PION PHOTOPRODUCTION AT BACKWARD ANGLES NEAR THE SECOND NUCLEON-PION RESONANCE*

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(Received February 7, 1961)

During the past several years there has been much evidence for a resonant $T=1/2$ state in the pion-nucleon interaction at c.m. energy about 320 Mev above the $J=3/2$, $T=3/2$ resonance. The evidence for the second resonance comes from π^--p total cross sections,[1-3] and the photoproduction of single π^+ mesons from hydrogen.[4-6] This Letter describes a photoproduction experiment which confirms differences between the scattering and the photoproduction peaks already inferred from the data of Dixon and Walker at the California Institute of Technology[5] and of the Frascati group.[6]

The peak in the differential cross section for photoproduction at 90° c.m. appears at a photon energy of 680-700 Mev and shows a width[7] of about 150 Mev in the Dixon and Walker data, and 60-70 Mev in the Frascati data which have better photon-energy resolution. The cross section at 20° c.m. measured at Frascati exhibits similar peaks. For the total nucleon-pion scattering cross-section data in the $T=1/2$ state the peak cross section occurs at a pion laboratory kinetic energy of 600 ± 15 Mev,[3] or 605 ± 6 Mev,[2] with a width of 120 Mev. The energy scale of photoproduction experiments is 150 Mev higher than that of the scattering experiments for equal c.m. energies. The total scattering cross-section peak, if plotted at the corresponding photon energies, is thus shifted upwards by 50-70 Mev and is broader than the Frascati photoproduction data would indicate. Walker pointed out[8] that at 180° (and 0°) the contribution to the photoproduction cross section of the meson current term and its interference with other terms is zero. This is characteristic of any term which does not flip the nucleon spin. Dixon and Walker extrapolated their measurements to 180° using a Moravcsik fit[9] to their data at smaller angles. The extrapolated cross section showed no resonant behavior near the second resonance energy.[8]

The present experiment measures with good statistics the photoproduction cross sections under the following two conditions: (a) photon energy 500-820 Mev, laboratory angle 180°; (b) photon energy 500-770 Mev, laboratory angle 135° (i.e., c.m. angle from 149° to 152°). The results are shown in Fig. 1. Estimated resolution functions in photon energy for the two angles are traced in the figure. The broadening of the 135° resolution is caused by the angular variation of the kinematics.

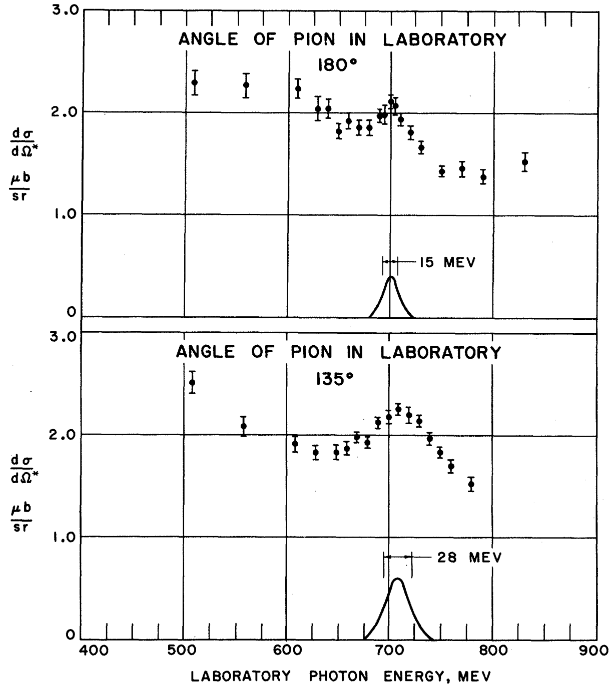

FIG. 1. Differential cross section in the center-of-mass system as a function of photon energy at fixed laboratory angles of the pion. The solid lines indicate the photon energy resolution as calculated from the spectrometer momentum acceptance, the angular variation of the kinematics, and the finite target size.

For the 180° measurements, a beam of 880-Mev electrons from the Mark III linear accelerator struck a 0.052-radiation-length tantalum radiator and was then bent by a small sweeping magnet. The photon beam passed through a $\frac{1}{2}$-in. diameter lead collimator; it then passed through a hole in the spectrometer yoke, a $3\frac{1}{2}$-in. liquid hydrogen target, a second sweeping magnet, and finally was monitored by a pressurized hydrogen ion chamber preceded by 6.5 inches of copper. Momentum analysis of the pions was by a double-focusing zero-dispersion spectrometer[10] set for

$\Delta p/p = 1\,\%$. Pions were counted in a single 10-in. Čerenkov counter filled with paraffin oil. The spectrometer field removed low-energy particles coming from the collimator, and the second sweeping magnet reduced the empty-target background by a factor of 2-3, because pions produced in the copper could not enter the spectrometer. At 135° the same arrangement was used, but the photons did not pass through the spectrometer and the second sweeping magnet was absent. On the basis of pulse-height distributions taken simultaneously with most data points, counter efficiency is estimated to be greater than 90%. The efficiency for the 180°, 500-Mev point may be somewhat less. The pulse height varied with pion momentum but was always well separated from the majority of background pulses. Pion pairs could possibly have contributed to the 500-Mev, 180° point; but the reversed-field count showed this effect to be quite small.

A correction was made for decay in flight without allowing for the possible detection of the resultant muons. This correction varied from 45% to 37% over the range of pion momenta. The effect of a more accurate treatment of the decay was estimated to be 10% or less insensitive to spectrometer settings.

