

Polarization & collectivity across scales

Correlated or not?

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The 5th Small System Workshop

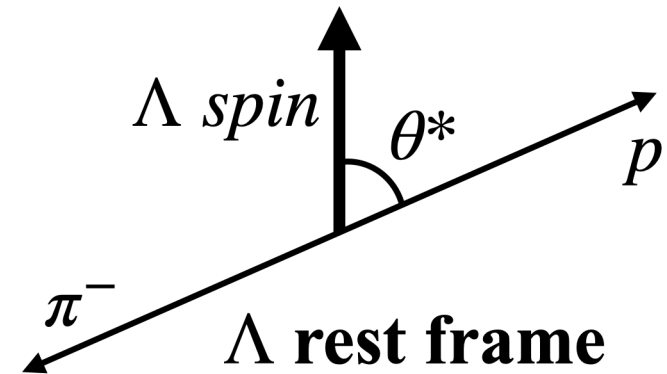
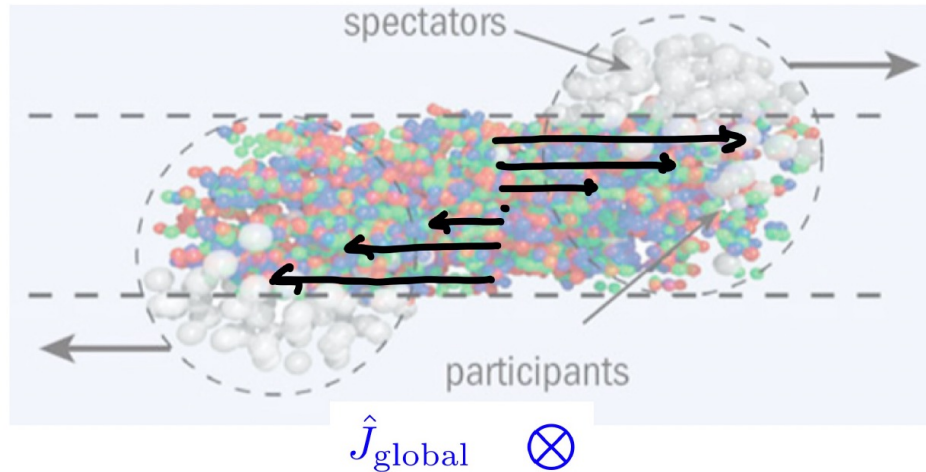
Paris, 2026



山东大学

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“The most vortical fluid”

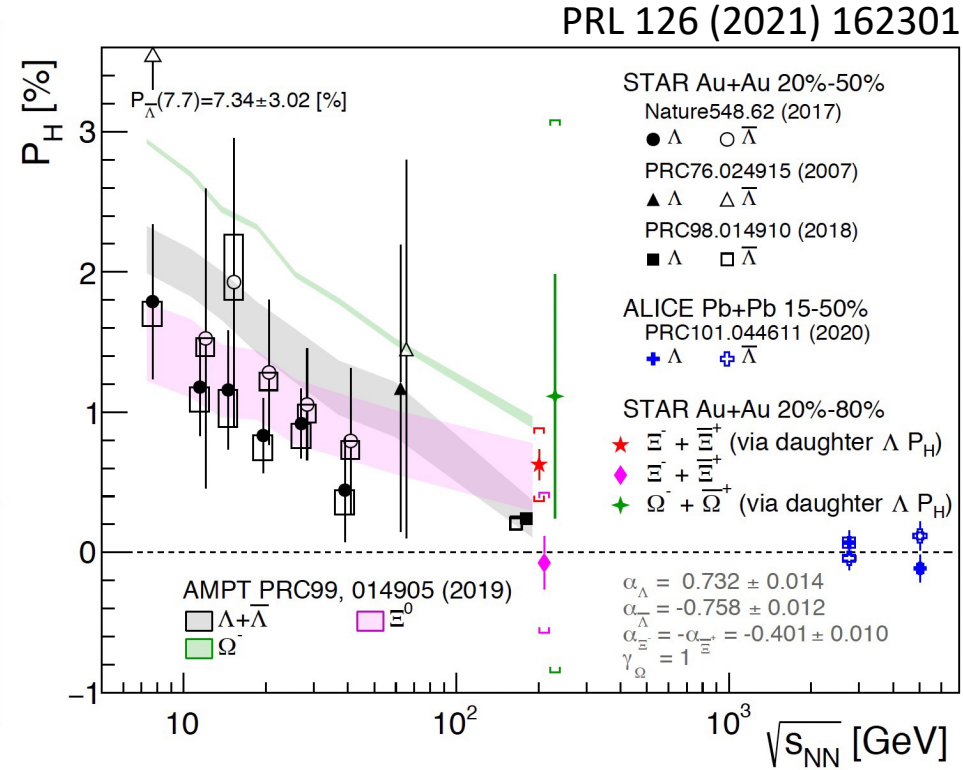
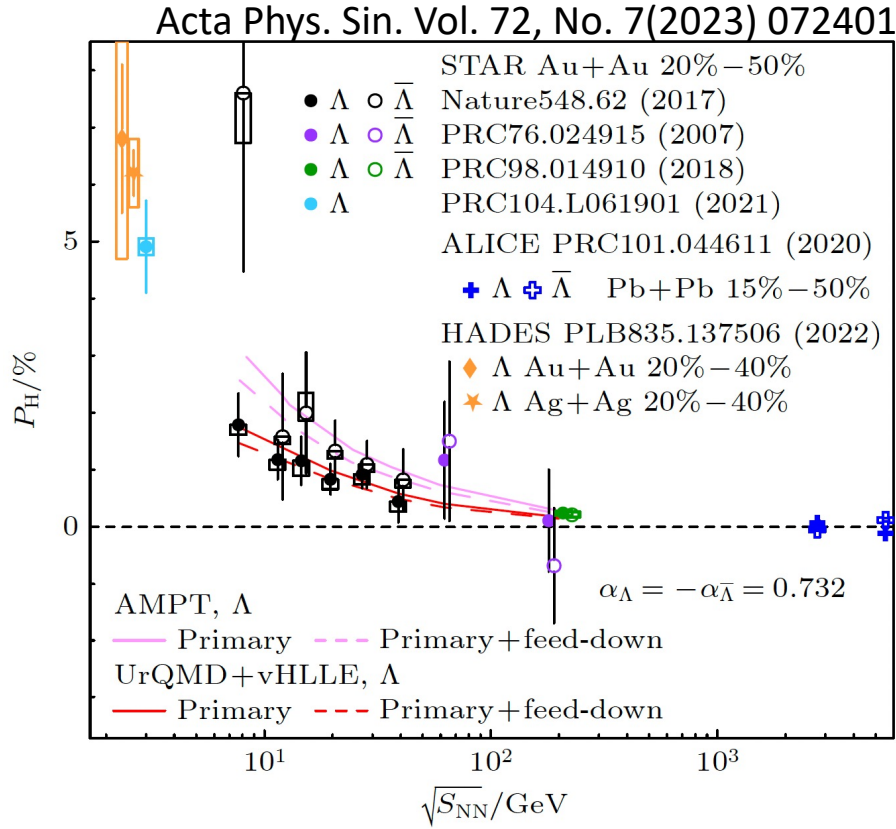


Large initial orbital angular momentum

Can polarize particles through spin-orbit coupling in parton scattering

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

“The most vortical fluid”



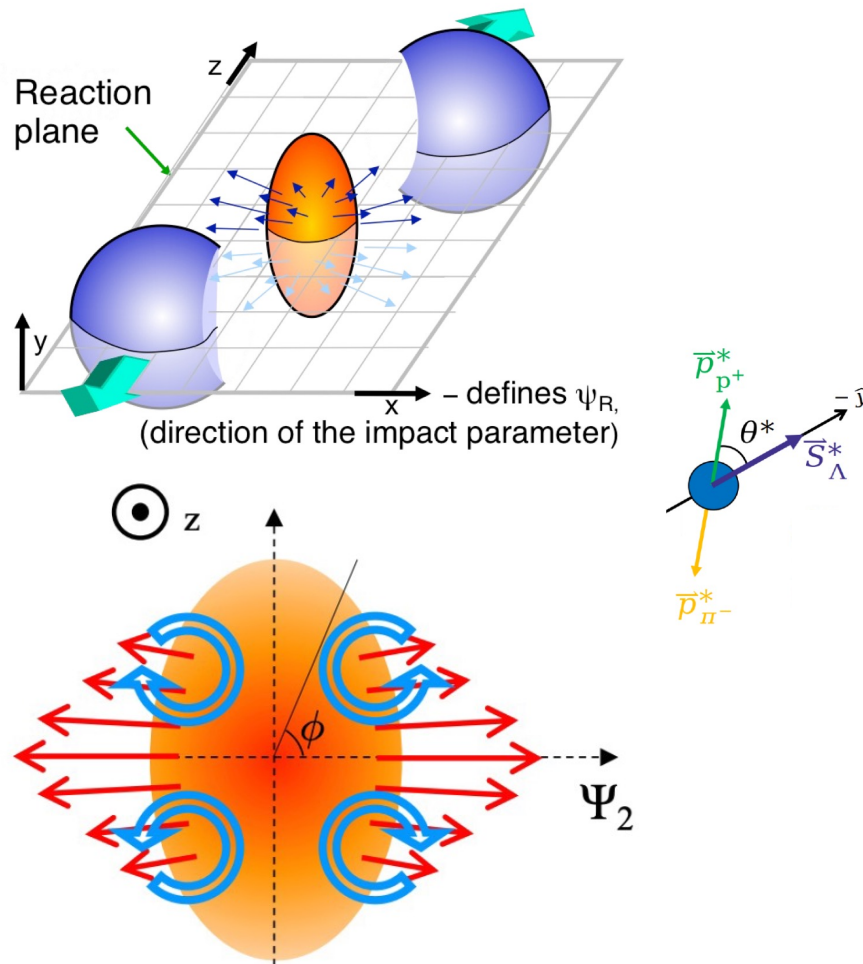
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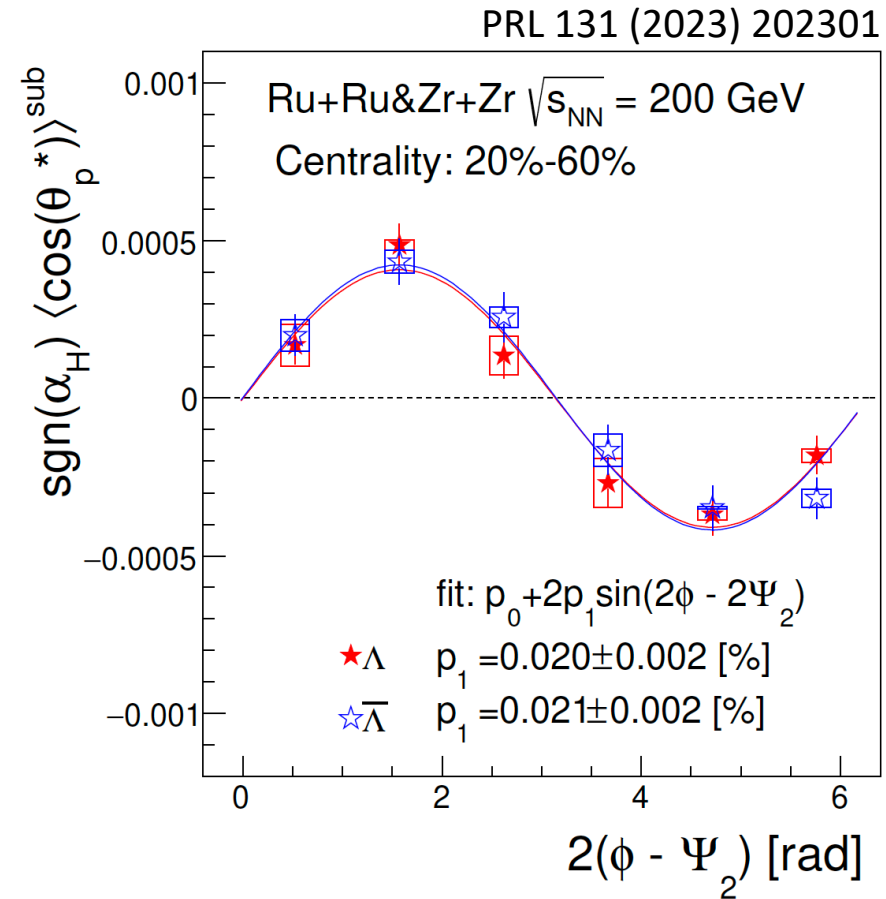
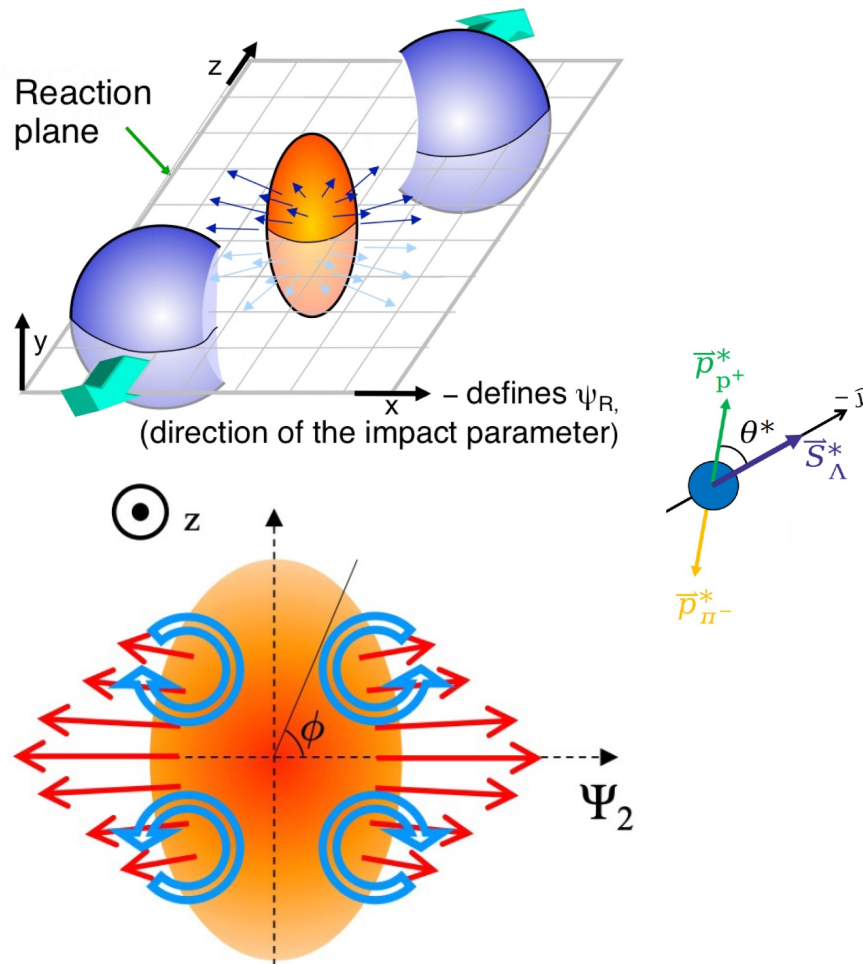
Largest vorticity ever seen $\omega \approx (9 \pm 1) \times 10^{21} \text{ s}^{-1}$

