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DIFFERENTIAL CROSS SECTION AND POLARIZATION IN THE REACTION $\pi^+ + p \to K^+ + \Sigma^+$ FROM 3 to 7 GeV/c*

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We have measured the differential cross section and polarization for the reaction $\pi^+ + p \to K^+ + \Sigma^+$ for K laboratory angles between 3° and 17°. The reaction is dominated by a large forward peak which shrinks rapidly and decreases slowly in size with increasing energy. A break in this exponential occurs at $-t = 0.4$ (GeV/c)^2 beyond which the cross section falls much more slowly. The polarization is small for values of $-t$ less than 0.3 beyond which it becomes large and positive and remains positive to the largest angles measured. It is independent of energy within experimental errors.

The reaction $\pi^+ + p \to K^+ + \Sigma^+$ is of interest because according to present ideas it should be dominated by the exchange of the strange counterparts of the ρ and A_2 trajectories. We report here a measurement of $d\sigma/dt$ and polarization from 3° to 17° in the laboratory frame based on 40 000 events which greatly increases the knowledge of the reaction.

The apparatus is shown in Fig. 1. It consists of wire spark chambers before and after a magnet to measure the K^+ momentum and angle. The Cherenkov counter C is placed in anticoincidence to reject π^+ mesons. The solid-angle acceptance of the experiment was defined by a counter just upstream from the bending magnet. In addition a set of wire chambers detected the proton from the decay $\Sigma^+ \to p + \pi^0$. From the K^+ momentum and angle the missing mass could be calculated. An additional kinematic restriction could be applied by requiring a track in the kinematically allowed region for a proton from the Σ^+ decay. The spark chamber data was read out and calculated on line with an ASI-6020 computer.

During the experiment elastic $\pi^+ + p$ scattering runs were interspersed with $K^+ + \Sigma^+$ runs by removing the Cherenkov anticoincidence require-

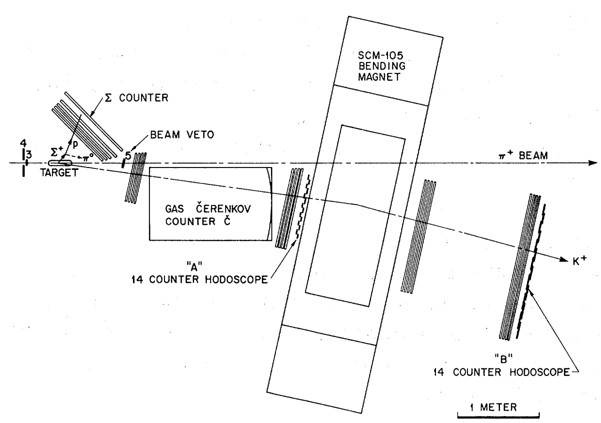

FIG. 1. A plan view of the experimental apparatus.

ment. This provided a check of the normalization and angular distribution by comparison with existing elastic scattering data. The $\pi^+ + p$ elastic-scattering angular distributions measured in this experiment were found to be in good agreement with existing data.[1] If extrapolated to $t = 0$ they agree with the absolute value calculated from the total cross section[2-4] using the optical point including a small real part in the scattering amplitude.

Corrections were made for K decay, μ contamination in the beam, chamber efficiency, background, and secondary interactions of the particles in the target and spark chambers. For the decay mode $\Sigma^+ \rightarrow \pi^+ + n$ only a small fraction (5-15 %) of the π^+ are within the kinematically allowed proton cone of the $\Sigma^+ \rightarrow p + \pi^0$ decay mode. A correction was made to account for this. We also corrected for the fact that some of the π^0 gamma rays from the $\Sigma^+ \rightarrow p + \pi^0$ decay mode convert in the target body and subsequently trigger anticoincidence counters.

