Λ PRODUCTION IN COMPASS

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Abstract
First Λ's and $\bar{\Lambda}$'s have been reconstructed from the COMPASS 2002 data. We briefly recall the motivation for measurements of longitudinal polarization of these hyperons. The role of hadronization mechanism in polarization phenomena in DIS and a purity method for extraction of polarized distribution functions are discussed. A model for the longitudinal polarization of Λ baryons produced in deep-inelastic lepton scattering is presented. Within the context of our model, the NOMAD data imply that the intrinsic strangeness associated with a valence quark has anticorrelated polarization. Predictions of our model for the COMPASS experiment are also given and the importance of $\bar{\Lambda}$ polarization measurements is discussed.

1. INTRODUCTION

It is generally accepted that information from deep inelastic scattering (DIS) experiments is an excellent source for investigating the internal structure of the nucleon. Experimental progress in recent years allows one to investigate the semi inclusive DIS (SIDIS). There is hope that, for example, the measurement of different hadron production asymmetries on proton and neutron targets will allow a further flavour separation of polarized quark distributions.

The knowledge of the hadronization mechanism is playing a very important role in the interpretation of SIDIS data. Traditionally one distinguishes two regions for hadron production: the current fragmentation region: $x_F > 0$ and the target fragmentation region: $x_F < 0$. The common assumption is that when selecting hadrons in the current fragmentation region and imposing a cut $z > 0.2$ we are dealing with the quark fragmentation.[1]

The measurements of the longitudinal polarization of the Λ hyperon produced in SIDIS was believed to provide two types of information. In the target fragmentation region it will provide an access to the polarization of intrinsic strangeness of the nucleon [1]. And in the current fragmentation region it will measure the polarization transfer from the quark q to the Λ hyperon, see, for example, Refs. [2–4]: $C_q^\Lambda(z) \equiv \Delta D_q^\Lambda(z)/D_q^\Lambda(z)$, where $D_q^\Lambda(z)$ and $\Delta D_q^\Lambda(z)$ are unpolarized and polarized fragmentation functions. Several experimental measurements of Λ polarization have been made in neutrino and antineutrino DIS. Longitudinal polarization of Λ hyperons was first observed in the old bubble chamber (anti) neutrino experiments [5–7] and according to Ref. [1] support the negative polarized strangeness scenario. The NOMAD Collaboration has recently published new and interesting results on Λ and $\bar{\Lambda}$ polarization with much larger statistics [8]. There are also recent results on longitudinal polarization of Λ hyperons from polarized charged lepton nucleon DIS processes coming from the E665 [9] and HERMES [10] experiments.

Recently the new preliminary data from HERMES on quark flavour separation has been presented [11]. The LO analysis of semi-inclusive DIS has been done by using the purity method and suggests that "the strange sea appears to be positively polarized" in contrast to generally accepted negatively polarized strange sea scenario at LO.

The natural question arises: *Is the negatively polarized strangeness scenario wrong or are the polarized quark distributions extracted by the purity method not precise?* In our opinion the second

[1] In this paper we are using the standard SIDIS notations.

alternative is right. In Section 2 the stability of purity method for polarized distribution function extraction is discussed. A method of calculation of the longitudinal polarization of Λ hyperons produced in SIDIS [12] is presented in Section 3, and our model predictions are compared to the available data in Section 4. A Short discussion on $\bar{\Lambda}$ polarization measurement is presented in Section 5. In Section 6 the preliminary distributions for Λ and $\bar{\Lambda}$ from COMPASS are presented. Finally, in Section 7 some conclusions are presented.

2. REMARKS ON THE PURITY METHOD

To make flavour decomposition of polarized quark distributions, the purity method has been used in the HERMES analysis [11]. In the LO approximation the virtual photon asymmetry is given by

$$A_1^h \simeq \frac{\sum_q e_q^2 \Delta q(x,Q^2) \int_{z_{min}}^1 dz D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) \int_{z_{min}}^1 dz D_q^h(z,Q^2)}. \tag{1}$$

