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STUDY OF Λ HYPERON PRODUCTION IN THE HERMES EXPERIMENT*

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Semi-inclusive Λ hyperon production has been studied in the HERMES experiment using the $E_{\rm e} = 27.5$ GeV polarized positron beam incident on polarized or unpolarized internal gas target. The multiplicity distribution over fractional Λ energy z has been investigated and the fragmentation function $D_u^\Lambda(z)$ has been extracted. The $D_u^\Lambda(z)$ found by HERMES is well described with the help of the parametrization based on the experiments on Λ production in high energy proton–proton collisions, but it is substantially smaller then that deduced from the e^+e^- annihilation data. The distribution over Λ transverse momentum squared $p_{\rm T}^2$ has also been analyzed. The results show that at $z > 0.2$ the $p_{\rm T}^2$ distribution is dominated by the quark transverse motion in the fragmentation process. The longitudinal spin transfer from the beam to the Λ has been measured. The systematic uncertainty of the spin transfer has been reduced by reversal of the beam polarization several times during the data taking period. The spin transfer coefficient is found to be $S_\Lambda = 0.04 \pm 0.08({\rm stat}) \pm 0.03({\rm syst})$ at an average fractional energy of the produced Λ hyperons of $\langle z \rangle = 0.45$. The dependence of the longitudinal spin transfer on z is presented and compared with recent theoretical calculations.

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1. Unpolarized Λ hyperon production

1.1. Fragmentation function

The multiplicity distribution $n_h(z) = (1/N_{\rm e})(dN^h/dz)$ is a convenient experimental parameter to describe a hadron yield in lepto-production. Here $N_{\rm e}$ is the number of inclusive DIS events, dN^h is the number of hadrons detected in a bin dz, $z = E^h/\nu$, E^h is the hadron energy, ν is the energy of

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virtual photon. In the Quark Parton Model (QPM) the multiplicity distribution $n_h(z)$ in current fragmentation region is given by

$$n_h(z) = \sum_f \omega_f D_f^h \left(\bar{Q}^2, z\right) . \tag{1}$$

Here ω_f is the fractional contribution of a quark with flavor f to the inclusive DIS cross section ($\sum_f \omega_f = 1$), Q^2 is the momentum transfer squared. Monte Carlo (MC) simulations based on the Lund fragmentation model show the dependence of fragmentation functions on Q^2 in the Deep Inelastic Scattering (DIS) regime: ($Q^2 > 1$ Gev^2) for the HERMES kinematics is very weak, and one may assume that $D_f^h(Q^2, z) \simeq D_f^h(\bar{Q}^2, z)$, where $\bar{Q}^2$ is average over kinematic range value which in Λ production case is $\bar{Q}^2 = 2.5\,\mathrm{GeV}^2$. It has also been shown that in HERMES kinematics Λ production is dominated by the u and d quarks. Moreover, due to the fact that Λ hyperon is isosinglet one has $D_u^\Lambda = D_d^\Lambda$. Therefore, one can rewrite Eq. (1) as

$$n_\Lambda(z) = \underbrace{(\omega_u + \omega_d) D_u^\Lambda(z)}_{75\%} + \sum_{f=s,\bar{u},\bar{d},\bar{s}} \omega_f \, D_f^\Lambda(z) \, . \tag{2}$$

This equation has been used to extract $D_u^\Lambda(z)$ fragmentation function using the experimentally measured multiplicity distribution $n_\Lambda^{\mathrm{exp}}(z)$. The value of $\omega_u + \omega_d$ and the sea quark contribution have been found using MC. The normalization factor C has been taken equal to the ratio of normalized Λ yields:

$$\frac{\int_0^1 n_\Lambda^{\mathrm{exp}}(z) dz}{\int_0^1 n_\Lambda^{\mathrm{MC}}(z) dz} ,$$

where $n_\Lambda^{\mathrm{MC}}(z)$ is the multiplicity distribution calculated with the help of MC. The procedure of Λ event selection and correction of the measured $n_\Lambda^{\mathrm{exp}}(z)$ for the spectrometer acceptance is described in [1].

