Proton Compton Effect for 300-MeV Photons*

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The scattering of photons by protons has been measured with a spark-chamber technique using 335-MeV bremsstrahlung. The experimental values obtained at 90° and 135° are compared with those calculated by Contogouris using dispersion relations. The agreement is reasonable except for a persistently low point for 310 MeV at 90°.

I. INTRODUCTION

MEASUREMENTS of cross sections for the scattering of photons by protons have been made at the Illinois 340-MeV betatron using a spark-chamber technique. These extend the earlier Illinois measurements[1] to the top of the first pion-nucleon resonance and overlap those made at Cornell.[2] The results at this resonance are of particular interest since these provide another indication of the extent to which photopion processes are understood theoretically. At the present time other experimental results are available at 247 MeV from the Lebedev Institute,[3] for 300–700 MeV from the University of Tokyo,[4] for 600–1300 MeV from M.I.T.,[5] and recently for 450–1350 MeV from Cornell University.[6]

II. EXPERIMENTAL METHOD

The principal difficulty associated with the measurement of the scattering in this energy region is the necessity of distinguishing the Compton-scattered photons from the hundred-times-larger intensity of photons originating from the decay of photo-produced neutral mesons, indicated by the relations

$$\gamma+p\rightarrow\gamma'+p'$$

and

$$\gamma+p\rightarrow p'+\pi^0 \searrow \gamma+\gamma.$$

Since the energy of the incident photon γ is not defined in a bremsstrahlung spectrum, the measurement of the energy and angle of the recoil proton is not sufficient to distinguish between the two reactions. However, this measurement, when combined with the observation of the direction of the recoil photon γ', allows a statistical separation of the two processes, since the scattering requires a unique direction for the scattered photon. This correlation is determined experimentally by means of a system of spark chambers.

III. EXPERIMENTAL ARRANGEMENT

The arrangement of the experimental equipment is shown in Fig. 1. The bremsstrahlung beam was obtained from the betatron operating at 335 MeV. A radio-frequency cavity was used to replace the energy loss by synchroton radiation. The frequency of the cavity was modulated so as to move the beam slowly outward into a small platinum target to get a yield pulse about 300 μsec long. The x rays were collimated to produce a beam 1.4 in. high and 0.7 in. wide at the liquid-hydrogen target, which was contained in a cylinder 1.5 in. in diameter with 0.003-in. Mylar walls. The energy flux in the bremsstrahlung beam was measured by a quantameter. Its sensitivity at 250 MeV was determined by comparison with a calibrated chamber of the type used at the National Bureau of Standards.[7] The sensitivity was found to be $(7.37\pm0.15)\times10^6$ ergs/μC, in agreement with those for similar quantameters[8] to within 2%.

A scattered photon or a neutral pion event was indicated when photons and protons emerging from the target caused a coincidence between the scintillation counters P_1 and P_2 in the proton channel and either of the two pairs of scintillators G_1 or G_2 behind the lead plates in the photon channel. This coincidence triggered the spark chambers S which displayed the positions and directions of the proton track and the origin of the photon shower. The spark-chamber tracks were recorded by means of a single camera mounted 30 ft above the target. Mirrors were used to obtain perpendicular views. The spark chambers S1, S2, S3,

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TABLE I. Neutral-pion photoproduction. Differential cross sections in microbarns per steradian.

C.m. angle	Energy bin (MeV)	Number of events	Experimental cross section	Theoretical cross section
135°	285–335	3940	18.7 ±0.3	17.48
135°	235–285	2390	10.1 ±0.2	10.73
135°	185–235	542	2.98±0.13	3.14
84°	285–335	5973	26.4 ±0.16	26.53
84°	260–285	1696	18.5 ±0.4	17.16
84°	235–260	405	9.6 ±0.4	9.06

and S4 in the proton channel each had five foils of 1 mil Dural, two of which were pulsed to a high voltage. T-he position and angle of the incident proton were determined by S1 and S2, while S3 and S4 served to determine the deflection of the proton during its traversal of the magnetic field and hence to give a measure of its momentum.

