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Eta Photoproduction on the Proton

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Abstract. Eta photoproduction experiments have proven a useful tool in the search for narrow nucleon resonances. In recent years, there has been much interest in the possible existence of the N*(1685) narrow nucleon resonance. Several experiments have been performed that rely on extracting neutron observables from deuteron target data. These have shown some evidence of narrow structure, however, no structure was observed on the proton channel. Within the A2 collaboration at Mainz, a more detailed study has been undertaken using eta photoproduction on an LH$_2$ target ($\gamma p \rightarrow \eta p$); it has high resolution and high precision, in an attempt to overcome the predicted low photocoupling between the N*(1685) and the proton. This paper provides an overview of the experiment and detector systems, and shows the current state of the data analysis. The $\gamma p \rightarrow \eta p$ total cross section is presented for the 2γ η-decay channel. This shows no evidence of the N*(1685) in η photoproduction on the proton.

1. Introduction

It is not possible to solve QCD analytically. However, in the high energy regime, where the strength of the strong coupling constant is relatively small, there has been significant progress in finding solutions using perturbation theory. In contrast, the coupling is large in the low energy regime in which the nucleon ground state and nucleon resonances lie, thus making perturbation theory inapplicable. The development of phenomenological QCD inspired quark models has addressed this gap in describing nucleon behaviour.

A key factor in the advancement of these models is the experimental study of nucleon resonances via the measurement of their properties, such as mass, width, transition modes and multipoles. One experimental program to access this information involves the photoproduction of mesons from a nucleon target via the intermediate excitation of one or more nucleon resonances.

The focus of the current work is on η photoproduction using a proton (LH$_2$) target, given by the reaction: $\gamma p \rightarrow \eta p$. Due to its short lifetime, the η meson can not be detected directly and is reconstructed from its decay products. The two main decay modes are two photon (2γ) and three neutral pion ($3\pi^0$) decay, with respective branching ratios of 39.3% and 32.5%.

Eta photoproduction experiments have proven a useful tool in the search for narrow nucleon resonances. In particular there has been much interest in recent years in the search for the N*(1685) narrow resonance. In 2007, the GRAAL collaboration observed narrow structure in the quasi-free neutron cross section ($d\sigma/dW$), and the ηn invariant mass (figure 1) [1]. Subsequently the CBELSA/TAPS collaboration reported narrow structure in the neutron cross section at approximately W = 1.68 GeV (Figure 1) [2]. Both studies used a deuteron target, with neither
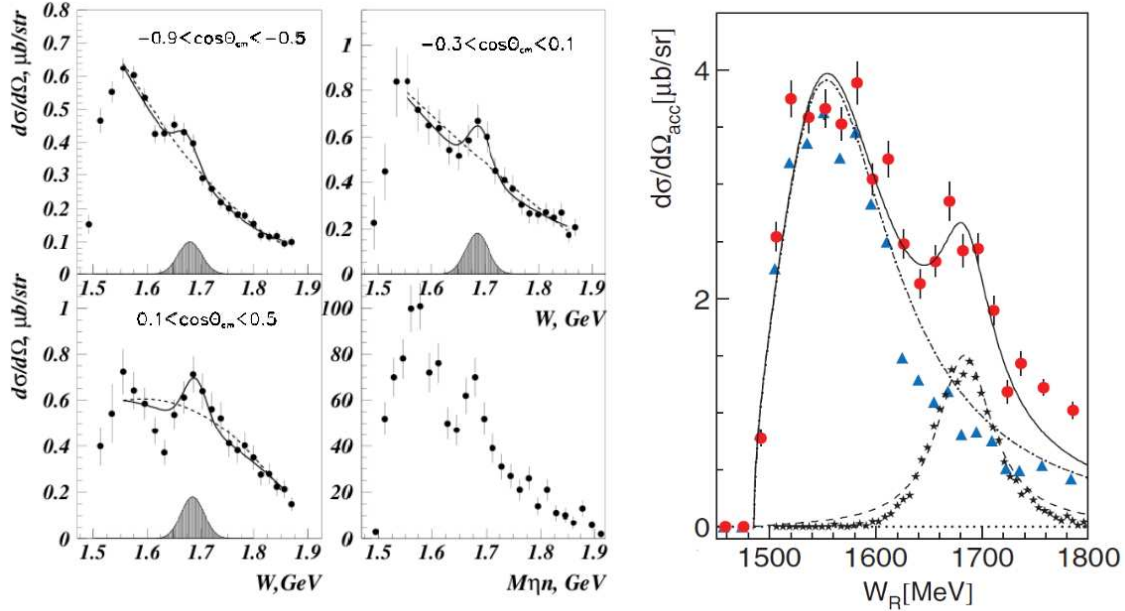
Figure 1. Left: Differential $\gamma n \to \eta n$ cross section measurements at GRAAL [1]. The solid line is a fit to a narrow resonance on a 3rd order polynomial background. The dashed line is a fit without any narrow resonance. The shaded peak is a simulation of the narrow resonance. Right: Excitation function as a function of invariant mass from measurements at CBELSA/TAPS [2]. The circles are neutron-η data and the triangles are proton-η data.

