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

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Abstract

The longitudinal polarization of Λ and $\bar{\Lambda}$ produced in deep-inelastic scattering of 160 GeV/c polarized muons is studied in the COMPASS experiment. Preliminary results on $x-$ and $y-$ dependence of the longitudinal polarization of Λ and $\bar{\Lambda}$ from data collected during the 2003 run are presented.

The study of longitudinal polarization of Λ and $\bar{\Lambda}$ hyperons in the deep-inelastic scattering (DIS) is important for understanding fundamental properties of the nucleon. Comparing the longitudinal polarizations of Λ and $\bar{\Lambda}$ in DIS one could test if strange $s(x)$ and antistrange $\bar{s}(x)$ quark distributions are equal and, in principle, it would be possible to obtain information about polarization of the strange quarks in the nucleon [1]-[2]. The useful information about the spin structure of Λ could be obtained [3]-[9].

The polarized nucleon intrinsic strangeness model [1, 2] predicts negative longitudinal polarization of Λ hyperons produced in the target fragmentation region [10, 11]. The 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 [12] and subsequent experiments [13]- [15] 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:

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

The prediction of the model was confirmed in the neutrino DIS experiments, where large and negative longitudinal polarization $P(\Lambda)$ of the Λ hyperons at the target fragmentation region was found. The best statistics was obtained in the NOMAD experiment [16], where $P(\Lambda) = -0.21 \pm 0.04 \pm 0.02$ was measured at $x_F < 0$.

Negative polarization of the strange sea was also found in the recent QCD analysis of the available world data [17]: $\Delta s = -0.049 \pm 0.013$. However the question about polarization of the nucleon strange quarks can not be considered to be solved. Thus the HERMES collaboration, after analysis of the semi-inclusive DIS channels in the LO approximation, found that $\Delta s = 0.028 \pm 0.033 \pm 0.009$ [18], i.e. consistent with zero within the errors (for the discussion of the HERMES result, see [19],[20]). Therefore, the possibility to obtain an information on Δs from data on longitudinal polarization of Λ and $\bar{\Lambda}$ is quite important.

The Λ production in the current fragmentation region $x_F > 0$ is believed to be dominated by the struck quark fragmentation. Then the longitudinal Λ polarization in the parton model is determined as follows [5]:

$$P_\Lambda = \frac{\Sigma_q e_q^2 [P_b D(y) q(x) + P_T \Delta q(x)] \Delta D_q^\Lambda(z)}{\Sigma_q e_q^2 [q(x) + P_b D(y) P_T \Delta q(x)] D_q^\Lambda(z)} \tag{2}$$

Here e_q is the quark charge, P_b and P_T are the polarization of the beam and target, $q(x)$ and $\Delta q(x)$ are unpolarized and polarized quark distribution functions, $D_q^\Lambda(z)$ and $\Delta D_q^\Lambda(z)$ are unpolarized and polarized fragmentation functions. $D(y)$ is the longitudinal depolarization factor of the virtual photon with respect to the initial state lepton, y is the fraction of the lepton energy carried out by the virtual photon $y = \nu/E$ ($\nu = E - E'$, E and E' are lepton energies in the initial and final states). z is the fractional hadron energy, $z = E_h/\nu$, x is the Bjorken scaling variable.

The expression (2) helps to understand salient features of the spin transfer to Λ. For the scattering on the unpolarized target $P_T = 0$, assuming that only one quark flavor dominates, it may be expected that the polarization will be proportional to the $D(y)$. The depolarization factor $D(y)$ increases with y, therefore one should expect that the P_Λ will also grow up with y.

From (2) it is clear that the polarizations of Λ and $\bar{\Lambda}$ should be the same if we are in the region where $q(x) = \bar{q}(x)$ and $\Delta q(x) = \Delta\bar{q}(x)$. Again this statement is valid if the Λ has been produced mainly due to quark fragmentation and if the contribution from the diquark fragmentation is small.

Essential ingredient of the (2) is the polarized fragmentation function $\Delta D_q^\Lambda(z)$. There are different approaches to the choice of $\Delta D_q^\Lambda(z)$ [3]-[9]. All logically possible values of the Λ polarization (positive, negative and zero) have been predicted.

In 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 if we are in the region where Λ is produced in the fragmentation of u and d quarks, one may expect that $P_\Lambda \sim 0$.

