Hyperon polarization in heavy ion collisions at STAR

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(for the STAR Collaboration)

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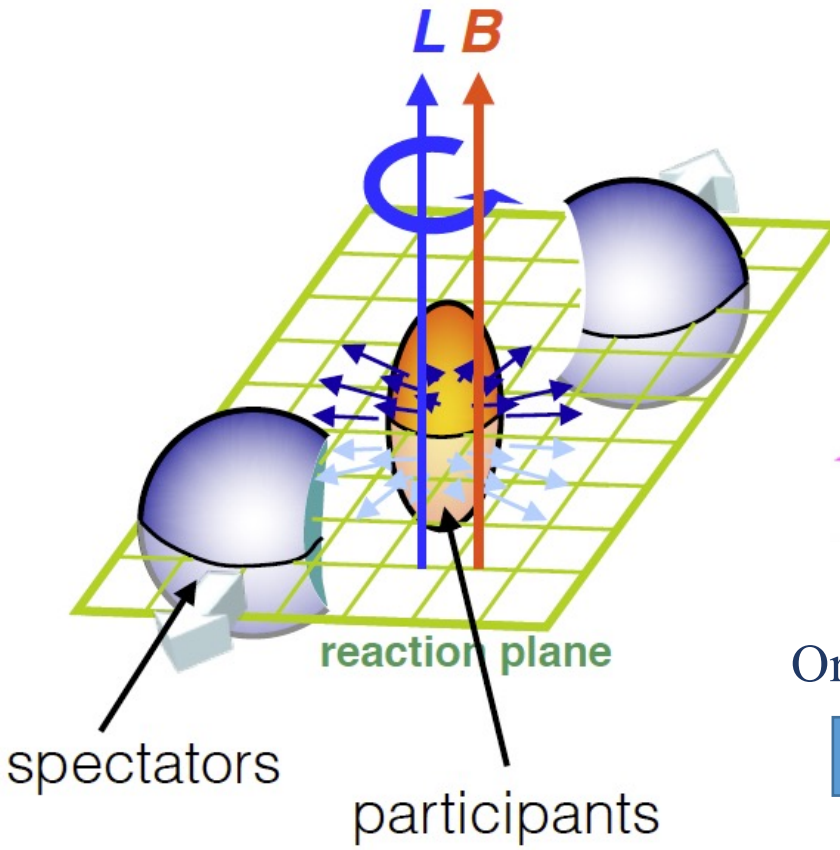
SpicyGluons 胶麻2024

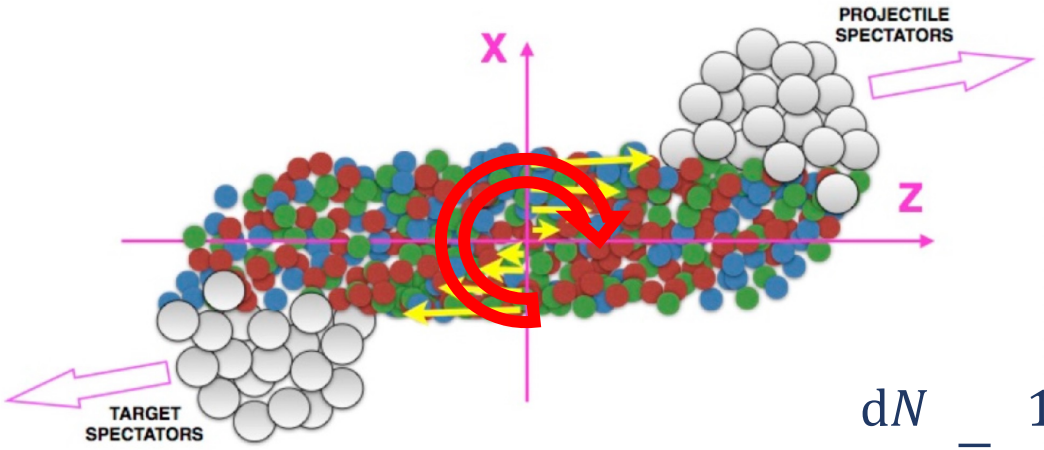
NSFC

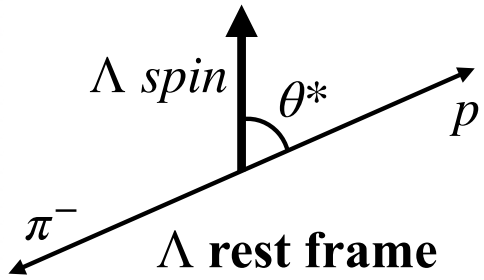
Outline

- 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)

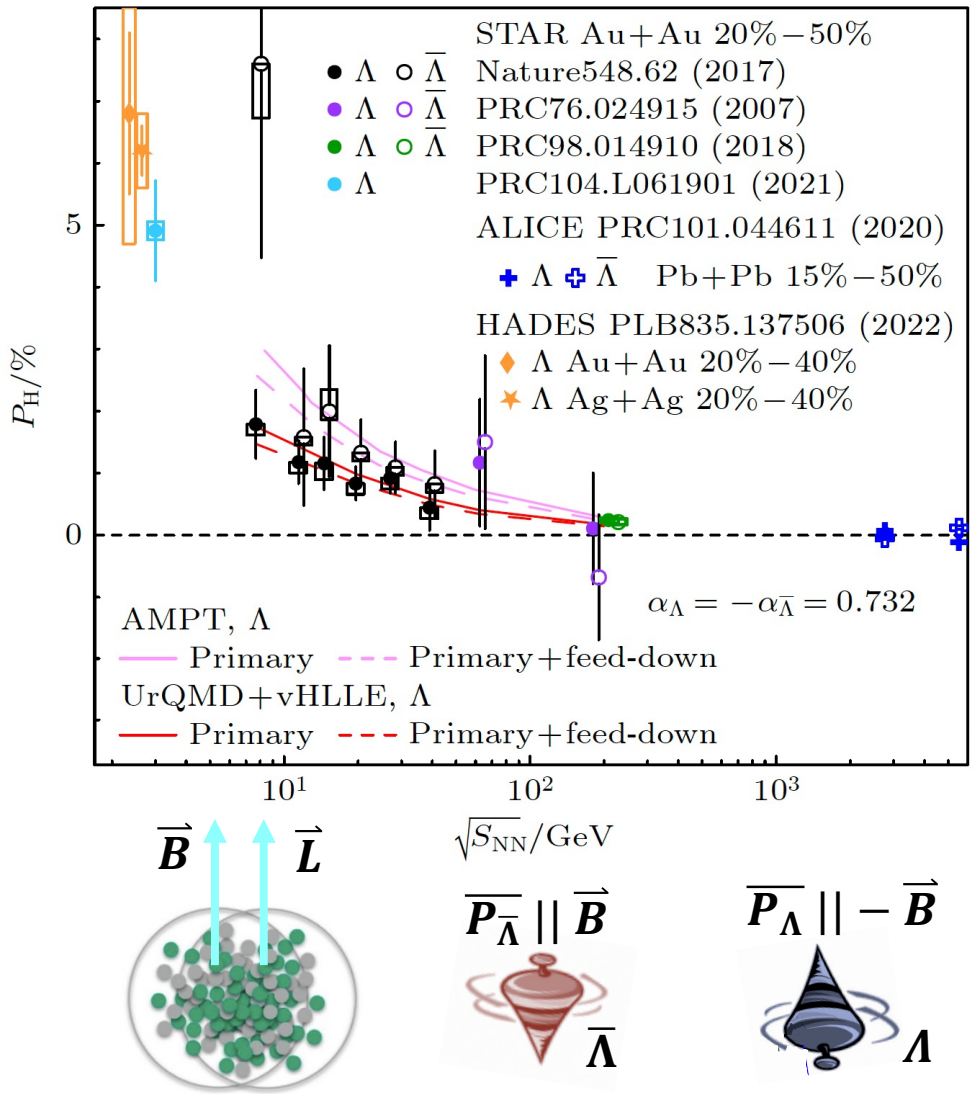
$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}(1 + \alpha_\Lambda P_\Lambda cos\theta^*)$$

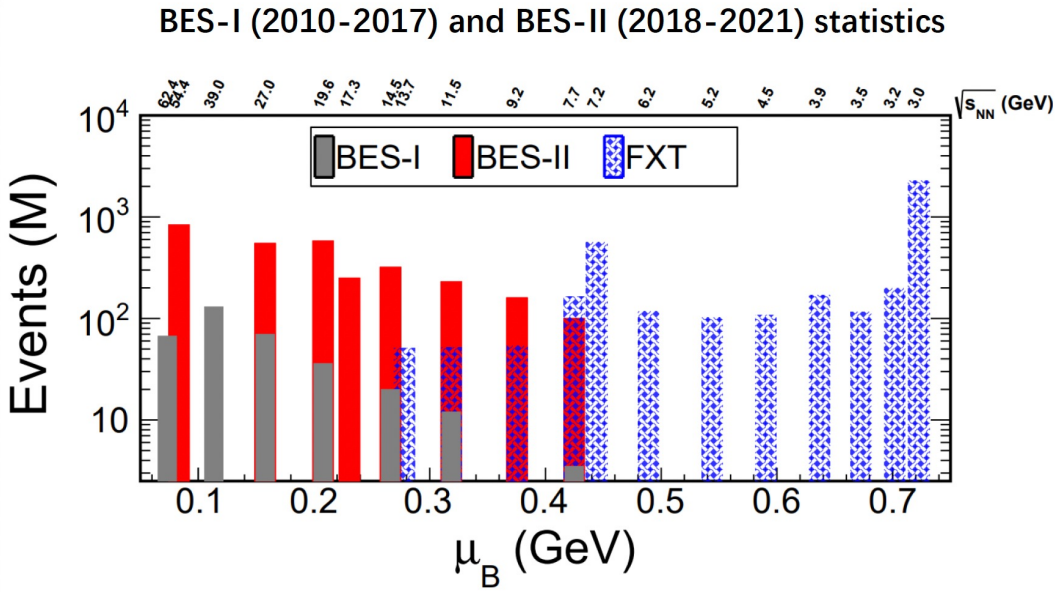
$$P_\Lambda = \frac{8}{\pi\alpha_\Lambda}\frac{1}{A_0}\frac{\langle \sin(\Psi_1 - \phi_p^*)\rangle}{Res(\Psi_1)}$$

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

Hyperon polarization in heavy ion collisions

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





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

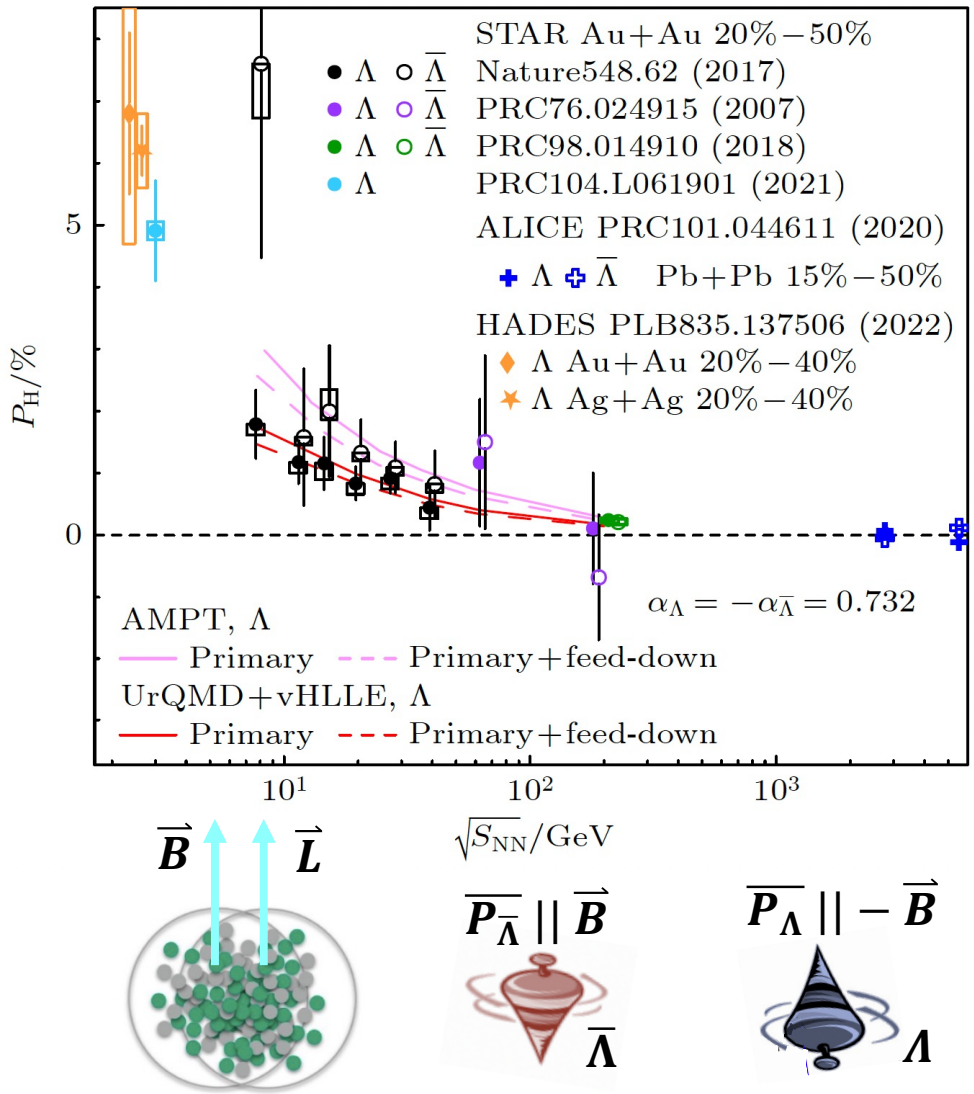
$$^{197}_{79}Au > ^{96}_{44}Ru, ^{96}_{40}Zr > ^{63}_{29}Cu > ^{16}_{8}O$$

