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Beam asymmetry Σ in η' photoproduction off the proton at the GRAAL experiment

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Abstract. The only recent η' photoproduction data off proton available in literature are the differential and total cross sections published by the CLAS and CB-ELSA-TAPS Collaborations. However, the wide information about reaction cross sections are not

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sufficient to understand the role of resonances involved in the process. Different theoretical works stressed the importance to measure also polarization observables in order to solve the ambiguities in the choice of the parameters used in their models. We present the analysis of η' photoproduction off the proton analysis, identifying the investigated meson by the $\pi^+\pi^-\eta$, $\pi^0\pi^0\eta$, and $\gamma\gamma$ decay modes by using the GRAAL apparatus; and we show the preliminary GRAAL results on the beam asymmetry Σ at beam energy of 1475 MeV.

1. Introduction

The investigation of meson photoproduction off nucleon with polarized photons is a powerful tool to identify the contribution of the broad and widely of the overlap baryon resonances, not easily accessible with the differential cross section measurements only. Polarization observables (Σ, T, P) are sensitive, via the interference between complex helicity amplitudes, and consequently allow to reveal small resonance contributions which remain hidden under some dominant contribution in the differential cross section [1–4]. The detailed description of the photon-nucleon interaction requires a complete data set containing, at least, eight independent observables: the cross differential section, the three single polarization observables (beam, target and recoil nucleon) and four, appropriately chosen, double polarization observables [5]. The η' meson photoproduction is a very interesting subject of investigation in baryon spectroscopy because it offers the possibility to extract information on N^* nucleon resonances, in the less explored N^* mass region. Recently, the CLAS experiment at Jlab and the CB-ELSA-TAPS in Bonn have produced a rich amount of cross section data on the proton [6–8] from threshold (1.447 GeV) up to 2.84 GeV. This huge experimental effort established that the η'N channel couples mainly to $S_{11}(1535)$ and $P_{11}(1710)$. A marginal role is played by J=3/2 resonances, namely $P_{13}(1720)$ and $D_{13}(1520)$[6]; $g_{\eta' NN} = 1.3$–1.5, a value consistent with existing theoretical estimates[6]; above 2 GeV, where the process is dominated by ρ and ω exchange, the dynamics of η' photoproduction are similar to those of η photoproduction[8].

Different theoretical approaches developed to describe these data [9, 10], stressed the importance to have also polarization observables like beam asymmetry to solve the ambiguity on the parameters used in their models.

In this work, we present the preliminary beam asymmetry of η' photoproduction off proton just above the threshold at Graal.

2. GRAAL experimental set-up

The GRAAL experiment was located at the ESRF (Grenoble, France) and has been taking data until the end of 2008. The experiment consisted of a polarized photon beam (600-1550 MeV), a unpolarized Hydrogen and Deuterium liquid target and a 4π solid angle detector LAGRANγE (Large Acceptance GRaal-beam Apparatus for Nuclear γ Experiments). The peculiarities of the γ-ray beam of the experiment, produced by the backward Compton scattering of laser photons on the relativistic electrons (6.03 GeV) circulating in the storage ring, are the very high degree polarization and the good energy resolution. The energy resolution of the tagged beam is limited by the optics of the ESRF magnetic lattice and is 16 MeV (FWHM) over the entire spectrum. The energy of the γ-rays is provided by the tagging set-up which is located inside the ESRF shielding, attached to the ESRF vacuum system. The correlation between photon energy and polarization is calculated with QED and it is about 96% in the investigated energy above the η' photoproduction threshold (1.446 GeV).

The Graal apparatus has been described in several papers [11–16]. The LAGRANγE detector can be schematically divided into three polar angle region; forward ($\theta \leq 25^\circ$), central ($25^\circ < \theta \leq 155^\circ$), and backward ($\theta > 155^\circ$). The forward region is covered by two planar multi-wire proportional

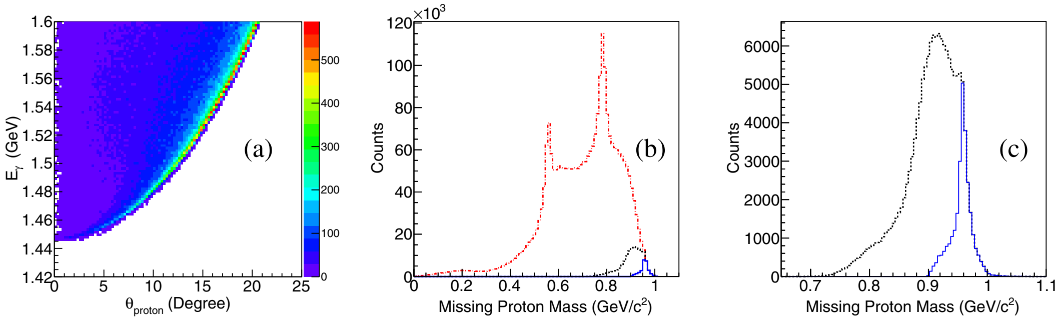

Figure 1. Panel a): energy of the beam versus the proton polar angle distribution for a simulated $\gamma p \rightarrow \eta' p$ reaction. Panels b) and c) experimental proton missing mass with the cuts defined in condition i) (dash-dotted line); i) and ii) (dashel line), and all conditions i)–iii) (solid line).

chambers (MWPC) measuring the charged particle angles ($\delta\theta \sim 1.5°$, $\delta\phi \sim 2°$, FWHM), a double layer scintillator walls (26 vertical × 26 horizontal bars) and a shower wall (16 vertical modules) placed at about 3 and 3.3 meters from the target, respectively. The first scintillator wall is able to measure charged particle position, specific ionization and time of flight, while the other one, made of a sandwich of scintillators and lead, is able to detect and identify charged particles, γ-rays and neutrons measuring their angles, time of flight and energy loss. In the central region, the target is surrounded by two cylindrical-MWPCs measuring with high efficiency charged particle angles ($\delta\theta \sim 3.5°$, $\delta\phi \sim 4°$, FWHM), 32 scintillator bars (barrel) measuring the energy loss and the azimuthal angle of charged particles and 480 BGO crystals (15 crowns of 32 crystals) constituting the electromagnetic calorimeter, which is able to measure angles and energy of photons, protons, electrons, and to detect pions and neutrons measuring their angles only. Backward angles, $\theta > 155°$, are covered by two disks of plastic scintillators separated by 6 mm of lead to detect charged particles and gamma-rays escaping in the backward direction, and used for veto purposes.

