HERMES measurements of Λ polarization

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Abstract. The HERMES experiment at DESY has measured the transfer of polarization from longitudinally polarized 27.6 GeV positrons to Λ hyperons produced in semi-inclusive deep-inelastic scattering from unpolarized gas targets internal to the electron/positron ring of the HERA collider. The longitudinal spin transfer coefficient is found to be $D_{LL'}^{\Lambda} = 0.11 \pm 0.10$ (stat) ± 0.03 (syst) at an average fractional energy carried by the Λ hyperon $\langle z \rangle = 0.45$

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The HERMES measurements of Λ polarization address several different aspects:

- the longitudinal spin transfer to the Λ hyperon in semi-inclusive deep-inelastic positron nucleon scattering with a longitudinally polarized lepton beam, which contains information about both the Λ spin structure and the spin transfer in the fragmentation of the struck quark and/or the target remnant in the fragmentation process,
- the transverse Λ polarization in quasi-real photoproduction from longitudinally polarized or unpolarized targets,
- the transverse polarization in quasi-real photoproduction from a transversely polarized hydrogen target, which might contain some information about the quark transversity distribution in the nucleon.

In this contribution I will restrict the discussion to the recently published results for longitudinal spin transfer from data taken in the years 1996-1997 and 1999-2000 [1].

The Λ hyperon is an especially interesting particle in spin physics. It is the lightest strange baryon ($M_{\Lambda} = 1115.684$ MeV) and thus can only decay weakly ($\tau = 2.632 \times 10^{-10}$ s), the dominant decay channels being $\Lambda \rightarrow p\pi^{-}$ (63.9%) and $\Lambda \rightarrow n\pi^0$ (35.8%). In the HERMES experiment Λ particles are only detected via the charged decay channel. The weak decay is parity violating, the proton is being emitted preferentially into the direction of the Λ spin. The angular distribution of the decay nucleon in the Λ rest frame has the form

$$\frac{dN}{d\Omega_p} \propto 1 + \alpha \vec{P}^{\Lambda} \cdot \hat{k}^p. \quad (1)$$

Here, $\hat{k}^p$ is the unit vector along the proton momentum in the Λ rest frame, $\vec{P}^{\Lambda}$ is the polarisation of the Λ and $\alpha = 0.642 \pm 0.013$ is the asymmetry parameter of the weak decay. Information about the Λ polarisation can therefore be directly obtained from the angular distribution of the decay particles.

Longitudinal Λ polarization can, e.g., be generated by deep-inelastic scattering of longitudinally polarized charged leptons from an unpolarized target. By angular momentum conservation the outgoing quark has the same helicity as the incident lepton and the exchanged virtual photon. It will acquire a polarization $P_q = P_b D(y)$ along its momentum, where P_b is the beam polarization and $D(y)$ is the depolarization factor taking into account the loss of polarization of the virtual photon as compared to that of the incident lepton. Here $y = v/E$ is the ratio of the energies of the virtual photon and the incident lepton. The component of the polarization transferred along the direction L' from the virtual photon to the produced Λ is given by

$$P_{L'}^\Lambda = P_b D(y) D_{LL'}^\Lambda, \quad (2)$$

where L is the primary quantization axis, directed along the virtual photon momentum. The spin transfer coefficient $D_{LL'}^\Lambda$ in Eq. 2 describes the probability that the polarization of the struck quark is transferred to the Λ hyperon along the secondary quantization axis L' . It depends on the variables x , z and Q^2 , where $-Q^2$ is the squared momentum transfer, x is the Bjorken variable, and $z = E_\Lambda/v$. Neglecting the Q^2 dependence and integrating over x one obtains to a good approximation:

$$D_{LL'}^\Lambda(z) \simeq \sum_f D_{LL',f}^\Lambda(z) \int \frac{e_f^2 q_f(x) D_{1,f}^\Lambda(z)}{\sum_{f'} e_{f'}^2 q_{f'}(x) D_{1,f'}^\Lambda(z)} dx. \quad (3)$$

Here the quantity $D_{LL',f}^\Lambda(z)$ denotes the *partial* spin transfer from a struck quark of flavor f and charge e_f to a Λ hyperon:

$$D_{LL',f}^\Lambda(z) = \frac{D_{1,f+}^{\Lambda+}(z) - D_{1,f+}^{\Lambda-}(z)}{D_{1,f+}^{\Lambda+}(z) + D_{1,f+}^{\Lambda-}(z)}, \quad (4)$$

where the symbols $D_{1,f+}^{\Lambda+}$ or $D_{1,f+}^{\Lambda-}$ are used to denote the fragmentation functions for a quark of helicity $+$ to produce a Λ of helicity $+$ or $-$, respectively. It is assumed that $D_{1,f+}^{\Lambda+} = D_{1,f-}^{\Lambda-}$ and $D_{1,f+}^{\Lambda-} = D_{1,f-}^{\Lambda+}$. Since the strength of the electromagnetic interaction between a lepton and a quark is proportional to the square of the quark charge e_f , the Λ production in the current fragmentation region is dominated by scattering from u quarks.

