FORSCHUNGSZENTRUM ROSSENDORF

FZR-202
November 1997
Preprint

A.I. Titov, B. Kämpfer, V.V. Shklyar

Polarization observables in the reaction $NN \to NN\,\Phi$

Herausgeber:
FORSCHUNGSZENTRUM ROSSENDORF
Postfach 51 01 19
D-01314 Dresden
Telefon (03 51) 26 00
Telefax (03 51) 2 69 04 61

Polarization observables in the reaction $NN \to NN\Phi$

A.I. TITOV[a,b], B. KÄMPFER[a], V.V. SHKLYAR[b]

[a]Research Center Rossendorf, PF 510119, 01314 Dresden, Germany

[b]Bogoliubov Theoretical Laboratory, Joint Institute for Nuclear Research, 141980 Dubna, Russia

Abstract:

We study the reaction $NN \to NN\Phi$ slightly above the threshold within an extended one-boson exchange model which also accounts for *uud* knock-out. It is shown that polarization observables, like the beam-target asymmetry, are sensible quantities for identifying a $s\bar{s}$ admixture in the nucleon wave function on the few per cent level.

1. Introduction: The investigation of the $NN \to NN\Phi$ reaction is interesting for several reasons. First, the elementary total cross section [1, 2] is an important input for the calculation of the Φ production in heavy-ion collisions [3]. In this case one might expect some change of the Φ width [4] due to the coupling to the decay channel $\Phi \to K^+K^-$ and peculiarities according to the in-medium modification of the kaon properties [5, 6]. Indeed, such measurements are under way with the 4π detector FOPI at SIS in GSI/Darmstadt [7]. The electromagnetic decay channel $\Phi \to e^+e^-$ will be investigated with the spectrometer HADES [8] also in GSI. Note, that a threshold-near measurement of the total cross section of the reaction $pp \to pp\Phi$ has been performed at SATURNE [9] and precision measurements of polarization observables are envisaged with the ANKE spectrometer at the cooler synchrotron COSY in Jülich [10].

Second, the Φ meson is thought to consist mainly of strange quarks, i.e. $s\bar{s}$, with a rather small contribution of the light u, d quarks. According to the OZI rule [11] the Φ production should be suppressed if the entrance channel does not possess a considerable admixture of hidden or open strangeness. Indeed, the recent experiments on the proton annihilation at rest, $p\bar{p} \to \Phi X$ (cf. [12] for a compilation of data), point to a large apparent violation of the OZI rule, which is interpreted [12] as a hint to an intrinsic $s\bar{s}$ component in the proton. Analyses of the πN sigma term [13] also suggest that the proton might contain a strange quark admixture as large as 20%.

It would be important and interesting to look for another clear signal [12, 14] that might be related directly with the strangeness content of nucleons. In ref. [15] it is shown that the polarization observables in the Φ photoproduction are sensitive even to a small strangeness admixture in the proton. Other investigations concern the polarization observables in $pp \to pp\Phi$ reactions at the threshold [12, 16]. It is found [16] that spin and parity conservation arguments result in a precise prediction for the beam-target asymmetry C_{zz}^{BT} for the $pp \to pp\Phi$ reaction at the threshold,

$$C_{zz}^{BT} = \frac{d\sigma(S_i = 1) - d\sigma(S_i = 0)}{d\sigma(S_i = 1) + d\sigma(S_i = 0)} = 1, \tag{1}$$

where S_i is the total spin in the entrance channel. It is also claimed [16] that the decay matrix density amounts $\rho_{00} = 0, \rho_{11} = \rho_{-1-1} = \frac{1}{2}$, where the quantization axis is directed along the velocity of the Φ meson. Real experiments, however, are performed at some finite energy above threshold, therefore the questions arise (i) how are the threshold predictions modified above threshold (say in the order of 100 MeV), and (ii) how sensitive are polarization observables to a certain strangeness admixture in the proton wave function. In this Letter we answer these questions. We show that the finite-energy modification of the asymmetry is rather strong and that the strangeness component modifies the previous predictions. We study both the $pp \to pp\Phi$ and the $pn \to pn\Phi$ reactions.