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

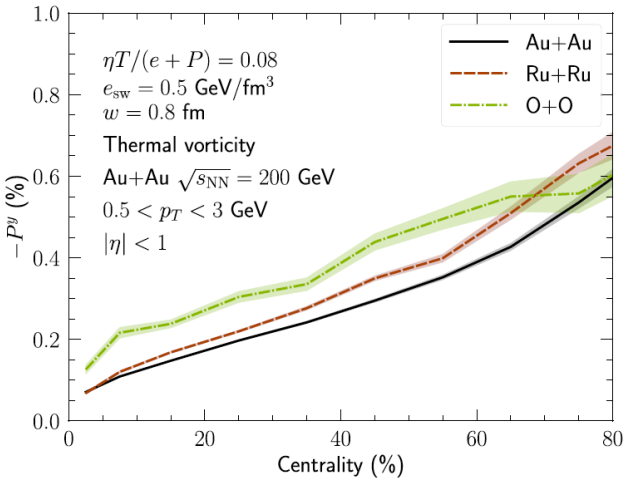
- Local polarization in isobar collisions

Hyperon polarization in heavy ion collisions

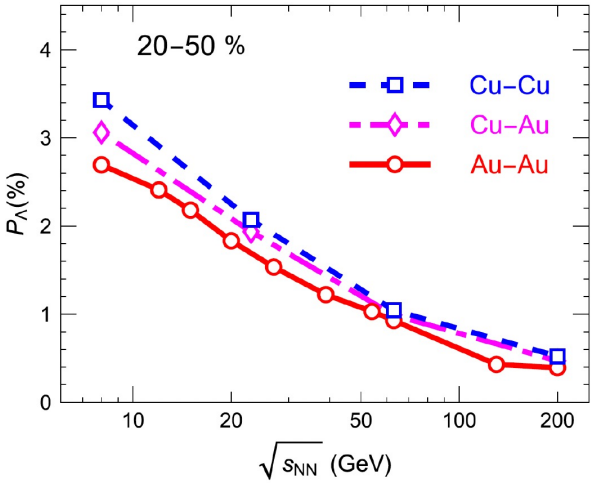
Acta Phys. Sin. Vol. 72, No. 7(2023) 072401



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**

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

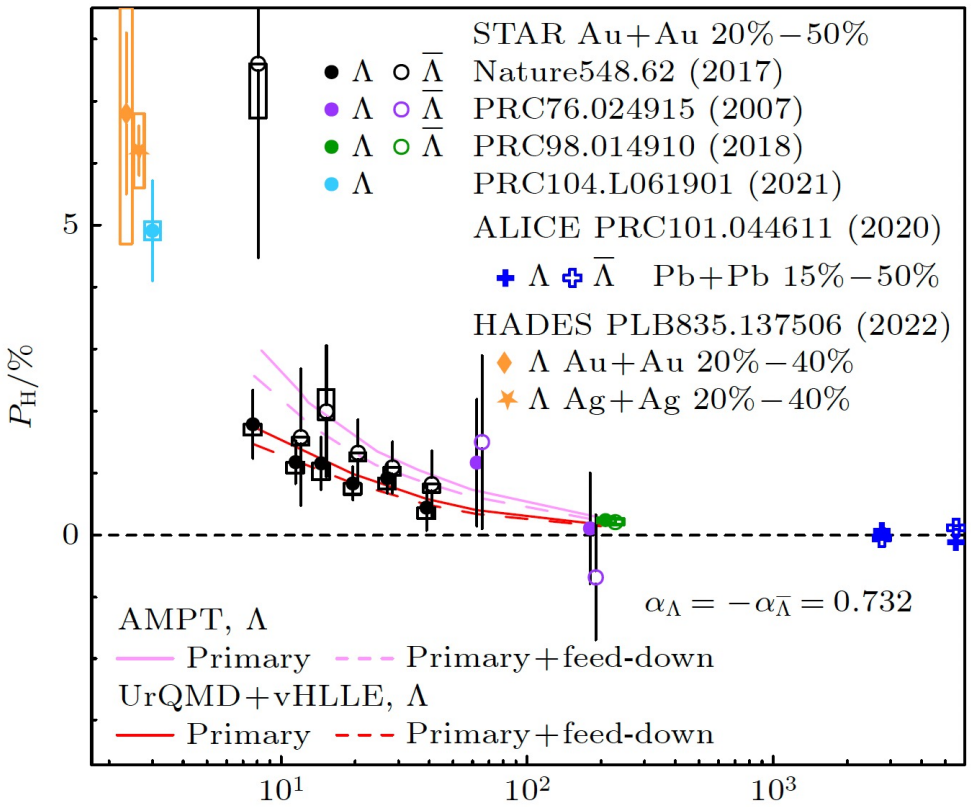
?

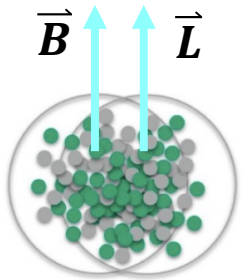
$$P_\Lambda^{Au} < P_\Lambda^{Ru} \approx P_\Lambda^{Zr} < P_\Lambda^{Cu} < P_\Lambda^{O}$$

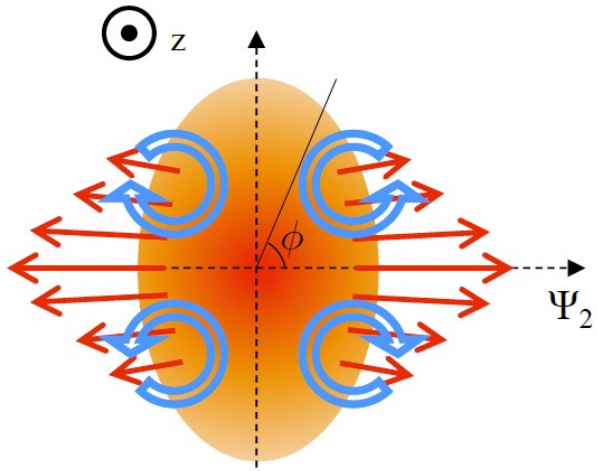
- Local polarization in isobar collisions

Hyperon polarization in heavy ion collisions

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







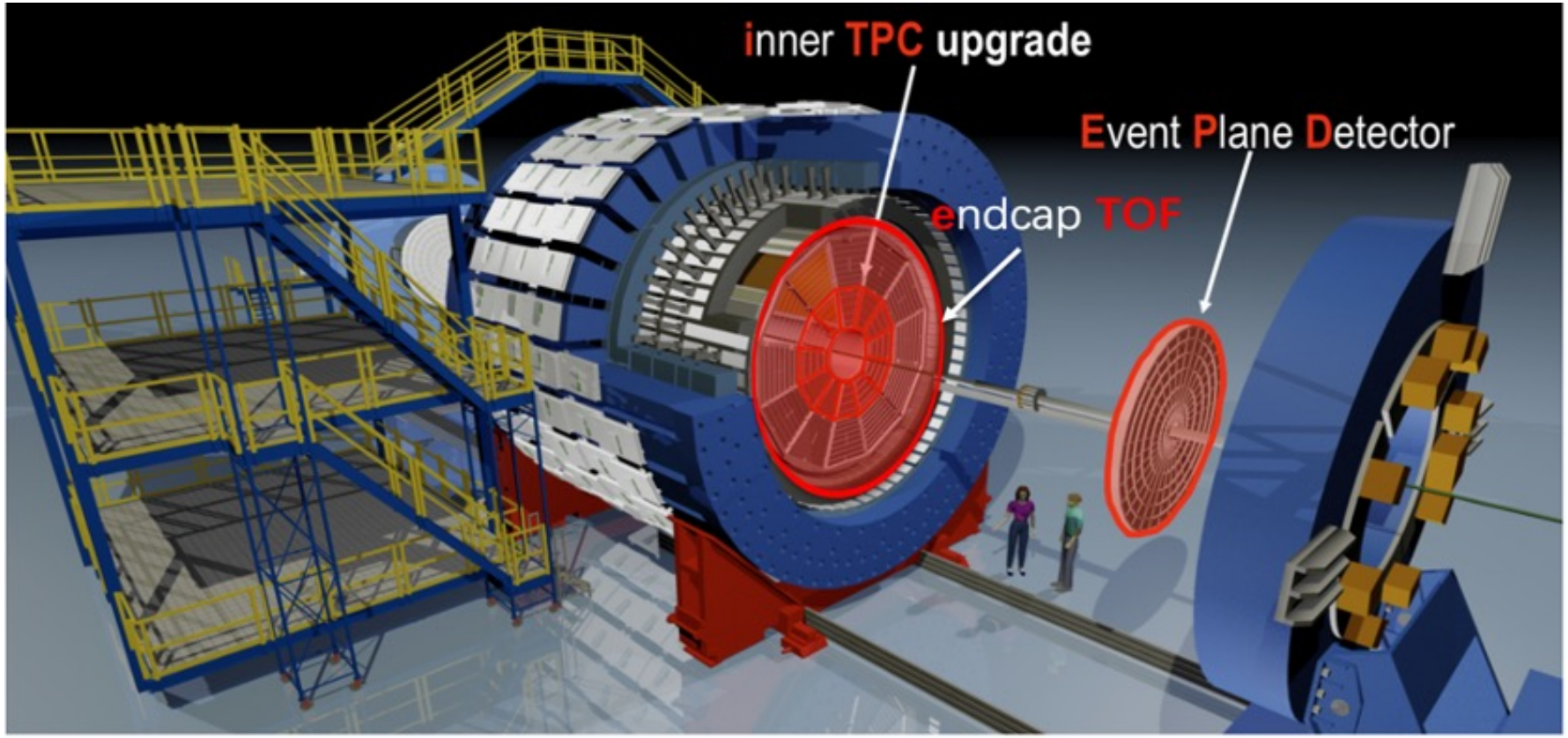
- Λ / $\bar{\Lambda}$ global polarization splitting with BES-II data?
- Global polarization collision system size dependence

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

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

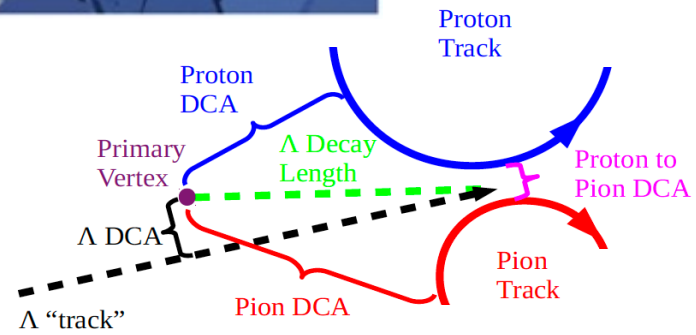
- **Local polarization in isobar collisions**

