Hyperon polarization at STAR and CMS

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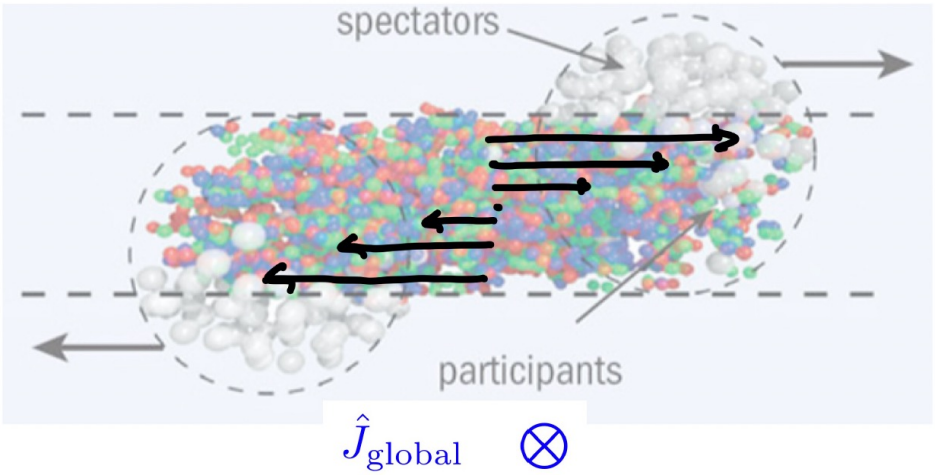
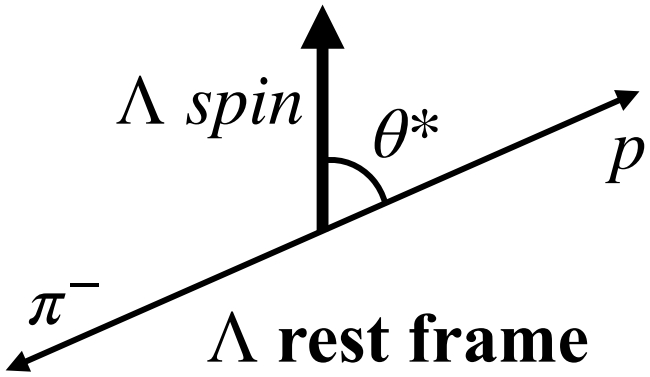
Shandong University 山东大学

And

Xingrui Gou

"The most vortical fluid"



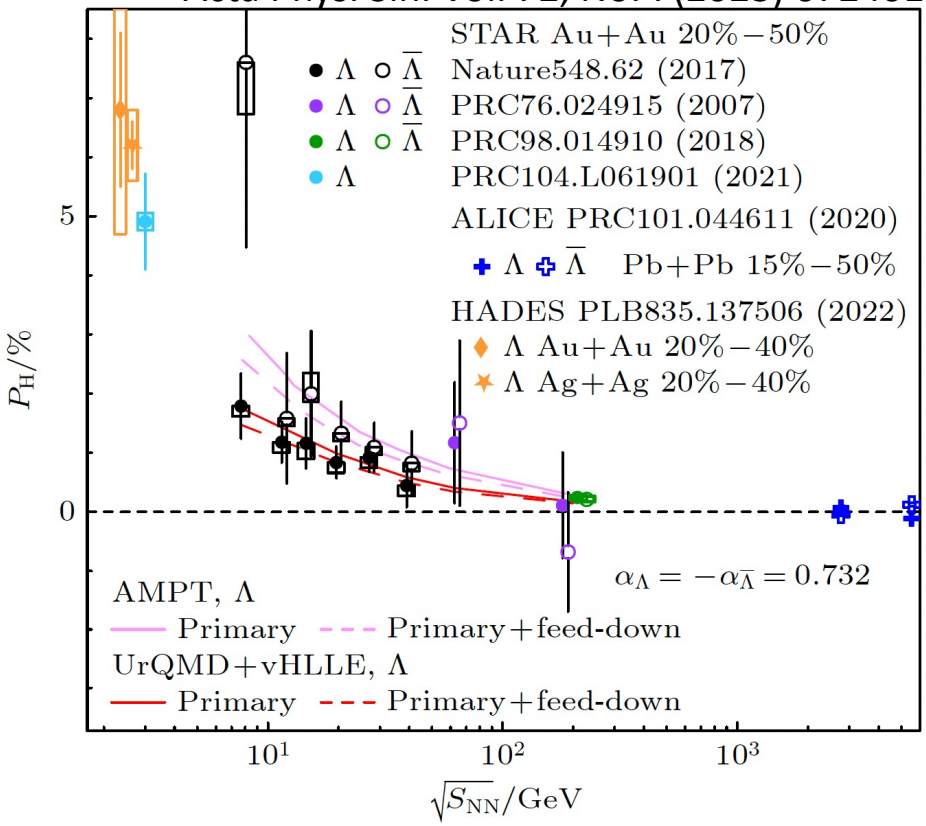


Large initial orbital angular momentum
Can polarize particles through spin-orbit coupling

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+vHLLE
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

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

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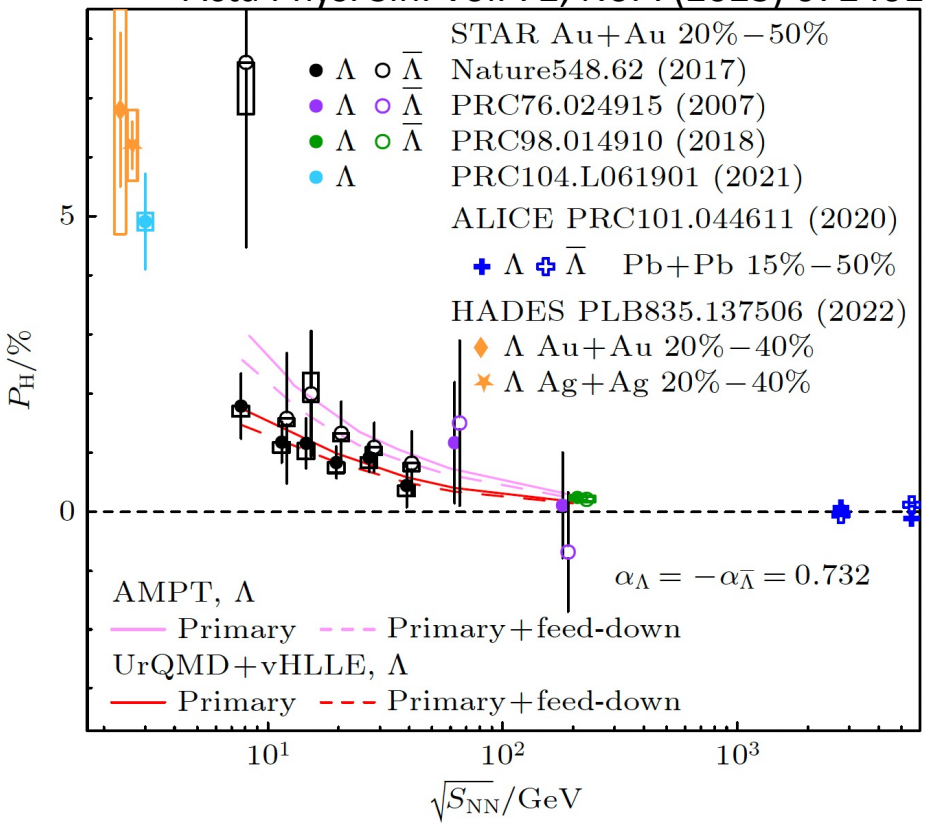

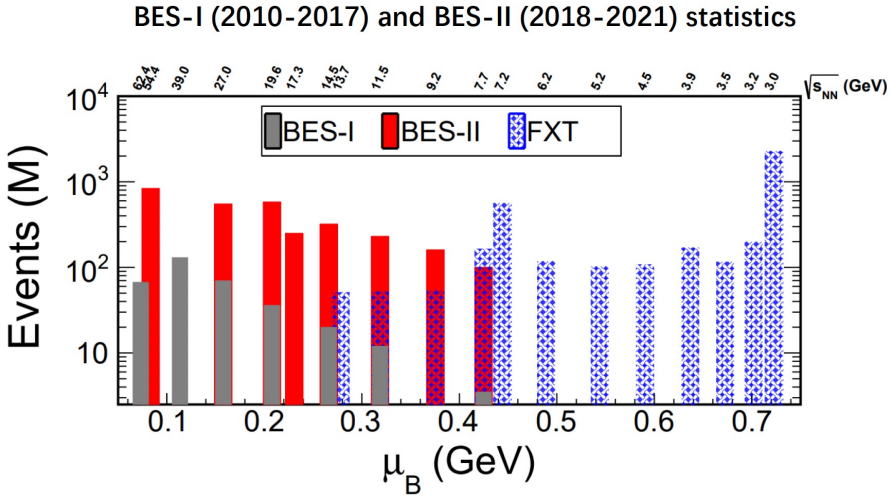

STAR BESII data can largely improve the precision especially at lower energies

Large initial orbital angular momentum

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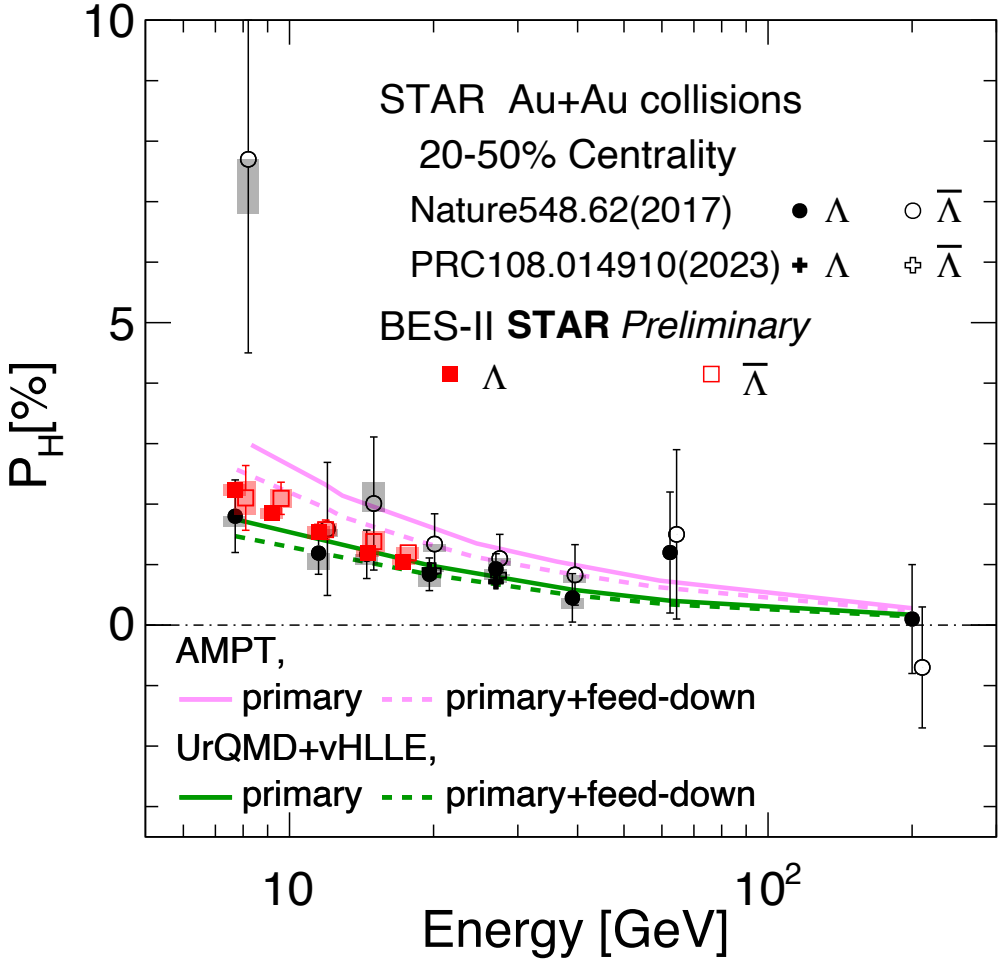
Λ global polarization from BESII



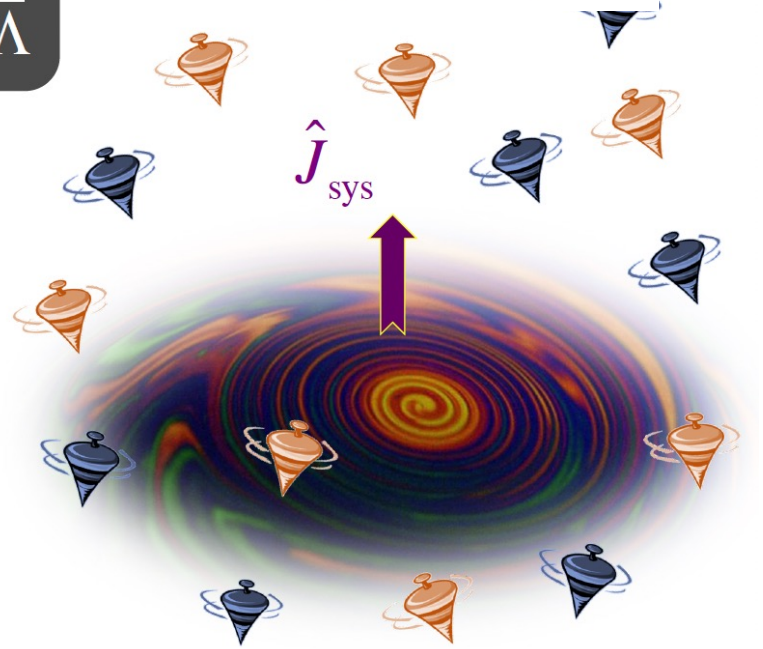
More than factor of 5 improvement in uncertainties

Potential to rule out models?

Λ global polarization from BESII: magnetic field

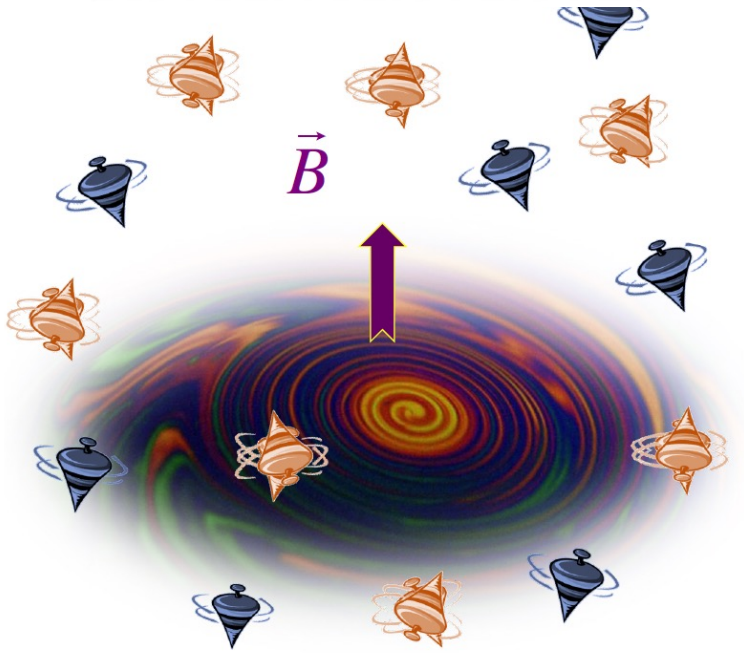
Vortical coupling: $P \propto \omega$

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



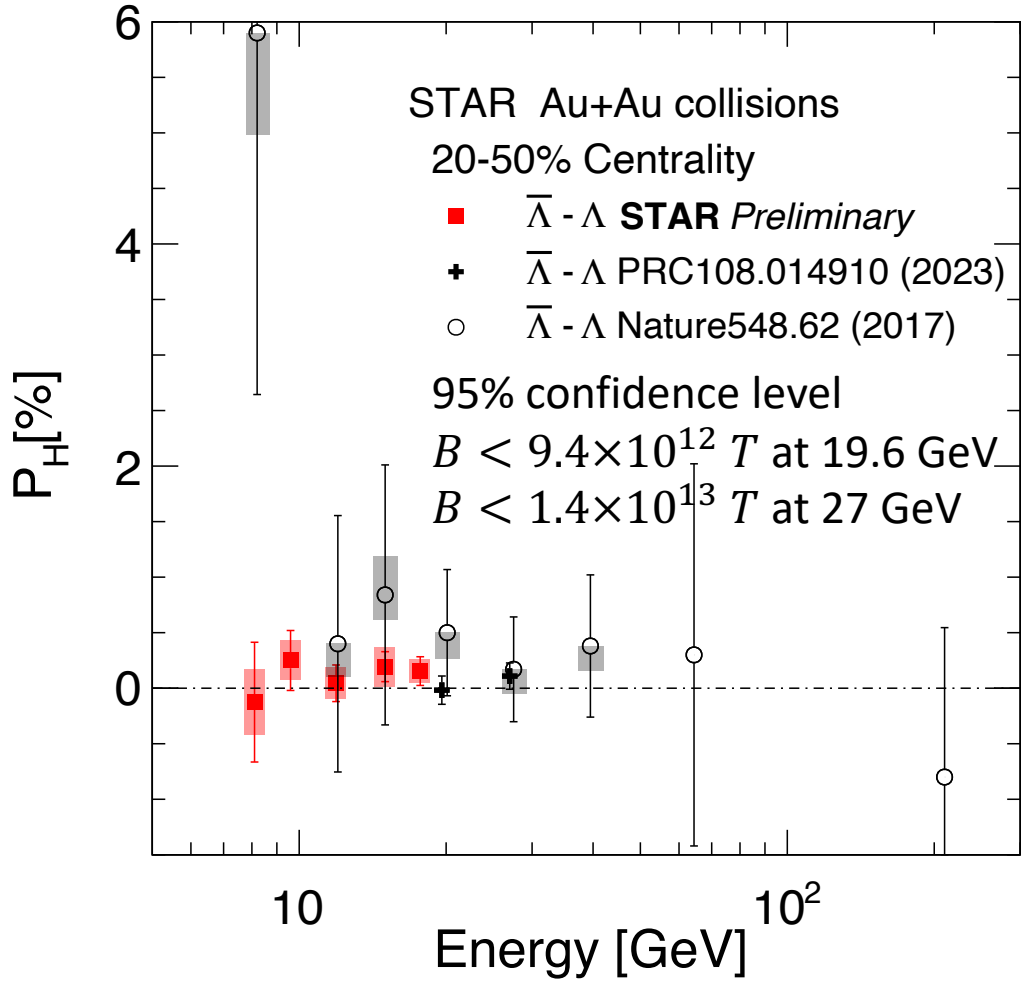
Magnetic coupling: $P \propto \vec{\mu} \cdot \vec{B}$

