

Probing novel baryonic spin Hall effect via measurement of local spin polarization of Λ hyperons in STAR Beam Energy Scan

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Outline



➤ Motivation

- Global and local spin polarization
- Baryonic spin Hall effect

➤ Measurements of Λ 's polarization

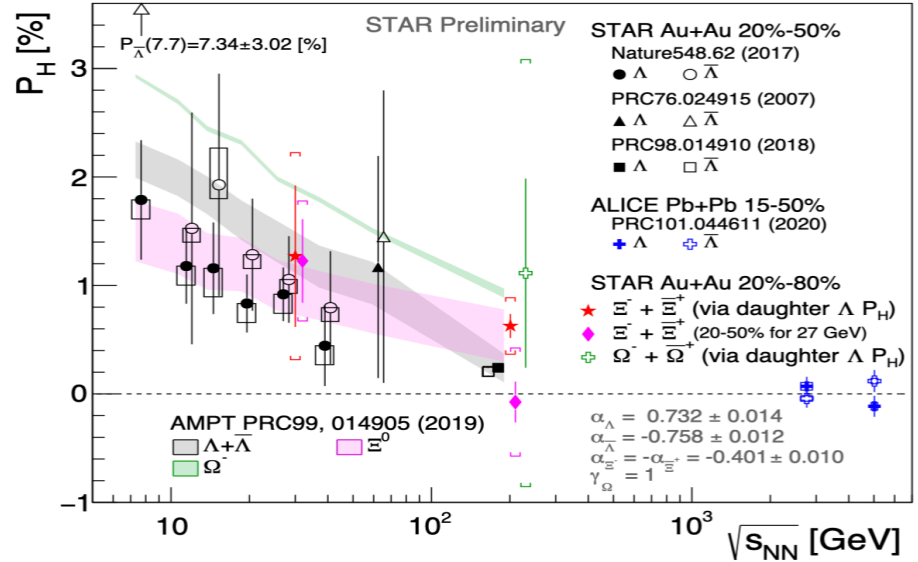
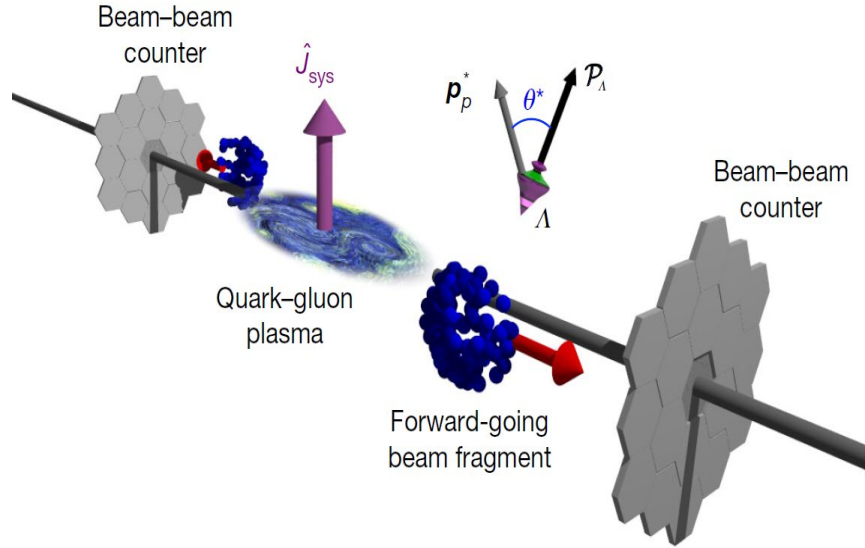
- The STAR detector
- Particle reconstruction
- Event plane calibration
- Signal extraction
- Λ 's net local polarization P_z

➤ Summary and outlook



Motivation

Global spin polarization



STAR Collaboration, Nature 548 (62) (2017)

- ✓ 2005: prediction of the global polarization
- ✓ 2017: observation of the Λ global polarization

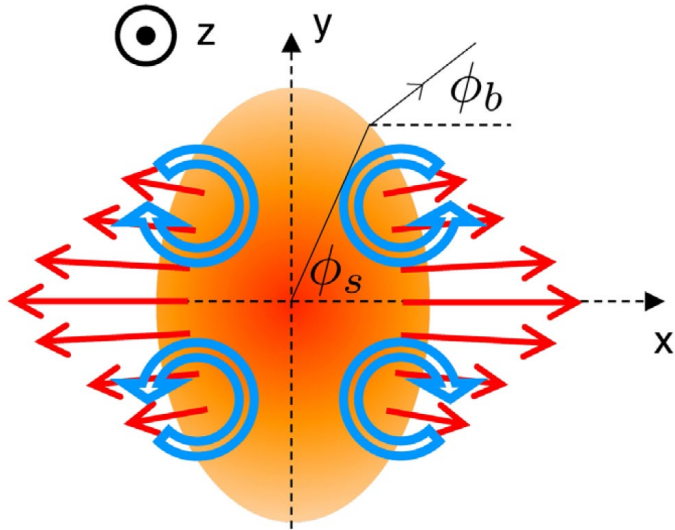
Z. -T. Liang and X. -N. Wang Phys. Rev. Lett. 94, 102301 (2005); erratum 96, 039901

$$P_y = \frac{8}{\pi \alpha_\Lambda} \frac{1}{R_{EP}^{(1)}} \langle \sin(\psi_1 - \phi_p^*) \rangle$$

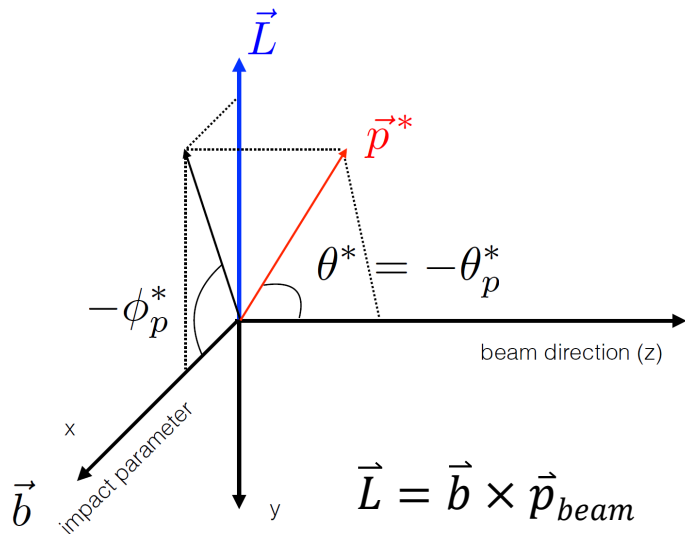
α_Λ : Λ 's decay parameter

ϕ_p^* : the azimuthal angle of the daughter proton in Λ rest frame

Local spin polarization P_z



- Elliptic flow (stronger flow in-plane than out-of-plane) is expected to generate a longitudinal component of polarization (P_z)

