



中国物理学会高能物理分会  
HIGH ENERGY PHYSICS BRANCH OF CPS

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

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Shandong University (山东大学)

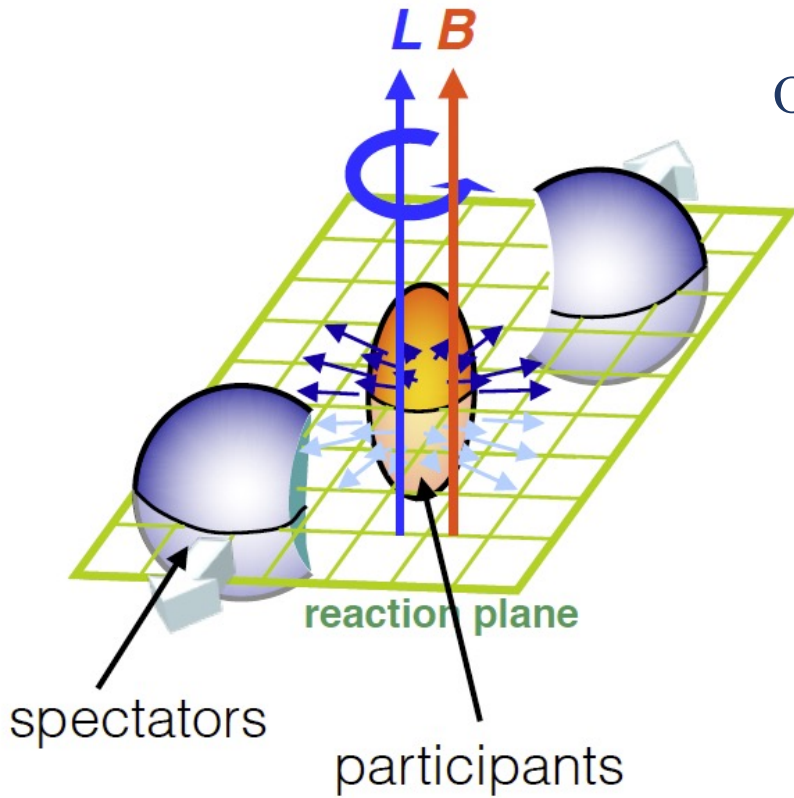


山东大学  
SHANDONG UNIVERSITY



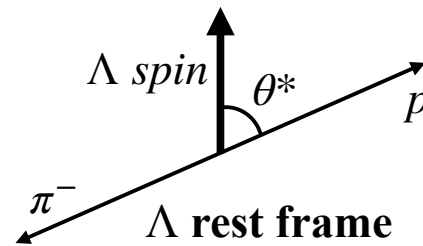
- Motivation
- Hyperon global polarization
- Hyperon local polarization
- Summary

# Global polarization of hyperons in heavy ion collisions



Orbital angular momentum  
 ↳ Lead to global polarization

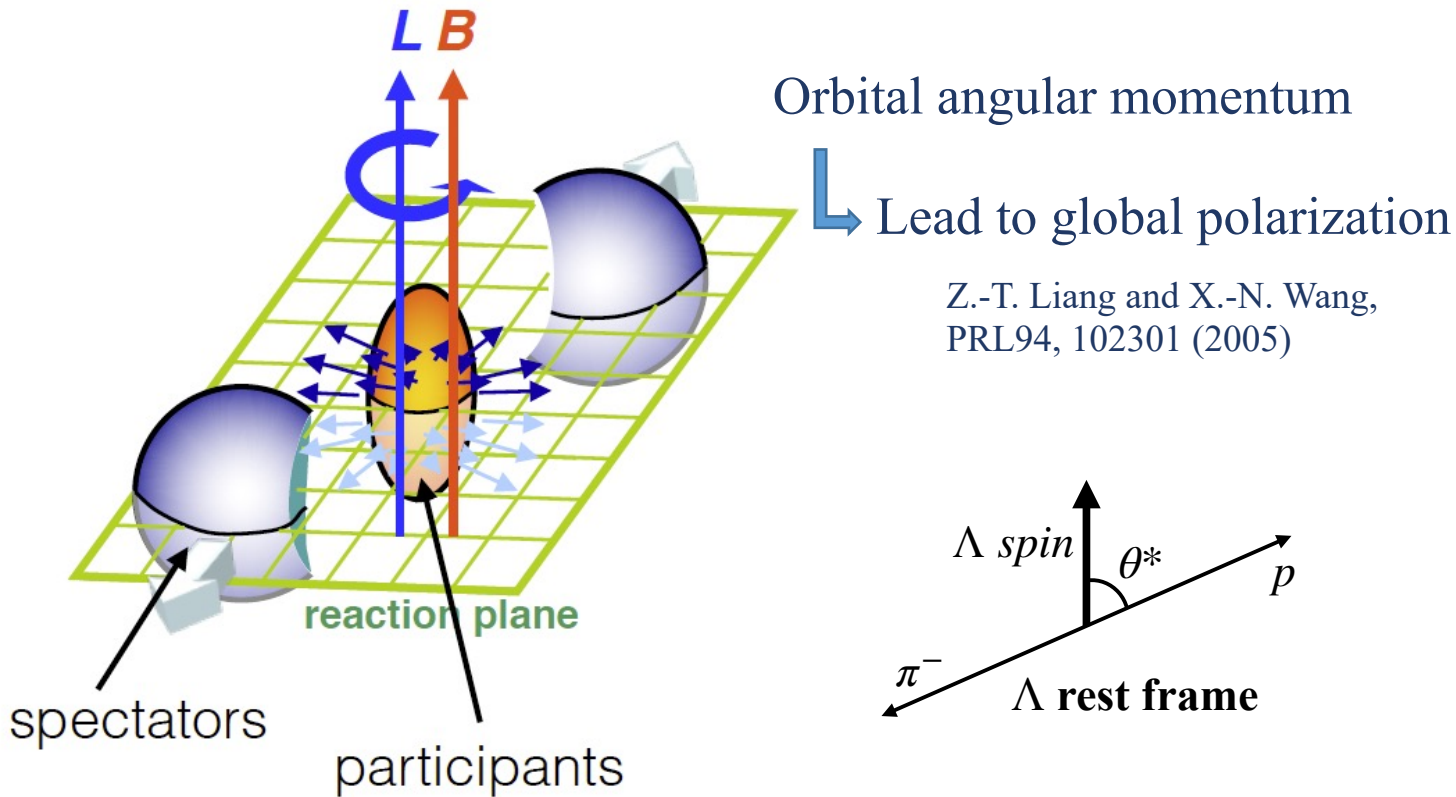
Z.-T. Liang and X.-N. Wang,  
 PRL94, 102301 (2005)



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

$\alpha_{\Lambda} = -\alpha_{\bar{\Lambda}} = 0.732 \pm 0.014$   
 $A_0$ : Acceptance correction factor  
 $\Psi_1$ : First - order event plane angle

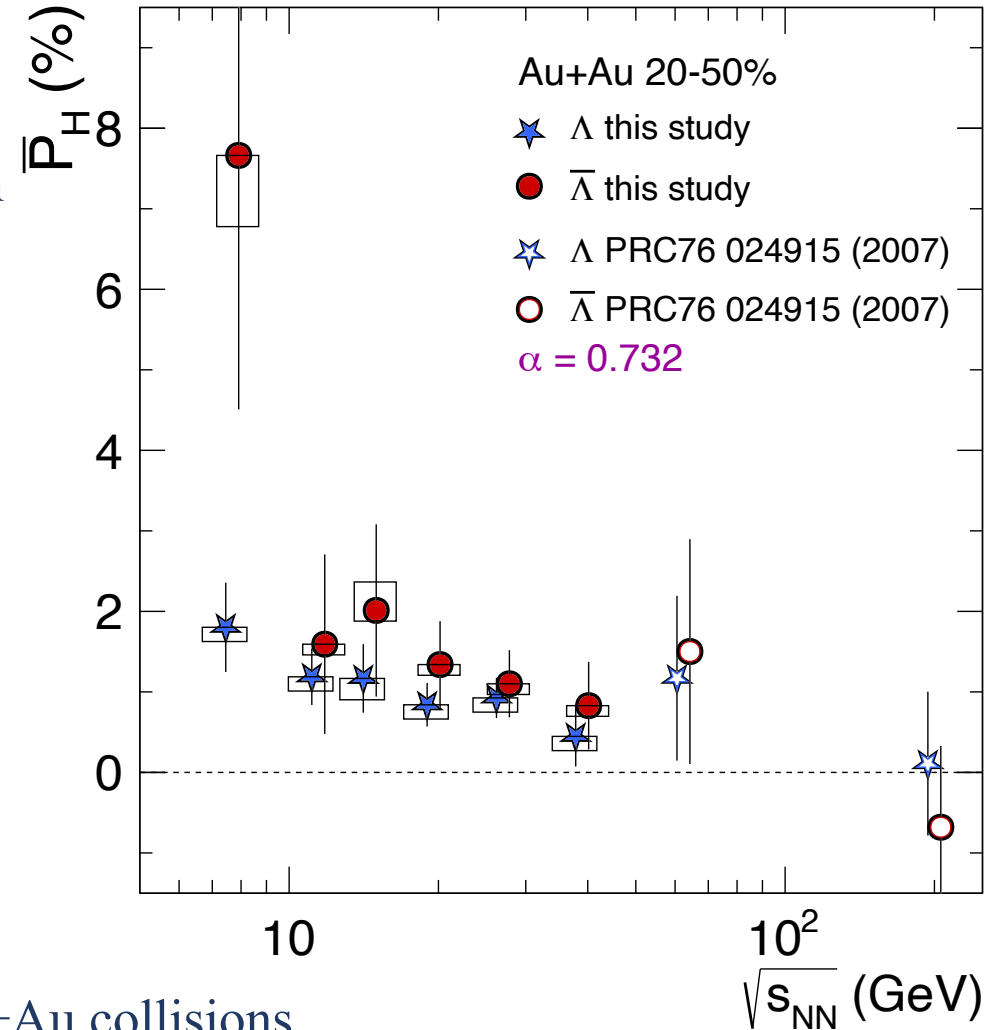
# Global polarization of hyperons in heavy ion collisions



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STAR, Nature 548, 62-65

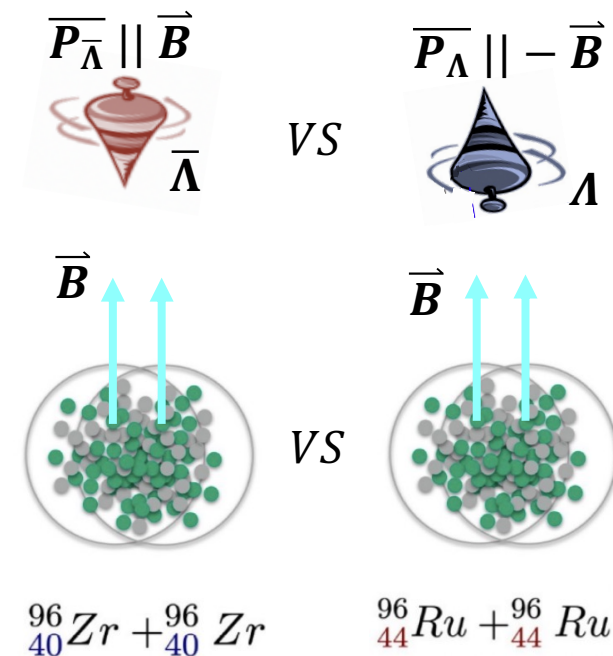
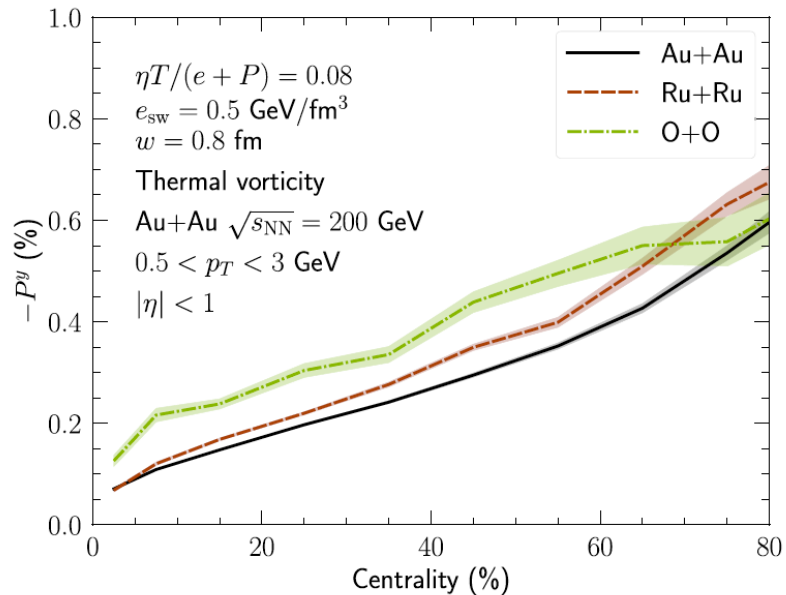
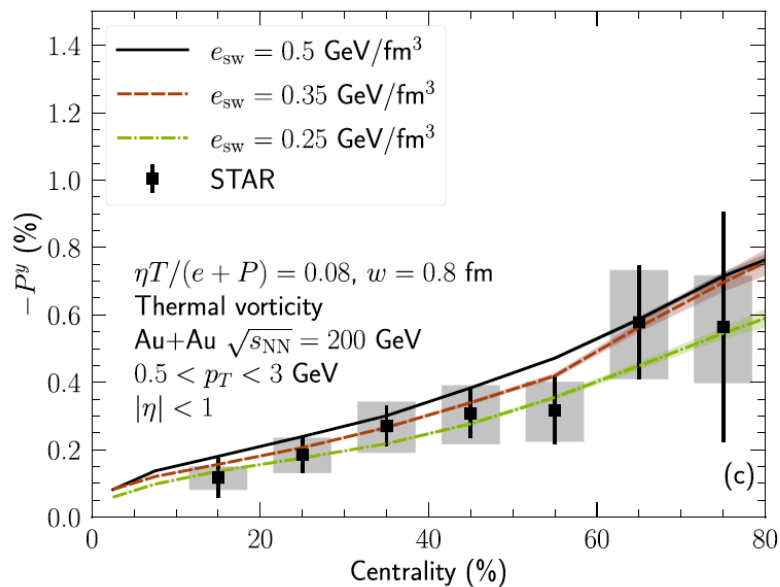