The authors of [3], using $SU(3)_f$ symmetry and experimental data for the spin-dependent quark distributions in the proton, predict that the contributions of u and d quarks to the Λ spin are negative and substantial, at the level of 20% for each light quark. In this model the fragmentation of the dominant u quark will lead to negative spin transfer to Λ.

Positive spin transfer to Λ has been predicted in the advanced NQM model [7], where indirect production of Λ from decays of heavy hyperons (such as $\Sigma, \Sigma(1385), \Xi$) were also considered. It was assumed that, as in NQM, the s quarks is responsible for the spin transfer to Λ produced directly. The spin transfer from u- and d-quarks is also possible due to production of polarized heavy hyperons, which decayed into Λ , having inherited a part of its polarization.

Positive spin transfer from u- and d-quarks was also predicted in the framework of $SU(6)$ based quark-diquark model [8],[9]. They found large and positive polarization of the u and d quarks in the Λ at large x.

The assumption about dominance of the quark fragmentation processes for the Λ production was questioned in [11]. It has been shown that the energies of the current experiments are not large enough and even at the COMPASS energy of 160 GeV most of Λ, even in the $x_F > 0$ region, are produced from the diquark fragmentation.

We have studied Λ and $\bar{\Lambda}$ production by polarized μ^+ of 160 GeV on a polarized ^{6}LiD target of the spectrometer constructed in the framework of COMPASS experiment

(NA58) at CERN. A detailed description of the COMPASS experimental setup is given elsewhere [21] (see, also talks of F.Bradamante and Y.Bedfer at this conference) and only the most relevant elements for the present analysis will be given below.

The muon beam polarization is $P_b = -0.76 \pm 0.04$. The polarized target consists of two oppositively polarized cells, 60 cm long and 3 cm in diameter, separated by 10 cm. The cells are located on the axis of a superconducting solenoid magnet providing a field of 2.5 T along the beam direction, and are filled with ^{6}LiD . This material is used as a deuteron target and was selected for its high dilution factor of about 40%, which accounts for the fact that only a fraction of the target nucleons are polarizable. Typical polarization values of 50% are obtained. The two cells are polarized in opposite directions by using different microwave frequencies so that data with both spin orientations are recorded simultaneously. For this analysis the data are averaged over the target polarization.

The COMPASS spectrometer has a large and small angle spectrometers built around two dipole magnets, in order to allow the reconstruction of the scattered muon and of the produced hadrons in broad momentum and angular ranges. Different types of tracking detectors are used to deal with the rapid variation of the particle flux density with the distance from the beam. Tracking in the beam region is performed by scintillating fibers. Up to 20 cm from the beam we use Micromegas and GEMs. Further away, tracking is carried out in multiwire proportional chambers and drift chambers. Large-area trackers, based on straw detectors and large drift chambers extend the tracking over a surface of up to several square meters. Muons are identified by dedicated trackers placed downstream of hadron absorbers. Hadron/muon separation is strengthened by two large iron-scintillator sampling calorimeters, installed upstream of the hadron absorbers and shielded to avoid electromagnetic contamination. The particle identification provided by the ring imaging Cherenkov detector is not used in the present analysis.

The trigger system [22] provides efficient tagging down to $Q^2 = 0.002\ (GeV/c)^2$, by detecting the scattered muon in a set of hodoscopes placed behind the two dipole magnets. A large enough energy deposit in the hadronic calorimeters is required to suppress unwanted triggers generated by halo muons, elastic muon-electron scattering events, and radiative events.

The COMPASS data taking was going on in 2002-2004. The preliminary analysis of the 2002 run was given in [23],[24]. Here we presented the first results of the analysis of data collected during the 2003 run. The data sample comprises about $8.7 \cdot 10^7$ DIS events with $Q^2 > 1\ \ (\mathrm{GeV}/c)^2$.

The V^0 events ($V^0 \equiv \Lambda$, $\bar{\Lambda}$ and K^0_S) were selected by requiring a primary vertex with incoming and outgoing muon tracks and at least two hadron tracks forming a secondary vertex. The primary vertex has to be inside the target. The secondary vertex must be downstream the both target cells. The angle θ_{col} between the vector of V^0 momentum and the vector between primary and V^0 vertices should be $\theta_{col} < 0.01$ rad. Cut on transverse momentum p_t 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. We select events with momenta of positive and negative particles greater than 1 GeV/c. The momenta p_V of the V^0 particles have to be larger than 10 GeV/c. The DIS cuts on $Q^2 > 1\ \ (\mathrm{GeV}/c)^2$ and $0.2 < y < 0.9$ have been applied.

