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THE HENRYK NIEWODNICZAŃSKI INSTITUTE OF NUCLEAR PHYSICS POLISH ACADEMY OF SCIENCES

Vorticity and spin in relativistic heavy-ion collisions

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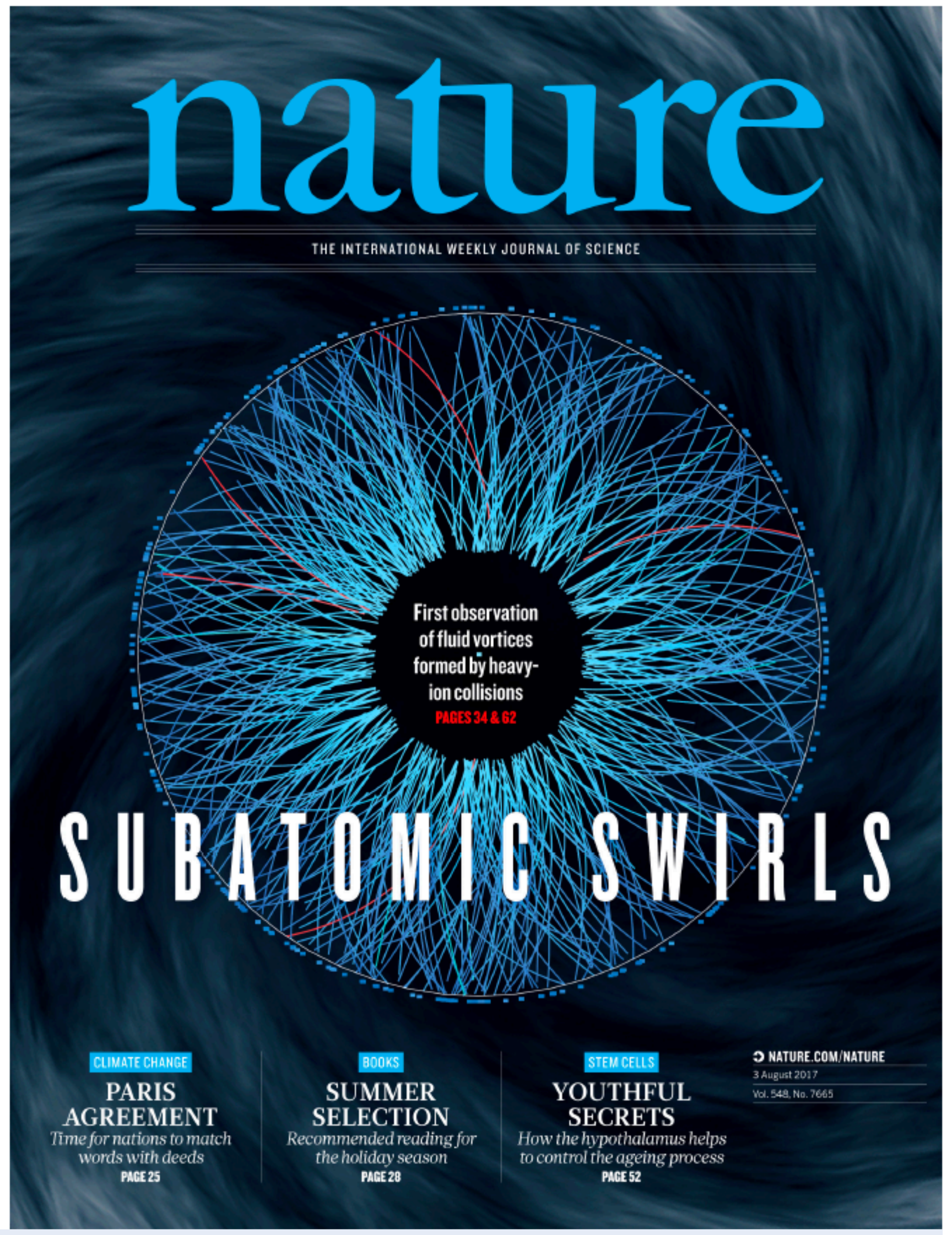
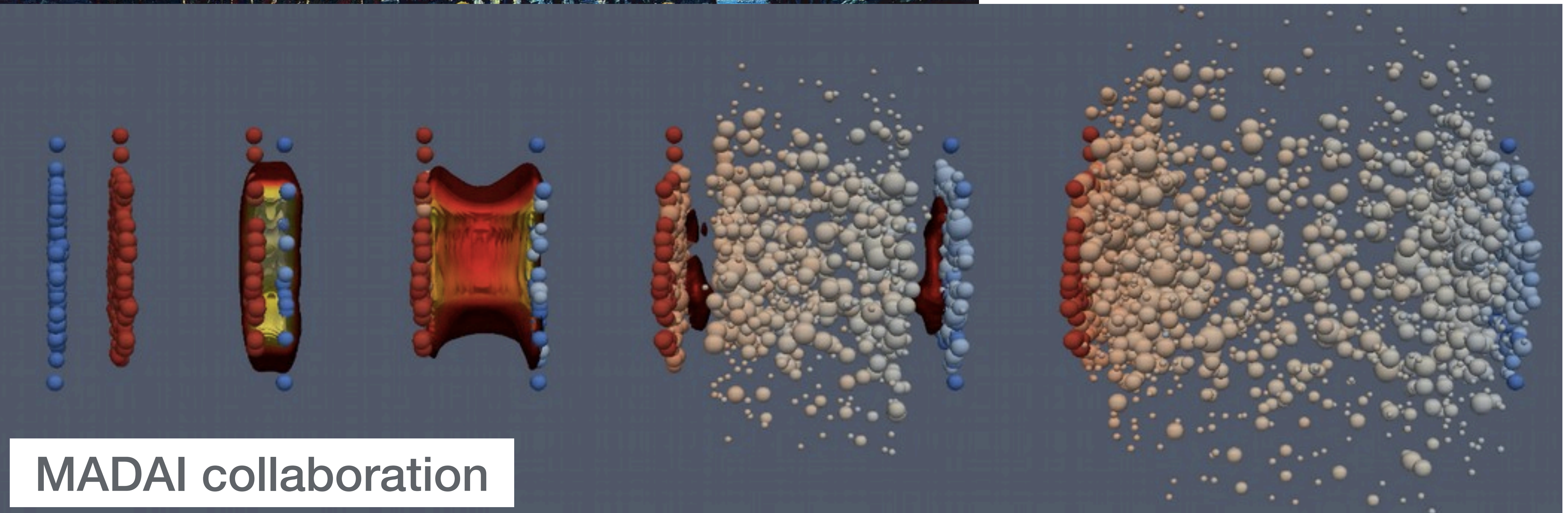
Based on: arXiv:2103.02592, arXiv:2011.14907, and arXiv:1901.09655.

