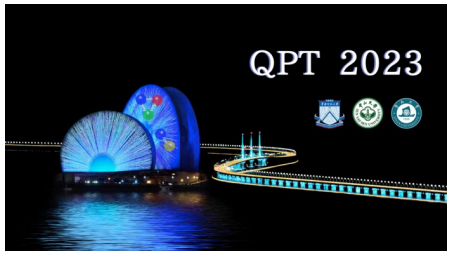


Measurements of Global and Local Polarization of Hyperons in Heavy Ion Collisions from STAR

Xingrui Gou(苟兴瑞)

(for the STAR Collaboration)

Shandong University(山东大学)

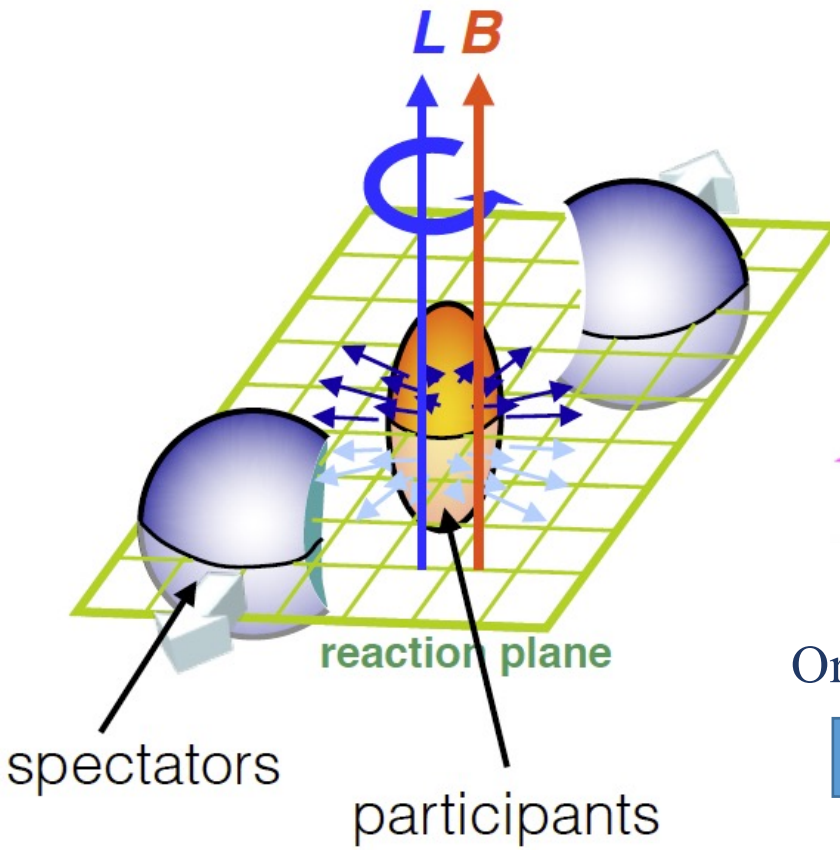
Supported in part by U.S. DEPARTMENT OF ENERGY Office of Science

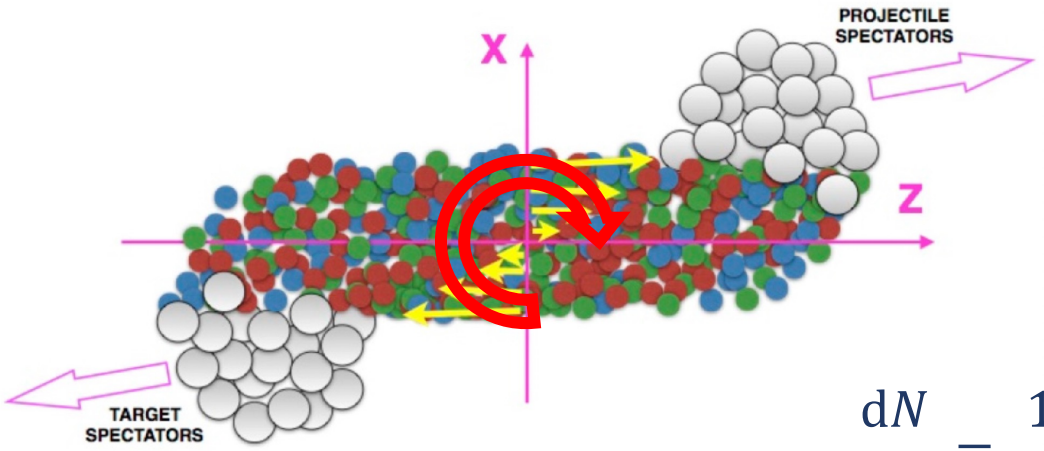
The 15th workshop on QCD Phase Transition and Relativistic Heavy Ion Collisions(QPT2023)

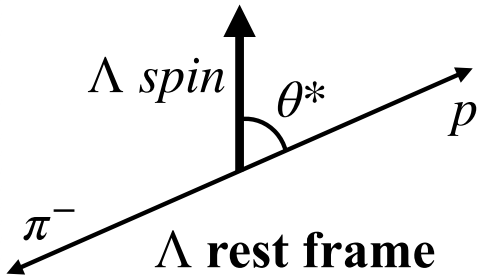
Outline

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

Hyperon polarization in heavy ion collisions







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

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

Orbital angular momentum

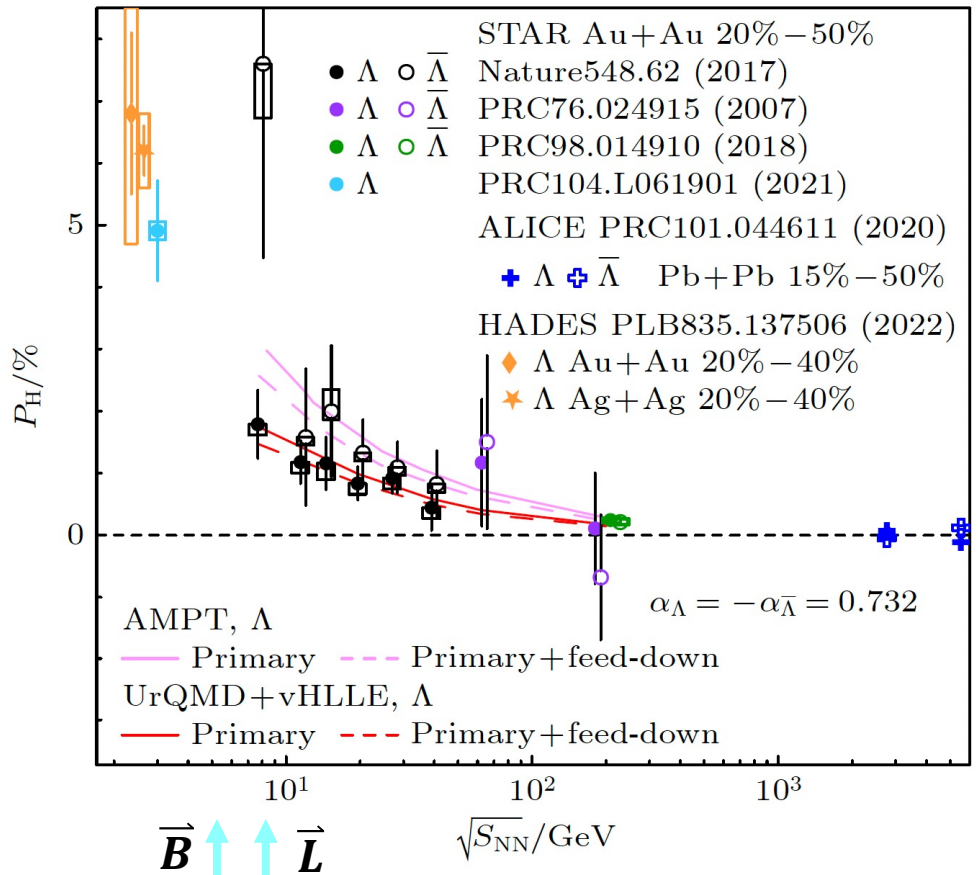
↳ Leads to global polarization

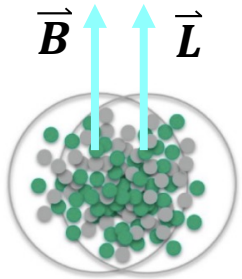
Z.-T. Liang and X.-N. Wang, PRL 94, 102301 (2005)

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

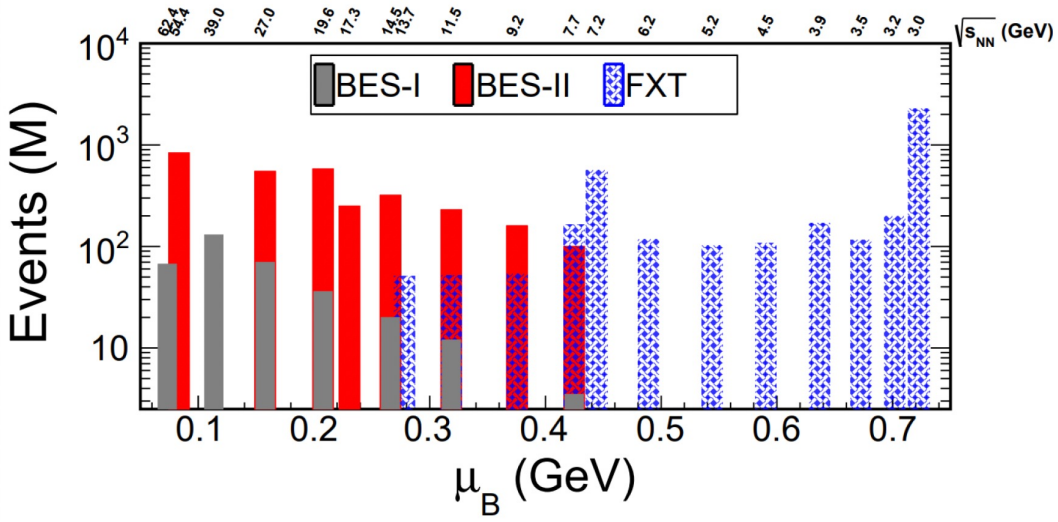
Hyperon polarization in heavy ion collisions

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





BES-I (2010-2017) and BES-II (2018-2021) statistics



- **Λ / Λ̄ global polarization splitting with BES-II data?**
- Global polarization collision system size dependence

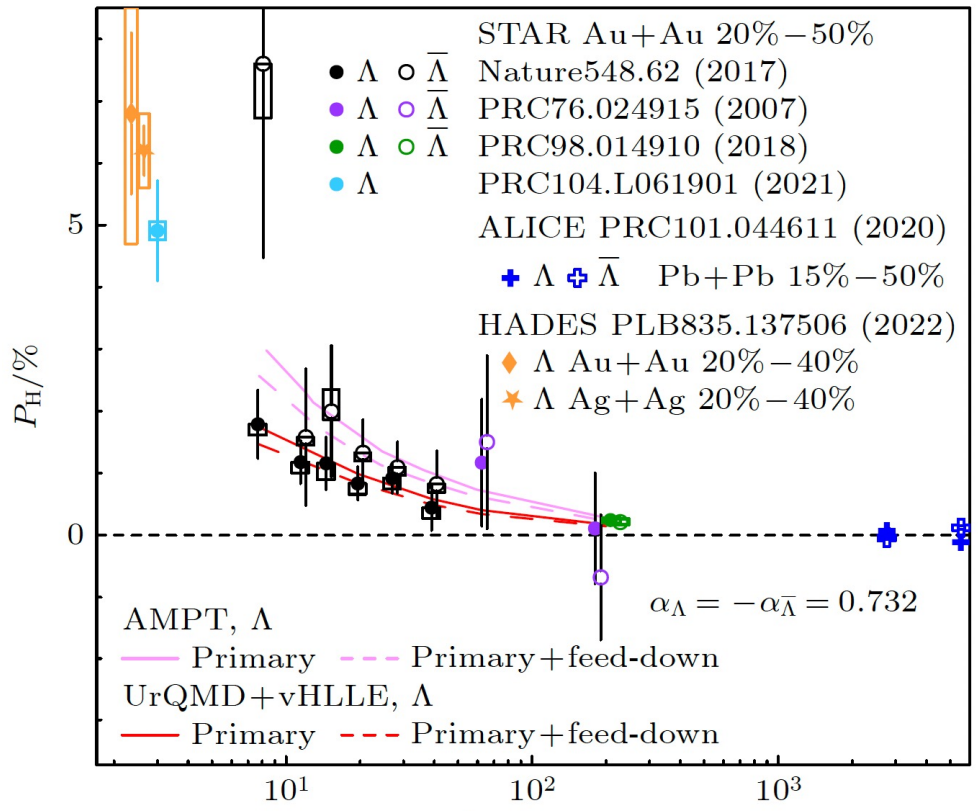
$$^{197}_{79}Au > ^{96}_{44}Ru, ^{96}_{40}Zr > ^{63}_{29}Cu > ^{16}_{8}O$$

