Baryon Spectroscopy at ELSA

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Abstract. The excitation spectrum of the proton consists of several strongly overlapping resonances, which are difficult to disentangle. To determine the exact contributions and identify these resonances, a solution of the partial wave analysis has to be found. For a complete experiment, which leads to an unambiguous solution, at least 8 well chosen single and double polarization observables are needed. With the new Crystal-Barrel/TAPS experiment at ELSA, the measurement of double polarization parameters like E and G in different reactions is possible by using a circularly or linearly polarized photon beam on a longitudinally polarized butanol target. The Crystal-Barrel/TAPS setup provides a nearly 4π angular coverage and a high detection efficiency for neutral states, which gives an ideal condition for the study of final state comprising neutral mesons. First preliminary results of the G asymmetry measurement in the reactions $\vec{\gamma}\vec{p}\rightarrow p\pi^0$ and $\vec{\gamma}\vec{p}\rightarrow p\eta$, which utilizes linearly polarized photons in combination with the longitudinally polarized target, are presented.
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1. Introduction

The understanding of the excitation spectrum of the baryon has been a major challenge in the past years. The measured cross section of photoexcitation off the proton shows resonant structures in the lower energy region and becomes flat for higher energies. The analysis of different final states like $\gamma p \rightarrow p\pi^0$ or $\gamma p \rightarrow p\eta$ indicates that the resonant structures vary for the reactions, which means that the resonances couple to different final states with varying intensities. The calculated Breit-Wigner amplitudes of the contributing resonances for the two reactions are shown in figure 1, where the different strengths and widths of the resonances become obvious.

The total cross section is composed of the quadratic sum of the contributing partial waves and their interferences, which poses the difficulty that weakly contributing resonances are dominated by other resonances and can therefore hardly be investigated in the total cross section. To access these resonances differential distributions of single and double polarization observables are needed. By using polarized photons on an unpolarized target, the beam asymmetry Σ becomes accessible. This observable is sensitive to the interference terms of the partial waves and gives more information of weakly contributing resonances. The results are still not unambiguous and can be described by different contributing resonances. To further disentangle the resonances new observables are needed, which can be measured by using a polarized photon beam on a polarized target. To measure the double polarization observable G linearly polarized photons impinging on a longitudinally polarized target are needed.

To determine all amplitudes unambiguously and model-independently, a set of 8 well chosen

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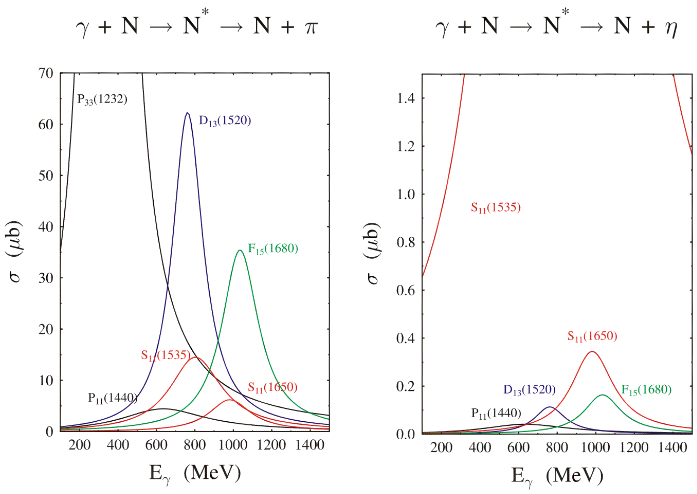

Figure 1. Calculated Breit-Wigner amplitudes for two different reactions.

polarization observables is needed for single meson photoproduction[1]. This will lead to a complete experiment, which describes all amplitudes without discrete ambiguities.