XI NExT PhD Workshop

28 June to 2 July 2021


Vincent van Gogh




MADAI collaboration

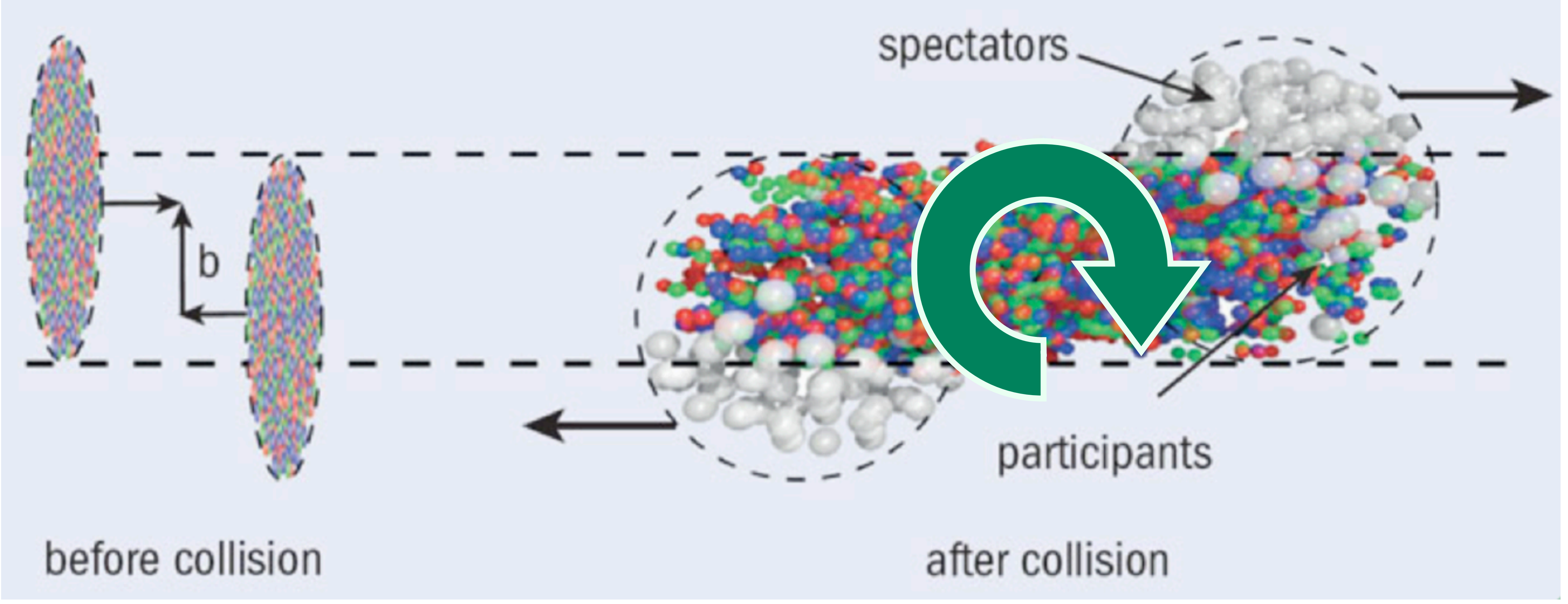
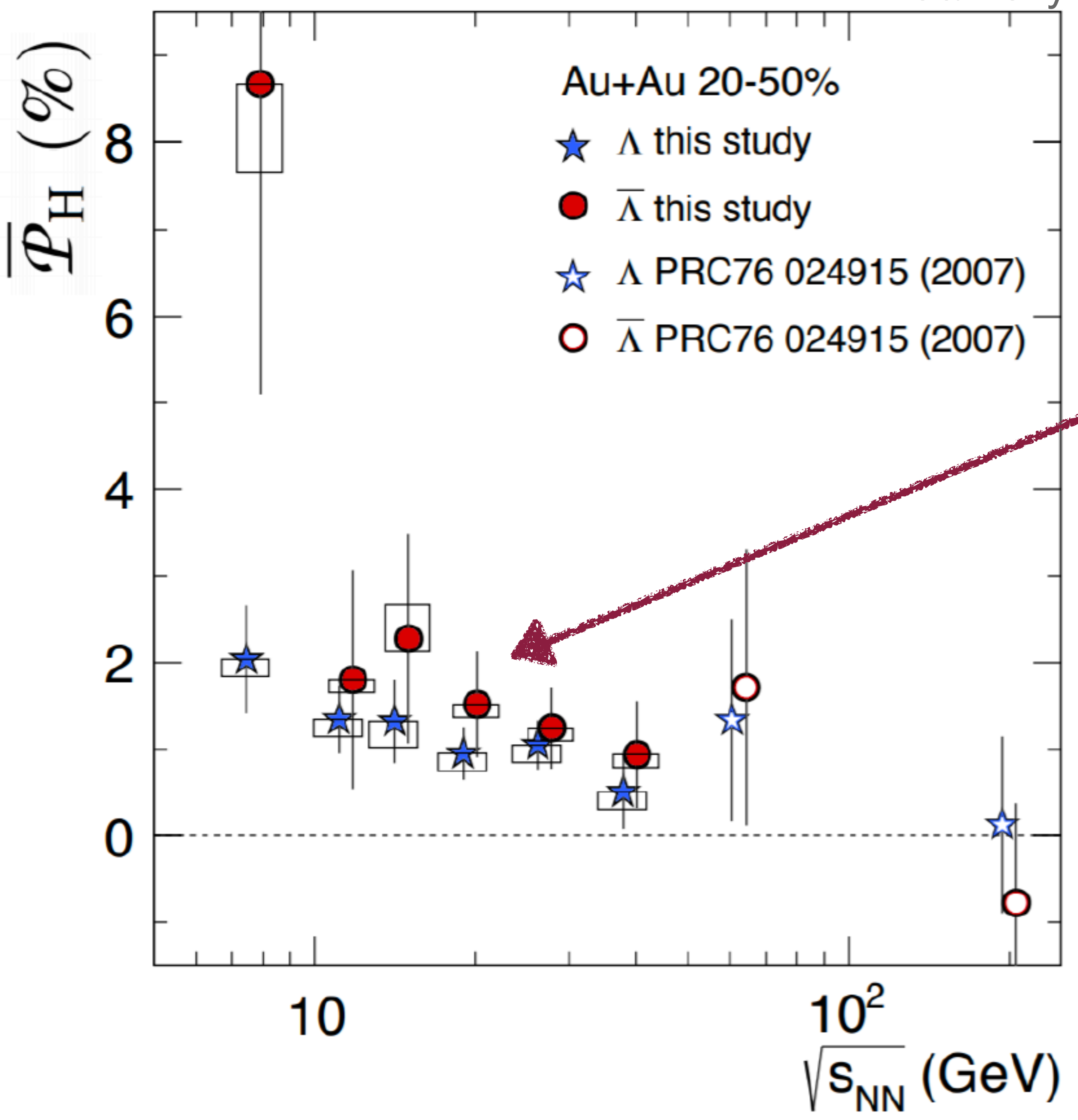


figure: M. Lisa, talk @ “Strangeness in Quark Matter 2016”

Measurement of Λ and $\bar{\Lambda}$ spin polarization in heavy-ion collisions

L. Adamczyk et al. (STAR) (2017), Nature 548 (2017) 62-65



~2% - small but measurable effect

Self-analysing parity-violating hyperon weak decay allows to measure polarization of Λ

Emitted particles are expected to be globally polarized along the system's angular momentum

