Inclusive Λ Production and Polarization in 16-GeV/c $\pi^- p$ Interactions

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The invariant differential cross sections and polarization ($0.5 < x_F < 0.8$, $0.0 < p_\perp < 1.5$ GeV/c) of Λ's produced in pion-induced reactions have been measured. The scaling cross section agrees with previous experiments performed at other energies. The $(1-x_F)^N$ dependence of the cross section gives an exponent of $N = 1.88 \pm 0.04$. These are the first polarization measurements in the pion fragmentation region. A mean polarization of $(-5.3 \pm 1.2)\%$ is observed with no trend toward large negative polarization with increasing transverse momentum.

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The inclusive polarization of Λ's produced in pp collisions has been well established.[1] It has been observed with beam momenta of 24 GeV/c up to 2000 GeV/c (CERN intersecting storage rings equivalent). The Λ polarization increases (negatively) with increasing transverse momentum ($p_\perp$), and is roughly independent of beam energy and Feynman x (x_F).[2] These results are quite interesting because of a QCD prediction[3] that the polarization should disappear at large $p_\perp$. Several models have been proposed[4] to explain the observed polarization; although the models vary in proposed mechanism they do have a common thread. The polarization comes about via the mechanism for producing an s quark and giving it enough momentum to join with a diquark from the proton to form a Λ. *A priori*, one might expect a similar mechanism for Λ production by pions in the beam-fragmentation region. In this case two quarks are produced. Thus one might expect to see (diluted) polarization increasing with $p_\perp$ in pion interactions. (Similar arguments would not hold for Λ's produced by K^- beams since in this case the strange quark is a spectator.) These are the first high-statistics measurements of Λ's produced by pions in the beam-fragmentation region.

The experiment was performed at the Brookhaven National Laboratory Multi-Particle Spectrometer (MPS) facility with the magnet operated at 1.0 T. We used a 16.1-GeV/c negative pion beam (identified by beam Cherenkov counter) impinging upon a 60-cm liquid-hydrogen target. The apparatus and the trigger have been described previously.[5] The trigger is based on identifying a fast forward proton produced in the interaction.

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Momentum and angle selections were made by using two wire proportional chambers in the MPS magnet and a scintillation hodoscope behind the magnet to define trajectories as part of the trigger. Hit patterns in the chamber were compared to preset memory locations to select positive particles with momenta in the allowed range of 8 to 13 GeV/c and with a direction consistent with a Λ produced in the target and decaying before the first trigger chamber.[6] A large-area threshold Cherenkov counter (γ threshold = 13) provided the proton identification (π/K rejection efficiency > 99%). There was approximately one trigger for every 10 000 pions incident on the hydrogen target. The spark chambers had sufficient redundancy (typically, a π from Λ had $\geqslant 35$ hits) to ignore spark-chamber efficiencies. Trigger-detector efficiencies were determined by taking random triggers with the data.

The data were processed through pattern-recognition and kinematic fitting programs to identify events satisfying the Λ hypothesis. The effective mass of the $p\pi^-$ system was required to be 1115.6 ± 15 MeV/c^2. The full width at half maximum at the Λ peak was 6 MeV/c^2. No evidence of K^0 contamination was found for events reconstructed with a $\pi^+\pi^-$ hypothesis.

The data sample for this paper consists of 62 000 events selected from 2.4×10^6 triggers which yielded 208 000 Λ's. This sample has a raw sensitivity of 62 events/nb. The Λ polarization was analyzed in the helicity frame. A right-handed-coordinate system is formed where the z axis is given by the transformation direction from the production c.m. system to the Λ rest frame, the y axis is defined as the production-plane normal ($\hat{p}_{\text{beam}} \times \hat{p}_\Lambda$), and the x axis is given by $\hat{y}\times\hat{z}$. The polar angle θ is defined with respect to the z axis, and the azimuthal angle φ is defined with respect to the x axis. The angles θ and φ define the direction of the decay proton in the Λ rest frame.

The analysis of the polarization was done in fixed bins of x_F and $p_\perp$ with use of χ^2 minimization. The χ^2 was computed over a 10×10 grid in the $\cos\theta$ vs φ plane and was of the form

$$\chi^2 = \sum\nolimits_{\text{grid}} (N_k - N_k^{\text{th}})^2/\sigma_k^{\,2},$$

where N_k is the number of events observed in the kth bin of the $(\cos\theta, \varphi)$ $(=\Omega)$ grid and $\sigma_k^{\,2} = N_k$. The expected number of events in the bin is given by

$$N_k^{\text{th}} = \Delta\Omega A(\Omega_k) \sum_{\substack{l \\ m\geq 0}} [t_{lm} \operatorname{Re}Y_{lm}(\Omega_k) + s_{lm} \operatorname{Im}Y_{lm}(\Omega_k)],$$

