

Polarization measurements from CMS

Zhenyu Chen 陈震宇

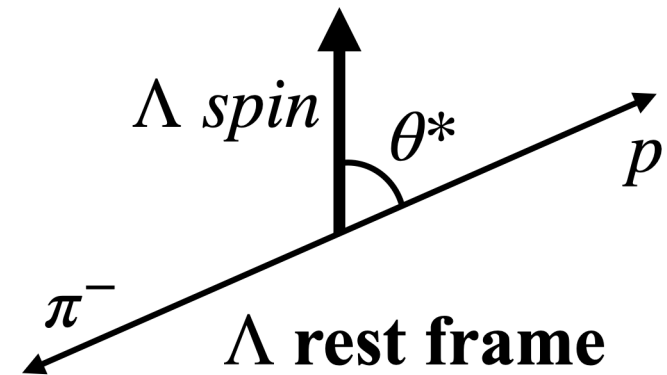
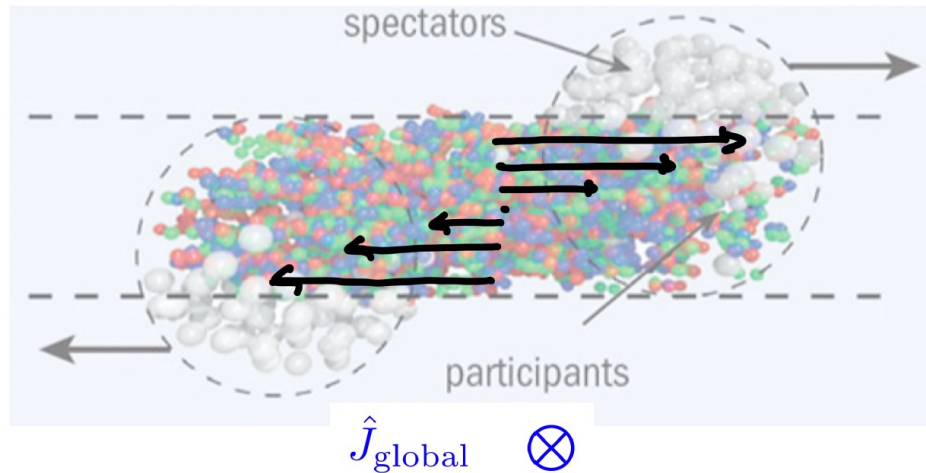
Shandong University 山东大学

QCD Matter under Rotation and Magnetic Fields, Huainan, 2026



山东大学
SHANDONG UNIVERSITY

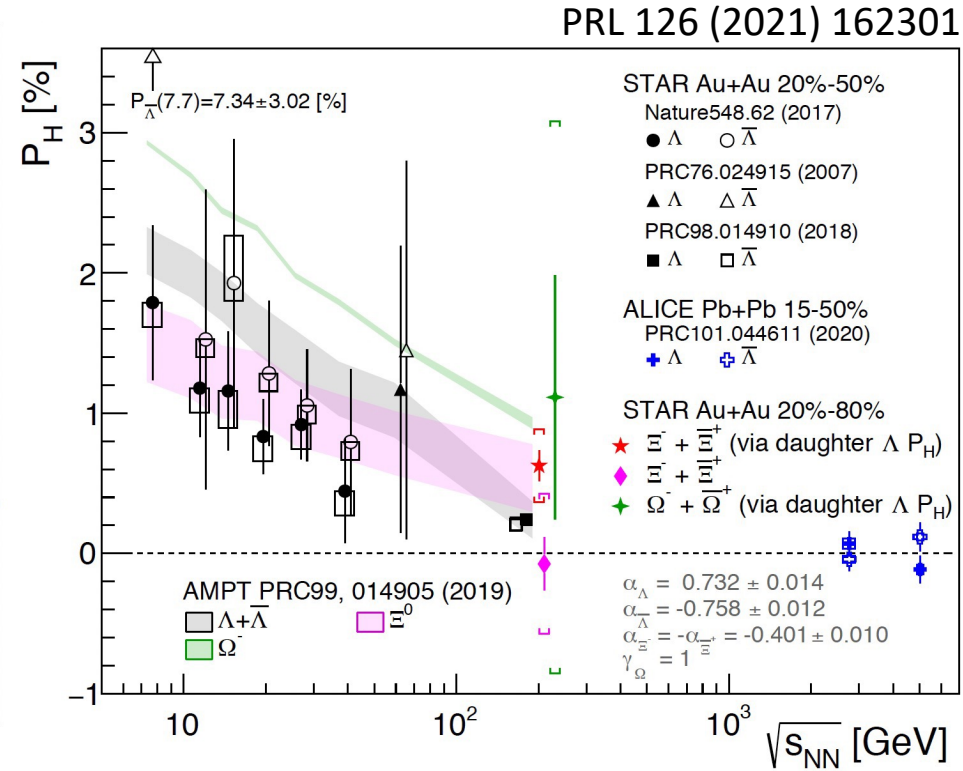
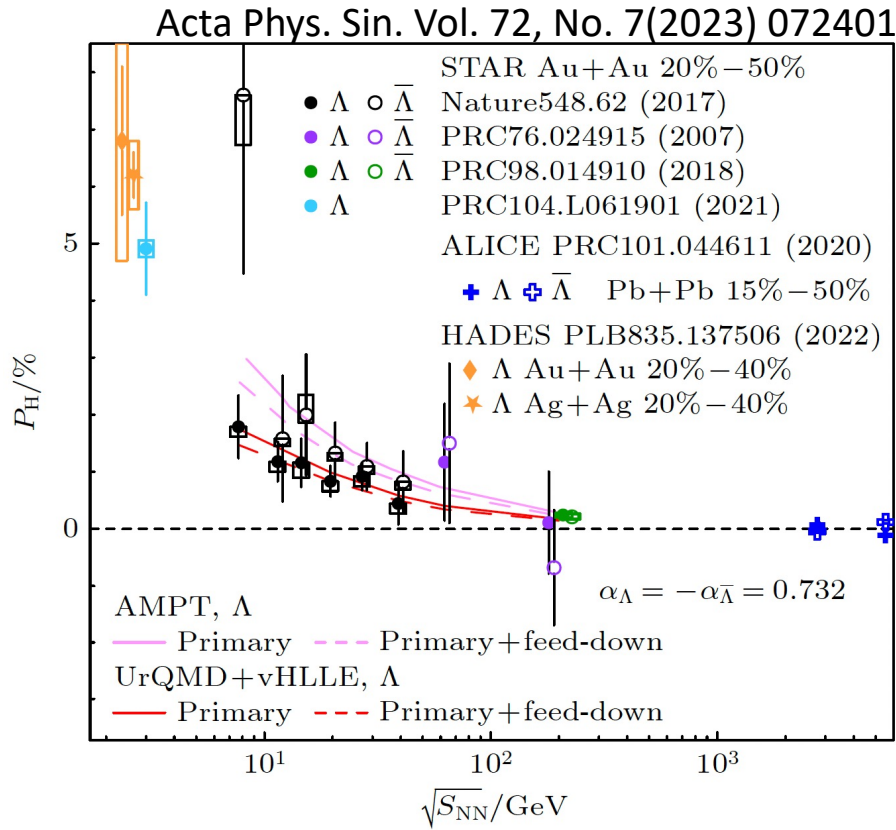
Polarization as unique probe of QCD matter



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”

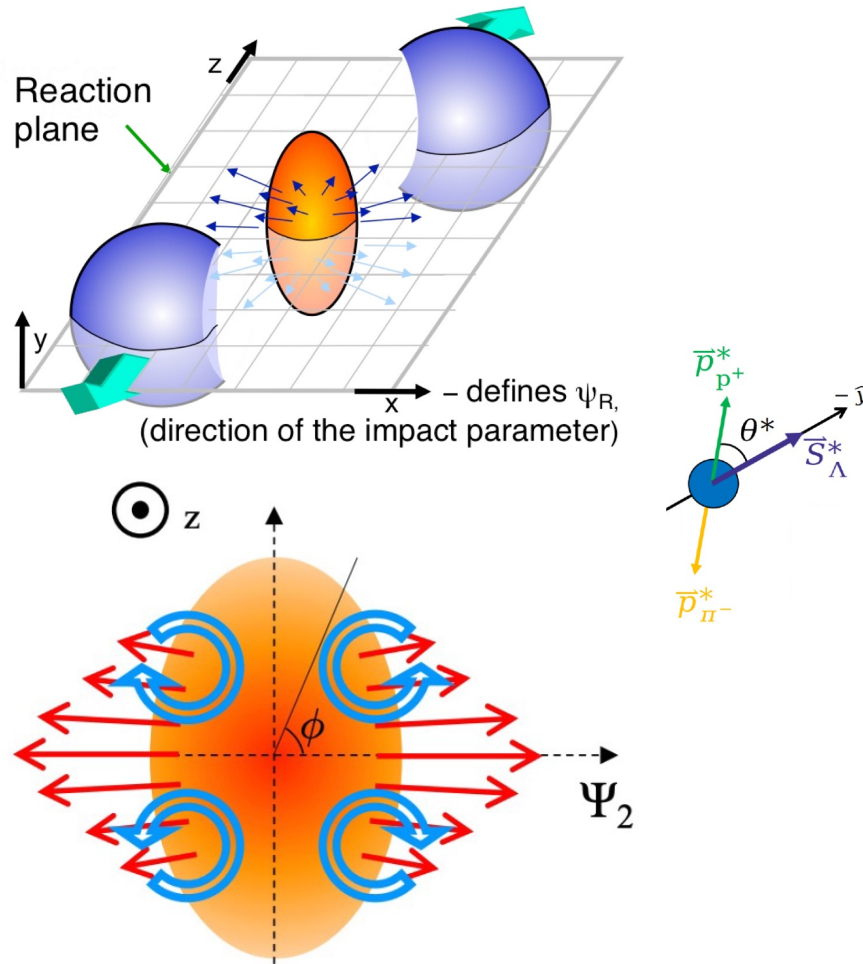


Large initial orbital angular momentum
 Can polarize particles through spin-orbit coupling

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

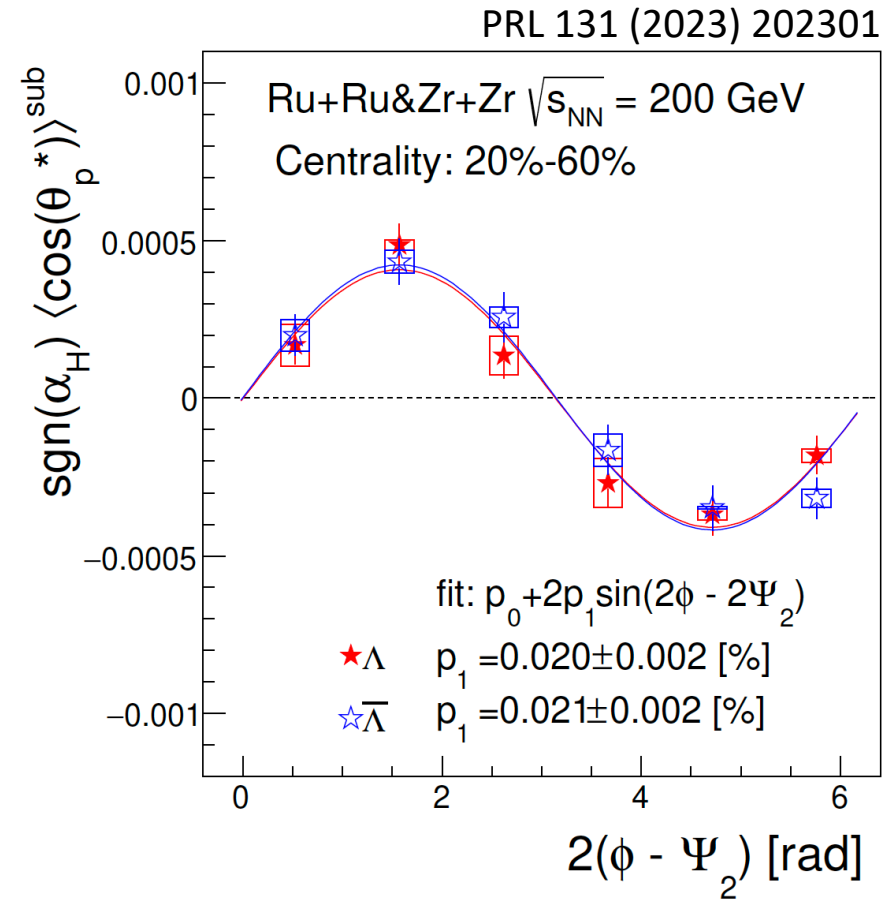
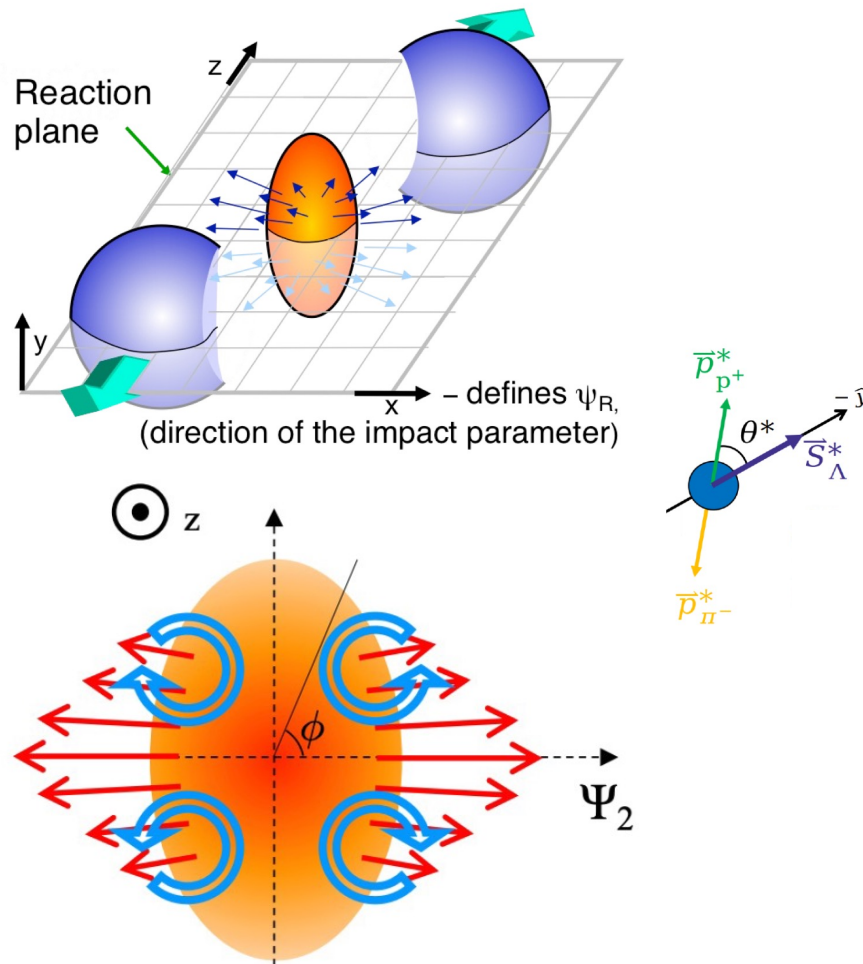
Largest vorticity ever seen $\omega \approx (9 \pm 1) \times 10^{21} \text{ s}^{-1}$

Hyperon polarization along beam direction



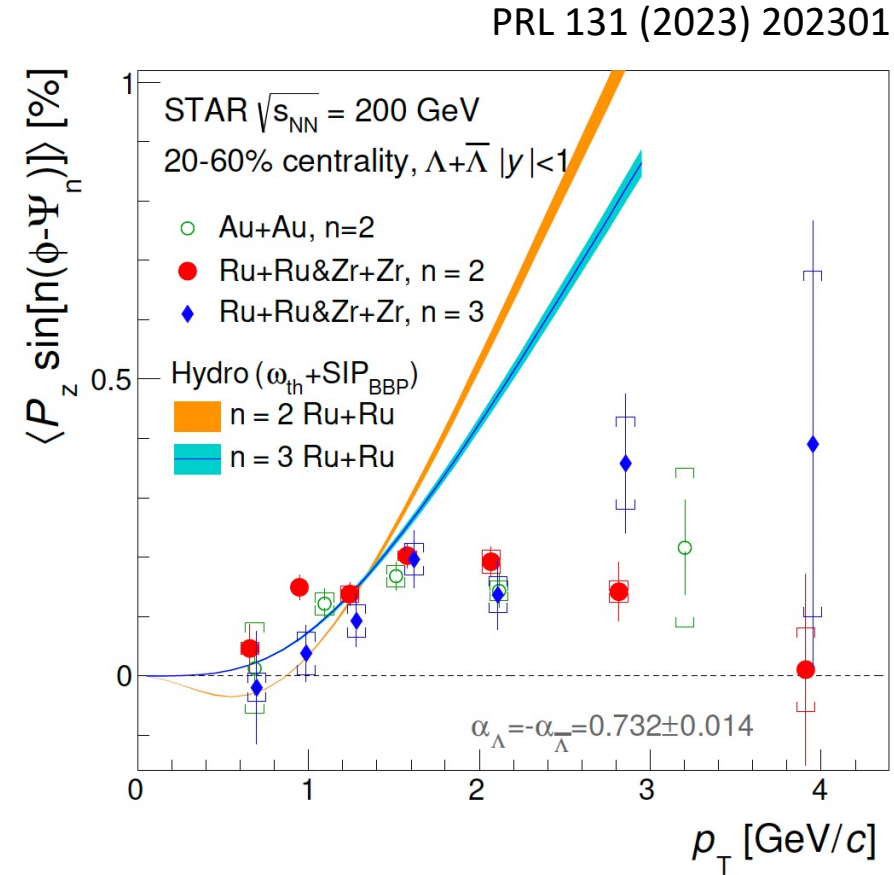
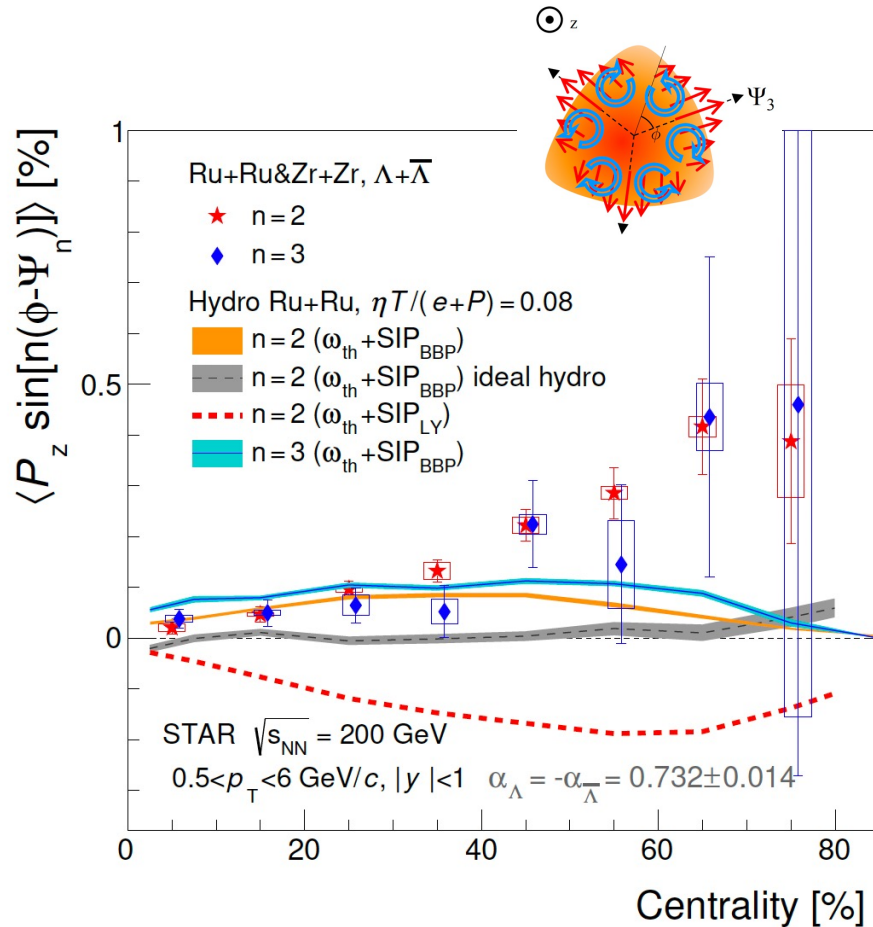
Simple expectation of vorticity from the anisotropic expansion of QGP

Hyperon polarization along beam direction



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

Hyperon polarization linked to collective flow(?)

