THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

“Spin” in relativistic heavy-ion collisions

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

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NATIONAL SCIENCE CENTRE
POLAND

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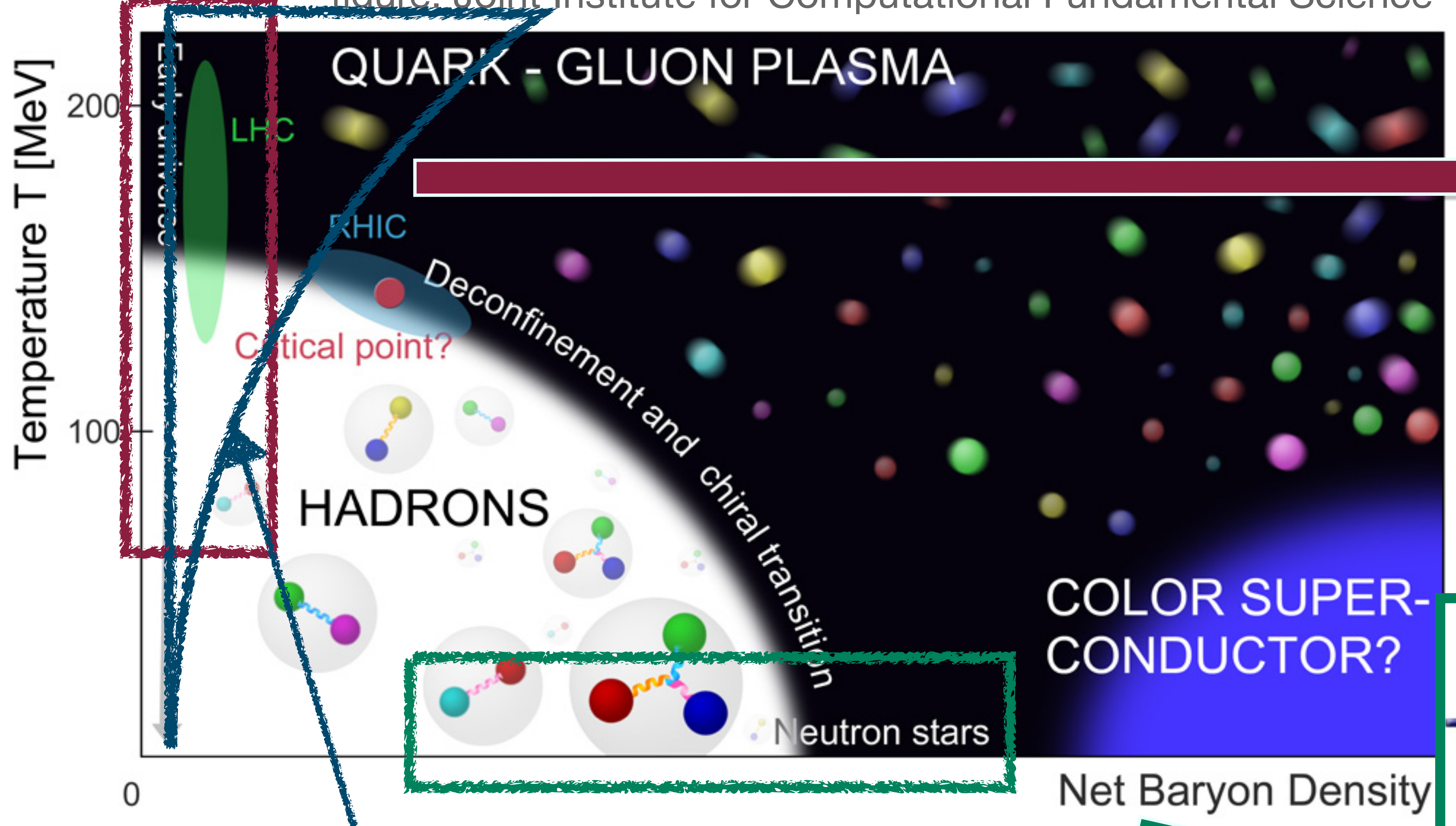
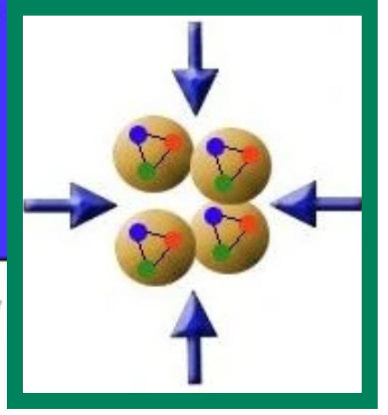
Quantum Chromodynamics (QCD) pushed to extreme