Hyperon polarization along beam direction



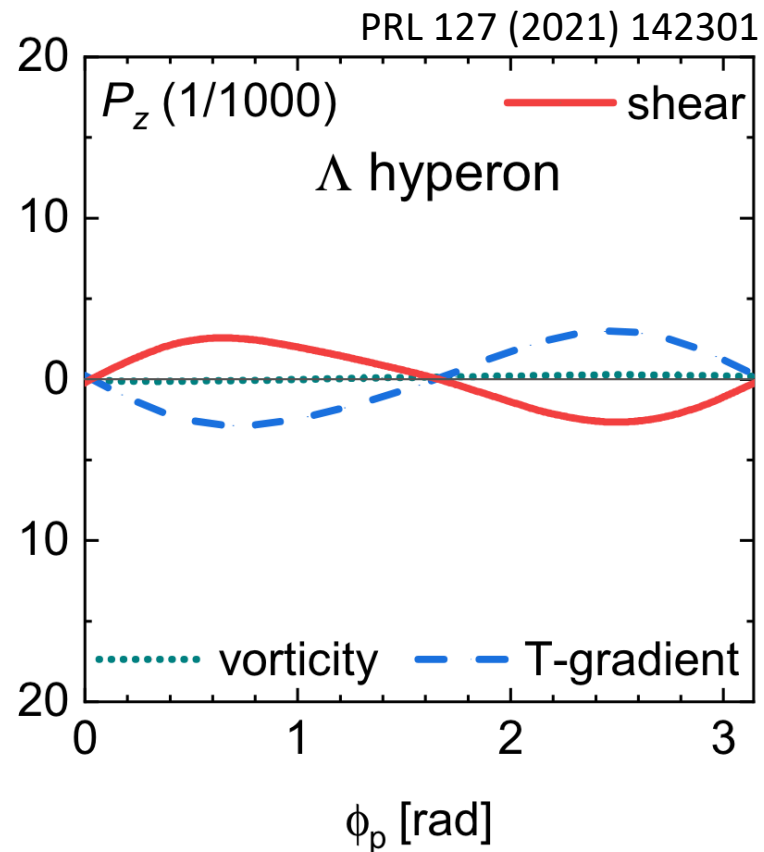
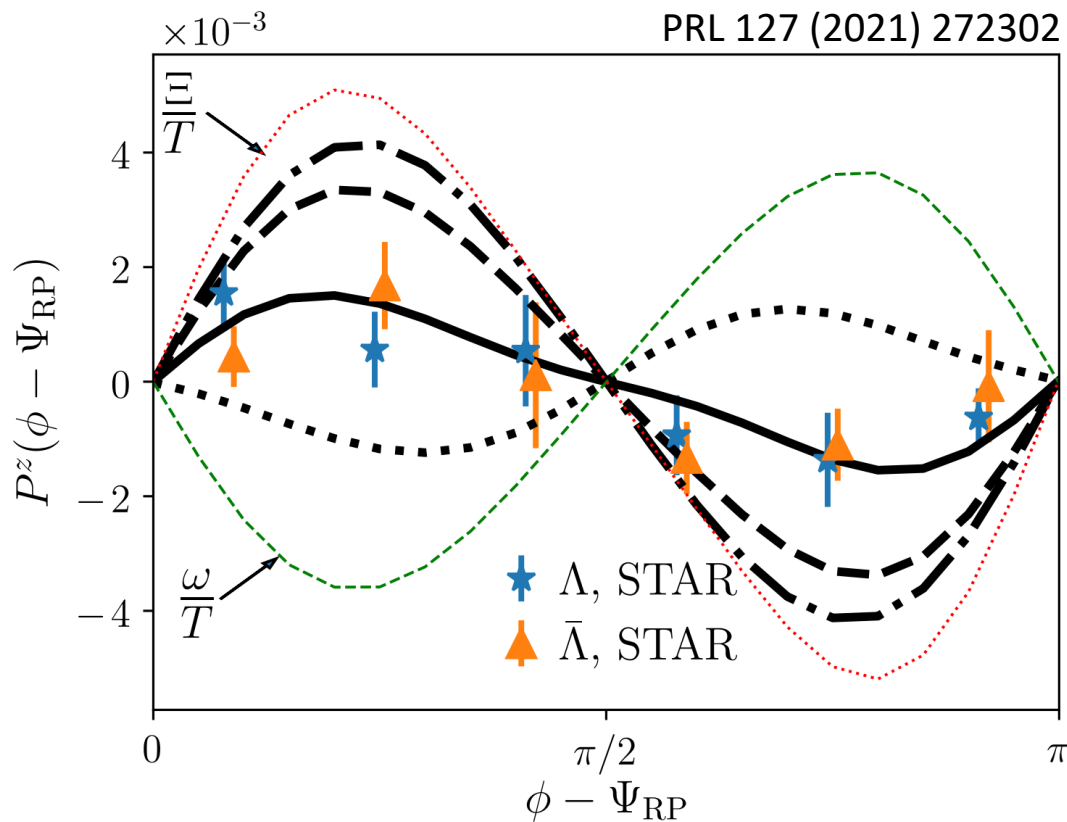
Simple expectation of vorticity from the anisotropic expansion of QGP

Hyperon polarization along beam direction



Simple expectation of vorticity from the anisotropic expansion of QGP
Confirmed by experimental measurements

“ P_z puzzle”

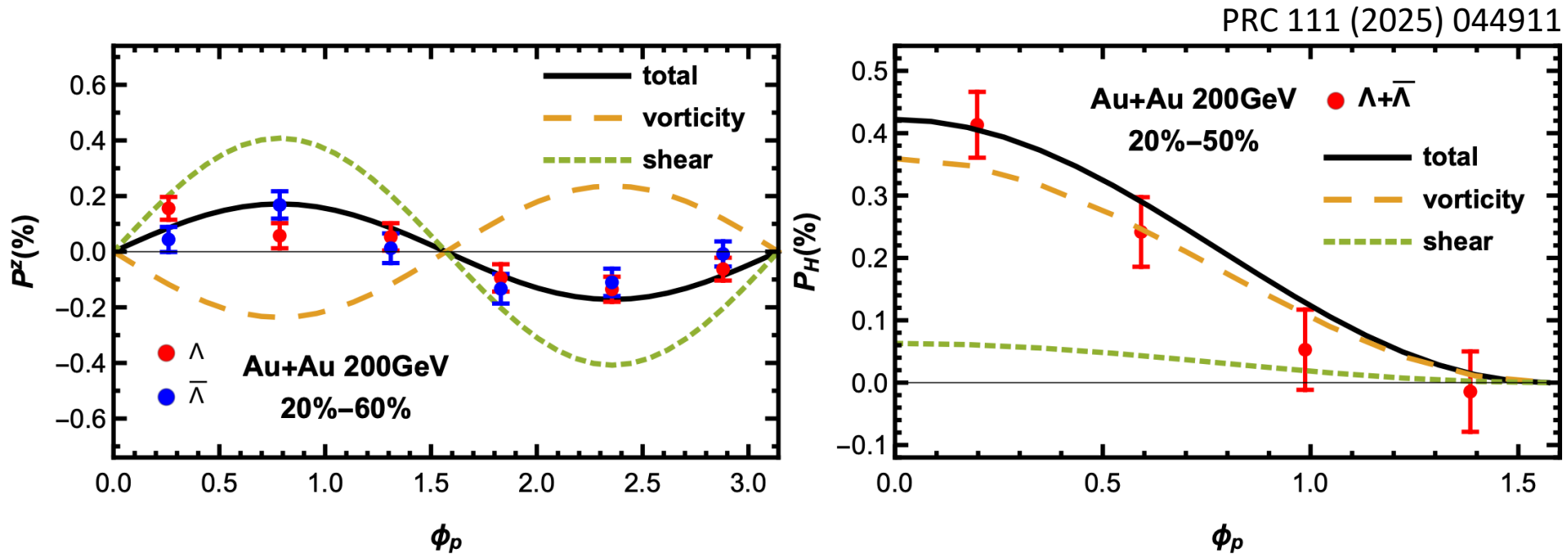


Thermal vorticity leads to wrong sign of P_z

Contribution from shear induced polarization needed to get the correct sign

Calculations depend on the details of theory implementation

“ P_z puzzle”



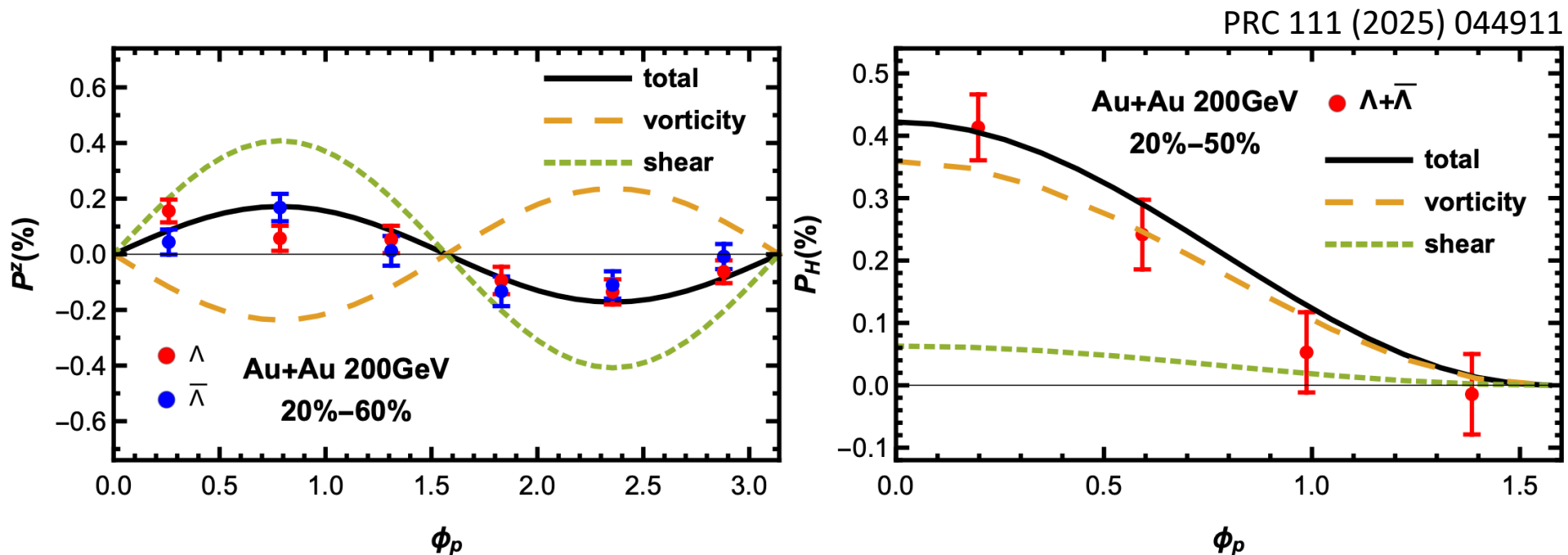
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A blast wave calculation describes data well

“ P_z puzzle”