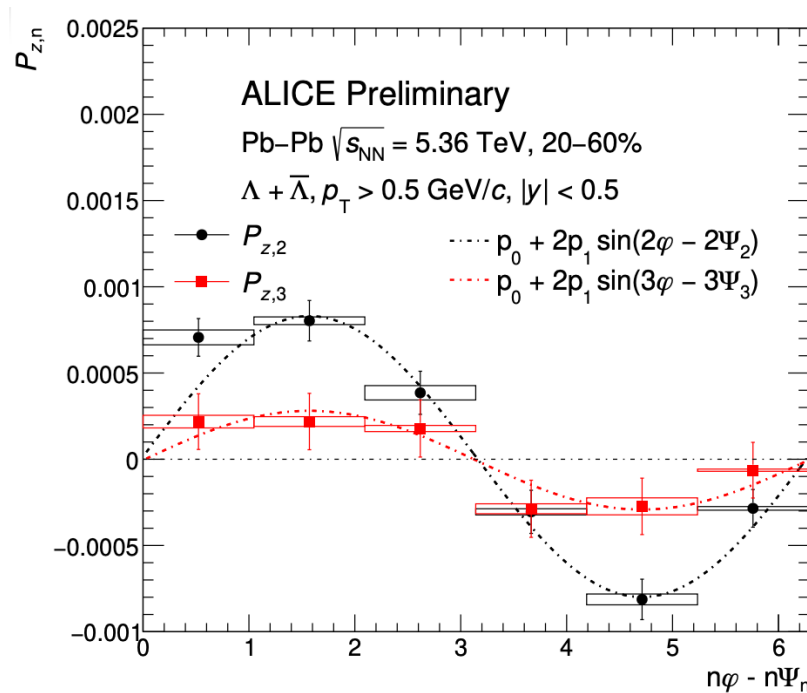


Same expectation of vorticity from higher order flow observed

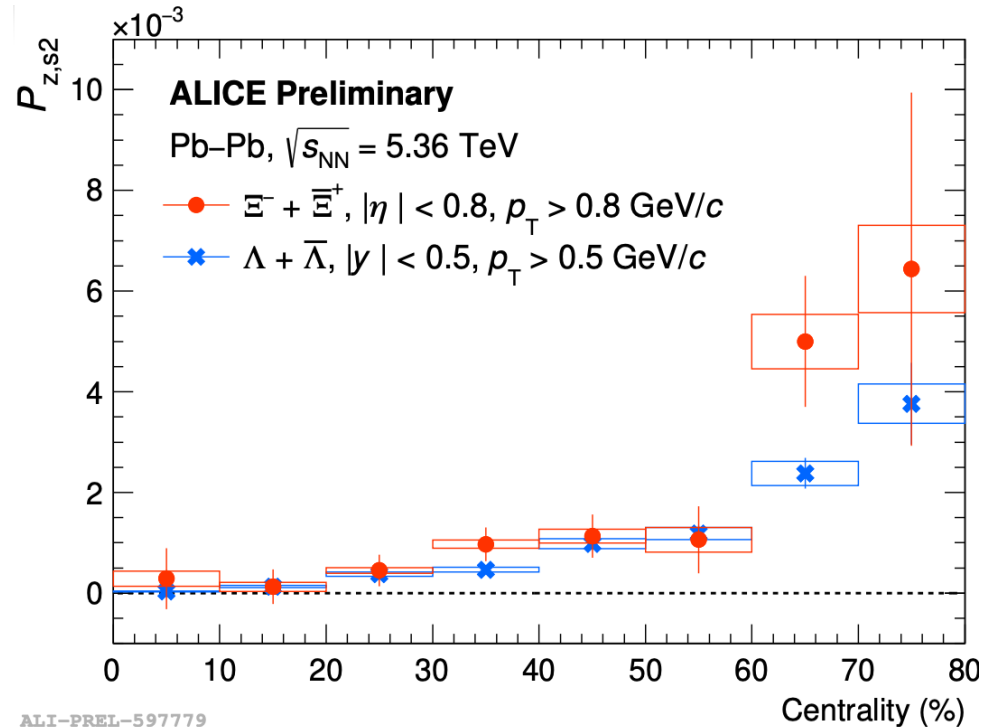
Details of model calculations need to be investigated

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

Hyperon polarization linked to collective flow(?)



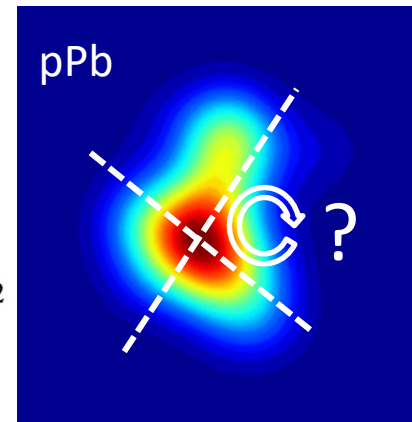
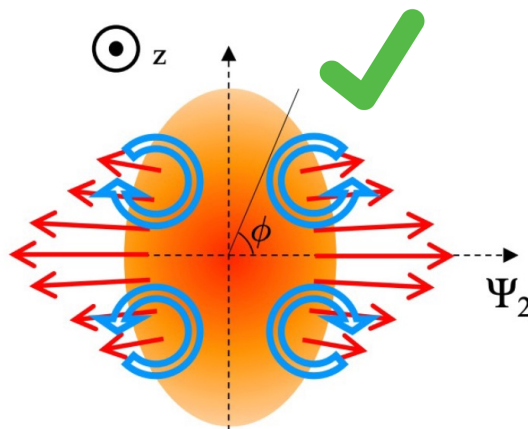
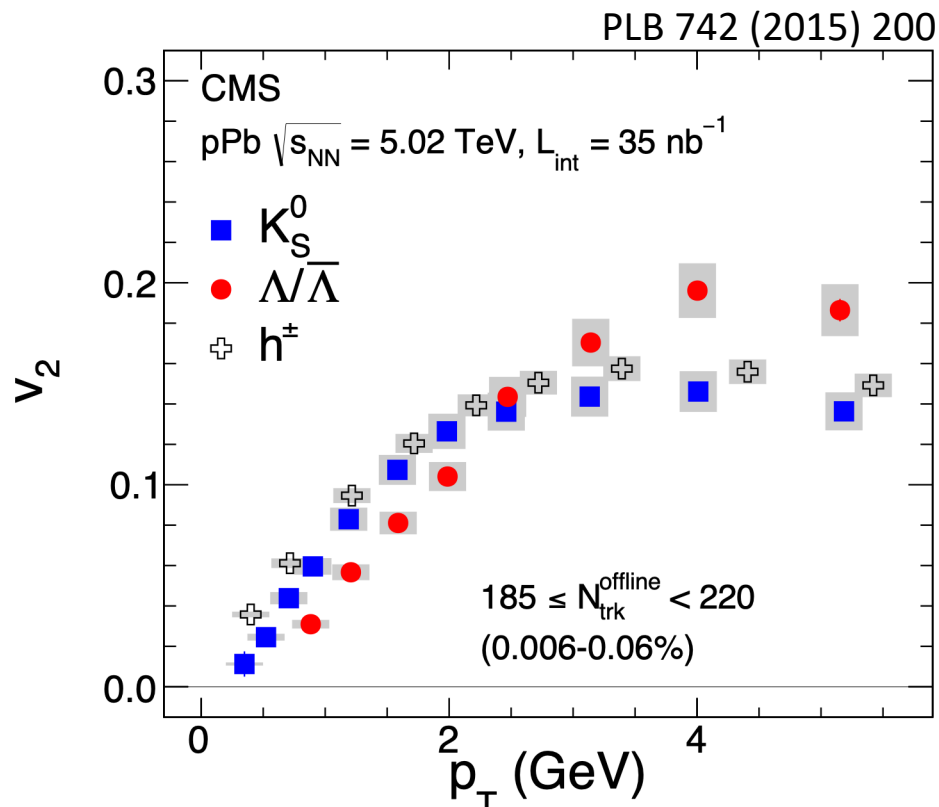
ALI-PREL-597386



ALI-PREL-597779

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 extended to multi-strange hyperons

A test in small system

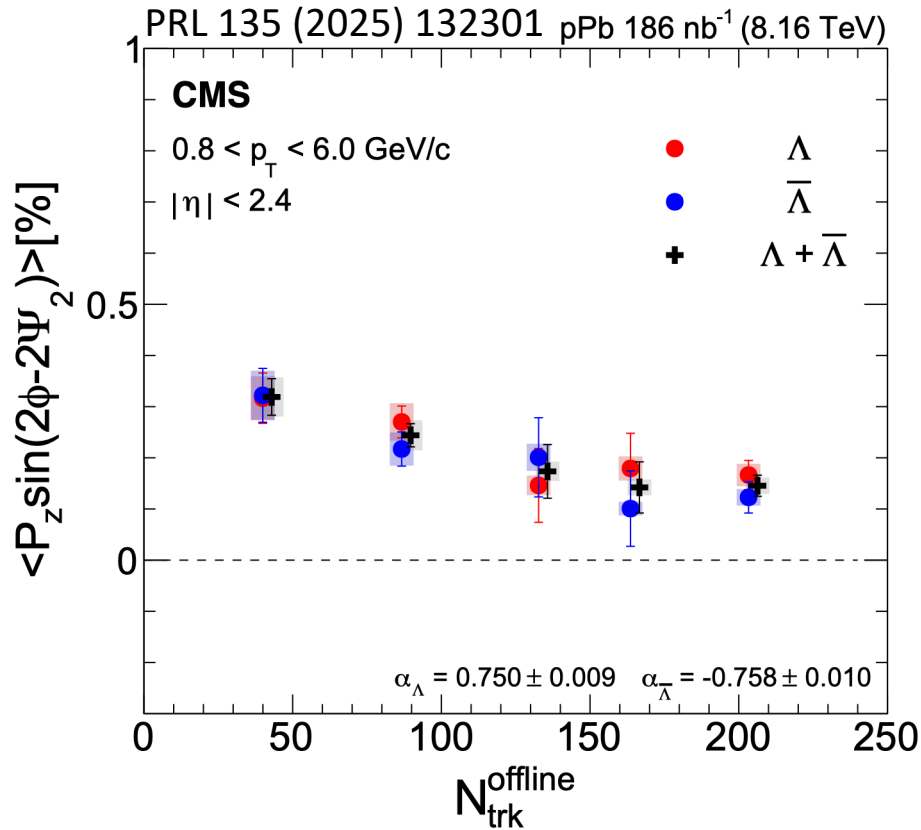


Features of QGP droplets observed in small but dense systems

Can we see hyperon polarization P_z there?

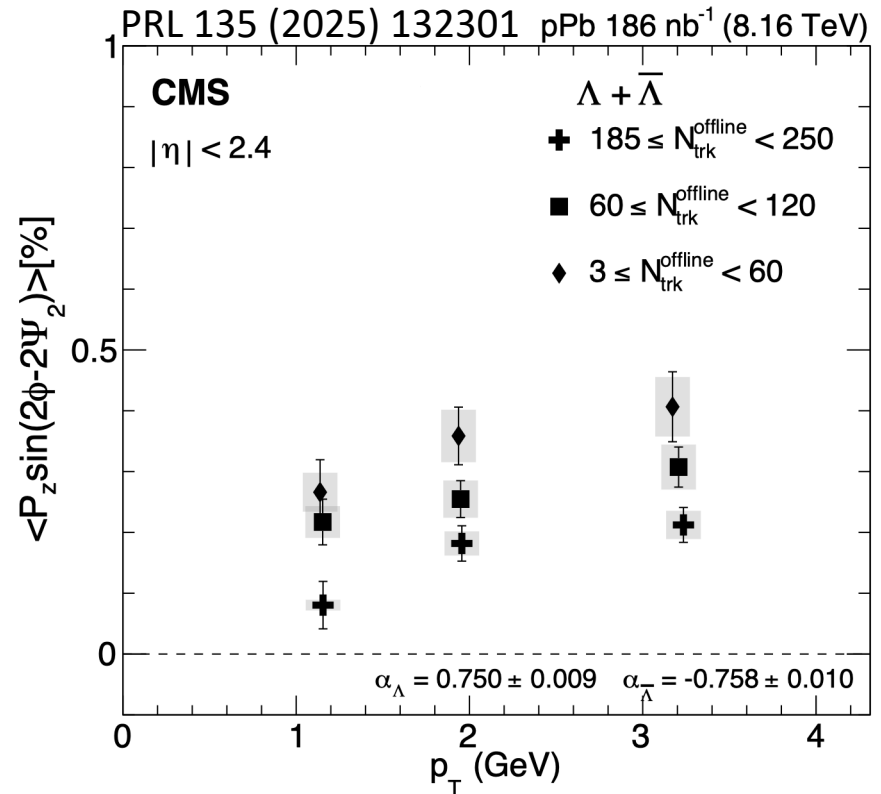
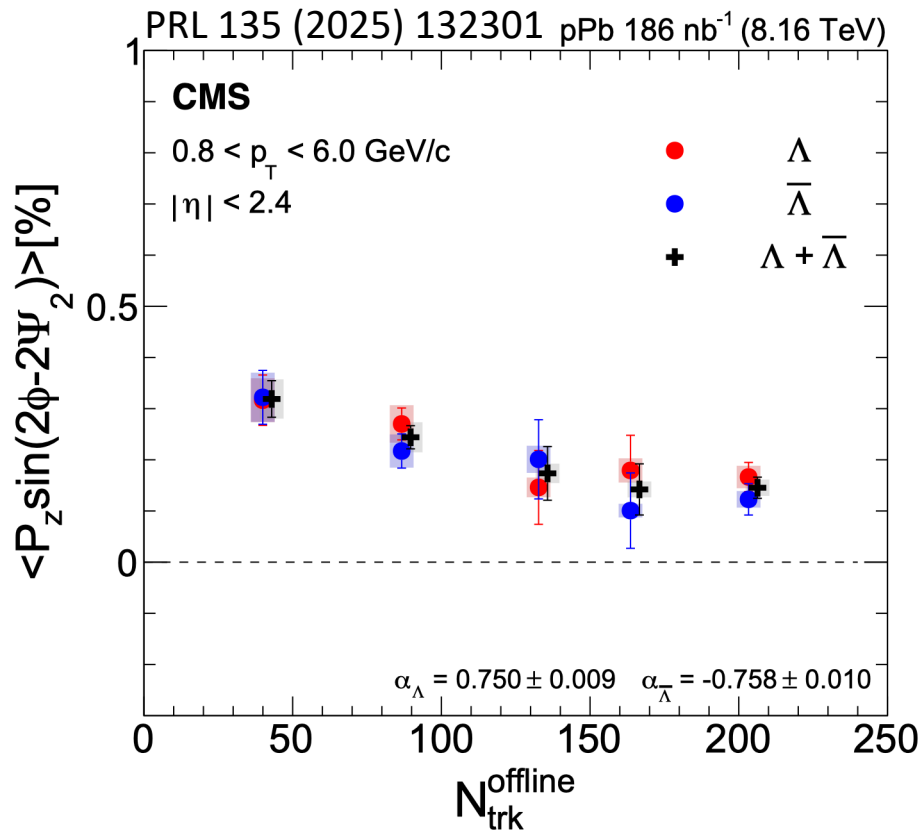
A test of QGP formation & different mechanisms of P_z

$P_{z,s2}$ 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



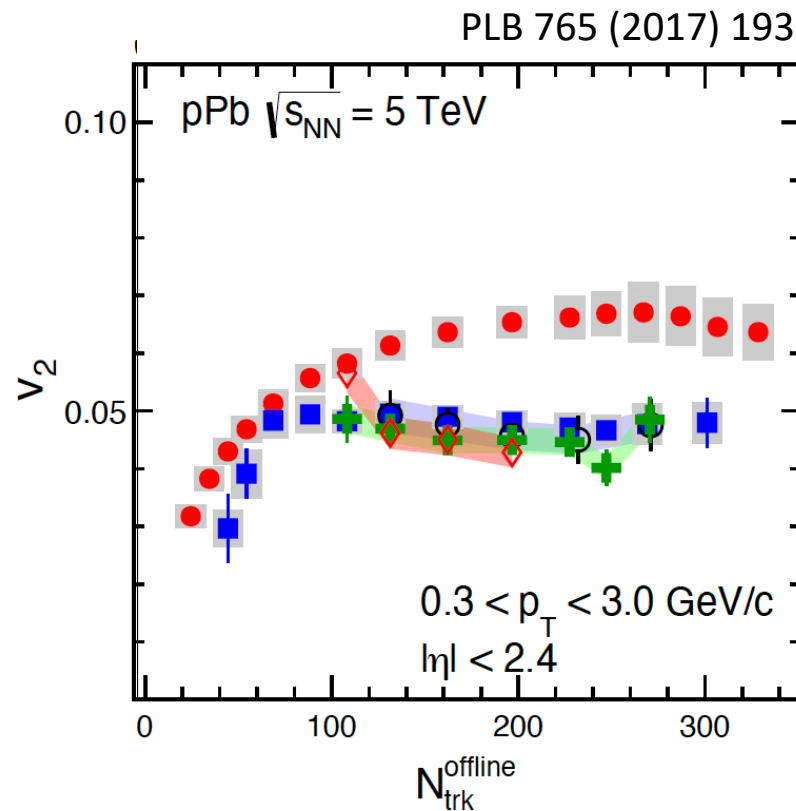
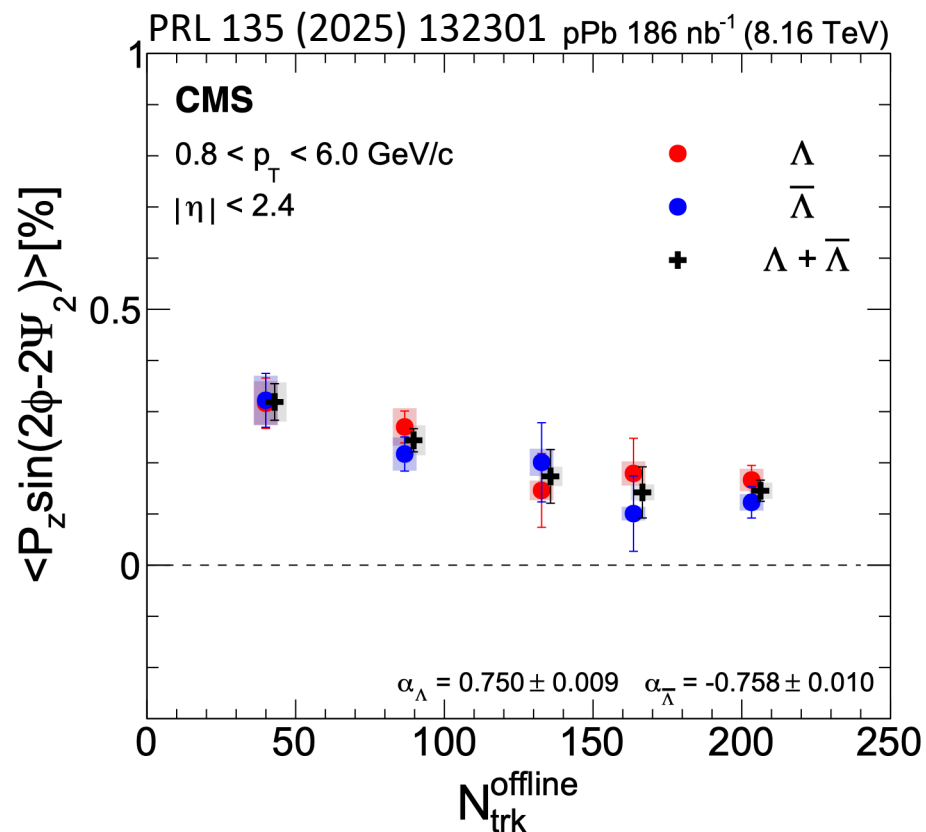
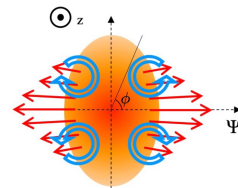
Significant positive $P_{z,s2}$ observed over entire multiplicity range

Consistent results for Λ and anti- Λ

Decrease towards high multiplicity

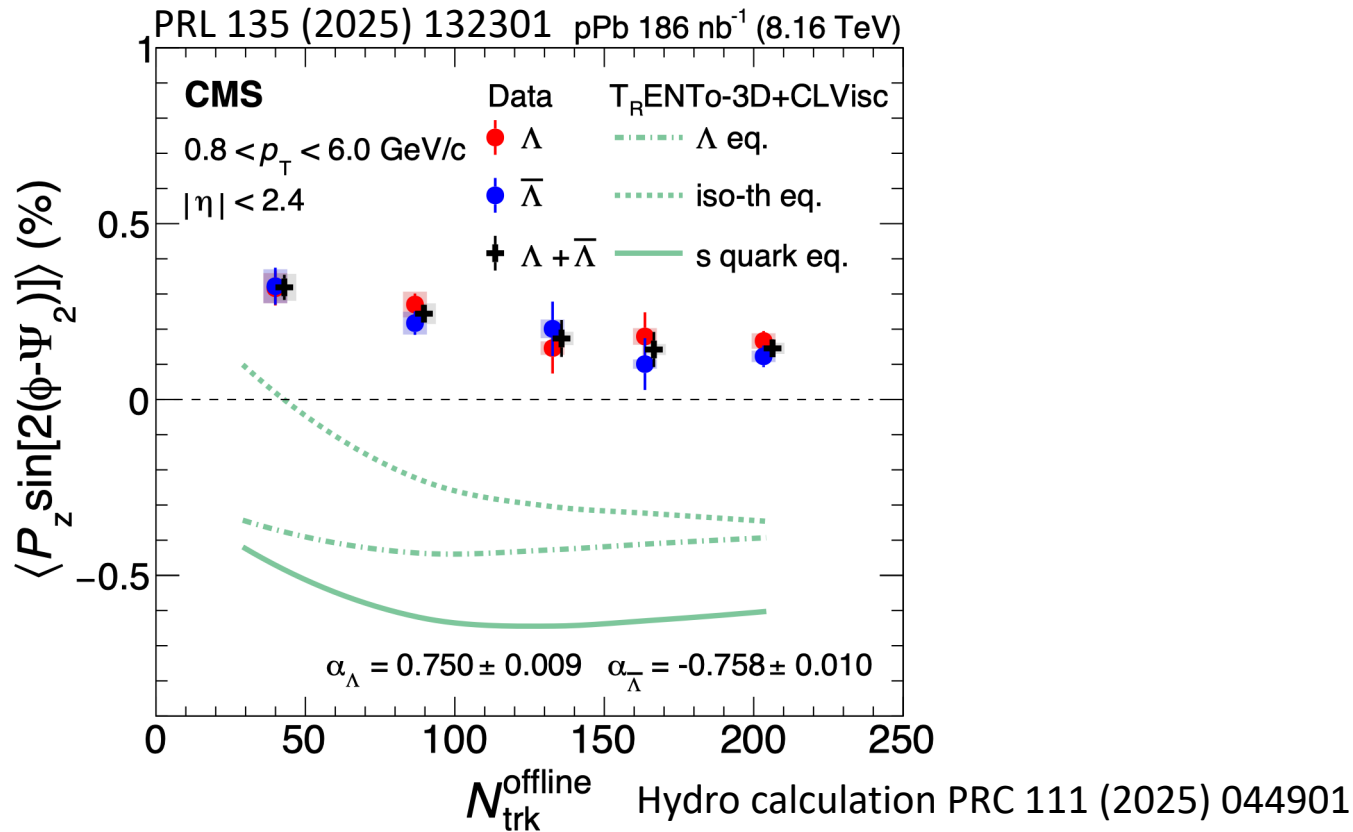
Increase towards higher p_T – becomes flat at higher p_T ?

