Strange hadron production in Au+Au collisions at $\sqrt{s_{NN}} = 3 - 27$ GeV with UrQMD

Artem Timofeev[1,2], Artem Korobitsin[1]

[1]Joint Institute for Nuclear Research, Dubna - Russia
[2]Lomonosov Moscow State University, Moscow - Russia

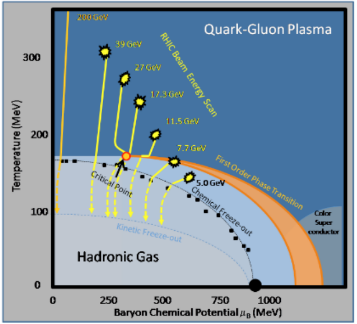
XXVIth International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics", Sep 15 – 20, 2025, VBLHEP JINR

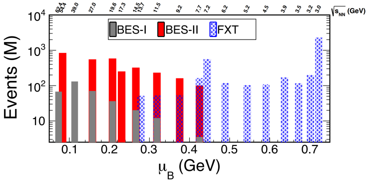
Overview

- Motivation
- Particle reconstruction at STAR (work in progress)
- Strange hadrons production
- Near threshold kinematics
- Summary

Motivation

- Strange hadrons are suggested as exceptional probe for identifying phase boundary and onset of deconfinment
- Strange baryons-to-meson and antibaryons-to-baryons ratios may give insights on hadroonization mechanism and baryon stopping
- UrQMD model comparison to STAR data

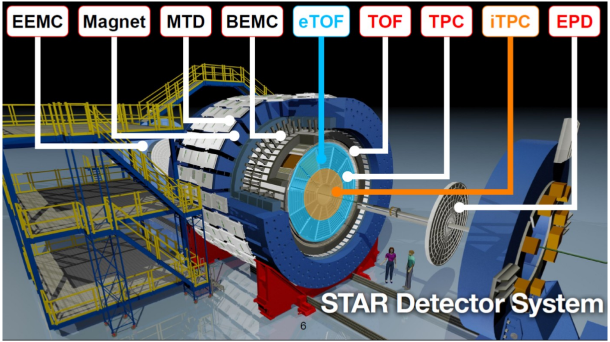




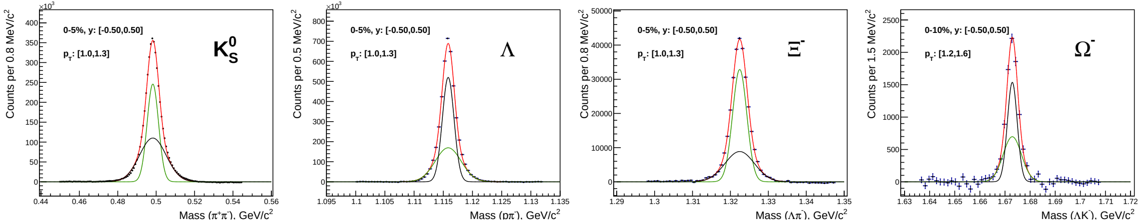
STAR Experiment

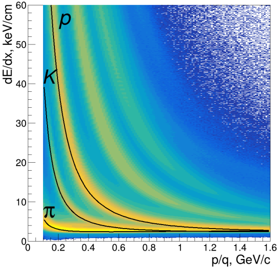
TPC (Time Projection Chamber):

- Tracking and particle identification by dE/dx
- Magnetic field: 0.5 Tesla
- 2π azimuthal angle acceptance
- Pseudorapidity $|\eta| < 1$ acceptance
- $p_T > 0.1\ GeV/c^2$