Significant global polarization of  $\Lambda$  and  $\bar{\Lambda}$  observed in Au+Au collisions.

# Global polarization of hyperons in heavy ion collisions



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



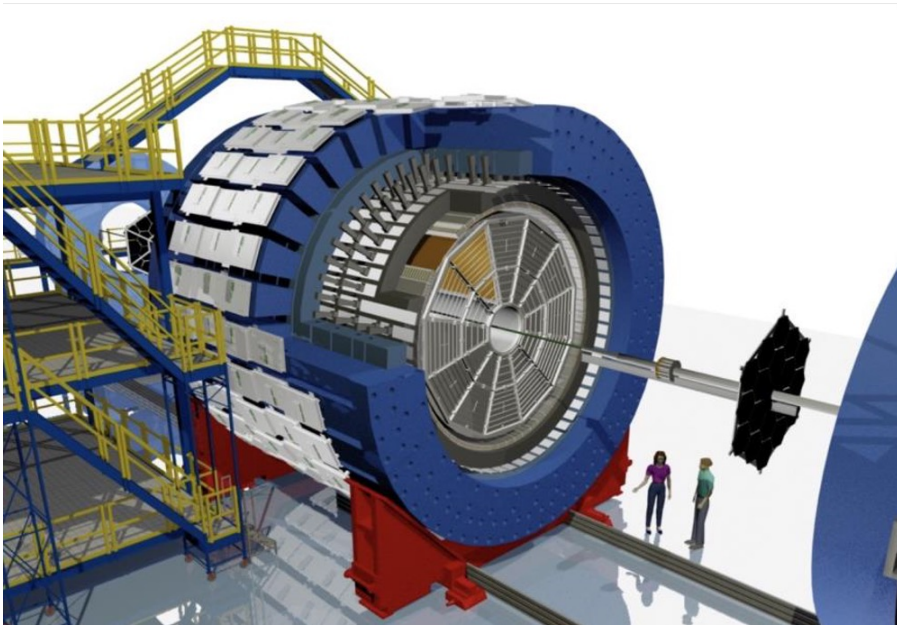
## Global Polarization from different models:

- Li, Pang, Wang, Xia PRC(2017);      Xie, Wang, Csernai, PRC(2017);
- Sun, Ko, PRC(2017);      Shi, Li, Liao, PLB(2018);      Wei, Deng, Huang, PRC(2019);
- B.C. Fu, K. Xu, X.G. Huang, H.C. Song, Phys. Rev. C 103, 024903 (2021);
- S. Ryu, V. Jovic, C. Shen, arXiv:2106.08125;      Y.X. Wu, C. Yi, G.Y. Qin, SP arXiv:2204.02218;

□ System size dependence of global polarization?

□ Global polarization difference from different magnetic fields in Zr+Zr and Ru+Ru?

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



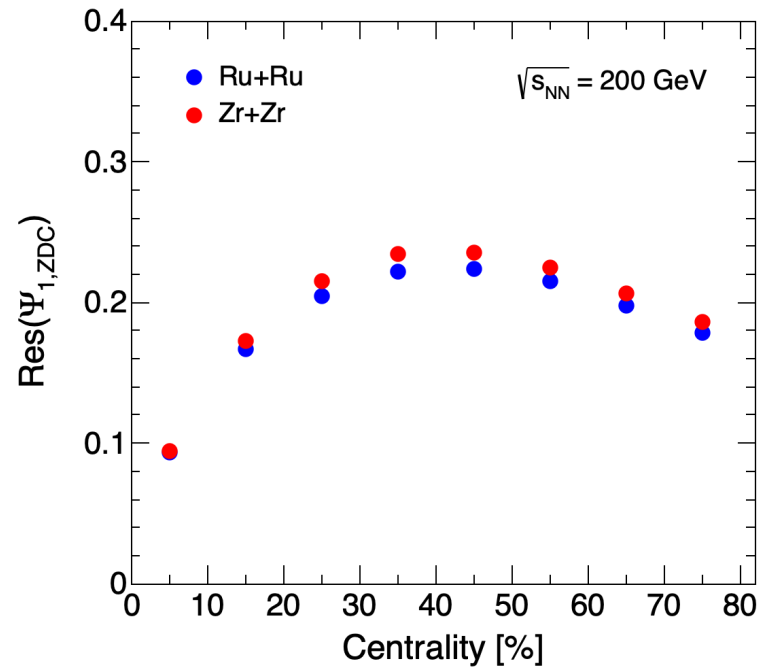
## Event plane reconstruction:

Time Projection Chamber  
Zero Degree Calorimeters

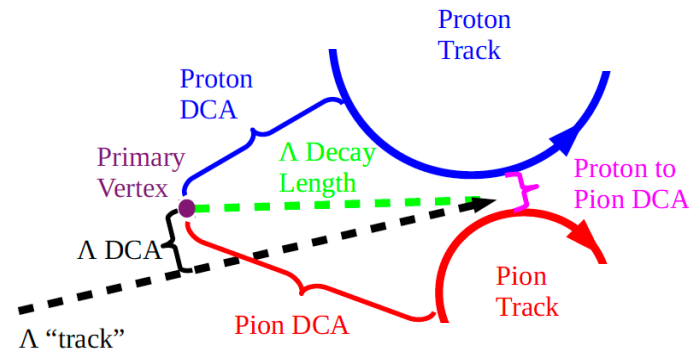
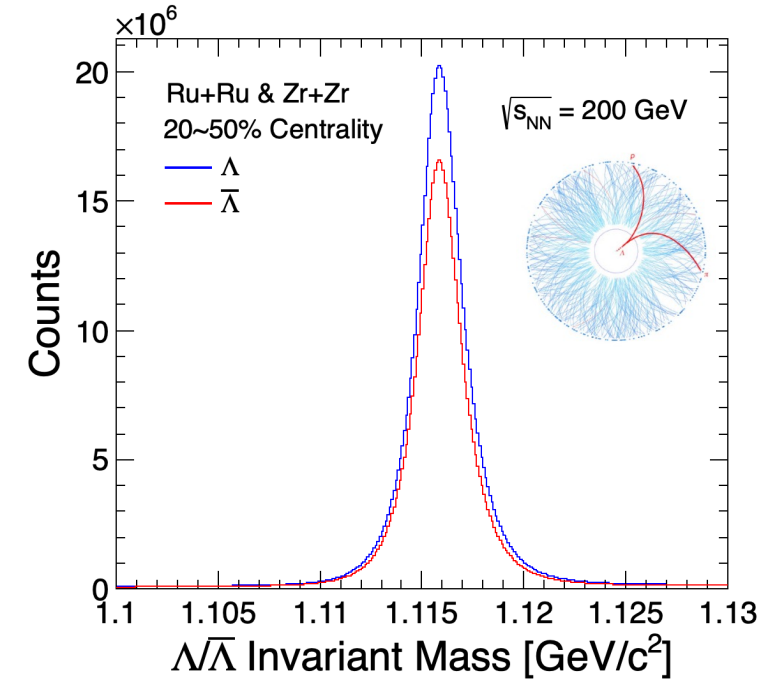
## $\Lambda/\bar{\Lambda}$ reconstruction:

Time Projection Chamber  
Time Of Flight

## Event plane resolution



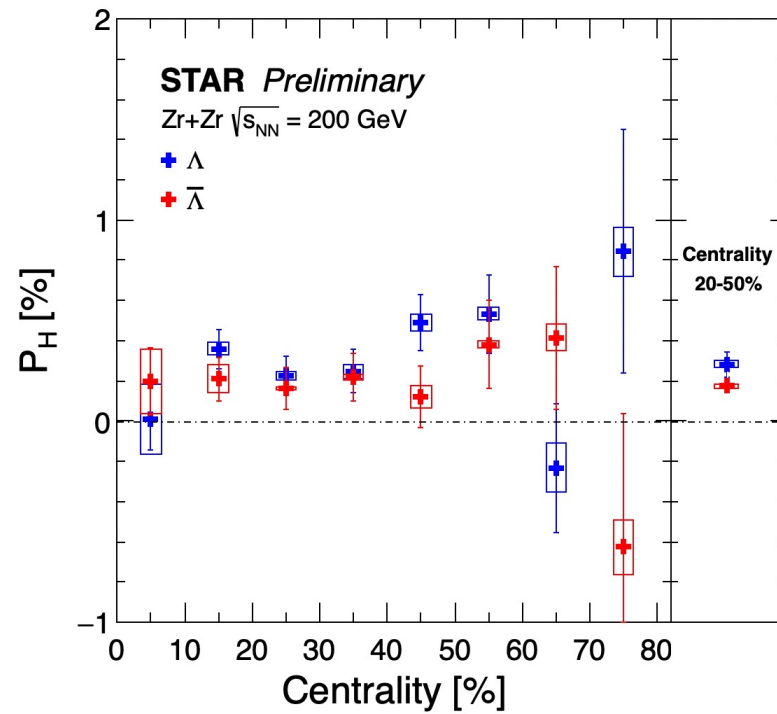
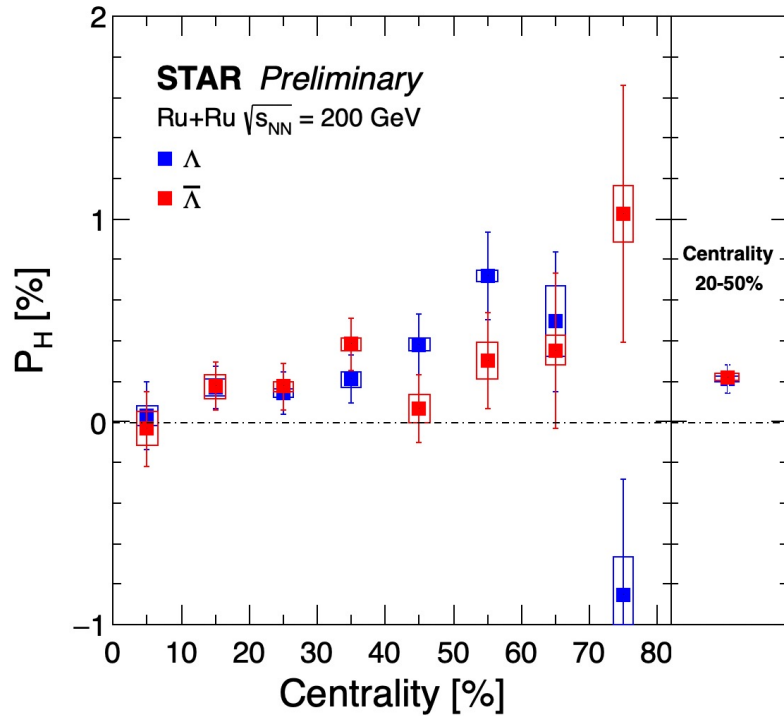
## $\Lambda/\bar{\Lambda}$ reconstructed with TPC tracks