2. Experimental Setup

The CBELSA/TAPS experiment, which is shown in figure 2, is located at the electron stretcher accelerator ELSA in Bonn. The accelerator provides electrons up to 3.5 GeV, which are used to produce photons via bremsstrahlung. By using a diamond crystal as a radiator target, it is possible to produce linearly polarized photons with different energies. To determine the energies

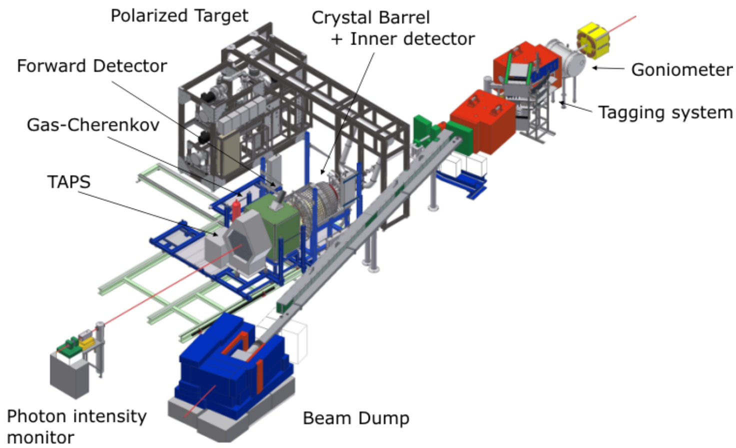

Figure 2. Setup of the CBELSA/TAPS experiment.

of the photons, a tagging spectrometer is used. It consists of the 96 scintillating bars, which cover a range of 18% to 95% of the incident electron energies. For a better energy resolution in the part of the lower photon energies, 480 scintillation fibres are used. With this setup an energy resolution of 0.2% to 2.2% can be reached.

The reaction of the polarized photons takes place in the frozen spin target. Polarization up to 80% was reached during the measurement, with the need to repolarize the target every few days.

The target is surrounded by the main calorimeter setup, which is composed of an inner detector for the identification of charged particles and the Crystal Barrel detector with its 1230 CsI(Tl) crystals. The crystals have a high detection efficiency for photons, therefore the detector is well suited for the detection of reactions with neutral mesons like π^0 or η in the final state. The Crystal Barrel experiment is a fixed target experiment, the reaction particles are boosted in forward direction. To detect these particles a forward detector is used, which covers the angular range down to 21°. It consists of 90 CsI crystals with 180 scintillating tiles mounted in front of them for charge identification. To cover the θ-angle down to 1°, the MiniTAPS detector is set up behind the forward detector. It is composed of 513 BaF_2 crystals and uses plastic scintillators to identify charged particles like protons. For the photon flux determination, several detectors are mounted at the end of the beam line.

3. Analysis Outline

In this analysis two different data sets as shown in figure 3 (left) are used: one with the coherent peak at 840 MeV with a maximal polarization of 61%, the second set has a polarization of 58% at the coherent peak at 1032 MeV. These sets were segmented into energy bins of $E_\gamma = 33$ MeV width for $\gamma p \rightarrow p\pi^0$ and for $\gamma p \rightarrow p\eta$ into energy bins of $E_\gamma = 100$ MeV width. With these energy bins the energy range of 700 MeV up to 1150 MeV has been covered. For events with two neutral and one charged particle the $\gamma\gamma$ invariant mass is shown in figure 3 (center) for the higher energy coherent peak. The peaks for the π^0 and the η meson can clearly be seen on small background contribution. To extract the events cuts on the time and the charge of the particles, coplanarity and a cut on the missing mass of the proton were used.

