PHOTOPRODUCTION OF NEUTRAL PION PAIRS OFF THE PROTON WITH THE CRYSTAL BARREL DETECTOR AT ELSA

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The photoproduction of two neutral pions off of the proton was investigated with the Crystal Barrel detector at the ELectron Stretcher Accelerator (ELSA) in Bonn, Germany. Data shows clear resonance structures and hints of cascading decays of baryon resonances with the $\Delta(1232)P_{33}$, $N(1520)D_{13}$ and $X(1660)$ as intermediate states. A partial wave analysis (PWA) was accomplished on the selected events to determine contributing resonances and properties thereof. Additionally results of the PWA were used in a new method of acceptance correction which takes the correct dynamics of the reaction into account. With this method the total and the differential cross sections were calculated for photon energies up to 3 GeV. The total cross section shows two clear peaks at 700 and 1100 MeV. In the differential cross section for $m(p\pi^0)$ contributions of the $\Delta(1232)P_{33}$, $N(1520)D_{13}$ and $X(1660)$ are revealed as well as enhancements from the $f_0(980)$ in the differential cross section for $m(\pi^0\pi^0)$.

1. Introduction

Recent quark model calculations predict many more resonances than have been experimentally discovered so far [1]. The expected small coupling [2] of these missing states to the πN channel is one possible explanation for these 'missing resonances'. Most of the current data stems from πN scattering experiments. Calculations showed that these states have strong couplings to $\Delta\pi$, Nρ and a non-vanishing coupling to γN and hence photoproduction experiments have a good chance to discover these states.

The analysis discussed in this paper is based on the same data set and reconstruction methods as [3] and [4]. Differences appear within the data selection and in the determination of the acceptance.

2. Experiment

Fig. 1 shows the experimental setup at the **EL**ectron **S**tretcher **A**ccelerator (ELSA) in Bonn. The tagging system consisted of 14 scintillators and two multi-wire proportial chambers for improved energy resolution. Data was taken at two different electron energies of 1.4 and 3.2 GeV resulting in photon energies between 300 MeV and 3.0 GeV.

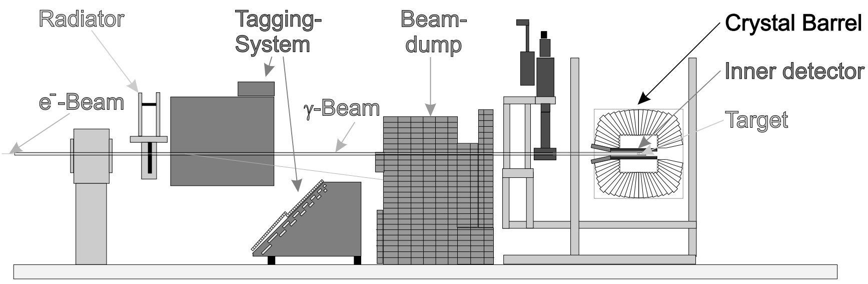

Figure 1. Experimental setup at ELSA in Bonn

The tagged photon beam hit a liquid H_2 target of 5 cm length and 3 cm diameter. A three–layer scintillating fiber (scifi) detector [5] encircling the target identified charged particles in a polar angle range between 15° and 165°. The Crystal Barrel calorimeter [6] surrounding the target was primarily used to detect photons. It was comprised of 1380 CsI(Tl) crystals with photodiode readout covering 98% of 4π.

3. Reconstruction and Selection

Data selection started by selecting only events with 4 and 5 clusters in the Crystal Barrel detector. By comparing the intersection points from the scifi with the clusters in the calorimeter proton candidates were found. The identified proton was handled as a 'missing' particle, and was not used in the further analysis.

The remaining uncharged clusters were considered as photons. Energy and momentum conservation was assured by performing a kinematic fit and applying a cut of 1% on the confidence level (CL) of the 1C hypothesis $p(\gamma, 4\gamma)p_{\mathrm{missing}}$. Fig. 2 shows the reconstructed $\gamma\gamma$ versus $\gamma\gamma$ invariant mass of these events.

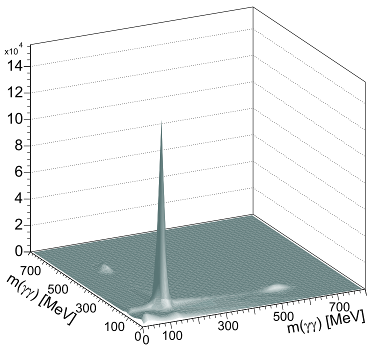

Figure 2. $\gamma\gamma$ – $\gamma\gamma$ invariant mass spectrum.