We assume here that in the threshold-near region the strongest contributions to the reaction come from the conventional one-boson exchange mechanism and the *uud* knock-out by exchanged mesons, similar to the Φ photoproduction and electroproduction [15, 17]. (We do not consider here the $s\bar{s}$ knock-out, thereby assuming that the corresponding meson-$s\bar{s}$-Φ coupling constants are small.) Both reaction channels are depicted in fig. 1 as Feynman diagrams. We use the notation $p_\alpha = (E_\alpha, \mathbf{p}_\alpha)$ with $\alpha = a, b, c, d$ for the four-momenta of nucleons, and $q = (E_\Phi, \mathbf{q}))$ for the produced Φ meson in the center of mass system (c.m.s.). Hereafter ϑ denotes the polar Φ meson angle, and $s = E_a + E_b$. We use a coordinate system with $\mathbf{z} \parallel \mathbf{p}_a$, $\mathbf{y} \parallel \mathbf{p}_a \times \mathbf{q}$.

2. One-boson exchange model: Let us consider first the one-boson exchange (OBE) model for the conventional $NN \to NN\Phi$ reaction dynamics. Our OBE model is close to the previously employed model [2]. The meson-nucleon interaction Lagrangian reads in obvious standard notation

$$\mathcal{L}_{MNN} = -ig_{\pi NN}\bar{N}\gamma_5 \boldsymbol{\tau}\boldsymbol{\pi} N - g_{\rho NN}\left(\bar{N}\gamma_\mu \boldsymbol{\tau} N \boldsymbol{\rho}^\mu - \frac{\kappa_\rho}{2M_N}\bar{N}\sigma^{\mu\nu}\boldsymbol{\tau} N \partial_\nu \boldsymbol{\rho}_\mu\right), \qquad (2)$$

while the $\Phi\rho\pi$ Lagrangian is

$$\mathcal{L}_{\Phi\rho\pi} = g_{\Phi\rho\pi}\,\epsilon^{\mu\nu\alpha\beta}\,\partial_\mu \Phi_\nu\,\mathrm{Tr}(\partial_\alpha \rho_\beta \pi), \qquad (3)$$

where $\mathrm{Tr}(\rho\pi) = \rho^0\pi^0 + \rho^+\pi^- + \rho^-\pi^+$, and bold face letters denote isovectors. All coupling constants are dressed by monopole form factors $F_i = (\Lambda^2 - m_i^2)/(\Lambda^2 - k_i^2)$, where k_i is the four-momentum of the exchanged meson.

The total invariant OBE amplitude is the sum of 4 amplitudes

$$T_{fi} = T_{fi}[ab; cd] + T_{fi}[ba; dc] + T_{fi}[ab; dc] + T_{fi}[ba; cd], \qquad (4)$$

where the last two terms stem from the antisymmetrization or from charged meson exchange for *pp* or *pn* reactions, respectively. The first term in eq. (4) reads explicitly

$$T^r_{m_c,m_d;m_a,m_b} = K(k_\pi^2, k_\rho^2)\,\Pi_{m_d,m_b}(p_b, p_d)\,W_{m_c,m_a}(p_a, p_c) \qquad (5)$$

with

$$\begin{aligned}
K(k_\pi^2, k_\rho^2) &= \frac{g_{\pi NN}\, g_{\rho NN}\, g_{\Phi\rho\pi}}{(k_\pi^2 - m_\pi^2)(k_\rho^2 - m_\rho^2)}\,\frac{\Lambda_\pi^2 - m_\pi^2}{\Lambda_\pi^2 - k_\pi^2}\,\frac{\Lambda_\rho^2 - m_\rho^2}{\Lambda_\rho^2 - k_\rho^2},\\
\Pi_{m_d,m_b}(p_b, p_d) &= \bar{u}(p_d, m_d)\gamma_5\, u(p_c, m_c),\\
W_{m_c,m_a}(p_a, p_c) &= i\,\epsilon_{\mu\nu\alpha\beta} k_\rho^\mu \Sigma^\nu_{m_c,m_a}(k_\rho) q_\Phi^\alpha \epsilon^{*\,r,\beta},\\
\Sigma^\nu_{m_c,m_a}(k_\rho) &= \bar{u}(p_c, m_a)\left[\gamma^\nu - i\frac{\kappa_\rho}{2M_N}\sigma^{\nu\nu'} k_{\rho_{\nu'}}\right] u(p_a, m_a).
\end{aligned} \qquad (6)$$

$\epsilon^{r,\beta}$ denotes the Φ polarization four-vector, and the index r describes the polarization of the Φ meson in the helicity basis; $m_a ... m_d$ are the nucleons spin projection on the quantization axis, and $k_\rho = p_c - p_a$, $k_\pi = p_b - p_d$.

