The 8th International Conference on Chirality, Vorticity and Magnetic Field in Quantum Matter

Measurement of global and local spin polarization of Λ and $\bar{\Lambda}$ in Au+Au collisions from the RHIC Beam Energy Scan-II

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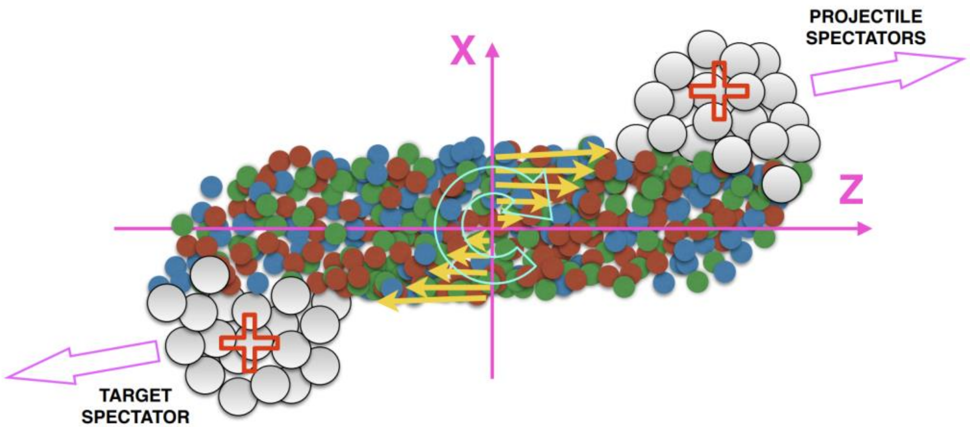
Outline

- Global polarization
- Local polarization
  - Shear Induced Polarization (SIP)
  - Baryonic Spin Hall Effect (SHE)
- Summary

Introduction to Global Polarization



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

- Non-central HICs have large initial angular momentum and magnetic field

⬇

- Polarize quarks due to "spin-orbit" interaction

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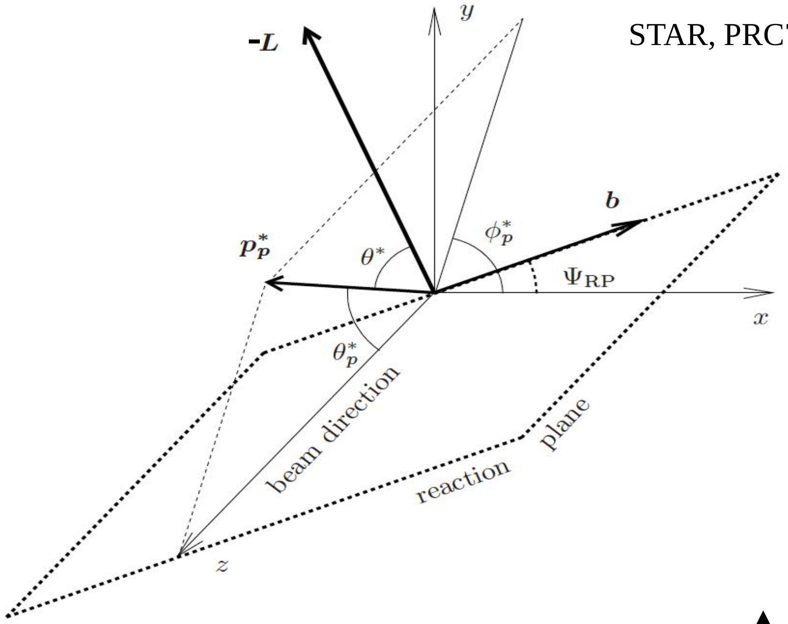
- Polarization of the final-state hadrons

Provide the unique opportunity to probe the spin degrees of freedom of the QGP

STAR, PRC76, 024915 (2007)



$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}(1 + \alpha_H P_H \cos\theta^*)$$

Λ spin
θ^*
p
π^-
Λ rest frame

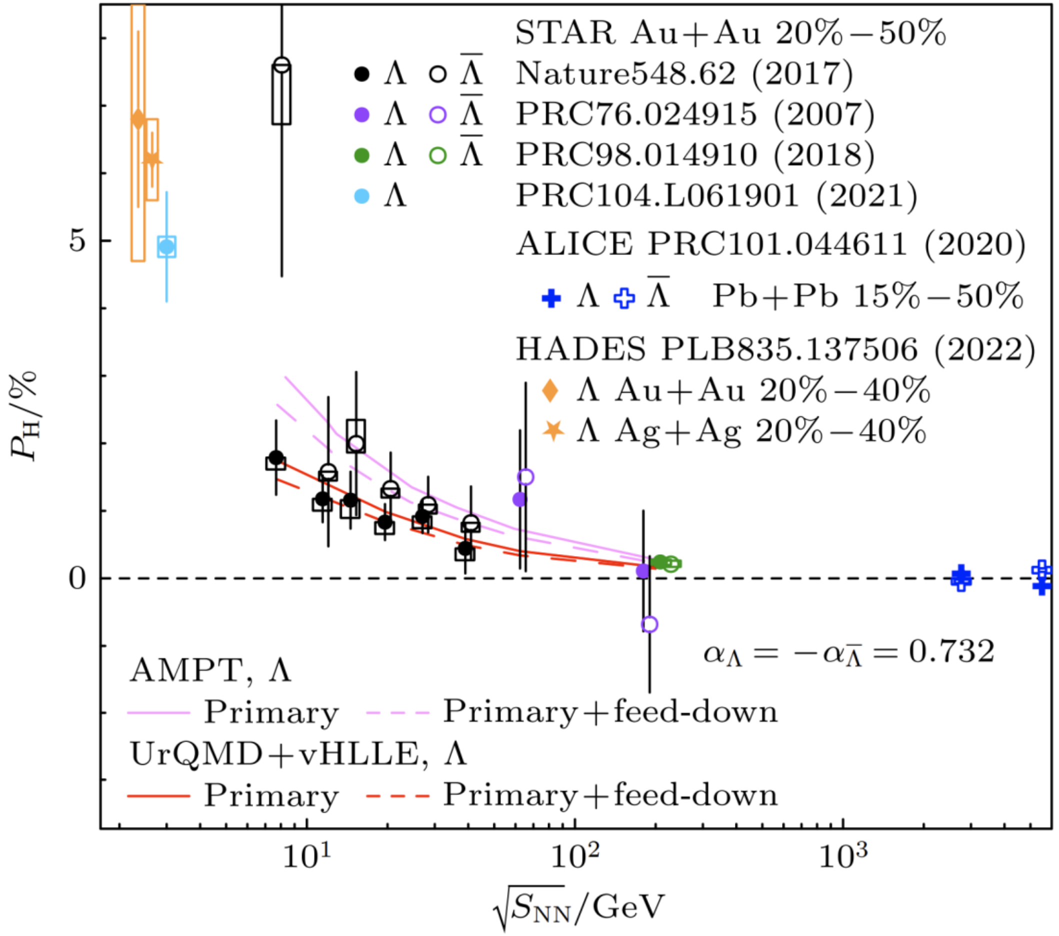
⬇

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

- α_H is the hyperon decay parameter, $\alpha_H = 0.732 \pm 0.014$
- ϕ^* is the azimuthal angle of the daughter proton in Λ rest frame
- A_0 is an acceptance correction factor, $A_0 = \langle \sin\theta_p^* \rangle$

Introduction to Global Polarization

Sun Xu et al., Acta Phys. Sin. 72(7), 072401 (2023)



