Λ and $\overline{\Lambda}$ hyperons polarization in heavy-ion collisions within transport model

Different space-time freeze-out picture - an explanation of different Λ and $\overline{\Lambda}$ polarization?

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Motivation

Non-central heavy-ion collisions generate enormous orbital angular momenta of order up to $10^5\hbar$. The created QGP should possess extremely high vorticity. Still not clear mechanism of transition of angular momentum to particle spin and difference in polarization of particles and antiparticles. Thus it is important to find out if vorticity really exists in different models and calculate related quantities such as polarization.

UrQMD and statistical model of ideal hadron gas

The UrQMD model [1,2] is employed to investigate polarization of Λ and $\bar{\Lambda}$ hyperons in non-central Au+Au collisions in the energy range $7.7 \leq \sqrt{s} \leq 62.4$ GeV. The model permits us to trace the history of each hadron back to the last collision. After that one can investigate the conditions of local equilibrium in a given point. After generation of high number of collisions, one can extract energy density ε^{mic}, net baryon density ρ_B^{mic} (Fig. 1) and net strangeness density ρ_S^{mic}. To obtain $\{T, \mu_B, \mu_S\}$ one has to insert the extracted microscopic parameters $\{\varepsilon^{mic}, \rho_B^{mic}, \rho_S^{mic}\}$ into the system of nonlinear equations

$$\rho_B^{mic} = \sum_i B_i \frac{g_i}{(2\pi)^3} \int f(p, m_i) d^3p$$

$$\rho_S^{mic} = \sum_i S_i \frac{g_i}{(2\pi)^3} \int f(p, m_i) d^3p$$

$$\varepsilon^{mic} = \sum_i \frac{g_i}{(2\pi)^3} \int \epsilon_i f(p, m_i) d^3p,$$

where $f(p, m_i)$ is the distribution function of hadron specie with mass m_i (Fermi-Dirac or Bose-Einstein), baryon charge B_i and strange charge S_i. The extracted temperature (Fig. 2) will be used for calculation of thermal vorticity of the system.

