SEARCH FOR η-MESIC ^{4}He WITH WASA-at-COSY

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1.1 Introduction

The investigation of the exotic objects in the nuclear physics is a proven method for revealing many interesting properties of nuclear systems and for accessing to an unexplored areas of physics. The recent progress in the spectroscopy of pionic and kaonic atoms, as well as pionic and kaonic nuclei has permitted to obtain deeper insights into the meson-nucleus interaction and the in-medium behaviour of spontaneous chiral symmetry breaking [1].

Analogically to the other exotic nuclear systems, the investigation of the η-mesic nuclei would provide many interesting informations about the η-N interaction, N* in-medium properties [2] and would deepen our knowledge of the fundamental structure of the η meson [3]. The η meson is electrically neutral, therefore such a system can be formed only via the strong interaction which distinguishes it qualitatively from pionic atoms where the binding is the effect of the sum of the attractive electromagnetic force and the repulsive strong interaction.

The search of the η - mesic nucleus was performed in many experiments in the past [4, 5, 6, 7, 8, 9] and is being continued at COSY [12, 10, 11], JINR [6], J-PARC [13] and MAMI [9]. Many promising indications where reported, however, so far there is no direct experimental confirmation of the existence of mesic nucleus. In the region of the light nuclei systems such as η-He or η-T, the observation of the strong enhancement in the total cross-section and the phase variation in the close-to-threshold region provided strong evidence to the hypothesis of the existence of a pole in the scattering matrix which can correspond to the bound state [14]. However, as it was stated in [15, 16], the theoretical predictions of width and binding energy of the η-mesic nuclei is strongly dependent on the not well known subtreshold η-nucleon interaction. Therefore, the direct measurements which could confirm the existence of the bound state, are mandatory.

1.2 Experiment

In June 2008 we performed a search for the $^4\mathrm{He}-\eta$ bound state by measuring the excitation function of the $dd \rightarrow ^3\mathrm{He} p \pi^-$ reaction near the η meson production threshold using the WASA-at-COSY detector[17]. 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 η production in the $dd \rightarrow ^4\mathrm{He}\,\eta$ reaction at 2.336 GeV/c. This range of beam momenta corresponds to the variation of $^4\mathrm{He}-\eta$ excess energy from -51.4 MeV to 22 MeV. The experimental method is based on measuring the excitation function for $dd \rightarrow ^3\mathrm{He} p\pi^-$ and a search for a resonance-like structure below the $^4\mathrm{He}-\eta$ threshold. The relative angle between the outgoing $p-\pi^-$ pair which originates from the decay of the N*(1535) resonance created via absorption of the η meson on a nucleon in the ^{4}He nucleus, is 180° in the N* reference frame and is smeared by about 30° in the reaction center-of-mass frame (CM) due to the Fermi motion of nucleons inside the $^4\mathrm{He}-\eta$ nucleus. The ^{3}He plays the role of a spectator and therefore its momentum in the CM frame is relatively low and determined only by the Fermi momentum distribution in the $^4\mathrm{He}-\eta$. This signature distinguishes production of mesic helium from other reactions, in which the distribution of the ^{3}He momentum reaches much higher values.

Figure 1.1 presents the not normalized excitation functions for a "signal-rich" region: $p^{CM}_{He} <$ 0.3 GeV/c (top) and a "signal-poor" region: $p^{CM}_{He} >$ 0.3 GeV/c in 20 intervals in beam momentum (middle). Also, the difference between two regions is shown in the same Figure (bottom).

