Investigation of $\gamma \mathrm{p} \rightarrow \mathrm{p}\pi^0\eta$ at ELSA in Bonn

Volker Credé for the CB-ELSA and CB/TAPS collaboration

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

Abstract. The Crystal-Barrel detector is the ideal instrument to study various multi-photon final states over the full dynamical range due to its almost 4π coverage of the solid angle and its high energy resolution. It allows to identify highly-excited baryon states by observing cascades of high-mass states to the ground state via the emission of pion and eta mesons. This could be observed in the 2000/2001 CB-ELSA data for the reaction $\gamma \mathrm{p} \rightarrow \mathrm{p}\pi^0\eta$. Moreover, the investigation of $\gamma \mathrm{p} \rightarrow \Delta(1232)\eta$ ($I = \frac{3}{2}$) allows to search for *missing* Δ states and will shed some light on the rather unknown Δ spectrum. Preliminary results of a partial wave analysis indicate the need for new resonances to describe the data. However, it could be shown that linearly polarised photons are very important in order to avoid ambiguities in determining the corresponding quantum numbers. In 2002/2003, polarised data have been taken off the proton as well as off the neutron with the Crystal-Barrel detector and TAPS in the forward direction. The latter has fast trigger capabilities and provides high granularity in the forward direction.

INTRODUCTION

Photon-induced reactions on the nucleon are a rich source of information for the baryon resonance spectrum. The full knowledge of possible baryon excitations and their properties would allow the extraction of the relevant degrees of freedom. Spectroscopic predictions are not possible in the non-perturbative regime of QCD. For this reason, effective theories and models are necessary in order to determine the masses, couplings and decay widths of resonances. Various constituent quark models are quite successful in describing the spectra. However, many open questions still remain. All models predict a series of hitherto unobserved states, for instance. The persistent non-observation would be a big problem as those models would have failed to describe physical reality. On the other hand, almost all existing data result from πN elastic scattering experiments and models focussing on baryon strong decays predict baryon states to be missing in πN analyses but to show up in electromagnetic production [3]. Thus, photoproduction experiments offer a large discovery potential.

The decay chain $\gamma \mathrm{p} \rightarrow \Delta^* \rightarrow (\Delta\eta)(\mathrm{I} = \frac{3}{2}) \rightarrow \mathrm{p}\pi^0\eta$ is a suitable reaction to study Δ states and to search for *missing* Δ^*. Additionally the region of Δ resonances with masses around 1950 MeV is of special interest in baryon spectroscopy. The PDG lists four well established states with positive parity in this mass region. In comparison, only three Δ^* with negative parity and poor experimental evidence are listed: $\Delta(1900)\mathrm{S}_{31}$ (**), $\Delta(1940)\mathrm{D}_{33}$ (*) and $\Delta(1930)\mathrm{D}_{35}$ (***). A confirmation of those states with negative parity would be in contradiction with constituent quark models predicting the three states at masses clearly above 2 GeV [1, 4].

