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相对论重离子碰撞中自旋霍尔效应信号的寻找

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Outline

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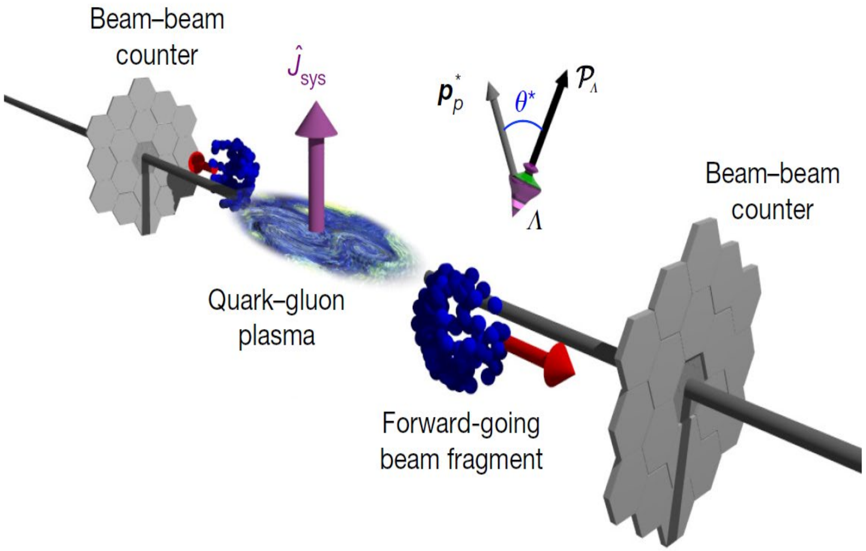
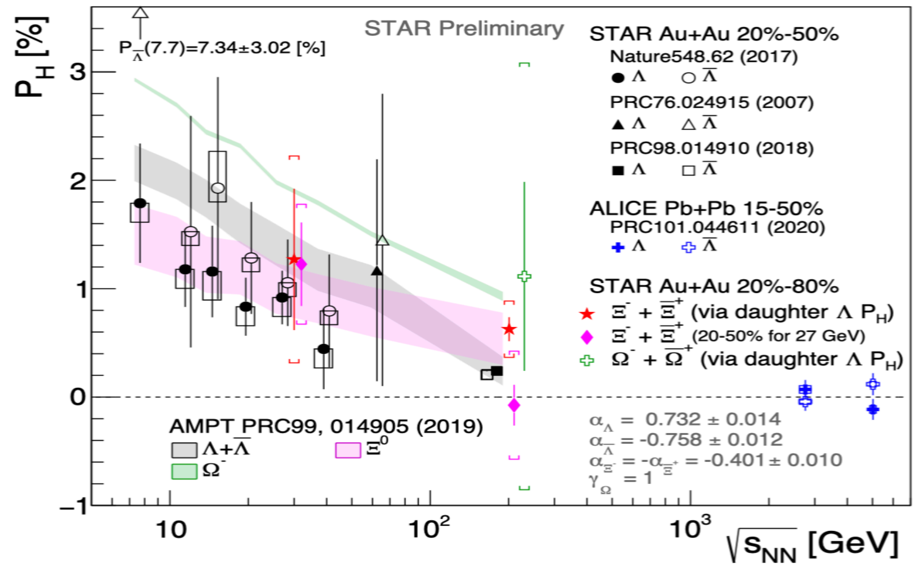
  - Baryonic spin Hall effect
- Measurements of Λ's polarization
  - The STAR detector
  - Particle reconstruction
  - Event plane calibration
  - Signal extraction
  - Λ's net local polarization Pz
- Summary and outlook

I. Motivation

Global spin polarization





STAR Collaboration, Nature 548 (62) (2017)

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

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

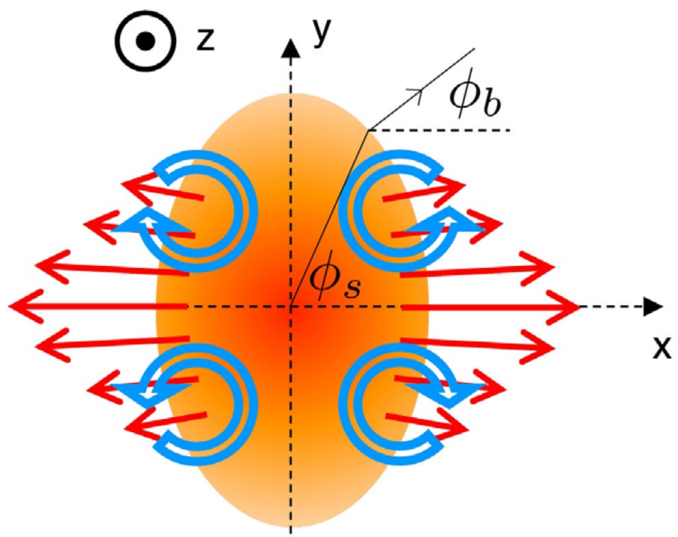
Z. –T. Liang and X. –N. Wang Phys. Rev. Lett. 94, 102301 (2005); erratum 96, 039901