QCD phase diagram

figure: Joint Institute for Computational Fundamental Science





Early Universe

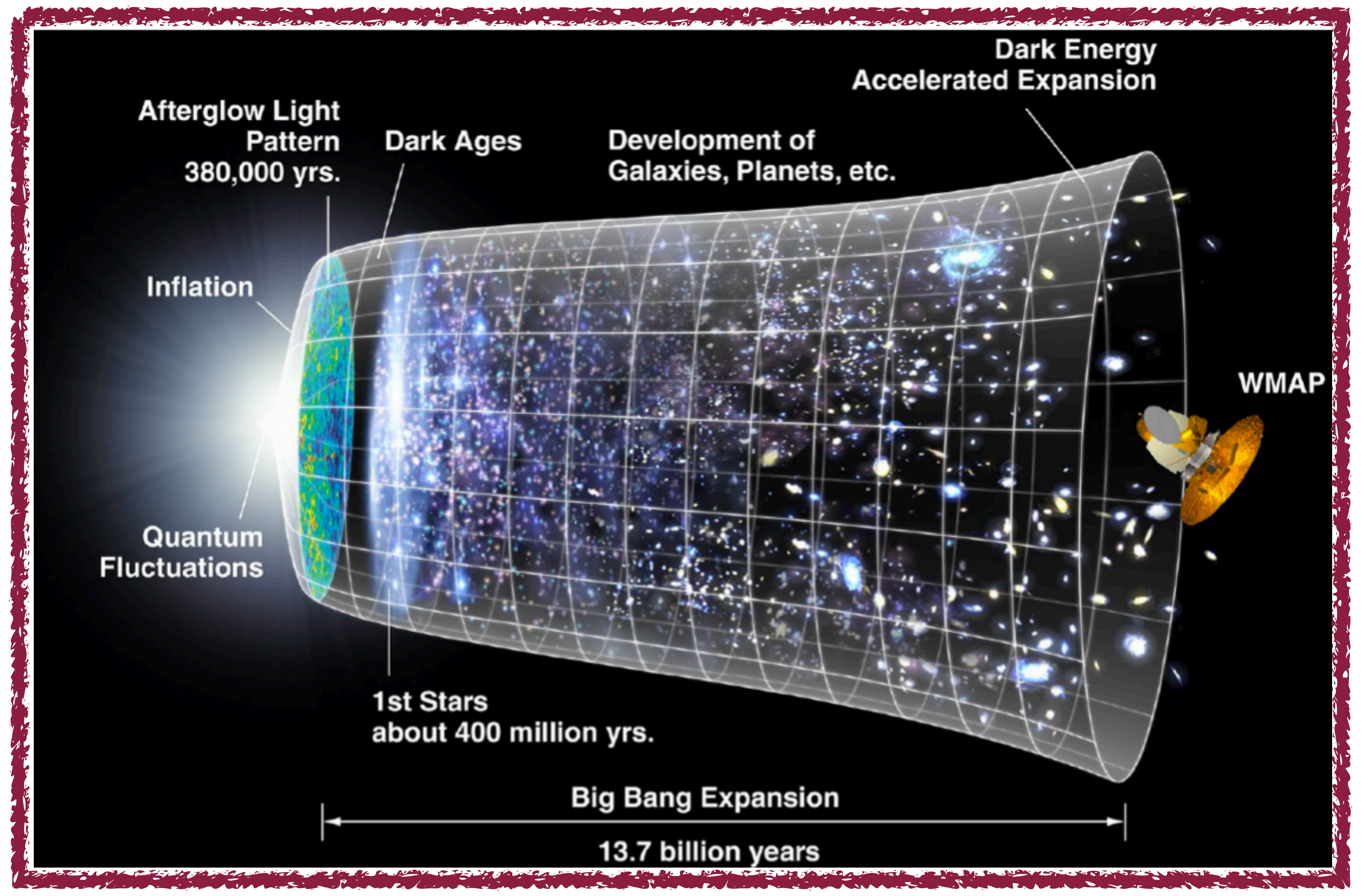


figure: NASA

Cores of neutron stars

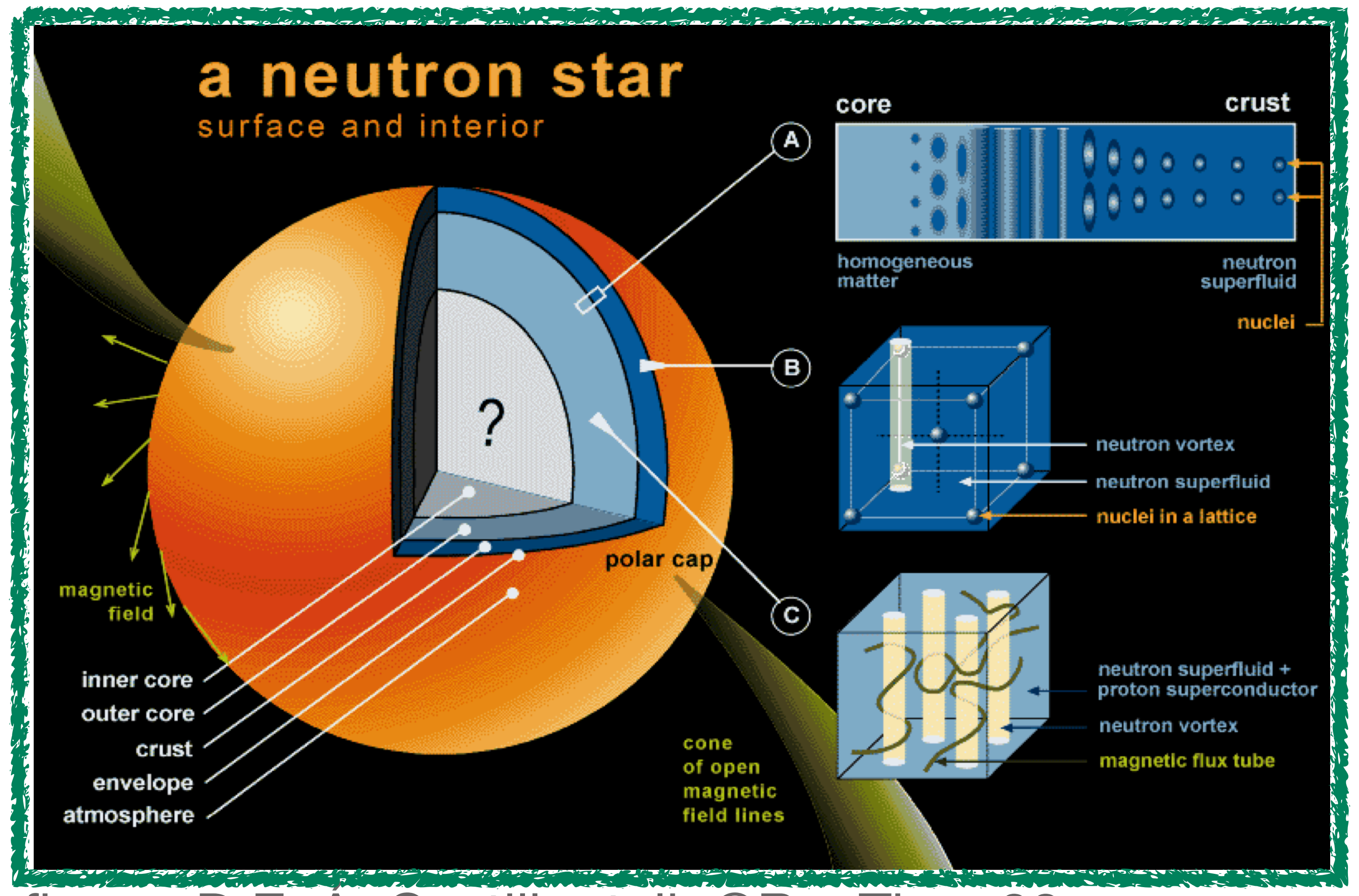
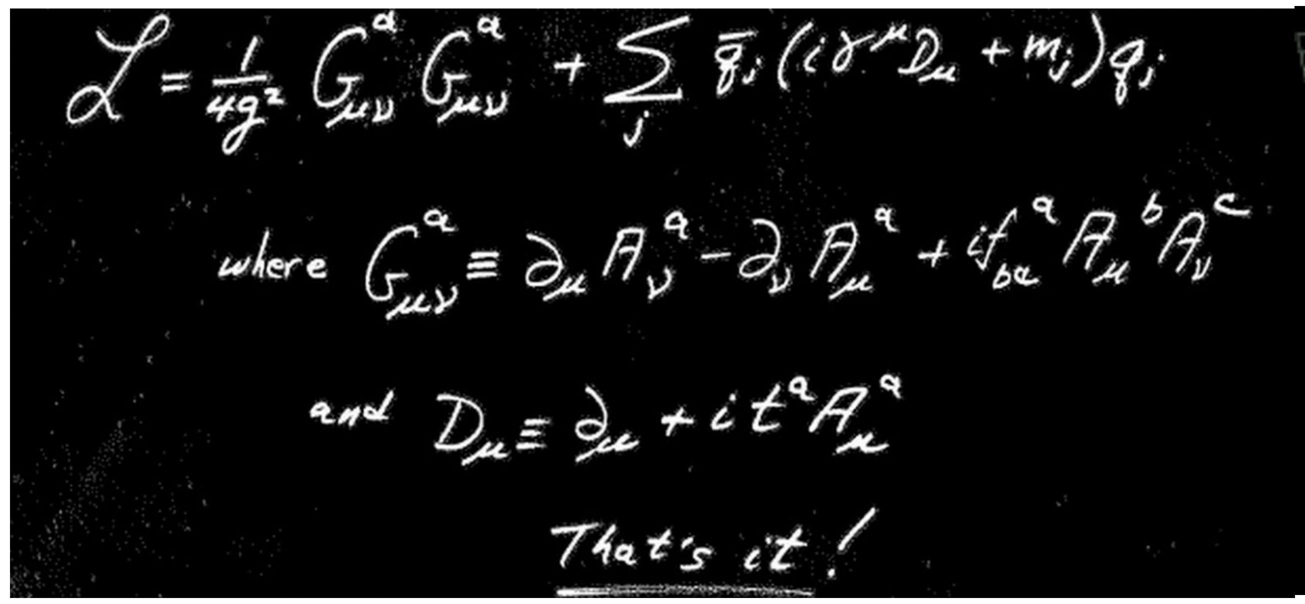


figure: D.E. A. Castillo, talk @RagTime 22

Lattice-QCD simulations



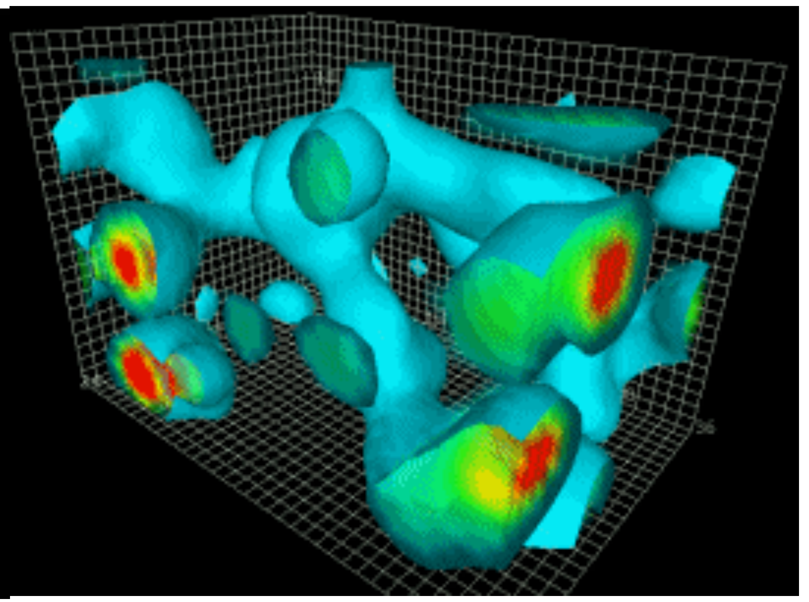
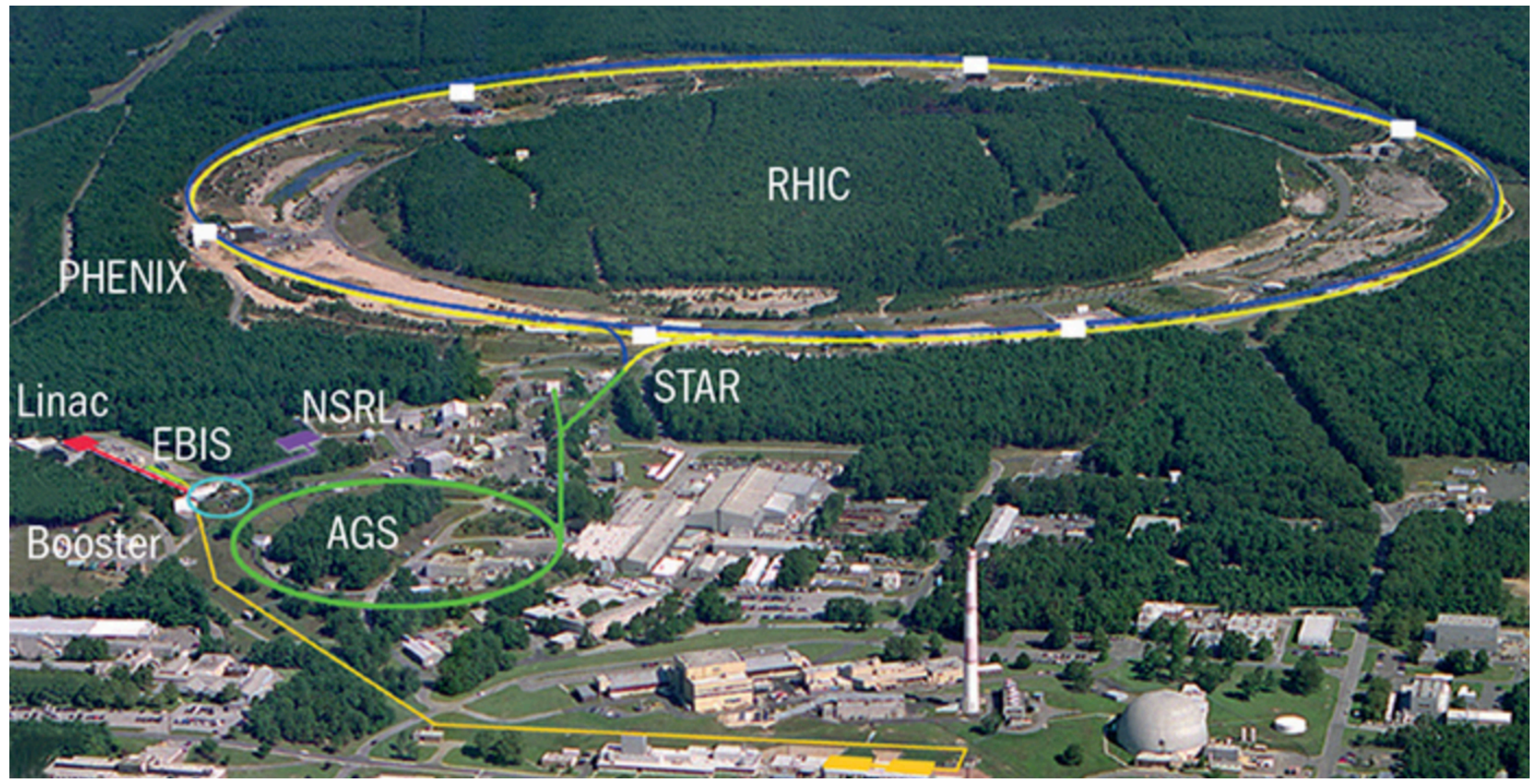