- Positive signal of global polarization observed in Λ at lower collision energies (7.7–39 GeV) from BES-I by STAR in 2017

$$\omega \approx K_B T\left(P_\Lambda + P_{\bar{\Lambda}}\right) \sim 10^{21} s^{-1}$$

Strongest vorticity observed in nature

- Higher statistics data at 200 GeV confirmed positive signal and energy dependence of global polarization by STAR in 2018

- High-energy region(ALICE, 2.76 TeV and 5.02 TeV), low-energy region(HADES, 2.4 GeV and 2.55 GeV)

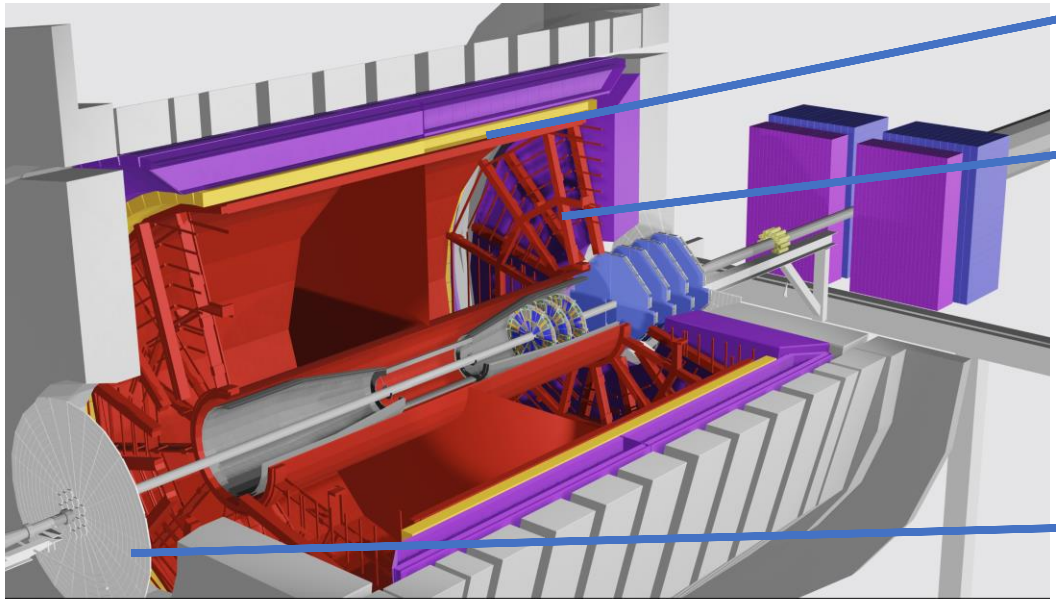
Becattini, Francesco et al., Phys. Rev. C 95.054902(2017)

? How does the late-stage magnetic field affect global polarization

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

The late-stage magnetic field may be extracted through the splitting of P_Λ and $P_{\bar{\Lambda}}$

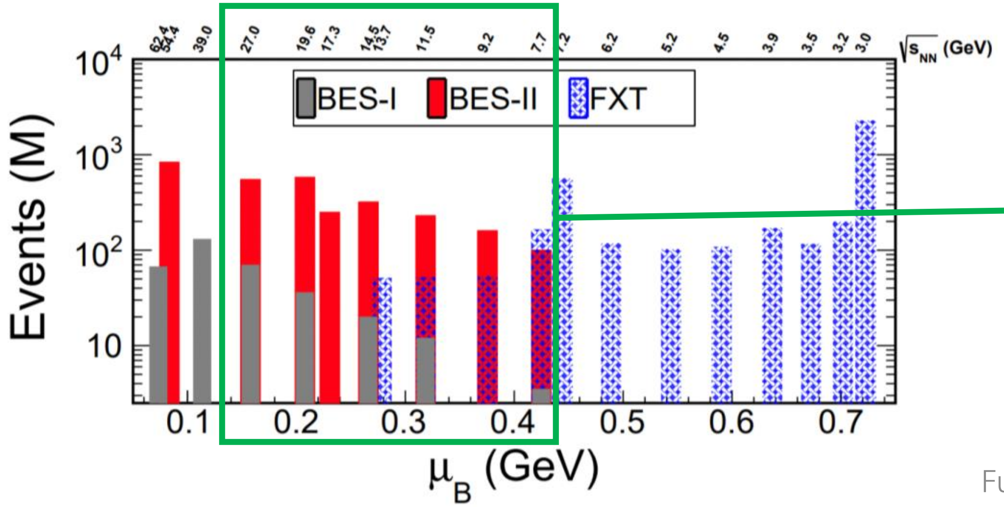
The STAR detector and BES-II data sets



Time **O**f **F**light
- Particle identification

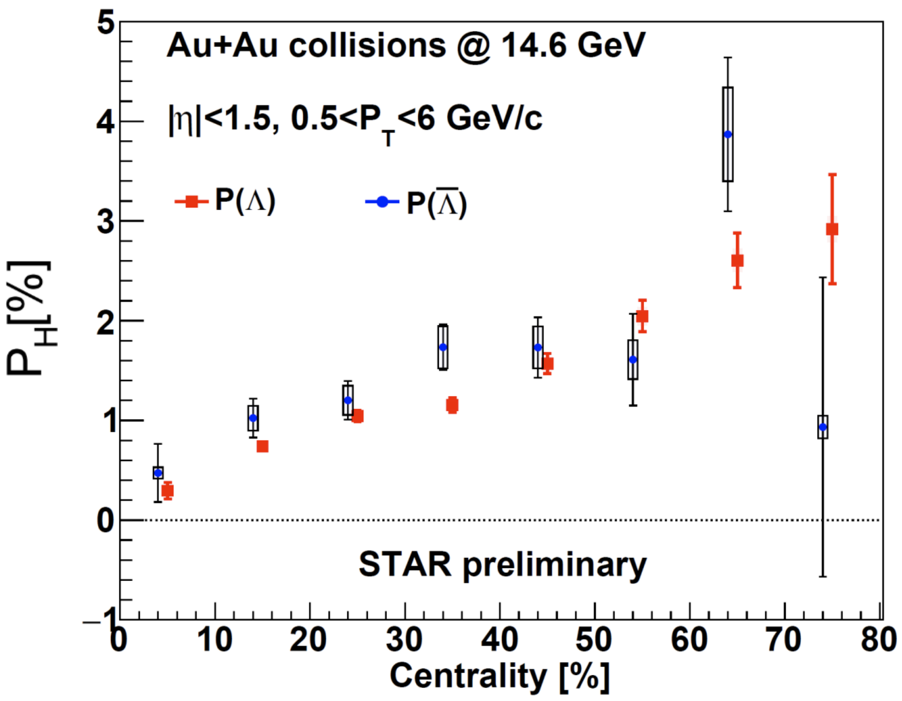
Time **P**rojection **C**hamber
- The iTPC upgrade extended the pseudorapidity coverage from $|\eta| < 1$ to $|\eta| < 1.5$
- Particle reconstruction
- Second-order event plane reconstruction

Event **P**lane **D**etector
- Improved the event plane reconstruction resolution by over 50%
- First-order event plane reconstruction

