POSSIBLE EVIDENCE FOR A RETARDATION TERM IN LOW-ENERGY π^0 PHOTOPRODUCTION*

Darrell J. Drickey and Robert F. Mozley
High-Energy Physics Laboratory, Stanford University, Stanford, California
(Received January 22, 1962)

We have used polarized bremsstrahlung[1] to study π^0 photoproduction at the energy of the first resonance and below. The asymmetry,

$$R=(N_t\sigma_\perp+N_r\sigma_\parallel)/(N_t\sigma_\parallel+N_r\sigma_\perp), \tag{1}$$

of production perpendicular and parallel to the electric field vector was measured at 235 Mev, $\theta=120°$; 285 Mev, $\theta=90°$; and 335 Mev, $\theta=60°$. The choice of center-of-mass pion angle, θ, was dominated by kinematic and experimental considerations. N_t and N_r refer to the number of photons transverse and parallel to the plane of emission of the photons, and $\sigma_\perp$ and $\sigma_\parallel$ are the differential cross sections for π^0 photoproduction perpendicular and parallel to the plane of polarization of the photon. The measurement was made by detecting the momentum-analyzed recoil proton. Polarizations,

$$P=(N_t-N_r)/(N_t+N_r), \tag{2}$$

of about 15% were available. Combining the first two equations gives

$$(\sigma_\perp-\sigma_\parallel)/(\sigma_\perp+\sigma_\parallel)=(1/P)(R-1)/(R+1). \tag{3}$$

Table I. π^0 photoproduction cross sections measured in this experiment with polarized bremsstrahlung.

E_γ (Mev)	θ	$(\sigma_\perp-\sigma_\parallel)/(\sigma_\perp+\sigma_\parallel)$
235	120°	0.309 ± 0.051
285	90°	0.508 ± 0.038
335	60°	0.481 ± 0.026

Table I lists our results using calculated values of P and measured values of R at the three points.

If only S and P waves contribute, the differential cross section may be written phenomenologically as[2]

$$\begin{aligned}\sigma=K\,\mathrm{Re}\{&[|E_{01}|^2+|M_{11}|^2+\tfrac{1}{2}|E_{13}|^2+\tfrac{5}{2}|M_{13}|^2+(M_{11}{}^*M_{13})+(M_{13}{}^*E_{13})-(M_{11}{}^*E_{13})]\\&+\cos\theta[2(E_{01}{}^*M_{11})-2(E_{01}{}^*M_{13})+2(E_{01}{}^*E_{13})]+\cos^2\theta[-\tfrac{3}{2}|M_{13}|^2+\tfrac{1}{2}|E_{13}|^2-3(M_{11}{}^*M_{13})-3(M_{13}{}^*E_{13})+3(M_{11}{}^*E_{13})]\\&+\sin^2\theta\cos2\varphi[-\tfrac{3}{2}|M_{13}|^2+\tfrac{1}{2}|E_{13}|^2-3(M_{11}{}^*M_{13})+(M_{13}{}^*E_{13})-(M_{11}{}^*E_{13})]\},\end{aligned}$$

where θ is the center-of-mass pion angle, φ is the angle between the plane of photon polarization and pion emission, and E_{01}, E_{13}, M_{11}, and M_{13} are complex constants representing the strength of the multipole moments. In this notation E and M refer to the electric or magnetic nature of the transition, and the subscripts refer consecutively to the pion orbital angular momentum and to twice the total angular momentum in the final state. Only S and P waves are included since qualitatively the D waves, attributed to proton recoil, should be small in this energy region. Using the CGLN[3] dispersion relation to give a qualitative estimate of its size, we find a value less than 3% of the other terms even at the resonance energy. The cross section can be written as

$$\begin{aligned}\sigma&=A+B\cos\theta+C\cos^2\theta+\alpha\sin^2\theta\cos2\varphi\\&=\sigma_0+\alpha\sin^2\theta\cos2\varphi,\end{aligned} \tag{5}$$

where A, B, and C are the angular coefficients and σ_0 the differential cross section measured in conventional experiments with unpolarized γ rays. For $\sigma_\perp$, $\varphi=\pi/2$ and for $\sigma_\parallel$, $\varphi=0$. Hence

$$(\sigma_\perp-\sigma_\parallel)/(\sigma_\perp+\sigma_\parallel)=(-\alpha\sin^2\theta)/\sigma_0. \tag{6}$$

Using the additional assumption, which at these energies seems reasonable, that the electric quadrupole terms can be neglected, it will be seen from Eqs. (3) and (4) that $\alpha=C$. In support of this assumption we can again make qualitative use of the CGLN theory, noting that the electric quadrupole term is due to a rescattering which causes a 90° phase shift with respect to the resonant magnetic term. The contribution of these terms is less than 2%.

