MEASUREMENT OF THE POLARIZATION IN BACKWARD-ANGLE π^+p ELASTIC SCATTERING BETWEEN 2.50 AND 3.75 GeV/c†*

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The polarization in π^+p elastic scattering in the backward hemisphere has been measured at 2.50, 2.75, 2.93, 3.25, and 3.75 GeV/c. The data cover a range u of -0.5 to $+0.1$ (GeV/c)^2 and show a positive peak at approximately the same c.m. angle as the minimum in the differential cross section. At angles farther away from 180° the polarization becomes negative. The data are not well explained by either resonance or Regge-pole models.

We report here the results of measurements of the polarization in π^+p elastic scattering for c.m. scattering angles between 140° and 175°. Data were taken for incident pion momenta of 2.50, 2.75, 2.93, 3.25, and 3.75 GeV/c. These are the first measurements of π^+p polarization at backward angles for momenta above 1.5 GeV/c. The data were taken at the Argonne National Laboratory zero-gradient synchrotron (ZGS) using the Argonne lanthanum magnesium nitrate polarized-proton target, and were part of an experiment carried out to measure the polarization in $\pi^{\pm}p$, K^+p, and pp elastic scattering at momenta between 2.5 and 5.1 GeV/c. Some results of the experiment have been reported previously.[1]

The experiment was carried out in an unseparated 0° secondary beam in the first external proton beam area of the ZGS. Gas Čerenkov counters were used to identify the beam particles, and forward-angle π^+p, pp, and (at 3.75 GeV/c) K^+p data were taken simultaneously with the data described here.

A schematic of the counter arrangement about the polarized proton target is shown in Fig. 1. Scintillation-counter hodoscopes were used to detect events scattered in the vertical plane, with the target protons polarized in the direction perpendicular to the scattering plane. Each detecting hodoscope (bank) consisted of two layers of scintillators. One layer defined the polar angle of scatter θ with respect to the unscattered beam line, while the other defined the azimuthal angle φ with respect to the vertical plane. For backward scattering the pion was bent downward by the field of the polarized proton target magnet and detected by one of two banks (labeled $C1$ and $C2$ in Fig. 1) below the target. The forward proton was detected in a bank (labeled $A2$) downstream from the target and above the beam line. (In the case of forward scattering the pion was detected in the $A1$ or $A2$ bank, and the recoil

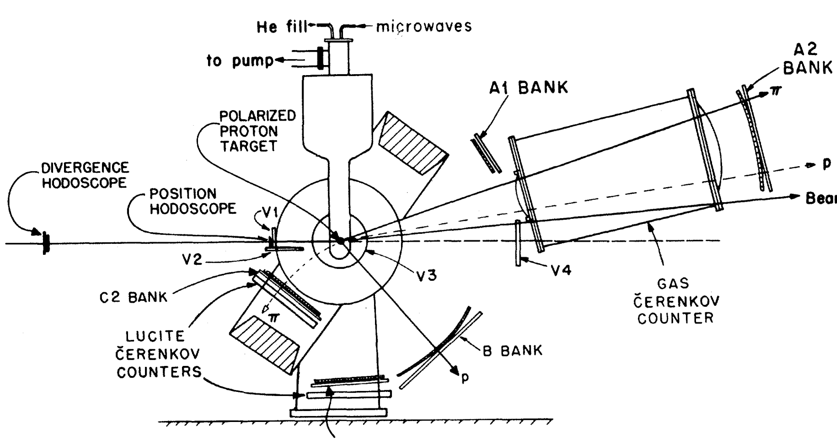

FIG. 1. Schematic view of the counter arrangement about the target. The solid trajectories indicate a forward-scattered event, and the dashed trajectories indicate a backward-scattered event.

proton in the B bank.)

During most of the experiment Lucite Čerenkov counters behind the C banks helped to identify the backward-going particle as a pion and to eliminate low-energy background. In the forward direction a large gas-threshold Čerenkov counter, placed in anticoincidence with signals from the two C banks to veto pions, identified the forward particle as a proton. This counter[2] was of extreme importance for the most nearly backward pion angles and eliminated 95% of the triggers for which the forward particle was detected in the bottommost counters of the $A2$ bank. Several veto counters were used to cover a large portion of the solid angle not covered by the detecting hodoscopes.

