MEASUREMENT OF $\pi^0\pi^{+/-}$ PHOTOPRODUCTION OFF THE DEUTERON AND DEUTERATED-BUTANOL TARGETS*

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Recent experiments using the Crystal Ball/TAPS setup at the MAMI accelerator in Mainz, Germany continue to study the properties and the excitation spectrum of the nucleon with meson photoproduction. Electromagnetic excitations of the proton and neutron are essential for understanding their isospin decomposition. The electromagnetic coupling of photons to protons is different than that of neutrons in certain states. Cross-section data alone is not sufficient for separating resonances, whereas polarization observables play a crucial role being essential in disentangling the contributing resonant and non-resonant amplitudes. Preliminary results of the polarization observable E of double π production measured with a polarized solid deuterated-butanol target are shown with comparison to predictions of recent analyses.

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1. Introduction

Quark models describe the behavior of quarks in nucleons at medium energies. Meson photoproduction allows to investigate the excited states (resonances) of nucleons. Unfortunately, many states overlap and cannot be easily differentiated from each other and many have been predicted, but not yet detected [1]. The states that have not yet been observed could be missing because they have not been seen experimentally until now or do not exist at all. Most earlier experiments were preformed with pion beams and some resonances might couple less strongly to pions and couple more strongly to rare channels, and have circumvented detection. Most results still arise from

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experiments on the proton, which does not allow for so much information regarding the isospin structure of the electromagnetic transitions. Therefore, advances in experiments on the neutron can provide an integral piece to the understanding of the nucleon spectrum [2]. Unfortunately, it is not possible to perform measurements on the free neutron, but a deuterated-butanol target has allowed for the possibility to study spin effects with quasi-free neutrons.

From the outcomes of total absorption experiment [3] in the past, there was a discussion whether there is a significant contribution from $D_{13} \to N\rho$ decay, because due to the predicted in-medium modifications of the ρ, this could modify the D_{13} shape as well. One of the motivations for the present experiments with proton and deuteron targets is the extraction of a much more precise $D_{13} \to N\rho$ branching ratio for proton and neutron targets.

For years, cross-section data has been used to study the nucleon spectrum. However, cross-section data alone is not enough to distinguish the broad overlapping resonances. Polarization observables can provide understanding of these overlapping resonances by discovering more information about the complex helicity amplitudes, which describe the interaction between photon beams and nucleons. These amplitudes are fully determined when a complete set of measurements is performed and they give rise to the cross section, complemented by polarization observables including beam, target, and recoil asymmetries. Here, the observable E (longitudinally polarized target and circularly polarized photon beam) will be discussed.

The relationship between the cross section and polarization observable E can be written in terms of the helicity of beam and target as follows:

$$E_{\text{version1}} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{\sigma_{\text{diff}}}{\sigma_{\text{sum}}}\,, \tag{1}$$

$$E_{\text{version2}} = \frac{\sigma_{\text{diff}}}{2\sigma_{\text{unpol}}}\,, \tag{2}$$

where $\sigma_{1/2}$ is the cross section for the beam and target polarizations being anti-parallel; $\sigma_{3/2}$ is the cross section when they are parallel.

2. Experimental setup

The measurements were performed at the MAMI-C accelerator in Mainz, Germany [4]. A longitudinally polarized electron beam of energy $\sim$1557 MeV and polarization degree of 80% is delivered into the A2 experimental Hall. Circularly polarized photons are produced from a radiator and their energy is tagged using the Glasgow–Mainz photon tagger [5] with energies between 470 and 1450 MeV. The target consists of a deuterated-butanol material (d-butanol) cooled to a low temperature with the deuterons either transversally or longitudinally polarized up to 80%. The target is surrounded by a cylindrical particle identification detector (PID) made up of 24 plastic scintillator strips, covering 15° in the azimuthal angle each. The PID is then surrounded by a multi-wire poroportional chamber (MWPC) and the MWPC is surrounded by the spherical Crystal Ball (CB) calorimeter [5]. The CB consists of 672 NaI (Tl) crystals and covers 20° to 160° in the polar angle. In the forward direction, the TAPS calorimeter built from 72 $PbWO_4$ (two innermost rings) and 366 BaF_2 crystals (remaining rings) is present. A veto wall in front of the TAPS is used for particle identification. The combination of the CB and the TAPS provides an almost 4 π acceptance in the center-of-mass frame with a high angular and energy resolution.