The differential cross section is related to the invariant amplitude T_{fi} via

$$\frac{d^5\sigma}{dE_\Phi d\Omega_\Phi d\Omega_c} = \frac{1}{8\sqrt{s(s-4M_N^2)}(2\pi)^5} \left|T_{fi}\right|^2 \frac{qp_c^2}{|Ap_c + CE_c|} \tag{7}$$

where the energy E_c of particle c in the c.m.s. is defined by

$$E_c = \frac{AB \pm C\sqrt{B^2 - M_N^2(A^2 - C^2)}}{A^2 - C^2}, \tag{8}$$

with $A = (\sqrt{s} - E_\Phi)$, $B = s - 2E_\Phi\sqrt{s} + M_\Phi^2$, $C = 2q\cos\vartheta_{qp_c}$, where ϑ_{qp_c} is the angle between $\mathbf{q}$ and $\mathbf{p_c}$. Both solutions in eq. (8) are to be taken into account.

2.1 Fixing parameters: The coupling constant $g_{\Phi\to\rho\pi}$ is determined by the $\Phi \to \rho\pi$ decay. Taking the most recent value $\Gamma(\Phi \to \rho\pi)$=0.69 MeV [18] we get $g_{\Phi\rho\pi}$ =1.10 GeV^{-1}.

The laboratory kinetic energy of the initial proton in the region with $\Delta \equiv \sqrt{s} - \sqrt{s_0} \sim 0.1\cdots 0.3$ GeV is about $3 \cdots 3.5$ GeV (here $\sqrt{s_0} = 2M_N + M_\Phi$). That is a quite large beam energy for the usual OBE model and, therefore, one must use energy dependent coupling constants. We use the minimal energy dependence of ref. [19], where each meson-nucleon coupling constant is modified by a cut-off factor, i.e. $g_{iNN} \to g_{iNN}^0 \exp(-l_i\sqrt{s})$ with l_i = 0.11 (0.18, 0.1, 0.1) GeV^{-1} for $i = \pi$ (ρ, σ, ω). We shall employ two sets of the OBE model parameters: set I relies on the Bonn OBE model as listed in Table B.1 (Model II) of Ref. [20], and set II uses the results of ref. [19]. The cut-off parameter $\Lambda_{\Phi\rho\pi}^\pi$ is adjusted by a comparison of additional calculations and data [21] for the $\pi^- p \to n\Phi$ reaction. We find $\Lambda_{\Phi\rho\pi}^\rho$ = 1.9 GeV for set I, and ∞ for set II. These relatively large cut-off values are in agreement with the pion photoproduction [22] and photon emission from the $V\pi\gamma$ ($V = \rho$, ω) vertices in NN bremsstrahlung [23]. Our cut-off parameter in set I is greater then the one found in ref. [2] because we use energy-suppressed coupling constants and we have a negative interference between vector and tensor parts in the $pn\rho$ vertex which is intimately related to the definition of the Lagrangian eq. (2). Note that we describe the data [21] in a limited region of $\Delta_{\pi^- p\to n\Phi} \equiv \sqrt{s} - M_N + M_\Phi \leq 0.15$ GeV. At higher energies the OBE model overestimates the data. (In this region one could use a stronger energy suppression in the vertices as in ref. [1].) We have checked that the momenta at the $\pi\rho\Phi$ vertex in the $NN \to NN\Phi$ reaction are in the region where we describe the $\pi^- p \to n\Phi$ reaction correctly. Taking into account the symmetry of the off-shell mesons in the $\Phi\rho\pi$ vertex we use $\Lambda_{\Phi\rho\pi}^\pi = \Lambda_{\Phi\rho\pi}^\rho$ for each parameter set.

2.2 Threshold limit: At the threshold, where $\Delta \to 0$, one can neglect terms proportional to $|\mathbf{q}|/M_\Phi$, $|\mathbf{p}_{c,d}|/M_N$ in the amplitude. Meson propagators and form factors become constants because they depend on the same variable $k_{\rho,\pi}^2 \to k_0^2 = -M_N M_\Phi$. Hence one can express the amplitudes in the form

$$T_{fi}^r[ab;cd] \;=\; T_0\, U_{fi}^r[ab;cd],$$

$$\begin{aligned}
T_0 &= K(k_0^2)\,(1-\kappa_\rho)M_N M_\Phi\sqrt{M_\Phi(M_N+\frac{1}{4}M_\Phi)},\\
U^0_{fi}[ab;cd] &= 2m_b\cos\vartheta_b\,\delta_{m_a,-m_c}\delta_{m_b,m_d}\,\sin\vartheta,\\
U^{\pm}_{fi}[ab;cd] &= \mp\frac{1}{\sqrt{2}}2m_b\cos\vartheta_b\,\delta_{m_a,-m_c}\delta_{m_b,m_d}\,(\cos\vartheta\pm 2m_a).
\end{aligned}\tag{9}$$

