

# Measurements of Global and Local Polarization of Hyperons in 200 GeV Isobar Collisions from STAR

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(for the STAR Collaboration)

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U.S. DEPARTMENT OF  
**ENERGY**

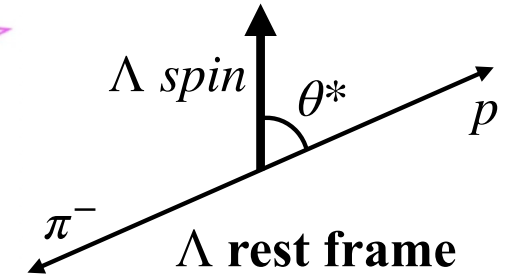
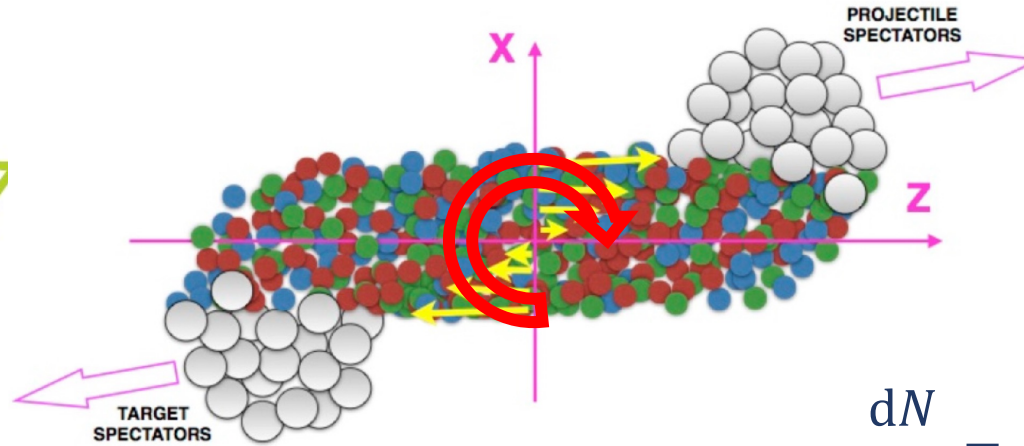
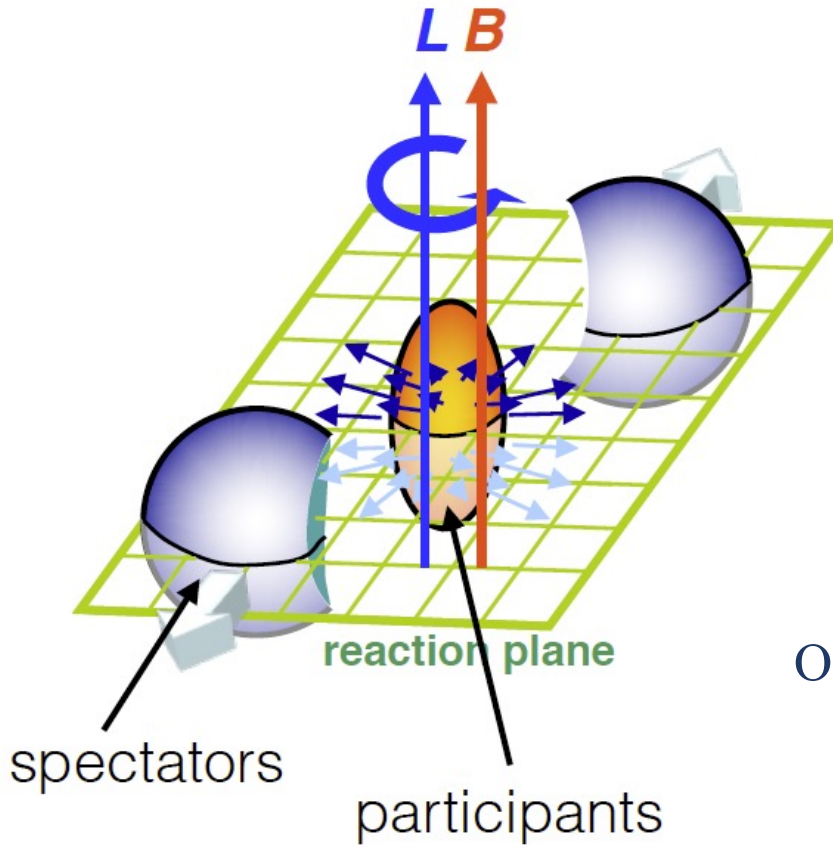
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Science

25th International Spin Symposium (SPIN 2023)



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

# Hyperon polarization in heavy ion collisions



Orbital angular momentum

↳ Leads to global polarization

Z.-T. Liang and X.-N. Wang,  
PRL 94, 102301 (2005)

$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi} (1 + \alpha_\Lambda P_\Lambda \cos\theta^*)$$

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

$$\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.732 \pm 0.014$$

$A_0$ : Acceptance correction factor

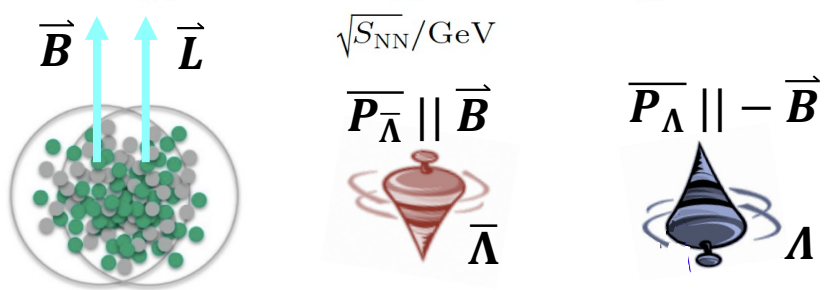
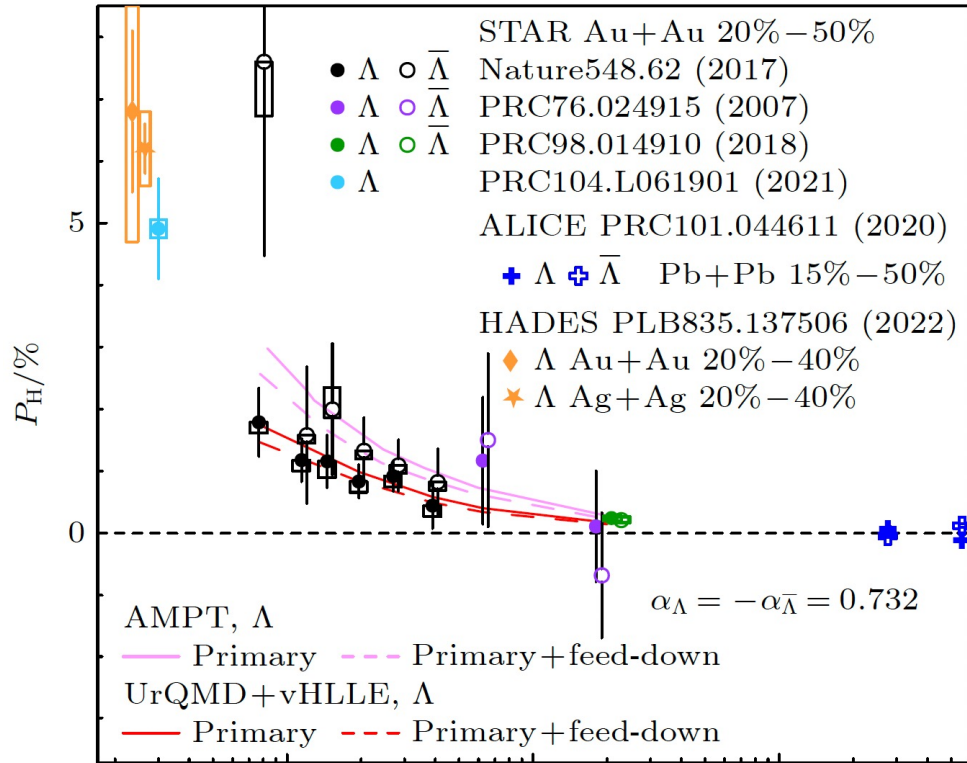
$\Psi_1$ : First-order event plane angle

$Res(\Psi_1)$ : Event plane resolution

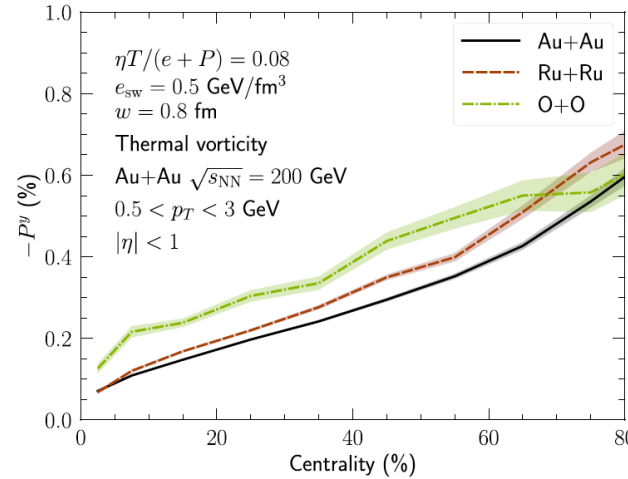
# Hyperon polarization in heavy ion collisions



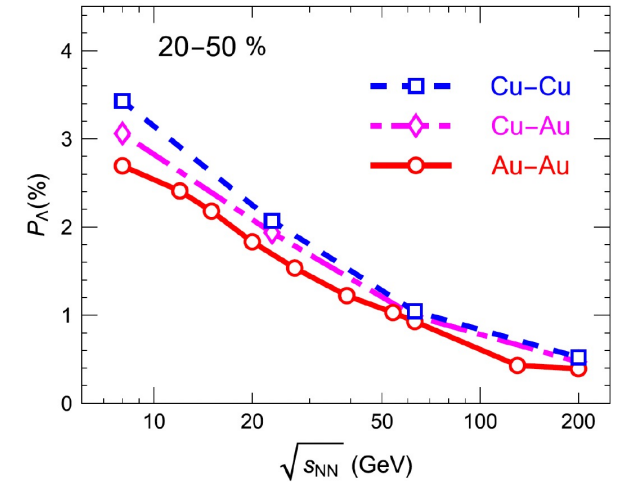
Acta Phys. Sin. Vol. 72, No. 7(2023) 072401



S. Alzhrani et al.,  
PRC 106.014905



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



□  $\Lambda / \bar{\Lambda}$  global polarization splitting ?

