Fermi National Accelerator Laboratory

FERMILAB Pub-94/015

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P.O. Box 500, Batavia, Illinois 60510

Janaury 1994

Submitted to *Physical Review Letters*

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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This work was performed at the Fermi National Accelerator Laboratory, which is operated by Universities Research Association, Inc., under contract DE-AC02-76CH03000 with the U.S. Department of Energy.

Abstract

We have measured the polarization of Λ and $\bar{\Lambda}$ hyperons produced by 800 GeV protons on a Be target at a fixed targeting angle of 4.8 mrad. Comparison with previous data at 400 GeV production energy and twice the targeting angle shows no significant energy dependence in Λ polarization. There is no evidence for $\bar{\Lambda}$ polarization at 800 GeV.

Although it has been known for more than 15 years that some hyperons are produced with a significant polarization in fixed target production experiments, there is still no generally accepted mechanism that can explain the pattern of polarizations.[1–4] The recent discovery that the anti-hyperons $\bar{\Xi}^+$ and $\bar{\Sigma}^-$ are produced polarized[5–6] upsets the idea that the pattern of polarization could be explained by characterizing the spin structure of baryons in a valence quark model.[7] One author suggests that this discrepency can be resolved if there is a difference in polarization between hyperon production at 400 GeV and 800 GeV.[4] Recently, evidence has been presented that in fact, both Ξ^- and Σ^+ hyperons differ in their polarization between 400 GeV and 800 GeV production.[8–9] Previous to these discoveries, it was thought that hyperon polarization was a function only of the hyperon transverse momentum, p_T, and the fraction of beam energy carried by the final state hyperon, x_F.[3] In this letter, we present results on Λ and $\bar{\Lambda}$ polarization in hadroproduction at 800 GeV. A comparison is made with Λ hadroproduction data at 400 GeV and no significant difference in polarizations is found. The $\bar{\Lambda}$ is found to be unpolarized at this energy.

The data discussed in this letter were obtained by Fermilab experiment 799. A secondary neutral hadron beam, including Λ's, was produced from a primary beam of 800 GeV protons hitting a beryllium target. The targeting angle was 4.8 mrad in the horizontal plane. After the target, collimators, lead absorbers, and a series of 4 magnets were used to create two neutral beams. After the last sweeping magnet, which was located approximately 55 meters from the target, the decay $\Lambda \to p\pi^-$ could occur without the final state particles being swept out of the beamline. The polarization direction of Λ particles produced from the target is perpendicular to the production plane, in the $\vec{p_P} \times \vec{p_\Lambda}$ direction. This direction is defined to be the +Y direction for this analysis. (The beamline is defined to be the +Z direction, and the target is at the origin.) By altering the field strength and polarity of one of the sweeping magnets, the direction of the Λ spin was precessed to be in either the positive or negative Y direction. The previously measured value of the magnetic moment of the Λ was used in calculating the required field strengths.[12] The field of the variable magnet was changed approximately every run, typically 8 hours. The data set used in this analysis spanned 109 runs.

The detector was designed to study decays of neutral kaons. The decay region for kaons extended between 120 meters and 160 meters from the target. The beam pipe in this region was not the limiting aperture. The beam pipe from about 18 meters from the target to the end of the decay region was evacuated. The spectrometer began after a distance of 160 meters from the target. The main components of the spectrometer were 4 drift chambers for charged particle tracking and a lead glass calorimeter for electromagnetic particle identification. Each drift chamber contained 2 X measuring views and 2 Y measuring views of wire planes, with each plane giving single hit resolution of approximately 100 μm. The wire spacing in the drift chamber planes was 12.7 mm, with one plane in each view offset from the other by half a wire spacing. There were 2 drift chambers on either side of an analyzing magnet, which had an integral transverse momentum kick of 200 MeV. The observed momentum resolution from the spectrometer was $(\sigma_p/p)^2 = (5 \cdot 10^{-3})^2 + (1.4 \cdot 10^{-4}p)^2$, where p is the momentum of the track in GeV/c. The calorimeter gave an average electron energy resolution for these data of 4.5%. To veto events that had additional decay products outside the acceptance of the drift chambers or calorimeter, there were veto counters at periodic stations in the decay region and spectrometer. Two sets of hodoscopes upstream of the lead glass array were used to form the trigger for charged particles. The detector is described in greater detail elsewhere.[10]

The trigger for $\Lambda \rightarrow p\pi^-$ decays used a trigger board which took a copy of the drift chamber X view hits and determined whether a path of hits existed in the central 10 wires from each plane such that the bend angle was less than or equal to 1 wire. The trigger was biased in favor of positively charged particles by using an offset in position of the last drift chamber. A further requirement of the trigger was that the number of drift chamber hits be consistent with a two track decay. Finally, the trigger required that there be 2 hits in each trigger counter bank (and vetoed events with 3 or more hits in both trigger banks) and that there be no energy in the various veto counters of the apparatus.

