Local polarization and local spin alignment

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Asian Triangle Heavy-Ion Conference @ Hefei 2018

outline

- Quick view on global polarization

- Circular vorticity and local Λ polarization

  Xia, H. Li, Z. Tang, Q. Wang, Phys. Rev., C98, 024905 (2018)

- Local φ meson spin alignment

  Xia, X.-G. Huang, 1811.xxxxx (new)

global polarization & spin alignment

Phys. Rev. Lett., 94, 102301 (2005)

Globally Polarized Quark-Gluon Plasma in Noncentral $A + A$ Collisions

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(Received 25 October 2004; published 14 March 2005)

Produced partons have a large local relative orbital angular momentum along the direction opposite to the reaction plane in the early stage of noncentral heavy-ion collisions. Parton scattering is shown to polarize quarks along the same direction due to spin-orbital coupling. Such global quark polarization will lead to many observable consequences, such as left-right asymmetry of hadron spectra and global transverse polarization of thermal photons, dileptons, and hadrons. Hadrons from the decay of polarized resonances will have an azimuthal asymmetry similar to the elliptic flow. Global hyperon polarization is studied within different hadronization scenarios and can be easily tested.

Phys. Lett., B629, 20 (2005)

Spin alignment of vector mesons in non-central $A + A$ collisions

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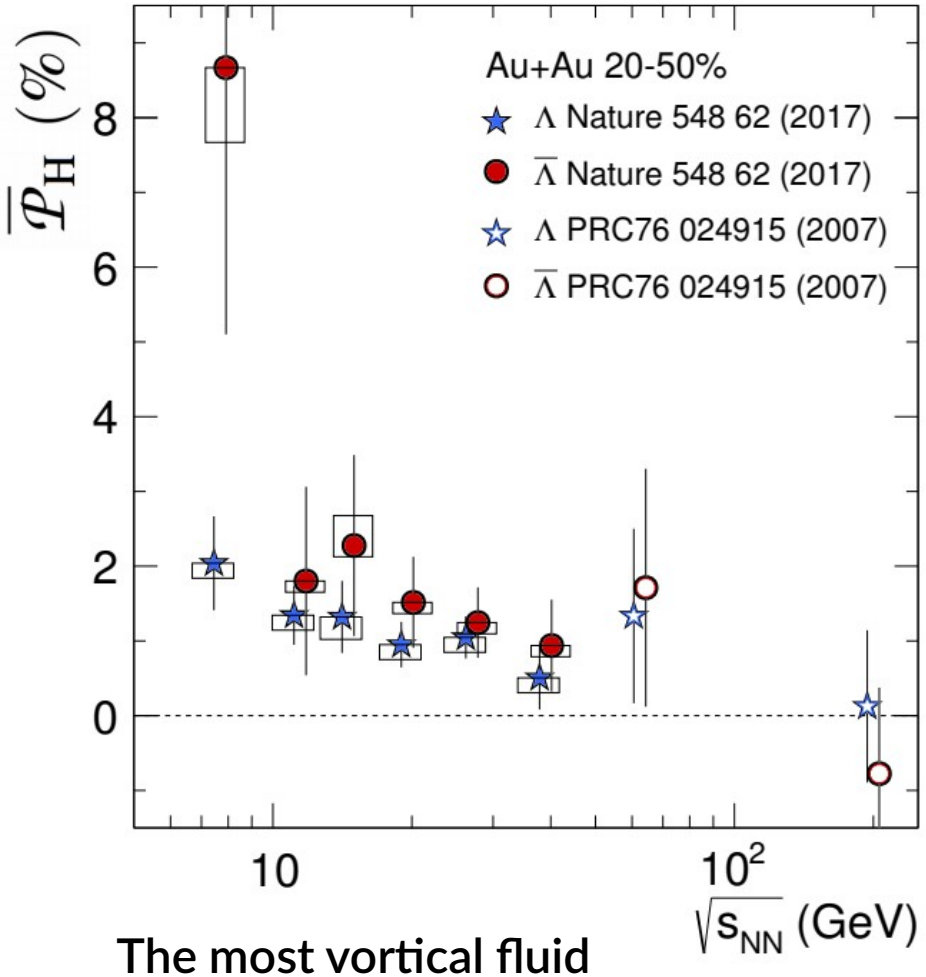
Editor: J.-P. Blaizot

STAR nature 2017

STAR Nature 548 62 (2017)

