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Measurement of helicity dependence of single π^0 photoproduction on deuteron

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Abstract. The study of the properties of the baryon resonances gives essential constraints on models for nucleon structure. Pion-photoproduction is a powerful tool to excite the nucleon to an intermediate resonant state and, in combination with polarised beams/targets, plays an important role in the investigation of the nucleon resonances. Data for polarisation observables accessible using a polarised photon beam and/or polarised nucleon targets are scarce in many channels, especially in those involving a neutron target. A systematic measurement is performed at the Mainz facility by the A2@MAMI collaboration. This talk will focus on the experiment performed at the Mainz Microtron, using a circularly polarised photon beam and a longitudinally polarised deuteron target, in conjunction with the large acceptance Crystal Ball/TAPS detection setup. An overview of the status of the experiment will be given, together with the preliminary results of polarised cross section from deuteron and of the double polarization observable E for the single π^0 photoproduction reaction from the quasi-free proton and quasi-free neutron.

1 Introduction

The nucleon gives the largest contribution to the visible mass of the Universe. Its internal structure, despite being intensively studied both from the experimental and theoretical point of view, is not yet fully understood. Electromagnetic probes provide a powerful tool to access the internal structure of the nucleon and to study its resonances. These are related to fundamental proprieties of the strong interaction, for this reason it is crucial to explore multiple meson production states, and access resonances that decay mainly via intermediate excited states [1].

The new precise results on double-polarization measurements on the proton and on the neutron, obtained by the A2 collaboration, extend the available statistics, especially on the neutron, thus providing essential constrains on models of the nucleon structure.

Photoproduction reactions of single pseudoscalar mesons from the nucleon are described theoretically by 4 helicity amplitudes, which lead to 16 different experimental observables. These observables are accessible by exploiting the polarisation degrees of freedom of the incident photon, and the spin degrees of freedom in target and recoiling nucleons. The measurement of 7 (8) properly chosen observables is necessary to describe the amplitudes without ambiguities [2, 3].

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2 The double polarization observable E

Measuring he double-polarisation observable E requires a circularly polarised photon beam and a longitudinally polarised target. It derives from the differential cross section of pseudo-scalar meson photoproduction;

$$\frac{d\sigma}{d\Omega}(\theta) = \frac{d\sigma}{d\Omega_0}(\theta)[1 \pm P_z P_\odot E)]. \tag{1}$$

It is possible to extract the E observable from eq. 1 in the following way:

$$N|^{\pm P_z}_{\pm\alpha}(\theta) = N(\theta)[1 \pm P_\odot P_z E] \rightarrow E = \frac{\sigma^{1/2} - \sigma^{3/2}}{\sigma^{1/2} + \sigma^{3/2}} = \frac{N_{\uparrow\downarrow} - N_{\uparrow\uparrow}}{N_{\uparrow\downarrow} + N_{\uparrow\uparrow}} \cdot \frac{1}{P_\odot} \cdot \frac{1}{P_z}, \tag{2}$$

where $N_{\uparrow\downarrow}$ and $N_{\uparrow\uparrow}$ are the helicity-dependent events, P_z and $P_\odot$ are the degrees of target and beam polarisation.

3 A2 experimental setup @ MAMI

The experimental setup of the A2 Collaboration is located in the tagger-hall at the MAMI beam facility in Mainz (Germany). The MAMI accelerator provides a polarised electron beam of 1557 MeV with a polarisation up to ~80%. The photon beam is produced via bremsstrahlung and the energy of the single photons is tagged using the Glasgow-Mainz tagger spectrometer. For the experiments described in this paper, a frozen-spin deuterated butanol target (C_4DOD_9) has been used. The nucleons are polarised via Dynamic Nuclear Polarisation (DNP) up to an initial polarisation degree of 70%. During the data taking the target is then kept in a frozen spin mode, with cryostat providing a temperature of 25 mK and, in combination with a magnetic field of 0.68 T, it is possible to have a relaxation time of ~1000 hours. This condition allows to collect data for one week with a high polarisation degree before the repolarisation is required [4]. Since a deuterated butanol target has been used, the count rates include the contribution of both the polarisable quasi-free protons and neutrons in deuteron nuclei and the unpolarised bound nucleons in carbon and oxygen nuclei. The amount of events generated from the polarisable deuteron is specified by introducing in the eq. 2 the dilution factor d:

$$E = \frac{N_{\uparrow\downarrow} - N_{\uparrow\uparrow}}{N_{\uparrow\downarrow} + N_{\uparrow\uparrow}} \cdot \frac{1}{P_\odot} \cdot \frac{1}{P_z} \cdot \frac{1}{d}, \tag{3}$$

which takes into account the number of polarised nuclei inside the target ($d = N_{deuteron}/(N_{butanol})$), and was extracted during a dedicated data taking with a carbon foam target. Differences in acceptance, photon flux and target density during the separate carbon and butanol beamtimes are taken into account.

The target cell is located at the centre of the A2 detector apparatus. Directly surrounding the target is the Particle IDentification (PID) detector, made of 24 plastic scintillators. Around the PID there are two Multi-Wire Proportional Chambers (MWPCs), tracking for charged particles. These detectors are enclosed inside the Crystal Ball (CB) calorimeter, which consists in 672 NaI crystals covering the full azimuthal (ϕ) range and the polar (θ) from 21° to 159°. In the forward region, TAPS, a calorimeter of 366 BaF_2 and 72 $PbWO_4$ scintillators, covers the polar region between 1° to 21°. The full setup provides precise energy and angle measurements, and particle identification in the 97% of the solid angle.

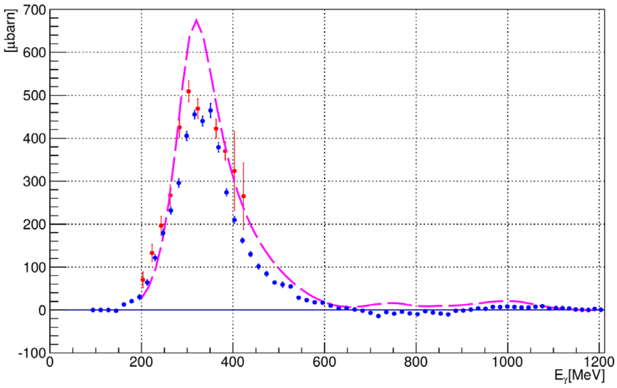

Figure 1. Helicity dependent total cross section for the semi-exclusive channel $\vec{\gamma}\vec{d} \rightarrow \pi^0 X$. The A2 results (blue circles) are compared with the results from the GDH Collaboration (red circles) and with the sum of MAID for free proton and neutron (dashed magenta line).

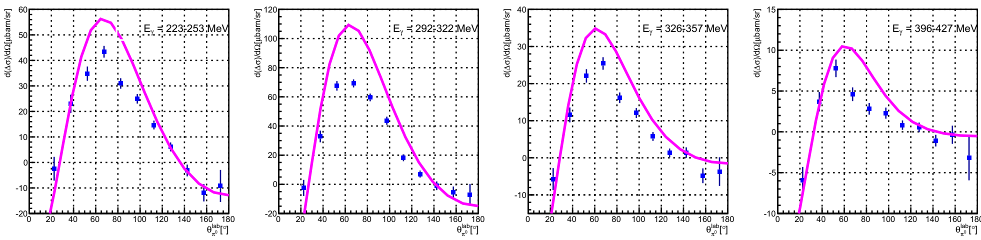

Figure 2. Helicity dependent differential cross section for the semi-exclusive channel $\vec{\gamma}\vec{d} \rightarrow \pi^0 X$. The A2 results (blue circles) are compared to the sum of MAID for free proton and neutron (dashed magenta line).