Thermal vorticity leads to wrong sign of P_z

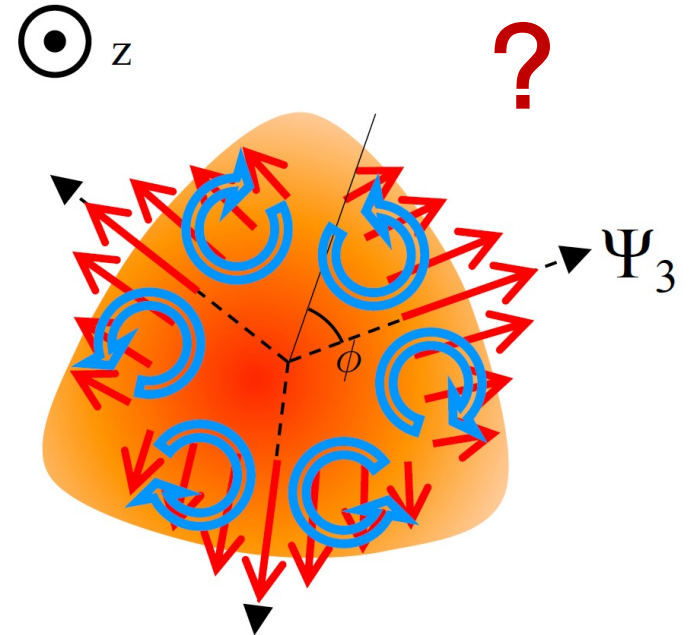
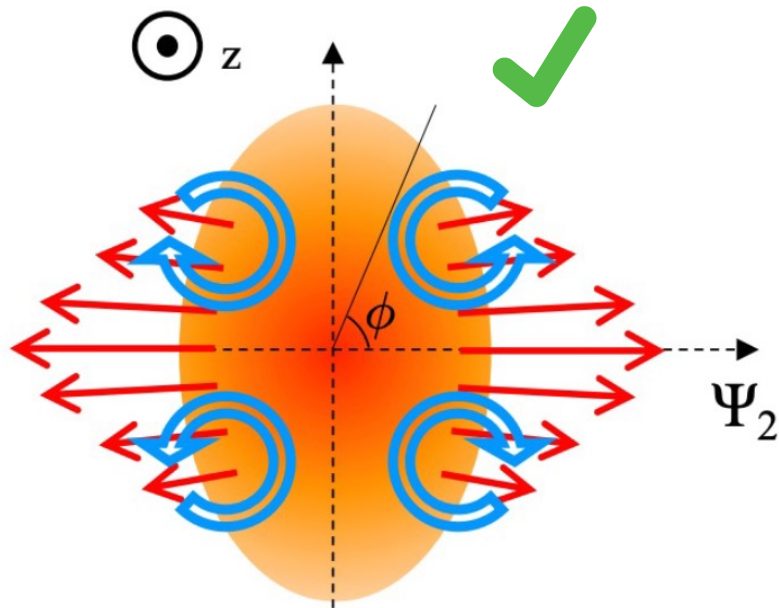
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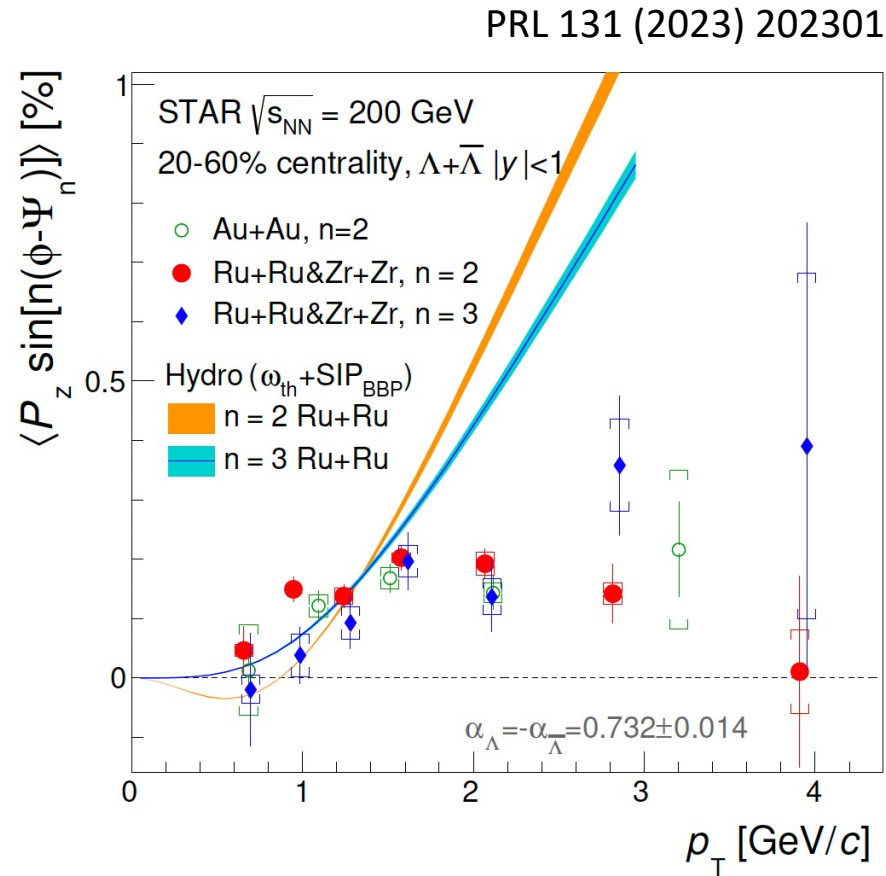
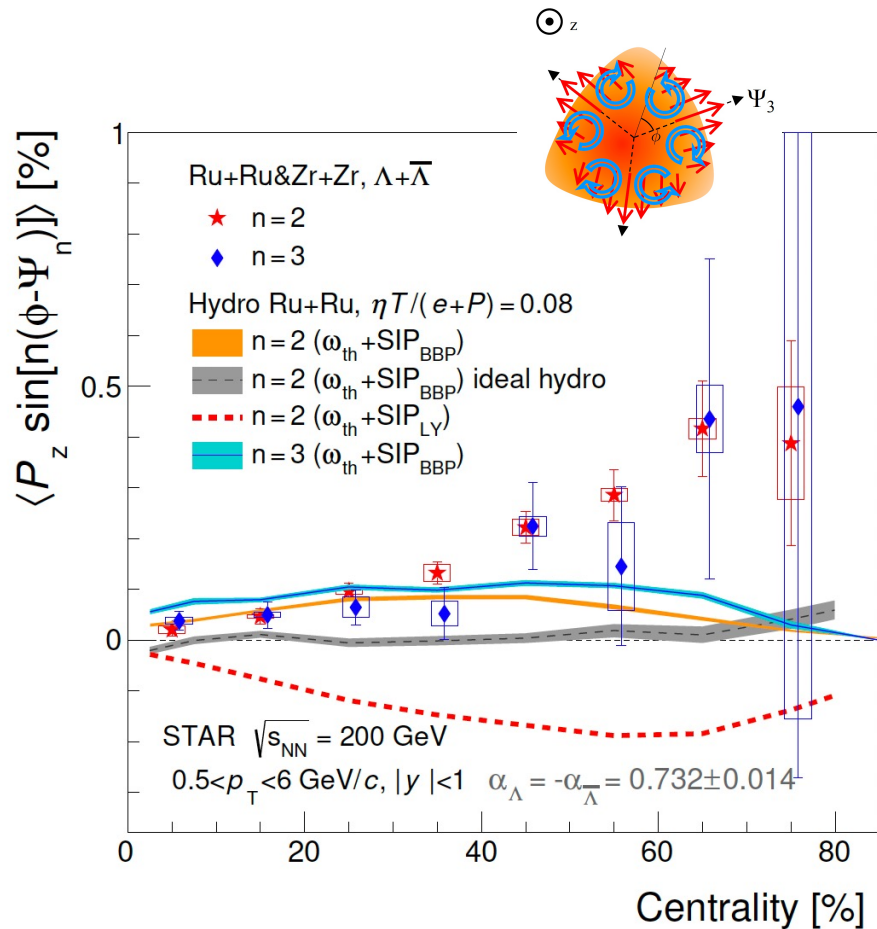
A blast wave calculation describes data well

But wait... Is polarization really induced by collective flow?

Polarization linked to collective flow?



Polarization linked to collective flow?

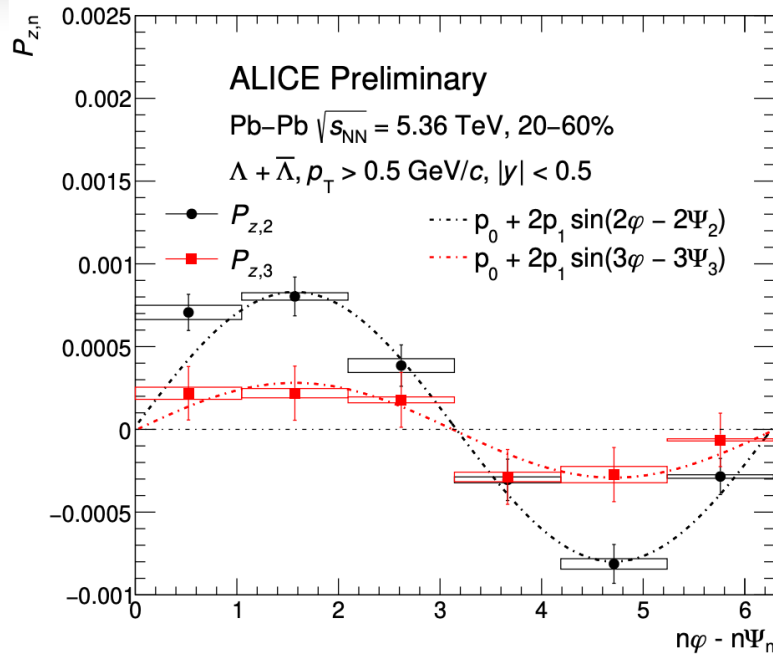


Same expectation of vorticity from higher order flow observed

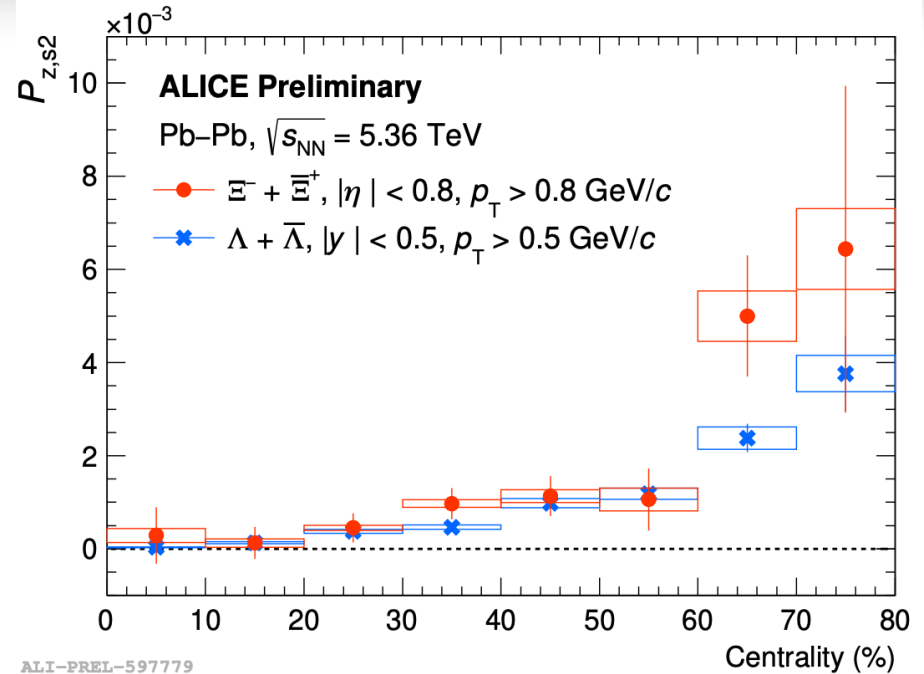
Details of model calculations need to be investigated

The observation of $P_{z,s3}$ indicates the link of vorticity to geometry

Hyperon polarization linked to collective flow(?)



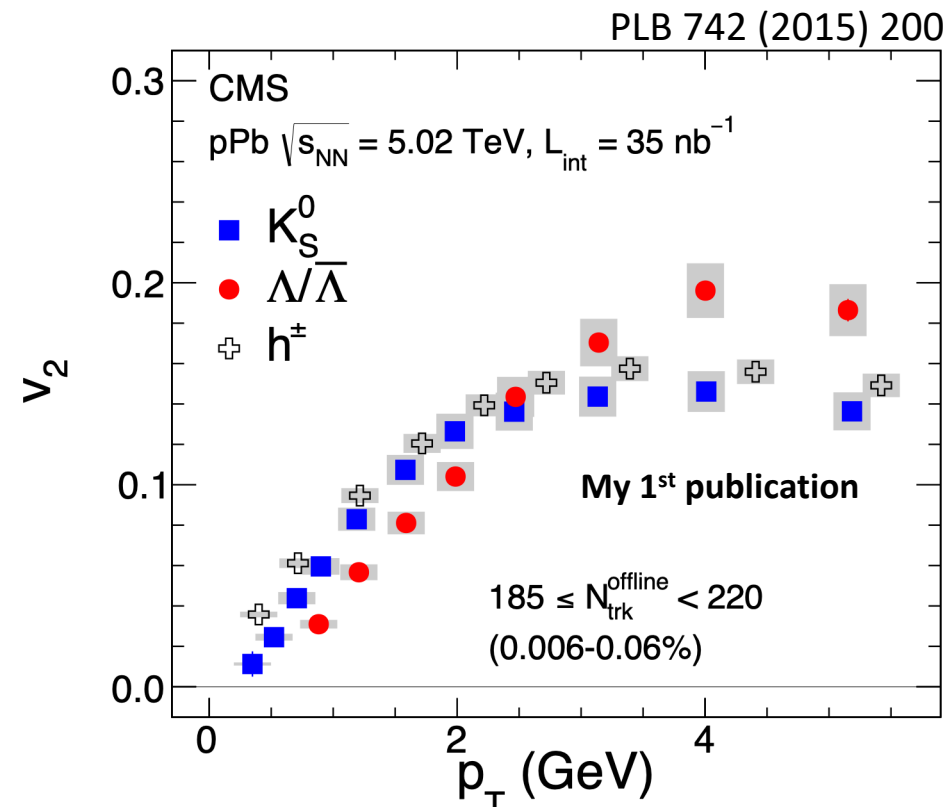
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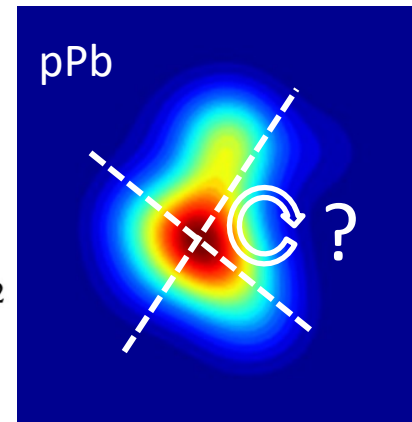
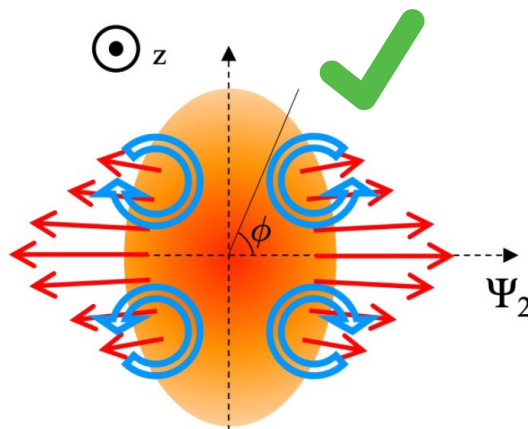
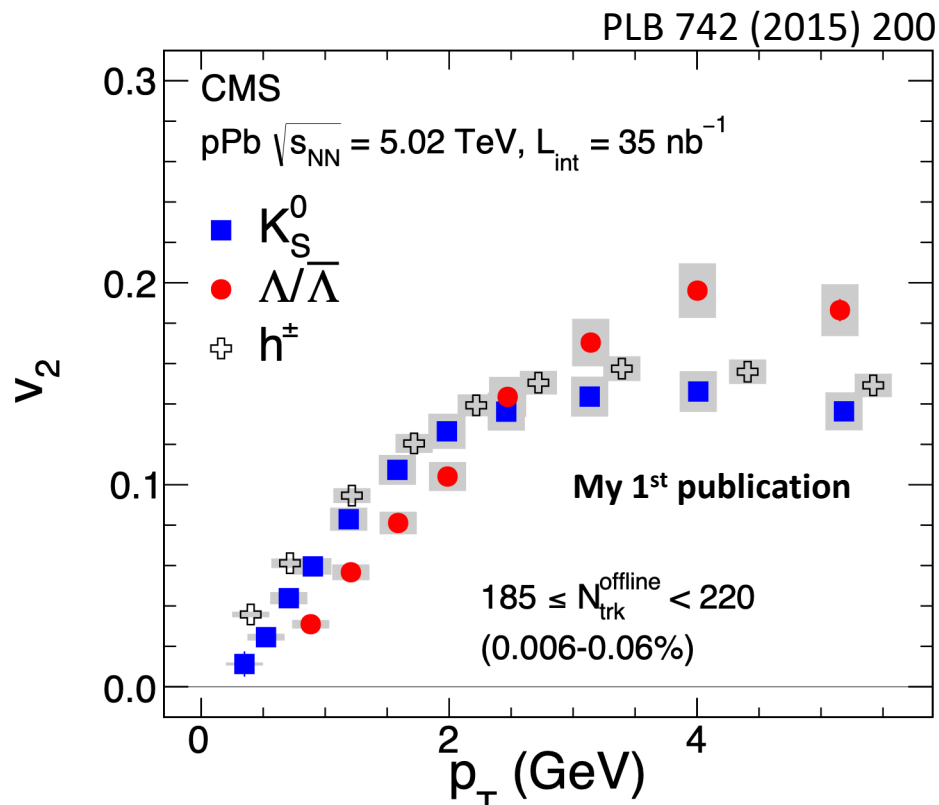
Same expectation of vorticity from higher order flow observed
 Details of model calculations need to be investigated
 The observation of $P_{z,s3}$ indicates the link of vorticity to geometry
 Recently confirmed by LHC & extended to multi-strange hyperons