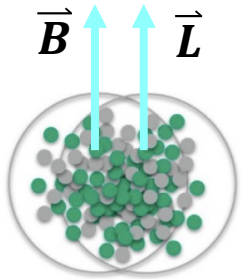
$$\xrightarrow{?} \quad P_\Lambda^{Au} < P_\Lambda^{Ru} \approx P_\Lambda^{Zr} < P_\Lambda^{Cu} < P_\Lambda^{O}$$

- Local polarization in isobar collisions

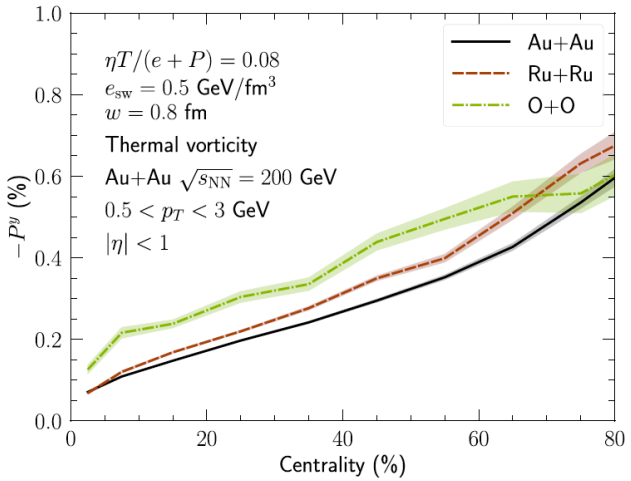
Hyperon polarization in heavy ion collisions

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

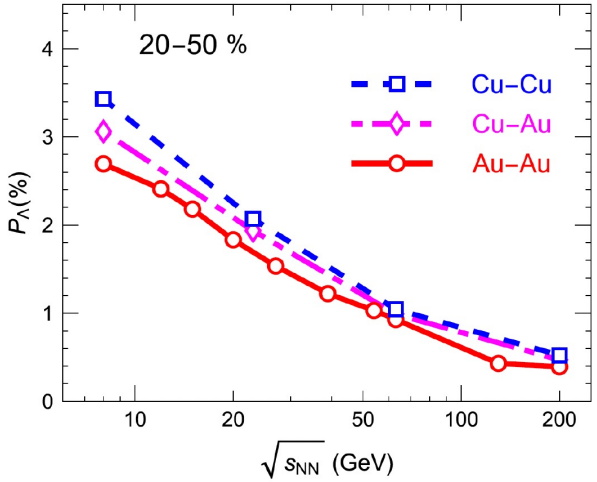




S. Alzhrani et al., PRC 106.014905



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



- ☐ Λ / $\bar\Lambda$ global polarization splitting with BES-II data?
- ☐ **Global polarization collision system size dependence**

$^{197}_{79}Au > ^{96}_{44}Ru, ^{96}_{40}Zr > ^{63}_{29}Cu > ^{16}_{8}O$

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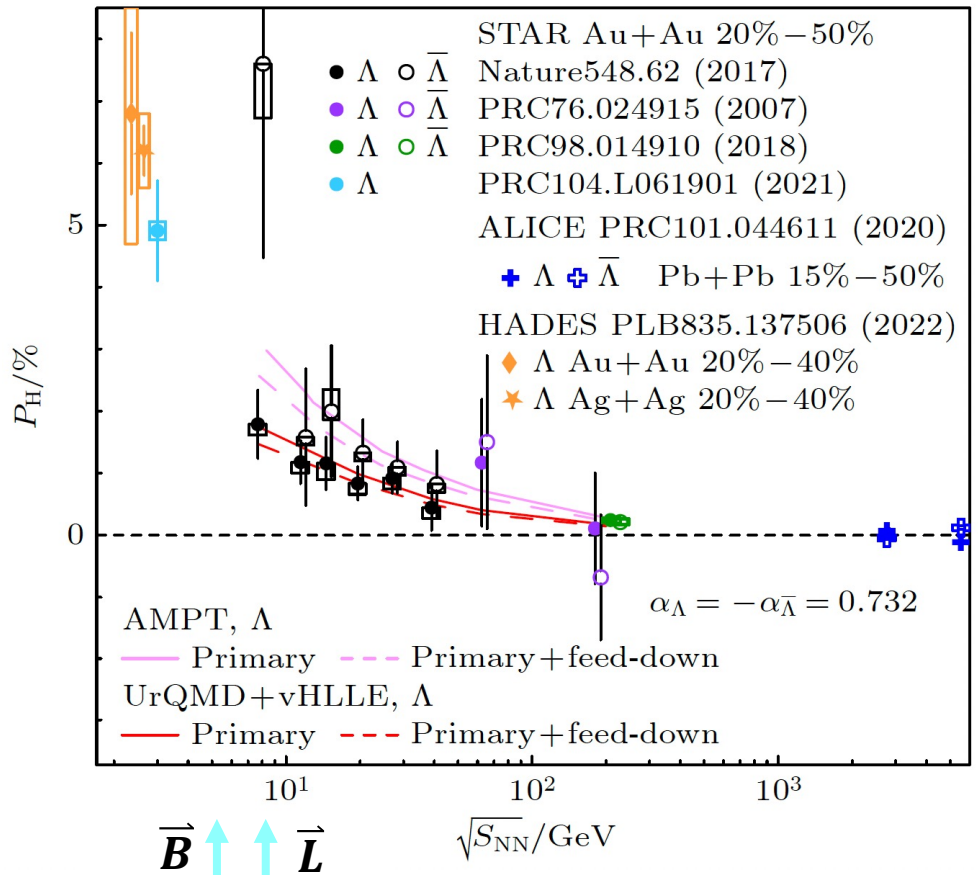
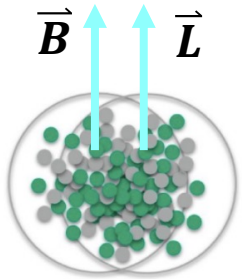
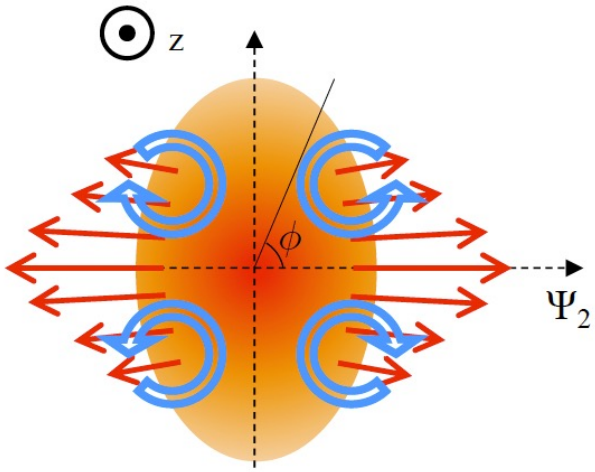
- ☐ Local polarization in isobar collisions

Hyperon polarization in heavy ion collisions

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







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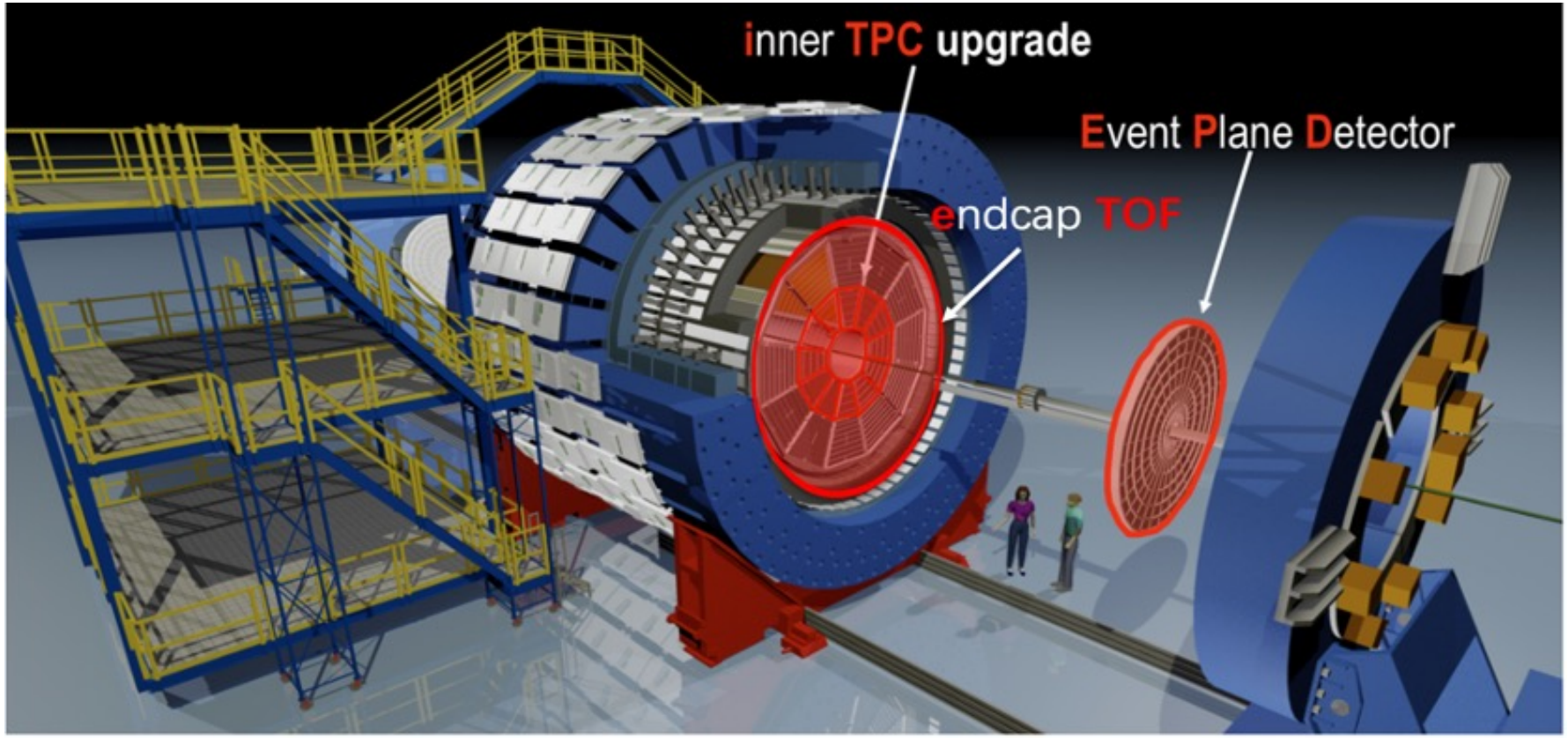
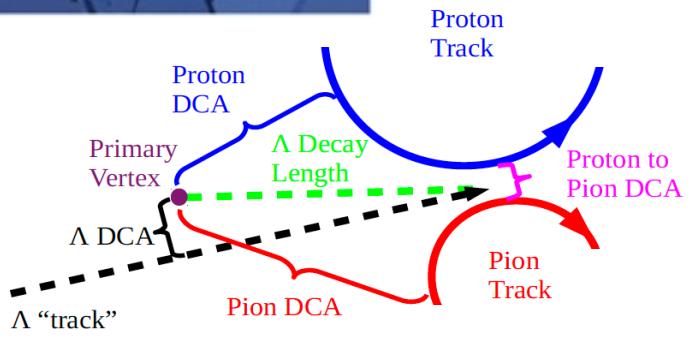
- ☐ **Local polarization in isobar collisions**

