Measurements of global and local polarization of hyperons in isobar collisions at 200 GeV from STAR

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Supported in part by
U.S. DEPARTMENT OF ENERGY | Office of Science

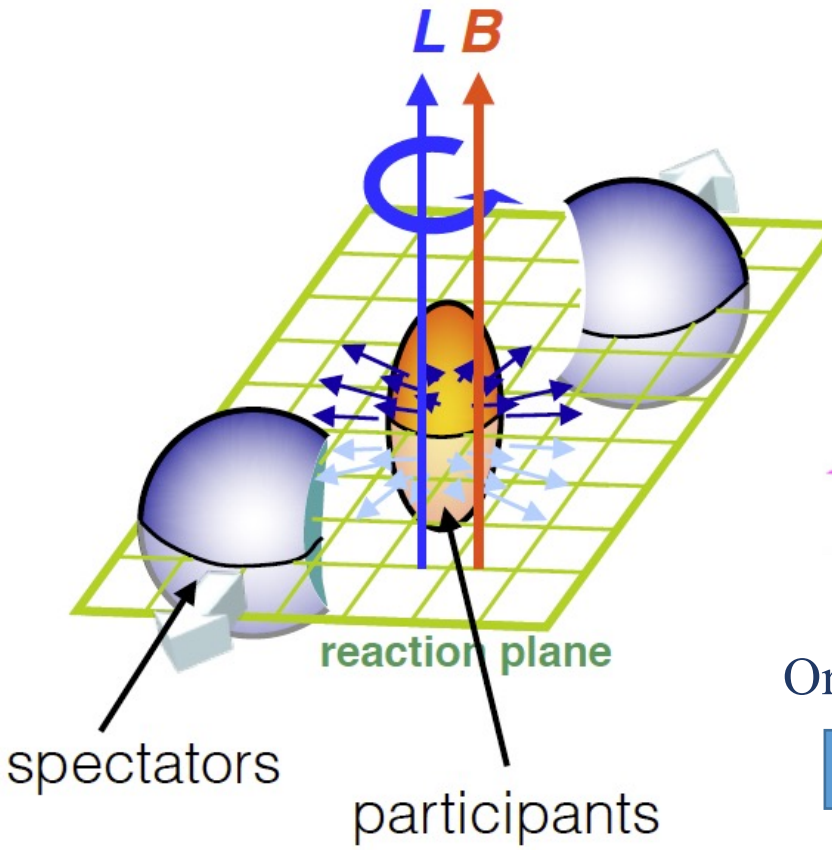
The 7th international Conference on Chirality, Vorticity and Magnetic Field in Heavy Ion Collisions
Beijing, China | July 15 ~ 19th, 2023

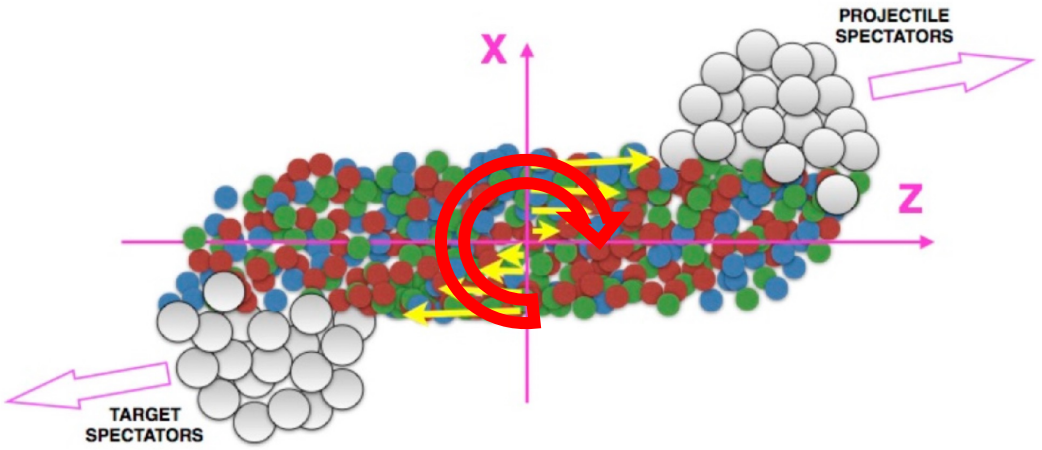
The STAR Collaboration
https://drupal.star.bnl.gov/STAR/presentations

Outline

- Motivation
- Hyperon global polarization
- Hyperon local polarization
- Summary

Global polarization of hyperons in heavy ion collisions



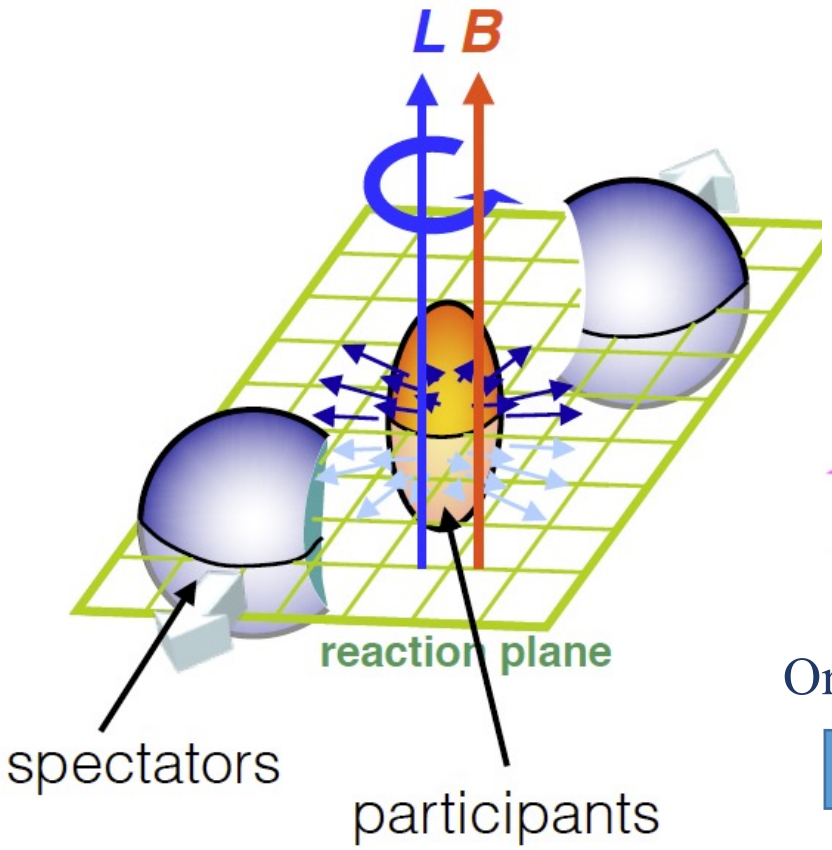


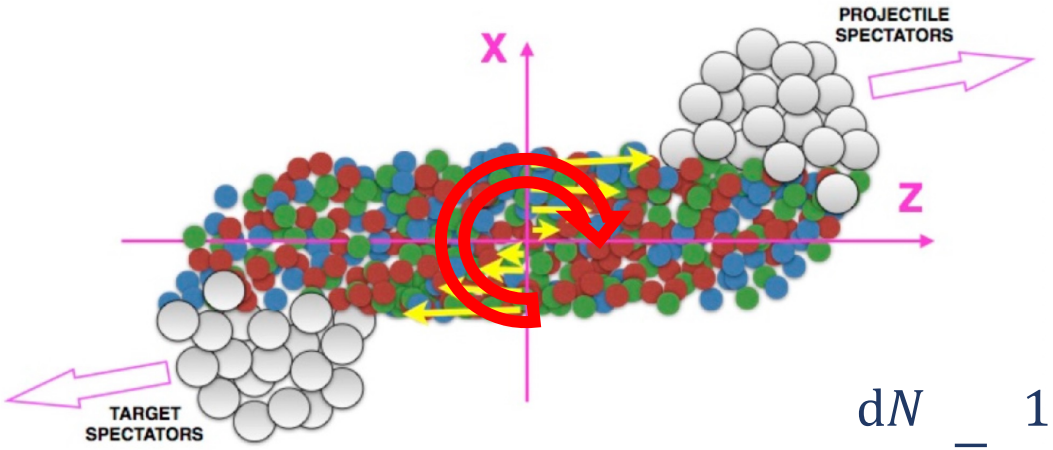
Orbital angular momentum

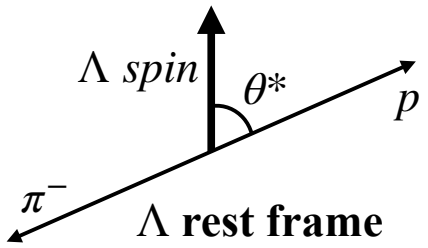
↳ Leads to global polarization

Z.-T. Liang and X.-N. Wang,
PRL94, 102301 (2005)

Global polarization of hyperons in heavy ion collisions







Orbital angular momentum

↳ Leads to global polarization

Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)

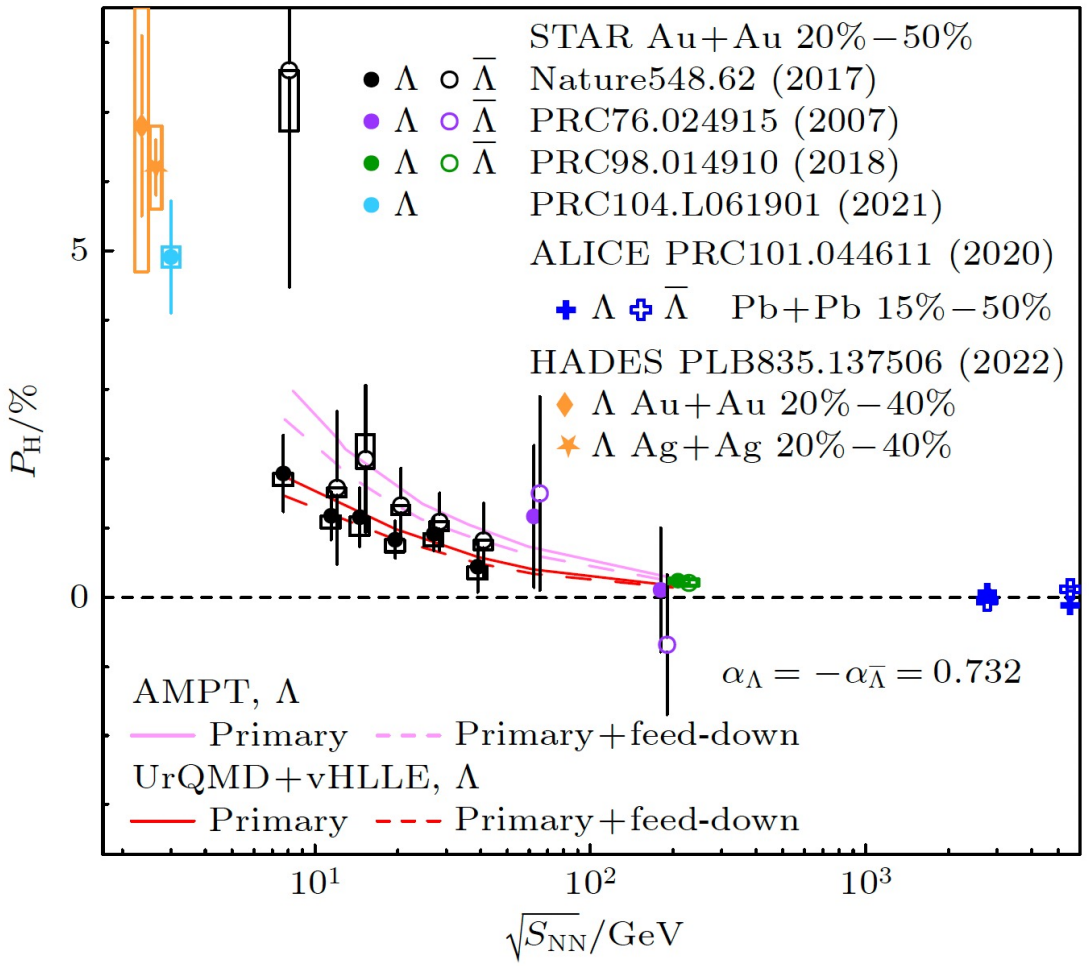
$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}(1 + \alpha_H P_H cos\theta^*)$$

$$P_\Lambda = \frac{8}{\pi \alpha_\Lambda} \frac{1}{A_0} \frac{\langle \sin(\Psi_1 - \phi_p^*) \rangle}{Res(\Psi_1)}$$