For $\vartheta = 0$ the spin is transferred to the Φ meson only at the $NN\rho$ vertex by a nucleon spin-flip. Then for the initial polarization $m_a = \frac{1}{2}$ $(-\frac{1}{2})$ only T^+ (T^-) is non-zero, while for $\vartheta = \pi$ only T^+ (T^-) is non-zero for $m_a = -\frac{1}{2}$ $(\frac{1}{2})$. Summation of $|T^r_{fi}|^2$ over spin projections of the outgoing particles leads to the following expressions for pp and pn collisions

$$\begin{aligned}
\sum_{m_{c,d}}|T^r_{fi,\alpha}|^2 &= T_0^2\,S^r_\alpha,\\
S^r_\alpha &= \sum_{m_{c,d}}\left(\xi^1_\alpha U^r_{fi}[ab;cd]+\xi^2_\alpha U^r_{fi}[ab;dc]+\xi^3_\alpha U^r_{fi}[ba;dc]+\xi^4_\alpha U^r_{fi}[ba;cd]\right)^2
\end{aligned}\tag{10}$$

with $\xi^1_{pp} = \xi^3_{pp} = -\xi^2_{pp} = -\xi^4_{pp} = 1$ $\xi^1_{pn} = \xi^3_{pn} = -1; \xi^2_{pn} = \xi^4_{pp} = 2$. Finally we get

$$S^0_\alpha = \Delta^\alpha_{m_a,m_b}\,\sin\vartheta,\qquad S^{\pm}_\alpha = \frac{1}{2}\Delta^\alpha_{m_a,m_b}\,(\cos\vartheta\pm 2m_a)^2,\tag{11}$$

where $\Delta^{pp}_{m_a,m_b} = 4(1+\delta_{m_a,m_b}-\delta_{m_a,-m_b})$ and $\Delta^{pn}_{m_a,m_b} = 2(1+4[1+\delta_{m_a,m_b}-\delta_{m_a,-m_b}])$. Using these equations we get the threshold limits for the beam-target asymmetry $C^{BT}_{zz} = 1$ and 0.8 for pp and pn collisions, respectively. For both reactions the Φ spin density matrix elements are $\rho_{00} = 0$ and $\rho_{11} = \frac{1}{2}$. For the pp reaction this result agrees with a previous prediction [16]. Moreover, eqs. (10, 11) predict the ratio of the corresponding total cross sections as $\sigma^{tot}_{np}/\sigma^{tot}_{pp} = 80/(32\cdot\frac{1}{2}) = 5$, where the additional factor $\frac{1}{2}$ in the pp cross section represents the symmetry factor.

3. ***uud* knock-out:** The main ingredient of the knock-out photoproduction mechanism is the assumption that the constituent quark wave function of the proton contains, in addition to the usual 3-quark (uud) component, a configuration with an explicit $s\bar{s}$ contribution. A simple realization of this picture is the following wave function in the Fock space [17]

$$|p\rangle = A|[uud]^{1/2}\rangle + B\left\{a_0|[[uud]^{1/2}\otimes[s\bar{s}]^0]^{1/2}\rangle + a_1|[[uud]^{1/2}\otimes[s\bar{s}]^1]^{1/2}\rangle\right\},\tag{12}$$

where B^2 denotes the strangeness admixture in the proton, and $a^2_{0,1} = \frac{1}{2}$ are the fractions of the $s\bar{s}$ pair with spin 0 and 1, respectively. The superscripts represent the spin of each cluster, and $\otimes$ represents the vector addition of spins of the uud and $s\bar{s}$ clusters and their relative orbital angular momentum ($\ell = 1$). Details on the wave functions in the relativistic harmonic oscillator model [24] can be found in refs. [15, 17]. We assume that the exchanged mesons interact with the uud cluster as with a structureless particle and describe this interaction within the OBE model with exchanged π, ρ, ω, σ mesons, see fig. 1b. The $s\bar{s}$ component is considered as spectator, that means only the configuration with spin $S_{s\bar{s}} = 1$ is realized. The corresponding S matrix element for the diagram with meson exchange shown in fig. 1b reads

$$S_{fi} = \sum_{i=\pi,\rho,\omega,\sigma} \left\langle c, \Phi \middle| \Gamma^i_\mu e^{ikx} \middle| a \right\rangle D^{i\,\mu\nu} \left\langle d \middle| \Gamma^i_\nu \middle| b \right\rangle, \tag{13}$$

