Λ polarization with a transversely polarized proton target at the COMPASS experiment

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Abstract. The transverse polarization of Λ and $\overline{\Lambda}$ hyperons is investigated at the COMPASS experiment at CERN. In 2007 a 160 GeV/c longitudinally polarized muon beam and a transversely polarized NH_3 target was employed to study events in semi-inclusive deep-inelastic scattering. Preliminary results for the Λ and $\overline{\Lambda}$ polarizations extracted from this new data set are presented as a function of x_{Bj} and z. The polarizations of Λ and $\overline{\Lambda}$ are compatible with zero within their error bars and are thus unpolarized and with no dependence on x_{Bj} or z.

Keywords: Transversely polarized Λ particles; transversely polarized proton target; transversely polarized fragmentation function; transversity function; Λ and $\overline{\Lambda}$ hyperons; COMPASS
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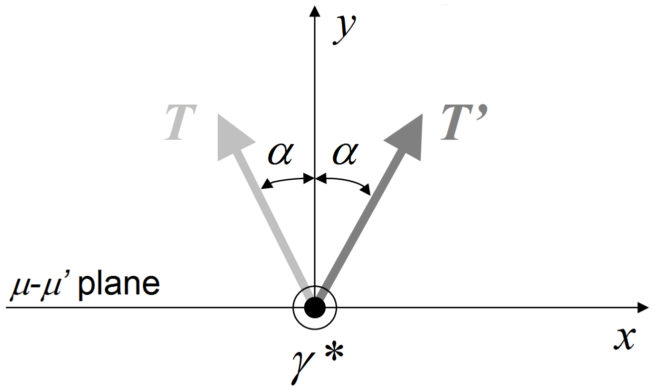
INTRODUCTION

The measurement of the transverse spin quark distribution functions $\Delta_T q(x)$ in the nucleon is an important part of the physics program of the COMPASS experiment[1] at CERN. These so-called transversity distributions, being chiral-odd objects, are not directly accessible in inclusive deep-inelastic scattering (DIS), but require the presence of another chiral-odd object. At COMPASS, $\Delta_T q(x)$ can be measured in semi-inclusive deep-inelastic lepton-nucleon scattering (SIDIS), where this additional object is provided by the fragmentation functions $\Delta_T D_q^{\Lambda}(z)$. A promising channel for the measurement of the transversity distributions in SIDIS is the spin transfer to the Λ hyperons[2]. When a lepton from the incoming beam interacts with one of the valence quarks of a transversely polarized nucleon, a scattered quark leaves the nucleon in a polarization state which is determined by its transverse spin distribution function inside the nucleon. This scattered valence quark fragments with a certain probability into a Λ hyperon and transfers a fraction of its polarization in this process. Thus the measurement of the spin transfer from the transversely polarized valence quark to the Λ hyperon provides an insight of $\Delta_T q(x)$. The polarization of the Λ is expressed by[3]

$$P_{\Lambda}(x,y,z) = f P_T D(y) \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T D_q^{\Lambda}(z)}{\sum_q e_q^2 q(x) D_q^{\Lambda}(z)}, \quad (1)$$

where f is the dilution factor and P_T is the target polarization. The factor $D(y) = 2(1-y)/(1+(1-y)^2)$ is the so-called virtual photon depolarization factor which describes the reduction of the quark polarization. Here, y is the fraction of the incoming lepton energy carried by the exchanged virtual photon. It is obvious that $\Delta_T q(x)$ is coupled to $\Delta_T D_q^{\Lambda}(z)$, having different factorizations of x_{Bj} and z, respectively. By measuring $P_{\Lambda}(x,y,z)$ in different bins of x_{Bj} and z, it is aimed to obtain knowledge about $\Delta_T q(x)$ by modeling $\Delta_T D_q^{\Lambda}(z)$, or to gain insight on both $\Delta_T q(x)$ and $\Delta_T D_q^{\Lambda}(z)$ in different regions of x_{Bj} and z[2].