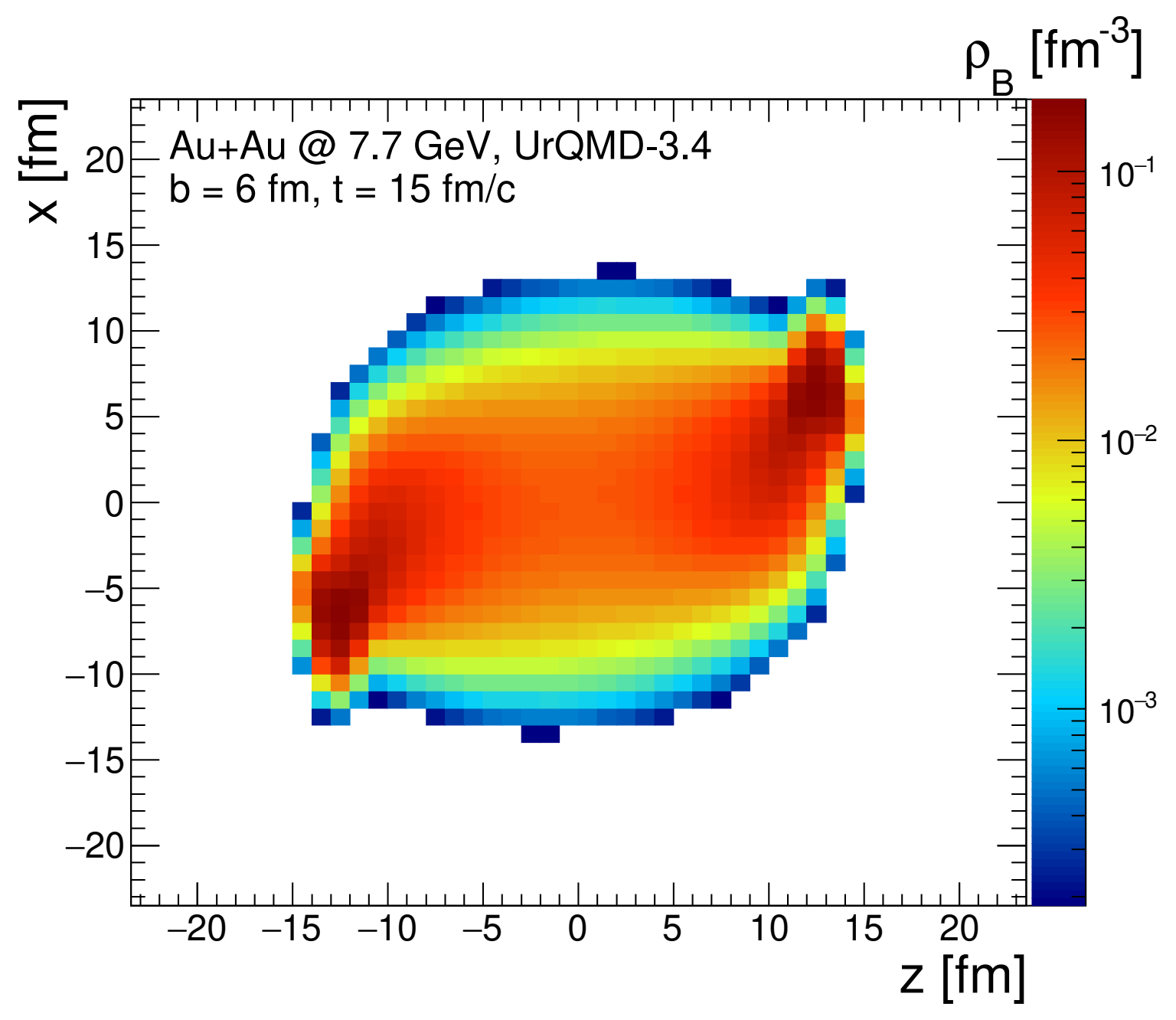

Figure 1: Averaged over 10^6 events baryon density in UrQMD calculations of Au+Au collisions with $b = 6$ fm at $\sqrt{s} = 7.7$ GeV at $t = 15$ fm/c.