This equation can be rewritten in the form

$$A_1^h \simeq \sum_q P_q^h(x) \frac{\Delta q(x)}{q(x)}, \tag{2}$$

where the purity, $P_q^h(x)$, is defined as

$$P_q^h(x) = \frac{e_q^2 q(x) \int_{z_{min}}^1 dz D_q^h(z)}{\sum_{q'} e_{q'}^2 q'(x) \int_{z_{min}}^1 dz D_{q'}^h(z)}, \tag{3}$$

and calculated using an unpolarized Monte Carlo event generator `LEPTO` [13] – `JETSET` [14]. Then using measured asymmetries for different hadrons one can find $\Delta q(x)$ by solving Eq. (2). The main assumption of this method is that all hadrons in the current fragmentation region with $z > 0.2$ are produced from the quark fragmentation so there are no additional terms in both the numerator and the denominator of Eq. (1). However, this assumption fails for moderate energies in the `LUND` fragmentation model incorporated in the `JETSET` program. In this program there is a pointer which shows the origin of produced hadrons. They can originate from quark or diquark fragmentation or low mass cluster decay. In Fig. 1, the fraction of events with hadrons produced via quark fragmentation

$$F_q = \frac{N_{hadron}(from\ quark\ fragmentation)}{N_{hadron}(tot)}, \tag{4}$$

is presented for different hadrons as a function of x_F. As one can see this fraction is less than one even at large values of x_F. Thus the assumption that hadrons in the current fragmentation region are produced only via quark fragmentation is not valid in the `LUND` model and purities obtained with the `LEPTO` Monte Carlo generator include contributions from the target remnant fragmentation.

When one takes into account the contribution from the target remnant, Eq. (1) for virtual photon asymmetry is modified:

$$A_{1p}^h = \frac{\sum_q [\Delta q(x) D_q^h(z) + \Delta M_q^{h/p}(x,z)]}{\sum_q [q(x) D_q^h(z) + M_q^{h/p}(x,z)]} \ . \tag{5}$$

The additional contributions from diquark fragmentation and other sources arise in the numerator and the denominator. It is important to note that even after tuning the `LEPTO` generator to unpolarized data nothing is known about $\Delta M_q^{h/p}(x,z)$.

To investigate the stability of the purity method the following MC exercise has been done. Using the `PEPSI` polarized MC generator [15] we generate the sample of 10^8 SIDIS events at HERMES energy for each polarization state of the target. The GRSV2000 LO (standard scenario) polarized and

