

## Search for $\eta$ -mesic Helium with the WASA-at-COSY detector

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**Abstract.** A search for the  ${}^4\text{He} - \eta$  bound state via exclusive measurement of the excitation function for the  $dd \rightarrow {}^3\text{He}p\pi^-$  reaction, was performed at the Cooler Synchrotron COSY-Jülich with the WASA-at-COSY detection system. The data were taken during a slow acceleration of the beam from 2.185 GeV/c to 2.400 GeV/c crossing the kinematic threshold for the  $\eta$  production in the  $dd \rightarrow {}^4\text{He}\eta$  reaction at 2.336 GeV/c. The corresponding excess energy in the  ${}^4\text{He} - \eta$  system varied from -51.4 MeV to 22 MeV. The shape of the excitation function for the  $dd \rightarrow {}^3\text{He}p\pi^-$  was examined. No signal of the  ${}^4\text{He} - \eta$  bound state was observed in the excitation function.

### 1 Introduction

It is conceivable that neutral mesons such as  $\eta, \bar{K}, \omega, \eta', J/\Psi$  [1–5] can form bound states with atomic nuclei. In this case the binding is exclusively due to the strong interaction and the bound state - *mesic nucleus* - can be considered as a meson moving in the mean field of the nucleons in the nucleus. Due to the strong attractive  $\eta$ -nucleon interaction [6, 7], the  $\eta$ -mesic nuclei are ones of the most promising candidates for such states.

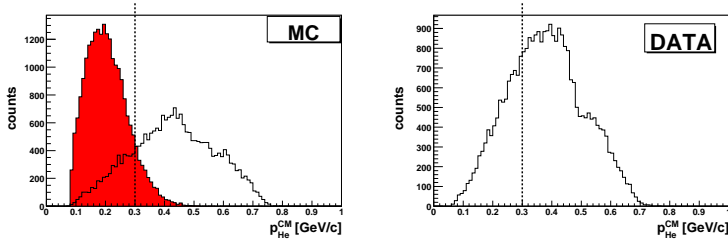
The existence of  $\eta$ -mesic nuclei was postulated in 1986 by Haider and Liu [11], and since then a search for such states was conducted in many experiments in the past [12, 13, 5, 14–17] and is being continued at COSY [18–22], JINR [5], J-PARC [23] and MAMI [16, 17]. Many promising indications were reported, however, so far there is no direct experimental confirmation of the existence of mesic nucleus.

A very strong final state interaction (FSI) observed in the  $dd \rightarrow {}^4\text{He}\eta$  reaction close to kinematical threshold and interpreted as possible indication of  ${}^4\text{He} - \eta$  bound state [24] suggests, that  ${}^4\text{He} - \eta$  system is a good candidate for experimental study of possible binding. This conclusion is strengthened by the predictions in reference [7]. However, as it was stated in [25, 26], the theoretical predictions for width and binding energy of the  $\eta$ -mesic nuclei are strongly dependent on the not well known subthreshold  $\eta$ -nucleon interaction. Therefore, direct measurements which could confirm the existence of the bound state, are mandatory.

### 2 Method

In our experimental studies, we used the deuteron-deuteron collisions at energies around the  $\eta$  production threshold for production of the  $\eta - {}^4\text{He}$  bound state. We expect, that the decay of such state proceeds via absorption of the  $\eta$  meson on one of the nucleons in the  ${}^4\text{He}$  nucleus leading to excitation of the  $N^*(1535)$  resonance which subsequently decays in pion-nucleon pair. The remaining three nucleons play a role of spectators and they are likely to bind forming  ${}^3\text{He}$  or  ${}^3\text{H}$  nucleus.

