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Update of baryonic spin Hall effect using Λ polarization at STAR

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STAR Collaboration Meeting, October 19, 2022

Outline

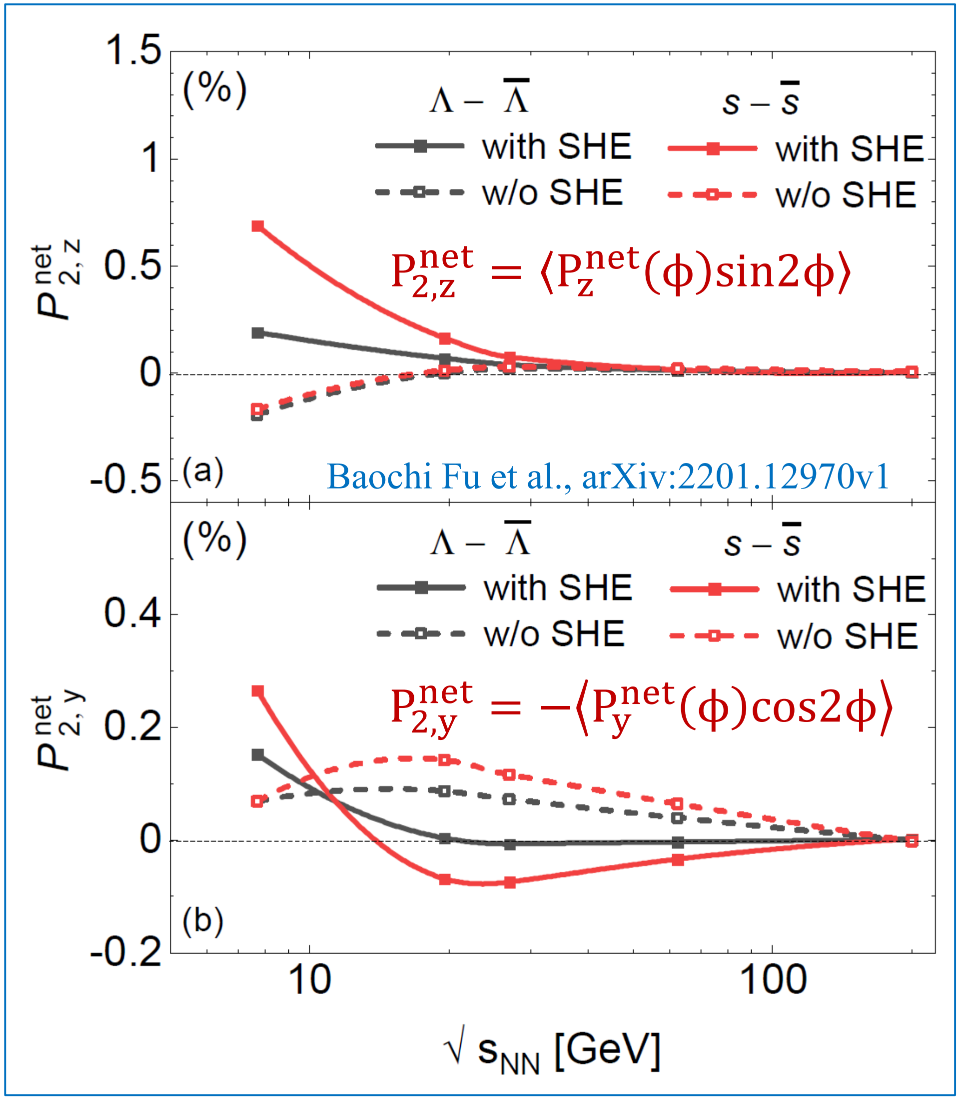
- **Motivation**

- **Data analysis of Au+Au @ 14.5 GeV**
  - **Measurement of Λ's local polarization P_z**
  - **Measurement of Λ's local polarization P_y**

- **Summary**

Part I: Motivation

Baryonic Spin Hall Effect



$\boldsymbol{P \propto \pm p \times \nabla \mu_B}$

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

$$P_{2,y}^{net} = -< P_y^{net}(\phi)\cos 2\phi >$$

$$P_z = \frac{< \cos\theta_p^* >}{\alpha_H < (\cos\theta_p^*)^2 >}$$

$$P_{2,z}^{net} = < P_z^{net}(\phi)\sin 2\phi >$$

$$P_{z,y}^{net}(\phi) = P_{z,y}(\phi) - \overline{P_{z,y}}(\phi)$$

α_Λ: Λ's decay parameter

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

θ^*: angle between daughter proton momentum vector in Λ rest frame and polarization direction

No investigation of proposed SHE in heavy ion collisions!

Part II: Data analysis

Dataset and analysis details

Au+Au @ 14.5 GeV, BES-II
production=P21ic

Event Cuts
— Vertex: $|Vz| < 70$ cm
$|Vr| < 2$ cm

— Trigger ID (650002)

— Pile-up is done via StRefMultCorr

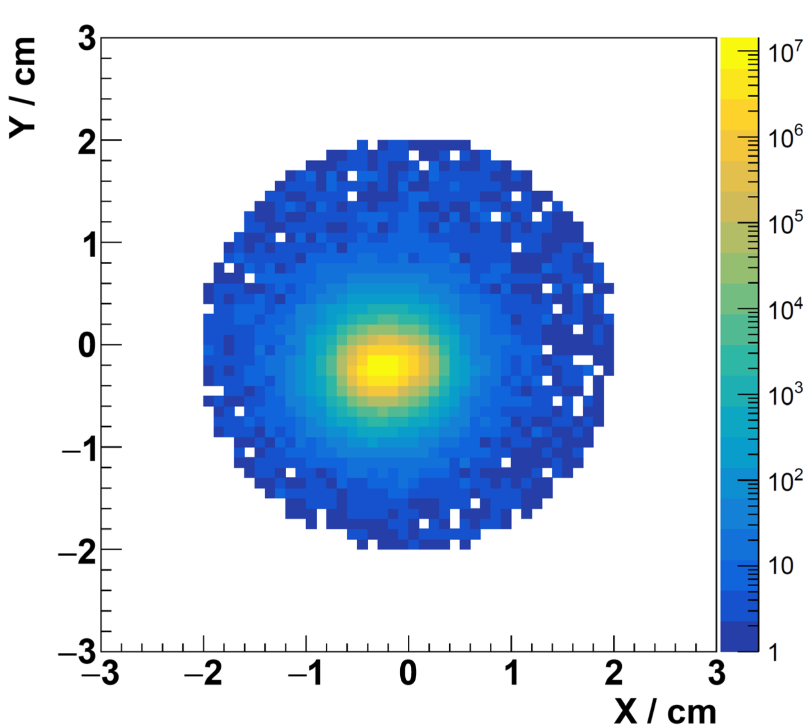
Single track Cuts
— 0.15 GeV/c $< p_t < 5$ GeV/c
— No. of TPC hits > 15
— Nhits-TPC/Possible Hits >= 0.52
— $|\eta| < 1.5$

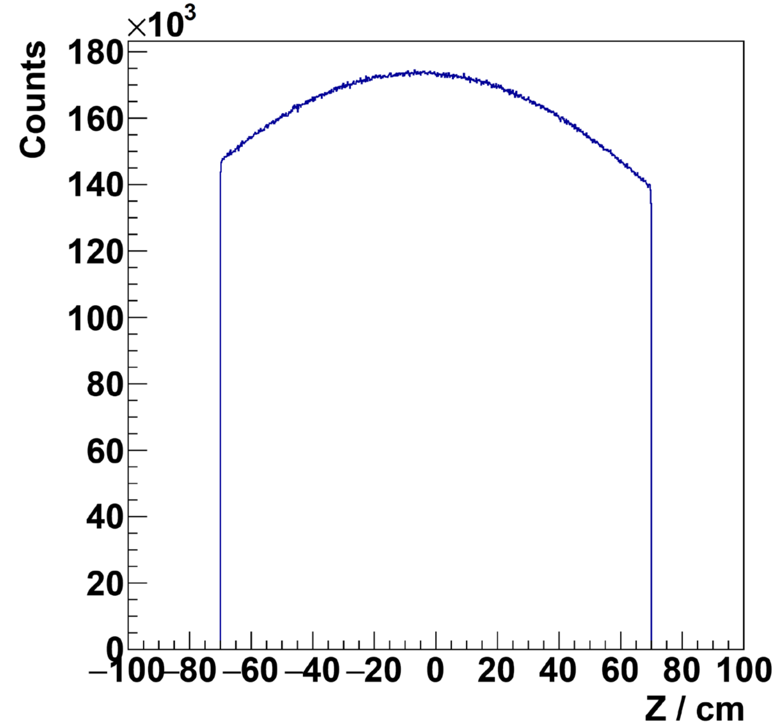
Pion/Proton PID Cuts
— if ToF available
$(1/\beta - 1/\beta_\pi) < 0.03$
$(1/\beta - 1/\beta_p) < 0.04$

— else use TPC
$|N\sigma| < 3$ for both π and p

No. of events for analysis: ~114 M

Part II: Data analysis





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

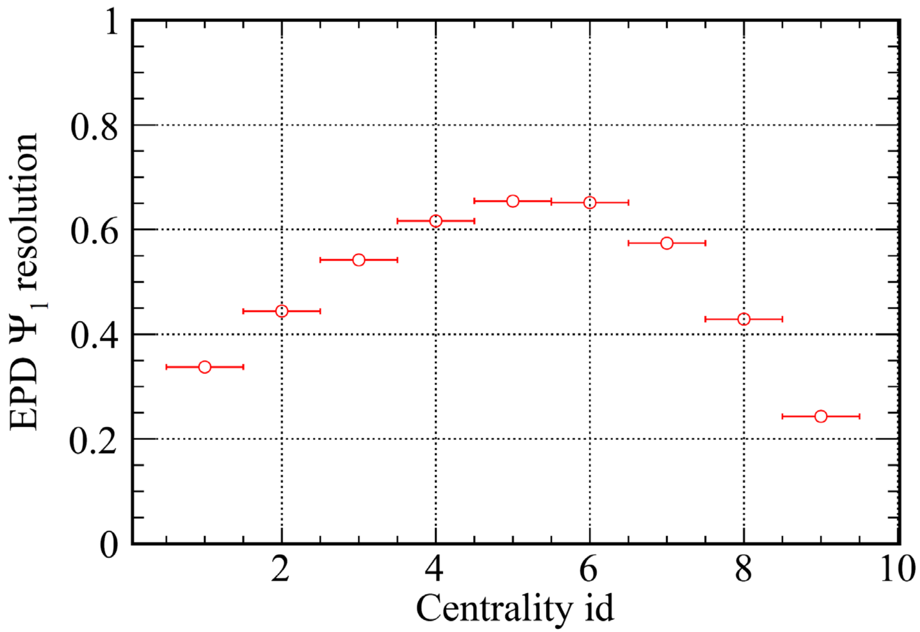
$\bar{\Lambda} \rightarrow \bar{p} + \pi^+$