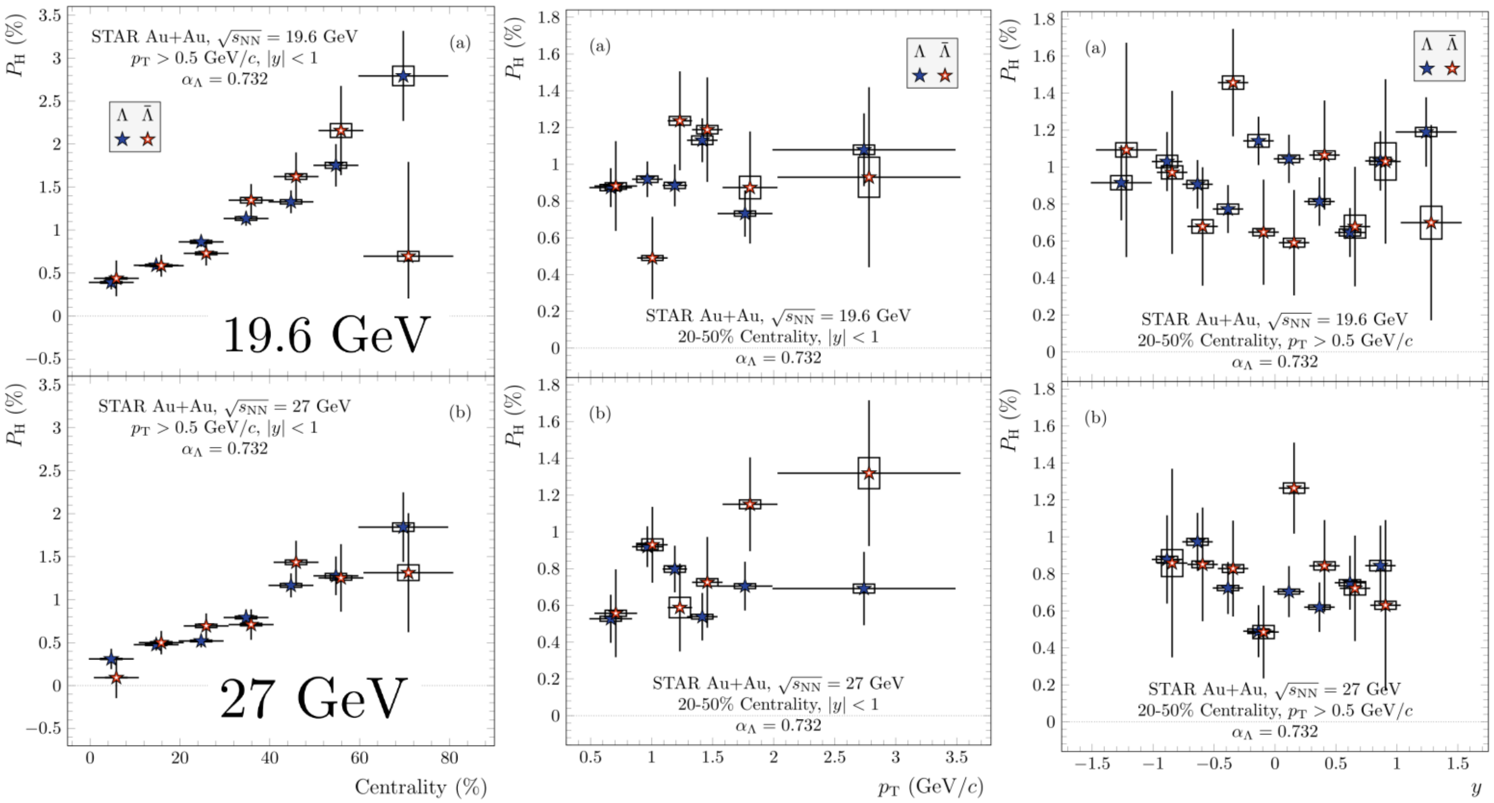


- The BES-II by STAR collected an order of magnitude more data compared to BES-I
- Collected data at two additional energy points compared to BES-I (9.2, 17.3 GeV)

Result of Global Polarization from BES-II

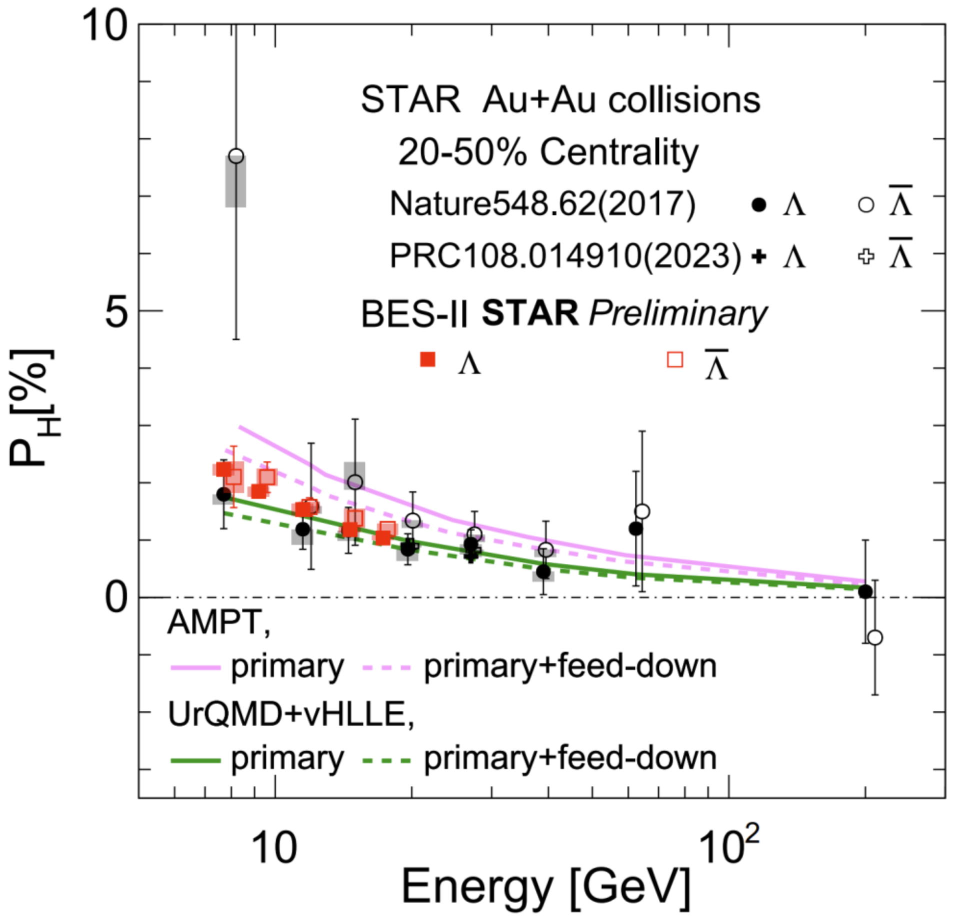


STAR, Phys. Rev. C 108, 014910 (2023)



- Clear centrality dependence of Λ and $\overline{\Lambda}$
- Trend consistent with expectation from vorticity

