Helicity Dependent Cross Sections in η Photoproduction off Quasi-Free Protons and Neutrons

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Preliminary results for the double polarisation observable E and the corresponding helicity dependent cross sections $\sigma_{1/2}$ and $\sigma_{3/2}$ of η photoproduction off quasi-free protons and neutrons have been obtained by a recent experiment at the MAMI electron accelerator at Mainz, Germany. The results will help to constrain the origin and quantum numbers of the bump-like structure in the η cross section off the neutron.

1 Introduction

The identification of the relevant effective degrees of freedom of QCD is the most important step in order to understand the structure of the nucleon. Since the resonances which contribute to the excitation spectrum are often broad and overlapping, the comparison of experimental data and theoretical models is rather difficult. Single and double polarization observables allow for the determination of the quantum numbers of the contributing resonances and are therefore an ideal tool to investigate the excitation spectrum of the nucleon.
A very selective channel in this context is the photoproduction of η mesons. Due to the isoscalar property of the η, Δ $(I = 3/2)$ resonances cannot decay to the ground state by emitting an η. Furthermore $P_{11}(1440)$ and $D_{13}(1520)$ resonances have a very small branching ratio into the $N\eta$ final state (close to threshold high orbital angular momenta are strongly suppressed). Especially, the investigation of this photoproduction channel is very interesting as the resulting cross section on the neutron shows a large resonance-like structure, beyond the dominating $S_{11}(1535)$, which is not seen on the proton. The structure has been reported by different collaborations [1, 2, 3, 4] and is visible on different nucleon systems (deuterium and helium), excluding origin from nuclear effects [5, 6]. Theoretical model descriptions have not yet lead to consistent results.
Using a circularly polarised photon beam and a longitudinally polarised target, the double polarisation observable E can be determined:

$$E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{\sigma_{1/2} - \sigma_{3/2}}{2\sigma_{tot}^{unpol}} \quad (1)$$

The corresponding helicity dependent cross-sections $\sigma_{1/2}$ (photon and target spin anti-parallel) and $\sigma_{3/2}$ (photon and target spin parallel) give direct hints to the spin of the underlying resonances and are therefore ideally suited to reveal the origin of the narrow structure on the neutron.

2 Experiment and Analysis

The experiment was carried out by the A2 collaboration at the electron accelerator facility MAMI in Mainz, Germany. A circularly polarised, tagged photon beam with energies up to 1.557 GeV impinged onto the longitudinally polarised deuterated Butanol target. The target had a diameter of 2.2 cm, a length of 2 cm and an effective density of 0.66 g/cm^3. A deuteron polarisation of around 60% was reached, the photons had a polarisation degree of up to 80%. The almost 4π covering detector system consisted of the two electromagnetic calorimeters Crystal Ball and TAPS. The particle identification detector surrounding the target and the plastic vetos in front of the TAPS detector were used to distinguish charged from neutral particles.
To determine the contribution of the unpolarised carbon and oxygen nuclei inside the deuterated butanol target, additional background measurements using a dedicated carbon foam target have been performed.
Both decay channels, $\eta \rightarrow 2\gamma$ and $\eta \rightarrow 3\pi^0 \rightarrow 6\gamma$, have been analysed using standard invariant mass and χ^2-techniques. Additional cuts have been applied to the missing mass of the nucleon and to the coplanarity of the meson-nucleon system. Using the two different scintillation components of the TAPS BaF_2 crystals, a Pulse-Shape-Analysis has been performed to distinguish neutrons from photons. The Fermi motion of the deuteron has been removed, the procedure is explained in detail in [5].

Two different methods have been used to determine the double polarisation observable E.

