Longitudinal Λ and $\bar{\Lambda}$ polarization in the COMPASS experiment

D.Kang[a] on behalf of the COMPASS collaboration

[a] Fakultät für Physik, Universität Freiburg, D-79104 Freiburg, Germany

At the COMPASS experiment at CERN, Λ and $\bar{\Lambda}$ particles are produced with high statistics in deep inelastic scattering processes of 160 GeV/c polarized μ^+ off a ^{6}LiD target. The main focus of the research is the understanding of the longitudinal Λ and $\bar{\Lambda}$ polarization and the spin transfer mechanism from quarks to hadrons through the fragmentation process. The results provide useful information to test different model predictions, which describe spin effects in hyperon production and the quark-antiquark asymmetry of the nucleon spin structure such as the polarization of s and $\bar{s}$ quarks in the nucleon. Preliminary results from data collected during 2002 and 2003 are presented for the current fragmentation region. We will compare our results with other measurements and discuss the dependence of the Λ and $\bar{\Lambda}$ polarization on various kinematic variables.

1. Introduction

The spin structure of hadrons is still not understood at a fundamental level, despite of having been extensively studied by the investigation of the spin structure of hadrons both theoretically and experimentally during the past several years. The first puzzling result for the nucleon spin was reported by EMC [1], that the quark contribution to the nucleon spin is substantially smaller than expected in the naïve quark-parton model (NQM), and subsequently confirmed by SMC [2]:

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s = 0.29 \pm 0.06, \qquad (1)$$

where Δq is the polarized quark-antiquark structure function in the nucleon. The interpretation of these results is that quarks in the nucleon carry only 30% of the nucleon spin. This comes as a surprise from the point of view of the simple constituent quark model, which suggest $\Delta u + \Delta d = 1$, and $\Delta s = 0$. This astonishing result was the so-called *spincrisis*. The experimental data also allow to extract the separate contribution of u, d, s quarks and their antiquarks. If the SU(3) flavour symmetry and zero contribution from gluons are assumed, the spin contribution of s quark in the nucleon is $\Delta s = -0.10 \pm 0.02$ from the data of inclusive deep inelastic scattering (DIS) measurement [2]. It is found that are significantly negative and non-negligible contributions of s quarks. Recently, the HERMES group has presented data on the polarized strange sea quark distribution from the analysis of semi-inclusive DIS, that the polarized s quark at $Q^2 = 2.5$ (GeV/c)^2 is compatible with zero: $\Delta s = +0.03 \pm 0.03 \pm 0.01$ [3]. However, this estimation has been questioned due to the fact that corrections to independent fragmentation, for instance diquark fragmentation, may be large [4].

Since the estimation of Δs and $\Delta\bar{s}$ have a strong model dependence, these two different results lead to the following question of how well do we understand the spin structure of other baryons with nucleon data. Further, what is the mechanism that polarizes the strange sea in the nucleon? It should be possible to access the Δs and $\Delta\bar{s}$ in nucleon and spin structure of other baryons directly from the measurement of the Λ and $\bar{\Lambda}$ polarization.

Another interesting subject of Λ and $\bar{\Lambda}$ polarization is the study of possible asymmetries of strange quark-antiquark. The possible quark-antiquark asymmetry in the nucleon sea could produce an observable contribution to the different behaviours of Λ and $\bar{\Lambda}$ production, either in the quark to Λ and $\bar{\Lambda}$ fragmentation functions or in the quark and antiquark distributions of the target nucleon [5]. The study of the Λ and $\bar{\Lambda}$ polarization could lead eventually to a deeper understanding of the spin structure of the hadrons.

2. Models for Spin transfer

In semi-inclusive DIS of a longitudinally polarized beam on an unpolarized nucleon target, the longitudinal Λ polarization is given by [6]

$$P_\Lambda(x,y,z) = P_B D(y) \frac{\sum_q e_q^2 q(x) \Delta D_q^\Lambda(z)}{\sum_q e_q^2 q(x) D_q^\Lambda(z)}. \qquad (2)$$

Here, e_q is the charge of quark, P_B is the polarization of the beam, and $q(x)$ are the unpolarized quark distribution functions, where x is the Bjorken scaling variable. D_q^Λ and ΔD_q^Λ are unpolarized and polarized fragmentation functions, where z=E_Λ/ν is defined as the fractional hadron energy, and $D(y)$ is the longitudinal depolarization factor of the virtual photon, where y is the fraction of the lepton energy carried by the virtual photon.

