HADRON PHYSICS AT ELSA
WITH THE CRYSTAL BARREL

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Abstract

Photoproduction data on final states involving neutral mesons has been taken by the CB-ELSA-experiment at the electron stretcher accelerator ELSA in Bonn. In this data clear peak structures due to resonance production can be seen. The data show evidence for successive decays of high-mass nucleon resonances via $\Delta(1232)\pi$ and via resonances of higher mass.

1 Introduction

After seven years of successful operation at the Low Energy Antiproton Ring LEAR at CERN the Crystal Barrel Calorimeter was moved to Bonn. Here it is used together with new detector components to investigate photo- and electroproduction processes at the electron stretcher ring ELSA. The aim of the experiment is to improve our understanding of QCD in the low energy domain where perturbative methods fail. To do so, nucleon resonances produced in photoproduction processes are investigated. At ELSA this is possible up to a resonance mass of 2.6 GeV. An important question of non-perturbative QCD is the origin of hadron masses. One step in this direction is the search for the Higgs-boson planned at LHC. If the Higgs is found one would understand where the $W^{\pm}$ and the Z^0 get their masses from. The quarks are expected to get their current quark masses by coupling to the Higgs-field. The current quark mass is in the order of 5 MeV; only a very tiny fraction (less than 30 MeV) of the large proton mass can be explained by current quark masses. The largest part of the proton mass is due to the complex structure of the QCD vaccum. The investigation of the excitation spectrum of the nucleon may help to understand better the masses of nucleons. Certainly models are needed to describe the measured spectrum and to provide a link between data and QCD.

2 The detector system

Before the actual setup at ELSA will be discussed a surview on the concept of the CB-ELSA experiment is given. The Crystal Barrel calorimeter consists of 1380 CsI crystals which cover about 98% of 4π. It is especially suited to measure photons. In order to be able to identify charged particles leaving the target a scintillating fibre detector was built. It provides an intersection point of the particle trajectory with the detector. This detector consists of 3 layers of scintillating fibres; one straight layer and two layers in $\pm 25^\circ$. It surrounds the liquid hydrogen target which has a length of 5 cm and a diameter of 3 cm. This detector system can be extended in forward direction by different other detectors depending on the physics one is interested in. Available are an electromagnetic spectrometer (EMS) and a time of flight detector (TOF) of the former ELAN experiment [1]. In addition, measurements with the TAPS detector [2, 3, 4, 5] built up as a hexagonal wall of 528 BaF_2 crystals are planned. A lead glas wall consisting of about 900 lead glas detectors is also available. The latter can e.g. be used to measure the scattered electrons of electroproduction experiments. The EMS and TOF are very well suited to determine the photoproduction cross sections directly at or near threshold, where the proton is emitted in forward direction. The TAPS is again an ideal detector to do baryon spectroscopy together with the CB-ELSA detector. The liquid hydrogen target can replaced by a target of higher Z to investigate meson masses in nuclear matter. Such measurements are scheduled for the data taking period with TAPS [2, 3]. The current setup of the experiment is shown in Fig. 1. The e^--beam enters the detector system from the right side and hits the radiation foil in which photons are produced by the bremsstrahlungs