STAR detector

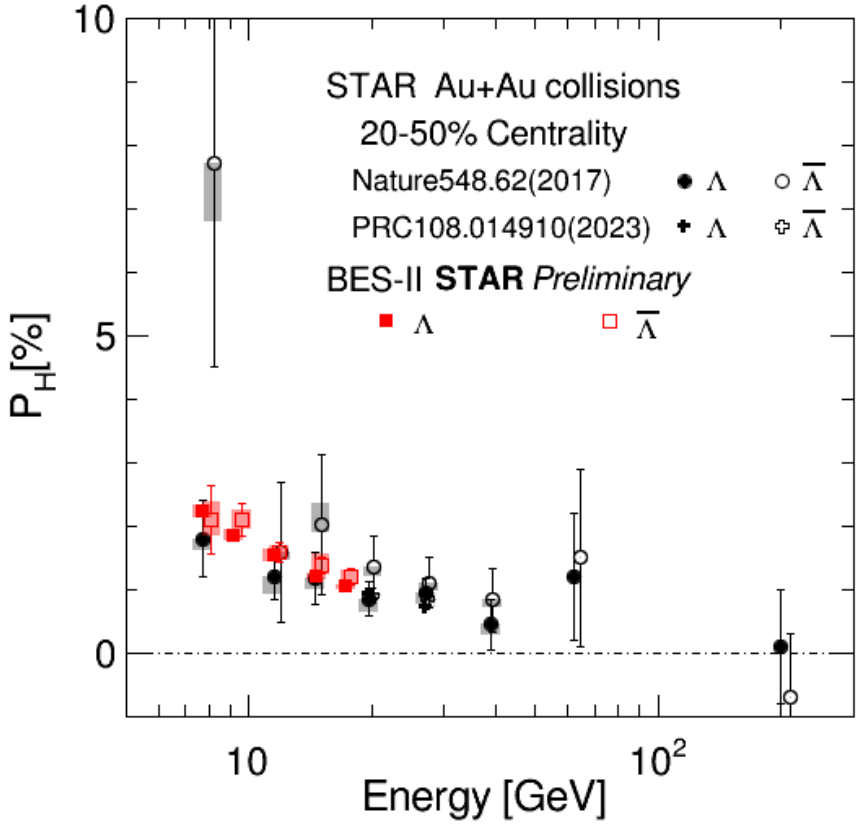


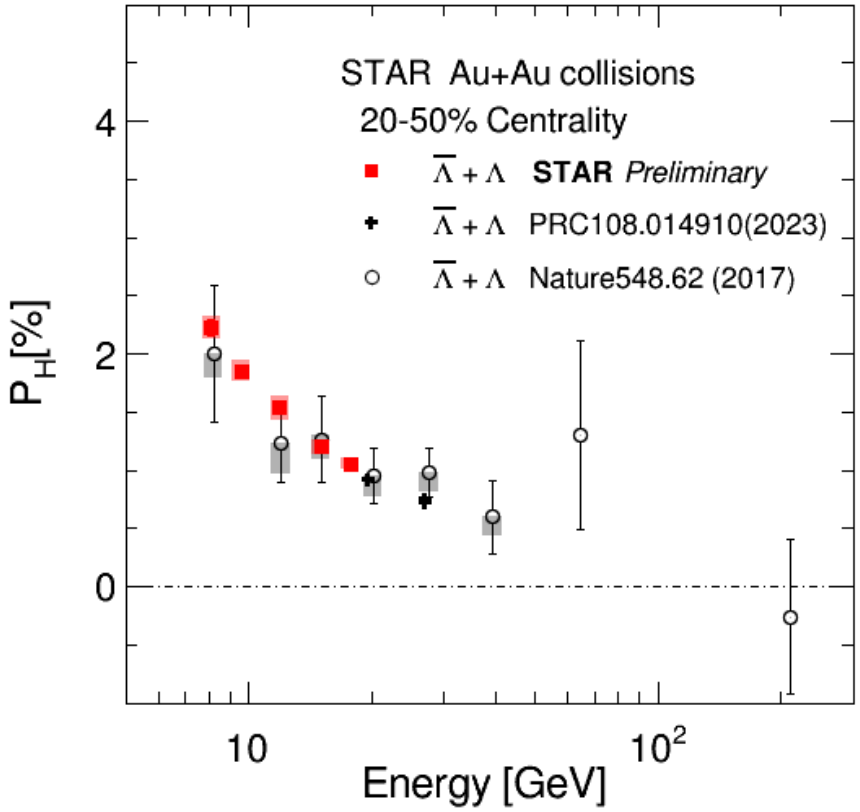
- **Event plane reconstruction:**
  - Time Projection Chamber
  - Event Plane Detector
  - Zero Degree Calorimeters

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



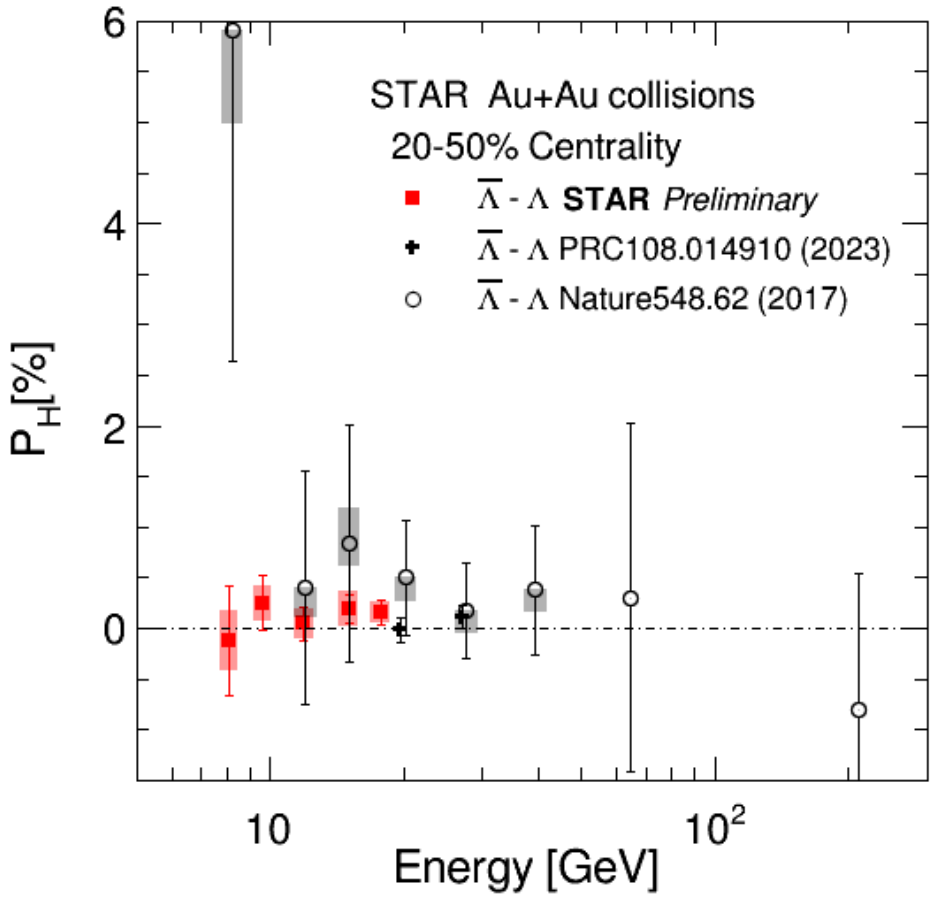
Global polarization in Au+Au with BES-II data (New)





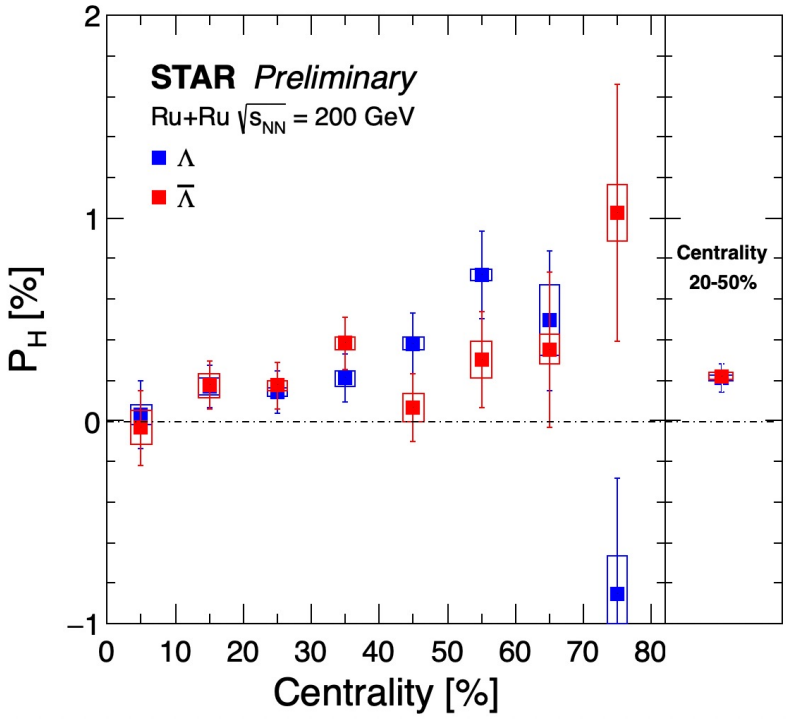
- Significant global polarization observed, results consistent with BES-I

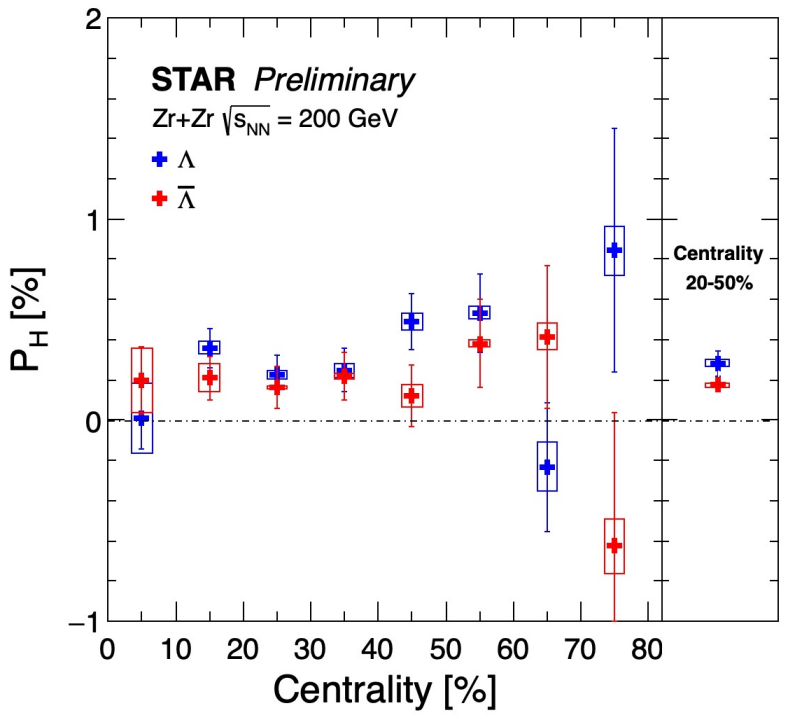
Global polarization in Au+Au with BES-II data (New)

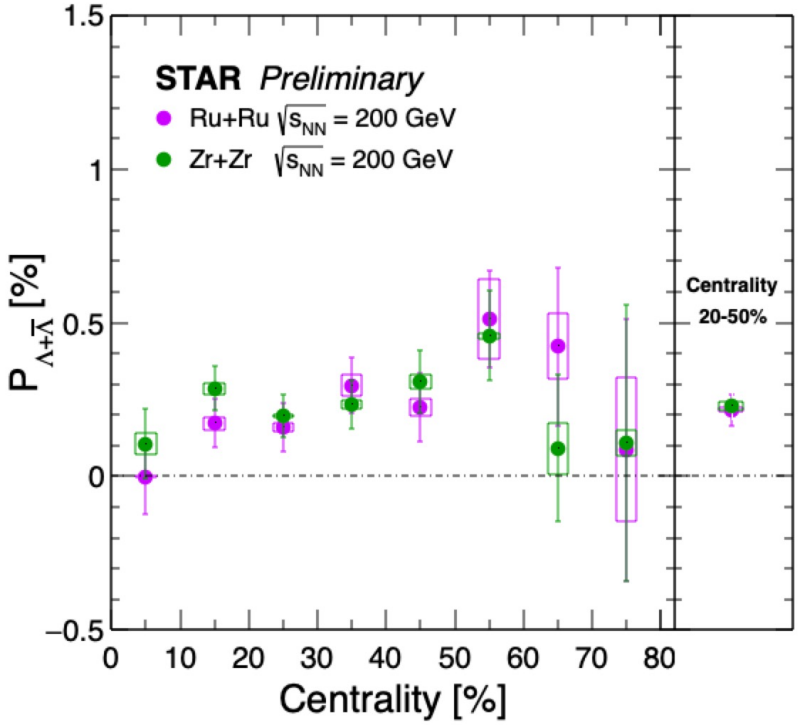


- No splitting between Λ / $\overline{\Lambda}$ global polarization within uncertainty

