Polarization of the Σ^0 and the Λ Particles Produced in the Reaction $\pi^- + p \rightarrow K^0 + \Sigma^0$ (Λ) at 1.17 and 1.32 BeV/c*

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The polarization of the Σ^0 and Λ particles in the reaction $\pi^- + p \rightarrow K^0 + \Sigma^0$ (Λ) has been measured at 1.17 and 1.32 BeV/c, using a spark-chamber–magnet system. Both polarizations are substantial and their angular distributions are clearly dependent on the beam momentum.

I. INTRODUCTION

PREVIOUS measurements of polarization of the Σ^0 particles produced in the reaction $\pi^- + p \rightarrow K^0 + \Sigma^0$ have been reported by several authors for incident-beam momenta of 1.8 BeV/c,[1,2] 1.17 BeV/c,[3,4] and also in the momentum interval 1.2 to 1.4 BeV/c.[5–7] These data indicate appreciable change in the polarization with beam momentum as well as with the Σ^0 production angle in the $\pi^- p$ c.m. system. Although the statistical uncertainties are large in these data, the magnitude of the polarization appears to be significantly nonzero In this paper, we report on our measurement of the Σ^0 polarization based on 846 events at 1.17 BeV/c and also at 1.32 BeV/c based on 919 events.

Our measurements of the polarization of Λ's produced in the reaction $\pi^- + p \rightarrow K^0 + \Lambda$ at the incident beam momenta of 1.17 BeV/c (1302 events) and 1.32 BeV/c (1156 events) are also presented in this paper.

Our measurements were taken from pictures obtained by an Argonne group at the CERN proton synchrotron in a magnetic spark-chamber system with a $1.4 \times 1.5 \times 8.0$ c.m. CH_2 target.[8]

II. EXPERIMENTAL PROCEDURE

The experimental setup used in this experiment has been described in detail elsewhere[8] and will not be discussed here.

Roughly 100 000 pictures were taken at each momentum. About 10% of these pictures showed two or more acceptable neutral V's associated with unambiguous beam tracks stopping in the CH_2 target. The scanners were instructed to classify these V's as K^0-, Λ-, or γ-conversion pair through track ionization and the opening angle of the V.

Pictures accepted by scanners were measured on an image-plane digitizer and then were processed through the GEOM–GRIND–RESONA[1] chain of computer programs. The data analysis was done at the Ohio State University (IBM 7090 computer, 1.32 BeV/c pictures) and also at the Argonne National Laboratory (CDC 3600 computer, 1.17 BeV/c pictures).

Each V was tested against the hypotheses $K^0 \rightarrow \pi^+ + \pi^-$ and $\Lambda \rightarrow \pi^- + p$. A 1% cutoff was imposed on the χ^2 probability, yielding about 15% rejection. A sample of these rejects has been carefully rescanned and remeasured. The results indicated that more than half of these rejects are conversion pairs and the remaining half are from pictures with excessive amount of background sparks or tracks.

Each $K^0\Lambda$ pair event was further checked against the following multivertex hypotheses:

$$\pi^- + p \rightarrow K^0 + \Lambda , \quad (1)$$

$$\rightarrow K^0 + \Sigma^0 , \quad (2)$$

$$\rightarrow K^0 + \Lambda + \pi^0 , \quad (3)$$

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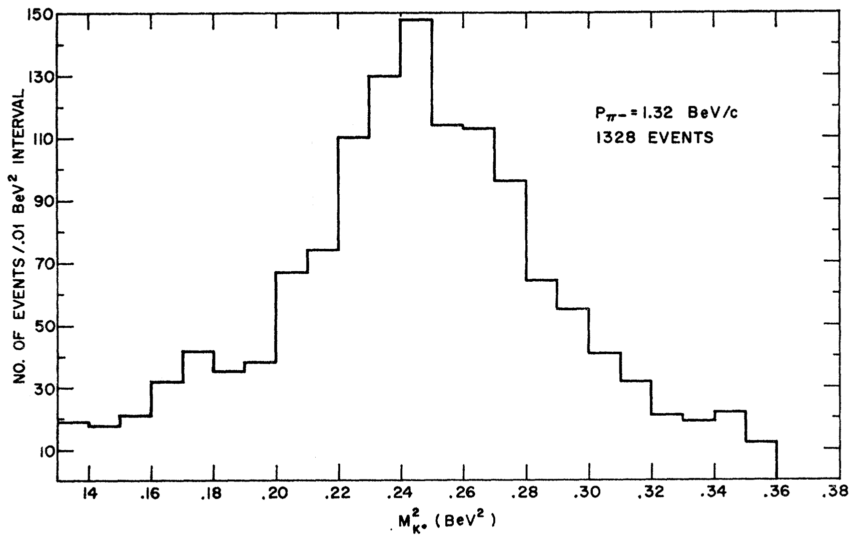

FIG. 1. Distribution of K^0 invariant mass squared computed from measured π^+, π^- momenta.

where the target proton is assumed to be at rest. Table I gives the number of events accepted for each of the production reactions listed above. In the multivertex fits, the beam momentum was assigned to the incident π^- track, but its direction cosines were those which were measured in each event.[9]

III. EXPERIMENTAL ERRORS AND BIASES

Figures 1 and 2 show, respectively, the square of K^0 and Λ invariant mass computed from the measured momenta from samples of our 1.32 BeV/c data. A similar resolution was obtained also at 1.17 BeV/c. The rms error on real-space spark position was about 1 mm and the average track length was about 20 cm.[10]

The various systematic biases inherent in our detection system have been described in detail elsewhere[1,8] and we discuss here only briefly biases which affect the polarization measurement.

TABLE I. Number of events.

Beam momentum P (BeV/c)	$K^0\Lambda^0$ Observed	$K^0\Lambda^0$ Corrected[a]	$K^0\Sigma^0$ Observed	$K^0\Sigma^0$ Corrected[a]	$K^0\Lambda^0\pi^0$ Observed	$K^0\Lambda^0\pi^0$ Corrected[a]
1.17	1302	3459	846	2369	...	...
1.32	1156	2920	919	2368	163	483

[a] Corrected for the fiducial-volume bias only. The correction is mainly for the minimum decay distance defined by the ac counter surrounding the target. Loss of events due to spark-chamber dead-time, hodoscope-counter inefficiency, etc. was not included in this correction.

Because of the requirement that both K^0 and Λ be observed in the fiducial volume of our system, the polarization could not be determined near the forward angle.

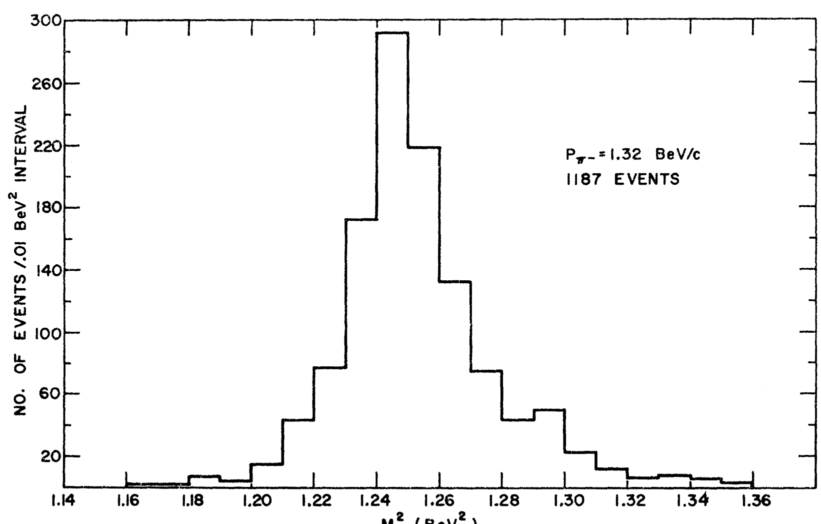

FIG. 2. Distribution of Λ invariant mass squared computed from measured π^-, p momenta.