Using STAR Helix method

— Decay length > 3.0 cm
— DCA to prim vertex < 0.8
— DCA between π/p < 0.8
— DCA to p > 0.3
— DCA to π > 1.6
— p & π: p_t>0.15 GeV/c;
— Λ(anti-Λ): p_t>0.5 GeV/c
— $|y_{p\text{-}\pi\ pair}| < 1.5$

Au+Au @ 14.5 GeV

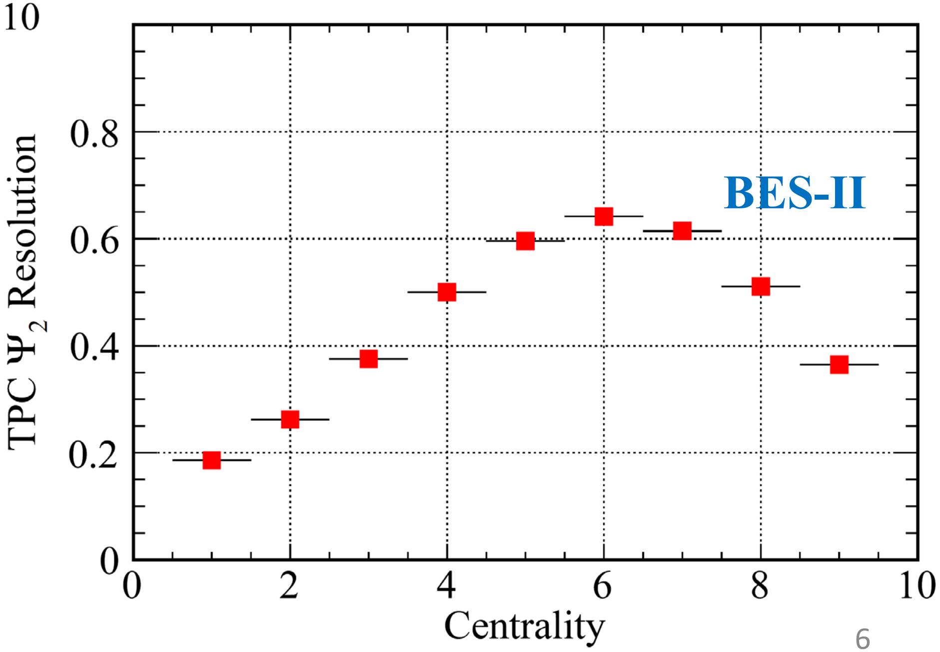
Part II: Event plane resolution



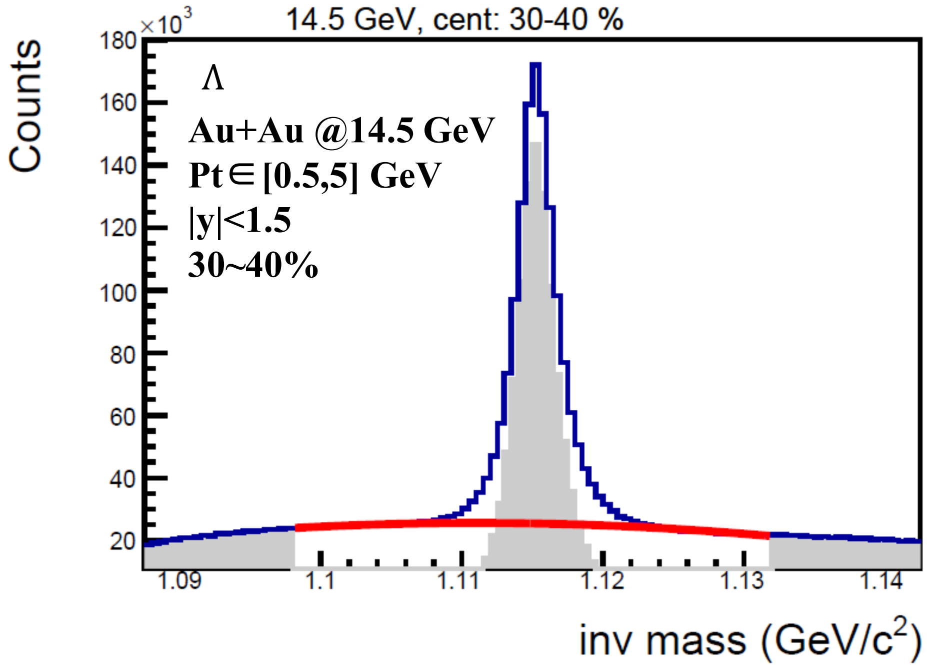
EPD event plane

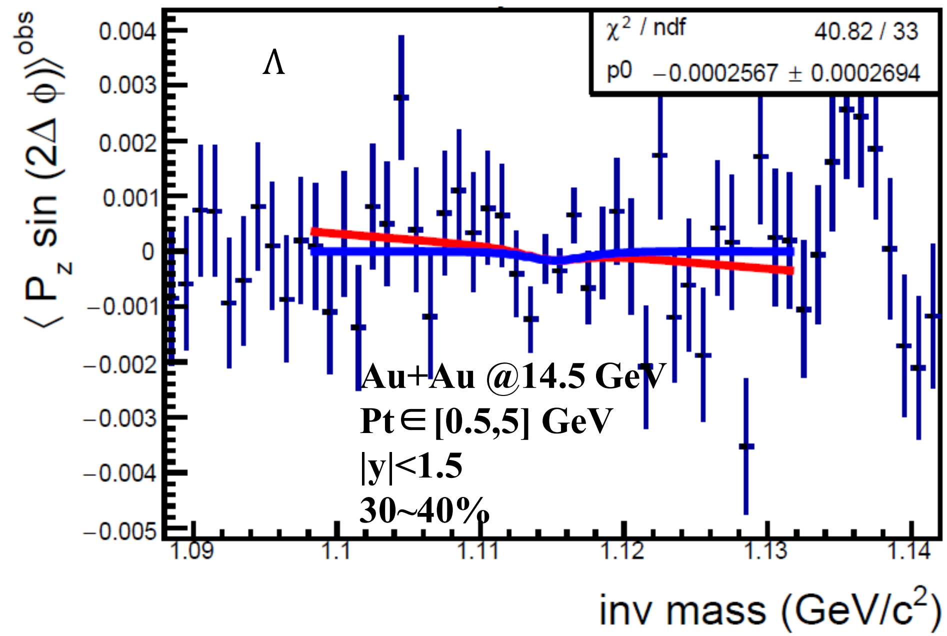
Au+Au @ 14.5 GeV

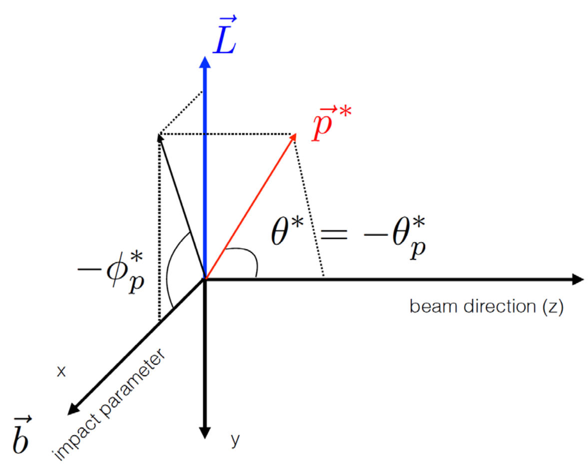
TPC event plane



Part II: Measurement of Λ's local polarization Pz







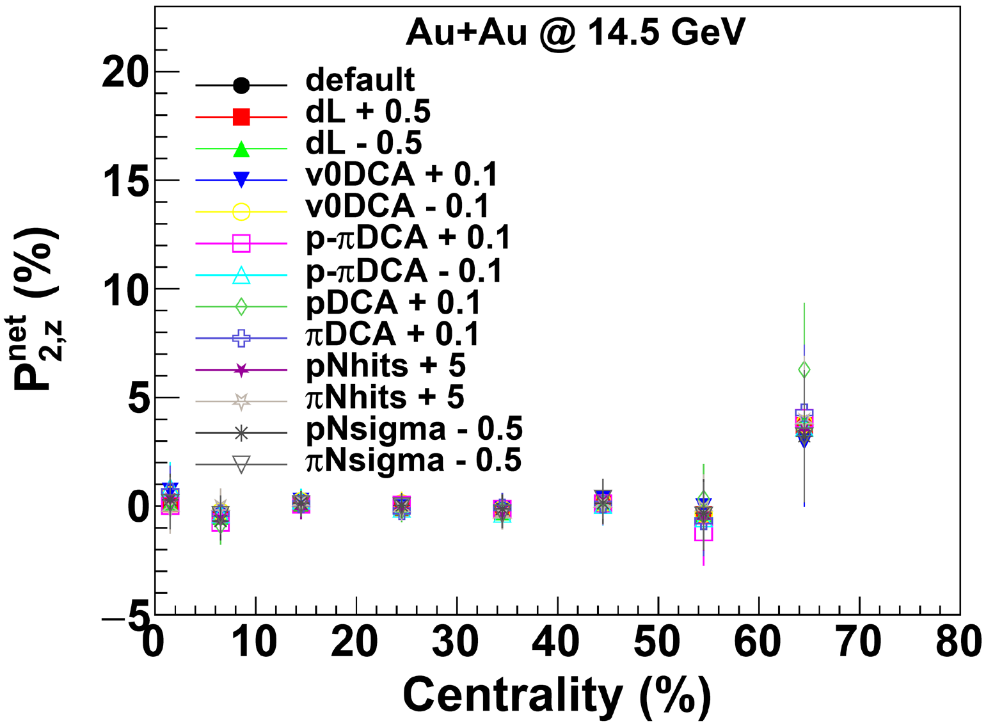
$$\langle P_z sin(2\Delta\phi)\rangle^{obs}$$
$$= \left(1 - f^{Bg}(M_{inv})\right)\langle P_z sin(2\Delta\phi)\rangle^{Sg}$$
$$+ f^{Bg}(M_{inv})\langle P_z sin(2\Delta\phi)\rangle^{Bg}$$