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

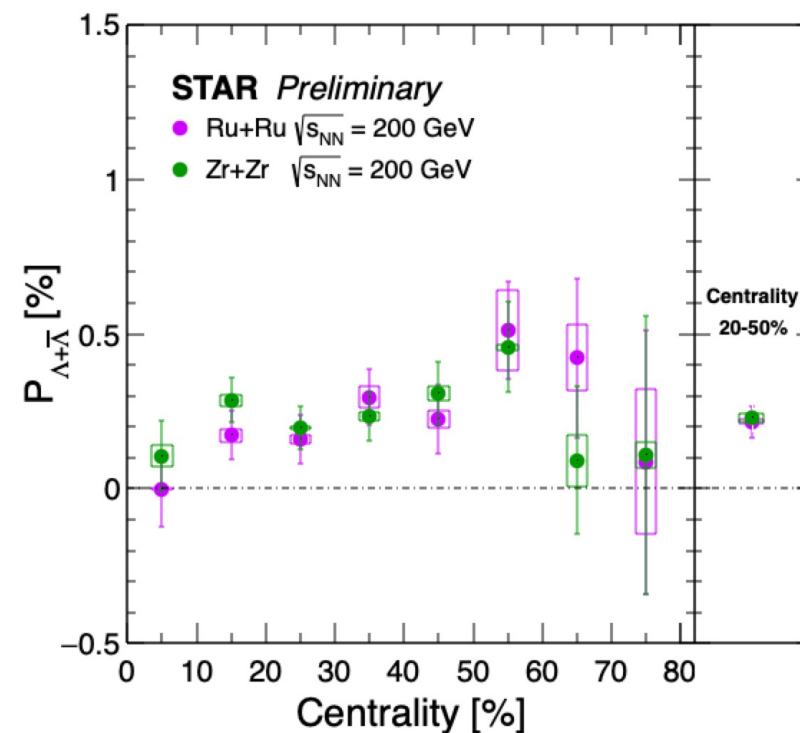
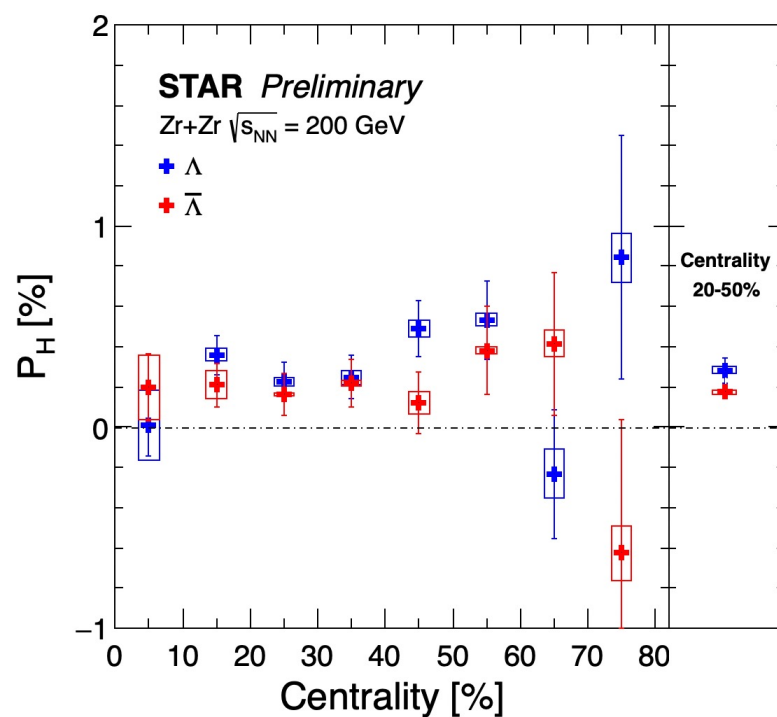
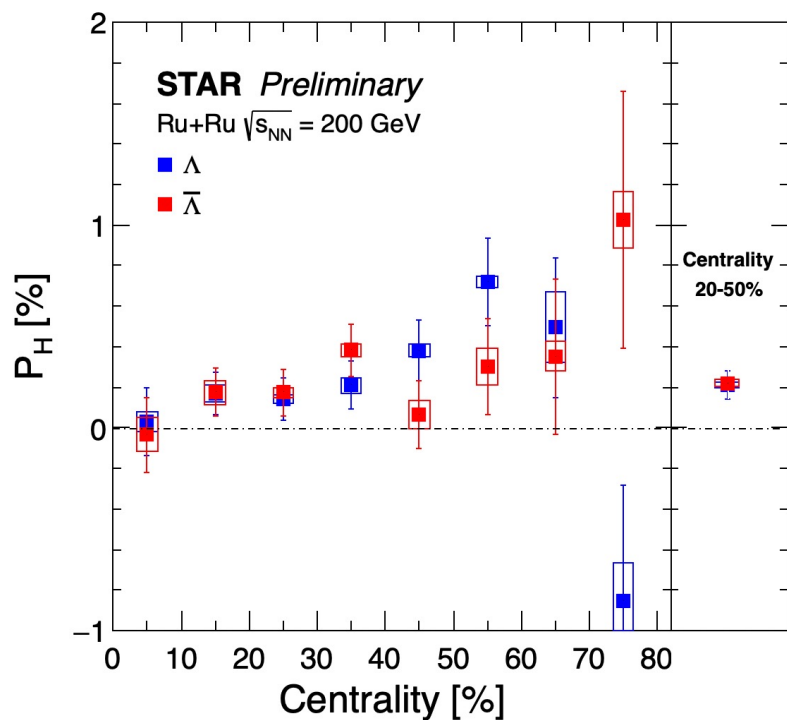


# Global polarization of $\Lambda$ and $\bar{\Lambda}$ in isobar collisions



- 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

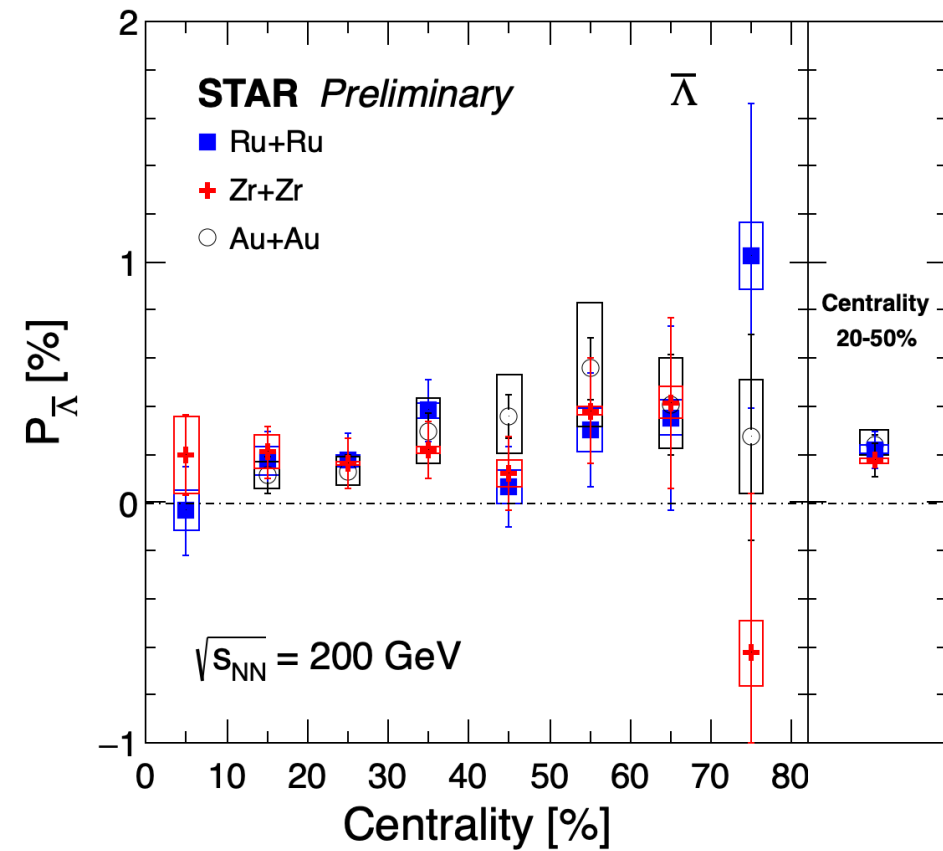
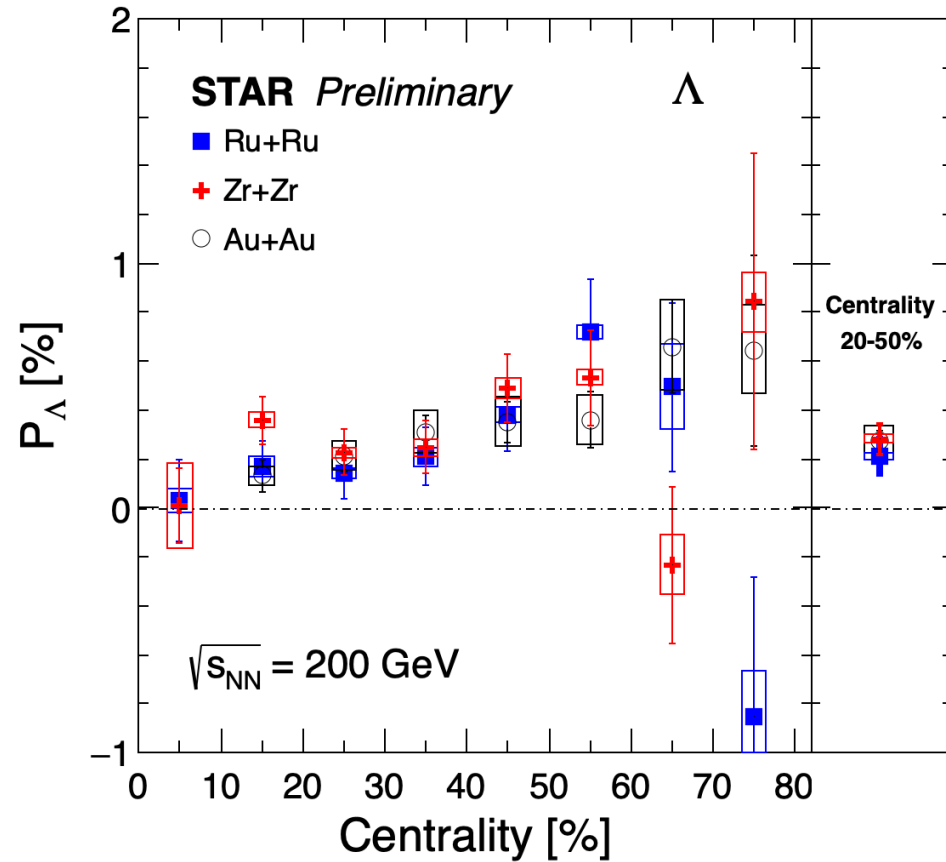
# Global polarization of $\Lambda$ and $\bar{\Lambda}$ in isobar collisions



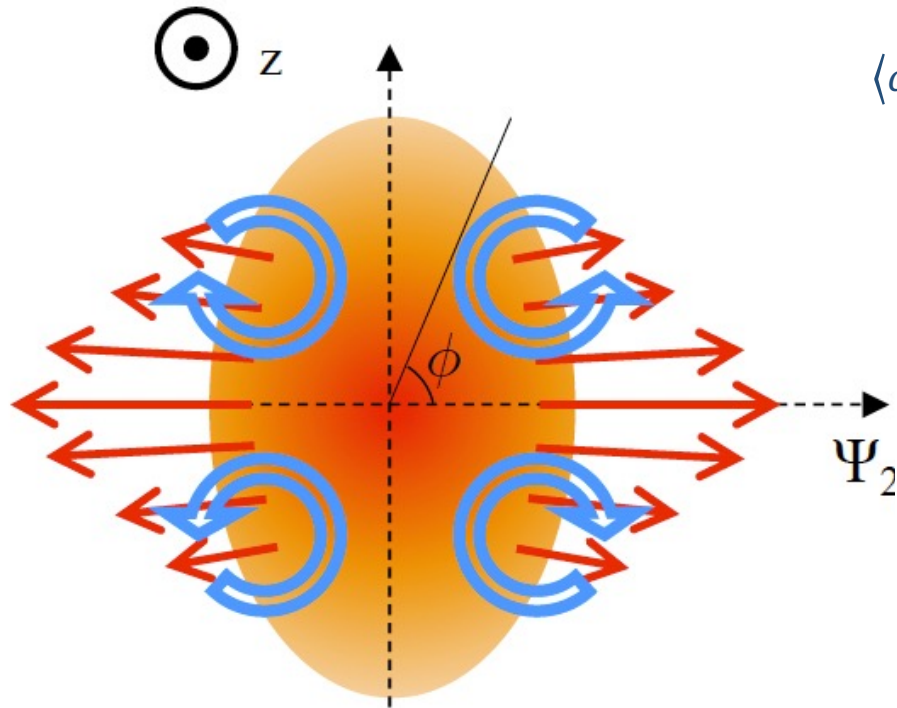
- Significant global polarization observed,  $P_{\Lambda}$  and  $P_{\bar{\Lambda}}$  increase with centrality
- No significant difference between  $P_{\Lambda}$  and  $P_{\bar{\Lambda}}$  in Ru+Ru and Zr+Zr collisions
- Global polarization of  $\Lambda + \bar{\Lambda}$  are consistent between Ru+Ru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



