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Baryon-Strangeness Correlations in Au+Au Collisions at RHIC-STAR

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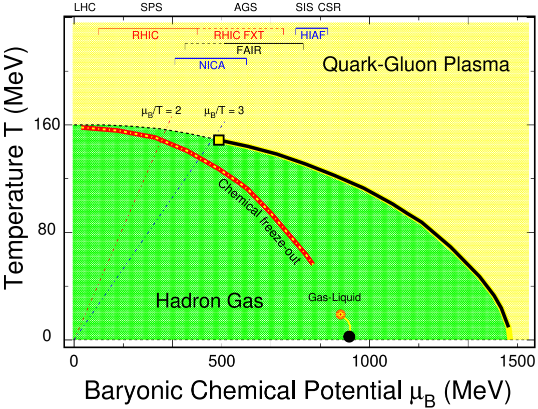
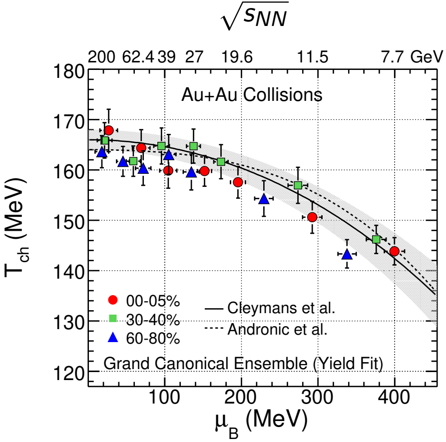
Outline

- Motivation
- STAR Experiment Setup
- Analysis Details
- Results
- Summary

Motivation

Beam Energy Scan (BES) program at RHIC has achieved a magnificent progress in mapping out the QCD phase diagram by tuning the beam energy to vary μ_B and T.





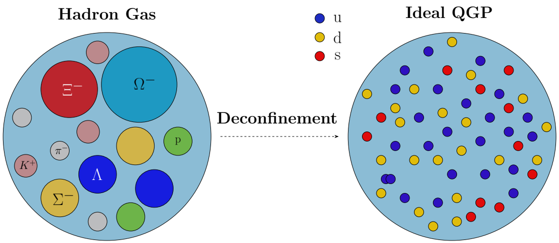
Particles **3**, 278-307 (2020); Phys. Rept. **853**, 1-87 (2020)

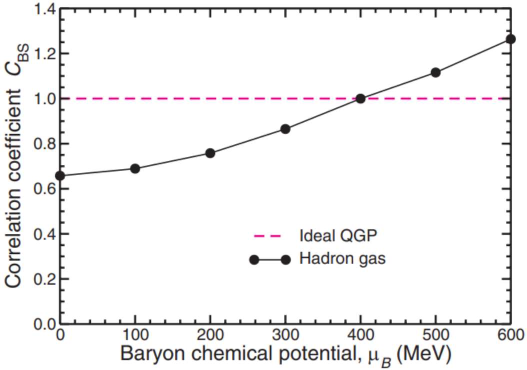
STAR: Phys Rev C 96 4, 044904 (2017)

Motivation

Baryon-Strangeness Correlations (C_{BS}) is proposed to diagnose the change of phases in the matter created in the heavy-ion collisions, which could be expressed as:

$$C_{BS} = -3\frac{\langle BS \rangle_c}{\langle S^2 \rangle_c} = -3\frac{\langle BS \rangle - \langle B \rangle \langle S \rangle}{\langle S^2 \rangle - \langle S \rangle^2}$$





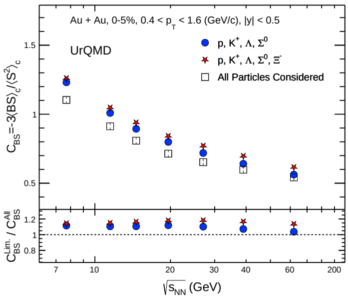
V. Koch et al., Phys.Rev.Lett.95.182301 (2005)

Observable

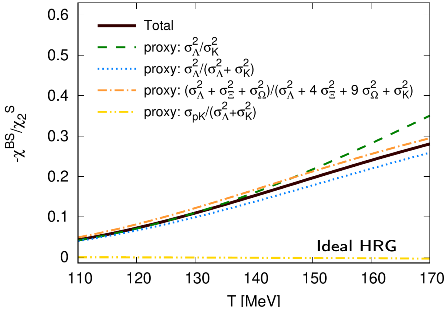
Experimentally, the baryon number (B) and strangeness (S) are defined as:

$$\text{net-B}: \delta p + \delta\Lambda(+\delta\Xi^-) \qquad \text{net-S}: \delta K^+ - \delta\Lambda(-2\delta\Xi^-)$$

where $\delta A = A - \bar{A}$ is the net number of particles of species A. UrQMD and HRG calculations show the set $p, K^+, \Lambda, \Sigma^0$ serves as a good proxy charge for C_{BS}.

