Fermi National Accelerator Laboratory

FERMILAB-Conf-82/84-EXP
7190.497

Σ^+ AND Σ^- PRODUCTION POLARIZATIONS*

P. S. Cooper, E. W. Anderson, C. Ankenbrandt, J. P. Berge, A. Breakstone, A. E. Brenner, J. Butler, T. Cardello, K. Doroba, J. Elias, J. Lach, P. Laurikainen, J. MacLachlan, J. Marriner, E. McCliment, L. J. Teig, J. Thron, and Y. W. Wah

Fermi National Accelerator Laboratory, University of Iowa, Iowa State University, and Yale University

November 1982

*Submitted to the 5th International Symposium on High Energy Spin Physics, Brookhaven National Laboratory, September 16-22, 1982

Σ^+ and Σ^- PRODUCTION POLARIZATIONS

P. S. Cooper, E. W. Anderson, C. Ankenbrandt, J. P. Berge
A. Breakstone, A. E. Brenner, J. Butler, T. Cardello, K. Doroba
J. Elias, J. Lach, P. Laurikainen, J. MacLachlan, J. Marriner
E. McCliment, L. J. Teig, J. Thron, Y. W. Wah

Fermilab, Univ. of Iowa, Iowa State Univ., and Yale Univ.

ABSTRACT

We report preliminary results from Fermilab experiment E497 on the production polarizations of Σ^+ and Σ^- hyperons. Hyperons were produced inclusively at non zero production angles by 400 GeV/c protons incident on a Cu target. The polarization was analyzed by the weak decay asymmetry in the hadronic decay modes $\Sigma^+ \to p\pi^0$ and $\Sigma^- \to n\pi^-$. Based upon samples of 38,000 Σ^+ and 317,000 Σ^- decays we observe polarizations as a function of P_t which average 22% at an X of 0.53 for Σ^+ and 40% at X of 0.68 and 0.78 for Σ^-. The direction of polarization for both Σ^+ and Σ^- is in the direction of $\underline{K}_p \times \underline{K}_\Sigma$ where the $\underline{K}$'s are the momentum vectors of the incident proton and produced hyperon respectively. This is opposite to the direction of polarization of inclusively produced lambdas.

INTRODUCTION

Experiment E-497 at Fermilab was a survey experiment of charged hyperon beam physics. The goals were to measure charged hyperon fluxes, production polarizations, and magnetic moments. We report here preliminary results for Σ^+ and Σ^- production polarizations. Fluxes[1] and magnetic moments[2] were reported in other talks at this conference. We also have data on Ξ^- and Ω^- production polarizations which are not ready for presentation at this time.

APPARATUS

The basic scheme of the experiment is to produce hyperons with 400 GeV/c protons incident on a Cu target, and define a hyperon beam with a narrow curved channel in a large dump magnet (7m x 35kG). By varying the direction and angle at which protons strike the target we can vary the hyperon production angle. Since the direction of any hyperon polarization must be normal to the scattering plane, we can thus vary the direction of hyperon polarization. We select the hyperon momentum by simply adjusting the magnetic field. The hyperon beam has a momentum spread of ± 7% and a momentum range of 100-350 GeV/c. Hyperons leaving the magnet are tagged by a set of high resolution proportional chambers which give hyperon momenta to 0.7%(σ) and angles to 30 μr(σ). The hyperons are then allowed to decay in a 20m long decay region. Following the decay region is a drift chamber spectrometer to measure the charged decay products. The angular resolution of the spectrometer is 100 μr(σ) and the momentum resolution ~ 1%(σ). Finally there are a set of counters for neutrons, gammas, and charged particles used only for the trigger.

