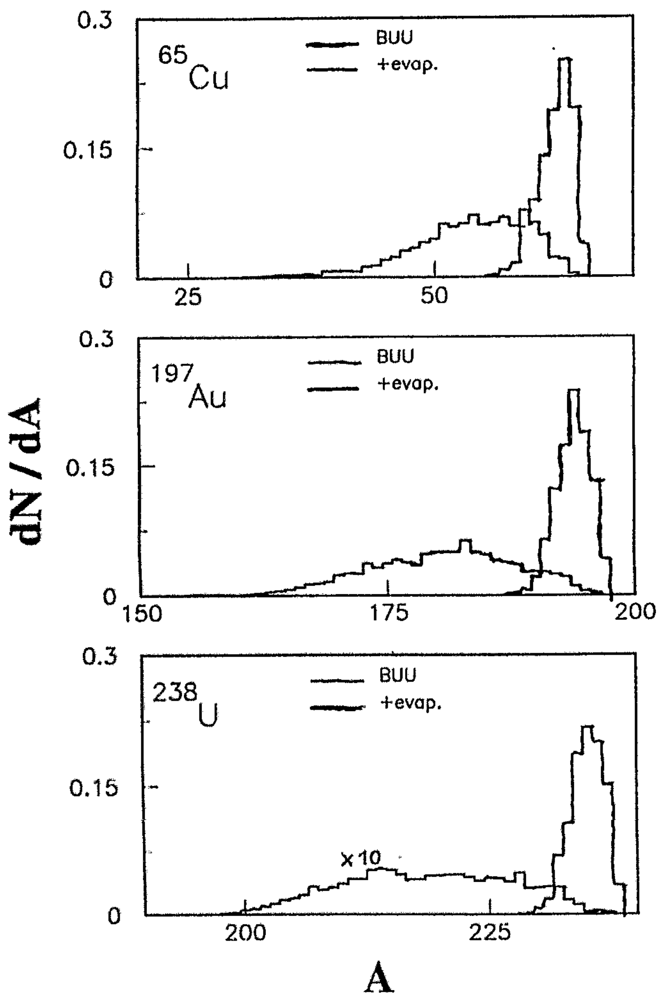
happens only in nuclei

medium effects!

(p,K) - production of heavy Hypernuclei

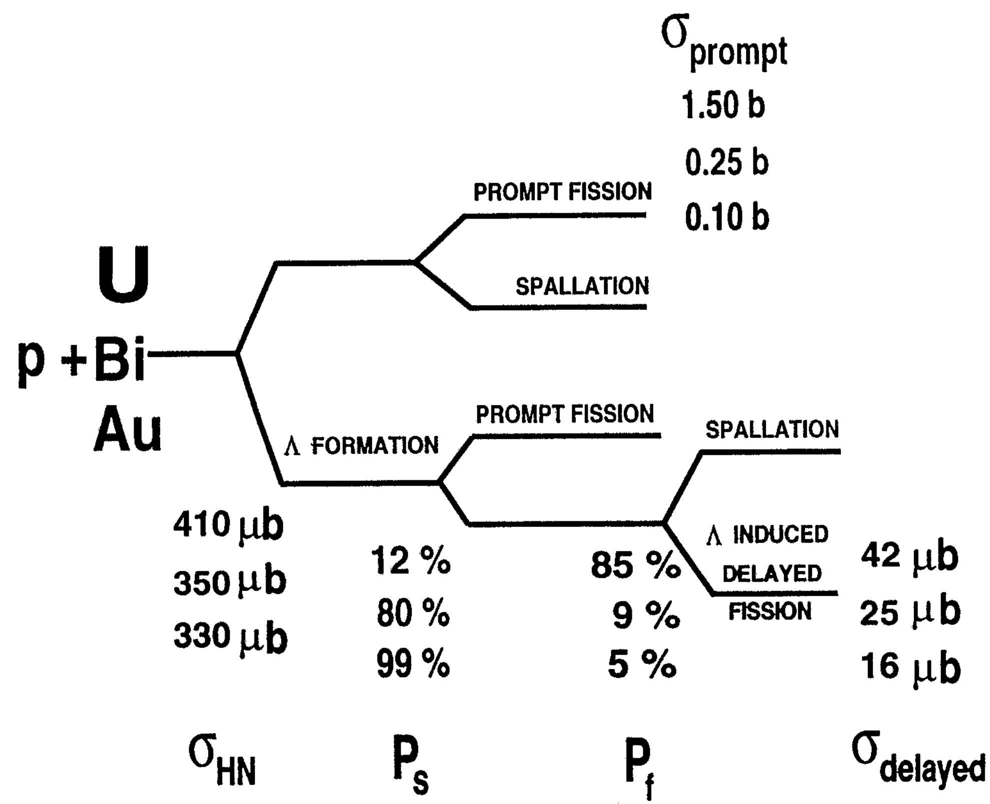


Mass distribution

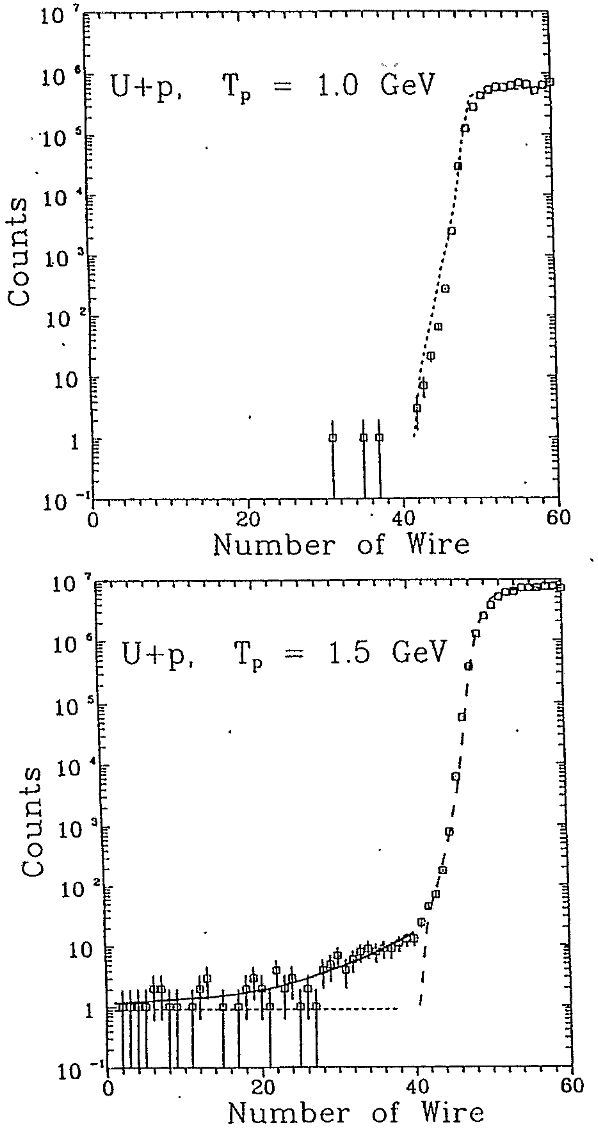


Hot
Cold

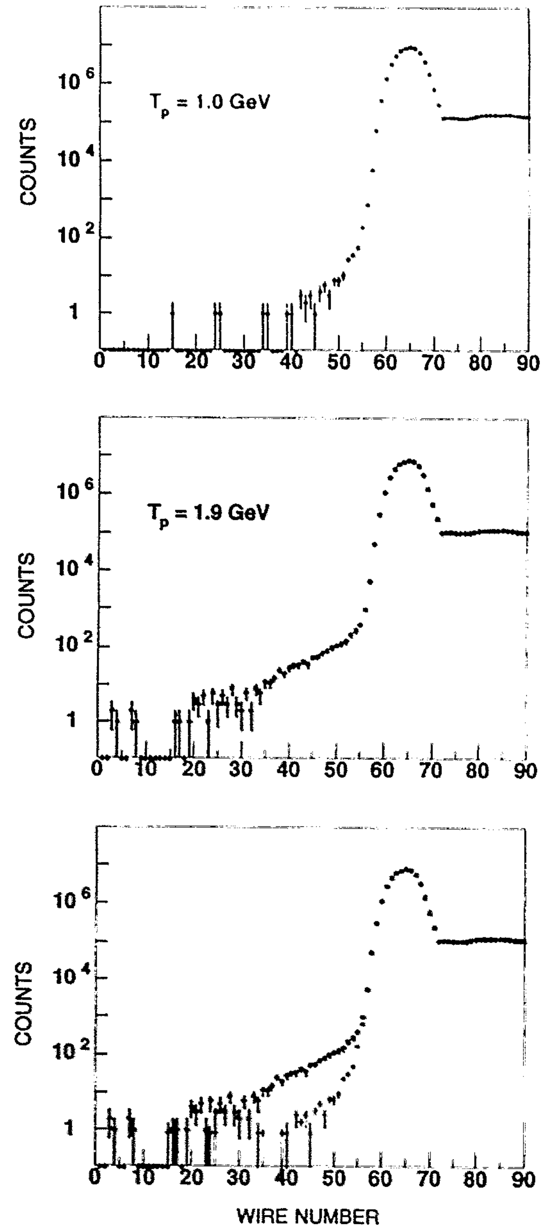
$T_p = 1.5\,GeV$

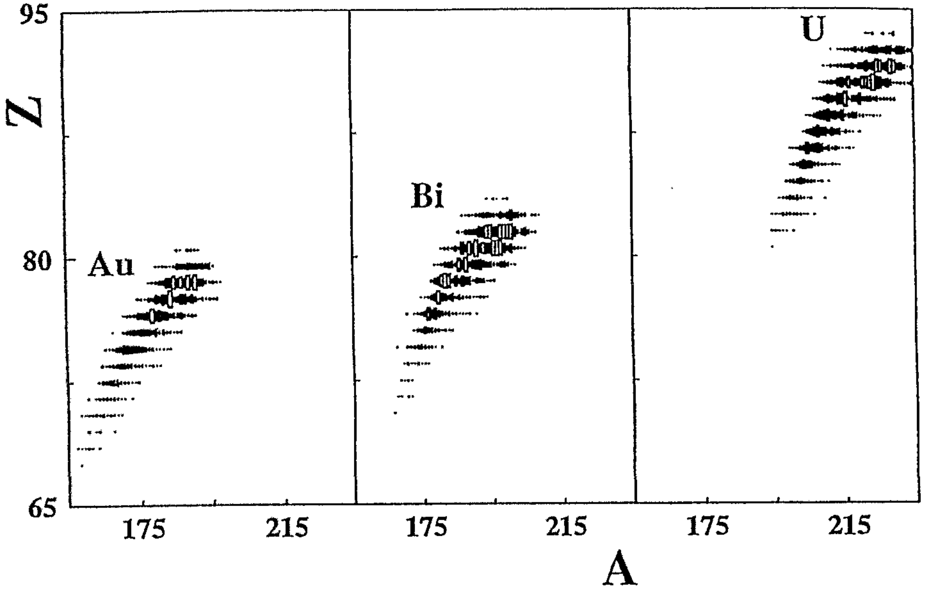


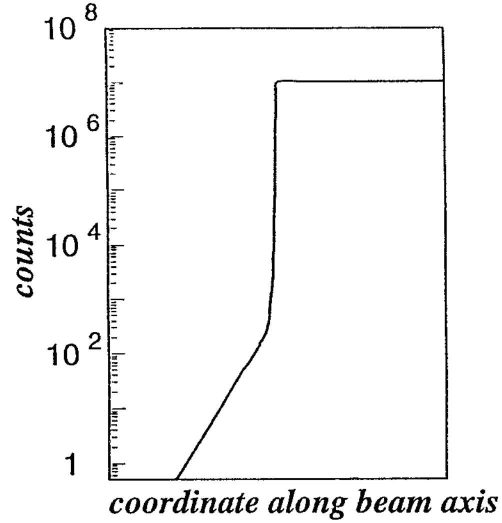
04.03.98 pawel

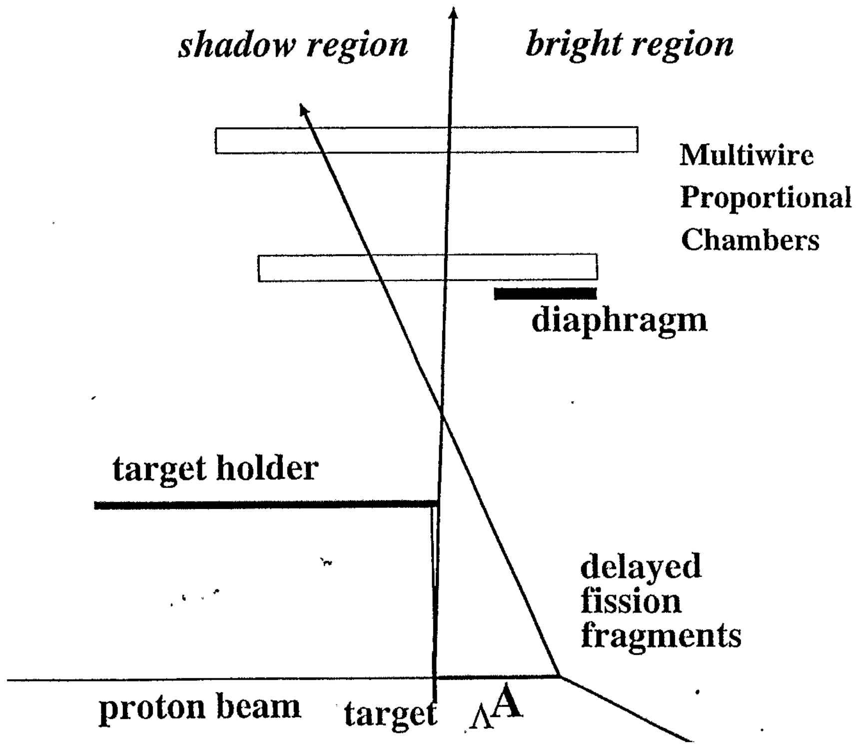


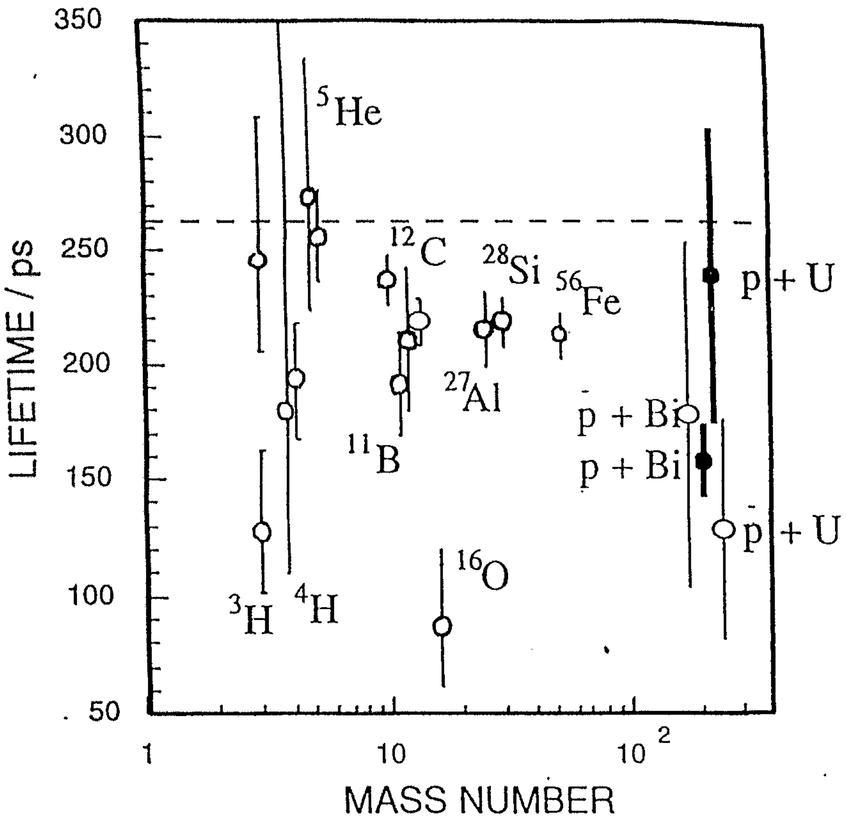
P + ^{209}Bi




95
80
65
Z
Au
Bi
U
175
215
175
215
175
215
A


10 8
10 6
10 4
10 2
1
counts
coordinate along beam axis


shadow region
bright region
Multiwire
Proportional
Chambers
diaphragm
target holder
delayed
fission
fragments
proton beam
target
A



U (240 ± 60) ps

Bi [161 ± 7(stat.) ± 14(syst.)] ps

Topics

- Decay of free and bound Λ
  - mesonic and nonmesonic decay
  - medium effect, Pauli blocking
- Production of heavy hypernuclei
  - Λ production
  - Hypernuclei production in the (p,K) reaction
- The hypernucleus experiment at COSY
  - principle, setup
  - results
- Summary

Cross Section

	Theory (hot)	Experiment (hot)
p + U (1.5 GeV)	110 μb	150^{+150}_{-80} μb
p + Bi (1.9 GeV)	330 μb	350 ± 140 μb

$\sigma_{2700 ps} < 80$ nb
(p + Bi at 1.9 GeV)

CONCLUSIONS

1. production of heavy hypernuclei (cross sections $\sim$ hundreds μb) and investigation of the Λ hyperon lifetime can be performed using protons as projectiles and the recoil shadow method with a very thin heavy target placed in the beam circulating in an accelerator.

2. with the supercycle at COSY it was possible to carry out the background measurement and hypernucleus production at higher energies under identical target conditions $\Rightarrow$ excitation functions.

PERSPECTIVES

continuation of measurements with Au and U targets to obtain precise lifetimes of Λ in hypernuclei.

A. Gillitzer:

K^- production at the GSI fragment separator

K^- production at the Fragment Separator

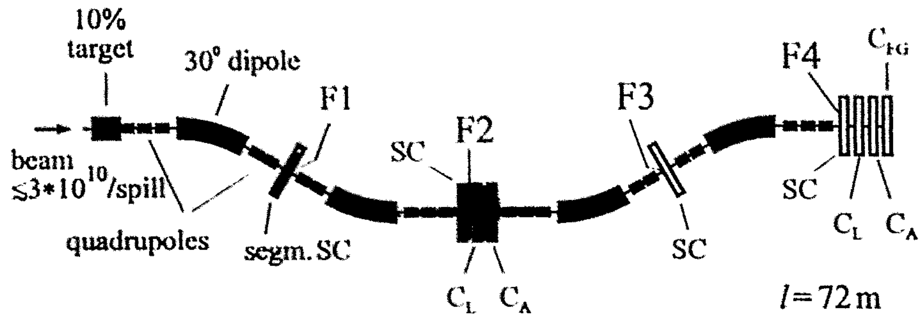
1. K^- production in Ne and Ni induced collisions
   - method
   - results
2. ideas for future experiments
   - detection of K^- with low cm momenta
   - K^- production in $A + p$ collisions

A. Gillitzer
Kaon workshop, FZ Rossendorf, 10.12.1998

subthreshold production of π^-, K^- and $\bar{p}$ at the GSI Fragment Separator (FRS)

problem: $\sigma_\pi : \sigma_K : \sigma_{\bar{p}} \approx 10^7 : 3*10^3 : 1$

$\Rightarrow$ requires high luminosity and good particle identification !



special ion optics: $\Omega = 3$ msr, $\Delta p/p = \pm 3$ %

SC: scintillation detector → 3 × time of flight

C_L : lucite Cerenkov detector → $\beta > 0.90$

C_A : aerogel Cerenkov detector → $\beta > 0.96, 0.98$

C_{FG}: glas/freon Cerenkov detector → $\beta > 0.98$

Cerenkov detectors used as veto counters

projectiles: ^{20}Ne, ^{58}Ni targets: NaF, Cu, Sn, Bi, Ni

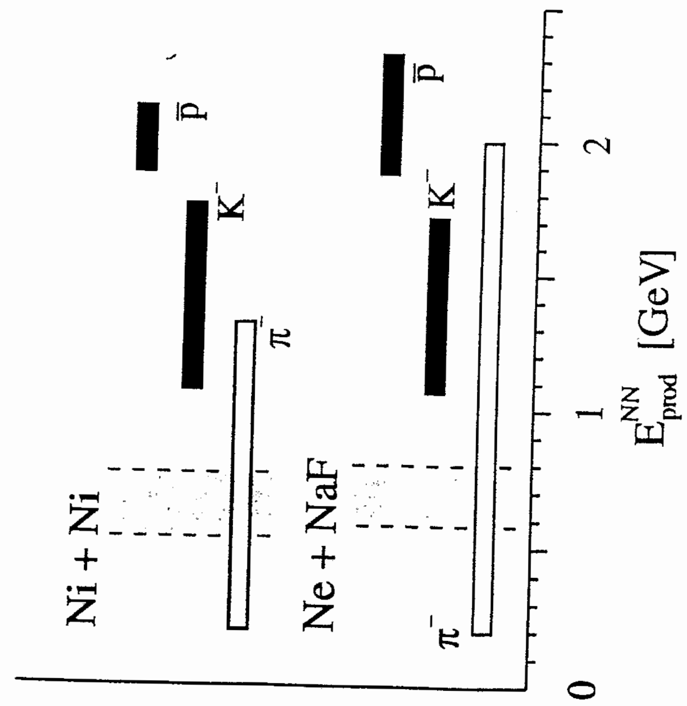
E = 1.3...2.0 AGeV (−0.06...0.08) AGeV

Teilchenerzeugung weit unter der Schwelle

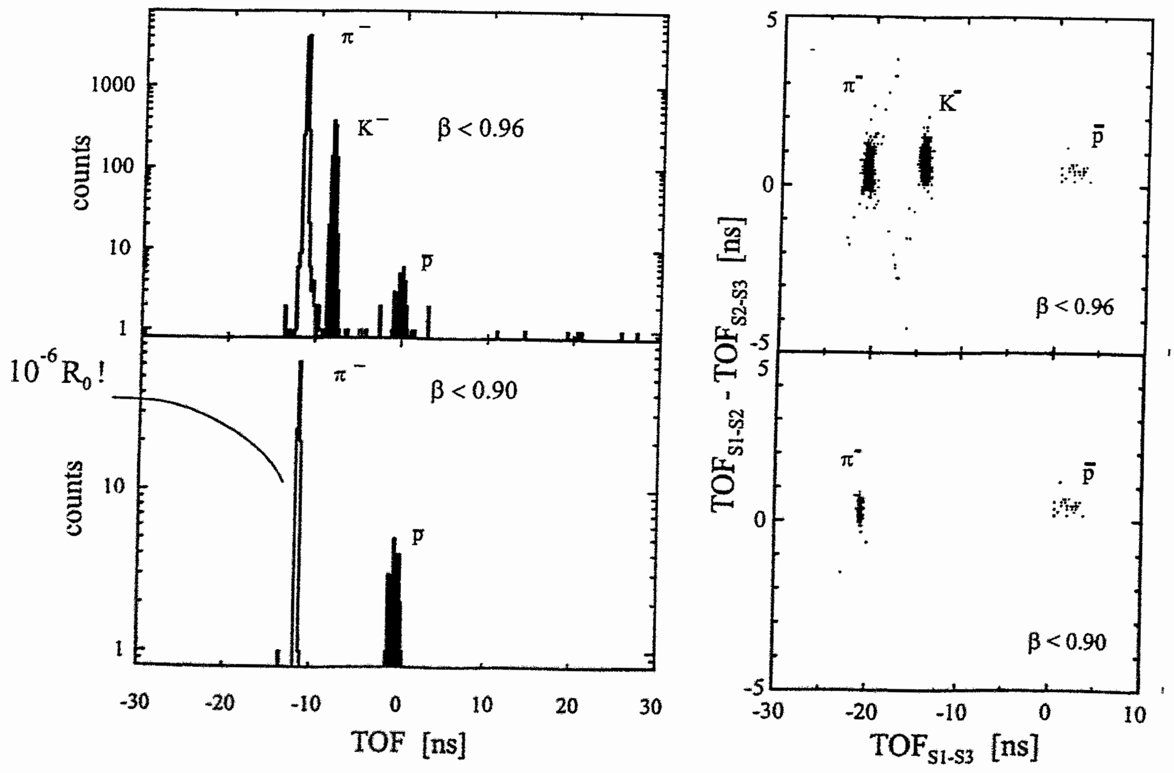
verfügbare Energie/NN: ca. 0.55 - 0.8 GeV

aufzuwendende Energie: ca. 0.2 - 2.0 GeV (π^-)
ca. 1.1 - 1.8 GeV (K^-)
ca. 1.9 - 2.3 GeV ($\bar{p}$)

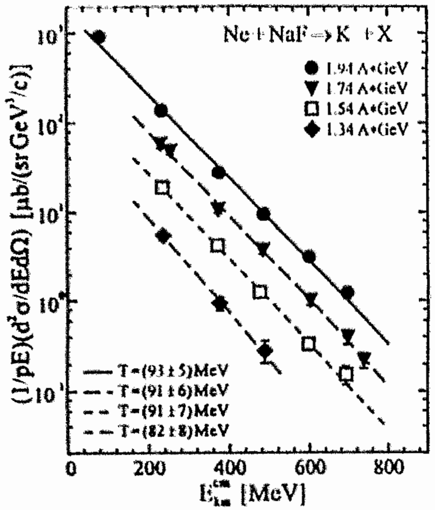
→ fehlende Energie im NN System bis ca. 1.6 GeV

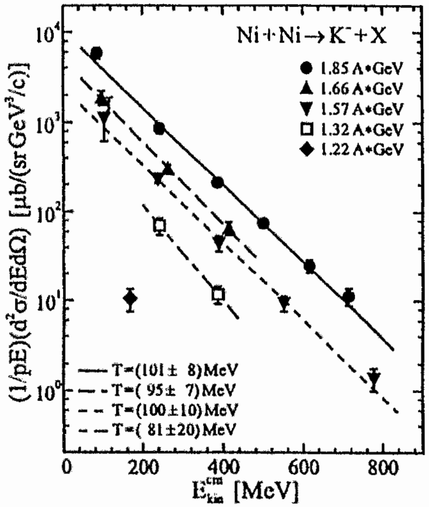


particle identification (1.94 *A*GeV ^{20}Ne+Sn, p_{lab}=1.5 GeV/c)

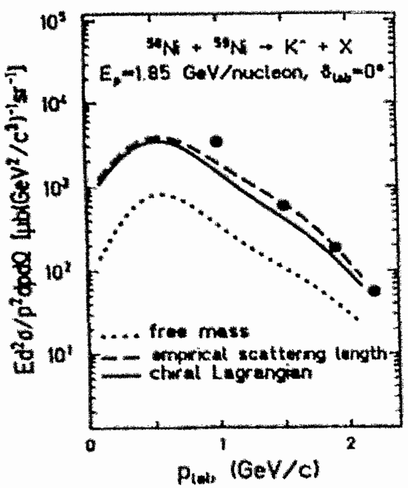


K^- production:

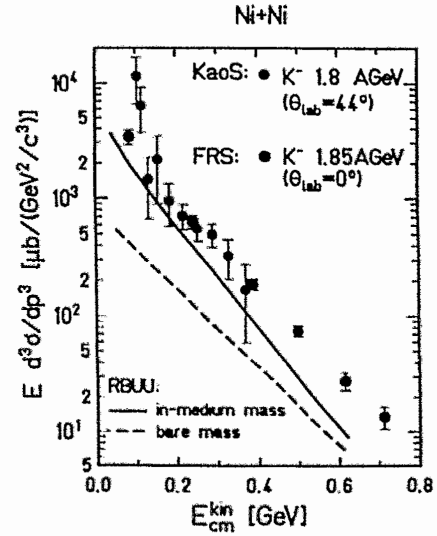




transport codes:



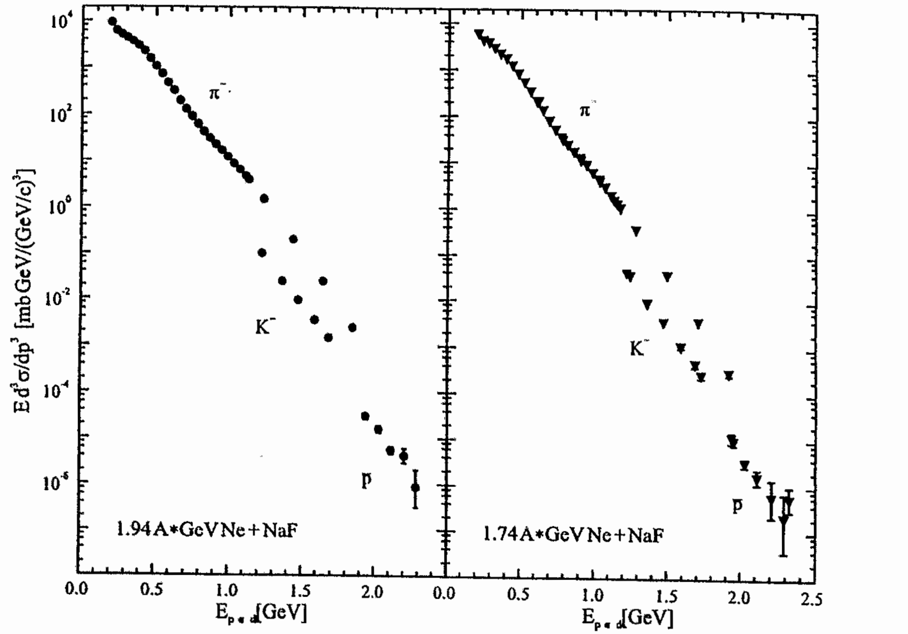
G.Q. Li *et al.*, Phys. Lett. B329 (94) 149

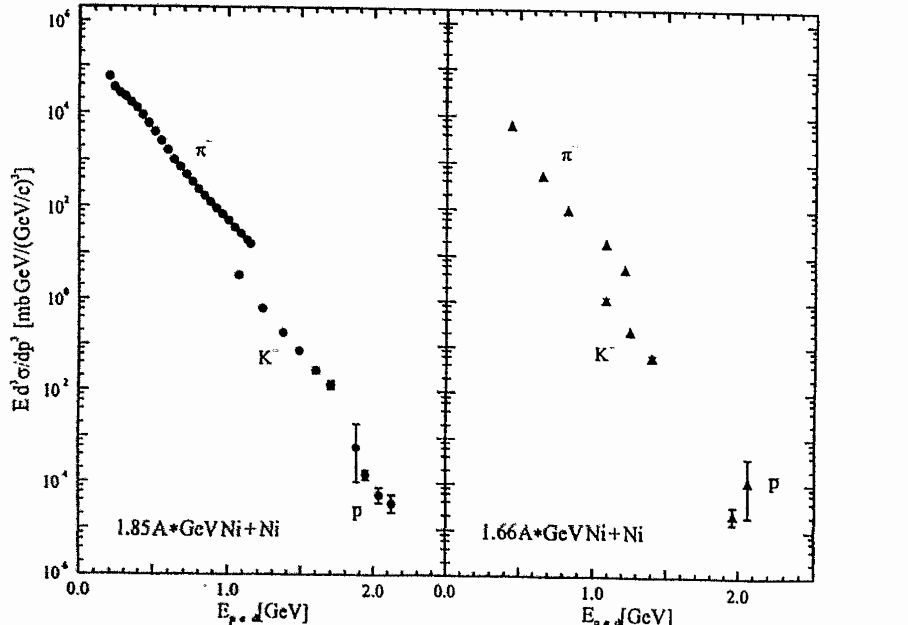


KaoS: R. Barth *et al.*, PRL 78 (97) 4007
RBUU: W. Cassing *et al.*, NPA 614 (97) 415

- observed K^- yields are not reproduced with the bare K^- mass

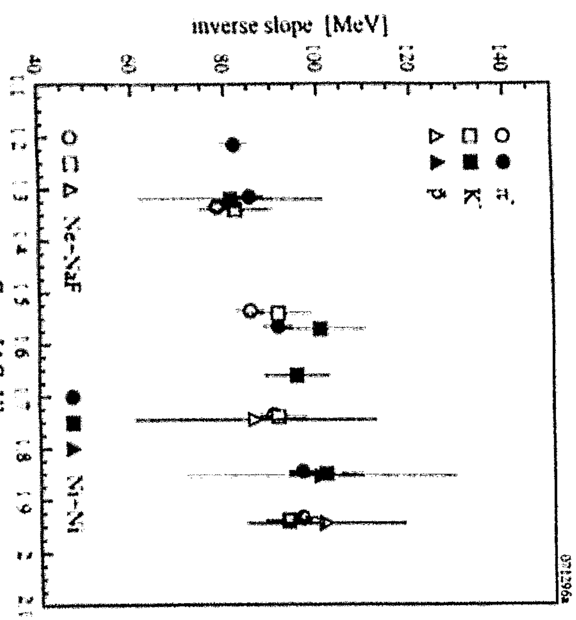
scaling of production cross section with required energy



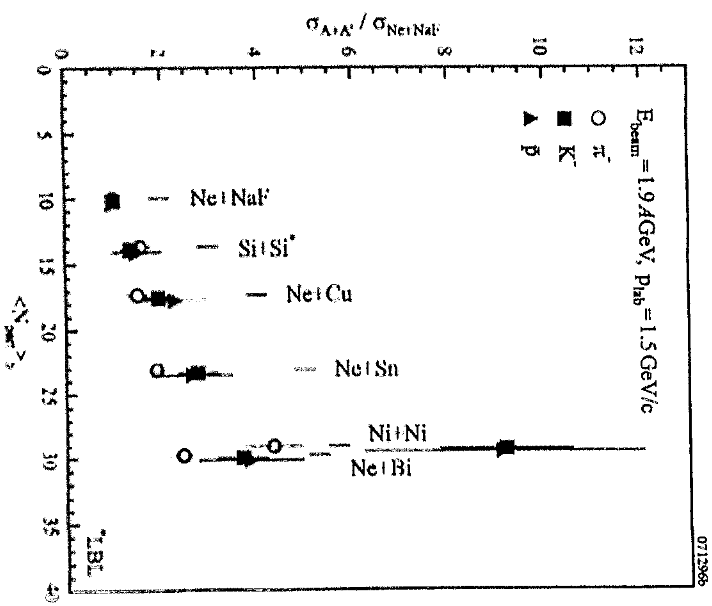


Anregungsfunktionen

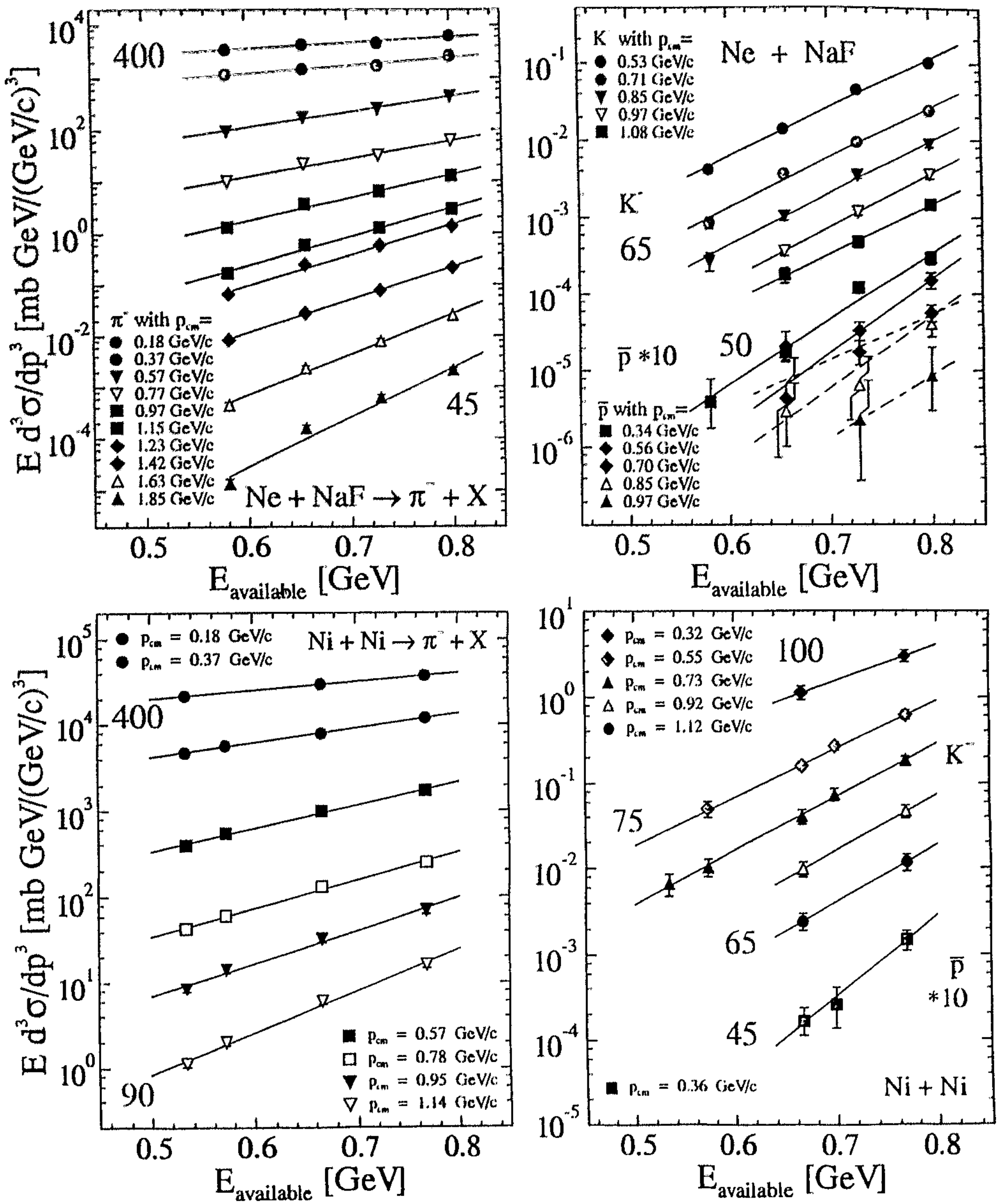
energy dependence of slope constants



system size dependence of cross sections

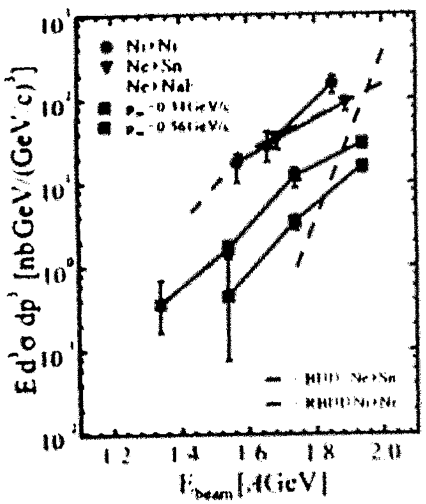


sysdep1



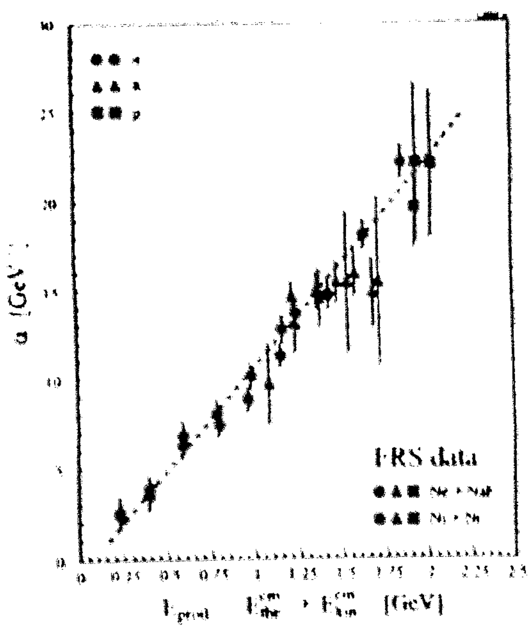
Anregungsfunktion: $\sigma_{inv} \propto \exp(-E_{avail}/E_0) \rightarrow E_0$ in MeV excitation function of $\bar{p}$ and K^- production:

- slope of excitation function not affected by reabsorption
- sensitivity to medium modifications?



RBUU calculations with attractive $\bar{p}$ mass shift reproduce slope of measured $\bar{p}$ excitation function

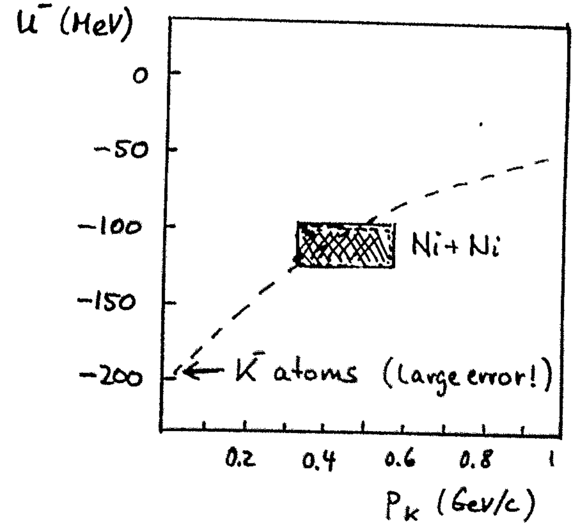
BUU W. Cassing, S. Teis, Priv. comm.
RBUU S. Teis *et al.*, Phys. Rev. C50 (1994) 388



- for given particle species and *cm* momentum: production cross section increases exponentially with the available *NN* energy: $\sigma_{inv} \propto \exp(\alpha E_{available})$
- common dependence of the slope parameter α for π^-, K^-, and $\bar{p}$ with the required energy is observed: $\alpha \propto E_{prod}$ ($E_{prod} = E_{thr}^{cm} + E_{kin}^{cm}$)

→ no obvious indication for $\bar{p}$ and K^- medium mass shifts (within exp. uncertainty)

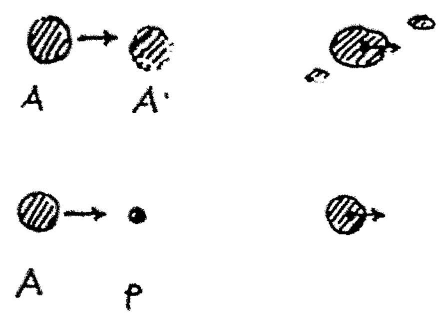
Momentum dependence of K^- potential



see A. Sibirtsev, W. Cassing nucl-th/9805021

⇒ most interesting: $p_L \to 0$

→ detect K^- with low in-medium momenta! → $p_L = 0$



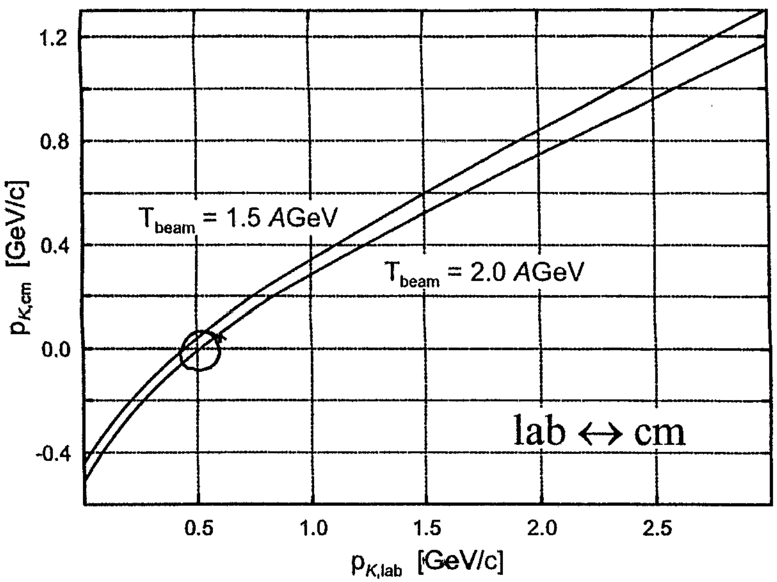
$\beta_{K^-} \approx \beta_{cm} \rightarrow p_K^{lab} \sim 0.5$ GeV/c

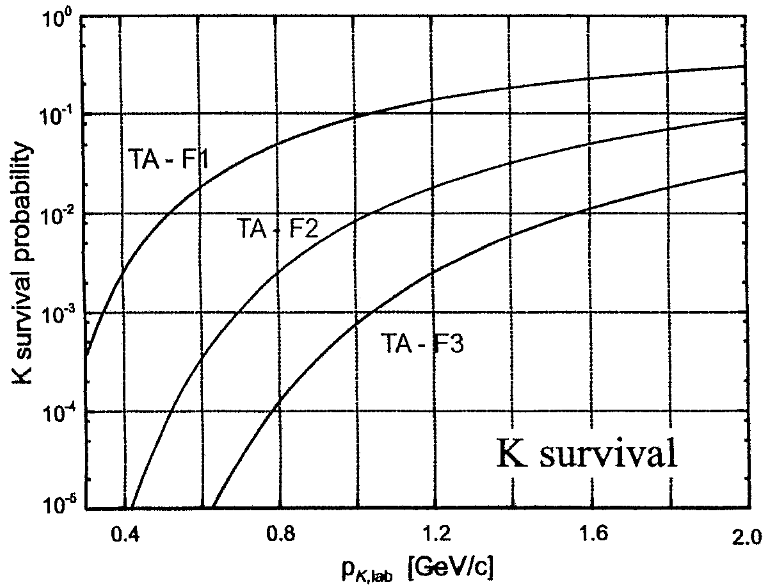
$\rho \sim (2\text{-}3)\rho_0$

$\beta_{K^-} \approx \beta_{proj} \rightarrow p_K^{lab} \sim 1.5$ GeV/c

$\rho \sim \rho_0$

K^- with low in-medium momenta





How to detect low momentum K^- ?

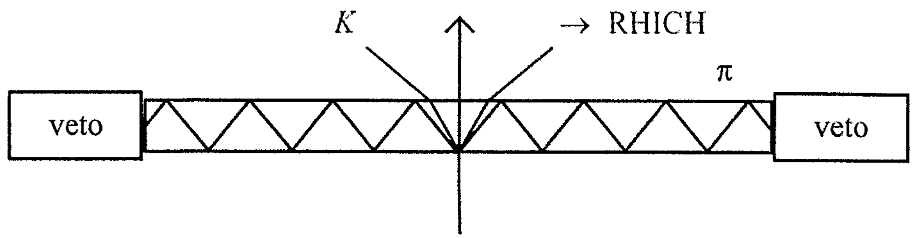
requirements:

- identify K^-
- suppress π^-

$p_{lab} = 0.50$ GeV/c $\rightarrow$ $\beta_\pi = 0.963$ $\beta_K = 0.712$

possible concept:

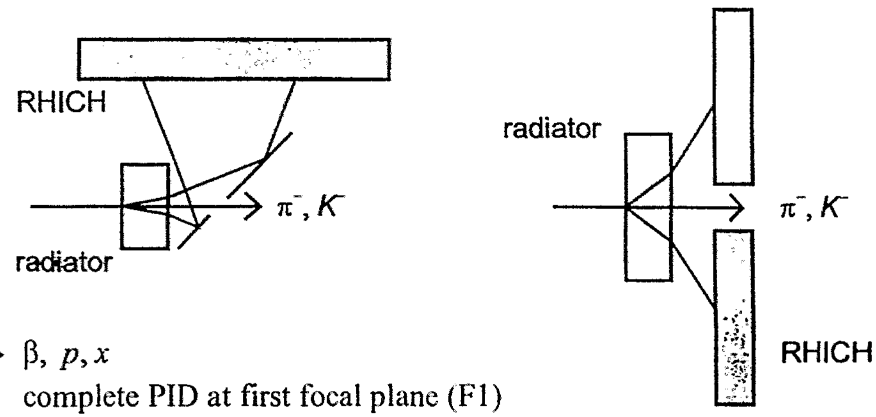
- threshold Cerenkov using total reflection combined with RHICH



total reflection:

$$\beta_{krit} = \frac{1}{\sqrt{n^2 - 1}}$$

lucite:	$n = 1.49$	$\rightarrow$ $\beta_{krit} = 0.905$
Pyrex glass:	$n = 1.474$	$\rightarrow$ $\beta_{krit} = 0.923$
Quartz glass:	$n = 1.458$	$\rightarrow$ $\beta_{krit} = 0.942$



$\rightarrow$ β, p, x

complete PID at first focal plane (F1)

$A + p \rightarrow K^- + X$ inverse kinematics ?

Estimate of observable K^- rate

Projectile : 2 GeV/u ^{40}Ca

Cross section estimate based on prediction by A. Sibirtsev, W. Cassing, nucl-th/9805021

2.5 GeV $p + {}^{12}C$, $p_K \rightarrow 0$ } $E\frac{d^3\sigma}{dp^3} \sim 2\,\mu b\,GeV^{-2}sr^{-1}$ abs., no med.

2.5 GeV $p + {}^{208}Pb$, $p_K \rightarrow 0$ } $E\frac{d^3\sigma}{dp^3} \sim 25\,\mu b\,GeV^{-2}sr^{-1}$ abs., no med.

$\rightarrow \sigma_{inv} \propto A \rightarrow$ extrapolate to ^{40}Ca

extrapolation to $T_{beam} = 2.0$ GeV :
using energy dependence of total K^- prod. cross sect. in $p + {}^{12}C \rightarrow K^- + X$

$\rightarrow \sigma_{inv}(2.0\,GeV) \sim 0.1 \cdot \sigma_{inv}(2.5\,GeV)$

$\Rightarrow$ for 2.0 GeV/u $^{40}Ca + p \rightarrow K^- + X$

$$E\frac{d^3\sigma}{dp^3} \sim 0.7\,\mu b / GeV^2 / sr$$

attractive K^- potential

$\rightsquigarrow$ enhancement $\times 45$ for ^{12}C
$\times 20$ for ^{208}Pb

$$R_{K^-} = E\frac{d^3\sigma}{dp^3}\frac{p^2}{E}\Delta\Omega\,\Delta p\, f_{decay} \cdot I_0 \cdot n_H$$

$\sigma_{inv} = 0.7\,\mu b\,GeV^{-2}sr^{-1}$

$p_K = 1.5$ GeV/c

$\Delta\Omega = 3$ msr

$\Delta p/p = \pm 3\,\%$

$f_{decay} = 0.041$ (TA $\rightarrow$ S2 = 36 m)

$I_0 = 5 \times 10^9$/spill $\sim 10^9$/s

$n_H = 4.3 \cdot 10^{23}/cm^2$ (10 cm LH_2)

$\rightarrow R_{K^-} \sim 17$/h no medium effects
~ 500/h with attractive K^- pot.

use shorter flight path :

- RICH instead of TOF and/or
- Pion (HADES) beamline instead of FRS

with $s = 18$ m $\rightarrow f_{decay} = 0.20 \rightarrow$ factor 5

$\rightarrow R_{K^-} \sim 85$/h no medium effects
~ 2500/h with K^- potential

SUMMARY

- Subthreshold K^- production yield indicates attractive K^- potential
- Problem: absorption in nuclear medium not well known
- slope parameter of excitation function for all particles ($\pi^-, K^-, \bar{p}$) increases linearly with energy required for the process
- Interesting to detect K^- with low in-medium momenta
- Such experiments seem to be feasible both for A+A and A+p

P. Crochet:

Results from FOPI (1)

Results from FOPI (1)

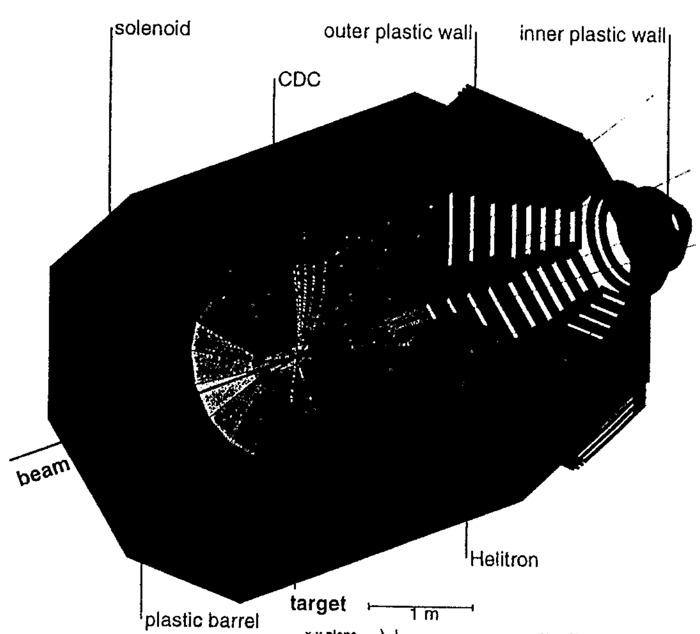
J.P. Alard, A. Andronic, R. Averbeck, Z. Basrak, N. Bastid, I. Belyaev, A. Bendarag, G. Berek,
D. Best, R. Čaplar, N. Cindro, P. Crochet, A. Devismes, P. Dupieux, M. Dželalija, M. Eskef, Z. Fodor,
L. Fraysse, A. Genoux-Lubain, A. Gobbi, Y. Grishkin, N. Herrmann, K.D. Hildenbrand, B. Hong,
J. Kecskemeti, Y.J. Kim, M. Kirejczyk, M. Korolija, R. Kotte, M. Kowalczyk, T. Kress, R. Kutsche,
A. Lebedev, K.S. Lee, Y. Leifels, V. Manko, H. Merlitz, S. Mohren, D. Moisa, W. Neubert, A. Nianine,
D. Pelte, M. Petrovici, C. Plettner, F. Rami, W. Reisdorf, B. de Schauenburg, D. Schüll, Z. Seres,
B. Sikora, K.S. Sim, V. Simion, K. Siwek-Wilczyńska, A. Somov, M. Stockmeier, G. Stoicea,
M. Vasiliev, P. Wagner, G.S. Wang, K. Wisniewski, D. Wohlfarth, J.T. Yang, I. Yushmanov, A. Zhilin

IPNE Bucharest, Romania
ITEP Moscow, Russia
CRIP/KFKI Budapest, Hungary
Kurchatov Institute, Moscow, Russia
LPC Clermont-Ferrand, France
Korea University Seoul, Korea
GSI Darmstadt, Germany
IReS Strasbourg, France
FZ Rossendorf/Dresden, Germany
Univ. of Warsaw, Poland
Univ. of Heidelberg, Germany
RBI Zagreb, Croatia

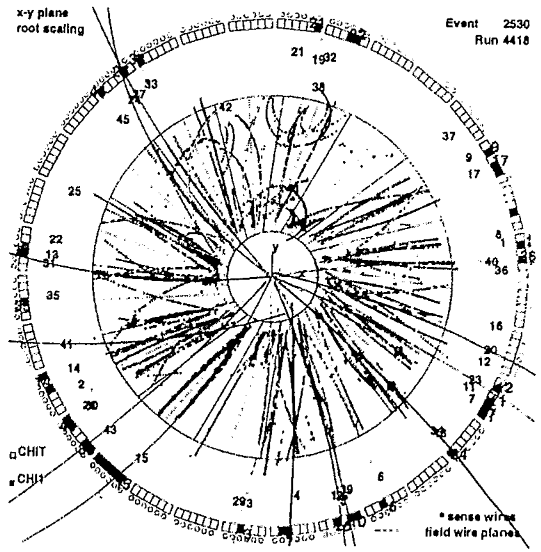
1. $K^{\pm}$ Id. with FOPI
2. K^{-}/K^{+} ratio
3. K^{+} sideward flow
4. Comparison with model predictions

Ni+Ni @ 1.93 AGeV & Ru+Ru @ 1.69 AGeV

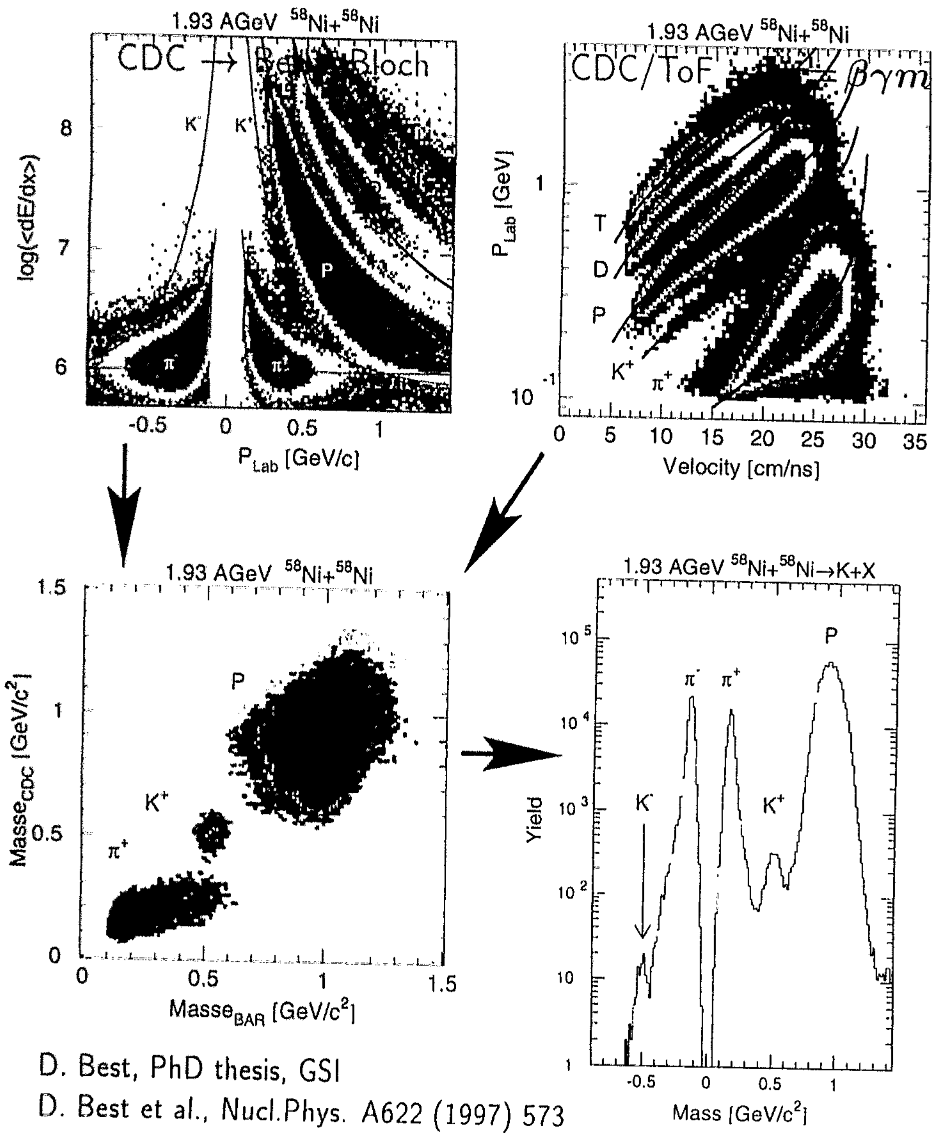
FOPI detector @ GSI



FOPI



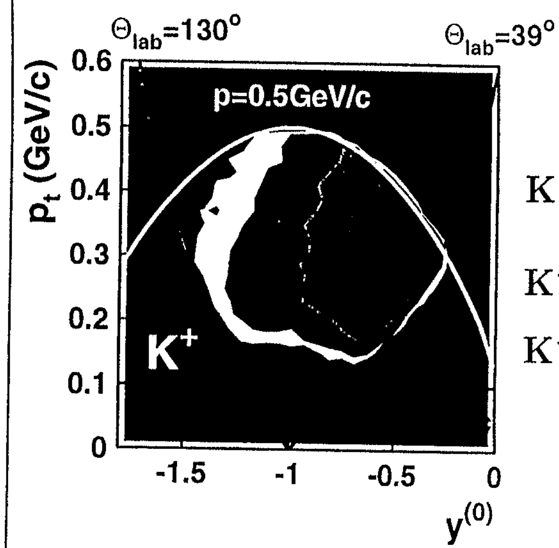
Charged Particle Identification



D. Best, PhD thesis, GSI

D. Best et al., Nucl.Phys. A622 (1997) 573

$K^\pm$ Acceptance & Statistics



$$K^\pm : \begin{cases} 39^\circ < \Theta_{lab} < 130^\circ \\ p_t > 0.1\ \mathrm{GeV/c} \end{cases}$$

$$K^+ : p < 0.5\ \mathrm{GeV/c}$$

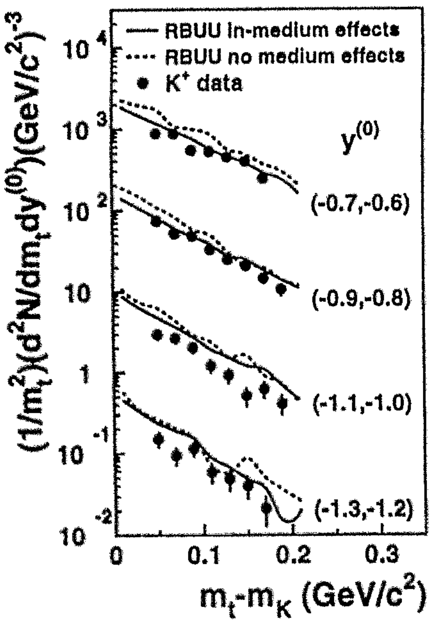
$$K^- : p < 0.33\ \mathrm{GeV/c}$$

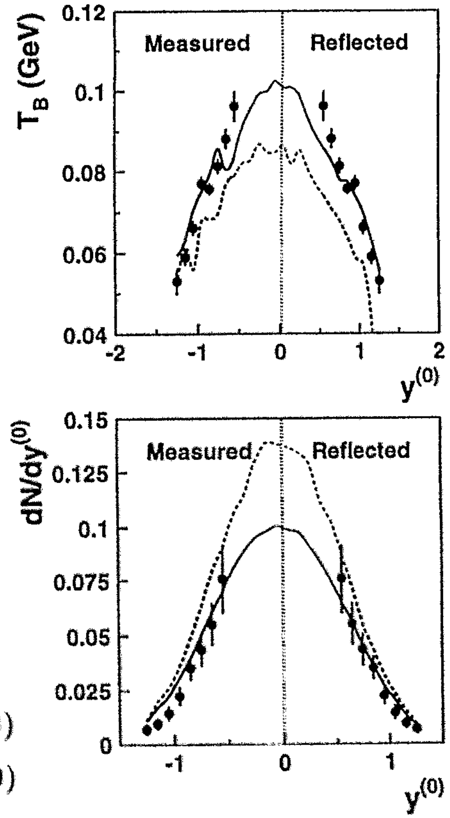
Year	System	Beam Energy	N events	K^+	K^-
1994	Ni+Ni	1.06 AGeV	$2.8 \cdot 10^6$	30	
		1.45 AGeV	$1.8 \cdot 10^6$	300	
		1.96 AGeV	$2.9 \cdot 10^6$	3000	50
1995	Ni+Ni	1.96 AGeV	$4.7 \cdot 10^6$	30000	220
1996	Ru+Ru/Zr	1.69 AGeV	$7.7 \cdot 10^6$	30000	240
1997	Ca+Ca	1.96 AGeV	$5 \cdot 10^5$	–	–
	Au+Au	1.49 AGeV	$5 \cdot 10^5$	–	–

T_B & dN/dy in Ru+Ru @ 1.69 AGeV

$$\frac{1}{m_t^2}\frac{d^2N}{dm_t dy^{(0)}} = A\, exp\left[\frac{-(m_t - m_0)}{T_B}\right] \qquad m_t = \sqrt{p_t^2 - m_0} \quad T_B = T/\cosh(y - y_{cm})$$

RBUU : E.L. Bratkovskaya and W. Cassing





With in-medium effects :

- higher T_B ($\sim 20\%$ at $y^{(0)} = 0$)
- lower yield ($\sim 40\%$ at $y^{(0)} = 0$)

Low sensitivity to IME in the explored $y^{(0)}$ range

Slight better agreement with data if IME

K. Wiśniewski

K^-/K^+ Ratio : Model Predictions

with in-medium effects

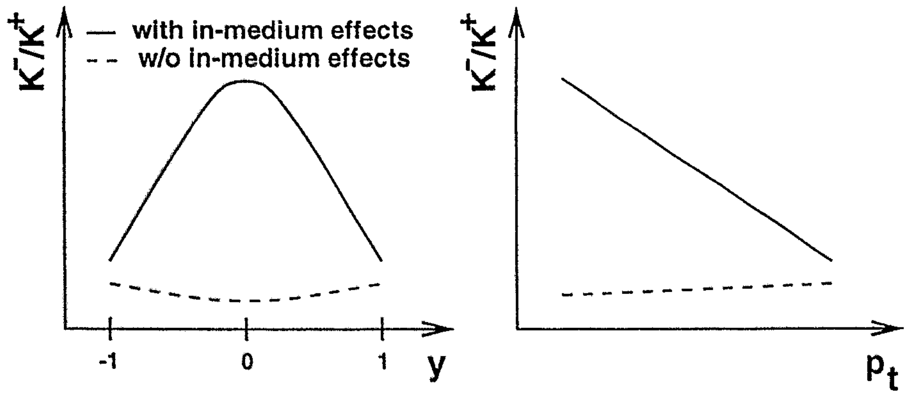
characteristic	mass	potential
K^-	decreased	attractive
K^+	increased	repulsive

observable	yield	momentum
K^-	increased	decreased
K^+	decreased	increased

In-medium effects act oppositely on K^- and K^+

$\Rightarrow$ relevant observable : K^-/K^+ ratio

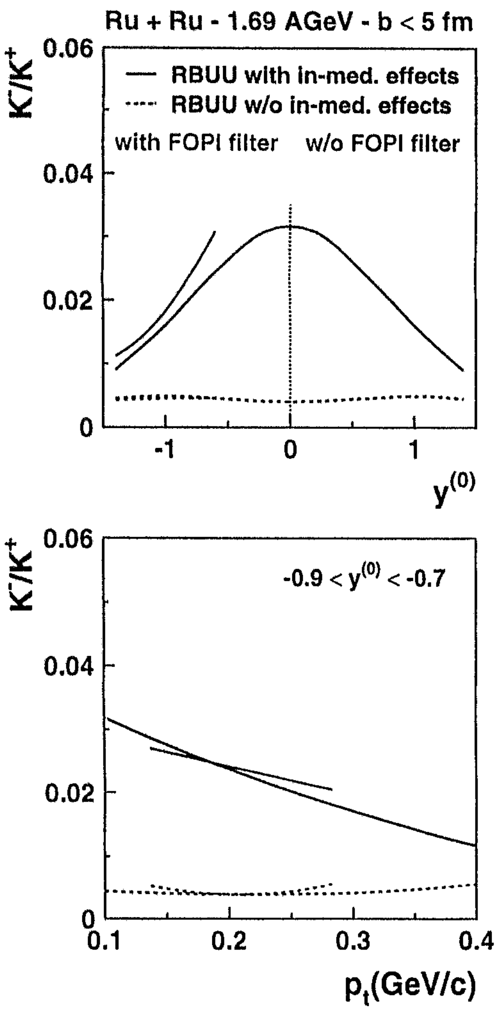
expected trends :



G.Q. Li and G.E. Brown, Phys. Rev. C 58 (1998) 1698

K^-/K^+ Ratio as Seen by FOPI

RBUU : E.L. Bratkovskaya and W. Cassing

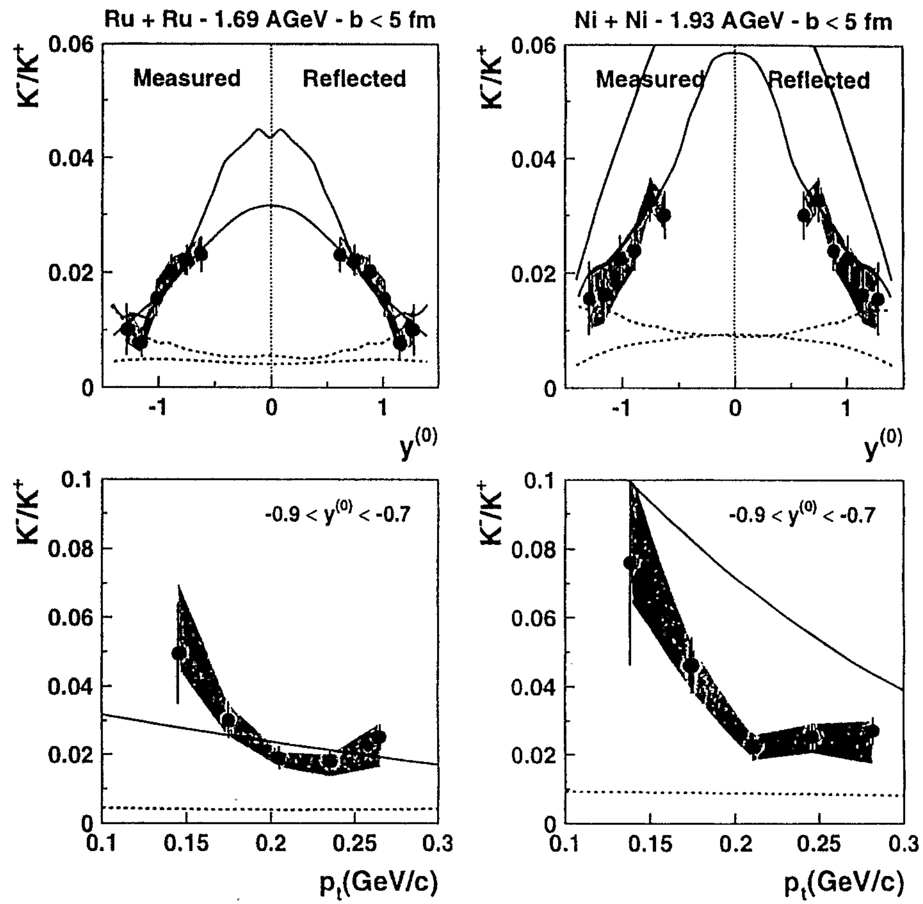


K^-/K^+ Ratio *versus* $y^{(0)}$ and p_t

● DATA ■ Syst. errors

— RBUU in-medium effects E.L. Bratkovskaya and W. Cassing

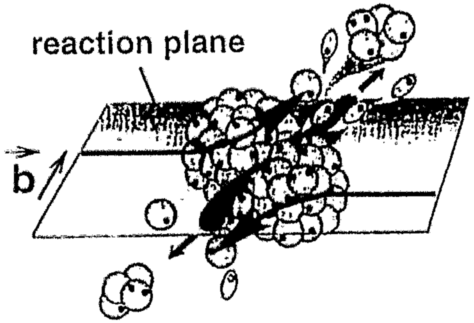
- - RBUU no medium effects G.Q. Li and G.E. Brown, PRC58(1998)1698

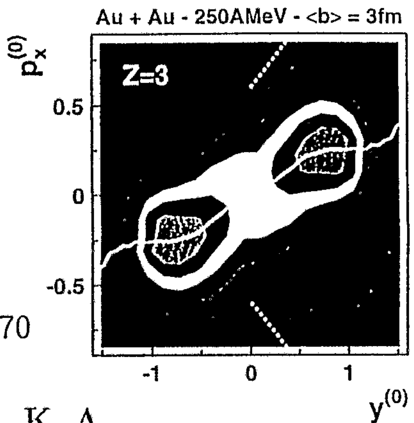


Data favour in-medium effects

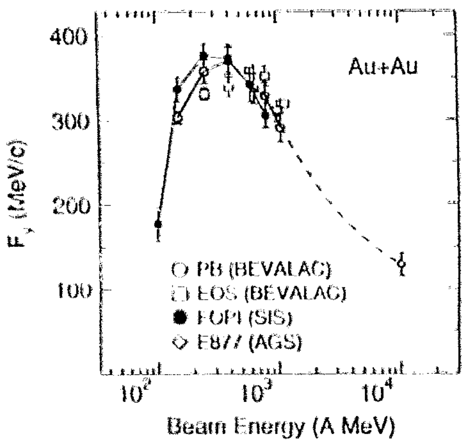
K. Wiśniewski et al., GSI-report (1997), submitted to Phys. Rev. Lett.

Sideward Flow





- o Predicted by hydrodynamics '70
- o Evidenced by Plastic Ball '80
- o Observed for LCP, IMF, n, π, K, Λ
- o Studied from GANIL/MSU to SPS

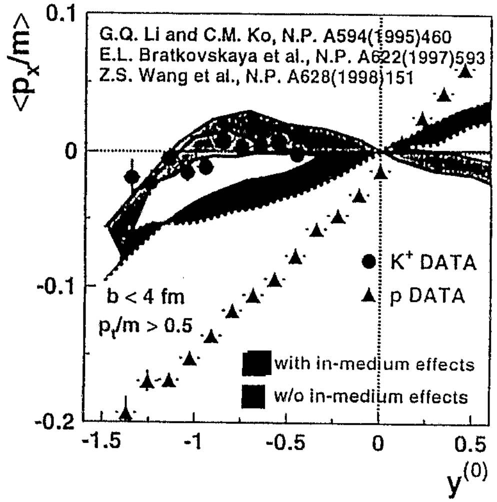


Excitation function :
maximum at SIS energie

$$F_y = \left.\frac{d < p_x >}{dy}\right|_{y=0}$$

W. Reisdorf and H.G. Ritter, Annu.Rev.Nucl.Part.Sci. 47 (1997)

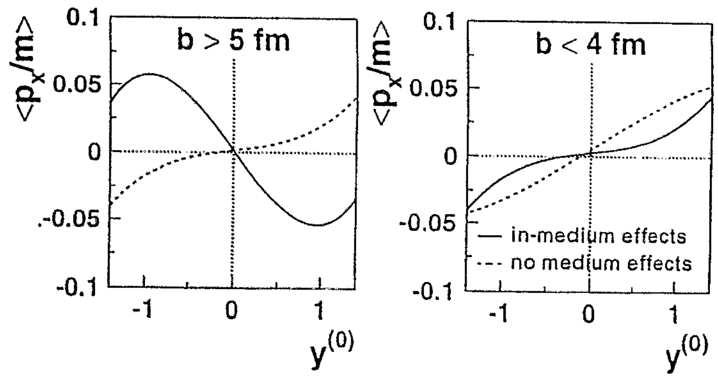
K^+ Flow in Ni+Ni @ 1.93 AGeV



3 ≠ models favour
in-medium potential for K^+
BUT influence of :
production channels :
C. David et al., nucl-th/9805017
momentum dependent potential :
C. Fuchs et al., P.L. B 434 (98) 24!