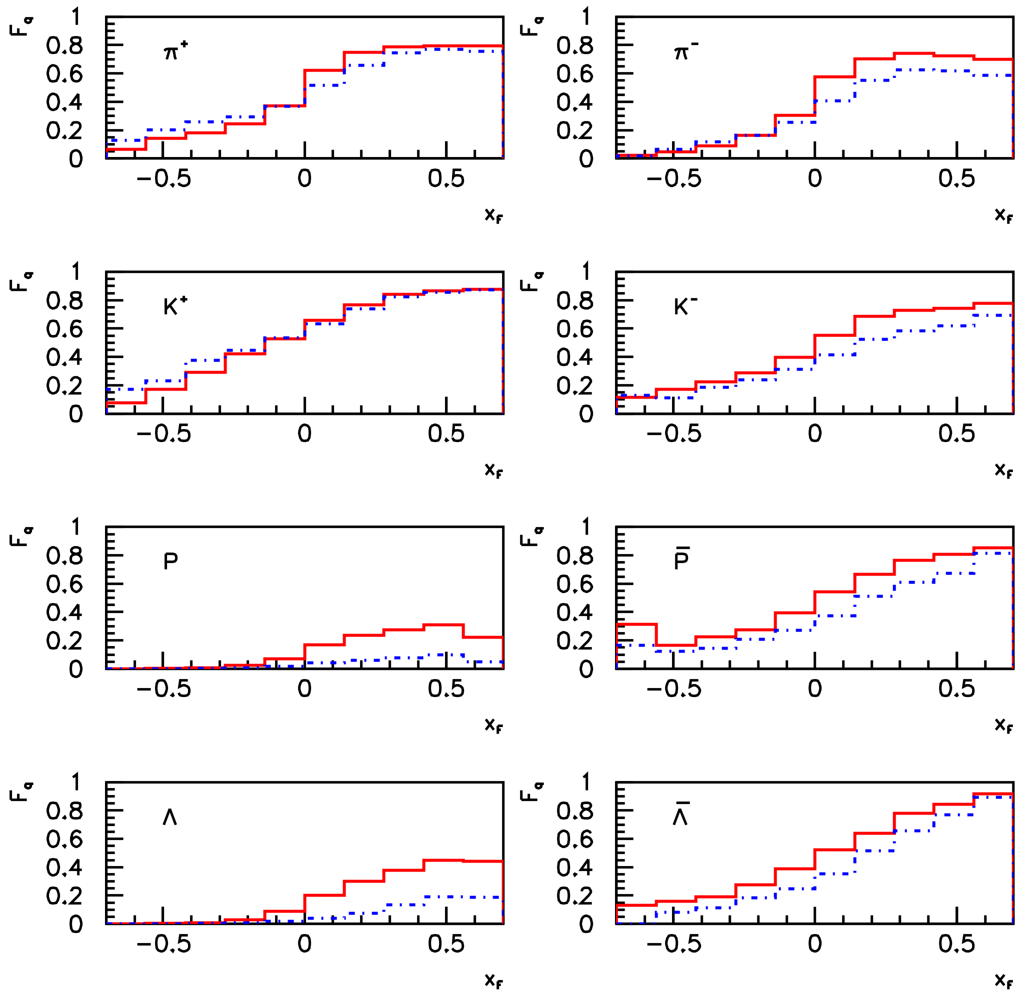

Fig. 1: Fraction of hadrons originating from quark fragmentation for COMPASS (solid line) and HERMES energies (dot-dashed line).

corresponding unpolarized GRV98 LO distribution functions have been chosen. To deal with current fragmentation we have selected $\pi^+, \pi^-, K^+, K^-, h^+$ and h^- with $x_F > 0$ and $z > 0.2$. To calculate asymmetries we considered two possibilities:

- **Model 1:** all hadrons give a contribution to the numerator of Eq. (5)
- **Model 2:** only hadrons from the quark fragmentation give a contribution to the numerator.

In both cases we assume that the purities are calculated from an unpolarized sample with non-zero $M_q^{h/p}(x, z)$. The polarized quark distributions are obtained by solving Eq. (2) and presented in the Fig. 2.

As one can see, the two models give rather different results. In particular, with *negative* input for the polarized strange sea distribution, **Model 2** leads to *positive* $\Delta s + \Delta \bar{s}$.

Up to now little is known about non-perturbative effects in hadronization. We see that at least in the `LUND` model Eq. (1) is incomplete and has to be replaced by Eq. (5). Even assuming that `LEPTO` is well tuned to unpolarized data we don't know anything about $\Delta M_q^{h/p}(x, z)$. The purity method is based on Eq. (1) and does not take into account non-perturbative effects of diquark or cluster hadronization in the polarized case. Without taking these effects into account it is hard to trust the polarized quark distribution obtained by the purity method.