STAR detector

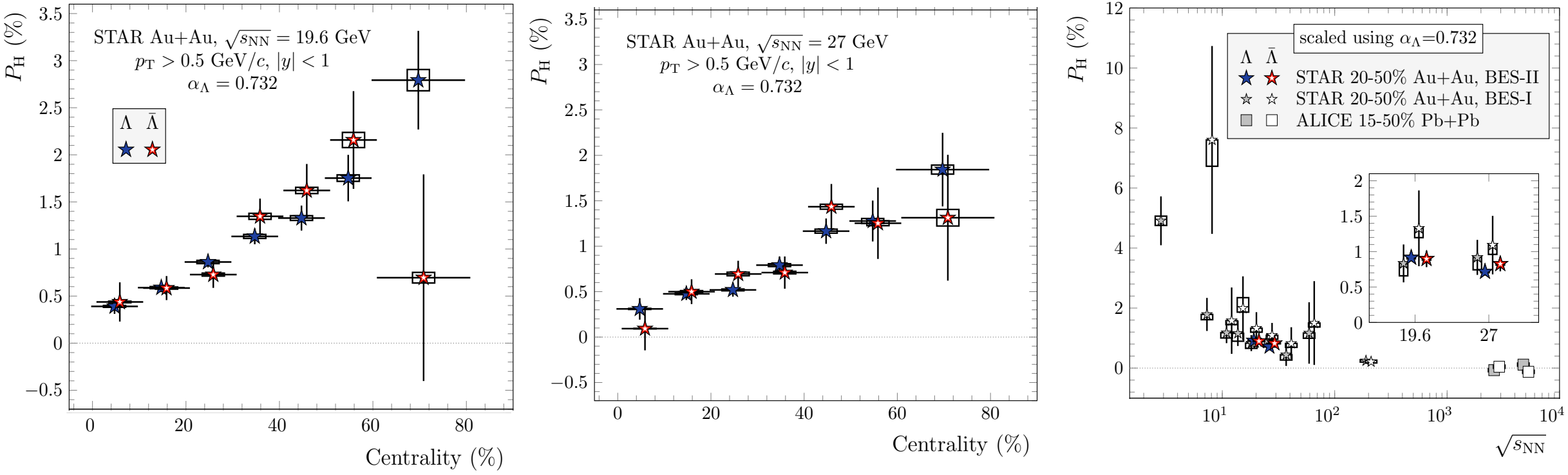


- **Event plane reconstruction:**
  - Time Projection Chamber
  - Event Plane Detector
  - Zero Degree Calorimeters

- **$\Lambda/\bar{\Lambda}$ reconstruction:**
  - Time Projection Chamber
  - Time Of Flight



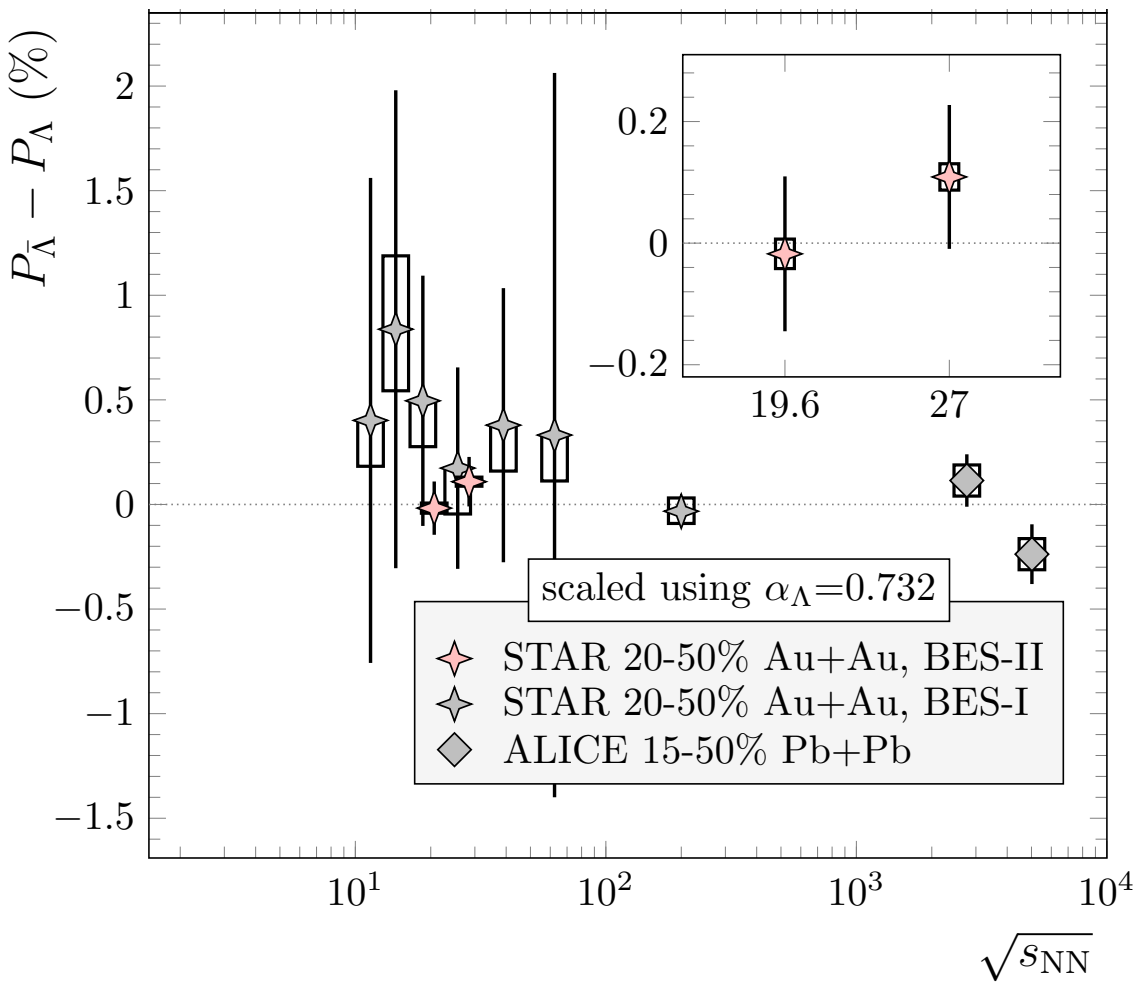
Global polarization in Au+Au with BES-II data (19.6, 27 GeV)



STAR, PRC 108, 014910 (2023)

- About 10 times increase in statistics than BES-I
- Significant global polarization centrality dependence observed, results consistent with BES-I

Global polarization in Au+Au with BES-II data (19.6, 27 GeV)

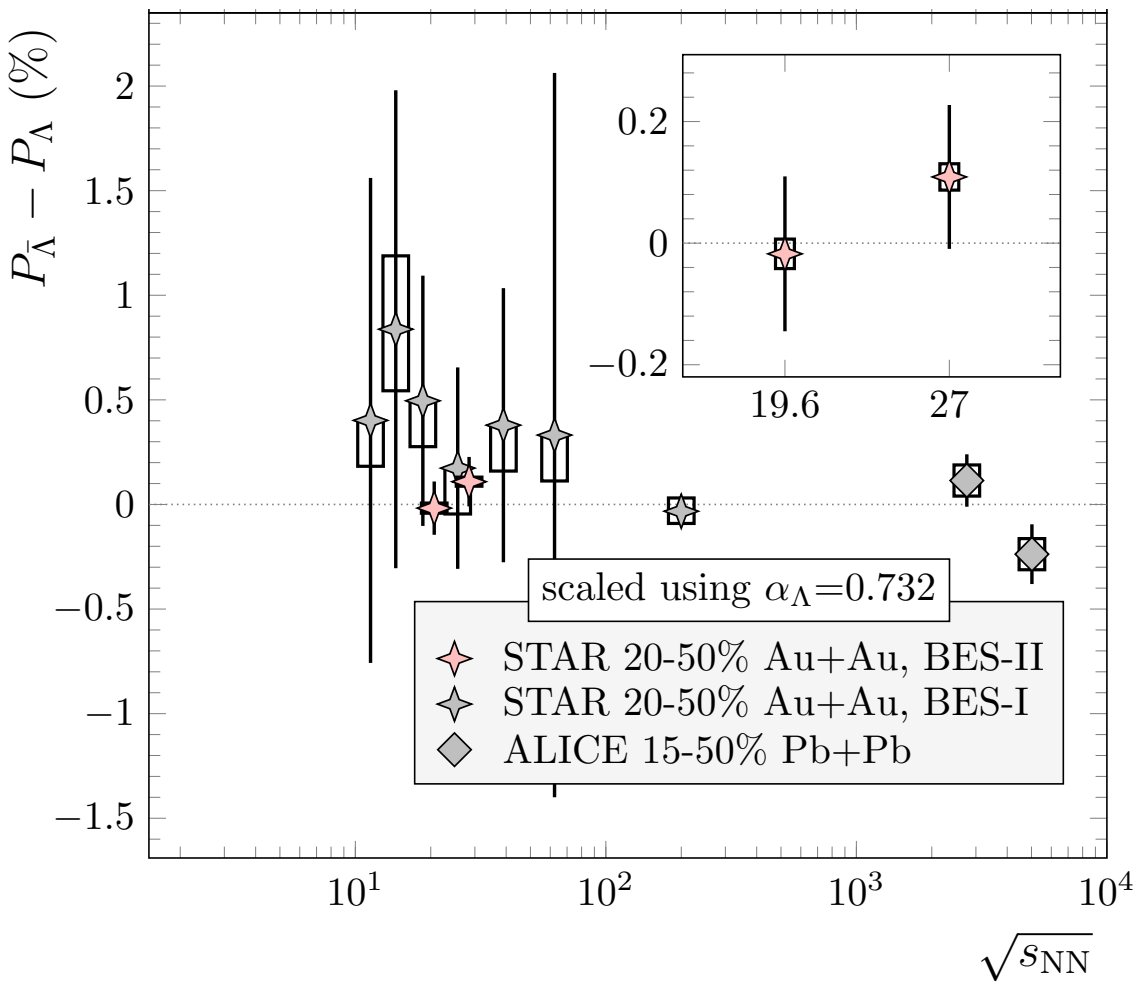


- No splitting of Λ / $\bar{\Lambda}$ observed

Au+Au	19.6 GeV	27 GeV
$P_{\bar{\Lambda}} - P_{\Lambda}$ (%)	-0.018 $\pm 0.127(stat.)$ $\pm\ 0.024(sys.)$	0.109 $\pm 0.118(stat.)$ $\pm\ 0.022(sys.)$

STAR, PRC 108, 014910 (2023)

Global polarization in Au+Au with BES-II data (19.6, 27 GeV)



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- $|B| \approx \frac{T_s|P_{\bar{\Lambda}}-P_{\Lambda}|}{2|\mu_A|}$, using hydrodynamics