K^+ Flow in Ru+Ru @ 1.69 AGeV

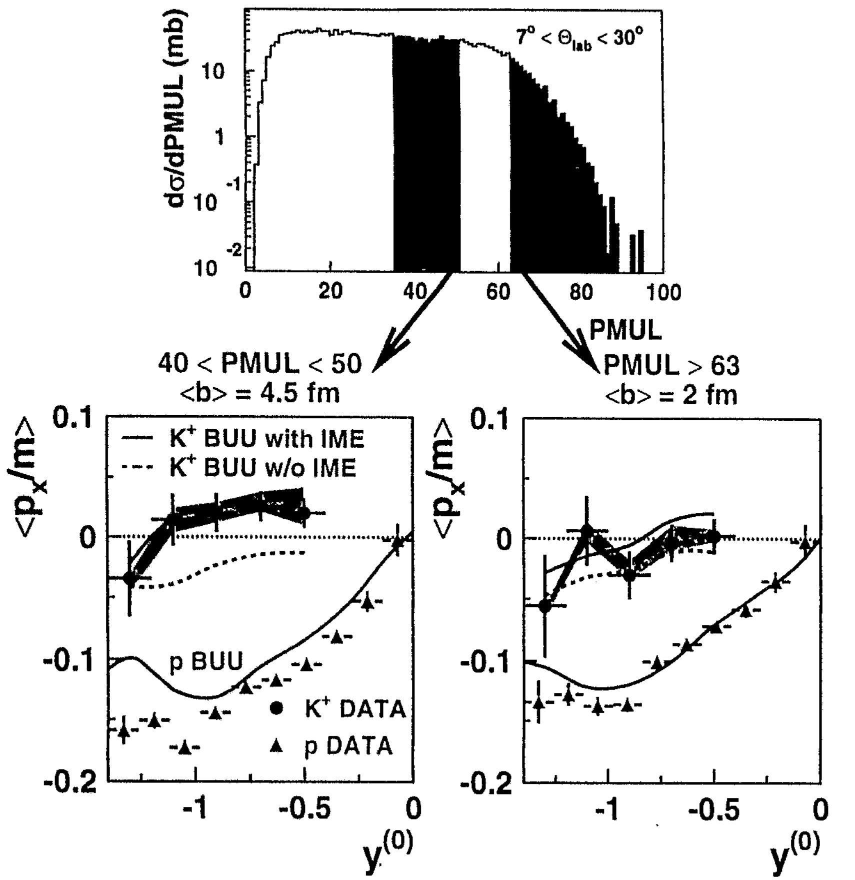
RBUU : E.L. Bratkovskaya and W. Cassing



Large sensitivity expected in non-central collisions
from NME to IME ⇒ flow to antiflow

K^+ Flow in Ru+Ru @ 1.69 AGeV

Centrality selection : charged particle multiplicity PMUL



- K^+ anti-flow in non-central reactions
- BUU reproduces K^+ data if IME on
- BUU reproduces proton data

BUU : E.L. Bratkovskaya and W. Cassing

p_t Dependence of K^+ Flow

Fourier expansion of azimuthal distributions

$$\frac{d^3N}{dy\,p_t dp_t d\Phi} = \frac{d^2N}{dy\,p_t dp_t}\frac{1}{2\pi}\left(1 + 2v_1\cos(\Phi) + 2v_2\cos(2\Phi) + \ldots\right)$$

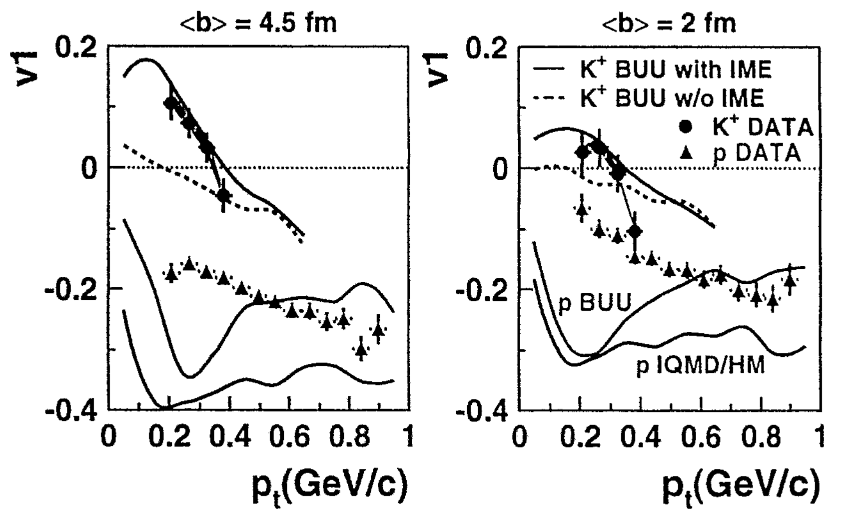
$$\Phi = \phi - \phi_{rp}$$

Fourier coefficients : $v_n = <\cos(n(\Phi))>$

In-plane flow : $v_1 = < p_x/p_t >$

S. Voloshin and Y. Zhang, Z. Phys. C70 (1996) 665
J.Y. Ollitrault, Nucl. Phys. A 638 (1998) 195c

Ru + Ru @ 1.69AGeV $\quad -1.2 < y^{(0)} < -0.5$

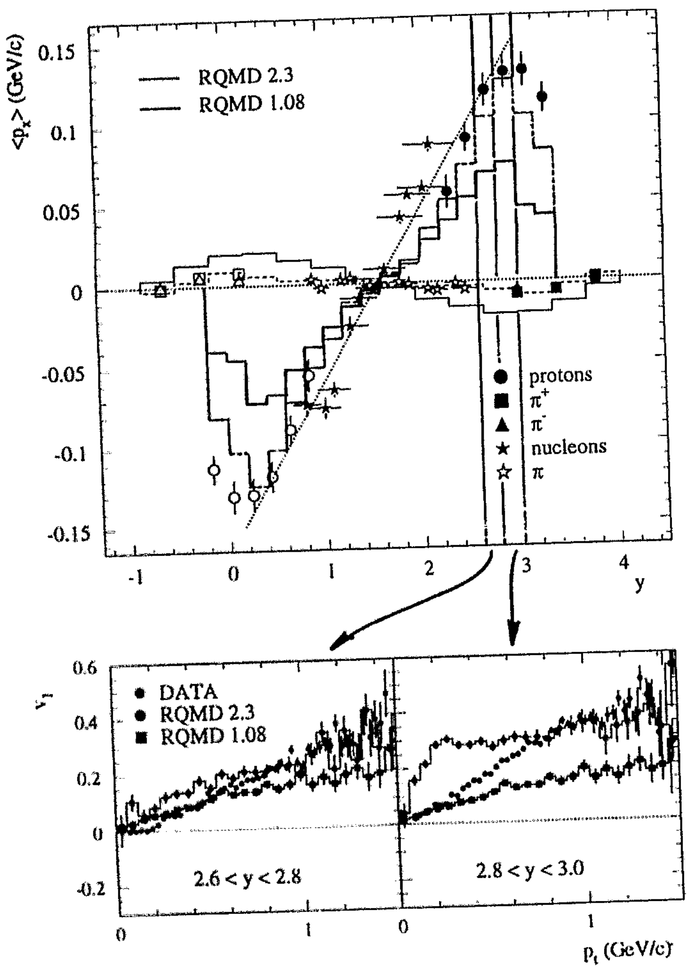


Sensitivity to in-medium effects at low p_t

Neither BUU nor IQMD reproduces proton flow

BUU : E.L. Bratkovskaya and W. Cassing, IQMD/HM : C. Hartnack

Au+Au @ 11 AGeV



J. Barrette and the E877 Collaboration, Phys. Rev. C 56 (1997) 3254

SUMMARY

FOPI Results (1)

Experimental data on
$\mathbf{K^-/K^+}$ ratio and $\mathbf{K^+}$ sideward flow
in Ni+Ni @ 1.93 AGeV and Ru+Ru @ 1.69 AGeV
need in-medium modification of kaon properties
to be satisfactory reproduced by transport models

Open questions and problems :

Theory : { alternative explanations for kaon data; description of baryon data (v_1 % p_t) }

Experiment : { systematical errors; limited statistic }

Future : $\mathbf{K^-}$ flow, Φ

Larger sensitivity to in-medium effects

FOPI ToF upgrade : { more precise measurements; better statistic }

C. Plettner:

Results from FOPI (2): Investigation of charged K mesons at low $p_\perp$ and around midrapidity

Investigation of charged K-mesons at low p_T and around midrapidity

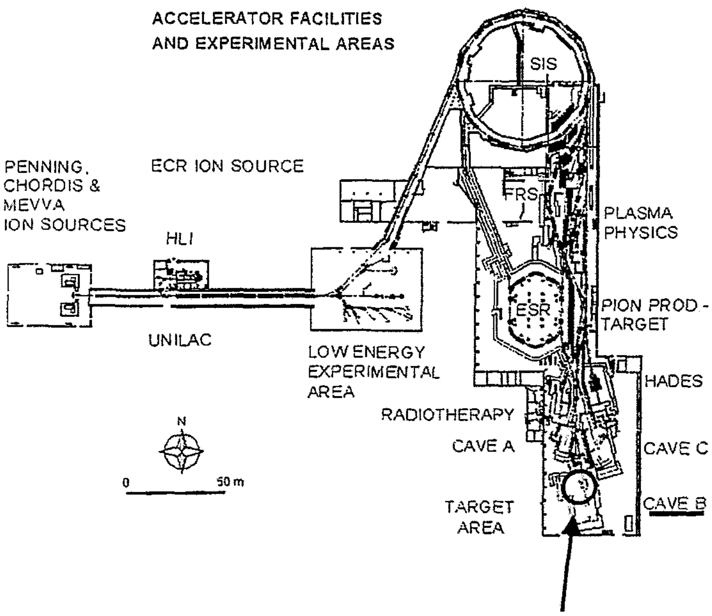
- Presentation of the FOPI detector at GSI, Darmstadt
- (Anti)Kaon identification at low p_T and around midrapidity with FOPI

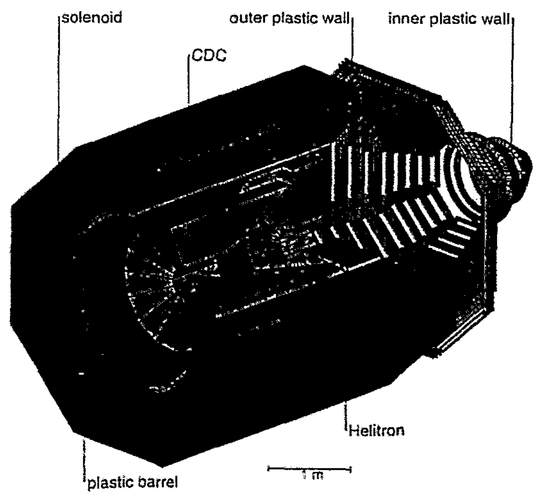
  analysed system: $^{96}Ru + ^{96}Ru$ @ 1.7 AGeV

- Preliminary K^-/K^+ ratio, comparison with model prediction
- Preliminary momentum dependence of Kaon squeeze-out signal

C. Plettner
Institut für Kern- und Hadronenphysik

The 4π Detektor FOPI





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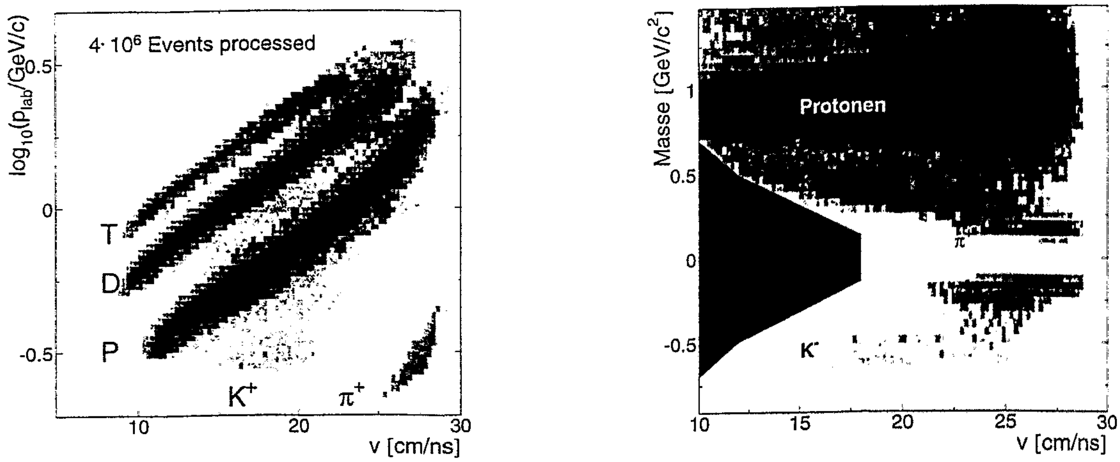
Particle Identification (Z=±1)

$^{96}Ru+^{96}Ru$ @ 1.69 AGeV, b_{geo} < 4.2 fm



$$Mass = \frac{p}{\beta\gamma} + corrections$$

Rel. Resolution:
$\Delta m/m$ = 6 % (Protons)

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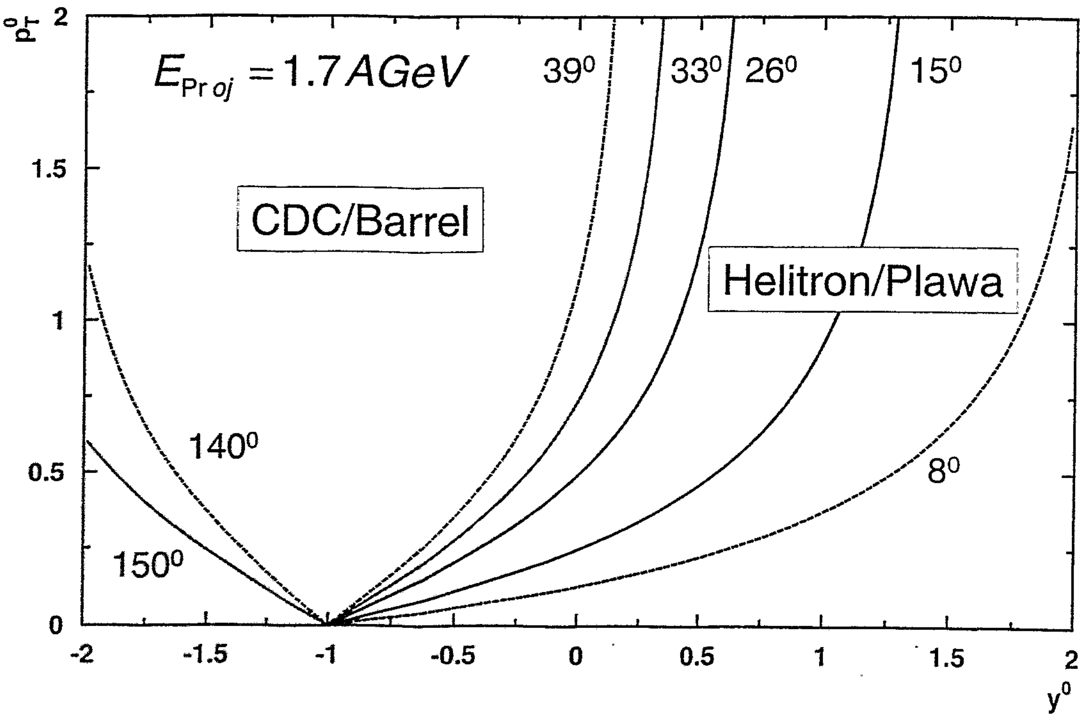
FOPI phase space



Symmetric system: $Y^0 = (Y_{lab} - Y_{cm}) / Y_{cm}$

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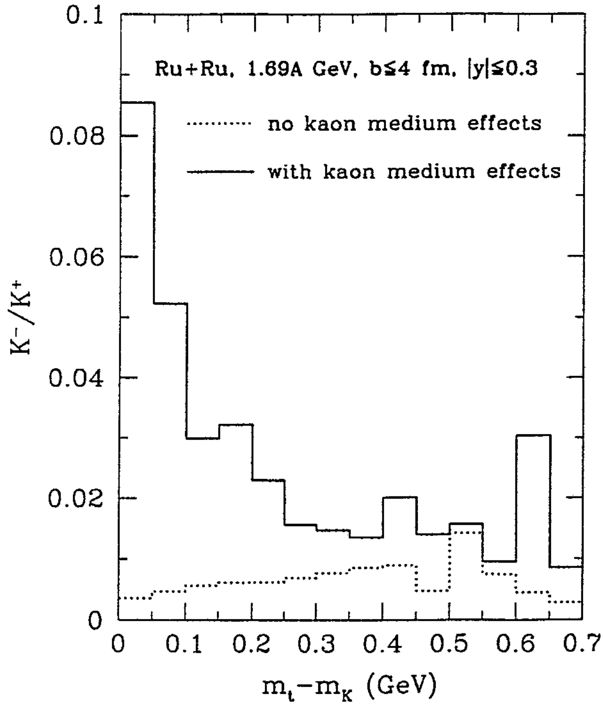
Comparison with RBUU predictions



G.Q. Li and G.E. Brown, Phys. Rev. C58 (1998), 1698

Analysis of Helitron data

^{96}Ru + ^{96}Ru @ 1.69 AGeV, $b_{Geo} < 4.2$ fm

accessible transverse momenta range

$p_t = (100 - 250)$ MeV/c

transformation into transverse mass

$m_t = \sqrt{(p_T/c)^2 + m_K^2} = (10 - 50)$ MeV/c^2 + m_K

rapidity range

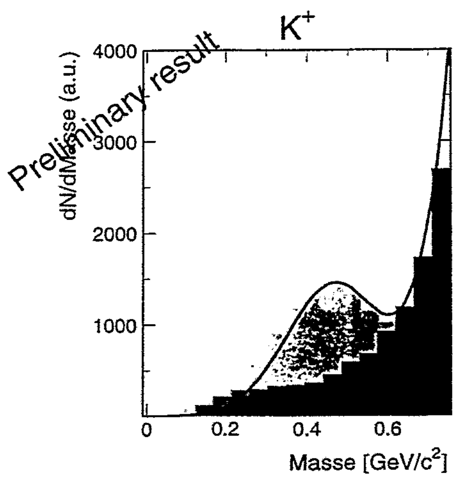
$|y^0| \leq 0.3$

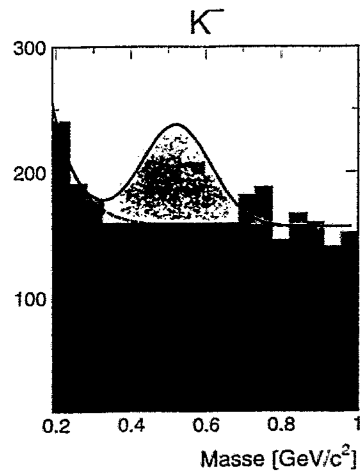
K^-/K^+ ratio

$(7.5 \pm 3.5)\%$

⇒ compatible with in-medium modification of (Anti)Kaon mass

Identification of charged K-Mesons





Velocity [cm/ns]

$16 < v < 23$

Center of Mass velocity.

≈ 21 cm/ns

Momenta [MeV/c]

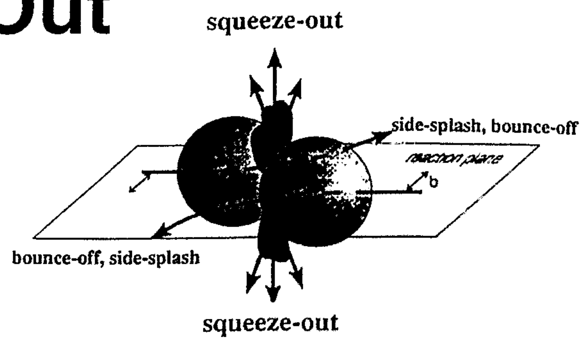
$310 < p_{lab} < 590$

$\sum_{K^+} = 4904 \pm 2000$

$\sum_{K^-} = 368 \pm 50$

$\Rightarrow K^-/K^+ = (7.5 \pm 3.5)\%$

Squeeze-Out



Parametrization of azimuthal distributions

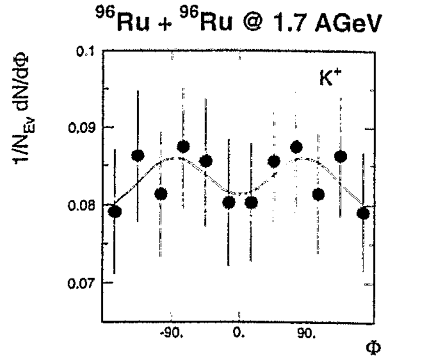
$$\frac{dN}{d\phi} = a_0'(1 + a_1' \cos\phi + a'_2 \cos 2\phi)$$

Out-of plane emission ratio

$$R_N' = \frac{1 - a_2'}{1 + a_2'}$$

Correction

$$R_N' \Rightarrow R_N$$



Symmetrised azimuthal distributiongs of K^+

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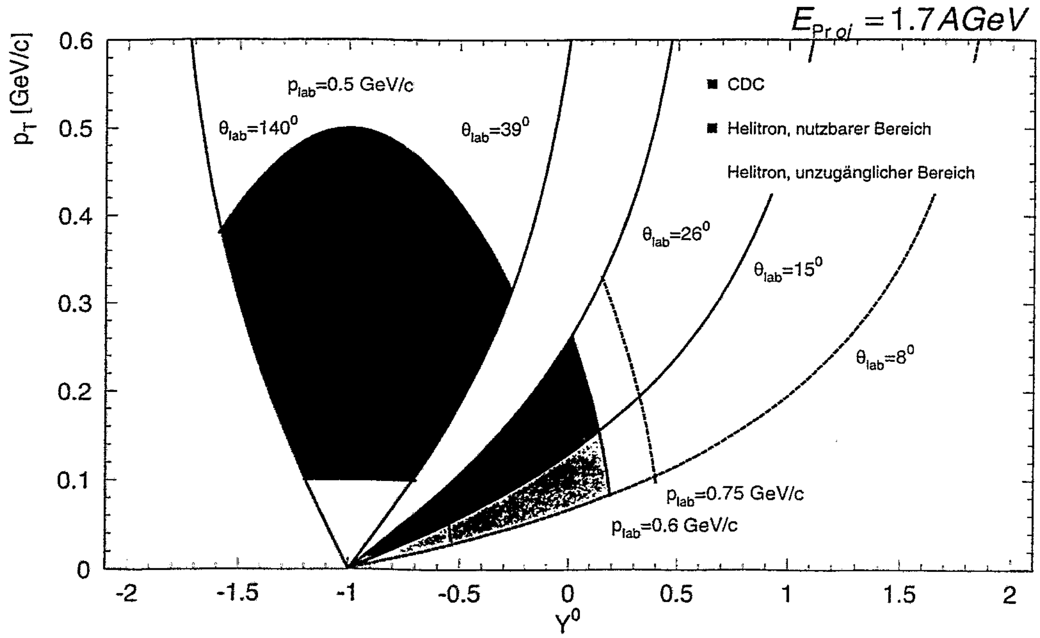
Institut für Kern- und Hadronenphysik

K^+ phase space



Symmetric system $\quad Y^0 = (Y_{lab} - Y_{cm}) / Y_{cm}$

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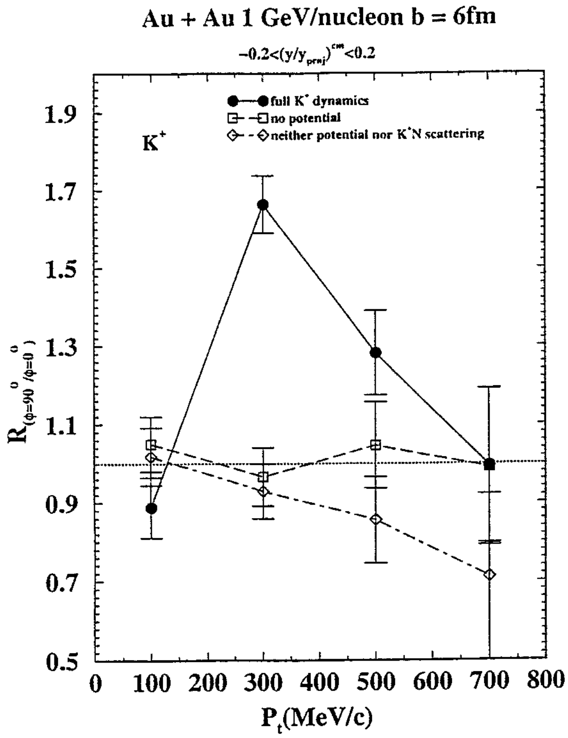
Comparison with QMD



Z.S. Wang et al., Phys. Rev. C57 (1998), 3284

- in system *Au + Au @ 1.0 AGeV* prediction of a momenta dependent squeeze-out signal in case of a KN potential
- without a KN potential model predicts within error bars that $R_N \leq 1$
- analysis of momentum dependence of Kaon squeeze out signal in the system *Ru + Ru @ 1.7 AGeV* shows within error bars $R_N \geq 1$

⇒Hint for existence of an in-medium potential?

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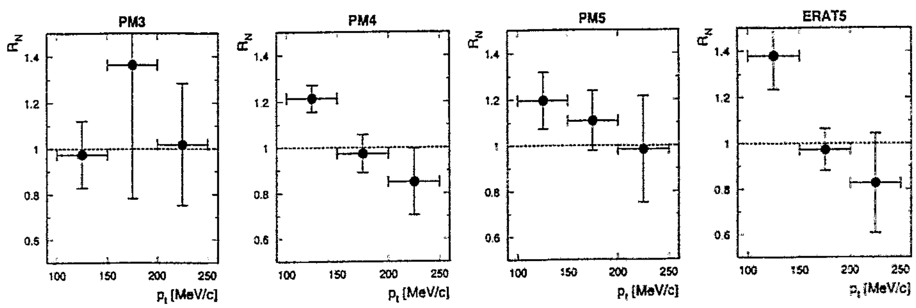
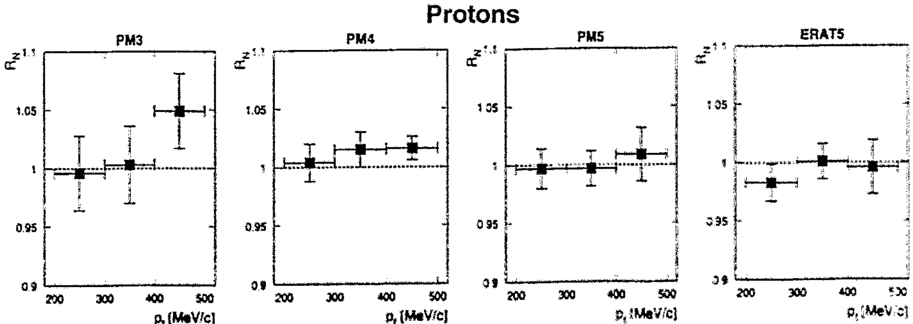
Momentum dependence of Squeeze-Out signal

Kaons, background corrected



centrality →

Protons



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Summary

- With detector combination Helitron/Plastic Wall (Anti)Kaons can be identified at midrapidity for low transverse momenta

- Measured K^-/K^+ ratio compatible with in-medium modification of (Anti)Kaon mass

- Measured p_T dependence of Kaon squeeze-out signal gives hint to existence of KN potential
  On our wish list: calculations for ^{96}Ru + ^{96}Ru @ 1.7 AGeV

Y. Shin:

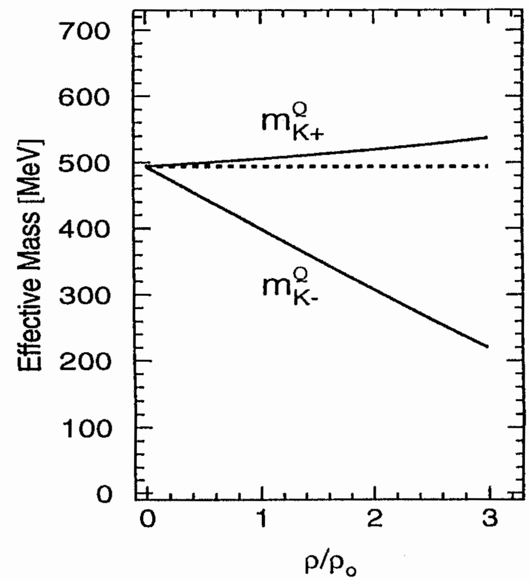
Azimuthally anisotropic emission of K^+ mesons in Au + Au collisions at 2 AGeV

Azimuthal Anisoptrop Emission of K^+ Mesons in Au + Au Collisions at 1 AGeV

Y. Shin (Univ. Frankfurt)
for the KaoS Collaboration

1. Motivation
2. Experiment Setup
3. Analysis
4. Results
   - Spectral Distribution
   - Azimuthal Distribution
5. Summary

- **Properties of Hadrons in Nuclear Medium**



$$m^*_{K,\bar{K}} \approx m_K[1 - \frac{\Sigma_{KN}}{f_K^2 m_K^2}\rho_s + (\frac{3}{8}\frac{1}{f_K^2 m_K}\rho_N)^2]^{1/2} \pm \frac{3}{8}\frac{\rho_N}{f_K^2}$$

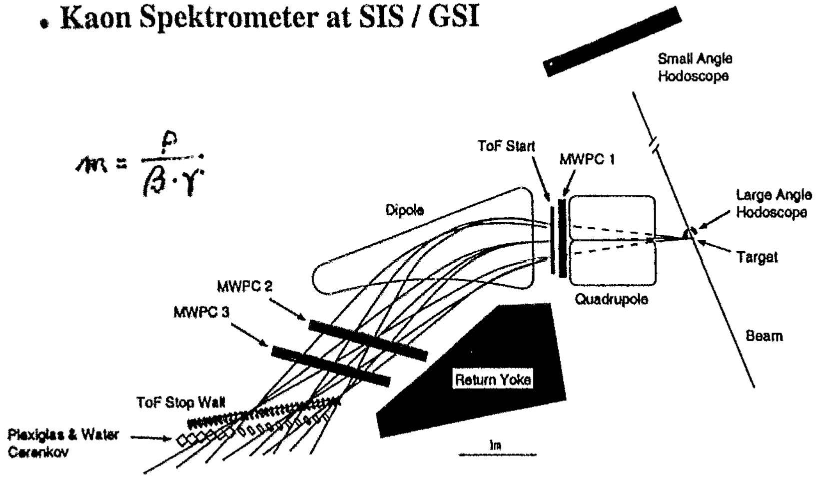
$$= \sqrt{m_K^2 + p^2} + U_s + U_v$$

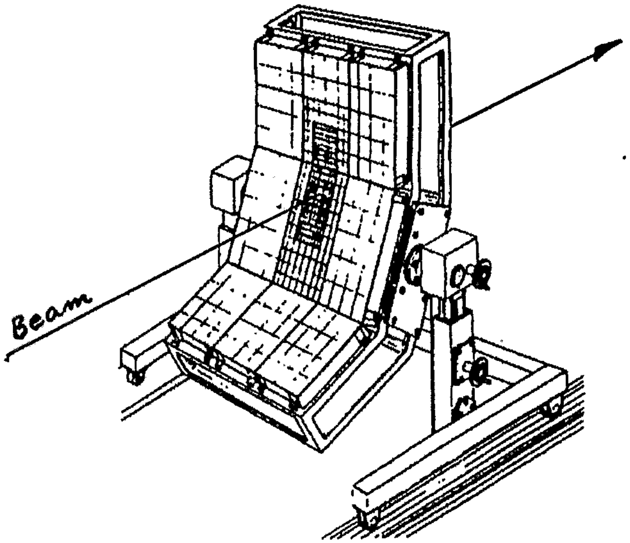
RBUU : C. Ko and G. Li, JPG, V. 22(1996)

$\Longrightarrow$ **Repulsive KN Potential for K^+ Mesons**

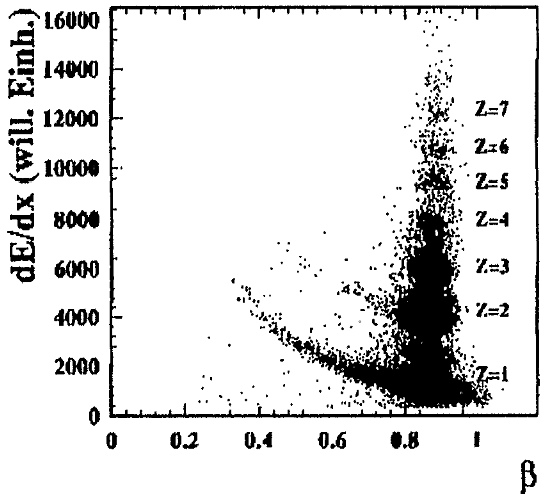
- **Kaon Spektrometer at SIS / GSI**

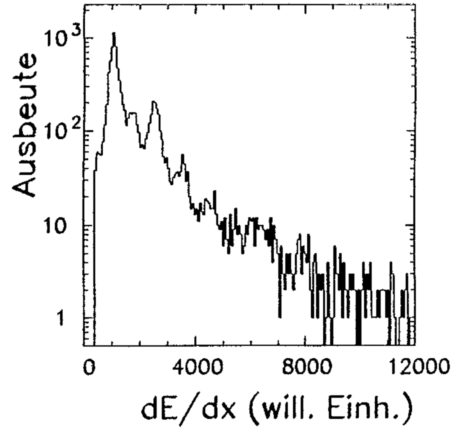
$$m = \frac{p}{\beta \cdot \gamma}$$



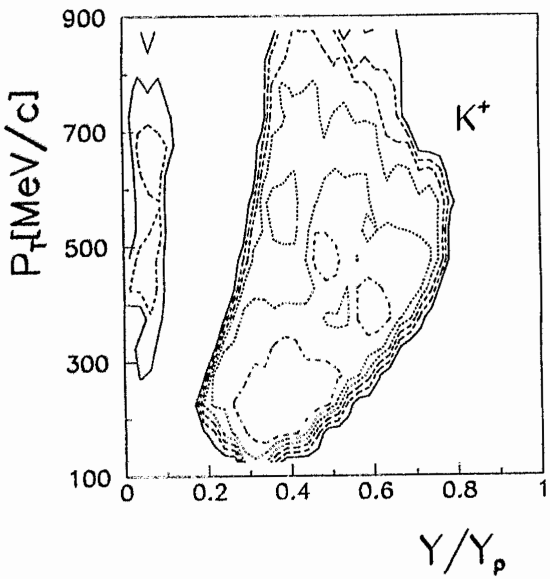


- **Identifikation der Teilchen im Kleinwinkel Hodoskop**





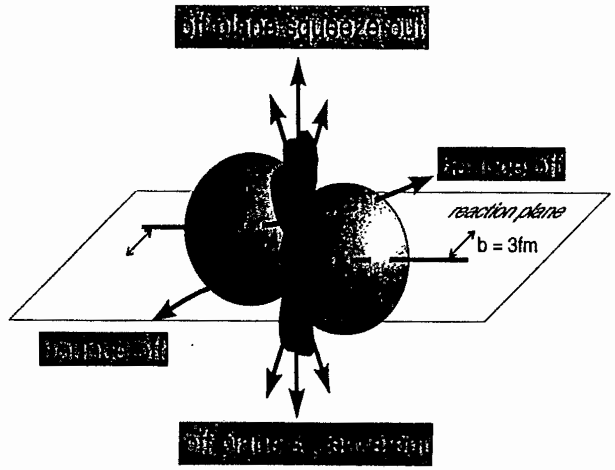
- **K⁺ Acceptance at 1 AGeV**



- $\Theta_{Lab} = 34°, 44°, 54°, 84°$
  $(N_{K^+} = 8600, 9700, 5000, 250)$

- $B_{Dipol} = 0.6, 0.9, 1.4, 1.9$**T**
  $(270 MeV/c \leq p_{Lab} \leq 1500 MeV/c)$

1. Collective Flow of Nuclear Matter



$$\vec{Q} = \sum_{\nu} \omega_{\nu} \vec{p}_t(\nu)$$

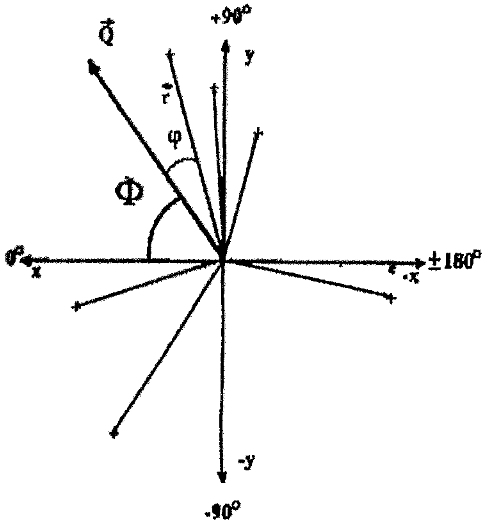
P. Danielewicz : Phys.Lett. 157B(1985)

2. K⁺ as Probe for the hot and dense Phase

(a) Subthreshold Production : $E_{th} = 1.58$ **GeV** $(NN \rightarrow N\Lambda K^+)$

(b) Large Mean Free Path : $\lambda_{K^+} \approx 5$ **fm** $(\sigma_{Kp} \approx 12$ **mb**$)$

- **Determination of the Reaction Plane**



$$\vec{Q} = \sum_{\nu} \omega_\nu \cdot \vec{p}_t(\nu)$$

$\Longrightarrow$ **for Particles with $\beta > 0.7$**

$\Longrightarrow$ $\omega_\nu = 1$ **or** $\omega_\nu = Z_\nu$

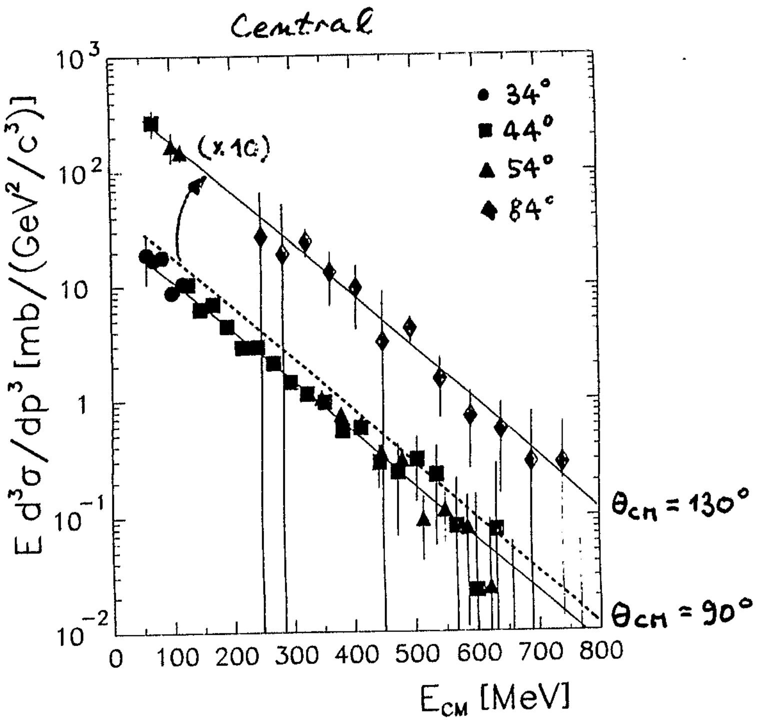
- **Resolution of the Reaction Plane**

Impactparameter	$< \Delta\phi_{12}^2 >^{1/2}$	$< \Delta\phi^2 >^{1/2}$	$< \cos(\Delta\phi) >$	$< \cos(2\Delta\phi) >$
MUL 1	91.2°	54.9°	0.66 (0.71)	0.30 (0.16)
MUL 2	77.5°	40.0°	0.81 (0.78)	0.50 (0.36)
MUL 3	73.1°	36.4°	0.84 (0.79)	0.55 (0.38)
MUL 4	89.0°	55.9°	0.65 (0.71)	0.31 (0.17)
MUL 5	101.1°	80.5°	0.35 (0.66)	0.08 (0.05)

- **Spectral Distribution of K^+ Mesons**

$$\sigma_{inv} = E \cdot \frac{d^3\sigma}{dp^3} = A \cdot E \cdot exp(-E/T)$$

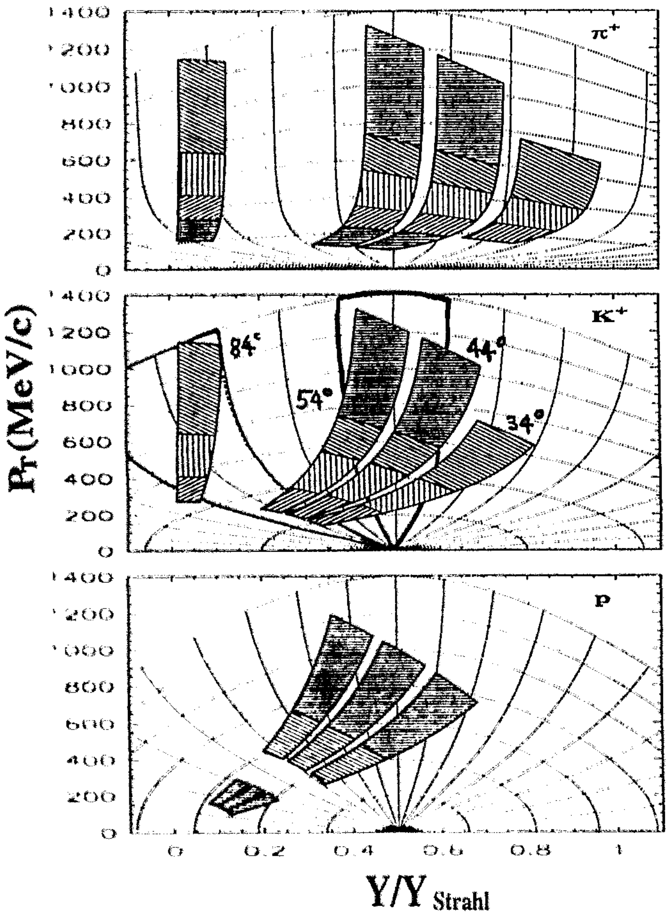
$$\Longrightarrow T \approx 87 MeV$$



$\Longrightarrow$ **Polar Anisotropy**

$\Longrightarrow$ **C. Sturm : Next Talk**

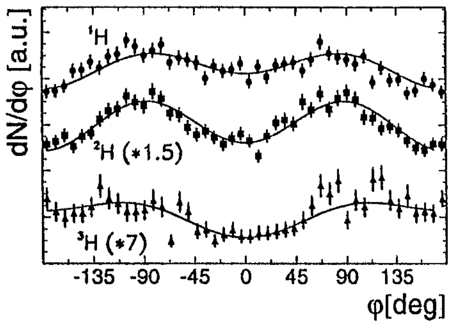
- **Experiment Au + Au at 1 AGeV**



- Squeeze - Out of Nucleons and light Fragments

  Bi+Bi at 0.4, 0.7, 1.0 AGeV

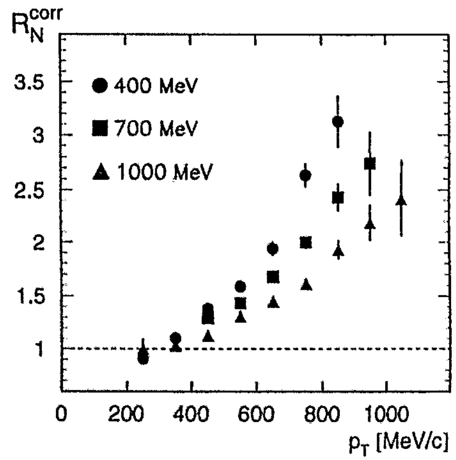
0.4 AGeV, Semicentral



$$\frac{dN}{d\varphi} \sim 1 + \underline{a_1} \cdot \cos\varphi + \underline{a_2} \cdot \cos 2\varphi$$

D. Brill et al., Z.Phys.A 355(1996)

Beam Energy Dependency, Semicentral

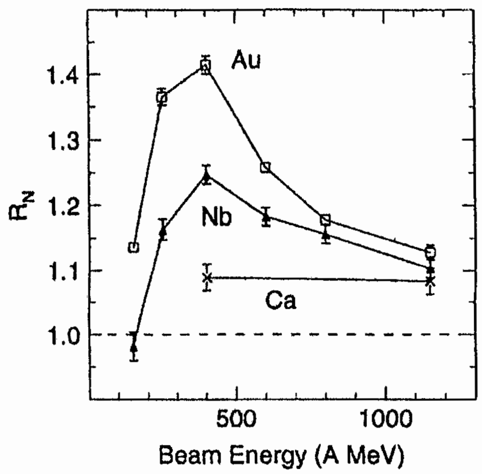


$$R = \frac{N(90^o) + N(-90^o)}{N(0^o) + N(180^o)} = \frac{1 - a_2}{1 + a_2}$$

$$a_1^{cor} = \frac{a_1}{< cos(\varphi) >}$$

$$a_2^{cor} = \frac{a_2}{< cos(2\varphi) >}$$

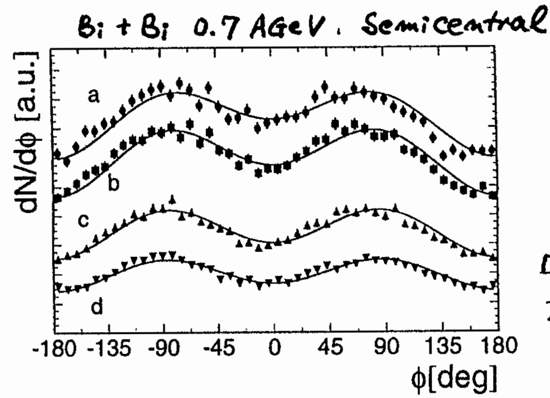
M. Demoulins et al., Phys.Lett. B241, 476(1990)



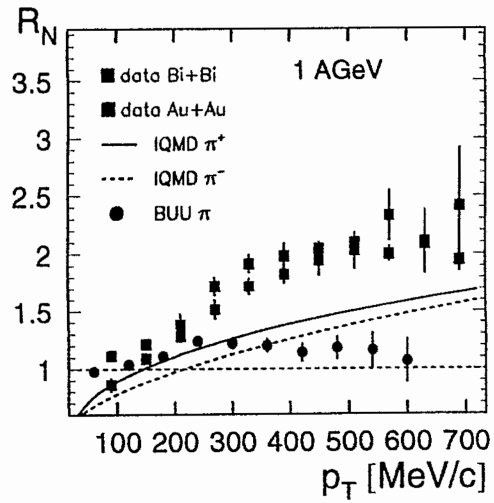
H. Gutbrod et al., PRC 42(1990)

$\Longrightarrow$ **Hydrodynamic Squeeze Out.**

• **Elliptic Flow of π Mesonen**



D.Brill et al.
Z.Phys. A 357 (1997)

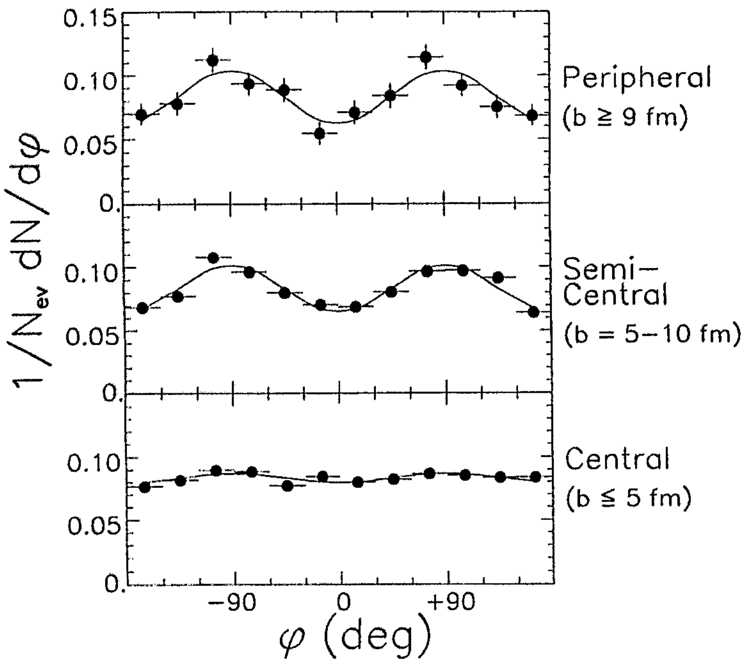


IQMD : S.A. Bass et al., Phys.Rev. C51, 3343(1995)
BUU : B.A. Li et al., Nucl.Phys. A570, 797(1994)

- **Elliptic Flow of K^+ Mesons**

Impact Parameter Dependence

$0.2 \leq y/y_P \leq 0.8$; $0.2 \leq p_T (GeV/c) \leq 0.8$

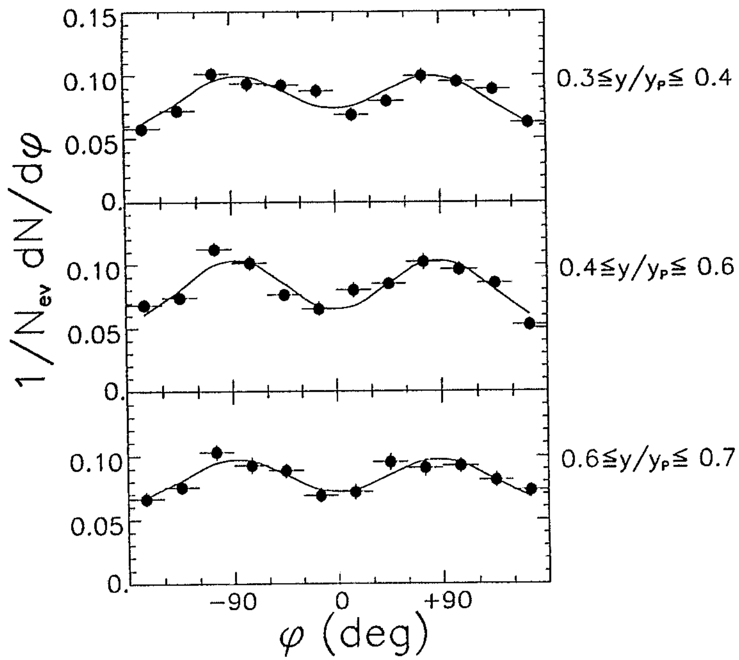


Y. Shin, PRL 81(1998)

- **Elliptic Flow of K^+ Mesons**

Rapidity Dependence

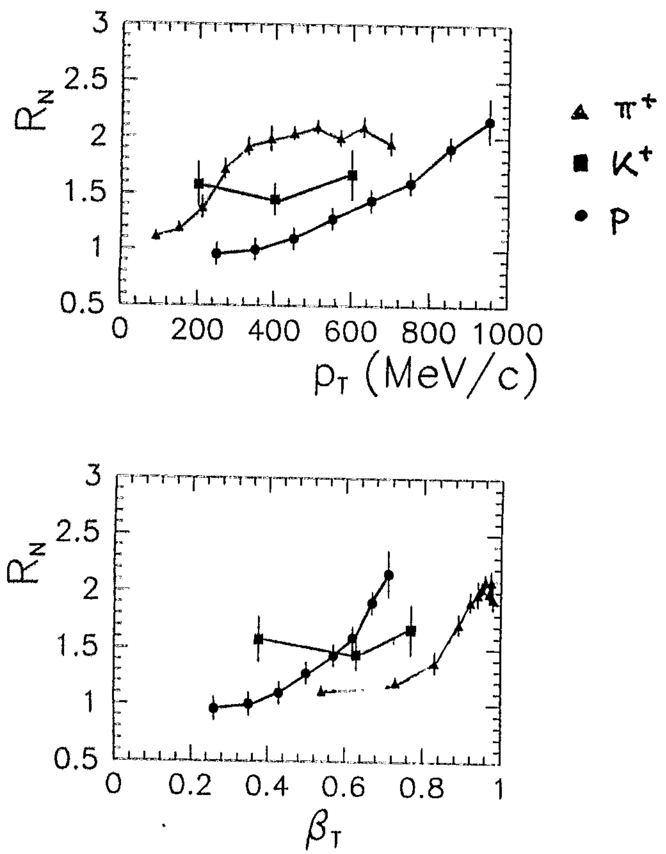
200 MeV/c $\leq p_T \leq$ 800 MeV/c, Semicentral



$\Longrightarrow$ **No Flow Component into the Reaction Plane!**

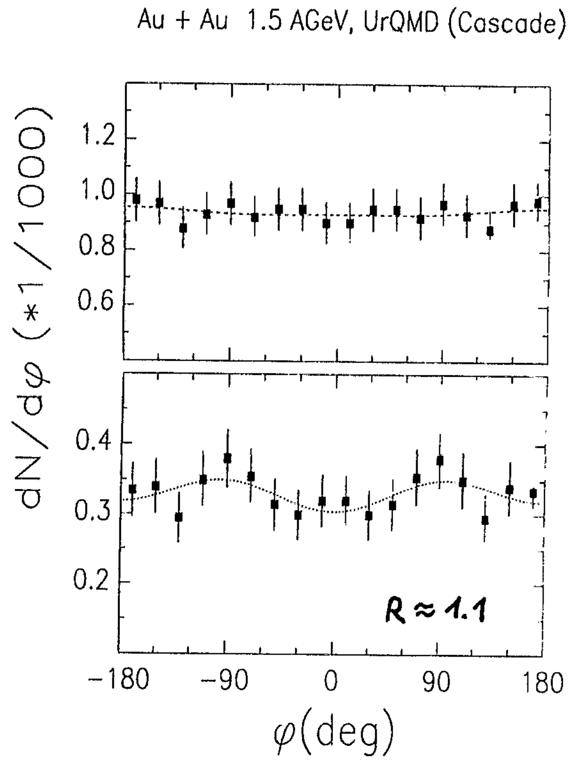
- **Elliptic Flow of π^+, K^+ and Nucleons**

p_T **Dependence, Semicentral Collisions**



- **UrQMD Model Calculation**

<u>**S. Soff (Univ. Frankfurt, priv. Communication)**</u>

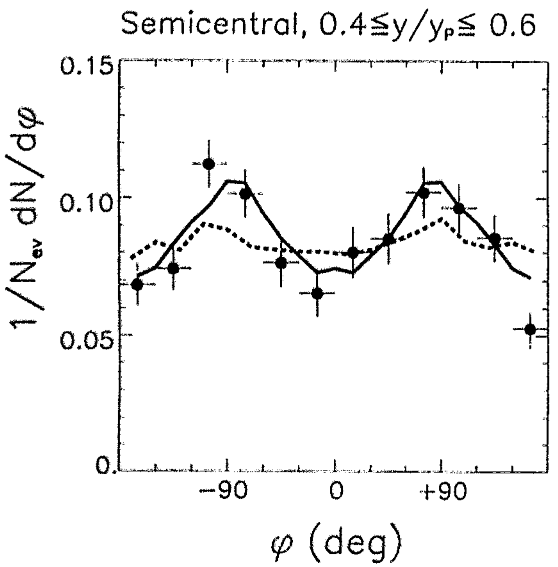


<u>**No Final Interaction**</u>

<u>**With Rescattering**</u>

- **Comparison with RBUU Model Calculation**

Exp. Data : Au + Au at 1 AGeV,   Semicentral



— With KN Potential

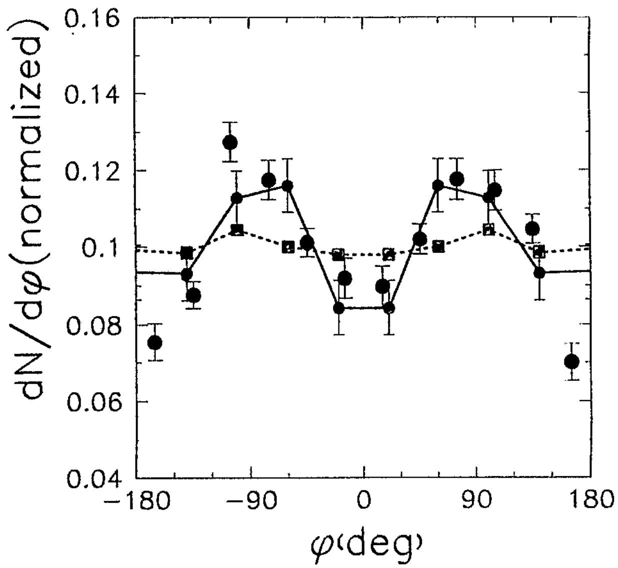
--- Coulomb + Rescattering

G.Q. Li : priv. Communication(1997)

⟹ repulsive KN Potential in the Medium!

- **Comparison with RQMD Model Calculation**

Exp. Data : Au + Au at 1 AGeV,   Semicentral



● With KN Potential

■ Coulomb + Rescattering

Z. Wang et al. : nucl-th/9809043

⟹ repulsive KN Potential in the Medium!

Summary

1. Spectral Distribution of K^+ Mesons

- Slope Parameter $T \approx 87$ MeV in Central Collisions.
- At $\Theta_{CM} \approx 120°$ nearly 2 times more Yield then at $\Theta_{CM} \approx 90°$.

  ⟹ *Polar Anisotropy*

2. Azimuthal Distribution of K^+ Mesons

- Preferential Emission *perpendicular* to the Reaction Plane.
  The Effect increases with the increasing Impact Parameter.
  No p_t-Dependence.
  Decreases slightly in Forward- and Backward Hemisphere.
- No Flow Component *into* the Reaction Plane.

  ⟹ According to Transport Models,

  an Indication for the KN-Potential in the Nuclear Medium?

3. Outlook

- K^+ Sideward Flow at Target Rapidity in Au + Au 1 AGeV.
- K^- Elliptic and Sideward Flow in Au + Au 1.5 AGeV
  and Ni + Ni 1.93 AGeV.

- K^- Mesons in nuclear Medium

  RQMD Calculation by Z. Wang et al., nucl-th/9809043

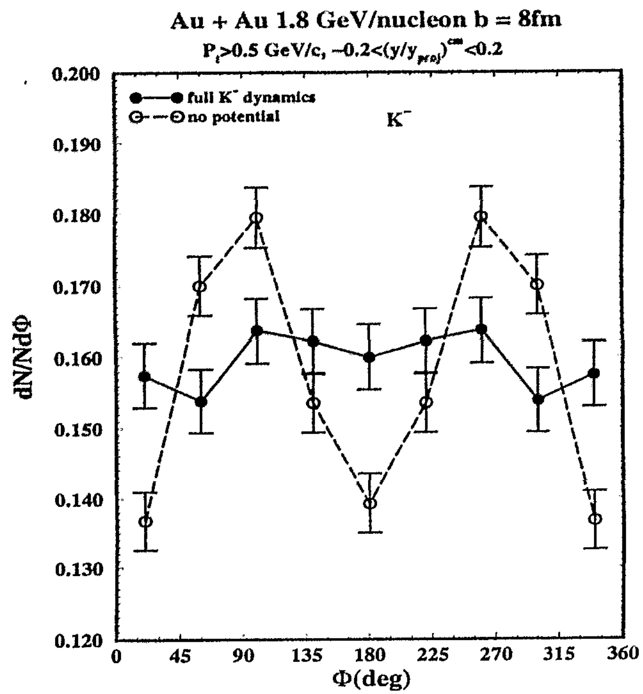


Fig. 4

KaoS Collaboration

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F. Laue:

Kaons and anti-kaons in hot and dense nuclear matter

Kaons and Antikaons in Hot and Dense Nuclear Matter

F.Laue
for the
KaoS Collaboration

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[f] TU Dresden, [h] Michigan State University, USA

Outline

- Introduction
- Setup
- Experimental Data C+C (Ni+Ni)
- Comparision with RBUU C+C (Ni+Ni)
- Summary
- Outlook (The C+Au System)

K^+ and K^-–Production at SIS $(0.6AGeV < E_{Beam} < 2AGeV)$

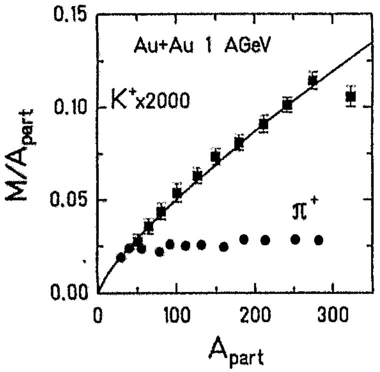
Production thresholds:

$$NN \to N\Lambda K^+ \qquad E_{th}^{Lab} = 1.58GeV$$

$$NN \to NNK^+K^- \qquad E_{th}^{Lab} = 2.5GeV$$

Subthreshold $K^{\pm}$–production via multiple collisions

Experiment:



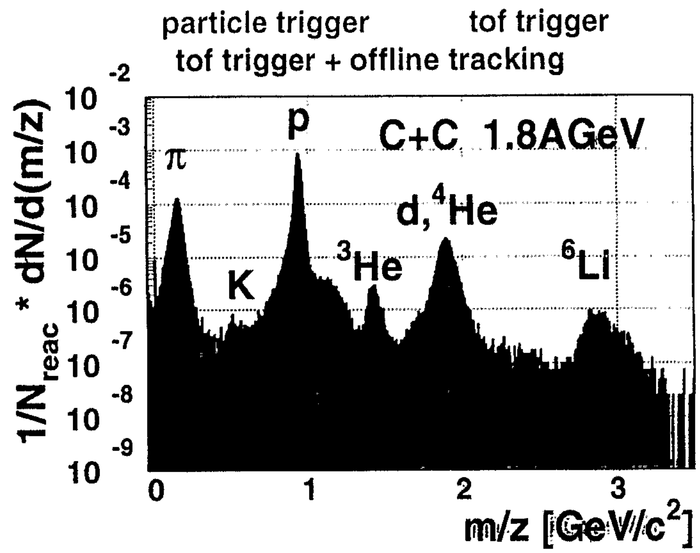
$$\frac{M_{K+}}{A_{part.}} \propto A_{part.}^{1.8 \pm 0.15}$$

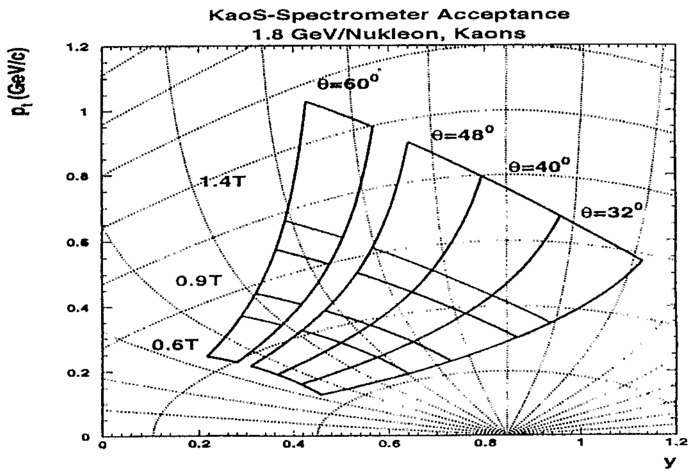
Transport models:

$$NN \to \Delta N$$
$$\Delta N \to NK^+Y$$
$$\Delta\Delta \to NK^+Y$$
$$NN \to NN\pi$$
$$\pi N \to K^+Y$$
$$\pi\pi \to K^-K^+$$
$$\pi\Delta \to K^+Y$$

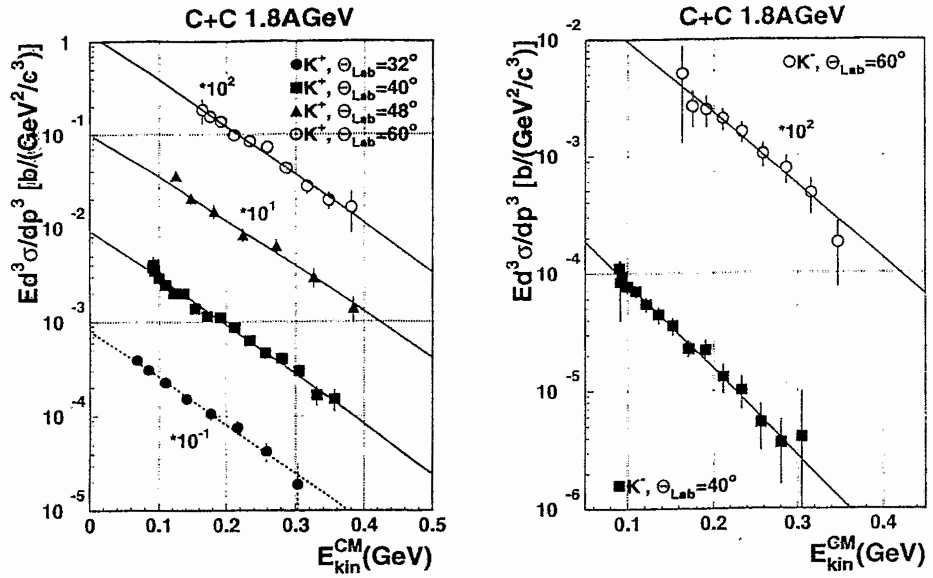
Medium effects are important

- nuclear equation of state (→ Ch. Sturm)
- hadron properties in matter





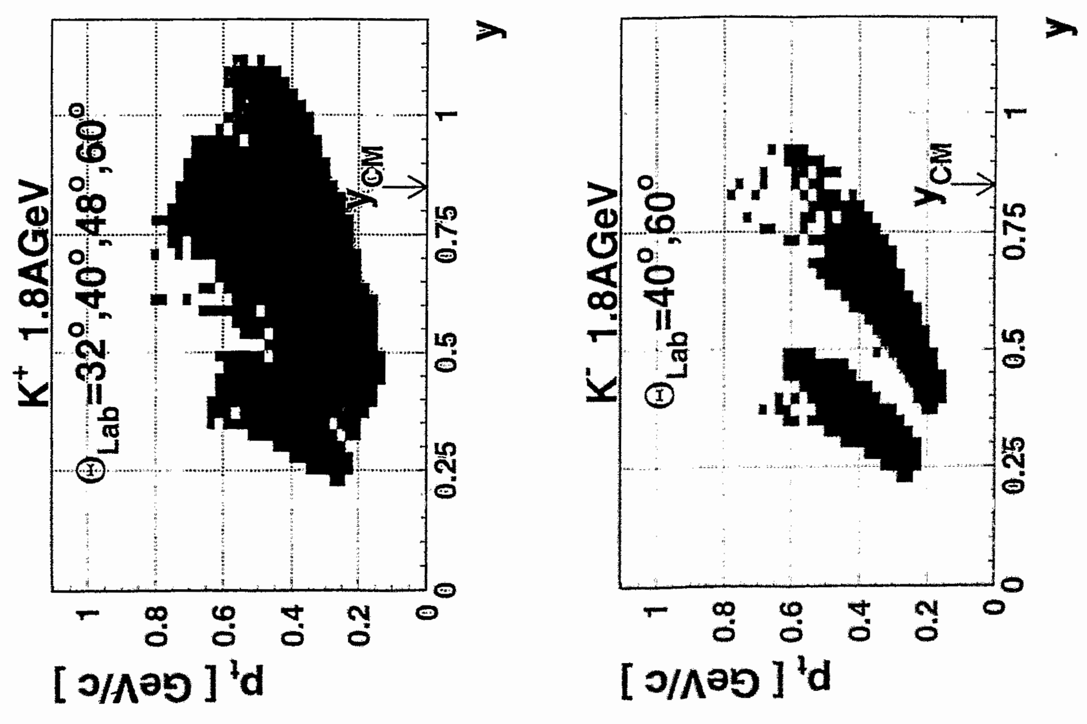
K^+ and K^- Spectra



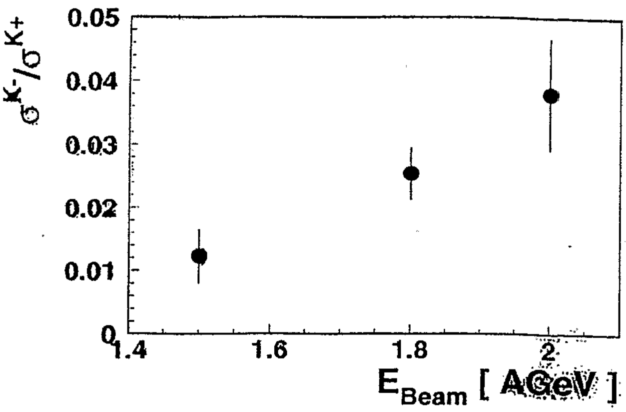
The data can be fitted by Maxwell–Boltzmann distributions.

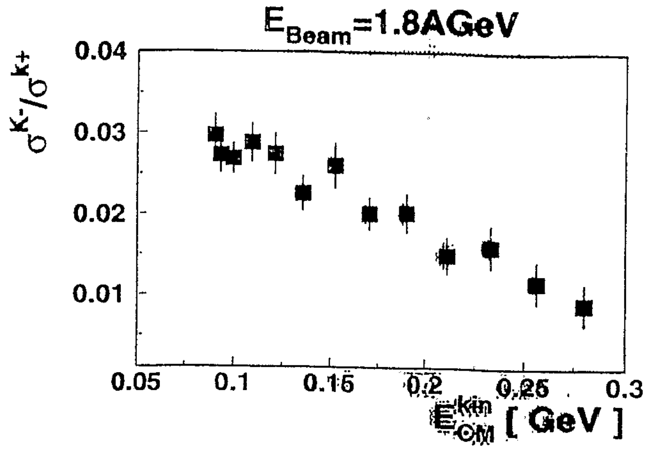
In C+C collisions we have data for $0.8, 1.0, 1.2, 1.5, 1.8$ and $2.0 AGeV$.

Phasespace Coverage

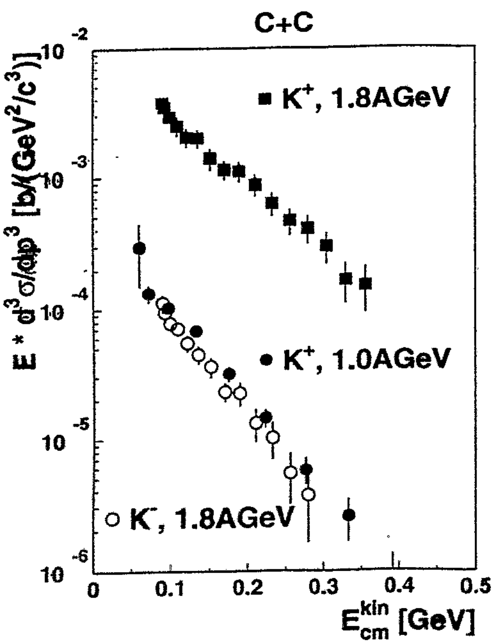


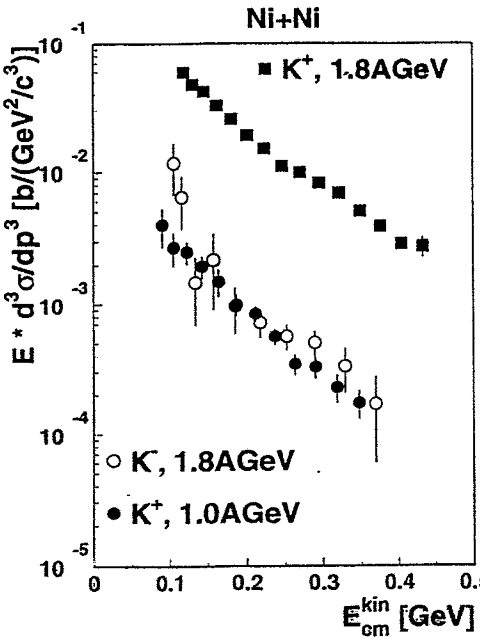
The K^+/K^- Ratio in C+C





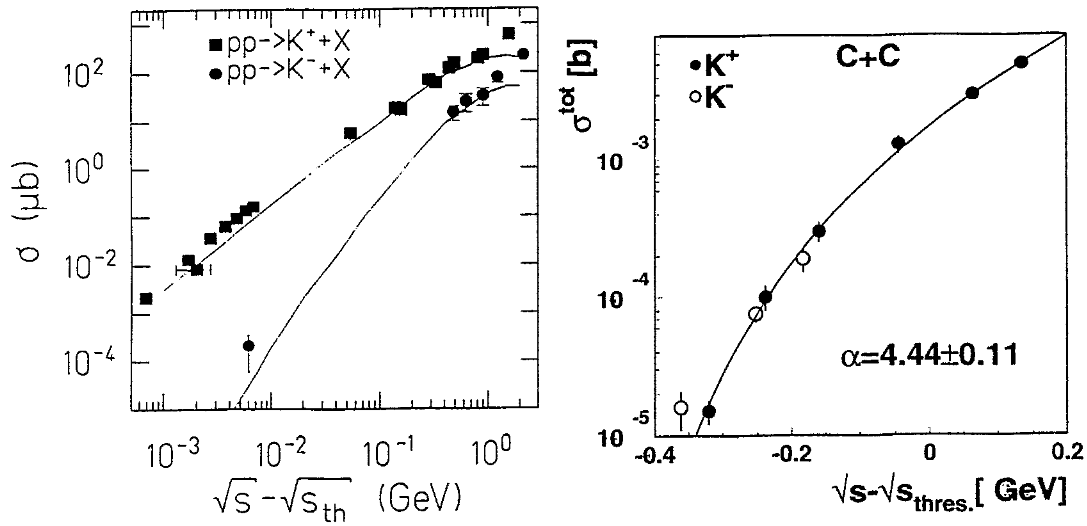
excitation function for K^- is steeper than for K^+
because of the different thresholds





equivalent energies: $\begin{cases} K^+@1.0AGeV: \sqrt{s} - \sqrt{s_{thres.}^{K^+}} \approx -0.23GeV \\ K^-@1.8AGeV: \sqrt{s} - \sqrt{s_{thres.}^{K^-}} \approx -0.23GeV \end{cases}$

$K^{\pm}$ Production as a function of Excess–Energy



$\Longrightarrow$ medium effects are important

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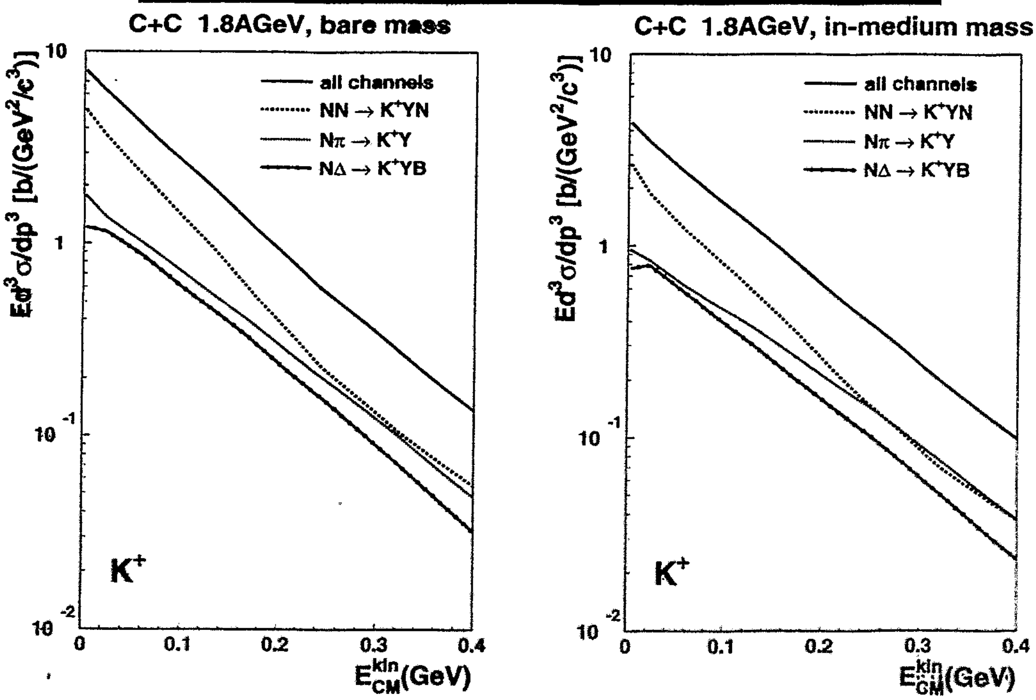
RBUU Calculations (Giessen)



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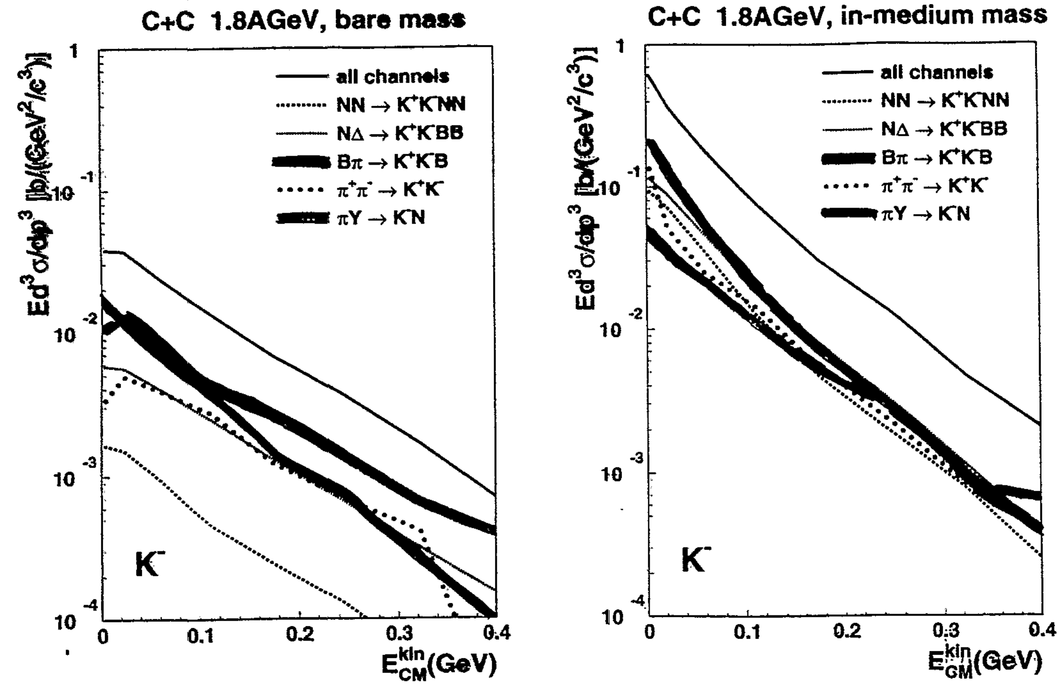
RBUU Calculations (Giessen)



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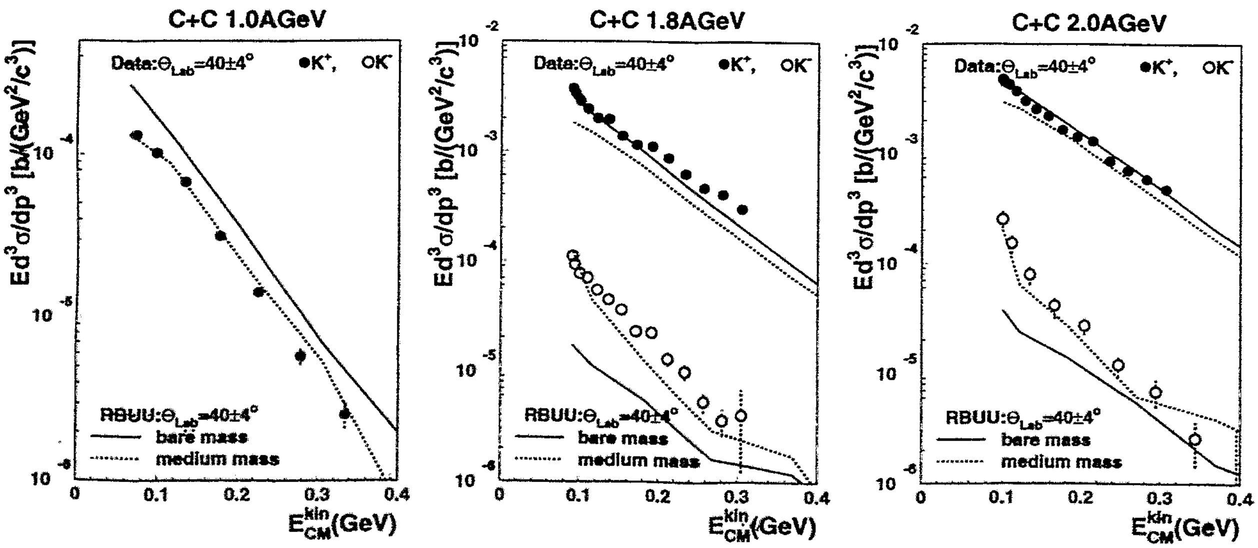
Comparision to RBUU



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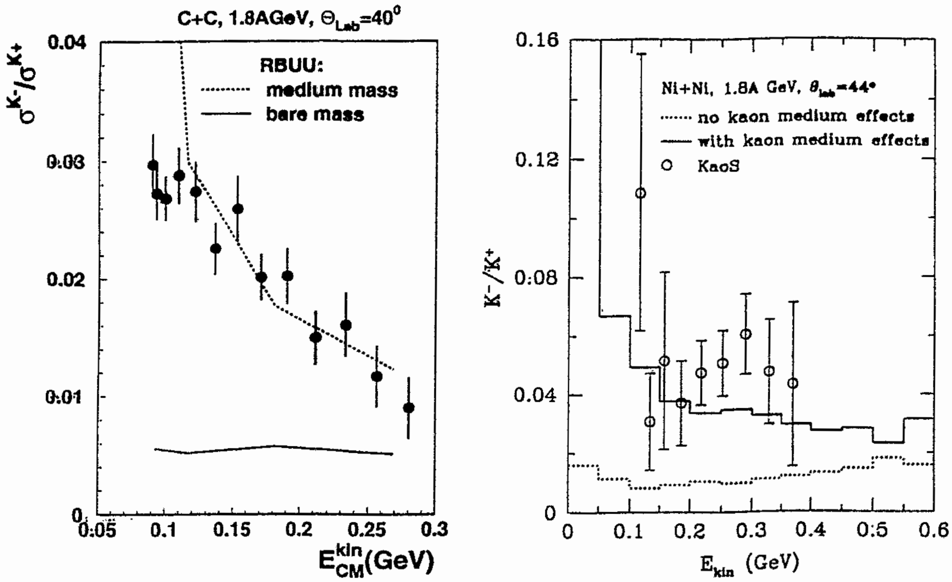
Comparision to RBUU



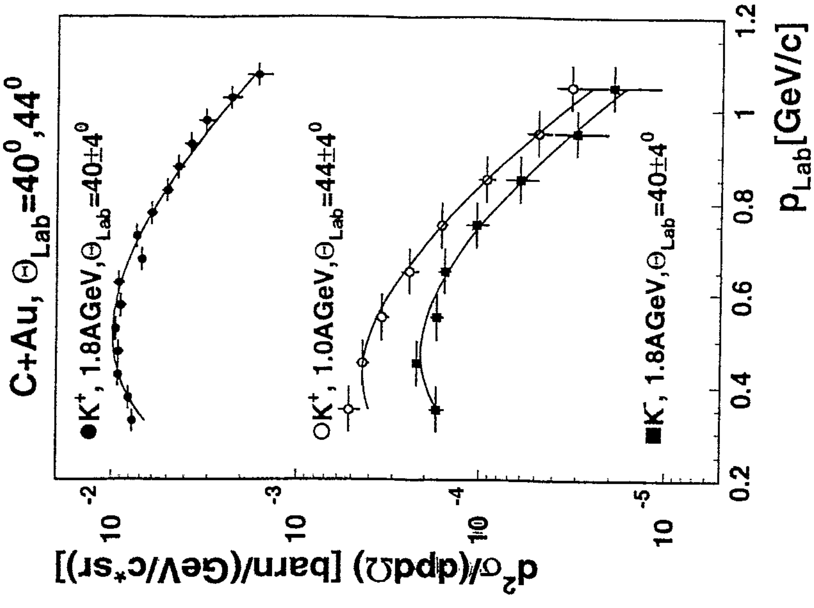
RBUU: C+C [Bra97], Ni+Ni [Li98, Li97]

- measurements at low E_{CM}^{kin}, p_T should be performed

Summary

- The C+C data cover a large fraction of the phasespace for $K^\pm$ (and π).
  The time of flight trigger allows to study kaons and antikaons even far below threshold.
  $K^\pm$ @ $E_{Beam} = 0.8$—$2.0AGeV$
  K^- @ $E_{Beam} = 1.5$—$2.0AGeV$
- $K^\pm$ spectra can be fitted by Maxwell-Boltzmann distribution (with small correction due to a polar angular distributions).
  $\Rightarrow$ C.Sturm (next talk)
- K^+ and K^- production cross-sections (and inverse slope parameters) seem to scale with $\sqrt{s} - \sqrt{s_{th}}$ (total yield, shape).
- Transport models can explain the data only by assuming in-medium potentials or by neglecting K^- absorption.

