LAMBDA POLARIZATION MEASURED AT HERMES AND LAMBDA SPIN STRUCTURE

S. Belostotski and O. Grebenyuk
on behalf of the HERMES collaboration

Petersburg Nuclear Physics Institute, Gatchina, 188350, Russia

Received XXX

Polarizations of Λ and $\bar{\Lambda}$ hyperons have been measured in leptoproduction by the HERMES Experiment. Data were accumulated in years 1996 and 1997 using the 27.5 GeV polarized HERA positron beam and unpolarized gas targets. In semi-inclusive reactions with $Q^2 > 1$ GeV^2, the preliminary result is $P_\Lambda = 0.03 \pm 0.06\ (stat) \pm 0.03\ (syst)$ at an average Λ fractional energy $\langle z \rangle$=0.446 and Feynman scaling variable $\langle x_F \rangle$=0.3. The spin transfer coefficient from the virtual photon to the Λ was found to be $D^\Lambda_{LL'} = 0.11 \pm 0.17\ (stat) \pm 0.09\ (syst)$. This result is consistent with both the naive expectation of zero polarization of the up quark in the Λ ($D^\Lambda_{LL'} = 0$), and the Burkardt-Jaffe prediction of $D^\Lambda_{LL'}$ =-0.2 for the up quark contribution. Inclusive reactions with only the Λ or $\bar{\Lambda}$ detected in the final state were also studied. In this case most Λ's and $\bar{\Lambda}$'s are produced in the photoproduction regime with $Q^2 < 0.08$ (GeV/c)^2. Transverse Λ and $\bar{\Lambda}$ polarizations perpendicular to the production plane have been measured. Averaged over the spectrometer acceptance for the transverse Λ and $\bar{\Lambda}$ momentum $0 < p_t < 1.7$ GeV, the preliminary results are $P_n = 0.066 \pm 0.011(stat) \pm 0.025(syst)$ for Λ and $P_n = -0.066 \pm 0.037(stat) \pm 0.025(syst)$ for $\bar{\Lambda}$. This is the first clear indication of transverse Λ polarization in leptoproduction. Theoretical analysis of these results is underway.

1 Longitudinal spin transfer in the electroproduction of Λ

As has been pointed out in ref. [1], polarization transfer from a longitudinally polarized lepton beam to the Λ in the current fragmentation region is sensitive to the spin-dependent fragmentation function. In the Quark Parton Model (QPM), the measured Λ polarization can be written as [1, 2]:

$$P_\Lambda = P_B D(y) \frac{\sum\limits_f e_f^2 q_f^N(x,Q^2) \Delta D_f^\Lambda(z,Q^2)}{\sum\limits_f e_f^2 q_f^N(x,Q^2) D_f^\Lambda(z,Q^2)} \equiv P_B D(y) \sum_f \omega_f \frac{\Delta D_f^\Lambda(z,Q^2)}{D_f^\Lambda(z,Q^2)}, \qquad (1)$$

where P_B is the beam polarization, $-Q^2$ is the squared mass of the virtual photon with energy $\nu = yE$, x is the Bjorken variable, $z = E_\Lambda/\nu$ is the fractional Λ energy, $D(y) \approx y(2-y)/(1+(1-y)^2)$ is the virtual photon depolarization factor, e_f is the fractional quark charge, q_f^N is the quark distribution for flavor f in the unpolarized nucleon, D_f^Λ is the fragmentation function for Λ production from quark flavor f, ΔD_f^Λ is the corresponding longitudinal spin dependent fragmentation function and ω_f is the purity for quark flavor f. According to ref. [1], $\Delta D_f^\Lambda / D_f^\Lambda$ can be interpreted as the polarization of the quark with flavor f in the Λ hyperon.

The longitudinal spin transfer coefficient from the virtual photon to the Λ can be defined as $D^{\Lambda}_{LL'} \equiv \frac{P_{\Lambda}}{P_B D(y)} = \sum_f \omega_f \frac{\Delta D^{\Lambda}_f}{D^{\Lambda}_f}$, where subscripts L and L' denote the directions of the virtual photon and Λ polarization vectors, which can be different in general.