where $D^{\mu\nu}$ is the propagator and Γ_ν is the vertex function when the exchanged mesons are ρ and ω; the Lorentz indices at the vertex and propagator disappear for π and σ exchange. The T matrix is calculated in the rest frame of the decaying nucleon and is expressed via the two-body scattering T matrix and the transition amplitude by

$$T_{fi} = \sum_{i=\pi,\rho,\omega,\sigma} \sum_{m_x} M^{N\to N\Phi}_{m_x,m_\Phi;m_a} \, {}^{i}T^{NN\to NN}_{m_c m_d; m_x, m_b}(p_c, p_d; zp_a, p_b) \tag{14}$$

(z is the momentum fraction carried by the uud cluster) with the abbreviations

$$\begin{aligned} {}^{i}T^{NN\to NN}(pc, d; x, b) &= i\bar{u}(c)\Gamma^i_\mu u(x)\, D^{i\,\mu\nu} \bar{u}(d)\Gamma^i_\nu u(b), \\ M^{N\to N\Phi}_{m_x,m_\Phi;m_a} &= -i\sqrt{\frac{3}{2}} \frac{V(q^*)}{\gamma^*_\Phi \gamma^{*2}_c} \sum_{m, J_c=0,1; m_c} \left\langle 1 m_\Phi 1 m \middle| J_c m_c \right\rangle \left\langle J_c m_c \frac{1}{2} m_x \middle| \frac{1}{2} m_a \right\rangle \hat{q}^*_m, \end{aligned} \tag{15}$$

where $\mathbf{q}^*$ is the Φ momentum in the laboratory system, $\hat{q}^*_m$ denotes its projected unit vector in the circular basis, and $V(\mathbf{k})$ stands for the wave function of the relative motion normalized as $\int V^2(\mathbf{k}) d\mathbf{k}/(2\pi)^3/2\sqrt{(\mathbf{k}^2 + M^2_\Phi)} = 1$; $\gamma^*_{\Phi,c}$ is the corresponding Lorentz factor which reflects the Lorentz contraction in the relativistic constituent model. In our calculations we use a Gaussian distribution $V(x) = Nx\exp(-x^2/2\Omega)$ with $\sqrt{\Omega} = 2.41$ fm^{-1} [15, 17]. The final amplitude contains the sum over all exchanged mesons and consists of 2 direct and 2 exchange amplitudes for the pp reaction, and 2 direct and 0 (ω, σ) or 2 (π, ρ) exchange amplitudes for the pn reaction to be taken with their proper isospin factors.

The corresponding amplitudes in the Φ helicity basis can be obtained by $T^r = \sum_{m_\Phi} d^1_{m_\Phi,r}(\vartheta)\, T_{m_\Phi}$ with the Wigner rotation functions $d^1_{m_\Phi,r}$. Note that this amplitude may be expressed in the covariant form $T^r = W^\mu \epsilon^{r*}_\mu$, where the time component W^0 is found from the transversality condition. The net result is a renormalization of the component with $r = 0$ as $T^0 \to T^0 M_\Phi / E_\Phi$.

In the threshold limit the beam-target asymmetry is 1 (pp reaction) or ~ 0 (pn reaction). $\sigma^{tot}_{pn}/\sigma^{tot}_{pn}$ depends on the model for the two-body T matrix, and in our case it is close to 1. The Φ spin density matrix elements here coincide with the conventional OBE model predictions.

4. Results: Our result for the total cross section in the pp reaction is shown in fig. 2. The lower (upper) solid lines correspond to the conventional OBE channel for the set I with