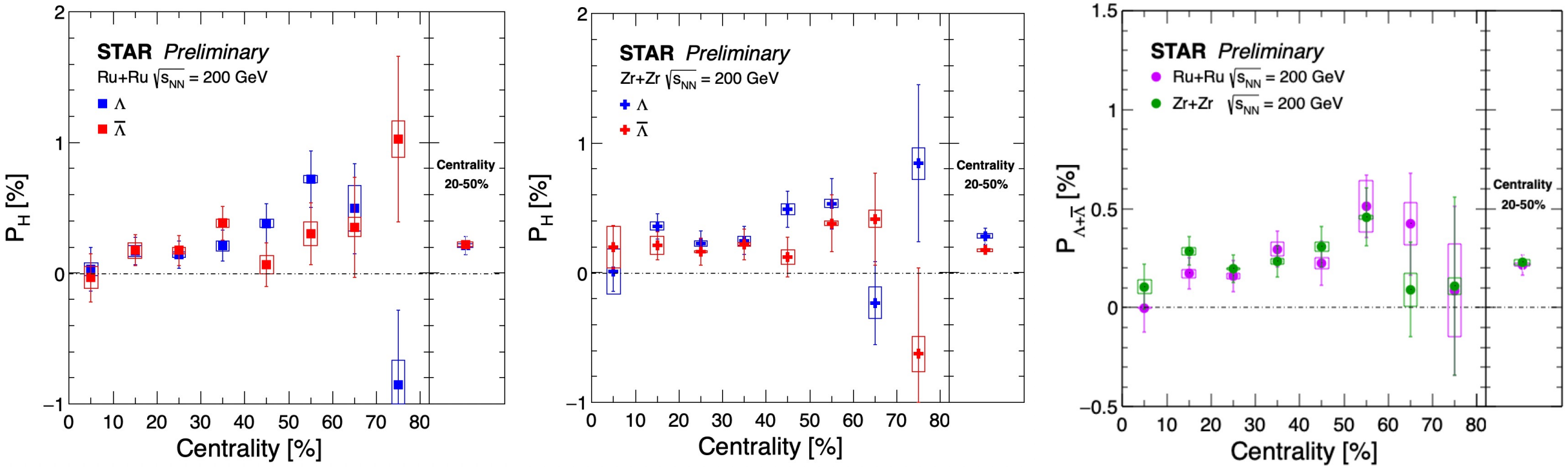
  T_s =150 MeV : the temperature of the emitting source

  $\mu_A = -1.93\times10^{-14}$ MeV/T : the magnetic moment of the Λ hyperon

- Upper limit on late stage magnetic field
  - 95% confidence level
  - $B < 9.4\times10^{12}\ T$ at 19.6 GeV
  - $B < 1.4\times10^{13}\ T$ at 27 GeV

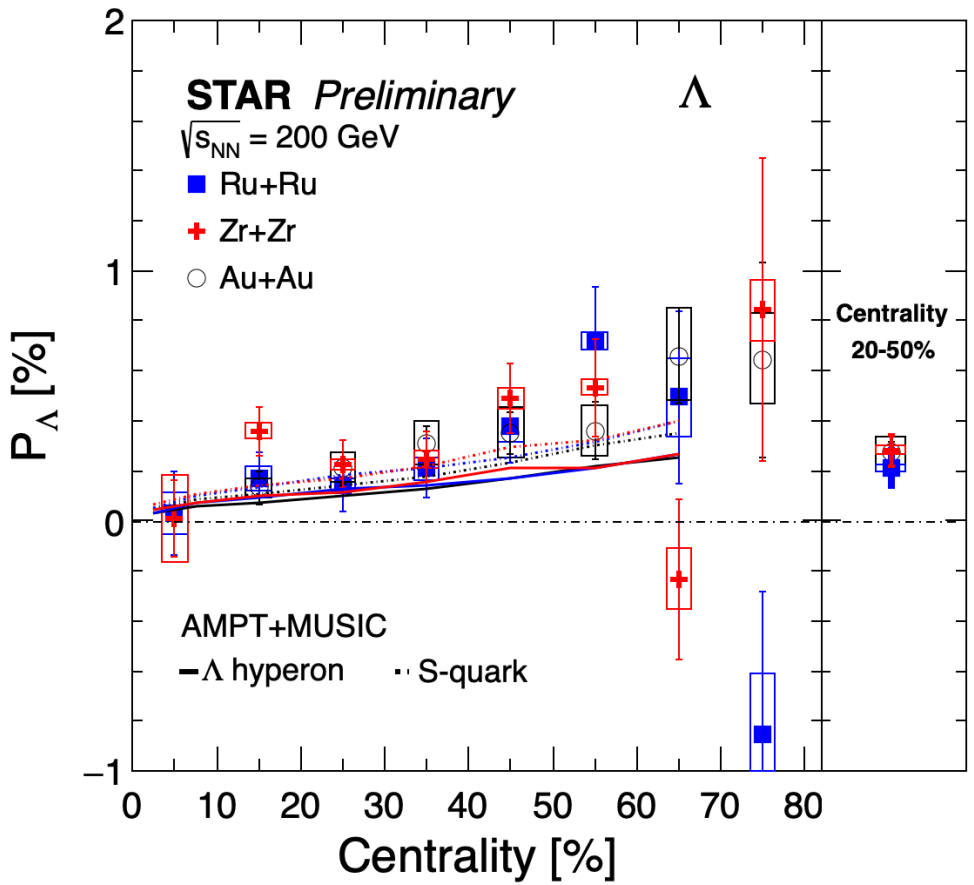
STAR, PRC 108, 014910 (2023)

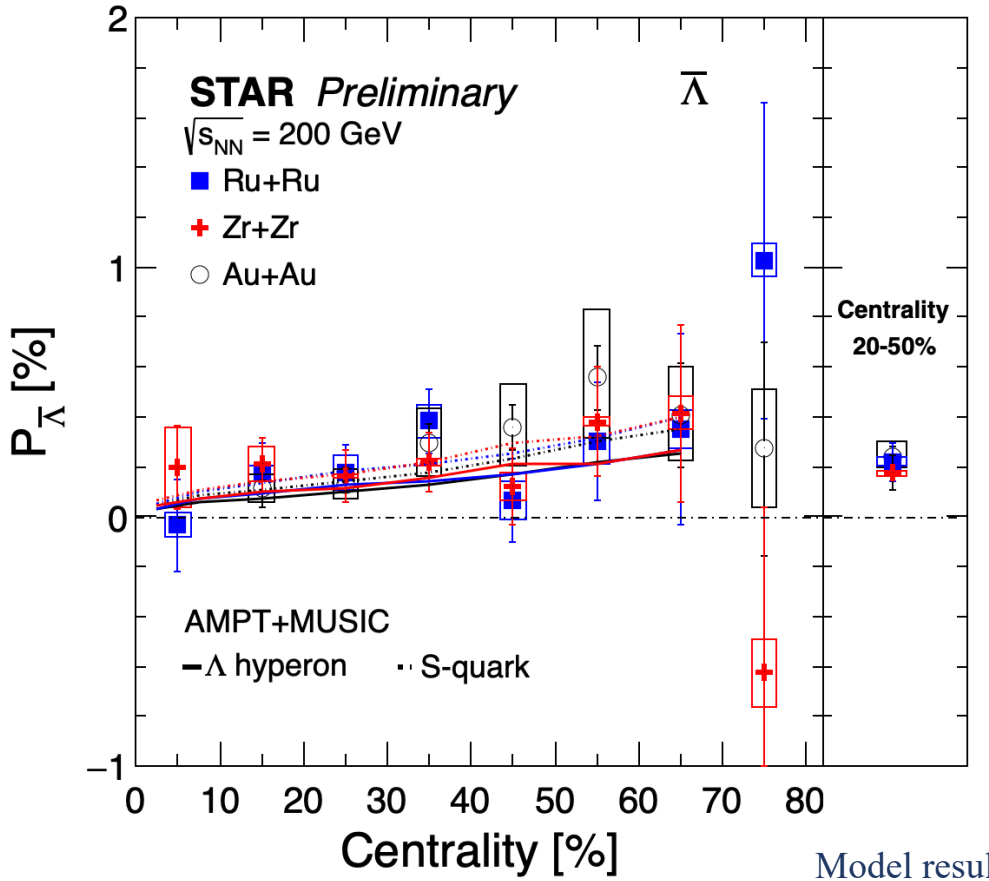
Global polarization in Ru+Ru and Zr+Zr at 200 GeV



- Significant global polarization observed, P_{Λ} and $P_{\bar{\Lambda}}$ increase with centrality
- No significant difference between P_{Λ} 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