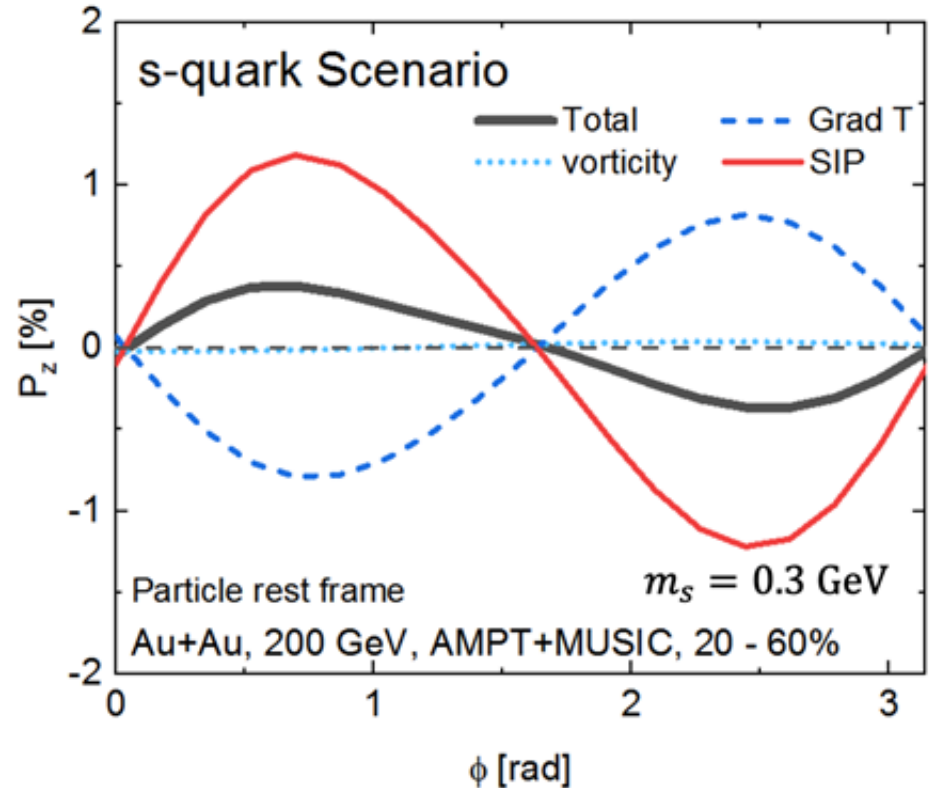
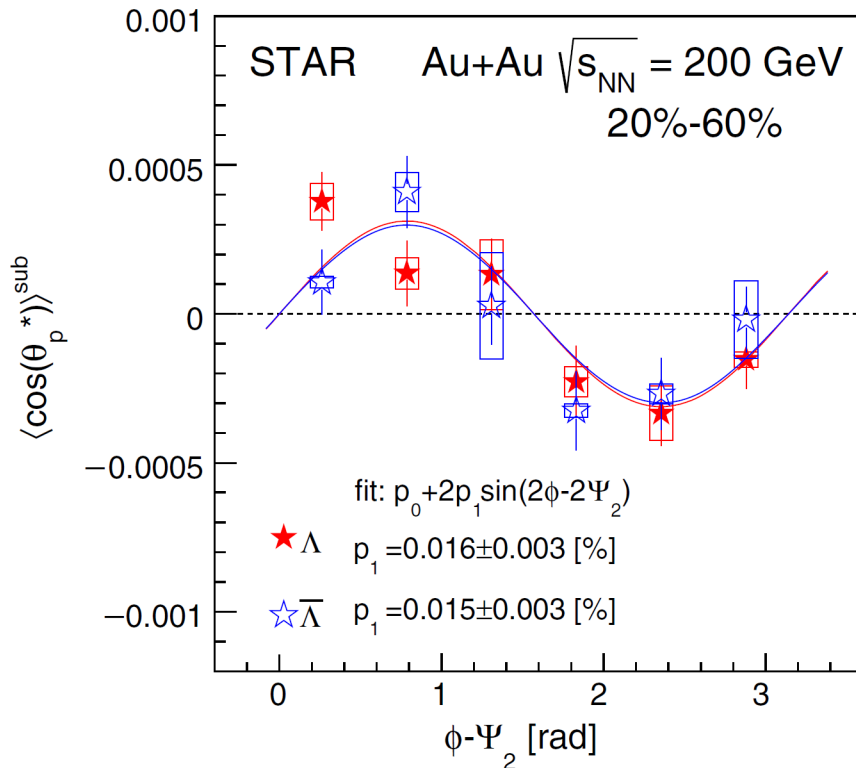


$$P_z = \frac{\langle \cos \theta_p^* \rangle}{\alpha_H \langle (\cos \theta_p^*)^2 \rangle}$$

θ_p^* : polar angle

STAR, PRL 123,132301 (2019)

Local spin polarization P_z



Total: Vorticity + Grad T + **SIP**

STAR, PRL 123,132301 (2019)

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

F. Becattini et al. PRL 127, 272302 (2021)

- **Observation of (P_z) in Au+Au @ 200 GeV**
- **Many models fail to capture trend with proper sign**
- **New developments, Shear Induced Polarization (SIP) can capture the trend**

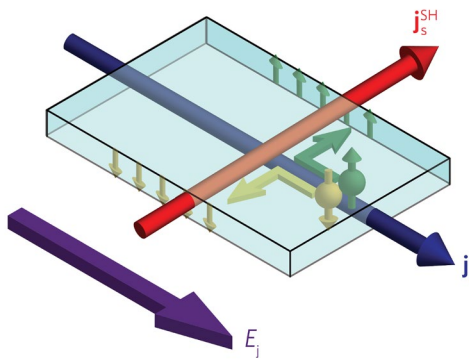
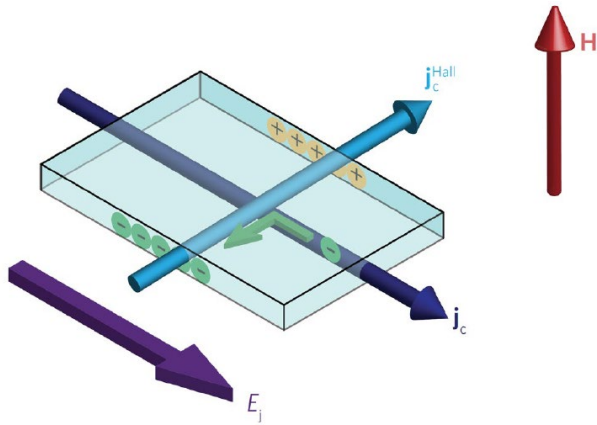
What is spin Hall effect ?



