Lambda polarization at HERMES

S. Belostotski[a], Yu. Naryshkin[a] and D. Veretennikov[a]

(on behalf of the HERMES collaboration)

[a]Petersburg Nuclear Physics Institute RAS Gatchina, Leningrad district 188300, Russia.

Transverse polarization of Λ and $\bar{\Lambda}$ hyperons produced inclusively in quasi-real photon-nucleon scattering has been studied for several nuclear targets in a wide range of atomic-mass numbers A. A strong A-dependence of the Λ polarization is observed.

1. INTRODUCTION

The transverse polarization of Λ, $\bar{\Lambda}$ and other hyperons has been studied in many inclusive high-energy scattering experiments, with a wide variety of hadron beams and atomic numbers of targets [1–4]. In inclusive photo- and electroproduction of Λs and $\bar{\Lambda}$s, previous data are not conclusive because of their limited statistical accuracy [5,6].

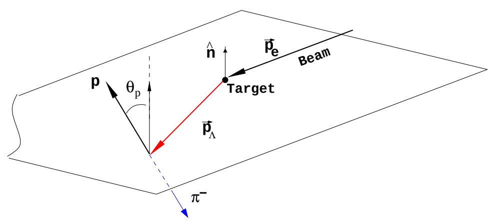

Figure 1. Schematic diagram of inclusive Λ production and decay. The angle θ_p of the decay proton with respect to the normal $\hat{n}$ to the scattering plane is defined in the Λ rest frame.

The Λ hyperon is a uniquely useful particle in spin physics: the parity-violating nature of its weak decay $\Lambda \to p\pi^-$ results in an angular distribution where the protons are preferentially emitted along the spin direction of their parent Λ. The angular distribution of the Λ decay products may thus be used to measure its polarization, providing a rare opportunity to explore spin degrees of freedom in the fragmentation process. In the rest frame of the Λ it has the form

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p}(1 + \alpha P_n^\Lambda \cdot cos\theta_p). \quad (1)$$

Here, θ_p is the angle between the proton momentum and the Λ-polarization direction in the Λ rest frame (Fig.1), P_n^Λ is the transverse polarization of the Λ, and $\alpha = 0.642 \pm 0.013$ is the analyzing power of the parity-violating weak decay. The symbols $dN/d\Omega_p$ and $dN_0/d\Omega_p$ denote the distributions for the decay of polarized and unpolarized Λ samples, respectively. Because of the parity-conserving nature of the strong interaction, any final-state hadron polarization in a reaction with unpolarized beam and target must point along a pseudo-vector direction. In the case of inclusive hyperon production with a positron beam, the only available direction of this type is the normal $\hat{n}$ to the production plane formed by the cross-product of the vectors along the laboratory-frame momenta of the beam ($\vec{p}_e$) and the Λ ($\vec{p}_\Lambda$):

$$\hat{n} = \frac{\vec{p}_e \times \vec{p}_\Lambda}{|\vec{p}_e \times \vec{p}_\Lambda|}. \quad (2)$$

2. Measurement of transverse Λ and $\bar{\Lambda}$ polarization

The experiment has been performed using the HERMES spectrometer described in detail in Ref. [7]. The 27.6 GeV positron beam of the HERA *e*-*p* accelerator facility passed through an open-ended tubular storage cell into which polarized or unpolarized gaseous target atoms (^{1}H, ^{2}H, ^{3}He, ^{4}He, and the heavier gases N, Ne, Kr and Xe in natural abundance) were continuously injected. The positron beam was always longitudinally polarized. For the longitudinally polarized ^{1}H and ^{2}H targets and the transversely polarized ^{1}H target the target-spin direction was reversed in time intervalls of 1-3 minutes and therefore the average target polarization was negligibly small. The scattered positron was not requested for this analysis and therefore the data sample is dominated by events from quasi-real photoproduction.