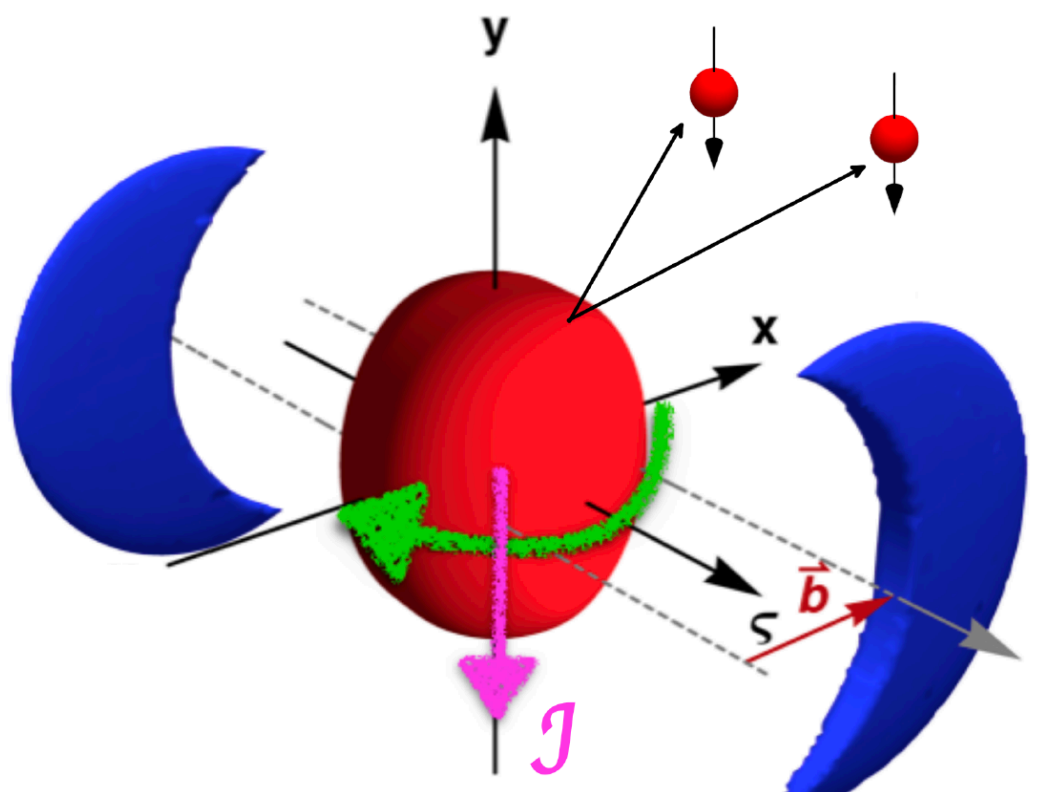
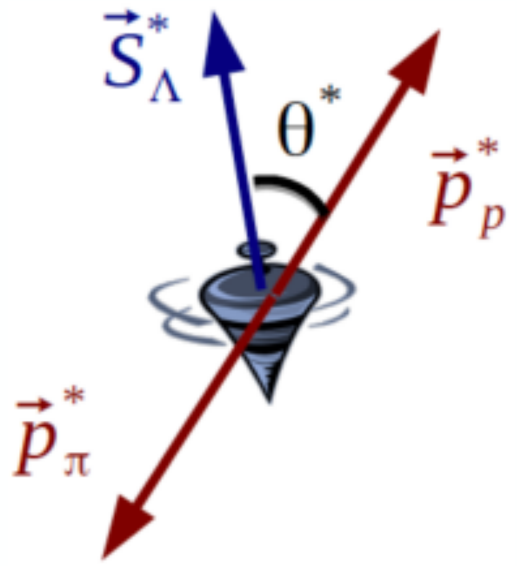