where $A(\Omega_k)$ is the computed acceptance for the particular x_F, $p_\perp$, $\cos\theta$, and φ of the kth bin and t_{lm} and s_{lm} are parameters determined by the fit. By parity conservation in the production process we have $t_{lm}=0$ for l odd, and $s_{lm}=0$ for l even. Further, since the Λ is spin $\frac{1}{2}$ the only allowed moments are t_{00} and s_{11} where the number of produced events in the bin of x_F and $p_\perp$ is given by $N = (4\pi)^{1/2} t_{00}$ and the polarization is $P = -(\frac{3}{2})^{1/2} s_{11}/\alpha t_{00}$. The Λ asymmetry parameter α is equal to 0.642.[7] This expression is the usual polarization definition written in the helicity frame. Although there were only two allowed moments, t_{lm}'s and s_{lm}'s up to $l=2$, $m=2$ were examined as a consistency check. All moments that the physics requires to be zero turned out consistent with zero (χ^2/DF = 1.11). The data were then refitted with only the allowed moments. No substantial difference was observed between the two fits.

$A(\Omega)$ was determined by generating 2.6 million Λ's according to the x_F and $p_\perp$ distributions consistent with the data. The Λ's were made to decay isotropically and were processed through the same cuts as were applied to the real data. The Monte Carlo (MC) events were divided into fine bins of x_F and $p_\perp$ ($\Delta x_\text{F} = 0.025$, $\Delta p_\perp = 0.05$ GeV/c). For convenience of combining bins the maps were generated as unnormalized acceptance moments $\langle Y_{lm}\rangle_{\text{acc}}$ up to $l=7$, $m=7$. Samples of MC events with and without polarization were converted to spark coordinates, consistent with chamber resolutions and efficiencies, and processed through the entire chain of analysis programs. Within errors, the fitted polarization was consistent with the generated polarization.

The data were carefully studied for possible systematic errors that could affect the polarization. Because the MPS has an asymmetric magnet and systematic tests such as reversing the field could not be done, quite stringent cuts were necessary to ensure data reliability. The following cuts and corrections were made to the data and MC event samples: (1) The reconstructed proton passed a trigger simulation. (2) The reconstructed primary vertex originated in the target. (3) Λ's decaying in the plane perpendicular to the magnetic field are ambiguous in terms of the true Λ vertex and were therefore removed. (4) Events with overlapping beam and trigger tracks were eliminated. This cut affected only the low-$p_\perp$ data. (5) Particles near the support wires of the trigger proportional wire chambers were lost. (6) The allowed proton momentum range was 7.5 to 12.5 GeV/c. (7) A correction of 1.28 was made for trigger-detector efficiencies. (8) A minimum lifetime cut ($> 0.2\tau_\Lambda$) was imposed to ensure separation of the primary and Λ decay vertices. In general, the cuts did not affect the polarization but did reduce fluctuations in the high-order moments.

Furthermore, as a result of averaging over Λ production in a large-aperture magnet, the precession of the Λ spin has no statistically significant effect upon the polarization measurement. This was confirmed by MC studies which indicated that the polarization varied by $<1\%$ less as a result of the Λ spin precession.

To check for acceptance asymmetries the data were divided into Λ's produced up/down and left/right in the MPS magnet. The data in these four overlapping classes were refitted for polarization and within the statistical uncertainties no differences were observed.

The invariant differential cross section

$$F(x_F) = \int_{p_\perp^2} \frac{2}{\pi} \frac{E^*}{\sqrt{s}} \frac{d^2\sigma}{dx_F dp_\perp^2} dp_\perp^2$$

is shown in Fig. 1(a). The integral was evaluated by correcting for acceptance event by event and summing over bins of $p_\perp$. The solid circles are our data and are in reasonable agreement with data at high energies[8] and low energies.[9,10]

The differential cross section as a function of $1-x_F$ is shown in Fig. 1(b). A number of models predict the invariant cross section to have a functional form of

$$E\, d^3\sigma/dp^3 = f(\sqrt{s}, p_\perp)(1-x_F)^N$$

for large x_F. The exponent N is independent of the initial beam momentum and transverse momentum of the produced particle. In the quark-counting rules suggested by Gunion the forward-going Λ produced in the beam-fragmentation region obtains its constituent quarks from the pointlike quark sea via gluon bremsstrahlung.[11] If forward Λ production is dominated by such gluon-bremsstrahlung diagrams, he predicts $N=2$ in the above equation.

