Spin Transfer in Hyperon Production

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(Received 29 September 1986)

We have measured the polarization of Λ's inclusively produced by the polarized proton beam at the Brookhaven National Laboratory Alternating Gradient Synchrotron at 13.3 and 18.5 GeV/c. Data were taken in the central and beam-fragmentation regions with hyperon transverse momenta from 0.4 to 2.5 GeV/c. The Λ polarization parameter P is found to be large in agreement with earlier data at other energies. The analyzing power A_N and spin transfer D_{NN} are nearly zero in the same kinematic region, as predicted by certain models of particle production.

PACS numbers: 13.88.+e, 13.85.Ni

The fact that hyperons are produced with large polarization[1] independent of $\sqrt{s}$ from 5 to 60 GeV/c^2 is a surprising effect which has eluded a satisfactory explanation for more than a decade. The polarization sets in at rather low values of transverse momentum (~ 1 GeV/c), and so perturbative QCD calculations are not applicable. Models which invoke string breaking[2] or Thomas precession[3] as the underlying quark-polarizing mechanism can explain the relative signs of the polarization, but the magnitudes are in disagreement with some recent data.[4] In these models the strange quarks are produced polarized and then recombine with constituent quarks from the incident particle to form polarized hyperons. Many predictions of this picture are *independent* of the specific quark-polarizing mechanism and follow from the use of SU(6) spin wave functions and the assumption that the spins of the through-going quarks are preserved in the scattering and recombination process.

Crucial tests of these ideas become posssible if the incident proton beam is polarized, since two additional spin parameters, D_{NN} (spin transfer) and A_N (analyzing power), can then be measured.[5] For most hyperons, the incoming proton's spin is predicted to have a strong effect on the outgoing hyperon's polarization.[6] However, for (direct) Λ production the proton's spin should have *no* effect. (Actually, since the experiment does not distinguish direct Λ's from those arising from Σ^0 decay,[7] the theoretical prediction has to be modified to allow for this.)

We have measured A_N and D_{NN} for Λ production at 13.3 and 18.5 GeV/c using the Brookhaven National Laboratory Multiparticle Spectrometer (MPS)[8] and the recently commissioned[9] polarized proton beam at the Brookhaven National Laboratory Alternating Gradient Synchrotron (AGS). The experimental layout is shown in Fig. 1. The Λ's are produced in the beryllium target and decay between the scintillators S4 and S5. The decay proton and pion tracks are reconstructed and momentum analyzed via the MPS drift chambers D1–D7 and the proportional chambers R1 and P1–P3. The trigger utilized both C7 and H7, which are Cherenkov and scintillation hodoscopes, respectively.

The incident polarized proton beam was counted by scintillator S2. Hole scintillator S3 vetoed halo particles and assured that the beam position was constant. The average intensity was $(2.5-3.0)\times 10^6$ per 800-msec AGS pulse. The polarization of the beam was measured at 13.3 GeV/c with horizontal scintillator telescopes which viewed the beryllium production target. At 18.5 GeV/c, a polarimeter, consisting of a CH_2 target and horizontal and vertical scintillator telescopes, was located a few meters upstream of the beryllium target. The calibration of

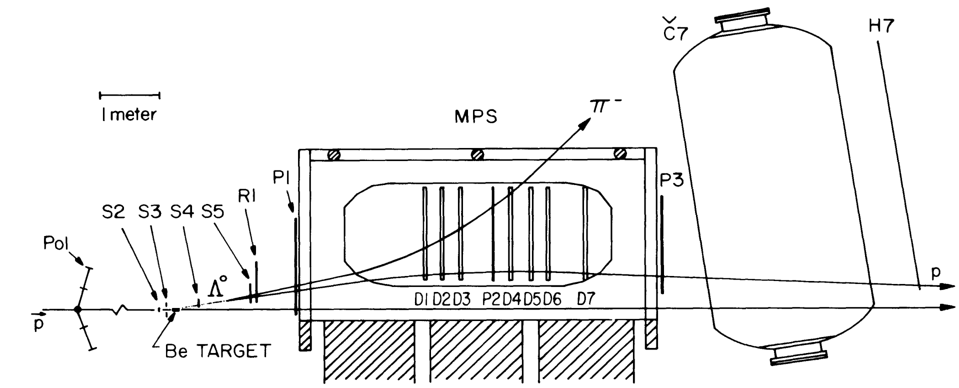

FIG. 1. Plan view of the experimental apparatus showing the polarized proton beam and the multiparticle spectrometer at the AGS.