The C+Au System



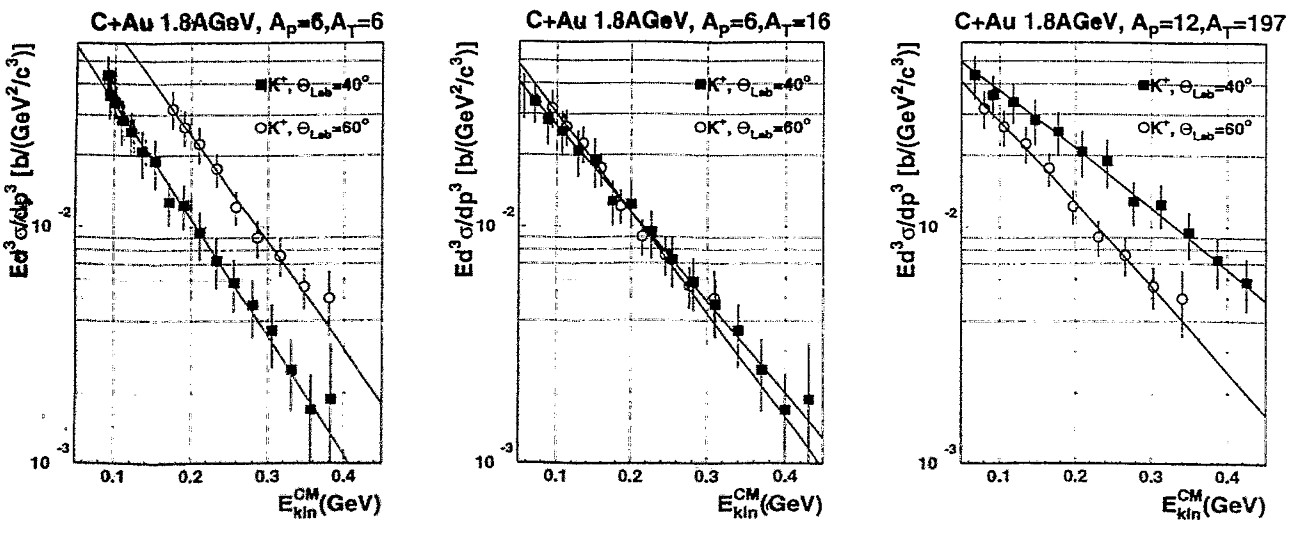
- Why is the C+Au system interessting ?

  You can learn about absorption.
- Why is the C+Au system difficult ?

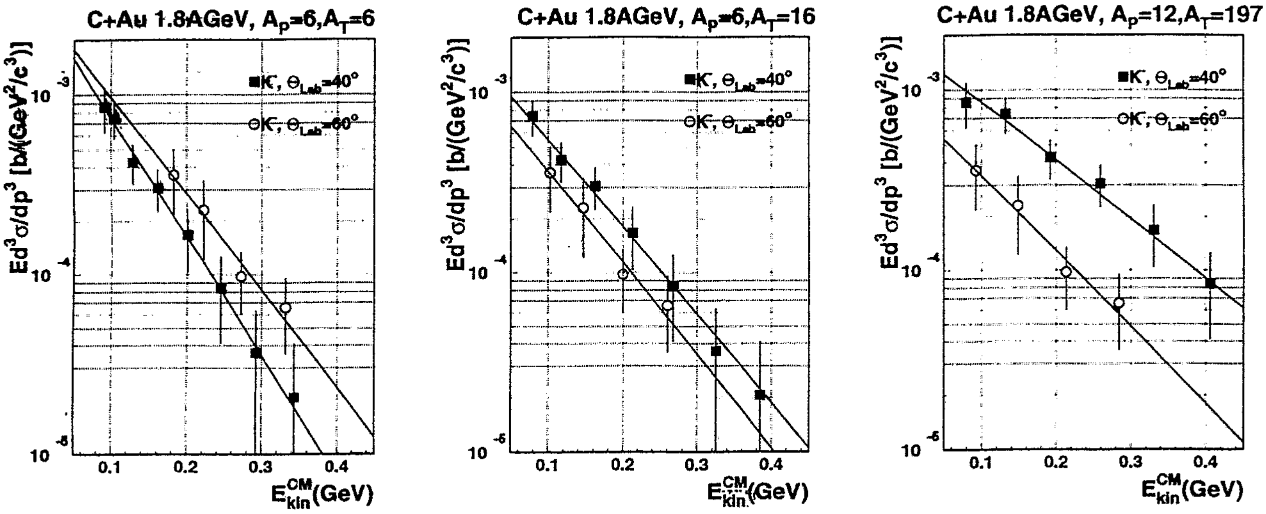
  Where is midrapidity ?

  Different for each individual collision.

The C+Au System



The C+Au System



C. Sturm:

K^+ production in heavy-ion reactions as a probe for the nuclear equation of state

K^+ Production in Heavy Ion Reactions

as a Probe for the Nuclear Equation of State

C.Sturm (TU Darmstadt)

for the

KaoS Collaboration

method:
the comparison of the K^+ production excitation function in a heavy and light collision system

Outline

- Can K^+ serve as a probe for the EOS?
- Experimental results of the collision systems Au+Au and C+C
  - Spectral distributions
  - Polar angle distributions
  - Excitation functions
- Summary

K^+ - a Probe for the High-Density Phase

Production

- direct production

$$NN \rightarrow NK^+Y$$

- two-step production

$$NN \rightarrow N\Delta$$
$$N\Delta \rightarrow NK^+Y$$
$$\pi N \rightarrow K^+Y$$
$$\pi\Delta \rightarrow K^+Y$$

$\Rightarrow$ multi-step processes

Emission

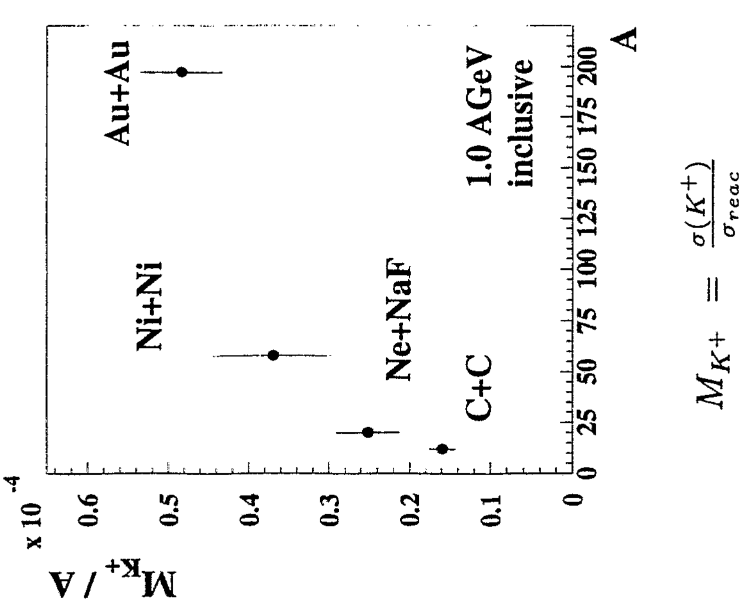
- K^+ mean free path at ρ_0: $\lambda_{K^+} \approx 5\ fm$

- no absorption due to strangeness conservation

$\Rightarrow$ direct information

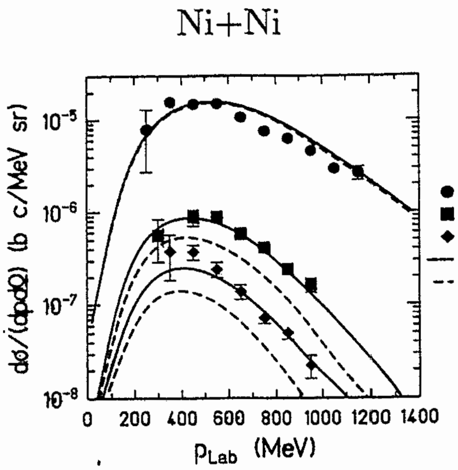
K^+ Production in A+A Collisions

via Collective Effects

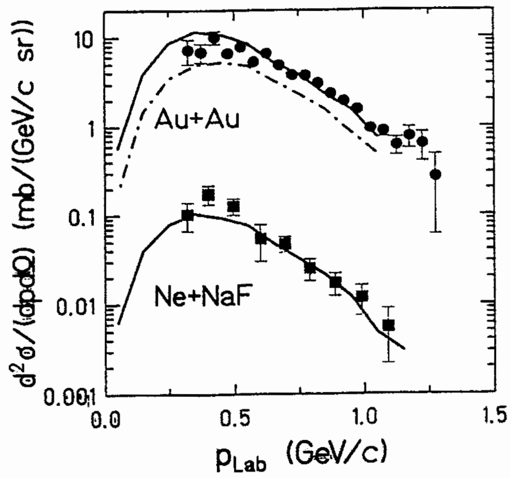


$$M_{K^+} = \frac{\sigma(K^+)}{\sigma_{reac}}$$

Dependence of Incident Energy and System Size



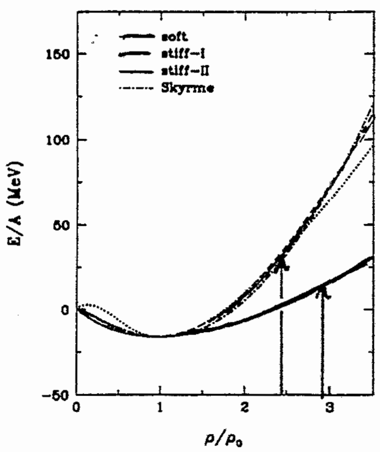
RBUU Li,Ko



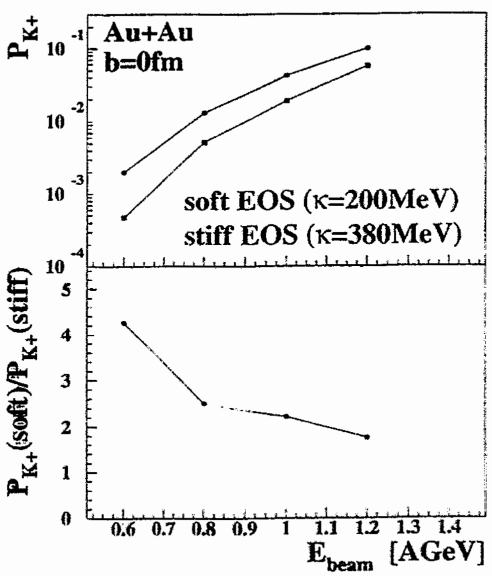
QMD Hartnack

K^+ Production and the EOS

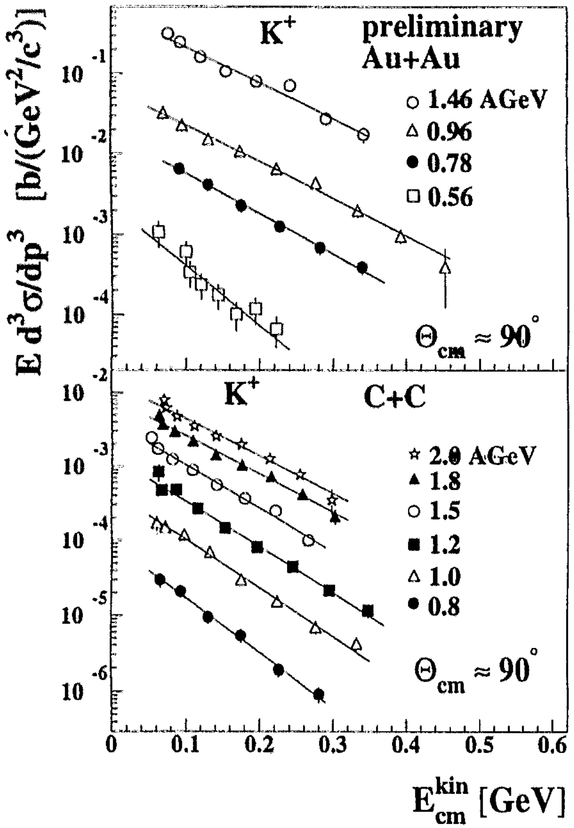
RBUU: G.Q. Li and C.M. Ko, Physics Letters B 349 (1995)



$$(\rho_{max}/\rho_0)_{stiff} \cong 2.4$$
$$(\rho_{max}/\rho_0)_{soft} \cong 2.9$$



K^+ Spectral Distributions



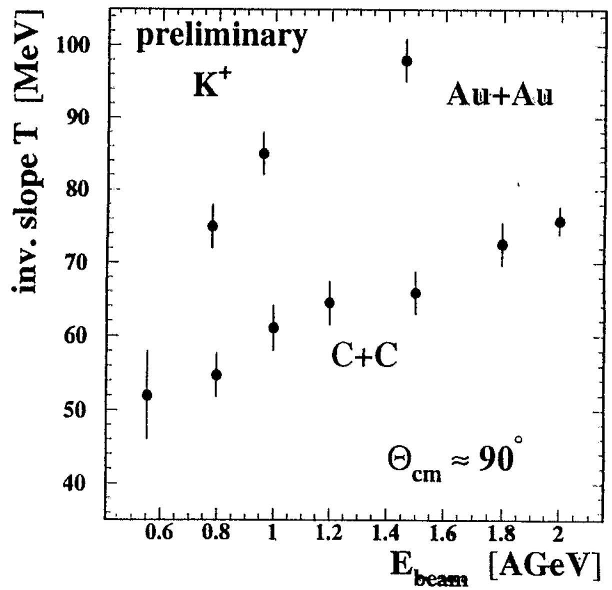
Au+Au, 0.56AGeV:

I.Böttcher, Uni. Marburg

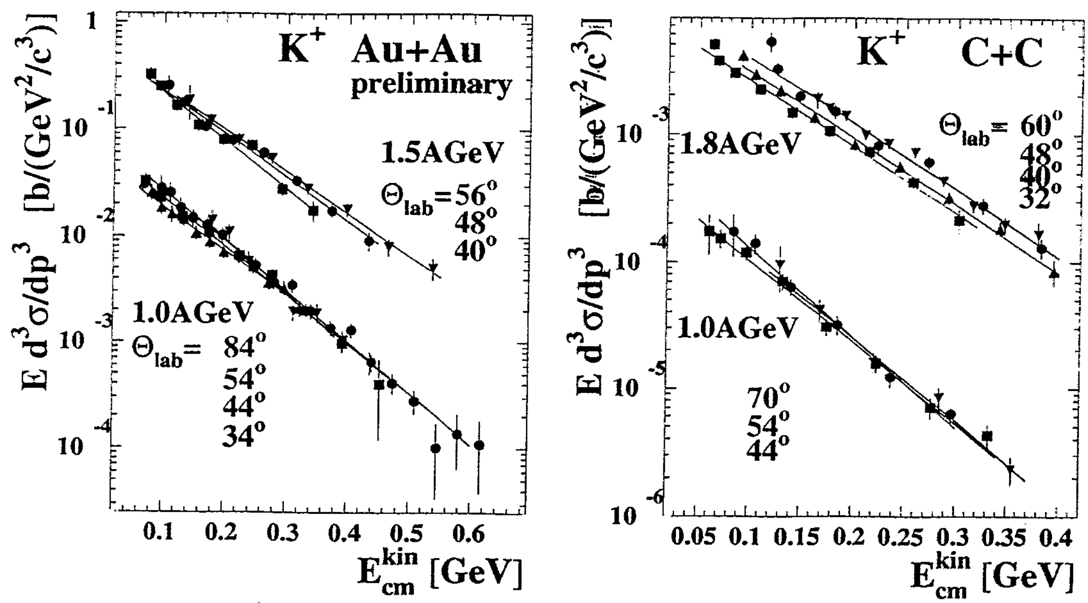
K^+ Slope Parameters

Boltzmann distribution

$$\frac{d^3\sigma}{dp^3} \propto exp\left(\frac{-E}{T}\right)$$



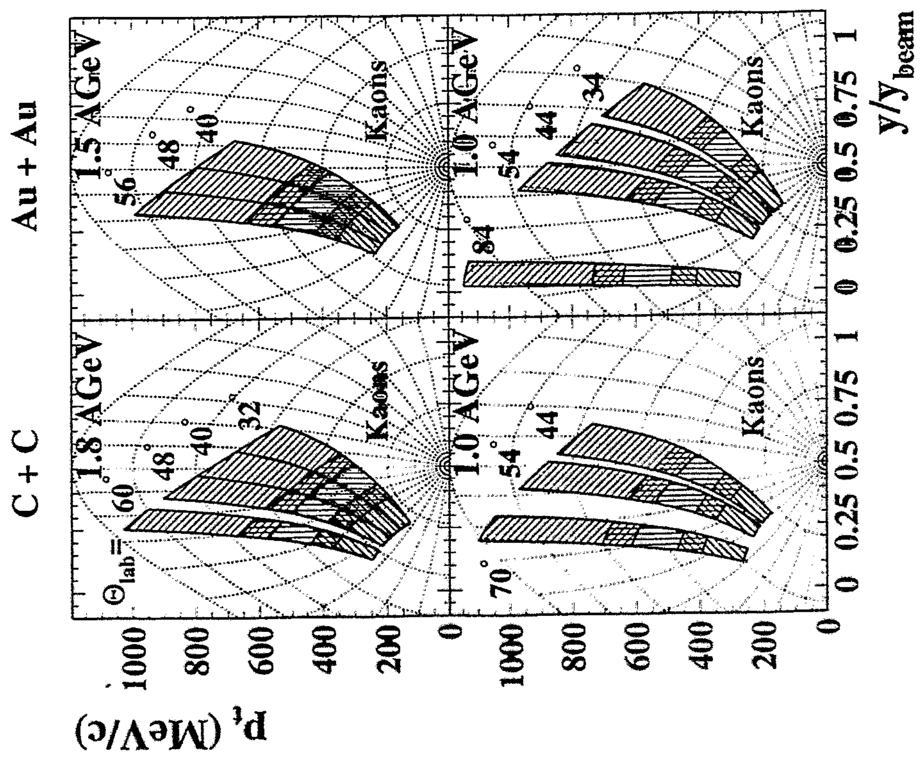
K^+ Spectral Distributions



1.0 AGeV, 84° I.Böttcher

1.8 AGeV, 60° +
1.0 AGeV, 70° F.Laue

Phase Space Coverage

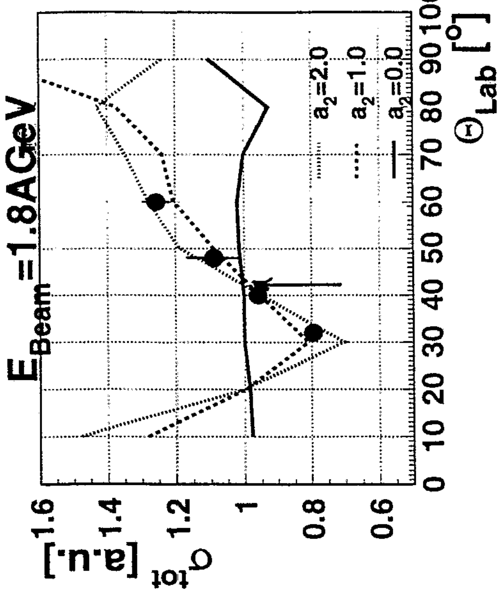


Total Cross Sections

Monte Carlo Simulation:

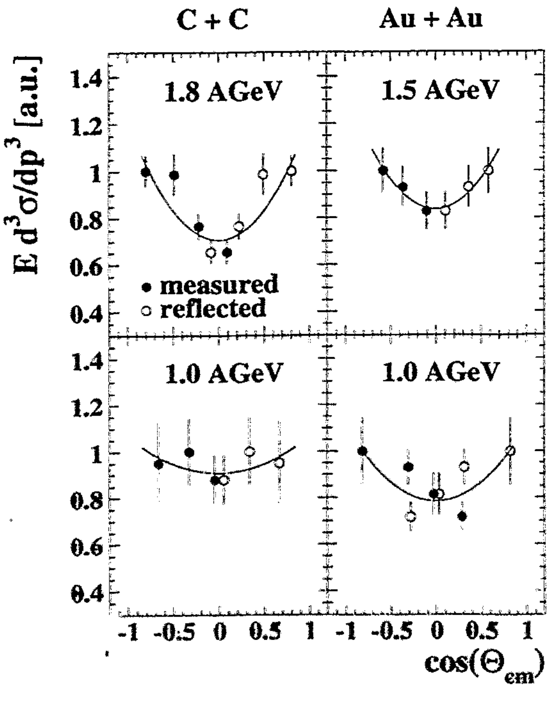
thermal source + anisotropic polar emission

$$\frac{d\sigma}{d\Theta_{cm}} \propto 1 + a_2 \cdot cos^2(\Theta_{cm})$$

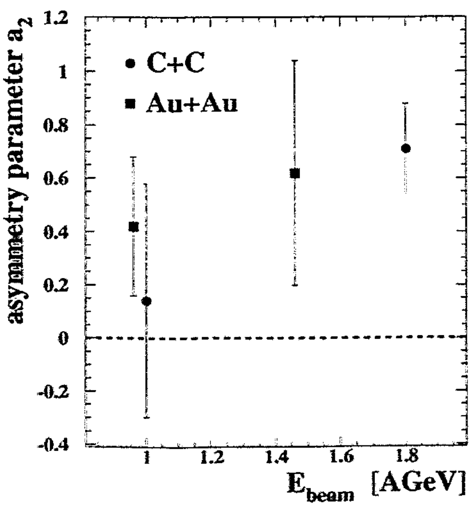


(F.Laue, PHD)

K^+ Polar Angle Distribution



$$E \cdot \frac{d^3\sigma}{dp^3} \propto 1 + a_2 \cdot cos^2(\Theta_{cm})$$



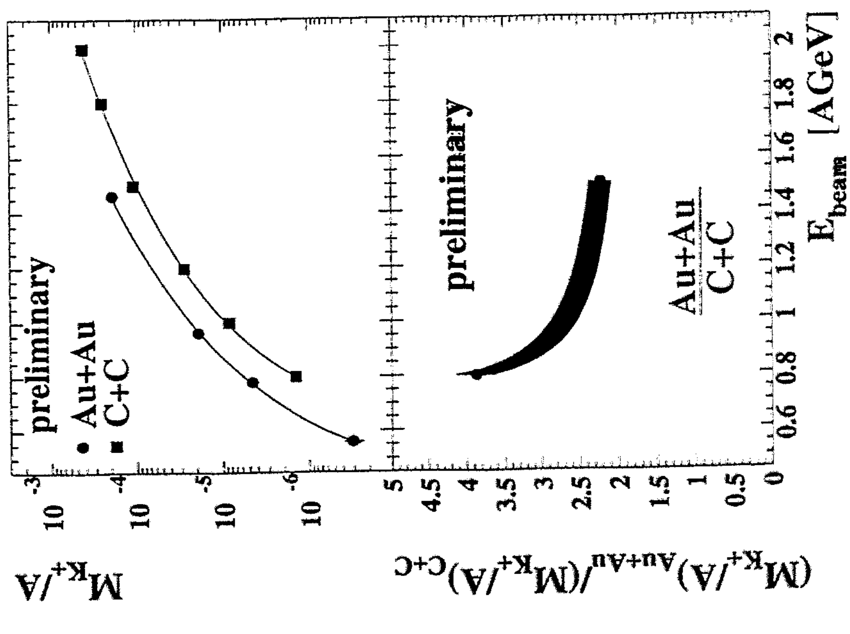
for $a_2 \cong 0.5$:

$$\sigma_{tot} \cong 1.2 \cdot 4\pi \cdot \left(\frac{d\sigma}{d\Omega}\right)_{\Theta_{cm}=90°}$$

Summary

- A new observable sensitive to the EOS: comparison of the K^+-production in a heavy and a light collision system - experimental and theoretical uncertainties are strongly reduced
- Rise of $\frac{K^+(Au+Au)}{K^+(C+C)}$ with decreasing incident energy
  $\Rightarrow$ evidence for a soft EOS
- K^+ production excitation functions
  - in Au+Au (0.56 - 1.46 AGeV) (0.38 mb - 230 mb)
  - in C+C (0.8 - 2.0 AGeV) (0.017 mb - 5.0 mb)
- K^+ polar angle distributions:
  slight forward backward peaked

K^+ Excitation Functions



$\Rightarrow$ evidence for a soft EOS

$\rightarrow$ comparison with transport model calculations

The KaoS Collaboration

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Wanted ...

... detailed transport calculations which describes the available observables:

- K^+-Production
  - K^+ production excitation functions for $C + C$ and $Au + Au$ collisions
  - K^+ polar angle distributions
- π-Production
  - π-production excitation functions
  - spectral distributions
  - angular distributions

K.R. Schubert:

Recent results on symmetry breaking in the K^0 system

K. R. Schubert, TU Dresden
Kaon Workshop Rossendorf, 11/12/98

Recent Results on Symmetry Breaking in the K^0 System.

Introduction.

$\not{CP}$, $\not{T}$, and CPT in $K^0\overline{K^0}$ Oscillations.

Oct. 98: Direct T Violation in CPLEAR.

Oct. 98: Direct T Violation in KTeV.

Conclusion.

Introduction

Neutral K mesons have played important rôles in uncovering the properties of the weak interaction. Six highlights:

1956 P violation because of $K^0 \to \pi^+\pi^-, \pi^+\pi^-$
Dalitz, Lee + Yang ...

1961 $K^0 - \overline{K}^0$ oscillations Pais, Good...

1963 $\sin^2\vartheta_c\,(K^0 \to e^+\pi^-\nu) + \cos^2\vartheta_c\,(^{14}O \to {}^{14}N^* e$
$= 1\ (\mu^+ \to e^+\nu\bar{\nu})$ Cabibbo

1964 $K^0_L \to \pi^+\pi^-$, $\not{CP}$. Cronin, Fitch

1964 $K^0_L \not\to \mu^+\mu^-$, $\not{FCNC}$ Bj, Glashow

1973 $\Delta m(K^0_L - K^0_S) \to m_c \approx 2\,GeV$ Gaillard, L

Summary on $\not{CP}$-, $\not{T}$- and CPT-Properties in K^0 Decays and Oscillations. 1964-71

Oscillations $K^0 \leftrightarrow 2\pi, 3\pi, u\bar{u}, c\bar{c} \leftrightarrow \overline{K^0}$ lead to two eigenstates of time evolutions like in coupled pendulae of classical mechanics.

$$K_S = (1+\varepsilon+\delta)\,K^0 + (1-\varepsilon-\delta)\,\overline{K^0}$$

$$K_L = (1+\varepsilon-\delta)\,K^0 - (1-\varepsilon+\delta)\,\overline{K^0}$$

CP symmetry $\curvearrowright$ $\varepsilon = \delta = 0$, $K_L \not\to \pi^+\pi^-$.

1964 seen. $\eta_{+-} = \dfrac{K_L \to \pi^+\pi^-}{K_S \to \pi^+\pi^-} = \varepsilon - \delta \neq 0$.

Origin in $K^0\overline{K^0}$ Oscillations, Δm & $\Delta\Gamma$.

Four possible contributions to $\eta = \frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00}$

1.) CPT conserved, $\not{T}$ in Δm, $\mathrm{Re}\,\varepsilon + \mathrm{Im}\,\varepsilon$

2.) —"— $\not{T}$ in $\Delta\Gamma$, $\mathrm{Re}\,\varepsilon - \mathrm{Im}\,\varepsilon$

3.) T conserved, $\not{CPT}$ in Δm, $\mathrm{Re}\,\delta - \mathrm{Im}\,\delta$

4.) —"— $\not{CPT}$ in $\Delta\Gamma$, $\mathrm{Re}\,\delta + \mathrm{Im}\,\delta$

Experimental Separation in 1970/71

K.R. Schubert et al, PL 31B (1970) 662
+ Proc. Int. Conf. HEP Amsterdam (1971) 333

using Bell-Steinberger Unitarity Relation:

$$i \cdot \Delta m (K_L - K_S) \cdot \langle K_S | K_L \rangle = \sum_f \langle f|T|K_S\rangle^* \langle f|T|K_L\rangle$$

$\mathrm{Re}\,\varepsilon + \mathrm{Im}\,\varepsilon = (2{,}7 \pm 0{,}3)\,10^{-3}$ ⟸

$\mathrm{Re}\,\varepsilon - \mathrm{Im}\,\varepsilon = (0{,}1 \pm 0{,}4)\,10^{-3}$ /

$\mathrm{Re}\,\delta - \mathrm{Im}\,\delta = (0{,}0 \pm 0{,}5)\,10^{-3}$ /

$\mathrm{Re}\,\delta + \mathrm{Im}\,\delta = (-0{,}2 \pm 0{,}2)\,10^{-3}$ /

CPT is conserved and T is violated in "virtual" (Δm) part of $K^0\overline{K^0}$ oscillations.

Max. $\not{CPT}$ contribution $= \frac{1}{3}\,\not{T}$ contribution.

Uses unitarity, i.e. all decaying K mesons decay into observable final states.

Well known result. Remember:

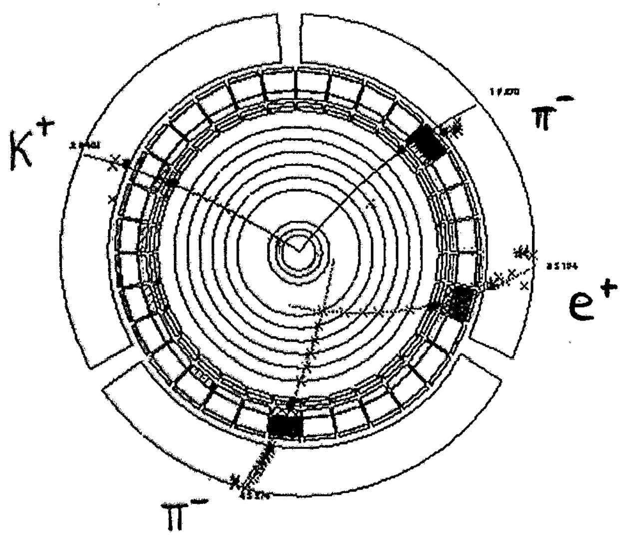
$\Gamma(\overline{K^0} \to K^0) > \Gamma(K^0 \to \overline{K^0})$ $\not{CP}$, $\not{T}$.

$K_L = p\,K^0 + q\,\overline{K^0}$ with $|p| > |q|$.

More "direct" observations of T violation in the K^0 system came only this October (apart from conference contributions from CPLEAR a few years ago).

Direct T Violation in CPLEAR

LEAR @ CERN : 200 MeV/c $\bar{p}$ into H_2 gas

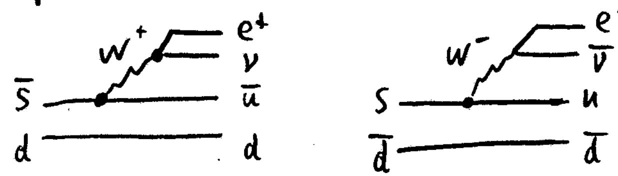


$$\bar{p}p \rightarrow \begin{cases} K^{*0}\,\overline{K^0} \rightarrow \pi^+ e^- \bar{\nu},\ \pi^- e^+ \nu. & (K^{*0} \to K^+\pi^-) \\ \overline{K^{*0}}\,K^0 \rightarrow \pi^- e^+ \nu,\ \pi^+ e^- \bar{\nu}. & (\overline{K^{*0}} \to K^-\pi^+) \end{cases}$$

$1.3 \cdot 10^6$ tagged $\pi e \nu$ decays with $t > 1\tau_S$

Four classes of events $K^0, \overline{K^0} \rightarrow \pi^+ e^- \bar{\nu}, \pi^- e^+ \nu$.

Time dependence confirms "$\Delta S = \Delta Q$" with high precision:



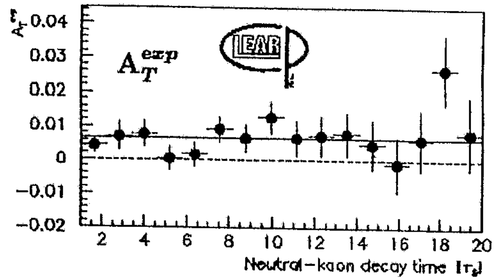
Lepton charge tags K flavour at t_{decay}.

Kaon charge $(K^\pm \pi^\mp)$ tags –"– at $t_{production}$.

CP- and T- violating result:

Direct measurement of T violation

$$A_T = \frac{R(\overline{K^0} \rightarrow K^0) - R(K^0 \rightarrow \overline{K^0})}{R(\overline{K^0} \rightarrow K^0) + R(K^0 \rightarrow \overline{K^0})} = 4\,\mathrm{Re}\,\varepsilon$$



→ $\mathrm{Re}\,\varepsilon = (1.65 \pm 0.32 \pm 0.25) \cdot 10^{-3}$

Not new, but new way.

$A_T = (6.6 \pm 1.3_{stat.} \pm 1.0_{syst.}) \cdot 10^{-3}$

This result, called "direct" by CPLEAR assumes CPT in the decay and tests CPT in oscillations. Result: All ~~CP~~ is ~~T~~.

In a second paper

A. Angelopoulos et al, CERN-EP/98-154, 12/10/98

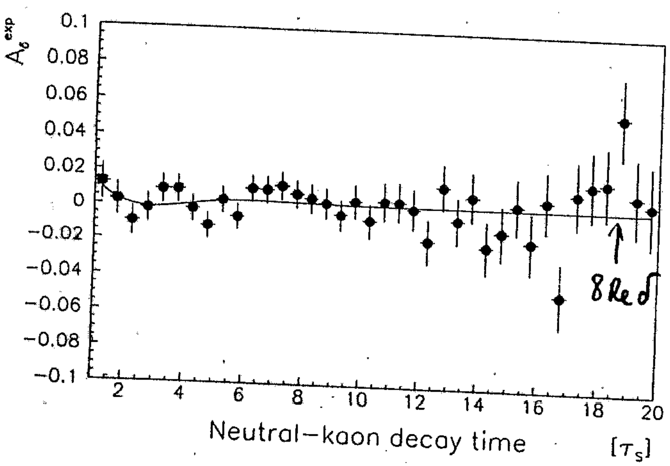
CPLEAR gives up CPT assumption in semileptonic decays. "Nicer" result:

$\mathrm{Re}\,\delta = (0{,}30 \pm 0{,}33 \pm 0{,}06) \cdot 10^{-3}$. CPT ✓

using all four observed rates.

$\mathrm{Im}\,\delta = (-15 \pm 23) \cdot 10^{-3}$. CPT ✓

$= (-0.9 \pm 2{,}9) \cdot 10^{-3}$ if $\Delta S = \Delta Q$ strict.



Direct T Violation in KTeV

Experiment E832 at FNAL, J. Adams et al,

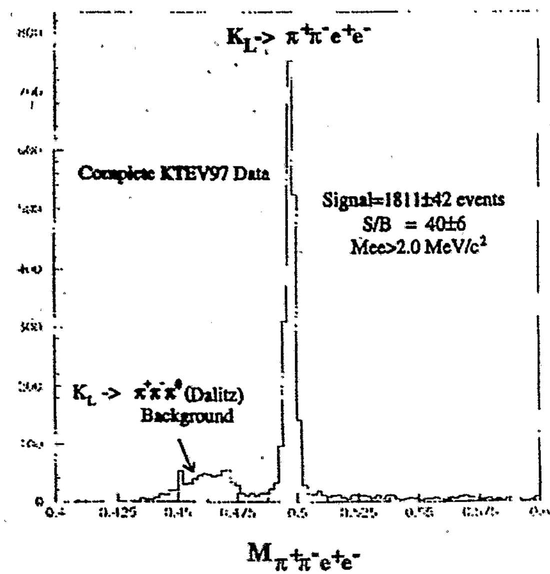
Main goal: $\mathrm{Re}(\varepsilon'/\varepsilon) \pm 3 \cdot 10^{-4}$.

1997 data: $2.5 \cdot 10^{11}\ K_L^0$

Search for $K_L^0 \to \pi^+\pi^- e^+ e^-$.

$1.3 \cdot 10^8$ triggers with 4 tracks.

1800 events reconstructed, $S/B \approx 40$.

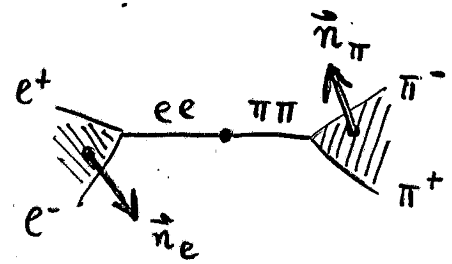


First obser-vation!

$\mathcal{B} = (3{,}2 \pm 0{,}4 \pm 0{,}6) \cdot 10^{-7}$

Phys. Rev. Lett. 80 (1998) 4123

$K_L^0 \to \pi^+\pi^-\gamma$ has CP-conserving and CP-violating part. Interference leads to γ polarisation. Leads to angular asymmetry in $\pi^+\pi^-e^+e^-$.



$$\phi = \sphericalangle(\vec{n}_e, \vec{n}_\pi)$$

$$\sin\phi = \frac{[\vec{p}(e^+)\times\vec{p}(e^-)]\times[\vec{p}(\pi^+)\times\vec{p}(\pi^-)]\cdot[\vec{p}(\pi^+)+\vec{p}(\pi^-)]}{|\vec{p}(e^+)\times\vec{p}(e^-)|\cdot|\vec{p}(\pi^+)\times\vec{p}(\pi^-)|\cdot|\vec{p}(\pi^+)+\vec{p}(\pi^-)|}$$

The triple product S is odd under P ($\vec{p}\to-\vec{p}$), even under C ($Q\to-Q$), odd under T ($\vec{p}\to-\vec{p}$).

An asymmetric distribution around zero of S, or $\sin\phi$, or $\sin\phi\cos\phi$, or ϕ is P-violating, CP-violating, T-violating.

L.M. Seghal et al, PRD 46 (1992) 1035 + 5209 predict large effect on the basis of known ε.

From
M. Arenton (U. Virginia, KTeV)
Heavy Quarks 98

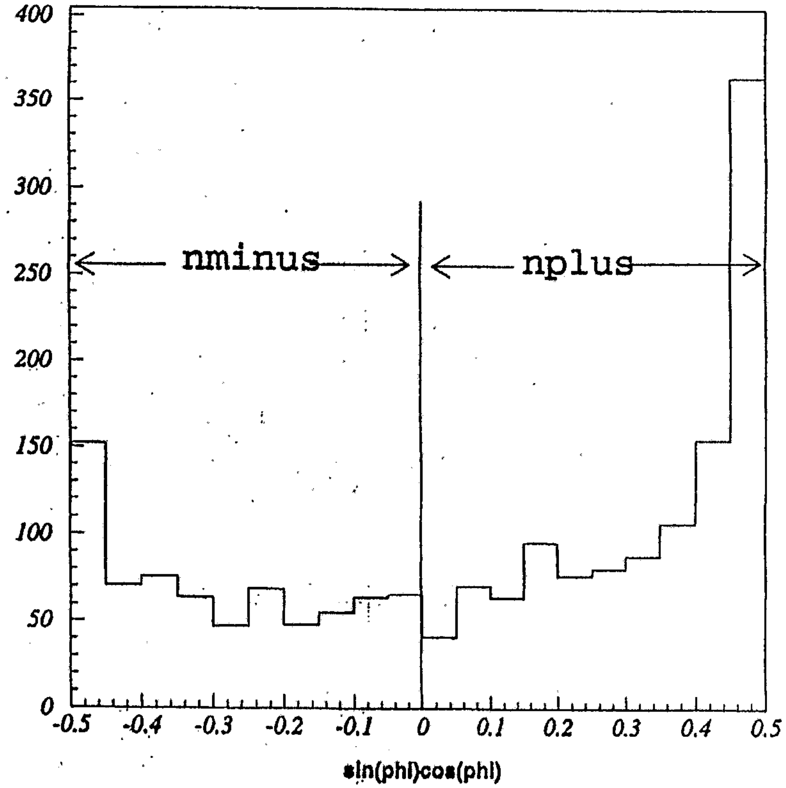


Figure 14: $\sin\phi\cos\phi$ distribution for the total data sample, where nplus and nminus are also shown

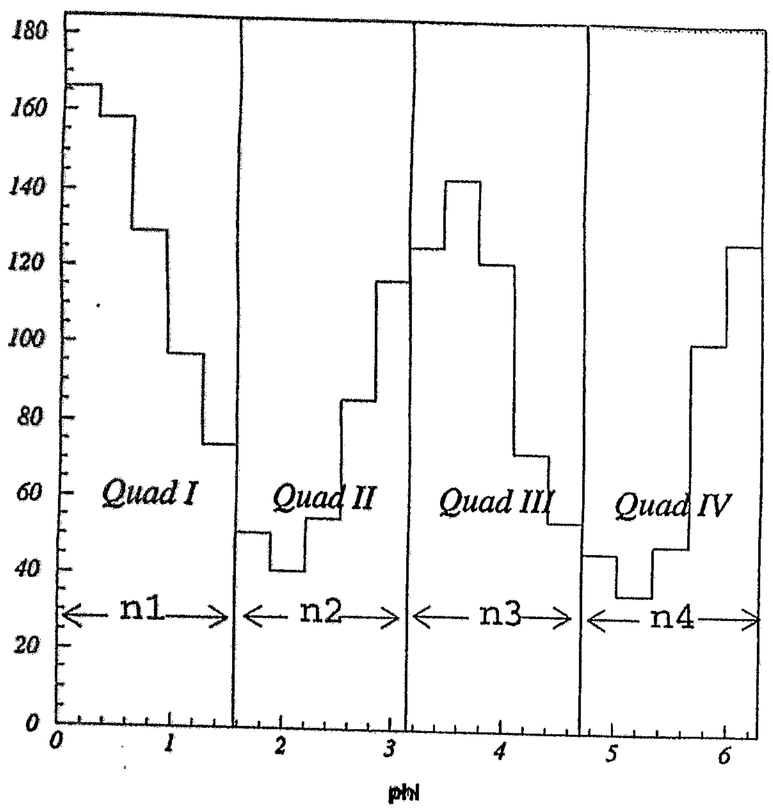


Figure 15: sinφcosφ distribution for the total data sample, where the Quadrants, n1, n2, n3 and n4 are also shown

$$A = \frac{n_1 + n_3 - n_2 - n_4}{n_1 + n_2 + n_3 + n_4} = (13.5 \pm 2.5 \pm 3.0)\%$$

in perfect agreement with the 1992 prediction of Seghal and the known value of ε.

Conclusion

Both new results demonstrate T violation and are, therefore, 'ripe' for text books.

But they do not contribute to progress in understanding and predicting CP violating effects. All effects so far depend on one parmeter ε only ($\delta = 0$, $\varepsilon' = ?$).

In the Standard Model $\varepsilon_K = \varepsilon(m_t, \theta_{12}, \theta_{23}, \theta_{13}, \delta \ldots)$ Knowledge on θ_{13} and δ from other rare K decays like $K^{\pm} \to \pi^+ \nu\bar{\nu}$ and from B decays.

B decays have also the potential to look for non-standard contributions to $\not{CP}$. Cosmology needs them, Standard $\not{CP}$ is far too weak to explain antimatter disappearance in the Universe.

Eeach new $\not{CP}$ contribution **must** also be tested for $\not{T}$ and $\not{CPT}$.

Theoretical Part

W. Cassing & E. Bratkovskaya:

The RBUU (HSD) approach to strangeness production

The RBUU (HSD) approach – strangeness production

W. Cassing, E.L. Bratkovskaya

Contens

1. Introduction

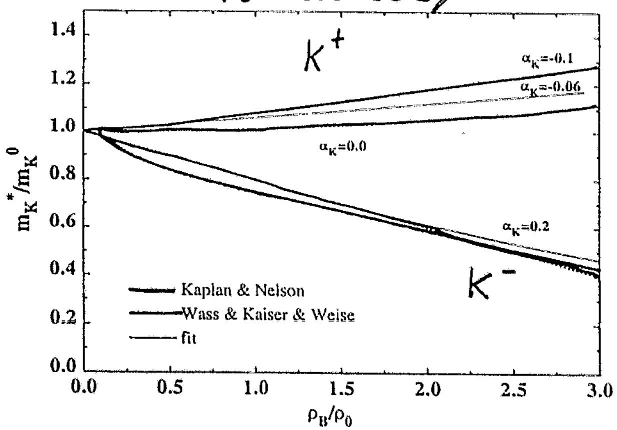
2. The HSD approach

3. $s\bar{s}$-production and observables

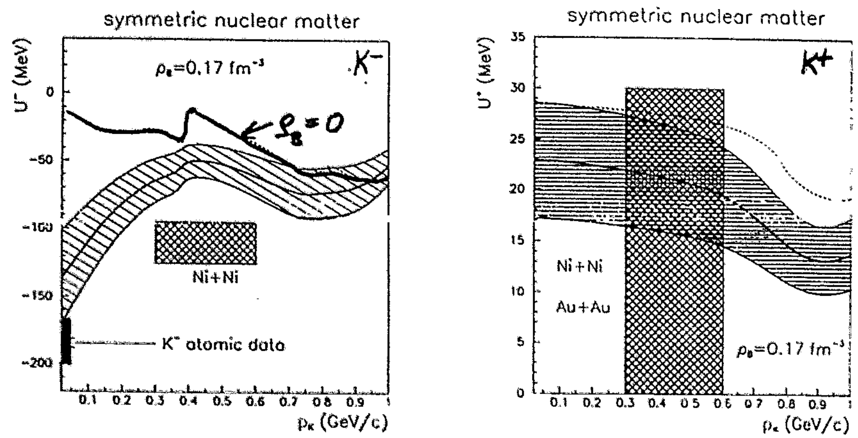
4. Benchmark tests for Ni + Ni at 1.8 A·GeV

$K^{\pm}$ – potentials

vs. density



vs. momentum



HSD[1] - a covariant transport approach

W. Ehehalt and W. Cassing, Nucl. Phys. A602 (1996) 449

The covariant transport equations for the phase-space distributions $f_h(x,p)$ of hadron h read:

$$\left\{\left(\Pi_\mu - \Pi_\nu \partial_\mu^p U_h^\nu - M_h^* \partial_\mu^p U_h^S\right)\partial_x^\mu + \left(\Pi_\nu \partial_\mu^x U_h^\nu + M_h^* \partial_\mu^x U_h^S\right)\partial_p^\mu\right\} f_h(x,p)$$
$$= \sum_{h_2 h_3 h_4 \ldots} \int d2d3d4 \ldots [G^\dagger G]_{12\to 34\ldots}\,\delta^4(\Pi + \Pi_2 - \Pi_3 - \Pi_4 \ldots)$$
$$\times \{ f_{h_3}(x,p_3) f_{h_4}(x,p_4) \bar{f}_h(x,p) \bar{f}_{h_2}(x,p_2)$$
$$- f_h(x,p) f_{h_2}(x,p_2) \bar{f}_{h_3}(x,p_3) \bar{f}_{h_4}(x,p_4) \} \ldots \quad .$$

with the quasi-particle dispersion relation

$$\delta(\Pi_\mu \Pi^\mu - M_h^{*2}) \quad , \qquad (1)$$

with effective masses and momenta given by

$$M_h^*(x,p) = M_h + U_h^S(x,p)$$
$$\Pi^\mu(x,p) = p^\mu - U_h^\mu(x,p) \quad ,$$

and scalar and vector selfenergies $U_h^S(x,p)$, $U_h^\mu(x,p)$ for 'all' hadrons. The phase-space factors

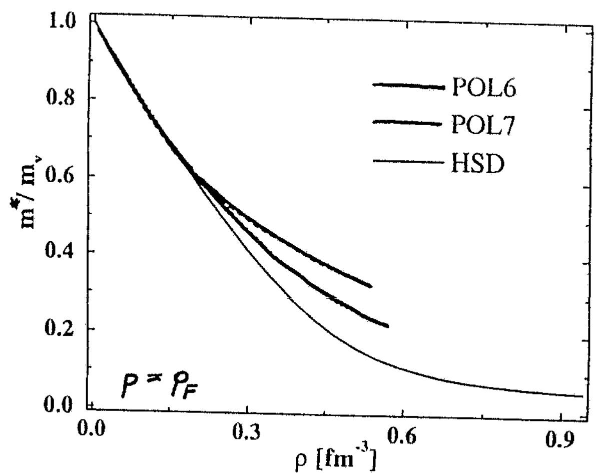
$$\bar{f}_h(x,p) = 1 \pm f_h(x,p) \qquad (2)$$

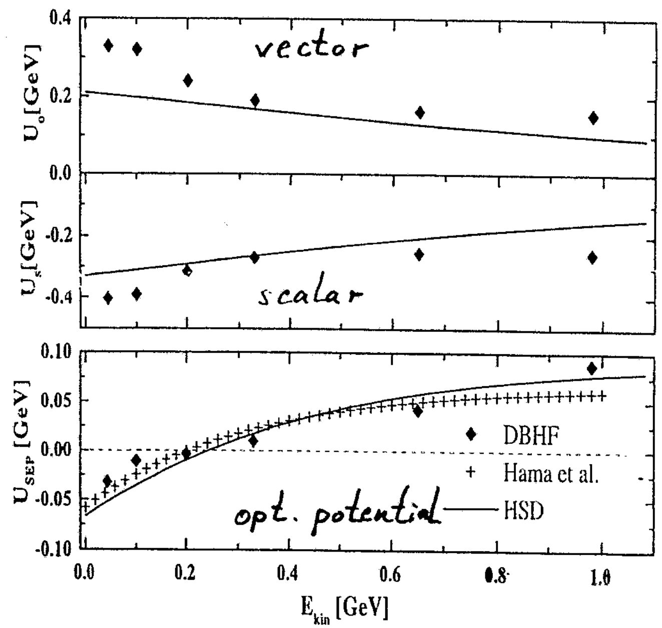
are responsible for fermion Pauli-blocking or Bose enhancement, respectively.

[1] Hadron String Dynamics

W. Ehehalt, W.C., NPA 602 (1996) 449

$m^* = m_v + U_s(\rho_s, p)$





W. C., E. L. Bratkovskaya, Phys. Rep. 308 (1999) 65

quasi-particles in the medium

$$(\omega - U_0(x,p))^2 = (\underbrace{\vec{p} - \vec{U}(x,p)}_{\vec{\Pi}(x,p)})^2 + (m_0 + U_s(x,p))^2$$

or

$$\omega^2 = \vec{p}^{\,2} + m_0^2 + \Pi(x,p,\varrho_B,\varrho_s) \quad \text{(mesons)}$$

equations of motion:

$$\dot{x} = \frac{\partial \omega}{\partial p_x} \qquad \dot{p}_x = -\frac{\partial \omega}{\partial x}$$

$$\dot{y} = \frac{\partial \omega}{\partial p_y} \qquad \dot{p}_y = -\frac{\partial \omega}{\partial y} \qquad \text{Hamilton Eq.}$$

$$\dot{z} = \frac{\partial \omega}{\partial p_z} \qquad \dot{p}_z = -\frac{\partial \omega}{\partial z}$$

treatment of collisions:

impact parameter $b \leq \sqrt{\frac{\sigma_R(\sqrt{s})}{\pi}}$

formation time $\tau_f \approx 0.5$ fm/c

+ energy-momentum conservation

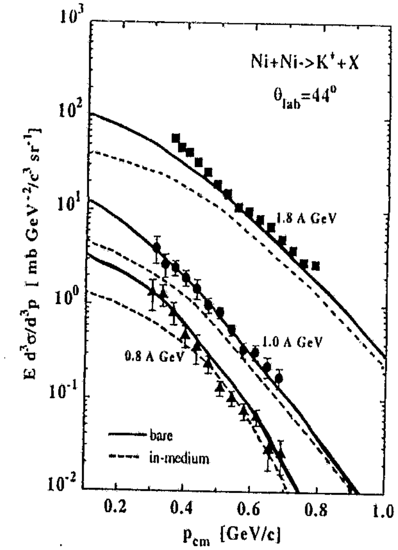
$$\omega_1(x,p_1) + \omega_2(x,p_2) = \omega_3(x,p_3) + \omega_4(x,p_4) + \omega_5(x,\ldots$$

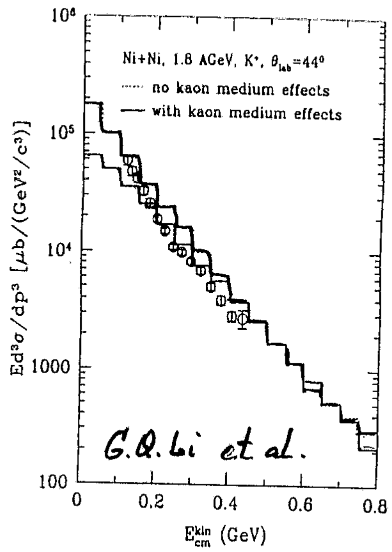
$$\vec{\Pi}_1(x,p_1) + \vec{\Pi}_2(x,p_2) = \vec{\Pi}_3(x,p_3) + \vec{\Pi}_4(x,p_4) + \vec{p}_5$$

'historical' treatment of mesons:

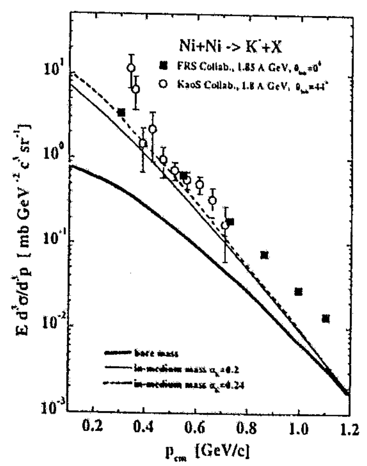
$$\Pi(x,p) = m^{*2}(x,p) - m_0^2, \quad m^* = m_0(1 - \alpha_m \varrho_B(x)/\varrho_0)$$

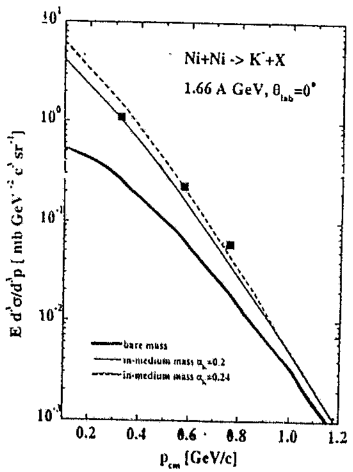
with coefficient α_m





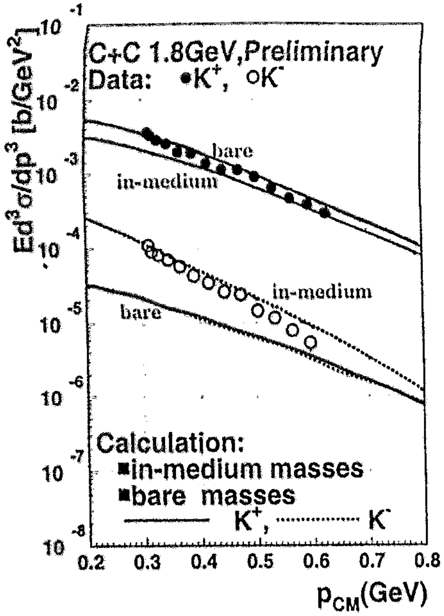
G.Q. Li et al.

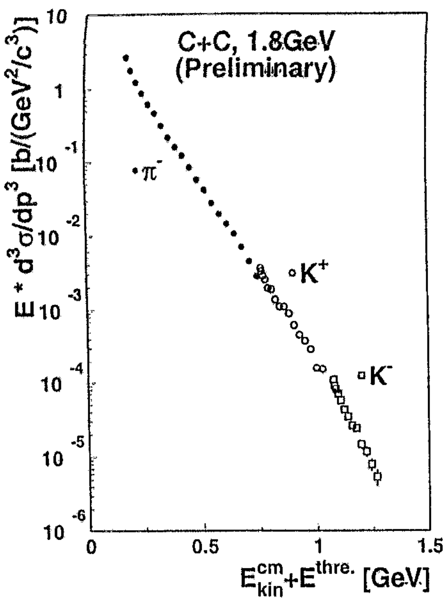


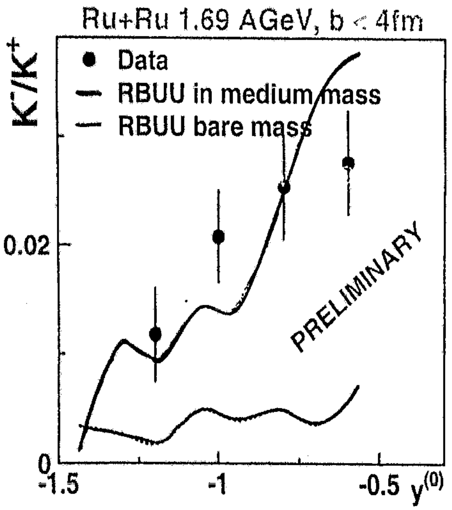


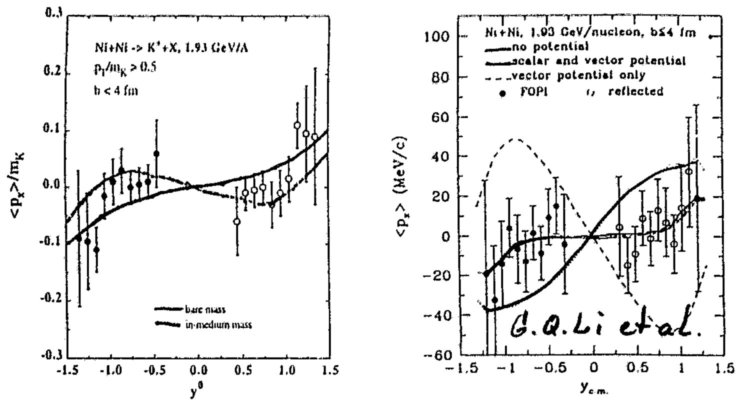
W. C., E.L. Bratkovskaya; Phys. Rep. 308 (1999) 65

W. C., E.L. Bratkovskaya; Phys. Rep. 308 (1999) 65

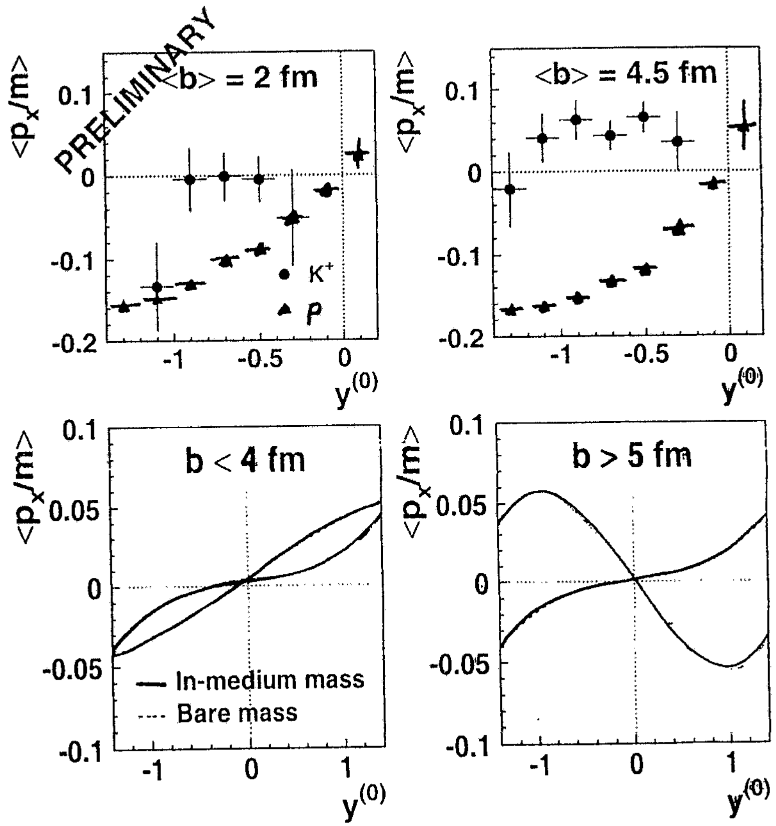




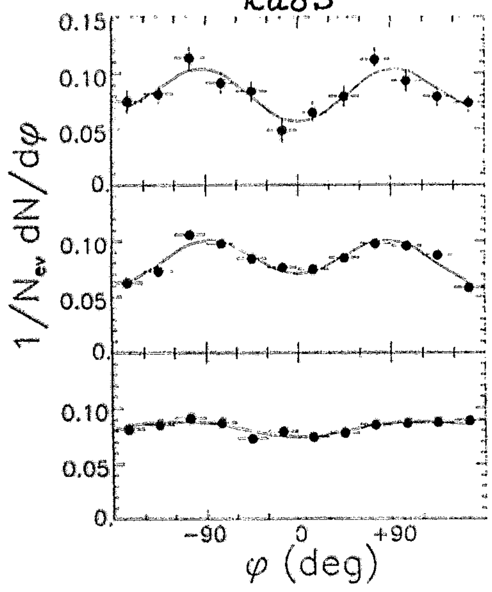




in - plane K+-flow



K^+ azimuthal angular distribution for



peripheral

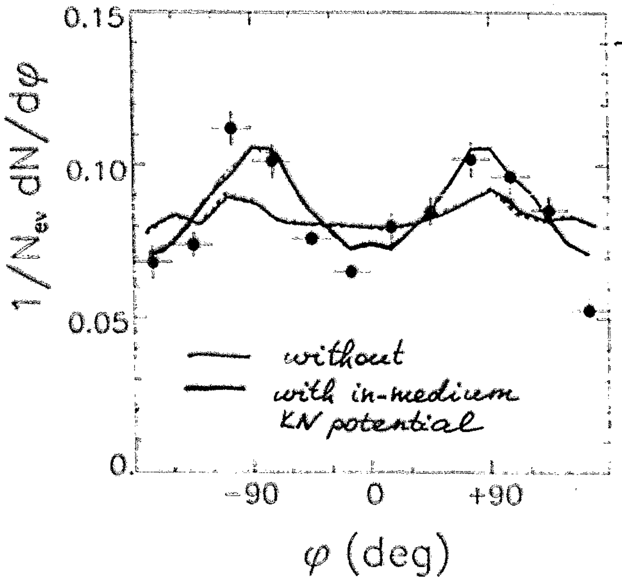
semi-central

central collisions

$0.2 \le \frac{y}{y_{proj}} \le 0.8$

$0.2 \le p_t \le 0.8$ GeV/c

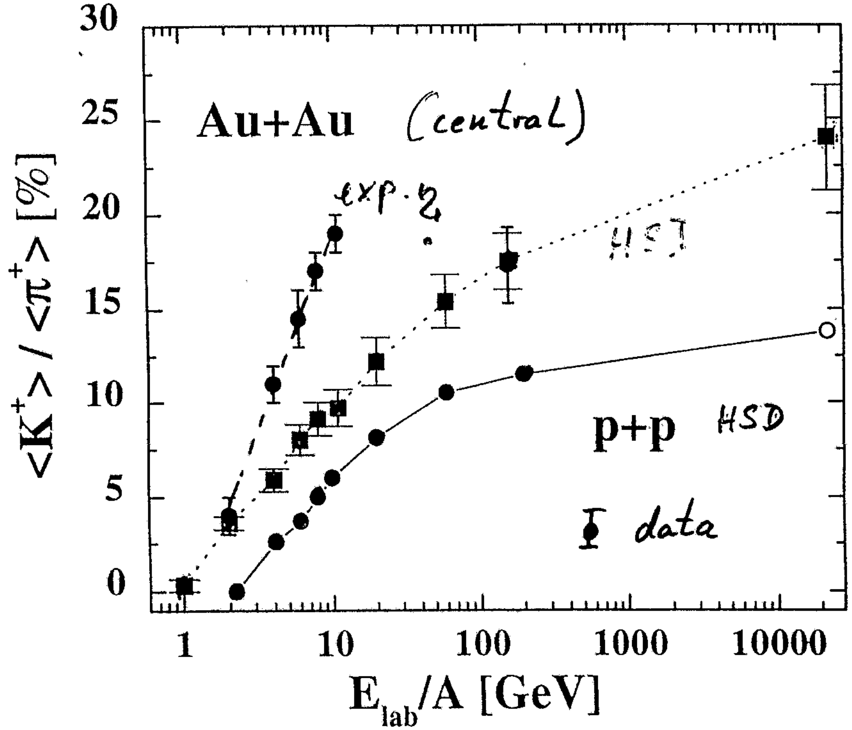
Au + Au, 1 A·GeV



semi-central Au+Au, 1 A·G

RBUU calcul.:
G.Q. Li, C.M. Ko, and G.E. Brown
Phys. Lett. B 381 (1996) 17.

$\frac{K^+}{\pi^+}$ at midrapidity



→ chiral symmetry restoration?
parton degrees of freedom?