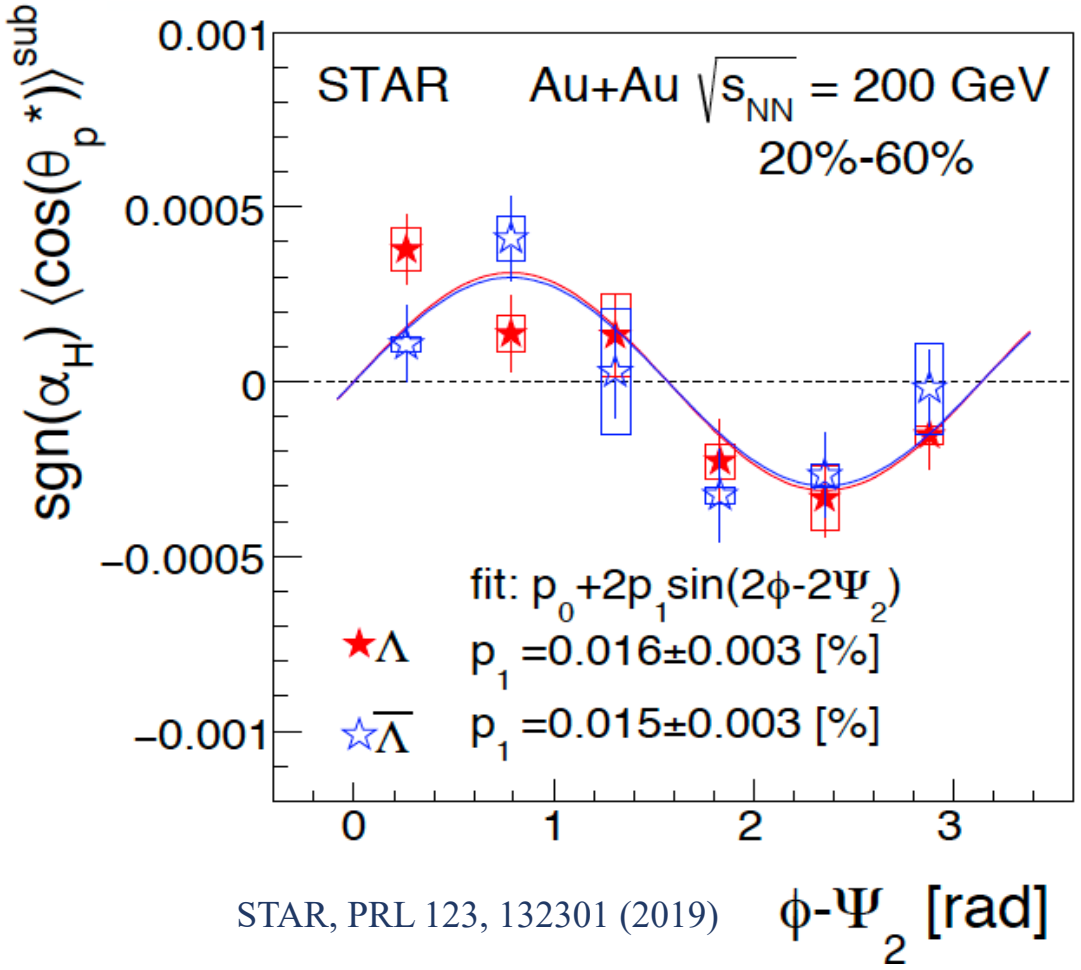




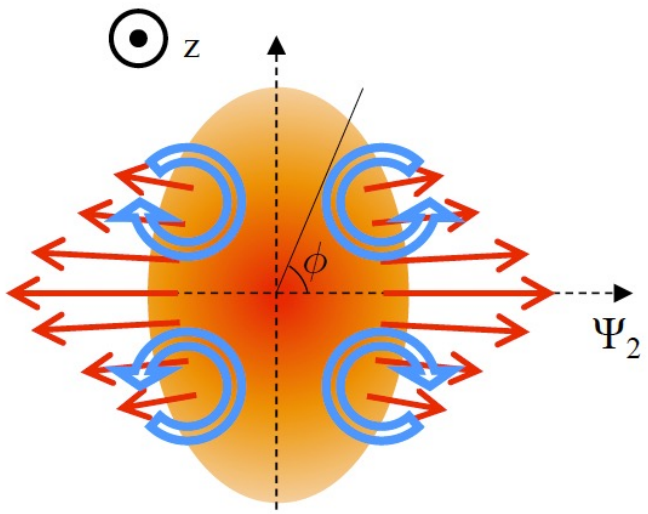
Model results from arXiv:2201.12970v1

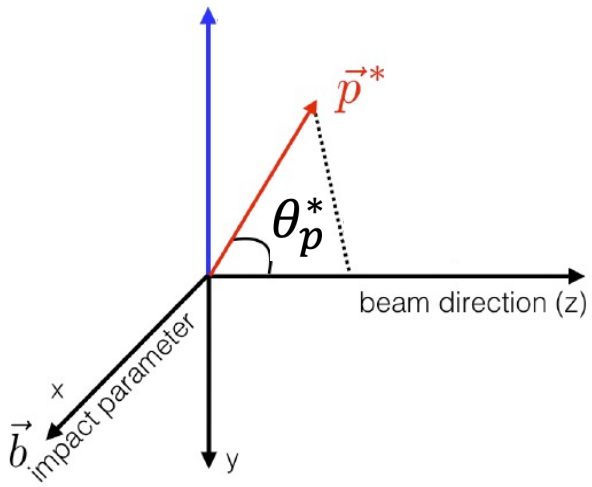
- Global polarization of Λ and $\bar{\Lambda}$ are consistent in isobar and Au+Au collision systems

Local polarization in heavy ion collisions



STAR, PRL 123, 132301 (2019)



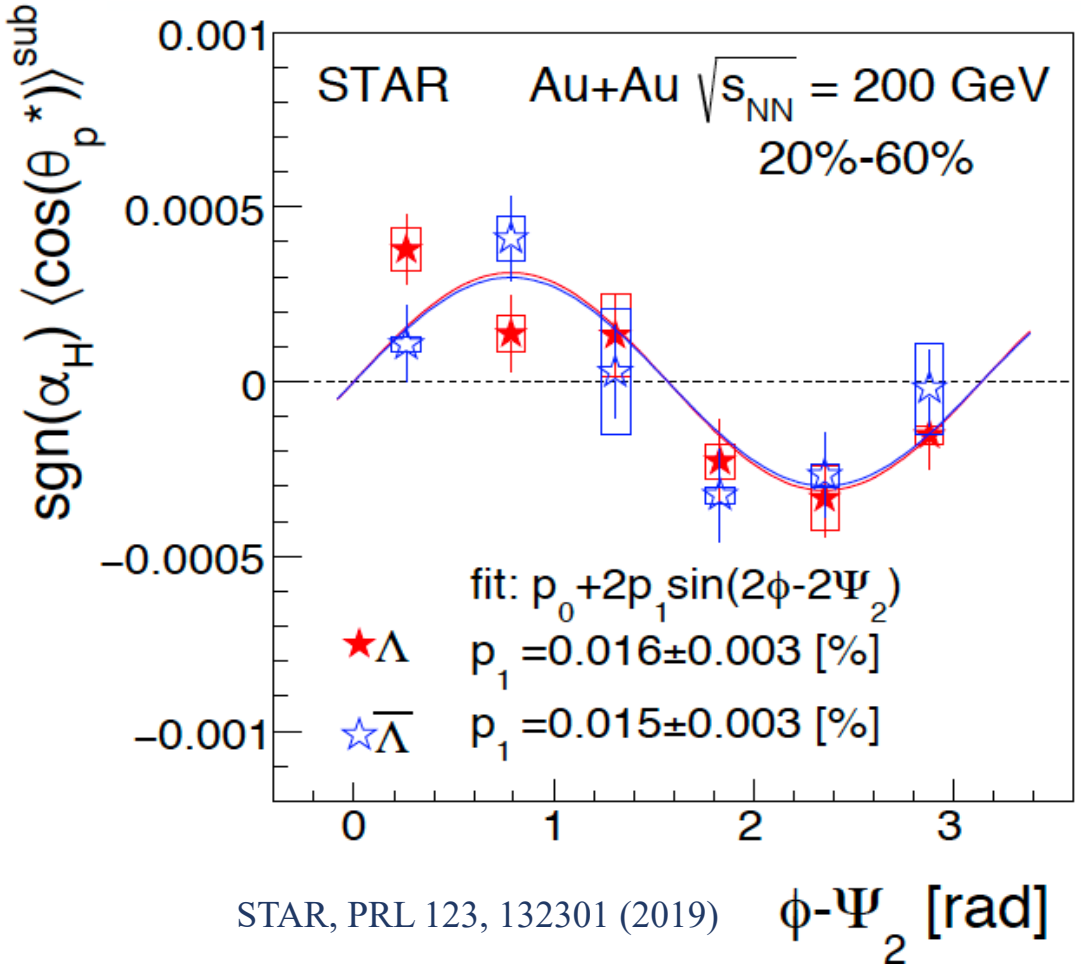


$$\langle cos\theta_p^* \rangle = \int \frac{dN}{d\Omega^*} cos\theta_p^* d\Omega^* = \alpha_\Lambda P_z \langle (cos\theta_p^*)^2 \rangle$$

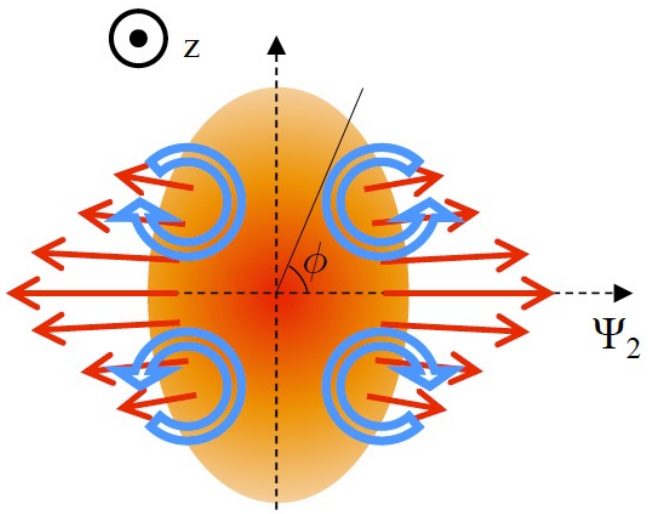
$$P_z = \frac{\langle cos\theta_p^* \rangle}{\alpha_\Lambda \langle (cos\theta_p^*)^2 \rangle}$$

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

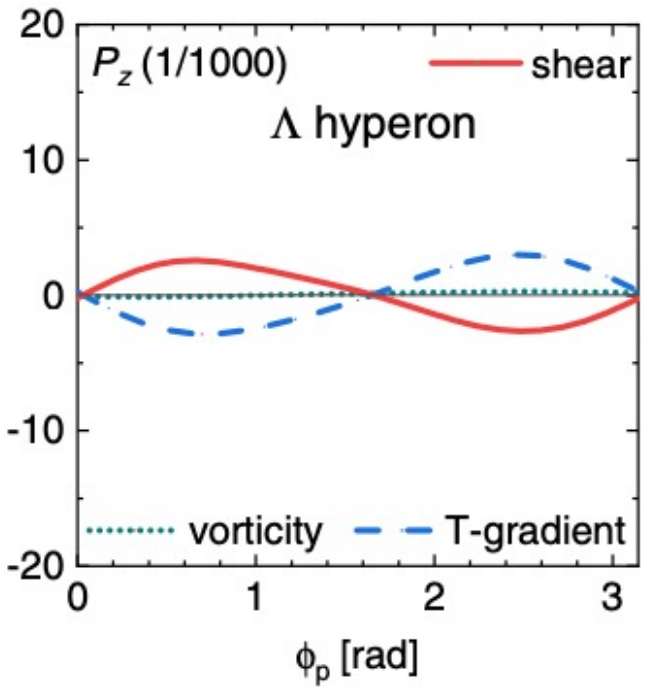
Local polarization in heavy ion collisions



STAR, PRL 123, 132301 (2019)



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



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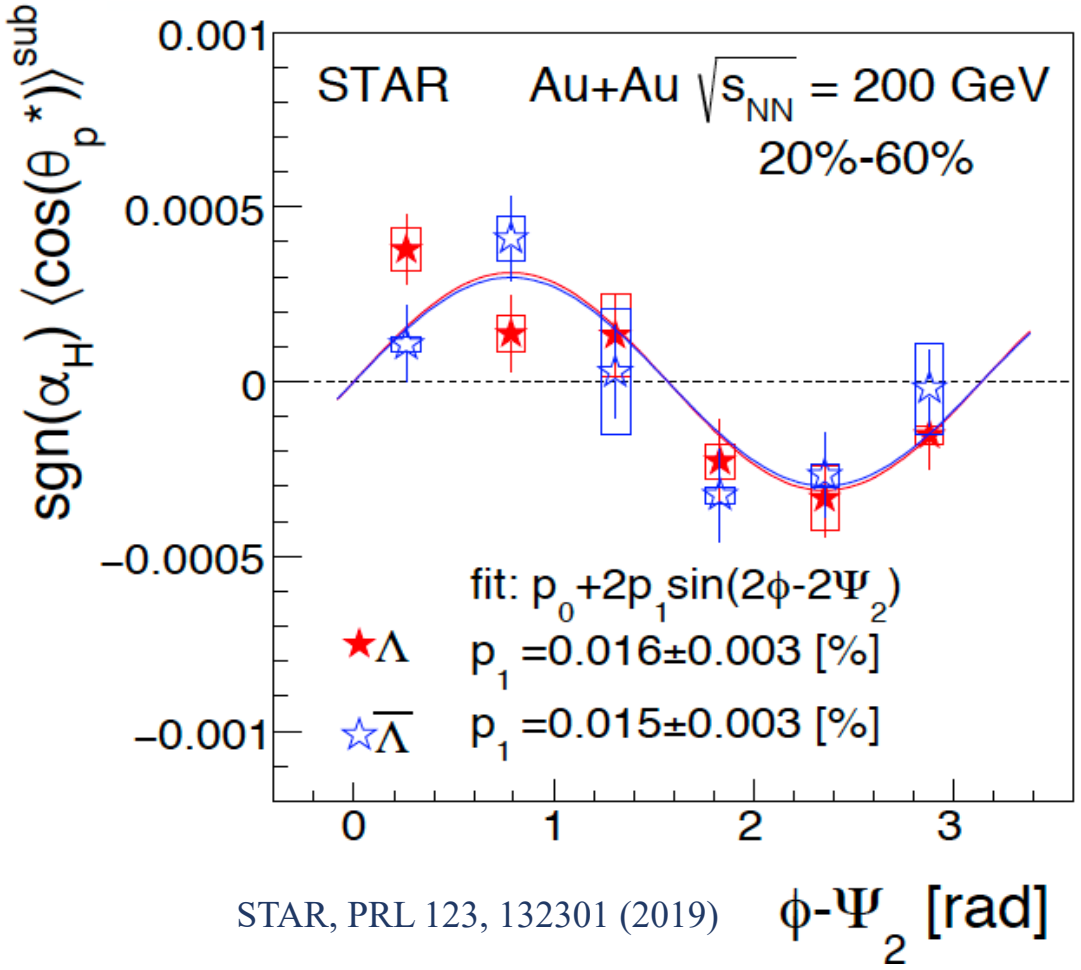
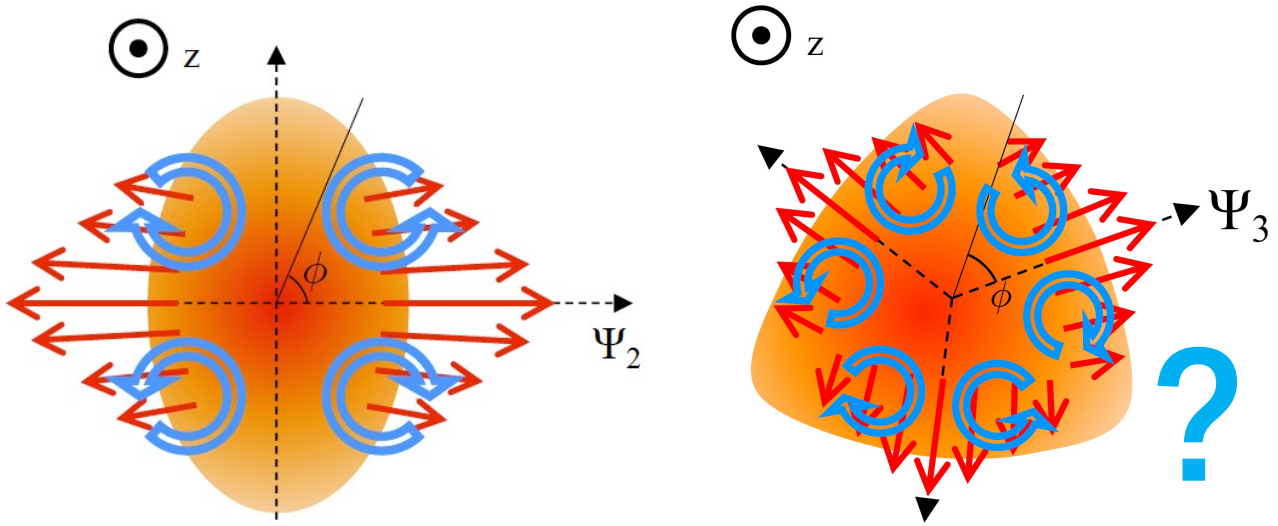
Local polarization in heavy ion collisions