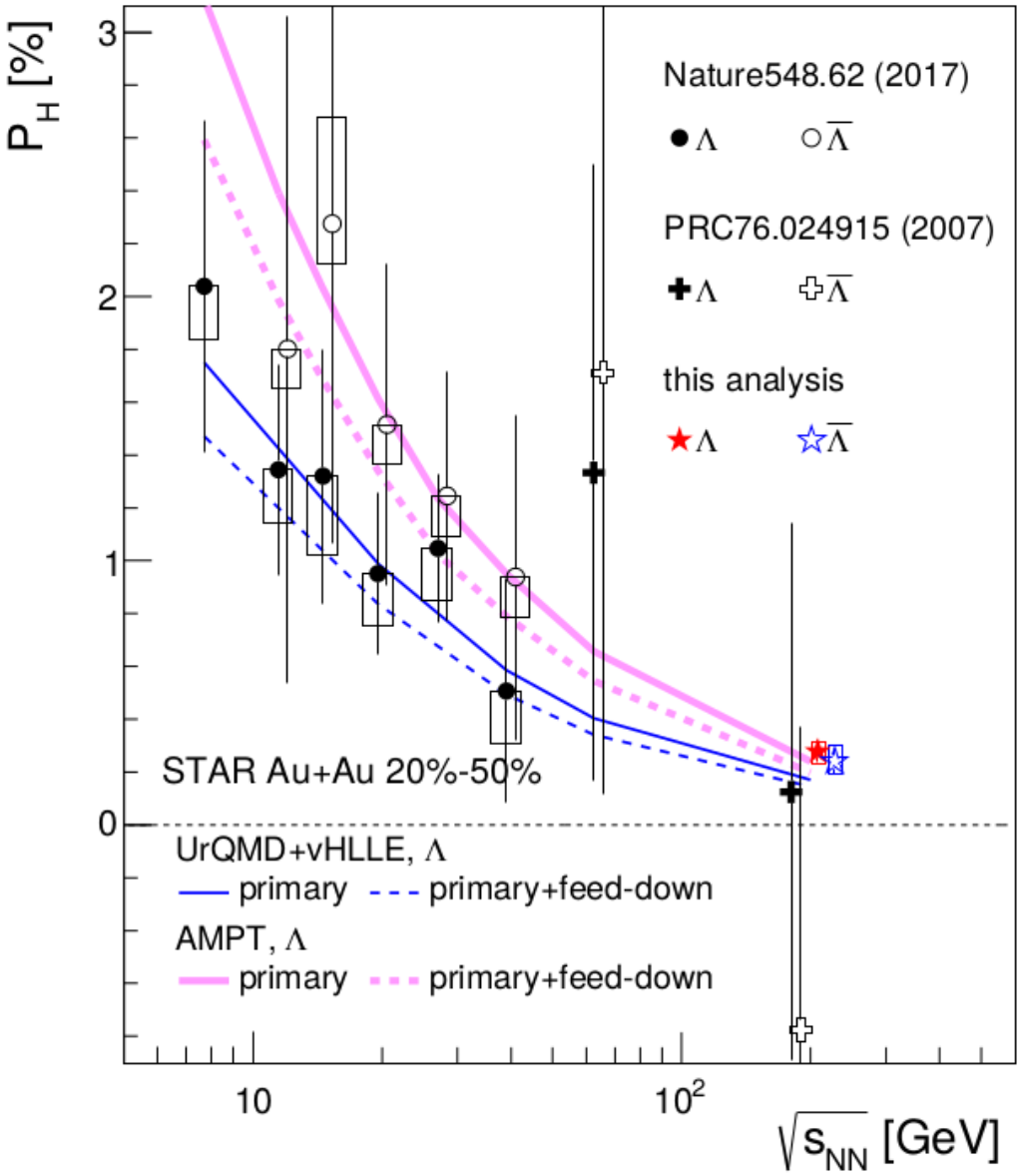


The most vortical fluid

$$\omega \sim 10^{21} \mathrm{s}^{-1}$$

energy dependence

STAR PRC 98, 014910 (2018)



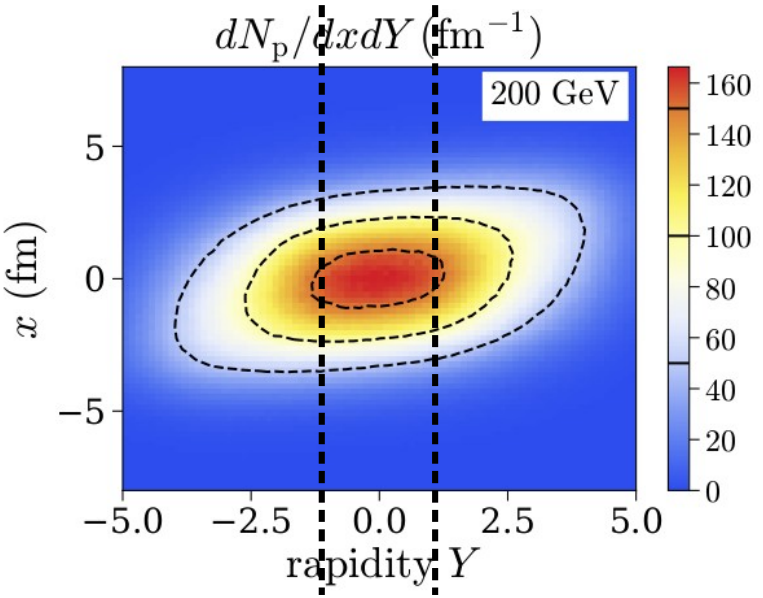
- Blue curve: hydro

Karpenko, Becattini, EPJC (2016)

- Pink curve: AMPT

Li, Pang, Wang, Xia, PRC (2017)

Fireball in central rapidity:
less ***tilted*** at higher energy.



Beyond global polarization

- Collective longitudinal polarization:

Phys. Rev. Lett., 120, 012302 (2018)

Collective Longitudinal Polarization in Relativistic Heavy-Ion Collisions at Very High Energy

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Università di Firenze and INFN Sezione di Firenze, Via G. Sansone 1, I-50019 Sesto Fiorentino (Firenze), Italy

(Received 28 July 2017; published 5 January 2018)

- Local transverse polarization:

Phys. Rev., C98, 024905 (2018)