Benchmark tests

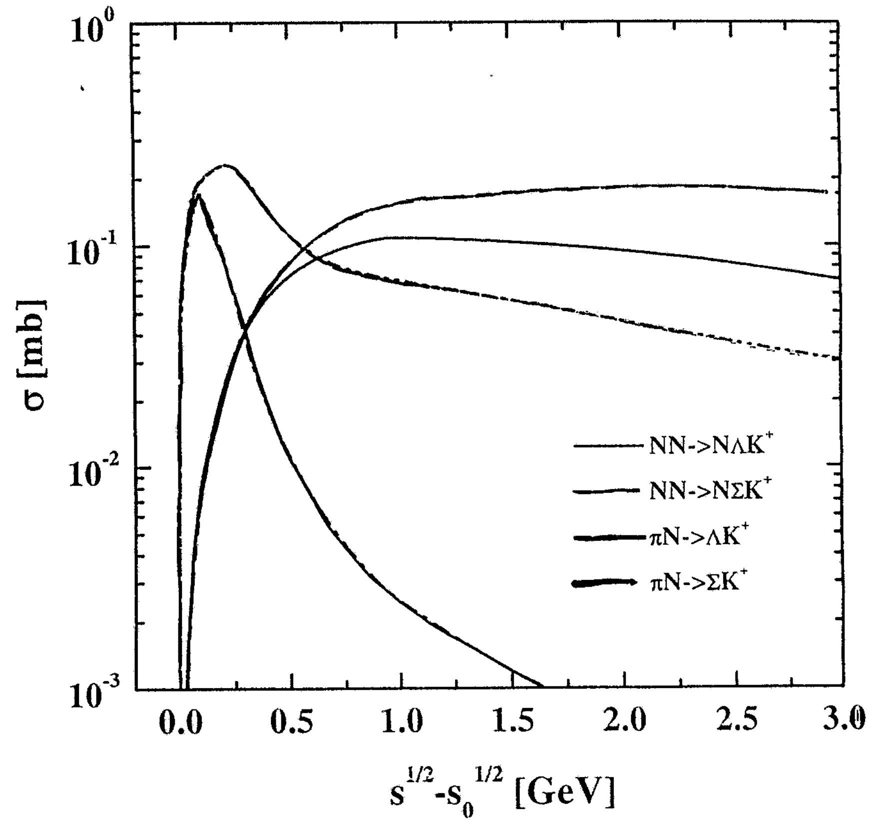
Ni+Ni at 1.8 A·GeV, b=2 fm

Included processes for K^+ and K^- productions:

1. a) $NN \to N\Lambda K^+$
2. b) $NN \to N\Sigma K^+$
3. c) $N\Delta \to N\Lambda K^+$
4. d) $N\Delta \to N\Sigma K^+$
5. e) $\Delta\Delta \to N\Lambda K^+$
6. f) $\Delta\Delta \to N\Sigma K^+$
7. g) $\pi N \to \Lambda K^+$
8. h) $\pi N \to \Sigma K^+$
9. i) $\pi\Delta \to \Lambda K^+$
10. k) $\pi\Delta \to \Sigma K^+$

11. l) $NN \to NNK^+K^-$
12. m) $N\Delta \to NNK^+K^-$
13. n) $\Delta\Delta \to NNK^+K^-$
14. o) $\pi N \to NK^+K^-$
15. p) $\pi\Delta \to NK^+K^-$
16. q) $\pi\Lambda \to NK^-$
17. r) $\pi\Sigma \to NK^-$
18. s) $N\Lambda \to NNK^-$
19. t) $N\Sigma \to NNK^-$
20. u) $\pi\pi \to K^+K^-$

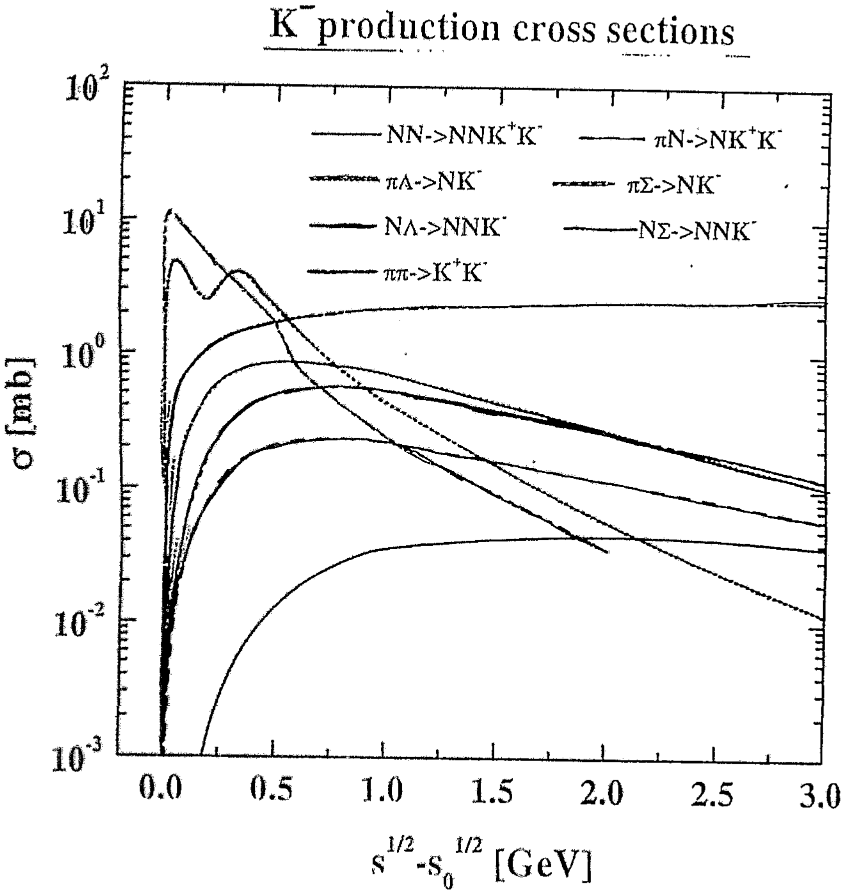
K^+ production cross sections



$\sigma(N\Delta) = \frac{3}{4}\,\sigma(NN)$

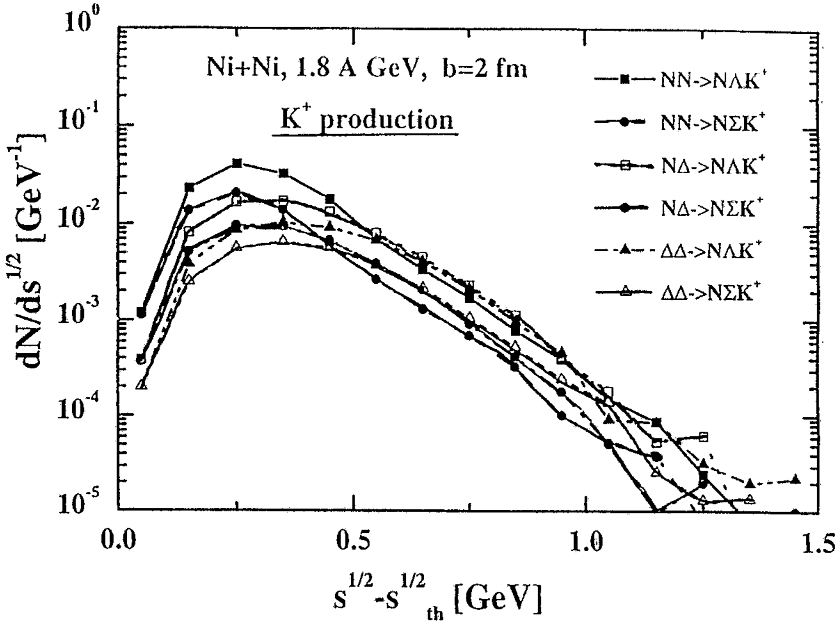
$\sigma(\Delta\Delta) = \frac{1}{2}\,\sigma(NN)$

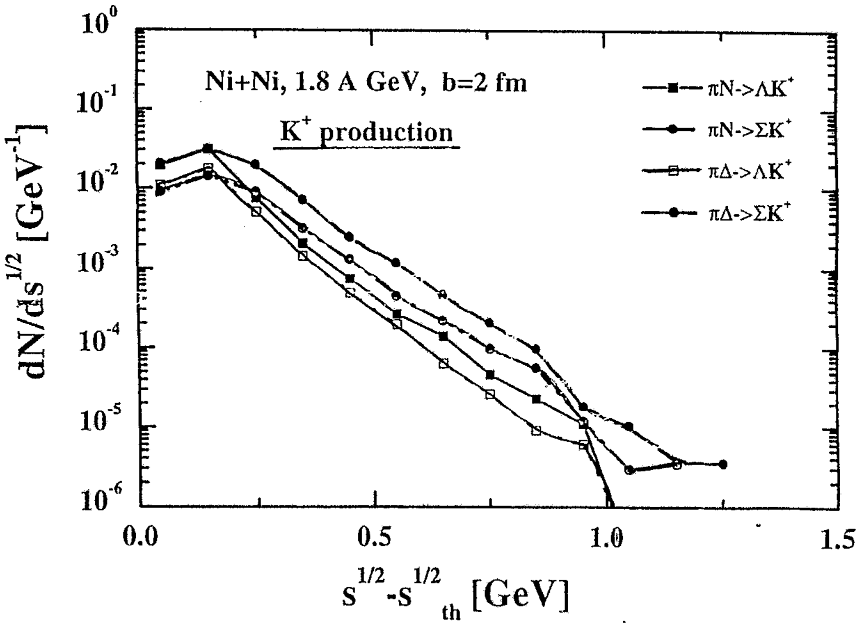
$\sigma(\pi\Delta) = \sigma(\pi N)$

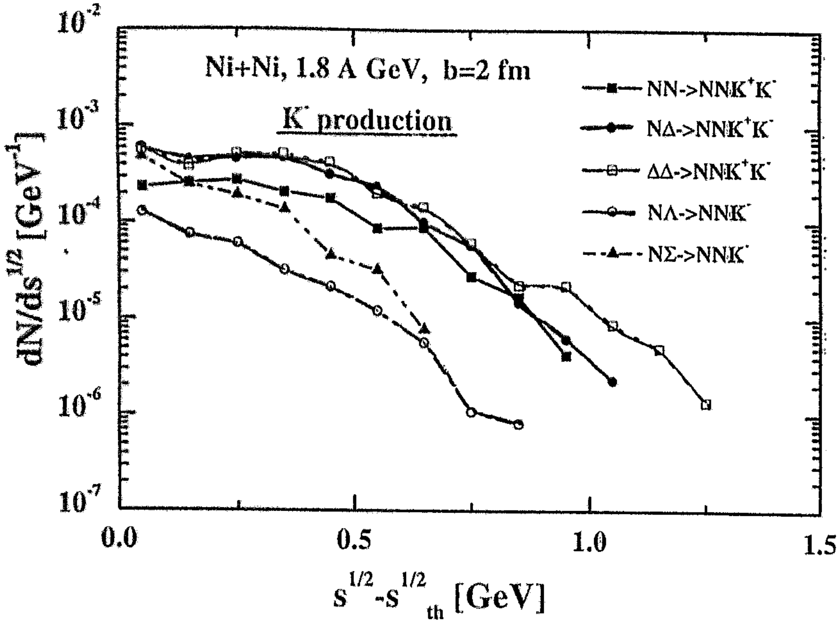


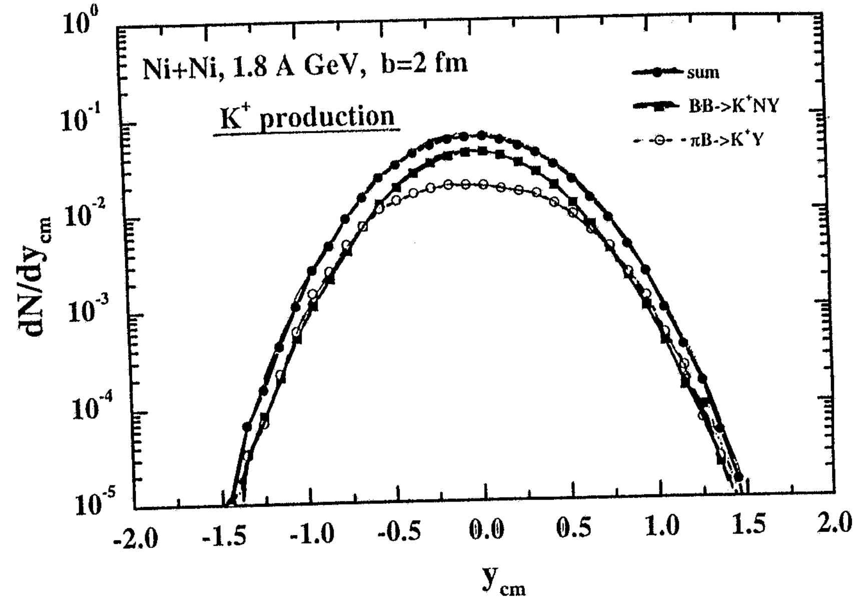
$\sigma(N\Delta) = \sigma(\Delta\Delta) = \sigma(NN)$

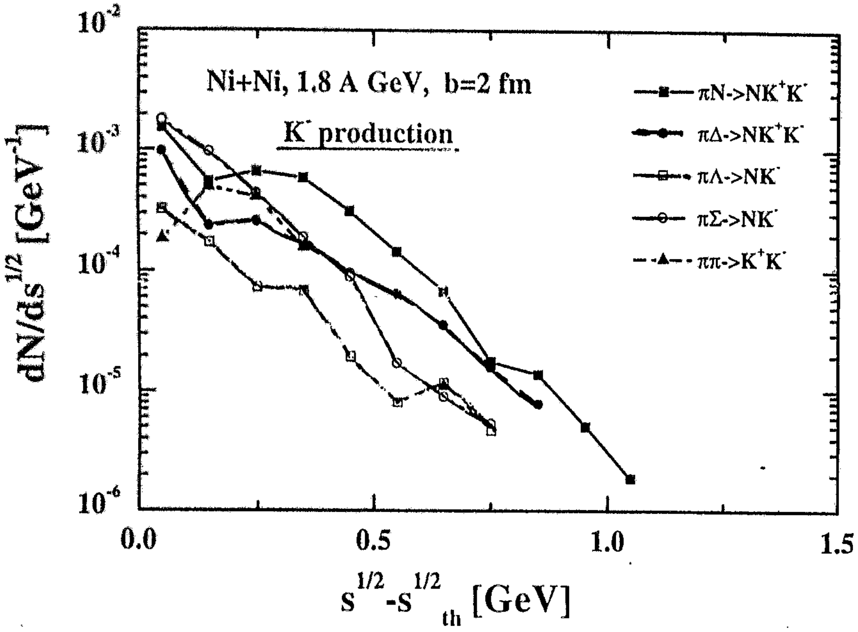
$\sigma(\pi\Delta) = \sigma(\pi N)$

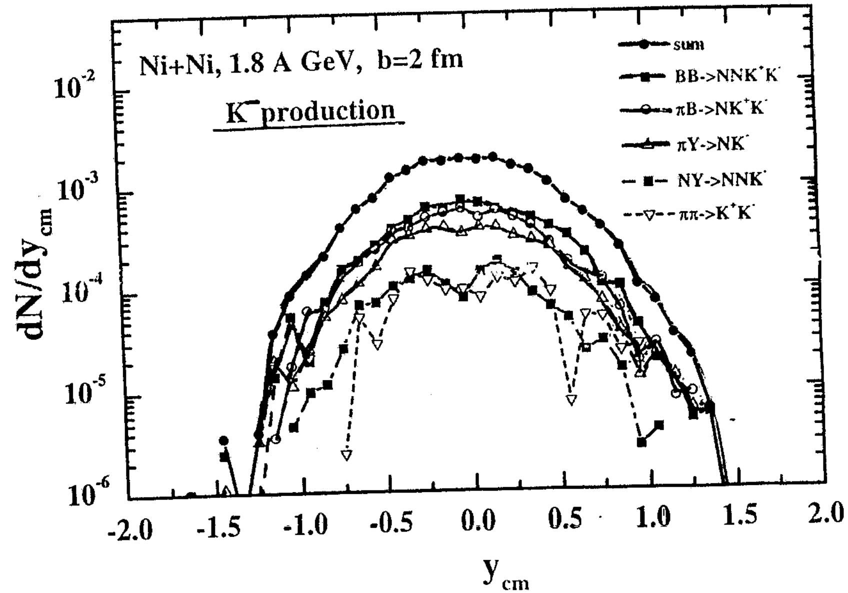


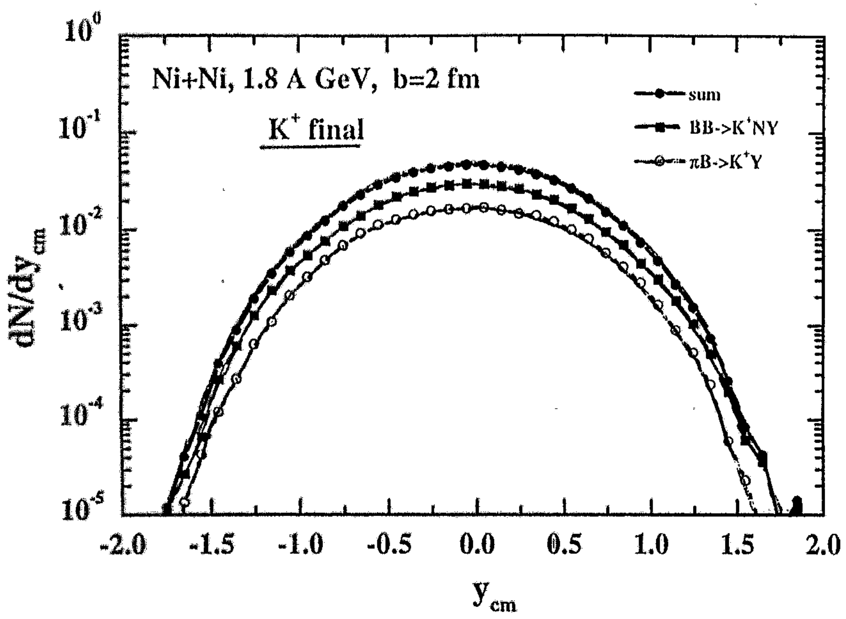


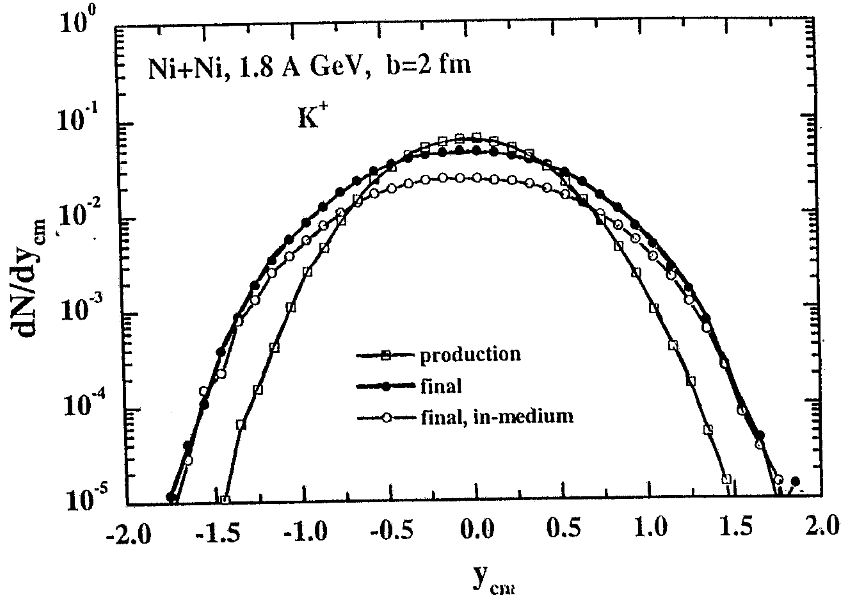

Ni+Ni, 1.8 A GeV, b=2 fm
K⁻ production
NN->NNK⁺K⁻
NΔ->NNK⁺K⁻
ΔΔ->NNK⁺K⁻
NΛ->NNK⁻
NΣ->NNK⁻
dN/ds^1/2 [GeV⁻¹]
s^1/2-s^1/2_th [GeV]

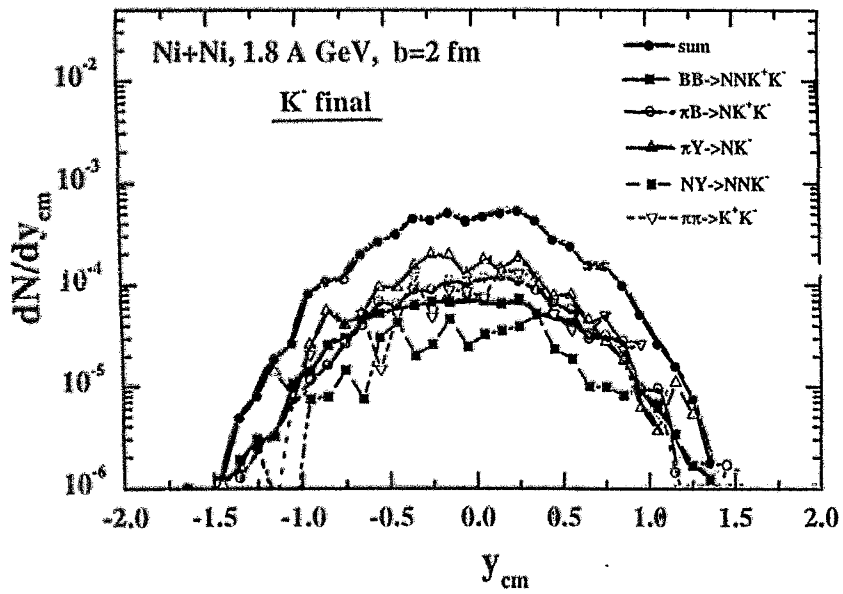

Ni+Ni, 1.8 A GeV, b=2 fm
K⁺ production
sum
BB->K⁺NY
πB->K⁺Y
dN/dy_cm
y_cm

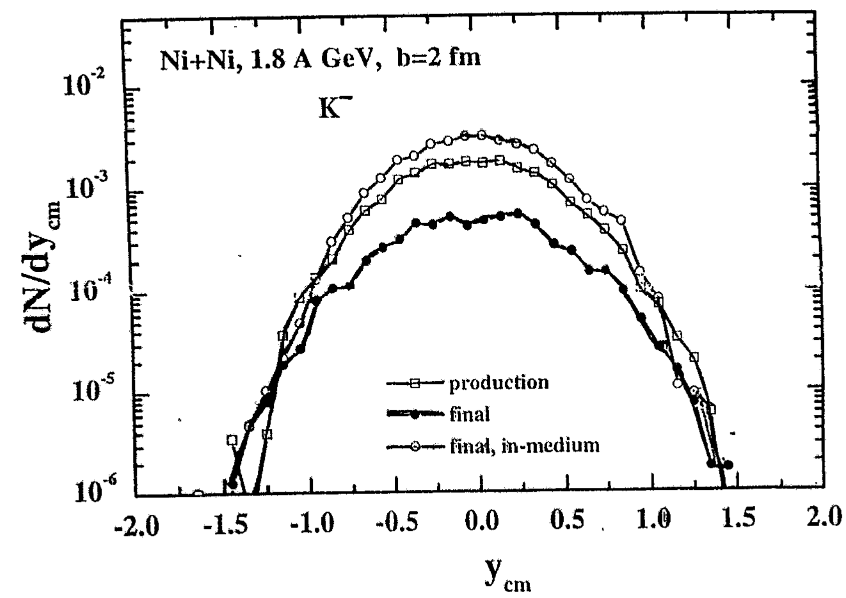

Ni+Ni, 1.8 A GeV, b=2 fm
K⁻ production
πN->NK⁺K⁻
πΔ->NK⁺K⁻
πΛ->NK⁻
πΣ->NK⁻
ππ->K⁺K⁻
dN/ds^1/2 [GeV⁻¹]
s^1/2-s^1/2_th [GeV]

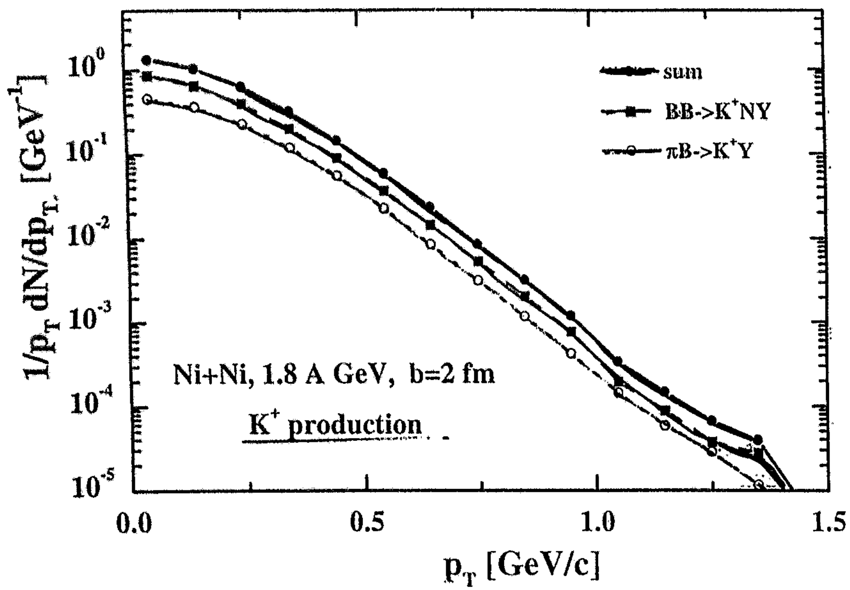

Ni+Ni, 1.8 A GeV, b=2 fm
K⁻ production
sum
BB->NNK⁺K⁻
πB->NK⁺K⁻
πY->NK⁻
NY->NNK⁻
ππ->K⁺K⁻
dN/dy_cm
y_cm


Ni+Ni, 1.8 A GeV, b=2 fm
K+ final
sum
BB->K+NY
πB->K+Y
dN/dy_cm
y_cm

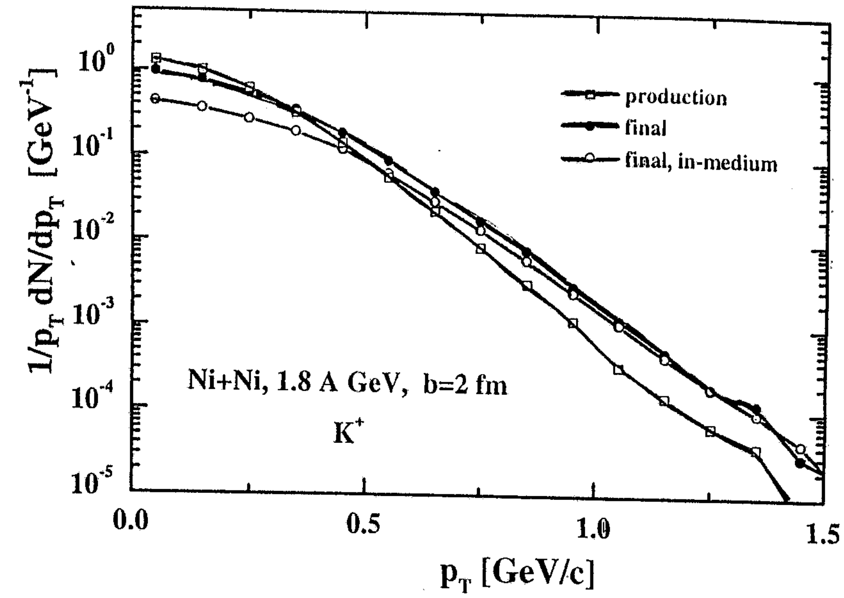

Ni+Ni, 1.8 A GeV, b=2 fm
K+
production
final
final, in-medium
dN/dy_cm
y_cm


Ni+Ni, 1.8 A GeV, b=2 fm
K- final
sum
BB->NNK+K-
πB->NK+K-
πY->NK-
NY->NNK-
ππ->K+K-
dN/dy_cm
y_cm

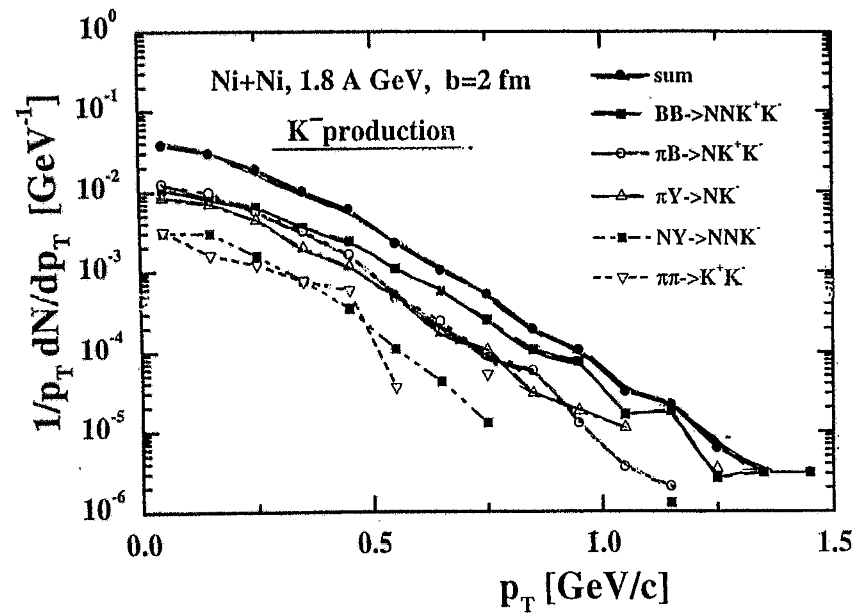

Ni+Ni, 1.8 A GeV, b=2 fm
K−
production
final
final, in-medium
dN/dy_cm
y_cm



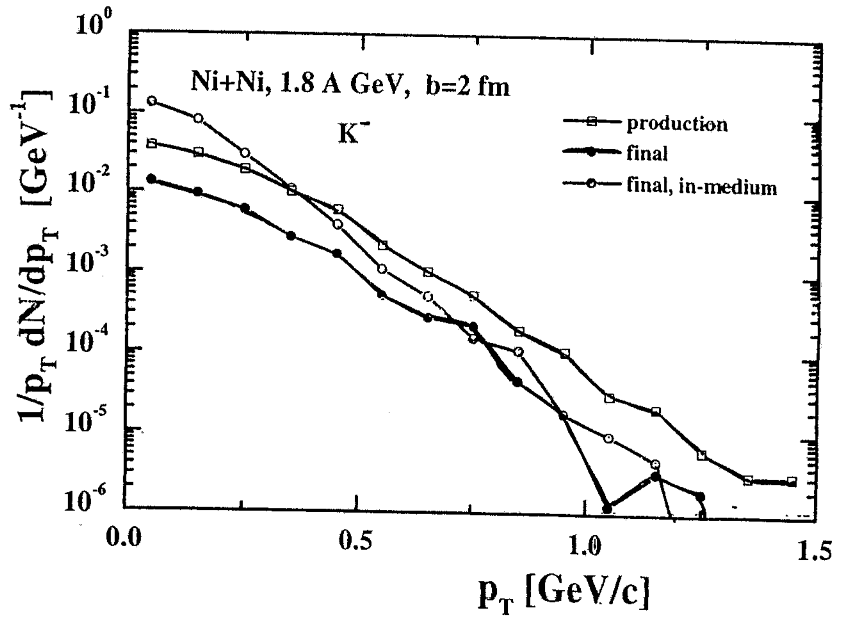
1/p_T dN/dp_T [GeV^-1]
sum
BB->K+NY
πB->K+Y
Ni+Ni, 1.8 A GeV, b=2 fm
K+ production
p_T [GeV/c]



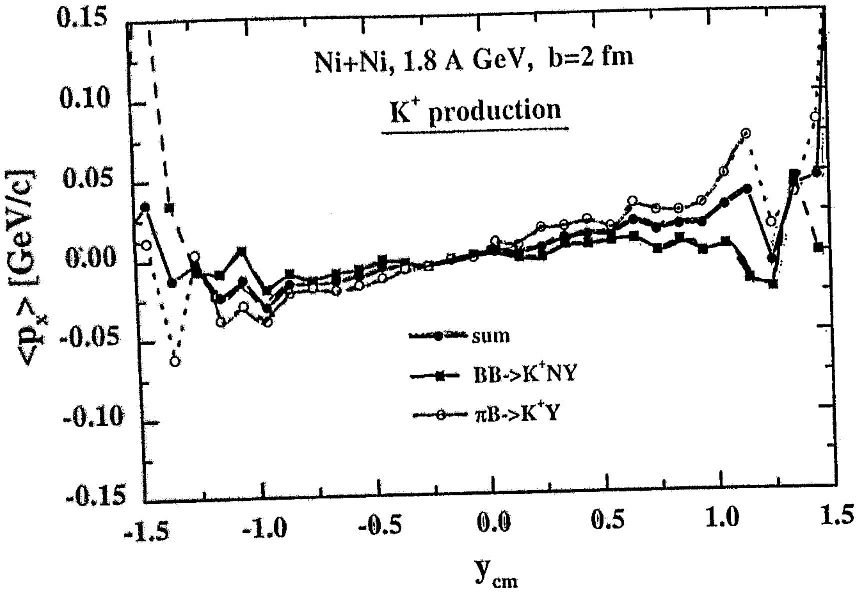
1/p_T dN/dp_T [GeV^-1]
production
final
final, in-medium
Ni+Ni, 1.8 A GeV, b=2 fm
K+
p_T [GeV/c]

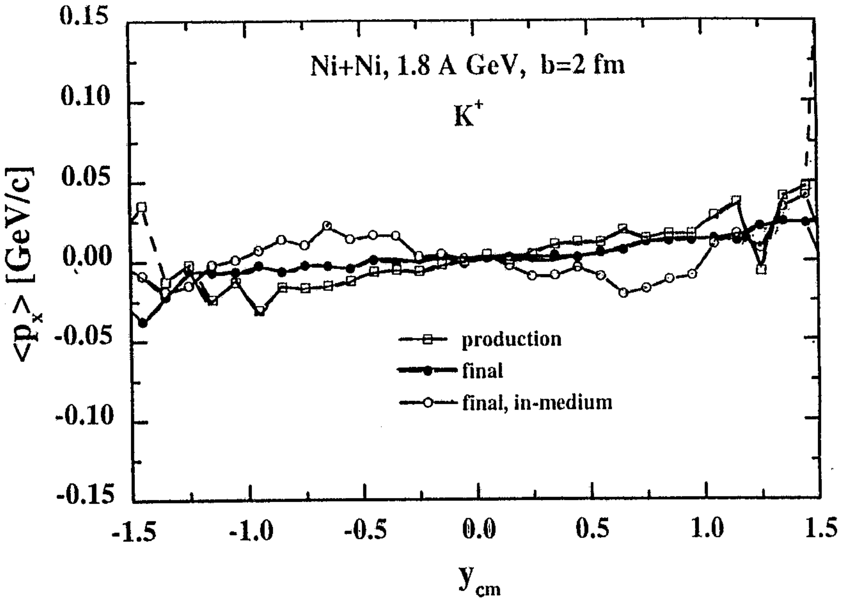


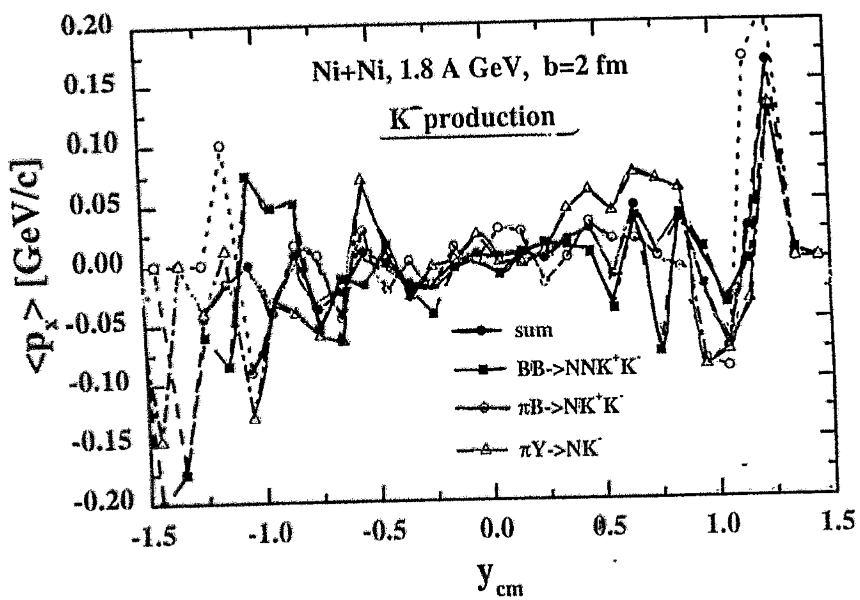
1/p_T dN/dp_T [GeV^-1]
sum
BB->NNK+K-
πB->NK+K-
πY->NK-
NY->NNK-
ππ->K+K-
Ni+Ni, 1.8 A GeV, b=2 fm
K- production
p_T [GeV/c]

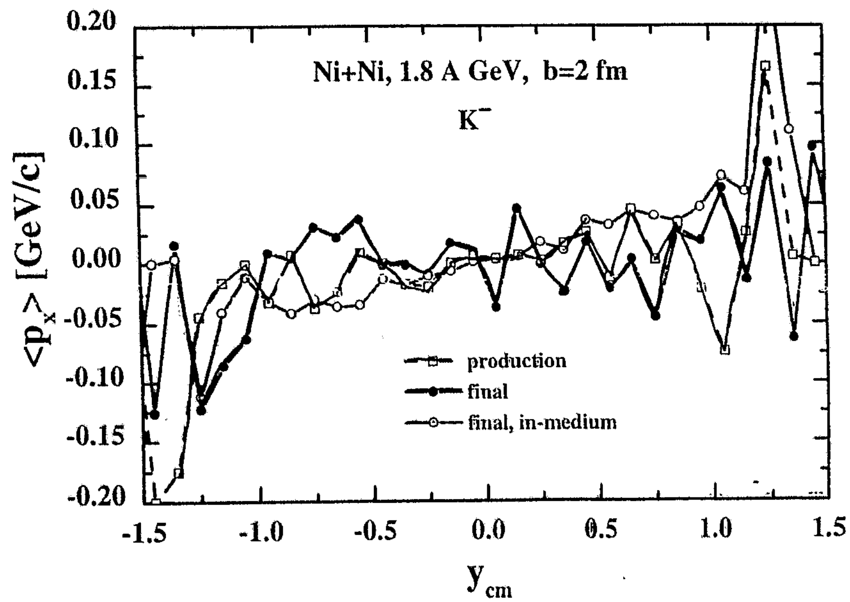


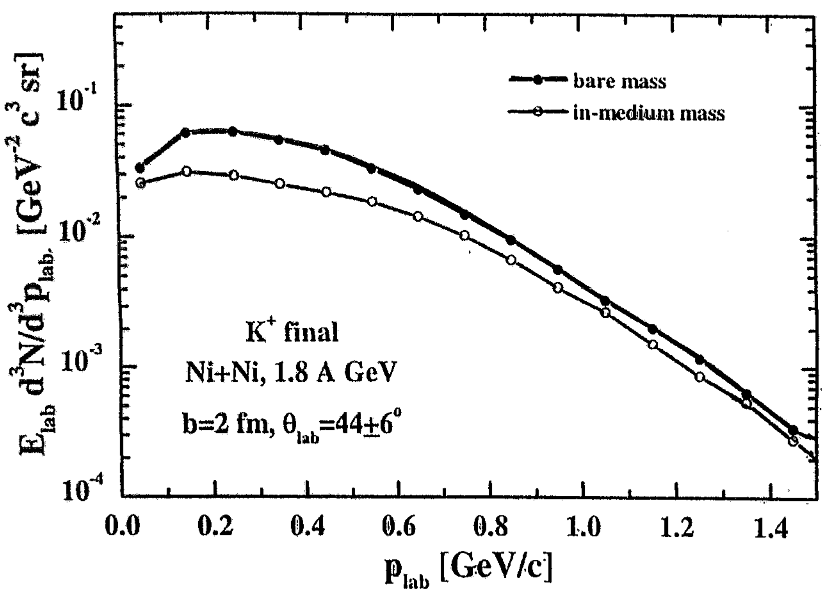
1/p_T dN/dp_T [GeV^-1]
production
final
final, in-medium
Ni+Ni, 1.8 A GeV, b=2 fm
K-
p_T [GeV/c]


Ni+Ni, 1.8 A GeV, b=2 fm
K+ production
sum
BB->K+NY
πB->K+Y
<p_x> [GeV/c]
y_cm

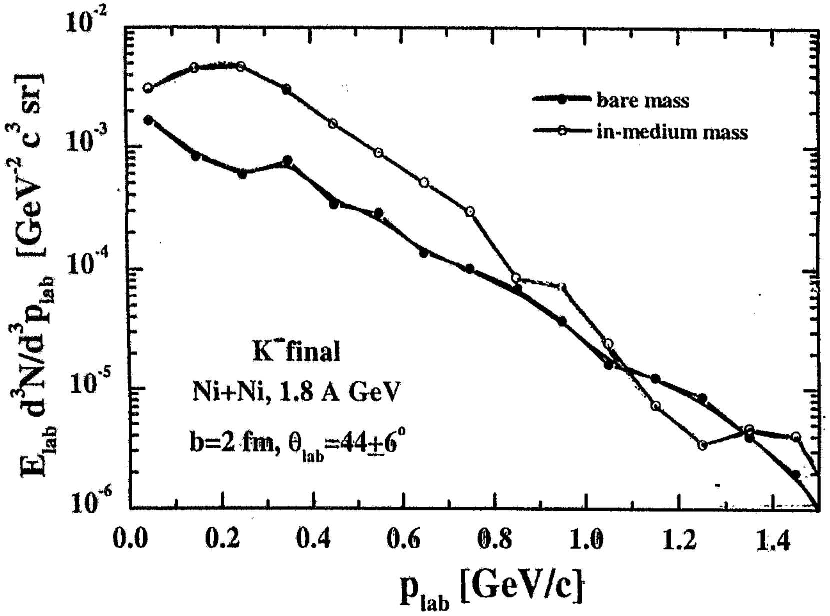

Ni+Ni, 1.8 A GeV, b=2 fm
K+
production
final
final, in-medium
<p_x> [GeV/c]
y_cm


Ni+Ni, 1.8 A GeV, b=2 fm
K- production
sum
BB->NNK+K-
πB->NK+K-
πY->NK-
<p_x> [GeV/c]
y_cm


Ni+Ni, 1.8 A GeV, b=2 fm
K-
production
final
final, in-medium
<p_x> [GeV/c]
y_cm



bare mass
in-medium mass
K+ final
Ni+Ni, 1.8 A GeV
b=2 fm, θlab=44±6°
Elab d3N/d3plab. [GeV-2 c3 sr]
plab [GeV/c]



bare mass
in-medium mass
K- final
Ni+Ni, 1.8 A GeV
b=2 fm, θlab=44±6°
Elab d3N/d3plab [GeV-2 c3 sr]
plab [GeV/c]

C.-H. Lee:

Bechmark test of the RVUU model

Benchmark Test of
RVUU Transport Model.

Chang-Hwan Lee
SUNY at Stony Brook

* based on
Guoqiang Li's code.
NPA 625 (1997) 372.

— G.E. Brown —

You have to say
" I just get into Transport Code.
So, I came here to learn
from <u>Older and Wiser</u> people

Then, they <u>won't</u> give you
hard time.

RVUU model

$$\frac{1}{p_0^*}\left\{\left[\partial_x^\mu - (\partial_x^\mu \Sigma_\nu^\nu - \partial_x^\nu \Sigma_\nu^\mu)\partial_\nu^{p^*}\right] p_\mu^* + m^*(\partial_x^\mu m^*)\partial_\mu^{p^*}\right\} f(x, p^*) = I_c$$

$$I_c = \frac{1}{(2\pi)^3}\int d^3p_2^* \int d^3p_3^* \int d\Omega_\nu \frac{d\sigma}{d\Omega}\,\delta^3(p^* + p_2^* - p_3^* - p_4^*)$$
$$\times \left\{ f(x, p_3^*) f(x, p_4^*)[1 - f(x, p^*)][1 - f(x, p_2^*)] - f(x, p^*) f(x, p_2^*)[1 - f(x, p_3^*)][1 - f(x, p_4^*)] \right\}$$

$$\frac{dx}{dt} = \frac{p^*}{E^*}$$

$$\frac{dp}{dt} = -\nabla_x\left(E^* + \left(\frac{g_\omega}{m_\omega}\right)^2 \rho_N\right)$$

σ-ω model.

$$\mathcal{L} = \bar{\psi}\left[i\partial\!\!\!/ - m - g_\sigma\sigma - g_\omega\gamma_\mu\omega^\mu\right]\psi + \frac{1}{2}(\partial^\mu\sigma)^2 - \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{3}b\sigma^3 - \frac{1}{4}c\sigma^4 - \frac{1}{4}(\partial_\mu\omega^\nu - \partial_\nu\omega^\mu)^2 + \frac{1}{2}m_\omega^2\omega_\mu^2$$

$$m^* = m - \Sigma_s, \qquad \Sigma_s = g_\sigma\langle\sigma\rangle$$
$$p_\mu^* = p_\mu - \Sigma_{v\mu}, \qquad \Sigma_{v\mu} = g_\omega\langle\omega_\mu\rangle$$

$\Downarrow$

$$m_\sigma^2\langle\sigma\rangle + b\langle\sigma\rangle^2 + c\langle\sigma\rangle^3 \simeq g_\sigma\rho_s$$
$$\langle\omega_\mu\rangle = (g_\omega/m_\omega)^2\rho_\mu$$

$$\rho_s = \int\frac{d^3p}{(2\pi)^3} f(x, p^*)\frac{m^*}{E^*}$$

$$\rho_\mu = \int\frac{d^3p}{(2\pi)^3} f(x, p^*)\frac{p_\mu^*}{E^*}$$

$$E^* = (m^{*2} + p^{*2})^{1/2}$$

parameter we used

$$C_\sigma = \left(\frac{g_\sigma}{m_\sigma}\right) m \approx 13.95$$

$$C_\omega = \left(\frac{g_\omega}{m_\omega}\right) m \approx 8.498$$

$$B = b/g_\sigma^3 m = 0.0199$$

$$C = c/g_\sigma^4 = -0.00296$$

$$\varepsilon/A\ (\rho = \rho_0) = -15.96\ \text{MeV}$$

$$K \qquad K|_{\rho_0} = 200\ \text{MeV}$$

$$\left.\frac{m^*}{m}\right|_{\rho_0} = 0.88$$

$$m_\sigma = 550\ \text{MeV}$$
$$m_\omega = 783\ \text{MeV}$$

KN interaction

(density dependent Kaon Mass)

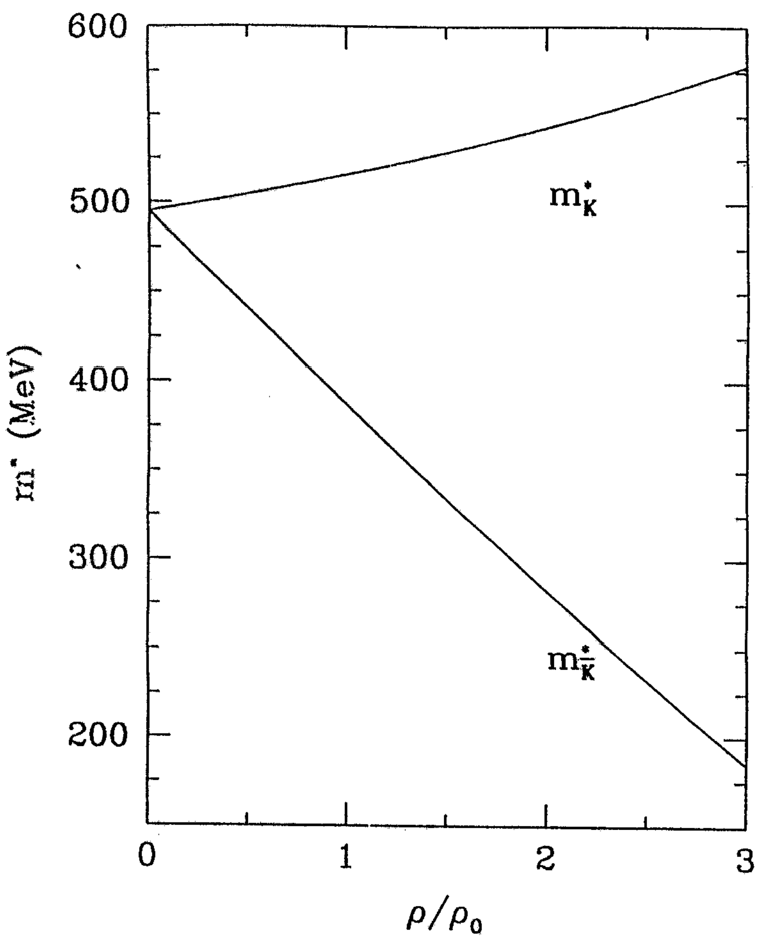
$$\mathcal{L}_K = \partial_\mu \bar{K} \partial^\mu K - (m_K^2 - g_{\sigma K} m_K \sigma) K\bar{K} + i g_{\omega K} \omega_0 \bar{K} \overleftrightarrow{\partial_t} K$$

$$\omega_K = \left[m_K^2 + k^2 - g_{\sigma K} m_K \sigma + (g_{\omega K}\omega_0)^2\right]^{1/2} + g_{\omega K}\omega_0$$

$$\omega_{\bar{K}} = \left[m_K^2 + k^2 - g_{\sigma K} m_K \sigma + (g_{\omega K}\omega_0)^2\right]^{1/2} - g_{\omega K}\omega_0$$

$$\sigma = \langle \sigma \rangle$$
$$\omega_0 = \langle \omega \rangle$$

$$g_{\omega K}/g_{\omega N} = 1/3$$



Processes in our code

K^+ production

a) $NN \to N\Lambda K$, $N\Lambda\pi K$, $N\Lambda\pi\pi K$

b) $NN \to N\Sigma K$, $N\Sigma\pi K$, $N\Sigma\pi\pi K$

c) $ND \to N\Lambda K$, $N\Lambda\pi K$, $N\Lambda\pi\pi K$

d) $ND \to N\Sigma K$, $N\Sigma\pi K$, $N\Sigma\pi\pi K$

e) $\Delta\Delta \to N\Lambda K$, $N\Lambda\pi K$, $N\Lambda\pi\pi K$

f) $\Delta\Delta \to N\Sigma K$, $N\Sigma\pi K$, $N\Sigma\pi\pi K$

g) $\pi N \to \Lambda K$, $\Lambda\pi K$

h) $\pi N \to \Sigma K$, $\Sigma\pi K$

i) $\pi\Delta \to \Lambda K$, $\Lambda\pi K$

k) $\pi\Delta \to \Sigma K$, $\Sigma\pi K$

20~30% (bracketing the πK and $\pi\pi K$ channels of a–f)

20~30% increase in K^+-production

K^- production

l) $NN \to NNK^+K^-$, $NN\pi KK$, $NN\pi\pi KK$

m) $N\Delta \to NNKK$, $NN\pi KK$ "

n) $\Delta\Delta \to NNKK$, $NN\pi KK$ "

o) $\pi N \to NKK$, $N\pi KK$

p) $\pi\Delta \to NKK$, $N\pi KK$

q) $\pi\Lambda \to N\bar{K}$

$\pi\Sigma \to N\bar{K}$

K^- annihilation

r) $N\bar{K} \to \pi\Lambda$

$\searrow \pi\Sigma$

Quite Important. (q, r)

BB Cross Sections

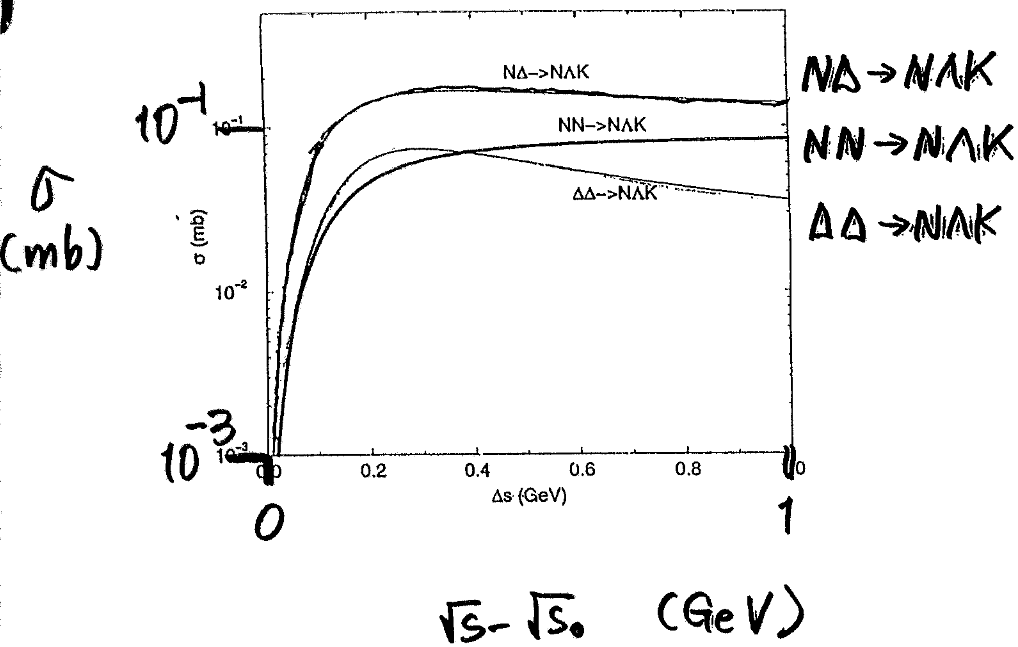
[NPA 625 (1997) 372]

$$\sigma_{BB \to NYK} = \frac{a\,(\sqrt{s}-\sqrt{s_0})^2}{b + (\sqrt{s}-\sqrt{s_0})^x} \text{ mb}$$

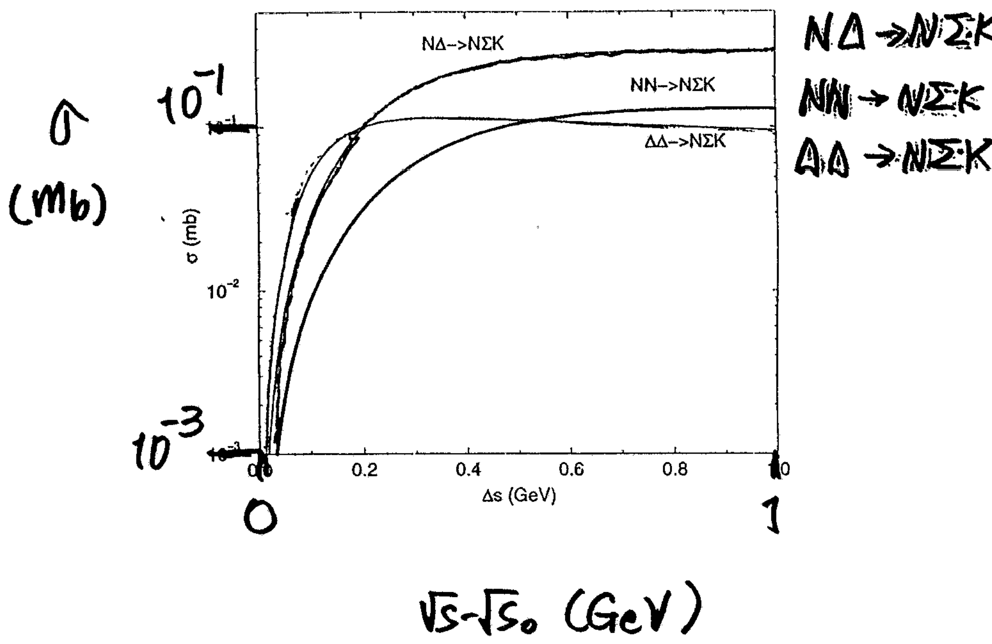
		a	b	x
$NN \to N\Lambda K$		0.0865	0.0345	2.0
	$N\Sigma K$	0.1499	0.167	2.4
$N\Delta \to N\Lambda K$		0.1397	0.0152	2.3
	$N\Sigma K$	0.3221	0.107	2.3
$\Delta\Delta \to N\Lambda K$		0.0361	0.0137	2.9
	$N\Sigma K$	0.0965	0.014	2.3

* done by Guoqiang Li

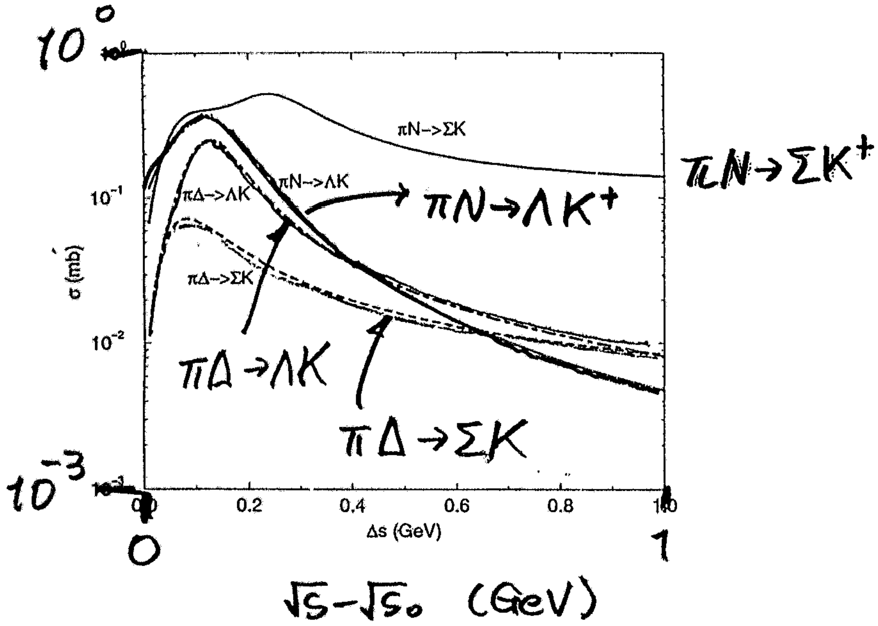
I. $BB \to N\Lambda K$ PRODUCTION CROSS SECTIONS



II. $BB \to N\Sigma K$ PRODUCTION CROSS SECTIONS



III. $\pi B \to \Lambda, \Sigma K$ PRODUCTION CROSS SECTIONS

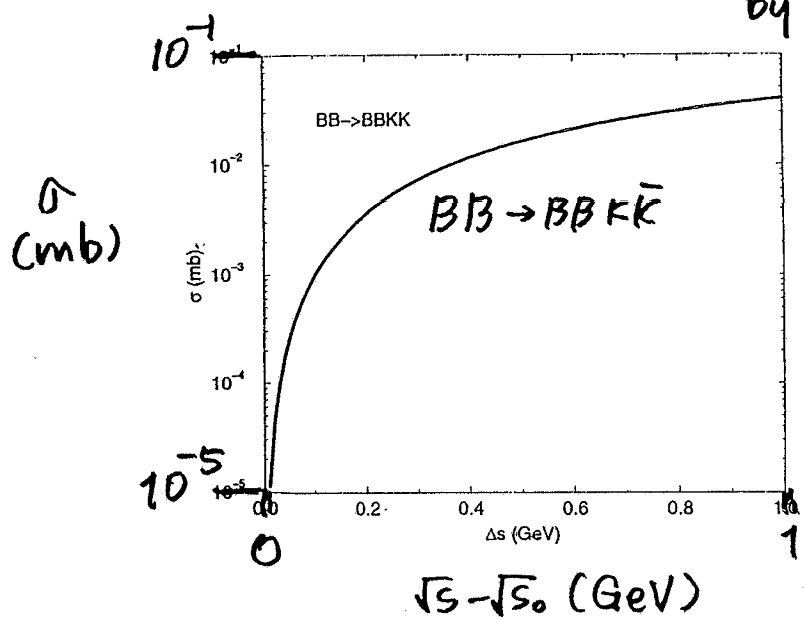


[Tsushima, Huang, Faessler.
PLB 337 (1994) 245
J. Phys. G 21 (1995) 33.]

NPA 625 (97) 372.

by Guoqiang Li.

IV. $BB \to BBKK$ PRODUCTION CROSS SECTIONS

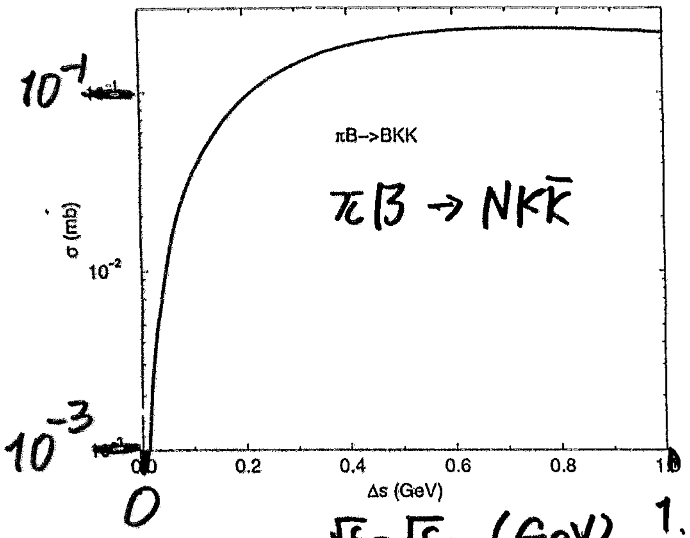


Used the same cross sections

NN, NΔ, ΔΔ → $NNK\bar{K}$

$$\sigma = \frac{5}{4} \cdot 0.19 \left(1 - \frac{s_0}{s}\right)^2 \left(\frac{s_0}{s}\right)^{0.31} \text{mb}$$

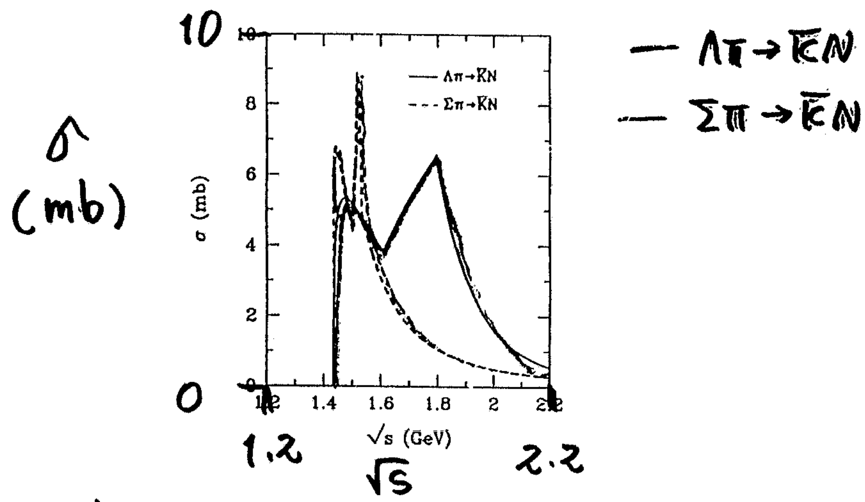
V. $\pi B \to BKK$ PRODUCTION CROSS SECTIONS

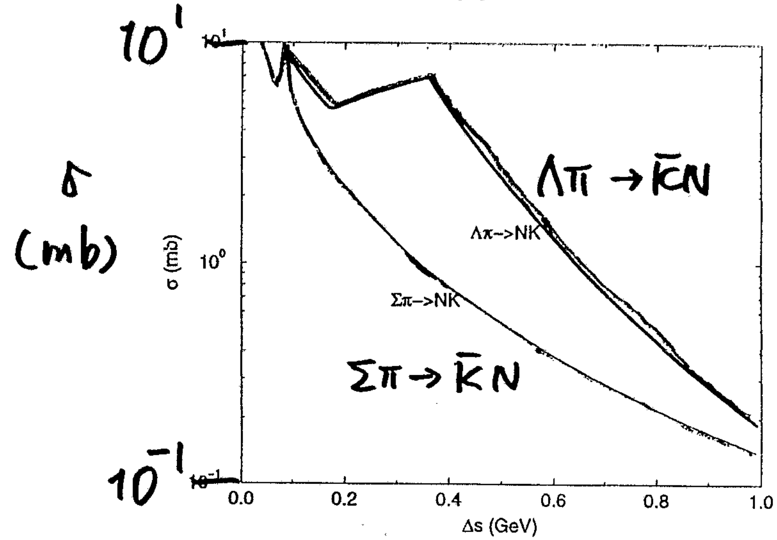


$$\sigma = 3.363 \left(1-\frac{s_0}{s}\right)^{1.86} \left(\frac{s_0}{s}\right)^2 \text{ mb}$$

* The same for πN, $\pi\Delta$
by Guoqiang NPA 625 (97) 372.

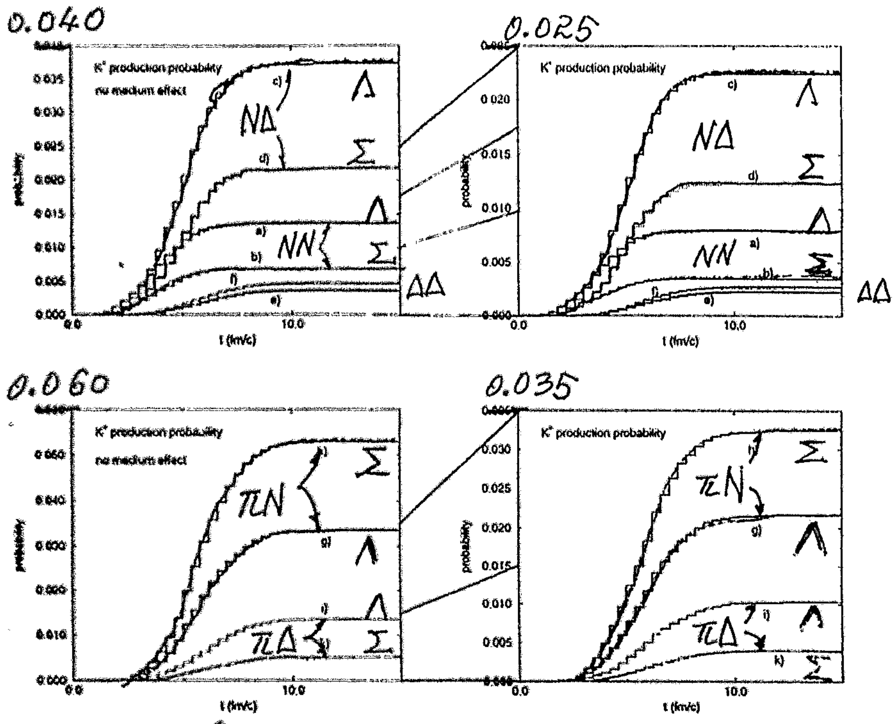
VI. $\Lambda, \Sigma\pi \to N\bar{K}$ PRODUCTION CROSS SECTIONS





K^+ production.

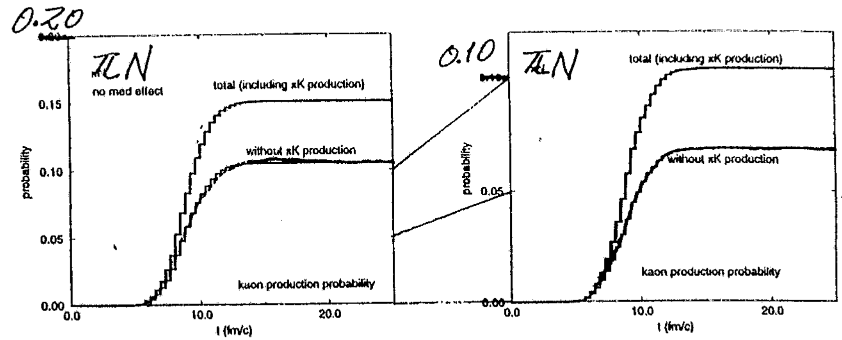
A. K^+ production without/with KN optical potential



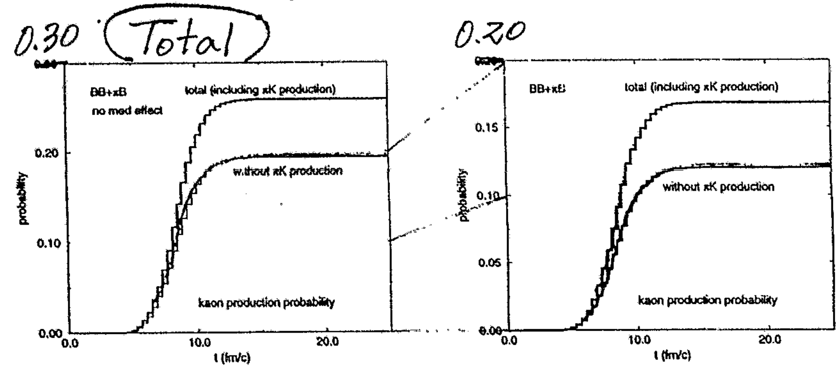
⇑ No KN opt pot ⇑ with KN opt-pot.

* $\pi N \to HK^+$, $N\Delta \to NHK^+$ dominant.

M. K^+ production probability with/without $piB \to Y\pi K^+$ channel.

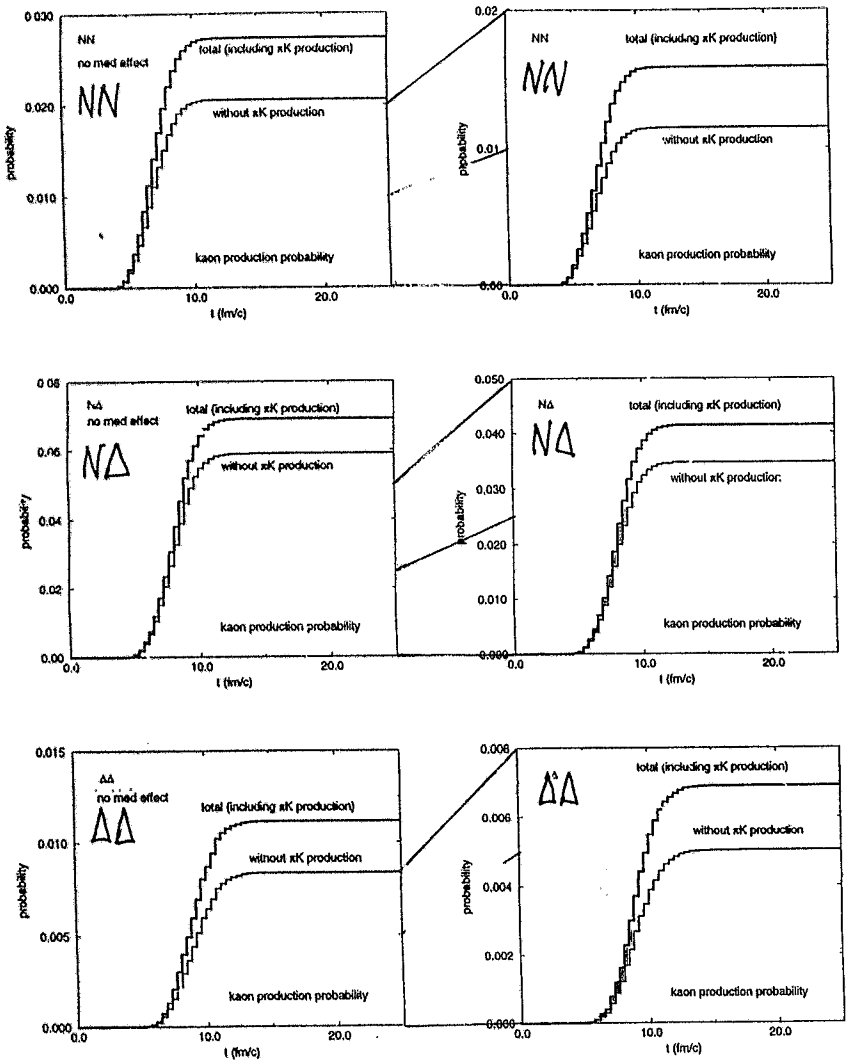


N. Total K^+ prod. prob. with/without $XX \to Y + \pi K^+$.



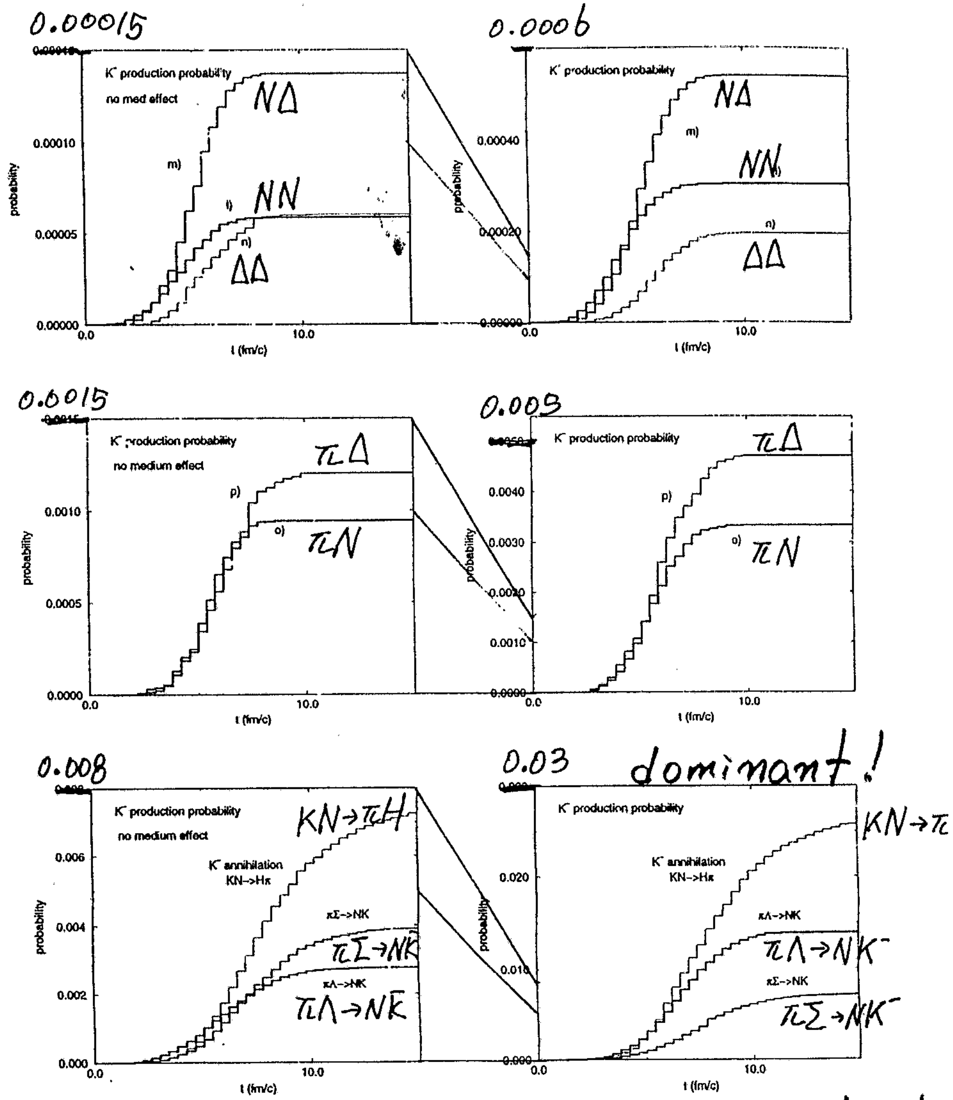
* upper curve : with $NN \to NH\pi K, NH\pi\pi K$
lower curve : without " "

L. K^+ production probability with/without $BB \to Y\pi K^+$ channel.



K⁻ production

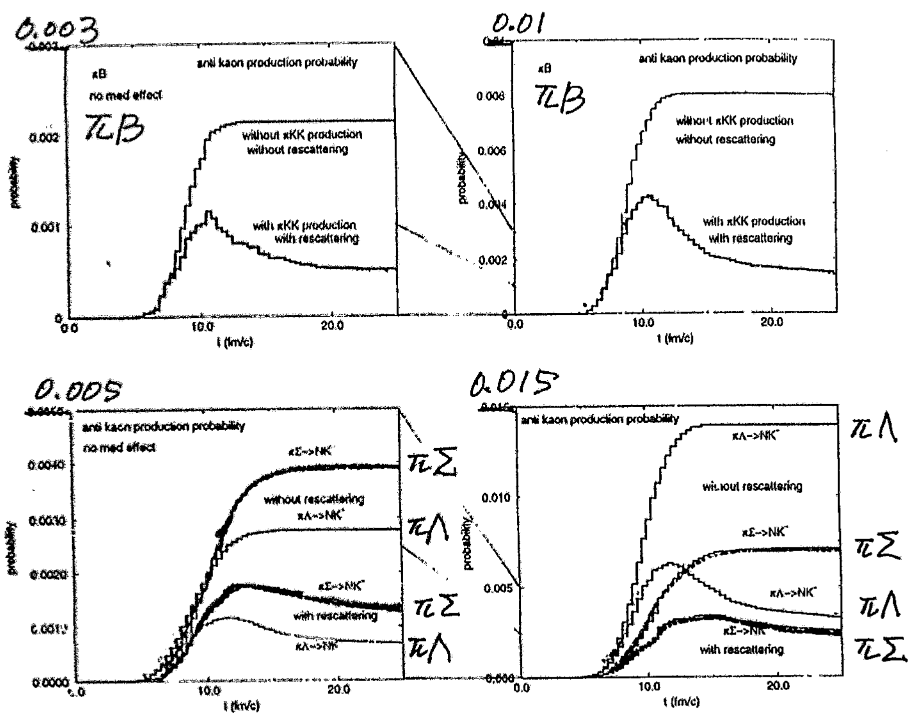
B. K^- production and annihilation probability



Kaon Absorption is important.

Effect of Rescattering

P. $\pi B \to XK\bar{K}$ probability with/without rescattering

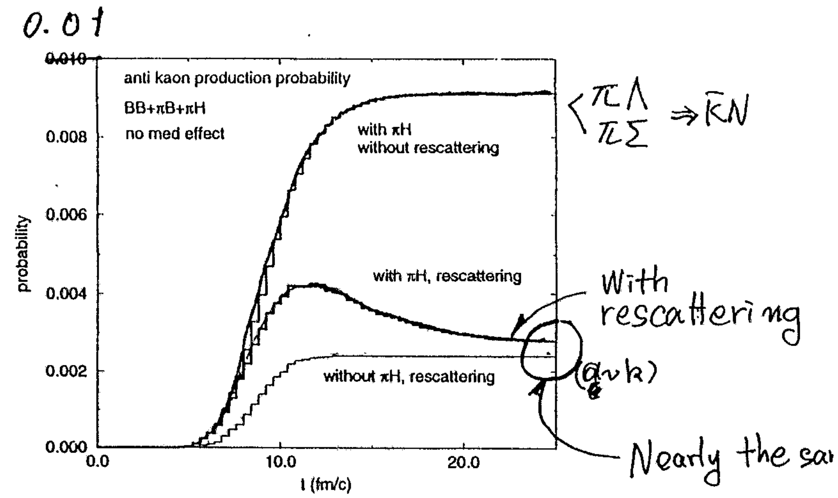


⇑ No KN opt-pot ⇑ with KN opt pot.

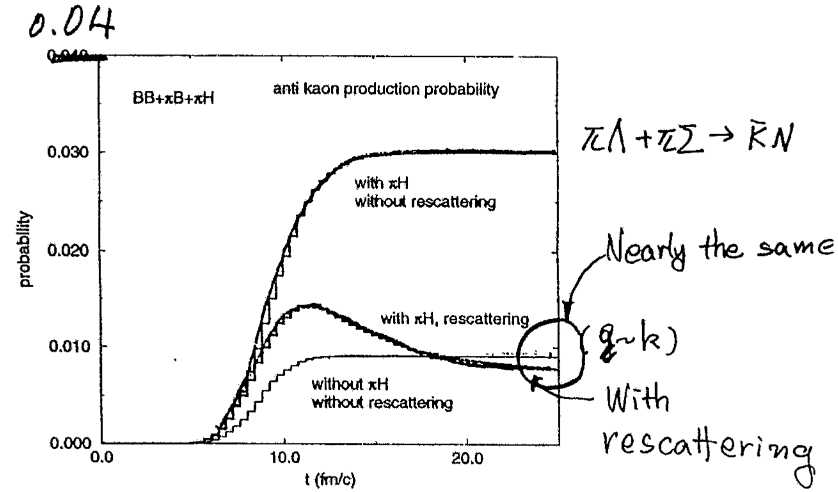
Total K^-

Q. Total and $\pi\Lambda, \Sigma \to K^- N$ channel K^- production probability.

No Pot

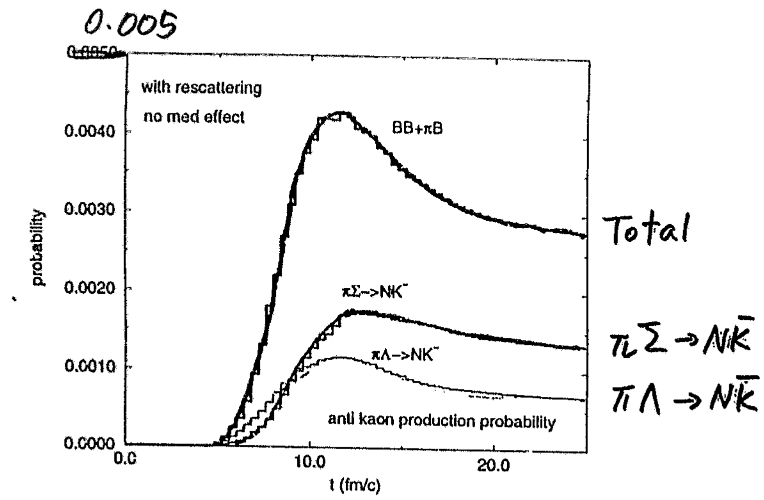


With Pot

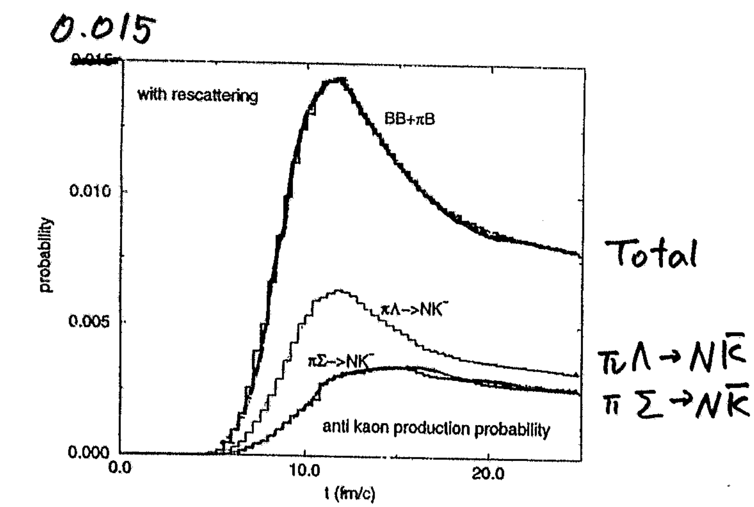


* Total & (a-k) gives the same # of K^-
But Rapidity & P_t Spectrum will change

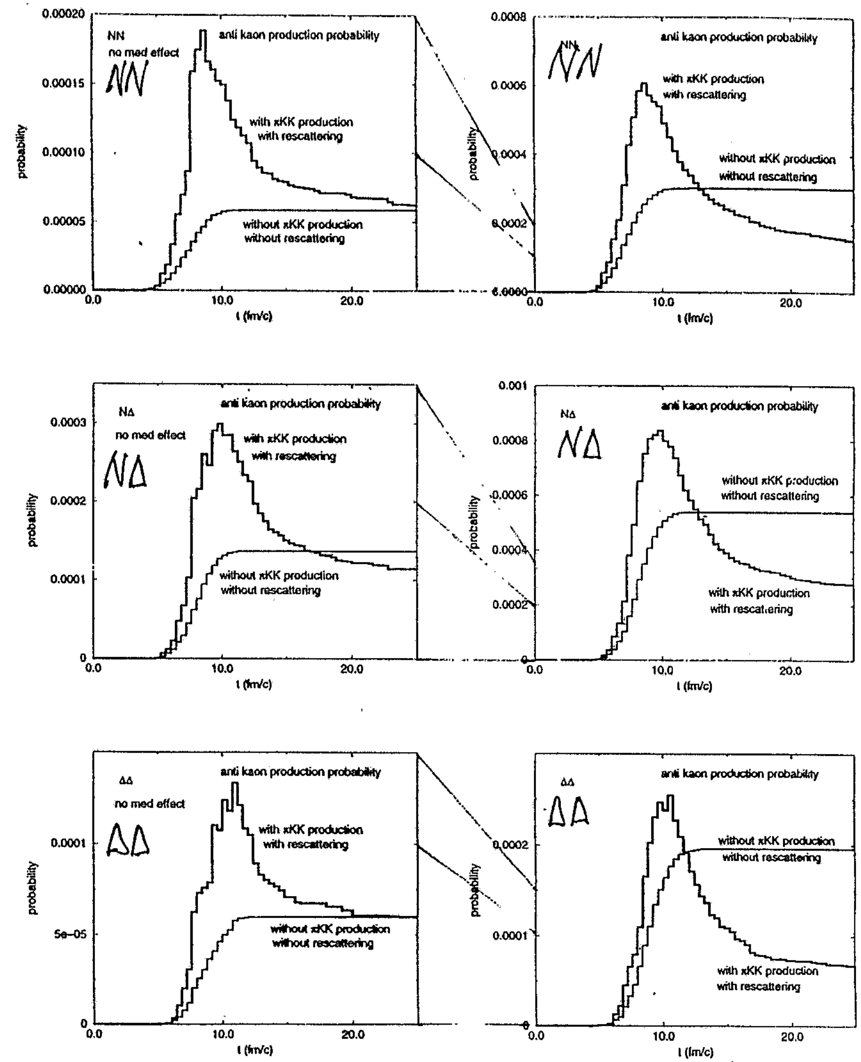
No Pot



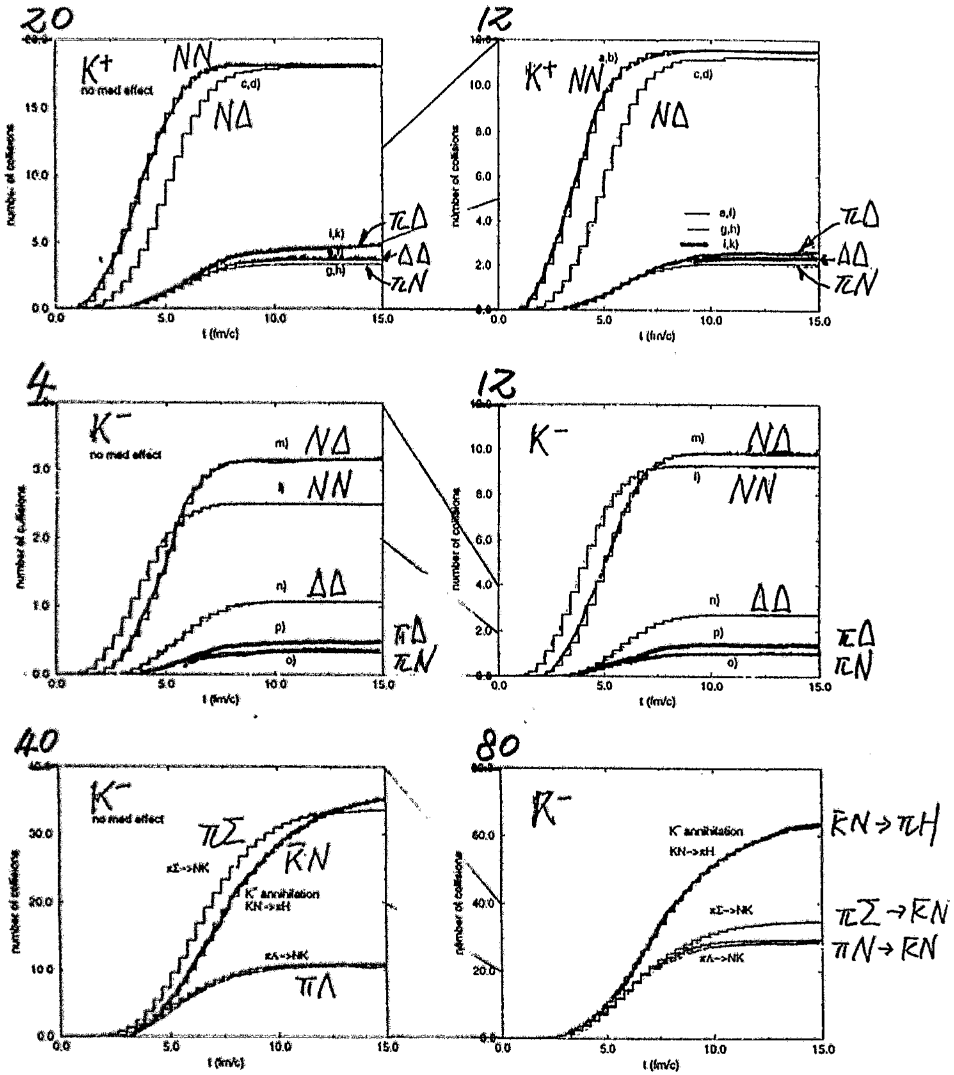
With Pot.



