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Polarization of Σ^+ Hyperons Produced by 400 GeV Protons

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Abstract

We have measured the polarization of 22,000 Σ^+ hyperons produced by 400 GeV protons on Be. The polarization is opposite in sign to that of the Λ. The magnitude increases with momentum at 5 mrad production angle, and averages 22% over the momentum range 140 to 280 Gev/c.

This letter reports the first observation of polarization in high energy charged hyperon production. A short positive 200 GeV/c secondary beam produced by 400 GeV protons incident on a beryllium target contained Σ^+ hyperons which were detected via the decay $\Sigma^+ \to p\pi^\circ$. Preliminary data reported here show that the polarization is comparable in magnitude, but opposite in sign, to that previously observed for Λ's.[1] The sign change is anticipated by a simple quark model picture of the production reaction.[2]

The experiment was performed in the M2 beam at Fermilab. A schematic view of the apparatus is shown in Figure 1. A series of bending magnets permitted steering of the proton beam onto the one-half interaction length Be target at angles of +5 or -5 mrad in the vertical plane. Parity conserving polarization was defined to be positive in the direction $\vec{k}_p \times \vec{k}_\Sigma$, where $\vec{k}_p$ and $\vec{k}_\Sigma$ were the incident proton and outgoing Σ^+ momenta. This vector pointed along + x for +5 mrad. A vertical magnetic field (parallel to -y) steered the charged beam through a 5.3 m long curved channel. The field integral was 6.6 Tm. A central ray through the collimator was bent 10 mrad, corresponding to 200 GeV. The channel transmitted useful numbers of particles between 140 and 280 GeV/c.

The detector was the basic multi-wire proportional chamber (MWPC) spectrometer used in the neutral beam experiment,[3] augmented by a scintillation counter S1, a set of three drift chambers (D1-D3) and two MWPC's (C1, C2) located upstream. These served to detect the

$\Sigma^+ \rightarrow p\pi^\circ$ decay vertex and to measure the Σ^+ momentum from its trajectory through the channel. The daughter proton momentum was measured in the downstream spectrometer (MWPC C3 - C5, bending magnet, C6 - C8). A lead glass array at the back of the spectrometer detected at least one γ ray from the π° decay.

The trigger selected events in which a high momentum, positively charged particle passed through the upstream detectors and the spectrometer, accompanied by a signal in the lead glass. The charged track signature was S = S1*C3*PC. The gamma trigger (GOR) required a pulse height from the summed lead glass counters corresponding to a shower energy greater than 3 GeV. Triggers from charged particles striking the glass were prevented by the veto counter (T). The full event trigger coincidence was $\Sigma = S*GOR*\overline{T}$. A small fraction (1/1024) of particles with only the S signature was mixed into the event trigger in order to obtain a sample of beam tracks.

Data at one production angle were taken under stable conditions for about four hours (2 tapes of $\sim$52,000 triggers each), after which the production angle was reversed and the process repeated. The beam intensity was kept at a level compatible with high, stable drift chamber efficiency. This corresponded to about 1.5×10^9 protons per pulse on the beryllium target, and 2×10^5 charged tracks through the upstream part of the apparatus. About 0.5% of the positively charged beam after the magnetic channel was Σ^+ hyperons.

The horizontal and vertical position of the beam on the production target were carefully maintained at optimum for each production angle. Approximately 2,800,000 triggers were collected of which 4.5% could be reconstructed and identified as Σ^+. The data used for this report comprise 18% of the total sample. Matched pairs of tapes for +5 mrad and -5 mrad production angle data were selected at intervals from the whole data set.

Only the charged track information was used for this analysis. A geometric fitting program searched for a single, positively charged track through the spectrometer with a kink between D1 and C3. Events which also fit a "no-kink" hypothesis were classified as beam tracks and rejected. The momentum of the Σ^+ was determined by fitting the tentative Σ^+ track through the curved collimator with the target and the collimator apertures as constraints. Figure 2 shows the invariant mass computed under the hypothesis that the positive decay product is a proton and the missing neutral is a π°.

