

Polarization measurement in HI collisions

Recent experimental progress

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10th Asian Triangle Heavy-Ion Conference – ATHIC 2025

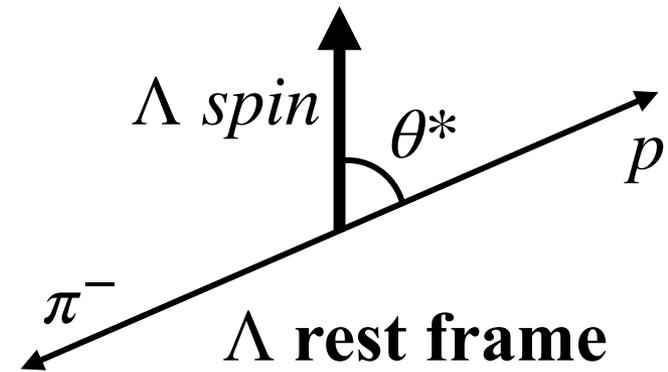
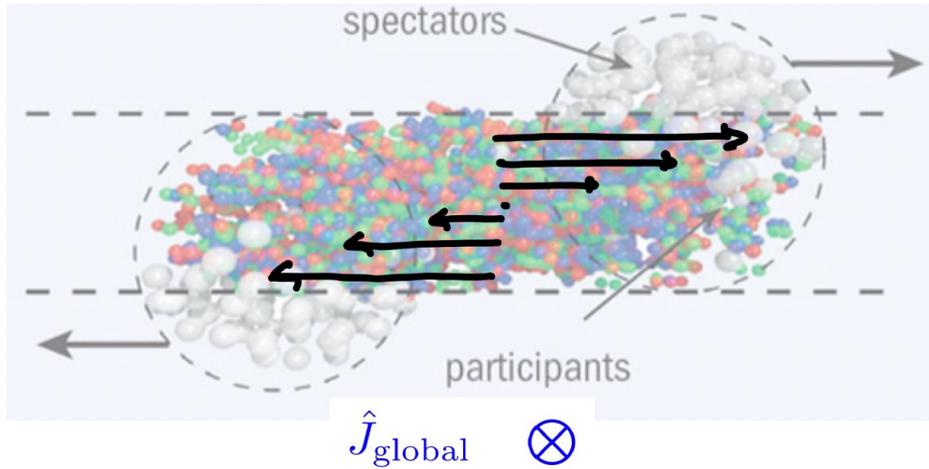
Berhampur, India



山东大学

SHANDONG UNIVERSITY

“The most vortical fluid”

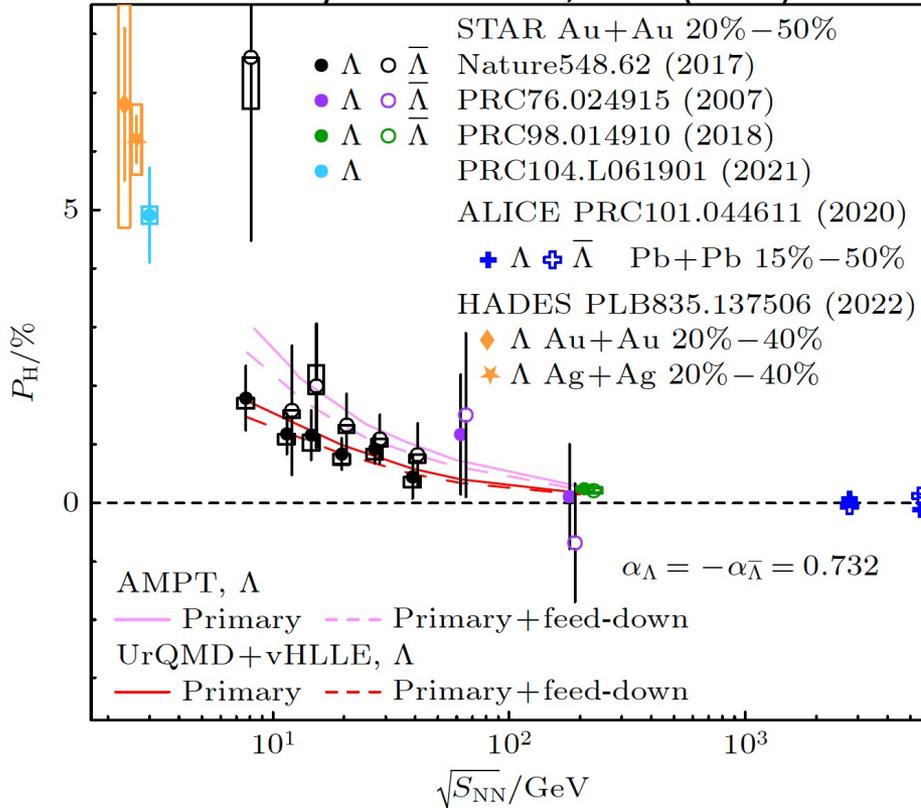


Large initial orbital angular momentum
Can polarize particles through spin-orbit coupling

Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)

“The most vortical fluid”

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



Theoretical models for energy dependence

Liang and Wang, PRL 94,102301(2005)

Voloshin, nucl-th/0410089

Gao et al., PRC 77, 044902(2008)

I. Karpenko and F. Becattini, EPJC(2017)77:213, UrQMD+vHLLJ

H. Li et al., PRC 96, 054908 (2017), AMPT

Becattini, Lisa, Ann. Rev. Nucl. Part. Sci. 70, 395 (2020)

Huang, Liao, QW, Xia, Lect. Notes Phys. 987, 281 (2021)

Becattini, Rept. Prog. Phys. 85, No.12, 122301 (2022)

QW, Liang, ActaPhys. Sin. 72, No. 7 & 11 (2023)

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Large initial orbital angular momentum

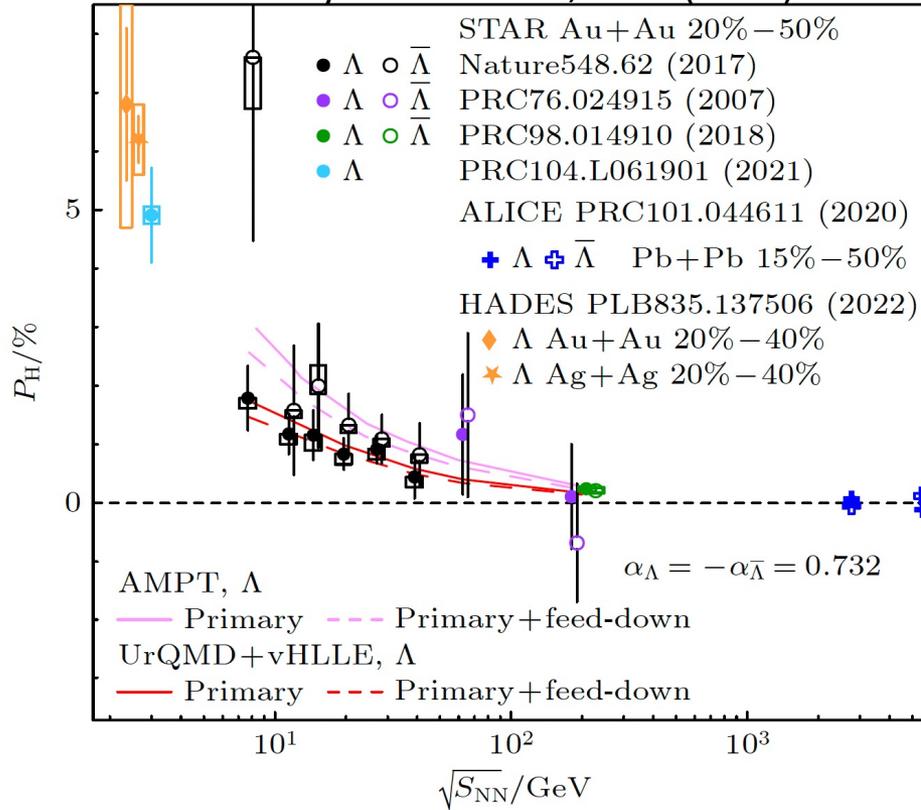
Can polarize particles through spin-orbit coupling

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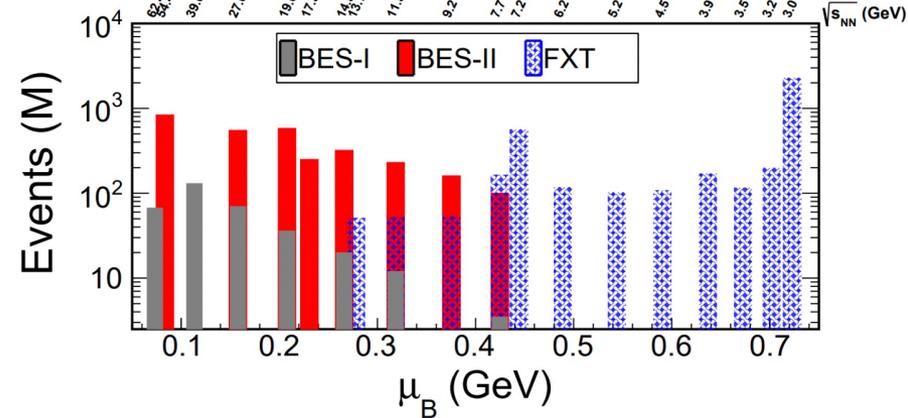
Largest vorticity ever seen $\omega \approx (9 \pm 1) \times 10^{21} \text{ s}^{-1}$

“The most vortical fluid”

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BES-I (2010-2017) and BES-II (2018-2021) statistics



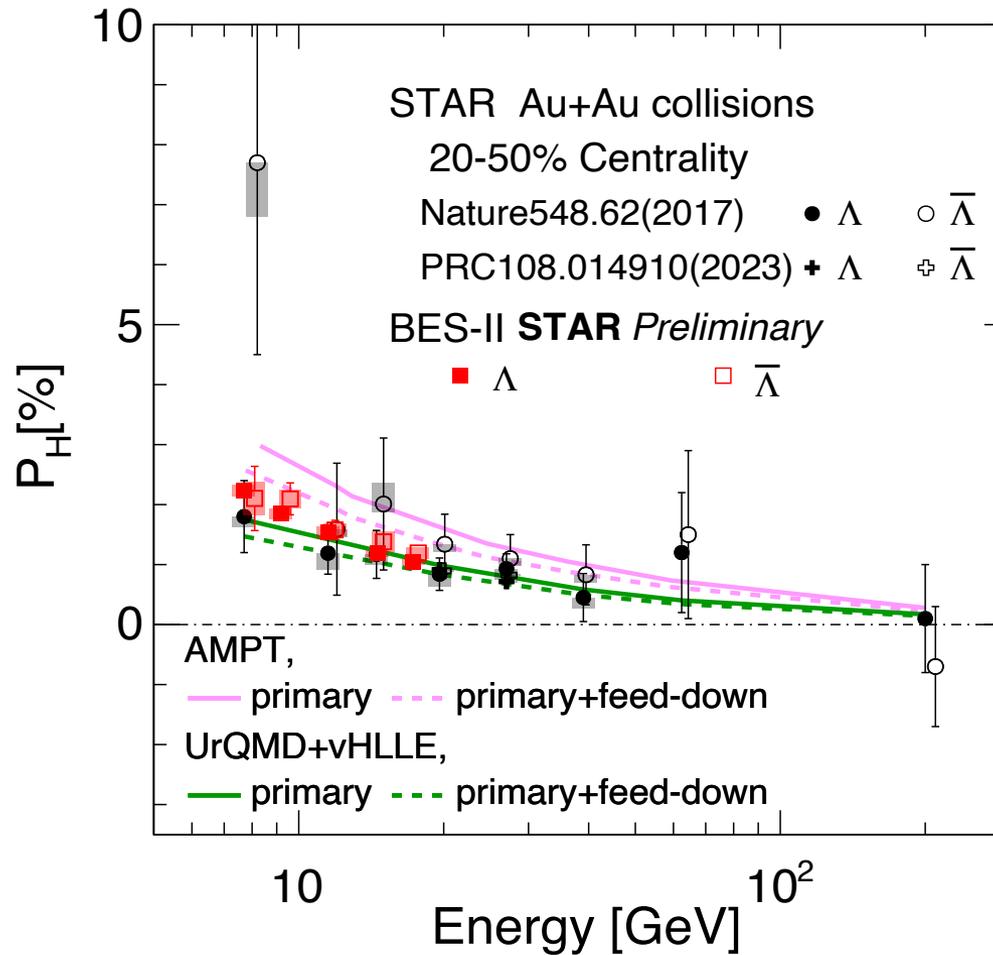
STAR BESII data can largely improve the precision especially at lower energies

Large initial orbital angular momentum
 Can polarize particles through spin-orbit coupling

Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)

Largest vorticity ever seen $\omega \approx (9 \pm 1) \times 10^{21} \text{ s}^{-1}$

Λ global polarization from BESII



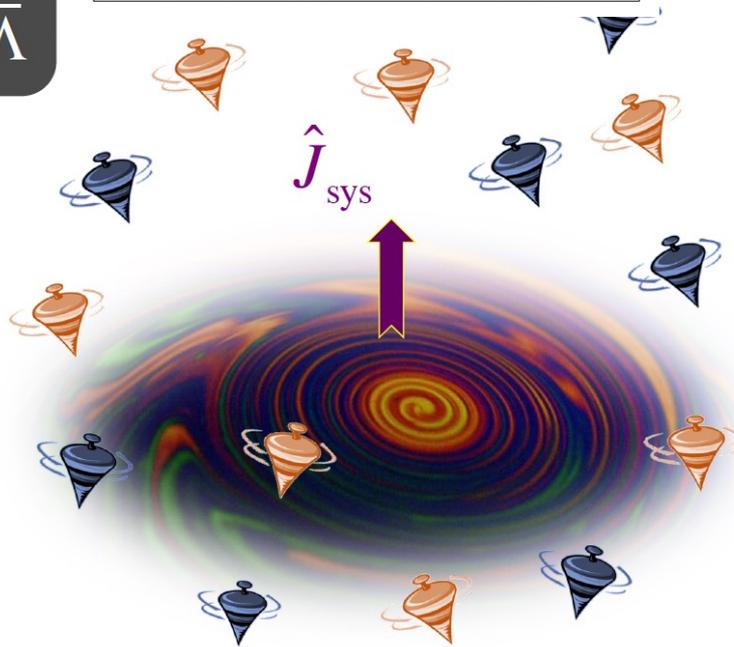
More than factor of 5 improvement in uncertainties
Potential to rule out models

Λ global polarization from BESII: magnetic field



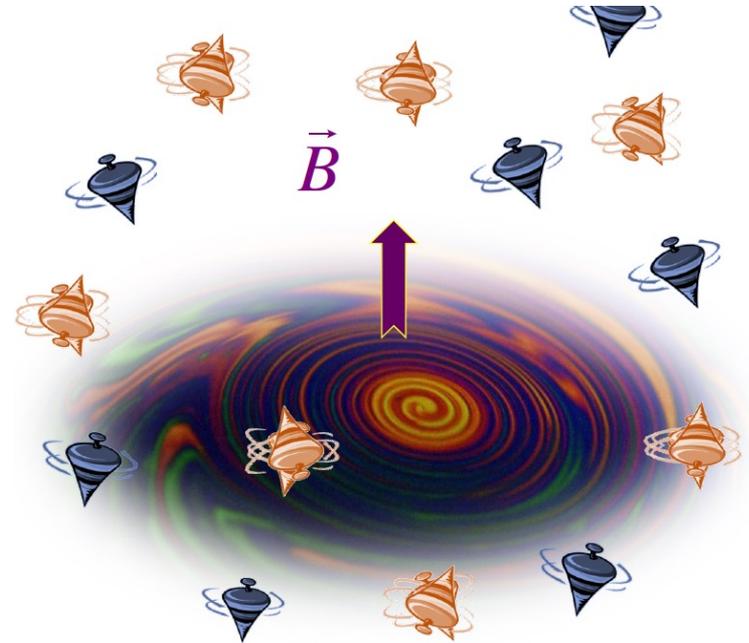
Vortical coupling: $P \propto \omega$

$$\vec{P}_\Lambda \parallel +\hat{J}_{\text{sys}} \quad \vec{P}_{\bar{\Lambda}} \parallel +\hat{J}_{\text{sys}}$$



