

# Search for mesic nuclei in the photoproduction of $\eta\pi^0$ mesons off light nuclei

Irakli Keshelashvili, Alexander Käser

Department of Physics, University of Basel, CH-4056 Basel, Switzerland

E-mail: [i.keshelashvili@unibas.ch](mailto:i.keshelashvili@unibas.ch)

**Abstract.** For the understanding of the strong nuclear force, the study of interaction between mesons and nuclei is important. In case of long lived charged mesons, like  $\pi$  and  $K$ , secondary beams can be used for experiments. But the situation is different for the short lived neutral mesons, like  $\pi^0$ ,  $\eta$  and  $\eta'$ . The only access is indirect, making use of final-state interaction (FSI). The mesons are produced with some initial reaction in the nucleus and then their interaction with the same nucleus is studied. It is much discussed whether it is possible to form, via the strong interaction, quasi-bound states of mesons and nuclei, which would be the ideal tool for such studies. We will present preliminary results from the Crystal Ball/TAPS experiment at the Mainz MAMI accelerator for double neutral meson photoproduction, showing interesting potential to study meson nucleon interaction and discuss their relevance. The very first attempt has been made to measure the quasi-free behavior of the photoproduction of  $\eta\pi^0$  mesons from the  ${}^2H$ .

## 1. Introduction

In the past three decades, many attempts to study meson nucleon interaction has been made. Using charged pion beams off different light targets has been investigated to find possible meson nucleon bound state [1, 2]. Furthermore, the TAPS experimet at MAMI accelerator has tried to investigate photon induced production of  $\pi^0$  and  $\eta$  for the different light targets, like deuteron, helion ( ${}^3He$ ) and helium ( ${}^4He$ ) [3, 4, 5, 6, 7]. All attempts were inconclusive towards finding meson nucleon bound state. In the most cases, the single meson production was in focus of interest, it was caused mainly due to limited capabilities of old detector systems. But using modern, fast and more dedicated/customisable trigger systems, combined with fast data acquisition systems, allow us to investigate multiple meson production with high statistics. The  $\eta$  production at the ANKE spectrometer in the reaction  $pd \rightarrow {}^3He\eta$  [8] and the recent measurement by our group using Crystal Ball/TAPS detector of the reaction  $\gamma{}^3He \rightarrow {}^3He\eta$  [9] shows a very rapid rise of the total cross section close to threshold implying a very large  $\eta{}^3He$  scattering length and hence the existence of a quasibound state very close to threshold.

Unfortunately, coherent photoproduction of  $\eta$ -mesons is forbidden for the spin, isospin  $J = I = 0$  nucleus since  $\eta$ -photoproduction in the threshold region is dominated by an isovector, spin-flip transition [10]). To the contrary, coherent threshold photoproduction of  $\eta\pi^0$ -pairs will be not suppressed, since it does not require a nucleon spin-flip. Due to the specific decay chain and the emission of the  $\eta$ -mesons in  $s$ -wave, one may expect strong contributions where the available kinetic energy is taken by the pion and the relative momentum of nucleus and  $\eta$ -meson is small, which are ideal conditions for the formation of a quasi-bound state. Very preliminary



results from the coherent photoproduction of  $\eta\pi^0$  pairs off the deuteron [11] seem to support this expectation.