Edwin Herbert Hall (1855-1938)

Mikhail I. Dyakonov

Vladimir I. Perel



HE: charge imbalance (1879)

SHE: spin imbalance (2004)

S. Meyer et al., Nature Materials, 2017

Spin Hall Effect

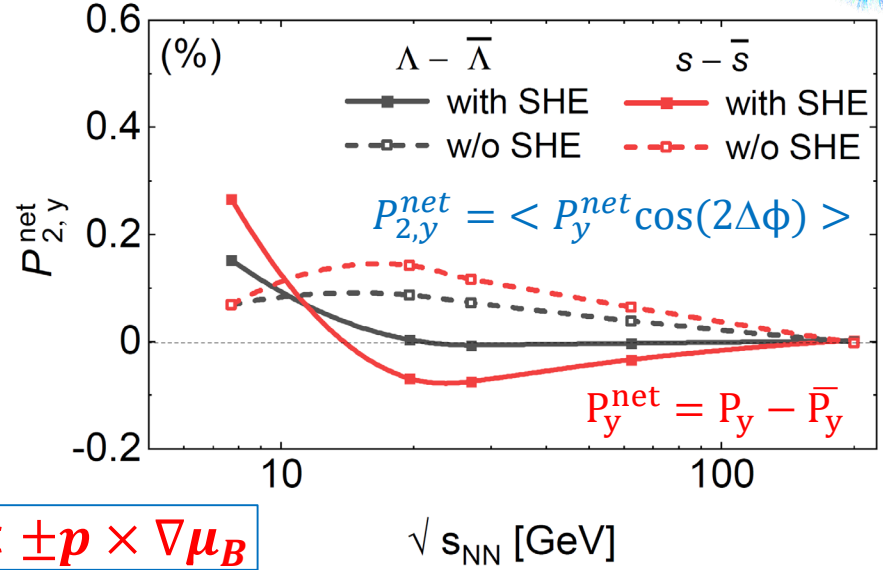
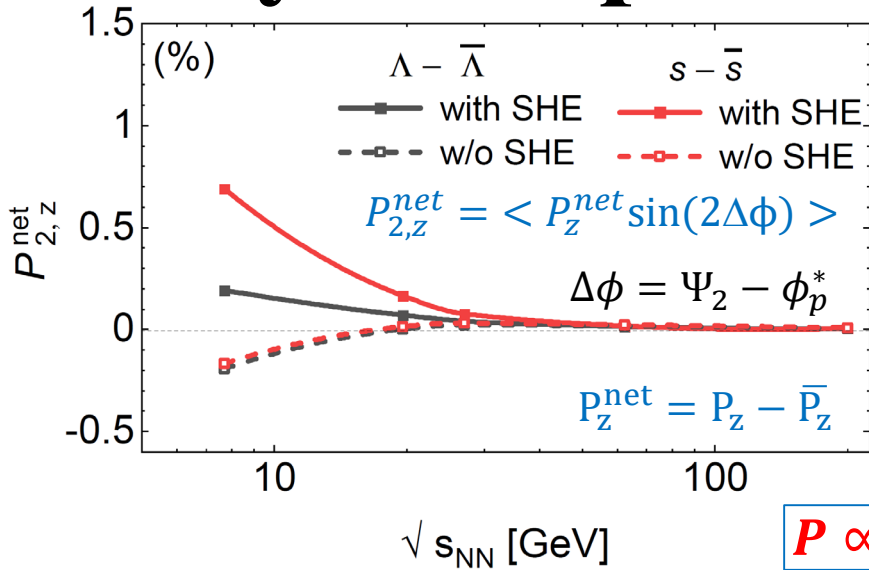
1971: predicted by Mikhail I. Dyakonov and Vladimir I. Perel

30 years later, it was observed in semiconductors (Y. K. Kato et al., Science 306,1910(2004))