Figure 1 shows the ratio α/C determined by our measurement of α/σ_0 and values of C/σ_0

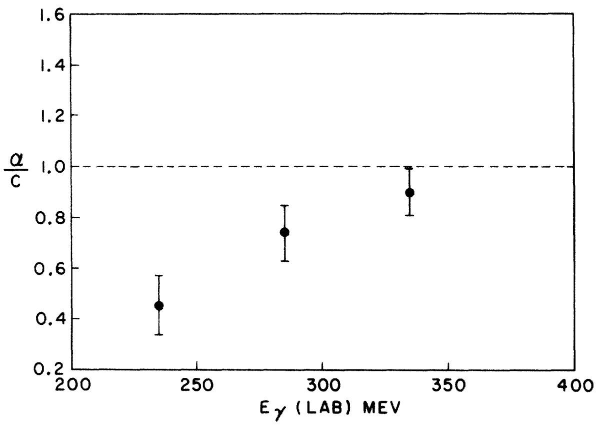

FIG. 1. Results of the analysis combining the data of this experiment with published values of angular coefficients, assuming that only S and P waves contribute to the production. $\alpha/C=1$ is to be expected since electric quadrupole production should be small.

given by experiments with unpolarized photons interpolated to our energies. The data at 285 and 335 Mev are from the best values estimated by Berkelman and Waggoner,[4] while the low-energy data are from Vasilkov et al.[5] Under the above assumptions α/C should equal one, and the significant disagreement at 235 Mev indicates that terms higher than S and P waves are needed in the analysis.

The fact that α/C might be less than one at points below resonance has been suggested by De Tollis and Verganelakis,[6] who considered the possible contributions of retardation-like terms due to the ρ and ω mesons to π^0 photoproduction as suggested by the diagrams in Fig. 2. Although there are now at least three resonances, this does not affect the validity of their argument and our data constitute a determination of a nonzero coupling constant, Λ,[7] at at least one of the photon, pion, di-pion, or tri-pion vertices.

Alternatively, if the contribution to π^0 photoproduction from the vector mesons is small, our measurement constitutes a measure of $|C/\sigma_0|$ which is smaller than that of Vasilkov et al. Since the B coefficient should not be large, involving only interference terms with E_{01}, electric dipole S-wave production, this indicates in addition a smaller value of $|C/A|$.

Our measurement of $\alpha \simeq C$ near resonance gives us confidence in our calculated value of

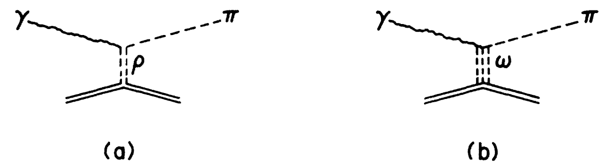

FIG. 2. Diagrams used in the analysis of De Tollis and Verganelakis to predict $\alpha/C<1$ below resonance.

polarization, since retardation-like effects cannot contribute to the cross section because they will be out of phase with the main resonant term, and since extensive measurements of the C/A ratio have been made in this energy region.

The error in α/C is due to two contributions. That of α/σ_0 is entirely due to counting statistics since our estimated systematic errors are appreciably smaller if our method of calculating the polarization is correct. The slightly larger error in C/σ_0 or essentially C/A is determined from the square root of the sum of the squares of the quoted fractional errors of C and A using the error of the nearest measured point. Since the primary contribution comes from the error in C, we feel that a more complete analysis is not justified.

We would like to thank Dr. Raymond C. Smith and Earl Maninger for their assistance in performing the experiment.

*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.

[1]R. Taylor and R. Mozley, Phys. Rev. 117, 835 (1960).

[2]M. Gell-Mann and K. M. Watson, Ann. Rev. Nuclear Sci. 4, 241 (1954).

[3]G. F. Chew, M. L. Goldberger, E. F. Low, and Y. Nambu, Phys. Rev. 106, 134 (1957).

[4]K. Berkelman and J. Waggoner, Phys. Rev. 117, 1364 (1960).

[5]R. Vasilkov, B. Govorkov, and V. Goldanski, J. Exptl. Theoret. Phys. (U.S.S.R.) 37, 11 (1959) [translation: Soviet Phys.—JETP 37, 7 (1960)].

[6]B. De Tollis and A. Verganelakis, Nuovo cimento 22, 406 (1961).

[7]In the notation of De Tollis and Verganelakis,[6] Λ is determined as positive under the restrictions that only the ρ and ω mesons are considered and analyzed between $\Lambda \pm 1$.