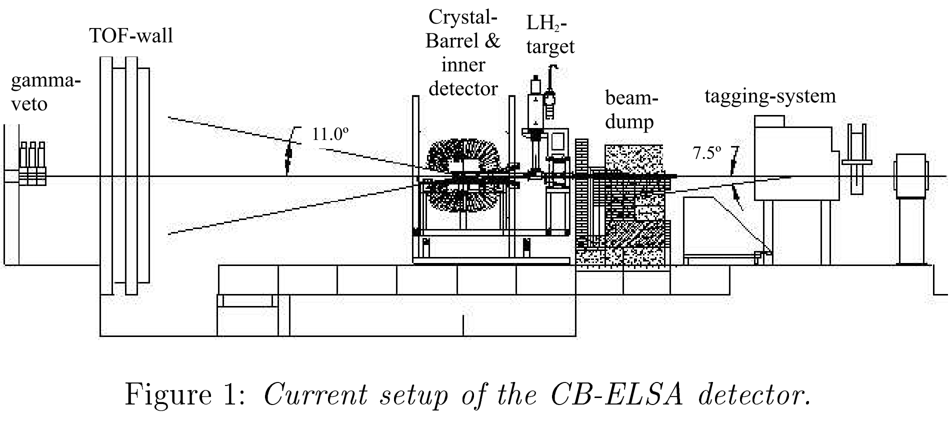

Figure 1: *Current setup of the CB-ELSA detector.*

process. The electrons are bent downwards in the tagging magnet. The energy of the photon is determined by measuring the energy of the corresponding e^- in the tagging system. Unscattered electrons are deflected into the beam dump. The tagger provides photons with energies from 22 - 93% of the incoming electron energy. At a distance of about 6.5 m from the radiation foil, the liquid hydrogen target of the CB-ELSA detector is placed. The TOF walls are used as forward detector for the present set-up. The first level trigger is derived from the signals of the tagging system, the inner detector and/or the TOF walls; the second level trigger consists of a fast cluster encoder which allows to determine the number of clusters in the barrel.

3 Proposals for the present setup

There are four accepted proposals for the present experimental period [6, 7, 8, 9]. In addition, several new proposals for the CB-ELSA + TAPS era exist [2, 3, 4, 5].
In the following the proposals related to the current data taking period will be discussed, starting with:

- Study of baryon resonances decaying into $\Delta(1232)\pi^0$ in the reaction $\gamma\mathrm{p} \to \mathrm{p}\pi^0\pi^0$ with the Crystal Barrel detector at ELSA [6]

- Photoproduction of η and η'-mesons [7]

which are both related to the search for missing resonances. Afterwards we shortly discuss the proposals:

- A search for new baryonic resonances and for the exotic meson $\hat{\rho}(1380)$ in the reaction $\gamma p \to p\pi^0\eta$ [8]

- Inelastic photon scattering in the exclusive channels $\mathrm{p}(\gamma, \pi^0\gamma\mathrm{p})$ and $\mathrm{p}(\gamma, \eta\gamma\mathrm{p})$ [9]

3.1 Search for missing resonances

Quantum chromodynamics (QCD) is almost certainly the correct theory of strong interactions. However, it is not yet possible to solve the QCD Lagrangian in the low energy regime and for bound states. Instead quark models have been developed which are amazingly successful in their predictions of hadron properties. But there seems to exists a serious disagreement between the quark model and experimental findings. A large number of baryon resonances predicted by the quark model has not been observed experimentally.

One possible solution to this problem was proposed by Lichtenberg [10] who suggested that baryons have a quark-diquark structure. This would freeze one internal degree of freedom and would lead to a smaller number of expected resonances. Another solution with less dramatic consequences would be that these states simply have not been observed so far. Nearly all the existing data on non-strange baryon production result from πN scattering experiments. If the missing resonances do not couple to πN they would not have been discovered [11]. This idea is supported by more recent quark model calculations [12],[13]. In addition, these resonances do not have anomalously small couplings to photons [14] and should couple to final states such as e.g. $\Delta\pi$, Nη, Nρ, Nω and $N\eta'$. Photoproduction experiments investigating channels like e.g. $\Delta\pi$ or Nη, $N\eta'$ thus have a big potential to discover missing resonances.
We examplify the need for precise data on various final states by discussing the S_{11}-resonances around 2 GeV. In the Particle Listing [15] only one resonance, the $S_{11}(2090)$, is mentioned in this mass region and even that one is considered as badly established. Following the quark model one would expect five S_{11}-resonances in this mass region. The mass spectrum [12] and the decay widths [13] of a large number of resonances have been calculated by Capstick and Roberts. In the region of the $S_{11}(2090)$ five states with different masses and different decay patterns occur. Tab. 1 reproduces part of their results. It seems to be very difficult to establish 5 different states in such a small mass interval. However, if the states do exist, their mass as observed in the Nη' and $\Delta\pi$ must differ in mass by more than 100 MeV! (Tab.1). The comparison of the mass spectra from photoproduced η' mesons and of the $\Delta\pi$ system would give therefore a strong indication if more than one state is produced. Other examples can be derived from the tables in [13].
Photoproduction of two pions is obviously one of the reactions one should