finding any evidence for narrow structure in the corresponding proton channel. It is possible that this is due to the predicted weaker photo-coupling between the N*(1685) and the proton, as compared to the neutron case. The quark model that predicts the N*(1685) states that excitation of the resonance on the proton would require explicit SU(3) symmetry breaking, with a strength that depends linearly on the strange current quark mass [3]. Thus, in order to make a meaningful conclusion on the existence of this narrow resonance on the proton, a high precision, high resolution cross section measurement is needed. The Glasgow-Mainz tagged photon facility, CB detector and data acquisition systems available at the A2 collaboration at MAMI offer the potential for such a measurement.

2. Experiment

The experiment took place within the A2 hall at the Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Germany. The electron beam was provided by the MAMI (MAinzer MIcrotron) accelerator [4]. Using three traditional race track microtrons and a harmonic double sided microtron [5] electrons are accelerated up to an energy of 1557 MeV.

In order to produce the photon beam a 10μm Cu radiator was positioned in the beamline. As the electrons interact in the radiator bremsstrahlung photons are produced, and collimated as they travel downstream to the LH$_2$ target. Energy and timing information of the photons is determined by the Glasgow-Mainz tagged photon spectrometer [6, 7, 8]. The scattered electrons pass through a dipole magnet and are registered in the focal plane detector. The position of impact determines the energy of the electron and thus the energy of the corresponding photon. The focal plane detector consists of 353 overlapping plastic scintillators, the energy width of each channel ranges from 2 MeV at the maximum photon energy of 1447 MeV through to 4

MeV at the ηp threshold of 707 MeV. For the current experiment a microscope detector [9] was also included in the experimental setup. Positioned in front of the main detector, with its mid point at W = 1685 MeV, the microscope increased the photon energy resolution over a 100 MeV energy range by approximately a factor of 5.
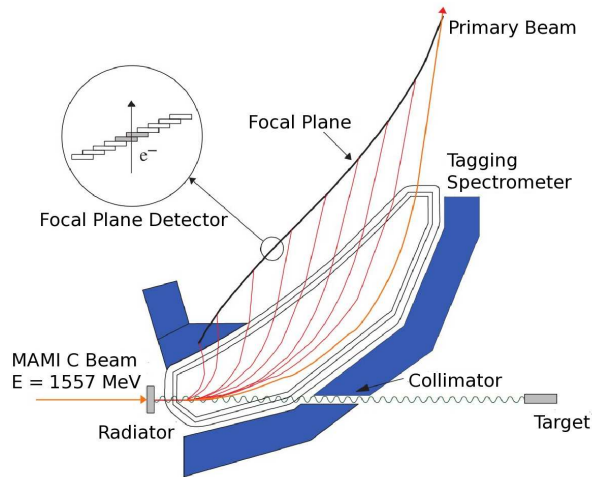
**Figure 2.** Diagram of the Glasgow-Mainz tagged photon spectrometer.
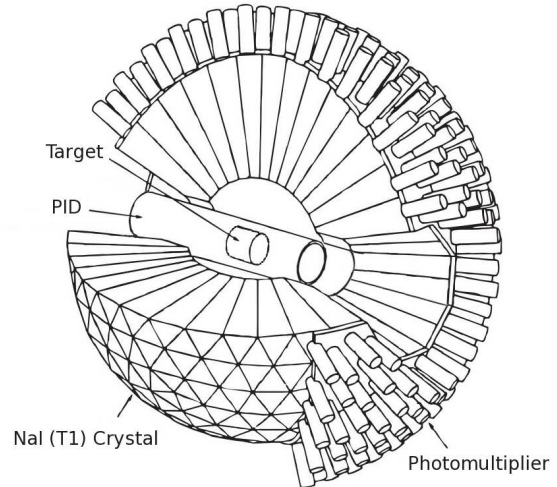
Figure 3. Diagram showing the liquid hydrogen target, Crystal Ball (CB) and particle identification (PID) detector.