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



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

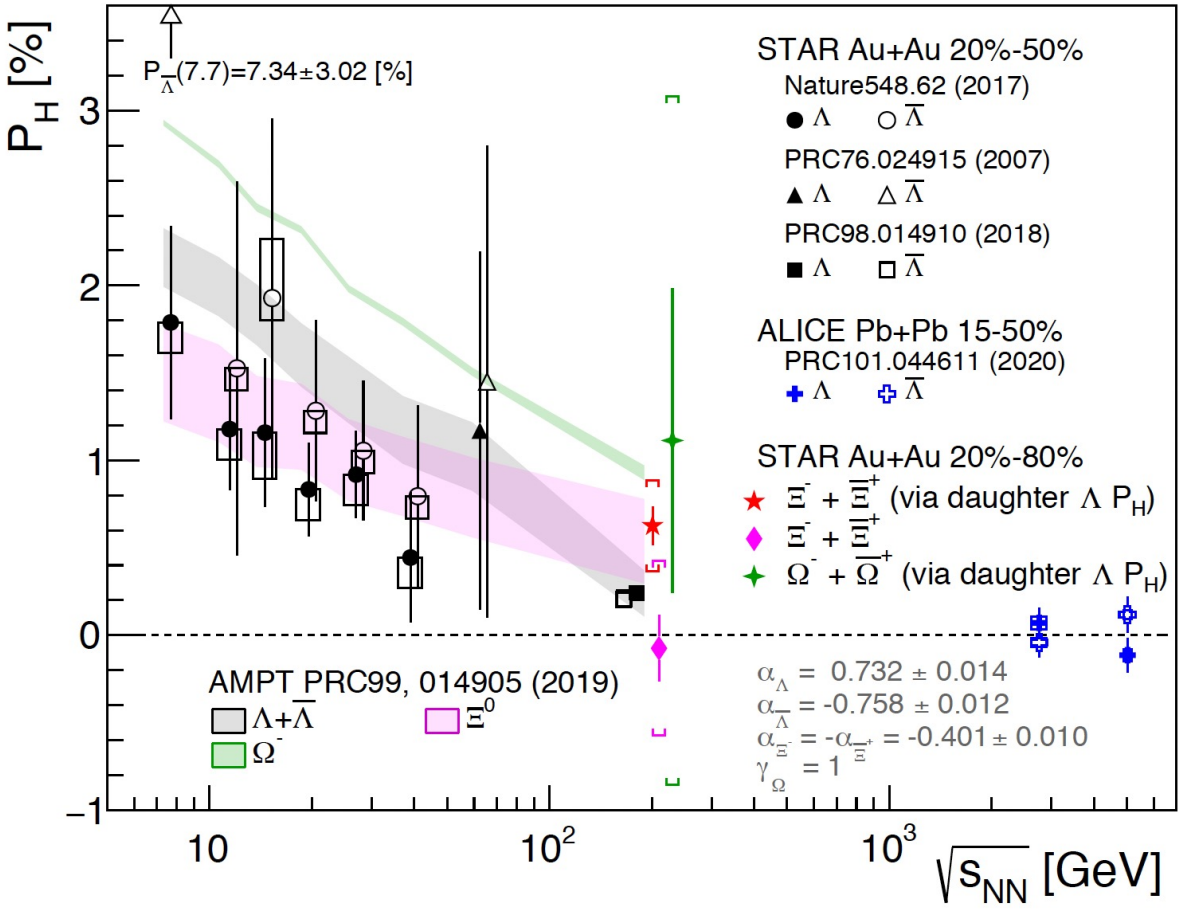
Λ global polarization from BESII: magnetic field



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

No obvious splitting observed with high precision

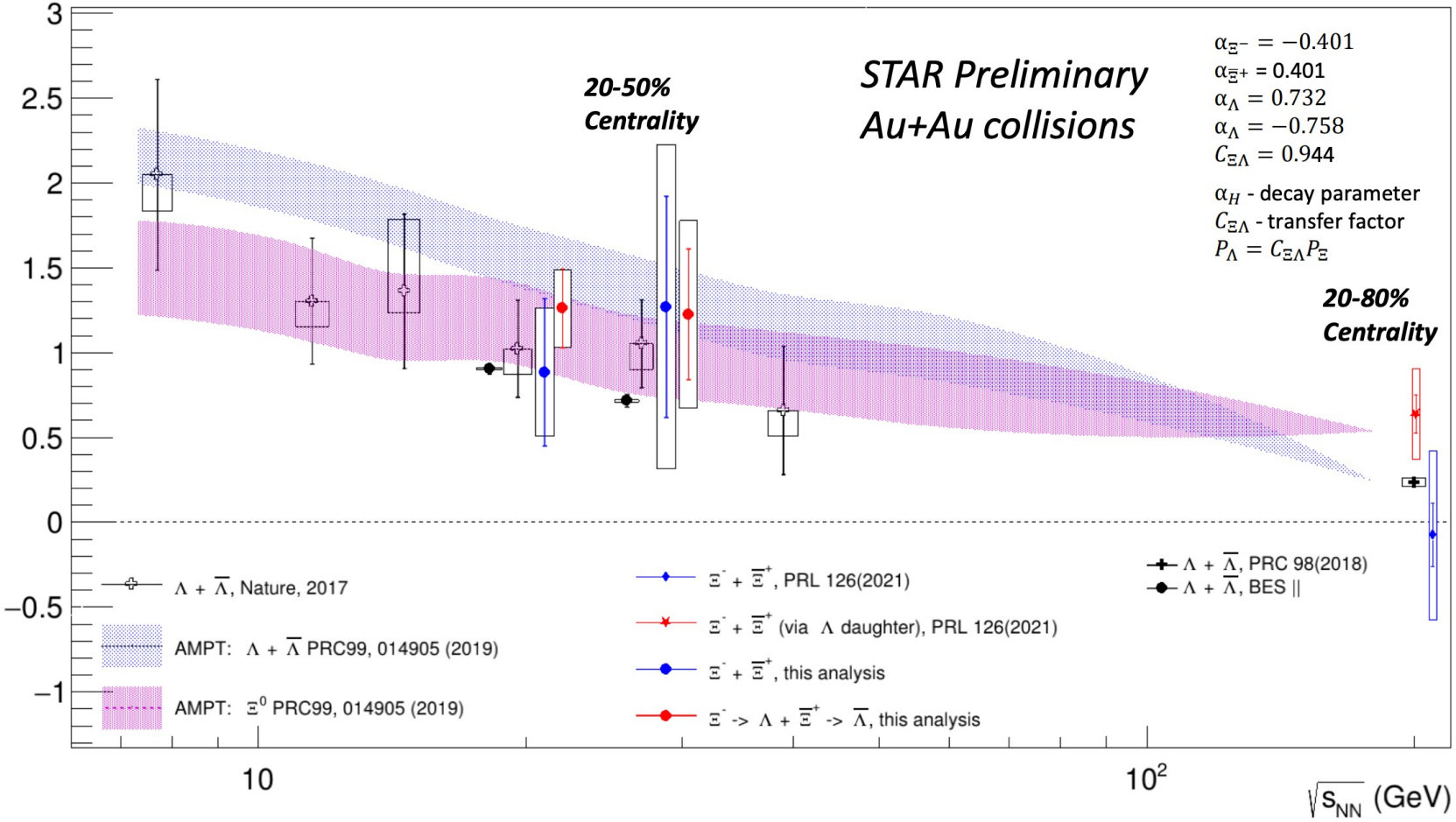
Ξ global polarization



Possible difference between hyperons due to production time

Indication of Ξ and Ω polarization at 200 GeV

Ξ global polarization

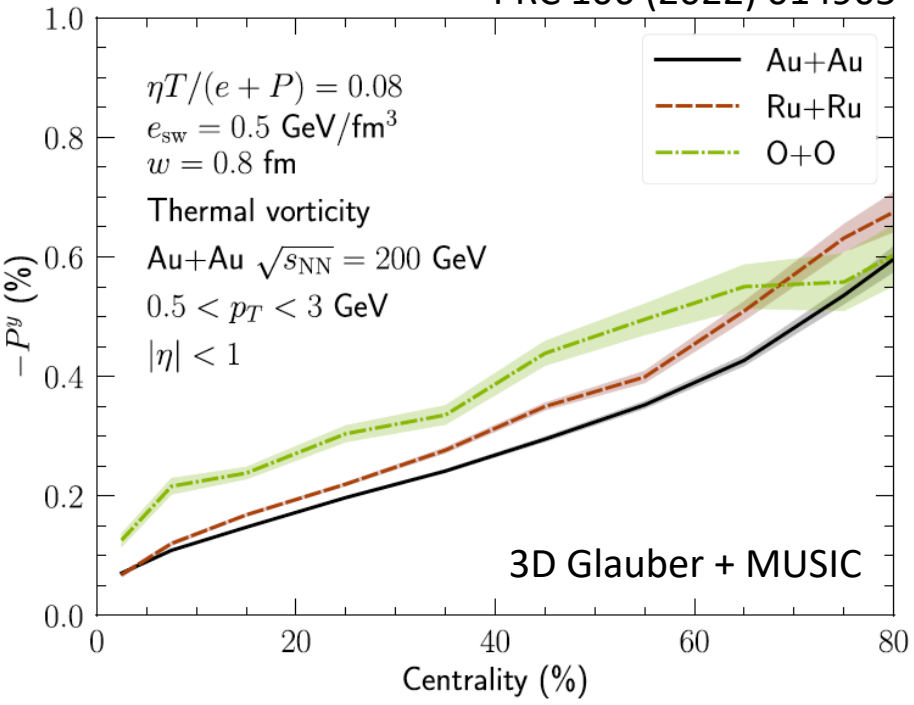


Significant Ξ global polarization observed in 19.6 and 27 GeV Au+Au

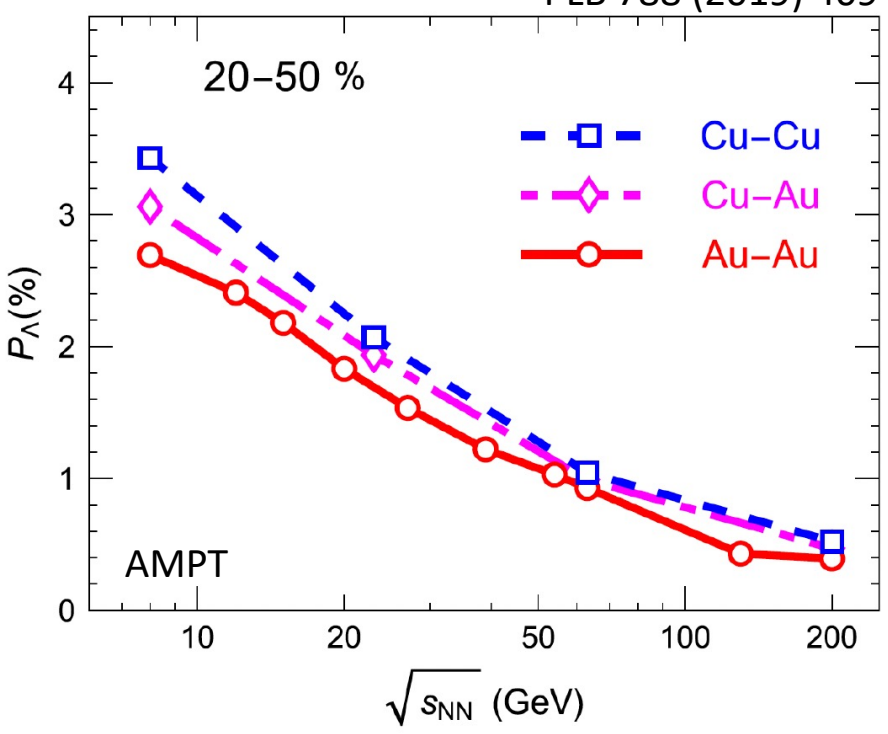
Stay tuned for lower energies and Ω results

