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Direct observation of a three-body mechanism in the reaction ^{3}He(γ,pp)n

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The reaction ^{3}He(γ,pp)n was measured in a kinematic region which isolates the three-body absorption mechanism corresponding to the production of a pion on one nucleon, and its subsequent reabsorption on the remaining two-nucleon pair. Differential cross sections were obtained as a function of neutron recoil momentum P_n at fixed neutron recoil angle $\theta_n = 45°$, and as a function of θ_n for fixed $P_n = 300$ MeV/c. The results are quite consistent with expectations of multiple-scattering calculations. Final-state interactions between outgoing nucleons play an important role, and are predicted to be minimized in out-of-plane kinematics.

During recent years considerable interest and activity have been devoted to the study of multinucleon mechanisms involved in the absorption of photons and pions by few nucleon systems. The results of several experiments demonstrated that the primary mode of absorption involves correlated neutron-proton (n-p) pairs. The signature for two-nucleon absorption is rather well defined by strong kinematic correlation of the outgoing particles resulting from the absorption by an n-p pair having Fermi motion in the nucleus.

Recent experiments involving pion [1–4] and photon [5,6] absorption on ^{3}He indicate that three-nucleon absorption may also account for a significant fraction of photon and pion absorption. However, three-nucleon mechanisms are more difficult to identify because the phase space for three-body final states is quite broad. Since these experiments were able to observe a limited phase space, the conclusions were based upon extrapolations of their data assuming a three-body phase-space distribution.

In the calculated [7,8] distribution of two- and three-body contributions in the inclusive reaction ^{3}He(γ,p) as a function of proton momentum at fixed emission angle, the two-body strength is rather well concentrated at the high-momentum end of the spectrum while the three-body strength is broad, and lies mostly within the phase space where the photon absorption is dominated by pion production. The detection of two nucleons in coincidence is therefore required to disentangle these two channels.

Figure 1 shows diagramatically two important mechanisms contributing to the absorption of real photons by three nucleons. Diagram 1(b) involves two virtual pions and is expected to be important at photon energies in which the two-pion production cross section is large, i.e., $E_\gamma \sim 500$–600 MeV. Diagram 1(a) involves the production of a pion on one nucleon, and its subsequent reabsorption on the remaining two-nucleon pair. The exchanged pions do not have to remain on the mass shell, but in the rather narrow kinematical region of phase space where the first pion propagates on shell this two-step mechanism is expected to exhibit a triangular singularity. The cross section peaks when a real pion is created on the first nucleon, and is absorbed by a nucleon pair at rest. If one fixes the two-proton system this situation occurs at a specific neutron momentum $\mathbf{P}_n$, and a signature of this mechanism will be a maximum in the cross section at this particular value of θ_n and P_n.

This paper reports a measurement of the reaction ^{3}He(γ,pp)n in such a kinematic region which isolates the two-step process [Fig. 1(a)]. The invariant mass W_{pp} of the two protons was fixed at 2160 MeV ($\sim M_p + M_\Delta$), corresponding to the maximum in the reaction $\pi +$ "NN" $\rightarrow p + p$. Differential cross sections were obtained as a function of neutron recoil momentum P_n at fixed neutron recoil angle $\theta_n = 45°$, and as a function of θ_n for fixed $P_n = 300$ MeV/c. This is the kinematical domain where the effect of the triangular singularity of the diagram of Fig. 1(a) is maximized [7]. To facilitate the spectrometer settings, the proton emission angle θ_p^* in the center-of-mass frame of the outgoing proton pair was set at 42°.

The experiment was carried out at the Accélérateur Linéaire de Saclay. The photon beam consisted of a con-

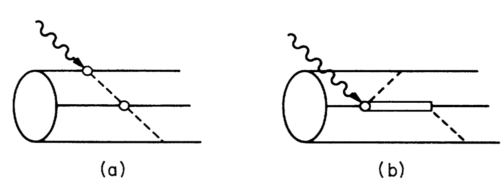

FIG. 1. Important mechanisms contributing to the three-nucleon photoabsorption. (a) Photon absorption on one nucleon with the resulting pion absorbed on the remaining pair. (b) Double-pion exchange. The bubble represents the full π and γ nucleon interaction, as described in Refs. [7] and [10].

tinuous bremsstrahlung spectrum produced by passing the electron beam through a 0.05-r.l. copper radiator. An additional virtual photon spectrum due to the electron beam passing through the experimental target was also taken into account. The number of effective virtual photons was about 20% of the real bremsstrahlung. The target consisted of ^{3}He gas under a pressure of about 12 bars, at a temperature of 20 K. The protons were detected with two dipole magnetic spectrometers having maximum momentum capabilities of 600 and 900 MeV, respectively. The p-p coincidence resolution time was about 1 ns full width at half maximum which was achieved by reconstructing the tracks of the protons in the two spectrometers. The true to accidental ratio was always quite favorable, typically about 10:1. Empty target measurements indicated that the target wall contribution was negligible. This facility has been described in detail elsewhere [9].

