$\pi^{\mp}$ PHOTOPRODUCTION IN FORWARD DIRECTION*

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The ratio of π^- to π^+ off deuterium was measured as a function of incident photon energy from 600 to 1700 MeV in the forward direction. The ratio shows a broad dip around a center-of-mass energy of 1700 MeV, resulting presumably from the collective effect of several isospin-$\frac{1}{2}$ resonances in this energy region. Such a change in the ratio is reflected in the rapid variation of the isoscalar photoproduction amplitude since we found the isovector photoproduction amplitude to be a relatively smooth function decreasing slowly with increasing incident photon energy.

We have measured the ratio R of the π^- and π^+ photoproduction cross sections from deuterium, and the ratio of positive-pion production cross section of hydrogen to that of deuterium in the following reactions:

$$\gamma + d \to \pi^+ + n + n,$$

$$\gamma + d \to \pi^- + p + p,$$

$$\gamma + p \to \pi^+ + n.$$

The ratios were measured in the exact forward direction as a function of incident gamma-ray energy ranging between 600 and 1700 MeV, which corresponds to 1416 and 2017 MeV for the total energy, W, in the γp center-of-mass system. In this exact forward direction only one helicity amplitude contributes which at these energies is dominated by the Born-term contribution, so that the measurement gives directly a fairly accurate result for the real part of the amplitude at this angle, and can be understood in terms of simple phenomenological analysis.

The apparatus used is shown in Fig. 1. A bremsstrahlung photon beam from the Cornell University 2-GeV electron synchrotron was directed onto a $7\frac{1}{2}$-in.-long target filled with liquid deuterium or liquid hydrogen. The pions were focused and momentum-analyzed by a magnetic spectrometer whose axis was aligned with the photon beam. Momentum resolution of the spectrometer was set by counters 1L and 1R to be ±1.5%. The total geometrical angular acceptance was 0.15 msr.

To eliminate electron-positron background we used a radiation length of lead at the first focus of the spectrometer and a threshold gas Cherenkov counter. Electrons lost energy in the lead by the bremsstrahlung process and were then swept out of the spectrometer by the subsequent magnets. Pions underwent multiple scattering in this radiator, which changed the absolute acceptance of the spectrometer. We used the positive-pion photoproduction data from hydrogen to find the absolute acceptance of the spectrometer. We were also able to reproduce the absolute acceptance of the spectrometer by a Monte Carlo calculation using known π^+ data and spectrometer parameters. Knowledge of the acceptance is not

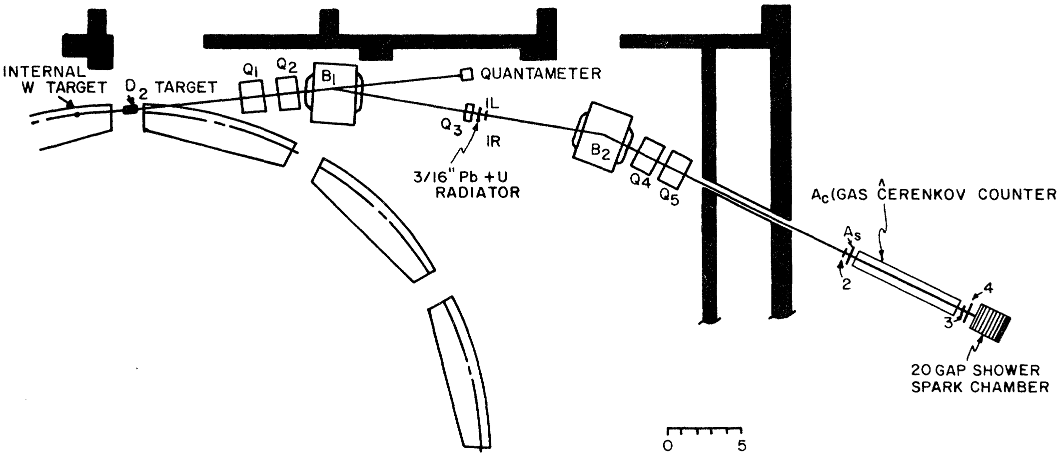

FIG. 1. Diagram of apparatus.

necessary for the ratio measurements but was used to check against systematic errors.

Separation of protons and positrons was done by measuring time of flight of the particles between counters 1 and 4. To separate pions from electrons we used a 20-gap optical shower spark chamber loaded with $8\frac{1}{2}$ radiation lengths of lead. It was triggered by particles which went through scintillation counters 1, 2, 3, and 4 but were not detected by the Cherenkov counter. We then scanned the spark-chamber pictures for events which did not shower but went straight through the chamber. The uncertainty in the scanning was found to be 3.5%. A correction of about 3% for differences in π^- and π^+ cross sections in lead was made. The electron or positron contamination in the pion was estimated to be about 1%.