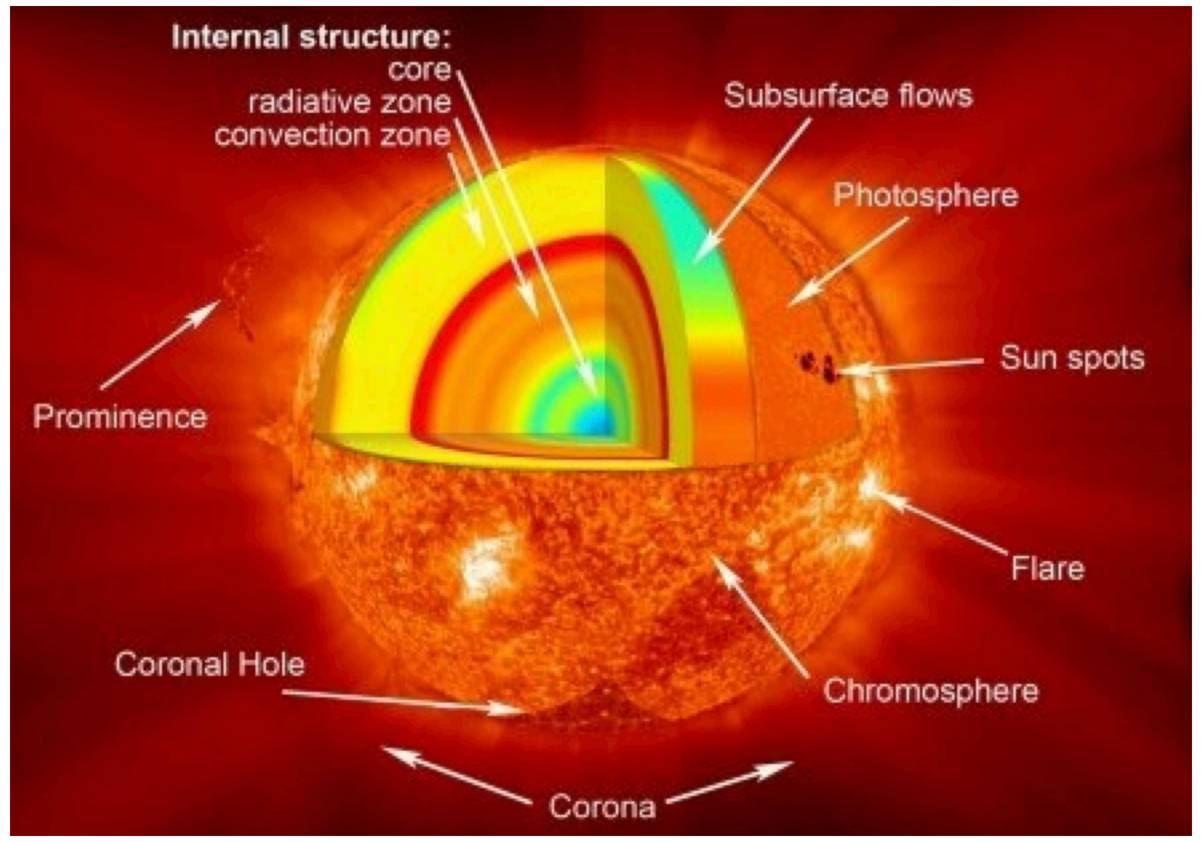
figure: D. Leinweber (www.physics.adelaide.edu.au)

Relativistic heavy-ion collisions - a tool to study QGP

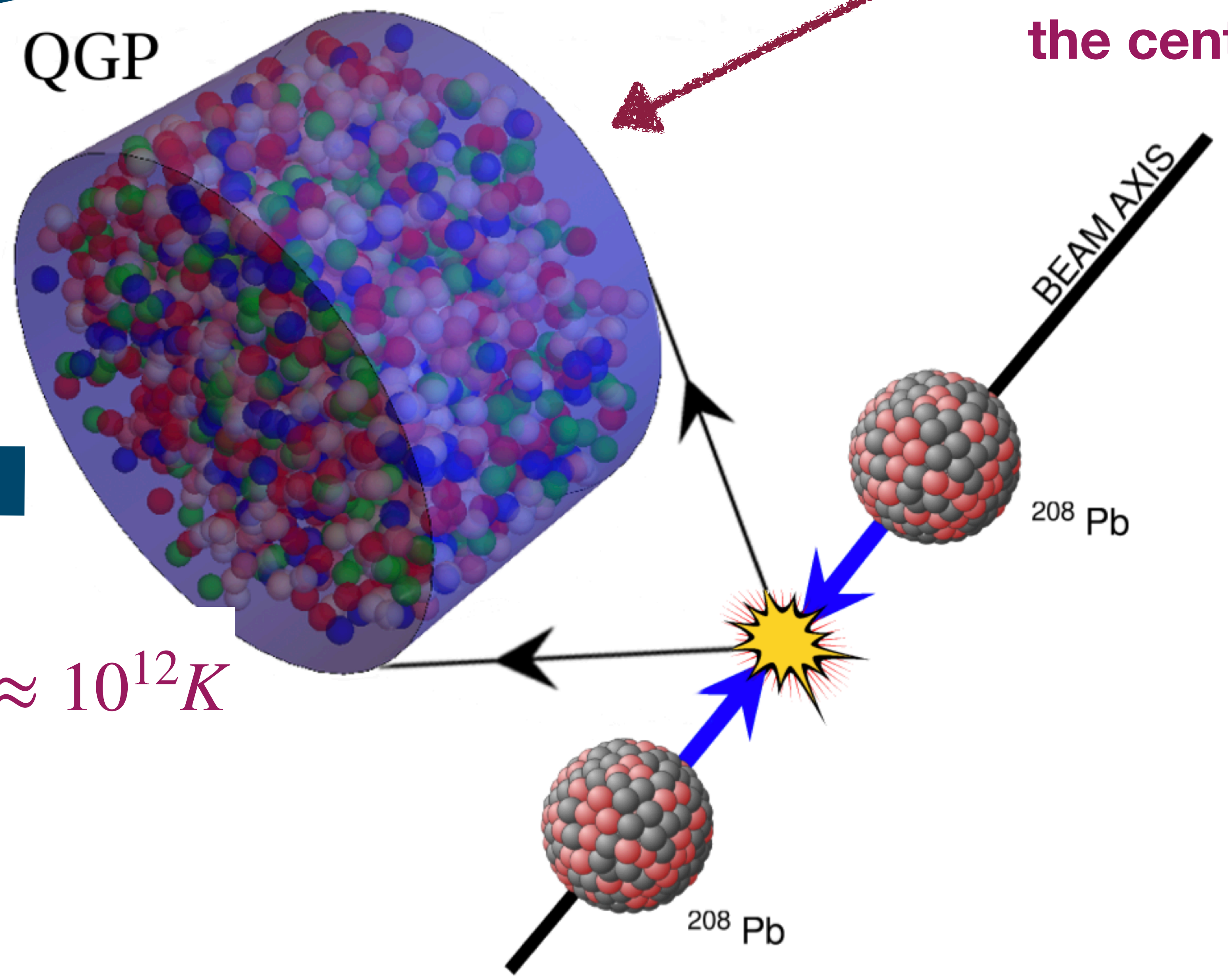


At high beam energies we observe many particles being produced

figure: NASA



100 000 times hotter than the center of the Sun



$T \approx 10^{12} K$

The study of QGP possible only indirectly through the energy and momenta of emitted particles