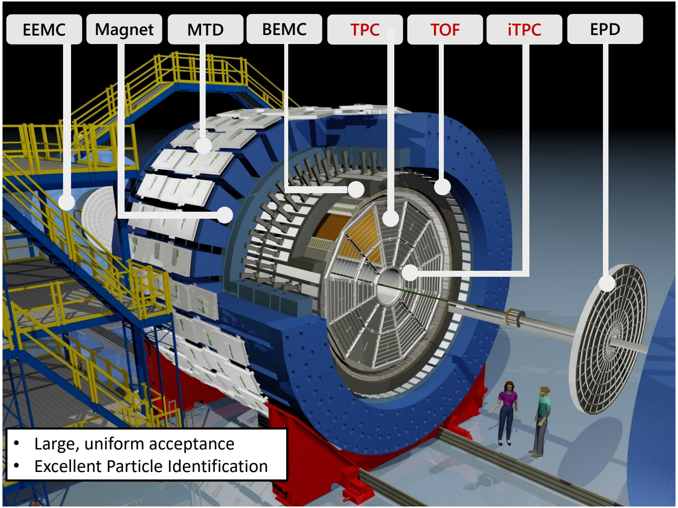


Calculations without $\Xi^-(\bar{\Xi}^+)$ is closer to the one including all the particles in UrQMD.



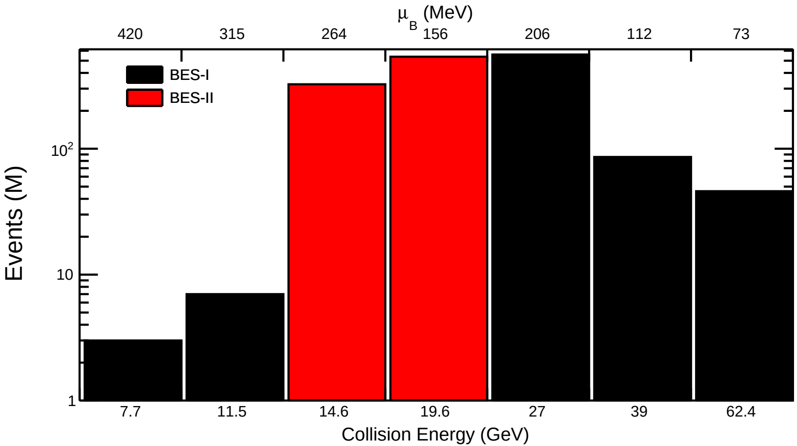
T dependence at $\mu_B = 0$. Λ contains the entire Σ^0 contribution.
R. Bellwied et al., Phys.Rev.D **101**, 034506 (2020)

STAR Experiment Setup



- Full 2π azimuthal coverage
- Upgrade of inner-TPC in BES-II provides better PID performance at low p_T and wider acceptance ($|\eta| < 1.5$)

