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DOUBLE-POLARIZATION OBSERVABLES, η-MESON AND TWO-PION PHOTOPRODUCTION[1]

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Photoexcitation of the nucleon yields structures in the total absorption cross section that indicate the existence of resonances. In order to explore resonance contributions, the total photabsorption cross section does not deliver a satisfying set of information. Fixing degrees of freedom by selection of partial reaction channels achieved a more detailed set of information over the last years. Further defined conditions could be reached in the recent past by fixing the polarization orientation and type between photon beam and target. This allows to observe double-polarization observables of the differential photoabsoption cross section. This article gives an overview of the double-polarization observables G and E and presents what can be learned from the polarization dependent photoproduction of the η- and $\pi\pi$-mesons.

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1 Introduction

The total photoabsorption cross section of the nucleon as shown for the proton in Figure 1 reveals structures indicating the existence of resonances. The Breit-Wigner parametrization presented by Figure 2 shows that the first resonance region is mainly described by the $P_{33}(1232)$ ($\Delta(1232)$) resonance at laboratory photon energies of 340 MeV, which can be very well observed by the partial reaction channel $\gamma\mathrm{p} \rightarrow \mathrm{p}\pi^0$. The second structure at higher photon energies consists of overlapping resonances that are mainly $D_{13}(1520)$, $S_{11}(1535)$ and $P_{11}(1440)$. Besides the single-pion channels, up to 50% of the total photoabsorption cross section is made up of two-pion- and η-production channels in this region. η-production on the proton via the channel $\gamma\mathrm{p} \rightarrow \mathrm{p}\eta$ is well suited to explore properties of the $S_{11}(1535)$ resonance. With increasing complexity of channels having more than two final state particles such as $\pi\pi$-production, an approach using multipole descriptions is hard to find. For η-production as also for η'-production first multipole approaches exist, such as MAID.

Separation into partial photoproduction channels is a suitable way to get information about resonances. Small resonance contributions such as $P_{11}(1440)$ and $S_{11}(1535)$ are however hard

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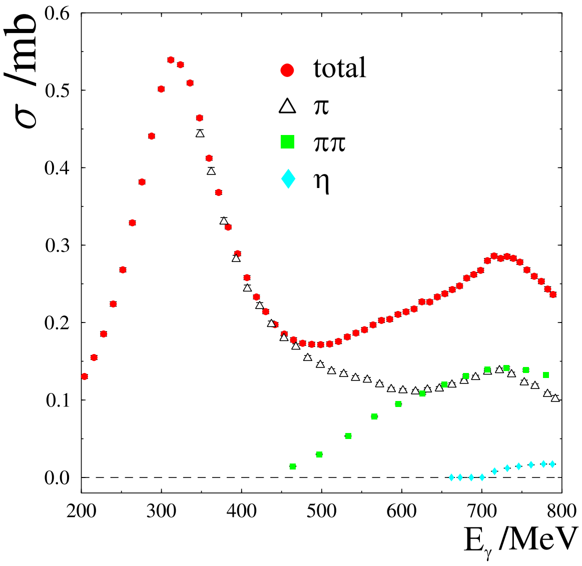

Fig. 1. Unpolarized photoabsorption cross section on the proton versus the photon energy in lab frame, measured by experiments carried out by the A2 collaboration at MAMI.

to observe. Therefore, single and double-polarization observables have to be investigated in order to limit the degrees of freedom of the observed photoproduction reactions. Single polarization is given if a linearly or circularly polarized photon beam hits an unpolarized target, while double polarization is given if the target is in addition longitudinally polarized into a defined direction with respect to the photon beam. Helicity dependencies can be observed, if a circularly polarized photon interacts with a longitudinally polarized nucleon aligned in parallel to the axis of the photon beam. The photon- and nucleon-spins can be combined as $\pm 1 \pm 1/2 = \pm 3/2 \rightarrow \sigma_{3/2}$ and $\pm 1 \mp 1/2 = \pm 1/2 \rightarrow \sigma_{1/2}$. A defined set of polarization observables exists that contributes to the differential photoabsorption cross section. Figure 3 shows the orientation of the incoming photon beam versus the reaction plane for two particles final states. The differential cross section for this type of reactions is given by

