Search for $^4\text{He}-\eta$ bound state: status of the 2010 experiment

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1. Introduction
2. Experimental method
3. Status of the experiment in 2010
4. Summary
η-mesic bound state

Atomic nucleus

η-mesic nucleus

\[ m = Z \cdot m_p + N \cdot m_n - B_s \]

\[ B_s = \Delta mc^2 \]

\[ m_{bs} = m_{4He} + m_\eta - B_s \]
Conditions for the existence of eta-mesic nuclei

\[ \Re a_{\eta-nucleus} < 0 \]
\[ |\Re a_{\eta-nucleus}| > |\Im a_{\eta-nucleus}| \]

Attractive interaction between \( \eta \) and \( N \)


possible existence of \( \eta \)-mesic bound state for \( A>12 \)

Recent theoretical investigations of hadronic- and photoproduction of $\eta$ meson

$0.27 \, fm \leq \text{Re} \, a_{\eta N} \leq 1.05 \, fm$

$0.19 \, fm \leq \text{Im} \, a_{\eta N} \leq 0.39 \, fm$


$\Gamma \in (7,40) MeV$

$B_s \in (5,15) MeV$

$\left( ^4\text{He}-\eta \right)_{bs}$

$\left( ^3\text{He}-\eta \right)_{bs}$

$\left( \text{T-}\eta \right)_{bs}$

$\left( \text{d-}\eta \right)_{bs}$
Production of $^4\text{He}\,\eta$ bound state in dd reaction

- Possible reaction channels

\[ dd \rightarrow \left( ^4\text{He} - \eta \right)_{bs} \rightarrow ^3\text{He} \ p \ \pi^- \]
\[ dd \rightarrow \left( ^4\text{He} - \eta \right)_{bs} \rightarrow ^3\text{He} \ n \ \pi^0 \rightarrow ^3\text{He} \ n \ \gamma \ \gamma \]
\[ dd \rightarrow \left( ^4\text{He} - \eta \right)_{bs} \rightarrow d \ p \ p \ \pi^- \]
\[ dd \rightarrow \left( ^4\text{He} - \eta \right)_{bs} \rightarrow T \ p \ \pi^0 \rightarrow T \ p \ \gamma \ \gamma \]
Kinematical mechanism of the reaction

Scheme of reaction process, in which \( \eta \)-mesic nucleus is formed

\[ \text{dd} \rightarrow (^{4}\text{He} - \eta)_{bs} \rightarrow ^{3}\text{He} \ p \ \pi^- \]
Search for eta-mesic nuclei with WASA-at-COSY facility
Search for eta-mesic nuclei with WASA-at-COSY facility

- Expected results of the measurements

**Angle between p i π⁻ in the CM frame**

\[ \theta_{CMN^*} = 180^0 \]

**Resonant structure below η meson production threshold**

\[ dd \rightarrow \left( ^4\text{He} - \eta \right)_{bs} \rightarrow ^3\text{He} \ p \ \pi^- \]
Reaction: \[ dd \rightarrow \left( ^4He - \eta \right)_{bs} \rightarrow ^3He \ p \ \pi^- \]

Time of measurement: \( T = 16.5h \)
Luminosity: \( L \approx 3 \cdot 10^{30} \text{ cm}^{-2}\text{s}^{-1} \)
Acceptance: \( A = 53\% \)

Upper limit of the total cross section: \( \sigma \approx 20\text{nb} \)

Wojtek Krzemień
Reactions:

\[ dd \rightarrow \left( ^{4}\text{He} - \eta \right)_{bs} \rightarrow ^{3}\text{He} \ p \ \pi^- \]

\[ dd \rightarrow \left( ^{4}\text{He} - \eta \right)_{bs} \rightarrow ^{3}\text{He} \ n \ \pi^0 \rightarrow ^{3}\text{He} \ n \ \gamma \ \gamma \]

\[ Q \in (-70,30)\text{MeV} \rightarrow p_d \in (2.127,2.422)\text{GeV} / c \]

\[ p_d^{\text{thr}} = 2.336\text{GeV} / c \]

Main trigger: fHedwr1 - at least one charged particle in FD, track matching between FWC, FTH and FRH, high thr. for FWC

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>TIME [h]</th>
<th>( L \left[ \frac{1}{\text{cm}^2\text{s}} \right] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>with magnetic field</td>
<td>43</td>
<td>( 5.68 \cdot 10^{30} )</td>
</tr>
<tr>
<td>without magnetic field</td>
<td>111.5</td>
<td>( 9.11 \cdot 10^{30} )</td>
</tr>
<tr>
<td>all measurement</td>
<td>154.5</td>
<td>( 8.15 \cdot 10^{30} )</td>
</tr>
</tbody>
</table>

40x higher statistics than 2 years ago

Luminosity calculated based on Tr. 17 (elastic scattering)

220kHz => \( L=4 \cdot 10^{30} \text{ cm}^{-2}\text{s}^{-1} \)
$^3$He identification in FD

$^3$He selection bases on $\Delta E-\Delta E$ ($\Delta E-E$) method
$^3\text{He}$ identification in FD

Wrong calibration for 23 layer of FRH2
$^3$He identification in FD
$^3\text{He}$ identification in FD

$dd \rightarrow ^3\text{He} \ n$ - for normalization
$^3$He identification in FD
Summary

- During the experiment in 2010 two channels were measured with average luminosity $L \approx 8.15 \cdot 10^{30} \text{ cm}^{-2} \text{s}^{-1}$
  
  40 times higher statistics

- Main task: determination of the excitation functions

- If no peak observed => determination of the upper limit of the total cross section with accuracy of few nb.
Thank you for attention 😊