To ensure that the detected pions came from the desired reactions, we studied the pion yield for a constant spectrometer setting by varying the peak bremsstrahlung energy. We found the multipion contamination to be between 1.6% at 600 MeV and 8% at 1400 MeV for both π^- and π^+. The slight dependence of the spectrometer acceptance on the particle charge was carefully investigated by examining the pion beam profile at the spark chamber for various magnet settings and counter positions, and was at worst 2%. Table I shows the π^-/π^+ ratios and corrections.

Figure 2(a) shows R after the above corrections to the data. To obtain the π^-/π^+ ratio for a free nucleon target from our data, it is necessary to correct R for Coulomb interactions in the final π^-pp state.

In our kinematical region where the momentum transfer to the nucleons is very low, Baldin's[1] approximation for calculating Coulomb correction has been used by Schult[2] to show that it is valid to use the closure approximation. The difference between the π^-/π^+ ratio from a free nucleon and R was found to be less than $\frac{1}{2}$%.

The pion production amplitude A can be decomposed in isotopic spin space into A_S, the isoscalar part, and A_V, the isovector part. The π^-/π^+ ratio can then be expressed as

$$R=\frac{d\sigma^-/d\Omega}{d\sigma^+/d\Omega}=\frac{|A_S-A_V|^2}{|A_S+A_V|^2}.$$

In the following discussion one should remember that the isospin $I=\frac{1}{2}$ final states contribute to A_S and A_V, whereas the $I=\frac{3}{2}$ states contribute only to A_V.

In the forward direction the Born term dominates the amplitude and, therefore, the real part of the amplitude is much larger than the imaginary part.[3] We define the ratio $X=\mathrm{Re}A_S/\mathrm{Re}A_V$, and express it in terms of the observable R as $X=(1-\sqrt{R})/(1+\sqrt{R})$ since $\mathrm{Im}A\ll\mathrm{Re}A$. Since A_S is never more than 15% of A_V, we neglect $|A_S|^2$ in in comparison with $|A_V|^2$ and obtain

$$\mathrm{Re}A_V=[\tfrac{1}{2}(1+R)\sigma_{\pi^+}]^{1/2},$$

$$\mathrm{Re}A_S=X\,\mathrm{Re}A_V.$$

Figure 2(b) shows X as a function of photon energy k and Fig. 3 shows the amplitudes $\mathrm{Re}A_V$ and

Table I. Ratio $R=\sigma(\gamma+d\to\pi^-pp)/\sigma(\gamma+d\to\pi^+nn)$ as a function of incident photon energy together with various corrections.

K_γ (MeV)	π^+ deadtime correction	π^+ beamspot shift correction	π^+ nuclear absorption correction	π^- deadtime correction	π^- beamspot shift correction	π^- nuclear absorption correction	$R=\frac{\sigma(\gamma d\to\pi^-pp)}{\sigma(\gamma d\to\pi^+nn)}_{\theta=0°}$	Combined statistical and systematic error(%)
600	1.045	0.981	1.153(±0.016)	1.058	1.019	1.175(±0.019)	1.17±0.11	9.6
700	1.043	0.983	1.154(±0.016)	1.052	1.014	1.175(±0.019)	1.24±0.13	10.4
800	1.039	0.989	1.156(±0.016)	1.047	1.011	1.181(±0.020)	0.85±0.09	10.4
900	1.034	0.992	1.171(±0.018)	1.032	1.009	1.201(±0.022)	0.78±0.08	9.7
1000	1.030	0.993	1.190(±0.020)	1.027	1.007	1.220(±0.023)	0.64±0.07	11.0
1100	1.026	0.995	1.197(±0.022)	1.026	1.006	1.222(±0.023)	0.56±0.07	12.1
1200	1.021	0.995	1.195(±0.022)	1.020	1.005	1.208(±0.022)	0.78±0.09	11.7
1300	1.021	0.996	1.198(±0.022)	1.023	1.004	1.199(±0.022)	1.00±0.11	11.1
1400	1.019	0.997	1.198(±0.022)	1.017	1.003	1.202(±0.022)	0.96±0.10	10.2
1550	1.016	0.998	1.212(±0.023)	1.013	1.002	1.207(±0.022)	1.01±0.11	10.9
1700	1.009	0.998	1.213(±0.023)	1.010	1.002	1.207(±0.022)	1.09±0.12	11.4

