Kinematics of threshold (γ,π^0) reactions

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The kinematics for the (γ,π^0) reaction near threshold is discussed. The pion formed in this reaction decays into two gammas whose angular distribution can be calculated from the pion differential cross section. The sensitivity of the angular distribution of the two gammas to various models of the reaction on ^{6}Li is shown.

The (γ,π) reaction has attracted interest as a probe of the nucleon constituents of nuclei because the elementary reaction $\gamma N \rightarrow \pi N$ is reasonably well known. Theoretical analysis of the reaction is simplified by the absence of nuclear distortion in the initial state because the coupling between the nucleus and the electromagnetic field is weak. The reaction can produce a Δ by conversion of a nucleon through a quark spin flip and thus provides a means for testing models of Δ's in nuclei. This subject has been reviewed by Bernstein.[1]

Experiments with the (γ,π) reactions have focused on the charged pion channels because of the difficulty of detecting the neutral pion. However, neutral pions are of interest because their production can excite both isoscalar and isovector nuclear modes unlike charged pions which only excite isovector modes. Also, charged pion photoproduction occurs mainly in the region of the nuclear surface while neutral pion photoproduction can probe the nuclear matter distribution and pion wave function throughout the nuclear volume.

In this Brief Report we extend a discussion of the (p,π^0) reaction given in Ref. 2 to a discussion of the kinematics of (γ,π^0) and describe techniques which allow measurement of the differential cross section of the π^0.

At threshold, where the amplitude can be represented by an s and p wave interaction, the differential cross section for the (γ,π^0) reaction can be written

$$\sigma(\theta) = A + B\cos(\theta) + C\cos^2(\theta) \quad , \tag{1}$$

where θ is the angle of the π^0 in the center of mass and A, B, and C are functions of the incident photon energy. Using the techniques of Ref. 2 this differential cross section can be transformed into the angular distribution of the gammas in the laboratory. A measurement of the angular distribution of the two decay gammas determines A, B, and C which in turn gives the differential cross section in Eq. (1).

As an application of this angular distribution function, we consider the (γ,π^0) reaction on ^{6}Li as discussed by Vergados and Woloshyn.[3] Their calculation of the differential cross section for the (γ,π^0) reaction includes both direct production from a nucleon and production of a charged pion which then charge-exchange scatters on a second nucleon. They present two sets of differential cross section parameters for direct production: one set includes the contribution of an elementary Δ pole term as well as nucleon and pion pole graphs, whereas the other set does not include the contribution of the Δ pole. They find a large difference in the shape of the differential cross section for these two calculations. The parameters A, B, C of Eq. (1), derived from the data given in Ref. 3 for direct production, are given in Table I. As can be seen, the parameters are much different for the two models.

Figure 1 indicates the coordinate system we use to represent the angular distribution of the two gammas. For reactions near threshold, the production and decay of the pion can be considered as occurring at the same point since the π^0 has a very short lifetime. In the following calculations, the direction of one gamma is fixed along the negative x axis ($\theta'=90°$, $\phi'=180°$). The intensity of the second gamma is then plotted as a fuction of θ and ϕ.

The distribution of the second gamma, as derived in Ref. 2, is shown in Fig. 2. Values for the parameters A, B, and C were taken from Table I for the ground state to ground state reaction using an incident beam energy of 140 MeV. If the two gammas were emitted by a pion at rest, they would come out in exactly opposite directions. Because of the motion of the π^0, there is a spread in direction of the second gamma relative to the first. The second gamma is

TABLE. I. Angular distribution parameters for (γ,π^0) reaction as derived from the results of Vergados and Woloshyn (Ref. 3). E_γ is the laboratory energy of the incident photon and T_π is the energy of the pion in the center of mass. Parameters given in units of 10^{-2} μb/sr, energies in MeV.