The photon detector consisted, in the order encountered by the photon shower, of a 1-in. Lucite plate for stopp ng low-energy electrons, a set of spark chambers usedi as an anticoincidence indicator to detect and eliminate events triggered by charged particles, a $\frac{1}{4}$-in. lead plate, a set of three 0.03-in.-wall aluminum spark chambers with six gaps to display the emerging electrons, and a pair of $\frac{1}{2}$-in.-thick scintillators (G2) which were used in the triggering arrangement. This was followed by a second $\frac{1}{4}$-in. Pb plate, a spark chamber, and a second trigger pair (G1). An auxiliary lens and prism arrangem ent recorded an oscilloscope display of the pulses from P1 and P2 as well as the trigger signals from G1 and G2 on the same film. These traces provided auxiliary timing and pulse-height information which could be used to examine dubious events, but were found to be unnecessary.

IV. EXTRACTION OF DATA

A total of 20 000 pictures were taken and scanned, of which about 16 000 corresponded to possible events and were indicated for measurement. These were read on a Hydel film reader having a traveling stage that provided a digitized readout of the coordinates of the spark positions as well as the pulse heights and time delays from the proton detectors P1 and P2 directly on computer cards. These cards were used in conjunction with a computer program to obtain the proton momentum and the vertical and horizontal angles for the proton and the photon. The program also computed the position of the photon shower (x,y) relative to that expected for a Compton event. The events were then sorted into energy bins corresponding to certain limits in photon energy and subsequently divided according to the distance $R=(x^2+y^2)^{1/2}$ of the observed shower from that expected if it were a Compton event.

Figure 2 shows a histogram of the number of events in successive annular rings of equal area. The scale is

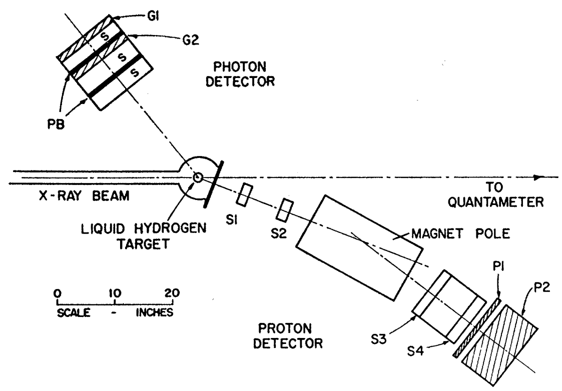

FIG. 1. Experimental arrangement.

such that bin 8 extends out to a radius of 1 in. and bin 72 to 3 in. It can be seen that the events corresponding to π^0 events give an almost uniform background in this region. The excess events which can be seen to lie mostly within the first 10 bins are considered as Compton events. The complete π^0 distribution is not shown but these made up about 90% of the measured events.

V. RESULTS AND CONCLUSIONS

Since most of the events observed were associated with the production of neutral pions and since this cross section is known fairly well, it is useful to calculate the cross sections associated with such events and to compare them with those based on the theory of Chew, Goldberger, Low, and Nambu (CGLN).[9] The number of events attributed to the π^0 production and the cross sections which follow from Monte Carlo simulations of the experiment are summarized in Table I. The errors given represent the rms errors associated with the number of events and do not include systematic errors. The theoretical values are from a computer evaluation

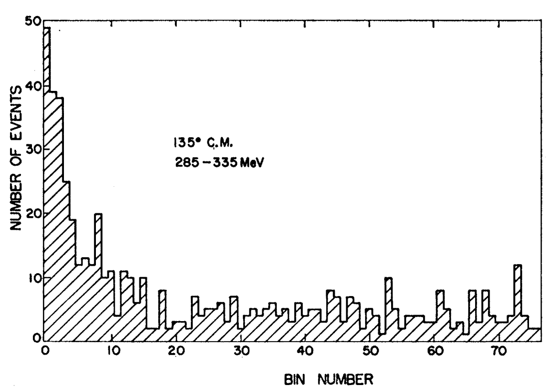

FIG. 2. Histogram of the number of photon showers in equal concentric areas about the position expected for a Compton-scattered photon. The scale is such that bin 8 represents an annular ring at a radius of 1 in. and bin 72 one at 3 in.

[9] G. F. Chew, M. L. Goldberger, F. E. Low, and Y. Nambu, Phys. Rev. 106, 1345 (1957).

