

Hyperon polarization in heavy ion collisions at STAR

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(for the STAR Collaboration)

Shandong University(山东大学)

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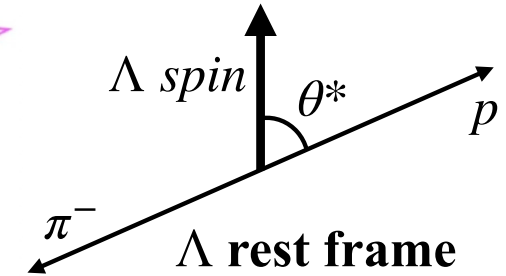
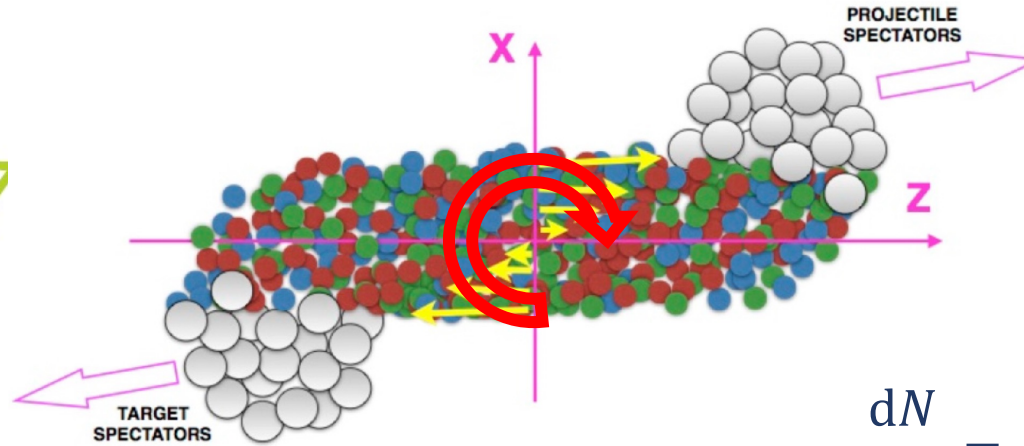
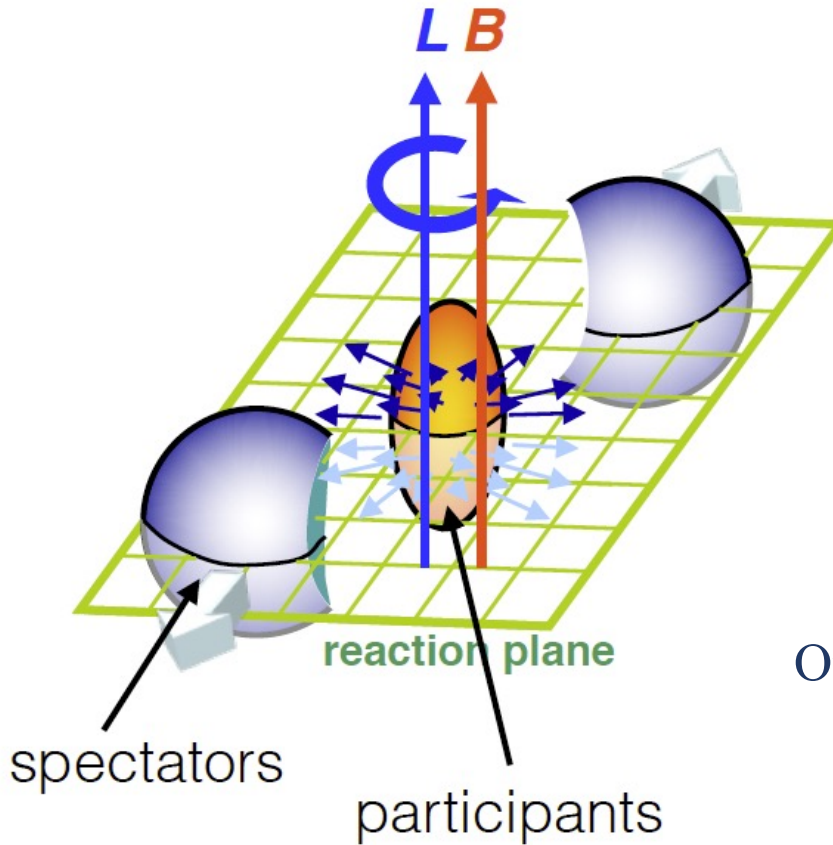
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Science



NSFC

- Motivation
- Hyperon global polarization
- Hyperon local polarization
- Summary
- Outlook for spin Hall effect

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

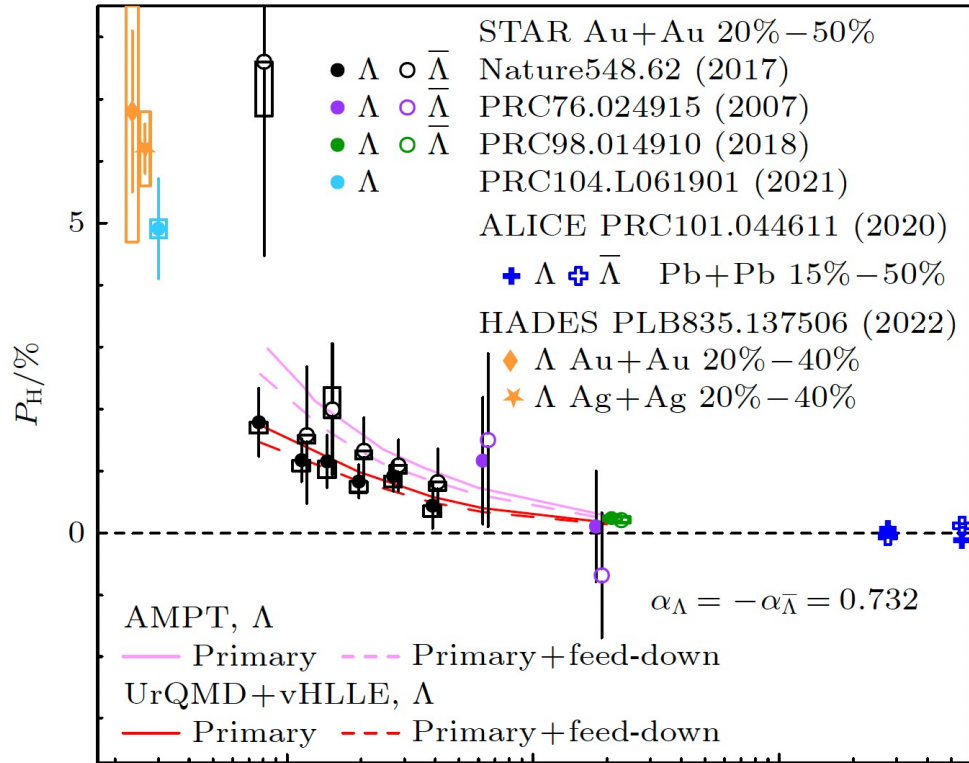
Ψ_1 : First-order event plane angle

$Res(\Psi_1)$: Event plane resolution

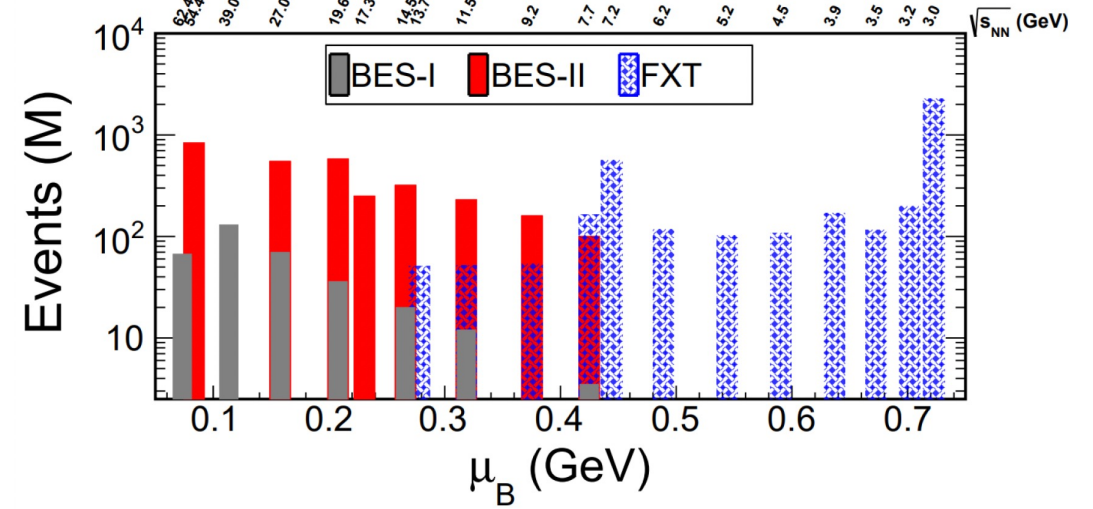
Hyperon polarization in heavy ion collisions



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



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



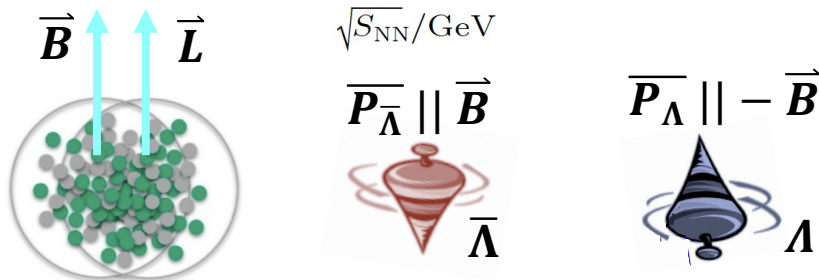
\square $\Lambda / \bar{\Lambda}$ global polarization splitting with BES-II data?

\square Global polarization collision system size dependence

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

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

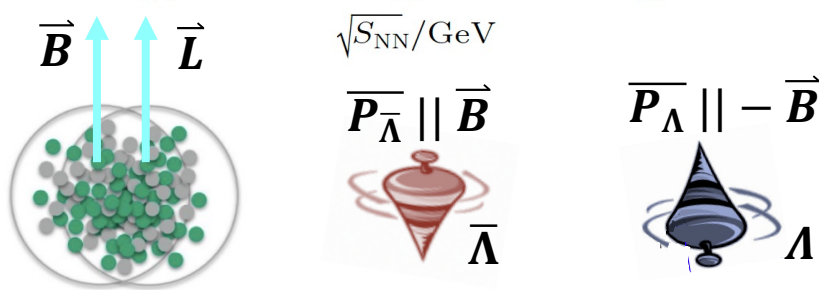
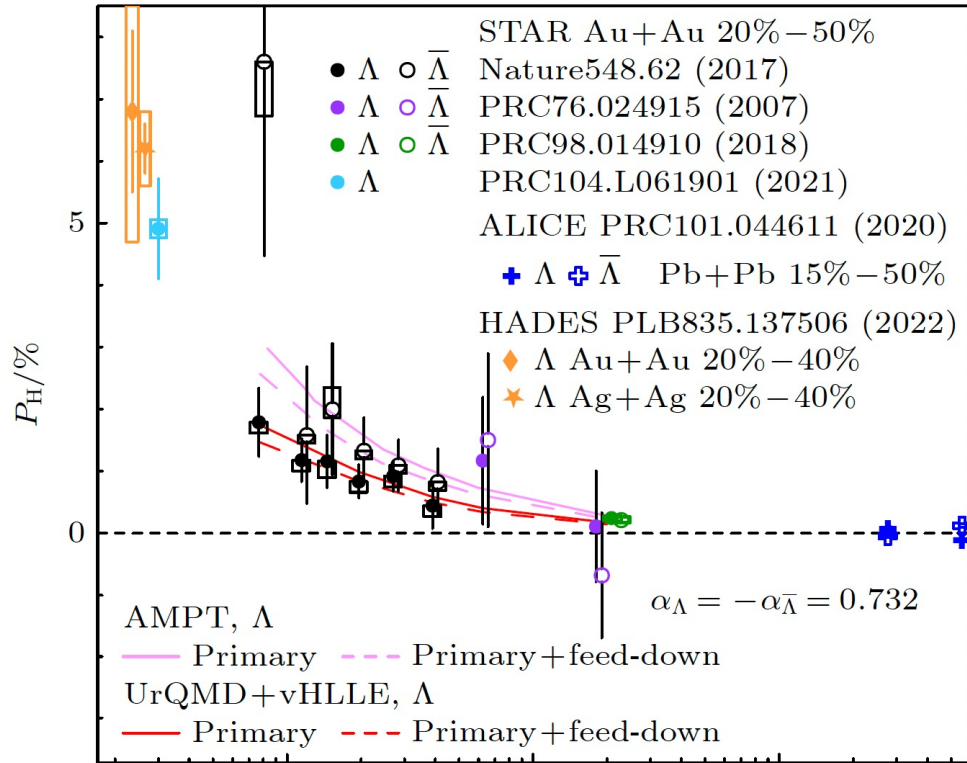
\square Local polarization in isobar collisions



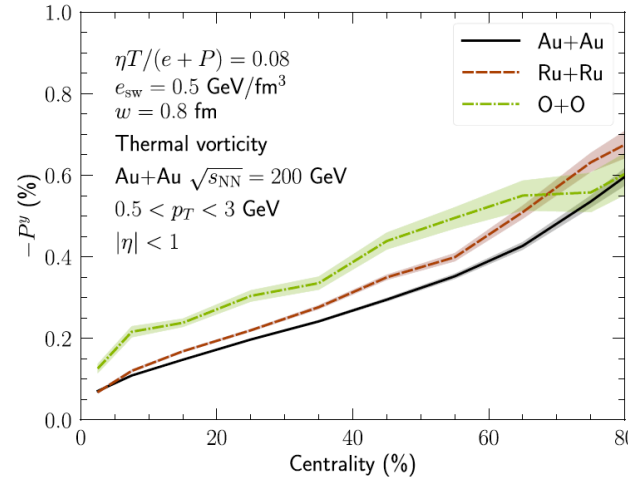
Hyperon polarization in heavy ion collisions