The Λ ($\bar{\Lambda}$) hyperons were identified in the analysis through their $p\pi^-$ ($\bar{p}\pi^+$) decay channel. The kinematics of the Λ ($\bar{\Lambda}$) decay products is such that the proton (antiproton) momentum is always much higher than that of the pion. Two spatial vertices were reconstructed for each event. First the secondary (decay) vertex was determined from the intersection (i.e., point of closest approach) of the proton (antiproton) and pion tracks. Then the intersection of the reconstructed hyperon track with the nominal beam axis was used to determine the primary (production) vertex. The distance between the two vertices was required to be larger than 15 cm. The invariant-mass distribution was fitted with a Gaussian plus a second order polynomial. Events within a window of $\pm 3.3\sigma$ around the mean value of the Gaussian fit were selected for further analysis. The extraction of the Λ polarization from the data was accomplished using the moment method which exploits the top/bottom symmetry of the detector [8,9]. In order to estimate the systematic uncertainty of the measurement a similar analysis was carried out for reconstructed h^+h^- hadron pairs, both with leading protons (like in Λ kinematics) and with leading anti-protons (like in $\bar{\Lambda}$ kinematics). Events within two mass windows above and below the Λ ($\bar{\Lambda}$) mass window ($1.093\ GeV < M_{h^+h^-} < 1.108\ GeV$, and $1.124\ GeV < M_{h^+h^-} < 1.139\ GeV$) were selected with the hadron point of closest approach required to be inside the target region. False polarization values of 0.012 ± 0.002 (0.018 ± 0.002) were found in the Λ-like ($\bar{\Lambda}$-like) case, and were

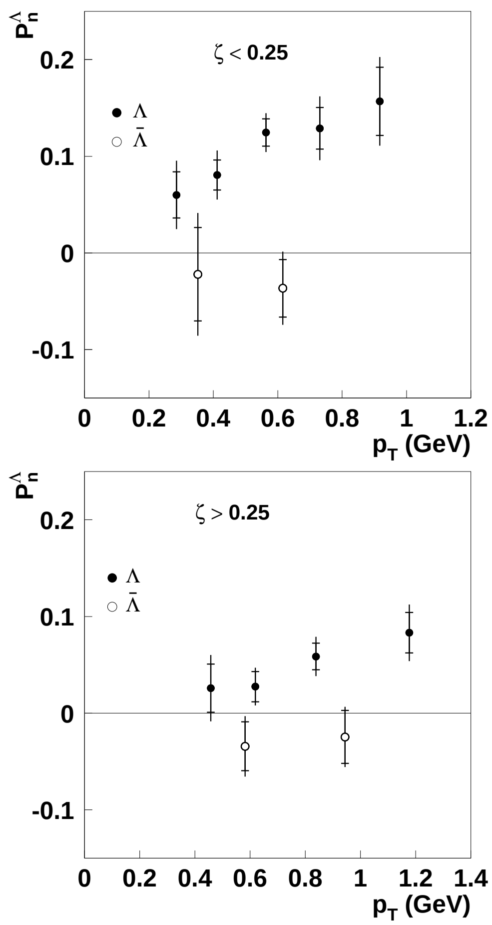

Figure 2. Transverse polarizations P_n^{Λ} and $P_n^{\bar{\Lambda}}$ as a function of p_T for hyperons from the regions $\zeta < 0.25$ (upper panel) and $\zeta > 0.25$ (lower panel). The inner error bars represent the statistical uncertainties; the outer error bars represent the statistical and systematic uncertainties added in quadrature.

used as estimates of the systematic uncertainty of the Λ ($\bar{\Lambda}$) polarization. As an additional check the decay $K_s^0 \rightarrow \pi^+\pi^-$ was studied. The false polarization of the K_s^0 sample was found to be 0.012 ± 0.004 (0.002 ± 0.004) in the Λ-like ($\bar{\Lambda}$-like) case.