□ Global polarization collision system size dependence

$${}^{197}_{79}\text{Au} > {}^{96}_{44}\text{Ru}, {}^{96}_{40}\text{Zr} > {}^{63}_{29}\text{Cu} > {}^{16}_8\text{O}$$

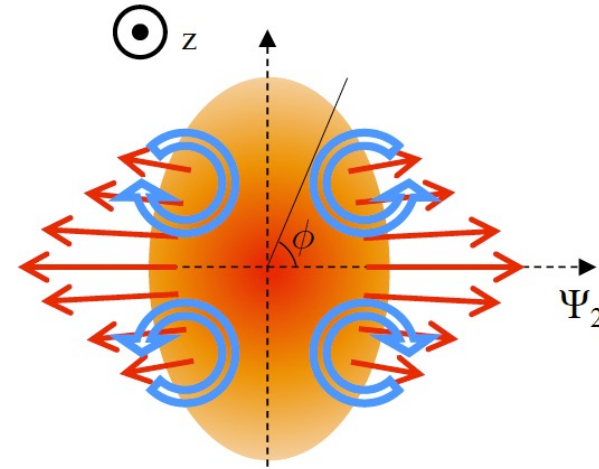
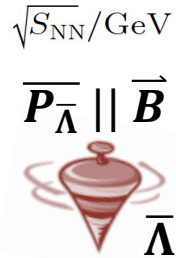
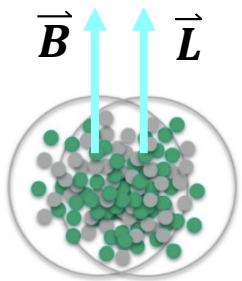
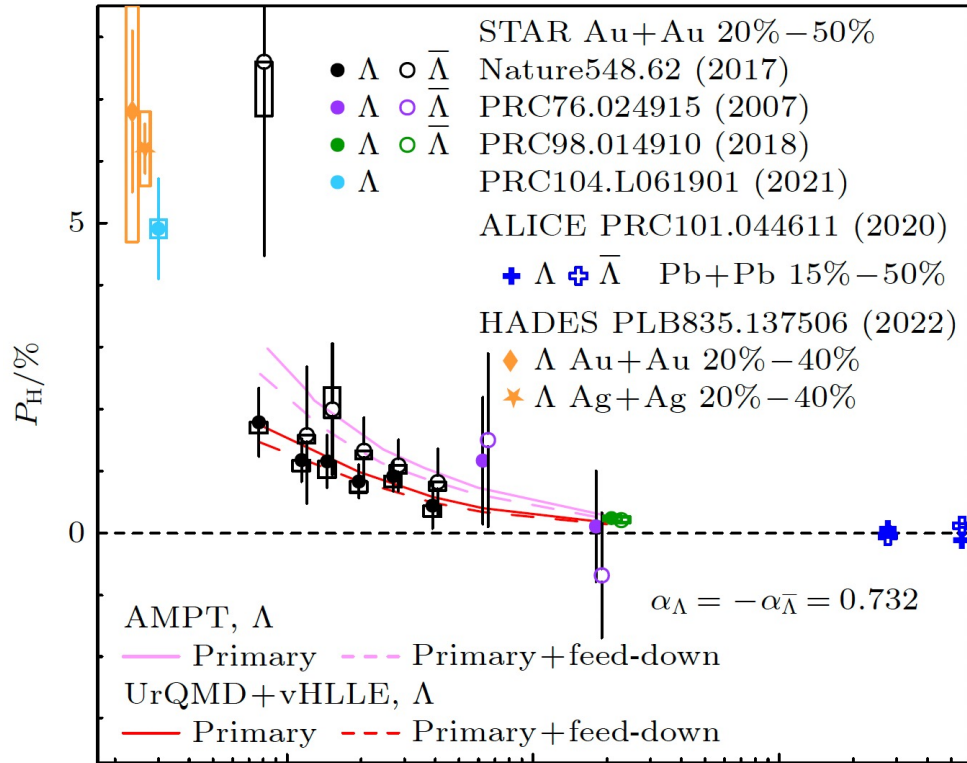
$$P_\Lambda^{\text{Au}} < P_\Lambda^{\text{Ru}} \approx P_\Lambda^{\text{Zr}} < P_\Lambda^{\text{Cu}} < P_\Lambda^{\text{O}}$$

□ Local polarization in isobar collisions

# Hyperon polarization in heavy ion collisions



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



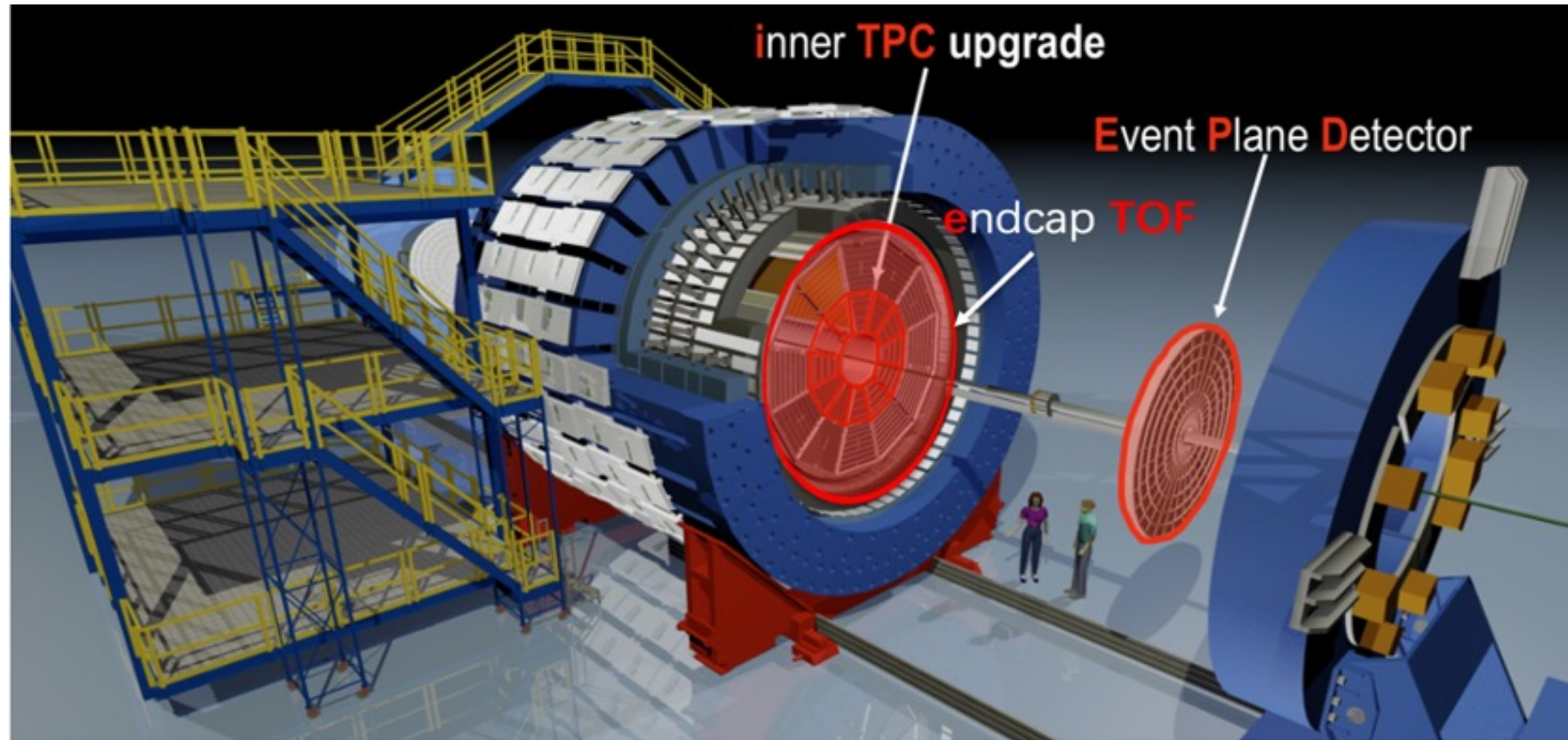
- $\Lambda / \bar{\Lambda}$  global polarization splitting with BES-II data?
- Global polarization collision system size dependence

$${}^{197}_{79}\text{Au} > {}^{96}_{44}\text{Ru}, {}^{96}_{40}\text{Zr} > {}^{63}_{29}\text{Cu} > {}^{16}_8\text{O}$$

$$P_{\Lambda}^{\text{Au}} < P_{\Lambda}^{\text{Ru}} \approx P_{\Lambda}^{\text{Zr}} < P_{\Lambda}^{\text{Cu}} < P_{\Lambda}^{\text{O}}$$

- Local polarization in isobar collisions





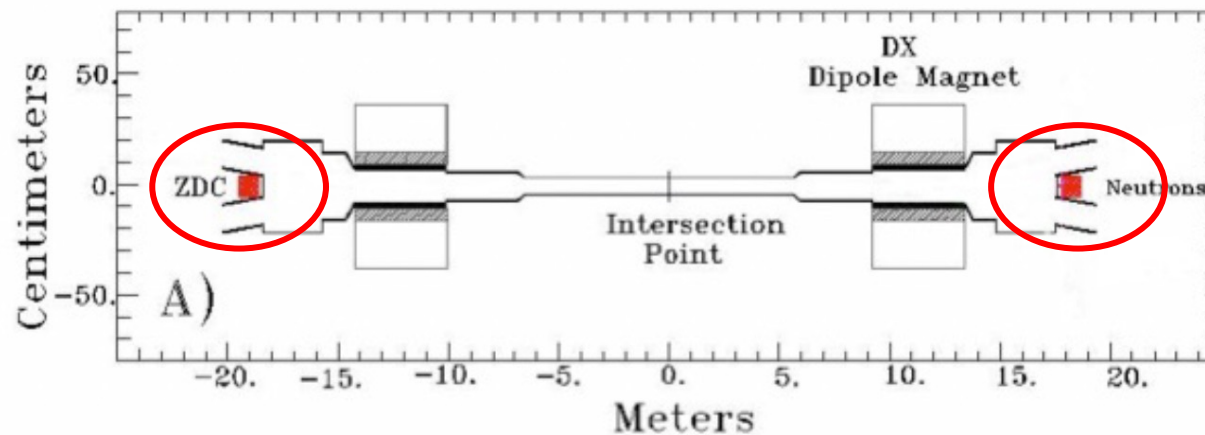
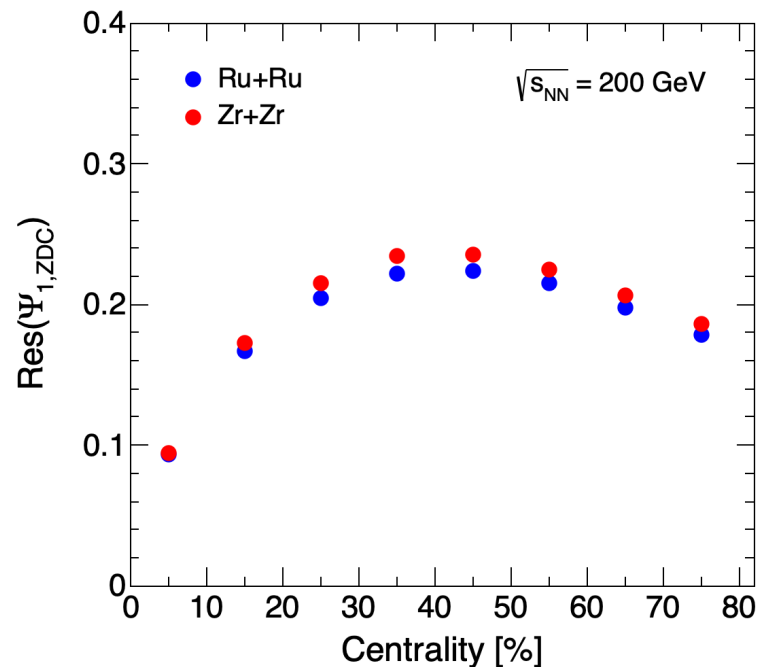
## □ Event plane reconstruction:

Zero Degree Calorimeters  
Time Projection Chamber

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

Time Projection Chamber  
Time Of Flight

## First-order event plane resolution



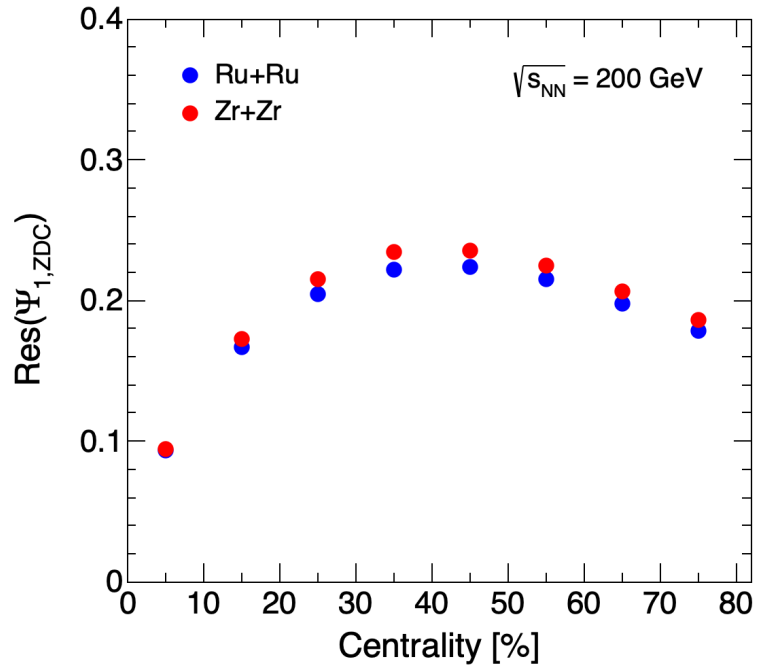
- First-order event plane reconstruct by ZDC
  - $|\eta| > 6.3$
- Second and third-order event plane reconstruct by TPC
  - $|\eta| < 1.0$

## □ Event plane reconstruction:

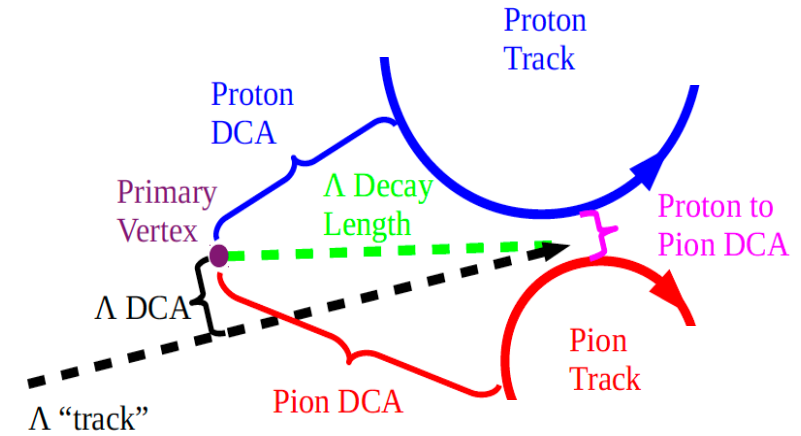
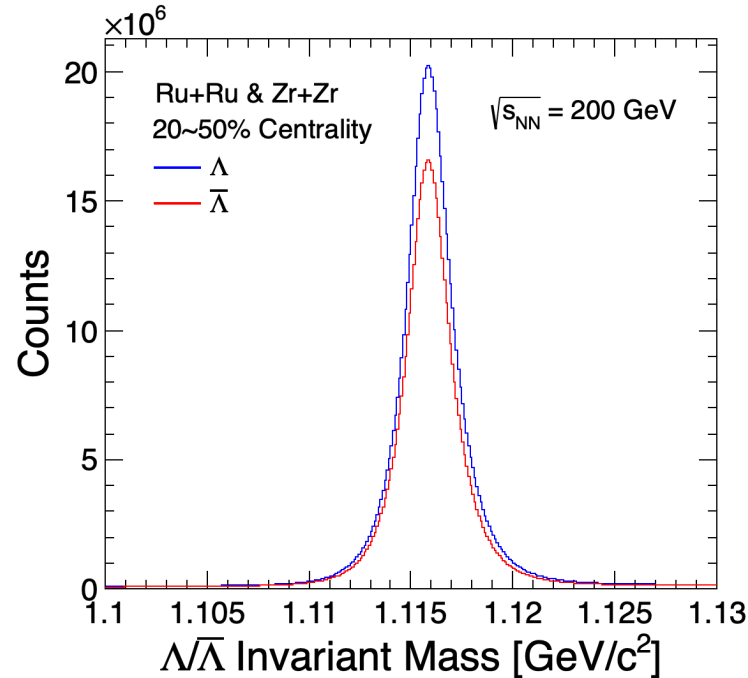
Zero Degree Calorimeters

Time Projection Chamber

## First-order event plane resolution



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



### Event plane reconstruction:

- Zero Degree Calorimeters
- Time Projection Chamber

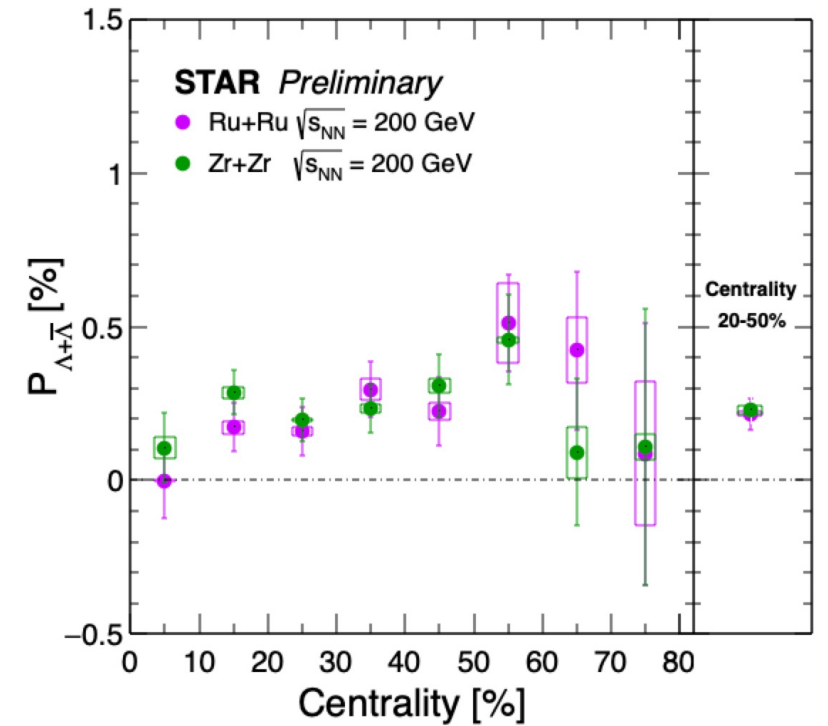
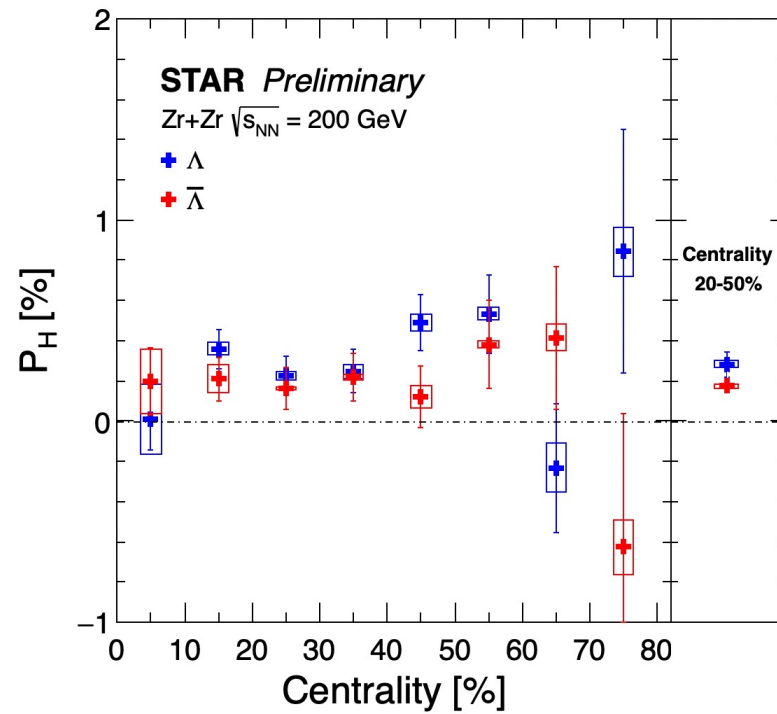
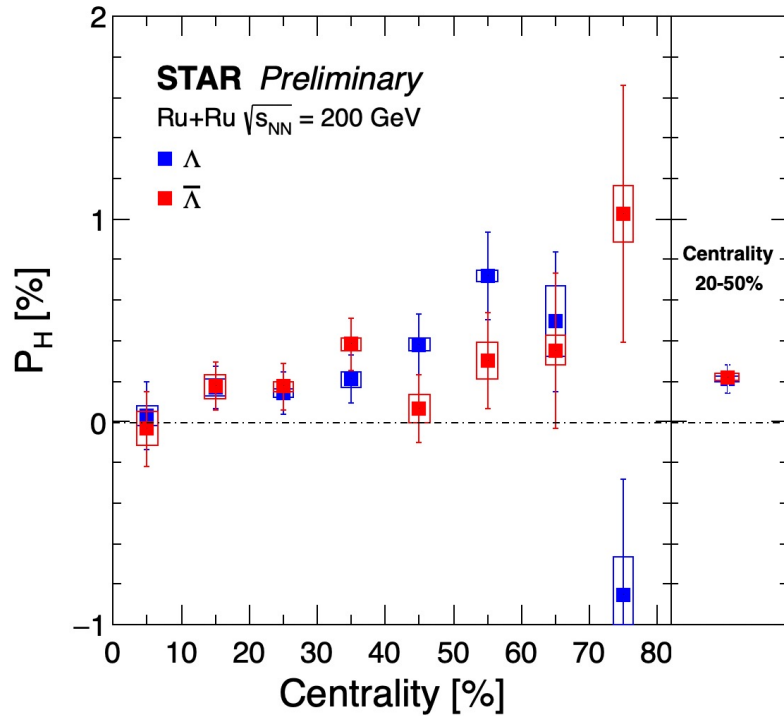
### $\Lambda/\bar{\Lambda}$ reconstruction:

- Time Projection Chamber
- Time Of Flight

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

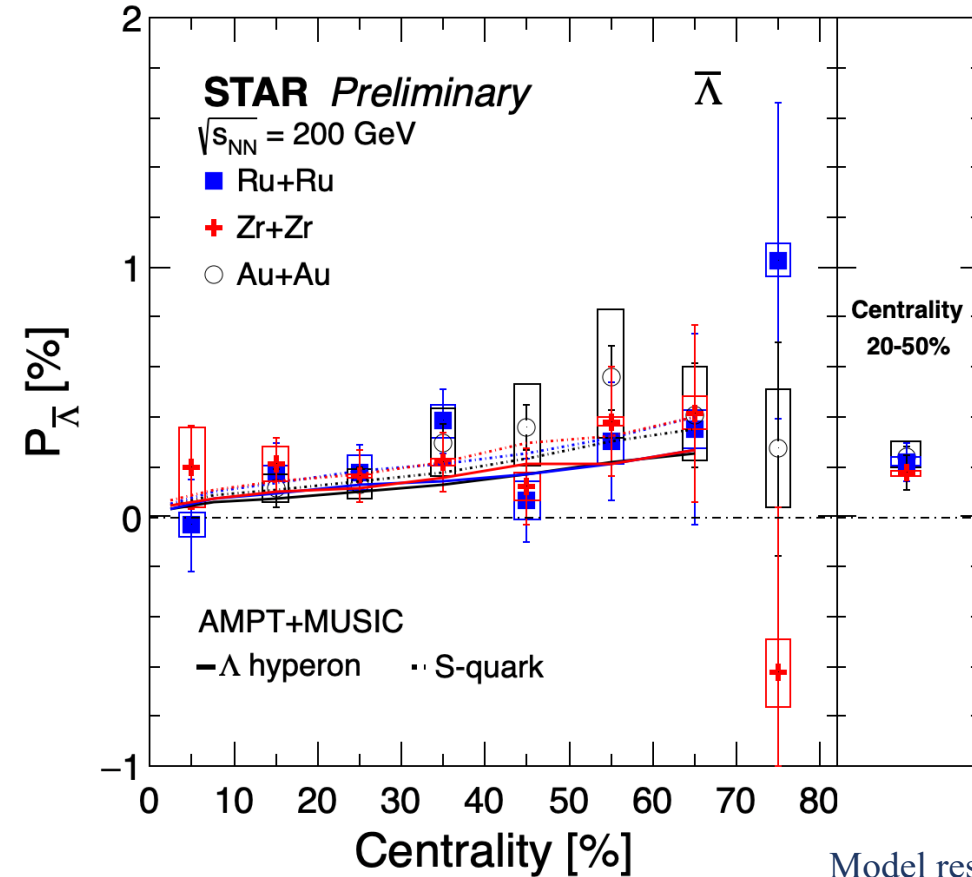
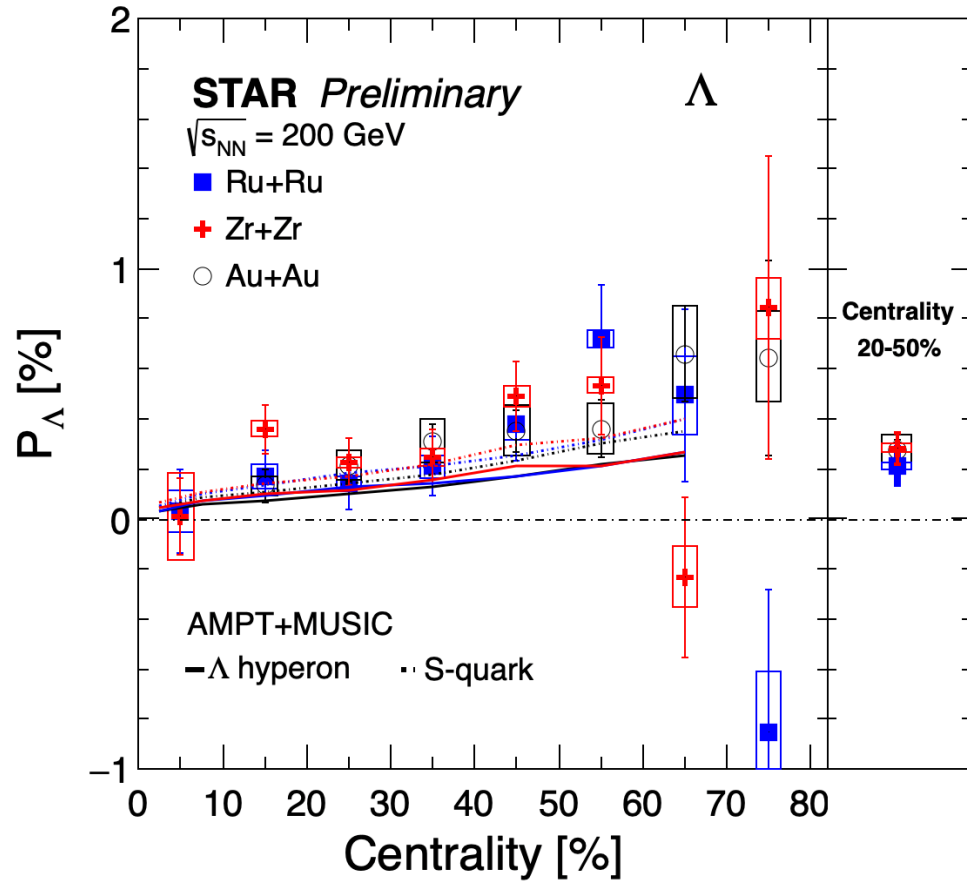


# Global polarization in Ru+Ru and Zr+Zr at 200 GeV



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

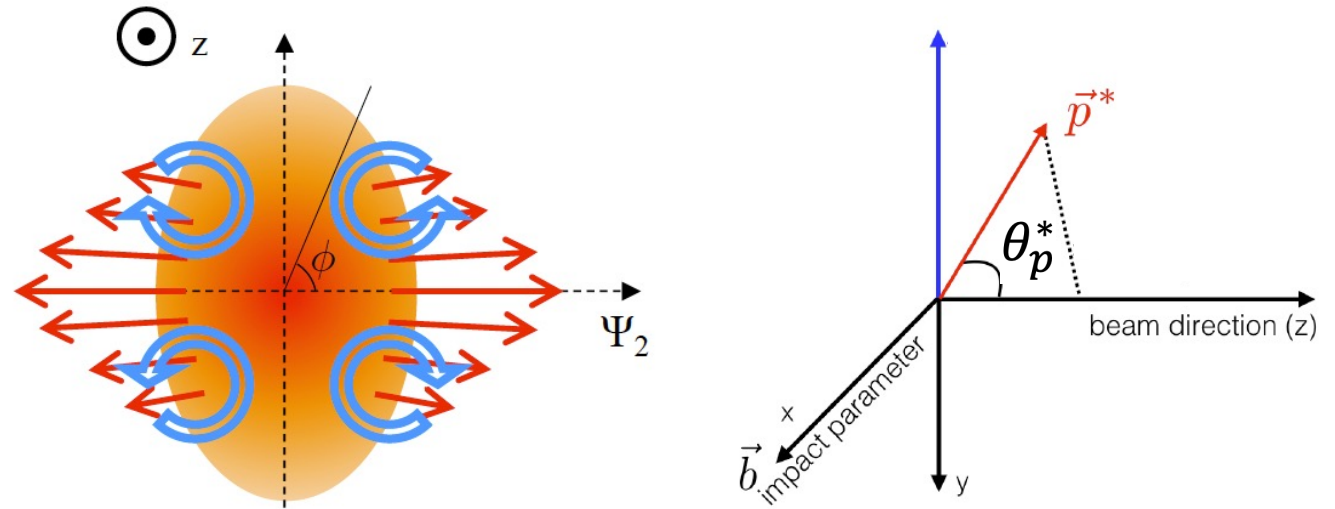
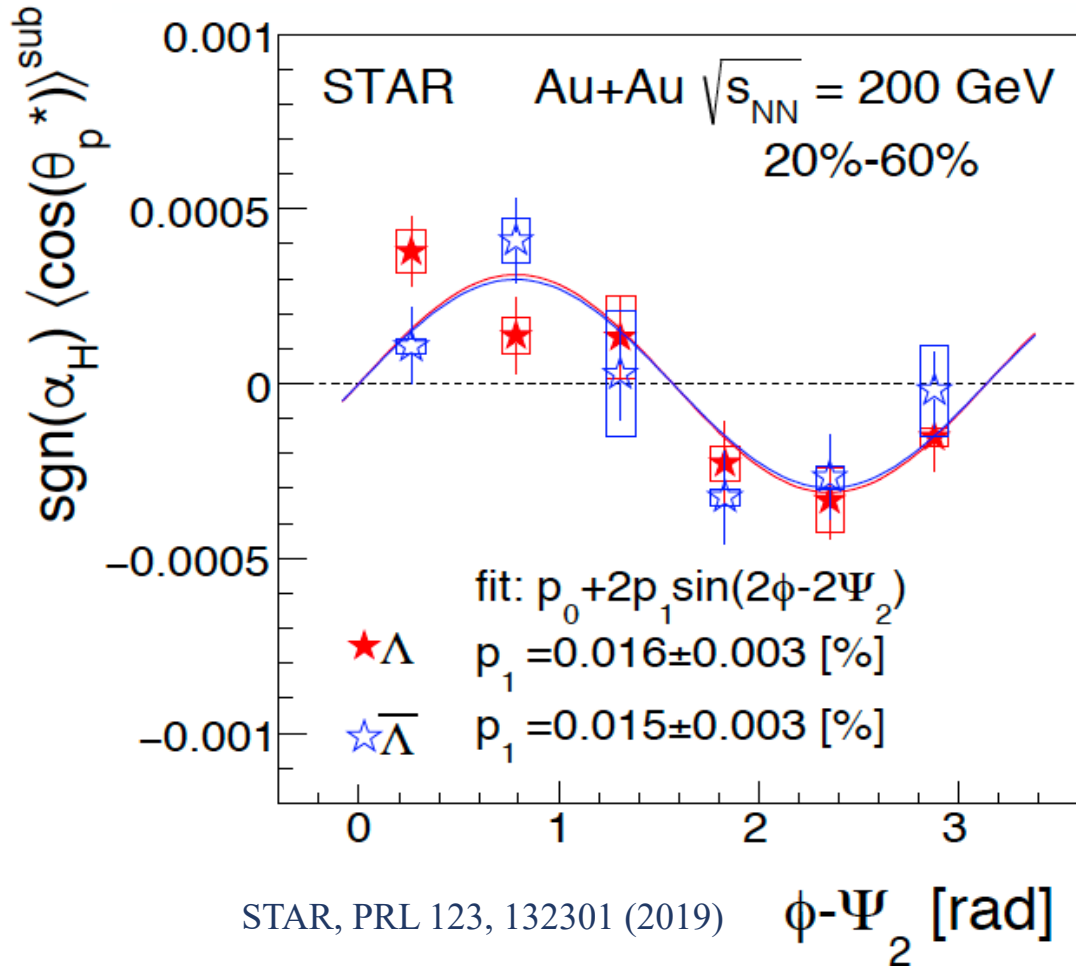
# Global polarization in Ru+Ru, Zr+Zr and Au+Au at 200 GeV



Model results from  
 arXiv:2201.12970v1

□ Global polarization of  $\Lambda$  and  $\bar{\Lambda}$  are consistent in isobar and Au+Au collision systems