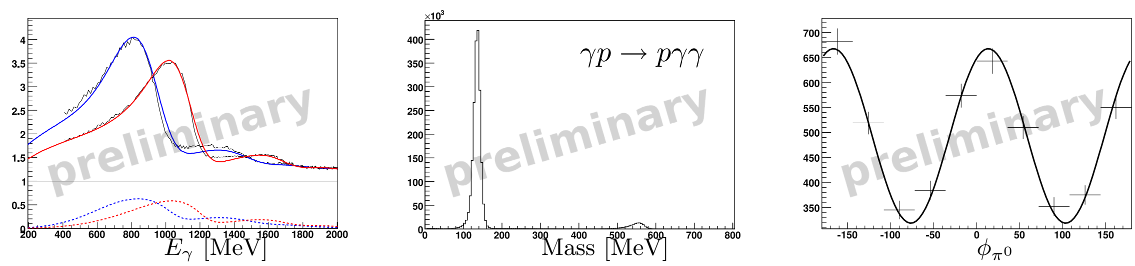

Figure 3. Left: the coherent peak of the polarized photons for the two different polarization settings used, center: invariant mass of the two photons after the cuts, right: example fit of the fitfunction to the preliminary data.

The frozen spin target is composed of butanol, which beside hydrogen consists also of bound protons from the carbon part of the target. The protons inside the carbon are not polarized. To determine the polarization observable G it is necessary to know the fraction of the carbon inside the target. The equation of the count rate of a butanol target is shown below with $N(\theta, \phi)$ being the overall count rate, N_C (N_H) the count rate due to the protons bound in the carbon (free protons).

$$N(\theta, \phi) = (N_C + N_H) \cdot [1 - \frac{N_C\Sigma_C + N_H\Sigma_H}{N_C + N_H} \cdot p_\gamma^{lin} \cos(2\phi) + \frac{N_H}{N_C + N_H} p_z \cdot p_\gamma^{lin} G \sin(2\phi)] \quad (1)$$

To successfully determine the double polarization observable G the following equation was used to fit the data:

$$N(\theta, \phi) = A \cdot [1 - B \cdot \cos(2\phi) + C \cdot \sin(2\phi)] \quad (2)$$

An example of the fitfunction on a θ-bin is shown in figure 3 (right).
The double polarization observable G can be extracted by the fit parameter C, which is still

reduced by the degree of the beam and the target polarization and the dilution factor. To determine the observable, it is therefore important to know the dilution factor $D = \frac{N_H}{N_C+N_H}$. The determination of the dilution factor is further described in the next section.
The fit parameter B contains information about the beam asymmetry Σ for the butanol target. These values are compared to the previous measurements below.
The results of Σ and G are compared to the different partial wave analyses BnGa, MAID[2][3] and SAID[4].

3.1. The Dilution Factor

The dilution factor is necessary for an absolute determination of the double polarization observable G. Two additional measurements where made, one with a hydrogen and one with a carbon target. To determine the factor, it is important to know how the different ingredients of the target contribute to the measured events. One way to measure this is to look at the distribution of the missing mass as shown in figure 4 (left). By comparing the missing mass on the hydrogen to the missing mass of the carbon, it becomes obvious that the measured missing mass on the carbon (open squares) is widened up due to fermi motion and shows more background than the hydrogen measurement (stars). Both missing mass distributions summed up (open triangles) are needed to describe the distribution of the missing mass of the butanol target, as can be seen in figure 4 (left).

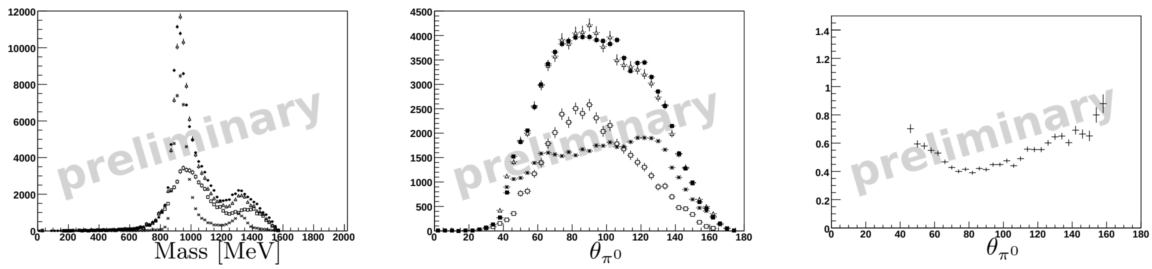

Figure 4. Missing mass (left) and θ-distribution (center) of the π^0 for butanol target (solid squares), hydrogen target (stars), carbon target (open squares) and the sum of the hydrogen and carbon target (open triangles). Right: dilution factor for $E_\gamma = 1033$ MeV.