Result of Global Polarization from BES-II

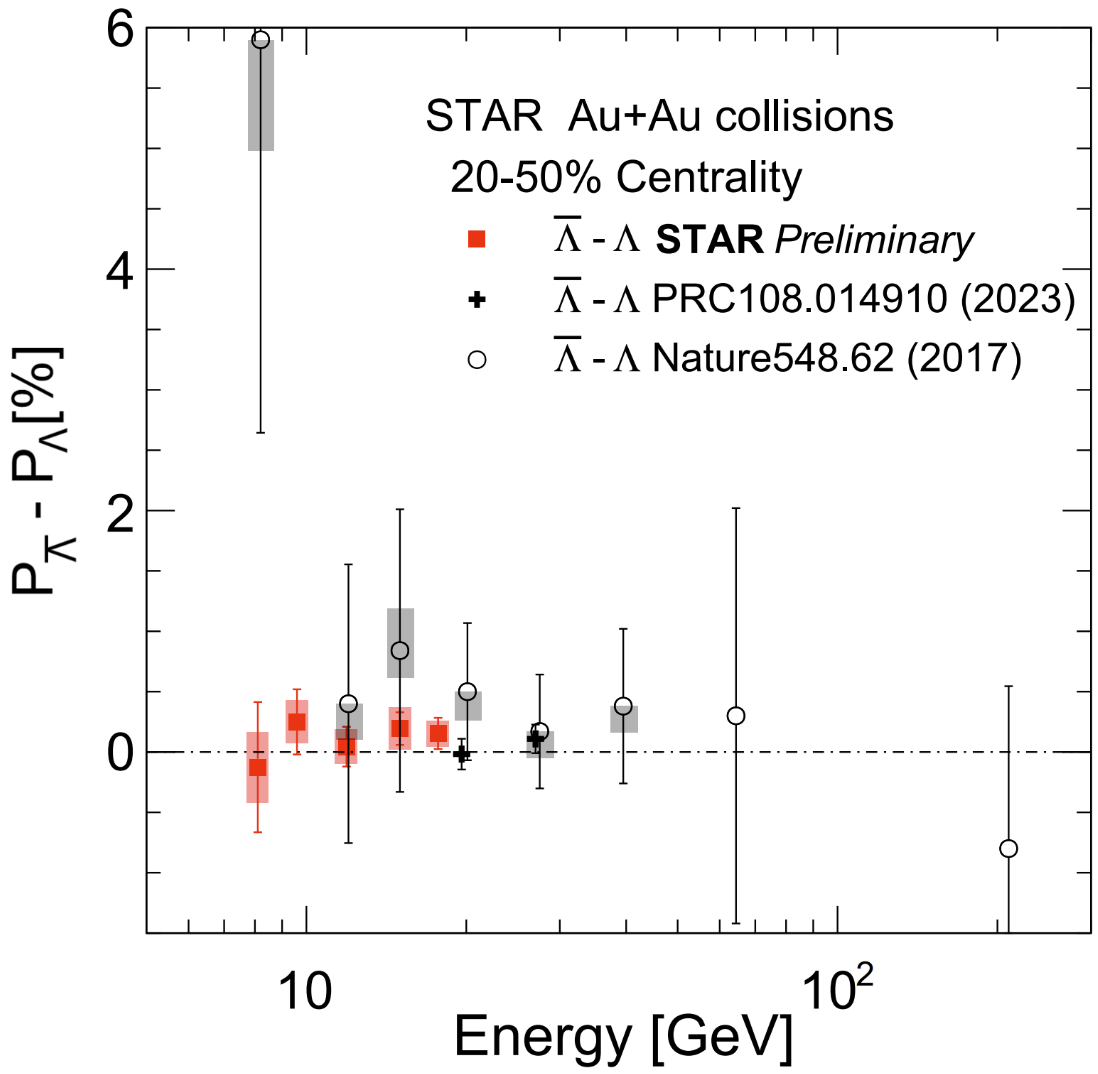


- The results from BES-II have much higher precision compared to BES-I, and include two new energy (9.2, 17.3 GeV)
- The global polarization decreases with increasing collision energy

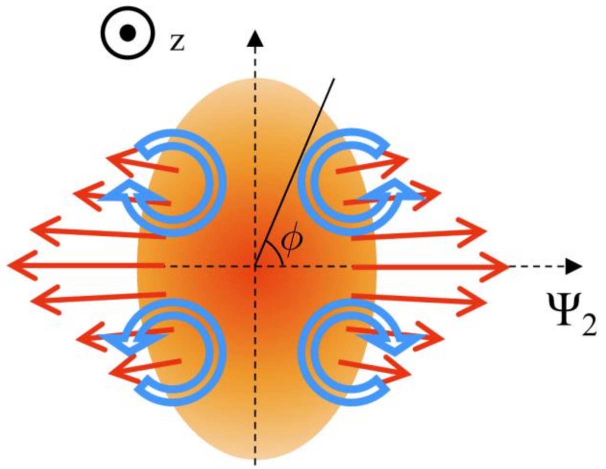
Splitting Between Λ and $\bar{\Lambda}$ Global Polarization

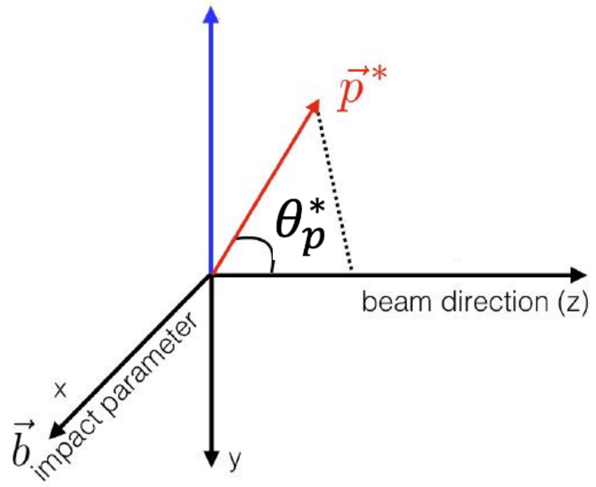
- The results are consistent with the measurements from BES-I
- No splitting between Λ and $\bar{\Lambda}$ global polarization within uncertainties
- Upper limit on late stage magnetic field
  - 95% confidence level
  - $B < 9.4 \times 10^{12}\ T$ at 19.6 GeV
  - $B < 1.4 \times 10^{13}\ T$ at 27 GeV

STAR, Phys. Rev. C 108, 014910 (2023)

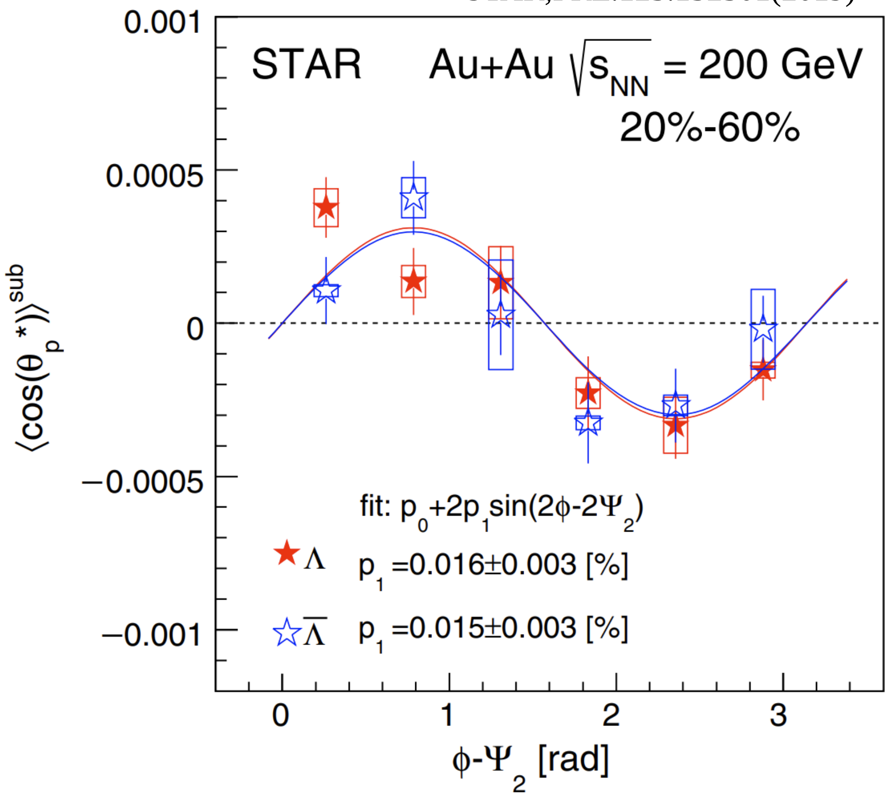


Introduction to Polarization along the Beam Direction





STAR,PRL.123.132301(2019)



- Anisotropic expansion of QGP leads to vorticity and particle polarization

$$P_z = \frac{\langle \cos\theta_p^* \rangle}{\alpha_H \langle \cos^2\theta_p^* \rangle} \qquad \langle P_z \sin(n\phi - n\Psi_n)\rangle = \frac{\langle P_z \sin(n\phi - n\Psi_n^{obs})\rangle}{\mathrm{Res}(\Psi_n)}$$

- Measurements of polarization along the beam direction are important for understanding vorticity dynamics and its relation to polarization.

