Measurement of $\sigma_{1/2}$ and $\sigma_{3/2}$ in Photoproduction of $\pi^0\pi^0$ Pairs off Neutrons in the Nucleon Resonance Region

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Helicity dependent cross sections $\sigma_{1/2}$ and $\sigma_{3/2}$ of photoproduction of $\pi^0\pi^0$ meson pairs off quasi-free protons and off quasi-free neutrons in the second and third nucleon resonance region have been measured for the first time at the Mainzer Mikrotron (MAMI) electron accelerator facility. The knowledge of $\sigma_{1/2}$ and $\sigma_{3/2}$ will put stringent constraints on the different resonances that contribute to the nucleon excitation spectrum and will clearly help to improve its theoretical understanding.

1 Introduction

Meson photoproduction offers unique possibilities to investigate the nucleon and its excited states. Double meson photoproduction has the great advantage of enabling access to higher lying nucleon resonances that have no significant decay mode to the nucleon ground state via photoproduction of single mesons. Among the different meson pairs $2\pi^0$ is in particular interesting as non-resonant background terms (i.e. pion-pole, Kroll-Rudermann) are strongly suppressed because photons couple only weakly to neutral pions. Whereas for the reactions on the proton a lot of experimental data is available, data for the reactions on the neutron are sparse. In addition, even though in recent years much progress in the theoretical description of the results was achieved, the available models are still controversial even at low energies where only few resonances contribute. From the total cross sections of e.g. π^0 or η meson photoproduction off quasi-free protons and neutrons it is well known that rather different resonances contribute to the reactions on the proton compared to those on the neutron [1, 2, 3, 4]. The measurement of single and double polarization observables will help to reveal the different resonance contributions and thereby serve as an important input for the theoretical description of the structure and the excitation spectrum of the nucleon.

The double polarization observable E is defined as the asymmetry of the two helicity dependent cross sections $\sigma_{1/2}$ and $\sigma_{3/2}$ (1/2 (3/2): photon and target spins anti- (parallel)) normalized by the sum of both:

$$E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{\sigma_{1/2} - \sigma_{3/2}}{2 \cdot \sigma_{\text{unpol}}} \tag{1}$$

2   Experiment

The experiment was performed at the MAMI electron accelerator at Mainz, Germany. The primary longitudinally polarized electron beam of 1.557 GeV was directed onto a 10 μm thick cobalt-iron radiator foil where a cirularly polarized photon beam of energies in the range of 0.45 GeV and 1.5 GeV was produced by the bremsstrahlung process. In order to determine the energy of the photons, the scattered electrons were detected in the focal plane of the Glasgow-Mainz Tagged Photon Spectrometer to analyze their momentum. The produced photon beam impinged on a longitudinally polarized deuterated Butanol (C_4D_9OD) target of 2 cm length and 2.2 cm diameter which was mounted in the center of the Crystal Ball (CB) detector. An additional electromagnetic calorimeter, the TAPS detector, was placed as forward wall downstream of the target. A charged particle identification detector (PID) mounted around the target inside CB and plastic scintillators (Vetos) in front of each of the crystals of TAPS allowed for the identification of charged particles. The experiment provided almost 4π angular coverage. The degree of target polarization was up to 60% and of the photon beam, depending on the energy, up to 80%.

3   Analysis

Double π^0 photoproduction was analyzed in coincidence with recoil protons and neutrons in the reactions $\gamma p(n) \to \pi^0\pi^0 p(n)$ and $\gamma n(p) \to \pi^0\pi^0 n(p)$. The nucleon in brackets is treated as undetected spectator nucleon. The photons, protons and neutrons have been identified in an analysis that combined the energy deposited in CB and the PID, the Vetos, the time-of-flight versus energy and a pulse-shape analysis in TAPS. The π^0 pairs were identified from the measured invariant mass of the photon pairs. In order to achieve a clean identification of the reaction, conditions on the coplanarity of the two-meson system and the recoil nucleon as well as a missing mass analysis have been determined on data from a comparable experiment with a liquid deuterium (LD_2) target. In the latter case, no background contribution from unpolarized nuclei inside carbon or oxygen contribute to the spectra, allowing for a much more precise determination of the kinematical limits. The data from deuterated butanol were then analyzed and only the events within these limits have been accepted and resulted in nearly background free invariant mass distributions (see figure 1).