To verify that the determined carbon and hydrogen contributions of the target are correct, the θ-distribution of mesons produced in the carbon and the hydrogen target were compared to the θ-distribution on the butanol target, see figure 4 (center). Again the distributions of the measurements on the hydrogen and the carbon target sum up nicely to describe the measured θ-distribution on the butanol target. These θ-distributions can now be used to determine the dilution factor $D = \frac{N_H}{N_C+N_H}$. The θ-dependent dilution factor was extracted for every energy bin. An example dilution factor for the reaction $\gamma p \to p\pi^0$ in the energy bin $E_\gamma = 1000$ MeV is shown in figure 4 (right). It can now be used to correct the measured data.

4. Results

4.1. The Beam Asymmetry Σ

Due to the carbon fraction in the target, it is not possible to measure the beam asymmetry Σ on the free proton directly. The fit parameter B from equation 2 depends on an interference term of the beam asymmetry of the bound and the free proton: $B = \frac{N_C\Sigma_C+N_H\Sigma_H}{N_C+N_H} \cdot p_\gamma^{lin}$. Under the assumption, that the beam asymmetry is the same on the bound proton inside the carbon as on the free proton, the relation above simplifies to $B = \Sigma_H \cdot p_\gamma^{lin}$ and the fit parameter B allows for the comparison of the measurement of the beam asymmetry to previous measurements. In figure 5, upper row, the extracted values are compared the the GRAAL data[5] (open circles), whereas the different lines show the predictions of the different partial wave analyses. For the reaction $\gamma p \rightarrow p\eta$ the extracted values again agree well with the previous measurement[6] as shown in figure 5, lower row.

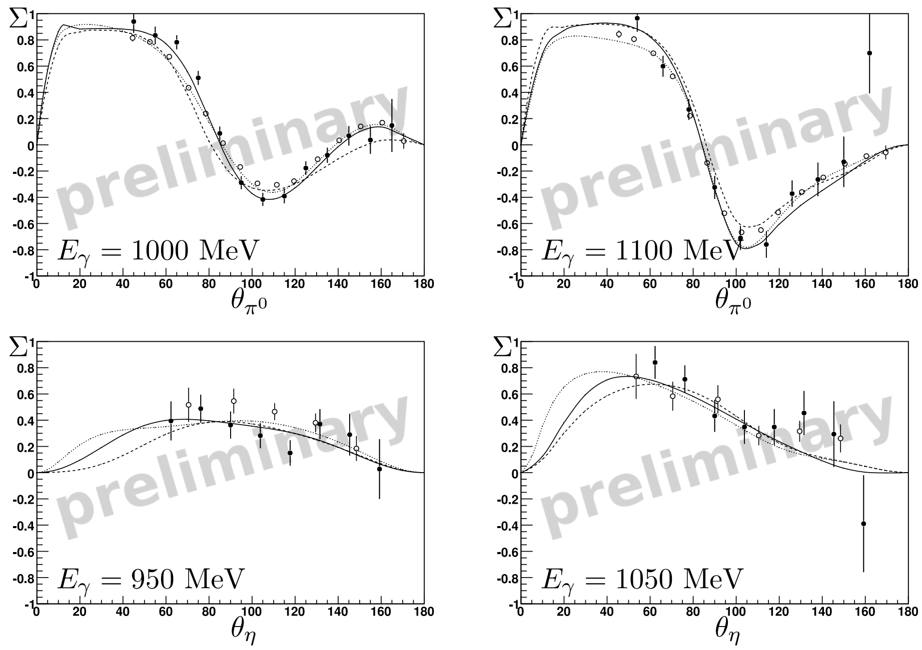

Figure 5. Beam asymmetry Σ: top: $\gamma p \rightarrow p\pi^0$, bottom: $\gamma p \rightarrow p\eta$. The preliminary data (filled circles) is compared to the GRAAL data[5] for π^0 and the data from D. Elsner[6] for η, both in open circles. The solid lines are the different PWA solutions MAID (dashed line), SAID (solid line) and BnGa (dotted line).