Finally, a full kinematic fit was performed to the hypothesis $\Sigma^+ \to p\pi^\circ$, with the Σ^+ mass as a constraint. From the parameters of this fit, the direction cosines of the proton momentum in the Σ^+ rest system were computed along the local coordinate axes: $\hat{z}$ parallel to the Σ^+ lab momentum, $\hat{y} \perp \hat{z}$ in the vertical plane, and $\hat{x} = \hat{y} \times \hat{z}$ (horizontal). The Σ^+ polarization $\vec{P}$ was determined by the asymmetry in the angular distribution of the daughter protons along each of these axes.

The event distribution in the x direction cosine was expressed as

$$R_x^{\pm}(\cos\theta_i) = \frac{\Delta}{2} A_x(\cos\theta_i)(1 \pm \alpha_\Sigma P_x \cos\theta_i), \qquad (1)$$

with similar equations for the y and z components. Here the ± signs refer to ±5 mrad production, $\alpha_\Sigma = -0.979 \pm 0.016$,[4] $\cos\theta_i$ is histogrammed in 20 equal bins of width $\Delta = 0.1$, and $A_x(\cos\theta_i)$ is the acceptance of the apparatus. The acceptance depended on the component x, the $\cos\theta_i$ bin, and the Σ^+ momentum. It was normalized to unity over the range $-1 < \cos\theta_i < +1$. For each bin $\cos\theta_i$ the asymmetry was calculated from the ratio

$$\alpha_\Sigma P_x \cos\theta_i = (R_x^+(\cos\theta_i) - R_x^-(\cos\theta_i))/(R_x^+(\cos\theta_i) + R_x^-(\cos\theta_i)), \qquad (2)$$

and then a least squares fit was performed to determine the best value of αP_x. This technique cancelled effects due to acceptance biases. The data were divided in 20 GeV/c wide Σ^+ momentum bins between 140 GeV/c and 280 GeV/c. The data for the ratio defined by Equation (2), averaged over all momenta, are plotted in Figure 3.

The vector $\vec{P}$ determined by these components must then be corrected for precession in the field of M2. Using $\mu_\Sigma = (2.33 \pm 0.13)$[5] nuclear magnetons as the Σ^+ magnetic moment, the angle between $\vec{P}$ and the Σ^+ momentum vector $\vec{k}_\Sigma$ should change by 186° ± 16°. Rotating $\vec{P}$ by this amount gave the polarization vector at the production target, which was along the direction $\vec{k}_p \times \vec{k}_\Sigma$ within statistical uncertainties.

Systematic uncertainties in the polarization are estimated to be 0.05, and were combined in quadrature with the statistical uncertainty. The values of $\vec{P}_o$ as a function of p_Σ, the momentum of the Σ^+, are plotted in Figure 4, along with comparable data for Λ.[6] The magnitude of the Σ^+ polarization is the same as that of the Λ at the same momentum. The most remarkable feature of this new data is that the sign of the polarization is opposite that of Λ.

The simple quark model referred to above assumes that one quark in the incident proton is lost through a hard collision, leaving a spectator di-quark (uu or ud) which then picks up an s quark to form the forward out-going hyperon. Thus uud $\rightarrow$ uus produces a Σ^+, while uud $\rightarrow$ uds produces either a Λ or a Σ°. Assume that the s quark is polarized by some unspecified mechanism. Then $P_\Lambda = P_s$, because the (ud) spectator is in a singlet state. For the Σ^+ and Σ° the non-strange quarks must be in a triplet state, so that the polarization of the composite baryon is opposite to that of the strange quark: $P_{\Sigma^+} = P_{\Sigma^\circ} = -\frac{1}{3} P_\Lambda$. The observed sign reversal is thus expected from the model, although the predicted magnitude $|P_{\Sigma^+}| = \frac{1}{3} |P_\Lambda|$ is smaller than the measured one.