The polarization measurement depends on the fact that the $\Sigma^+ \rightarrow p + \pi^0$ decay mode has a very large value of the asymmetry parameter α. By measuring the up-down asymmetry of the proton relative to the production plane of the reaction we determine the product αP and thus the polarization. A correction was made for background under the Σ^+ peak which was assumed to be unpolarized. Also, a correction was made for contamination from the $\Sigma^+ \rightarrow \pi^+ + n$ mode since $\alpha = 0$ for this mode and π^+ from this decay occur within the allowed proton cone. To check instrumental asymmetries we considered data with particle tracks inside the proton cone but missing mass outside of the Σ^+ mass region and also data with a particle track outside the allowed proton cone but missing mass inside the Σ^+ mass region. In both cases a small (~5%) asymmetry was seen, which was corrected. This is most probably attributable to a small error in knowledge of the incoming beam direction.

The polarization was obtained from the equation

$$\alpha P = 2(U - D)/(U + D),$$

where U is the number of protons emitted at angles above the production plane and D is the number of protons emitted below the plane. The production plane was defined by the vector $\vec{\pi} \times \vec{K}$. We have used the value[5] $\alpha = -1.0$ in plotting data. More formally,

$$P = \frac{3}{\alpha} \left\langle \frac{\vec{n}_p \cdot (\vec{\pi} \times \vec{K})}{|\vec{\pi} \times \vec{K}|} \right\rangle,$$

where $\vec{n}_p$ is a unit vector in the proton direction.

The data are given together with statistical errors in Table I and shown graphically in Fig. 2. In addition there is an error of ±5 % in $d\sigma/dt$ largely due to uncertainty in the background subtraction. Previous data have been taken in bubble chambers with much lower statistics at 3.23,[6] 5.4,[7] and 8 GeV/c.[8] Our data are in reasonable agreement with the 5.4- and 8-GeV/c data. They disagree with the 3.23-GeV/c data.

There are several rather prominent features of the cross-section data. The forward peak shrinks rapidly going from $e^{6.4t}$ to $e^{9.3t}$ between

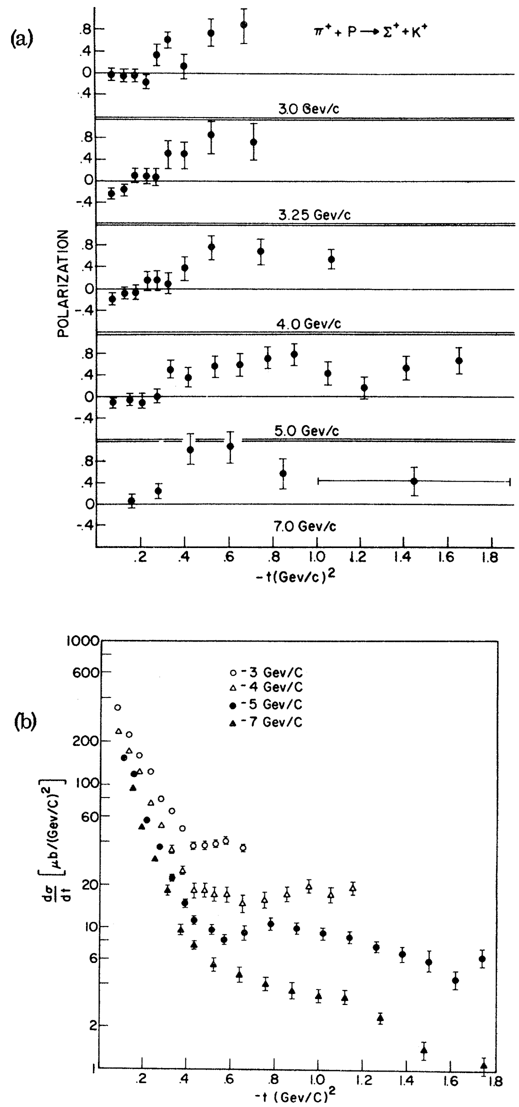

FIG. 2. (a) Polarization of the Σ^+ assuming $\alpha = -1$. Sign convention is given in text. (b) Differential cross sections for the reaction $\pi^+ + p \rightarrow \Sigma^+ + K^+$. In addition to the statistical errors shown there is a ±5 % systematic error due to background uncertainty.