our polarimeter was periodically checked throughout the run against the University of Michigan absolute polarimeter located in another beam line.[10] The analyzing power was 0.00900 ± 0.00025 at 13.3 GeV/c and 0.0124 ± 0.0048 at 18.5 GeV/c. The beam polarization P_B was found to be rotated from the vertical in a direction transverse to the beam momentum by $27° \pm 3°$ in the azimuthal angle ϕ, which is consistent with calculations of the spin precession by the magnets in the extracted proton beam lines.[11] The calculation predicts a small polarization component ($\sim 0.1 P_B$) parallel to the beam momentum which has no effect on this experiment. The beam polarization direction was reversed on alternate pulses. The average P_B was $57.6\% \pm 1.5\%$ at 13.3 GeV/c and $39.1\% \pm 1.4\%$ at 18.5 GeV/c.

The polarization of the hyperons has been found to be approximately independent of the production target nucleus.[12] Therefore, a 4-cm Be production target rather than liquid H_2 was used to give a nearly pointlike source of Λ's so that the veto scintillation counter S4 would be geometrically efficient.

A simple trigger was used to minimize bias in measuring Λ polarization from reconstructed decays. The veto of charged particles emerging from the production target by S4 along with the requirement of two or more minimum-ionizing particles emerging downstream of the 1-m decay region in S5 were the most powerful elements in the trigger. Monte Carlo calculations show that S4 vetos some Λ's, largely those arising from N^* and Y^* decays, but these constitute only a few percent of the total sample in the p_T range of this experiment.[13] The Cherenkov counter C7 with threshold $\gamma = 20$ and the hodoscope H7 were used to identify the decay proton which was required to traverse the entire MPS. The chamber P2 was used to require that the decay pion also reach at least the midpoint of the MPS magnet before exiting. An upper limit (≤ 5) on charged particles in P1–P3 suppressed events in which the trigger requirement was partially satisfied by a photon shower. No pattern recognition in the chambers was used in the triggering; P1–P3 only counted numbers of particles.

The MPS drift chambers D1–D7 were used to reconstruct the pion and proton tracks; the tracks were then extrapolated through the magnetic field to the proportional chambers P1(x) and R1(x,u,v) to find a decay vertex. A vertex was reconstructed in over 20% of the Λ triggers; more than half of these had the vertex in the specified decay region and gave the proper Λ effective mass. The peak in the effective-mass distribution (Fig. 2) is at 1115.6 MeV/c^2 and has a width of ± 2.9 MeV/c^2. Events within 3σ of the mean are used. This distribution is Gaussian with an extrapolated background of 1.5% beneath the peak. This background is approximately 7% K^0's, determined by reconstructing the background events by assigning the pion mass to

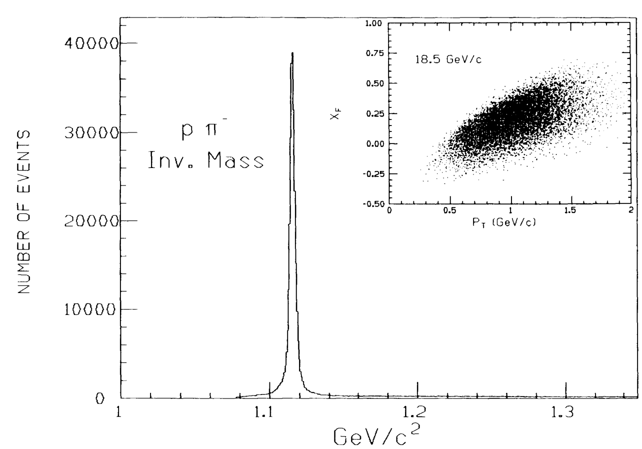

FIG. 2. Proton-π^- invariant-mass distribution at 18.5 GeV/c. Inset: Scatter plot of x_F-p_T for reconstructed Λ's at 18.5 GeV/c.

both decay products. Reconstructing events in the Λ peak in this fashion gives no visible K^0 signal. All of the data at 18.5 GeV/c have been analyzed, yielding 2.3×10^5 Λ's. About 30% of the 13.3-GeV/c data have been analyzed, yielding 1.6×10^5 Λ's.