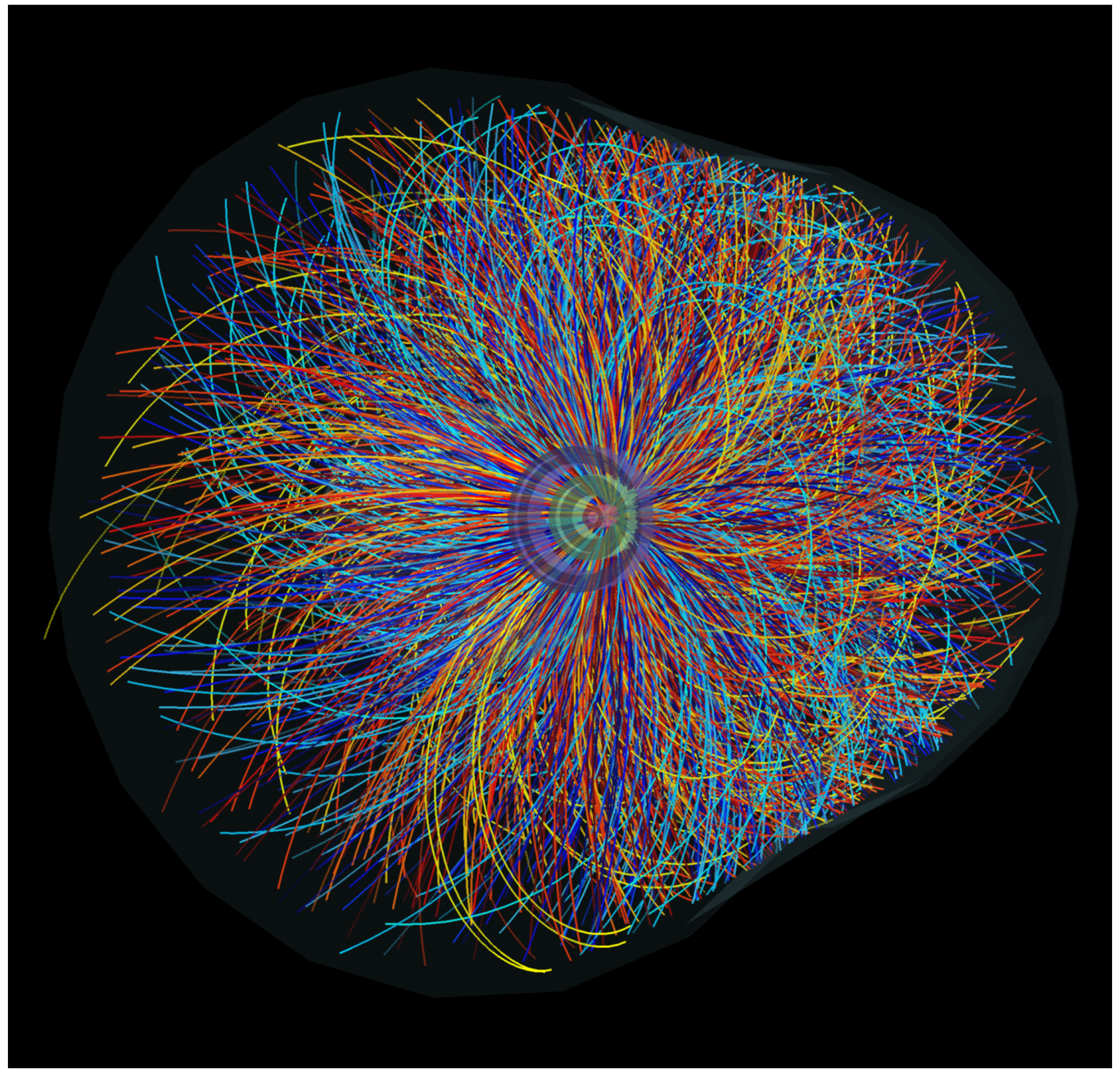


figure: Nature Physics 16, 615–619(2020)

Spin polarization in heavy-ion collisions - new sensitive probe!

Non-central heavy-ion collisions create fireballs with large global orbital angular momenta

F. Becattini, F. Piccinini, J. Rizzo, PRC 77 (2008) 024906

$$\boldsymbol{L}_{\text{init}} \sim 10^5 \boldsymbol{\hbar}$$

Part of the angular momentum can be transferred from the orbital to the spin part

$$\boldsymbol{J}_{\text{init}} = \boldsymbol{L}_{\text{init}} = \boldsymbol{L}_{\text{final}} + \boldsymbol{S}_{\text{final}}$$

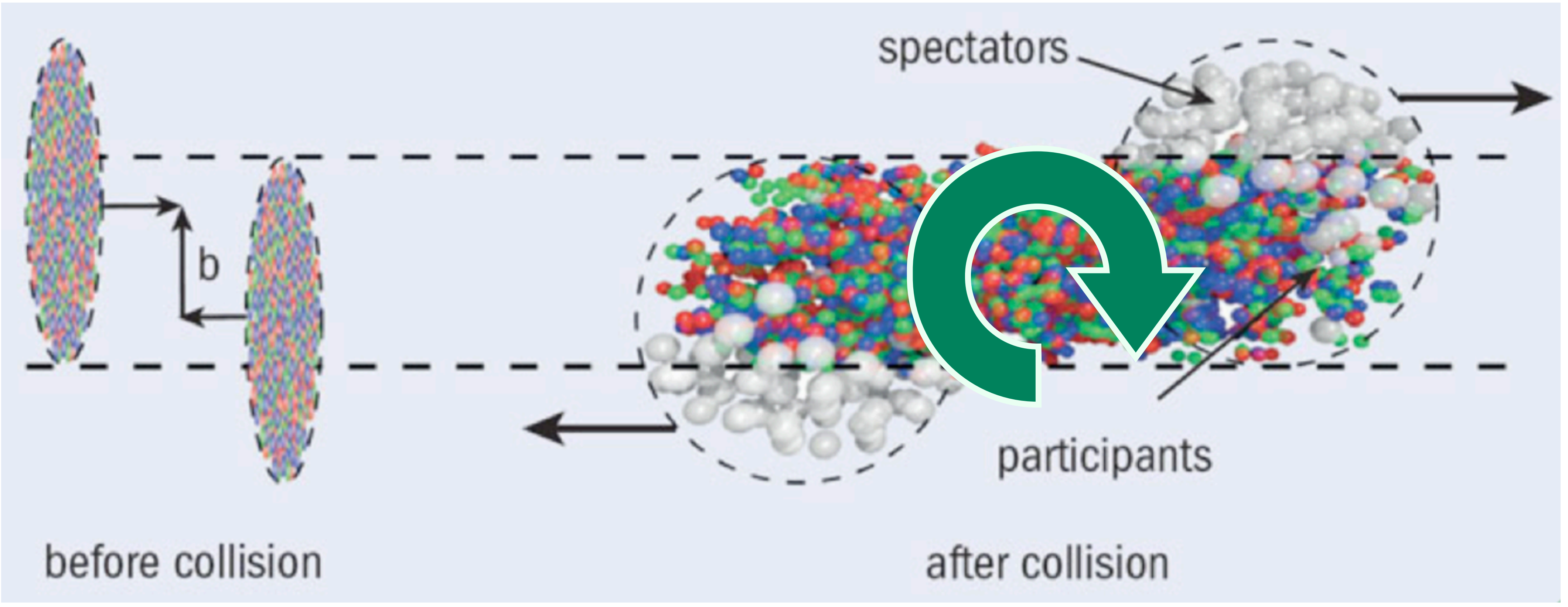
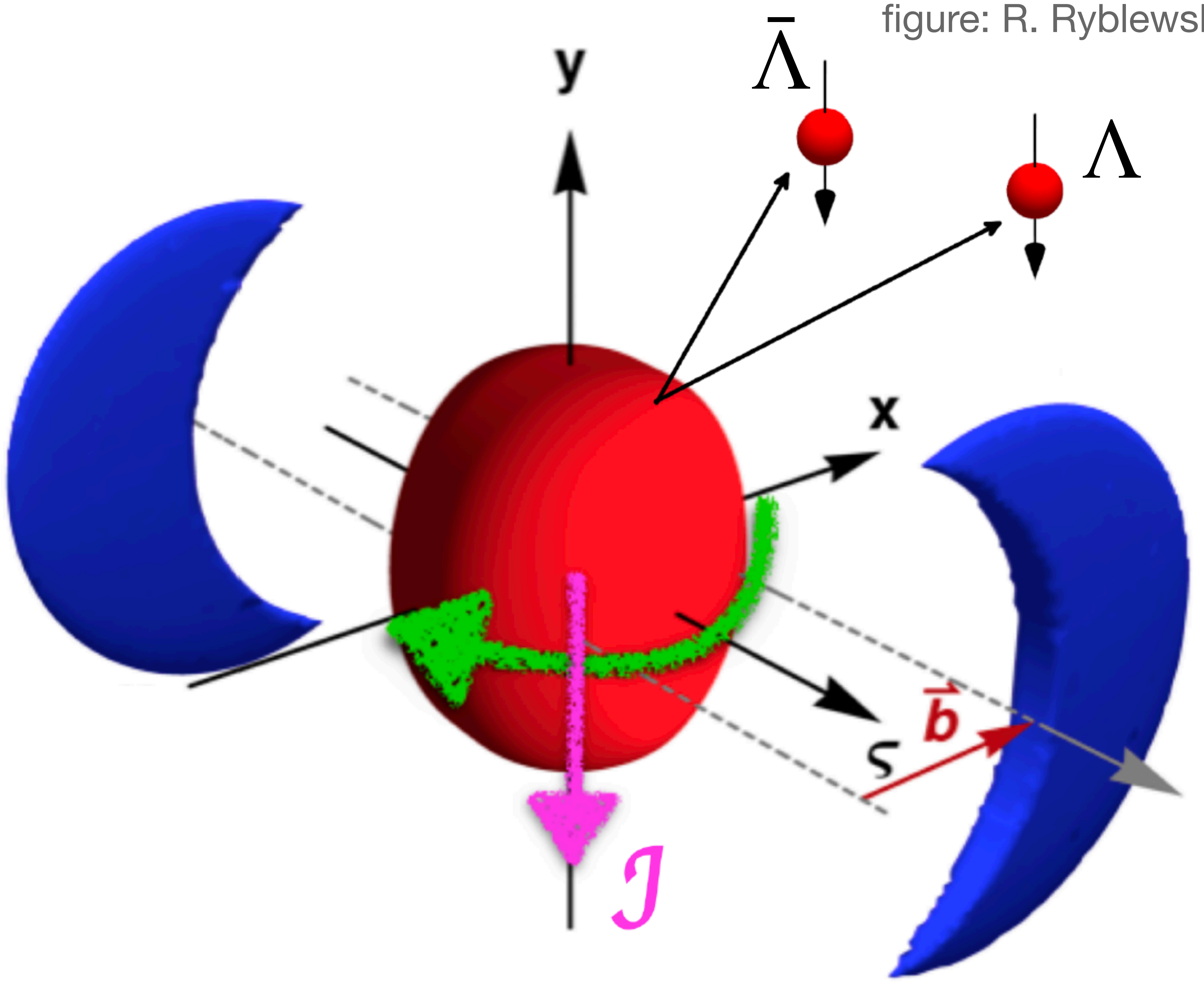


