Constraining Heavy-Ion Transport Models with Light and Strange Hadrons in STAR BES-I Au+Au Collisions ($\sqrt{s_{NN}}$ = 3-27 GeV)

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Introduction

The STAR BES program scans the QCD phase diagram at high baryon chemical potential (μ_B) using collision energies $\sqrt{s_{NN}}$ = 3–27 GeV, a critical region where the transition from hadronic to partonic matter is expected. We present a systematic study of strange hadron production using two transport approaches: AMPT (Default and String Melting versions) and UrQMD (purely hadronic). The specific energy of $\sqrt{s_{NN}}$ = 7.7 GeV is particularly compelling: it lies near the predicted first-order phase transition boundary and the possible critical endpoint. We studied light hadron production under these conditions with models: AMPT, EPOS4 (based on hydrodynamics, Pomeron exchange and a core-corona approach), SMASH (a purely hadronic transport with resonance propagation), and PYTHIA (modified for heavy-ion collisions via the Angantyr model). The use of different models allows us to disentangle robust signals from model-dependent assumptions such as the presence or absence of partonic phases, hadronization mechanisms and to assess which features are genuinely required to reproduce STAR data.This comparative approach provides critical insight into the nature of the QCD phase transition at high baryon density.

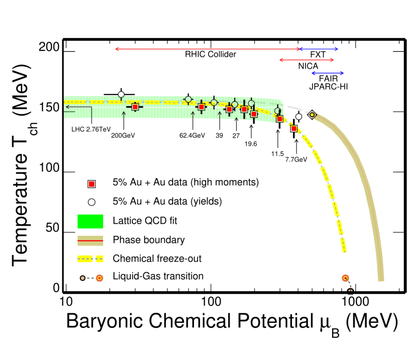


Figure 1: A summary of the chemical freeze-out temperature $T_{ch}(\mu_B)$ distribution. Data points are from the 0-5% central Au+Au collisions at STAR BESI.

Invariant Yield For Strange Hadrons

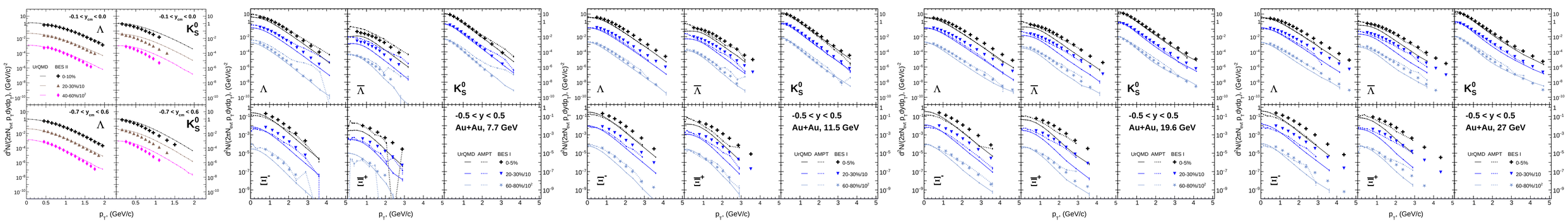


Figure 2: Invariant Yield (p_T) for Λ and K^0_S in the $0.1 < y_{cm} < 0$ and $-0.7 < y_{cm} < 0.6$ rapidity range, for 0 – 10%, 20 – 30% and 40 – 60% centrality classes at $\sqrt{s_{NN}}$ = 3 GeV with UrQMD model and for Λ, $\overline{\Lambda}$, Ξ^+, $\overline{\Xi^+}$, and K^0_S in $|y| < 0.5$, for 0 – 5%, 20 – 30% and 60 – 80% centrality classes at $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, and 27 GeV Au+Au collisions with AMPT and UrQMD. All distributions were compared with data from STAR experiment BES-I program [1].

Invariant Yield For Light Hadrons at $\sqrt{s_{NN}}$ = 7.7 GeV

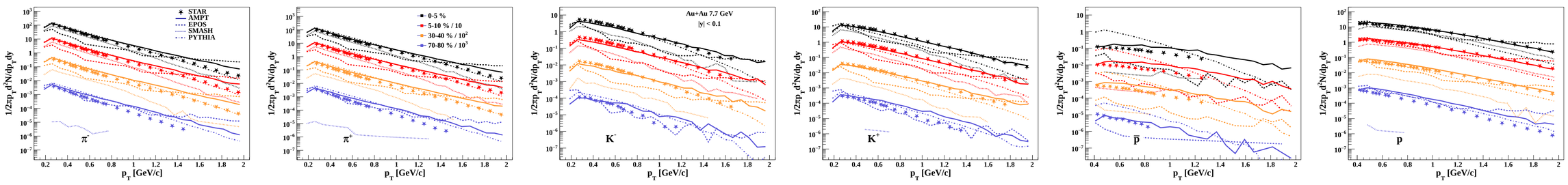


Figure 3: Invariant yield for $\pi^{\pm}$, $K^{\pm}$, p and $\overline{p}$ particles, in the $|y| < 0.1$ rapidity range, for 0 – 5%, 5 – 10%, 30 – 40% and 70 – 80% centrality classes for Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV with AMPT-Default, EPOS4, SMASH and PYTHIA8 event generators, and compared with STAR BES-I experimental data [2]. Excluding the 0 – 5% spectra, the rest were scaled by a factor of 10 for visual clarity.