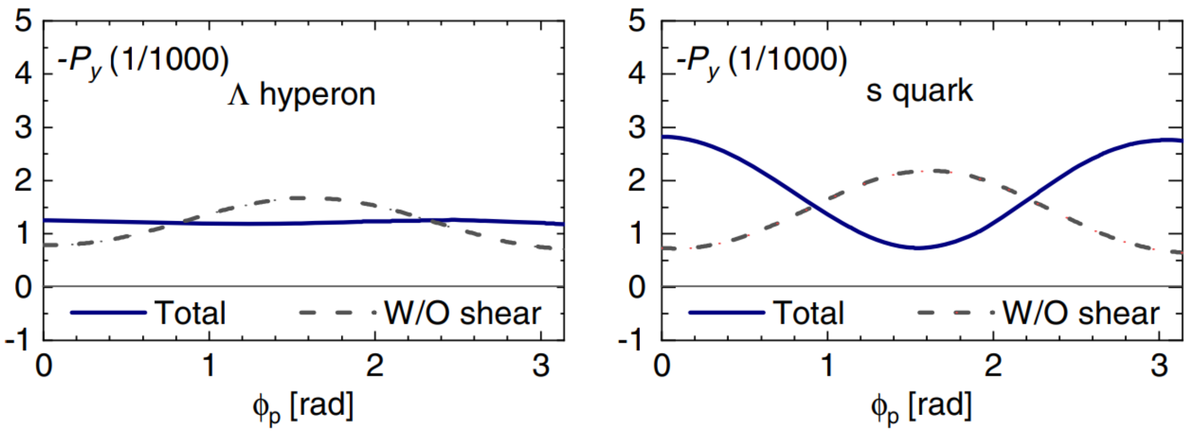
Introduction to Shear Induced Polarization (SIP)

- Predicted Λ spin polarization along the beam direction differs qualitatively from experimental observations.

⬇

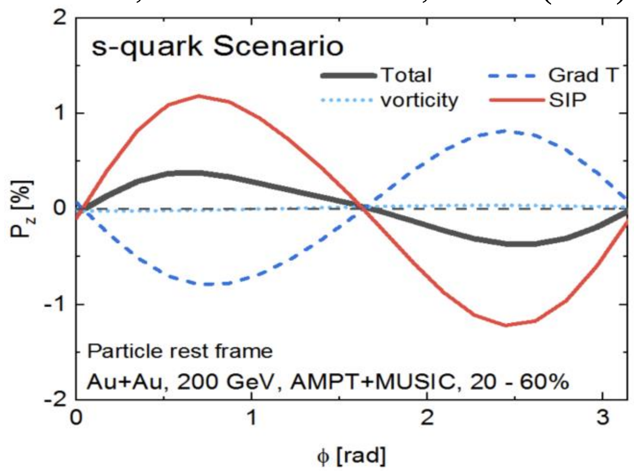
- Shear Induced Polarization (SIP) may plays an essential role

$$P_{2,y} = \frac{8\langle \sin(\Psi_1 - \phi_p^*)\cos[2(\Delta\phi)]\rangle}{\pi \alpha_H}, \quad \Delta\phi = \phi_\Lambda - \Psi_2$$