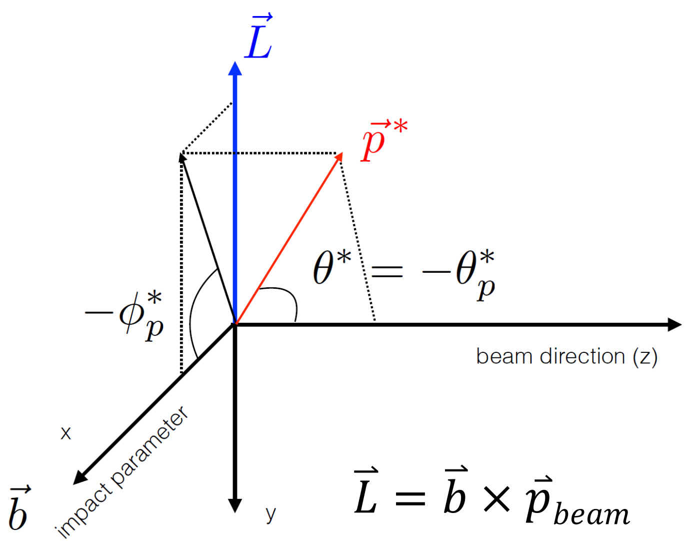
α_Λ: Λ's decay parameter

ψ_1: first-order of reaction plane angle

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

Local spin polarization P_z





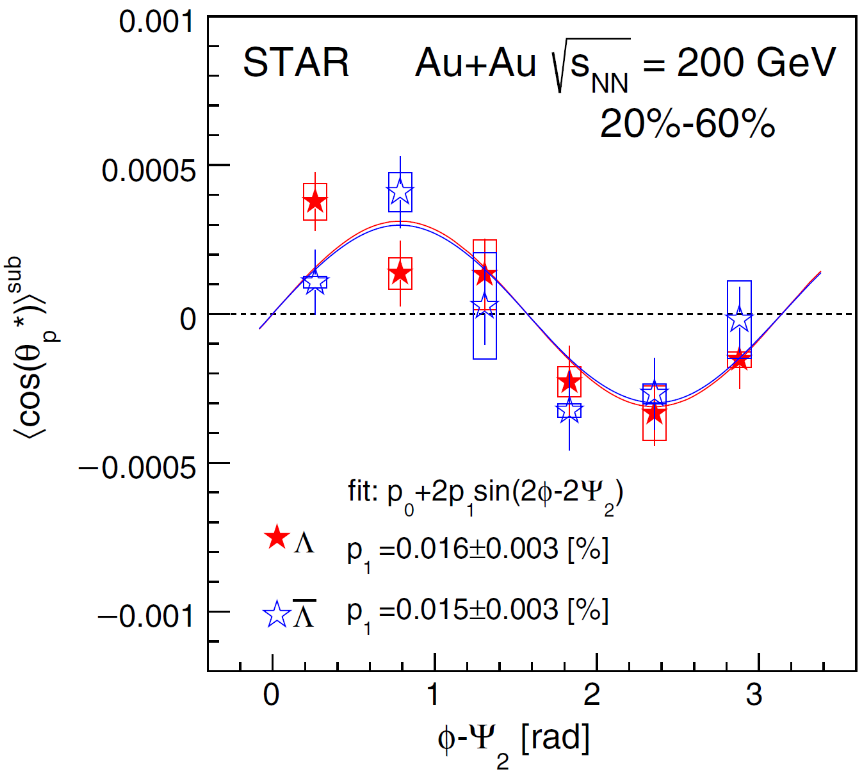
- Elliptic flow (stronger flow in-plane than out-of-plane) is expected to generate a longitudinal component of polarization (P_z)

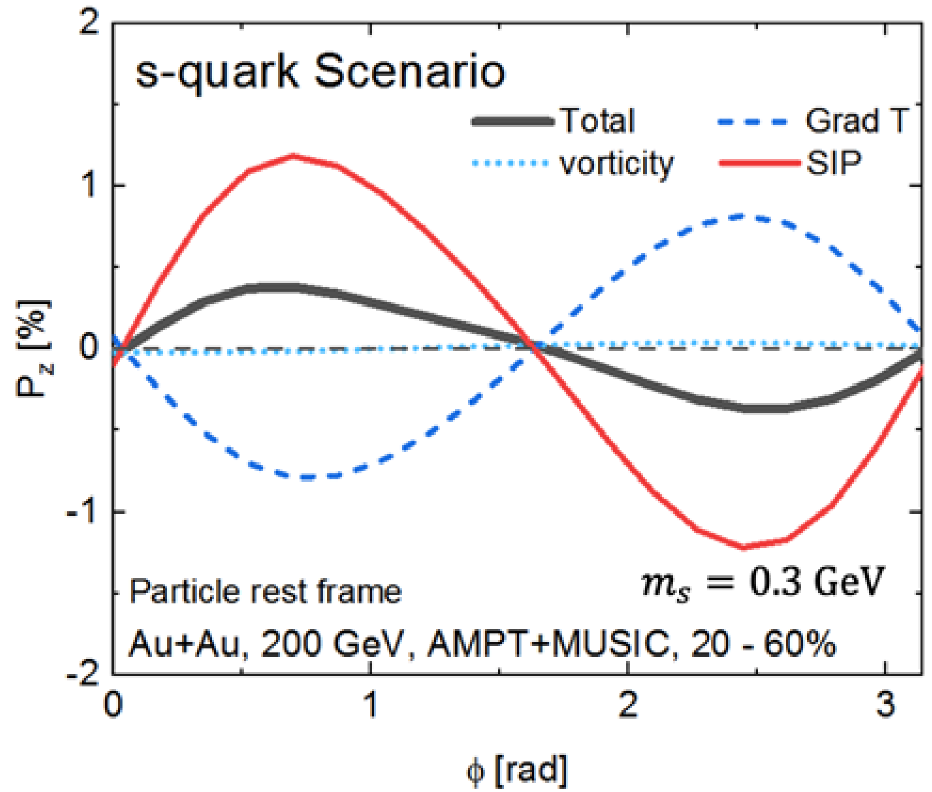
$$P_z = \frac{\langle \cos\theta_p^\star \rangle}{\alpha_H \left\langle \left(\cos\theta_p^\star\right)^2 \right\rangle}$$

$\theta_p^\star$: 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)

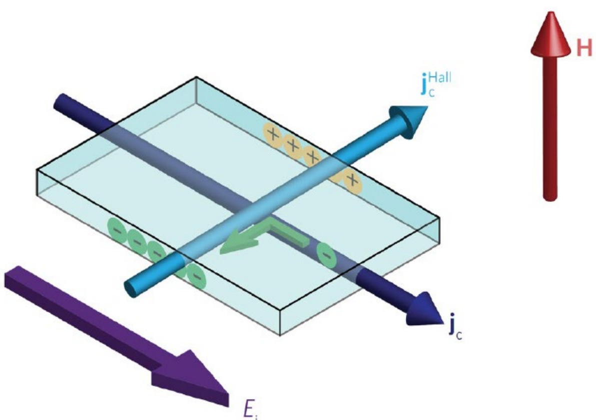
- **Observation of (P_z) in Au+Au @ 200 GeV**
- **Many models fail to capture trend with proper sign**
- **New developments, Shear Induced Polarization (SIP) can capture the trend**

What is spin Hall effect ?