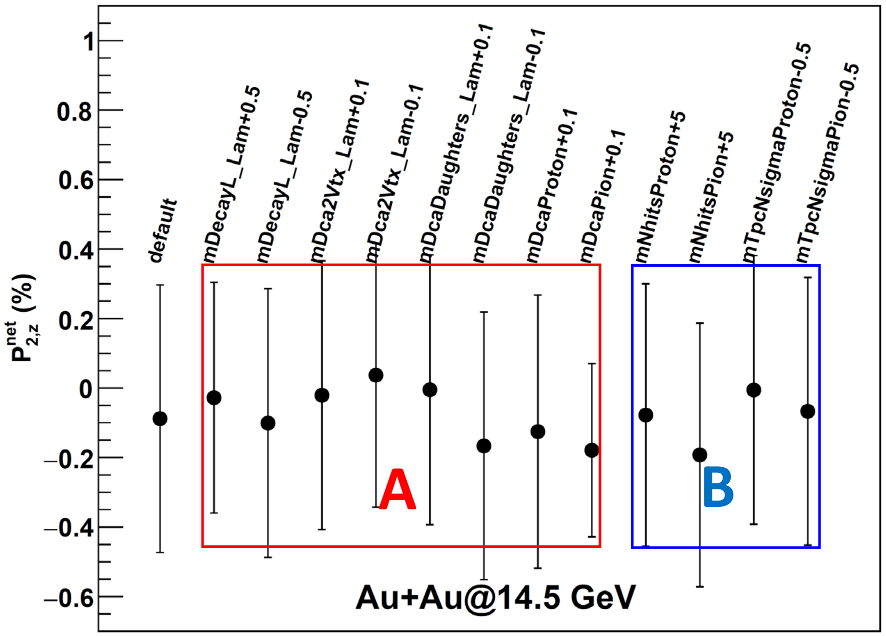
$\Delta\phi=\psi_2-\phi^*_p$

Blue: w/o bkg;

Red: with bkg ($\alpha+\beta M_{inv.}$)

Part II: Measurement of Λ's local polarization Pz



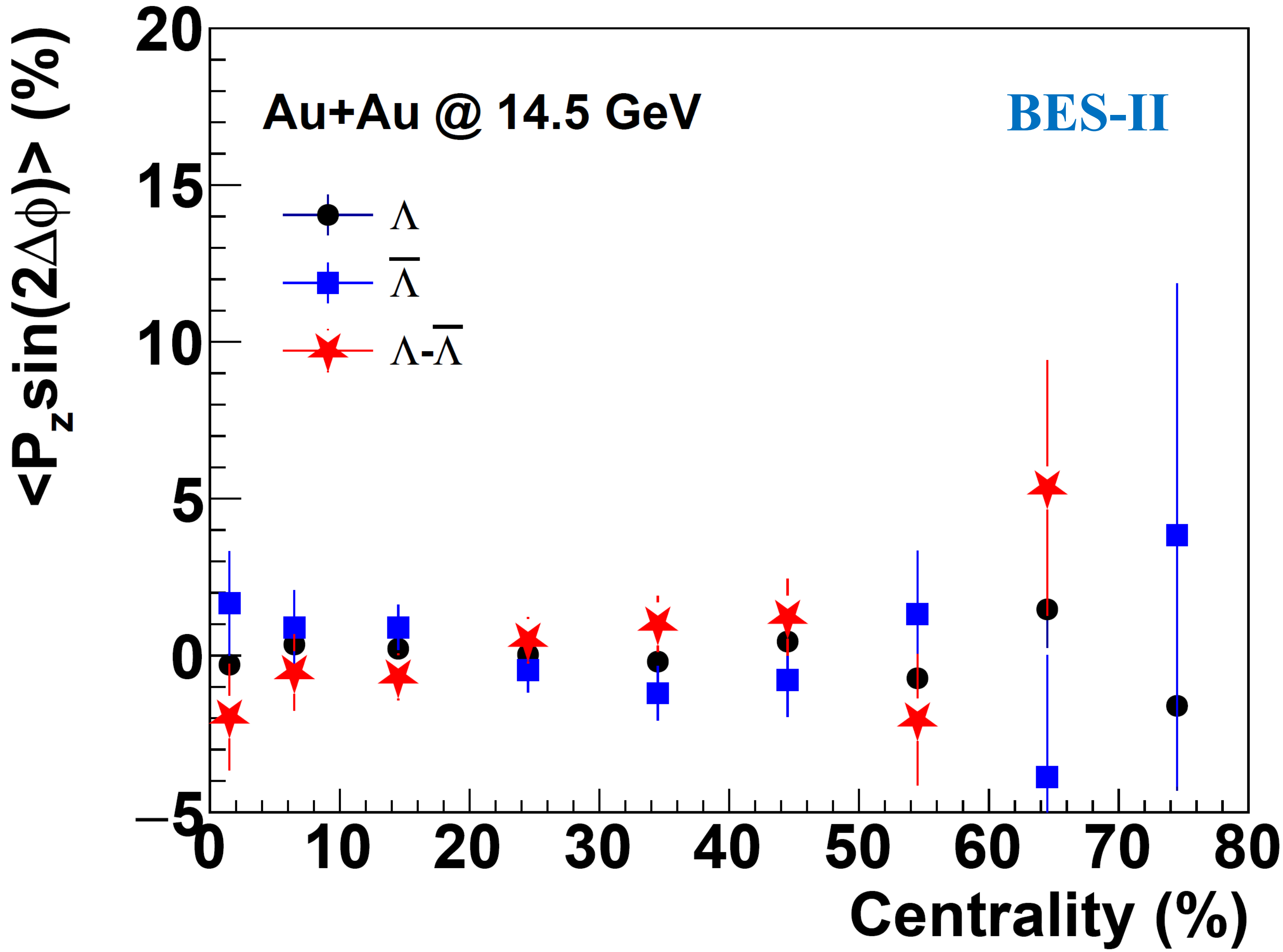


A: Topo cuts

B: Track quality

$$\sigma_{sys.} = \sqrt{A^2 + B^2}$$

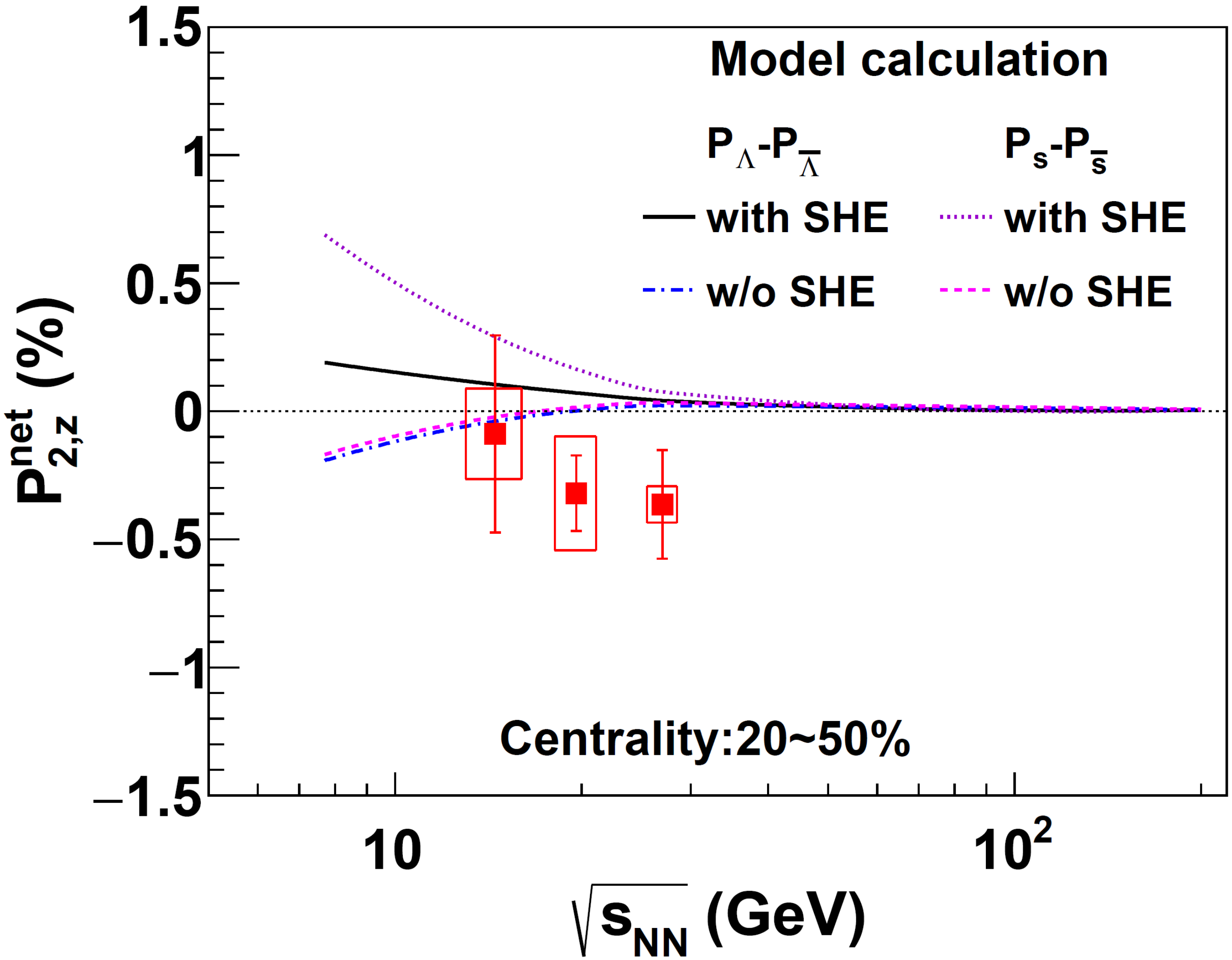
Part II: Measurement of Λ's local polarization Pz



