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INS-Rep.-495
May, 1984

Neutral Pion Photoproduction from Deuteron at 90°, 120° and 130° CM Angles

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ABSTRACT

Cross sections for $\gamma d \rightarrow \pi^0 d$ are presented in the photon energy range from 500 to 1000 MeV. As the photon energy increases, the cross sections decrease monotonically with small structures. A significant discrepancy between experimental and theoretical cross sections is found over the range from 600 to 850 MeV. The difference is indicative of dibaryon resonances around 2.5 GeV.

A two-nucleon system has offered an idea for the dibaryon resonances.[1] In particular the reaction $\gamma d \rightarrow \pi^0 d$ is one of dibaryonic examples interested in looking for the dibaryon resonances of the isospin unity. In addition, this type of reaction will prefer to the photodisintegration of the deuteron for resonance hunting, since the elasticity of the dibaryon resonances is in general at 10 % level.[2] According to Zayats and Omelaenko,[3] a behavior of differential cross sections in a large angular region is sensitive to the dibaryon resonances.

On the other hand, experimental cross sections so far measured are almost concentrated in a region out of our interest. We have intended, therefore, to measure an excitation behavior in a backward region. In this report, we will provide the first systematic data for the reaction in CM angles greater than 90° and photon energies above 500 MeV. As well we expect our data will stimulate a theoretical study on this reaction.

An alignment of experimental apparatus consisted of a magnetic spectrometer and a photon detector as shown in Fig.1. The electron synchrotron of the Institute for Nuclear Study(INS), University of Tokyo, was used as a photon source. A bremsstrahlung beam hit a deuterium target. A recoil deuteron passed through a counter hodoscope(H), which was made of six finger counters each 1(wide) x 2.6(high) x 0.3(thick) cm^3. Subsequently the deuteron traveled through a multiwire proportional chamber (MWPC), a wedge type magnet, a pair of counter telescopes (T1 and T2) and four hold drift chambers (DC's) between the telescopes. One of photons decayed from π^0 was detected by the photon detector which was a lead glass Cherenkov counter (C) located in the direction of π^0.

In this experiment, there were a lot of background events, some of which would severely affect the wanted event $\gamma d \to \pi^0 d$. Thus the event identification was performed by means of the procedures mentioned below.

As this reaction is a two-body process, the kinematical condition is determined uniquely by the deuteron arm, that is, momentum and angle of the recoil deuteron. However only a single arm measurement was not easy to extract the deuteron event out of copious background events. A simple but reliable method to eliminate the background events was achieved by using the photon detector C in coincidence with the deuteron arm. Then in off-line analysis, two-dimensional discrimination was applied with respect to flight time versus energy deposit in C. A further discrimination was done to counter data for flight time versus pulse height distribution.

Events so obtained as above were reconstructed in space. Tracking in front of the magnet was simply done by connecting two points, namely center of hit counter of H's and position of fired wire of MWPC. A track behind the magnet was determined by using the data on four or three planes of DC's. In this reconstruction procedure, events which had multiple signals in either H or MWPC were thrown away. A reconstruction efficiency was estimated to be 82 %.

Since the momentum of the deuterons ranges from several to ten hundred MeV/c, the present experiment was appreciably subject to the following effects in materials along the deuteron path: (i) energy loss, (ii) multiple Coulomb scattering and (iii) nuclear interactions. As these processes cumulatively intervened, only a Monte Carlo method would be practically applied to

corrections for energy resolution, angular resolution and acceptance of the detector system. For this purpose, Monte Carlo data were generated by taking into account the above items for the deuterons, a conversion rate of photons into electron pairs along the path of decay photons and a spectrum of the incident beam.

From the Monte Carlo simulation, the resolution of the incident photon energy was estimated to be approximately 10 MeV. The angular resolution was almost 1° in CM angle.