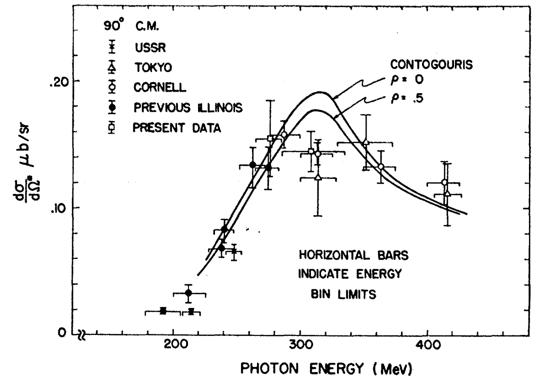

FIG. 3. Proton Compton scattering. Differential cross sections at 90° in the center-of-mass system. The experimental points other than those of the present experiment are from Refs. 1 to 4. The solid lines represent the calculations of Contogouris for two values of the ratio of the electric quadrupole to the magnetic dipole contributions.

of the CGLN theory by Blecher and Staples.[10] Since the efficiency factors for detecting the photon in the shower arrangement are very nearly the same for both π^0 and Compton events the agreement indicates that this efficiency has been evaluated correctly.

A summary of the number of Compton events assigned to various photon-energy bins at the two laboratory angles and the corresponding cross sections is given in Table II. These also have been adjusted for unequal spillage of events across the bin boundaries due to the 5% energy resolution of the protons.

VI. COMPARISON WITH THEORY

Although a large number of calculations of the proton Compton effect have been made using various phenomenological approaches, only those of Müller and of Contogouris which apply particularly to this energy region will be mentioned here.

TABLE II. Compton scattering. Differential cross sections in μb/sr.

C.m. angle	Energy bin (MeV)	Number of events	Compton cross section
136°	285–335	221±19	0.213±0.018
138°	235–285	213±21	0.152±0.016
142°	185–235	72±13	0.044±0.008
90°	285–335	122±14	0.145±0.016
92°	260–285	77±15	0.155±0.031

Müller[11] made a dispersion relation calculation which takes the absorptive part of the amplitude from single-pion photoproduction amplitudes only as given by Chew, Goldberger, Low, and Nambu. He also includes the Thomson amplitude and the small contribution from the Low amplitude for π^0 exchange.

The calculation of Contogouris[12] also makes use of dispersion relations, except that it includes the contributions from two-pion photoproduction amplitudes and therefore should be useful to higher energies. In this calculation the ratio of the electric quadrupole to the magnetic dipole amplitude is treated as a parameter ρ. The normalization is different by a factor of 6 from that of CGLN, so that the value $(E_{1+}/M_{1+})=0.045$ used in their work corresponds to $\rho=0.27$.

The experimental cross sections are shown together with those calculated in Figs. 3 and 4. The solid lines representing the cross sections at 90° and 135° in Figs. 3 and 4 are from the calculation of Contogouris. Müller's calculated cross sections agree very closely with the lower curve in each of these figures. The other experimental points are from previous measurements at Illinois,[1] Cornell,[2] Lebedev,[3] and Tokyo.[4] Figure 5 shows the measured cross section as a function of angle at 310 MeV together with curves calculated by Contogouris. This work presents the only measured cross section at 310 MeV at 135°. This value should be the most reliable of those reported here since these

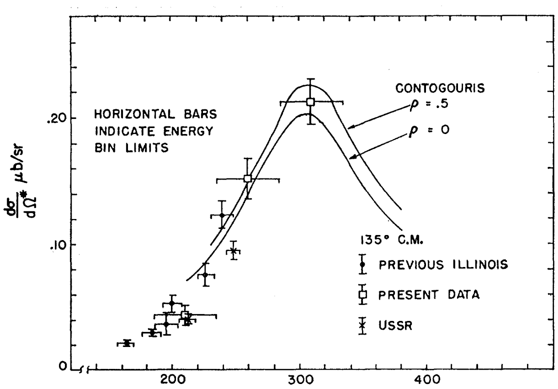

FIG. 4. Proton Compton-scattering cross sections at 135° in the center-of-mass system.

