Single π^0 and η Photoproduction off the Proton at CB–ELSA

Olivia Bartholomy for the CB–ELSA Collaboration

Helmholtz–Institut für Strahlen– und Kernphysik,
University of Bonn, Germany

Abstract. Photoproduction of mesons provides an opportunity to access the properties of nucleon resonances. The study is complementary to πN scattering from which most known properties of resonances have been extracted. Many resonances predicted by quark model calculations have not been observed experimentally or are only weakly established. Photoproduction of mesons offers an additional tool to study the baryon spectrum, to gain information about masses, couplings, and decay widths of the contributing resonances.

In 2001, during its first period of taking data at the electron accelerator ELSA in Bonn, the CB–ELSA experiment gathered a large amount of high–quality data on meson photoproduction off the proton. The detector system is ideally suited for measuring photoproduction reactions with neutral mesons in the final state over the full angular range and at high energies. Differential cross sections of $\gamma\text{p} \to \text{p}\pi^0$ and $\gamma\text{p} \to \text{p}\eta$ have been extracted for incident photon energies up to $E_\gamma = 3$ GeV. At low energies, results of the TAPS, GRAAL, and CLAS experiments are well reproduced. New data points were added for forward angles of the meson and at energies above 2 GeV.

INTRODUCTION

When comparing theoretical predictions [1] with experimental findings [2], very good agreement is found at low masses, while experimental evidence for theoretically predicted states becomes sparse with growing M; more and more gaps appear on the experimental side. In order to account for these gaps, the so called *missing resonances*, several theoretical explanations have been suggested, e. g.

- Baryons are not formed by three individually interacting quarks, but have a quark–diquark structure [3]. The consequence would be one frozen degree of freedom inside the baryon resulting in less accessible states.
- The *missing resonances* might simply not couple to the so far mainly investigated channel πN, which has been studied in scattering experiments. Models predict that the missing states have a sufficiently strong coupling to photons and multi–particle final states, which makes photoproduction of multi–meson final states off the proton an ideal tool to study nucleon resonances [4, 5].

The goal of the CB–ELSA experiment is to contribute with its high–statistics and high–quality data to a clarification of the baryon spectrum and to help describe the internal structure of the nucleon.

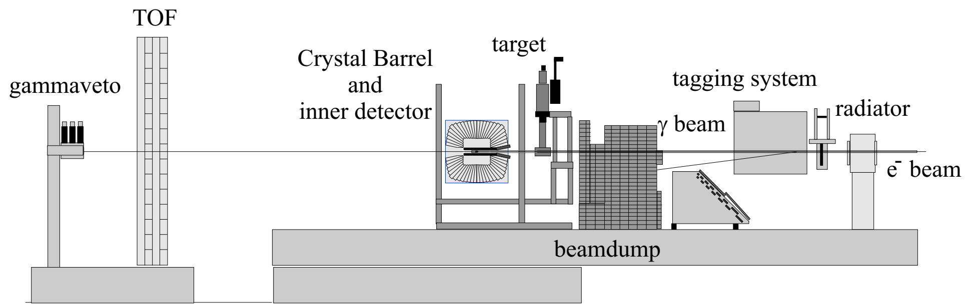

FIGURE 1. Experimental setup: Initial configuration of the CB–ELSA experiment

EXPERIMENTAL SETUP

The data presented here was taken in 2001 with the initial setup of the CB–ELSA experiment as shown in Fig. 1 at the electron accelerator facility ELSA in Bonn. The electron beam comes in from the right side and hits a radiator target where photons are produced via bremsstrahlung. In good approximation, the photon spectrum is proportional to $1/E_\gamma$. An energy is assigned to the photons by detecting the scattered electrons in a spatially and time resolving tagging detector. The trajectory of the electrons is bent in the field of a dipole magnet, so that a coordinate in the detector corresponds to an electron energy, and thus to the energy of the photon. The photons then are guided to a liquid hydrogen target. If no reaction takes place, the photons are detected by the γ–veto detector. If a proton is hit, the final state particles stemming from the reaction are detected in the main detector sytem. The heart of the CB–ELSA experiment, the Crystal Barrel detector, is a high–granularity calorimeter made of 1380 CsI crystals covering 98% of 4π. It is ideally suited for the detection of photons, and hence the investigation of neutral mesons in the final state which decay into photons. Charged particles are also detected in the calorimeter; they cannot be distinguished from photons by the Crystal Barrel alone, though. In order to identify them as charged particles, an inner detector consisting of three layers of scintillating fibres is used, which helps to determine the direction of charged particles.