figure: M. Lisa, talk @ "Strangeness in Quark Matter 2016"

figure: R. Ryblewski

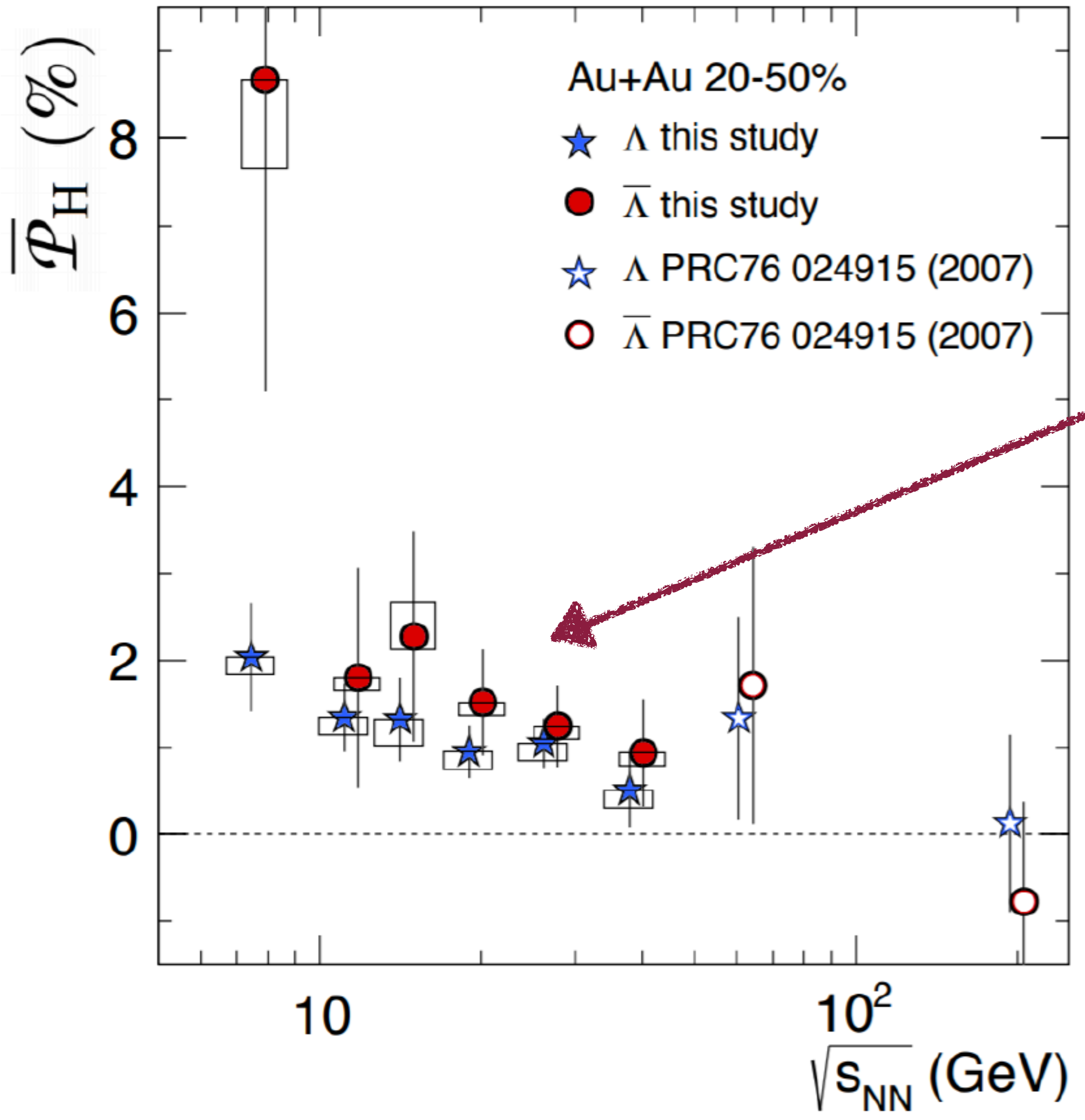


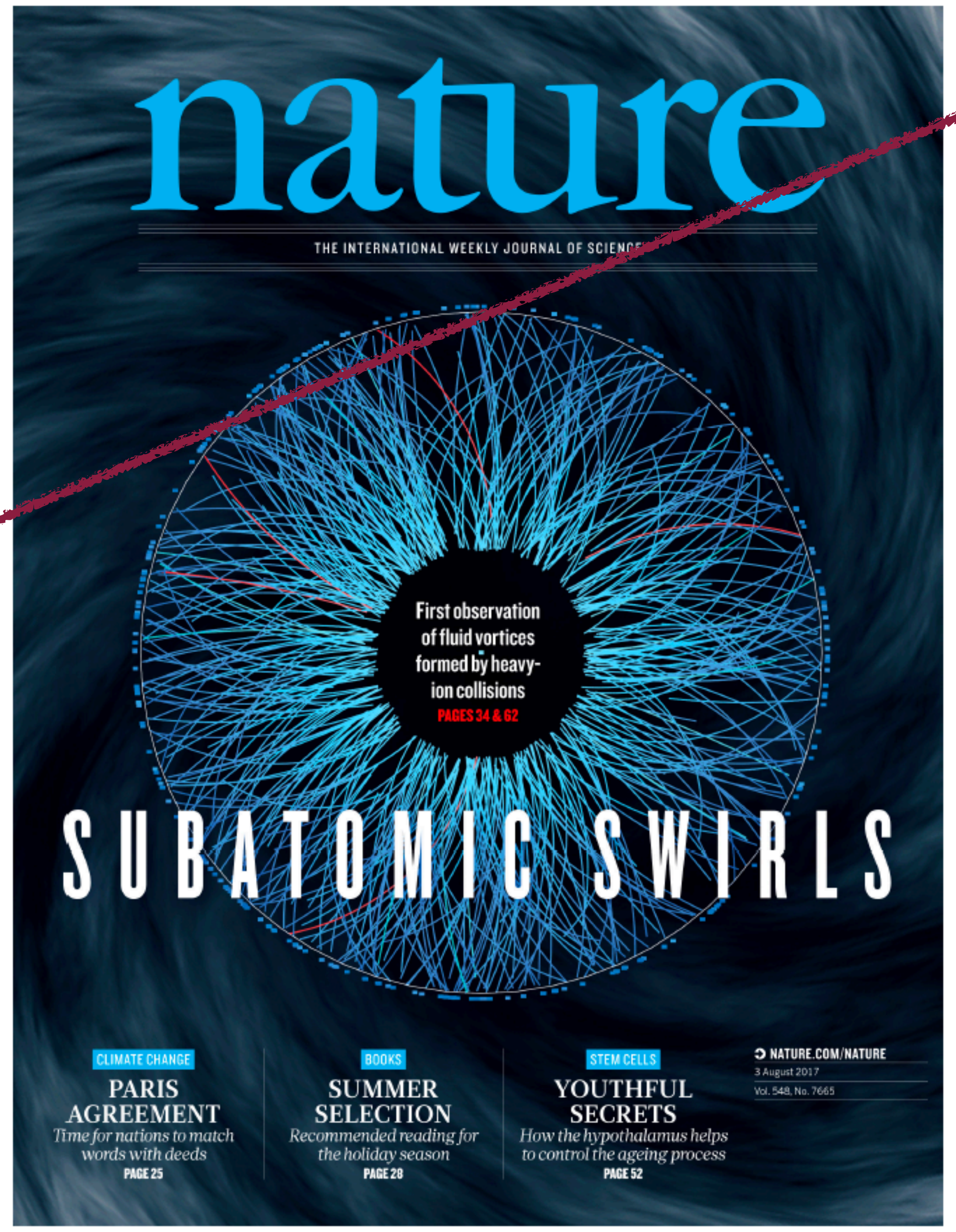
Emitted particles are expected to be globally polarized along the system's angular momentum

