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

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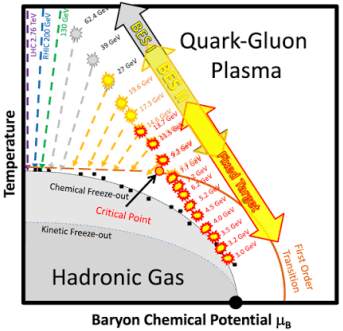
Overview

- Motivation
- Particle reconstruction at STAR (work in progress)
- Strange-hadron spectra and yields
- Blast-Wave analysis of freeze-out parameters
- Conclusions

Motivation

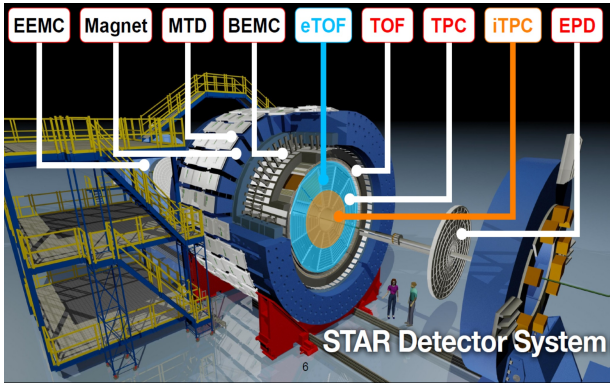
- Strange hadrons are suggested as probes of the QCD phase boundary and the onset of deconfinement.
- Comparison with STAR BES I data will test the hadronic transport baseline provided by UrQMD.
- Extraction of Blast-Wave freeze-out parameters from UrQMD spectra will allow us to study how these parameters depend on collision energy, centrality, rapidity and the particle species included in the fit.



STAR Detector

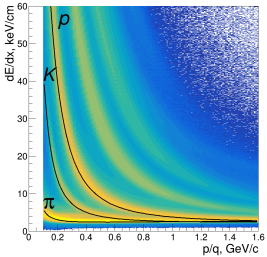
TPC (Time Projection Chamber):

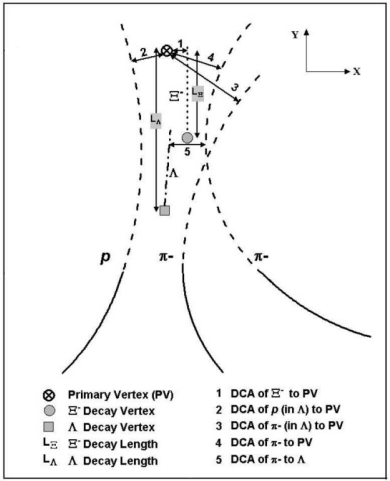
- Tracking and particle identification by dE/dx
- Magnetic field: 0.5 Tesla
- 2π azimuthal angle acceptance
- Pseudorapidity $|\eta| < 1.5$ (iTPC upgrade in 2018)
- $p_T > 0.06$ GeV/c (iTPC upgrade in 2018)



Particle reconstruction at STAR

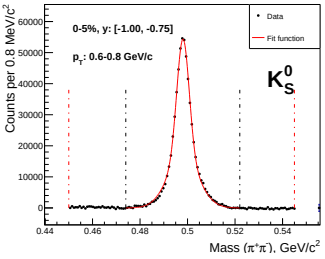
$$K_S^0 \to \pi^+ + \pi^- \quad (69.20\%)$$
$$\Lambda(\overline{\Lambda}) \to p(\overline{p}) + \pi^-(\pi^+) \quad (63.9\%)$$
$$\Xi^-(\Xi^+) \to \Lambda(\overline{\Lambda}) + \pi^-(\pi^+) \quad (99.887\%)$$
$$\Omega^-(\Omega^+) \to \Lambda(\overline{\Lambda}) + K^-(K^+) \quad (67.8\%)$$