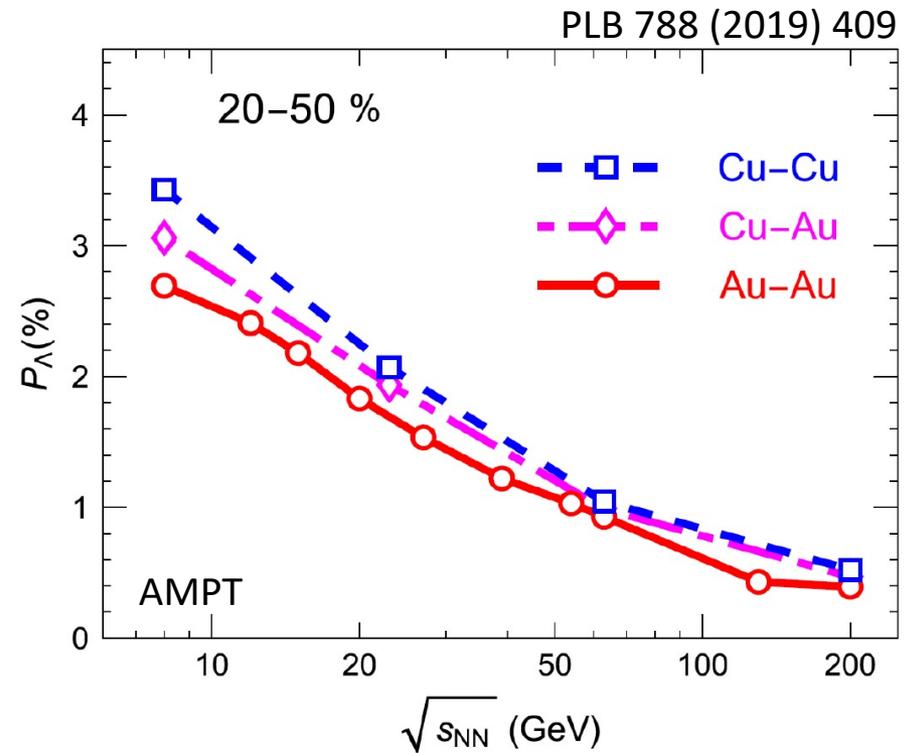
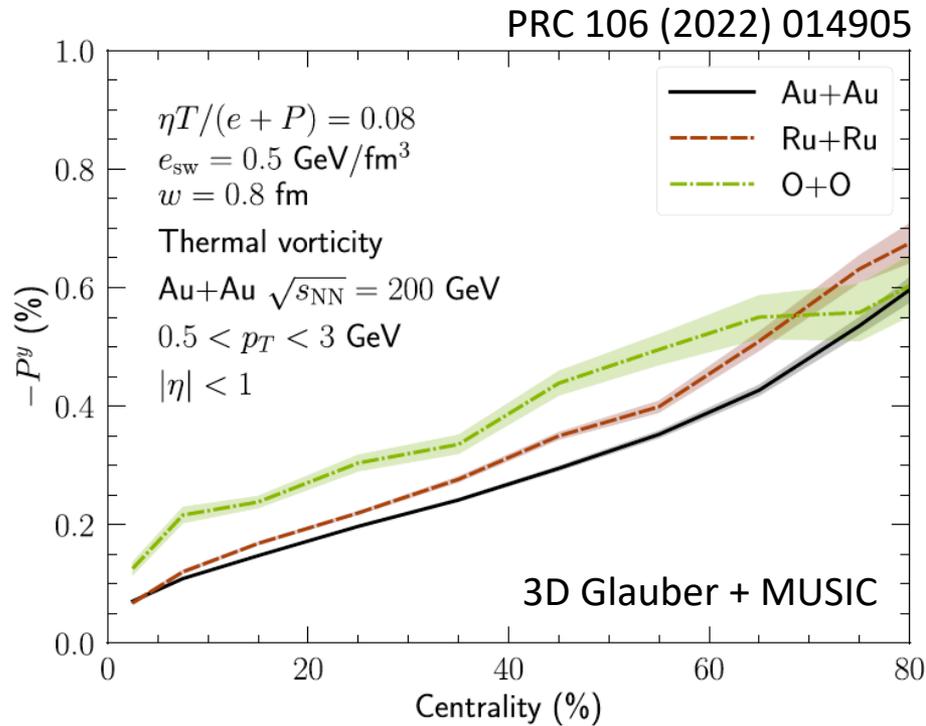
Magnetic coupling: $P \propto \vec{\mu} \cdot \vec{B}$

$$\vec{P}_\Lambda \parallel -\vec{B} \quad \vec{P}_{\bar{\Lambda}} \parallel +\vec{B}$$



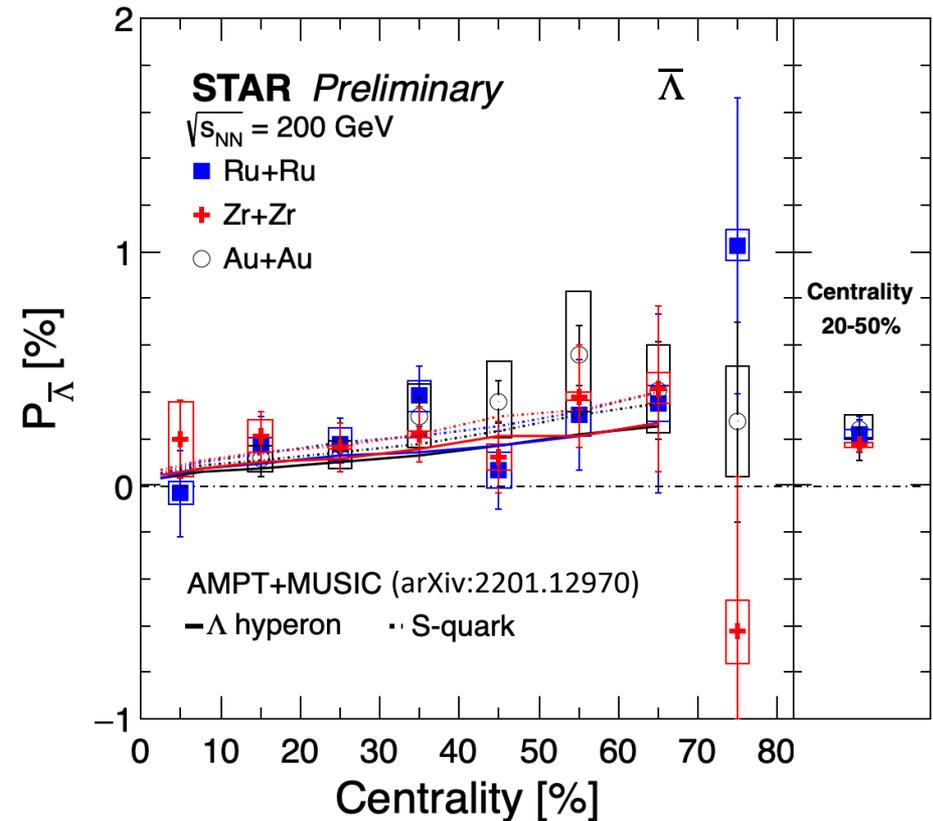
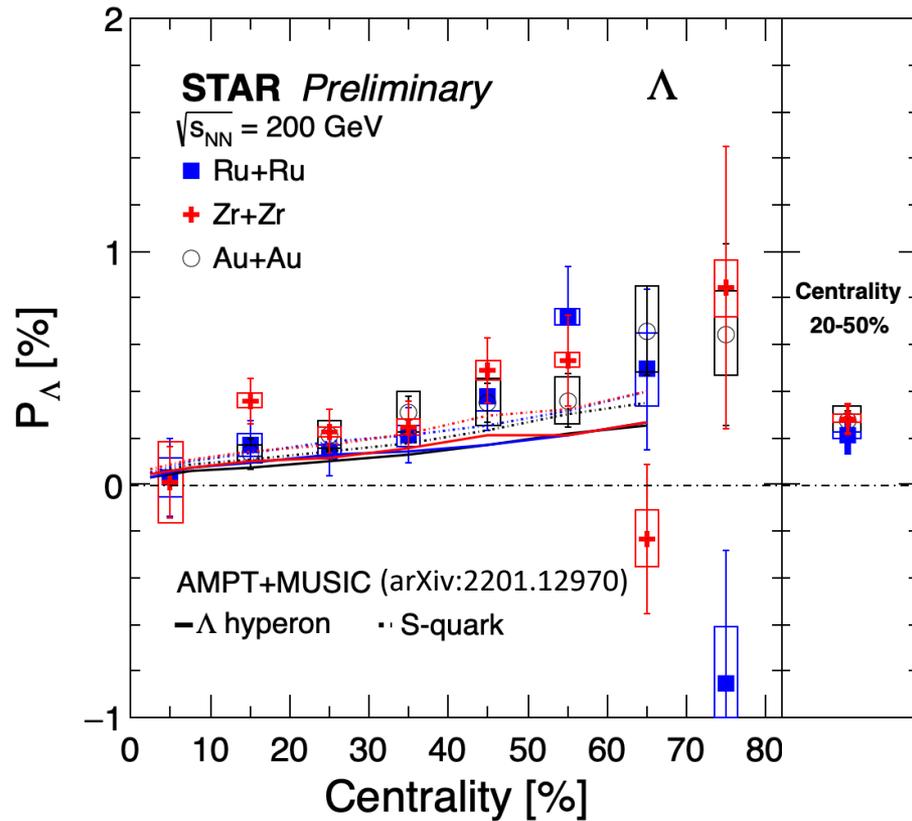
QGP trapped magnetic field leads to splitting between Λ & anti- Λ

Λ global polarization: system size dependence



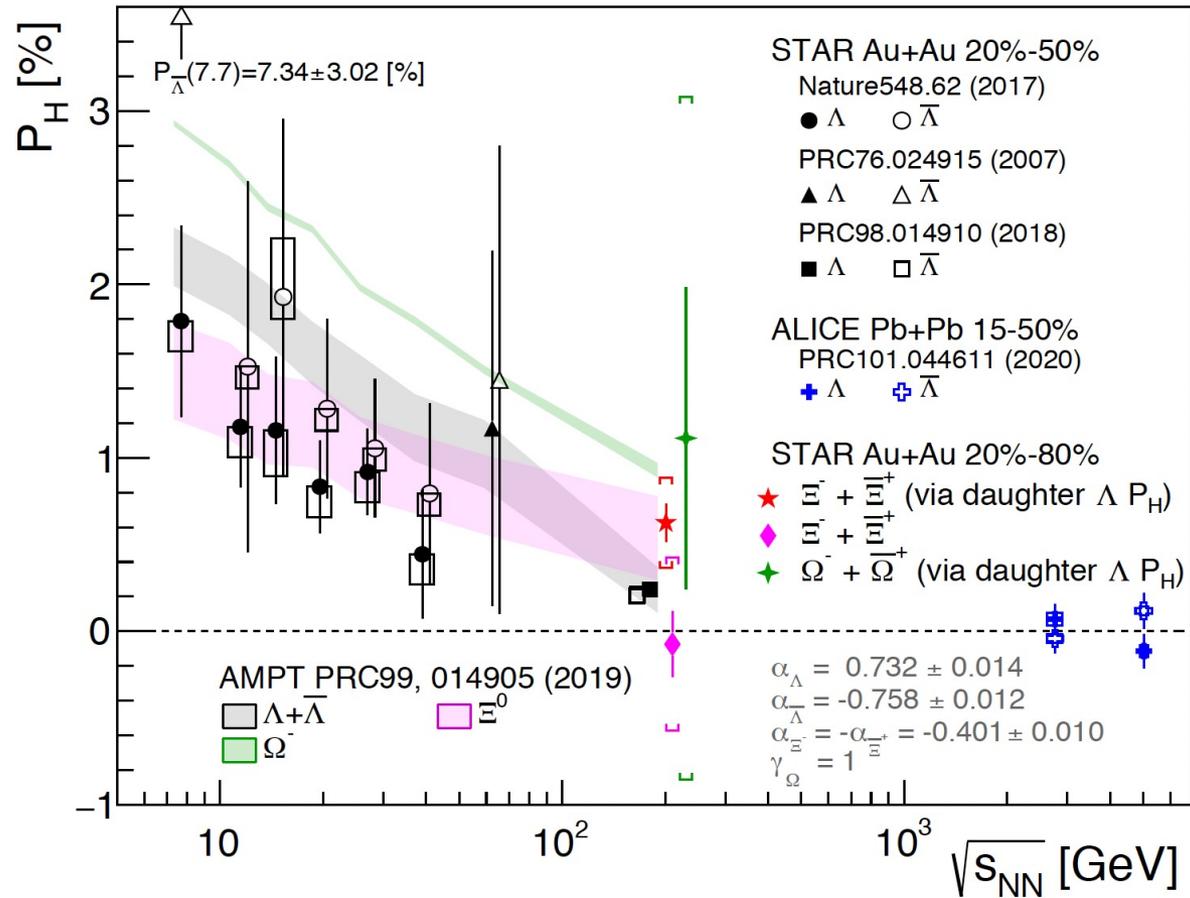
Smaller polarization predicted for larger system due to longer lifetime

Λ global polarization: system size dependence



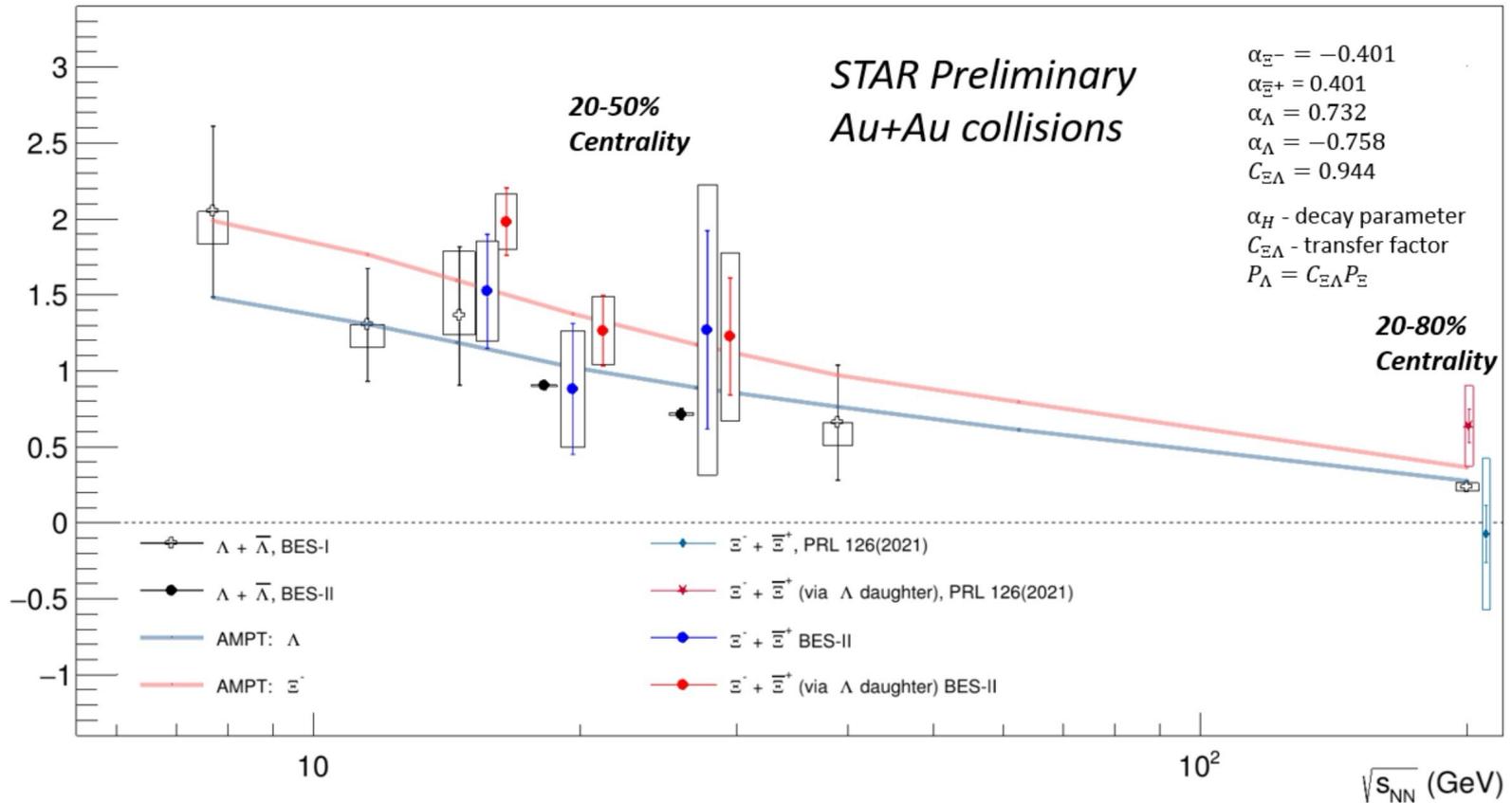
Smaller polarization predicted for larger system due to longer lifetime
No obvious difference between Ru, Zr and Au results