[9] For further details on our kinematics, see Refs. 1 and 8.

[10] The spark chambers were placed in a magnetic field of about 14 kG.

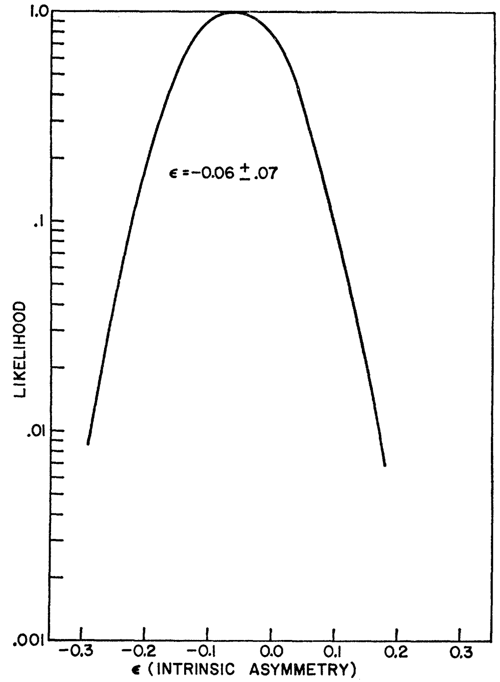

FIG. 3. The maximum-likelihood function for the up-down asymmetry of π^- (from the decay of K^0's produced in the reaction $\pi^-+p \rightarrow K^0+\Sigma^0$) with respect to the production plane.

The presence of any significant false up-down asymmetry in the detection system with respect to any production plane was checked by measuring the up-down asymmetry of the π^- from K^0 decay with respect to the K^0 production plane. The relative likelihood for this asymmetry (see Fig. 3) indicates that there was no significant intrinsic asymmetry present in our system.

Because of the limited resolution, a number of the events accepted as Σ^0's may be actually $K^0\Lambda$'s. The extent of this background can be seen in Fig. 4, where the Λ–emission-angle distribution $(\mathbf{P}_\Lambda \cdot \mathbf{P}_{\Sigma^0})$ is given in the Σ^0 rest frame. This distribution should be isotropic. The deviation from isotropy in the forward direction is apparently due to Λ contamination.[11] However, in most events in which Λ's simulate Σ^0's, they appear to be emitted forward with respect to the Σ^0 line of flight (see Fig. 4) and hence have little analyzing power [see Eq. (5)] for the Σ^0 polarization.[1]

The fraction of Σ^0's made from protons in the carbon of the CH_2 target is about 25% of our Σ^0 sample, whereas the fraction of Λ's made from carbon is less than 10% of our Λ sample. These figures are based on our comparative study of events produced in CH_2 and in carbon targets at 1.17[8] and 1.23 BeV/c. We find that these quasi-hydrogen events are mostly made from carbon protons with low Fermi momentum and show production and polarization angular distributions very similar to those of hydrogenic events. Hence, we have made no attempts to subtract these background events from our Σ^0 and Λ samples.

IV. RESULTS AND DISCUSSIONS

A. Λ Polarization

The polarization was estimated using the maximum-likelihood function

$$L(\alpha_\Lambda\langle\sigma_\Lambda\rangle)=\prod_i(1+\alpha_\Lambda\langle\sigma_\Lambda\rangle\mathbf{N}\cdot\mathbf{P}_{\pi^-}), \qquad (4)$$

where α_Λ is the usual Λ-decay asymmetry parameter; $\mathbf{P}_{\pi^-}$ is the vector along the π^- momentum in the Λ