The Λ electroproduction data presented here were accumulated by the HERMES experiment in the years 1996-1997 and 1999-2000 with a 27.6 GeV positron beam. The HERMES detector is described in detail in Ref. [2]. Most of the data were collected from hydrogen and deuterium, but ^3He , ^4He , ^{14}N , ^{20}Ne and ^{84}Kr targets were also included, and the data from all targets were combined. Λ hyperons were identified in the analysis by their $p\pi^-$ channel. At least three reconstructed tracks were required: a positron track in coincidence with two hadron candidates of opposite charge. The requirements $Q^2 > 0.8 \text{ GeV}^2$ and $W > 2 \text{ GeV}$ (W is the invariant mass of the photon-nucleon system) were imposed on the positron kinematics to ensure that the events originated from the deep-inelastic scattering domain. The primary vertex between the scattered positron and the beam was required to be within the total length of the target cell. For the data from 1996-97 hadron pairs with leading pions were suppressed with the

FIGURE 1. Dependence of the longitudinal spin-transfer coefficient D_{LL}^{Λ} on z , for $x_F > 0$ (left panel). The curves represent the phenomenological model calculations of Refs. [3, 4], as described in the text. Error bars are statistical only. Dependence of the longitudinal spin-transfer coefficient D_{LL}^{Λ} on x_F (right panel). The HERMES measurements are represented by the solid circles, while the open symbols represent data from NOMAD [5] (squares) and E665 [6] (circles). Error bars are statistical only. For the neutrino-induced NOMAD data the quantity plotted is $-P_{\Lambda}^{\nu}$.

help of the threshold Cherenkov counter, and the positron interaction vertex and the Λ decay vertex were required to be separated by more than 10 cm to eliminate background hadrons originating from the primary vertex. For both vertices the distance of closest approach between the positron track and the beam and also between the proton and pion tracks was required to be less than 1.5 cm. For the data after 1998 protons with momenta larger than 4 GeV could be distinguished from other hadrons with the help of the Ring Imaging Cherenkov counter, and no vertex separation cut was necessary. All tracks were also required to satisfy a series of fiducial volume cuts designed to avoid the inactive edges of the detector. The Λ hyperon was identified by reconstructing the invariant mass of the $p\pi^-$ system under the assumption that the high-momentum track is a proton and the low-momentum track is a pion. Without background suppression, 8,200 Λ events were extracted from all unpolarized data in the current fragmentation region, ($x_F > 0$). The Feynman-variable x_F is defined as $x_F \equiv p_{\parallel}/p_{\parallel max}$, $p_{\parallel}$ being the projection of the Λ momentum on the virtual-photon direction and $p_{\parallel max}$ being its maximum possible value. The final data sample, with all requirements imposed, contained 7,300 Λ events. These numbers were obtained by integrating the Λ peak between the boundaries $\pm 3.3 \sigma$ around the central value.

The acceptance of the HERMES spectrometer for the reconstruction of the Λ hyperons is limited and strongly depends on the angle between the proton momentum and the Λ spin quantisation axis. The HERA lepton beam is always longitudinally polarised at the location of the HERMES experiment and data have been taken with both beam he-

licities. To minimise acceptance effects, the spin transfer to the Λ has been determined by combining the two data sets measured with opposite helicity in such a way that the luminosity-weighted average beam polarisation for the selected data sample is zero.

The measured value for $D_{LL'}^\Lambda$ shows no significant dependence on the choice of the longitudinal spin-quantization axis, like the directions of the virtual photon, of the produced Λ , and of the lepton beam. The spin transfer to the Λ along its momentum direction, averaged over the kinematic region with $Q^2 > 0.8 \text{ GeV}^2$, $y < 0.85$, and $x_F > 0$ extracted from these helicity-balanced data has the value:

$$D_{LL'}^\Lambda = 0.11 \pm 0.10 \text{ (stat)} \pm 0.03 \text{ (syst)}. \quad (5)$$

The average fractional energy of the Λ hyperons in this sample is $\langle z \rangle = 0.45$, the average momentum transfer $\langle Q^2 \rangle = 2.4 \text{ GeV}^2$, and the average Bjorken variable $\langle x \rangle = 0.088$.

The dependence of $D_{LL'}^\Lambda$ on the energy fraction z is presented in the left panel of Fig. 1. Superimposed on the data are the phenomenological model calculations of Refs. [3, 4]. In these models the Λ hyperon is assumed to be produced directly from the polarized struck quark, i.e., the contribution from the heavier hyperon decays is not included in these models.

In the right panel of Fig. 1 the HERMES data are shown as a function of x_F together with data obtained by the NOMAD experiment [5] at CERN with a 43 GeV ν_μ -beam and by the Fermilab E665 experiment [6] with a 470 GeV polarized muon beam. The NOMAD and HERMES results are compatible in the kinematic region of overlap.

The measured longitudinal spin transfer is rather small and compatible with zero. When trying to interpret this result, one should however keep in mind that according to estimates in the framework of the Lund-based Monte Carlo model, only about 40 % of the Λ s are produced directly from string fragmentation in the range $z < 0.7$ and the fraction of Λ s produced via hyperon decays is large. Furthermore at the moderate energy of the HERMES experiment the distinction between the current and target fragmentation region is not very sharp and there might still be a substantial contribution from target fragments in the data sample.

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