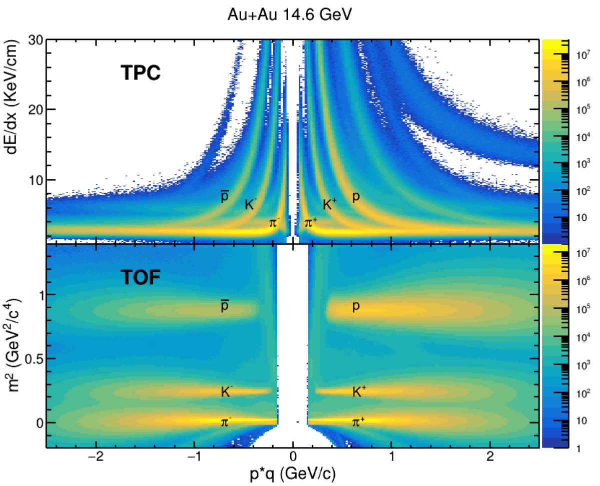
Dataset

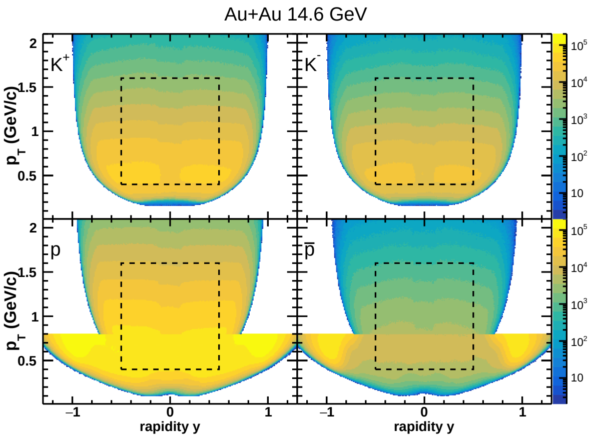


- Seven datasets are analyzed. $\sqrt{s_{NN}}$ ranges from 7.7 to 62.4 GeV and μ_B covers 73-420 MeV.
- Two (14.6 and 19.6 GeV) of them are from BES-II and the others are from BES-I.

Particle Identification

Particles are identified with high purity by TPC and TOF.

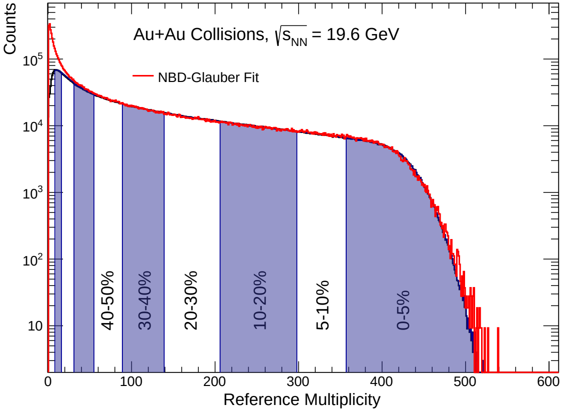




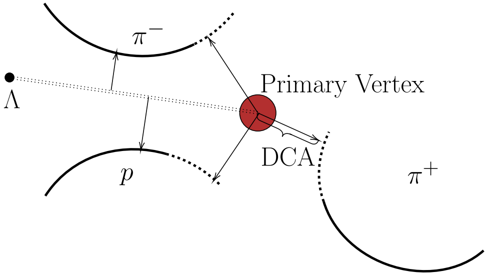
- $p(\bar{p})$: $0.4 < p_T < 0.8$ GeV/c, TPC; $0.8 < p_T < 1.6$ GeV/c, TPC+TOF
- $K^{\pm}$: $0.4 < p_T < 1.6$ GeV/c, TPC+TOF

Centrality Determination

- The centrality is determined with $\pi^{\pm}$ ($|\eta| < 1$) identified by TPC and TOF:



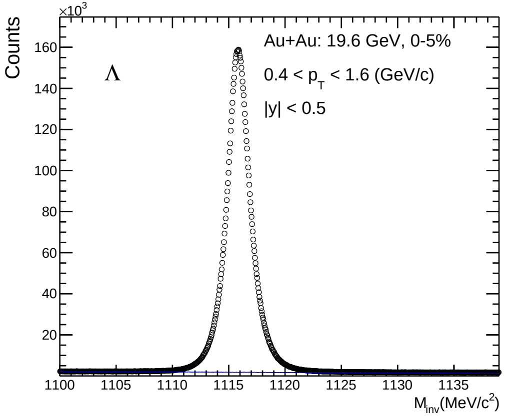
- $\pi^{\pm}$ used in centrality determination does not contain the one used in hyperon reconstruction, which are *Separated* by the distance of closest approach (DCA) of pions to the primary vertex (PV).

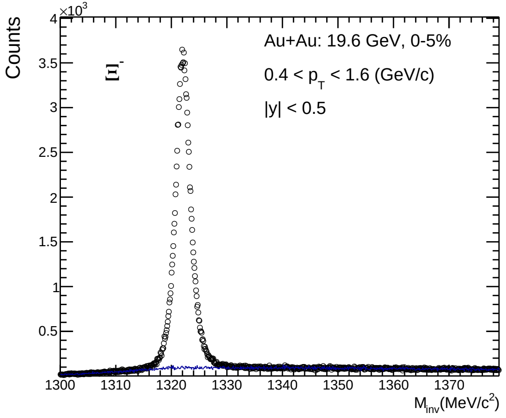


Hyperon Reconstruction

$\Lambda(\bar{\Lambda})$ and $\Xi^-(\bar{\Xi}^+)$ are reconstructed via the decay channels:

$$\Lambda(\bar{\Lambda}) \rightarrow p(\bar{p}) + \pi^-(\pi^+) \quad (\mathcal{B} = 63.9\%) \qquad \Xi^-(\bar{\Xi}^+) \rightarrow \Lambda(\bar{\Lambda}) + \pi^-(\pi^+) \quad (\mathcal{B} = 99.9\%)$$