$\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.732 \pm 0.014$
A_0: *Acceptance correction factor*
Ψ_1: *First − order event plane angle*
$Res(\Psi_1)$: Event plane resolution

Global polarization of hyperons in heavy ion collisions

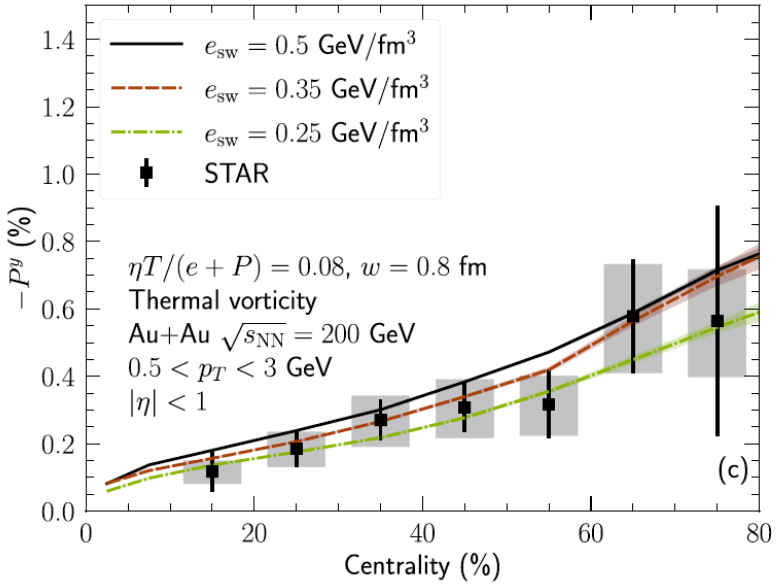
Acta Phys. Sin. Vol. 72, No. 7(2023) 072401

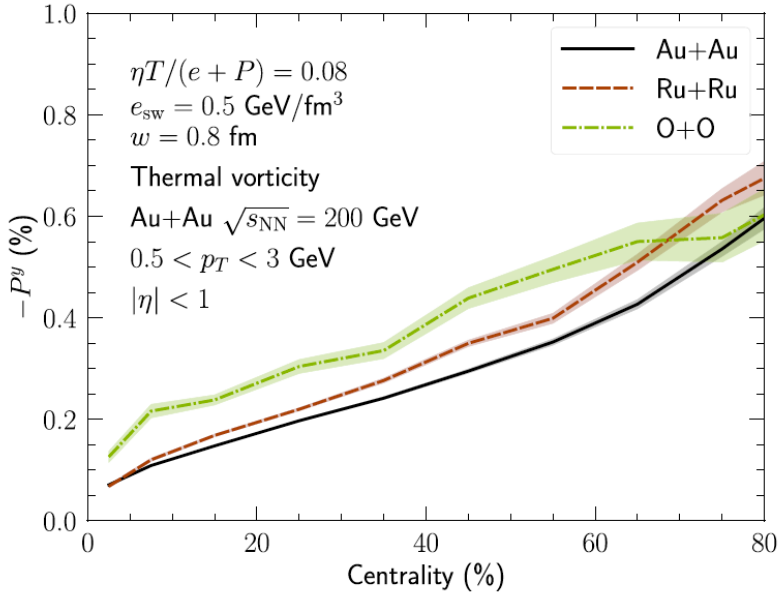


- Significant global polarization of Λ and $\bar{\Lambda}$ observed at RHIC energies and HADES.

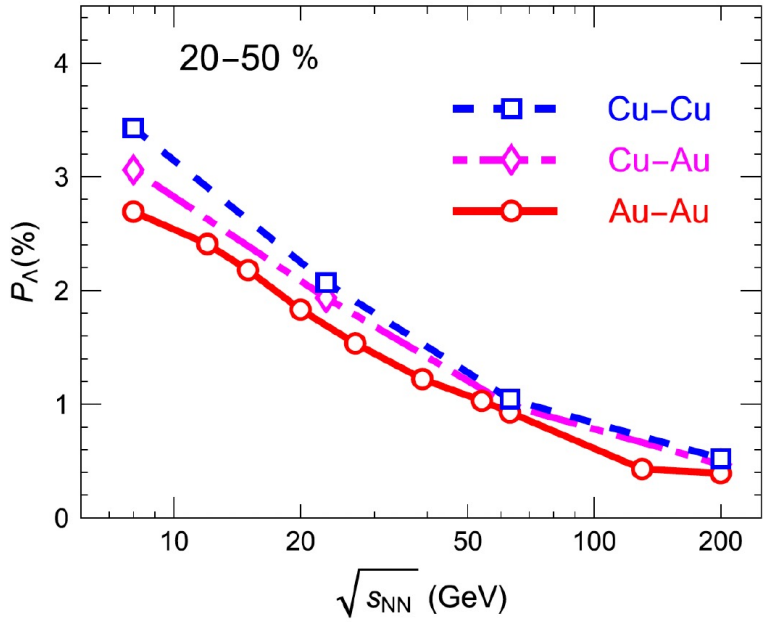
Global polarization system size dependence

S. Alzhrani et al., Phys. Rev. C 106.014905





S.Z, Shi, K.L. Li, J.F. Liao, PLB 788 (2019) 409–413

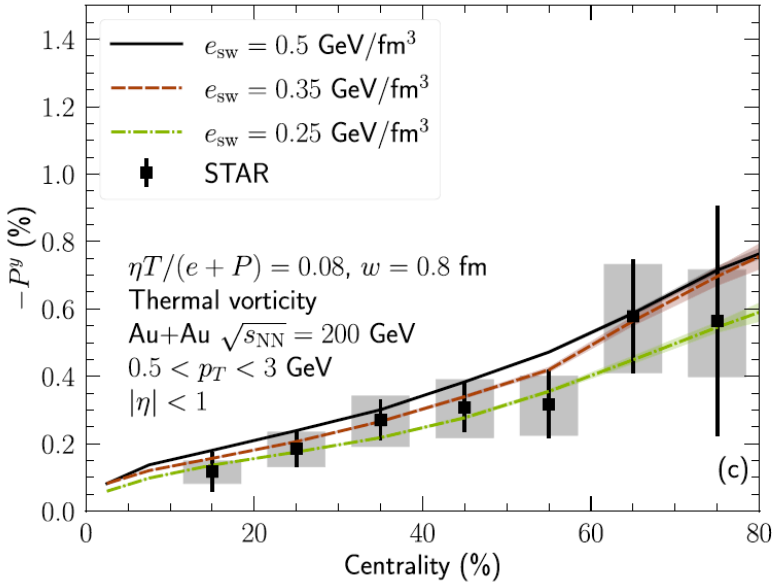


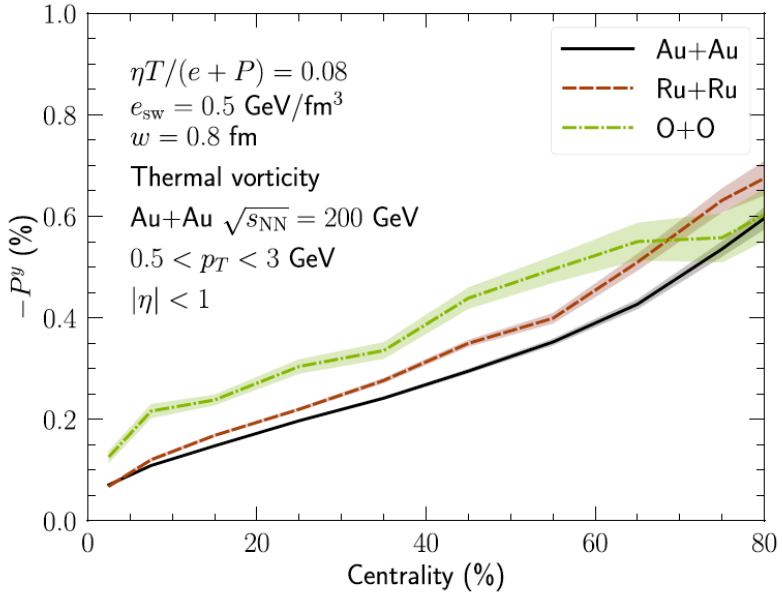
System size dependence of global polarization?

