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Search for the η-mesic ^{4}He with WASA-at-COSY

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Abstract. We conduct a search for the He $-$ η bound state with the WASA-at-COSY facility measuring the excitation functions for the reaction channels: $dd \rightarrow {}^{3}\mathrm{He}p\pi^{-}$ and $dd \rightarrow {}^{3}\mathrm{He}n\pi^{0}$, where the outgoing $N - \pi$ pairs originate from the conversion of the η meson on a nucleon inside the He nucleus. Two dedicated experiments were performed at the Cooler Synchrotron COSY-Jülich with the WASA detector. The analysis of the 2008 data shows no signal of the ^{4}He $-$ η bound state. An upper limit for the cross-section for the bound state formation and decay in the process $dd \rightarrow ({}^{4}\mathrm{He} - \eta)_{bound} \rightarrow {}^{3}\mathrm{He}p\pi^{-}$, was determined at the 90 % confidence level. In November 2010 a new data set was collected.

1 Introduction

The existence of η-mesic nuclei was postulated in 1986 by Haider and Liu [1]. The η-mesic nucleus is created exclusively due to the strong interaction and the bound state can be considered as a meson moving in the mean field of the nucleons in the nucleus.

The search for the η-mesic bound state has been and it is being performed by many experiments [2–14], so far no firm experimental confirmation of the existence of mesic nuclei has been performed. The discovery of the η-mesic nuclei would be interesting on its own but it would be also valuable to understand the $\eta - N$ interaction and for the study of the in-medium properties of the N^{*} resonance [15] and of the η meson [16]. It could also help to determine the flavor singlet component of the η wave function [17].

The observation of a strong enhancement in the total production cross-section and the phase variation of the scattering amplitude in the close-to-threshold region in the $dd \rightarrow {}^{4}\mathrm{He}\eta$ reaction is interpreted as a possible indication of ^{4}He$-\eta$ bound state [18, 19]. This conclusion is supported by the predictions in Reference [20, 21].

2 Method

We carry out a search for η-mesic helium with the WASA detector, installed at the cooler synchrotron COSY of Research Center Jülich [22]. The signature of the η – ^{4}He bound state is derived measuring the excitation functions for reactions at energies around the η production threshold. We expect that the decay of such a state proceeds via the absorption of the η meson on one of the nucleons in the

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^{4}He nucleus leading to the excitation of the N^* (1535) resonance which subsequently decays in a pion-nucleon pair. The remaining three nucleons are spectators likely binding forming a ^{3}He or ^{3}H nucleus.

This scenario is schematically presented in the Fig. 1.

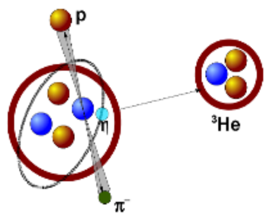

Figure 1. Schematic picture of the $(^4\text{He} - \eta)_{bound} \rightarrow {}^3\text{He}p\pi^-$ decay. In the first step the η meson is absorbed on one of the neutrons and the $N^\star$ resonance is formed. Next, the N* decays into a $p - \pi^-$ pair. The ^{3}He is a spectator.

The outgoing ^{3}He nucleus is a spectator and, therefore, we expect that its momentum in the c.m. frame is relatively low and can be approximated by the Fermi momentum distribution of nucleons inside the ^{4}He nucleus [23]. This signature allows us to suppress background from reactions leading to the $^3\text{He}p\pi^-$ and $^3\text{He}n\pi^0$ final state but without forming the intermediate $(^4\text{He}-\eta)_{bound}$ state and, therefore, resulting on average in much higher c.m. momenta of ^{3}He (see Fig. 2).

The principle of the experiment is based on the measurement of the excitation function of the $dd \rightarrow {}^3\text{He}p\pi^-$ and the $dd \rightarrow {}^3\text{He}n\pi^0$ reactions for energies in the proximity of the η production threshold selecting events with low ^{3}He center-of-mass (c.m.) momenta. In the case of existence of the $^4\text{He}-\eta$ bound state we would expect to observe a resonance-like structure in the excitation function below the $^4\text{He}-\eta$ threshold.