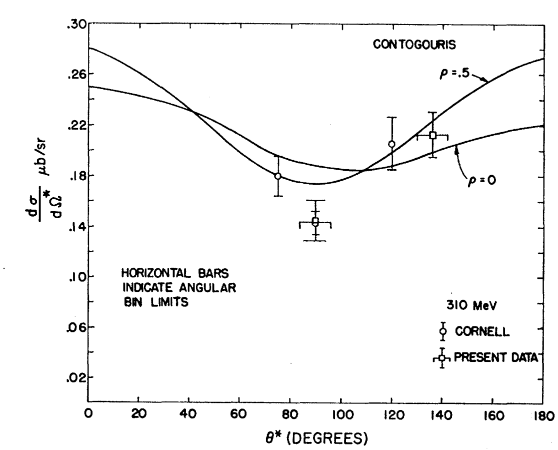

FIG. 5. Proton Compton-scattering cross sections at 310 MeV as a function of the angle in the center-of-mass system.

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recoil protons have the highest energy and are most easily resolved from the background events.

The measured cross sections can be seen to agree reasonably well with those calculated except for the persistently low point at 310 MeV for 90°. The experimental errors, however, are too large to provide a reliable check on the CGLN value of ρ. It seems that the remaining uncertainties in the interpretation of the proton Compton effect in this energy region could be resolved most clearly by a detailed measurement of the angular distribution at the resonance energy.

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Photoproduction of Charged Pion Pairs and $N^*(1238)^{++}$ in Hydrogen from 0.9 to 1.3 GeV*

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The momentum spectrum of negative pions produced in the reaction $\gamma+p\rightarrow\pi^-+\pi^++p$ has been measured at eight photon laboratory energies from 0.9 to 1.3 GeV at c.m. angles from 7° to 150°. The reaction was produced in a liquid-hydrogen target illuminated by a bremsstrahlung beam from the Caltech synchrotron. The π^- were detected and momentum analyzed with a magnetic spectrometer employing a combination of scintillation counters and Cherenkov counters. The incident photon energy was fixed by using the technique of bremsstrahlung subtraction. The cross section for the pseudo-two-body reaction $\gamma+p\rightarrow\pi^-+N^*(1238)^{++}$ was obtained by fitting the π^- momentum spectrum at each angle and energy with a linear combination of a resonance term and three-body phase space. The angular distribution of the π^- in N^* production shows the small-angle peak and decrease near 0° predicted by the one-pion-exchange (OPE) model. Gauge-invariant models are in poorer agreement with the data. Moravcsik fits to the angular distributions are presented, and are extrapolated to obtain a value for the πNN^* coupling constant of 23.1 ± 2.0 GeV^{-2}, in fair agreement with the value obtained from the width of the $N^*(1238)$. The total cross section for pion pair production decreases smoothly from 78.9 ± 2.9 μb at 0.93 GeV to 59.1 ± 5.2 μb at 1.29 GeV, whereas the N^* part of the cross section decreases from 45.0 ± 2.4 μb to 18.2 ± 3.5 μb over the same range. There is no strong evidence for formation of the $N^*(1688)$ as an intermediate state.

I. INTRODUCTION

EVIDENCE for the photoproduction of charged pion pairs from hydrogen, $\gamma+p\rightarrow\pi^-+\pi^++p$, was first reported in 1954.[1] Although numerous experimental investigations of this process have been made since then, only in the past few years have sufficient data been obtained to permit comparison with the detailed predictions of dynamical models. This paper gives the results of a counter experiment in which momentum spectra and angular distributions of negative pions produced in this reaction were measured for incident photon energies from 0.9 to 1.3 GeV.

A model for the mechanism of this reaction was proposed by Drell in an investigation of the production of beams of high-energy particles.[2] The Drell model, or one-pion-exchange (OPE) model, is based upon the amplitude given by the Feynman diagram shown in Fig. 1. This model predicts that the angular distribution of the π^- will be peaked strongly forward, but that the cross section should be small at 0° since the contribution of the OPE diagram vanishes there. In the pole approximation, the lower vertex in Fig. 1 is given by the π^+-p scattering amplitude for real pions, which is dominated by the $N^*(1238)$ at low excitation energies.

The interesting features predicted by this model prompted Kilner, Diebold, and Walker[3] to study π^-

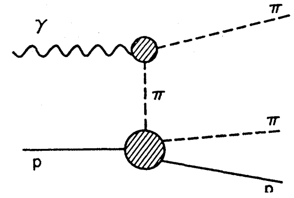

FIG. 1. Diagram for the one-pion-exchange model of pion-pair photoproduction.

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