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

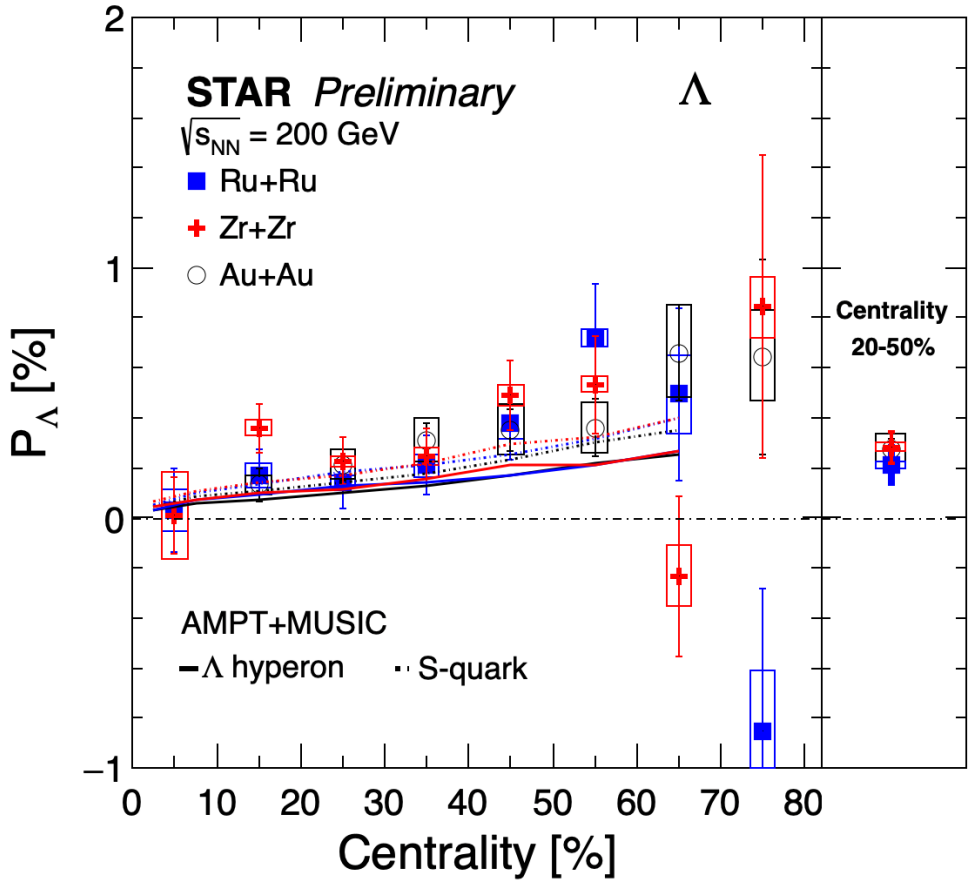


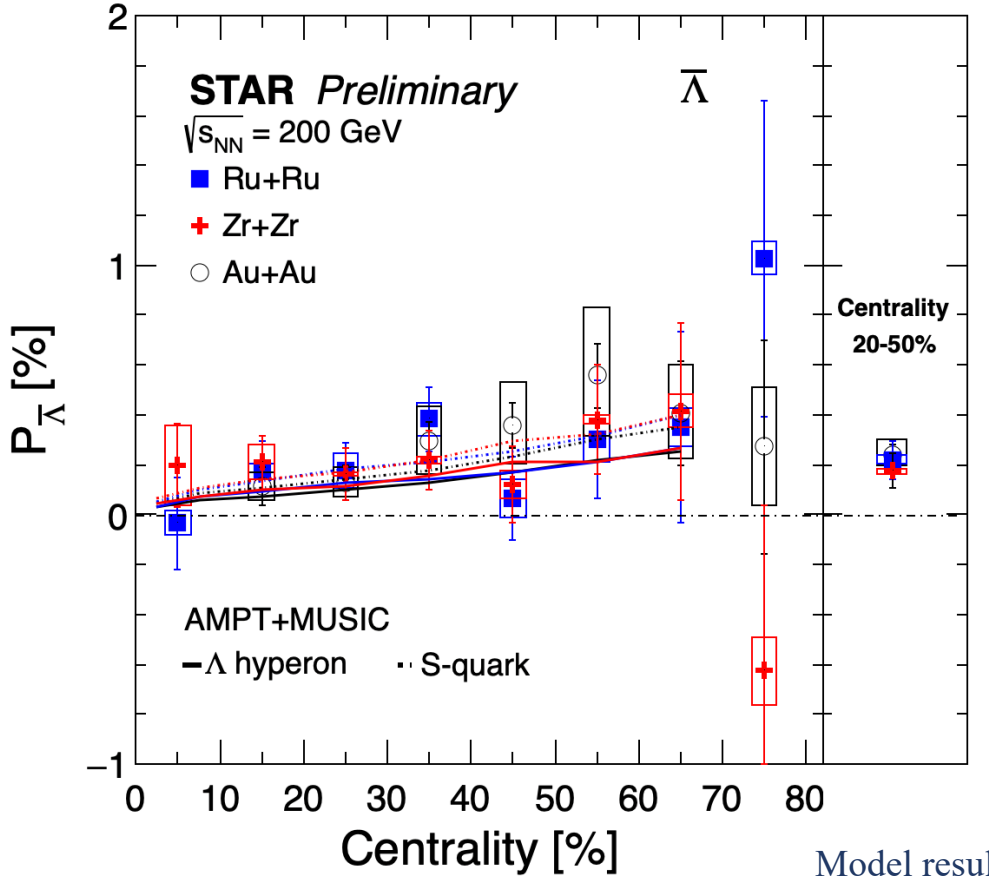




- Significant global polarization observed, P_{Λ} and $P_{\bar{\Lambda}}$ increase with centrality
- No significant difference between P_{Λ} and $P_{\bar{\Lambda}}$ in Ru+Ru and Zr+Zr collisions
- Global polarization of $\Lambda + \bar{\Lambda}$ are consistent between Ru+Ru and Zr+Zr collisions

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

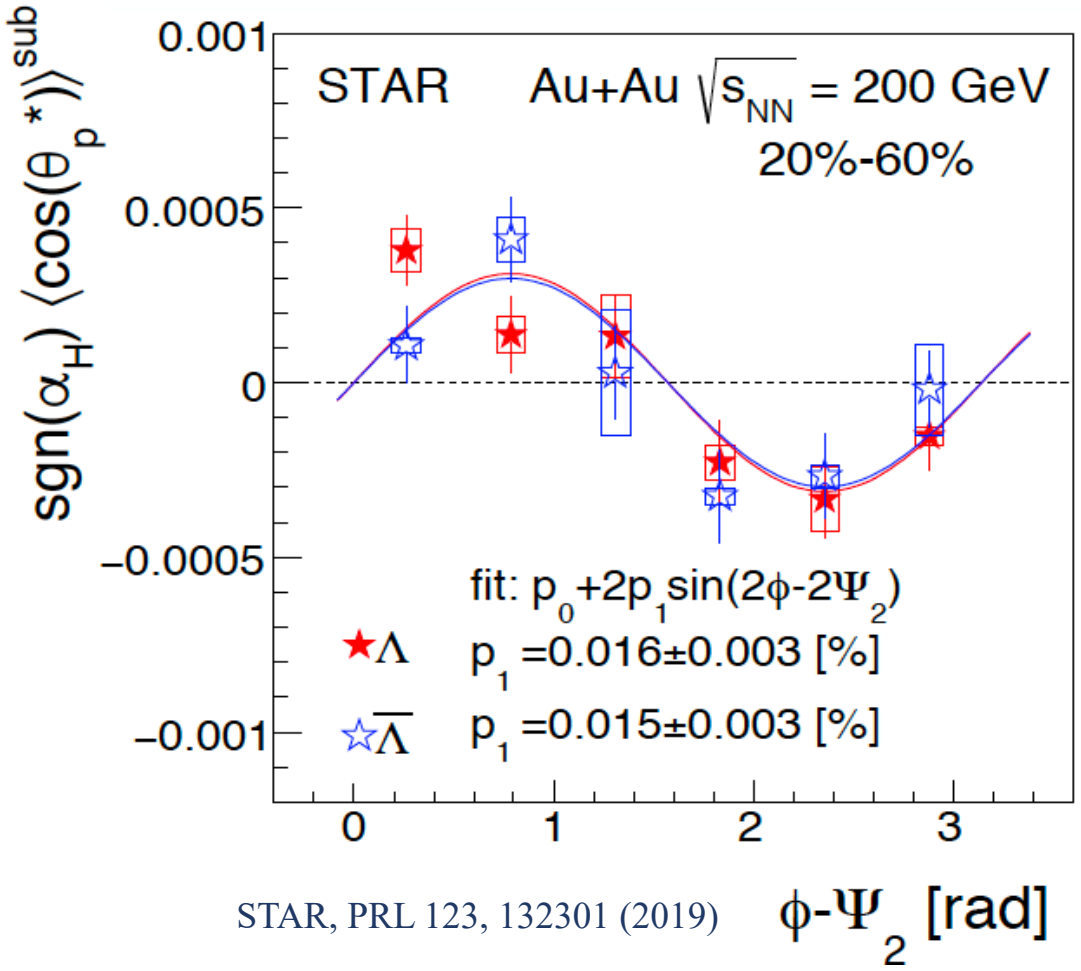




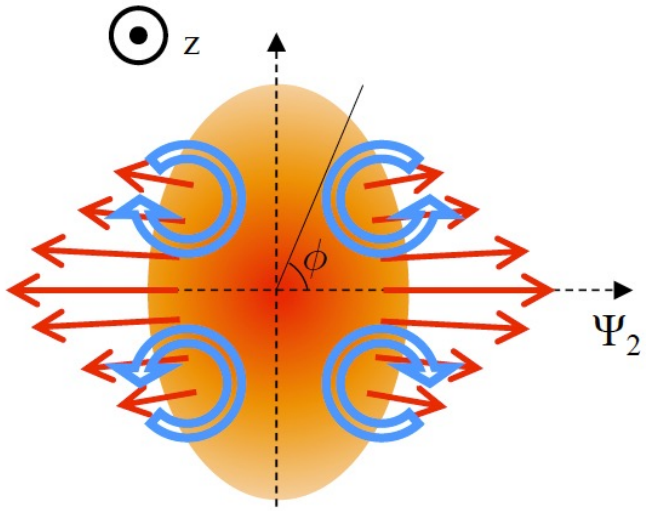
Model results from arXiv:2201.12970v1

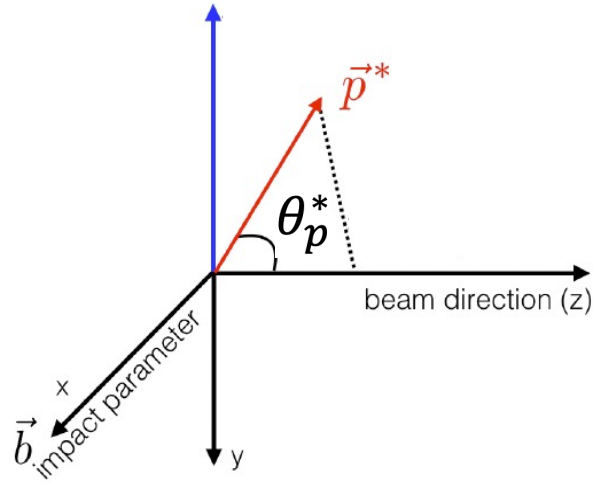
- Global polarization of Λ and $\overline{\Lambda}$ are consistent in isobar and Au+Au collision systems

Local polarization in heavy ion collisions



STAR, PRL 123, 132301 (2019)

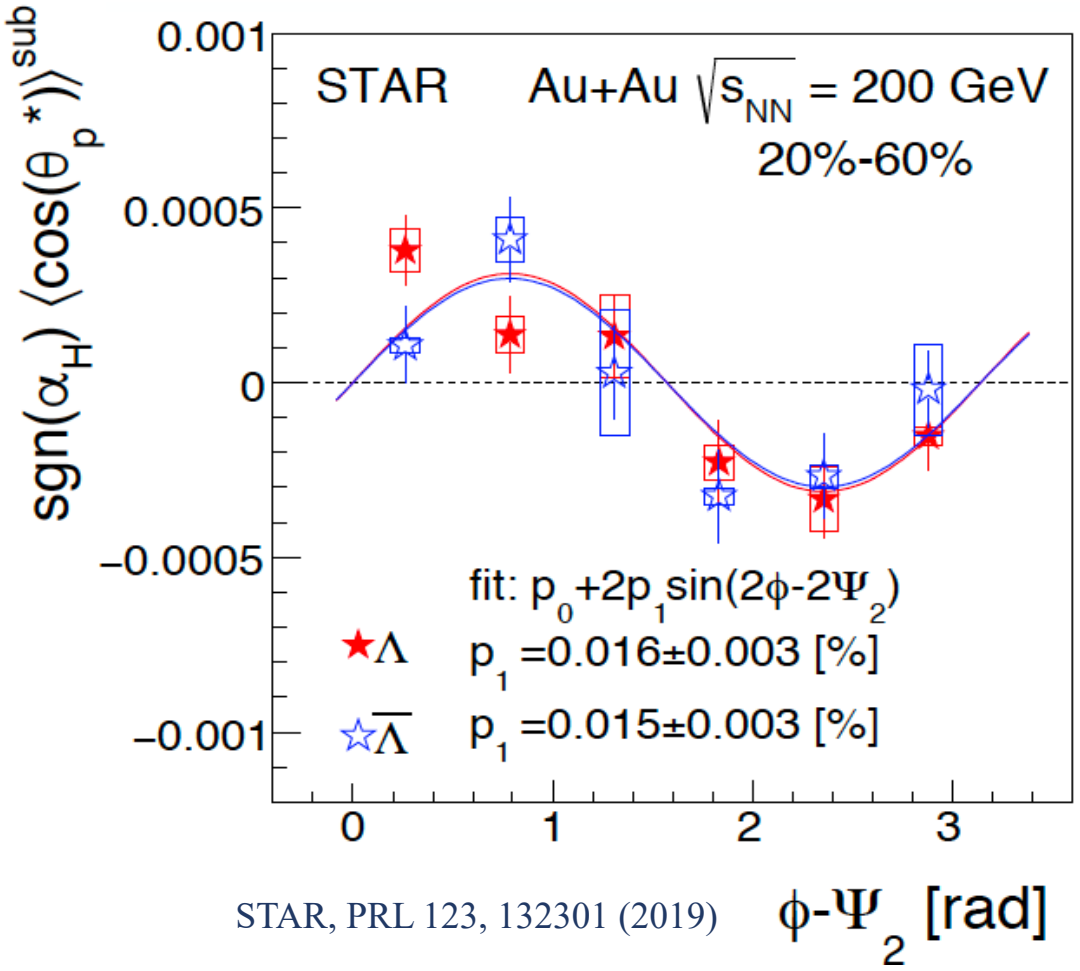




- Collision system size and energy dependence
- Measurements in smaller systems and relative to higher harmonic event planes provide new insights into polarization phenomena