# Global polarization of hyperons in isobar and Au+Au collisions



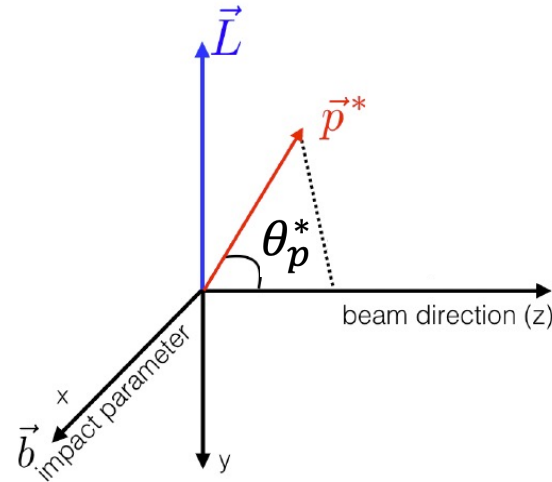
- Global polarization of  $\Lambda$  and  $\bar{\Lambda}$  are consistent between isobar and Au+Au collision systems
- No collision system size dependence is observed



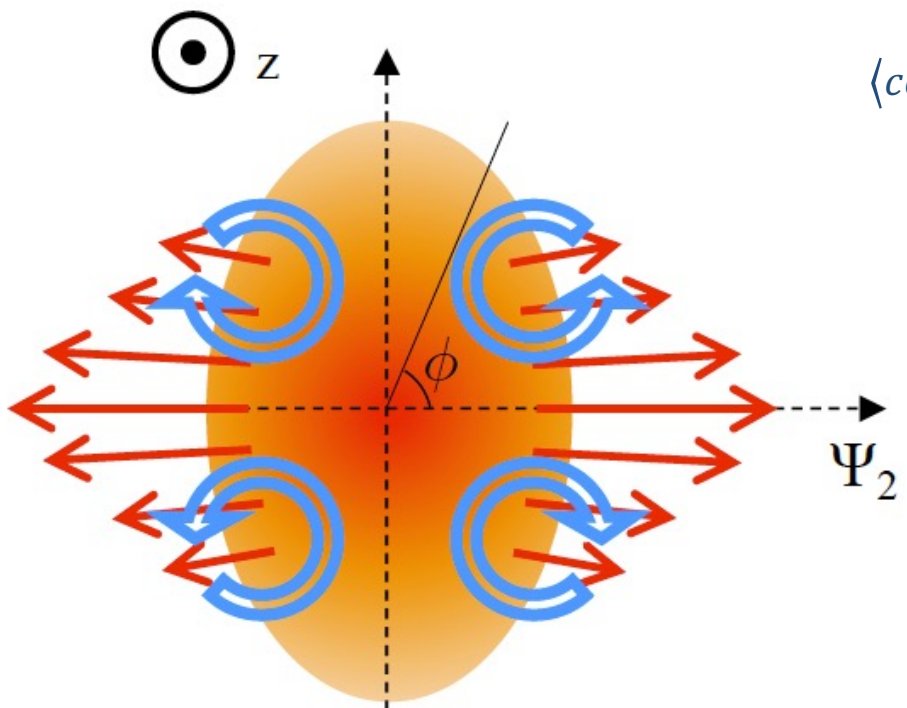
$$\langle \cos\theta_p^* \rangle = \int \frac{dN}{d\Omega^*} \cos\theta_p^* d\Omega^*$$

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

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



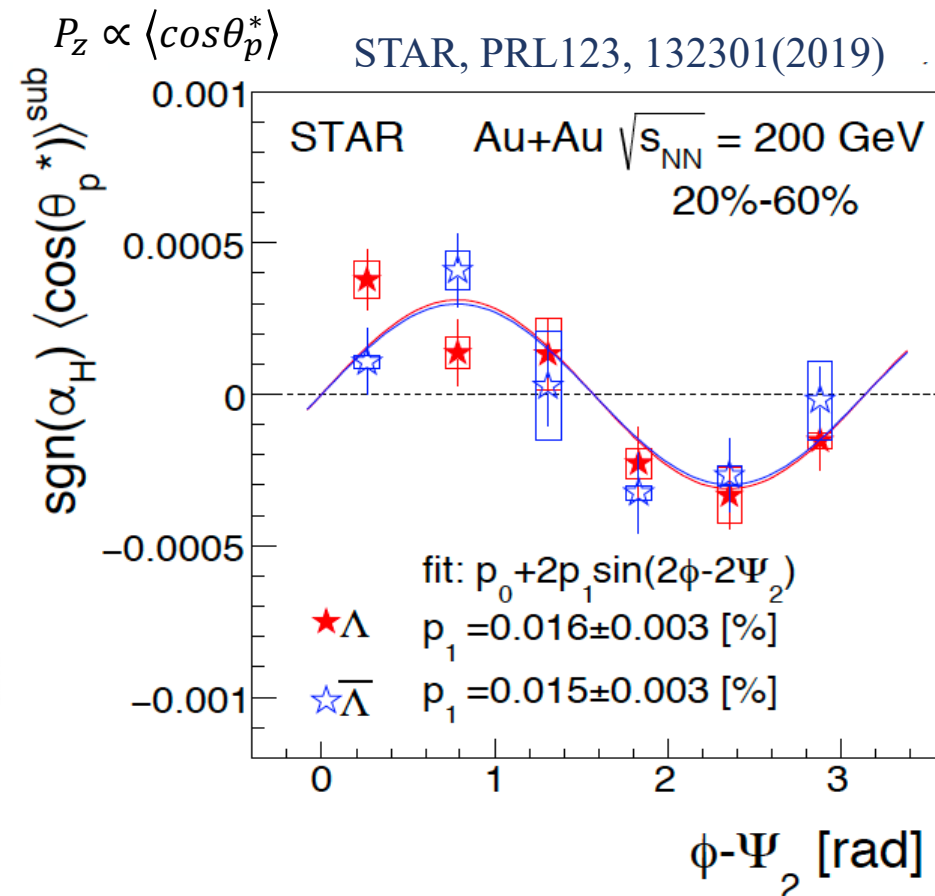
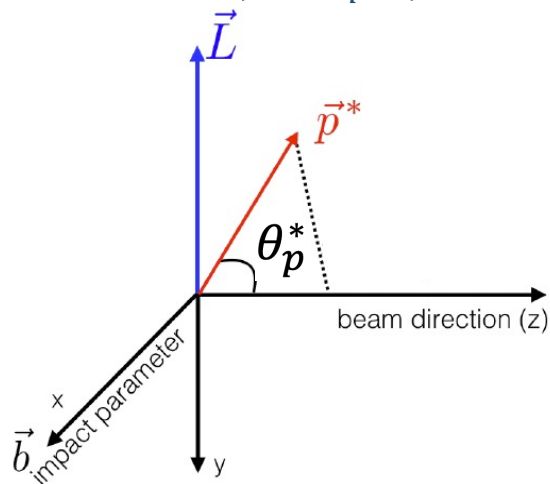
- ❑ Polarization along the beam direction expected from the “elliptic flow”
- ❑ STAR has observed the local polarization with second order event plane in Au+Au collisions



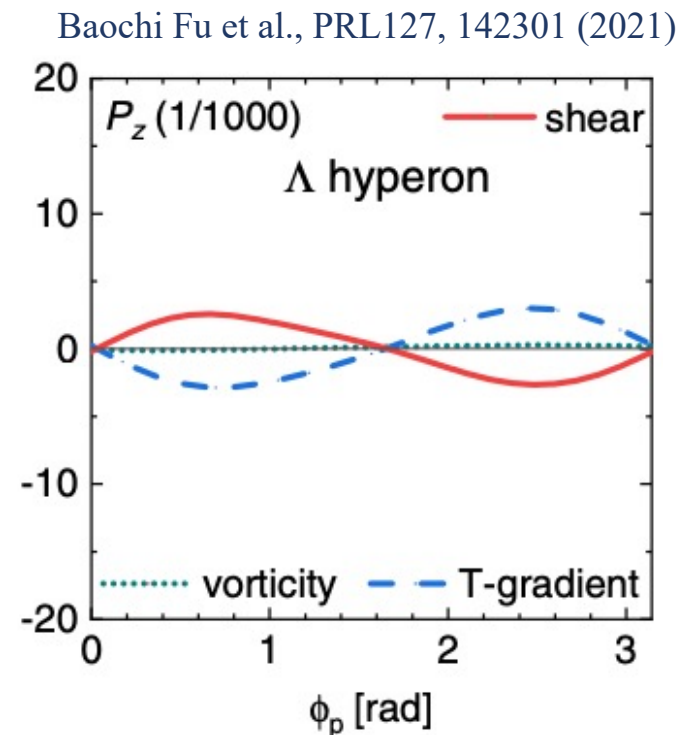
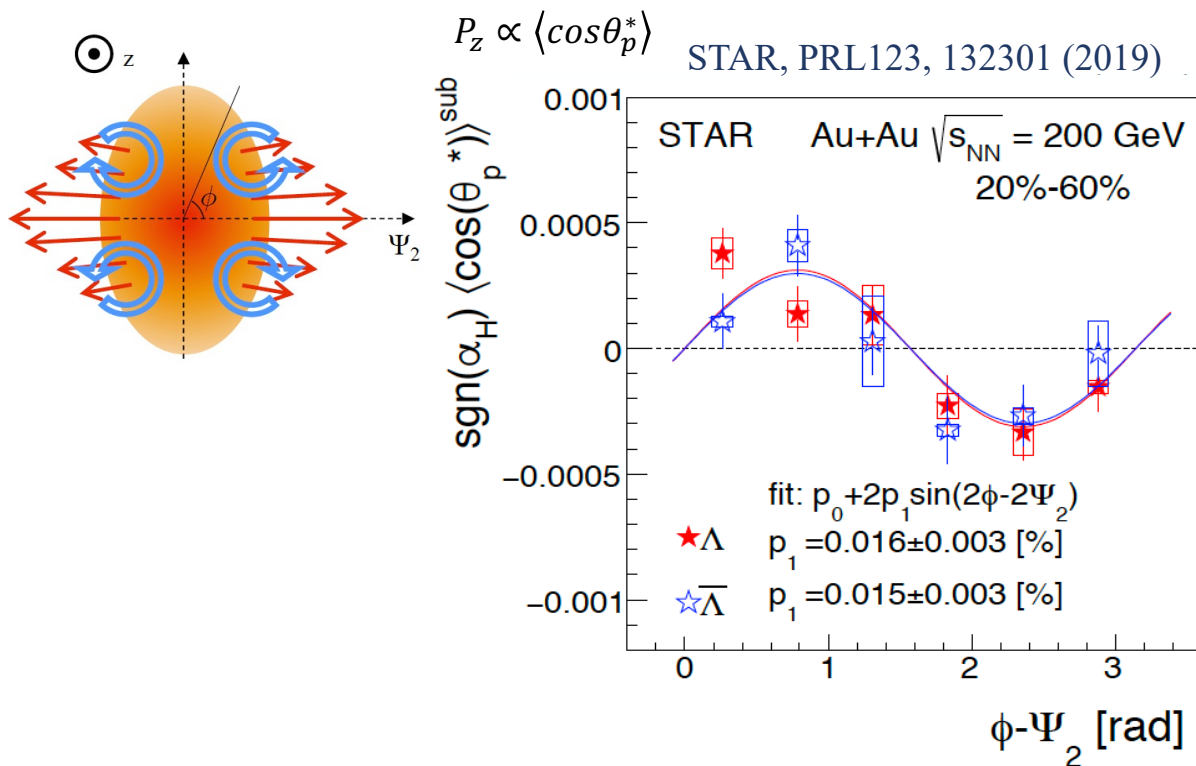
$$\langle \cos\theta_p^* \rangle = \int \frac{dN}{d\Omega^*} \cos\theta_p^* d\Omega^*$$