The possible correlation between the polarization of the struck quark and the final-state Λ hyperon is described by the spin-transfer coefficient:

$$D_{LL} = \frac{P_\Lambda}{P_B \cdot D(y)}. \qquad (3)$$

It describes the probability that the polarization of the struck quark is transferred to the Λ hyperon. An essential ingredient of the spin transfer coefficient is the fraction of polarized and unpolarized fragmentation functions $\Delta D_q^\Lambda / D_q^\Lambda$. Interesting information on the mechanism of the spin transfer can be obtained by a measurement of the longitudinal Λ polarization. Under the assumptions that the original helicity of the quark is preserved during the fragmentation process and using the reciprocity relation of Gribov and Lipatov [7] between the fragmentation functions and quark distributions in the hadron, the spin transfer coefficient is expected to be related to the spin structure of the Λ hyperon. In other words, it may be interpreted as the average spin of quarks in the Λ hyperon.

In the NQM the spin of the Λ is carried completely by the s quark and the spin transfer from the u and d quarks to the Λ is equal to zero. It means that if Λ is produced in the fragmentation of u and d quarks, one may expect that $P_\Lambda \sim 0$.

Another model approach is based on the non-relativistic SU(6) quark model [8]. It assumes that the s quark is only to be responsible for the spin transfer to the produced Λ directly as NQM. In addition, other heavier hyperon decays such as Σ, $\Sigma(1385)$, and Ξ are considered for the Λ polarization as well. It is expected that a polarization of Λ and $\bar{\Lambda}$ is about -12% and -14%, respectively.

Using SU(3) flavor symmetry and experimental data for the spin dependent quark distributions in the proton, one can try to reproduce the spin structure of Λ. It has been predicted by Burkardt and Jaffe [9] 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 and the contribution of s quarks to the Λ polarization is about 60%, positively. In this model, the fragmentation of the dominant u quark will lead to the negative spin transfer to Λ.

Recently, the importance of diquark fragmentation assumes in a semi-inclusive measurement. The dominance of the diquark fragmentation process for the Λ production is suggested in the framework of SU(6) quark-diquark model [11]. This model takes into account that Λ is mainly originating from diquark fragmentation even in the current fragmentation region, large positive spin transfers are predicted at large x and z [10,11].

All of these predictions can be tested by measuring the Λ and $\bar{\Lambda}$ polarization with COMPASS.

3. Experiment and Event Selection

The Λ and $\bar{\Lambda}$ production by polarized μ^+ of 160 GeV/c on a ^{6}LiD target has been studied at the COMPASS experiment, whereas the beam polarization is $P_B = -0.76 \pm 0.04$. A detailed description of COMPASS detectors can be found in Ref [12]. The data presented here have been recorded during the period of 2002 and 2003. The total sample comprises about 8.7×10^7 DIS events with $Q^2 > 1$ (GeV/c)^2.

The V^0 events ($V^0 \equiv \Lambda, \bar{\Lambda}$) were selected by requiring a primary vertex with incoming and outgoing muon tracks and at least two hadron tracks forming a secondary vertex. We required that 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. A transverse momentum $p_T > 23$ MeV/c of the decay products with respect to the direction of V_0 particle was applied to reject the background of e^+e^- pairs. We select events with momenta of positive and negative particles greater than 1 GeV/c, and the momenta p_{V^0} of the V_0 particles have to be larger than 10 GeV/c. The cuts $Q^2 > 1$ (GeV/c)^2 and $0.2 < y < 0.9$ have been applied in order to select the DIS events.

The Λ and $\bar{\Lambda}$ polarization are measured by the angular asymmetry of the positive decay particle in the parity violating weak decay, $\Lambda \rightarrow p\pi^-$, $\bar{\Lambda} \rightarrow \bar{p}\pi^+$. In the V_0 rest frame the angular distribution of decay protons and pions is given as

$$\frac{dN}{dcos\theta} = \frac{N_{tot}}{2}(1 \pm \alpha P cos\theta) A(cos\theta), \qquad (4)$$

where N_{tot} is the total number of events. The decay parameters of Λ and $\bar{\Lambda}$ are $\alpha = \pm 0.642 \pm 0.013$, P is the projection of the polarization vector on the direction of the virtual photon in the V_0 rest frame, and θ is the angle between the direction of the decay proton (π^+ for $\bar{\Lambda}$) and the direction of the virtual photon in the V_0 rest frame. $A(cos\theta)$ is the acceptance function of the spectrometer. The acceptance correction was determined using the unpolarized LEPTO Monte Carlo simulation. The invariant mass distribution of positive and negative particles has been reconstructed under the assumption of $p\pi^-$ and $\bar{p}\pi^+$ hypothesis in 10 $cos\theta$ bins. The parameterized kaon background from the Monte Carlo simulation was used to estimate the number of events in each fitting procedure. The reconstructed data sample contains about 31000 Λ and 18000 $\bar{\Lambda}$ after integrating the Λ and $\bar{\Lambda}$ peak. This is significantly larger than the 2002 data sample, which comprises about 9000 Λ and 5000 $\bar{\Lambda}$. Finally, Λ and $\bar{\Lambda}$ polarization has been determined from the parameter of the linear fit to the corrected angular distributions.