global polarization



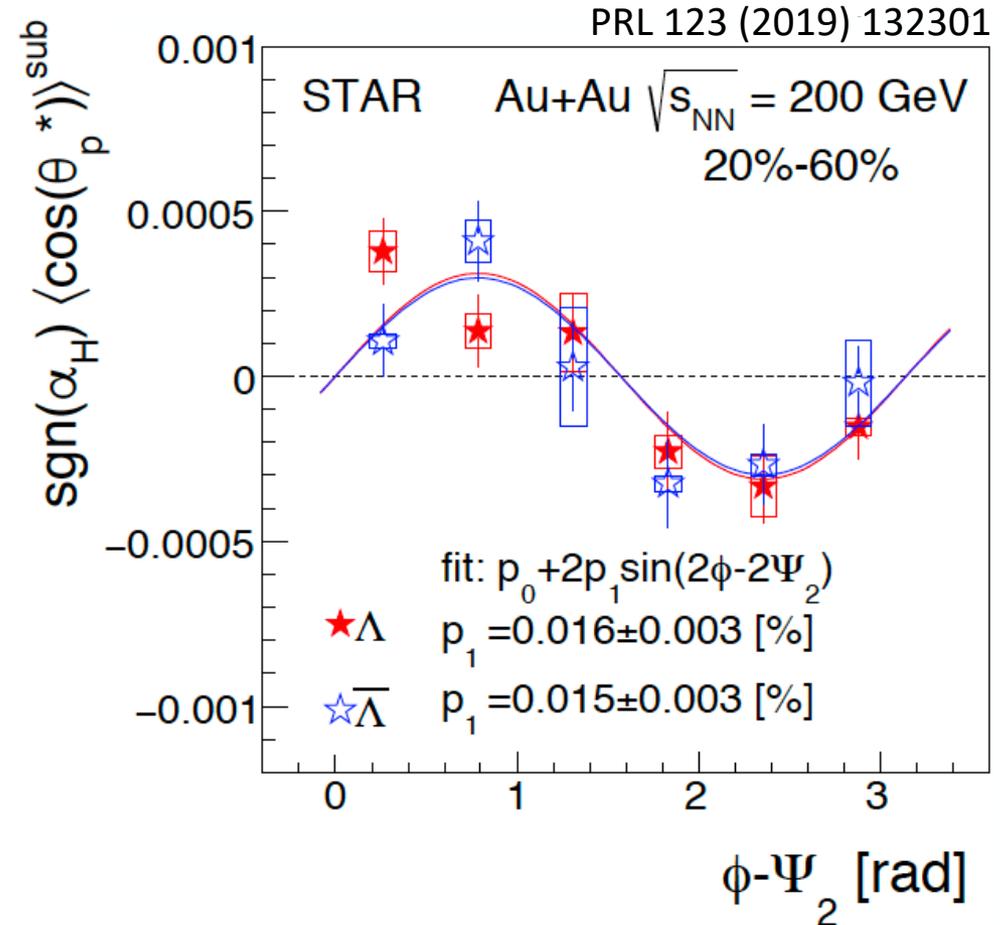
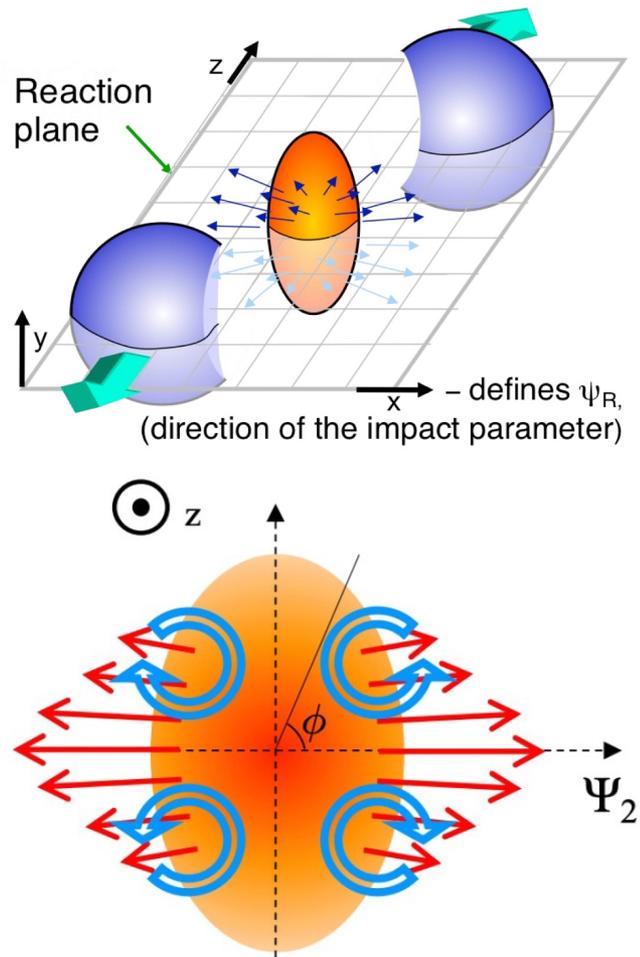
Possible difference between hyperons due to production time
 Observed hint of Ξ and Ω polarization at 200 GeV

Ξ global polarization



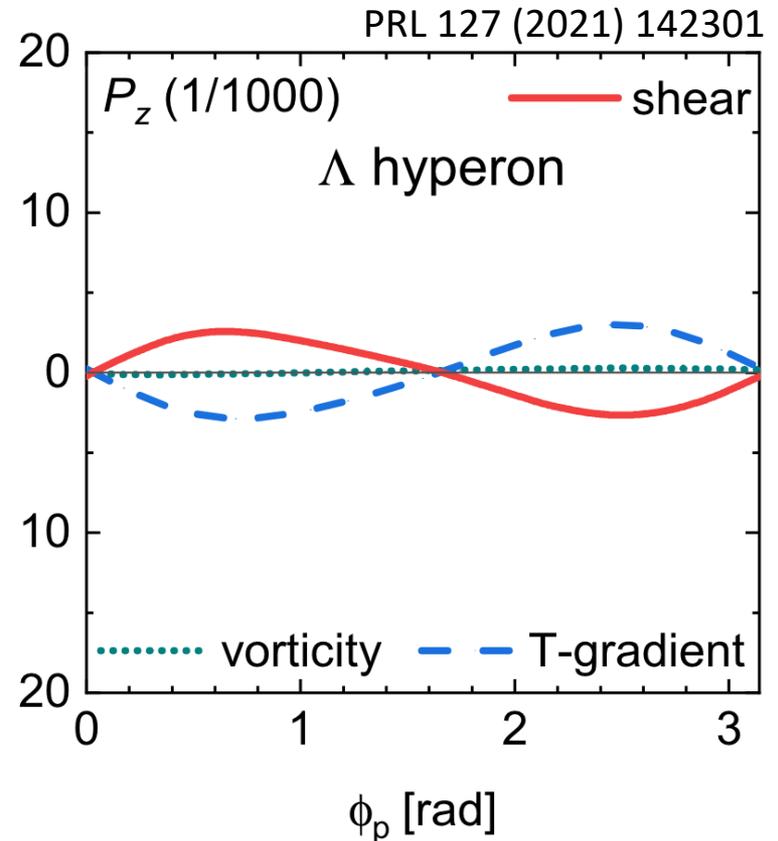
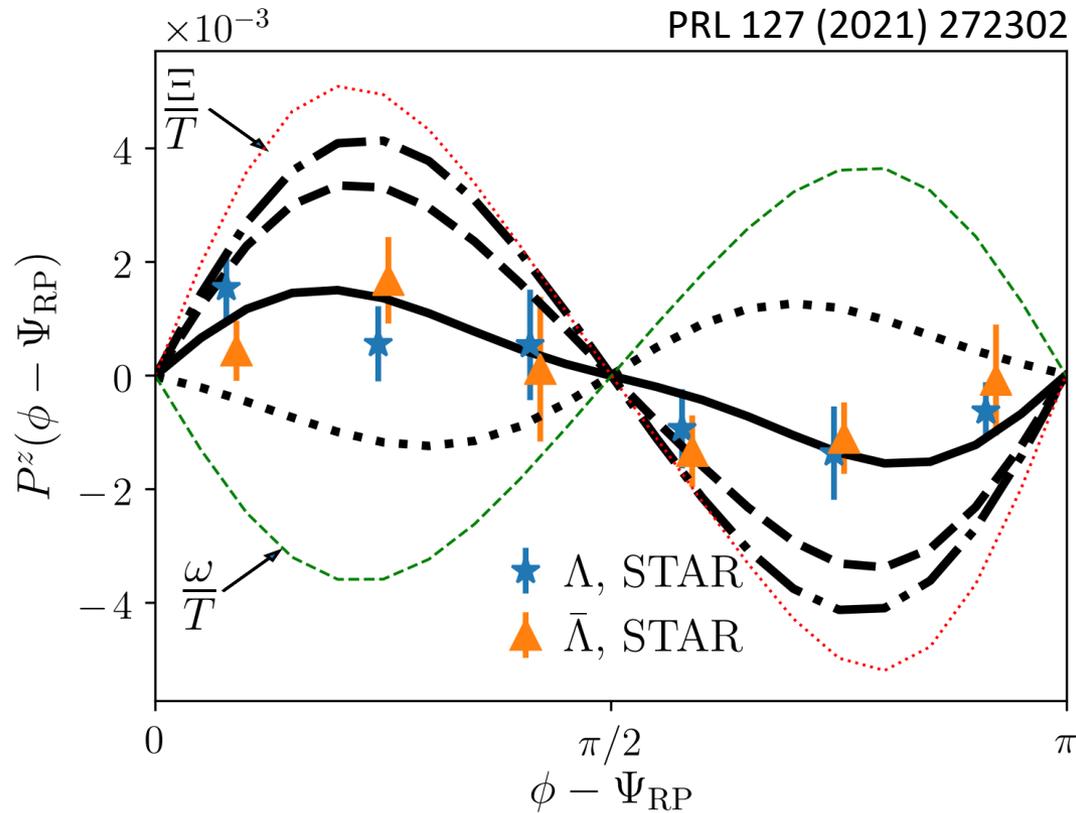
Significant Ξ global polarization in 14.5, 19.6 and 27 GeV Au+Au
 Stay tuned for lower energies and Ω results

Hyperon polarization along beam direction



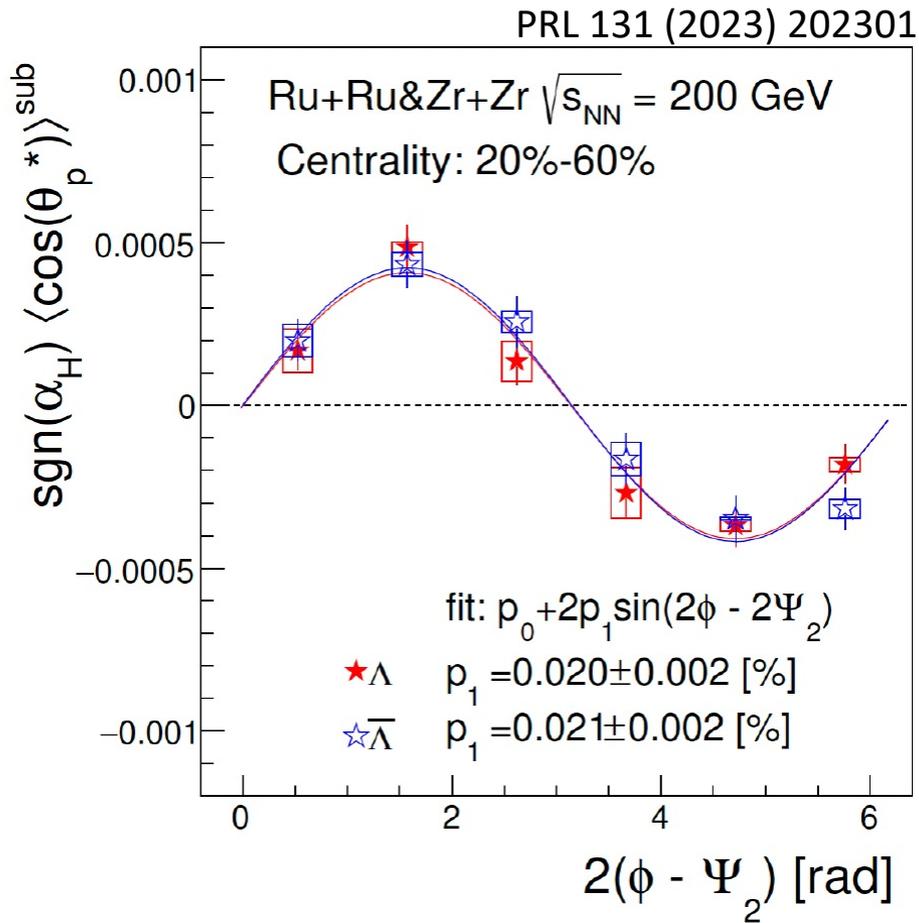
Simple expectation of vorticity from the anisotropic expansion of QGP
Confirmed at RHIC and LHC

“ P_z puzzle”



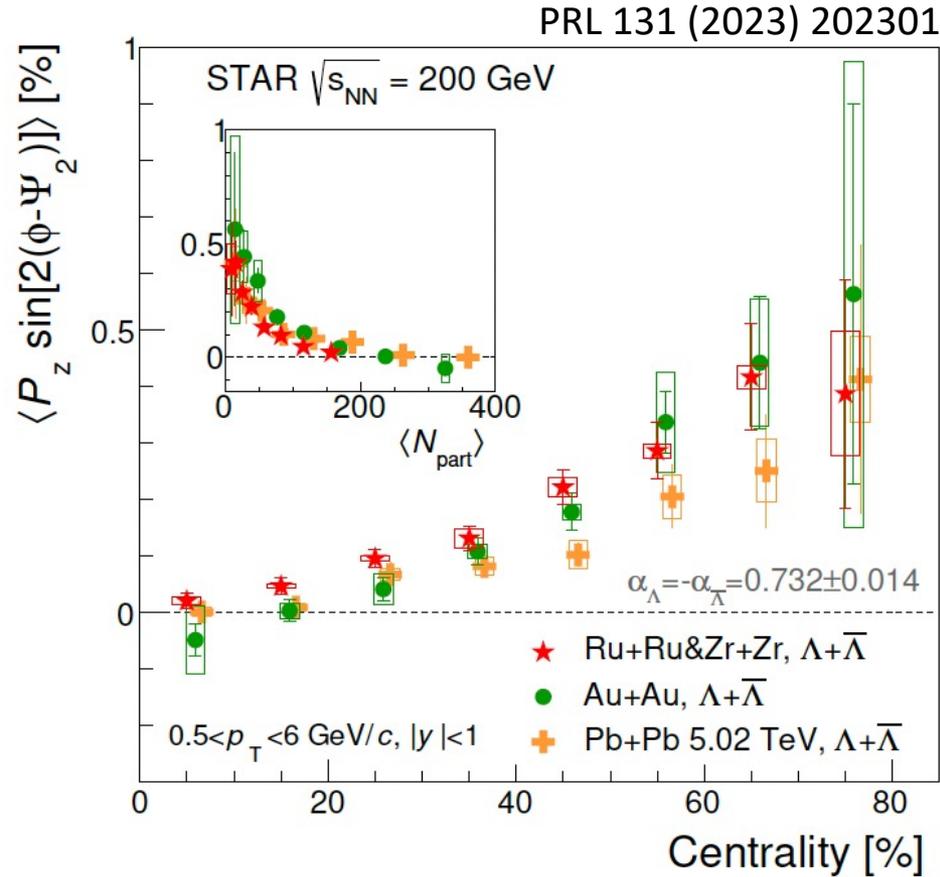
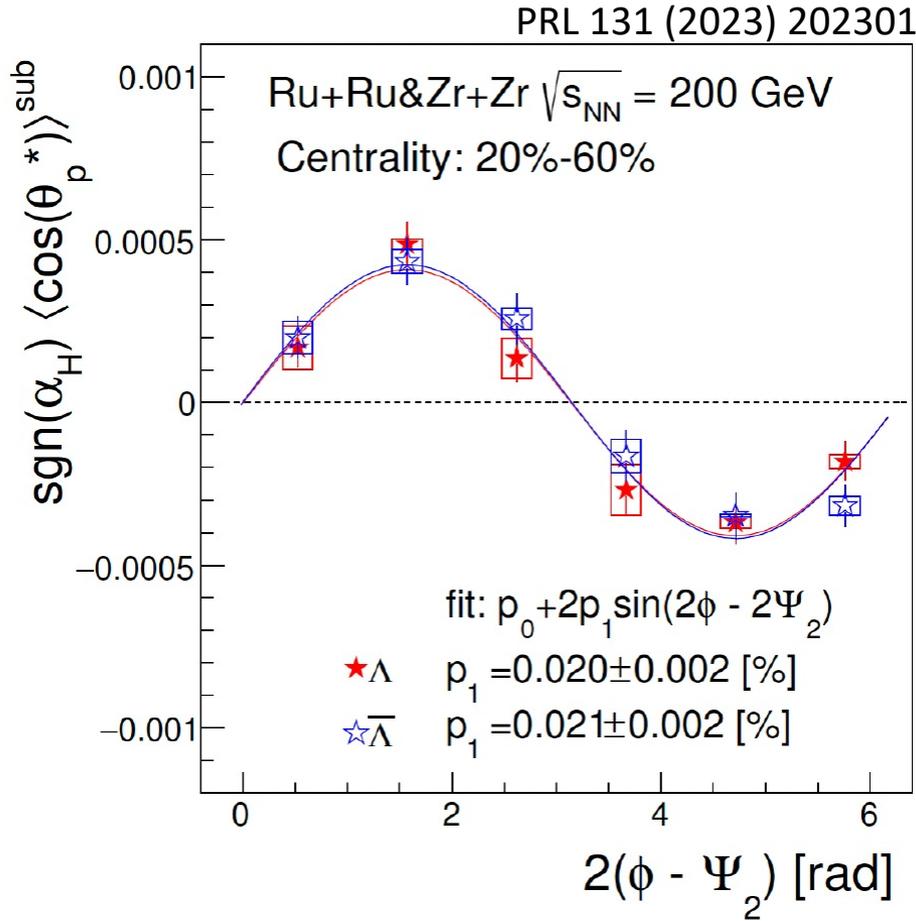
Contribution from shear induced polarization needed to get the correct sign
Calculations depend on the details of shear term implementation