Λ global polarization: system size dependence

PRC 106 (2022) 014905

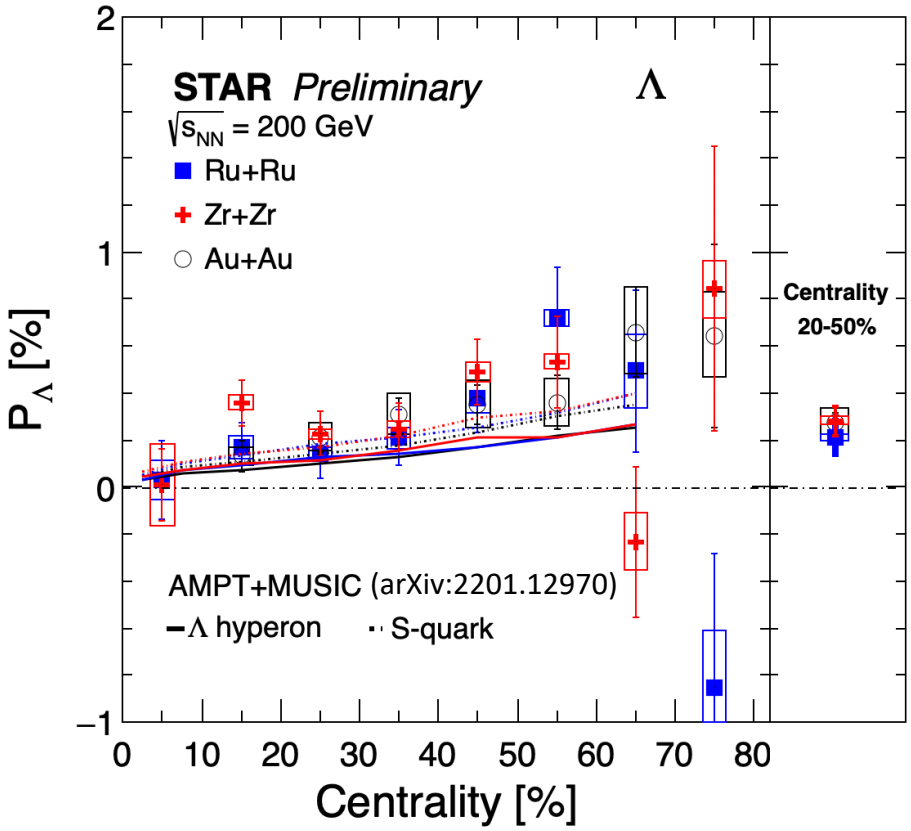


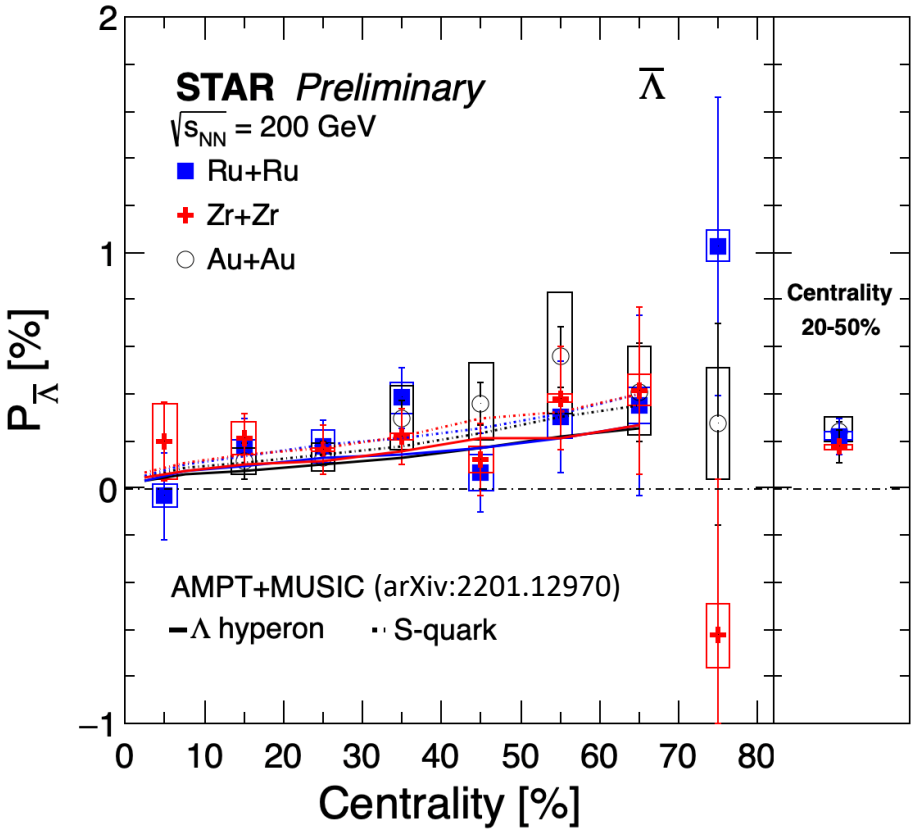
PLB 788 (2019) 409



Smaller polarization predicted for larger system due to longer lifetime

Λ global polarization: system size dependence

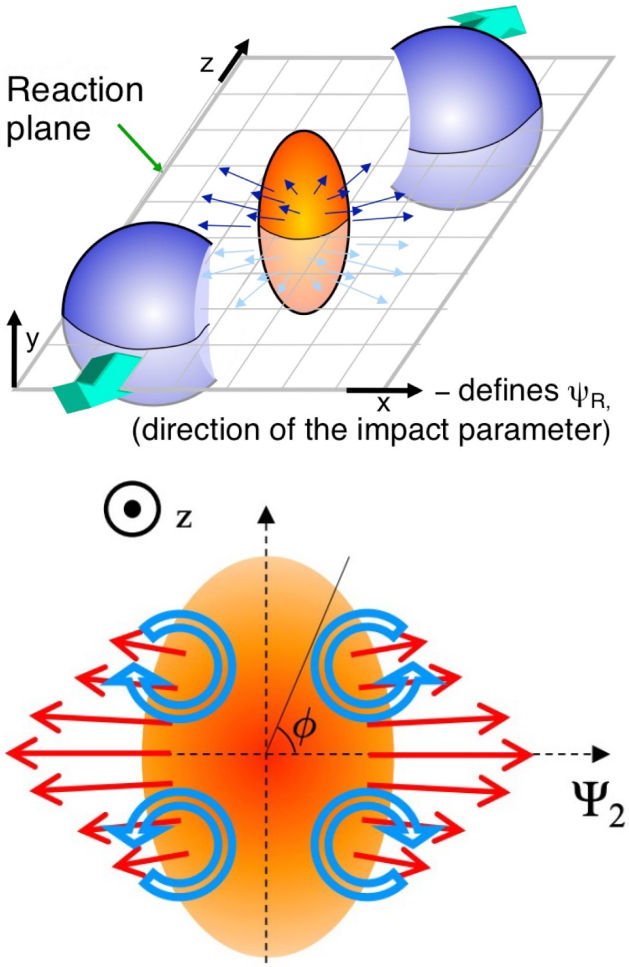




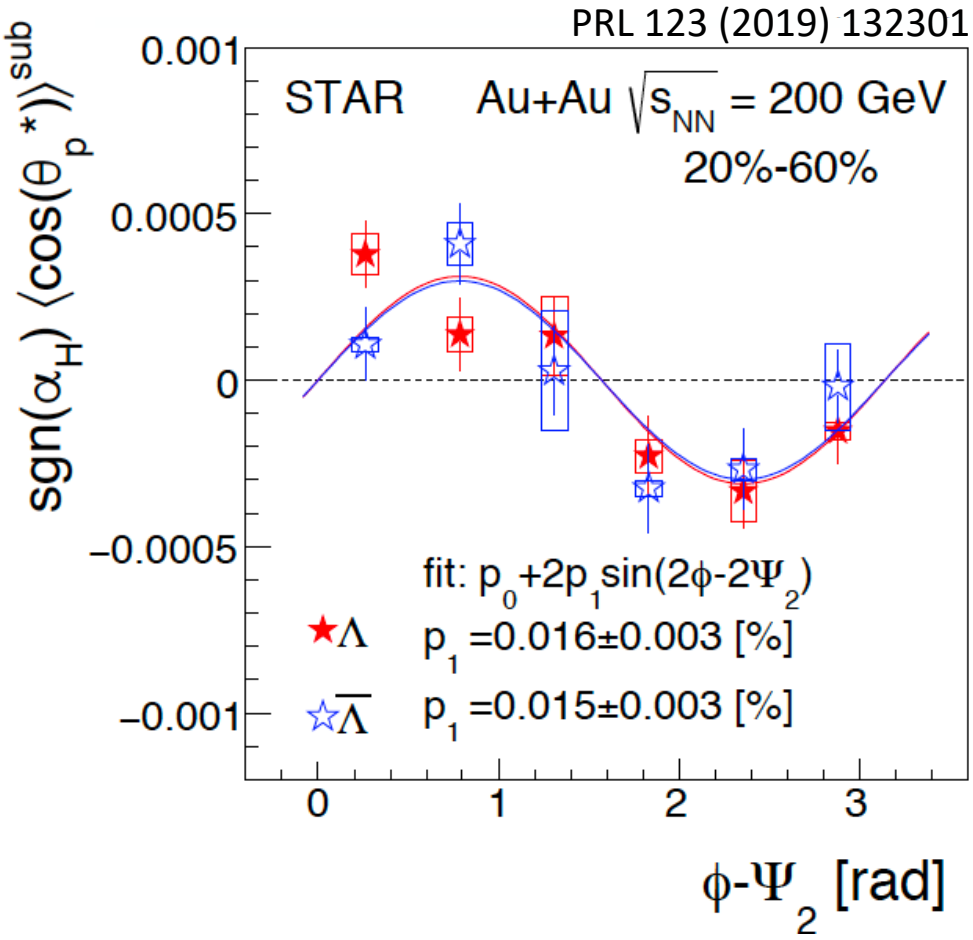
Smaller polarization predicted for larger system due to longer lifetime

No obvious difference between Ru, Zr and Au results

Hyperon polarization along beam direction



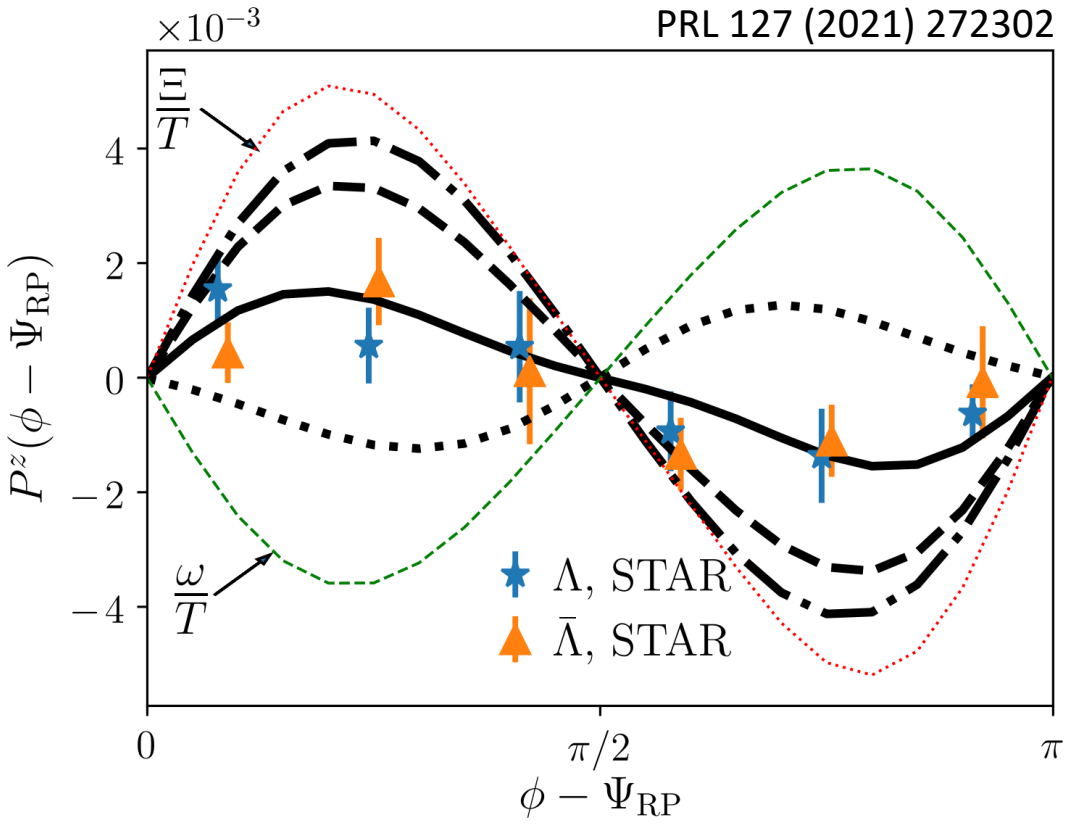
PRL 123 (2019) 132301

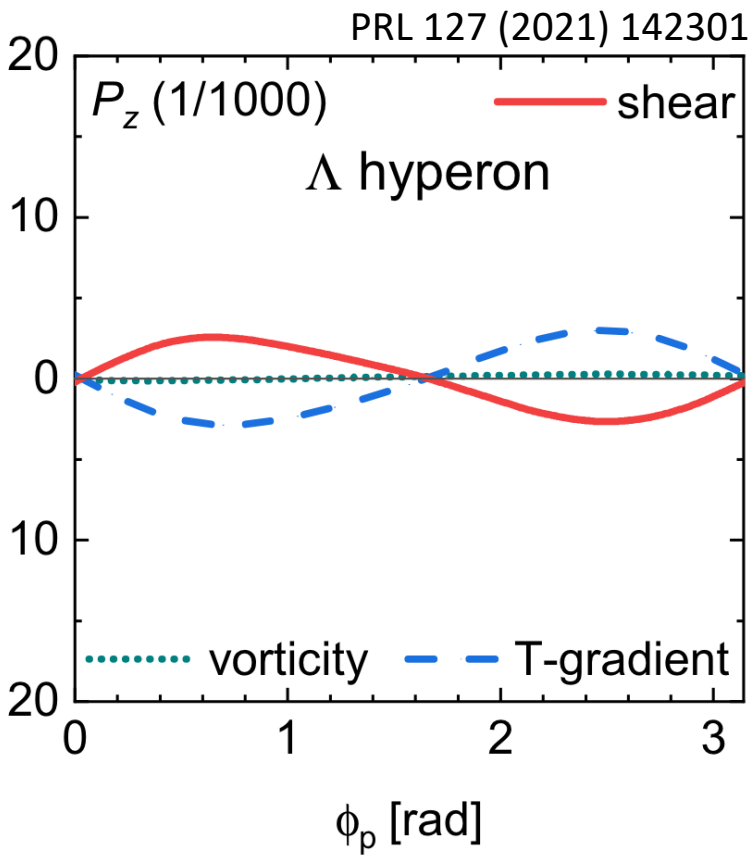


Simple expectation of vorticity from the anisotropic expansion of QGP

Observed in data

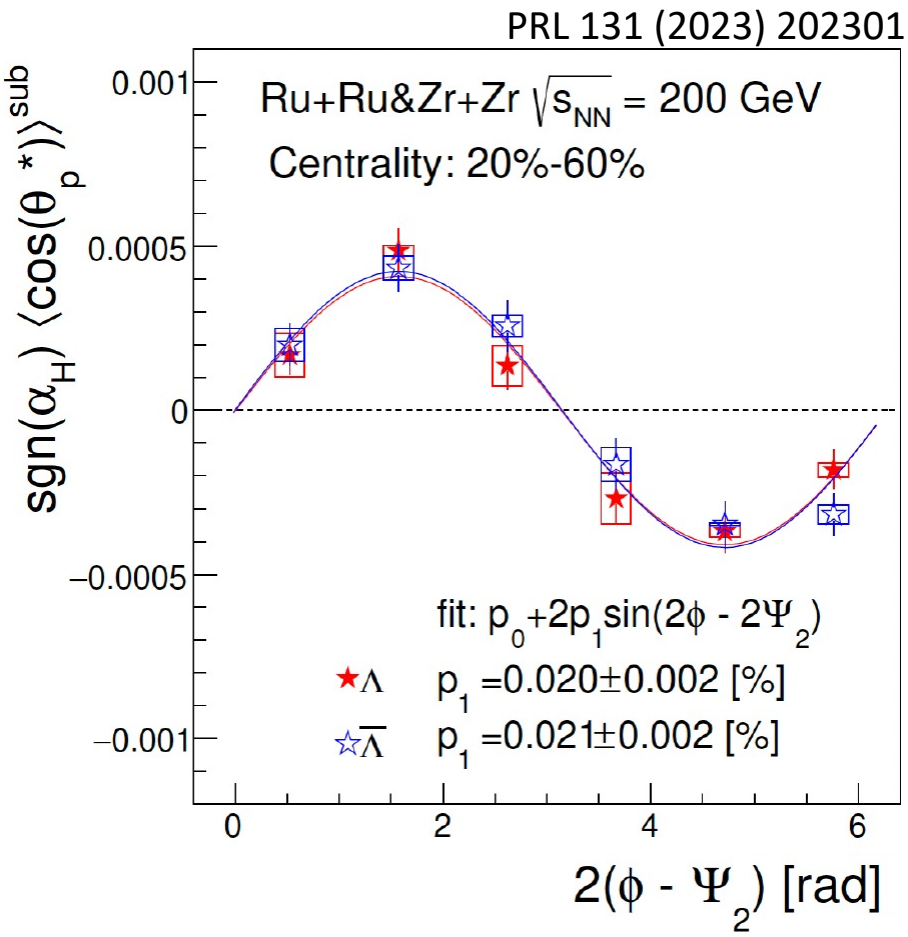
"P_z puzzle"





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

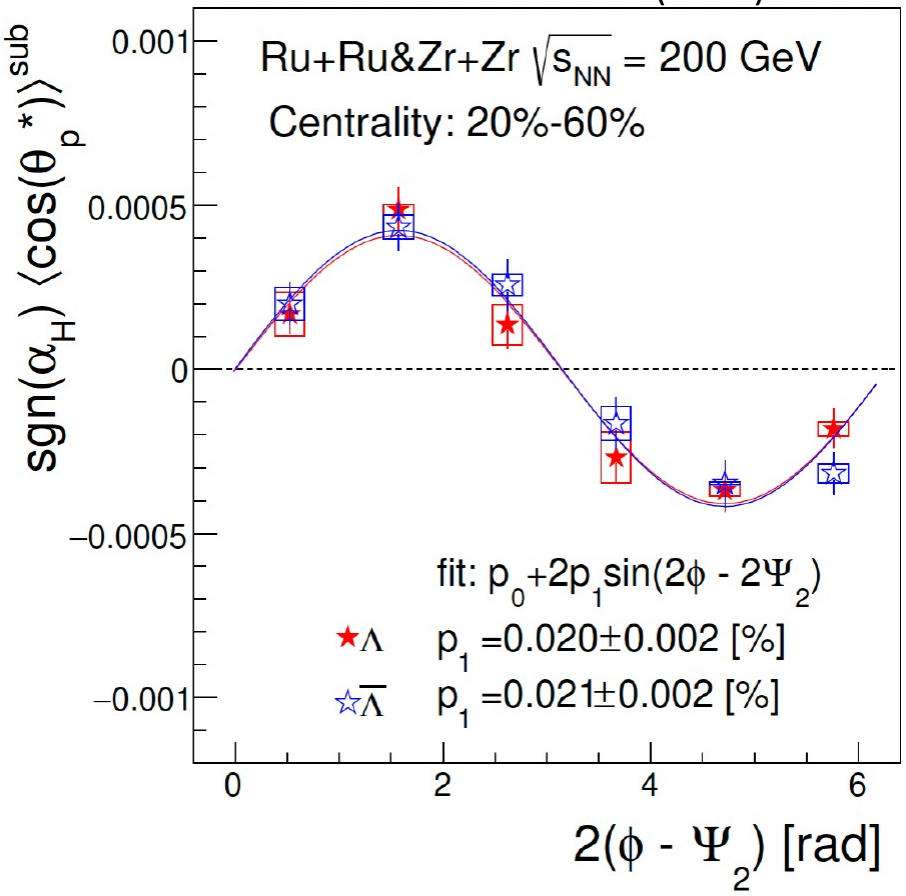
System size dependence of P_z



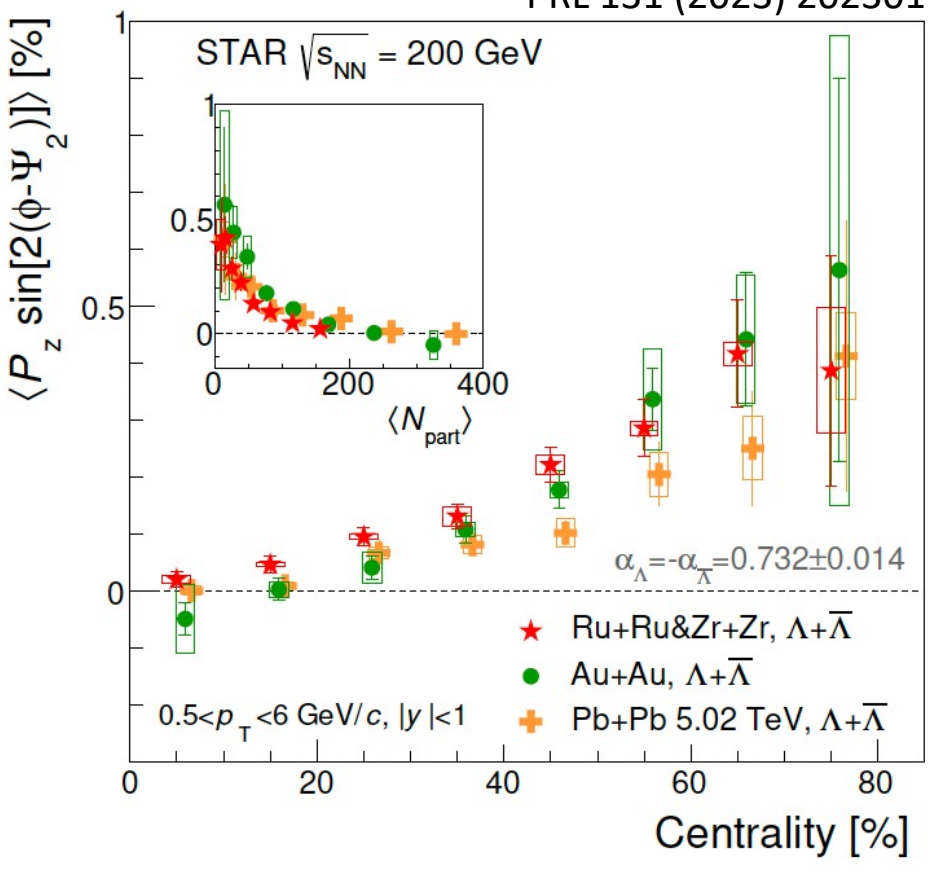
More precise measurements in isobar collisions

System size dependence of P_z

PRL 131 (2023) 202301



PRL 131 (2023) 202301

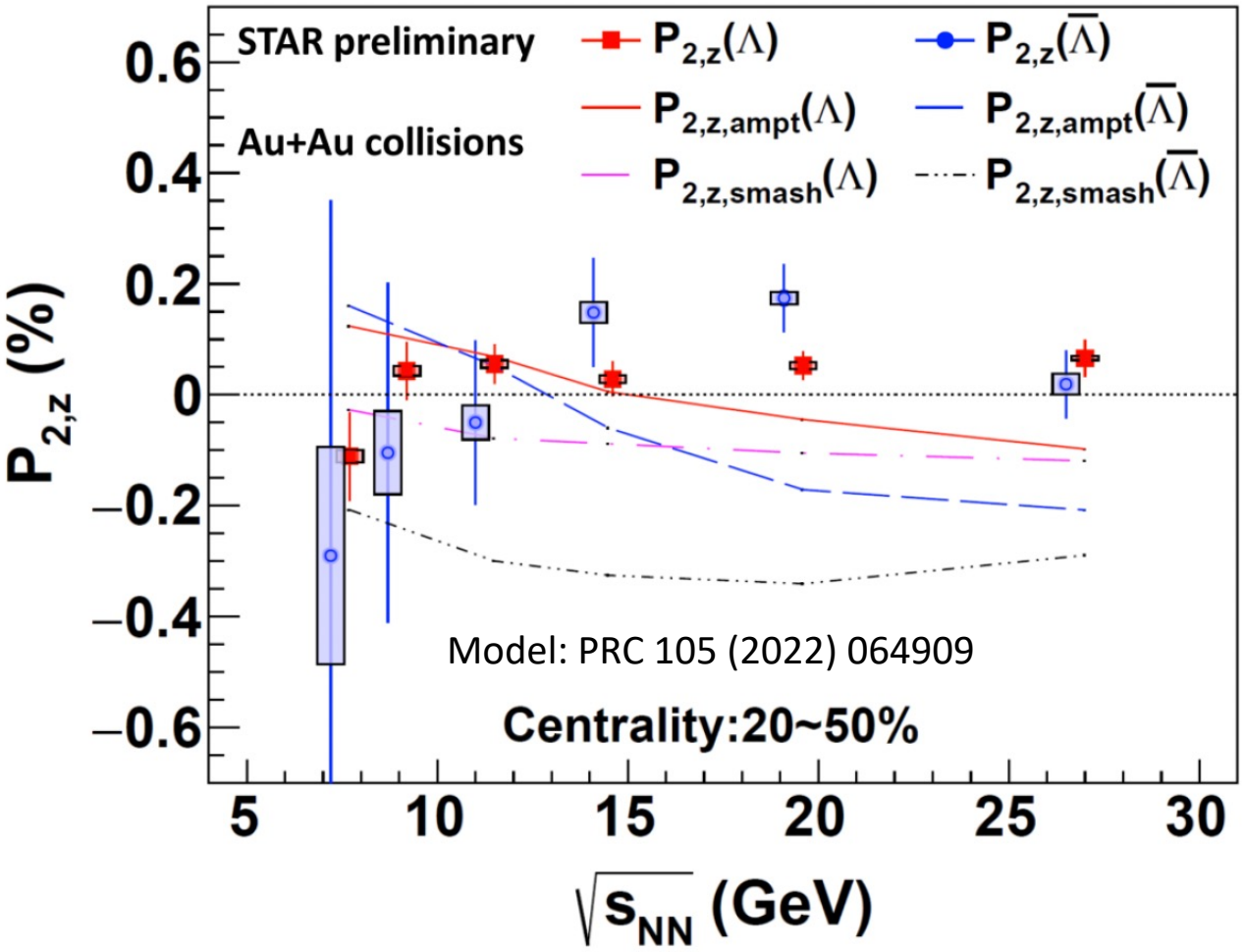


More precise measurements in isobar collisions

No significant system size dependence comparing isobar & AuAu

Hint of energy dependence comparing RHIC & LHC?