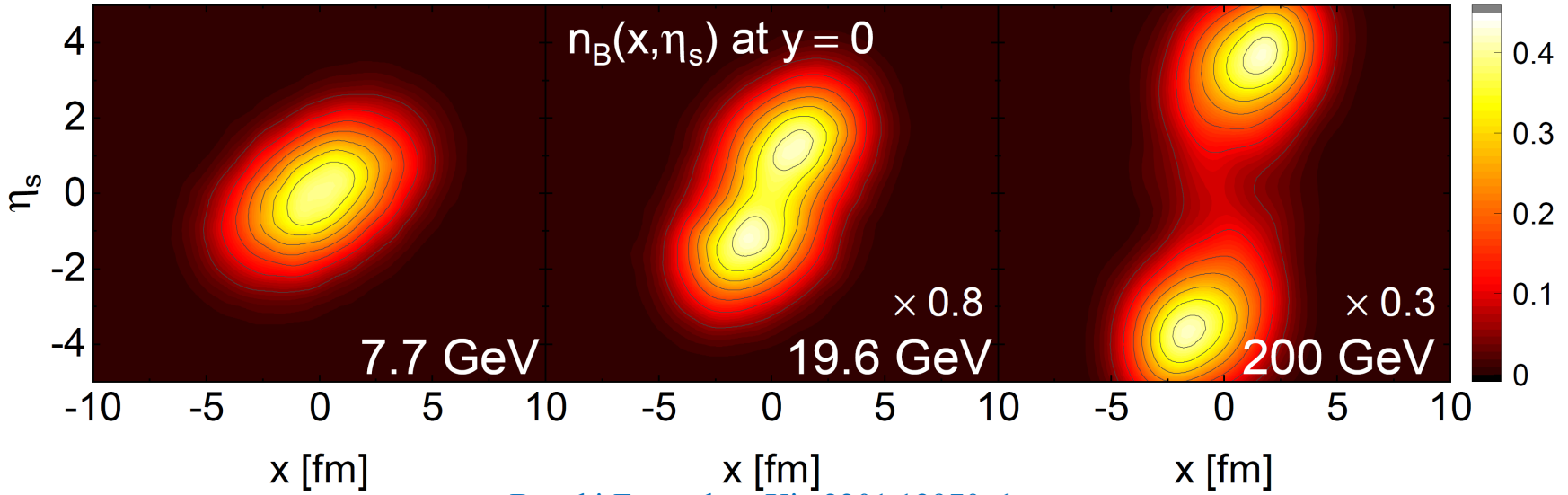
“Spin-orbit” interaction

$$P \propto \pm p \times E$$

Baryonic spin Hall effect



$$P \propto \pm p \times \nabla \mu_B$$



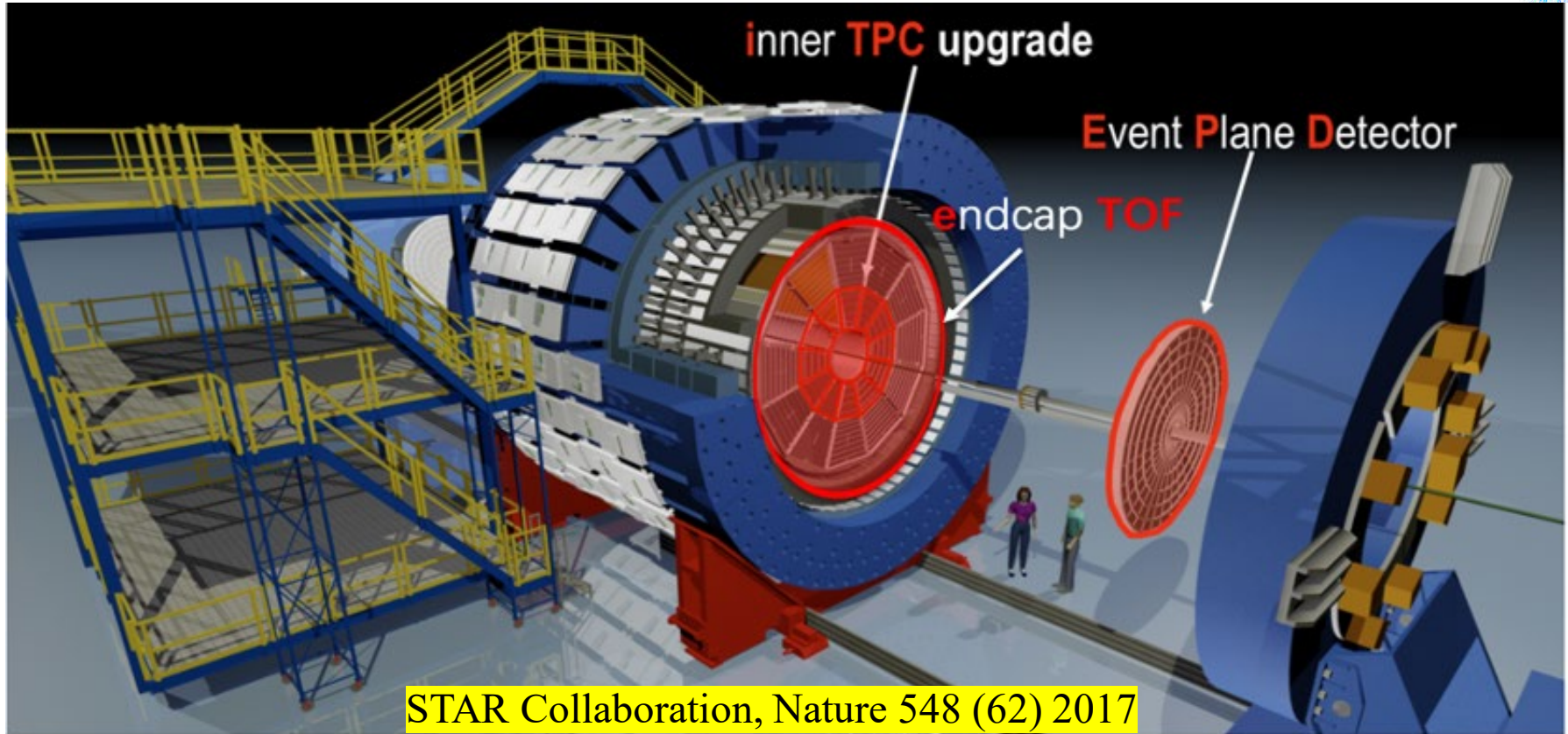
Baochi Fu et al., arXiv:2201.12970v1

New proposal of probing baryonic spin Hall effect in heavy-ion collisions via local Λ polarization !



Measurements of Λ 's polarization

The STAR detector



TPC: **T**ime **P**rojection **C**hamber (PID & Event plane reconstruction)

