Transverse and Longitudinal Lambda Polarization in Lepton Scattering by Unpolarized Nucleons at HERMES

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Transverse and longitudinal polarization of Λ hyperons has been studied. The transference of polarization from high-energy positron to Λ^0 hyperon has been measured. The longitudinal spin transverse coefficient is found to be $D_{LL'}^\Lambda = 0.11 \pm 0.10(stat) \pm 0.03(sys)$. The transverse polarization of Λ and $\bar{\Lambda}$ hyperons has been measured in inclusive quasireal photoproduction process for various target nuclei. The polarization observed is positive for light target nuclei and compatible with zero for heavy target nuclei.

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1. Introduction

A study of Λ polarization, i.e. the polarization of the lightest hyperon with strange quark content has an important role. Due to its parity violating weak decay it has a self-analyzing power, since the decay protons prefer to follow the spin direction of a parent Λ . The measurements of the longitudinal spin transfer from longitudinally polarized beam leptons to the Λ hyperon are sensitive to two unknowns: the spin structure of the Λ and the spin-dependent dynamics of the fragmentation process in deep-inelastic scattering. More precisely, when a longitudinally-polarized lepton beam is scattered at high energies from a nucleon target, angular momentum conservation dictates that quarks of a particular spin orientation participate predominantly in the interaction. The outgoing struck quark is thus polarized, and hyperons produced from its fragmentation may “remember” its spin orientation and carry a longitudinal polarization themselves. Formally such a correlation may be expressed in terms of a spin-dependent fragmentation function $G_{1f}^\Lambda(z)$ Ref. 1. This

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fragmentation function has often appeared in the literature with different symbols, most notably as $\Delta D^\Lambda(z)$ Ref. 2. or as $\Delta \hat{q}_\Lambda(z)$ Ref. 3.

The transverse polarization of Λ hyperons produced in inclusive unpolarized hadron-nucleon, hadron-nucleus, and nucleus-nucleus collisions at high energies is a well-established phenomenon. A substantial transverse Λ polarization was first observed in proton-beryllium collisions at a proton-beam energy of 300 GeV Ref. 4. The polarization $|P_n^\Lambda|$ is essentially independent of the beam momentum; its magnitude rises with p_T , the momentum component transverse to the beam direction, for p_T values up to about 1 GeV, where it reaches values of up to $|P_n^\Lambda| \approx 0.4$. At fixed p_T , $|P_n^\Lambda|$ rises with the Feynman variable $x_F = p_L^*/p_{L,max}^*$ where p_L^* is the component of the Λ momentum in the beam direction measured in the beam-target center-of-mass system and $p_{L,max}^*$ is its maximal possible value. At higher transverse momenta, P_n^Λ measured in such experiments was found to be similar to that observed in $p-p$ or $p-nucleus$ scattering Ref. 5. While the transverse polarization of hyperons was studied in detail with hadron beams, very little experimental information about P_n^Λ is available from photo or electroproduction. The x_F dependence observed in early measurements Ref. 6, Ref. 7 was very similar to the one seen in $\pi^- - p$ reactions, but the data were of low statistical accuracy.

2. Experiment

The Λ hyperons were accumulated by the HERMES spectrometer at DESY. In this measurements, the 27.6 GeV longitudinally polarized and unpolarized positron beams are passed through an open-ended tubular storage cell into which polarized or unpolarized target atoms in undiluted gaseous form are continuously injected. The HERMES detector is described in detail in Ref. 8. The scattered positrons and

Fig. 1. The HERMES spectrometer.

the Λ decay products were detected by the HERMES spectrometer in the polar angle range from 40 to 220 $mrad$. The Λ^0 hyperons were identified in the analysis through their $p\pi^-$ decay channel. Events were selected by requiring the presence of at least three reconstructed tracks: a positron track and two hadron candidates of opposite charge or without requiring a positron track for quasisreal photoproduction. Track reconstruction was performed with a track fitting algorithm based on the Kalman filter with substantially improved vertex determination and momentum resolution. This algorithm allows for the best possible estimates on track parameters at the beam crossing and/or at the (possible) vertices with other tracks of a given event. The resulting invariant mass distributions for the combined hydrogen and deuterium (H+D) and the combined krypton and xenon (Kr+Xe) data are shown in Fig. 2. They were fitted by a Gaussian plus a second-order polynomial line shape. The position of the Λ peak agrees within ~ 0.10 MeV with the world average of (1115.684 ± 0.006) MeV Ref. 9. Events within an invariant mass window of $\pm 3.3\sigma$ around the mean value of the Gaussian fit were selected. The fraction $\eta = N^\Lambda / (N^\Lambda + N^{bgr})$ of Λ events in the selected mass window is about $\sim 96\%$ for all targets.