Particle reconstruction at STAR





- Particle identification with $n\sigma$ on dE/dx
- Cuts on η, p_T, nHitsFit, nHitsdEdx are applied on π, K, p
- Topological cuts are applied on strange particles and daughter particles

$$K^0_S \to \pi^+ + \pi^- \quad (69.20\%) \qquad \Xi^-(\Xi^+) \to \Lambda(\overline{\Lambda}) + \pi^-(\pi^+) \quad (99.887\%)$$

$$\Lambda(\overline{\Lambda}) \to p(\overline{p}) + \pi^-(\pi^+) \quad (63.9\%) \qquad \Omega^-(\Omega^+) \to \Lambda(\overline{\Lambda}) + K^-(K^+) \quad (67.8\%)$$

UrQMD

UrQMD is transport model that solves a relativistic Boltzmann–type transport equation by tracking hadrons and resonances, incorporating string excitation/fragmentation at high energies.

Initialization via Gaussian wave packets:

$$\varphi_j(x_j, t) = \left(\frac{2\alpha}{\pi}\right)^{3/4} \exp\left[-\alpha(x_j - r_j(t))^2 + \frac{i}{h} p_j(t) \cdot x_j\right]$$

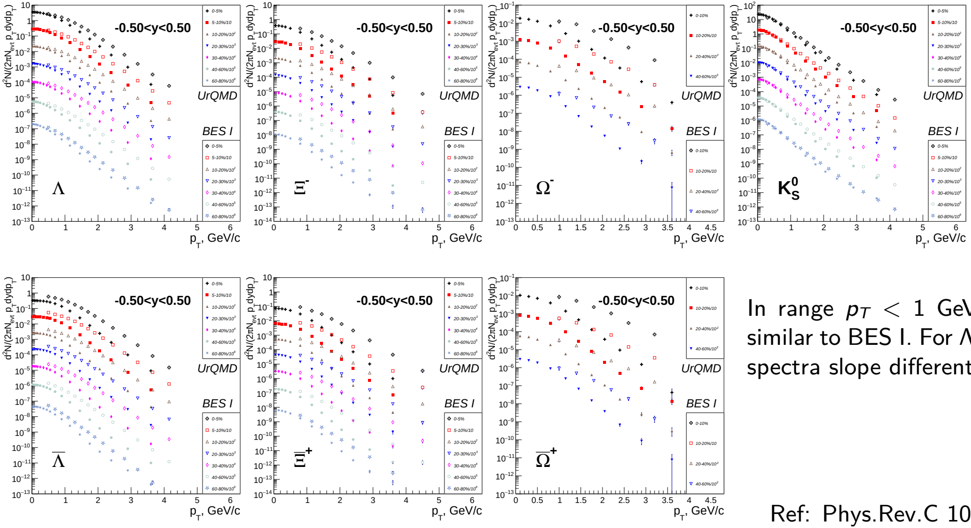
Collision condition via impact parameter and total cross section:

$$d_{\mathrm{trans}} \leq \sqrt{\frac{\sigma_{\mathrm{tot}}}{\pi}}, \quad \sigma_{\mathrm{tot}} = \sigma(\sqrt{s}, \text{particle types})$$

In this work UrQMD 3.4 (CASCADE mode, EoS $= 0$) was used.

