Search for the exotic nuclear matter with WASA-at-COSY

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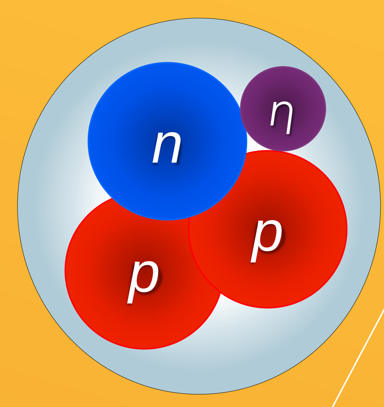
The negatively charged pions and kaons can be trapped in the Coulomb potential of atomic nucleus forming so called mesonic atoms. It is also conceivable that a neutral meson could be bound to a nucleus. In this case the binding is exclusively due to the strong interaction and hence such object can be referred to as a mesic nucleus. Here the most promising candidate is the η-mesic nucleus since the η-nucleon interaction is strongly attractive.
The existence of mesic nuclear matter was postulated over thirty years ago [1], however, until now it has not been confirmed experimentally. Such system in the form of the η-mesic helium may be created for example in the deuteron-deuteron or proton-deuteron fusion.
The search for η-mesic nuclei is performed by WASA-at-COSY group since 2008. We search for the signal of the production of the ^{4}He-η and ^{3}He-η bound states using the WASA detector system with a deuteron target of pellet type installed at the COSY synchrotron. COSY provided deuteron and proton beam for the search for ^{4}He-η and ^{3}He-η mesic nuclei, respectively.