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

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



- Local 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

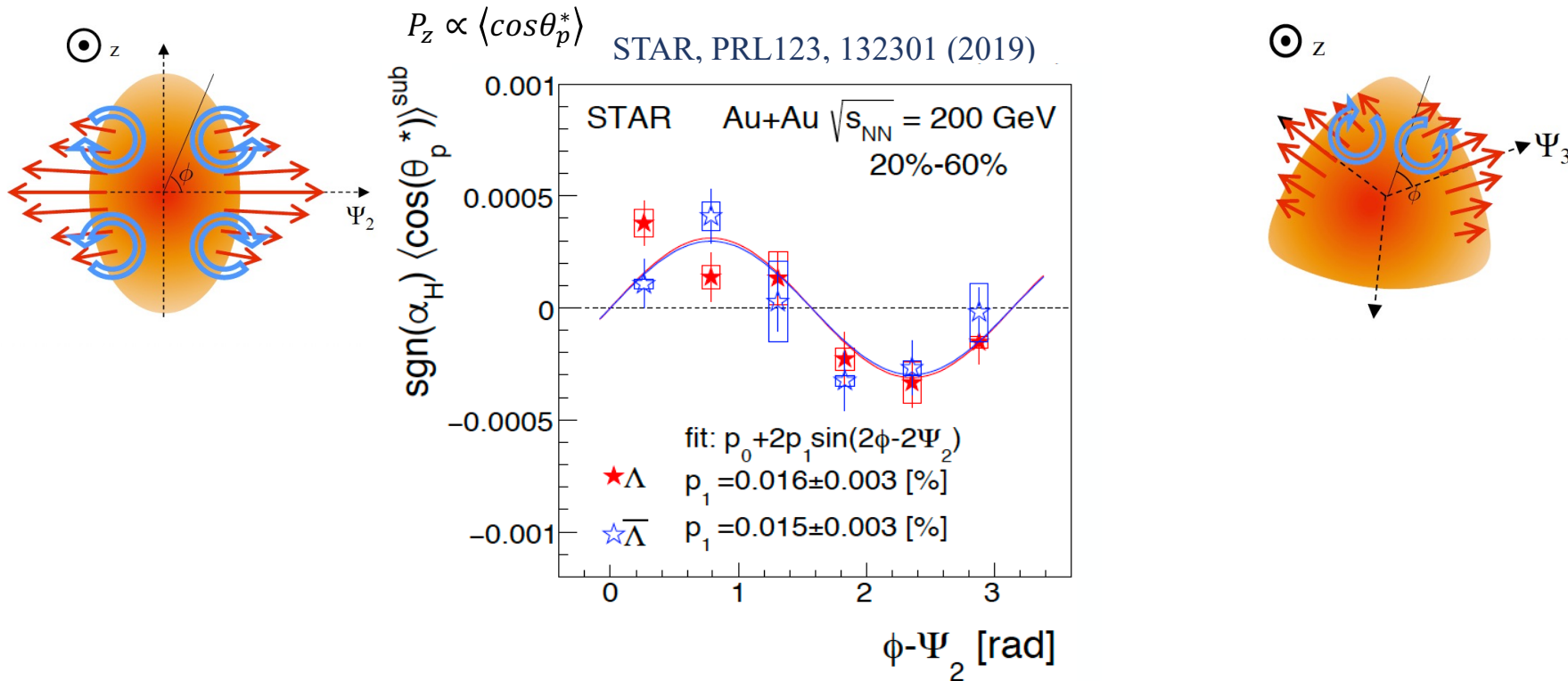


- Models based on thermal vorticity cannot explain the data, but inclusion of a shear term might explain the  $P_z$  measurement

### Local Polarization from different models:

Hattori, Hongo, Huang, Matsuo, Taya PLB(2019) ; arXiv: 2201.12390; arXiv: 2205.08051;  
 Wang, Fang, SP, PRD(2021); Wang, Xie, Fang, SP, PRD (2022); S.Y. Li, M.A Stephanov, H.U Yee, arXiv:2011.12318;  
 D. She, A. Huang, D.F. Hou, J.F Liao, arXiv: 2105.04060; Weickgenannt, Sheng, Speranza, Wang, Rischke, PRD 100, 056018 (2019)  
 Hattori, Hidaka, Yang, PRD100, 096011 (2019); Yang, Hattori, Hidaka, arXiv: 2002.02612; Liu, Mameda, Huang, arXiv:2002.03753.  
 Wang, Guo, Shi, Zhuang, PRD100, 014015 (2019) ; Z.Y. Wang, arXiv:2205.09334; Li, Yee, PRD100, 056022 (2019);  
 Hou, Lin, arXiv: 2008.03862; Lin, arXiv: 2109.00184; Lin, Wang, arXiv:2206.12573; Fang, SP, Yang, PRD (2022)

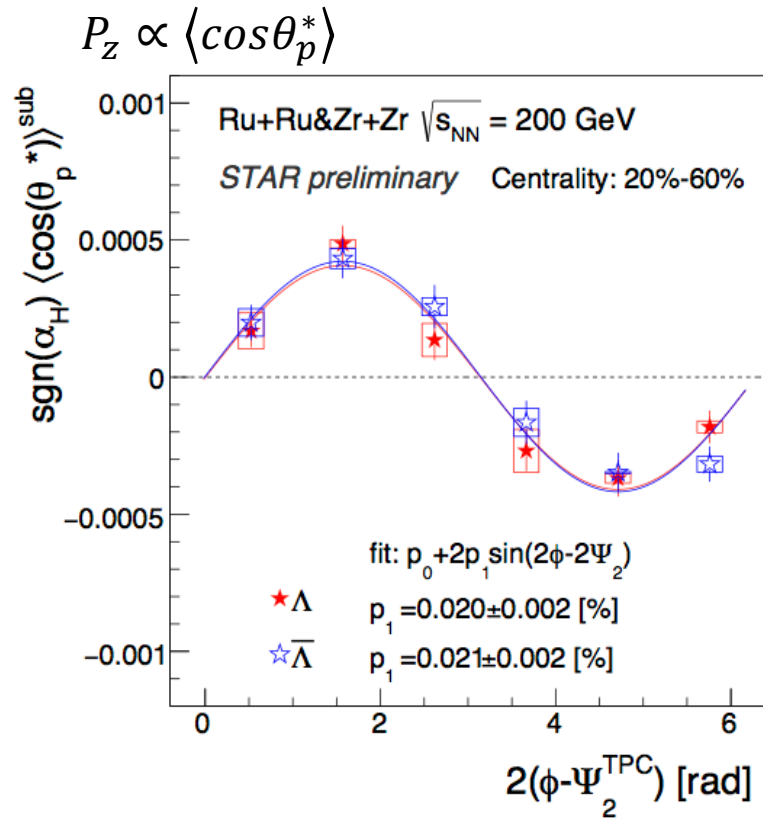
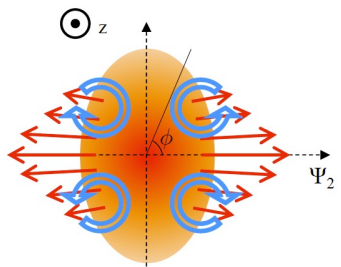
# Local polarization of hyperons in heavy ion collisions



- ❑ Models based on thermal vorticity cannot explain the data, but inclusion of a shear term might explain the  $P_z$  measurement
- ❑ Measurements in smaller systems and relative to higher harmonic event planes provide new insights into polarization phenomena



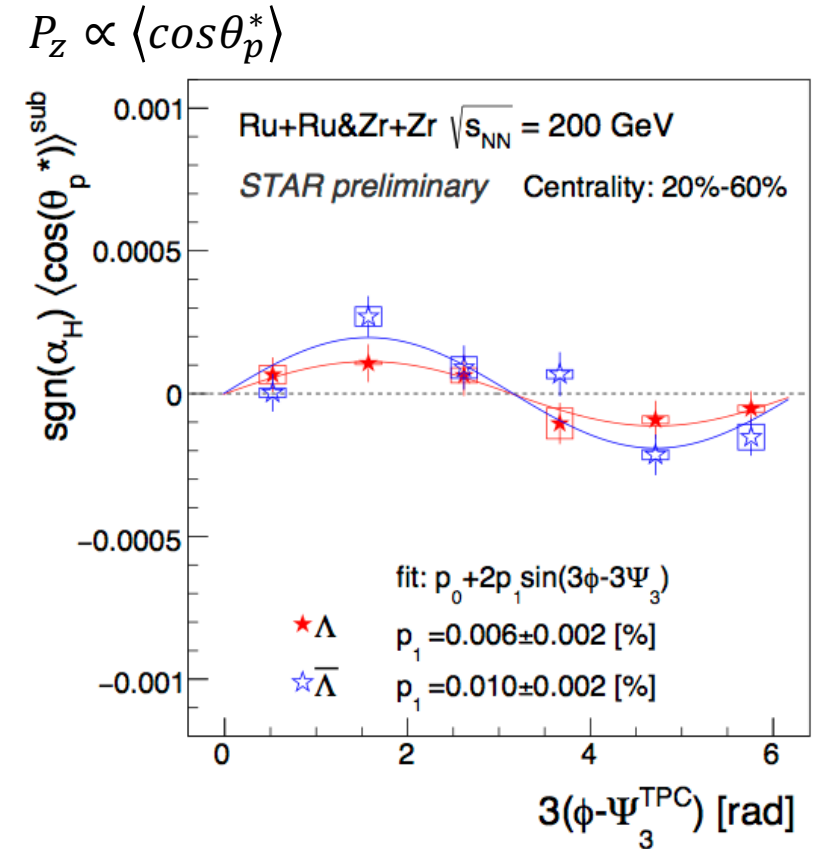
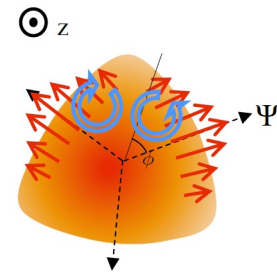
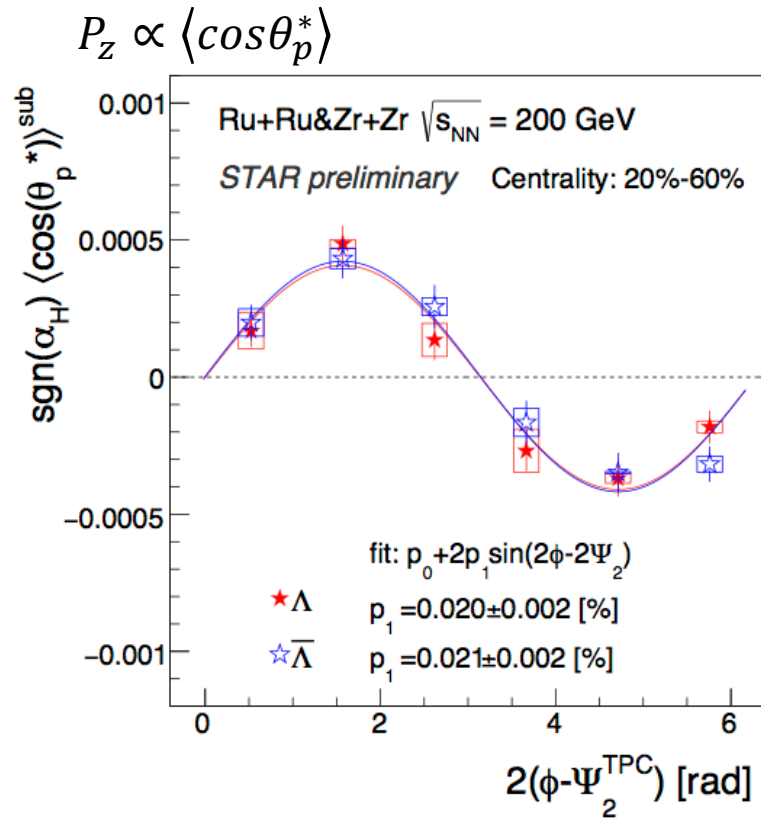
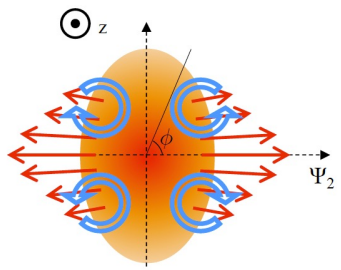
# Local polarization in isobar collisions



