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Abstract

The total cross section for the $\gamma n \to p\pi^-\pi^0$ reaction has been measured over the photon energy range 450 – 800 MeV at the 855 MeV MAMI Microtron in Mainz with the large acceptance detector DAPHNE and using a deuterium target. As expected, this reaction has a very similar cross section than the $\gamma p \to n\pi^+\pi^0$ channel and its amplitude is strongly underestimated by the existing double pion photoproduction models.

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I. INTRODUCTION

Our recent measurement of the total cross section for all three $\gamma p \to N\pi\pi$ channels [1] in the photon energy range E_γ= 400 – 800 MeV has stimulated theoretical efforts ([2]- [3]) to understand these reactions with a particular emphasis on the role played by the higher baryon resonances, especially the $P_{11}(1440)$ and $D_{13}(1520)$. However, while the $\gamma p \to p\pi^+\pi^-$ and $\gamma p \to p\pi^0\pi^0$ channels are reasonably well reproduced by both models (albeit with completely different interpretations), they both strongly underestimate the $\gamma p \to n\pi^+\pi^0$ channel and the reason of this important discrepancy has not yet been found.

In order to provide more experimental evidence that could help to solve this problem, we present in this paper the measurement, of the total cross section for the $\gamma n \to p\pi^-\pi^0$ reaction between 450 and 800 MeV obtained using a deuterium target. This channel has the same isospin coefficients as $\gamma p \to n\pi^+\pi^0$ and a very similar total cross section is expected since the basic elementary mechanisms contributing to them are the same.

II. EXPERIMENTAL SET UP

The experimental set up has been previously described in detail ([4]- [5]) and we present here only its main characteristics.

The tagged photon beam was produced by bremsstrahlung of the 855 MeV electrons from the Mainz accelerator MAMI [6] on a thin nickel convertor of 10^{-4} radiation lengths. The photon energy is determined by the broad band Glasgow-Mainz tagging spectrometer which analyses in a 352 channel focal plane detector the momentum of the electrons that have radiated the bremsstrahlung photon. This detector system is able to tag photons in the range from 50 to 800 MeV with a resolution of about 2 MeV [7]. The collimation of the photon beam gives an experimental tagging efficiency of about 55%. This value was continuously monitored throughout the experiment in such a way that the photon flux could be determined with a precision of ±2% [4]- [5]. A tagged photon flux of $10^6\gamma$/s in the 350-800 MeV energy range was used during this experiment. The reaction products were detected using the 3.7π acceptance detector DAPHNE built by the INFN-sezione di Pavia and the CEA/DAPNIA-SPhN at Saclay. Its detailed description is given in Ref. [8]. Its main characteristics are: (i) a large angular acceptance (polar acceptance : $22° \leq \theta \leq 158°$ and azimuthal acceptance $0° \leq \phi \leq 360°$); (ii) high precision angular measurements for charged particle trajectories ($\Delta\theta$ (FWHM) $\leq 1°$, $\Delta\phi$ (FWHM) $\simeq 2°$); (iii) a large momentum acceptance (for protons : $p_p \geq 300$ MeV/c ; for pions : $p_\pi \geq 78$ MeV/c); (iv) good proton/pion particle discrimination as long as the proton has $p_p \leq 900$ MeV/c; (v) good proton momentum resolution ($\Delta p_p/p_p$=2.5-10% in the measured range); (vi) a useful π^0 efficiency ($\simeq$40% when at least one of the two photons of the π^0 decay is required). Three weaknesses are, unfortunately, inherent to the system. These are: (i) no $\pi^+\pi^-$ discrimination, (ii) no momentum measurement for charged pions that do not stop in the detector and (iii) no measurement of the emission angle for neutral pions.

The liquid deuterium cryogenic target was contained in a 43 mm diameter, 275 mm long Mylar cylinder with a wall thickness of 0.1 mm. The target density was stabilized and known to an accuracy of $\pm 0.5\%$ by means of an automatic pressure and temperature control system.