DATA AND SELECTION

Data used for the analysis presented here was taken at incident electron energies of 1.4 and 3.2 GeV, resulting in photon energies from 0.3 to 3.0 GeV. A hit in the inner detector and the correct photon multiplicity in the Crystal Barrel were required, for the analyses of $\gamma p \to p\pi^0$ and $\gamma p \to p\eta$ two or six photons, respectively.

The event structure returned by tracking routines served as input for a kinematic fit with known four–vectors for the incident photon and final–state photons, but leaving the detected proton free of constraints (missing particle). Additional mass constraints were imposed by using the masses of mesons (the π^0 mass for $\gamma p \to p\pi^0$, the η mass for $\gamma p \to p\eta_{2\gamma}$, three π^0 masses for $\gamma p \to p\eta_{3\pi^0}$).

Background subtraction was applied by sidebin subtraction only for the η channel. The background underneath the π^0 signal was not explicitly treated, because it was

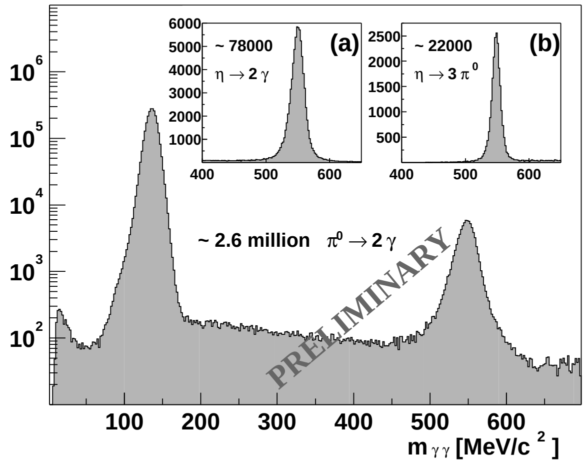

FIGURE 2. Invariant mass of two photons, (a) $\eta \to 2\gamma$, (b) $\eta \to 3\pi^0$

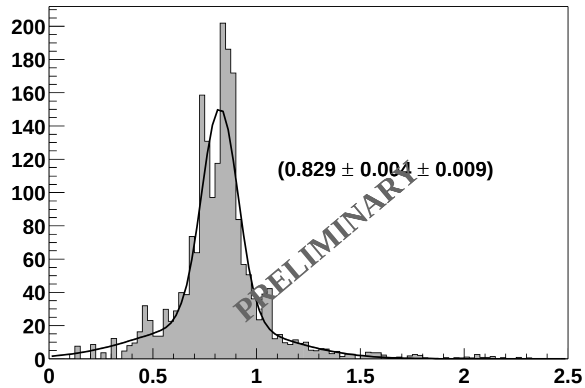

FIGURE 3. Branching ratio $\frac{\Gamma(\eta\to3\pi^0)}{\Gamma(\eta\to2\gamma)}$ as measured, PDG–Average: (0.832±0.011)

of the order of only 10^{-3} compared to the signal. The mass spectra are shown in Fig. 2. A complete analysis of systematic errors was performed for both π^0 and η photoproduction.

In order to account for the acceptance of the detector system and reconstruction routines, a full GEANT–based Monte Carlo Simulation was carried out. The very good understanding of the CB–ELSA detection efficiency can be seen in the excellent agreement of the measured angular distributions with previously published data (Figs. 4 and 5) and the good match between the PDG value [2] for the branching ratio the two different analysed decay modes of the η meson into $3\pi^0$, a six photon final state, and into 2γ, as shown in Fig. 3.

