CPC(HEP & NP), 2009, **33**(12): 1340—1344 Chinese Physics C Vol. 33, No. 12, Dec., 2009

Photoproduction of mesons off the deuteron: quasifree and coherent processes*

I. Jaeglé[1)] (for the CBELSA/TAPS collaboration)

(Departmement of Physics, University of Basel, CH-4056 Basel, Switzerland)

Abstract Photoproduction of mesons off the deuteron has been investigated at a tagged photon beam of the Bonn ELSA accelerator with the combined Crystal Barrel - TAPS electromagnetic calorimeter for incident photon energies up to 2.5 GeV. The mesons have been detected in coincidence with recoil protons, neutrons and deuterons. This allow the measurement of meson production reactions off the quasifree nucleons bound in the deutron, as well as the coherent production off the deuteron. The comparison of quasifree proton reactions to free proton reactions can confirm or invalidate possible nuclear effects on the extracted cross section reactions. Furthermore the isospin composition of a resonance can be estimated from the comparison of quasifree proton and neutron reactions. The quasifree photoproduction of the η' and $\pi^{\circ}\eta$ mesons off nucleons and the coherent photoproduction of $\pi^{\circ}\eta-$pairs off the deuteron are discussed.

Key words quasifree, coherent, photoproduction, η', $\pi^{\circ}\eta$, neutron, proton, deuteron

PACS 13.60.Le, 14.20.Gk, 25.20.Lj

1 Introduction

The study made of the photoproduction of mesons off the deuteron, is related to the discussed problem "missing resonances"[1, 2] and the studies of the nature and properties of the known resonances[3] in particular in cases where the resonances couple strongly to the neutron. Another topic is the study of the interaction of mesons with nucleons and nuclei[4—16].

The main difficulty of this study stems from the fact that there are no free neutron targets, hence the choice of a light nucleus such as deuterium. With a deuterium nucleus, there are two possible mecanisms: breakup and coherent. In the breakup mecanism, the nucleon is not at rest but has a motion the so-called Fermi motion. Thus in the breakup case, the reaction is quasifree and one has to take into account the Fermi motion and possible FSI effects. A contrario, the coherent mecanism is more simple as the nucleus in the intial and final states is identical.

The η' as the $\eta-$ works as an isospin filter, due to isospin conservation: only N^* resonances contribute to $N\eta$ and $N\eta'$ final states while resonances in $\Delta\eta$ and $\Delta\eta'$ belong to the Δ^* series. Very little is known on the η' photoproduction and the results from different analyses are contradictory. The old bubble chamber data was analyzed, by Mukhopadhyay et al.[17] with an effective Lagrangian model, that concluded that the dominant contribution comes from the excitation of a $D_{13}(2080)$ resonance. A more recent measurement, of $p(\gamma,\eta')p$ with the SAPHIR detector[18], shows the contributions from different resonances (S_{11}, P_{11}) and t-channel. But these results are not in good agreement with the most recent measurement by the CLAS-group[20]. The analysis of the CLAS data by Nakayama and Haberzettl[21] exhibits possible contributions from S_{11}, P_{11}, P_{13}, D_{13} and t-channel processes.

In this parallel contribution the quasifree photoproduction of η' (preliminary results), $\pi^{\circ}\eta-$pairs (very preliminary results) off neutrons bound in the deuteron are summarized. The very preliminary results for the coherent photoproduction of $\pi^{\circ}\eta-$pairs off the deuteron are also discussed. This coherent reaction may open up new possibilities for the search for $\eta-$mesic nuclei and in general in the study of interaction of $\eta-$meson with nucleons and nuclei.

Received 7 August 2009

* Supported by Schweizerischer Nationalfonds and Deutsche Forschungsgemeinschaft (SFB/TR-16)

1) E-mail: igal.jaegle@unibas.ch

2 Experimental setup

The experiments were done in four beam times at the electron accelerator ELSA in Bonn[22, 23] using two different electron beam energies 2.6 GeV and 3.2 GeV. The real photon beam was made by directing the electron beam on a copper foil (0.3% radiation length), where it produces photons by the Bremsstrahlung process. The photon energies were tagged via the momentum analysis of the scattered electron by a magnetic spectrometer[24]. The Bremsstrahlung photons are nearly collinear with the incident electron beam and pass through a hole in the magnet yoke, after which they are collimated, and then impinge on the deuterium target (of 5.3 cm length) which sits in the center of an almost 4π detection system. It was composed of: the Crystal Barrel (CB, 1290 CsI crystals covering the full azimuthal angle for polar angles between 30° and 168°)[25] and the TAPS detectors (528 BaF_2 crystals mounted as a hexagonal forward wall covering polar angles down to 4.5°)[26, 27], and their respective Charge Particle Counters (CPC), the inner detector (three layers of plastic scintillating fibers)[28] and the veto wall (528 plastic scintillators). More details can be found in[29].