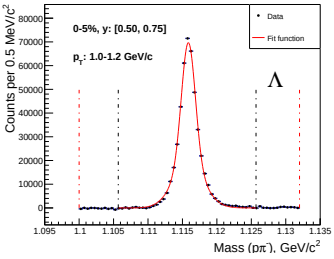


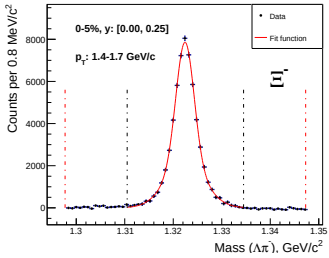


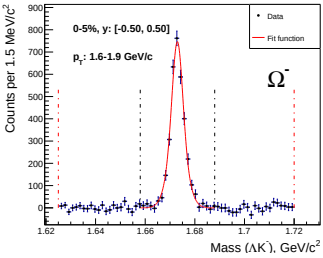
- Particle identification with $n\sigma$ on dE/dx
- Cuts on η, p_T, nHitsFit, nHitsdEdx are applied on π, K, p
- Topological cuts are applied on strange particles and daughter particles

Invariant-mass reconstruction









Signal fit: sum of two Gaussians with a common mean μ:

$$A_1\mathcal{N}(\mu,\sigma_1) + A_2\mathcal{N}(\mu,\sigma_2).$$

Background estimation: rotational technique.

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:

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

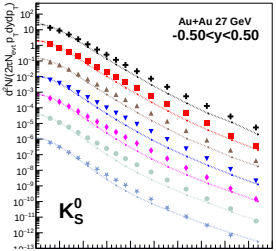
Collision condition via impact parameter and total cross section:

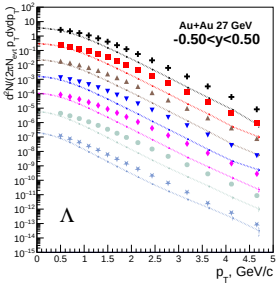
$$d_{\text{trans}} \leq \sqrt{\frac{\sigma_{\text{tot}}}{\pi}}, \quad \sigma_{\text{tot}} = \sigma(\sqrt{s}, \text{particle types})$$

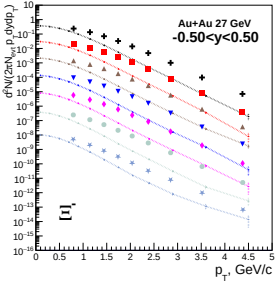
In this work UrQMD 3.4 (CASCADE mode) was used.

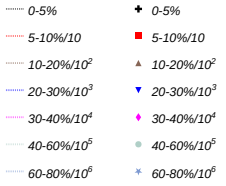
Ref: S.A. Bass et al., Prog. Part. Nucl. Phys. 41, 255–369 (1998).

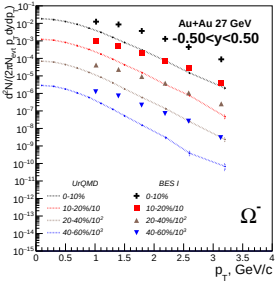
p_T Spectra for 27 GeV







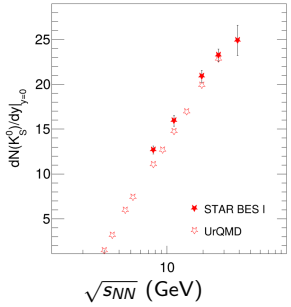




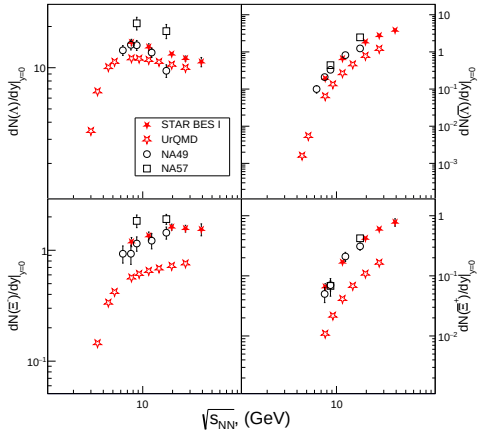
For $p_T < 1$ GeV/c, K^0_S spectra are similar to BES I.
For Λ, Ξ and Ω, the UrQMD spectra slopes differ from BES I.

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

Energy dependence of yields



UrQMD reproduces the experimental yield trends qualitatively, but not quantitatively. The K^0_S yields are close to STAR BES I, while the Λ and Ξ^- yields are generally underestimated.