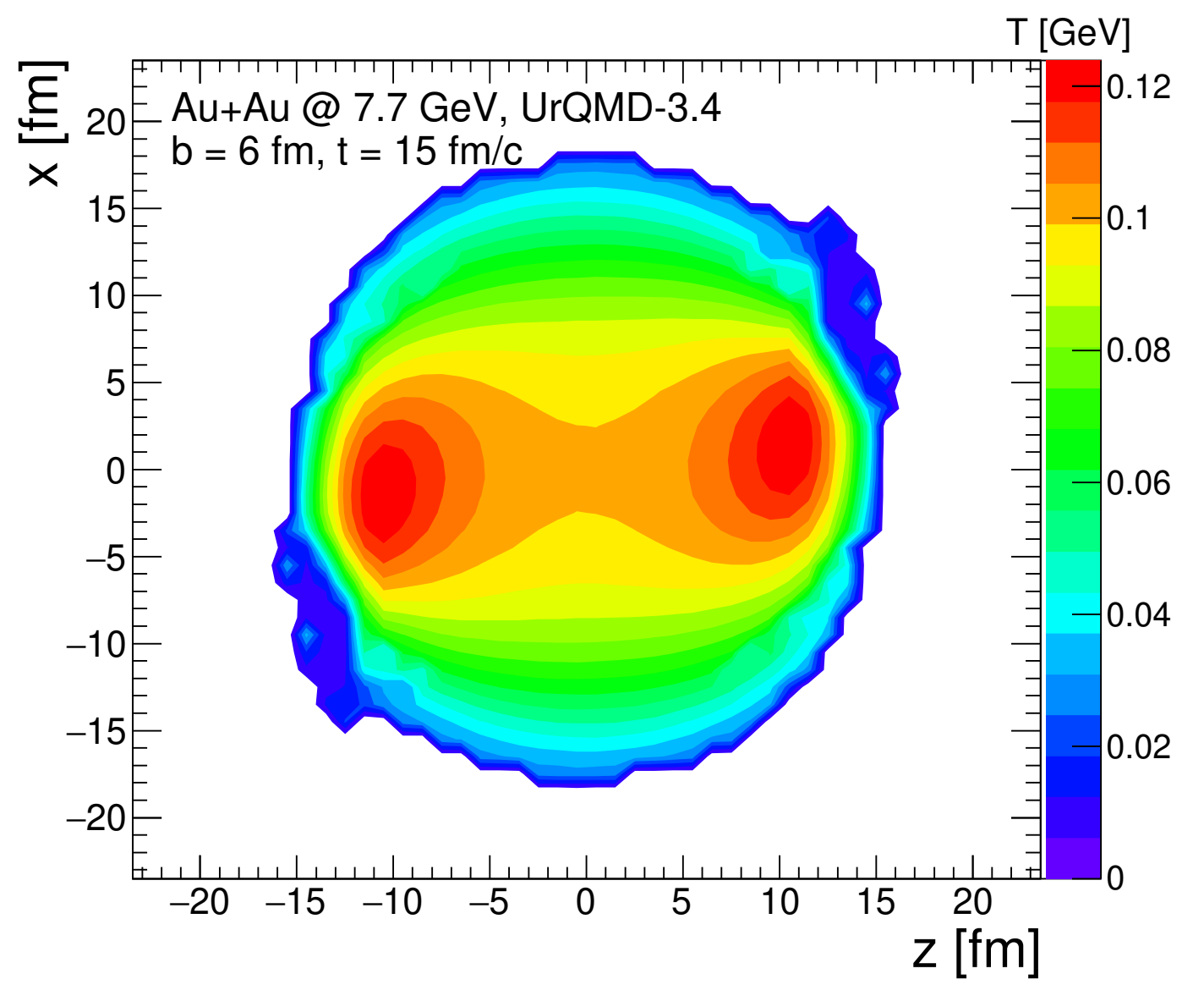

Figure 2: Proper temperature in the reaction plane in UrQMD calculations of Au+Au collisions with $b = 6$ fm at $\sqrt{s} = 7.7$ GeV at $t = 15$ fm/c.

Freeze-out of Λ and $\overline{\Lambda}$

Firstly, one has to study freeze-out conditions of both hyperon. Emission functions dN/dt for Λ and $\bar{\Lambda}$ are shown in Fig. 3 (arrow indicates maximum of emission). The distributions of freeze-out points of both hyperons in the reaction plane depicted in Fig. 4 are quite different. Maximum densities of Λ are in the spectator's areas, $\bar{\Lambda}$ are concentrated mainly in the baryon-less zones. Thus, these hyperons are emitted from different areas of space with different temperatures and thermal vorticity values.