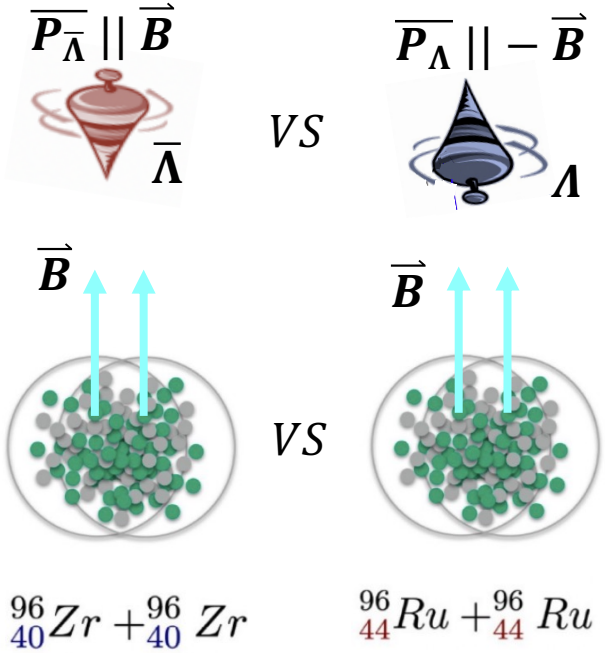
- $^{197}_{79}Au > ^{96}_{44}Ru, ^{96}_{40}Zr > ^{63}_{29}Cu > ^{16}_{8}O$? $P_\Lambda^{Au} < P_\Lambda^{Ru} \approx P_\Lambda^{Zr} < P_\Lambda^{Cu} < P_\Lambda^{O}$

Global polarization magnetic fields effect

S. Alzhrani et al., Phys. Rev. C 106.014905

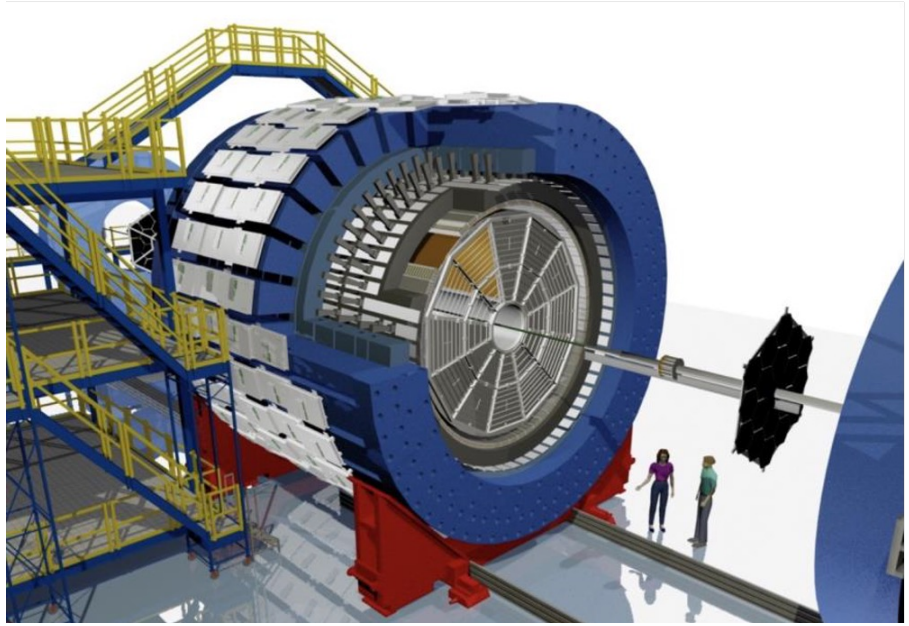






- System size dependence of global polarization?
  - $^{197}_{79}Au > ^{96}_{44}Ru, ^{96}_{40}Zr > ^{63}_{29}Cu > ^{16}_{8}O$? $P_\Lambda^{Au} < P_\Lambda^{Ru} \approx P_\Lambda^{Zr} < P_\Lambda^{Cu} < P_\Lambda^{O}$
- Global polarization difference from different magnetic fields in Zr+Zr and Ru+Ru?

STAR detector and $\Lambda/\bar{\Lambda}$ reconstruction



Event plane reconstruction:

Time Projection Chamber

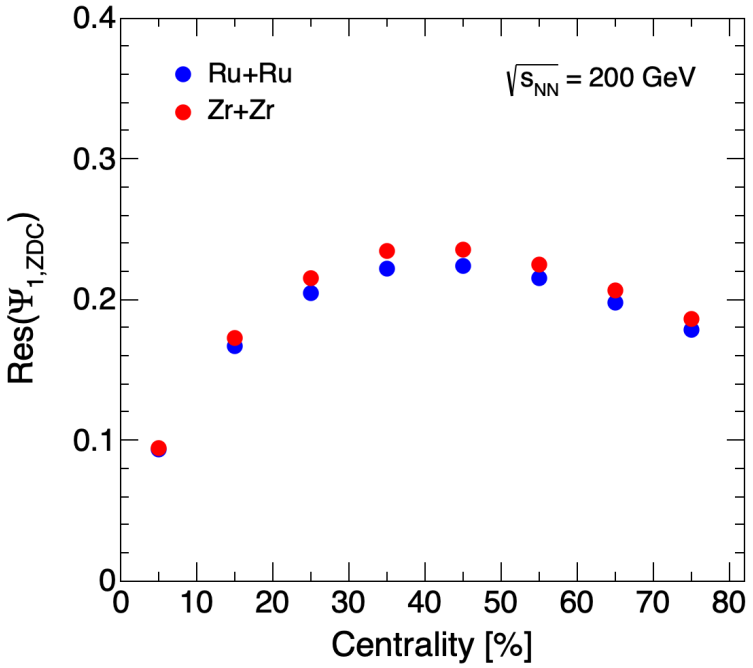
Zero Degree Calorimeters

$\Lambda/\bar{\Lambda}$ reconstruction:

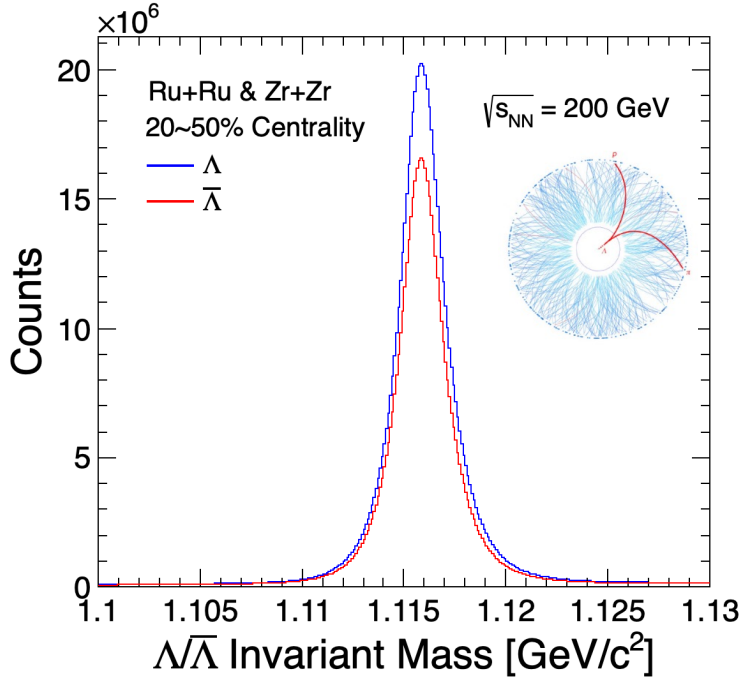
Time Projection Chamber

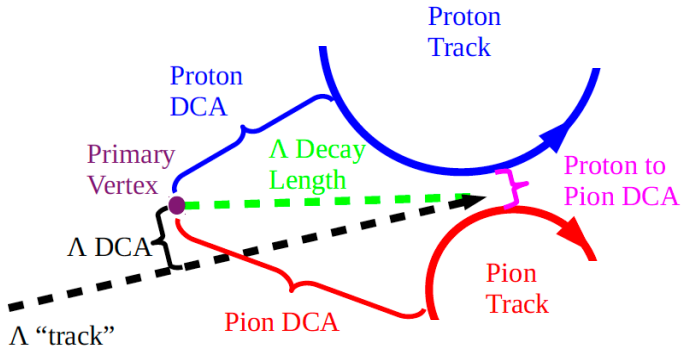
Time Of Flight

Event plane resolution



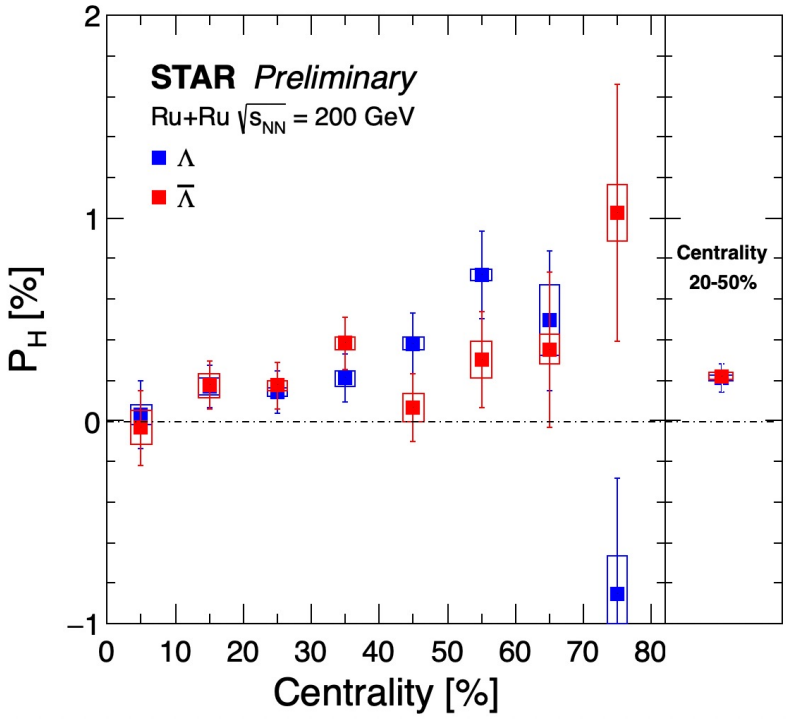
$\Lambda/\bar{\Lambda}$ reconstructed with TPC tracks

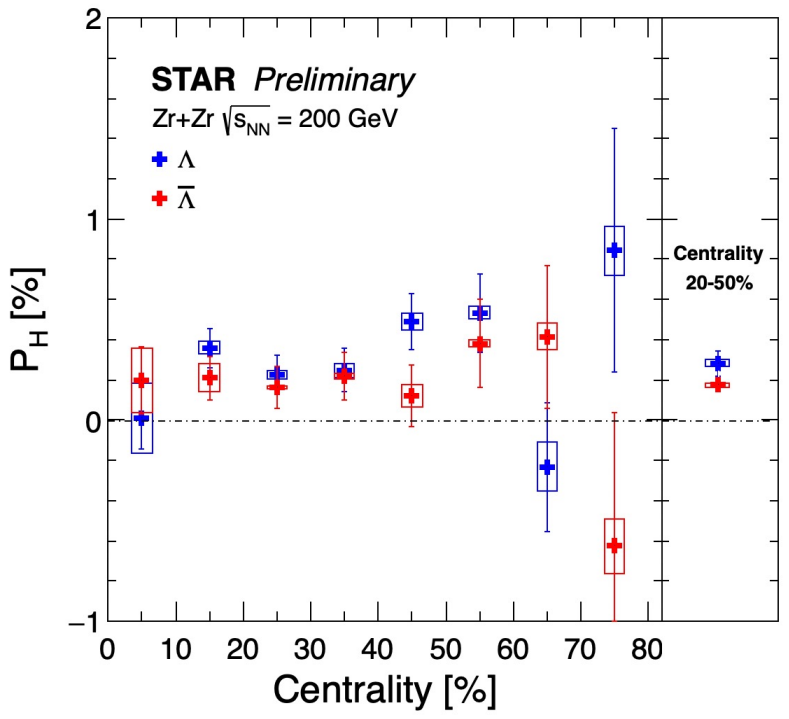


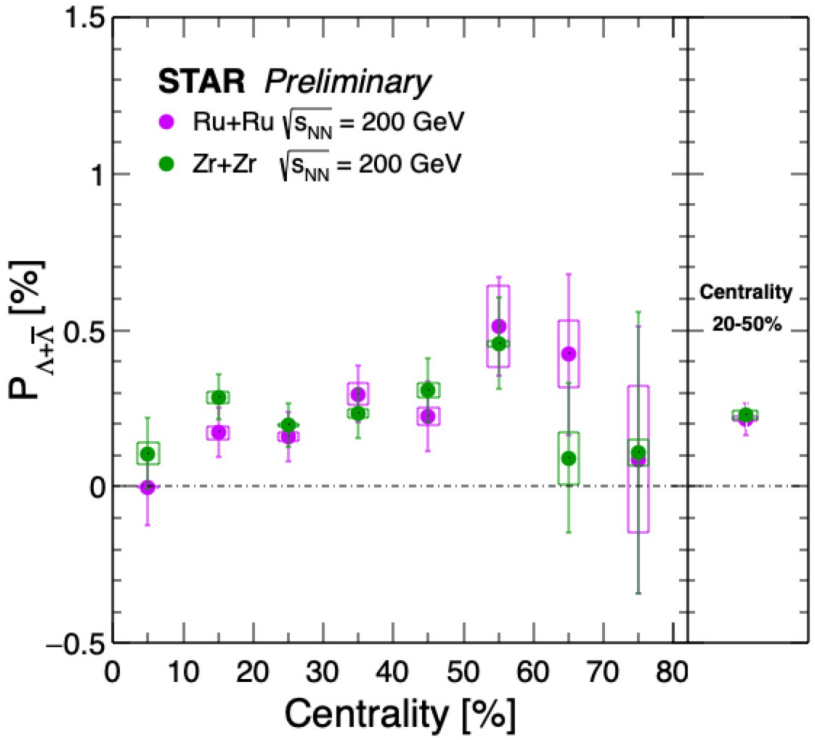


- $\Lambda \rightarrow p + \pi^-$
- $\bar{\Lambda} \rightarrow \bar{p} + \pi^+$
- Background fraction < 3%