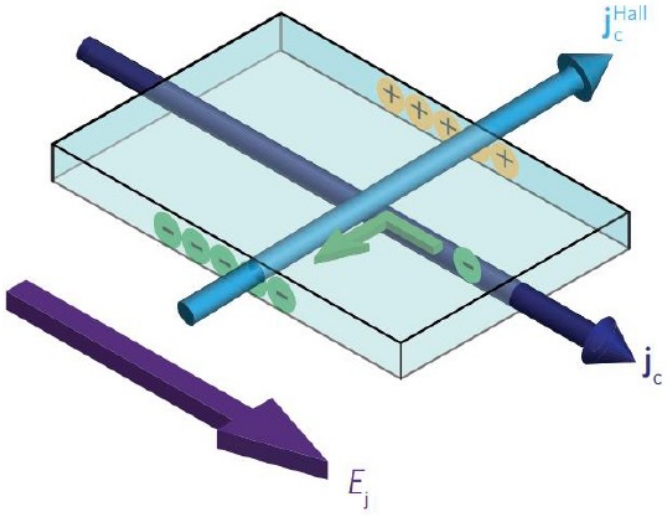
Energy dependence of P_z



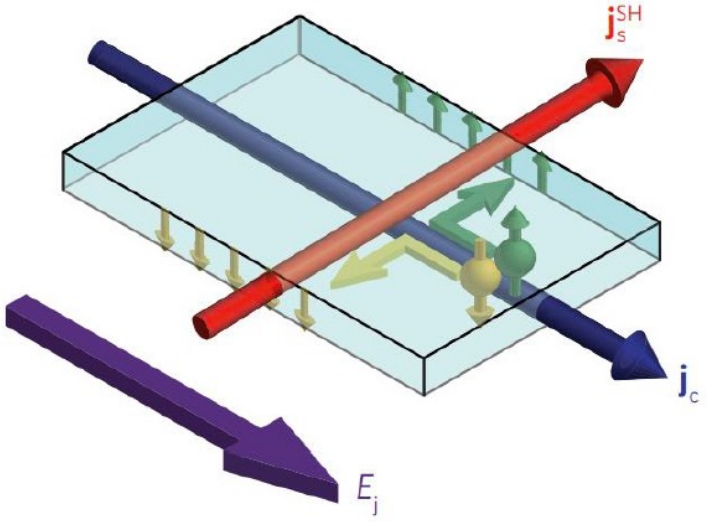
No obvious energy dependence observed 9.2 - 200 GeV

Hint of sign change at 7.7 GeV? Why?

Baryonic Spin Hall Effect



S. Meyer et al., Nature Materials, 2017



Hall effect, 1879

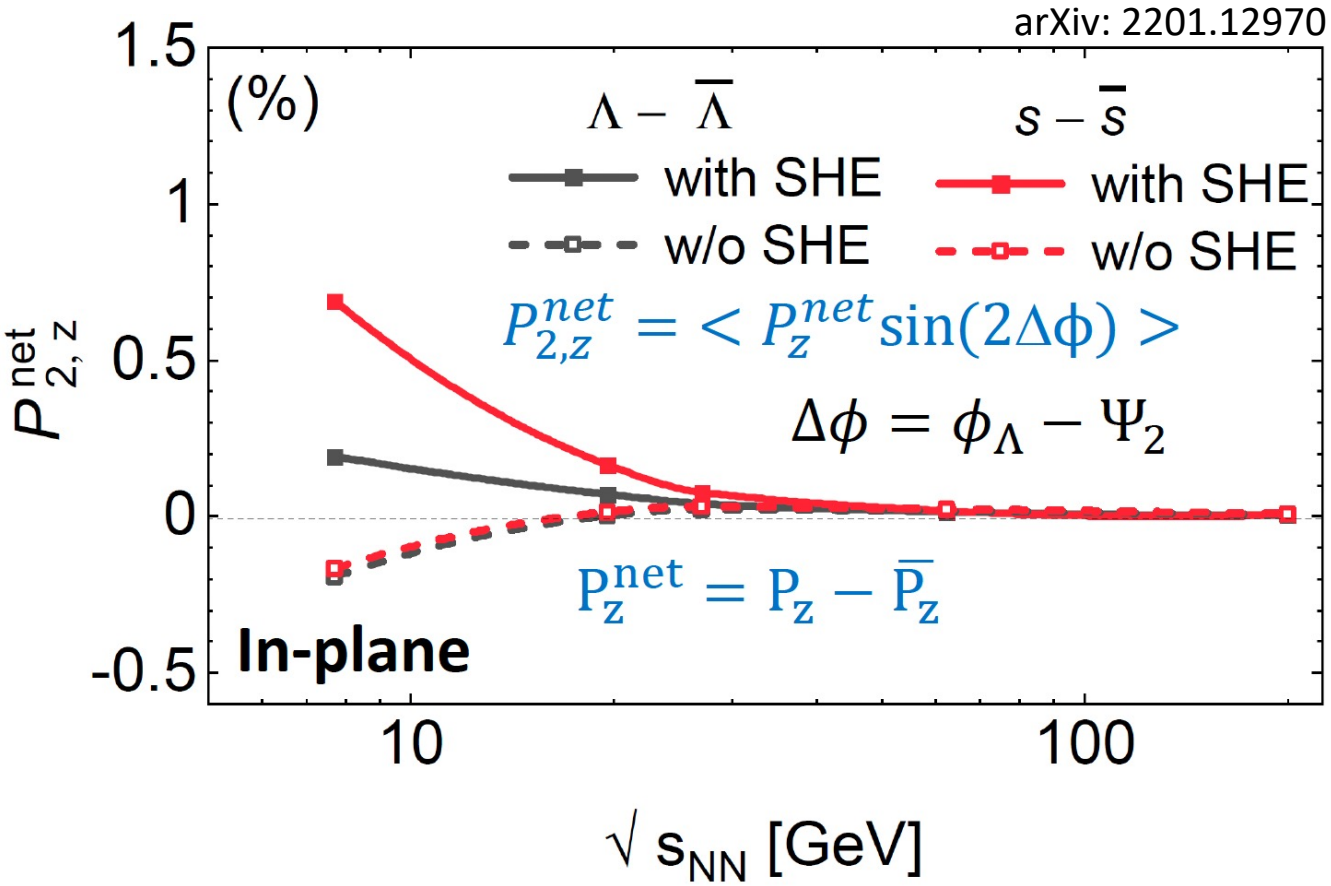
$$P \propto \boldsymbol{p} \times \boldsymbol{E}$$

Spin Hall effect, (1972) 2004

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

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

Baryonic Spin Hall Effect



Spin Hall effect driven by baryon potential predicted
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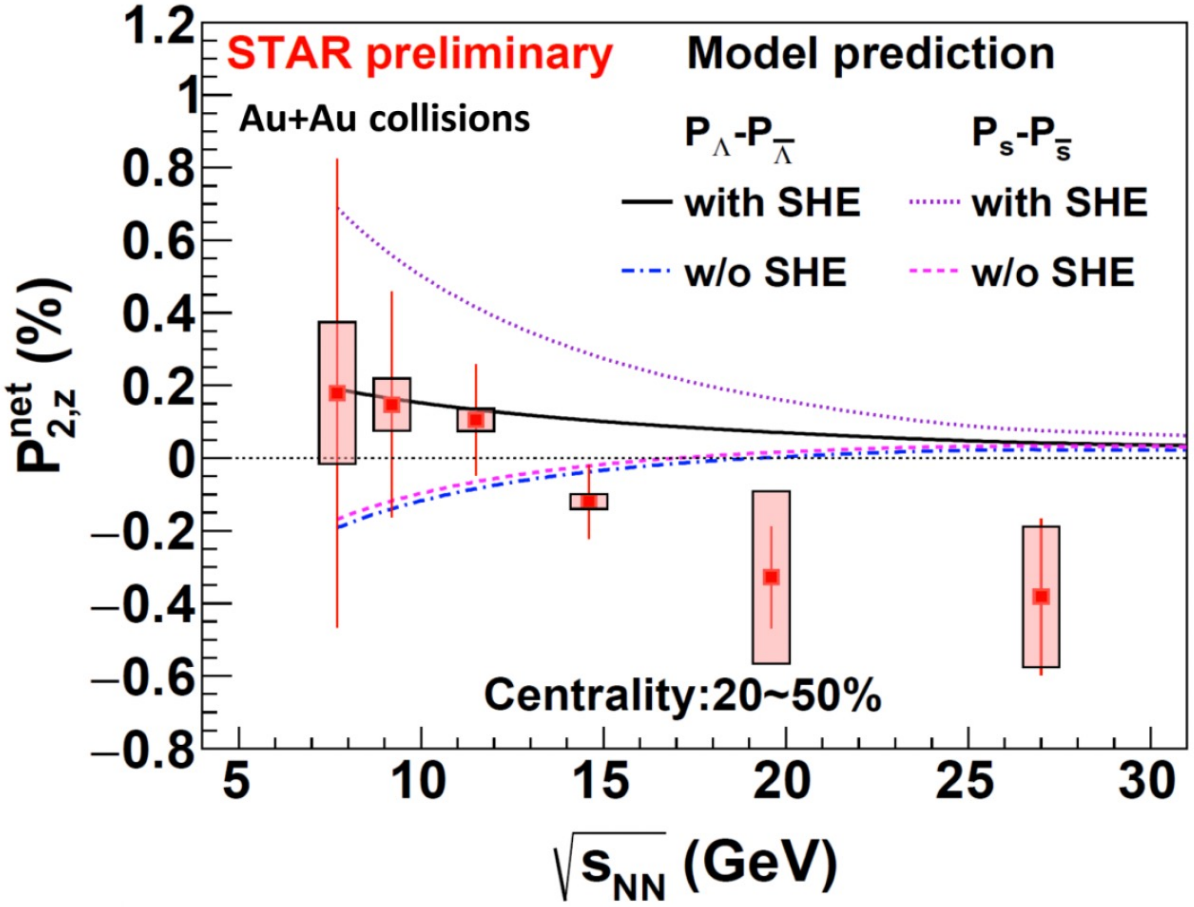
Predicts energy dependent net-Λ polarization

Baryonic Spin Hall Effect



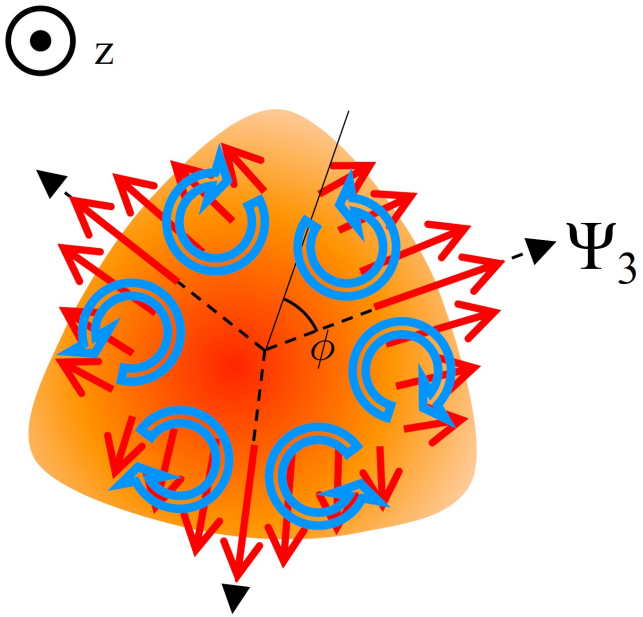
Spin Hall effect driven by baryon potential predicted

Could introduce a splitting in polarization between Λ & anti-Λ

Predicts energy dependent net-Λ polarization

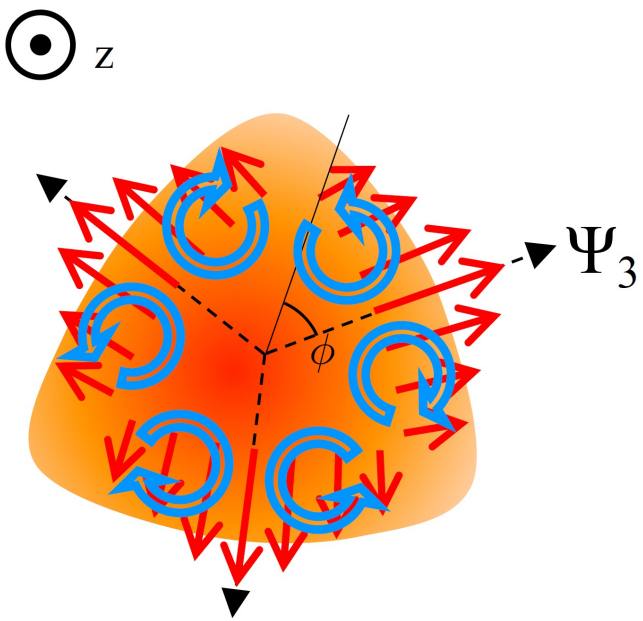
No obvious evidence with large undertainties

P_z wrt higher order collective flow plane

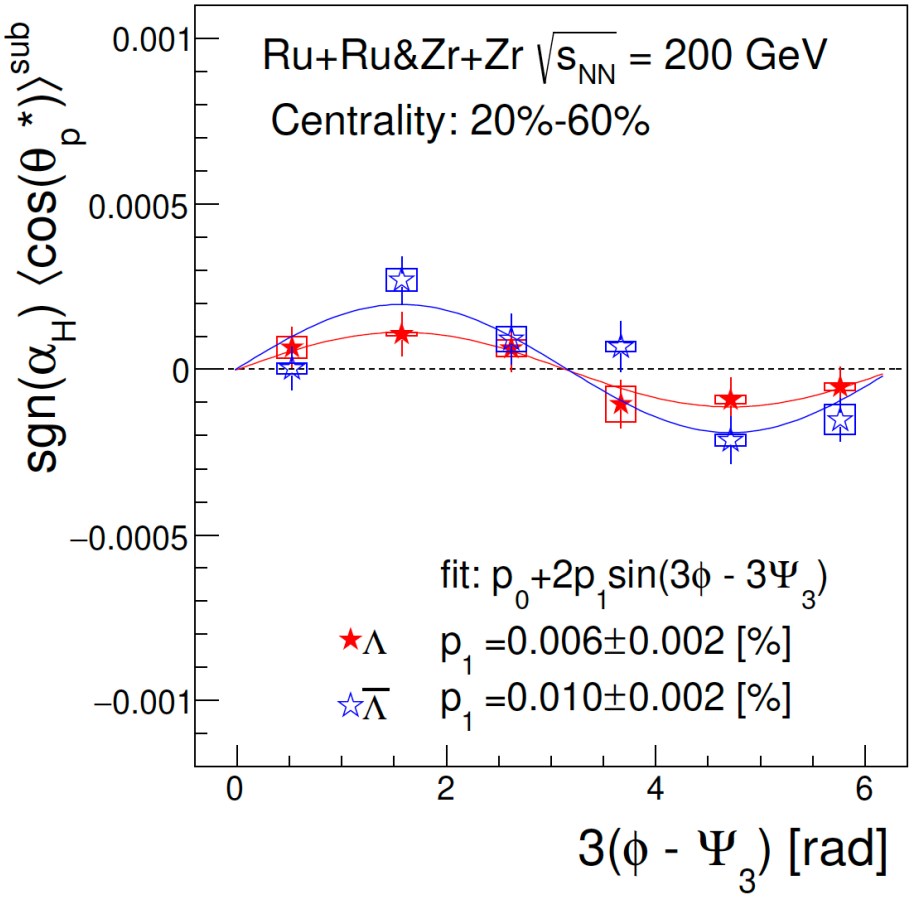


Does the same mechanism extends to higher order flow?