To construct angular distributions of V^0 events, the so called bin-by-bin method was used. All angular distributions were divided in some bins. In each bin the invariant mass distribution of positive and negative particles was constructed assuming the $\pi^+\pi^-$, $p\pi^-$ or $\bar{p}\pi^+$ hypothesis. The peak of the corresponding V^0 particle was fitted obtaining the number of the V^0 in the bin. This procedure allows to construct practically background-free angular distributions.

An example is shown in Fig.1, where the invariant mass distribution of $p\pi^-$ at different $\cos\theta_X$ bins are shown (θ_X is the angle between the direction of the decay proton for Λ and the direction of the virtual photon in the V^0 rest frame). A part of the background is coming from kaons, which passed all selection criteria. We have estimated the kaon background from the Monte Carlo simulation, it is shown by hatched regions in Fig.1.

The total data sample contains about 31000 Λ and 18000 $\bar{\Lambda}$. That is significantly larger than the data sample of the 2002 run, which comprises about 9000 Λ and 5000 $\bar{\Lambda}$.

In Fig.2 the experimental distributions on different kinematical variables for Λ (a) and $\bar{\Lambda}$ (b) are shown.

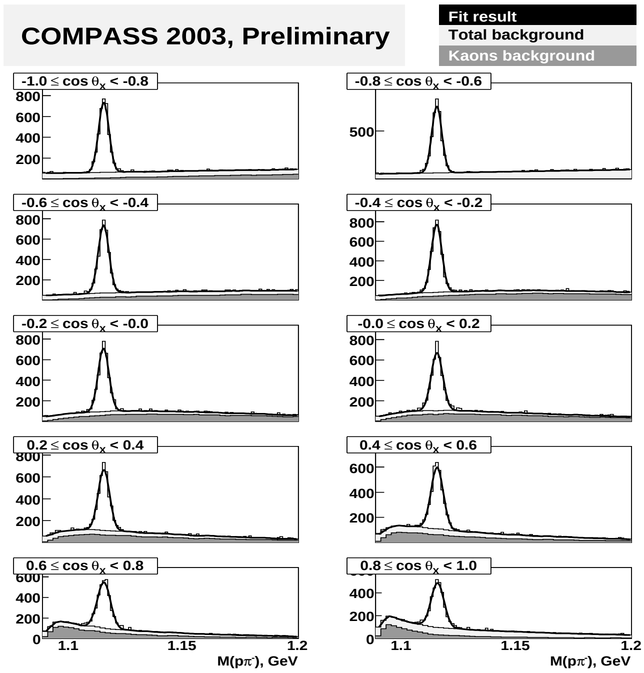
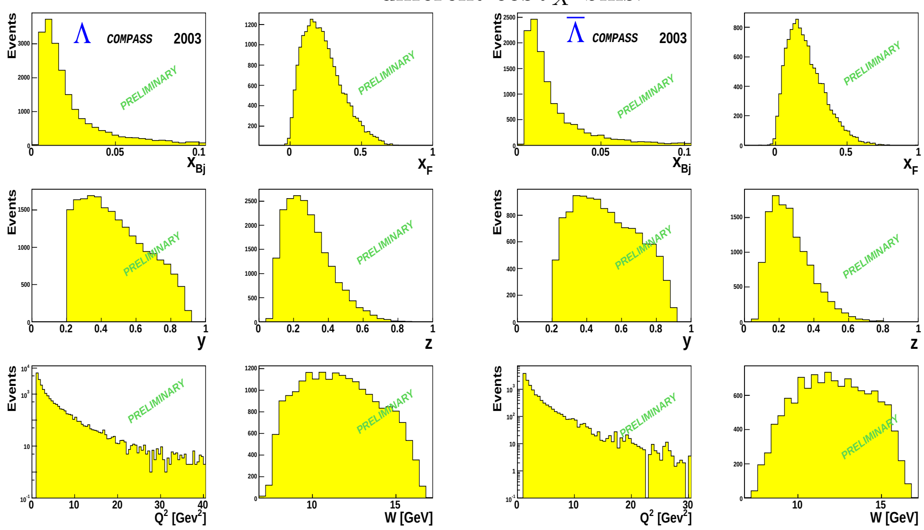


Figure 1. The invariant mass distribution of $p\pi^-$ at different $\cos\theta_X$ bins.