Probing vorticity structure in heavy-ion collisions by local Λ polarization

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(Received 4 March 2018; published 8 August 2018)

circular vorticity

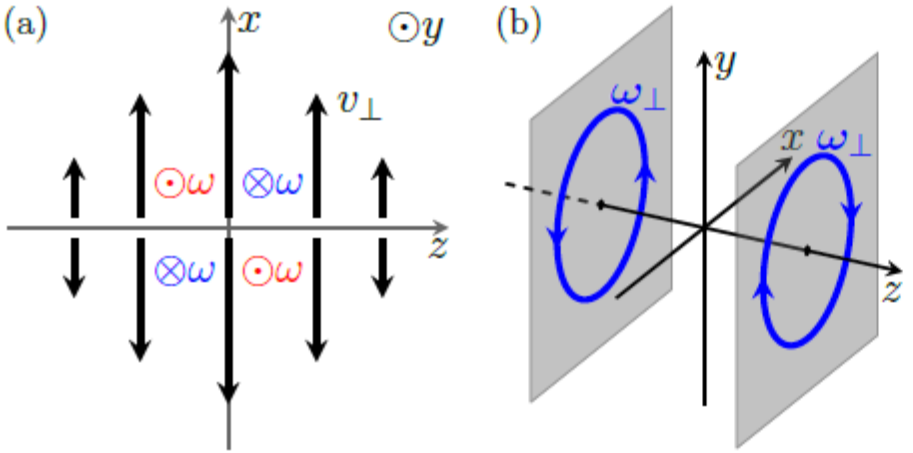


FIG. 2. Left: Schematic illustration of the quadrupole pattern of ω_y generated from $\partial_z v_\perp$ in the reaction plane, where the vorticity is along the $-y$ direction ($\otimes$) in the $xz > 0$ quadrants and the y direction ($\odot$) in the $xz < 0$ quadrants. Right: A three dimensional view of the circular structure of the transverse vorticity $\omega_\perp = (\omega_x, \omega_y)$.

Xia, Li, Tang, Wang, PRC (2018)

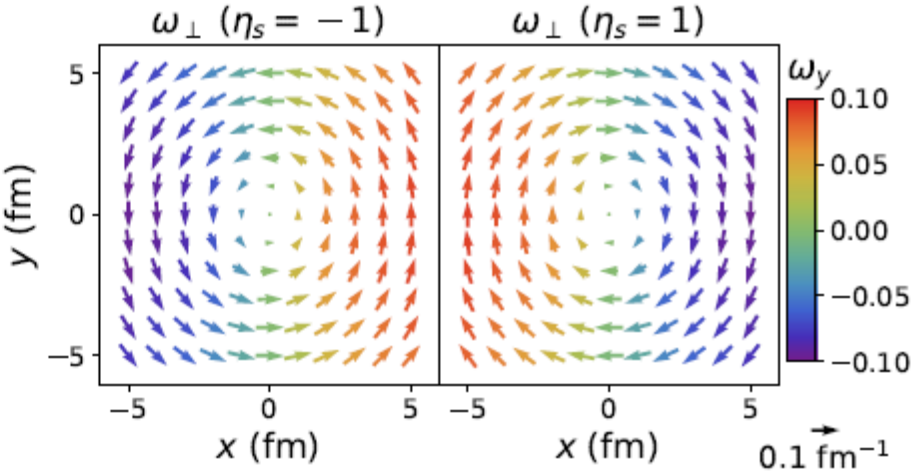
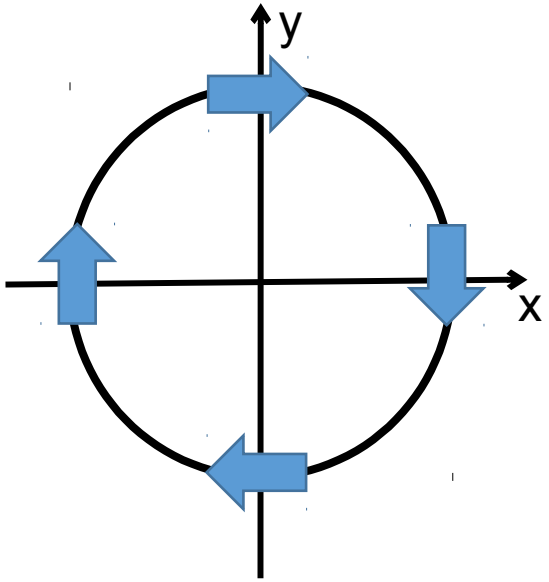
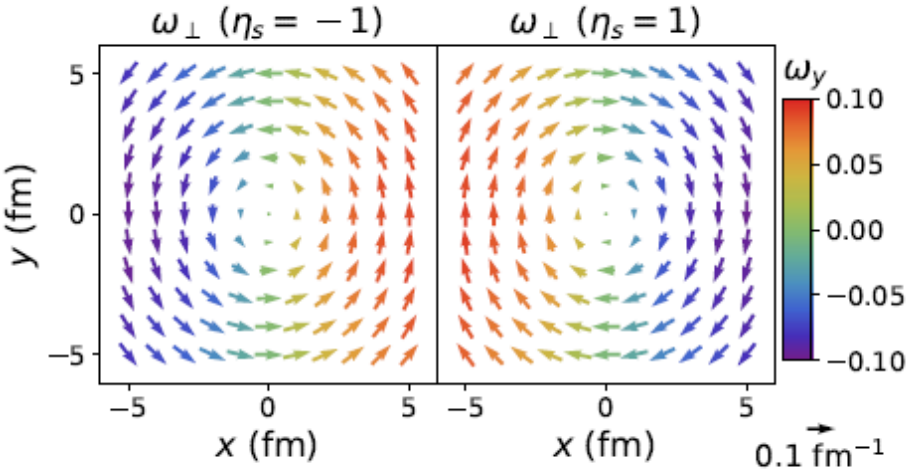


FIG. 3. The distribution of the transverse vorticity $\omega_\perp = (\omega_x, \omega_y)$ in the transverse plane at longitudinal positions $\eta_s = -1$ (left) and $\eta_s = 1$ (right) at time $t = 5$ fm/c in 20-30% central Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV. The color represents the value of the component ω_y.

