POLARIZATION OF Λ AND $\bar{\Lambda}$ IN DEEP-INELASTIC SCATTERING AT COMPASS

M.G.Sapozhnikov
on behalf of the COMPASS Collaboration

Joint Institute for Nuclear Research, Laboratory of Particle Physics, Dubna
E-mail: sapozh@sunse.jinr.ru

Abstract

Λ and $\bar{\Lambda}$ production in deep-inelastic scattering of 160 GeV/c polarized muons on a polarized ^{6}LiD target is under study in the COMPASS experiment. Preliminary results from data collected during 2002 beam period are presented.

The study of polarization of $\Lambda(\bar{\Lambda})$ hyperons in the deep-inelastic scattering (DIS) can provide an information on the fundamental properties of the nucleon, such as polarization of the strange quarks in the nucleon [1] and offers a possibility to determine the mechanism of spin transfer from polarized quark to a polarized baryon [2]-[7].

The polarized nucleon intrinsic strangeness model [8, 9] predicts negative longitudinal polarization of Λ hyperons produced in the target fragmentation region ($x_F < 0$). Main assumption of the model is the negative polarization of the strange quarks and antiquarks in the nucleon. This assumption was inspired by the results of EMC [10] and subsequent experiments [11]- [13] on inclusive deep-inelastic scattering which gave indication that the $s\bar{s}$ pairs in the nucleon are negatively polarized with respect to the nucleon spin:

$$\Delta s \equiv \int_0^1 dx[s_\uparrow(x) - s_\downarrow(x) + \bar{s}_\uparrow(x) - \bar{s}_\downarrow(x)] = -0.10 \pm 0.02. \quad (1)$$

Experiments on elastic neutrino scattering [14] also have suggested that the nucleon strange quarks are negatively polarized, though within large uncertainties: $\Delta s = -0.15 \pm 0.07$. Indication of negative polarization of strange quarks in proton was obtained also in the lattice QCD: $\Delta s = -0.12 \pm 0.01$ [15], $\Delta s = -0.109 \pm 0.030$ [16].

The polarized strangeness model [1] was successfully applied to explain the large violation of the OZI rule in the annihilation of stopped antiprotons and its strong dependence on the spin of the initial state (for review, see [17]). The predictions of the model were confirmed in different processes of proton-proton, antiproton-proton interactions and lepton DIS. Specifically, the negative longitudinal polarization of the Λ hyperons at $x_F < 0$ predicted in [8, 9] was found in the neutrino DIS experiments [18].

However the question about polarization of the nucleon strange quarks is by no means solved. Recently the HERMES collaboration [19] claimed slightly positive strange quarks polarization $\Delta s = 0.03 \pm 0.03 \pm 0.01$ found after analysis of the semi-inclusive DIS channels (for the discussion of the HERMES result, see [20],[21]).

The meson cloud model [22] predicts that in the target fragmentation region the polarization of Λ should be anticorrelated with the target polarization. Therefore, it is expected that $P_\Lambda \sim 0$ for production on unpolarized target.

The measurement of the longitudinal Λ polarization in the current fragmentation region $x_F > 0$ is traditionally connected with investigation of spin transfer from quark to hadron [2]-[7]. According to the naive quark model (NQM) the spin of Λ is carried by the s quark and the spin transfer from the u and d quarks to Λ is equal to zero. It means that the longitudinal polarization of Λ produced in fragmentation of the u and d quarks is $P_\Lambda \sim 0$.

Another scheme of the spin transfer was suggested in [2]. Using $SU(3)_f$ symmetry and experimental data for the spin-dependent quark distributions in the proton, it was found that the contributions of u and d quarks in the Λ spin are negative and substantial, on the level of 20% for each light quark. Therefore, one might expect that in this model the fragmentation of the dominant u quark will lead to $P_\Lambda = -0.2$.

However, a large part (up to 30-40%) of the Λ observed in DIS is from decays of heavy hyperons, such as Σ^0, $\Sigma(1385)$ and Ξ, significantly changing the pattern of the spin transfer. The consequences of different spin transfer schemes and influence of the indirect Λ production was investigated in [5] for the conditions similar to the COMPASS experiment. The calculations were done for the positive muon energy E=200 GeV, polarization of the muon beam $P_B = -0.80$, $Q^2 > 4\ (GeV/c)^2$, $x_F > 0$ and $z > 0.2$, where z is the quark energy fraction carried by the Λ hyperon. Longitudinal polarization of Λ turns out to be $P_\Lambda = -0.12$ for the NQM model and $P_\Lambda = -0.02$ for the spin-transfer mechanism of [2]. For the $\bar{\Lambda}$ the corresponding predictions are $P_{\bar{\Lambda}} = -0.14$ for the NQM model and $P_\Lambda = -0.05$ for the spin-transfer mechanism of [2].

