Search for ^{4}He-η bound state via $dd \to {}^3\text{He}p\pi^-$ and $dd \to {}^3\text{He}n\pi^0$ reaction with the WASA-at-COSY facility

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In November 2010, the search for a ^{4}He-η bound state was performed by measuring the excitation function of the $dd \to {}^3\text{He}n\pi^0 \to {}^3\text{He}n\gamma\gamma$ and $dd \to {}^3\text{He}p\pi^-$ reactions in the vicinity of the η production threshold. The measurement was carried out using a ramped beam technique. The beam momentum was varying continuously from 2.127 GeV/c to 2.422 GeV/c which corresponds to a range of excess energies Q∈(-70,30) MeV.

Independent analyses for the $dd \to {}^3\text{He}n\pi^0 \to {}^3\text{He}n\gamma\gamma$ and $dd \to {}^3\text{He}p\pi^-$ reactions were carried out. The ^{3}He for both cases 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 π^- identification in Central Detector was based on the measurement of the energy loss in the Plastic Scintillator combined with the energy deposited in the Electromagnetic Calorimeter. Neutron and proton were identified via the missing mass technique. The appropriate spectra with applied cuts are presented in Fig. 1.

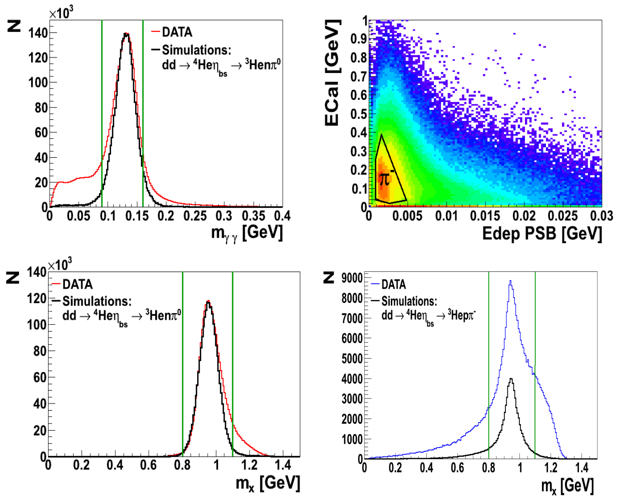


Fig. 1: π^0 and π^- identification (upper panel). Proton and neutron identification (lower panel). The data were marked with red and blue lines, the Monte Carlo simulations of the signal are marked with the black line, while the applied cuts are marked in green.

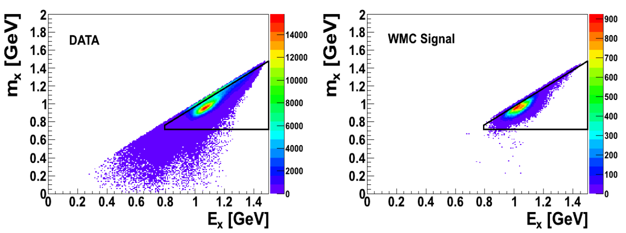


Fig. 2: Missing mass m_x vs. missing energy E_x for data (left panel) and Monte Carlo (right panel). The applied cut is marked in black.

In case of the $dd \to {}^3\text{He}n\pi^0$ reaction, before particle identification, an additional cut on the $m_x(E_x)$ spectrum was applied as shown in Fig. 2 (left). The cut is based on Monte Carlo simulations and is presented in Fig. 2 (right).

In case of the $dd \to {}^3\text{He}p\pi^-$ reaction an additional coplanarity cut was applied. As a measure of the coplanarity the angle between the vector $\vec{p}_{beam} - \vec{p}_{^3He}$ and the cross product of the vectors $\vec{p}_1$ and $\vec{p}_2$: $\theta_{k,1x2} = \angle(\vec{p}_{beam} - \vec{p}_{^3He}, \vec{p}_1 \times \vec{p}_2)$ was defined. In the case of coplanarity $\theta_{k,1x2}$=90°. In data we applied a cut $\theta_{k,1x2} \in (90 \pm 5)°$ which is presented in Fig. 3.

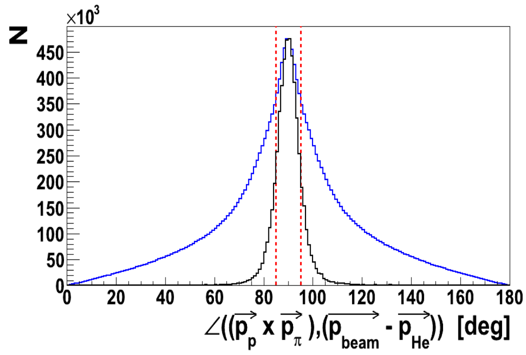


Fig. 3: Distribution of the coplanarity observable determined for simulations of $dd \to {}^3\text{He}p\pi^-$ (black line) and for experimental data (blue line). The cut applied to the data - $\theta_{k,1x2} \in (90 \pm 5)°$ - is marked by the vertical dotted red lines.