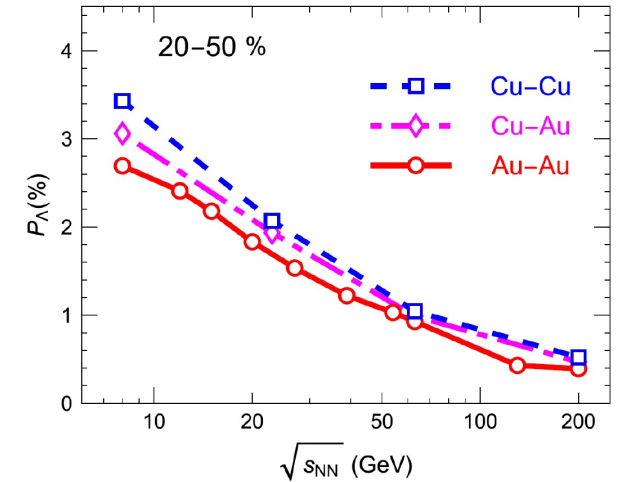
Acta Phys. Sin. Vol. 72, No. 7(2023) 072401



S. Alzhrani et al.,
PRC 106.014905



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



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

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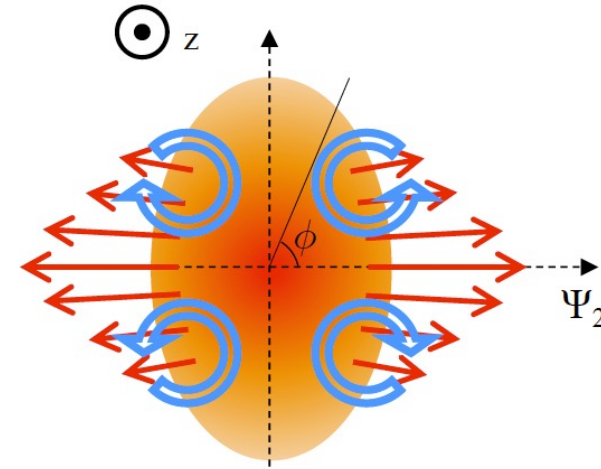
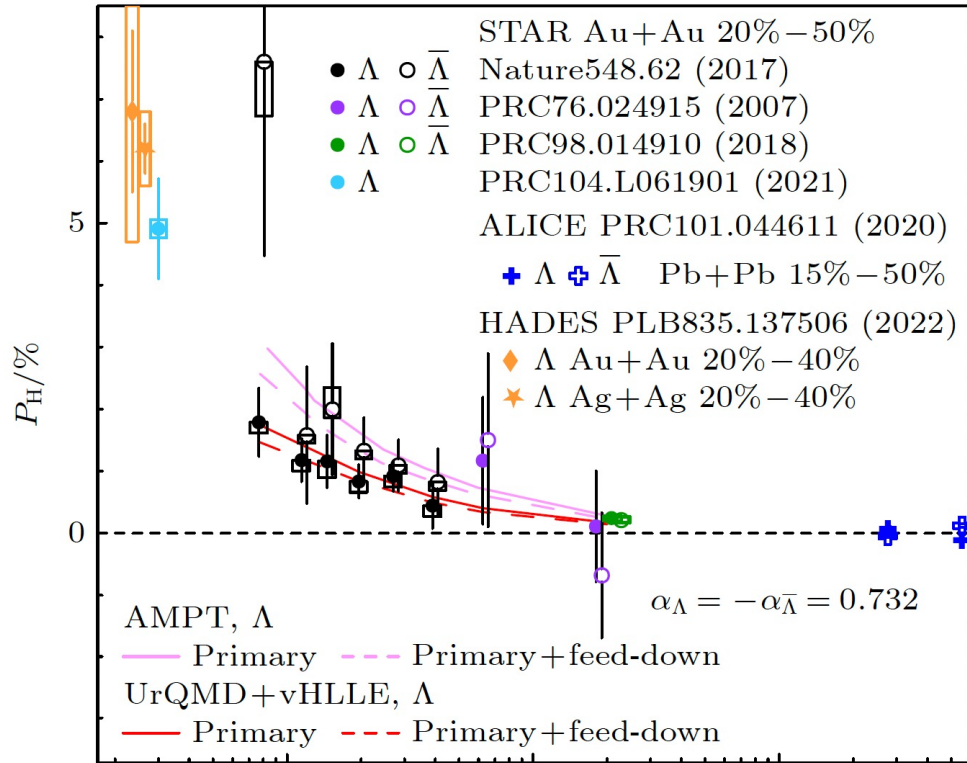
$$P_{\Lambda}^{\text{Au}} < P_{\Lambda}^{\text{Ru}} \approx P_{\Lambda}^{\text{Zr}} < P_{\Lambda}^{\text{Cu}} < P_{\Lambda}^{\text{O}}$$

- Local polarization in isobar collisions

Hyperon polarization in heavy ion collisions



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

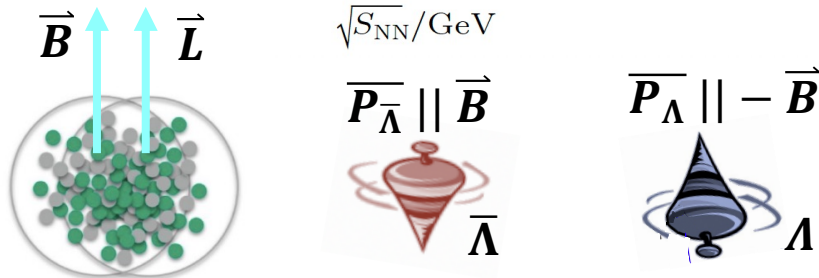


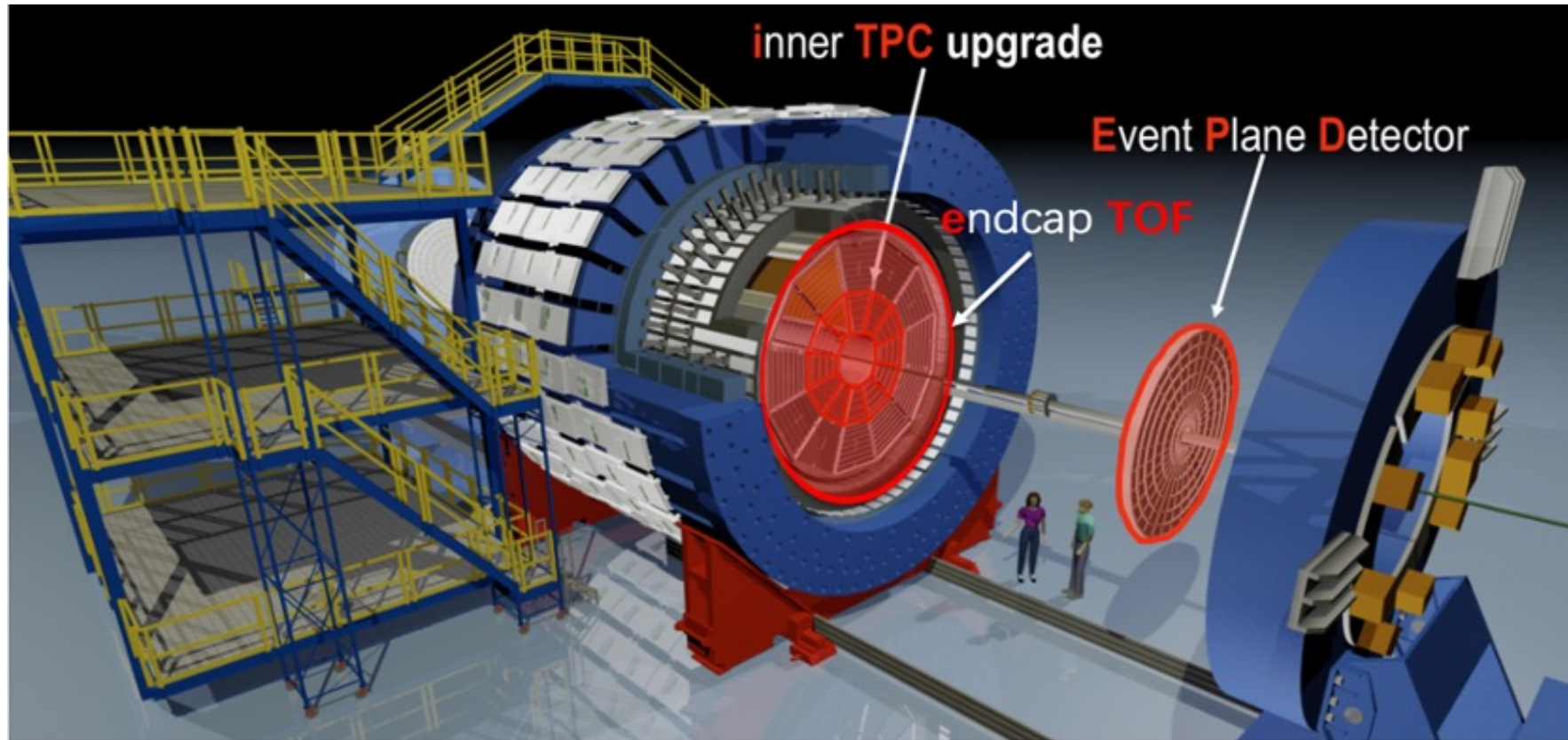
- $\Lambda / \bar{\Lambda}$ global polarization splitting with BES-II data?
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$${}^{197}_{79}\text{Au} > {}^{96}_{44}\text{Ru}, {}^{96}_{40}\text{Zr} > {}^{63}_{29}\text{Cu} > {}^{16}_8\text{O}$$

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- Local polarization in isobar collisions



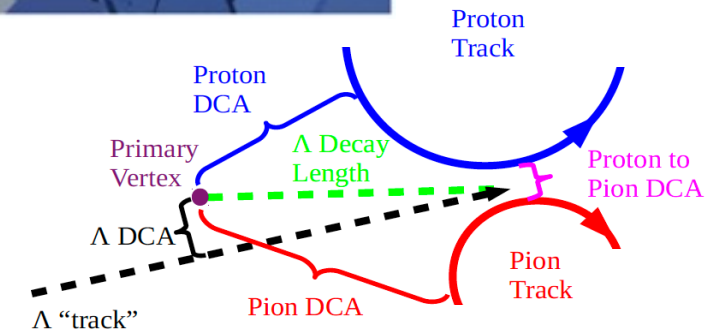


□ Event plane reconstruction:

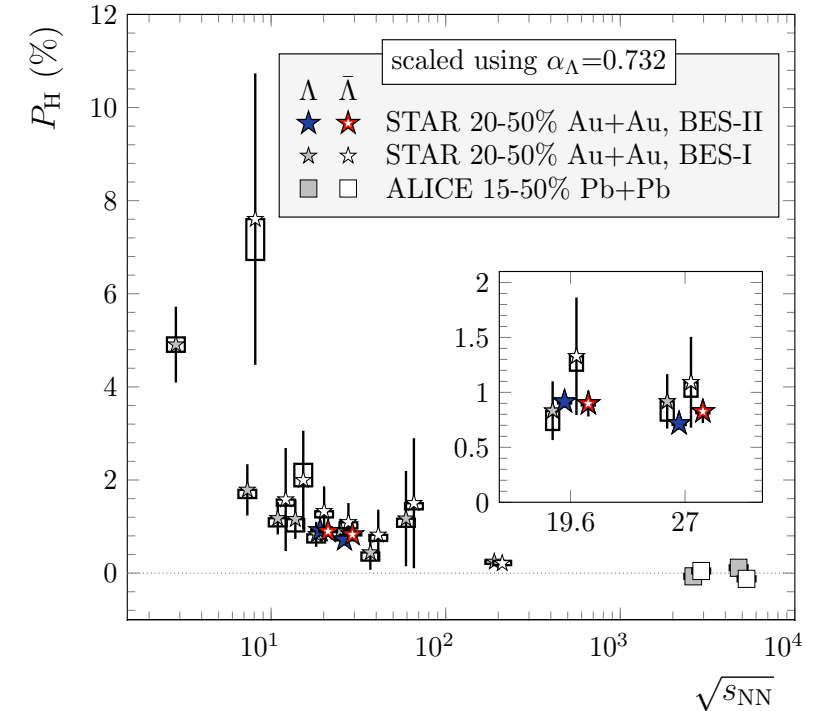
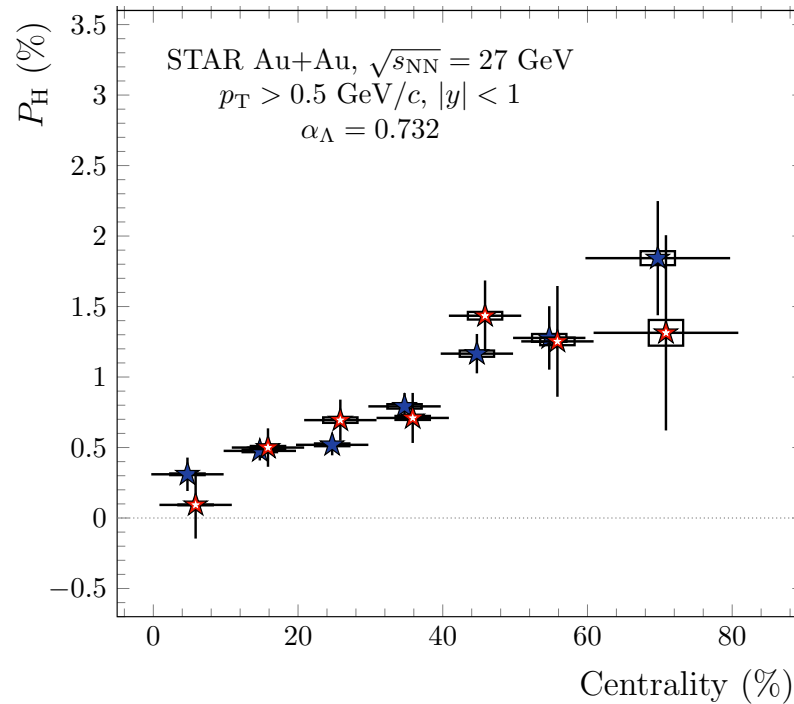
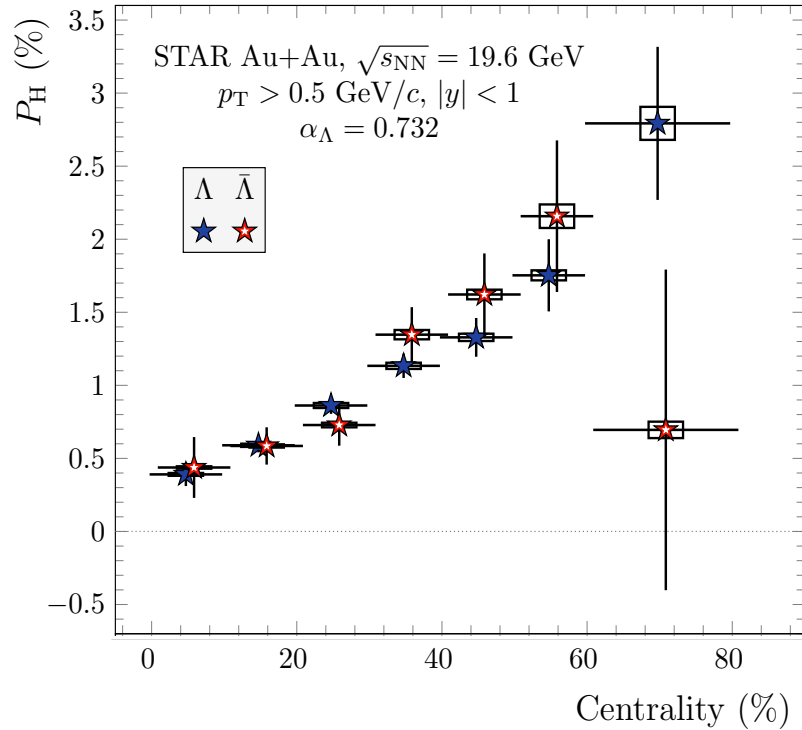
Time Projection Chamber
Event Plane Detector
Zero Degree Calorimeters