Alternative scheme of the spin transfer appears in the framework of $SU(6)$ based quark-diquark model [7]. According to this model a large positive polarization of the u and d quarks in the Λ is expected at large x. Due to this fact the spin transfer to Λ should be as large as +1 at $z \sim 0.8 - 0.9$. The quark-diquark model predicts also [23] a large ratio between cross sections of $\bar{\Lambda}$ and Λ production: $R = \bar{\Lambda}/\Lambda \sim 1$ at $z \sim 0.8 - 0.9$.

However the possibility to study real spin transfer from the quark to baryon at the energies of the current experiments was questioned in [9]. It turns out that even at the COMPASS energy of 160 GeV most Λ, even in the $x_F > 0$ region, are produced from the diquark fragmentation. It is predicted that in the COMPASS kinematics the longitudinal Λ polarization is $P_\Lambda = -0.004, -0.07$, depending on the fragmentation model. More clear situation is with the $\bar{\Lambda}$ production, however up to now the statistics of $\bar{\Lambda}$ produced in the DIS experiments was marginal.

The experimental situation with measurements of Λ and $\bar{\Lambda}$ longitudinal polarization $P_\Lambda (P_{\bar{\Lambda}})$ in DIS is summarized in the Table 1.

One can see that in the target fragmentation region the Λ polarization is indeed negative. The spin transfer for current fragmentation region seems small, however the experimental data are quite scarce, especially for $\bar{\Lambda}$.

We have studied Λ and $\bar{\Lambda}$ production by polarized μ^+ of 160 GeV/c on a polarized ^{6}LiD target of the COMPASS spectrometer constructed in the framework of CERN experiment NA58. A detailed description of the COMPASS experimental setup is in the talk of F.Bradamante at this Conference. For this analysis we use data collected during the 2002 run. Total amount of the acquired data is about 260 TB. The analysis comprises about $1.7 \cdot 10^8$ DIS events, which corresponds to 60% of the total 2002 statistics.

The V^0 events ($V^0 \equiv \Lambda$, $\bar{\Lambda}$ and K^0_s) were selected by requiring the outgoing muon tracks together with two hadron tracks of opposite charge. The primary vertex should be

Reaction Exp.	$<E_b>$ (GeV)	$<x_F>$	N_Λ	P_Λ	$N_{\bar\Lambda}$	$<x_F>$	$P_{\bar\Lambda}$
$\bar\nu_\mu Ne$	40	-0.47	469	-0.56 ± 0.13			
WA59[24]		>0	66	-0.11 ± 0.45			
μN	470	0.15	750	1.2 ± 0.5	650	0.15	-0.26 ± 0.6
E665 [25]		0.44		0.32 ± 0.7		0.44	-1.1 ± 0.8
$\nu_\mu N$	43.8	-0.36	5608	-0.21 ± 0.04	248	-0.2	0.23 ± 0.20
NOMAD [18]		0.21	2479	-0.09 ± 0.06	401	0.18	-0.23 ± 0.15
eN	27.5	0.30	10568	$S_\Lambda =$	1687		
HERMES [26]				0.06 ± 0.09			

Table 1: Summary of experimental measurements of $\Lambda(\bar\Lambda)$ longitudinal polarization in DIS. Sign of polarization is given with respect to virtual photon momentum.The results of HERMES collaboration were presented in terms of the spin transfer $S_\Lambda = \frac{P_\Lambda}{P_b D}$, where P_b is the beam polarization and D is the depolarization factor.

inside the target. The polarized ^{6}LiD target consists of two oppositively polarized 60 cm long cells. The data presented here are averaged over the target polarization.

The secondary vertex must be downstream of the both target cells. The angle between vector of V^0 momentum and vector between primary and V^0 vertices should be $\theta_{col} < 0.01$ rad. Cut on transverse momentum of the decay products with respect to the direction of V^0 particle, $p_t > 23$ MeV/c was applied to reject e^+e^- pairs from the γ conversion seen as the band at the bottom of the Armenteros plot shown in Fig.1.