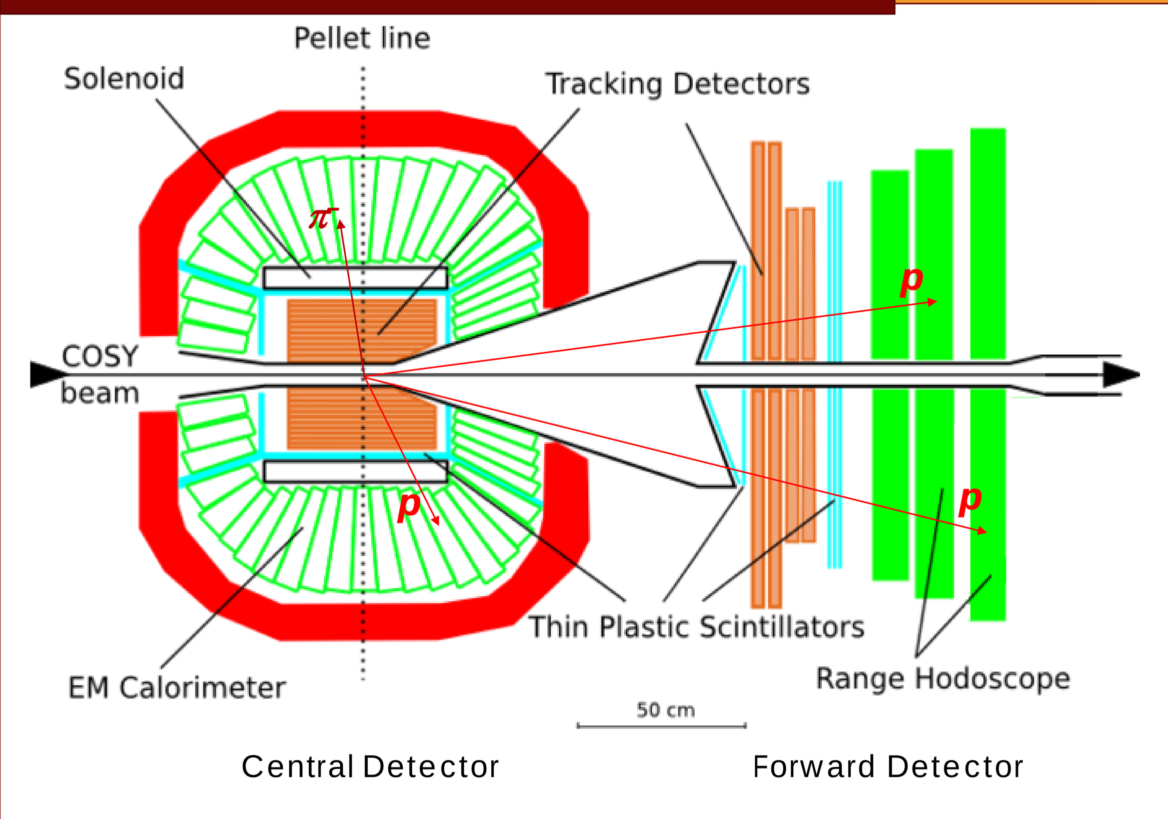
η-mesic nucleus
^{3}He-η



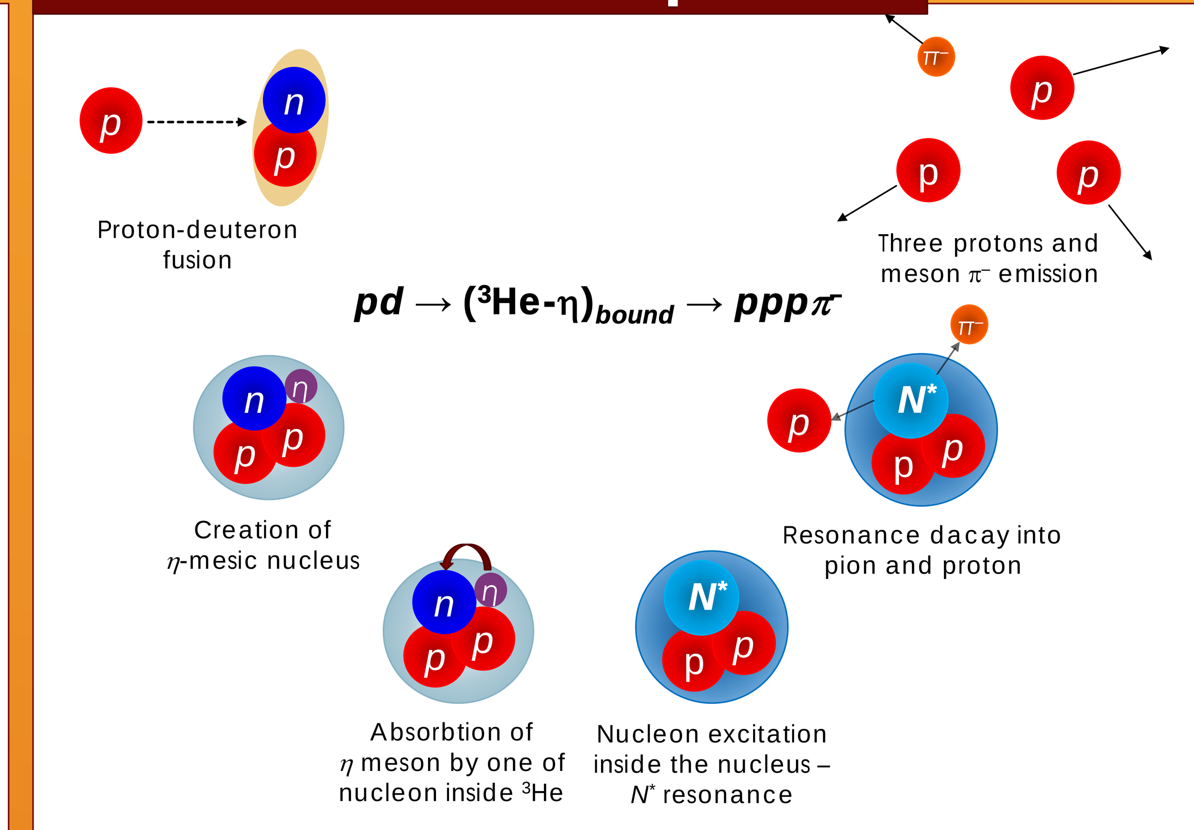
strong interaction

$$m_{bound} = m_{^3He} + m_\eta - B_s$$

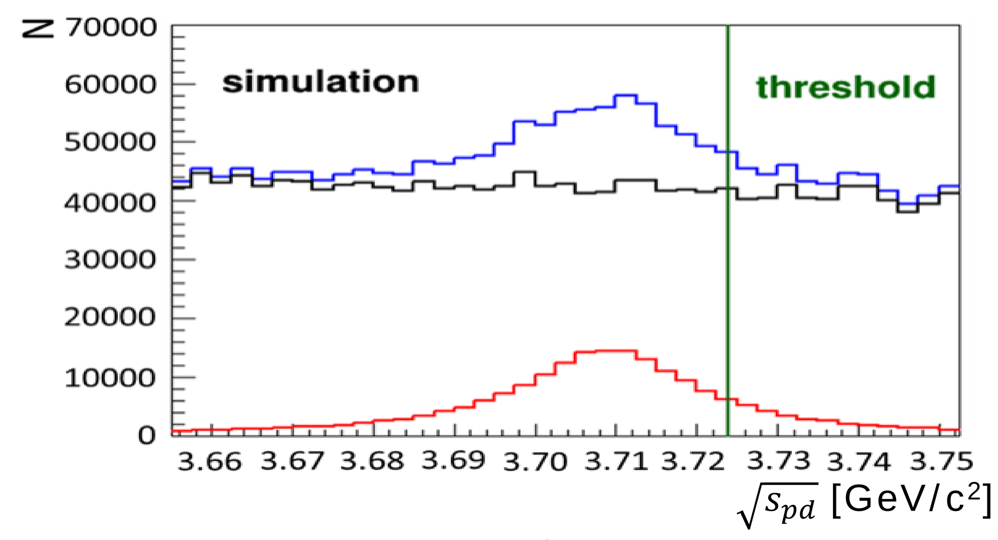
WASA-at-COSY detector



Scheme of reaction process



Experimental method



$pd \to ppp\pi^-$ and $pd \to (^3$He-$\eta)_{bound} \to ppp\pi^-$
$pd \to ppp\pi^-$
$pd \to (^3$He-$\eta)_{bound} \to ppp\pi^-$
$(^3$He-$\eta)_{bound}$ existence manifested by resonant-like structure below η production threshold

Results for the search for ^{4}He-η mesic nuclei

In 2008 and 2010 we performed the measurements dedicated to search for the ^{4}He-η bound states in deuteron-deuteron fusion reaction. The η-mesic nuclei were searched via studying of excitation function for the $dd \to {}^3$He$p\pi^-$ (2008 and 2010) [2, 3] and $dd \to {}^3$He$n\pi^0$ (2010) [3, 4] reactions in the vicinity of the ^{4}Heη threshold.

Our first results did not reveal any statistically significant signal from the η-mesic ^{4}He nucleus. The upper limit of the cross-section for the bound state formation and decay in the $dd \to (^4$He-$\eta)_{bound} \to {}^3$He$p\pi^-$ process was determined at the 90% confidence level [2] and it varies from 20 nb to 27 nb as the width of the bound state varies from 5 MeV to 35 MeV.

