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Short note

Double-π^0 photoproduction from the deuteron

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Abstract. The photoproduction of two neutral pions from the deuteron has been studied for incident photon energies from 200 MeV to 820 MeV with the TAPS spectrometer at MAMI (Mainz Microtron). The total cross-section was determined and used to deduce the cross-section from the neutron. Due to the good statistical quality of the data Dalitz plots for the three particles in the exit channel ($\pi^0\pi^0 N$) could be constructed. The invariant mass distributions derived from them are presented in this paper. They indicate that the important reaction mechanism in the second resonance region is a sequential decay pattern involving the population of the $\Delta(1232)$-resonance as an intermediate state.

PACS. 13.60.Le Meson production – 25.20.Lj Photoproduction reactions

1 Introduction

The electromagnetic excitation of nucleons with real photons and the subsequent decay via mesons allow insight into the structure of nucleons and their couplings. The study of meson photoproduction therefore is an established method to test modern hadron models due to the well-known electromagnetic interaction.

In contrast to the production of two pions with at least one charged pion only few reaction mechanisms contribute to double-π^0 photoproduction, since other contributions like Kroll-Rudermann and pion pole terms are strongly suppressed due to the weak coupling of photons to neutral pions. Processes like ρ-meson decays into two neutral pions are strictly forbidden. Consequently, double-π^0 photoproduction is a very suitable reaction for the study of nucleon excitations.

Double-π^0 photoproduction from the proton has been studied in detail [1–3], however, the isospin decomposition of the electromagnetic transition amplitudes requires the measurement of the reaction $n(\gamma, 2\pi^0)n$ in addition. Double-π^0 photoproduction from the deuteron offers the possibility to deduce the cross-section from the neutron while experiments with neutron targets are not feasible. Deuterium is well suited since its nuclear structure is well understood and its binding energy is small. An earlier measurement of $d(\gamma, 2\pi^0)pn$ provided sufficient statistics to deduce the total cross-section of the reaction $n(\gamma, 2\pi^0)n$ [4]. The present data offers substantially improved statistical quality and allows the construction of Dalitz plots providing valuable insight into the reaction mechanisms.

2 Experimental setup

The experiment was carried out at MAMI (Mainz Microtron) [5] with the Glasgow-Mainz tagged photon facility [6]. Its bremsstrahlung beam tagged by the residual electrons was used as a source of quasimonochromatic photons. These hit a 10 cm long liquid deuterium target [7]. Neutral pions were detected with the TAPS spectrometer via their 2γ decays [8].

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Data were taken in two runs. The first experiment covered the energy range from 530 MeV to 820 MeV, the second one used photon energies between 200 and 790 MeV.

3 Data analysis

3.1 Identification of the reaction $d(\gamma, \pi^0\pi^0)np$

Neutral pions decay almost exclusively into two photons. The analysis requires the identification of photons followed by the reconstruction of pions by their invariant mass as described in [3,4,9].

Events with at least four photons out of which two neutral pions could be reconstructed were considered in the analysis. The reaction channel was then identified by a missing mass analysis:

$$\Delta m = \sqrt{(E_{\gamma_i} + m_N - \sum_{j=1}^{4} E^j_{\gamma_f})^2 - (\mathbf{p}_{\gamma_i} - \sum_{j=1}^{4} \mathbf{p}^j_{\gamma_f})^2} - m_N \quad (1)$$

(γ_i, γ_f^{1-4} symbolise the initial photon and the final decay photons, respectively, m_N is the mass of a nucleon (938 MeV)).

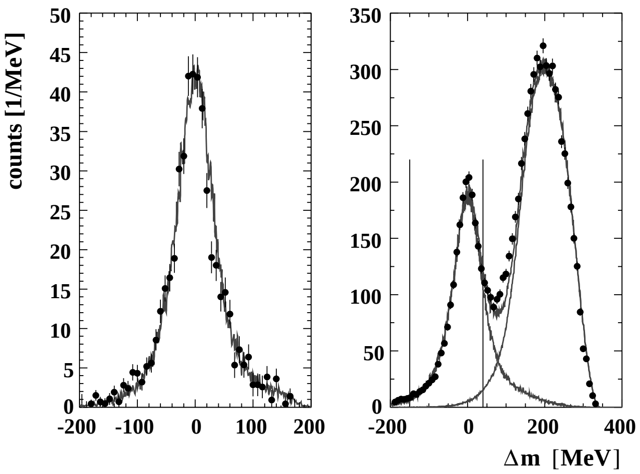

Fig. 1. Missing mass distribution. The filled circles represent the data, the solid curves the result of the simulation. The distribution on the right side is obtained for incident photon beam energies from 200 to 820 MeV. Two peaks are seen. On the left side the distribution is shown for photon beam energies from 200 to 610 MeV (η production threshold from the deuteron: 629 MeV). The peak at positive masses has vanished.