After processing the data, those events with two reconstructed tracks in both the X and Y views of the drift chambers and with a calorimeter cluster of energy $E > 0.5$ GeV matching the low momentum track position were kept for further analysis. Cuts were made to ensure good quality tracks matched to a vertex. The hits in the drift chambers associated with the two tracks were required to satisfy the conditions of the trigger. The two tracks had to be opposite in sign, with the higher momentum track being positively charged for the Λ sample and negatively charged for the $\bar{\Lambda}$ sample. The lower momentum track was required to be at least 1.2 cm away from either of the beam holes in the calorimeter to ensure good particle identification.

Figure 1a shows the number of lambda proper lifetimes from the target, τ_Λ, for the data in the Λ decay sample. As can be seen, there are a number of events beyond 10 lifetimes from the target. This long-lived sample is correlated with a response in the calorimeter that is consistent with an electron signal. These events are background coming from the decay $K_L \rightarrow \pi e \nu_e$ (Ke3). The level of this background is the same for the two polarization settings. A cut of $\tau_\Lambda < 10$ and $E/p < 0.8$ was imposed on the data sample, reducing the Ke3 background to below 1%. To ensure that each event was consistent with a Λ or $\bar{\Lambda}$ decay, the invariant mass of the two tracks was calculated, with the higher momentum track assumed to be a proton and the lower momentum track a pion. This reconstructed mass, $m_{p\pi}$, was required to be within 15 MeV/c^2 of the nominal Λ mass, 1115.6 MeV/c^2.[12] The reconstructed momentum transverse to the Λ direction of motion from the target was required to be less than 45 MeV/c. Figure 1b shows the distribution of $m_{p\pi}$ before and after the cuts on τ_Λ and E/p. The number of decays passing all of the cuts in the Λ data sample is 379247, of which 186146 events have 0° precession of the polarization. The number of events in the $\bar{\Lambda}$ sample is 11464, of which 5522 have 0° precession of the polarization.

Another source of background comes from decays $K^\circ \rightarrow \pi^+\pi^-$, with the positive pion misidentified as a proton. An estimate can be made for the level of this background from the data in the sidebands of the invariant mass spectrum, or $15 < |m_{p\pi} - m_\Lambda| < 30$MeV/c^2. A clear pion-pion mass peak is evident at the value of the neutral kaon mass, 498 MeV/c^2. The number of K° decays in the mass sidebands that pass all other cuts is then an estimate for the background under the Λ mass peak itself. The estimate of the background level from K° decays is about 0.4% for the Λ sample and about 6.4% for the $\bar{\Lambda}$ sample.

The polarization of the Λ particles in our beam is determined by first splitting the data into two oppositely polarized samples. The direction cosines of the pion momentum vector in the center of mass of the decay, $[cos\theta_x, cos\theta_y, cos\theta_z]$, were calculated. For a sample of decays where the Λ has an average polarization, $\vec{\mathbf{P}}$, the distribution of the direction cosines will be:[11]

$$N_\pm(cos\theta_i) \propto A(\cos\theta_i)[1 \pm \alpha_\pi P_i cos\theta_i] \qquad (1)$$

for i=x,y,z and with α_π being the previously determined value for the pion asymmetry in lambda decays, $\alpha_\pi = -0.642 \pm 0.013$.[12] The function $A(cos\theta_i)$ describes the acceptance for Λ decays as a function of their center of mass decay angle. The distribution N_+ refers to the set of data with no net precession of the lambda polarization vector while N_- refers to the set of data with the opposite polarization. We then form the ratio:

$$R_i = \frac{(N_+ - N_-)}{(N_+ + N_-)} = \alpha_\pi P_i cos\theta_i \qquad (2)$$

The slope of this ratio with respect to $cos\theta_i$ then gives the asymmetry $\alpha_\pi P_i$, from which the polarization P_i can be obtained. The acceptance of the detector does not enter this calculation of the polarization.