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

Time Projection Chamber
Time Of Flight



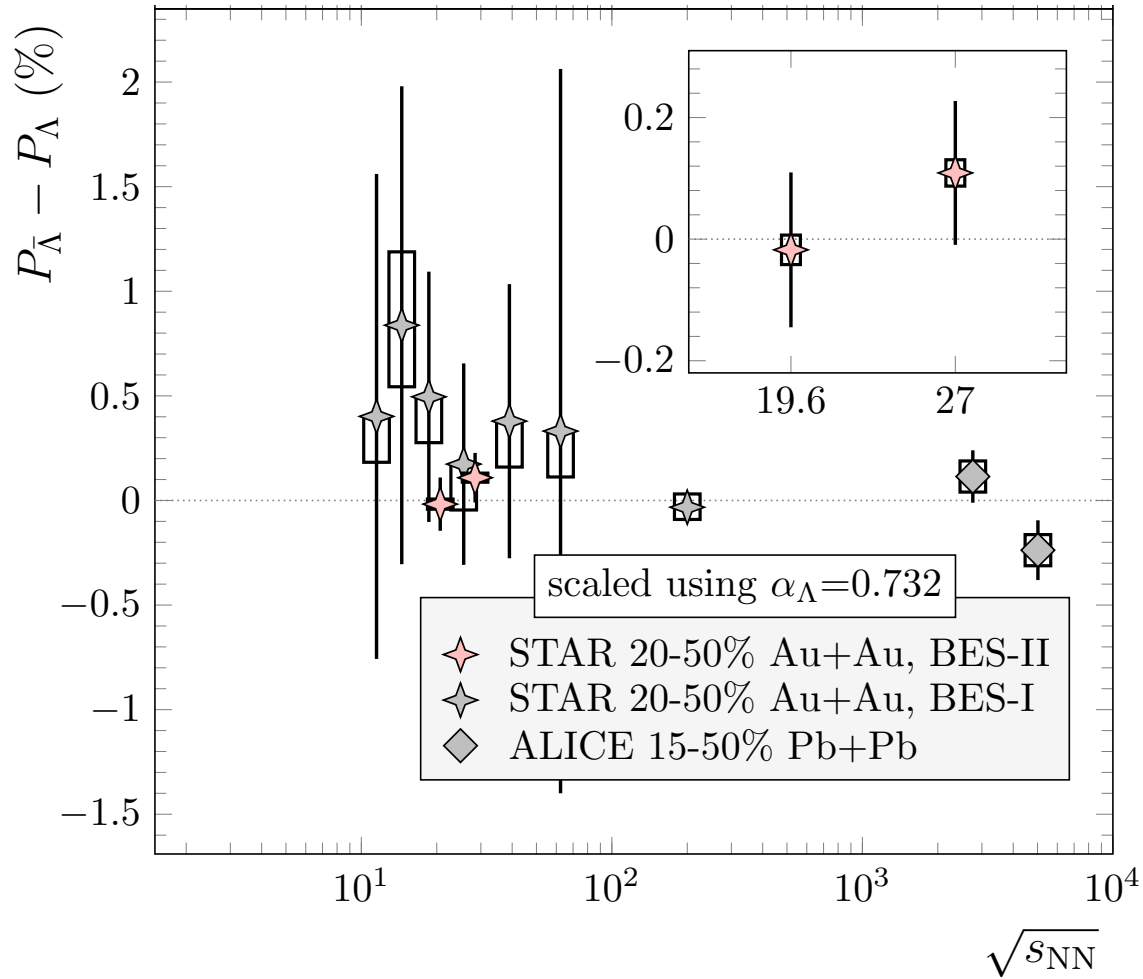
Global polarization in Au+Au with BES-II data (19.6, 27 GeV)



STAR, PRC 108, 014910 (2023)

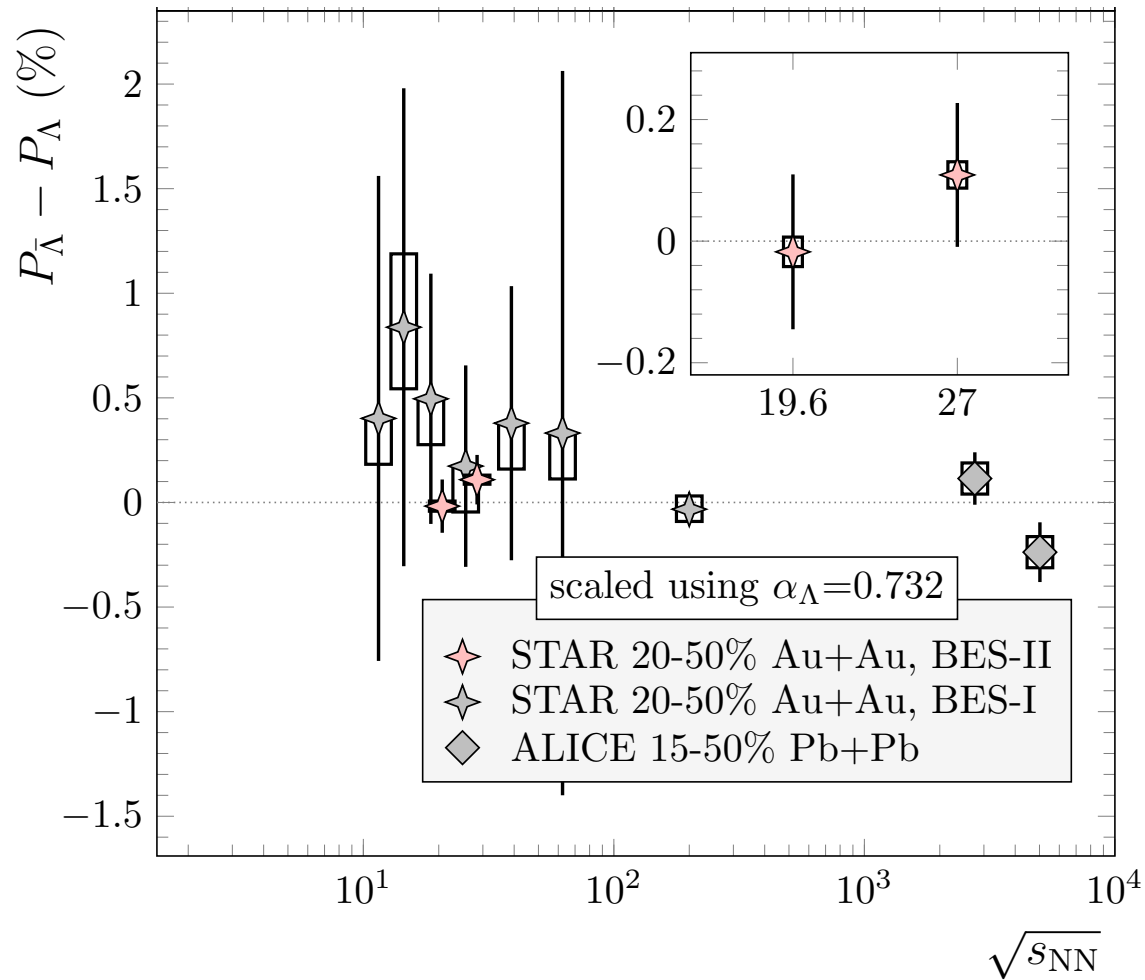
- About 10 times increases in statistics than BES-I
- Significant global polarization centrality dependence observed, results consistent with BES-I

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



□ No splitting of $\Lambda / \bar{\Lambda}$ 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 $\pm 0.118(stat.)$ $\pm 0.022(sys.)$



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

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

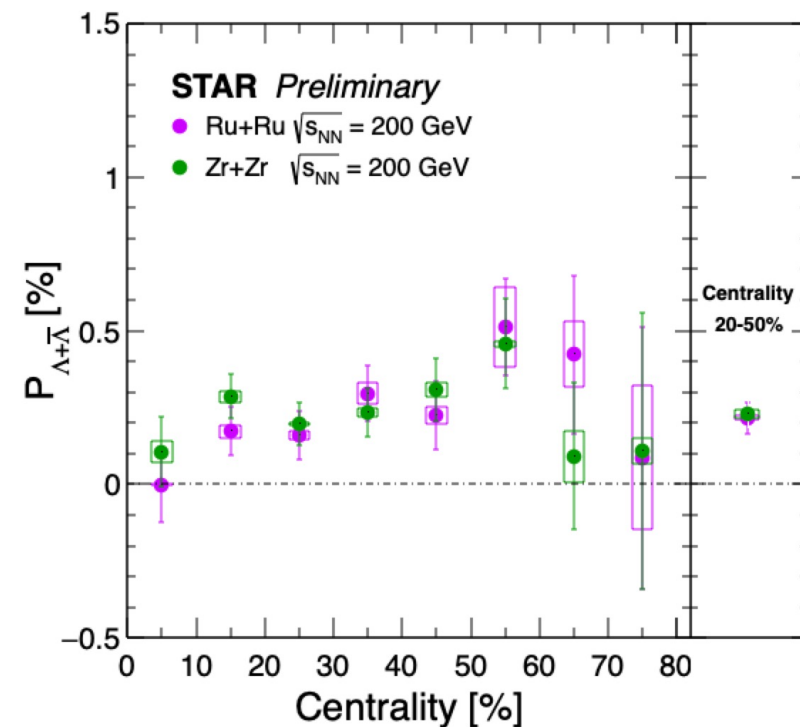
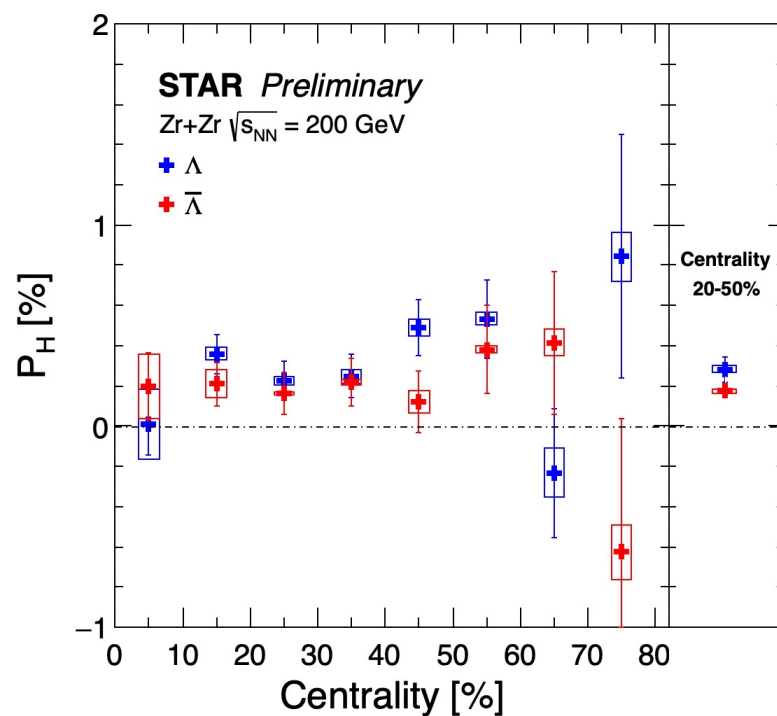
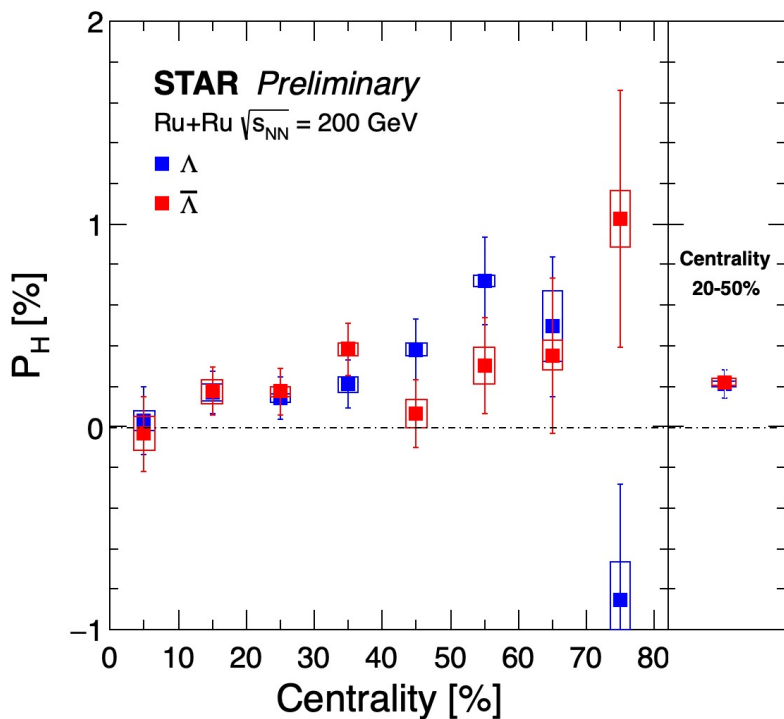
$T_s = 150$ MeV : the temperature of the emitting source