To subtract the contribution from reactions on the unpolarized carbon and oxygen nuclei inside the deuterated butanol target, an additional experiment using the same setup and target but filled with carbon foam (^{12}C) of identical geometry and of about the same density was performed and analyzed in the same way as the deuterated butanol data.

In order to determine the double polarization observable E according to equation (1) either the sum of the two helicity dependent cross sections or the unpolarized cross section can be used for the normalization of the asymmetry. Both calculations have been carried out to ensure that the contributions from unpolarized nuclei are well under control. The contribution of reactions on such unpolarized nuclei was determined by a comparison of the missing mass spectra of the three datasets: deuterated butanol, liquid deuterium and carbon. The result is presented in figure 2. It is clearly visible that in each spectrum the yield from the LD_2 and ^{12}C data perfectly add up to the C_4D_9OD data, as expected.
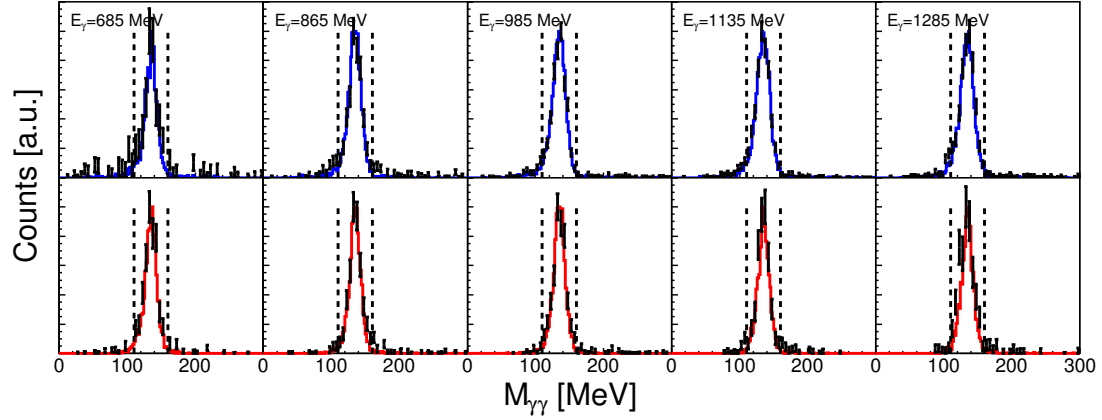
Figure 1: Final invariant mass spectra for five selected energy bins of one selected angular bin. Upper row: Reaction $\gamma p(n) \rightarrow \pi^0\pi^0 p(n)$, Lower row: Reaction $\gamma n(p) \rightarrow \pi^0\pi^0 n(p)$. Points: data, solid line: MC yield. Vertical dashed lines: region of the invariant mass cut.
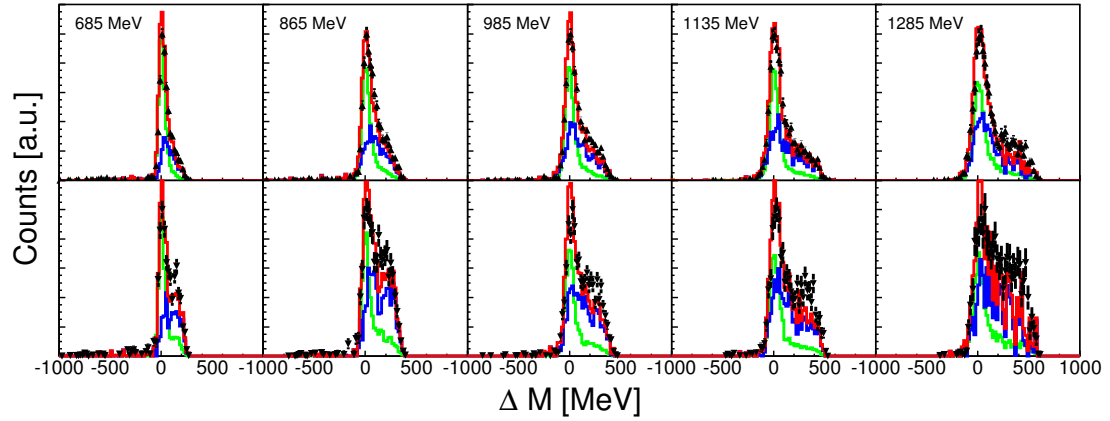

Figure 2: Carbon subtraction method using missing mass for five selected energy bins of one selected angular bin. Upper row: Reaction $\gamma p(n) \rightarrow \pi^0\pi^0 p(n)$, Lower row: Reaction $\gamma n(p) \rightarrow \pi^0\pi^0 n(p)$. Solid triangles: dButanol data. Solid lines: LD_2 (green), Carbon (blue) and sum of both (red).