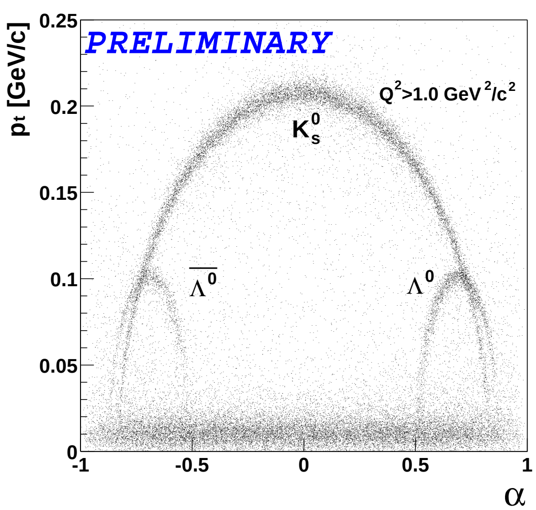

Figure 1: The Armenteros plot: p_t is the transverse momentum of the V^0 decay products with respect to the direction of V^0 momentum, $\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$, where p_L is the longitudinal momentum of the V^0 decay particle.

The typical elliptical bands from the K_s^0, Λ and $\bar\Lambda$ decays are seen in Fig.1. Both Λ and $\bar\Lambda$ signals stand out clearly. The large number of produced $\bar\Lambda$ is a specific feature of the COMPASS experiment.

The standard DIS cut on $Q^2 > 1$ $(\mathrm{GeV}/c)^2$ and $0.2 < y < 0.8$ have been used. After background subtraction the experimental sample contains about 10800 Λ and 5900 $\bar{\Lambda}$.

The kinematical characteristics of produced Λ, $\bar{\Lambda}$ and K_s^0 are shown in Fig.2 and Fig.3. The x_F and Q^2 experimental distributions (crosses) are compared to Monte-Carlo (hatched histograms) in Fig. 2. One can see that we are able to access mainly current fragmentation region. The averaged value of x_F is $< x_F >= 0.21$, whereas for the Bjorken scaling variable x it is $< x >= 0.02$.

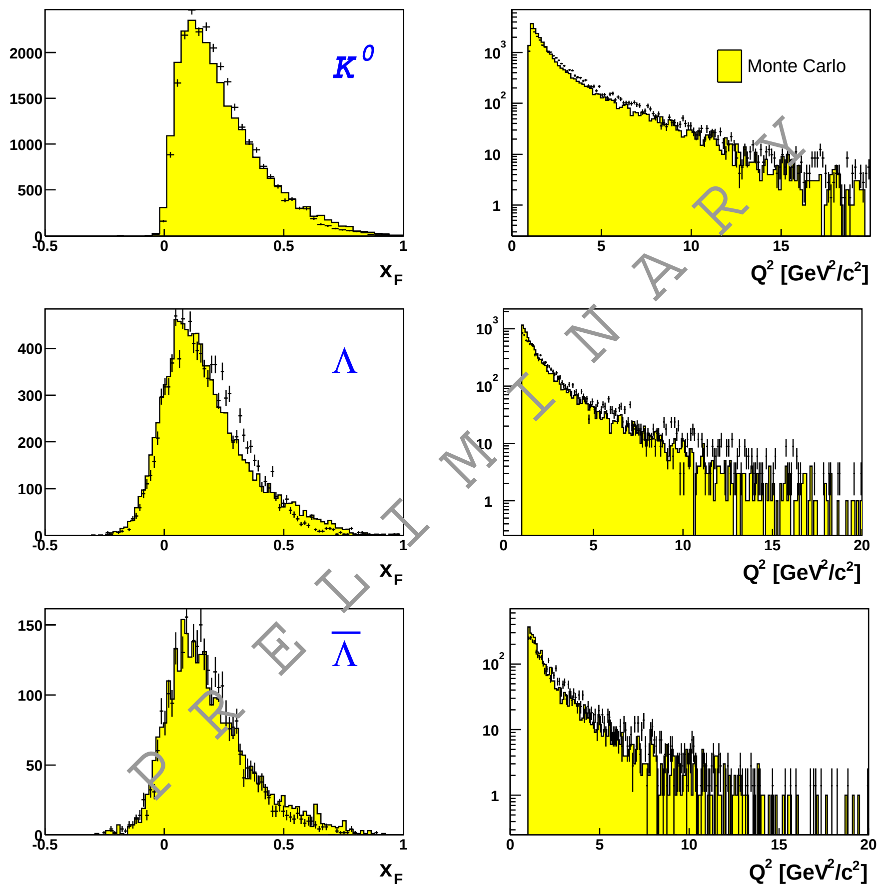

Figure 2: x_F (left column) and Q^2 (right column) distributions for K_s^0 (upper row), Λ (middle row) and $\bar{\Lambda}$ (lower row). The experimental data points are shown together with results of Monte-Carlo simulations (histograms).