$\Lambda^{\rho,\pi}_{\Phi\rho\pi} = 1.9$ GeV ($\Lambda^{\rho}_{\Phi\rho\pi} = 1.9$ GeV, $\Lambda^{\pi}_{\Phi\rho\pi} = \infty$); the short-dashed line is the prediction for set II. The dashed line depicts the calculation with the constant matrix element of eq. (10). One can see that up to $\Delta \sim 1$ GeV the cross section is described fairly well by the phase space integral alone. The space between upper solid and dashed curves indicates upper and lower limits for the OBE model prediction. In spite of the fact that the OBE model is reliable in the region of $\Delta \leq 0.2$ GeV it fits satisfactorily the available experimental data [9, 25] in a much wider interval. The cross section for the pn reaction is greater by a factor $\simeq 5$ as given already in our threshold-near prediction above. Open squares and black dots show the predictions for the knock-out channel within the OBE model with sets I and II, respectively, and a strangeness probability $B^2 = 0.01$. The distance between them is indicative for the accuracy of the theoretical prediction. Taking into account that, contrary to set II, the set I overestimates the elastic NN scattering at $-t \sim 1 \cdots 2$ GeV^2 by a factor of $20 \cdots 40$, the prediction based on set II seems to be more realistic. So, we can conclude, that the difference between conventional OBE and knock-out channels for the total cross section is about two orders of magnitude at $\Delta \simeq 0.1$ GeV for $B^2 = 1\%$. However, in the differential cross section this ratio changes, because the knock-out model predicts a large enhancement for the Φ production in forward and backward directions when the recoil nucleons move along the z axis. In this case the difference between two channels drastically decreases and becomes a factor $5 \cdots 8$. The interference between these two channels is negligible, and in coplanar geometry it disappears because the OBE amplitude is real, while the knockout amplitude is imaginary since the exchanged meson is absorbed by the 5-quark component in the proton wave function.

Figs. 3 and 4 show our predictions for the beam-target asymmetry as a function of the Φ production angle ϑ at fixed recoil nucleon angles at $\Delta = 0.1$ GeV and $|\mathbf{q}| = \frac{2}{3}\lambda(s, M_\Phi^2, 4M_N^2)/2\sqrt{s}$ for pp and pn reactions, respectively (λ is the usual triangle function). The left panels of figs. 3 and 4 show separately the asymmetry for pure OBE and knock-out channels. For the pp reaction the long-dashed line is the threshold prediction. One can see that at finite energy the asymmetry differs significantly from the threshold value for both the conventional OBE (solid lines) and knock-out (short-dashed line) mechanisms. The same is seen for the pn reaction, where the dashed line is the threshold prediction for the knock-out channel. The right panels of figs. 3 and 4 display the asymmetry for the sum of the two channels for two strangeness probabilities $B^2 =$ 2 and 5% (dashed and short-dashed curves). One can see that the knock-out channel modifies the OBE model prediction strongly in the forward and backward directions in pp reactions. In pn reactions this modification is smaller because the total cross section for the OBE channel is about 5 times greater then in pp reaction, while for the knock-out channel it is on same level.

The Φ meson spin density is modified too. At finite energy their modifications for the OBE channel are negligible and the matrix elements are $\rho_{00} \simeq 0$, $\rho_{11} \simeq 0.5$. The inclusion of knock-out channel changes them to $\rho_{00} = 0.12$ (0.22), $\rho_{11} \simeq 0.44$ (0.39) for the strangeness probabilities $B^2 = 2$ (5)% in backward and forward directions.

5. Summary: In summary we calculate within an extended OBE model with a *uud* knock-out mechanism the cross section and polarization observables for the reaction $NN \to NN\Phi$. While the total cross section is hardly sensitive to an admixture of a $s\bar{s}$ configuration in the nucleon, a measurement of the target-beam asymmetry should reveal the presence of hidden strangeness. Already slightly above the threshold the interaction dynamics becomes important and changes the threshold predictions.

Acknowledgments: Useful discussions with A. Brenschede are gratefully acknowledged. One of the authors (A.I.T.) acknowledges the warm hospitality of the nuclear theory group in the Research Center Rossenorf. This work is supported by the BMBF grant 06DR829/1 and the Heisenberg-Landau program.

References

[1] A.A. Sibirtsev, Nucl. Phys. A 604 (1996) 455

[2] W.S. Chung, G.Q. Li, C.M. Ko, Phys. Lett. B 401 (1997) 1

[3] W.S. Chung, G.Q. Li, C.M. Ko, nucl-th/9704002

[4] F. Klingl, T. Wass, W. Weise, hep-ph/9709210

[5] E.E. Kolomeitsev, D.N. Voskresensky, B. Kämpfer, Nucl. Phys. A 588 (1995) 889

[6] R. Barth et al. (KAOS collaboration), Phys. Rev. Lett. 78 (1997) 4007

[7] N. Herrmann (FOPI collaboration), Nucl. Phys. A 610 (1996) 49c

[8] J. Friese et al. (HADES collaboration), GSI report 97-1, p. 193 (1997)

[9] A. Brenschede, Ph.D. thesis, Giessen 1997 (unpublished),
A. Brenschede et al. (DISTO collaboration), to be published

[10] M.G. Sapozhnikov et al., COSY Letter of Intent # 35 (1995)

[11] S. Okubo, Phys. Lett. B 5 (1963) 165,
G. Zweig, CERN report No. 8419/TH 412 (1964),
I. Iizuka, Prog. Theor. Phys. Suppl. 37/38 (1966) 21

