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Recoil-proton polarization in the reaction $\pi^{\pm}p \rightarrow pX^{\pm}$ in the A_2 region*

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We report here the results of an experiment which studies the polarization of the recoil proton in the inclusive reaction $\pi^{\pm}p \rightarrow pX^{\pm}$ at 4 GeV/c, where M_X varies from 1200 to 1450 MeV, and t varies from -0.2 to -0.8 (GeV/c)^2. The recoil proton was identified by its time of flight and its momentum, as determined by a wire-chamber magnetic spectrometer. The polarization of the recoil proton normal to the scattering plane was measured with a wire-chamber carbon analyzer. Polarizations are presented as a function of mass M_X for all t and as a function of t for all masses. The typical error in the polarization is ± 0.1. A significant difference is observed in the behavior of the polarization associated with the X^+ and the X^-. Possible implications of this disparity are explored.

We present here the results of an experiment performed at the Argonne ZGS (zero-gradient synchrotron) to determine the recoil-proton polarization in the inclusive reaction $\pi^{\pm}p \rightarrow pX^{\pm}$ at 4 GeV/c incident pion momentum. The missing mass M_X varied from 1200 to 1450 MeV and the four-momentum transfer squared varied from -0.2 to -0.8 (GeV/c)^2. The polarization measurements were made in conjunction with an experiment designed to make a high-statistics, high-resolution study of the A_2 mass spectrum. The inclusion of a magnetostrictive wire-chamber carbon analyzer as the last element in the proton arm allowed the simultaneous recording of missing-mass and polarization data. The missing-mass results have been reported in Ref. 1. The physics goals of the polarization measurements were (a) to determine if a significant polarization asymmetry might be associated with the two halves of the A_2 meson and (b) to examine the t dependence of the recoil-proton polarization for M_X in the region of the A_2 to check the prediction of certain production models.

The experimental layout is shown in Fig. 1. A beam of ~10^5 pions per burst was incident on a 10-inch-long liquid hydrogen target. Beam particles were detected by scintillation counters $B1$ and $B2$ and by proportional chambers. A gas Čerenkov counter was used to distinguish pions from kaons and protons in the incident beam. The momentum and angle of the recoil proton were determined by a magnetostrictive wire spark-chamber spectrometer. The momentum was determined with a resolution of ~1.1%, and the recoil scattering angle was measured with a resolution of 1 mrad. In addition, the time of flight between counters $B2$ and P was measured for each event to an accuracy of ± 0.5 ns. This allowed a very clean separation to be made between protons and other particles in the proton arm. The carbon-block wire-cham-

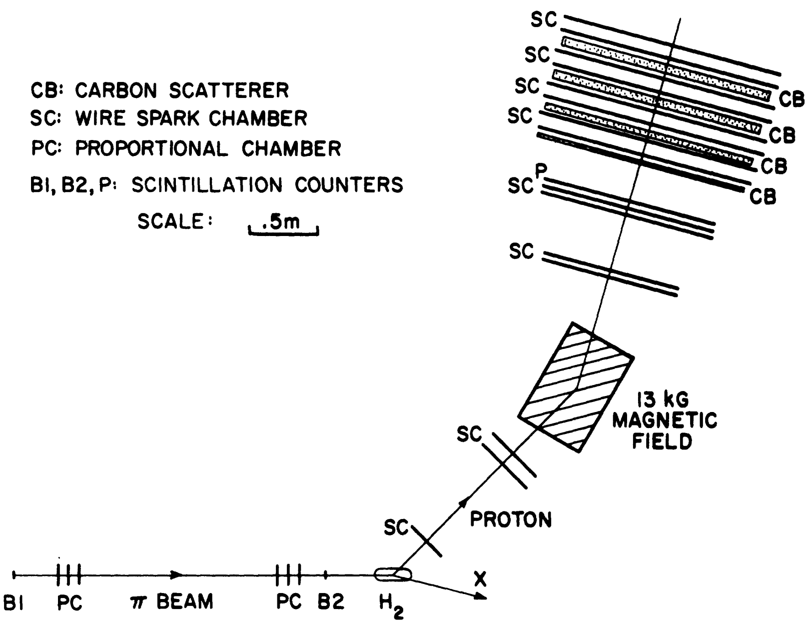

FIG. 1. Schematic diagram of the experimental apparatus.

ber sandwich shown downstream of counter P allowed the polarization of the recoil proton to be determined from the left-right azimuthal asymmetry exhibited by the protons in scattering from carbon nuclei. The carbon analyzing power for protons with energies in the range covered by this experiment is known from previous measurements (Ref. 2).

