cally identified as a proton. This simplification makes it possible to count simultaneously several groups of protons falling into different range intervals; moreover, the background counting rate from target material other than hydrogen is substantially reduced.

Bremsstrahlung from the Cornell electron synchrotron passed through a liquid hydrogen target[2] and was monitored in a Quantameter.[3] The end-point energy was set in each case sufficiently above the maximum energy being studied so that the detailed shape of the spectra was unimportant; thin-target Bethe-Heitler spectra were assumed.

Protons were counted in a range telescope of six scintillators with copper absorbers. The first counter (4 in.×4 in. at 52 in. from the target) was the smallest and defined the solid angle. The angle and energy of the proton determine the reaction completely and are used to measure the energy of the incident photons. To minimize the effect of the finite angular resolution on the energy spread, the absorbers in the proton telescope were suitably tapered in steps equal to the width of the target. Incident energies were defined in 100- or 50-Mev intervals; only at the forward meson angles did the angular spread contribute significantly to smearing out these intervals.

Pion decay quanta passed through an aperture in a 6-in. thick lead wall and were detected in a total-absorption lead glass Čerenkov counter 12 in. in diameter and 14 in. long. The aperture was 3 in. square and was 16 in. from the target, except at the forward meson angle, where the distance was 21 in. Charged particle counts were excluded by a scintillation counter placed behind the aperture and operated in anticoincidence.

Since the meson angle and energy are known from the proton parameters, the efficiency for detecting one of the decay quanta can be calculated readily; its value ranged from 0.06 to 0.4, with an estimated uncertainty of 5%.

Subsidiary experiments showed that only protons were counted in the telescope, and that the kinematics of the reaction agreed with those expected. Also, observations of the pulse-height spectrum delivered by the Čerenkov counter gave distributions as calculated for pion decay quanta under the experimental geometry.

The empty-target background was about 10% of the total. Corrections were made as follows: for random coincidences, at most 8%; for nuclear absorption of protons in the copper absorbers, from 2% to a factor[4] of 2.6; for conversion of decay quanta ahead of the anticoincidence counter, up to 12%. The absolute calibration of the beam monitor is known to within a few percent.

Differential center-of-mass cross sections for pions produced at 52°, 90°, and 125° are shown in Fig. 1. These exhibit results substantially similar to those obtained by other workers[5] and join smoothly with the cross sections measured at lower energies.[6] A simple extension of the $(\frac{3}{2},\frac{3}{2})$ resonance production to these energies would not appear to account well for the results; contribution from one or more higher levels is strongly suggested.[7]

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

1 T. Yamagata, thesis, University of Illinois (unpublished). By measuring the angular distribution of quanta associated with a given proton, it should be possible to determine the contribution from elastic scattering in the present experiment. Such a measurement is planned.

2 Raphael Littauer, Rev. Sci. Instr. **29**, 178 (1958).

3 Robert R. Wilson, Nuclear Instr. **1**, 101 (1957).

4 A constant absorption cross section of 0.7 barn was used for copper. To check this correction at the worst point, a bremsstrahlung end-point subtraction was taken to define the energy interval 0.9–1.0 Bev, and the protons were allowed to traverse the telescope without stopping. The results agreed to within the statistical accuracy of 20%. The effects of proton scattering were also checked and found to be negligible.

5 J. I. Vette, Phys. Rev. (to be published); P. C. Stein and K. C. Rogers, Phys. Rev. **110**, 1209 (1958), following Letter.

6 McDonald, Peterson, and Corson, Phys. Rev. **107**, 577 (1957). This paper also summarizes earlier results of other workers.

7 Robert R. Wilson, Phys. Rev. **110**, 1212 (1958), this issue.

Photoproduction of π^0 Mesons from Hydrogen at 500–900 Mev*

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THE photoproduction of single π^0 mesons from hydrogen has been studied using the bremsstrahlung beam of the 1.5-Bev Cornell electron synchrotron. Differential cross sections were measured at meson angles of 60°, 90°, and 120° in the center-of-mass system and photon energies in the range 500–900 Mev. The process was identified by counting the recoil protons. Since the reaction is a two-body one, an identification of the recoil proton energy and lab angle suffices to fix the meson center-of-mass angle and the incident photon energy.