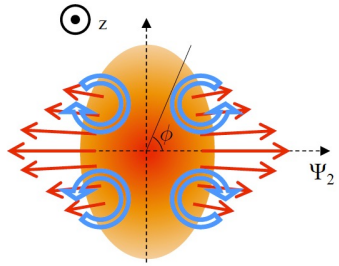


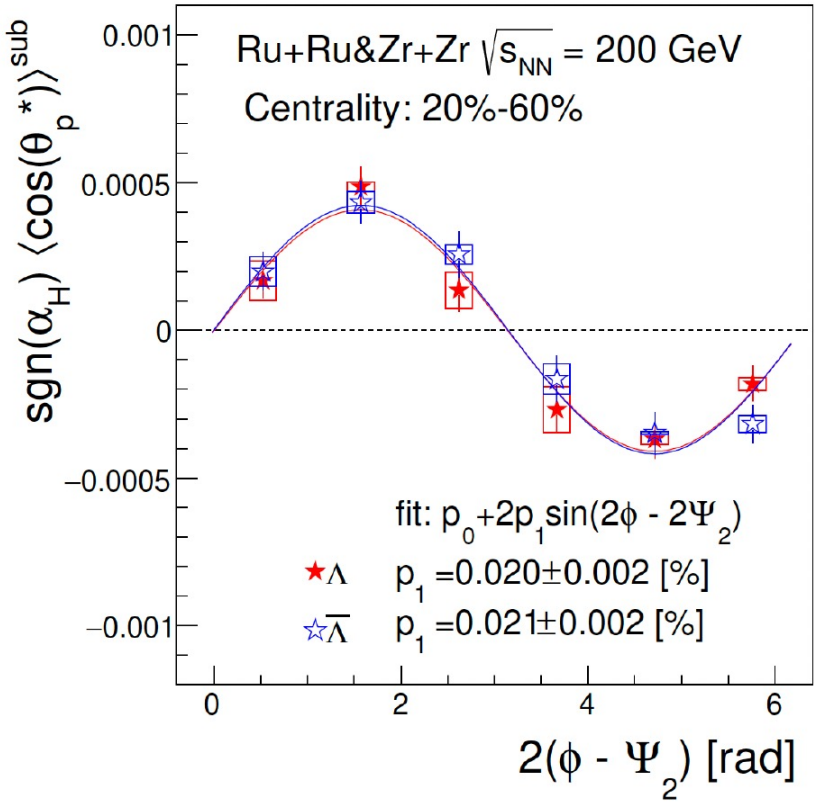
STAR, PRL 123, 132301 (2019)



- 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

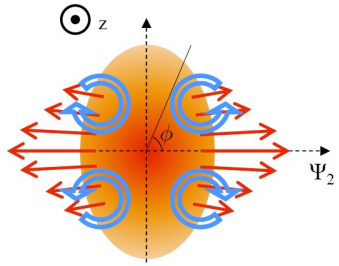


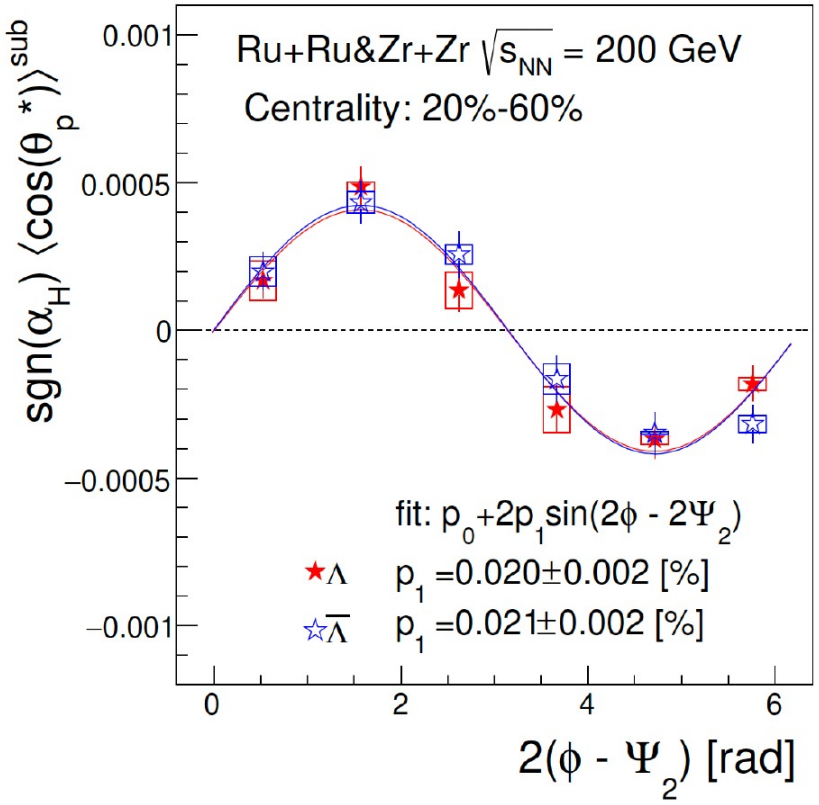


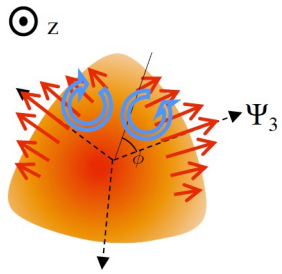
STAR,
PRL 131, 202301 (2023)

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

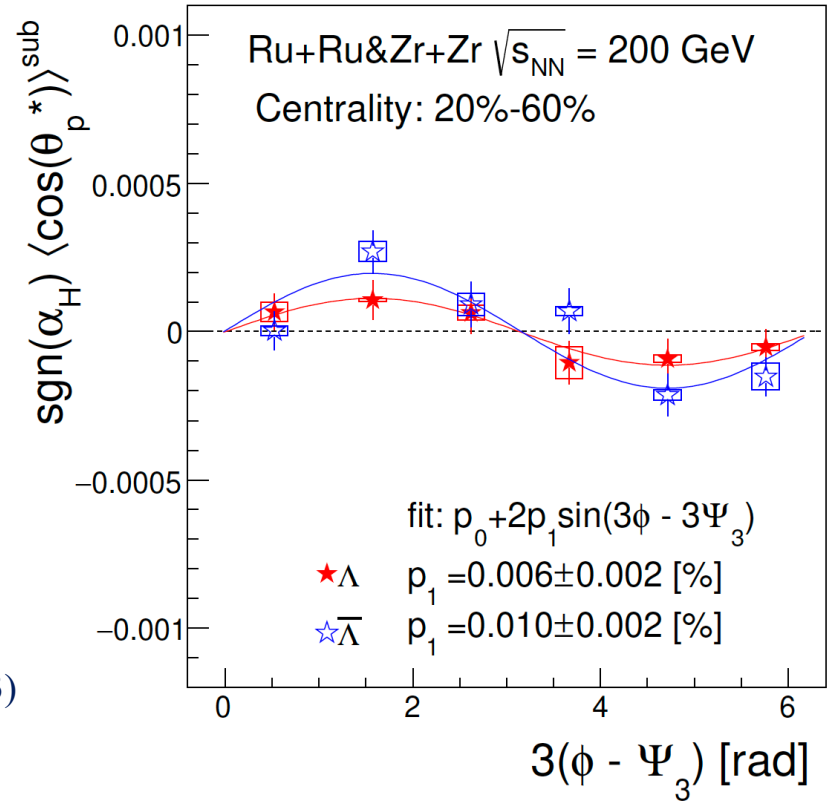
Local polarization in Ru+Ru&Zr+Zr at 200 GeV





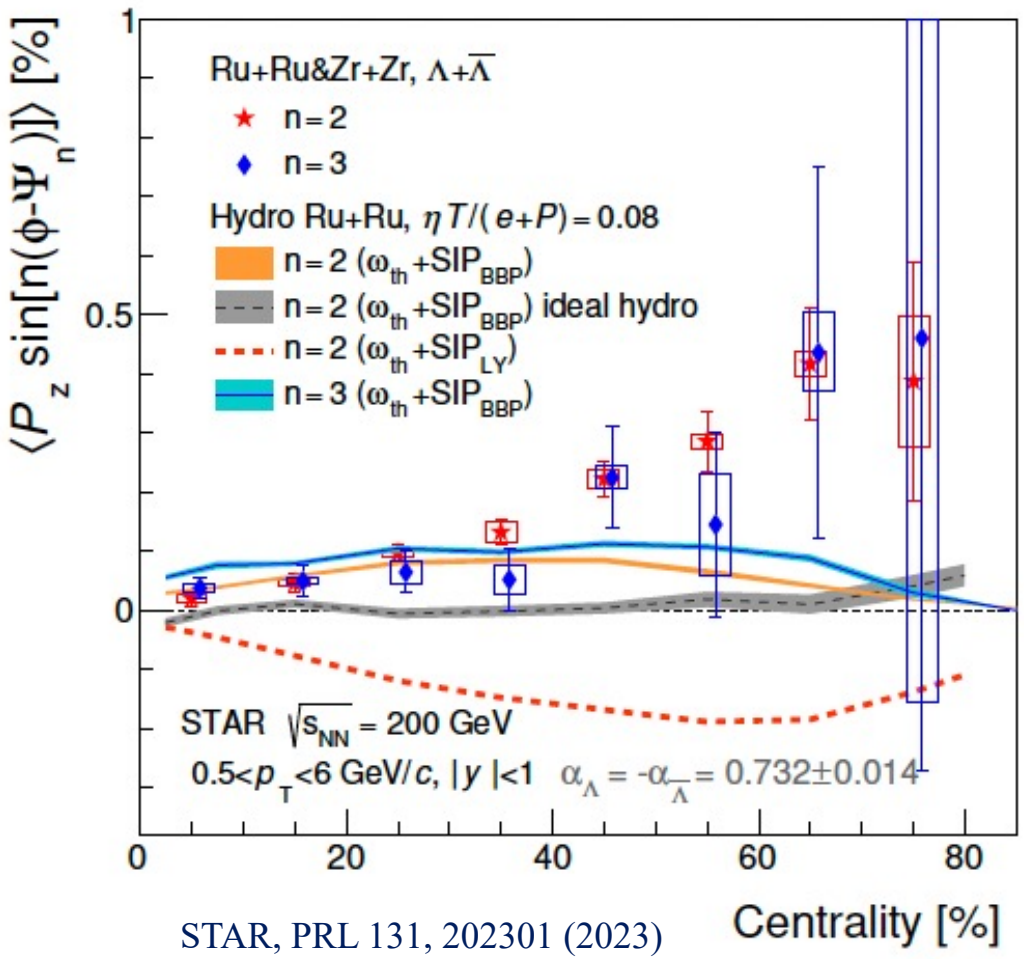


STAR,
PRL 131, 202301 (2023)



