Polarization observables in heavy ion collisions

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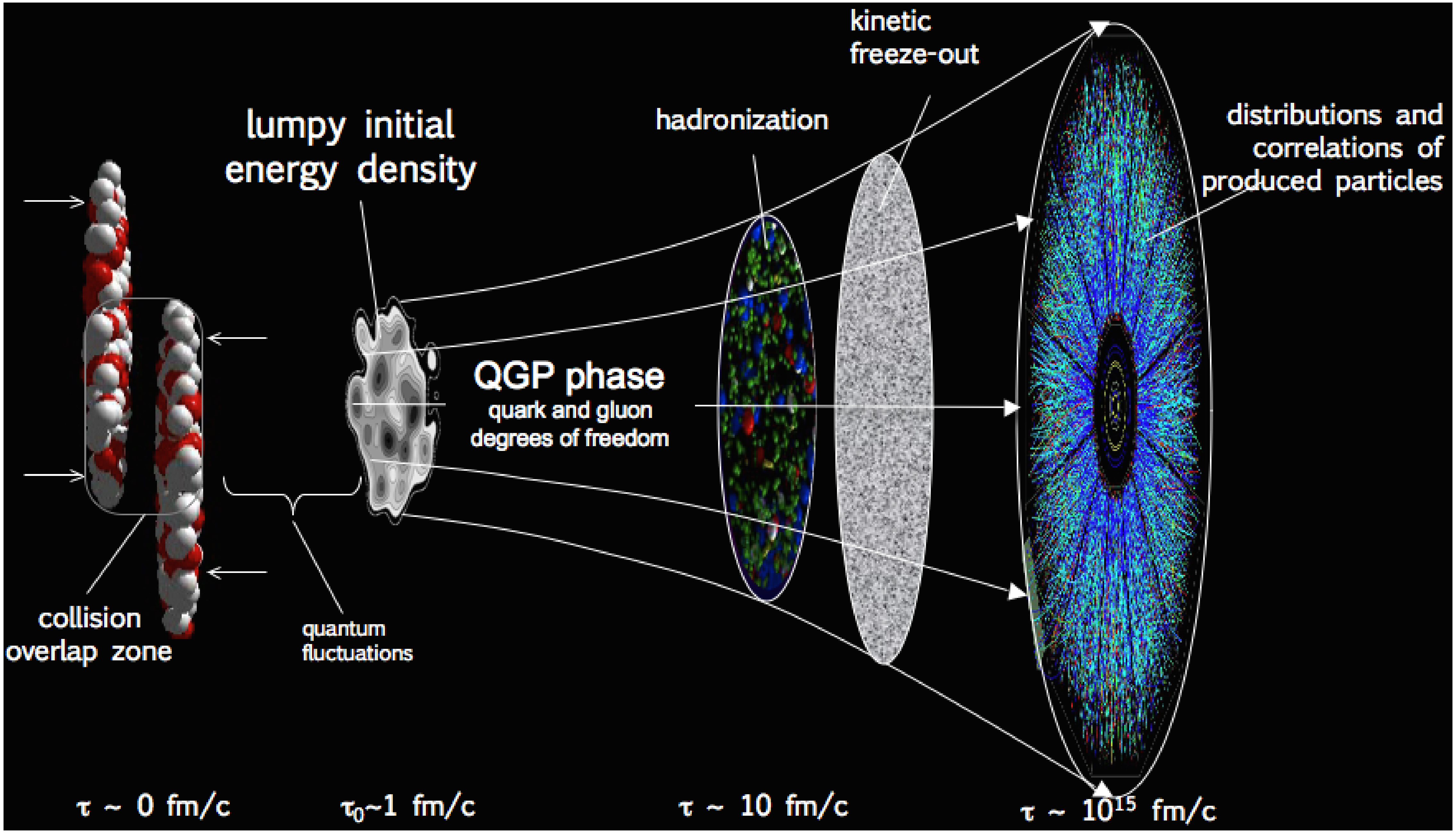
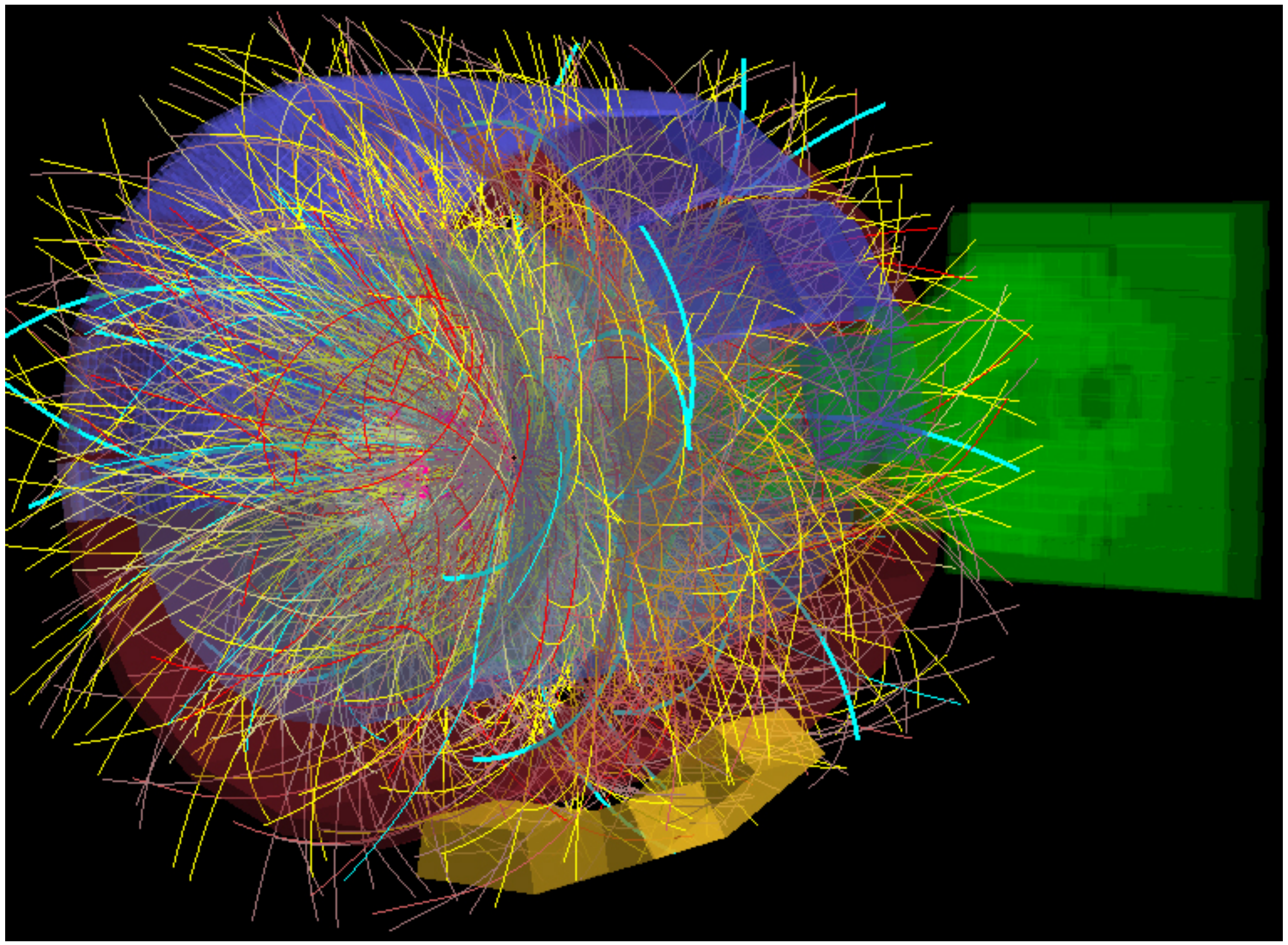
Heavy ion Collision