A dominant $\pi^0\pi^0$ peak and two small bumps due to $\pi^0\eta$ events can be seen with almost no background visible. Neutral pions were identified by a cut on the invariant mass of two γ in an interval of $m(\pi^0) \pm 2\sigma$. The standard deviation $\sigma = 8\,\mathrm{MeV}$ was determined as the width of the invariant $\gamma\gamma$ mass peak for events fullfilling energy and momentum conservation. The final data set was obtained by a cut on the CL of the 3C hypothesis $\gamma\mathrm{p} \to \mathrm{p}\pi^0\pi^0$ greater than 10%. For better suppression of background due to misidentified $\pi^0\eta$ events the condition $\mathrm{CL}(\gamma\mathrm{p} \to \mathrm{p}\pi^0\pi^0) > \mathrm{CL}(\gamma\mathrm{p} \to \mathrm{p}\pi^0\eta)$ had to be fullfilled. The background was determined to be less than 1% for the 1.4 GeV dataset and less than 2% for the 3.2 GeV dataset.

4. Acceptance

A reaction with three particles in the final state (e.g. $\gamma\mathrm{p} \to \mathrm{p}\pi^0\pi^0$) depends on five independent variables. Calculating the acceptance of such a reaction in only one dimension implies an integration over the other four variables. If the acceptance in at least one of these four variables changes strongly the calculation for a one dimensional acceptance will lead to incorrect results if the dynamics of the process is not properly included in the MC simulation. This would e.g. be the case if phase space MC is used for acceptance correction.

The solution for this problem is to calculate the acceptance not based on phasespace (PS) distributed Monte Carlo (MC) events but rather on a modified set of MC events. This set was created by using a Partial Wave Analysis (PWA) to calculate a weight factor for each of the PS generated MC events. After normalizing these weight factors to the maximum value a new MC set was created by comparing the normalized weight factor with a generated random number. An event was copied to the new set if its weight factor was greater than the generated random number.

The acceptance correction used for all results in this paper are based on this newly created set of Monte Carlo events. This set now includes the correct dynamics of the process to the extent the PWA describes the process correctly.

5. Results

The absolute normalization of the cross section was derived in two different ways. In the low energy range up to 1.3 GeV the angular distributions [3] for $\gamma p \rightarrow p\pi^0$ were compared to theoretical predictions from SAID[a] resulting in the normalization. To the 3.2 GeV dataset an absolute normalization with a scaling factor was applied. The error was determined to be 5% for photon energies below 1.3 GeV and 15 % above 1.3 GeV.

Data, acceptance and flux normalization were determined for each wire of the proportional wire chamber as the smallest experimentally given energy unit resulting in a cross section for each wire. For data presentation, wires were combined and a weighted average cross section for these energy intervals was calculated. The error of the average was calculated by error propagation.

5.1. *Total cross section*

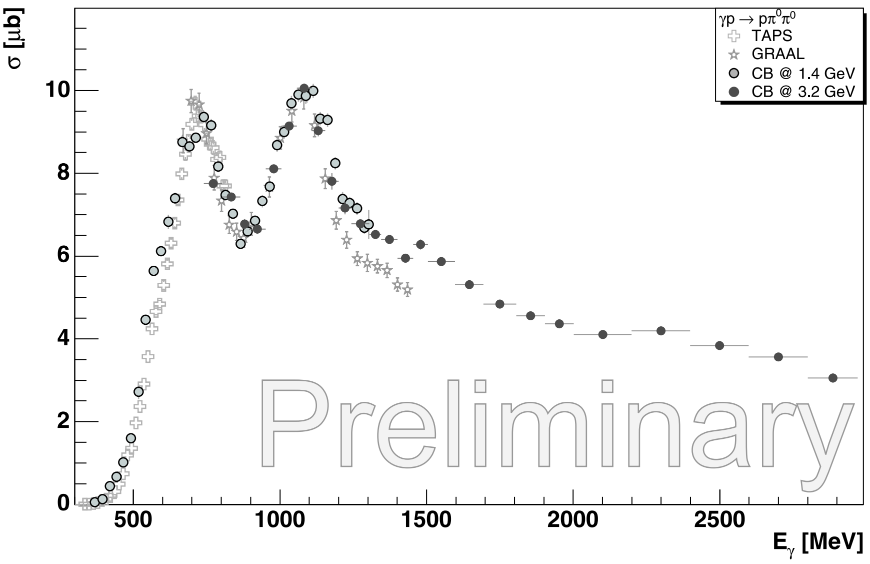

Figure 3. Total cross section with statistical errors only; systematic errors: flux: 5% for $E_\gamma < 1.3$ GeV and 15% otherwise, acceptance: 6%, reconstruction: 5%

Fig. 3 shows the total cross section of the reaction $\gamma p \rightarrow p\pi^0\pi^0$ for

[a]Virginia Tech Partial-Wave Facility

the two analyzed energies in comparison to published data [7,8,9]. Our data confirms the cross section in the energy range between 700 and 1200 MeV and extends the measured energy range up to 3.0 GeV. Deviations are visible between 500 and 700 MeV and at energies above 1200 MeV.