- 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

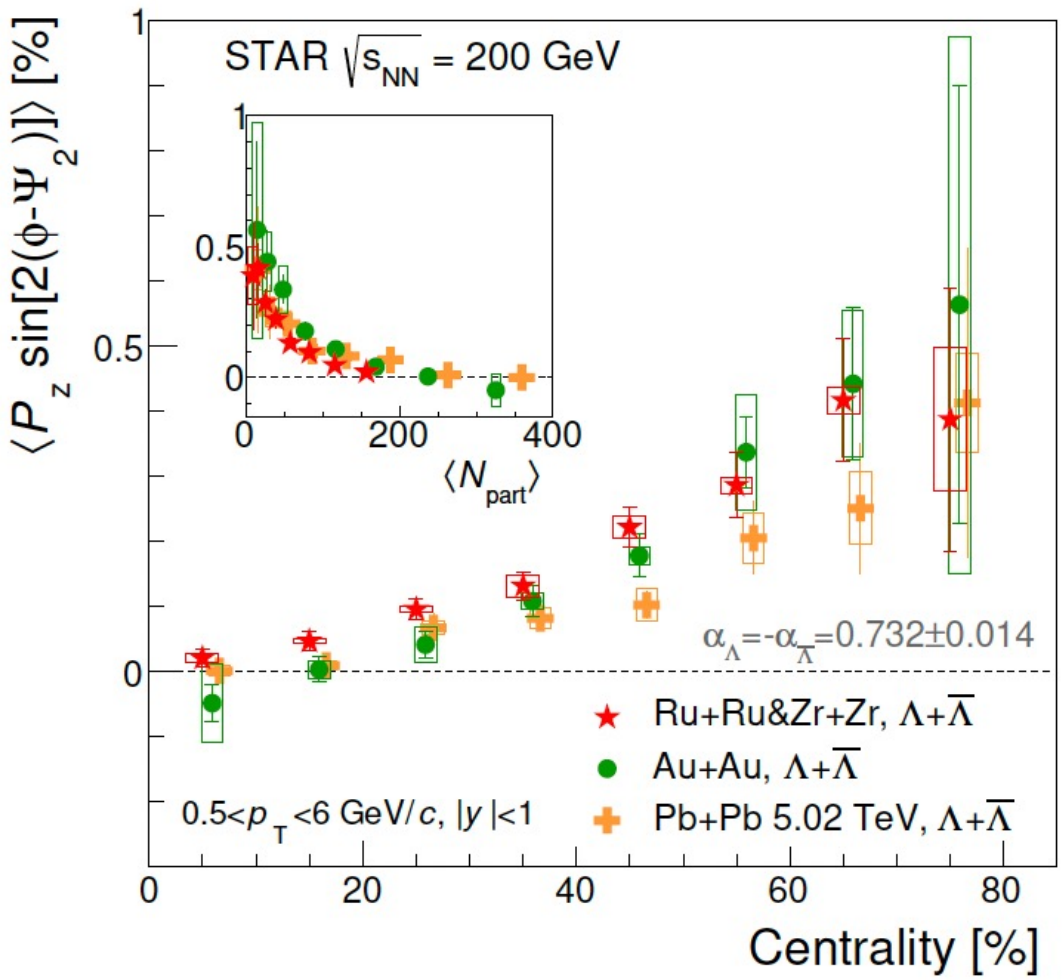


STAR, PRL 131, 202301 (2023)

- 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. Alzhrani et al., PRC 106.014905

Local polarization in different collisions



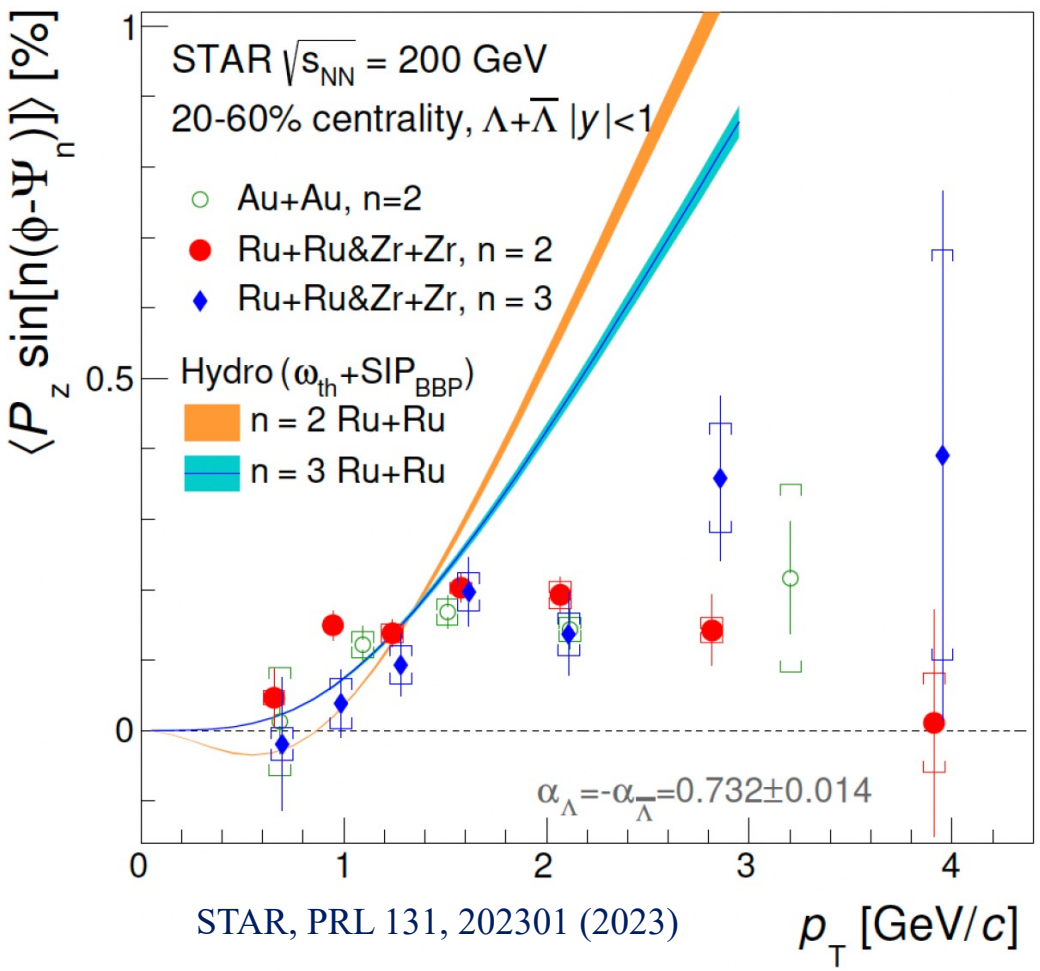
- Hint of system size dependence between isobar and Au+Au collisions
- Energy dependence is not obvious between 200 GeV Au+Au and 5.02 TeV Pb+Pb collisions

STAR, PRL 131, 202301 (2023)

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

Pb+Pb: ALICE, arXiv:2107.11183

p_T dependence of local polarization



STAR, PRL 131, 202301 (2023)

- 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

Summary

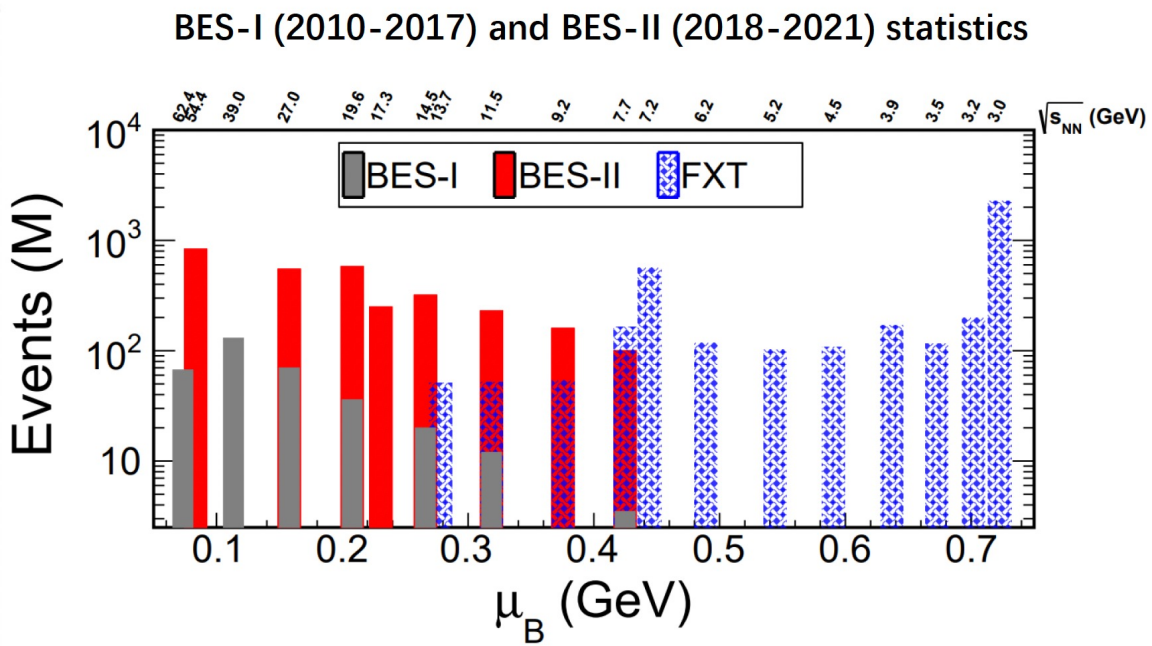
Global polarization

- No splitting observed between Λ and $\bar{\Lambda}$ global polarization in Au+Au collisions at 19.6, 27 GeV and ${}^{96}_{44}\mathrm{Ru} + {}^{96}_{44}\mathrm{Ru}$, ${}^{96}_{40}\mathrm{Zr} + {}^{96}_{40}\mathrm{Zr}$ collisions at 200 GeV
- No collision system size dependence between Ru+Ru, Zr+Zr and Au+Au collisions at 200 GeV