Surrounding the LH_2 target are the Crystal Ball (CB) [10] and particle identification detector (PID). The CB is a highly segmented photon calorimeter, consisting of 672 NaI crystals arranged into two hemispheres covering approximately 94% of 4π steradians. The PID is a barrel of 24 plastic scintillators that sits around the target within the CB cavity (figure 3). Energy and angular correlations between the CB and PID allow charged particles to be detected.
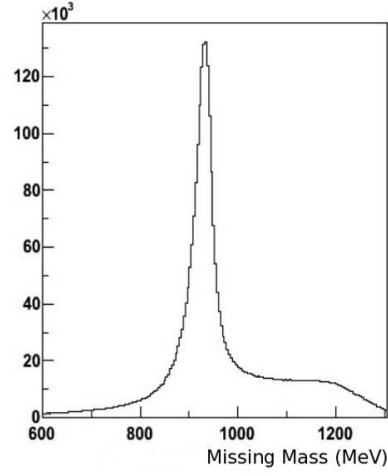
3. Cross Section Extraction

The invariant masses of all 2γ events within the CB were determined (figure 4) and a 3σ cut either side of the η mass was applied. The missing mass of the system was then reconstructed showing a clear proton peak (figure 5).

The missing mass was binned in both E_γ and $Cos(\theta_{CM})$. The η yield was determined by the counts within the proton peak after the random tagger-CB coincidences and the background from other physical processes had been subtracted. A Monte Carlo event generator was used to create pseudo-ηp events which were then passed through a Geant 4 simulation of the detector setup. The simulated data were analysed using the same method as the production data in order to determine the detector acceptance for each E_γ,$Cos(\theta_{CM})$ bin.
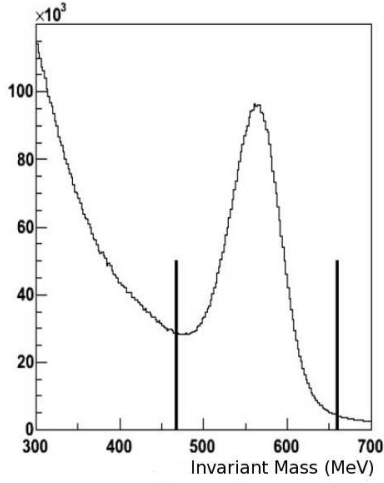
Figure 4. Invariant mass for all 2γ events.

Figure 5. Total missing mass before random coincidence subtraction.