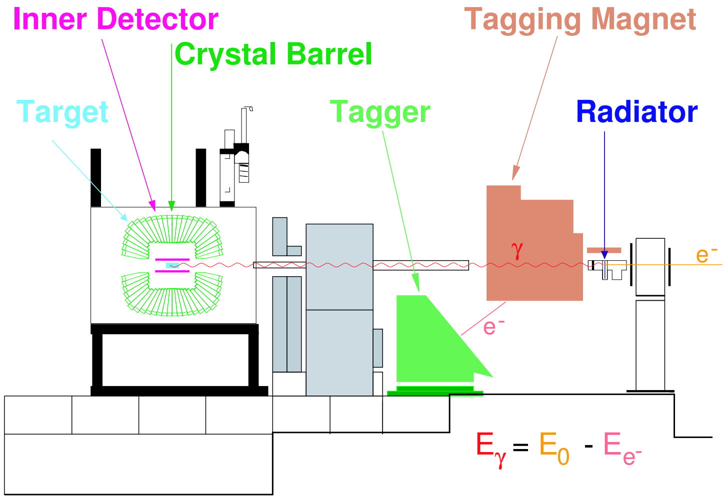

FIGURE 1. Setup of the CB-ELSA detector for a first series of measurements

THE CRYSTAL-BARREL EXPERIMENT AT ELSA

For the data presented here, electrons extracted from ELSA hit a primary radiation target with energy E_0 and produced bremsstrahlung. The corresponding energy of the photons ($E_\gamma = E_0 - E_{e^-}$) was determined in a tagging system by the deflection of the scattered electrons in a magnetic field. This detector provided a tagged beam in the photon energy range from 0.8 GeV up to 3.0 GeV. The setup of the CB-ELSA detector used for a first series of experiments is shown in Fig. 1. The calorimeter (Crystal-Barrel) consisting of 1380 CsI(Tl) crystals covering about 98 % of 4π solid angle is an ideal detector for photons. The photoproduction target in the center of the Crystal-Barrel (5 cm in length, 3 cm in diameter) was filled with liquid hydrogen. It was surrounded by a scintillating fibre detector built to detect and to trigger on charged particles leaving the target (proton trigger). In addition, it provided an intersection point of a particle's trajectory with the detector and hence helped to identify clusters of charged particles in the barrel. The general concept of the experiment is to combine the calorimeter with suitable forward detectors. Besides Time-Of-Flight walls in the start configuration, the TAPS detector (calorimeter consisting of 528 hexagonal BaF_2 crystals) was used in a second series of measurements. The latter is a fast trigger and provides an ideal granularity in the forward direction.

Investigation of the reaction $\gamma p \rightarrow p\pi^0\eta$

Data was taken from December 2000 with the whole apparatus fully operational. Measurements at three different ELSA energies were performed: E_0 =1400, 2600 and 3200 MeV. In the following, results are presented for a data run of $\approx 22\,000$ $\pi^0\eta$ events at $E_0 = 3200$ MeV.