Edwin Herbert Hall (1855-1938)

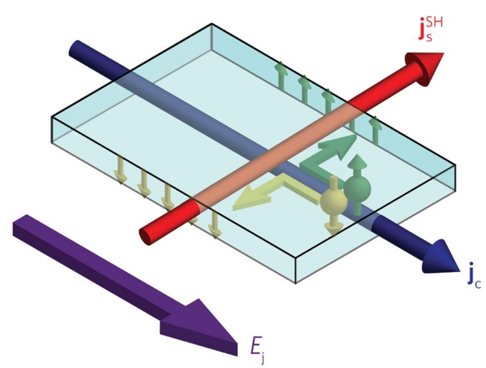
Mikhail I. Dyakonov

Vladimir I. Perel



HE: charge imbalance (1879)

S. Meyer et al., Nature Materials, 2017



SHE: spin imbalance (2004)

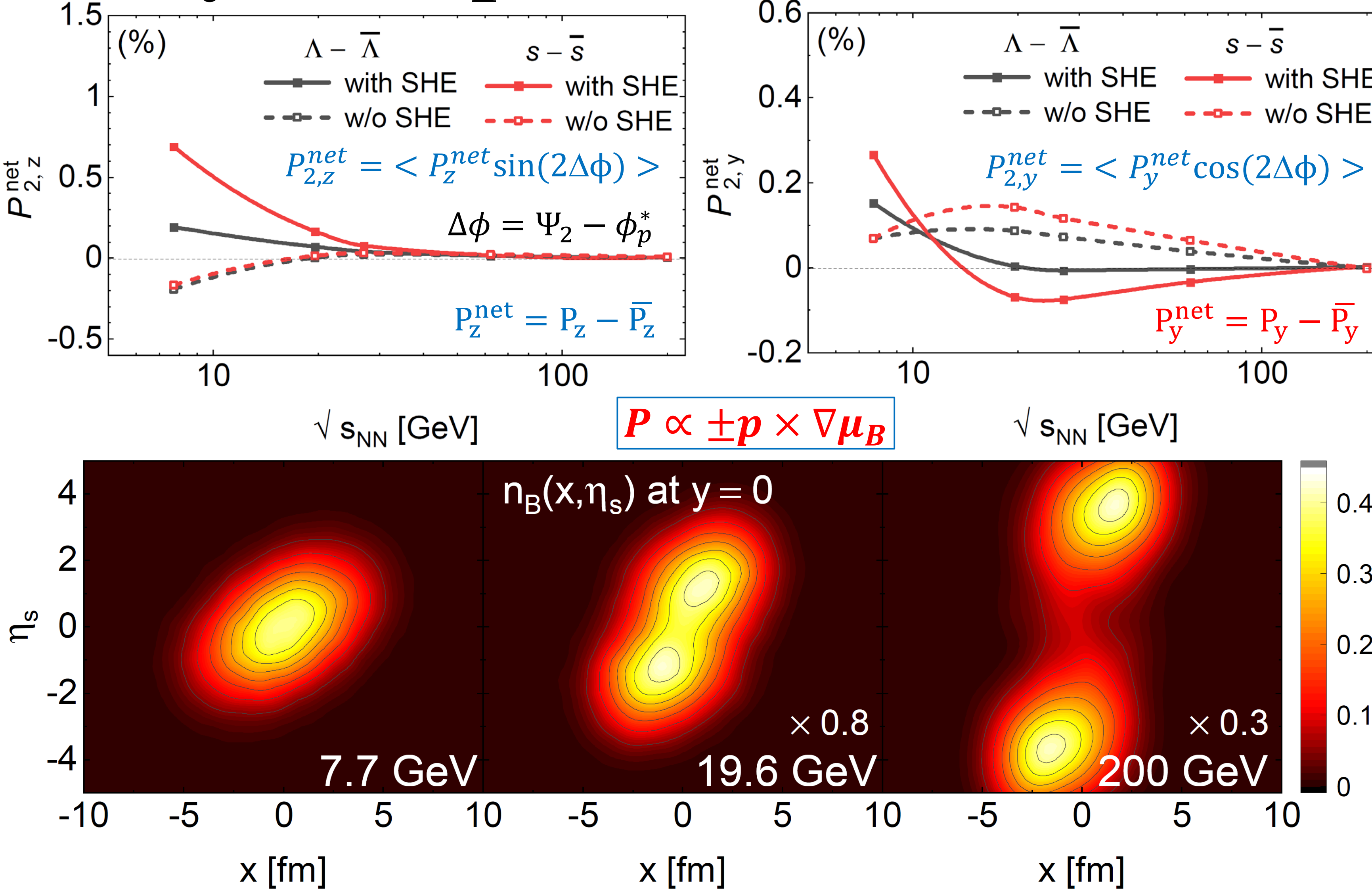
Spin Hall Effect
1971: predicted by Mikhail I. Dyakonov and Vladimir I. Perel

