Recoil-Proton Polarization in Neutral-Pion Photoproduction and in Proton Compton Scattering*

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We have measured the polarization of the recoil proton in the reactions $\gamma p \to \pi^0 p$ and $\gamma p \to \gamma p$ for incident photon energies between 3 and 7 GeV, and t values from -0.2 to -0.65 GeV^2. The polarization in neutral-pion production varies from 0 to -1 over this range. Contrary to expectation, it does not agree completely with the polarized-target asymmetry.

Neutral-pion photoproduction has been described by a variety of models.[1] While adequately describing the differential–cross-section data, these various models contain different physical input, and predict different values for the individual amplitudes themselves. Measurement of polarization effects can help distinguish among models and, more importantly, can lead to an understanding of the amplitudes. Recently, the polarized-photon asymmetry[2] and the polarized-target asymmetry[3] have been measured in neutral-pion photoproduction above the resonance region.

We have measured the recoil-proton polarization in the reaction $\gamma p \to \pi^0 p$ at the Cornell 10-GeV electron synchrotron. Compton scattering was observed simultaneously in the same apparatus, which is shown schematically in Fig. 1.[4] A bremsstrahlung beam with an end-point energy between 6 and 7 GeV strikes a hydrogen target 1 in. in diameter and $2\frac{1}{2}$ in. long. Scattered Compton photons and π^0-decay photons are detected by showers initiated in 1 cm of lead. The shower position is measured by a hodoscope of ten vertical and fourteen horizontal scintillation counters, and the energy is measured by an array of eighteen lead glass counters, of which the central nine counters form a square covering the hodoscope. The other nine counters are placed around the central array to increase the two-photon acceptance. Charged particles are partially swept from the detector by an electromagnet and further rejected by a veto counter.

A detailed view of the proton arm is shown in Fig. 2. The angle of the recoil proton is determined by the first four of a series of magnetostrictive wire spark chambers. The proton can scatter in a total of ten carbon plates, each about 2.5 g/cm^2 thick. The direction of the proton before and after the scatter is measured by a maximum of sixteen wire chambers. Interspersed in the stack of carbon and chambers are scintillation counters used for triggering and measuring dE/dx. A combination of range determined from the chambers and dE/dx obtained from the counters gives us a measure of the energy of the proton. There are four counters beyond the stack of analyzer chambers to measure proton energies up to about 350 MeV. The trigger consists of a coincidence between the first three scintillators

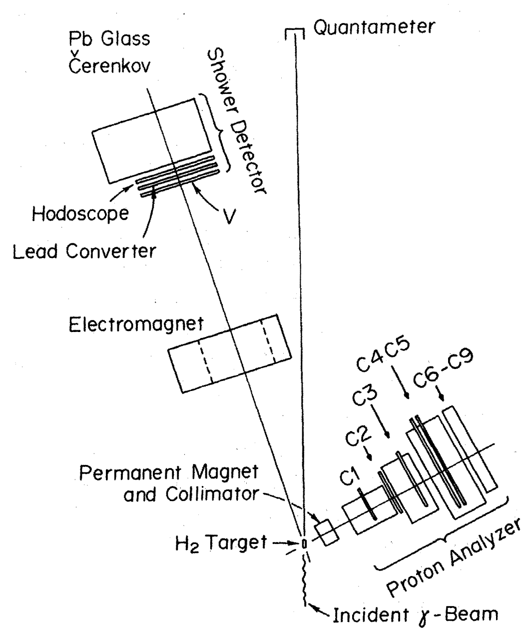

FIG. 1. Floor plan of the experiment.