Figure 2 shows a comparison between the distributions of the direction cosines of the pion for the entire set of Λ decays for the two magnet settings. The error bars are statistical only. As can be seen, the cosine distributions are essentially identical in the X and Z directions. In the Y direction, however, the distributions differ dramatically, showing the effect of the differing polarizations on the pion decay distribution. Also shown in Figure 2 are the plots of the ratio defined in Equation 2. A slope fit to these graphs gives average asymmetries of -0.0002 ± 0.0037 in the X direction, 0.0639 ± 0.0028 in the Y direction and 0.0071 ± 0.0028 in the Z direction. The asymmetry is consistent with zero in the X and Z directions. The data were split into separate groups of runs to determine if there was any time dependence to the asymmetry calculated in this fashion. Figure 3 shows that there is no significant time variation in the calculated Λ asymmetries.

The Λ data sample was then divided into E_Λ bins and the polarization was obtained for each energy range. Results for the Y direction polarization are shown in Table 1. In all cases, the polarizations in the X and Z directions were consistent with zero to less than two standard deviations.

The entire $\bar{\Lambda}$ data sample was analyzed using the same method. A Y polarization of 0.013 ± 0.025 was obtained for this sample, which had an average energy of $251.8 \pm .6$ GeV, or average transverse momentum of 1.22 GeV/c. The polarizations in the X and Z directions were consistent with zero as well.

An estimate for the level of systematic error on our measurement of the Λ polarization was obtained from the largest value of polarization in the X or Z direction, where there should be no net polarization. This value was 0.0071, in the Z direction. A systematic check was made on the data to see if there were any variation in the calculated Y polarizations in a given energy range when additional constraints on the data were imposed. These constraints included determining polarization from each of the two beams separately and comparing the polarization obtained from decays upstream of 85 meters to the decays downstream of that position. The changes seen in the calculated Y polarization indicate a systematic error consistent with ± 0.0071. An estimate for the error in the calculated polarization induced by any uncertainty in the field values of the magnets in the beamline indicates that there would be at most an error of 0.002. The value of 0.007 was therefore used as the estimate for our systematic error. In the presentation of data in Table 1 we have combined statistical and systematic errors in quadrature.

Table 1: Polarization of Λ produced at 800 GeV. The errors are combined statistical and systematic.

Energy Range	# of events	Average Energy	p_T	x_F	$< P_Y >$
100-150 GeV	6308	137.5 $\pm$ .1 GeV	0.67 GeV/c	0.172	-0.066$\pm$0.038
150-200	50344	180.5 $\pm$ .1	0.87	0.226	-0.064$\pm$0.016
200-250	104902	226.2 $\pm$ .1	1.09	0.283	-0.079$\pm$0.014
250-300	101896	273.7 $\pm$ .1	1.32	0.342	-0.089$\pm$0.014
300-350	64629	322.5 $\pm$ .1	1.56	0.403	-0.126$\pm$0.015
350-400	31999	371.5 $\pm$ .1	1.80	0.465	-0.163$\pm$0.019
400-800	19123	444.2 $\pm$ .3	2.15	0.556	-0.198$\pm$0.023

Figure 4 shows the polarization of Λ particles with respect to their average transverse momentum from the target. On this same graph, data from Fermilab experiment 555 has been superimposed.[13] This set of data had a targeting angle of approximately 9.6 mrad, twice our targeting angle, and a proton beam energy of 400 GeV, half the energy of our own. The E555 data will have the same x_F values as the data presented here, for the same values of p_T of the Λ, and are therefore directly comparable. No significant energy dependence in Λ polarization is seen between the two production energies of 400 and 800 GeV. This contrasts markedly to the situation with the Ξ^- hyperon, where differences in polarization between the two production energies are as large as a factor of two, with the 800 GeV data having a greater polarization than the 400 GeV data.[8] The polarizations at these two energies for the Σ^+ hyperon also differ by as much as a factor of 2, but with the 800 GeV data having a lower polarization than the 400 GeV data.[9]

In conclusion, we have determined the polarization of Λ hyperons produced in hadroproduction at 800 GeV at a fixed targeting angle of 4.8 mrad. By comparing this level of polarization with that determined previously for hadroproduction at 400 GeV at a fixed targeting angle of 9.6 mrad, we find that there is no significant energy dependence in Λ polarization at these energies. This is in significant contrast to the energy dependence found in the polarizations of both Ξ^- and Σ^+ at these same energies. We find no significant polarization for $\bar{\Lambda}$ produced at 800 GeV.

