High Strangeness Dibaryon Search with STAR Data

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Outline

☒ Introduction

☒ NΩ dibaryon

☒ Two-particle correlation function
  – PΩ correlation function

☒ Summary and Outlook
Standard Model: Baryons – 3 quarks and Mesons – pair of quark-antiquark

1977: within Quark Bag Model, Jaffe predicted H-dibaryon made of six quarks (uuddss) \( (\text{Phys. Rev. Lett. 38,195 (1977); 38, 617(E)(1977)}) \)

Exotic hadrons – long standing challenge in hadron physics

Tetraquark
Meson-Meson molecule

Pentaquark
Meson-Baryon molecule

Hexaquark
Baryon-Baryon molecule
Observation of exotic states @ WASA-at-COSY, Belle, LHCb

Multi-quark states or molecular states?

...
Exotics in Strangeness Sector

Quark content, decay modes and mass of exotic states in strangeness sector:

<table>
<thead>
<tr>
<th>particle</th>
<th>Mass (MeV)</th>
<th>Quark composition</th>
<th>Decay mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0$</td>
<td>980</td>
<td>$q \bar{q} s \bar{s}$</td>
<td>$\pi\pi$</td>
</tr>
<tr>
<td>$a_0$</td>
<td>980</td>
<td>$q \bar{q} s \bar{s}$</td>
<td>$\pi\eta$</td>
</tr>
<tr>
<td>$K(1460)$</td>
<td>1460</td>
<td>$q \bar{q} q \bar{s}$</td>
<td>$K\pi\pi$</td>
</tr>
<tr>
<td>$\Lambda(1405)$</td>
<td>1405</td>
<td>$qqq s \bar{q}$</td>
<td>$\pi\Sigma$</td>
</tr>
<tr>
<td>$\Theta^+(1530)$</td>
<td>1530</td>
<td>$qqq q \bar{s}$</td>
<td>$K\Sigma$</td>
</tr>
<tr>
<td>$H$</td>
<td>2245</td>
<td>$uuddss$</td>
<td>$\Lambda\Lambda$</td>
</tr>
<tr>
<td>$N\Omega$</td>
<td>2573</td>
<td>$qqqssss$</td>
<td>$\Lambda\Xi$</td>
</tr>
<tr>
<td>$\Xi\Xi$</td>
<td>2627</td>
<td>$qqssss$</td>
<td>$\Lambda\Xi$</td>
</tr>
<tr>
<td>$\Omega\Omega$</td>
<td>3228</td>
<td>$ssssss$</td>
<td>$\Lambda K^-+\Lambda K^-$</td>
</tr>
</tbody>
</table>

Recent results on H-dibaryon search:

NΩ Dibaryon

- **Nucleon-Ω (NΩ):** A strangeness = -3 dibaryon is stable against strong decay

  “…there is no color-magnetic effect and the energies are dominated by modification to the single-quark wave function”


- **Scattering length, effective range and binding energy (BE) of NΩ-dibaryon:**

<table>
<thead>
<tr>
<th></th>
<th>Scattering length ($a_0$) fm</th>
<th>Effective range ($r_{\text{eff}}$) fm</th>
<th>BE (sc) MeV</th>
<th>BE (cc) MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SU(2)</td>
<td>1.87</td>
<td>0.87</td>
<td>23.2</td>
<td>19.6</td>
</tr>
<tr>
<td>SU(3)</td>
<td>-4.23</td>
<td>2.1</td>
<td>ub</td>
<td>ub</td>
</tr>
<tr>
<td>QDCSM</td>
<td>2.58</td>
<td>0.9</td>
<td>8.1</td>
<td>7.3</td>
</tr>
<tr>
<td>HALQCD</td>
<td>-1.28+0.13</td>
<td>0.499+0.026</td>
<td>18.9+5.0</td>
<td></td>
</tr>
</tbody>
</table>

Venues for Dibaryon Search

- Systematic study of double strangeness systems
  - Binding energies
  - Experiments at J-PARC, KEK

- Heavy Ion Collisions
  - Hot and dense, strongly interacting partonic matter
  - Environment suitable for existence of exotic hadron
NΩ-dibaryon from Heavy-Ion Collisions

NΩ-dibaryon is an isospin 1/2 doublet and has both pΩ and nΩ channels possible.