## 2. Experiment

A schematic view of the Crystal Ball/TAPS experimental setup is shown in figure 1. The beam for this experiment is produced at the so called continuous wave accelerator facility MAMI [12, 13] in Mainz. Using an electron beam of fixed 1.5 GeV energy on a copper radiator a bremsstrahlung photon beam is produced. The energy of the photons was determined by a momentum analysis of the scattered electron in a magnetic spectrometer (Glasgow photon tagger [14, 15, 16]). After collimation the beam impinged on the target (liquid deuterium or  $^3\text{He}$ , respectively). The target is surrounded by a thin plastic scintillator barrel [17], which was used for charged particle identification, and the spherical electromagnetic calorimeter Crystal Ball [18]. This detector consists of 672 NaI crystals and covers 94% of  $4\pi$  steradians. The acceptance in the forward direction of the Crystal Ball is covered by the TAPS detector [19, 20] which for the part of the data taking was made of 384  $\text{BaF}_2$  crystals and for the second part of measurement, its 6 crystals were exchanged by 24  $\text{PbWO}_4$  crystals in order to meet higher countrate. During all measurements, in front of every crystal a 5mm plastic scintillators are installed as a charged particle identification/veto detector. As trigger condition a deposited energy sum of 300 MeV in the Crystal Ball and a total multiplicity of two or more hits in whole calorimeter was requested.

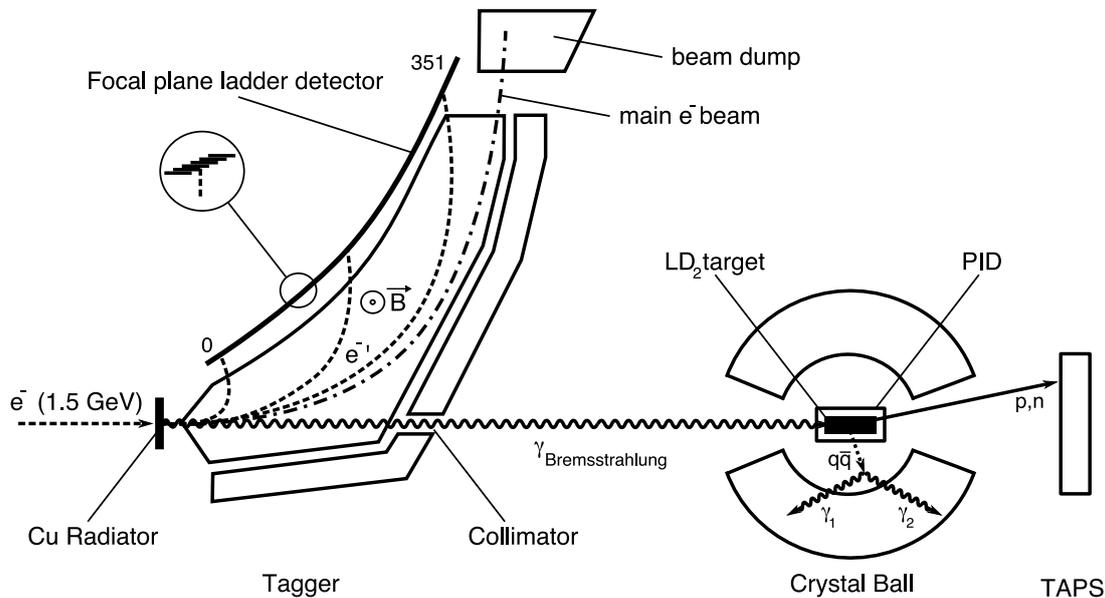
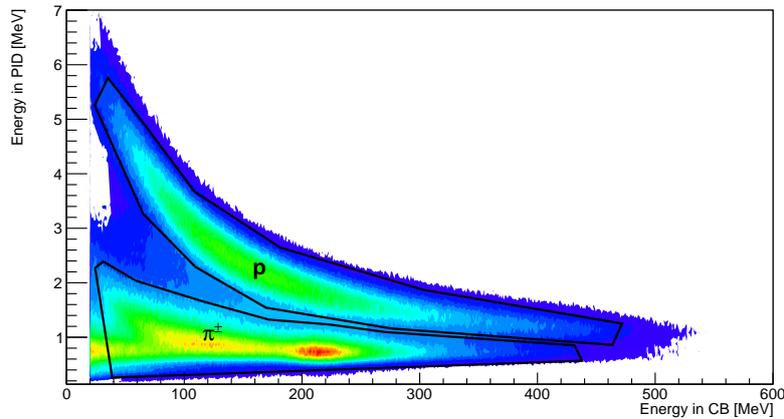


Figure 1. Scheme of the experimental setup.