5.2. *Differential cross section*

The differential cross sections $\mathrm{d}\sigma/\mathrm{d}m(\mathrm{p}\pi^0)$ (Figs. 4a–4d) and $\mathrm{d}\sigma/\mathrm{d}m(\pi^0\pi^0)$ (Figs. 4e–4h) were calculated the same way as the total cross section.

In the energy range between 1350 and 1570 MeV in $\sqrt{s}$ (Fig. 4a) the reaction is dominated by $\gamma\mathrm{p} \to X \to \Delta(1232)\pi^0$. With increasing energy a shoulder builds up in Fig. 4b and can be identified as $\mathrm{N}(1520)\mathrm{D}_{13}$ in Fig. 4c. With even higher energies in Fig. 4d an indication for an additional resonance at 1660 MeV is seen.

The differential cross section $\mathrm{d}\sigma/\mathrm{d}m(\pi^0\pi^0)$ does not show clear structures in the lower energy intervals (Figs. 4e–4g). A peak only appears in the highest energy interval (Fig. 4h) and it can be identified with the production of $\mathrm{f}_0(980)$ mesons.

Acknowledgments

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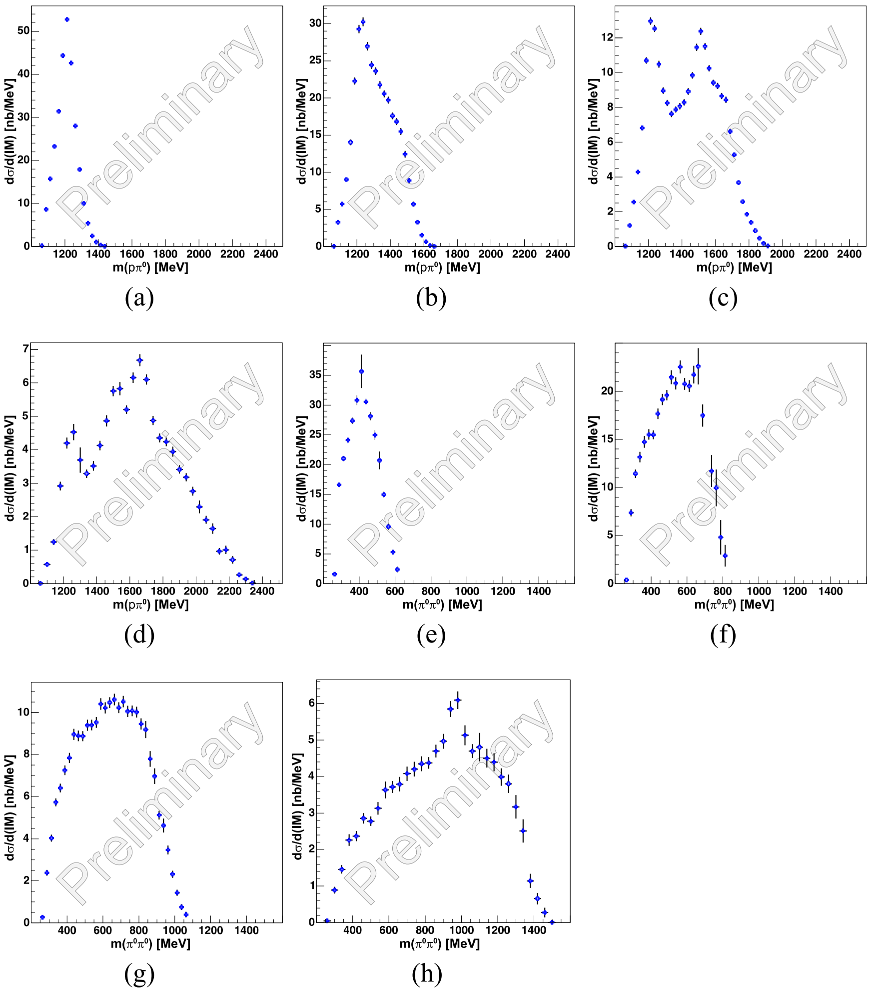

Figure 4. Differential cross section $\mathrm{d}\sigma/\mathrm{d}m(\mathrm{p}\pi^0)$ (a–d) and $\mathrm{d}\sigma/\mathrm{d}m(\pi^0\pi^0)$ (e–h) with statistical errors only; systematic errors: flux: 5% for $E_\gamma < 1.3\,\mathrm{GeV}$ and 15% otherwise, acceptance: 6%, reconstruction: 5%. The following energy intervals were used (a),(e) : $1350\,\mathrm{MeV} < \sqrt{s} < 1570\,\mathrm{MeV}$, (b),(f) : $1570\,\mathrm{MeV} < \sqrt{s} < 1800\,\mathrm{MeV}$ (c),(g) : $1800\,\mathrm{MeV} < \sqrt{s} < 2060\,\mathrm{MeV}$ and (d),(h) : $2060\,\mathrm{MeV} < \sqrt{s} < 2550\,\mathrm{MeV}$