The analysis presented here covers the mean $< Q^2 >= 3.55$ (GeV/c)^2, $< x_{Bj} >= 0.02$, $< y >= 0.45$, and $< x_F >= 0.23$, which corresponds to Λ produced in the current fragmentation region. The Λ and $\bar{\Lambda}$ are distributed nearly identically in these kinematic variables.

4. Results

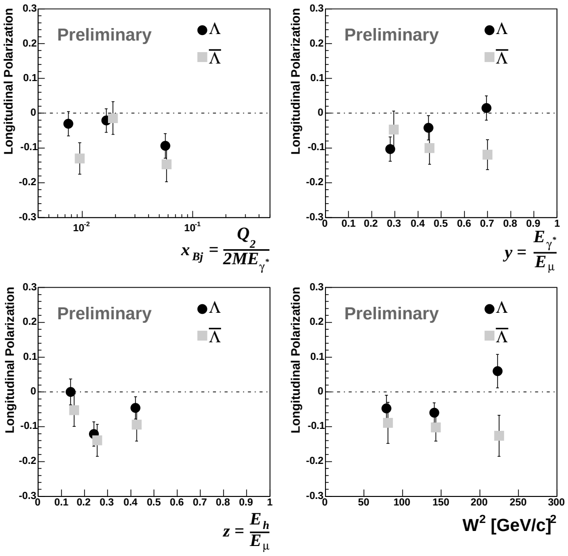

Figure 1. Dependence of the longitudinal Λ and $\bar{\Lambda}$ polarization on x_{Bj}, y, z, and W^2.

The measured polarization of Λ and $\bar{\Lambda}$ for the 2003 run are presented as a function of different kinematic variables in Fig. 1. The systematic errors have been evaluated to be smaller than 5%. Contributions are differences of extraction methods and possible effects of different MC settings for each data point.

One may conclude that the longitudinal polarizations of Λ and $\bar{\Lambda}$ in DIS at the COMPASS energy seems to be the same. The exception is the region of large y, W^2, and small x_{Bj}, where some indication occurs that the polarizations of Λ and $\bar{\Lambda}$ are slightly different. It is interesting that the Λ polarization is large at small y and decreases with large y, while the $\bar{\Lambda}$ polarization seems to be constant. This trend appears in the dependence on W^2 again, because of strong correlation between y and W^2. Since there is also a correlation between x_{Bj} and y for fixed Q^2, it is possible that the difference in Λ and $\bar{\Lambda}$ polarizations at small x_{Bj} is a reflection of the difference at large y and W^2. The distinctions between Λ and $\bar{\Lambda}$ polarization might be interpreted as a different mechanism for the Λ and $\bar{\Lambda}$ production.

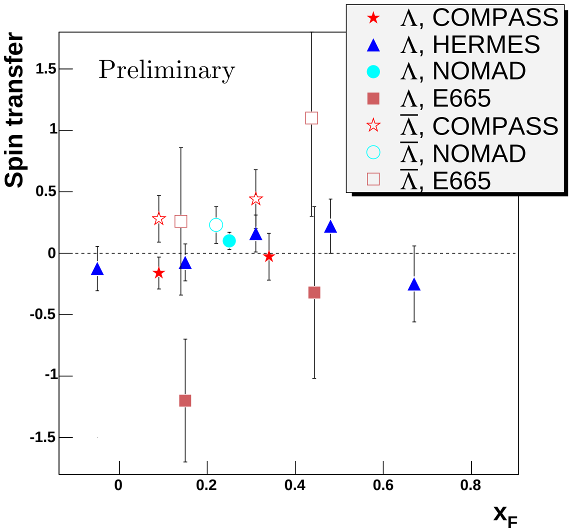

Figure 2. Dependence of the spin transfer to Λ and $\bar{\Lambda}$ as function of x_F. The COMPASS [13] measurements are compared with the results of E665 [14], NOMAD [15], and HERMES [16] experiment.

The preliminary results of the spin transfer Λ and $\bar{\Lambda}$ are presented for 2002 data in Fig. 2. There is a reasonable agreement between the COMPASS and the world data. The spin transfer to Λ seems to be consistent with zero in the kinematic region of x_F, however, it is showing a trend toward higher positive values of the spin transfer at high x_F. This behaviour might suggest a change in the dominant reaction mechanism for Λ and $\bar{\Lambda}$ production between target and current fragmentation regions and a significant contribution from target fragmentation effects below $x_F < 0.2$. The spin transfer to $\bar{\Lambda}$ seems to be slightly larger, but the limited statistics and x_F range of the present data do not allow to confirm this trend and the existence of differences between Λ and $\bar{\Lambda}$. However, the results are still consistent with the expected trend toward positive spin transfer to Λ and $\bar{\Lambda}$ with increasing x_F [5,6,8–11].

For definite conclusions, more precise experimental data and detailed theoretical calculations are needed. The analysis of the 2004 data will increase the statistics by a factor of 2.

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