SEARCH FOR η-MESIC NUCLEI WITH WASA-at-COSY*

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We search for an evidence of η-mesic He with the WASA detector. Two dedicated experiments were performed at the Cooler Synchrotron COSY-Jülich. The experimental method is based on the measurement of the excitation functions for the two reaction channels: $dd \rightarrow {}^3\text{He}\, p\pi^-$ and $dd \rightarrow {}^3\text{He}\, n\pi^0$, where the outgoing N–π pairs originate from the conversion of the η meson on a nucleon inside the He nucleus. In this contribution, the experimental method is shortly described and the current status of the analysis is presented.

1. Introduction

One can define exotic atoms and nuclei as systems in which one of the standard component particles is replaced by an exotic particle *e.g.* pionic atoms, where the negatively charged pion replaces an electron. The studies of exotic systems were proved to be very fruitful in the past, *e.g.* experiments on hypernuclei started a new branch of investigations — the strangeness physics. More recently, studies of meson–nucleus interaction have attracted a lot of interest because they serve not only to better understand the meson–nucleon interaction but also provide information about meson properties embedded in nuclear matter, which are directly linked with the postulated partial restoration of the chiral symmetry and the structure of the QCD vacuum [1–15]. In general, meson–nucleon binding is the result of an

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interplay of electromagnetic and strong forces but in the case of neutral mesons it is exclusively due to the strong interaction, thus the mesic nucleus can be considered as a meson captured in the mean field of the nucleons.

The η-mesic nucleus is one of the most promising candidates for such a state because of the relatively strong η-nucleon interaction [16, 17]. Already in 1986, Haider and Liu postulated the hypothesis of a η-mesic nucleus [18]. Since then, many tries have been undertaken to experimentally confirm its existence but without any conclusive result.

2. Experimental method

The search for the η-mesic bound states can be divided into two categories. In-direct-search methods consist of study η production cross section right above the threshold to infer its subthreshold behaviour, and to establish binding conditions *e.g.* expressed as η-nucleus scattering length. Although, such studies [19–22] provided important experimental indications in the case of ^{3}He and ^{4}He systems, where they showed the existence of an *s*-wave pole in the scattering matrix, they are not able to give the decisive answer whether the pole corresponds to a virtual or bound state as it was stated by [23]. The second category contains direct-search methods, which look for a subthreshold manifestation of a bound state in the excitation functions for chosen decay modes. This approach impose special experimental requirements *e.g.* very accurate knowledge of the total reaction energy, and good control over the luminosity and acceptance for consecutive energy bins.

Both aforementioned conditions are fulfilled with the WASA detector at COSY synchrotron. The WASA detection system [24] provides a high acceptance combined with the possibility of registering all final state particles. Also, we take advantage of the COSY synchrotoron ramped beam mode, which permits to smoothly change the beam momentum within one acceleration cycle and, in consequence, to obtain an excellent reaction energy resolution. We carry out the search of an η-mesic helium produced in proton–deuteron and deuteron–deuteron collisions. We concentrate on the η–He decay mode, in which the trapped η meson is absorbed on one of the nucleons in the He nucleus. The nucleon is excited to the $N^*(1535)$ state, which subsequently decays into a pion–nucleon pair. In the case of the $dd \rightarrow (\eta\text{–}^4\text{He})_{\text{bound}}$ channel, the remaining three nucleons are likely to form a ^{3}He or ^{3}H nucleus. The outgoing ^{3}He nucleus is expected to have a relatively low momentum in the center-of-mass (c.m.) frame that can be approximated by the Fermi momentum distribution of the nucleons inside the ^{4}He nucleus. The process described above should result in a resonance-like structure in the excitation function of the $dd \rightarrow ^3\text{He}\,p\pi^-$ and the $dd \rightarrow ^3\text{He}\,n\pi^0$ reactions if we select events with low ^{3}He center-of-mass momenta.