The experiment was kinematically complete since knowledge of the momenta and direction of the two protons, and the direction of the incident photon, along with conservation of energy and momentum, determine the kinematics of the undetected neutron as well as the energy of the incident photon. The photon energy ranged from about 320 to 450 MeV. The electron energy E_{e^-} was carefully chosen ($E_{e^-} < E_\gamma + 140$ MeV) in order to be sure that there was no additional pion in the final state.

The reaction ^{3}He(γ,pd) was also measured, and the results compared to a Monte Carlo calculation in order to determine the mean value of each kinematic acceptance bin for a flat cross section. The cross sections provide us with an overall calibration of the experimental setup.

Results for the reaction ^{3}He(γ,pp)n are shown in Figs. 2 and 3. The proton momenta and angular acceptances were imposed such that the recoil neutron momentum acceptance ΔP_n was fixed at 20 MeV/c, and angular acceptance $\Delta\theta_n < 4°$. Figure 2 shows the experimental neutron momentum distribution. Also shown in Fig. 2 are the results of a theoretical multiple scattering calculation as in Ref. [7]. Above 200 MeV/c the two-body mechanisms are unimportant since the ^{3}He wave function becomes small at large momenta. The dot-dashed curve indicates the calculated two-body absorption cross section including nucleon-nucleon rescattering in the final state. The dashed curve includes in addition the calculated contribution from Fig. 1(a). This is significantly modified by the n-p final-state rescattering (FSI). This FSI contribution is computed according to the method described in Refs. [8–10], and uses the half-off-shell n-p scattering matrix element corresponding to the Paris potential. This method has proven successful in the description of FSI in various photonuclear reactions [11].

Figure 3 shows the neutron angular distribution at a fixed momentum $P_n = 300$ MeV/c. Once again, the cross section is significantly greater than that which is calculated for the two-body mechanisms. The dashed curve is the result of the calculation involving the three-body mechanism, and the solid curve results when FSI are included. The two-body contribution is very small on the scale of the figure and has been omitted.

This simple model, when integrated over the full phase space at $E_\gamma = 350$ MeV, predicts a cross section for three-nucleon photoabsorption which is about 50% of that predicted for photoabsorption by an n-p pair, in agreement with the result obtained in the pion absorption experiment of Ref. [12]. We have specially designed our experiment to enhance the contribution of the on-shell pion exchange term. As can be seen in Fig. 4, it turns out that this mechanism dominates in a narrow kinematical region, outside of which the off-shell pion exchange term takes over, and exhibits a flat behavior. The effects of rescattering, which are considerable in our coplanar kinematics, obscures the effect of the triangular singularity due to the on-shell pion

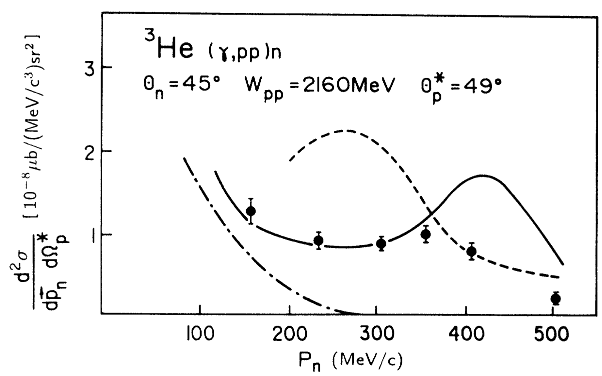

FIG. 2. Cross section for the reaction ^{3}He(γ,pp)n as a function of recoil neutron momentum at a fixed recoil neutron angle of 45°. The kinematics were fixed such that $W_{pp} = 2160$ MeV and $\theta_p^* = 49°$ in the p-p c.m. The curves are the result of a multiple-scattering calculation [7]. The dot-dashed curve is the results of including only two-nucleon mechanisms, including FSI. The dashed curve results when the two-step three-nucleon diagram is included. The solid curve is the result of including FSI corrections to the three-body mechanism. The photon energy varies from $E_\gamma = 320$ MeV at $P_n = 150$ MeV/c to $E_\gamma = 450$ MeV at $P_n = 450$ MeV/c.

