# LAMBDA ASYMMETRIES

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ON BEHALF OF THE COMPASS COLLABORATION

The measurement of the transverse spin quark distribution functions $\Delta_T q(x)$ is an important part of the physics program of the COMPASS experiment at CERN. The transversity distributions, being chiral-odd objects, are not accessible in inclusive deep inelastic scattering (DIS). The most promising channels for the measurement of the transversity distributions in semi-inclusive DIS (SIDIS) are the Collins effect, the azimuthal asymmetries in two hadrons production and the spin transfer to the Lambda hyperons. In this paper we focus on the semi-inclusive Lambda production mechanism, showing the connection between the measured polarization and the $\Delta_T q(x)$ functions. We derive an expression for the experimental $\Lambda \to p\pi^-$ angular distribution that is at first order independent of the experimental acceptance, and we present the preliminary results for the Lambda polarization as a function of the $x$ Bjorken variable. The analysis is based on the 2002 and 2003 COMPASS data with transverse spin target configuration.

## 1. Introduction

The quark structure of the nucleon at twist-two level is fully specified by three distribution functions: the momentum distributions $q(x)$, the helicity distributions $\Delta q(x)$ and the transverse spin distributions $\Delta_T q(x)$. The transverse spin distributions, being chiral-odd objects, are only accessible in semi-inclusive deep inelastic scattering (SIDIS) or in hadron-hadron collisions, and are therefore difficult to be measured experimentally.

The "golden channels" for the measurement of $\Delta_T q(x)$ in SIDIS are the azimuthal asymmetries in pion production [1] and the azimuthal asymmetries in two hadrons production [2]. A possible alternative approach, based on the measurement of the spin transfer to the Lambda hyperons produced in the deep inelastic scattering on transversely polarized targets, has been originally suggested in[3-5], and more recently by Anselmino et al.[6]. The measurement is based on the following idea: when a lepton interacts with one of the valence quarks of a transversely polarized nucleon, the scattered quark leaves the nucleon in a polarization state that is completely determined by its transverse spin distribution function inside the nucleon ($\Delta_T q(x)$) and the kinematics of the lepton-photon vertex. In particular, if the struck quark was initially in the same polarization state as the parent nucleon, then after the scattering the quark will be polarized along an axis that is obtained by reflecting the target polarization axis with respect to the normal to the lepton scattering plane. The final quark polarization is reduced by the so-called virtual photon depolarization factor, originating from the lepton-photon QED vertex and given by $D(y) = 2(1-y)/[1+(1-y)^2]$, where is $y$ is the fraction of the incoming lepton energy carried by the exchanged virtual photon.

The struck quark has a certain probability to fragment into a Lambda hyperon. If at least part of its polarization is transferred in the fragmentation process, the angular distribution in the weak $\Lambda \to p\pi^-$ decay can provide information on the initial polarization state of the quark in the nucleon. The Lambda polarization measured experimentally is therefore given by:

$$\begin{aligned} P_T^\Lambda &= \frac{d\sigma^{lp^\uparrow \to \Lambda^\uparrow X} - d\sigma^{lp^\uparrow \to \Lambda^\downarrow X}}{d\sigma^{lp^\uparrow \to \Lambda^\uparrow X} + d\sigma^{lp^\uparrow \to \Lambda^\downarrow X}} = \\ &= f P_S D(y) \cdot \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T D_{\Lambda/q}(z)}{\sum_q e_q^2 q(x) D_{\Lambda/q}(z)}, \end{aligned} \tag{1}$$

where the $T$-axis is the polarization vector of the struck quark as described before, $P_S$ and $f$ are the target polarization and dilution factor respectively, and $\Delta_T D_{\Lambda/q}(z)$ is the polarized fragmentation function that describes the spin transfer from the quark to the final state hyperon.

## 2. Selection of Lambda events

The analysis is based on the data sample with transverse target polarization collected in 2002 and 2003 by the COMPASS [7] experiment at CERN. For a detailed description of the apparatus, please refer to [8] and references therein.

The event selection is based on the requirement of a scattering with large momentum transfer ($Q^2 > 1$ GeV$^2$/c$^2$) in the $^6$LiD target material, together with a two-body charged decay of a neutral particle downstream of the target. The reconstructed position of the primary interaction vertex must be within the geometrical volume occupied by the target material. In order to ensure an equal beam flux in both target cells, the extrapolated beam trajectory must not intersect the cylindrical surfaces of the cell volumes.

The $\Lambda$ hyperons undergo the decay $\Lambda \rightarrow p\pi^-$ in about 64% of the cases. The decay is detected as a V-shaped vertex in the reconstructed events, with the two oppositely charged decay particles bent in opposite directions by the spectrometer magnets. The typical decay length at the COMPASS energies is about 50 cm.

The main sources of background in the $\Lambda$ sample come from $K^0$ decays, photon conversion and fake vertices from accidental track associations. The background is significantly reduced when the longitudinal position of the decay vertex is restricted to a region between the target exit window and the first MicroMega station. The contamination of $e^+e^-$ pairs from photon conversions is significantly reduced by requiring a minimal transverse momentum $p_T > 23$ MeV/c of the decay proton with respect to the decaying hyperon. The background is further reduced when a cut on the collinearity between the Lambda momentum vector and the line connecting the primary and decay vertex is applied. The angle between the two vectors must be lower than 10 mrad.