System size dependence of P_z



More precise measurements in isobar collisions

System size dependence of P_z

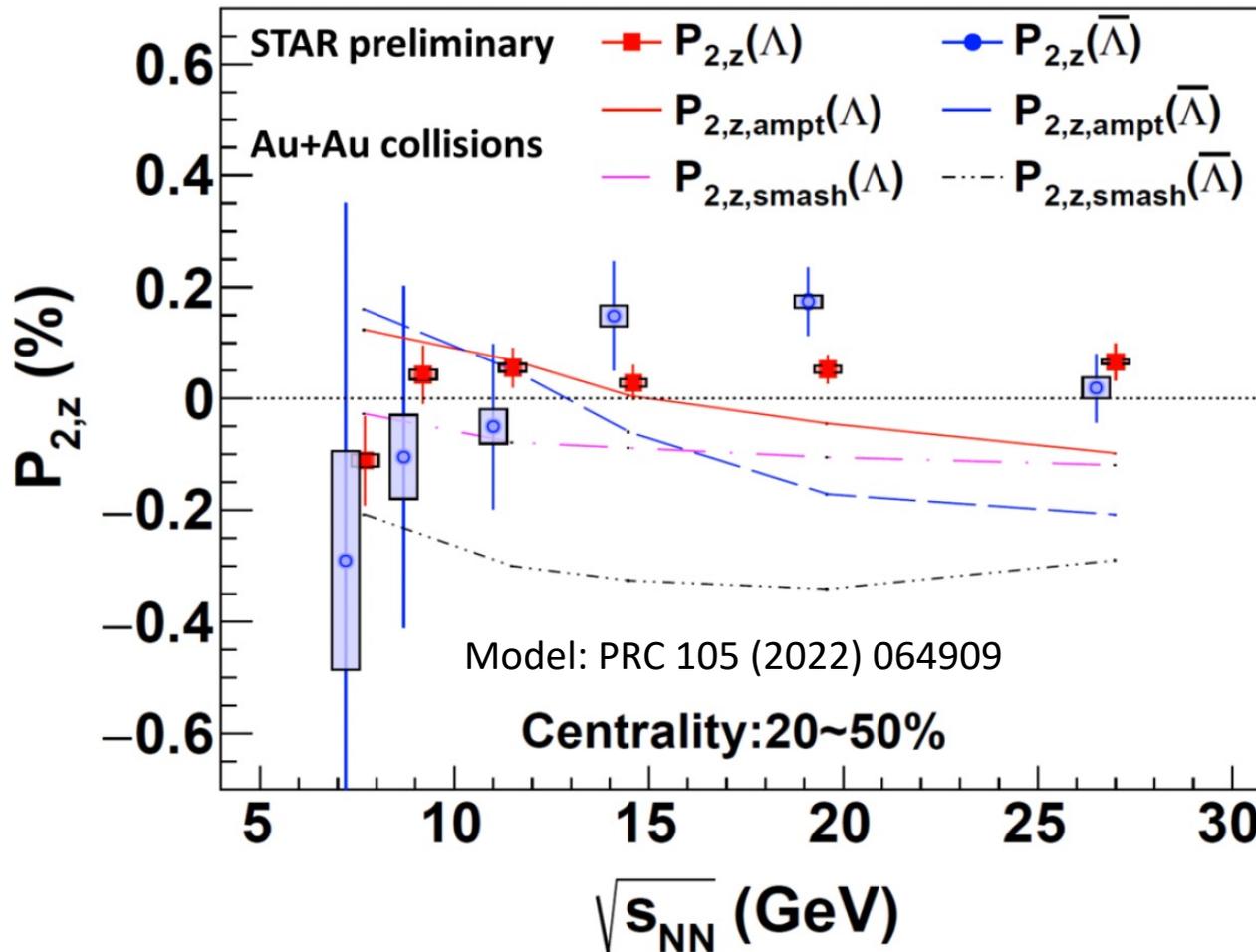


More precise measurements in isobar collisions

No significant system size dependence comparing isobar & AuAu

No significant energy dependence comparing RHIC & LHC

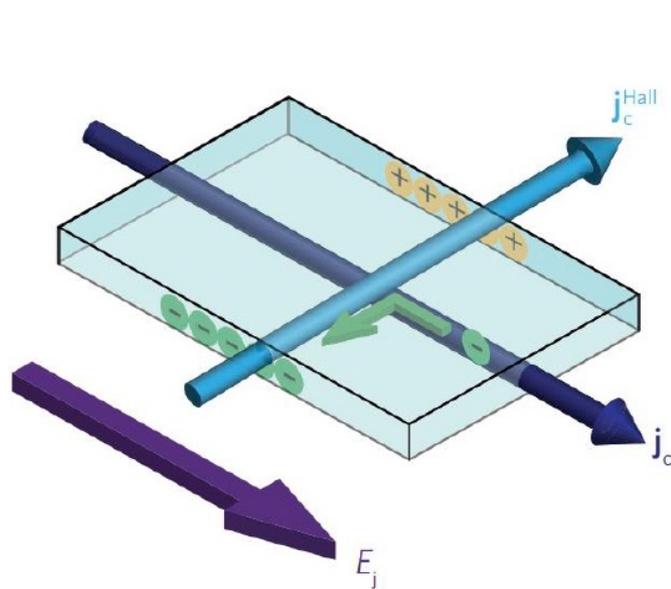
Energy dependence of P_z



No obvious energy dependence observed 9.2 - 200 GeV
 Hint of sign change at 7.7 GeV? Why?

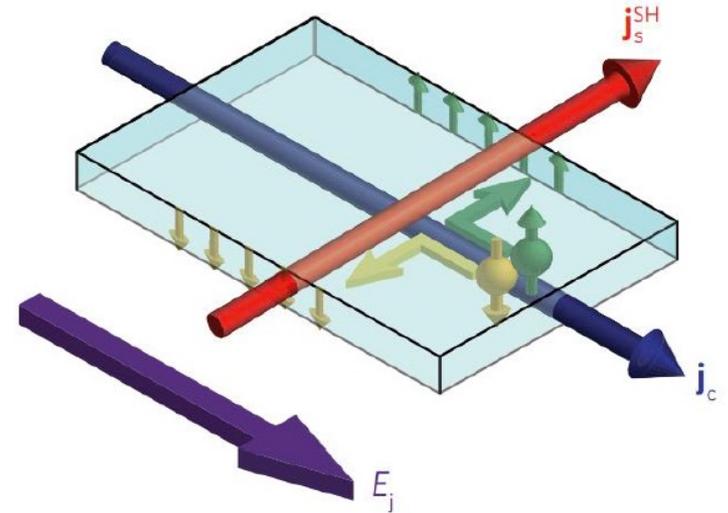
Baryonic Spin Hall Effect

S. Meyer et al., Nature Materials, 2017



Hall effect, 1879

$$P \propto \mathbf{p} \times \mathbf{E}$$

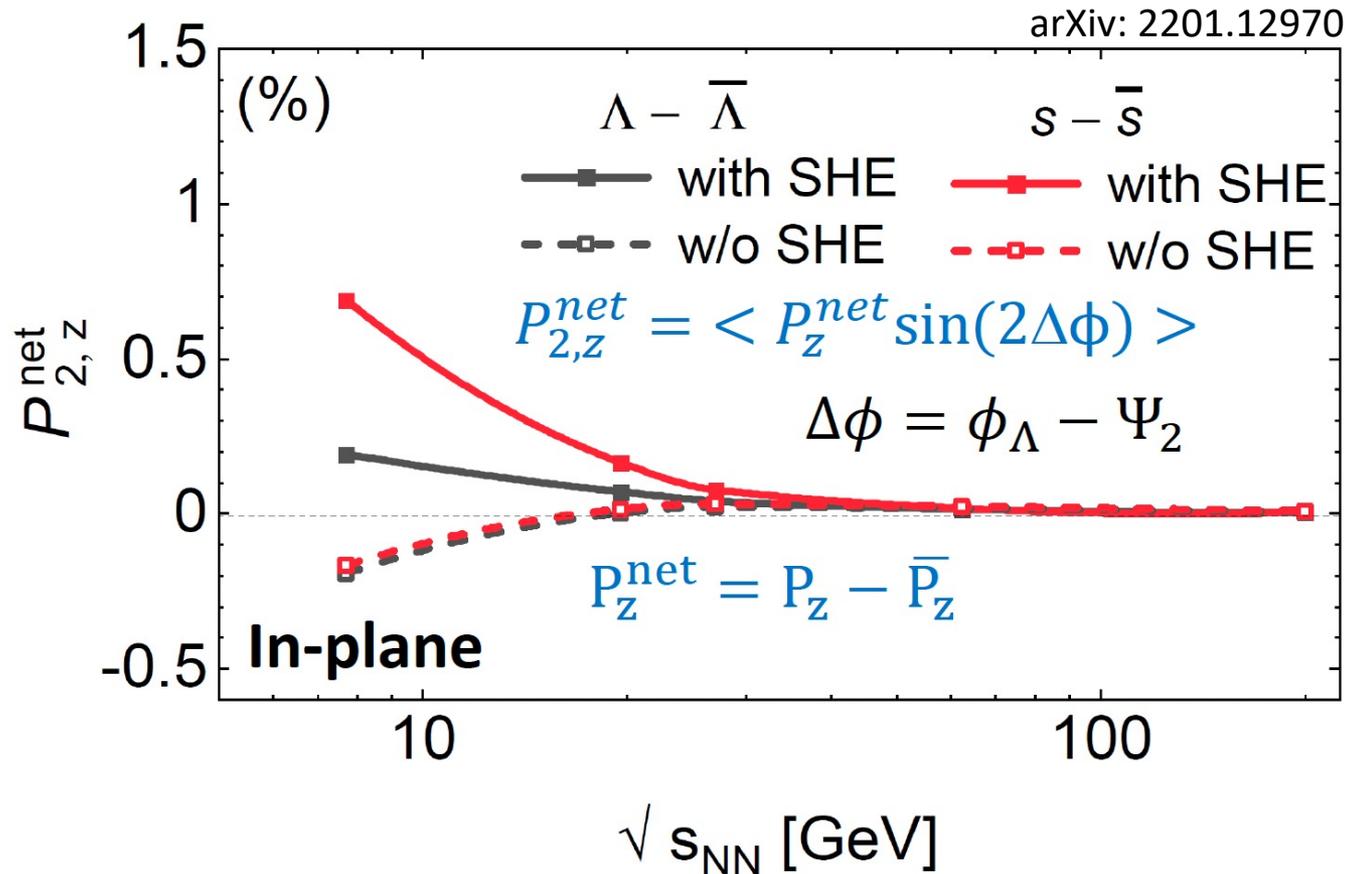


Spin Hall effect, (1972) 2004

$$P \propto \mathbf{p} \times (q_B \nabla \mu_B)$$

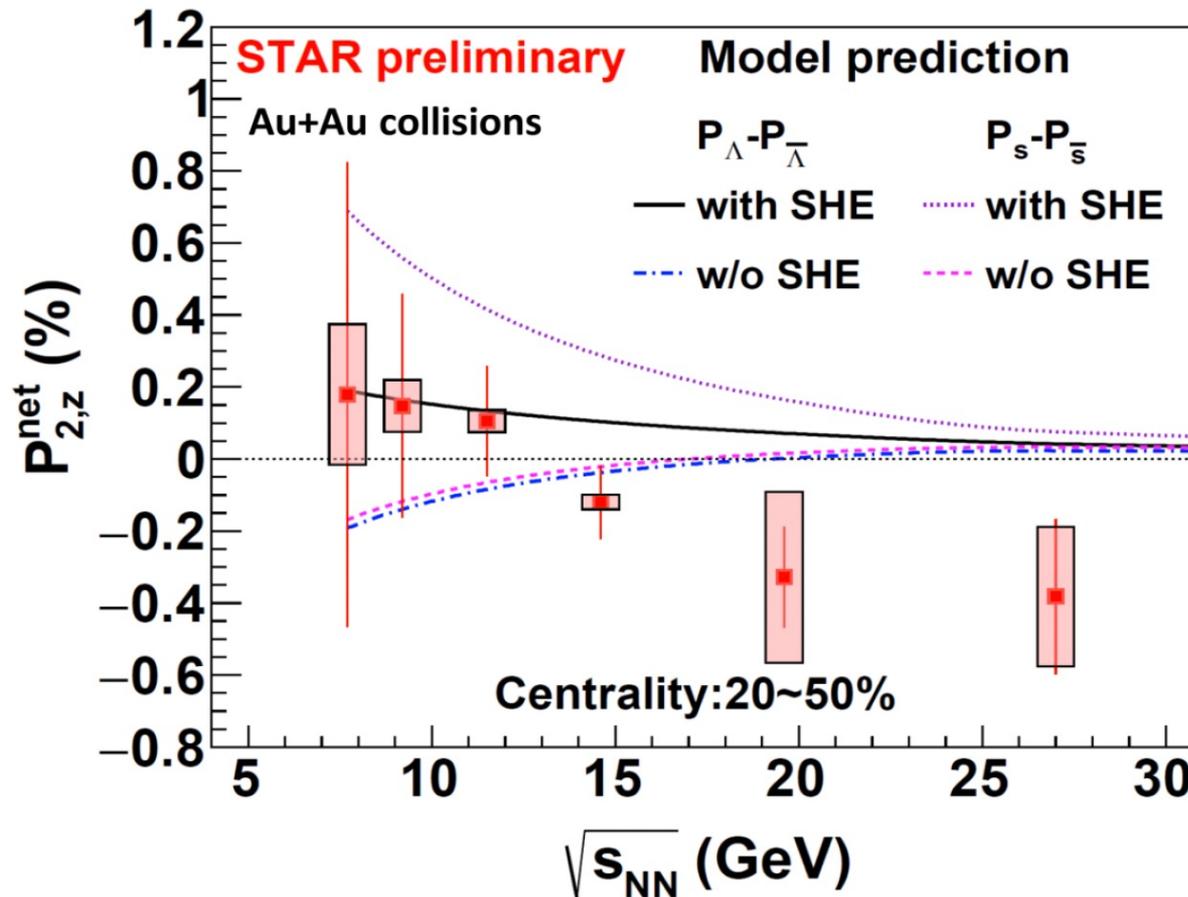
Spin Hall effect driven by baryon potential predicted
 Could introduce a splitting in polarization between Λ & anti- Λ

Baryonic Spin Hall Effect



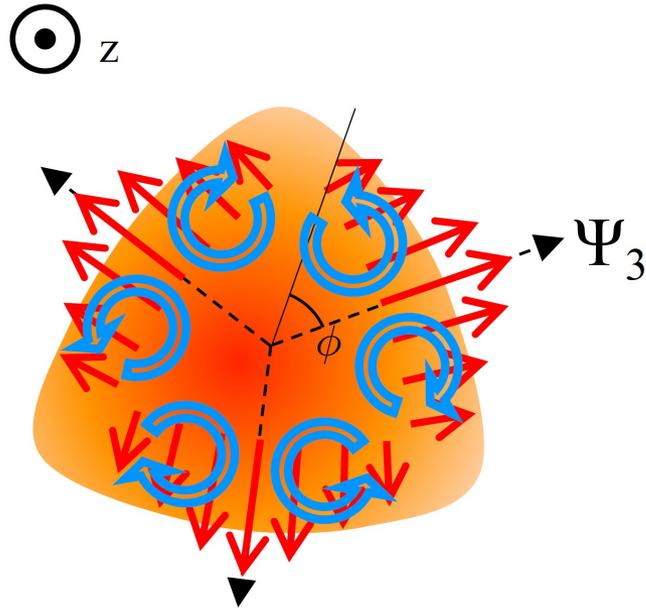
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 Predicts energy dependent net- Λ polarization

Baryonic Spin Hall Effect



Spin Hall effect driven by baryon potential predicted
 Could introduce a splitting in polarization between Λ & anti- Λ
 Predicts energy dependent net- Λ polarization
 No obvious evidence with large uncertainties