# Local polarization in heavy ion collisions



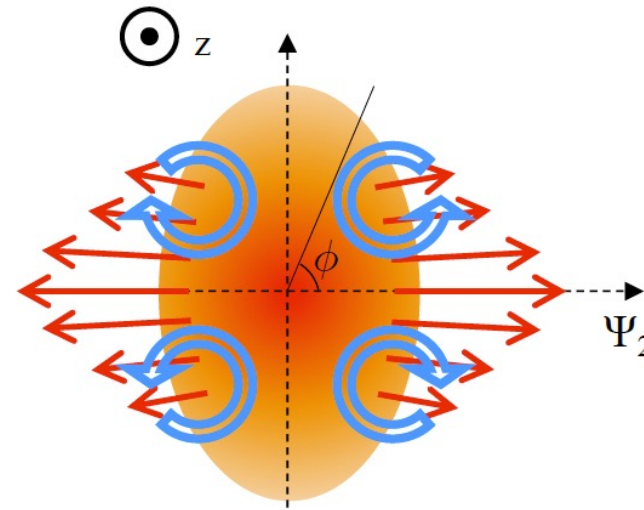
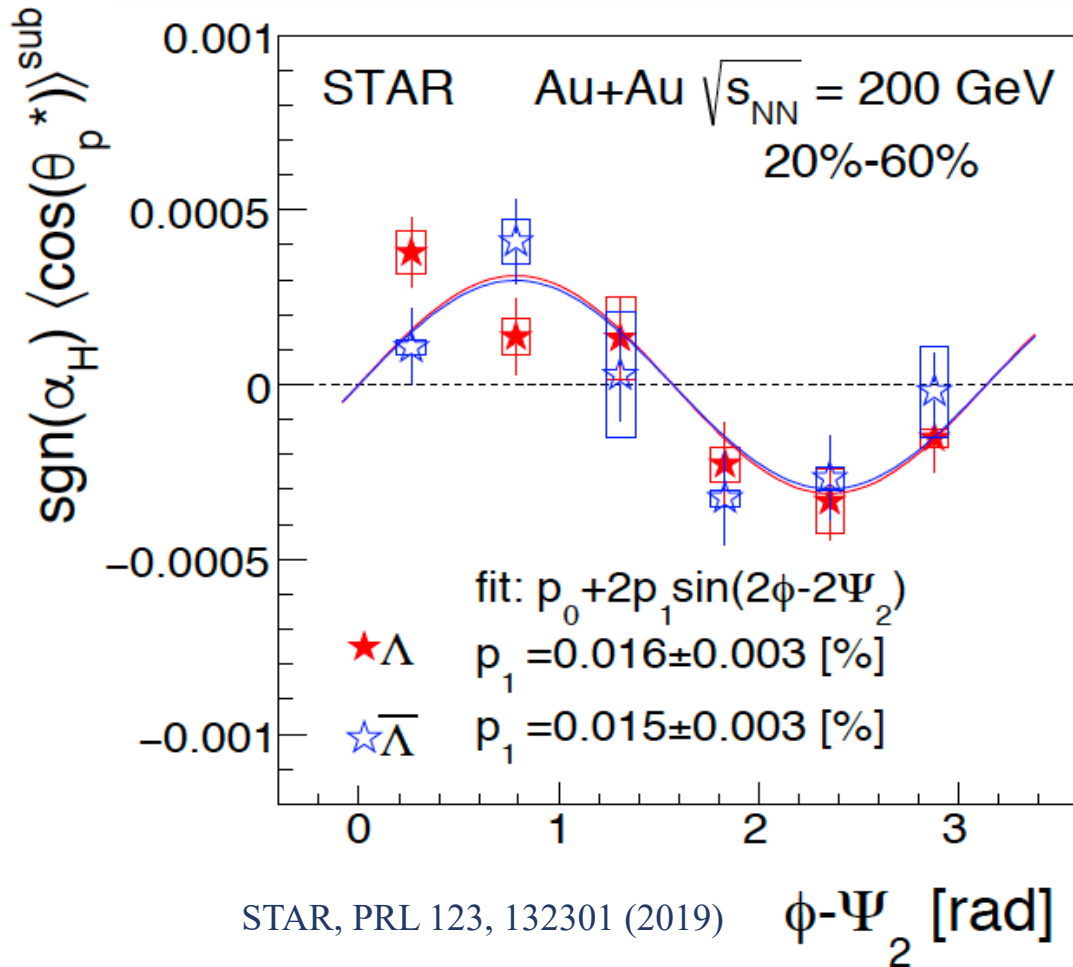
- Collision system size and energy dependence
- Measurements in smaller systems and relative to higher harmonic event planes provide new insights into polarization phenomena

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

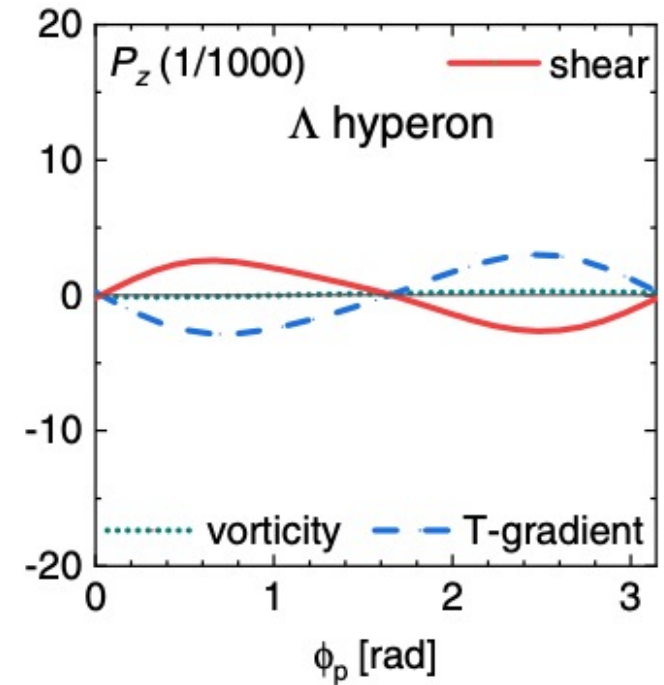
$$= \alpha_\Lambda P_z \langle (\cos\theta_p^*)^2 \rangle$$

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

# Local polarization in heavy ion collisions

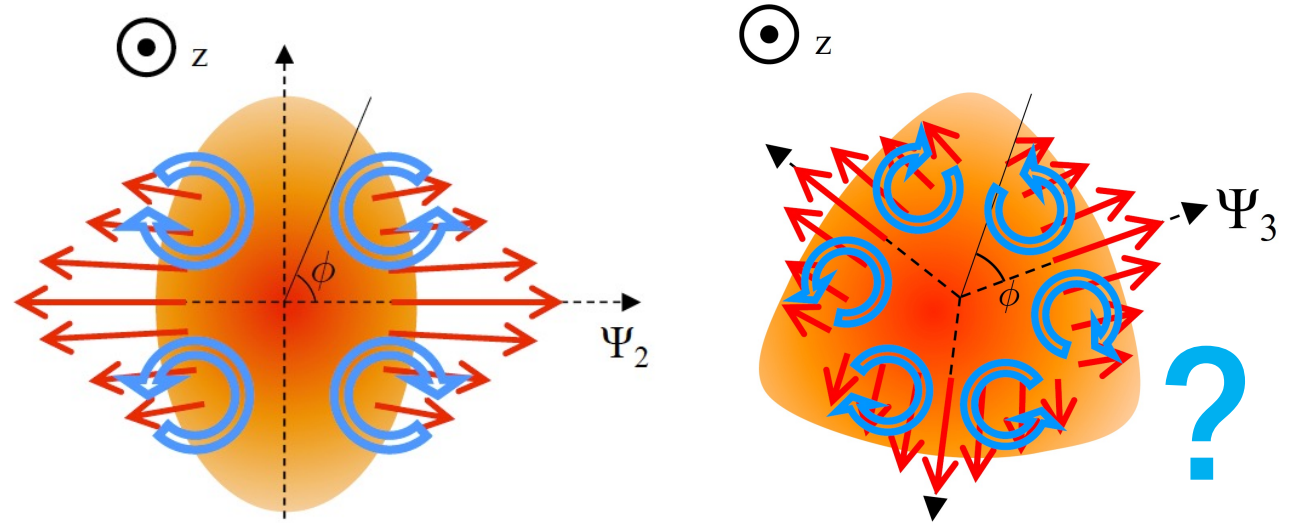
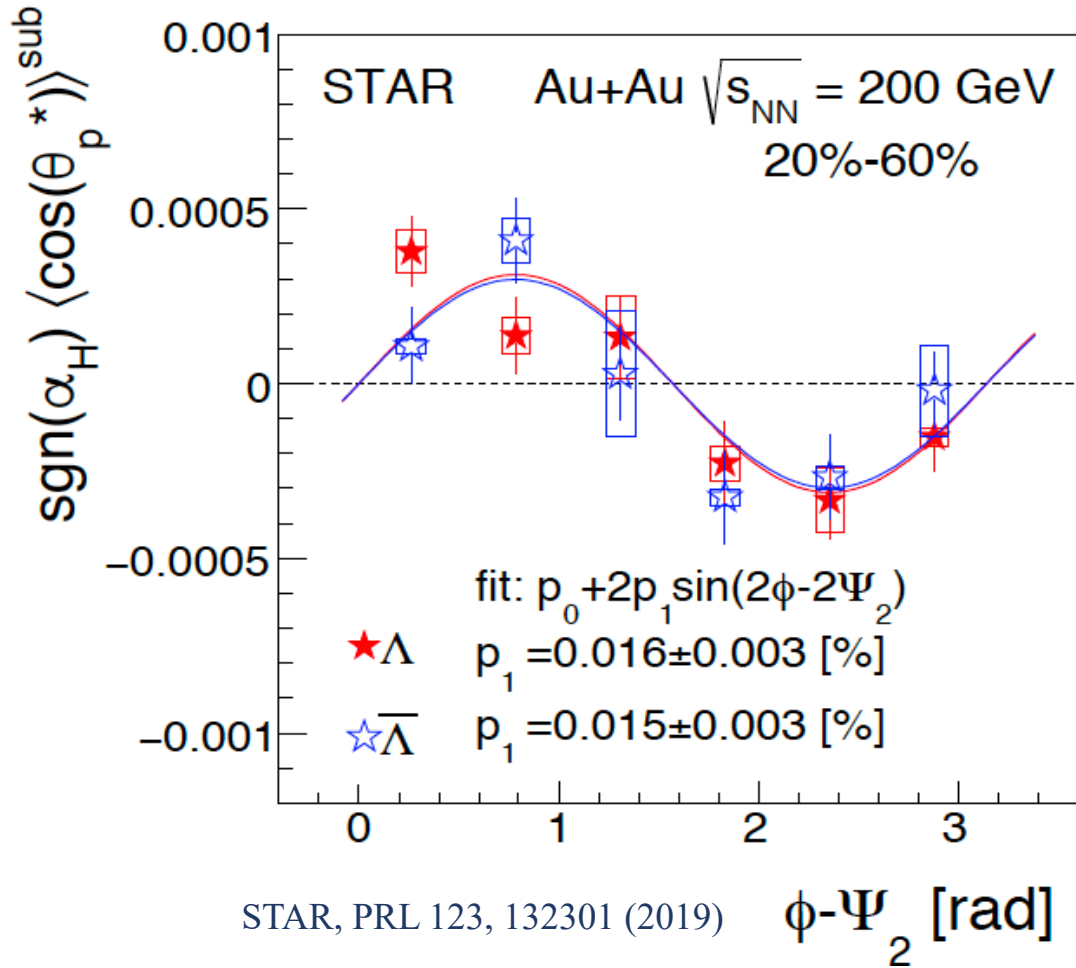


Baochi Fu et al., PRL 127, 142301 (2021)



- ▣ Collision system size and energy dependence
- ▣ Measurements in smaller systems and relative to higher harmonic event planes provide new insights into polarization phenomena