Global polarization of Λ and $\overline{\Lambda}$ in isobar collisions

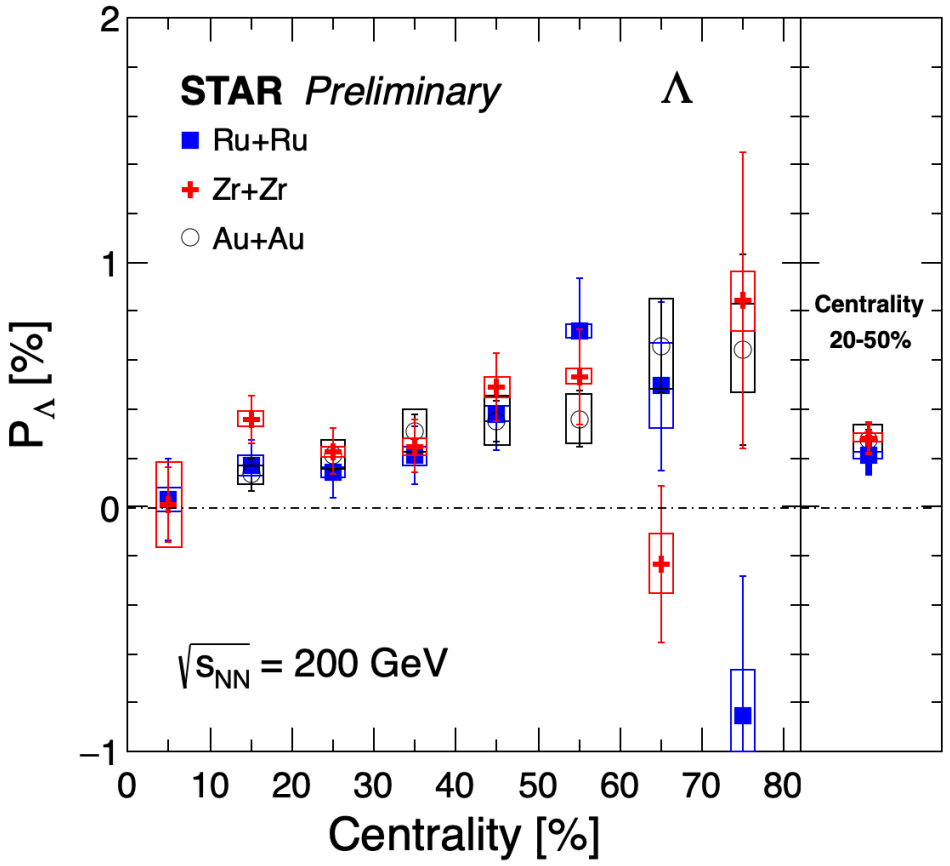


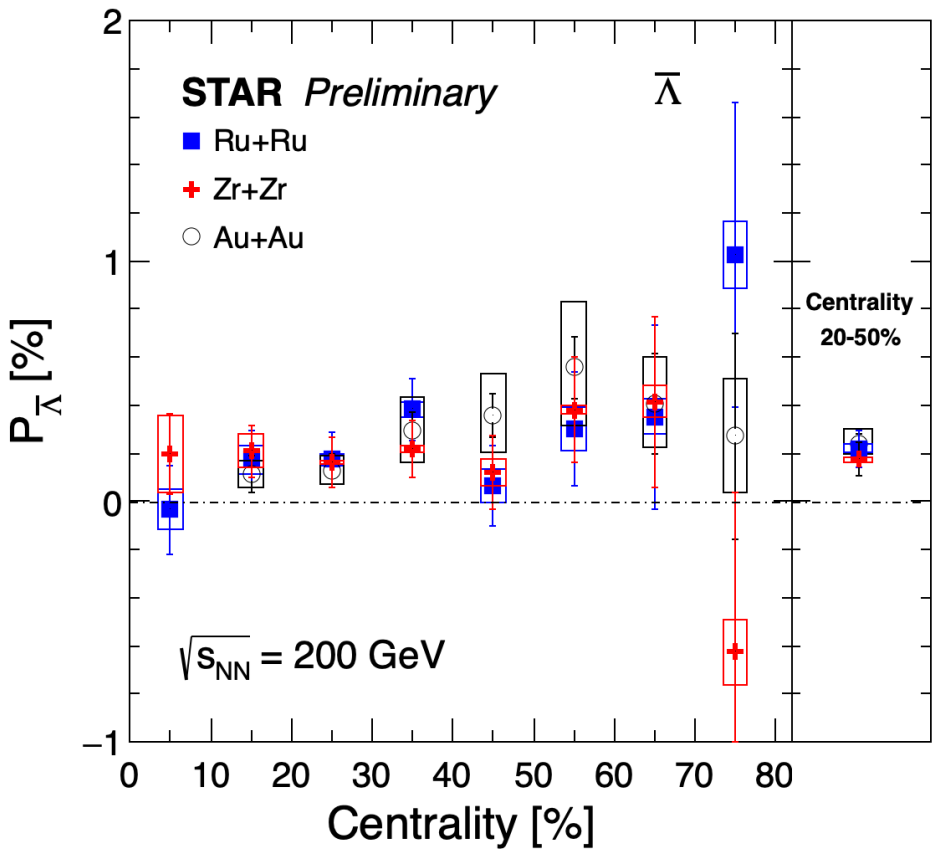




- Significant global polarization observed, P_Λ and $P_{\overline{\Lambda}}$ increase with centrality
- No significant difference between P_Λ and $P_{\overline{\Lambda}}$ in Ru+Ru and Zr+Zr collisions
- Global polarization of $\Lambda + \overline{\Lambda}$ are consistent between Ru+Ru and Zr+Zr collisions

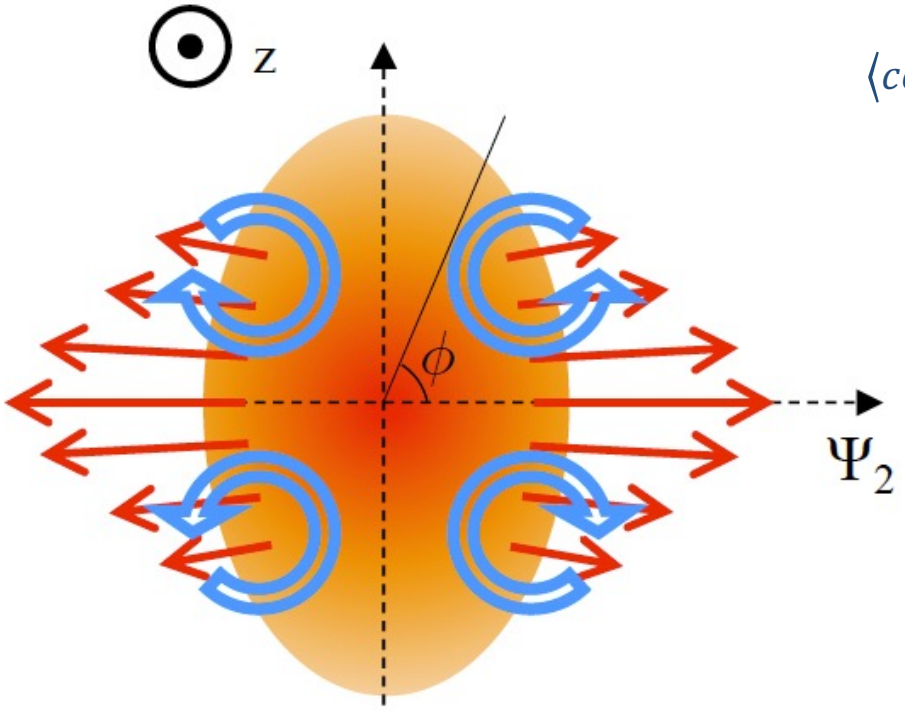
Global polarization of Λ and $\overline{\Lambda}$ in isobar and Au+Au collisions



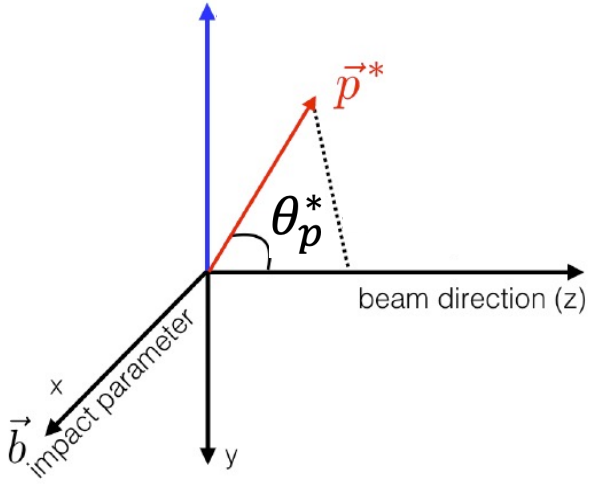


- Global polarization of Λ and $\overline{\Lambda}$ are consistent between isobar and Au+Au collision systems
- No collision system size dependence is observed