3. Analysis and results

Using information from the detectors, events are collected and then selected based on the number of charged or neutral hits. Neutral mesons are identified via a χ^2 test, which tries to find the best combination of photon clusters for the meson-invariant mass. To eliminate accidental coincident tagger photons, coincidence time cuts are applied and random background subtraction was performed. To separate the background from the signal, kinematic cuts were applied for each W (center-of-mass energy) and cosθ bin (θ being the polar angle).

The analysis of $\gamma p(n) \to \pi^0\pi^+ n(n)$ requires the decay photons of the π^0 meson to be detected as well as the π^+ and the recoil neutron. Therefore, all events with 3 neutral clusters and 1 charged cluster are selected. A dE–E analysis was used to identify the charged pion [6]. The main source of background in this reaction comes from the following reaction that has the same final state: $\gamma p(n) \to \eta\pi^+ n$.

The analysis of $\gamma n(p) \to \pi^0\pi^- p(p)$ requires the decay photons of the π^0 meson to be detected as well as the π^- and the recoil proton. Therefore, all events with 2 neutral clusters and 2 charged clusters are selected [6].

Different methods were used to extract the beam asymmetry E. Method 1 refers to where a normalization with twice of the unpolarized cross section σ_0 is used, which was measured with a liquid deuterium target, and does not need to utilize carbon background subtraction since the background is canceled in the difference of the two helicity states ($\sigma_\Delta = \sigma_{1/2} - \sigma_{3/2}$). Method 2 refers to the normalization of the numerator using the sum of the two spin configurations ($\sigma_\Sigma = \sigma_{1/2} + \sigma_{3/2}$). Here, the background from unpolarized carbon and oxygen nuclei inside the target has to be subtracted, allowing for events only on polarized protons and neutrons.

Preliminary results regarding comparison plots of total cross sections in terms of E_γ (photon energy) for d-butanol targets are shown in Fig. 1.

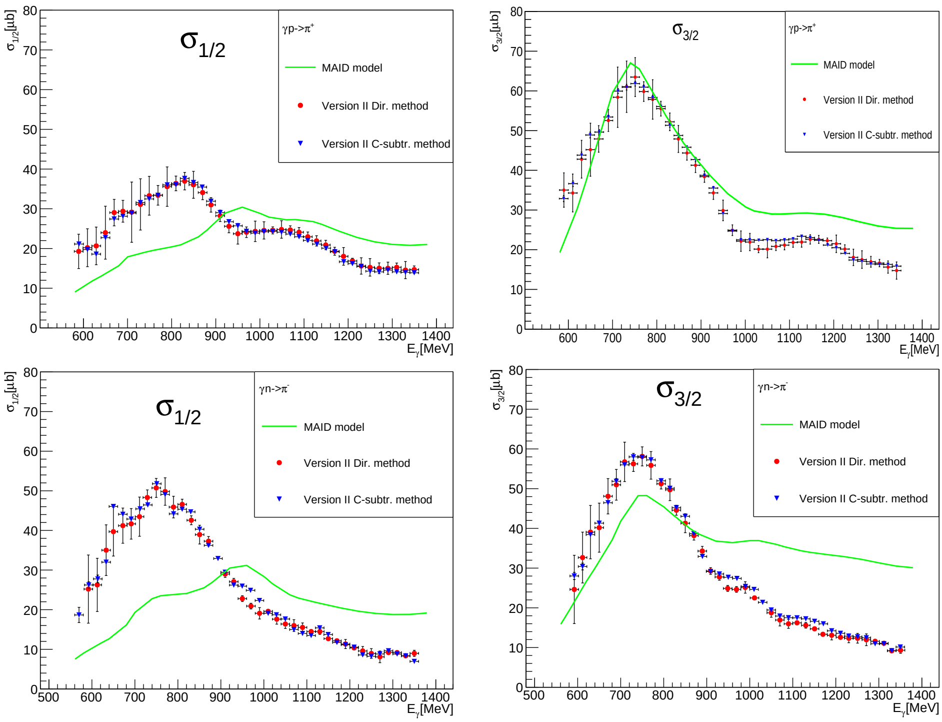

Fig. 1. (Color online) Total cross-section comparison for $\gamma p(n) \to \pi^0\pi^+ n(n)$ ((a) and (b) spectra) and $\gamma n(p) \to \pi^0\pi^- p(p)$ ((c) and (d)). Different colored symbols in each case represent the cross sections determined with the direct and carbon subtracted methods, the gray/green line shape corresponds to MAID model predictions.

