PHOTOPRODUCTION OF BARYON RESONANCES FIRST RESULTS OF THE CRYSTAL BARREL EXPERIMENT AT ELSA*

J. Junkersfeld

for the CB-ELSA Collaboration

Institut für Strahlen- und Kernphysik, Universität Bonn
Nussallee 14–16, 53115 Bonn, Germany
e-mail: junkersfeld@iskp.uni-bonn.de

(Received February 11, 2002)

Photoproduction data on various final states involving neutral mesons have been taken by the CB-ELSA-experiment at the Electron Stretcher Accelerator ELSA (Bonn). The data show clear structures due to resonance production. Evidence for successive decays of high-mass nucleon resonances via $\Delta(1232)\pi^0$, $\Delta(1232)\eta$ and $N(1535)S_{11}\pi^0$ have been observed. There is evidence for production of $a_0(980)$-mesons in their $\pi^0\eta$ decay.

PACS numbers: 14.20.Dh

1. Introduction

It is widely believed that QCD is the correct theory of strong interaction. Nevertheless, a quantitative description of the quark confinement has not been achieved. Instead, constituent quark-models have been developed, which describe the baryon spectrum with good success. However, they predict a larger number of resonances than have been experimentally observed. There are at least two — very different — explanations for this discrepancy:

- The *missing resonances* do not exist. The baryon resonances could have a quark-diquark structure, as proposed by Lichtenberg [1], which would reduce the degrees of freedom and therefore the number of states.

---

* Presented at the VI TAPS Workshop, Krzyże, Poland, September 9–13, 2001.

- The *missing* states do exist but they have not yet been established due to the lack of high quality data in channels other than πN. Most experiments have investigated πN-scattering, therefore it is likely that states which have only a weak coupling to πN have not been discovered. Several quark model predictions support this hypothesis [2, 3].

A good overview of the current status of the *missing resonances* was given by Bennhold on this workshop. If the *missing* states exist, they are expected to couple to channels like ηN, $\eta' N$, ωN, $\Delta\pi$ or ρN, which are produced in photoproduction. Therefore photoproduction experiments investigating these channels have a large potential for the discovery of these states. The investigation of different final states is the topic of several CB-ELSA-proposals [4–7].

Another interesting aspect of the baryon spectrum is the very selective decay of resonances into their ground state and an η-meson. Among the five nucleon-resonances with angular momentum $L = 1$ and negative parity only one, the $N(1535)S_{11}$, couples strongly to $N\eta$; the others ($N(1520)D_{13}$, $N(1650)S_{11}$, $N(1700)D_{13}$ and $N(1675)D_{15}$) couple only with a branching ratio of a few percent to this final state.

The situation is similar for the Σ- and Λ-resonances with negative parity and $L = 1$; only the $\Lambda(1670)S_{01}$ and the $\Sigma(1750)S_{11}$ couple strongly to decays into $\Lambda\eta$ and $\Sigma\eta$, respectively. The question arises what the situation in the corresponding Δ-resonance section is, which is partly not well established. An investigation of this would allow to extend the pattern and would give further insight in a possible hidden symmetry [7].

2. The CB-ELSA detector

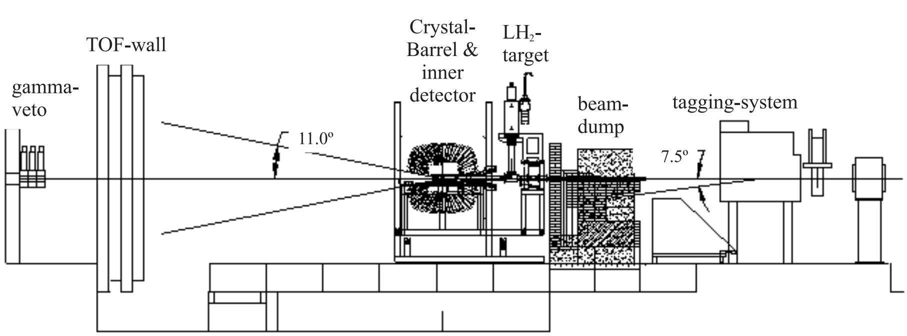

Fig. 1. Setup of the CB-ELSA detector during the first data taking period.