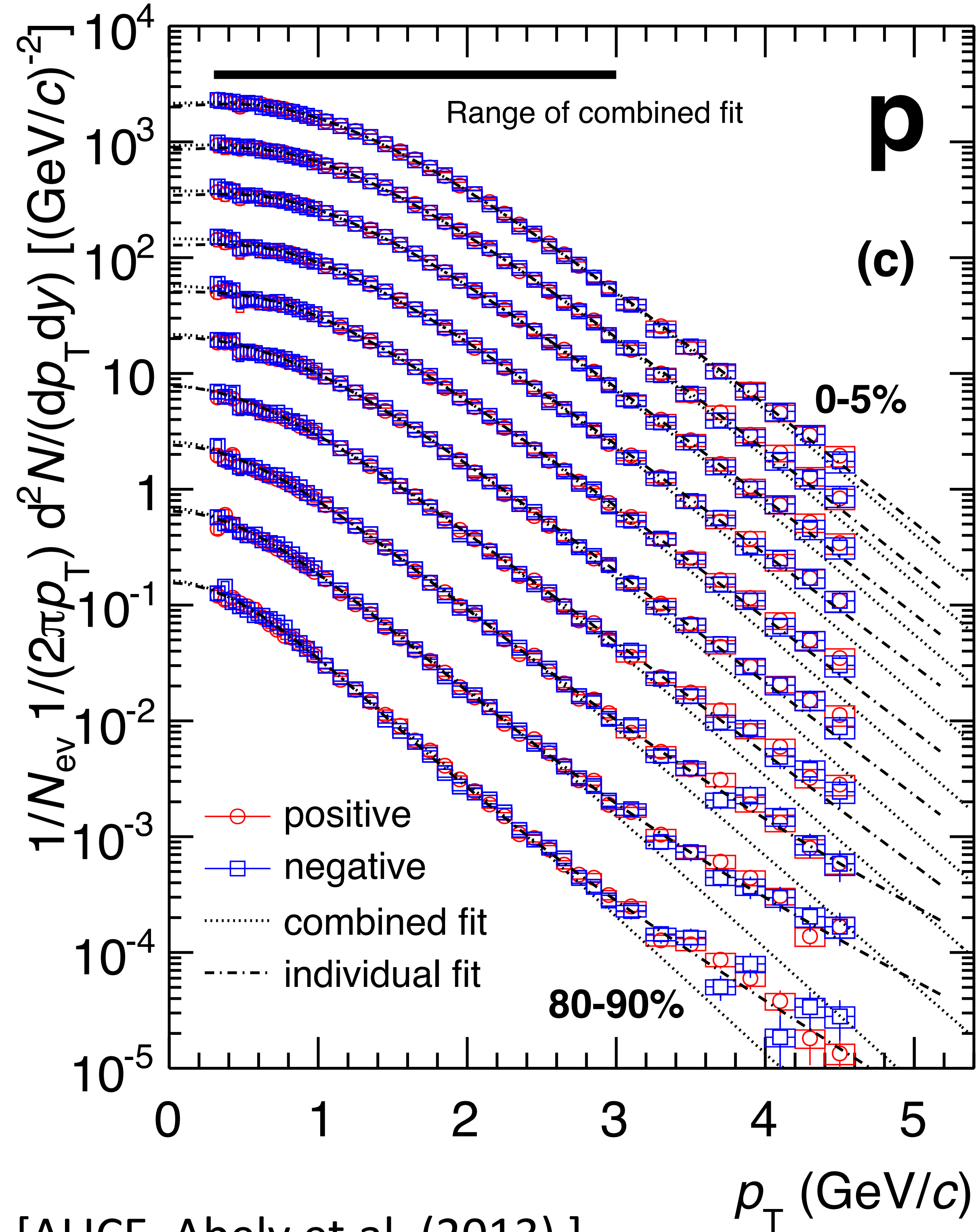


Spectra of identified particles



Events recorded by ALICE from the first lead ion collisions in 2011

Pt : Transverse momenta to the beam axis



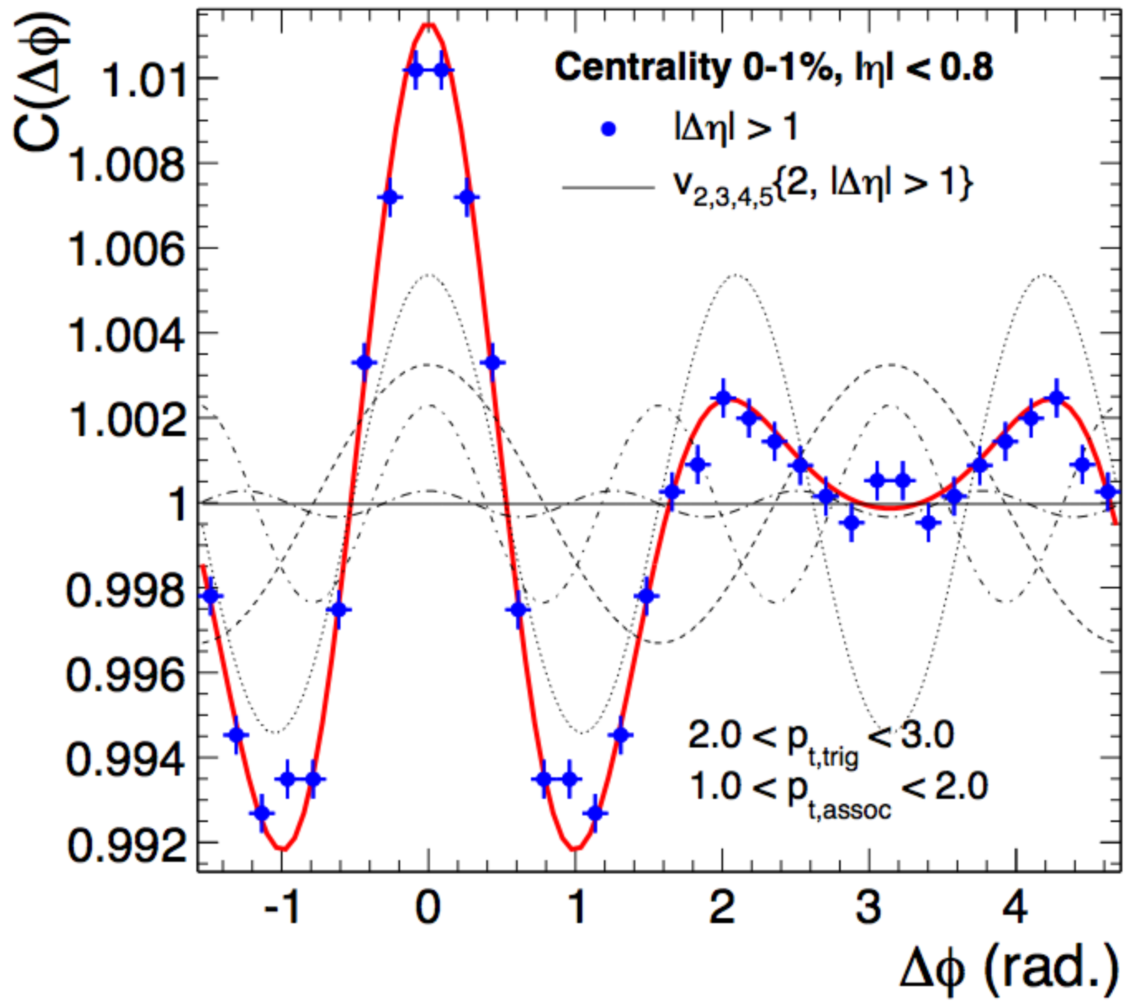
[ALICE, Abelv et.al. (2013)]