Local polarization of hyperons in heavy ion collisions

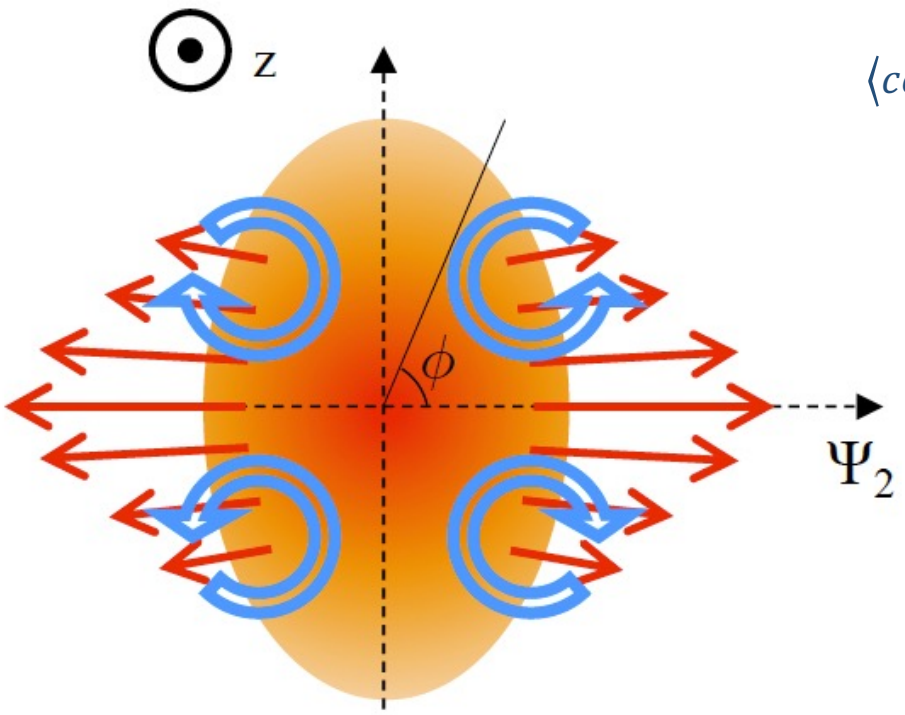


$$\langle cos\theta_p^* \rangle = \int \frac{dN}{d\Omega^*} cos\theta_p^* d\Omega^*$$
$$= \alpha_\Lambda P_z \langle (cos\theta_p^*)^2 \rangle$$
$$P_z = \frac{\langle cos\theta_p^* \rangle}{\alpha_\Lambda \langle (cos\theta_p^*)^2 \rangle}$$



- Polarization along the beam direction expected from the "elliptic flow"
- STAR has observed the local polarization with second order event plane in Au+Au collisions

Local polarization of hyperons in heavy ion collisions



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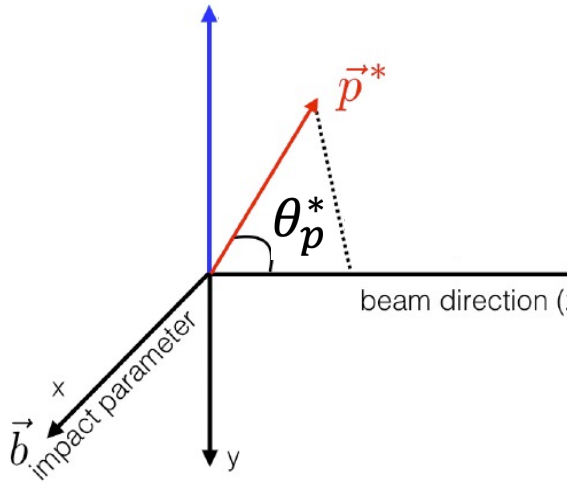
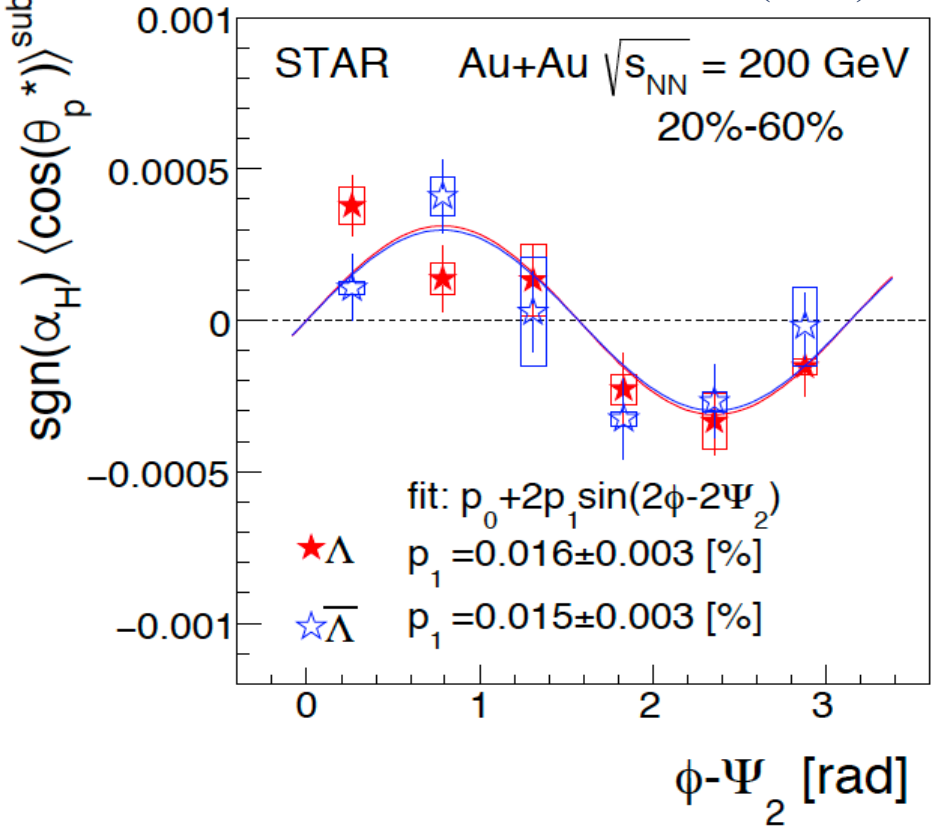


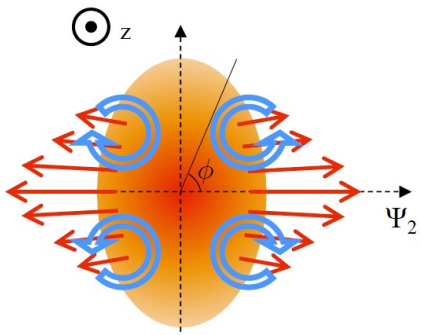
$P_z \propto \langle cos\theta_p^* \rangle$

STAR, PRL123, 132301(2019)



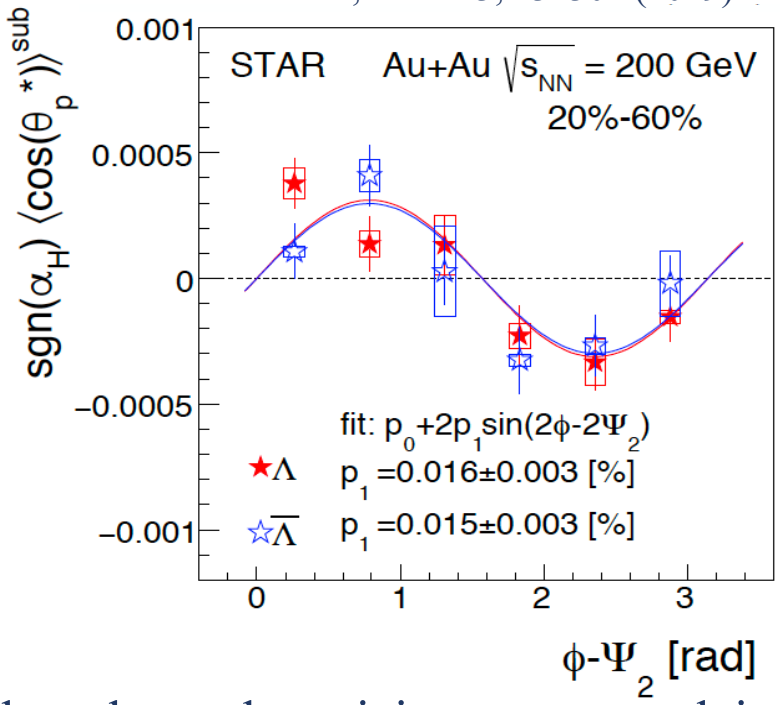
- Local vorticity induced by anisotropic flow results in polarization along the beam direction, expected from the "elliptic flow"
- STAR has observed the local polarization with second order event plane in Au+Au collisions

Local polarization of hyperons in heavy ion collisions

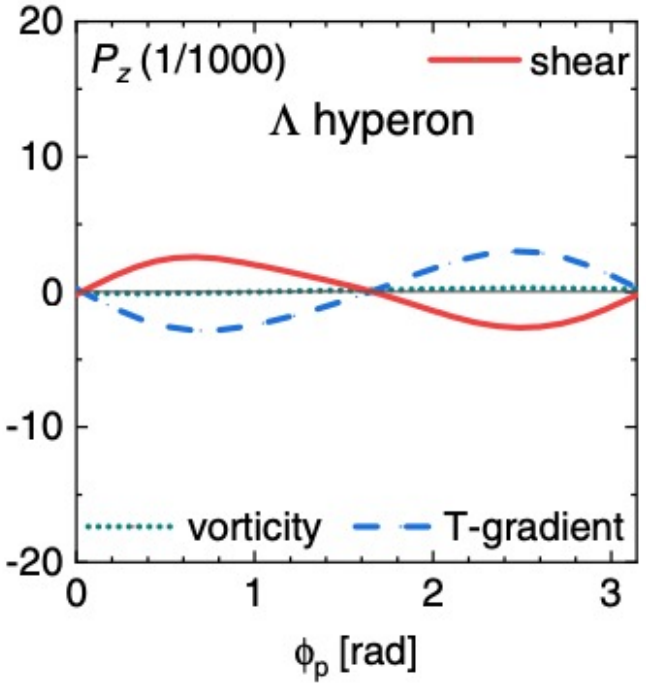


$P_z \propto \langle cos\theta_p^* \rangle$

STAR, PRL123, 132301 (2019)

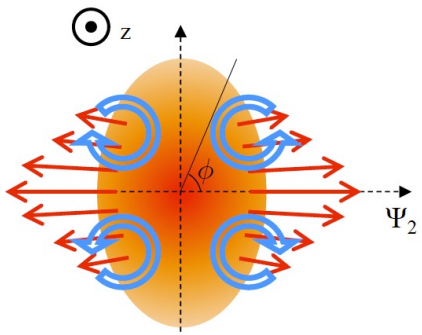


Baochi Fu et al., PRL127, 142301 (2021)



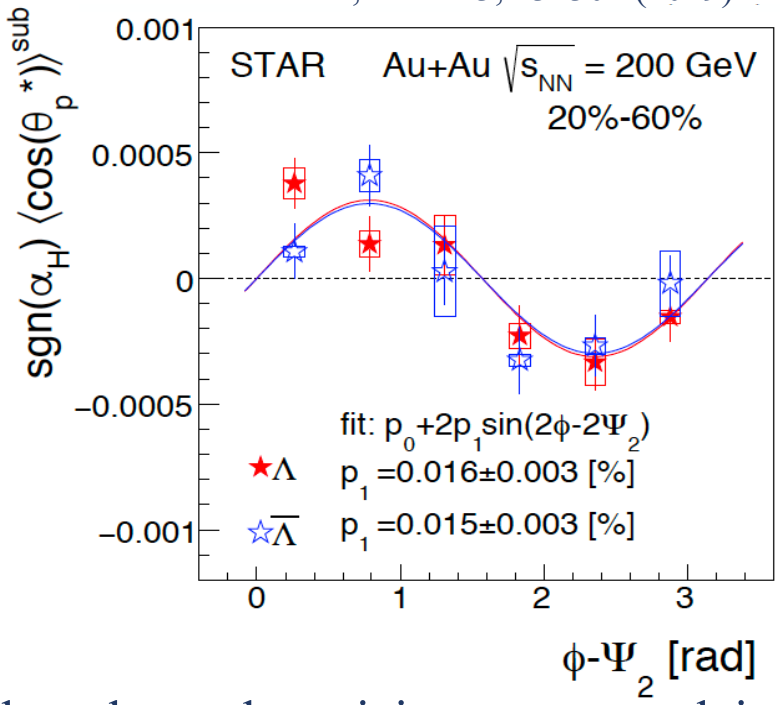
- Models based on thermal vorticity cannot explain the data, but inclusion of a shear term might explain the P_z measurement

