Differential Study of Λ-hyperon Polarization in Central Heavy-Ion Collisions Within Transport Model Approach

Oleksandr Vitiuk, University of Wroclaw, Poland

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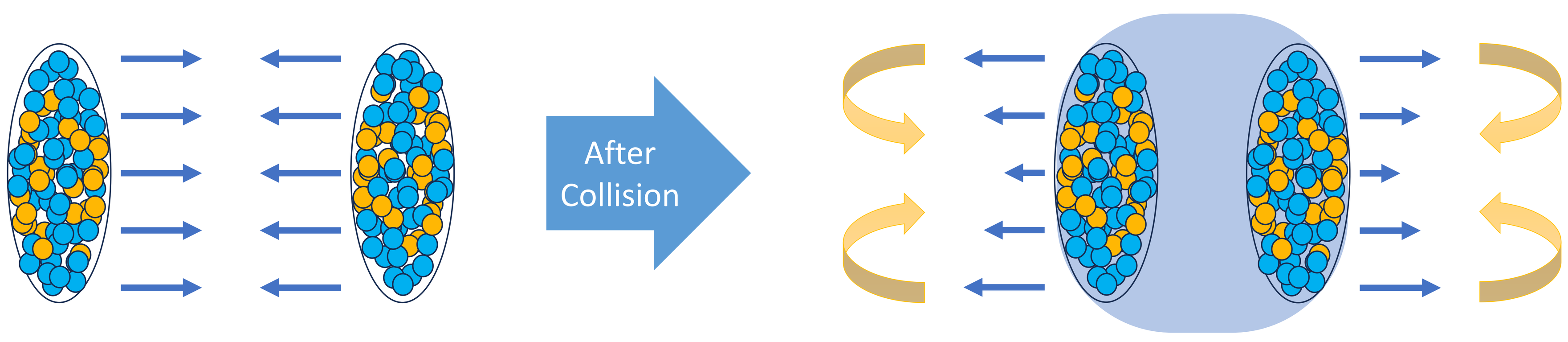
Introduction



We present a differential study of hyperon polarization in central Au+Au collisions at $\sqrt{s_{NN}} = 7$ GeV, employing the microscopic transport model UrQMD [1,2] in conjunction with the statistical hadron-resonance gas model. The resulting thermal vorticity configuration effectively manifests as the formation of two vortex rings in the forward and backward rapidity regions. The polarization of Λ-hyperons exhibits oscillatory behaviour as a function of the azimuthal angle, offering a novel means to probe the structure of the fireball in central heavy-ion collisions.

Λ-hyperon polarization in thermal approach

In the assumption of local thermal equilibrium, the Λ spin 4-vector is [3]:

$$S^\mu(p,x) \approx -\frac{1}{8m}\epsilon^{\mu\nu\rho\sigma}p_\nu\varpi_{\rho\sigma}(x), \qquad \varpi^{\mu\nu} = \frac{1}{2}\left(\partial^\nu\frac{u^\mu}{T} - \partial^\mu\frac{u^\nu}{T}\right)$$

From this one can find Λ polarization in the hyperon rest frame:

$$\vec{S}^*(x,p) = \vec{S} - \frac{(\vec{p}\cdot\vec{S})}{E(m+E)}\vec{p}, \qquad \langle\vec{S}\rangle = \frac{1}{N}\sum \vec{S}_i^*(x_i,p_i), \qquad P_\Lambda = 2\langle\vec{S}\rangle\cdot\vec{n}$$

Λ-hyperon polarization in transport model

Here use the methodology developed in [4]:

1. The heavy-ion collision was simulated with timestep $\Delta t = 1\ fm/c$
2. For each timestep, whole space was subdivided into cells with $V = 1\ fm^3$
3. Collective velocity as well as $\varepsilon, n_B, n_S, n_Q$ in each cell were calculated
4. Temperature field extracted with the help of HRG Model
5. With 4-velocity and T fields thermal vorticity field was obtained
6. For each Λ-hyperon we found spin 4-vector at its freeze-out 4-position
7. Finally, polarization and other observables were calculated

$$\varepsilon^{UrQMD} = \sum \frac{g_i}{(2\pi\hbar)^3}\int\frac{Ed^3p}{e^{(E-\mu)/T}+a_i}, \qquad n_X^{UrQMD} = \sum\frac{g_iX_i}{(2\pi\hbar)^3}\int\frac{d^3p}{e^{(E-\mu)/T}+a_i}$$