A diagram of the apparatus is shown in Fig. 1. Protons were counted in a seven-counter range telescope. Counters 1–6 were scintillation counters, and

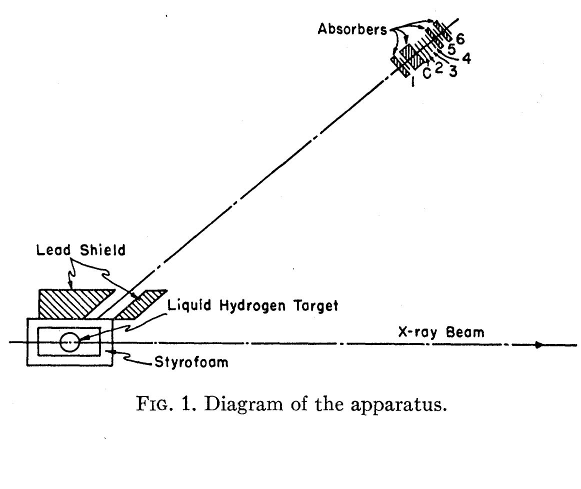

FIG. 1. Diagram of the apparatus.

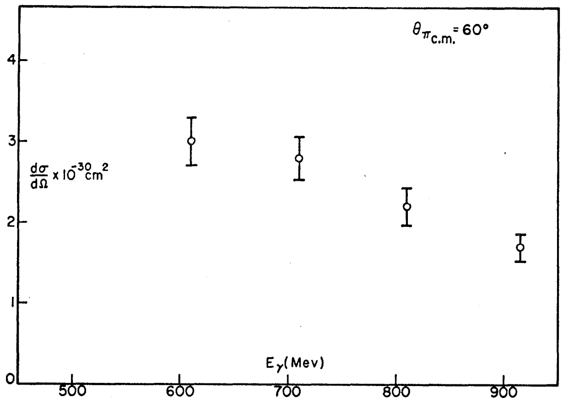

FIG. 2. Excitation function for pion angle of 60° in the center-of-mass system.

counter C was a CS_2 Čerenkov counter. Absorbers between counters 5 and 6 determined the range acceptance width of the telescope, and the absorber between 1 and C, the mean energy of the telescope. Pulse-height discrimination was used in counters 2, 3, and 4 to discriminate between mesons and protons. Counter 1 was smaller than the rest of the counters in the telescope, and thus served to define the solid angle of the telescope. It also served to eliminate counts from neutrons converting to protons in the main absorber. The Čerenkov counter was run in anticoincidence, and eliminated most of the mesons and multiple electron events with the proper range for counting in the telescope. Coincidence circuits with resolving times of $\frac{1}{4}$ μsec were used throughout. All events of the type $1+2+3+4+5-(3+6)-(2+C)$ with the proper pulse heights in counters 2, 3, and 4 were counted.

The target used in the experiment was a Styrofoam-insulated liquid hydrogen target whose walls were made of 0.001-in. Mylar.[1] The Styrofoam insulation proved to be a large source of background protons, and it was necessary to shield the counters from it with lead channels, which are shown in Fig. 1. The background rate was in general 10% of the hydrogen rate.