Particle	Nπ	Nη	Nη'	Nω	$\Delta\pi$	Nρ
$S_{11}(1945)$	32	6	13	32	45	330
$S_{11}(2030)$	14	1	2	8	32	1
$S_{11}(2070)$	4	<1	1	42	170	60
$S_{11}(2145)$	<1	<1	<1	<1	1	5
$S_{11}(2195)$	<1	<1	<1	<1	4	10

Table 1: *Partial widths of S_{11} baryon resonances. Masses and partial widths are taken from [13]. Errors are suppressed for clarity.*

study to clarify if there are unresolved high-mass baryon resonances. Production of $\pi^+\pi^-$ pairs is also a rather frequent process; however it is dominated by diffractive scattering of ρ mesons produced by conversion of the incoming photon in the field of a proton. It is known that diffractive ρ scattering increases in importance with increasing photon energy. Fig. 2 shows the $\pi^+\pi^-$ invariant mass for different ranges of the photon energy. With increasing photon energy the ρ meson becomes more and more the dominant feature of the mass distribution. But at all energies there is also a significant contribution from the Δ^{++} resonance which mainly stems from the seagull term. High-mass Δ excitations

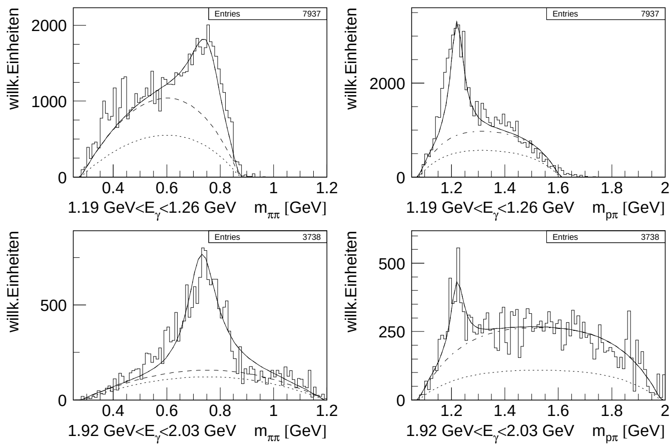

Figure 2: *The $\pi^+\pi^-$ (left) and $p\pi$ (right) invariant mass distributions as produced in photoproduction for different photon energy intervals (SAPHIR data [16]). Diffractive ρ production dominates the process, particularly at high energies. The Δ^{++} is observed at all energies. The dotted line shows the phase space contribution, the dashed line the phase space and the Δ^{++} contribution, the dashed dotted line the phase space and the ρ contribution.*

would show up in Fig. 2 as enhancement of the Δ^{++} yield as a function of the photon energy. The Nρ decay mode of a baryon resonance would show up in an increased ρ photoproduction rate. The reaction $\gamma p \rightarrow p\pi^+\pi^-$ has thus a large discovery potential even though background contributions are large. The SAPHIR collaboration has taken data on this reaction. A preliminary analysis can be found in [16]. Its study has also been proposed at CEBAF [17].
However, the theoretical interpretation of the results is not straightforward. The ρ mesons can be produced diffractively or via formation of s-channel resonances. The Δ^{++} and the Δ^0 are both produced but need not to come from high-mass resonances but could also originate from the seagull Born-term.