As LEPTO based Monte Carlo calculations show, in the HERMES kinematic domain current fragmentation ($x_F > 0$) dominates semi-inclusive production of Λ hyperons, typically with an up or down quark knocked out from the target and fragmenting to the Λ. With Λ kinematics restricted by the Deep Inelastic Scattering (DIS) cuts: $Q^2 >1$ GeV^2, $y <0.85$ and $0.02< x <0.8$, 95% of Λ's are produced via a parent up or down quark and only 5% via a parent strange quark. These numbers include both Λ's produced directly through string fragmentation ($\simeq$ 40%) and also those coming from $\Sigma^0 \to \Lambda\gamma$ and $\Sigma(1385) \to \Lambda\pi$ decays. Under the assumption of light quark dominance and isotopic symmetry, the polarization transfer can be approximated by: $D^{\Lambda}_{LL'} = 0.95\frac{\Delta D^{\Lambda}_u}{D^{\Lambda}_u} + 0.05\frac{\Delta D^{\Lambda}_s}{D^{\Lambda}_s}$; $\quad \frac{\Delta D^{\Lambda}_u}{D^{\Lambda}_u} = \frac{\Delta D^{\Lambda}_d}{D^{\Lambda}_d}$. In the naive QP model, $D^{\Lambda}_{LL'} \simeq 0$ is expected, since there is no contribution from up or down quarks to the Λ spin ($\Delta u = \Delta d = 0,\ \Delta s = 1$). In another model using SU(3) flavor symmetry [1, 3, 4], the contributions of the up and down quarks are negative ($\Delta u = \Delta d = -0.2,\ \Delta s = 0.6$) and $D^{\Lambda}_{LL'} = -0.15$ is expected, provided the strange quark contribution is taken into account.

The HERMES spectrometer [5] detects the scattered positrons (electrons) and hadrons produced by the 27.5 GeV polarized positron (electron) beam of the HERA collider incident on the internal polarized or high density unpolarized gas targets. Here we report on an experimental study of the semi-inclusive reactions with Λ and $\bar{\Lambda}$ in the final states. They are detected through their $p\pi^-$ and $\bar{p}\pi^+$ decays in coincidence with the scattered positron.

The analyzed data were accumulated in years 1996-1997 in two dedicated runs on unpolarized H, D, ^{3}He, and ^{14}N targets. The opposite signs for the beam polarization in the two runs reduced the systematic error of the measured Λ polarization resulting from the spectrometer acceptance. The target density was restricted only by its effect on the positron beam lifetime. The number of inclusive DIS positrons detected by the spectrometer in this unpolarized run was $7.24 \cdot 10^6$, which corresponds to an integrated luminosity of 163 pb^{-1}.

The Λ and $\bar{\Lambda}$ events were selected so that at least one of the detected particles was identified as a scattered positron and two others as hadrons. Primary and secondary (decay) vertices were reconstructed and hadron pair invariant masses were calculated, revealing Λ and $\bar{\Lambda}$ peaks even without background suppression. In order to suppress the combinatorial background, a vertex separation cut $z_2 - z_1 > 10$ cm has been used, where z_1 and z_2 are primary and secondary vertex positions along the beam direction, respectively. Together with data quality cuts and DIS cuts, this reduced the residual background to the level of $\simeq$ 10% of 1692 Λ and $\simeq$ 25% of 320 $\bar{\Lambda}$ events. Distributions over the kinematic variables Q^2, x, y and z show a reasonable agreement with unpolarized Monte Carlo calculations [7].

The Λ polarization can be measured by the parity-violating decay $\Lambda \to p\pi^-$ through the angular correlation of the final state in the Λ rest frame: $\frac{dN_p}{d\Omega} \propto 1 + \alpha P_\Lambda \cos\Theta_{p\Lambda}$, where $\alpha = 0.642$ is the asymmetry parameter and $\Theta_{p\Lambda}$ is the angle between the proton momentum and the direction of Λ spin polarization.

Following the moment method, the spin transfer coefficient $D^\Lambda_{LL'}$ can be extracted from the unified data set with luminosity-weighted average $\langle P_B \rangle = 0$ [6]:

$$D^\Lambda_{LL'} = \frac{1}{\alpha \langle P_B^2 \rangle} \cdot \frac{\sum_{i=1}^N P_{B\,i} \cos\Theta^i_{p\Lambda}}{\sum_{i=1}^N D(y_i) \cos^2\Theta^i_{p\Lambda}}, \tag{2}$$

where $\langle P_B^2 \rangle$ is the luminosity-weighted square of the beam polarization.