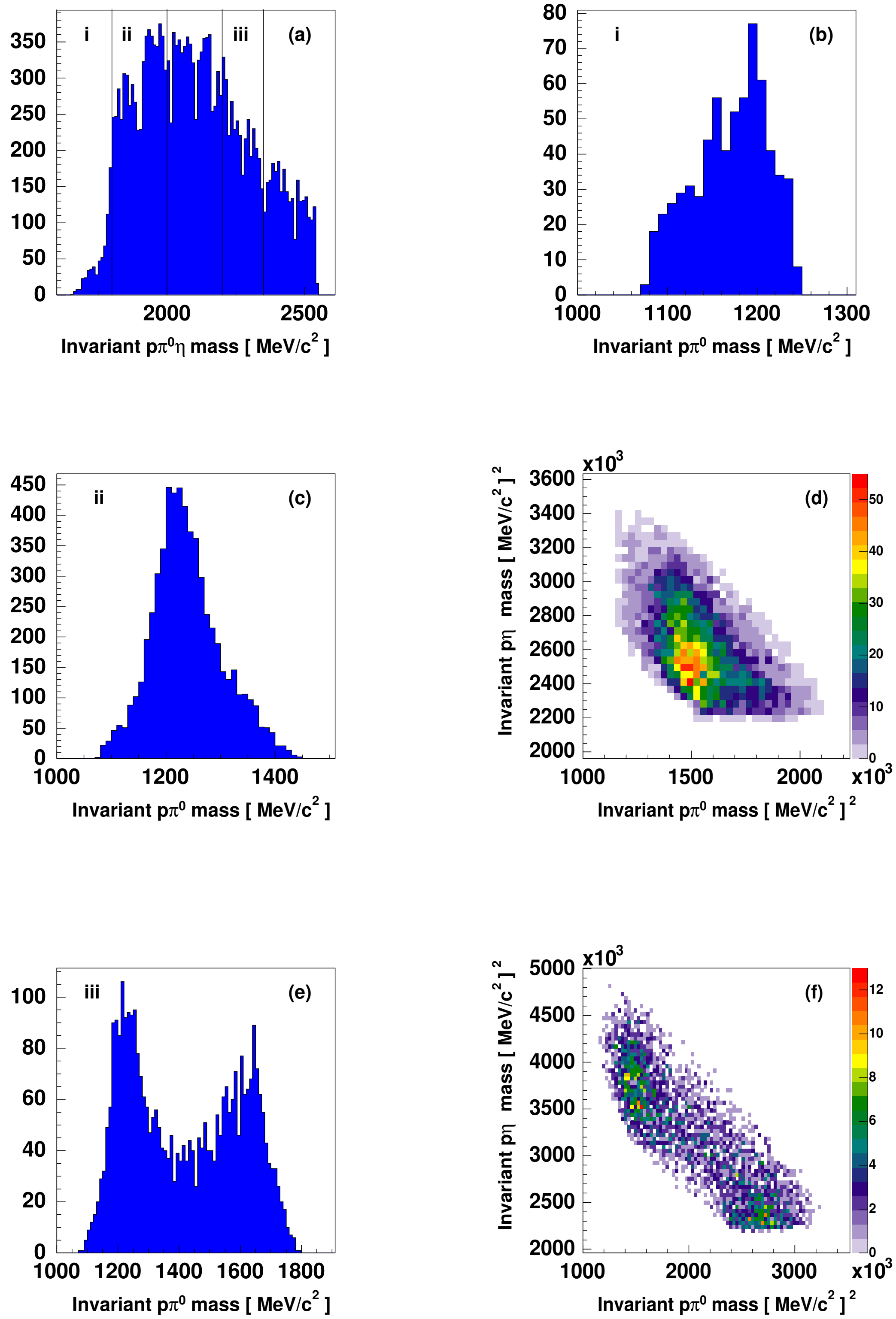

FIGURE 2. Different plots on the reaction $\gamma p \rightarrow p\pi^0\eta$. *(a) shows the total invariant $p\pi^0\eta$ mass. In (b),(c),(e), the $p\pi^0$ mass is plotted for the three different $p\pi^0\eta$ mass regions indicated in (a). Clear evidence for the $\Delta(1232)$ can be observed and, thus, hints for resonances decaying via $\Delta\eta$ become obvious. (d) and (f) show Dalitz plots for two different $p\pi^0\eta$ mass regions (ii and iii). Resonance structures become even more transparent.*

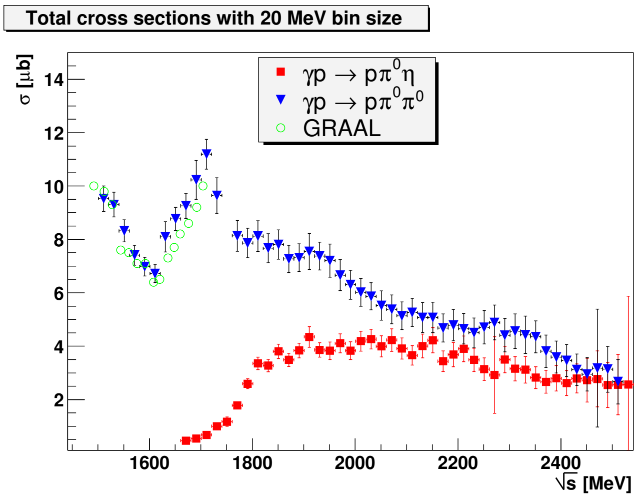

FIGURE 3. Preliminary total cross sections for the reaction $\gamma p \rightarrow p\pi^0\pi^0$ as well as $\gamma p \rightarrow p\pi^0\eta$. The low-energy part of the CB-ELSA double-pion cross section agrees well with the GRAAL data. It should be mentioned that no proper five-dimensional acceptance correction has been applied yet.

Figure 2 (a) shows the total invariant mass for the $p\,\pi^0\,\eta$ final state. No structures are visible at first sight. Different mass regions are indicated and the corresponding $p\pi^0$ mass spectra given. Hints for baryon resonances decaying into $\Delta\eta$ now become visible. In the total mass region around 1700 MeV, no structure can be seen, Fig. 2 (b). However, a clear peak at the Δ mass can be observed in the mass region around 1900 MeV, Fig. 2 (c). As a matter of fact, we expect a series of resonances in this mass region with positive as well as with negative parity. In principle, it would be very difficult to disentangle them. However, in the $\Delta\eta$ threshold region, we expect a small angular momentum between the emitted η meson and the $\Delta(1232)$. Hence, it should be possible to excite some resonances selectively. For orbital angular momenta $l = 0$ or 1, we should expect contributions from the $\Delta(1910)P_{31}$, $\Delta(1920)P_{33}$, $\Delta(1905)F_{35}$ ($l = 1$) and $\Delta(1940)D_{33}$ ($l = 0$).