No significant centrality depend of P_z is observed

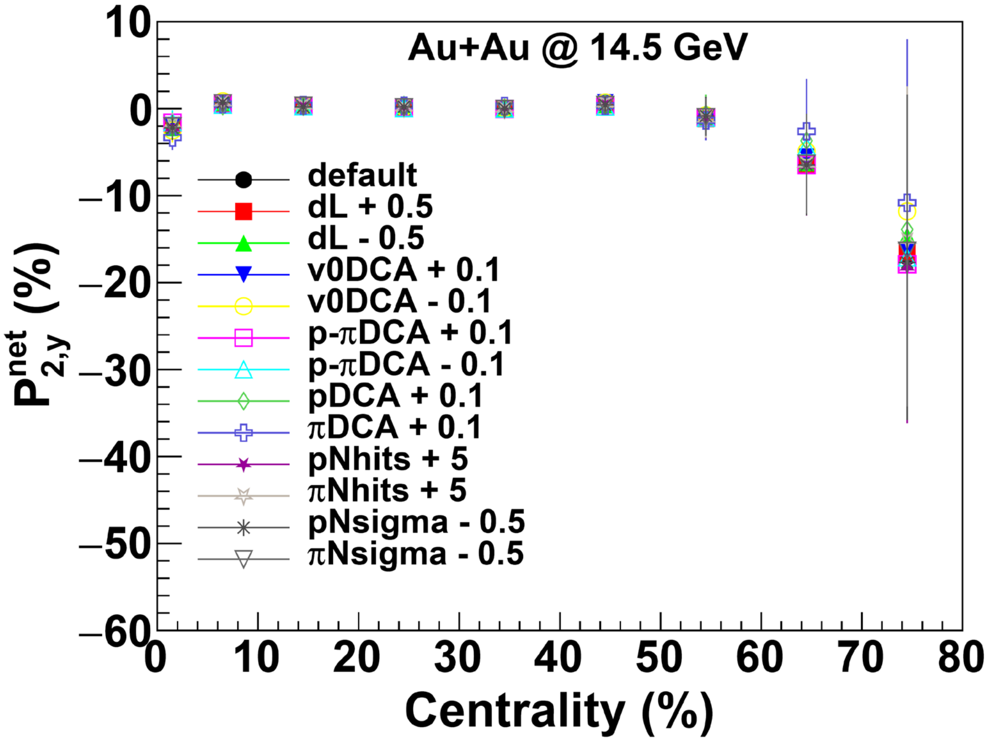
Part II: Measurement of Λ's local polarization Pz

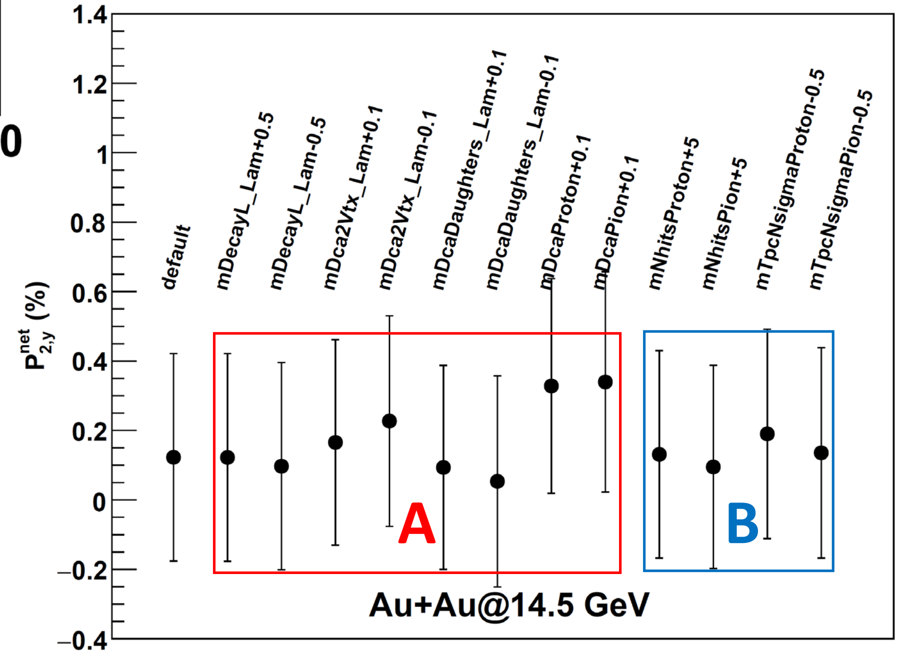
Comparison of net local polarization $P^{net}_{2,z}$ with theory prediction



No significant signal is observed!

Part II: Measurement of Λ's local polarization Py





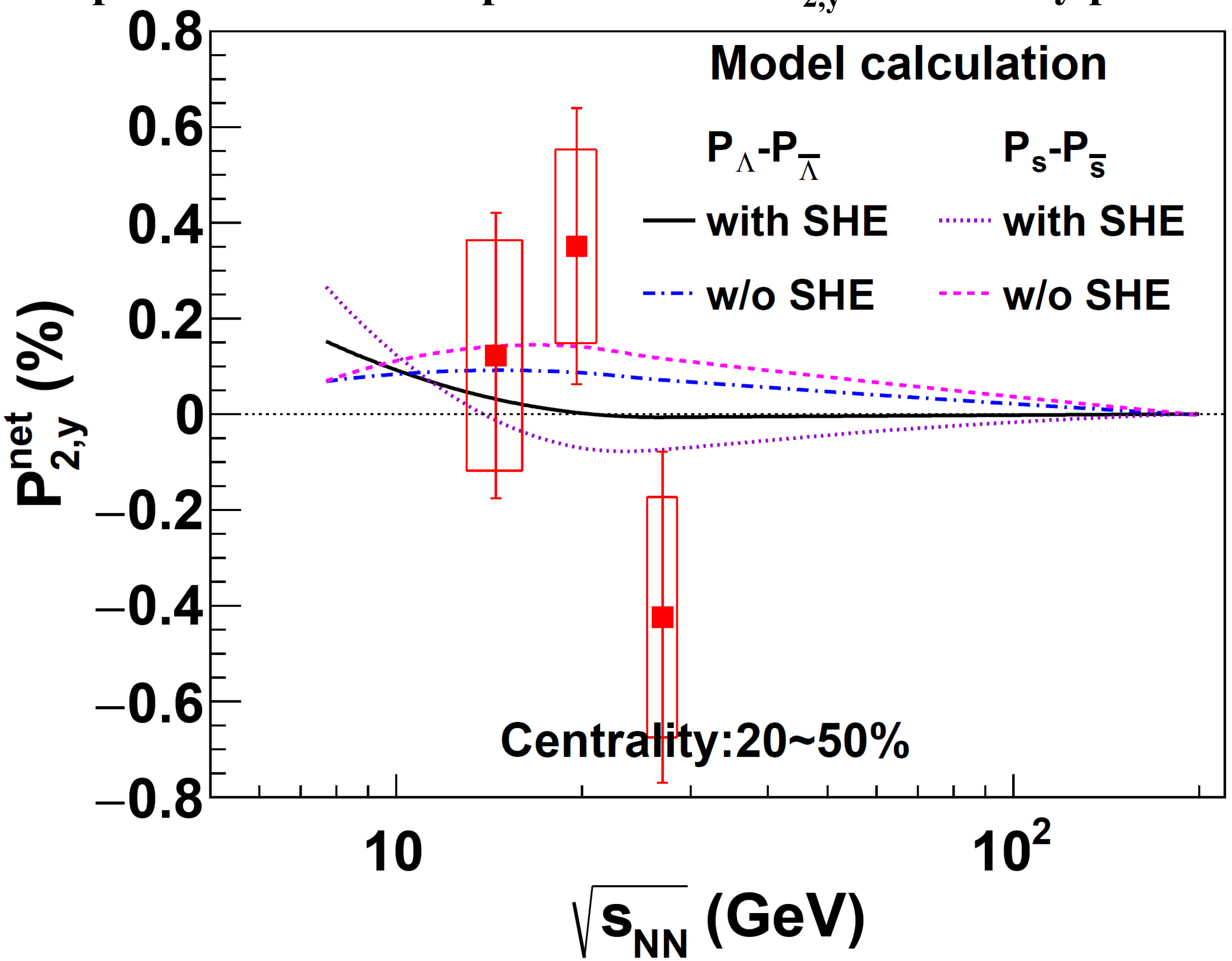
A: Topo cuts

B: Track quality

$$\sigma_{sys.} = \sqrt{A^2 + B^2}$$

Part II: Measurement of Λ's local polarization Py

Comparison of net local polarization $P^{net}_{2,y}$ with theory prediction



$$P^{net}_{2,y} = -< P^{net}_{y}(\phi)cos2\phi >$$

$$\bar{P}_{y} = \frac{8}{\pi\alpha_{\Lambda}}\frac{1}{R^{(1)}_{EP}R^{(2)}_{EP}}\langle\sin\left(\phi^{*}_{p}-\psi_{1}\right)cos2(\phi^{*}_{p}-\psi_{2})\rangle$$