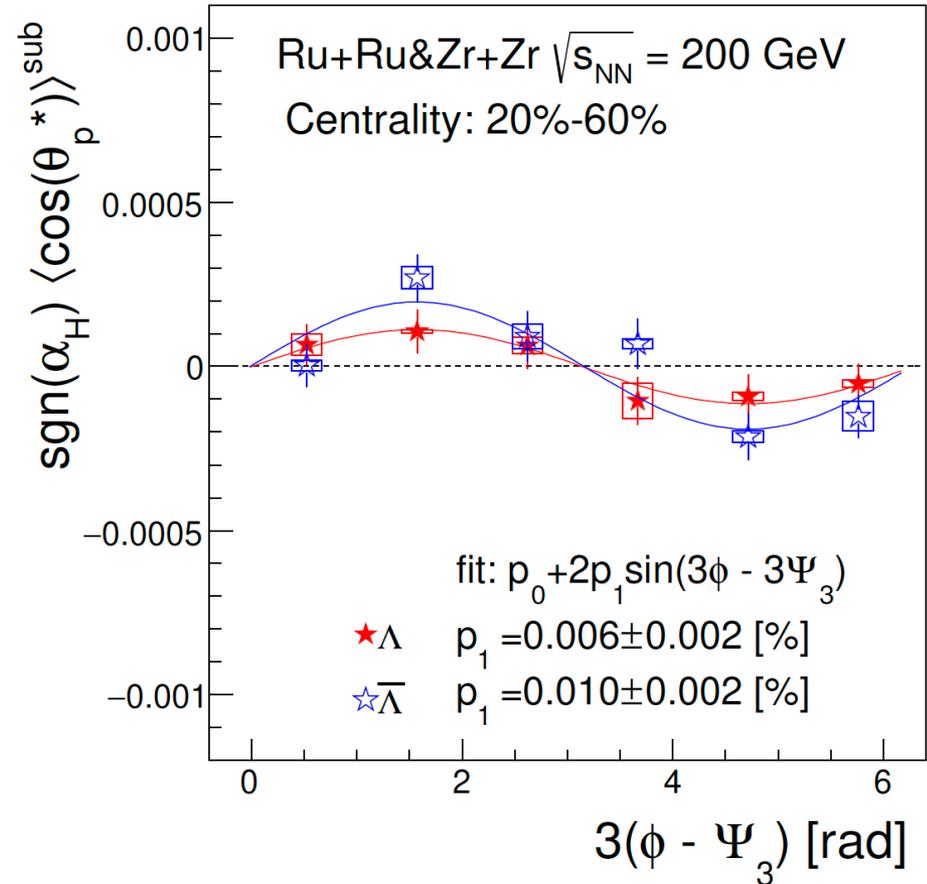
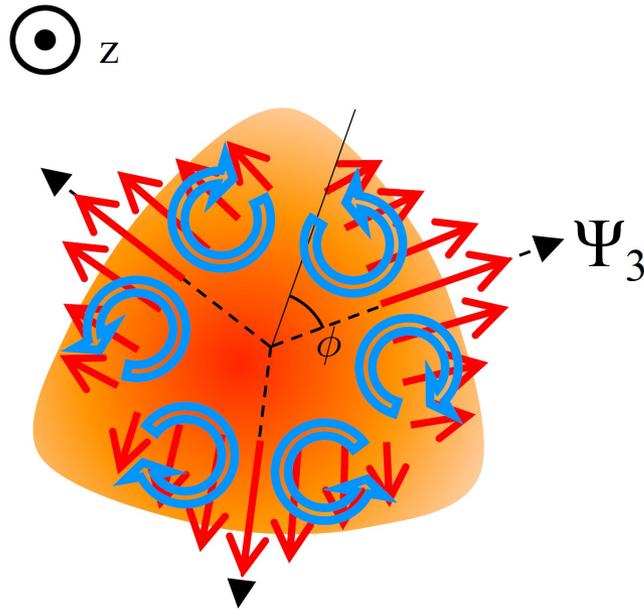
P_z wrt higher order collective flow plane



Does the same mechanism extend to higher order flow?

P_z wrt higher order collective flow plane

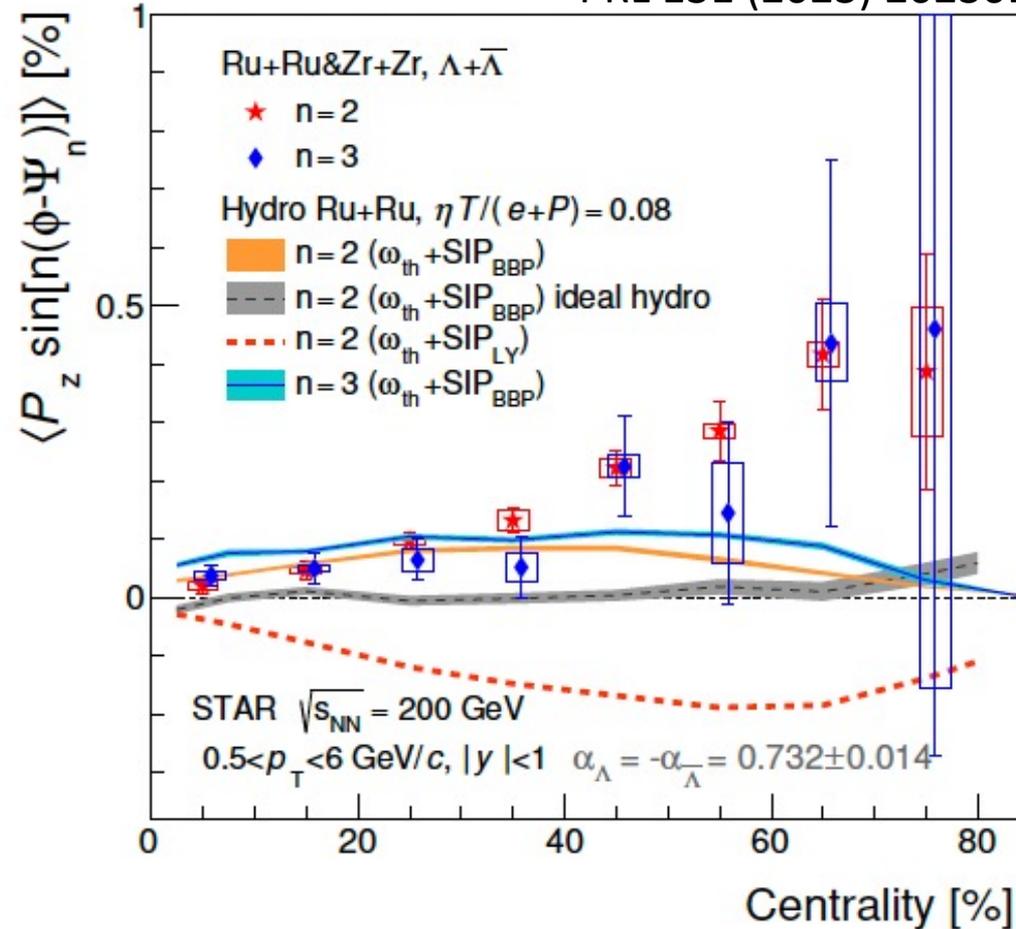
PRL 131 (2023) 202301



Does the same mechanism extend to higher order flow?
Observed in isobar collisions

P_z wrt higher order collective flow plane

PRL 131 (2023) 202301

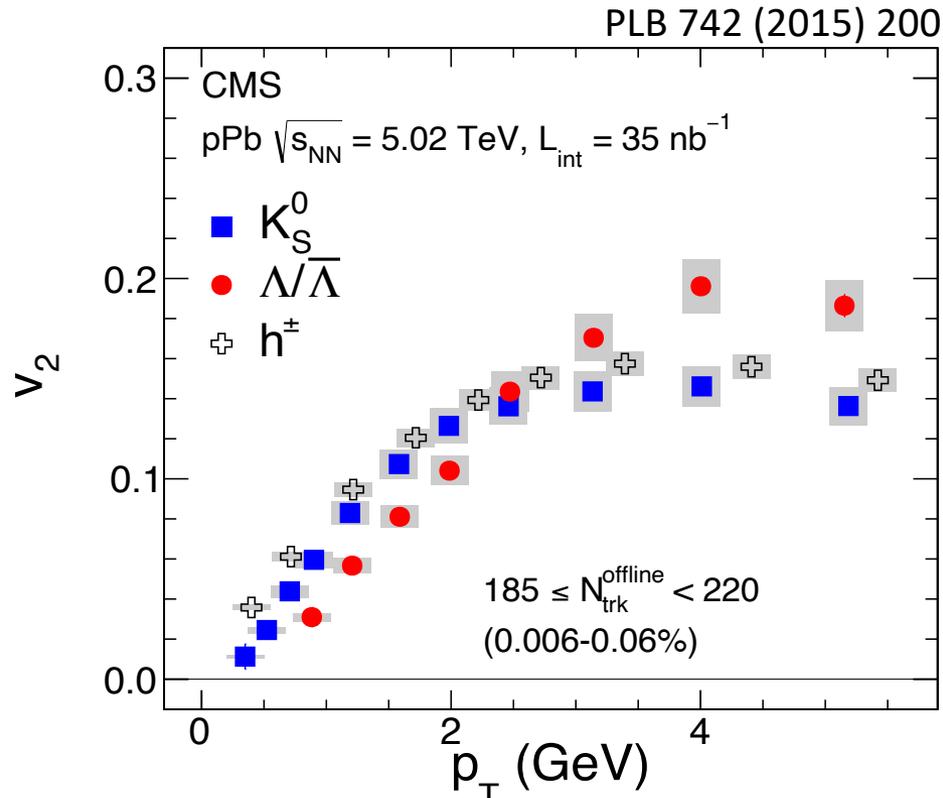


Significant signal comparable to $P_{z,2}$

Hydro with shear contribution describe the data for most centralities

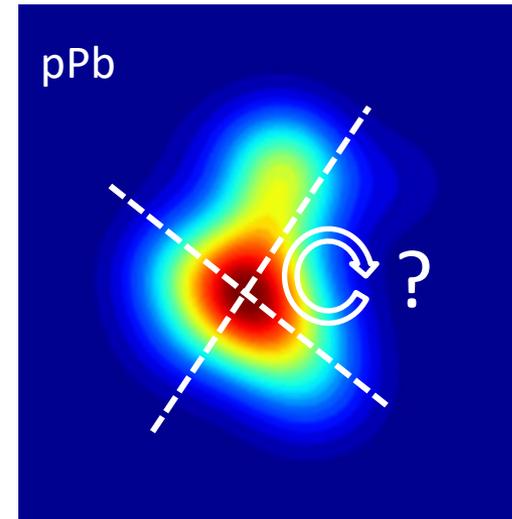
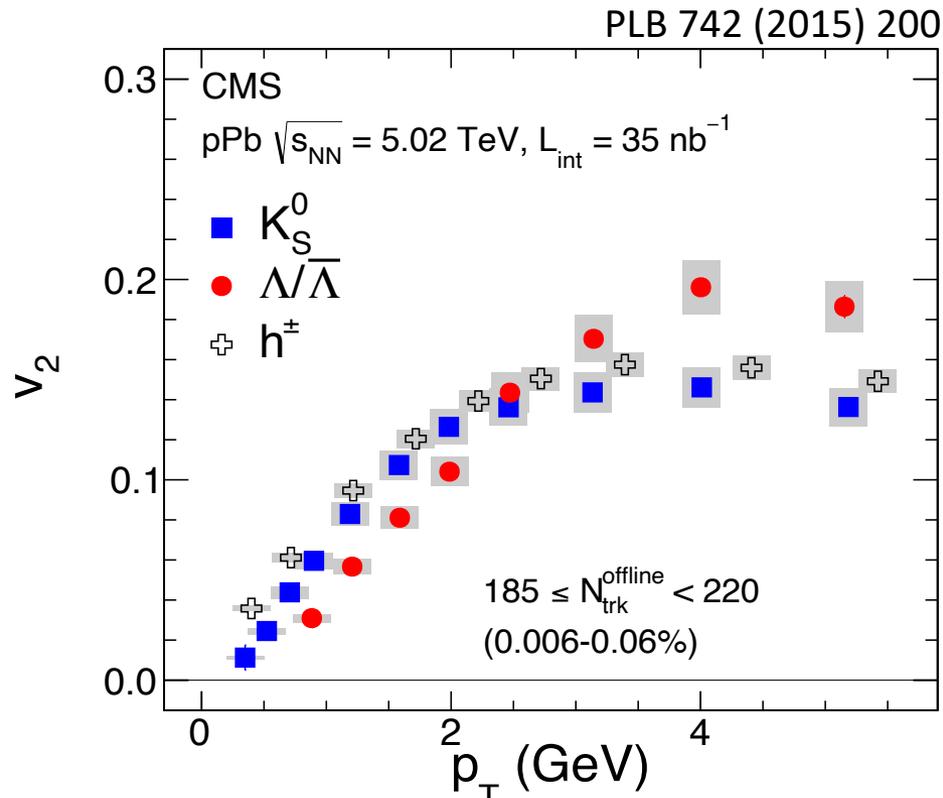
Indicate the link between P_z and collective flow

Extend to small system



Features of QGP droplets observed in small but dense systems

Extend to small system

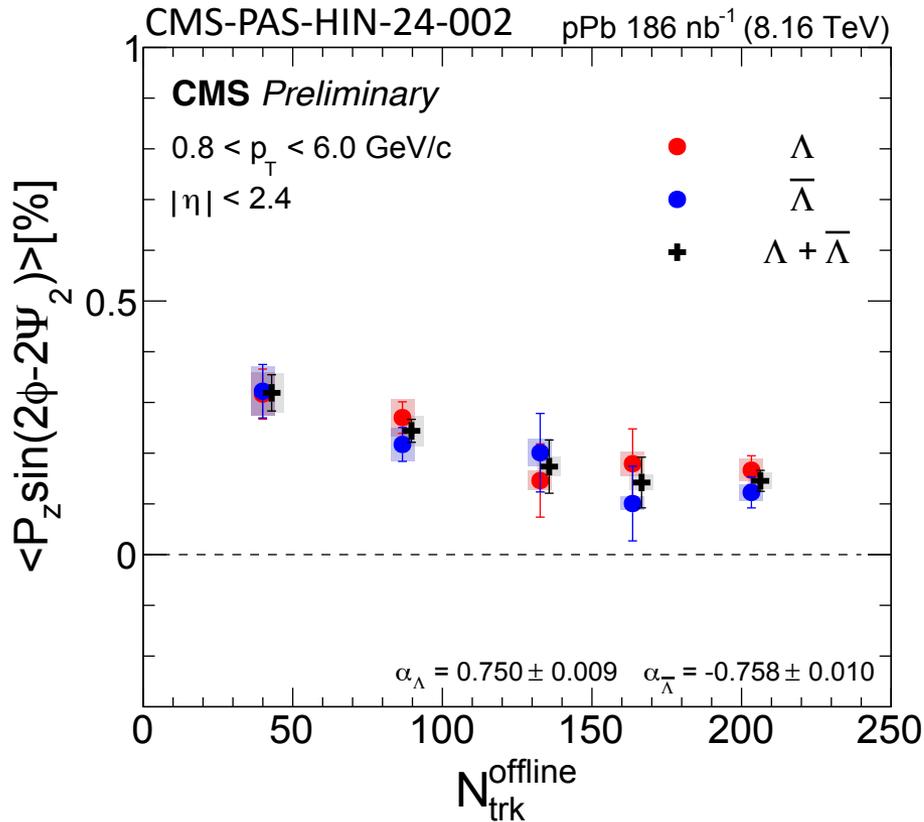


Features of QGP droplets observed in small but dense systems

Can we see hyperon polarization P_z there?