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

"Spin-orbit" interaction

$$\boxed{\boldsymbol{P} \propto \pm \boldsymbol{p} \times \boldsymbol{E}}$$

Baryonic spin Hall effect

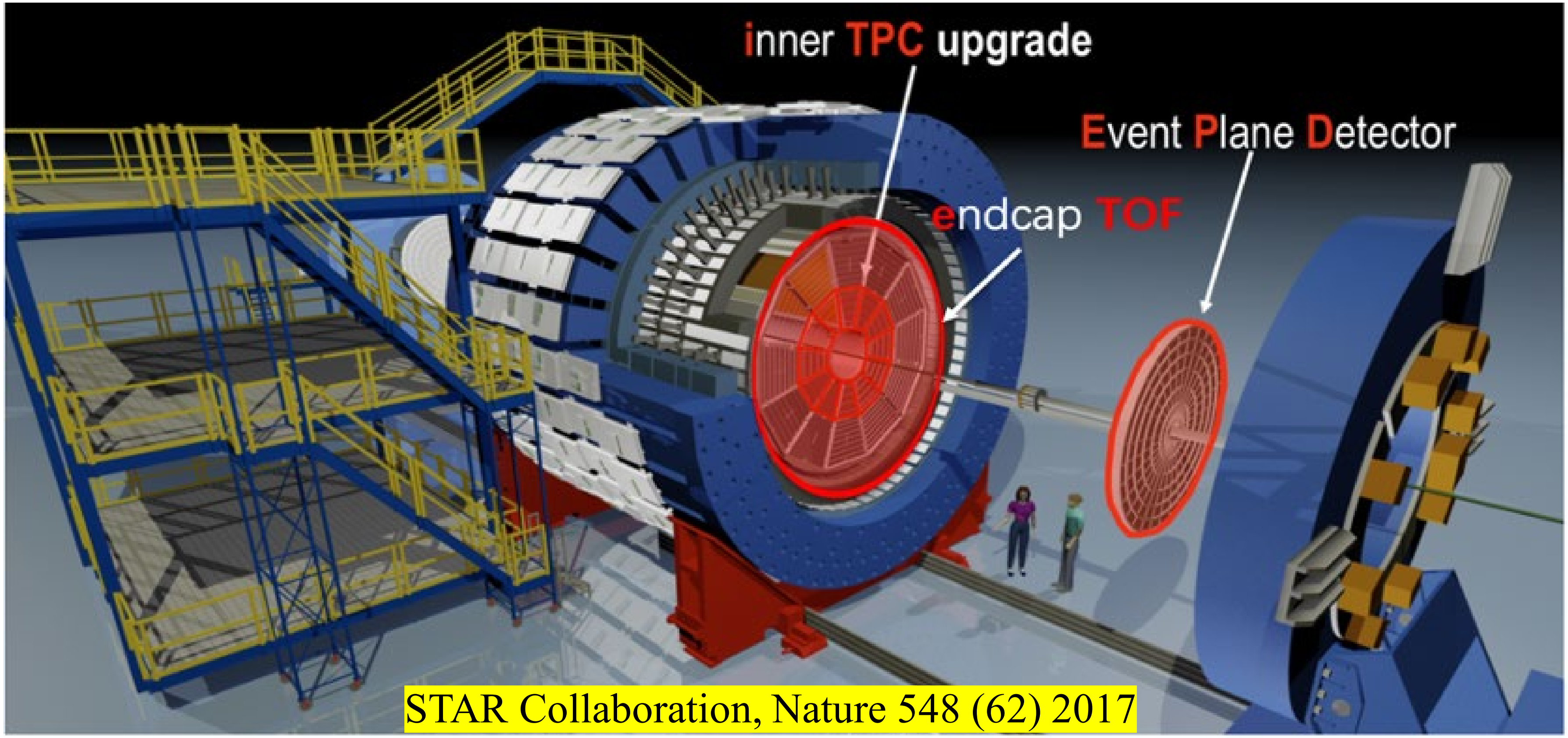


Baochi Fu et al., arXiv:2201.12970v1

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

II. Measurements of Λ's polarization

The STAR detector



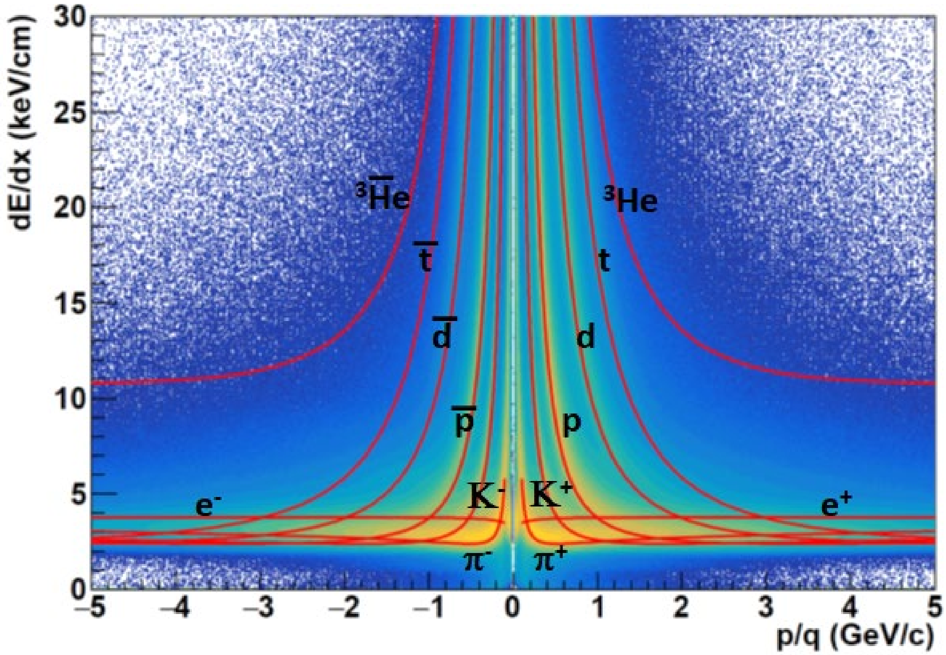
TPC: Time Projection Chamber (PID & Event plane reconstruction)