We thank the Fermilab management and staff and the technical staffs of the participating institutions for their vital contributions. This work was supported in part by the U.S. Department of Energy and the U.S. National Science Foundation. One of us (Y.W.W.) wishes to acknowledge support from a DOE Outstanding Young Investigator grant and a Block Grant Award from the University of Chicago Enrico Fermi Institute.

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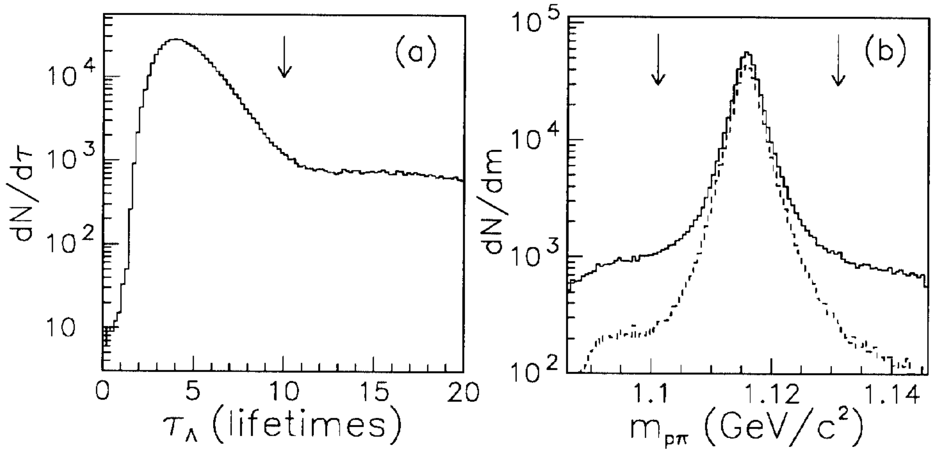

Figure 1: For the Λ decay sample discussed in the text, a) is the number of proper lifetimes, τ_Λ, from the target of the event vertex. b) is the reconstructed $p\pi^-$ mass, in GeV/c^2, with the solid line before cuts on the variables τ_Λ and E/p, and the dashed line after cuts on these variables. Arrows indicate cut values.