Local polarization of hyperons in heavy ion collisions

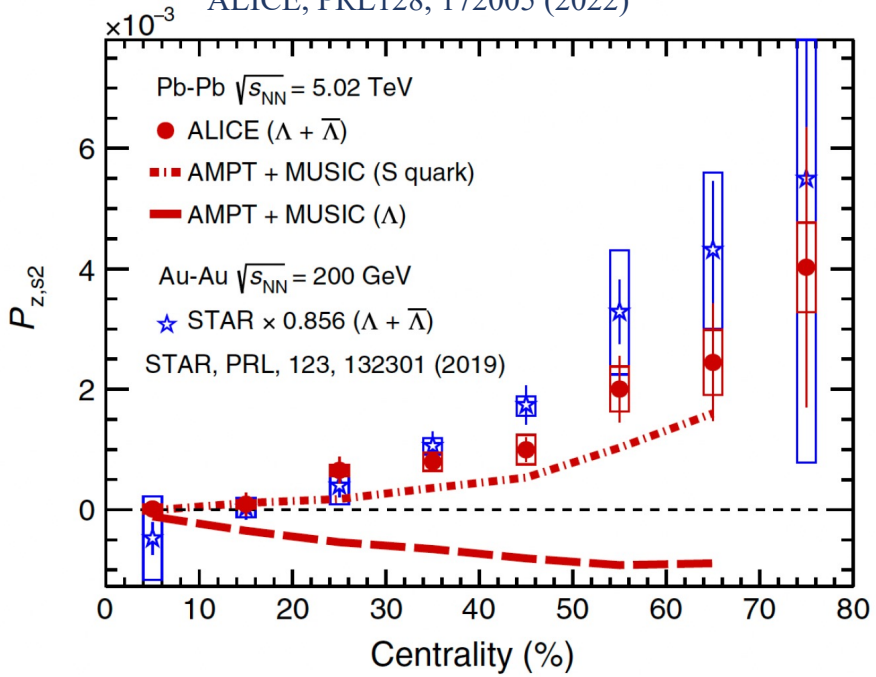


$P_z \propto \langle cos\theta_p^* \rangle$

STAR, PRL123, 132301 (2019)

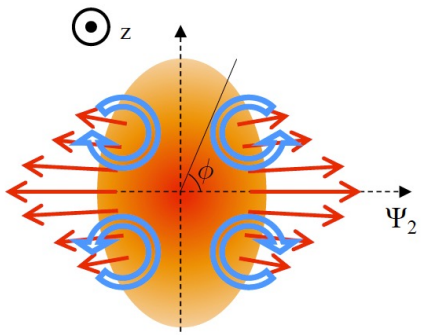


ALICE, PRL128, 172005 (2022)



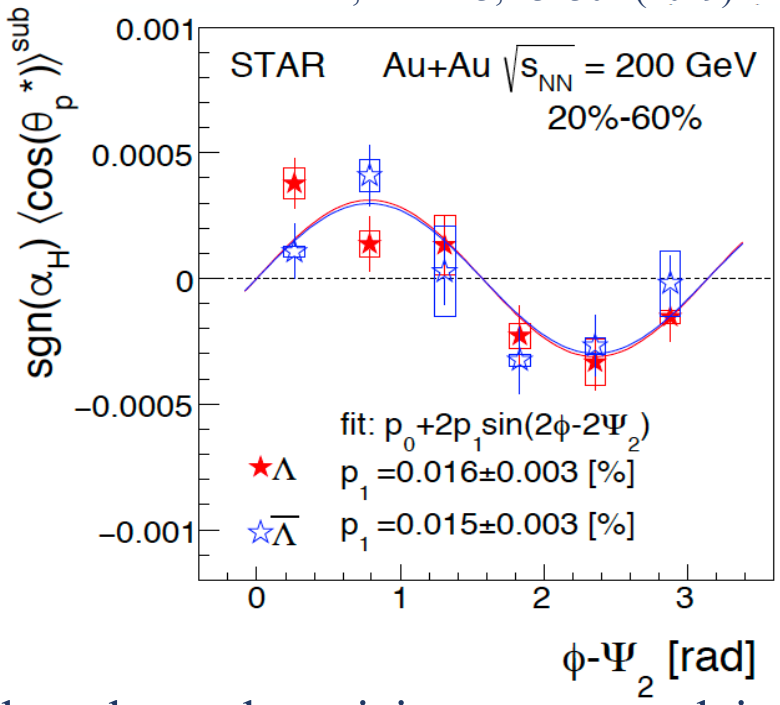
- Models based on thermal vorticity cannot explain the data, but inclusion of a shear term might explain the P_z measurement
- **Collision system size and energy dependence of local polarization?**

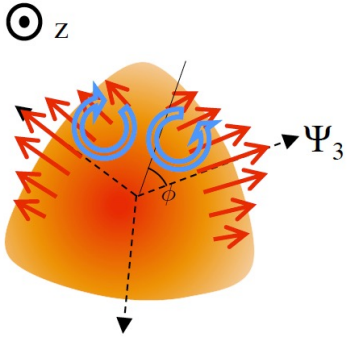
Local polarization of hyperons in heavy ion collisions



$P_z \propto \langle cos\theta_p^* \rangle$

STAR, PRL123, 132301 (2019)

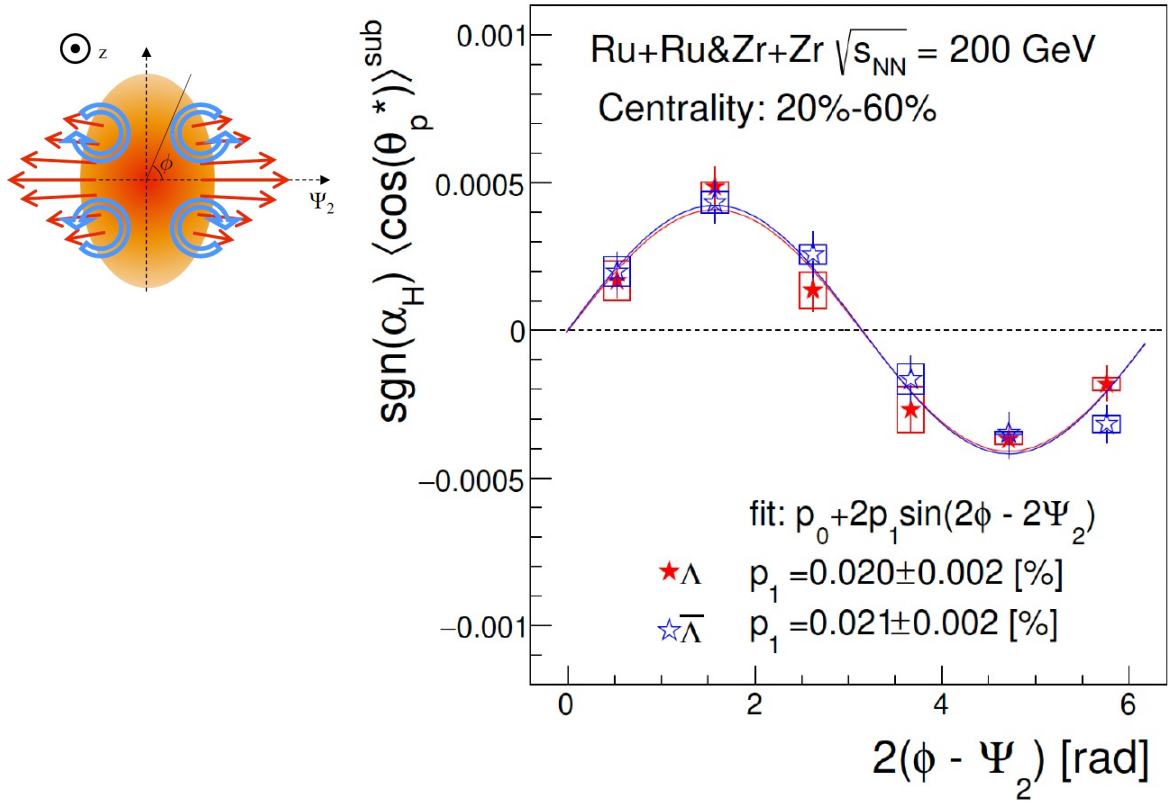




?

- Models based on thermal vorticity cannot explain the data, but inclusion of a shear term might explain the P_z measurement
- Collision system size and energy dependence of local polarization?
- **Measurements in smaller systems and relative to higher harmonic event planes provide new insights into polarization phenomena**

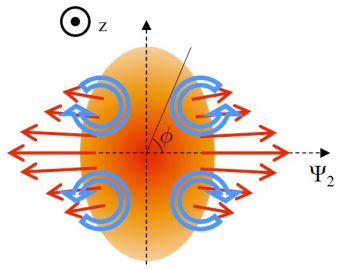
Local polarization in isobar collisions

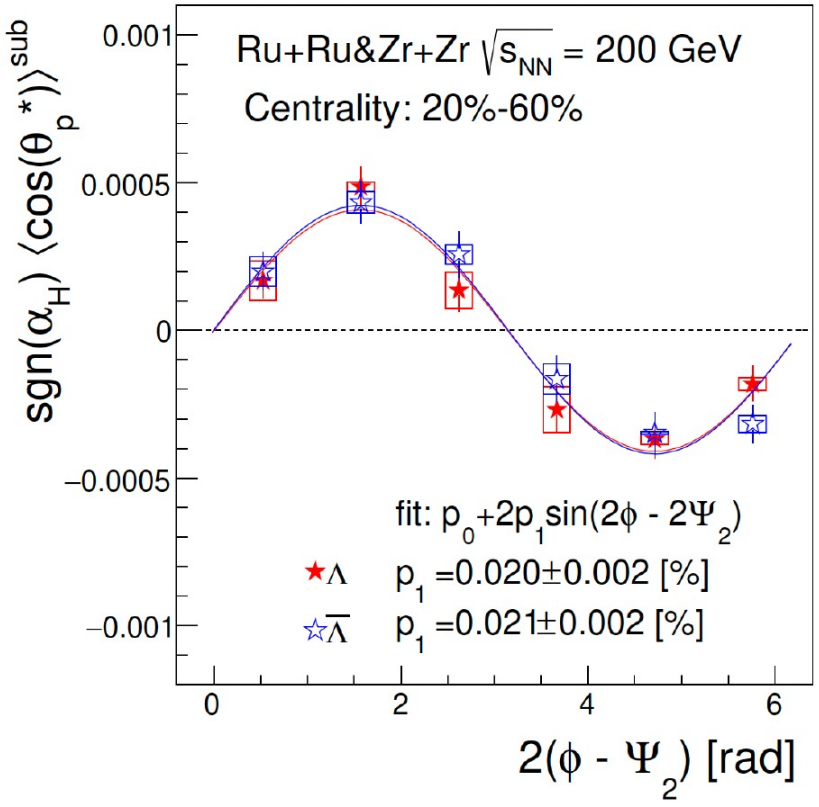


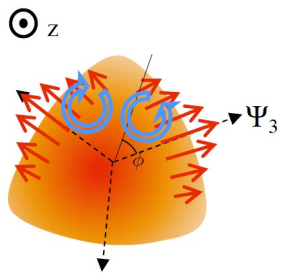
arXiv:2303.09074

- Significant local polarization w.r.t second order event plane observed in isobar collisions