Since only the recoil protons are observed, it is necessary to insure that all protons arise only from the single photoproduction of neutral pions. Other reactions which can produce recoil protons are

$$\gamma+p\rightarrow 2\pi+p, \qquad (1)$$

$$\gamma+p\rightarrow (3 \text{ or more})\pi+p, \qquad (2)$$

$$\gamma+p\rightarrow p+\gamma. \qquad (3)$$

Since reactions (1) and (2) are three-body reactions, a specification of the recoil angle and energy does not uniquely determine the incident photon energy. However, for a given recoil proton, the threshold energy for (1) is about 120 Mev higher than the photon energy that will produce the same recoil proton from single π^0 production. The threshold for (2) is even higher. Due to the photon energy resolution of the telescope, which, by means of shaped absorbers, was kept to a maximum of ± 60 Mev, it was not possible to keep the peak of the bremsstrahlung spectrum below the threshold for (1). The peak of the bremsstrahlung spectrum was, in general, 120 Mev above the particular photon energy being investigated. The cross sections were corrected for multiple pion production using the experimental cross section of Sellen.[2] Checks on the latter correction were made by varying the peak energy of the bremsstrahlung beam.

Because of the fact that reaction (3) has very similar kinematic properties to the photoproduction of single pions, we were unable to discriminate against it in the same manner that we discriminated against reactions (1) and (2). We are forced to rely on the supposition that at these energies, it remains at most a few percent of the π^0 cross section, as it does at 300 Mev.[3]

Of the various corrections made to the data, the most serious was that for nuclear absorption in the copper absorbers. For this correction, we used the absorption cross sections given by Chen, Leavitt, and Shapiro[4] and Hicks and Kirschbaum.[5]

The cross sections obtained are shown in Figs. 2, 3, and 4. If these data are roughly integrated to obtain a

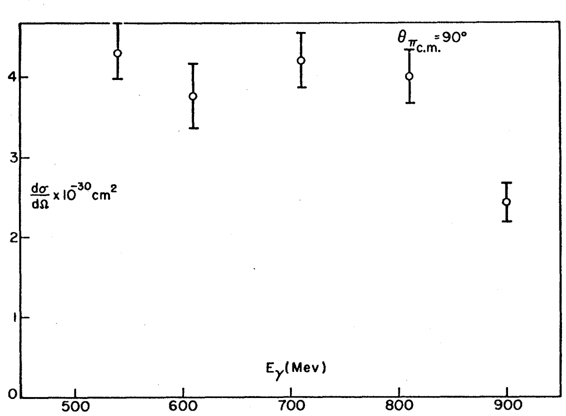

FIG. 3. Excitation function for pion angle of 90° in the center-of-mass system.

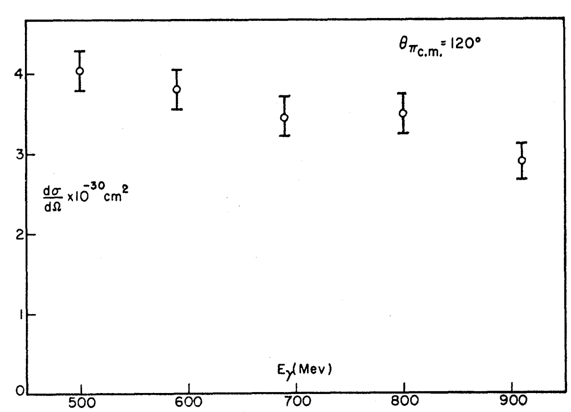

FIG. 4. Excitation function for pion angle of 120° in the center-of-mass system.

total cross section, this cross section stays approximately flat in the region of 600–900 Mev, and has a value of about one-seventh of the total cross section at the peak of the 300-Mev resonance.

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[1] R. M. Littauer, Rev. Sci. Instr. **29**, 178 (1958).
[2] J. M. Sellen (private communication).
[3] T. Yamagata, thesis, University of Illinois (unpublished).
[4] Chen, Leavitt, and Shapiro, Phys. Rev. **99**, 857 (1955).
[5] D. A. Hicks and A. J. Kirschbaum, Livermore Report M.T.A.-28, 1952 (unpublished).