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



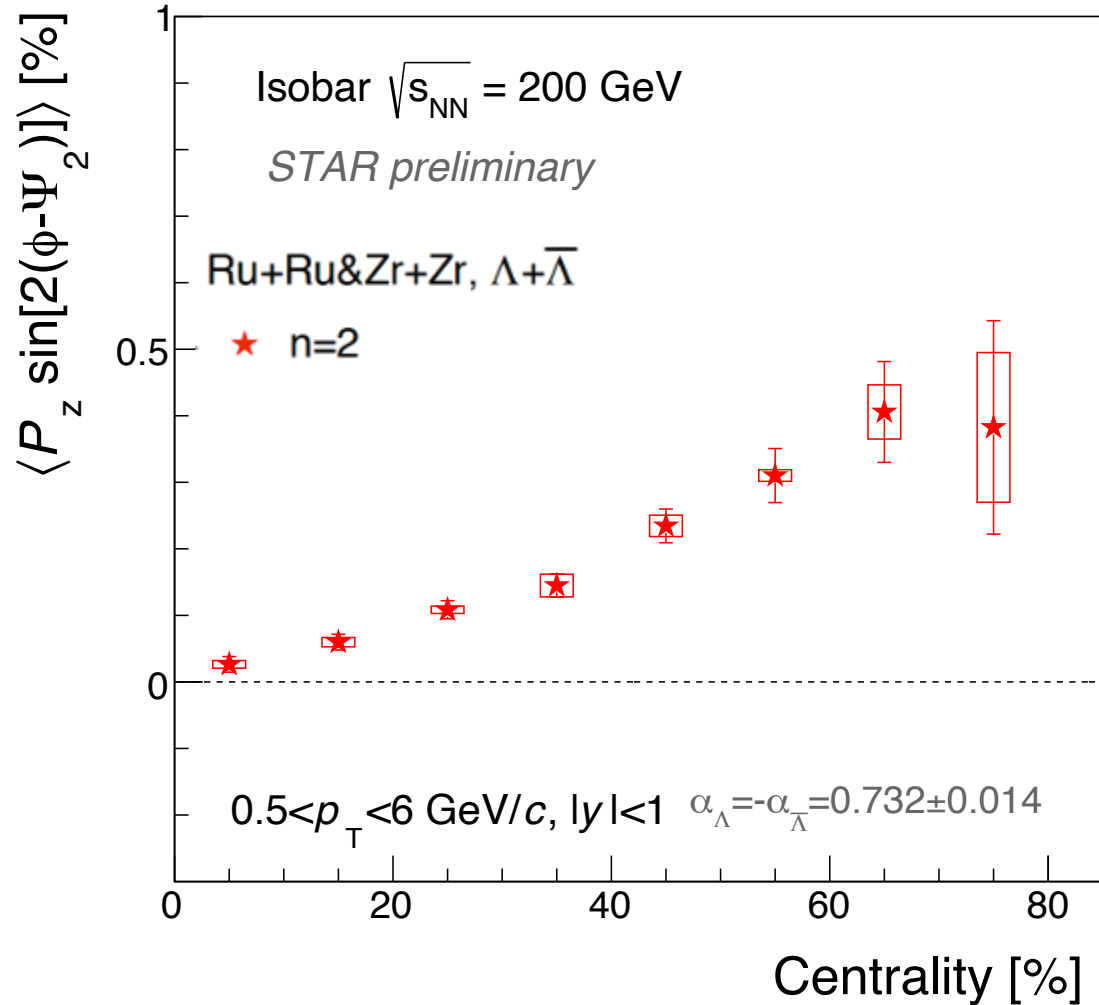
# Local polarization in isobar collisions



- 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 $P_{z,n}$

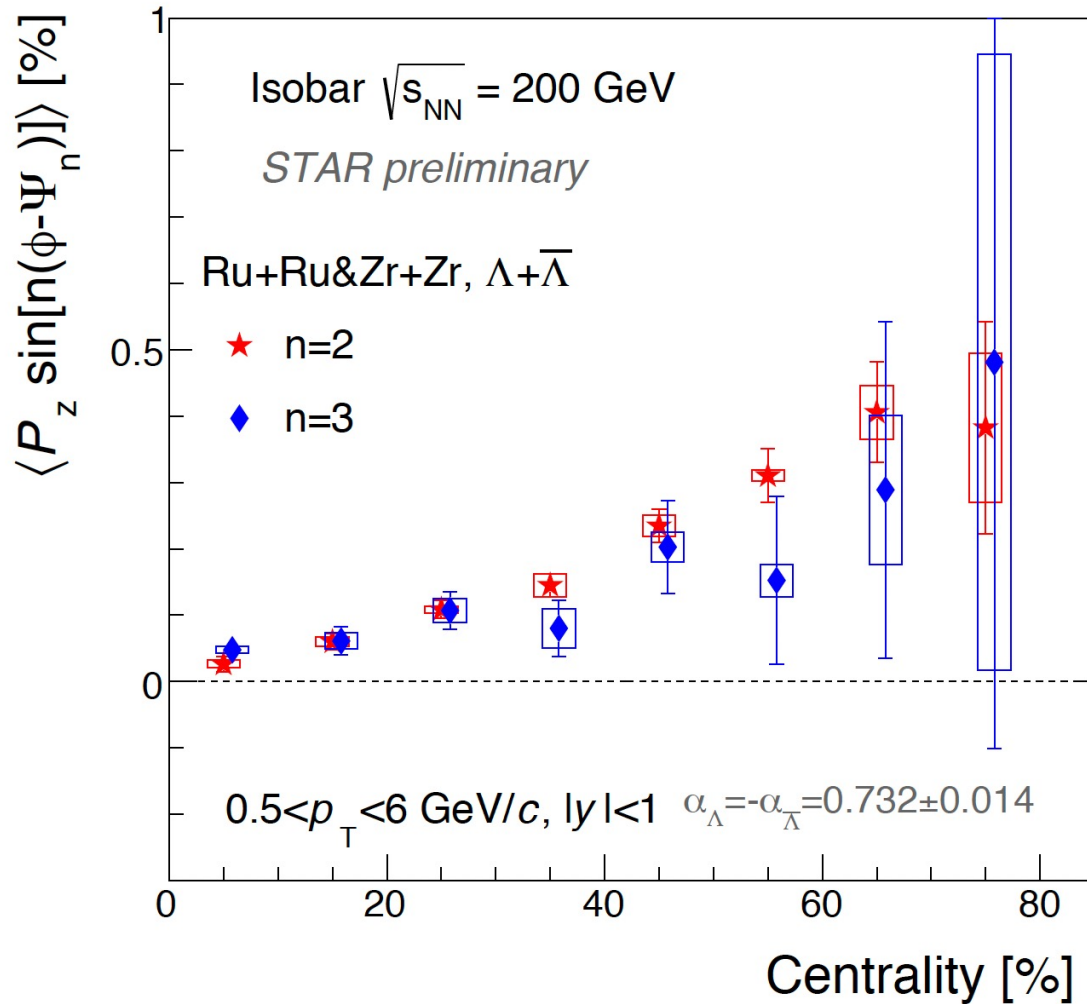
$$P_{z,n} = \langle P_z \sin[n(\phi - \Psi_n)] \rangle$$



- Second Fourier sine coefficient of the local polarization increases with centrality

# Centrality dependence of $P_{z,n}$

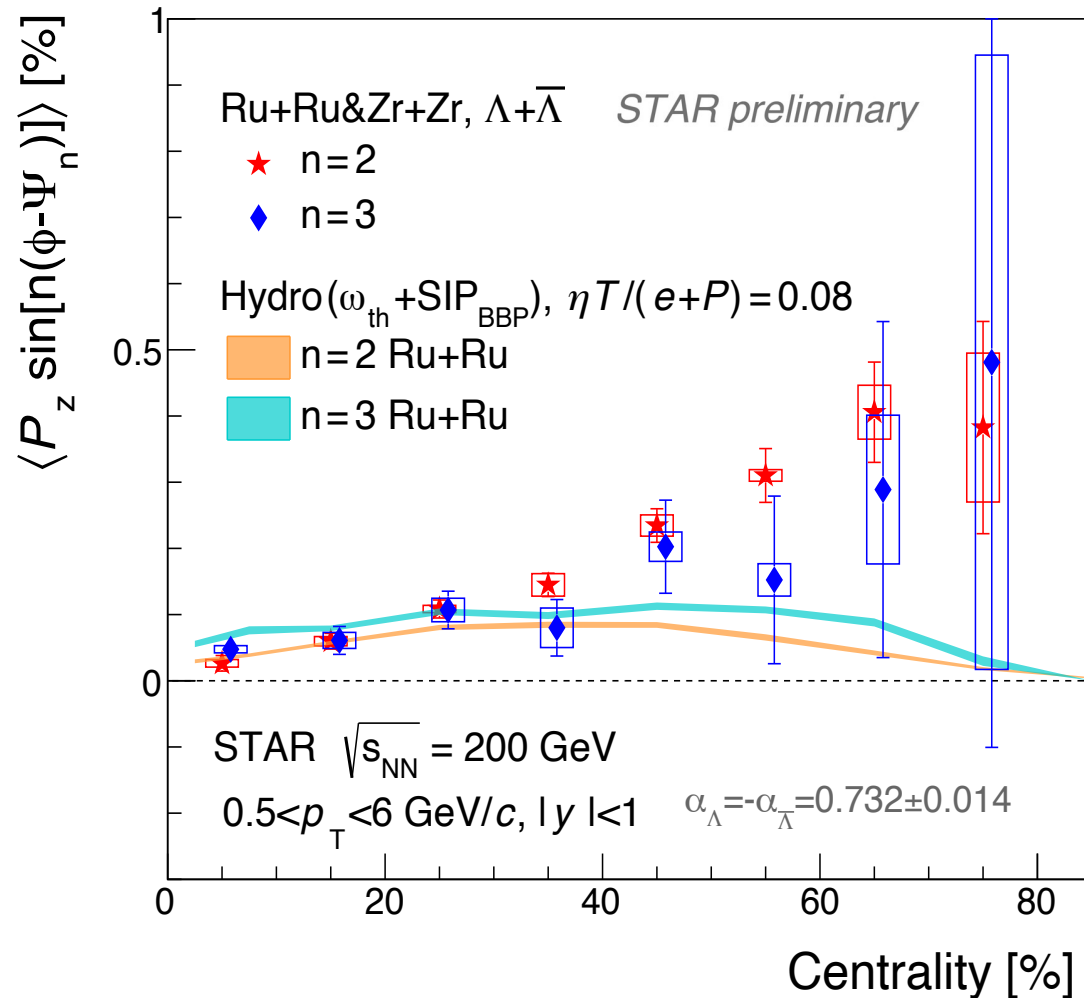
$$P_{z,n} = \langle P_z \sin[n(\phi - \Psi_n)] \rangle$$