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

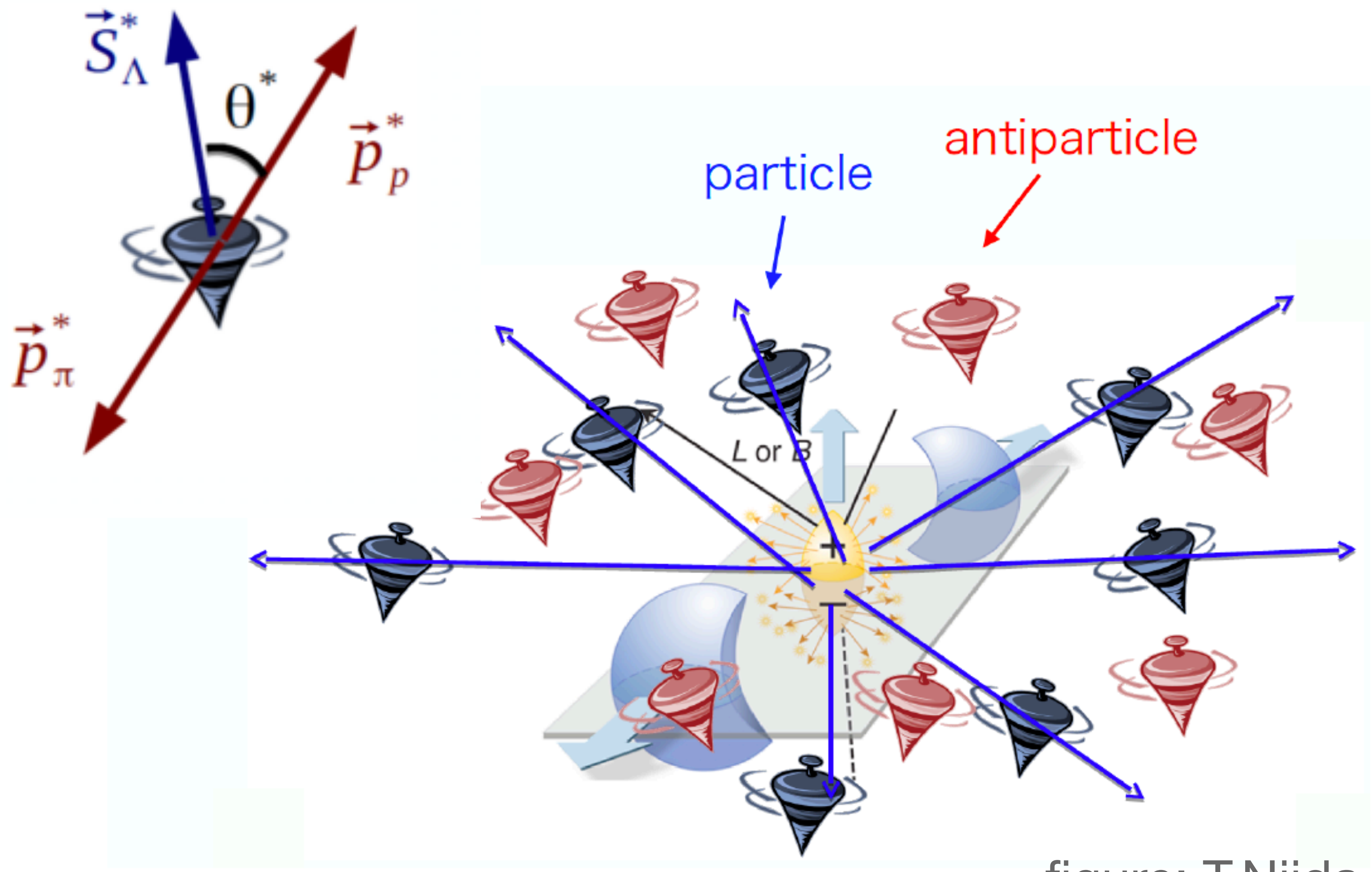


figure: T.Niida

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

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

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

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

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

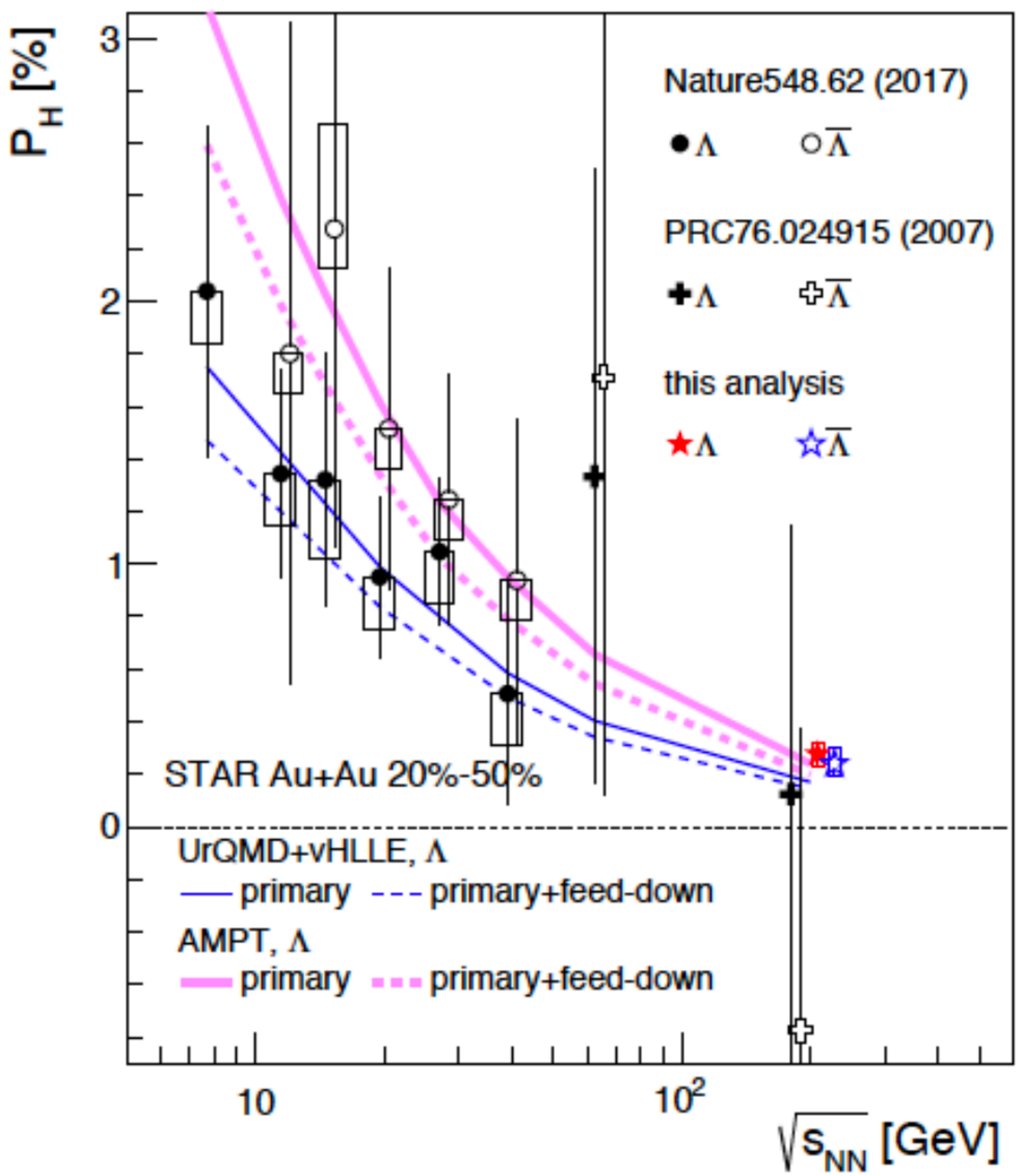
Global polarization

Global polarization data supports the spin-thermal approach

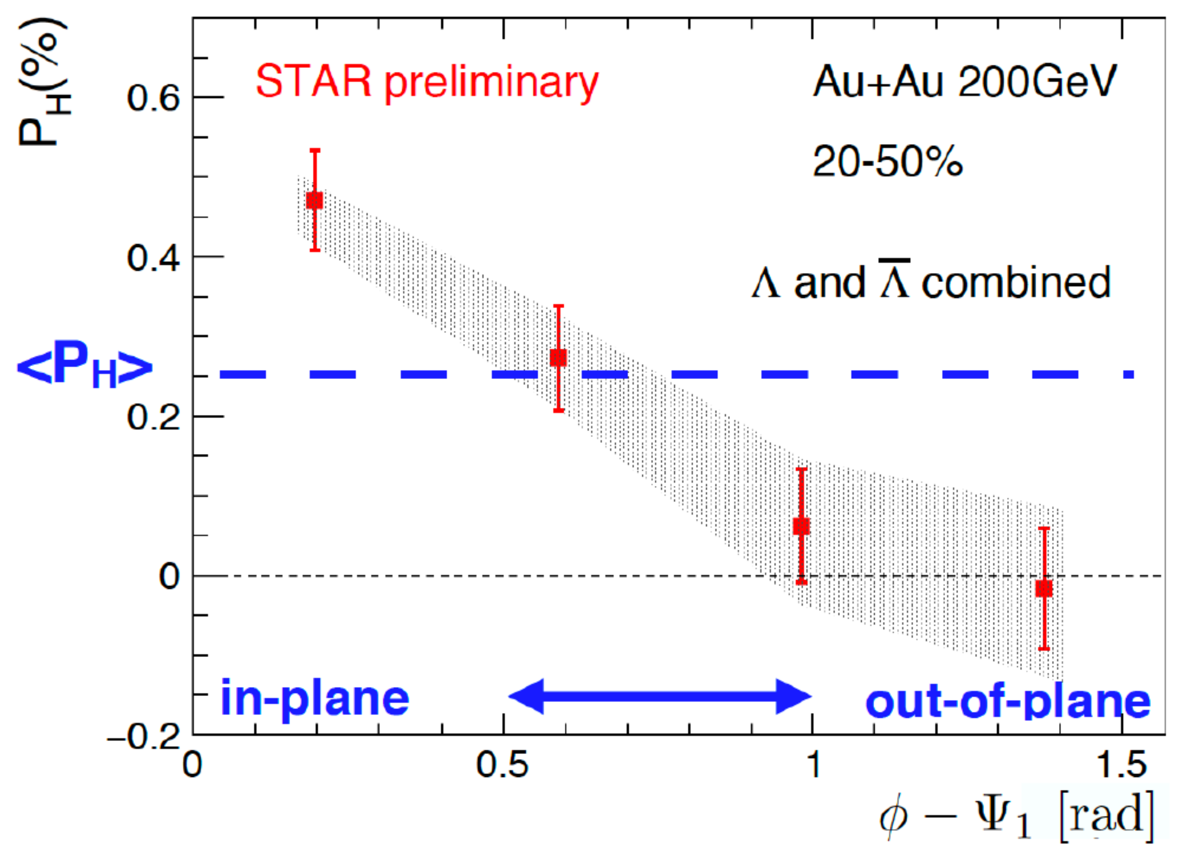
Signal is pretty robust and agrees for both multiphase transport model (AMPT) and viscous hydrodynamics (UrQMD+vHLLE)