$P_{z,s2}$ in pPb collision



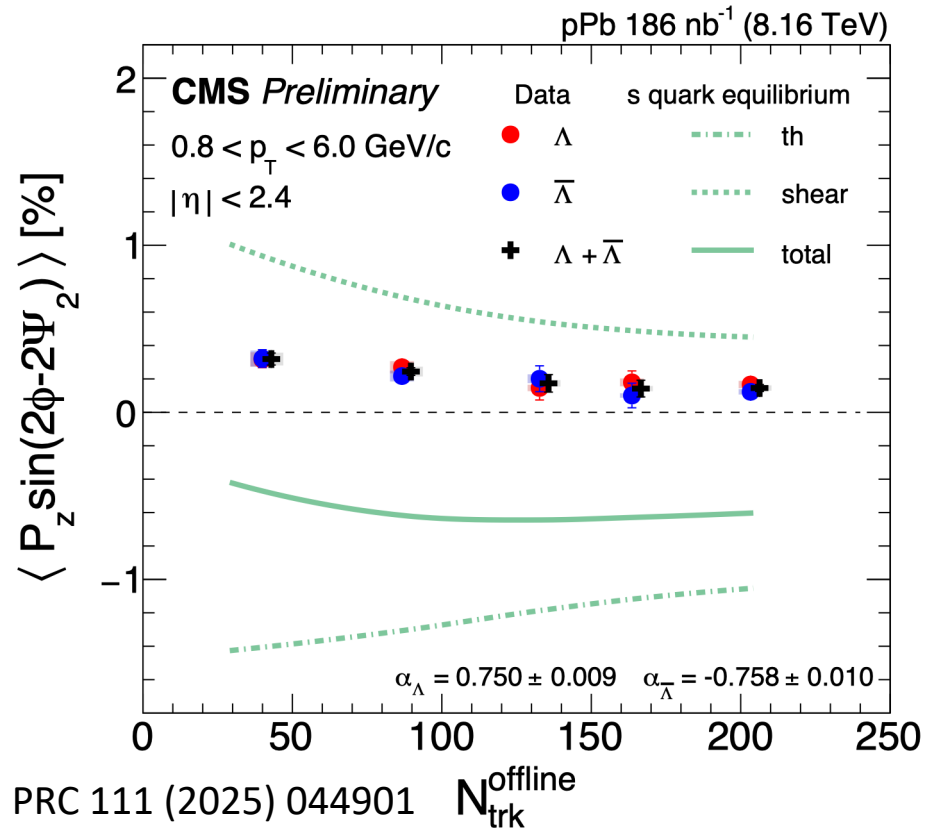
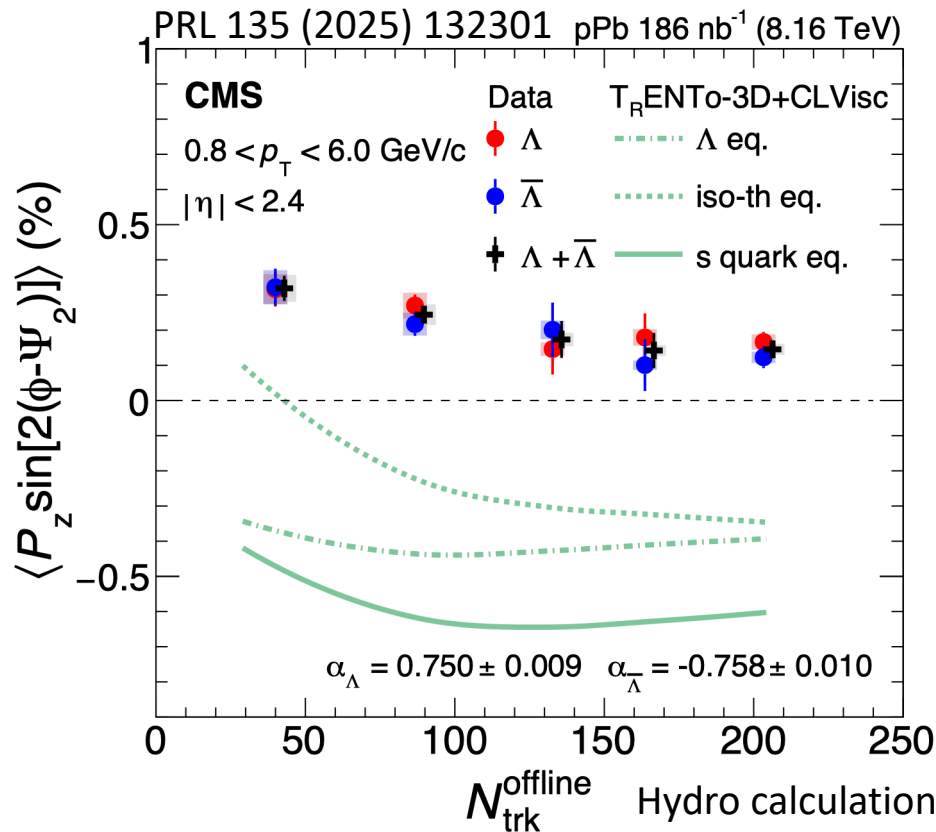
Not consistent with the trend of v_2

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



Hydro calculations result in negative P_z
 Post challenge to current theoretical framework

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

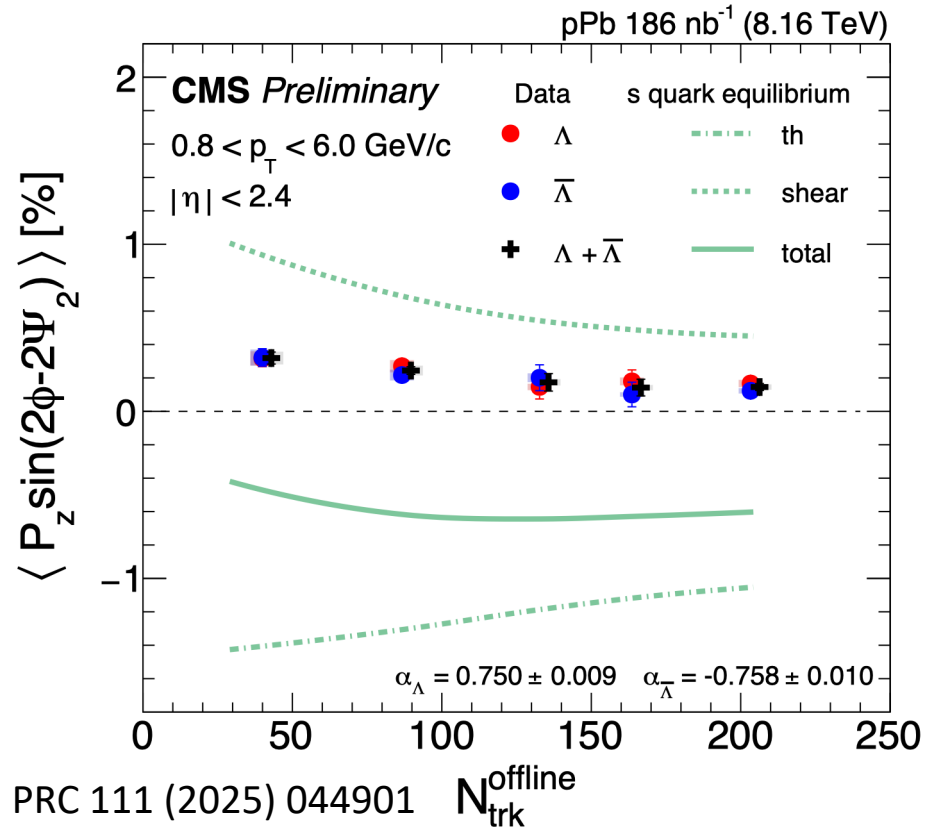
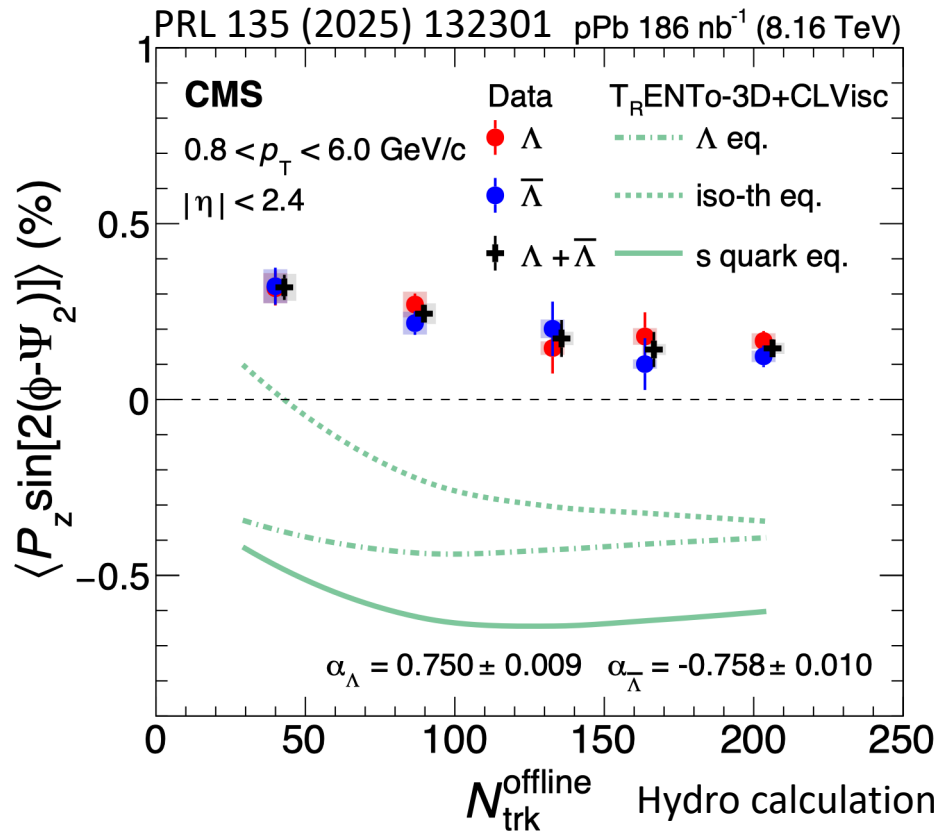


Hydro calculations result in negative P_z

Post challenge to current theoretical framework

Different contributions in small systems need to be understood further

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



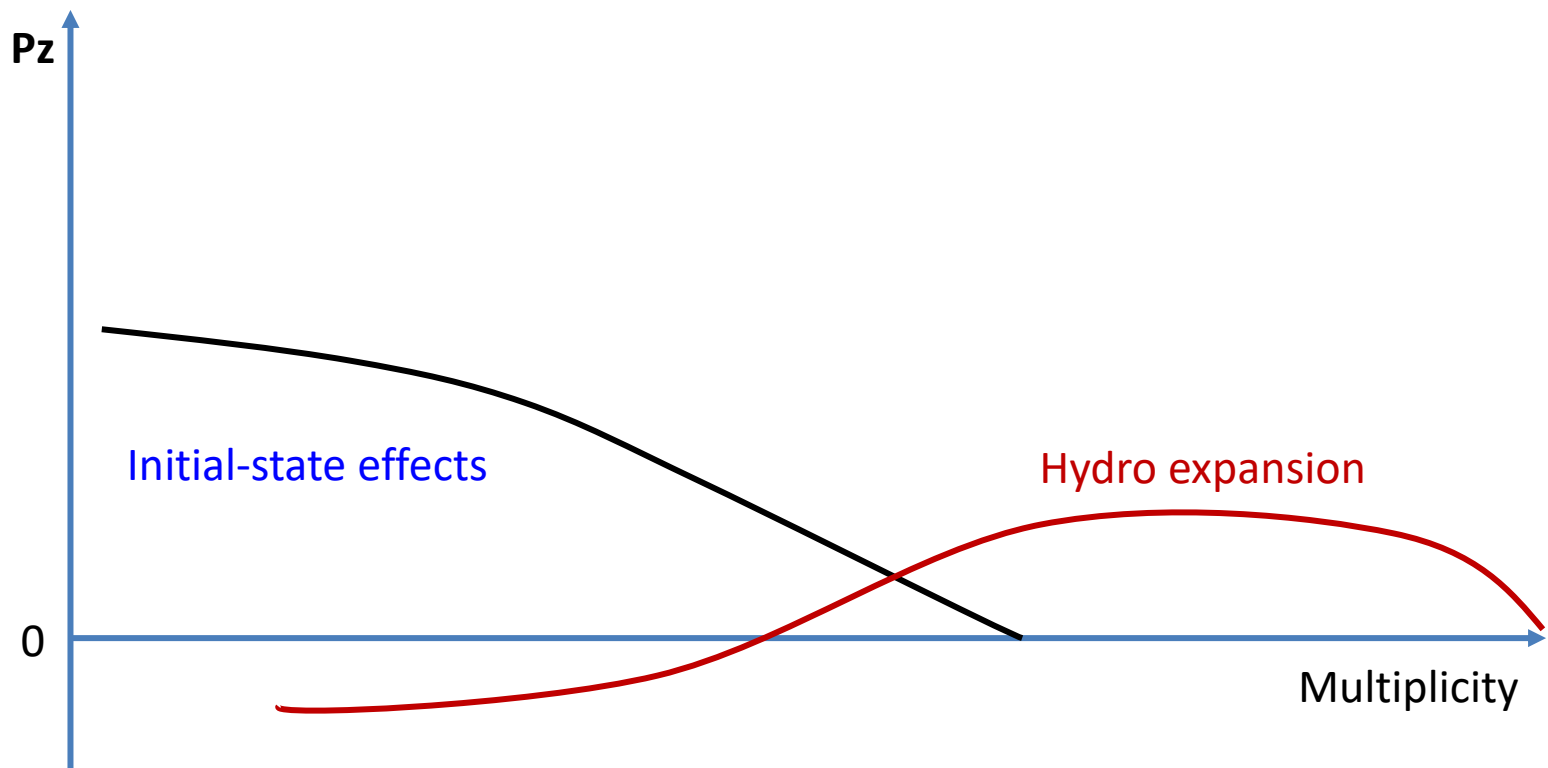
Hydro calculations result in negative P_z

Post challenge to current theoretical framework

Different contributions in small systems need to be understood further

Are there contributions from initial-state or non-equilibrium effects?

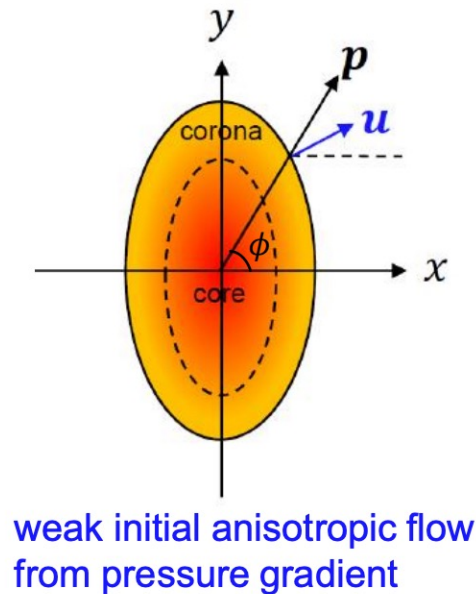
Hyperon polarization across systems



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

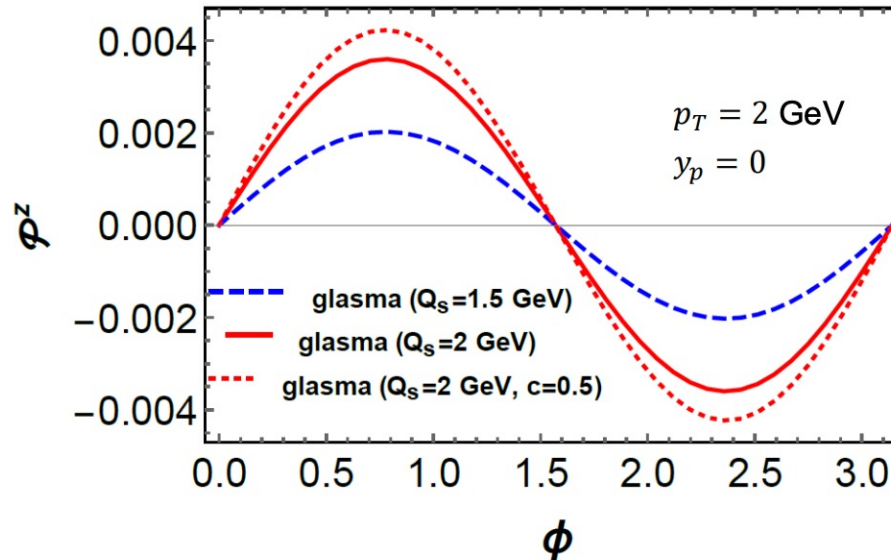
Core-corona + color-field correlators

- 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)

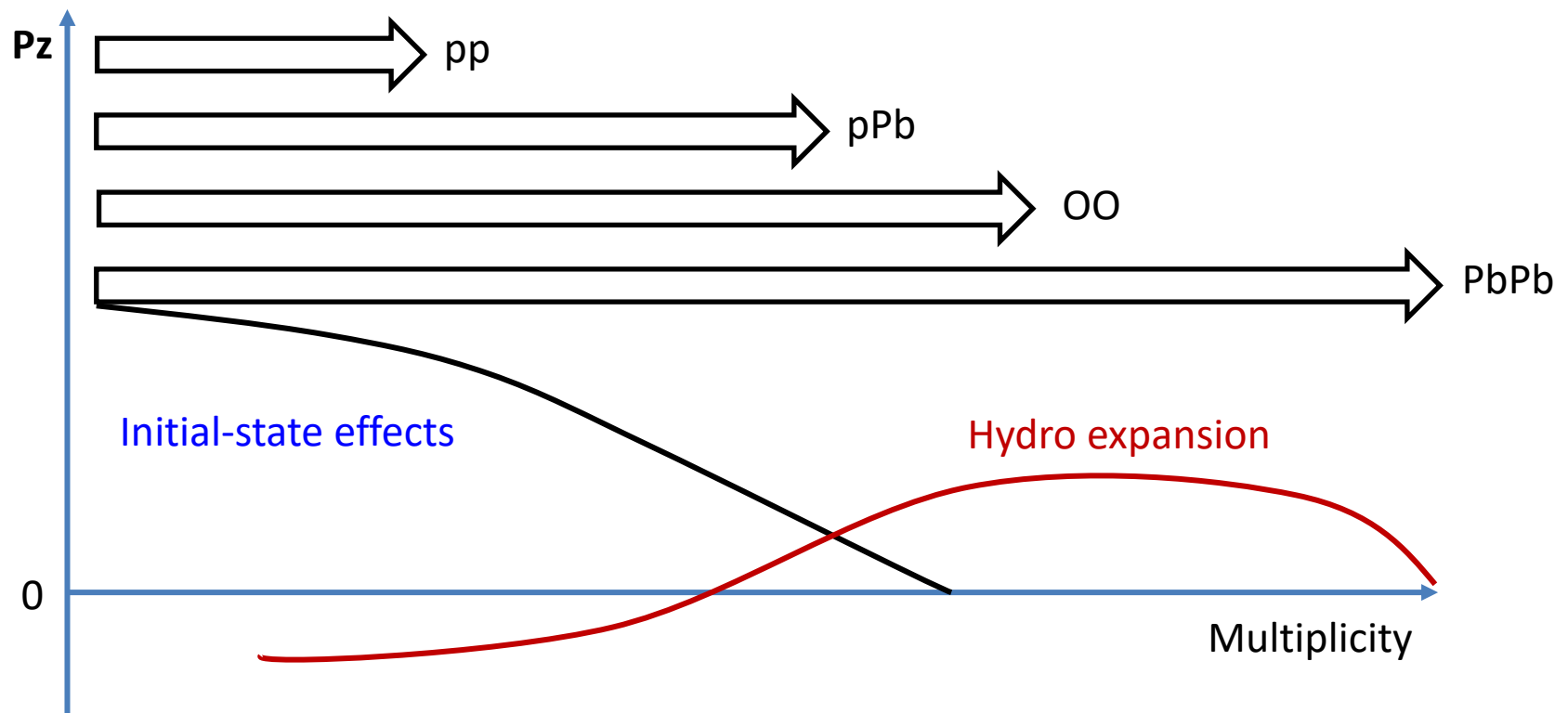


H. Sung, B. Müller, DY, arXiv: 2507.23210

- ✓ consistent sign & comparable order of magnitude with observations

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

Hyperon polarization across systems

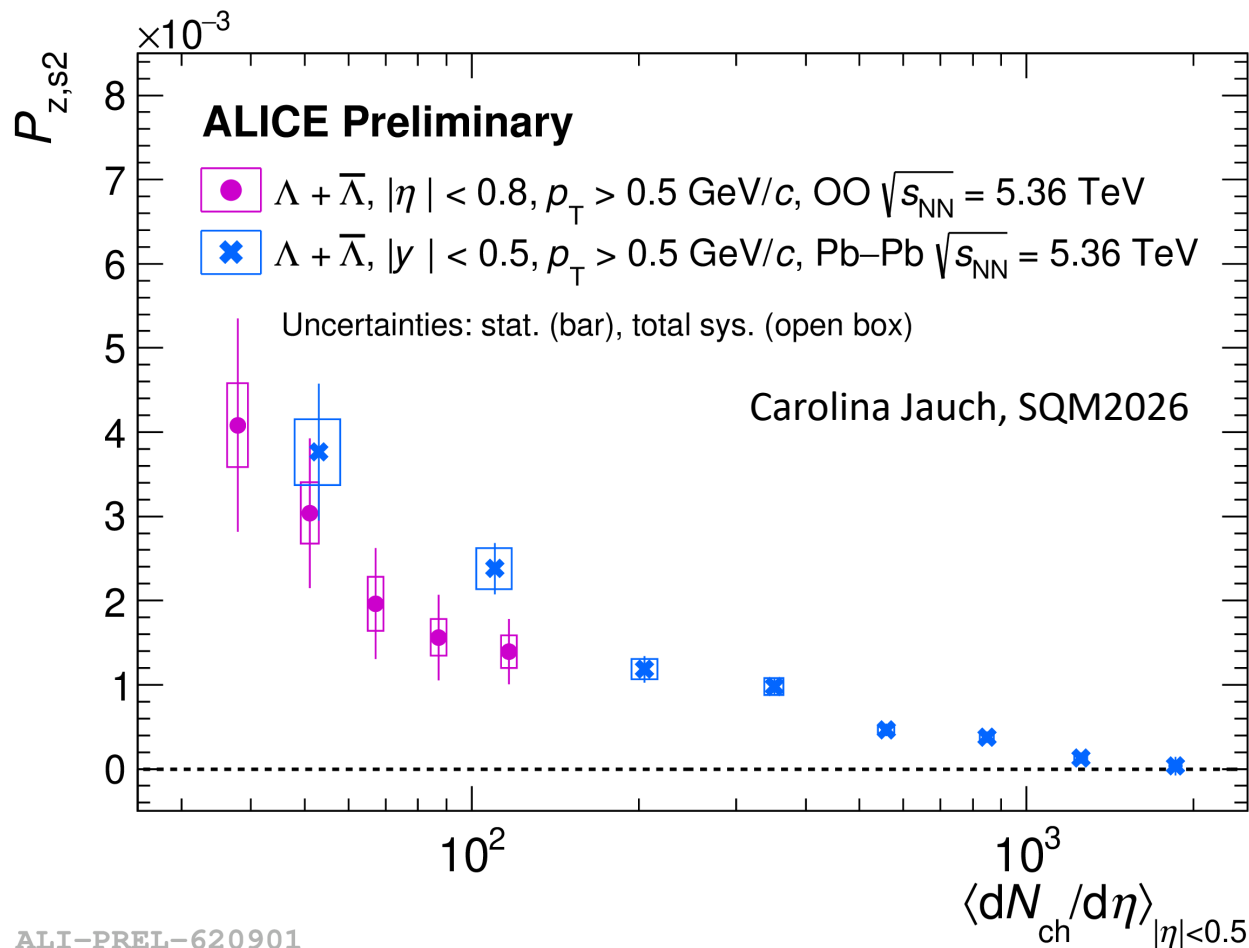


A naïve guess of contributions to hyperon local polarization

How do they evolve and what is the implication for AA and vice versa?