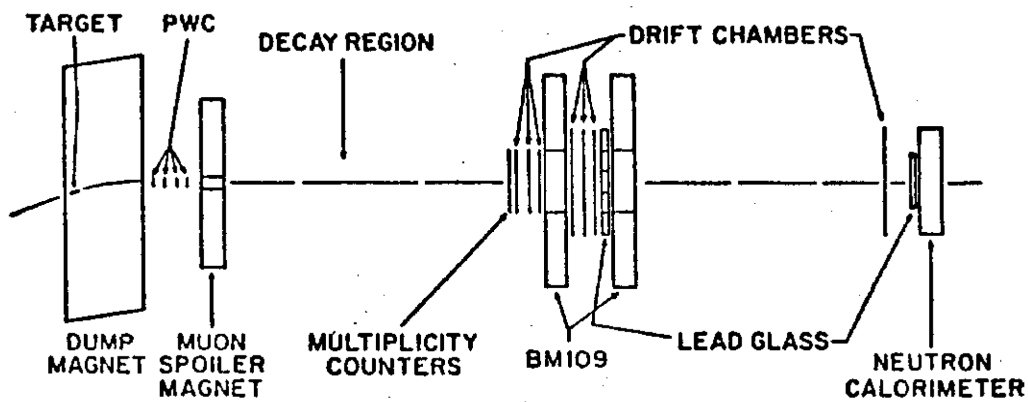

Figure 1 - Plan view of the apparatus

This apparatus has a geometrical acceptance of > 95% for the decay modes $\Sigma^+ \rightarrow p\pi^0$ and $\Sigma^- \rightarrow n\pi^-$. The mass resolution for these modes are 24 MeV/c^2 and 7 MeV/c^2 respectively. The larger Σ^+ mass resolution is due to the smaller lab angles of the proton in Σ^+ decay.

The trigger consisted of a beam track plus a neutral particle. For Σ^- this was the neutron seen in the neutron calorimeter. For Σ^+ a gamma from the decay of the π^0 was detected in either of the two lead glass arrays.

ANALYSIS

In negative beam 60% of the triggers reconstruct as good hyperon decays. The balance are essentially all hyperon decays upstream of the fiducial volume. At the kinematic points where most of the data were taken the hyperon beam was ~ 25% Σ^-. In positive beam 5 - 10% of the triggers reconstruct as good $\Sigma^+ \rightarrow P\pi^0$ candidates. The beam is ~1% Σ^+ due to the large number of diffractive protons.

The only significant cuts applied to the data are the requirement that the hyperon extrapolate back to the production target in the vertical (non-bend) plane (28% loss) and that the reconstructed mass be within 10 standard deviations of the Σ mass (5% loss). For a subset of the Σ^- data where the targeting angle was in the horizontal plane a fiducial volume cut; $7\text{m} < Z_{vertex} < 25\text{m}$ was also made (~ 26% loss).

For each good hyperon candidate we calculate center of mass direction cosines for the charged final state particle directly from lab quantities as follows:

$$\cos\theta_t = \frac{P_t^c}{q} = P^c\{\theta_t^c - \theta_t^\Sigma\} \qquad t=x,y \tag{1}$$

$$\cos\theta_z = 2(P_z^c - P_z^{90})/(P_z^{max} - P_z^{min}) \tag{2}$$

where P_x^c, P_y^c, P_z^c is the lab momentum vector of the charged secondary with magnitude P^c, q is P_t^{max} for the decay mode. The constants in (2), like q, depend only upon particle masses. Our coordinate system is such that Z is the hyperon beam direction, Y is up, and X is horizontal so as to form a right handed system.

The observed angular distributions in these variables are given by:

$$\frac{dN}{d(\cos\theta_i)} = N_o\, A_i(\cos\theta_i)\,\{1 \pm \alpha P_i \cos\theta_i\} \qquad i=x,y,z \qquad (3)$$

where P_i are the components of the hyperon polarization, α, the alpha parameter of the decay mode ($\alpha_{p\pi^o}$= -.979, $\alpha_{n\pi^-}$= -.068), and the $A_i(\cos\theta_i)$ are functions which describe the acceptance and efficiency of the apparatus including all cuts. The negative sign is taken for Σ^- decay since the alpha parameters are defined for the final state baryon and we measure the π^+.

TARGETING

We have taken data for both horizontal and vertical targeting angles. For horizontal targeting the incident protons are bent by upstream magnets in the horizontal plane through the range $\theta_x = \pm 3.5$ mr. The normal to the scattering plane is in the vertical (Y) direction parallel to the magnetic field of the dump magnet. Thus for horizontal targeting the magnetic moment, and therefore any polarization, of the hyperon does not precess in passing through the field of the dump magnet. In this way we can measure the production polarization independent of knowledge of the magnetic moment. Note that for horizontal targeting we expect only P_y to be non zero in (3), giving only an up-down asymmetry.

For vertical targeting the protons are bent in the vertical plane by up to $\theta_y = \pm 7$ mr, producing an initial polarization in the X direction which then precesses about the vertical field. Therefore in the decay region we expect only P_x and P_z to be non zero. From the ratio of these components we can calculate the magnetic moment[2].

We adopt the standard sign convention defining a positive polarization in the direction $\underline{K}p$ X $\underline{K}y$ where the $\underline{K}$'s are the momentum vectors of the incident proton and produced hyperon respectively.