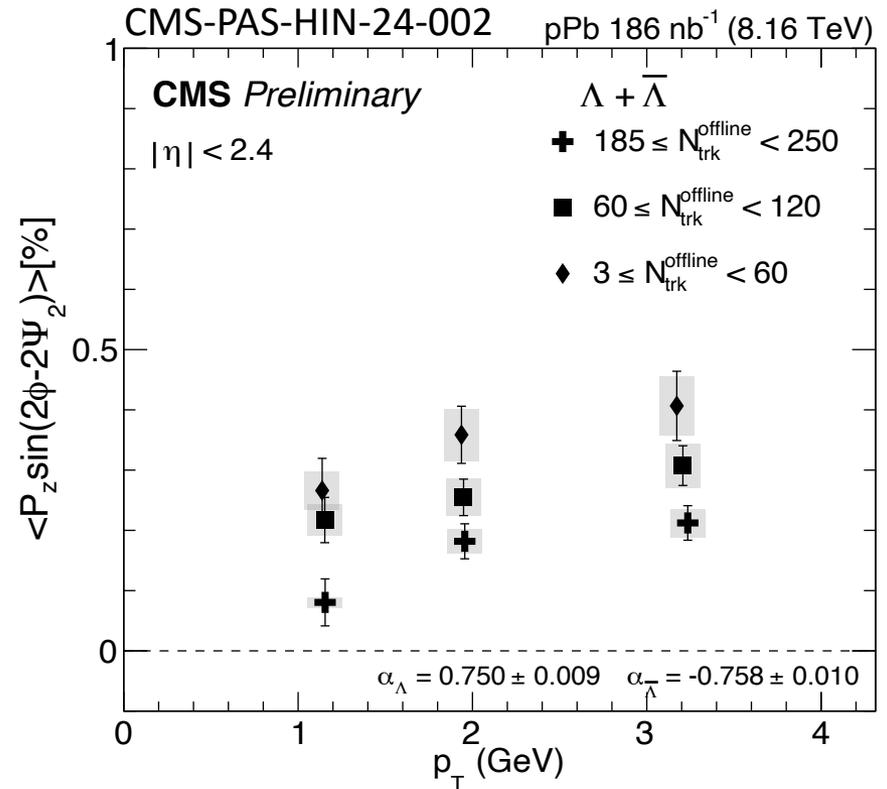
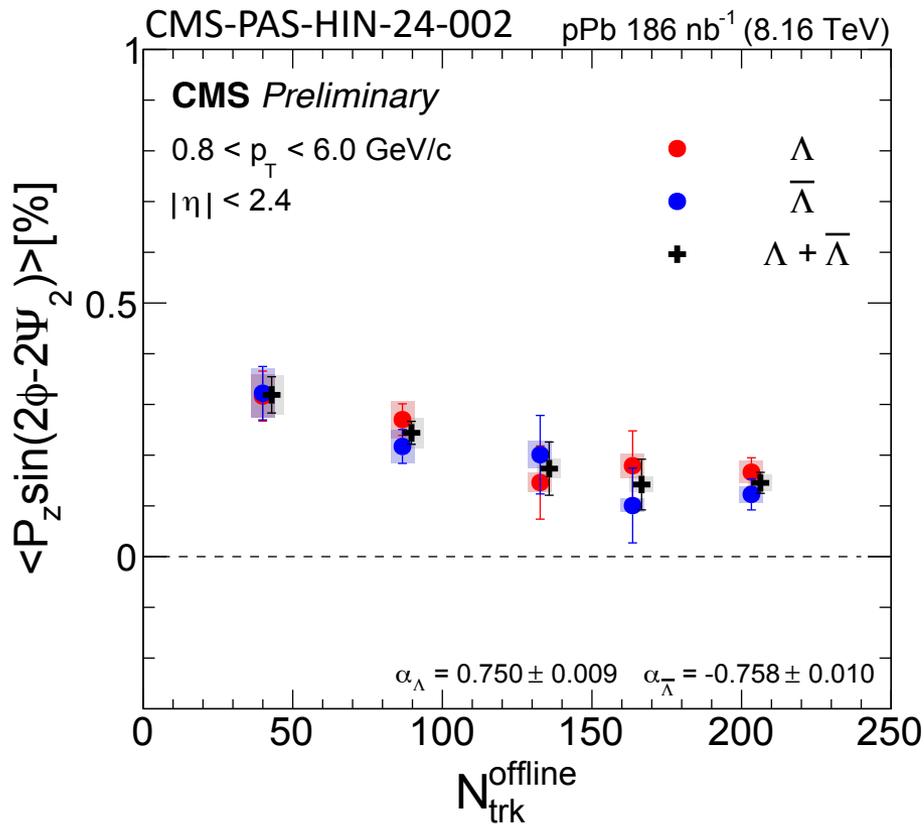
A test of QGP formation & different contributions to P_z

$P_{z,s2}$ in pPb collision



Significant positive $P_{z,s2}$ observed over entire multiplicity range
Consistent results for Λ and anti- Λ
Decrease towards high multiplicity

$P_{z,s2}$ in pPb collision



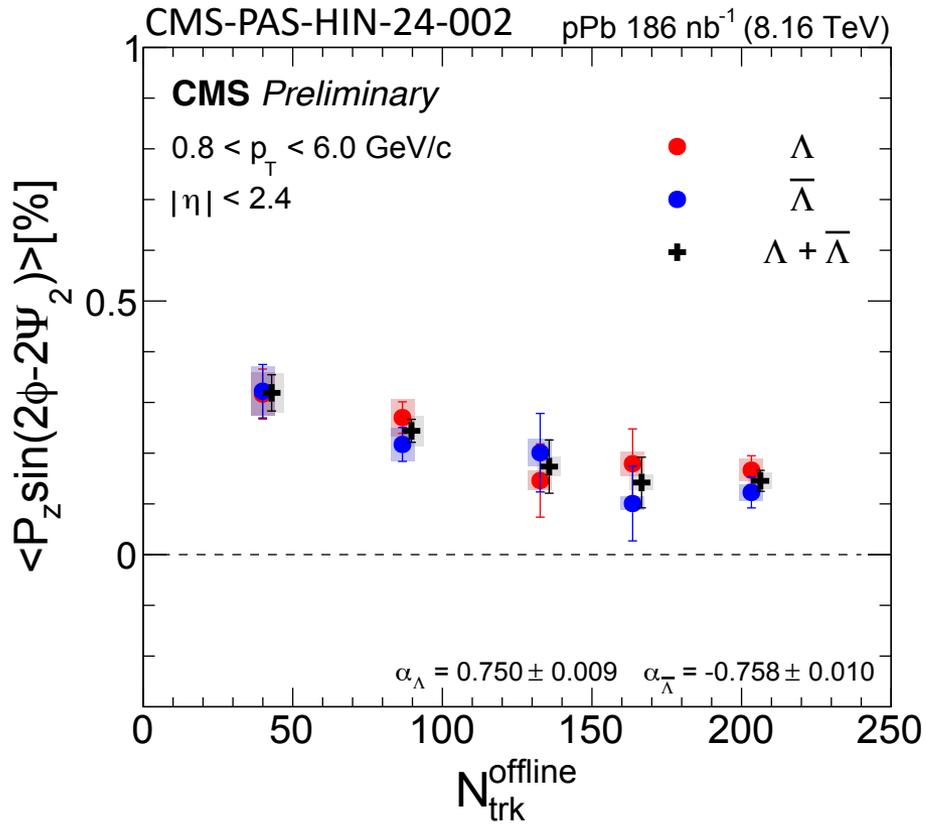
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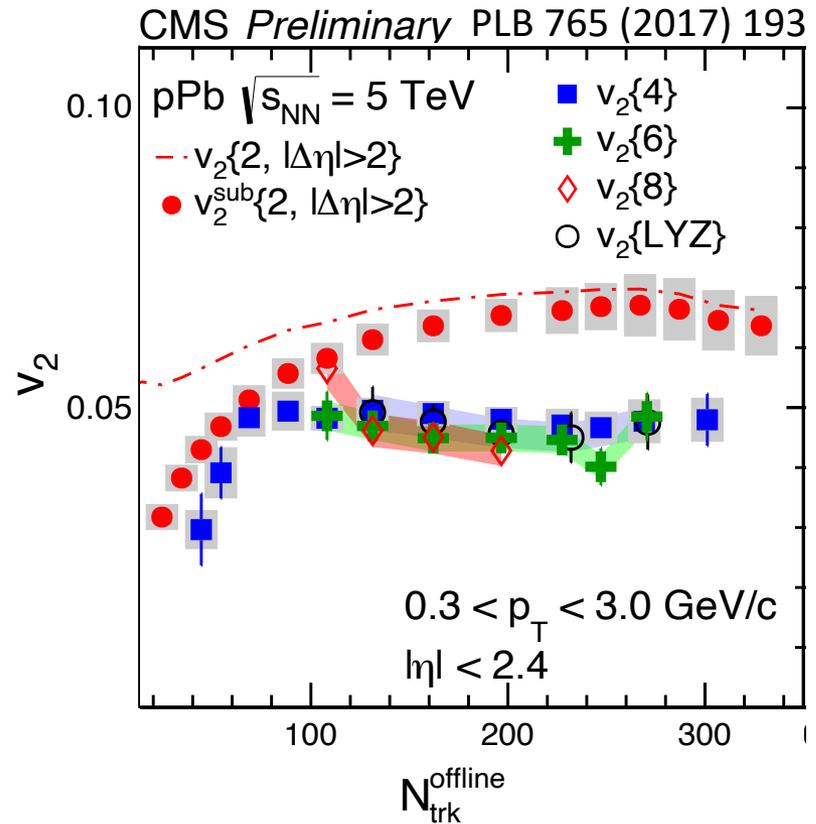
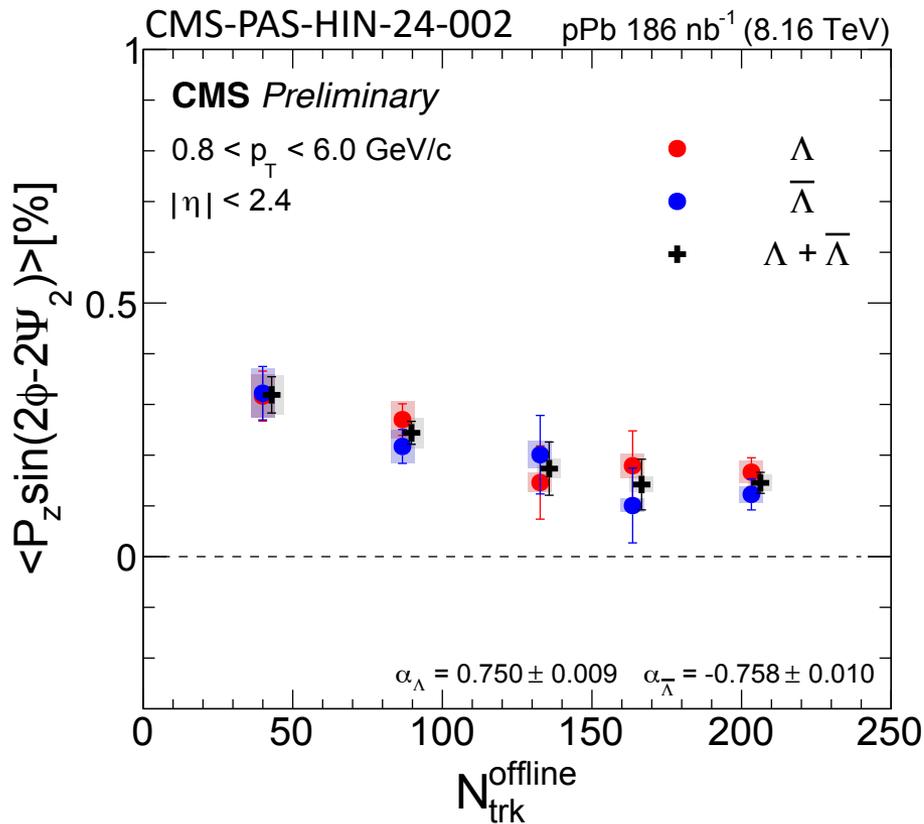
Increase towards higher p_T – hint of saturation at intermediate p_T

$P_{z,s2}$ from medium expansion?



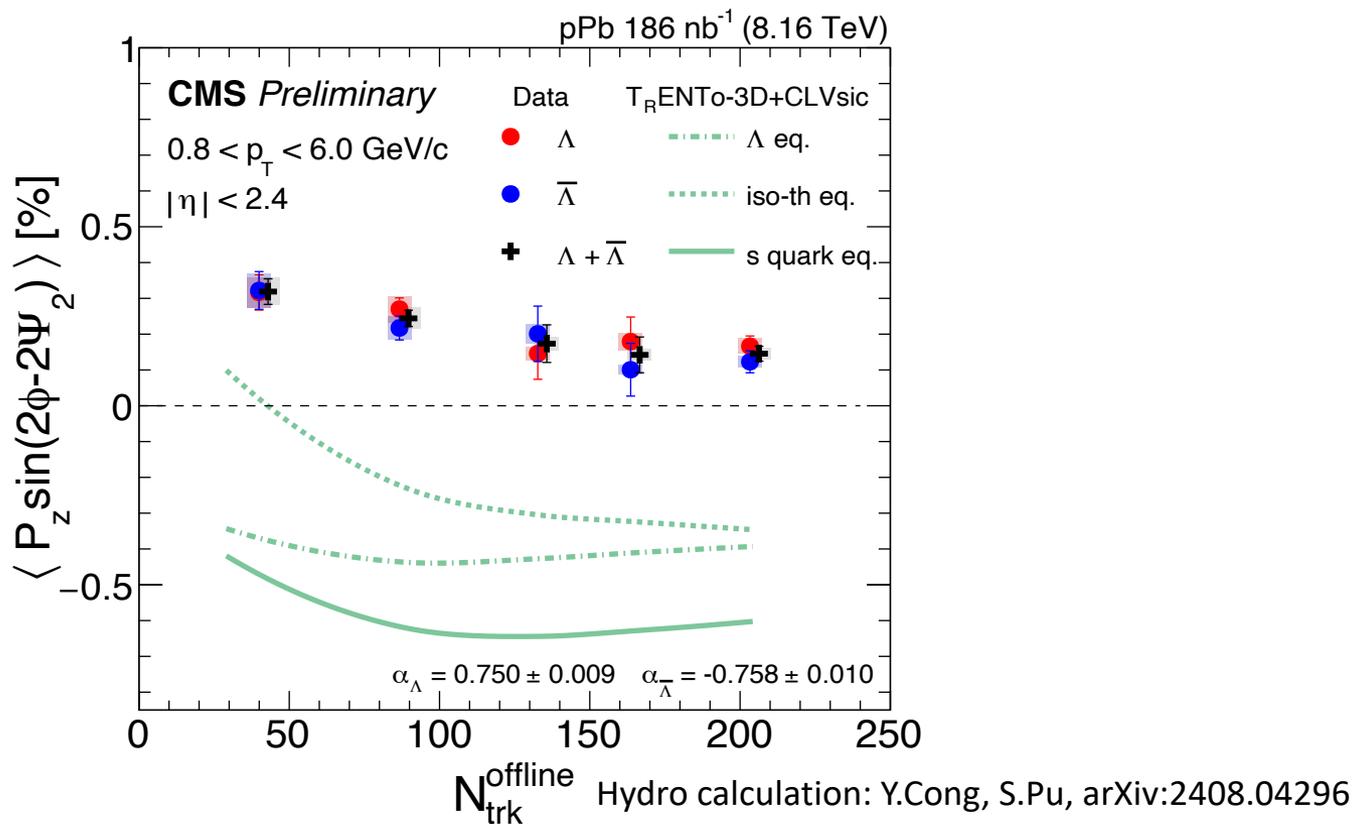
Why is it increasing monotonically towards 0 multiplicity?

$P_{z,s2}$ from medium expansion?



Why is it increasing monotonically towards 0 multiplicity?
 Not consistent with the trend of v_2

$P_{z,s2}$ from medium expansion?

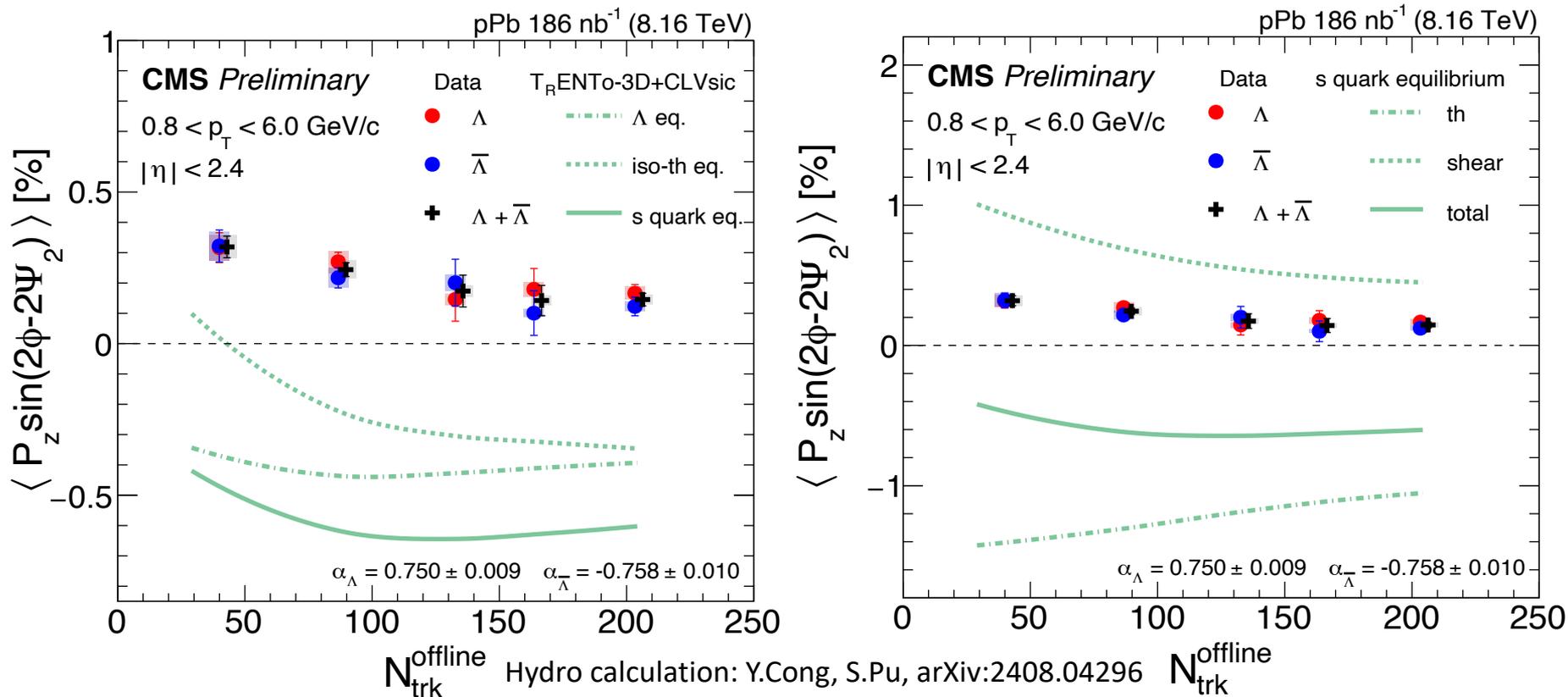


Why is it increasing monotonically towards 0 multiplicity?

Not consistent with the trend of v_2

A hydro calculation results in negative P_z

$P_{z,s2}$ from medium expansion?



