SEARCH FOR THE ^{3}He–η BOUND STATE VIA $pd \to pd\pi^0$ REACTION*

A. Khreptak[a], M. Skurzok[a,b], O. Rundel[a]

for the WASA-at-COSY Collaboration

[a]M. Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland
[b]INFN, Laboratori Nazionali di Frascati, 00044 Frascati, Italy

(Received October 7, 2019)

We present status and perspectives of the search for the η-mesic helium nuclei via $pd \to pd\pi^0$ reaction with the WASA-at-COSY. In this report, the experimental method is shortly described and preliminary excitation function is presented.

DOI:10.5506/APhysPolB.51.361

1. Introduction

Meson–nucleus bound systems are considered to be very interesting objects in the modern nuclear and hadronic physics. The existence of the η-nuclear bound states was first predicted by Haider and Liu [1] in 1986. Experimental searches have been performed by several experiments [2–13], although, so far, there is no direct experimental confirmation of the existence of mesic nuclei.

Three experiments dedicated to the search for η-mesic helium have been performed by the WASA-at-COSY Collaboration in Forschungszentrum Jülich (Germany). The measurements were carried out with high statistics and high acceptance with the WASA detection setup [14] in deuteron–deuteron (^{4}He–η) and proton–deuteron (^{3}He–η) fusion reactions.

Excitation functions determined for $dd \to ^3\text{He}p\pi^-$ [8–10], $dd \to \to ^3\text{He}n\pi^0$ [9, 10], $pd \to ^3\text{He}2\gamma$ and $pd \to ^3\text{He}6\gamma$ [11, 12] processes do not reveal any direct narrow structure which could be a signature of the bound state. The upper limits at the 90% confidence level vary from 2.5 to 3.5 nb for the first process, from 5 to 7 nb for the second process, from 2 to 15 nb for the last two processes within the binding energy range from 0 to 60 MeV and the width from 2.5 to 40 MeV.

* Presented at the 3[rd] Jagiellonian Symposium on Fundamental and Applied Subatomic Physics, Kraków, Poland, June 23–28, 2019.

The analysis assuming a mechanism of bound state decay via N^* excitation and its decay into the nucleon–pion pair ($pd \to pd\pi^0$, $pd \to ppn\pi^0$, $pd \to ppp\pi^-$) is in progress [15]. The preliminary results for the first channel are presented in next sections.

2. Identification of the $pd \to pd\pi^0$ process

The selection of the events corresponding to the bound state production in the $pd \to pd\pi^0$ reaction was carried out using criteria based on the Monte Carlo simulations.

The deuterons and proton–pion pairs were registered in the Forward and Central Detector, respectively. Proton identification is based on the pattern of energy deposited in the electromagnetic calorimeter and thin plastic scintillator. The events corresponding to the charged pions registered in the detector were subtracted (left panel of Fig. 1).

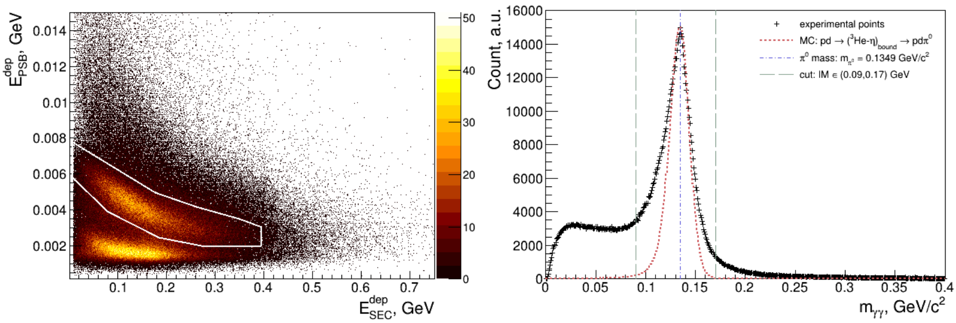

Fig. 1. Left panel: Experimental spectra of the energy loss in the Central Detector. The selected area for protons is marked with white line. Right panel: π^0 identification based on invariant mass spectrum of two gamma quanta. Vertical dashed lines indicate the applied selection cut criteria.

The neutral pions π^0 four-vectors were reconstructed by combining the four-vectors of gamma quanta pairs registered in the electromagnetic calorimeter and selected under the condition imposed on their invariant mass (right panel of Fig. 1).

The selection of the region corresponding to η-mesic bound state was performed applying cuts in the π^0-proton opening angle as well as in the deuteron scattering angle spectra based on MC simulations. The spectra with marked boundaries are presented in Fig. 2.

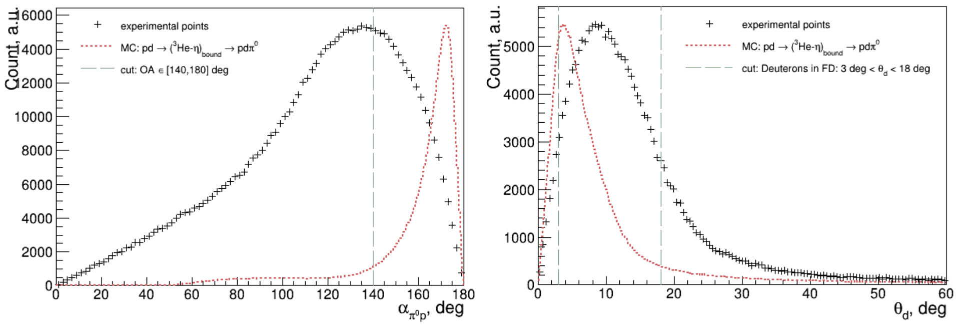

Fig. 2. Left panel: π^0-proton opening angle in the center-of-mass frame $\theta^{\rm cm}_{\pi^0 p}$. Right panel: Deuteron scattering angle spectrum in the laboratory frame. Vertical dashed lines indicate the applied selection cuts.