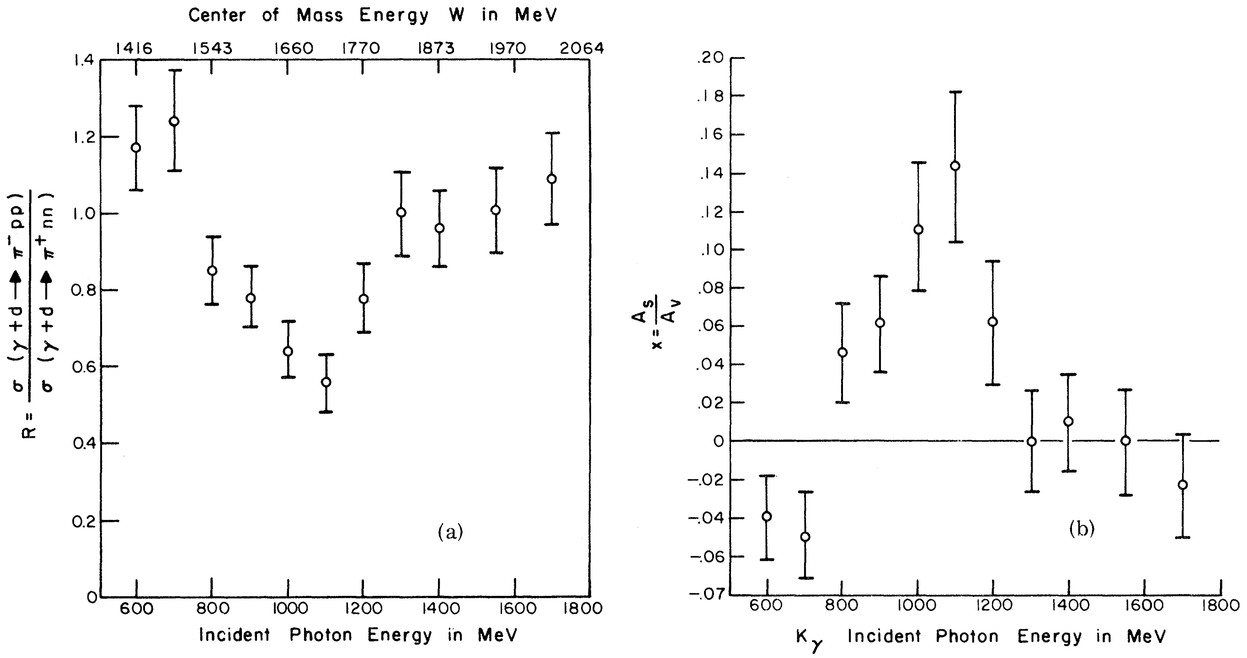

FIG. 2. (a) Ratio $\sigma(\gamma + d \rightarrow \pi^- pp)/\sigma(\gamma + d \rightarrow \pi^+ nn)$ as a function of incident photon energy. (b) Ratio of ReA_V to ReA_S as a function of incident photon energy.

ReA_S. The cross section $\sigma_{\pi^+}(0°)$ was obtained from Walker's phenomenological fit[3] and the value $\sigma_{\pi^+}(0°)$ at 1484 MeV was obtained by extrapolating the $\sigma_{\pi^+}(2.5°)$ measurement of Buschhorn et al.[4]

The most striking feature of X is its rapid energy dependence around $W = 1.7$ GeV. This is mostly due to ReA_S since ReA_V decreases slowly with energy in our energy region. The rapid energy variation of ReA_S occurs in the region where several $I = \frac{1}{2}$ resonances such as $D_{13}(1570)$, $S_{11}(1550)$, $P_{11}(1470)$, $F_{15}(1690)$, and $D_{15}(1690)$ are located. It is, therefore, remarkable that these resonances altogether yield no pronounced dips and peaks in ReA_V at $\theta = 0$, which in its general trend and magnitude follows fairly well a P_{33}-isobar approximation in fixed-t dispersion relations[5] which involves no adjustable parameter. The result of the calculation is shown as a solid line in Fig. 3.

It seems to be a fact well established by photoproduction fits in our energy region that the D_{13} and F_{15} pion-nucleon resonances contribute only weakly to the helicity amplitude nonvanishing in forward direction and more strongly to the others for photoproduction reactions off protons. Figure 3 then shows (excluding the possibility of cancellation of resonances) that this empirical fact is not due to an accidental cancelation between the isovector and isoscalar components contributing to photoproduction off protons. There exist some rudimentary theoretical arguments on the basis of internal symmetries, from which such predictions follow.[6]