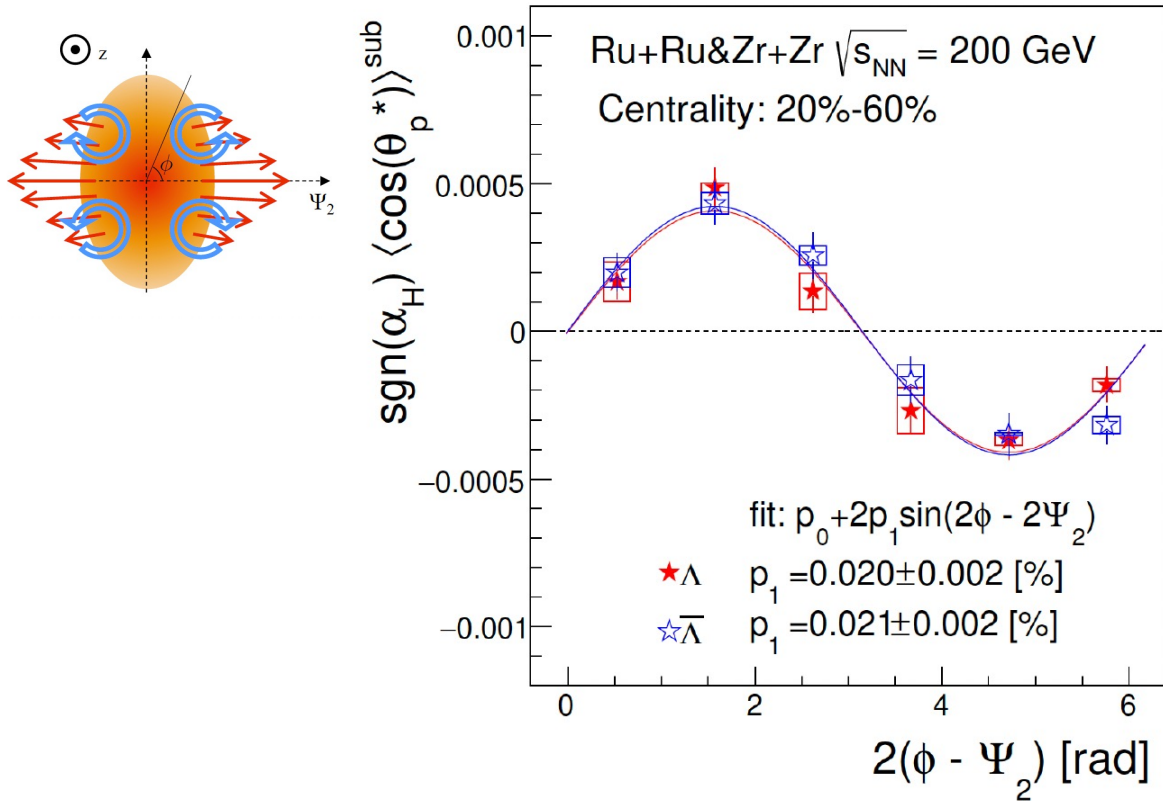
# Local polarization in heavy ion collisions



- Collision system size and energy dependence
- Measurements in smaller systems and relative to higher harmonic event planes provide new insights into polarization phenomena



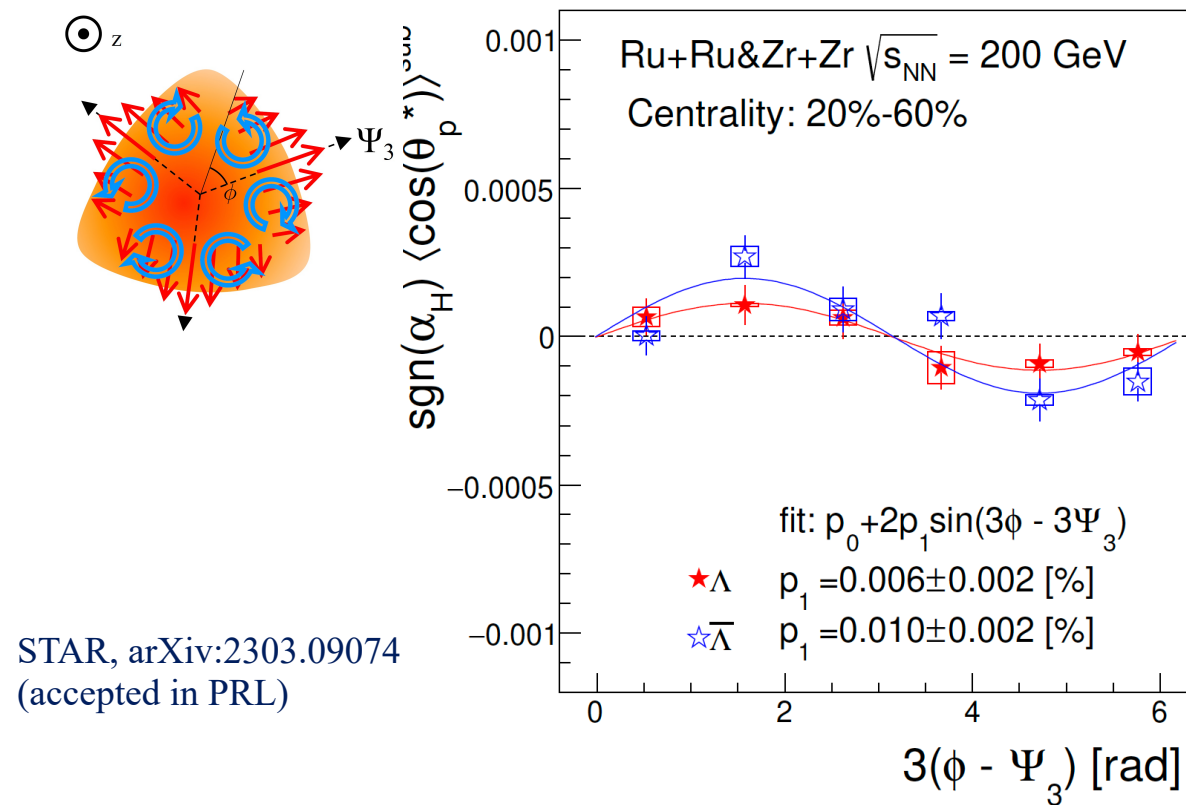
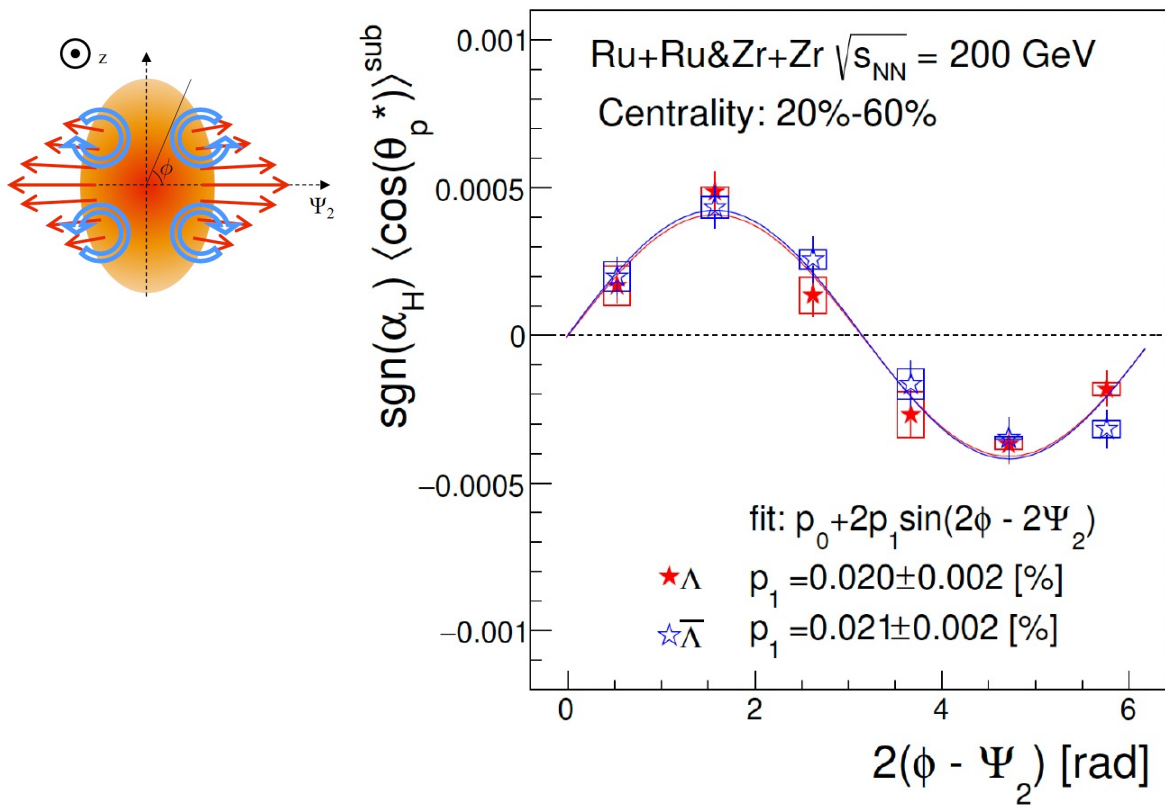
# Local polarization in Ru+Ru&Zr+Zr at 200 GeV



STAR, arXiv:2303.09074  
(accepted in PRL)

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

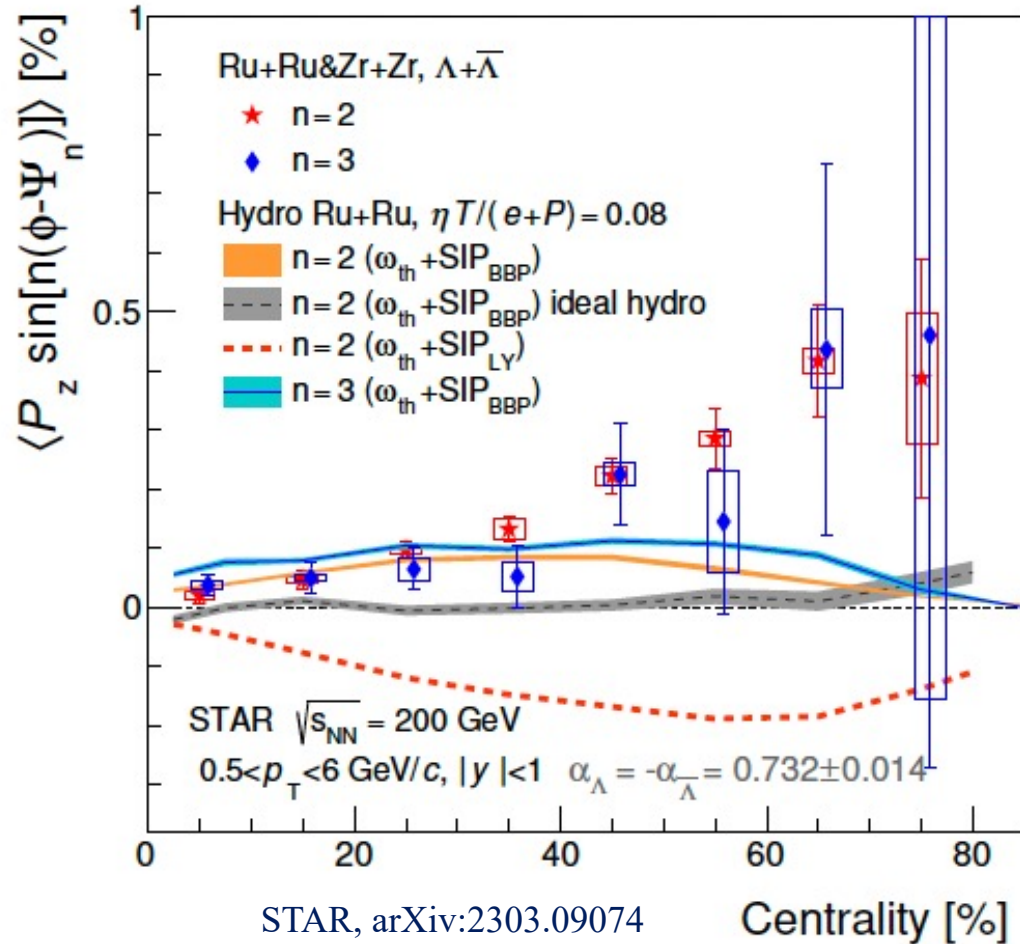
# Local polarization in Ru+Ru&Zr+Zr at 200 GeV