3. Experiments

So far, three dedicated measurements were done with WASA-at-COSY. The first experiment was performed in June 2008 by measuring the excitation function of the $dd \to {}^3\mathrm{He}\,p\pi^-$ reaction near the η-meson production threshold. An upper limit for the formation and decay of the bound state in the process $dd \to ({}^4\mathrm{He}\text{–}\eta)_{\mathrm{bound}} \to {}^3\mathrm{He}\,p\pi^-$ at the 90% confidence level, was determined from 20 nb to 27 nb for the bound state width ranging from 5 MeV to 35 MeV, respectively [25]. During the second experiment, in November 2010, two channels of the η-mesic helium decay were registered: $dd \to ({}^4\mathrm{He}\text{–}\eta)_{\mathrm{bound}} \to {}^3\mathrm{He}\,p\pi^-$ and $dd \to ({}^4\mathrm{He}\text{–}\eta)_{\mathrm{bound}} \to {}^3\mathrm{He}\,n\pi^0 \to {}^3\mathrm{He}\,n\gamma\gamma$ [26–28] in the excess energy range from -70 MeV to 30 MeV.

The preliminary excitation functions for the "signal-rich" region, corresponding to the low ${}^3\mathrm{He}$ momenta c.m. frame, in which we expect the highest signal to noise ratio, are presented in Fig. 1.
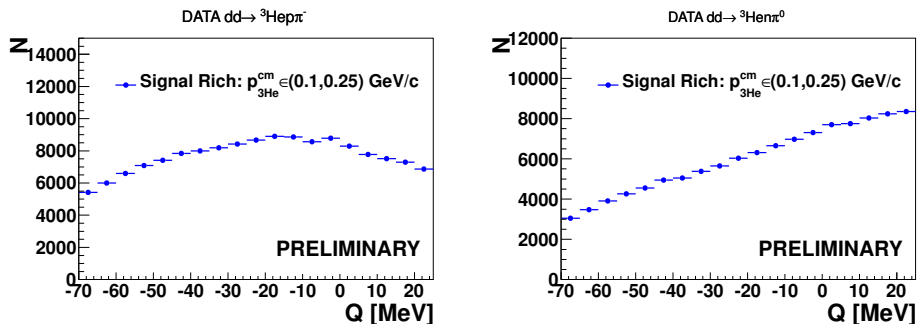

Fig. 1. Preliminary excitation function for the $dd \to {}^3\mathrm{He}\,p\pi^-$ and for the $dd \to {}^3\mathrm{He}\,n\pi^0$ reactions under condition that the ${}^3\mathrm{He}$ momentum in c.m. frame is in the range from 0.1 to 0.25 GeV/c ("signal-rich" area). The distributions are not corrected for efficiency.

The predictions given in [29], state a cross section of 4.5 nb. This can be confronted with the expected sensitivity from the 2010 data, which is of the order of few nb. Therefore, the ongoing analysis should be able to reveal the hypothetical signal from the decay of mesic nucleus in ${}^4\mathrm{He}$ state.

4. Future prospects

In May 2014, we carried out the third complementary experiment in proton–deuteron collisions, aiming at the exploration of the ${}^3\mathrm{He}$ mesic nuclei. This was motivated by the recent experimental and theoretical results [8, 23, 30–32], which favour η–${}^3\mathrm{He}$ over η–${}^4\mathrm{He}$ bound states. In addition to the previously described decay mode via $N^\star$ resonance, we also considered

a second mechanism, in which the bound η decays, while still "orbiting" around a nucleus *e.g.*, via $pd \rightarrow (^3\mathrm{He}\text{--}\eta)_{\mathrm{bound}} \rightarrow {}^3\mathrm{He}\,6\gamma$ reaction. Although, the predicted cross section for this decay mode is relatively small (0.4 nb [23]) the background is expected to be highly suppressed. A week-long measurement with an average luminosity of about $6 \times 10^{30}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ allowed to collect high statistics of data. The analysis is in progress.

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