The photon flux was determined by a χ^2 fit of the π^0 data to the SAID [6] prediction for energies up to 1.3 GeV. The cross sections for energies above 1.3 GeV were normalized to the measured photon flux, scaled by 0.75 to account for experimental deficiencies in the flux determination. The error of the normalization has been estimated to be in the order of 5% up to 1.3 GeV and 15% above.

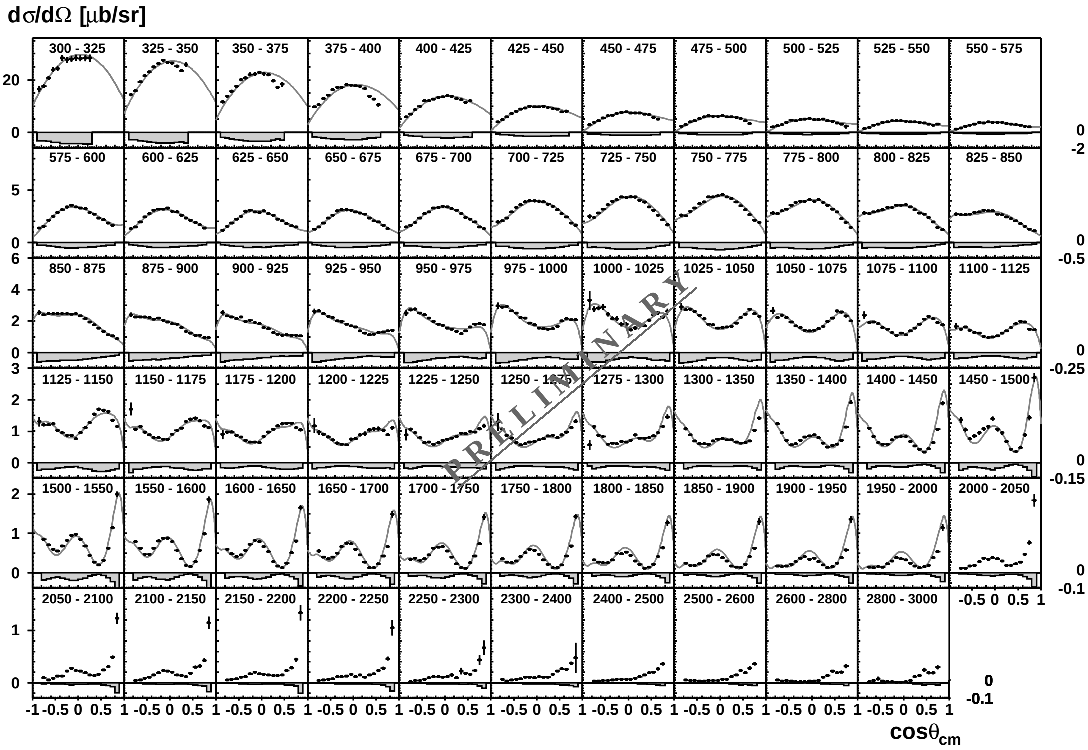

FIGURE 4. Differential cross sections of $\gamma p \rightarrow p\pi^0$ for photon energies between 0.3 and 3.0 GeV. ■: CB–ELSA, —: SAID, ■: systematic errors

PRELIMINARY RESULTS ON π^0 AND η PHOTOPRODUCTION

The preliminary results of CB–ELSA on the differential cross sections for neutral pion photoproduction as shown in Fig. 4 show a good agreement with the SAID model that had been fitted to previously measured data. Even the complicated structures indicating contributions from several nucleon and Δ resonances are well reproduced. Towards high photon energies, resonance contributions start to vanish around 2.2 GeV, a strong peak to forward angles of the meson develops, suggesting the production of pions via t–channel exchange.

