Search for the He-\(\eta\) bound state with WASA-at-COSY

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Exp. No. 186.2: Search for the $\eta$-He bound state with WASA-at-COSY

Beamtime: Nov 26 - Dec 13, 2010

Channels: $dd \rightarrow (^4\text{He}-\eta)_{bs} \rightarrow ^3\text{He}p\pi^-$
           $dd \rightarrow (^4\text{He}-\eta)_{bs} \rightarrow ^3\text{He}n\pi^0 \rightarrow ^3\text{He}n\gamma\gamma$

Measurement: performed with the beam momentum ramping from 2.127GeV/c to 2.422GeV/c, corresponding to the range of excess energy $Q \in (-70,30)$MeV

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

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>TIME [h]</th>
<th>$L \left[ \frac{1}{cm^2s} \right]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>with magnetic field</td>
<td>43:01</td>
<td>$5.68 \cdot 10^{30}$</td>
</tr>
<tr>
<td>without magnetic field</td>
<td>111:33</td>
<td>$9.11 \cdot 10^{30}$</td>
</tr>
<tr>
<td>all measurement</td>
<td>154:35</td>
<td>$8.15 \cdot 10^{30}$</td>
</tr>
</tbody>
</table>

- The cooling system of Superconducting Solenoid failed $\Rightarrow$ the measurement with magnetic field was carried out only 43 hours

- Taking into account the fact that there were two reactions measured, in total more than 40 times higher statistics were collected than in experiment carried out in 2008.
Luminosity determination

Measured channels:
\[ dd \rightarrow ^3\text{He}p\pi^- \]
\[ dd \rightarrow ^3\text{He}n\pi^0 \rightarrow ^3\text{He}n\gamma\gamma \]

Search for \((^4\text{He}-\eta)_{bs}\)
\[ p_{\text{beam}} \in (2.127, 2.422) \text{ GeV}/c \]

Normalization reaction:
\[ dd \rightarrow ^3\text{He}n \]

\[ N = L \cdot \sigma \cdot \epsilon \]
\[ L = \int_{t_1}^{t_2} L(t)dt \]

\[ \frac{dN}{dx}(x) = L \cdot \frac{d\sigma}{dx}(x) \cdot \epsilon(x) \]
\[ x = \cos\theta, \quad dx = d(\cos\theta) = d\Omega / 2\pi \]

\[ p_i \]

\[ L_i = \frac{dN}{d\Omega}(\cos\theta, p_i) \cdot \epsilon(\cos\theta, p_i) \]
\[ \Rightarrow \frac{d\sigma_{bs}}{d\Omega}(\cos\theta, p_i) = \frac{dN_{bs}}{d\Omega}(\cos\theta, p_i) \frac{L_i \cdot \epsilon(\cos\theta, p_i)}{L_i} \]
Estimation of number of events for $dd \rightarrow {}^3\text{He}n$ reaction:

$$N = L_{av} \sigma A t$$

- $L_{av} = 8.15 \cdot 10^{30}$
- $A = 80\%$
- $t = 154.5\ h$
- $\sigma = 8.5\ \mu\text{b}$

$$N = 31\text{mln}$$
Kinematics of $dd \rightarrow ^3\text{He}\eta$

Cross section for $dd \rightarrow ^3\text{He}\eta$

Two energies for one angle

$\tan \theta = \frac{\sin \theta^*}{\gamma_{cm} (\cos \theta^* + \beta_{cm}/\beta^*)}$
$p_{beam} = 2.334$ GeV/c

\[ E_{3He}^{\text{kin}}(\theta_{3He}) \]

\[ \theta_n(\theta_{3He}) \]
$p_{\text{beam}} \in (2.127, 2.422) \text{ GeV/c}$

$E^{\text{kin}}_{3\text{He}}(\theta_{3\text{He}})$

$\theta_n(\theta_{3\text{He}})$
\( \sigma_{dd \rightarrow ^3\text{He}n} \) is a function of transferred momentum squared 
\( t = (P_{^3\text{He}} - P_{\text{beam}})^2 \) and beam energy \( E_{\text{beam}} \)

t-spectra measured in experiment fitted with the sum of exponentials:
\[
\sigma(t - t_{\text{max}}) = \sum_{i=1}^{3} a_i e^{b_i x}
\]

energy dependance of fit parameters was fitted with hyperbolical functions:
\[
par_i(W) = \frac{p_i}{x - q_i} + r_i
\]

\[
\begin{array}{|c|c|c|c|}
\hline
  & p_i & q_i & r_i \\
\hline
a_1 & 11.64 & 4.05 & -14.49 \\
b_1 & 0.78 & 3.92 & 9.04 \\
a_2 & 2327.04 & -1.44 & -399.27 \\
b_2 & 0.78 & 3.92 & 9.04 \\
a_3 & 0.22 & 4.08 & 1.24 \\
b_3 & 0.78 & 3.92 & 9.04 \\
\hline
\end{array}
\]