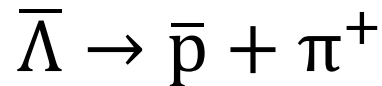
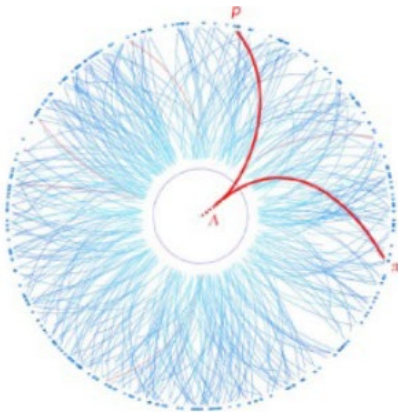
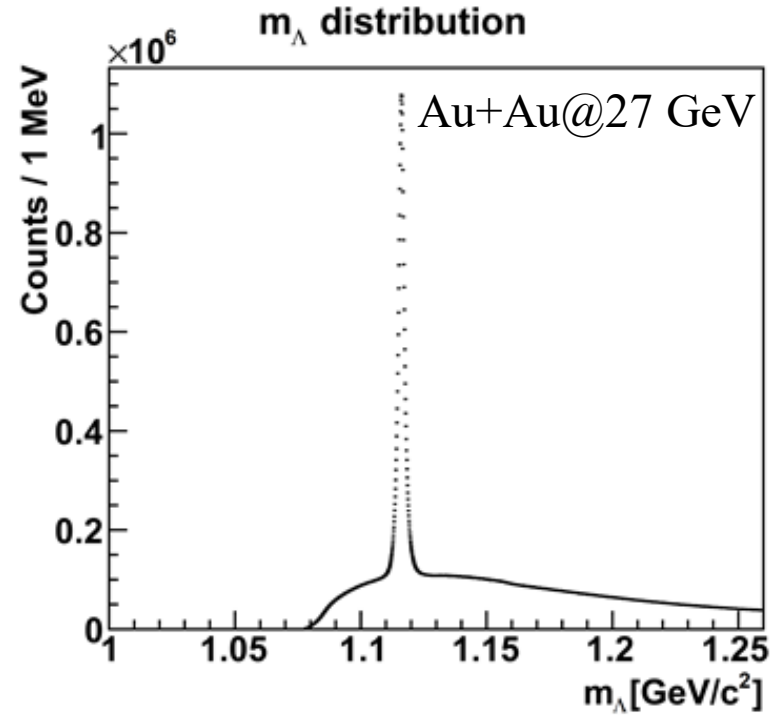
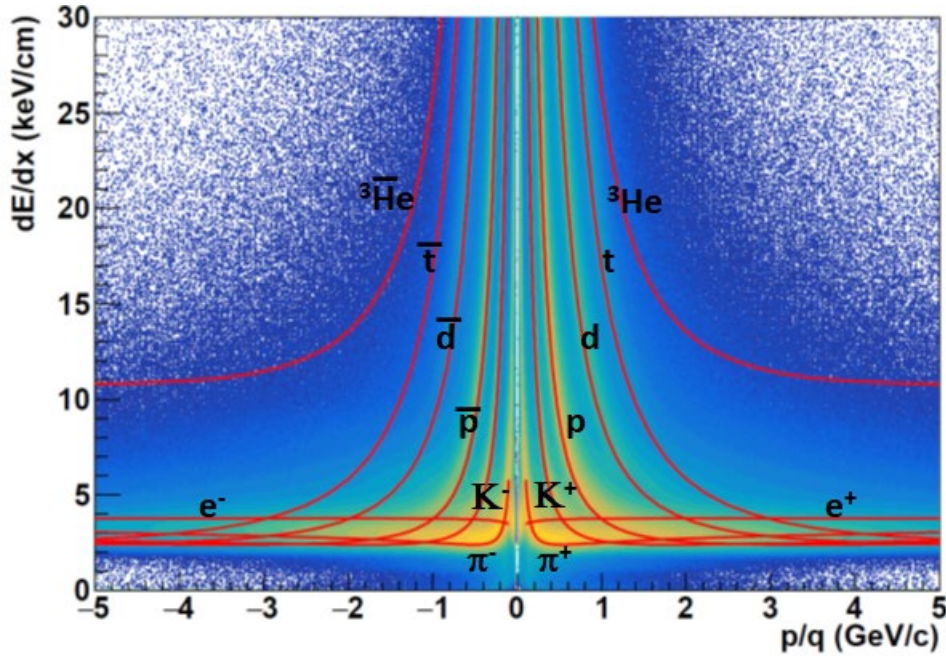
$|\eta| < 1.5$ @ 19.6 GeV

$|\eta| < 1.0$ @ 27 GeV

TOF: **T**ime **O**f **F**light \rightarrow PID

EPD: **E**vent **P**lane **D**etector (Event plane reconstruction), $|\eta| \in [2.1, 5.1]$

Particle reconstruction



Single track Cuts

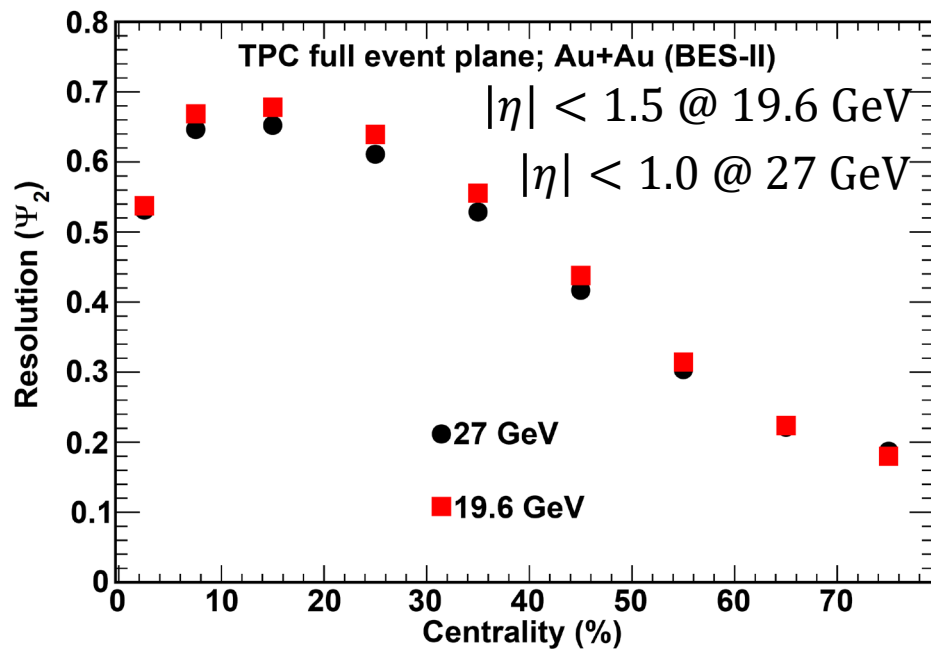
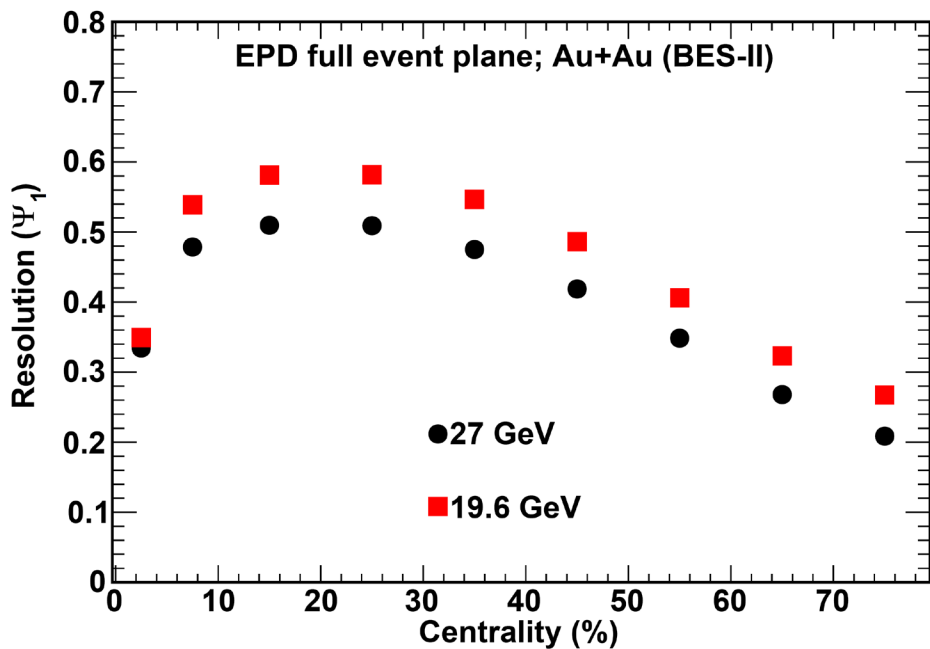
- $0.15 \text{ GeV}/c < p_t < 5 \text{ GeV}/c$
- $|\eta| < 1.0$