figure: R. Ryblewski



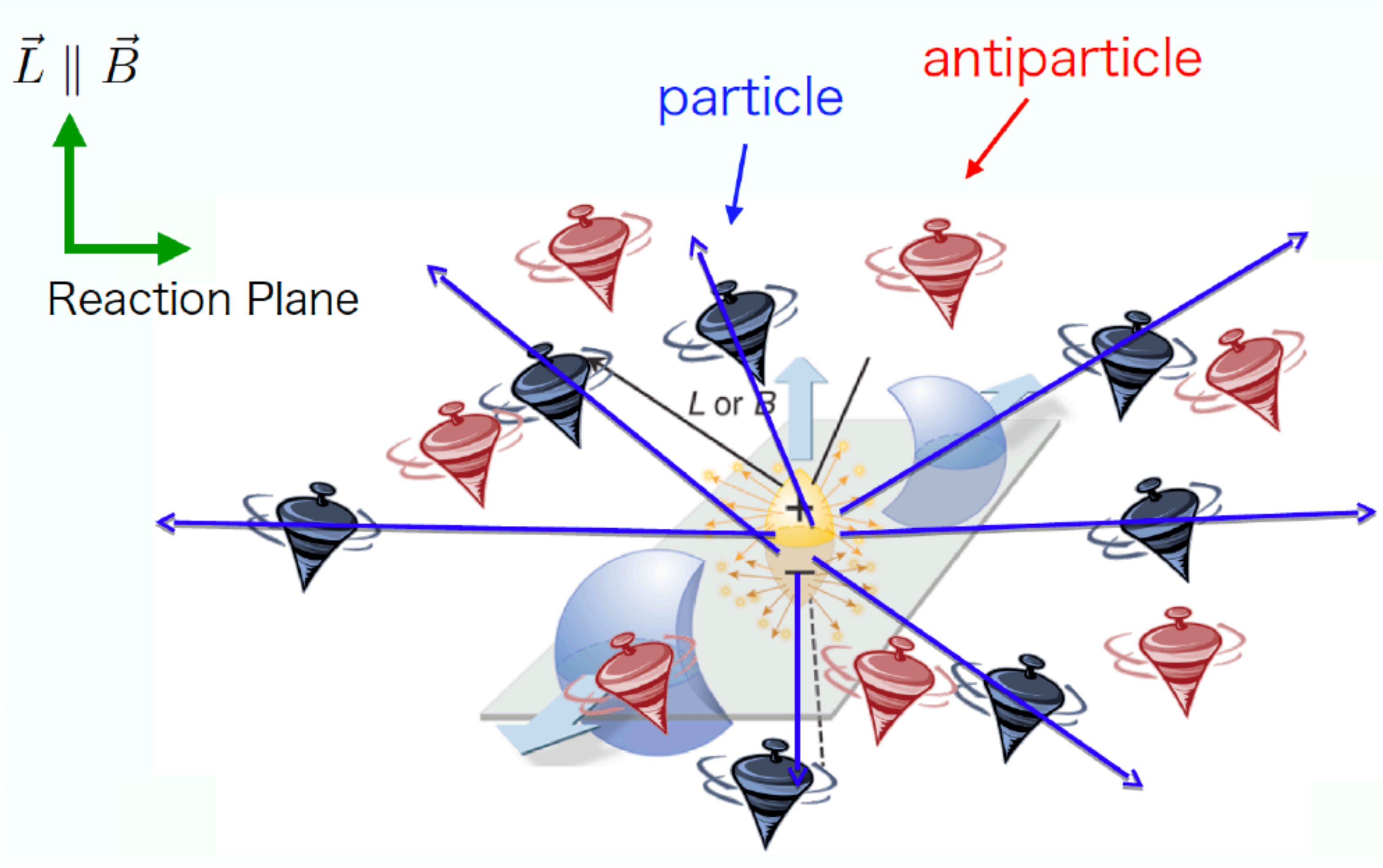


figure: T.Niida

. . . the hottest, least viscous – and now, most vortical – fluid produced in the laboratory . . .

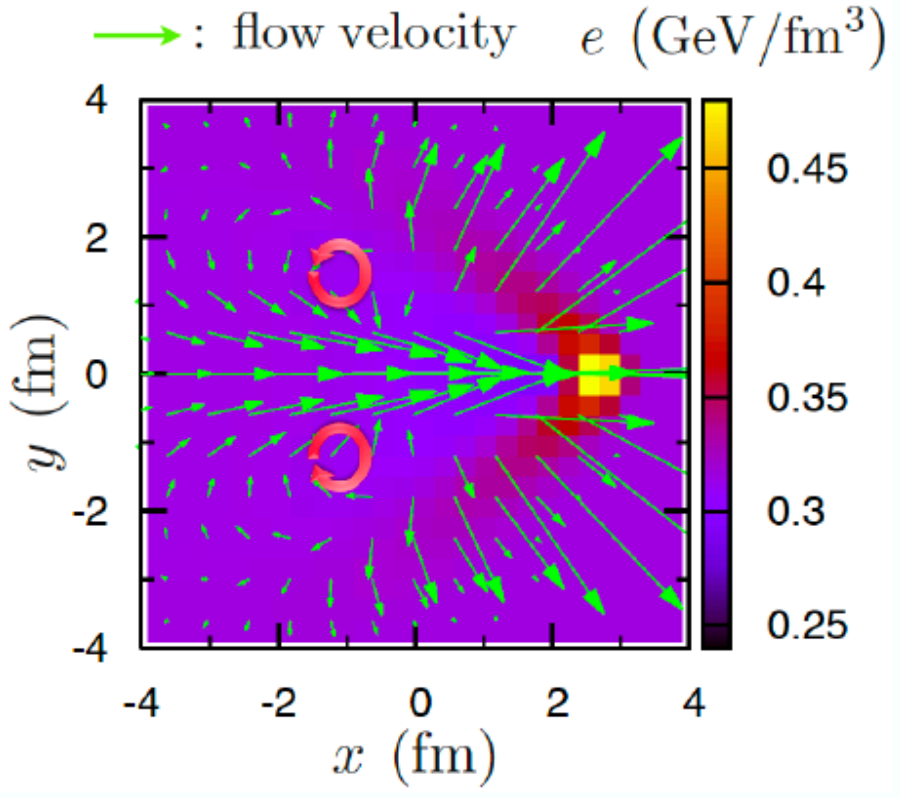
$$\omega = (P_\Lambda + P_{\bar{\Lambda}}) k_B T/\hbar \sim 0.6 - 2.7 \times 10^{22}\ \mathrm{s}^{-1}$$

$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}\left(1 + \alpha_{\mathrm{H}} \mathbf{P}_{\mathrm{H}} \cdot \mathbf{p}^*_{\mathbf{p}}\right)$$