Antiparticle-to-particle Ratio

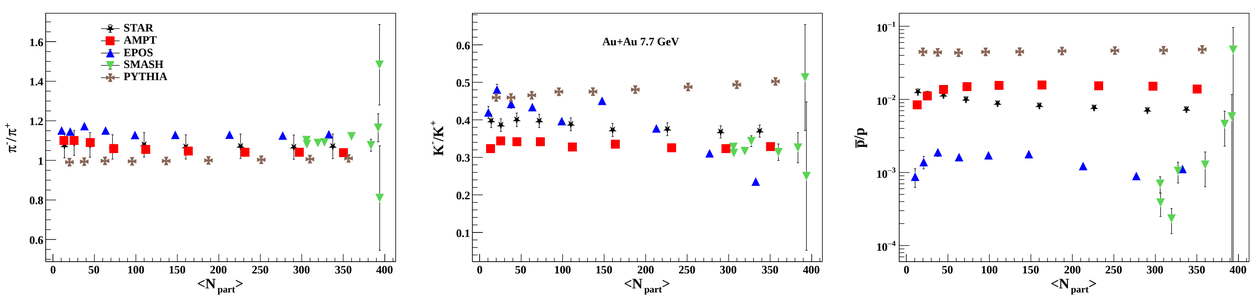


Figure 4: π^-/π^+ (left panel), K^-/K^+ (middle panel) and $\overline{p}/p$ ratios in dependence of $\langle N_{part} \rangle$ for AMPT-Default, EPOS4, SMASH and PYTHIA8 theoretical models, compared with STAR BES-I experimental data [2].

Conclusions

- With a tendency to underestimate the experimental result, AMPT and UrQMD models inadequately fitted the invariant yield (p_T) for strange hadrons, with a closer correspondence for K^0_S.
- AMPT-Default and PYTHIA8 fairly describe the experiment for positive light hadrons for central to mid collisions at 7.7 GeV. EPOS4 and SMASH predicts are too soft.
- AMPT-Default reproduces the STAR BES-I π^-/π^+ ratio.
- For the baryon-to-pion ratio and collision energy dependent integrated yield (dN/dy) of $\overline{\Xi^+}$ and $\overline{\Lambda}$, AMPT shows better aggrement with experimental data when compared with UrQMD.

Baryon-to-Pion Ratio

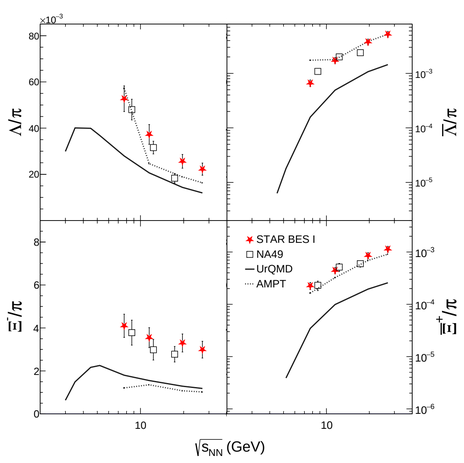


Figure 5: Λ, $\overline{\Lambda}$, Ξ^- and $\overline{\Xi^+}$ ratio to $0.5/(\pi^+ + \pi^-)$ at mid-rapidity, for central collisions (0 – 5%), with UrQMD (straigthed line) and AMPT (dashed line) models. Results are compared with BES-I [3] and NA49 [4] data.

dN/dy as a function of $\sqrt{s_{NN}}$

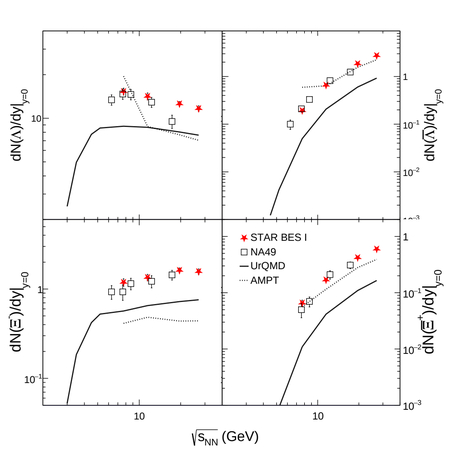


Figure 6: Collision energy dependence of the Λ, $\overline{\Lambda}$, Ξ^- and $\overline{\Xi^+}$ integrated yields (dN/dy), at mid-rapidity in central Au+Au collisions at $\sqrt{s_{NN}}$ = 3–27 GeV with AMPT and UrQMD models, compared with BES-I [3] and NA49 [4] data.

References

References:

1. Adam, Jaroslav, et al. "Strange hadron production in Au+ Au collisions at $\sqrt{s_{NN}}$= 7.7, 11.5, 19.6, 27, and 39 GeV." arXiv preprint arXiv:1906.03732 (2019).
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4. NA49 Collaboration. "Energy dependence of Lambda and Xi production in central Pb+ Pb collisions at 20A, 30A, 40A, 80A, and 158A GeV measured at the CERN Super Proton Synchrotron." arXiv preprint arXiv:0804.3770 (2008).

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