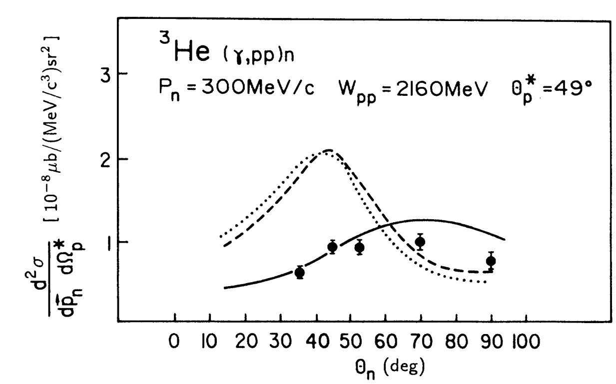

FIG. 3. As in Fig. 2 but as a function of θ_n with P_n fixed at 300 MeV/c. The contribution of the two-body mechanism is negligible at this kinematics in the scale of the figure [$< 0.5 \times 10^{-9}$ μb/(MeV^3/c^3)sr^2] and is omitted. The dashed and solid curves have the same meaning as in Fig. 2. The dotted curve is the result of including the FSI when the plane of the emitted p-p pair is rotated by an angle $\phi_{pp} = 90°$ about the direction of the p-p center of mass. The photon energy varies little around $E_\gamma = 350$ MeV.

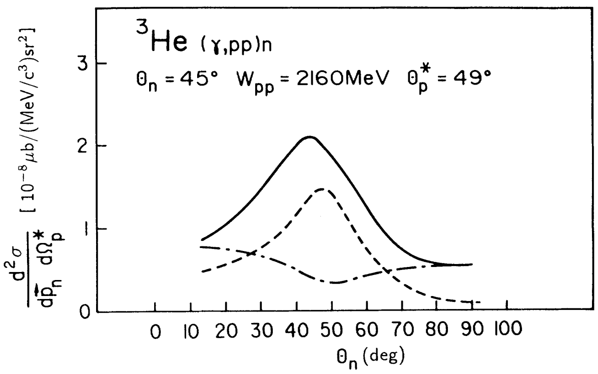

FIG. 4. The singular (dashed) and regular (dot-dashed) parts of the contribution of diagram 1(a) in the same kinematics as in Fig. 3. These two contributions add to give the solid curve.

propagator. However, our result is well reproduced when only the process shown in Fig. 1(a) is taken into account.

In future experiments the relative kinetic energy between the neutron and each proton should be kept large in order to avoid the large n-p rescattering contribution. This can be done by rotating the p-p emission plane around the direction of their center-of-mass motion, so that it makes a large angle ϕ_{pp} relative to the n-γ plane. With all other kinematic variables held constant, the basic three-nucleon cross section remains unchanged. For example, the calculated result including FSI for $\phi_{pp} = 90°$ is shown by the dotted curve in Fig. 3. In this case the FSI effects are very small, and the strong peaking of the cross section near $\theta_n = 45°$ would be a definitive signature of the two-step process. This will require out-of-plane capabilities which are expected to become available with large acceptance spectrometers such as the 4π detector DAPHNE which will be used at Mainz, and other new facilities currently under construction.

In summary, we have observed three-nucleon photoabsorption in a kinematic region around the singularity of the two-step process [Fig. 1(a)]. The agreement between theory and the obtained cross section is quite good, both in shape and in magnitude, when the FSI are taken into account. At photon energies above 400 MeV the diagram of Fig. 1(b), which is not included in the calculation, could become important, and might explain the remaining discrepancy.

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[1] K. A. Aniol *et al.*, Phys. Rev. C **33**, 1714 (1986).
[2] G. Backenstoss *et al.*, Phys. Rev. Lett. **55**, 2782 (1985); **61**, 923 (1988).
[3] C. Smith *et al.*, Phys. Rev. C **40**, 1347 (1989).
[4] P. Weber *et al.*, Phys. Lett. B **233**, 281 (1989).
[5] G. Audit *et al.*, Phys. Lett. B **227**, 331 (1989).
[6] N. D'Hose *et al.*, Phys. Rev. Lett. **63**, 856 (1989).
[7] J-M. Laget, J. Phys. G **14**, 1445 (1988).
[8] J-M. Laget, Nucl. Phys. A **497**, 391 (1989).
[9] C. Marchand *et al.*, Phys. Rev. Lett. **60**, 1703 (1988).
[10] J. M. Laget, Phys. Rep. **69**, 1 (1981).
[11] J. L. Faure, Nucl. Phys. A **244**, 383 (1984).
[12] G. Backenstoss *et al.*, Phys. Lett. B **222**, 7 (1989).