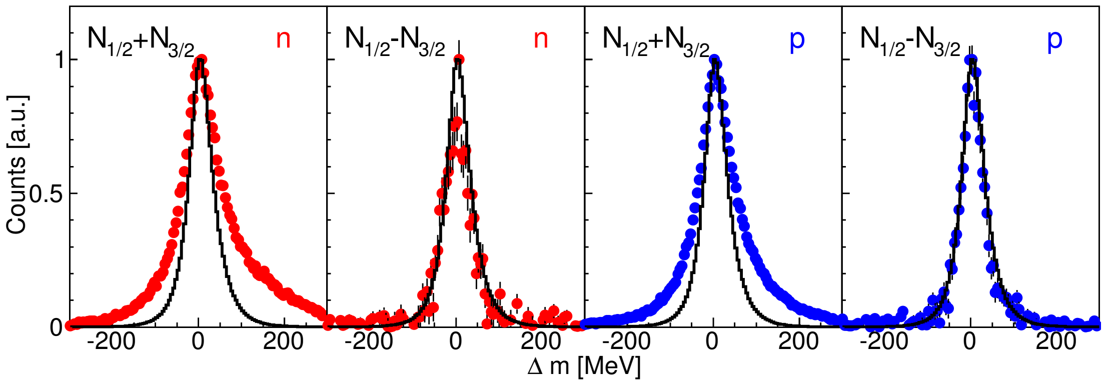

Figure 1: The missing mass of the sum (first and third figure) and the difference (second and fourth figure) of the two helicity states. Data (dots) are compared to simulation (line). The two left-hand figures show the situation for the neutron, the two right-hand for the proton. In both cases the carbon contribution in the sum of the two helicity states is clearly visible and leads to a broadening of the peak compared to the simulation. In the countrate difference, the carbon contribution automatically drops out and the data are consistent with the simulation.

First, a direct approach was chosen, the difference of the two helicity states has been divided by the known unpolarised total cross section (second part of equation 1). In this case the unpolarised carbon automatically drops out (see figure 1), but a accurate total normalisation is needed. In the second approach the carbon background measurement was used and the difference was divided by the carbon subtracted sum of the two helicity states (first part in equation 1). Whereas in this case the overall normalisation cancels out, the carbon contribution has to be known exactly. The contribution of the carbon is determined by fitting the missing mass spectra of the deuteron and carbon data to the one of butanol, see Figure 2. The fitting procedure was performed for every bin of photon energy and polar angle. In the range of the missing mass cut (vertical black lines) the contribution of unpolarised carbon and oxygen nuclei is well under control.

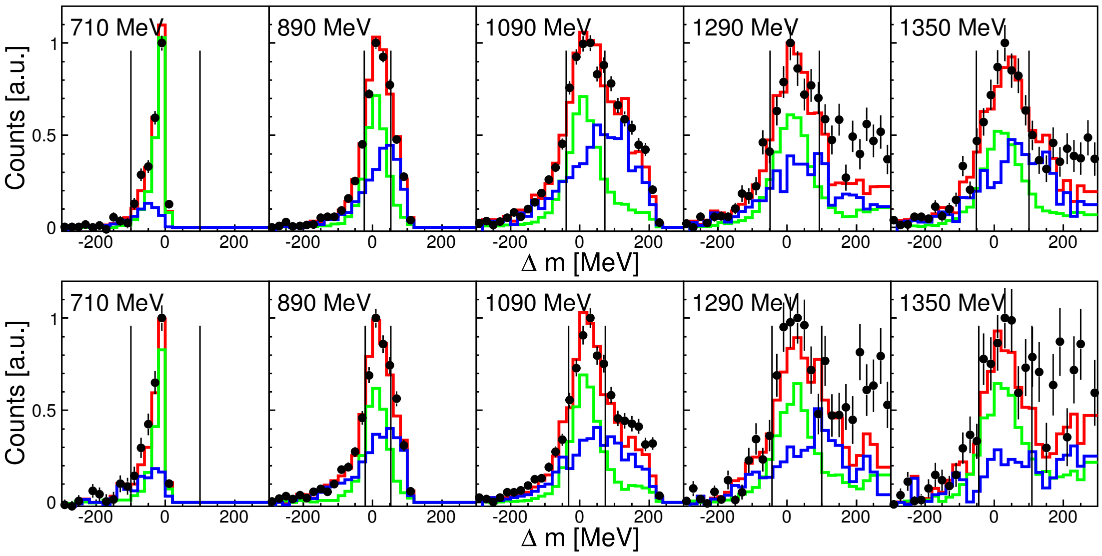

Figure 2: Upper (lower) row: the missing mass distribution of the proton (neutron) for the $\eta \rightarrow 2\gamma$ channel for five different photon energy bins intergrated over all angular bins. Solid lines: The contributions of the reactions on the deuteron (green) and the carbon (blue) and the sum of both (red). Within the range of the missing mass cut (vertical black lines), the sum is consistent with the measured distribution on the deuterated butanol (black dots).