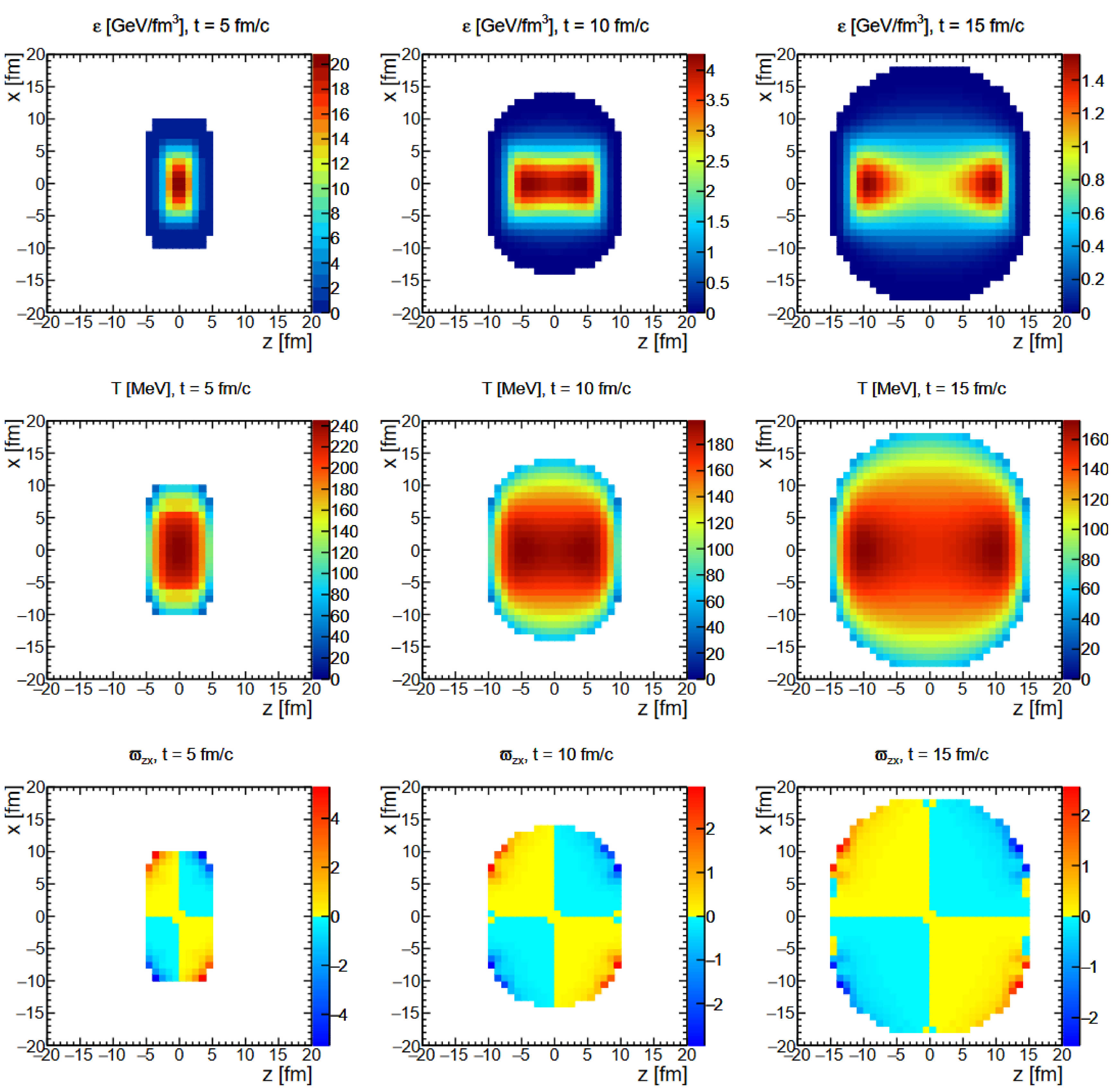


Figure 1. Top row: Energy density of the system formed in UrQMD calculations of central Au+Au collision at $\sqrt{s_{NN}} = 7.7$ GeV in $y = 0$ fm plane. Middle row: The same as top row, but for temperature. Bottom row: The same as top row, but for ϖ_{zx} component of the thermal vorticity.

