Search for $(^4\text{He-}\eta)_{bound}$ with WASA-at-COSY

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We carried out a search for the ^{4}He-η bound state by measuring the excitation function for the $dd \to {}^3\text{He}p\pi^-$ and $dd \to {}^3\text{He}n\pi^0 \to {}^3\text{He}n\gamma\gamma$ reactions at energies in the vicinity of the η production threshold.
In 2008 an exclusive measurement of the excitation function for the $dd \to {}^3\text{He}p\pi^-$ reaction was performed. The data were taken during a slow acceleration of the beam from 2.185 GeV/c to 2.400 GeV/c crossing the kinematic threshold for the η meson production in the $dd \to {}^4\text{He}\,\eta$ reaction at 2.336 GeV/c. The integrated luminosity in the experiment was determined using the $dd \to {}^3\text{He}n$ reaction. The shape of the excitation function for the $dd \to {}^3\text{He}p\pi^-$ reaction was examined. No signal from η-mesic ^{4}He was observed. An upper limit for the cross-section for the bound state formation and decay in the process $dd \to (^4\text{He-}\eta)_{bound} \to {}^3\text{He}p\pi^-$ was determined to the 90 % confidence level and it varies from 20 nb to 27 nb as the width of the bound state varies from 5 MeV to 35 MeV. The upper limits depend mainly on the width of the bound state and only slightly on the binding energy.

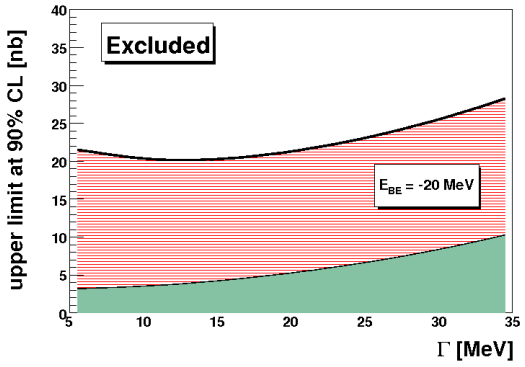

Fig. 1: Upper limit at the 90 % confidence level of the cross-section for formation of the $^4\text{He}-\eta$ bound state and its decay via the $dd \to (^4\text{He-}\eta)_{bound} \to {}^3\text{He}p\pi^-$ reaction as a function of the width of the bound state. The binding energy was set to E_{BE}=-20 MeV. The green area at the bottom represents the systematic uncertainties.

For the first time in the experimental search for mesic nuclei all ejectiles were measured and the reaction was identified exclusively. The results of this analysis have been accepted for publication in Phys. Rev. C [2].
In November 2010 a factor 30 higher statistics was collected compared to the 2008 measurement. Until now the $dd \to (^4\text{He-}\eta)_{bound} \to {}^3\text{He}n\pi^0 \to {}^3\text{He}n\gamma\gamma$ reaction was analysed. The ^{3}He was identified in the Forward Detector based on the ΔE-E method. The neutral pion π^0 was reconstructed in the Central Detector from the invariant mass of two gamma quanta originating from its decay while the neutron four-momentum was calculated using the missing mass technique.
The excitation function for the $dd \to {}^3\text{He}n\pi^0 \to {}^3\text{He}n\gamma\gamma$ reaction is determined for the "signal-rich" region corresponding to the momenta of the ^{3}He in the CM system below 0.3 GeV/c and the "signal-poor" region for the ^{3}He CM momenta above 0.3 GeV/c. The cut applied is indicated by the blue line in Fig. 2.

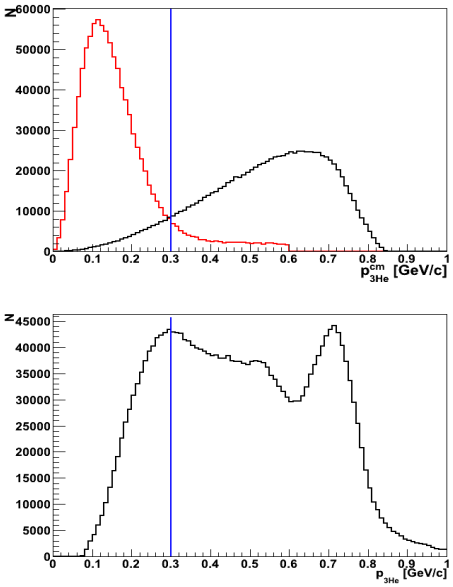

Fig. 2: (Upper plot) Distribution of generated the ^{3}He momentum in the CM for Monte Carlo simulations for $dd \to (^4\text{He-}\eta)_{bound} \to {}^3\text{He}n\pi^0 \to {}^3\text{He}n\gamma\gamma$ (red line) and for the phase-space $dd \to {}^3\text{He}n\pi^0 \to {}^3\text{He}n\gamma\gamma$ (black line). (Lower plot) The distribution of ^{3}He in the CM system measured in the experiment. The blue line in both plots marks the cut applied to separeate "signal-rich" and "signal-poor" regions.

The simulation was done for the beam momentum range $p_{beam} \in (2.127, 2.422)$ GeV/c. The shape of the background and relative contribution of various reaction channels is under investigation.
Additional selection criteria such as cut in the opening angle between neutron an π^0 in CM frame or cut in θ_{3He} in LAB will be applied to investigate the shape of the excitation functions.
The luminosity is determined based on the $dd \to {}^3\text{He}n$ reaction. The ^{3}He is selected via a cut on the Edep(FRH1) vs Edep(FRH2) spectrum (Fig. 3 left panel). In the next step of the analysis, helium stopped in FRH3 or in FRH4 (Fig. 3 left panel) is taken into account.
The number of $dd \to {}^3\text{He}n$ events is determined from the missing mass spectrum. To reject three and four-body reactions we take into account only events which gives no more than one neutral cluster in the Central Detector. Monte Carlo simulations show that using of this condition reject only about 6% of $dd \to {}^3\text{He}n$ events. Therefore it allows to considerably reduce the background without significant loss of signal counts. The analysis and studies of systematics of applied cuts are in progress. Luminosity will be determined as a function of $cos\theta_{cm}$ and the excess energy Q.

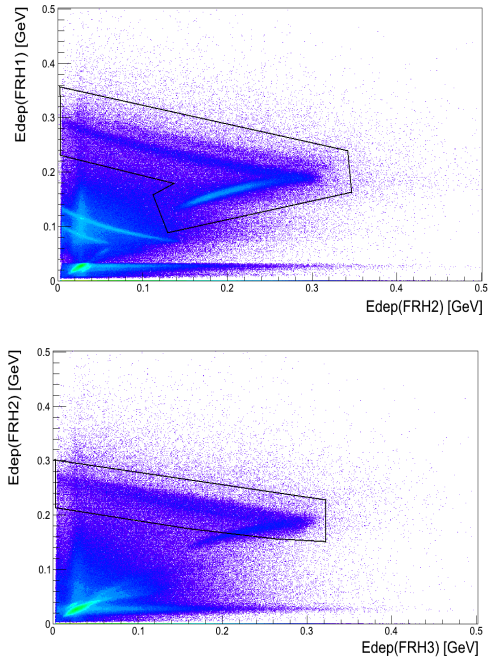

Fig. 3: Cuts in Edep(FRH1) vs Edep(FRH2) spectrum (upper panel) as well as in Edep(FRH2) vs Edep(FRH3) (lower panel) applied for helium identification in $dd \rightarrow {}^{3}\mathrm{He}n$ reactions.

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References:

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[2] P. Adlarson, *et al., arXiv:1301.0843* (2013)

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