A test in small system



Features of QGP droplets observed in small but dense systems

A test in small system

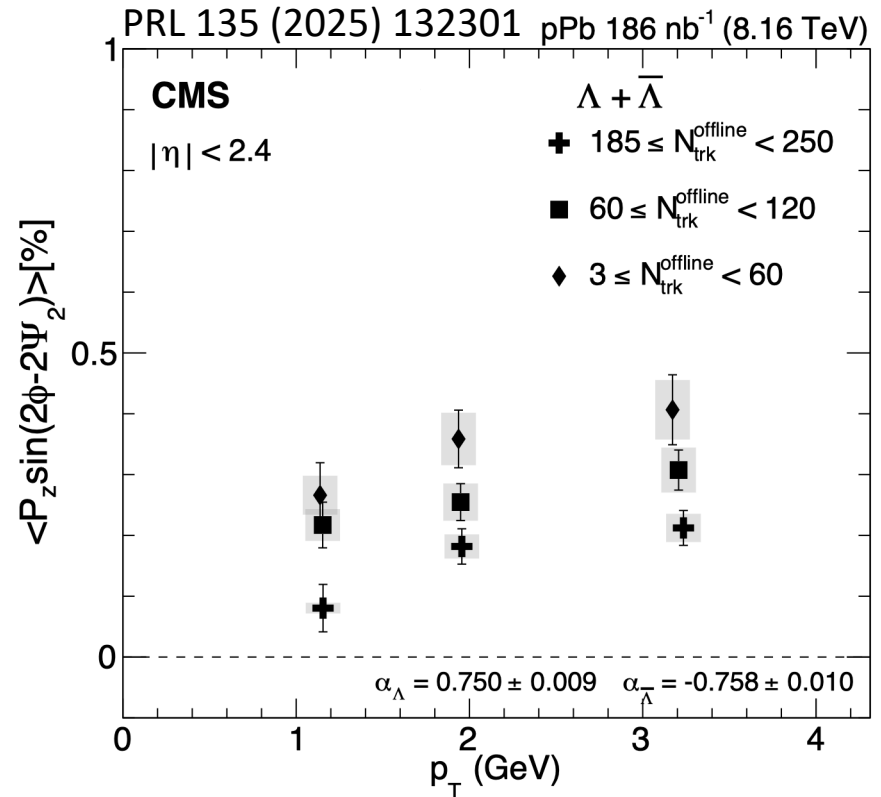
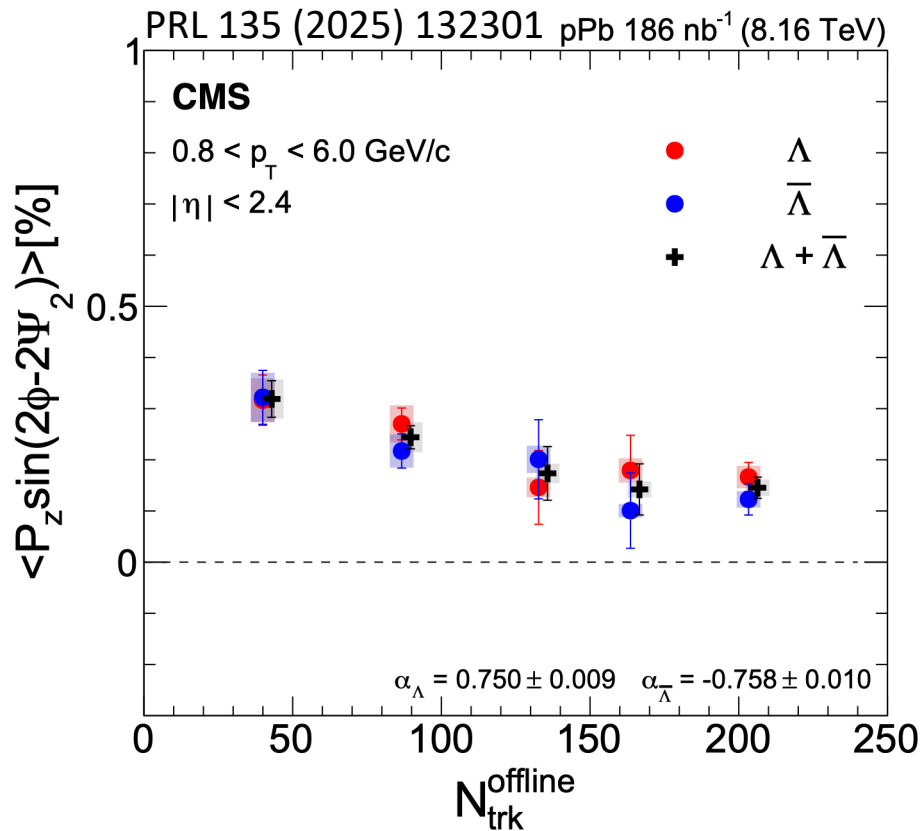


Features of QGP droplets observed in small but dense systems

Can we see local polarization P_z there?

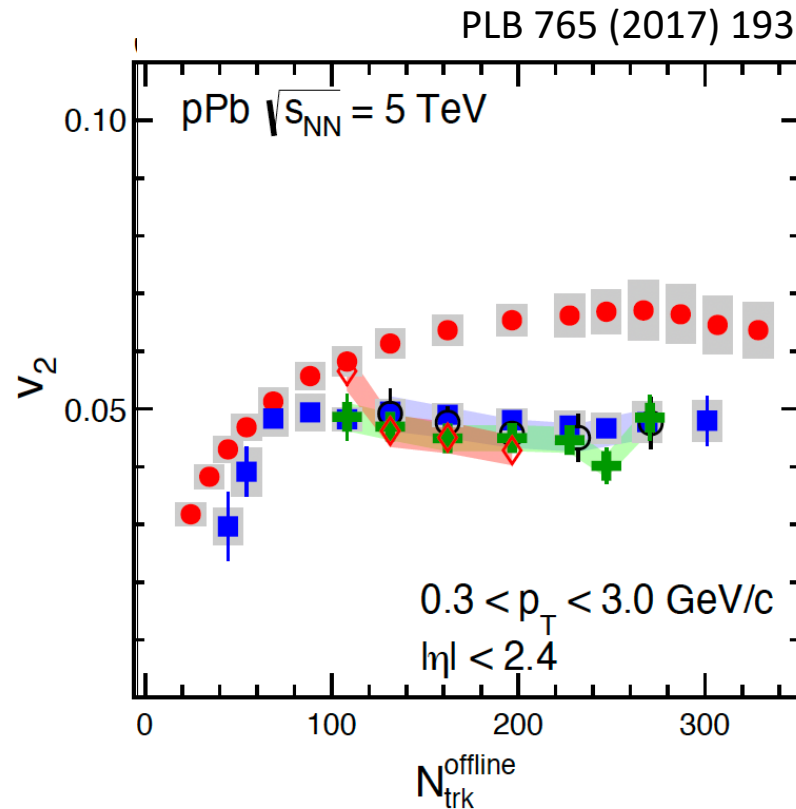
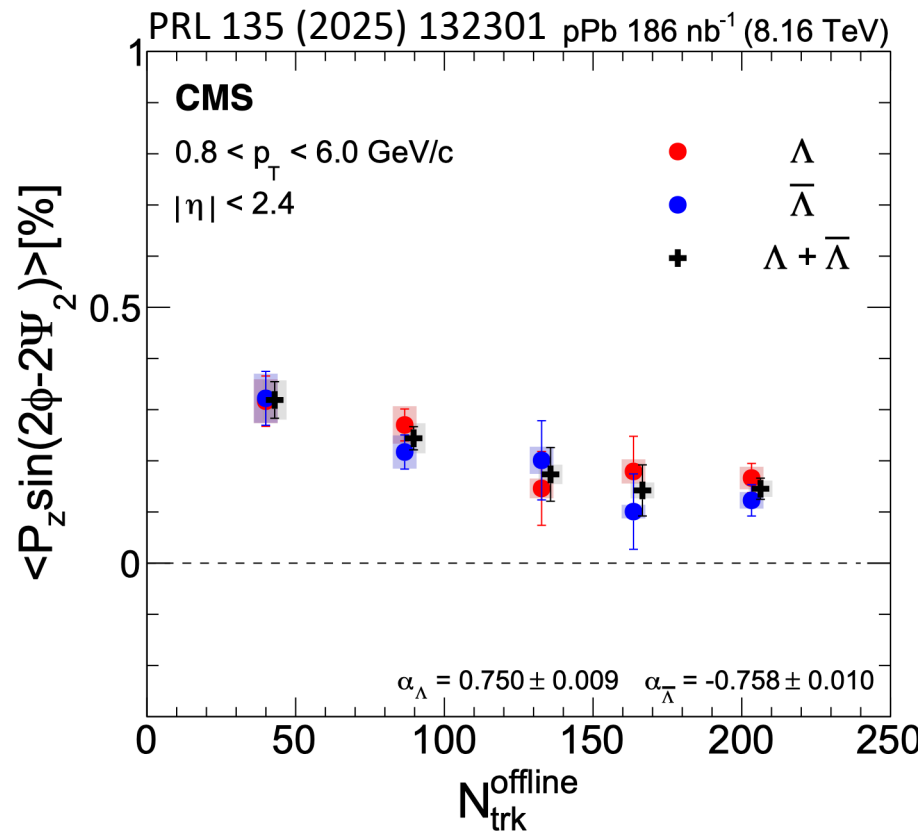
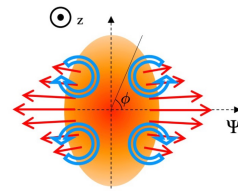
A test of QGP formation & different mechanisms of P_z

$P_{z,s2}$ in pPb collision



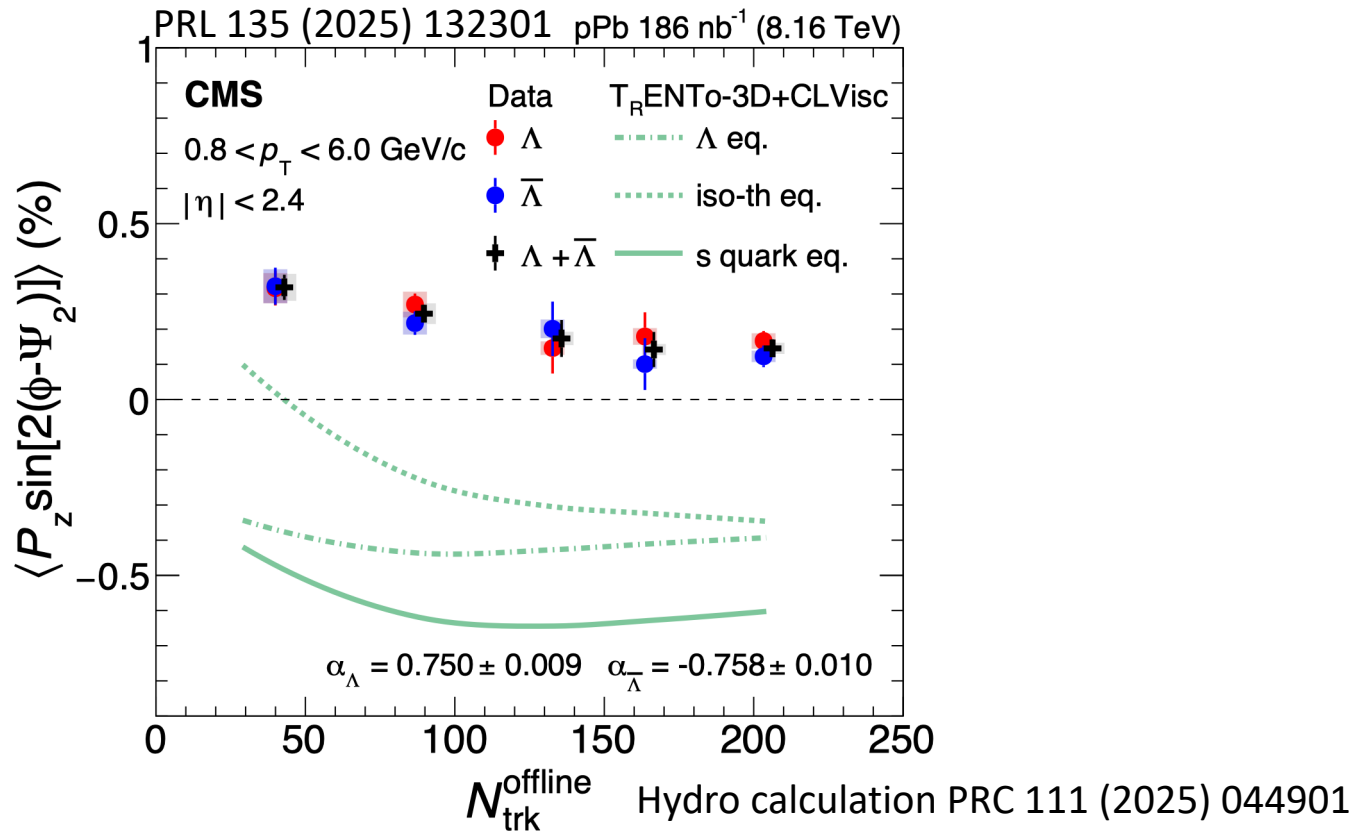
Significant positive $P_{z,s2}$ observed over entire multiplicity range
 Consistent results for Λ and anti- Λ
 Decrease towards high multiplicity