Polarization measurements and model calculations across pp, pA, AA needed!

Hyperon polarization across systems



ALI-PREL-620901

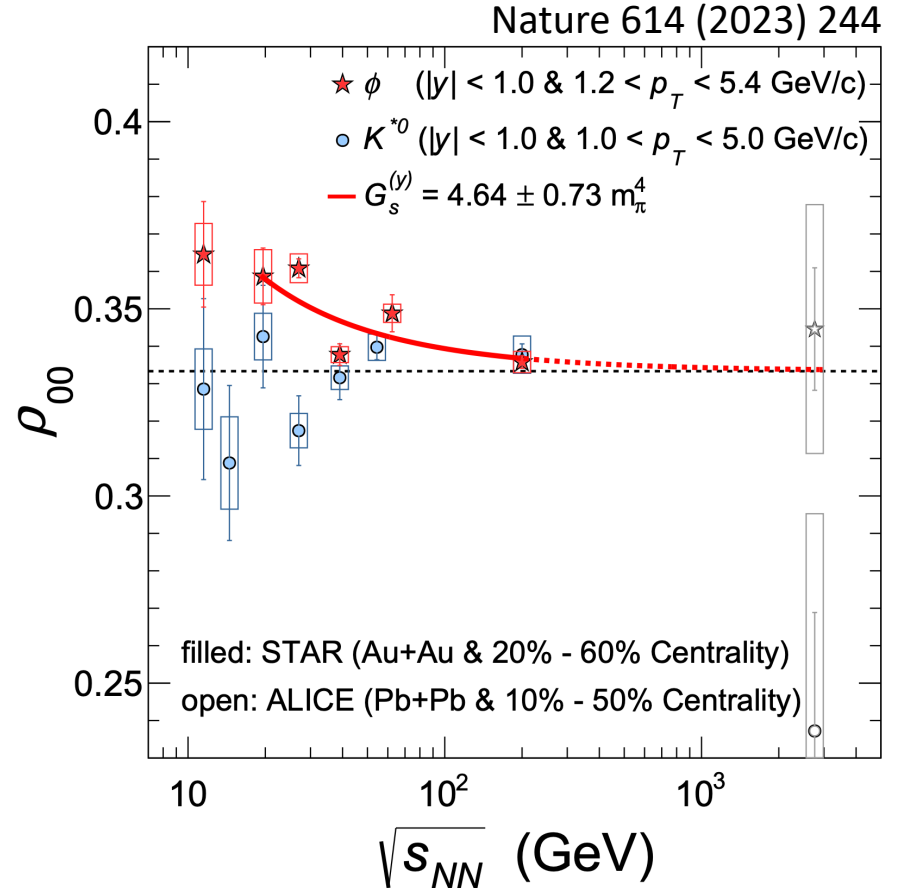
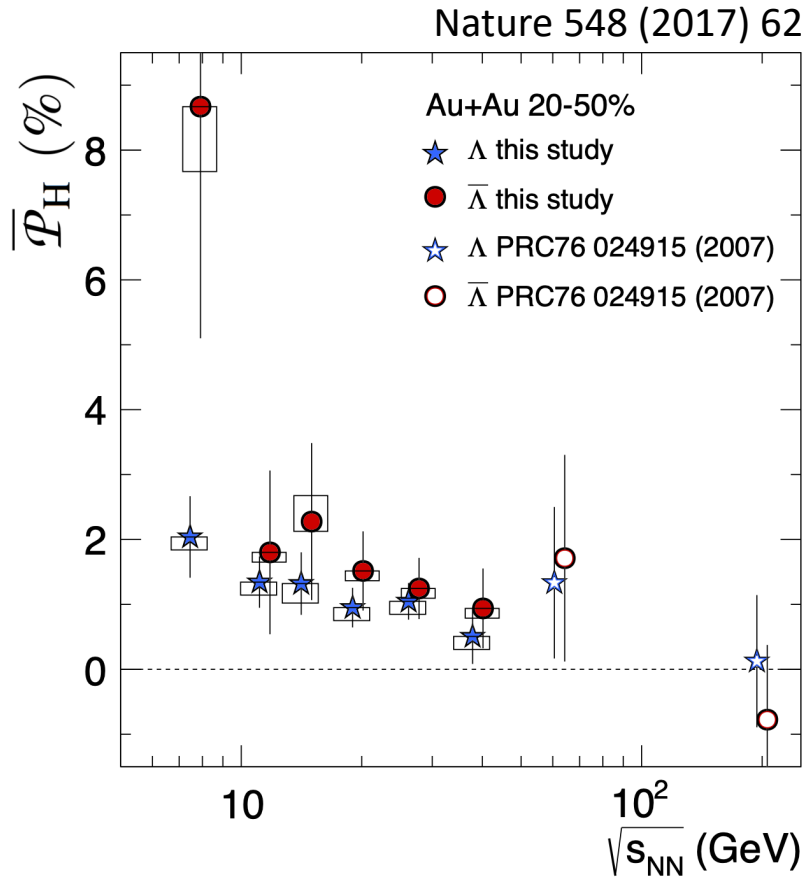
Significant local polarization observed in OO

Similar behavior as in PbPb

Important to compare different system at same multiplicity, esp. pPb vs OO

Looking forward to more results & theory comparison

Global polarization vs spin alignment

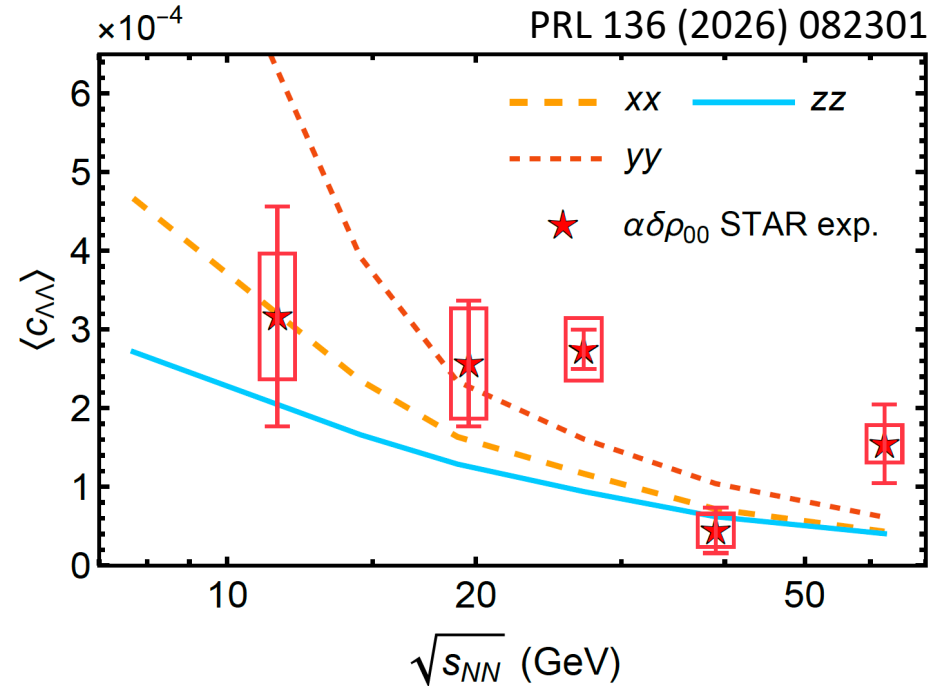
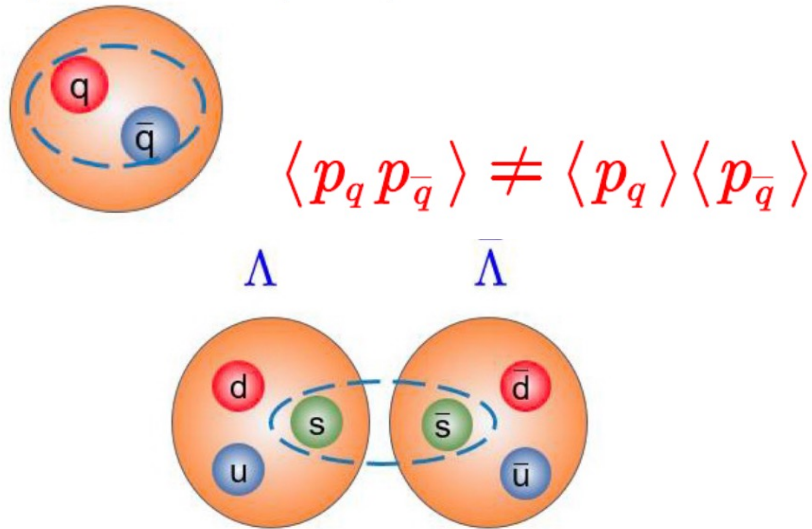


Global polarization and spin alignment in HI post a question why

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

Spin correlation

PRD 109 (2024) 114003



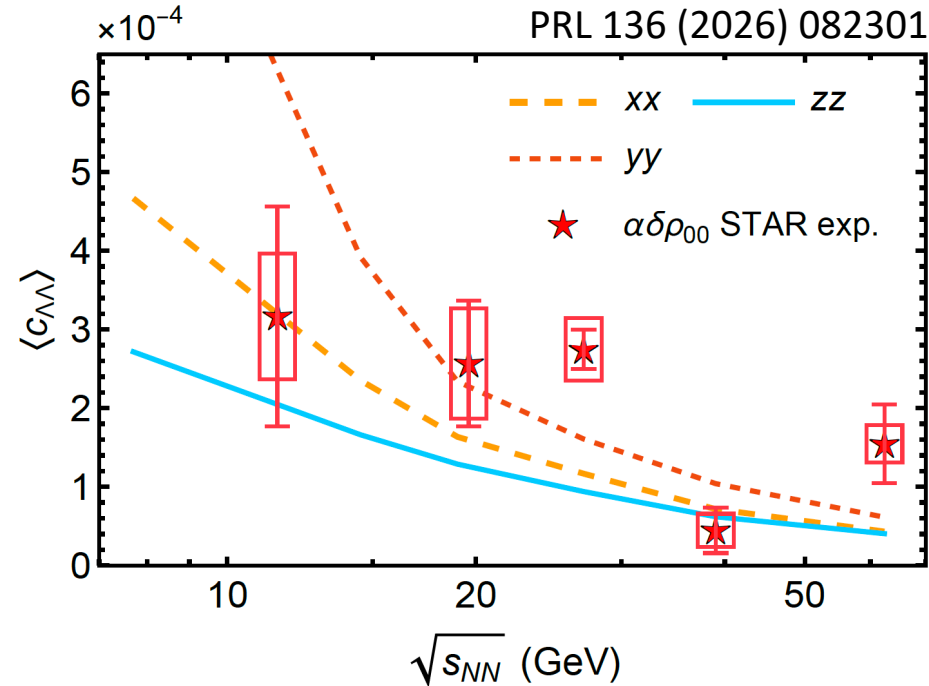
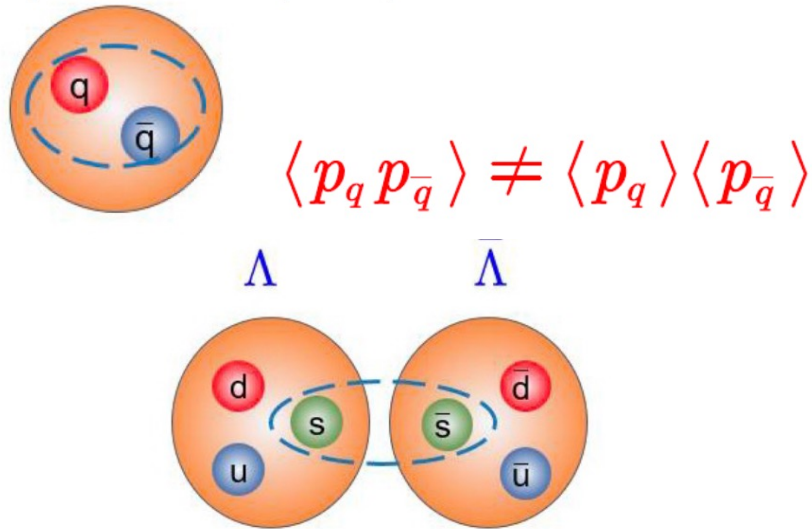
Global polarization and spin alignment in HI post a question why

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

Spin-spin correlation proposed as a solution

Spin correlation

PRD 109 (2024) 114003



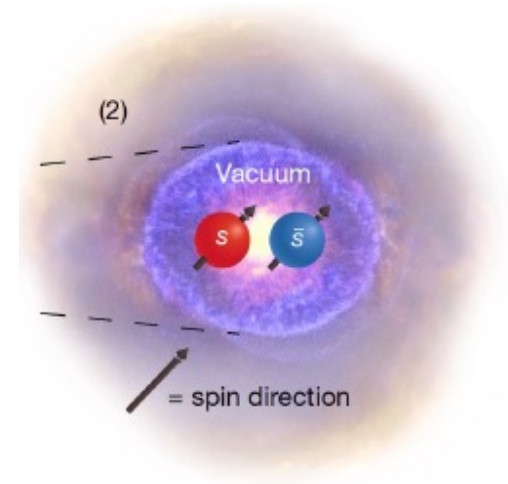
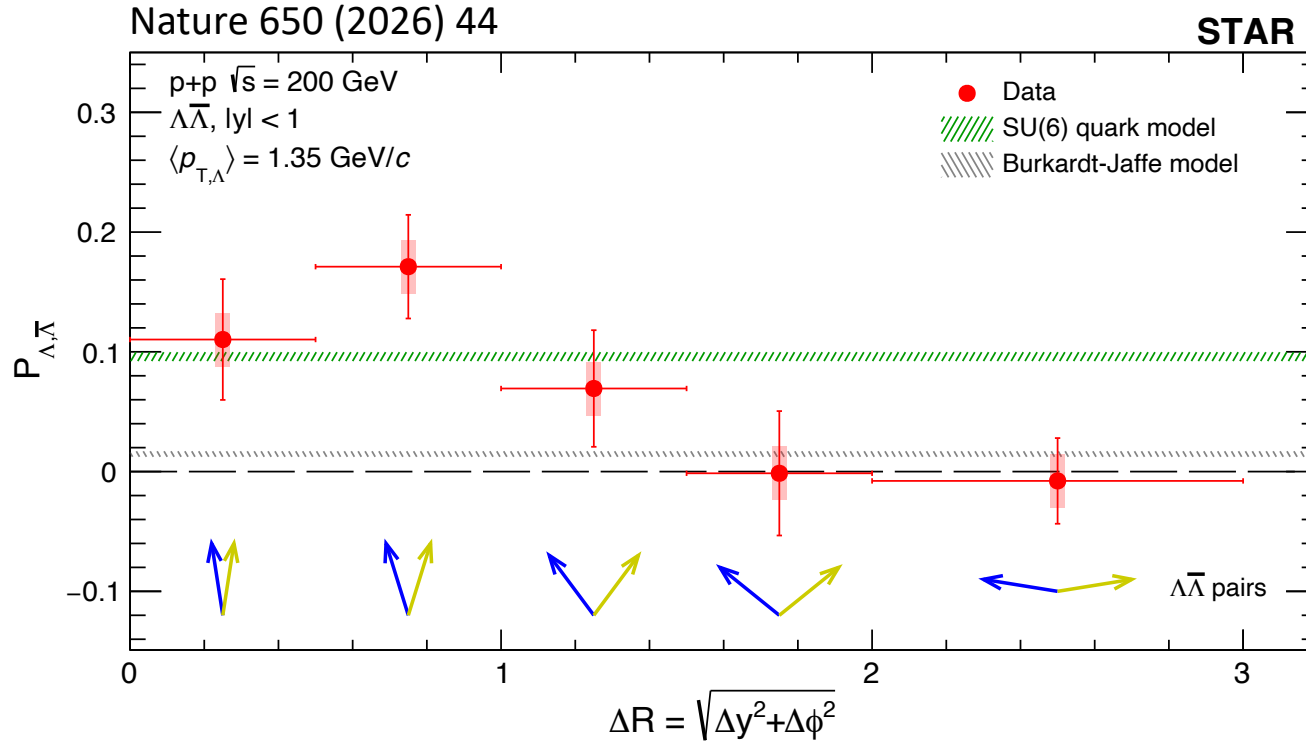
Global polarization and spin alignment in HI post a question why

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

Spin-spin correlation proposed as a solution

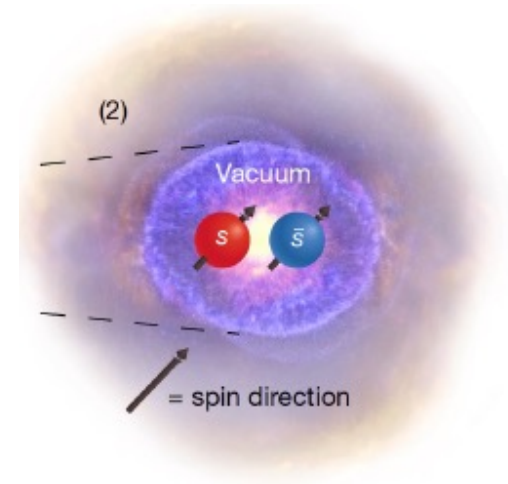
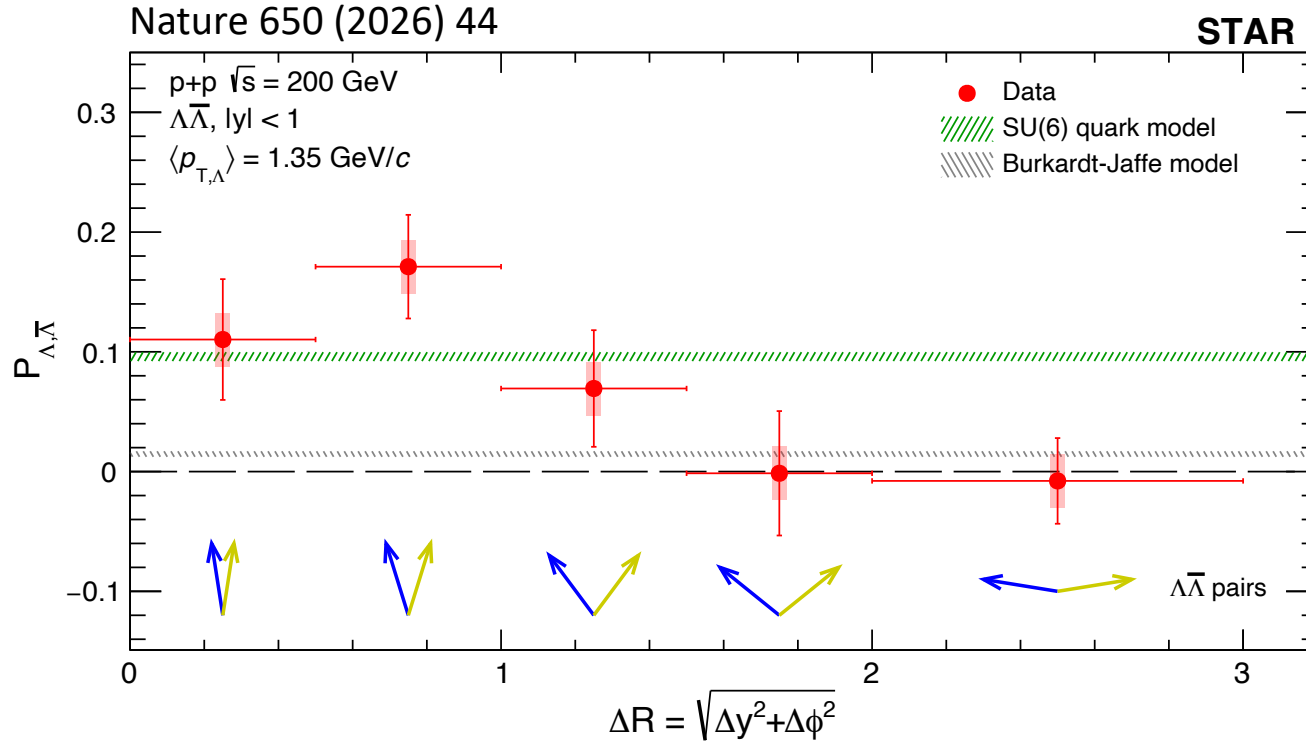
Every HI-QGP observable needs a 'vacuum' reference

Spin correlation in pp at RHIC



Evidence of positive signal observed by STAR for Lambda + anti-Lambda
 Interpreted as reflecting the spin structure of $s\bar{s}$ from QCD vacuum

Spin correlation in pp at RHIC



Evidence of positive signal observed by STAR for Lambda + anti-Lambda
 Interpreted as reflecting the spin structure of $s\bar{s}$ from QCD vacuum