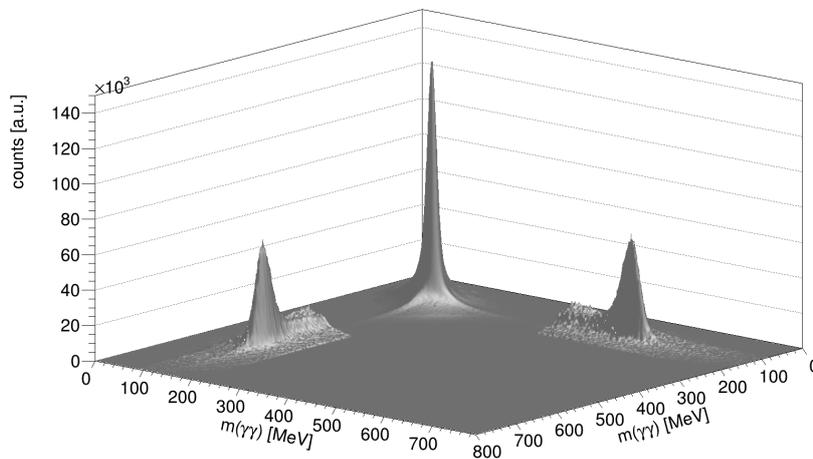
## 3. Data Analysis

The analyzed reactions were  $\gamma d \rightarrow \eta\pi^0 p(n)$  (photoproduction off quasi-free protons bound in the deuteron),  $\gamma d \rightarrow \eta\pi^0 n(p)$  (photoproduction off quasi-free neutrons bound in the deuteron),  $\gamma d \rightarrow \eta\pi^+ n(p)$  (photoproduction off quasi-free protons bound in the deuteron) and  $\gamma d \rightarrow \eta\pi^- p(n)$  (photoproduction off quasi-free neutrons bound in the deuteron). As a first step charged particles were distinguished from neutral particles. This was done, using the veto detectors and the PID and in TAPS with time-of-flight vs. energy spectra. The  $\eta$  and  $\pi^0$  were detected via their  $2\gamma$  decay channels and after applying a  $\chi^2$  test, identified via a invariant mass



**Figure 2.** Energy deposited in the PID plotted against energy plotted in the CB. The polygons depict the regions in which a charged particle is considered to be a proton or a charged pion

analysis. The remaining neutral particles of the  $\chi^2$  test (in case of 3 or 5 neutral hits) were treated as neutron candidates. Charged pions and protons in the crystal ball were identified with dE-E cuts as shown in figure 2. To get rid of background from competing reactions a precise missing mass analysis was performed using a Monte Carlo simulation of the detector systems for each respective reaction.