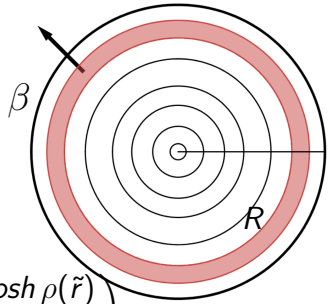


Ref: STAR Collaboration, Phys. Rev. C 102, 034909 (2020)
NA49 Collaboration, Phys. Rev. C 78, 034918 (2008)
NA57 Collaboration, Phys. Lett. B 595, 68–74 (2004)

Blast-Wave model

Assume particles to be emitted from a longitudinally and transversely expanding fireball. Transverse expansion velocity parametrisation:

$$\beta(\tilde{r}) = \beta_{surface}\tilde{r},$$



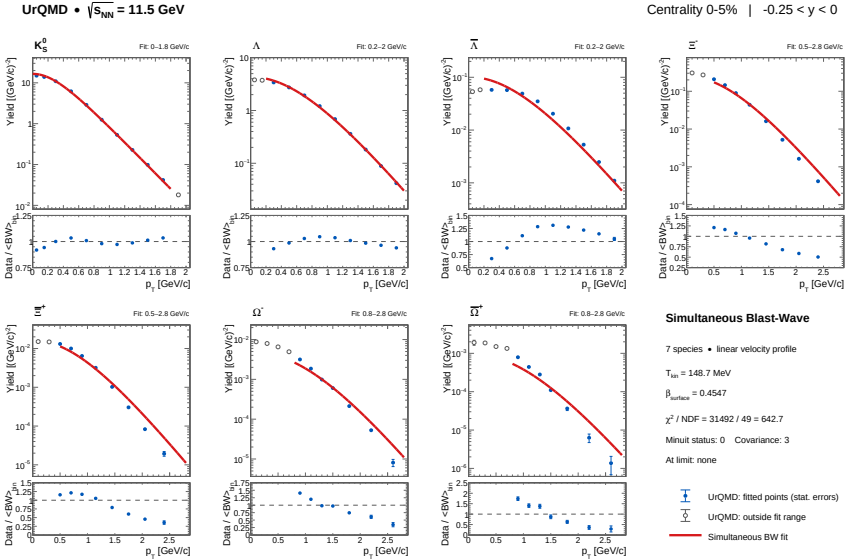
where $\tilde{r} = \frac{r}{R}$.

$$\frac{dN}{p_T\, dp_T} \propto \int_0^1 \tilde{r}\, d\tilde{r}\; m_T \times I_0\left(\frac{p_T\ sinh\,\rho(\tilde{r})}{T_{kin}}\right) \times K_1\left(\frac{m_T\ cosh\,\rho(\tilde{r})}{T_{kin}}\right),$$

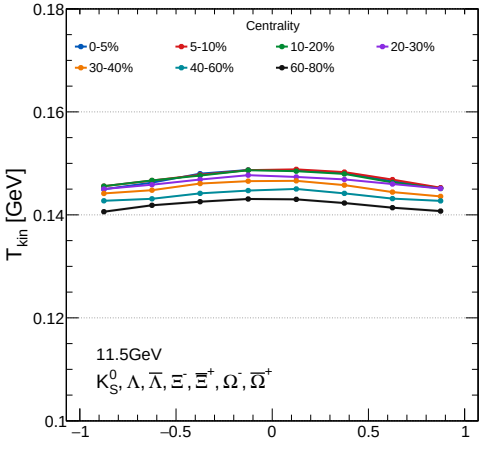
where $\rho = \tanh^{-1}\beta$, I_0 and K_1 are the modified Bessel functions.

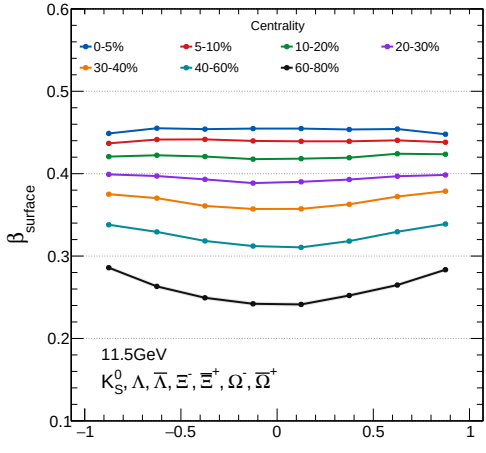
Ref: E. Schnedermann, J. Sollfrank, U. Heinz, Phys. Rev. C 48, 2462–2475 (1993)