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References

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2. The model is discussed in Reference (1). See also B. Andersson, et al., Phys. Lett. 85B, 417 (1979).
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4. Particle Data Group, Rev. Mod. Phys. 51, 51 (1980). This number is the average of several experiments.
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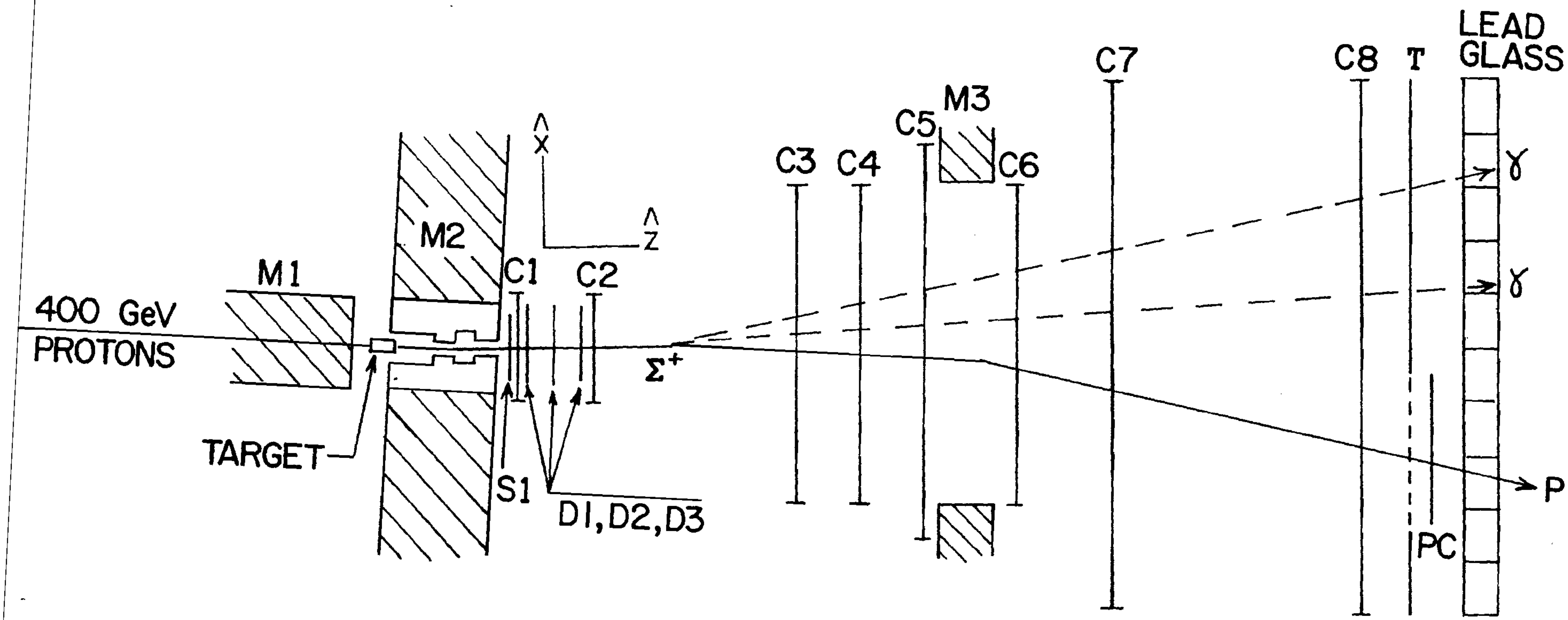
Figure Captions

1. Schematic of the charged hyperon beam in plan view. Magnet M1 deflected the protons onto the target in the vertical plane. M2 defined the charged beam by a 10 mrad horizontal bend angle. The defining collimator was in the center of M2, 4 mm in diameter and 3 m from the target. The x z coordinate axes rotated with the charged beam. The upstream detector and spectrometer system are described in the text. At the back of the apparatus decay protons were counted in the scintillator PC (proton counter). T was a large veto scintillator to reject charged particles which hit the glass. There were no lead glass blocks directly behind PC.