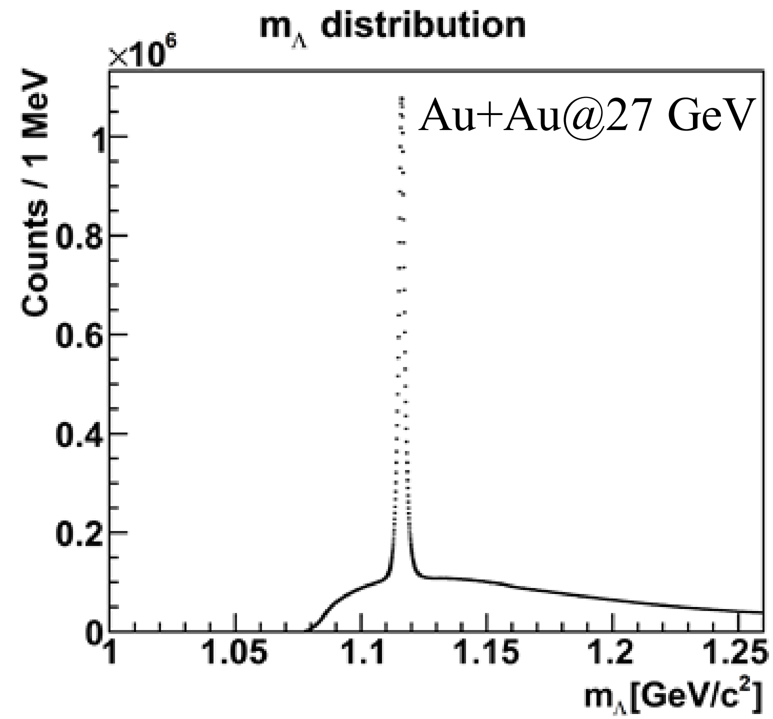
$|\eta| < 1.5$ @ 19.6 GeV $\qquad$ $|\eta| < 1.0$ @ 27 GeV

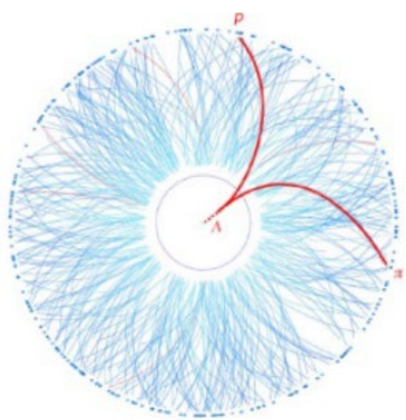
TOF: Time Of Flight →PID

EPD: Event Plane Detector (Event plane reconstruction), $|\eta| \in [2.1, 5.1]$

Particle reconstruction







$$\Lambda \rightarrow p + \pi^-$$

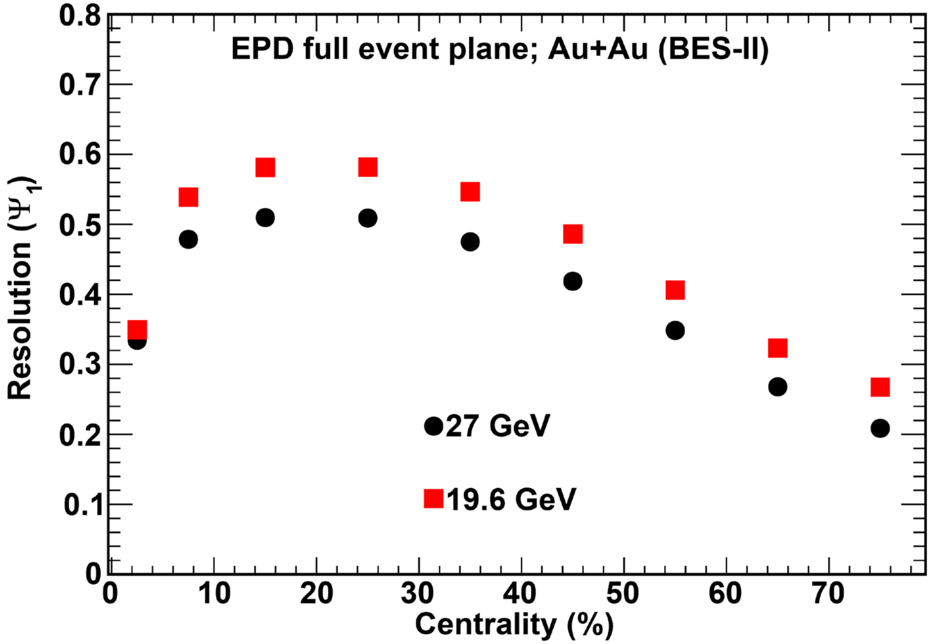
$$\bar{\Lambda} \rightarrow \bar{p} + \pi^+$$

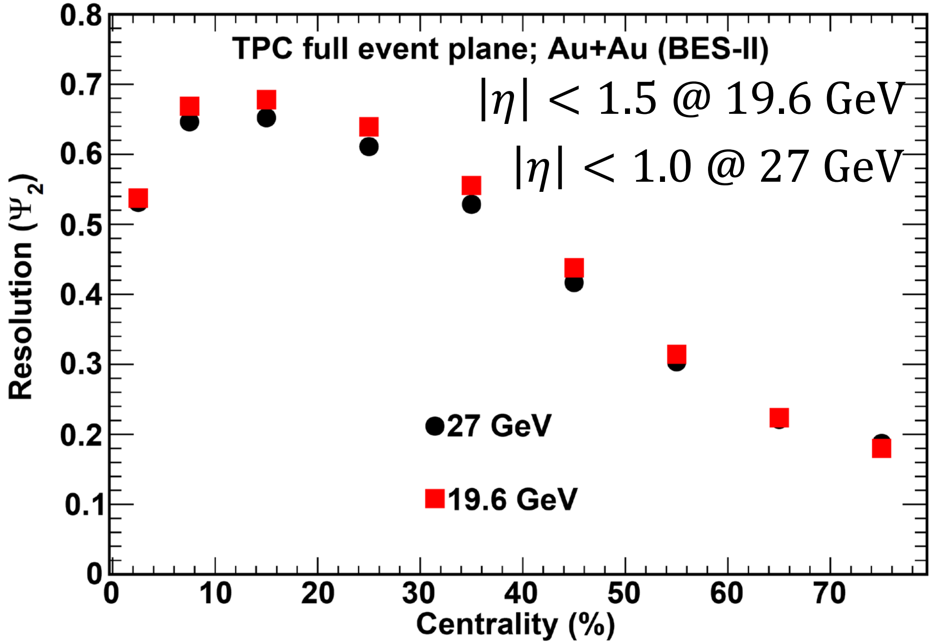
Single track Cuts
— 0.15 GeV/c < p_t < 5 GeV/c
— $|\eta| < 1.0$