3 Data analysis

The neutral mesons were reconstructed from their decay modes into photons ($\eta \rightarrow 3\pi^\circ \rightarrow 6\gamma$, $\eta \rightarrow 2\gamma$, $\eta' \rightarrow \pi^\circ\pi^\circ\eta \rightarrow 6\gamma$, $\pi^\circ \rightarrow 2\gamma$). Because of trigger restrictions (see Ref. [29] for details) only channels with at the least four photons were investigated. The identification of photons, neutrons, proton and deuteron in TAPS can be achieved with the veto detectors and a time-of-flight versus energy analysis (see Ref. [30] for details). The photon identification in the CB (see Ref. [30] for details) is based on a cluster search algorithm and uses the information from the inner detector for rejection of charged particles.

The analysis is similar for the different final states. We will shortly describe as an example the quasifree η' production and the identification of the coherent production of $\pi^\circ\eta-$pairs (see Ref. [30] for details). For the η' production, in the first step, events with six or seven neutral hits are selected. The invariant mass of all photon pairs is built. A cut on the π° mass is applied between 110 MeV and 160 MeV and on the η mass between 500 MeV and 600 MeV. The best combination of 6γ to $2\pi^\circ\eta$ is seletect by the χ^2-test. The π° and the η masses were used as constrains. Fig. 1 summarizes the most two important steps of the reaction identification: the six-photon invariant mass analysis for η' identification and the missing mass analysis of the nucleon for the suppression of $\pi\eta'$ final states. The missing mass (see Fig. 1) was calculated under the assumption of quasifree meson production on a nucleon at rest from the incident photon energy and the energy and momentum of the η' meson. Good events correspond to the nucleon mass. A very strict cut on the missing mass was used, in order to avoid any contamination from $\pi\eta'$ background channel. Nevertheless the background level coming from un-correlated $\pi^\circ\pi^\circ\eta$ was still high after the missing mass cut on the invariant mass spectra

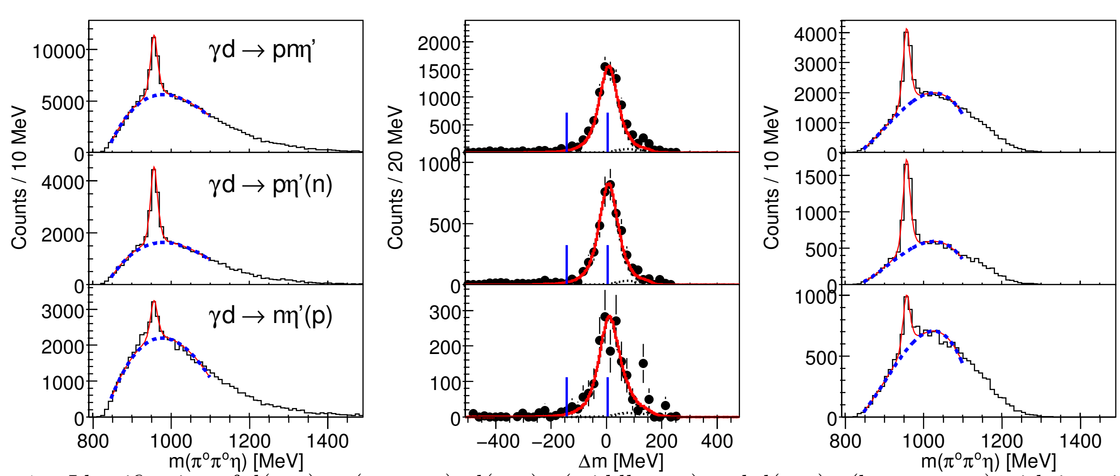

Fig. 1. Identification of d(γ,η)pn (top raw), d(γ,η)p (middle raw) and d(γ,η)n (bottom raw) with invariant and missing mass analysis for incident photon beam energy between 1.4 GeV and 2 GeV. Left-hand side: 6 photons invariant mass spectra. Right-habd side: 6 photons invariant mass spectra aftercut on missing mass. Middle column: missing mass spectra, the mass of nucleon has been substracted. Dashed lines: simulation of peak line shape. dotted: simulation of background from $\pi\eta'$ final states. Solid: sum of both.