- 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

# Centrality dependence of $P_{z,n}$

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

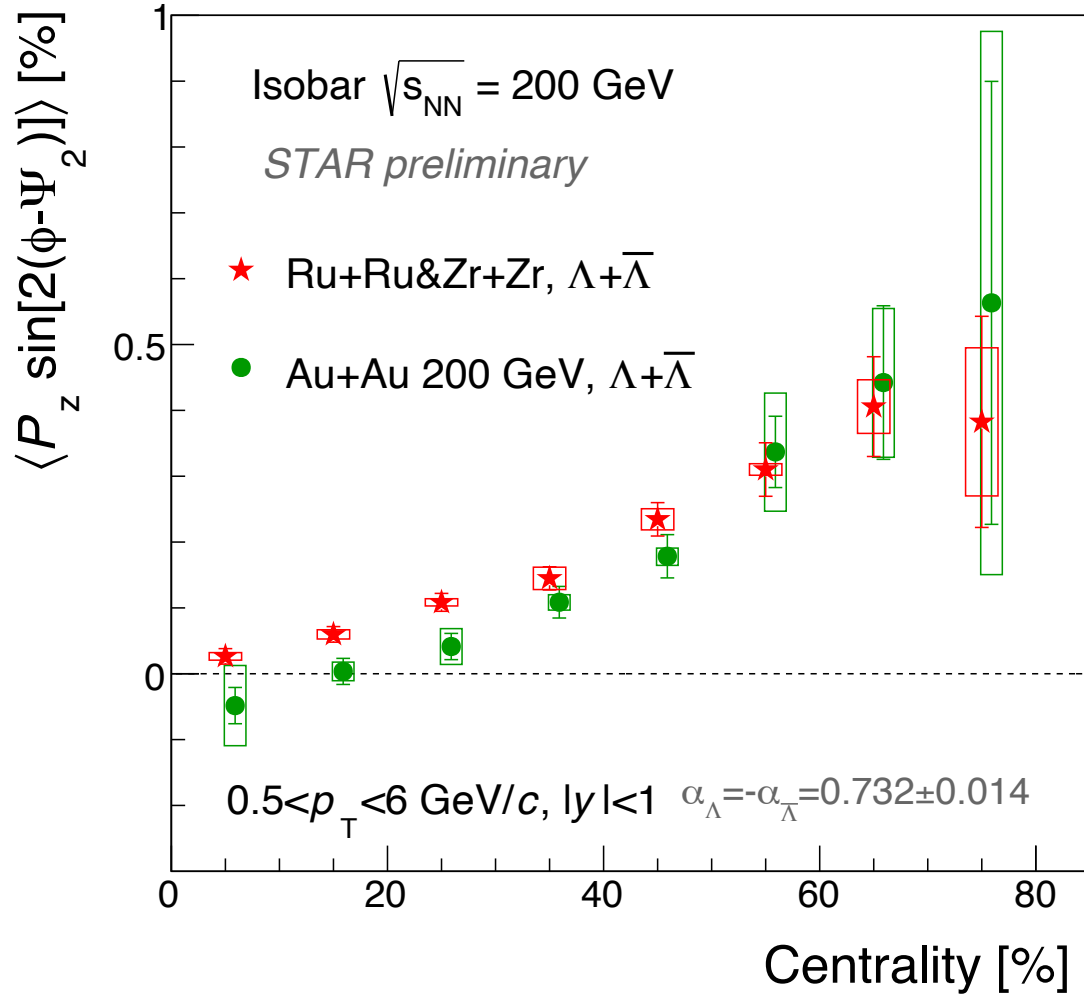


S. Alzhvani et al., PhysRevC.106.014905

- 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

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

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



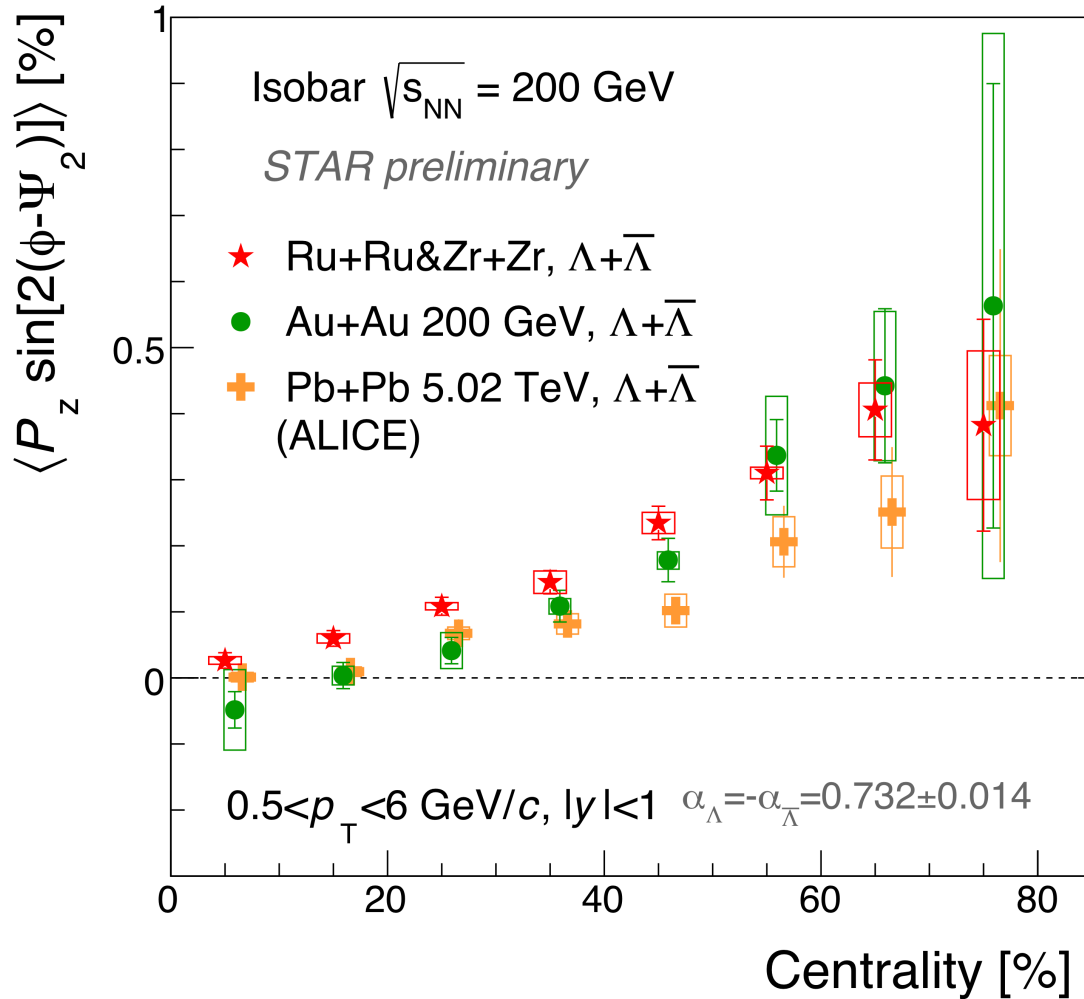
□  $P_{z,2}$  from isobar data compared to Au+Au collisions

□ Hint of system size dependence between isobar and Au+Au collisions

Au+Au: STAR, PRL123, 132301 (2019)

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

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



- $P_{z,2}$  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

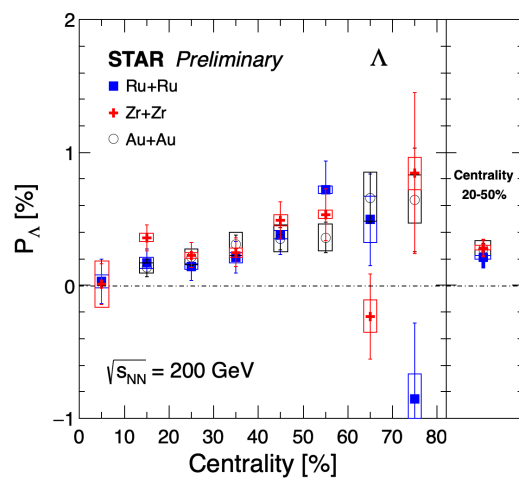
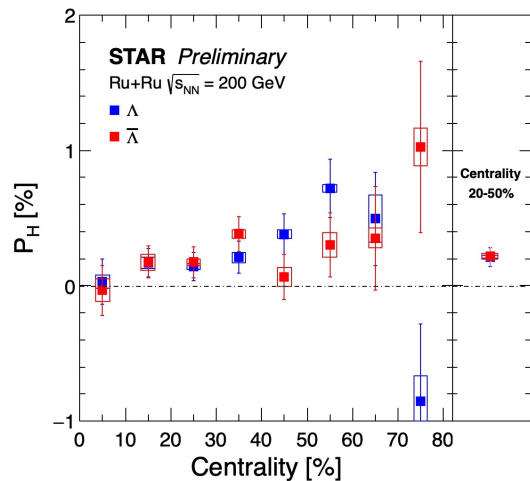
Au+Au: STAR, PRL123, 132301 (2019)  
 Pb+Pb: ALICE, arXiv:2107.11183



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

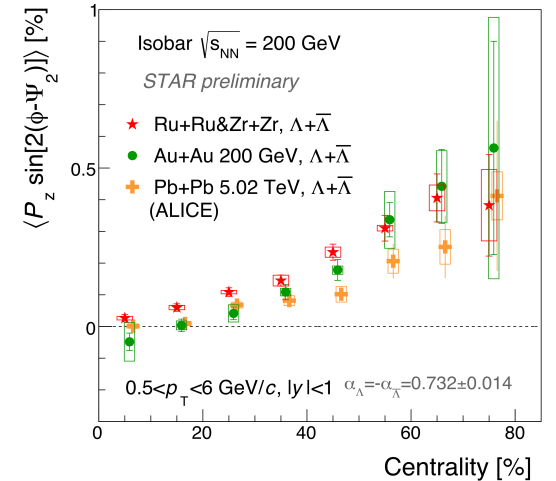
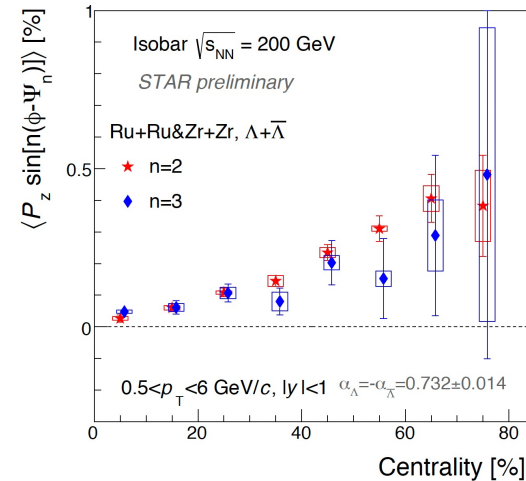
## Global polarization