The Λ polarization P_Λ is calculated from the parity-nonconserving distribution of decay protons evaluated in the Λ rest frame:

$$\frac{dN}{d\cos\theta^*}=N_0(1+\alpha P_\Lambda\cos\theta^*), \tag{1}$$

where the analyzing power[14] $\alpha=0.645\pm0.017$, and θ^* is the angle of the decay proton momentum with respect to the Λ polarization vector. The present results are for that component of the Λ polarization normal to the production plane. When averaged over incident beam polarization, this yields the Λ polarization parameter P. Since the Λ's are produced and decay outside the magnetic field, no precession of the Λ spin occurs.

The distribution of accepted events in Feynman x (x_F) and transverse momentum p_T is shown in Fig. 2. The upper left-hand edge shows the small-angle cutoff caused by the inner edge of the MPS drift chambers. We observed a bias in the decay distributions due to this and the other chamber edges. Geometrical corrections to the decay distributions were applied based on a Monte Carlo simulation of the experimental setup. However, the Λ polarization is insensitive to the acceptance corrections to within statistical errors. For example, for the bin $0.35<x_F<0.45$ and $0.8<p_T<1.2$, the Monte Carlo corrections change P_Λ by 0.009, whereas the statistical error on P_Λ is 0.037.

The Λ polarization parameter P is plotted in Figs. 3(a) and 3(b) along with some previous Fermilab, KEK, and AGS data. At both 13.3 and 18.5 GeV/c, our data are in good agreement with other experiments, including those at higher energies. The polarization P increases almost linearly with x_F, and goes well into the region where the quark-fragmentation-recombination model (QFR) should apply.

The spin observables A_N and D_{NN} are given[15] by

$$A_N=\frac{1}{P_B\cos\phi}\frac{N_\uparrow(\phi)-N_\downarrow(\phi)}{N_\uparrow(\phi)+N_\downarrow(\phi)}, \tag{2}$$

$$D_{NN}=\frac{1}{2P_B\cos\phi}[P_{\Lambda\uparrow}(1+P_BA_n\cos\phi) - P_{\Lambda\downarrow}(1-P_BA_n\cos\phi)].$$

The azimuthal angle ϕ is that between the beam polarization direction (which is tilted 27° from the vertical) and the normal to the Λ production plane. $N_{\uparrow(\downarrow)}$ is the number of Λ's produced and $P_{\Lambda\uparrow(\downarrow)}$ is the measured Λ polarization for beam spin up (down). We have found $A_N\simeq0.01$; hence, D_{NN} is well approximated by

$$D_{NN}\cong\frac{1}{2P_B\cos\phi}[P_{\Lambda\uparrow}-P_{\Lambda\downarrow}]. \tag{3}$$

Thus D_{NN} is a measure of the transfer of the incident proton spin to the produced Λ.

The measurement of A_N is independent of the acceptance of the MPS: It depends only on our knowledge of the magnitude and direction of the beam polarization and on being able to reconstruct Λ's. Corrections for differences between spin states of beam position, beam intensity, and instrumental dead time were negligible in comparison with statistical uncertainties. The magni-

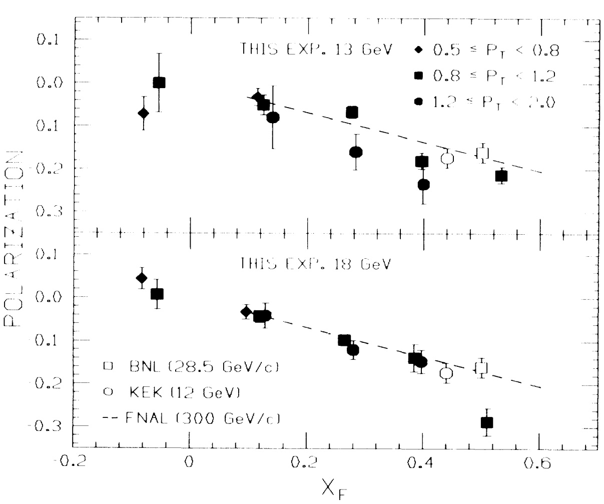

FIG. 3. Λ polarization parameter P from this experiment compared to data from Refs. 1 plotted vs x_F for 13.3 and 18.5 GeV/c. The dashed line is a fit to the 300-GeV/c data.

