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QUARK MATTER KRAKÓW 2022

Measurements of Λ-Λ and Ξ-Ξ correlations in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at RHIC-STAR

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Abstract

The interaction between hyperon-hyperon (YY) is not well understood theoretically and experimentally. The YY interaction is important to understand the equation of state of neutron star interior as well as to search for exotic hadrons such as H-dibaryon. The H-dibaryon was proposed as a stable six-quark state resulting from combination of two Λ hyperons. According to the lattice QCD calculation [1], H-dibaryon could be in a deeply bound state or in a shallow bound state, or two Λ hyperons have weak unbound attractive interaction, depending on quark mass. On the other hand, the observation of double hypernuclei [2] suggests that they are not in a deeply bound state, although more experimental inputs are needed to clarify the nature of possible H-dibaryon state. For the case of two Ξ (strangeness S = -4) interaction, whether or not there is a bound state of Ξ-Ξ is being discussed.

In high-energy heavy-ion collisions, a large number of particles including (multi-) strangeness are produced, which allows us to study those interactions via femtoscopic measurements with better precision. The correlation function is affected by strong interaction, quantum statistics, and Coulomb interaction in low relative momentum of particle pairs of interest.

In this poster, the status of measurements of Λ-Λ and Ξ-Ξ correlation functions in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at RHIC-STAR will be reported.

[1] T. Inoue *et al.* (HAL QCD Collaboration), Nucl. Phys. A881, 28 (2012)

[2] H. Takahashi *et al.*, Phys. Rev. Lett. 87, 212502 (2001)

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Physics Motivation

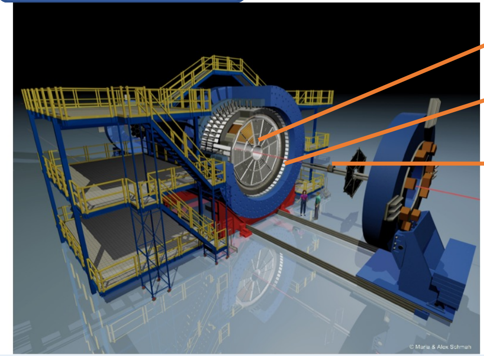
What is the interior of neutron stars ???

-Inside of neutron stars, there are a lot of hyperon particles. Understanding the hyperon interaction's bound state and interaction range is important to determine the equation of state.

-In high energy nuclear collision, a lot of hyperons are generated.

-Study Λ-Λ and Ξ-Ξ correlations and quantify the hyperon interactions by femtoscopic measurement in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

STAR Detector

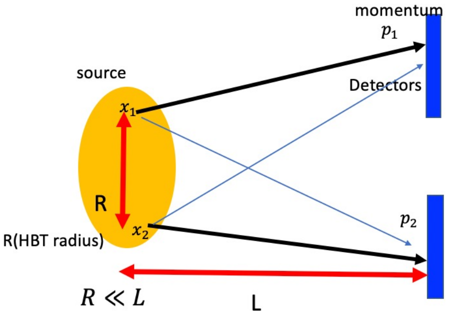


	Λ-Λ and Ξ-Ξ
Run year	2011, 2014, 2016
Total events	2.8 billion

Femtoscopy method

-In 1956, Hanbury Brown & Twiss measured the apparent diameter of Sirius.

-Technique based on Bose-Einstein/Fermi-Dirac correlation has been used in heavy-ion collisions to measure the spatial and temporal extent of particle emitting source.



Theoretical formula

$$C(q)=\int s(r)|\psi(q,r)|^2 dr^3$$

r: relative distance (of pair)

q: relative momentum $Q_{inv} = \sqrt{q_x^2 + q_y^2 + q_z^2 - E_0^2}$

$s(r)$ source function $\psi(q,r)$: wave function of two-particles

Analysis method

$$C(q) = \frac{A(q)}{B(q)}$$

A: actual pairs from same events

B: background pairs from mixed events

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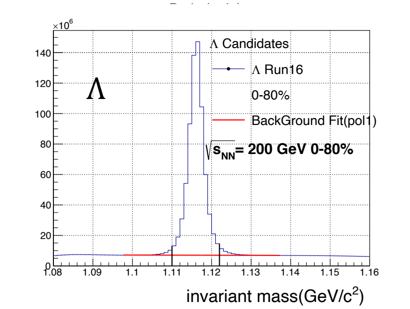
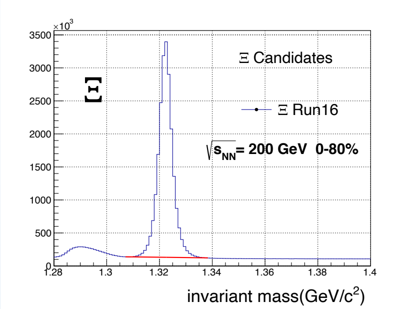
Hyperon Decay mode

	Decay channel	Mass (from PDG 2018)
Λ (uds) $\bar{\Lambda}$	$\Lambda -> \pi^- + p$ $\bar{\Lambda} -> \pi^+ + \bar{p}$ (63.9%)	$1.115683\ (\mathrm{GeV}/c^2)$
$\Xi\ (dss)$ $\bar{\Xi}$	$\Xi -> \Lambda + \pi^+$ $\bar{\Xi} -> \bar{\Lambda} + \pi^-$ (99.87%)	$1.32171\ (\mathrm{GeV}/c^2)$

Invariant mass





-Very good Purity for Λ(~88%) and Ξ(~90%).