Spin correlation measurement at CMS in pp and pPb

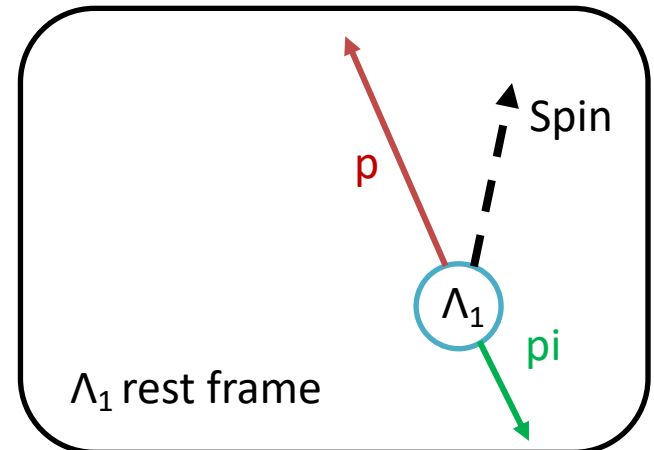
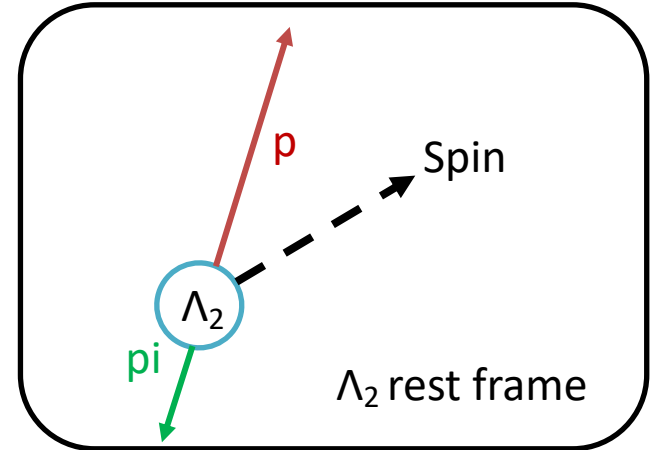
1. Energy and system dependence of proposed interpretation
2. Test of underlying mechanism with different type of pairs
3. The 'vacuum' baseline for HI measurements

$P_{\Lambda,\Lambda}$ extraction

Spin correlation extracted from θ^* distributions:

$$\frac{1}{N} \frac{dN}{d \cos \theta^*} = \frac{1}{2} (1 + \alpha_1 \alpha_2 P_{\Lambda_1, \Lambda_2} \cos \theta^*)$$

Spin correlation
magnitude



$P_{\Lambda,\Lambda}$ extraction

Spin correlation extracted from θ^* distributions:

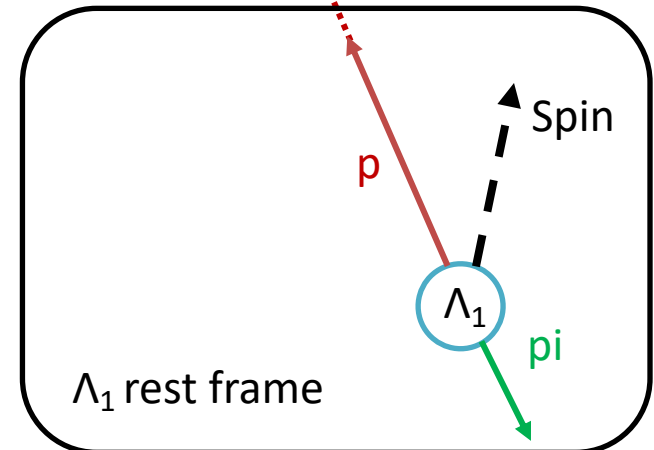
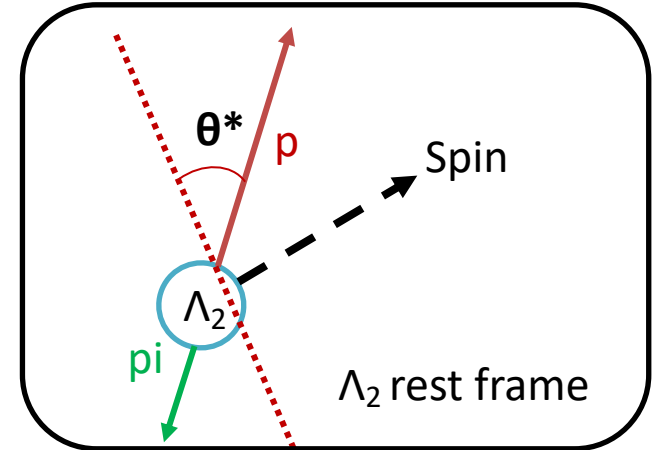
$$\frac{1}{N} \frac{dN}{d \cos \theta^*} = \frac{1}{2} (1 + \alpha_1 \alpha_2 P_{\Lambda_1, \Lambda_2} \cos \theta^*)$$

Spin correlation
magnitude

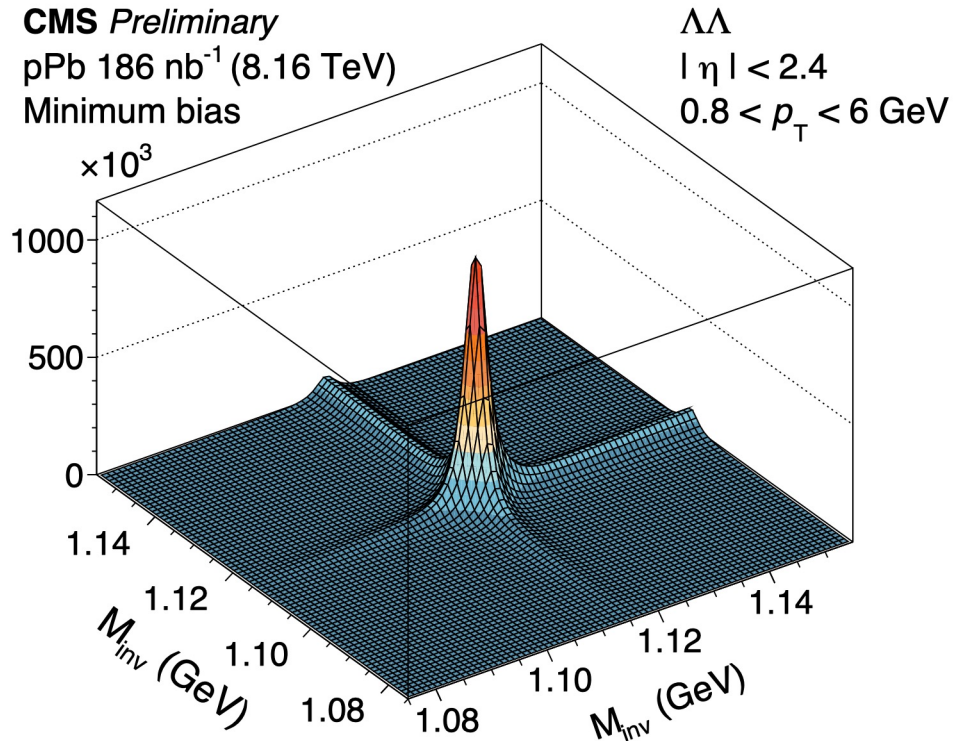
Hyperon pair $\cos \theta^*$ distribution extraction

Acceptance correction

Fit for slope $P_{\Lambda,\Lambda}$

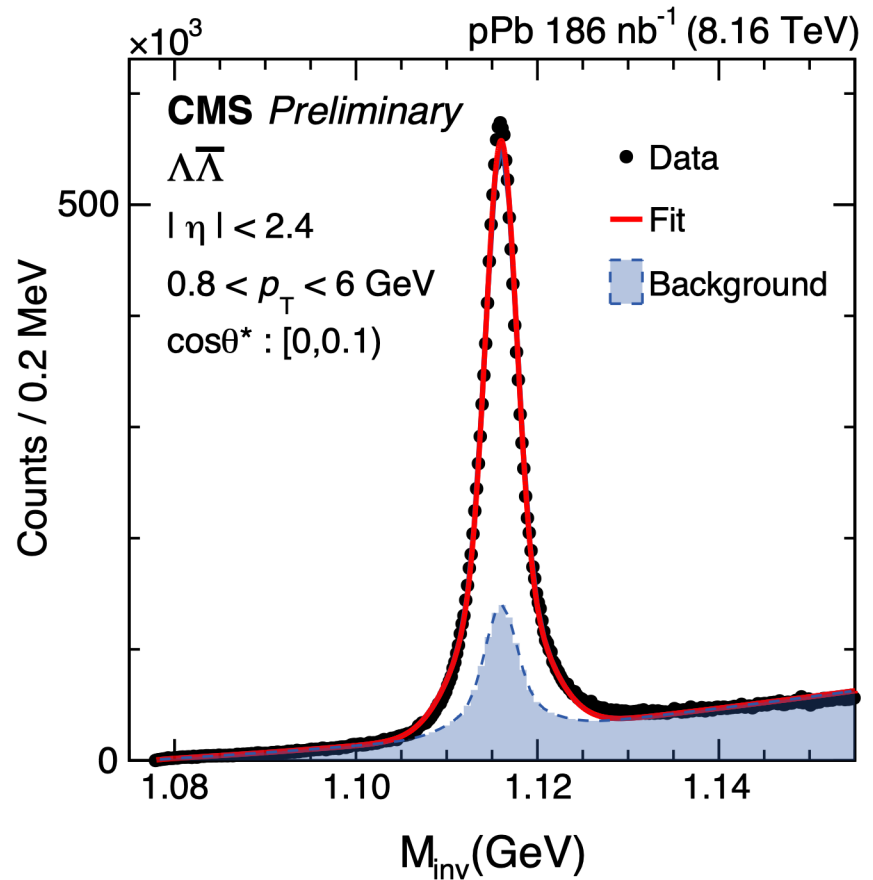
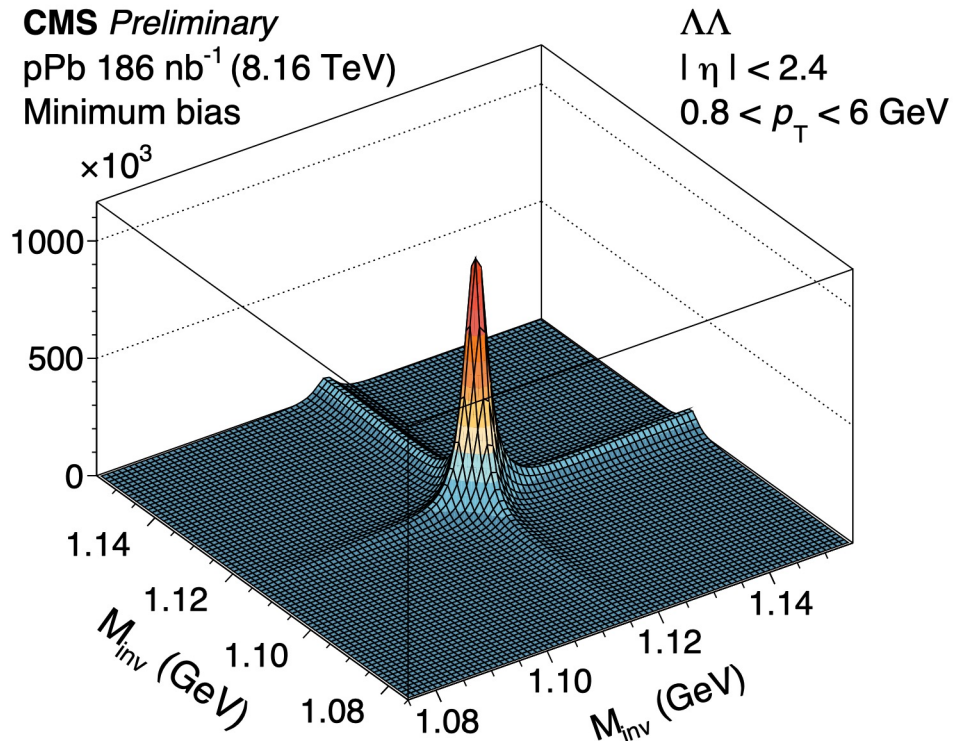


$P_{\Lambda,\Lambda}$ extraction - $\cos\theta^*$ distributions



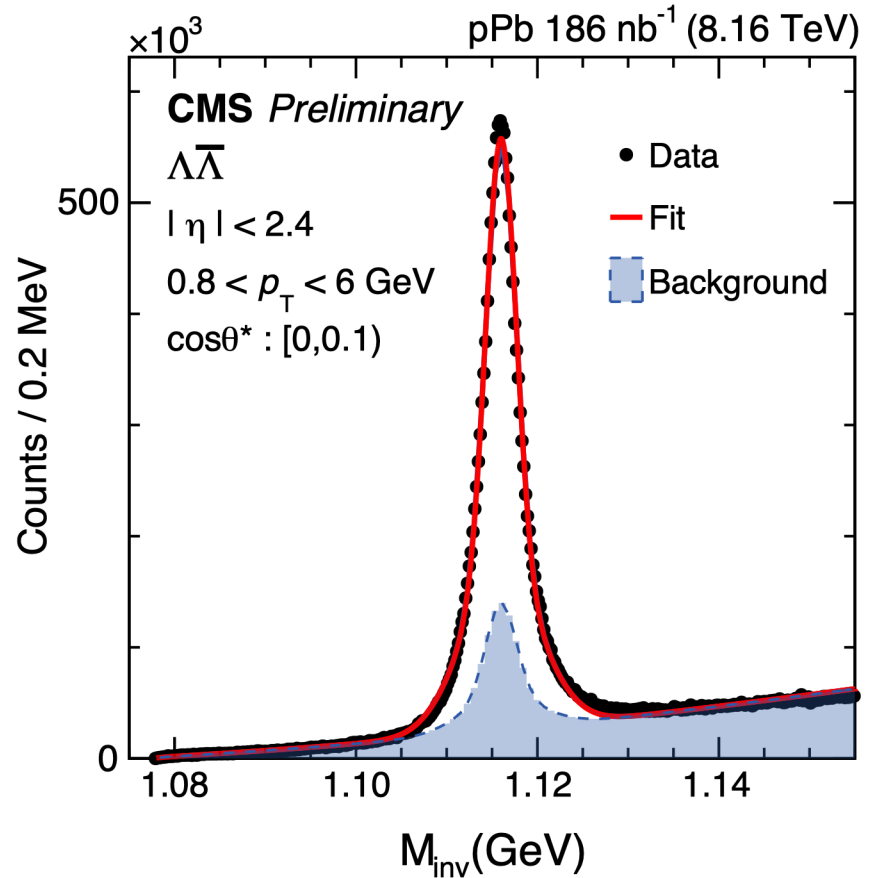
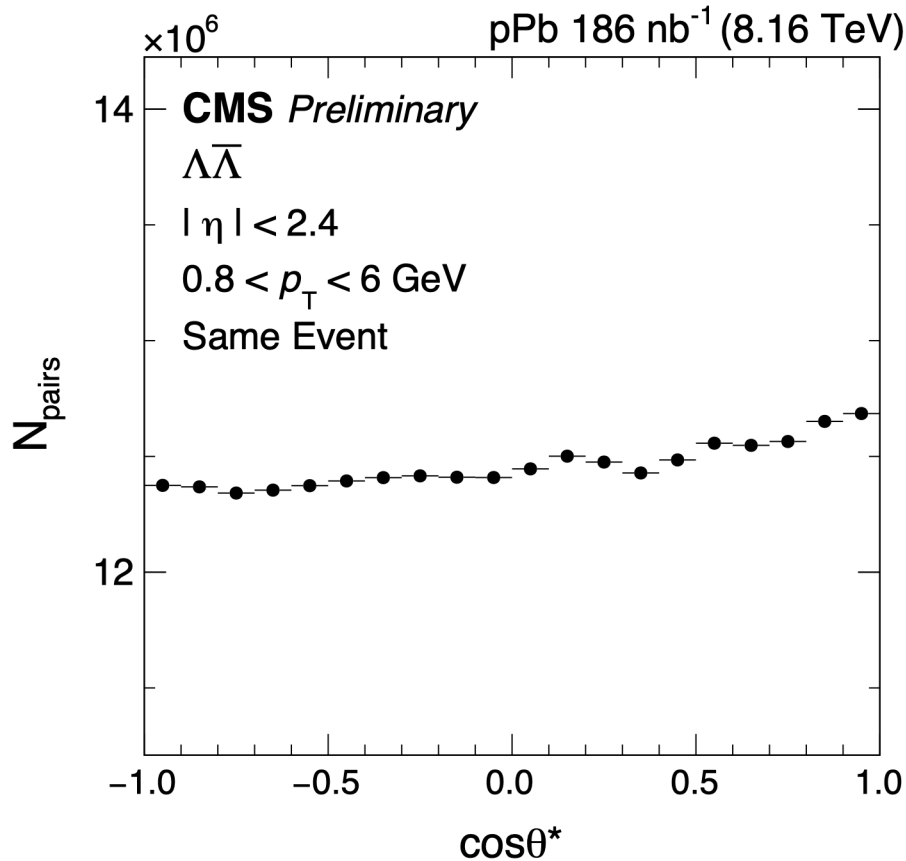
Yield of Λ pairs measured in $\cos\theta^*$ intervals

$P_{\Lambda,\Lambda}$ extraction - $\cos\theta^*$ distributions



Yield of Λ pairs measured in $\cos\theta^*$ intervals
A '2D- $\rightarrow$ 1D' fit is utilized to exclude combinatorial background

$P_{\Lambda,\Lambda}$ extraction - $\cos\theta^*$ distributions

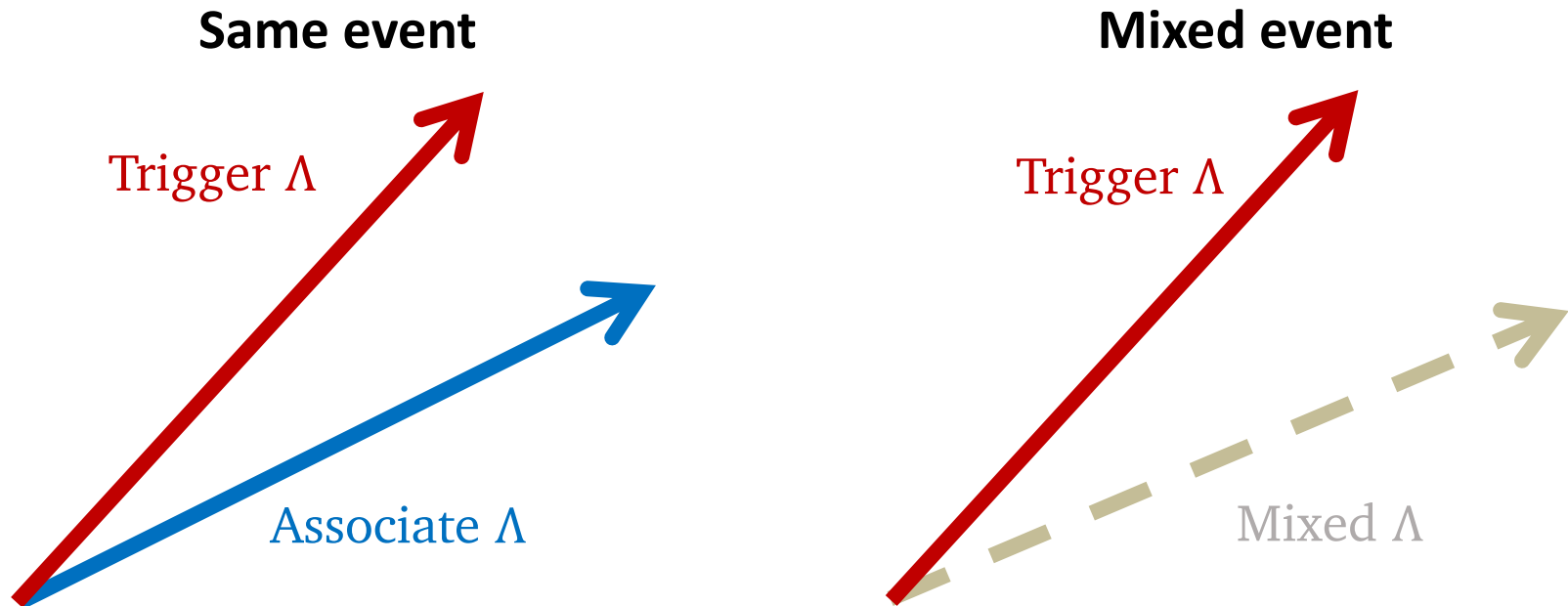


Yield of Λ pairs measured in $\cos\theta^*$ intervals

A '2D->1D' fit is utilized to exclude combinatorial background

The $\cos\theta^*$ distribution is determined

$P_{\Lambda,\Lambda}$ extraction - acceptance correction

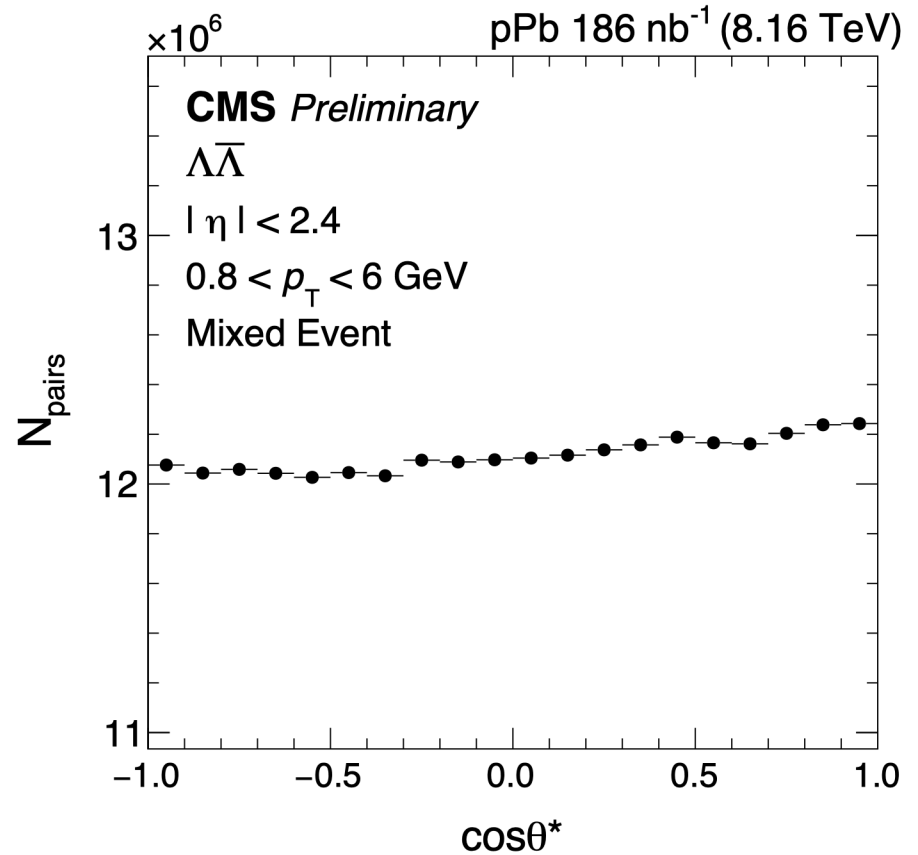
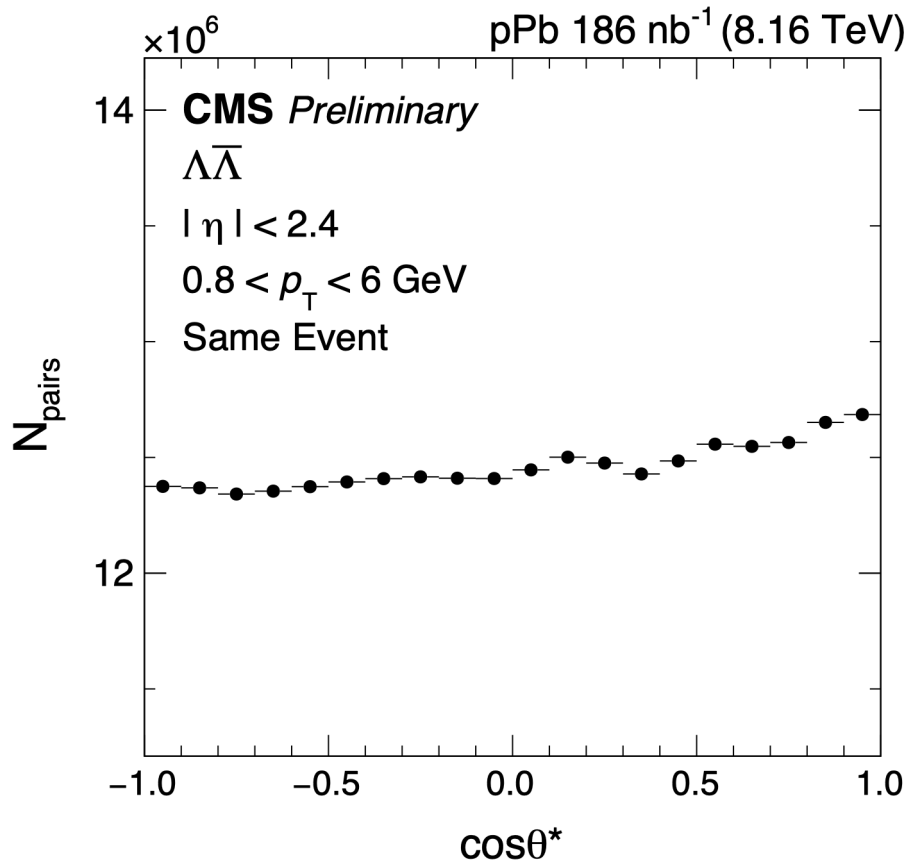