Empty-target data were taken for most of the points reported, and linear interpolation used for some intermediate photon energies. At 180° the empty-target rate was 20-33% of the full-target rate, and at 135° it was 2.5-10%. Except for statistical variations, the empty-target counts decreased smoothly with increasing spectrometer momentum settings.

It is estimated that the absolute accuracy of these points is about 25%, with the relative comparison between 135° and 180° valid to 10% plus statistical error. The thick-target γ-ray spectrum used was computed by R. Alvarez. Saturation of the ion chamber appeared at much higher current levels than those occurring during data-taking. Absolute normalization was effected by use of elastic scattering of electrons in liquid hydrogen and integration over primary electron energies.[11] The 135° resolution curve measured gave good agreement with that calculated for Fig. 1. The recoil momentum of the scattered electrons was equal to that of π^+ mesons at 135° from 700-Mev γ rays. The cross section for electron scattering was taken to be 2.18×10^{-33} cm^2/sr at 600 Mev and 135°, with small corrections for energy loss due to ionization and radiation losses.[12] A correction of 12% for the change in effective target length at 180°, relative to 135°, was applied to the 180° data; this number was taken from previously measured profiles of this spectrometer. The absolute energy calibration is accurate to better than 1% in photon energy as measured by the position of the electron elastic-scattering peak. The spectrometer field was measured with a rotating coil, and the current in the magnets was measured with a precision shunt. These gave agreement of 1 part in 1000 at each momentum setting over a period of two days. The correction for the pion energy loss in the liquid H_2 shifts the 135° and 180° peaks upward by ~9 Mev. χ^2 and F tests give no evidence for other than statistical variations between runs.

We draw the following conclusions:

(a) At 180° there is strong evidence for a peak at a photon energy of 700 ± 7 Mev (corrected for ionization energy loss in the target).

(b) The width of the peak observed at 180° could be instrumental.

(c) At 135° the peak is larger and broader than at 180°; the width is approximately 50 Mev. It appears shifted upwards, relative to the 180° data, by 10 Mev.

The narrowness of the peak at 180° gives further support to the explanation that it is the effect of a single resonant state. The shift observed at other angles could be explained by the energy dependence of terms interfering with the non-spin-flip part of the resonant amplitude. However, it appears very difficult to explain the peak observed in the π^--p total cross section in terms of the same resonant state. In effect, it is hard to explain a shift in the position of the peak by an amount significantly larger than the width of the resonance. It is an open question as to what mechanism could lead to so narrow a resonance.

The authors express their thanks to Professor W. K. H. Panofsky for continual encouragement and discussions. They also benefitted greatly from frequent discussions with Professor B. Richter, and are greatly indebted to E. A. Allton who constructed the liquid hydrogen target. The expert and skillful cooperation of Lynn Boyer in setting up the experiment and of the accelerator crew in maintaining a high-energy electron beam are appreciated.

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*This work was supported by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the Air Force Office of Scientific Research.

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ELASTIC AND QUASI-ELASTIC COLLISIONS OF PROTONS WITH MOMENTA BETWEEN 9 AND 25 Gev/c

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(Received February 3, 1961)

The analysis of the interactions of ultrarelativistic[1] cosmic-ray nucleons has provided some evidence that these particles often emerge from collisions against nucleons at rest with little loss of energy (quasi-elastic collisions). It has appeared difficult to reconcile this behavior with the Fermi statistical model, which was the most commonly accepted description of the ultrarelativistic nucleon-nucleon interaction. Recently, however, theoretical arguments have been advanced[2,3] for expecting quasi-elastic collisions.

The CERN 25-Gev proton synchrotron is an intense source of monochromatic ultrarelativistic protons with which phenomena of this kind can now be quantitatively studied. This Letter describes the results of a first series of experiments in which quasi-elastic collisions have actually been observed.

The proton beam utilized was the internal circulating beam. These protons are well collimated and of well-defined energy. Their energy spread is due partly to the ionization losses experienced in the multiple traversals of the target (~100 Mev) and partly to the fluctuations of the top energy from burst to burst, also of the same order of magnitude. The internal target was a Be foil 50 μ thick and the region of the target hit by the protons was roughly circular, about 1 cm in diameter.[4] The protons, scattered by the target at an angle $\theta = 60$ mrad, first passed through an iron collimator, 6 mm wide, 3 cm high, and 1.5 m long, placed 30 m away[5]; the collimated proton beam was then momentum-analyzed by a 4-m long bending magnet (bending angle 90 mrad) and detected by a double coincidence telescope consisting of two scintillators each 1 cm wide and 2 cm high, placed 25 m away from the magnet. The resolving power $\Delta p/p$ of this arrangement was about 1% and was determined by source dimension, slit width, counter width, scattering in the air, energy spread of the circulating beam, and the Fermi motion of the nucleons in the target.

Figure 1 shows the momentum spectra observed for nine values of the circulating beam momentum. The scales given for the cross sections were deduced from another scattering measurement, performed with the external proton beam. Their absolute values must be considered only indicative, as an error even larger than two cannot be excluded at this time.

In the first seven spectra of Fig. 1, two peaks are well resolved. We call the most energetic one the elastic peak, and the second one the quasi-elastic peak. In all nine spectra a continuum is also present, the quasi-elastic continuum, extending from the largest momenta to the lowest. Eventually, this continuum merges with that due to the already well-known process of multiple production.