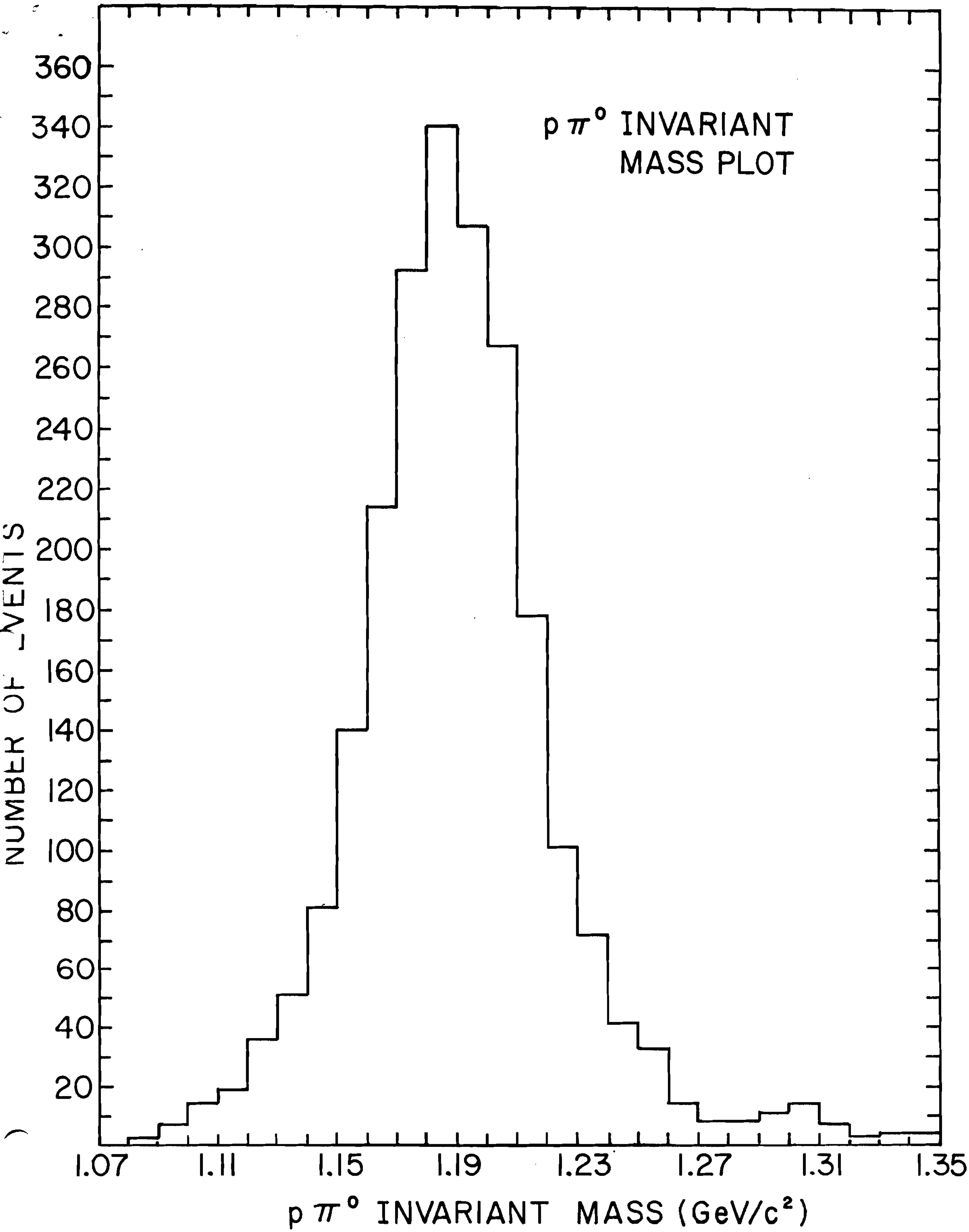
2. The $p\pi^\circ$ invariant mass plot obtained from the measured values of $\vec{p}_p$ and $\vec{p}_\Sigma$: $M^2 = \left(\sqrt{p_p{}^2 + m_p{}^2} + \sqrt{(\vec{p}_\Sigma - \vec{p}_p)^2 + m_\pi{}^2}\right)^2 - p_\Sigma{}^2$.

3. The measured ratio $\alpha_\Sigma P_x \cos\theta_i$ vs. $\cos\theta_i$ as defined by Equation (2) in the text for all Σ^+ data with 140 GeV/c $\leq p_\Sigma \leq$ 280 GeV/c. The slope of the solid line is αP_x for the total data sample. This asymmetry was observed after precession through 186°±16° in the magnetic channel, which explains the sign difference between P_x here (negative) and P_x at the production target in Figure (4) (positive).