STAR, arXiv:2303.09074  
(accepted in PRL)

- 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 local polarization

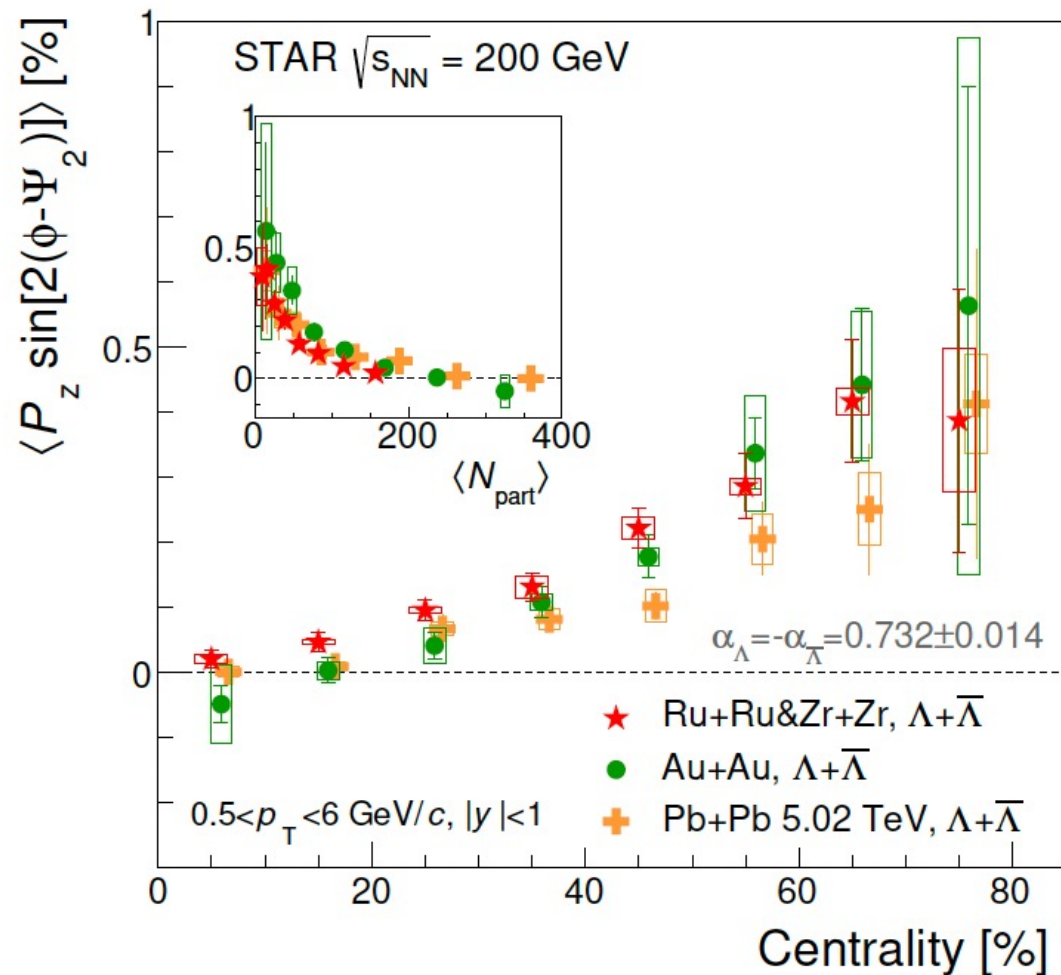


STAR, arXiv:2303.09074  
(accepted in PRL)

- Local polarization w.r.t second-order event plane increases with centrality
- Significant local polarization w.r.t third-order event plane
- Comparable local polarization w.r.t second and third order event plane
- Hydrodynamic models with shear term reasonably describe the data for central collisions, but not for peripheral

S. Alzhvani et al., PRC 106.014905

# Local polarization in different collisions



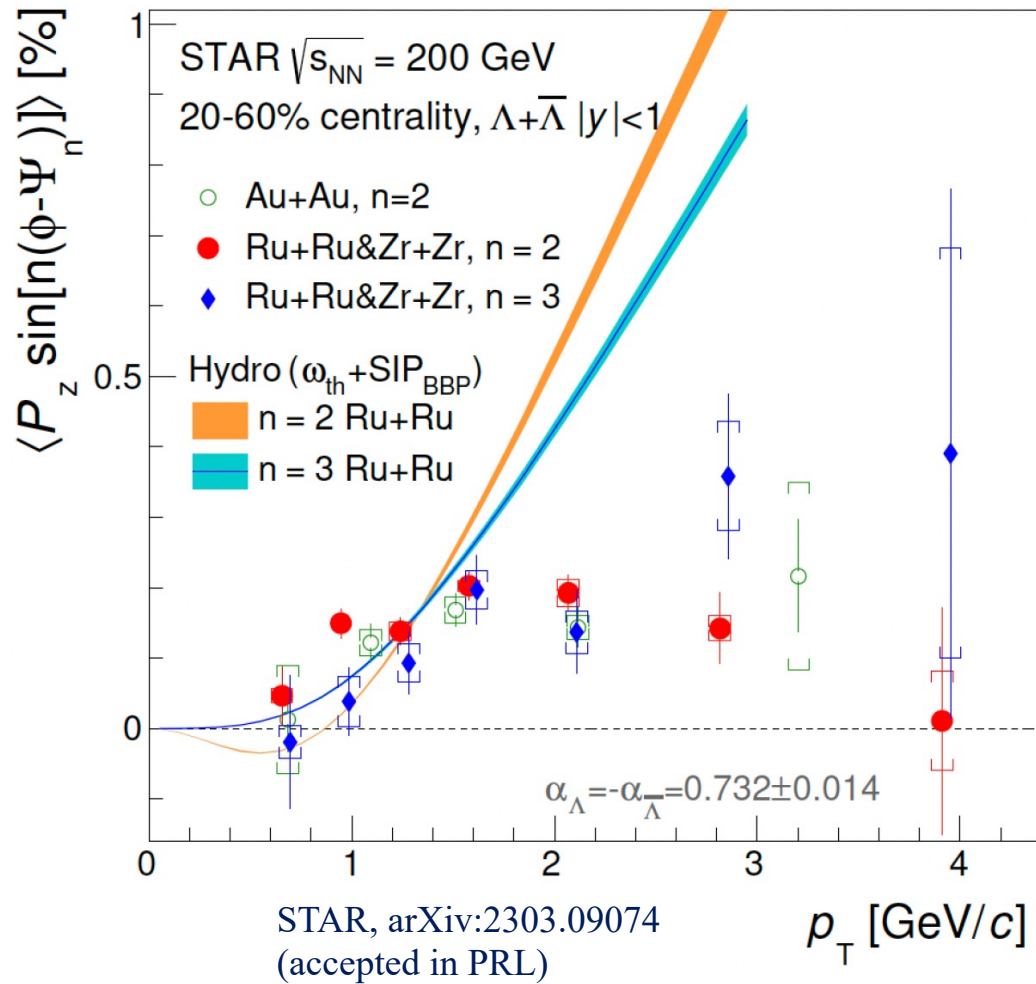
- Hint of system size dependence between isobar and Au+Au collisions
- Energy dependence is not obvious between 200 GeV Au+Au and 5.02 TeV Pb+Pb collisions

STAR, arXiv:2303.09074 (accepted in PRL)

Au+Au: STAR, PRL 123, 132301 (2019)

Pb+Pb: ALICE, arXiv:2107.11183

# $p_T$ dependence of local polarization



- Local polarization  $p_T$  dependence is observed
- Observed  $p_T$  dependence similar to that of elliptic ( $v_2$ ) and triangular ( $v_3$ ) flow
- Results are consistent between isobar and Au+Au collisions



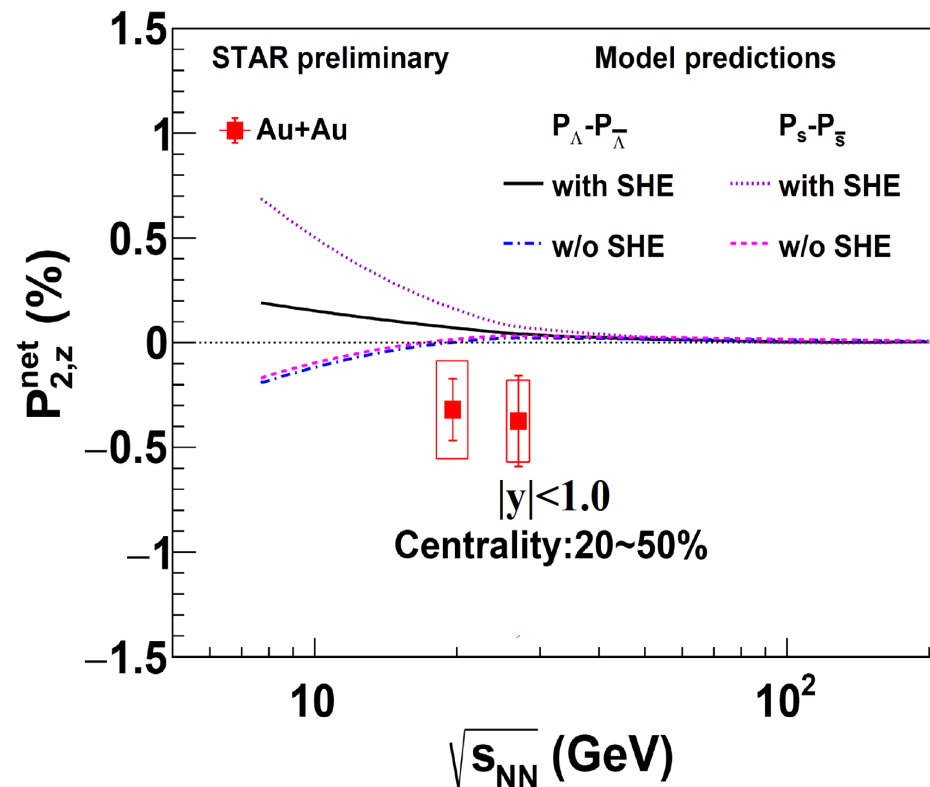
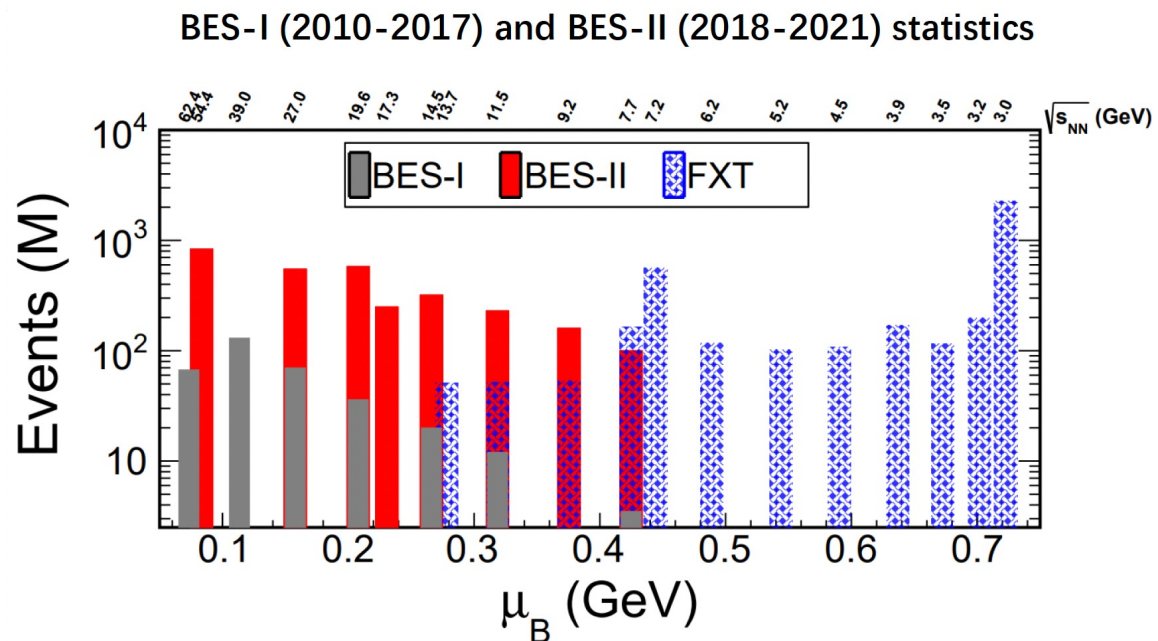
## *Global polarization*