$\mu_{\Lambda} = -1.93 \times 10^{-14}$ MeV/T : the magnetic moment of the Λ hyperon

□ Upper limit on late stage magnetic field

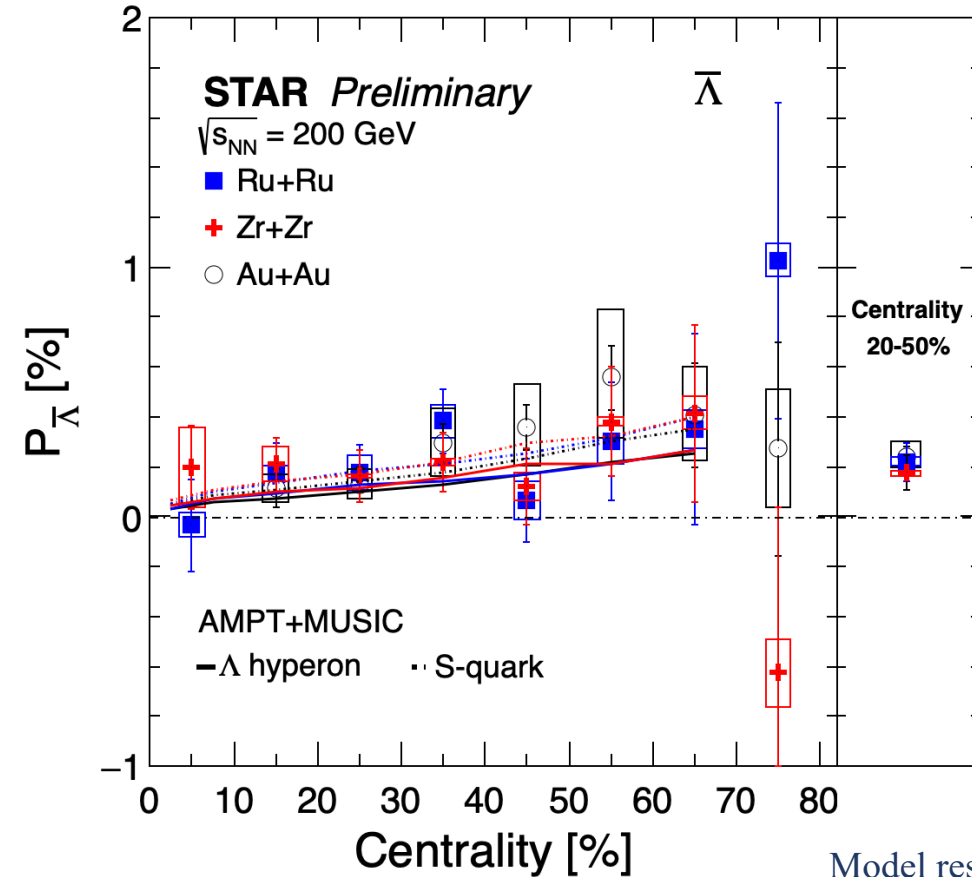
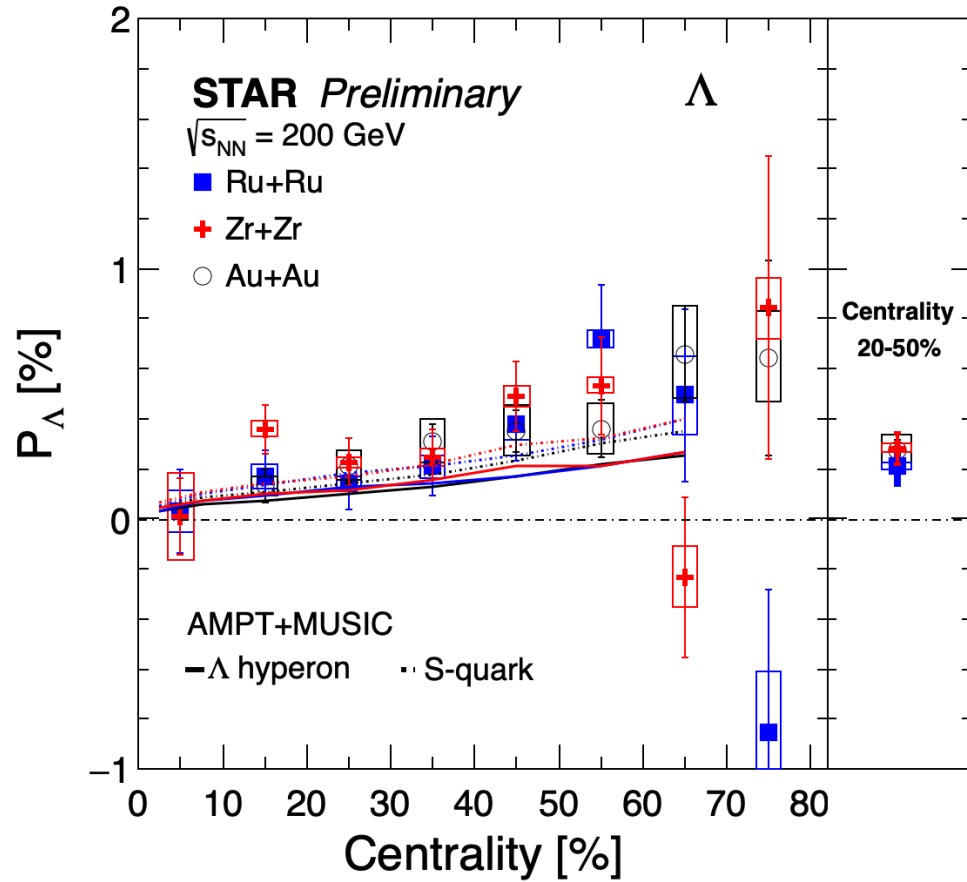
- 95% confidence level
- $B < 9.4 \times 10^{12}$ T at 19.6 GeV
- $B < 1.4 \times 10^{13}$ T at 27 GeV

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

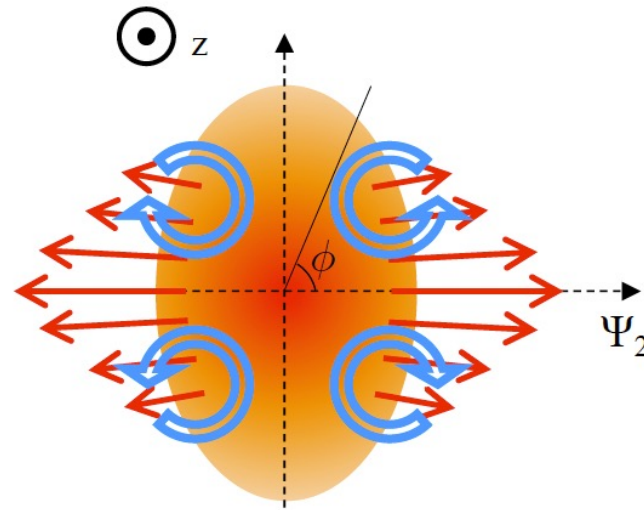
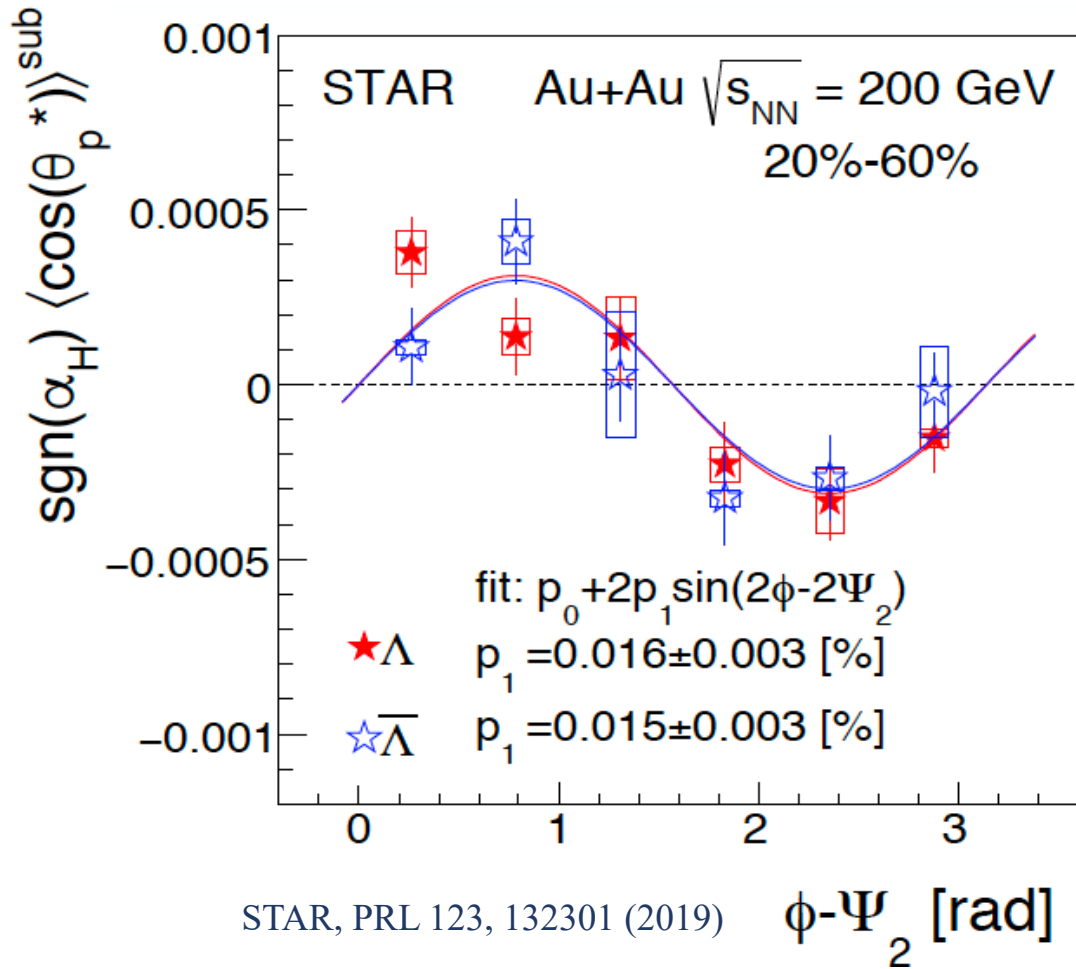
Global polarization in Ru+Ru, Zr+Zr and Au+Au at 200 GeV



