TRANSVERSE POLARIZATION OF Λ AND $\bar{\Lambda}$ PRODUCED INCLUSIVELY IN eN SCATTERING AT HERMES *

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The transverse polarization of inclusively produced Λ and $\bar{\Lambda}$ hyperons has been studied at HERMES using the 27.6 GeV positron beam of HERA and an internal gas target. From the data taken in the years 1996–2000, 386,000 Λ and 72,000 $\bar{\Lambda}$ events have been reconstructed, allowing the measurement of the Λ and $\bar{\Lambda}$ polarizations with high statistical accuracy. Averaged over the full kinematic range of the data, the transverse polarizations were measured to be $P_n^{\Lambda} = 5.4 \pm 0.5\,(\text{stat}) \pm 1.5\,(\text{syst})\,\%$ and $P_n^{\bar{\Lambda}} = -4.0 \pm 1.3\,(\text{stat}) \pm 1.2\,(\text{syst})\,\%$. The dependence of the polarization on several transverse momentum p_{T} and on the hyperons' light cone momentum fraction ζ has been investigated.

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1. Introduction

It was generally believed at the beginning of the Fermilab hyperon program [1] that spin effects in hadronic reactions should be of little importance at high energies. The hard scattering processes, when calculated in perturbative QCD, do not give rise to large polarization effects. It was therefore surprising that a significant polarization was measured for high energy Λ's produced by 300 and 400 GeV unpolarized protons scattered from an unpolarized Beryllium target [2]. The Λ polarization was transverse and negative, directed opposite to the normal $\hat{n} = \hat{p}_{\text{beam}} \times \hat{p}_{\Lambda}$ to the production plane. The absolute value of the polarization increased linearly with the transverse momentum p_{T} up to $p_{\text{T}} \simeq 1$ GeV/c.

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This transverse "self-polarization" of Λ's and other hyperons has now been investigated in many scattering experiments with a wide variety of hadronic beams [3]. The polarization of Λ's is almost always found to be negative, as in the original pN experiment. One notable exception to this rule is the positive polarization measured in the $K^- p$ interaction, where the beam particles contain valence s quarks. The polarization of $\bar{\Lambda}$ is consistenly found to be zero (provided the beam does not contain any valence anti-quarks). As yet no model is able to explain the full body of data that has been collected.

While hyperon polarization has been studied extensively in hadron–hadron reactions, very little experimental information exists about the effect in photo- and electro-production. Transverse polarization in the inclusive photoproduction of neutral strange particles was investigated 20 years ago at CERN [4] and SLAC [5]. However, the statistical quality of the published data is rather poor. The CERN measurements, for incident tagged photon energies between 25 and 70 GeV, resulted in an average transverse polarization of $6 \pm 4\%$ for Λ and $5 \pm 10\%$ for $\bar{\Lambda}$. At SLAC the overall polarizations were observed to be $9 \pm 7\%$ for Λ and -4 ± 4 % for $\bar{\Lambda}$, produced using a 20 GeV photon beam.

The HERMES experiment offers a good opportunity to measure the polarization of Λ and $\bar{\Lambda}$ hyperons produced inclusively and semi-inclusively, using the 27.6 GeV positron beam of HERA collider and an internal gas target with a storage cell. The analysis presented here is of transverse polarization in the inclusive reaction $\gamma^* N \to \Lambda^\uparrow X$, where the yields are much higher than in the semi-inclusive case. The inclusive data come mostly from the photoproduction peak in the cross-section at $Q^2 \approx 0$. In this regime the beam positrons are scattered at very small angles and are not detected by the HERMES spectrometer.

This analysis combines the data collected at HERMES in the years 1996-2000. The sample includes data taken with both longitudinally polarized and unpolarized targets (the latter being of much higher density than the former), while the positron beam was always longitudinally polarized. The target species included hydrogen, deuterium and a variety of heavier gases. After background suppression cuts, the final data sample contained 386,000 Λ and 72,000 $\bar{\Lambda}$ hyperons.