Azimuthal modulation is not captured

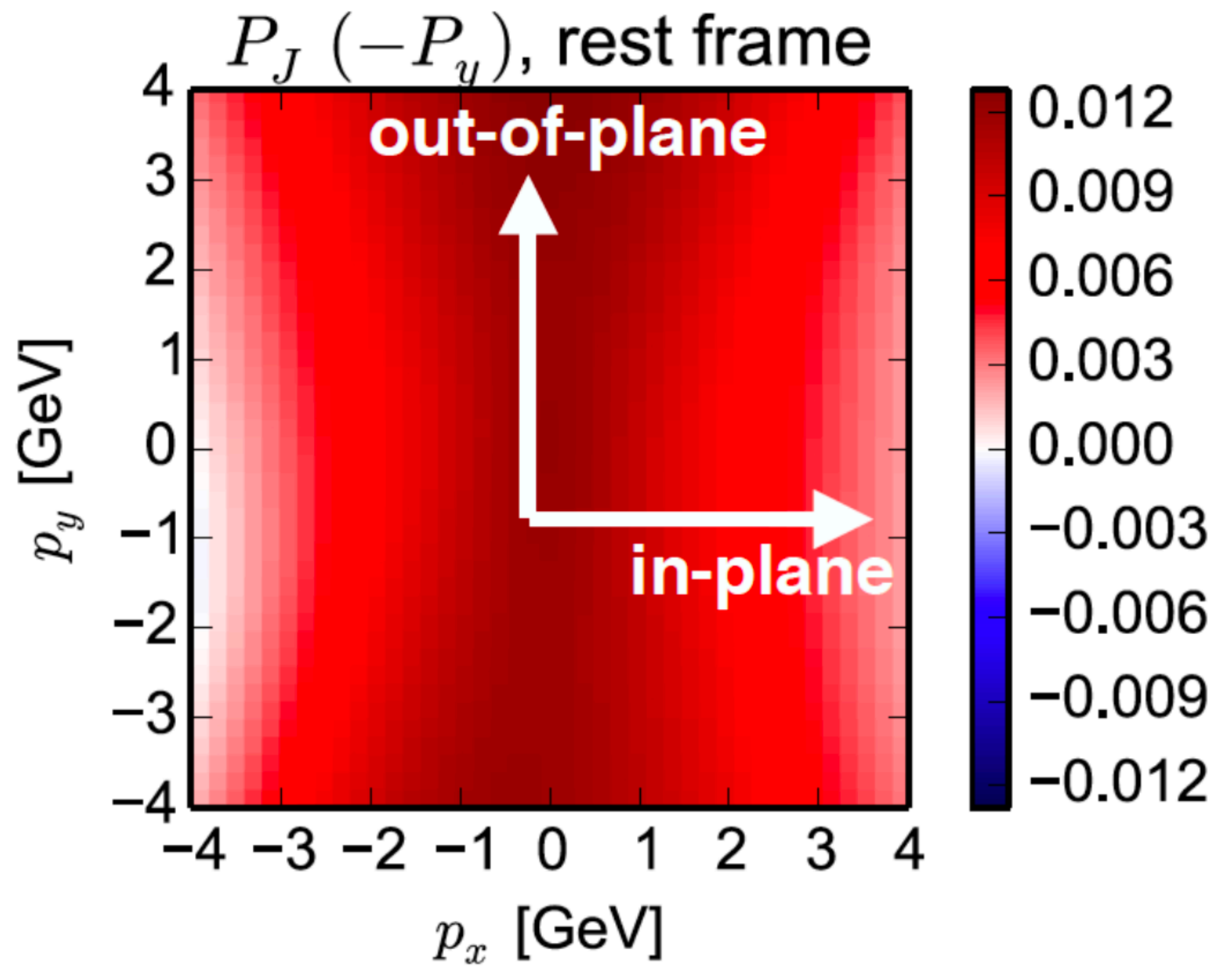
J. Adam, et al., Phys. Rev. C 98, 014910 (2018)



UrQMD+vHLLE: I. Karpenko, F. Becattini, EPJC 77, 213 (2017)
AMPT: H. Li, L. Pang, Q. Wang, and X. Xia, PRC 96, 054908 (2017)

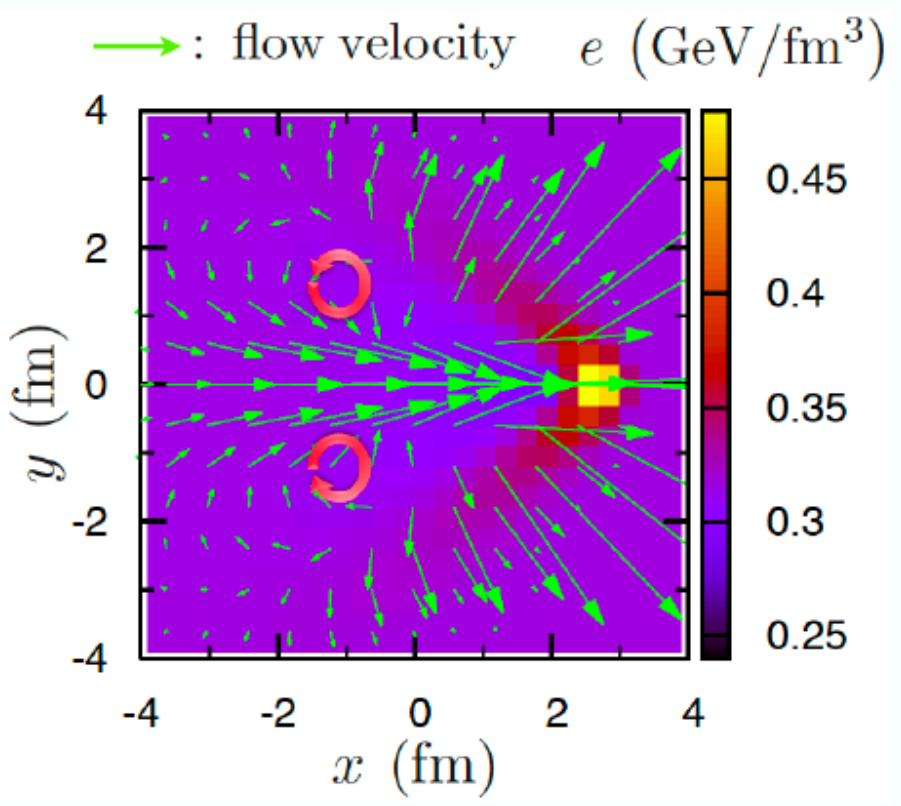


Credit: T.Niida, The 5th Workshop on Chirality, Vorticity and Magnetic Field in Heavy Ion Collisions, 2019