In order to select events corresponding to the production of bound states, cuts in the ^{3}He CM momentum, nucleon CM kinetic energy, pion CM kinetic energy and the opening angle between nucleon-pion pair in the CM were applied based on Monte Carlo simulations. These cuts are presented in Fig. 4.

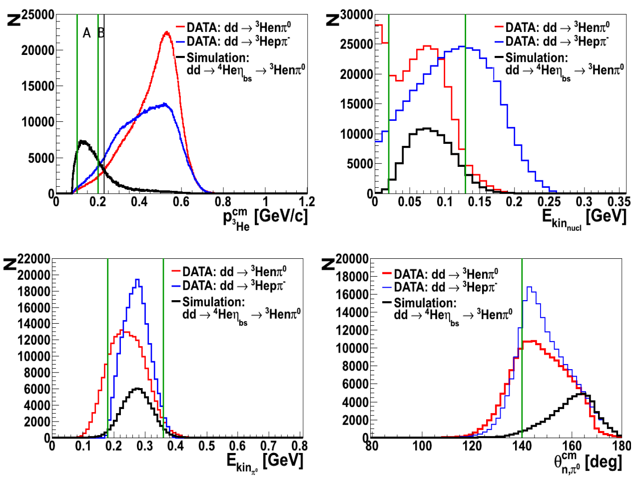
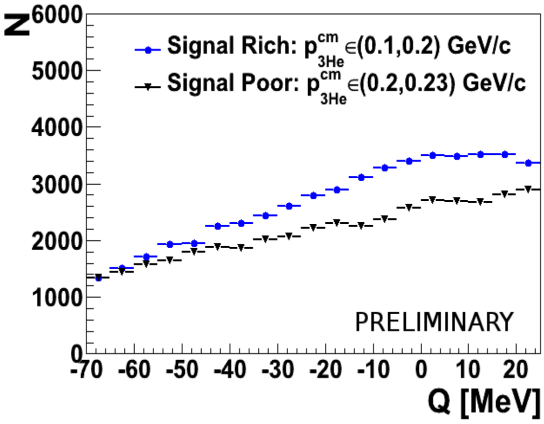


Fig. 4: Spectrum of $p^{cm}_{^3He}$ (left upper panel), $E^{cm}_{kin_{nucl}}$ (right upper panel), $E^{cm}_{kin_\pi}$ (left lower panel) and $\theta^{cm}_{nucl,\pi}$ (right lower panel). Data are shown in red and blue for $dd \to {}^3\text{He}n\pi^0$ and $dd \to {}^3\text{He}p\pi^-$ reaction, respectively. Monte Carlo simulations of signal are shown in black, while the applied cuts are marked with the green lines.

The excitation functions for both reactions were determined for a "signal rich" region corresponding to momenta of the ^{3}He in the CM system with $p^{cm}_{^3He} \in (0.1, 0.2)$GeV/c and for a "signal poor" region with $p^{cm}_{^3He} \in (0.2, 0.23)$GeV/c which are marked with (A) and (B) in the left upper panel in Fig. 4, respectively.
The excitation functions for the $dd \to {}^3\mathrm{He}n\pi^0$ and $dd \to {}^3\mathrm{He}p\pi^-$ reactions are presented in Fig. 5.



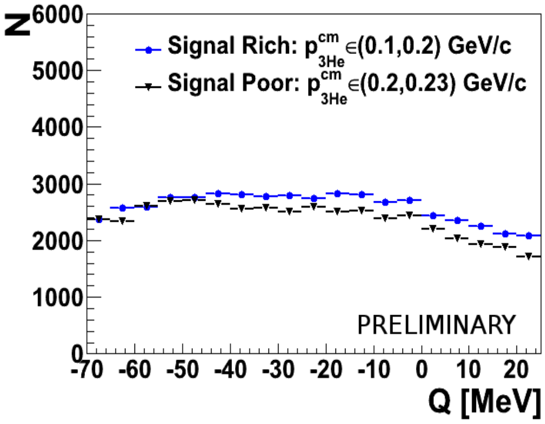


Fig. 5: Excitation function for the $dd \to {}^3\mathrm{He}n\pi^0$ reaction (left panel) and the $dd \to {}^3\mathrm{He}p\pi^-$ reaction (right panel). The "signal rich" region is shown in blue while the "signal poor" region normalized to the first bin of the "signal rich" region is shown in black. The analysis is based on the whole data sample.

The preliminary results presented in Fig. 5 reveal no structure which could be interpreted as a signature of a bound state. The shape of the spectra in the "signal rich" and "signal poor" regions differs from each other. A detailed studies of the background and signal channels are in progress.

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