Fig. 2. Invariant-mass distributions for Λ events obtained with hydrogen and deuterium targets (top panel) and with krypton and xenon targets (bottom panel). The vertical lines indicate the invariant-mass interval used for the determination of the Λ polarization. The quantities given in the legends are the number of analyzed Λ events, N^Λ , in the selected invariant-mass window after subtraction of background events, the reconstructed Λ mass M^Λ , the resolution of the invariant-mass distribution, and the fraction η of Λ events in this mass window.

Fig. 3. Dependence of the longitudinal spin-transfer coefficient $D_{LL'}^{\Lambda}$ on z , for $x_F > 0$. The curves represent the phenomenological model calculations. Error bars are statistical only.

3. Results

The polarization transfer $D_{LL'}^{\Lambda}$ from a polarized beam positron to a semi-inclusively produced Λ^0 hyperon has been measured in deep-inelastic positron scattering off various unpolarized targets Ref. 10. The spin transfer for the background $D_{LL',bgr}^{\Lambda}$ was determined from the events above and below the peak outside of the 3.3σ invariant mass window. In order to obtain the final result for the net Λ^0 events, the spin transfer within the Λ^0 peak was corrected for this background contribution in each kinematic bin as

$$D_{LL'}^{\Lambda} = \frac{\hat{D}_{LL'}^{\Lambda} - \epsilon D_{LL',bgr}^{\Lambda}}{1 - \epsilon}. \quad (1)$$

where $\epsilon = N_{bgr}/(N_{\Lambda} + N_{bgr})$. The overall systematic uncertainty of the measured spin transfer is estimated to be ± 0.03 . The result for the spin transfer coefficient $D_{LL'}^{\Lambda}$ is presented in Fig. 3.

The transverse Λ polarization P_n^{Λ} was measured in inclusive quasireal photoproduction on various nuclei Ref. 11. The systematic uncertainty of P_n^{Λ} has been estimated to be ± 0.02 . This value was derived from detailed Monte Carlo studies that took into account possible detector misalignments, and also from the false polarization measured for $K_s^0 \rightarrow \pi^+\pi^-$ events that provide an event topology with two separated vertices similar to Λ decays. The experimental results for the extracted transverse polarization P_n^{Λ} as a function of the atomic-mass number A are shown in Fig. 4.

Fig. 4. Dependence of the transverse polarization P_n^Λ on the atomic-mass number A of the target nuclei. The inner error bars represent the statistical uncertainties; the full error bars represent the total uncertainties, evaluated as the sum in quadrature of statistical and systematic uncertainties.

Fig. 5. Dependence of the transverse polarization P_n^Λ on the transverse Λ momentum p_T . Closed circles (squares) represent the combined hydrogen and deuterium data for the region $\zeta < 0.2$ ($\zeta > 0.3$). The combined krypton and xenon data (open triangles) are shown for the full range. The error bars represent the statistical uncertainty. The values of ζ for each p_T bin are shown in the lower panel.

In Fig. 5 the transverse polarization is shown as a function of p_T .

The H+D data are presented for two intervals in the variable ζ ($\zeta = (E^\Lambda + p_L)/(E+k) \approx E^\Lambda/E$, here E^Λ and E are energies of the produced Λ and beam lepton respectively). The p_T dependence in these two intervals is rather different. In the

region $\zeta < 0.2$, where the produced hyperons mainly stem from the backward region, the polarization increases linearly with p_T up to a value of ~ 0.12 at $p_T \simeq 0.75$ GeV (closed circles), while in the region $\zeta > 0.3$ (closed squares) the polarization is substantially smaller with very little dependence on p_T .

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