(Anti-) matter and hyper-matter production at the LHC with ALICE

Benjamin Dönigus
for the ALICE collaboration
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• ALICE performance
• Anti-Alpha
• Hypertriton
• Search for H-Dibaryon
• Search for \( \Lambda n \) bound state
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Motivation

- Explore QCD predictions for unusual multi-baryon states
- Search for rarely produced anti- and hyper-matter
- Test thermal model predictions

A. Andronic, private communication, model described in Andronic et al., PLB 697, 203 (2011) and references therein
Particle identification techniques involved:

- Energy loss (dE/dx)
- Time-Of-Flight
- Topological
Excellent dE/dx performance of TPC (6.5% (2010) and 7.2% (2011) resolution in central Pb-Pb collisions)

An offline trigger selects events with at least one $^3\text{He}/^4\text{He}$ candidate
Time-Of-Flight (TOF)

Excellent TOF performance

$$\sigma_{\text{TOF}} = 85 \text{ ps}$$

TOF performance is allowing a $2\sigma$ p/K-separation up to 5 GeV/c
In 2010 data we clearly identified four Anti-Alphas by combining TPC and TOF information.

Full statistics 2010 (13.8x10^6 min. bias events)
For the full statistics of 2011 we identified 10 Anti-Alphas using TPC and TOF.

Corresponds to $23 \times 10^6$ events of a trigger mix (central, semi-central and min. bias).

\[ \text{Pb-Pb, 2011 run, } \sqrt{s_{NN}} = 2.76 \text{ TeV} \]
Hypertriton

- Decay topology is similar to a V0 decay
- Identification of light nuclei which are daughter tracks originating from decay vertices

\[
m(\overset{3}{\Lambda}H) = 2.991 \pm 0.001 \pm 0.002 \text{ GeV}/c^2
\]
decay length \(c\tau = 5.5^{+2.7}_{-1.4} \pm 0.8 \text{ cm} \)
life time \(\tau = 182^{+89}_{-45} \pm 27 \text{ ps} \)

\[
\overset{3}{\Lambda}H \rightarrow \overset{3}{\Lambda}\text{He} + \pi^+
\]
\[
\overset{3}{\Lambda}\text{H} \rightarrow \overset{3}{\Lambda}\text{He} + \pi
\]

*STAR Collaboration, Science 328, 58 (2010)*
Signal of the hypertriton from the 2011 run
\( \rightarrow \) currently working on the \( p_T \) spectra extraction

\[
\begin{align*}
\mu &= (2.990 \pm 0.001) \text{ GeV}/c^2 \\
\sigma &= (3.35 \pm 0.7) \times 10^{-3} \text{ GeV}/c^2
\end{align*}
\]
H-Dibaryon

• Hypothetical bound state of uuddss (ΛΛ)
• First predicted by Jaffe in a bag model calculation (Jaffe, PRL 38, 617 (1977))
• Recent lattice calculations suggest (Inoue et al., PRL 106, 162001 (2011) and Beane et al., PRL 106, 162002 (2011)) a bound state (20-50 MeV/c^2 or 13 MeV/c^2)
• Shanahan et al., PRL 107, 092004 (2011) and Heidenbauer, Meißner, PLB 706, 100 (2011) made chiral extrapolation to a physical pion mass and got as result:
  – the H is unbound by 13±14 MeV/c^2, respectively lies close to the Ξp threshold
→ Renewed interest in experimental searches
H-Dibaryon

Two cases:

- $m_H < \Lambda \Lambda$ threshold
  $\rightarrow$ weakly bound
  measurable channel
  $H \rightarrow \Lambda p \pi$
  $2.2 \text{ GeV}/c^2 < m_H < 2.231 \text{ GeV}/c^2$

- $m_H > \Lambda \Lambda$ threshold
  $\rightarrow$ resonant state
  measurable channel
  $H \rightarrow \Lambda \Lambda$
  $m_H > 2.231 \text{ GeV}/c^2$
H-Dibaryon

Efficiency estimation from Monte Carlo simulation (generated flat in $y$ and $p_T$) for the detection of the H-Dibaryon

Assuming the lifetime to be that of the $\Lambda$
$p_T$-shape of the H-Dibaryon (and $\Lambda n$ bound state) estimated from the extrapolation of blast-wave fits for $p, K, \pi$

Normalised to 1 and convoluted with Acceptance x Efficiency to get a weighted efficiency

Unknown $p_T$-shape is the main source of uncertainty: Therefore used different functions for the systematics (limiting cases: blast-wave of deuteron and helium-3)
H-Dibaryon

\[ N_{H^0} = \left(1.38 \times 10^7\right) \cdot \left(0.0385\right) \cdot \left(0.64\right) \cdot \left(3.1 \times 10^{-3}\right) \cdot 2 = 2110 \]