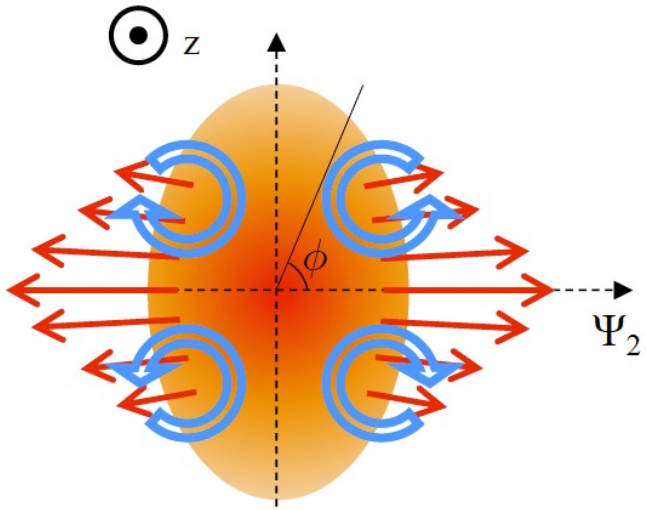
$$\langle cos\theta_p^* \rangle = \int \frac{dN}{d\Omega^*} cos\theta_p^* d\Omega^* = \alpha_\Lambda P_z \langle (cos\theta_p^*)^2 \rangle \qquad P_z = \frac{\langle cos\theta_p^* \rangle}{\alpha_\Lambda \langle (cos\theta_p^*)^2 \rangle}$$

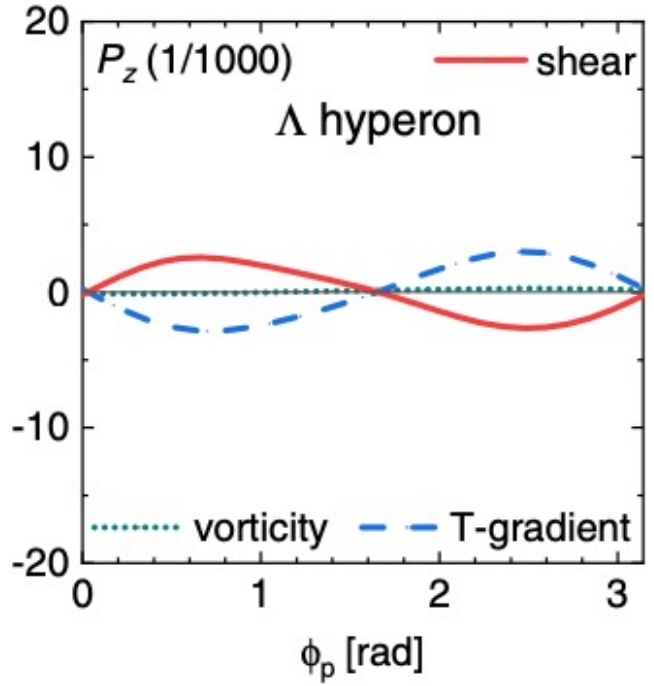
Local polarization in heavy ion collisions



STAR, PRL 123, 132301 (2019)

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





- Collision system size and energy dependence
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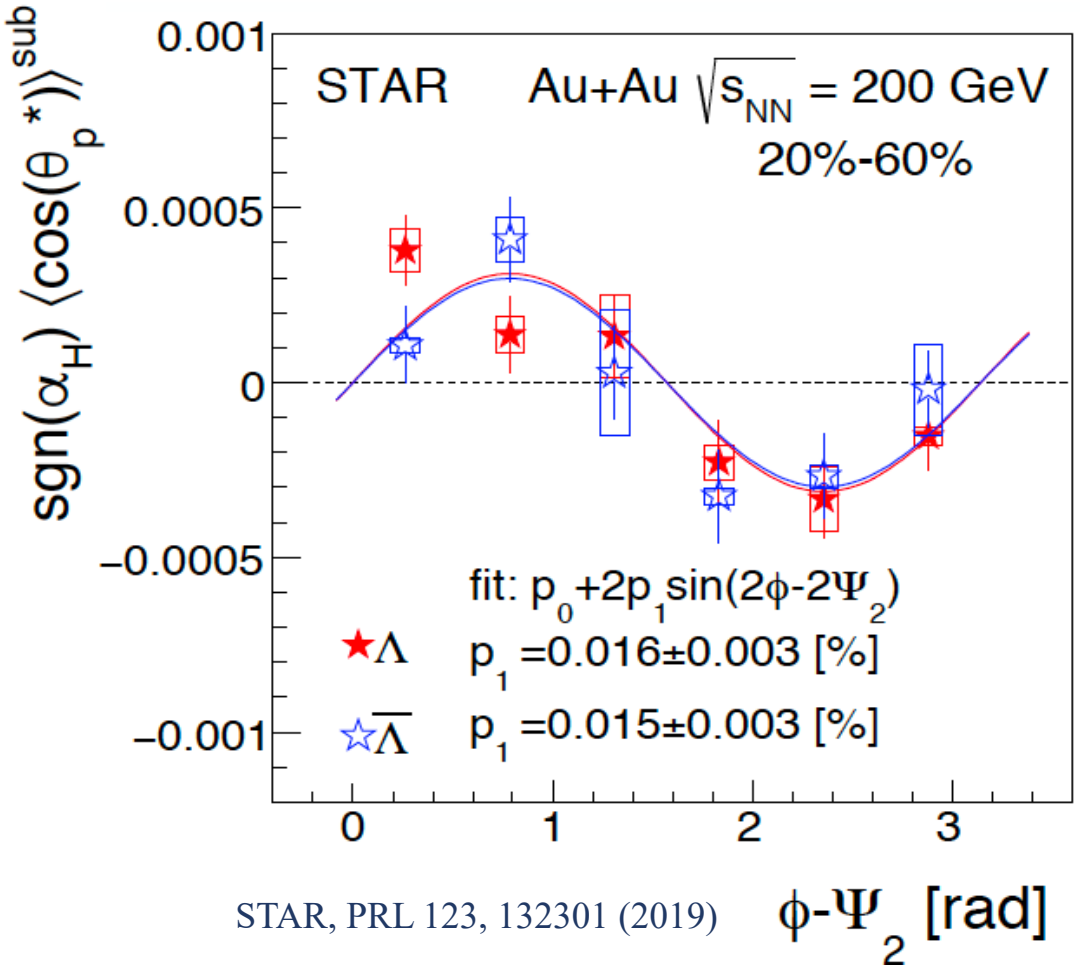
Local polarization in heavy ion collisions



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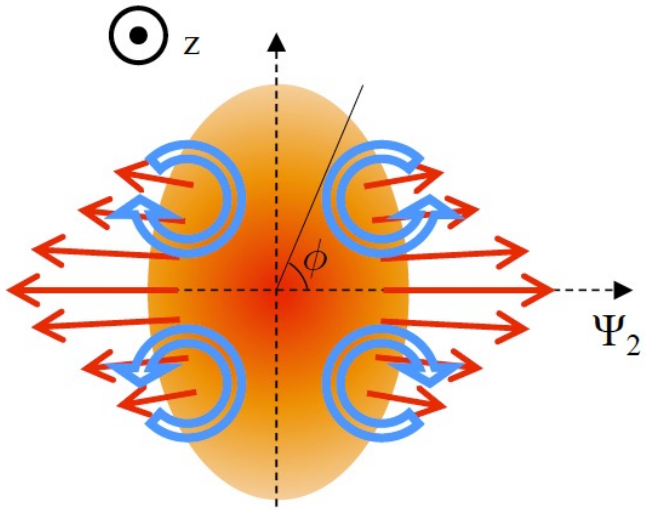
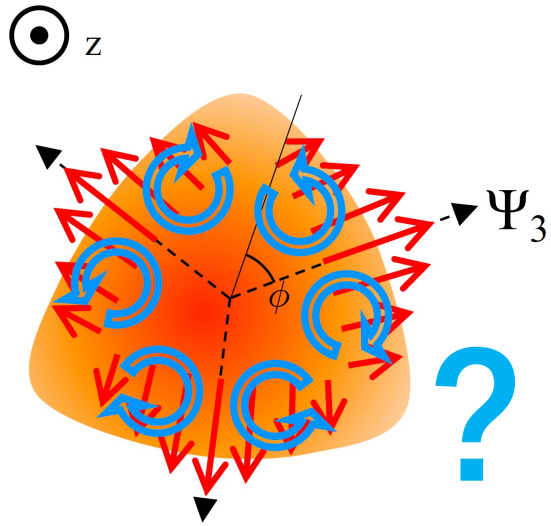
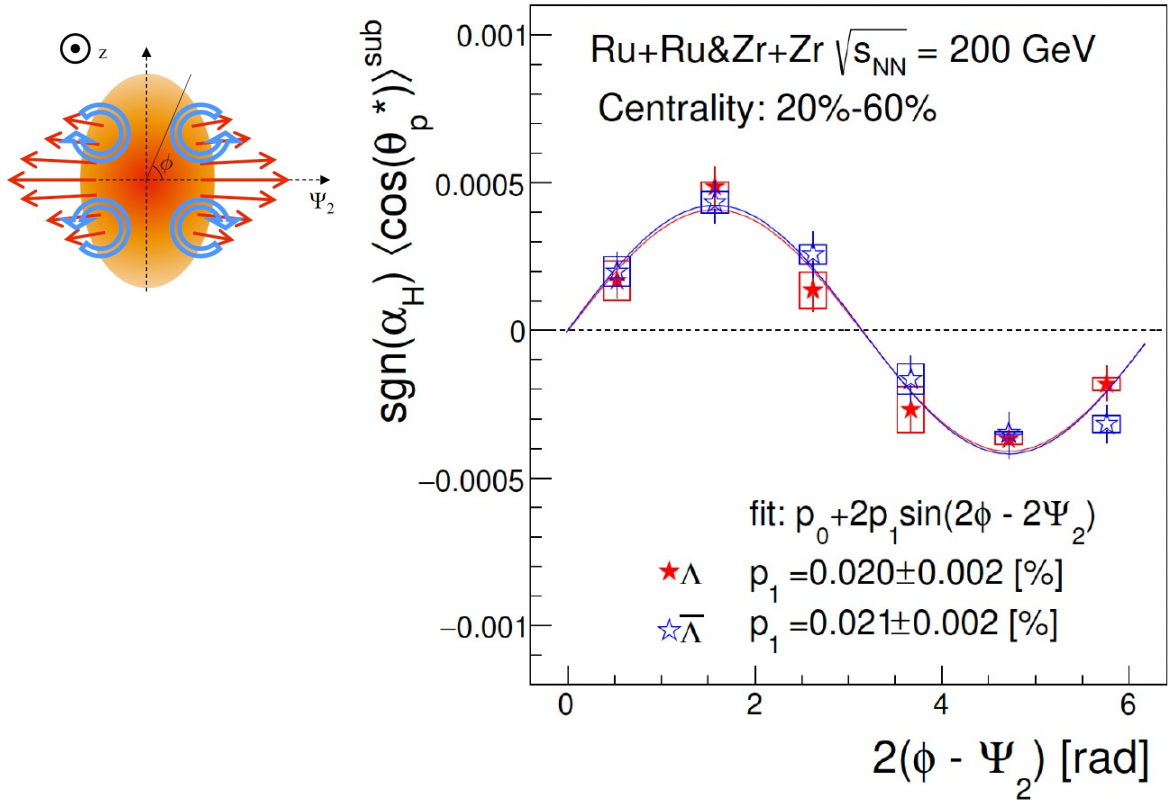