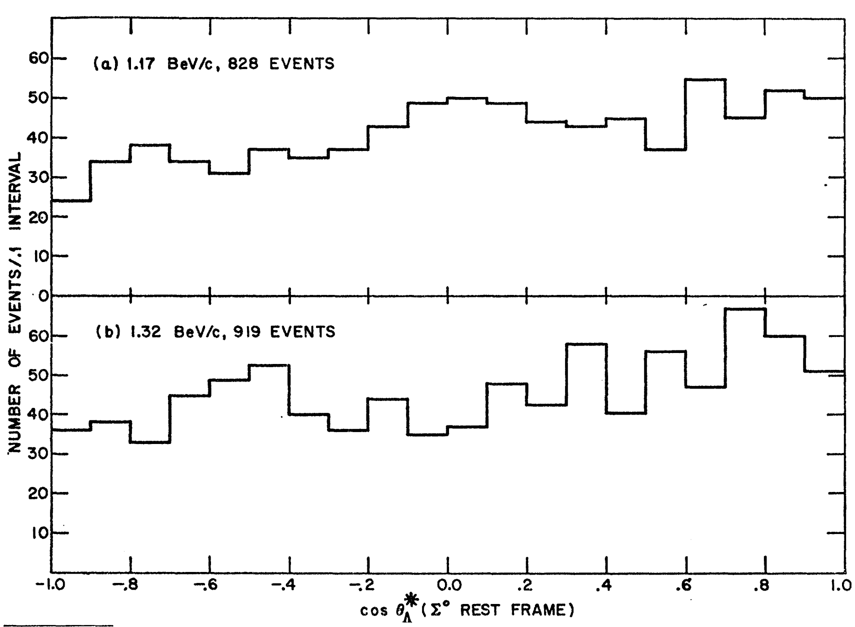

FIG. 4. Angular distribution of Λ from Σ^0 decay in the Σ^0 rest frame. The anisotropy is due to $K^0\Lambda$ contamination at forward angles and to detection bias against low-momentum particles at backward angles.

[11] The depletion of events in the backward direction in Fig. 4 is due to our bias against low-momentum particles.

rest frame, Lorentz-transformed[12]; $\mathbf{N}$ is the unit vector normal to the production plane, i.e.,

$$\mathbf{N}=(\mathbf{P}_{K^0}\times\mathbf{P}_\Lambda)/|\mathbf{P}_{K^0}\times\mathbf{P}_\Lambda|\,.$$

Figure 5 shows our measurements of the Λ polarization at π^- beam momenta 1.17, 1.32, 1.5, and 1.8 BeV/c. We also show Λ-polarization data given by other authors[2,3] for comparison. Our 1.17-BeV/c data are in excellent agreement with the data of Anderson *et al.*[3] Our 1.5-BeV/c data are in good agreement with those of Yoder *et al.*[2]

B. Σ^0 Polarization

The Σ^0 polarization was estimated using the maximum-likelihood function

$$L(\alpha_\Lambda\langle\sigma_{\Sigma^0}\rangle)+\Pi_i[1-\alpha_\Lambda\langle\sigma_{\Sigma^0}\rangle(\mathbf{N}\cdot\mathbf{P}_\Lambda)(\mathbf{P}_\Lambda\cdot\mathbf{P}_\pi)], \quad (5)$$

where $\mathbf{P}_\pi$=unit vector along the π^- momentum in the Λ rest frame, $\mathbf{P}_\Lambda$=unit vector along the Λ momentum in the Σ^0 rest frame, and $\mathbf{N}$ is the unit vector normal to the Σ^0 production plane, i.e., $(\mathbf{P}_{K^0}\times\mathbf{P}_{\Sigma^0})/|\mathbf{P}_{K^0}\times\mathbf{P}_{\Sigma^0}|$. In Eq. (5), α_Λ is the usual Λ-decay asymmetry parameter and the appropriate momenta were translated through