A mixed event correction is implemented with requirements

$$|\Delta v_z| < 2cm, |\Delta N_{trk,offline}| < 5$$

$$|\Delta p_T| < 0.1, |\Delta \eta| < 0.1, |\Delta \phi| < 0.1$$

$P_{\Lambda,\Lambda}$ extraction - acceptance correction

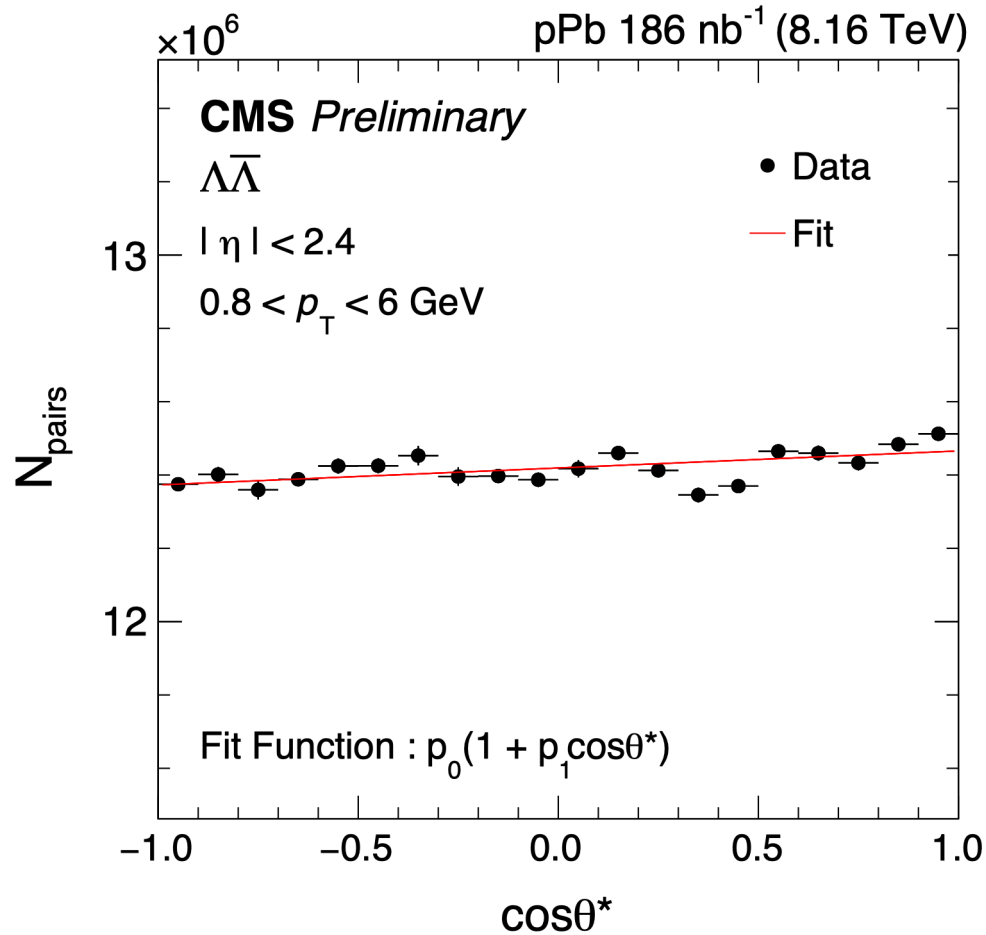


A mixed event correction is implemented with requirements

$$|\Delta v_z| < 2cm, |\Delta N_{trk,offline}| < 5$$

$$|\Delta p_T| < 0.1, |\Delta \eta| < 0.1, |\Delta \phi| < 0.1$$

$P_{\Lambda,\Lambda}$ extraction - acceptance correction

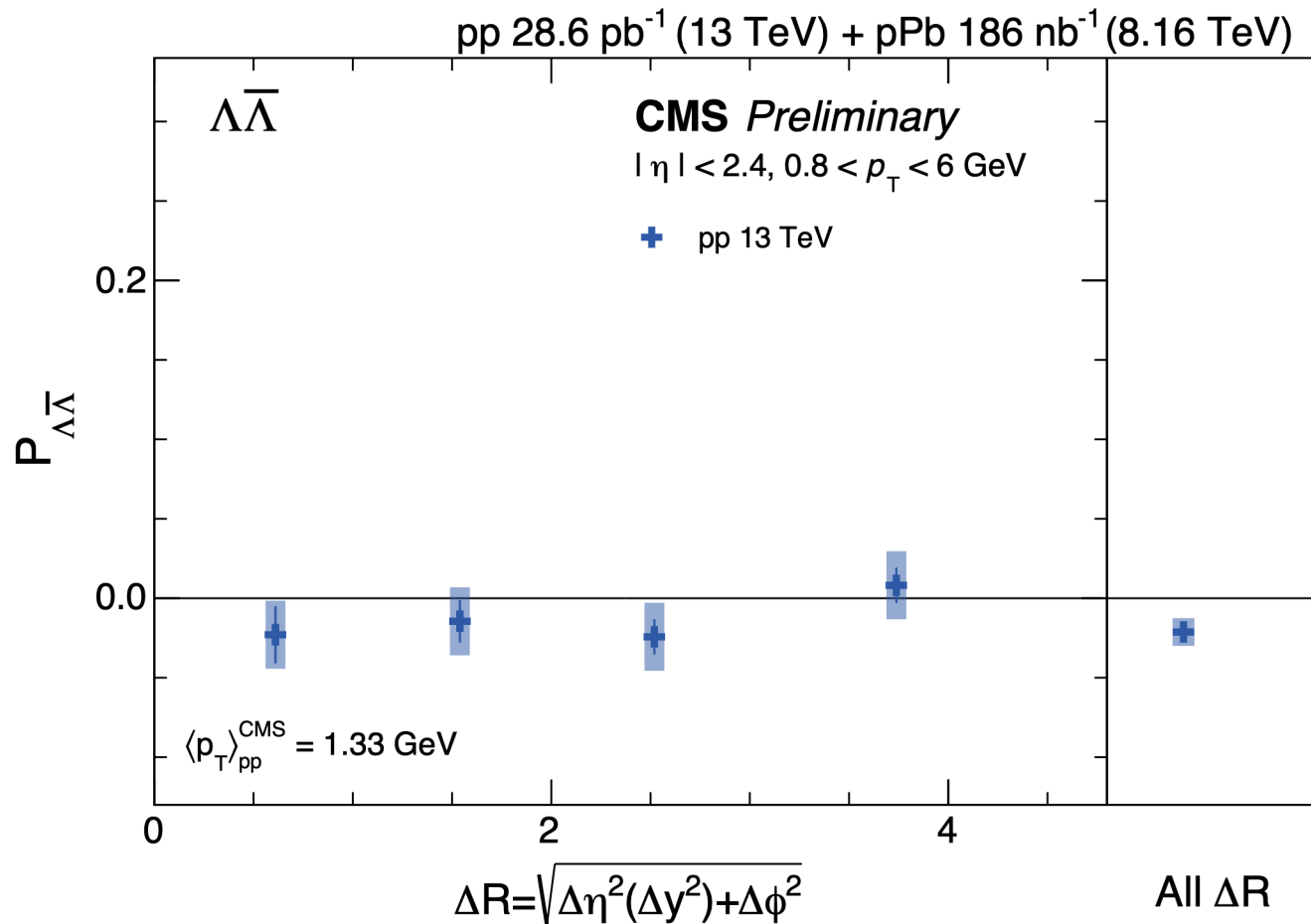


Same event divided by mixed event to correct acceptance

$P_{\Lambda,\Lambda}$ extracted with a linear fit

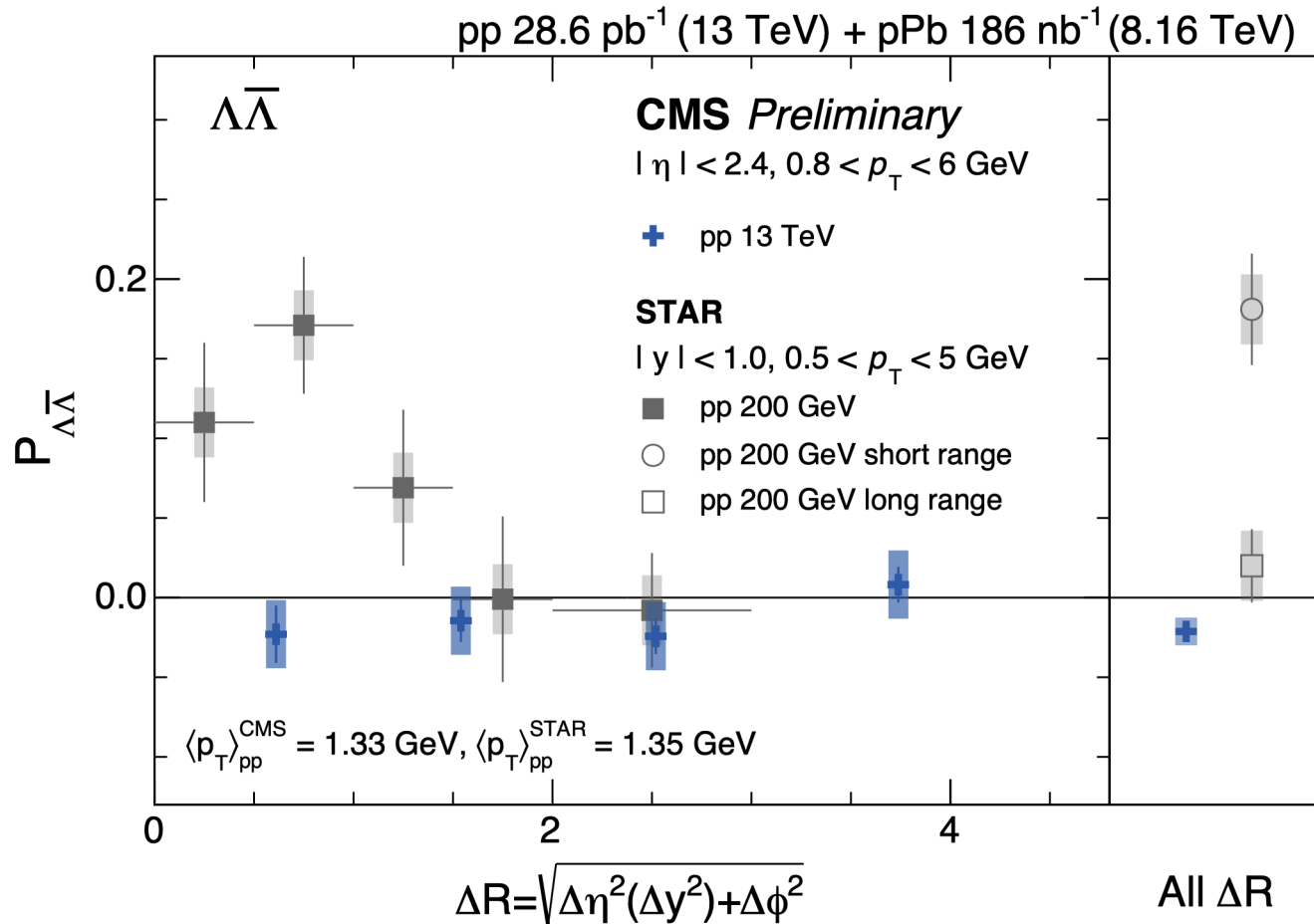
$$p_1 = \alpha_1 \alpha_2 P_{\Lambda\Lambda}$$

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



ΔR differential results consistent with zero within uncertainties
 The integrated result hints a negative value

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



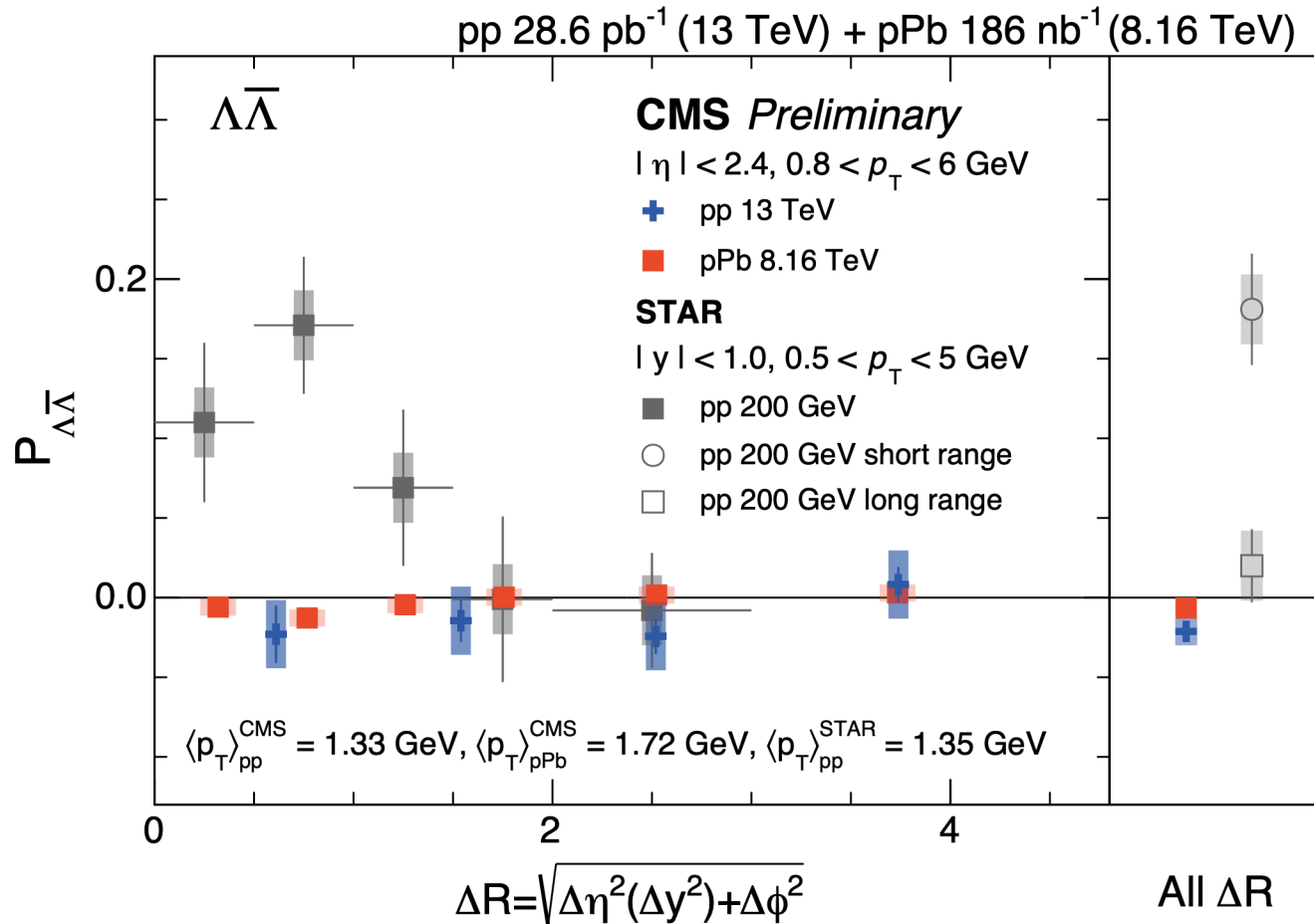
ΔR differential results consistent with zero within uncertainties

The integrated result hints a negative value

Different behavior from STAR results at 200 GeV

Might be due to different production mechanism?

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

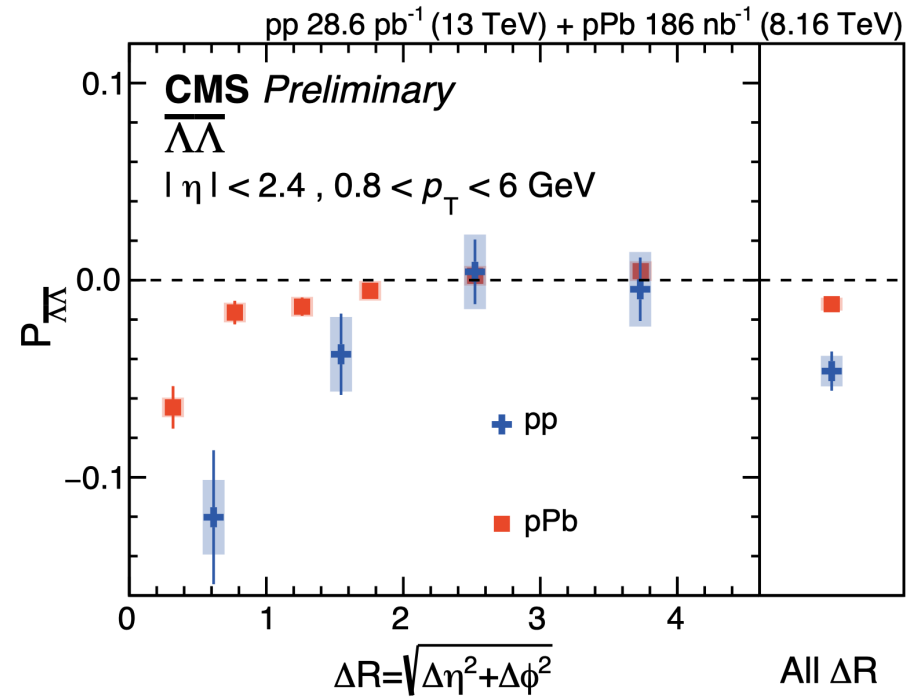
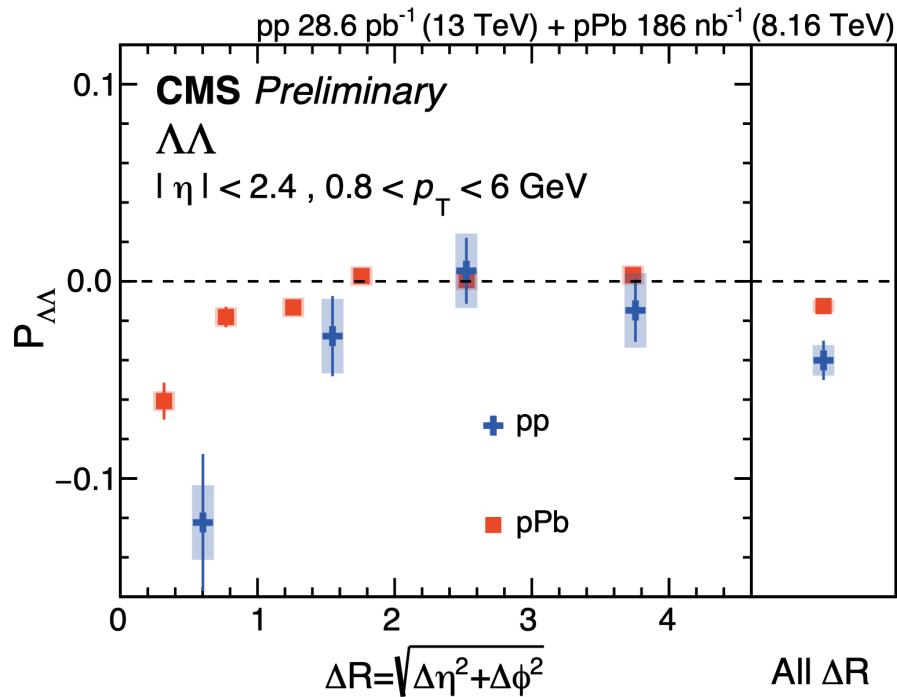