BIASES

In order to cancel asymmetries induced by biases in our apparatus we use two independent techniques for the horizontal and vertical targeting data. For the horizontal targeting data we made a fiducial volume cut so that the $A_i(\cos\theta_i)$ of (3) are essentially flat from Monte Carlo studies. We then fit each $\cos\theta_i$ distribution to the form $I_i + S_i\cos(\theta_i)$ in the region $|\cos(\theta_i)| < .88$. The polarization component is extracted as $\alpha P_i = S_i/I_i$. We check for biases by calculating:

$$B_i = (P^+_i + P^-_i)/2 \qquad (4)$$

$$\bar{P}_i = (P^+_i - P^-_i)/2 \qquad (5)$$

where the signs refer to runs with equal and opposite horizontal targeting angles. B_i is the bias and $\bar{P}_i$ the average polarization for these runs. Results are shown in Table I below.

TABLE I Σ^- Horizontal targeting data

P(GeV/c)	θ_p(mr)	events	$\bar{P}_x$	B_x	$\bar{P}_y$	B_y	error
-271	±1.2	60K	.02	-.11	.29	.06	.12
-271	±3.5	54K	-.32	-.51	.50	.02	.13

For vertical targeting data we use the up-down symmetry of the apparatus to cancel any bias and simultaneously measure $A_i(\cos\theta_i)$. By dividing the $\cos\theta_i$ distributions for two runs of equal and opposite vertical targeting angles we can cancel $A_i(\cos\theta_i)$.

$$R_i(\cos\theta_i) = \frac{1 + \alpha P_i \cos\theta_i}{1 - \alpha P_i \cos\theta_i} = \frac{\frac{1}{N_o^+}\frac{dN^+}{d(\cos\theta_i)}}{\frac{1}{N_o^-}\frac{dN^-}{d(\cos\theta_i)}} \qquad (6)$$

$$P_i = \frac{1}{\alpha\cos\theta_i}\ \frac{R_i - 1}{R_i + 1} \qquad (7)$$

by averaging (7) over all $\cos\theta_i$ bins we obtain P_i. Plots of R_i versus $\cos\theta_i$ are shown in figures 3 and 4 of reference 2.

DATA

Our results are shown in Tables II and III and figures 2 and 3 where the magnitude of the polarization is plotted versus P_t. We also show the measurements of experiment E-620[3].

TABLE II Σ^+ Polarizations

P(GeV/c)	θ_p(mr)	events	X	P_t(GeV/c)	Pol
210	±2.5 V	6K	.53	0.53	.227 ± .034
210	±3.25 V	6K	.53	0.68	.297 ± .034
210	±5.0 V	18K	.53	1.05	.194 ± .019
210	±7.0 V	14K	.53	1.47	.147 ± .021

TABLE III - Σ^- Polarizations

P(GeV/c)	θ_p(mr)	events	X	P_t(GeV/c)	Pol
-271	±1.2 H	60K	.68	0.32	.29 ± .11
-271	±3.5 H	54K	.68	0.95	.50 ± .13
-271	±5.0 V	80K	.68	1.27	.40 ± .13
-310	±5.0 V	90K	.78	1.46	.54 ± .12
-271	±7.0 V	33K	.68	1.88	.21 ± .14

These data include our total sample of Σ^+ decays and 15% of our Σ^- data sample. All polarization components expected to be zero are in fact consistent with zero with the exception of the Σ^- ±3.5mr horizontal data where the bias is all due to one run. Note that the horizontal and vertical data give consistent results. These are independent analyses and are sensitive to biases in quite different ways. The Σ^- results are by far the most sensitive to systematic effects since the α parameter is so small.

CONCLUSIONS

We have measured production polarizations for Σ^+ and Σ^- in the large X region. The Σ^+ results are in agreement with previous measurements giving 22% polarization at P_t=1 GeV/c in a direction opposite to that of inclusively produced lambdas[4]. The Σ^- results are much larger than previous measurements[5] which tend to indicate an X dependence of production polarization. In terms of future experiments we have a source of 50% polarized Σ^- at the rate of ~ 10^4/sec! Work is continuing on the analysis of the balance of the Σ^- data and the other hyperons. Specifically we will be able to better understand our systematic biases in the Σ^- result and reduce the statistical error by more than a factor of 2 within the next few months.