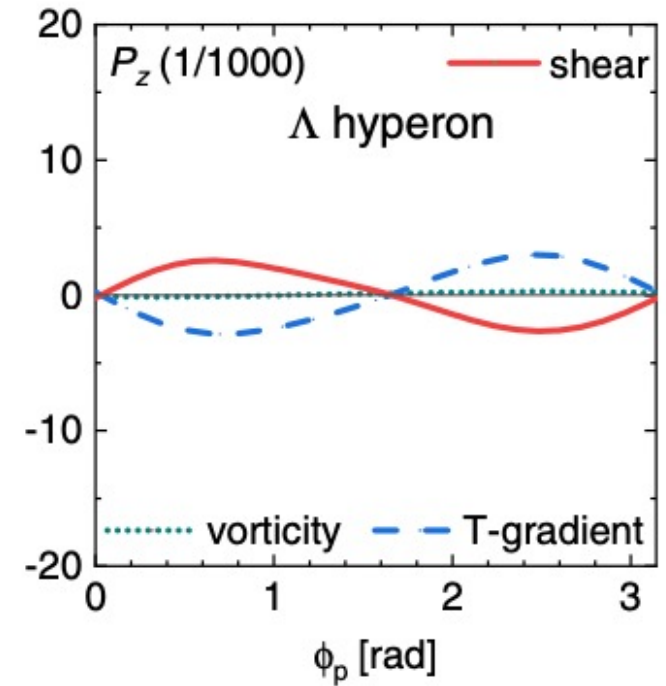
Model results from
 arXiv:2201.12970v1

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

Local polarization in heavy ion collisions

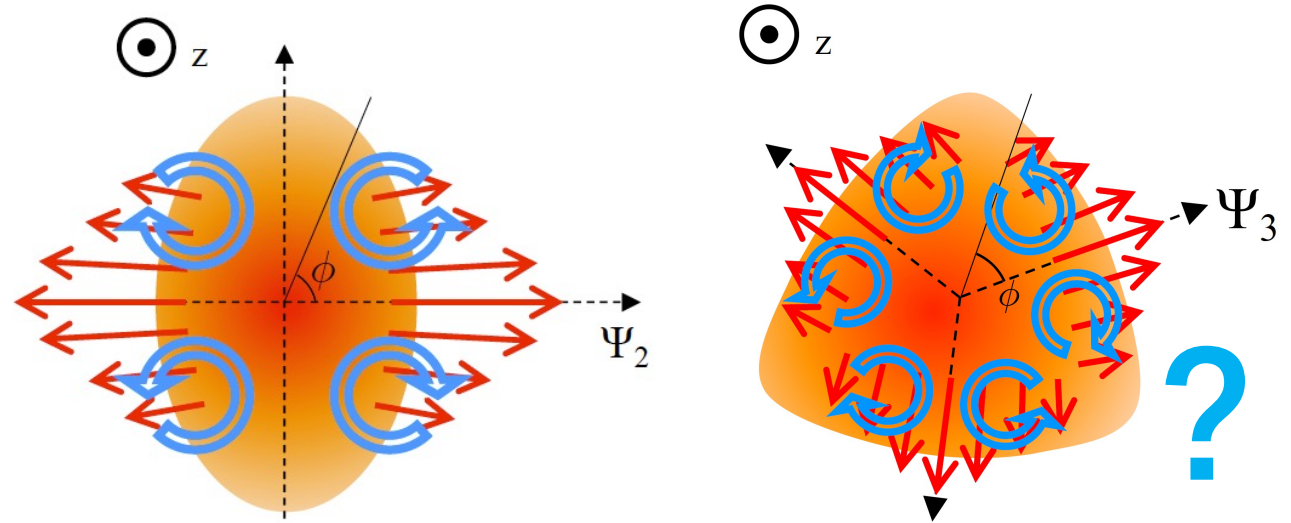
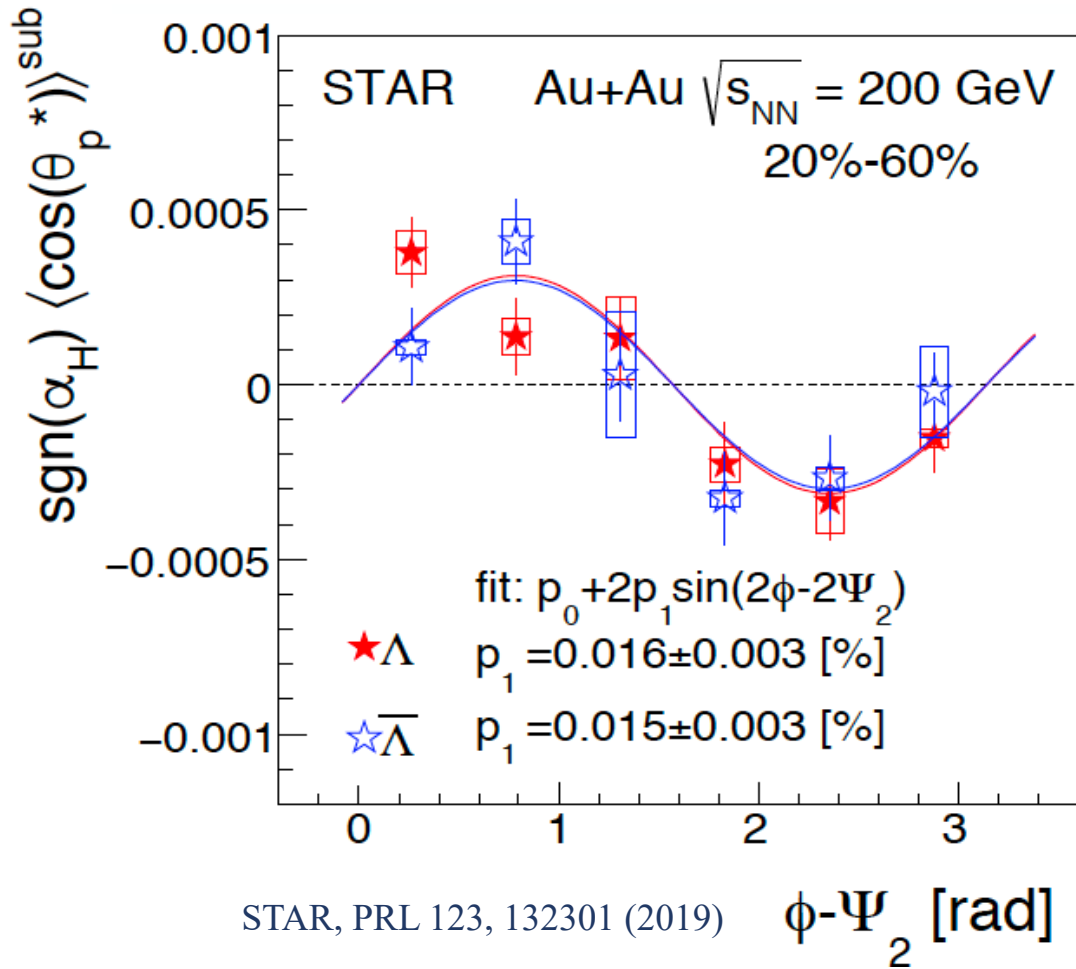


Baochi Fu et al., PRL 127, 142301 (2021)



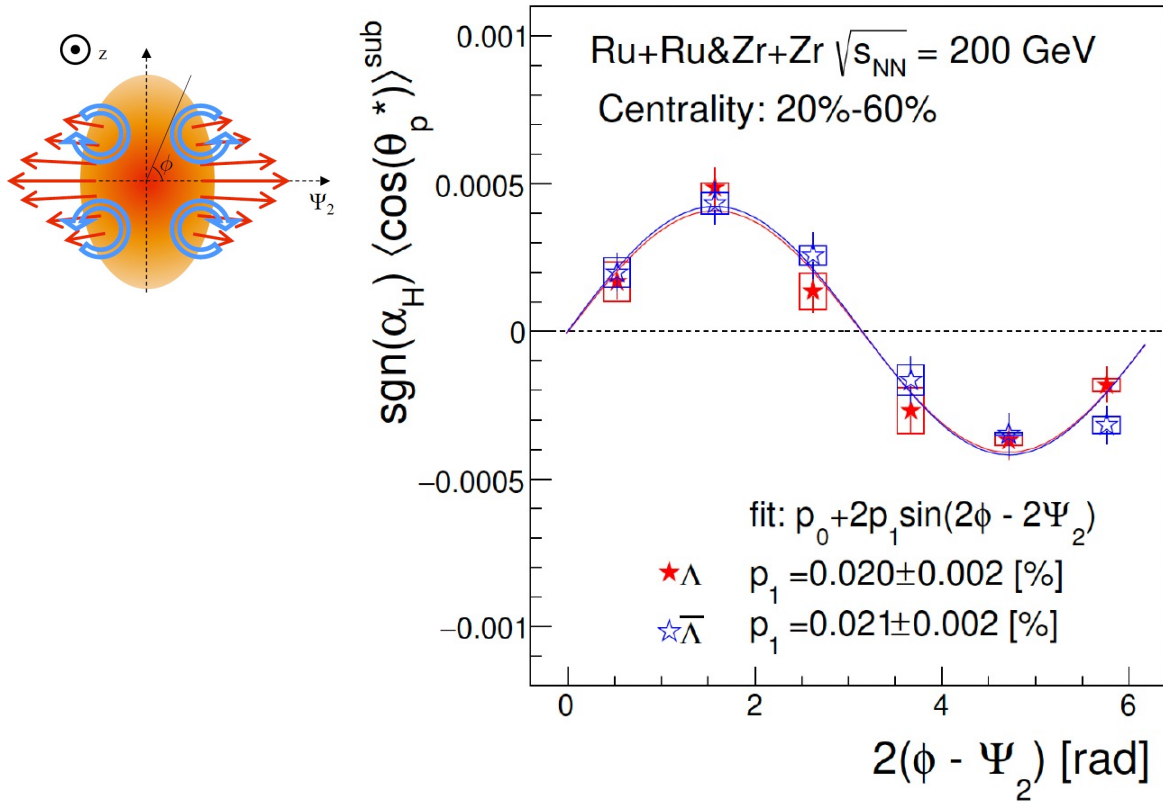
- Collision system size and energy dependence
- Measurements in smaller systems and relative to higher harmonic event planes provide new insights into polarization phenomena

Local polarization in heavy ion collisions



- Collision system size and energy dependence
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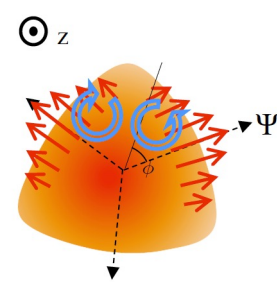
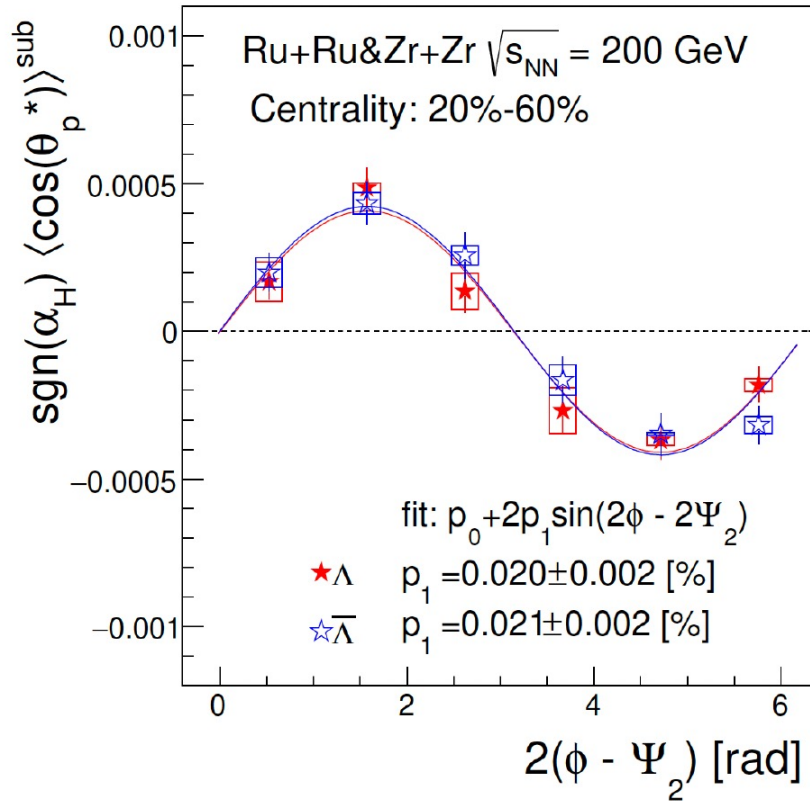
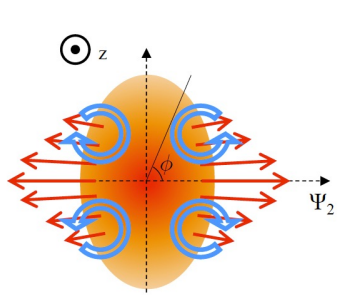
Local polarization in Ru+Ru&Zr+Zr at 200 GeV