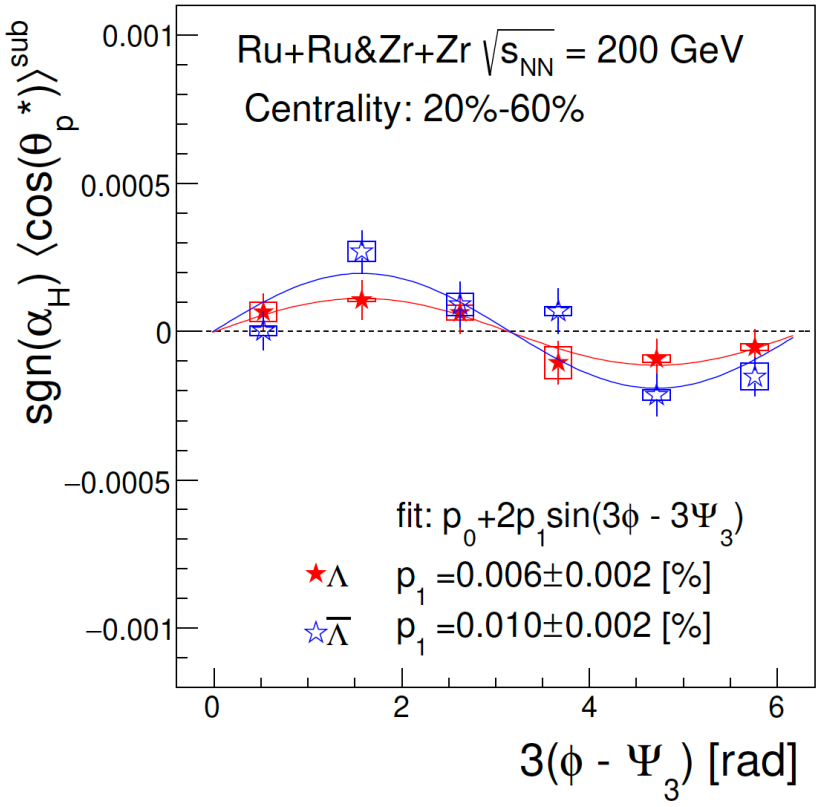
Local polarization in isobar collisions







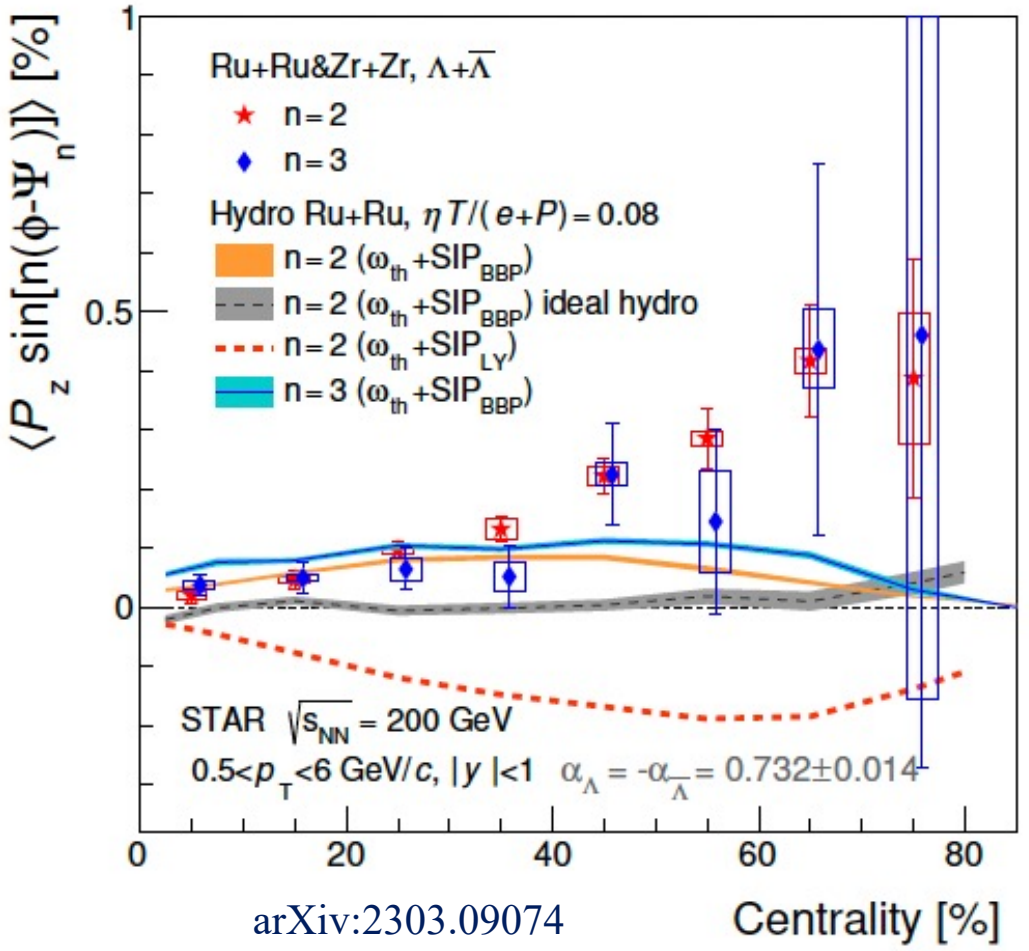
arXiv:2303.09074



- Significant local polarization w.r.t second-order event plane observed in isobar collisions
- First observation of local polarization w.r.t the third-order event plane

Centrality dependence of $P_{z,n}$

$P_{z,n} = \langle P_z \sin[n(\phi - \Psi_n)] \rangle$

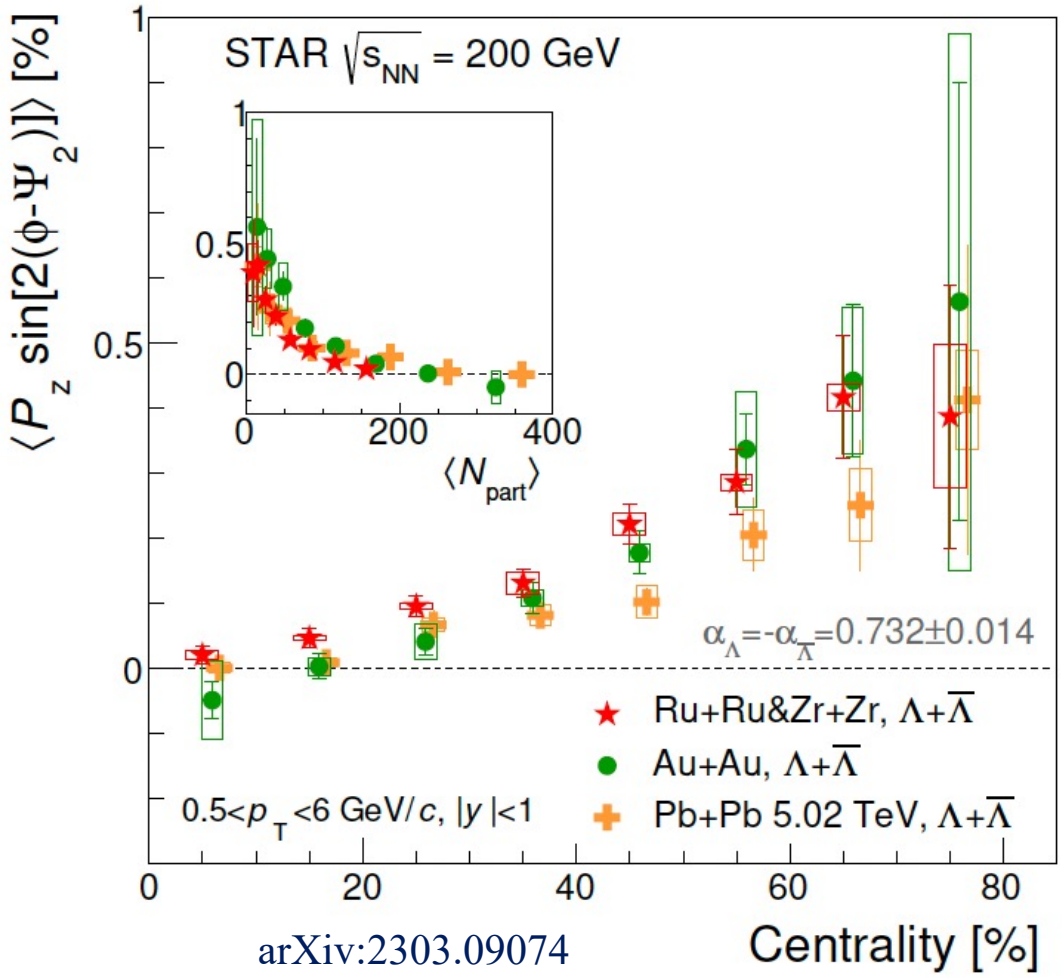


- Second Fourier sine coefficient of the local polarization increases with centrality
- Significant local polarization w.r.t third-order event plane
- Comparable second and third order sine coefficients of $P_{z,n}$, consistent with each other
- Hydrodynamic models with shear term reasonably describe the data for central collisions, but not for peripheral