3 Preliminary Results

The preliminary results of the double polarisation observable E as well as the helicity dependent cross sections $\sigma_{1/2}$ and $\sigma_{3/2}$ as a function of the center-of-mass energy W are shown in figure 3. The direct method (open circles) and the carbon subtraction method (solid circles) are in good agreement. As predicted by the models, the contribution from the helicity 1/2 state is significantly larger than the contribution from 3/2. This is mainly caused by the dominating $S_{11}(1535)$ resonance. Even at higher energies, the contribution of the helicity 3/2 state is very small. The resonance like structure on the neutron only appears in $\sigma_{1/2}$, as predicted by the BnGa model [7]. The MAID model [8] with the strong contributing $D_{15}(1675)$ in $\sigma_{3/2}$ does not reproduce the helicity dependent cross-sections for the neutron. For the proton the overall situation seems to be well understood by the models.

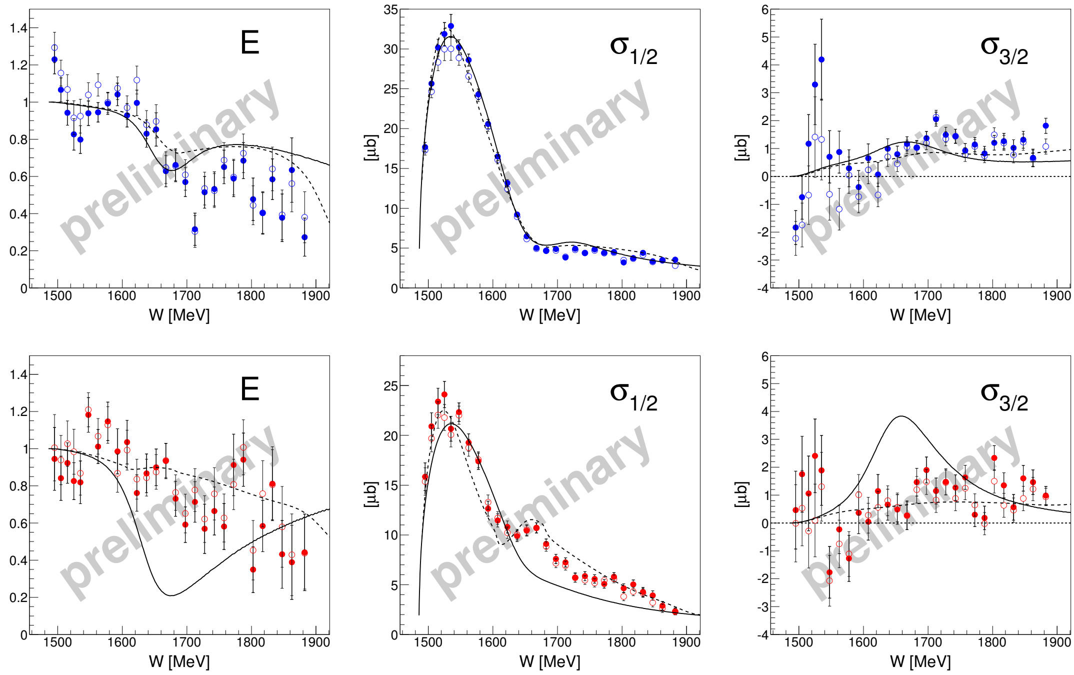

Figure 3: Preliminary Results. Double polarisation observable E and helicity dependent cross sections $\sigma_{1/2}$, $\sigma_{3/2}$ for η photoproduction on the proton (upper row) and on the neutron (lower row). Solid circles: normalised with carbon subtracted deuterated butanol, open circles: normalised with unpolarised total cross section. The results are compared to the BnGa model [7] (dashed line) and the MAID model [8] (solid line).

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