$P_{z,s2}$ in pPb collision



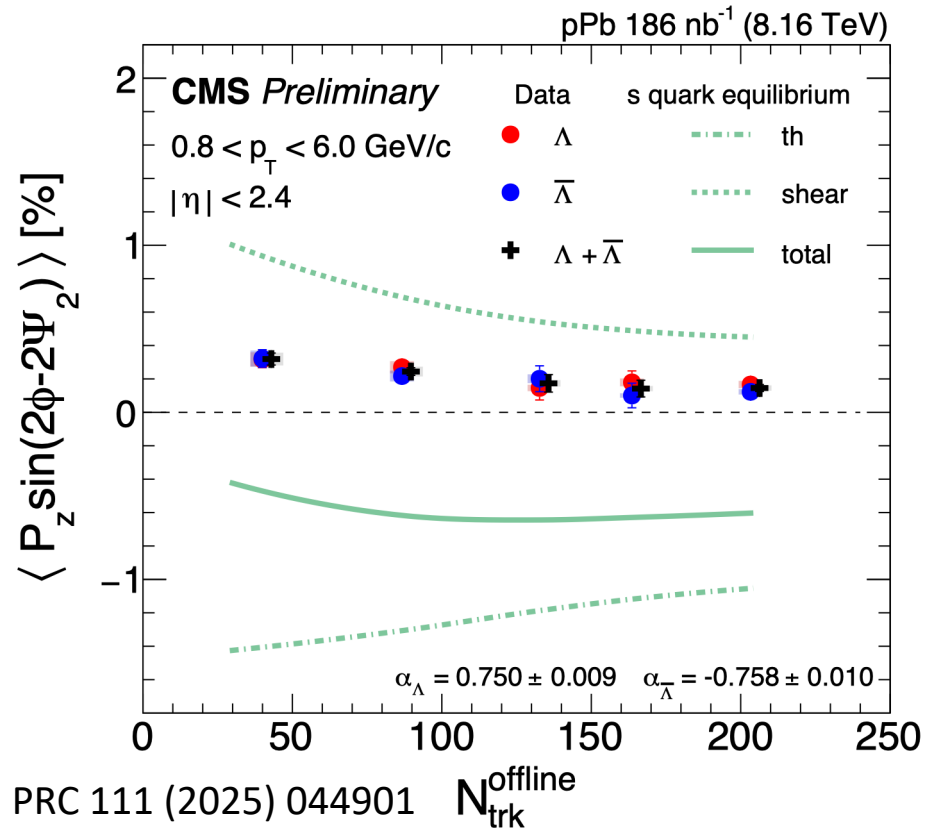
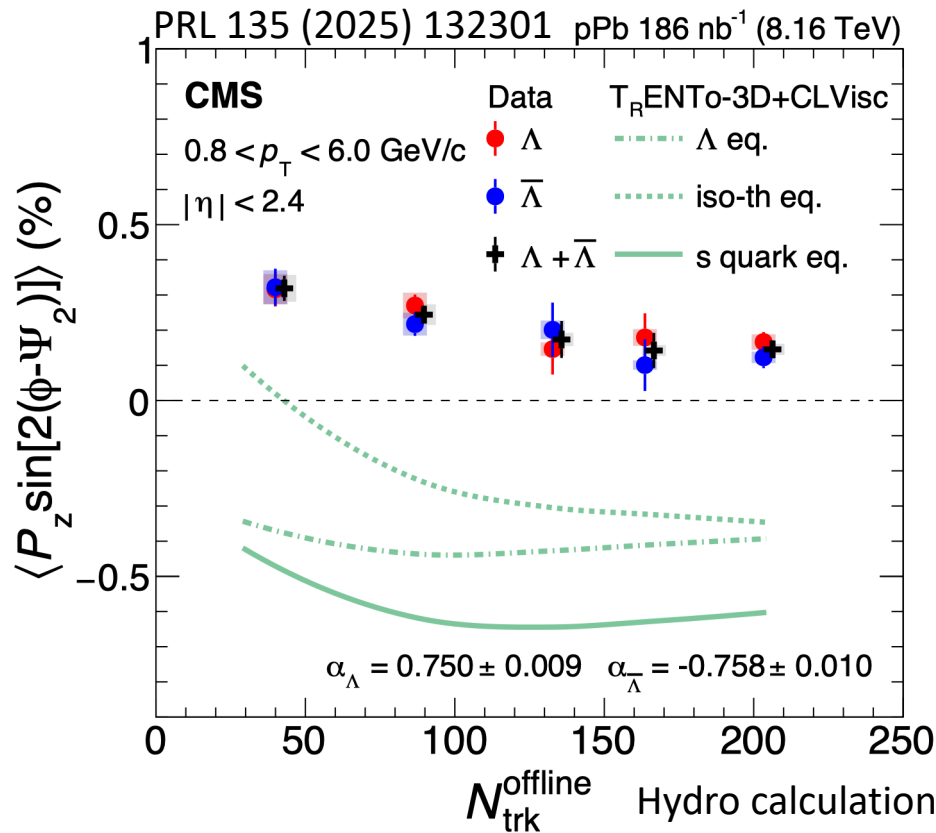
Not consistent with the trend of v_2 vs multiplicity

$P_{z,s2}$ in pPb collision - model calculations



Hydro calculations result in negative P_z

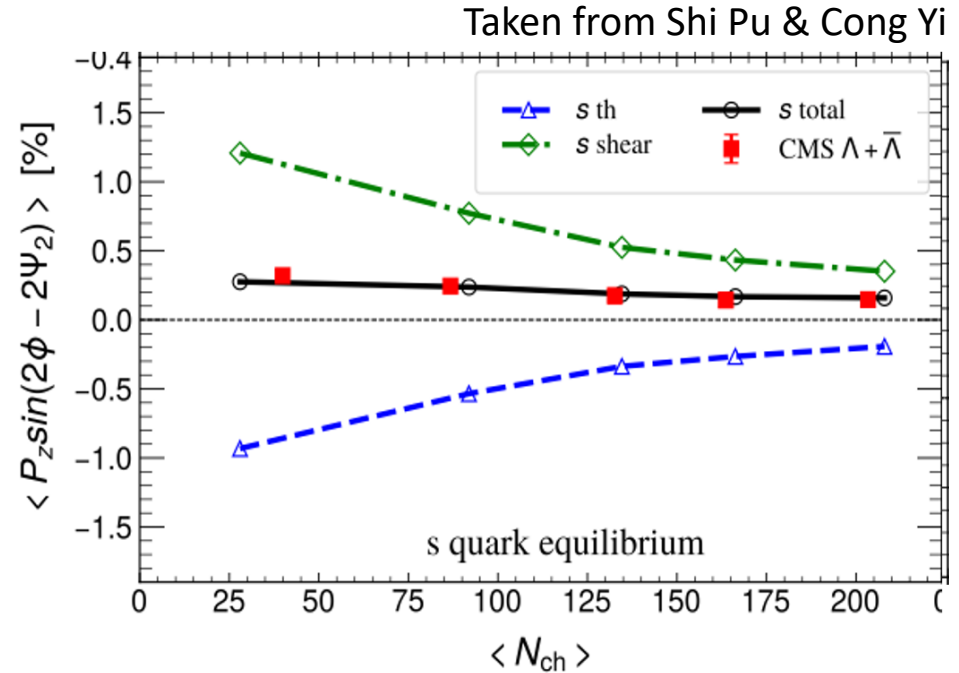
$P_{z,s2}$ in pPb collision - model calculations



Hydro calculations result in negative Pz

Different contributions in small systems need to be understood further

$P_{z,s2}$ in pPb collision - model calculations

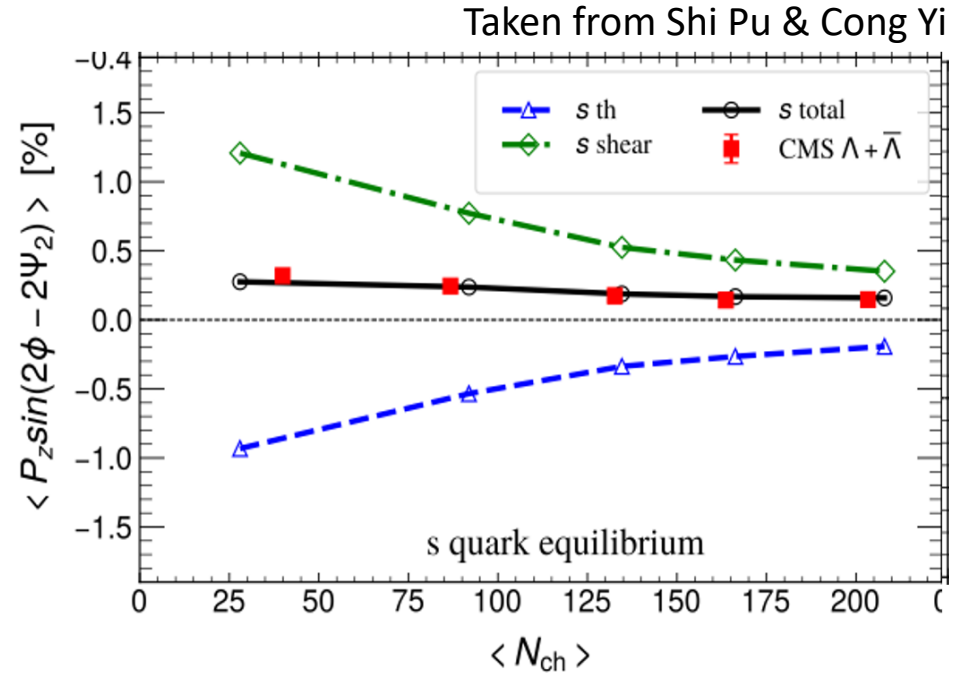
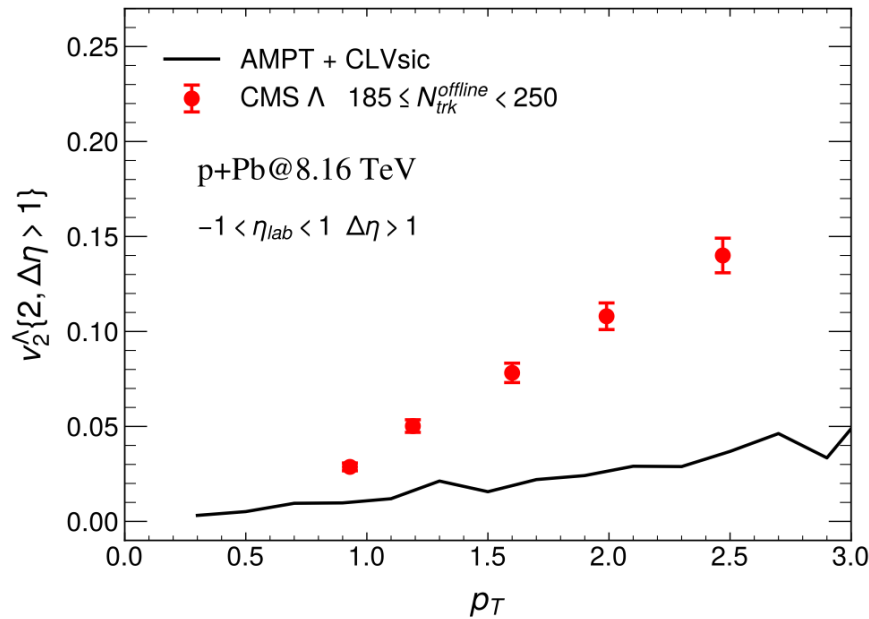


Hydro calculations result in negative P_z

Different contributions in small systems need to be understood further

Tune the model to reproduce P_z

$P_{z,s2}$ in pPb collision - model calculations

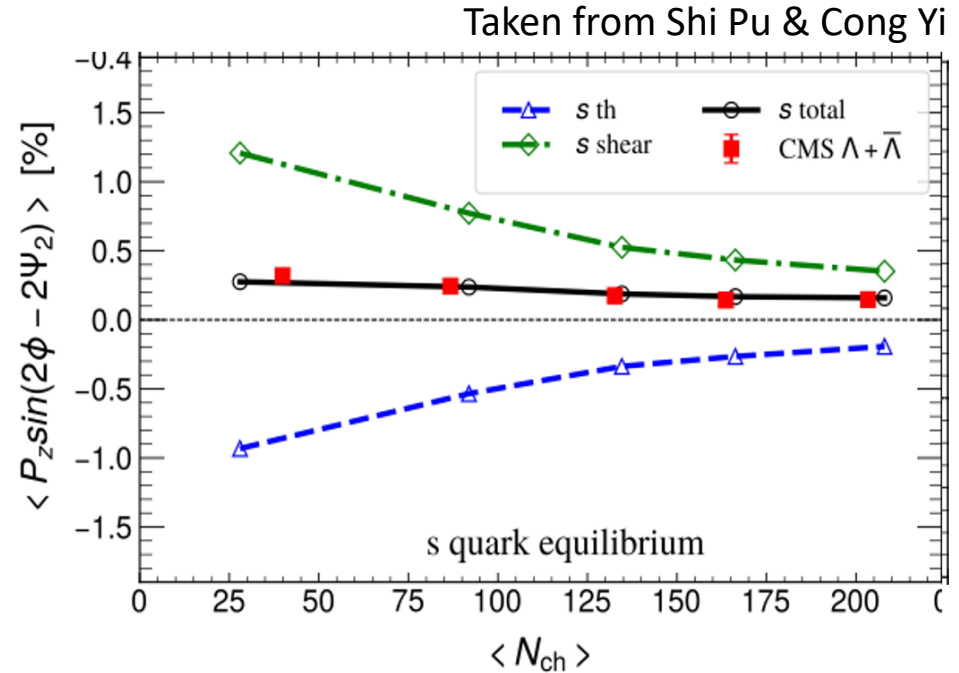
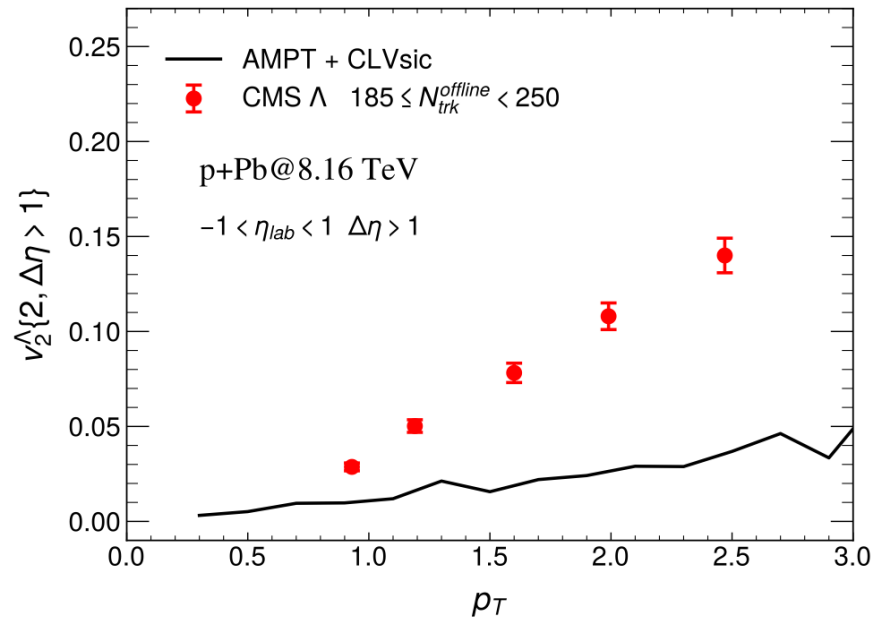


Hydro calculations result in negative P_z

Different contributions in small systems need to be understood further

Tune the model to reproduce P_z results in too small v_2

$P_{z,s2}$ in pPb collision - model calculations



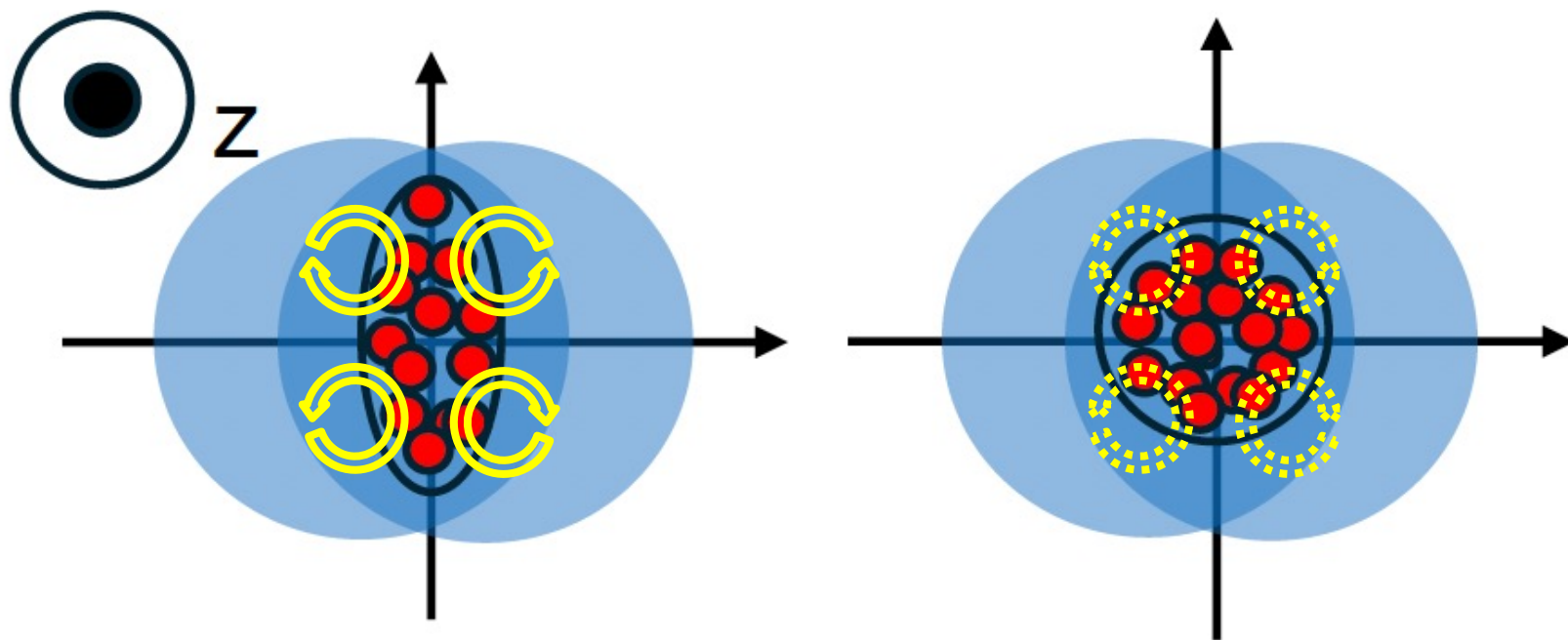
Hydro calculations result in negative P_z