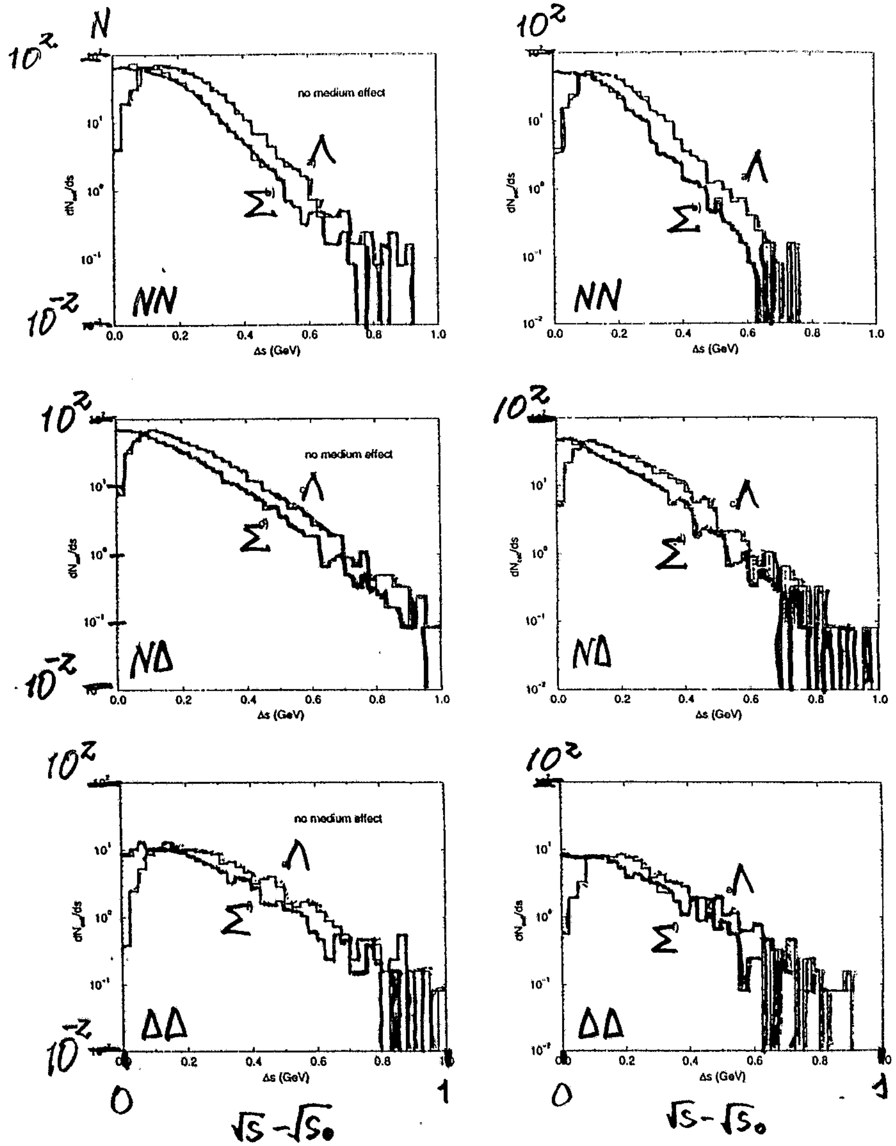
O. $BB \to XKK$ probability with/without rescattering



C. Number of collisions for $K^{\pm}$ production

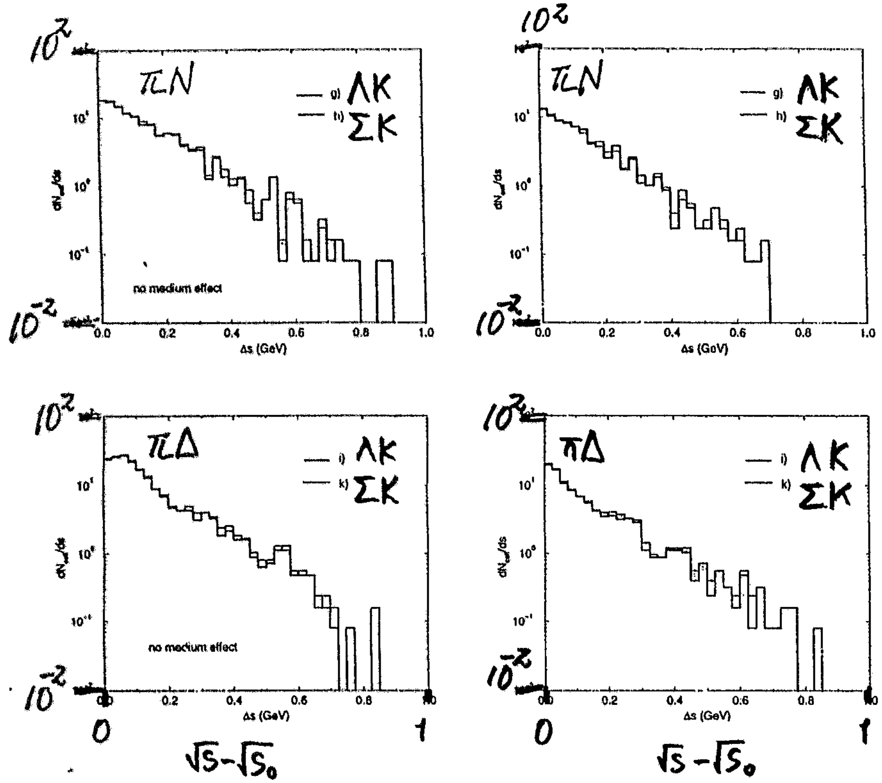


D. $dN/d\sqrt{s}$: Number of collisions for K^{+} production (a-f)



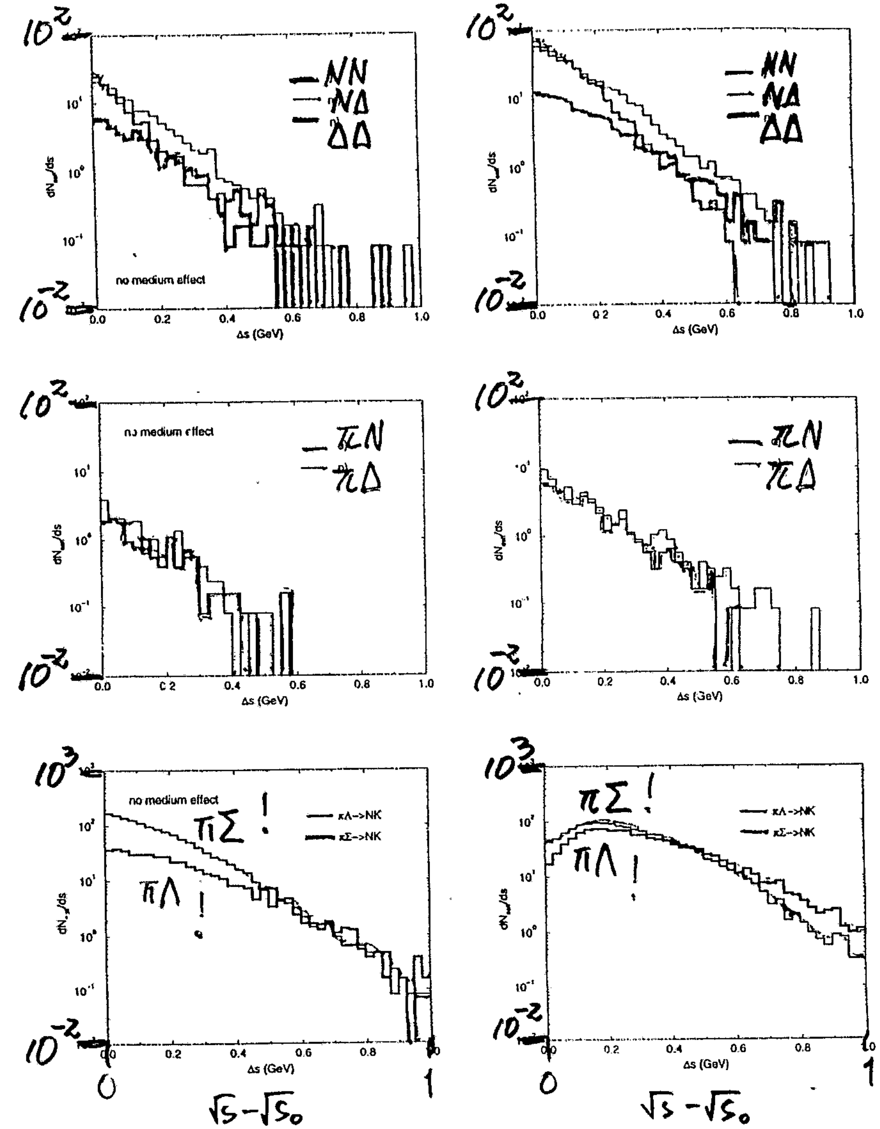
dN/d√s

E. $dN/d\sqrt{s}$: Number of collisions for K^+ production (g-k)



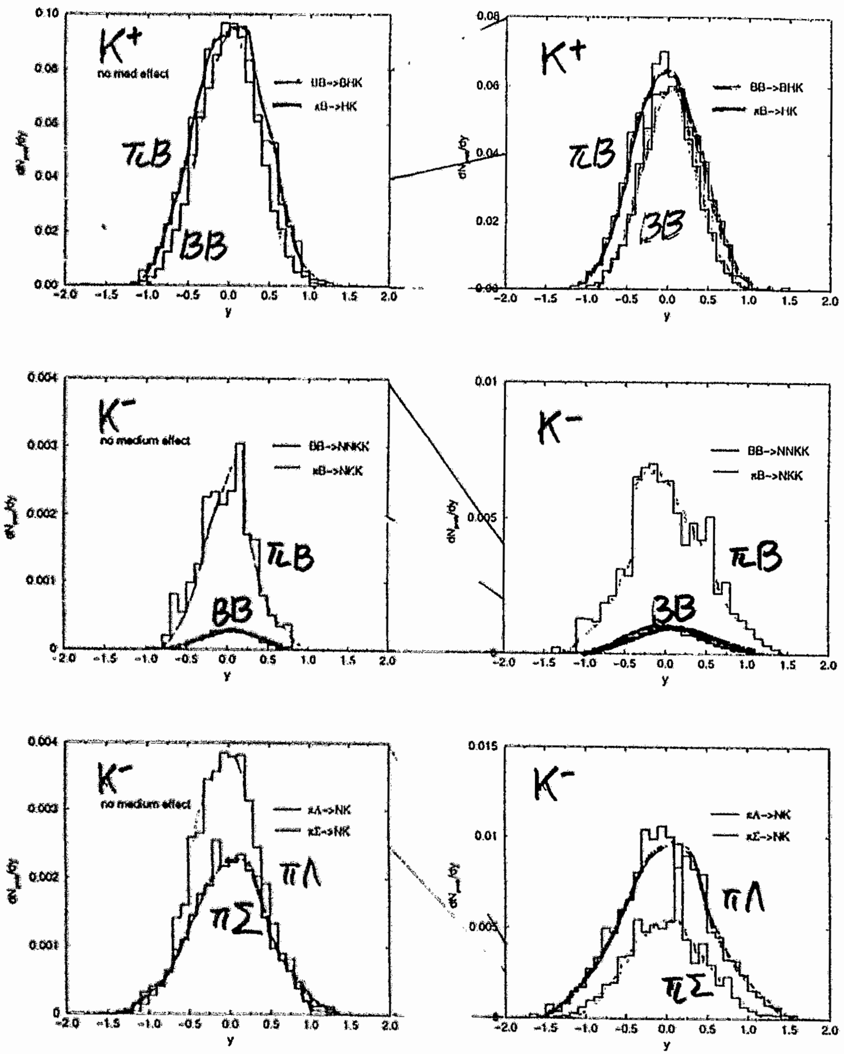
K⁻ prod

F. Number of collisions for K^- production and annihilation



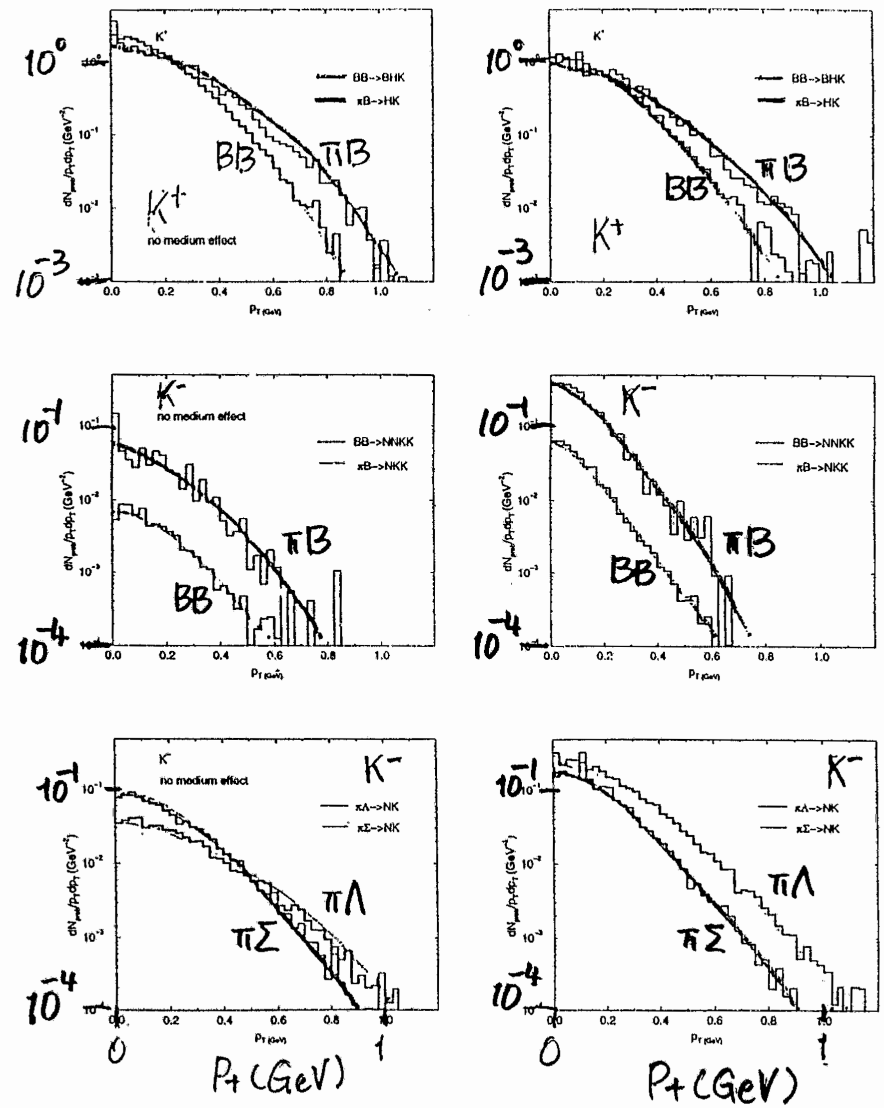
Rapidity dist. dN/dy

G. dN_{prob}/dy : Rapidity distribution ($K^{\pm}$)



dN/p+dp+

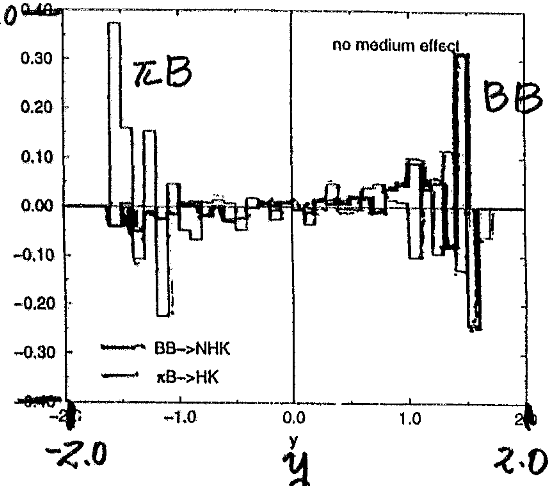
H. $dN_{prob}/p_T dp_T$: Transverse momentum distribution ($K^{\pm}$)



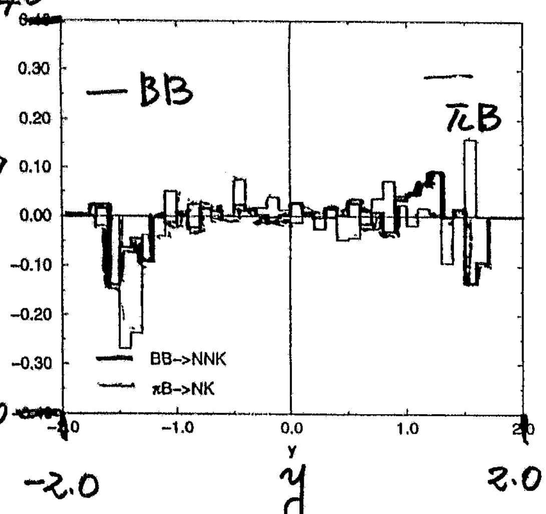
Kaon flow

I. Kaon flow

No pot

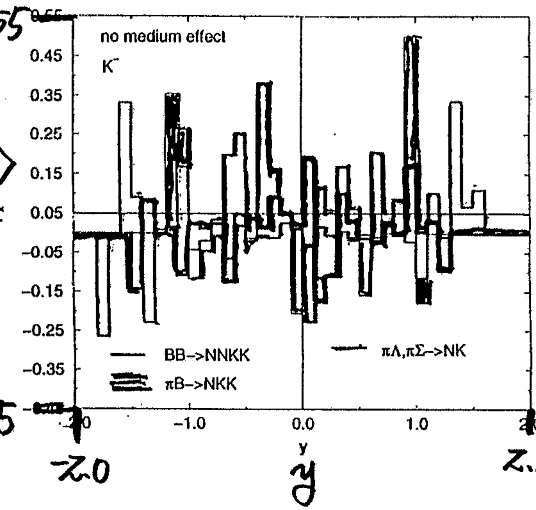


With Pot

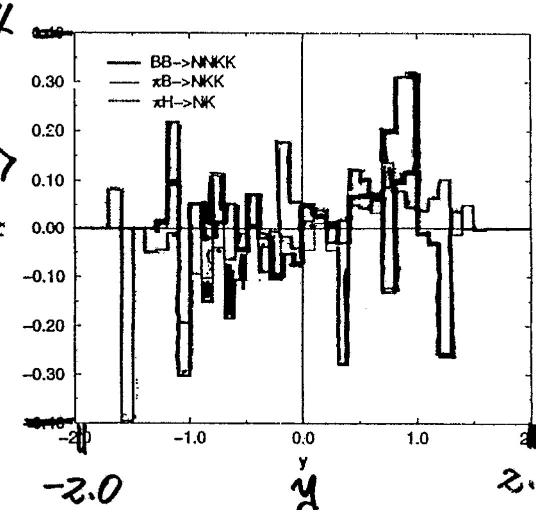


Anti Kaon Flow

No pot



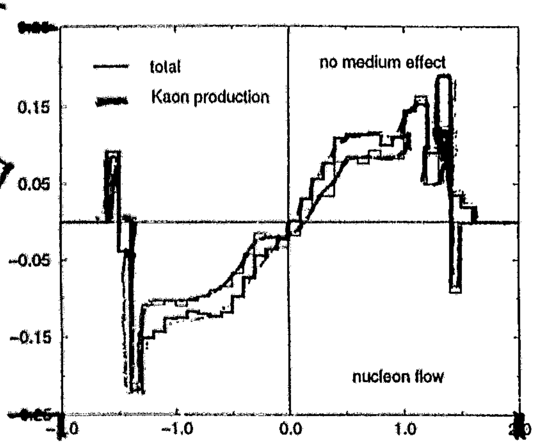
With pot



Nucleon Flow

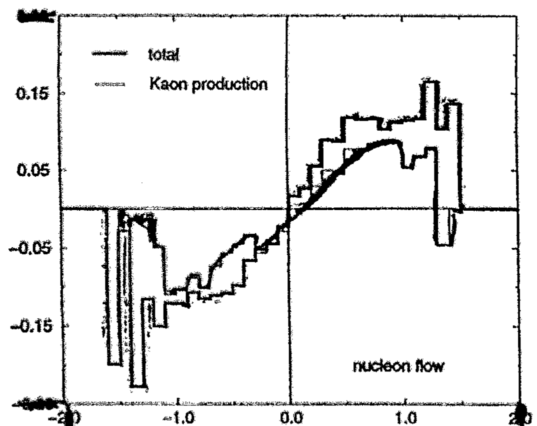
J. Nucleon flow

No Pot



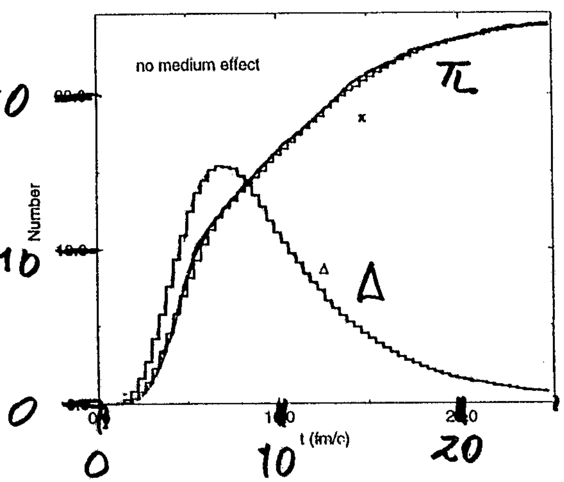
— N : K-prod
— total

With Pot



# of π, Δ

K. Number of pions and deltas



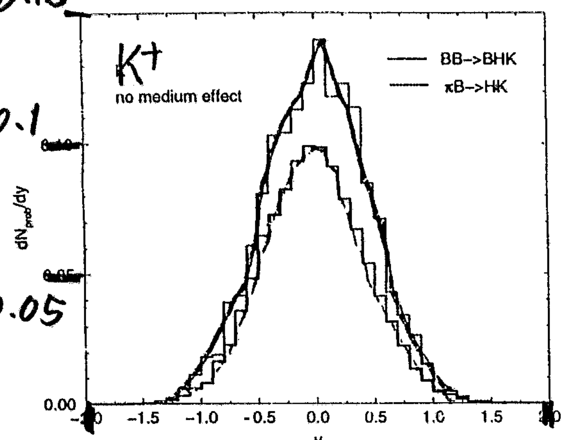
Indep. of KN optical pot.

* Dynamics of N, π, Δ is independent of $K^{\pm}, \Lambda, \Sigma$ production.

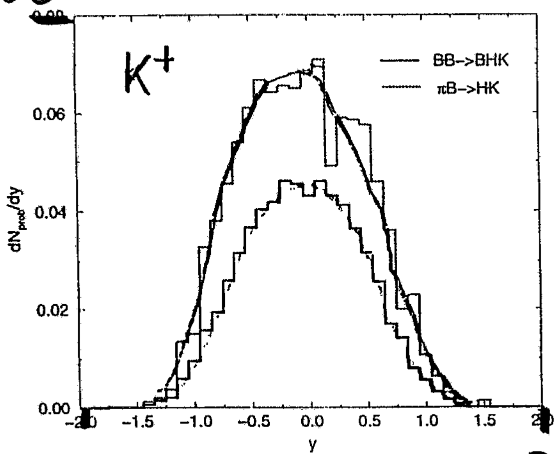
Final K+ rapidity distribution

R. Final $K^{\pm}$ rapidity distribution

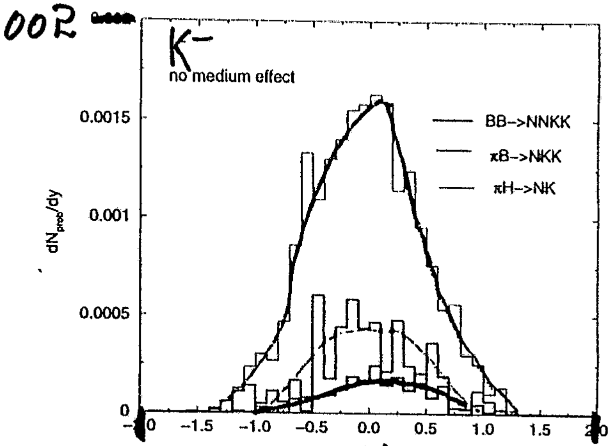
No pot

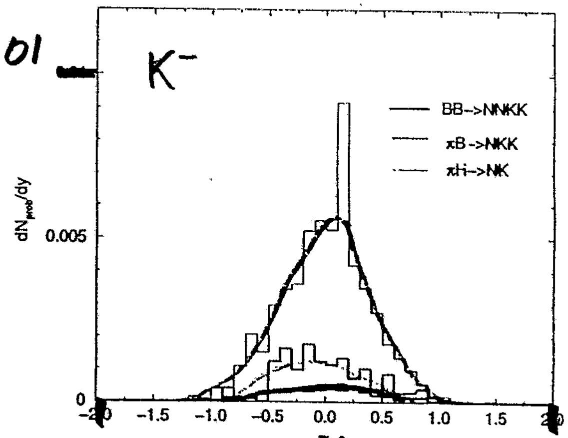


With pot



Final K⁻ rapidity dist.

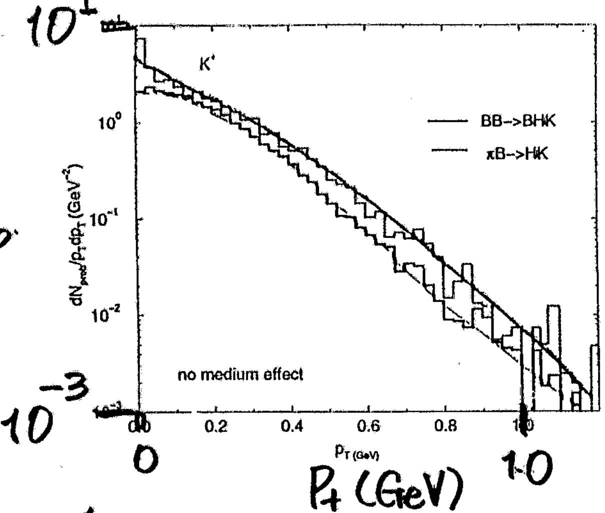




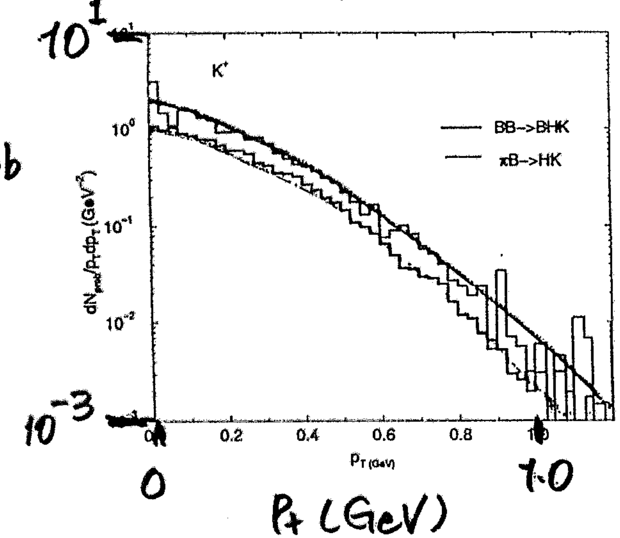
Final K^+

S. Final transverse momentum distribution

No Pot

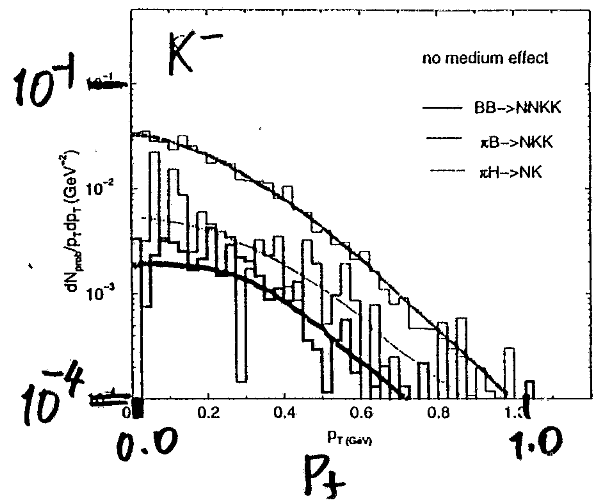


With Pot

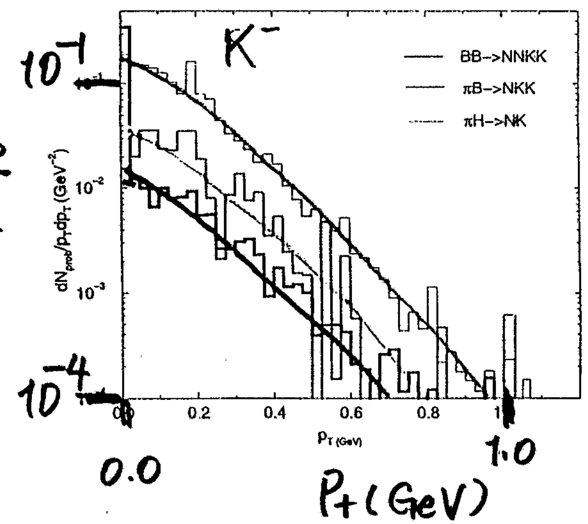


Final K^-

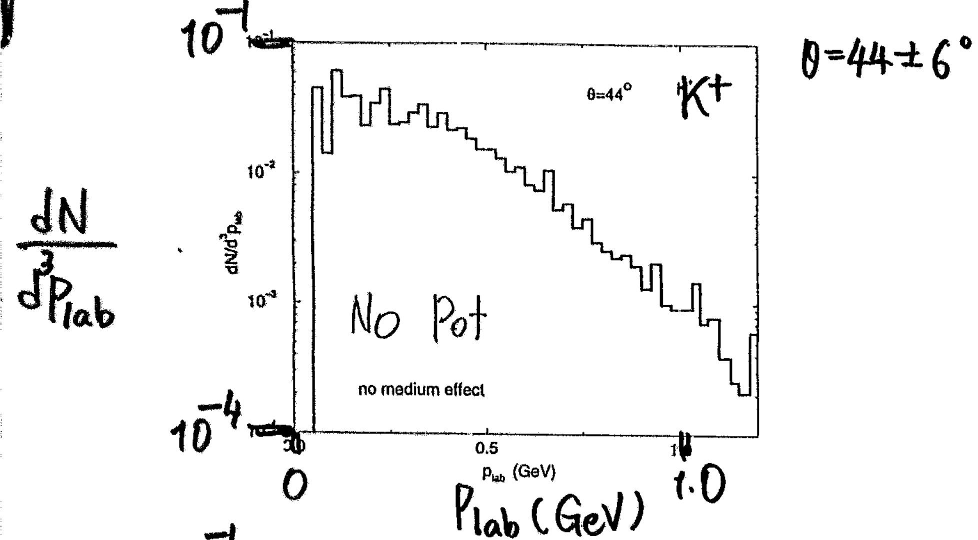
No Pot

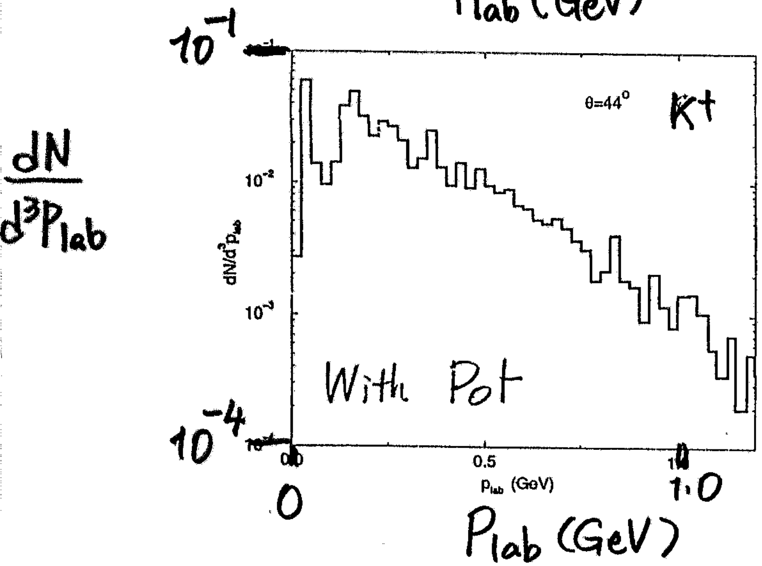


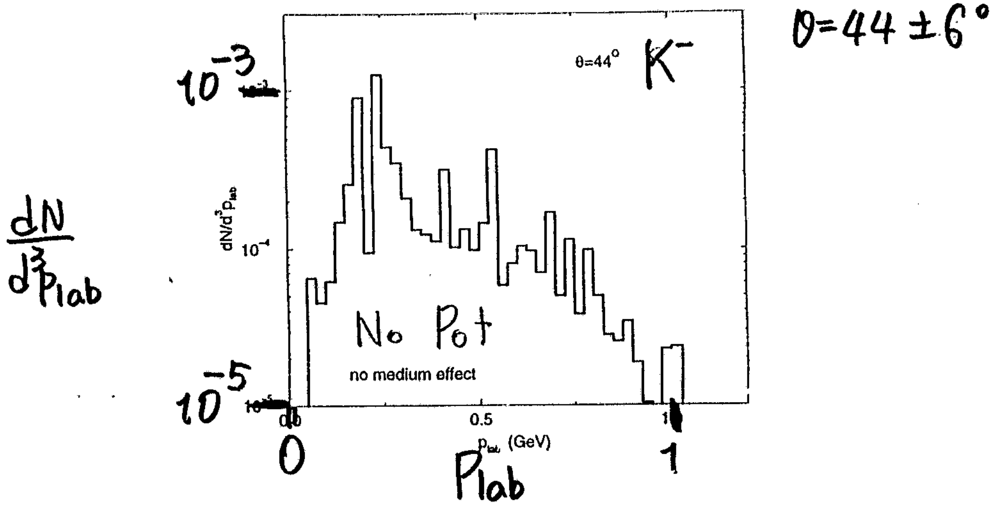
With Pot

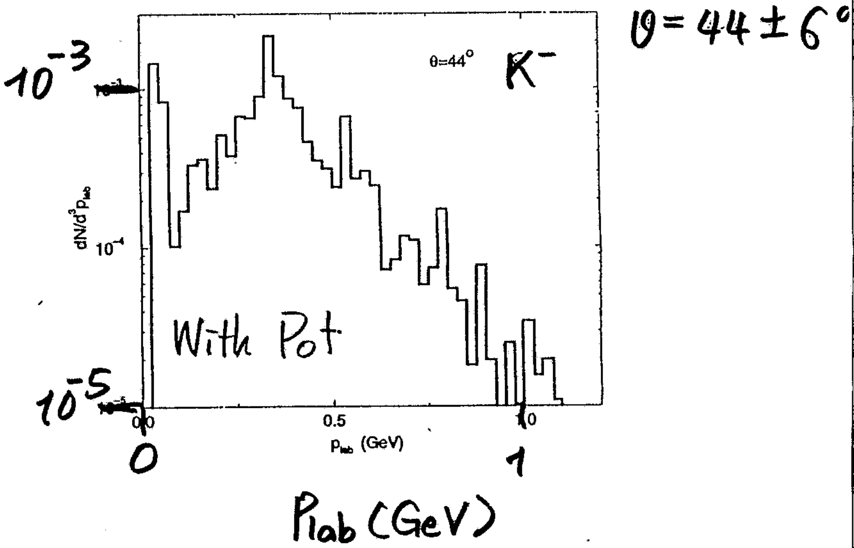


T. Final lab momentum distribution









Discussion.

1. KN optical potential is crucial for K^- production

2. $\pi\Lambda, \Sigma \rightarrow K^-N$ is dominant for K^- production

3. $K^-N \Rightarrow \pi\Lambda, \Sigma$ ($\bar{K}$ annihilation) is very important for K^- production.

For The Reunification of South & North Korea.

Thank you.

J. Aichelin:

QMD

Kaonen - Workshop

QMD

C. Hartnack, C. David J. A.

What influences the kaon production

- cross sections $a+b \to K + X$
- K-N potentials (H.v.!.(.!) angular distribution

- Influence of NN potential
  comparison QMD - RBUU

- Life time of Δ resonance

Nonrelativistic reduction of the DIRAC equation

$m^* = m - \Sigma_s \; ; \; \vec{p}^* = \vec{p} - \vec{\Sigma} \; , \; u = \binom{\Phi}{\chi}$

$$\begin{pmatrix} E - m^* - \Sigma_0 & -\vec{\sigma}\vec{p}^* \\ -\vec{\sigma}\vec{p}^* & E + m^* - \Sigma_0 \end{pmatrix} \begin{pmatrix} \Phi \\ \chi \end{pmatrix} = 0$$

Assumption: Φ is the Schrodinger two component spinor

$$\left((E - \Sigma_0)^2 - m^{*2} - p^{*2}\right)\Phi = 0$$

Hamilton operator for Schrodinger eq.

$$H = \frac{p^2}{2m} + \Sigma_0 + \Sigma_s + \frac{\Sigma_s^2 - \Sigma_0^2}{2m} + \frac{\Sigma_0}{m} E_{kin} + \vec{\sigma}(\vec{p}^* \times \vec{p}^*)$$

If the $\Sigma's$ depend on the density only

$\rightarrow U_{opt} = a E_{kin}$.

Correct up to $E_{kin} = 200 \quad MeV$ but not at higher energies.

In the Dirac Brueckner approach the self energy Σ is defind as

$$\Sigma_{DB}(k) = \int d^3q \, \frac{m^*(q)}{E^*(q)} \frac{m^*(k)}{E^*(k)} < kq|G(z)|kq - qk >$$

where G(z) is the relativistic analogon to the Brueckner G-matrix

$$G(q,p,P,z) = v(q,p,P) + \int \frac{d^3k}{(2\pi)^3} \, v(q,k,P) \left(\frac{m^*(k)}{E^*(k)}\right)^2 \cdot$$

$$\cdot \frac{Q(k,P)}{E^*(\vec{P}+\vec{k}) - E^*(\vec{P}-\vec{k}) - z} G(k,p,P,z)$$

where

$$E(k) = \sqrt{m^{*2} + k^2}$$

z=energy of entrance channel, $m^* = m + U_s$

Σ is usually complex. It can be presented as

$$\Sigma(k) = \Sigma_s - \gamma_0 \Sigma_0 + \vec{\gamma}\,\vec{\Sigma}$$

if one neglects tensor and γ_5 contributions.

The RBUU Hamiltonian

$$\omega = \sqrt{\left(\vec{p} - \vec{\Sigma}\right)^2 + (m - \Sigma_s)^2} + \Sigma_0$$

$$= \sqrt{p^{*2} + m^{*2}} + \Sigma_0 = E^* + \Sigma_0$$

gives the equations of motion:

$$\dot{\vec{r}} = \frac{\vec{p}^*}{E^*}$$

$$\dot{\vec{p}}^* = \frac{-(p_i - \Sigma_i)\vec{\nabla}_r \Sigma_i + \vec{\nabla}\Sigma_s}{E^*} + \vec{\nabla}\Sigma_0$$

RBUU: mean field approach:

the $\Sigma's$ depend on densities only $\rightarrow$ no momentum dependence.

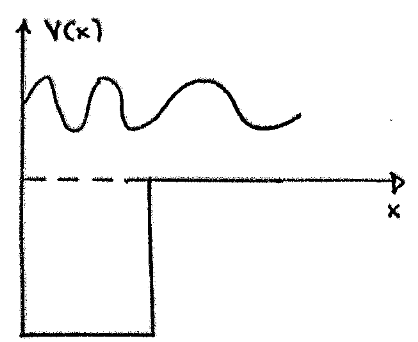
$$\Sigma_0 = \left(\frac{g_\omega}{m_\omega}\right)^2 \rho_B$$

Σ_s is the solution of $a\Sigma_s + b\Sigma_s^2 + c\Sigma_s^3 = g_\sigma \rho_s$

$$\vec{\Sigma} = 0$$

Time delay of wave packets

A) One dimensional potential scattering



No potential:

$$\psi_{free}(x) = \frac{1}{2i}\left(e^{ikx} - e^{-ikx}\right) = \sin kx$$

(outgoing: e^{ikx}, incomming: e^{-ikx})

with potential

$$\psi_{pot}(x) = \frac{1}{2i}\left(e^{ikx+2i\delta(E)} - e^{-ikx}\right) = e^{i\delta(E)} \sin(kx+\delta(E))$$

$$\psi_{Scatter} = \psi_{pot} - \psi_{free} = \frac{e^{ikx}}{2i}\left(e^{2i\delta} - 1\right) \quad \text{outgoing !}$$

→ We can define a scattering amplitude

$$f = \frac{e^{2i\delta}-1}{2i} \quad \text{with } |f|^2 = \sin^2\delta$$

Wave packets

$$\psi_{pot}^{in} = e^{-ikx} \longrightarrow \int dE\, f(E)\, e^{-ikx - iEt} \qquad k = \sqrt{2mE}$$

$$\psi_{pot}^{out} = -e^{ikx+2i\delta} \longrightarrow -\int dE\, f(E)\, e^{ikx + 2i\delta - iEt}$$

$$\text{with } \delta(E) = \delta(E_0) + \left.\frac{\partial \delta(E)}{\partial E}\right|_{E_0} (E-E_0) \qquad E_0 = \text{center of the packet}$$

$$\psi_{pot}^{out} = -e^{2i\delta(E_0) - iE_0 t} \int dE\, f(E)\, e^{ikx}\, e^{-i(E-E_0)[t - 2\delta'(E_0)]}$$

$$\psi_{free}^{out} = -e^{-iE_0 t} \int dE\, f(E)\, e^{ikx}\, e^{-i(E-E_0)t}$$

⇒ time delay for the outgoing wave

For the scattered wave we find

$$\psi_{scatter} = \psi_{pot} - \psi_{free}$$

$$\psi_{scatter} = c\int dE\, f(E)\, e^{ikx - iEt + i\delta} \sin\delta \;\ldots\ldots$$

$\psi_{scatter}(x)$ is maximal at the position where the phase is stationary

$$\nabla_k (kx - Et + \delta(E))\Big|_{k_0} = 0$$

(k_0: center of wave packet)

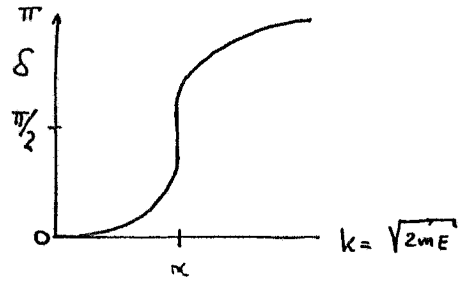
$$x = v_0 - \left.\frac{d\delta(E)}{dk}\right|_{k_0} = v_0\left(t - \left.\frac{d\delta}{dE}\right|_{E_0}\right)$$

→ Time delay for outgoing wave = 2x time delay of scattered wave

In three dim at finite angles one measures $|\psi_{scatter}|^2$

→ one expects a time delay of $\Delta t = \frac{d\delta}{dE}\hbar$

Resonances



Close to a resonance

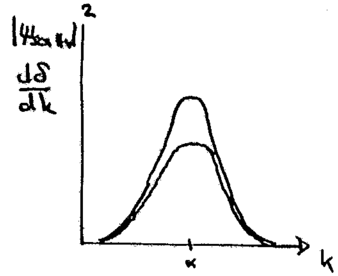
$$\delta \simeq \tan^{-1} \frac{\beta}{\alpha - k} \qquad \frac{1}{\beta} = \left.\frac{d\delta}{dk}\right|_{k_0 = \alpha}$$

$$f = \frac{e^{2i\delta} - 1}{2i} = \frac{-2i\beta}{(k-\alpha) + i\beta}$$

$$|\psi_{scatt}|^2 = |f|^2 = \frac{\beta^2}{(k-\alpha)^2 + \beta^2}$$

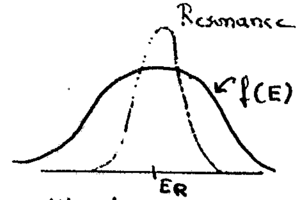
with $\Gamma = \frac{2\alpha\beta}{m}$ and $E - E_\alpha = \frac{\alpha(k-\alpha)}{m}$ $= \dfrac{\Gamma^2/4}{(E-E_\alpha)^2 + \Gamma^2/4}$

$$\frac{d\delta}{dk} = \frac{\beta}{(k-\alpha)^2 + \beta^2}$$



What is the difference between Γ and $\Delta\tau$

$$\psi_{scatt} = \int dE\, f(E)\, e^{ikx - iEt} \qquad \underbrace{\frac{e^{2i\delta} - 1}{2i}}_{\frac{\Gamma/2}{E - E_R + i\Gamma/2}}$$



width of resonance < width of w.p.

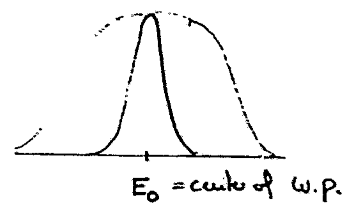
$$\hbar k \approx p_R + \frac{m}{p_R}(E - E_R)$$

$$f(E) \approx f(E_R)$$

$$\psi_{scatt} = 2\Gamma f(E_R)\, e^{i(p_R x - E_R t)} \int dE\, \frac{e^{i\left(\frac{x}{v_R} - t\right)(E - E_R)}}{E - E_R + i\Gamma/2}$$

$$\boxed{\psi_{scatt}(x,t) = 2\Gamma f(E_R)\, e^{i(p_R x - E_R t)}\, e^{-\frac{\Gamma}{2}\left(t - \frac{x}{v_R}\right)}}$$

→ Γ measures the lifetime of the resonant state populated with a wave packet with a large width



→ $\delta(E) \approx \delta(E_0) + \delta'(E - E_0)$

$$\psi_{scatt} = \int dE\, f(E)\, e^{ikx - iEt + i\delta(E_0) + i\delta'(E - E_0)}$$

$\cdot \sin \delta(E)$

The maximum of the scattered wave is the where the phase is stationary

$$x = v_0(t - \delta') = v_0 t - \frac{2\hbar/\Gamma}{[illegible]} v_0 \qquad E_0 = E_R \quad 2\frac{2\hbar}{\Gamma} v_0$$

Lifetime of Δ's in simulations

$$\tau = \frac{d\delta}{dE} \quad \text{if width of wavepacket} \ll \Gamma$$

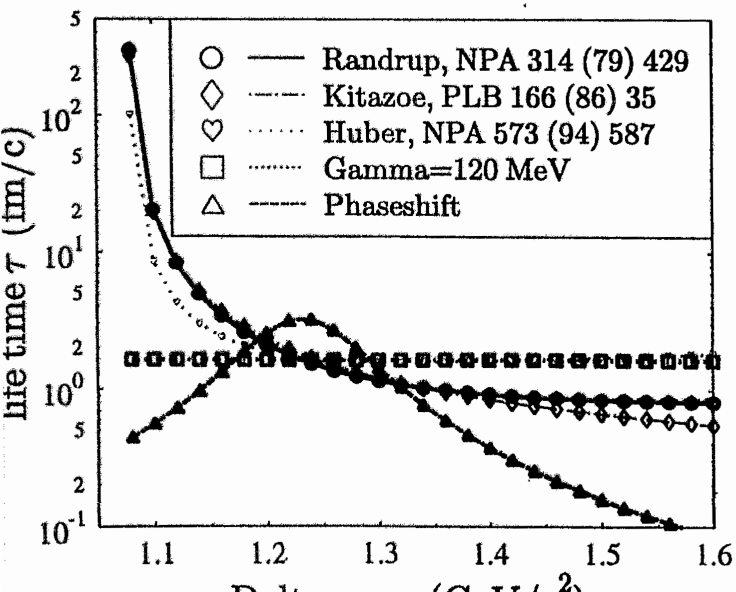
$$= \frac{\Gamma_0/2}{(E-E_0)^2 + \Gamma^2/4} \quad \text{for Breit-Wigner}$$

Up to now

$$\Gamma = \int \frac{d^3p_f}{E} \, |M|^2 \, \delta(p_i - p_f)$$

$$\tau = 1/\Gamma$$

Delta lifetime



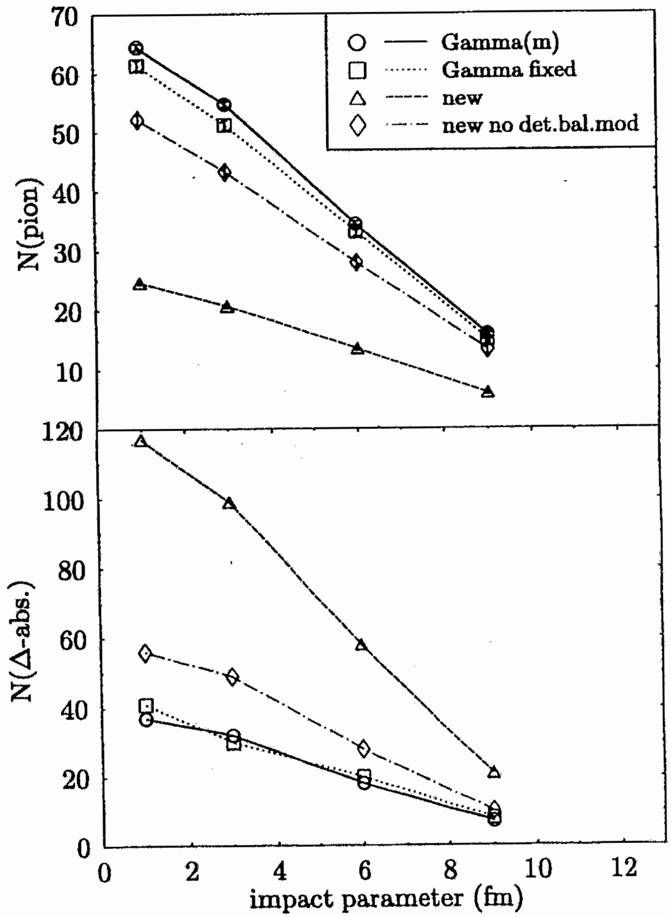
Δ lives much shorter than assumed

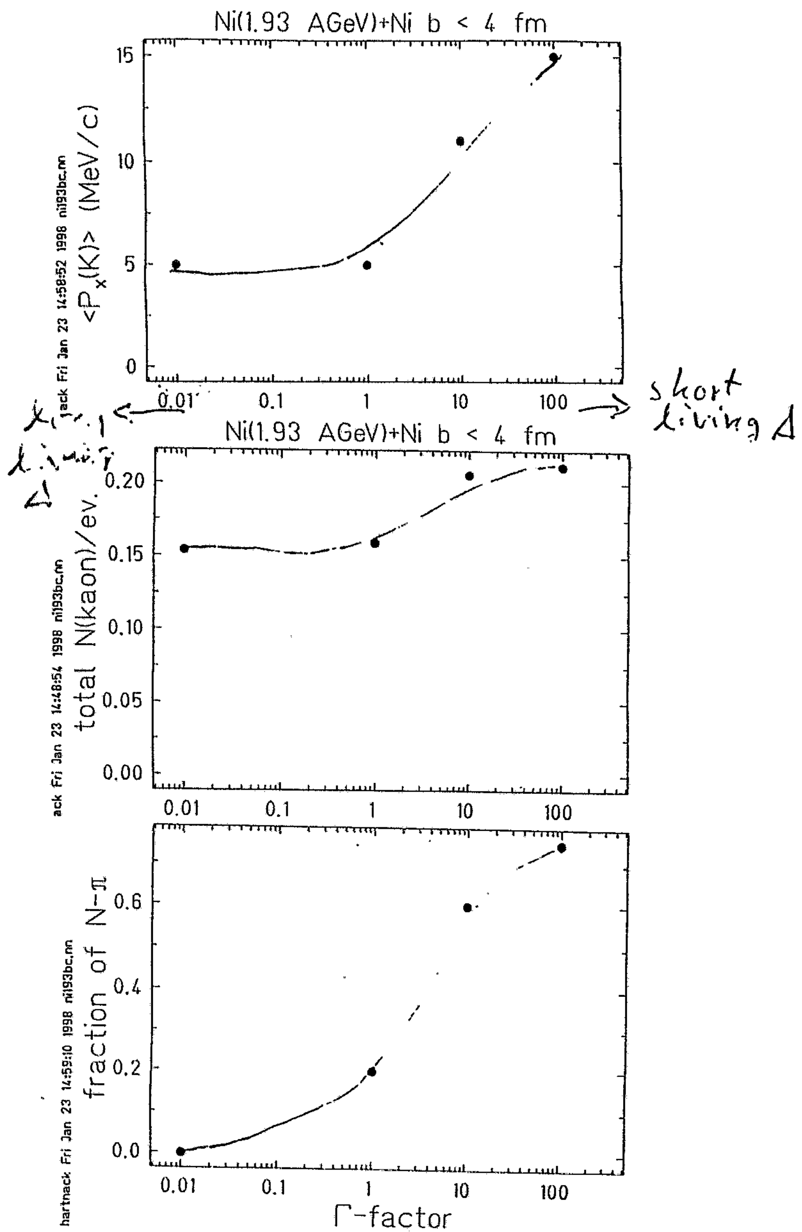
⇓

Probability for ΔN → ΛKN small

Pion yield

The new parametrisation yields less pions due to absorption. Au(1AGeV)+Au HM





Creation de kaons

- perturbative :

  reference cross section 40 mb

  - each time two hadrons h_1 and h_2 come closer than

    $r = \sqrt{4/\pi}$ [fm]

  - a kaon is produced with the probability

    $$P_K \quad \frac{\sigma_{h_1h_2 \to K+X}}{40\text{ mb}}$$

- the hadrons continue as if no K were produced!

- at the point of closest distance
  the kaons (as all particles) are produced if the
  the hadrons are closest.

- actual production
  - initially we assume that

    $$\sqrt{s} = \sqrt{(p^1+p^2)^2} \underbrace{+ \; V_{opt}(h_1) + V_{opt}(h_2)}_{>0}$$

    because particles can use this energy

    $$\text{threshold} = m_{h_1} + m_{h_2} + \omega_K(k_K=0) - \underbrace{\left(V_{h_1}(\rho) + V_{h_2}(\rho)\right)/6}_{\text{negative}}$$

    $$V_\Lambda(\rho) \approx \frac{2}{3} V_N(\rho)$$

Cross section (1) is calculated with these quantities

The momenta of the kaons and the outgoing hadrons are calculated with this $\sqrt{s}$ assuming that they are determined by phase space

This procedure does not conserve energy because the outgoing hadrons live in an optical potential

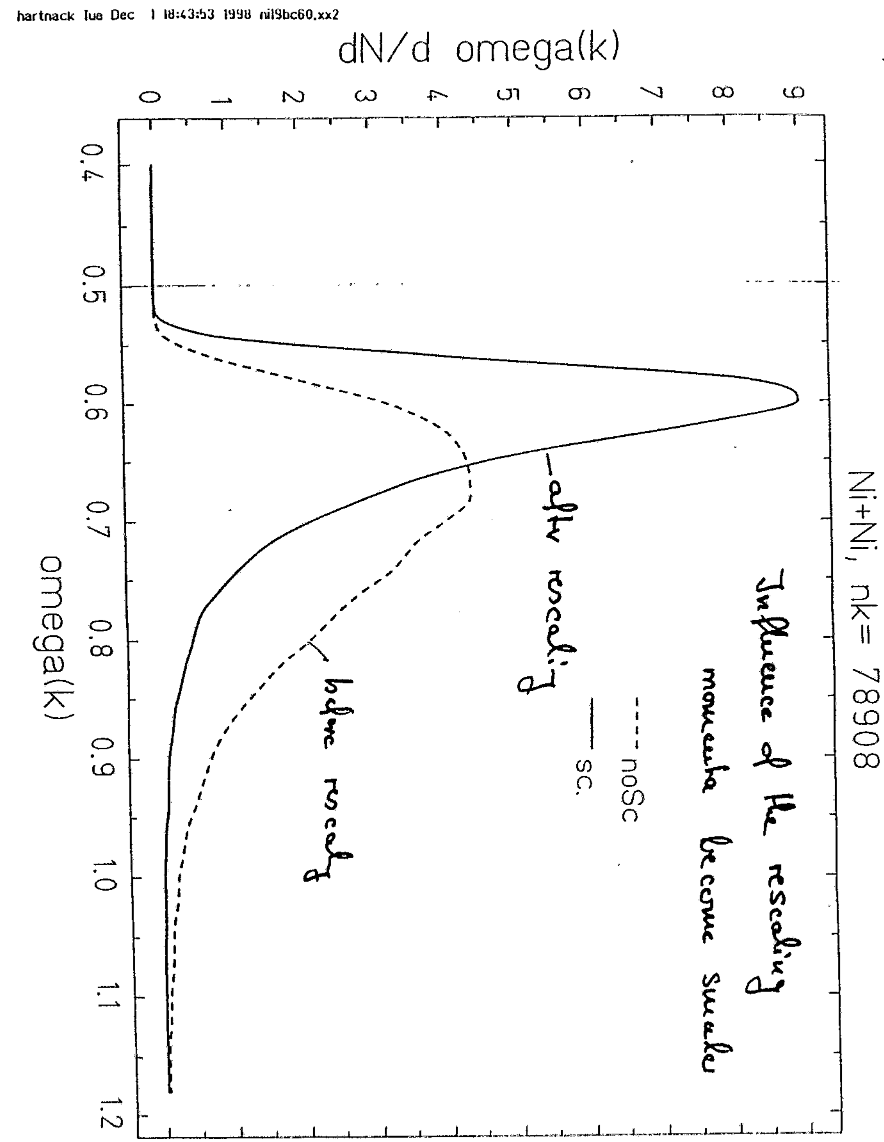
⇒ iteration procedure.

- rescale all momenta by a factor α
- recalculate
  $V_{opt}(h_1)$
  $V_{opt}(h_2)$
  $\omega(K)$
- if the energy difference between the incoming and outgoing particles is smaller than 1,0 MeV assume that we have found the right momenta.

• recalculate the true $\sqrt{s}$ of the reaction

$$\sqrt{s} = \sqrt{(p^1+p^2)^2} + \Delta V_{opt}(h_1) + \Delta V_{opt}(h_2)$$

cross section ② is calculated with this $\sqrt{s}$



Our approach

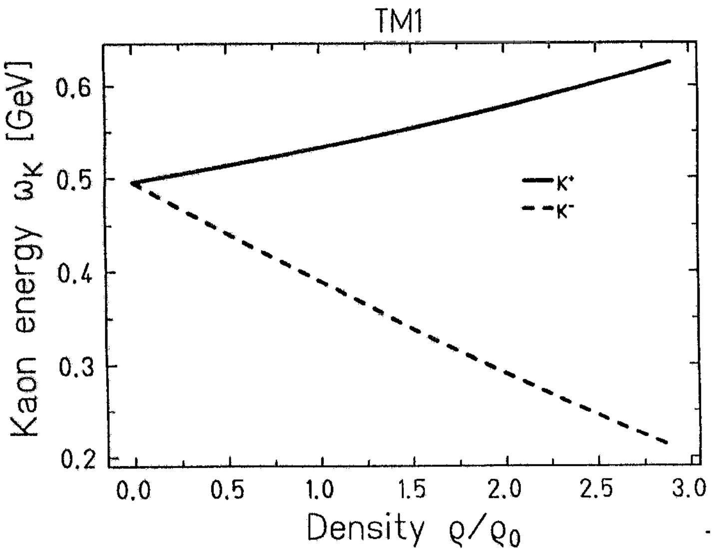
$$L_{KN} = D^*_\mu \overline{K} D^\mu K - m_K^2 \overline{K} K - g_{\sigma K} m_K \overline{K} K \sigma - g_{\delta K} m_K \overline{K} \vec{\tau} K \vec{\delta}$$

gives in infinite matter the equation of motion

$$(\partial_\mu \partial^\mu + m_K^2 + m_K \Sigma_S + 2(\Sigma_V^0) i\partial^0 - \Sigma_V^2) K = 0$$
$$(-2\vec{\Sigma}_V \cdot \vec{\partial}_x)$$

Energy of K $\longrightarrow$ enters for the cross section calculation

Optical potential $= \omega - \sqrt{m_K^2 + k^2}$



Kaon dispersion relation in nuclear medium

$$\omega_K^{*2} = m_K^2 + \vec{p}_K^{\,2} - \frac{\Sigma_{KN}}{f^2}\rho_S \pm \frac{3\omega_K^*}{4f^2}\rho_V$$

$\frac{\Sigma_{KN}}{f^2}\rho_S$ attractive scalar field

$\frac{3\omega_K^*}{4f^2}\rho_V$ vector field:

Repulsive for kaons

Attractive for antikaons (leading to a reduction of energy in medium)

K and $\bar{K}$ energies in medium

K^+ $$\omega_K^* = \sqrt{m_K^{*2} + \vec{p}_K^{\,2} + \left(\frac{3}{8f^2}\rho_V\right)^2} + \frac{3}{8f^2}\rho_V$$

K^- $$\omega_{\bar{K}}^* = \sqrt{m_K^{*2} + \vec{p}_K^{\,2} + \left(\frac{3}{8f^2}\rho_V\right)^2} - \frac{3}{8f^2}\rho_V$$

with

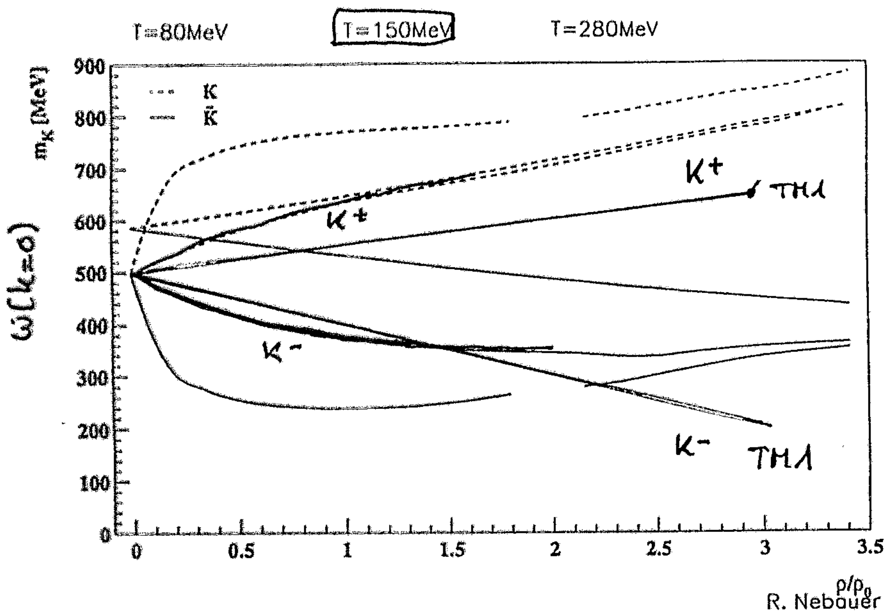
$$m_K^{*2} = m_K^{*2} - \frac{\Sigma_{KN}}{f^2}\rho_S$$

$$U_{opt} = \omega^* - \sqrt{m_K^2 + k^2}$$

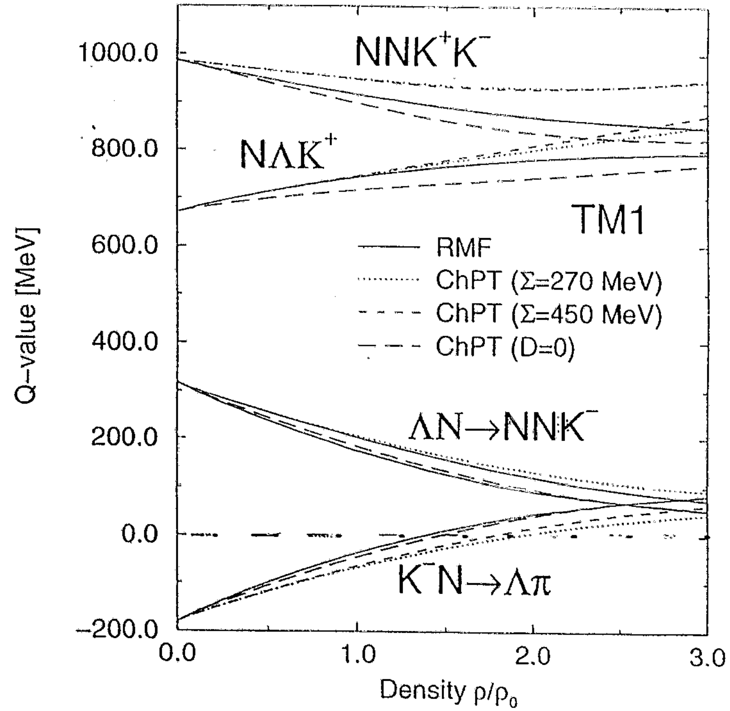
Changes of thresholds in medium

NJL - Kaon masses

Nambu - Jona - Lasinio



Schaffner et al. $(\vec{k}_{\bar{J}N} = 0)$



$K^-N - \Lambda\pi$: Q-value > 0

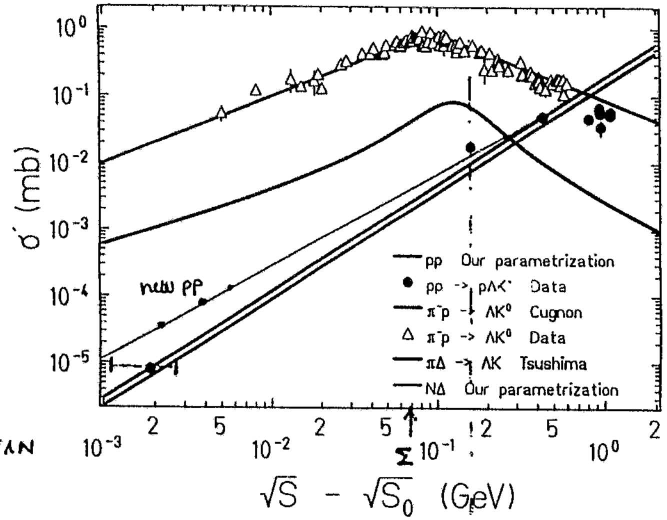
no K^- absorption

⇓

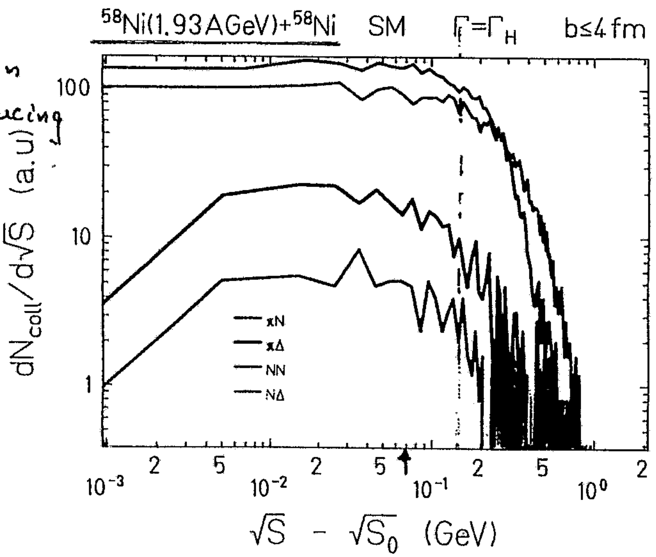
data

$\sigma_{\pi N \to \Lambda K} = \frac{1}{2}\,\sigma_{\pi^- p \to \Lambda K_0}$

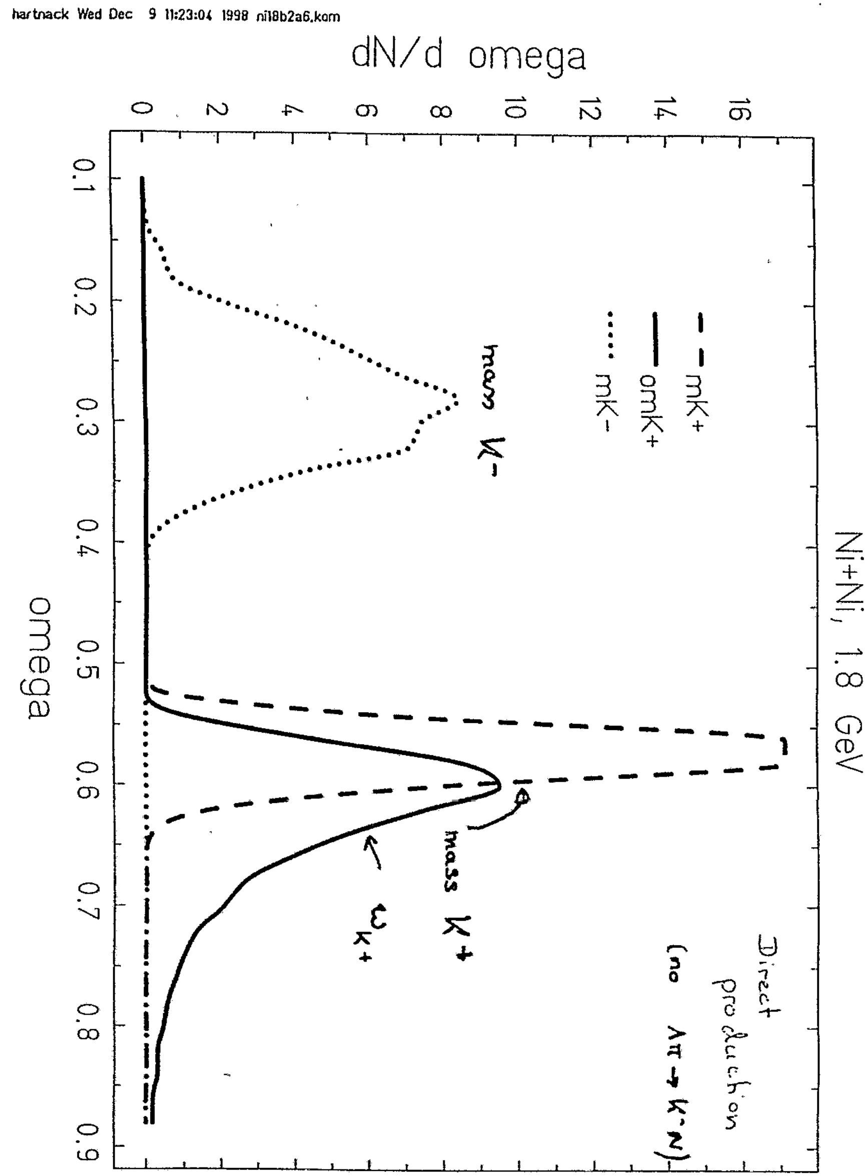
↳ this cross section controls the $\pi N \to K$ channel



$\sigma_{NN \to \Lambda K N} = 3\,\sigma_{pp \to K^+ \Lambda N}$



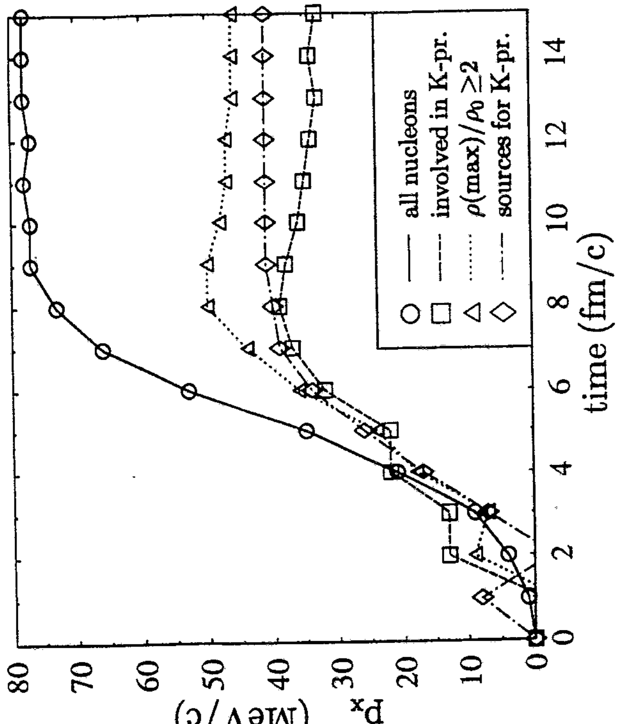
$\sqrt{s}$ distribution of kaon producing collisions in QMD



Time evolution of flow

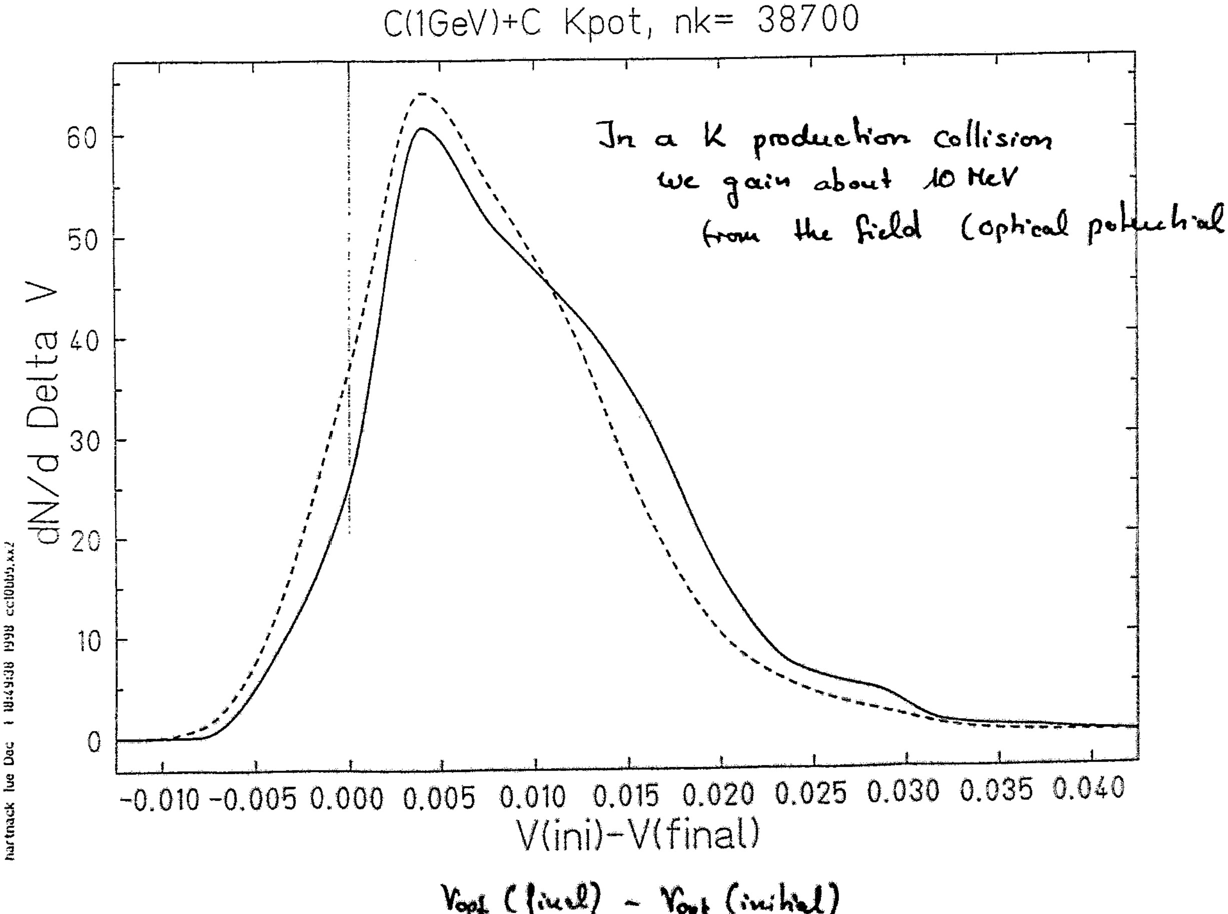
Nucleons involved in kaon production show much less flow than the average of all nucleons.