- **Strongly bound**: \(2110 \times 0.1 = 211\)
- **Lightly bound**: \(2110 \times 0.64 = 1350\)

A. Andronic, private communication

Schaffner-Bielich et al., PRL 84, 4305 (2000)
• No signal visible

From the non observation we obtain as upper limits:

For a strongly bound $H$:
\[ dN/dy \leq 8.4 \times 10^{-4} \text{ (99\% CL)} \]

For a lightly bound $H$:
\[ dN/dy \leq 2 \times 10^{-4} \text{ (99\% CL)} \]

Thermal model prediction is $dN/dy = 3.1 \times 10^{-3}$ \(\rightarrow\) thermal model would need to be wrong by a factor $\sim 10$

But the model describes the hypertriton yields measured with STAR correctly within uncertainties \(\text{(Andronic et al., PLB 697, 203 (2011) and Cleymans et al., PRC 84, 054916 (2011))}\)
An bound state

- HypHI experiment at GSI see evidence of a new state:
  \( \Lambda n \to d \pi^- \)

6Li beam at 2 AGeV on \(^{12}\)C target

We assume a V0 type decay topology

\[ \Lambda n \] bound state

Efficiency estimation from Monte Carlo simulation

\[ m_{\Lambda n} = 2.054 \text{ GeV/c}^2 \]
\[ c\tau = 7.89 \text{ cm} \]
Λn bound state

Schaffner-Bielich, private communication

\[
N_{\Lambda n, \text{rec}} = \frac{1.38 \cdot 10^7 \cdot 0.0255 \cdot 0.35 \cdot 0.01625 \cdot 2}{\text{events}} = 4003
\]

\( m_{\Lambda n} = 2.054 \text{ GeV/c}^2 \)

\( c\tau = 7.89 \text{ cm} \)
\( \Lambda n \) bound state

- No visible signal

From the nonobservation we can set an upper limit:

\[ \frac{dN}{dy} \leq 1.5 \times 10^{-3} \quad (99\% \text{ CL}) \]

→ thermal model input

\[ \frac{dN}{dy} = 1.65 \times 10^{-2} \]

→ thermal model would need to be wrong by a factor \(~10\)
Clear separation of nuclei in $dE/dx$ of the Transition Radiation Detector allows to trigger on them.

→ Working on the efficiency and rejection estimation from data in pp and Pb-Pb.
Conclusion

- ALICE is well suited for the detection of different particle species (stable, weakly and strongly decaying)
- By combining the different particle identification techniques (TPC dE/dx and TOF) we have
  - observed 10 Anti-Alphas in the run of 2011
  - observed hypertriton signal and work on the $\rho_T$ spectra
  - set an upper limit for the H-Dibaryon for two bound cases
  - set an upper limit for the $\Lambda n$ bound state (observed by the HypHI collaboration $\rightarrow$ different production mechanism?)
  - made first steps towards an online trigger on light nuclei
Backup
Hypertriton

LHC11h - ESDs Pass 2 reconstruction; 23 M events, trigger selection kAny

TRACK CUTS:
TPC refit;
No pure SA;
No SA tracks;
  # TPC cluster > 60;
  chi2 < 5;
No kink daughter

PID:
3He tracks: asymmetric n-sigma band;
Negative tracks : symmetric 2-s band;
|DCAz| 3He track < 1cm;
He3 rigidity > 1.2 GeV/c && < 6 GeV/c

SECONDARY Vertex
DCA tracks < 0.7 cm;
Cos(Pointing angle)>0.99;
DCA neg to PV > 0.4 cm;
c*tau < 40 cm.

LHC11h - ESDs Pass 2 reconstruction; 23 M events, trigger selection kAny

TRACK CUTS:
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No SA tracks;
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No kink daughter

PID:
Anti-3He tracks: asymmetric n-sigma band;
Positive tracks : symmetric 2-s band;
|DCAz| Anti-3He track < 1cm;
Anti-He3 rigidity > 1.2 GeV/c && < 6 GeV/c

SECONDARY Vertex
DCA tracks < 0.7 cm;
Cos(Pointing angle)>0.99;
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c*tau < 40 cm.
H-Dibaryon