Pion/Proton PID

- combination of ToF and TPC

STAR Collaboration, Nature 548 (62) 2017

Event plane resolution



The first and second order event plane resolutions follow expected centrality dependence trend

$$\Psi_n = \frac{1}{n} \tan^{-1} \left(\frac{Q_{n,y}}{Q_{n,x}} \right) \quad Q_{n,x} = \sum \omega_i \cos(n\phi_i) \quad Q_{n,y} = \sum \omega_i \sin(n\phi_i)$$

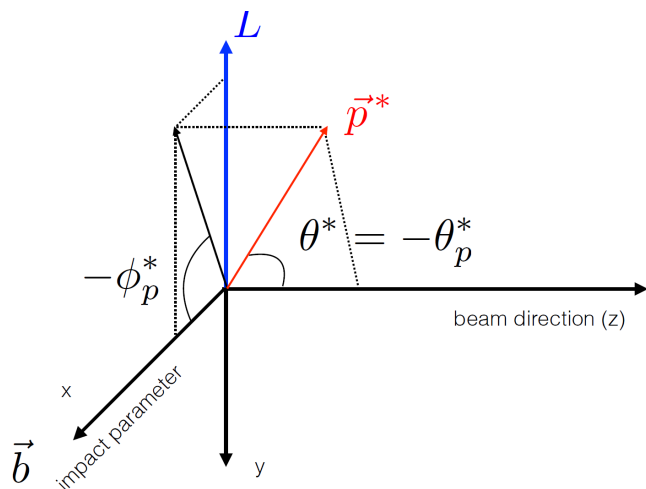
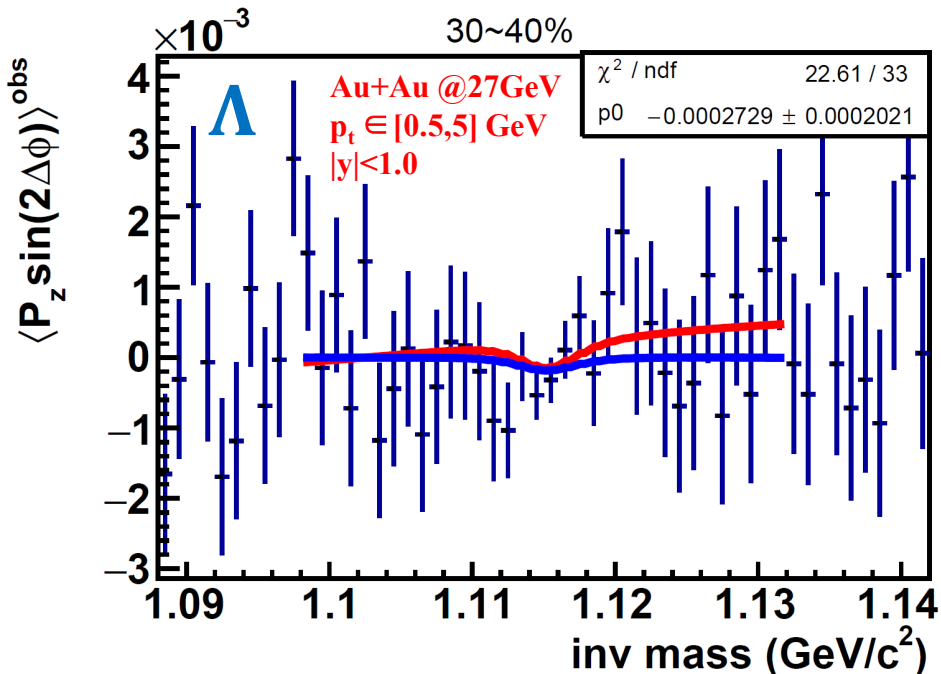
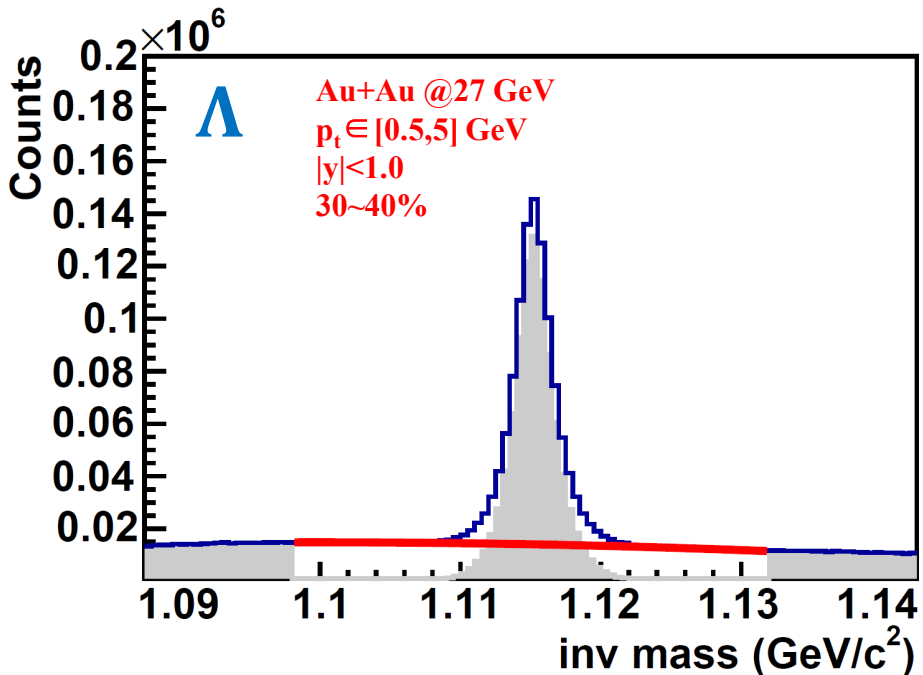
ω_i (TPC): p_t weight