(a) **(b)**

Figure 2. Experimental distributions on x, x_F, y, z, Q^2 and W for the Λ (a) and $\bar{\Lambda}$ (b).

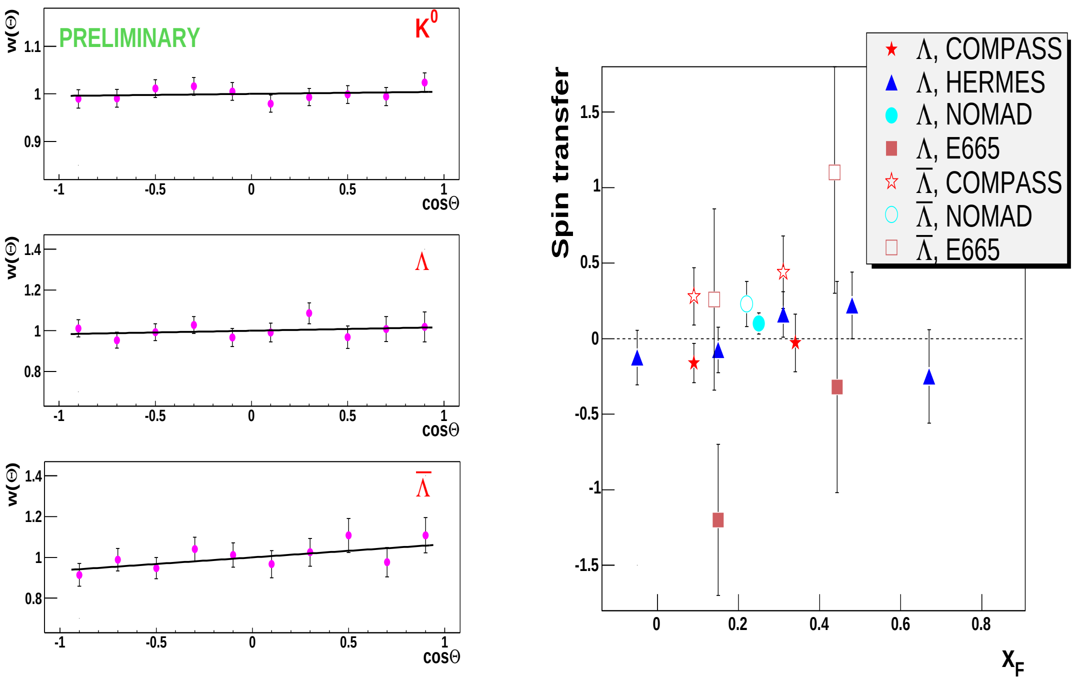
One can see that our working interval is at a small x region, with the averaged value $\bar{x} = 2.8\cdot10^{-2}$. The COMPASS spectrometer selects Λ in the current fragmentation region, starting from $x_F > -0.1$, with the averaged value $\bar{x_F} = 0.23$. The trigger enriched the data sample with events having high y, the averaged value is $\bar{y} = 0.48$. The typical Λ fractional energy z is not large $\bar{z} = 0.29$. The averaged values of Q^2 and W are $\bar{Q}^2 = 3.55\ (GeV/c)^2$ and $\bar{W} = 11.7$ GeV, respectively. The $\bar{\Lambda}$ has very similar distributions of the kinematical variables.

The angular distribution of the decay particles in the V^0 rest frame is

$$w(\theta) = \frac{dN}{d\cos\theta} = \frac{N_{tot}}{2}(1 + \alpha P \cos\theta), \tag{3}$$

where N_{tot} is the total number of events, $\alpha = +(-)0.642 \pm 0.013$ is $\Lambda(\bar{\Lambda})$ decay parameter, P is the projection of the polarization vector on the direction of the virtual photon in the V^0 rest frame, θ is the angle between the direction of the decay proton for Λ (antiproton - for $\bar{\Lambda}$, positive π - for K^0) and the direction of the virtual photon in the V^0 rest frame.