- ❑ No splitting observed between  $\Lambda$  and  $\bar{\Lambda}$  global polarization in  ${}^{96}_{44}\text{Ru} + {}^{96}_{44}\text{Ru}$ ,  ${}^{96}_{40}\text{Zr} + {}^{96}_{40}\text{Zr}$  collisions
- ❑ No collision system size dependence between Ru+Ru, Zr+Zr and Au+Au collisions at 200 GeV

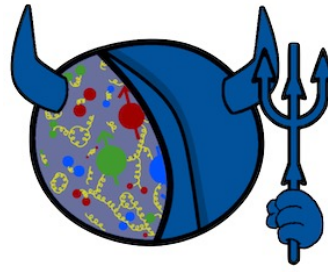
## *Local polarization*

- ❑ First observation of local polarization w.r.t third-order event plane in isobar collisions at 200 GeV
- ❑ Hint of collision system size dependence of local polarization when comparing between isobar and Au+Au
- ❑ Local polarization  $p_T$  dependence is observed, trend are similar to that of elliptic ( $v_2$ ) and triangular ( $v_3$ ) flow

Model predictions from Baochi Fu et al., arXiv:2201.12970v1



- Hyperon local polarization collision energy dependence in BES-II?
- First study of baryonic spin Hall effect by measuring net local polarization



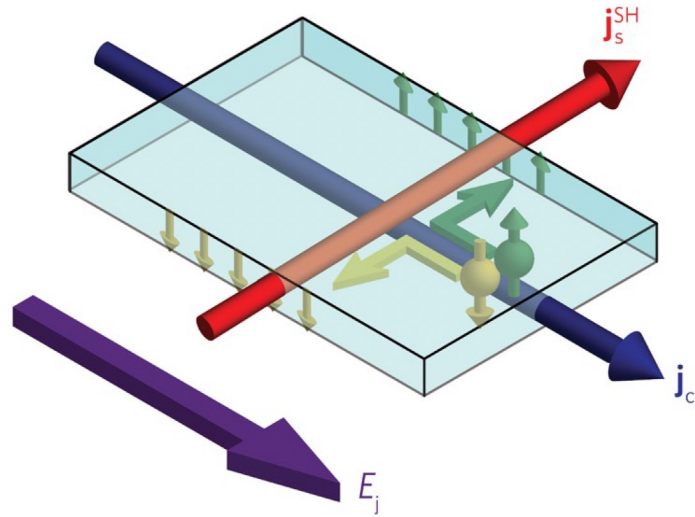
山东大学  
SHANDONG UNIVERSITY

*Thanks for your attention*

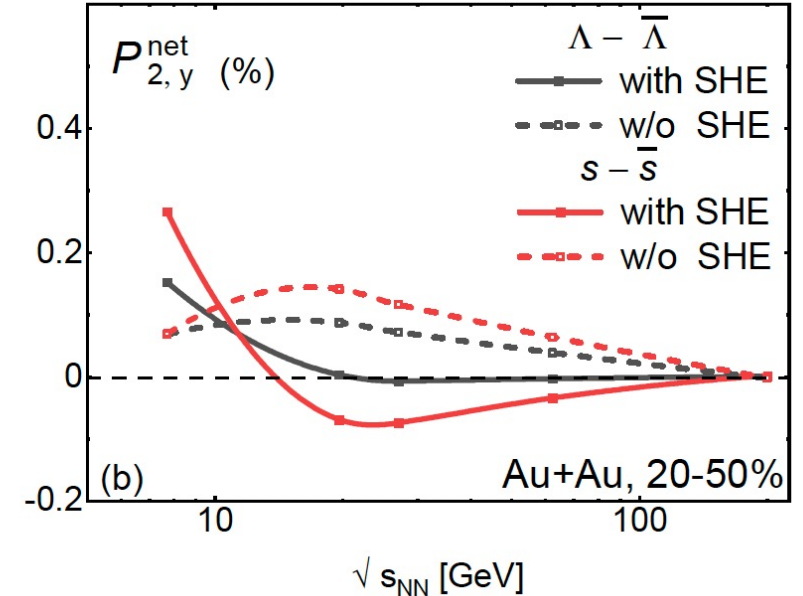
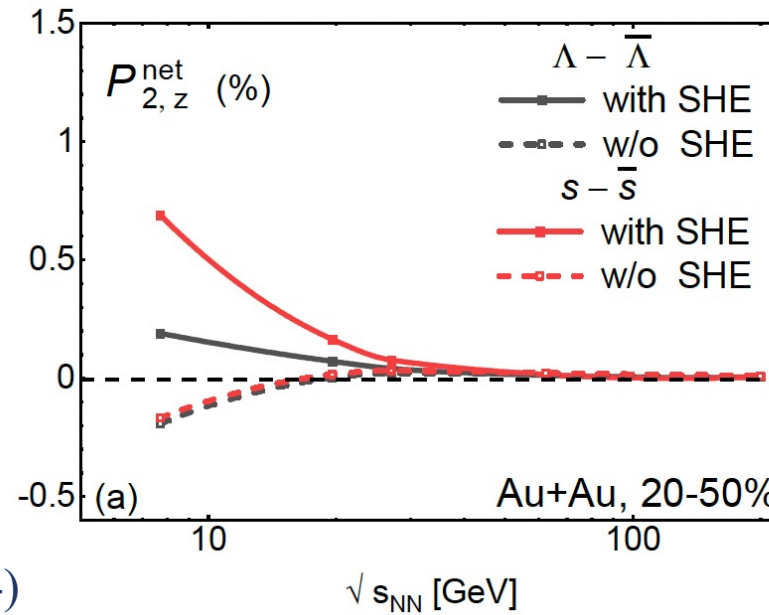
# Outlook - Baryonic Spin Hall Effect (SHE)



Baochi Fu et al., arXiv:2201.12970v1



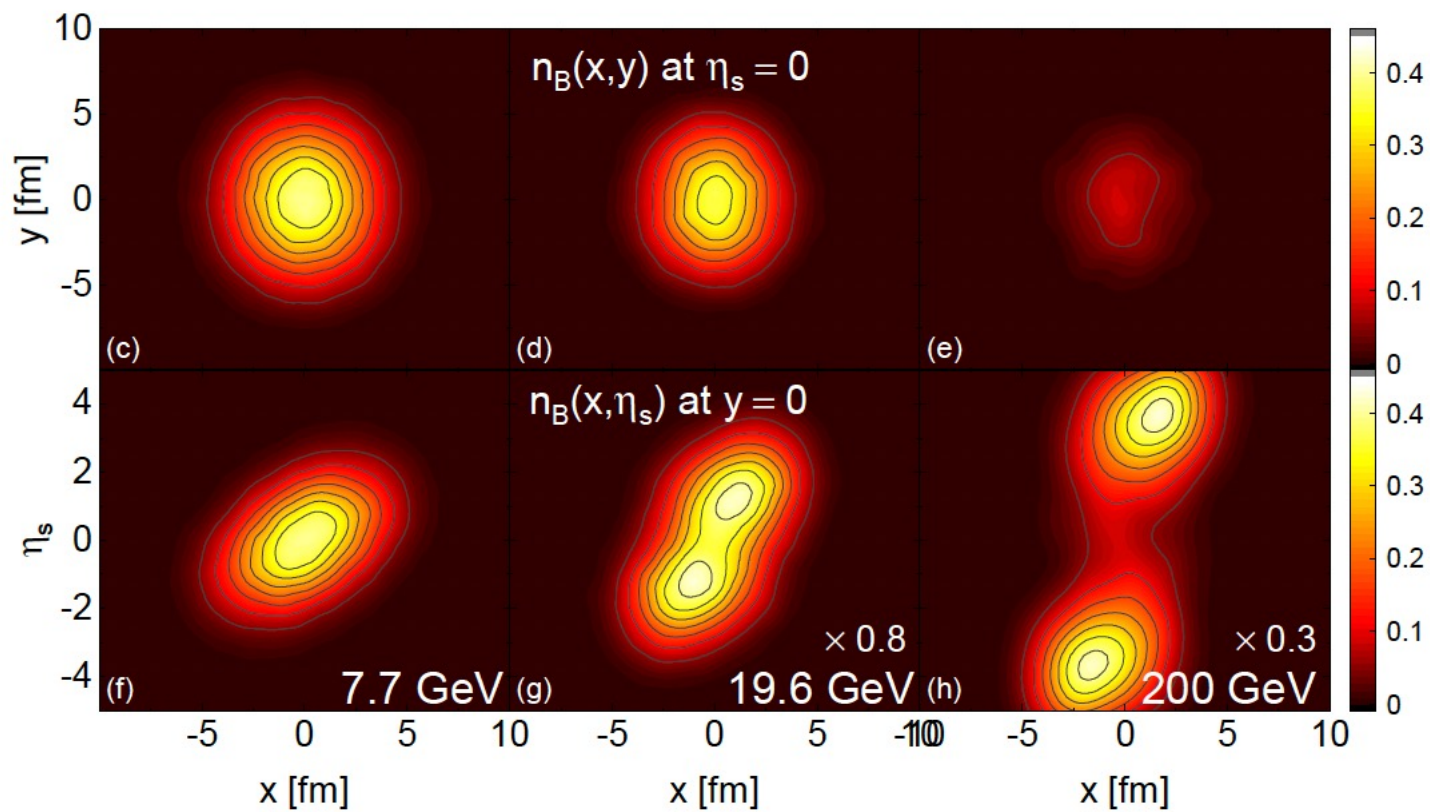
Spin Hall effect : spin imbalance (2004)



$$P_{2,z}^{net} \equiv \langle P_z^{\Lambda - \bar{\Lambda}} \sin(2\phi_\Lambda - 2\Psi_2) \rangle$$

$$P_{2,y}^{net} \equiv \langle P_y^{\Lambda - \bar{\Lambda}} \cos(2\phi_\Lambda - 2\Psi_2) \rangle$$

□ Probing baryonic spin Hall effect in heavy-ion collisions via  $\Lambda / \bar{\Lambda}$  local polarization



Baochi Fu et al., arXiv:2201.12970v1