**Figure 3.** Invariant mass of the best  $\gamma\gamma$  pairs after the  $\chi^2$  test

#### 4. Results

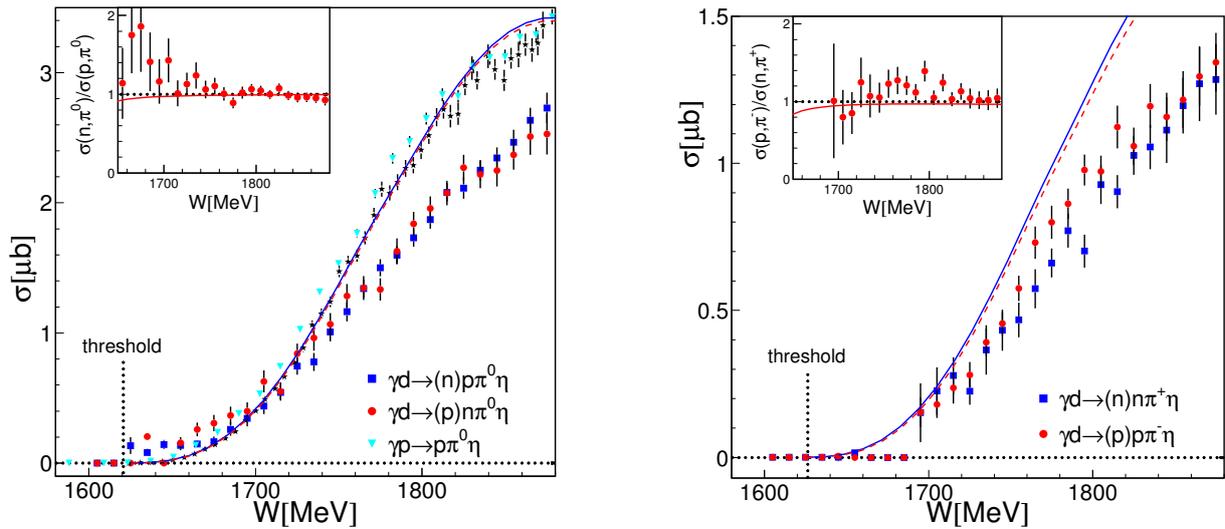
The total cross sections of the reactions  $\gamma d \rightarrow \eta\pi^0 p(n)$ ,  $\gamma d \rightarrow \eta\pi^0 n(p)$ ,  $\gamma d \rightarrow \eta\pi^- p(p)$  and  $\gamma d \rightarrow \eta\pi^+ n(n)$  were extracted from experimental data. Figure 5 shows the ratios of the total cross sections as function of the final state center of mass Energy. It is clearly visible, that the cross sections fulfill the following equations:

$$\begin{aligned}\sigma(\gamma p \rightarrow \eta \pi^0 p) &= \sigma(\gamma n \rightarrow \eta \pi^0 n) \\ 2\sigma(\gamma p \rightarrow \eta \pi^+ n) &= 2\sigma(\gamma n \rightarrow \eta \pi^- p)\end{aligned}\quad (1)$$

Together with a isospin analysis considering the proper Clebsch-Gordon coefficients, this confirms, that the reaction has a dominant contribution from photoexcitation of a  $\Delta^*$ -resonance decaying via either a  $\eta\Delta$  or  $\pi N^*$  intermediate state. The specific cascade can be identified via the analysis of the invariant mass distribution of the nucleon-meson pairs. A preliminary analysis considering invariant mass distributions as well as angular distributions suggests, that quasifree  $\eta\pi$  photoproduction is dominated by the following cascade decay:

$$\gamma N \rightarrow D_{33}(1700) \rightarrow \eta\Delta(1232)\eta\pi N$$

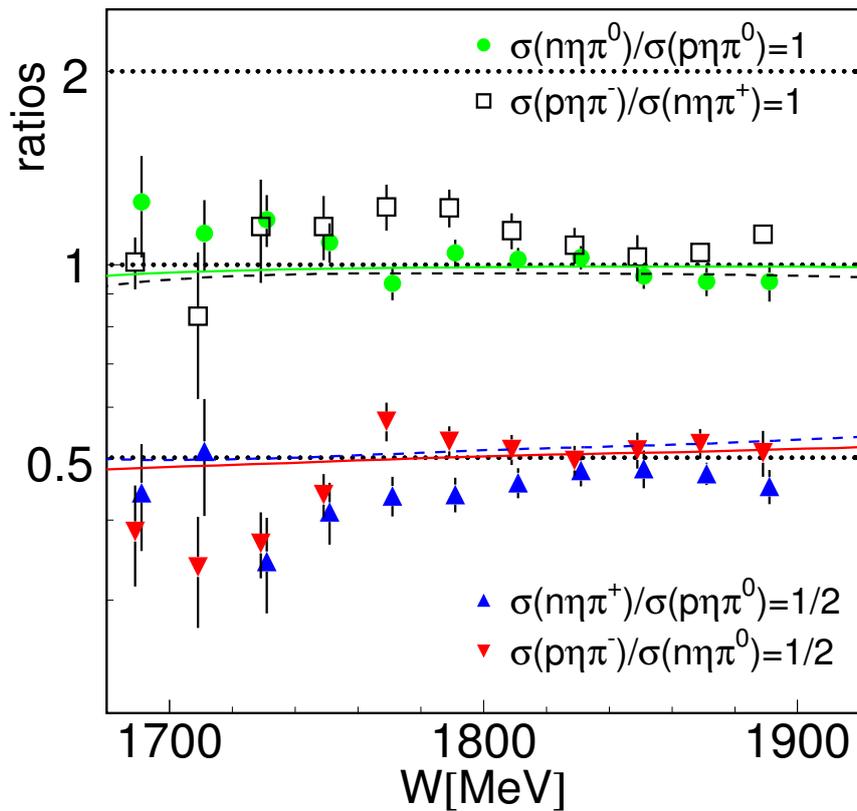
Final results will also include an analysis of the coherent photoproduction of  $\eta\pi$  pairs off the deuteron. This is a well suited tool to investigate the formation of  $\eta$ -mesic nuclei. Significant contributions are thought to come from events where the pion takes most of the available kinetic energy and the relative moment of  $\eta$  and nucleus is small, which increases the probability of forming a bound state.



**Figure 4.** Very preliminary total cross sections for the  $\pi^0\eta N$  left and for the  $\pi^\pm\eta N$  final states as function of reconstructed final state invariant mass  $W(N_p, \pi^0, \eta)$

## References

- [1] R.S.Bhalerao and L.C.Liu, Phys. Rev. Lett. 54 (1985) 865.
- [2] L.C.Liu and Q.Haider, Phys. Rev. C 34 (1986) 1845.
- [3] B. Krusche et al., Phys. Rev. Lett. 74 (1995) 3736.
- [4] B. Krusche et al., Phys. Lett. B 397 (1997) 171.
- [5] V. Hejny et al., Eur. Phys. J. A 6 (1999) 83.
- [6] V. Hejny et al., Eur. Phys. J. A 13 (2002) 493.
- [7] M. Pfeiffer et al., Phys. Rev. Lett. **92**, 252001 (2004).
- [8] T. Mersmann et al., Phys.Rev.Lett. **98** 242301 (2007)
- [9] F. Pheron et al., Phys. Lett. B **709**, 21 (2012).
- [10] B. Krusche and S. Schadmand, Prog. Part. Nucl. Phys. **51**, 399 (2003).



**Figure 5.** Very preliminary ratios of total cross sections as function of final state invariant mass  $W(N_p, \pi, \eta)$ .

- [11] B. Krusche, *Eur. Phys. J. Special Topics* **198**, 199 (2011).
- [12] H. Herminghaus et al., *IEEE Trans. Nucl. Sci.*, **30**, 3274, (1983).
- [13] K.-H. Kaiser et al., *Nucl. Instrum. Methods A*, **593**, 159, (2008).
- [14] I. Anthony et al., *Nucl. Instrum. Methods A*, **301**, 230, (1991).
- [15] S. J. Hall et al., *Nucl. Instrum. Methods A*, **368**, 698, (1996).
- [16] J. C. McGeorge et al., *Eur. Phys. J. A*, **37**, 129, (2008).
- [17] D. Watts., *Proc. of the 11th International Conference on Calorimetry in Particle Physics, Perugia, Italy, 2004, World Scientific, Singapore, 2005*, (2005).
- [18] A. Starostin et al., *Phys. Rev. C*, **64**, 055205, (2001).
- [19] R. Novotny., *IEEE Trans. Nucl. Sci.*, **38**, 379, (1991).
- [20] A. R. Gabler et al., *Nucl. Instrum. Methods A*, **346**, 168, (1994).