The acceptance corrected multiplicity distribution and the extracted fragmentation function $D_u^\Lambda(z)$ are shown in Fig. 1. The multiplicity distribution (Fig. 1, left) is in a good agreement with the EMC [2] and FNAL E398 [3] data obtained at higher energy. The fragmentation function $D_u^\Lambda(z)$ found with the help of Eq. (2) and the MC corrections are shown in Fig. 1 together with the "raw" $n_\Lambda(z)$. One can see that MC corrections are typically small. The experimentally found $D_u^\Lambda(z)$ is compared with the parametrization based on Λ production data obtained in the high energy proton–proton

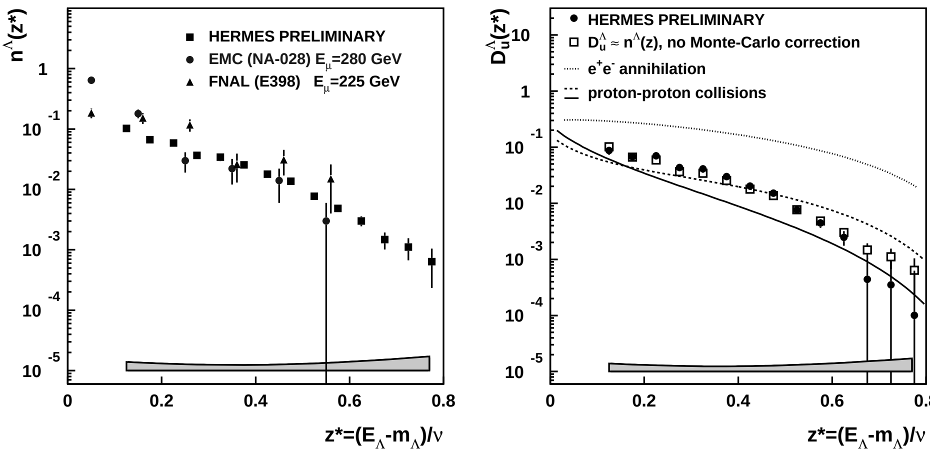

Fig. 1. Multiplicity distribution $n^{\Lambda}(z)$ (left) and fragmentation function $D_u^{\Lambda}(z)$ (right) extracted from the data of 1996–1997 years ($\bar{Q}^2 = 2.55$ GeV^2).

collision experiments [4] and recent similar calculations [5]. These calculations (in particular the latter one) describe well the HERMES result. On the other hand, a significant deviation from the parameterization resulting from e^+, e^- annihilation [6] is apparent. This discrepancy might be partly related to an assumption that $D_u^{\Lambda} = D_s^{\Lambda}$ which has been used in the latter analysis. This assumption contradicts the Lund fragmentation model in which, because of strong suppression of the strange diquark, D_s^{Λ} is larger by a factor of ~ 2.5 than D_u^{Λ}.

1.2. Transverse momentum distribution

The transverse momentum of a hadron produced in a semi-inclusive reaction is defined as a the component of the hadron momentum perpendicular to the direction of the virtual photon momentum. According to Ref. [7] one can write

$$\langle p_{\mathrm{T}}^2 \rangle = \langle p_{\mathrm{T}}^2 \rangle_{\mathrm{QCD}} + \langle p_{\mathrm{T}}^2 \rangle_{\mathrm{FRAG}} + z^2 \langle k_{\mathrm{T}}^2 \rangle \,,$$

where $\langle p_{\mathrm{T}}^2 \rangle$ is the mean of the transverse momentum squared of the produced hadron, $\langle p_{\mathrm{T}}^2 \rangle_{\mathrm{QCD}}$, $\langle p_{\mathrm{T}}^2 \rangle_{\mathrm{FRAG}}$, and $\langle k_{\mathrm{T}}^2 \rangle$ are contributions from the hard gluon emission process, from quark and gluon fragmentation, and from the internal motion of the quarks in the target, respectively. As one can see, the latter contribution is suppressed at low hadron fractional energy z, that dominates in semi-inclusive hadron production[1]. The hard gluon emission is important only at high ($\simeq 1.2$ GeV) $\langle p_{\mathrm{T}} \rangle$ and at energies much higher than those in the HERMES case.

[1] The cut $z > 0.16$ has been applied to the experimental data set.

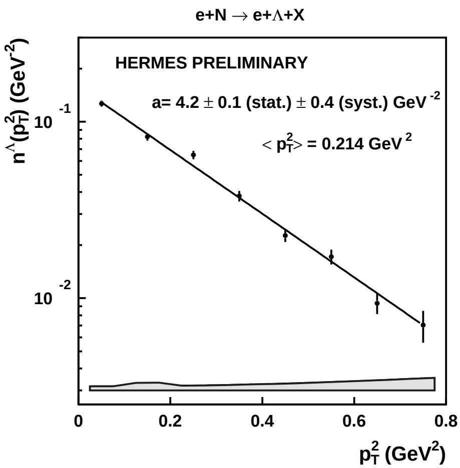

Fig. 2. p_{T}^2 distribution for Λ events extracted from the data taken in 1996–1997.

