Polarization Observables T and F in single π^0- and η-Photoproduction off quasi-free Nucleons

Thomas Strub

Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland

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Meson photoproduction has developed into a powerful tool to study the nucleon excitation spectrum and test effective quark models which operate in the non-perturbative regime of QCD. An insight into the J^P configurations and isospin decompositions of the contributing resonances is gained by measuring a minimal set of polarization observables on both the proton and the neutron.

Single π^0- and η-photoproduction off a transversally polarized d-butanol target has been measured with circularly polarized bremsstrahlung photons generated by the MAMI-C electron microtron. With the nearly 4π acceptance of the combined Crystal Ball/TAPS setup the double polarization observable F and the target asymmetry T can be extracted for the first time for polarized, quasi-free neutrons over a wide energy and angular range.

1 Introduction

The nucleon and its excitation spectrum has been of great interest since many decades in order to study quantum chromodynamics in the non-perturbative regime. Due to the fact that many broad, overlapping resonances contribute to the excitation spectrum within a small energy range it cannot be understood from differential cross sections alone. While, for a long time, the method of choice to explore nucleon resonances was pion scattering with its large cross sections the attention came to photo- and electroproduction experiments when reaching higher intensity polarized electron beams, highly polarized targets with long relaxation times, and modern detector systems.

In the most general relativistic approach single pseudoscalar meson photoproduction gives access to four complex production amplitudes from which 16 real-valued polarization observables can be constructed [1]. These observables depend on beam, target and recoil polarization, and are, as well as the production amplitudes, functions of the invariant mass W and the production angle of the meson θ. The θ-dependence can be expanded in a partial-waves series by means of the electric and magnetic multipols $E_{l\pm}$ and $M_{l\pm}$, respectively, where l denotes the angular momentum. Thus, high statistic measurements of these observables in the (W, θ)-space allow to construct a uniquely determined solution of the production amplitudes up to a global phase through the partial wave analysis (PWA). It can be shown that eight carefully chosen observables have to be measured in order to find such a unique solution, which is called *complete experiment* [2].

Since the electromagnetic interaction does not conserve isospin the production vertex for single pseudoscalar meson photoproduction decomposes, in general, into three isospin amplitudes, namely one isoscalar ($\Delta I = 0$), A^{IS}, and two isovector ($\Delta I = 0, \pm 1$), A^{IV} and A^{V3} (cf., e.g., [3]). Due to the fact that pions form an isospin triplet ($I = 1, I_3 = 0, \pm 1$) all three amplitudes contribute to π-photoproduction. In contrast, since η is an isospin singlet state, the isospin changing amplitude A^{V3} will not contribute to η-photoproduction. This makes photoproduction of isoscalar mesons especially interesting because it is selective to $N^*(I = 1/2)$ resonances only, whereas $\Delta(I = 3/2)$ resonances will not contribute. Nevertheless, in both cases, it is necessary to measure not only photoproduction off the proton but also off the neutron in order to fix all isospin amplitudes. A second reason for the interest in η-photoproduction off the neutron is the recent observation of a narrow structure around $W = 1670$ MeV which is not seen for the proton channel [4].

Due to the lack of free neutron targets photoproduction measurements off the neutron have always to be made with neutrons (weakly) bound in light nuclei within the quasi-free approximation. This gives rise to additional nuclear effects such as final state interactions (FSI). Indeed, a suppression of the free total cross section of about 25% is observed in π^0-photoproduction off quasi-free protons from the deuterium target [5]. However, η-photoproduction off quasi-free protons from the deuterium target does not show a significant difference [6]. In any case, it is reasonable to assume that this effect cancels out when measuring polarization observables.

In the following we present a preliminary analysis of the polarization observables T and F for single π_0- and η-photoproduction. Following the notation of [7] the differential cross section for a circularly polarized photon beam and a transversally polarized target reads

$$\frac{d\sigma}{d\Omega} = \frac{1}{2}\frac{d\sigma_0}{d\Omega}\left(1 + TP_T \sin\phi + FP_\odot P_T \cos\phi\right),$$

where P_T and $P_\odot$ denote the target and beam degree of polarization, respectively and ϕ is the angle between the target spin an the reaction plane.