pPb results similar to pp

Hint of smaller integrated value in pPb than pp

NOTE: Average multiplicity in pPb around 101, collectivity starts to emerge

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

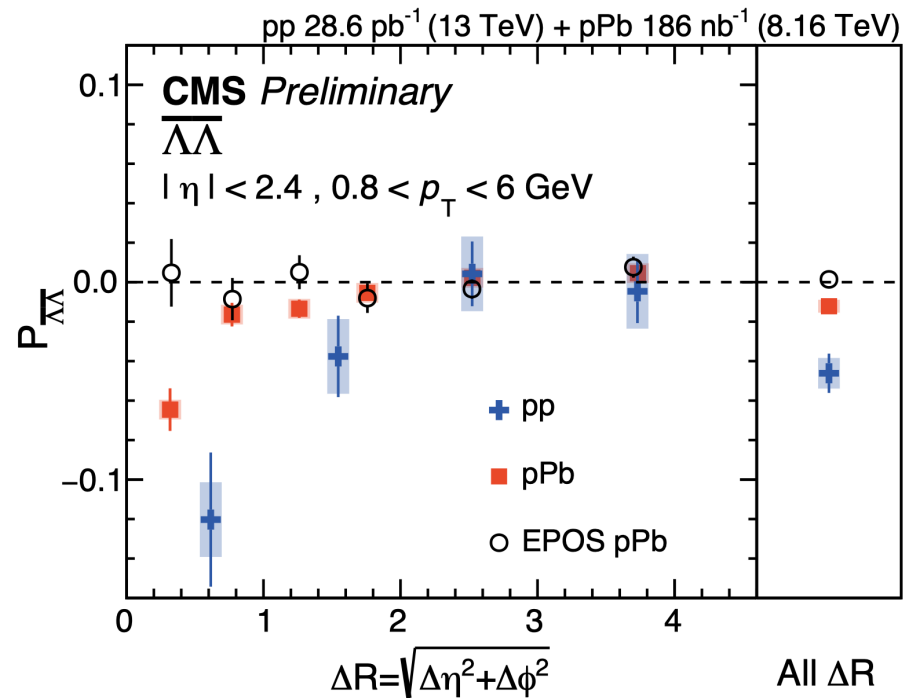
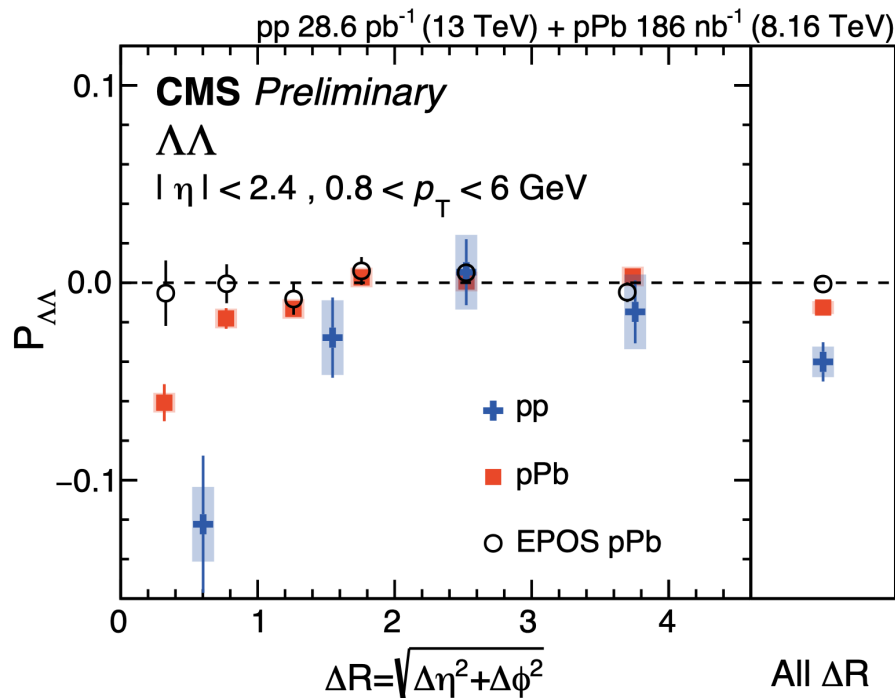


Negative spin correlation observed at small ΔR

Converge to 0 at large ΔR

A hint of larger magnitude in pp than pPb

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



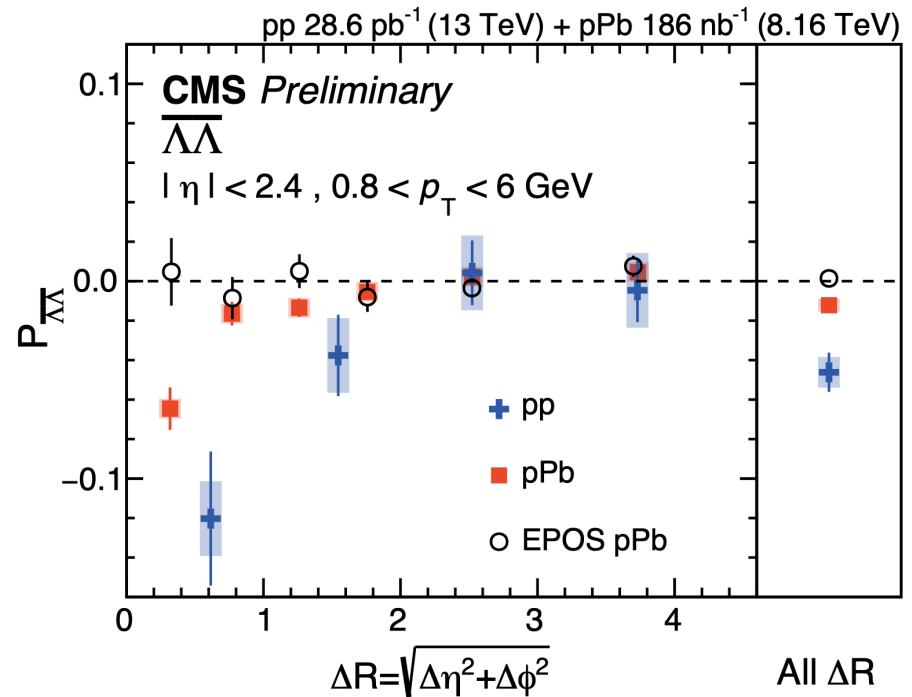
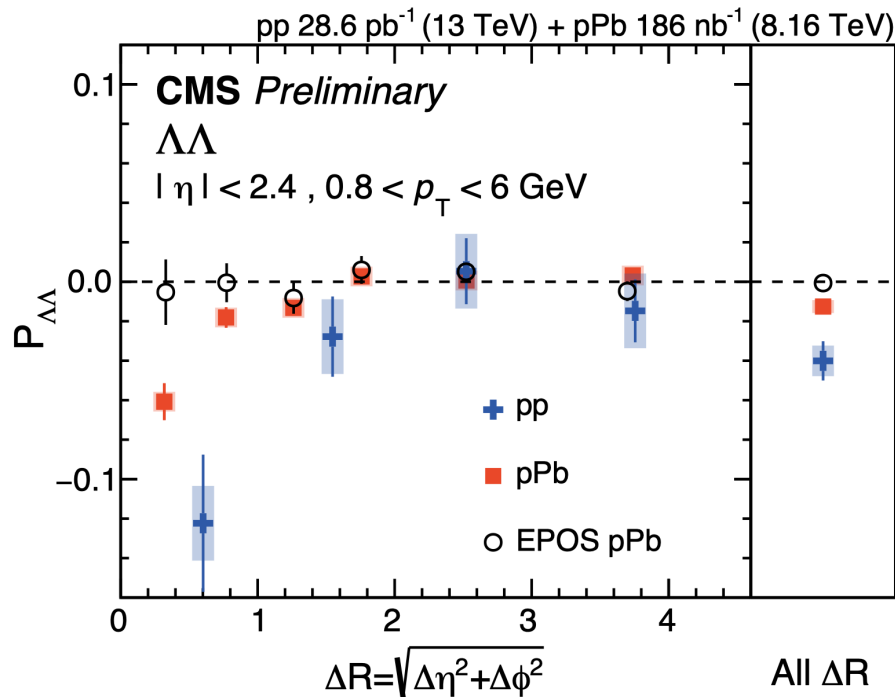
Negative spin correlation observed at small ΔR

Converge to 0 at large ΔR

A hint of larger magnitude in pp than pPb

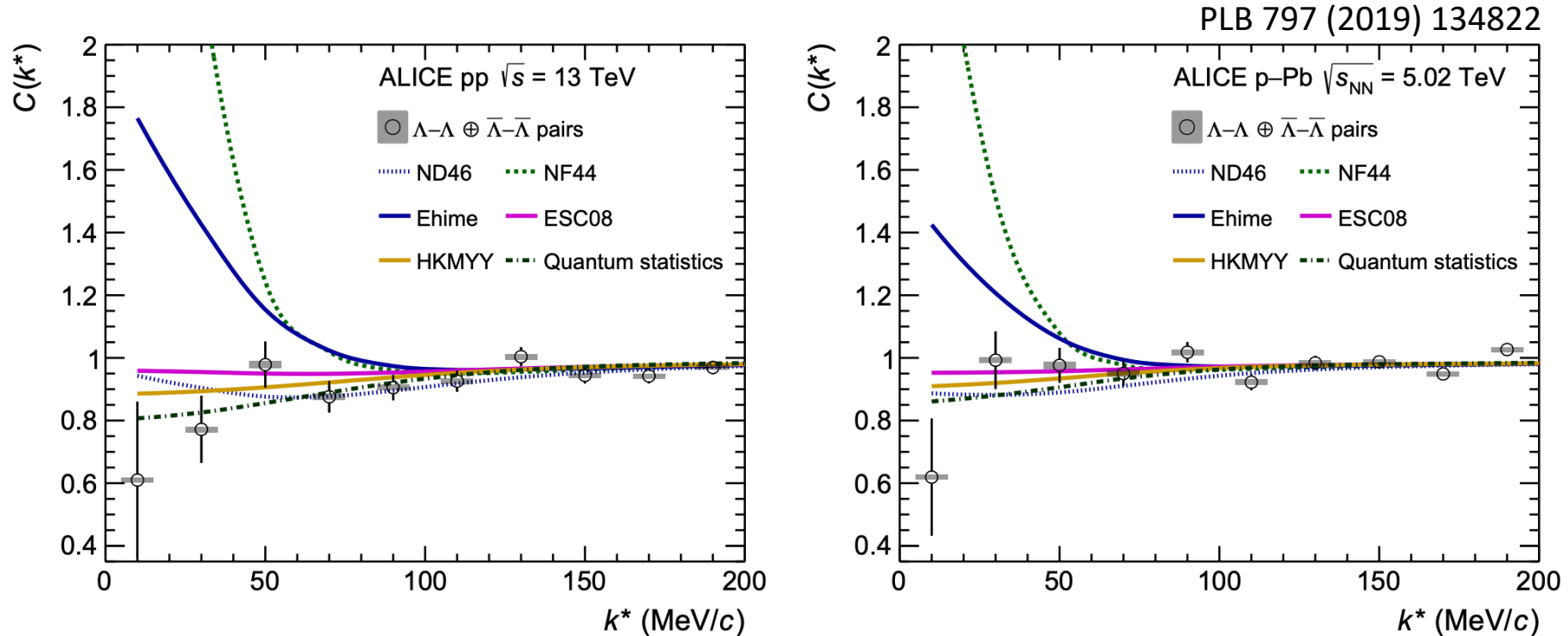
Same analysis in EPOS yield 0 as expected

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



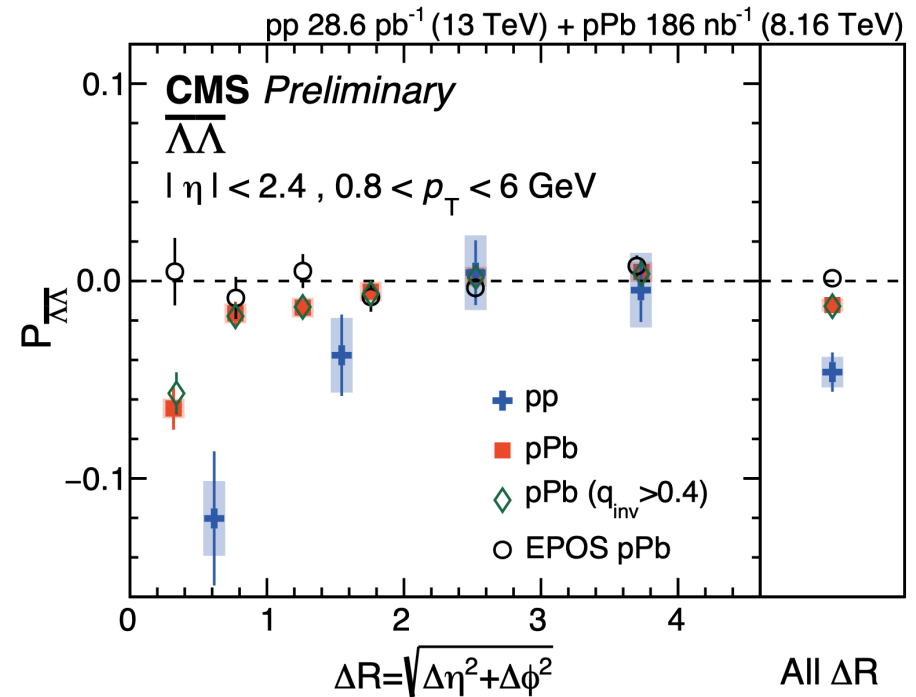
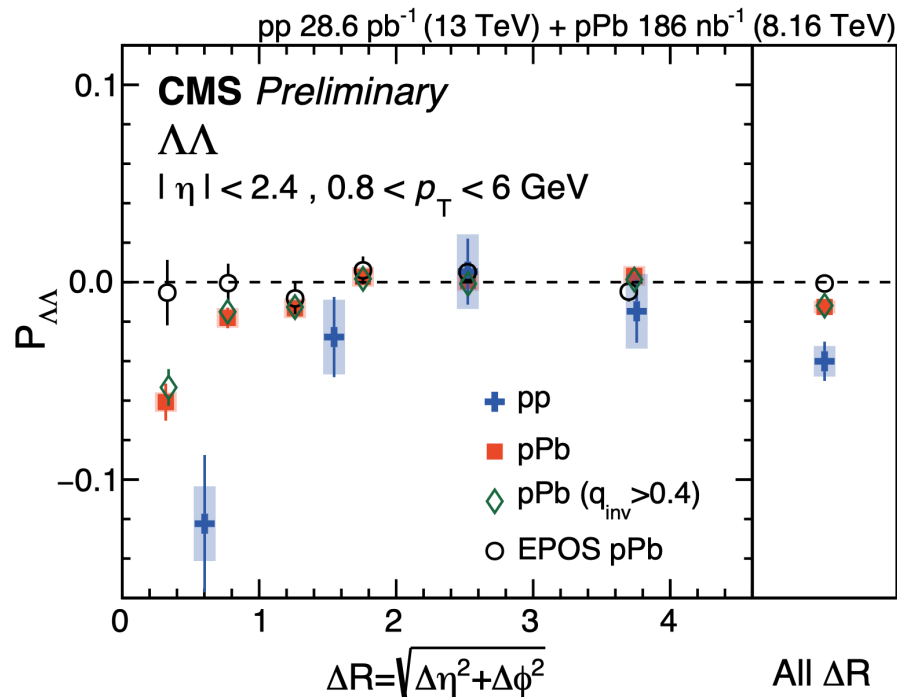
A signal for identical particles when close in space?
 Hmmm... Hanbury-Brown-Twiss correlations?

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



A signal for identical particles when close in space?
 Hmmm... Hanbury-Brown-Twiss correlations?
 Typical HBT effects are at $k^* < 0.2$ GeV ($q_{inv} < 0.4$ GeV)

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



A signal for identical particles when close in space?

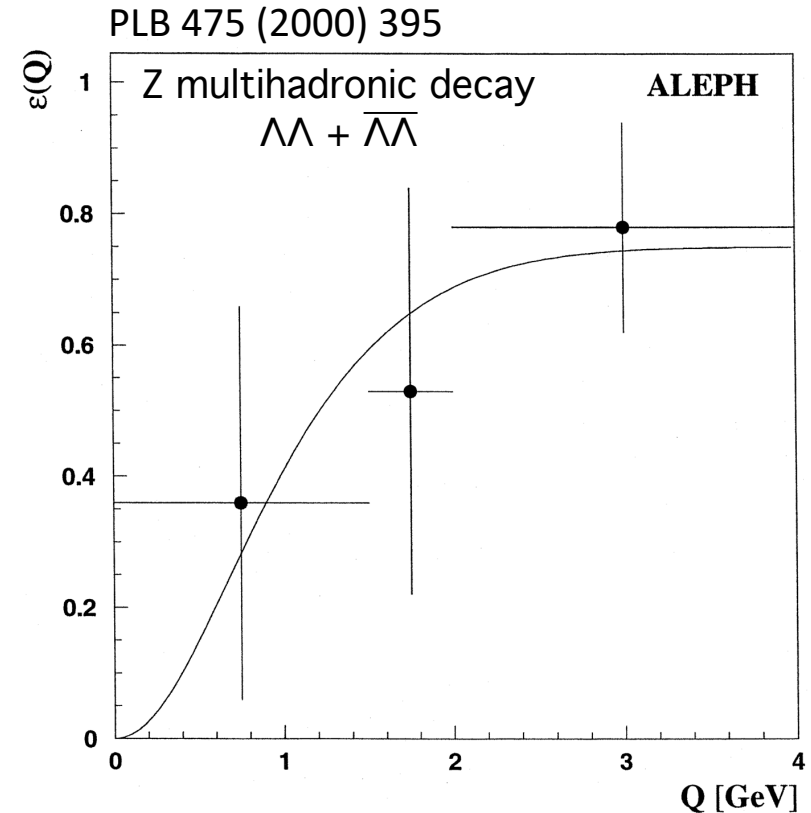
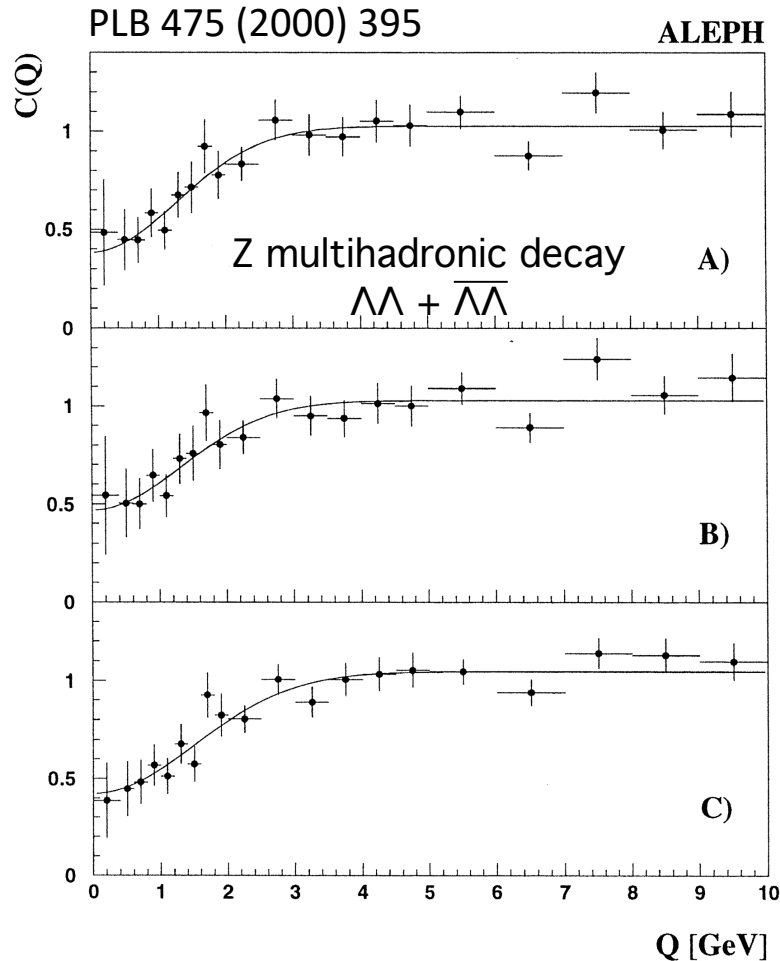
Hmmm... Hanbury-Brown-Twiss correlations?