Fig.3a shows the measured angular distributions for all events of 2002 run for the K^0_S, Λ and $\bar{\Lambda}$ decays, corrected for the acceptance. The acceptance was determined by the Monte Carlo simulation of unpolarized $\Lambda(\bar{\Lambda})$ decays.



(a) (b)

Figure 3. The angular distributions for K^0_S, Λ and $\bar{\Lambda}$ for all events of 2002 run (a). Comparison of the spin transfer to Λ and $\bar{\Lambda}$ hyperons measured in different DIS experiments [16],[25],[26] (b).

One could see that the angular distribution for K^0_S decays is flat, as expected. The value of the longitudinal polarization is $P_K = 0.007 \pm 0.017$. The polarization of Λ, averaged over all kinematical variables, is small. The corresponding polarization of $\bar{\Lambda}$ is small and negative.

The comparison between the COMPASS data of 2002 run on the spin transfer to Λ and $\bar{\Lambda}$ hyperons with results of other DIS experiments is shown in Fig. 3b. The spin transfer S determines which part of the lepton polarization P_b is transferred to the hyperon polarization P. It is defined as $P = S \cdot P_b \cdot D(y)$, where $D(y)$ is the virtual photon depolarization factor.

One can see that there is a reasonable agreement between the COMPASS and world data. The spin transfer to Λ seems to be small in all the region of $x_F > 0$. The spin transfer to $\bar{\Lambda}$ seems to be slightly larger but the statistics is not enough to prove the existence of this difference.

In Fig. 4a the y-dependence of the longitudinal polarization is shown for data of the 2003 run. The data sample has been divided it 3 bins: $0.2 \leq y < 0.36$, $0.36 \leq y < 0.55$ and $0.55 \leq y \leq 0.9$. The number of events in each bin was approximately the same. The errors on the plot are statistical. The systematic error have been evaluated to be not larger than 5% for each data point.

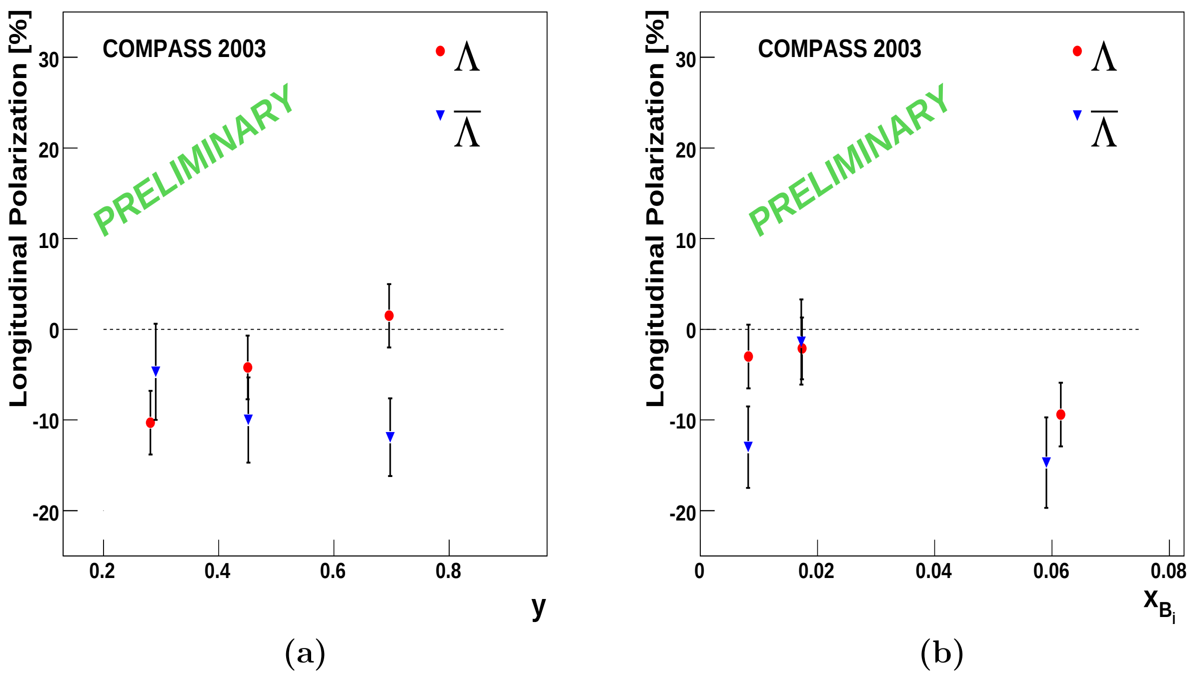


Figure 4. The longitudinal polarization of Λ and $\bar{\Lambda}$ for different y (a) and x (b) regions. The errors are statistical.