The carbon polarimeter consisted of four elements. Each element contained a block of carbon followed by two wire spark chambers with magnetostrictive readout. The thickness of the carbon block was 0.5 in. for the upstream element, 1.5 in. for the next element, and 2.5 in. for the two downstream elements. For any given carbon block the incoming and outgoing trajectories could be determined. These trajectories were examined for each event and each block to check if a double scattering had occurred. To determine the recoil-proton polarization, a standard analysis was made of the azimuthal distribution of the doubly scattered protons whose polar angles were in the region $6° < \theta < 22°$.[2] This angular region corresponds to that used in Ref. 2 in determining the carbon analyzing power. Since the double scattering vertex could be determined, it was possible to calculate the actual recoil-proton energy at the point of scattering in carbon. An example of a vertex distribution is shown in Fig. 2. This information allowed us to eliminate double scatters corresponding to proton energies below 120 MeV, where the carbon analyzing power is rapidly varying with energy.

Although only those events with double scatters in the range $6° < \theta < 22°$ were used in the actual polarization determination, the remaining ~96% of the events was invaluable in examining various possible system biases. For example, since double scatters with $\theta < 3°$ should show no significant left-right asymmetry, it was instructive to examine the asymmetry for these events for numerous different chamber regions, for different proton angles of attack, and for different proton energies. The ϕ distribution for small θ scatterings was extremely sensitive to chamber position. This allowed us to ensure precise relative chamber

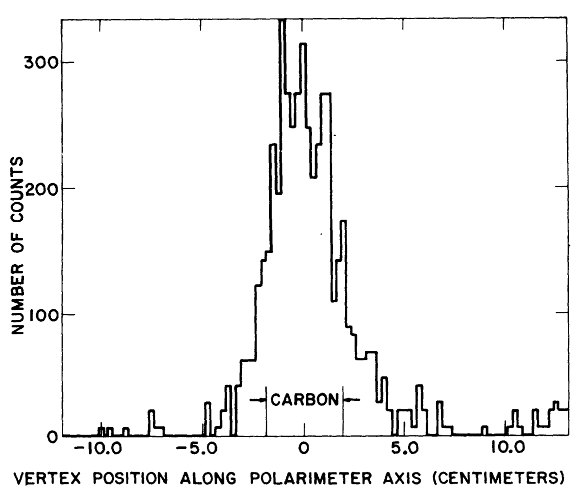

FIG. 2. Typical distribution of vertex position along the polarimeter axis at carbon block 2.

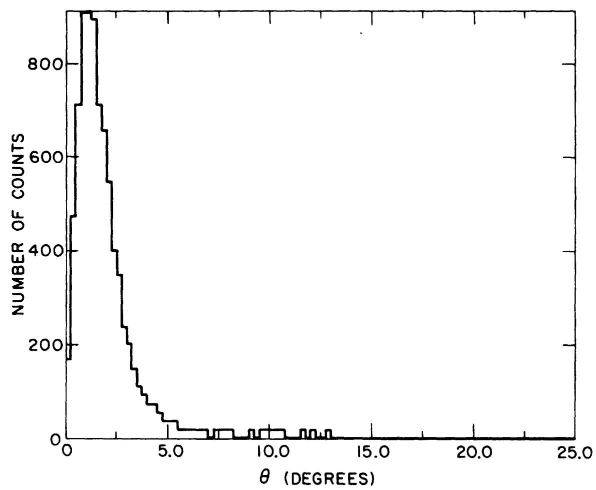

FIG. 3. Typical distribution of the scattering angle (θ) after carbon block 2.

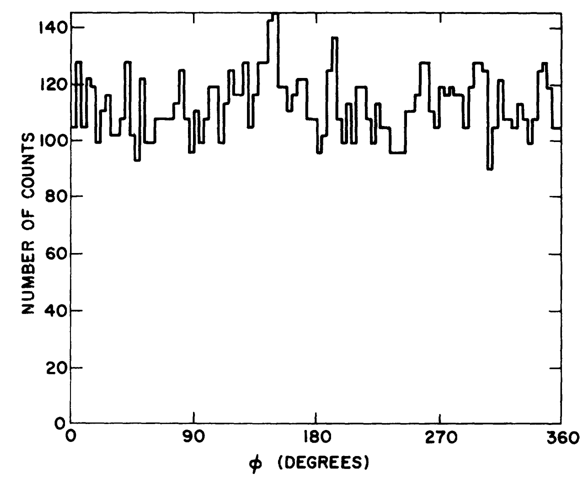

FIG. 5. Typical distribution of the azimuthal angle (ϕ) after carbon block 2.

alignment in all regions of the chambers. Thus, to a high order, any left-right asymmetries observed should be due to the spin dependence of the p-C interaction and not to system misalignment.