P_z wrt higher order collective flow plane



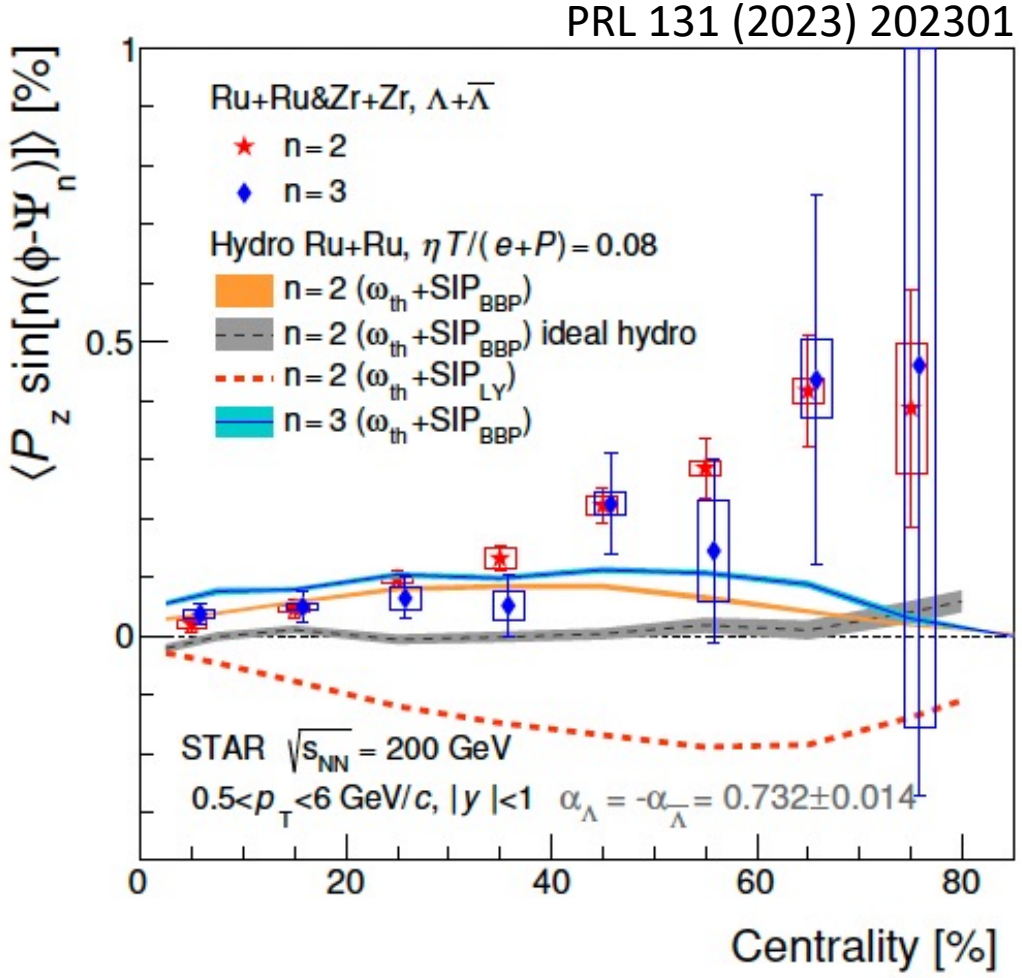
PRL 131 (2023) 202301



Does the same mechanism extends to higher order flow?
Indeed observed in isobar collisions

P_z wrt higher order collective flow plane

PRL 131 (2023) 202301

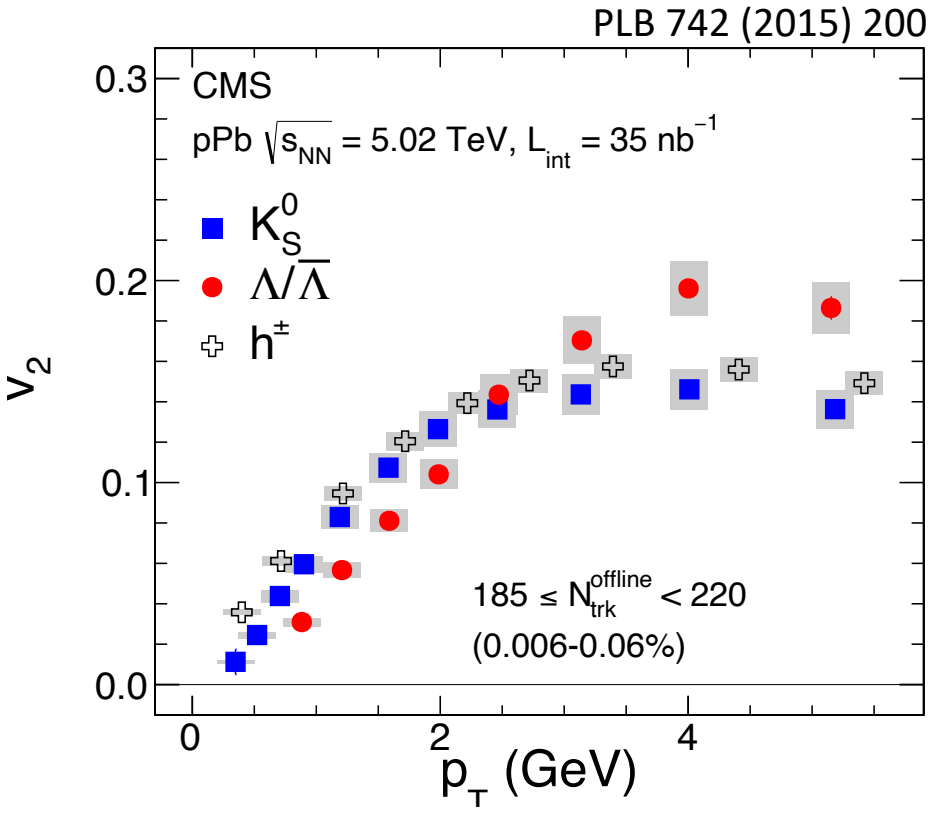


Significant signal comparable to $P_{z,2}$

Hydro with shear contribution describe the data for most centralities

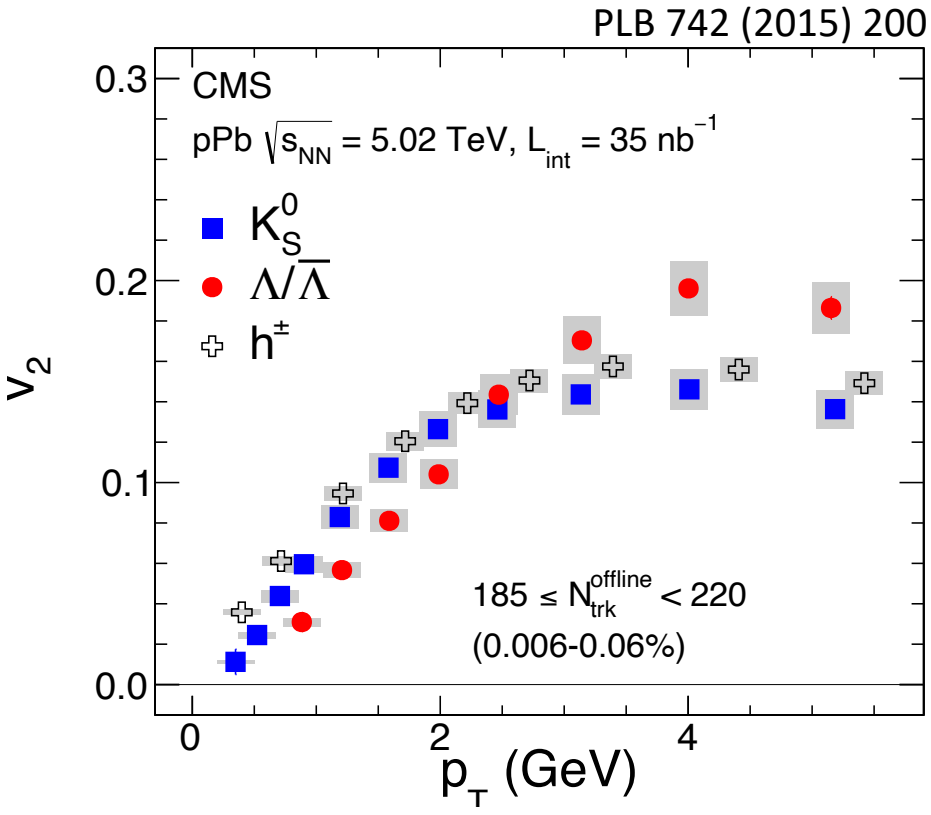
Confirm the link between P_z and collective flow

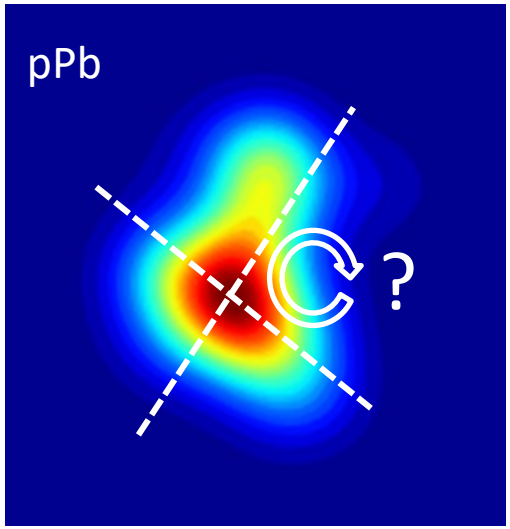
Extend to small system



Features of QGP droplets observed in small but dense systems

Extend to small system



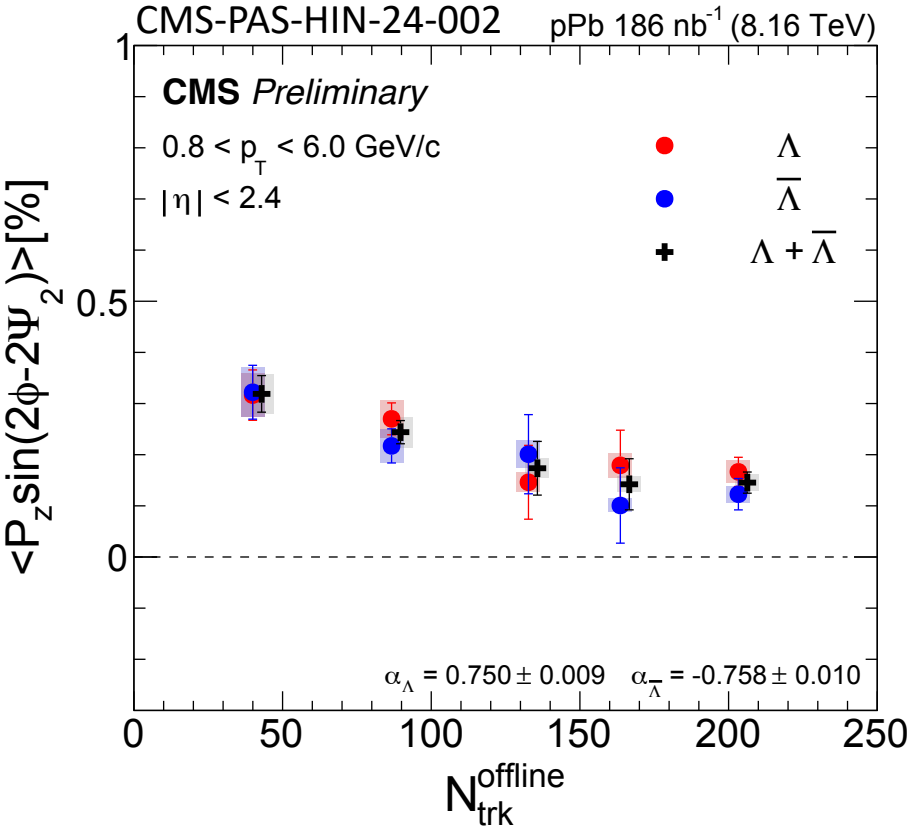


Features of QGP droplets observed in small but dense systems

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

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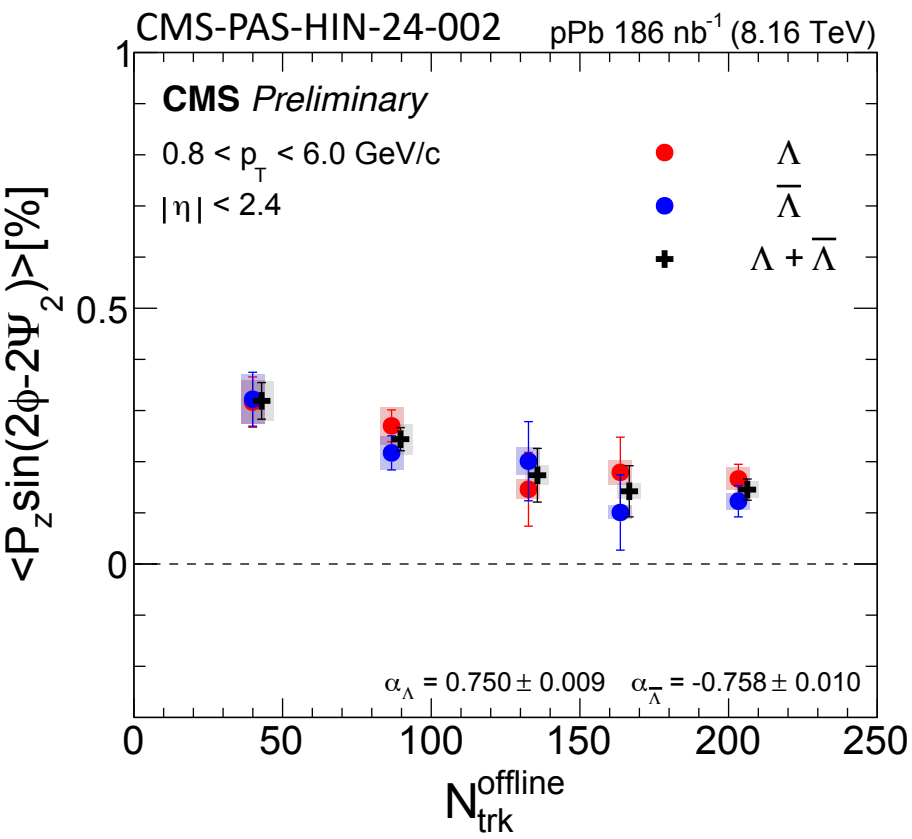

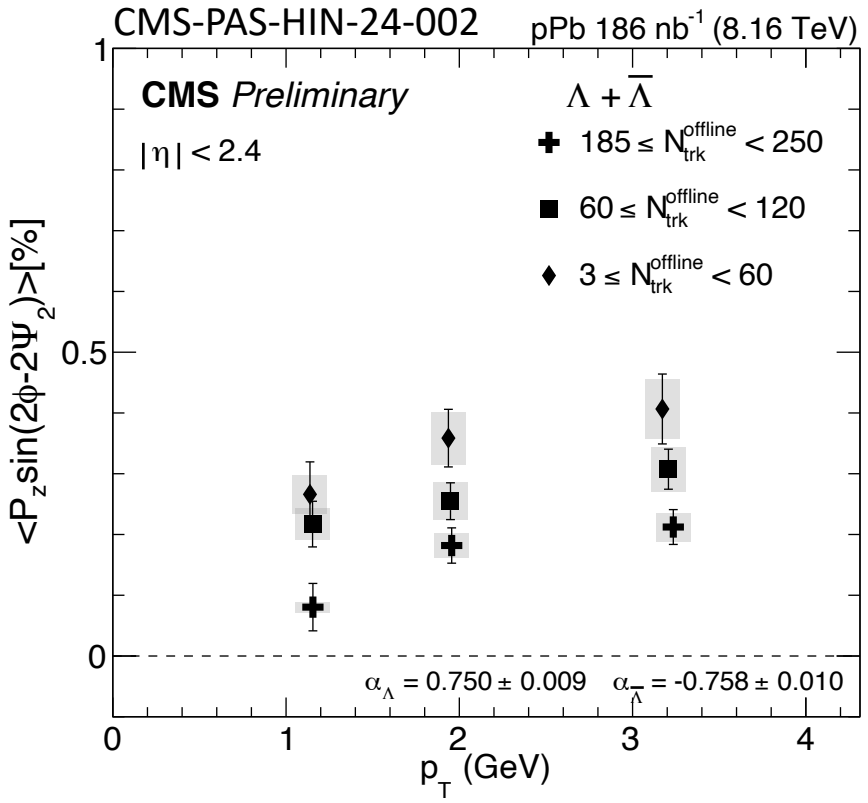

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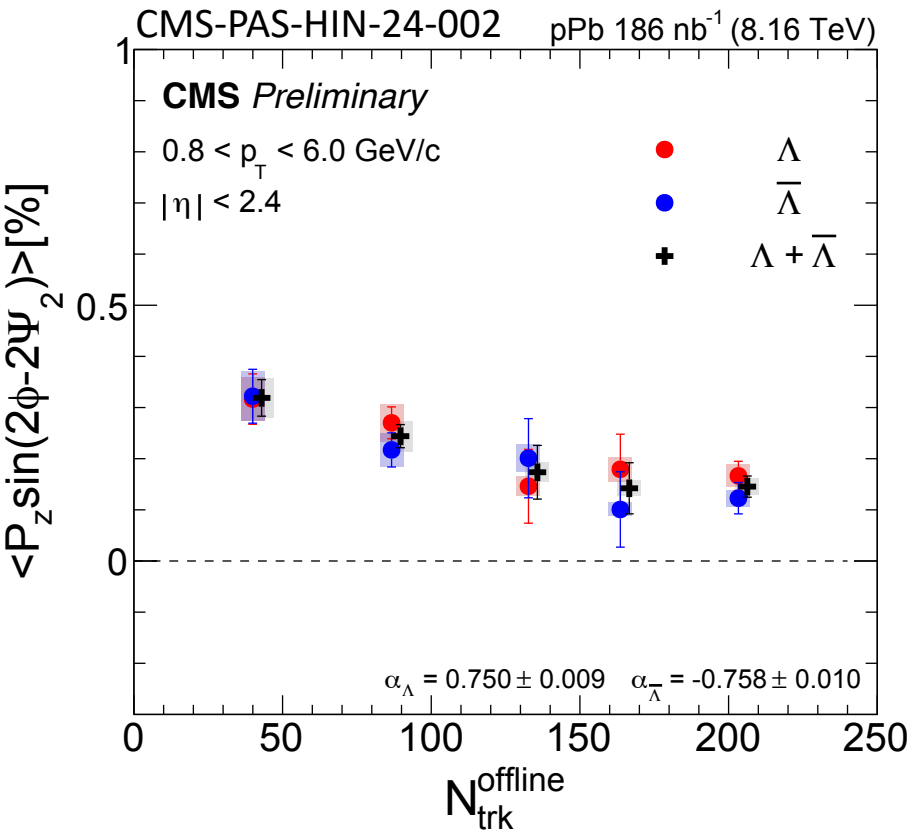
Decrease towards high multiplicity