EXTRACTION OF Λ POLARIZATION



1: Definition of the reference frame: The initial (T) and final (T') transverse quark spin-polarization vectors are shown with respect to the μ - μ' scattering plane [4].

In Fig. 1 the reference system of the Λ production is shown. Here, the virtual photon γ^* moves along the positive z-axis. The transversely polarized target fixes the initial transverse quark-spin polarization vector T. Symmetric to the T-vector with respect to the normal of the μ - μ' scattering plane is the final transverse quark spin-polarization vector T'. The Λ polarization P_T^{Λ} is measured with respect to its reference axis T'. P_T^{Λ} is accessible through the angular distribution of the parity violating weak decay in the Λ rest frame by

$$\frac{dN}{d\cos\theta_{T'}} = \frac{N}{2}(1+\alpha P_T^{\Lambda}\cos\theta_{T'}), \tag{2}$$

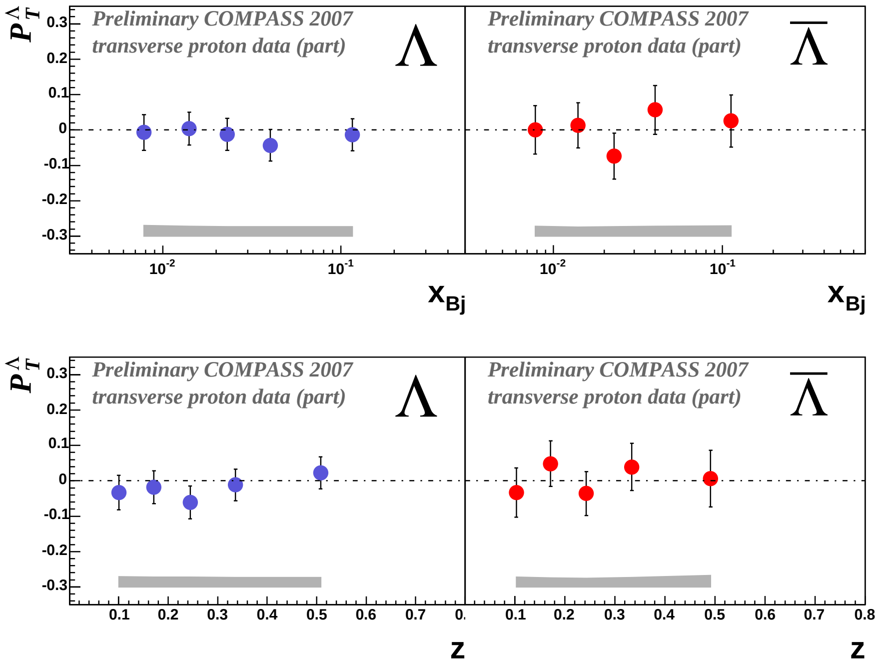
where N is the final number of produced Λ hyperons, $\theta_{T'}$ is the decay angle of the proton with respect to the T'-axis, $\alpha = \pm 0.642 \pm 0.013$ is the analyzing power of the parity violating Λ decay. The final number of Λ hyperons in each $cos\theta_{T'}$ bin is determined by fitting the invariant Λ mass distributions. Since P_T^{Λ} can not be directly extracted from the experimental data due to apparatus acceptance effects, symmetry relations of the apparatus are combined to cancel any terms related to these effects. Two data sub-sets taken under the exact same experimental conditions but with opposite directions of target cells polarizations can be combined by a geometric mean method in such a way that only a term being proportional to the pure Λ polarization remains. In this analysis, the $cos\theta_{T'}$ bins with two target spin orientations and two data taking periods are combined to a counting rate asymmetry $\varepsilon_T(\theta_{T'}) = \alpha P_T^{\Lambda}\cos\theta_{T'}$ [5]. The Λ polarization can be extracted from the slope of this $\varepsilon_T(\theta_{T'})$ distribution.

