EPJ Web of Conferences **81**, 02021 (2014)
DOI: 10.1051/epjconf/20148102021
© Owned by the authors, published by EDP Sciences, 2014

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

Thomas Strub[1,a]
for the A2 Collaboration

[1] *Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland*

Abstract. 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

Since many decades the nucleon and its excitation spectrum is being investigated with experiments but also from the theoretical side in order to study quantum chromodynamics in the non-perturbative regime. On the experimental side, the focus was lying on pion-nucleon scattering for a long time, i.a., due to its large cross section. With increasing intensity and quality of polarized electron beams, polarized targets with high polarization degrees and long relaxation times, and modern detector systems the attention came to photo- and electroproduction experiments. On the theory side, different effective quark models are being developed, and recent progress in non-perturbative lattice gauge methods show great promise. In order to test such approaches experimental input for the nucleon resonance spectrum is needed, including excitation energies, widths and coupling constants.

In the most general relativistic approach, the production amplitude of single pseudoscalar meson photoproduction can be expanded in four complex production amplitudes $\{F_i(W,\theta)\}_{i=1,...,4}$, where W is the center of mass energy and θ the production angle of the meson (cf., e.g., [1]). The θ-dependence of the F_i's can be expanded in terms of partial waves with angular momentum l by means of electric and magnetic multipols $E_{l\pm}$ and $M_{l\pm}$. From these four complex amplitudes 16 real-valued polarization observables can be constructed, each depending on beam, target and recoil polarization, and each being a bilinear hermitian form H of the amplitudes, i.e., $O = F_i{}^*(H_O)_{ij}F_j$. It can be shown that eight carefully chosen observables have to be measured in order to find a unique solution of the partial wave analysis (PWA), i.e., in order to fix the production amplitudes up to a global phase [2].

[a] e-mail: thomas.strub@unibas.ch

This is an Open Access article distributed under the terms of the Creative Commons Attribution License 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Article available at http://www.epj-conferences.org or http://dx.doi.org/10.1051/epjconf/20148102021

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 ($I = I_3 = 0$), the isospin changing amplitude A^{V3} will not contribute to η-photoproduction. This makes isoscalar meson photoproduction 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

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

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.

After introducing the experimental setup in Sec. 2, the analysis methods are discussed in Sec. 3. Finally, in Sec. 4, we present worldwide unique preliminary data for the polarization observables T and F off quasi-free neutrons.

2 Experimental Setup

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.

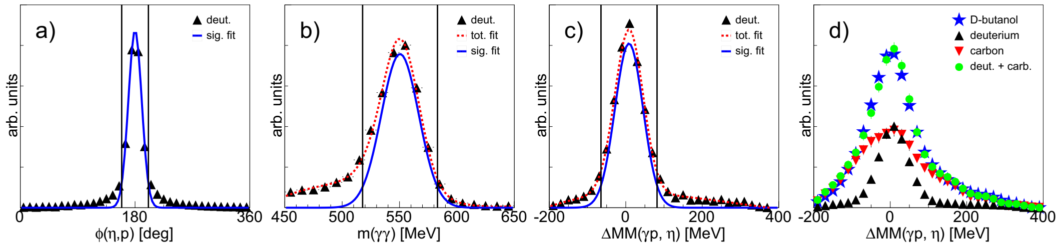

Figure 1: (Color online) Spectra for $\gamma p \to \eta p \to 2\gamma p$ ($\cos\theta = -0.167 \pm 0.067$, $W = (1675 \pm 50)$ MeV). η-p-coplanarity spectrum (a), $\gamma\gamma$ invariant mass spectrum (b), γp-η-missing mass spectra (c,d). Red dashed lines: total fit, blue line: signal fit, black vertical lines indicate the 1.5σ-cut. Sub-figure (d) shows the fit of carbon and deuterium data to the d-butanol data for the carbon background subtraction.

3 Data Analysis

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 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. Background channels for π^0-photoproduction are, e.g., $\gamma N \to \eta N$, $\gamma n \to \pi^0\pi^- p$, $\gamma p \to \pi^0\pi^+ n$, $\gamma N \to \eta N \to \pi^0\pi^+\pi^-$ and $\gamma N \to \pi^0\pi^0 N$. Since all relevant events come from reactions off the polarized deuterons from the d-butanol target all cuts were determined from deuterium data. Figure 1 shows the applied cuts for the $\gamma p \to \eta p \to 2\gamma p$ analysis. First, a coplanarity cut on the meson-nucleon system was applied (a). Then, an invariant mass cut on the reconstructed meson was performed (b). Finally, a γp-η missing mass cut was used to eliminate most of the background (c).