Two particle correlation function

- Normalized Correlation function

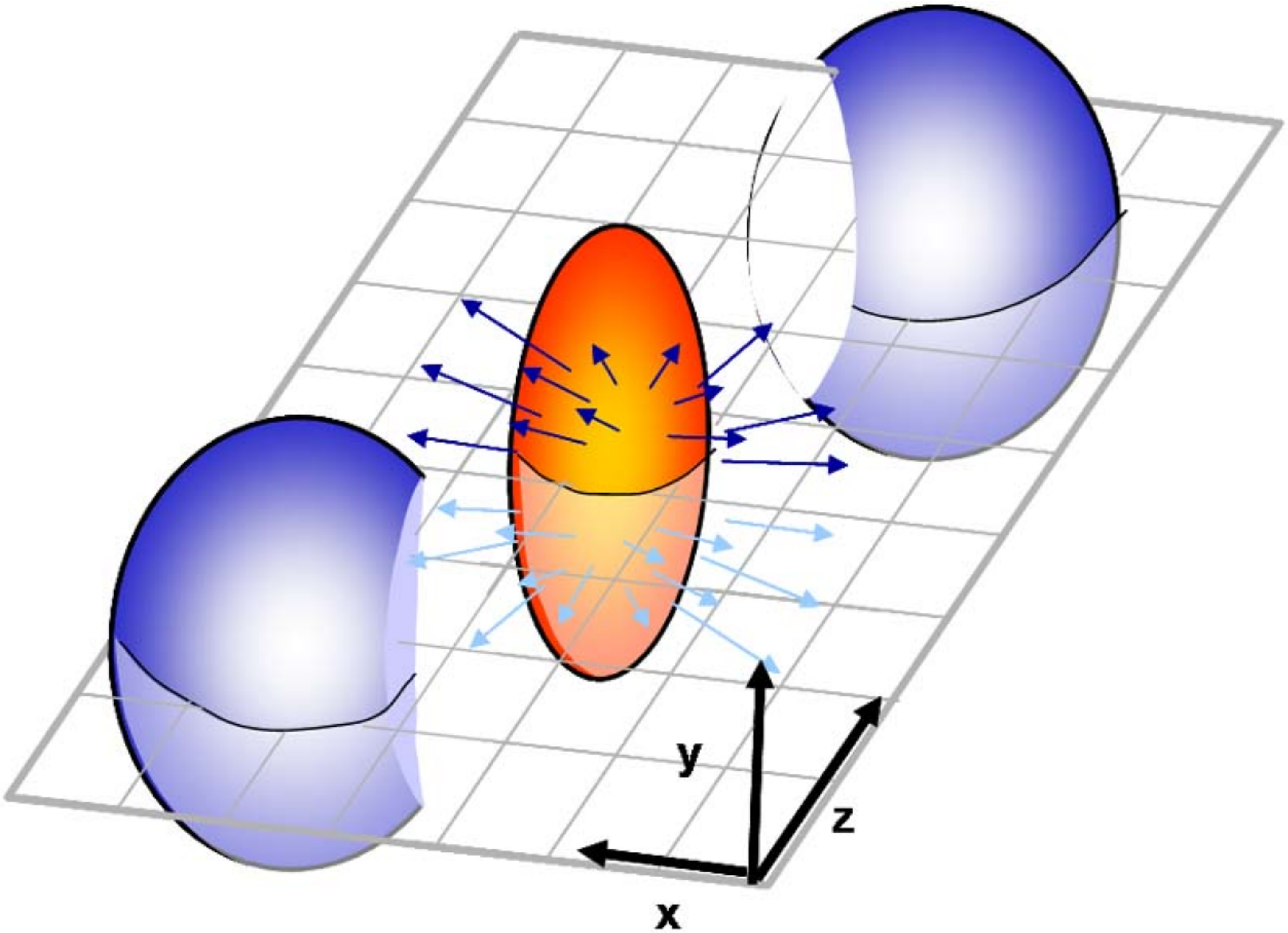
$$C(\phi_1,\phi_2) = \frac{\langle \frac{dN}{d\phi_1}\frac{dN}{d\phi_2}\rangle_{\text{events}}}{\langle \frac{dN}{d\phi_1}\rangle_{\text{events}}\langle \frac{dN}{d\phi_2}\rangle_{\text{events}}} = 1 + 2\sum_m v_m^2 \cos(m(\phi_1-\phi_2))$$