An additional check of the ability of the polarimeter to properly detect proton polarization was made by running a 1.4-GeV/c proton beam into our hydrogen target and, without moving any part of the apparatus, making an independent determination of the p-p elastic polarization at $\theta_{\text{c.m.}}=65°$, 75°, and 85°. The actual values of these elastic polarizations are well known from several previous experiments (see Ref. 3) and are in statistical agreement with our test results. The total χ^2 for the three measurements is 2.2.

The operation of the experiment was monitored with an on-line PDP-15 computer. Plan and vertical view displays of all proportional chambers and magnetostrictive chambers were available upon request. The efficiencies of the chambers, and the magnet and photomultiplier voltages were continuously monitored. A record was written on magnetic tape for each event which satisfied the beam coincidence requirement ($B1\cdot B2\cdot CG$) and the proton arm requirement (P), provided no associated count occurred in a small beam veto counter. CG represents the threshold Čerenkov counter located in the incident beam.

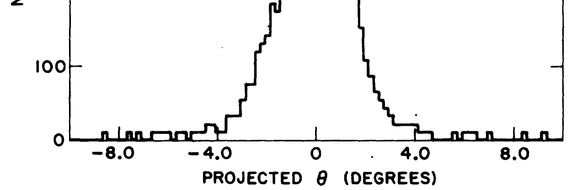

FIG. 4. Typical distribution of the horizontally projected scattering angle.

In Fig. 3 we illustrate the second scattering polar angle distribution of recoil protons for a typical run. As mentioned above, only those events for $6°<\theta<22°$ are used for polarization determination and the small-θ scatters are utilized for various checks. The projection of this distribution onto the horizontal plane results in the distribution shown in Fig. 4. Since the analyzing power for carbon for small-angle scatters is vanishingly small, one would expect this projected distribution to be centered about 0°, which is the case. Figure 5 shows a typical example of the azimuthal angle (ϕ) distribution when all θ values are accepted. Since the distribution is dominated by events with small θ, the high degree of isotropy is anticipated.

In Fig. 6 results are presented for the recoil-proton polarization normal to the production plane for all t covered by the apparatus $[-0.2$ to -0.8 $(\text{GeV}/c)^2]$ as a function of the missing mass M_X. Three comments can be made concerning these results: (a) for both X^- and X^+ production the polarization is symmetric about the A_2 mass, 1.3 GeV; (b) the polarization associated with the X^- is consistent with being small and negative for all masses examined; and, (c) the polarization associated with the X^+ appears to rise from 0% near 1225 MeV to a maximum of ~40% near the A_2 mass and then to fall to zero near 1425 MeV.

The t distribution of the polarization data is shown in Fig. 7. The data correspond to the missing-mass interval of 1200 to 1450 MeV. The results for X^+ production are consistent with a slowly increasing polarization rising from ~20% to a value of ~30%. On the other hand, the X^- data exhibit a decrease from about 0% at $t = -0.25$ to -40% at $t = -0.73$ $(\text{GeV}/c)^2$. Since that part of the experiment associated with the recoil-proton spin determination has no direct knowledge of the sign of the incoming pion beam charge, the chance is remote that the above differences are due to systematics. The systematic error in the polarization due to uncertainties in the analyzing power and instrumental biases is estimated to be $\lesssim 0.08$.

Since the t-averaged polarization is consistent with being zero in regions outside the A_2 peak and since the polarization is symmetric about the A_2 mass, one might be led to attribute a sizable fraction of observed polarization to the A_2 meson and its interference with the background. If one adopts this point of view and further assumes that no significant changes occur in the background amplitudes over the region of the A_2, then the data support the proposal that the two halves of the A_2 are similar, at least as far as the recoil-proton polarization is concerned.

Alternatively, one may take the point of view that since the A_2 events represent a small fraction of the total spectrum, the reactions should be regarded as being inclusive ones. Here, even though many channels may be contributing, one might nevertheless expect sizable polarizations.[4] For "polarization out of the blob,"[5] the Regge exchanges for $\pi p \to pX$ at small t should be similar to those in πp elastic scattering, the main difference between the two being that the Pomeranchuk contribution is greatly reduced for the inelastic processes. Whereas the ρ and P' couplings for inelastic processes are comparable to those in elastic scattering, it is well known that the Pomeranchuck off-diagonal couplings are much smaller than its corresponding elastic couplings. Indeed, in the present case the P couplings are expected to be comparable to those of the ρ and P'. This contrasts with the situation in elastic scattering where the ρ spin-flip coupling is only 10–20% of that of the Pomeranchuk coupling in the nonflip amplitude, leading to a polarization of 10–20%. Hence, for our inclusive process, one might well expect sizable polarizations, and if the ρ exchange again dominates the proton-flip amplitude (as it does in the elastic case) one would expect the polarizations for the two reactions $\pi^\pm p \to pX^\pm$ to be mirror symmetric.