Only events with a reconstructed Lambda invariant mass between 1.07 $(\mathrm{GeV/c})^2$ and 1.37 $(\mathrm{GeV/c})^2$ are kept in the final event sample used for the polarization calculation. The number of Lambda decay events in the sample are estimated by fitting the invariant mass distribution with a Gaussian peak combined with a 3rd degree polynomial for the background parameterization. The mass range includes a significant fraction of the background on both sides of the Lambda peak.

The overall number of detected Lambda decays in the sample used in the analysis, corresponding to the full transversity data collected by the experiment in the years 2002 and 2003, is about 20000.

## 3. Extraction of the polarization

The angular distribution of the decay proton in the Lambda rest frame, measured in the experiment, is given by

$$\frac{dN}{d\theta^*_T} = N_0 \cdot \left(1 + \alpha P^\Lambda_T \cos(\theta^*_T)\right) \cdot Acc(\theta^*_T), \tag{2}$$

where $\theta^*_T$ is the proton emission angle with respect to the $T$-axis in the Lambda rest frame. The $Acc(\theta^*_T)$ function represents the distortion of the theoretical angular distribution introduced by the experimental apparatus. This distortion is usually corrected by combining real data and MonteCarlo (MC) simulations. This approach is however quite sensitive to the accuracy of the MC description of the experiment, and requires huge MC data

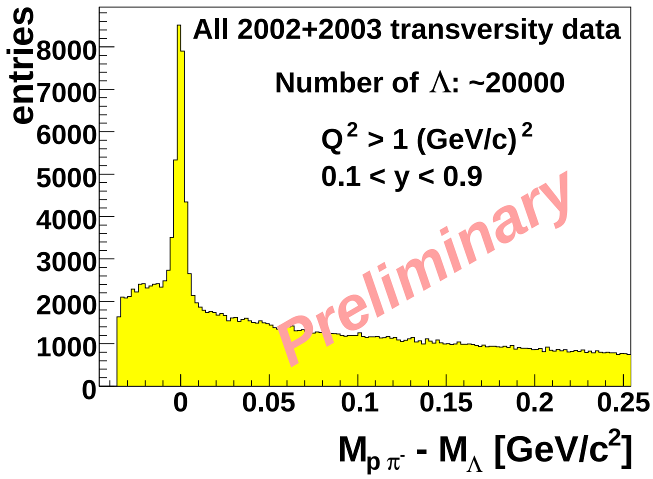


Figure 1. Invariant mass spectrum of the data sample used in this analysis, after all the event selection cuts. The overall number of detected $\Lambda$ decays is about 20000.

samples to get a good statistical accuracy.

In this analysis we used a technique based only on real data samples, exploiting some of the symmetries of the experimental apparatus. The technique is based on the combination of two data taking periods, in the same experimental conditions but with opposite target cell polarizations, so that the acceptance functions cancel and only the terms proportional to the true Lambda polarization remain.

We will denote with $Acc_{1(2)}^{+(-)}(\theta_T^*)$ the acceptance for Lambdas coming from the target cell with spin orientation $+(-)$ and data taking period $1(2)$. The number of Lambdas emitting the proton at an angle $\theta_T^*$ with respect to the $T$-axis is therefore given by

$$N_{1(2)}^{+(-)}(\theta_T^*) \;=\; \Phi_{1(2)}^{+(-)} \cdot \left(\frac{d\sigma}{d\Omega}\right)^0 \cdot \left(1 + \alpha P_T^{+(-)} \cos(\theta_T^*)\right) \cdot Acc_{1(2)}^{+(-)}(\theta_T^*), \quad (3)$$

where $\Phi_{1(2)}^{+(-)}$ denotes the muon beam flux.

The experimental symmetries and the muon flux normalizations allow to write the following relations:

$$Acc_1^{+(-)}(\theta_T^*) \;=\; Acc_2^{-(+)}(\theta_T^*) \quad (4)$$

$$\Phi_1^+ \cdot \Phi_2^+ \;=\; \Phi_1^- \cdot \Phi_2^- \;=\; \Phi_1 \cdot \Phi_2 \quad (5)$$