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

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

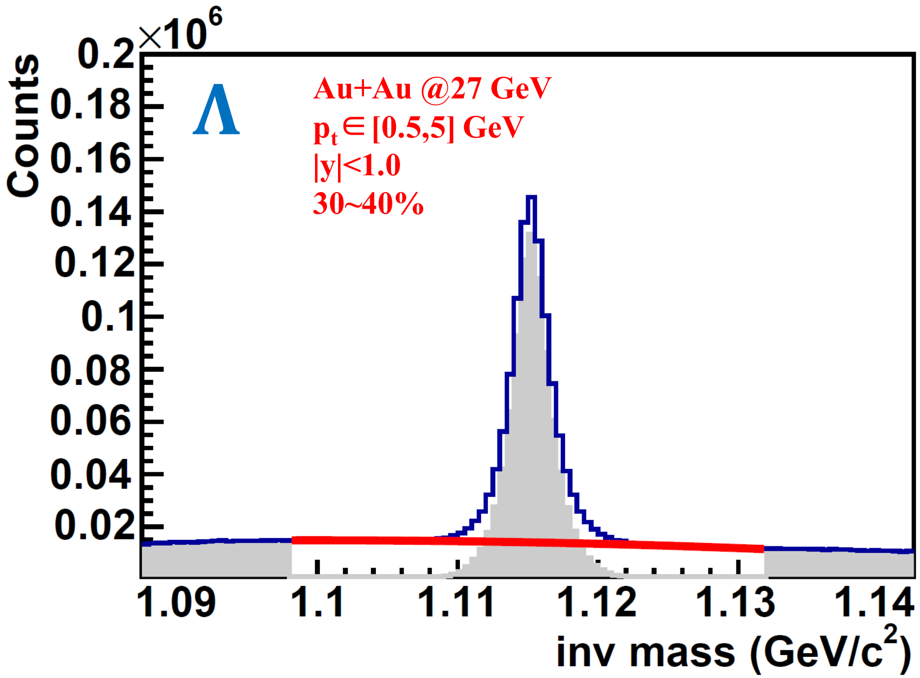
ω_i (TPC): p_t weight

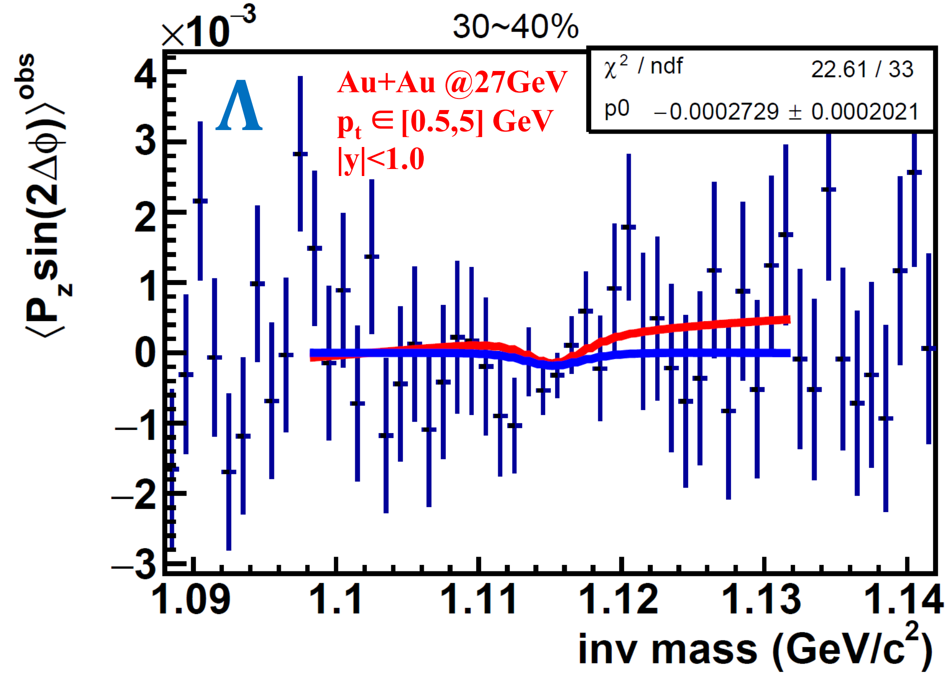
ω_i (EPD): nMip weight

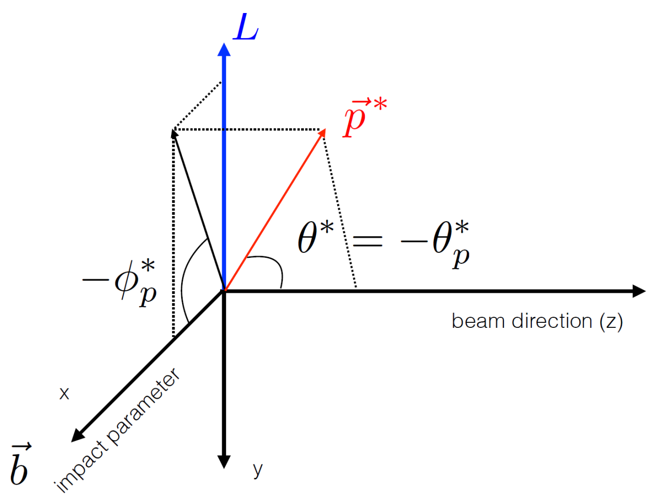
ϕ_i and ω_i are the lab azimuthal angle and weight for particle *i*