In experiments, we can look at pΩ channel with two particle correlation analysis or invariant mass analysis (the J=2, S=-3 state weakly decay is challenging)

- Invariant mass
  - Significant combinatorial background in central Au+Au collisions makes exotic particle searches difficult in heavy-ion collisions

Two Particle Correlation in HIC

- Baryon interaction via two particle correlation

\[ C_{AB}(Q) = \frac{N^\text{pair}_{AB}(k_A, k_B)}{N_A(k_A)N_B(k_B)} \]

- Uncorrelated Interaction
- Interference (HBT) etc.
- \( C_{AB}(Q) = \begin{cases} 1, & \text{Uncorrelated} \\ \text{others} \end{cases} \)
- Interaction
- Interference (HBT) etc.
Lambda-Lambda Correlation Function

Au+Au at 200 GeV, 0-80%

| $a_{\Lambda\Lambda}$ | $a_{p\Lambda}$ | $a_{NN}$ |

All model fits to data suggest that a rather weak interaction is present between $\Lambda\Lambda$ pairs.

$t \rightarrow$ for triplet state
$s \rightarrow$ for singlet state

p-p → Mod. Phys. 39 (1967) 584
$\Lambda\Lambda$ → Nucl. Phys. A 707 (2002) 491
The STAR Detector at RHIC

STAR: a complex set of various detectors, a wide range of measurements and a broad coverage of different physics topics
Particle identification

Au+Au $\sqrt{s} = 200$ GeV (1.41 B events)
$\Omega \rightarrow \Lambda K$ (Mass = 1.672 GeV/c$^2$)
Branching ratio = 67.8%
Mean Life time: $\tau = 0.82 \times 10^{-10}$ s
$c\tau = 2.46$ cm
Ω Reconstruction (2)

Reconstructed invariant mass of Ω+\Omega^-

STAR Preliminary

Ω +\Omega^-

0-40%
1.5<p_T<2.0 GeV/c

selection range

Ω +\Omega^-

40-80%
1.5<p_T<2.0 GeV/c

selection range

Ω +\Omega^-

0-40%
3.0<p_T<3.5 GeV/c

selection range

Ω +\Omega^-

40-80%
3.0<p_T<3.5 GeV/c

selection range
Proton Identification with TPC+TOF

Excellent PID with TPC+TOF

- Number of fit points > 15
- Ratio of fit points to possible points > 0.52
- $p_T$ cut for proton tracks > 0.15 GeV/c
  - DCA < 0.5 cm
  - $0.75 < m^2 < 1.1$ (GeV/c^2)^2

Particle identification

With proton and anti-proton $S/(S+B) \sim 99\%$
Few Definitions and Corrections

**Step-I Raw correlations**

![Equation](C(k*) = \frac{P(p_a, p_b)}{P(p_a)P(p_b)} = \frac{\text{real pairs}}{\text{mixed pairs}})

- \( p \) – momentum of particles a and b
- \( Q \) – relative momentum

**Step-II Purity correction**

\[
CF_{\text{corrected}}(k^*) = \frac{CF_{\text{measured}}(k^*) - 1}{PP(k^*)} + 1
\]

- \( PP(k^*) = P(\Omega) \times P(p) \) is pair purity.
- \( P(\Omega) = S/(S+B) \times Fr(\Omega) \) and \( P(p) = S/(S+B) \times Fr(p) \)
- \( Fr(\Omega) = 1 \) and \( Fr(p) = 0.52 \)

**Step-III Momentum smearing**

\[
CF(k^*) = CF(k^*) \frac{CF_{\text{nosmearing}}}{CF_{\text{smearing}}}
\]

Smearing correction factor is 0.99
Comparison of measured $PΩ$ correlation function from 0-40 and 40-80% centrality with the predictions for $PΩ$ interaction potentials $V_I$, $V_{II}$ and $V_{III}$.