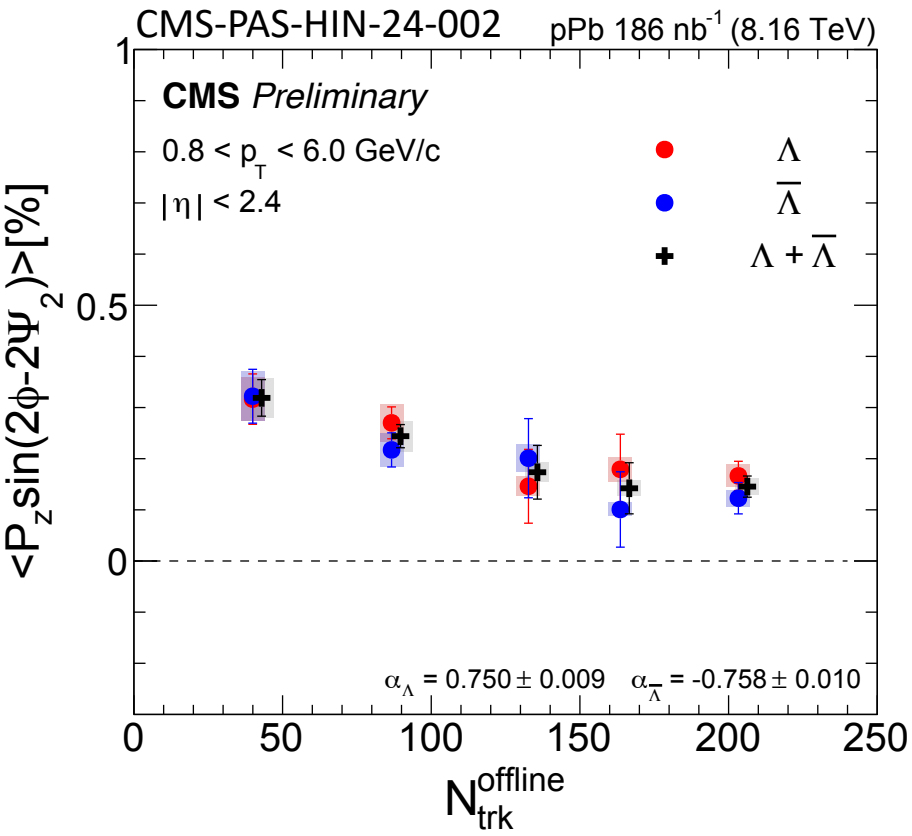
Increase towards higher p_T – hint of saturation at intermediate p_T

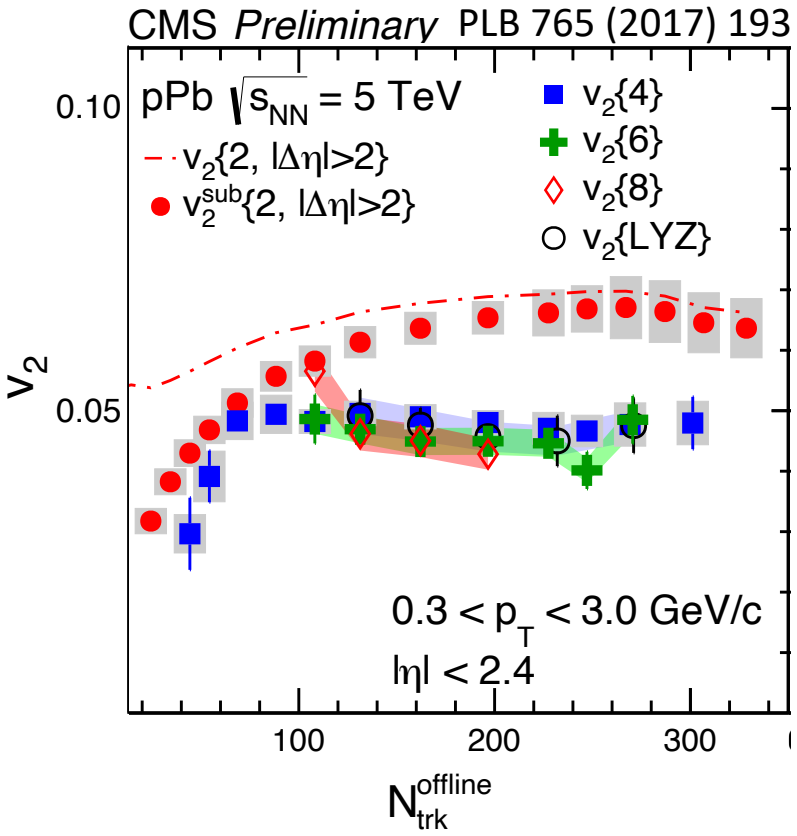
$P_{z,s2}$ from medium expansion?



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

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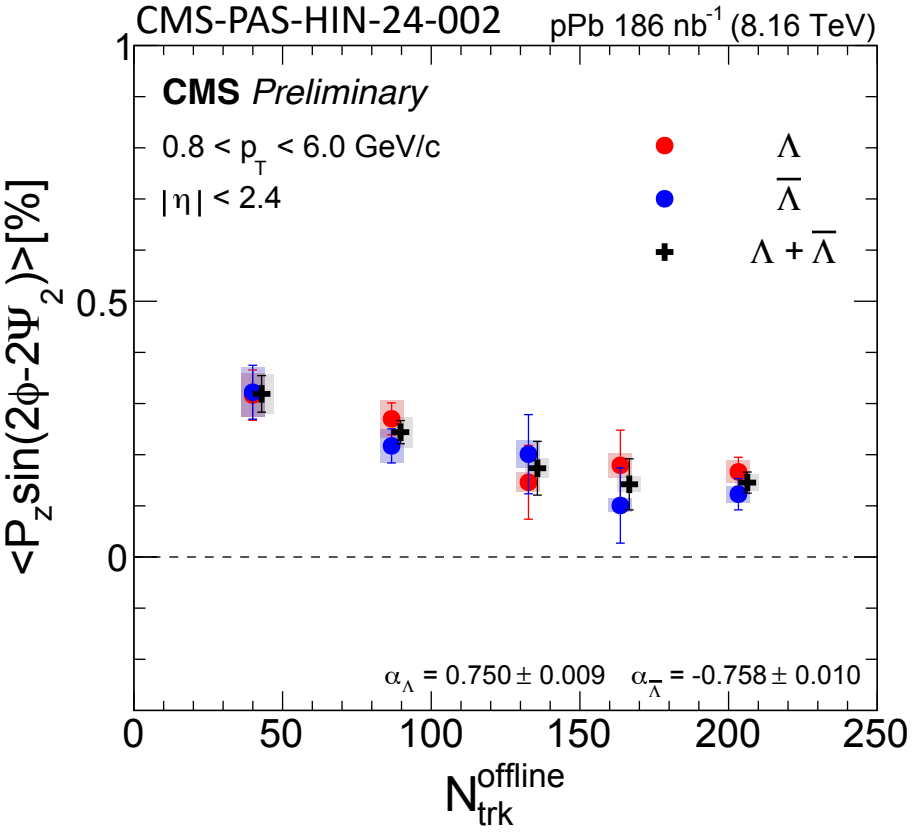

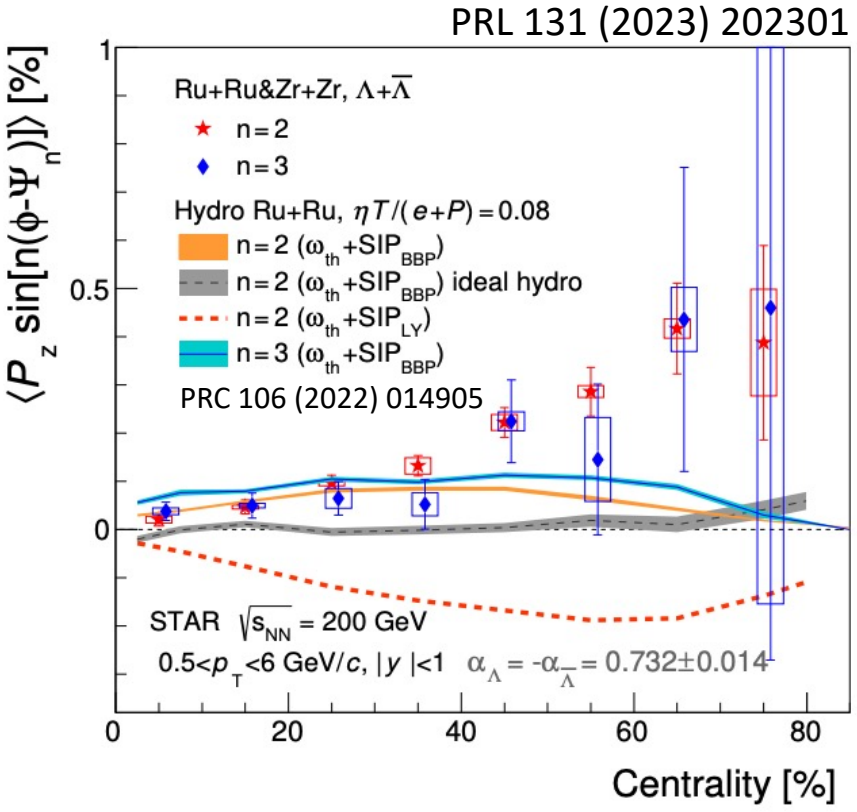

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Similar to the behavior for peripheral AA; not captured by hydro?

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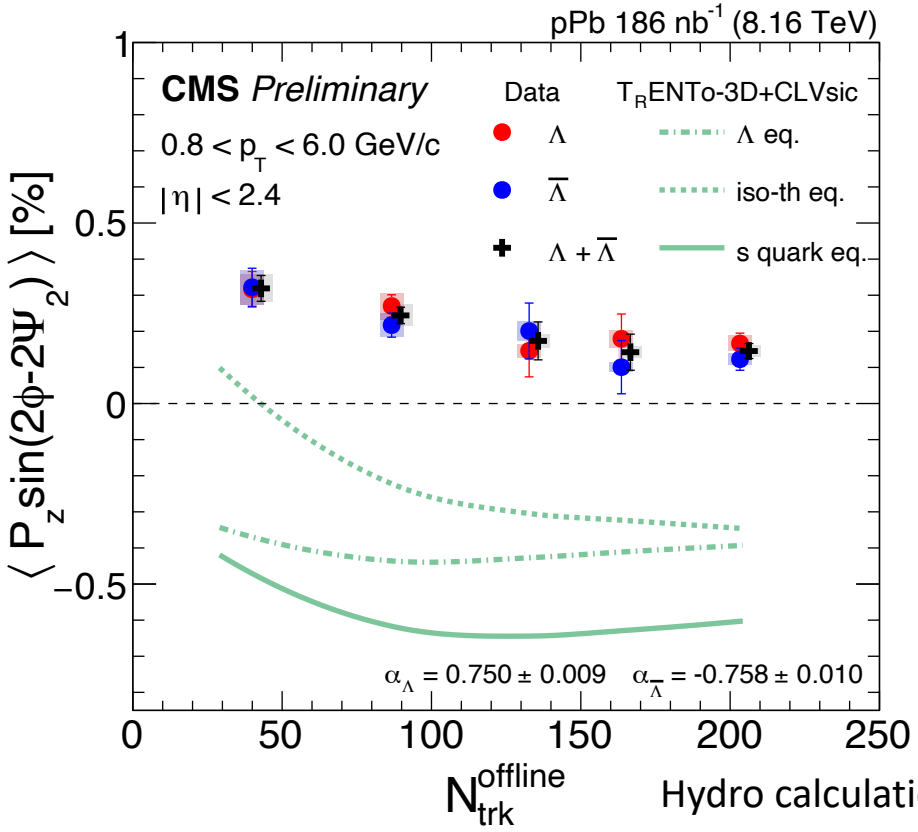

Hydro calculation arXiv:2408.04296

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A hydro calculation results in negative Pz

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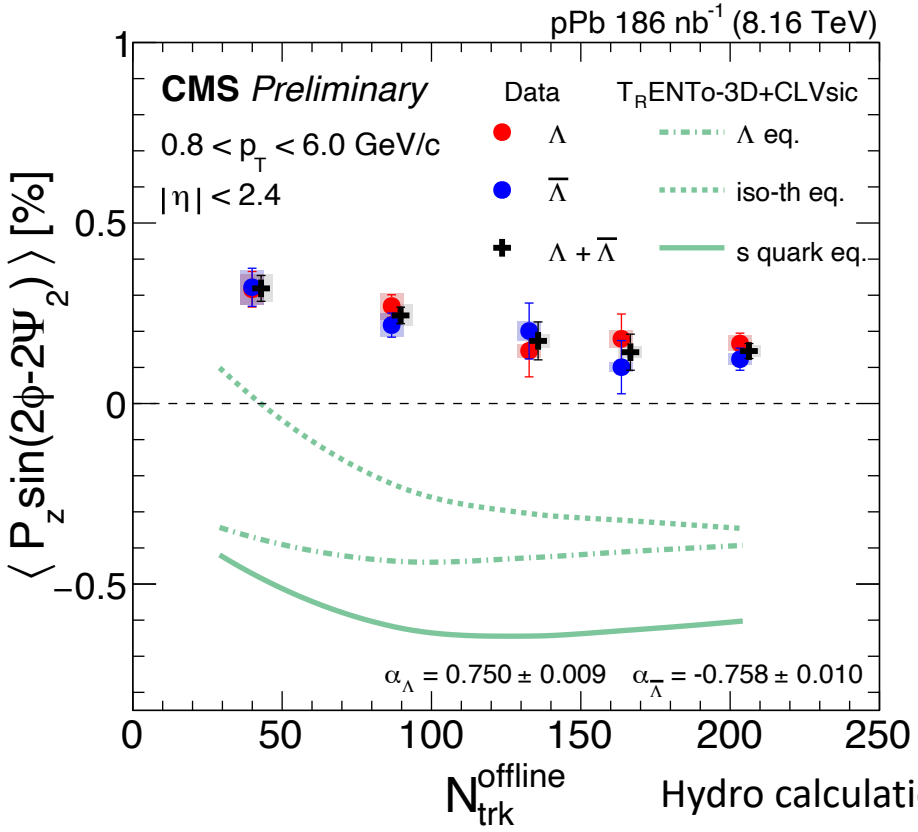