The missing mass distribution shows two structures (fig. 1, right side). Events at $\Delta m \approx 0$ MeV arise from $2\pi^0$ production. The second structure at positive masses stems from events where an η-meson decayed via $\eta \to 3\pi^0 \to 6\gamma$ and four photons were detected. This can be demonstrated by restricting the missing mass distribution to events below the η production threshold (fig. 1, left side). In this case a single peak at $\Delta m \approx 0$ MeV is observed. Both figures also show the simulated distributions (solid curves) which have the same shape as the experimental data. The simulation is briefly described below (see sect. 4). In comparison to the reaction from the free proton the missing mass distributions are broadened by Fermi motion.

Two steps were undertaken in order to extract the four photon events belonging to $2\pi^0$ production. First, only events were accepted which have a missing mass between -150 MeV and 40 MeV (see fig. 1). Second, η production from the deuteron has been simulated and the small fraction of events between -150 MeV and 40 MeV belonging to the decay of η-mesons was determined and subtracted as background.

4 Normalisation of the cross-section

The absolute normalisation of the cross-section was obtained from the number of target nuclei, the photon flux, the detection efficiency and the π^0 decay branching ratio. The photon flux was derived from the number of deflected electrons counted in the focal plane of the tagger and the tagging efficiency, *i.e.* the ratio of the number of tagged photons on the target and the number of detected electrons. The tagging efficiency was determined at regular intervals using a photon detector in-beam at reduced beam intensity. The TAPS detection efficiency has been determined by Monte Carlo simulations using GEANT 3 [10]. The simulation code is based on the participant spectator model [11] assuming phase space distribution for the two neutral pions which is a reasonable approximation (see fig. 1). The momentum distribution of the bound nucleons was calculated from the deuteron wave function [12] and included into the simulation.

5 Results and discussion

5.1 Cross-section of $2\pi^0$ photoproduction from the deuteron

The resulting cross-section of $2\pi^0$ photoproduction is shown in fig. 2 as a function of the incident photon energy. While the threshold is at 292 MeV, the cross-section starts to rise at a photon energy of about 400 MeV. A broad maximum is reached at about 750 MeV. The error bars represent statistical errors. The systematic error due to analysis cuts, target thickness, photon flux and Monte Carlo simulation of the detection efficiency is estimated to be 6 %. The open circles show the cross-section from a pilot measurement [4] for comparison. The data from the two experiments are consistent within the statistical uncertainties.

5.2 Cross-section of $2\pi^0$ photoproduction from the neutron

The cross-section of the reaction $n(\gamma, \pi^0\pi^0)n$ can be deduced from the cross-section of $2\pi^0$ photoproduction from

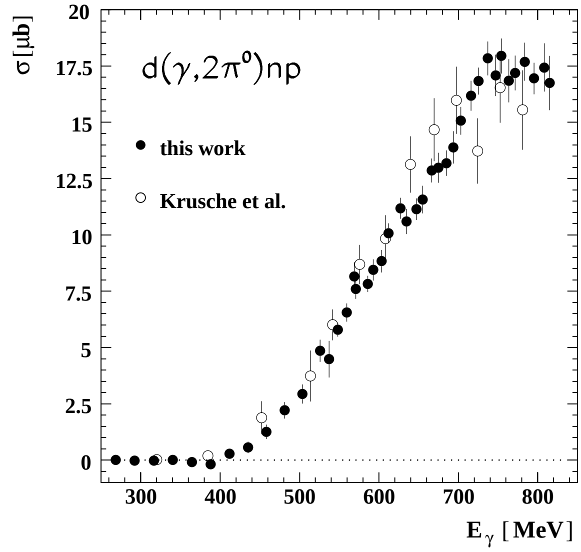

Fig. 2. Cross-section of double-π^0 photoproduction from the deuteron as a function of the incident photon energy. The filled circles symbolise the cross-section obtained in this analysis. Below 400 MeV the cross-section is compatible with zero. The open circles represent the results of an earlier measurement [4].