E_γ	T_π	Final state	A	B	C	Δ pole?
138.5	1.82	1^+, g.s.	0.147	0.145	0.144	no
138.5	1.82	1^+, g.s.	1.84	0.226	−1.27	yes
140	3.25	1^+, g.s.	4.21	0.242	−2.98	yes
140	1.12	3^+, 1st exc	0.120	−0.001	−0.101	yes

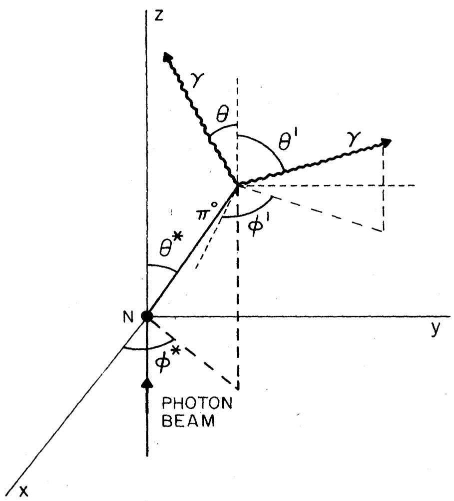

FIG. 1. Definition of coordinate system used in Fig. 2 through Fig. 5. θ^*, ϕ^* are the polar and azimuthal angles for the pion in the center of mass with respect to the incident photon beam. θ, ϕ (ϕ is not shown) and θ', ϕ' give the angle of the two gammas in the laboratory. Since the flight path of the π^0 is very short, θ, ϕ can be considered as the polar and azimuthal angles for the second gamma with respect to the incident photon beam.

confined by the kinematics to a cone centered near the direction of the positive x axis ($\theta = 90°, \phi = 0°$). The distribution of the second gamma has a singularity at the edge of this kinematic cone which has been suppressed for visual reasons.

Figure 2 represents the gamma distribution for the reac-

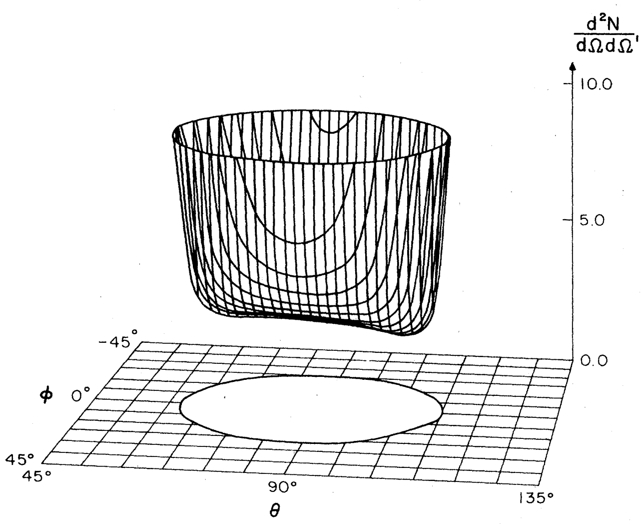

FIG. 2. Angular distribution of one gamma when the other gamma is emitted along the negative x axis for a 140 MeV incident photon. Only the reaction channel with the final nucleus in the ground state is included. $d^2N/d\Omega d\Omega'$ is the number of gammas/sr^2 atom emitted at a polar angle θ and azimuthal angle ϕ for a flux of 10^{30} photons/cm^2. The definition for the vertical scale is the same in Figs. 3–5. The edge of the distribution, which extends to infinity, has been cut for visual reasons.

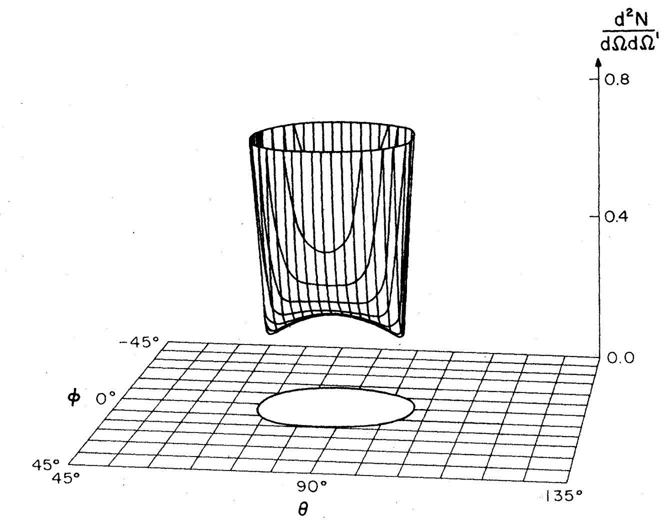

FIG. 3. Angular distribution for the same case as Fig. 2 but for the reaction channel with the final nucleus in the first excited state.

tion which leaves the nucleus in the ground state, using an incident photon energy of 140 MeV. Figure 3 shows the distribution obtained with an incident gamma energy of 140 MeV for a reaction which leaves the nucleus in the first excited state at 2.185 MeV. In this case the kinematic cone is smaller than the one in Fig. 2 because the pion kinetic energy is smaller. The actual experimental distribution at 140 MeV would be the sum of Figs. 2 and 3. Thus, by looking at the angular distribution one can gain some information regarding the relative strengths of transitions to different nuclear states.