The setup of the CB-ELSA experiment which was used during the first data taking period between October 2000 and May 2001, is shown in figure 1. The experiment is located at the *electron stretcher accelerator* ELSA in Bonn, which has a maximal electron energy of 3.5 GeV. The extracted electron beam produces bremsstrahlungs-photons at a radiation target. The deflected electrons are measured by a tagging system, resulting in a tagged photon beam with energies between 22 and 93 % of the incoming electron energy. This allows to reach nucleon resonances up to a mass of 2.7 GeV. The target consists of liquid hydrogen and is surrounded by an inner detector consisting of three layers of scintillating fibres. The inner detector is surrounded by the *Crystal Barrel* calorimeter, an electro-magnetic calorimeter consisting of 1380 CsI(Tl)-crystals in a cylindrical-symmetric setup; it covers 98 % of the 4π solid angle in the laboratory system. Located in the forward direction is a *Time-of-Flight* spectrometer.

The experiment uses a two-level trigger system. The first-level trigger is produced by a coincidence of an electron in the tagging system and a charged particle in the inner detector or the ToF-spectrometer; in the second level the number of electro-magnetic showers in the crystal barrel calorimeter is counted by a *Fast Cluster Encoder*.

The setup has been changed since May 2001 and the TAPS detector has been installed between the calorimeter and the ToF-walls. The setup and the schedule for this modification was presented in a talk by Schadmand [8].

3. First preliminary results

Data have been taken with electron-beam energies of 1400 MeV, 2600 MeV and 3200 MeV. For the following spectra, around 60 % of the data from the 3200 MeV-beamtime have been evaluated. The ToF-spectrometer was not yet included in the analysis therefore the used statistics is further decreased. The spectra are preliminary and no flux normalization or acceptance correction has taken place. The channels have been kinematically fitted, with the energy of the proton and the energy of the bremsstrahlungs-photon as free parameters.

The electron energy of 3200 MeV corresponds to an energy spectrum for the tagged bremstrahlungs-photons from 700 to 2980 MeV or invariant masses between 1480 and 2540 MeV.

Here, events with four photons and a proton in the final state will be discussed. The figures 2(a) and (b) contain the $\gamma\gamma$-invariant mass combinations and they show strong signals for $p\pi^0\pi^0$ and $p\pi^0\eta$ final states; they contain approximately 150000 $p\pi^0\pi^0$ and 20000 $p\pi^0\eta$ events, respectively. Events have been selected by a confidence level cut of 10 %, respectively.

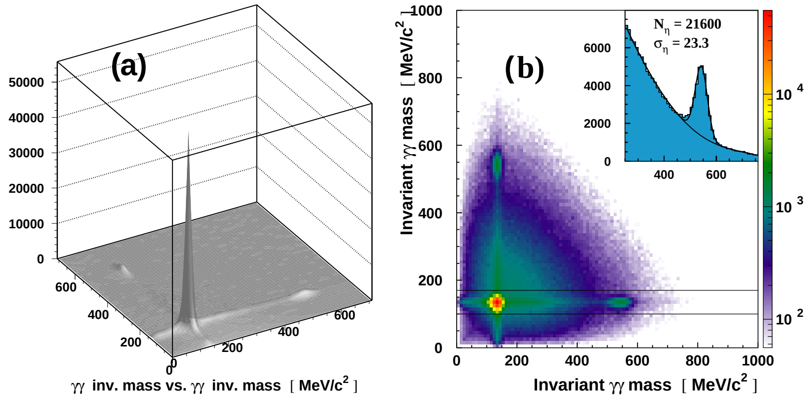

Fig. 2. Final state with 4 photons and a proton in the final state, all $\gamma\gamma$-combinations are displayed. In (a) a linear and in (b) a logarithmic scale has been used; the inset in figure (b) shows the projection of the marked region.

3.1. The channel $p\pi^0\pi^0$

In figure 3(a) the $p\pi^0\pi^0$-invariant mass spectrum is displayed. It shows a strong resonance structure at around 1700 MeV. In plot (b) the $p\pi^0\pi^0$-invariant mass is plotted against the $p\pi^0$-invariant mass; this shows that decays into $\Delta(1232)\pi^0$ are strong in the whole mass range. The diagonal enhancement in this plot is a kind of reflection, due to the fact that we cannot distinguish between the two π^0. If the proton and one of the pions stem from the Δ-resonance, then the other π^0 and the proton, due to the kinematical constraints, lie on this diagonal.