Our results shown in Fig. 7 reveal that the inclusive polarizations are indeed comparable to the corresponding elastic polarizations. Moreover, consistent with the above arguments, the $\pi^+ p \to pX^+$ and $\pi^- p \to pX^-$ polarizations are statistically compatible with approximate mirror symmetry. The shape of the polarization at small t, however, is not similar to that of the corresponding elastic

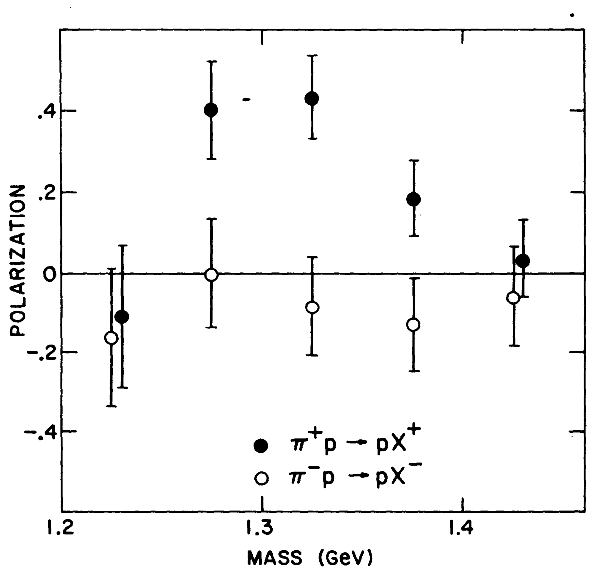

FIG. 6. Polarization parameter in $\pi^+ p \to pX^+$ and $\pi^- p \to pX^-$ as a function of missing mass.

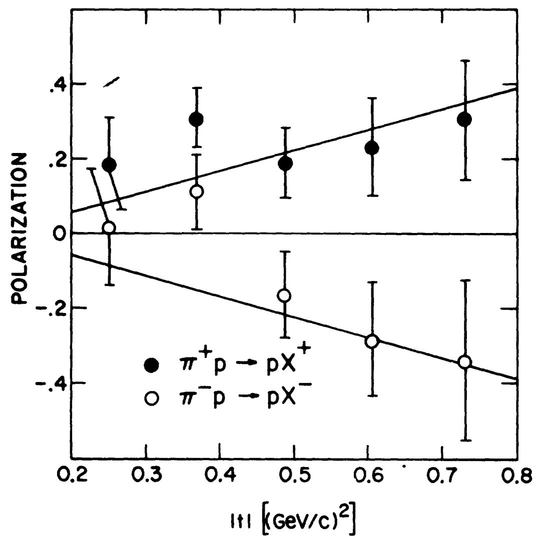

FIG. 7. Polarization parameter in $\pi^+ p \to pX^+$ and $\pi^- p \to pX^-$ as a function of the four-momentum transfer squared. The mirror symmetric lines shown are included to illustrate the possibility of approximate mirror symmetry in the X^+ and X^- data.

polarization. The possibility of mirror symmetry is emphasized by the mirror symmetric lines drawn in Fig. 7. Such symmetry is not suggested by the polarization vs. mass plot in Fig. 6, however, since this plot is dominated by the small-t data which, as seen in Fig. 7, do not alone indicate mirror symmetry.

In summary, we have examined a parameter of the reactions $\pi^{\pm}p \to pX^{\pm}$, which could be relevant both to possible A_2 structure and to our general understanding of inclusive processes. Our results suggest no polarization distinction between the two halves of the A_2. If a significant part of the observed polarization were due to the A_2, then perhaps polarization differences in the two halves of the A_2 at the ~40% level could have been detected. If the process can indeed be treated as an inclusive process, the Regge predictions may be regarded to be in general agreement with the data. This experiment, to the best of our knowledge, is the first to study the continuous variation of polarization with missing mass. Since the principle interest in the present experiment was the A_2 meson, the missing-mass range studied was restricted. To explore inclusive model polarization predictions in depth, additional measurements are warranted.

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