A hint of sign change is observed

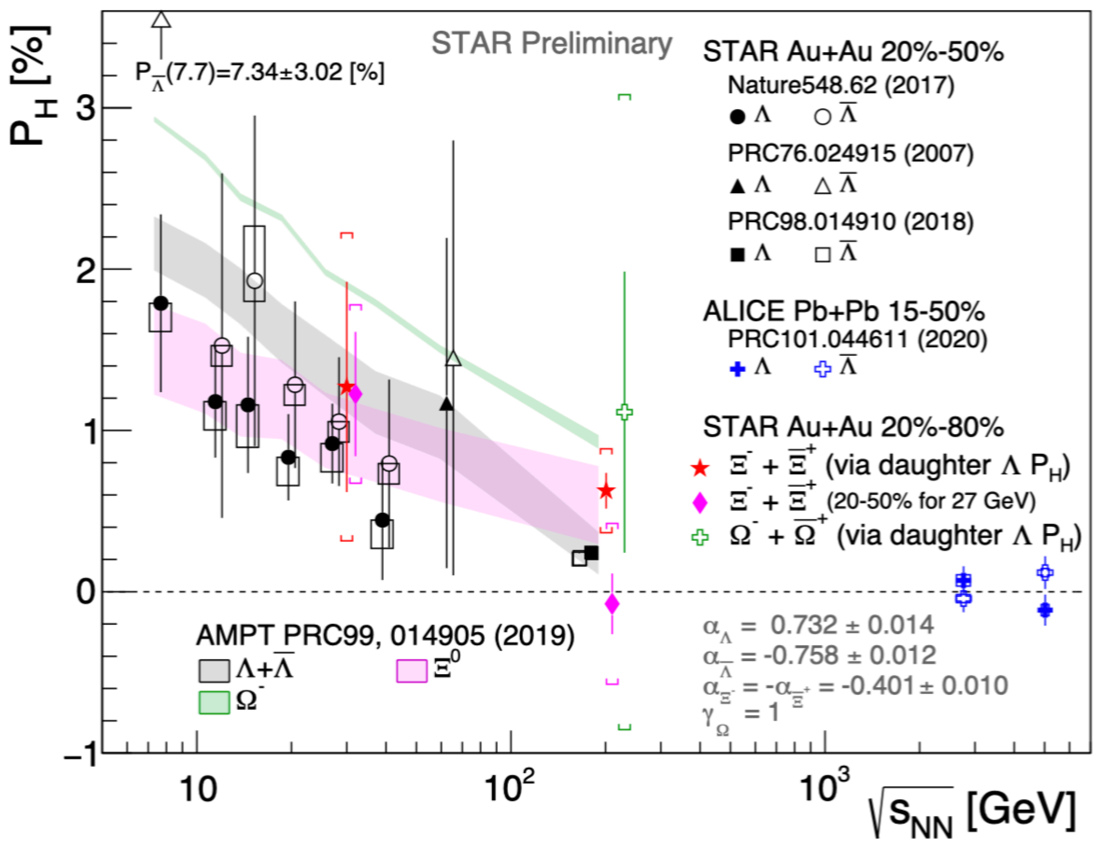
Summary

- ✓ First study of spin Hall effect by measuring net local polarization in Au+Au @ 14.5, 19.6 and 27 GeV
- ✓ The event plane resolutions at 14.5 GeV are obtained
- ✓ Net local polarization $P_{2,z}^{net}$ and $P_{2,y}^{net}$ have been obtained
- ✓ No significant signal has been observed for $P_{2,z}^{net}$
- ✓ A hit of sign change is observed for $P_{2,y}^{net}$

Thank you for your attention!

Part I: Motivation

Global spin polarization of hyperons



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

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

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

α_Λ: Λ's decay parameter

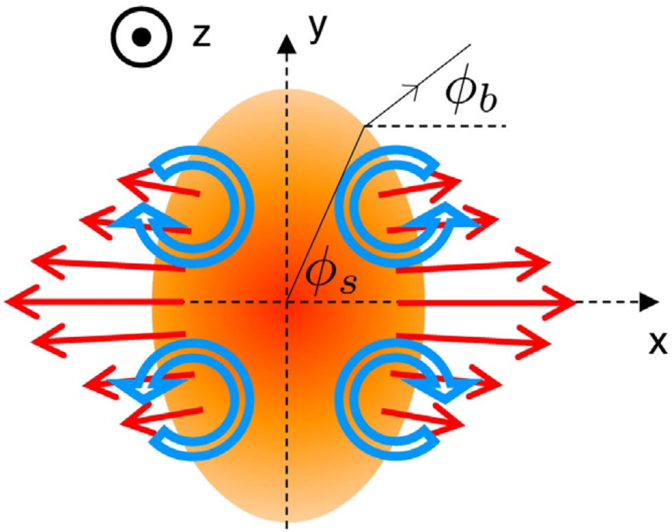
ϕ_p^*: the azimuthal angle of the daughter proton in Λ rest frame

$P_{\Lambda,\,\Xi,\,\Omega}$ ~ Positive and non-zero across BES energies

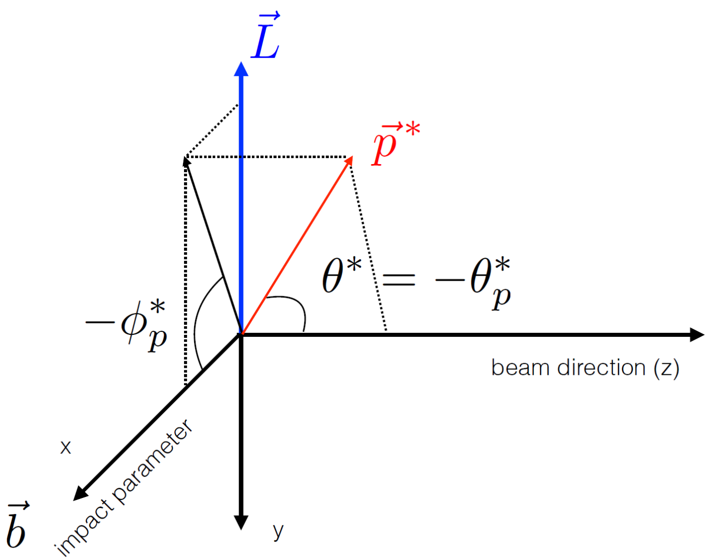
→ Global nature of hyperon polarization in HIC

Part I: Motivation

Local spin polarization of hyperons



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



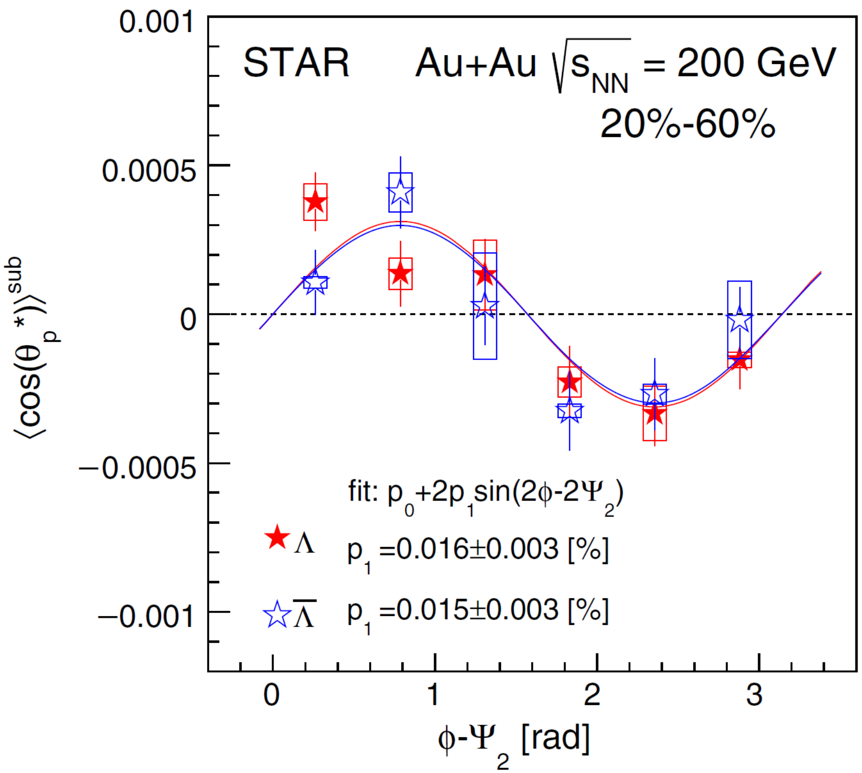
$$P_z = \frac{< cos\theta_p^* >}{\alpha_H < (cos\theta_p^*)^2 >}$$

θ*: angle between daughter proton momentum vector in Λ rest frame and polarization direction

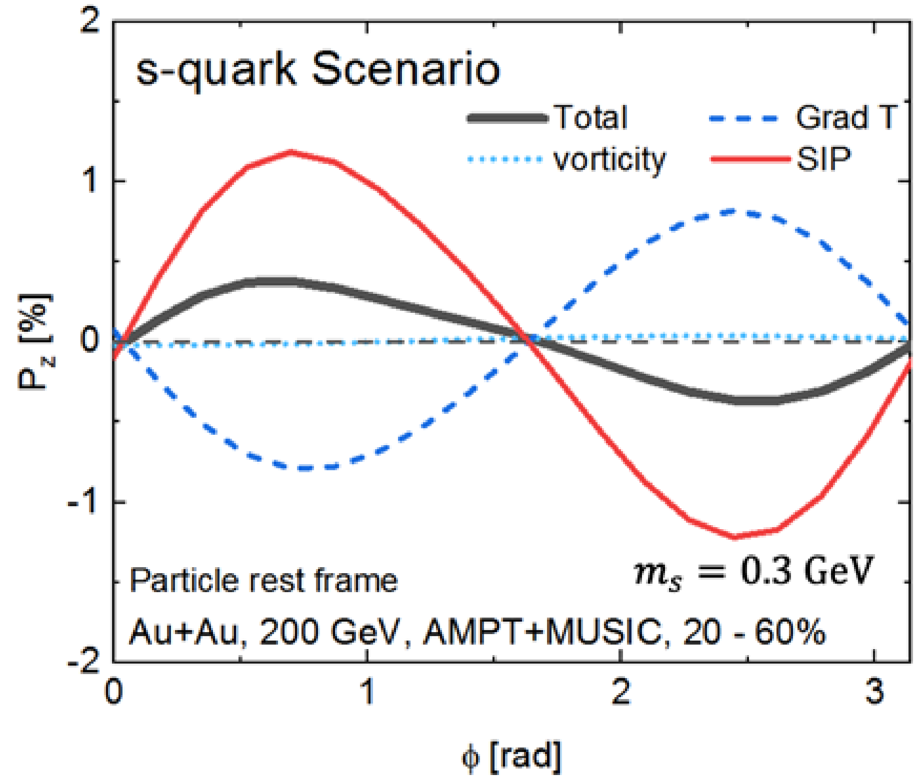
PRL 123,132301 (2019)