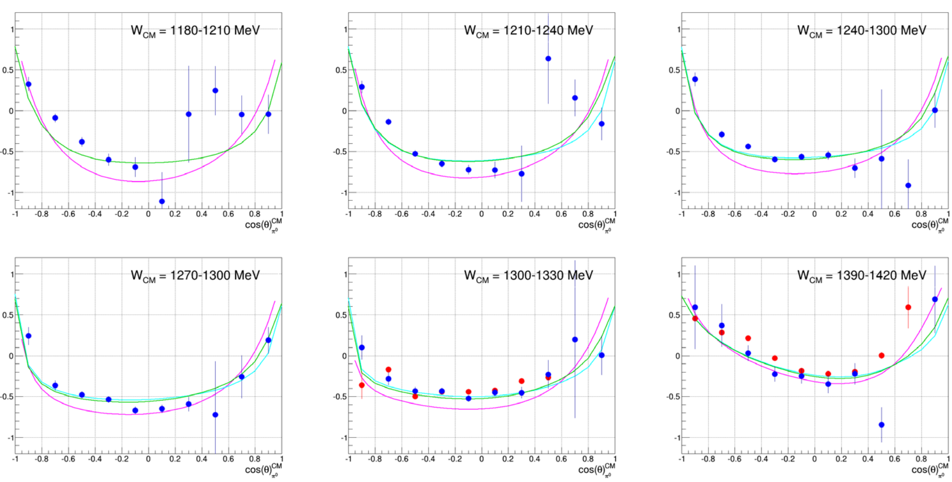

Figure 3. Double polarisation observable E for the single π^0 from quasi-free proton, the new data from A2 (blue point) cover the full A2 energy range. The new data are compared with [7] and with the theoretical model MAID 2007 for the free proton (magenta line). In order to take into account the fact that the nucleon in the deuterium target are quasi-free, additional corrections are applied to the free proton model: the impulse approximation correction (green line) and impulse approximation correction plus final state interaction (light blue line) based on the Fix-Arenhovel model [8].

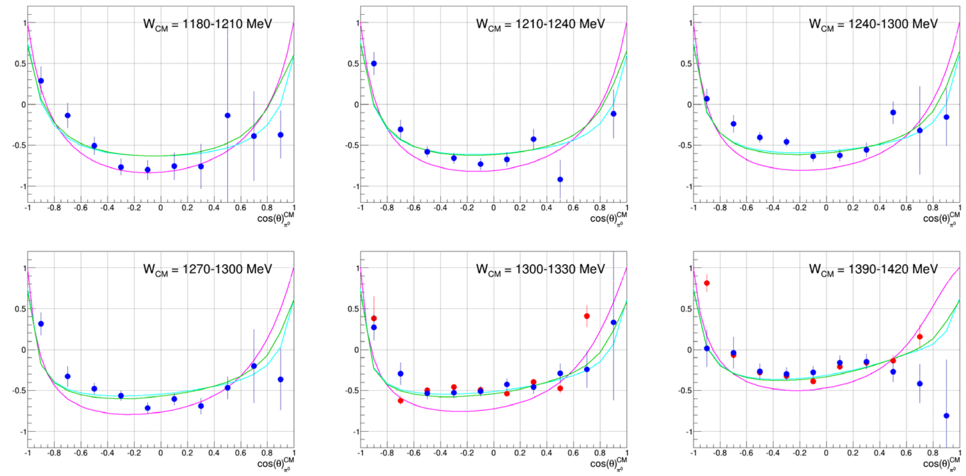

Figure 4. Double polarisation observable E for the single π^0 from quasi-free neutron, the new data from A2 (blue point) cover the full A2 energy range. The new data are compared with [7] and with the theoretical model MAID 2007 for the free neutron (magenta line). In order to take into account the fact that the nucleon in the deuterium target are quasi-free, additional corrections are applied to the free neutron model: the impulse approximation correction (green line) and impulse approximation correction plus final state interaction (light blue line) based on the Fix-Arenhovel model [8].

4 Results and conclusions

Fig. 1 shows the preliminary results of the helicity dependence cross section for the channel $\vec{\gamma}\vec{d} \to \pi^0 X$ on the deuteron. The new data (blue points) are in good agreement to the GDH Collaboration results (red points) [5], and they are compared also with the MAID model sum for free-proton and free-neutron [6]. In Fig. 2 there are 4 examples of differential cross section for the same channels. The preliminary results for the double polarization observable E from proton and from the neutron are presented in Fig. 3 and Fig. 4, respectively. In comparison with existing data, these new data give a larger energy and angle coverage [7]. It is possible to observe that the E observable is only slightly affected by final state interaction corrections. This is due to the fact that the correction is almost equivalent for $\sigma^{1/2}$ and for $\sigma^{3/2}$, and, from Eq. (2), the total contribution for the E observable is cancelled out.

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