It should be noted that the direction of Λ polarization is not known *a priori* and strictly speaking a three dimension analysis should be done. Here for simplicity the calculation has been done for two variants: the polarization vector is assumed to be directed along the Λ momentum in the laboratory frame or along the momentum of the absorbed virtual photon. In the kinematic domain with $x_F > 0$ and mean values $\langle Q^2 \rangle$=2.48 GeV^2, $\langle z \rangle$=0.446, and $\langle D(y) \rangle = 0.694$, it was found that

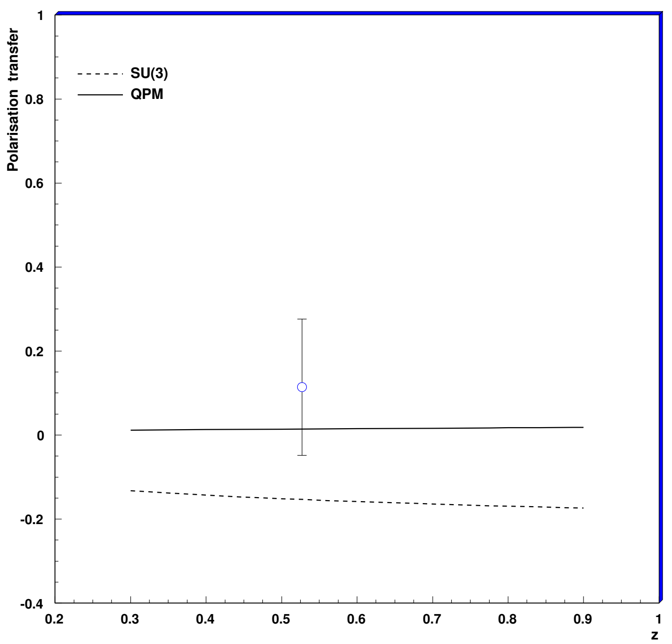

Fig. 1. Spin transfer as a function of z. The curves correspond to different models for the Λ spin structure: the naive model and the SU(3) flavor-symmetric model, and are explained in the text.

$D^{\Lambda}_{LL'} = 0.11 \pm 0.17(stat) \pm 0.09(syst)$ for the Λ polarization along the Λ momentum, and $D^{\Lambda}_{LL'} = 0.03 \pm 0.17(stat) \pm 0.09(syst)$ for the virtual photon momentum as the Λ polarization direction. Within the statistical uncertainty, both results are compatible with expectations based on both the naive QP model and SU(3) flavor-symmetric models. Fig. 1 shows the measured $D^{\Lambda}_{LL'}$ point for the first choice of the Λ polarization direction, along with two theoretical scenarios: the naive model, where only the strange quark carries the spin and contributes to polarized Λ production, and the SU(3) model, in which up and down quarks also contribute with the negative sign [8].

2 Transverse polarization of inclusive Λ and $\bar{\Lambda}$

Transverse Λ polarization has been intensively studied in hadron collisions using various beams and targets [9, 10]. In the case with beam and target unpolarized, it has been found that inclusive Λ's are usually strongly polarized perpendicular to the Λ production plane. For Λ production by leptons or photons, polarization is little studied up to now. Inclusive photoproduction of neutral strange particles including the measurement of the transverse Λ and $\bar{\Lambda}$ polarization has been studied at CERN [11] and SLAC [12], and the polarizations were found to be consistent with zero. The CERN measurements resulted in an average transverse polarization of 6±4% for Λ and 5±10% for $\bar{\Lambda}$, while at SLAC the polarizations were observed to be 9±7% for Λ and -4±4% for $\bar{\Lambda}$.

The HERMES spectrometer provides a good opportunity to measure the transverse polarization of inclusively produced Λ's. If neither beam nor target is (transversely) polarized, the only allowed direction of polarization is along the normal to the Λ production plane, the choice of normal vector sign coinciding with that in hadron collision experiments. Λ polarization can be extracted as usual from the decay asymmetry with respect to this normal vector. The $\Lambda(\bar{\Lambda})$ event selection was similar to that in the semi-inclusive case except that the primary vertex was reconstructed by continuation of the reconstructed Λ track to the positron beam line. The inclusive yields are much higher than those from the semi-inclusive reactions, arising mostly from photoproduction; *i.e.* from positrons scattered at very small angles with $Q^2 < 0.08$ (GeV)^2. After the background suppression cuts, the remaining numbers of events were $N_{\Lambda} = 125 \cdot 10^3$ and $N_{\bar{\Lambda}} = 23 \cdot 10^3$.