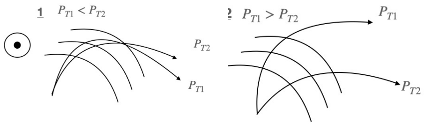
Pair Cut

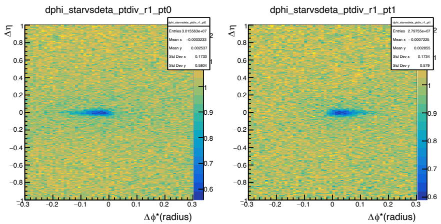
-Track crossing is a pair inefficiency causing one track to be lost in pairs that have close trajectories inside the TPC.

- Reject pairs that fall into the inefficient region of $\Delta\phi^*$vs$\Delta\eta$ distribution.

$$\Delta\phi^* = \phi_1 - \phi_2 + sin^{-1}\left(\frac{0.3eB_zR}{2p_{T_1}}\right) - sin^{-1}\left(\frac{0.3eB_zR}{2p_{T_2}}\right) \qquad p_T \geq 0.4\ \mathrm{GeV/c}$$

Daughter p-p correlation

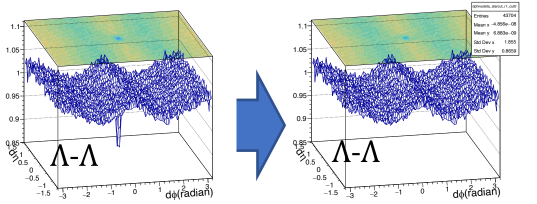




Λ-Λ correlation

$$C_2(\Delta\phi,\Delta\eta) = \frac{N_{mix}^{pair}Y_{real}(\Delta\phi,\Delta\eta)}{N_{real}^{pair}Y_{mix}(\Delta\phi,\Delta\eta)} \qquad \Delta\eta = \eta_2 - \eta_1 \quad \Delta\phi = \phi_2 - \phi_1$$

Y=yield of pairs



-The anti-correlation by detector inefficiency was largely mitigated.

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Result

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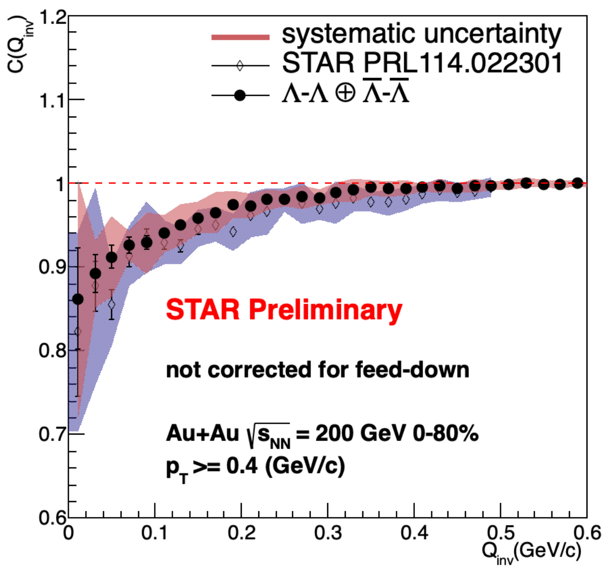
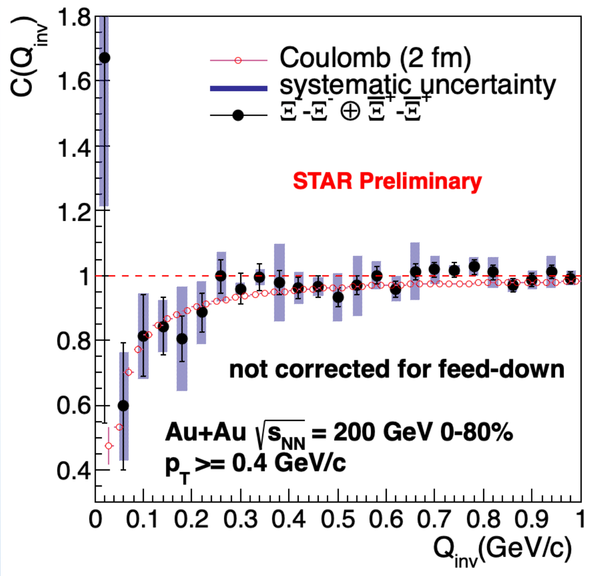
Λ-Λ correlation function



Ξ-Ξ correlation function



-New result with high statistics data (2.8 billion events) is consistent with the previous result (0.79 billion events) within systematic uncertainty.
-There is a long tail of residual correlation in high Q_{inv}.

-First measurement of Ξ-Ξ correlation in Au+Au collisions.
-The result shows anti-correlation at $Q_{inv} < 0.25$ GeV/c.
 - quantitatively agree with Coulomb repulsion only (2fm source).

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Summary and outlook

-High statistics mesurements of Λ-Λ correlations and the first mesurement of Ξ-Ξ correlations in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

➢Λ-Λ **correlation function**

- New result with high statistics data (2.8 billion events) is consistent with previous result.
- Anti-correlation is observed.

➢Ξ-Ξ **correlation function**

- Anti-correlation seems to be observed for the first time, which agrees quantitatively with a model including only Coulomb repulsion (2fm source).

It seems that quantum statistics and strong interaction are canceled.

-This new first measurement is beneficial both to heavy-ion and neutron star research as it provides insight into the new hyperon correlation state.

Outlook

-Correct the correlation functions for feed-down and momentum resolution.

-Fit the correlation functions using Lednicky-Lyuboshitz model including Coulomb interaction to understand these hyperon systems.

-More events of Au+Au $\sqrt{s_{NN}}$ = 200 GeV will be taken in 2023 (10B events) and 2025 (10B events).