Λ AND ¯Λ POLARIZATION AND SPIN TRANSFER IN PHOTOPRODUCTION AT HERMES

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Abstract

Transverse Λ and ¯Λ polarization and spin transfer from longitudinally polarized target have been measured in the HERMES experiment. The data were accumulated in the years 1996-2000 using the 27.6 GeV polarized HERA positron beam incident on hydrogen, deuterium and heavier gaseous targets. The average transverse polarizations were found to be \( P_\Lambda^T = 0.078 \pm 0.006_{\text{stat}} \pm 0.012_{\text{syst}} \) and \( P_{\bar{\Lambda}}^T = -0.025 \pm 0.015_{\text{stat}} \pm 0.018_{\text{syst}} \) for Λ and ¯Λ respectively. The longitudinal spin transfer coefficient is found to be \( K_{\Lambda LL}^T = 0.026 \pm 0.009_{\text{stat}} \pm 0.005_{\text{syst}} \) and \( K_{\bar{\Lambda} LL}^T = 0.002 \pm 0.022_{\text{stat}} \pm 0.008_{\text{syst}} \). The dependences of \( P_\Lambda^T \) and \( K_{\Lambda LL}^T \) on the transverse and longitudinal momenta of the Λ hyperon were also studied.

1 Introduction

The transverse polarization of Λ particles has been observed and investigated in many high-energy scattering experiments, with a wide variety of hadron beams and kinematic settings [1, 2]. It is almost always found to be negative. A rather consistent kinematic behavior of the polarization has also been observed: its magnitude increases almost linearly with the transverse momentum \( p_T \) of the Λ hyperon up to \( p_T \approx 1 \) GeV, where a plateau is reached. In lepto/photoproduction, the data existing to date are not conclusive because of lack of statistics [3, 4].

Spin-transfer coefficient from the transversely or longitudinally polarized proton to the Λ has been measured by E704 [5], STAR [6] and PS185 [7]. In E665 [5] and COMPASS [8] experiments longitudinal spin transfer has been studied using polarized muon beams. The HERMES [9] experiment has measured \( D_{\Lambda LL} \) using the polarized positron beam of the HERA accelerator [10, 11]. The data on spin transfer from the polarized target, reported here, have been obtained in photoproduction regime for the first time.

2 Transverse Λ and ¯Λ polarization

The final-state hadron polarization in a reaction with unpolarized beam and target must point along a pseudo-vector direction, because of the parity-conserving nature of the strong interaction. In the case of inclusive hyperon production, the only available direction of this type is the normal \( \vec{n} \) to the scattering plane formed by the cross-product of the vectors along the laboratory-frame momenta of the positron beam \( (\vec{p}_e) \) and the Λ \( (\vec{p}_\Lambda) \):

\[
\vec{n} = \frac{\vec{p}_e \times \vec{p}_\Lambda}{|\vec{p}_e \times \vec{p}_\Lambda|}
\]
Figure 1. Transverse polarization $P^\Lambda_n$ and $P^{\bar{\Lambda}}_n$ as function of $p_T$ for the region $\zeta < 0.25$ (left panel) and $\zeta > 0.25$ (right panel).

The extraction of the $\Lambda$ polarization $P_n$ from the data was accomplished using a moment method which exploits the top/bottom symmetry of the detector [12, 13].

In order to study possible effects of detector misalignment and inefficiency detailed Monte-Carlo simulations were performed. A contribution from the background under the $\Lambda$ invariant mass peak to the extracted polarizations was taken into account using a sideband subtraction method.

In order to estimate the systematic uncertainty of the measurement an identical analysis was carried out for reconstructed $h^+h^-$ hadron pairs, both with leading protons ($\Lambda$-like case) and with leading antiprotons ($\bar{\Lambda}$-like case).

Events within two mass windows above and below the $\Lambda$ ($\bar{\Lambda}$) mass peak were selected under condition that the hadrons point of closest approach is found inside the target region. False polarization values of $0.012 \pm 0.002$ and $0.018 \pm 0.002$ were found in the $\Lambda$-like and $\bar{\Lambda}$-like cases respectively. These values were used as estimates of the systematic error on the $\Lambda$ and $\bar{\Lambda}$ polarization. The decay $K_S^0 \rightarrow \pi^+\pi^-$ was studied as an additional check on a possible false polarization. The false polarization of the $K_S^0$ sample was found to be $0.012 \pm 0.004$.

The net $\Lambda$ polarization summing over events for all targets is found to be positive: $P^\Lambda_n = 0.078 \pm 0.006_{\text{stat}} \pm 0.012_{\text{syst}}$, while the net polarization is consistent with zero: $P^{\bar{\Lambda}}_n = -0.025 \pm 0.015_{\text{stat}} \pm 0.018_{\text{syst}}$. As information on the virtual photon kinematics was not available in this inclusive measurement, the kinematic dependence of the polarization could only be studied as a function of variables derived from the $eN$ system. The selected variables were $p_T$ and $\zeta \equiv (E_\Lambda + p_z^\Lambda)/(E_e + p_e)$, where $p_T$ is the transverse momentum with respect to the (lepton) beam, $E_\Lambda$ and $p_z^\Lambda$ are the energy and $z$-component of the
\( \Lambda \) momentum (where the z-axis is along the lepton beam direction), and \( E_e, p_e \) are the energy and momentum of the positron beam.