3. Results

Averaged over the experimental kinematics, the net transverse Λ polarization is found to be significantly positive while the net $\bar{\Lambda}$ polarization is consistent with zero: $P_n^{\Lambda} = 0.078 \pm 0.006(stat) \pm 0.012(syst)$. and $P_n^{\bar{\Lambda}} = -0.025 \pm 0.015(stat) \pm 0.018(syst)$ [9].

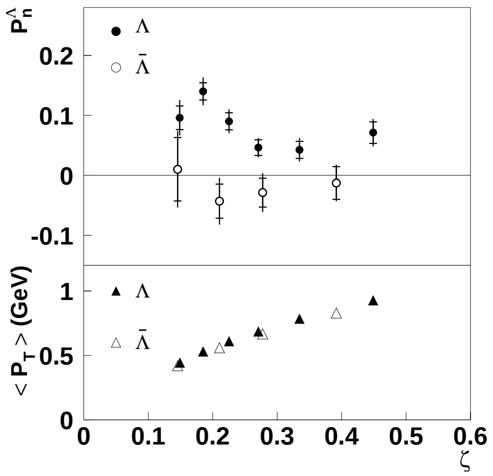

Figure 3. Transverse polarizations P_n^{Λ} and $P_n^{\bar{\Lambda}}$ (upper panel) and mean $\langle p_T \rangle$ (lower panel) as functions of ζ.

As no information on the virtual photon kinematics was available in this inclusive measurement, the kinematic dependence of the polarization could only be studied as a function of variables derived from the positron-nucleon system. The selected variables were p_T and $\zeta \equiv (E_\Lambda + p_{z\Lambda})/(E_e + p_e)$, where p_T ($p_{z\Lambda}$) is the transverse (longitudinal) component of the Λ momentum with respect to the beam direction, E_Λ is

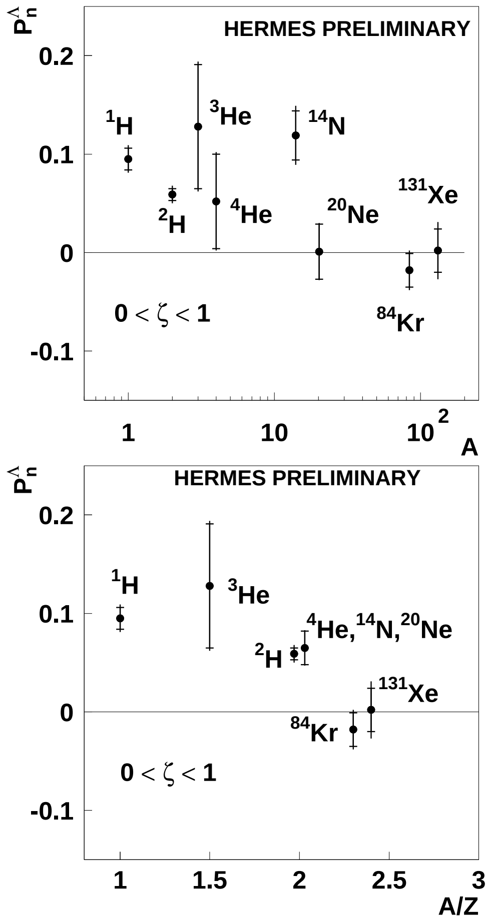

Figure 4. Transverse Λ polarization vs atomic number of nuclei (upper plot) and vs A/Z (bottom plot).

the Λ energy and E_e, p_e are the beam energy and momentum.