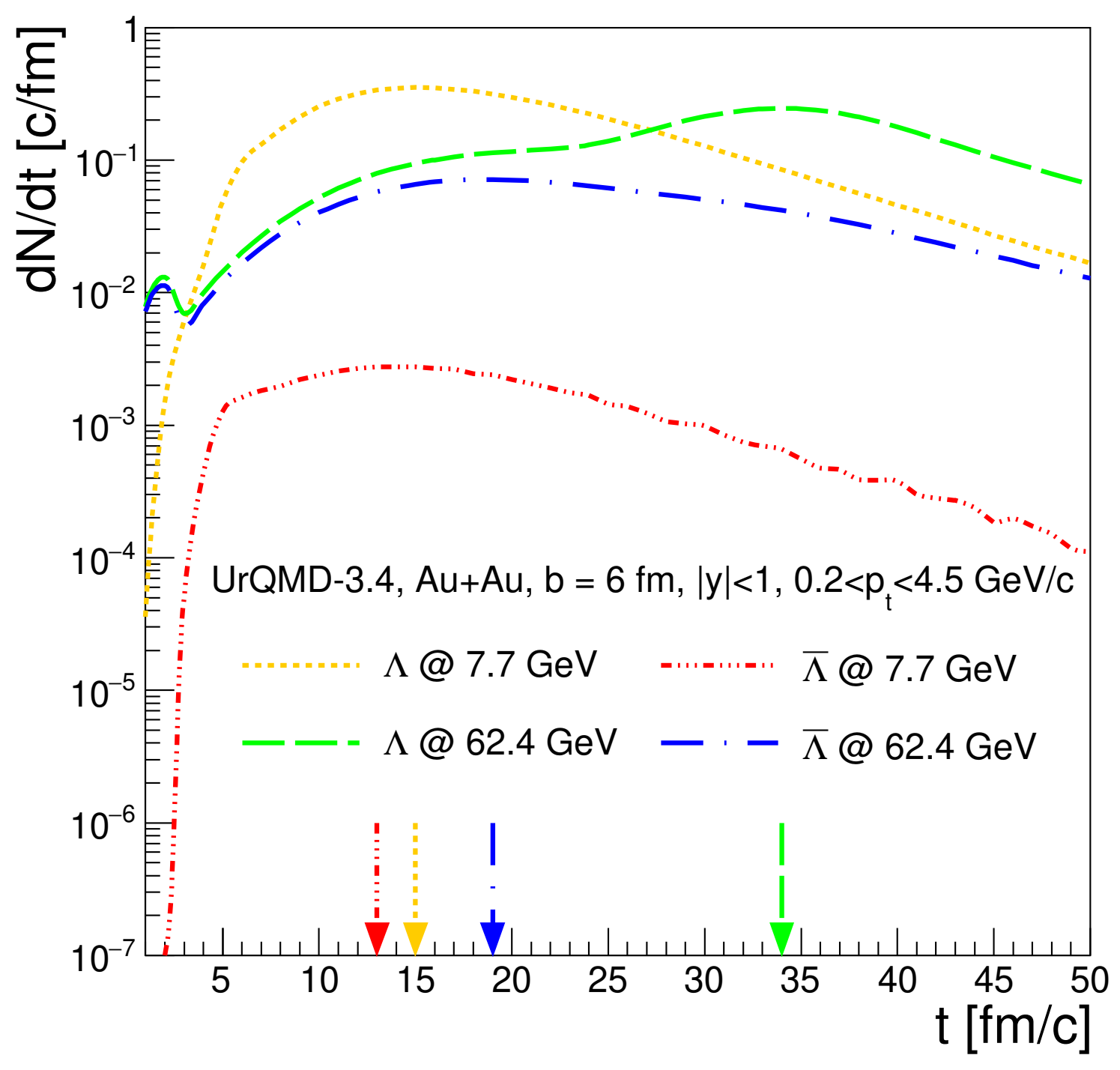

Figure 3: Emission functions for $\Lambda/\overline{\Lambda}$ hyperons in UrQMD calculations of Au+Au collisions with b = 6 fm at $\sqrt{s} = 7.7$ and 62.4 GeV.