The momenta of V^0 particles and of their decay products are shown on Fig.3. The mean Λ momentum is 12 GeV/c, while decay pion momentum is 2 GeV/c. Both figures shows reasonable agreement between the experimental data and the Monte-Carlo simulations.

Λ ($\bar{\Lambda}$) hyperon polarization can be measured via the angular asymmetry of positive particle in $\Lambda \to p\pi^-$ ($\bar{\Lambda} \to \bar{p}\pi^+$) decays. Angular distribution of the positive particle in Λ ($\bar{\Lambda}$) rest frame is

$$\frac{dN}{d\Omega} = \frac{N_{tot}}{4\pi}(1 + (-)\alpha\vec{P}\vec{n}) \qquad (2)$$

where N_{tot} is total number of events, $\alpha = 0.642 \pm 0.013$ is the decay asymmetry parameter, $\vec{P}$ is the polarization vector and $\vec{n}$ is the unit vector in the direction of proton (for Λ decays)

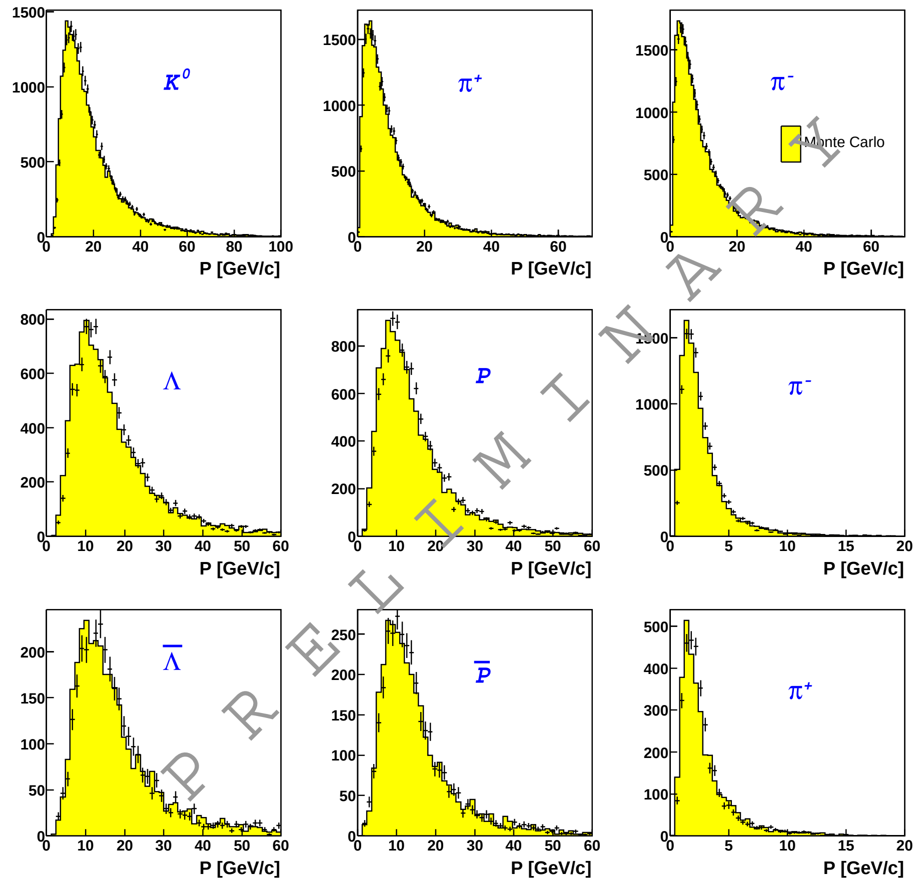

Figure 3: The momentum spectra for strange particles and their decay products are shown: K_s^0, π^+ and π^- in upper row; Λ, proton and π^- in middle row; and $\bar{\Lambda}$, $\bar{p}$ and π^+ in lower row. The experimental data points are shown together with results of Monte-Carlo simulations (histograms).

or π^+ (for $\bar{\Lambda}$). The coordinate system is defined using directions of virtual photon ($\mathbf{e}_\gamma$) and target nucleon ($\mathbf{e_T}$) in the Λ rest frame:

$\mathbf{n_x} = \mathbf{e}_\gamma$,

$\mathbf{n_y} = \mathbf{e}_\gamma \times \mathbf{e_T}/|\mathbf{e}_\gamma \times \mathbf{e_T}|$,

$\mathbf{n_z} = \mathbf{n_x} \times \mathbf{n_y}$.