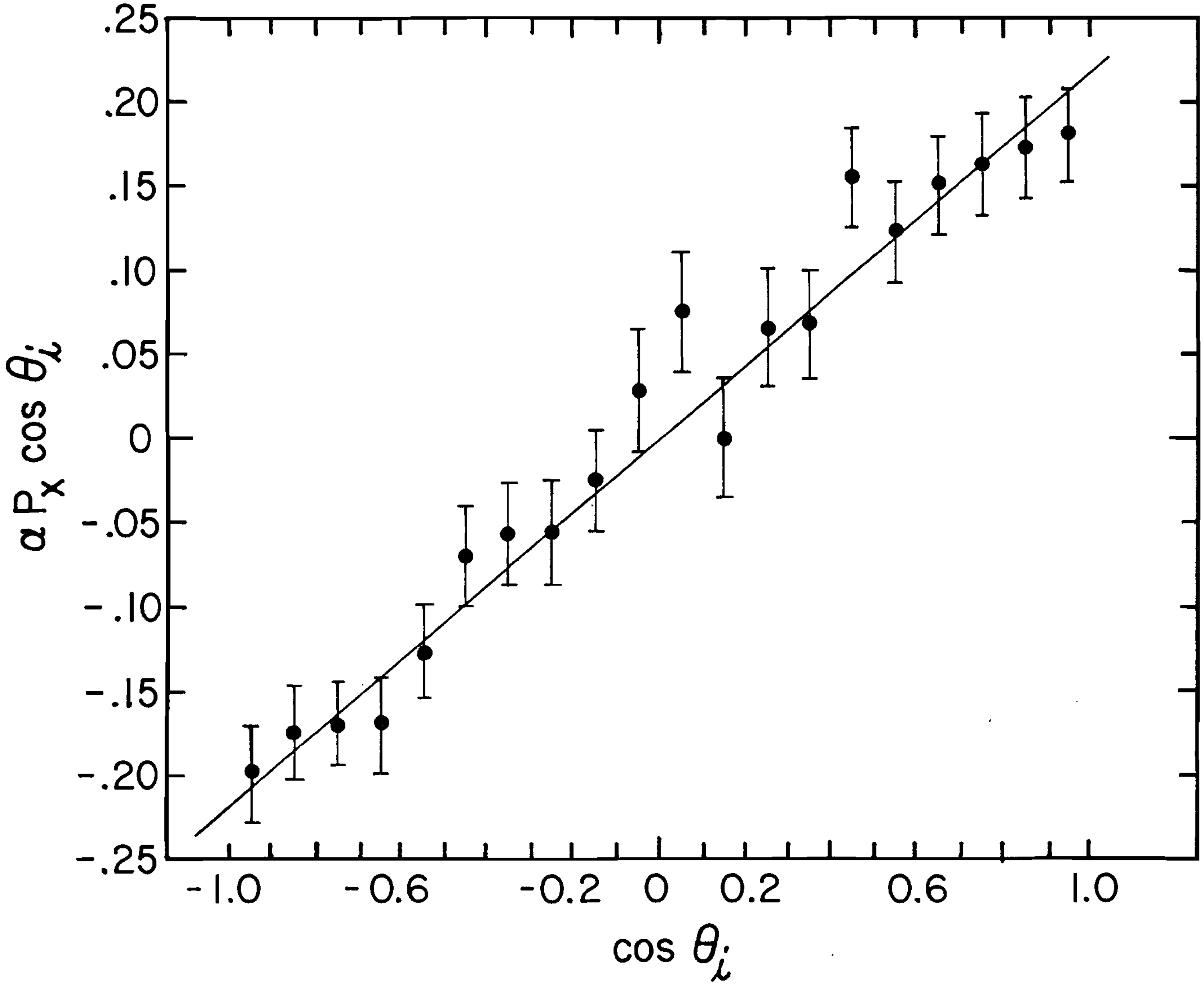
4. Polarization of Σ^+ hyperons vs. laboratory momentum for 5 mrad production. The sign choice is $+\vec{P}_\Sigma$ in the direction of $\vec{k}_p \times \vec{k}_\Sigma$. The 5 mrad Λ polarization data from Reference (6) are plotted for comparison. The observed polarizations are opposite in sign and approximately equal in magnitude.