circular Λ polarization



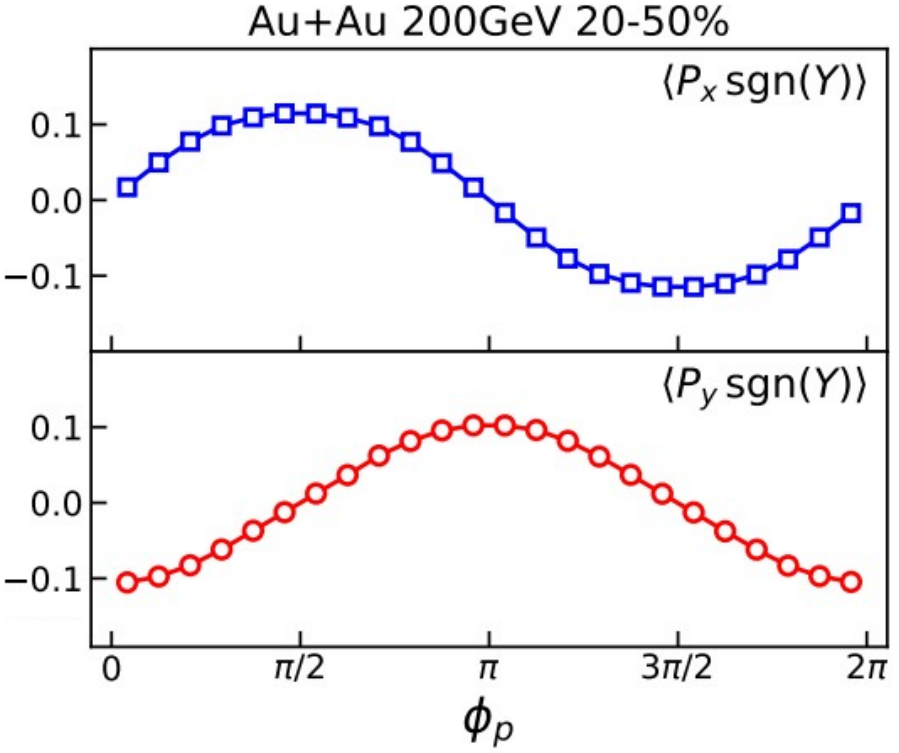
Xia, Li, Tang, Wang, PRC (2018)



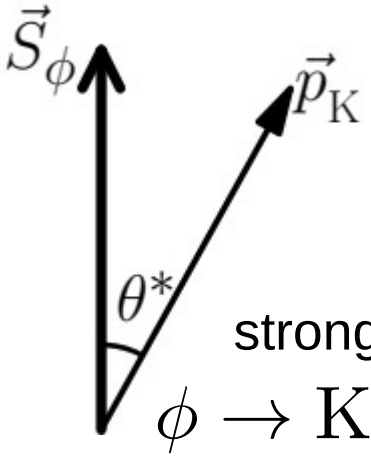
$$P_x = +f_{\rm odd}(\eta)\sin(\phi) + \ldots$$
$$P_y = -f_{\rm odd}(\eta)\cos(\phi) + \ldots$$

$$\langle P_{x,y}\mathrm{sgn}(\eta)\rangle \sim \mathcal{O}(0.1)$$

$\langle P_y \cos(\phi)\rangle$ see Xu-Guang's talk



φ meson spin alignment

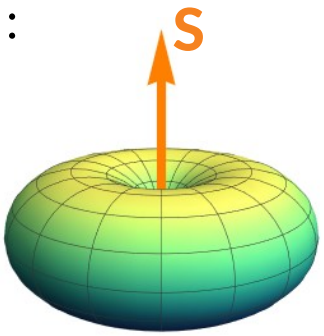


strong decay

$$\phi \to \mathrm{K}^+ + \mathrm{K}^-$$

$$\frac{dN}{d\cos\theta^*} = \frac{3}{4}\left[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*\right]$$

$\rho_{00} < 1/3$:



✖ $P_y = \rho_{11} - \rho_{-1-1}$

☺ $\rho_{00} = 1 - (\rho_{11} + \rho_{-1-1})$

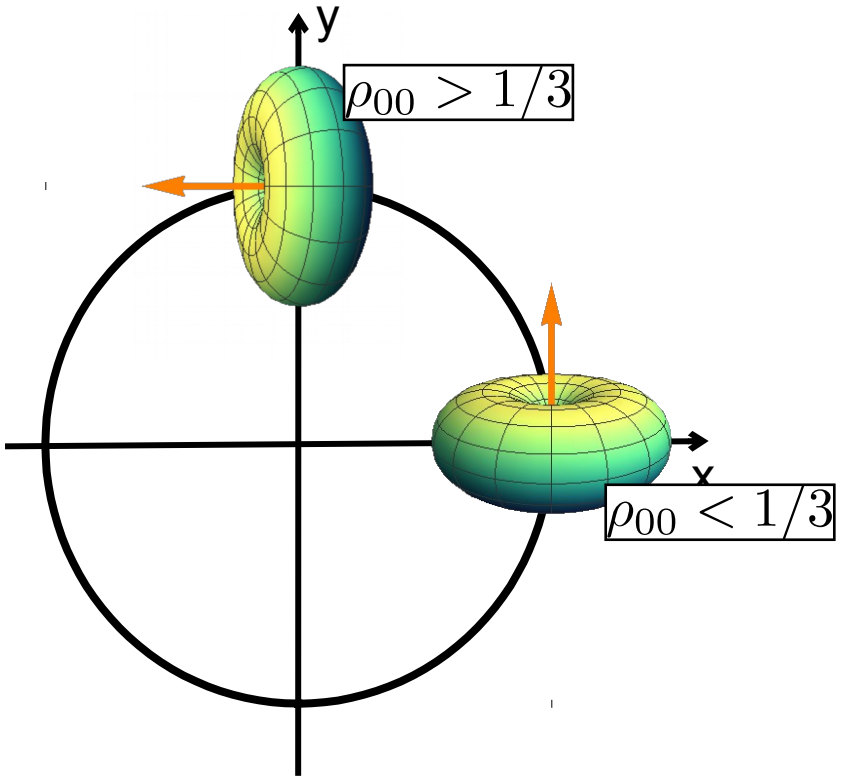
$$\rho_\phi = \begin{pmatrix} \rho_{11} & \cdots & \ddots \\ \vdots & \rho_{00} & \vdots \\ \ddots & \cdots & \rho_{-1-1} \end{pmatrix}$$

