Study of hyperon-hyperon correlations and search for the H-dibaryon with the STAR detector at RHIC

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Outline:
- Introduction
- Results and discussions
  - Correlation Function for \( \Lambda\Lambda \)
  - Correlation Function for \( \Lambda \bar{\Lambda} \)
  - Search for \( H \rightarrow \Lambda p\pi \)
- Summary
Heavy Ion Collisions: unique place

- Hadronic physics involving short-lived particles
- Search of exotic particles with multiple strangeness

RHIC: high rate of strange particle production

Hyperon-hyperon interactions:

- Study two particle correlation functions
- Determination of $\Lambda\Lambda$, $\Lambda\Xi$ interactions
- Also possible to study $\Lambda\Omega$, $\Xi\Xi$, $\Xi\Omega$, $\Omega\Omega$ interactions, which are difficult to study @ kaon beam facilities
Measurement of $\Lambda\Lambda$ correlation functions:

- Related to the size $r_0$ of the emitting region
- no Coulomb interactions
- The two particle Correlation Function (Greiner and Muller, Phys. Lett. B 219 (1989) 199)

$$R(Q) = \lambda \exp(-Q^2r^2)$$

where $Q$ is relative momentum between two particles and $\lambda$ is degree of incoherence of the source

- Search for H-dibaryon
Six quark state (uuddss)*

Properties: $J^\pi = 0^+$, mass: $(1.9-2.8)$ GeV/$c^2$

Predicted production rate $\sim 10^{-3} – 10^{-5}$

Recent lattice results on Binding Energy $\sim 20-50$ MeV/$c^2$ or $13$ MeV/$c^2$

Depending on the mass we have different decay modes of $H$:

<table>
<thead>
<tr>
<th>Channel</th>
<th>Threshold mass (GeV/$c^2$)</th>
<th>$\Delta S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda\Lambda$</td>
<td>2.231</td>
<td>0</td>
</tr>
<tr>
<td>$\Lambda\rho\pi$</td>
<td>2.192</td>
<td>1</td>
</tr>
<tr>
<td>$NN\pi\pi$</td>
<td>2.152</td>
<td>2</td>
</tr>
</tbody>
</table>

* Possible to look with STAR

* Phy Rev Lett 38 (1977) 195
Depletion of phase space due to bound state formation of \( H \Rightarrow \) inclusive measurement, sensitive to total yield

\[ \Lambda - \Lambda \text{ correlation with resonance} \]

\[
\begin{align*}
\text{R}(Q) & = P_{\text{res}} = 50 \text{ MeV/c} \\
R_{\text{res}} & = 2.4 \text{ fm} \\
\text{Width} & = 2.7 \text{ MeV}
\end{align*}
\]

\[
\frac{d^2N}{2\pi p_T dp_T dy} (c^2/\text{GeV}^2)
\]

\( N_{\Lambda} = 15 \)

\( N_{\Lambda\Lambda} = 1.52 E-4 \)

Au+Au@200 GeV
y=0 and centrality: 0-5%

*Lie-Wen Chen, 9th Workshop on QCD phase transitions and relativistic heavy ion collisions, China July 18-20, 2011

Greiner and Muller, Phy Lett B 219, 199 (1989)
Previous measurements

$\Lambda\Lambda$ correlations

- Nagara Event (KEK-E373 experiment) : $^6\Lambda\Lambda$He hypernuclei
  
  \[ \Xi^- + {}^{12}\text{C} \rightarrow ^6\Lambda\Lambda\text{He} + ^4\text{He} + t \]
  
  \[ ^6\Lambda\Lambda\text{He} \rightarrow ^5\Lambda\Lambda\text{He} + p + \pi^- \]

No deeply bound H

Scattering length

$a_{\Lambda\Lambda} = -0.10^{+0.45}_{-2.35} \pm 0.04$ fm

No bound H/ weakly bound H
STAR detector

\[ p \frac{dE}{dx} (\text{GeV}/\text{cm}) \]

*\( p \otimes q \) (GeV/c)*
Correlation Functions

Correlation Function (CF):

\[ CF_{measured}(Q) = \frac{A(Q)}{B(Q)} \]

A(Q) – real pair, B(Q) – pair from mixed event and Q – relative momentum between two particles