The preliminary results of measured angular distributions for the η meson are shown in Fig. 5. Due to its isospin $I = 0$, only nucleon resonances can be excited in the intermediate state. The cross sections show fewer structures as in the π^0 case. Data is in good agreement with measurements from TAPS [8], GRAAL [9], and CLAS [10], and the SAID and MAID models [6, 7] below about 1.4 GeV. Close to threshold, the dominance of the $S_{11}(1535)$ is clearly seen as an isotropic distribution, while going to higher energies, an interference term of this resonance with a P wave appears, resulting in a distribution proportional to $\cos\theta_{cms}$, which changes sign around 1 GeV photon energy. At photon energies around 1.9 GeV the contribution of s–channel resonances disappears, a strong forward peaking (t–channel exchange) is observed. The rise of the cross sections at backward meson angles might indicate contributions in the u–channel.

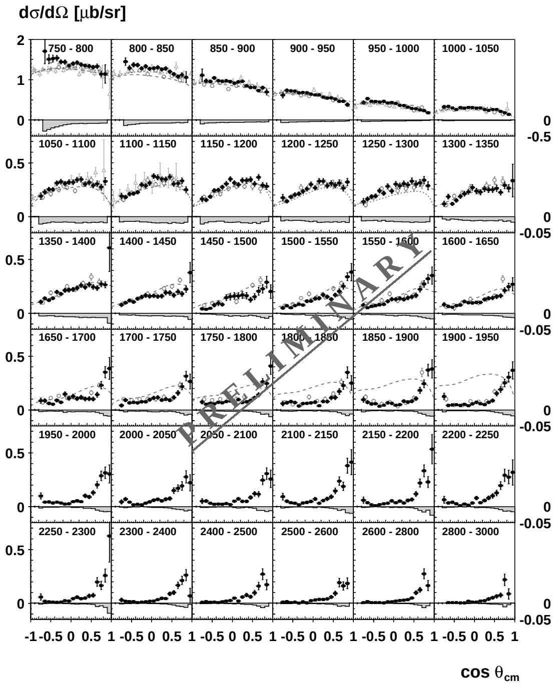

FIGURE 5. Differential cross sections of $\gamma p \rightarrow p\eta$ for photon energies between 0.75 and 3.0 GeV. ■: CB–ELSA, ○: CLAS, △: GRAAL, ⋆: TAPS, - - -: SAID, ···: MAID, ■: systematic errors

SUMMARY AND CONCLUSION

The first experimental phase of the CB–ELSA experiment yielded high–statistics and high–quality data on photoproduction of neutral mesons. Angular distributions of $\gamma p \rightarrow p\pi^0$ and $\gamma p \rightarrow p\eta$ were derived for photon energies up to 3.0 GeV covering almost the full angular range. The preliminary results of the CB–ELSA experiment are compatible with previously published experimental findings. New data points are added at high energies and forward angles. An isobar model analysis is currently being performed, the results of which will contribute to a more detailed comprehension of resonance properties. Statistics is even improved for data taken more recently with the TAPS detector as a fast trigger covering the forward direction with high granularity.

REFERENCES

1. U. Löhring, K. Kretzschmar, B.Ch. Metsch and H.R. Petry: EPJ **A 10** (2001) 309
2. The Particle Data Group: Phys. Rev. **D 66** (2002) 1
3. D.B. Lichtenberg: Phys. Rev. **178** (1969) 2197
4. R. Koniuk and N. Isgur: Phys. Rev. **D 21** (1980) 1868
5. S. Capstick, W. Roberts: Phys. Rev. **D 49** (1994) 4570
6. http://gwdac.phys.gwu.edu/
7. http://www.kph.uni-mainz.de/maid/
8. B. Krusche et al.: Phys. Rev. Lett. **74** (1995) 3736
9. F. Renard et al.: Phys. Lett. **B 528** (2002) 215, J. Ajaka et al.: Phys. Rev. Lett. **81** (1998) 1797
10. M. Dugger et al.: Phys. Rev. Lett. **89** 2002 222002