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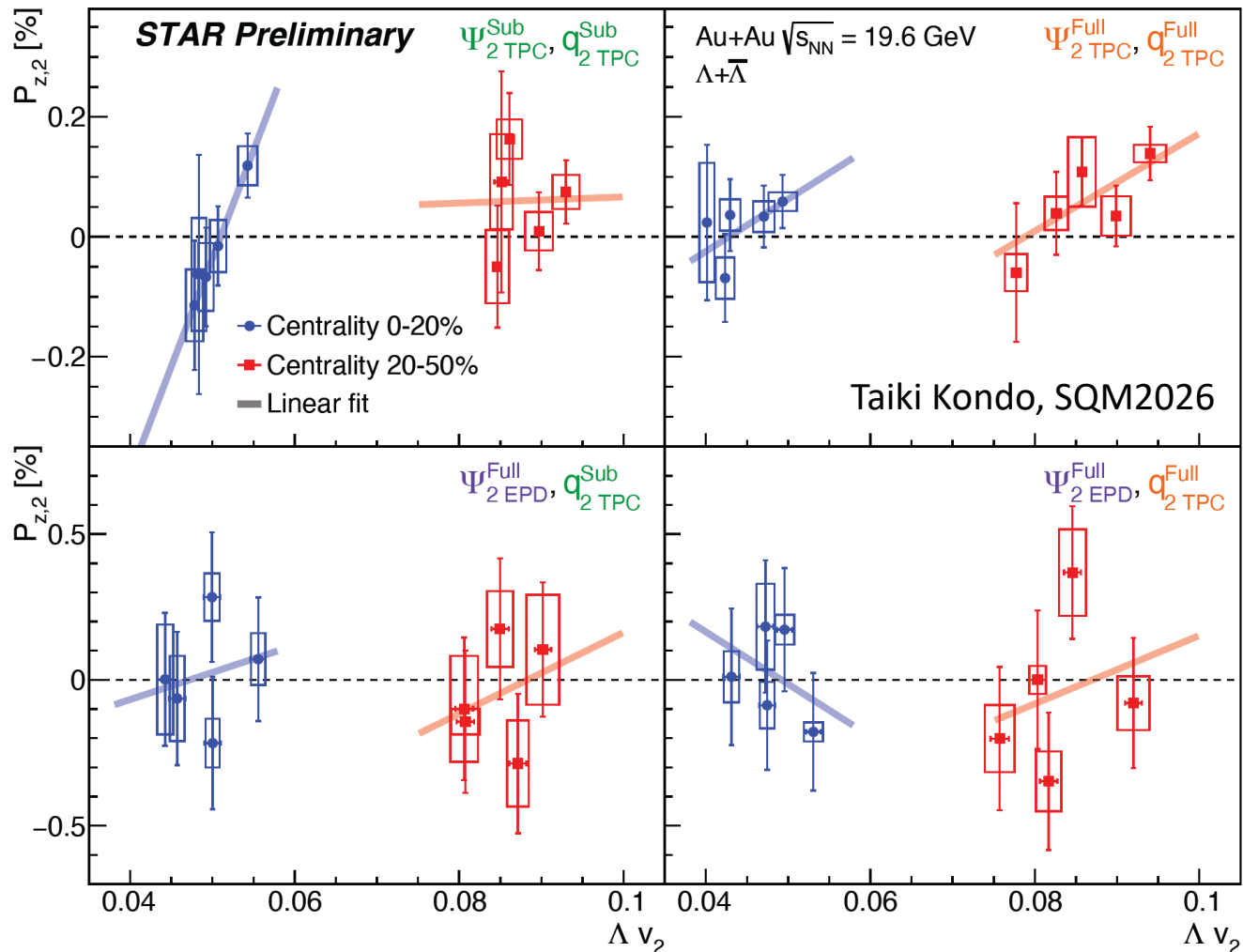
Both related to initial geometry but different response?

$P_{z,s2}$ vs v_2 – event shape engineering



Does $P_{z,s2}$ change with v_2 ?

$P_{z,s2}$ vs v_2 – event shape engineering

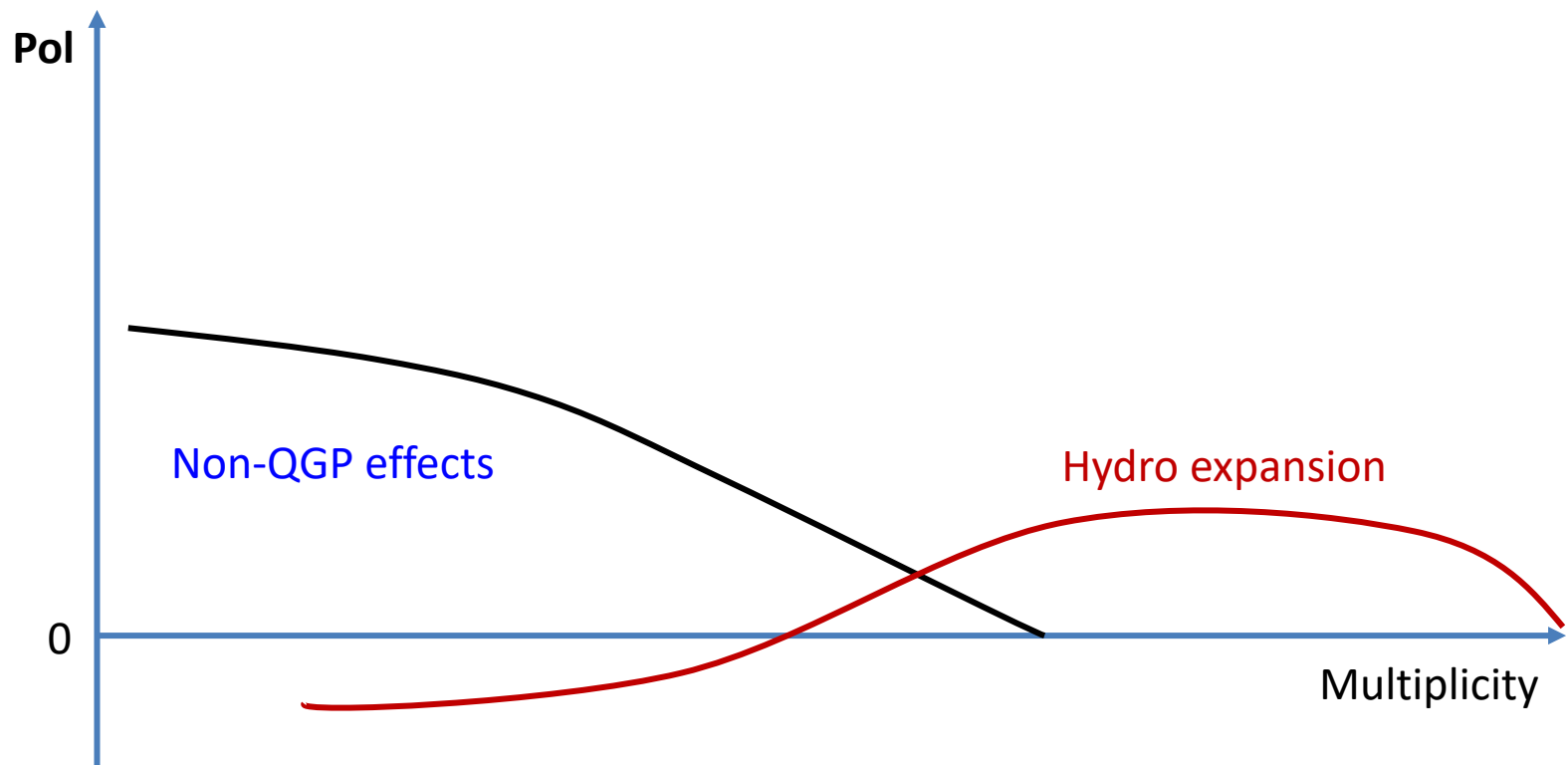


Does $P_{z,s2}$ change with v_2 ?

The results in 19.6 GeV AuAu shows a hint

Works on-going to extend to higher energies & small system

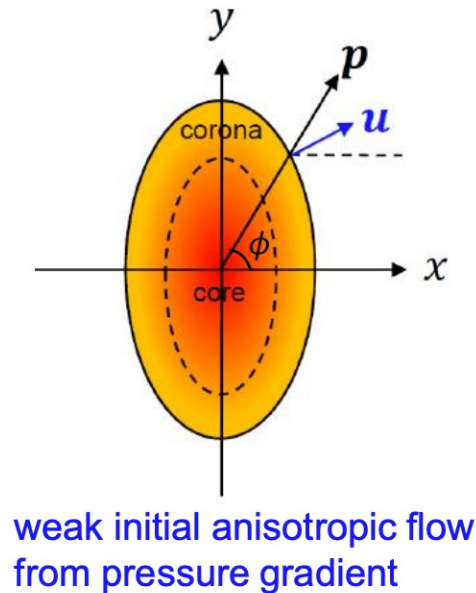
Polarization from other physics



A naïve guess of contributions to hyperon local polarization
How do they evolve and what is the implication for AA and vice versa?

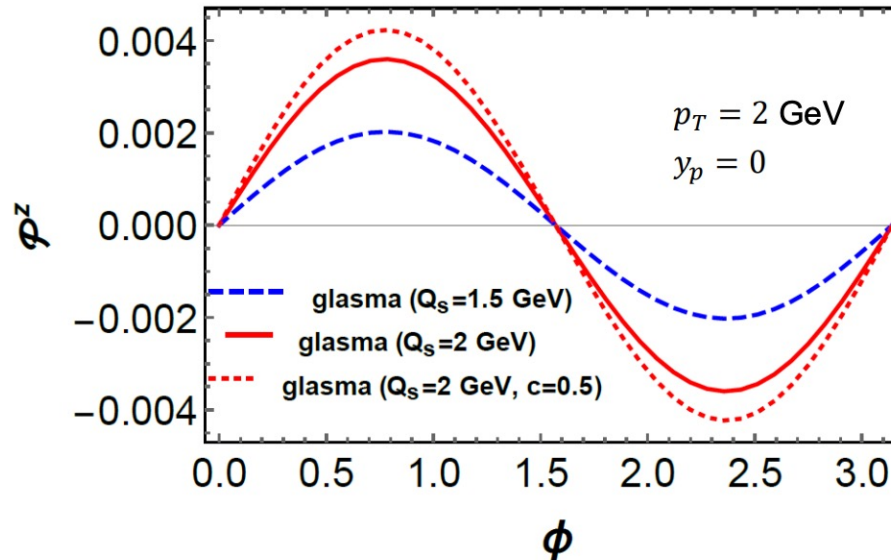
Core-corona + color-field correlators

- Longitudinal polarization from the corona of glasma (early hadronization) :



$$\mathcal{P}^z \approx \frac{\hbar(N_c^2 - 1)Q_s^2 \Delta t}{16M_\Lambda N_c^2 \epsilon_p \int d\Sigma \cdot p f_V^s} \int d\Sigma \cdot p (\overset{\text{traveling time in corona}}{p^x u^y - p^y u^x}) \overset{\text{p} \times \text{u structure}}{\times f_V^s (1 - f_V^s) ((1 - 2f_V^s)u^0 + Q_s/\epsilon_p)}, \quad f_V^s = \frac{1}{e^{p \cdot u / Q_s} + c}.$$

(the overall sign is related to the freeze-out hypersurface)