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 (superscripts $\pm$) and nucleon spin (superscripts $\uparrow\downarrow$). Eq. 1 can then be rewritten and reads, for T and F,

$$\begin{aligned} T\sin\phi &= \frac{1}{P_T}\frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma_0} = \frac{1}{P_T}\frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} = \frac{1}{P_T}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}\frac{1}{1-d}, \\ F\cos\phi &= \frac{1}{P_\odot}\frac{1}{P_T}\frac{d\sigma^{+} - d\sigma^{-}}{d\sigma_0} = \frac{1}{P_\odot}\frac{1}{P_T}\frac{d\sigma^{+} - d\sigma^{-}}{d\sigma^{+} + d\sigma^{-}} = \frac{1}{P_\odot}\frac{1}{P_T}\frac{N^{+} - N^{-}}{N^{+} + N^{-}}\frac{1}{1-d}, \end{aligned} \tag{2}$$

where N denotes the count rate and d is the dilution factor. The last equality in both lines of Eq. 2 holds for the following two reasons. First, flux normalization and efficiency corrections cancel out. Second, the cross sections in Eq. 2 refer to the reaction off polarized nucleons, i.e., the deuterons. Since the contributions of unpolarized carbon and oxygen only cancel in the numerator, the additional contribution in the denominator has to be factorized out by the determination of the dilution factor, e.g., from missing mass spectra. Figure 1 (d) shows the missing mass spectra of deuterium and carbon data fitted to spectrum of d-butanol data. From this, the dilution factor is then given by

$$d(W,\theta) = \left.\frac{d\sigma_{0,\,\mathrm{carbon}}(W,\theta)}{d\sigma_{0,\,\mathrm{deuterium}}(W,\theta)}\right|_{\text{all cuts }(W,\theta)}. \tag{3}$$

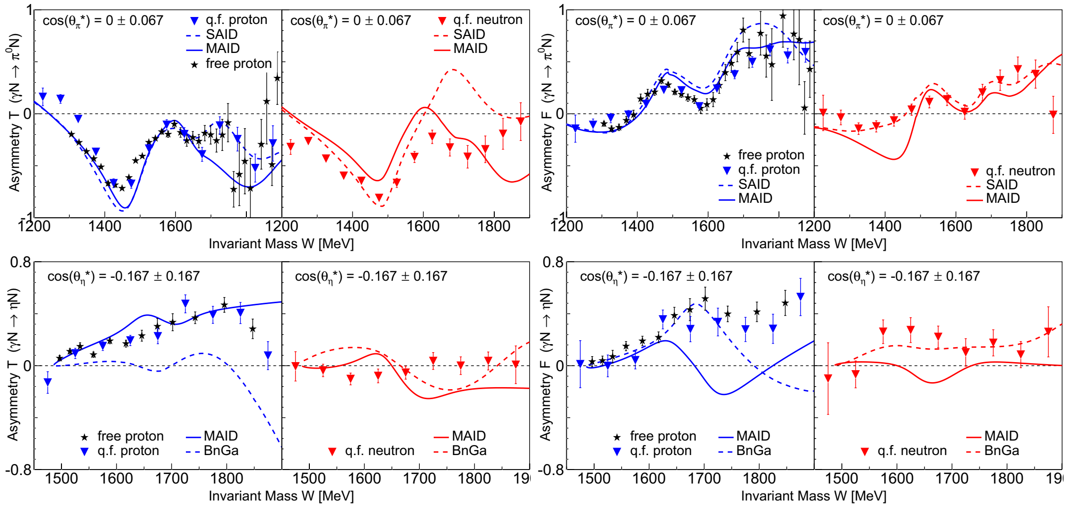

Figure 2: (Color online) Preliminary results for the observables T and F. Top (bottom) row: π^0-(η-)photoproduction. Left (right) side: observable T (F) off free/quasi-free proton and quasi-free neutron. *Free proton data:* V. Kashevarov (preliminary); for final free proton $\gamma p \to \eta p$ results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

4 Preliminary Results

Figure 2 shows preliminary results for the observables T and F for single π^0- and η-photoproduction off quasi-free protons and neutrons together with preliminary results off the free proton for a selected $\cos\theta$-bin. The free and quasi-free proton data are in nice agreement. At this stage of the analysis 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).

Non of the plotted models can reproduce the data for all channels. The best agreement is found for π^0-photoproduction off the proton at lower energies, which is the best-known channel, and where the different models make the same predictions. For π^0-photoproduction off the quasi-free neutron and η-photoproduction off quasi-free protons and neutrons the models differ already at lower energies.

The final results will contribute to the complete experiment, and thus, will probably be able to improve the model predictions and give a better understanding of the underlying physics.

References

[1] G.F. Chew, M.L. Goldberger, F.E. Low and Y. Nambu, Phys. Rev. **106** 1345 (1957)

[2] W.-T. Chiang and F. Tabakin, Phys. Rev. C**55** 2054 (1997)

[3] B. Krusche and S. Schadmand, Prog. Part. Nucl. Phys. **51** 399 (2003)

[4] D. Werthmüller *et al.*, Phys. Rev. Lett. **111** 232001 (2013)

[5] M. Dieterle *et al.*, Phys. Rev. Lett. **112** 142001 (2014)

[6] D. Werthmüller *et al.*, Phys. Rev. C**90** 015205 (2014)

[7] A.M. Sandorfi *et al.*, J. Phys. G**38** 053001 (2011)

[8] H. Olsen and L.C. Maximon, Phys. Rev. **114** 887 (1959)

[9] C.S. Akondi *et al.*, Phys. Rev. Lett. **113** 102001 (2014)