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Searching for η-mesic Helium with WASA-at-COSY facility

Oleksandr Rundel[1,⋆], Oleksandr Khreptak[1], Magdalena Skurzok[1], Wojciech Krzemien[2], and Pawel Moskal[1]
for the WASA-at-COSY Collaboration

[1] *M. Smoluchowski Institute of Physics, Jagiellonian University, 30-059 Cracow, Poland*
[2] *National Centre for Nuclear Research, 05-400 Otwock, Świerk, Poland*

Abstract. The search for the ^{4}He-η and ^{3}He-η bound states was performed with the WASA-at-COSY facility using a ramped beam technique in 2008, 2010 and 2014, respectively. The 2008 and 2010 data analyses has already been completed and resulted in the upper limits for the total cross sections for the η-mesic ^{4}He production in $dd \rightarrow {}^3\mathrm{He}n\pi^0$ and $dd \rightarrow {}^3\mathrm{He}p\pi^-$ processes. No narrow structure which could be interpreted as a bound state was observed. The experiment carried out in 2014 collected the largest data sample for ^{3}He-η in the world. The data analysis is in progress. This article presents results of the 2010 data analysis and preliminary results of the 2014 data analysis.

1 Introduction

The existence of η-mesic nuclei in which the η meson is bound with the nucleus with the strong interaction was postulated by Haider and Liu already in 1986 [1], however till now no experiment confirmed it empirically. Recent theoretical studies of hadronic- and photo- production of the η meson, reveal the possibility of the existence of η-mesic bound states for light nuclei like ^{4}He and ^{3}He [2, 3], and give hope of their observation in deuteron-deuteron and proton-deuteron fusion reactions, respectively. Interested readers could find valuable information in the recent reviews on mesic nuclei search [4–12].

This article presents brief description of the search for the η-mesic Helium performed by the WASA-at-COSY collaboration carried out in 2008, 2010 (^{4}He-η nucleus) and 2014 (^{3}He-η nucleus). The results concerning ^{4}He-η bound states have been already published in references [4, 13–15] while analysis of the data taken in 2014 is still in progress.

2 Experiment

The search for η-mesic Helium was carried out using the WASA detector system [16] with a deuteron target of pellet type installed at the COSY synchrotron [17] in the Jülich Research Center in Germany. COSY provided deuteron and proton beam for the search for ^{4}He-η and ^{3}He-η bound systems, respectively. The main advantage of the used experimental setup was the possibility of continuous beam energy changing and the simultaneous registration of all particles taking part in the reaction. The

⋆e-mail: alexrndl@gmail.com

deuteron beam momentum was varying from 2.127 GeV/c to 2.422 GeV/c, while the proton beam momentum from 1.426 GeV/c to 1.635 GeV/c, crossing the kinematic threshold for η production.

The signatures of the η-mesic nuclei are searched for by studying the excitation function for the chosen decay channels of the ^{4}He-η and ^{3}He-η systems, formed in *d-d* and *p-d* collisions, respectively.

3 Results for the search of ^{4}He-η bound states

The first experiment carried out in June 2008, was focused on the measurement of the excitation function of the $dd \rightarrow {}^3\mathrm{He}p\pi^-$ process near the η production threshold covering the excess energy range from -51.4 MeV up to 22 MeV. The excitation function does not reveal the resonance structure which could be interpreted as the η-mesic ^{4}He. Therefore, only the upper limit of the total cross-section for the bound state formation and decay in the $dd \rightarrow ({}^4\mathrm{He}\text{-}\eta)_{bound} \rightarrow {}^3\mathrm{He}p\pi^-$ reaction was determined which varies from 20 nb to 27 nb at the confidence level of 90% [18, 19].