$$\begin{aligned}\frac{d\sigma}{d\Omega} = & \left(\frac{d\sigma}{d\Omega}\right)_{\text{unpol}} \left(1 - P_\gamma^{lin}\Sigma(\theta)\cos(2\phi)\right. \\ & +P_x\left[-P_\gamma^{lin}H(\theta)\sin(2\phi) + P_\gamma^{circ}F(\theta)\right] \\ & +P_y\left[-T(\theta) + P_\gamma^{lin}P(\theta)\cos(2\phi)\right] \\ & \left.+P_z\left[-P_\gamma^{lin}G(\theta)\sin(2\phi) + P_\gamma^{circ}E(\theta)\right]\right) . \end{aligned} \tag{1}$$

A so called "full experiment" is necessary to measure all given polarization observables in equation 1. Various experiments such as TAPS, DAPHNE and GDH have been carried out which contribute measured values to these polarization observables. Table 1 shows the polarization parameters between photon beam and target for these observables.

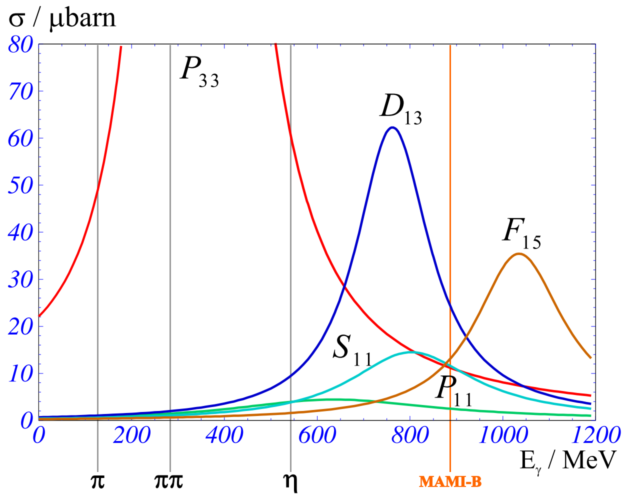

Fig. 2. Breit-Wigner parametrization of resonances of the photoproduction on the nucleon between 0 MeV and 1200 MeV photon energy in lab frame. The π, $\pi\pi$, η production thresholds and the maximum energy of MAMI B are additionally shown in the plot.

2 Double-Polarization Observables

With a target, providing longitudinally polarized nucleons parallel to the photon beam axis, the two double-polarization observables G and E can be measured. During the GDH experiment in 1998, a first measurement for G was done in order to explore contributions to the $P_{11}(1440)$. Figure 4 shows the observable G which can be used to explore properties of the $P_{11}(1440)$ resonance [18]. The main aim of the GDH experiment in 1998 was the verification of the Gerasimov-Drell-Hearn sum rule which puts dynamic properties of the nucleon, such as the helicity dependent cross sections $\sigma_{3/2}$ and $\sigma_{1/2}$ in relation to static properties such as the anomalous magnetic moment of the nucleon [1–3, 6]. $\sigma_{3/2}$ and $\sigma_{1/2}$ were well suited not only to verify the GDH sum rule but also to do partial channel analysis and to give contributions to the observable E [7–9, 20]. $\sigma_{3/2}$ and $\sigma_{1/2}$ required for the determination of $E = (\sigma_{3/2} - \sigma_{1/2})/(\sigma_{3/2} + \sigma_{1/2})$ are also suitable to explore helicity dependent resonance properties in η photoproduction (for $S_{11}(1535)$). The sensitivity of resonances for η photoproduction is shown in Figure 5. Two-pion photoproduction is used to mainly explore properties of $D_{13}(1520)$, $\Delta(1700)$ and higher orders. Various models exist which attempt to explain the cross section contributions of the $\pi\pi$ channels. Results are compared with predictions of the theory groups in Valencia and in Gent / Mainz.