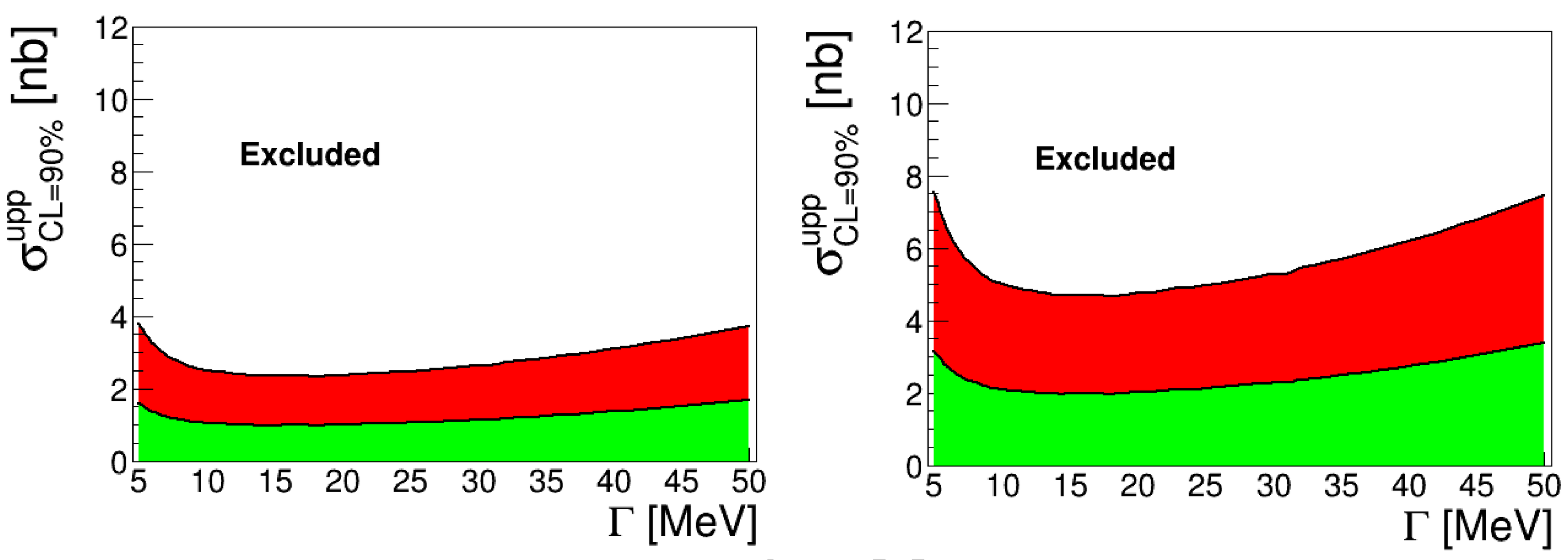


Fig. 1 [4]

In 2015 we have completed analysis of the 2010 data [3, 4] sample with 20 times larger statistics with respect to the 2008 data. The excitation functions determined for $dd \to {}^3$He$p\pi^-$ and $dd \to {}^3$He$n\pi^0$ processes do not show any narrow structure which could be interpreted as a signature of the bound state. Upper limit of the total cross-section for the η-mesic ^{4}He formation and decay are presented in Fig. 1 and varying in the range from 2.5 to 3.5 nb for the $dd \to (^4$He-$\eta)_{bound} \to {}^3$He$n\pi^0$ process (left panel of Fig. 1) and from 5 nb to 7 nb for the $dd \to (^4$He-$\eta)_{bound} \to {}^3$He$p\pi^-$ process (right panel of Fig. 1) [4]. The green area presents the systematics errors.