These background amplitudes should be strongly suppressed in the channel $\gamma p \rightarrow p\pi^0\pi^0$. Here e.g. the diffractive ρ-production can not occur. This leads to big advantages in the analysis. The contribution from s-channel resonances decaying into $\Delta\pi$ should clearly manifest its existence in this data. Of course additional information e.g. on the $N\rho$ decay can be obtained from the charged data.

3.2 The search for $\Delta(1232)\eta$-resonances in photoproduction processes

The $N(1535)S_{11}$ is the lowest mass nucleon resonance which can be reached by an electric dipol-transition. The knowledge of its nature is therefore of fundamental interest. The $S_{11}(1535)$ decays strongly into $N\eta$ while for most other nucleon resonances this decay mode is at most in the order of a few %. This decay pattern can also be observed in the case of the Λ^*-resonances and in a different form for the Σ^* resonances. In all these cases only one resonance is observed which decays strongly into an η. If the Δ^* resonances show the same behaviour is unclear. The experimental situation is summarised in Tab. 3.2. Despite of the special role of the $N(1535)S_{11}$ its nature remains unclear. There exists many very different attempts to describe its properties leading to a quite different interpretation of its nature [18, 19, 20].
The decay pattern observed in the N^*-, Λ^*- and Σ^*decays suggests that also one Δ^*-resonance should exist which decay strongly into $\Delta\eta$. Indeed, this would be very interesting; it could lead to a deeper understanding of these states. Their decay modes could e.g. be related to the intrinsic spin and angular momentum of the resonances. Of course, the symmetry of the wave function may also be important. Following a dynamical calculation of S. Capstick and

$N(1650)S_{11}$	$N(1700)D_{13}$	$N(1675)D_{15}$		$\Lambda(1800)S_{01}$	$\Lambda(????)D_{03}$	$\Lambda(1830)D_{05}$
$\underline{\mathbf{N(1535)S_{11}}}$	$N(1520)D_{13}$			$\underline{\Lambda(\mathbf{1670})\mathbf{S_{01}}}$	$\Lambda(1690)D_{03}$	
$\underline{\Sigma(\mathbf{1750})\mathbf{S_{11}}}$	$\Sigma(????)D_{13}$	$\Sigma(1775)D_{15}$		$\Delta(1900)S_{31}$	$\Delta(\mathbf{1940})\mathbf{D_{33}}$	$\Delta(1930)D_{35}$
$\Sigma(1620)S_{11}$	$\Sigma(1670)D_{13}$			$\Delta(1620)S_{31}$	$\Delta(\mathbf{1700})\mathbf{D_{33}}$	

Table 2: *Baryons with negative parity and their decays into η-mesons. The underlined resonances show a strong decay into their ground state and an η. The resonances in the upper line have an intrinsic spin of $s = 3/2$, the states in the lower row of $s = 1/2$. Resonances with the same total quantum numbers can mix.*

W. Roberts [21] the $\Delta(1232)\eta$ strength should be distributed over many resonances, some of them also belonging to the missing states. The investigation of the experimental situation should make it possible to distinguish between the two scenarios and should lead to a better understanding of their nature.

3.3 Inelastic Photon Scattering in the Exclusive Channels $p(\gamma, \pi^0\gamma p)$ and $p(\gamma, \eta\gamma p)$

The investigation of the reaction $\gamma p \rightarrow p\pi^0\gamma$ allows e.g. to measure the transition from a high mass $\Delta(1232)$ to a lower mass $\Delta(1232)$. This transition is sensitive to the magnetic dipole moment of the Δ^+ which is so far unknown. First results have been obtained with the TAPS-Detector at MAMI [22]. In addition, further radiative transitions between the low mass resonances can be investigated. This represents a different approach to the spectrum of the nucleon. Of course these measurements are difficult; one has to handle background channels which could fake a single photon.