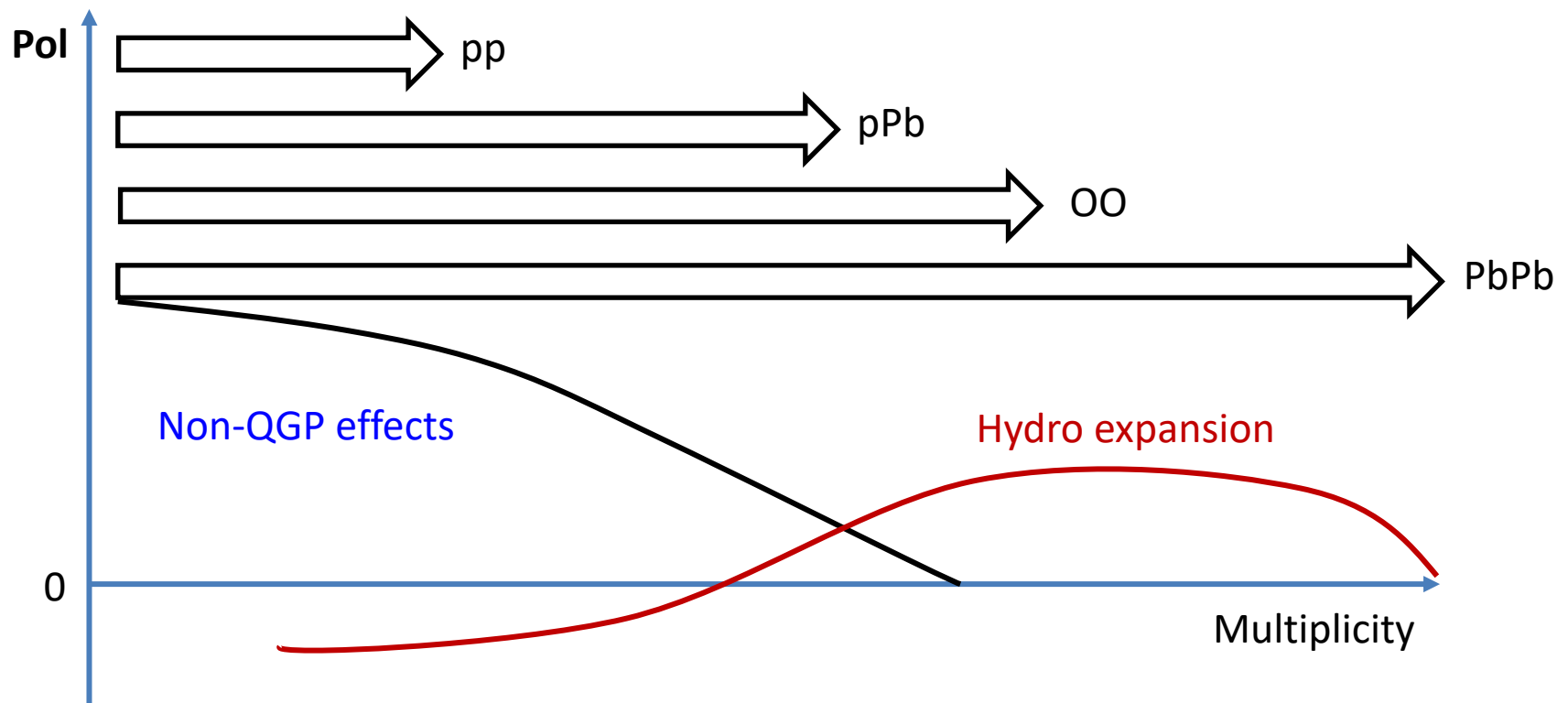


H. Sung, B. Müller, DY, arXiv: 2507.23210

- ✓ consistent sign & comparable order of magnitude with observations

Slide taken from Di-Lun Yang's Initial Stages talks

Polarization across systems

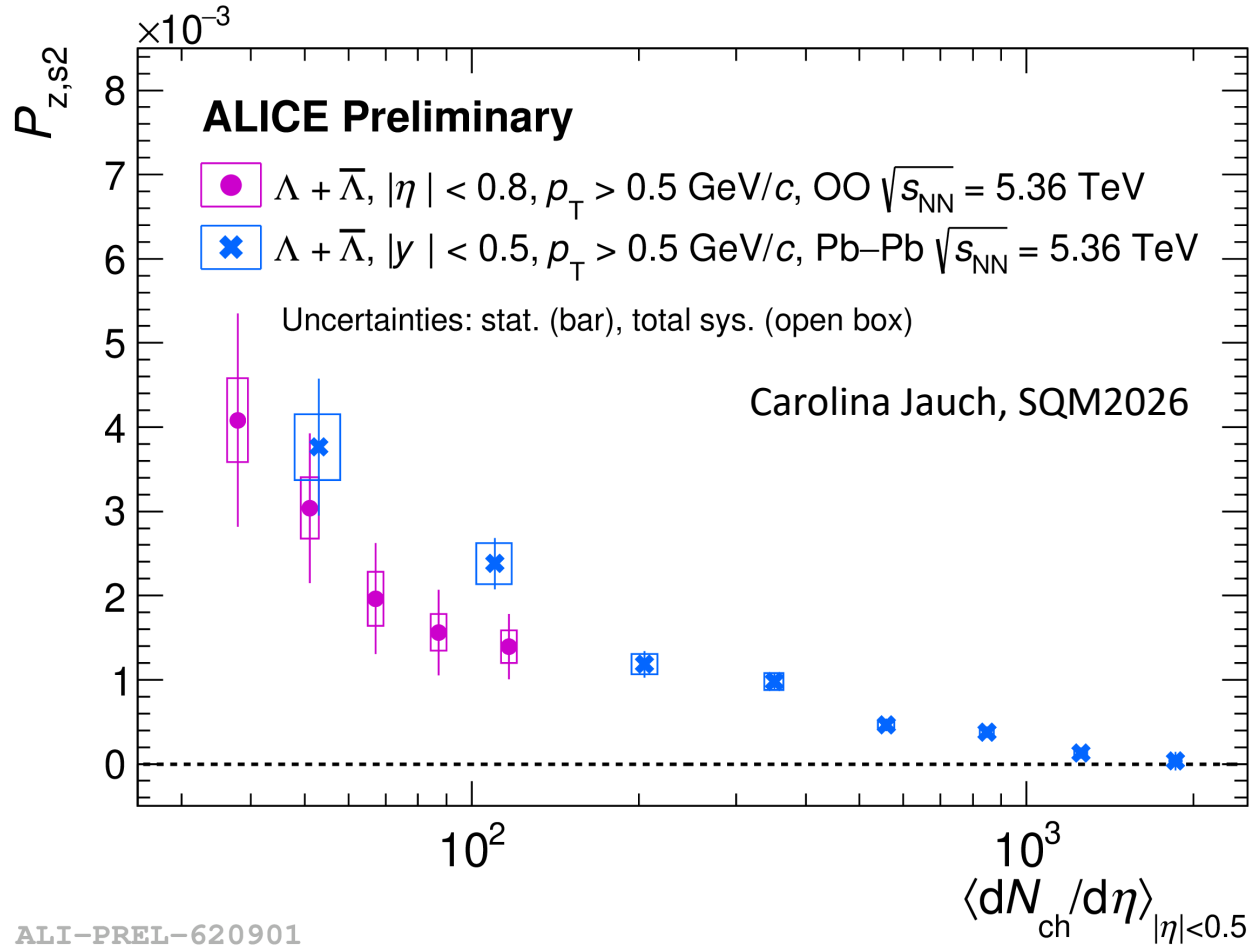


A naïve guess of contributions to hyperon local polarization
How do they evolve and what is the implication for AA and vice versa?

Measurements and model calculations across pp, pA, AA needed!

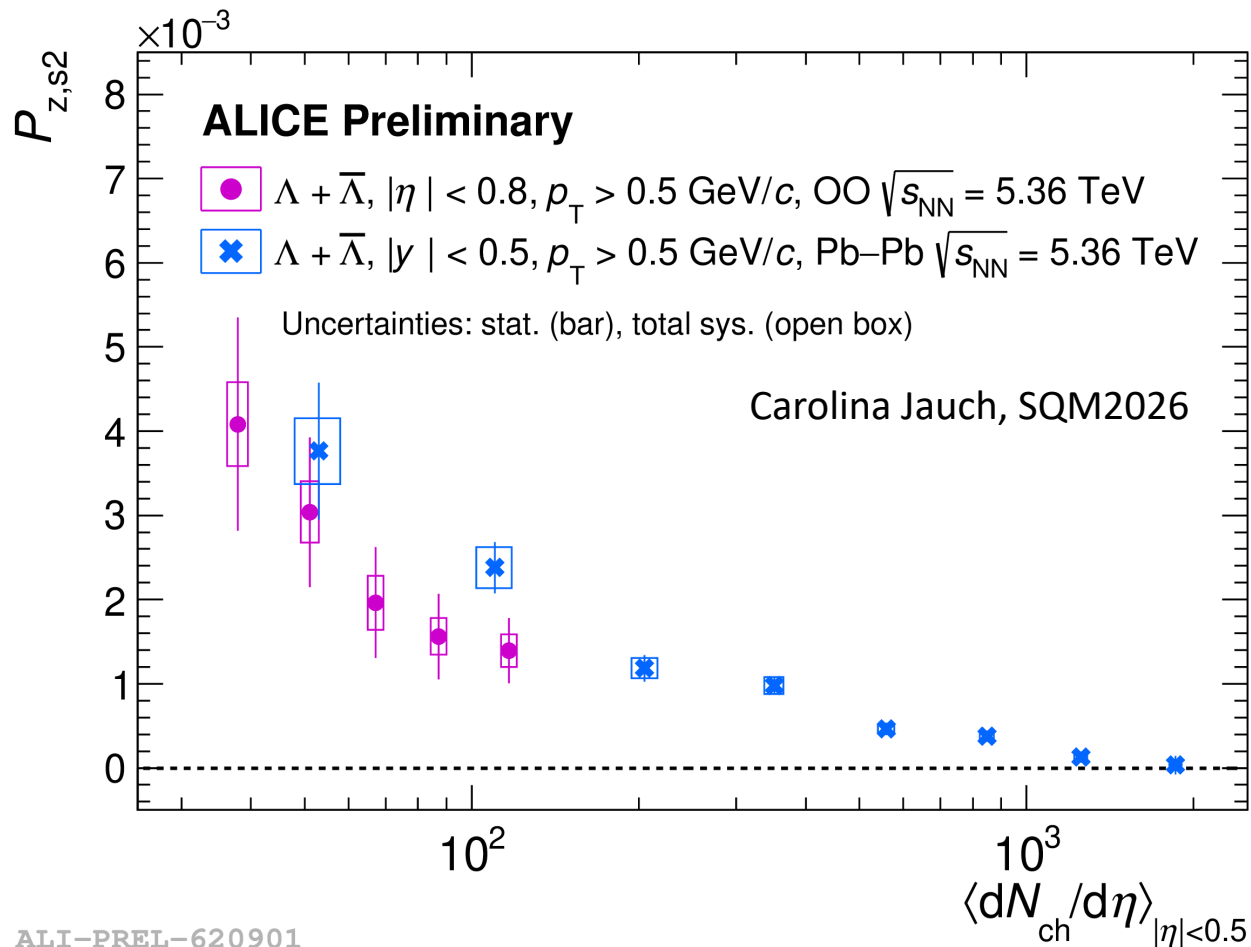
The transition from small to large system is crucial – OO & NeNe

Polarization across systems



Significant local polarization observed in OO
 Similar behavior as in PbPb

Polarization across systems



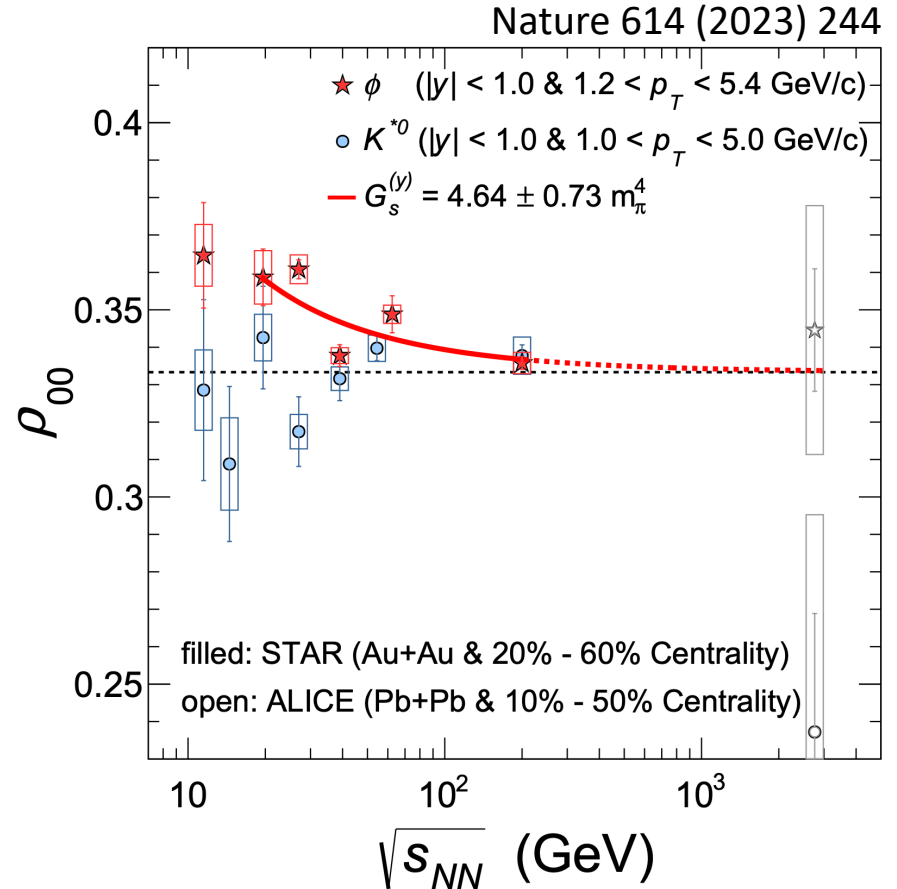
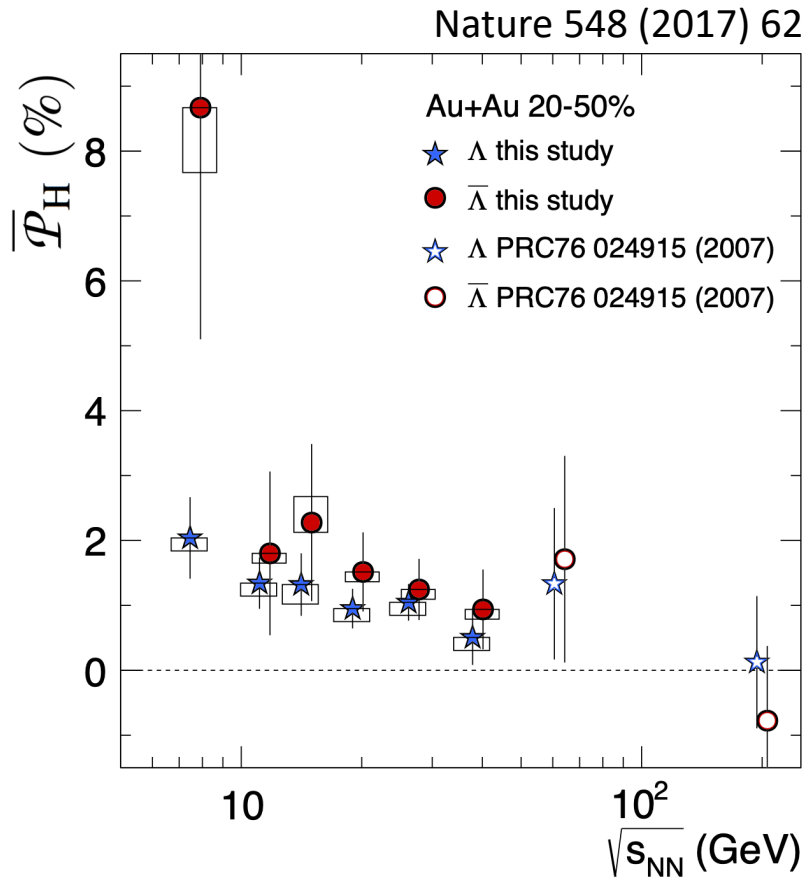
Significant local polarization observed in OO

Similar behavior as in PbPb

P_z does not go to zero at 0% centrality?

