PROCEEDINGS OF SCIENCE

# Differential study of $\Lambda$-hyperon polarization in central heavy-ion collisions within transport model approach

**Oleksandr Vitiuk***

*Institute of Theoretical Physics, University of Wrocław, Plac Maxa Borna, 50-204 Wrocław, Poland*

*E-mail:* oleksandr.vitiuk@uwr.edu.pl

We present a differential study of $\Lambda$ hyperon polarization in central Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV, employing the microscopic transport model UrQMD 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 $\Lambda$ 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.

*42nd International Conference on High Energy Physics (ICHEP2024)*
*18-24 July 2024*
*Prague, Czech Republic*

*Speaker



https://pos.sissa.it/

PoS(ICHEP2024)648

## 1. Λ polarization in central heavy-ion collisions

There are various approaches to addressing the polarization problem in heavy-ion collisions. In this work, we adopt a method based on the assumption of local thermal equilibrium at the system's freeze-out stage [1]. In this framework, the spin four-vector $S^\mu$ of the Λ hyperon is proportional to the thermal vorticity field:

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

where $m$ is the hyperon mass, $u^\mu$ is the collective four-velocity, and $T$ denotes the temperature. The tensor $\varpi^{\mu\nu}$ represents the thermal vorticity, while $\epsilon^{\mu\nu\rho\sigma}$ is the Levi-Civita symbol.

To compute the polarization, we follow the procedure outlined in [2]. Initially, we simulated an ensemble of heavy-ion collision events using the UrQMD model [3, 4], with a timestep of $\Delta t = 1$ fm/c. For each timestep, the simulation space was divided into cells of 1 fm$^3$ in volume. In each cell, collective velocity, as well as energy, baryon number, strangeness, and electric charge densities, were computed by averaging over all events. Subsequently, the temperature and chemical potentials in each cell were determined using a hadron-resonance gas model. With these inputs, we obtained the thermal vorticity field by combining the collective four-velocity and temperature distributions. The time evolution of the thermal vorticity field is shown in Fig. 1, where a distinct quadrupole structure is evident, indicating the formation of a structure which resembles two vortex rings propagating in opposite directions. It is also seen that while the structure remains stable, the magnitude of the vorticity field decreases due to system expansion.

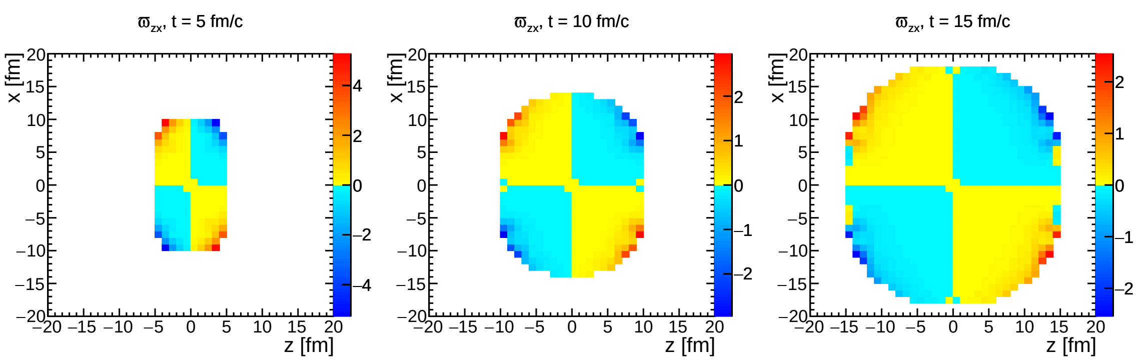


**Figure 1:** Thermal vorticity $\varpi_{zx}$ component in the system formed in UrQMD calculations of central Au+Au collision at $\sqrt{s_{NN}} = 7.7$ GeV in $y = 0$ fm plane.