Table I. $d\sigma/dt$ in μb(GeV/c)$^{-2}$ for $\pi^+ + p \rightarrow K^+ + \Sigma^+$ and the best ae^{bt} fits to the forward peak.

3.00 GeV/c		3.25 GeV/c		4.00 GeV/c		5.05 GeV/c		7.00 GeV/c	
-t	dσ/dt	-t	dσ/dt	-t	dσ/dt	-t	dσ/dt	-t	dσ/dt
.075	354. ± 9	.075	343. ±10	.075	243. ± 7	.105	159. ± 5	.145	99. ± 7
.125	227. ± 6	.125	232. ± 7	.125	176. ± 6	.150	123. ± 3	.19	52.6± 2.4
.175	162. ± 5	.175	163. ± 6	.175	128. ± 4	.210	59.5± 1.9	.25	31.9± 1.7
.225	116. ± 4	.225	107 ± 5	.225	76.3± 2.9	.270	39.2± 1.5	.31	19.1± 1.3
.275	83.1± 3.1	.275	73.0± 3.5	.275	54.2± 2.5	.330	23.6± 1.1	.37	10.2± .9
.325	69.0± 2.9	.325	49.3± 2.8	.325	36.8± 2.0	.390	15.6± 0.9	.43	7.8± .7
.375	52.2± 2.7	.375	38.8± 2.5	.375	26.6± 1.7	.450	12.0± 0.8	.52	5.7± .5
.425	38.9± 2.3	.425	32.3± 2.3	.425	19.2± 1.4	.510	10.2± .7	.64	4.9± .5
.475	39.7± 2.5	.475	30.3± 2.3	.475	19.1± 1.4	.570	8.6± .7	.76	4.2± .4
.525	40.7± 2.6	.525	28.9± 2.5	.525	18.4± 1.4	.660	10.1± .5	.88	3.7± .4
.575	42.7± 2.6	.575	29.2± 2.7	.575	18.3± 1.5	.780	11.2± .6	1.0	3.4± .4
.650	37.8± 2.0	.650	31.4± 2.0	.650	15.4± 1.0	.900	10.6± .7	1.12	3.38± .41
.750		.750	30.9± 2.4	.750	16.8± 1.2	1.02	9.6± .7	1.27	2.43± .30
.850		.850		.850	18.0± 1.4	1.14	9.0± .7	1.48	1.44± .22
.950		.950		.950	20.8± 1.6	1.26	7.8± .7	1.75	1.12± .19
1.050		1.050		1.050	18.3± 1.6	1.38	7.0± .7		
1.150		1.150		1.150	20.2± 2.0	1.50	6.1± .7		
						1.62	4.6± .6		
						1.74	6.5± .9		
$(500\pm40)e^{(6.4\pm.4)t}$		$(540\pm40)e^{(7.2\pm.4)t}$		$(430\pm30)e^{(7.6\pm.4)t}$		$(360\pm40)e^{(8.8\pm.5)t}$		$(320\pm50)e^{(9.3\pm.6)t}$	

3.0 and 7.0 GeV/c. Extrapolating the data to $t_{\min}$ gives a rather slow decrease of $|d\sigma/dt|_{t_{\min}}$ with energy. There is no evidence of a turnover at small t which would indicate a large spin-flip contribution. Only at the lower energies do our data extend to low enough t that one might expect to see such an effect, however, and then only if the effect is large. A good fit to all the data in the forward peak is obtained with $(d\sigma/dt)$ [μb(GeV/c)$^{-2}$]$=1700s^{2\alpha-2}$, where $\alpha = 0.7 + 1.7t$. It should be noted that the lower energy points might be affected by resonances although there is no evidence of such irregularities in the data.

At $-t = 0.4$ (GeV/c)^2 the cross section has a rather remarkable change in slope. There is only a hint of a secondary peak if one is there at all. A more accurate description would be a flat section trailing off to smaller values at larger angles. To the extent that we have measured it the cross section in this region falls gradually with increasing s and increasing $-t$. There are no signs of resonance effects.