2. Results

Averaged over the full kinematic range of the data, the transverse polarization of the Λ and $\bar{\Lambda}$ hyperons was measured to be $P_n^\Lambda = 5.4 \pm 0.5\,(\text{stat}) \pm 1.5\,(\text{syst})\%$ and $P_n^{\bar{\Lambda}} = -4.0 \pm 1.3\,(\text{stat}) \pm 1.2\,(\text{syst})\%$. The systematic uncertainty was estimated by measurements of the false "transverse polarization" of K^0_{s} mesons, and of hadron-hadron pairs which did not originate from

$\Lambda(\bar{\Lambda})$ decay. The average hyperon kinematics are $\langle p_{\mathrm{T}} \rangle = 0.56$ GeV/c and $\langle E_\Lambda \rangle = 6.3$ GeV, where p_{T} is the transverse momentum defined with respect to the eN system and E_Λ is the energy of the Λ. To estimate the average virtual-photon kinematics, a Monte Carlo simulation of the process was performed, using the PYTHIA 6.2 event generator and a GEANT model of the detector. An average virtual photon energy of $\langle \nu \rangle = 16$ GeV was obtained.

The good statistical quality of the full data set allows the dependence of the Λ and $\bar{\Lambda}$ polarization on certain kinematic variables to be studied. Unfortunately, in the inclusive case information on the virtual photon kinematics is not available; consequently, only kinematic variables related to the eN system may be studied.

Quark recombination models [6–8] describe inclusive hadron polarization in the infinite momentum frame of the projectile. To facilitate comparison with these models, the HERMES measurements have been studied as a function of $\zeta \equiv (E_\Lambda + p_{z\Lambda})/(E_{\mathrm{B}} + p_{\mathrm{B}})$, which represents the light cone momentum fraction of the beam positron carried by the outgoing Λ or $\bar{\Lambda}$. Here $p_{z\Lambda}$ is the z component of the Λ momentum, and E_{B}, p_{B} are the energy and momentum of the beam. The Λ and $\bar{\Lambda}$ polarizations are shown as a function of the ζ variable in Fig. 1(a). The Λ polarization is around 8% in the region $\zeta < 0.2$, and around 3.5% at high ζ. The limited statistics of the $\bar{\Lambda}$ measurement make it difficult to come to a strong conclusion as to its kinematic behavior, but it may be noted that the average negative value for $P_n^{\bar{\Lambda}}$ originates from the data points at low ζ.

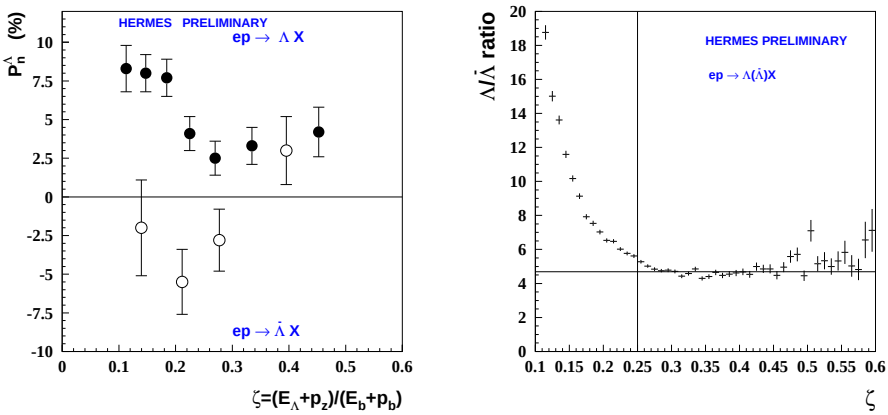

Fig. 1. (a) Transverse polarization of Λ and $\bar{\Lambda}$ hyperons as a function of the light cone momentum fraction $\zeta = (E_\Lambda + p_{z\Lambda})/(E_{\mathrm{B}} + p_{\mathrm{B}})$. (b) Ratio of Λ to $\bar{\Lambda}$ yields versus light cone fraction ζ observed in the data, after background subtraction.

The light cone momentum fraction ζ is an approximate measure of whether the hyperons were 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 $x_{\rm F} = p_{||}^{\Lambda}/p_{\rm beam}$, evaluated in the $\gamma^* N$ system, but this variable is not available in an inclusive measurement. Nevertheless, a simulation of the reaction using the PYTHIA program reveals a reasonable correlation between ζ in the eN system and $x_{\rm F}$ in the $\gamma^* N$ system. In particular, all events at $\zeta \geq 0.25$ are produced in the forward hemisphere $x_{\rm F} > 0$. As another indication of this "watershed", the ratio of Λ to $\bar{\Lambda}$ yields observed in the data after background subtraction is displayed in Fig. 1(b). Above $\zeta = 0.25$, a constant ratio of 4.7 is seen. At lower values the ratio increases dramatically, likely indicating the influence of the nucleon target remnant in Λ formation. It may thus be speculated that the different behaviors of P_n^{Λ} and $P_n^{\bar{\Lambda}}$ in the low and high ζ regions are related to the different hadron-formation mechanisms of the target- and current-quark fragmentation regions respectively.