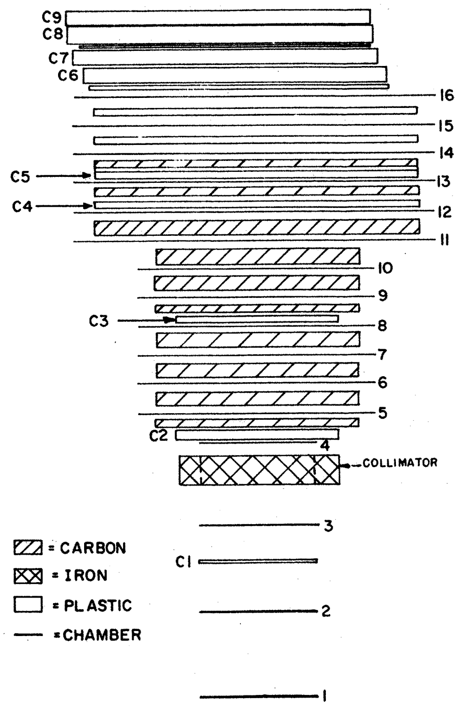

FIG. 2. Proton detector and polarization analyzer.

in the proton arm and at least one photon hodoscope counter from each plane, together with a large pulse in the sum of the central nine lead glass counters. We also require the absence of a pulse in the veto counter. For each event we record the pulse heights in the proton scintillators and in all eighteen lead glass blocks, up to four spark coordinates in both the x and y planes of the wire spark chambers, which photon hodoscope counters fired, and time-of-flight information. We have recorded a total of 1.2×10^6 events with this apparatus with a trigger rate as high as 2 events/sec; 1% of the events contain proton scatters useful for a polarization measurement.

Stopping protons are easily separated from pions and electrons using pulse-height and range information. A clean signal from one or two photons is required on the photon side. Single shower π^0 events are identified using the single constraint that the proton energy calculated from angles and the shower energy agrees with the proton energy determined from the range. We also extract Compton events which must satisfy three kinematic constraints.

Since we can only measure an asymmetry directly, and not the polarization, we must rely on previous analyzing-power measurements of proton-carbon scatters. The analyzing-power data we used were taken from a compilation by McNeely.[5] We avoid dilution of the analyzing power from the tail of the small-angle Coulomb-scattering peak by introducing a lower cutoff on the measured angle varying from 4° to 6°, depending on the proton energy. Since the scattering angle is measured with a standard deviation of 0.8° to 1.6°, this cutoff suffices to eliminate the Coulomb-scattering peak. We do include some inelastic proton-carbon scatters in our sample because our proton energy measurement has a resolution of about ±8 MeV. This results in a decrease in the analyzing power that varies from 0% to 20%. A good measure of the sensitivity of our apparatus to the polarization is the effective analyzing power, defined by $A_{\rm eff} = [\sum A(\theta,t)^2\cos^2(\varphi)/N]^{1/2}$. The sum is over all N events used in the polarization analysis; $A(\theta,t)$ is the analyzing power; φ is the azimuthal angle. The polarization is inversely proportional to $A_{\rm eff}$ and the error is given by $(\sqrt{N}A_{\rm eff})^{-1}$. For our experiment $A_{\rm eff}$ is 0.24 at $t=-0.22$ GeV^2, rises to 0.45 at $t=-0.45$ GeV^2, and falls again to 0.31 at $t=-0.65$ GeV^2.

The inherent symmetry of the polarization analyzer is the most crucial part of this experiment. We have taken extensive precautions to avoid introducing any false asymmetries into the data. Because of the steep angular distribution of the proton-carbon cross section, a systematic error in the angle of scattering of 1 mrad can shift the measured polarization by 0.017. The alignment of the wire chambers was checked carefully throughout the entire experiment with the help of unscattered protons. As a result the maximum systematic shift in the scattering angle is kept below 1 mrad. Apparent scatters resulting from displaced sparks are eliminated by requiring that the sparks before and after the scatter be collinear and that the proton tracks intersect in the scattering material. To avoid asymmetries due to our limited fiducial volume, we construct for each track that scatters to the right a corresponding track that scatters to the left, and vice versa. If either track falls outside the fiducial volume, the event is rejected. Of the many possible asymmetries we have considered there is only one which is large enough to require an explicit correction. It is caused by the fact that the proton does not enter the analyzer perpendicular to its axis. The correction amounts to $\Delta P = -0.16$ in the lowest t bin, and it is negligible