Ref: arXiv:nucl-th/9803035v2

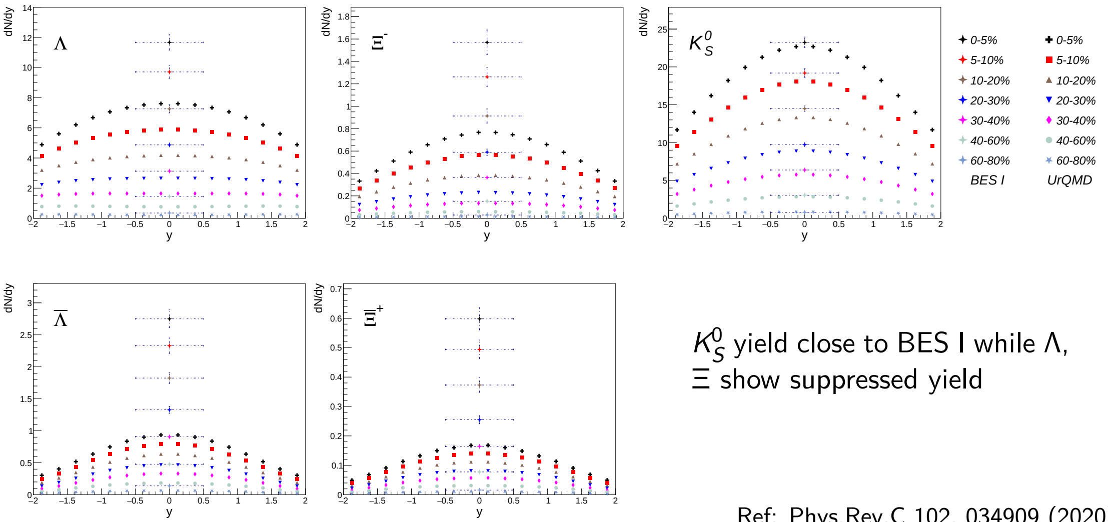
p_T Spectra for 27 GeV



In range $p_T < 1$ GeV/c K^0_S spectra similar to BES I. For Λ, Ξ, Ω UrQMD spectra slope different to BES I

Ref: Phys.Rev.C 102, 034909 (2020)

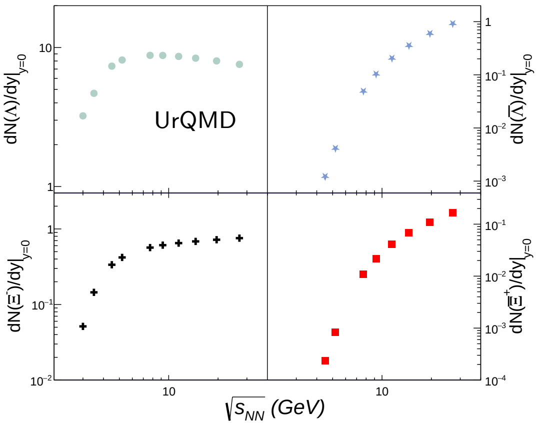
Particle Yield at 27 GeV

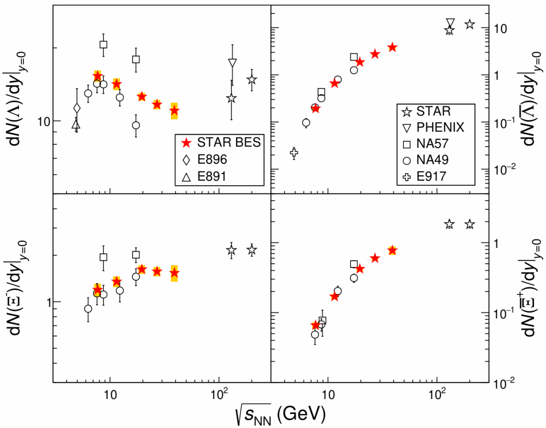


K_S^0 yield close to BES I while Λ, Ξ show suppressed yield

Ref: Phys.Rev.C 102, 034909 (2020)