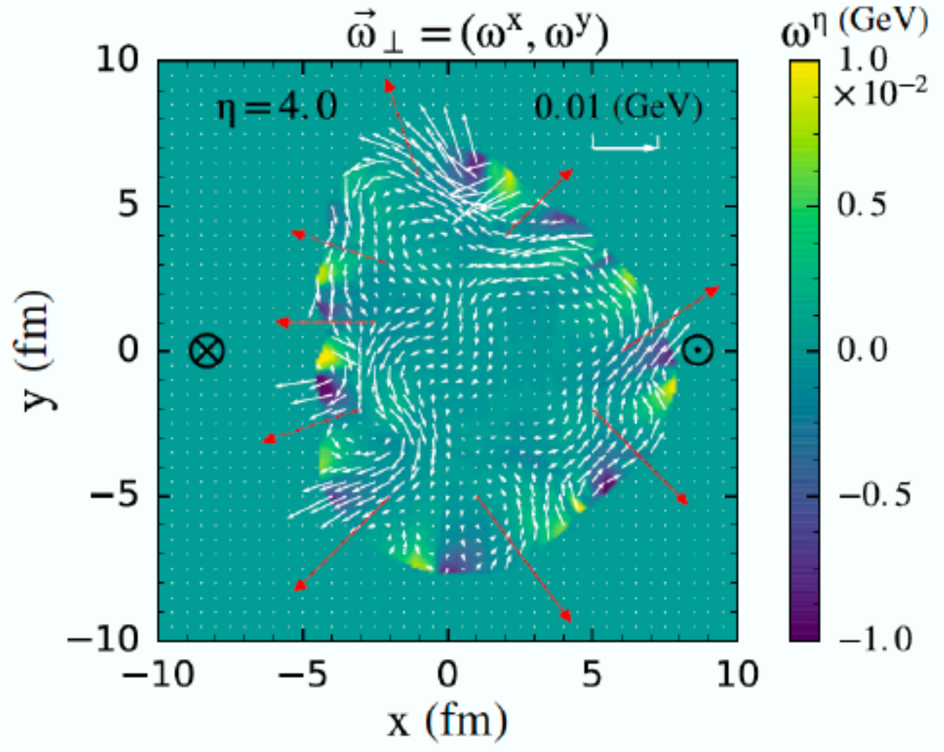
$$P_\Lambda \approx \frac{1}{2}\frac{\omega}{T} + \frac{\mu_\Lambda B}{T} \qquad P_{\bar{\Lambda}} \approx \frac{1}{2}\frac{\omega}{T} - \frac{\mu_\Lambda B}{T}$$

$P_\Lambda \approx P_{\bar{\Lambda}}$ ➡ **first direct observation of spin**

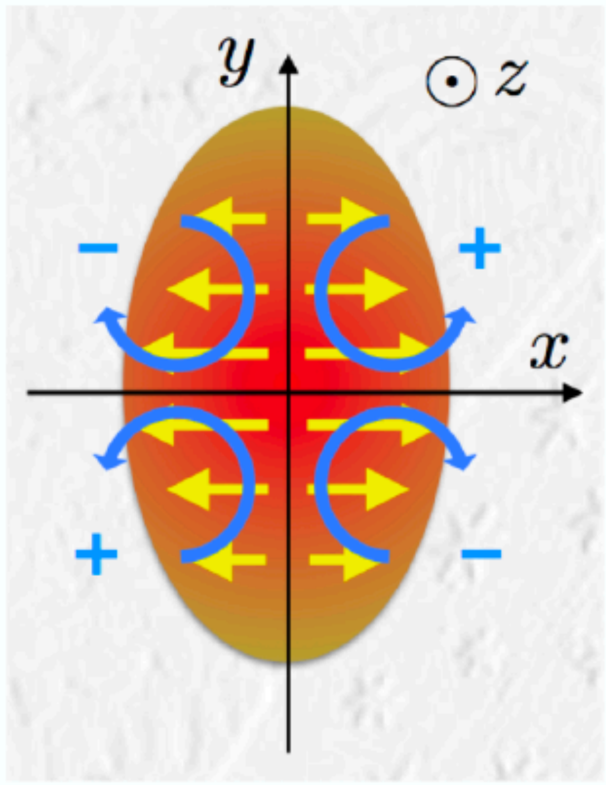
Local (momentum-differential) polarization



Y. Tachibana and T. Hirano, NPA904-905 (2013) 1023



L.-G. Pang, H. Peterson, Q. Wang, and X. ... PRL117, 192301 (2016)