Correction Methods

Purity Correction → **Efficiency Correction** → **Centrality Bin Width Correction**

T. Nonaka, NIM A 1039 (2022) 167171

A. Bzdak and V. Koch, PRC 91, 027901 (2015)

X. Luo, T. Nonaka , PRC 99, 044917 (2019)

X. Luo et al, J. Phys. G: Nucl. Part. Phys. 40 (2013)

Purity correction

The reconstruction of $\Lambda(\bar{\Lambda})$ and $\Xi^-(\bar{\Xi}^+)$ are troubled by the combinotorial background. The purity correction is applied to remove the contribution from background.

Methodology

$$\langle N_S \rangle_c = \langle N_{SC} \rangle_c - \langle N_{B,i} \rangle_c$$

$$\langle N_S^2 \rangle_c = \langle N_{SC}^2 \rangle_c - \langle N_{B,i}^2 \rangle_c + 2 \langle N_{SC} N_{B,i} \rangle_c - 2 \langle N_{SC} N_{B,i} \rangle_c + 2 \langle N_{B,i} N_{B,j} \rangle_c$$

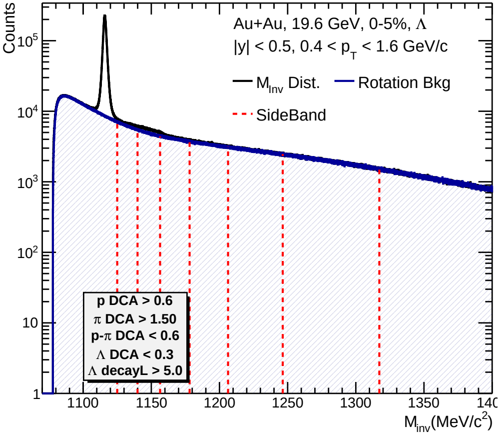
S: Signal; SC: Signal candidates; B: Background

Multiple cumulants of background need to be calculated.

Cumulants in different windows

Those invariant mass windows estimating the background are determined such that:

$$\int_{Signal} N_{Rotation}(M_{Inv})\mathrm{d}M_{Inv} = \int_{Band} N_{Reconstruction}(M_{Inv})\mathrm{d}M_{Inv}$$



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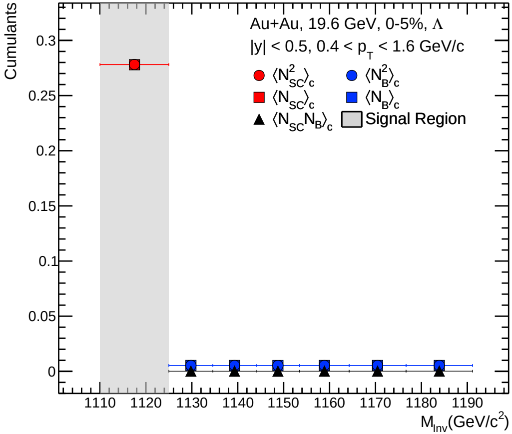
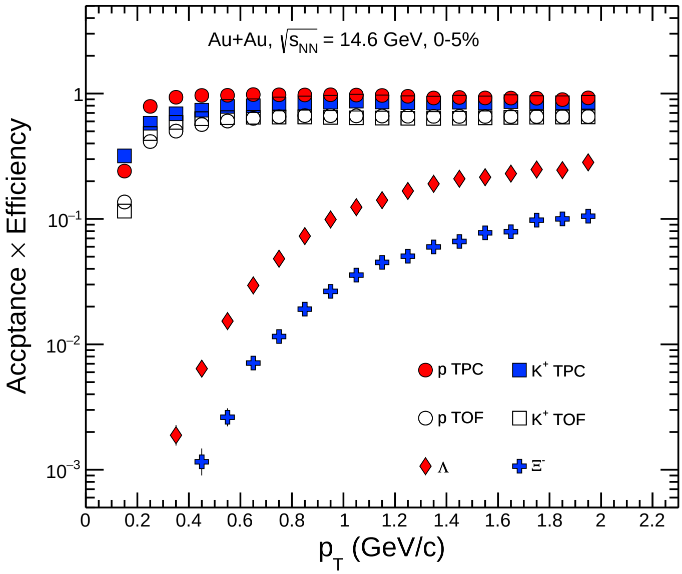