REFERENCES

1. L. J. Teig, et. al., Charged Hyperon Fluxes, Published in this proceedings.
2. J. Marriner, et. al., Magnetic Moments of the Σ^+ and Σ^-, ibid.
3. C. Wilkinson, et. al., Phys. Rev. Lett. 46, 803 (1981).
4. K. Heller, et. al., Phys. Rev. Lett 41, 607 (1978).
5. L. L. Deck, Ph.D thesis, Rutgers Univ., 1981 (unpublished).

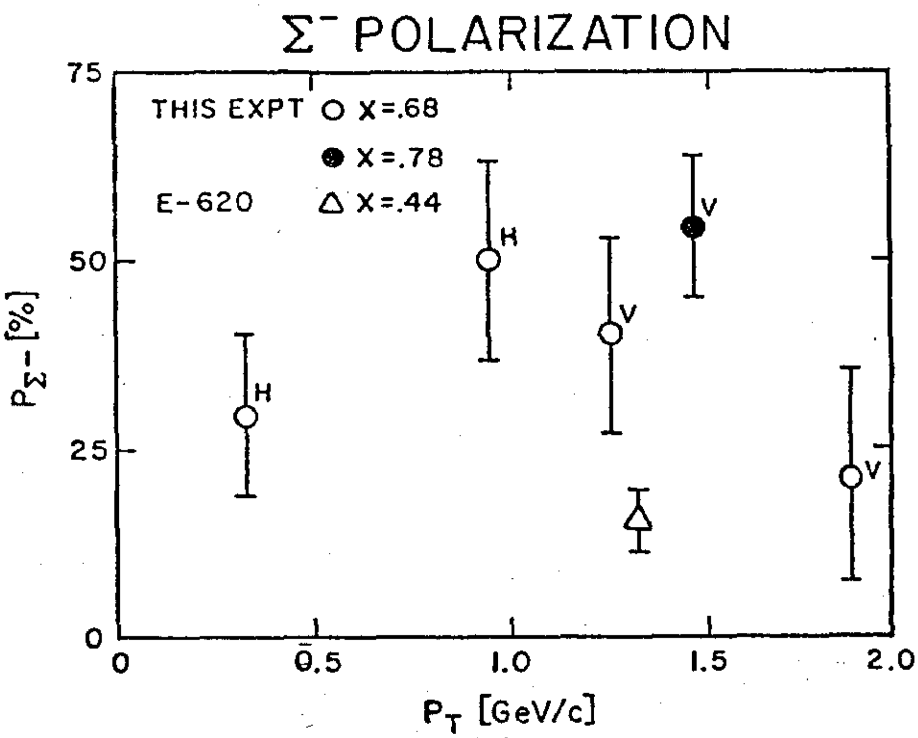

Figure 2. Σ^- production polarization plotted versus P_t. H and V indicate horizontal and vertical targeting data respectively. The E-620 datum is from Reference 5.

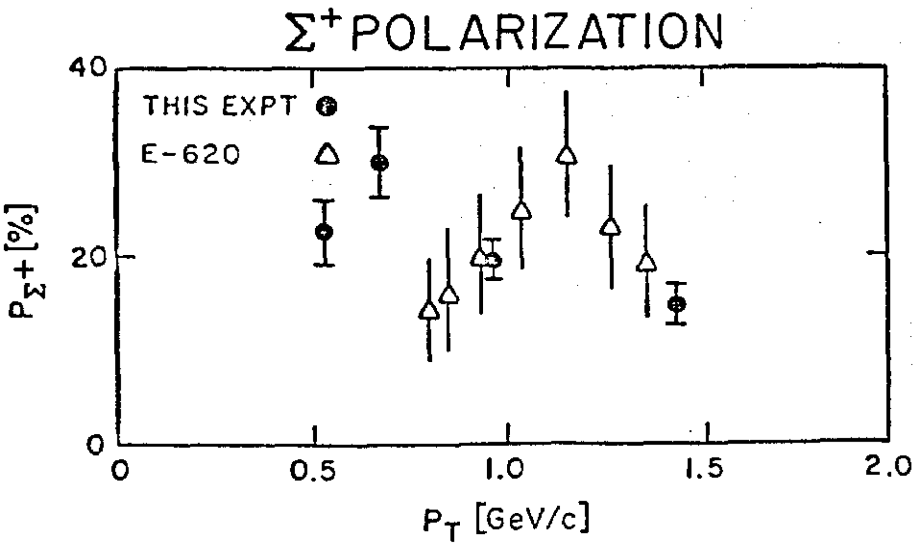

Figure 3. Σ^+ production polarization plotted versus P_t. All data from this experiment are at X=0.53. The E-620 data are at $X=P_t/2.0$ GeV/c (Reference 3).