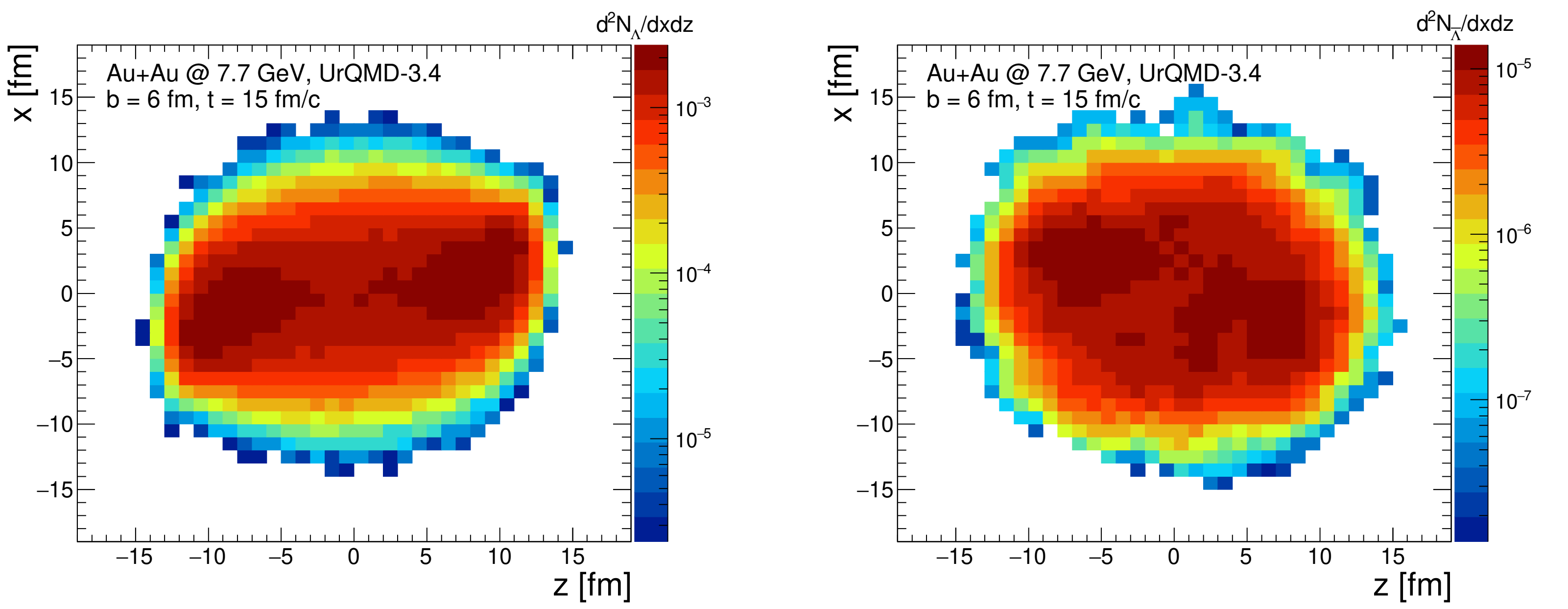

Figure 4: Distributions $d^2N/dxdz$ of freeze-out points of Λ's (left) and $\overline{\Lambda}$'s (right) in the reaction plane in UrQMD calculations of Au+Au collisions with $b = 6$ fm at $\sqrt{s} = 7.7$ GeV at $t = 15$ fm/c.

Thermal vorticity and $\Lambda, \overline{\Lambda}$ polarization

There are several approaches to the vorticity problem in heavy-ion collisions. In the present work we will use the assumption of local thermal equilibrium at the system freeze-out [3]. In this approach polarization is generally determined by thermal vorticity tensor

$$\varpi_{\mu\nu} = \frac{1}{2}(\partial_\nu \beta_\mu - \partial_\mu \beta_\nu),$$

where $\beta^\mu = u^\mu / T$ is the inverse-temperature four-velocity. Of three vorticity space-like components, the ϖ_{zx} is the most important for calculation of Λ and $\bar{\Lambda}$ polarization (Fig. 5). Using the thermal vorticity and momentum of each hyperon at its emission point, one can calculate the global polarization of both hyperon species. Result of this study is presented in Fig. 6. The difference between the global polarization of Λ and $\overline{\Lambda}$, clearly seen in experimental data [4,5], is correctly reproduced in the model. It is explained by the difference in space and time freeze-out conditions of Λ and $\overline{\Lambda}$ hyperons with respect to the thermal vorticity field.