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**Fig. 1.** (Left plot) Distribution of the  ${}^3\text{He}$  momentum in the CM system simulated for the processes leading to the creation of the  ${}^4\text{He}\eta$  bound state:  $dd \rightarrow ({}^4\text{He}\eta)_{\text{bound}} \rightarrow {}^3\text{He}p\pi^-$  (red area) and of the direct  $dd \rightarrow {}^3\text{He}p\pi^-$  reaction (black line). The simulation was done for a momentum of the deuteron beam of 2.307 GeV/c. The Fermi momentum parametrization was taken from [28]. (Right plot) Experimental distribution of the  ${}^3\text{He}$  momentum in the CM system. In both plots the dashed line demarcates the "signal-poor" and the "signal-rich" regions. Decrease of the counts at 0.48 GeV/c is due to geometry of the border of the barrel and the end-caps of the Scintillator Barrel detector which was used in the  $p - \pi^-$  identification process. This region has no relevance in the next steps of the analysis.

According to the discussed scheme, there exist four equivalent decay channels of the  $({}^4\text{He} - \eta)_{\text{bound}}$  state.

In our experiment we concentrated on the  ${}^3\text{He}p\pi^-$  decay mode. In the case of a similar system, the  ${}^4\text{He}$  hypernucleus, it was observed that in the  $\pi^-$  decay channel the decay mode  ${}^4\text{He} \rightarrow {}^3\text{He}p\pi^-$  is dominant [27].

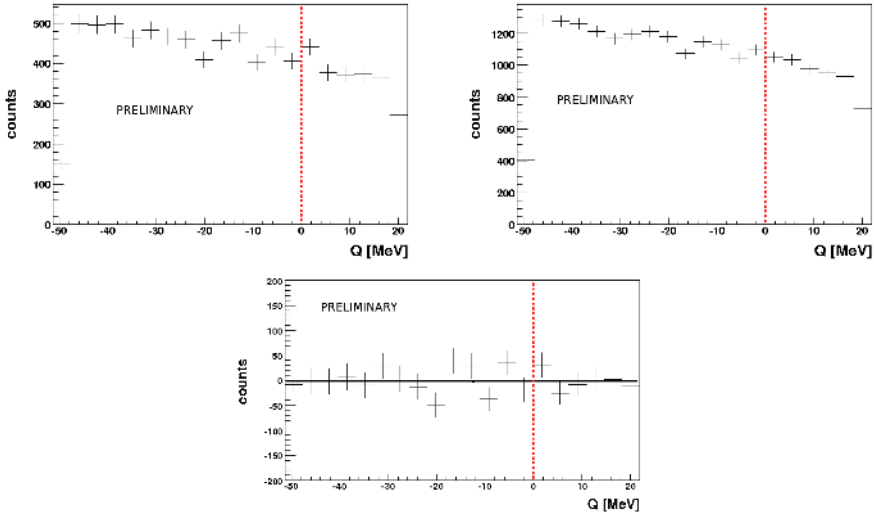
The outgoing  ${}^3\text{He}$  nucleus plays the role of a spectator and, therefore, we expect that its momentum in the CM frame is relatively low and can be described by the Fermi momentum distribution of nucleons in the  ${}^4\text{He}$  nucleus. This signature allows to suppress background from reactions leading to the  ${}^3\text{He}p\pi^-$  final state but proceeding without formation of the intermediate  $({}^4\text{He} - \eta)_{\text{bound}}$  state and, therefore, resulting on the average in much higher CM momenta of  ${}^3\text{He}$  (see Fig. 1).

The principle of the present experiment was based on the measurement of the excitation function of the  $dd \rightarrow {}^3\text{He}p\pi^-$  reaction for energies in the vicinity of the  $\eta$  production threshold and on the selection of events with low  ${}^3\text{He}$  CM momenta. In the case of existence of the  ${}^4\text{He} - \eta$  bound state we expected to observe a resonance-like structure in the excitation function at the reaction CM energies below the  $\eta$  threshold.