The variable ζ provides an approximate measure of whether a hyperon was produced in the forward or backward region in the center-of-mass frame of the γ^*-nucleon reaction. It was used instead of the Feynman variable $x_F = p_{\|}^{\Lambda}/p_{max}^{\Lambda}$ which is not available in this inclusive measurement. A Monte-Carlo simulation with the PYTHIA event generator shows a reasonable correlation between these two variables. In Fig. 2, the transverse Λ and $\bar{\Lambda}$ polarization P_n is shown versus p_T for the two kinematical regimes $\zeta < 0.25$ and $\zeta > 0.25$. In both cases, the Λ polarization rises linearly with p_T. Fig. 3 shows P_n versus ζ. The Λ polarization appears to increase in the low-ζ region while the $\bar{\Lambda}$ polarization shows no visible dependence on either ζ or p_T within available statistics.

In the years 1996-2000 data were collected mostly on ^{1}H, ^{2}H targets. Afterwards the increased statistics collected with the heavy target nuclei Kr and Xe allowed to study the dependence of P_n^{Λ} on the atomic mass A. Such a dependence has been investigated in many experiments with hadron beams and only small effects of the nuclear medium on the measured polarization have been observed [10–12]. The results obtained by HERMES are presented in Fig. 4. A clear indication of an A-dependence of P_n^{Λ} is observed: the polarization for light nuclei (^{1}H,^{2}H) is statistically significant positive, while it is compatible with zero within the statistical uncertainty for the heavier nuclei Kr and Xe. Note that the kinematical distributions for the various nuclei are very similar such that the average values of $\langle p_T \rangle$ and $\langle \zeta \rangle$ are practically the same. Therefore the observed effect cannot be explained by the kinematical dependencies of P_n^{Λ}.

A possible explanation of the observed A dependence might be related to the mechanism of Λ photoproduction in the nuclear medium. In the case of hadron-nucleus reactions, due to the strong absorbtion of the hadrons in the nuclear matter, the Λs are mostly produced on the outer nucleons and thus Λ production is a surface effect. Since surface nucleons are mostly loosely bound the polarization of the produced Λs is practically not affected by the nuclear medium. In the photoproduction case the photon may produce the Λ deep inside the nucleus and nuclear medium effects resulting in a decrease of the Λ polarization compared to the production from free nucleons might become more essential.

4. Acknowledgments

We gratefully acknowledge the DESY staff and the staffs of the collaborating institutions. This work was supported by the Russian Academy of Science and the Russian Federal Agency for Science and Innovations.

REFERENCES

1. K. Heller, in "Proceedings of the 12$^{\text{th}}$ International Symposium on High-Energy Spin Physics (SPIN 96)", edited by C.W. de Jager, T.J. Ketel, P.J. Mulders, J.E.J. Oberski, M. Oskam-Tamboezer (World Scientific, Singapore, 1997), p.23.
2. A.D. Panagiotou, Int. J. Mod. Phys. **A5**, 1197 (1990).
3. J. Lach, Nucl. Phys. (Proc. Suppl.) **50**, 216 (1996).
4. WA89 Collaboration, M.I. Adamovich , Eur. Phys. J. **C32**, 221 (2004).
5. SLAC-BC-072 Collaboration, K. Abe *et al.*, Phys. Rev. D **29**, 1877 (1984).
6. CERN-WA-004 Collaboration, D. Aston *al.*, Nucl. Phys. **B195**, 189 (1982).
7. HERMES Collaboration, K. Ackerstaff *et al.*, Nucl. Instrum. Methods **A417**, 230 (1998).
8. S. Belostotski, DESY-HERMES-06-57. Prepared for 58th Scottish Universities Summer School in Physics (SUSSP58): A NATO Advanced Study Institute and EU Hadron Physics 13 Summer Institute, St. Andrews, Scotland, 22-29 Aug 2004.
9. HERMES Collaboration, A. Airapetian *et al.*, Phys. Rev. D **76**, 092008 (2007).
10. K. Raychaudhuri *et al.*, Phys. Lett. **90B**, 319 (1980).
11. L. Pondrom, Phys. Rep. **122**, 57 (1985).
12. R. Bellwied (for the E896 Collaboration), Nucl. Phys. **A698**, 499 (2002).