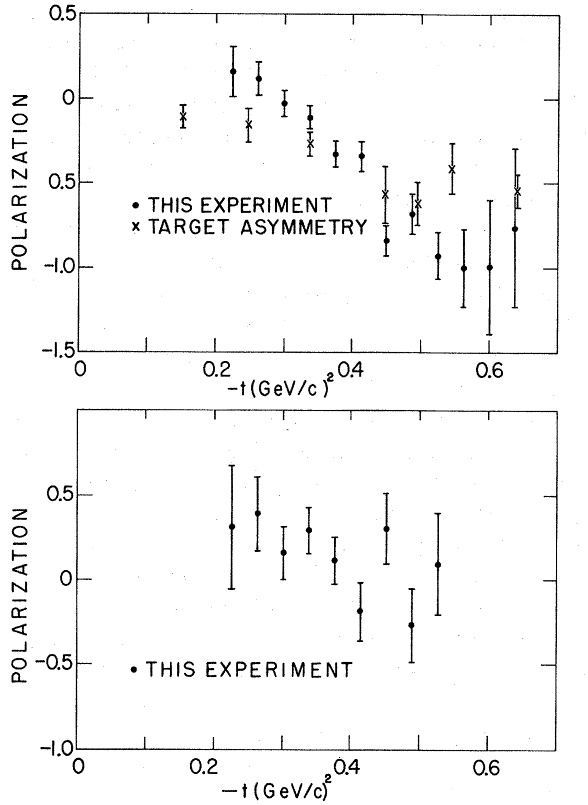

FIG. 3. Polarization of the recoil proton. Top, $\gamma+p \to \pi^0+p$; bottom, $\gamma+p\to\gamma+p$. Target-asymmetry result shown for comparison. Note that the difference between the circles and the crosses can be written in terms of the π^0 photoproduction amplitudes as follows: $2\,\mathrm{Im}(N+D) \times (F_1-F_2)^*/(|F_1|^2+|F_2|^2+|N|^2+|D|^2)$.

in the other bins. As a check on the performance of the analyzer, we have made a measurement of the polarization of the highly inelastic events. We include inelastic scatters as well as production inelastics. The small result of $P=0.07\pm0.05$ over the entire t range indicates that there are no significant asymmetries in our apparatus.

Our results for the recoil-proton polarization for $\gamma p\to\pi^0 p$ are shown in Fig. 3. The direction of the positive polarization coincides with the vector $\vec{k}\times\vec{q}$, where $\vec{k}$ is the incident photon momentum and $\vec{q}$ is the π^0 momentum (Basel convention). We plot only statistical errors, which dominate systematic effects. Also plotted are the Daresbury polarized-target asymmetry results. As discussed below, many Regge-pole models predict that P, the recoil-proton polarization and A, the target asymmetry, are equal. The general features of the two sets of data are the same but there are differences in magnitude in the low-$|t|$ range and in our high-$|t|$ range.

TABLE I. Definitions of the s-channel helicity amplitudes for pseudoscalar-meson photoproduction. λ_γ, λ_p, and $\lambda_{p'}$ are the helicities of the incident photon, initial proton, and final proton, respectively. The differential cross section and polarization and asymmetry parameters can be written in terms of these amplitudes as follows: $d\sigma/dt=|N|^2+|F_1|^2+|F_2|^2+|D|^2$, $P\,d\sigma/dt=2\,\mathrm{Im}(DF_1^*+F_2N^*)$, $A\,d\sigma/dt=2\,\mathrm{Im}(-NF_1^*+DF_2^*)$, $\Sigma\,d\sigma/dt=2\,\mathrm{Re}(F_1\times F_2^*-ND^*)$.