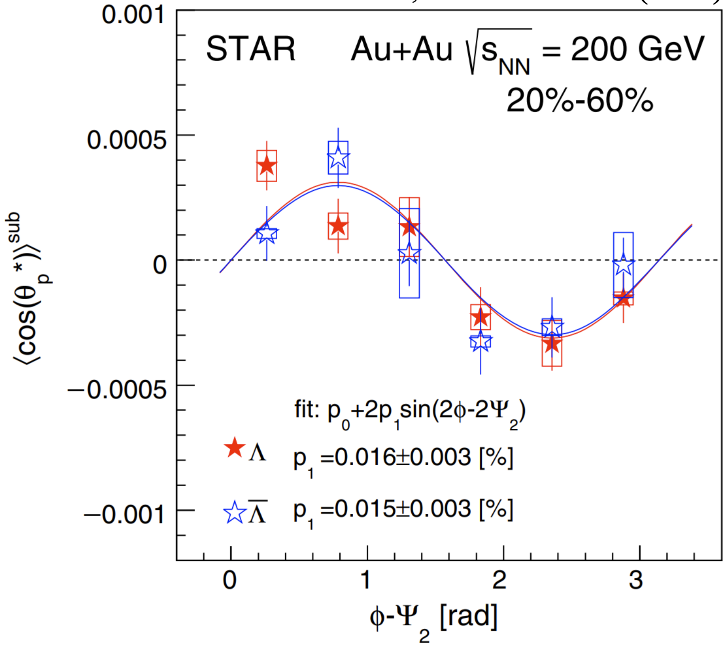


B. Fu, S. Liu et al. PRL 127, 142301 (2021)

B. Fu, S. Liu et al. PRL 127, 142301 (2021)

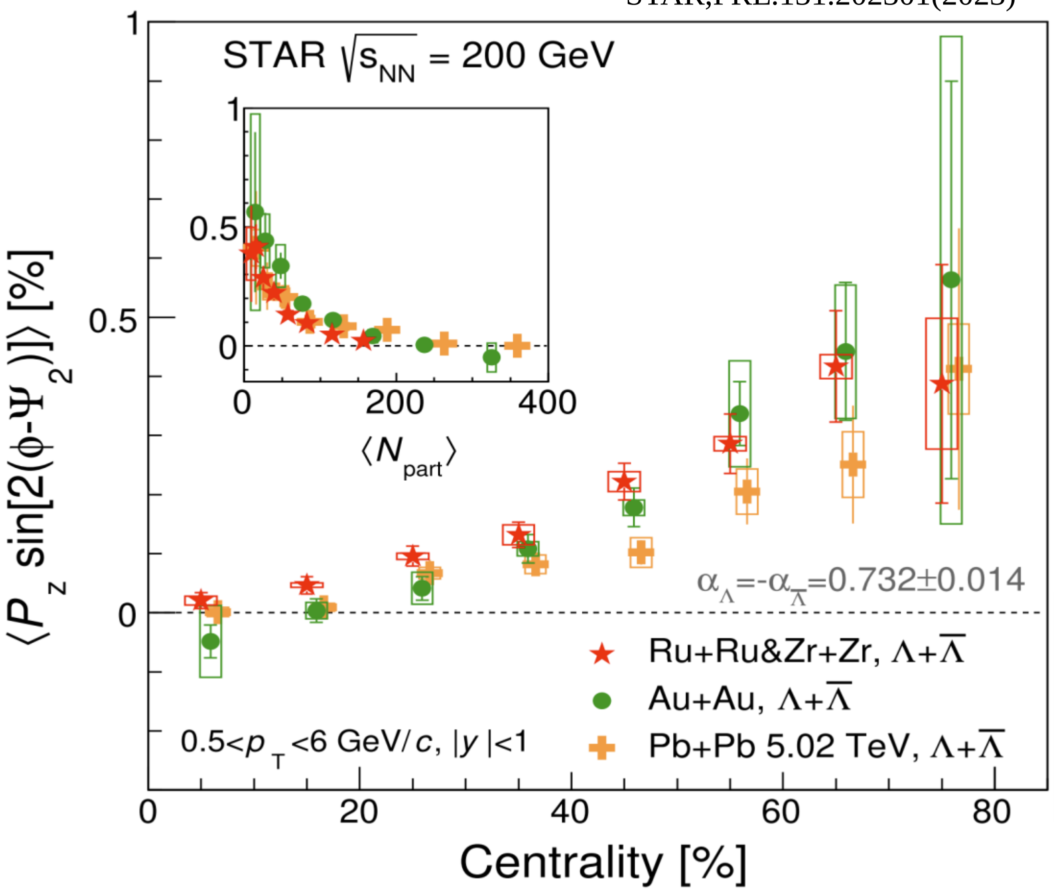


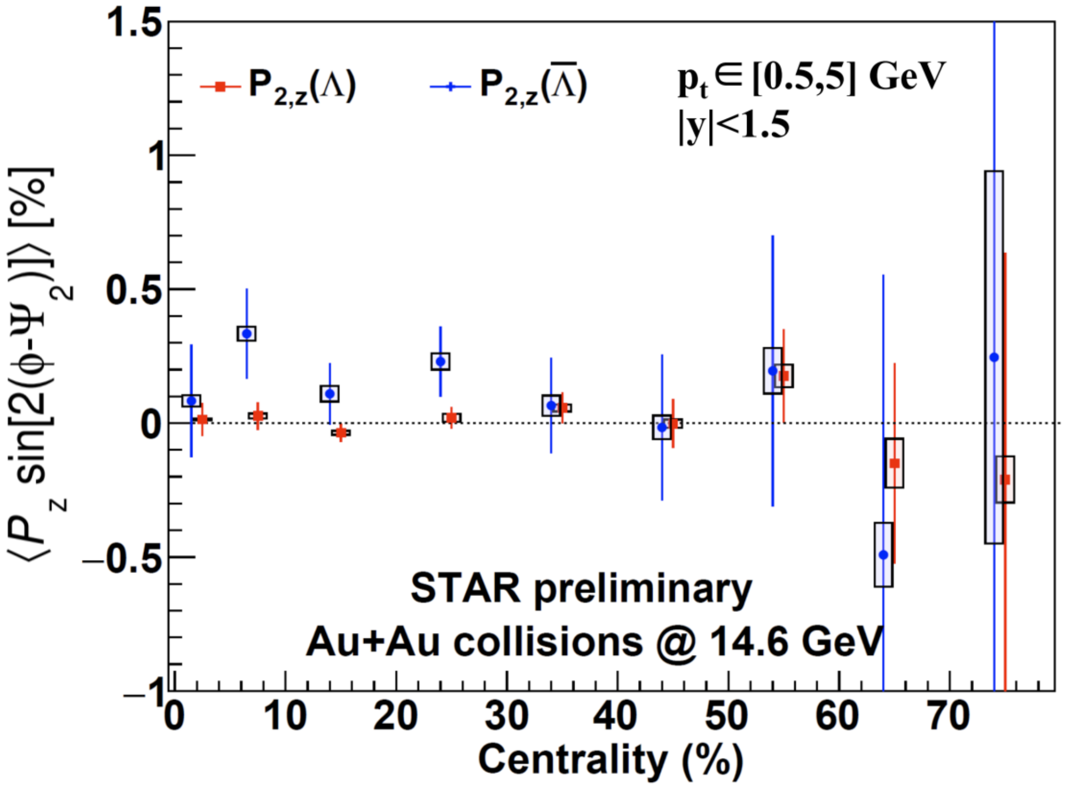
STAR,PRL.123.132301(2019)



Result of Local Polarization from BES-II

STAR,PRL.131.202301(2023)