Part I: Motivation

Local spin polarization of hyperons



PRL 123,132301 (2019)



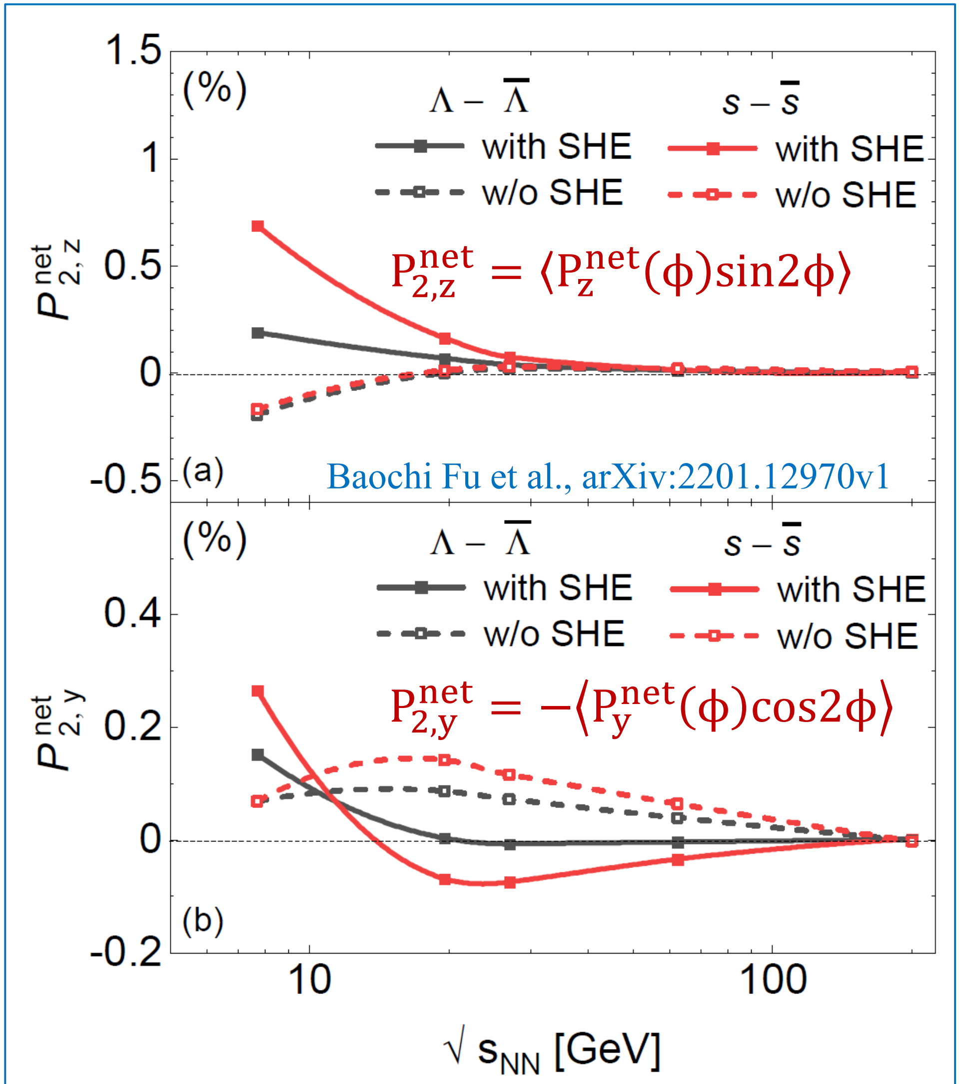
Total: Vorticity + Grad T + SIP

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

Part I: Motivation

Baryonic Spin Hall Effect



$\boldsymbol{P} \propto \pm \boldsymbol{p} \times \nabla \mu_B$

$$\bar{P}_y = \frac{8}{\pi \alpha_\Lambda} \frac{1}{R^{(1)}_{EP}} \langle \sin(\psi_1 - \phi^*_p) \rangle$$

$$P^{net}_{2,y} = -< P^{net}_y(\phi) cos2\phi >$$

$$P_z = \frac{< cos\theta^*_p >}{\alpha_H < (cos\theta^*_p)^2 >}$$

$$P^{net}_{2,z} = < P^{net}_z(\phi) sin2\phi >$$

$$P^{net}_{z,y}(\phi) = P_{z,y}(\phi) - \overline{P_{z,y}}(\phi)$$

α_Λ: Λ's decay parameter

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

θ^*: angle between daughter proton momentum vector in Λ rest frame and polarization direction

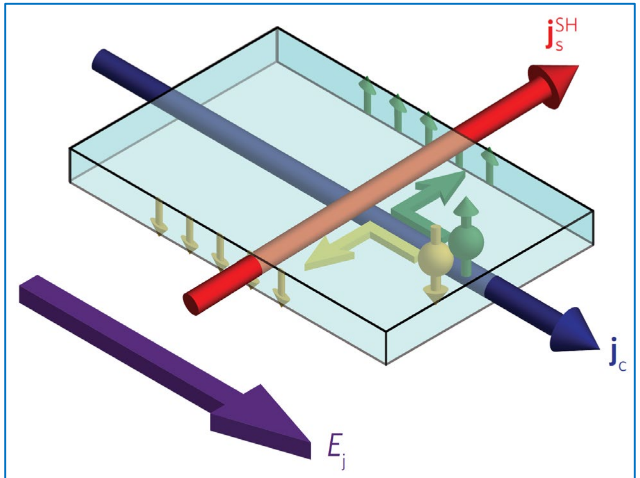
No investigation of proposed SHE in heavy ion collisions!

Part I: Motivation

Baryonic Spin Hall Effect

Spin Hall Effect in Condensed matter: $\boldsymbol{P} \propto \pm \boldsymbol{p} \times \boldsymbol{E}$

Electric field (E) —"Spin-orbit" interaction→ **Splitting in spin in opposite directions**

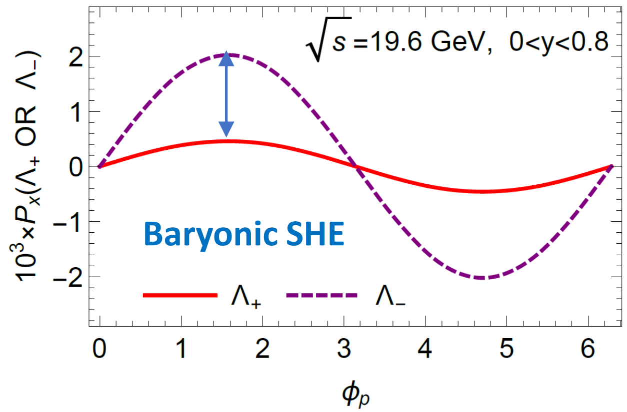


Spin Hall effect, (1972) 2004

Spin Hall Effect in hot QCD matter: $\boldsymbol{P} \propto \pm \boldsymbol{p} \times \nabla \mu_B$

Baryon density gradient ($\nabla \mu_B$) —"Spin-orbit" interaction→ **Splitting in spin between Λ and anti-Λ local spin polarization**

S. Liu & Y. Yin, Phys. Rev. D 104 (2021) 054043 (IMP,CAS)



Barlow test for systematic uncertainty

- Calculate the difference between the value(P) and statistic(σ) error:

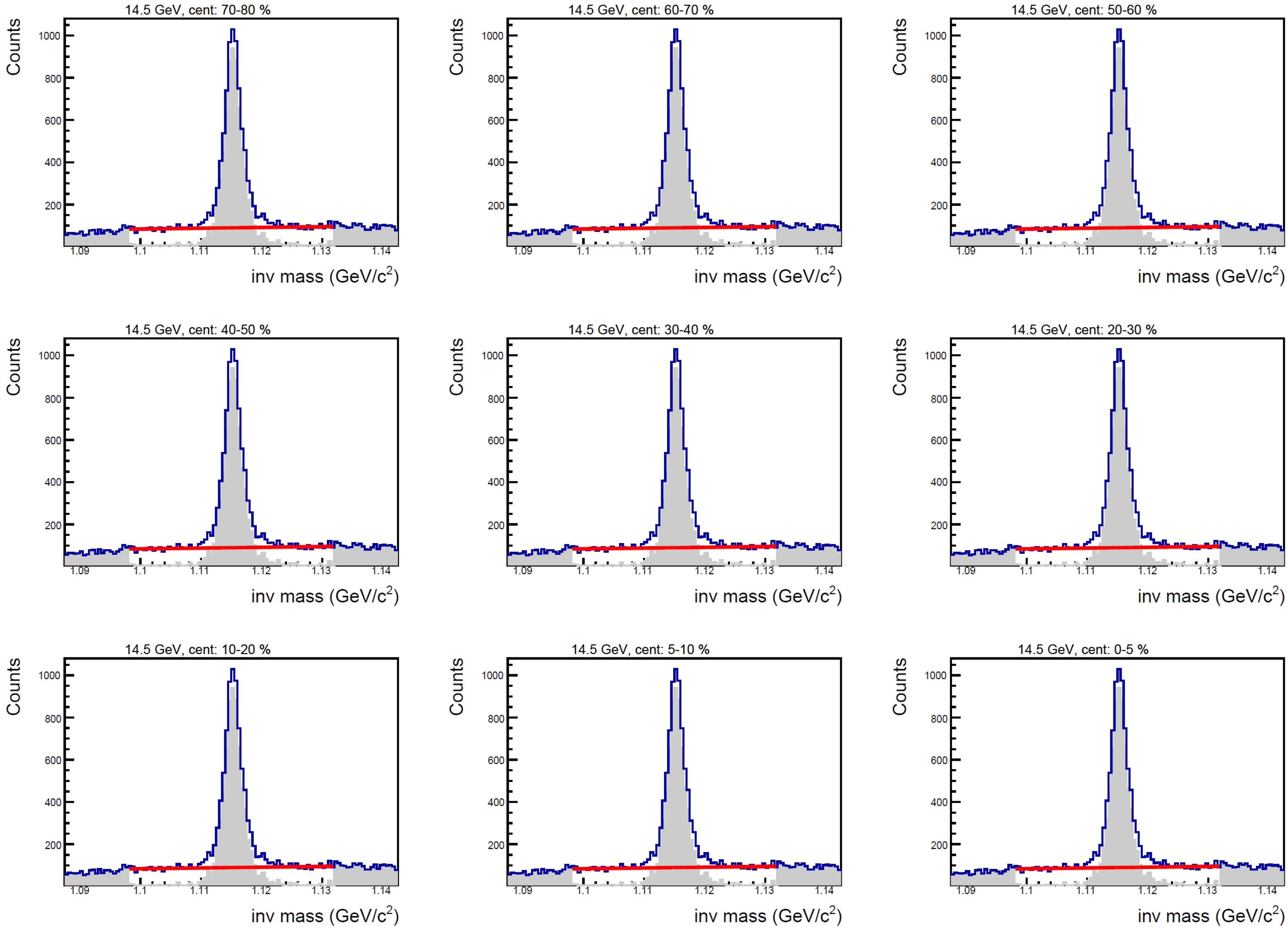
$$\Delta_P^2 = (P_{default} - P_{vary})^2 \tag{1}$$
$$\Delta_\sigma^2 = \sigma_{default}^2 - \sigma_{vary}^2 \tag{2}$$