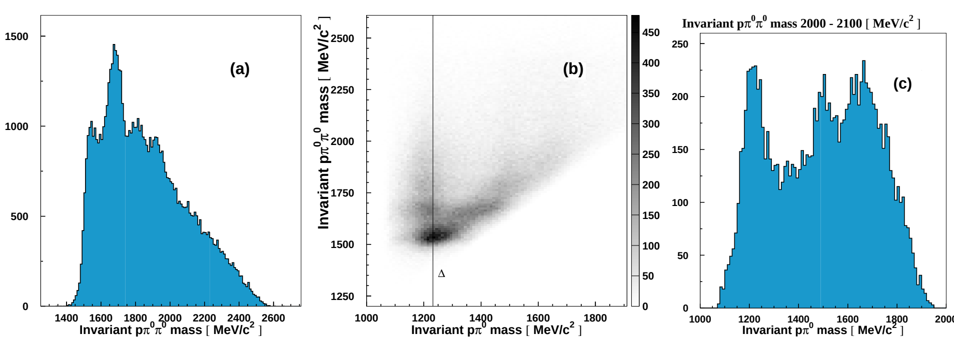

Fig. 3. (a) $p\pi^0\pi^0$ invariant mass spectrum, (b) $p\pi^0\pi^0$ *versus* $p\pi^0$ invariant mass, (c) $p\pi^0$ invariant mass for a $p\pi^0\pi^0$ mass between 2000 and 2100 MeV.

In plot (c) the invariant $p\pi^0$-mass is shown for a $p\pi^0\pi^0$-mass between 2000 and 2100 MeV. At 1232 MeV the signal for resonances decaying into $\Delta\pi^0$ is visible and at around 1700 MeV the corresponding reflection can be seen. At around 1550 MeV another structure in the spectrum is visible, probably the $N(1520)D_{13}$.

3.2. The channel $p\pi^0\eta$

For figure 4, the events with a $p\pi^0\eta$ final states have been selected. In plot (a) the invariant mass spectrum is shown. Plot (b) presents the $p\pi^0$ mass for a $p\pi^0\eta$-mass between 1800 and 2000 MeV and plot (c) for a mass between 2200 and 2350 MeV; it is evident that a large part of the produced resonances decay via the $\Delta\eta$-channel. In figure 5(a) and (b) the Dalitz-plots for $p\pi^0\eta$, with $p\pi^0$ on the horizontal and $p\eta$ on the vertical axis are shown. The plots cover the same $p\pi^0\eta$ mass regions as figures 4(b) and (c). In the $p\pi^0\eta$ mass region between 2200 to 2350 MeV — besides the $\Delta\eta$ signal — the channel $N(1535)S_{11}\pi^0$ is well visible.

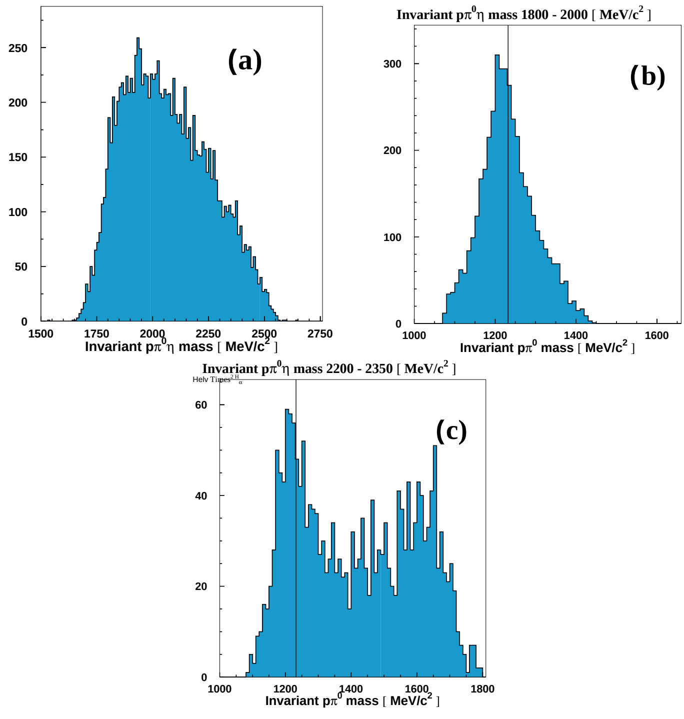

Fig. 4. (a) $p\pi^0\eta$ invariant mass spectrum, (b) $p\pi^0$ invariant mass for a $p\pi^0\eta$ mass between 1800 and 2000 MeV and (c) between 2200 and 2350 MeV ($\Delta(1232)$-mass marked by a line).