Having the thermal vorticity tensor $\varpi^{\mu\nu}$, the spin four-vector of each Λ hyperon at its freeze-out position and time was computed using Eq. (1). This spin vector was then boosted to the hyperon's rest frame. To obtain the local polarization, we averaged the spin vectors over all Λ hyperons within a given phase space bin.

The local Λ hyperon polarization as a function of its azimuthal angle is displayed in Fig. 2. The polarization demonstrates a clear oscillatory pattern as a function of the azimuthal angle, with the amplitude of this oscillation decreasing and behaving as an odd function of rapidity.

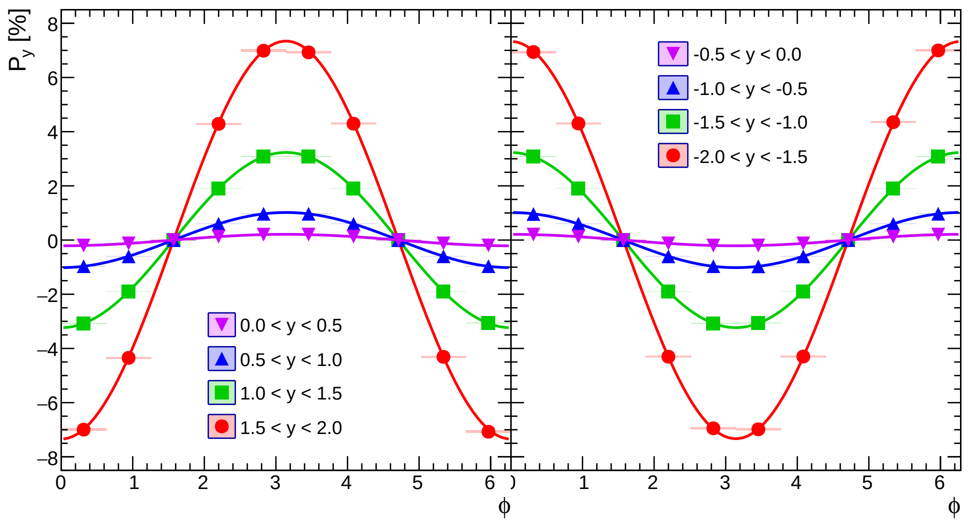


**Figure 2:** Λ hyperon polarization in central Au+Au collision at $\sqrt{s_{NN}}$ = 7.7 GeV along y-axis as function of the hyperon azimuthal angle for different rapidity intervals. Solid lines represent fits with periodic function.

## 2. Conclusions

We have found that the thermal vorticity field in central heavy-ion collisions exhibits a structure reminiscent of two vortex rings propagating in opposite rapidity hemispheres. This configuration remains stable over time, though the vorticity magnitude gradually diminishes as the system expands. The resulting polarization of Λ hyperons shows a clear oscillatory dependence on the hyperon azimuthal angle. Additionally, the amplitude of the local hyperon polarization decreases with rapidity, following an odd functional form.

## References

[1] F. Becattini, I. Karpenko, M.A. Lisa, I. Upsal and S.A. Voloshin, *Global hyperon polarization at local thermodynamic equilibrium with vorticity, magnetic field, and feed-down*, *Phys. Rev. C* **95** (2017) 054902.

[2] O. Vitiuk, L. Bravina and E. Zabrodin, *Is different Λ and $\overline{\Lambda}$ polarization caused by different spatio-temporal freeze-out picture?*, *Physics Letters B* **803** (2020) 135298.

[3] S. Bass, M. Belkacem, M. Bleicher, M. Brandstetter, L. Bravina, C. Ernst et al., *Microscopic models for ultrarelativistic heavy ion collisions*, *Progress in Particle and Nuclear Physics* **41** (1998) 255.

[4] M. Bleicher, E. Zabrodin, C. Spieles, S.A. Bass, C. Ernst, S. Soff et al., *Relativistic hadron-hadron collisions in the ultra-relativistic quantum molecular dynamics model*, *Journal of Physics G: Nuclear and Particle Physics* **25** (1999) 1859.