Spin transfer \( K_{LL} \) from the longitudinally polarized target to the \( \Lambda \) and \( \bar{\Lambda} \) hyperons produced inclusively in quasi-photoproduction regime has been measured for the first time. Dependence of the spin-transfer coefficient on kinematical variables has been investigated. \( K_{LL} \) shows a trend towards higher positive values at small longitudinal \( \Lambda \) momenta \( p_z \) (negative \( x_F \)). No dependence on transverse \( \Lambda \) momentum is found in the investigated \( p_t \) range. The \( K_{LL} \) is shown not to be sensitive to the beam polarization. Averaged over \( \Lambda \) kinematics, spin transfer \( K_{LL} \) is found to be 0.024 ± 0.008_{stat} ± 0.003_{syst}. For the \( \bar{\Lambda} \) hyperon, averaged spin transfer coefficient is found to be compatible with zero: 0.002 ± 0.019_{stat} ± 0.008_{syst}. The systematic uncertainty has been investigated using hadron pairs and \( K_s \) meson data samples.

1 Introduction

The \( \Lambda \) hyperon is a uniquely useful particle in spin physics: the parity-violating nature of its weak decay \( \Lambda \rightarrow p\pi^- \) results in an angular distribution where the protons are preferentially emitted along the spin direction of their parent \( \Lambda \). The angular distribution of the \( \Lambda \) 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 \( \Lambda \) it has the form

\[
\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p} (1 + \alpha P_L \cos \theta_p). \tag{1}
\]

Here, \( \theta_p \) is the angle between proton momentum and \( \Lambda \) polarization direction in the \( \Lambda \) rest frame (Fig.1), \( P_L \) is the polarization of the \( \Lambda \), 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 \( \Lambda \) samples, respectively. In the case of polarized target \( \Lambda \) polarization may depend on the target polarization and spin transfer coefficient \( K_{LL'} \) is defined as the ratio of \( \Lambda \) polarization projection on an axis \( L' \) to the target polarization \( P_{\text{Target}} \):

\[
P_L = K_{LL'} P_{\text{Target}}. \tag{2}
\]

Here \( L \) is the direction of the primary (target) polarization, \( L' \) is assumed to be along the direction of the produced \( \Lambda \) momentum.
In proton-proton collision, spin-transfer coefficient from the transversely or longitudinally polarized proton to the Λ has been measured by E704 [2], STAR [3] and PS185 [7].

Longitudinal spin transfer has also been studied in deep-inelastic scattering using lepton beams. In the NOMAD experiment [8], production of Λ hyperons was studied in charged-current neutrino interactions. In contrast to the LEP experiments the NOMAD data are concentrated in the kinematical domain corresponding to the target fragmentation region.

It should be noted that, in distinction from meson production case, baryon fragmentation in DIS is strongly affected by the target remnant-diquark contribution, which dominates at negative $x_F$. In the E665 experiment [2] and COMPASS [6] longitudinal spin transfer has been studied using polarized muon beams. The HERMES experiment has measured $D_{LL'}$ using the polarized positron beam of the HERA accelerator [4, 5]. In all these charge-lepton experiments, the $D_{LL'}$ was investigated predominantly at positive values of $x_F$, and the targets were unpolarized. In all these cases $D_{LL'}$ denotes the spin transfer coefficient from the longitudinally polarized beam to the Λ. The spin transfer from the polarized target, neither in DIS nor in photo-production, has never been measured till now.

2 Mechanism of Λ production in photo-production case

The measured spin transfer coefficient is sensitive to the nucleon target spin structure. The Λ hyperon may be produced directly from the string fragmentation or via decay of a heavier (than Λ) hyperon $Y$. These two typical hyperon production mechanisms suggested by the PYTHIA Monte Carlo are shown in Fig.2. It is well-known that the real, or quasi-real, photon has a hadronic structure and may turn into a $q\bar{q}$ system, as it is shown in Fig.2.

A current quark $q$ from the photon dissociation interacts with a diquark $uu, ud, dd$ in a singlet or triplet spin state pre-existing in the target nucleon, and a highly exited, baryon like (quark-diquark), system (string) is formed. Another string is formed by the current antiquark $\bar{q}$ emitted from the photon and a quark $q$ emitted from the target. This meson like string does not contribute to the hyperon production. At the HERMES kinematics, almost all $Λ$s or heavier hyperons are produced in the result of hadronization of the quark-diquark string. Polarization state of the target diquark is thus defines the produced Λ polarization and $K_{LL'}$. 

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3 Extraction of $K_{LL'}$ and results

Extraction of $K_{LL'}$ has been performed using moment method similar to that for $D_{LL'}$, as described in [9]. 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 $P_{\text{Targ}} = \frac{1}{L} \int P_{\text{Targ}} dL = 0$. Here $L = \int dL$ is the integrated luminosity. The details may be found in [9].

Averaged over $\Lambda$ 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: $K_{LL}^{\bar{\Lambda}} = 0.002 \pm 0.022_{\text{stat}} \pm 0.008_{\text{syst}}$.

In order to estimate the systematic uncertainty of the measurement an identical analysis was carried out for $h^+h^-$ hadron pairs with invariant masses outside of the $\Lambda$ mass peak, both with leading protons ($\Lambda$-like case) and with leading antiprotons ($\bar{\Lambda}$-like case). In addition, the $K_S^0 \rightarrow \pi^+\pi^-$ decay was studied as a check of possible false polarization. For $h^+h^-$ pairs false spin transfer of $-0.0065 \pm 0.0028$ and $-0.002 \pm 0.003$ are found in the $\Lambda$-like and $\bar{\Lambda}$-like cases, respectively. For $K^0 \rightarrow \pi^+\pi^-$ it is obtained $0.006 \pm 0.008$.

The spin transfer is measured within photo-production forward peak of the scattered positrons with $Q^2 \approx 0$. The scattered positrons are not detected and the photon energy is not experimentally defined. As calculated using PYTHIA, the average photon energy is 14.2 GeV. Since the photon energy is unknown the $x_F$ variable is not defined. It should be noted that in the case of spin transfer from the target, Mandelstam variable $t \equiv -(p_\Lambda - p_p)^2$ is also very informative. There is a correlation between $x_F$ and $\sqrt{t}$: all events at $\sqrt{t} > 3.31$ GeV are produced in the kinematical region $x_F > 0$, while for $\sqrt{t} < 3.31$ GeV there is a mixture of events originating from the kinematical regions $x_F > 0$ and $x_F < 0$.

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Fig. 3 shows dependencies of the $K_{LL'}$ on $\sqrt{t}$ variable and transverse $\Lambda$ momentum $p_T$.

The spin transfer for $\Lambda$ are $p_T$ independent and increasing for $\sqrt{t} < 3.31$ GeV, while for $\sqrt{t} > 3.31$ 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 using 200 GeV transversely polarized proton beam and the STAR collaboration with a longitudinally polarized proton beam and center of mass energy $\sqrt{s} \approx 200$ GeV. As seen from Fig. 4 the HERMES result confirms a trend to increase spin transfer at small $\sqrt{t}$ in the region $\sqrt{t} < 3.31$ GeV.

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[1] Slides: http://indico.cern.ch/materialDisplay.py?contribId=262&sessionId=22&materialId=slides&confId=24657

Figure 4: Compilation the world data of spin transfer.