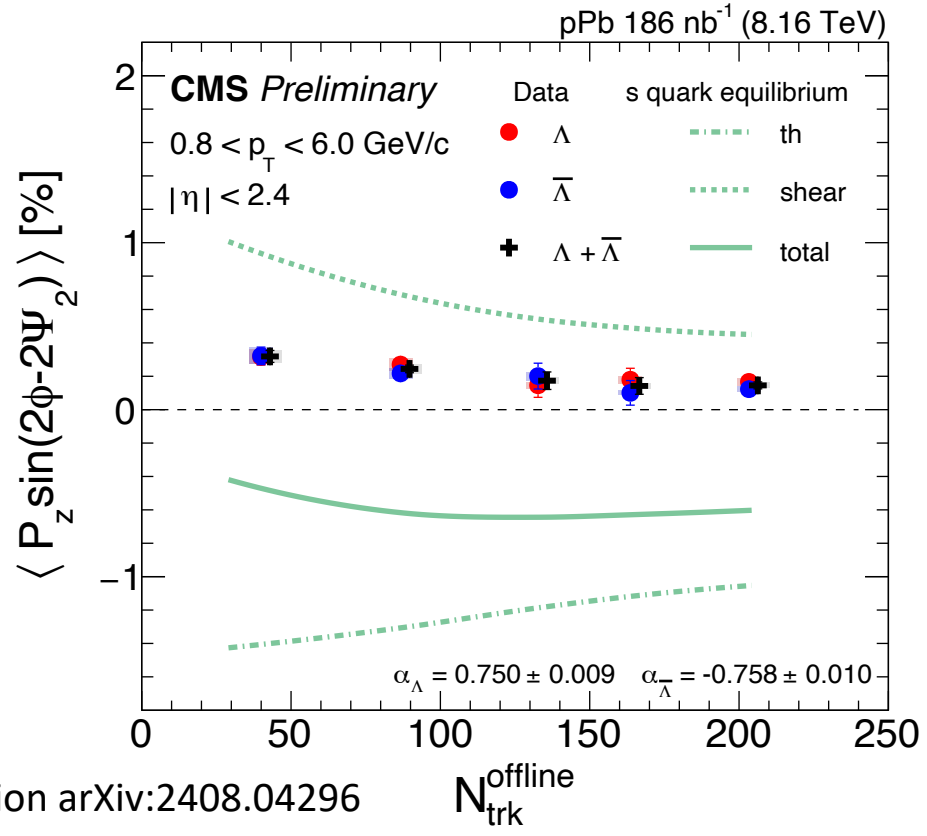

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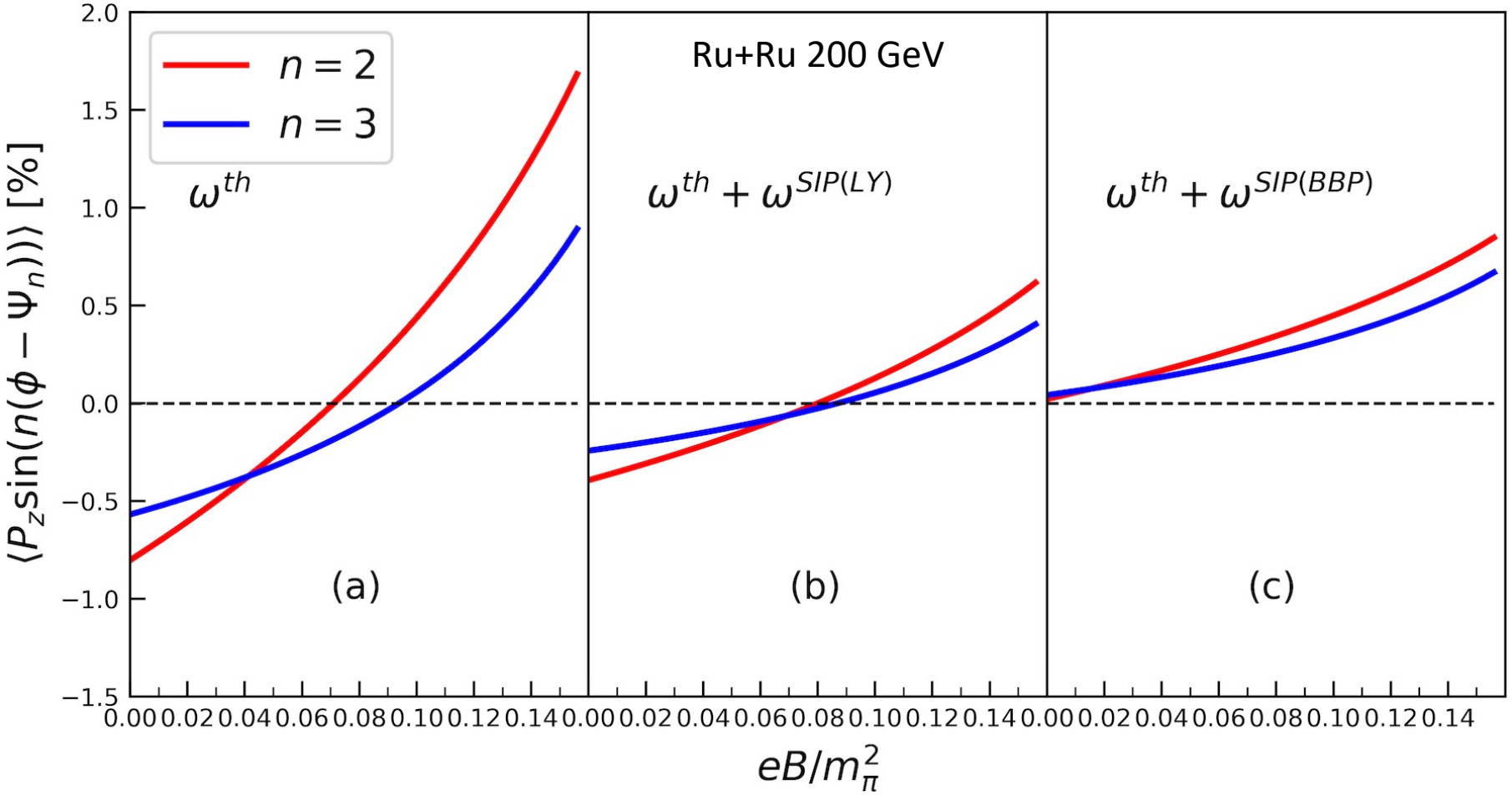
$P_{z,s2}$ from magnetic field?

arXiv:2401.07458



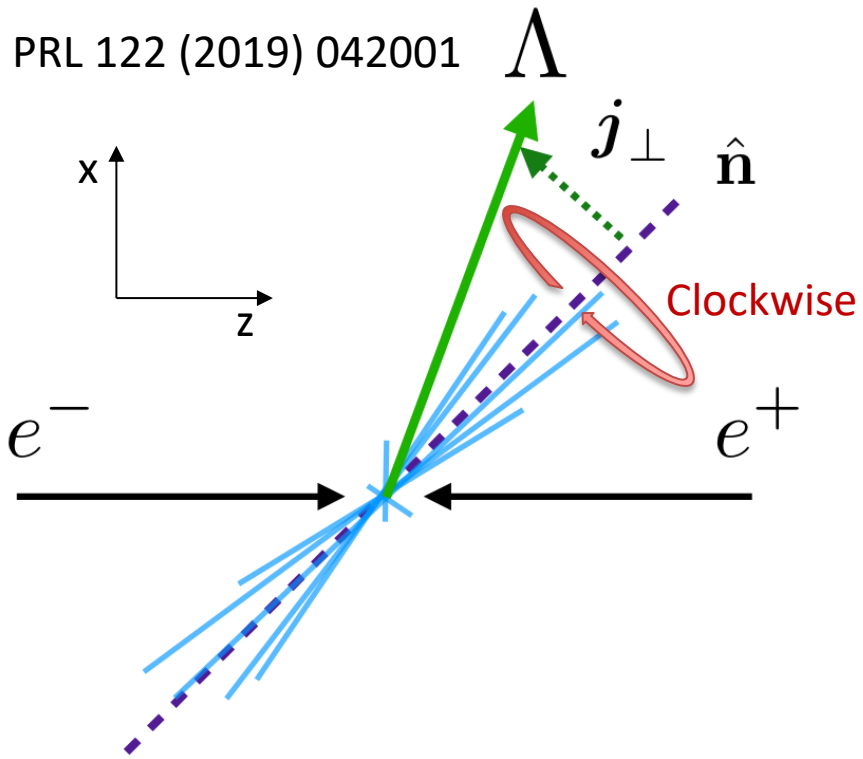
Magnetic field could flip the sign of P_z

Λ and anti-Λ should have different P_z?

Look forward to the final calculations in pPb

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

PRL 122 (2019) 042001

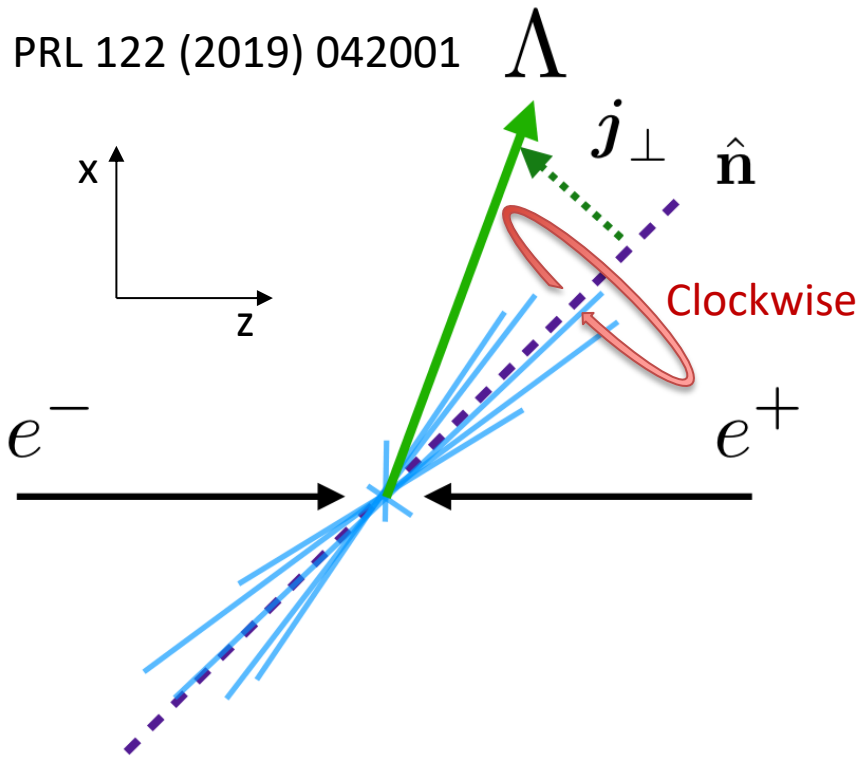


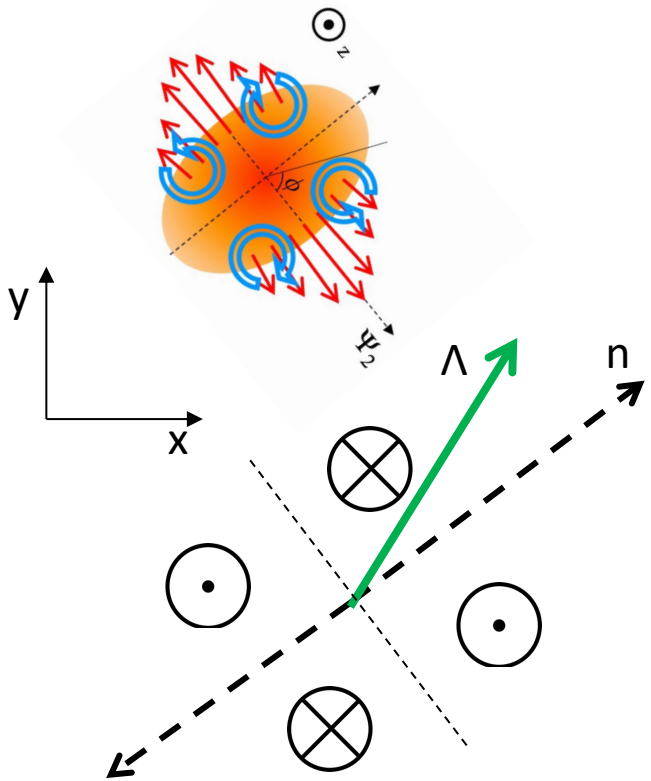
Transverse polarization of Λ has been a long standing puzzle

Recent Belle measurement in e^+e^- shows a significant signal wrt thrust axis

$P_{z,s2}$ 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

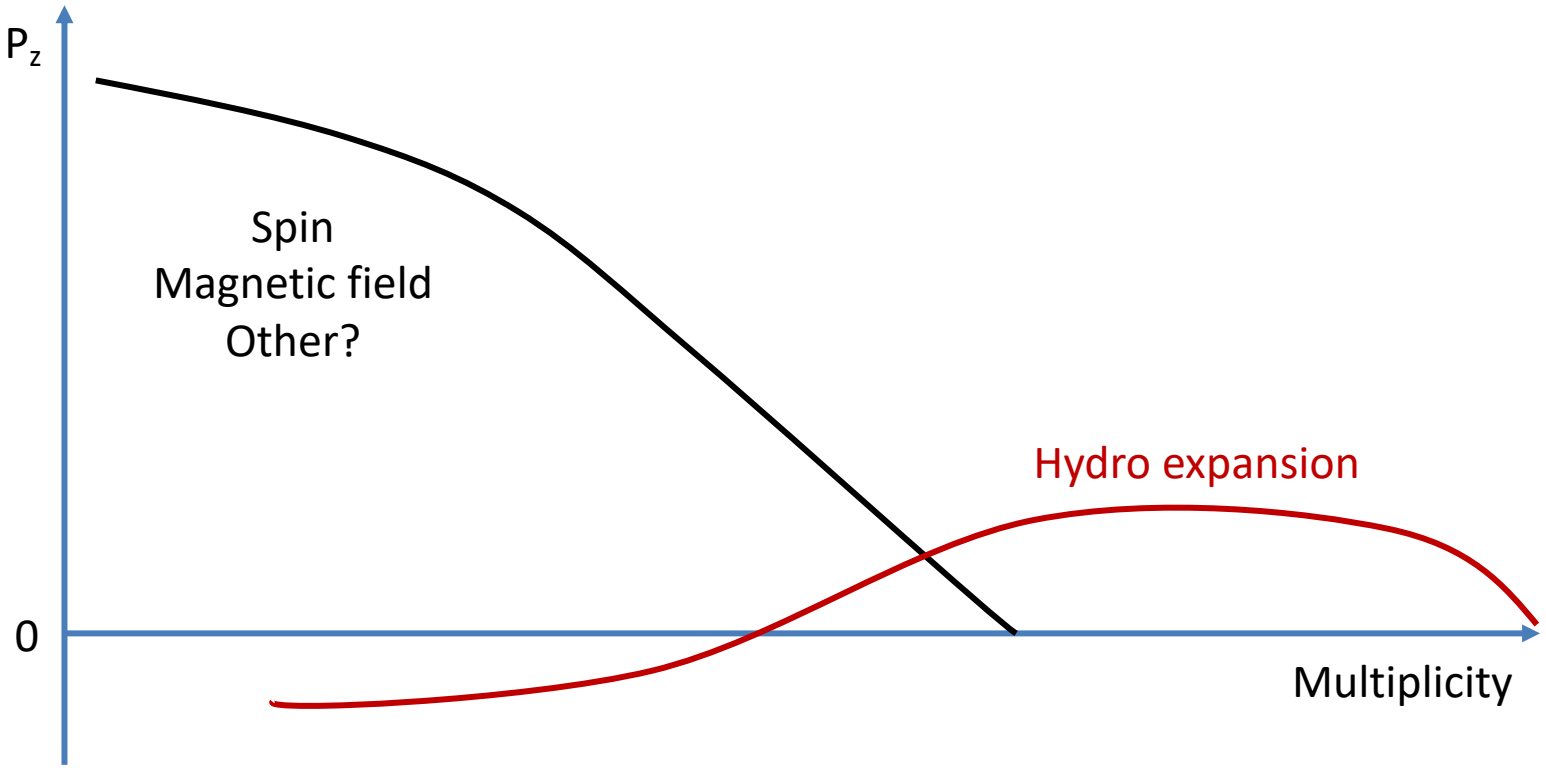
Projection into x-y plane introduce a P_z wrt thrust axis

Thrust axis coincide with 2nd order event plane at low multiplicity

Opposite direction than our signal, but could have a z_Λ dependence

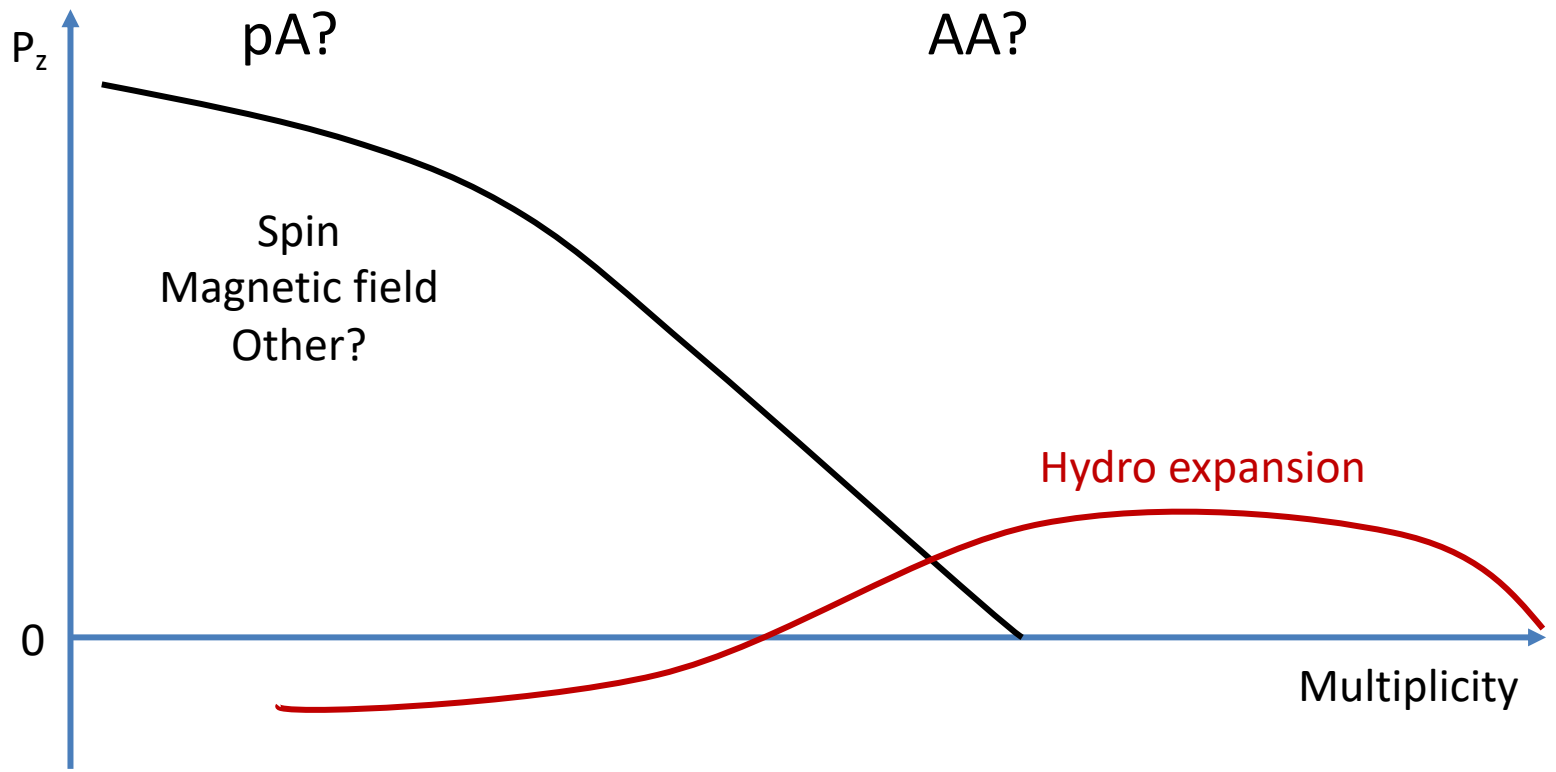
Diluted towards high multiplicity

Different contributions vs multiplicity?



A naïve guess of the picture

Different contributions vs multiplicity?



A naïve guess of the picture

Where is the switching point and what does it imply for AA?