The analysis was performed slicing each angular distribution in 10 bins and fitting the invariant mass distribution of the V^0 decay products to determine the number of V^0 events in each bin. Fig. 4 shows measured angular distributions for K_s^0, Λ and $\bar{\Lambda}$ decays, corrected for the acceptance. The acceptance was determined by the Monte Carlo simulation of unpolarized $\Lambda(\bar{\Lambda})$ decays.

One could see that all angular distributions for K_s^0 decays are flat as expected. It means that no significant bias is introduced by the apparatus and by the analysis procedure.

The invariant mass distributions of K_s^0, Λ and $\bar{\Lambda}$ are shown in the first column of Fig.4 for a part of analyzed events. The level of the background events is not negligible and the procedure of the bin-by-bin fitting for determination of the angular distributions is essential for correct rejection of the background events.

The experimental $\cos\theta_i$ distributions are flat. It means that the Λ and $\bar{\Lambda}$ polarizations,

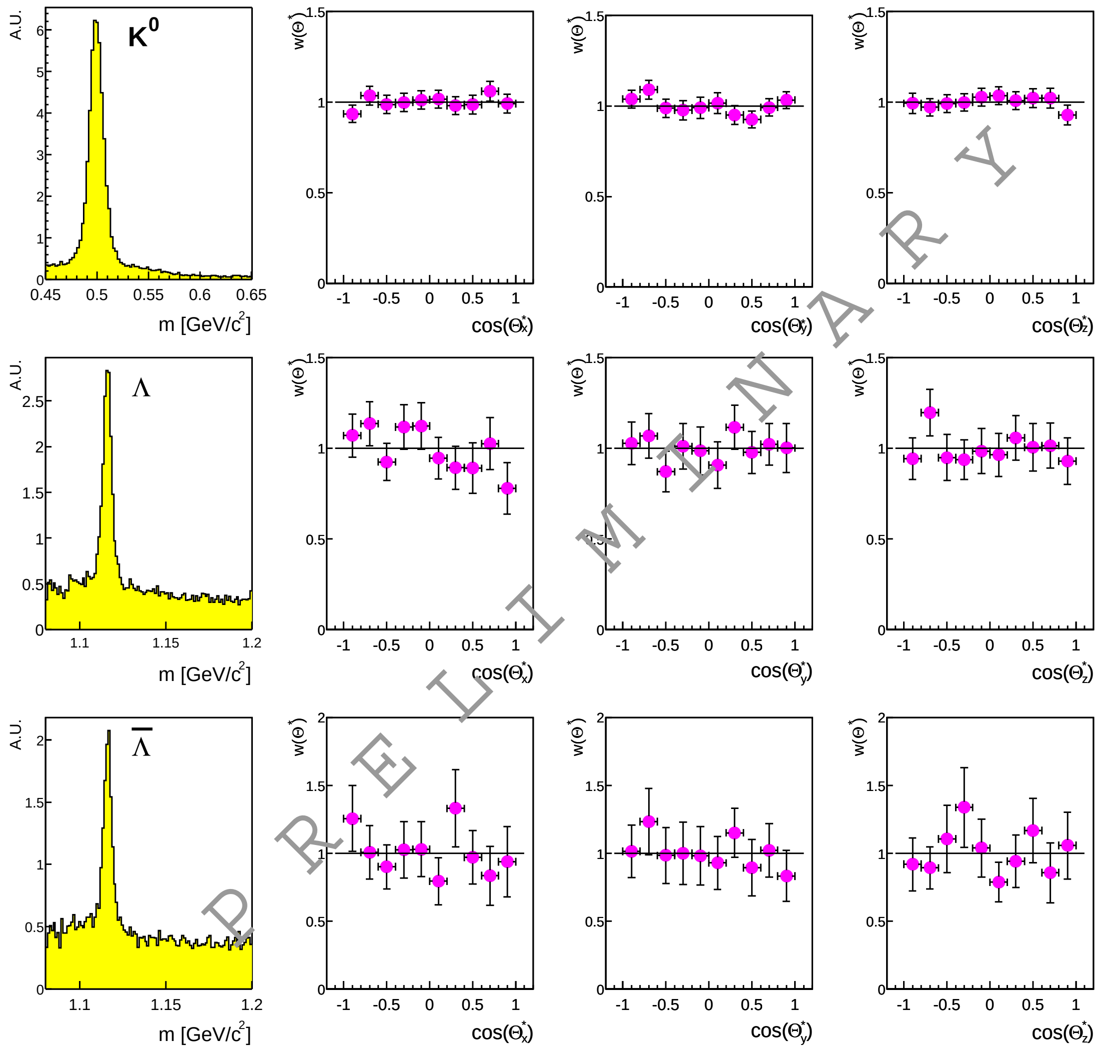

Figure 4: The $\cos\theta_x$ (second column) $\cos\theta_y$ (third column) and $\cos\theta_z$ (forth column) distributions for K_s^0 (upper row), Λ (middle row) and $\bar{\Lambda}$ (lower row). The first column shows invariant mass distributions for K_s^0, Λ and $\bar{\Lambda}$, respectively.

averaged over the full kinematical range of COMPASS, are small.

Work on the determination of the polarizations and their systematic errors is continuing. The results from our 2002 data presented here demonstrate the good potential of COMPASS for measurements of Λ and $\bar{\Lambda}$ polarizations in DIS.

References

[1] J.Ellis et al, Phys.Lett. **B353**, 319 (1995); Nucl.Phys. **A673**, 256 (2000).

[2] M. Burkardt, R. L. Jaffe, Phys. Rev. Lett. **70**, 2537 (1993).

[3] M. Anselmino et al, Phys. Lett. **B509**, 246 (2001).