Sergei A. Voloshin et al.,arXiv:08092.2949

Signal extraction







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

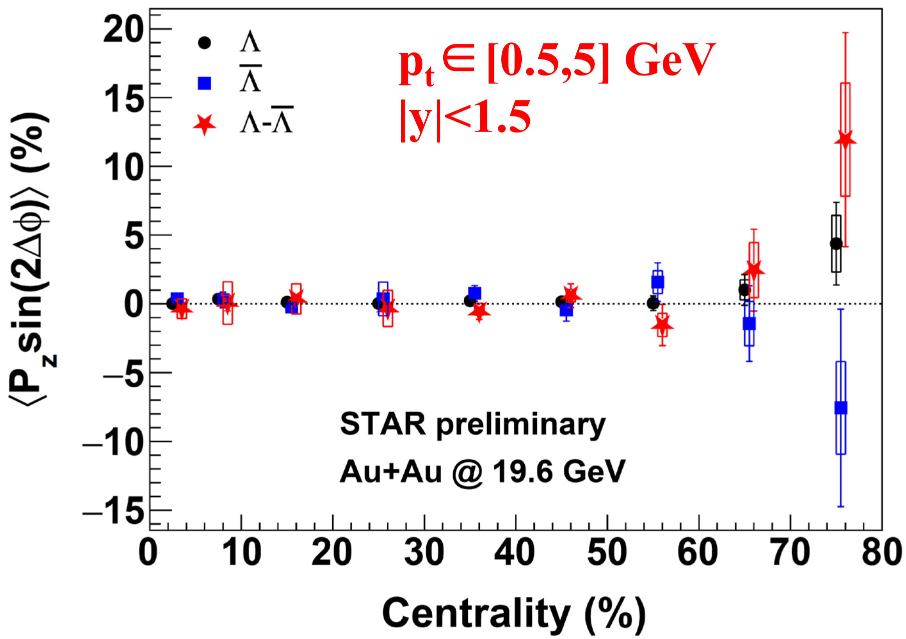
$$= \left(1 - f^{Bg}(M_{inv})\right)\langle P_z sin(2(\phi_\Lambda - \psi_2))\rangle^{Sg}$$

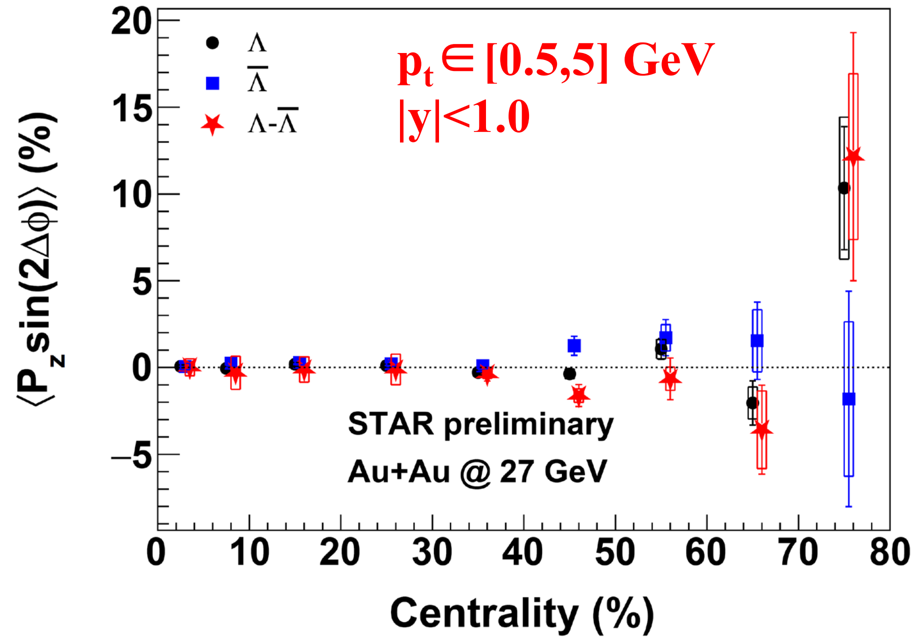
$$+ f^{Bg}(M_{inv})\langle P_z sin(2(\phi_\Lambda - \psi_2))\rangle^{Bg}$$