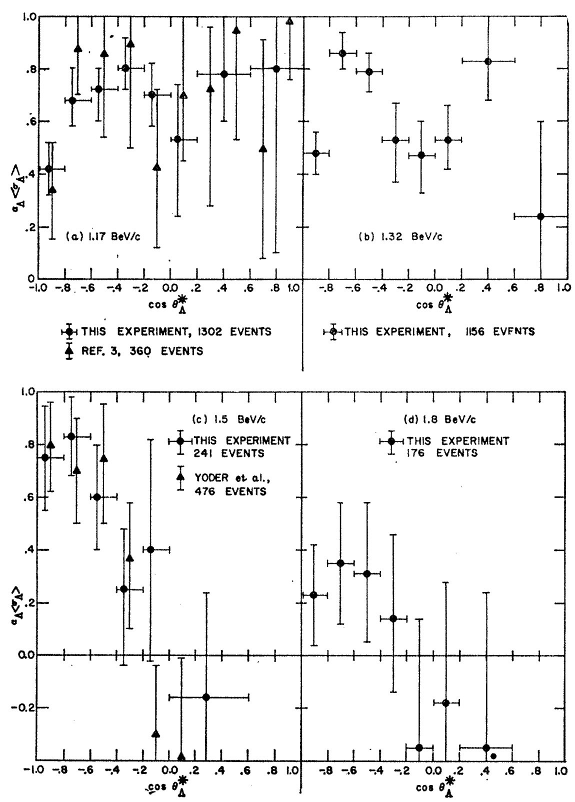

FIG. 5. Λ polarization as function of Λ production angle in the π^-p c.m. system.

[12] See for example, H. P. Stapp, Phys. Rev. **103**, 425 (1956): W. Koch, in *Proceedings of the 1964 Eastern School for Physicists* (CERN, Geneva, 1964), Vol. 2, p. 75.

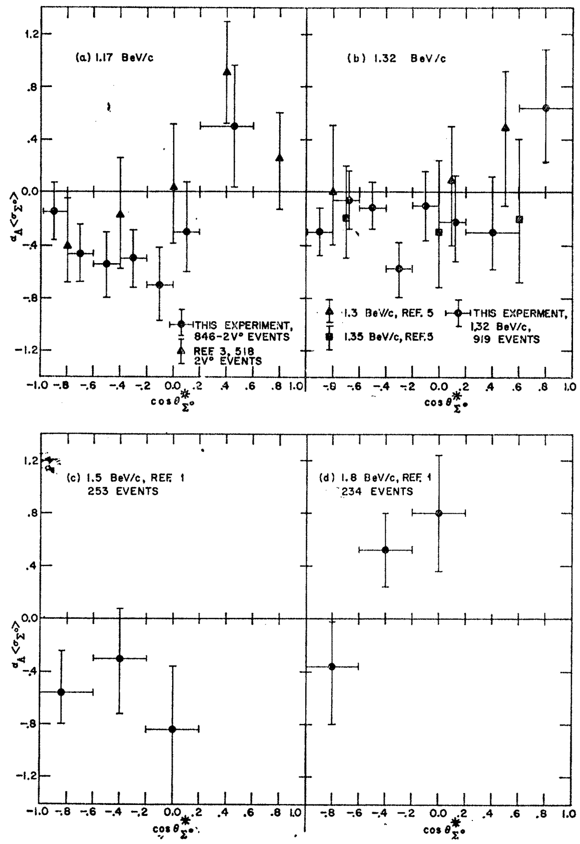

FIG. 6. Σ^0 polarization as function of Σ^0 production angle in the π^-p c.m. system.

the "direct" Lorentz transformation,[12] from the laboratory system to the π^-p c.m. system, from there to the Σ^0 rest frame, and finally to the Λ rest frame.

Figure 6 shows our measurements of the Σ^0 polarization at π^- beam momenta of 1.17 and 1.32 BeV/c along with our previous measurements at 1.5 and 1.8 BeV/c.[1] We also present for comparison data given by other authors.[3–5] Within statistics, our 1.17-BeV/c data seem to agree with Anderson's[3] and our 1.32-BeV/c data are in qualitative agreement with Crolius' data.[5]

It is seen that the Σ^0 polarization is large and changes somewhat with the π^- beam momentum from 1.17 to 1.8 BeV/c. Conceivably such change in polarization may be explained in terms of the existence of resonances as N^* (1924). However, we have made no attempt at a theoretical interpretation of the data.

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