Annette Pricking, PhD
Differential cross section $dd \rightarrow ^3\text{He}n$

\[
t-t_{\text{max}} = 2p_3\text{He}p_{\text{beam}}(\cos \theta - 1)
\]
Differential cross section $dd \rightarrow ^3 \text{He} n$

![Graph showing differential cross section](graph.png)

- Cross section for three different beam momentum values.
  - $p_{beam} = 2.127 \text{ GeV/c}$
  - $p_{beam} = 2.334 \text{ GeV/c}$
  - $p_{beam} = 2.422 \text{ GeV/c}$

![Graph showing $t_{max}$ for $p_{beam} = 2.334 \text{ GeV/c}$](graph2.png)

- $t_{max}$ for $p_{beam} = 2.334 \text{ GeV/c}$
  - Cross section weight
  - Phase space

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Search for the $\text{He-}\eta$ bound state with WASA-at-COSY
Total cross section $dd \rightarrow^3 \text{He}n$
$p_{beam} \in (2.127, 2.422) \text{ GeV/c}$

$E^{\text{kin}}_{3\text{He}}(\theta_{3\text{He}})$

$\theta_n(\theta_{3\text{He}})$

Search for the He-$\eta$ bound state with WASA-at-COSY
$p_{\text{beam}} \in (2.127, 2.422) \text{ GeV/c}$

$E_{3\text{He}}^{\text{kin}}(\theta_{3\text{He}})$

$\theta_n(\theta_{3\text{He}})$
WMC \( dd \rightarrow ^{3}He \eta \) \( p_{\text{beam}} \in (2.127,2.422) \) GeV/c

Condition: 1 charged particle in FD

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Search for the He-\( \eta \) bound state with WASA-at-COSY
**WMC** \( p_{\text{beam}} \in \{2.127, 2.2745, 2.422\} \) GeV/c

**Condition:** 1 charged particle in FD
General information about experiment
Luminosity determination
Analysis
Selection of \(dd \rightarrow ^3\text{He}\) events
Outlook

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Search for the He-\(\eta\) bound state with WASA-at-COSY
$\theta_n(\theta_{^3\text{He}})$ \hspace{1cm} dd $\rightarrow ^3 \text{He}\eta$ 

TEST

Conditions: 1 charged particle in FD, 1 neutral particle in CD
Difference Phi: \( dd \rightarrow ^3\text{He}n \) TEST

Conditions: 1 charged particle in FD, 1 neutral particle in CD
Cuts \( dd \rightarrow ^3 \text{He} n \)

**DATA**

- \( ^3 \text{He} n \) + 3He stopped in FRH3

**WMC**

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Search for the He-\( \eta \) bound state with WASA-at-COSY
Missing Mass-cuts: $dd \rightarrow ^3\text{He}X$

**cut1**

**cut2**
Missing Mass-data: $dd \rightarrow ^3HeX$ + 3He stopped in FRH3

![Graphs showing distributions of missing mass before and after cuts.](image)
Missing Mass-data: $dd \rightarrow^3 \text{HeX}$

before cuts  
cut1  
cut2  

Search for the $\text{He-}\eta$ bound state with WASA-at-COSY
Apply cut on missing mass spectrum which rejects three- or four-body reactions.

Luminosity determination:
- differential cross section $d\sigma/d(t-t_{max})$ can be fitted to experimental $N(t-t_{max})$, luminosity is a scaling factor (for each beam momentum interval).
- luminosity can be calculated for each bin for experimental distribution of $\cos\theta_{CM}$ and is given as weighted mean.
- acceptance correction.
Search for the He-\(\eta\) bound state with WASA-at-COSY
Differential cross section $dd \rightarrow ^3\text{He}\eta$
$E_{3\text{He}}^{\text{kin}}(\theta_{3\text{He}})$  \hspace{1cm} dd $\rightarrow$ $^3$He $\eta$

FRH3vsFRH4 + 3He stopped in FRH3

DATA

WMC
$E_{3\text{He}}^{\text{kin}}(\theta_{3\text{He}})$  \hspace{1cm} dd $\rightarrow$ $^3$He $\eta$

DATA

WMC

Search for the He-$\eta$ bound state with WASA-at-COSY