Looking forward to more results & theory comparison

Spin-spin correlation

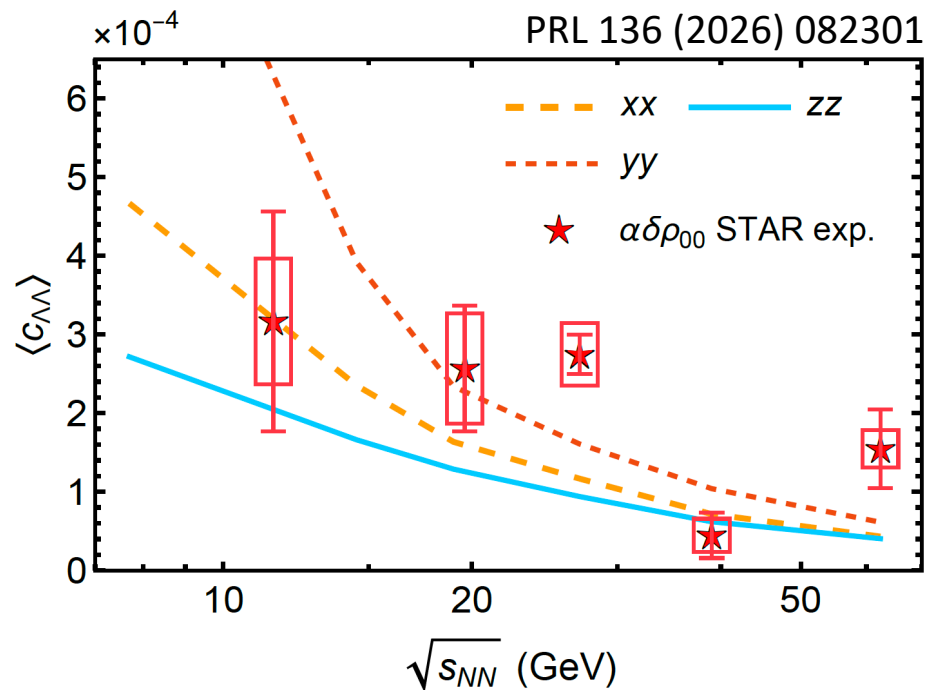
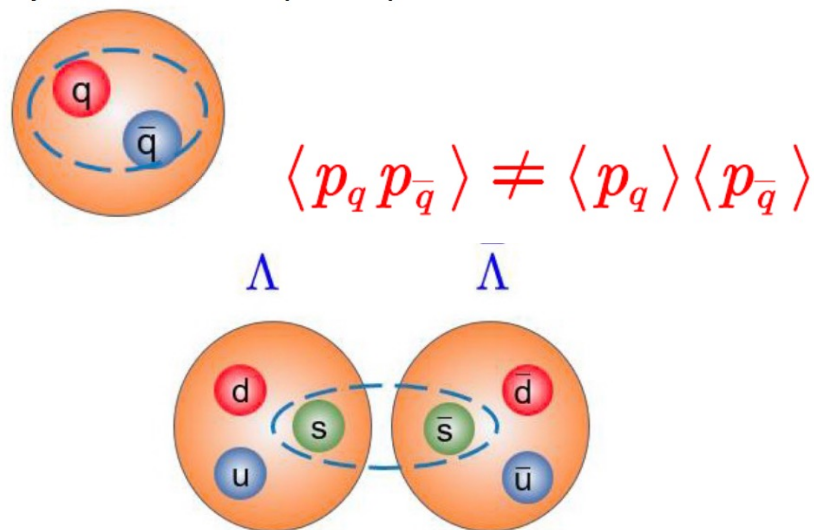


Global polarization and spin alignment in HI post a question why

$$\left| \rho_{00}^V - \frac{1}{3} \right| \gg P_\Lambda^2 \sim P_q^2$$

Spin-spin correlation

PRD 109 (2024) 114003



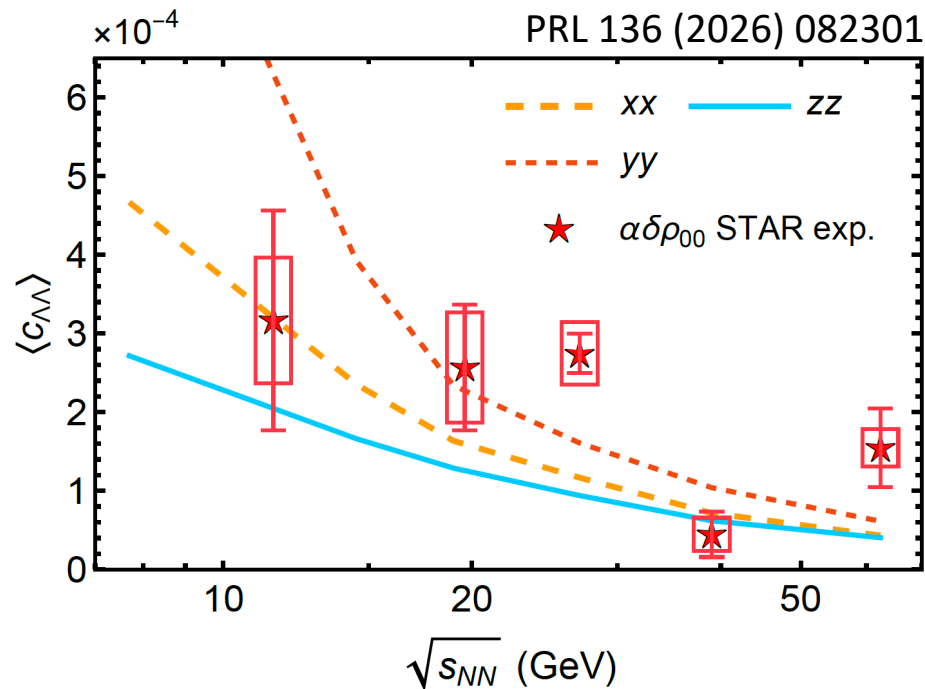
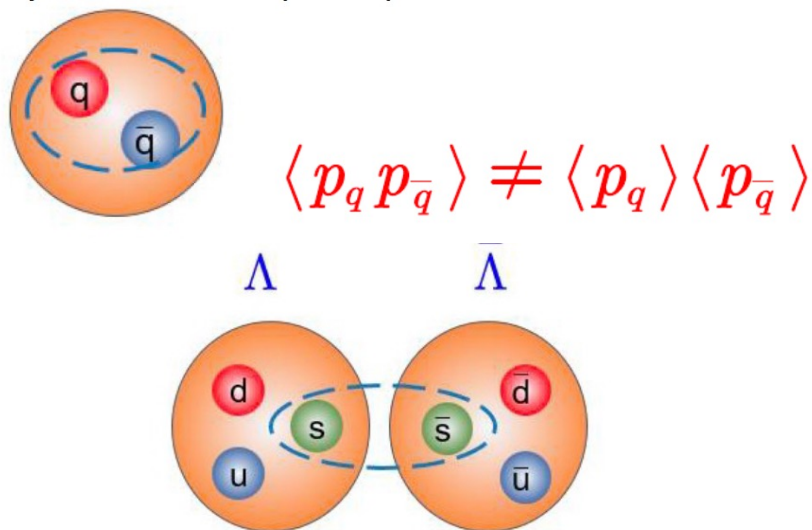
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Spin-spin correlation proposed as a solution

Spin-spin correlation

PRD 109 (2024) 114003



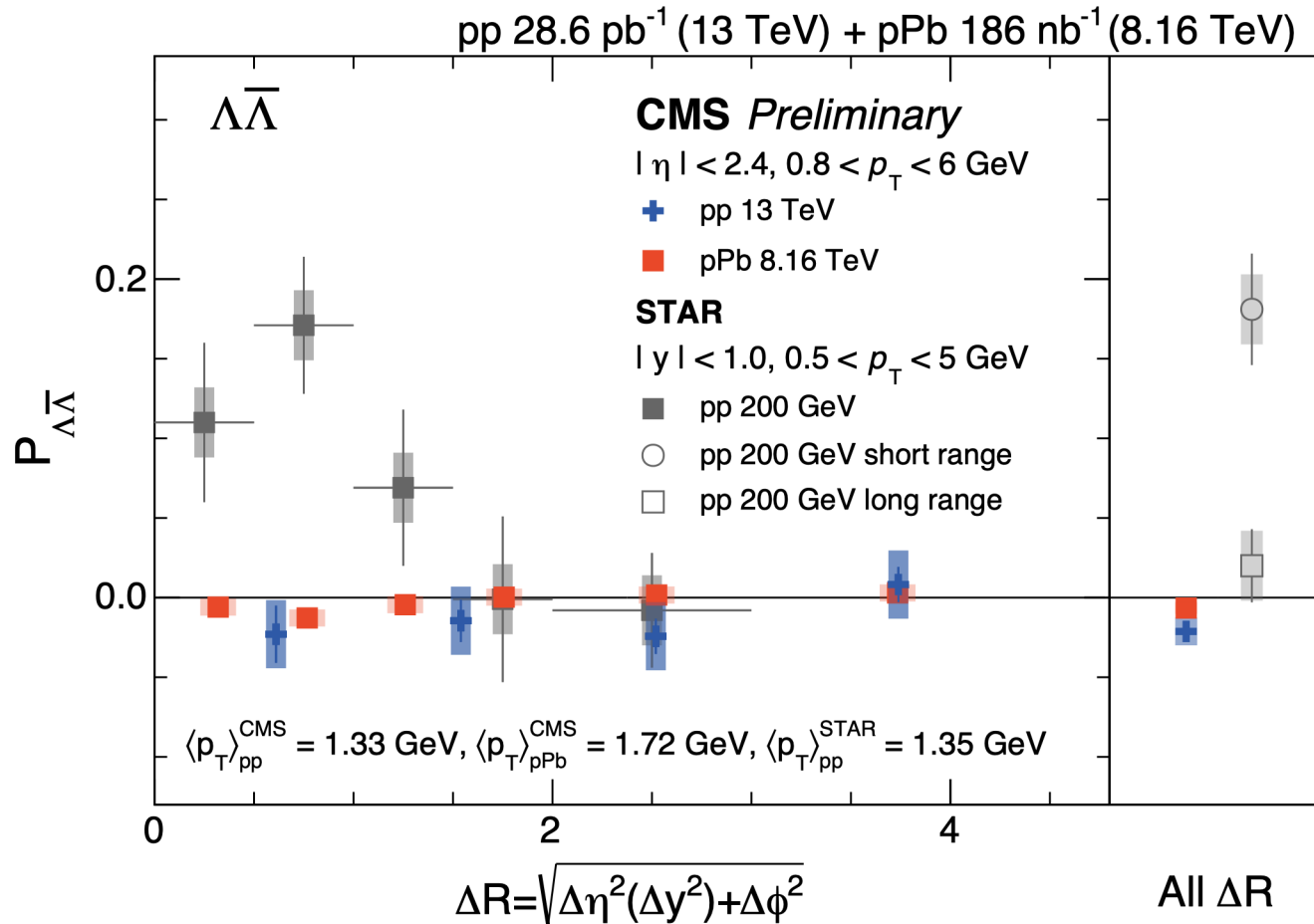
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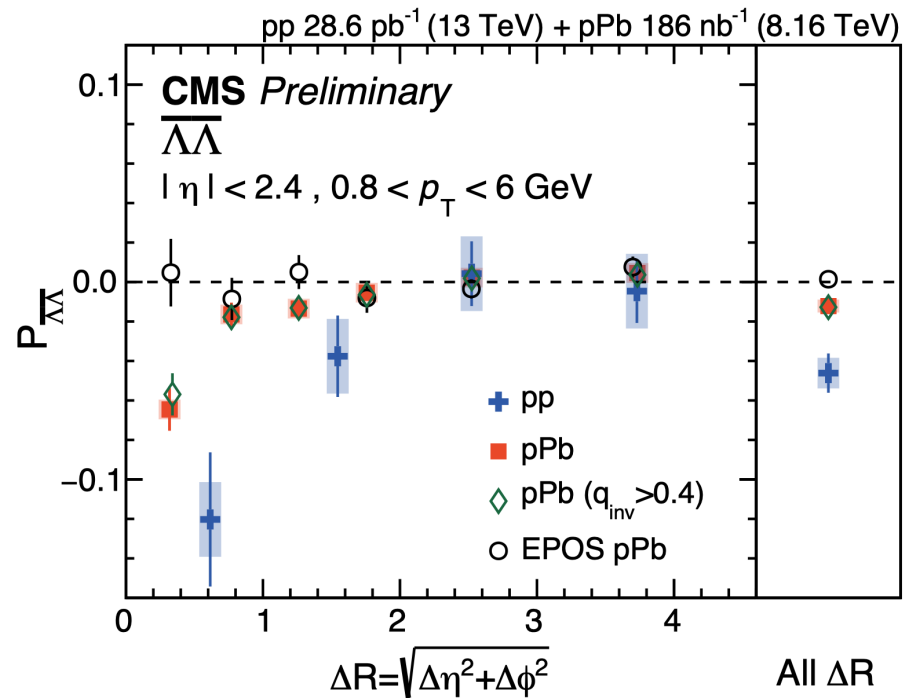
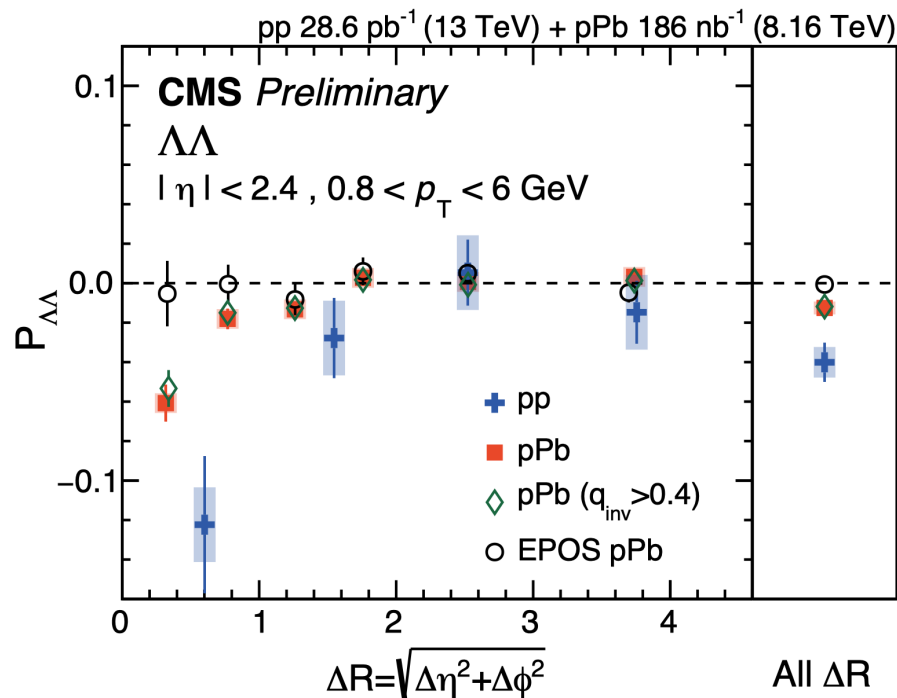
Every HI-QGP observable needs a 'vacuum' reference

Spin correlation of $\Lambda\bar{\Lambda}$ in pp & pPb



Similar results in pp & pPb at CMS, consistent with zero within uncertainties
 CMS results show different behavior than STAR
 Might be due to different production mechanism at RHIC & LHC

Spin correlation of $\Lambda\Lambda$ & $\overline{\Lambda}\overline{\Lambda}$ in pp & pPb



Significant negative correlation at small separation
 Larger in pp than pPb (multiplicity dependence?)
 Excluding the 'normal' HBT range does not change the results
 The underlying mechanism remains an open question

Summary

- Polarization and collectivity are connected, but their relationship is more complex than previously thought
- Polarization likely arises from the interplay of multiple mechanisms rather than a single source
- Measurements across collision systems are beginning to reveal the evolution of polarization mechanisms