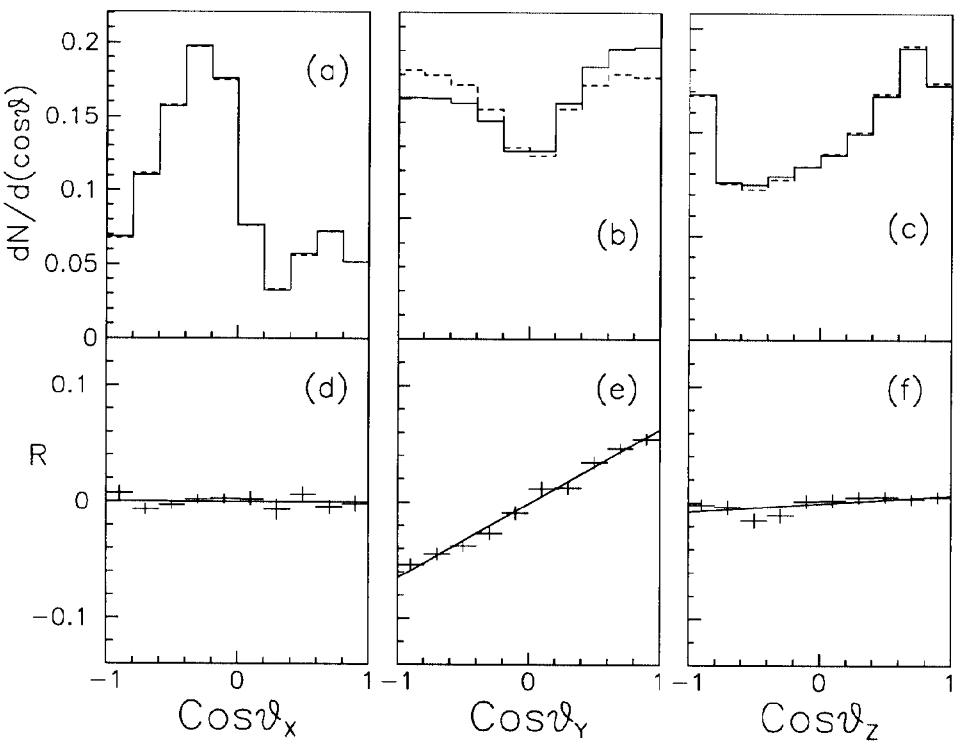

Figure 2: The normalized cosine distributions $N_{\pm}$ in the a) X, b) Y and c) Z directions. Solid lines are N_+ and dashed are N_-. Graphs d), e), and f) show the ratio defined in equation 2.

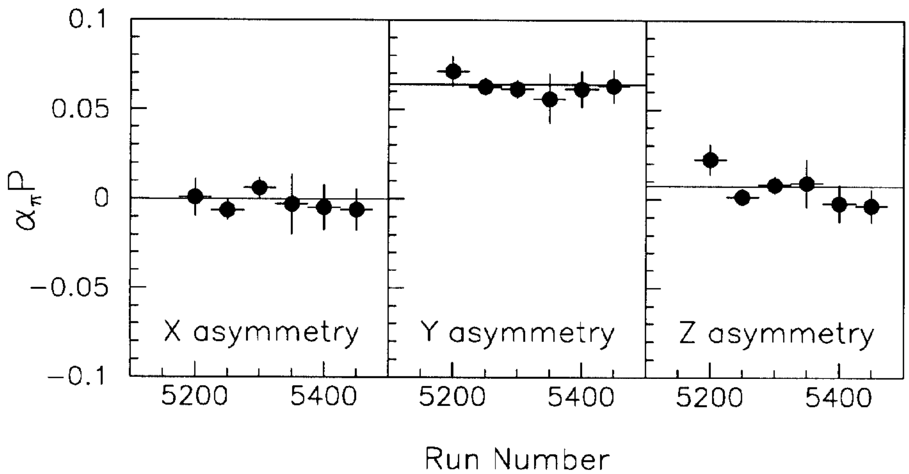

Figure 3: The run dependence of the Λ pion decay asymmetry in the X,Y and Z directions.

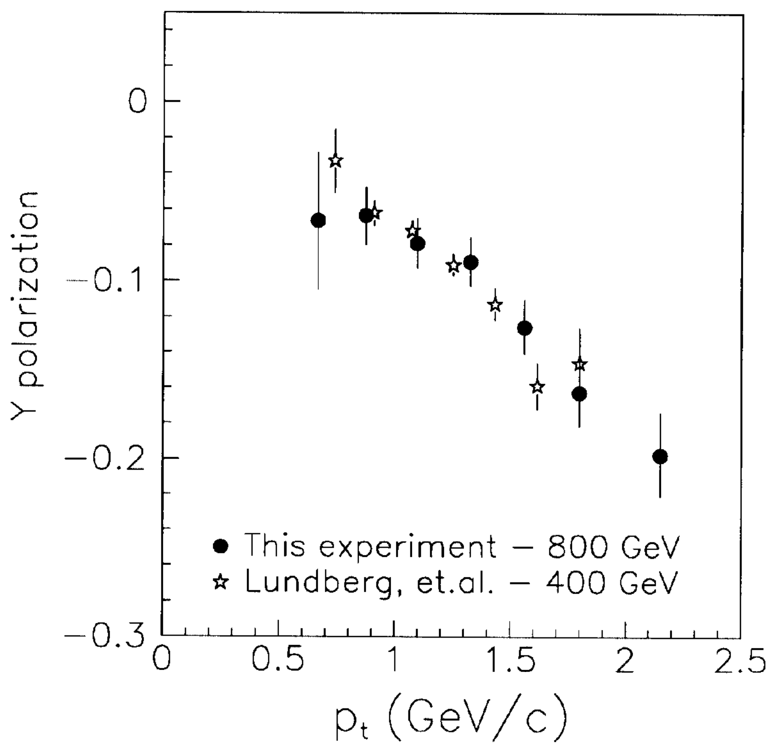

Figure 4: The average Λ polarization vs the average transverse momentum, p_T. For comparison, the data from 400 GeV production (ref. 13) are shown.