Simultaneous Blast-Wave fit



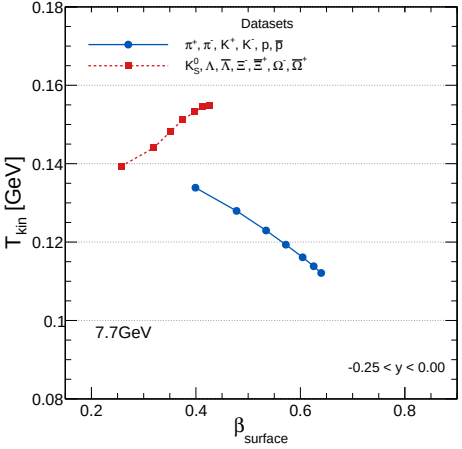
Blast-Wave parameters: centrality and rapidity

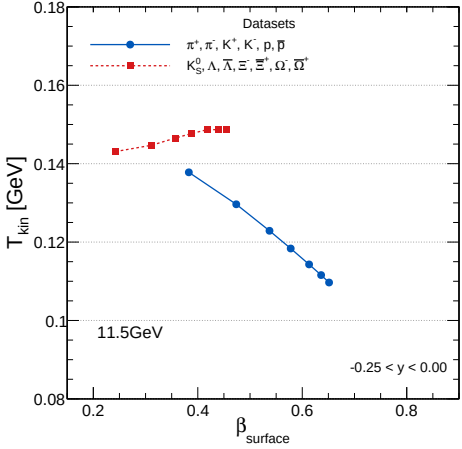




Combined strange-hadron fits yield $T_{\rm kin} \approx 0.14$–0.15 GeV with weak rapidity and centrality dependence. $\beta_{\rm surface}$ decreases from central to peripheral collisions. $\beta_{\rm surface}$ rapidity dependence is more notable in peripheral collisions.

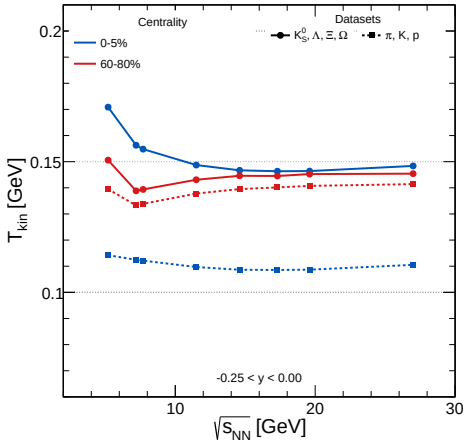
Blast-Wave parameters map

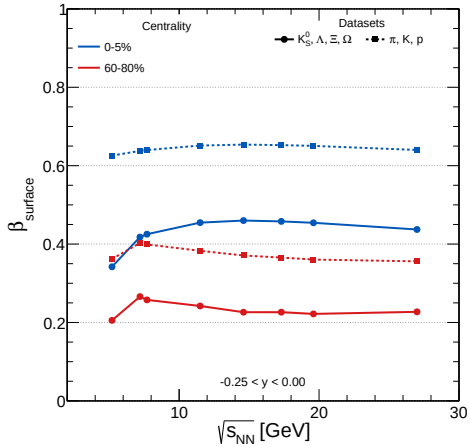




At both energies, combined strange-hadron fits yield higher T_{kin} and lower β_{surface} than fits to $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$. The two particle sets show distinct patterns in the T_{kin}–β_{surface} plane.

Blast-Wave parameters energy dependence





Strange-hadron fits yield higher T_{kin} and lower β_{surface} than π, K, p fits across the energy range. Above about 10 GeV, both parameters vary weakly with energy; β_{surface} is larger in central than in peripheral collisions for both particle sets.

Conclusions

- UrQMD reproduces experimental yield trends qualitatively, but not quantitatively
- At 11.5 GeV, simultaneous strange-hadron fits give $T_{\mathrm{kin}} \approx 0.14 - 0.15$ GeV with weak rapidity and centrality dependence. β_{surface} decreases towards peripheral collisions
- Strange-hadron fits yield higher T_{kin} and lower β_{surface} than π, K, p fits, demonstrating sensitivity to the fitted particle set
- Above about 10 GeV, both parameters vary weakly with collision energy, while β_{surface} shows a pronounced centrality dependence