**Table: Spin-2 $pΩ$ potentials**

<table>
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<tr>
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<th>$V_{II}$</th>
<th>$V_{III}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binding energy $E_B$ (MeV)</td>
<td>$-$</td>
<td>6.3</td>
<td>26.9</td>
</tr>
<tr>
<td>Scattering length $a_0$ (fm)</td>
<td>-1.12</td>
<td>5.79</td>
<td>1.29</td>
</tr>
<tr>
<td>Effective range $r_{eff}$ (fm)</td>
<td>1.16</td>
<td>0.96</td>
<td>0.65</td>
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**References:**

The ratio of the correlation function between the small and large collision system is insensitive to the Coulomb interaction and also to the source model of the emission, thus it provides a useful measure to extract the strong interaction part of the pΩ attraction from experiments at RHIC/LHC. 

ratio of C(Q): small/large system:
- Loose: Enhancement at low Q
- Tight: C(Q) < 1
- No Bound: Slightly above 1
The ratio of correlation function between small and large collision systems for the background is unity within uncertainties.

The ratio of correlation function between small and large collision systems at low $k^*$ is lower than background.

**Source Size Analysis on $PΩ$ Correlation Function**

SS → Static source
ES → Expanding source
Background → $Ω$ sideband is used
Boxes → systematic uncertainty

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<th>Spin-2 $pΩ$ potentials</th>
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<th>$V_Ⅱ$</th>
<th>$V_Ⅲ$</th>
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Present the 1st measurement of correlation function for $P\Omega$ from Au+Au collisions @ 200 GeV

The ratio of correlation function for the small (peripheral collisions) to the large (central collisions) system is smaller than unity at low $k^*$

The measured ratio of correlation function from peripheral to central collisions is compared with predictions based on the $P\Omega$ interaction potentials derived from lattice QCD simulations
STAR Major Upgrades before 2020

- **iTPC Upgrade:**
  - Rebuilds the inner sectors of the TPC
  - Continuous Coverage
  - Improves $dE/dx$
  - Extends $\eta$ coverage from 1.0 to 1.5
  - Lowers $p_T$ cut-in from 125 MeV/c to 60 MeV/c

- **EPD Upgrade:**
  - Allows a better and independent reaction plane measurement critical to BES physics
  - Improves trigger
  - Reduces background
Status of the Inner TPC Upgrade

☑ SAMPA FEE (MWP2)

- 2FEEs and RDO installed on one inner most row of TPC
- Running through USB port with beam
- Design and producing pre-production RDO and FEE to instrument one Full sector for tests in fall

☑ Sectors (strongback + padplane + MWPC)

- Precision assembly at LBL of padplane to strongbacks and sidemounts ongoing
- Sector production started at SDU (3 completed, testing ongoing) with first fully tested sectors expected to be installed in STAR in October

☑ Insertion tool

- Completed at UIC and currently being commissioned at BNL

SAMPA is well behaved
Thank You for Your Attention!
Proposal on source size dependence analysis

The ratio of correlation function between small and large collision systems to extract strong p-Omega interaction w/o much contamination from Coulomb interaction.

Morita etc. arXiv:1605.06765

Table I: The binding energy ($E_B$), the scattering length ($a_0$) and the effective range ($r_{\text{eff}}$) with and without the Coulomb attraction in the $p\Omega$ system. Physical masses of the proton and $\Omega$ are used.

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<th>$V_{III}$</th>
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<tr>
<td>without Coulomb $E_B$ [MeV]</td>
<td>−</td>
<td>0.05 24.8</td>
<td></td>
</tr>
<tr>
<td>$a_0$ [fm]</td>
<td>−1.0</td>
<td>23.1 1.60</td>
<td></td>
</tr>
<tr>
<td>$r_{\text{eff}}$ [fm]</td>
<td>1.15</td>
<td>0.95 0.65</td>
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