Efficiency correction



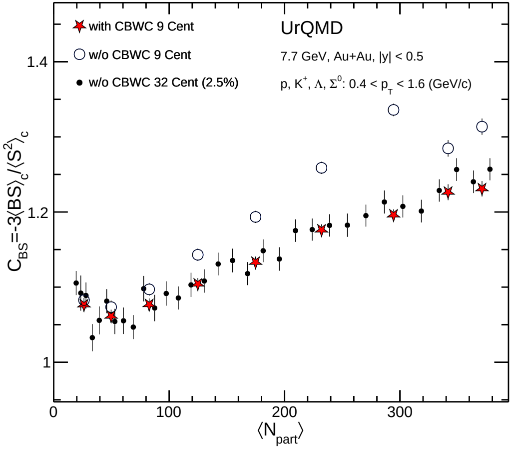
- The efficiency correction is applied with average efficiency ϵ:

$$\langle N^2\rangle_c = (\langle N^2\rangle_c + (\epsilon - 1)\langle N\rangle_c)/\epsilon^2$$
$$\langle N\rangle_c = \langle N\rangle_c/\epsilon$$

- The average efficiency $\epsilon_{\Lambda\to p\pi^-}$ and $\epsilon_{\Xi^-\to\Lambda\pi^-}$ are scaled by the corresponding branching ratio.

Centrality Bin Width Correction

Centrality Bin Width Effect (CBWE) arises from the impact parameter (or volume) variations due to the finite centrality bin, which could be suppressed by the Centrality Bin Width Correction.

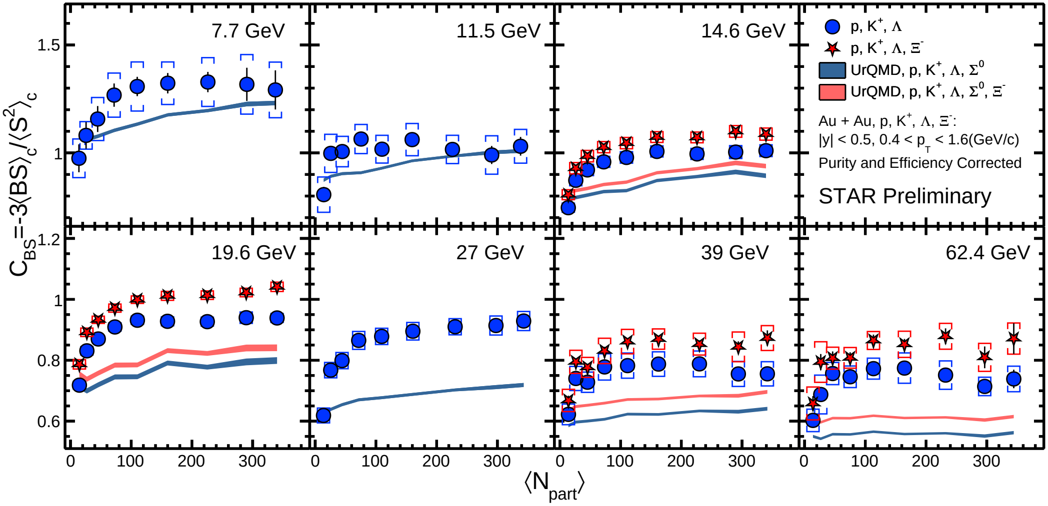


$$\langle BS \rangle_c = \frac{\sum_r n_r \langle BS \rangle_c}{\sum_r n_r} = \sum_r \omega_r \langle BS \rangle_c$$

$$\langle S^2 \rangle_c = \frac{\sum_r n_r \langle S^2 \rangle_c}{\sum_r n_r} = \sum_r \omega_r \langle S^2 \rangle_c$$

