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Measurement of the double polarization observable E in the reaction $\gamma p \rightarrow p\eta'$

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Abstract. The main goal of the CBELSA/TAPS experiment is the investigation of the nucleon excitation spectrum, which consists of many overlapping resonances. In order to disentangle the different resonance contributions, a partial wave analysis is necessary. In the field of photoproduction of single pseudoscalar mesons, the measurement of a well chosen set of at least eight single and double polarization observables allows for the determination of an unambiguous solution. Of particular interest is the η' meson since it couples only to resonances with isospin $I = \frac{1}{2}$, thus reducing the number of overlapping resonances. Additionally, its comparatively high mass gives access to the poorly understood regime of high-lying resonances.
With the CBELSA/TAPS experiment at the electron stretcher accelerator ELSA, double polarization observables such as E can be obtained by studying photoproduction reactions using a circularly polarized photon beam in combination with a longitudinally polarized butanol target. The decay mode $\eta' \rightarrow \gamma\gamma$ was analyzed for a beam photon energy range of 1447-2350 MeV. The preliminary results for the double polarization observable E are shown.

1 Introduction

Current baryon models predict more resonance states than experimentally observed in the excitation spectrum, especially in the high mass region [1]. The photoproduction of η' on the proton gives access to these high lying resonances. New data for the differential cross section of η' was obtained by the CBELSA/TAPS collaboration [2] and CLAS [3]. An effective Langrangian [4] and an isobar model [5] were recently used to fit the high precision data of CLAS and CBELSA/TAPS. The latter η'-MAID model takes t-channel vector meson exchange in combination with a set of resonances into account [5]. One of the fit solutions considers the four resonances $S_{11}(1904)$, $P_{13}(1926)$, $P_{11}(2083)$ and $D_{13}(2100)$ to play an important role in the photoproduction of η' [5]. The former two resonances are not listed in the Particle Data Tables and could contribute to the missing resonances, if they exist.
In order to ascertain an unambiguous solution for a partial wave analysis, the measurement of at least 8 single and double polarization observables is required [6]. One of the observables describing the helicity asymmetry is E and can be obtained using a circularly polarized photon beam in combination with a longitudinally polarized target. With the photon having a spin of $s = 1$ and the proton of $s = 1/2$, two spin configurations with a total spin of $1/2$ or $3/2$ are possible. The cross sections of both spin configurations for the photoproduction of single pseudoscalar mesons are given by

$$\frac{d\sigma}{d\Omega}^{1/2\,(3/2)} = \frac{d\sigma}{d\Omega}_0 \cdot \left(1 \pm p_T p_\gamma \cdot E\right), \tag{1}$$

where p_γ and p_T denote the photon and target polarization, respectively. $\frac{d\sigma}{d\Omega}_0$ describes the unpolarized cross section.

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2 Experimental setup

The Electron Stretcher Accelerator ELSA provides longitudinally polarized electrons with an energy of 2350 MeV for the CBELSA/TAPS experiment. Impinging on a radiator, the electrons produce bremsstrahl photons. Their energy is determined by a tagging spectrometer. The electron polarization is partially transferred energy dependent to the photon in the bremsstrahlung process. Thus circularly polarized photons are available with a polarization degree of up to 60% which is measured with a Møller polarimeter. The photon beam is subsequently guided towards a frozen-spin butanol (C_4H_9OH) target which provides longitudinally polarized protons with an average polarization degree of 70%. The reaction point is enclosed by the Crystal Barrel calorimeter (see figure 1). It is composed of 1230 CsI(Tl) crystals covering the entire azimuthal angle Φ and a polar angular range from 1° to 156°, together with the Forward (CsI(Tl)) and the MiniTAPS (BaF_2) calorimeters located in forward direction. Thus the setup is well suited for the detection of neutral mesons like π^0 or η' in the final state which decay to photons. The identification of charged particles e.g. protons is possible through the scintillating fibers of the Inner detector and the scintillating plates mounted in front of the Forward and MiniTAPS detectors' crystals.

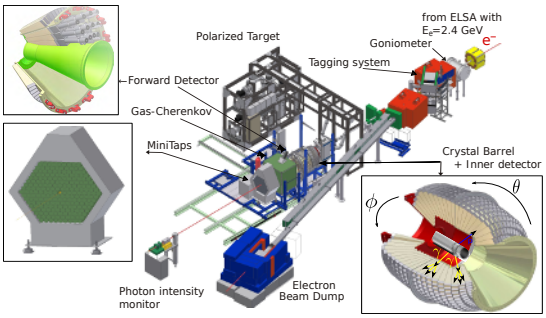

Fig. 1: The CBELSA/TAPS experimental setup.