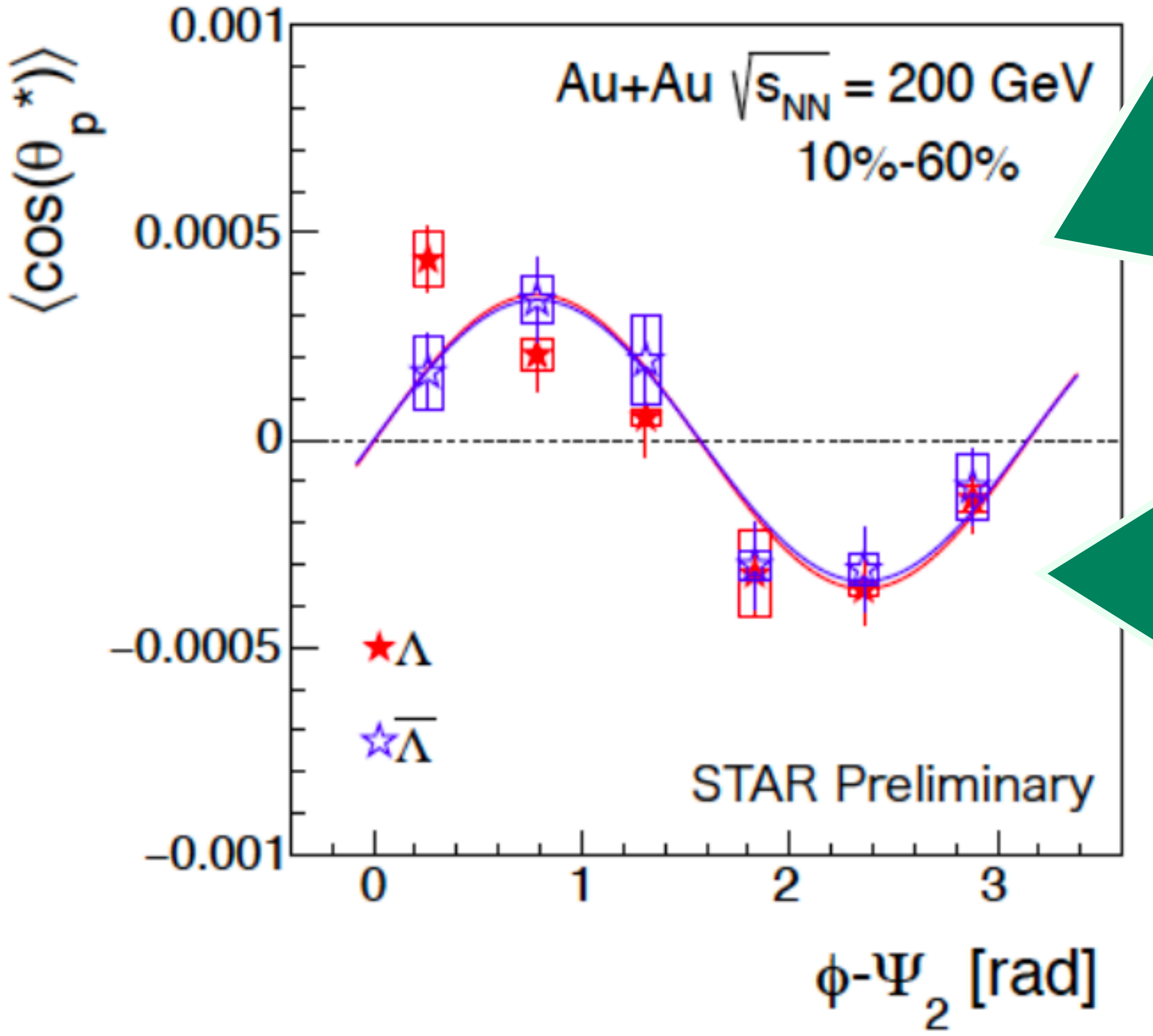
F. Becattini and I. Karpenko, PRL120.012302 (2018)
S. Voloshin, EPJ Web Conf.171, 07002 (2018)