In Fig. 1, the transverse \( \Lambda \) and \( \bar{\Lambda} \) polarizations are shown versus \( p_T \) for two kinematical domains \( \zeta < 0.25 \) and \( \zeta > 0.25 \). The \( \Lambda \) polarization rises linearly with \( p_T \) with higher slope at \( \zeta < 0.25 \). The \( \Lambda \) and \( \bar{\Lambda} \) polarizations as functions of \( \zeta \) are shown in Fig. 2. The \( \Lambda \) polarization appears to increase in the low-\( \zeta \) region while the \( \bar{\Lambda} \) polarization shows no visible dependence on either \( \zeta \) or \( p_T \).

3 Spin transfer \( K_{LL} \)

In order to cancel the effect of the limited HERMES acceptance, the spin transfer to the \( \Lambda \) and \( \bar{\Lambda} \) has been determined by combining the two data sets measured with opposite target polarizations into one helicity-balanced data sample, in which the luminosity-weighted average target polarization for the selected data is \( \bar{P}_{\text{Targ}} \equiv \frac{1}{L} \int P_{\text{Targ}} dL = 0 \). Here \( L = \int dL \) is the integrated luminosity. A detailed derivation based on the method of maximum likelihood leads to the relation [14]. The analysis of false asymmetries for \( h^+h^- \) pairs and \( K_S^0 \) decay was performed similar to the transverse polarization case. For \( h^+h^- \) pairs false spin transfer of \(-0.0005 \pm 0.0028 \) and \(-0.002 \pm 0.003 \) were found in the \( \Lambda \)-like and \( \bar{\Lambda} \)-like cases, respectively. For \( K_S^0 \to \pi^+\pi^- \) it was obtained \( 0.006 \pm 0.008 \).

Averaged over the experimental kinematics, spin transfer to the \( \Lambda \) is found to be positive: \( K_{LL}^\Lambda = 0.026 \pm 0.009_{\text{stat}} \pm 0.005_{\text{syst}} \) and spin transfer to the \( \bar{\Lambda} \) is consistent with zero: \( K_{LL}^\bar{\Lambda} = 0.002 \pm 0.022_{\text{stat}} \pm 0.008_{\text{syst}} \).

For spin transfer study in addition to \( \zeta \) the Mandelstam variable \( t \equiv -(p_\Lambda - p_\mu)^2 \) was used. The variable \( \zeta \) or \( t \) provides an approximate measure of whether a hyperon was produced in the forward or backward region in the center-of-mass frame of the \( \gamma^*N \) reaction. The natural variable to use to separate these kinematic regimes would be \( x_F \equiv p_\Lambda^\Lambda/p_{\text{max}}^\Lambda \) evaluated in the \( \gamma^*N \) system, but this variable is not available since primary photon energy is not measured in the experiment. Nevertheless, a simulation of the reaction using the PYTHIA program reveals a reasonable correlation between \( \zeta \) and \( x_F \) variables.

![Figure 3. Spin transfer coefficient \( K_{LL} \) for \( \Lambda \) and \( \bar{\Lambda} \) versus \( \sqrt{t} \) (left panel) and \( p_T \) (right panel).](image-url)
In particular, all events at $\zeta \geq 0.25(\sqrt{t} > 3.31 \text{ GeV})$ are produced in the kinematic region $x_F > 0$, while for $\zeta < 0.25(\sqrt{t} < 3.31 \text{ GeV})$ there is a mixture of events originating from the kinematic regions $x_F > 0$ and $x_F < 0$.

Fig. 3 shows $p_T$ and $\sqrt{t}$ dependences of spin transfer coefficient $K_{LL}$. The spin transfer for $\Lambda$ are $p_T$ independent and increasing for $\sqrt{t} < 3.31 \text{ GeV}$, while for $\sqrt{t} > 3.31 \text{ GeV}$ it compatible with zero. In $\bar{\Lambda}$ case both results are compatible with zero. In Fig. 4 the HERMES data for spin transfer as function of $\sqrt{t}$ are presented together with data obtained by the E704 collaboration 200 GeV transversally polarized proton beam and the STAR collaboration with a longitudinally polarized proton beam and center of mass energy $\sqrt{s} \approx 200 \text{ GeV}$. As seen from Fig. 4 the E704 result confirms a trend to increase spin transfer in the region $\sqrt{t} < 3.31 \text{ GeV}$. 

![Figure 4. Compilation the world data of spin transfer.](image)

References