Liang, Wang, PLB (2005)

$$\rho_q \otimes \rho_{\bar{q}} \Rightarrow \rho_{00} = \frac{1 - P_q P_{\bar{q}}}{3 + P_q P_{\bar{q}}}$$

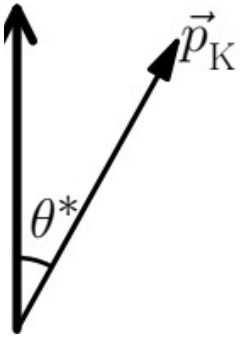
local φ spin alignment

XLX, X.-G. Huang, 1811.xxxxx



How to measure?

a fixed direction (y-axis)



$$\frac{dN}{d\cos\theta^*} = \frac{3}{4}\left[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*\right]$$

θ^*: angle between Kaon and y-axis

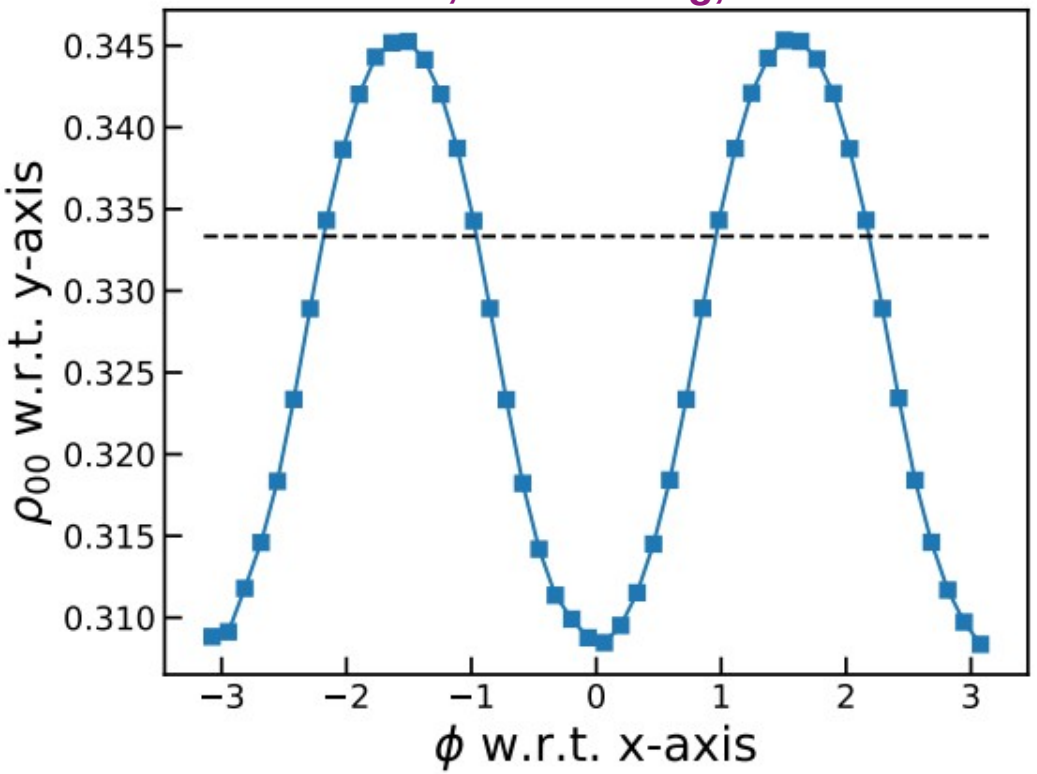
ρ_{00}: function of φ meson direction.

$$\rho_{00} = \frac{1 - P^2\cos(2\phi)}{3 + P^2}$$ (for central HIC)

* The measurement w.r.t. y-axis is comparable to the study on global spin alignment.