For each event the information as to whether or not each of the 166 counters (including the beam Čerenkov counters) had counted was sent to an on-line EMR 6020 computer for analysis and storage. The computer rejected any events in which more than two scattered particles were detected, and, for the remaining events, calculated the polar and azimuthal scattering angles θ and φ of each of the two detected particles. From two-body kinematics and the observed scattering angles of the particle detected in the pion bank, the computer could predict the scattering angles of the particle detected in the proton bank. For each counter in the pion bank, distributions were formed of the differences $\Delta\theta$ and $\Delta\varphi$ between the predicted and observed θ and φ angles of the particle detected in the proton bank. Cuts (determined on the basis of a Monte Carlo program) were introduced in the $\Delta\varphi$ distributions to define each event as coplanar or noncoplanar. Separate $\Delta\theta$ distributions were formed of the coplanar and noncoplanar events as shown in Fig. 2. The elastically scattered events then appeared as a peak in the coplanar $\Delta\theta$ distributions superimposed on a broad background due primarily to quasielastic scattering in the complex nuclei of the polarized-proton target.

The noncoplanar $\Delta\theta$ distributions outside the elastic peak were normalized to the coplanar distributions to simulate the background beneath the peak. This method of background subtraction was usually, although not always, satisfactory. In the final analysis the coplanar $\Delta\theta$ distributions outside the elastic peak were fitted with a low-order polynomial which was then interpolated beneath the peak to give the background.

The direction of the target polarization was reversed approximately every 6 hours, and the magnitude of the target polarization was determined from NMR signals which were recorded on paper tape during the run. After data taking at a given energy was completed the polarization of the scattering was calculated from the asymmetry in counting rates between runs of opposite target polarization.[3]

The results are shown in Fig. 3. The error bars shown include the statistical counting errors and the estimated uncertainty in the background subtraction. They do not include the estimated $\Delta P_T/P_T = \pm 10\%$ normalization error due to the uncertainty in the value of the target polarization P_T. Because of multiple scattering, the finite length of the target, and the finite spatial resolution of the counter hodoscopes, there is some overlap in adjacent c.m. bins. The bin widths shown in Fig. 3 are rms values as calculated by a Monte Carlo program. In some cases the data from adjacent c.m. bins have been combined.

At all momenta, with the possible exception

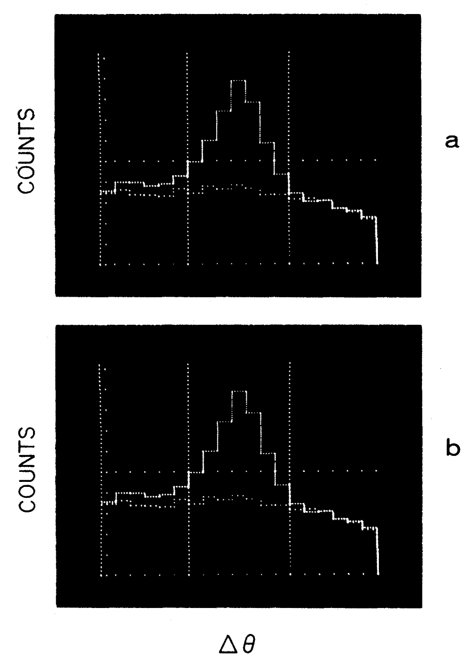

FIG. 2. On-line cathode-ray tube photographs of typical $\Delta\theta$ distributions. $\Delta\theta$ is the deviation of observed from expected scattering angle of the proton. The finely dotted distributions are of coplanar events, and the coarsely dotted distributions are of noncoplanar events. The vertical dotted lines in each distribution are cuts used to separate the elastic events from background. (a) 2.75 GeV/c for $u \simeq -0.4$ (GeV/c)^2. (b) 2.75 GeV/c for $u \simeq +0.1$ (GeV/c)^2.

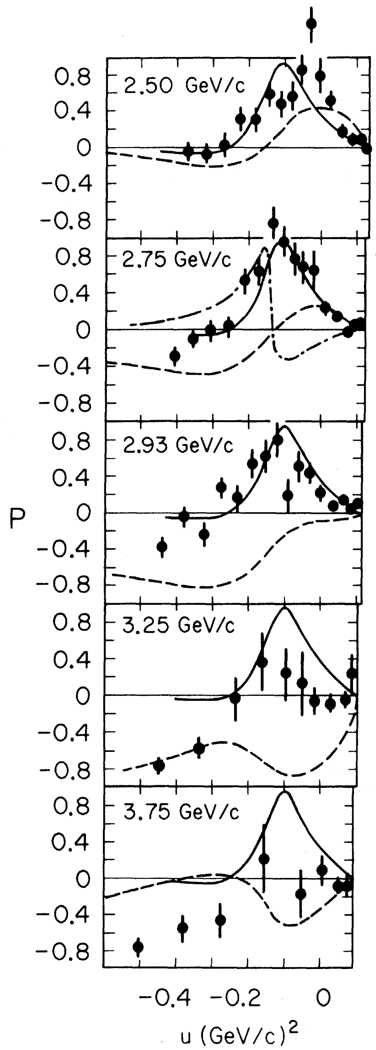

FIG. 3. The results for the polarization in backward π^+p scattering. The right-hand edge of each graph corresponds to $\cos\theta = -1.0$. The dashed curves are from the pure resonance model of Crittenden *et al.* (Ref. 4); the dot-dashed curve in (b) is from the Regge model of Barger and Cline (Ref. 5), with linear N_α and Δ_δ trajectories; the solid curves are from the Regge-pole model of Berger and Fox (Ref. 6), which includes the N_γ trajectory.