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





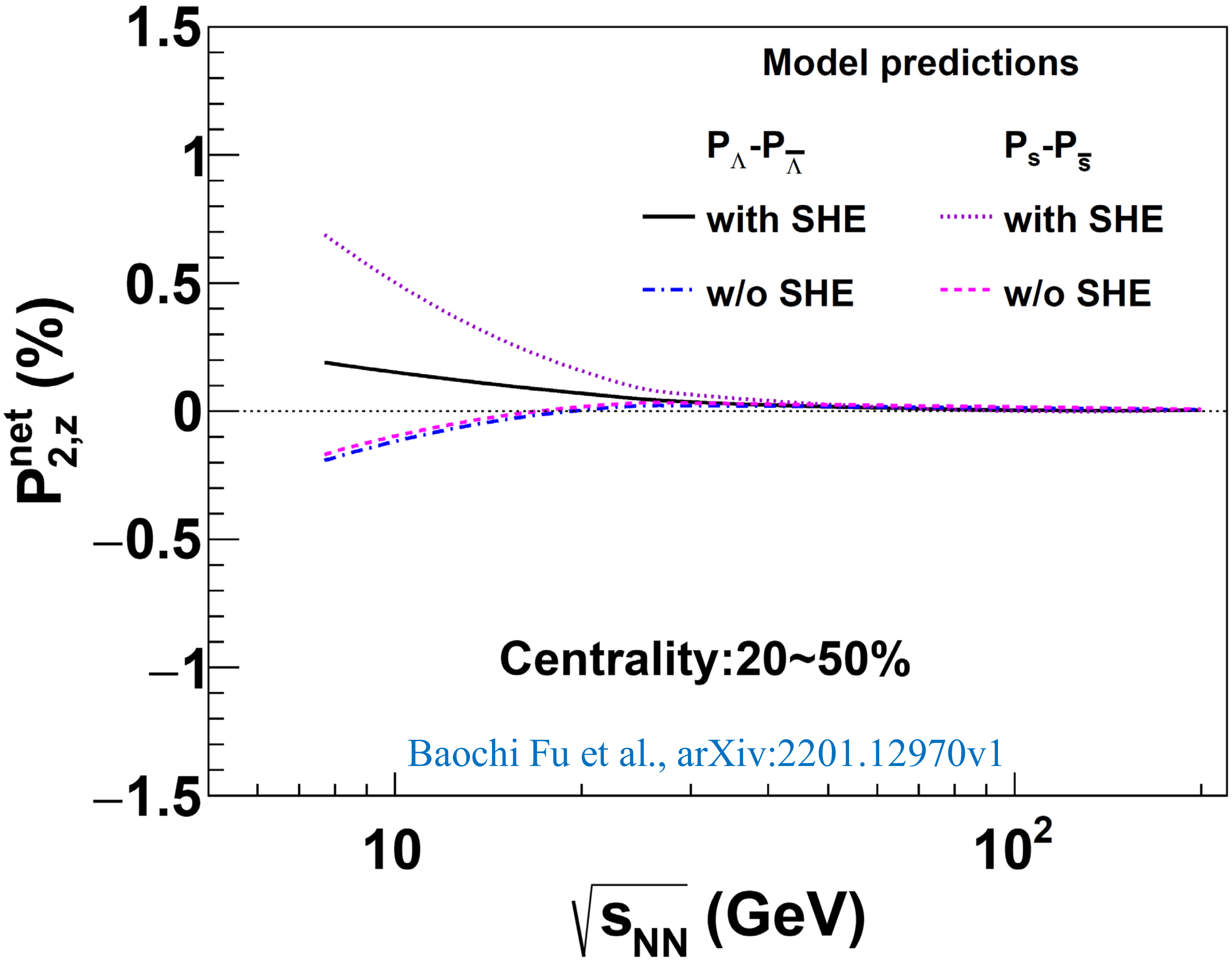
$$\Delta\phi = \phi_\Lambda - \psi_2$$

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

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

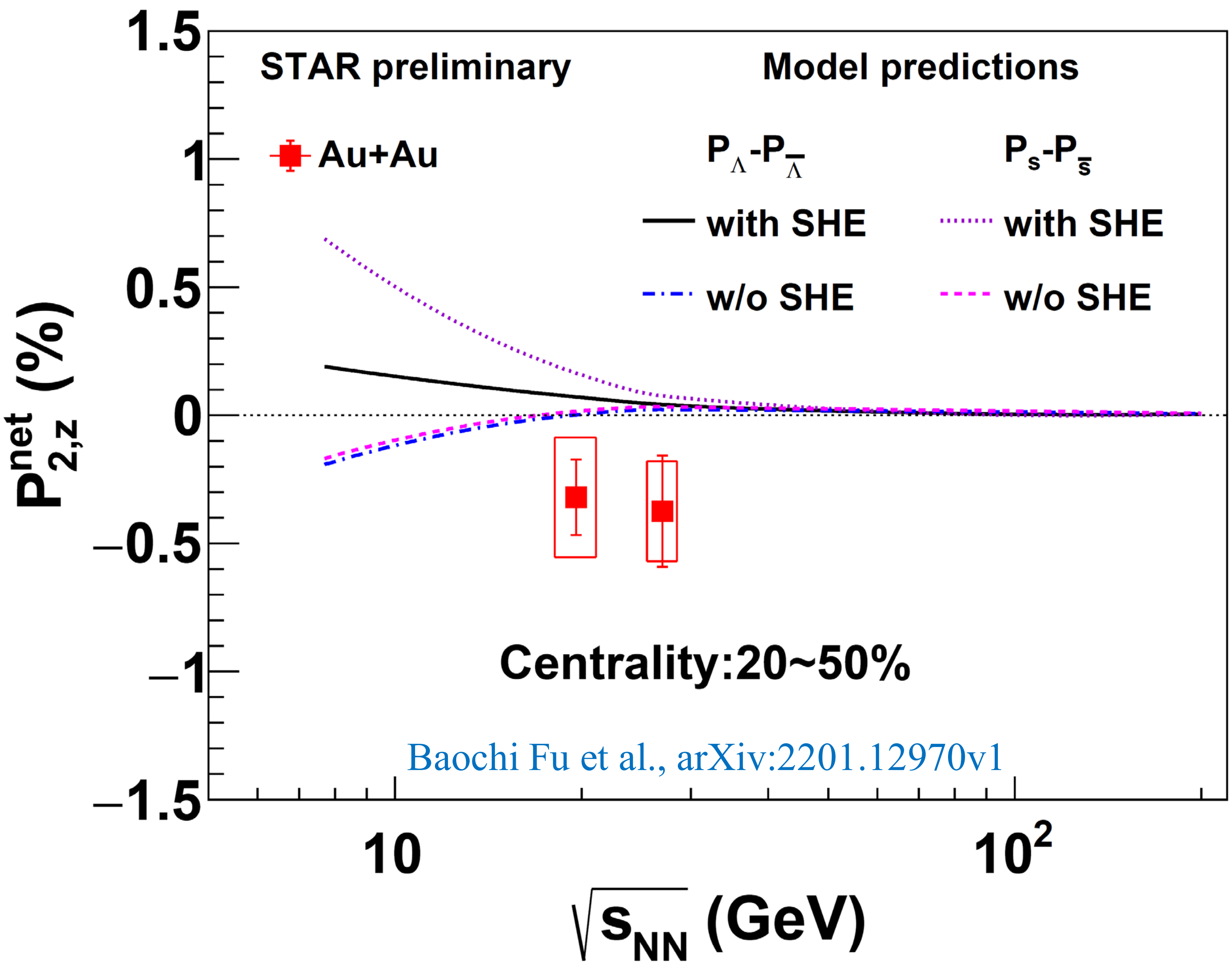
No significant centrality dependence of P_z is observed within present uncertainty

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 !