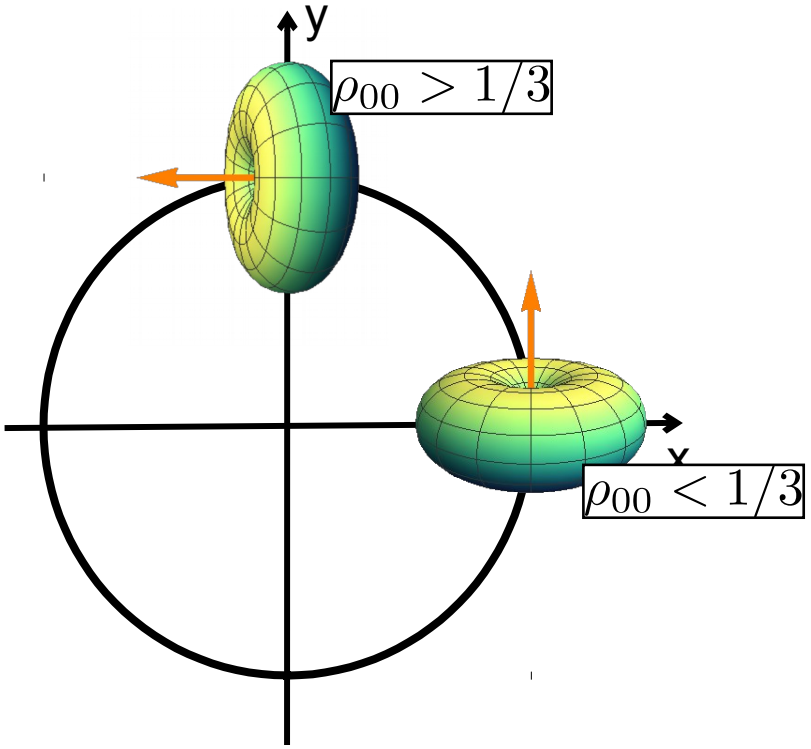
local φ spin alignment

XLX, X.-G. Huang, 1811.xxxxx



(Au+Au 200 GeV, b=0 fm, 1.2<pT<5.4 GeV)

$$\frac{dN}{d\cos\theta^*} = \frac{3}{4}\left[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*\right]$$

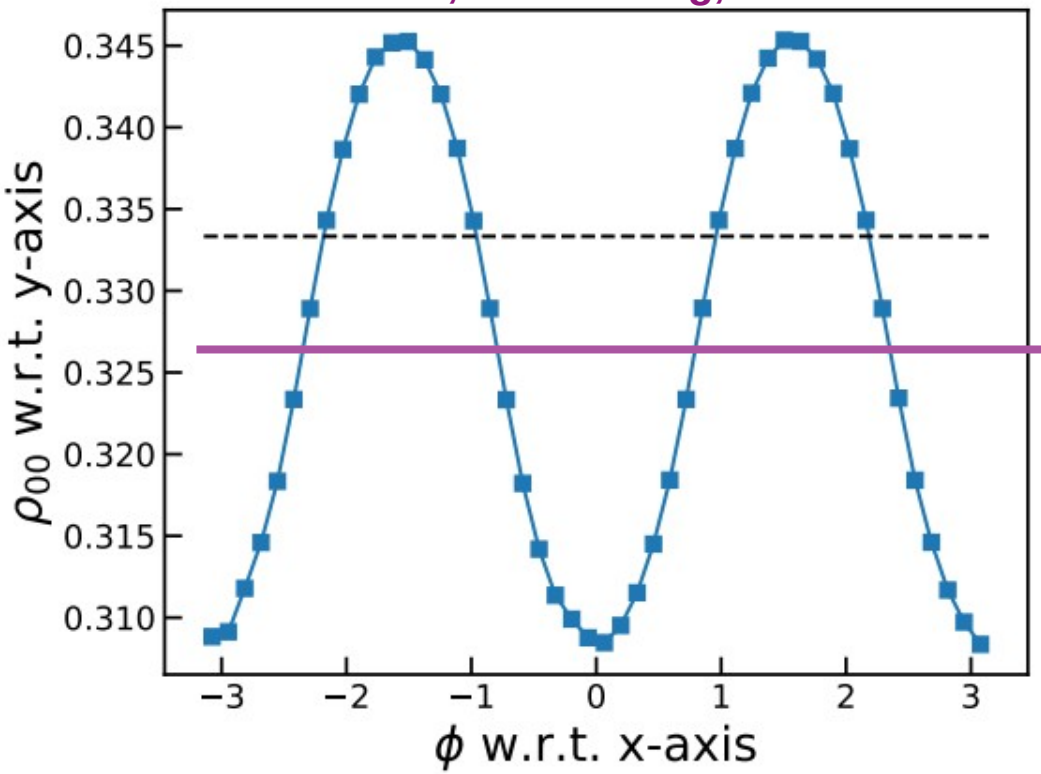


$$\rho_{00} = \frac{1 - P^2\cos(2\phi)}{3 + P^2} \simeq \frac{1}{3} - \frac{P^2}{9} - \frac{P^2}{3}\cos(2\phi)$$

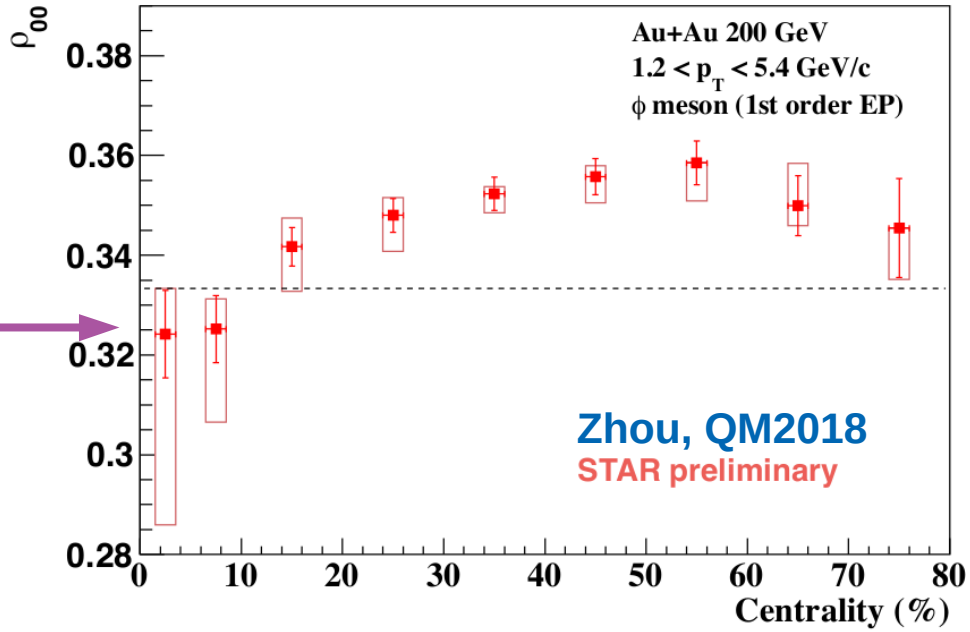
features:
- **average less than 1/3**
- **oscillation** = 3 * **deviation**