	λ_γ	λ_p	$\lambda_{p'}$
N	1	1/2	−1/2
F_1	1	−1/2	−1/2
F_2	1	1/2	1/2
D	1	−1/2	1/2

In principle such differences could arise from energy dependences in these observables. The target asymmetry data were taken with a bremsstrahlung end-point energy of 4 GeV whereas our data extend from 3 to 7 GeV with the average incident photon energy correlated with t as follows:

$$K(\mathrm{GeV})=2.9+5.33(-t).$$

However, this explanation seems unlikely since $s^2\,d\sigma/dt$ and Σ, the polarized-photon asymmetry, seem to have almost no energy dependence over a much wider range of energies.

Weaker, model-independence constraints on the observables also exist. Among these is the restriction $|P-A|\leq 1-\Sigma$, i.e., the difference between these two sets of data can be no larger than $1-\Sigma$. Σ is almost unity except in the neighborhood of the cross-section dip near $t=-0.5$ GeV^2, where Σ is about 0.7.

If $|P-A|\sim 1-\Sigma$ in this region as the data now now imply, then it follows[6] that the amplitudes $W_0^-=(F_1-F_2)/\sqrt{2}$ are close in magnitude and out of phase by nearly 90° (Table I). This is surprising since there is no established exchange to populate the W_0^- amplitude. Further, cuts arising from conventional absorption effects should modify F_1 and F_2 equally so that W_0^- is unaffected by such corrections.[6] More experiments in this region are needed before more definite conclusions can be drawn. The difference between P and A near $t=-0.2$ GeV^2 indicated by the data is inconsistent with the experimental values of Σ and is probably due to an undiscovered experimental asymmetry in either the Σ, A, or P data.

Our Compton result is also shown in Fig. 3. The result has been corrected for a 15% admixture of π^0 events using our π^0 polarization measurement. We observe no significant structure in the polarization. The average over our range of t is 0.12 ± 0.06, where the error includes statistics only. The polarization gives us a measure of the ratio $2\,\mathrm{Re}(F)/\mathrm{Im}(N)$, where F is the nucleon helicity-flip amplitude and N represents the diffractive part of the amplitude.

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[1]For example, see, B. Wiik, in *Proceedings of the Fifth International Symposium on Electron and Photon Interactions at High Energies, Cornell University, Ithaca, New York, 1971*, edited by N. B. Mistry (Cornell Univ. Press, Ithaca, N. Y., 1972). More recent references include R. Worden, Nucl. Phys. B37, 253 (1972); G. Goldstein and J. Owens, Tufts University Physics Department Report No. 11, 1971 (to be published).

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Small-Angle Elastic Proton-Proton Scattering from 25 to 200 GeV

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We have measured the differential cross section for small angle p-p scattering from 25 to 200 GeV incident energy and in the momentum transfer range $0.015 < |t| < 0.080$ $(\mathrm{GeV}/c)^2$. We find that the slope of the forward diffraction peak, $b(s)$, increases with energy and can be fitted by the form $b(s) = b_0 + 2\alpha' \ln s$, where $b_0 = 8.3 \pm 1.3$ and $\alpha' = 0.28 \pm 0.13$ $(\mathrm{GeV}/c)^{-2}$. Such dependence is compatible with the data existing both at higher and lower energies. We have also obtained the energy dependence of the p-p total cross section in the energy range from 48 to 196 GeV. Within our errors which are ± 1.1 mb the total cross section remains constant.

We have measured the differential cross section for p-p elastic scattering at small angles for incident energies from 25 to 200 GeV, in the momentum-transfer range from 0.015 to 0.080 $(\mathrm{GeV}/c)^2$. The data have been fitted by the form $d\sigma/dt = Ae^{-b|t|}$, and we have determined the coefficient