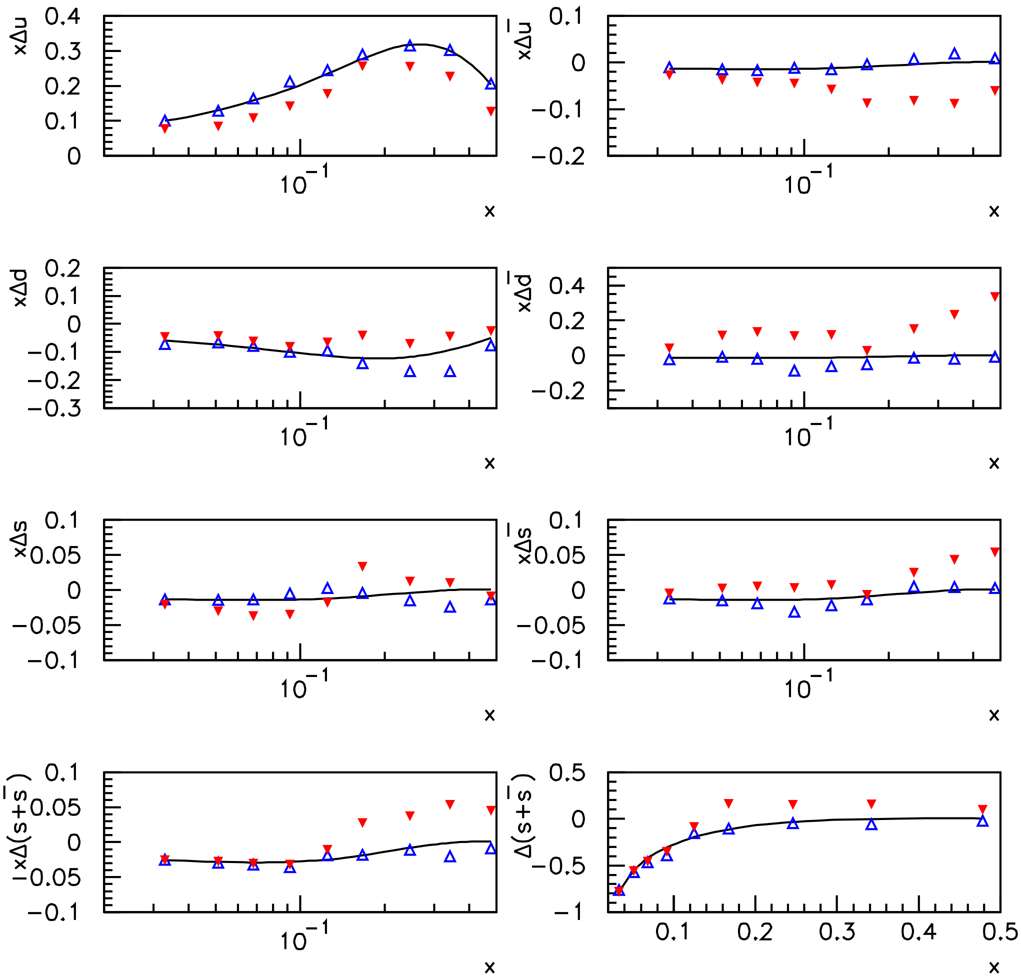

Fig. 2: Polarized quark distributions reconstructed by the purity method as a function of x_{Bj}: empty triangles – **Model 1**, full triangles – **Model 2**, solid line – the input distribution.

3. Λ PRODUCTION AND POLARIZATION IN DIS

Here a short description of the approach and results on Λ longitudinal polarization in DIS developed in the work [12] will be given.

Strange hadrons can be produced in SIDIS due to the struck quark or the nucleon remnant diquark fragmentation. The longitudinal polarization of the lepton can be transferred to strange hadrons during this fragmentation process. Λ hyperons can be produced *promptly* or as a decay product of heavier strange baryons (Σ^0, Ξ, $\Sigma^{\star}$). Therefore to predict a polarization for Λ hyperons in a given kinematic domain one needs to know the relative yields of Λ's produced in different channels and their polarization. We take into account all these effects by explicitly tracing the Λ origin predicted by the fragmentation model and assigning the polarization according to the polarized intrinsic strangeness model in the diquark fragmentation and by SU(6) and Burkardt–Jaffe models for the quark fragmentation.

3.1 Polarized intrinsic strangeness model

The main idea of the polarized intrinsic strangeness model applied to semi-inclusive DIS is that the polarization of s quarks and $\bar{s}$ antiquarks in the hidden strangeness component of the nucleon wave function should be (anti)correlated with that of the struck quark. This correlation is described by the spin correlation coefficients C_{sq}: $P_s = C_{sq} P_q$, where P_q and P_s are the polarizations of the initial struck (anti)quark and remnant s quark. In principle, C_{sq} can be different for the valence and sea quarks. We