The $J = \frac{1}{2}$ resonances contribute with equal

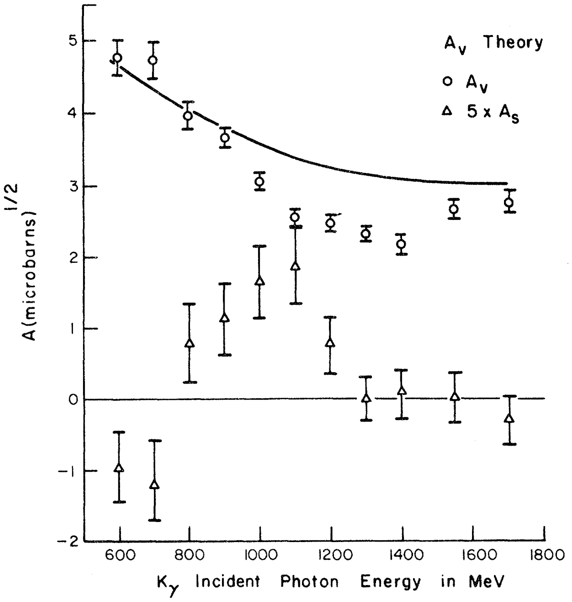

FIG. 3. ReA_V and ReA_S as a function of photon energy.

weight only to those two helicity amplitudes which do not vanish either in forward or in backward direction. According to Fig. 3 and again excluding cancelations, it also follows that the $J=\frac{1}{2}$ resonances contribute weakly to that isovector helicity amplitude which does not vanish in forward direction. Thus their effect has to be small in the isovector amplitudes at any angle.

Among the $J=\frac{1}{2}$ resonances, the $P_{11}(1470)$ resonance attracted particular attention. Because of pion loss due to multiple scattering in the lead, our data do not extend to small enough energies to overlook the whole energy range where the P_{11} resonance might appear. From our data we cannot identify a possible P_{11} contribution since its excitation is too weak. We therefore cannot draw a conclusion whether the excitation of P_{11} is stronger for photoproduction off neutrons compared with photoproduction off protons. In this context it is worthwhile to mention that Berends and Donnachie also concluded quite recently, on the basis of data at lower energies,[7] that there is no indication that the photoproduction of $P_{11}(1470)$ is favorable on a neutron. Such a rule would hold in case of an antidecuplet assignment of $P_{11}(1470)$[8] which at the moment seems out of the question anyway.

Positive-pion photoproduction off nucleons in deuterium is suppressed relative to photoproduction off free nucleons because of the Pauli exclusion principle. It has been shown that $\sigma(\gamma d\rightarrow\pi^+nn)/\sigma(\gamma p\rightarrow\pi^+n)=1-\frac{1}{3}S(q)$, where $S(q)$ is the deuteron form factor and q is the momentum transfer to the deuteron. In the forward direction q is very small and $S(q)\approx1$ so that $\sigma(\gamma d\rightarrow\pi^+nn)/\sigma(\gamma p\rightarrow\pi^+n)=\frac{2}{3}$. Figure 4 gives our measured values for this ratio as a function of energy.

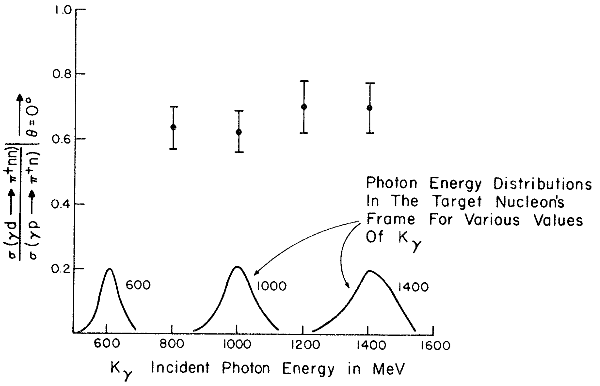

FIG. 4. Ratio $(\gamma+d\rightarrow\pi^+nn)/(\gamma+p\rightarrow\pi^+n)$ as a function of incident photon energy.

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[1] A. Baldin, Nuovo Cimento 8, 569 (1958).

[2] Roy L. Schult, private communication.

[3] W. Schmidt and G. Schwiderski, Kernforschungszentrum Karlsruhe External Report No. 3/67-1 (unpublished); R. L. Walker, California Institute of Technology Report No. Calt-68-158; Y. C. Chan, R. G. Moorhouse, and N. Dombey, Phys. Rev. 163, 1632 (1967).

[4] G. Buschhorn, J. Carroll, R. D. Eandi, P. Heide, R. Hübner, W. Kern, U. Kötz, P. Schmüser, and H. J. Skronn, Phys. Rev. Letters 18, 571 (1967).

[5] J. Engels, W. Schmidt, and G. Schwiderski, Phys. Rev. 166, 1343 (1968).

[6] P. G. O. Freund, A. N. Maheswari, and E. Schonberg, Phys. Rev. 159, 1232 (1967).

[7] F. A. Berends and A. Donnachie, to be published.

[8] H. J. Lipkin, Phys. Letters 12, 154 (1964).