***E* observable: Carbon subtraction method (Method 1):** For the determination of the carbon, background dedicated measurements were carried out, with the same experimental conditions as for the d-butanol, but with a carbon target of identical density. For a proper background subtraction, the relative contributions of carbon and oxygen nuclei to the d-butanol, also called dilution factor, has to be determined. This was done by comparing missing mass distributions of d-butanol data, carbon data and deuterium data [6].

Preliminary results of E observable for $\gamma p \to \pi^0\pi^+ n$ and $\gamma n \to \pi^0\pi^- p$ channels are shown in Fig. 2.

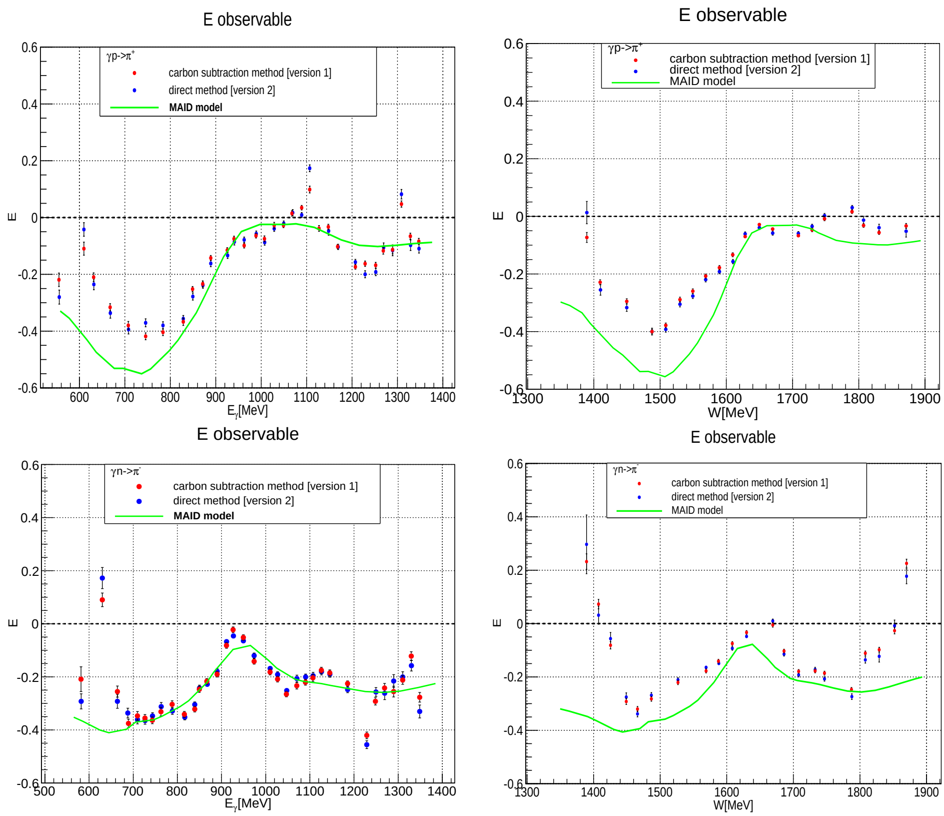

Fig. 2. (Color online) E-observable plots in terms of E_γ (photon energy) and W (center-of-mass energy) for $\gamma p \to \pi^0\pi^+ n$ (above row) and for $\gamma n \to \pi^0\pi^- p$ (bottom row); gray/red dots are for the method with carbon subtraction and the dark gray/blue dots correspond to the direct method; the gray/green line shape corresponds to that of predicted by MAID model.

4. Conclusion and outlook

For two studied channels, there is a non-vanishing E-observable asymmetry in terms of photon energy and center-of-mass energy. Extracted results from the two different methods (version 1 and version 2) also agree mostly with each other. Further investigation on background subtraction is under process for the final results. Data from further beamtimes with d-butanol target is also being analyzed.

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