- The modulation in angles are signals of the initial state shape

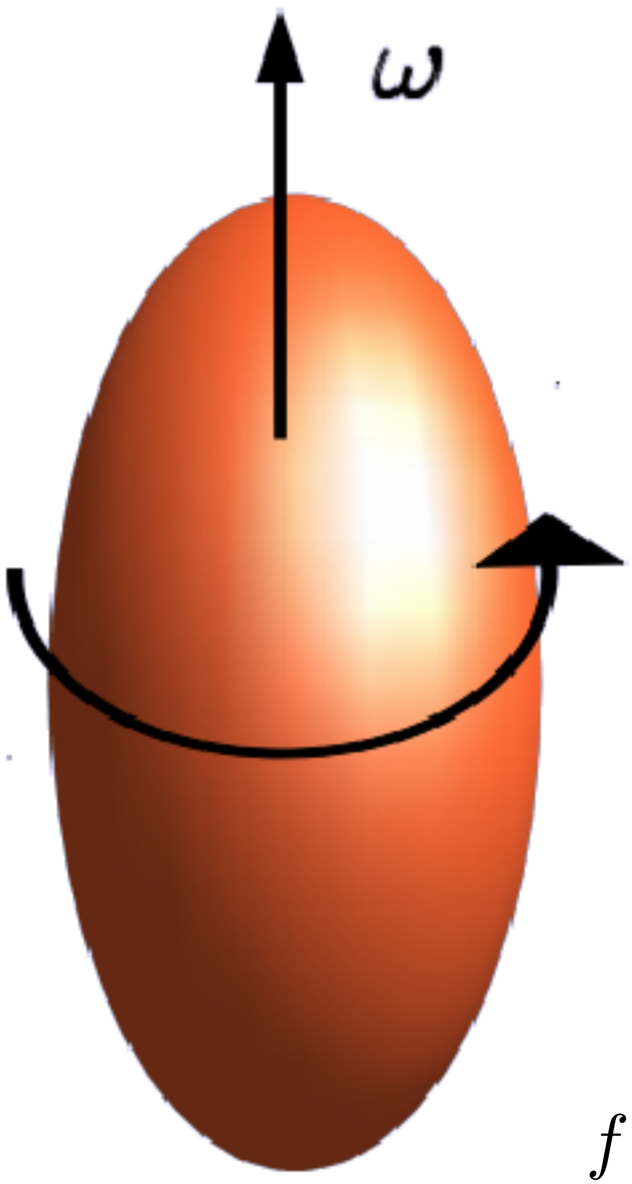


[ALICE 2011, similar results from CMS, ATLAS, Phenix, Star]

Polarization In HIC



In peripheral high energy heavy ion collisions the system has a large angular momentum and may manifest itself in the polarization of secondary produced particles



Rotating gas

F.Becattini, V.Chandra, L.Del Zanna and E.G (2013)

In rotating gas the particle, and antiparticle get polarized in the direction of the angular momentum.

For relativistic particle we propose an educated guess

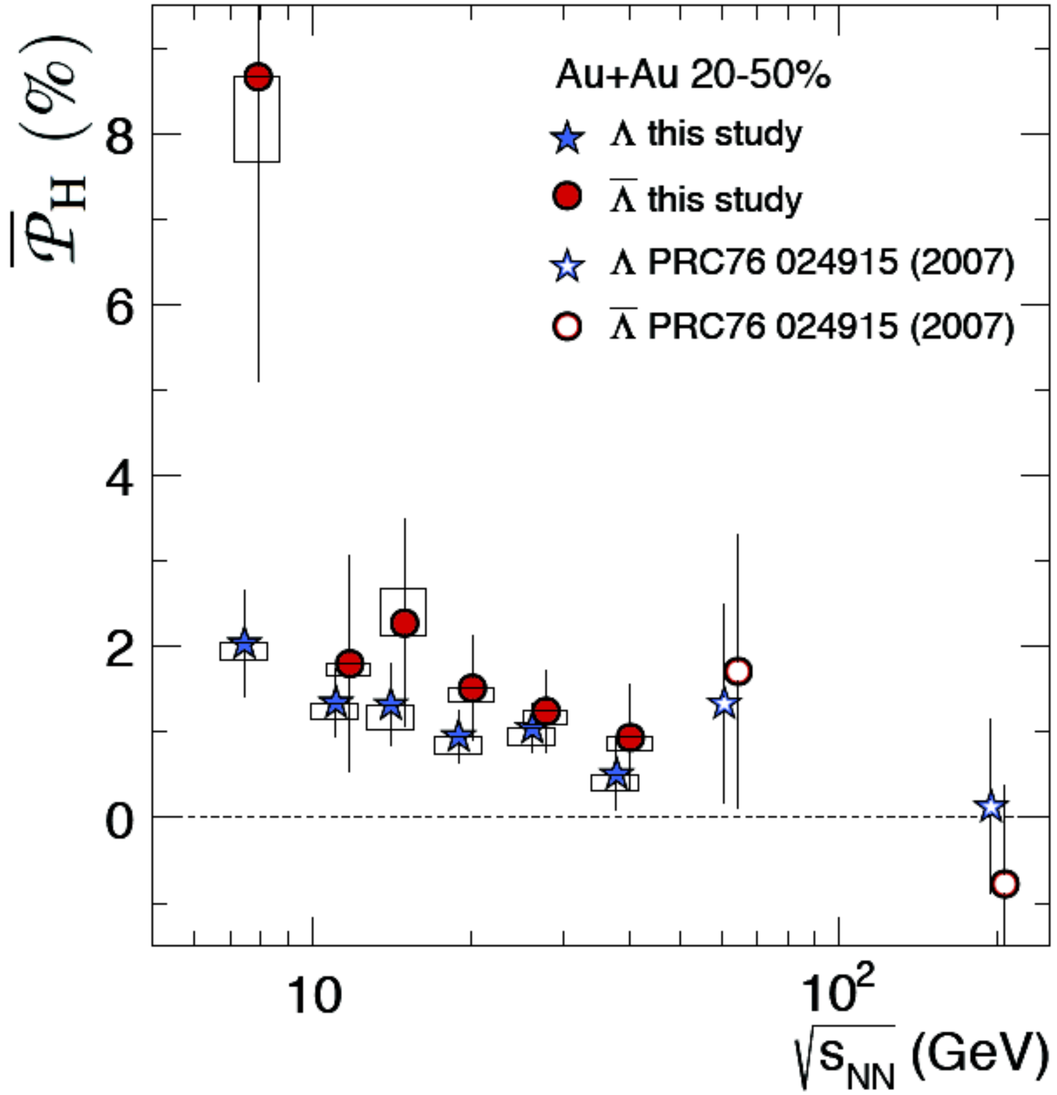
$$f(x,p)_{rs} = \frac{1}{2m}\bar{u}_r(p)\Big(\exp[\beta\cdot p - \xi]\exp[\varpi^{\mu\nu}\Sigma_{\mu\nu}] + I\Big)^{-1}u_s(p)$$

And similar for anti-particles

Only recently this formula as been proved a correct up to linear order (A.Palermo PhD thesis)

STAR measurement

STAR Collaboration, Global Lambda hyperon polarization in nuclear collisions, Nature 548 62-65, 2017