The acceptance corrected p_{T}^2 distribution for Λ production is shown in Fig. 2. The experimental data are well fitted with a single Gaussian: $A\exp(-ap_{\mathrm{T}}^2)$ thus confirming that only one (fragmentation) process dominates p_{T}^2 distribution. The slope parameter is found to be $a = 4.2 \pm 0.1(\mathrm{stat}) \pm 0.4(\mathrm{syst})$ GeV^{-2}, which is in agreement with the Cornell experiment result: $a = 4.3 \pm 0.3$ GeV^{-2} [8]. As has been demonstrated by the Monte Carlo simulation the deviation from the FNAL E665 experimental result ($a = 2.72 \pm 0.64$ GeV^{-2}) [9] is caused by a substantial contribution of the hard gluon emission at FNAL energies. The p_{T}^2 distributions has also been reconstructed for semi-inclusive production of K_{s}, π^+ and π^-. For these events $\sqrt{\langle p_{\mathrm{T}}^2\rangle} = 0.458, 0.515$ and 0.509, respectively. For Λ production $\sqrt{\langle p_{\mathrm{T}}^2\rangle} = 0.462$. These numbers corresponds to average transverse distances for the fragmentation processes of typically $\sim 0.4 - 0.5$ fm with a negligible difference between the strange meson (K_{s}) and baryon (Λ) fragmentations.

2. Spin transfer to the Λ hyperon

According to the Constituent Quark Model (CQM) the Λ spin is carried by the s quark coupled to the spinless ud diquark: $\Delta s_\Lambda = 1$, $\Delta u_\Lambda = \Delta d_\Lambda = 0$, where Δq_Λ ($q = u, d, s$) is the first moment integral for a given flavor of the spin-dependent quark distribution function $\Delta q_\Lambda(x)$, *i.e.* $\Delta q_\Lambda = \int_0^1 \Delta q_\Lambda(x)$. Using SU(3)$_f$ symmetry and the first moment integral for the proton measured in inclusive DIS by Burkardt, Jaffe [10] predicted for Λ: $\Delta u_\Lambda = \Delta d_\Lambda = -0.23 \pm 0.06$, $\Delta s_\Lambda = 0.58 \pm 0.07$.

Experimental information about the Λ spin structure can be obtained by measuring spin transfer S_Λ from longitudinally polarized leptons to the Λ hyperon in the current fragmentation regime. The spin transfer is defined by the equation $P_\Lambda = P_B D(y) S_\Lambda$, where P_Λ is the measured Λ polarization, P_B is the beam polarization, $D(y)$ is the virtual photon depolarization factor. One can show that due to u dominance $S_\Lambda \simeq \Delta u_\Lambda$. The Λ polarization has been measured by HERMES using a polarized positron beam and an unpolarized target. With a DIS cut $Q^2 > 0.8$ GeV^2 applied, about 10^4 Λ events have been selected for the analysis from the data set accumulated in the years 1996–2000. The procedure of the spin transfer extraction is described in Refs. [11–14].The systematic uncertainty of the measured S_Λ related to the spectrometer acceptance has been reduced by reversal of the beam polarization, the latter being done several times during the data taking period. The extracted value of the spin transfer coefficient at $x_f > 0$ and at an average fractional energy of accepted Λ hyperons $\langle z \rangle = 0.45$ is found to be $S_\Lambda = 0.04 \pm 0.08(\mathrm{stat}) \pm 0.03(\mathrm{syst})$. Within the statistical uncertainty of the experiment, this result is consistent both with CQM and Burkardt and Jaffe predictions, the latter being corrected for the s quark contribution and for Λ production via resonances.

In Fig. 3 the z dependence of the experimentally measured spin transfer is compared with the theoretical expectations. It is not possible to calculate $S_\Lambda(z)$ from the first principles, however it can be estimated in the limit $z \to 1$ using reciprocity relations [15]. According to the SU(6) based quark-diquark model $S_\Lambda(z)$ increases nearly up to 1 at $x \to 1$ [16]. Recent calculation done using SU(3)$_f$ symmetry shows a moderate increasing of $S_\Lambda(z)$ at high z [17]. The large positive limit as $z \to 1$ shown by the SU(6) quark-diquark model is not consistent with the HERMES data.

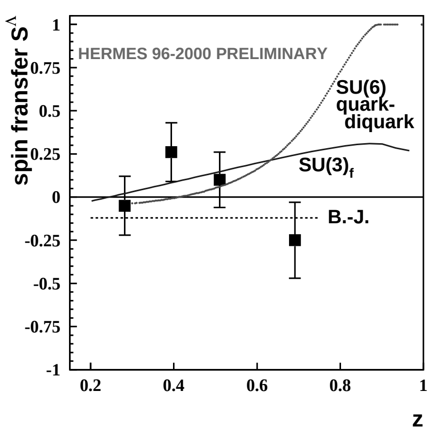

Fig. 3. Spin transfer *versus* z extracted from the data taken in 1996–2000 years ($x_f > 0$).

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