<table>
<thead>
<tr>
<th>cut</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Track cuts</strong></td>
<td></td>
</tr>
<tr>
<td>Kink daughters</td>
<td>rejected</td>
</tr>
<tr>
<td>TPC</td>
<td>refit</td>
</tr>
<tr>
<td>$n_{\text{clusters}}(\text{TPC})$</td>
<td>$&gt; 80$</td>
</tr>
<tr>
<td>$\chi^2/\text{cluster}$</td>
<td>$&lt; 5$</td>
</tr>
<tr>
<td>$</td>
<td>\eta</td>
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<tr>
<td><strong>V0 cuts</strong></td>
<td></td>
</tr>
<tr>
<td>dca V0 daughters</td>
<td>$&lt; 1 \text{ cm}$</td>
</tr>
<tr>
<td>dca positive V0 daughter - Vertex</td>
<td>$&gt; 1 \text{ cm}$</td>
</tr>
<tr>
<td>dca negative V0 daughter - Vertex</td>
<td>$&gt; 1 \text{ cm}$</td>
</tr>
<tr>
<td><strong>Kinematical cuts</strong></td>
<td></td>
</tr>
<tr>
<td>dca positive $H^0$ daughter - Vertex</td>
<td>$&gt; 1 \text{ cm}$</td>
</tr>
<tr>
<td>dca negative $H^0$ daughter - Vertex</td>
<td>$&gt; 1 \text{ cm}$</td>
</tr>
<tr>
<td>dca $H^0$ daughters</td>
<td>$&lt; 1 \text{ cm}$</td>
</tr>
<tr>
<td>Pointing angle of $H^0$</td>
<td>$&lt; 0.1 \text{ rad}$</td>
</tr>
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</table>
An bound state

<table>
<thead>
<tr>
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<th>value</th>
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<tr>
<td>Track cuts</td>
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<tr>
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<td>rejected</td>
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<tr>
<td>TPC</td>
<td>refit</td>
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<tr>
<td>( n_{\text{clusters}}(\text{TPC}) )</td>
<td>&gt; 60</td>
</tr>
<tr>
<td>( \chi^2/\text{cluster} )</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>\textit{pseudo-rapidity} (</td>
<td>\eta</td>
</tr>
<tr>
<td>\textit{rapidity} ( y )</td>
<td>(</td>
</tr>
<tr>
<td>V0 and kinematical cuts</td>
<td></td>
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<tr>
<td>VO finder</td>
<td>online</td>
</tr>
<tr>
<td>\textit{Cosine of pointing angle}</td>
<td>( \cos(\Theta) &gt; 0.99 )</td>
</tr>
<tr>
<td>\textit{DCA V0 daughters}</td>
<td>( dca &lt; 1 \text{ cm} )</td>
</tr>
<tr>
<td>Momentum ( p_{\text{tot}} ) of the anti-deuteron</td>
<td>( p_{\text{tot}} &gt; 0.2 \text{ GeV/c} )</td>
</tr>
<tr>
<td>Energy loss ( dE/dx ) deuteron or anti-deuteron</td>
<td>( dE/dx &gt; 110 )</td>
</tr>
</tbody>
</table>
### Lifetime dependency

**H-Dibaryon**

<table>
<thead>
<tr>
<th>Lifetime (s)</th>
<th>Decay length (cm)</th>
<th>Efficiency</th>
<th>Upper limit dN/dy 99% CL</th>
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</thead>
<tbody>
<tr>
<td>$1.3 \times 10^{-10}$</td>
<td>3.95</td>
<td>0.0531</td>
<td>0.00061</td>
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<td>$2.63 \times 10^{-10}$</td>
<td>7.89</td>
<td>0.0385</td>
<td>0.00084</td>
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<tr>
<td>$5.2 \times 10^{-10}$</td>
<td>15.8</td>
<td>0.0308</td>
<td>0.0011</td>
</tr>
<tr>
<td>$1.4 \times 10^{-9}$</td>
<td>42</td>
<td>0.0154</td>
<td>0.0017</td>
</tr>
</tbody>
</table>

### $\Lambda n$ bound state

<table>
<thead>
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<th>Decay length (cm)</th>
<th>Efficiency</th>
<th>Upper limit dN/dy 99% CL</th>
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<tbody>
<tr>
<td>$1.3 \times 10^{-10}$</td>
<td>3.95</td>
<td>0.022</td>
<td>0.001708</td>
</tr>
<tr>
<td>$2.63 \times 10^{-10}$</td>
<td>7.89</td>
<td>0.0255</td>
<td>0.001474</td>
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<tr>
<td>$5.2 \times 10^{-10}$</td>
<td>15.8</td>
<td>0.032</td>
<td>0.001174</td>
</tr>
<tr>
<td>$1.4 \times 10^{-9}$</td>
<td>42</td>
<td>0.044</td>
<td>0.000854</td>
</tr>
</tbody>
</table>
Minimum bias $dE/dx$

PbPb @ $\sqrt{s_{NN}} = 2.76$ TeV

negative particles
2.2 million min. bias events