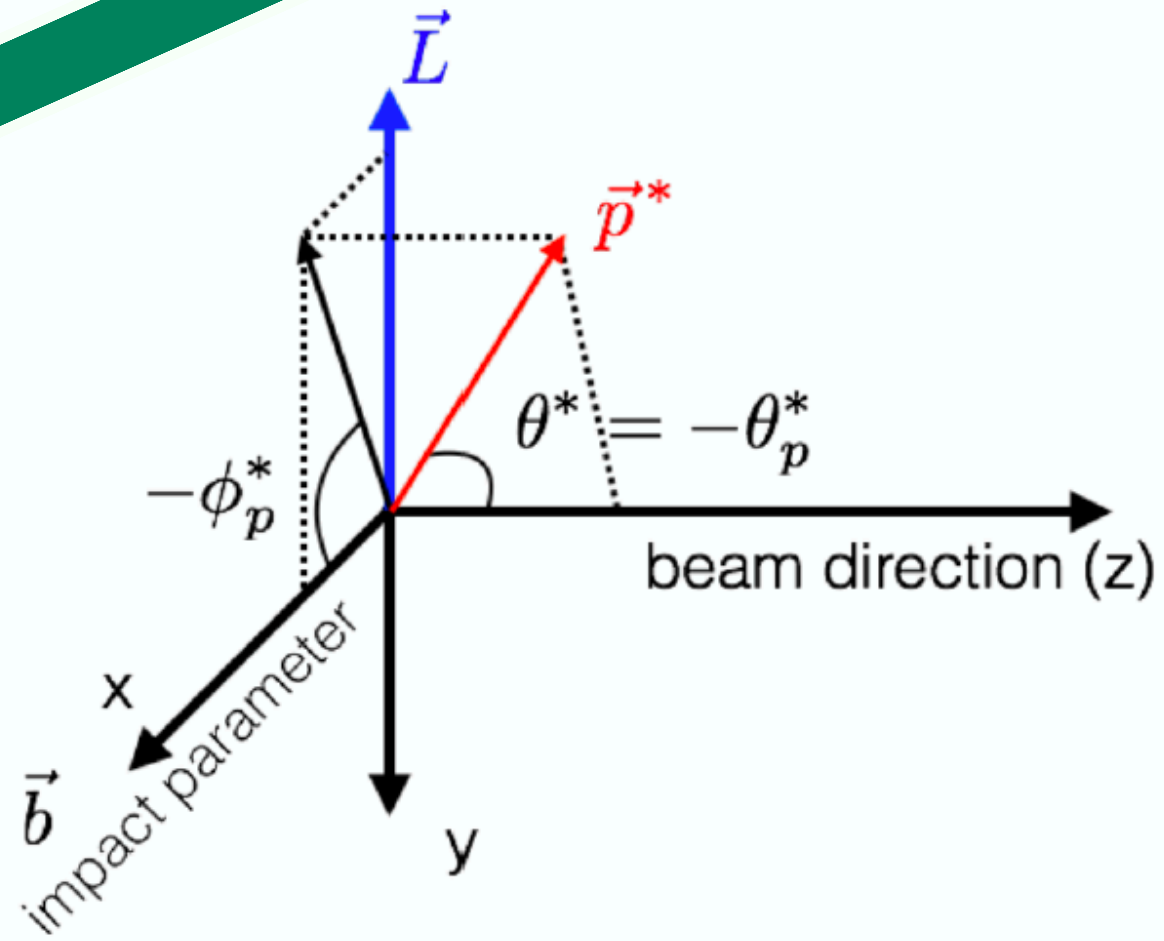
Flow structure in the transverse plane (jet, ebe fluctuations etc.) may generate longitudinal polarization

