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Σ^+ Polarization in $\pi^+ n \to K^0\Sigma^+$ from 1.1 to 2.4 GeV/c *

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We observe an energy-dependent polarization of the Σ^+ produced in the reaction $\pi^+ n \to K^0\Sigma^+$ at incident beam momenta between 1.1 and 2.4 GeV/c. These data form a significant source of information on the Σ^- polarization in the charge-symmetric reaction $\pi^- p \to K^+\Sigma^-$.

Previous authors have discussed two reasons for interest in the Σ^- polarization in $\pi^- p \to K^+\Sigma^-$. First, knowledge of the polarization might be useful for a study of the β decay of the Σ^-.[1] Also, the reactions

$$\pi^- p \to K^+\Sigma^-, \qquad (1)$$

$$\pi^+ p \to K^+\Sigma^+, \qquad (2)$$

$$\pi^- p \to K^0\Sigma^0 \qquad (3)$$

are related by charge independence; the two isospin amplitudes can be extracted from the cross sections and polarizations.[2-5]

The available data on reaction (2) (Refs. 6 and 7) and reaction (3) (Refs. 8–10) include information on the polarization of the Σ through observation of the Σ decay asymmetry. However, in studies of reaction (1) with unpolarized protons,[3,9,11] polarization information is unavailable because of the very small asymmetry parameter in the decay $\Sigma^- \to n\pi^-$ ($\alpha = -0.07 \pm 0.01$).[12] Some limited use has been made of polarized targets[1,2]; the Σ^- polarization has been measured at 1.74 GeV.[2]

If charge symmetry (which is weaker than charge independence) holds, the reaction

$$\pi^+ n \to K^0\Sigma^+ \qquad (4)$$

has properties identical to reaction (1). Then a measurement of the Σ^+ polarization in reaction (4) is equivalent to a measurement of the Σ^- polarization in reaction (1).

The data presented here come from a 250 000-picture experiment done at the LBL Bevatron.[13] The deuterium-filled 72-in. bubble chamber was exposed to π^+ beams of eight different momenta from 1.1 to 2.4 GeV/c. The film was subsequently scanned twice for events with a charged-mode decay of a neutral particle (vee) and measured on the Group-A Franckenstein measuring machines. The measured events were then processed through the standard geometrical reconstruction and kinematic fitting program SIOUX. Events indicated by the scanner as having a decaying positive particle, as well as a vee, were fitted to all final states possible for that topology, including

$$\begin{aligned} &\pi^+ d \to pK^0\Sigma^+, \\ &K^0 \to \pi^+\pi^-, \qquad (5)\\ &\Sigma^+ \to p\pi^0. \end{aligned}$$

Events which had acceptable fits to two or more

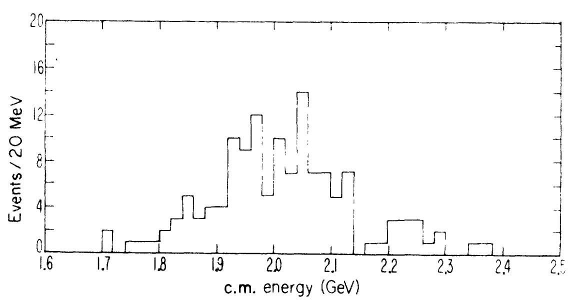

FIG. 1. Distribution of c.m. energy (excluding the spectator proton) for our sample of the reaction $\pi^+ d \to (p)K^0\Sigma^+$, $\Sigma^+ \to p\pi^0$ (135 events).