(see Fig. 1 left-hand side). This background was eliminated by fitting the invariant mass distributions for each bin of incident photon energy and η′ polar angle with the peak line shape and a polynomial background.

Figure 2 shows the identification of recoil protons, neutrons and deuteron in TAPS. The TOF-E pictures clearly show the bands for the proton and the deuteron while the neutral hits corresponding to the neutron are scattered over a large area since the neutrons only deposit partly their energy in the detector. The narrow width of the missing mass of the deuteron (which is not broadened by Fermi motion as in Fig. 1) in Fig. 2 demonstrates the clean identification of the coherent reaction d(γ,π°η)d. Recoil protons and deuterons going in the CB have been identified with the inner detector. In the CB neutrons cannot be separated from photons. Therefore for reactions with N decay photons and a further neutral hit in the CB first N neutral hits were assigned as decay photons via invariant mass analyses and then the left-over neutral hit was treated as recoil neutron.

The systematic uncertainty for the extraction of the quasifree neutron is dominated by the detection efficiency of the coincident recoil neutrons. The neutron detection efficiency was determined with Monte Carlo simulation. However , since the coherent reaction is negligible (for single η′ and π°η-pairs processes), the n(γ,x)n cross-sections have been determined in two different ways: directly by measuring the meson(s) and the recoil neutrons and indirectly by first measuring the inclusive cross-section without any condition for recoil nucleons and then substracting the measurement of the cross-section for reactions with coincident recoil protons. In the direct measurement, the analysis relies on the neutron detection efficiency, while in the indirect measurement on the proton detection efficiency which is completly different. This allows an independent test of the recoil nucleon detection efficiencies.

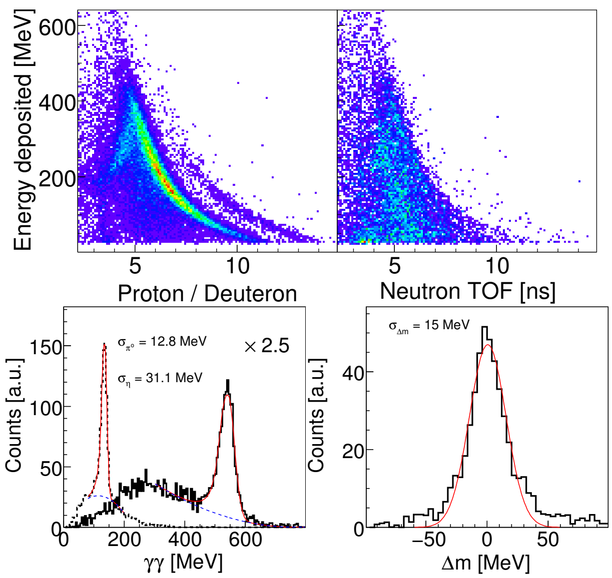

Fig. 2. Identification of d(γ,π°η)d. Upper row: time-of-flight as function of energy deposited for π°η candidates with additional charged (left-hand side) and neutral (right-hand side) hits in TAPS (veto fired). Bottom row: η and π° invariant mass spectra and missing mass spectrum in coherent kinematics for π°η (after a cut on the deuteron TOF-E-band).

Figure 3 illustrates the two neutron measurements for η′ and π°η photoproduction which are in very good agreement indicating a good control of the detection efficiencies.

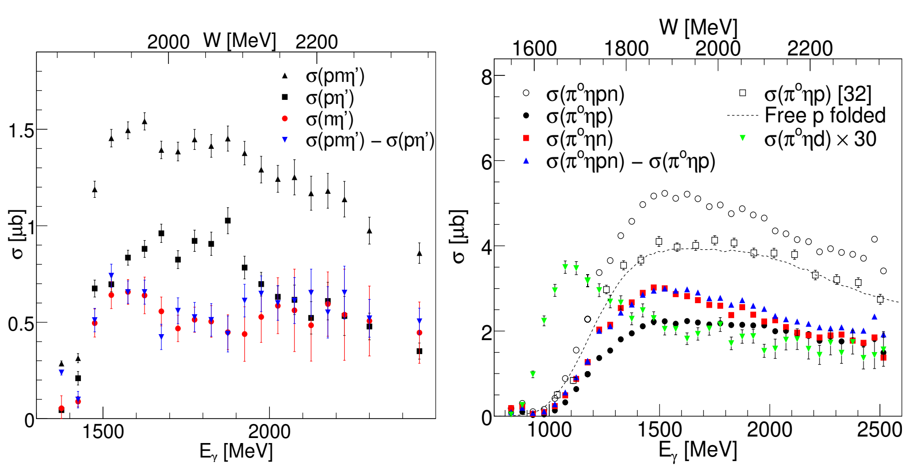

Fig. 3. Left-hand side: excitation function for inclusive and exclusive η′ photoproduction. Right-hand side: excitation function for inclusive, exclusive and coherent π°η′ photoproduction (very preliminary results).