3. Efficiency and luminosity

The reconstruction efficiency was determined based on the Monte Carlo simulation for the $pd \to (^3\mathrm{He}\text{–}\eta)_{\rm bound} \to pd\pi^0$ process taking into account the response of detection system and selection criteria applied in the data analysis and is presented in the left panel of Fig. 3.

The integrated luminosity dependence on the excess energy, used for normalization of the excitation functions, was determined based on quasi free $pd \to ppn_{\rm spectator}$ reaction and is presented in the left panel of Fig. 3. Total integrated luminosity is equal to $L = (2295 \pm 3_{\rm stat} \pm 91_{\rm syst})$ nb^{-1}. The detailed description of the luminosity determination can be found in Ref. [15].

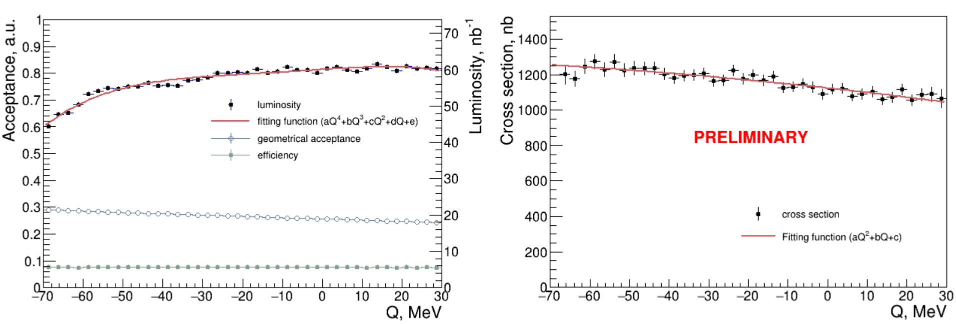

Fig. 3. Left panel: Efficiency for $pd \to pd\pi^0$ reactions as a function of excess energy Q and integrated luminosity calculated for the experimental data for the quasi-free $pd \to ppn_{\rm spectator}$ reaction. Right panel: Excitation function for $pd \to pd\pi^0$ process after applying selection criteria described in the text.

4. Cross section

In order to determine excitation function, the number of events identified as $pd \to pd\pi^0$ in each excess energy interval was corrected for the efficiency calculated for the signal process and divided by the corresponding integrated luminosity $L(Q)$ (left panel of Fig. 3). The obtained preliminary excitation function for about 50% of collected statistics does not show any structure for energies below the η-production threshold which could be the signature of the narrow ^{3}He–η bound state existence and is presented in the right panel of Fig. 3.

5. Summary

We search for evidence of η-mesic helium with the WASA-at-COSY detector. The excitation functions, determined for the $dd \to ^3\mathrm{He}p\pi^-$, $dd \to ^3\mathrm{He}n\pi^0$, $pd \to ^3\mathrm{He}2\gamma$ and $pd \to ^3\mathrm{He}6\gamma$ reactions, do not reveal a structure which could be interpreted as a narrow mesic nucleus. The upper limits of the total cross sections for the bound state production and decay in these processes were determined. The preliminary excitation function for the $pd \to pd\pi^0$ channel was determined. The analysis of the $pd \to ppn\pi^0$ and $pd \to ppp\pi^-$ channels is in progress.

We acknowledge the financial support from the National Science Centre, Poland (NCN) through grant No. 2016/23/B/ST2/00784, from the Ministry for Science and Higher Education through grants No. 7150/E338/M/2017, 7150/E-338/M/2018 and from the Jagiellonian University through grant DSC2019 No. N17/MNS/000024.

REFERENCES

[1] Q. Haider, L.C. Liu, *Phys. Lett. B* **172**, 257 (1986).
[2] J. Smyrski *et al.*, *Phys. Lett. B* **649**, 258 (2007).
[3] B. Krusche *et al.*, *J. Phys.: Conf. Ser.* **349**, 012003 (2012).
[4] F. Pheron *et al.*, *Phys. Lett. B* **709**, 21 (2012).
[5] V. Metag, M. Nanova, E.Ya. Paryev, *Prog. Part. Nucl. Phys.* **97**, 199 (2017).
[6] S.D. Bass, P. Moskal, *Rev. Mod. Phys.* **91**, 015003 (2019).
[7] M. Skurzok, P. Moskal, W. Krzemień, *Prog. Part. Nucl. Phys.* **67**, 445 (2012).
[8] P. Adlarson *et al.*, *Phys. Rev. C* **87**, 035204 (2013).
[9] P. Adlarson *et al.*, *Nucl. Phys. A* **959**, 102 (2017).
[10] M. Skurzok *et al.*, *Phys. Lett. B* **782**, 6 (2018).
[11] O. Rundel, Ph.D. Thesis, Jagiellonian Univ. [arXiv:1905.04544 [hep-ex]].
[12] O. Rundel, M. Skurzok, A. Khreptak, *EPJ Web Conf.* **199**, 02029 (2019).
[13] P. Moskal, J. Smyrski, *Acta Phys. Pol. B* **41**, 2281 (2010).
[14] H.-H. Adam [WASA-at-COSY Collaboration], arXiv:nucl-ex/0411038.
[15] A. Khreptak, O. Rundel, M. Skurzok, *EPJ Web Conf.* **199**, 05026 (2019).