local φ spin alignment

XLX, X.-G. Huang, 1811.xxxxx



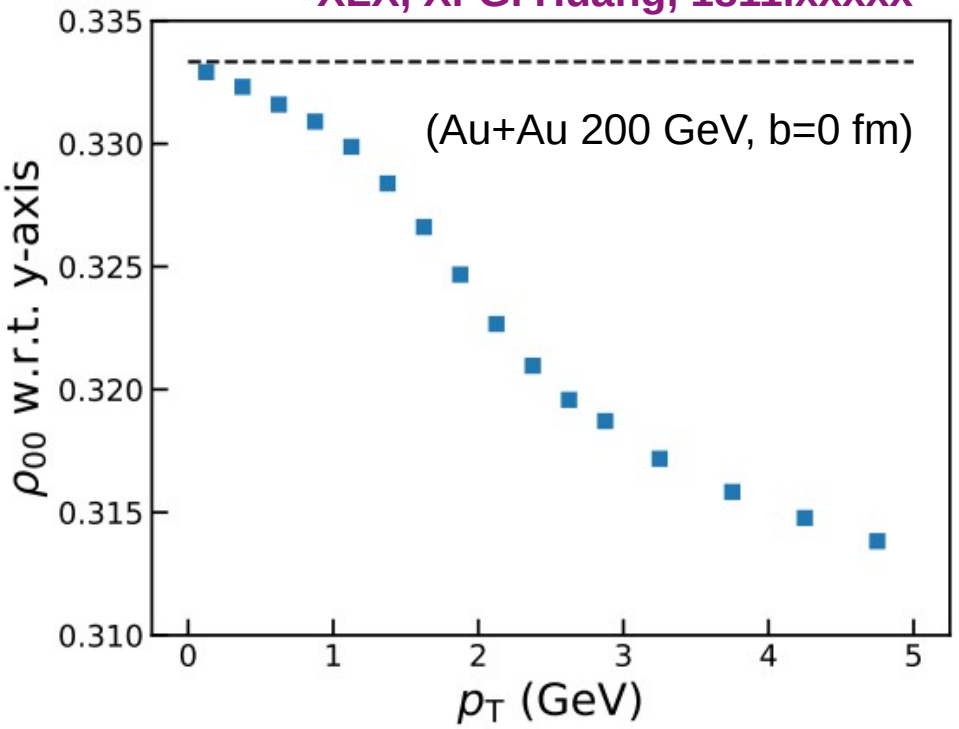
(Au+Au 200 GeV, b=0 fm, 1.2<pT<5.4 GeV)



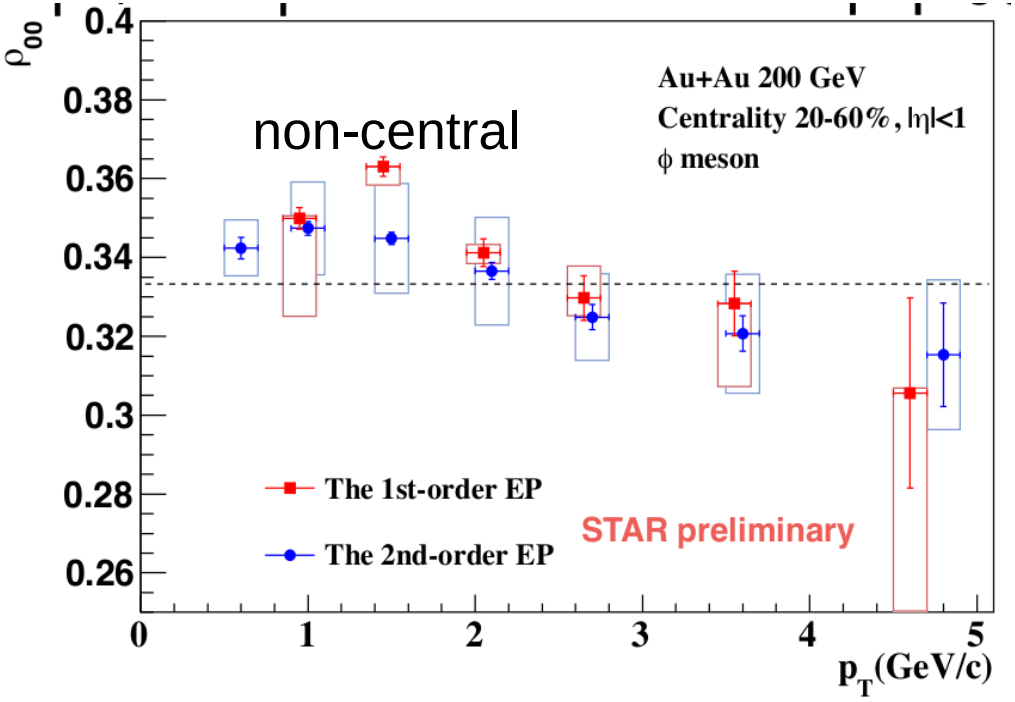
- EP is not needed in central case.
- Remove uncertainty caused by EP resolution.