ω_i (EPD): nMip weight

ϕ_i and ω_i are the lab azimuthal angle and weight for particle i

Sergei A. Voloshin et al., arXiv:08092.2949

Signal extraction



$$\langle P_z \sin(2(\phi_\Lambda - \psi_2)) \rangle^{obs}$$

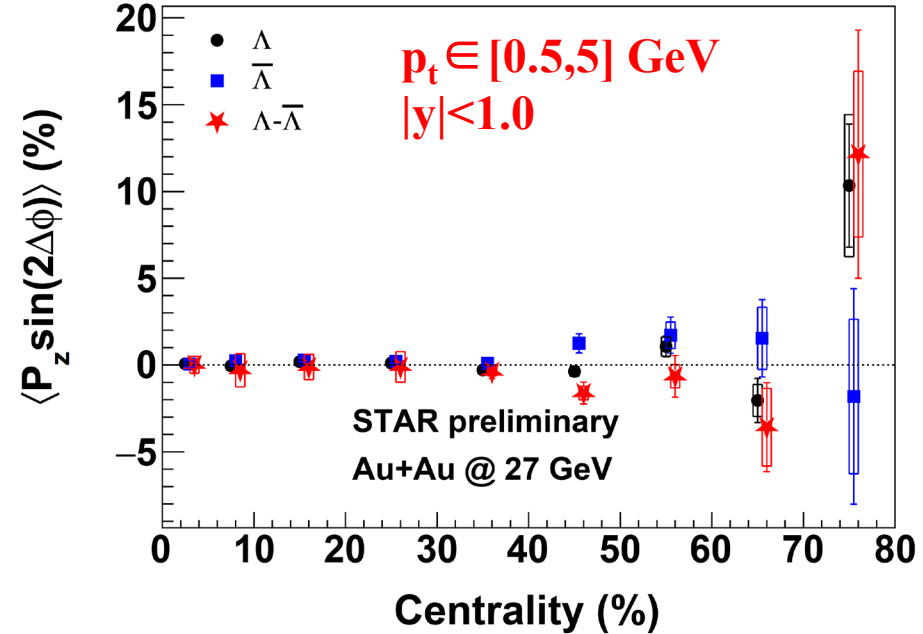
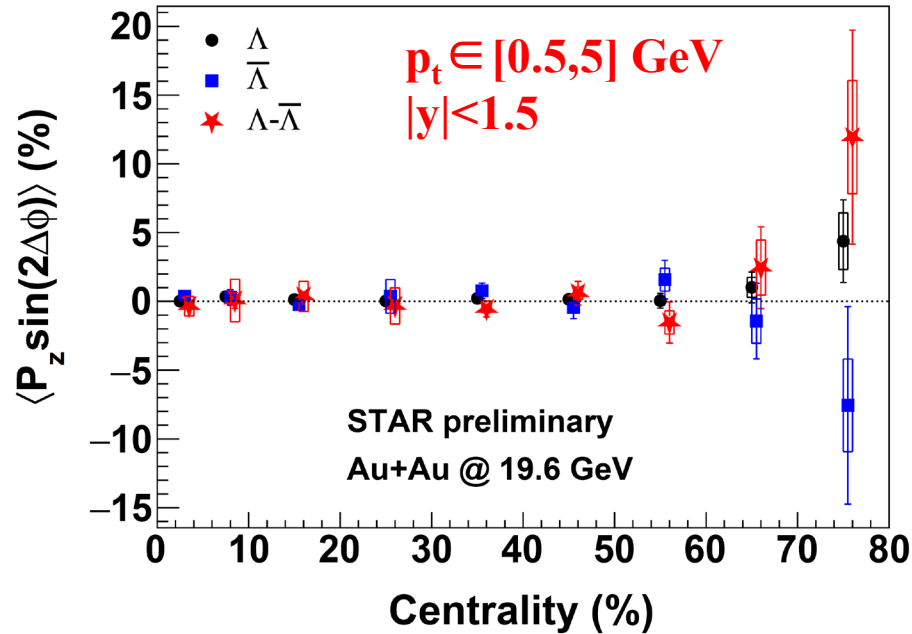
$$= (1 - f^{Bg}(M_{inv})) \langle P_z \sin(2(\phi_\Lambda - \psi_2)) \rangle^{Sg}$$

$$+ f^{Bg}(M_{inv}) \langle P_z \sin(2(\phi_\Lambda - \psi_2)) \rangle^{Bg}$$

ϕ_p^* : azimuthal angle of the daughter (anti)proton in Λ 's rest frame

Blue: w/o bkg; Red: with bkg ($\alpha + \beta M_{inv.}$)

Λ 's local polarization P_z



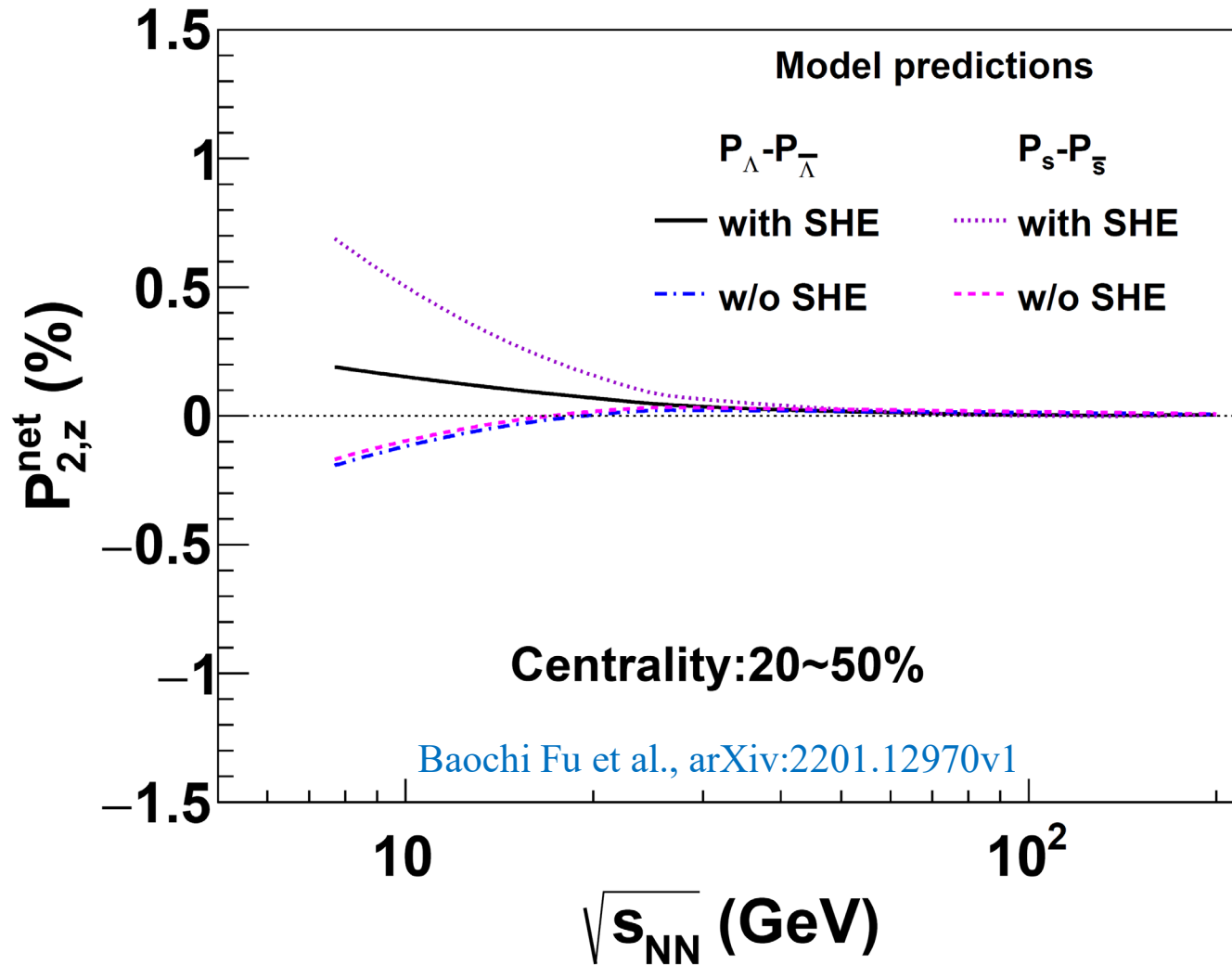
$$\Delta\phi = \phi_{\Lambda} - \psi_2$$