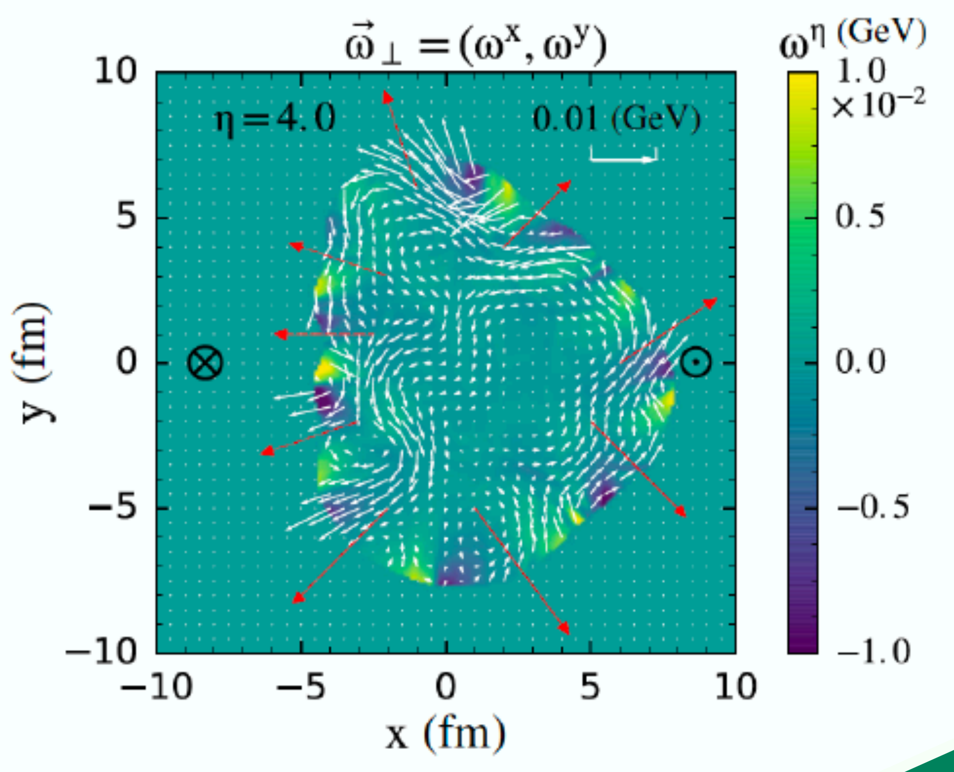


I. Karpenko, F. Becattini, EPJC 77, 213 (2017)

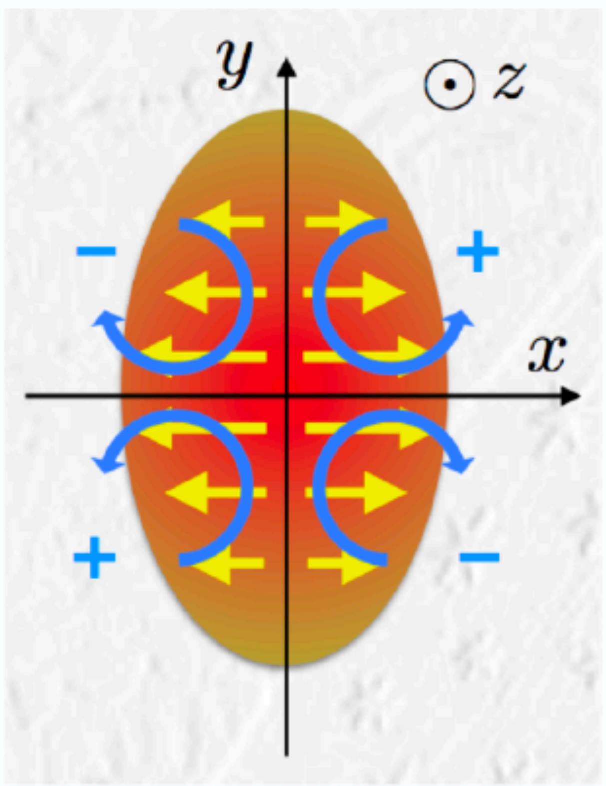
Local (momentum-differential) polarization



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

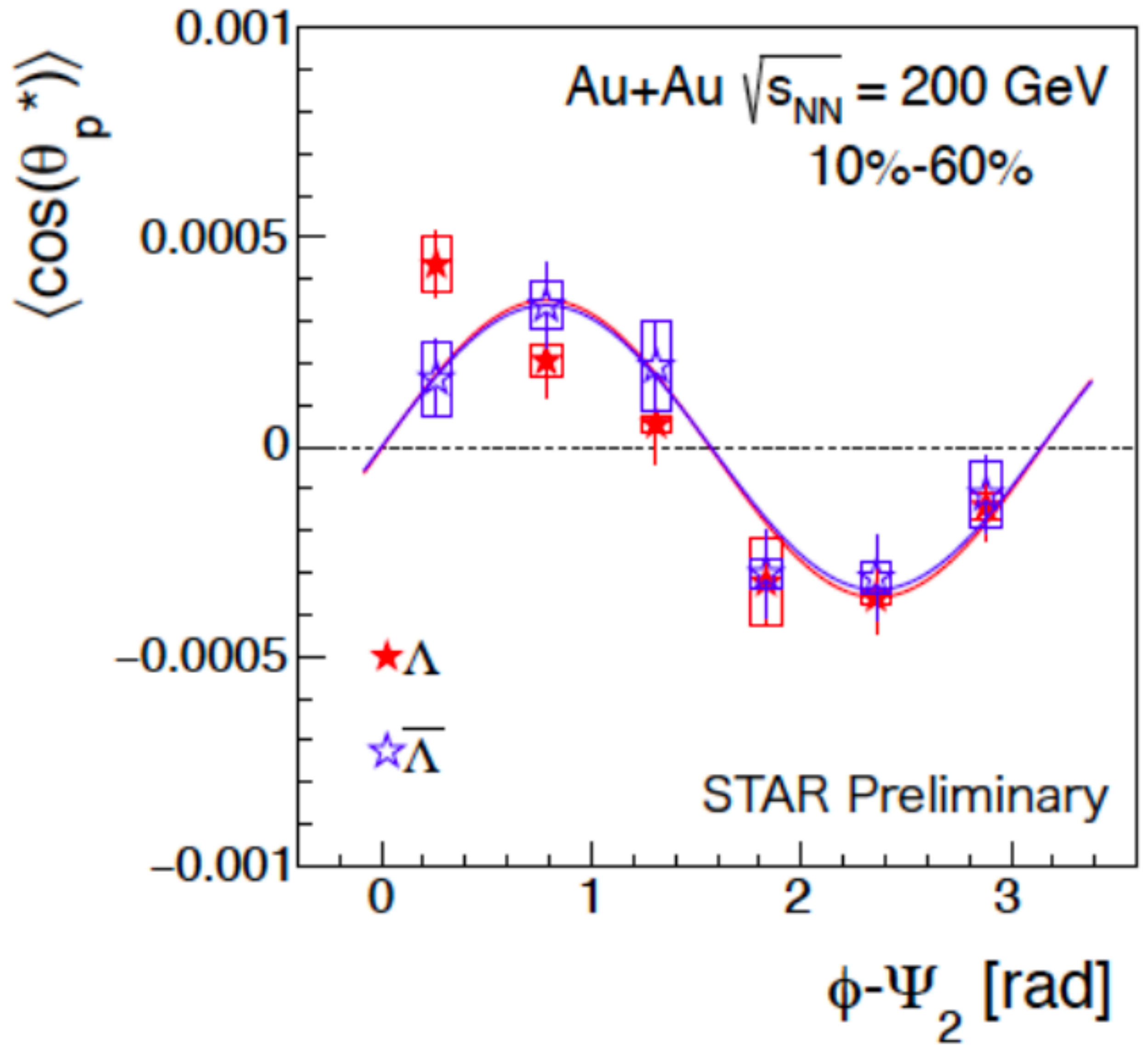


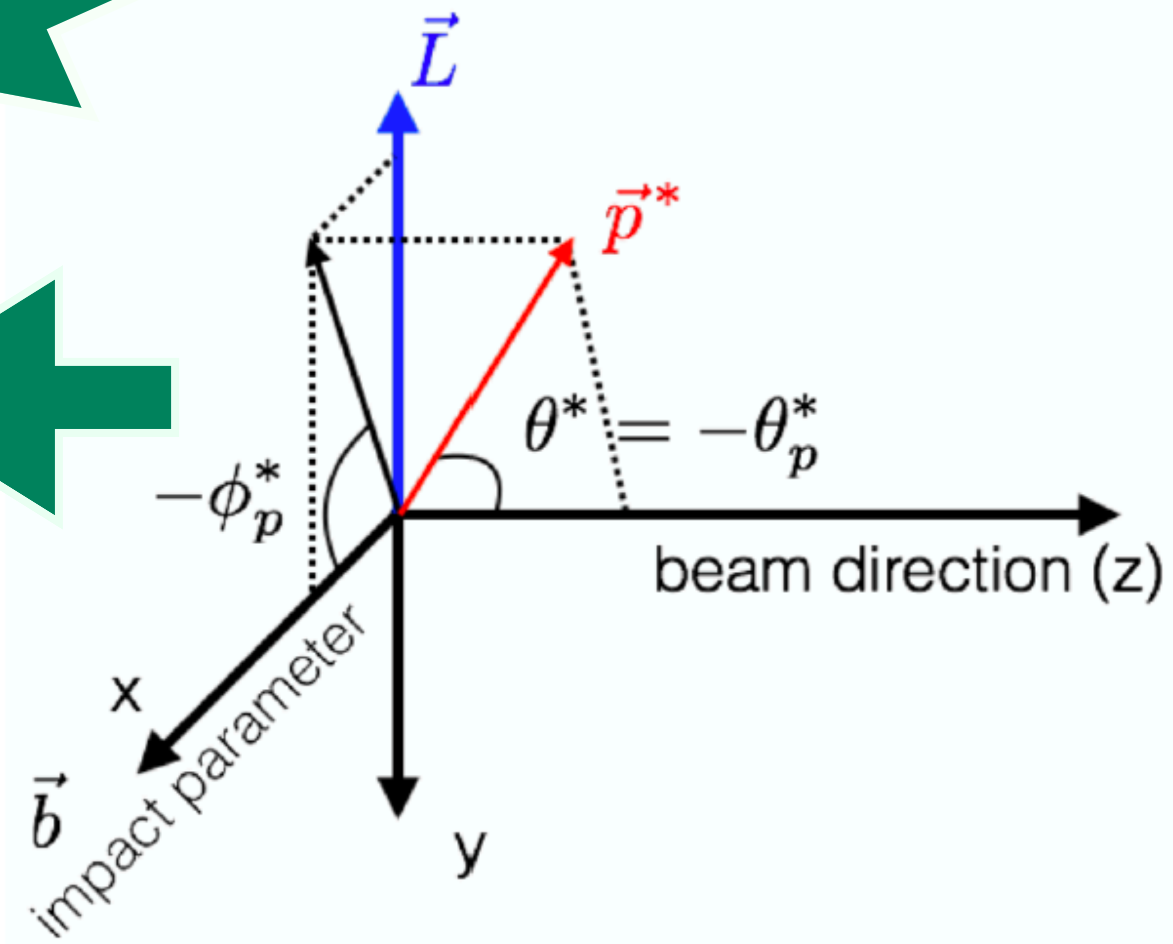
L.-G. Pang, H. Peterson, Q. Wan... Wang
PRL117, 192...



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





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

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

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

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

$$= \frac{3\langle \cos\theta_p^* \rangle}{\alpha_H} \quad \text{(if perfect detector)}$$

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