The forward-peak shrinkage and very slow decrease of $(d\sigma/dt)_{t_{\min}}$ with energy are difficult to reconcile with a simple Regge analysis using the strange vector and tensor trajectories associated with the ρ and A_2. Both of these effects may be illusory however since interpretation of the forward peak at these energies depends strongly on what causes the behavior at large $-t$ and how this amplitude interferes with that causing the forward peak. For example, if we extrapolate the measured differential cross section in the large-$(-t)$ region into the forward-peak region and subtract if from the measured forward-peak cross section ignoring interference terms, the resulting forward peak has a slope of e^{10t} at all energies. The interference may or may not be small enough to be ignored. Even the idea of considering amplitudes from two different causes may or may not be sensible. What is clear is that an interpretation of forward-peak behavior which does not also contain an explanation of the large-$(-t)$ region is probably meaningless at these energies although it might be viable at higher energies.

The polarization is consistent with 0 at all energies for $-t < 0.3$, although a small negative polarization as large as -0.2 is not ruled out. Between $-t = 0.3$ and 0.5 the polarization shows a dramatic change to a large positive value of about 0.7 at all energies. This is just the t region in which the forward peak dies out. Beyond

$-t=0.5$ the polarization at all energies and t values measured is consistent with 0.7. Both polarization and angular distribution therefore point to some general nonresonant mechanism with sizable flip and nonflip terms as the dominant mechanism in this large-t region.

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POLARIZATION IN K^+-p ELASTIC SCATTERING AT 3.75 AND 4.40 GeV/c *

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The polarization parameter in K^+-p elastic scattering has been measured at 3.75 and 4.40 GeV/c in the range of squared momentum transfer $0.2 \lesssim -t \lesssim 1.0$ (GeV/c)^2. The data are compared with the predictions of recent Regge-pole models.

We report here the final results of measurements of the polarization $P(t)$ in K^+-p elastic scattering at 3.75 and 4.40 GeV/c for squared momentum transfers in the interval $0.2 \lesssim -t \lesssim 1.0$ (GeV/c)^2. Earlier results on polarization in K^+-p elastic scattering above 1 GeV/c have been obtained at 1.22 and 2.48 GeV/c [1] and at 14 GeV/c.[2]

The data were obtained in a polarized-target experiment set up to measure polarization in $\pi^\pm$-p, K^+-p, and p-p elastic scattering in the momentum region between 2.5 and 5.0 GeV/c. Preliminary results on polarization in $\pi^\pm$-p and p-p scatterings have already been reported.[3,4]

The measurements were carried out in an unseparated 0° secondary beam in the external proton beam area of the zero-gradient synchrotron at Argonne National Laboratory. The beam had a momentum acceptance of ±3.5% and an intensity of about 10^6 particles per pulse. For momenta around 4 GeV/c, it contained pions and protons in the ratio 1:2 and about 1% positive kaons. Two gas threshold Cherenkov counters in the beam were used to veto positrons and to identify pions, and a gas differential Cherenkov counter,[5] placed about three meters upstream of the polarized target, selected kaons. The K^+-p polarization data were taken simultaneously with π^+-p and p-p data. Particles identified as kaons had a pion and proton contamination of less than 1%.

Information about incoming beam particles was obtained from scintillation-counter hodoscopes placed in the beam upstream of the polarized target. Other arrays of counters detected particles scattered in the vertical plane. Whenever a beam particle and two particles coming from the target (one above and one below the beam line) were detected in coincidence, the information on which counters had been triggered was sent to an on-line computer which computed the azimuthal and polar angles of the two outgoing particles. The information was also written on magnetic tape to permit a more detailed off-line analysis. Events from elastic scattering by the free protons of the target were selected on the basis of coplanarity and angular correlation in the scattering plane.

The free protons contained in the lanthanum magnesuim nitrate polarized target used in the experiment had an average polarization of about 0.55. The sign of the polarization was reversed approximately every six hours.

The results are presented in Table I and in Fig. 1. The errors are statistical and include the contribution due to background subtraction. The uncertainty in the target polarization contributes an additional normalization error of