$$\alpha(\Lambda) = -\alpha(\bar{\Lambda}) = 0.732 \pm 0.014$$

P. A. Zyla et al. (Particle Data Group), PTEP 2020,083C01 (2020)

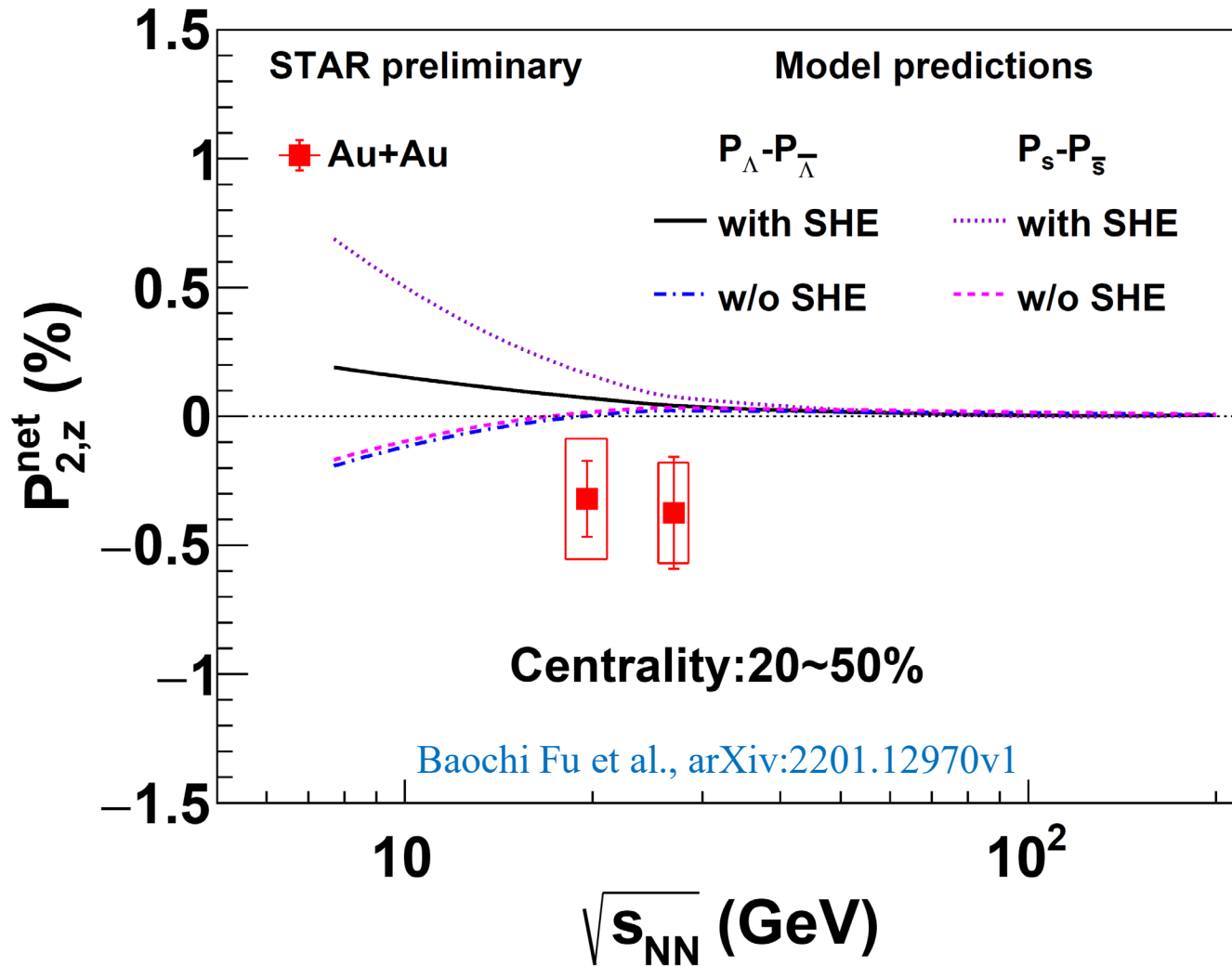
No significant centrality dependence of P_z is observed within present uncertainty

Comparison of Λ 's polarization



With (without) SHE, local polarization of P_z^{net} is monotonic energy dependence and the predicted sign is opposite for with and without SHE case at lower energies

Comparison of Λ 's polarization



- Negative P_z^{net} has been observed, but no significant energy dependence
- Study at lower beam energies is underway



Summary

- ✓ First study of baryonic spin Hall effect by measuring net local polarization in Au+Au @ 19.6 and 27 GeV (BES-II)
- ✓ Negative net local polarization $P_{2,z}^{net}$ has been obtained
- ✓ No significant energy dependence of $P_{2,z}^{net}$ is observed within present uncertainty

Outlook

- ✓ Analysis on other BES-II energies (7.7, 11.5 and 14.6 GeV as well as FXT data) is ongoing

Thank you !