2 Experiment and analysis

The experiment was performed at the MAMI-C accelerator in Mainz, Germany, which delivered a longitudinally polarized electron beam with energy of 1.557 GeV and a polarization degree of about 80%. Circularly polarized bremsstrahlung photons were produced in a radiator foil and were energy tagged with the Glasgow-Mainz photon tagger with energies between 0.47 GeV and 1.45 GeV. The resulting degree of polarization of bremsstrahlung photons from relativistic electrons depends on the photon energy E_γ and is described by Olsen and Maximon [8]. Transversally polarized target nucleons were provide by polarized deuterons of a frozen spin d-butanol (C_4D_9OD) target with a mean degree of polarization of about 80%.

The target was surrounded by the cylindrical particle identification detector (PID) made of 24 plastic scintillator strips, each covering an azimuthal angle of 15°. The PID was surrounded by a multi-wire proportional chamber (MWPC), which was not used in the current analysis. The spherical Crystal Ball calorimeter (CB) surrounding the MWPC consists of 672 NaI(Tl) crystals and covers polar angles from 20° to 160°. The forward direction was covered by the hexagonal two arm photon spectrometer (TAPS) built from 72 $PbWO_4$ (inner two rings) and 366 BaF_2 crystals (ring 3 to 11). A VETO wall in front of TAPS was used for particle identification. The combined CB/TAPS setup gives an almost 4π acceptance in the center of mass frame with a high angular and energy resolution.

The fist step of the data analysis was to select only events with the correct number of charged and neutral hit information from the detector. For the neutron channel the photons were

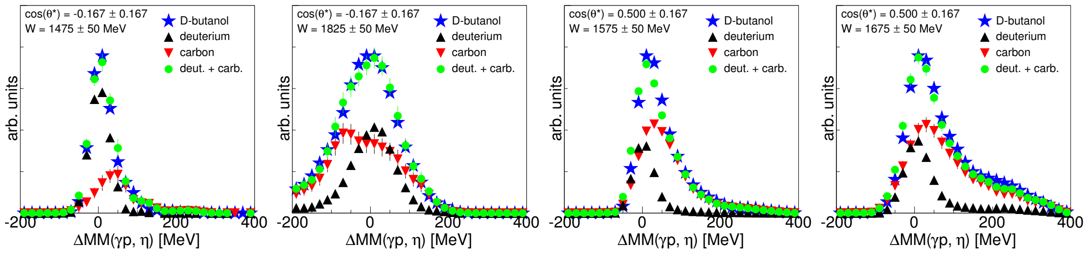

Figure 1: (Color online) Missing mass spectra for $\gamma p \to \eta p \to 2\gamma p$ for the carbon background subtraction. The spectra for deuterium and carbon are fitted to the d-butanol spectra. The ratio of carbon and deuterium, withing the missing mass cuts, is equal to the dilution factor.

identified by a χ^2-test finding the best combination for the meson invariant mass. Coincidence time cuts were applied to all photons and to eliminate accidentally coincident tagger photons, a random background subtraction was performed.

In order to separate the background channels kinematic cuts were applied separately for each W-θ-bin. Since all relevant events come from the polarized deuterons from the d-butanol target all cuts were determined from deuterium data. First, a coplanarity cut on the meson-nucleon system was applied. Then, an invariant mass cut on the reconstructed meson was performed. Finally, a γp-η missing mass cut was used to eliminate most of the background. The last step was to reconstruct the full event using four-momentum conservation, i.e., the Fermi momentum of the initial nucleon was determined from the knowledge of the incident photon energy and the complete final state. With this, the kinematics was transferred into the center of mass frame.

The observables were extracted using two opposite spin states for both, the photon helicity and nucleon spin. The above definition of the polarization observables can then be rewritten and reads, for F (and analogous for T),

$$F \cos\phi = \frac{1}{P_\odot}\frac{1}{P_T}\frac{d\sigma^+ - d\sigma^-}{d\sigma_0} = \frac{1}{P_\odot}\frac{1}{P_T}\frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{1}{P_\odot}\frac{1}{P_T}\frac{N^+_{\rm db} - N^-_{\rm db}}{N^+_{\rm db} + N^-_{\rm db}}\,\frac{1}{1-d}.$$

Here, the superscripts $(+,-)$ refer to the two photon helicity states, $N^\pm_{\rm db}$ denotes the count rate from d-butanol data and $d = d\sigma_0^{\rm carbon}/d\sigma_0^{\rm deuterium}$ is the dilution factor.