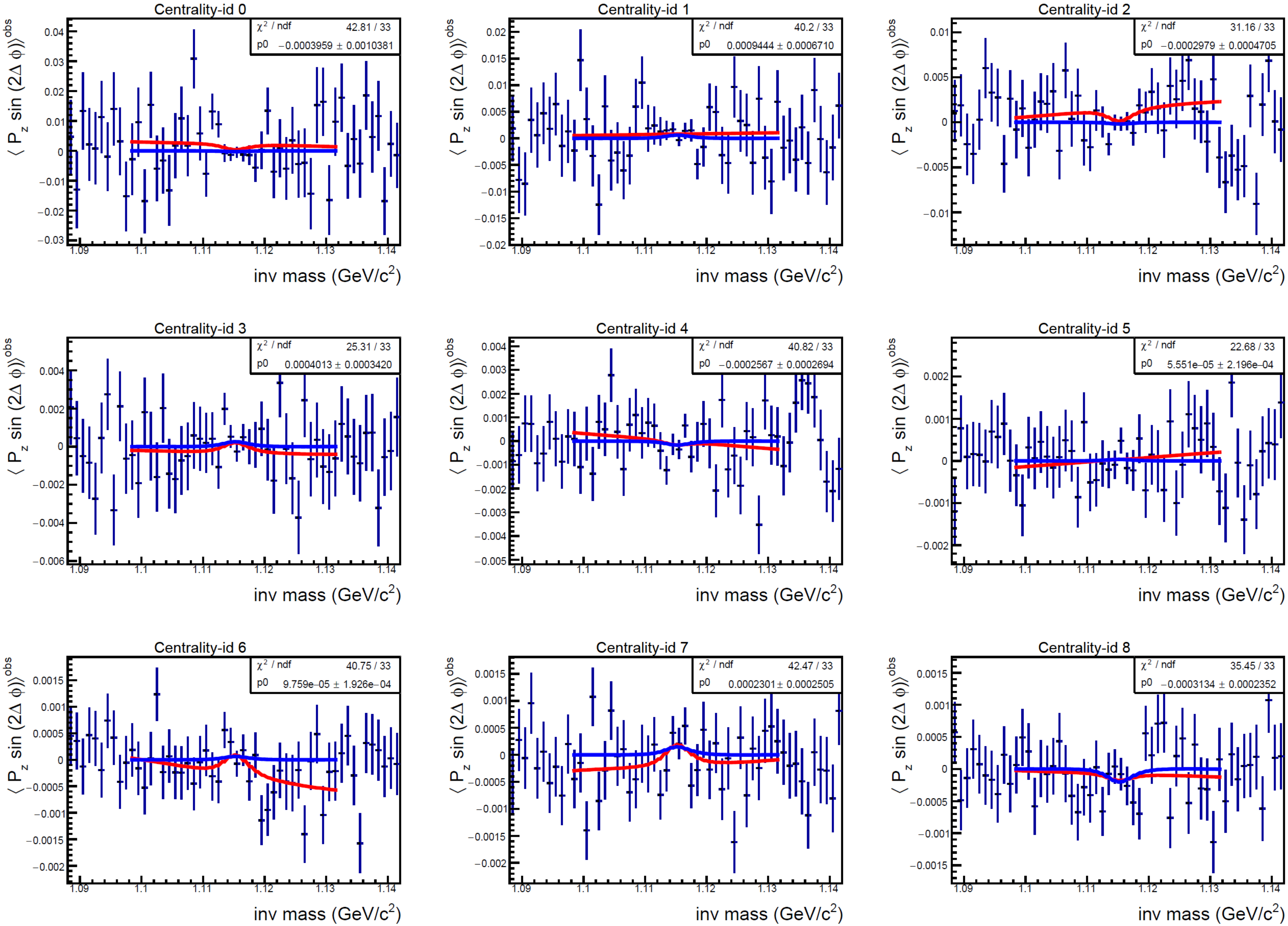
- Compare the difference between Δ_P^2 and Δ_σ^2
  If $\Delta_P^2 < \Delta_\sigma^2$, $\sigma_{sys}^2 = 0$
  If $\Delta_P^2 > \Delta_\sigma^2$, $\sigma_{sys}^2 = \Delta_P^2 - \Delta_\sigma^2$
- If one vary two times for the same cut, then the systematic uncertainty due to this cut is(like DCA):

$$\sigma_{dca}^2 = (\sigma_{dca1}^2 + \sigma_{dca1}^2)/2 \tag{3}$$

- Once all uncertainty sources are checked, one can get the total systematic uncertainty:

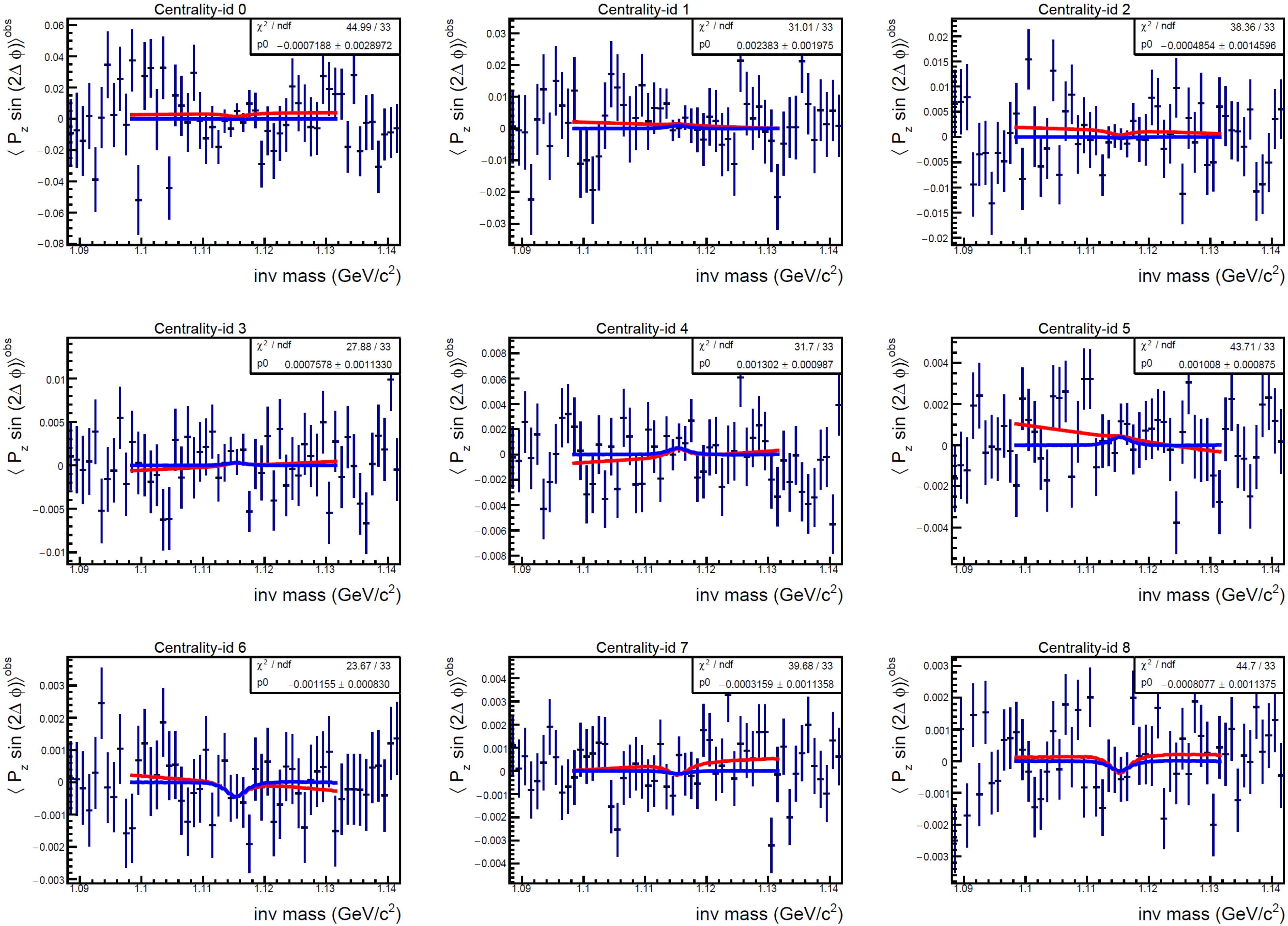
$$\sigma_{total}^2 = \sum_i \sigma_{variation_i}^2 \tag{4}$$


14.5 GeV, cent: 70-80 %
14.5 GeV, cent: 60-70 %
14.5 GeV, cent: 50-60 %
14.5 GeV, cent: 40-50 %
14.5 GeV, cent: 30-40 %
14.5 GeV, cent: 20-30 %
14.5 GeV, cent: 10-20 %
14.5 GeV, cent: 5-10 %
14.5 GeV, cent: 0-5 %
Counts
inv mass (GeV/c²)
1.09
1.1
1.11
1.12
1.13
1.14
200
400
600
800
1000