At the end of beamline, two flux monitoring detectors are used.

3. Data analysis and results

The analysis of η' photoproduction in the $\gamma\gamma$, $\pi^0\pi^0\eta$ and $\pi^+\pi^-\eta$ decays channels was performed by using the large number of quantities measured with the LAGRANγE detector. We were able to identify protons and charged pions at all angles, photons and neutrons in forward direction $\theta < 25°$; to measure angles and energy of protons, angles and energy of photons in the BGO-calorimeter, angles of charged pions with MWPCs.

The preliminary event selection was defined by the following conditions: i) to detect at least two neutral particles in the BGO calorimeter, in order to be able to reconstruct the invariant mass; ii) the energy of the beam has to overcome the η' photoproduction threshold ($E_\gamma \geq 1.446$ GeV); iii) the events are only detected in the acceptance region defined by the relation between the energy of the beam and the polar angle of proton showed in Fig. 1a.

In Fig. 1b we present the missing mass from the detected proton, in the hypothesis of two particles in the final state reaction, by applying the condition i), (dash-dotted line), the conditions i) and ii) (dashed line), all conditions i-iii) (solid line). Solid line in Fig. 1c clearly shows the presence of the η' mass peak (mass = 0.957 GeV) dominant over a small and flat background.

The residual background was suppressed by additional constraints on the decay products of η' meson, like good η' and η invariant mass reconstruction, presence (or absence) of identified charged pions etc. In particular, we were able to identify the decay channels $\pi^+\pi^-\eta$ (B.R. 42.6%), $\pi^0\pi^0\eta$

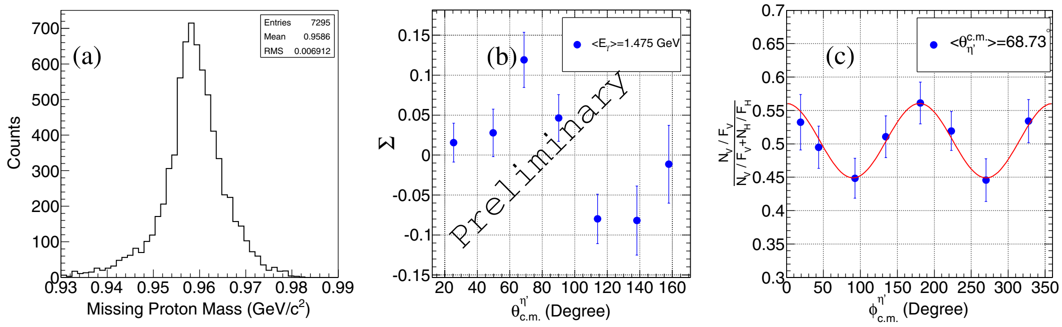

Figure 2. Proton missing mass after all cuts on the final state of η' (panel a). Preliminary η' beam asymmetries off proton at the average energy beam value of 1.475 GeV (panel b). The azimuthal distribution of the ratio in Eq. (1) for $< E_\gamma >=$ 1.475 GeV and $\theta^{\eta'}_{c.m.} = 68.73°$ (panel c).

(B.R. 21.6%) and $\gamma\gamma$ (B.R. 2.18%) . The missing mass of proton after all cuts on the η' decay particles in the final state is presented in Fig. 2a. By simulation we estimate that the residual background for the three considered cases is lower than 4%.

Fig. 2b shows the preliminary beam asymmetry of η' photoproduction off proton. We report in the figure, 7 bins in $\theta^{\eta'}_{c.m.}$ estimated for an average energy beam of about 1475 MeV. The beam asymmetry $\Sigma(E_\gamma,\ \theta^{\eta'}_{c.m.})$ was estimated at fixed intervals of E_γ and $\theta^{\eta'}_{c.m.}$ by fitting the azimuthal distribution of the following ratio:

$$\frac{N_V/F_V}{N_V/F_V + N_H/F_H} = \frac{1}{2}[1 + P(E_\gamma)\Sigma\cos(2\phi)] \qquad (1)$$

where the N_V (N_H) and F_V (F_H) are the number of events and the total flux for vertical (horizontal) beam polarization, while $P(E_\gamma)$ is the polarization degree of the beam calculated by QED. The fit of the ratio distribution in the bin ($\langle E_\gamma\rangle$=1.475 GeV, $\langle\theta^{\eta'}_{c.m.}\rangle$=68.73°) is presented in Fig. 2c. The systematic error due to the efficiency ϵ is canceled in the ratio.

The stability of the present results was verified by different checks (as in Refs. [11, 13, 15]). The trend of the beam asymmetry is in average zero confirming the dominant role of the s-wave function [7, 8], but the presence of values clearly higher (lower) than zero for $\theta^{\eta'}_{c.m.}$ lower (higher) than 90° could be a sign of a possible S_{11}(1535) and P_{11}(1710) interference as suggested in Ref. [6]. The interpretation of results is actually under discussion.

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