Potential to reveal connections between different physics mechanisms

Summary and outlook

Hyperon global polarization measurements @ RHIC are in precision era

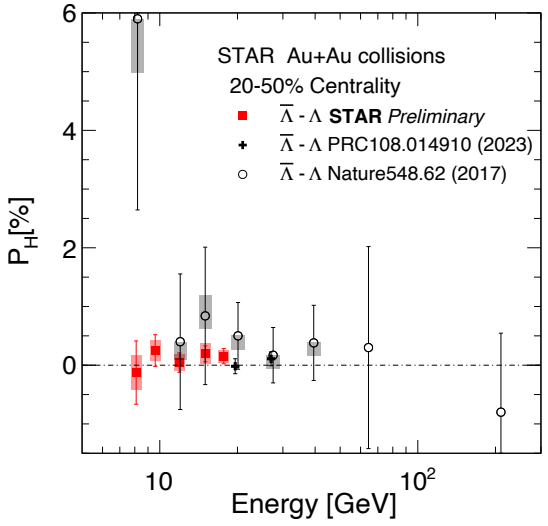
- No significant splitting between Λ and anti-Λ
- No obvious system size dependence
- Hint of different polarization for Λ and Ξ

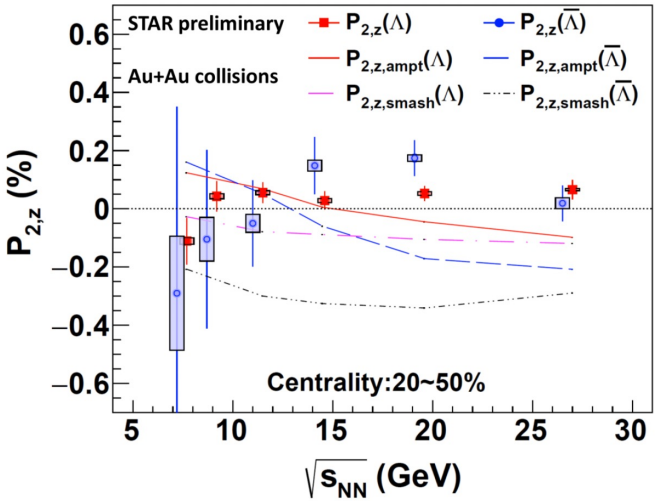
Open questions in polarization along the beam direction measurements

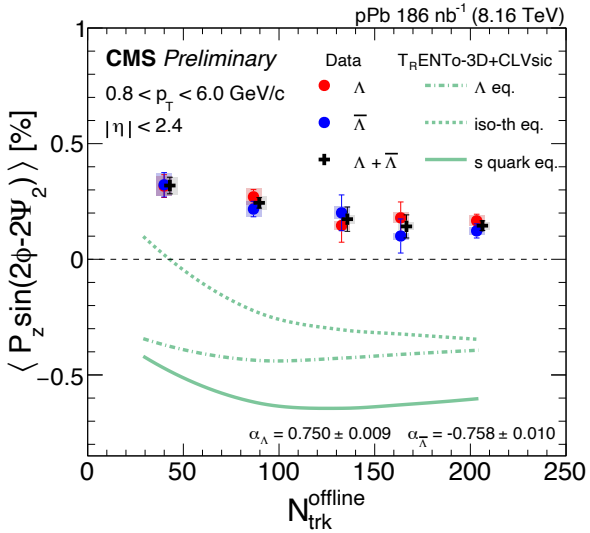
- Energy dependence and potential sign change
- Multiplicity dependence in pPb collisions

Future directions

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

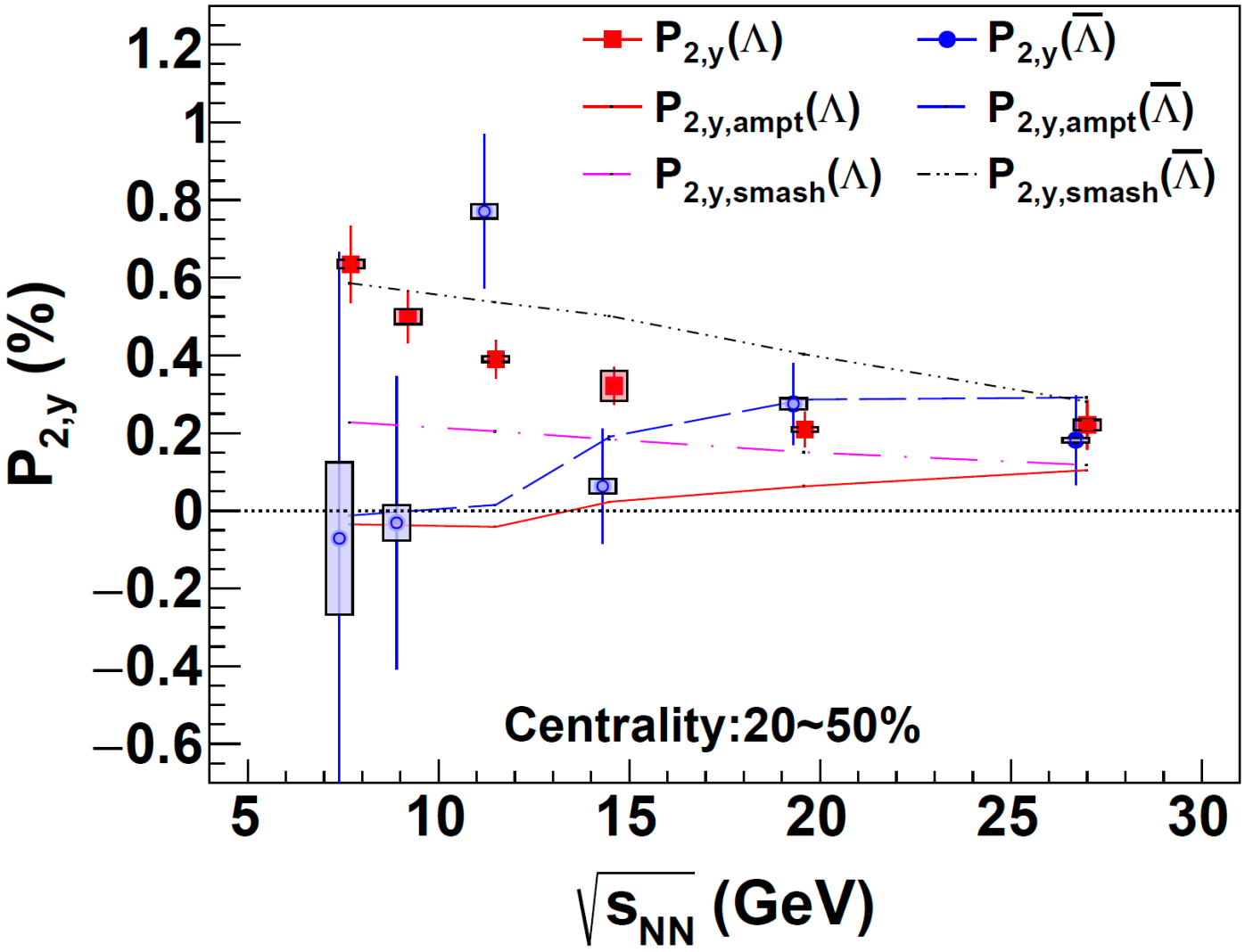




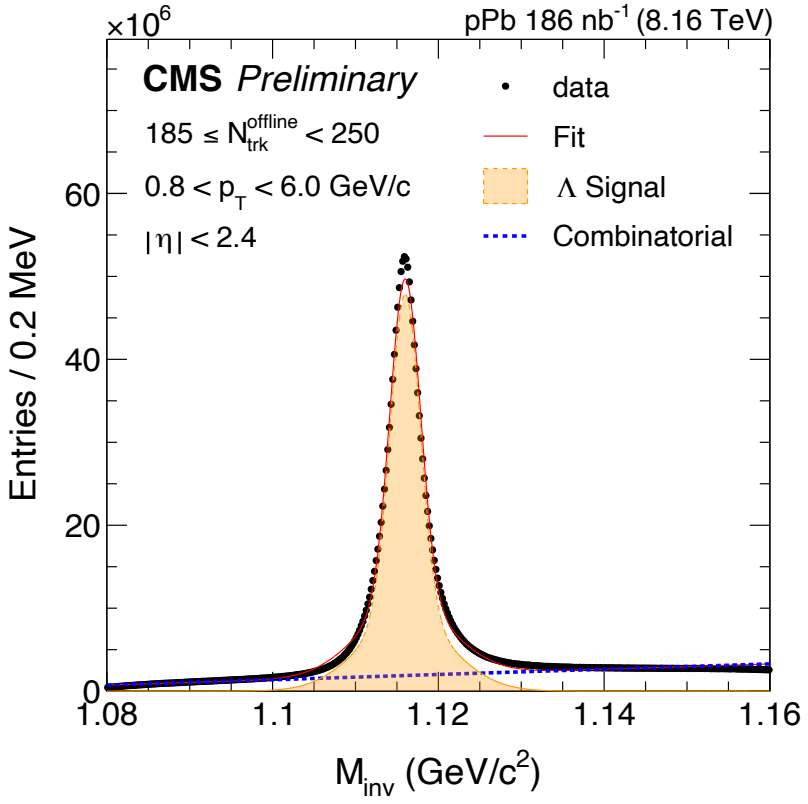


Back up

$P_{2,y}$


$P_{2,y}(\Lambda)$
$P_{2,y}(\bar{\Lambda})$
$P_{2,y,ampt}(\Lambda)$
$P_{2,y,ampt}(\bar{\Lambda})$
$P_{2,y,smash}(\Lambda)$
$P_{2,y,smash}(\bar{\Lambda})$
Centrality:20~50%
$P_{2,y}$ (%)
$\sqrt{s_{NN}}$ (GeV)
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
5
10
15
20
25
30

Λ hyperon in pPb collision

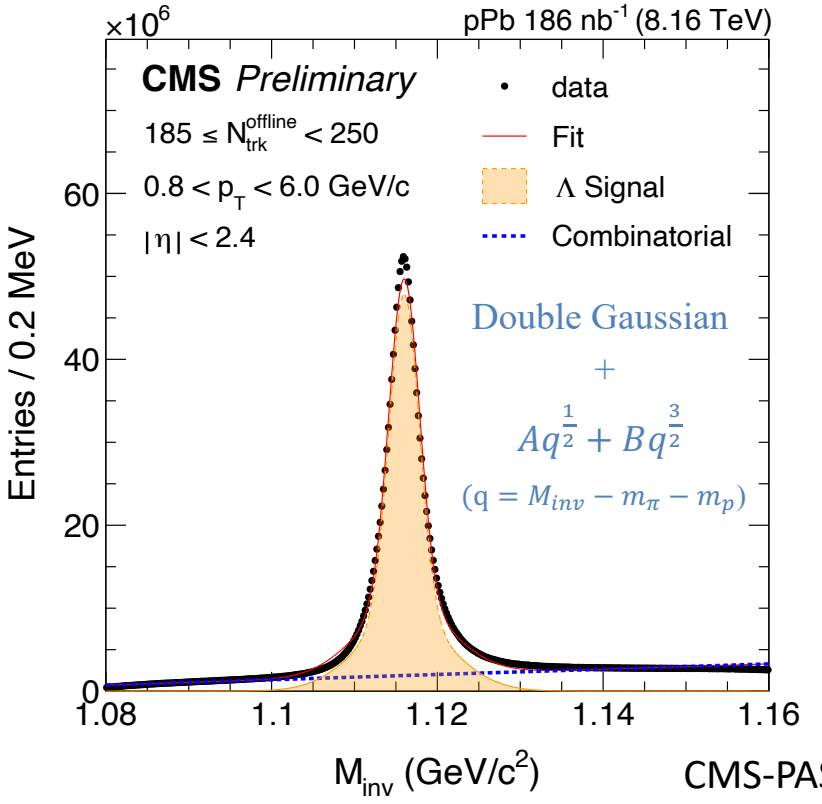


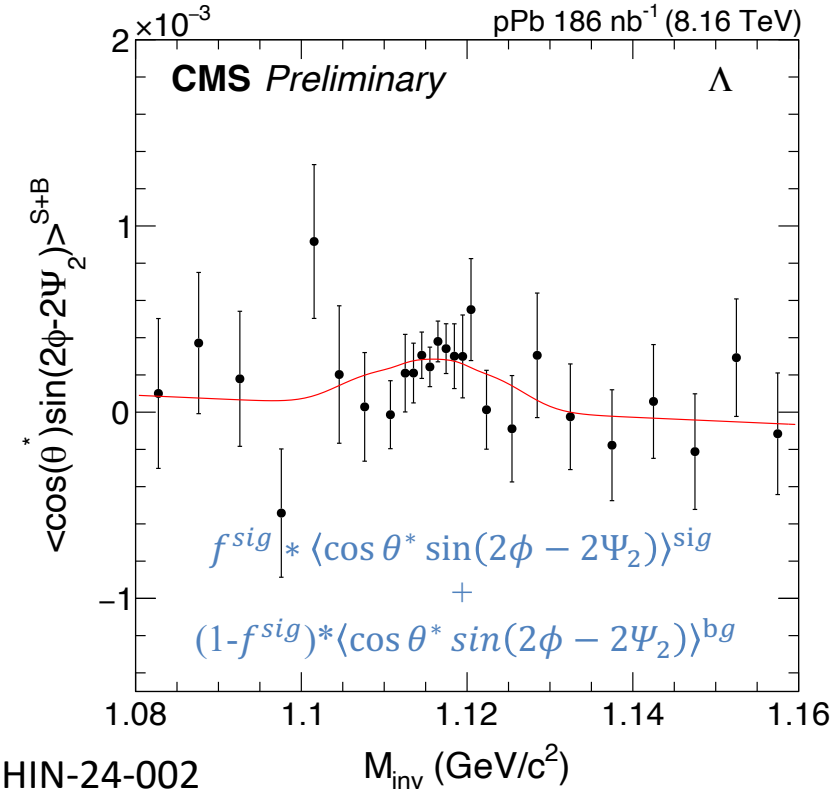
Multiplicity interval ($N_{\mathrm{trk}}^{\mathrm{offline}}$)	$\langle N_{\mathrm{trk}}^{\mathrm{offline}} \rangle$	$\langle N_{\mathrm{trk}}^{\mathrm{corrected}} \rangle$
$[3, 60)$	40.0	48.5 ± 1.9
$[60, 120)$	86.7	105.3 ± 4.2
$[120, 150)$	132.7	161.2 ± 6.4
$[150, 185)$	163.6	198.7 ± 7.9
$[185, 250)$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

CMS-PAS-HIN-24-002

Clean reconstruction of Λs in pPb collsions over wide multiplicity range

Λ hyperon polarization in pPb collision





CMS-PAS-HIN-24-002

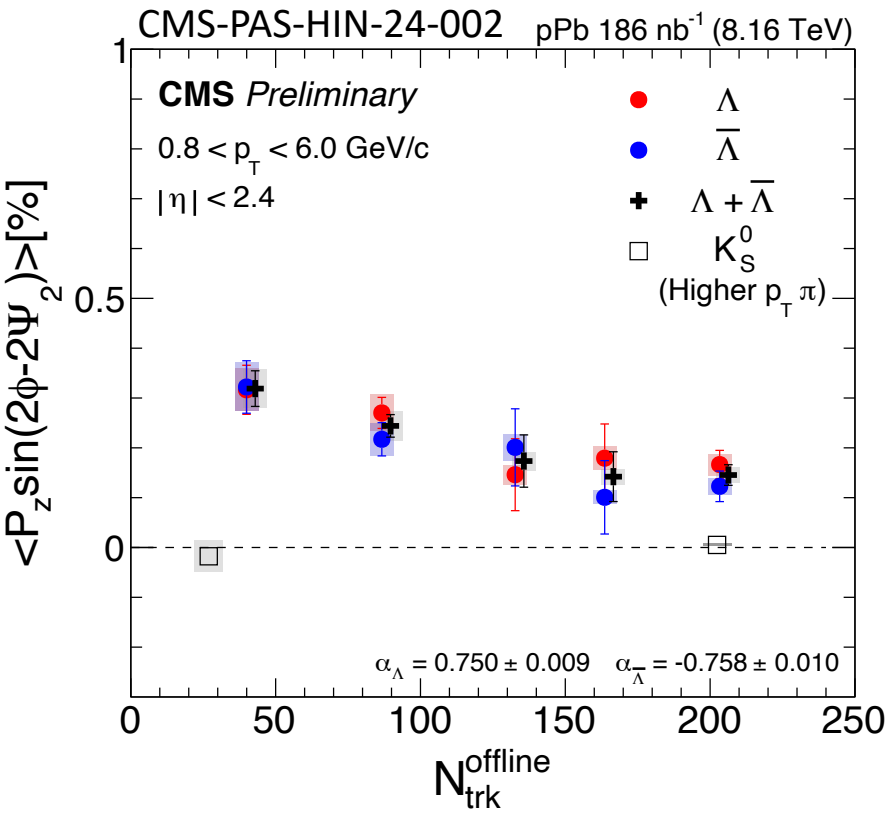
Clean reconstruction of Λs in pPb collsions over wide multiplicity range

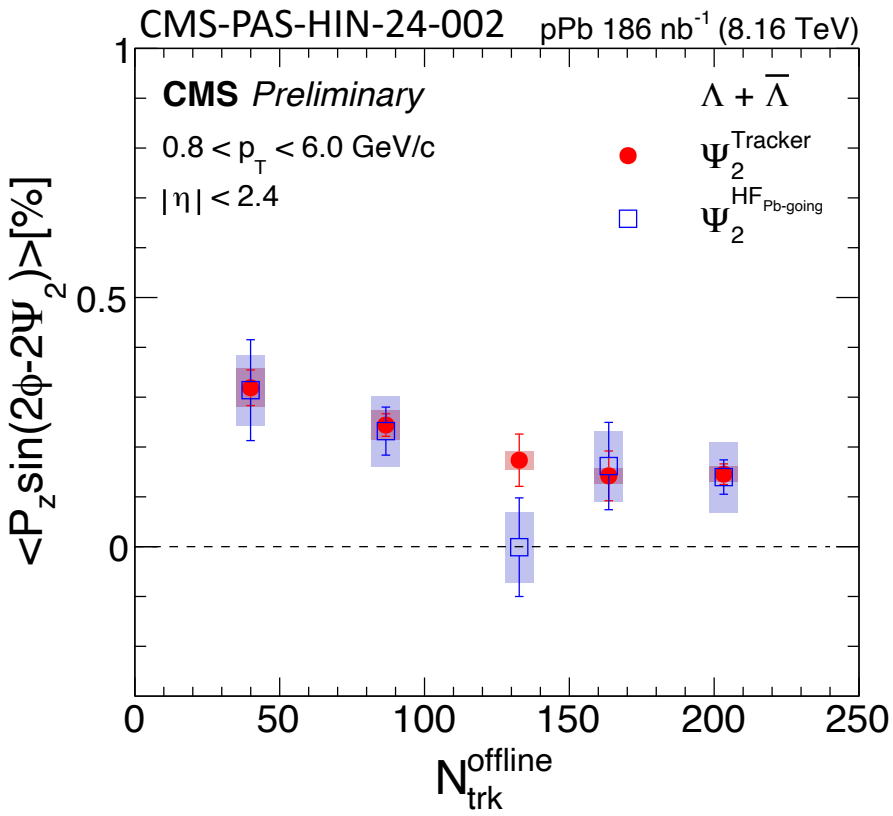
Polarization along beam direction extracted from direct measurement

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

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

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





Crosschecks done to ensure

K0S has 0 signal - no strange detector effects

Consistent results wrt forward event plane – no short range/self correlation