As mentioned above, the momentum and angle of the deuteron determined by the kinematical reconstruction will have a systematic deviation from the true values with which the event was originally produced. A calculation for the acceptance, therefore, was necessary to involve such a possible variation of the kinematical variables. Consequently the number of events produced originally at photon energy E_0 and CM angle θ_0 has to be deduced from that of observed at energy E and angle θ. Let $N_p(E_0,\theta_0)$ and $N_0(E,\theta)$ denote the numbers of events produced at a bin (E_0,θ_0) and observed at (E,θ), respectively. Then $N_p(E_0,\theta_0)$ would be obtained from $N_0(E,\theta)$ through a correction factor $F(E_0,\theta_0;E,\theta)$ defined by the expression

$$N_p(E_0,\theta_0;E,\theta) = \sum_{E,\theta} F(E_0,\theta_0;E,\theta)\cdot N_0(E,\theta).$$

The correction factor was calculated by the Monte Carlo data.

The differential cross sections are plotted as a function of the incident photon energy in Fig.2, where only statistical errors are indicated. Systematic errors are estimated to be 9 %. Other experimental data[4)] are also shown for comparison. At present we have few theories available for this reaction.

Here we take a model proposed by Nakamura et al.[5] The model is based on the Glauber theory, where single and double scattering terms are represented by diagrams A and B in Fig.3, respectively. The vertex where photopion production occurs is described by the Metcalf-Walker amplitudes.[6] In Fig.2, the theoretical curves calculated with a sum of the above diagrams are shown at each scattering angle.

From Fig.2, it is found that (i) the observed cross sections decrease exponentially with increasing the incident photon energy, (ii) there seems to be sudden changes in slope around 600 MeV and 800 MeV, but within the present level of errors, there is no distinct dip-bump structure as reported[7] in the elastic scattering $\pi d \rightarrow \pi d$, (iii) the observed cross sections lie above the theoretical curves and (iv) there is a significant excess of experimental over theoretical cross sections in the energy range from 600 MeV to 850 MeV.

Reasonably to say that the reaction $\gamma d \rightarrow \pi^0 d$ would not be fully described within a scope of the model presented in Fig.3. Then it is plausible to assume that the excess would be attributed to an effect of the dibaryon resonances. The excess region corresponds to an invariant mass around 2.5 GeV. A possible candidate will be $^1G_4$(2.43 GeV). It is worth while pointing out a fact that Kanai et al.[8] have conjectured one candidate of the mass around 2.5 GeV from data analysis of the elastic πd scattering. Siemiarczuk and Sielinski[9] have reported an interesting signal in the $nn\pi^+$ invariant mass spectrum. To get closer discussion, it is necessary to polish up available theories as well as to learn characteristic parameters of the resonances.

In conclusion, (1) the observed cross sections vary from 10 to 200 nb/sr over the measured region, (2) the general behavior of the cross sections is smoothly decreasing but shows an indication of small structures around 600 MeV and 800 MeV, (3) the difference is obvious between the experimental data and the theoretical cross sections based on the Glauber theory and (4) to investigate the structures and the difference, which may reflect an effect of the dibaryon resonances, further accumulation of experimental data is required with a better accuracy as well as theoretical study should be worked out in a more comprehensive form.

The authors appreciate the operational staff for providing the beam in a good condition. We also express our thanks to Messrs T. Kitami and K. Watanabe for their technical support in target preparation and detector construction. Mr M. Ishii and Miss Y. Morishige participated in data taking. The data analysis was done by FACOM M180IIAD of INS computer room. This work was partly supported by a Grant-in-Aid from the Japanese Ministry of Education, Science and Culture.

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FIGURE CAPTIONS

Fig.1 Experimental alignment.

Fig.2 Differential cross sections for $\gamma d \to \pi^{\circ} d$ as a function of the incident photon energy. From top to bottom, 90°, 120° and 130° CM angles. In the middle and bottom sections, results of Ref. 3 are plotted by open circles, but they are measured at 117° and 134°, respectively. Solid curves are referred to Ref.5.