III. DATA ANALYSIS

A. $\gamma p \to p\pi^+\pi^-$ on the deuteron

The goal of this experiment is to compare the total cross sections of the two elementary reactions on a nucleon at rest: (a) $\gamma p \to n\pi^+\pi^0$; (b) $\gamma n \to p\pi^-\pi^0$. As the reaction (b') $\gamma d \to pp\pi^-\pi^0$ was used to measure (b), the first stage of the analysis was to evaluate the effect on the total cross section of a bound and moving nucleon. This operation was done by comparing the results obtained on the reaction (c) $\gamma p \to p\pi^+\pi^-$ when i) directly measured with a pure hydrogen target (these results are published in [1]) and ii) when derived from the (c') $\gamma d \to np\pi^+\pi^-$ process. The first step of the analysis of reaction (c') was the selection of events with three charged particles in the final state, among which only one proton was identified by a range method [9]. Under this conditions the selected events from (c') were mostly from the quasi-free double pion photoproduction on the bound proton with the neutron as a spectator. Since in the present photon energy domain the contribution due to three pion photoproduction channels is negligible, the only possible source of background is due to the single pion photoproduction process (e) $\gamma + d \to pp\pi^-$ when all three final state particle are detected by DAPHNE and when one of the two protons is not positively identified because of its hadronic interaction inside the detector materials. The kinematics of (e) is overdetermined, since the momentum of the identified proton and all the particle angles are known, and a kinematical fit was performed under the assumption that either of the two pions was a misidentified proton. About 10% of the selected three particle events satisfied the kinematical constraints and were rejected. A direct comparison of the results obtained for the reactions (c) and (c') can thus be made since this background rejection is the only difference between the two analyses.

The measured yields of the $\gamma p \to p\pi^+\pi^-$ reaction obtained with the deuterium and the pure hydrogen target are depicted in fig. 1. The comparison between these two different data sets shows that the influence on the total cross section of the Fermi motion of the target nucleon above 500 MeV is small (a few % at maximum) and can be neglected in a first approximation.

B. $\gamma n \to p\pi^-\pi^0$

The quasi-free $\gamma n \to p\pi^-\pi^0$ events were identified by a triple coincidence between two charged particles, of which only one identified as a proton by the range method, and at least one photon resulting from the π^0 decay. The correction for the π^0 detection efficiency was evaluated using the GEANT code and assuming a uniform three-body phase space distribution for the outgoing particles.

Neglecting again the three π photoproduction processes, the only parasitic reaction which can contaminate the data is process (e) when one of the two outgoing protons is not emitted within detector's acceptance (this condition is almost always fulfilled in the quasi-free $\gamma n \to p\pi^-$ kinematics) and when the emitted π^- gives rise to a secondary particle inside the detector materials which is identified as a photon. This contamination is clearly highlighted by looking at missing mass spectra $\gamma n \to pX$. As an example, we show in Fig. 2(a) the missing mass spectrum at $E\gamma$ = 400 MeV. At this energy the contribution of the double pion photoproduction channels is negligible and only one peak, coming from the quasi-free $\gamma n \to p\pi^-$ process and corresponding to the squared mass of the π^-, can be seen. The solid curve is the result of a simulation which takes into account the detector acceptances and resolutions. A uniform phase space distribution was assumed for the quasi-free $\gamma n \to p\pi^-$ process and the momentum distribution of the undetected proton was taken from [10]. Figure 2(b) shows the same spectrum at $E\gamma$ = 703 MeV. The broad distribution found at higher squared masses, that corresponds to the quasi-free $\gamma n \to p\pi^-\pi^0$ reaction, can clearly be seen on the right of the previous peak. The shape of this contribution was simulated using the same hypotheses as before. The solid curve shows the result of a fitting procedure where the two simulated contributions were adjusted to the data. The agreement is quite good and the measured cross section for the $p\pi^-\pi^0$ channel is obtained by subtracting from the data the fitted contribution of the single pion photoproduction channel.

C. Evaluation of the total cross section

The contribution from that part of the total cross section unmeasurable with our detector was estimated using both a pure three-body phase space distribution and the Murphy-Laget [3] model. This model does not reproduce the magnitude of the total cross section but predicts angular distributions different from that of a pure phase space as it contains the Born terms and the intermediate excitation of the P_{11} and D_{13} resonances. The two line styles in Fig. 3 show the DAPHNE acceptance evaluated using these hypotheses. To extrapolate our data we used the mean value between these two curves. Due to the fact that the proton polar angular distribution is strongly forward peaked, this correction is quite large. It ranges from $\simeq 90\%$ at $E_\gamma = 450$ MeV to $\simeq 55\%$ at $E_\gamma = 800$ MeV. A difference in the extrapolation of at most 10% was found between the two evaluations. This value gives an estimate of the systematic error due to the extrapolation, that is of the order of 5%. The other contributions to the overall systematic experimental error come from photon flux evaluation (2%), MWPC's efficiency (1%), π^0 efficiency (4%) and target density (0.5%) [1].