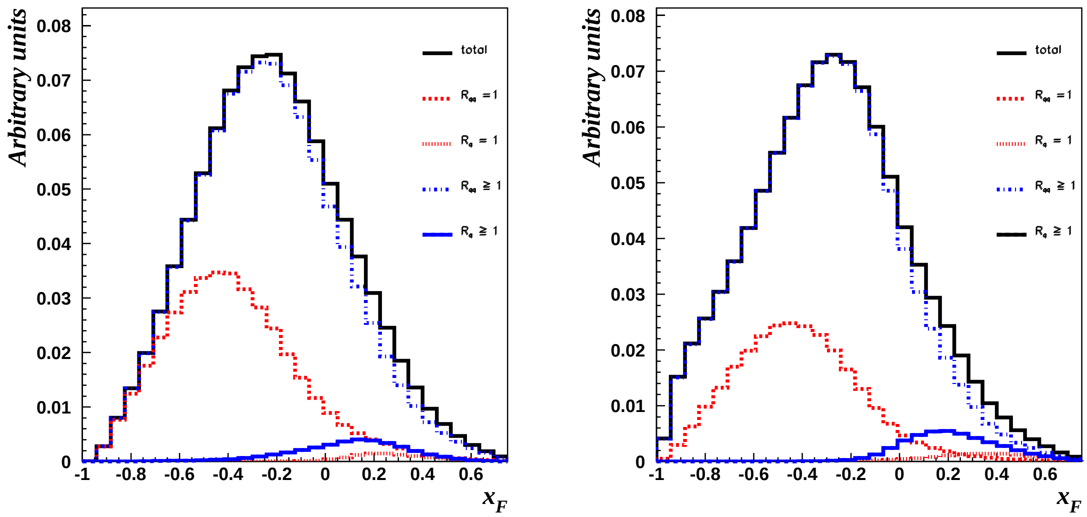

Fig. 3: Predictions for the x_F distributions of all Λ hyperons (solid line), of those originating from diquark fragmentation and of those originating from quark fragmentation, for the two model variants A and B, as explained in the legend on the plots. The left panel is for ν_μ CC DIS with $E_\nu = 43.8$ GeV, and the right panel for μ^+ DIS with $E_\mu = 160$ GeV.

leave $C_{sq_{val}}$ and $C_{sq_{sea}}$ as free parameters, that are fixed in a fit to the NOMAD data [8].

3.2 Polarization of strange hadrons in (di)quark fragmentation

We define the quantization axis along the three-momentum vector of the exchanged boson. To calculate the polarization of Λ hyperons produced in the diquark fragmentation we assume the combination of a non-relativistic $SU(6)$ quark–diquark wave function and the polarized intrinsic strangeness model described above. The polarization of Λ hyperons produced in the quark fragmentation via a strange baryon (Y) is calculated as: $P_\Lambda^q(Y) = -C_q^\Lambda(Y)P_q$, where $C_q^\Lambda(Y)$ is the corresponding spin transfer coefficient, P_q is the struck quark polarization which depends on the process. We use SU(6) and BJ models to compute $C_q^\Lambda(Y)$.

3.3 Fragmentation model

To describe Λ production and polarization in the full x_F interval, we use the `LUND` string fragmentation model, as incorporated into the `JETSET7.4` program. We use the `LEPTO6.5.1` Monte Carlo event generator to simulate charged-lepton and (anti)neutrino DIS processes. We introduce two rank counters: R_{qq} and R_q which correspond to the particle rank from the diquark and quark ends of the string, correspondingly. A hadron with $R_{qq} = 1$ or $R_q = 1$ would contain the diquark or the quark from one of the ends of the string. However, one should perhaps not rely too heavily on the tagging specified in the `LUND` model. Therefore, we consider the following two variants of nonzero spin transfer in fragmentation:

Model A: The hyperon contains the struck quark (the remnant diquark) only if $R_q = 1$ ($R_{qq} = 1$).

Model B: The hyperon contains the struck quark (the remnant diquark) if $R_q \geq 1$ and $R_{qq} \neq 1$ ($R_{qq} \geq 1$ and $R_q \neq 1$).

Clearly, **Model B** weakens the `LUND` tagging criterion by averaging over the string, while retaining information on the end of the string where the hadron originated.

In the framework of `JETSET`, it is possible to trace the particles' parentage. We use this information to check the origins of the strange hyperons produced in different kinematic domains, especially at various x_F. According to the `LEPTO` and `JETSET` event generators, the x_F distribution of the diquark to Λ fragmentation is weighted towards large negative x_F.

However, its tail in the $x_F > 0$ region overwhelms the quark to Λ x_F distribution at these beam energies. In Fig. 3, we show the x_F distributions of Λ hyperons produced in diquark and quark fragmentation, as well as the final x_F distributions. These distributions are shown for ν_μ CC DIS at the NOMAD mean neutrino energy $E_\nu = 43.8$ GeV, and for μ^+ DIS at the COMPASS muon beam energy $E_\mu = 160$ GeV. The relatively small fraction of the Λ hyperons produced by quark fragmentation in the region $x_F > 0$ is related to the relatively small centre-of-mass energies — about 3.6 GeV for HERMES, about 4.5 GeV for NOMAD, about 8.7 GeV for COMPASS, and about 15 GeV for the E665 experiment — which correspond to low W.