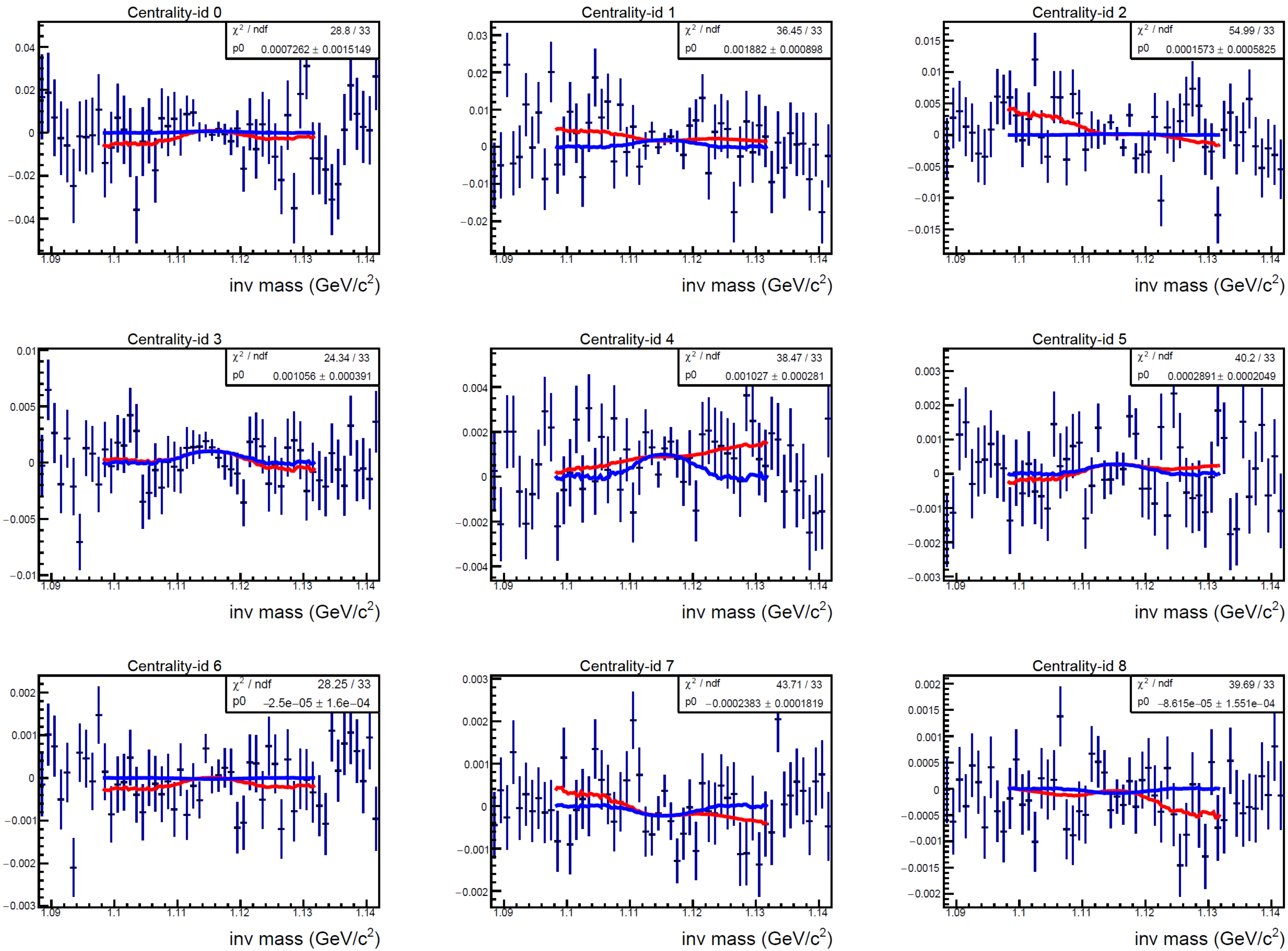


Centrality-id 0
χ2 / ndf 42.81 / 33
p0 −0.0003959 ± 0.0010381
Centrality-id 1
χ2 / ndf 40.2 / 33
p0 0.0009444 ± 0.0006710
Centrality-id 2
χ2 / ndf 31.16 / 33
p0 −0.0002979 ± 0.0004705
Centrality-id 3
χ2 / ndf 25.31 / 33
p0 0.0004013 ± 0.0003420
Centrality-id 4
χ2 / ndf 40.82 / 33
p0 −0.0002567 ± 0.0002694
Centrality-id 5
χ2 / ndf 22.68 / 33
p0 5.551e−05 ± 2.196e−04
Centrality-id 6
χ2 / ndf 40.75 / 33
p0 9.759e−05 ± 1.926e−04
Centrality-id 7
χ2 / ndf 42.47 / 33
p0 0.0002301 ± 0.0002505
Centrality-id 8
χ2 / ndf 35.45 / 33
p0 −0.0003134 ± 0.0002352
⟨ Pz sin (2Δ φ)⟩obs
inv mass (GeV/c2)

Lamda Pz

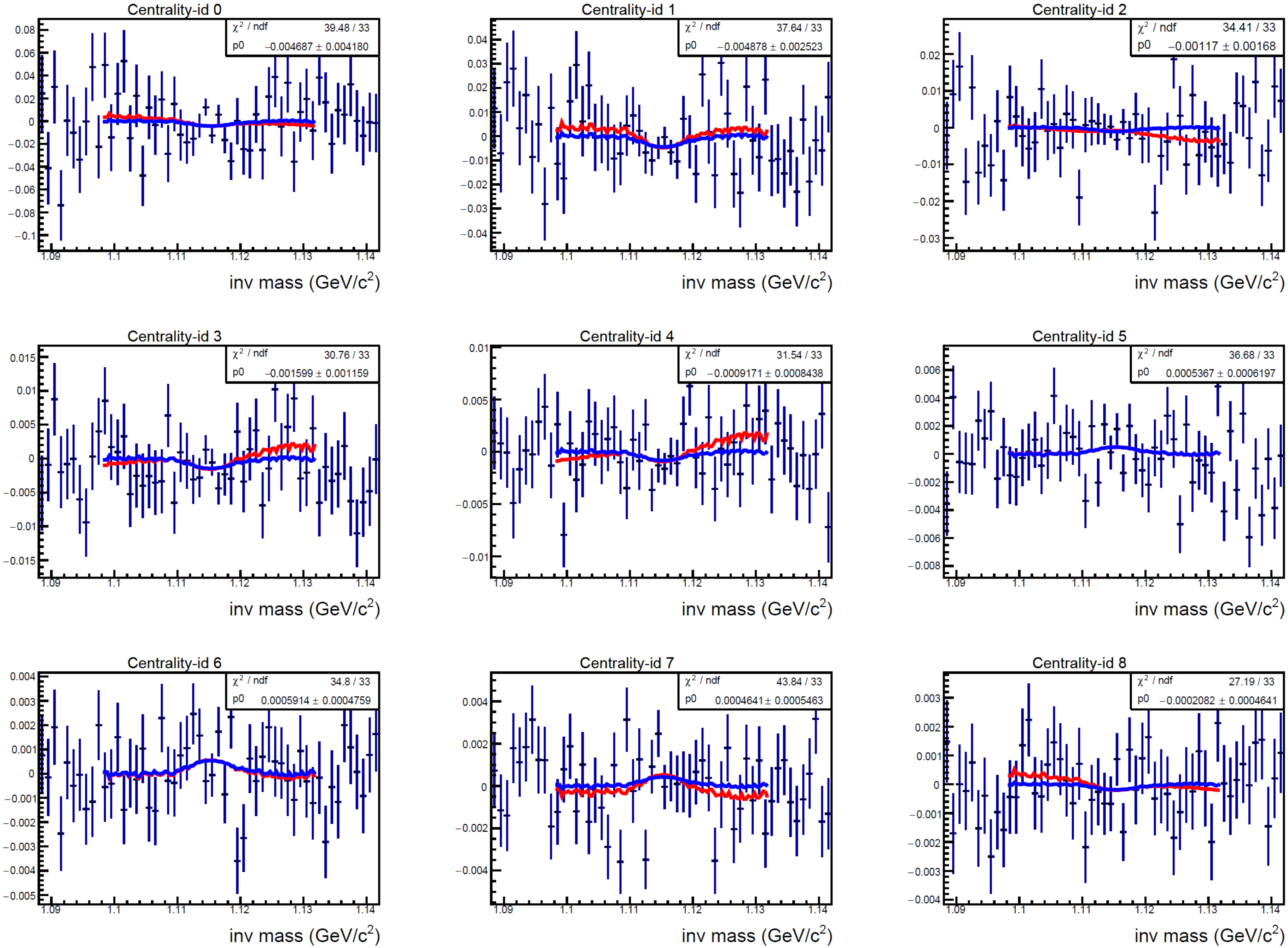


Anti-Lamda Pz



Centrality-id 0
χ2 / ndf 28.8 / 33
p0 0.0007262 ± 0.0015149
Centrality-id 1
χ2 / ndf 36.45 / 33
p0 0.001882 ± 0.000898
Centrality-id 2
χ2 / ndf 54.99 / 33
p0 0.0001573 ± 0.0005825
Centrality-id 3
χ2 / ndf 24.34 / 33
p0 0.001056 ± 0.000391
Centrality-id 4
χ2 / ndf 38.47 / 33
p0 0.001027 ± 0.000281
Centrality-id 5
χ2 / ndf 40.2 / 33
p0 0.0002891 ± 0.0002049
Centrality-id 6
χ2 / ndf 28.25 / 33
p0 −2.5e−05 ± 1.6e−04
Centrality-id 7
χ2 / ndf 43.71 / 33
p0 −0.0002383 ± 0.0001819
Centrality-id 8
χ2 / ndf 39.69 / 33
p0 −8.615e−05 ± 1.551e−04
inv mass (GeV/c2)

Lamda Py



Anti-Lamda Py