Purity correction:

\[ CF_{corrected}(Q) = \frac{CF_{measured}(Q) - 1}{PP(Q)} + 1 \]

Pair Purity PP(Q):

\[ PP(Q) = \frac{S}{S + B} (p_{Ti}) \times \frac{S}{S + B} (p_{Tj}) \]

S – signal, B – background and \( p_T \) – transverse momentum
$\Lambda \rightarrow p\pi$ ($M = 1.1156 \text{ GeV}/c^2$)
Branching ratio = 63%
Mean Life time: $\tau = 2.63 \times 10^{-10} \text{ s}$
$c\tau = 7.89 \text{ cm}$

Topological cuts:
- $DCA_\Lambda$ to Primary Vertex < 0.4 cm
- $DCA_p$ to Primary Vertex > 0.6 cm
- $DCA_\pi$ to Primary Vertex > 1.5 cm
- $DCA_p$ to $\pi$ < 0.8 cm
- $|M_\Lambda - M_{\text{PDG}}| < 0.004 \text{ GeV}/c^2$

Pair selection cuts:
- $|n_1 \cdot n_2| < 0.98$, where $n = p \times p_\Lambda$
- $|R| > 3 \text{ cm}$, where $R = V_{\Lambda_1} - V_{\Lambda_2}$
* $DCA \rightarrow$ Distance of Closest Approach
Correlation functions for 0-40 % Au+Au collisions at $\sqrt{s_{\text{NN}}} = 200$ GeV

- Inclusive $\Lambda\Lambda$ correlations: Feed down contributions included in theoretical models.

- Type of $\Lambda\Lambda$ interaction:
  - Meson exchange models: Nijmegen model D, F, Soft Core (89, 97)
  - Quark cluster model interaction: fss2
  - Phenomenological model: Ehime

- $\Lambda\Lambda$ interaction $\rightarrow$ Attractive

Fits: A. Ohnishi, HHI Workshop, 2012
$\Lambda\Lambda$ correlation function

- Scattering length ($a_o$) is negative in most fits

- Current fit from different potential models to data gives indication towards non-existence of bound $H$-dibaryon

Fits: A. Ohnishi, HHI Workshop, 2012
$\Lambda$ $\bar{\Lambda}$ correlation function

- Inclusive $\Lambda$ $\bar{\Lambda}$ correlations

- $\Lambda$ $\bar{\Lambda}$ correlations $\rightarrow$ clear suppression at low $Q$

STAR Preliminary

Au+Au $\sqrt{s_{NN}} = 200$ GeV
Search for $H \rightarrow \Lambda p \pi$ (Mass $= 2.192 \text{ GeV}/c^2$)

STAR Preliminary

0-10\% Au+Au $\sqrt{s_{NN}} = 200 \text{ GeV}$

✓ Expected events $N_H \sim 200$ in the range $M_H < 2M_\Lambda$

✓ No visible signal with respect to mixed event or rotational background
Summary

- The $\Lambda$-$\Lambda$ interaction is attractive

- Current fit to the data for $a_0$ and $r_{\text{eff}}$ gives indication towards non-existence of strong bound state of $\Lambda\Lambda$.

- Preliminary measurement of $\Lambda\bar{\Lambda}$ correlation is presented

- Preliminary measurement of $\Lambda p\pi$ mass spectrum to look for $H$ signal is presented
Search for $H \rightarrow \Lambda p \pi$ ($\text{Mass} = 2.192 \text{ GeV/c}^2$)

- Topological cuts to look for Weak decay $H \rightarrow \Lambda p \pi$
  
  0.25 cm < $\Lambda$ dca to PV < 1cm
  
  $\Lambda$ decay length > 5 cm
  
  P $\pi$ decay length > 3 cm
  
  $|d_\Lambda| > 3.5$ cm
  
  $|M_\Lambda - M_{\text{PDG}}| < 0.004$ GeV/c$^2$
  
  $M_{p\pi} < 1.110$ GeV/c$^2$
  
  $\theta_\Lambda < 10$ Deg
  
  $\theta_H < 10$ Deg
H dibaryon production

Blast-wave + Coalescence*

Preliminary

\[ N^\Lambda_\Lambda = 15 \]

\[ N^\Lambda = 1.52 \times 10^{-4} \]

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