We vary the two correlation coefficients $C_{sq_{val}}$ and $C_{sq_{sea}}$ in fitting Models A and B to the following four NOMAD points:

1) νp: $P_x^\Lambda = -0.26 \pm 0.05(stat)$, 3) $W^2 < 15$ GeV^2: $P_x^\Lambda(W^2 < 15) = -0.34 \pm 0.06(stat)$,
2) νn: $P_x^\Lambda = -0.09 \pm 0.04(stat)$, 4) $W^2 > 15$ GeV^2: $P_x^\Lambda(W^2 > 15) = -0.06 \pm 0.04(stat)$.

We find from these fits similar values for both the $SU(6)$ and BJ models: $C_{sq_{val}} = -0.35 \pm 0.05$, $C_{sq_{sea}} = -0.95 \pm 0.05$ (**Model A**) and $C_{sq_{val}} = -0.25 \pm 0.05$, $C_{sq_{sea}} = 0.15 \pm 0.05$ (**Model B**).

4. RESULTS ON Λ POLARIZATION

In Figs. 4 and 5 we show our model predictions compared to the available data from the NOMAD [8] and HERMES [10] experiments. One can conclude that our model quite well describes all the data. The NOMAD Collaboration has measured separately the polarization of Λ hyperons produced off proton

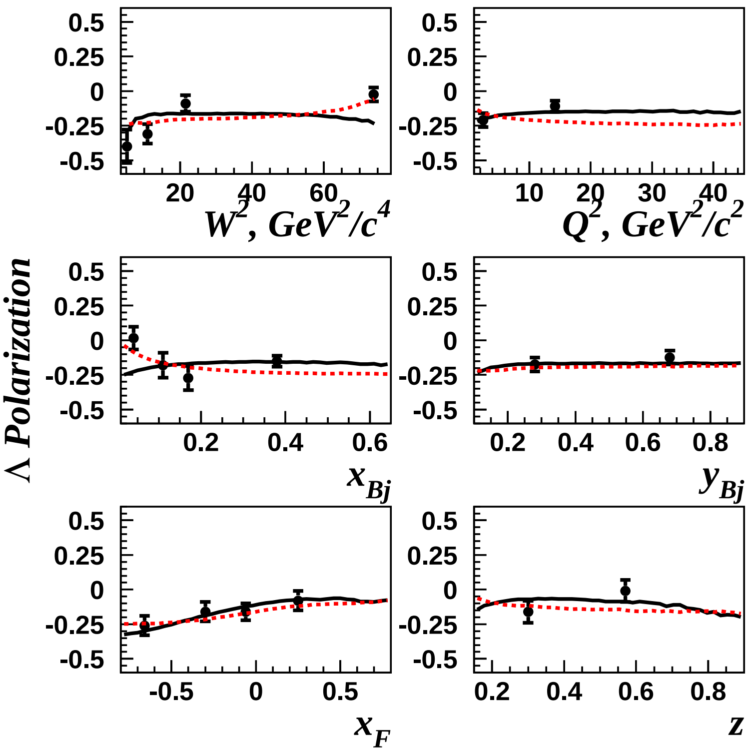

Fig. 4: The predictions of **Model A** – solid line and **Model B** – dashed line, for the polarization of Λ hyperons produced in ν_μ charged-current DIS interactions off nuclei as functions of W^2, Q^2, x_{Bj}, y, x_F and z (at $x_F > 0$). The points with error bars are from the NOMAD experiment.