To extract the Λ polarization, the moment method has been slightly modified for the transverse polarization case. Due to the up/down mirror symmetry of the HERMES spectrometer, one can see that

$$\langle cos\Theta_{p\Lambda}\rangle^{U} = -\langle cos\Theta_{p\Lambda}\rangle^{D}, \tag{3}$$

where $\langle cos\Theta_{p\Lambda}\rangle^{U(D)}$ is the first moment of the **unpolarized** $cos\theta_{p\Lambda}$ distributions for the upper(lower) half of the spectrometer. Using the HERMES Monte Carlo, it was found that $\langle cos\Theta_{p\Lambda}\rangle^{U,D} = \pm 0.077 \pm 0.015(syst)$. Because of property (3), the first moment of the acceptance function is ruled out and the transverse Λ

polarization can be found as

$$\alpha P_\Lambda = \frac{\frac{1}{N^U}\sum_{i=1}^{N^U}\cos\Theta_{p\Lambda}^{i(U)} + \frac{1}{N^D}\sum_{i=1}^{N^D}\cos\Theta_{p\Lambda}^{i(D)}}{\frac{2}{N}\sum_{i=1}^{N}\cos^2\Theta_{p\Lambda}^{i}}, \tag{4}$$

where N^U and N^D are numbers of Λ events detected by the upper and lower halves of the spectrometer, respectively, and $N = N^U + N^D$. Higher order terms have been neglected in Eq. (4), with a resulting systematic error δP_Λ due to this approximation less than 0.005.

Departures from up/down symmetry of the spectrometer have been studied by comparison of various kinematic distributions for Λ events detected by the upper and lower halves of the spectrometer. Differences between first moments of the distributions were observed to be typically less than 2%. Assuming this number for the $\langle cos\Theta_{p\Lambda}\rangle^{U,D}$ difference,

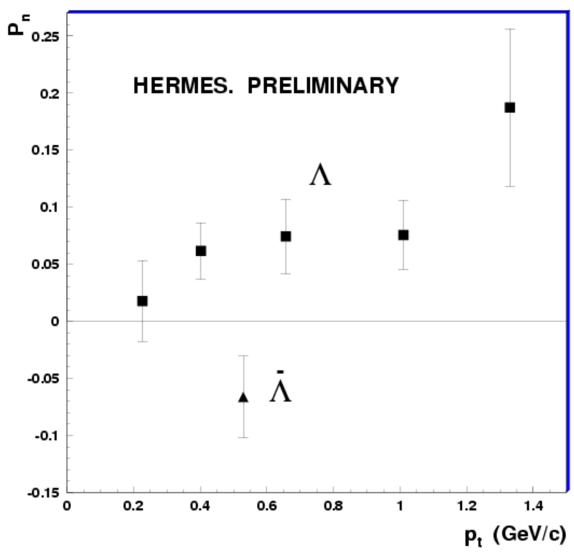

Fig. 2. Transverse polarizations of inclusive Λ and $\bar{\Lambda}$.

it has been found that its effect on the measured polarization is on the level of $\delta P_\Lambda \simeq 0.003$.

The false asymmetry as a function of the transverse momentum p_t has been experimentally investigated using K_s decays and hadron h^+h^- pairs not originating from Λ and $\bar{\Lambda}$ decays. The maximum false asymmetry observed for K_s decays corresponds to $\delta P_\Lambda \simeq 0.025$.

The transverse Λ polarization versus p_t is shown in Fig. 2. The $\bar{\Lambda}$ statistics are sufficient for only one point — the average over the p_t range. It should be noted that the sign of the Λ polarization is opposite to that in pp collision. The $\bar{\Lambda}$ result is compatible with zero within statistical uncertainty.

3 Conclusion and Outlook

The first HERMES measurement of the coefficient of longitudinal spin transfer from the virtual photon to the Λ hyperon in positron deep-inelastic scattering is compatible within statistical uncertainty with both the naive QP and SU(3) flavor-symmetric models. Additional data at higher luminosity and better spectrometer efficiency are planned. In addition, a three-dimension analysis should be done in order to reduce the systematic uncertainty due to the assumption of Λ polarization direction. With all these improvementsit is hoped to distinguish between these two theoretical expectations.

The Λ transverse polarization measured in the photoproduction regime shows a linear dependence on p_t. While its magnitude is close to that measured in pp collisions, it has the opposite sign. The $\bar{\Lambda}$ transverse polarization is compatible with zero within statistical uncertainty. Several models have been proposed to account for the transverse polarization of photoproduced Λ's (see *e.g.* [13] and references herein). It is hypothesized that this polarization is generated by soft processes. These data are expected to test the models.

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