3 The experiment

Two experiments dedicated to the search of the η-mesic helium were conducted up to now using the WASA-at-COSY detector. The first one, was performed in June 2008, by measuring the excitation

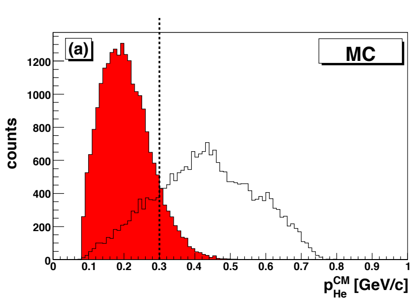

Figure 2. Distribution of the ^{3}He momentum in the c.m. system simulated for the processes leading to the creation of the $^4\text{He}\eta$ bound state: $dd \rightarrow (^4\text{He}\eta)_{bound} \rightarrow {}^3\text{He}p\pi^-$ (red area) and of the phase-space $dd \rightarrow {}^3\text{He}p\pi^-$ reaction (black line).

function of the $dd \to^3$ He$p\pi^-$ reaction near the η meson production threshold [24]. The analysis does not show any structure which could be interpreted as a resonance originating from the decay of the η-mesic ^{4}He. The upper limit for the cross-section for the bound state formation and decay in the process $dd \to (^4\text{He}{-}\eta)_{bound} \to^3Hep\pi^-$, was determined on the 90 % confidence level and it varies from 20 nb to 27 nb for the bound state width ranging from 5 MeV to 35 MeV, respectively. The upper limits depend mainly on the width of the bound state and only slightly on the binding energy.

During the second experiment, in November 2010, two channels of the η-mesic helium decay were measured: $dd \to (^4\text{He-}\eta)_{bound} \to {}^3\text{He}p\pi^-$ and $dd \to (^4\text{He-}\eta)_{bound} \to {}^3\text{He}n\pi^0 \to {}^3\text{He}n\gamma\gamma$ [7]. During the experimental run the momentum of the deuteron beam was varied continuously within each acceleration cycle from 2.127 GeV/c to 2.422 GeV/c, crossing the kinematic threshold for η production in the $dd \to^4$He η reaction at 2.336 GeV/c. This range of beam momenta corresponds to a variation of the $^4\text{He} - \eta$ excess energy from -70 MeV to 30 MeV. Data were taken for about 155 hours. The average luminosity was estimated counting for triggers used for the elastic proton-proton scattering (L=$8.15 \cdot 10^{30} cm^{-2} s^{-1}$). Taking into account the fact that two reactions were measured, in total more than 40 times higher statistics were collected than in the 2008 run.

The ^{3}He was identified in the Forward Detector based on the ΔE-E method. In case of the $dd \to (^4\text{He-}\eta)_{bound} \to {}^3\text{He}n\pi^0 \to {}^3\text{He}n\gamma\gamma$ reaction the neutral pion π^0 is reconstructed in the Central Detector from the invariant mass of two gamma quanta originating from its decay (Fig. 3, left panel) while the neutron four-momentum is calculated using the missing mass technique (Fig. 3, right panel).

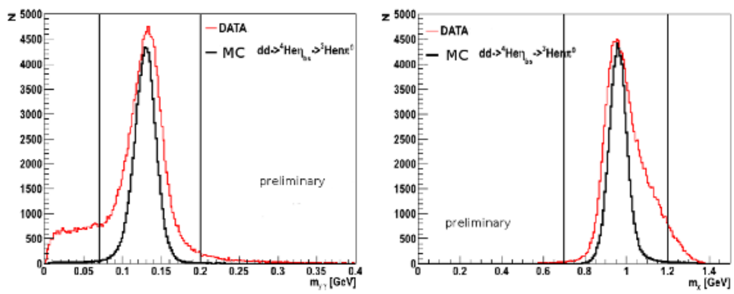

Figure 3. (left)Distribution of the invariant mass of two gamma quanta. The black vertical lines indicate the cut applied to select pion candidates. (right) Distribution of the missing mass of $^3\text{He}\pi^0$. The maximum from neutron mass is visible. The black vertical lines indicate the selection of the neutron candidates. The experimental spectrum is depicted by the red line while MC simulations are shown as a black line. The presented experimental spectra are based on about 2.5 % of overall data.

4 Summary

We are performing a search for the $^4\text{He}{-}\eta$ bound state measuring the excitation function for the $dd \to^3$He$p\pi^-$ and the $dd \to^3$He$n\pi^0$ reactions. The measurement was carried out with the internal deuteron beam of the COSY accelerator scattered on a deuteron pellet target and with the WASA-at-COSY detection system used for registration of the reaction products.

In the analysis of 2008 data no signal from η-mesic ^{4}He was observed. The cross-section upper limit for the bound state formation and decay in the process $dd \to (^4\text{He}{-}\eta)_{bound} \to^3Hep\pi^-$, was determined at the 90 % confidence level and it varies from 20 nb to 27 nb for the bound state width ranging from 5 MeV to 35 MeV, respectively. The upper limits depend mainly on the width of the bound state and only slightly on the binding energy. 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 $dd \to {}^3\mathrm{He}p\pi^-$ channel we registered also the $dd \to {}^3\mathrm{He}n\pi^0$ reaction. The analysis of the new data is in progress.

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