3 Experimental Set-Up

In order to measure the helicity-dependent cross sections $\sigma_{3/2}$ and $\sigma_{1/2}$, three main experimental apparatus are required: a circularly polarized photon beam, a longitudinally polarized proton target, and a detector system with a high momentum and angular acceptance in order to mea-

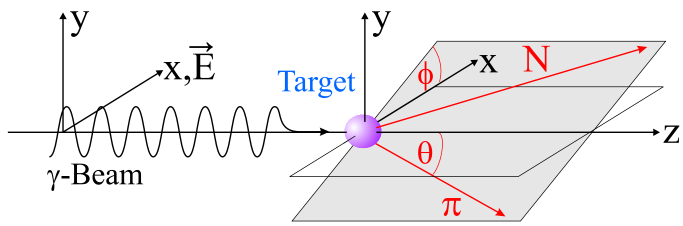

Fig. 3. Orientation of the photon beam versus the reaction plane for photoproduction reactions on the nucleon with two particles final states.

Beam / Target	γ_{unpol}	P_γ^{lin} $(0, \pi/2)$	P_γ^{lin} $(+\pi/2, -\pi/2)$	P_γ^{circ}
P^{unpol}	$(d\sigma/d\Omega)$	$\Sigma(\theta)$	–	–
P_x	–	–	$H(\theta)$	$F(\theta)$
P_y	$T(\theta)$	$P(\theta)$	–	–
P_z	–	–	$G(\theta)$	$E(\theta)$

Tab. 1. Required parameters of photon beam and target for the measurement of polarization observables. For P_γ^{lin} the relative angles between the linear polarization vector of the photon beam and the reaction plane are given in addition.

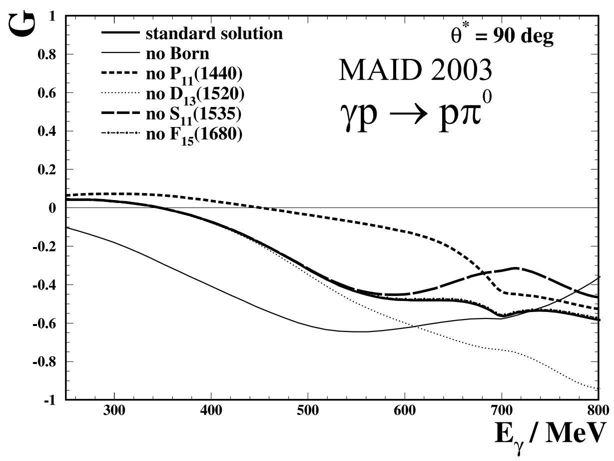

Fig. 4. Observable G plotted as function of the photon energy in lab frame. A good sensitivity for $P_{11}(1440)$ can be found around $E_\gamma \approx 600$ MeV. Predictions are taken from the MAID2003 model for the reaction $\gamma \mathrm{p} \rightarrow \mathrm{p}\pi^0$.

sure the total photoabsorption cross sections. A polarized photon beam is generated by the Bremsstrahlung process from longitudinally polarized electrons of MAMI, where the degree of

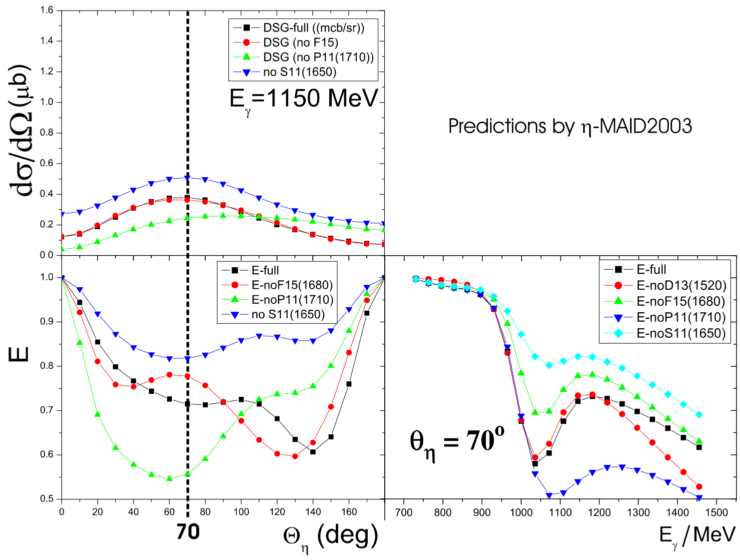

Fig. 5. Behaviour of the observable E in η photoproduction, predicted by the η-MAID2003 model. The top left plot shows the unpolarized differential cross section. The lower left image shows E as function of the scattering angle of the η and the lower right plot shows E as function of the photon energy in lab frame [23].

