MEASUREMENT OF POLARIZATION OBSERVABLES IN NEUTRAL DOUBLE PION PHOTOPRODUCTION OFF THE PROTON WITH THE CBELSA/TAPS EXPERIMENT*

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The Crystal Barrel/TAPS experiment is ideally suited to measure neutral mesons decaying into photons due to its high detection efficiency for photons, good energy resolution, and the nearly complete solid angle coverage. In combination with a longitudinally or transversely polarized target and an energy tagged, linearly or circularly polarized photon beam the experiment allows the measurement of a large set of polarization observables. The presented preliminary results for polarization observables of neutral double pion production obtained with a transversely polarized target show significant deviations from current predictions of partial wave analyses. This clearly indicates that $2\pi^0$ -photoproduction is not yet understood.

Keywords: Polarization observables; double pion photoproduction; CBELSA/TAPS.

1. Introduction

In order to extract the contributing resonances from experimental data a partial wave analysis needs to be performed. To resolve ambiguities, the measurement of polarization observables is indispensable. In the regime of high mass baryon resonances multi-meson final states are of particular importance. Their cross section increases relative to the single meson photoproduction and cascading decays via other baryon (and meson) resonances occur. Neutral double pion production is of great interest due to its quite low contribution from background amplitudes compared to charged multi-pion final states.

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In a quasi two-body approach the differential cross section $\frac{d\sigma}{d\Omega}$ is given according to the single pseudoscalar meson photoproduction cross section:¹

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} \cdot \left[1 - \delta_\ell \Sigma \cos(2\phi) + \Lambda_x \cdot (-\delta_\ell H \sin(2\phi)) + \Lambda_y \cdot (-\delta_\ell P \cos(2\phi) + T) \right] \quad (1)$$

where δ_ℓ is the degree of linear polarization, $\Lambda_x(\Lambda_y)$ the transverse target polarization in (perpendicular to) the reaction plane and Σ, T, P, H the polarization observables.

2. Experimental Setup

In the CBELSA/TAPS setup electrons from the electron stretcher accelerator ELSA² produce linearly polarized photons via coherent bremsstrahlung on a diamond crystal.³ The crystal orientation was chosen such that the coherent edge was positioned at 950 MeV and polarizations up to 65% were reached. The photons then hit the transversely polarized butanol (C₄H₉OH) frozen spin target⁴ which provides an average polarization degree of 75%. The interaction point is surrounded by the Crystal Barrel calorimeter⁵ and the Forward Plug consisting out of 1320 CsI(Tl) crystals. Together with the MiniTAPS detector⁶ (216 BaF₂ crystals) for the very forward directions nearly the complete solid angle is covered. In order to identify the charge of the final state particles there is a scintillating fiber detector⁷ between the target and the Crystal Barrel and plastic scintillator plates mounted in front of the Forward Plug and MiniTAPS crystals.

3. Results

In order to select the reaction $\gamma p \rightarrow p\pi^0\pi^0 \rightarrow p4\gamma$ several cuts were applied. Since a low energetic proton in the final state might not reach the calorimeters only a hit in the charge sensitive detectors is required to measure the proton direction. Additionally there need to be four neutral hits in the calorimeters. The measured direction of the proton and the four photon system in the center of mass system (CMS) needs to be back to back. The final state proton can be treated as a missing particle and a cut on its missing mass is performed. Lastly the invariant mass of each 2γ system is required to be around the pion mass. The background contamination after all cuts is estimated to be about 1.5%.

Since butanol is used as a target material, there are unpolarized protons in the carbon and oxygen nuclei. Reactions on the unpolarized protons reduce the measured asymmetries by the effective dilution factor f . In order to determine this effective dilution factor a measurement using a carbon foam target was performed making use of the same target infrastructure as with the butanol target. It is then

Fig. 1. Effective dilution factor as function of (E_γ, ϑ) .