[12] J. Ellis, M. Karliner, D.E. Kharzeev, M.G. Sapozhnikov, Phys. Lett. B 353 (1995) 319,
J. Ellis, E. Gabathuler, M. Karliner, Phys. Lett. B 217 (1989) 173

[13] J.F. Donoghue, C.R. Nappi, Phys. Lett. B 168 (1986) 105,
J. Gasser, H. Leutwyler, M.E. Sainio, Phys. Lett. B 253 (1991) 252

[14] D.B. Kaplan, A.V. Manohar, Nucl. Phys. B 310 (1988) 527,
R.D. McKeown, Phys. Lett. B 219 (1989) 140,
E.M. Henley, G. Krein, S.J. Pollock, A.G. Williams, Phys. Lett. B 269 (1991) 31,
D.B. Kaplan, Phys. Lett. B 275 (1992) 137

[15] A.I. Titov, Y. Oh, S.N. Yang, Phys. Rev. Lett. 79 (1997) 1634,
A.I. Titov, S.N. Yang, Y. Oh, Nucl. Phys. A 618 (1997) 259

[16] M.P. Rekalo, J. Arvieux, E. Tomasi-Gustafsson, Z. Phys. A 357 (1997) 133

[17] E.M. Henley, G. Krein, A.G. Williams, Phys. Lett. B 281 (1992) 178

[18] R.M. Barnett et al. (Particle Data Group), cf. http://pdg.lbl.gov

[19] M. Schäfer, H.C. Dönges, A. Engel, U. Mosel, Nucl. Phys. A 575 (1994) 429

[20] R. Machleidt, Adv. Nucl. Phys. 19 (1989) 189

[21] V. Flaminio, CERN preprint CERN-HERA 01/84 (1984)

[22] H. Garsilazo, E.M. de Goya, Nucl. Phys. A 562 (1993) 521

[23] M. Jetter, H.W. Fearing, Phys. Rew. C 51 (1995) 1666

[24] R.P. Feynman, M. Kisslinger, F. Ravndal, Phys. Rev. D 3 (1971) 2706,
K. Fujimura, T. Kobayashi, M. Namiki, Prog. Theor. Phys. 44 (1970) 193; 43 (1970) 73

[25] R. Baldi et al., Phys. Lett. B 68 (1977) 381,
V. Blobel et al., Phys. Lett. B 59 (1975) 88

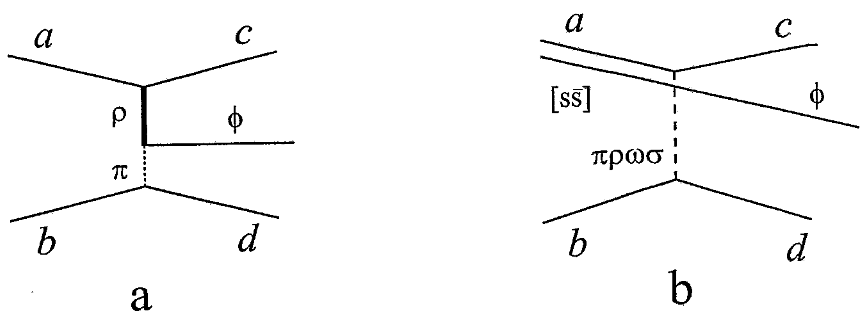

Figure 1: Tree level Feynman diagrams for the Φ production.