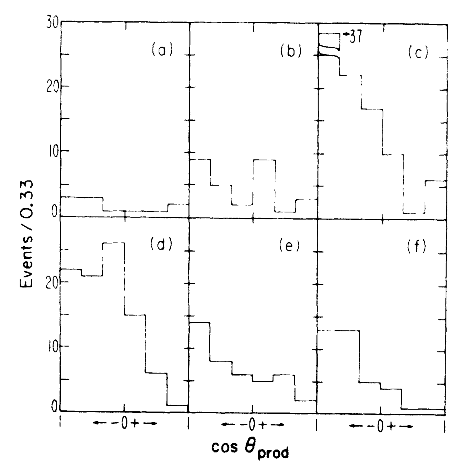

FIG. 2. Production distribution of the Σ^+ for c.m. energies (a) 1.7–1.8, (b) 1.8–1.9, (c) 1.9–2.0, (d) 2.0–2.1, (e) 2.1–2.2, (f) 2.2–2.4 GeV. $\cos\theta_{prod} = \hat{\pi}\cdot\hat{K}$ (302 events).

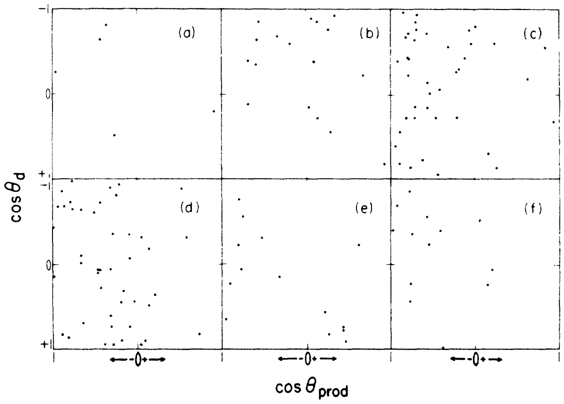

FIG. 3. Decay cosine ($\hat{p}\cdot\hat{n}$) of $\Sigma^+ \to p\pi^0$ vs production cosine ($\hat{\pi}\cdot\hat{K}$) for the six c.m. energy intervals of Fig. 2.

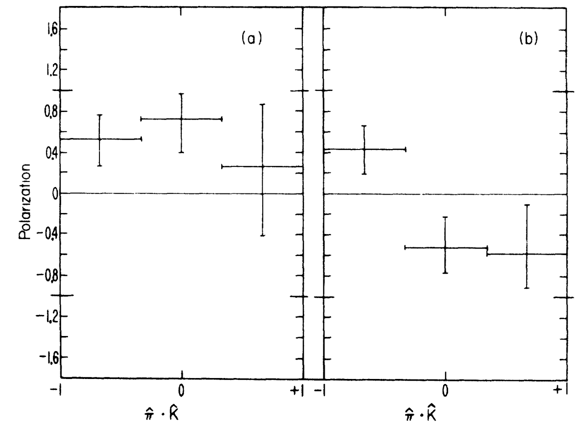

FIG. 5. Polarization as a function of production angle for c.m. energy (a) 1.7–2.0 GeV and (b) 2.0–2.4 GeV.

reactions were examined on the scanning table; the ambiguity was resolved, if possible, by comparing the predicted track ionization for the various hypotheses with the observed bubble density. The end result was 164 events with a "best" fit to reaction (5), only 3 of which remained ambiguous. (See Ref. 13 for the definition of the "best" fit.)

To select those events in which the proton is a "spectator" to the reaction, we require the final-state proton to have a momentum compatible with the internal momentum of the deuteron. All commonly used deuteron wave functions show little probability that the nucleons would have more than 300-MeV/c momentum; therefore events with proton laboratory-frame momentum greater than 300 MeV/c have been omitted from the rest of the analysis.[13] The remaining 135 events were divided into six intervals in the center-of-mass energy $M(K^0\Sigma^+)$. See Fig. 1 for the c.m. energy distribution.