For higher $p\,\pi^0$ masses, further resonance intensity may be hidden in a structure around 1600 MeV, Fig. 2 (e). One has to be careful interpreting structures in the mass projections as those are often reflections of the corresponding Dalitz plots (Fig. 2 (d) and (f)).

Figure 3 shows the total cross sections for the reactions $\gamma p \rightarrow p\pi^0\eta$ and $\gamma p \rightarrow p\pi^0\pi^0$. The latter agrees very well with the GRAAL data in the low energy region. Above 2 GeV both cross sections are almost equal in magnitude. However, it should be mentioned that no proper five-dimensional acceptance correction has been carried out yet.

Preliminary solutions of a partial wave analysis are based on an unbinned maximum likelihood fit taking all correlations among five independent variables properly into account (event-based fit) [5]. New resonances are needed to describe the data. There is evidence for a new Δ state at ≈ 2.2 GeV as well as hints for $\Delta^* \rightarrow a_0(980)p$ as the dominant contribution for $a_0(980)$ production. Solutions can be ambiguous and therefore

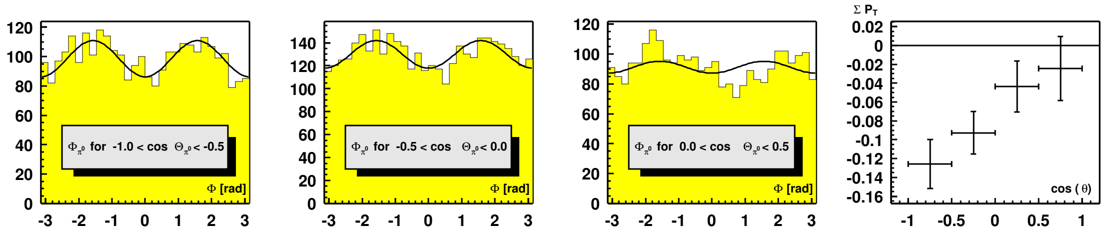

FIGURE 4. Φ_{π^0} distributions for different Θ_{π^0} bins. The data are not acceptance corrected. The incoming photon energy is limited to 1440 MeV $\leq E_\gamma \leq$ 1640 MeV, i.e. the polarisation maximum.

the question of negative-parity Δ states around 1950 MeV cannot be answered, yet. Polarisation data is needed to discriminate between different contributing amplitudes.

OUTLOOK

Simulations have shown that under certain conditions the mass and angular distributions of a Δ^* resonance ($J^P = 3/2^-$) cannot be distinguished from those of a Δ^* ($J^P = 1/2^+$), at least when interference effects are neglected. The CB/TAPS collaboration has taken data with linearly polarised photons created by coherent bremsstrahlung in a well-oriented diamond crystal. In general, the use of linear polarisation breaks the Φ symmetry. Thus, polarisation allows a better determination of contributing amplitudes by adding further constraints in the PWA, e.g. small contributions may have large effects in certain polarisation variables.

In a two-body decay, the use of linearly polarised photons (polarisation P_T) leads to a photon asymmetry Σ:

$$\sigma = \sigma_0(1 + P_T \cdot \Sigma \cdot \cos(2\Phi))$$

In a three-body final state like $p\pi^0\eta$, there is more than one asymmetry depending on the choice of the corresponding Φ distribution. Fig. 4 shows the first results from a 2003 data-taking period. A photon asymmetry can clearly be extracted from the Φ_{π^0} distribution for different Θ_{π^0} bins, for instance. Even considering only 40 % polarisation and contributions from background processes, statistics should be sufficient to investigate the 1950 MeV/c^2 mass region and, therefore, contribute to the question of negative-parity states as well as to the problem of *missing* resonances.

REFERENCES

1. S. Capstick and N. Isgur, *Phys. Rev.* **D34**, 2809 (1986).
2. D. B. Lichtenberg, *Phys. Rev.* **178**, 2197 (1969).
3. E. S. Ackleh et al, *Phys. Rev.* **D54**, 6811 (1996).
4. U. Löhring et al, *EPJ* **A10**, 309 (2001).
5. A. Anisovich: Proceedings of this conference