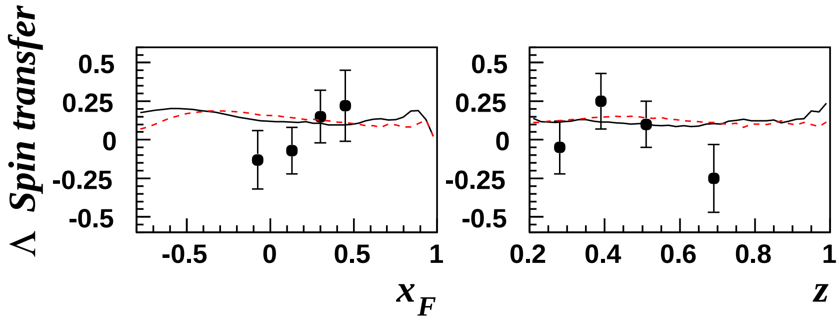

Fig. 5: The predictions of **Model A** – solid line, **Model B** – dashed line, for the spin transfer to Λ hyperons produced in e^+ DIS interactions off nuclei as functions of x_F and z (at $x_F > 0$). We assume $E_e = 27.5$ GeV, and the points with error bars are from HERMES experiment.

and neutron targets. We observe good agreement, within the statistical errors, between the **Model B** description and the NOMAD data while **Model A**, quite well reproducing the polarization of Λ hyperons produced from an isoscalar target, fails to describe target nucleon effects. We provide many possibilities for further checks of our approach for future data (see for details Ref. [12]).

The COMPASS Collaboration plans to investigate the polarization of Λ hyperons produced in the DIS of polarized μ^+ on a ^{6}LiD target. The beam energy and polarization are 160 GeV and -0.8, respectively. Thanks to the large statistics expected in this experiment, one can select kinematic regions where the predicted polarization is very sensitive to the value of the spin correlation coefficient for sea quarks, $C_{sq_{sea}}$. For example, in the region $x_F > -0.2$, which is experimentally accessible, and imposing the cut $0.5 < y < 0.9$, one ensures a large spin transfer from the incident lepton to the struck quark, and enhances the contribution from the sea quarks. The predicted Λ polarization is presented in Table 1.

Table 1: Predicted Λ polarization for COMPASS experiment

	Target nucleon		
P_Λ (%)	isoscalar	proton	neutron
Model A	-7.3	-7.3	-7.2
Model B	-0.4	-0.4	-0.4

As one can see the two models give quite different predictions and a new measurement of the Λ polarization can give preference to one of the models described.

5. $\bar{\Lambda}$ PRODUCTION AND POLARIZATION

As one can see in Fig. 1, $\bar{\Lambda}$'s in the current fragmentation region are mainly produced via quark fragmentation and the measurement of their polarization can provide information on spin transfer coefficients

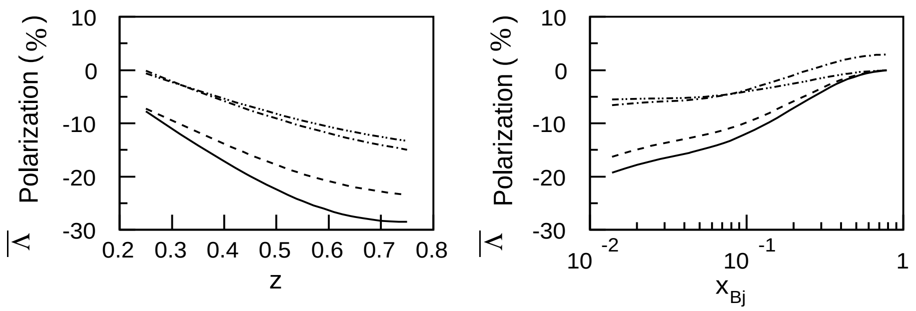

Fig. 6: Predictions for $\bar{\Lambda}$ polarization in COMPASS for different mechanisms of spin transfer: NQM, BGH (SU(6)+heavier hyperons) and BJ. For details see Ref. [3].