Figures 4 and 5 show the gamma distribution for a 138.5 meV energy incident gamma. Figure 4 does not include the Δ pole term, while Fig. 5 does include it. There is a sharp

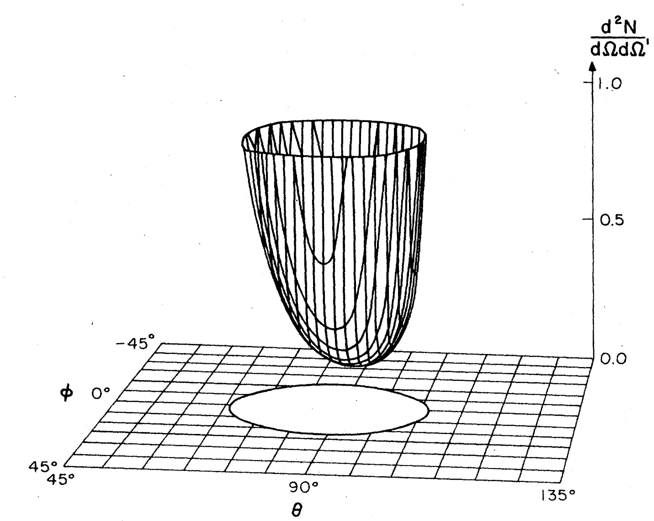

FIG. 4. Angular distribution of one gamma when the other gamma is emitted along the negative x axis for a 138.5 MeV incident photon. No delta pole is included in the calculation.

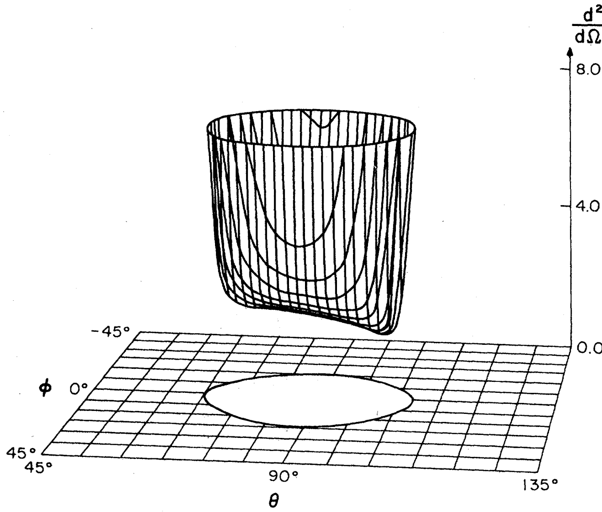

FIG. 5. Same parameters as Fig. 4 but with a Δ pole included in the calculation.

contrast in the shape and magnitude of the distributions shown in Figs. 4 and 5. Even a crude measurement of the angular distribution of the decay gammas should be able to distinguish between the two models.

In an experiment one could not, of course, restrict the first gamma to fall along the negative x axis. A means for analyzing an experiment which measures the angle of both of the decay gammas relative to the incident beam is given in Ref. 2.

The total cross section for (γ,π^0) reaction on ^{6}Li has been measured by Dodson *et al.*[4] Their measurement required a coincidence between the two gammas, but did not measure the gamma direction. If position sensitive detectors could be used in this measurement, such as those described by Heusch, Kline, and Yellin,[5] some information about the angular distribution could be learned by the techniques described above. The measurement of Dodson and co-workers utilized a bremsstrahlung beam which did not have a well defined energy. With the monochromatic photon beams proposed for the new generation of electron accelerators, experimental uncertainties associated with this measurement should be greatly reduced and allow a determination of the two-photon angular distribution.

A method of analysis has been described which allows the determination of the (γ,π^0) differential cross section from a measurement of the angular distribution of the π^0's decay gammas. The method is restricted to pion production reactions very near threshold where the cross section can be represented by an s- and p-wave parametrization.

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