- Collision system size and energy dependence
- Measurements in smaller systems and relative to higher harmonic event planes provide new insights into polarization phenomena

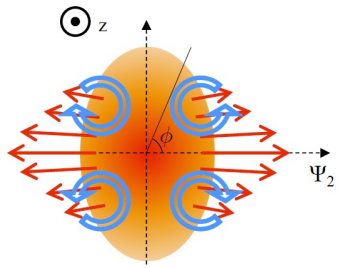
Local polarization in Ru+Ru&Zr+Zr at 200 GeV

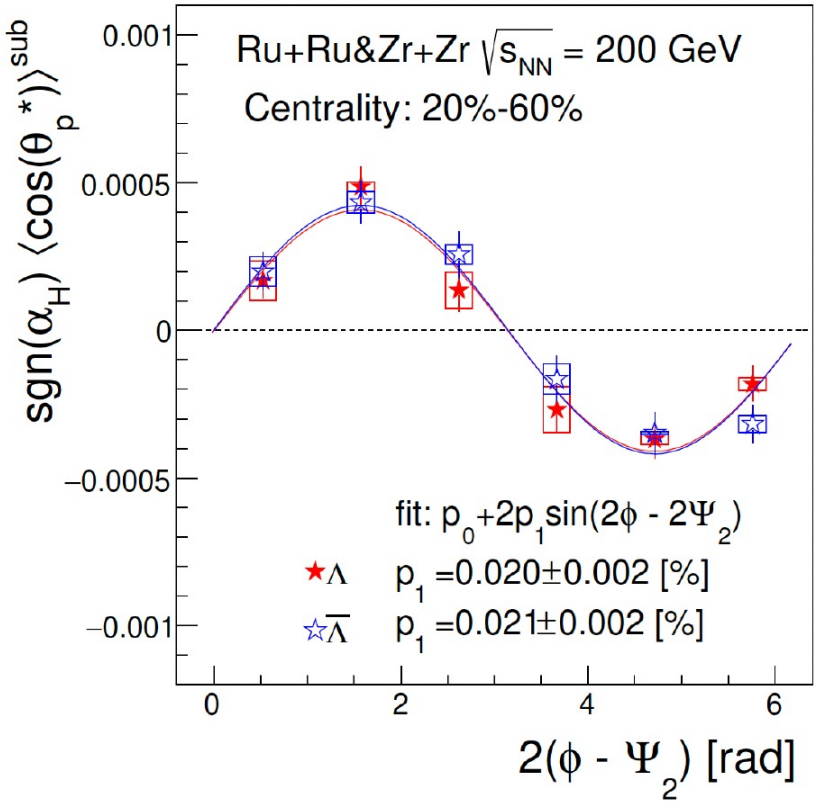


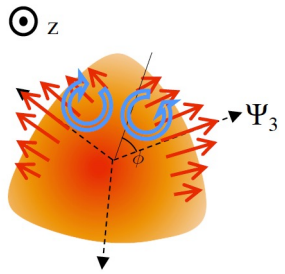
STAR,
PRL 131, 202301 (2023)

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

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







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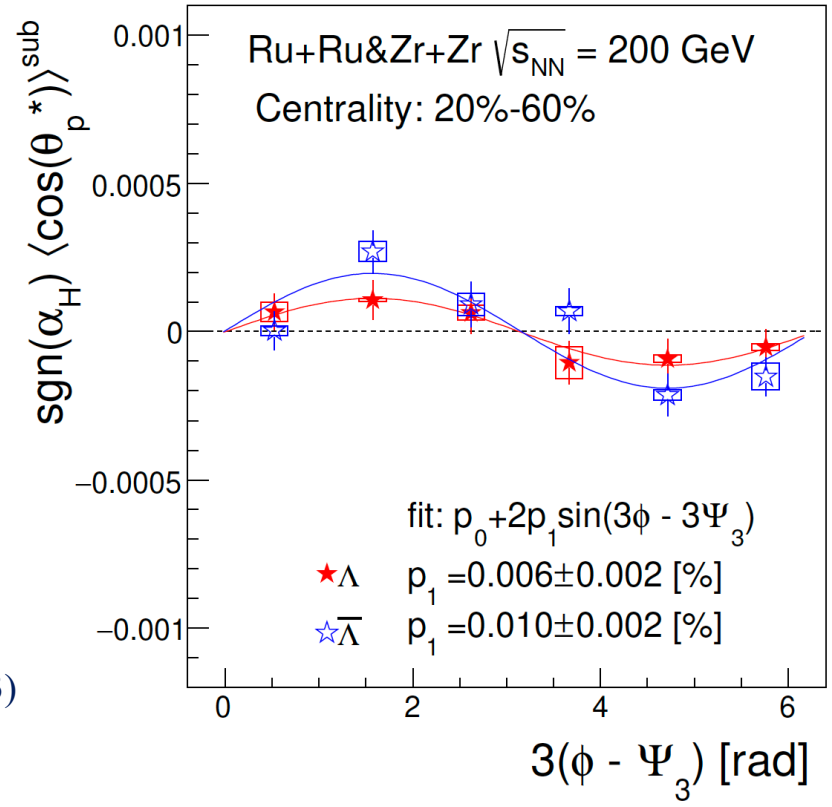
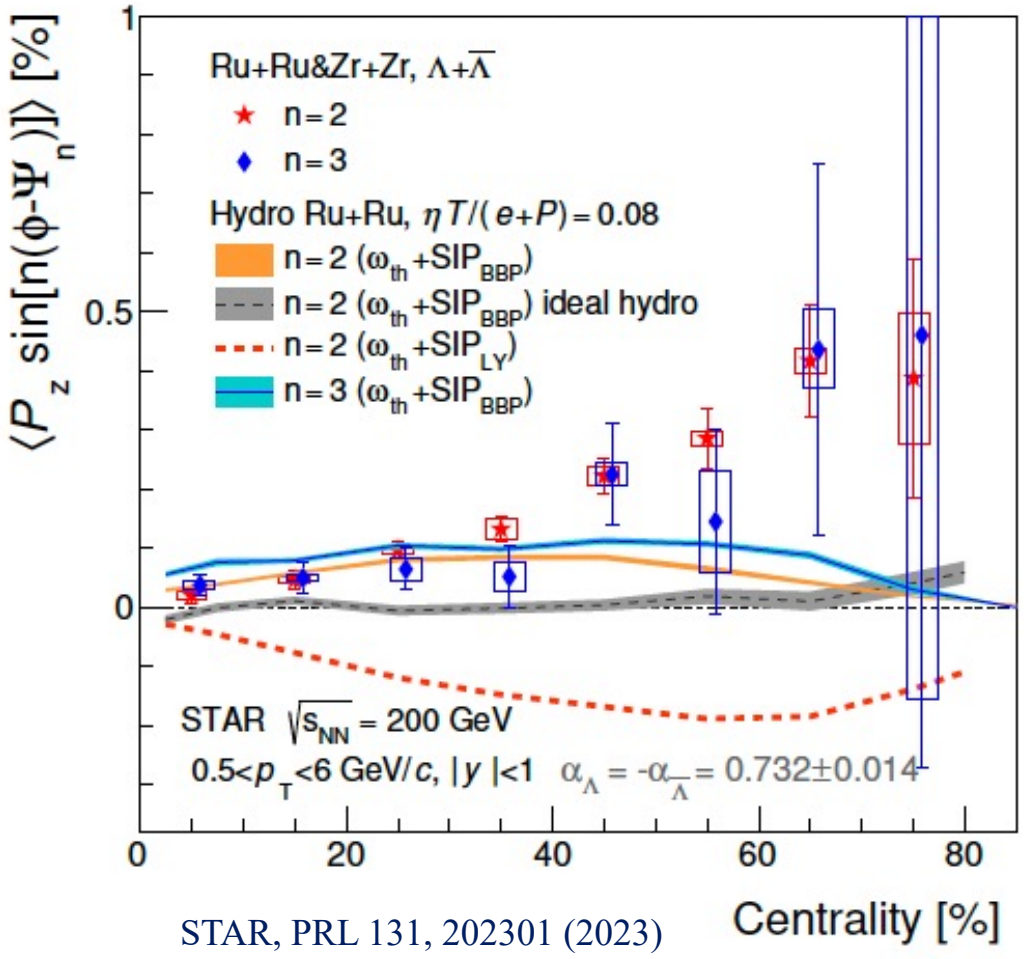


- Significant local polarization w.r.t second-order event plane observed in isobar collisions
- First observation of local polarization w.r.t the third-order event plane

Centrality dependence of local polarization

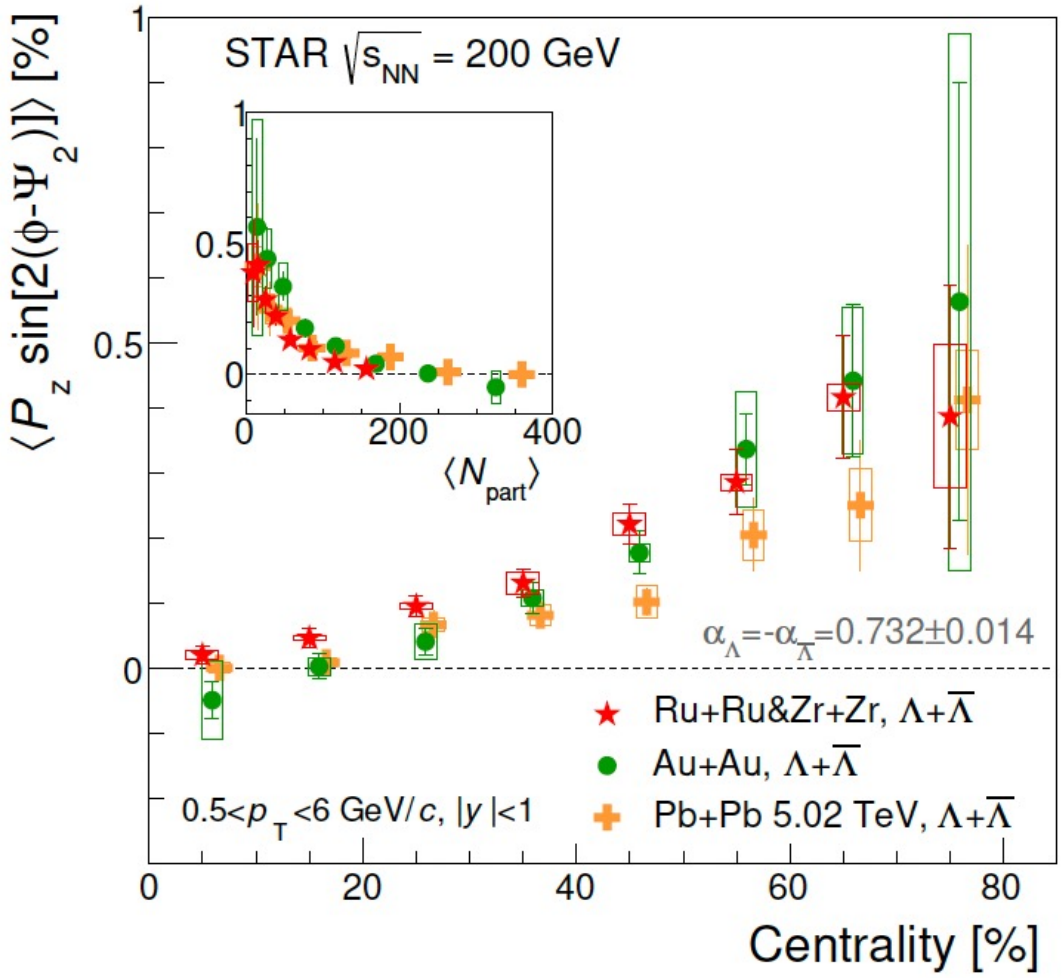


STAR, PRL 131, 202301 (2023)