4 First data

So far, data at four different e^--beam energies has been taken with the CB-ELSA experiment: 800 MeV, 1400 MeV, 2600 MeV and 3200 MeV. For the first calibration of the detector system in the new surroundings at ELSA the 800 MeV data was used; at this energy the forward boost is small and each crystal gets enough statistics to perform the calibration. The calibration is done using the known π^0 mass as reference. In the following preliminary data obtained at the other three energies are discussed. The spectra shown are not corrected for acceptance. Fig. 3 shows the $\gamma\gamma$ invariant mass of selected proton 2γ events. A clear π^0 and η peak above a small background is observed. The spectra for the two beam-energies look similar. Of course the energy window of the incoming photons relative to the particle thresholds effects the relative strength of the η and π^0 peak. Fig. 4 shows the $p\pi^0$ invariant mass of selected $p\pi^0$ events. The different resonance regions starting with the $\Delta(1232)$, (1400 MeV data), to the second and third resonance region are clearly visible.

The reaction $\gamma p \rightarrow p\eta$ was not only observed using the $\eta \rightarrow 2\gamma$ decay discussed above, but also by the $\eta \rightarrow 3\pi^0$ decay (see Fig. 5). The η-events clearly show up above a small background. The $p\eta$-invariant mass shows a strong peaking structure due to the $S_{11}(1535)$. Further resonance intensity may be hidden in the spectrum; this has to be investigated further. As discussed before not only the η-photoproduction but also the photoproduction of $2\pi^0$ is interesting for

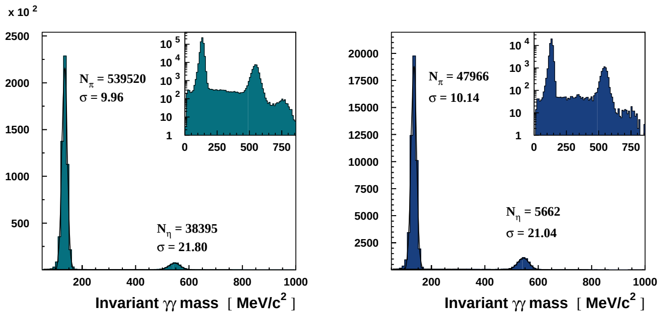

Figure 3: *Invariant $\gamma\gamma$-mass of $\mathrm{p}\gamma\gamma$-events; beam-energies:* $\mathrm{E_{e^-}}$ *=2.6 GeV, 3.2 GeV.*

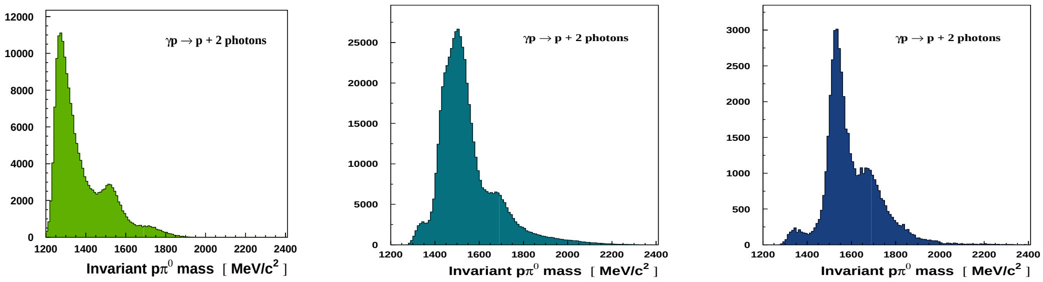

Figure 4: $\mathrm{p}\pi^0$ *invariant mass for different beam-energies: 1400 MeV, 2600 MeV and 3200 MeV. Clearly observed are the different resonances regions.*