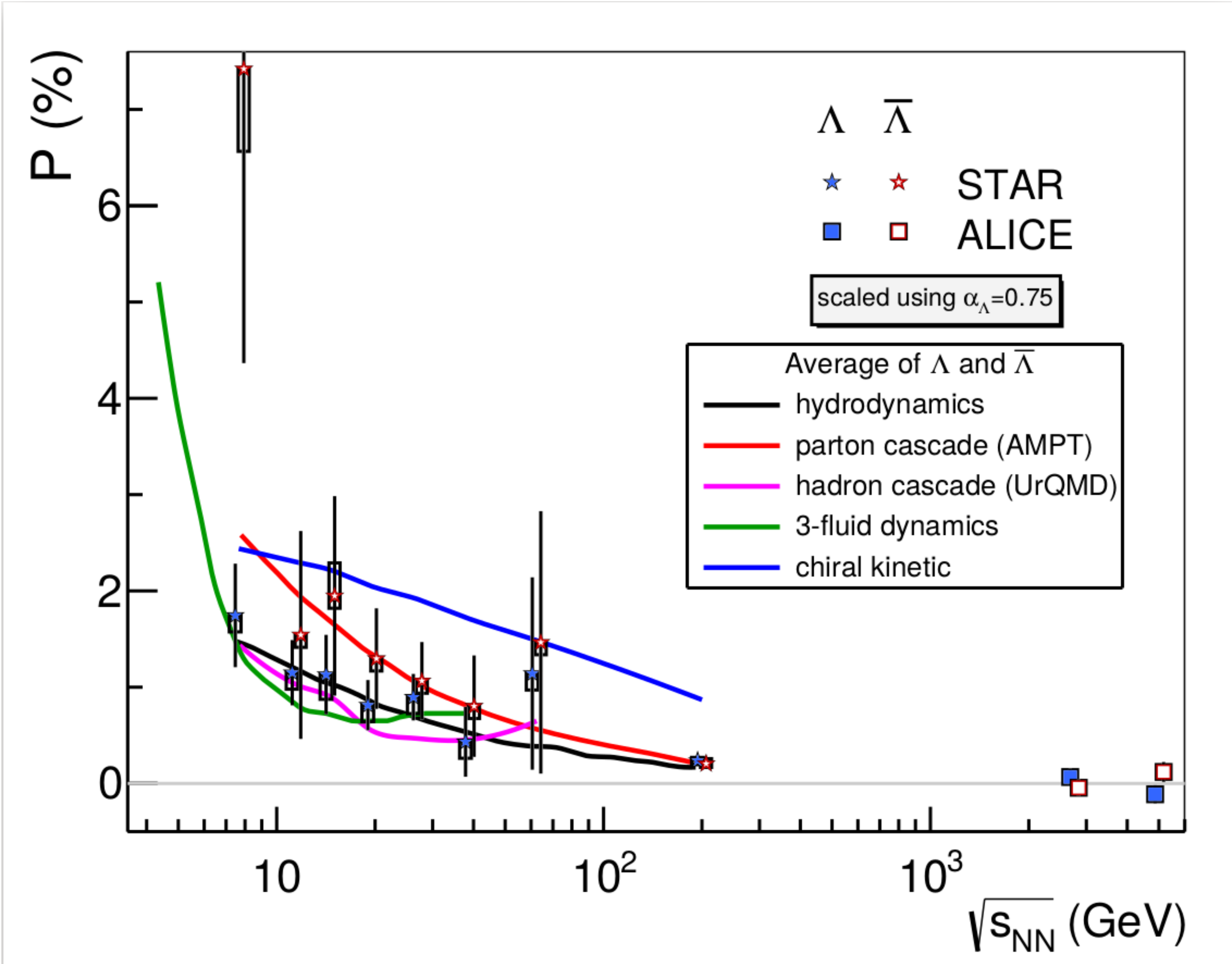
Particle and antiparticle have the same polarization sign.

Not driven by a EM field

Definitely favours the thermodynamic (equipartition) interpretation

Comparison with the data

Becattini, Lisa, Polarization and vorticity in the QGP, Ann. Rev. Part, Nucl. Sc. 70, 395 (2020)

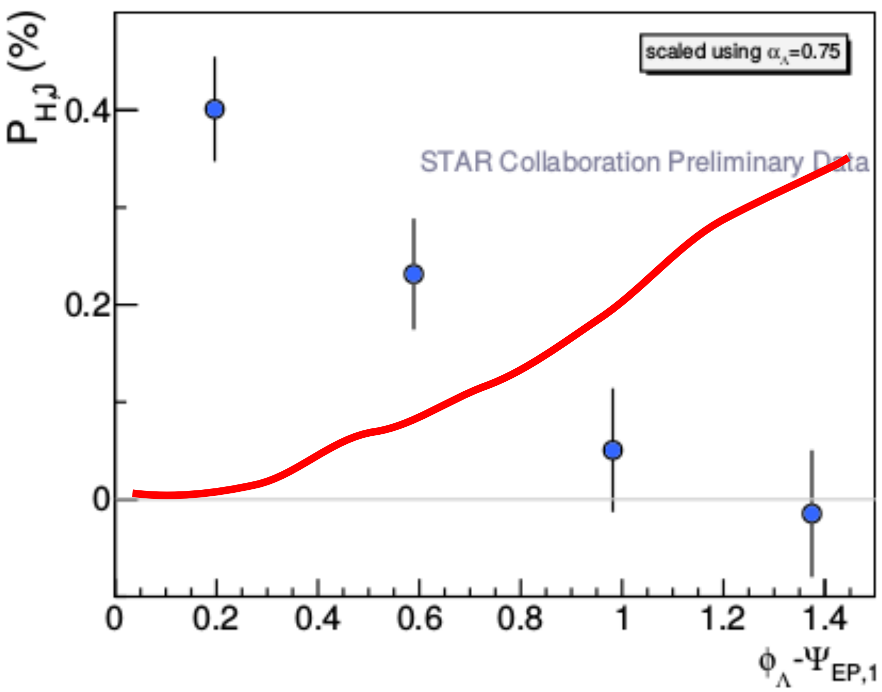


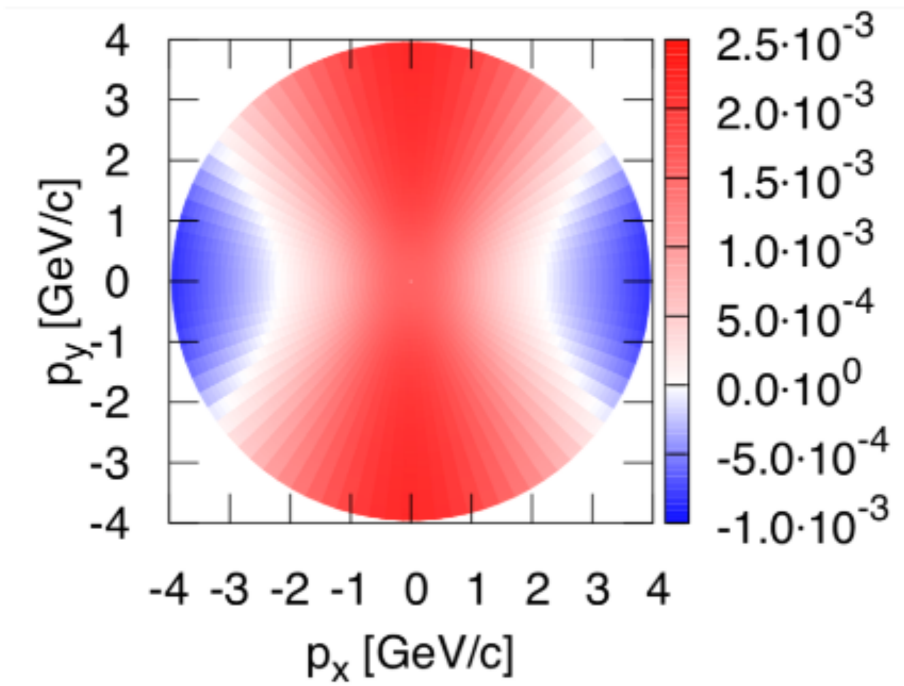
$$S^\mu(p) = \frac{1}{8m}\epsilon^{\mu\nu\rho\sigma}p_\sigma \frac{\int_\Sigma \mathrm{d}\Sigma_\tau p^\tau n_F(1-n_F)\partial_\nu\beta_\rho}{\int_\Sigma \mathrm{d}\Sigma_\tau p^\tau \; n_F}$$