Fig.3 Diagrams included in the theoretical calculation. A: single scattering, B: double scattering.

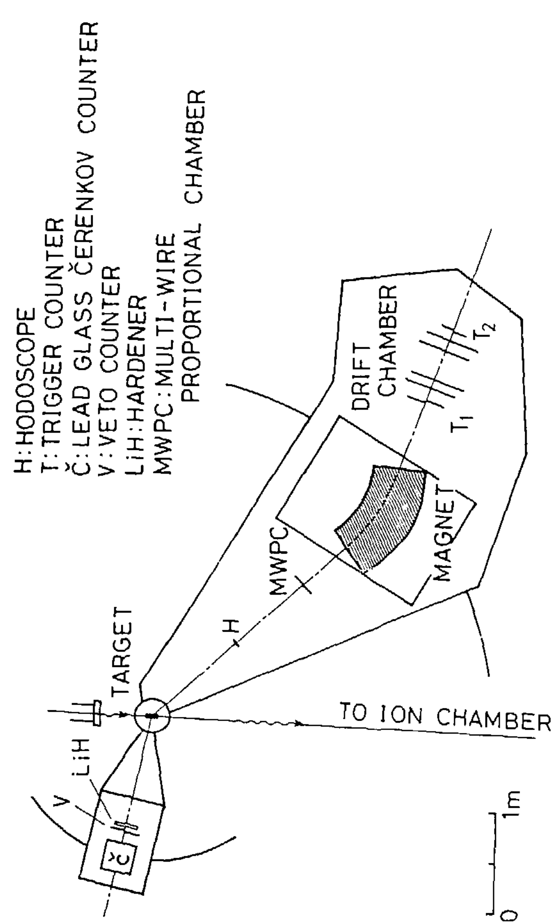
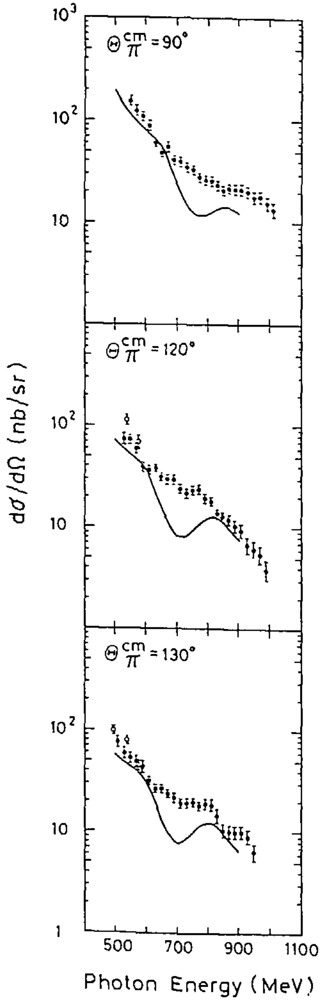
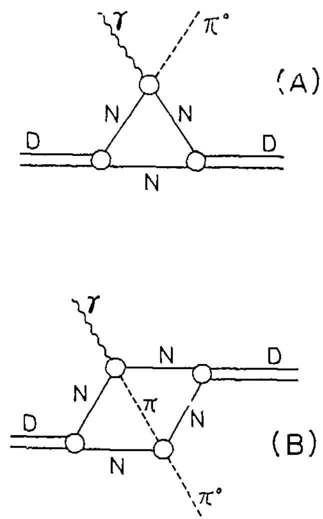


Fig. 1



$\Theta_{\pi}^{cm}=90°$
$\Theta_{\pi}^{cm}=120°$
$\Theta_{\pi}^{cm}=130°$
$d\sigma/d\Omega$ (nb/sr)
Photon Energy (MeV)

Fig. 2



(A)
(B)

Fig. 3