Energy dependence of the yield

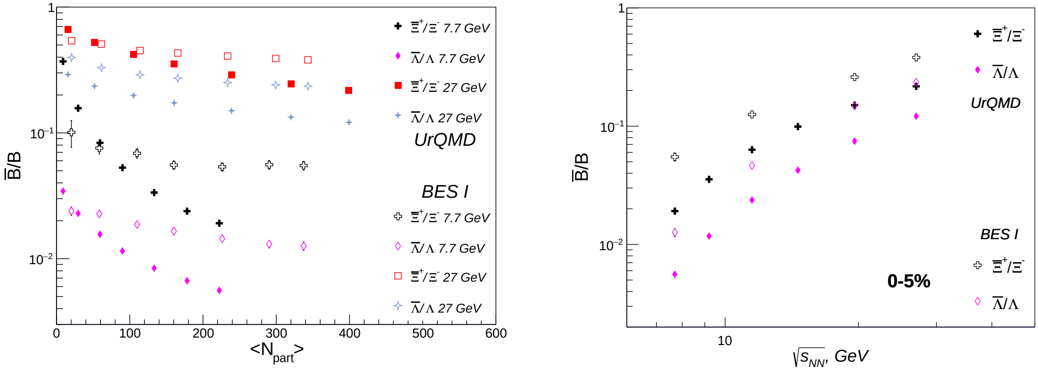




$$|y_{cm}| < 0.5$$

Ref: Phys.Rev.C 102, 034909 (2020)

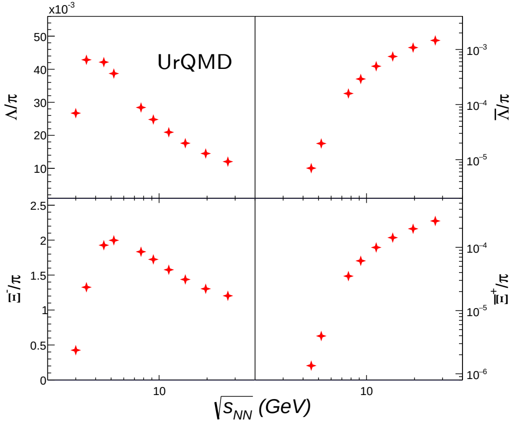
Antibaryon-to-baryon ratio

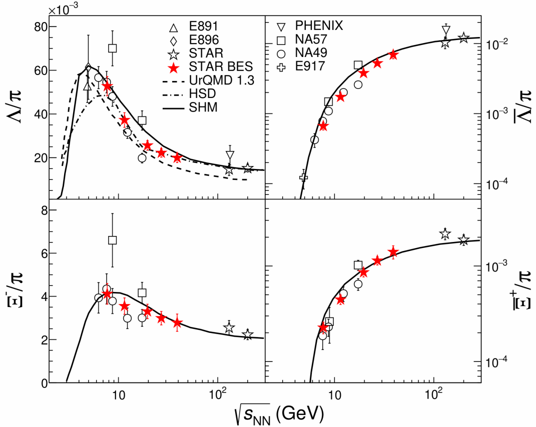


UrQMD ratios decrease from peripherial to central collisions. Compared to BES I, in central collisions UrQMD underestimate $\bar{B}/B$ ratio and overestimate in perpherial collisions.

Ref: Phys.Rev.C 102, 034909 (2020)

Strangeness production I

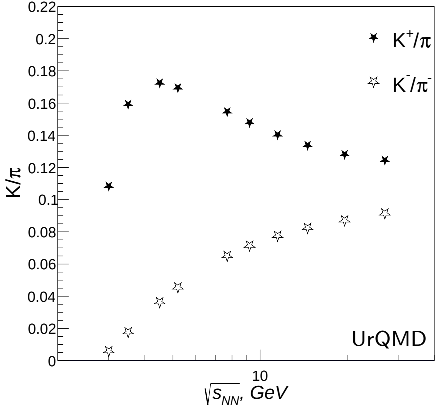


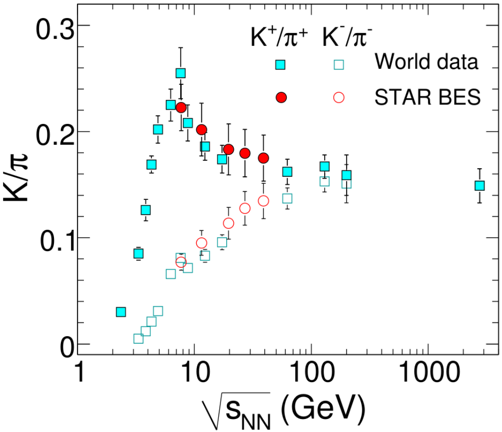


While the general trend of the dependencies is consistent, the absolute values of the ratios are significantly underestimated in the UrQMD model