4. Results

Figure 6 shows the total $\gamma p \to \eta p$ cross section using the 2γ η-decay branch. The $S_{11}(1535)$ resonance is clearly seen at 0.8 GeV, but with a lower than expected strength of 11 μb rather than 16 μb. This is attributed to a known outstanding normalisation issue. There is currently no evidence of any narrow structure which could be interpreted as a narrow resonance in the E_γ = 1045 MeV (W = 1685 MeV) region.
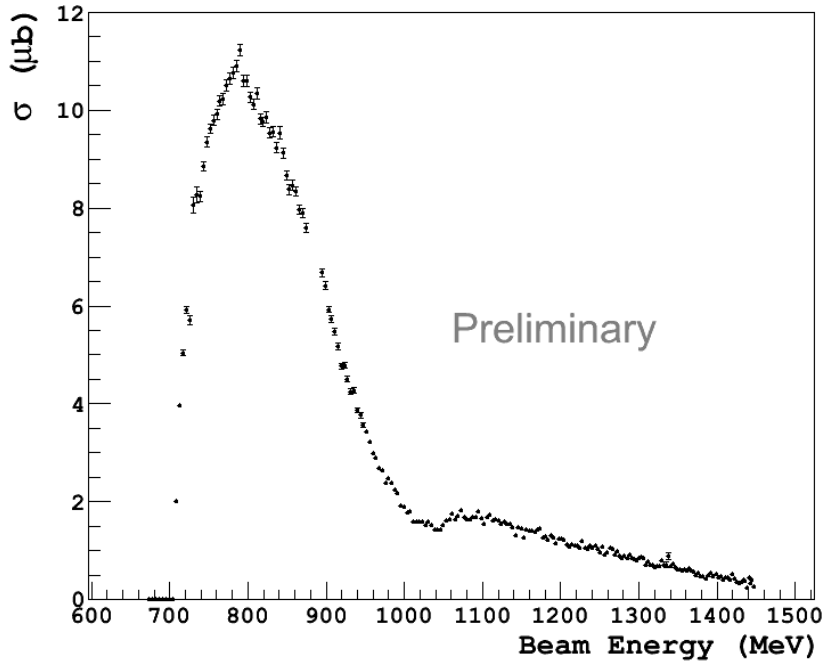
Figure 6. Preliminary total $\gamma p \to p\eta$ cross section, obtained from $\eta \to 2\gamma$ decay branch, for E_γ = 700-1400 MeV.

Figure 7 shows the cross section using the high resolution microscope. Again, there is no sign of any narrow structure in the $E_\gamma = 1045$ MeV region. The outlying microscope points in the $E_\gamma = 1070$ - 1085 MeV region are attributed to inefficient channels, these will be corrected in the final analysis.

Future plans include a more detailed analysis using a kinematic fitting technique in order to refine the event selection and a study of the Legendre polynomial fits to the differential cross sections.
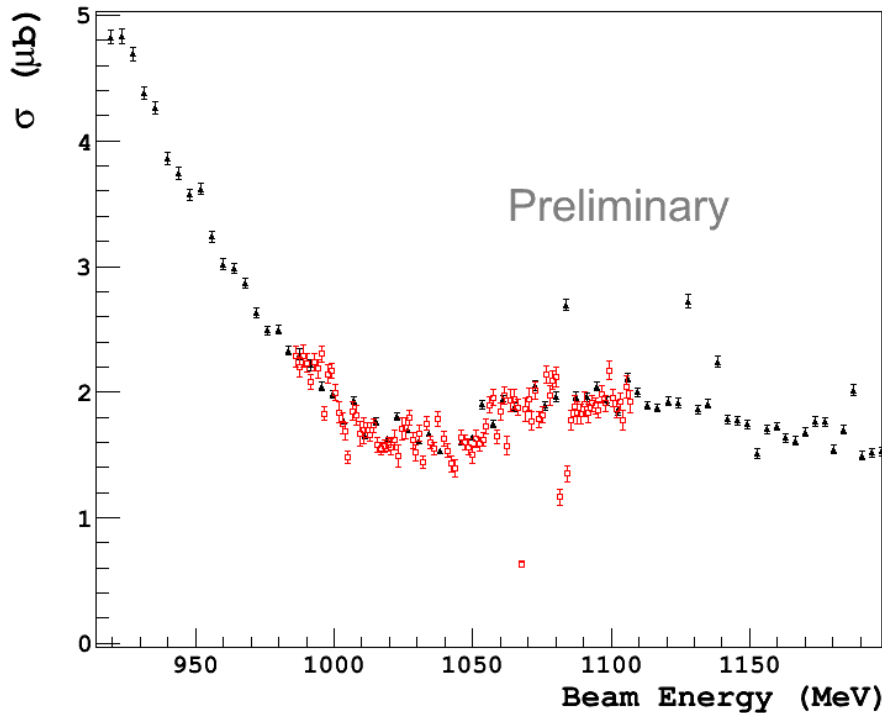
Figure 7. Preliminary total $\gamma p \to p\eta$ cross section for $E_\gamma = 920$-1180 MeV using both the focal plane detector (solid triangles) and high resolution microscope (hollow squares).

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