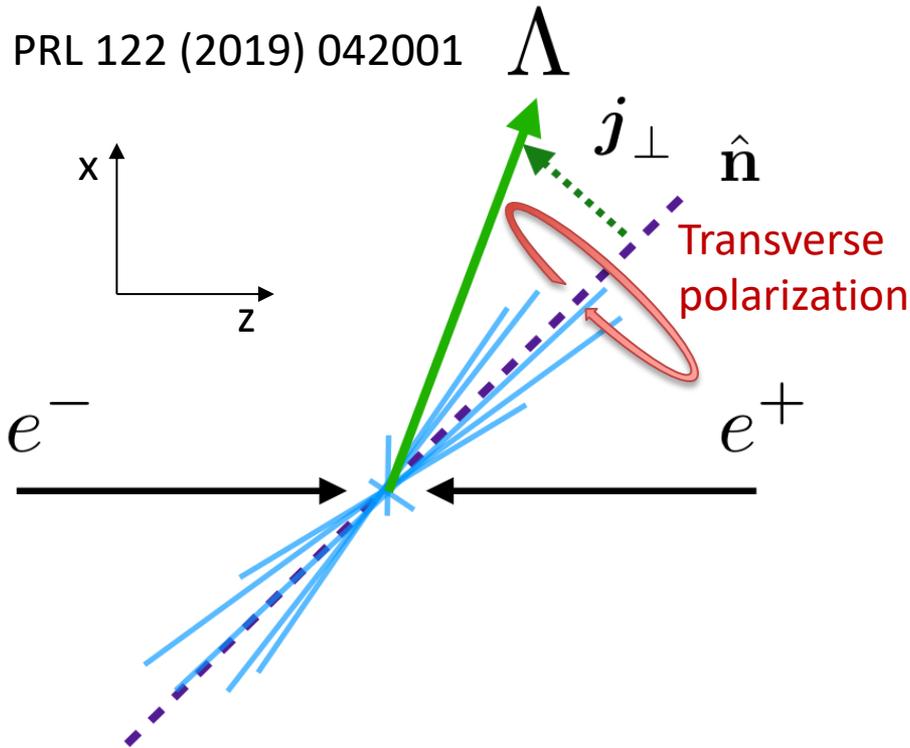
Why is it increasing monotonically towards 0 multiplicity?

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A hydro calculation results in negative P_z

Shear term is positive but thermal term is too negative

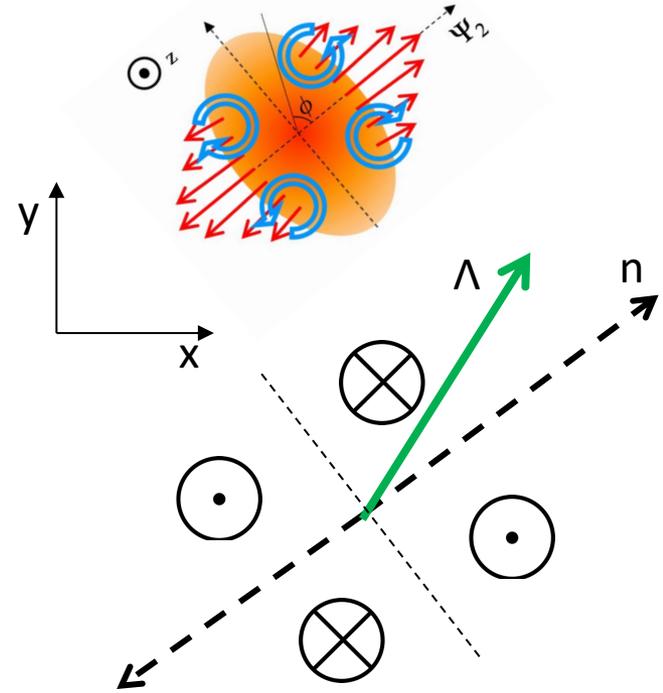
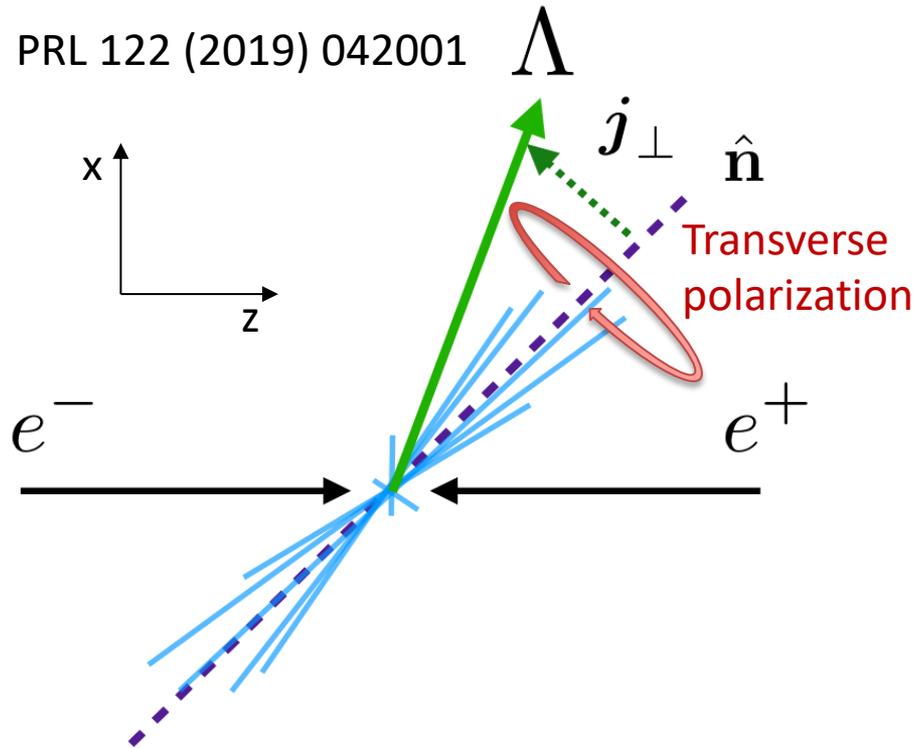
$P_{z,s2}$ from spin physics?



Transverse polarization of Λ has been a long-standing puzzle
Recent Belle measurement in $e^{+}e^{-}$ shows a significant signal wrt thrust axis

$P_{z,s2}$ from spin physics?

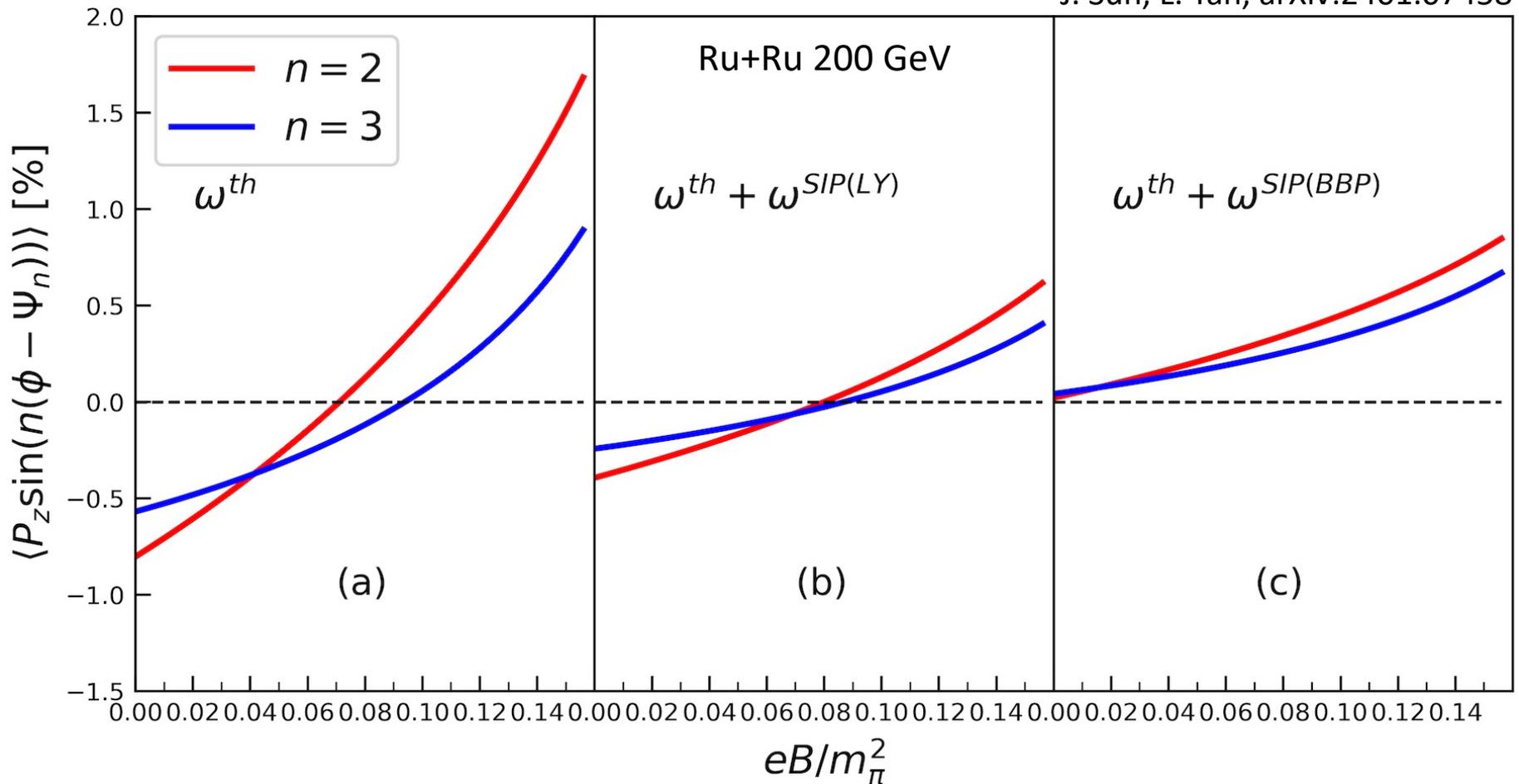
PRL 122 (2019) 042001



Transverse polarization of Λ has been a long-standing puzzle
 Recent Belle measurement in e^+e^- shows a significant signal wrt thrust axis
 Projection into x - y plane introduce a P_z wrt thrust axis
 Thrust axis coincide with 2nd order event plane at low multiplicity
 Diluted towards high multiplicity

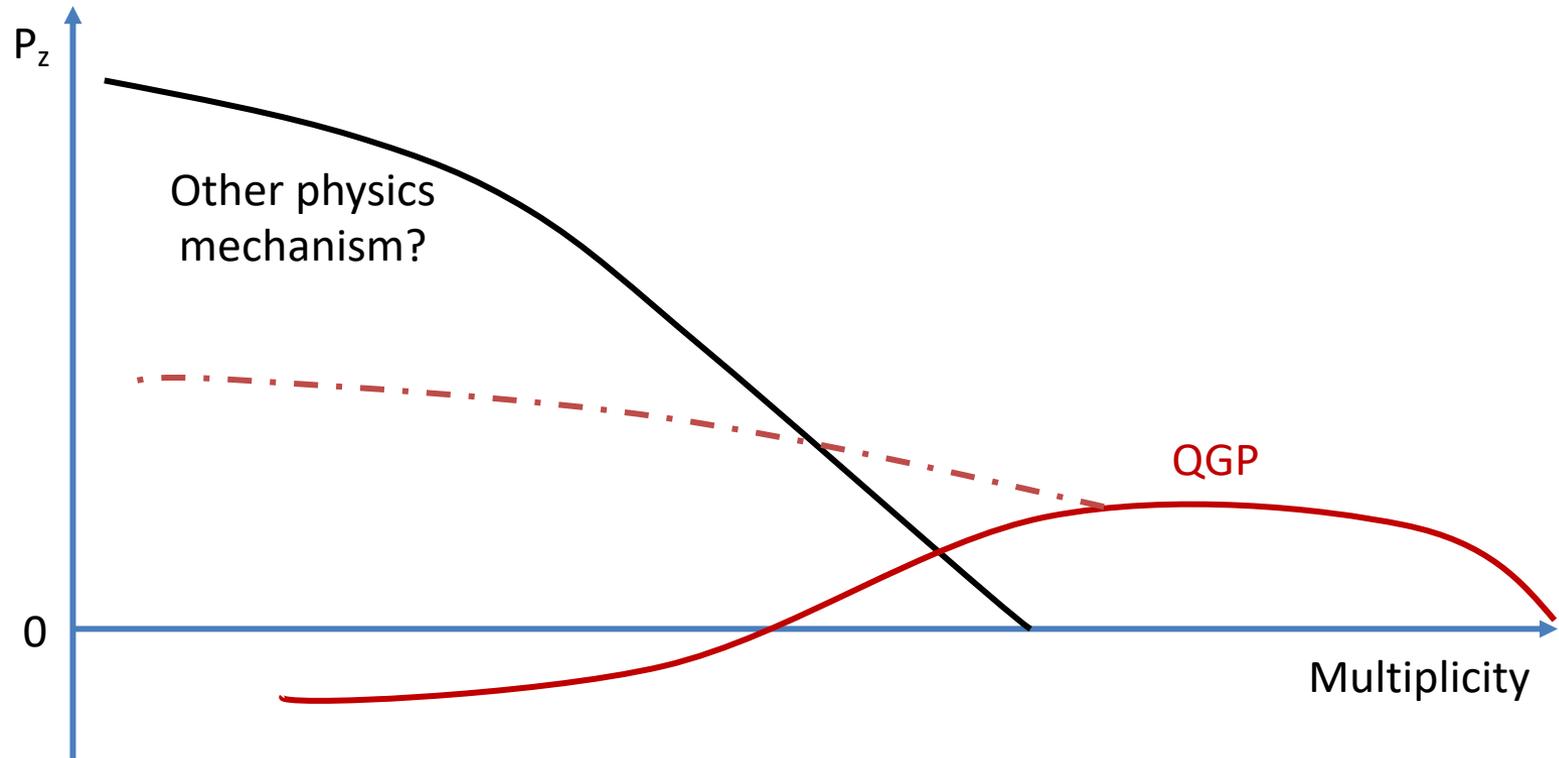
$P_{z,s2}$ from magnetic field?

J. Sun, L. Yan, arXiv:2401.07458



Magnetic field could flip the sign of P_z
 Λ and anti- Λ should have different P_z ?
Look forward to the final calculations in pPb

Different contributions vs multiplicity?



A naïve sketch of the picture

Need other mechanisms to explain local polarization?

What is the implication for the other spin polarization observables?

More experimental results needed

Summary and outlook

Hyperon global polarization measurements @ RHIC are in precision era

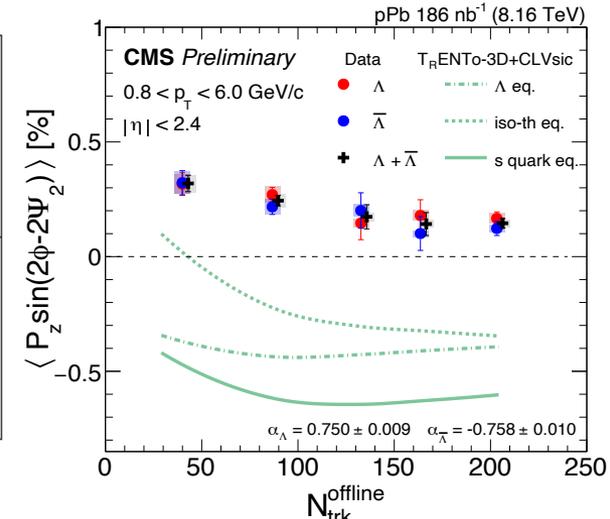
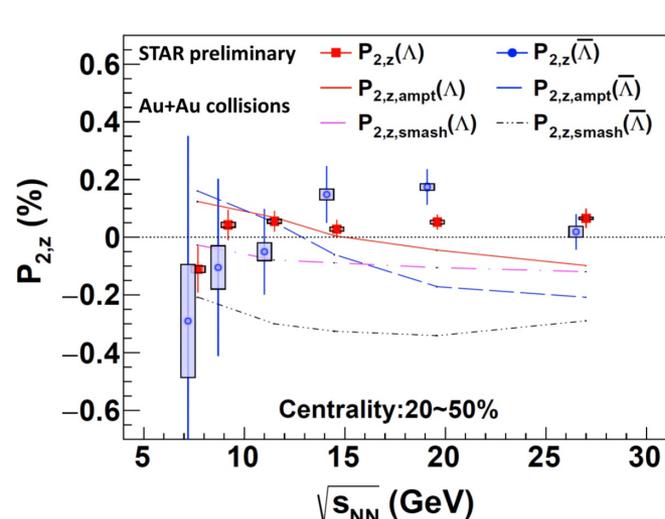
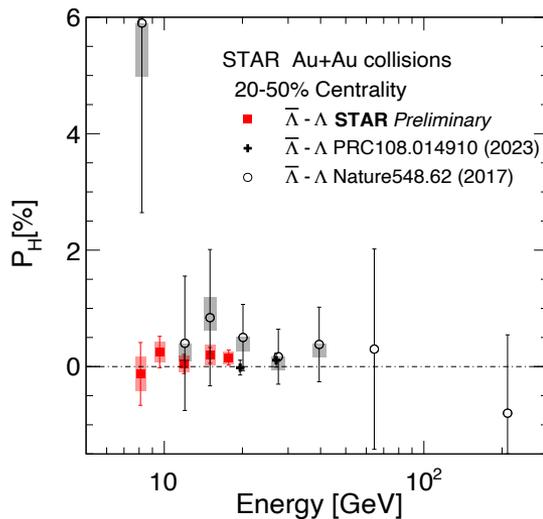
- No significant splitting between Λ and anti- Λ
- No obvious system size dependence
- Hint of different polarization for Λ and Ξ