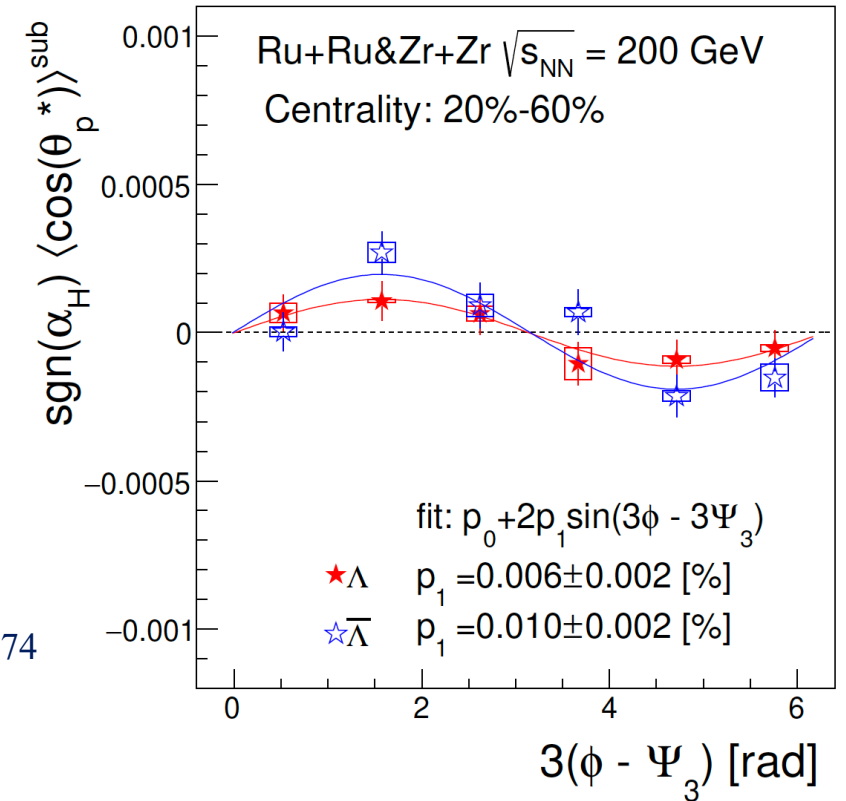
STAR, arXiv:2303.09074

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

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

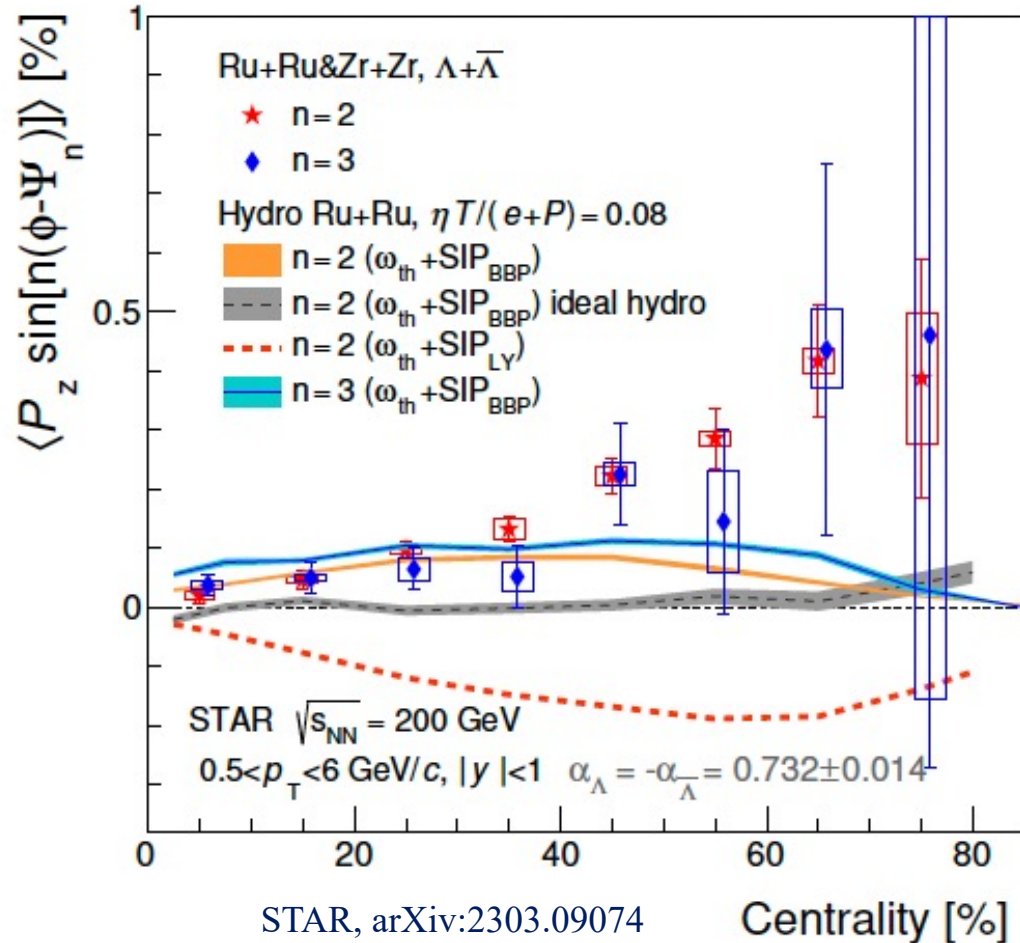


STAR, arXiv:2303.09074



- 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

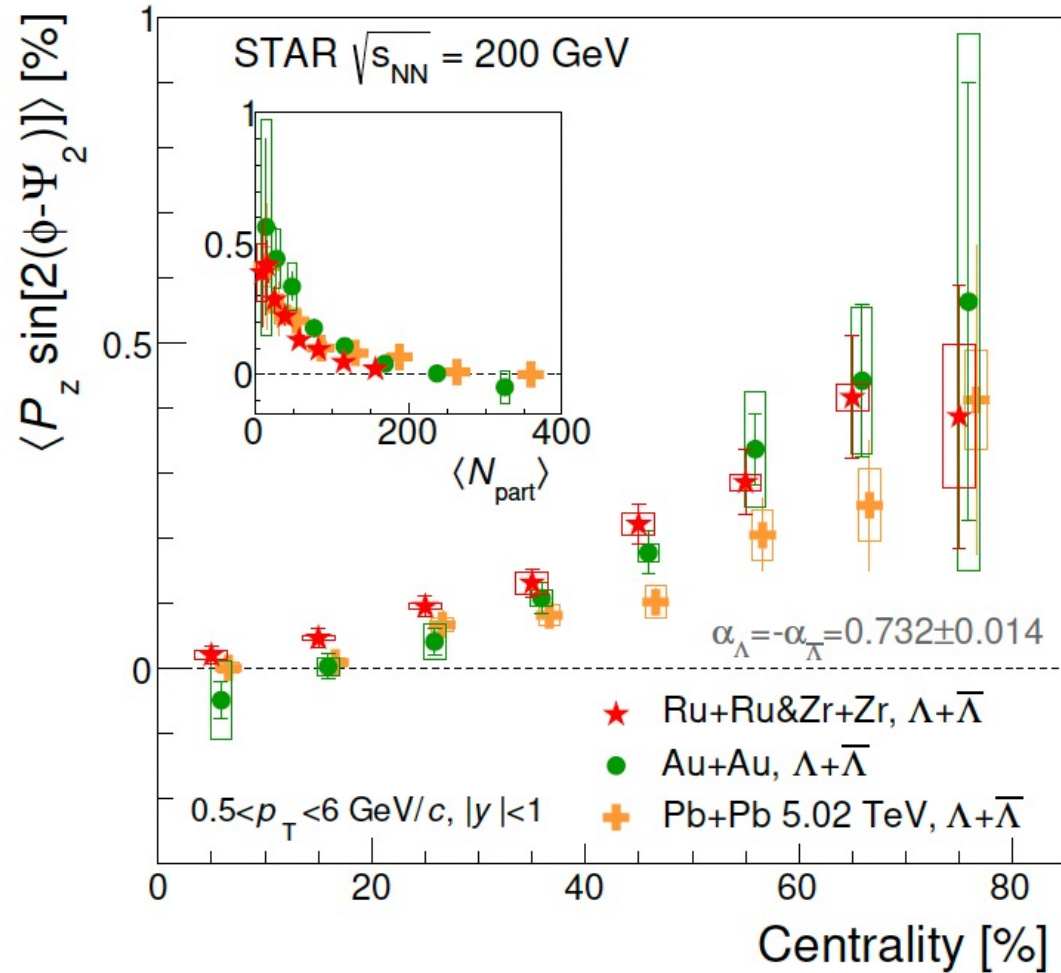
Centrality dependence of local polarization



- 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



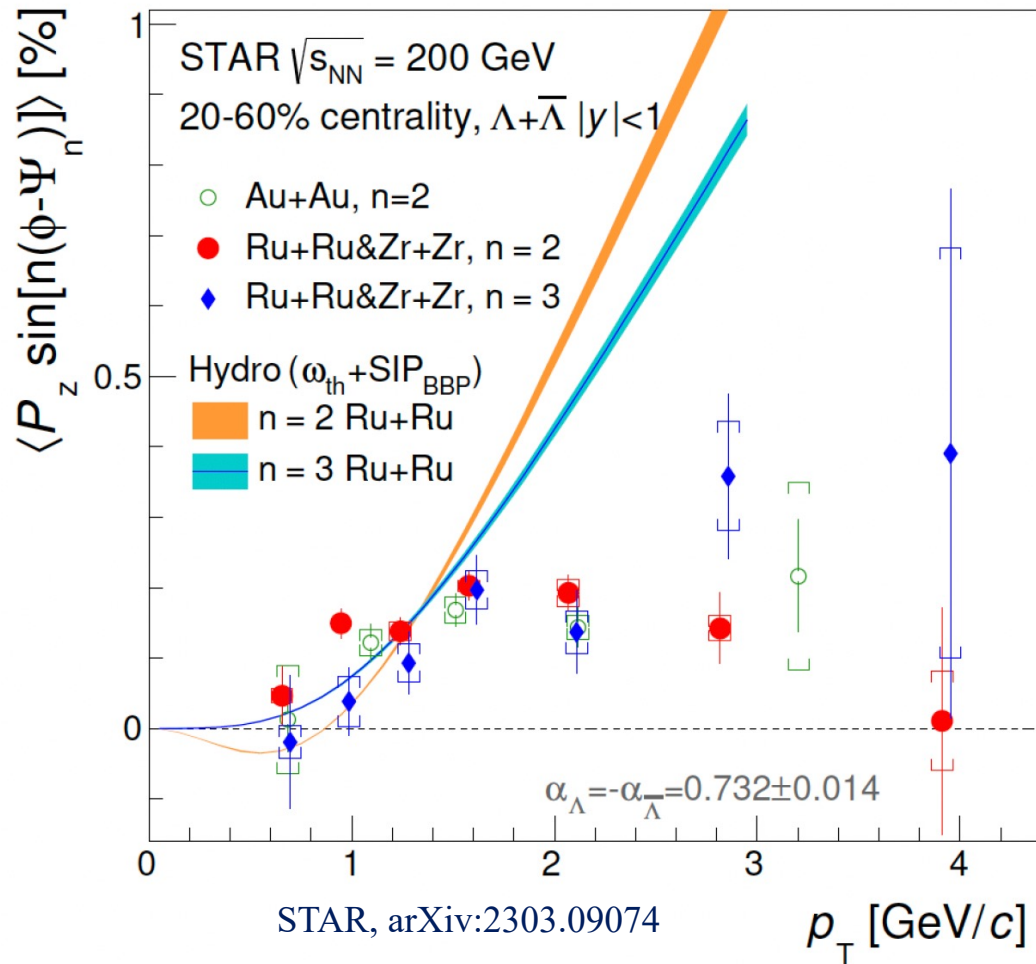
- Hint of system size dependence between isobar and Au+Au collisions
- Energy dependence is not obvious between 200 GeV Au+Au and 5.02 TeV Pb+Pb collisions

STAR, arXiv:2303.09074

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

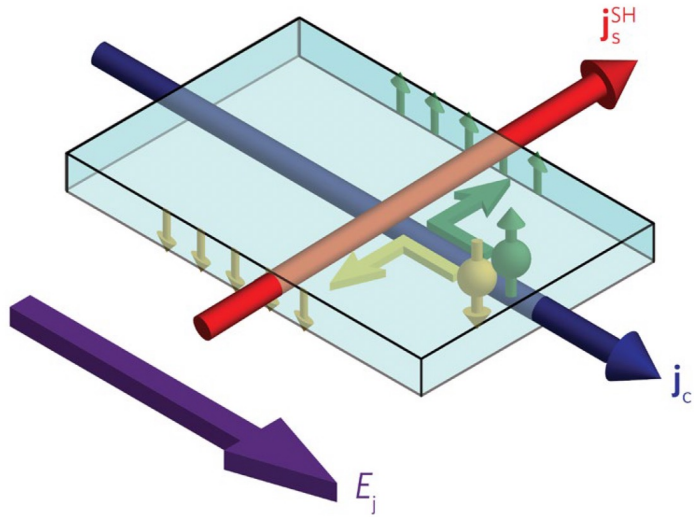
Local polarization

- ❑ 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

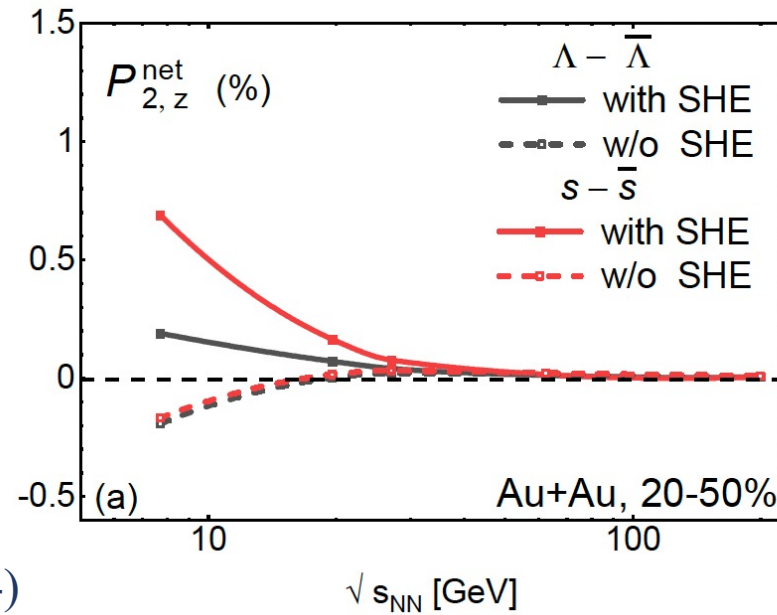
Outlook - Baryonic Spin Hall Effect (SHE)



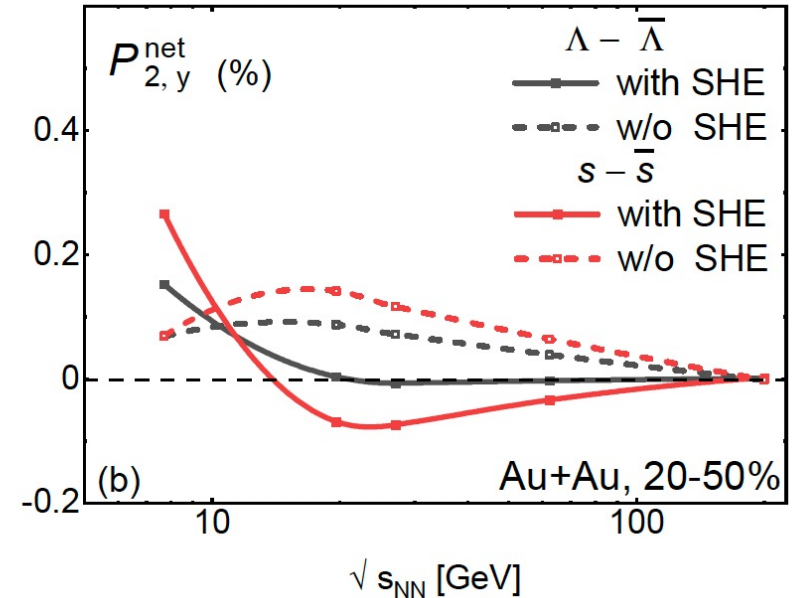
Baochi Fu et al., arXiv:2201.12970v1



Spin Hall effect : spin imbalance (2004)

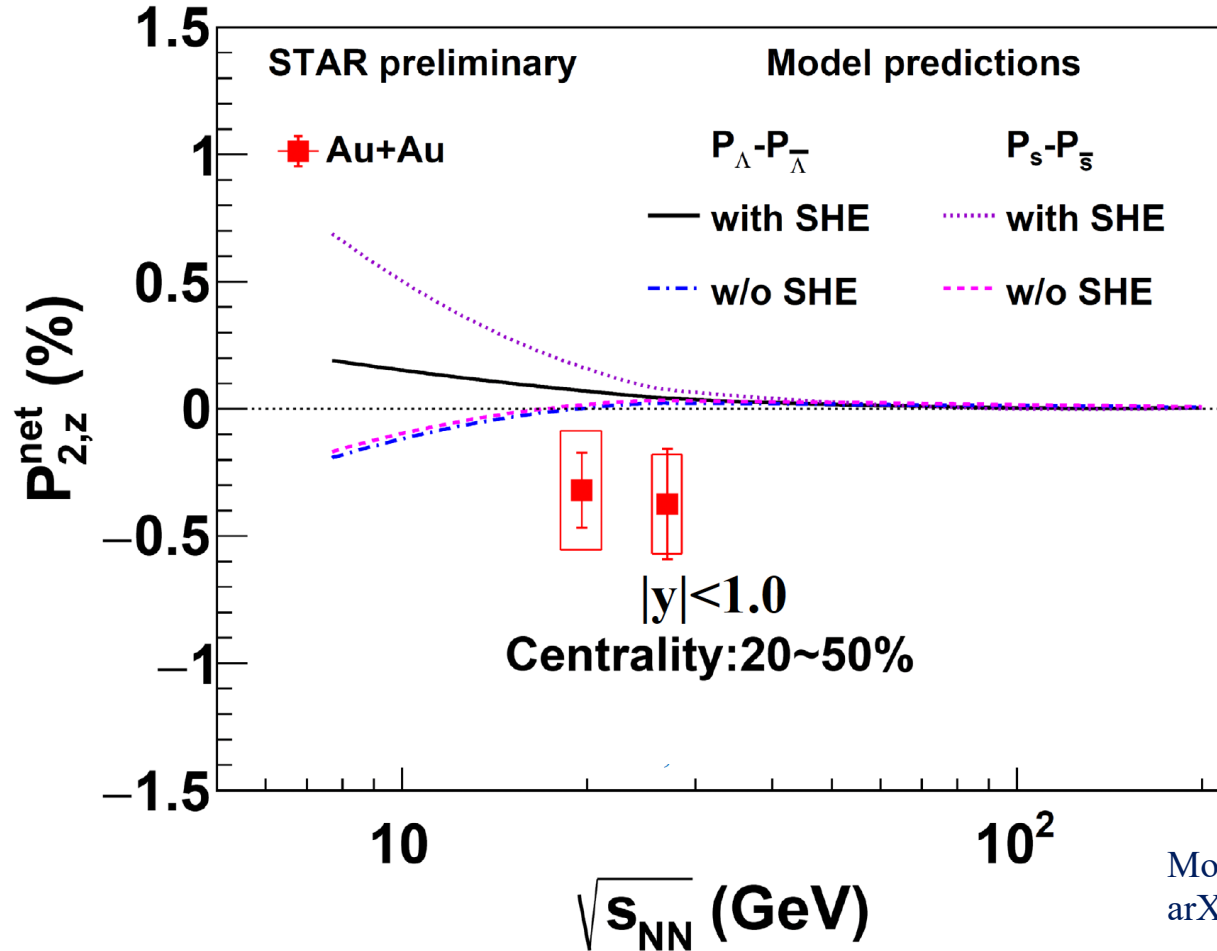


$$P_{2,z}^{net} \equiv \langle P_z^{\Lambda - \bar{\Lambda}} \sin(2\phi_\Lambda - 2\Psi_2) \rangle$$