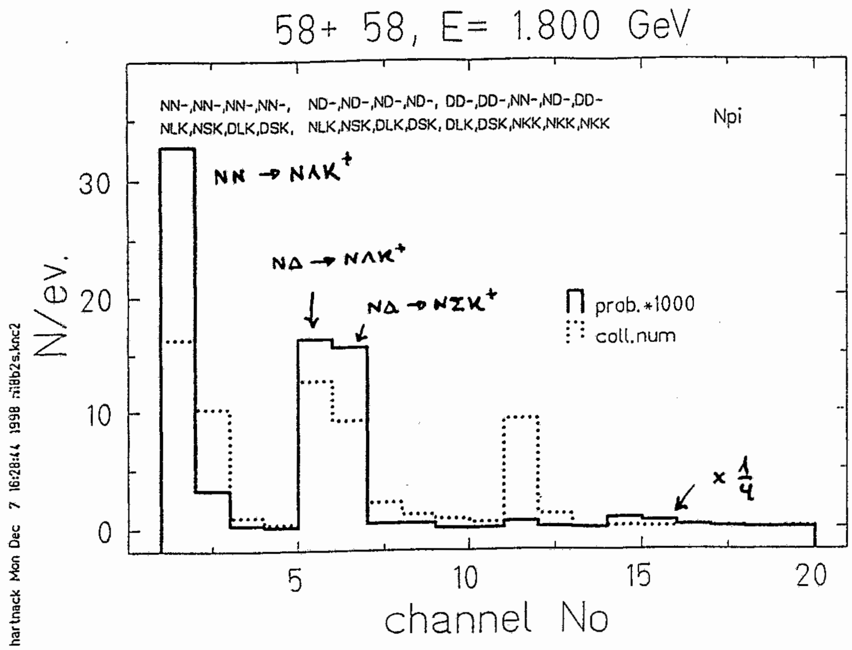
Ni(1.93 AGeV)+Ni b=2fm

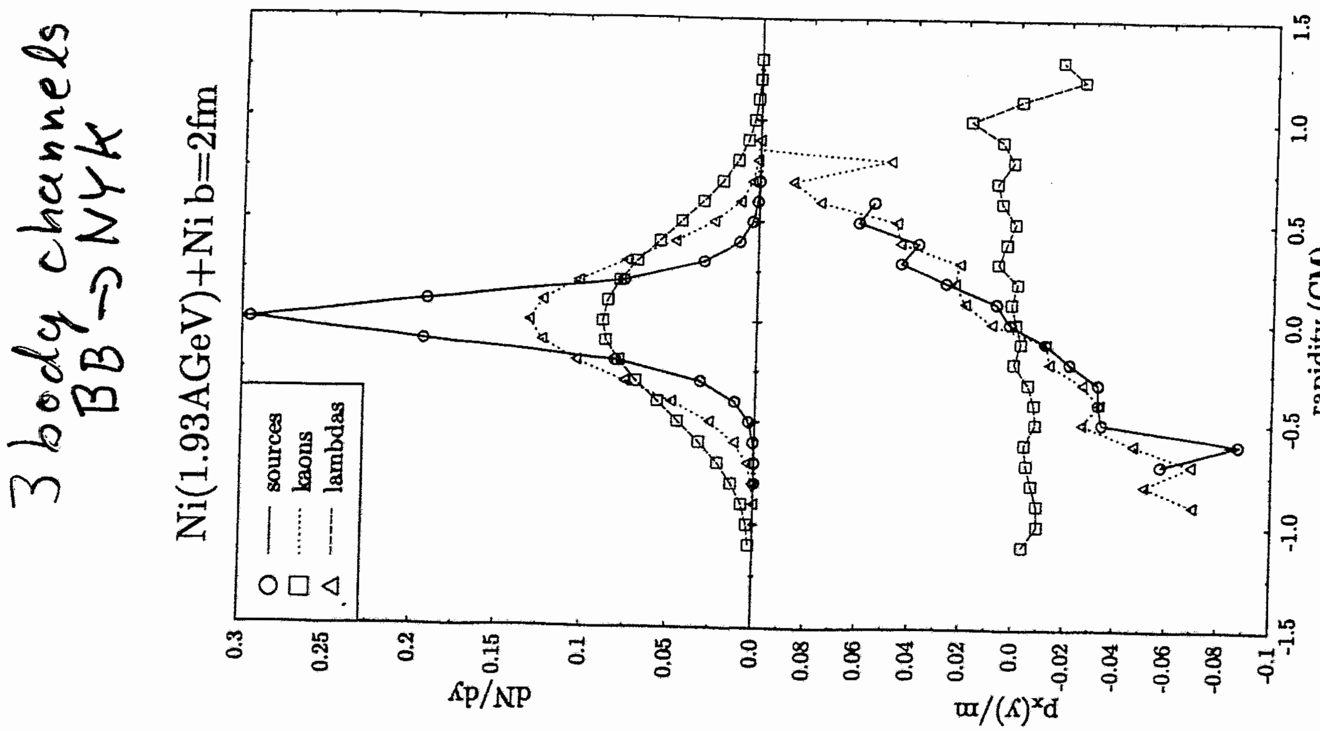


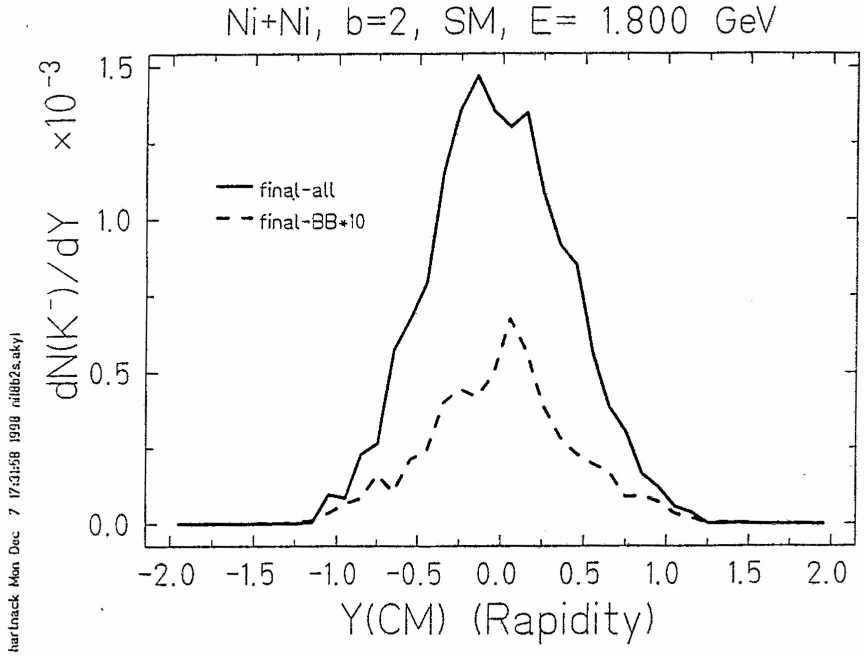
Similarly the flow of particles which felt highest densities is reduced.

The flow of the sources is strongly reduced, if we take into account their higher masses.

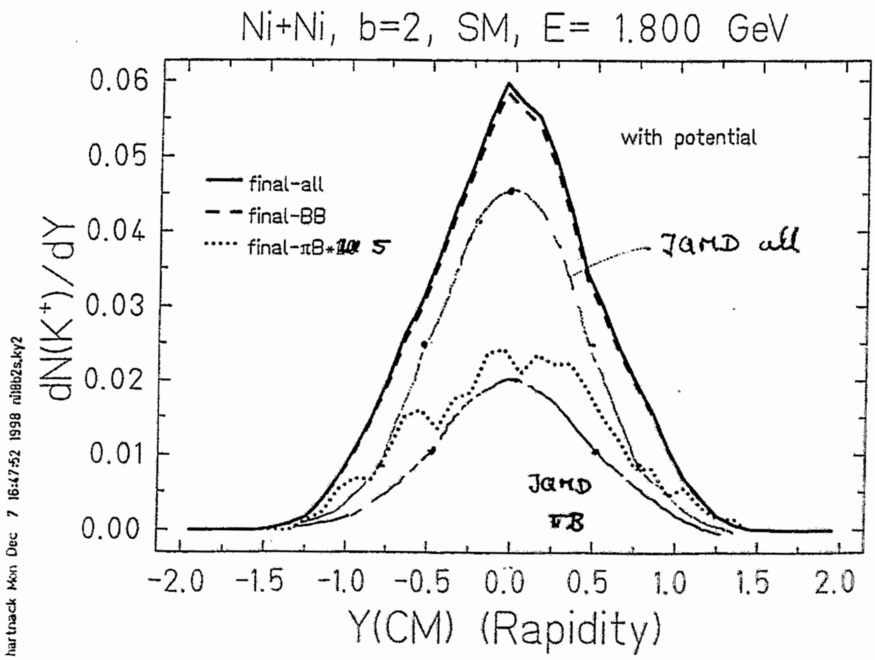


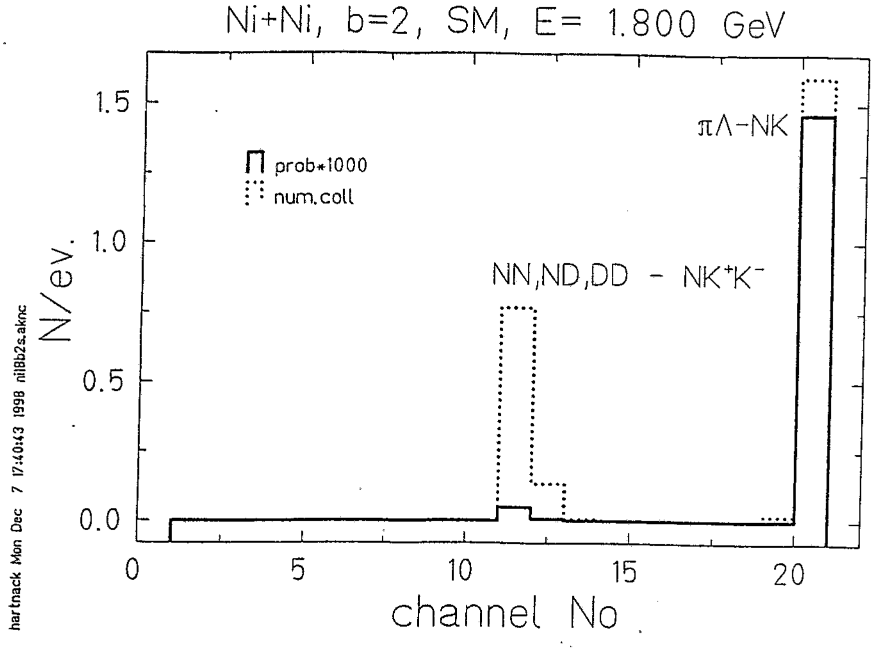

58+ 58, E= 1.800 GeV
NN-,NN-,NN-,NN-, ND-,ND-,ND-,ND-, DD-,DD-,NN-,ND-,DD-
NLK,NSK,DLK,DSK, NLK,NSK,DLK,DSK, DLK,DSK,NKK,NKK,NKK
Npi
NN → NΛK+
NΔ → NΛK+
NΔ → NΣK+
prob.*1000
coll.num
× 1/4
N/ev.
channel No
hartnack Mon Dec 7 16:28:44 1998 ni8b2s.knc2


3 body channels
BB → NYK
Ni(1.93AGeV)+Ni b=2fm
sources
kaons
lambdas
dN/dy
p^x(y)/m
rapidity (CM)

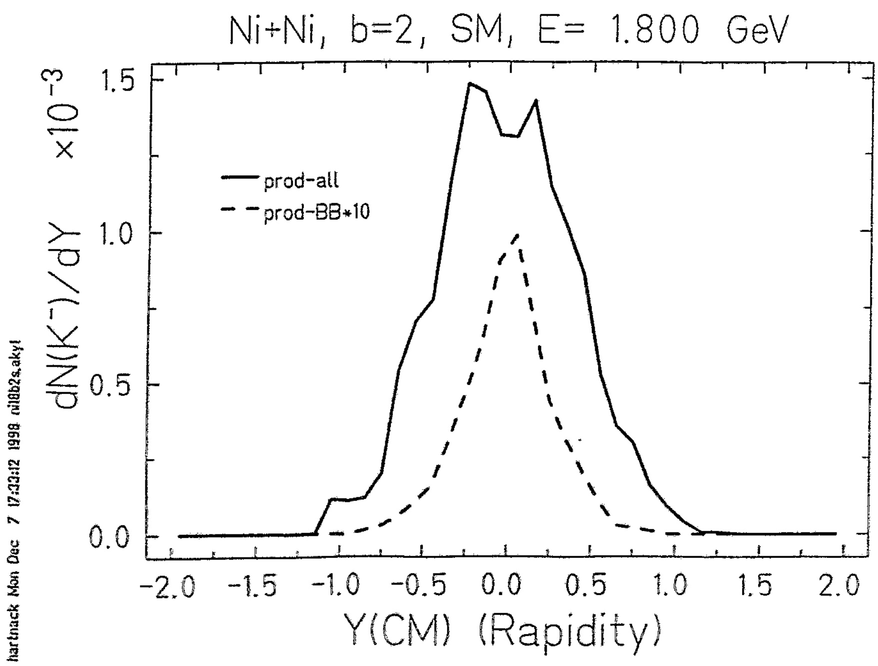


potential change only weakly the rapidity distribution





K⁻ production channel



S. Soff:

Kaon production at SIS energies in the UrQMD approach

Kaon Production at SIS energies
in the UrQMD approach

H. Weber, C. Ernst, M. Belkacem, S.S., H. Stöcker, W. Greiner

Inst. f. Theoret. Physik, Universität Frankfurt

– Some Ingredients of the UrQMD model.

– Modeling the elementary production channels via Resonances

– Example Ni (1.8 AGeV) Ni , b = 2 fm
  – standard phase space observables

– Comparison to C (2 AGeV) C , min. bias

– classification of production channels.

UrQMD

UrQMD hadron multipletts

N	Δ	Λ	Σ	Ξ	Ω
938	1232	1116	1192	1317	1672
1440	1600	1405	1385	1530	
1520	1620	1520	1660	1690	
1535	1700	1600	1670	1820	
1650	1900	1670	1790	1950	
1675	1905	1690	1775	2025	
1680	1910	1800	1915		
1700	1920	1810	1940		
1710	1930	1820	2030		
1720	1950	1830			
$1990^\dagger$		2100			
2080		2110			
2190					
2200					
2250					

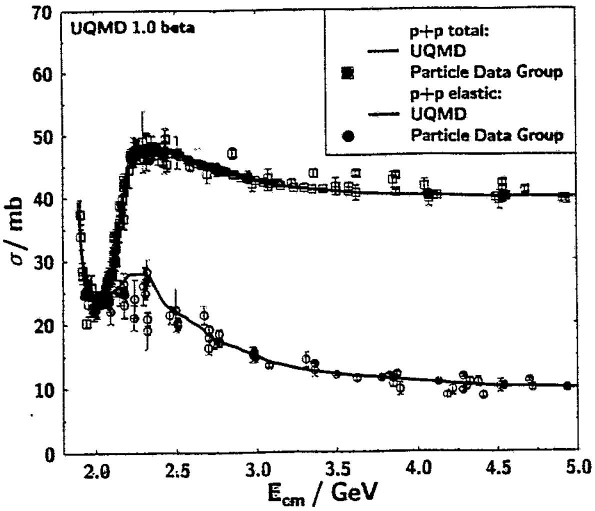
0^{-+}	1^{--}	0^{++}	1^{++}
π	ρ	a_0	a_1
K	K^*	K_0^*	K_1^*
η	ω	f_0	f_1
η'	ϕ	f_0^*	f_1'
1^{+-}	2^{++}	$(1^{--})^*$	$(1^{--})^{**}$
b_1	a_2	ρ_{1450}	ρ_{1700}
K_1	K_2^*	K^*_{1410}	K^*_{1680}
h_1	f_2	ω_{1420}	ω_{1662}
h_1'	f_2'	ϕ_{1680}	ϕ_{1900}

+ all charge conjugated states

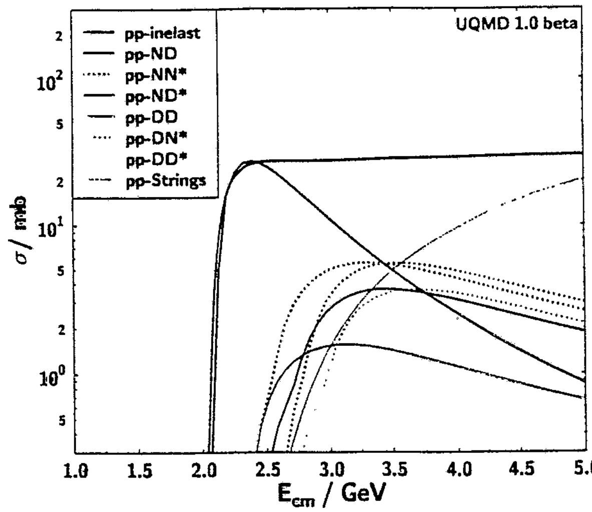
+ meson- & (anti-)baryon-strings

p+p Cross Sections

p+p total and elastic cross sections

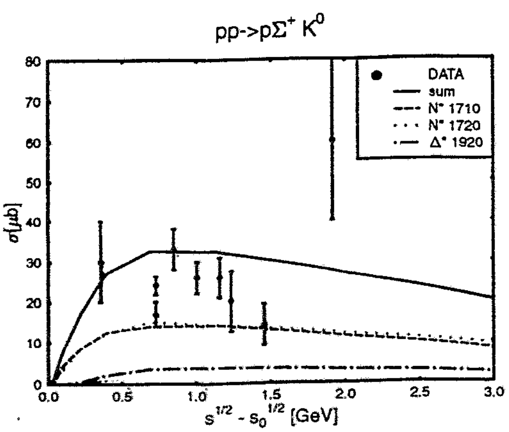


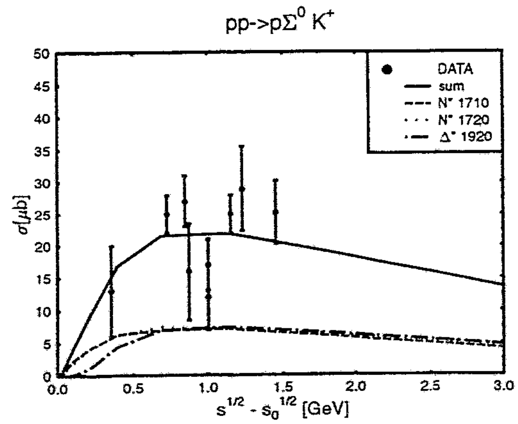
p+p inelastic channels



- total and elastic cross section via table lookup
- inelastic cross sections are parameterized (fixed to data)

Elementary Kaon Production

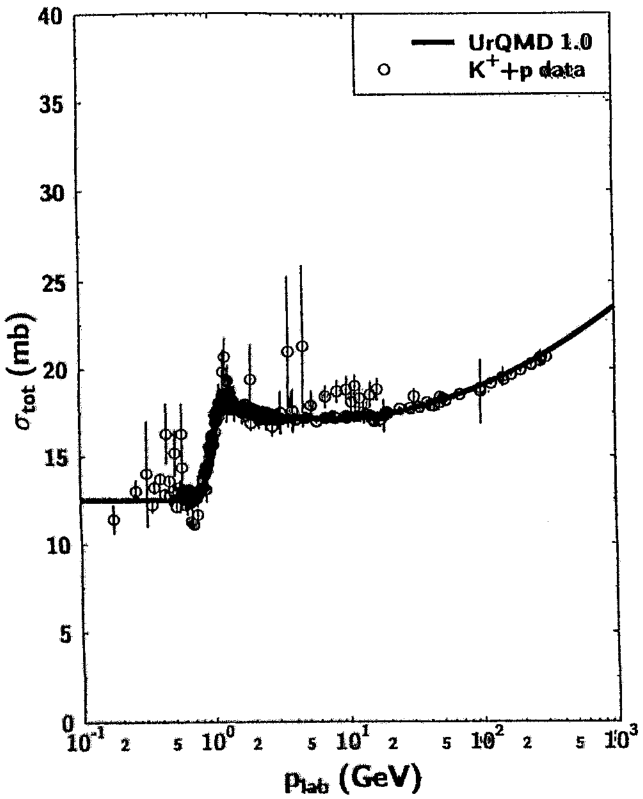




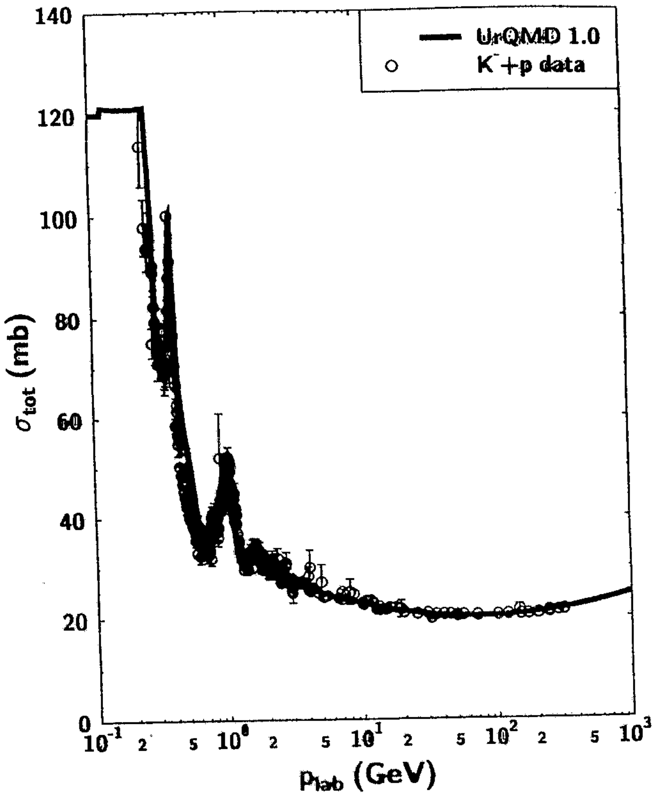
- $pp \to pN^*_{1710} \to p\Sigma^+ K^0$
- $pp \to pN^*_{1720} \to p\Sigma^+ K^0$
- $pp \to p\Delta^*_{1920} \to p\Sigma^+ K^0$

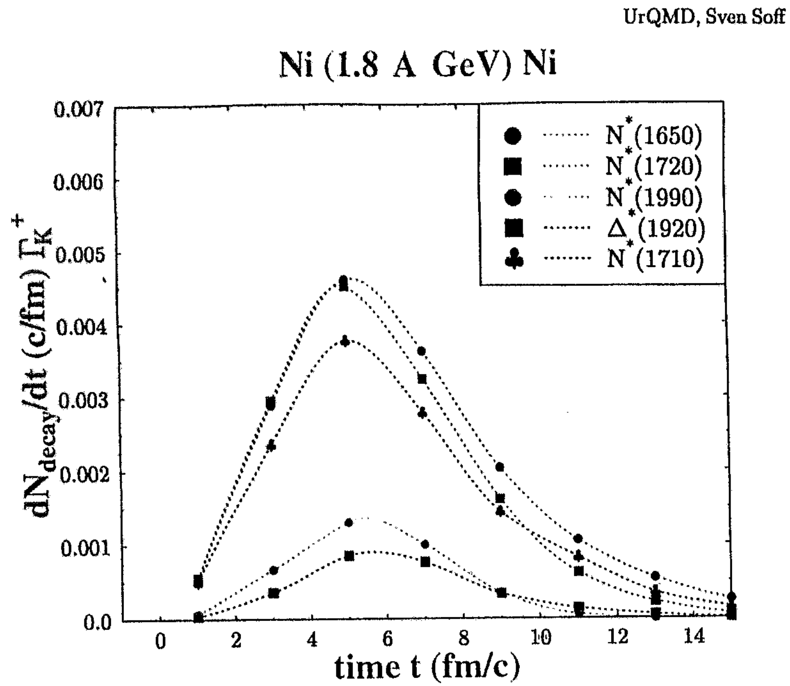
- $pp \to pN^*_{1710} \to p\Sigma^0 K^+$
- $pp \to pN^*_{1720} \to p\Sigma^0 K^+$
- $pp \to p\Delta^*_{1920} \to p\Sigma^0 K^+$

$K^+ p$ cross section
parametrized according to
experimental data (non-resonant)



$K^- p$ cross section
Hyperon Resonances





Resonance Abundancies weighted with branching ratio

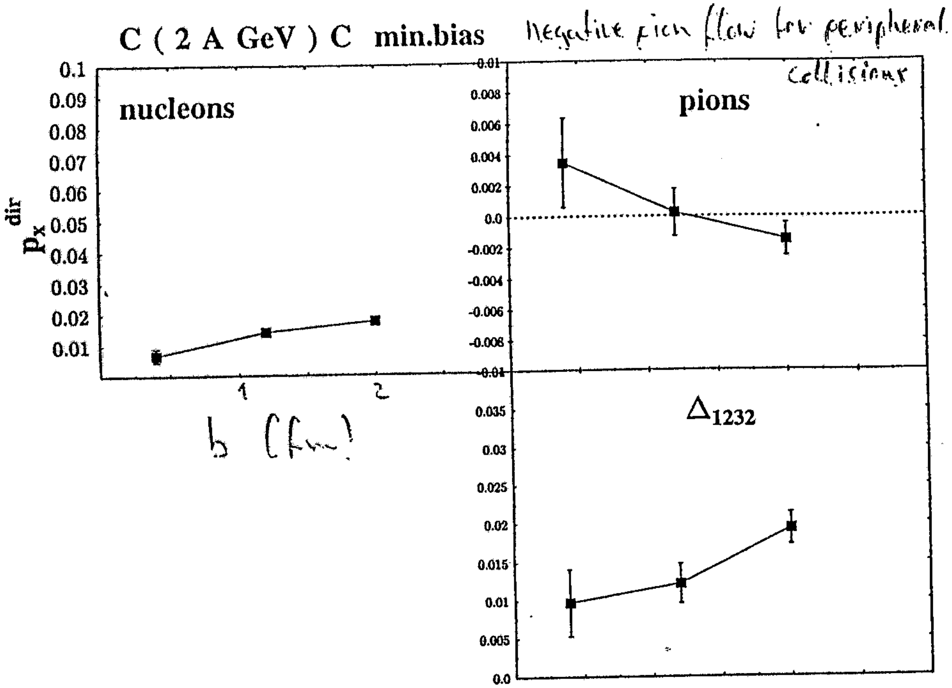
Ni (1.8 AGeV) Ni b = 2 fm

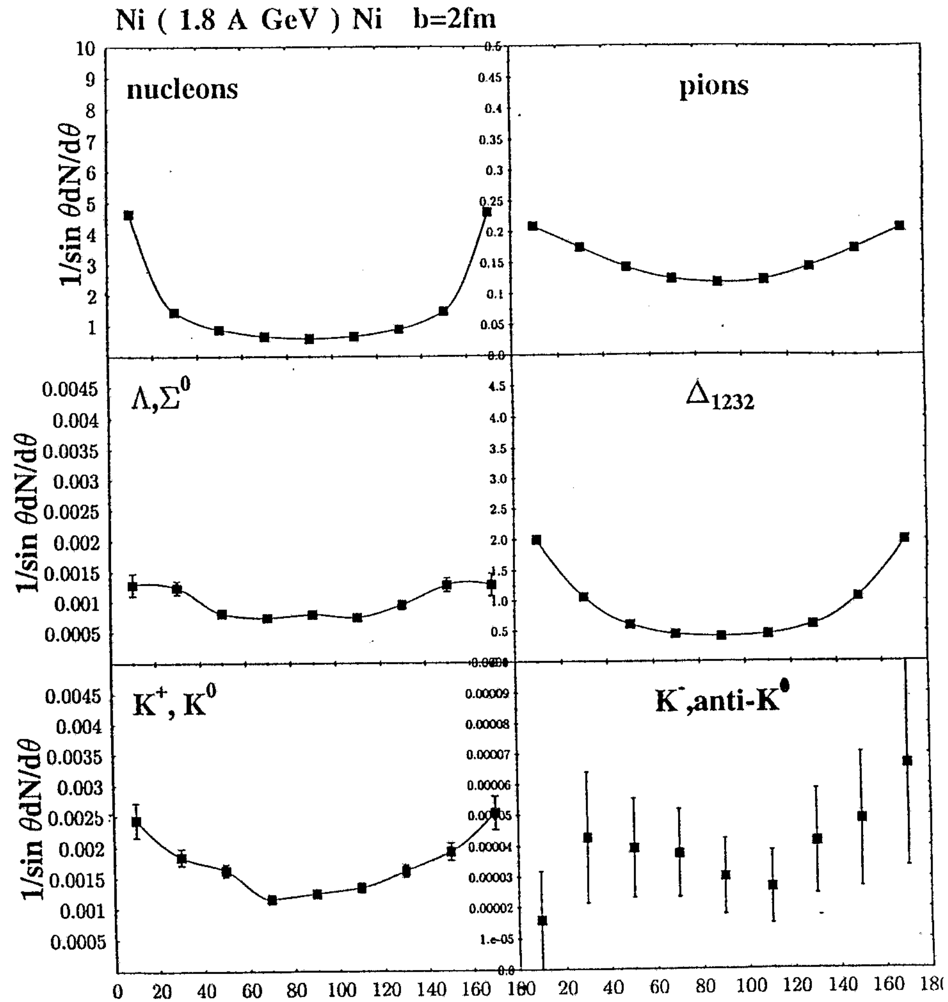
σ = 12.5,7 mb

# K^+ produced	0,10	→	$\sigma \approx$ 12,8 mb
# K^- produced	0,01	→	$\sigma \approx$ 1,3 mb
# K^+ absorbed	0,015	→	15% of produced
# K^- absorbed	0,008	→	76% of produced

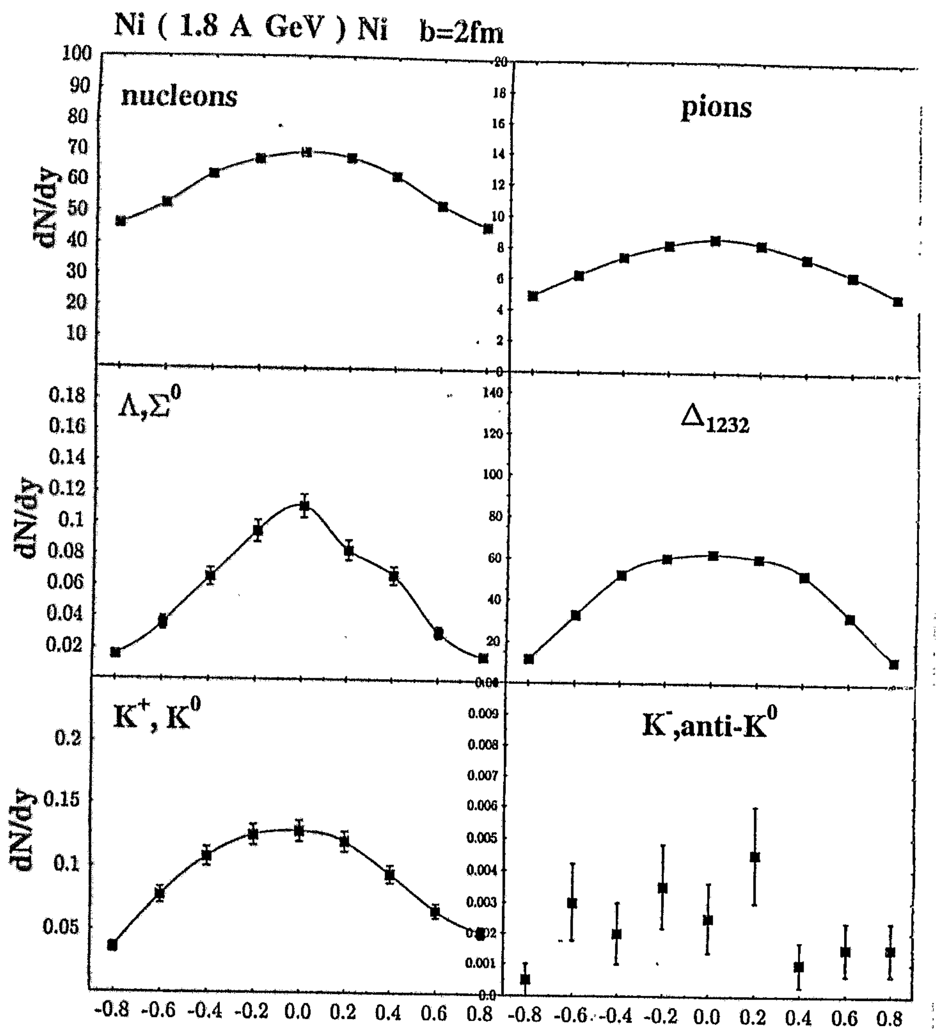
↳ K^- absorption essential

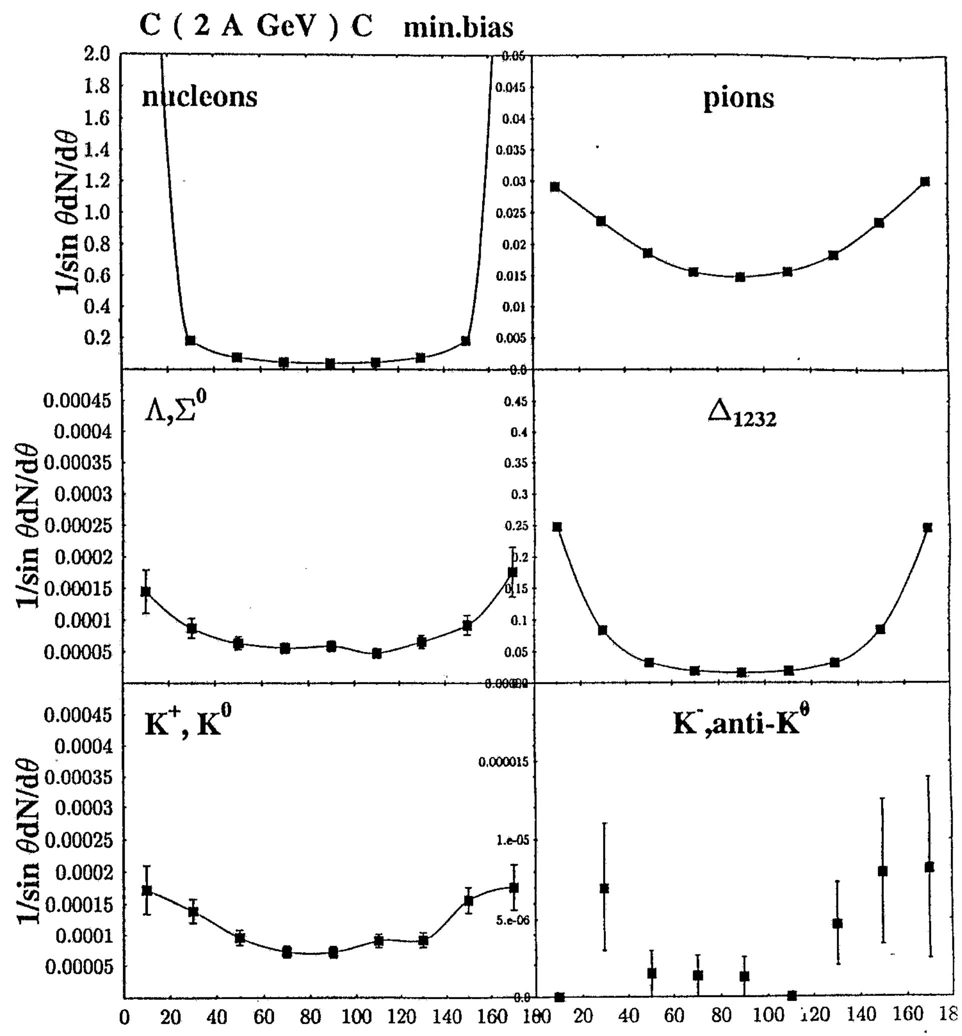
K^+ absorption important





Centrality Dependence of the strength and sign of the in-plane flow



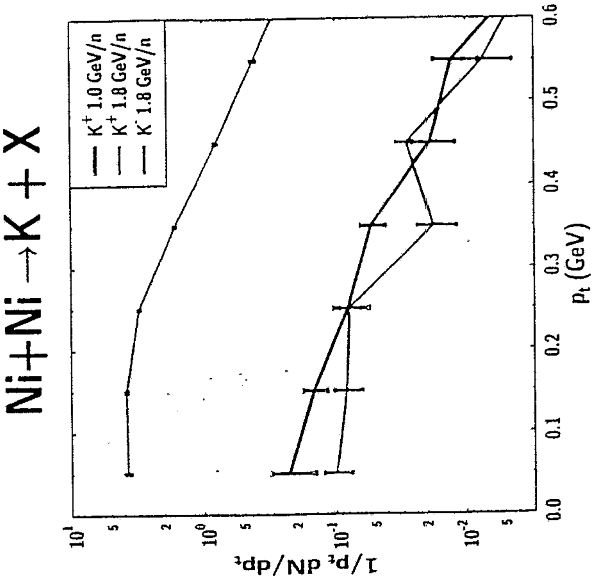


pions are broader than K$^+$ (than Δ!)

Forward backward peaking already in C+C

$$\approx \frac{(dN/d\cos\vartheta)_{max}}{(dN/d\cos\vartheta)_{min}} \approx 2-3 \; !$$

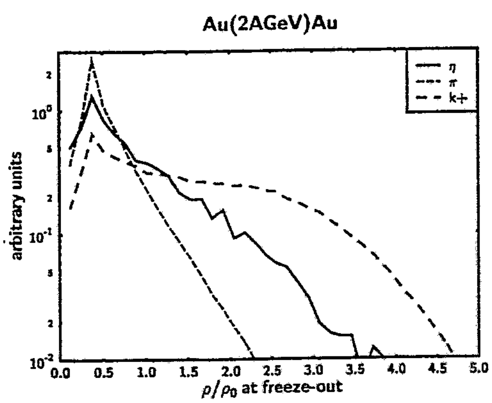
K^- enhancement: Pion – Hyperon Scattering

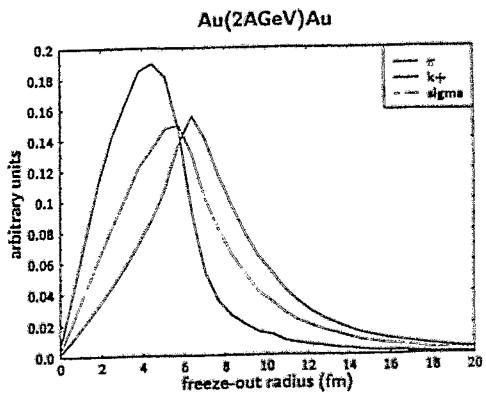


- UrQMD calculation in CASCADE mode
- at equivalent beam energies strong enhancement of K^- yield

$\Rightarrow$ enhancement due to $\pi\Sigma \to \Lambda^* \to N\bar{K}$

Freeze–out densities and radii





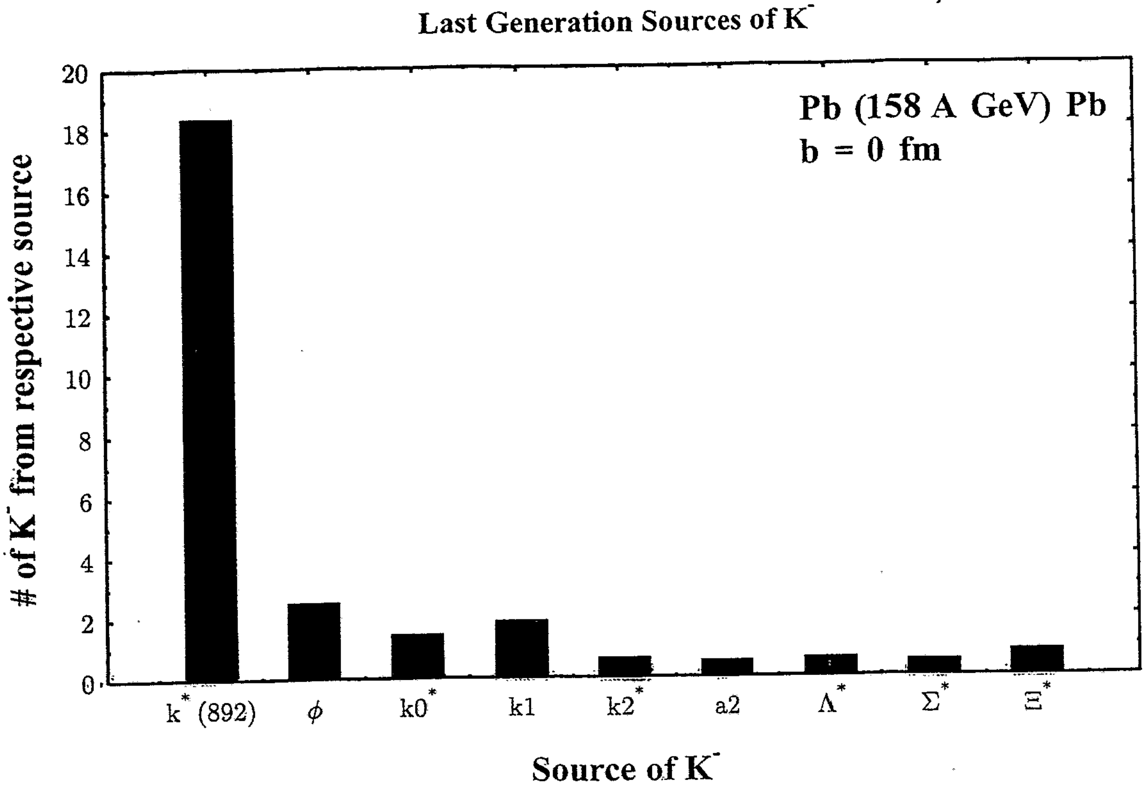
- most pions freeze out below ground state density
- K^+ are a good signal for the high density phase at SIS

- different source sizes for different particle species

$\Rightarrow$ no global freeze–out radius !

$\Rightarrow$ no global freeze–out density !

≃ 60 % of Last decays from Resonances (40 % 'direct')



Gy. Wolf:

Kaon production – benchmark test

Kaon Production, Benchmark test

G. Wolf

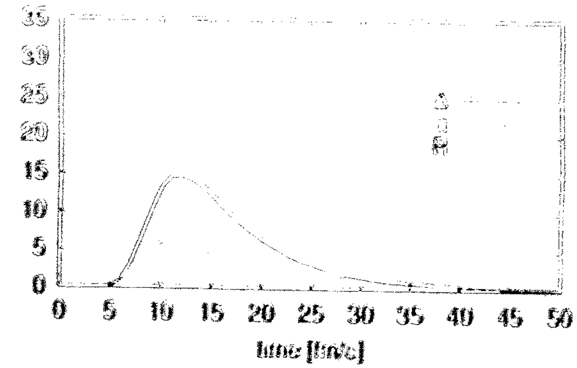
Properties of the model!

- 15 resonances
-- using energy dependent widths good description of meson production in hadron-hadron collisions.
- 5 mesons propagate $(\pi, \rho, \sigma, \eta, \omega)$
- potential : Skyrme, $k = 240$ MeV

kaons

- k^+
- it propagates and rescatters

$$\sigma_{el}^{k^+B} = 10 \text{ mb}$$



- creation :

$$\sigma^{pp \to pYK^+} = \frac{1.1 \left(\sqrt{s}-\sqrt{s_0}\right)^{1.71}}{\left(0.8\left(\sqrt{s}-\sqrt{s_0}\right)^{1.7} + 4.5\sqrt{\sqrt{s}-\sqrt{s_0}} + 1\right)} \text{ [m}$$

Randrup-Ko prescription:

$$\sigma^{N\Delta} = \frac{3}{4}\sigma^{NN}$$

$$\sigma^{\Delta\Delta} = \frac{1}{2}\sigma^{NN}$$

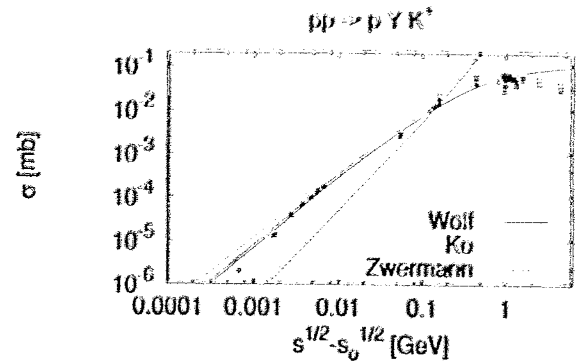
$$\sigma^{NR} = \sigma^{NN}$$

Cassing's fit:

$$\sigma^{\pi N} = \begin{cases} 1.47\,(\sqrt{s}-\sqrt{s_0}) & \sqrt{s} < 1.7 \\ 0.0225/(\sqrt{s}-\sqrt{s_0}) & \sqrt{s} \geq 1.7 \end{cases}$$

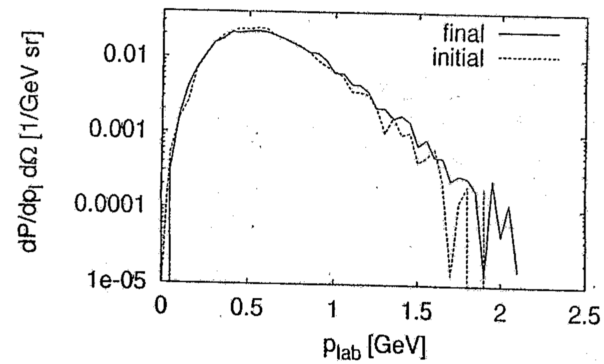
$$\sigma^{\pi^+ n} = 2\sigma^{\pi^0 p} = 4\sigma^{\pi N}$$

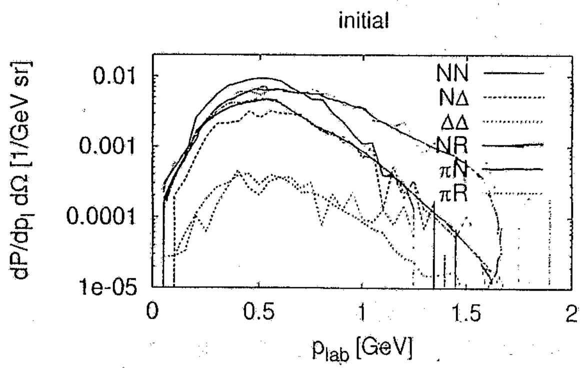
$$\sigma^{\pi R} = \frac{1}{4}\sigma^{\pi N}$$

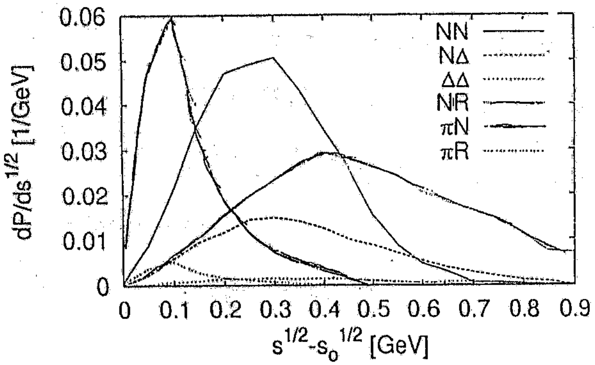


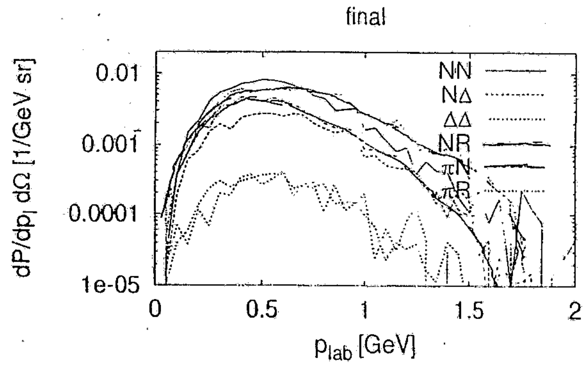
Total probabilities :

NN	NΔ	ΔΔ	NR	πN	πR
0.0175	0.00636	0.000788	0.0162	0.00979	0.000829
13076	7553	1256	8622	3559	1547

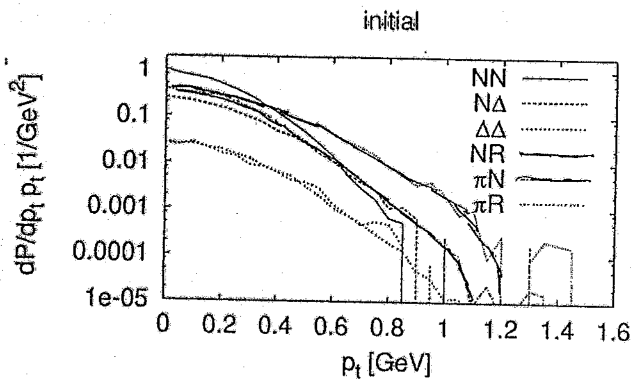


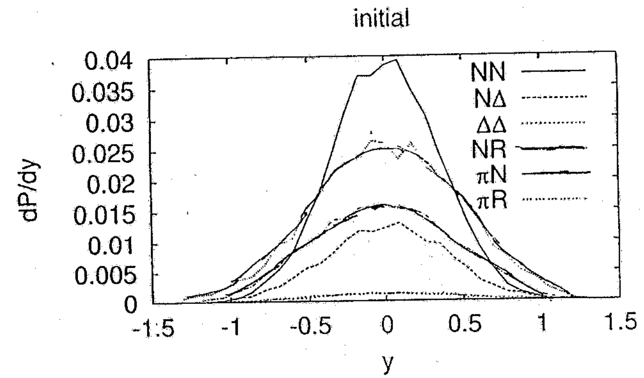


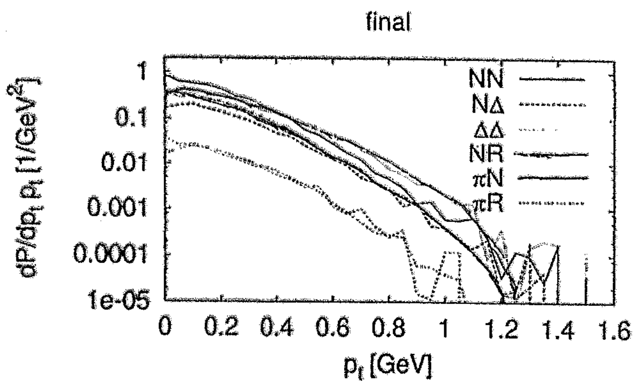


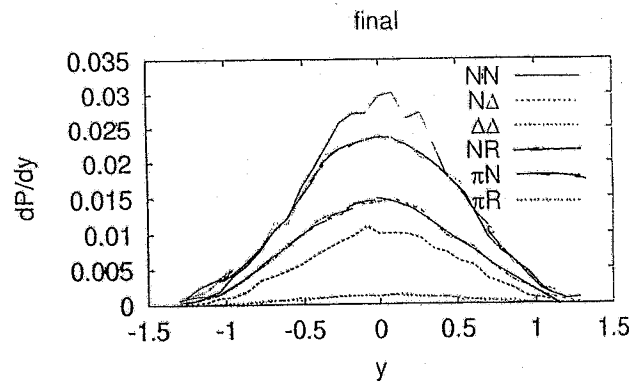


Budapest


initial
NN
NΔ
ΔΔ
NR
πN
πR
dP/dp_t p_t [1/GeV^2]
p_t [GeV]


initial
NN
NΔ
ΔΔ
NR
πN
πR
dP/dy
y


final
NN
NΔ
ΔΔ
NR
πN
πR
dP/dp_t p_t [1/GeV^2]
p_t [GeV]


final
NN
NΔ
ΔΔ
NR
πN
πR
dP/dy
y

C. Fuchs:

K^+ production with Tübingen QMD

K^+ production with Tübingen QMD

C. Fuchs

Tübingen

Benchmark tests:

Ni + Ni, 1.8 A.GeV, $b = 2$ fm

QMD, SMDI, $\Gamma_\Delta = 120$ MeV, $\Gamma_{N^*} = 200$ MeV

K^+ production:

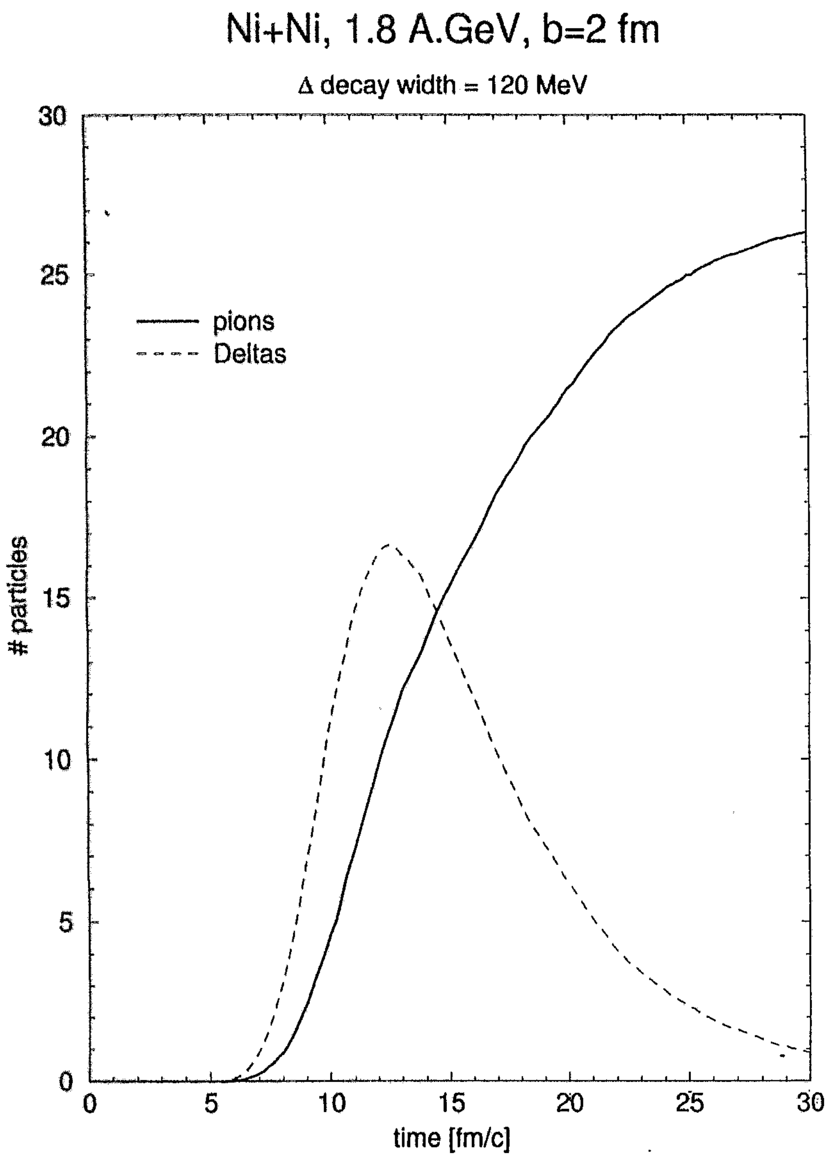
$BB \to BYK^+$: Tsushima et al. nucl-th/9801063

$NN \to N\Lambda K^+$, $NN \to N\Sigma K^+$
$NN \to \Delta\Lambda K^+$, $NN \to \Delta\Sigma K^+$
$N\Delta \to N\Lambda K^+$, $N\Delta \to N\Sigma K^+$
$N\Delta \to \Delta\Lambda K^+$, $N\Delta \to \Delta\Sigma K^+$
$\Delta\Delta \to \Delta\Lambda K^+$, $\Delta\Delta \to \Delta\Sigma K^+$

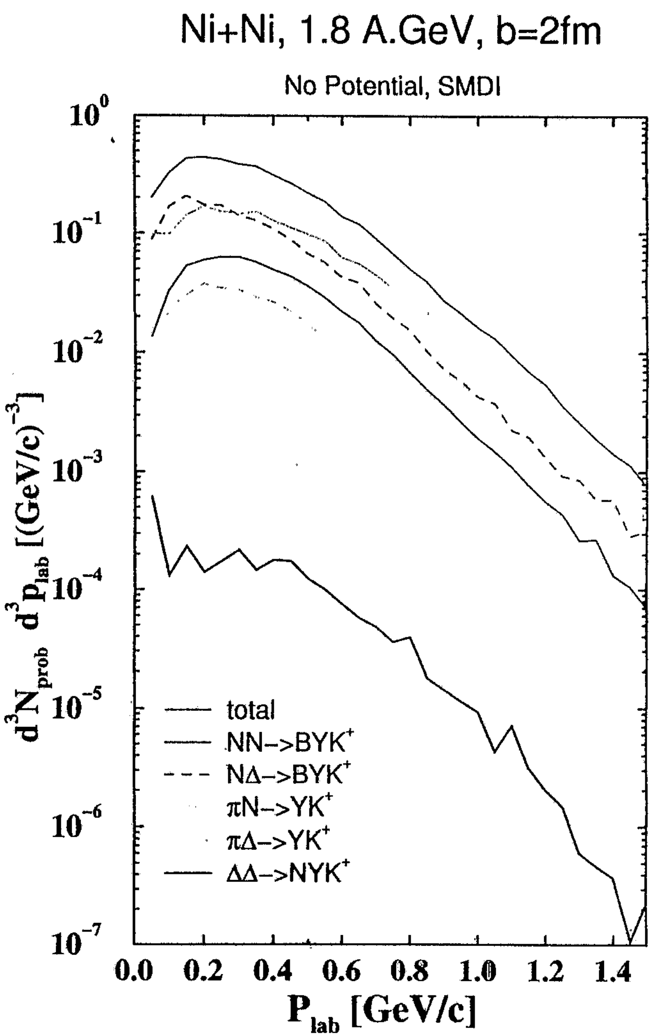
$\pi B \to YK^+$: Tsushima, Huang, Faessler, PLB 337 ('94) 245, JPG 21 ('95) 33

$\pi N \to \Lambda K^+$, $\pi N \to \Sigma K^+$
$\pi\Delta \to \Lambda K^+$, $\pi\Delta \to \Sigma K^+$

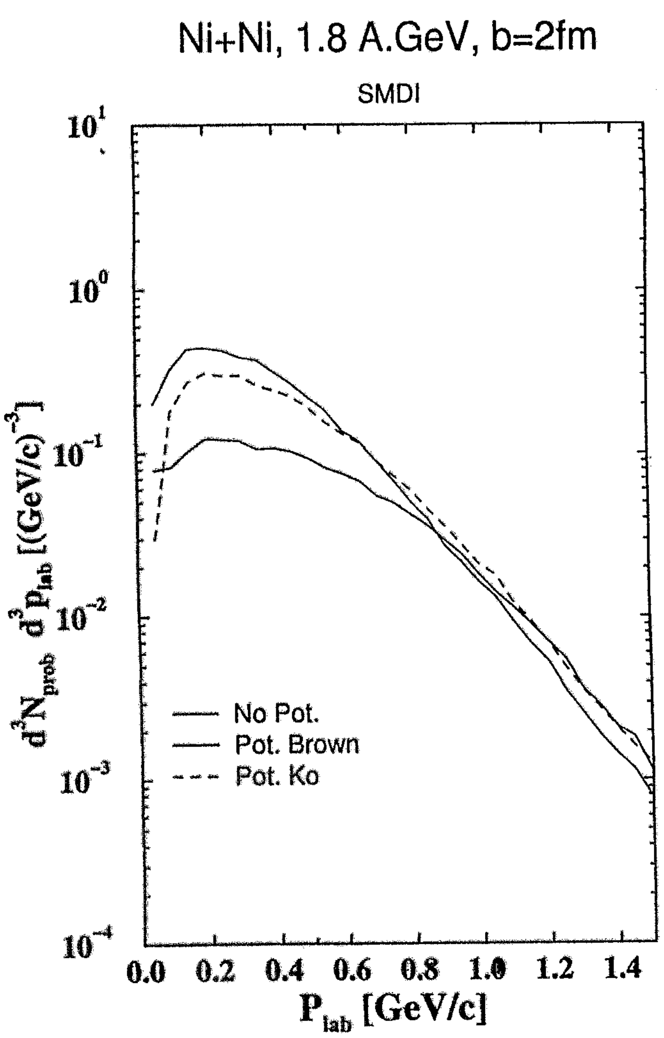
$K^+B \to K^+B$: Rescattering : Li et al., NPA 625 ('97) 372



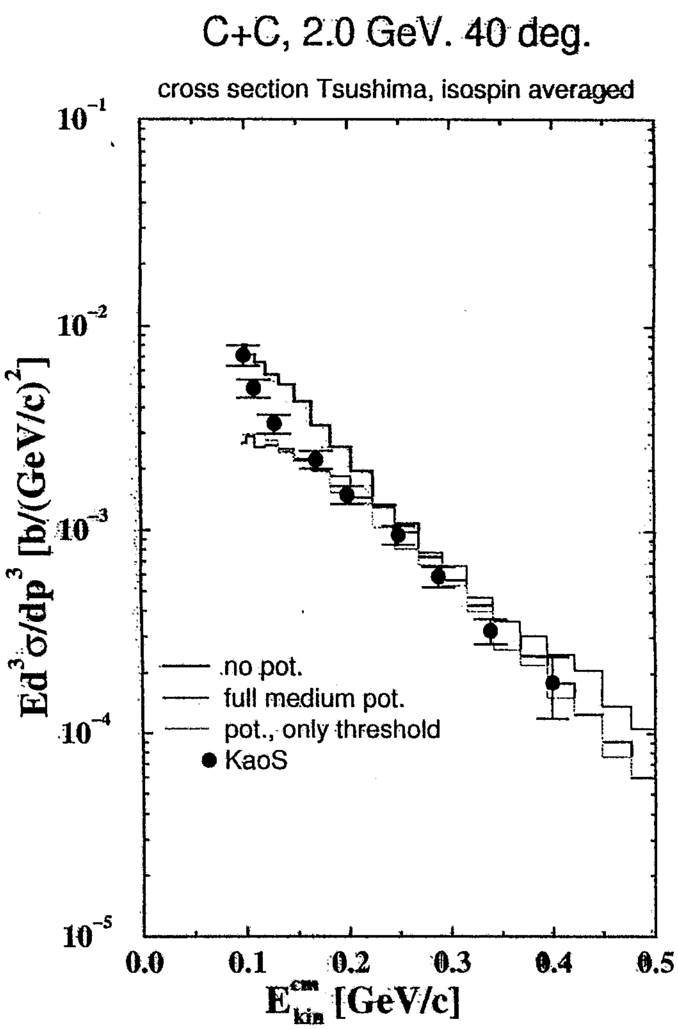
Ni+Ni, 1.8 A.GeV, b=2 fm
Δ decay width = 120 MeV
pions
Deltas
particles
time [fm/c]



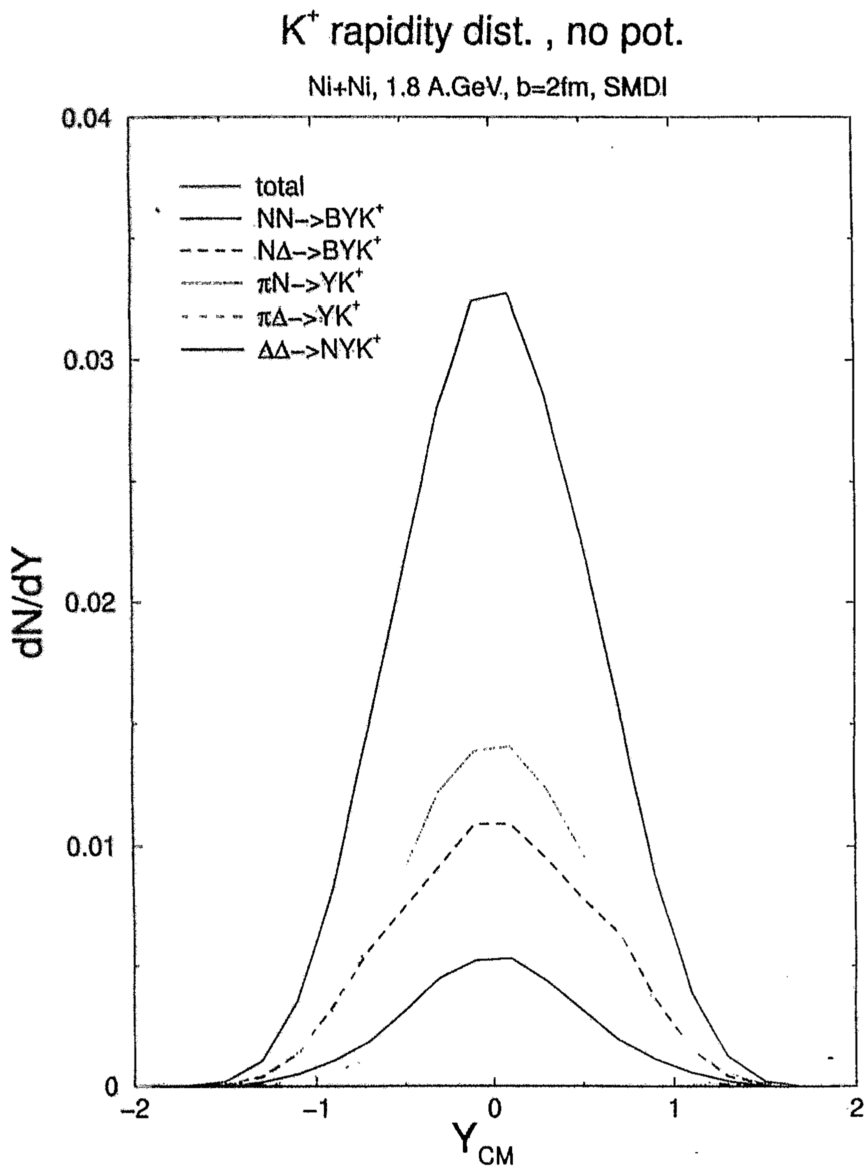
Ni+Ni, 1.8 A.GeV, b=2fm
No Potential, SMDI
total
NN->BYK+
NΔ->BYK+
πN->YK+
πΔ->YK+
ΔΔ->NYK+
d3Nprob d3plab [(GeV/c)-3]
Plab [GeV/c]

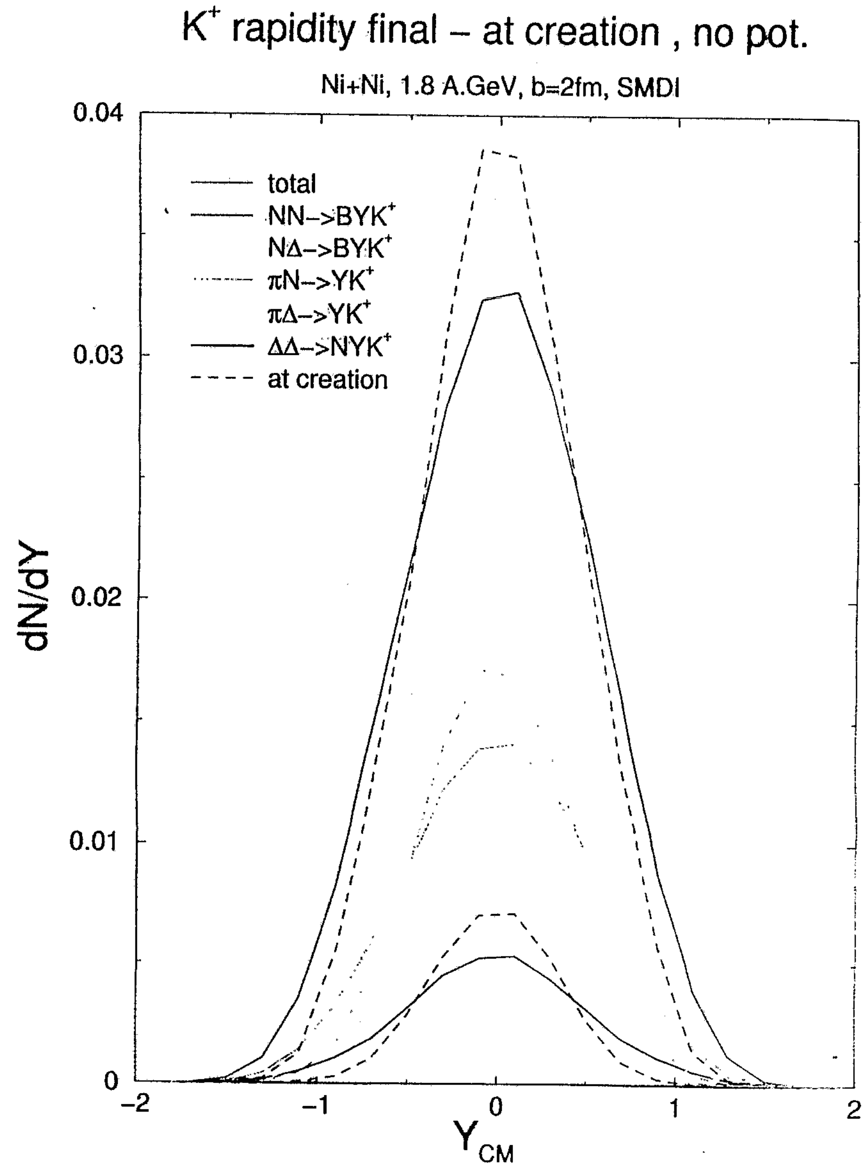


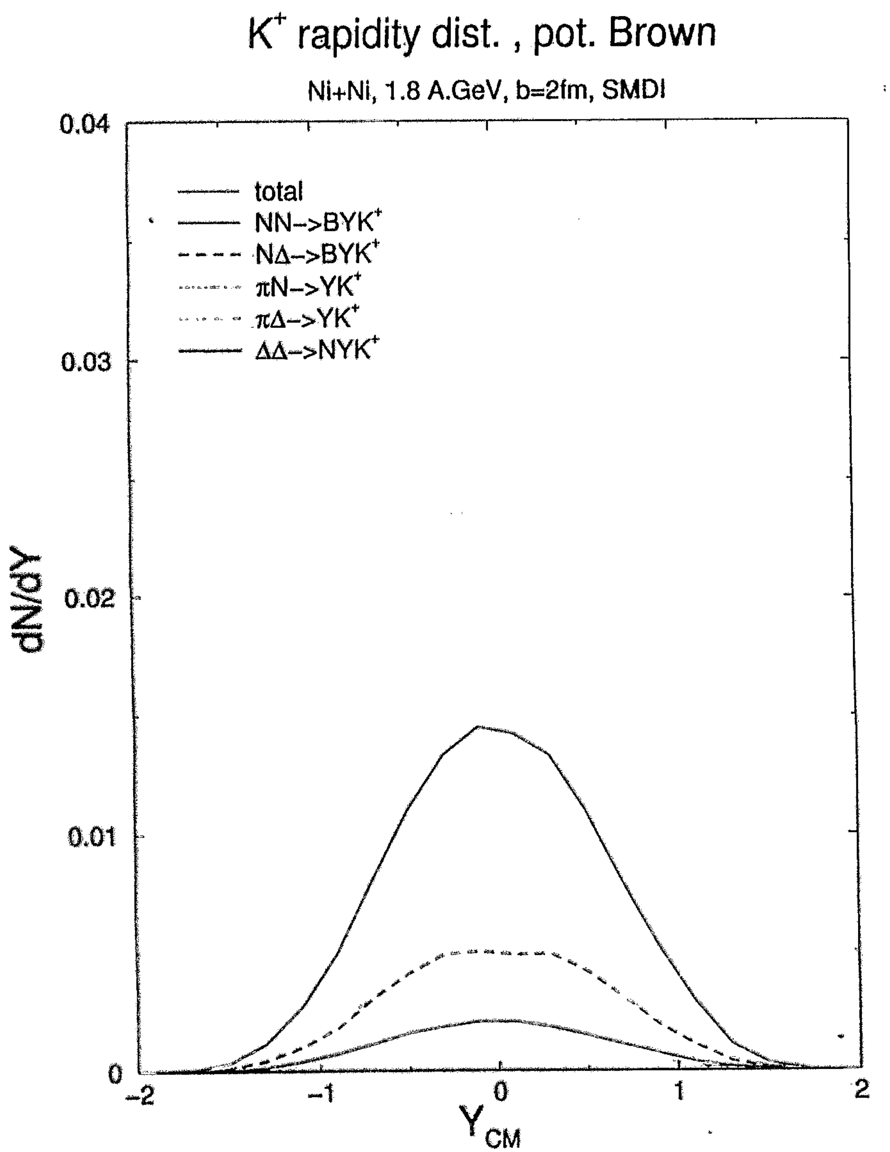
Ni+Ni, 1.8 A.GeV, b=2fm
SMDI
$d^3N_{prob}\ d^3p_{lab}\ [(GeV/c)^{-3}]$
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
No Pot.
Pot. Brown
Pot. Ko
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
P_{lab} [GeV/c]



