

# Search for $\eta$ -mesic ${}^3\text{He}$ in non-mesonic final state

Oleksandr Rundel<sup>1,\*</sup>, Magdalena Skurzok<sup>1</sup>, and Aleksander Khreptak<sup>1</sup> for the WASA-at-COSY Collaboration

<sup>1</sup>M. Smoluchowski Institute of Physics, Jagiellonian University, Cracow, Poland

**Abstract.** The experiment on searching for  $\eta$ -mesic  ${}^3\text{He}$  nucleus was performed in May 2014 at COSY accelerator in Juelich by WASA-at-COSY Collaboration. The measurements were carried out using ramped beam technique which allows for the slow and continuous beam momentum change near the threshold of  $\eta$  meson creation. The luminosity was obtained based on  $pd \rightarrow {}^3\text{He}\eta$  reaction and quasielastic proton-proton scattering. The bound state of  $\eta$ -meson and  ${}^3\text{He}$  nucleus is searched for in  $pd \rightarrow {}^3\text{He}2\gamma$  and  $pd \rightarrow {}^3\text{He}6\gamma$  channels. The analysis is still in progress and the estimated upper limit value is on the level of few nanobarns.

## 1 Introduction

The  $\eta$ -mesic nuclei were postulated more than 30 years ago [1] and currently are one of the hottest topic in nuclear physics from experimental and theoretical point of view [2–6]. The experimental searches for  $\eta$ -mesic helium-3 have been performed by MAMI [7, 8] and COSY11 [9, 10] collaborations but no bound state was observed. In the experiment studying  $\eta$  meson photoproduction [7, 8], a peak-like structure was observed though its interpretation is still a subject of discussion. In earlier experiments on hadronic  $\eta$  production [9, 10], the upper limit for bound state creation cross section upper  $70\text{ nb}$  was obtained.

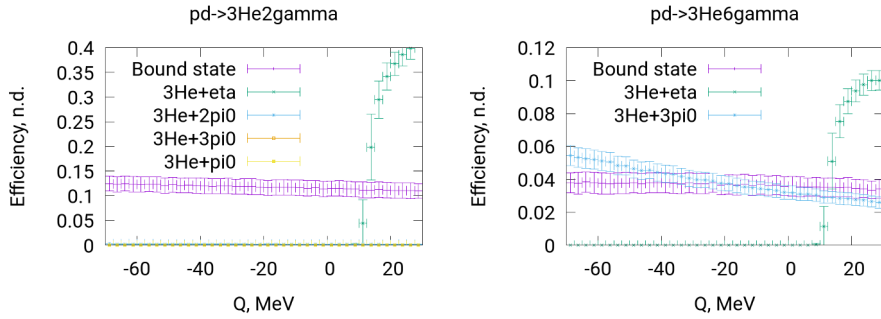
Earlier, WASA-at-COSY collaboration has performed measurements in order to search for  $\eta$  mesic  ${}^4\text{He}$  nucleus [11–14] and no bound state was observed. In current experiment [15], the statistics gathered is the largest one ever obtained for this experimental conditions. The expected result accuracy is of few nanobarns order of magnitude. In case if the bound state is observed, the width is expected to be larger then the binding energy [16].

## 2 Luminosity estimation

One of the most important questions in current experiment is data normalization. For this purpose we obtain luminosity analyzing reactions that have known cross sections. The luminosity as a function of the beam momentum is needed. This dependence can be essential because of small beam trajectory changes during each accelerator cycle that can influence the target overlapping [17]. Luminosity estimation is based on  $pd \rightarrow {}^3\text{He}\eta$  and  $pd \rightarrow ppn_{\text{spectator}}$  reactions [18, 19].