The last equality in the above equation holds for the following two reasons. First, flux normalization and efficiency corrections cancel out. Second, the cross sections refer to the reaction on the deuteron. However, unpolarized carbon and oxygen contributions only cancel in the numerator. Therefore, the additional contribution in the denominator has to be factorized out by the determination of the dilution factor. Figure 1 shows, for some selected bins, missing mass spectra of deuterium and carbon data fitted to the spectrum of d-butanol data. From this we can determine the unwanted contribution of events from carbon and oxygen from the d-butanol data.

3 Preliminary results and conclusion

Figure 2 shows some selected preliminary results for the polarization observables T and F for single π^0- and η-photoproduction off quasi-free protons and neutrons, respectively. Moreover, preliminary results for the reaction off the free proton and some model results are included.

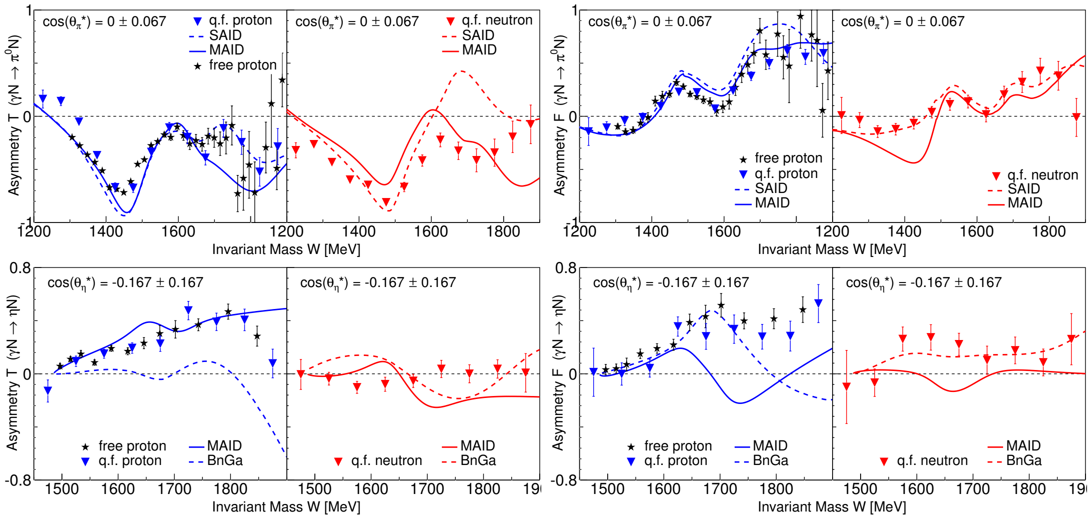

Figure 2: (Color online) Preliminary results for the polarization observables T and F. Top (bottom) row: π^0- (η-)photoproduction. Left (right) side: observable T (F) off free/quasi-free proton and quasi-free neutron. *Free proton data:* V. Kashevarov (preliminary); for final free proton $\gamma p \to \eta p$ results c.f. [9].

The free and quasi-free proton data are in nice agreement. The main contribution to the systematic uncertainties comes from the determination of the dilution factors caused by poorly matching missing mass spectra (only statistical errors are shown).

The best agreement with model predictions is found for π^0-photoproduction off the proton at lower energies, which is the best-known channel. There, the different models also make the same predictions. However, for higher energies the models deviate from each other and cannot reproduce the data consistently for both observables. For π^0-photoproduction off the quasi-free neutron the models already disagree at lower energies and for η-photoproduction off quasi-free protons and neutrons, respectively, the models even disagree down to the production threshold.

The final results will contribute to the complete experiment and will hopefully help to improve the model predictions and give a better understanding of the underlying physics.

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