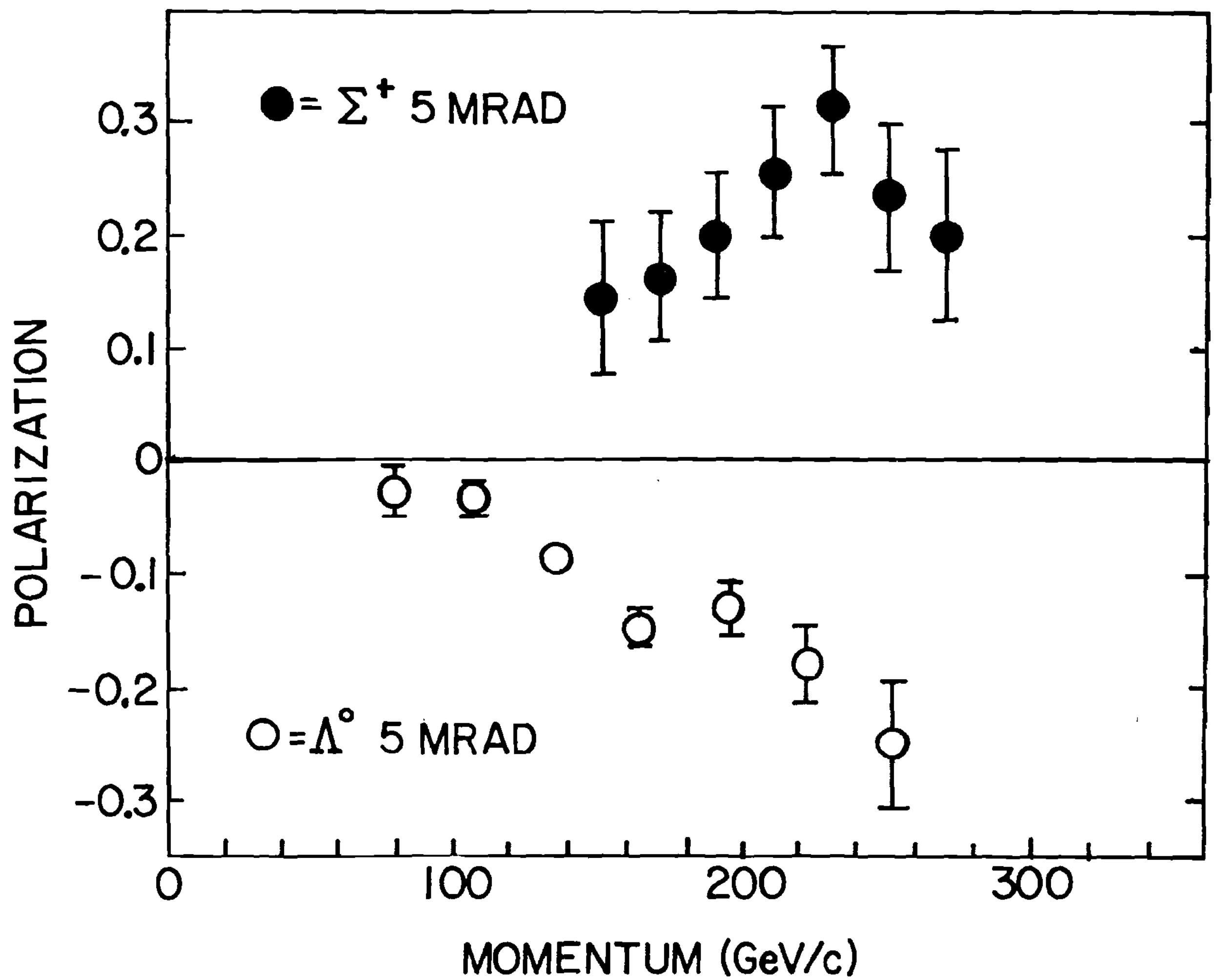

400 GeV
PROTONS
M1
TARGET
M2
X
Z
C1
C2
S1
D1,D2,D3
Σ+
C3
C4
C5
M3
C6
C7
C8
T
LEAD
GLASS
γ
γ
P
PC

PLAN VIEW



p π^0 INVARIANT
MASS PLOT
NUMBER OF EVENTS
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
1.07
1.11
1.15
1.19
1.23
1.27
1.31
1.35
p π^0 INVARIANT MASS (GeV/c^2)


.25
.20
.15
.10
.05
0
-.05
-.10
-.15
-.20
-.25
-1.0
-0.6
-0.2
0
0.2
0.6
1.0
$\alpha P_x \cos\theta_i$
$\cos\theta_i$



● = Σ⁺ 5 MRAD
○ = Λ° 5 MRAD
POLARIZATION
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
100
200
300
MOMENTUM (GeV/c)