Results for Λ polarization

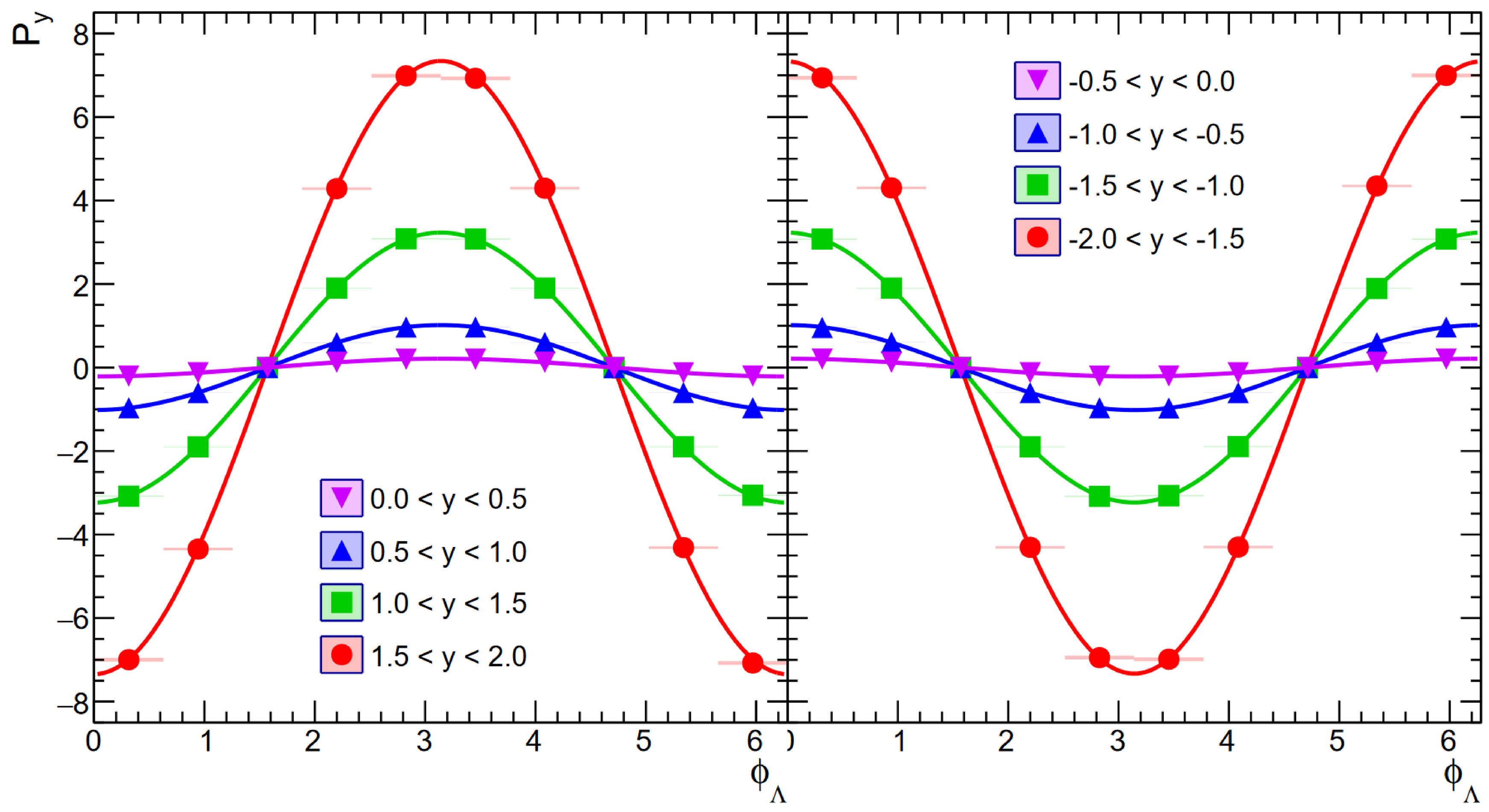


Figure 2. Λ hyperon polarization in central Au+Au collision at $\sqrt{s_{NN}} = 7.7$ GeV along y axis as function of the hyperon azimuthal angle for different rapidity intervals. Solid lines represent the fits with periodic function.