Photoproduction of π^+ Mesons from Hydrogen in the Region 350–900 Mev*

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EXCITATION functions for the reaction $\gamma+p\rightarrow\pi^++n$ have been measured in the energy region 350–900 Mev and at laboratory angles of 31°, 58°, and 115° corresponding to center-of-mass angles around 45°, 90°, and 135°. Positive mesons produced in a liquid hydrogen target by the bremsstrahlung beam of the Cornell 1.5-Bev synchrotron are first momentum-analyzed by a strong-focusing magnet and then identified by pulse-height and range requirements in a four-counter telescope. At the forward angles protons are eliminated by setting upper limits on the pulse heights in the first and third counters; there are no protons at 115°. Electron contamination was shown to be negligible at 31° by observing no counts from hydrogen with the current through the magnet coil reversed. Single-meson production was insured by keeping the peak energy of the bremsstrahlung spectrum below the threshold for multiple production for any given angle and momentum.

The excitation curves are shown in Fig. 1; the dashed curves represent an average of the previously existing data.[1] In computing the cross sections a thin-target bremsstrahlung spectrum was assumed; the total energy in the photon beam was measured by a Quantameter.[2] Corrections were made for decay in flight and for nuclear absorption in the telescope. For the latter the cross section was assumed to be geometric with $r_0=1.37\times10^{-13}$ cm; this correction was in the range 5%–20%. The momentum resolution of the apparatus is 8%, resulting in an 8%–15% resolution in E_γ at forward angles and 15%–40% resolution at 115°. The errors

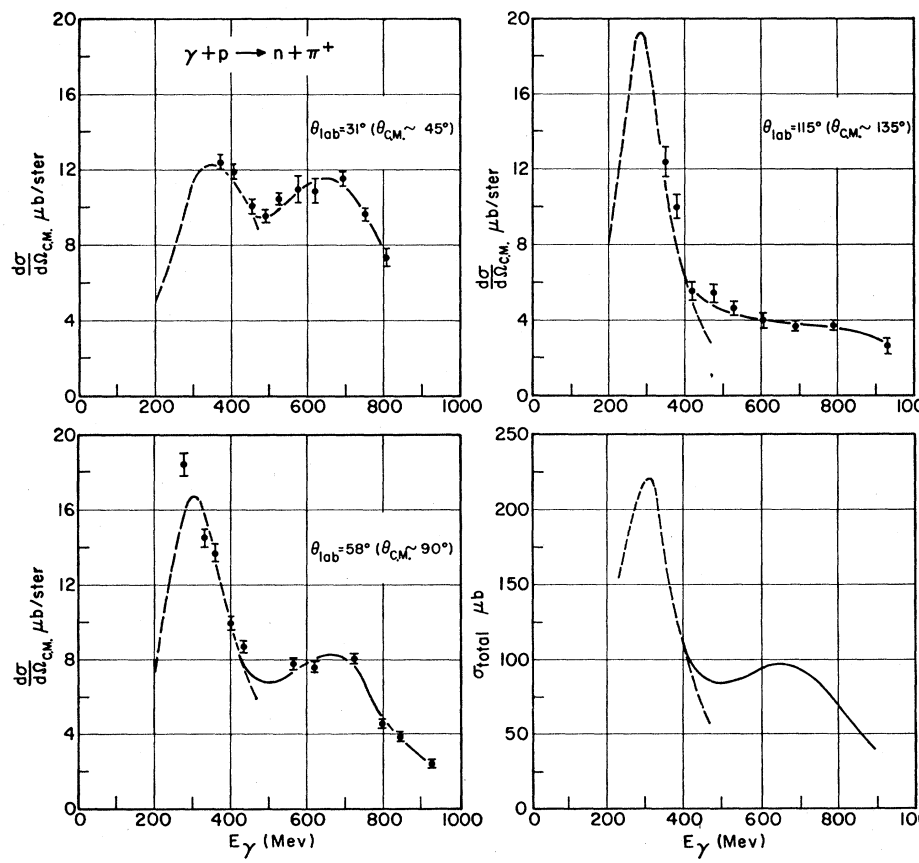

FIG. 1. Differential and total cross sections for photoproduction of π^+ mesons as a function of laboratory energy of γ ray. Dashed curve from reference 1.