IV. RESULTS AND COMMENTS

The total cross section of the $\gamma n \rightarrow p\pi^-\pi^0$ channel is shown by the black dots in Fig.4 and the corresponding values are listed in table 1 along with their statistical and systematic errors. In the same figure are also shown, by comparison, the only data available up to now for this reaction [11] and the total cross section of the $\gamma p \rightarrow n\pi^+\pi^0$ channel previously obtained by us [1]. These two reactions have very similar total cross sections as it is expected since they have the same isospin components. As it can be inferred from Fig. 1, a sizable fraction of the difference existing between the two total cross sections should be due to the bound nature of target neutron.

The two curves are the calculations by Gomez Tejedor-Oset [2] and Murphy-Laget [3] of the $\gamma n \rightarrow p\pi^-\pi^0$ channel. They both fail to reproduce the data, while giving a good description of the other measured double pion production channels. More theoretical work is clearly needed to explain this important discrepancy.

TABLE 1

Total cross section for $\gamma + n \rightarrow p\pi^-\pi^0$

E_γ(MeV)	$\sigma_{tot}(\mu b)$
785.0 ± 7.5	49.9 ± 0.9 ± 3.4
770.0 ± 9.0	49.2 ± 0.8 ± 3.3
752.0 ± 8.5	50.4 ± 0.8 ± 3.4
735.0 ± 8.0	48.3 ± 1.0 ± 3.3
719.0 ± 8.0	45.8 ± 0.8 ± 3.1
703.0 ± 9.0	43.4 ± 0.7 ± 3.0
685.0 ± 8.5	40.9 ± 0.7 ± 2.8
668.0 ± 9.5	36.6 ± 0.6 ± 2.5
649.0 ± 9.5	33.8 ± 0.6 ± 2.3
630.0 ± 10.0	30.0 ± 0.6 ± 2.0
610.0 ± 10.0	26.7 ± 0.5 ± 1.8
590.0 ± 10.5	24.5 ± 0.5 ± 1.7
569.0 ± 10.5	22.1 ± 0.5 ± 1.5
548.0 ± 11.0	17.1 ± 0.4 ± 1.2
526.0 ± 11.0	15.0 ± 0.5 ± 1.0
504.0 ± 11.0	9.0 ± 0.8 ± 0.6
482.0 ± 11.5	7.2 ± 0.8 ± 0.5
459.0 ± 11.5	3.0 ± 0.6 ± 0.3
436.0 ± 11.5	1.9 ± 0.6 ± 0.2

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FIGURE CAPTIONS

1. The measured yield of the $\gamma p \to p\pi^+\pi^-$ reaction obtained using the deuterium target (solid circles) is shown together with the same quantity previously obtained using a pure hydrogen target (open circles) [1].

2. Missing mass distributions at E_γ= 400 MeV (a) and E_γ= 703 MeV (b). Solid circles represent the experimental data while the different style lines indicate the different contributions as calculated by the fitting procedure: dashed line: single pion photoproduction process; dash-dotted line: double pion photoproduction process; solid line: sum of both contributions.

3. DAPHNE acceptance probability for the quasi-free $\gamma n \to p\pi^-\pi^0$ channel if a uniform phase space distribution (solid line) or the Murphy-Laget model (dash-dotted line) [3] is assumed for the outgoing particles.

4. Total cross section for the $\gamma n \to p\pi^-\pi^0$ reaction. The cross section measured in DAPHNE is shown by the open circles and the extrapolated one by full circles. This result is compared to the previous data available [11] (open crosses) and to the total cross section for the $\gamma + p \to n\pi^+\pi^0$ reaction [1] (open squares). Only statistical errors are shown. The continuous and the dash-dotted line are respectively the predictions of models of Gomez Tejedor-Oset [2] and Murphy-Laget [3] over all phase space.