polarization is determined using a Møller polarimeter. As the main detector component, DAPH-NE (built by DAPNIA Saclay / France) was used, which covers a solid angle of $\Omega = 0.94 \cdot 4\pi$ sr. Its measured momentum threshold for pions is 65 MeV/c and for protons 300 MeV/c. A detailed description of the GDH-experiment set-up and the detector DAPHNE can be found in [9] and [17]. The construction allows for the separation of partial channels. A more detailed description about the separation and analysis techniques concerning two-pion channels can be found in [9]. All new data presented here were measured with the DAPHNE detector only. The frozen-spin target (built by Bonn–Bochum / Germany and Nagoya / Japan) represents the realization of longitudinally polarized protons, where butanol is used as target material. Even though butanol contains oxygen and carbon in addition to hydrogen, this gives no helicity-dependent contribution. Therefore, the cross section difference $\Delta\sigma = \sigma_{3/2} - \sigma_{1/2}$ was measured in order to subtract the unpolarized background. Unpolarized cross sections (σ) measured with a liquid-hydrogen target during the calibration run of the GDH-experiment in 1997 allowed for the extraction of the observables $\sigma_{3/2} = (2\sigma + \Delta\sigma)/2$ and $\sigma_{1/2} = (2\sigma - \Delta\sigma)/2$.

4 Results and Comments

4.1 Two-Pion Photoproduction

To verify the detector set-up and its calibration, partial-channel cross sections measured on a liquid-hydrogen target in 1997 were compared to previously published data from other exper-

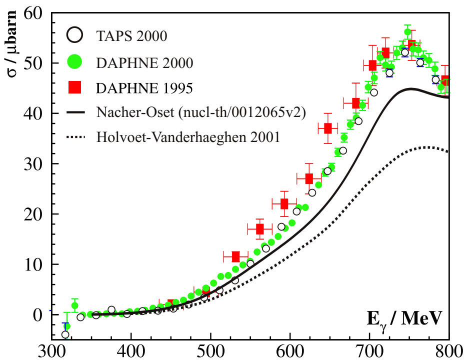

Fig. 6. Total cross section for $\gamma p \to n\pi^+\pi^0$ in comparison to previously measured data (curves: see text).

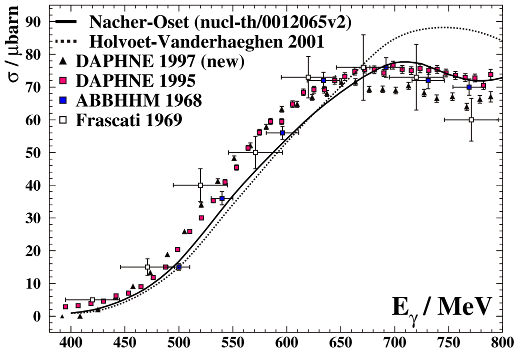

Fig. 7. Total cross section for $\gamma p \to p\pi^+\pi^-$ in comparison to previously measured data (curves: see text).

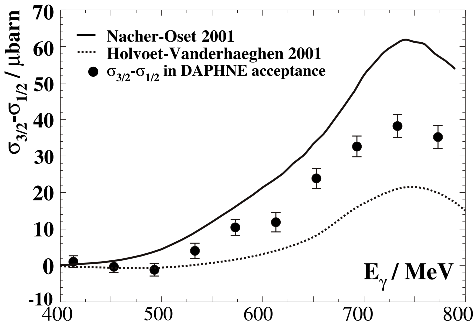

Fig. 8. Cross section difference $\sigma_{3/2} - \sigma_{1/2}$ for $\vec{\gamma}\vec{p} \to n\pi^+\pi^0$ inside DAPHNE acceptance ($\approx$ 80%).