4 Results

4.1 η′ photoproduction off the deuteron

The angular distributions have been fited by Legendre polynimials which are related to the contributing partial waves[19]. The total cross-sections have been determined from the integration of the angular distributions.

The quasifree proton data and the free proton data of CLAS[20] are in very good agreement for example the Legendre coefficient A_i exhibits the same behaviour indicating that the FSI are negligible. The proton and the neutron cross-section (see Fig. 2) differ around 1.8 GeV in incident photon beam energies indicating different resonance contributions. This also reflected in the behavior of the angular distributions (not shown).

4.2 π°η-pairs photoproduction off the deuteron

Multiple meson photoproduction is well suited for the investigation of nucleon resonances which decay more likely not directly to the nucleon ground state but to other excited states. The analysis of the $\pi^{\circ}\eta-$pair photoproduction off the free proton[31—35] has clearly pined down a dominant contribution from $\gamma p \rightarrow \Delta^* \rightarrow \Delta(1232)\eta \rightarrow p\pi^{\circ}\eta$. At thresold the excitation of the $D_{33}(1700)$ is dominant. The nature of the $D_{33}(1700)$ is questioned as an excitated nucleon. Indeed, Doring et al.[36] interpreted the $\Delta(1700)D_{33}$ as a dynamically generated resonance with strong coupling to the $\eta\Delta$ and $K\Sigma^*$ channels. Furthermore, in the case of excitation of Δ resonances the amplitudes for neutron and proton should be equal. Therefore, one is expecting that the proton cross-section is equal to the neutron cross-section. The very preliminary results show (see Fig. 3) that first the quasifree proton cross-section is a factor two smaller than expected. The Fermi motion, as shown in Fig. 3, has almost no effect on the amplitude of the proton cross-section. Thus FSI might play an important role. It should be noted a similar effect was observed for the single π° photoproduction off the deuteron in the second resonance energy region[37]. Secondly, the quasifree neutron cross-section is slightly bigger than the quasifree proton cross-section. This difference might indicate other contributions than only the Δ^*'s such as for example N^*'s which can decay sequentially into two different ways $N^* \rightarrow \eta N'^* \rightarrow \eta\pi^{\circ}N$ or $N^* \rightarrow \pi^{\circ}N'^* \rightarrow \pi^{\circ}\eta N$. For N^* resonances, the electromagnetic coupling to the neutron and to the proton are different and can have opposite signs. Finally, the coherent cross-section exhibits a peak structure around the mass location of the $D_{33}(1700)$. Fig. 4 which shows the kinetic energy distributions of the mesons, can be explained by the reaction chain $\gamma N \rightarrow \Delta^* \rightarrow \eta\Delta(1232) \rightarrow \pi^{\circ}\eta N$. In this reaction chain, the contribution of the proton and the neutron are adding up coherently since their amplitudes are the same for Δ^*'s. Another interesting aspect of this coherent production is that the $\eta-$meson is emitted with a very small kinetic energy as seen in Fig. 4.

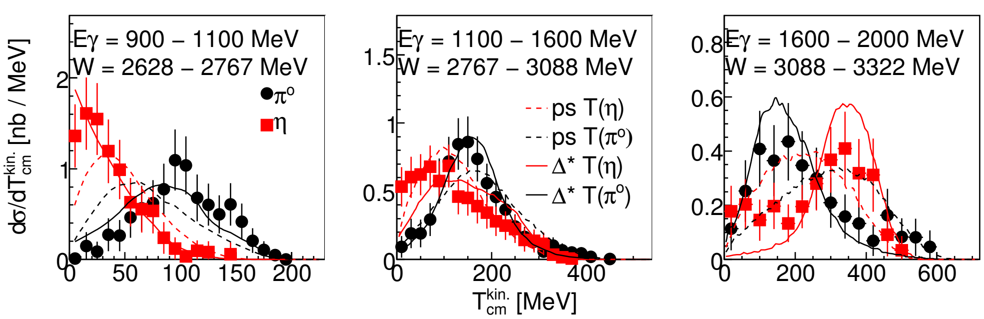

Fig. 4. Kinetic energy distributions of π° and η mesons from the reaction $\gamma d \rightarrow d\pi^{\circ}\eta$ for different bins of incident photon energies. Dashed curves: phase space simulations, solid curves: simulations of the $\gamma d \rightarrow d^*(\Delta^*) \rightarrow d^*(\Delta^*(1232))\eta \rightarrow d\pi^{\circ}\eta$ reaction chain (very preliminary results).