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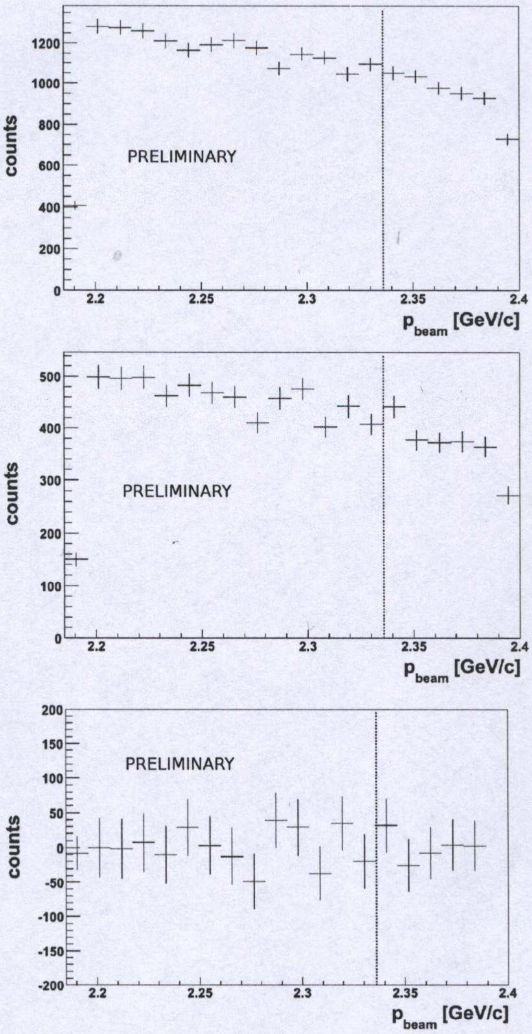

Figure 1.1: Excitation function for the $dd \to {}^3\mathrm{He}p\pi^-$ reaction for the "signal-poor" region ^{3}He momentum above 0.3 GeV/c (top plot) and the "signal-rich" region, low ^{3}He momentum below 0.3 GeV/c (middle plot). The excitation functions are not normalized. The beam momentum corresponding to the ${}^4\mathrm{He}-\eta$ kinematical threshold is marked as a red dashed line. The difference between the "signal-rich" and the "signal-poor" regions is shown at the bottom plot.

The figure indicates no structure below the kinematical threshold where the signal is expected. In order to estimate the maximum upper limit for the cross-section for the production of the bound state via $dd \to {}^4\mathrm{He}-\eta_{bound} \to {}^3\mathrm{He}\,p\,\pi^-$ reaction, the Breit-Wigner function along with the linear background was fitted to the normalized "signal-rich" region. The absolute normalization was obtained based on the $dd \to {}^3\mathrm{He}n$ reaction, whereas the luminosity dependence of the beam momentum was determined using the quasi-elastic $dd \to pp(n_{sp}n_{sp})$ reaction. The integrated luminosity equals $L = 117.9 \pm 13.6$ nb^{-1}.

1.3 Outlook

In November 2010 a new two-week measurement was performed with WASA-at-COSY. We collected the 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 data analysis is undergoing. After two weeks of measurement with an estimated luminosity of $4 \cdot 10^{30}$ cm^{-2} s^{-1}, we expect a statistical sensitivity of a few nb (σ). A non-observation of this signal will significantly lower the upper limit for the existence of the bound state.

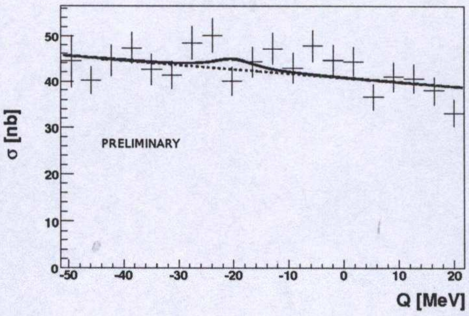

Figure 1.2: Normalized excitation function for the $dd \rightarrow {}^3\mathrm{He}p\pi^-$ reaction for the "signal-rich" region. The Breit-Wigner function $f(Q) = \frac{A\cdot(\frac{\Gamma}{2})^2}{(Q-E_{BE})^2+(\frac{\Gamma}{2})^2}$ along with the linear function was fitted. The parameters Γ and E_{BE} were fixed to the value of -20 MeV and 10 MeV respectively. The free parameter A is consistent with zero within the obtained accuracy. The dotted red line represents the linear background.

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