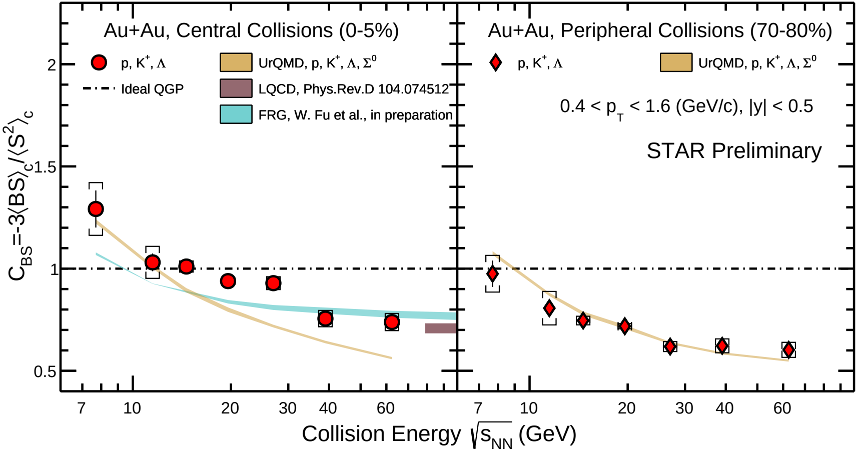
where n_r is the number of events in r-th multiplicity for centrality determination.

Centrality Dependence



UrQMD can describe the centrality dependence of 7.7 GeV, 11.5 GeV qualitatively and quantitatively, while it underestimates the higher energy.

Energy Dependence



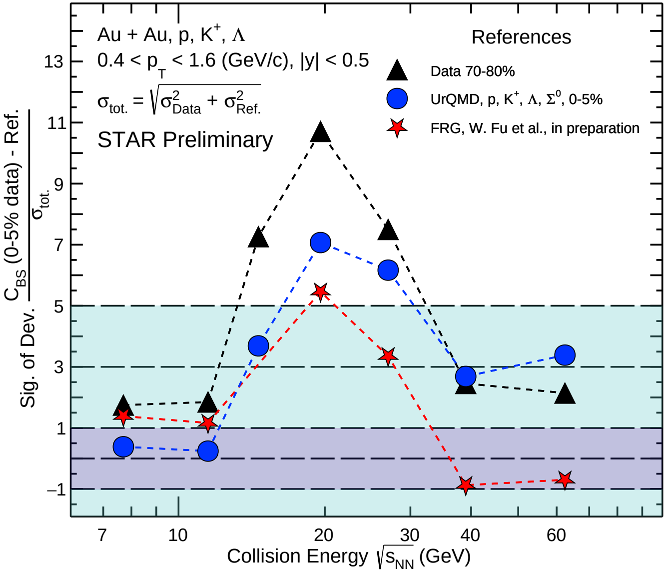
Central collisions:

- 39 and 62.4 GeV are consistent with functional renormalization group (FRG) and LQCD calculations.
- The results of 7.7 and 11.5 GeV are consistent with UrQMD.
- 14.6, 19.6 and 27 GeV cannot be reproduced by either UrQMD or FRG.

Peripheral collisions:

- The energy dependence can be well described by UrQMD.

Deviation from References

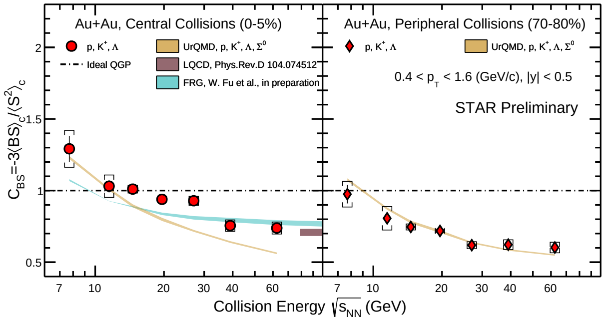


- 39 and 62.4 GeV agree with FRG calculations and HRG around 1σ but deviate from UrQMD around 3σ.
- The results of 7.7 and 11.5 GeV agree with UrQMD within 0.5σ.
- At 19.6 GeV, the largest discrepancies from all references are observed, which are more than 5σ.

Summary and Outlook

Summary

- We present the centrality and beam energy dependence of Baryon-Strangeness Correlations (C_{BS}) from Beam Energy Scan at STAR in Au+Au collisions from 7.7 to 62.4 GeV.
- The maximum deviation is found at 19.6 GeV, which is more than 5σ. The physics reason behind this discrepancy requires further investigation.



Outlook

- Analysis on more BES-II data (both collider and fixed target energy) are ongoing.
- Higher order correlations will be studied in the future.

Thank you!