- 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



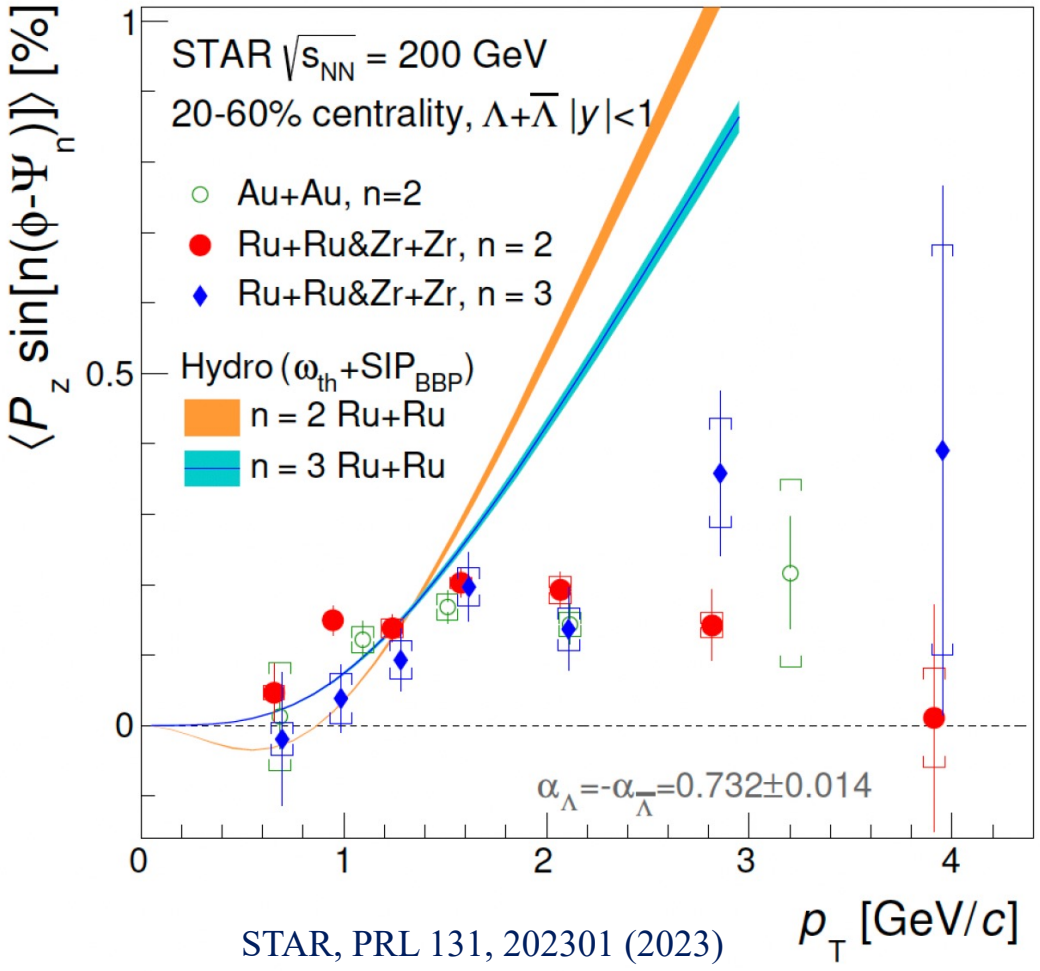
- Hint of system size dependence between isobar and Au+Au collisions
- Energy dependence is not obvious between 200 GeV Au+Au and 5.02 TeV Pb+Pb collisions

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

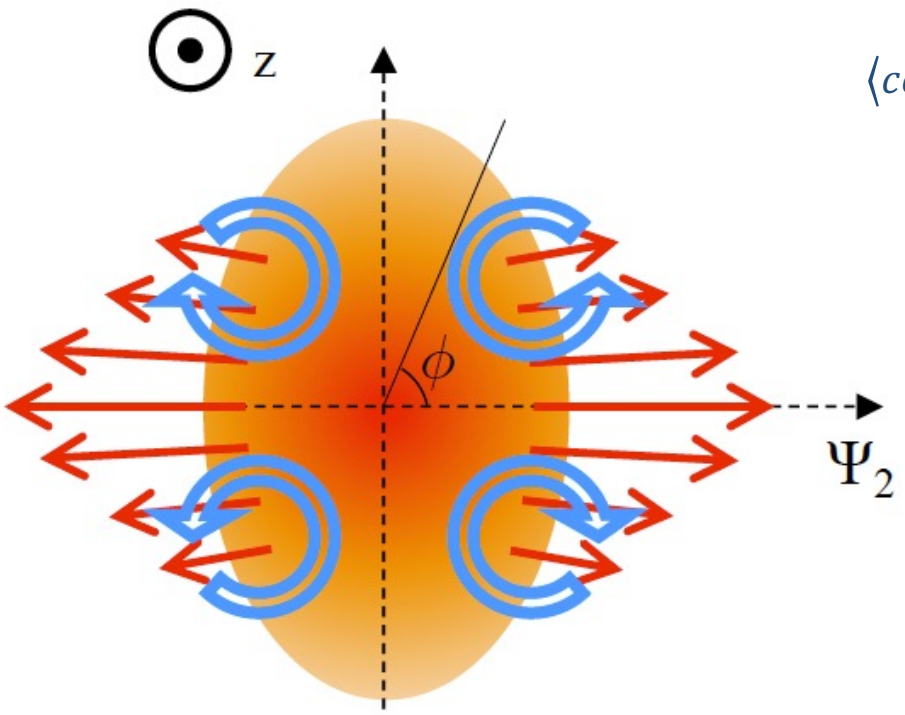
- No splitting observed between Λ and $\bar{\Lambda}$ global polarization in Au+Au collisions at 7.7-27 GeV BES-II and ${}^{96}_{44}\mathrm{Ru} + {}^{96}_{44}\mathrm{Ru}$, ${}^{96}_{40}\mathrm{Zr} + {}^{96}_{40}\mathrm{Zr}$ collisions at 200 GeV
- No collision system size dependence between Ru+Ru, Zr+Zr 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

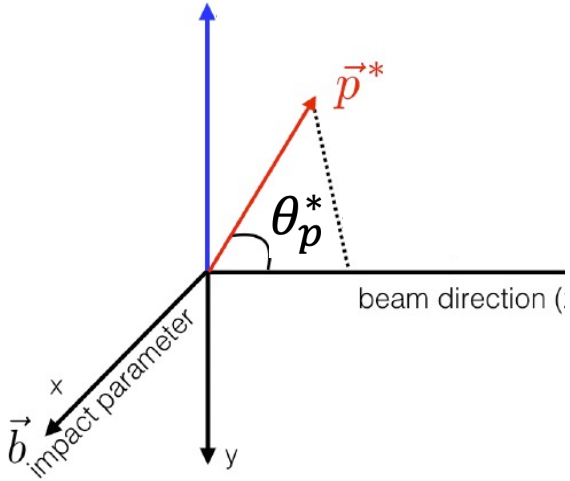
Thanks for your attention

Local polarization of hyperons in heavy ion collisions



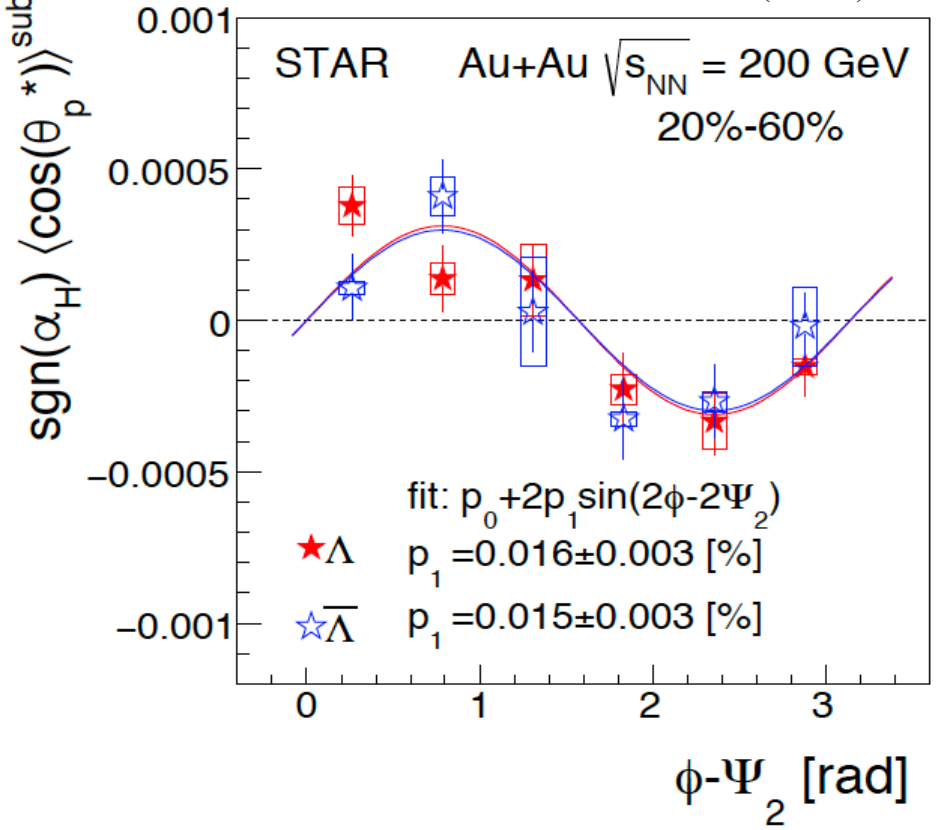
$$\langle cos\theta_p^* \rangle = \int \frac{dN}{d\Omega^*} cos\theta_p^* d\Omega^*$$
$$= \alpha_\Lambda P_z \langle (cos\theta_p^*)^2 \rangle$$

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



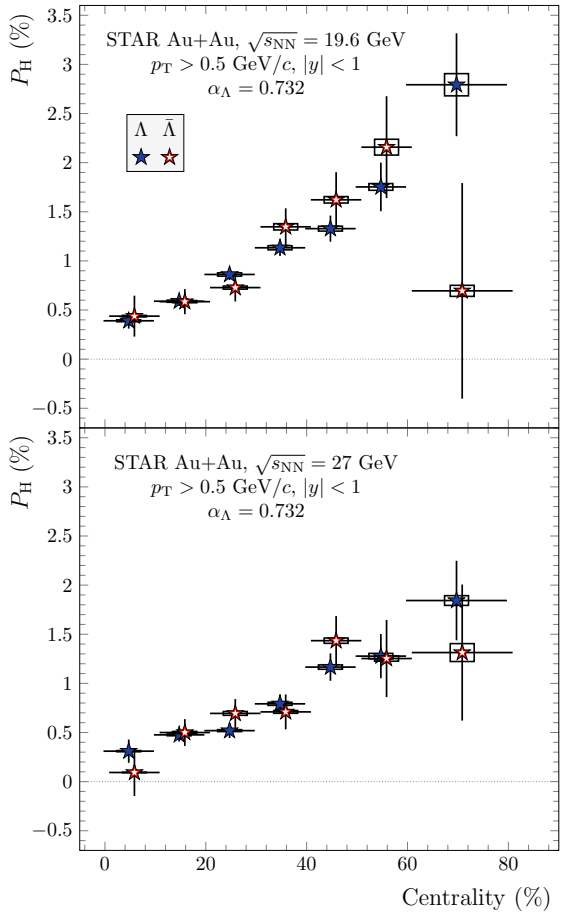
$P_z \propto \langle cos\theta_p^* \rangle$

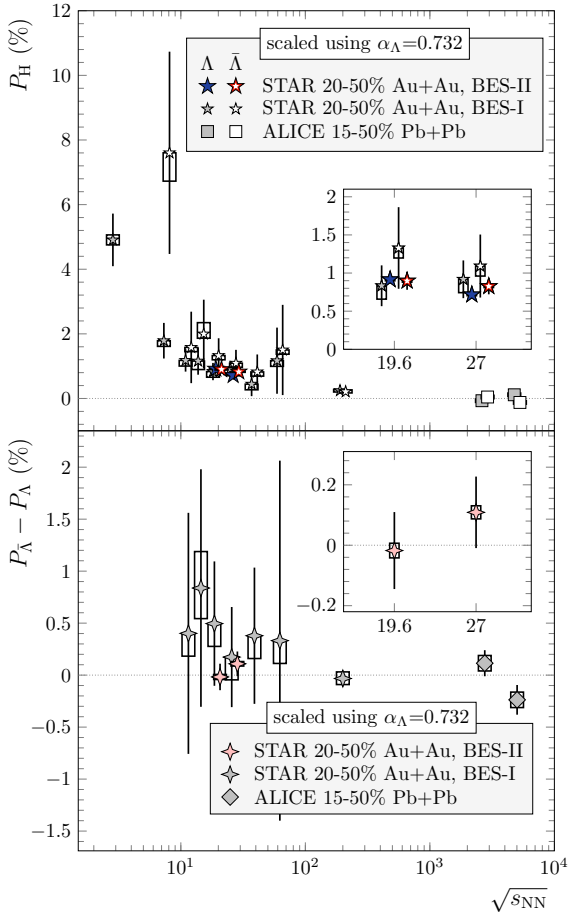
STAR, PRL123, 132301(2019)