3 Event Selection

The reaction $\gamma p \rightarrow \eta' p \rightarrow \gamma\gamma p$ (BR: 2.22%) was reconstructed by applying the following cuts: Firstly, two neutral and one charged particles were selected which had to correlate in time with the beam photon. Secondly, the calculated missing mass had to agree with the PDG proton mass within 3σ. Considering momentum conservation, proton and η' had to lie collinear when projected into the xy-plane perpendicular to the beam direction. This resulted in a 3σ-cut on the Φ angle: $162° < \Phi_p - \Phi_{\eta'} < 198°$. Furthermore, the consistency of the measured and calculated θ angle of the proton within 3σ was investigated. Additionally, only beam photons with an energy above the photoproduction threshold of η' (E_{γ_B} =1447 MeV) were considered. Approximately 2300 events were subsequently chosen within the invariant mass cut boundaries (dashed lines in figure 2 a). Taking the countrate difference of both spin 1/2 and 3/2 configurations, all remaining unpolarized background cancels out since only the hydrogen protons of the butanol target were polarized. The countrate difference of the invariant mass (cf. 2 b)) shows no indication of polarized background contributions from ω.

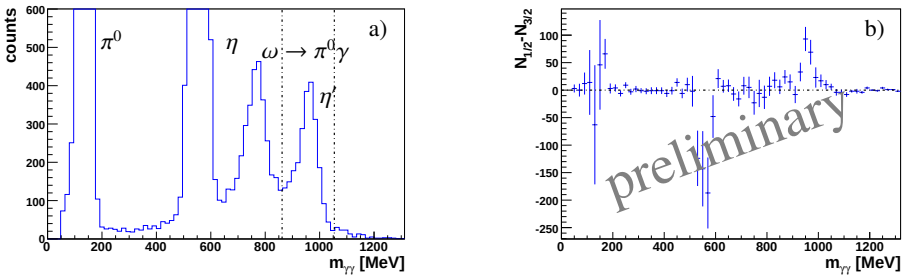

Fig. 2: The invariant mass $m_{\gamma\gamma}$ after all applied cuts a) and the countrate difference of the invariant mass b) for a beam photon energy range of 1447 MeV< E_{γ_B} <2350 MeV.

4 Results for the double polarization observable E

Subtracting the differential cross sections $\frac{d\sigma}{d\Omega}^{1/2}$ and $\frac{d\sigma}{d\Omega}^{3/2}$ (compare equation 1) and dividing by the sum of both terms yields

$$E = \frac{\frac{d\sigma}{d\Omega}^{1/2} - \frac{d\sigma}{d\Omega}^{3/2}}{2\frac{d\sigma}{d\Omega}_0} \cdot \frac{1}{p_T p_\gamma}. \quad (2)$$

The unpolarized differential cross section was obtained by analyzing data measured with a liquid hydrogen target as well. Using this approach one does not have to consider any carbon or oxygen contributions of the butanol target. The results for the observable E as a function of E_{γ_B} and $\cos\theta_{\eta',CMS}$ are shown in figures 3 and 4, respectively. All shown errors are of statistical origin. The data indicates an overall dominance of spin $1/2$ resonances in the photoproduction of η'. The η'-MAID prediction (solid line) agrees well with the data at E_{γ_B} =1681 MeV-1920 MeV and for higher energies. Discrepancies can be noticed in the energy range E_{γ_B} =1921 MeV-2160 MeV in backward direction.

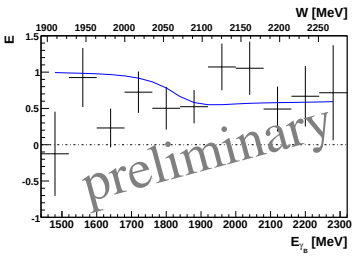

Fig. 3: The observable E in comparison with the η'-MAID prediction (solid line) [5].

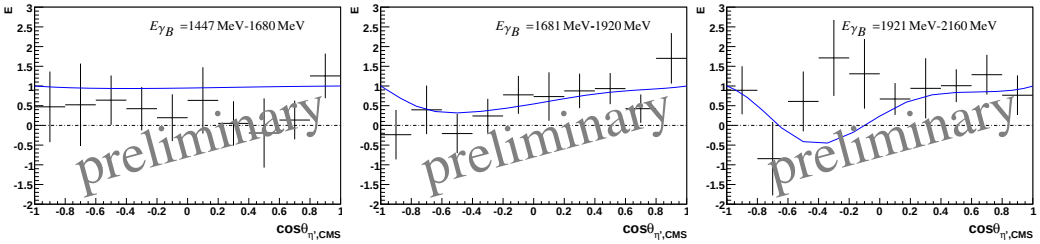

Fig. 4: The observable E as a function of $\cos\theta_{\eta',CMS}$ for three energy bins. The data is compared to the η'-MAID prediction (solid line) [5].

5 Summary

The first double polarization data has been taken with the CBELSA/TAPS experiment for the reaction $\gamma p \to \eta' p$ using circularly polarized photons and a longitudinally polarized target. Preliminary results for the helicity asymmetry E stress the important role of spin $1/2$ resonances in the photoproduction of η'. The observed deviations from the η'-MAID model will provide new constraints for the partial wave analyses.

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