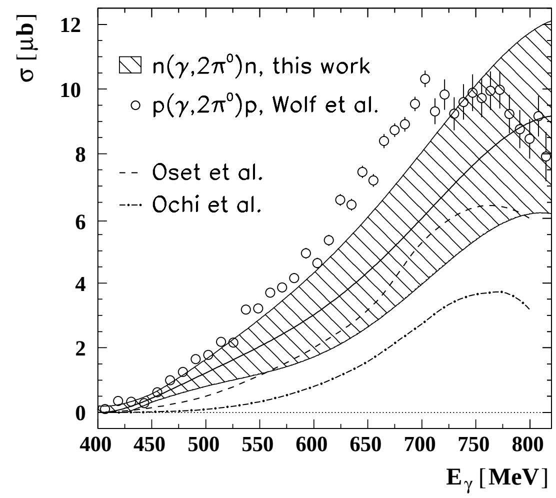

Fig. 3. Cross-section of the double-π^0 photoproduction from the free neutron as a function of the incident photon energy (black curve). The error band (hatched area) is obtained taking into account the statistical and systematic uncertainties of the cross-section from the deuteron and the proton and uncertainties due to the iteration method. The open circles are the elementary cross-section from the proton [3]. Also shown are the predictions of the models from Oset *et al.* [13] (dashed line) and Ochi *et al.* [14] (dashed-dotted line).

the proton [3] and deuteron. The cross-section from the proton was folded with the momentum distribution of the bound proton and subtracted from the cross-section from the deuteron. The result corresponds to the Fermi smeared neutron cross-section as long as other nuclear effects can be neglected. An ansatz for the free neutron cross-section folded with the Fermi distribution was varied until agree-

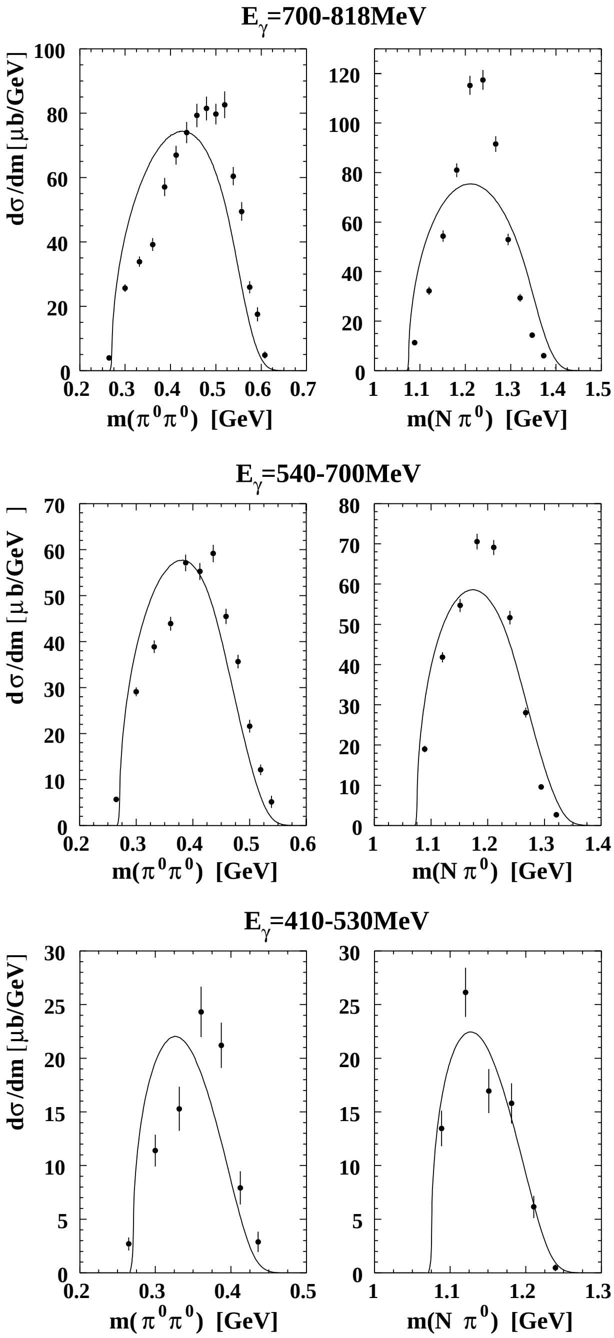

Fig. 4. Invariant mass distributions of the exit channel particles. Shown are plots for three different energy ranges. The filled circles represent the experimental data with statistical errors, the curves are the phase space distributions. Both distributions (experimental and simulated) are normalised to the average cross-section in this energy range whereas for every event there are two $m(N\pi^0)$ combinations.

ment with the data was achieved. The cross-section from the free neutron is shown in fig. 3 (black curve). The error band (hatched area) was derived from the statistical and systematic uncertainties of the cross-sections from the deuteron and proton. Also considered were uncertainties stemming from the iteration method at high energies caused by the unknown cross-sections of double-π^0 photoproduction from the proton and the deuteron above the Mainz energy range. Within the error band the cross-section is consistent with the earlier measurement [4]. The cross-section from the proton is represented by open circles with statistical error bars [3]. The model of Oset *et al.* [13] (dashed line) provides a better agreement with the results of this work than the model of Ochi *et al.* [14] (dashed-dotted line).