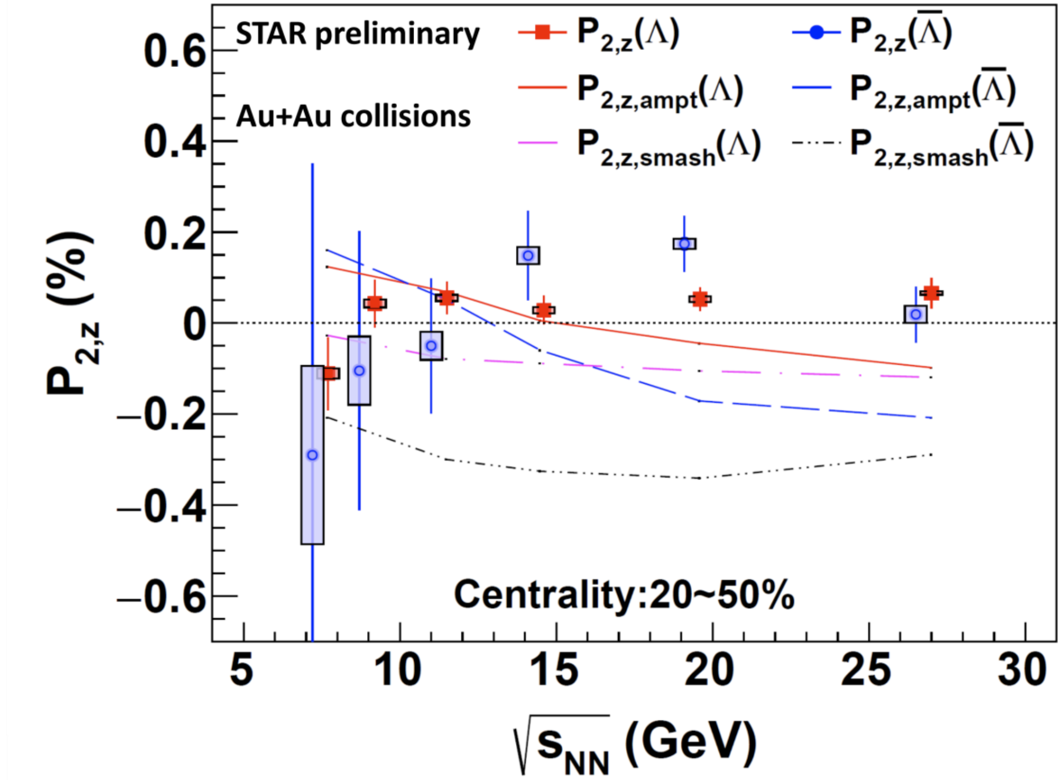




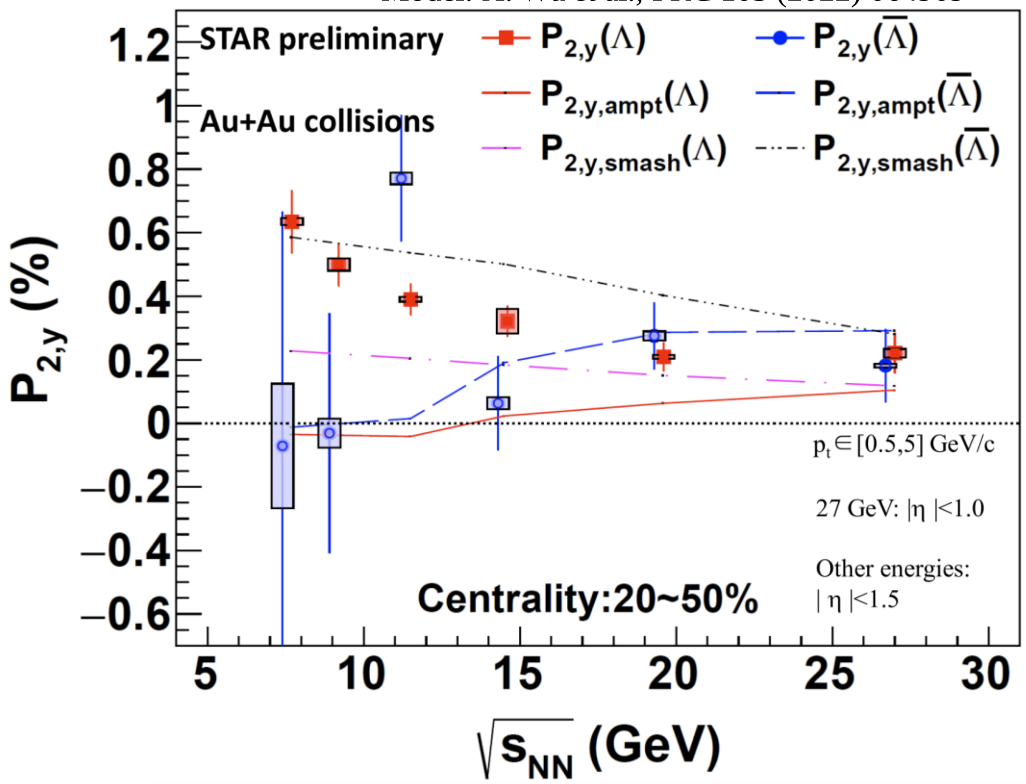
- STAR observed clear signal of polarization along the beam direction in AuAu and isobar collision
- Measurements extended to BES energies

Result of Local Polarization from BES-II

Model: X. Wu et al., PRC 105 (2022) 064909



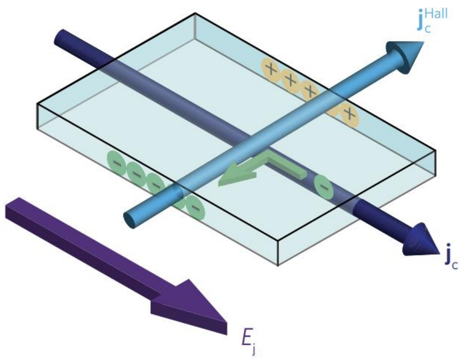
Model: X. Wu et al., PRC 105 (2022) 064909



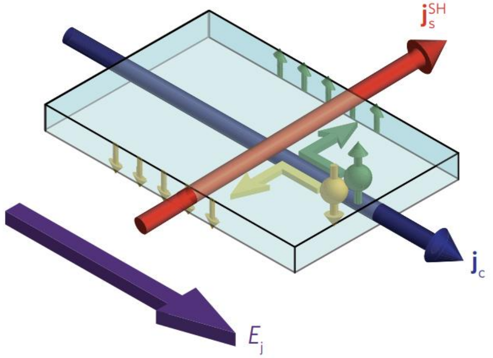
- Hints of sign change of $P_{2,z}$ at 7.7 GeV, baryon diffusion with Λ−scenario predicts sign change opposite to data
- $P_{2,y}$ of Λ increase with decreasing energy and current models cannot describe the results

Introduction to Baryonic Spin Hall Effect (SHE)

S. Meyer et al., Nature Materials, 2017



Hall effect, 1879



Spin Hall effect, (1972) 2004

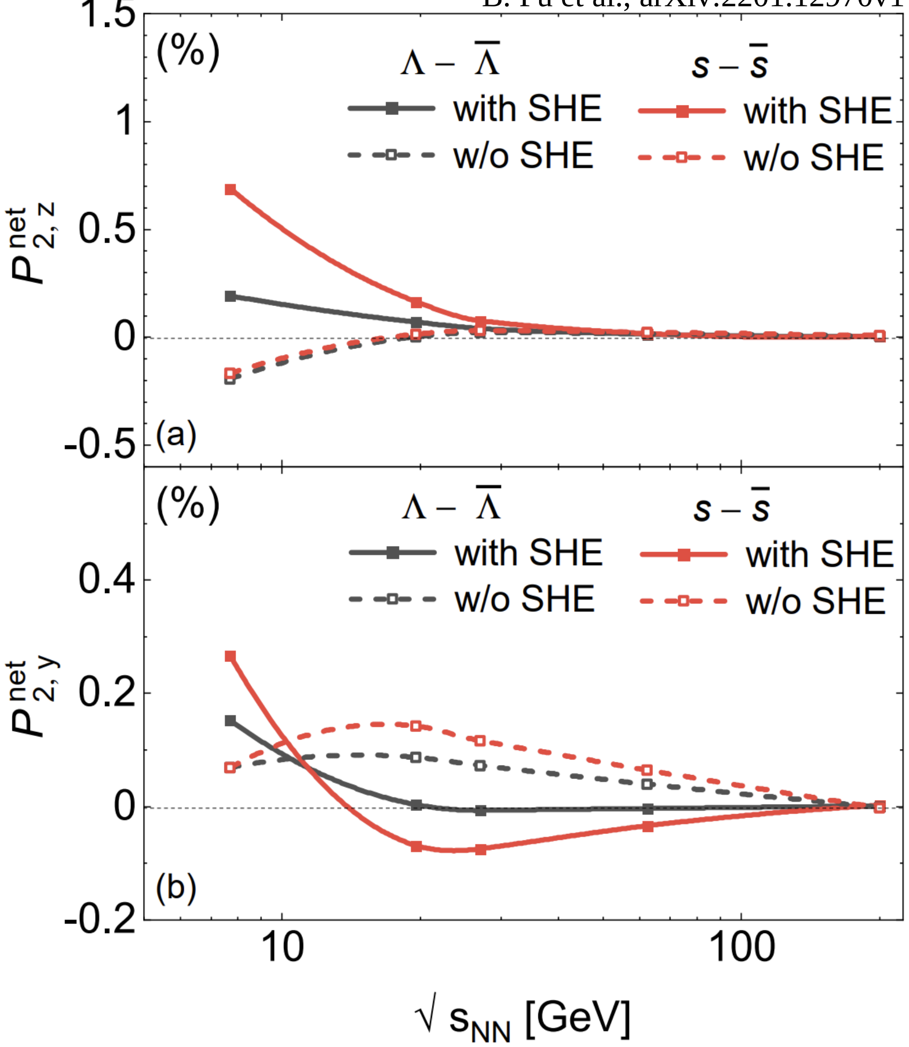
- Hall effect: $P \propto \boldsymbol{p} \times \boldsymbol{E}$
- Spin polarization by the SHE depends on momentum:

$$P \propto \boldsymbol{p} \times (q_B \nabla \mu_B)$$ → driven by $\nabla \mu_B$

- As the energy decreases, the system generates a stronger baryon chemical potential gradient
- Sign of $P_{2,z}^{net}$ is opposite with and without SHE at BES energies

$$P_{2,z} = \frac{\langle \cos\theta_p^* \sin[2(\phi_\Lambda - \Psi_2)] \rangle}{\alpha_H \langle (\cos\theta_p^*)^2 \rangle} \qquad P_{2,y} = \frac{8\langle \sin(\Psi_1 - \phi_p^*) \cos[2(\phi_\Lambda - \Psi_2)] \rangle}{\pi \alpha_H}$$