of 3.75 GeV/c, the data show a positive polarization rising away from 180° to a maximum at a crossed momentum-transfer squared of $u \approx -0.1$ (GeV/c)^2, which is the approximate position of the minimum in the differential cross section. At 3.25 and 3.75 GeV/c the polarization at small $|u|$ may be slightly negative before becoming positive. The maximum polarization is approximately 1 at 2.75 GeV/c and decreases at higher momenta. For larger values of $|u|$ the polarization is negative, becoming quite large for $u \approx -0.4$ (GeV/c)^2 at the higher momenta.

A number of authors[4,7-9] have fitted backward πp differential cross-section data using direct-channel resonance amplitudes alone at intermediate energies. If only the resonances of the dominant Δ_δ trajectory are included,[7] such a resonance model predicts large negative polarizations, in clear disagreement with our data. It also fails to reproduce the dip seen in intermediate energy cross-section data[9-11] above 2 GeV/c. Crittenden et al.[4] have obtained reasonable agreement with differential cross-section data[11] by including assumed Regge recurrences of several of the less prominent lower-energy resonances. However, the agreement of this model with the polarization data reported here is poor, as is shown by the dashed lines in Fig. 3.

In view of the obvious resonance effects present in the magnitude (although not the shape) of backward πN differential cross sections at intermediate energies, it is unreasonable to expect quantitative agreement with our data from pure Regge-pole models. However, one might expect that the qualitative features of the data can be reproduced since the shape of the differential cross sections at these energies are not dissimilar to those given by Regge-pole models.

Most Regge-pole fits[5,12] to backward π^+p scattering have included only the dominant N_α and Δ_δ exchanged trajectories. Assuming linear trajectories, the N_α amplitude vanishes near $u = -0.15$ (GeV/c)^2 where the trajectory $\alpha_N(u)$ passes through $J = -\frac{1}{2}$. This results in a zero in the polarization at this point whereas the data show a maximum. The polarization predicted by an N_α-Δ_δ model[5] is illustrated by the dot-dashed curve in Fig. 3(b). If the N_γ amplitude, which should also contribute, is comparable in magnitude with that of the Δ_δ (even though still small compared with the N_α), its effect on the polarization could be quite large. Recently several authors[6,13,14] have included the N_γ (as well as the N_α and Δ_δ) in fits to high-energy data. It is then possible to obtain qualitative agreement with the polarization data. As an example for comparison, the solid curves shown in Fig. 3 are from the model of Berger and Fox.[6] Somewhat similar results have been obtained by Barger but with a different parametrization.[14]

The results show only qualitative agreement with the data. They fail to reproduce the rather rapid energy dipendence of the peak in the polarization, indicating probable resonance effects.

They also fail to reproduce the large negative polarizations seen for large $|u|$ at 3.25 and 3.75 GeV/c, where resonance effects should be considerably smaller. The small polarizations given by the model are the result of the dominance by the N_α of the total amplitude in this region. If such large negative polarizations persist at high energies, then one must require that (1) the contribution from other trajectories or cuts be comparable in magnitude with that of the N_α in this region, or (2) the N_α trajectory contain significant terms which are odd in $u^{1/2}$.

Using nonlinear trajectories and N_α-N_γ interference to produce the cross-section dip, Contogouris, Tran Thanh Van, and LeBellac[15] have constructed a Regge-pole model which predicts polarizations qualitatively in accord with our data. Qualitative agreement has recently been obtained by Graham and Moffat[16] with a Regge-behaved amplitude possessing crossing symmetry and by Kelly, Kane, and Henyey[17] with an absorption model.

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[2]We are indebted to Professor D. Meyer of the University of Michigan for the loan of their counter during the early portion of the experiment.

[3]For a constant magnitude of target polarization P_T, the polarization P is given by $PP_T = (R^+ - R^-)/(R^+ + R^-)$, where $R^\pm$ are the counting rates for positive and negative signs of target polarization. The sign of the target polarization is defined as positive when parallel to the vector $\vec{k}_i \times \vec{k}_f$, where $\vec{k}_i$ and $\vec{k}_f$ are the initial and final momenta of the pion.

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