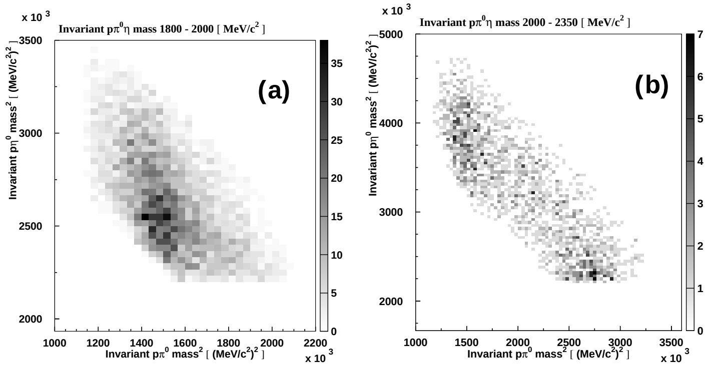

Fig. 5. *$p\eta$ versus $p\pi^0$* invariant mass squared for a $p\pi^0\eta$ mass between (a) 1800 and 2000 MeV and (b) between 2200 and 2350 MeV

3.3. *The channel pa_0*

In figure 6 the $\pi^0\eta$ invariant mass is plotted for different $p\pi^0\eta$ mass regions. In (a) an enhancement in the region around 1000 MeV can be seen. In the region of the a_0-threshold around 1920 MeV (b) no signal for an a_0-production is visible, but in the region 100 to 300 MeV above the threshold (c) a strong signal for a_0 production seems evident.

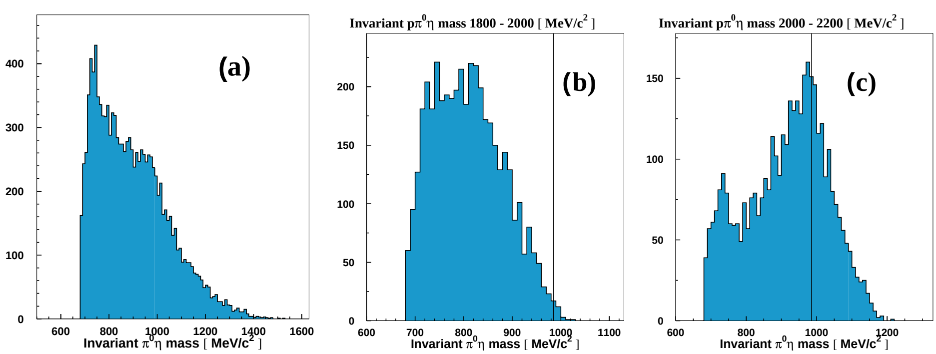

Fig. 6. $\pi^0\eta$ invariant mass spectrum (a) for the whole mass range, (b) for $p\pi^0\eta$ mass between 1800 and 2000 MeV and (c) between 2000 and 2200 MeV (a_0-mass marked by a line)

4. Conclusion

The $p\pi^0\pi^0$ final state contains strong signals for $\Delta(1232)\pi^0$-production over the whole energy range investigated and also signals for the production of resonances decaying into the π^0 and, probably, the $N(1520)D_{13}$.

In the $p\pi^0\eta$ final state decays into $\Delta(1232)\eta$ and into $N(1535)S_{11}\pi^0$ are clear to see and also a signal for a_0-production.

The data collected in the first data taking period of the CB-ELSA experiment look very promising; already in this early stage of the analysis, the high quality of the data is obvious. It can be expected that some light will be shed on the problem of the *missing resonances* and on some other open questions of baryon physics.

REFERENCES

[1] D.B. Lichtenberg, *Phys. Rev.* **178**, 2197 (1969).

[2] S. Capstick, W. Roberts, *Phys. Rev.* **D47**, 1994 (1993).

[3] S. Capstick, W. Roberts, *Phys. Rev.* **D49**, 4570 (1994).

[4] A. Fösel *et al.*, Photoproduction of η and η'-Mesons. Proposal to the PAC.

[5] U. Thoma *et al.*, Study of Baryon Resonances Decaying into $\Delta(1232)\pi^0$ in the Reaction $\gamma p \to p\pi^0\pi^0$ with the Crystal Barrel Detector at ELSA. Proposal to the PAC.

[6] M. Ostrick *et al.*, Production of ω-Mesons with Linearly Polarised Photons. Proposal to the PAC.

[7] J. Smyrski *et al.*, A Search for the Exotic Meson $\hat{\rho}(1380)$ and for New Baryonic Resonances in the Reaction $\gamma p \to p\pi^0\eta$ Using the CB-ELSA Detector at ELSA. Proposal to the PAC.

[8] S. Schadmand, *Acta Phys. Pol.* **B33**, 873 (2002).