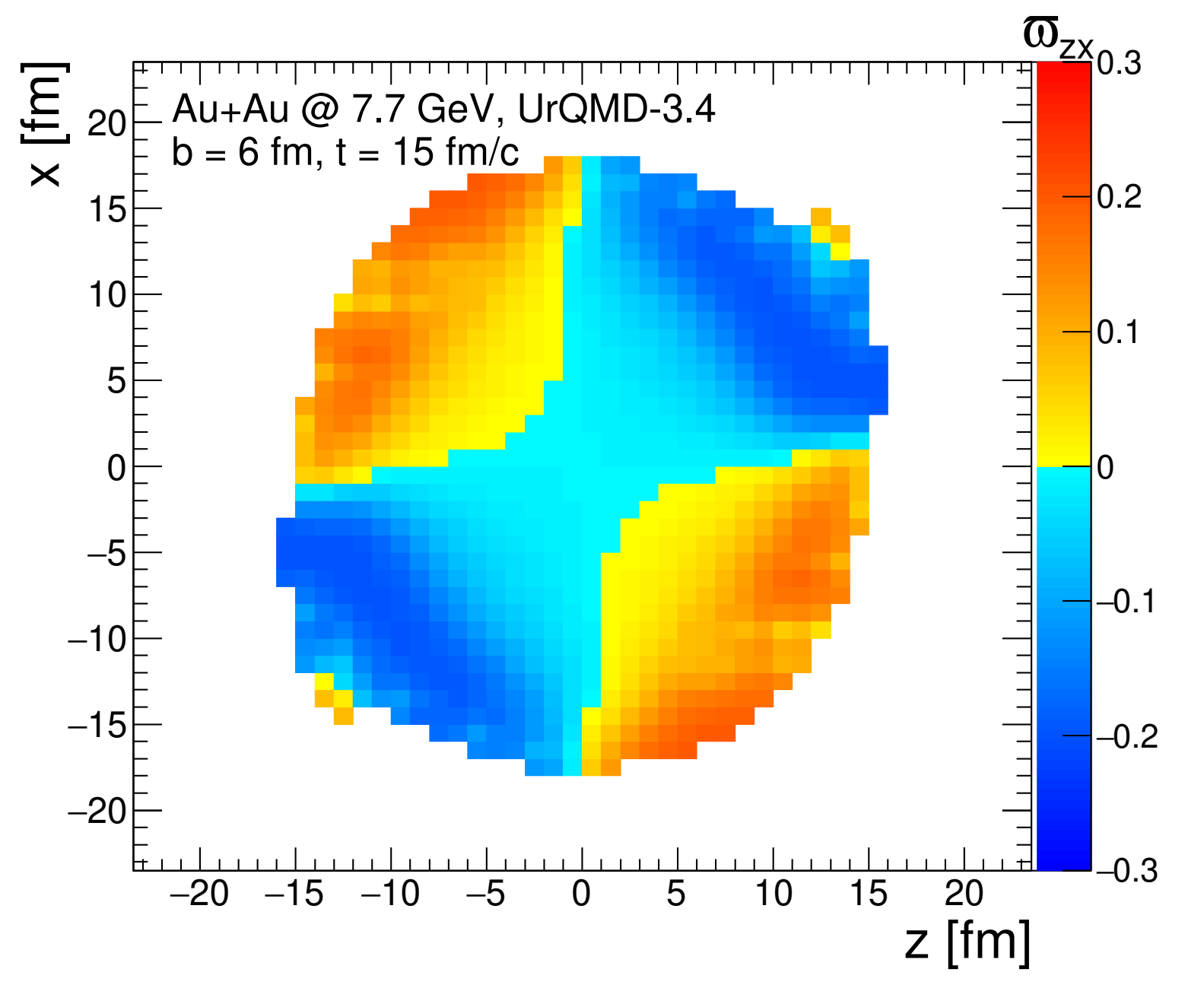

Figure 5: Thermal vorticity component ϖ_{zx} in $x - z$ plane in UrQMD calculations of Au+Au collisions with $b = 6$ fm at $\sqrt{s} = 7.7$ GeV at $t = 15$ fm/c.