The second experiment, performed in November 2010, brought in about a 10 times higher statistic with respect to the previous measurement. The search for the ^{4}He-η bound state was performed for two reactions $dd \rightarrow {}^3\mathrm{He}n\pi^0$ and $dd \rightarrow {}^3\mathrm{He}p\pi^-$ via the measurement of the excitation function for each of them in the excess energy range Q$\in$(-70,30) MeV. Since no narrow peak, which could originate from the mesic nuclei, was observed the upper limit of the total cross section for each process was determined independently at the confidence level of 90%. The obtained upper limits vary from 21 to 36 nb for the $dd \rightarrow ({}^4\mathrm{He}\text{-}\eta)_{bound} \rightarrow {}^3\mathrm{He}n\pi^0$ process and from 5 to 9 nb for the $dd \rightarrow ({}^4\mathrm{He}\text{-}\eta)_{bound} \rightarrow {}^3\mathrm{He}p\pi^-$ process for the bound state width ranging from 5 to 50 MeV [4, 14].

A new analysis taking into account the isospin relation between the $n\pi^0$ and $p\pi^-$ pairs outgoing from the N^* decay (probability of $p\pi^-$ pair production is two times higher than in case of $n\pi^0$ production) results in the upper limit varying in the range from 2.5 to 3.5 nb for the $dd \rightarrow ({}^4\mathrm{He}\text{-}\eta)_{bound} \rightarrow {}^3\mathrm{He}n\pi^0$ process and from 5 to 7 nb for the $dd \rightarrow ({}^4\mathrm{He}\text{-}\eta)_{bound} \rightarrow {}^3\mathrm{He}p\pi^-$ process (for the fixed binding energy B_s=30 MeV and width range $\Gamma \in$(5,50) MeV). The green area presents the systematics errors.

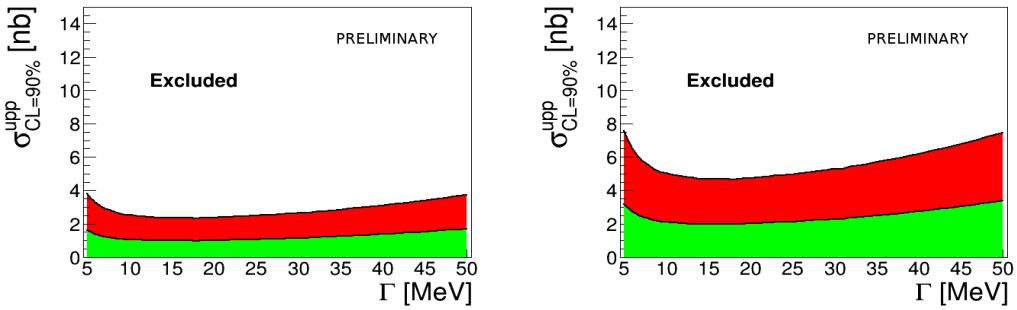

Figure 1. Upper limit of the total cross-section for $dd \rightarrow ({}^4\mathrm{He}\text{-}\eta)_{bound} \rightarrow {}^3\mathrm{He}n\pi^0$ (left panel) and $dd \rightarrow ({}^4\mathrm{He}\text{-}\eta)_{bound} \rightarrow {}^3\mathrm{He}p\pi^-$ (right panel) reaction as a function of the width of the bound state. The binding energy was fixed to 30 MeV. The upper limit was determined via the simultaneous fit for both channels. The green area denotes the systematic uncertainties.

4 Status of the search for ^{3}He-η nuclei

The experiment for searching ^{3}He-η mesic nuclei was carried out in May 2014. Three processes corresponding to the three mechanisms were measured: (i) absorption of the η meson by one of the nucleons, which subsequently decays into *N*-π pair e.g.: $pd \rightarrow ({}^3\mathrm{He}\text{-}\eta)_{bound} \rightarrow ppp\pi^-$, (ii) decay of