4 Preliminary Results

Preliminary results for the helicity dependent cross sections $\sigma_{1/2}$ and $\sigma_{3/2}$ (middle and right) as well as the double polarization observable E (left) are presented in figure 3 and are compared to the model predictions from Bonn-Gatchina [5] (currently only available for the reaction $\gamma p(n) \rightarrow \pi^0\pi^0 p(n)$) and MAID [6]. It is clearly visible that both normalization methods are in perfect agreement with each other indicating that the subtraction of the contributions from reactions on the unpolarized nuclei from carbon and oxygen is well understood. The comparison of the data with the theoretical descriptions again reveal the impact of the helicity dependent
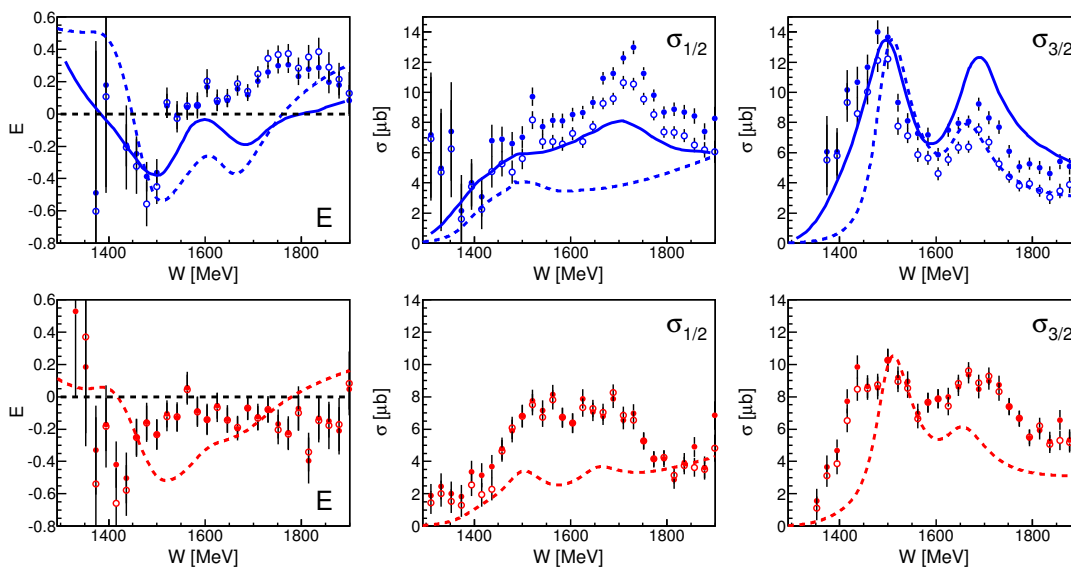
Figure 3: Preliminary results of the helicity dependent cross sections $\sigma_{1/2}$, $\sigma_{3/2}$ and double polarization observable E. Upper row: Reaction $\gamma p(n) \rightarrow \pi^0\pi^0 p(n)$, Lower row: Reaction $\gamma n(p) \rightarrow \pi^0\pi^0 n(p)$. Solid circles: normalized with carbon subtracted dButanol data, open circles: normalized with unpolarized total cross section. Solid line: BnGa model[5], dashed line: MAID model[6].

cross sections. Whereas the $\sigma_{1/2}$ cross section on the proton is better described by the BnGa model than by the MAID model, the opposite is true for the $\sigma_{3/2}$ cross section. Consequently neither one manages to describe the double polarization observable E, although the BnGa is closer to the result. Also for the neutron, the MAID model predicts a much better result for $\sigma_{3/2}$ than for $\sigma_{1/2}$. Obviously these results will clearly help to improve the models and to constrain the different resonance contributions.

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