Open questions in polarization along the beam direction

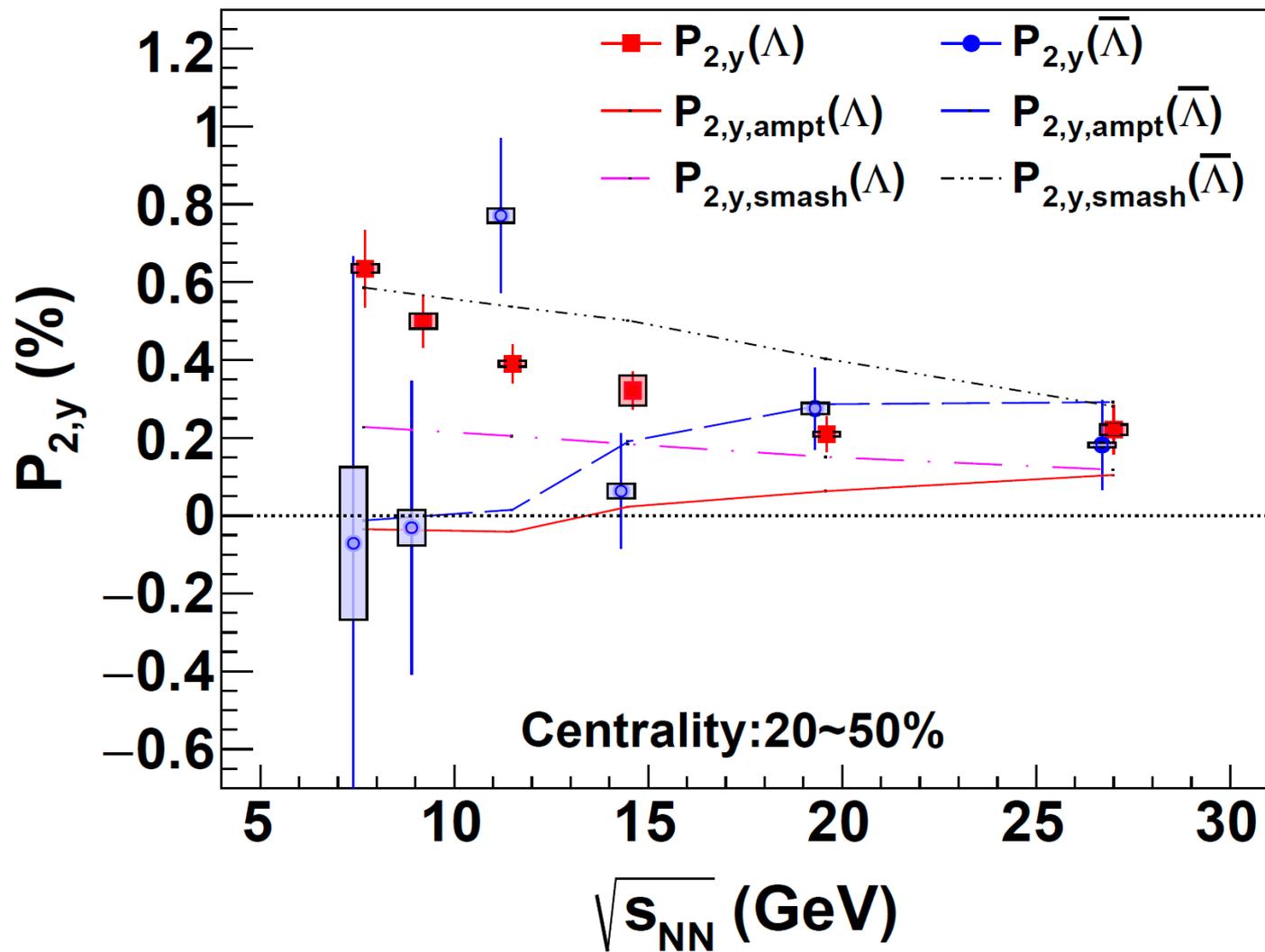
- Energy dependence and potential sign change
- Multiplicity dependence in pPb collisions

Future directions

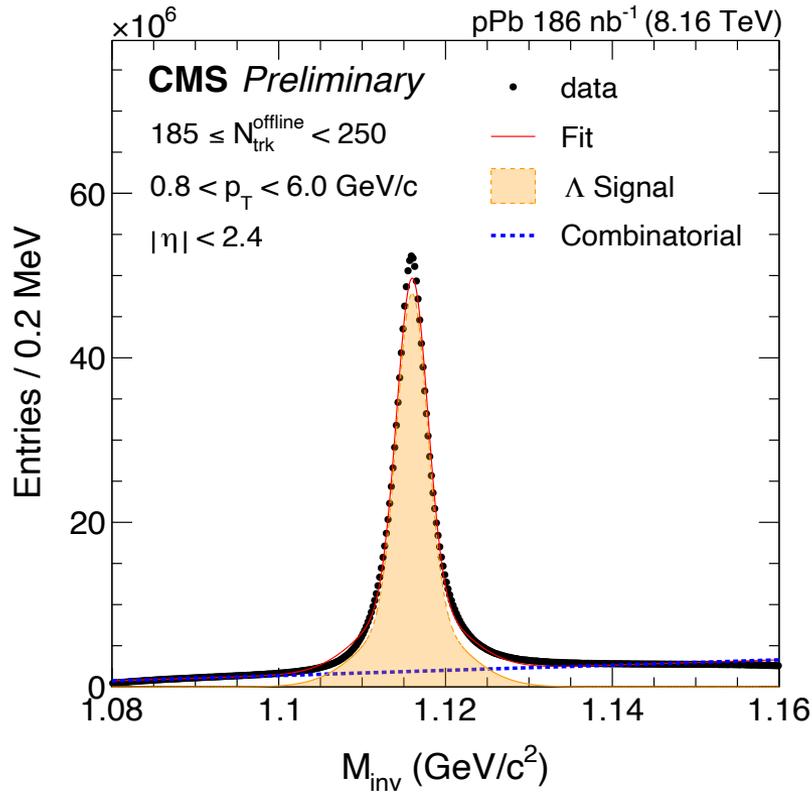
- pp, pAu, dAu, $^3\text{HeAu}$, OO, ...
- Lower energies; complex structures; effects from spin physics...



Back up

$P_{2,y}$ 

Λ hyperon in pPb collision

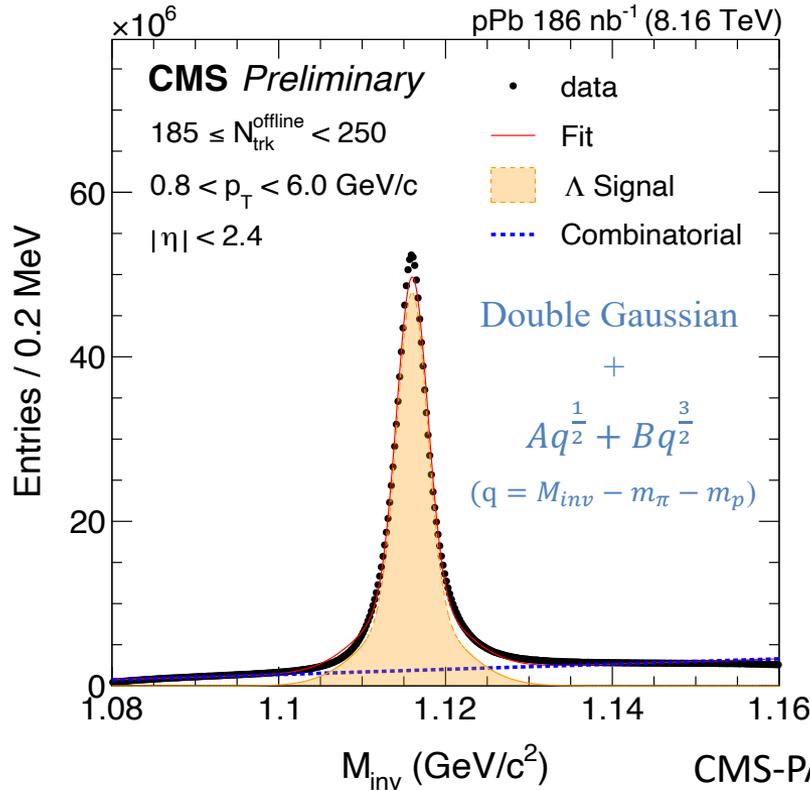


Multiplicity interval ($N_{\text{trk}}^{\text{offline}}$)	$\langle N_{\text{trk}}^{\text{offline}} \rangle$	$\langle N_{\text{trk}}^{\text{corrected}} \rangle$
[3, 60)	40.0	48.5 ± 1.9
[60, 120)	86.7	105.3 ± 4.2
[120, 150)	132.7	161.2 ± 6.4
[150, 185)	163.6	198.7 ± 7.9
[185, 250)	203.3	246.9 ± 9.9

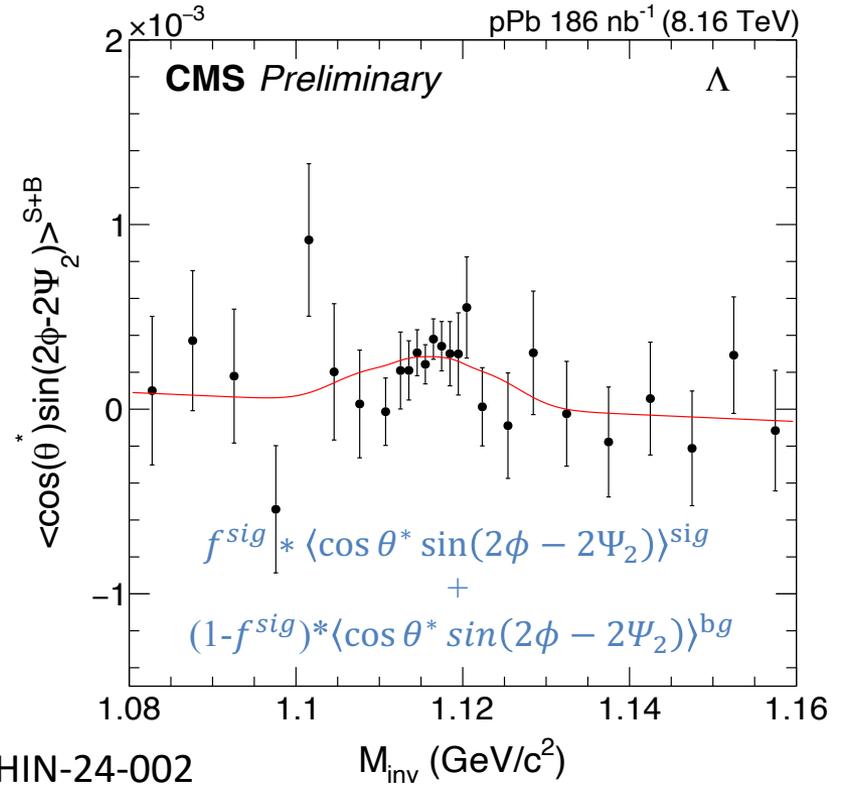
CMS-PAS-HIN-24-002

Clean reconstruction of Λ s in pPb collisions over wide multiplicity range

Λ hyperon polarization in pPb collision



CMS-PAS-HIN-24-002

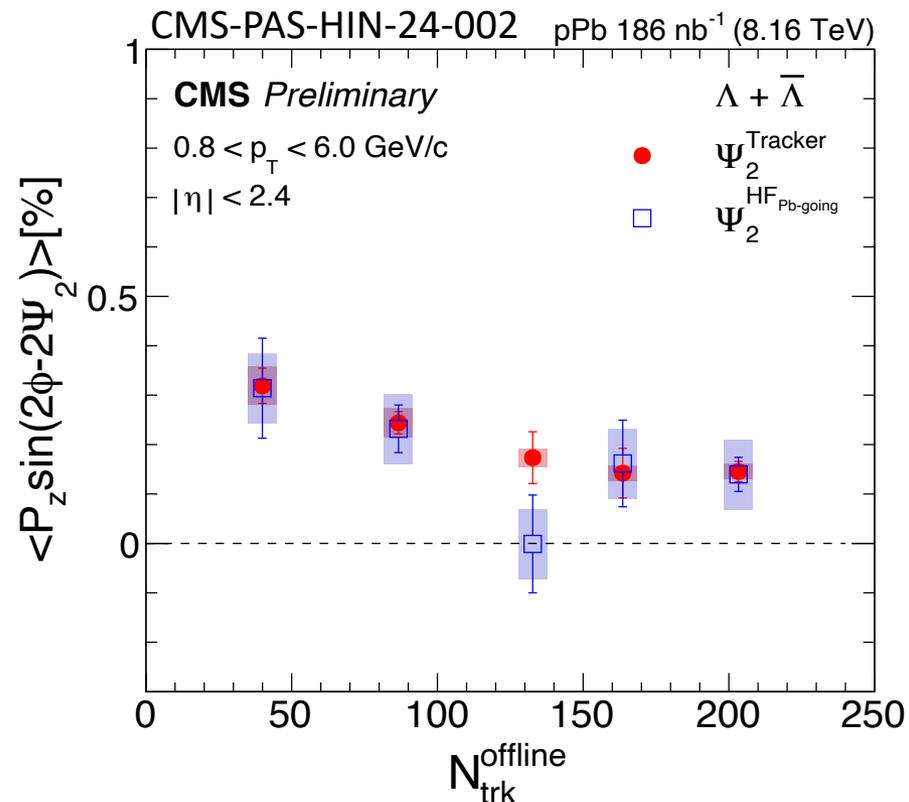
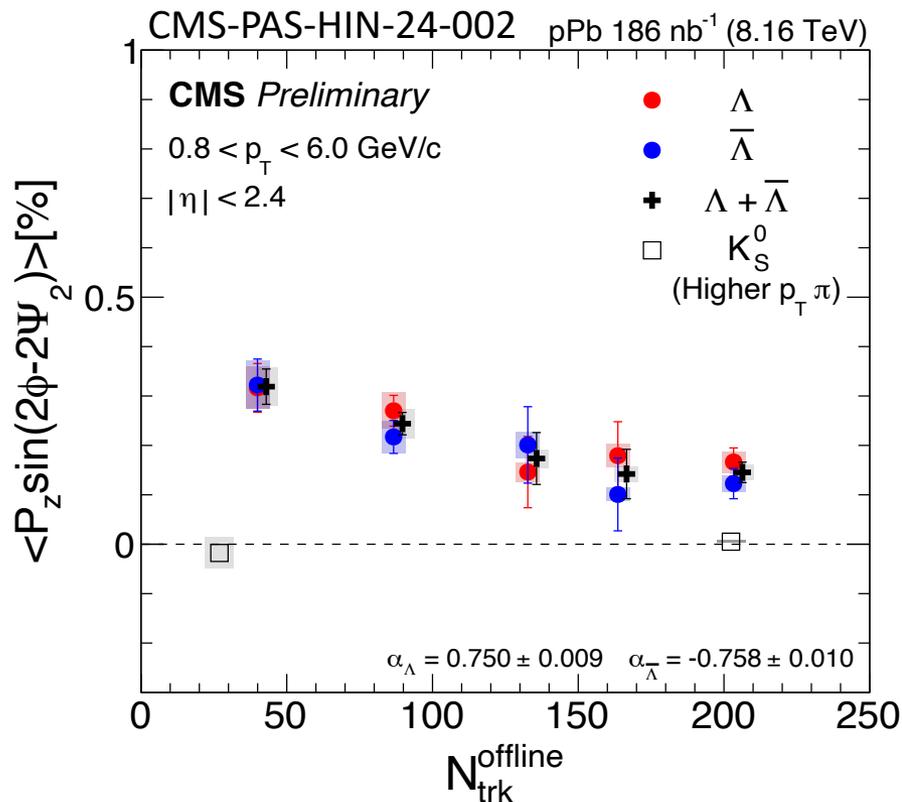


Clean reconstruction of Λ s in pPb collisions over wide multiplicity range
 Polarization along beam direction extracted from direct measurement

$$P_{Z,s2} = \frac{\langle \cos \theta^* \sin(2\phi - 2\Psi_2) \rangle^{sig}}{\langle \cos^2 \theta^* \rangle \alpha_H \text{Res}(\Psi_2)}$$

$$(\alpha_H: \alpha_{\Lambda} = 0.750 \pm 0.009, \alpha_{\bar{\Lambda}} = -0.758 \pm 0.010 \text{ Nature Phys. 15 (2019) 631-634})$$

$P_{z,s2}$ in pPb collision – crosschecks



Crosschecks done to ensure
 K_S has 0 signal - no strange detector effects
 Consistent results wrt forward event plane – no short range/self correlation