Different models of the collision, same formula for polarization

However

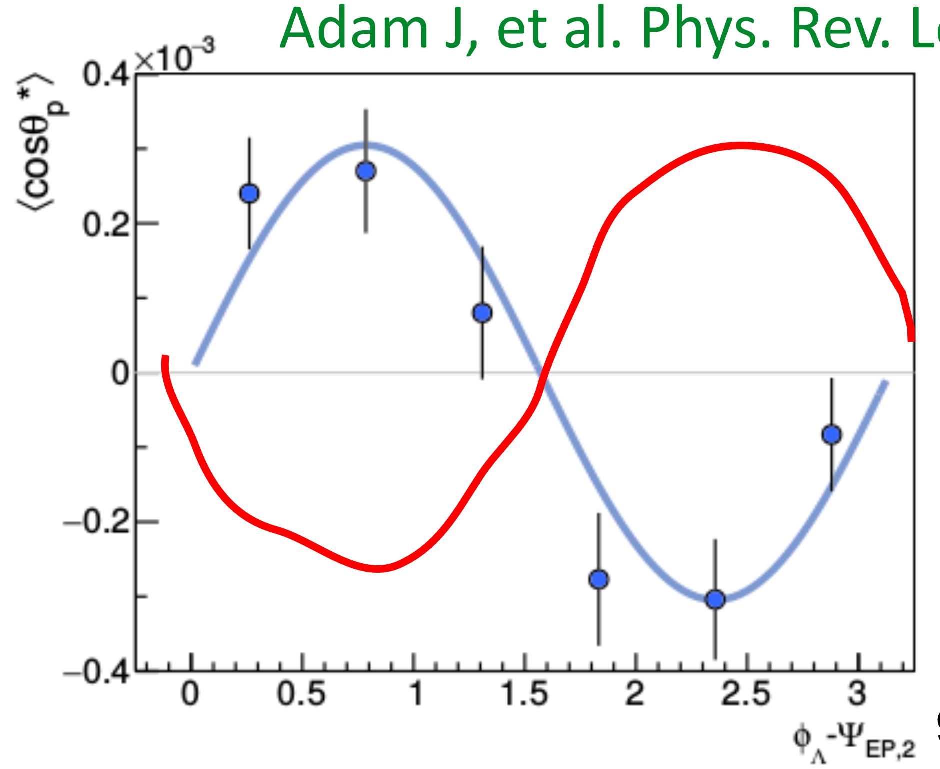
The dependence on the momentum (azimuthal angle) is the kind of the opposite !

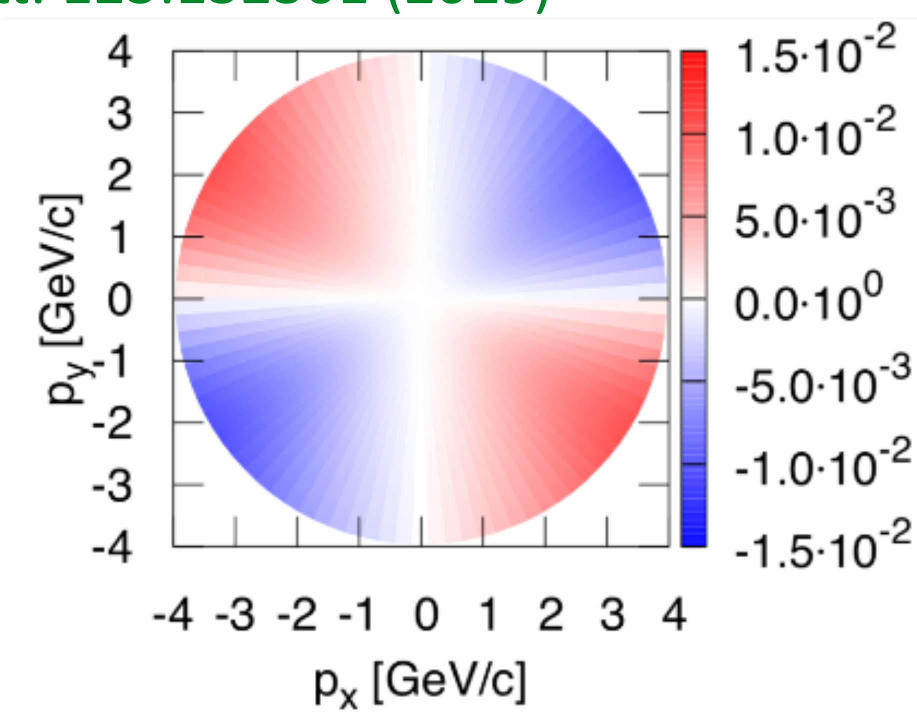




Niida T. Nucl. Phys. A982:511 (2019)

Adam J, et al. Phys. Rev. Lett. 123:132301 (2019)





Shear-Polarization

F. B., M. Buzzegoli, A. Palermo, Phys. Lett. B 820 (2021) 136519

The lambda get polarized also due to a symmetric gradient of the four-velocity too