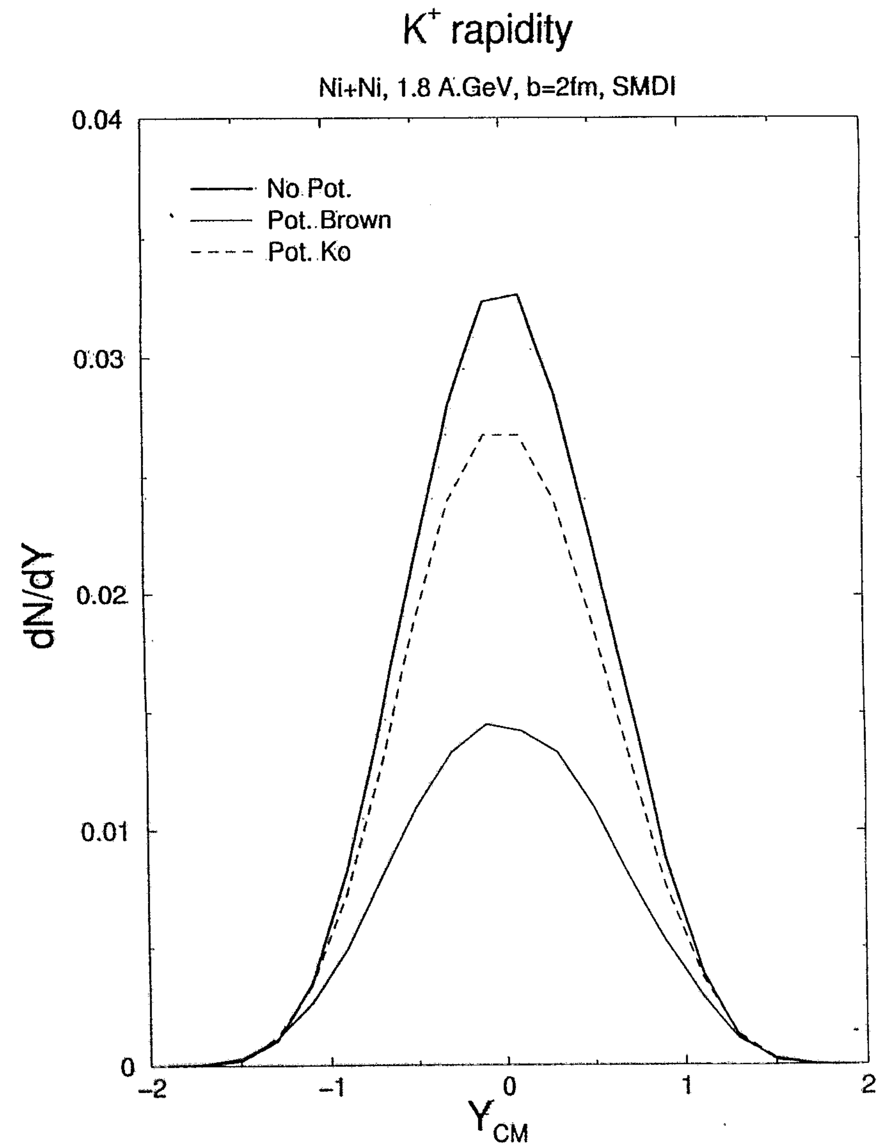
C+C, 2.0 GeV. 40 deg.
cross section Tsushima, isospin averaged
$Ed^3\sigma/dp^3\ [b/(GeV/c)^2]$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
no pot.
full medium pot.
pot., only threshold
KaoS
0.0 0.1 0.2 0.3 0.4 0.5
E_{kin}^{cm} [GeV/c]


K+ rapidity dist. , no pot.
Ni+Ni, 1.8 A.GeV, b=2fm, SMDI
total
NN->BYK+
NΔ->BYK+
πN->YK+
πΔ->YK+
ΔΔ->NYK+
dN/dY
0.04
0.03
0.02
0.01
0
−2
−1
0
1
2
YCM

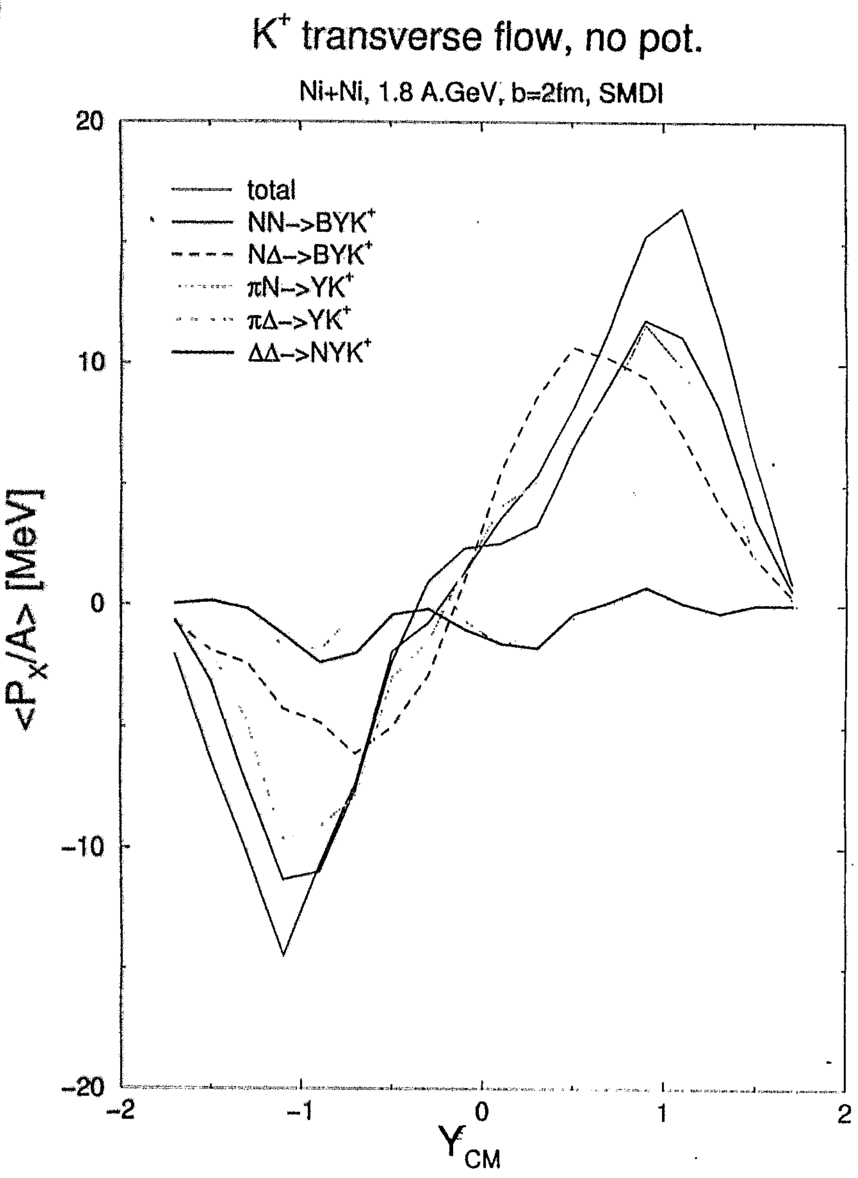

K+ rapidity final − at creation , no pot.
Ni+Ni, 1.8 A.GeV, b=2fm, SMDI
total
NN->BYK+
NΔ->BYK+
πN->YK+
πΔ->YK+
ΔΔ->NYK+
at creation
dN/dY
0.04
0.03
0.02
0.01
0
−2
−1
0
1
2
YCM



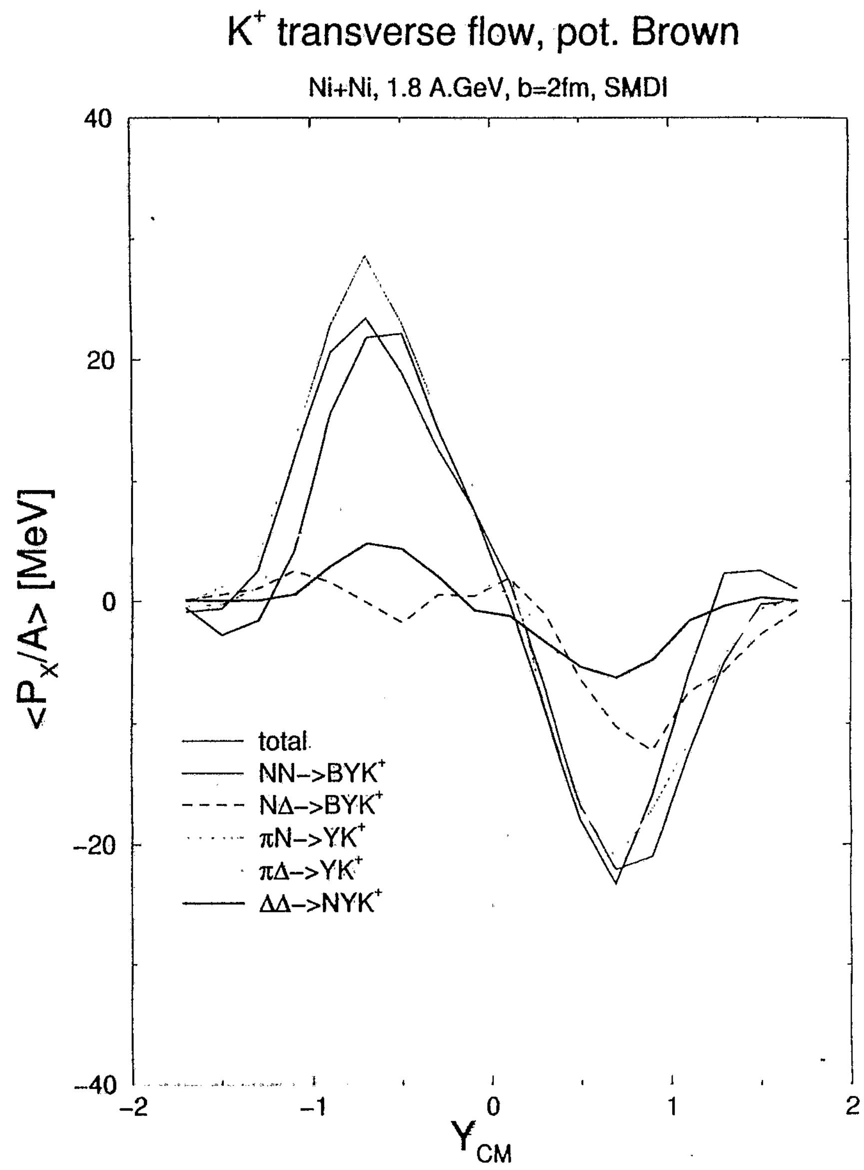
K+ rapidity dist. , pot. Brown
Ni+Ni, 1.8 A.GeV, b=2fm, SMDI
total
NN->BYK+
NΔ->BYK+
πN->YK+
πΔ->YK+
ΔΔ->NYK+
dN/dY
Y_CM



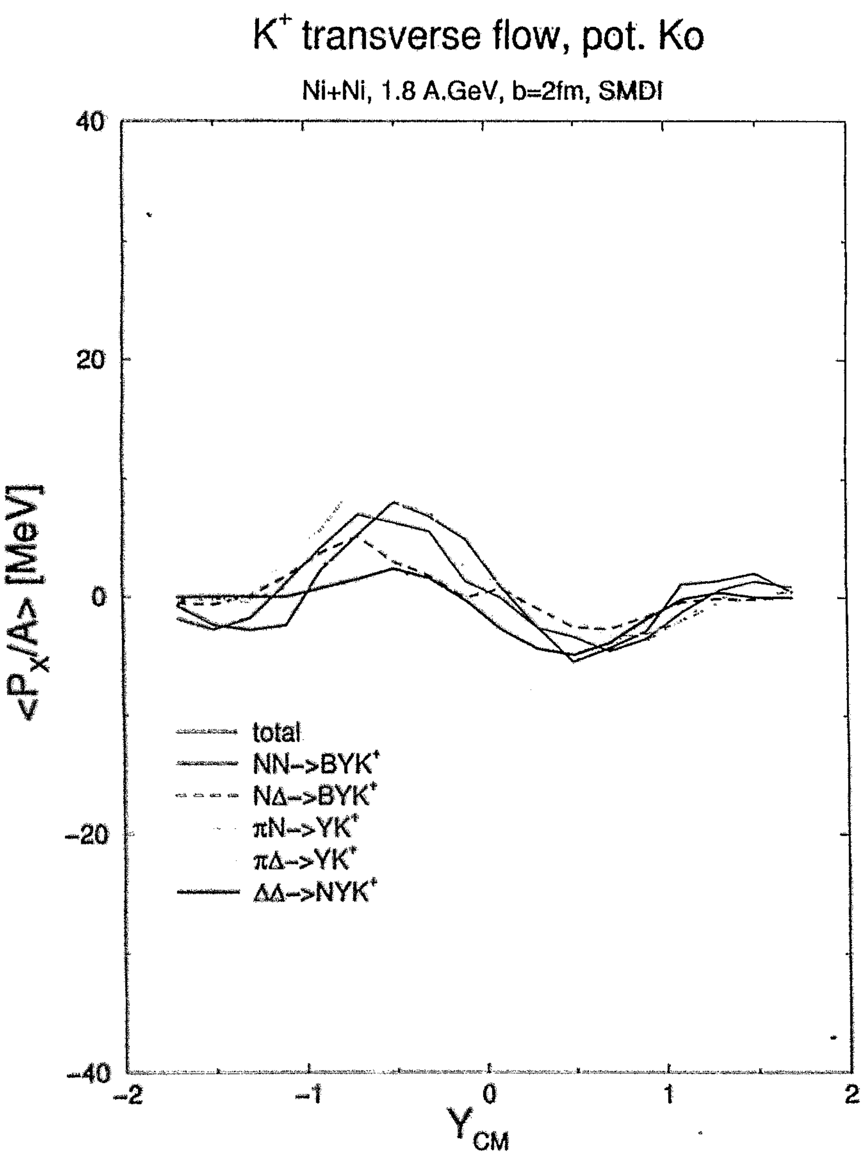
K+ rapidity
Ni+Ni, 1.8 A.GeV, b=2fm, SMDI
No Pot.
Pot. Brown
Pot. Ko
dN/dY
Y_CM

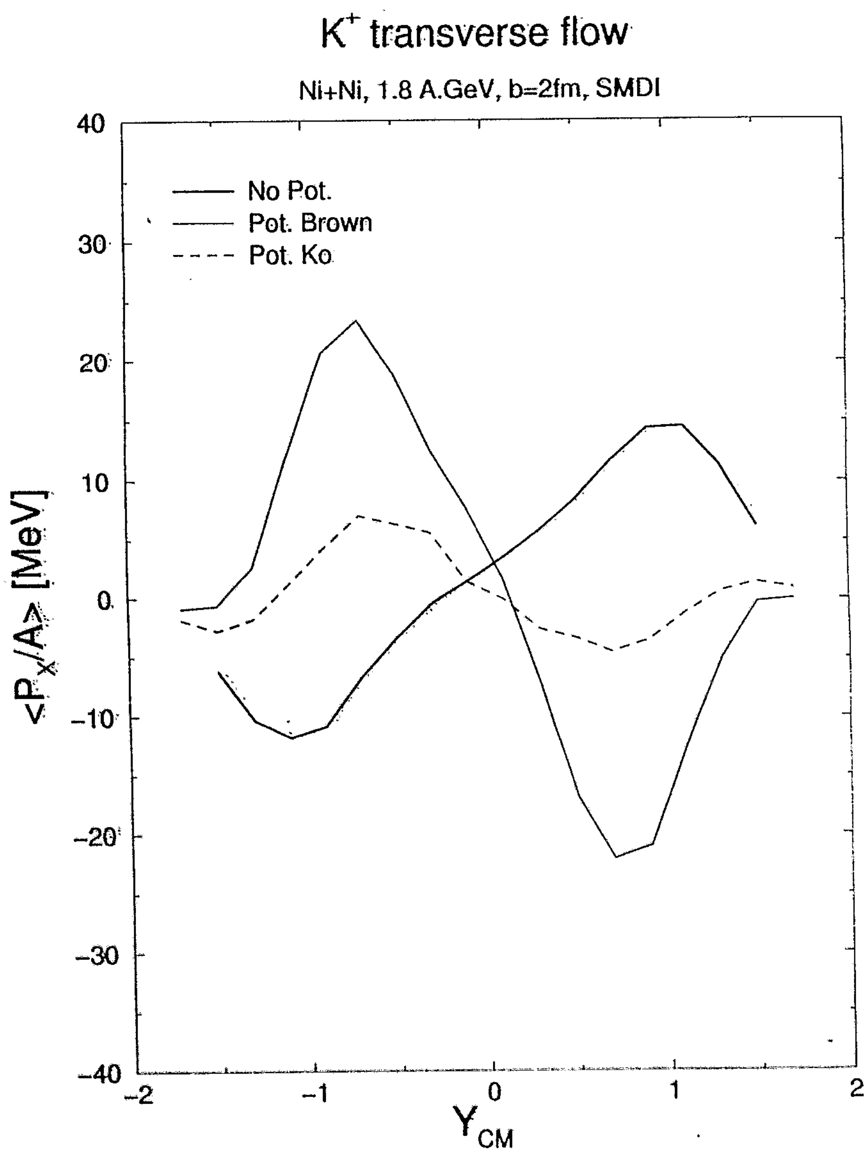


K+ transverse flow, no pot.
Ni+Ni, 1.8 A.GeV, b=2fm, SMDI
total
NN->BYK+
NΔ->BYK+
πN->YK+
πΔ->YK+
ΔΔ->NYK+
<Px/A> [MeV]
YCM
20
10
0
−10
−20
−2
−1
0
1
2



K+ transverse flow, pot. Brown
Ni+Ni, 1.8 A.GeV, b=2fm, SMDI
total
NN->BYK+
NΔ->BYK+
πN->YK+
πΔ->YK+
ΔΔ->NYK+
<Px/A> [MeV]
YCM
40
20
0
−20
−40
−2
−1
0
1
2


K+ transverse flow, pot. Ko
Ni+Ni, 1.8 A.GeV, b=2fm, SMDI
<P_x/A> [MeV]
Y_CM
total
NN->BYK+
NΔ->BYK+
πN->YK+
πΔ->YK+
ΔΔ->NYK+
40
20
0
-20
-40
-2
-1
0
1
2


K+ transverse flow
Ni+Ni, 1.8 A.GeV, b=2fm, SMDI
<P_x/A> [MeV]
Y_CM
No Pot.
Pot. Brown
Pot. Ko
40
30
20
10
0
-10
-20
-30
-40
-2
-1
0
1
2

In-medium potential

Weinberg-Tomozawa: $V_\mu = \frac{3}{8f^2} j_\mu$

Kaplan-Nelson: $S = \frac{\Sigma_{KN}}{f^2} g_s$

$$\left[\partial_\mu \partial^\mu \pm i V_\mu \partial^\mu + (m^2 - S) \right] \phi_K = 0$$

Covariant:

$V^2 = V_\mu V^\mu$

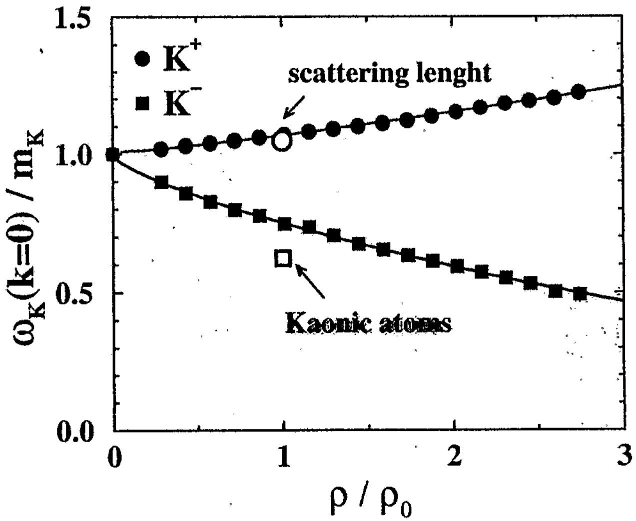
$$\left[(\partial_\mu \pm i V_\mu)^2 + (m^2 - S + V^2) \right] \phi_K = 0$$

$$\left[(\partial_\mu \pm i V_\mu)^2 + m^{*2} \right] \phi_K = 0$$

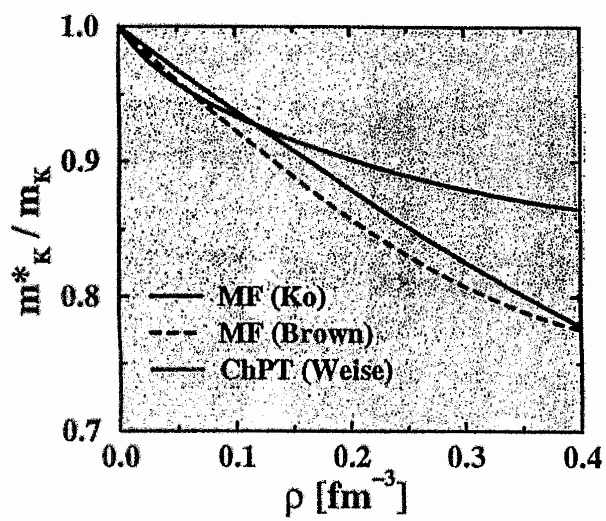
$$\left[k^*_\mu k^{*\mu} - m^{*2} \right] \phi_K = 0$$

In–Medium Kaon "Mass"

Waas et al.



In–medium Kaon Mass



$$\frac{dk^*_\mu}{d\tau} = \frac{k^*_\nu}{m^*_K} F^{\mu\nu} + \partial^\mu m^*_K$$

$$\Downarrow$$

$$\frac{d\vec{k}^*}{dt} = -\frac{m^*_K}{E^*}\frac{\partial m^*_K}{\partial \vec{q}} \underset{(+)}{-} \frac{\partial V^0}{\partial \vec{q}} \quad \Big\} -\frac{\partial}{\partial \vec{q}} U$$

$$\underset{(-)}{+} \frac{\vec{k}^*}{E^*} \times \left(\frac{\partial}{\partial \vec{q}} \times \vec{V}\right) \quad \Big\} \text{Lorentz Force}$$

Kinetic momenta:

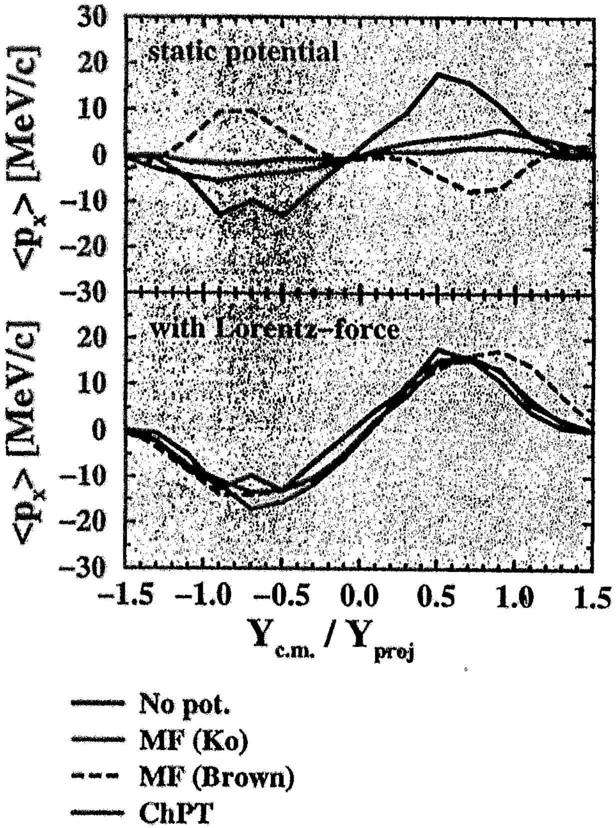
$$\frac{d\vec{k}}{dt} = -\frac{m^*_K}{E^*}\frac{\partial m^*_K}{\partial \vec{q}} \mp \underbrace{\frac{\partial V^0}{\partial \vec{q}} \pm \vec{\beta}_i \frac{\partial \vec{V}_i}{\partial \vec{q}}}$$

$$\simeq \mp \frac{3}{8 f_\pi^2}\left(1 - \vec{\beta}\cdot\vec{\beta}_N\right)\frac{\partial \rho_B}{\partial \vec{q}}$$

Kaon ... velocities

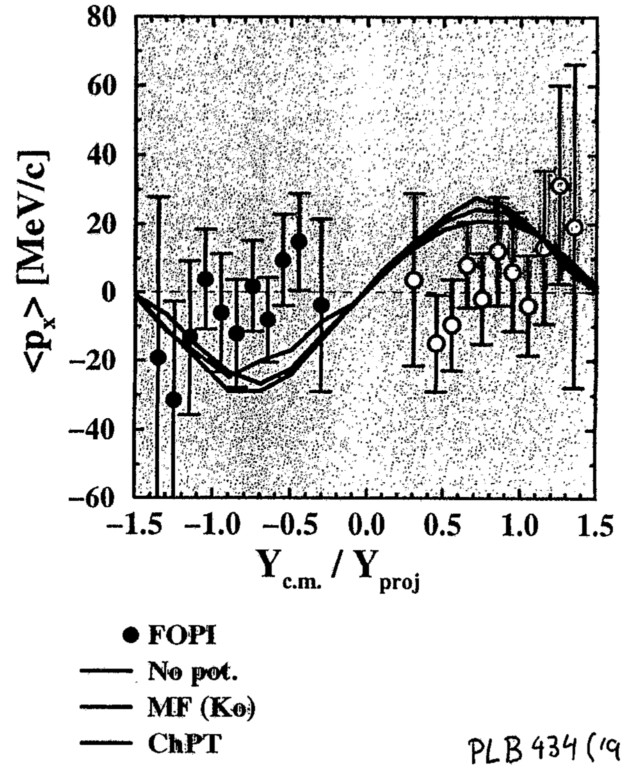
Influence of Lorentz–Forces on K^+ Flow

Ni+Ni, 1.93 A.GeV, b=3 fm, RQMD



K^+ Flow (covariant)

Ni+Ni, 1.93 A.GeV, RQMD



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B. Kämpfer:

Comparison of benchmark tests

Comparison of transport code results

B. KÄMPFER
Forschungszentrum Rossendorf

During the preparation of the workshop, J. Aichelin designed the attached benchmark test for the transport codes. The following theory groups replied by sending to me a lot of data and ps files:

Giessen (W. Cassing, E. Bratkovskaya: RBUU/HSD),
SUNY (C.H. Lee, relying on G.Q. Li's code: RVUU),
Nantes (J. Aichelin, C. Hartnack: QMD),
Frankfurt (S. Soff and collaborators, UrQMD),
Tuebingen (C. Fuchs: QMD),
Budapest (Gy. Wolf: BUU).

The results have been discussed in the Friday morning session. Here I try to give a compilation of a few comparisons. Note that the groups from Frankfurt, Tuebingen and Budapest focus on K^+ production.

1 Number of pions and deltas

The number of pions and deltas as a function of time is displayed in fig. 1. There are obvious differences in the zero points of time.

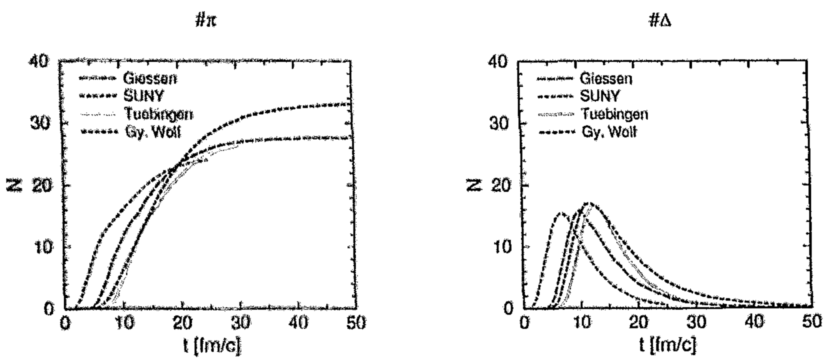


Figure 1: The number of pions (left panel) and deltas (right panel) as a function of time.

2 Elementary cross sections

The cross sections are displayed in figs. 2 – 28. Two groups (Frankfurt, Budapest) have parametrisations of the $pp \to p\Lambda p^+$ reaction which describe quite accurately both the older bubble chamber data and the results from COSY 11 and COSY TOF as well. A

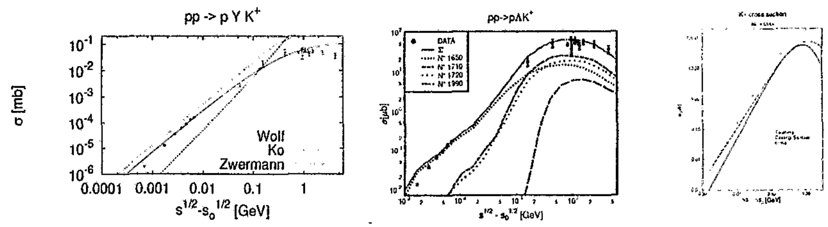


Figure 2: The cross section $pp \to p\Lambda K^+$ (left panel: Budapest parametrisation, middle: Frankfurt parametrisation, right: Tuebingen [=Tsushima]).

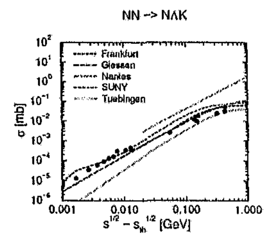


Figure 3: The cross section $NN \to N\Lambda K^+$.

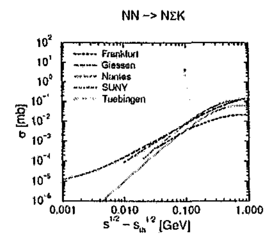


Figure 4: The cross section $NN \to N\Sigma K^+$.

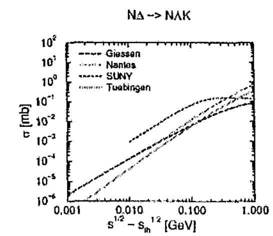


Figure 5: The cross section $N\Delta \to N\Lambda K^+$.

strong point has been made in the discussion by the Giessen group that it would be more appropriate to use the bare production cross sections by removing the final state interaction from the experimental data. The Giessen group is preparing such a parametrisation.

As seen in figs. 3 – 5 the elementary cross sections partially deviate noticeably. Reasons for these differences can be the following ones: consistency with previous stages of development of the codes, or compensation for other channels not included explicitly. Sometimes the authors told me that they use the cross sections "as every body", therefore they did not send data files for them. When I display data in the figures (fat dots) one should be aware that these correspond to pp reactions, while the elementary cross sections should refer to isospin averages used in the codes. Due to the too large differences the groups agreed to rely on a unique parameter set in a second round of benchmark test.

The Tuebingen and Nantes groups additionally use the cross sections displayed in figs. 23 – 28 instead of the cross sections where in the exit channel a nucleon appears. The Nantes group did not send files for the πX reactions; a few selected points from their input are marked by crosses.

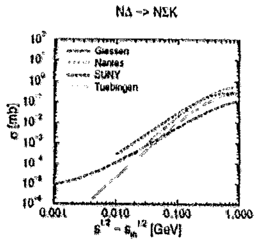


Figure 6: The cross section $N\Delta \rightarrow N\Sigma K^{+}$.

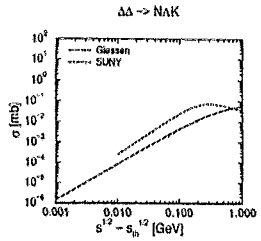


Figure 7: The cross section $\Delta\Delta \rightarrow N\Lambda K^{+}$.

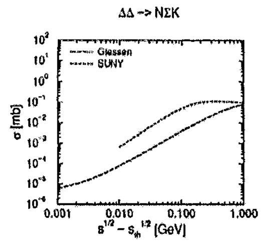


Figure 8: The cross section $\Delta\Delta \rightarrow N\Sigma K^{+}$.

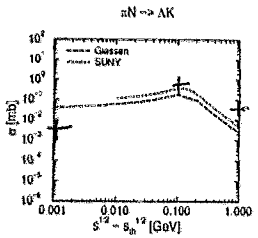


Figure 9: The cross section $\pi N \rightarrow \Lambda K^{+}$.

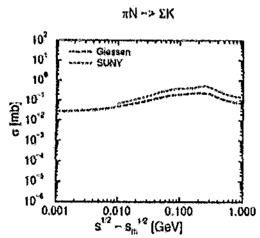


Figure 10: The cross section $\pi N \rightarrow \Sigma K^{+}$.

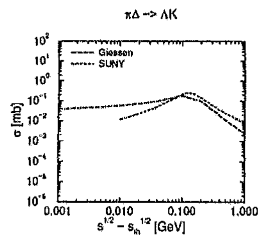


Figure 11: The cross section $\pi\Delta \rightarrow \Lambda K^{+}$.

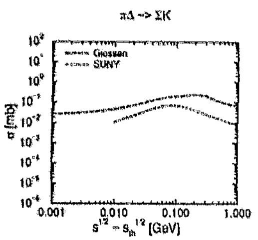


Figure 12: The cross section $\pi\Delta \rightarrow \Sigma K^{+}$.

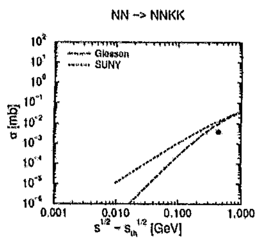


Figure 13: The cross section $NN \rightarrow NNK^{+}K^{-}$.

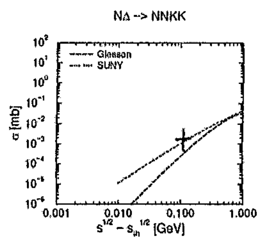


Figure 14: The cross section $N\Delta \rightarrow NNK^{+}K^{-}$.

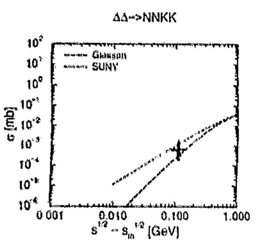


Figure 15: The cross section $\Delta\Delta \rightarrow NNK^{+}K^{-}$.

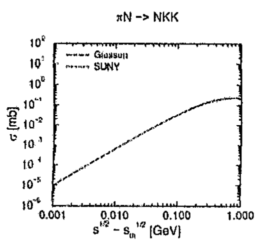


Figure 16: The cross section $\pi N \rightarrow NK^{+}K^{-}$.

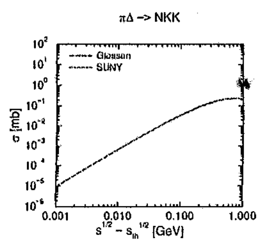


Figure 17: The cross section $\pi\Delta \rightarrow NK^{+}K^{-}$.

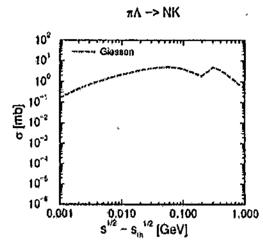


Figure 18: The cross section $\pi\Lambda \rightarrow NK^{-}$.

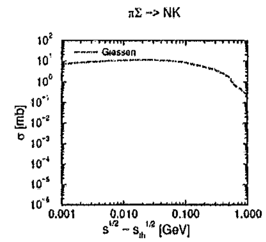


Figure 19: The cross section $\pi\Sigma \rightarrow NK^{-}$.

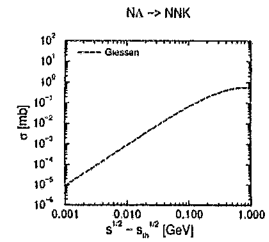


Figure 20: The cross section $N\Lambda \rightarrow NNK^{-}$.

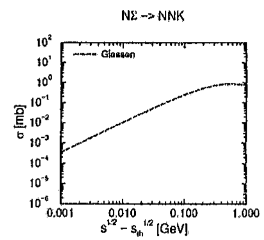


Figure 21: The cross section $N\Sigma \rightarrow NNK^{-}$.

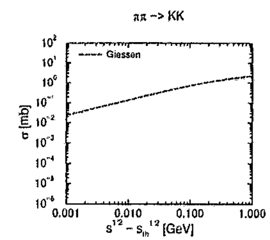


Figure 22: The cross section $\pi\pi \rightarrow K^{+}K^{-}$.

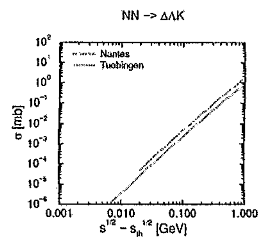


Figure 23: The cross section $NN \rightarrow \Delta\Lambda K^{-}$.

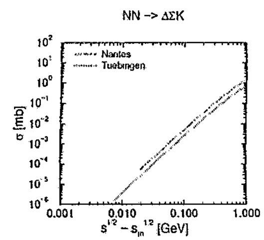


Figure 24: The cross section $NN \rightarrow \Delta\Sigma K^{+}$.

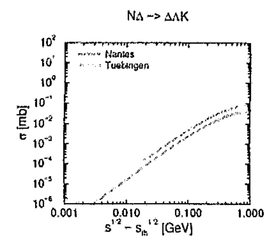


Figure 25: The cross section $N\Delta \rightarrow \Delta\Lambda K^{+}$.

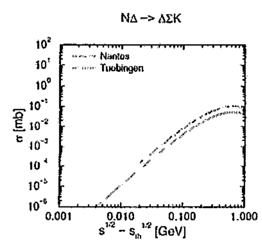


Figure 26: The cross section $N\Delta \rightarrow \Delta\Sigma K^{+}$.

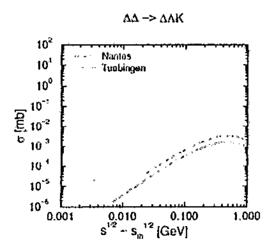


Figure 27: The cross section $\Delta\Delta \rightarrow \Delta\Lambda K^{+}$.

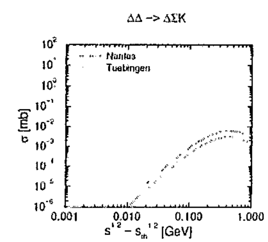
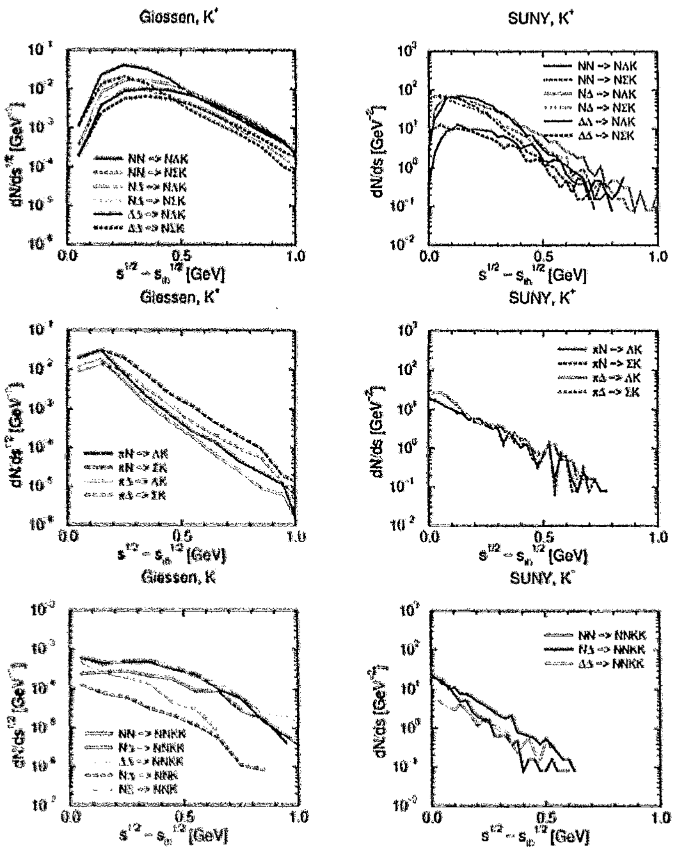


Figure 28: The cross section $\Delta\Delta \rightarrow \Delta\Sigma K^{+}$.

3 The distribution $dN/ds^{1/2}$

To see which channels contribute most significantly and which Q values above the corresponding threshold are most important one may inspect the distributions $dN/d\sqrt{s}$ as a function of $\Delta s^{1/2} \equiv s^{1/2} - s^{1/2}_{thresh}$, displayed in fig. 29. Dominating BB reactions contribute at $\Delta s^{1/2} \sim 300$ MeV in K^+ ($0 - 500$ MeV in K^-) production, while the πB channels have the tendency to peak at small values of $\Delta s^{1/2}$.



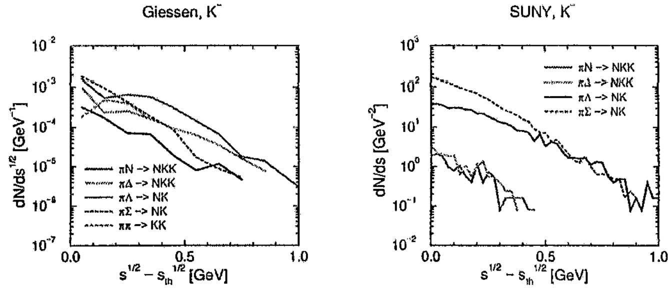


Figure 29: The distribution $dN/ds^{1/2}$ (left panel: Giessen, = probability) and dN/ds (right panel: SUNY, N = collision number) as a function of $\Delta s^{1/2}$.

4 Nucleon flow

The overall nucleon flow and the flow of nucleons involved in kaon production are displayed in fig. 30. The Giessen group communicated that their nucleon flow results are successfully compared in detail with the FOPI data; the same holds for the Tuebingen results.

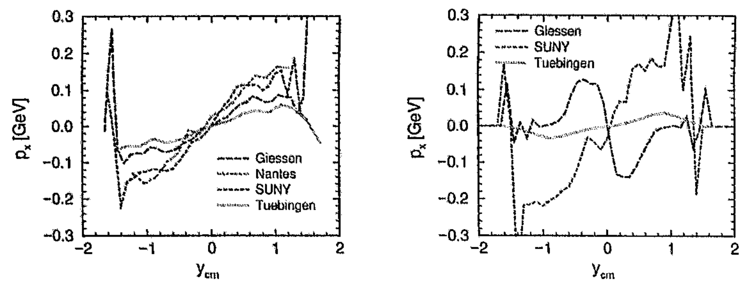


Figure 30: The overall nucleon flow (left panel) and the flow of nucleons involved in kaon production (right panel; the results of the Giessen group are for instant of kaon production, while the groups report results for the final nucleon flow).

5 Rapidity distributions

5.1 At production

The rapidity distributions of bare kaons just in the moment of production are displayed in figs. 31 and 32. Here the summed curves for BB (i.e. baryon-baryon) and MB (i.e. meson (π)-baryon channels are displayed. One observes here significant differences, which propagate through the following figures too.

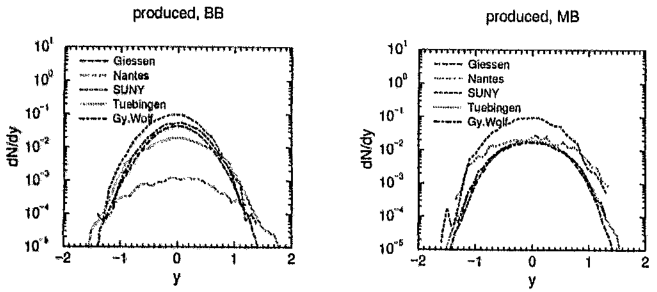


Figure 31: Bare K^+ rapidity distribution at production.

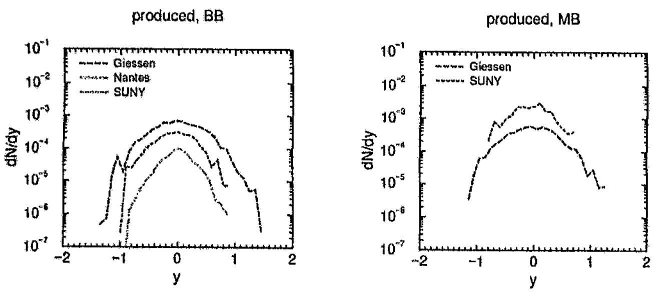


Figure 32: Bare K^- rapidity distribution at production.

5.2 Final distribution

The final rapidity distributions of kaons (with rescattering and in-medium effects) are displayed in figs. 33 and 34.

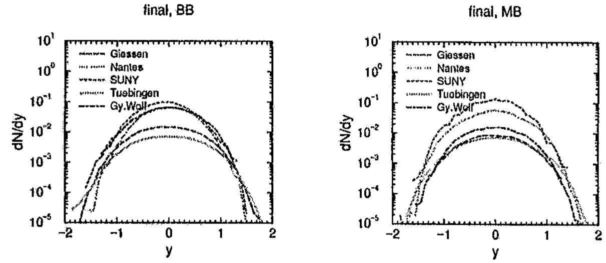


Figure 33: Final K^+ rapidity distribution.

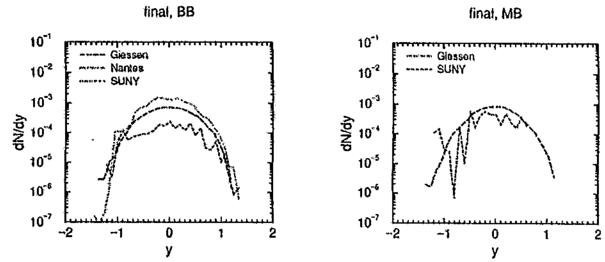


Figure 34: Final K^- rapidity distribution.

6 Transverse momentum distributions

6.1 At production

The transverse momentum distributions of bare kaons at production are displayed in figs. 35 and 36.

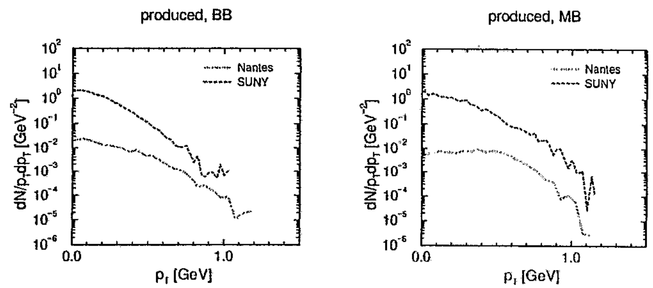


Figure 35: Bare K^+ transverse momentum distribution at production.

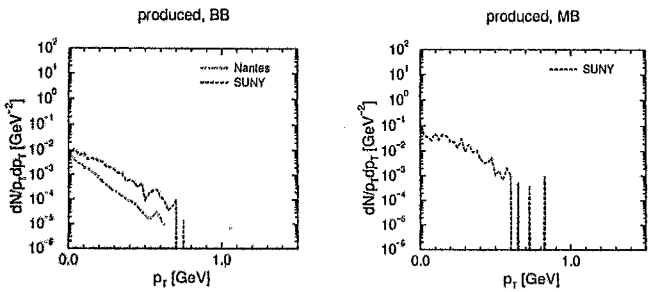


Figure 36: Bare K^- transverse momentum distribution at production.

6.2 Final distribution

The final distributions of kaons (with rescattering and in-medium effects) are displayed in figs. 37 and 38.

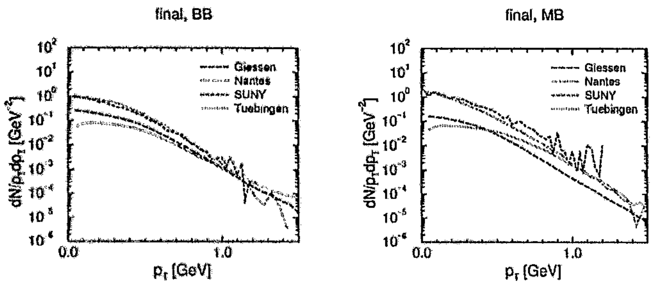


Figure 37: Final K^+ transverse momentum distribution.

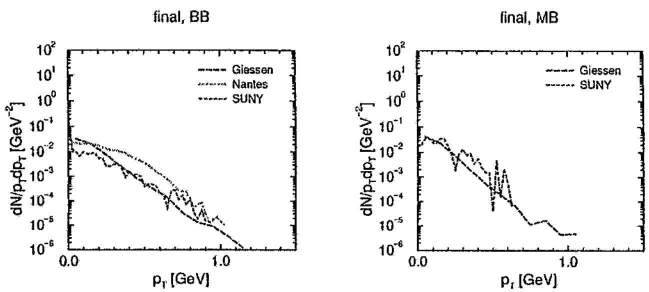


Figure 38: Final K^- transverse momentum distribution.

7 Laboratory transverse momentum distributions

The final laboratory transverse momentum distributions for $\Theta_{lab} = (44 \pm 6)^o$ are displayed in figs. 39 and 40 (with rescattering and in-medium effects).

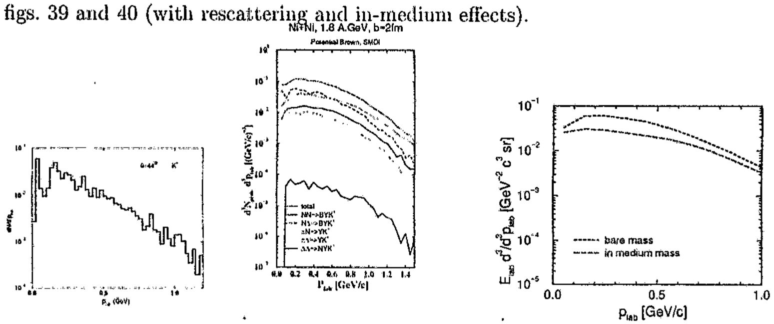


Figure 39: Final K^+ transverse momentum distribution in the lab system (SUNY, Tuebingen, Giessen from left to right; the results are obviously differently normalized).

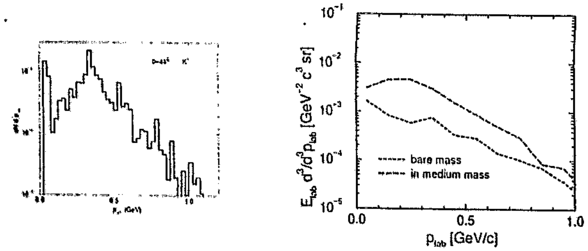


Figure 40: Final K^- transverse momentum distribution in the lab system (left [right] panel: SUNY [Giessen]; the results are obviously differently normalized).

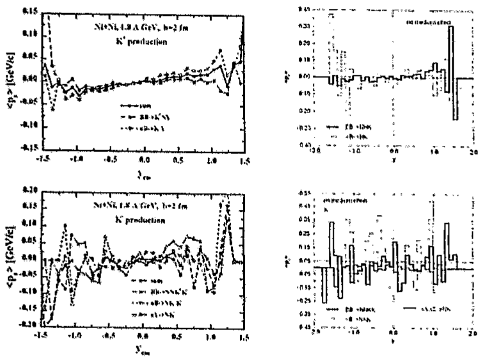


Figure 41: Bare $K^{\pm}$ flow at production (left [right] panel: Giessen [SUNY]).

8 Kaon flow

Results of the kaon flow are displayed in figs. 41 and 42.

9 Concluding remarks

This is a rough survey on a part of results I received from the active groups. There are obvious differences which must be discussed and clarified in a second round of test calculations relying on a unique input (elementary cross sections).

I hope that in the process of a unifying representation I did not mess up too many data. In a few places one observes obvious different normalizations employed; in a few cases I was asked to scale up/down some contributions and I tried to do so or to indicate in the figure captions these desires.

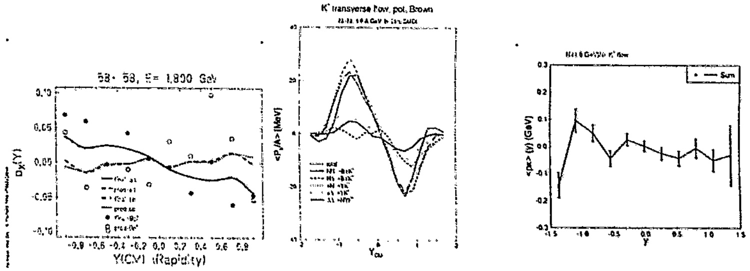


Figure 42: Final K^+ flow (form left to right: Nantes [pion channels must be upscaled by a factor four], Tuebingen, Frankfurt).

Big efforts have been made by the participating groups, and the workshop organizers are grateful to all activists for their attempts. I thank K. Gallmeister for assisting me in the preparation of the figures.

Attachment

KAON WORKSHOP
December 10 – 11, 1998
Forschungszentrum Rossendorf near Dresden

(homework for transport models)
J. Aichelin

In recent times it has been observed that the results of the simulations of the K^+ and K^- production in heavy ion collisions differ much more than expected from fluctuations. Therefore we find it appropriate to ask all groups which work in this field to discuss with us the details of their approaches in order to understand more about the origin of the differences. For this purpose we would like to invite you to come to Rossendorf.

Of course a comparison is only meaningful if all groups present results on a reaction which can be compared. The have chosen the reaction

Reaction : 1.8 GeV/N Ni + Ni b = 2 fm, Γ_{Delta} = 120 MeV energy independent.

In order to allow for a meaningful comparison between the progams and to find the differences of the different programs as fast as possible we would like to ask you to communicate the numbers and spectra to Burkhard Kampfer (kaempfer@fz-rossendorf.de) **until 4th of December.** All quantities should be in mb and GeV and for K^+ resp K^- production only. (Please do not include the K^0's).

It would be preferable if you can send PS files as will as data files. This would allow to prepare figures which contains the results of the different groups.

A) K^+ PRODUCTION

1) Which of the following processes are included

a)	$NN \to N\Lambda K$	b)	$NN \to N\Sigma K$
c)	$N\Delta \to N\Lambda K$	d)	$N\Delta \to N\Sigma K$
e)	$\Delta\Delta \to N\Lambda K$	f)	$\Delta\Delta \to N\Sigma K$
g)	$\pi N \to \Lambda K$	h)	$\pi N \to \Sigma K$
i)	$\pi\Delta \to \Lambda K$	k)	$\pi\Delta \to \Sigma K$

2) Fig. of the isospin average cross section for (y-log scale) of a-k (if included in your calculation) as a function of $\sqrt{s}$ - $\sqrt{s_{threshold}}$.

3) Time integrated kaon production probability and number of collisions for the processes a-k.

4) $\frac{dN_{coll}}{d\sqrt{s}}$ for the processes a-k as a function of $\sqrt{s}$ - $\sqrt{s_{threshold}}$ (y-log.scale)

5) Rapidity distribution $\frac{dN_{prob}}{dy}$ of kaons immediately after creation for πB(g-k) and BB(a-f) collisions separatly (N_{prob} = number of kaons weighted with their production probability).

6) Transverse momentum distribution $\frac{dN_{prob}}{P_T dP_T}$ of the kaons (y-log.scale) separated for a-g and h-k

7) In plane flow ($p_t(y)$) as a function of y of the kaons separated for a-g and h-k.

8) In plane flow for all nucleons and separatly for those which are involved in a kaon production collision.

9) Number of pions and deltas as a function of time.

B. FINAL K^+ DISTRIBUTION

1) Final kaon rapidily distribution $\frac{dN_{prob}}{dy}$ separated for a-g and h-k without KN potential (rescattering only).

2) Same as 1) but with KN optical potential (if included in the program)

3) Final transverse momentum distribution $\frac{dN_{prob}}{p_T dp_T}$ separated for a-g and h-k without KN potential.

4) Same as 3) but with KN optical potential.

5) $\frac{dN_{prob}}{d^3p_{lab}}(\theta_{lab} = 44 \pm 6°)$ (y -log scale)

C. K^- PRODUCTION

1) Which of the following production processes are included?

l) $NN \to NNK^+K^-$
m) $N\Delta \to NNK^+K^-$
n) $\Delta\Delta \to NNK^+K^-$
o) $\pi N \to NK^+K^-$
p) $\pi\Delta \to NK^+K^-$

2) Same as A) 2-8 for l-n and o-p, respectively.

3) Same as B) 1-5 for l-n and o-p, respectively.

For questions please contact Joerg Aichelin (Achelin@subatech.in2p3.fr), tel. +33 (0) 251 85 84 09.

E.E. Kolomeitsev:

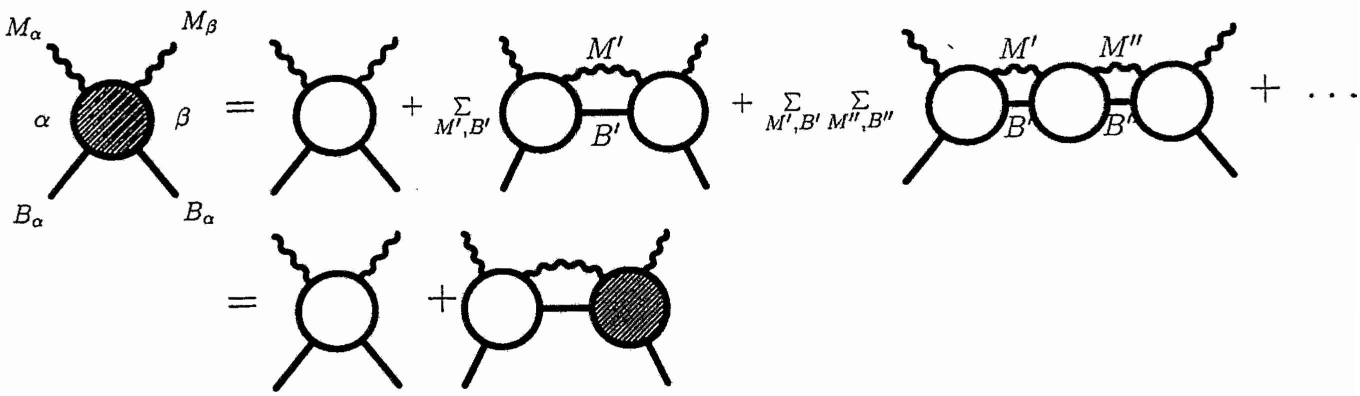
Kaonic excitation in HICs

Kaonic Excitations in HIC

M. Lutz , E.E.K. , D.N. Voskresensky , B. Kämpfer
(GSI, MEPhI, FZR)

- ✓ World of KN interaction
- ✓ Kaon In-medium Dynamics
- ✓ "Scaled mass" vs. Spectral Density
- ✓ Strangeness in HIC

Coupled Channel Equations



Ingredients:

- CHANNEL SET $\{M_\alpha, B_\alpha\}$ $\alpha = 1, 2 \ldots$ $(KN;\ \pi\Sigma;\ \pi\Lambda \ldots)$
- BARE COUPLINGS 
- LOOP REGULARIZATION  $\longrightarrow \int_0^\Lambda \frac{d^4p}{(2\pi)^4} \cdots,$ Λ cut-off parameter

Model Solution of Coupled Channel Equation

Matrix equation

$$T = V + (V \cdot J \cdot T)$$

Isospin 0 : channels $\{KN, \pi\Sigma\}$
Isospin 1 : channels $\{KN, \pi\Sigma, \pi\Lambda\}$

can be solved analytically in the approximations

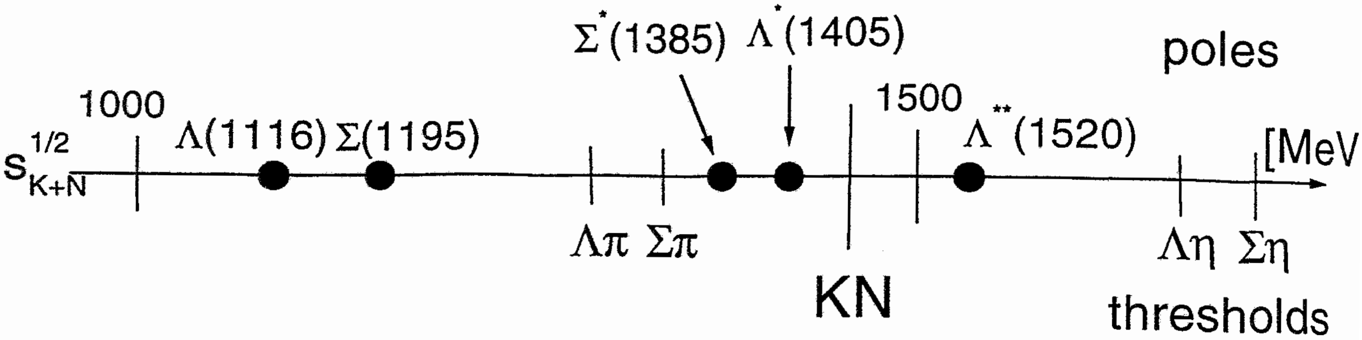
$$V = V(s) = V_0 + R\,s \quad \text{where } R \text{ is } \textit{range term}$$

Parameters V_0 and R are adjusted to reproduce experimental data on $K^- p \to K^- p, \to \bar{K}^0 n, \to \pi^{\pm 0}\Sigma^{\mp 0}, \to \pi^0\Lambda$ scattering
for I=0

$$T = \begin{pmatrix} T_{KN;KN} & T_{KN;\pi\Sigma} \\ T_{\pi\Sigma;KN} & T_{\pi\Sigma;\pi\Sigma} \end{pmatrix} \qquad V = \begin{pmatrix} V_{KK} & V_{K\Sigma} \\ V_{K\Sigma} & V_{\Sigma\Sigma} \end{pmatrix} \qquad J = \begin{pmatrix} J_{KN} & 0 \\ 0 & J_{\pi\Sigma} \end{pmatrix}$$

$$T^{(0)}_{KN \to KN} = \frac{V_{KK} + \dfrac{V_{K\Sigma}^2 J_{\pi\Sigma}}{1 - V_{\Sigma\Sigma} J_{\pi\Sigma}}}{1 - V_{KK} J_{KN} - \dfrac{V_{K\Sigma}^2 J_{\pi\Sigma}}{1 - V_{\Sigma\Sigma} J_{\pi\Sigma}} J_{KN}}$$

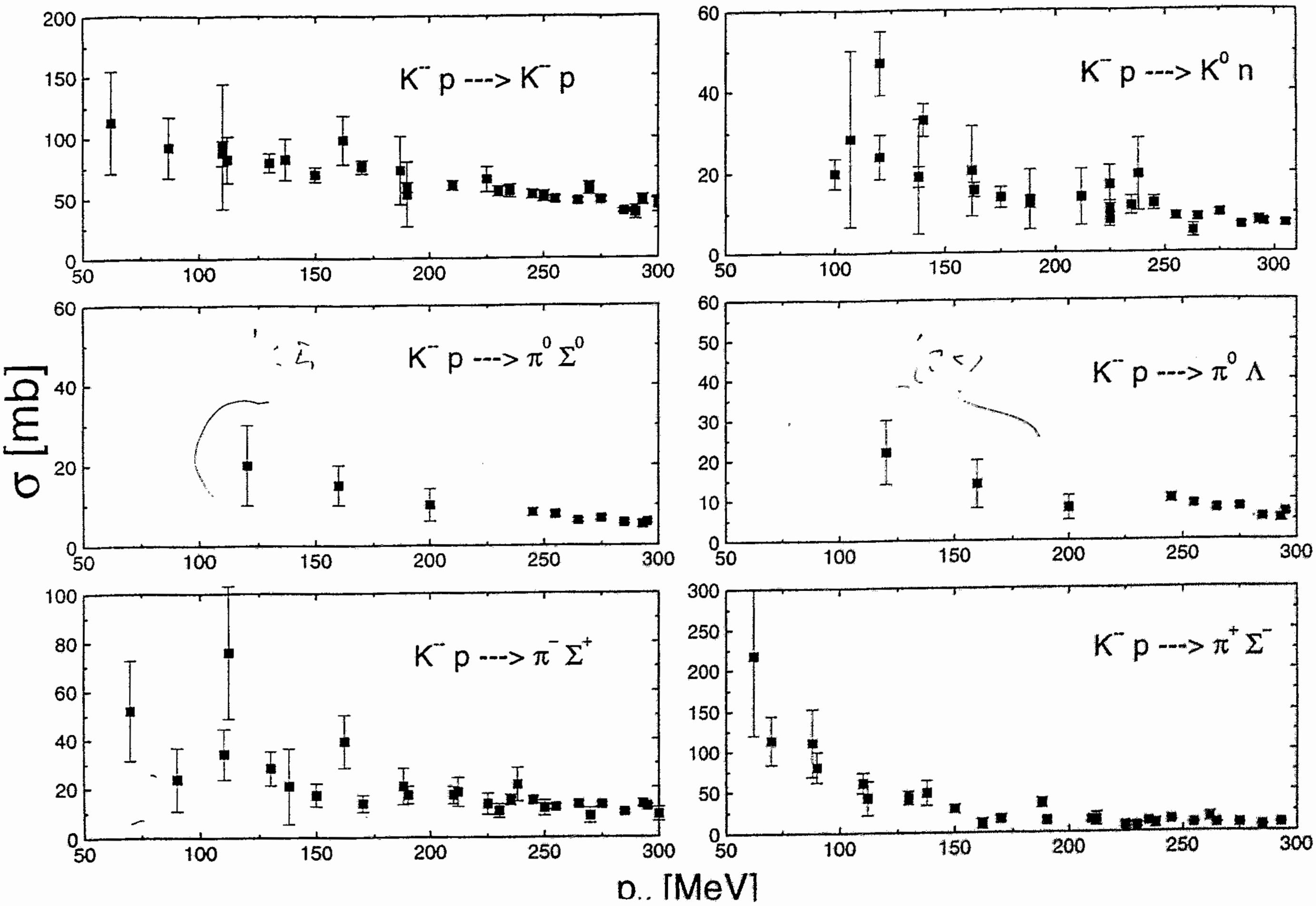
World of K⁻N interaction

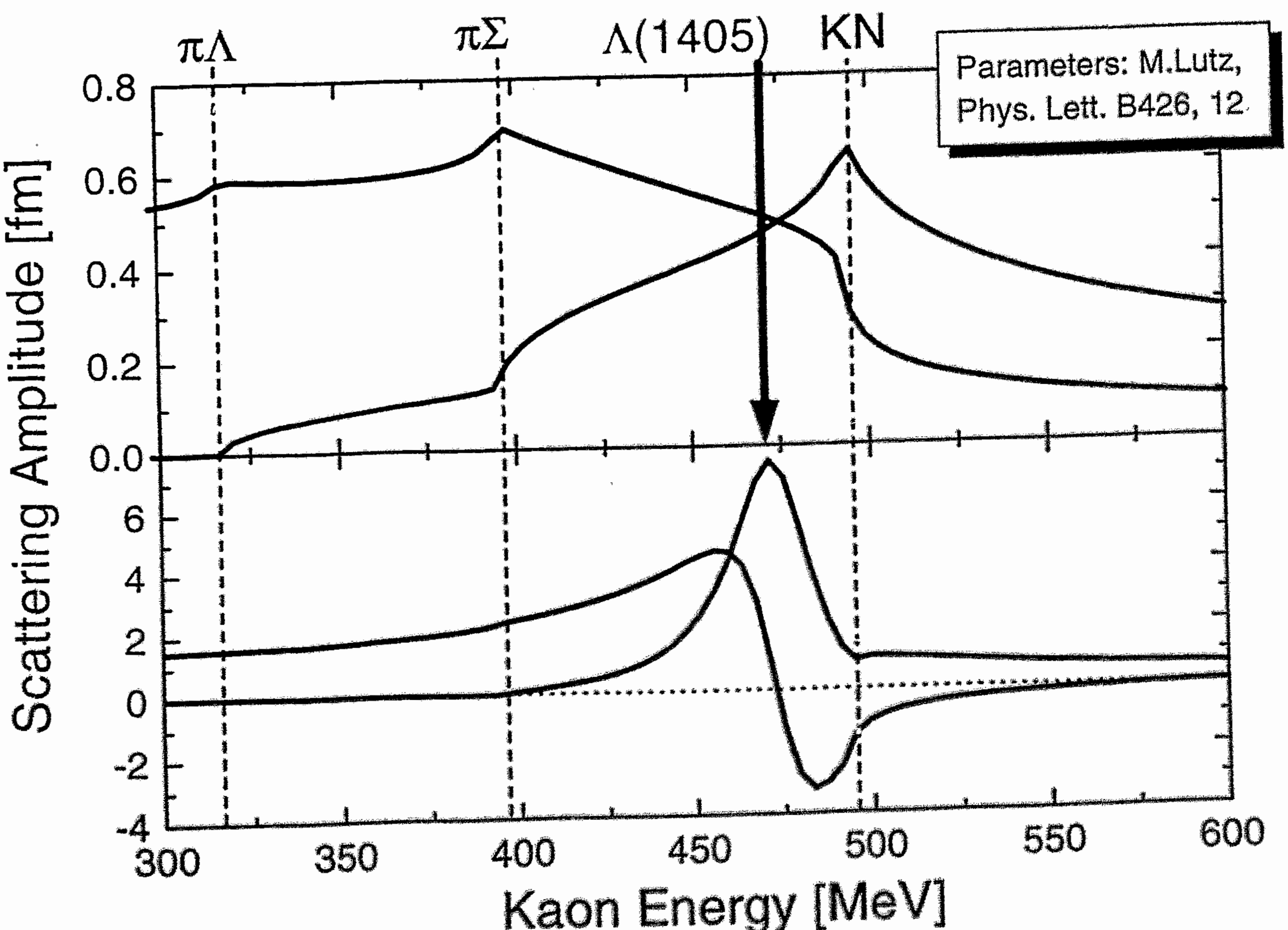


S wave : Λ*(1405) ⟵ Σπ, KN, Λη thres. dynamics

P wave : Λ(1116),Σ(1195), Σ*(1385)

D wave : Λ**(1520)


K⁻ p ---> K⁻ p
K⁻ p ---> K⁰ n
K⁻ p ---> π⁰ Σ⁰
K⁻ p ---> π⁰ Λ
K⁻ p ---> π⁻ Σ⁺
K⁻ p ---> π⁺ Σ⁻
σ [mb]
p.. [MeV]

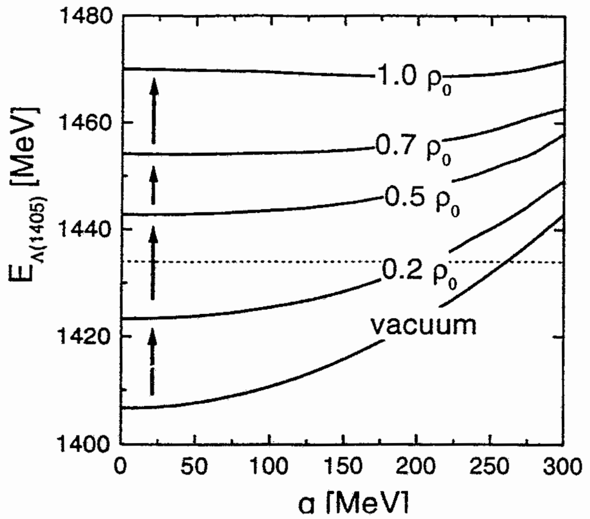

πΛ
πΣ
Λ(1405)
KN
Parameters: M.Lutz,
Phys. Lett. B426, 12
Scattering Amplitude [fm]
Kaon Energy [MeV]

$\Lambda(1405)$ in Medium. Pauli Blocking

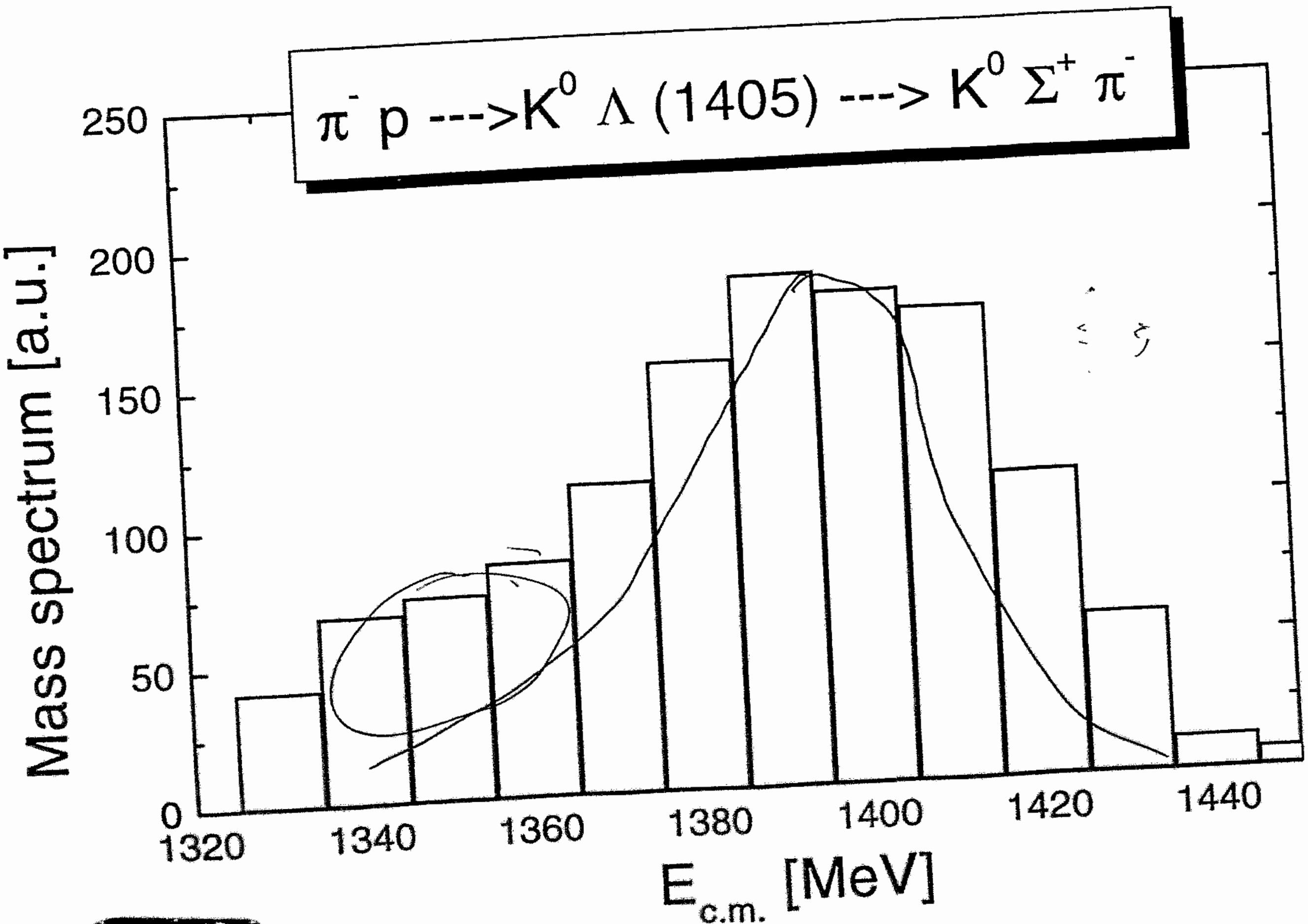
Equation for the Bound State

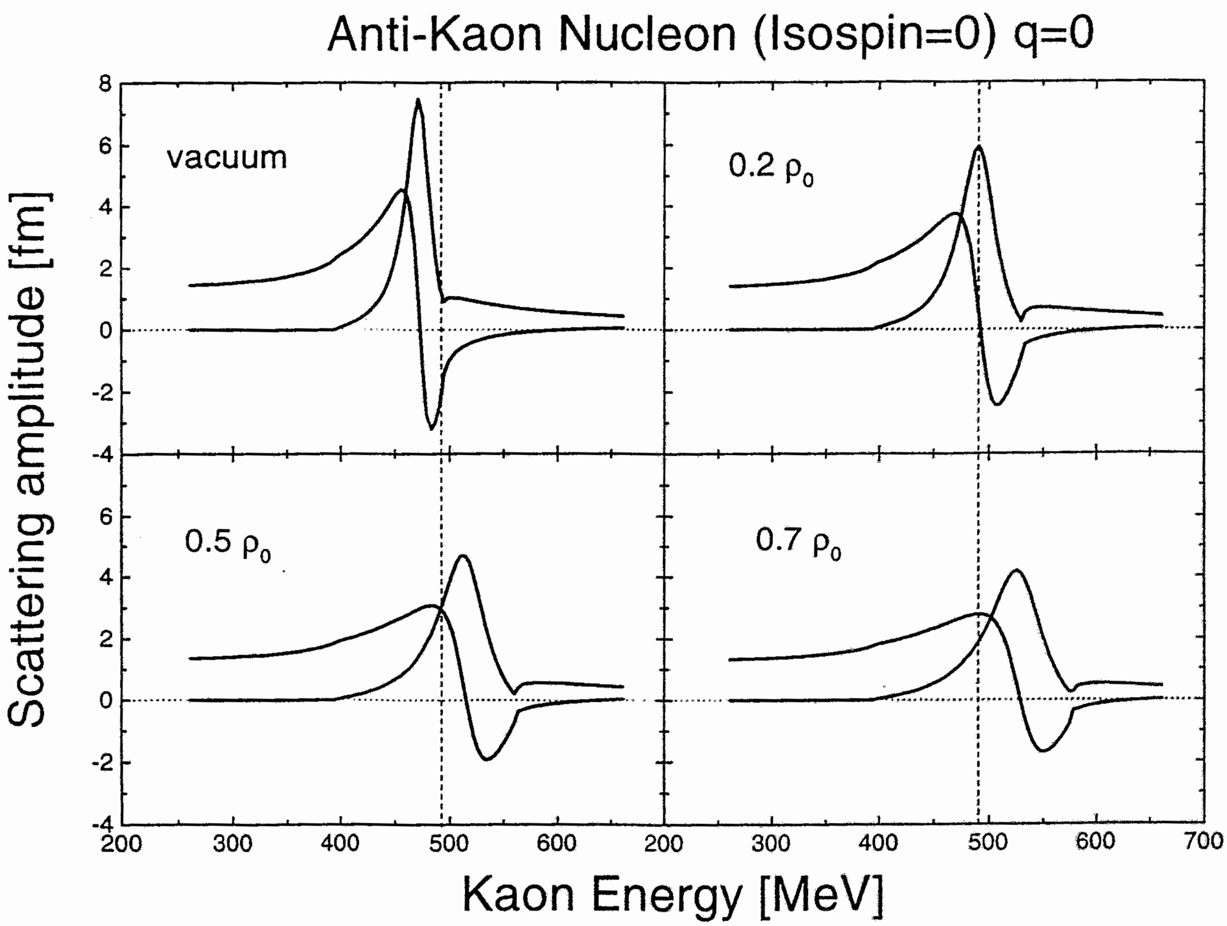
$$\mathrm{Re}\left\{1 - V_{KK}\, J_{KN} - \frac{V_{K\Sigma}^2\, J_{\pi\Sigma}}{1 - V_{\Sigma\Sigma}\, J_{\pi\Sigma}}\, J_{KN}\right\} = 0$$

in nuclear medium $J_{KN}(s) \longrightarrow J_{KN}(\omega, q) = \int_{p_F}^{\Lambda} \frac{d^3p}{(2\pi)^3} \frac{m_N}{E_N(p)} D_K^{\mathrm{vac}}(\omega - E_N(p), \vec{q} - \vec{p})$