Figure 2 shows the production cosine distribution for the six c.m. energy intervals. Here 167 events from the $\Sigma^+ \to n\pi^+$ decay mode have been included to increase the statistics of the production cosine distribution, although no polarization information can be extracted from these events because of the small decay asymmetry parameter. The distributions of Fig. 2 are consistent with, but not as precise as, the production cosine distributions for the charge-symmetric reaction $\pi^- p \to K^+\Sigma^-$.[9]

Any Σ^+ polarization must lie along the normal to the production plane. Figure 3 shows the cosine distribution of the decay protons in the Σ^+ rest frame plotted against production cosine. Here

$$\cos\theta_{\rm prod} = \hat{\pi}\cdot\hat{K},$$

$$\hat{n} \propto \hat{\pi}\times\hat{K},$$

$$\cos\theta_d = \hat{p}\cdot\hat{n},$$

where $\hat{\pi}$ and $\hat{K}$ are the directions of the beam π^+ and the K^0 in the c.m. system, $\hat{n}$ is the production

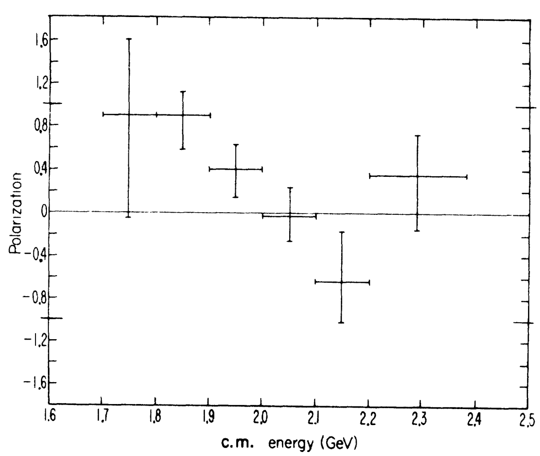

FIG. 4. Polarization integrated over production angle as a function of c.m. energy.

TABLE I. Polarization integrated over production angle.

c.m. energy (GeV)	Polarization
1.7–1.8	$0.90^{+0.60}_{-0.95}$
1.8–1.9	$0.90^{+0.21}_{-0.32}$
1.9–2.0	$0.40^{+0.23}_{-0.27}$
2.0–2.1	$-0.03^{+0.26}_{-0.23}$
2.1–2.2	$-0.64^{+0.47}_{-0.38}$
2.2–2.4	$0.35^{+0.38}_{-0.50}$

normal, and $\hat{p}$ is the direction of the proton in the rest frame of the Σ^+.

The decay distribution of a spin-$\frac{1}{2}$ particle must be of the form

$$\frac{dN}{d(\cos\theta_d)} \propto 1 + \alpha P \cos\theta_d ,$$

where α is the asymmetry parameter for the decay and P is the polarization. A maximum-likelihood fit was done to the function

$$f(A, \cos\theta_d) = 1 + A\cos\theta_d .$$

The value so obtained for A is then our best estimate of the product of the asymmetry parameter and the polarization. The scanning biases are expected to be even in $\cos\theta_d$ and therefore not to affect the maximum-likelihood estimate.[14]

Taking each of the six energy intervals separately, and integrating over production angle, we get the polarization given in Table I and Fig. 4. (We have used $\alpha = -1.0$.[12]) There is clear indication of a large net polarization in the lower-energy intervals. Noting a difference in the definitions of the normal, we see that our lowest-energy result has the same sign as that of Edgington *et al.* at 1.74 GeV.[2]

TABLE II. Polarization as a function of production angle.

c.m. energy (GeV)	$\cos\theta_{\text{prod}}$	Polarization
1.7–2.0	−1.00 to −0.33	$0.53^{+0.23}_{-0.27}$
	−0.33 to 0.33	$0.72^{+0.27}_{-0.33}$
	0.33 to 1.00	$0.27^{+0.59}_{-0.68}$
2.0–2.4	−1.00 to −0.33	$0.44^{+0.22}_{-0.25}$
	−0.33 to 0.33	$-0.52^{+0.30}_{-0.25}$
	0.33 to 1.00	$-0.58^{+0.47}_{-0.34}$

Because of poor statistics, we cannot divide each of the six energy intervals into bins in production cosine; instead, we have combined the three lower-energy intervals and the three upper ones, and calculated the polarization for three bins in production cosine. The results are given in Table II and Fig. 5.

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