The Λ polarization clearly exhibits oscillatory behaviour as a function of the hyperon azimuthal angle. In order to extract magnitude of the local hyperon polarization P_Λ as a function of rapidity we fit the azimuthal angle distribution with a periodic function:

$$P_y = P_\Lambda \cos\phi_\Lambda$$

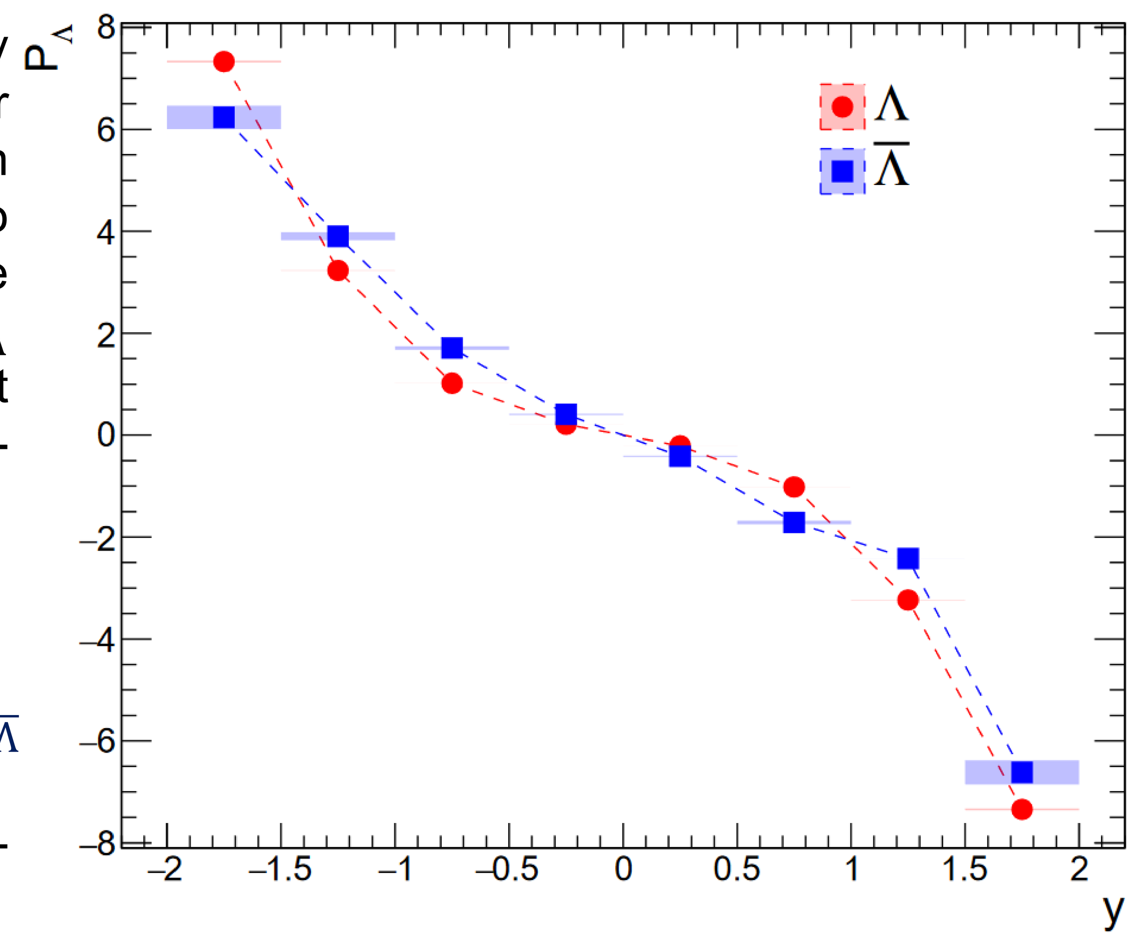


Figure 3. P_Λ as a function of rapidity for Λ (red circles) and $\bar{\Lambda}$ (blue squared) hyperons as a function of rapidity. Dashed lines are added to guide the eye.

Summary

- The thermal vorticity field has a structure which effectively resembles two vortex rings in the forward and backward hemispheres. The structure is stable in time, but the vorticity magnitude decreases due to system expansion.
- The polarization of Λ-hyperons exhibits oscillatory behaviour as a function of the hyperon azimuthal angle.
- The magnitude of the local Λ polarization is an increasing function of rapidity.
- The Λ and $\bar{\Lambda}$ hyperons polarization are consistent with each other.

References

[1] S. 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] O. Vitiuk et al., Phys. Lett. B 803 (2020) 135298
[4] F. Becattini et al., Phys. Rev. C 95, 054902 (2017)

Uniwersytet Wrocławski

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oleksandr.vitiuk@uwr.edu.pl