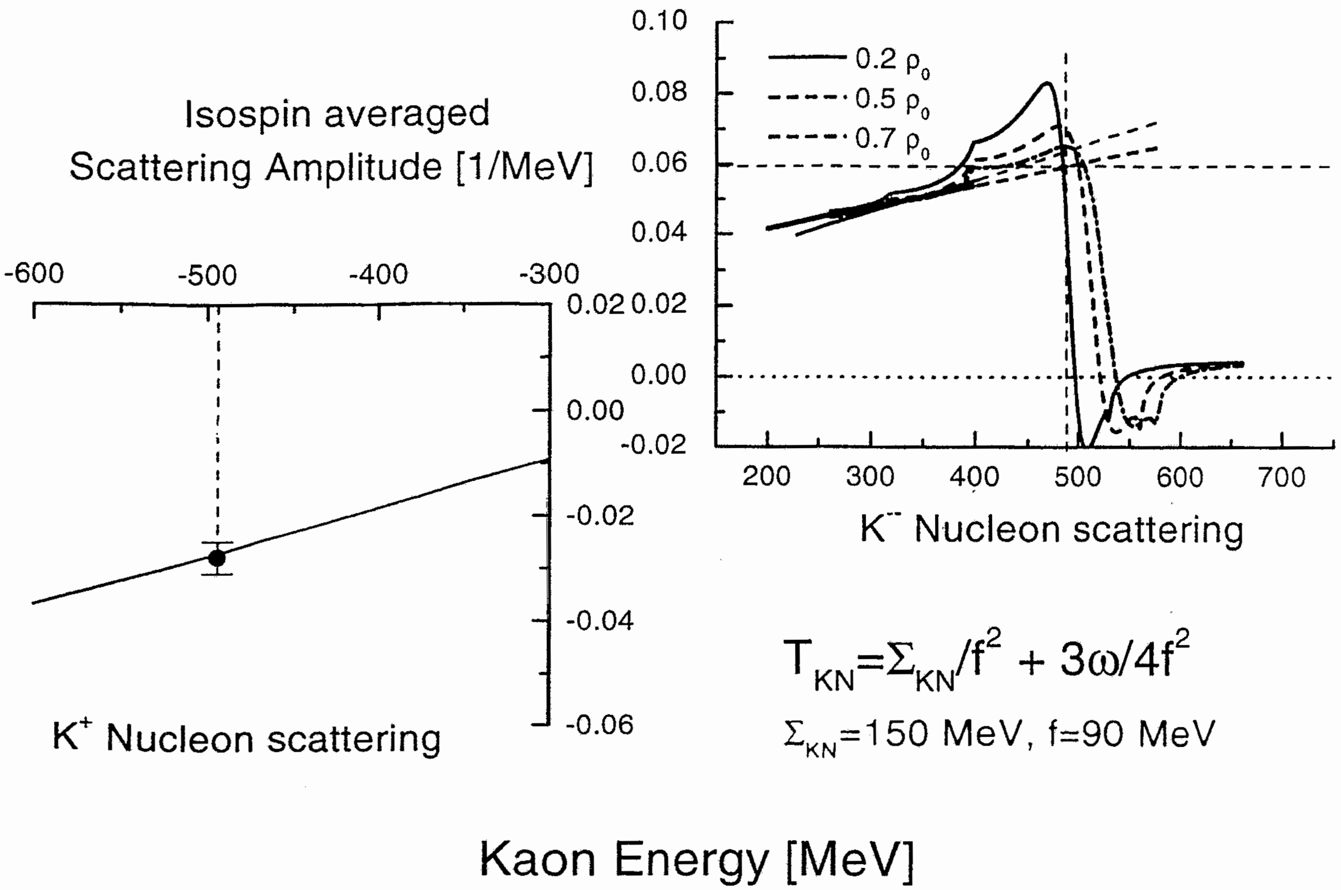


Pole position is shifted above KN threshold

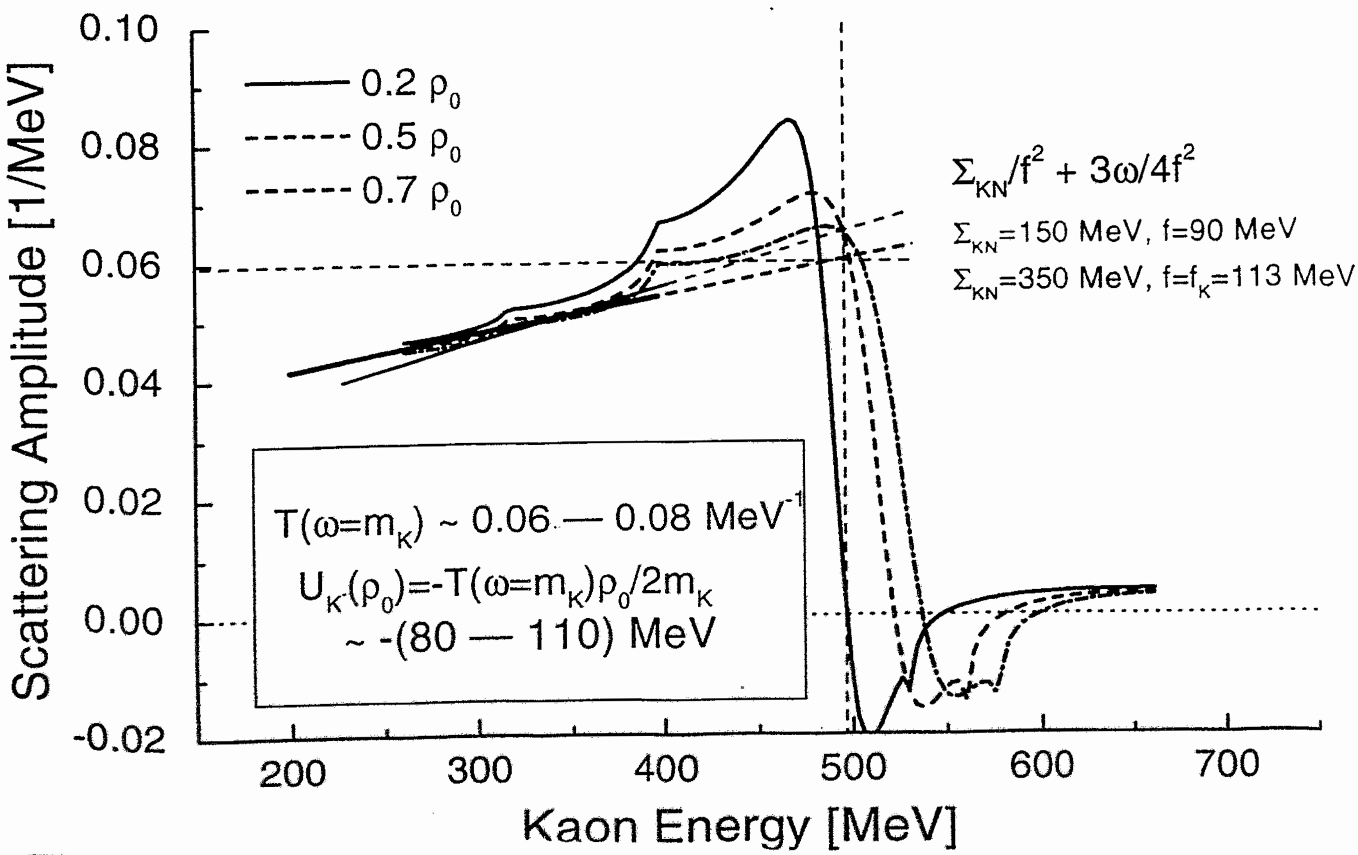




Due to the Pauli blocking
$\Lambda(1405)$ moves above KN threshold



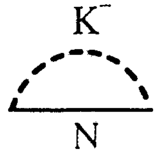
Isospin averaged
Scattering Amplitude [1/MeV]
0.2 ρ_0
0.5 ρ_0
0.7 ρ_0
K⁺ Nucleon scattering
K⁻ Nucleon scattering
$T_{KN}=\Sigma_{KN}/f^2 + 3\omega/4f^2$
Σ_{KN}=150 MeV, f=90 MeV
Kaon Energy [MeV]



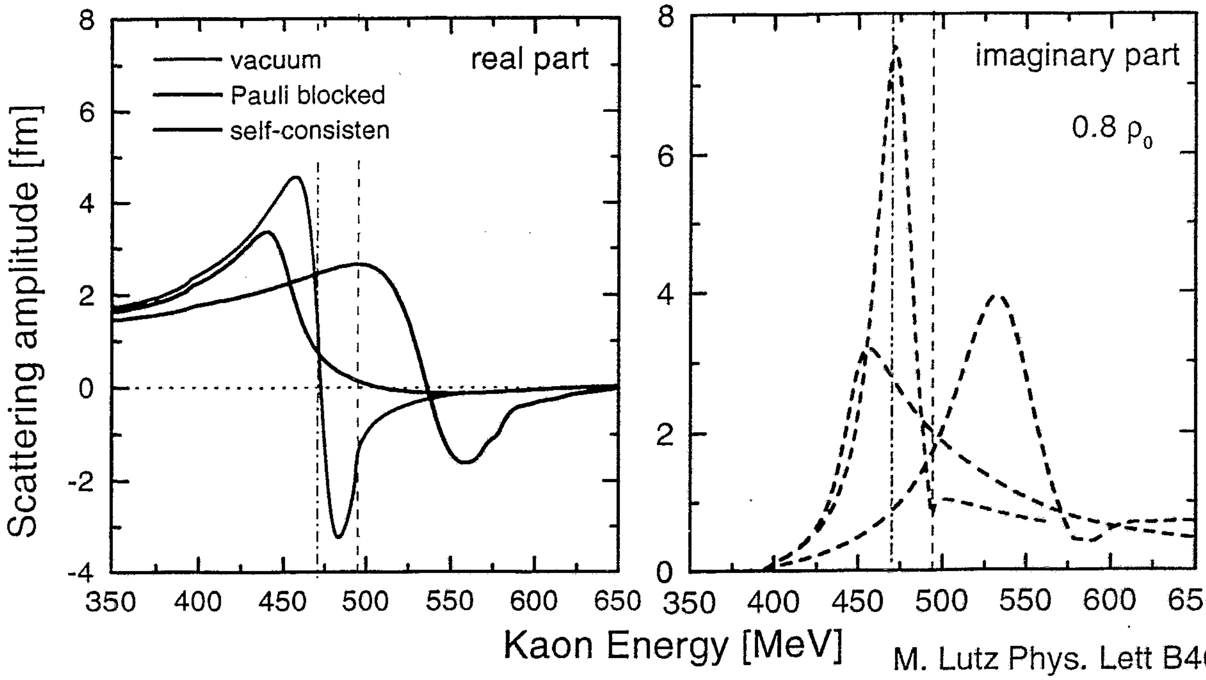
Scattering Amplitude [1/MeV]
0.2 ρ_0
0.5 ρ_0
0.7 ρ_0
$\Sigma_{KN}/f^2 + 3\omega/4f^2$
Σ_{KN}=150 MeV, f=90 MeV
Σ_{KN}=350 MeV, f=f_K=113 MeV
$T(\omega=m_K) \sim 0.06 — 0.08\ MeV^{-1}$
$U_{K^-}(\rho_0)=-T(\omega=m_K)\rho_0/2m_K$
$\sim -(80 — 110)$ MeV
Kaon Energy [MeV]

Self-Consisten Amplitude

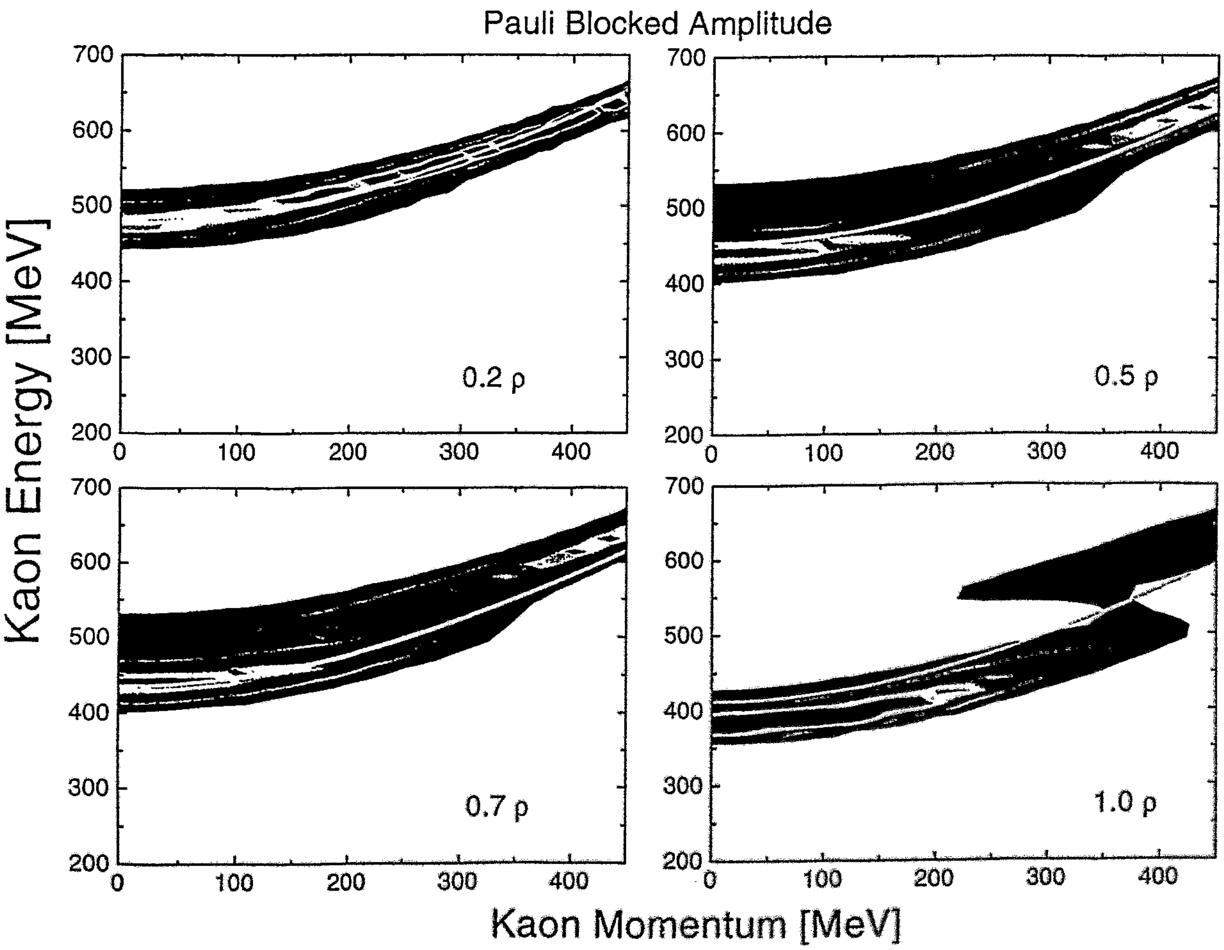
Kaon Nucleon Loop

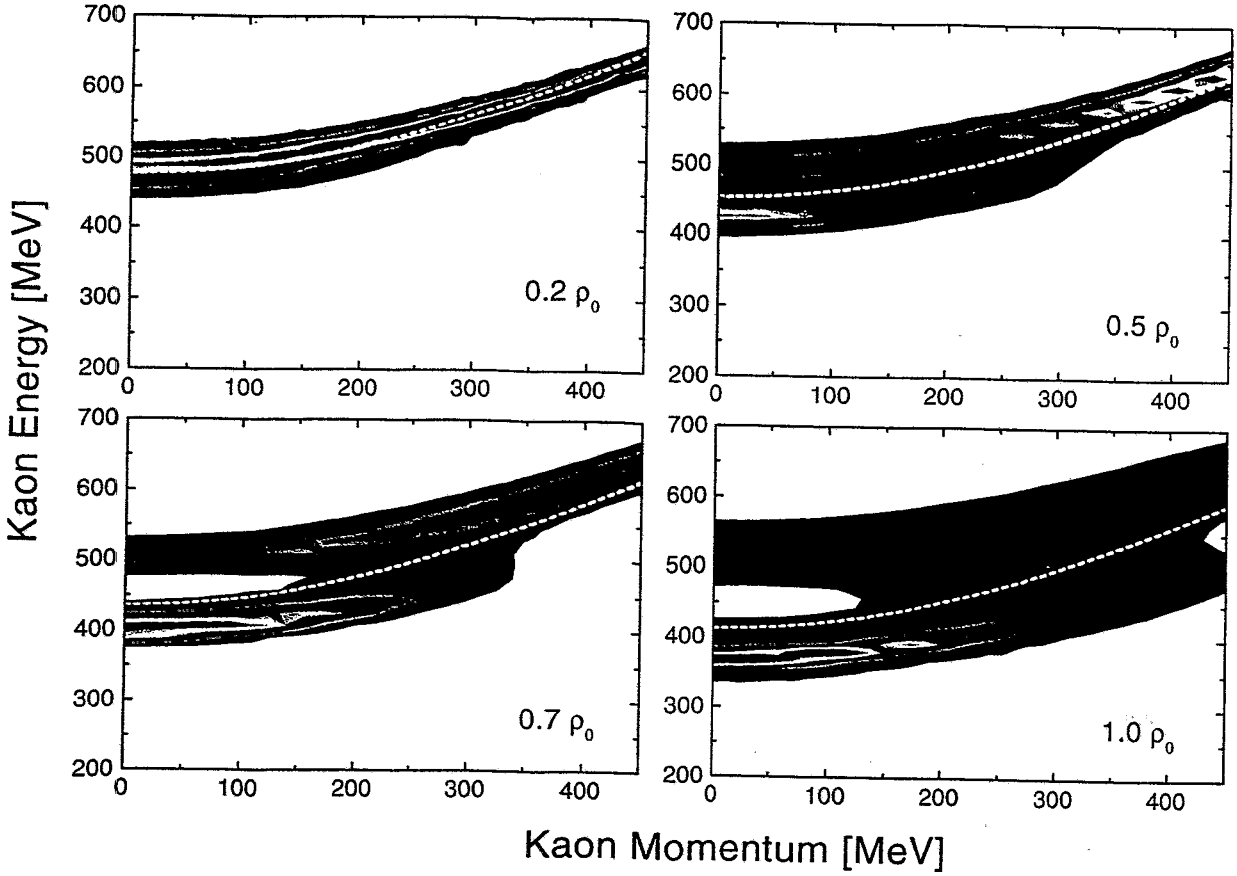


in-medium kaon Green's function



M. Lutz Phys. Lett B462, 12





"Λ (1405)" stays below KN threshold !!!

I

$$\omega^2 = k^2 + m_K^2 + \Pi, \quad \Pi = V_1 + V_2\,\omega + (V_3\,\omega^2)$$

OR

$$(\omega + V)^2 = m_K^2 + k^2 - S$$

** Reasonably adjusted potentials can imitate the effects of K^-N interaction in integral observables

** In transport eq. $\frac{d p_{K^-}}{dt} = -\nabla_x U_{K^-}$

instead of $U_{K^-} = \sqrt{m_K^2 + k^2 - S} - V - \sqrt{m_K^2 + k^2}$

one should use

$$\tilde{U}_{K^-} \sim \left. \frac{\mathrm{Re}\,\Pi\left(\sqrt{m_K^2+k^2},\, k\right)}{2\omega - \frac{\partial\, \mathrm{Re}\,\Pi}{\partial \omega}} \right|_{\omega = \sqrt{m_K^2 + k^2}}$$

(near mass shell)

retardation effects

$\Lambda(1405)$ in-medium dynamics generates non-trivial energy dependence

Equlibrium Number of K⁻ Mesons

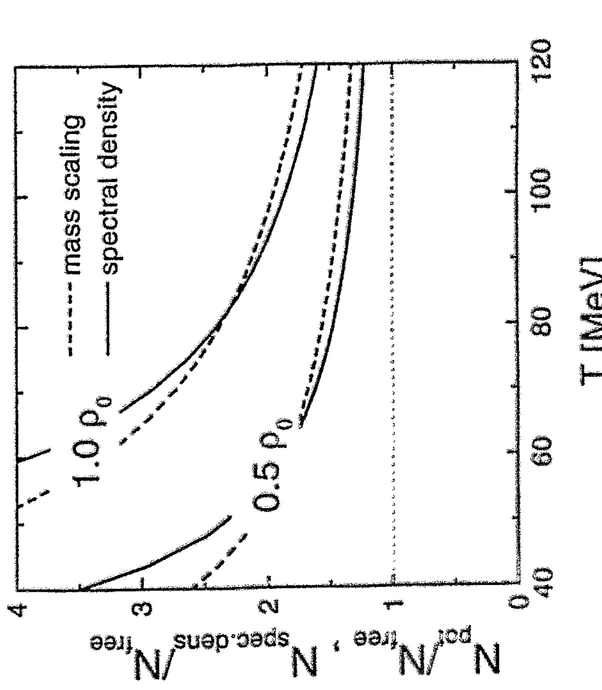
$$N_{\rm free}(T) = \int \frac{d^3p}{(2\pi)^3} \mathrm{Exp}\left[-\frac{\sqrt{m_K^2 + p^2}}{T}\right]$$

$$N_{\rm pot}(T,\rho) = \int \frac{d^3p}{(2\pi)^3} \frac{2\,E_{K^-}(p,\rho)}{2\,E_{K^-}(p,\rho) + 3\rho/8\,f_\pi^2} \mathrm{Exp}\left[-\frac{E_{K^-}(p,\rho)}{T}\right]$$

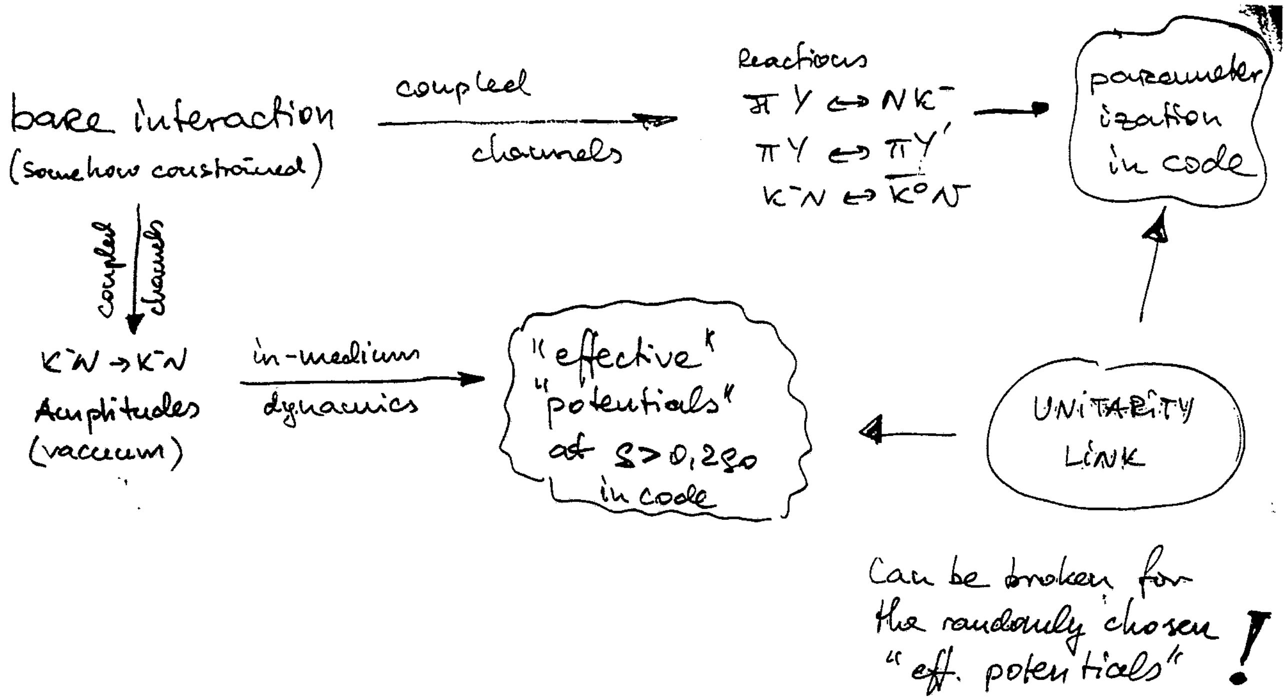
$$E_{K^-}(p,\rho) = \sqrt{m_K^2 + p^2 - \frac{\Sigma_{KN}}{f_\pi^2}\rho + \left(\frac{3\,\rho}{8\,f_\pi^2}\right)^2} -$$

$$N_{\rm spec.\,dens.} = \int \frac{dE}{\pi} \int \frac{d^3p}{(2\pi)^3} \left(E\,A_{K^-}(E,p)\right) \mathrm{Exp}\left[-\frac{E}{T}\right]$$

$A_{K^-}(E,p)$ spectral den



II



** In medium resonance dynamics can be consistently treated only in the coupled channel approach.

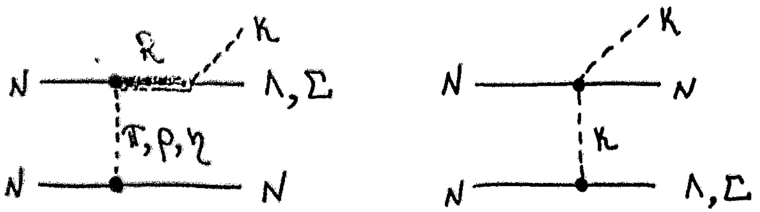
A. Sibirtsev:

Theoretical news on strangeness production in p + p collisions

Theoretical News on strangeness production from p+p collisions

A. Sibirtsev, W. Cassing, K. Tsushima, A. Thomas

Gießen & Adelaide University



R : $N^*(1650)$, $N^*(1710)$, $N^*(1720)$, $\Delta(1920)$

KN → KN scattering amplitude from data

[fix with πN → KΛ, πN → KΣ data]

J.M. Laget, Phys. Lett. [illegible]

R = 14 : 1 = 14 SATURNE data

A. Sibirtsev, Phys. Lett. [illegible]

R = 19.6 : 1.3 = 15 total cross sections NN → KNΛ and KNΣ

$R = g^2_{KNΛ} : g^2_{KNΣ}$

√ SU(6) R = 3 cot ε = 27 !!!

ε - mixing angle between Λ and Σ contents of the nucleon ε = 18.4°

√ Dispersion analysis [illegible] and real part of the forward scattering amplitudes (data)

R = 13.9 : 3.3 = 4.2

A. Sibirtsev, W. Cassing, Nucl. Phys. A 641 (1998) 476

Final State Interaction

$$\text{Jost function}_s^{-1} = \frac{q + i\beta}{q - i\alpha} \rightarrow 1 \text{ @ large } q$$

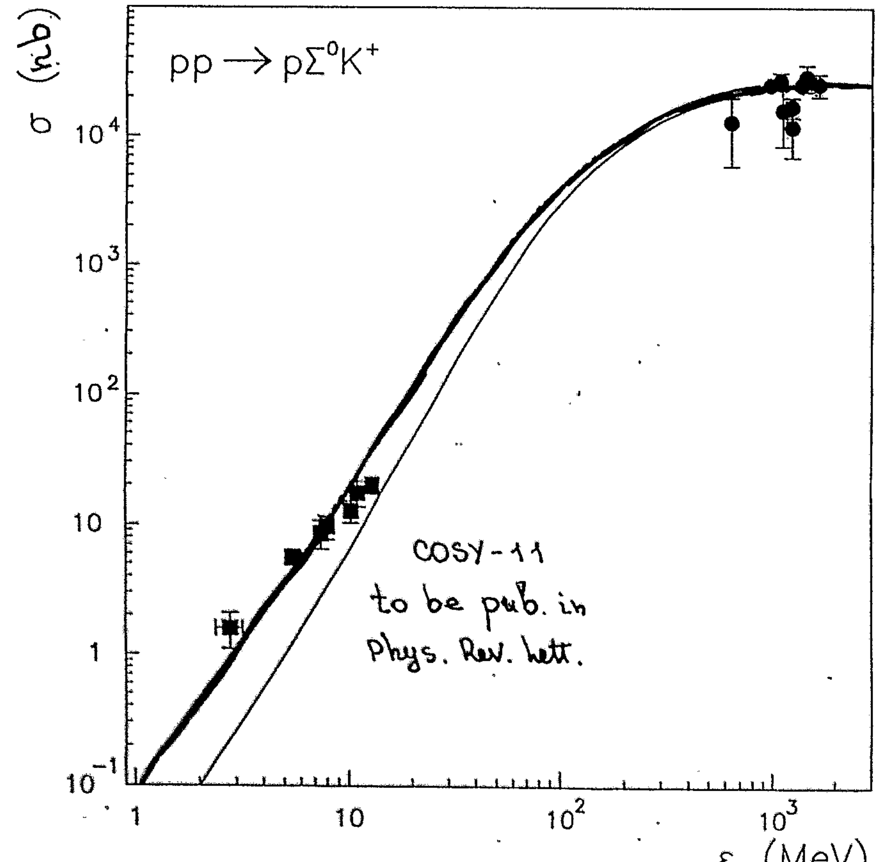
$$a_s = \frac{\alpha + \beta}{\alpha \cdot \beta} \qquad r_s = \frac{2}{\alpha + \beta} \quad \text{effective range expansion}$$

$$q \cot\delta = \frac{1}{a_s} + \frac{1}{2} r_s q^2 + \ldots$$

YN - Jülich model
Nucl. Phys. A500 (1989) 485; A570 (1994) 543

$a_s = -2.28$ fm
$r_s = 5.15$ fm

BUT for $\Sigma^+ p \rightarrow \Sigma^+ p$



The role of the P_{11} (1710)

A. Sibirtsev, K. Tsushima, W. Cassing, A.W. Thomas,
nucl-th / 9810070, sub. to. Nucl. Phys.

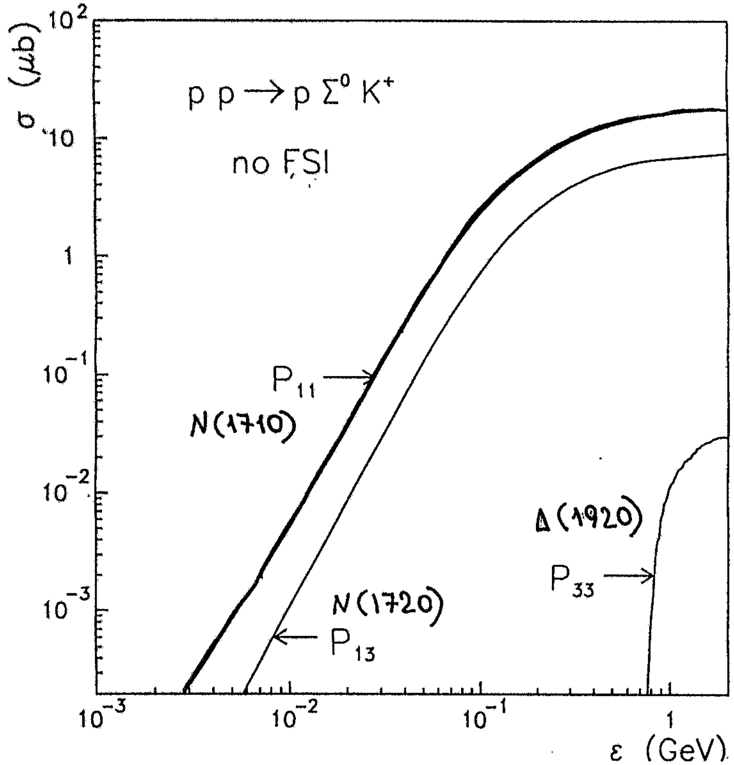
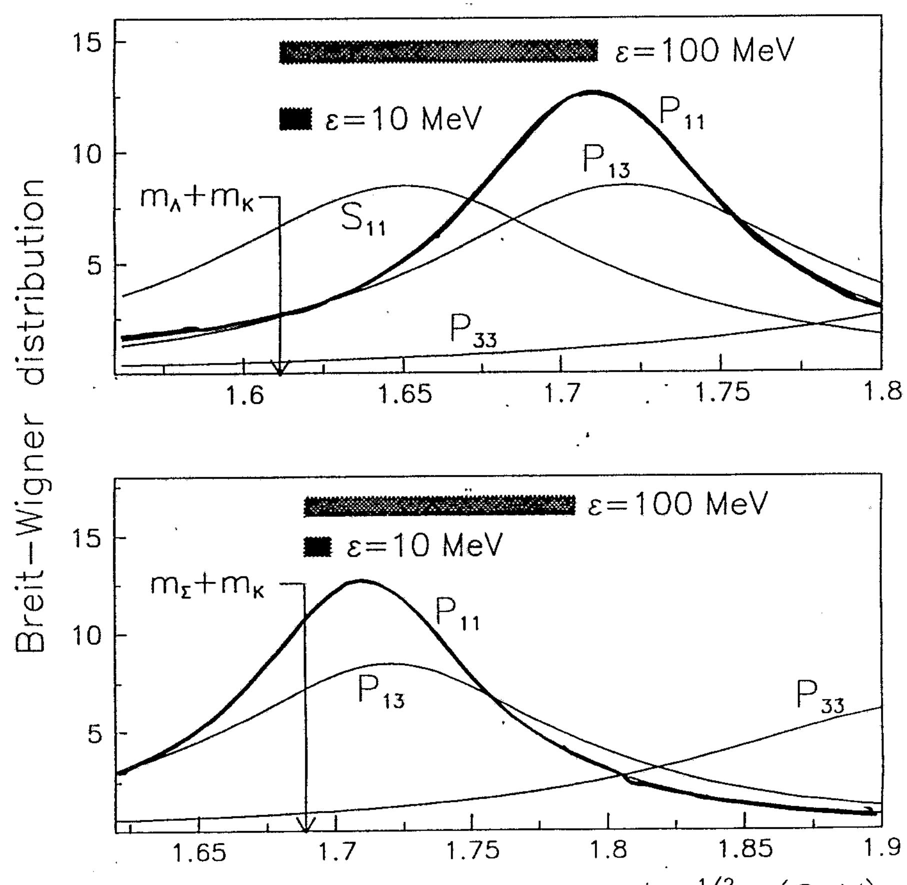


Figure 2: Decomposition of the total cross section in terms of individual resonance contributions, $N(1710)$ (P_{11}), $N(1720)$ (P_{13}) and $\Delta(1920)$ (P_{33}) resonances for the $pp \to p\Sigma^0 K^+$ reaction. The calculation was performed without the inclusion of final state interactions.

The role of the $N^*(1710)$

for $pp \to p\Lambda K^+$ N(1650), N(1710), N(1720) contribute with equivalent rates



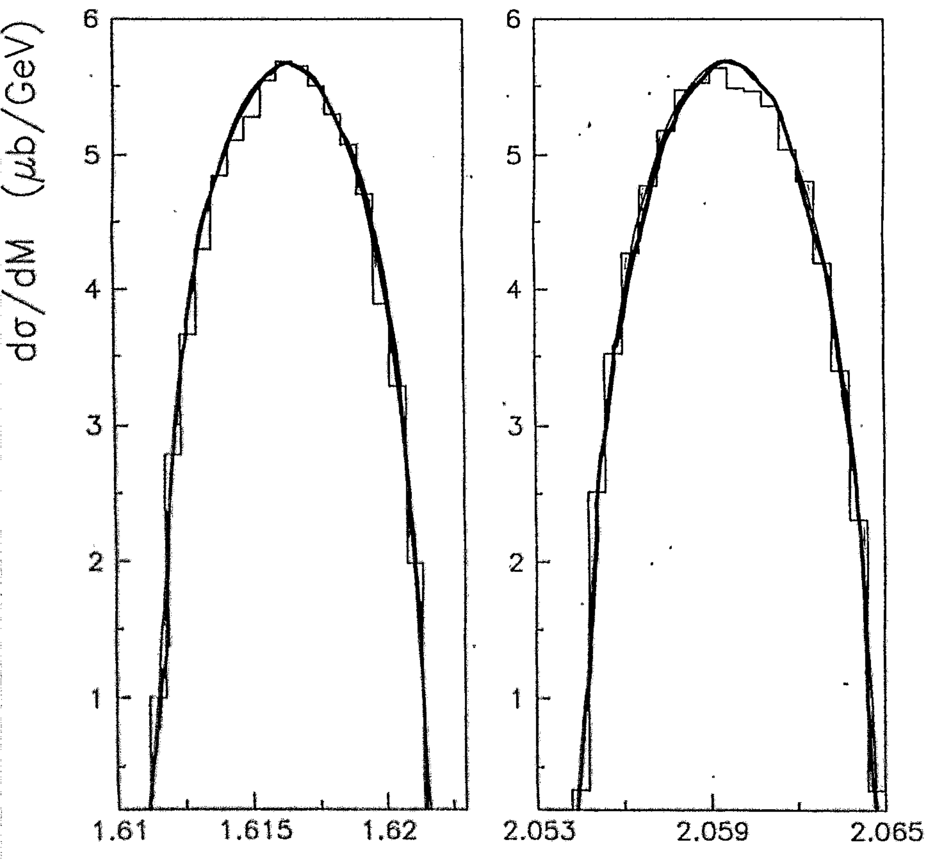
Do $R \to \Lambda K^+$ possible to detect by ΛK^+ invariant mass distribution?

A.S., K. Tsushima, A.W. Thomas,
Phys. Lett. B 421 (1998) 59

PREDICT

— real One Boson Exchange calculations } No difference
— phase space } confirmed experimentally

$pp \to p\Lambda^0 K^+$ at $\varepsilon = 10$ MeV



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

Dominant contribution from

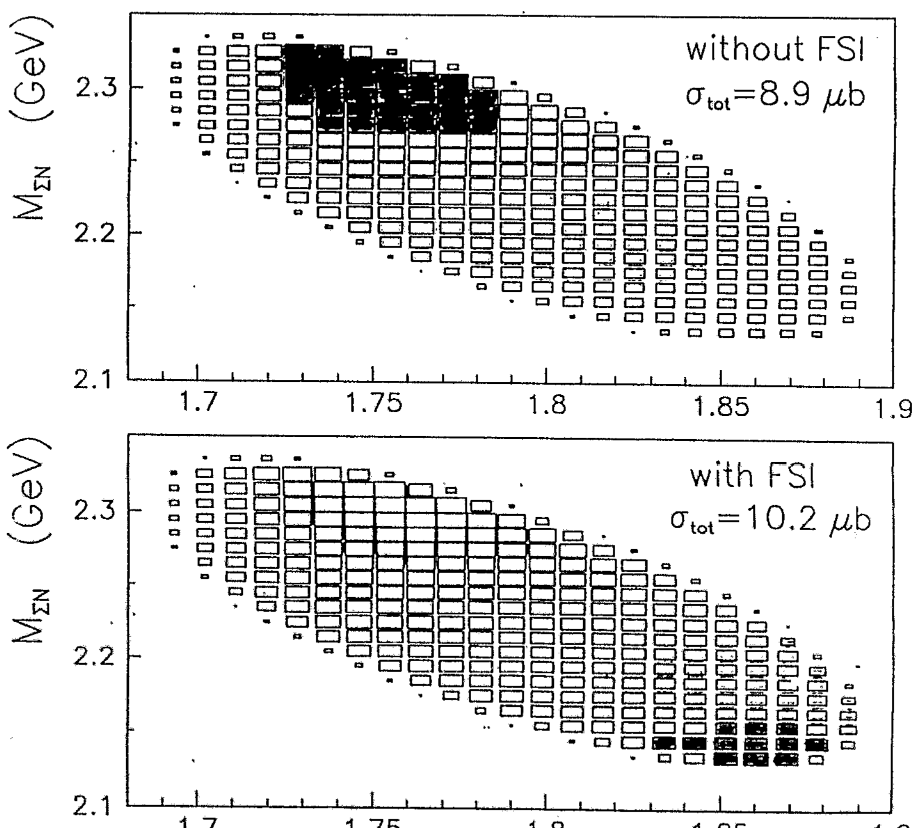
$P_{11}(1710)$ $\Gamma_{TOT} = 100$ MeV

$\to \Lambda K$ 15 %

$\to \Sigma K$ 8 %

fixed by studying $\pi N \to \Lambda K$, $\pi N \to \Sigma K$
total + differential cross sections

$pp \to p\Sigma^0 K^+$ at $\varepsilon = 200$ MeV



FSI and Jost function.

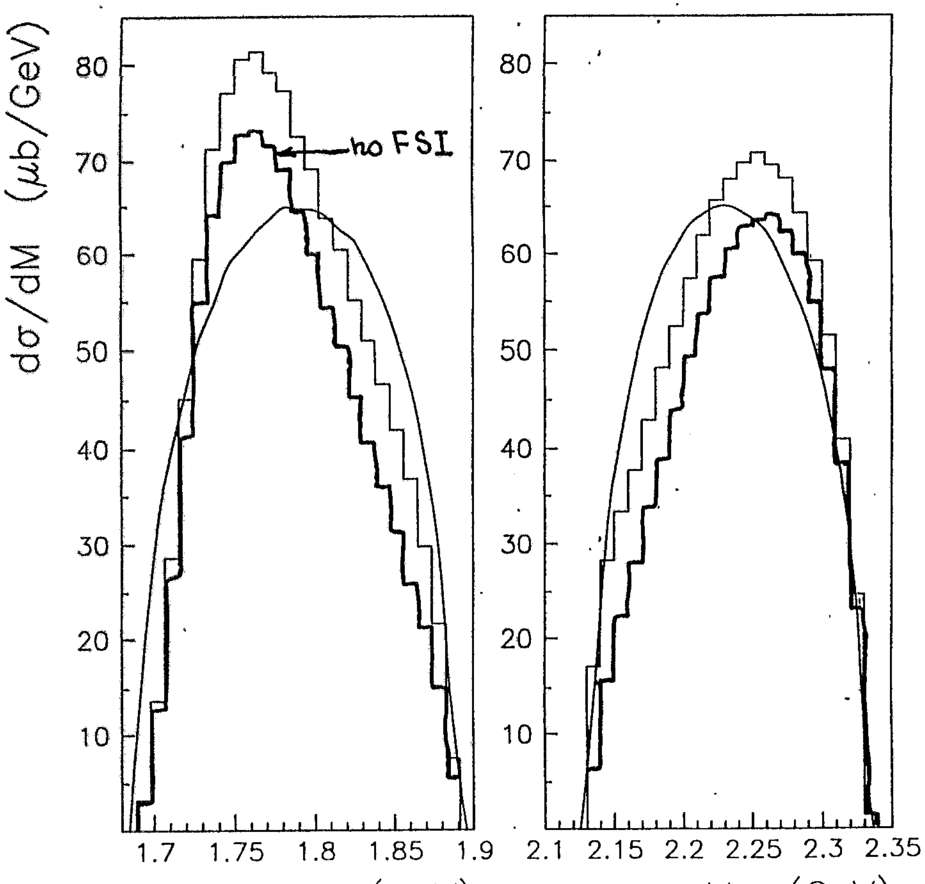
A.S. and W. Cassing, Eur. Phys. J. A2 (1998) 333

FSI and Watson-Migdal approximation

A.S. and W. Cassing, nucl_th/9802025

A.S., Acta Phys. Pol. (1998)

$pp \rightarrow p\Sigma^0K^+$ at ε=200 MeV



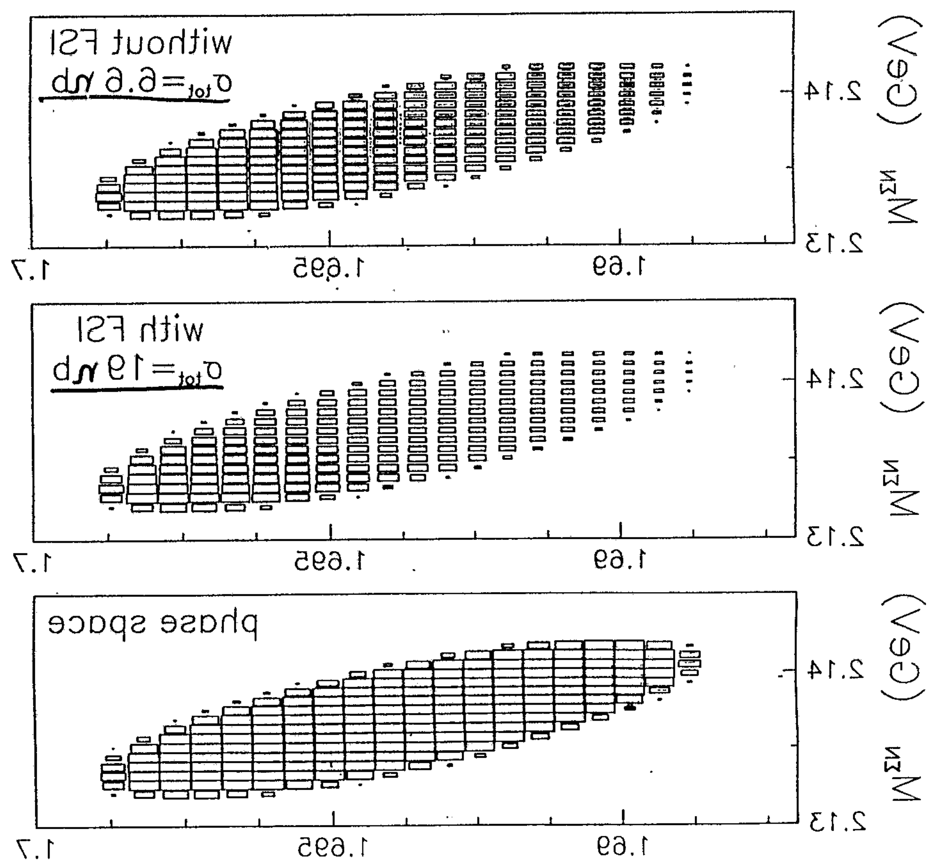
$pp \rightarrow p\Sigma^0K^+$

strong difference between calculations without FSI, with FSI and phase space at ε = 10 MeV

which was not predicted for $pp \rightarrow pK^+\Lambda$ and was not observed experimentally

total 'statistics' = 10^6 events

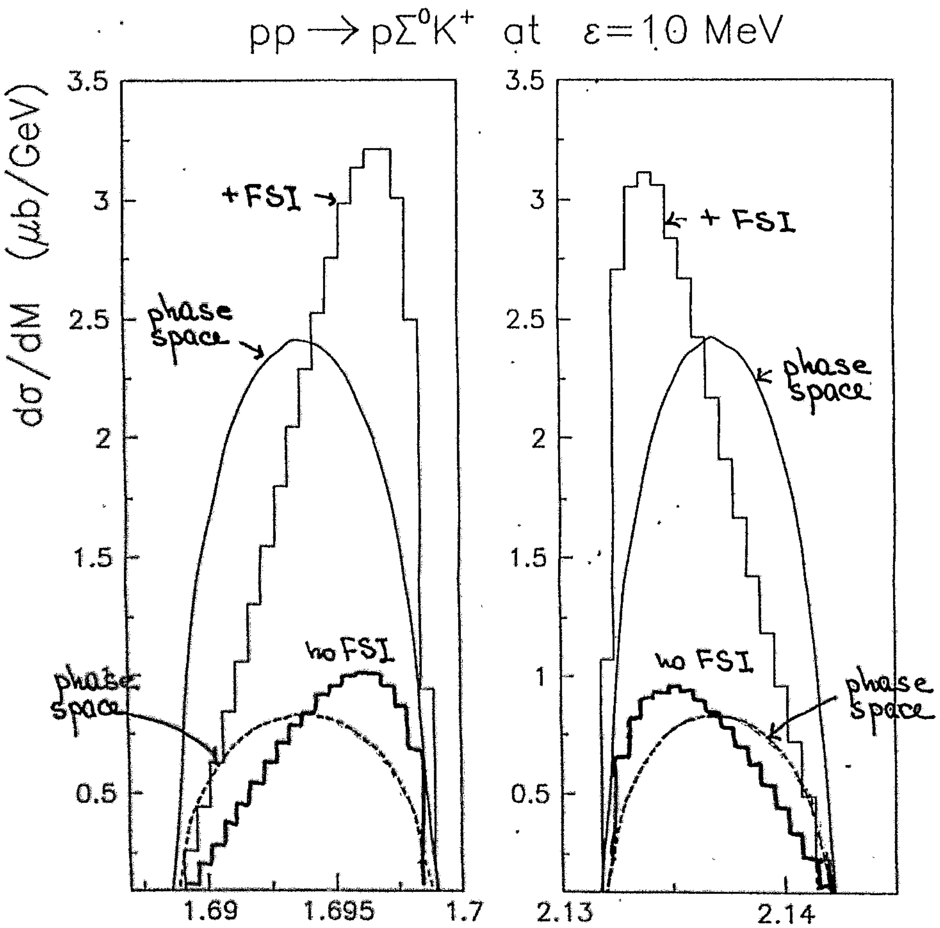
$pp \rightarrow p\Sigma^0K^+$ at ε=10 MeV



$M_{\Sigma K}$ (GeV) $M_{\Sigma N}$ (GeV)

Strong deviation from phase space @ $\varepsilon = 10$ MeV for
$pp \to p\Sigma^0 K^+$

both: with FSI and
without FSI



J. Knoll:

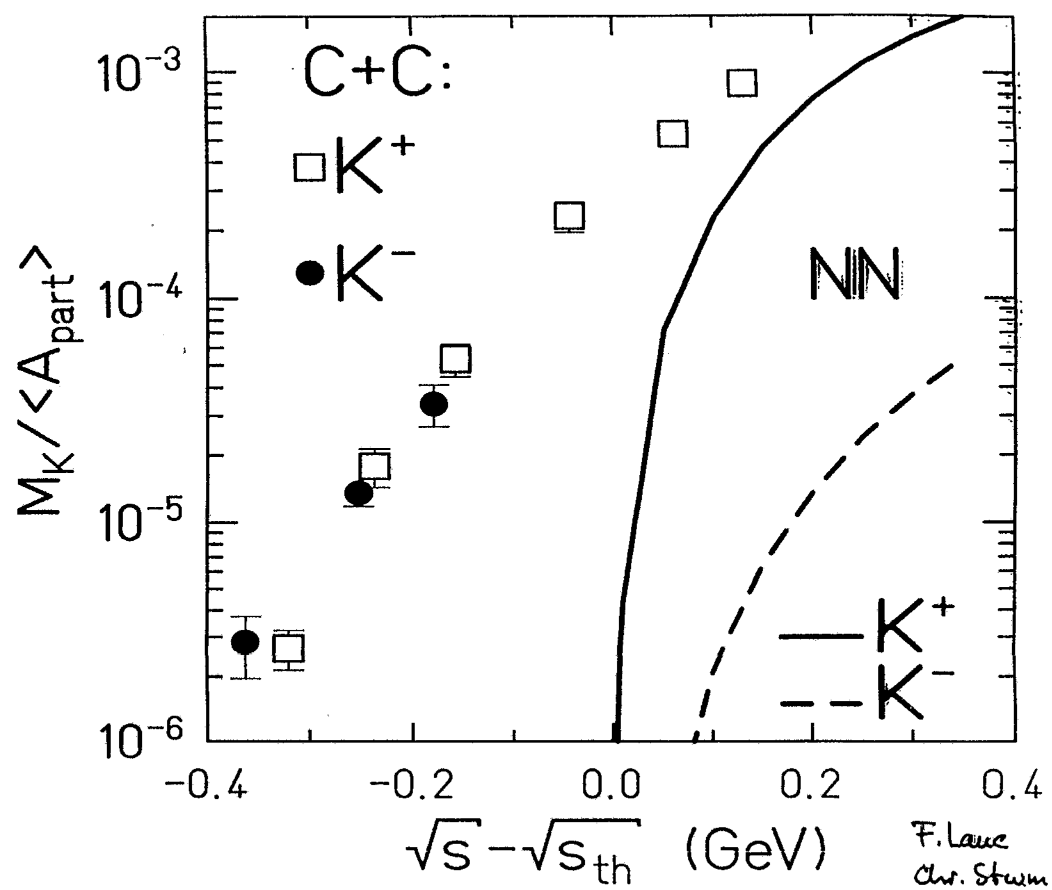
Transport kinetics of broad resonances

Transport kinetics
of
broad resonances

J. Knoll

GSI Darmstadt

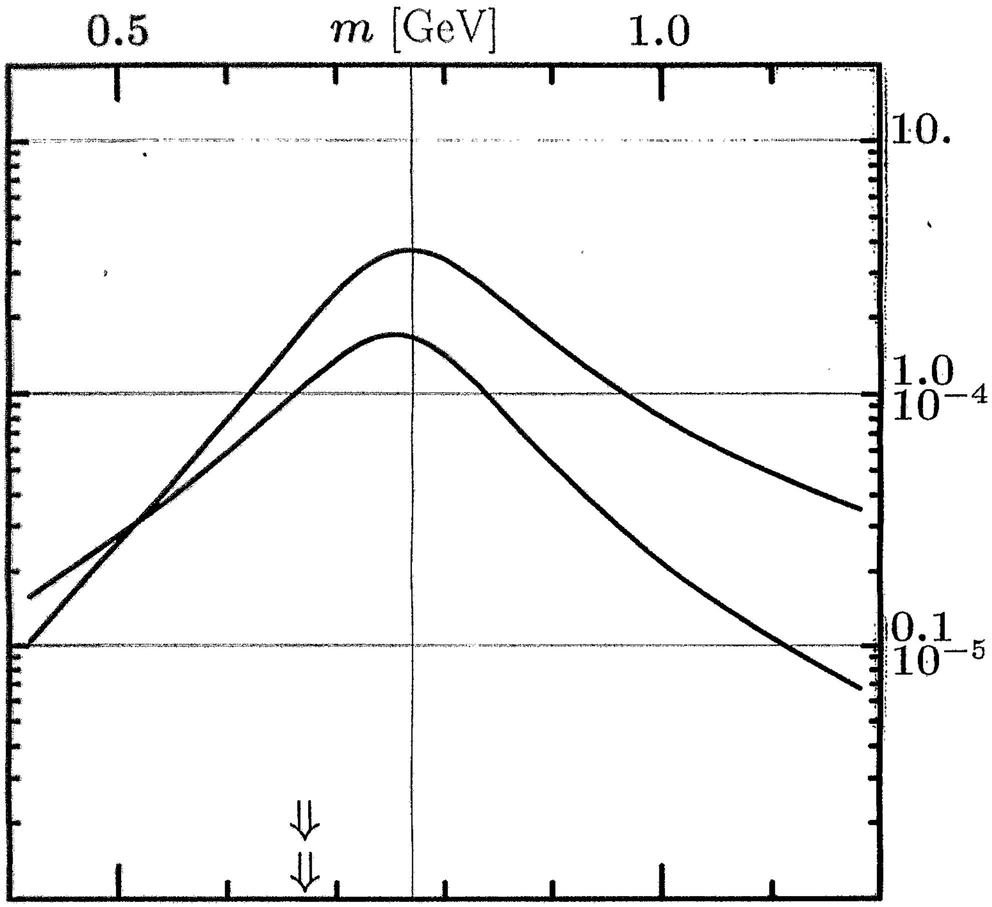
Threshold Mass Scaling



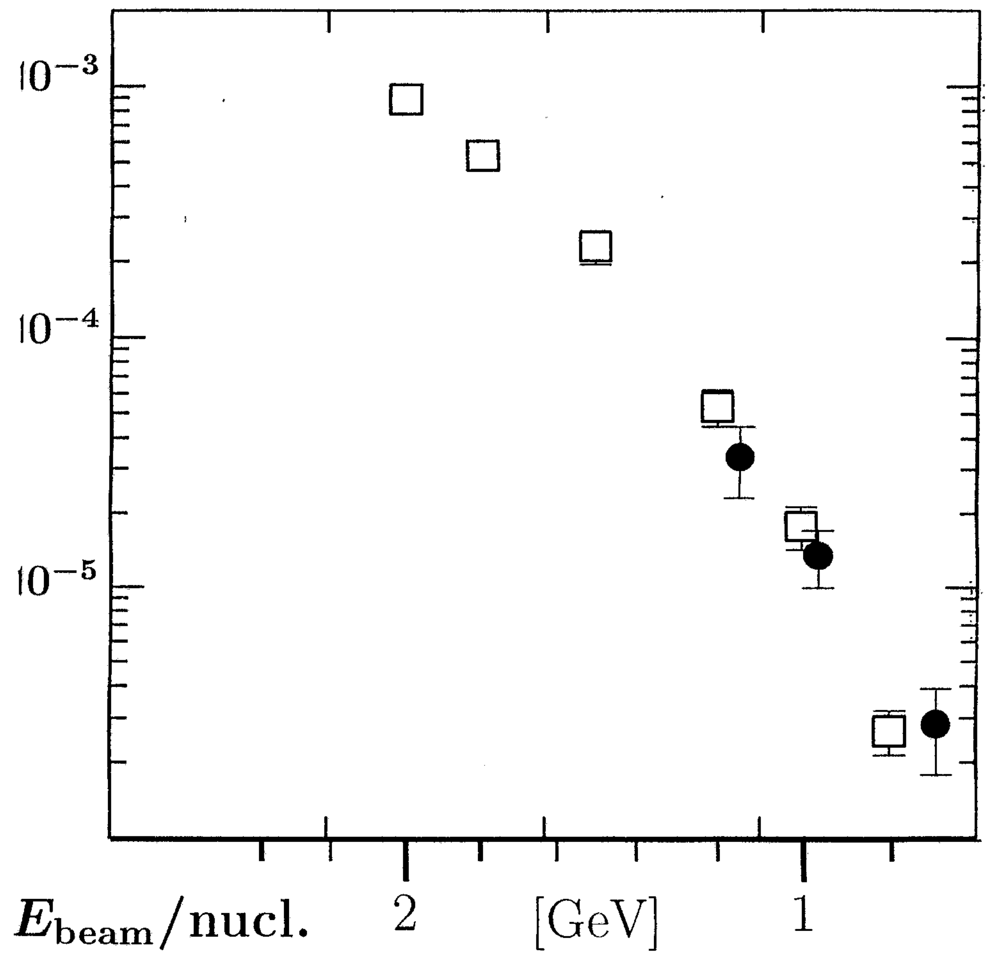
⇑ CM NN-energy ⇑ $m + 2m_N$

Y. Ivanov — ANN. PHYS. 249 (1996) 532
D. Voskresensky — HEP-PH/980
H. van Hees — TFT-98: HEP-PH/981
(Dipl. Thesis) — ERICE-98: NUCL-TH/981

Beam Energy Ruler



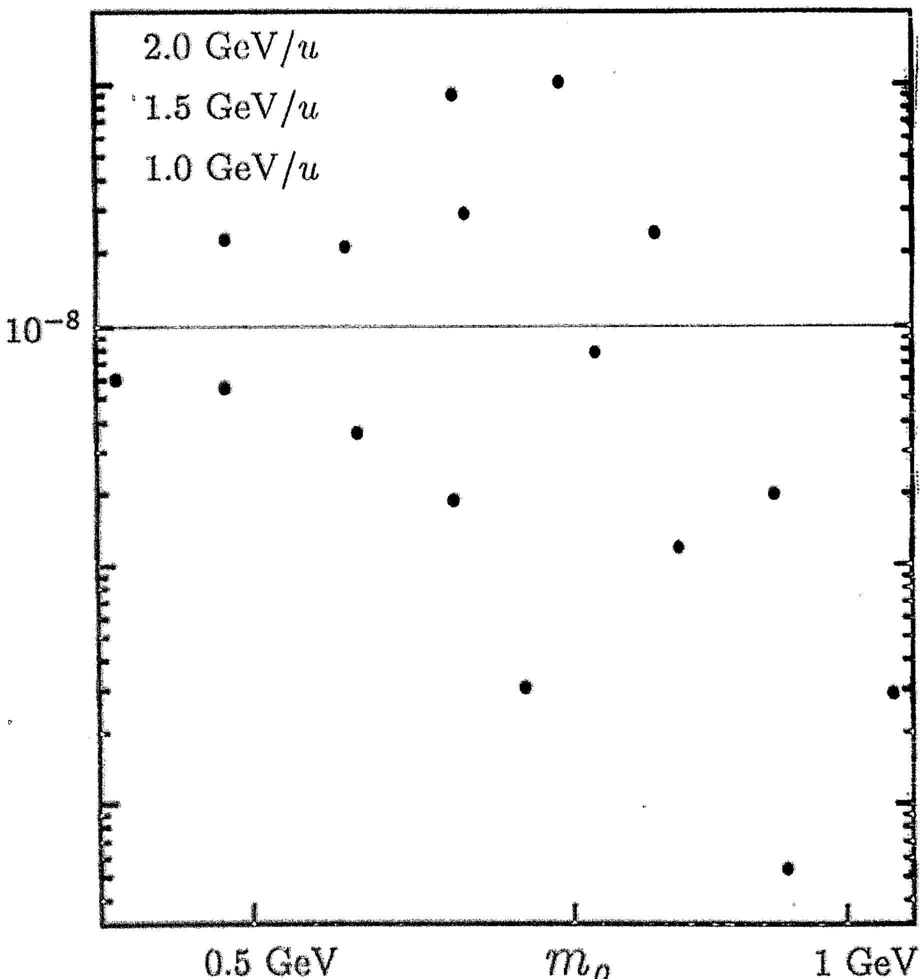
Mass Scaling



— ρ-mesons per 1 GeV
— di-electrons per 1 GeV

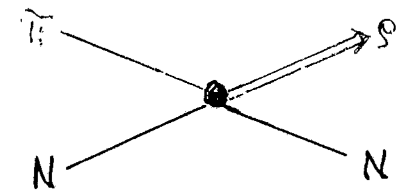
Di-leptons from Mass Scaling

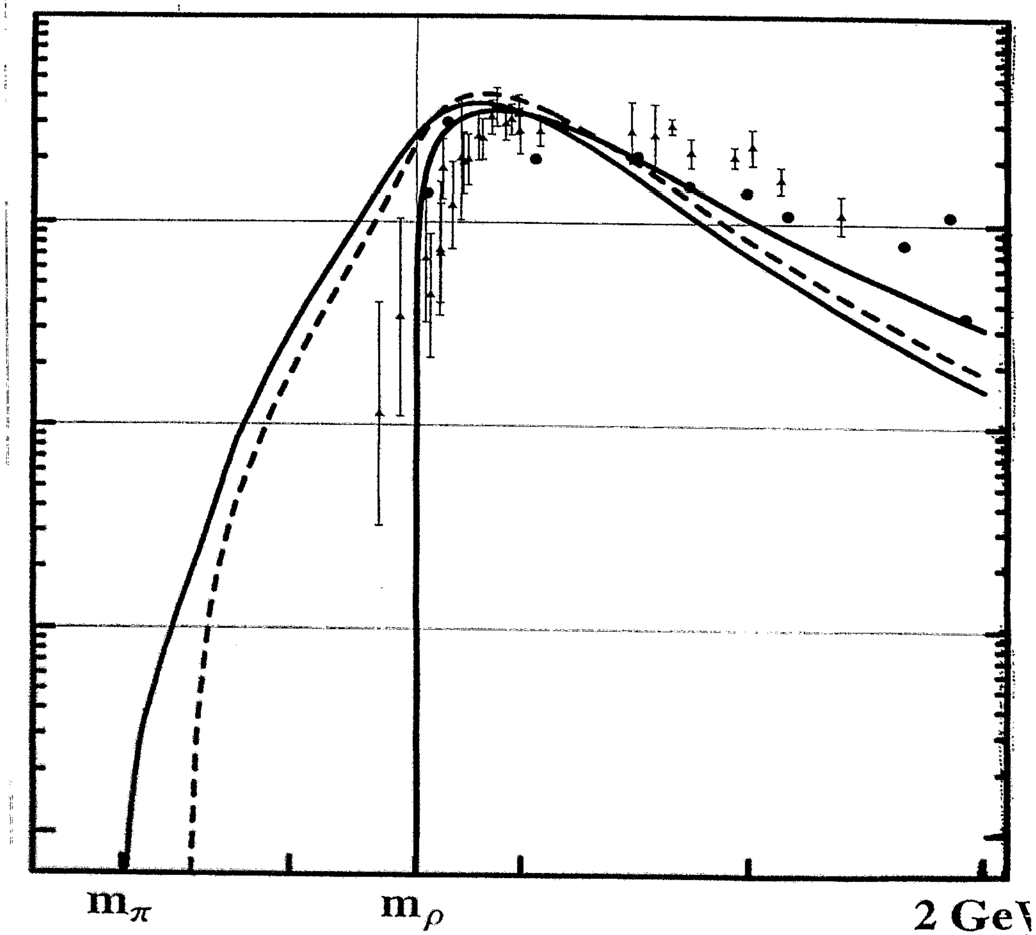
di-leptons per GeV and Participants



$\pi N \to \rho N$ Cross Section

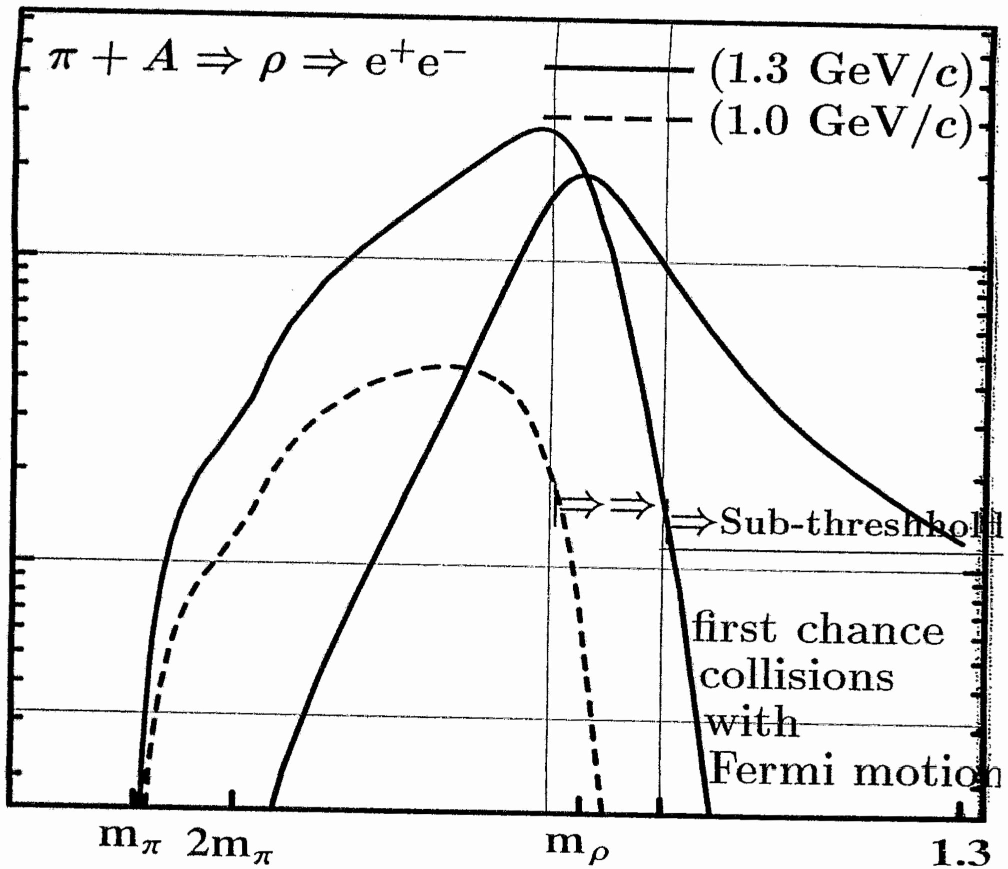
Constant Matrix element & $\Gamma_{tot} = \Gamma_{\rho\pi\pi} + \Gamma_{\rho\pi N}$



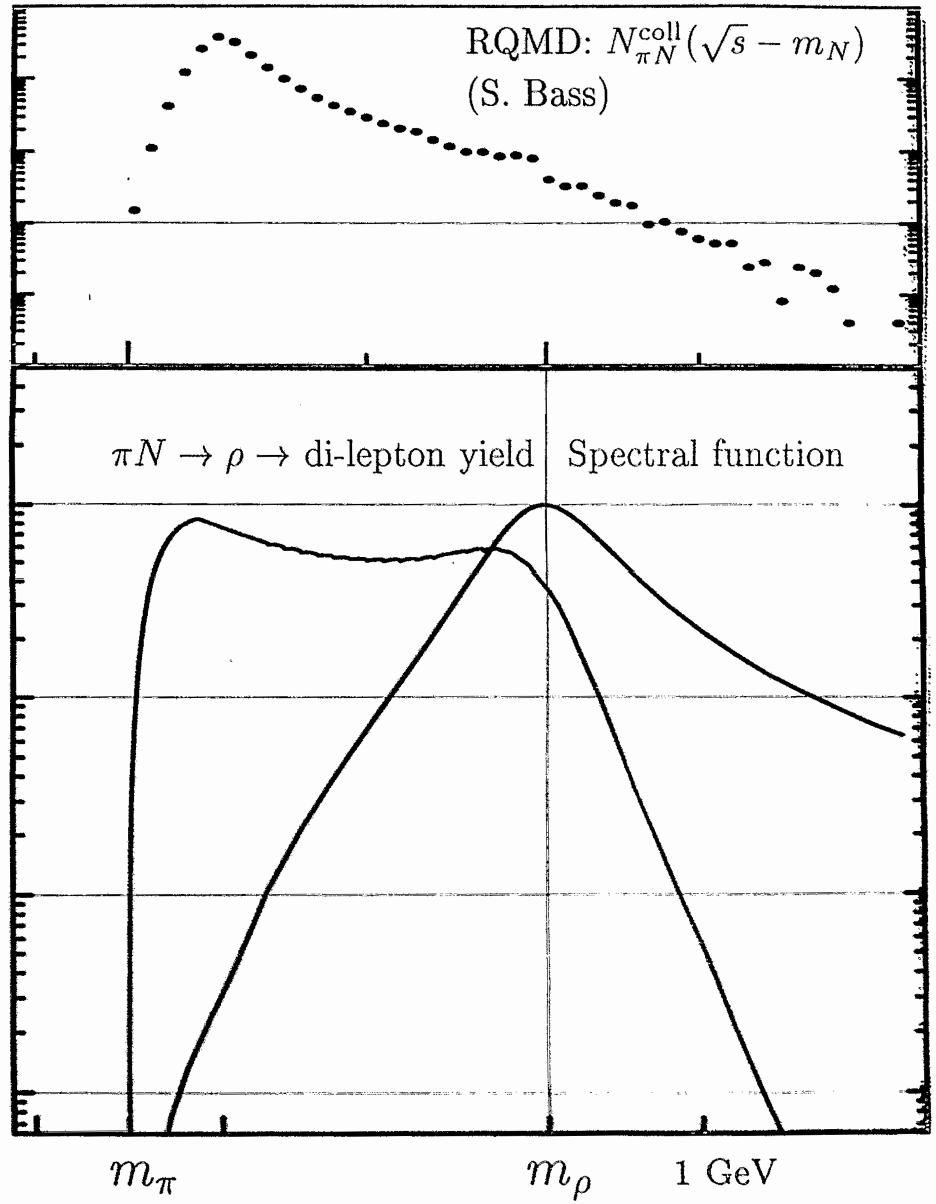


First Chance Collision Kinematics

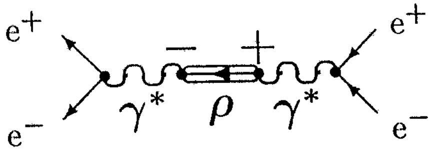
$$\frac{dn^{e^+e^-}}{dt\,dm} = \underbrace{F_\rho(m,p)}_{\text{Phase-Space}} \frac{\Gamma^{in}_{\pi N\rightarrow\rho N}(m,p)}{(m^2-m_\rho^2)^2+\Gamma^2_{tot}/4} \underbrace{\Gamma^{out}_{\rho\, e^+e^-}(m)}_{\propto 1/m^2 (\mathrm{VD})}$$



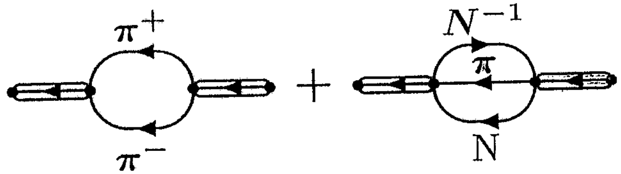
ρ-mesons from Ni+Ni at 1 GeV/u



e^+e^- from intermediate ρ-mesons

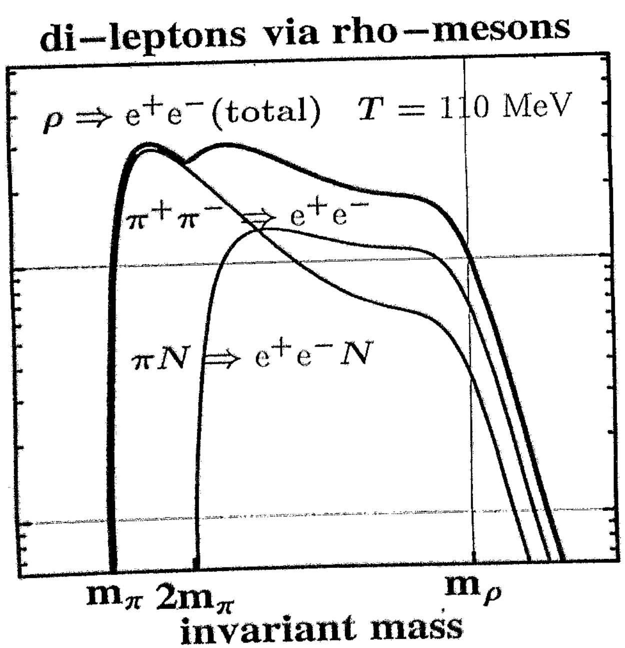
$\frac{dn^{e^+e^-}}{dtdm} =$ 

$= n_\rho(\omega, T)\ A_\rho(\omega, \vec{p})\ \Gamma^{\rho\, e^+e^-}(m)$

$A_\rho(\omega, \vec{p}) =$ 

$$= \frac{\Gamma^{\rho\,\pi^+\pi^-}(m) + \Gamma^{\rho\,\pi N N^{-1}}(m)}{\underbrace{\left(m^2 - m_\rho^2 - \mathrm{Re}\Sigma\right)^2}\ \underbrace{+\ \Gamma_{tot}^2/4}}$$

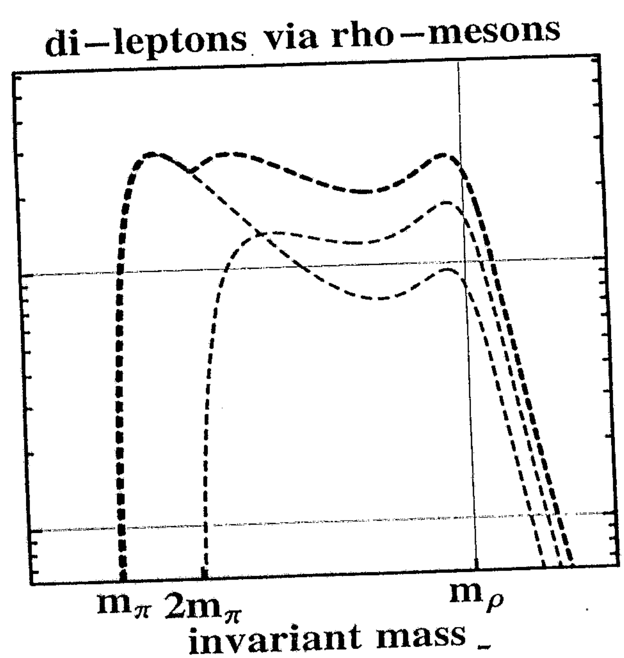
$\Rightarrow \quad \langle\sigma(\pi\pi \to \rho \to e^+e^-)\rangle + \langle\sigma(\pi N \to \rho N \to e^+e^- N)\rangle$



interacting
πN − System

Klingl et al.;
Friman Pirner

= —— free

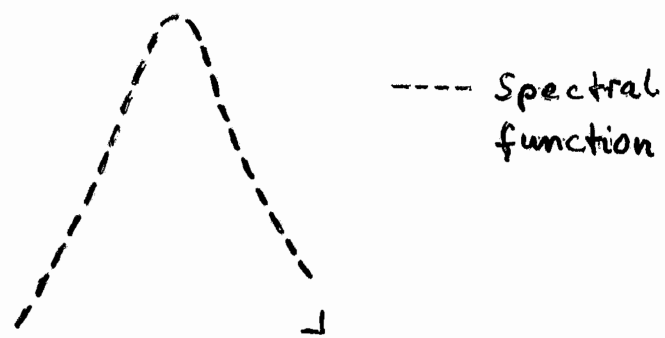


dashed lines:

free Cross sect.
$\Gamma_{tot} \Leftarrow \Gamma^{\rho\,\pi^+\pi^-}$

$\Downarrow$

Peak too large
violates Unitarity


---- Spectral function