Under these assumptions the following counting rate asymmetry:

$$\epsilon_T(\theta^*_T) \;=\; \frac{\left[\sqrt{\frac{N_1^+(\theta^*_T)}{\Phi_1^+}\cdot\frac{N_2^+(\theta^*_T)}{\Phi_2^+}}+\sqrt{\frac{N_1^-(\pi-\theta^*_T)}{\Phi_1^-}\cdot\frac{N_2^-(\pi-\theta^*_T)}{\Phi_2^-}}\right]-\left[\sqrt{\frac{N_1^+(\pi-\theta^*_T)}{\Phi_1^+}\cdot\frac{N_2^+(\pi-\theta^*_T)}{\Phi_2^+}}+\sqrt{\frac{N_1^-(\theta^*_T)}{\Phi_1^-}\cdot\frac{N_2^-(\theta^*_T)}{\Phi_2^-}}\right]}{\left[\sqrt{\frac{N_1^+(\theta^*_T)}{\Phi_1^+}\cdot\frac{N_2^+(\theta^*_T)}{\Phi_2^+}}+\sqrt{\frac{N_1^-(\pi-\theta^*_T)}{\Phi_1^-}\cdot\frac{N_2^-(\pi-\theta^*_T)}{\Phi_2^-}}\right]+\left[\sqrt{\frac{N_1^+(\pi-\theta^*_T)}{\Phi_1^+}\cdot\frac{N_2^+(\pi-\theta^*_T)}{\Phi_2^+}}+\sqrt{\frac{N_1^-(\theta^*_T)}{\Phi_1^-}\cdot\frac{N_2^-(\theta^*_T)}{\Phi_2^-}}\right]}. \tag{6}$$

is proportional to the Lambda polarization $P_T$:

$$\epsilon_T(\theta^*_T) \;=\; \alpha P_T^\Lambda \cos\theta^*_T, \tag{7}$$

and the Lambda polarization can be extracted from the slope of the $\epsilon_T(\cos\theta^*_T)$ distribution.

In the present analysis the proton decay angle distributions have been divided in only two bins. In this case the above formula simplifies to $\epsilon_T = \alpha P_T^\Lambda/2$.

## 4. Results

The multiplicative factors appearing on the right side of eq.1 all contribute to reduce the polarization that is measurable experimentally. In the COMPASS case, the average target polarization is about 50% and the dilution factor is $\sim 0.45$. The $D(y)$ depends on the scattering kinematics; the average value of $y$ in the event sample used in this analysis is $< y >\simeq 0.48$, giving a mean depolarization factor of $< D(y) >\simeq 0.8$. That means that the experimentally measurable polarization is not significantly reduced by the typical COMPASS trigger acceptance.

In addition, eq.1 is only valid in the case that the Lambda originates from the scattered quark (current fragmentation region). In the real case, the reconstructed Lambda sample contains also a fraction of Lambdas originating from the fragmentation of the target remnants (target fragmentation region). Nevertheless, the small acceptance of the COMPASS spectrometer for events at $x_F < 0$ and $z < 0.2$ naturally suppresses the contamination of Lambdas produced in the target fragmentation.

The number of Lambda decay events available in the sample allowed not only to extract the overall transverse polarization, but also to investigate its dependence over the Bjorken $x$ kinematical variable. The measured $P_T$ as a function of $x$ is shown in Fig.2 for the full data sample and in Fig.3 for the DIS region ($Q^2 > 1$ GeV$^2$/c$^2$). The measured values are compatible with zero in all the accessible $x$ range. The data points at $x \sim 0.1$, were the transversity distribution function is expected to be peaked, still needs improvement in statistics, therefore no conclusion can be drawn yet on the spin transfer from the target to the final state Lambdas. The addition of the 2004 data sample is expected to double the available statistics for all the considered $x$ bins.

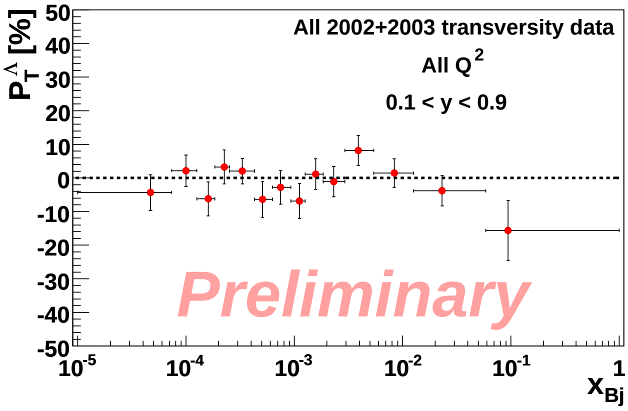


Figure 2. Measured $\Lambda$ polarization as a function of $x$, without the cut $Q^2 > 1$ GeV$^2$/c$^2$.

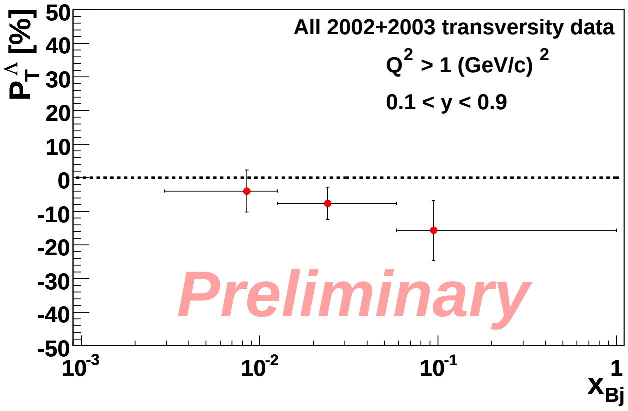


Figure 3. Measured $\Lambda$ polarization as a function of $x$, for the kinematical region of $Q^2 > 1$ GeV$^2$/c$^2$.

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