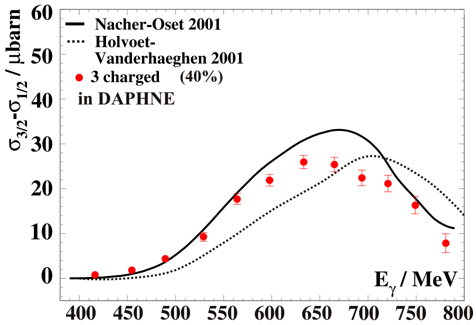

Fig. 9. Cross section difference for $\vec{\gamma}\vec{p} \to p\pi^+\pi^-$ for three charged tracks inside DAPHNE acceptance ($\approx$ 40%).

iments. Figure 6 shows the photoabsorption cross section for $\gamma p \to n\pi^+\pi^0$ in comparison to previous data [4]. The dotted line shows the model prediction of the Gent–Mainz group while the continuous line represents the prediction of the Valencia group. The structure of the cross section indicates a major contribution from $D_{13}(1520)$ and $\rho(770)$. According to reference [11], a $\rho(770)$ contribution of more than 50% is required to reach good agreement with the data. Figure 7 shows the photoabsorption cross section for $\gamma p \to p\pi^+\pi^-$ in comparison to previous data. Again, predictions are shown from the Valencia [11, 15] and Gent–Mainz [8, 16] groups. The maximum of this cross section is thought to be caused by interference between the Kroll-Rudermann and Δ-Kroll-Rudermann terms, which dominate this isospin channel due to the double-charged pion final-state.

4.2 η Photoproduction

The η photoproduction is very well suited to explore the properties of the $S_{11}(1535)$ resonance. Due to its isospin characteristics, it is expected that the helicity amplitude $\sigma_{1/2}$ gives the major contribution to it. The first measurement of the GDH sum rule in 1998 enabled us to analyze η photoproduction cross sections. As done for the two-pion data, the calibration measurement of 1997 was used to extract $\sigma_{1/2}$ and $\sigma_{3/2}$ from the unpolarized measurement ($\sigma = 1/2(\sigma_{3/2} + \sigma_{1/2})$) combined with data from the polarized GDH experiment ($\Delta\sigma = \sigma_{3/2} - \sigma_{1/2}$) [5]. Figure 10 shows the unpolarized η photoproduction. The points acquired from

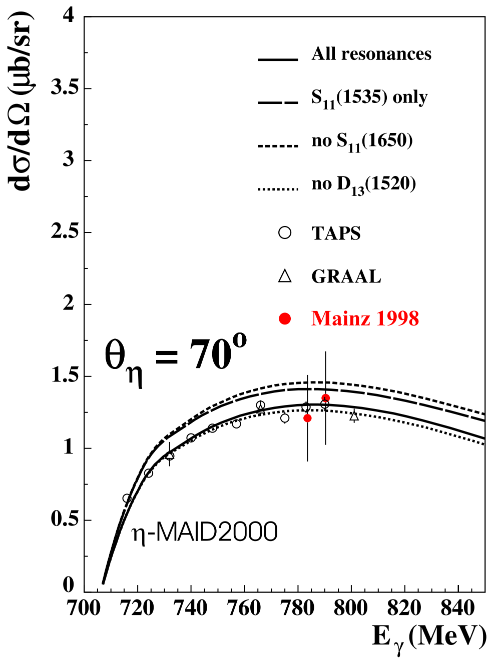

Fig. 10. Differential cross section of the unpolarized η photoproduction (Mainz 1998) plotted versus the photon energy in lab frame for a fixed η scattering angle of 70° in comparison with data from TAPS, GRAAL and predictions of the η-MAID2000 model [5].

the GDH experiment in 1998 are in good agreement with other experiments such as TAPS and GRAAL. The sensitivity for the $S_{11}(1535)$ resonance is shown using the η-MAID2000 model. Figure 11 shows the results for the helicity dependent case. The cross section of $\sigma_{1/2}$ is clearly dominating the helicity dependent case of the η photoproduction. This clearly shows that resonances with isospin 1/2 contributions dominate the η photoproduction.