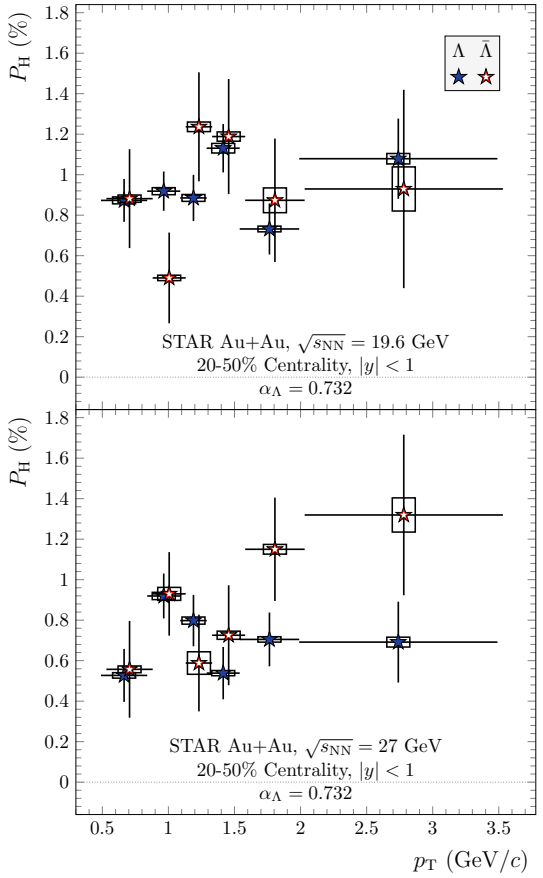


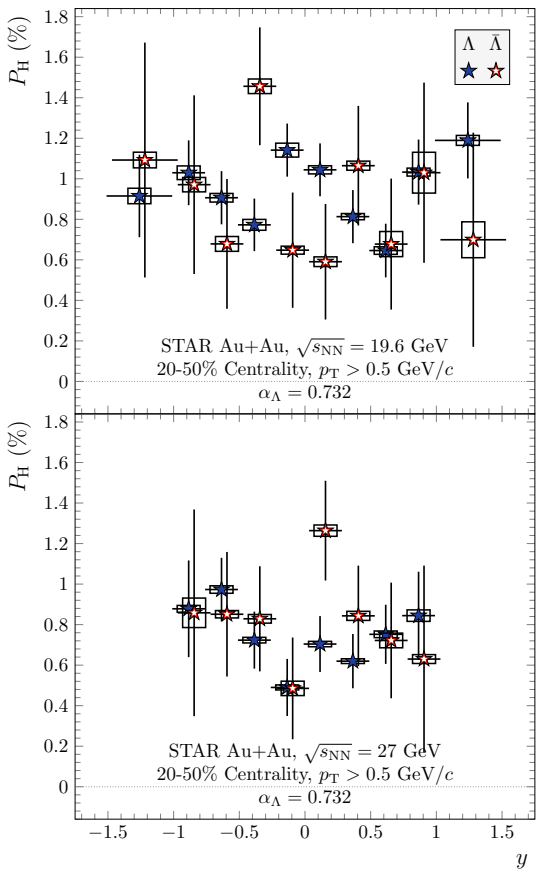
- Local vorticity induced by anisotropic flow results in polarization along the beam direction, expected from the "elliptic flow"
- STAR has observed the local polarization with second order event plane in Au+Au collisions

Global polarization collision energy dependence



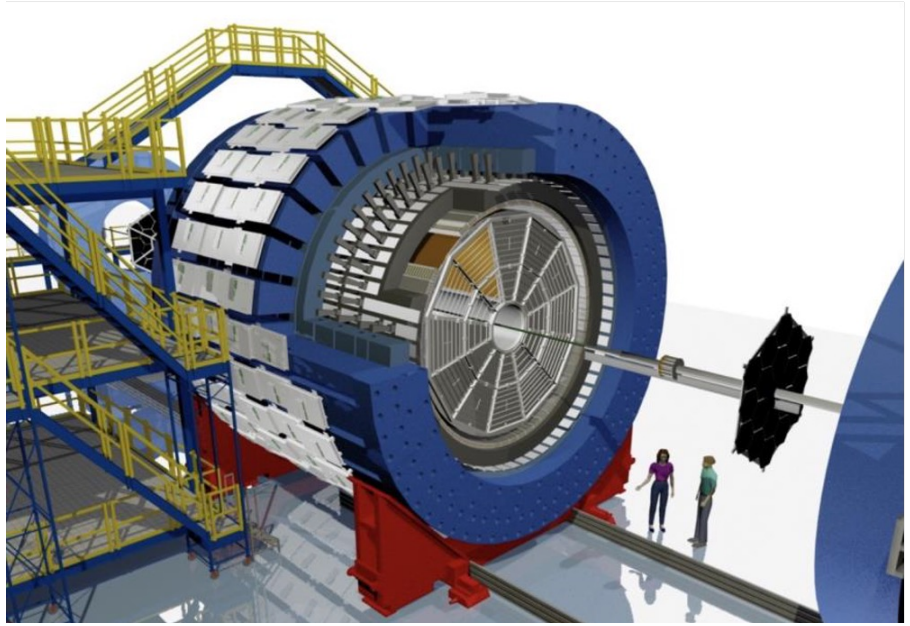






- Significant global polarization centrality dependence observed
- Lambda and antiLambda global polarization are consistent
- No observed dependence of global polarization on pt

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



Event plane reconstruction:

Time Projection Chamber

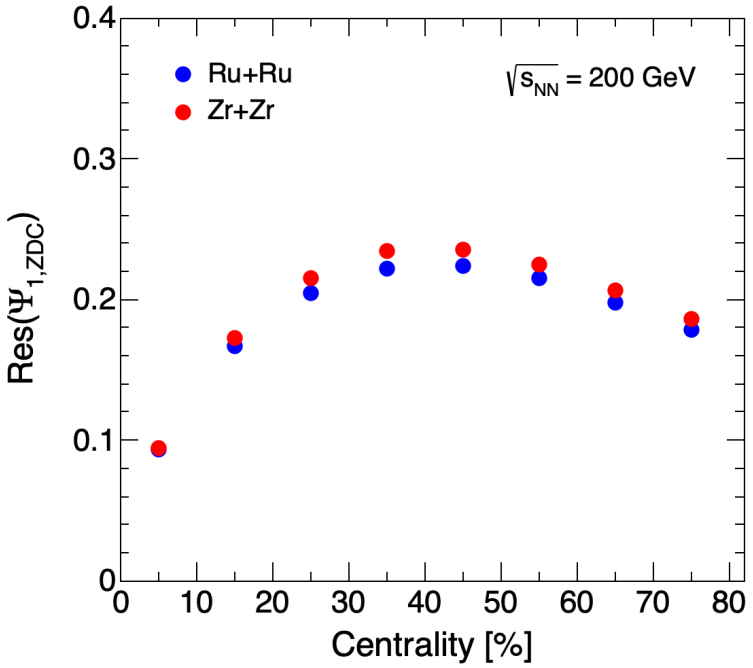
Zero Degree Calorimeters

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

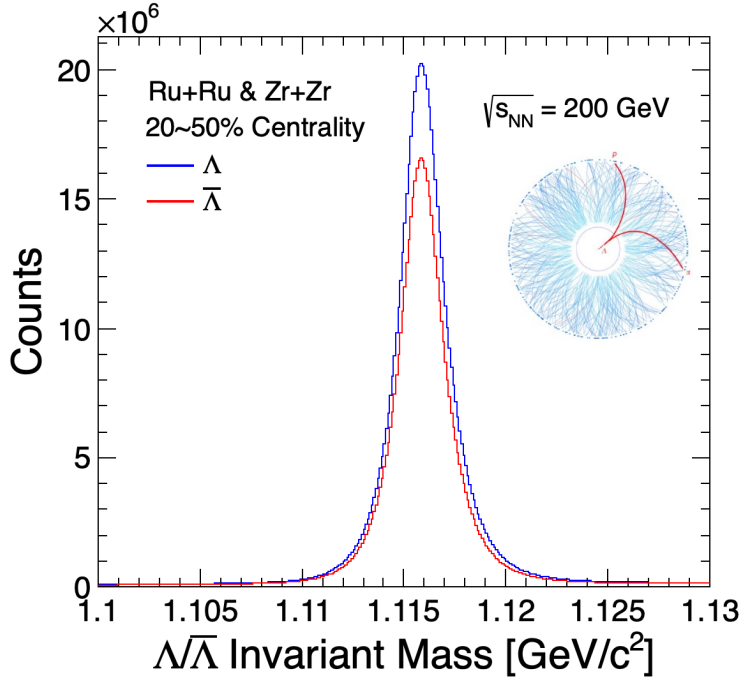
Time Projection Chamber

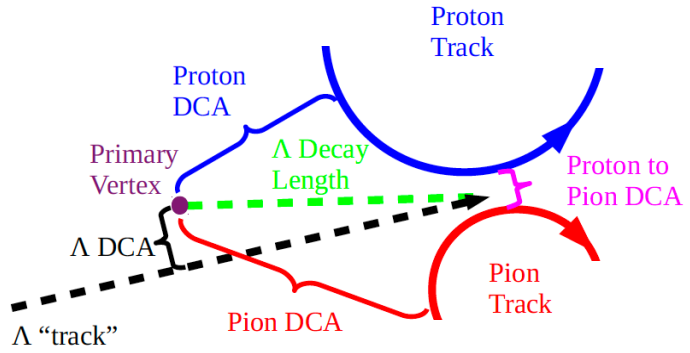
Time Of Flight

Event plane resolution



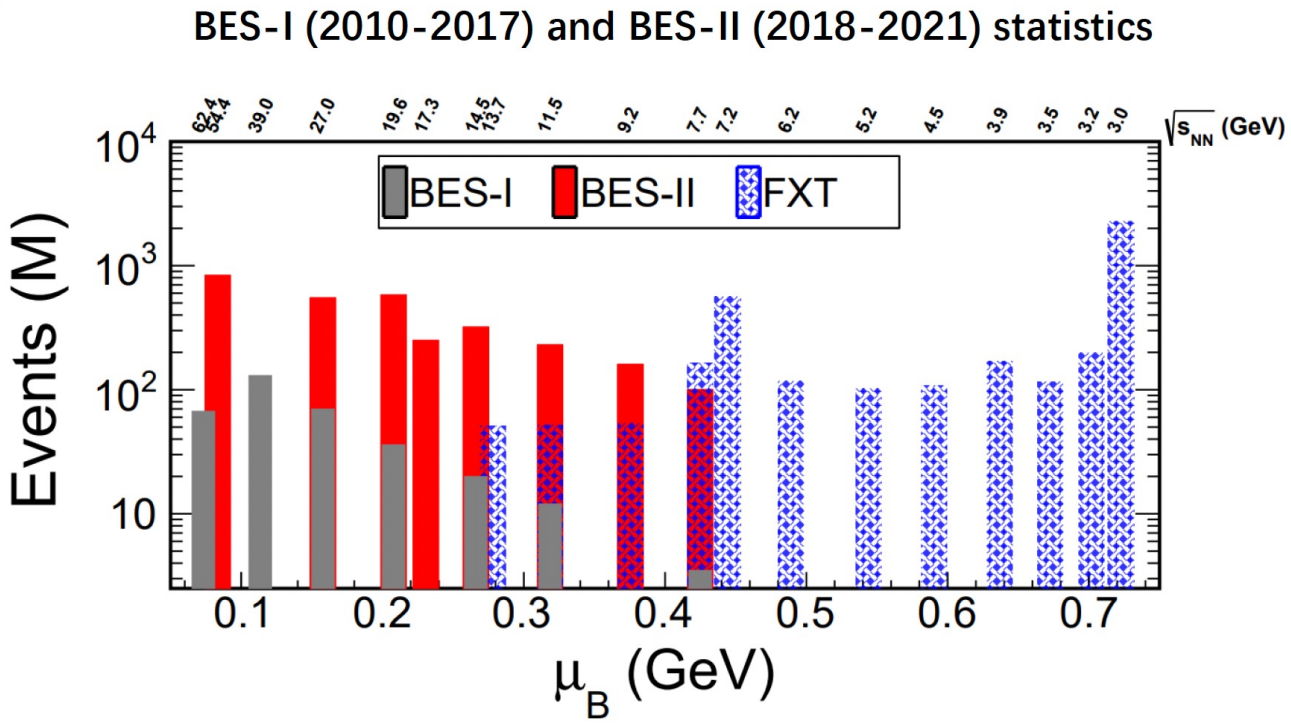
$\Lambda/\bar{\Lambda}$ reconstructed with TPC tracks



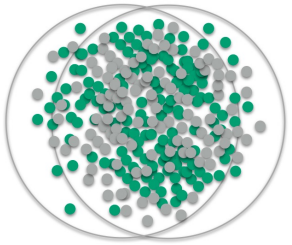


- $\Lambda \rightarrow p + \pi^-$
- $\bar{\Lambda} \rightarrow \bar{p} + \pi^+$
- Background fraction < 3%

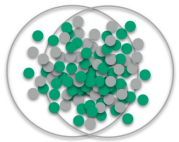
Outlook



System	$\sqrt{s_{NN}}$ (GeV)	Events (10^6)	Year
O+O	**200**	**400**	**2021**
Au+Au	200	20000	2023+ 2025



$^{197}_{79}Au + ^{197}_{79}Au$



$^{96}_{40}Zr + ^{96}_{40}Zr$ / $^{96}_{44}Ru + ^{96}_{44}Ru$

$^{16}_{8}O + ^{16}_{8}O$

- Global polarization splitting in low energy BES-II?
- Local polarization collision energy dependence?
- Global polarization in O+O collisions?