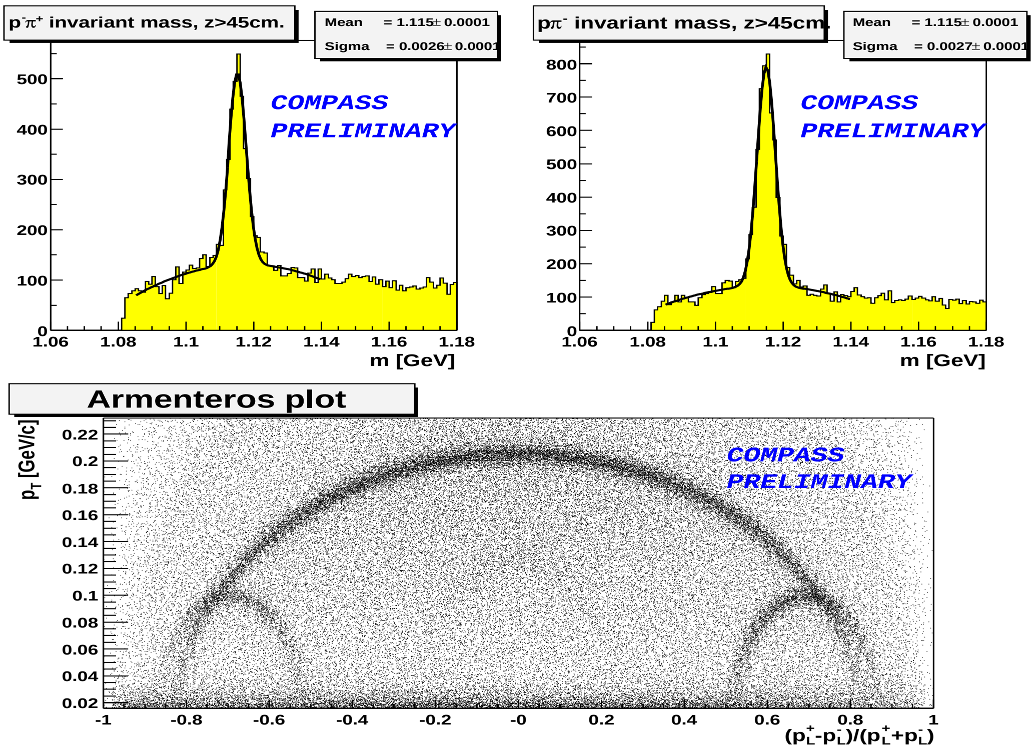

Fig. 7: Upper part: invariant mass distributions for $\bar{p}\pi^+$ and $p\pi^-$ pairs. Lower part: Armenteros plot with corresponding $\bar{\Lambda}$ (left) and Λ (right) ellipses

$C_q^{\Lambda}(z)$. In the literature one can find many models for $C_q^{\Lambda}(z)$. As an example in Fig. 6 the predictions of Ref. [3] for $\bar{\Lambda}$ polarization are presented for some of these models. These calculations have to be revised by taking into account the influence of the target remnant.

6. FIRST Λ's AND $\bar{\Lambda}$'s FROM COMPASS

The preliminary data analysis of the 2002 run demonstrated the COMPASS capability of Λ and $\bar{\Lambda}$ reconstruction. The selection criteria were the following:

- the V^0 vertex is 15 cm downstream of target,
- the transverse momentum of V^0's tracks with respect to its direction $p_T > 30$ MeV/c,
- the distance between V^0 momentum direction and primary vertex < 0.8 cm,
- with the $\pi^+\pi^-$ hypothesis, the V^0 mass is outside of the K_S^0 mass peak.

The invariant mass distribution of $\bar{p}\pi^+$ and $p\pi^-$ pairs and Armenteros plot are presented in Fig. 7. Estimations of the existing statistics show that COMPASS will have a sample of Λ and $\bar{\Lambda}$ larger than acquired in other experiments.

7. CONCLUSIONS

To treat the polarization phenomena in SIDIS it is very important to trace the origin of hadrons. The modern Monte Carlo event generators are very successful in the description of unpolarized SIDIS. We have learnt in Section 2 that according to the LUND model the essential part of hadrons are not produced by the quark fragmentation even in the current fragmentation region.

As we have demonstrated in Section 3 and Section 4 one can successfully describe the existing data on Λ longitudinal polarization in the combined SU(6) and intrinsic strangeness model when one take into account the origin of the strange hyperons predicted in the LUND model. Within the context of our model, the NOMAD data imply that the intrinsic strangeness associated with a valence quark has anticorrelated polarization.

In contrast, the purity method, also based on the `LEPTO` event generator, assumes that all hadrons in the current fragmentation region are produced via quark fragmentation. As demonstrated in Section 2 this is not a good approximation and the results obtained by this method are highly questionable.

Finally, the measurement of $\bar{\Lambda}$ polarization is still actual and can allow one to distinguish between different spin transfer mechanisms.

Acknowledgements

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