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

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



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

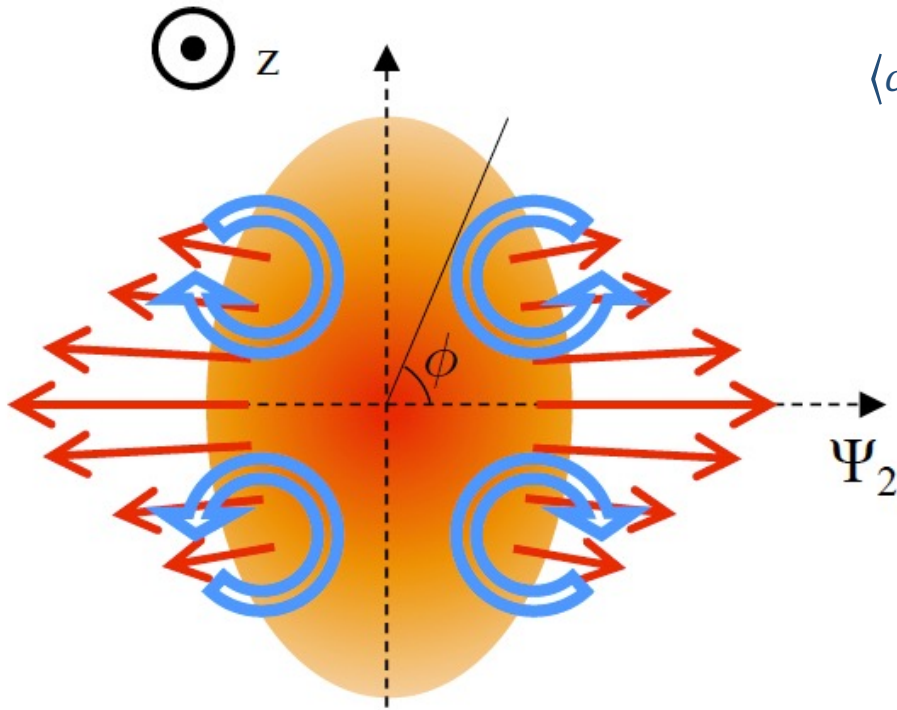
- First study of baryonic spin Hall effect by measuring net local polarization
- Hint of negative $P_{2,z}^{net}$ has been observed, study at more beam energies is underway



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Thanks for your attention

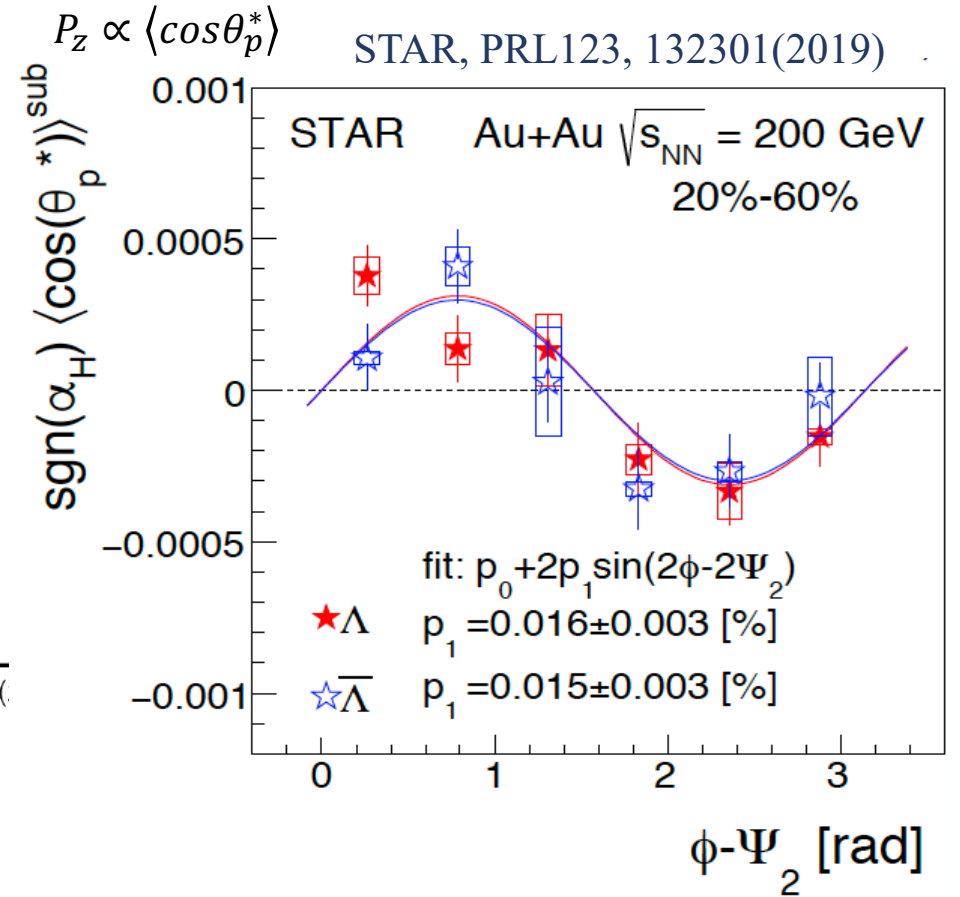
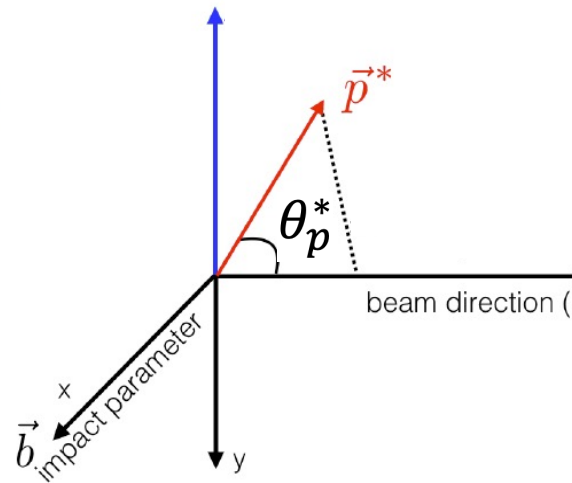
Local polarization of hyperons in heavy ion collisions



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

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

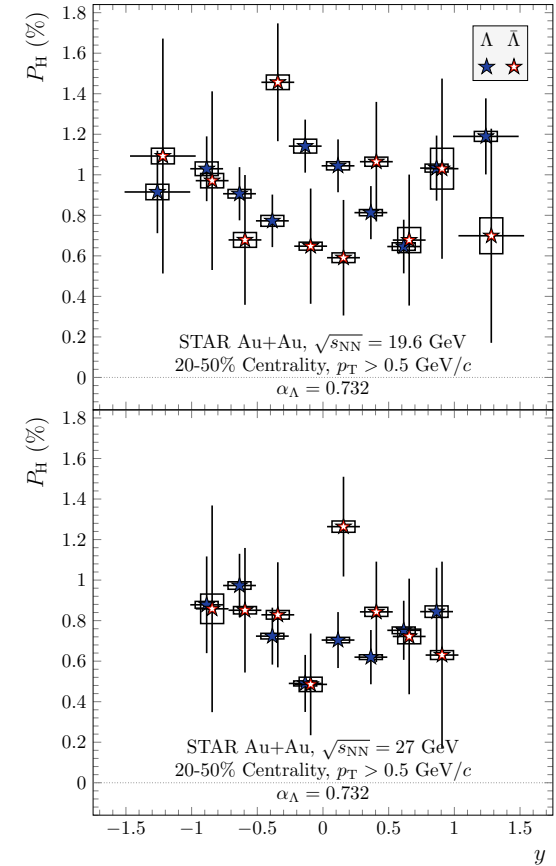
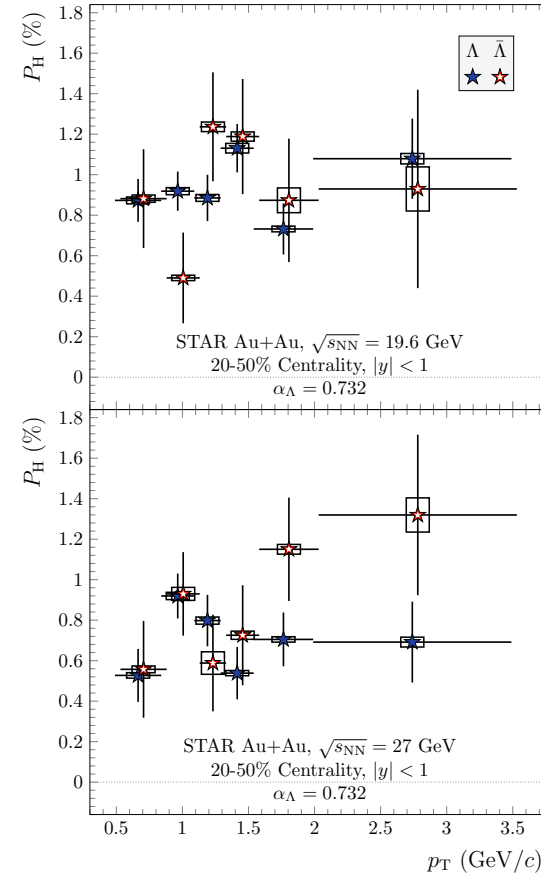
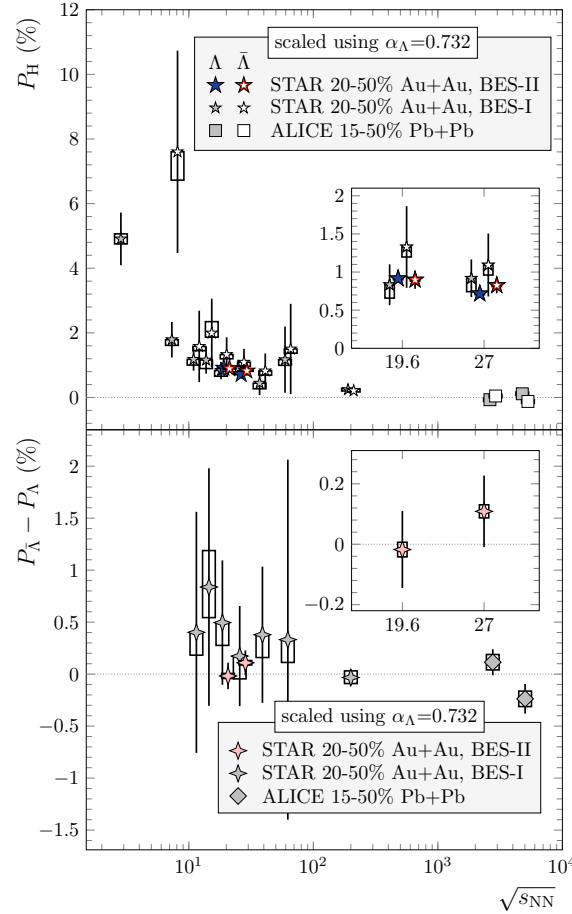
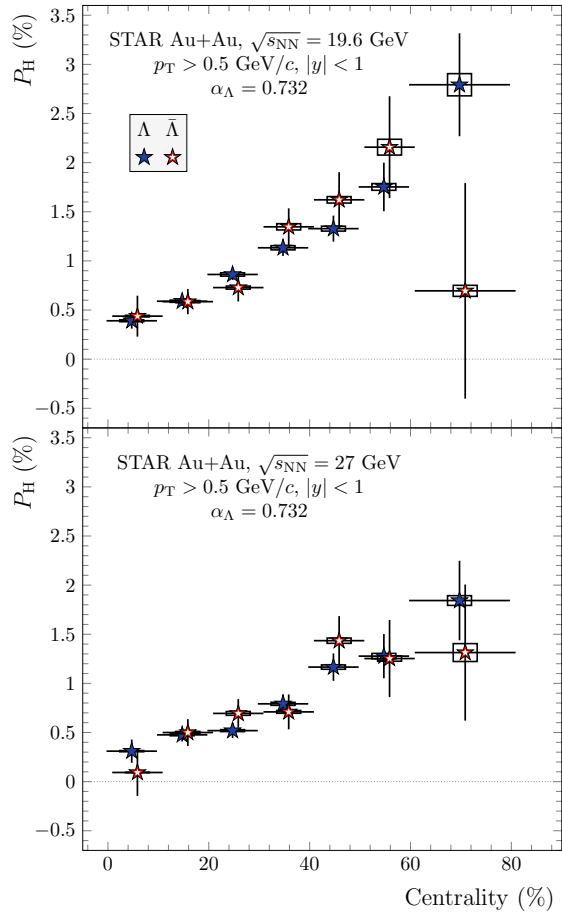
$$P_z = \frac{\langle \cos\theta_p^* \rangle}{\alpha_\Lambda \langle (\cos\theta_p^*)^2 \rangle}$$



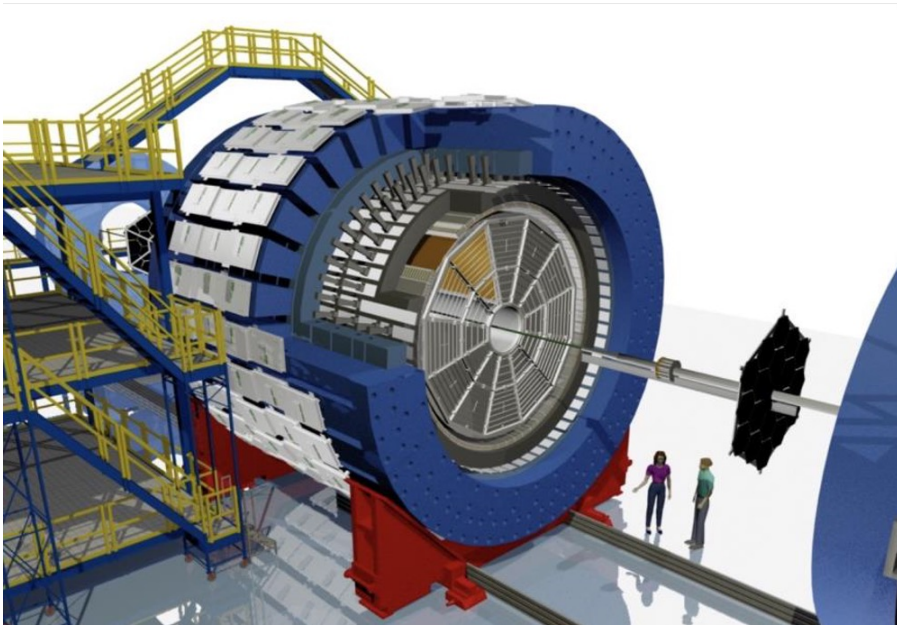
Local vorticity induced by anisotropic flow results in polarization along the beam direction, expected from the “elliptic flow”