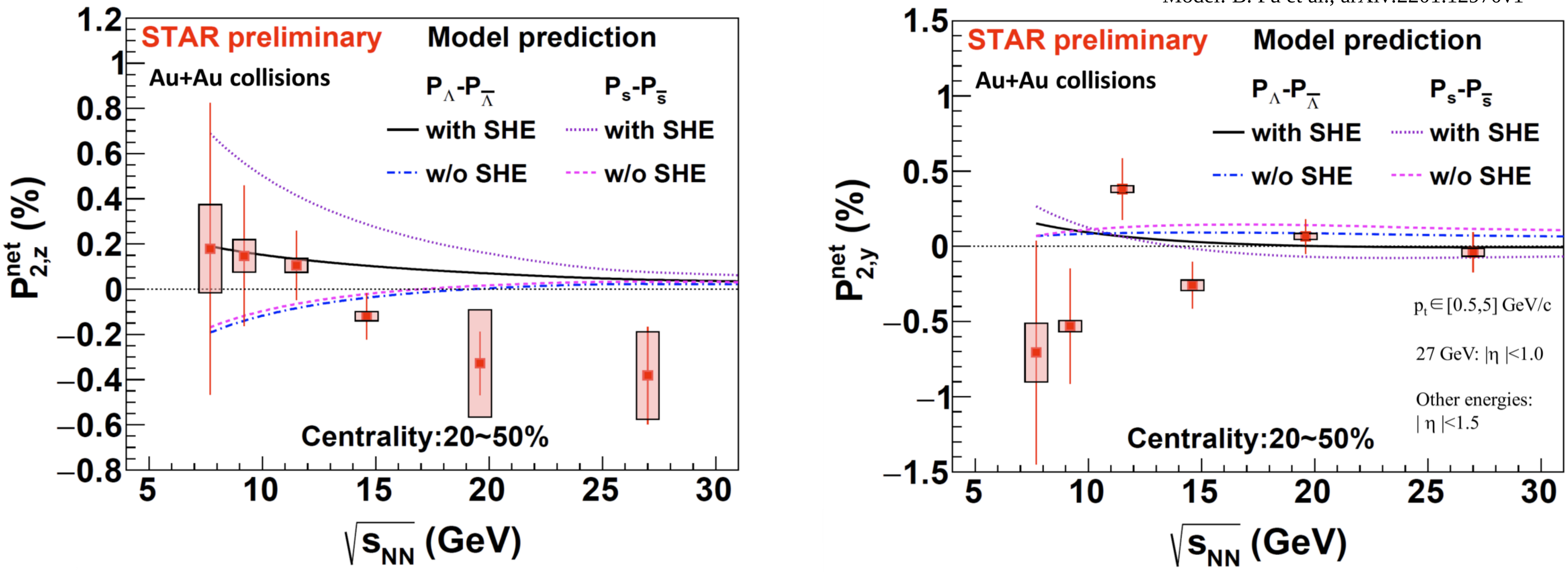
B. Fu et al., arXiv:2201.12970v1



Shuai Y. F. Liu, Yi Yin, Phys.Rev.D 104 , 054043 (2021)
B. Fu et al., arXiv:2201.12970v1

Result of Baryonic Spin Hall Effect

Model: B. Fu et al., arXiv:2201.12970v1



- Obtained the net polarization $P_{2,y}^{net}$ and $P_{2,z}^{net}$
- No significant energy dependence are observed within uncertainties
- Hints of sign change with decreasing energy

Summary

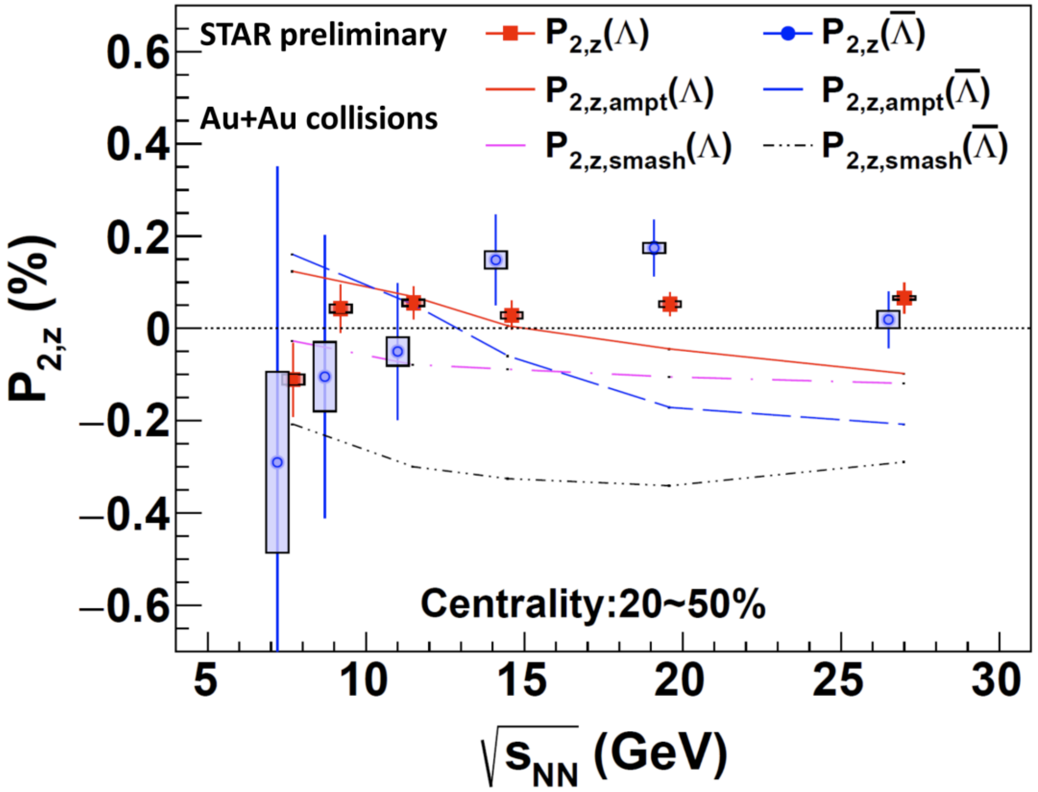
- ✓ The global polarization of Λ and $\bar{\Lambda}$ in Au+Au collisions at 7.7, 9.2, 11.5, 14.6, 17.3 GeV measured by STAR BES-II
  - Clear energy dependence
  - No splitting between Λ and $\bar{\Lambda}$
- ✓ The polarization along the beam direction of Λ and $\bar{\Lambda}$ in Au+Au collisions at 7.7, 9.2, 11.5, 14.6, 19.6, 27 GeV measured by STAR BES-II
  - Hints of sign change of $P_{2,z}$ at 7.7 GeV, baryon diffusion with Λ−scenario predicts sign change opposite to data
  - $P_{2,y}$ of Λ increase with decrease in energy
  - First study of baryonic Spin Hall Effect

Thanks for your attention!

Backup

Result of Polarization along the Beam Direction

Model: X. Wu et al., PRC 105 (2022) 064909



- $0.098 \pm 0.014(stat.)^{+0.019}_{+0.018}(syst.)$ in Au+Au 200 GeV — STAR, PRL 123, 132301 (2019)
- $0.082 \pm 0.011(stat.) \pm 0.014(syst.)$ in Pb+Pb 5.02 TeV — ALICE, PRL128, 172005 (2022)