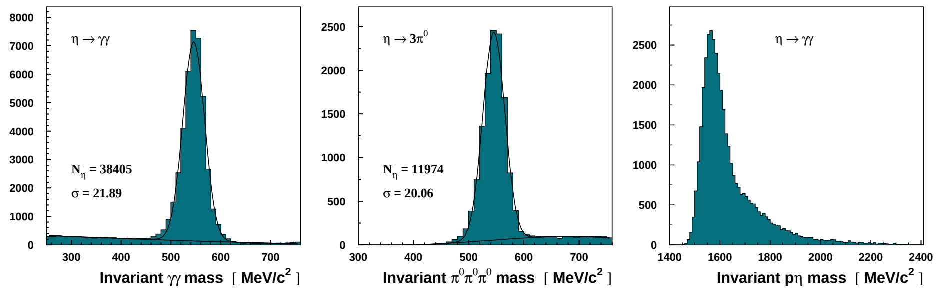

Figure 5: *Observed* $\mathrm{p}\eta$*-events, left: invariant $\gamma\gamma$ mass, middle: invariant* $3\pi^0$*-mass. Right: invariant* $\mathrm{p}\eta$*-mass. A peak due to the* $\mathrm{S_{11}}$*(1535) is clearly observed in the data.*

the search of missing resonances. To do so final states with four photons have to be investigated. Of course, the $\gamma\mathrm{p} \to \mathrm{p}\pi^0\eta$ events we are interested in, too, are included in this data set. Fig. 6 shows selected $\mathrm{p}4\gamma$ events. In the left picture a clear peak due to $\pi^0\pi^0$ events is observed. In addition, an enhancement in the region of the $\pi^0\eta$ events; it gets more obvious in the right picture where a horizontal cut on the dominant $2\pi^0$ peak was performed. Apart from the

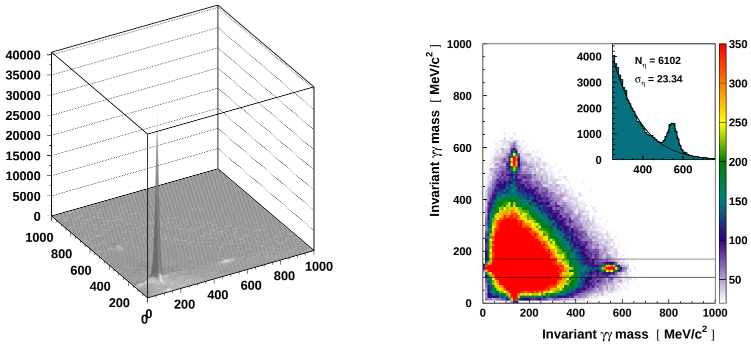

Figure 6: *In both plots the* $\gamma\gamma$*-invariant mass of one* $\gamma\gamma$*-pair is plotted against the* $\gamma\gamma$*-invariant mass of the other pair, left: complete spectrum, right: a maximum was set to the z-axis. There is strong* $\pi^0\pi^0$ *production; the* $\pi^0\eta$ *system is also clearly observed.*

strong $2\pi^0$ signal the $\pi^0\eta$ events are clearly observed in the data. Fig. 7 shows the $p\pi^0\pi^0$ and the $p\pi^0$ invariant masses as well as a two-dimensional plot where one is plotted against the other. Two resonance structures are