[4] M.Anselmino,M.Boglione, F.Murgia, Phys. Lett. **B481**, 253 (2000).

[5] A. M. Kotzinian, A. Bravar, D. von Harrach, Eur. Phys. J. **C2**, 329 (1998).

[6] C. Boros, L. Zuo-Tang, Phys. Rev. **D57**, 4491 (1998).

[7] J. J. Yang, B. Q. Ma, I. Schmidt, Phys. Lett. **B477**, 107 (2000); B. Q. Ma, I. Schmidt, J. Soffer, J. J. Yang, Phys. Lett. **B488**, 254 (2000).

[8] J. Ellis, D. Kharzeev, A.M. Kotzinian, Z.Physik **C69**, 467 (1996).

[9] J. Ellis, A.M. Kotzinian, D.V. Naumov, Eur. Phys. J. **C25**, 603 (2002).

[10] The EMC Collaboration, J.Ashman et al, Phys.Lett. **B206**, 364 (1988); Nucl.Phys. **B328**, 1 (1989).

[11] The SMC Collaboration. B.Adeva et al, Phys.Lett. **B412**, 414 (1997); D.Adams et al., Phys.Rev. **D56**, 5330 (1997).

[12] The E143 Collaboration. K.Abe et al, Phys.Rev. **D58**, 112003 (1998).

[13] The E155 Collaboration. P.L.Anthony et al, Phys.Lett, **B458**, 529 (1999).

[14] G.T.Garvey et al, Phys.Rev. **C48**, 761 (1993).

[15] S.J.Dong et al, Phys.Rev.Lett. **75**, 2096 (1995).

[16] M.Fukugita et al, Phys.Rev.Lett. **75**, 2092 (1995).

[17] V.P.Nomokonov, M.G.Sapozhnikov, Physics of Elementary Particles and Atomic Nuclei, **34**, 184 (2003), hep-ph/0204259, 2002.

[18] P. Astier et al., Nucl. Phys. **B588**, 3 (2000);
P. Astier et al., Nucl. Phys. **B605**, 3 (2001).

[19] The HERMES Collaboration. A.Airapetian et al, hep-ex/0307064, 2003.

[20] A.M.Kotzinian, Phys.Lett. **B552**, 172 (2003)

[21] E.Leader, D.Stamenov, Phys.Rev. **D67**, 037503 (2003)

[22] W.Melnitchouk and A.W.Thomas, Z.Phys. **A353** 311 (1996).

[23] B. Q. Ma, I. Schmidt, J.-J. Yang, Phys. Lett. **B574**, 35 (2003).

[24] S. Willocq et al, Z.Phys. **C53**, 207 (1992).

[25] M. R. Adams et al, Eur. Phys. J. **C17**, 263 (2000).

[26] A. Airapetian et al, Phys. Rev. **B64**, 112005 (2001); S. Belostotski, IXth Workshop on High-Energy Spin Physics, Dubna, Russia, Aug 2 - 7, 2001.