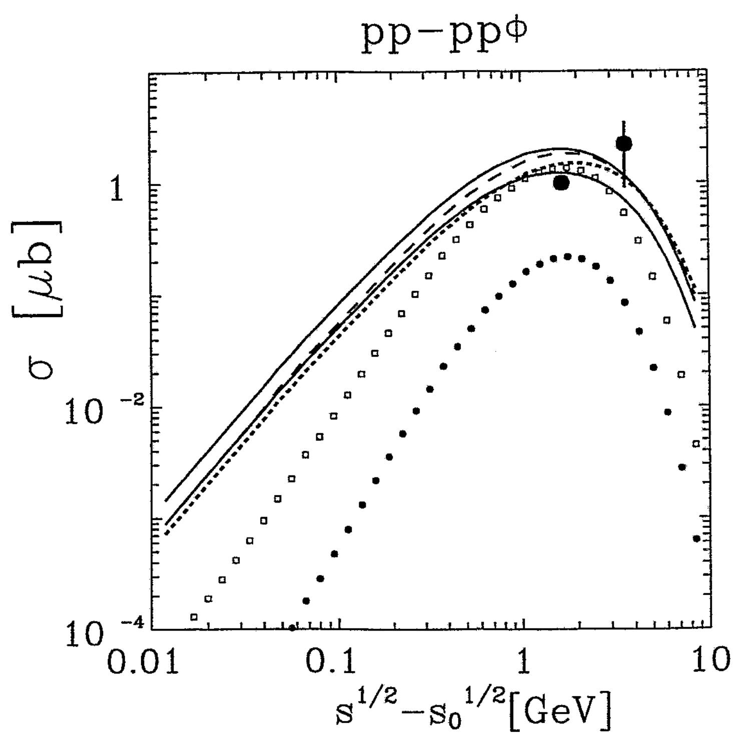

Figure 2: The total cross section fort the reaction $pp \to pp\Phi$. The meaning of symbols and curves is described in the text. Data from [25].

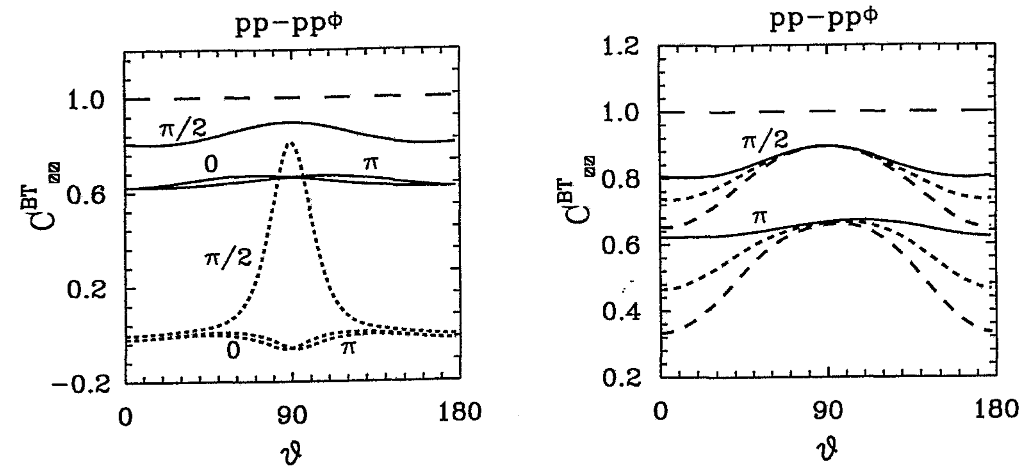

Figure 3: The beam-target asymmetry for the reaction $pp \to pp\Phi$ as a function of the c.m.s. polar angle ϑ of the Φ. Left (right) panel: contributions from conventional OBE model and *uud* knock-out mechanism separately (together). The meaning of symbols and curves is described in the text.

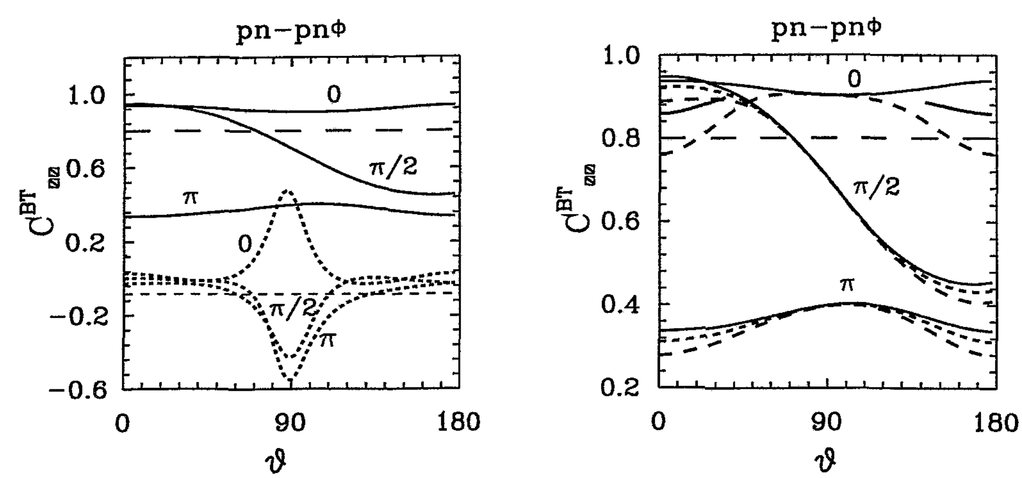

Figure 4: The same as in fig. 3 but for the reaction $pn \to pn\Phi$.