STAR has observed the local polarization with second order event plane in Au+Au collisions

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 p_T



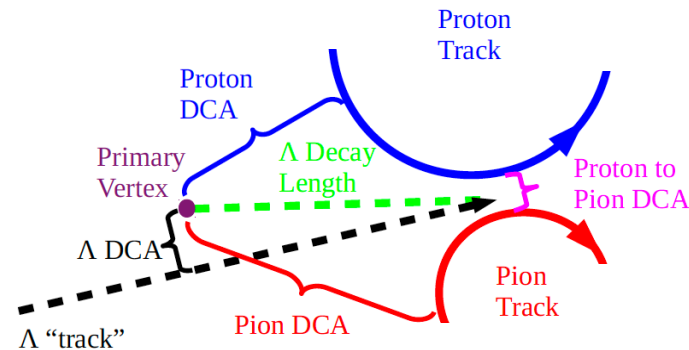
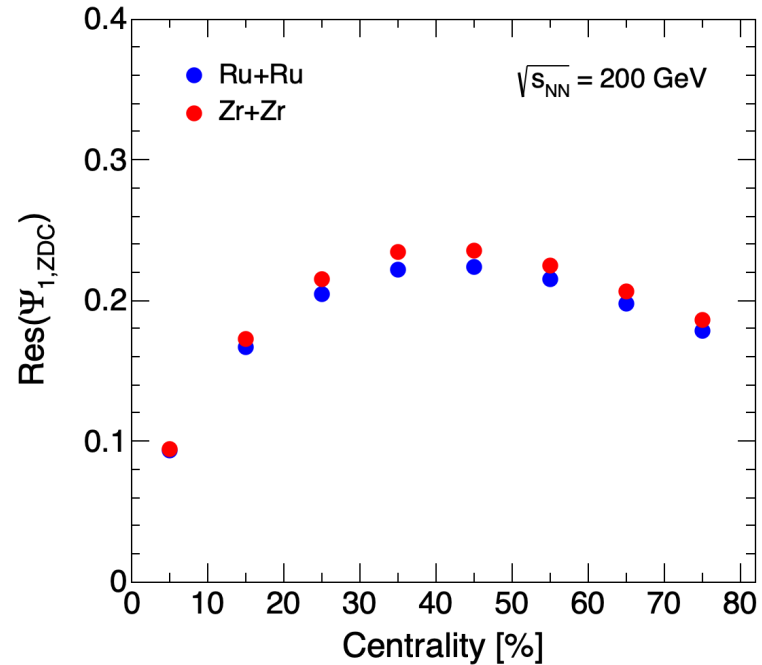
Event plane reconstruction:

Time Projection Chamber
Zero Degree Calorimeters

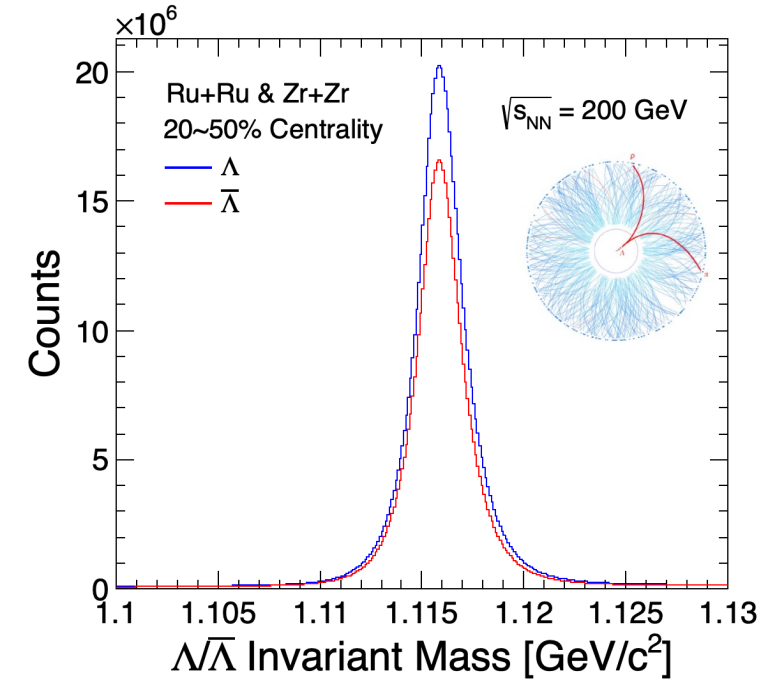
$\Lambda/\bar{\Lambda}$ reconstruction:

Time Projection Chamber
Time Of Flight

Event plane resolution

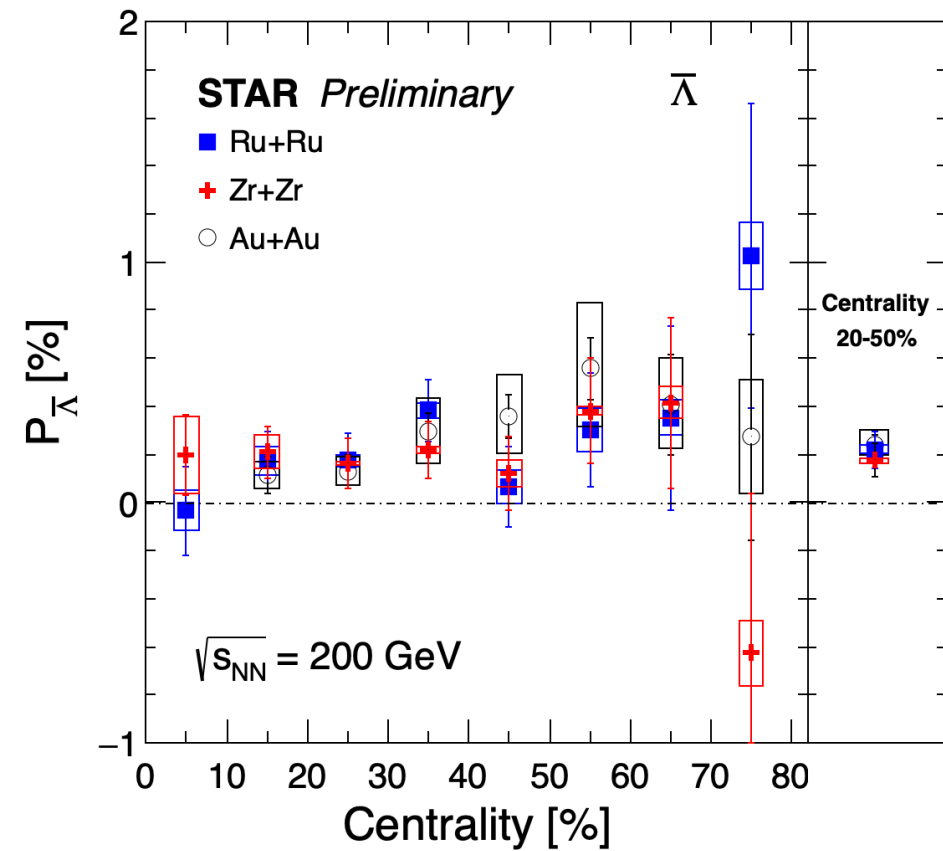
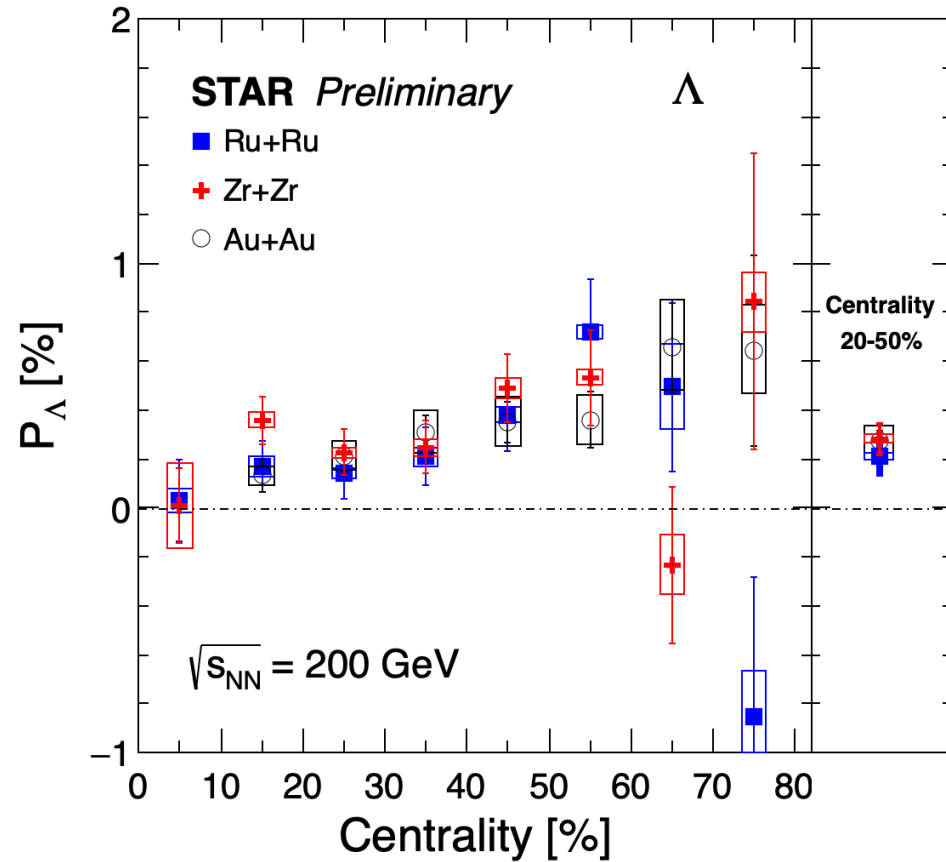


$\Lambda/\bar{\Lambda}$ reconstructed with TPC tracks

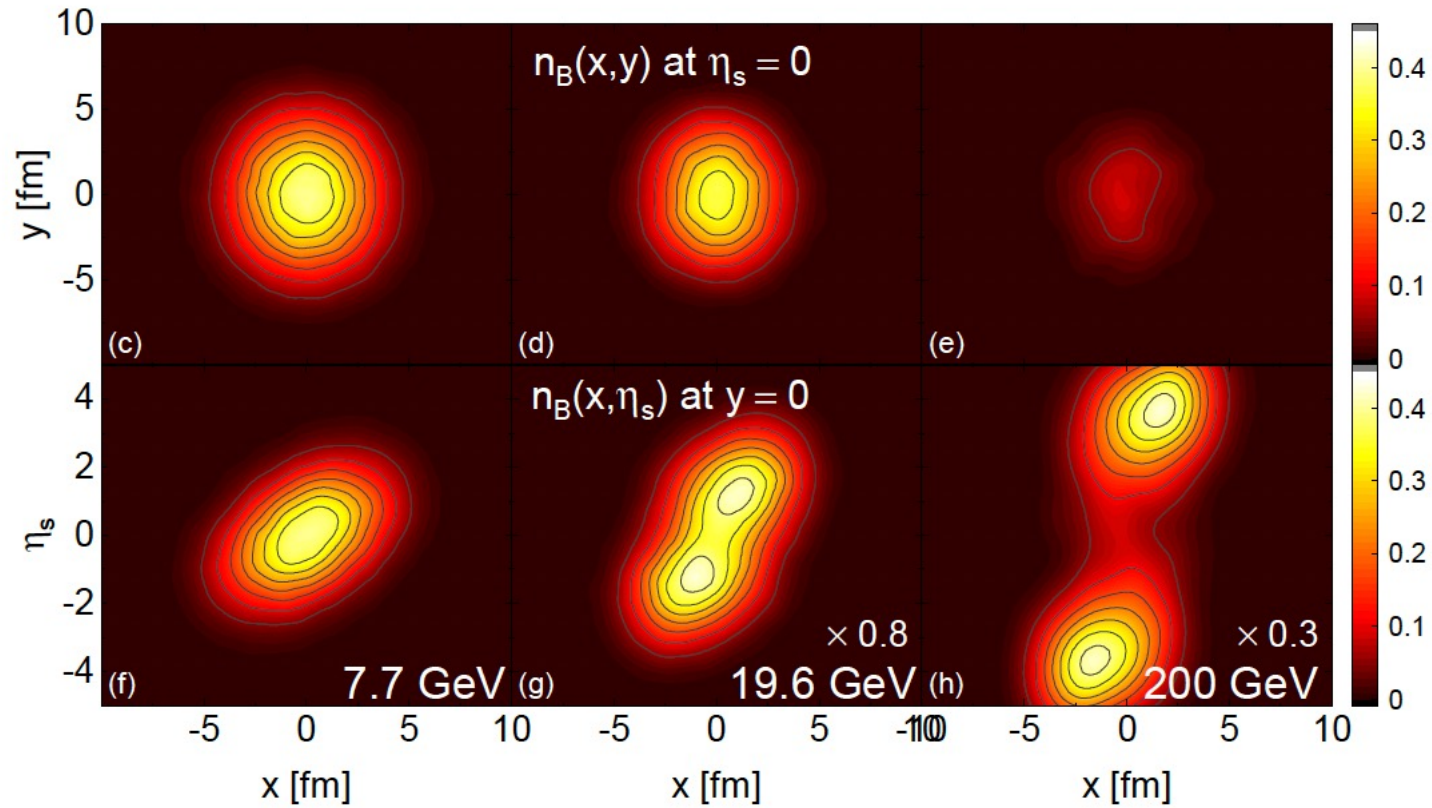


- $\Lambda \rightarrow p + \pi^-$
- $\bar{\Lambda} \rightarrow \bar{p} + \pi^+$
- Background fraction $< 3\%$

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



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



Baochi Fu et al., arXiv:2201.12970v1