5.3 Invariant mass distributions

Efficiency corrected Dalitz plots were constructed for three bins in incident photon energies. In fig. 4 invariant mass distributions of the $N\pi^0$ and $\pi^0\pi^0$ pairs derived from the Dalitz plots are compared to the phase space expectation including the effects of nuclear Fermi smearing. The $m(N\pi^0)$ distribution peaks at the mass of the Δ-resonance for the highest incident photon energies, suggesting that the reaction mechanism in the second resonance region involves the decay $\Delta \to N\pi^0$. This is in agreement with the prediction of Oset *et al.* [13] that the reaction from the proton and the neutron is dominated by the sequential decay chain $N^* \to \Delta\pi^0 \to N\pi^0\pi^0$. Based on their model the largest contribution is assigned to the $D_{13}(1520)$-resonance due to its strong photon coupling and its decay branching ratios. The Δ peak is less pronounced in the intermediate energy range where the decay of the $P_{11}(1440)$-resonance can contribute. It disappears at still lower incident photon energies in agreement with the expectation that Δ-Kroll-Rudermann and Δ-pion pole terms which produce a $\pi^0\Delta$ pair without excitation of a higher lying resonance are not important for double-π^0 photoproduction [3].

The $m(\pi^0\pi^0)$ distributions deviate from phase space behaviour for all incident photon energies. A similar excess of large invariant masses was observed for the reaction $n(\gamma,\pi^-\pi^0)p$ measured from neutrons bound in the deuteron [15]. In this case the excess was interpreted as possible evidence for an enhanced contribution from ρ-meson decays. However, ρ-meson decays cannot contribute to double-π^0 production. Such a deviation is less well established for the reaction $p(\gamma,2\pi^0)p$ from the proton [1,3] and thus hints at nuclear effects beyond Fermi smearing or a different behaviour of the reaction $n(\gamma,2\pi^0)n$. The latter is less likely since a large difference between the $m(\pi^0\pi^0)$ distributions from $p(\gamma,2\pi^0)p$ and $n(\gamma,2\pi^0)n$ would be necessary to explain the effect in the reaction $d(\gamma,2\pi^0)pn$ (contributions of the coherent reaction $d(\gamma,2\pi^0)pn$ are expected to be negligibly small).

6 Summary and conclusions

Double-π^0 photoproduction from the deuteron has been studied for photon beam energies from 200–820 MeV. The total cross-section for the inclusive reaction was used to extract the total cross-section for $2\pi^0$ photoproduction from the neutron. Invariant mass distributions of $N\pi^0$ pairs are in agreement with model predictions of a dominant contribution of sequential $N^* \to \pi^0\Delta \to \pi^0\pi^0N$ decays, most likely from the $D_{13}(1520)$-resonance [13]. In contrast to $2\pi^0$ photoproduction from the free proton the $m(\pi^0\pi^0)$ distributions deviate significantly from a phase space behaviour although effects of nuclear Fermi smearing were taken into account.

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References

1. F. Härter et al., Phys. Lett. B **401**, 229 (1997).
2. A. Braghieri et al., Phys. Lett. B **363**, 46 (1995).
3. M. Wolf et al., PhD thesis, University Giessen (1999), submitted to Eur. Phys. J.
4. B. Krusche et al., Eur. Phys. J. A **6**, 309 (1999).
5. Th. Walcher, Prog. Part. Nucl. Phys. **24**, 189 (1990).
6. I. Anthony et al., Nucl. Instrum. Meth. A **301**, 230 (1991).
7. F. Wissmann, Nucl. Phys. A **660**, 232 (1999).
8. R. Novotny, IEEE Trans. Nucl. Sci. **38**, 379 (1991).
9. V. Hejny et al., Eur. Phys. J. A **6**, 83, 309 (1999).
10. R. Brun et al., GEANT, Cern/DD/ee/84-1, 1986.
11. B. Krusche et al., Phys. Lett. B **358**, 40 (1995).
12. M. Lacombe et al., Phys. Lett B **101**, 139 (1981).
13. J.A. Gomez-Tejedor and E. Oset, Nucl. Phys. A **600**, 413 (1996).
14. K. Ochi et al., nucl-th/9703058 (1997); M. Hirata et al., nucl-th/9711031 (1997).
15. A. Zabrodin et al., Phys. Rev. C **60**, 055201 (1999).