5 Conclusion

The η' and $\pi^{\circ}\eta$ photoproduction off the neutron and the coherent photoproduction of $\pi^{\circ}\eta$ off the deuteron have been measured for the first time. The preliminary results show the neutron cross-sections for the η' and the $\pi^{\circ}\eta-$pairs are different than the proton cross-sections revealing more complex mecanisms than initially expected and maybe contribution of resonances than couple strongly to the neutron but only weakly to the proton. Furthermore the FSI seems to be negligible for the η' photoproduction while on the contrary for the $\pi^\circ\eta$ photoproduction, the FSI might be non negligible. The coherent photoproduction of the $\pi^\circ\eta-$pairs off the deuteron shows that the $\eta-$mesons are emitted with small kinetic energies. This property might be used later for the search of the $\eta-$mesic with ^{3}He and ^{4}He targets.

References

1 Kirchbach M. Mod. Phys. Lett. A, 1997, **12**: 3177
2 Mecking B et al. Nucl. Instr. and Meth., 2003, **94**: 262
3 Groom D E et al. Eur. Phys. J. C, 2000, **15**: 1
4 Hejny V et al. Eur. Phys. J. A, 2002, **13**: 493
5 Weiss J et al. Eur. Phys. J. A, 2003, **16**: 275
6 Pfeiffer M et al. Phys. Rev. Lett., 2004, **92**: 252001
7 Calén H et al. Phys. Lett. B, 1996, **366**: 366
8 Smyrski J et al. Phys. Lett. B, 2000, **474**: 182
9 Moskal P et al. Phys. Rev. C, 2004, **89**: 025203
10 Plouin F et al. Phys. Rev. Lett., 1990, **65**: 690
11 Calén H et al. Phys. Rev. Lett., **80**: 2069
12 Mayer B et al. Phys. Rev. C, 1996, **53**: 2068
13 Smyrski J et al. Phys. Lett. B, 2007, **649**: 258
14 Mersmann T et al. Phys. Rev. Lett., 2007, **98**: 242301
15 Willis N et al. Phys. Lett. B, 1997, **406**: 14
16 Hibou F et al. Eur. Phys. J. A, 2000, **7**: 537
17 Mukhopadhyay N C et al. Phys. Rev. C, 1989, **39**: 2339
18 Plötzke R et al. Phys. Lett. B, 1998, **444**: 555
19 Krusche B, Schadmand S. Prog. Part. Nucl. Phys., 2003, **51**: 399
20 Dugger M et al. Phys. Rev. Lett., 2006, **96**: 169905
21 Nakayama K, Haberzettl H. Phys. Rev. C, 2006, **73**: 045211
22 Husmann D, Schwille W J. Phys. Bl., 1988, **44**: 40
23 Hillert W. Eur. Phys. J. A, 2006, **28**: 139
24 Burgwinkel R. Aufbau un Test und Eichung des hochauföseneden Tagging-Systems TOPAS II am Bonner SAPHIR-Detektor, PhD thesis, university of Bonn, 1996
25 Aker E et al. Nucl. Instrum. Meth. A, 1992, **321**: 69
26 Novotny R. IEEE Trans. Nucl. Science, 1991, **38**: 379
27 Gabler A R et al. Nucl. Instrum. Meth. A, 1994, **346**: 168
28 Suft G et al. Nucl. Instrum. Meth. A, 2005, **538**: 416
29 Mertens T et al. Eur. Phys. J. A, 2008, **38**: 195
30 Jaeglé I. $\pi^\circ\pi^\circ$ η and η' photoproduction off the deuteron or The search for missing resonances. PhD thesis, 2007
31 Nakabayashi T et al. Phys. Rev. C, 2006, **74**: 035202
32 Horn I et al. Phys. Rev. Lett., 2008, **101**: 202002
33 Horn I et al. Eur. Phys. J. A, 2008, **38**: 173
34 Ajaka J et al. Phys. Rev. Lett., 2008, **100**: 052003
35 Kashevarov V L et al. submitted to Eur. Phys. J. A.
36 Doring M et al. Phys. Rev. C, 2006, **73**: 045209
37 Krusche B et al. Eur. Phys. J. A, 1999, **6**: 309