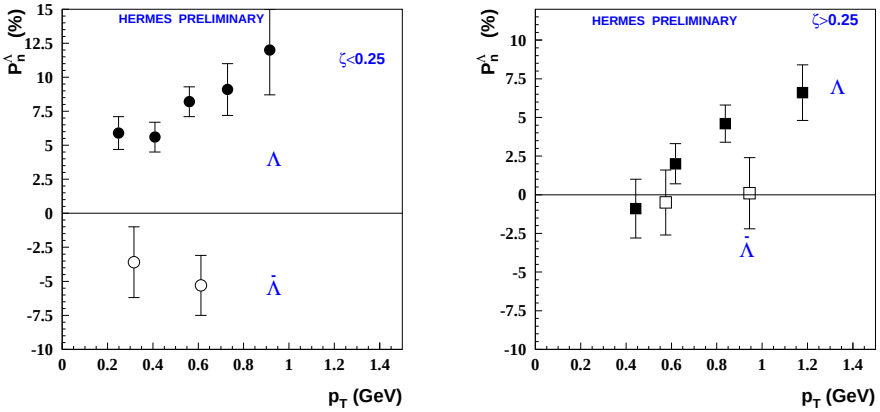

Fig. 2. Transverse polarization of Λ and $\bar{\Lambda}$ hyperons as a function of $p_{\rm T}$ for the intervals $\zeta < 0.25$ (left panel) and $\zeta > 0.25$ (right panel).

The dependence of the polarization on the transverse momentum $p_{\rm T}$ of the Λ (relative to the lepton beam) has also been explored. This dependence is shown in Fig. 2 for the two intervals $\zeta < 0.25$ and $\zeta > 0.25$. In both regimes the Λ polarization rises with $p_{\rm T}$, particularly for the forward-going hyperons where this behavior is more pronounced. This kinematic dependence is reminiscent of the linear rise of hyperon polarization with $p_{\rm T}$, up to $p_{\rm T} \approx 1$ GeV, that has been consistently observed in the forward production of hyperons in hadronic reactions. In the forward region the $\bar{\Lambda}$ polarization is consistent with zero, also in agreement with hadronic reactions. In the backward region, however, the measured $\bar{\Lambda}$ polarization favors a negative value.

3. Discussion

The results presented here, a first measurement of non-zero transverse polarization in the $\gamma^* N \to \Lambda^{\uparrow} X$ and $\gamma^* N \to \bar{\Lambda}^{\uparrow} X$ reactions at $Q^2 \approx 0$ adds an interesting new piece to the long-standing puzzle of hyperon polarization at high energies. In light of the negative values observed in almost all other reactions, the positive value of the transverse Λ polarization measured by HERMES is surprising. One may chose to speculate on the reason for this positive value. The model of DeGrand and Miettinen [6] (DGM) is one of the more successful proposed to date, and can at least account for the relative signs and magnitudes of the polarizations in numerous hadron-to-hyperon transitions. In the DGM picture of the $p \to \Lambda$ transition, a fast valence $(ud)_0$ diquark from the beam recombines with a sea s quark from the target to form the Λ. The s quark is accelerated in this process, and acquires a polarization in the $-\hat{n}$ direction due to the Thomas precession effect. This negative polarization is transferred to the Λ, whose spin is entirely carried by the s quark (in the constituent quark model). The positive Λ polarization observed with K^- beams is conversely indicative of the deceleration of valence strange quarks from the beam. The positive polarization observed in the HERMES photoproduction data might thus indicate that the $\gamma \to s\bar{s}$ hadronic component of the beam is the dominant source of inclusive Λ production. Further, quarks and anti-quarks in the photon beam are on an equal footing. If the polarization mechanism in the forward direction is indeed dominated by the valence quark content of the beam, the Λ and $\bar{\Lambda}$ polarizations should become similar at large ζ. This trend is qualitatively supported by the data. Conversely, Λ and $\bar{\Lambda}$ polarizations are seen to differ in the target fragmentation region, where quarks and anti-quarks are distinguished by the nuclear target.

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