The registration efficiencies have been obtained from Monte Carlo simulations. For  $pd \rightarrow {}^3\text{He}\eta$  reaction simulation, the cross sections and angular distributions have been taken

\*e-mail: alexrndl@gmail.com



**Figure 1.** Efficiency distribution for different reactions obtained in  $pd \rightarrow {}^3\text{He}2\gamma$  and  $pd \rightarrow {}^3\text{He}6\gamma$  reactions analysis. Systematic uncertainties are taken into account.

from references [20, 23]. For quasielastic proton-proton scattering, the simulation was performed in the frame of spectator model analogously as in analysis described in ref. [21, 22]. The distribution of Fermi motion momentum for nucleons in target deuteron was calculated using PARIS model [24] while the proton-proton scattering cross sections were taken from SAID database [25]. The obtained quasielastic scattering cross section was multiplied by a factor of 0.955 taking into account the shading effect [26].

The events from  $pd \rightarrow {}^3\text{He}\eta$  and  $pd \rightarrow ppn_{\text{spectator}}$  reactions are identified by algorithms that were applied for raw data and Monte Carlo simulation results in order to obtain the number of experimental events and to calculate the efficiency. The integrated luminosity in this experiment is calculated by the formula

$$\int Ldt = \frac{N_{\text{data}}}{\epsilon \sigma} = \frac{N_{\text{data}} S_{MC}}{N_{MC} \sigma}, \quad (1)$$

where  $N_{\text{data}}$  and  $N_{MC}$  are the number of events extracted from data and Monte Carlo simulation correspondingly,  $\sigma$  is the reaction's cross section, and  $\epsilon$  is the efficiency.  $S_{\text{trigger}}$  is the trigger's scaling factor set up during the measurements.  $S_{MC}$  is the total number of generated Monte Carlo events.

### 3 Searching for a bound state

The  $pd \rightarrow {}^3\text{He}\gamma\gamma$  and  $pd \rightarrow {}^3\text{He}6\gamma$  channels are investigated to search for  ${}^3\text{He} - \eta$  bound state. In these channels, the bound state would be visible in case of direct bound  $\eta$  decay without being absorbed by any nucleon:  $pd \rightarrow ({}^3\text{He}\eta)_{\text{bound}} \rightarrow {}^3\text{He}\gamma\gamma$  and  $pd \rightarrow ({}^3\text{He}\eta)_{\text{bound}} \rightarrow {}^3\text{He}\pi^0\pi^0\pi^0 \rightarrow {}^3\text{He}6\gamma$ .

For efficiency estimation, the Monte Carlo simulation for bound state production and decay was performed. The distribution of  ${}^3\text{He} - \eta$  relative momentum was calculated by S. Hirenzaki and H. Nagahiro [27]. The simulation was carried out with assumption that  ${}^3\text{He}$  plays a role of spectator. Coupled  $\eta$  meson decay on two  $\gamma$  quanta is assumed to be isotropic in the  $\eta$  rest frame and the decay into three  $\pi^0$  mesons was simulated assuming uniform phase space population. Each of  $\pi^0$  decays into two  $\gamma$  quanta isotropically in  $\pi^0$  rest frame.

The  $pd \rightarrow {}^3\text{He}\gamma\gamma$  and  $pd \rightarrow {}^3\text{He}6\gamma$  events identification is based on conditions applied for particle registration time, angles, and kinematic magnitudes such as invariant and missing

mass. For  $pd \rightarrow {}^3\text{He}\gamma\gamma$  reaction the background processes efficiency was decreased to the level below 0.5% while the bound state decay acceptance is about 10% in the whole beam momentum range (Fig. 1).

In the excess energy region  $Q_{^3\text{He}\eta} < 10 \text{ MeV}$  the acceptance for  $pd \rightarrow {}^3\text{He}\eta$  reaction is neglectable because of small  $\theta$  angle for  ${}^3\text{He}$  emission direction. This property is useful for searching the bound state near the threshold.

Actually, the analysis is still in progress. In case if the bound state is observed, a peak on the excitation curve for both  $pd \rightarrow {}^3\text{He}\gamma\gamma$  and  $pd \rightarrow {}^3\text{He}6\gamma$  reactions will be obtained.

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