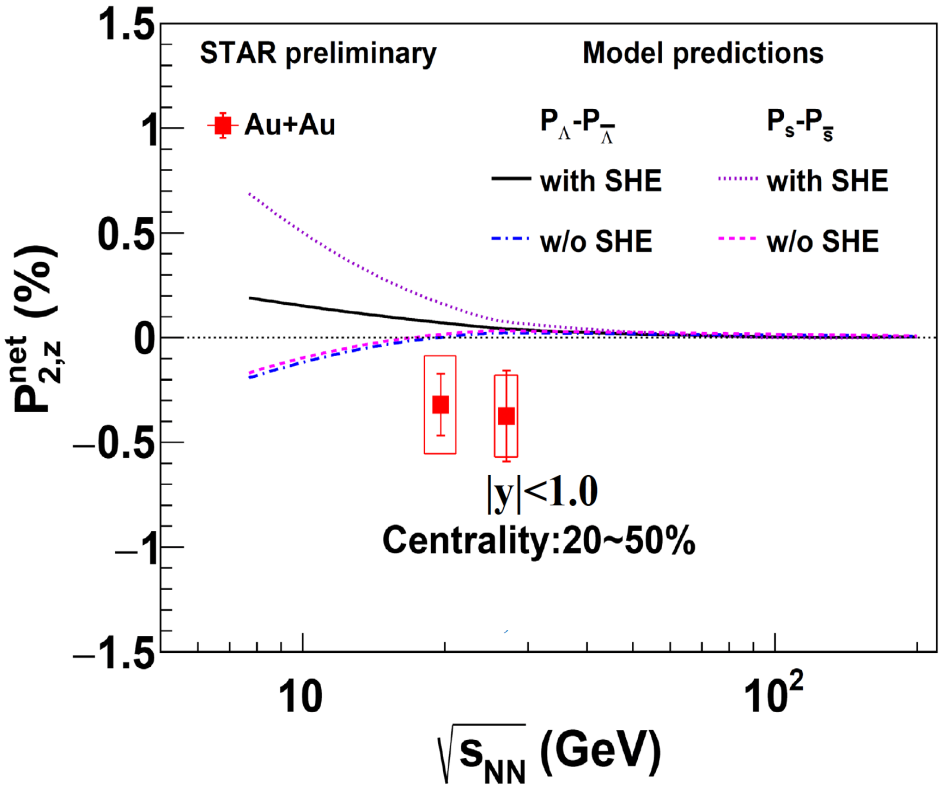
Local polarization

- 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

Outlook – Local polarization in Au+Au at BES-II



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

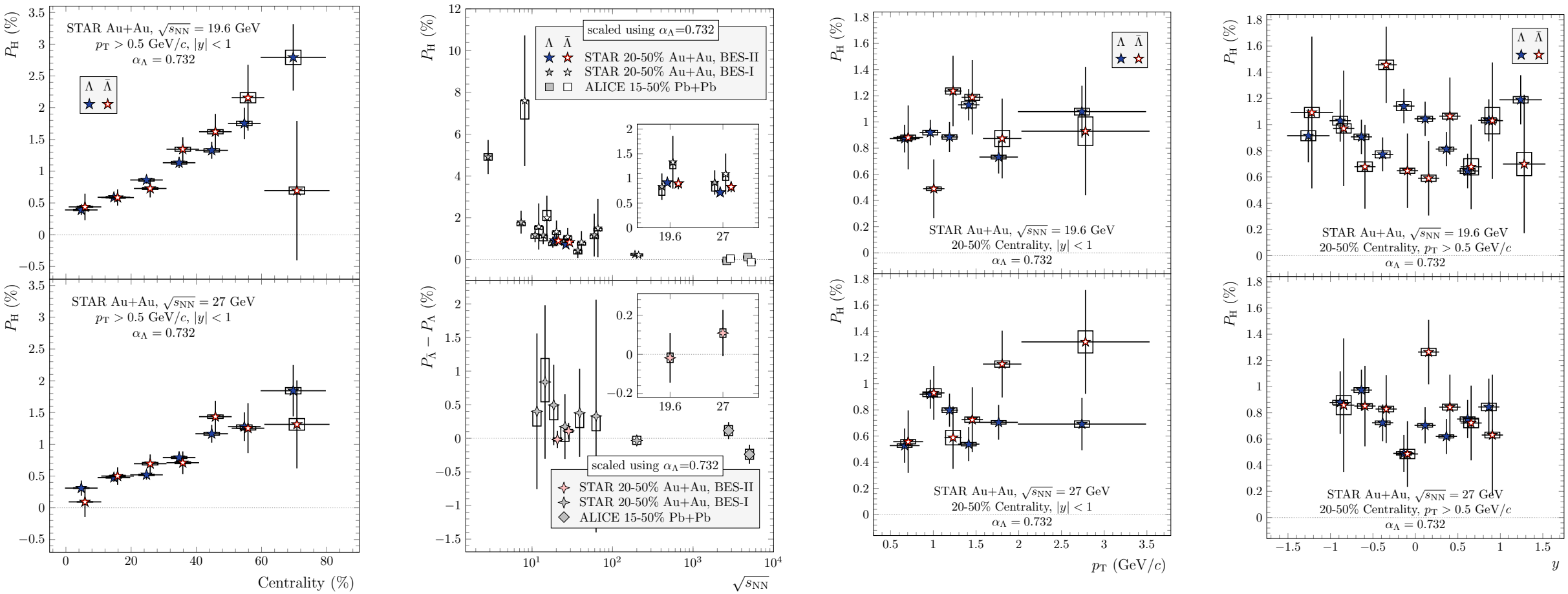


- Hyperon local polarization collision energy dependence in BES-II?
- First study of baryonic spin Hall effect by measuring net local polarization

QPT 2023

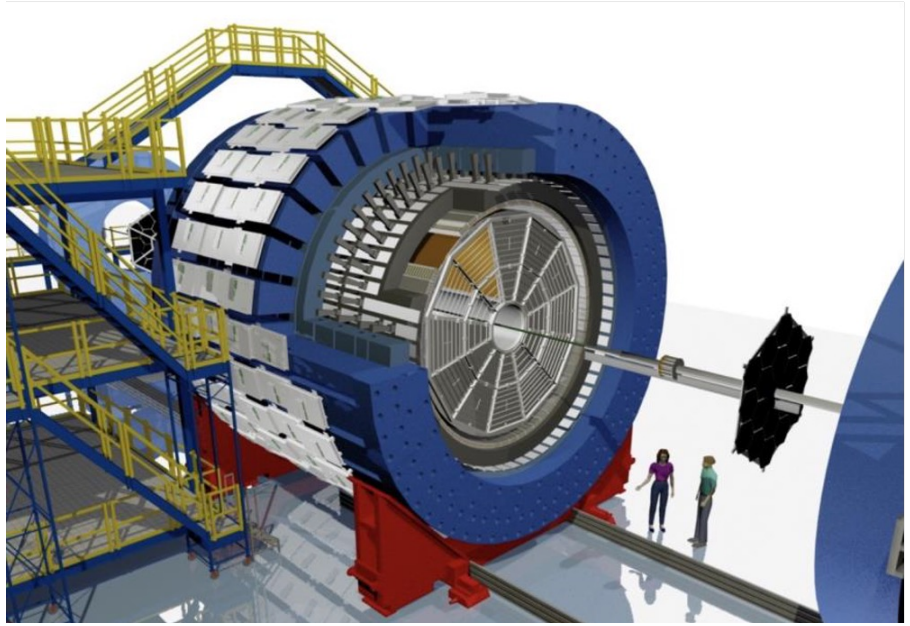
Thanks for your attention

Global polarization collision energy dependence



- Significant global polarization centrality dependence observed
- Lambda and antiLambda global polarization are consistent
- No observed dependence of global polarization on pt

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



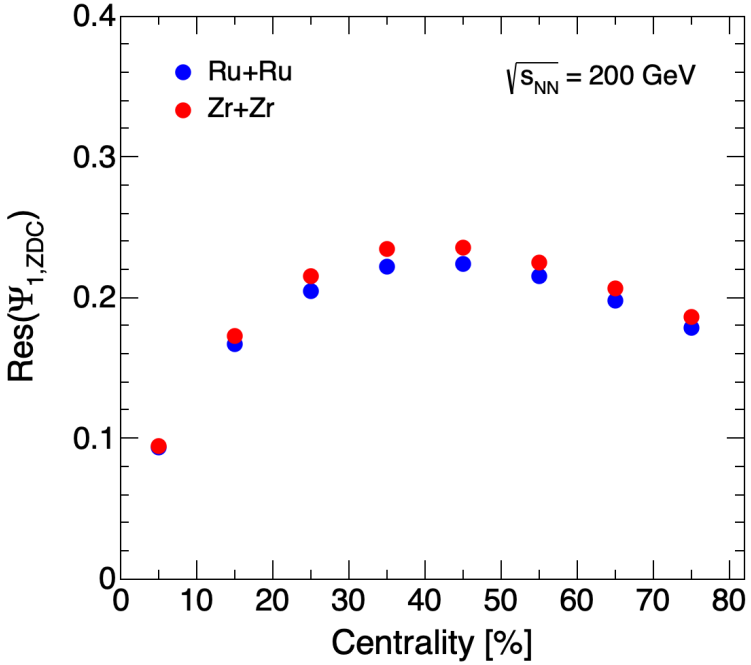
Event plane reconstruction:

Time Projection Chamber
Zero Degree Calorimeters

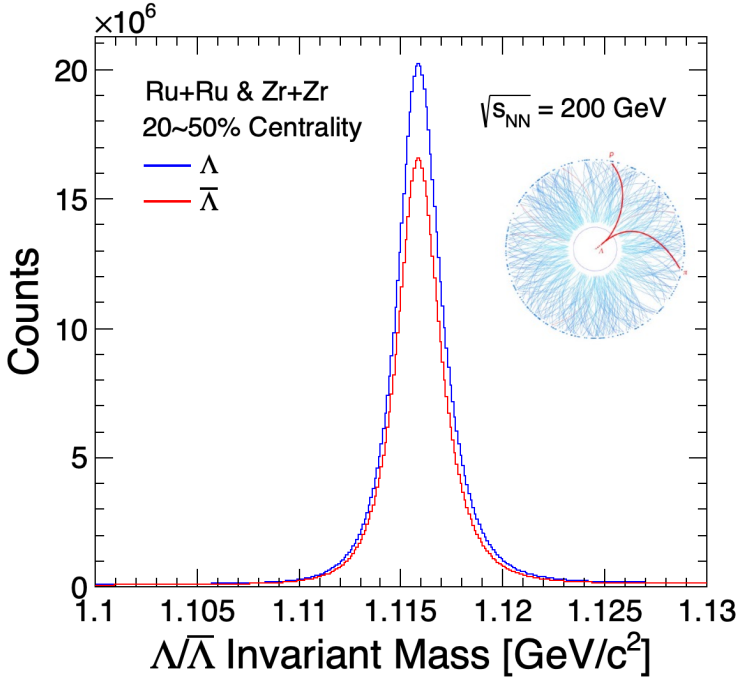
$\Lambda/\bar{\Lambda}$ reconstruction:

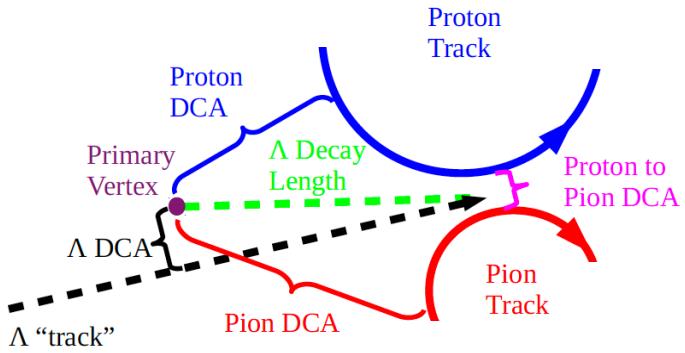
Time Projection Chamber
Time Of Flight

Event plane resolution



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





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