S. Alzhrani et al., PhysRevC.106.014905

$P_{z,2}$ in different collision systems

$P_{z,n} = \langle P_z \sin[n(\phi - \Psi_n)] \rangle$



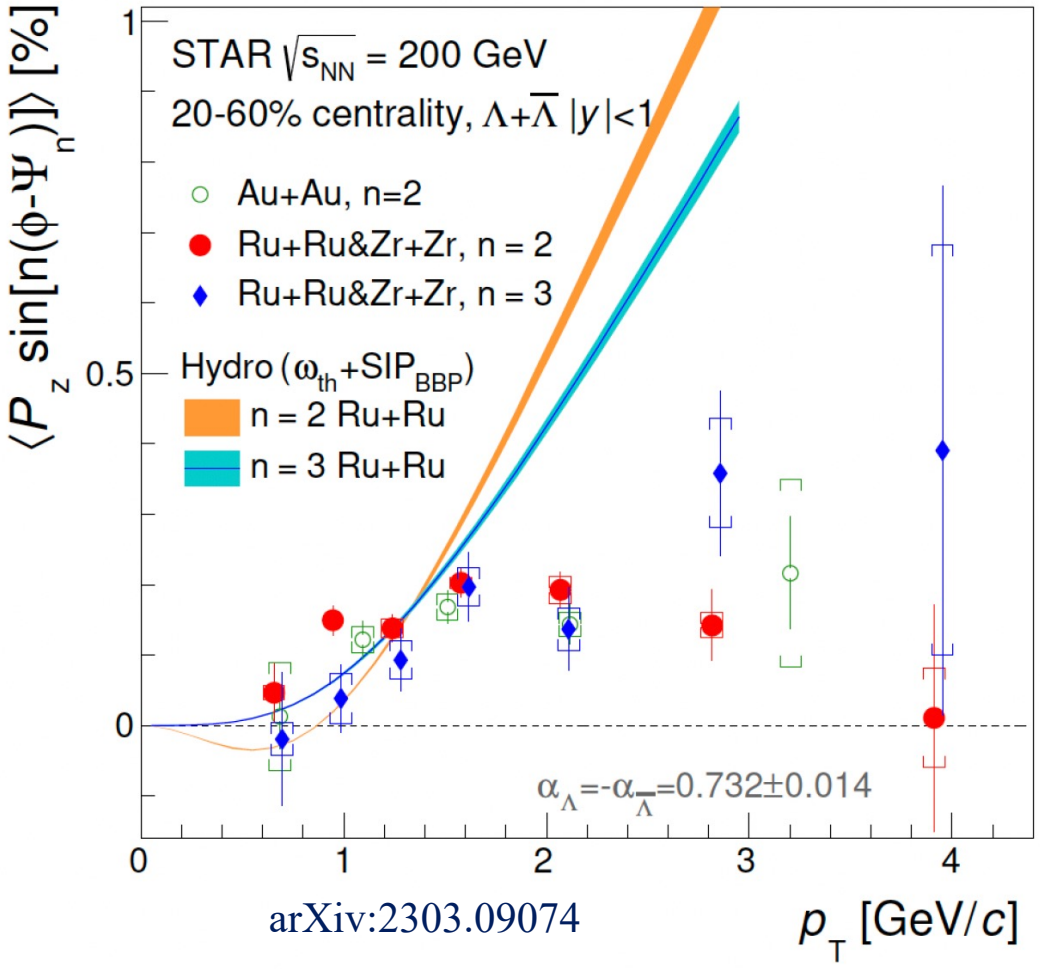
arXiv:2303.09074

- $P_{z,2}$ from isobar data compared to Au+Au and Pb+Pb collisions
- Hint of system size dependence between isobar and Au+Au collisions
- Energy dependence is not obvious between 200 GeV Au+Au and 5.02 TeV Pb+Pb collisions

Au+Au: STAR, PRL123, 132301 (2019)
Pb+Pb: ALICE, arXiv:2107.11183

$P_{z,2}$ p_T dependence

$P_{z,n} = \langle P_z \sin[n(\phi - \Psi_n)] \rangle$



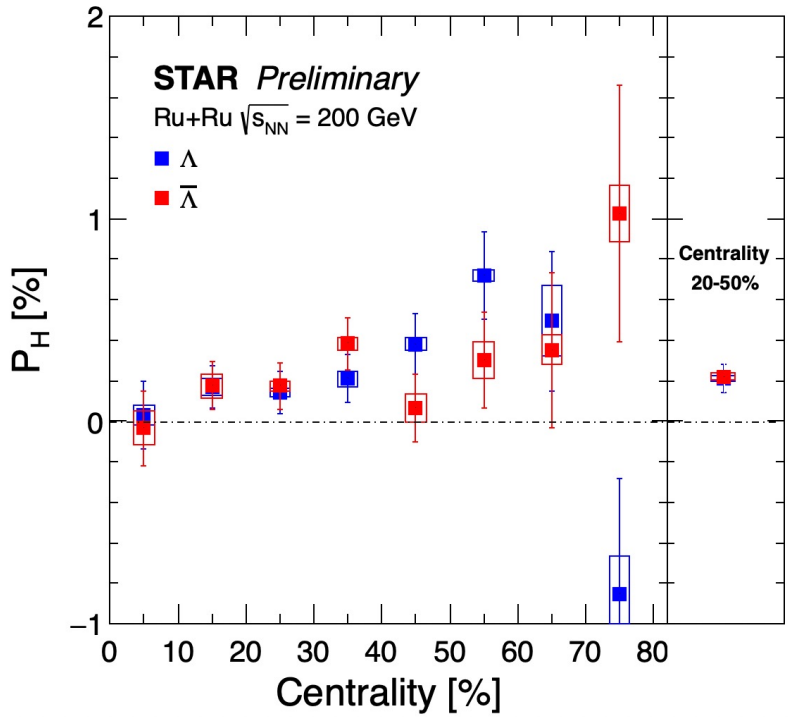
- $P_{z,2}$ p_T dependence is observed
- $P_{z,2}$ p_T dependence are consistent between isobar and Au+Au collisions
- $P_{z,2}$ p_T dependence of the polarization is indeed similar to that of elliptic (v_2) and triangular (v_3) flow
- The hydrodynamic model calculations exhibit stronger p_T dependence than that in the data

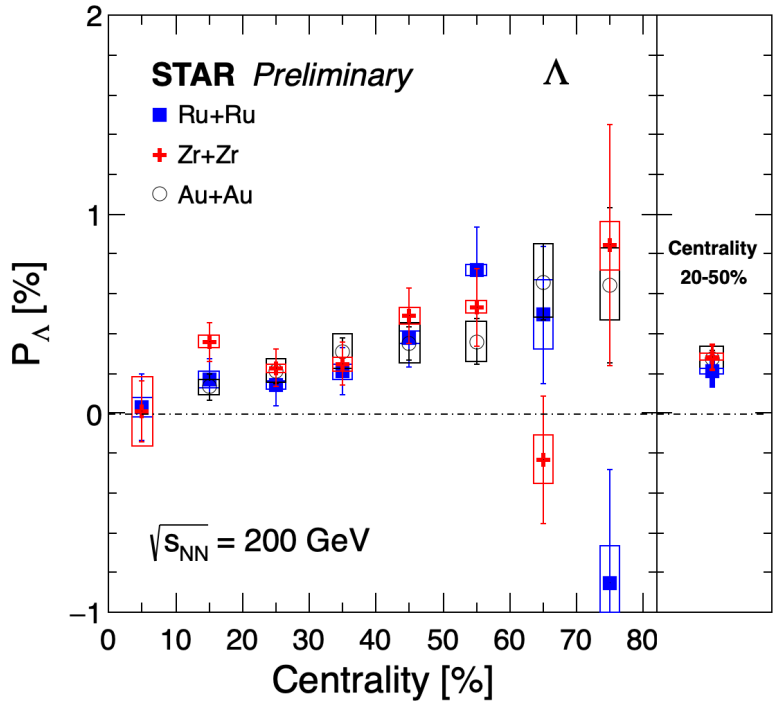
Summary

Measurements of $\Lambda/\bar{\Lambda}$ polarization in $^{96}_{44}$Ru + $^{96}_{44}$Ru and $^{96}_{40}$Zr + $^{96}_{40}$Zr collisions at $\sqrt{s_{NN}}$ = 200 GeV

☐ Global polarization

- ✓ P_Λ and $P_{\bar{\Lambda}}$ are consistent with each other
- ✓ P_Λ & $P_{\bar{\Lambda}}$ are consistent between Ru+Ru, Zr+Zr and Au+Au collisions, no collision system size dependence is observed within uncertainties



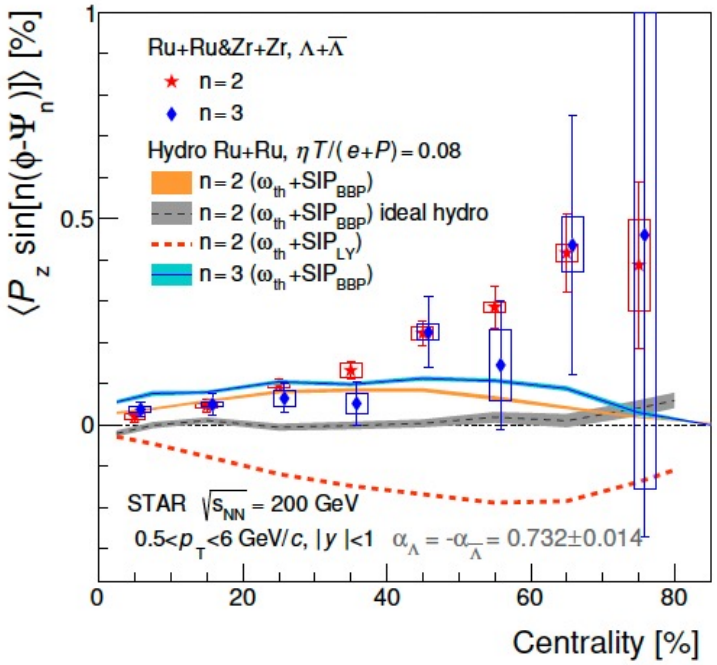


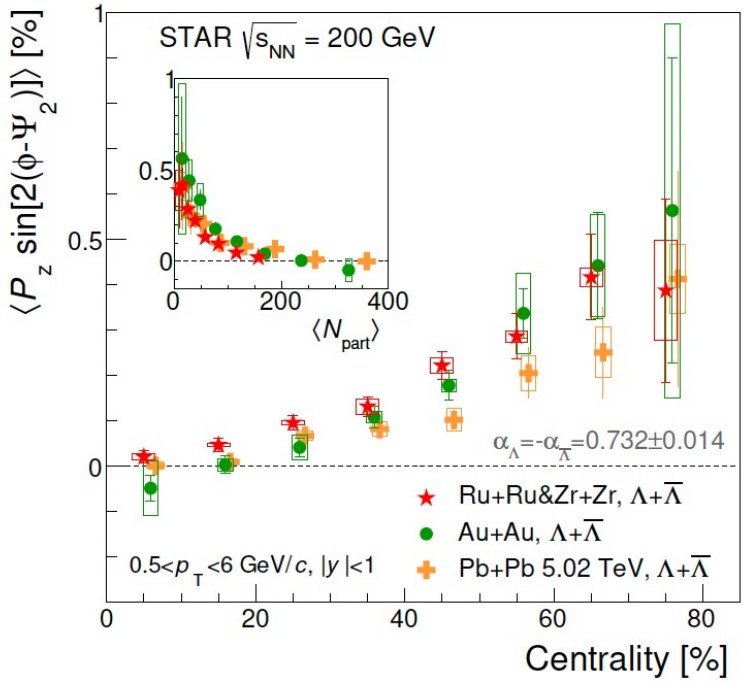
Summary

Measurements of $\Lambda/\bar{\Lambda}$ polarization in $^{96}_{44}$Ru + $^{96}_{44}$Ru and $^{96}_{40}$Zr + $^{96}_{40}$Zr collisions at $\sqrt{s_{NN}}$ = 200 GeV

☐ Local polarization

- ✓ First observation of local polarization w.r.t third-order event plane
- ✓ Hint of collision system size dependence of $P_{z,2}$ when comparing between Isobar and Au+Au





Thank you