A linear fit to the data yields a value of 1.88 ± 0.04 for the exponent in agreement with the predictions by Gunion. This is to be compared to the 200-GeV/c result of Edwards *et al.*, a value of 3.01 ± 0.09. This suggests that possibly different mechanisms may be responsible for Λ production at low and high energies. The polarization data as a function of $p_\perp$ for the entire data sample ($0.5 < x_F < 0.8$) are shown in Fig. 2. Also shown

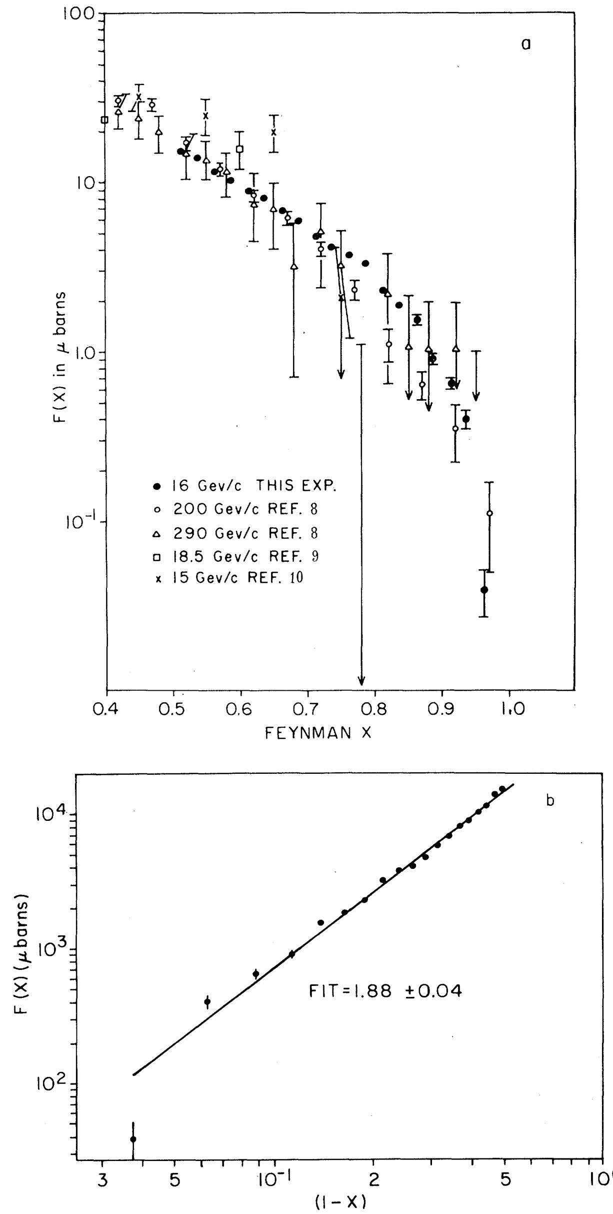

FIG. 1. (a) Invariant differential cross section vs x_F. (b) Invariant differential cross section vs $(1-x_F)$. Linear fit is for $0.5 \leq x_F \leq 0.9$.

is a comparison of our data with two pp experiments at similar energies. We measure a mean polarization of $(-5.3 \pm 1.2)\%$, and parity-nonconserving components along $\hat{x}$ of $(-2.0 \pm 1.3)\%$ and along $\hat{z}$ of $(-6.4 \pm 2.3)\%$ (mean values $\langle x_F \rangle = 0.645 \pm 0.007$, $\langle p_\perp \rangle = 0.508 \pm 0.013$). The z component is very sensitive to biases, as it is measured along the Λ direction, which overlaps with the beam region. We observe no increase in polarization as a function of $p_\perp$ nor do we find any significant

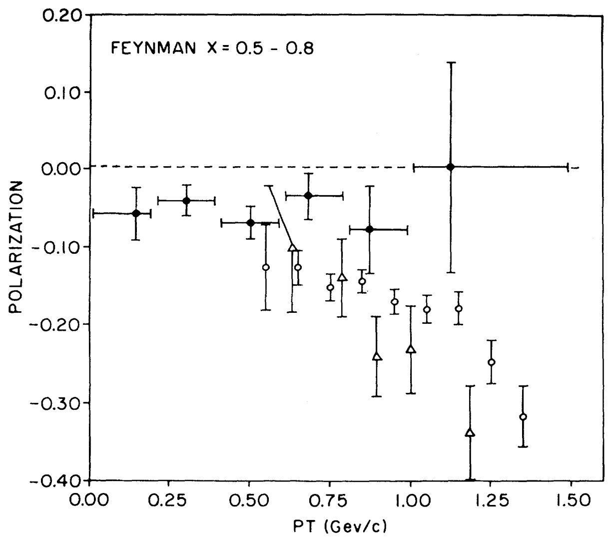

FIG. 2. Λ polarization vs $p_\perp$. The data from Lomanno *et al.* (open circles) and Rayachauduri *et al.* (triangles) (Ref. 1) are shown for comparison. Mean values are $\langle x_F \rangle = 0.65$, $\langle p_\perp \rangle = 0.14$, 0.30, 0.49, 0.68, 0.88, 1.11.

evidence of x_F dependence. It is possible that the small observed polarization could be due to an undiscovered systematic error; however, we have been unable to identify any such source. This result appears to differ with proton-induced Λ's where substantial increasing polarization with increasing $p_\perp$ has been reported.

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