$$S^\mu_{\rm ILE}(p) = \quad ($$

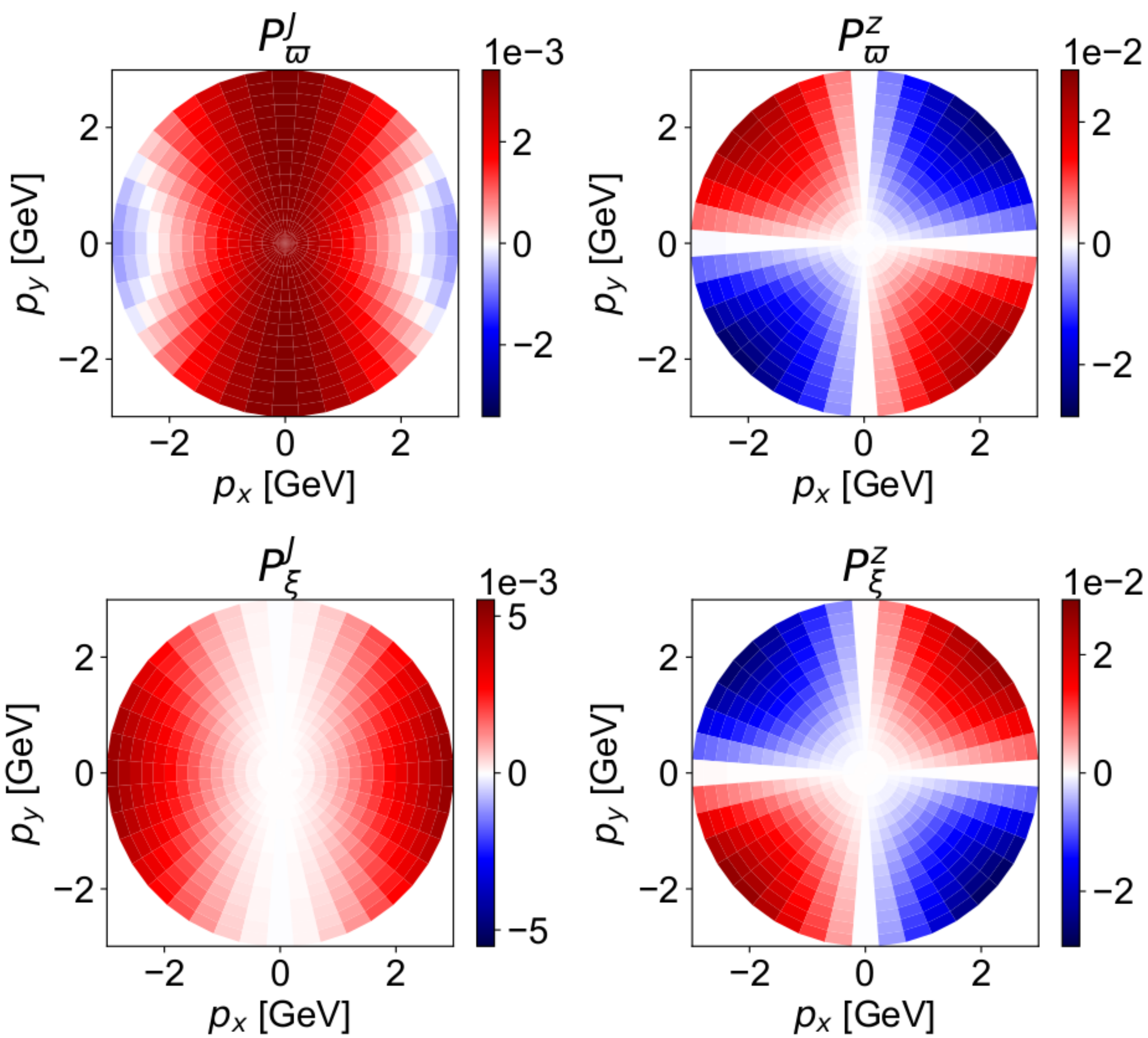
$$- \epsilon^{\mu\rho\sigma\tau} p_\tau \frac{\int_\Sigma {\rm d}\Sigma \cdot p \, n_F (1 - n_F) \left[\omega_{\rho\sigma} + 2\, \hat{t}_\rho \frac{p^\lambda}{\varepsilon} \Xi_{\lambda\sigma} \right]}{8 m T_{\rm dec} \int_\Sigma {\rm d}\Sigma \cdot p \, n_F}$$

$$\Xi_{\rho\sigma} = \frac{1}{2} \left(\partial_\sigma u_\rho + \partial_\rho u_\sigma \right)$$