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



## 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 with Isobar and Au+Au.

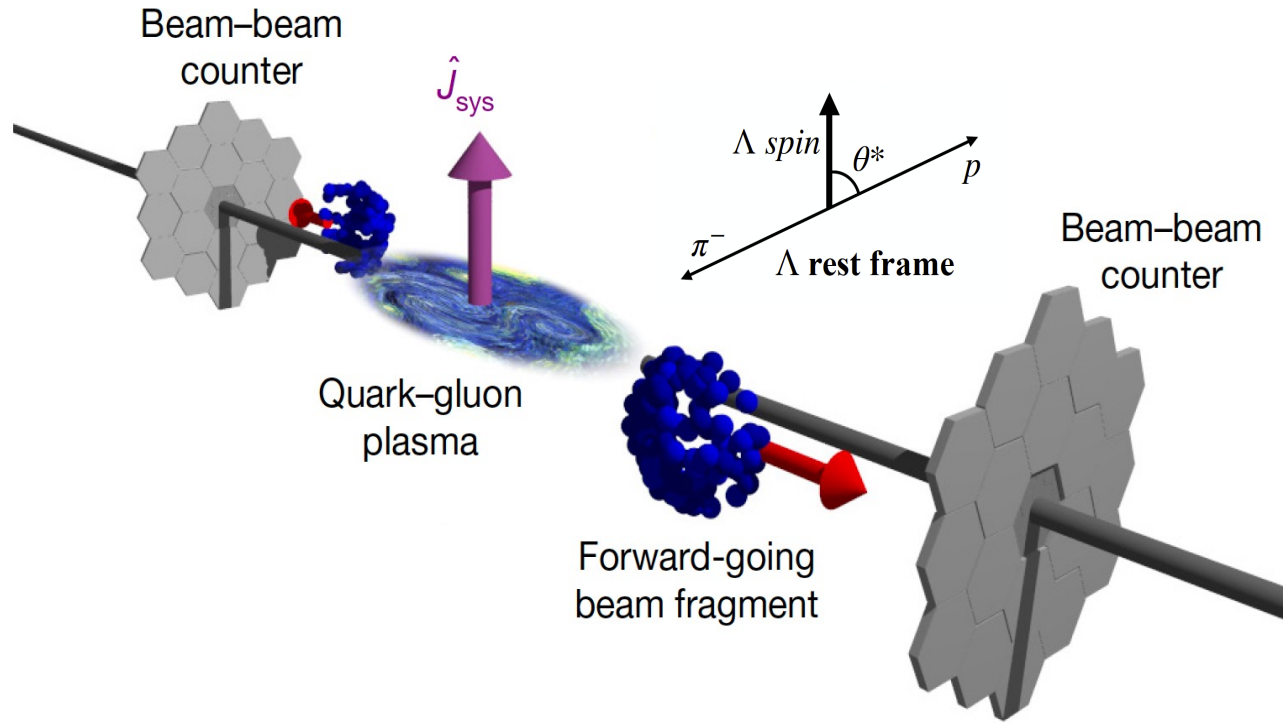


*Thank you*

# Global polarization of hyperons in heavy ion collision

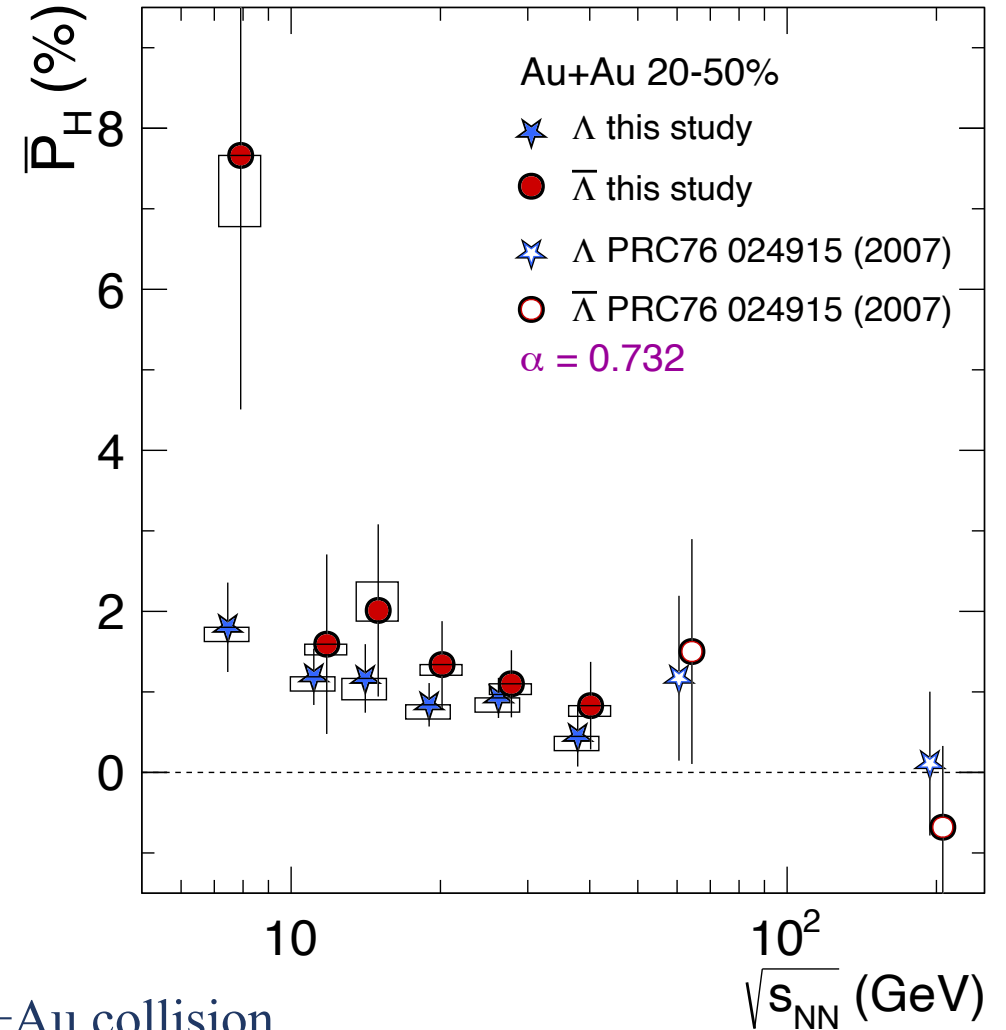


STAR, Nature 548, 62-65



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$\alpha_{\Lambda} = -\alpha_{\bar{\Lambda}} = 0.732 \pm 0.014$   
 $A_0$ : acceptance effect  
 $\Psi_1$ : first-order event plane angle

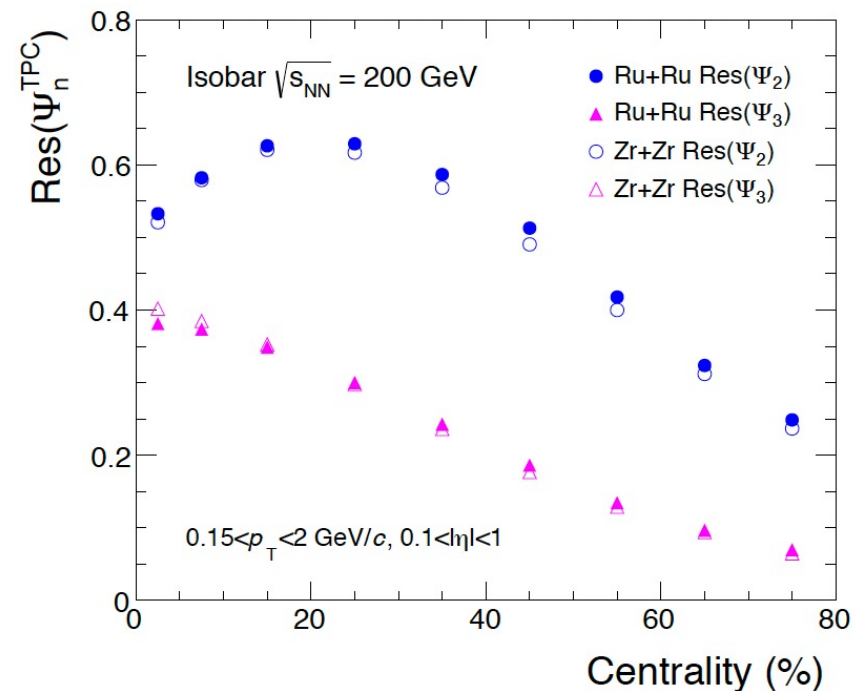
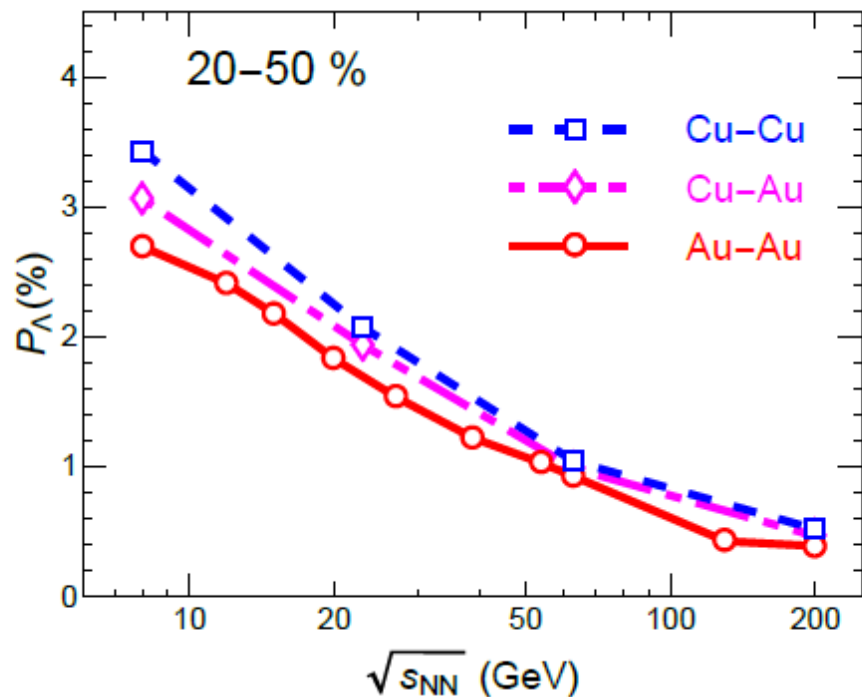


□ Significant global polarization of  $\Lambda$  and  $\bar{\Lambda}$  observed in Au+Au collision.

# Global polarization of hyperons in heavy ion collision

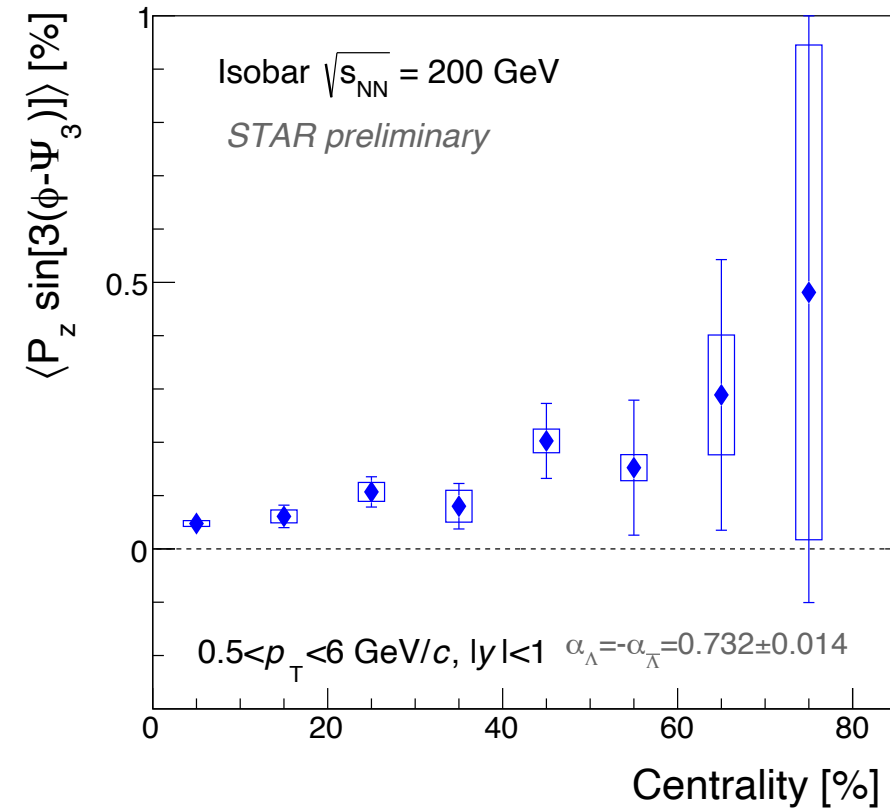
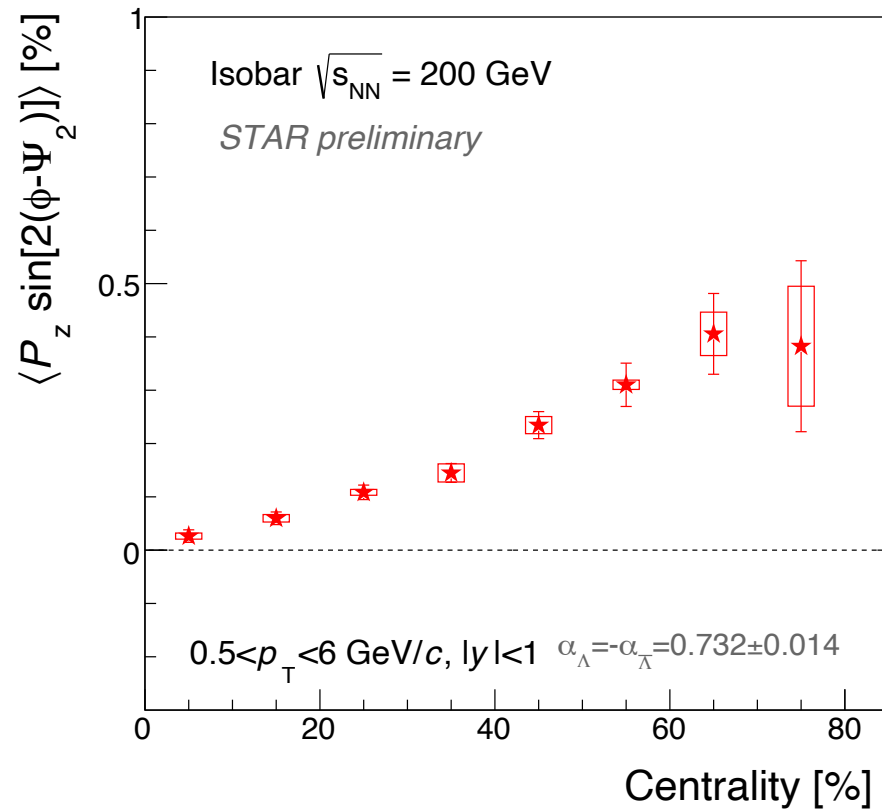


Shuzhe Shi, Kangle Li, Jinfeng Liao  
PLB 788(2019) 409413



Parameter	Description	Value
$w$ [fm]	initial hot spot width	0.4, 0.8, 1.2
$\eta_0$	space-time rapidity plateau size	2.5
$\sigma_{\eta}$	space-time rapidity fall off width	0.5
$f$	initial longitudinal flow fraction	0.15
$\tau_0$ [fm/c]	hydrodynamics starting time	1
$\eta T / (e + P)$	specific shear viscosity	0, 0.08, 0.16
$e_{sw}$ [GeV/fm <sup>3</sup> ]	particization energy density	0.25, 0.5

# Centrality dependence of $P_{z,n}$



- Local polarization increase with centrality
- Significant local polarization w.r.t third-order event plane