the η -meson while it is still "orbiting" around a nucleus e.g.: $pd \rightarrow (^3\text{He-}\eta)_{bound} \rightarrow {}^3\text{He}6\gamma$ or $pd \rightarrow (^3\text{He-}\eta)_{bound} \rightarrow {}^3\text{He}2\gamma$ reactions and (iii) η meson absorption by few nucleons [20, 21] e.g.: $pd \rightarrow (^3\text{He-}\eta)_{bound} \rightarrow ppn$ or $pd \rightarrow (^3\text{He-}\eta)_{bound} \rightarrow pd$. At present, the analysis of data is in progress. There are preliminary results of luminosity estimation obtained based on $pd \rightarrow {}^3\text{He}\eta$ reaction. The estimated average luminosity is equal to about $4.5{\cdot}10^{30}$ cm^{-2}s^{-1}. For the purpose of this research, the luminosity determination is crucial, both above and below the η meson production threshold. This will be determined based on the quasi-free proton-proton scattering reaction using methods described in [22, 23].

5 Conclusion

The upper limits for the cross section for the creation of ^{4}He-η mesic nuclei have been preliminary determined for $dd \rightarrow {}^3\text{He}n\pi^0$ and $dd \rightarrow {}^3\text{He}p\pi^-$ processes after analysing the data obtained in experiments in June 2008 and November 2010. The analysis of data obtained in the experiment for the search of ^{3}He-η mesic nuclei that took place in May 2014 is in progress. Based on preliminary calculations we expect to reach sensitivity of the cross section of about 10 nb which is much lower than in case of COSY-11 result obtained for $pd \rightarrow (^3\text{He-}\eta)_{bound} \rightarrow ppp\pi^-$ reaction (270 nb) [24].

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References

[1] Q. Haider, L. C. Liu, Phys. Lett. **B172**, 257 (1986)
[2] S. Wycech, A. M. Green, J. A. Niskanen, Phys. Rev. **C52**, 544 (1995)
[3] C. Wilkin, Phys. Rev. **C47**, 938 (1993)
[4] M. Skurzok, W. Krzemień, O. Rundel and P. Moskal, Acta. Phys. Polon. **B47**, 503 (2016)
[5] A. Gal et al., Acta Phys. Polon. **B45**, 673 (2014)
[6] H. Machner, J. Phys. **G42**, 043001 (2015)
[7] C. Wilkin, Acta Phys. Polon. **B47**, 249 (2016)
[8] B. Krusche, C. Wilkin, Prog. Part. Nucl. Phys. **80**, 43 (2014)
[9] N. G. Kelkar et al., Rept. Prog. Phys. **76**, 066301 (2013); Acta Phys. Polon. B46, 113 (2015)
[10] S. Bass et al., Acta Phys. Polon. **B47**, 373 (2016)
[11] Q. Haider, L. C. Liu, Int. J. Mod. Phys. **E24**, 1530009 (2015)
[12] P. Moskal, Few Body Syst. **55**, 667 (2014); Acta Phys. Polon. **B47**, 97 (2016)
[13] W. Krzemień, P. Moskal, M. Skurzok, Few Body Syst. **55**, 795 (2014)
[14] M. Skurzok, *arXiv:1509:01385*, Ph.D. thesis, Jagiellonian University (2015)
[15] W. Krzemień, *arXiv:1202:5794*, Ph.D. thesis, Jagiellonian University (2011)
[16] WASA-at-COSY Collaboration: H.-H. Adam *et al., arXiv:nucl-ex/0411038* (2004)
[17] R. Maier, Nucl. Instrum. Meth. **A390**, 1 (1997)
[18] W. Krzemien, P. Moskal, M. Skurzok, Acta Phys. Polon. **B45**, 689 (2014)
[19] P. Adlarson *et al.*, Phys. Rev. **C87**, 035204 (2013)
[20] C. Wilkin, Acta Phys. Polon. **B45**, 603 (2014)
[21] S. Wycech, W. Krzemien, Acta Phys. Polon. **B45**, 745 (2014)
[22] P. Moskal and R. Czyżykiewicz, AIP Conf. Proc. **950**, 118 (2007)
[23] P. Moskal et al., Phys. Rev. **C79**, 015208 (2009)
[24] P. Moskal, J. Smyrski, Acta Phys. Polon. **B41**, 2281 (2010)