The same effect, but different formula was proposed by

S. Liu, Y. Yin, JHEP 07 (2021) 188

Numerical Result



Thermal-vorticity

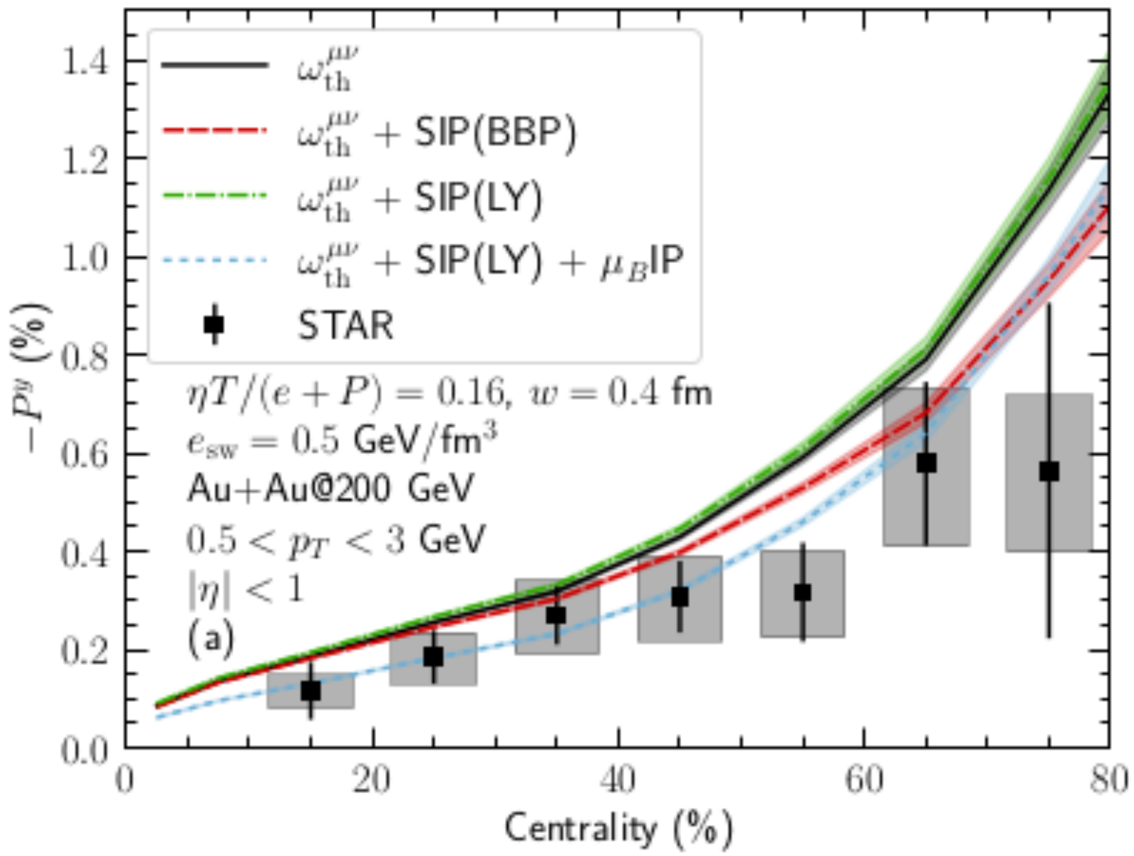
Thermal-shear

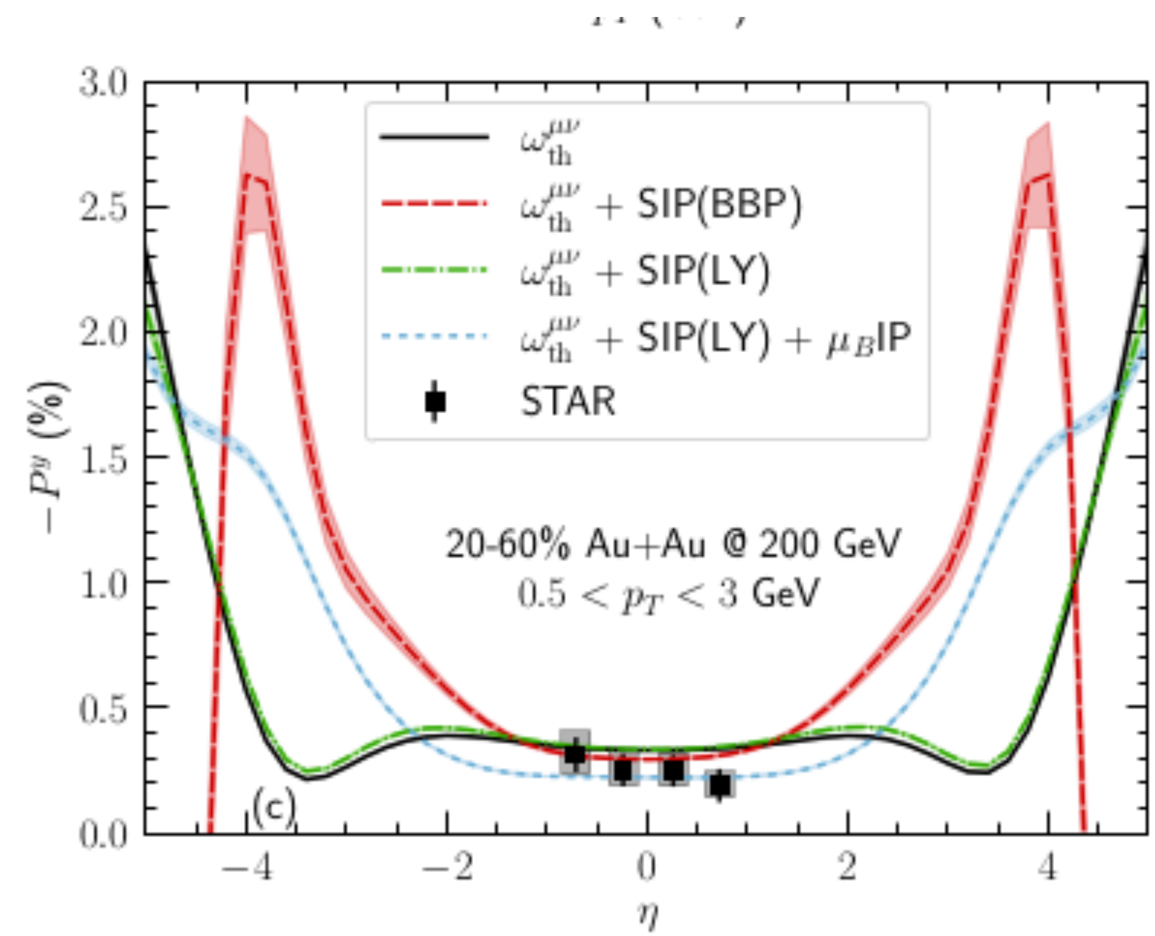
Based on the hydrodynamic code VHLLE (author I. Karpenko)
Similar output with ECHO-QGP (main author G. Inghirami).

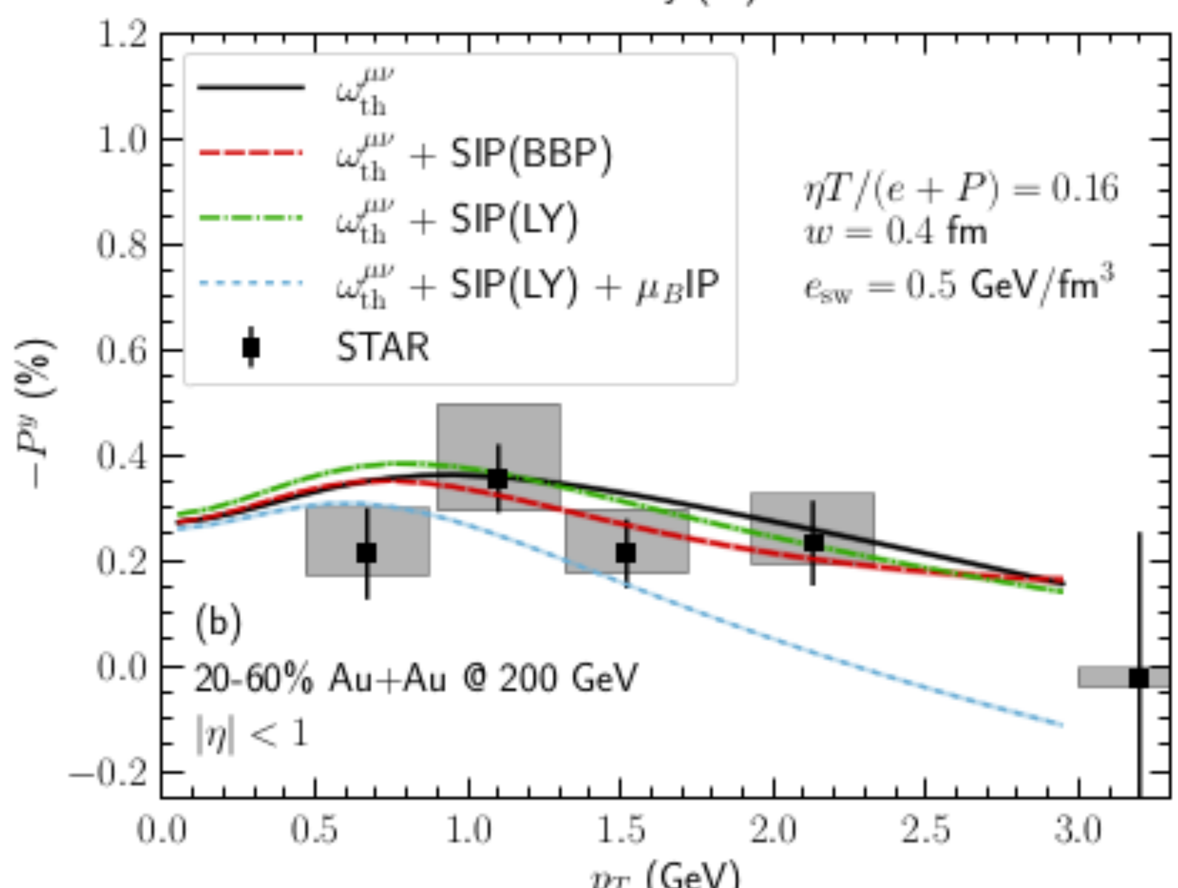
The opposite pattern as the previous calculations but still no precise comparison

Recent simulations

S. Alzhrani, S. Ryu, C. Shen, Phys.Rev.C 106 (2022) 1, 014905,







Different predictions of VHLLE and ECHO-QGP (see previous slides)

Higly sensitive to the initial conditions

Thanks!!