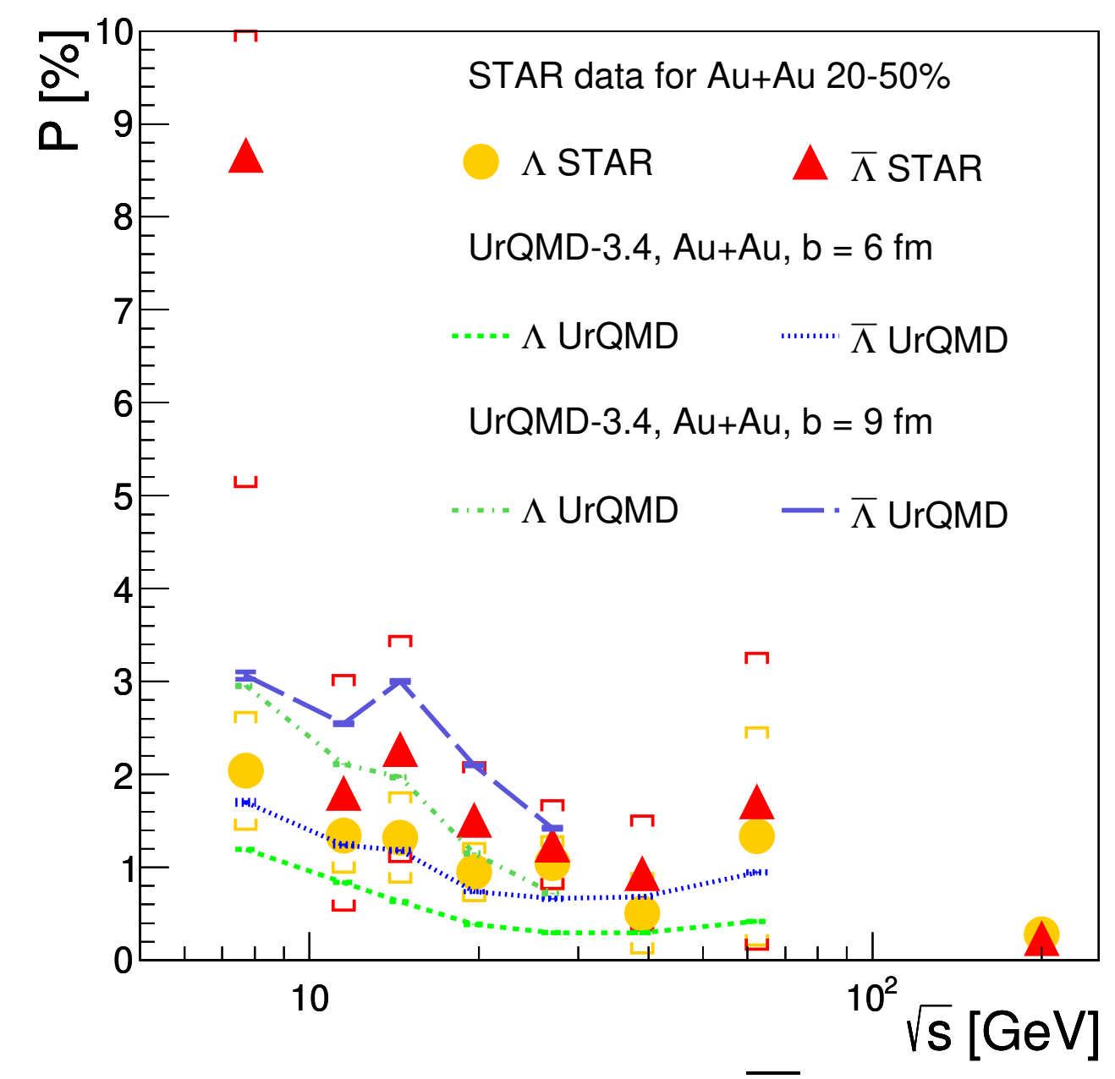

Figure 6: Global Λ and $\overline{\Lambda}$ polarization as function of $\sqrt{s}$ in UrQMD calculations of Au+Au collisions in comparison with the data from STAR

Conclusions

It was found that freeze-out conditions of Λ and $\bar{\Lambda}$ are different both in space and in time. Within the thermal approach the global polarization in transport models is jointly determined by the space-time distribution of $\Lambda/\bar{\Lambda}$ and the thermal vorticity field. The difference between global polarization of Λ and $\overline{\Lambda}$ is naturally explained by the difference in space-time distributions of Λ and $\overline{\Lambda}$ and different freeze-out with respect to the thermal vorticity field.

References

[1] S.A. Bass et al., Prog. Part. Nucl. Phys. 41 (1998) 255.
[2] M. Bleicher et al., J. Phys. G: Nucl. Part. Phys. 25 (1999) 1859.
[3] F. Becattini, L.P. Csernai, D.J. Wang, Phys. Rev. C 88 (2013) 034905; Erratum: ibid. 93 (2016) 069901.
[4] L. Adamczyk et al. (STAR Collaboration), Nature 548 (2017) 62.
[5] J. Adam et al. (STAR Collaboration), Phys. Rev. C 98 (2018) 014910.

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