pT dependence

XLX, X.-G. Huang, 1811.xxxxx

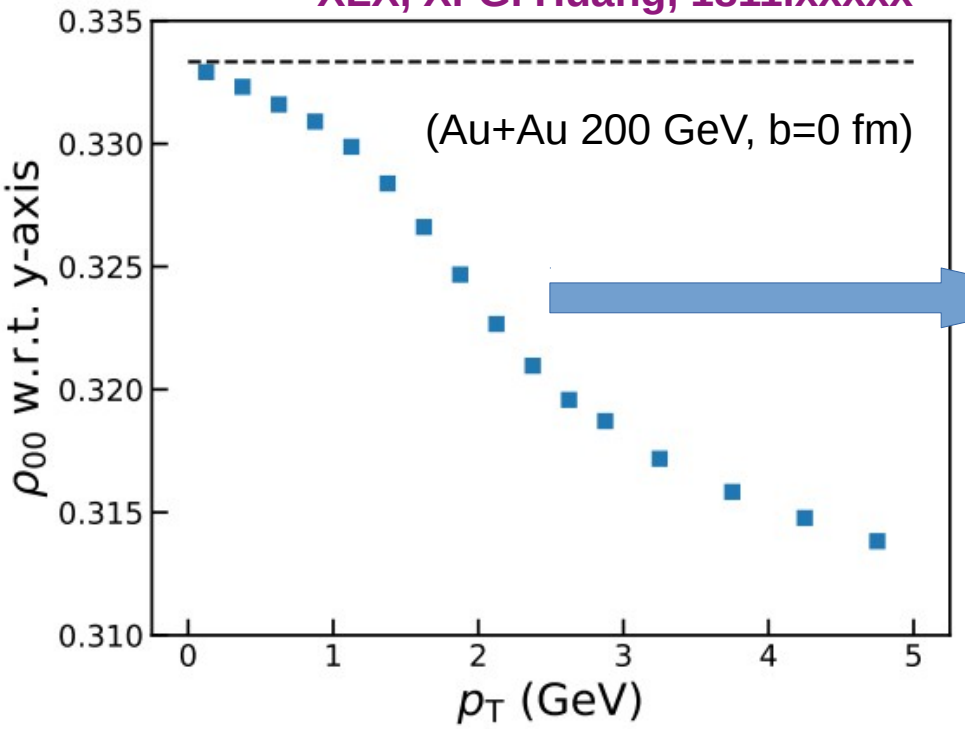


Zhou, QM2018

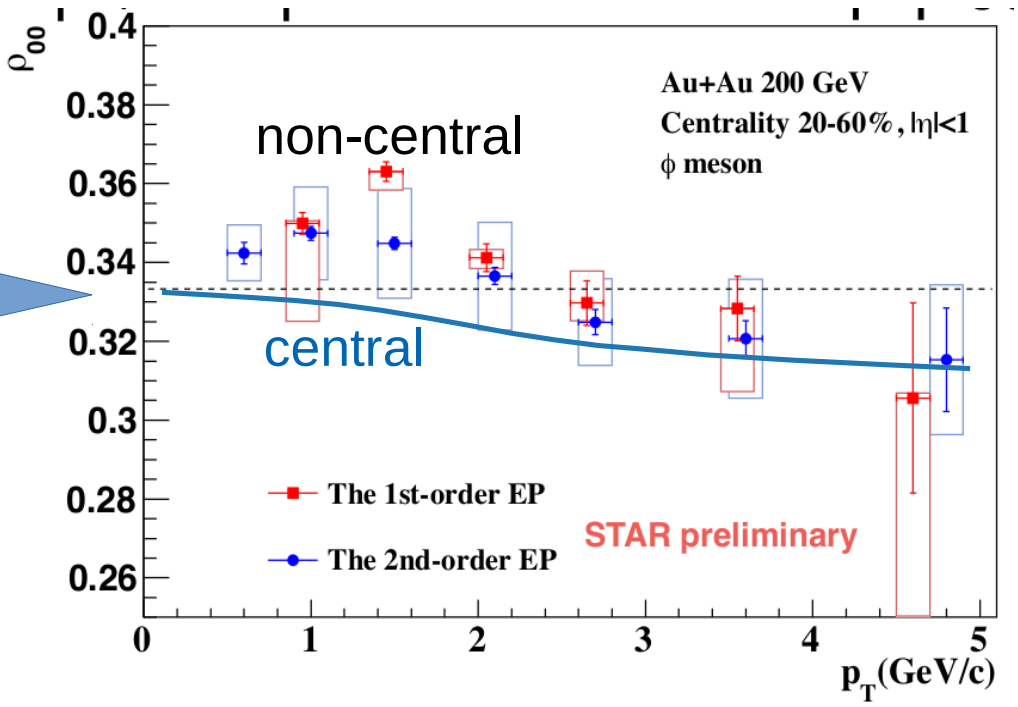


pT dependence

XLX, X.-G. Huang, 1811.xxxxx



Zhou, QM2018



- Baseline for studying additional physics in non-central case.

summary

Local polarization and **local spin alignment** from **circular vorticity**:

- harmonic oscillation.

$$P_x = +f_{\rm odd}(\eta)\sin(\phi) + \dots$$
$$P_y = -f_{\rm odd}(\eta)\cos(\phi) + \dots$$
$$\rho_{00} = \frac{1 - P^2\cos(2\phi)}{3 + P^2}$$

For local spin alignment in central collision:

- average rho00 < 1/3.
- oscillation magnitude = 3 times deviation.
- EP is not needed due to rotation symmetry.
- baseline for additional physics in non-central case.

Thank you!