Ref: Phys. Rev. C 102, 034909 (2020)

Strangeness production II





Horn-like effect can not be explained by hadron-hadron interactions

Ref: Phys. Rev. C 96, 044904 (2017)

Near threshold kinematics I

$$p + p \to S(K^0_S, \Lambda, \Xi, \Omega) + X$$

Since $E^*_{thresh} = M_S + M_X$:

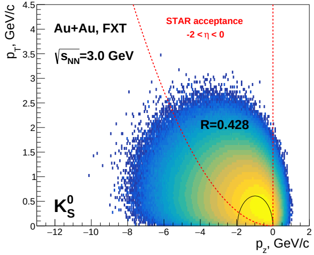
$$\left.\begin{array}{r} p + p \to p + K^0_S + \Sigma^+ \\ p + p \to p + \Xi^- + 2K^+ \end{array}\right\} \Rightarrow \left\{\begin{array}{l} E^*_{thresh, K^0_S} \approx 2.63\ GeV \\ E^*_{thresh, \Xi^-} \approx 3.25\ GeV \end{array}\right.$$

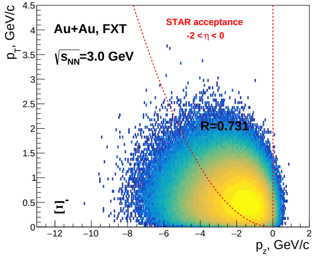
In center-mass system:

$$p_{cm} = \frac{(s - m_S^2 - m_X^2)^2}{2\sqrt{s}}, \quad \beta_{cm} = \frac{p_p}{E_p + m_p}, \quad \gamma_{cm} = \frac{s - m_p^2 + m_p^2}{2m_p\sqrt{s}}$$

Since $\left(\frac{p^*_T}{p^*}\right)^2 + \left(\frac{p^*_z}{p^*}\right)^2 = 1$, using Lorentz boost one obtain:

$$\left(\frac{p^*_T}{p^*}\right)^2 + \left(\frac{p_z - \gamma_{cm}\beta_{cm}E^*_S}{\gamma_{cm}p^*}\right)^2 = 1$$

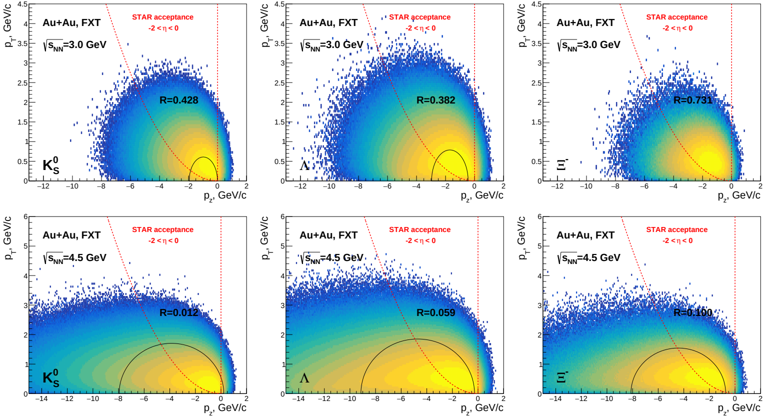




R - ratio of particle inside cumulative region inside STAR acceptance to all particles

Ref: Strokovsky E.A., ISBN: 978-5-317-04607-1

Near threshold kinematics II



A large number of strange particles are produced in the cumulative region. At energies below ≈4-5 GeV it became possible to measure collective effects of multi-nucleon correlations.

Summary

- UrQMD underestimates the yield of strange particles (except K^0_S)
- Particle ratios shows the same trends as STAR data
- At low energies, a significant fraction of particles is produced in the cumulative region, which gives sufficient statistics for measuring cumulative effects.