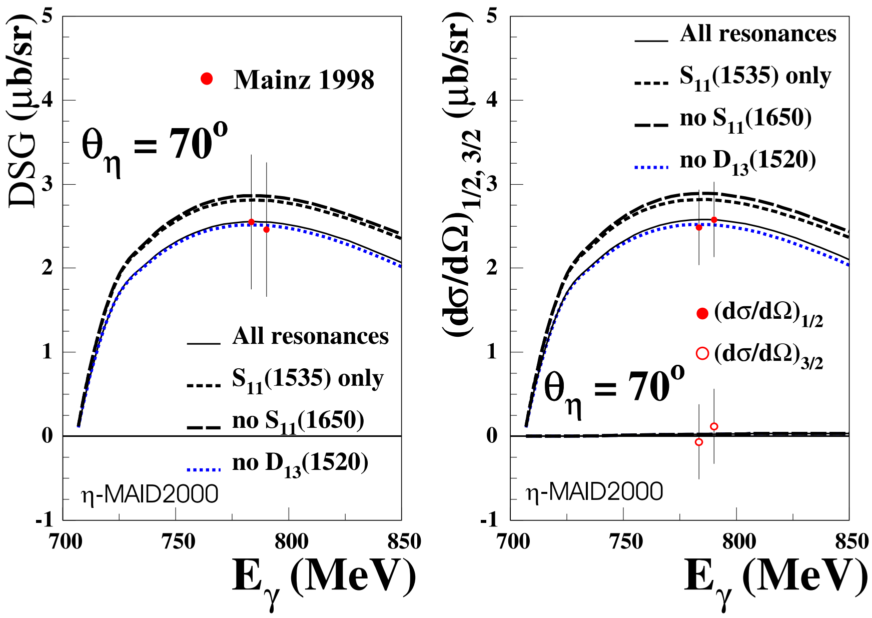

Fig. 11. Helicity dependent differential cross section of the η photoproduction plotted versus the photon energy in lab frame. The left plot shows the helicity dependent cross section difference $DSG = (\mathrm{d}\sigma_{1/2})/(\mathrm{d}\Omega) - (\mathrm{d}\sigma_{3/2})/(\mathrm{d}\Omega)$, The right plot shows the differential cross section for $(\mathrm{d}\sigma_{3/2})/(\mathrm{d}\Omega)$ and $(\mathrm{d}\sigma_{1/2})/(\mathrm{d}\Omega)$ separately. Predictions are given by the η-MAID2000 model approach [5].

5 Conclusions and Outlook

The measurement of double-polarization observables opens a completely new field of data for determining properties of resonances of the nucleon. Data for the η and the two-pion photoproduction were shown for the helicity dependent cases where circularly polarized real photons interact with a longitudinally polarized target. The helicity dependent cross sections $\sigma_{3/2}$ and $\sigma_{1/2}$ deliver contributions to the double-polarization observable E. The shown data were taken from the GDH experiment carried out by the GDH- and A2-collaborations in 1998. From the GDH experiment at MAMI which finished data taking in 2003, first results already exist [21]. The planing ahead is to carry out further double-polarization experiments. For MAMI in Mainz, the Crystal Ball detector is going to be used in beam of MAMI C with a photon energy up to 1500 MeV on from spring 2006. This detector is equipped together with the frozen spin target currently built in Mainz, that provides longitudinally polarized nucleons using butanol and deuterized butanol as target material [22]. For polarized neutron measurements, a ^{3}He gas target is currently under construction [19]. At ELSA in Bonn, the Crystal Barrel detector is going to be used to measure helicity dependent cross sections up to a photon energy of 3.2 GeV. The plans are to start data taking in spring 2006. It is planed to measure properties of the observable E [23] and G [24, 25] using partial photproduction reactions.

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