Perspectives for the search for ^{3}He-η mesic nuclei

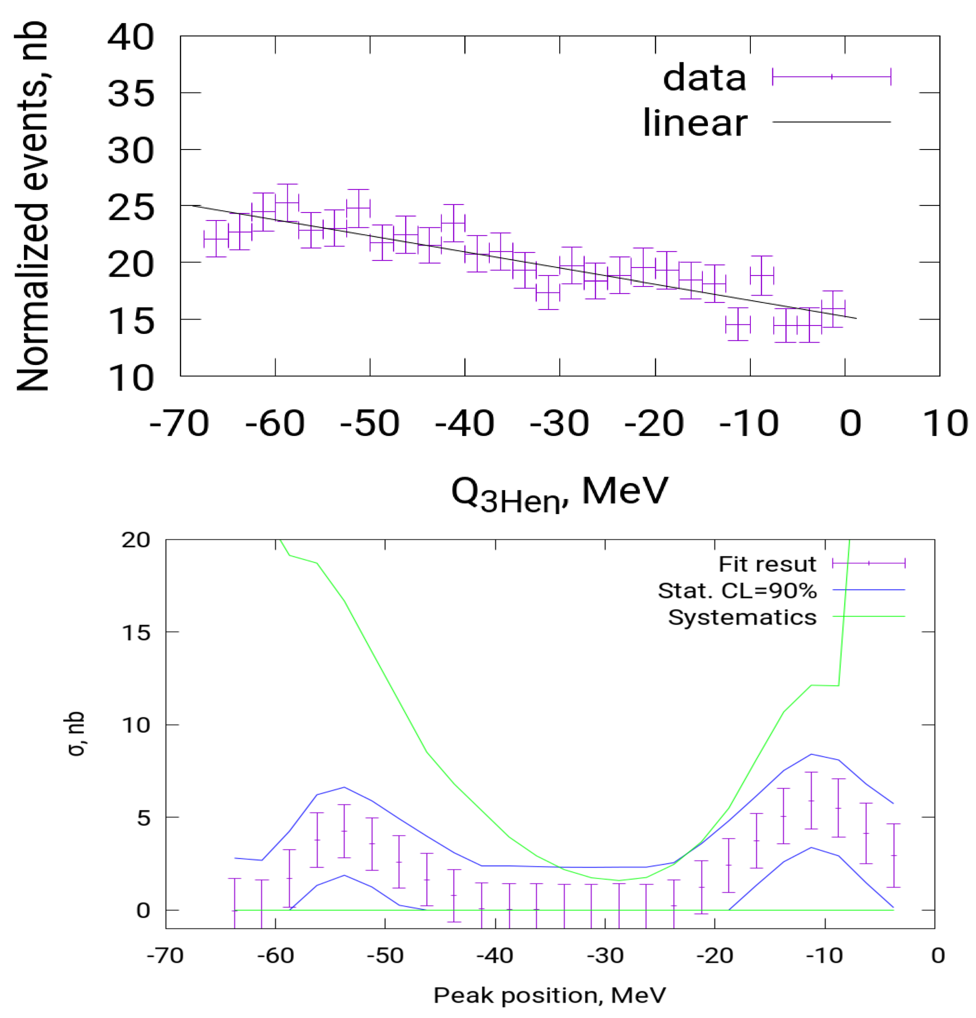


Fig. 2 [8]

Currently, we continue the search for the η-mesic ^{3}He. For this purpose a high statistics experiment was performed with the WASA detector in 2014 [3, 5]. With respect to the previous search [6] we expect to improve by at least an order of magnitude both the statistical and systematic precision. We considered processes corresponding to the three mechanisms: (i) η meson absorption by one of the nucleons inside ^{3}He, which subsequently decays into N-π pair e.g.: $pd \to (^3$He-$\eta)_{bound} \to ppp\pi^-$, (ii) η meson decay while it is still "orbiting" around a nucleus e.g.: $pd \to (^3$He-$\eta)_{bound} \to {}^3$He2γ reaction and (iii) few nucleon absorption of η meson e.g.: $pd \to (^3$He-$\eta)_{bound} \to ppn$ [7].

The excitation curves obtained in the analysis for the $pd \to (^3$He-$\eta)_{bound} \to {}^3$He2γ reaction (upper panel of Fig. 2) did not reveal any resonance-like structures. Thus, the upper limit for the bound state forming cross section was determined.

For different assumed η-mesic ^{3}He binding energies and widths, the simultaneous fit of two excitation curves with sum of linear function (for background) and Breit-Wigner function (for signal) was performed. The upper limit of the total cross section was determined at 90% confidence level (bottom panel of Fig. 2) [8].
Analysis of the $pd \to (^3$He-$\eta)_{bound} \to ppp\pi^-$, $pd \to (^3$He-$\eta)_{bound} \to ppn\pi^0$ and $pd \to (^3$He-$\eta)_{bound} \to dp\pi^0$ chanels is in progress.

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