One could see that, in general, the longitudinal polarizations of Λ and $\bar{\Lambda}$ are the same. The exception is the region of large y, where there is an indication that the polarization of Λ and $\bar{\Lambda}$ is different. It is interesting that the Λ polarization is large at small y and decreases with y, whereas the $\bar{\Lambda}$ polarization seems to be constant or increasing with y. It indicates on different mechanisms of Λ and $\bar{\Lambda}$ production and polarization.

The x-dependence of the longitudinal polarization is shown in Fig. 4b. The data sample has been divided it 3 bins: $x < 0.0121$, $0.0121 \leq x < 0.025$ and $x > 0.025$. The number of events in each bin is approximately the same. One could see that the polarizations of Λ and $\bar{\Lambda}$ are the same except, probably, the region of small $x < 10^{-2}$. Bearing in mind that our Q^2 region is not large and for the fixed Q^2 there is a correlation between x and y variables, it is possible that the difference in Λ and $\bar{\Lambda}$ polarizations at small x is a reflection of the difference at large y.

The longitudinal polarization of Λ and $\bar{\Lambda}$ hyperons has been calculated for the COMPASS energy region in [5],[11],[27]. The main prediction of [27], which follows from the eq.(2), is that the longitudinal polarizations of Λ and $\bar{\Lambda}$ must be the same if $q(x) = \bar{q}(x)$ and $\Delta q(x) = \Delta\bar{q}(x)$. In general, the results of Fig.4 confirm this prediction, though with some caveats on different y-dependence of Λ and $\bar{\Lambda}$ polarizations.

In [11] the longitudinal polarization of Λ was studied on the basis of static SU(6) quark-diquark wave functions and polarized intrinsic strangeness model [1],[2]. The free parameters of the calculation are fixed by fitting NOMAD data [16] on the longitudinal polarization of Λ hyperons in neutrino collisions. The small polarization of Λ was predicted $P_\Lambda = -0.4\%$ for $x_F > -0.2$ and $0.5 < y < 0.9$. This prediction is in a nice agreement with the experimental result shown in Fig. 4a (third bin). An important advantage of the model [11] is the consideration of both quark and diquark fragmentation processes. However, the polarization of $\bar{\Lambda}$ was not considered in [11].

In [5] the longitudinal polarization of Λ and $\bar{\Lambda}$ was calculated assuming quark fragmentation only. The set of cuts ($E_\mu = 200$ GeV, $P_b = -0.8$, $x_F > 0$, $z > 0.2$, $Q^2 > 4\ GeV^2$ and $0.5 < y < 0.9$) did not exactly coincide with the COMPASS conditions. However the trend is interesting. It was predicted for $\bar{\Lambda}$ polarization that $P_{\bar{\Lambda}} = -15\%$ for NQM-based fragmentation function and $P_{\bar{\Lambda}} = -5\%$ for the BJ-scheme [3]. Our experimental value for the $\bar{\Lambda}$ polarization shown in Fig.4a (third bin), better agrees with the NQM, though other models are not excluded at the present statistics and systematics levels.

Comparing the experimental results with the existing theoretical predictions, one may conclude that the longitudinal polarizations of Λ and $\bar{\Lambda}$ in DIS at the COMPASS energy seems to be the same, at least, in the low y-region. Nevertheless, the production mechanisms of Λ and $\bar{\Lambda}$ are different. The Λ hyperons, even in the current fragmentation region $x_F > 0$, are produced with large contribution from the diquark fragmentation, which destroys typical y-dependence and leads to a small spin transfer from the polarized lepton to Λ. The polarization of $\bar{\Lambda}$ seems to be more promising for investigation of the mechanisms of spin transfer from quark to hyperon.

For more definite conclusions, more precise experimental data and theoretical calculations are needed. In future, the analysis of the 2004 run data will increase the statistics of at least a factor 2. At the same time we intend to improve the Monte Carlo description of the spectrometer to decrease the systematics. The theoretical calculations of Λ and $\bar{\Lambda}$ longitudinal polarizations at the COMPASS conditions are highly desirable.

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