### 3 Experiment

In June 2008 we performed a search for the  $\eta$ -mesic  ${}^4\text{He}$  by measuring the excitation function of the  $dd \rightarrow {}^3\text{He}p\pi^-$  reaction near the  $\eta$  meson production threshold using the WASA-at-COSY detector [22]. During the experimental run the momentum of the deuteron beam was varied continuously within each acceleration cycle from 2.185 GeV/c to 2.400 GeV/c, crossing the kinematic threshold for the  $\eta$  production in the  $dd \rightarrow {}^4\text{He}\eta$  reaction at 2.336 GeV/c. This range of beam momenta corresponds to the variation of  ${}^4\text{He} - \eta$  excess energy from -51.4 MeV to 22 MeV.

We constructed two types of excitation function for the  $dd \rightarrow {}^3\text{He}p\pi^-$  reaction. They differ in the selection of the events and in the way of normalizing the data points. The first excitation function uses events from the "signal-rich" region corresponding to the  ${}^3\text{He}$  CM momenta below 0.3 GeV/c. The counts are plotted as a function of the excess energy ( $Q$ ) as it is shown Fig. 2(top left). The obtained function is smooth and no clear signal, which could be interpreted as a resonance-like structure, is visible. A similar dependence was obtained for events originating from the "signal-poor" region corresponding to  ${}^3\text{He}$  CM momenta above 0.3 GeV/c (see Fig. 2(top right)). We checked also for possible structures in the difference between the discussed functions for the "signal-rich" and "signal-poor" region. We multiplied the function for the "signal-poor" region by a factor chosen in such a way, that the difference of the two functions for the second lowest beam momentum bin is equal to zero.



**Fig. 2.** Excitation function for the  $dd \rightarrow {}^3\text{He}p\pi^-$  reaction for the "signal-rich" region corresponding to  ${}^3\text{He}$  momentum below 0.3 GeV/c (upper left) and the "signal-poor" region with  ${}^3\text{He}$  momentum above 0.3 GeV/c (upper right). Difference of the excitation functions for the "signal-rich" and "signal-poor" regions after the normalization to the second bin of  $Q$  is shown in the lower panel. The black solid line represents a straight line fit. The threshold of  ${}^4\text{He} - \eta$  is marked by the vertical dashed line.

This difference is presented in Fig. 2(bottom). The obtained dependence is flat and is consistent with zero. No resonance structure is visible.

In addition, further observables were taken into account in order to reduce the background.

We selected the kinetic energy of protons smaller than 200 MeV and of pions from the interval (180, 400) MeV. We applied also a cut on the relative  $p - \pi^-$  angle in the CM system in the range of ( $140^\circ - 180^\circ$ ).

The absolute value of the integrated luminosity in the experiment was determined using the  $dd \rightarrow {}^3\text{He}n$  reaction and the relative normalization of points of the  $dd \rightarrow {}^3\text{He}p\pi^-$  excitation function was based on the quasi-elastic proton-proton scattering [29].

Similarly as in the intermediate stage of the analysis (Fig. 2), in the final excitation function we observe no structure which could be interpreted as a resonance originating from the decay of the  $\eta$ -mesic  ${}^4\text{He}$ .

## 4 Outlook

In November 2010 a new two-week measurement was performed with WASA-at-COSY. We collected data with approximately 20 times higher statistics. In addition to the  $dd \rightarrow {}^3\text{He}p\pi^-$  channel we registered also the  $dd \rightarrow {}^3\text{He}n\pi^0$  reaction. The data analysis is undergoing (see [31]).

## Acknowledgements

This work has been supported by the Polish National Science Center as grants No. 0320/B/H03/2011/40 and 2011/01/B/ST2/00431, by the FFE funds of Forschungszentrum Jülich, by the European Commission under the 7th Framework Programme through the 'Research Infrastructures' action of the 'Capacities' Programme. Call: FP7-INFRASTRUCTURES-2008-1, Grant Agreement N. 227431 and by the Foundation for Polish Science - MPD program, co-financed by the European Union within the European Regional Development Fund.

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