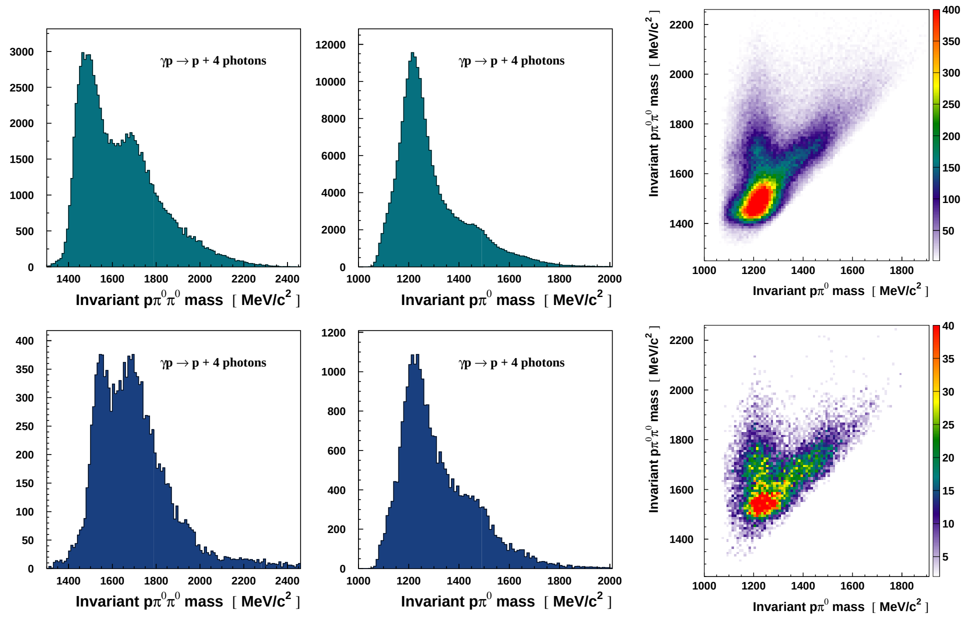

Figure 7: $\pi^0\pi^0$p-*data measured at two different beam-energies:* E_{e^-} *=2.6 GeV (upper row), 3.2 GeV (lower row).*

clearly visible: one around 1500 MeV decaying via $\Delta\pi$, and the other around 1700 MeV decaying via $\Delta\pi$ and a higher mass resonance (2-dim. plot). The

resonance region around 1700 MeV gets more clearly visible in the data taken at the higher beam energy. As expected the second peak in the pπ^0 invariant mass is also enhanced. These plots clearly show that we are already observing structures we are looking for; exited resonances which decay via $\Delta(1232)\pi$, where we would expect missing resonances to occur. Also additional decay modes via higher mass resonances are visible in the data.
Fig. 8 shows similar plots for the p$\pi^0\eta$ data set. The $\pi^0\eta$ invariant mass shows

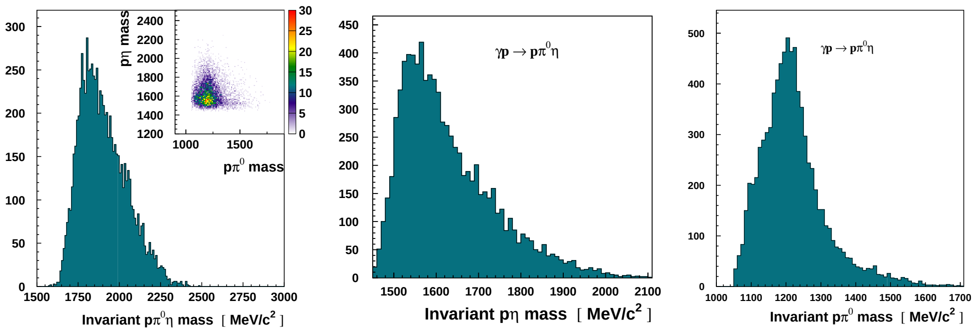

Figure 8: $\pi^0\eta$p-*data measured at:* E_{e^-}*=2.6 GeV.*

a peaking structure which may be related to resonance production. The inset and the projections show that there is enhanced intensity in the $\Delta(1232)$ and in the $S_{11}(1535)$ mass region which hints to the observation of possible decay modes via $\Delta(1232)\eta$ and $S_{11}(1535)\pi$. So like in the $\pi^0\pi^0$p case evidence for the decay modes we are searching for are already seen in the data.

5 Conclusions

A first look into the data taken so far with the CB-ELSA experiment shows already promising resonance structures and evidence for decay modes via $\Delta\pi$ and higher mass resonances. Further investigation of the data with improved statistics, including an improved reconstruction and a partial wave analysis, should lead to interesting results on nucleon resonances and their properties. This should help to understand better the spectrum of nucleon resonances and finally QCD in the non-perturbative regime.

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