EVENT SELECTION

This measurement of P_T^Λ is based on the data sample taken during the 2007 data recording with a transversely polarized proton target at the COMPASS experiment. DIS-events are selected at $Q^2 > 1\ (GeV/c)^2$ and $0.1 < y < 0.9$. An incoming beam muon μ and a scattered muon μ' are required along with a primary vertex position within the NH_3 target material. The secondary vertex must have two tracks of oppositely charged hadrons originating from it. A cut to the fiducial volume of both target cells has been applied in order to ensure an equal beam flux in the target cells. To reduce the background of photon conversion and false combinatorial track association, a cut on the collinearity angle is applied: The angle between the reconstructed Λ momentum and the vector between the primary and decay vertex must be smaller than 10 mrad. The contamination from electron positron pairs from photon conversion is further reduced by requiring a minimal transverse momentum $p_T > 23 MeV/c$ of the individual hadrons with respect to the reconstructed V^0 momentum. Since the Λ particles can not be identified properly if they decay too close to their primary vertex, the Λ decay length cut has been optimized to require a decay length 7 times larger than its error. The final step to reduce the remaining background is to employ information from the RICH detector. Since the momentum threshold of 16 GeV to identify a proton is too high and thus limiting the statistics significantly, a veto condition to select physics events is used instead. The veto condition is based on a likelihood method and rejects $e^+(e^-)$, $\pi^+(\pi^-)$ and $K^+(K^-)$ particles from the proton (anti-proton) candidates in the Λ ($\overline{\Lambda}$) decay. The background is significantly reduced by the RICH cut by a factor of 5 where physics events and background events could not be differentiated by kinematical cuts. The resulting invariant mass distributions are fitted with a Gaussian peak superimposed by a 3rd degree polynomial background parametrization. Since the background distribution is more flat by using the RICH cut, the error of the fit decreases significantly as well.

RESULTS & DISCUSSION

The polarization of the Λ and $\overline{\Lambda}$ hyperons is shown in Fig. 2 as a function of x_{Bj} and z. The polarizations of both Λ and $\overline{\Lambda}$ show no significant deviation from zero in the whole explored range of x_{Bj} and z. The shaded bands show the size of the corresponding systematic errors, which originate from the uncertainty of the background subtraction, the variation of selection cuts, and the uncertainty of the target spin orientation and target geometry. The systematic errors have been estimated by calculating the pulls distributions. For the Λ, the systematic error is below 60% of the statistical error, for the $\overline{\Lambda}$ the systematic error is below 40% of the statistical one. The polarization of the spinless K^0s is extracted to be close to zero. Therefore it is assumed that the derivation of the Λ and $\overline{\Lambda}$ polarizations is free of biases. The observed P_T^Λ in the DIS region might indicate that transversity distributions are absent for the Λ production in the investigated kinematic range. Recent publications from Belle, Hermes and COMPASS prove the existence of opposite transversity distributions for u and d quarks[6]. The transverse Λ and $\overline{\Lambda}$ polarizations extracted from COMPASS data collected on a deuteron target[7] show no polarization which could be attributed to the cancellation of the u and d quark contributions. However, since u quarks dominate in the proton, one might expect a different transverse Λ polarization in the proton target data than in the deuteron target data. It might be suspected that the statistics especially in the x_{Bj} range > 0.1 needs to be improved because the transversity distribution function is expected to be different in the higher x_{Bj} range. Another factor to be taken into consideration is the fact that the spin transfer from quark to Λ hyperon is proportional to the product of $\Delta_T q(x)$ and $\Delta_T D_q^\Lambda(z)$. If $\Delta_T D_q^\Lambda(z)$ is too small, even a larger $\Delta_T q(x)$ will be difficult to detect. The analysis of the full 2007 data sample will allow to extend the x_{Bj} and z range and therefore more insight will be gained about $\Delta_T q(x)$ and $\Delta_T D_q^\Lambda(z)$.



2: Transverse Λ and $\overline{\Lambda}$ polarizations as a function of x_{Bj} and z for $Q^2 > 1\ (GeV/c)^2$ in the 2007 transverse proton data. The lower band shows the upper limit of the systematic error.

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