Spin-thermal approach does not capture differential observables

Is spin polarization always enslaved to thermal vorticity?

Non-trivial space-time dynamics of spin?





$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}(1 + \alpha_H \mathbf{P_H} \cdot \mathbf{p}_p^*)$$

$$\langle \cos\theta_p^* \rangle = \int \frac{dN}{d\Omega^*} \cos\theta_p^* d\Omega^*$$

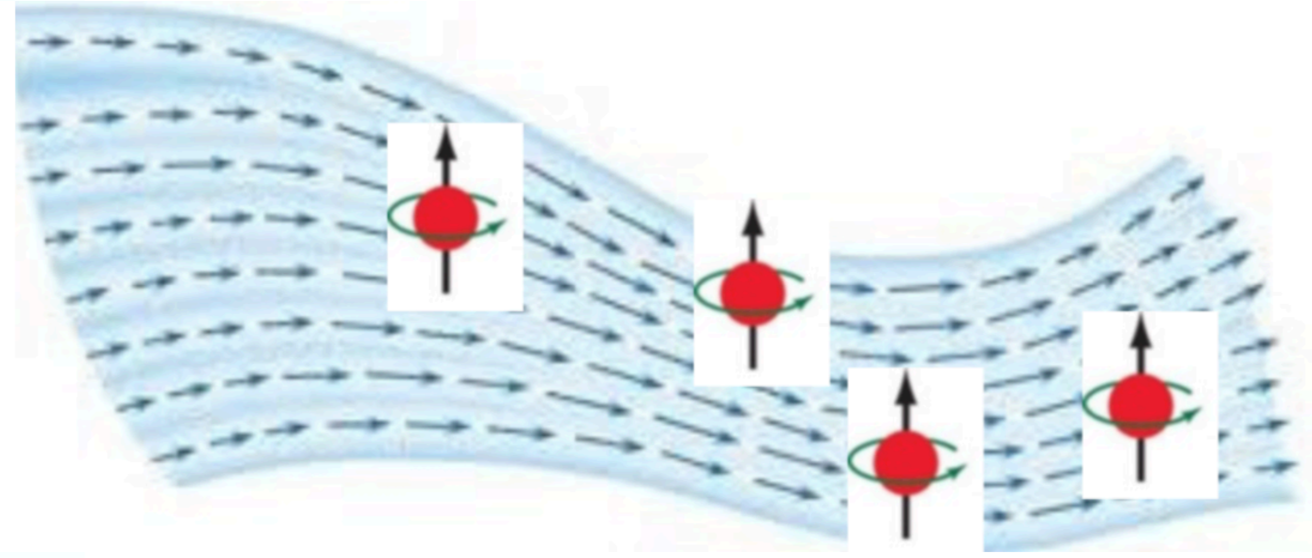
$$= \alpha_H P_z \langle (\cos\theta_p^*)^2 \rangle$$

$$\therefore \ P_z = \frac{\langle \cos\theta_p^* \rangle}{\alpha_H \langle (\cos\theta_p^*)^2 \rangle}$$

$$= \frac{3\langle \cos\theta_p^* \rangle}{\alpha_H}$$ (if perfect det

α_H: hyperon decay parameter
θ_p^*: θ of daughter proton in Λ rest frame

Fluid dynamics with spin?



$$\partial_\mu T^{\mu\nu} = 0, \quad \partial_\lambda S^{\lambda,\mu\nu} = 0, \quad \partial_\mu N^\mu = 0$$

Credit: T.Niida, The 5th Workshop on Chirality, Vorticity and Magnetic Field in Heavy Ion Collisions, 2019

Prog. Part. Nucl. Phys. 108 (2019) 103709

Summary

The spin polarization provides a new probe of the QGP properties

The disagreements between spin-thermal approach and data motivates developments of dynamical models

The fluid dynamics with spin is a natural framework one should seek for QGP

Present ideal spin hydro formulation is readily applicable

The theory is developing fast - future looks interesting!

some 1D applications
+
3+1D implementation forthcoming

W.Florkowski, A. Kumar., RR, R. Singh, *Phys.Rev.C* 99 (2019) 4, 044910
R. Singh, G. Sophys, R.R., *Phys.Rev.D* 103 (2021) 7, 074024
R. Singh, M. Shokri, R.R., 2103.02592 (accepted to *Phys.Rev.D)*