4.2. The Double Polarization Observable G

The values of the double polarisation observable G have been extracted from the fit parameter $C = \frac{N_H}{N_C+N_H} p_z \cdot p_\gamma^{lin} \cdot G$ of equation 2. The dilution factor $D = \frac{N_H}{N_C+N_H}$ was determined for every energy bin and was used in combination with the degree of beam and target polarization, to correct the values from the fit. These extracted results are shown in figure 6, compared to the solutions of the different partial wave analyses, MAID (dashed line), SAID (solid line) and BnGa (dotted line). The predictions are in the same order as the measured data, but clear differences between the different predictions and the data can be seen. None of the PWA solutions agrees completely with the measured observable, so it will give new input to improve the partial wave analysis.

5. Summary

The Crystal Barrel experiment allows the measurement of several polarization observables. The preliminary data for the beam asymmetry Σ shows already good agreement with the previous measurement for π^0 and η photoproduction. By using the dilution factor the values of the double polarization observable G for the reactions $\gamma p \rightarrow p\pi^0$ and $\gamma p \rightarrow p\eta$ could successfully be extracted from the data and compared to the predictions. Differences to the predictions can already be seen, which will give new information for the different partial wave analyses.

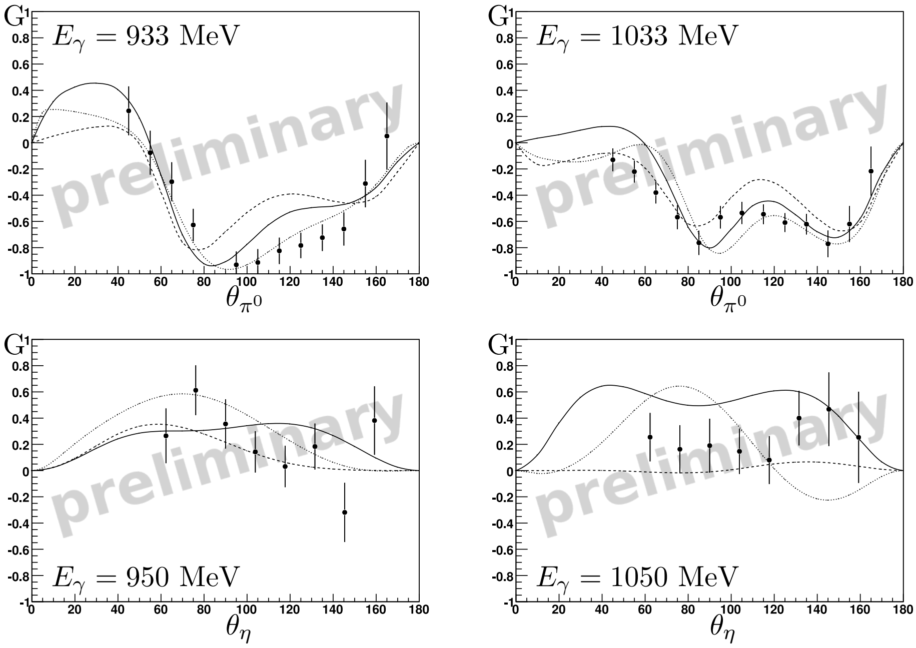

Figure 6. Double polarization observable G: top: $\gamma p \to p\pi^0$, bottom: $\gamma p \to p\eta$. The preliminary results are compared to the PWA solutions from BnGa (dotted line), MAID (dashed line) and SAID (solid line).

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