Fig. 2. φ distribution of the target asymmetry in the quasi 2-body approach for one $(E_\gamma, \cos \vartheta)$ -bin.

Fig. 3. Beam and target polarization observables in the quasi 2-body approach. Black dots: this work, red triangles: GRAAL data,⁸ black curve: $2\pi^0$ -MAID,⁹ red curve: BnGa-PWA.¹⁰ Σ contains contributions from the bound nuclei. For T only every second bin is shown.

possible to subtract the carbon contribution from the butanol and calculate the effective dilution factor. Results are shown in Fig. 1 as function of the $\cos \vartheta$ of the $\pi^0\pi^0$ system in the CMS.

In order to extract the polarization observables differences of the normalized and polarization weighted count rates N_i are taken:

$$\frac{1}{\delta_\ell} \frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} = \Sigma \cos(2(\alpha - \varphi)), \quad \frac{1}{f\Lambda} \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} = T \sin(\beta - \varphi) \quad (2)$$

Here α, β denote the direction of the beam and target polarization, respectively and $N_\perp, N_\parallel$ ($N_\uparrow, N_\downarrow$) the different beam (target) polarization settings. The resulting φ distributions are fitted for each kinematic bin. An example of such a fit for the target asymmetry can be found in Fig. 2. Preliminary results for the extracted beam asymmetry Σ and target asymmetry T plotted versus the $\cos \vartheta$ of the $\pi^0\pi^0$ system in the CMS are shown in Fig. 3. Although the extracted Σ contains a contribution from bound nuclei in the order of 15% (cf. Fig. 1) the results agree quite well with the previous GRAAL data. The target asymmetry T is roughly described at least by the BnGa-PWA solution in the lower energy bins, while at higher energies the theoretical predictions fail to describe the data.

When considering the full 3-body approach additional polarization observables and kinematic variables like ϕ^* (cf. Fig. 4) arise. The differential cross section can

Fig. 4. Definition of the angle ϕ^* .

Fig. 5. φ distribution of the target asymmetry in the 3-body approach for one (E_γ, ϕ^*) -bin.

Fig. 6. Beam and target polarization observables in 3-body kinematics. Solid symbols: derived directly from the data, open symbols: derived from symmetry of the observables. Red curve: BnGa-PWA.¹⁰ I^s, I^c contain contributions from the bound nuclei. For P_x, P_y only every second bin is shown.

be written in the form (only transverse target and linear beam polarization taken into account):¹¹

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} \cdot \left\{ (1 + \Lambda_x P_x + \Lambda_y P_y) + \delta_\ell \cdot \left[\sin(2\phi) \cdot (I^s + \Lambda_x P_x^s + \Lambda_y P_y^s) + \cos(2\phi) \cdot (I^c + \Lambda_x P_x^c + \Lambda_y P_y^c) \right] \right\} \quad (3)$$

There are then two beam (I^s, I^c) and two target asymmetries (P_x, P_y) as well as four double polarization observables ($P_x^s, P_y^s, P_x^c, P_y^c$). The occurrence of a second beam or target asymmetry observable in the cross section leads to a non-vanishing phase shift in the φ distribution relative to the direction of polarization if the data is binned in the angle ϕ^* (Fig. 4), as can clearly be seen in Fig. 5.

While the BnGa-PWA can describe the beam asymmetries fairly well (apart from I^s in the lowest energy bin) it fails to do so for the target asymmetry P_y over the whole range and in the lower energy bins for P_x (cf. Fig. 6).

4. Summary

The CBELSA/TAPS data with transversely polarized target and linearly polarized beam allow to extract beam and target asymmetries in neutral double pion photoproduction. While the beam asymmetry in a quasi 2-body approach agrees well with previous results, current PWA solutions fail to describe the target asymmetry in the 2-body approach as well as in the 3-body approach. This clearly shows that $2\pi^0$ -photoproduction is not yet well understood and that the new data will provide valuable input for the PWA.

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