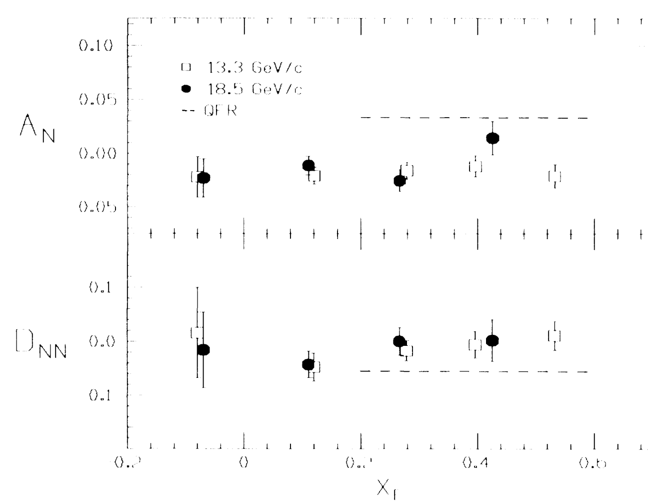

FIG. 4. (Upper) The analyzing power A_N for $p_{\rm pol}+{\rm Be}\rightarrow\Lambda+x$ plotted vs x_F. (Lower) The spin transfer D_{NN} for $p_{\rm pol}+{\rm Be}\rightarrow\Lambda_{\rm pol}+x$ plotted vs x_F.

tude of the beam polarization differed by a few percent for beam spin up and down, but A_N (and D_{NN}, in the limit $P_B A_N \ll 1$) depends only on the average value P_B. The measurement of D_{NN} depends, in addition, on the determination of $P_{\Lambda \uparrow(\downarrow)}$. The fact that our measurements of P at two momenta agree with one another (despite very different acceptances) and with previous measurements at other energies indicates that systematic effects in the determination of P_Λ are well understood.

To make optimum use of the statistical power of the experiment, we present our data as a function of the single variable x_F averaged over p_T (Fig. 4). The mean p_T of the data at both 13.3 and 18.5 GeV/c is about 1 GeV/c, well within the kinematic range where P has been found to saturate.[1] As x_F increases from 0 to 0.5, we move from the central region into the beam-fragmentation region, where the QFR model should apply.

The measured values of A_N [Fig. 4(a)] and D_{NN} [Fig. 4(b)] are close to zero, as predicted by the QFR model for direct Λ production. However, as in other inclusive-Λ polarization experiments, the Λ sample includes a proportion of Λ's which are decay products of Σ^0's. Data[7] at 28 GeV show that $(30 \pm 5)\%$ of inclusive Λ's arise from Σ^0 production and decay, independent of x_F and p_T. Using this information, and knowing that in Σ^0 decay the Λ spin is on average $-\frac{1}{3}$ that of its parent, we estimate that the QFR model predicts $A_N \simeq +0.033$ and $D_{NN} \simeq -0.055$ for the total Λ sample. As a result of this correction the agreement between data and theory worsens. This could be interpreted as a hint that the model's predictions for Σ^0 may not be correct. Direct measurements of A_N and D_{NN} for other hyperons, in particular the Σ^0, will provide crucial tests of the QFR picture of hyperon production.

We thank Dr. W. Glenn and Dr. A. Etkin and the entire staffs of the AGS Department and the MPS Group. We are indebted to Professor A. Krisch and Dr. L. Ratner for their considerable efforts in commissioning the polarized beam. We are grateful to Dr. L. Trueman for providing the computer time to analyze the data. This work was performed with the support of the United States Department of Energy under Contracts No. DE-AS05-81ER40032, No. DE-AC02-76ER03274, and No. DE-AC02-76CH0016.

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