Typical HBT effects are at $k^* < 0.2 \text{ GeV}$ ($q_{inv} < 0.4 \text{ GeV}$)

Results with $q_{inv} > 0.4 \text{ GeV}$ consistent with default

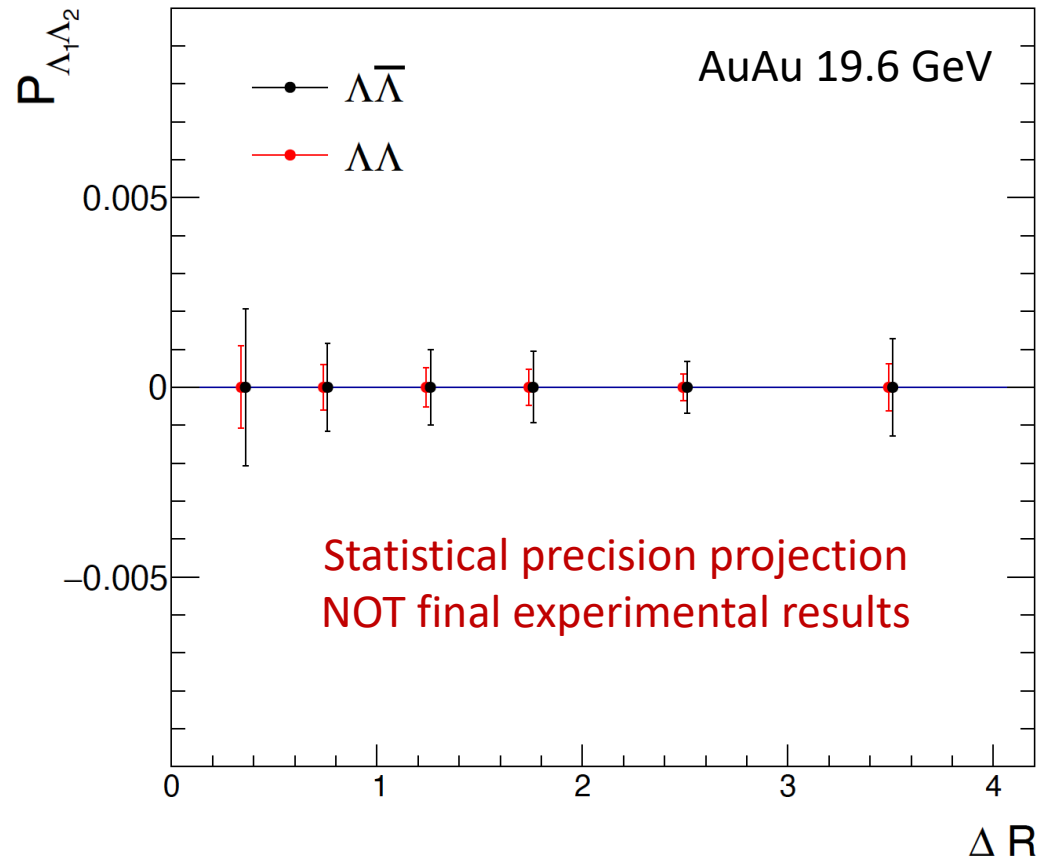
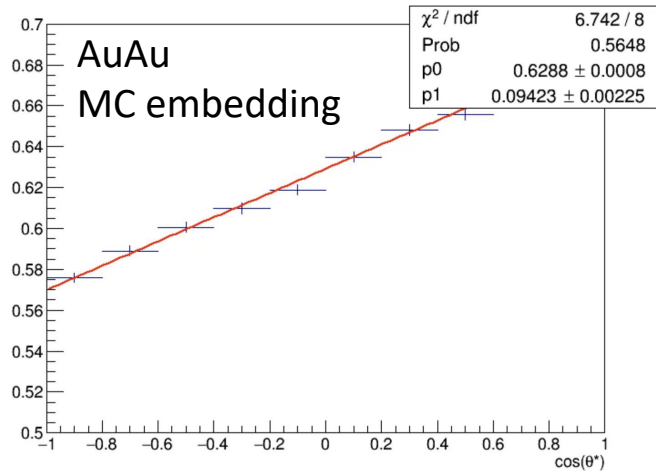
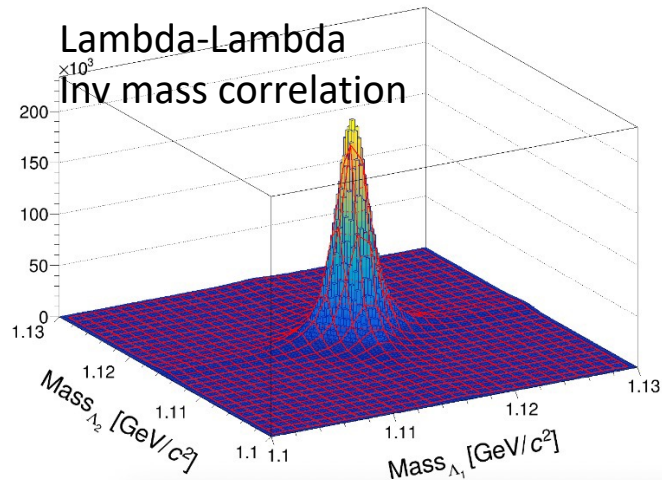
Indicate the signal is not dominated by simple HBT effects

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



Results with $q_{inv} > 0.4$ GeV consistent with default
 Indicate the signal is not dominated by 'simple' HBT effects
 A reminder of ALEPH Z-decay results?

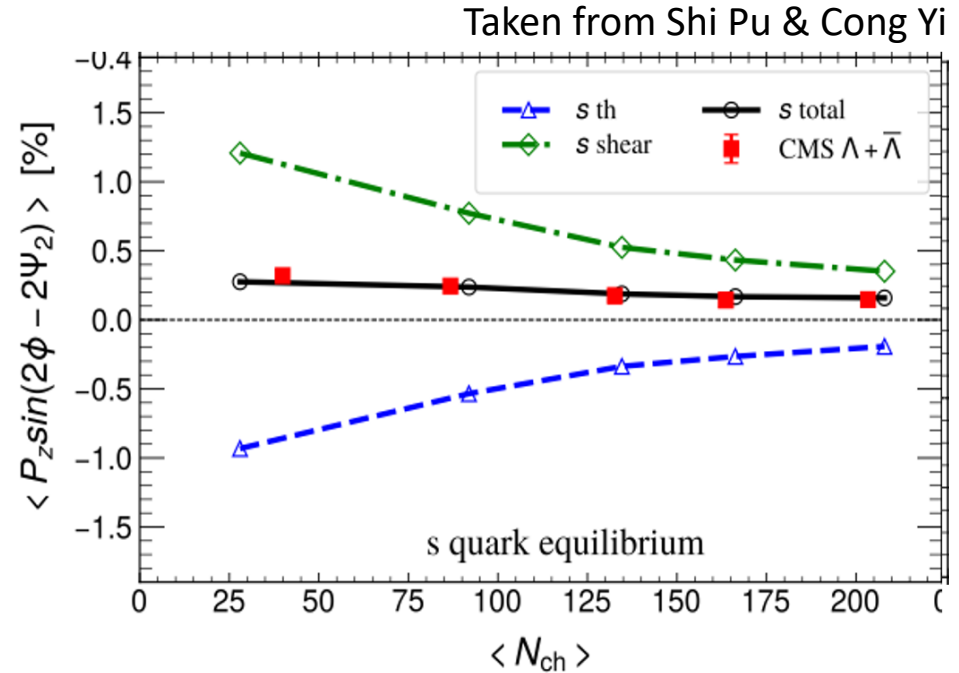
Spin correlation in AA collisions



Same analysis technique applicable to AA collisions
 Much higher precision can be achieved with RHIC & LHC AA collision data
 Multiple groups working on this topic at this moment

Back up

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

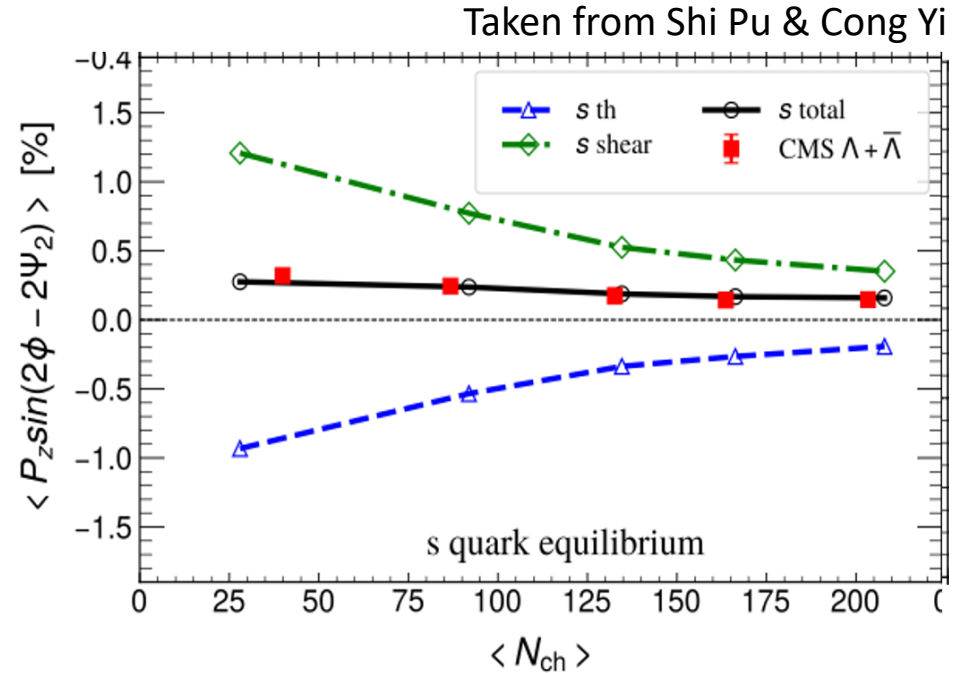
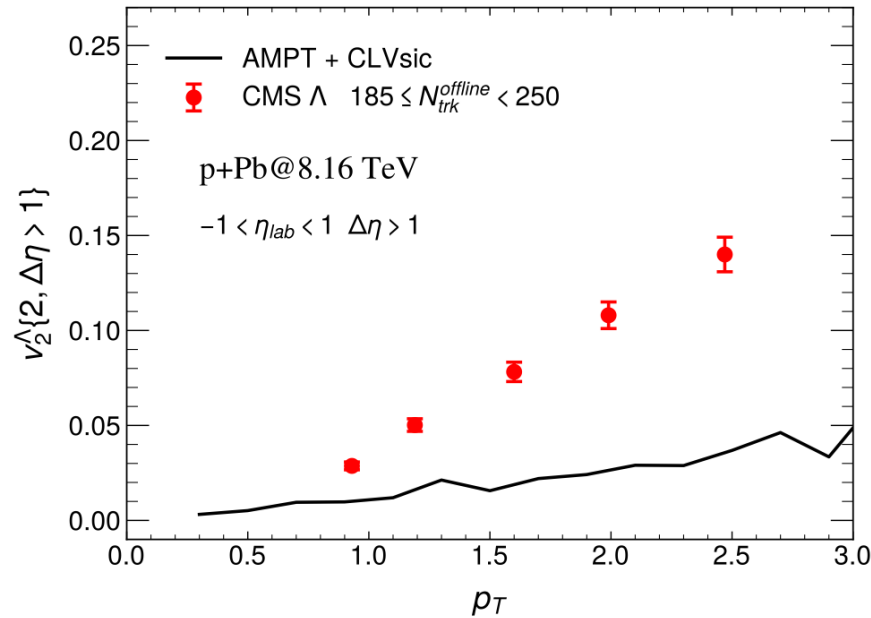


Hydro calculations result in negative P_z

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

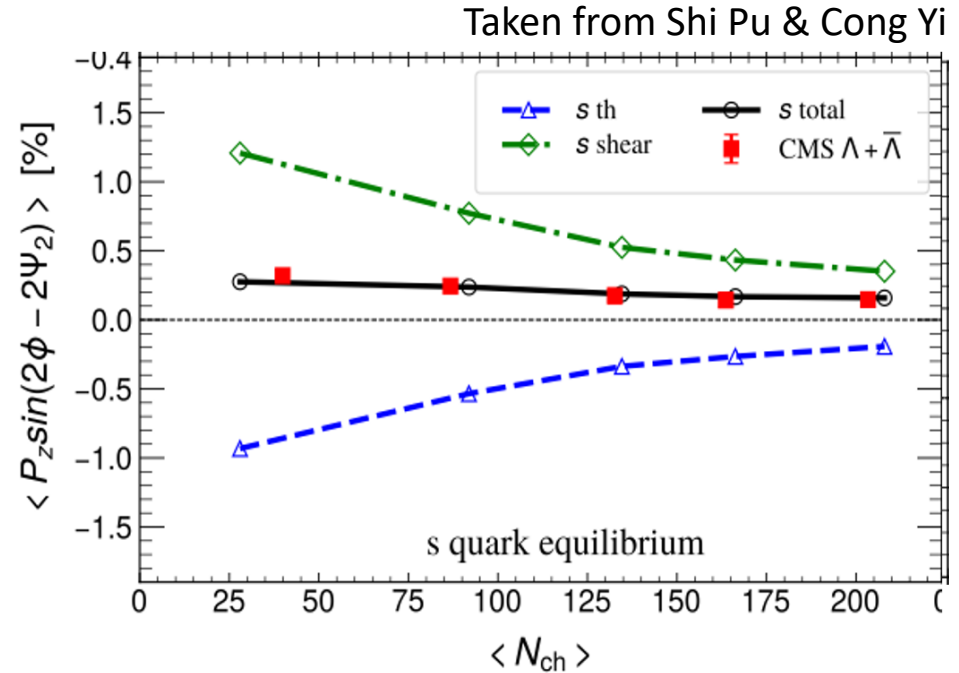
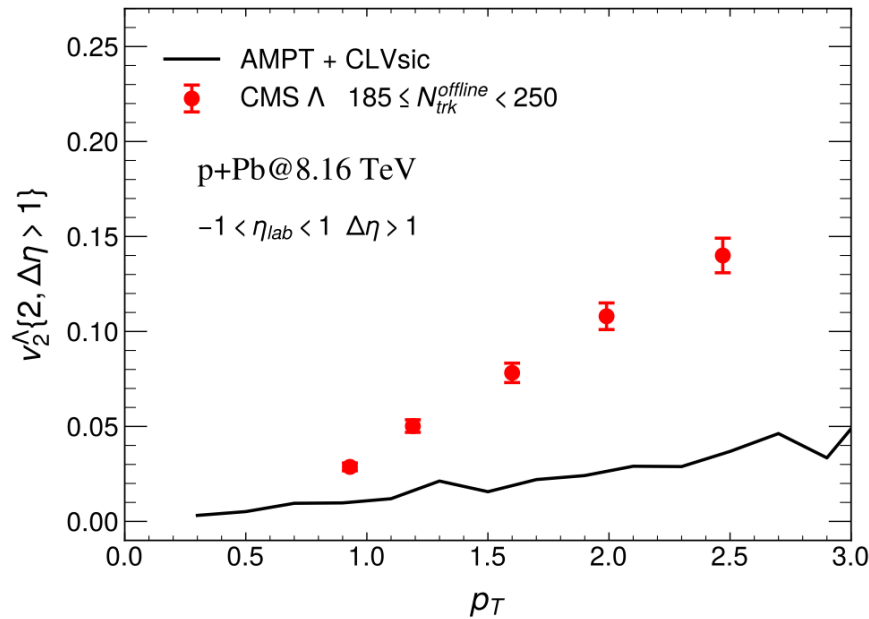


Hydro calculations result in negative P_z

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



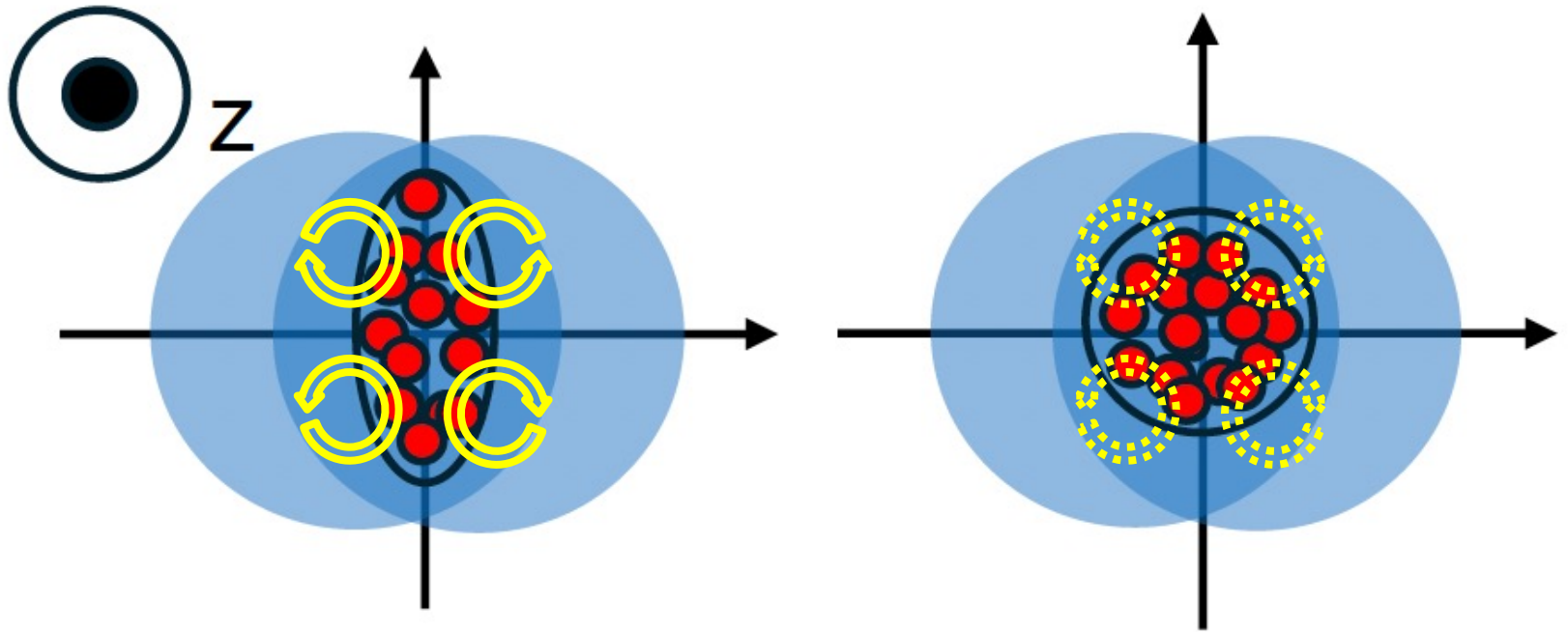
Hydro calculations result in negative P_z

Different contributions in small systems need to be understood further

Tune the model to reproduce P_z results in too small v_2

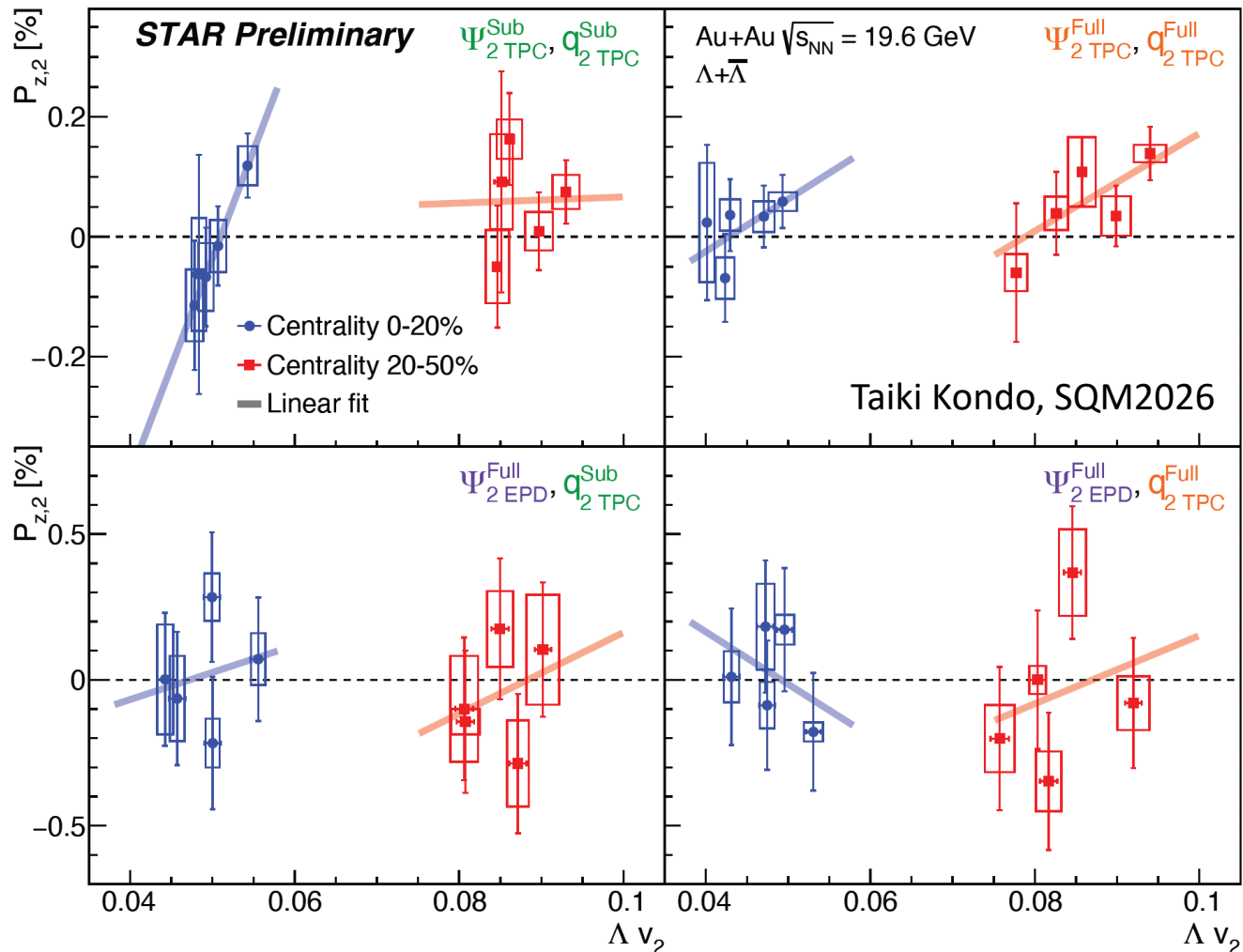
Both related to initial geometry but different response?

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



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

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

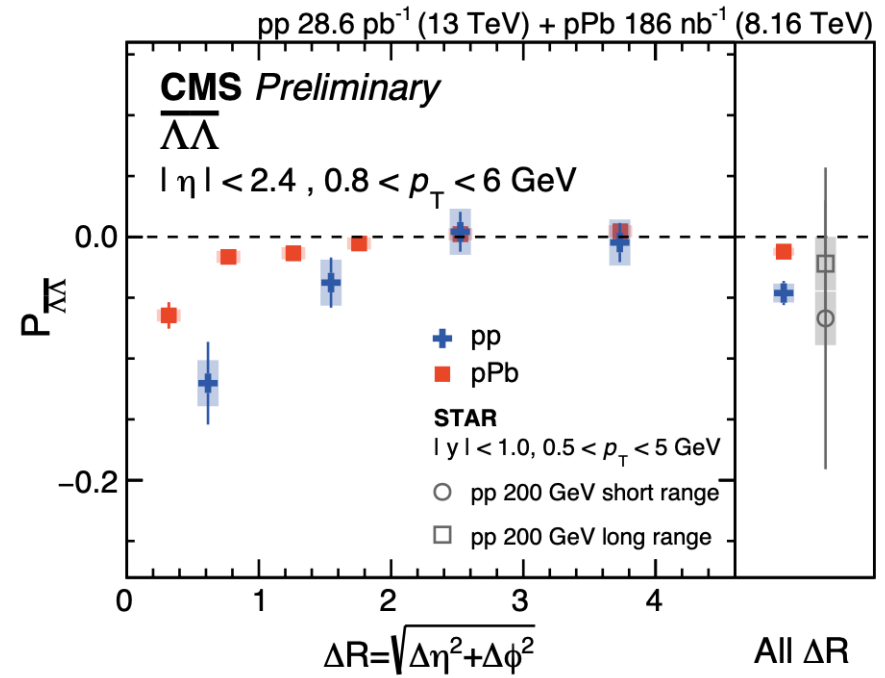
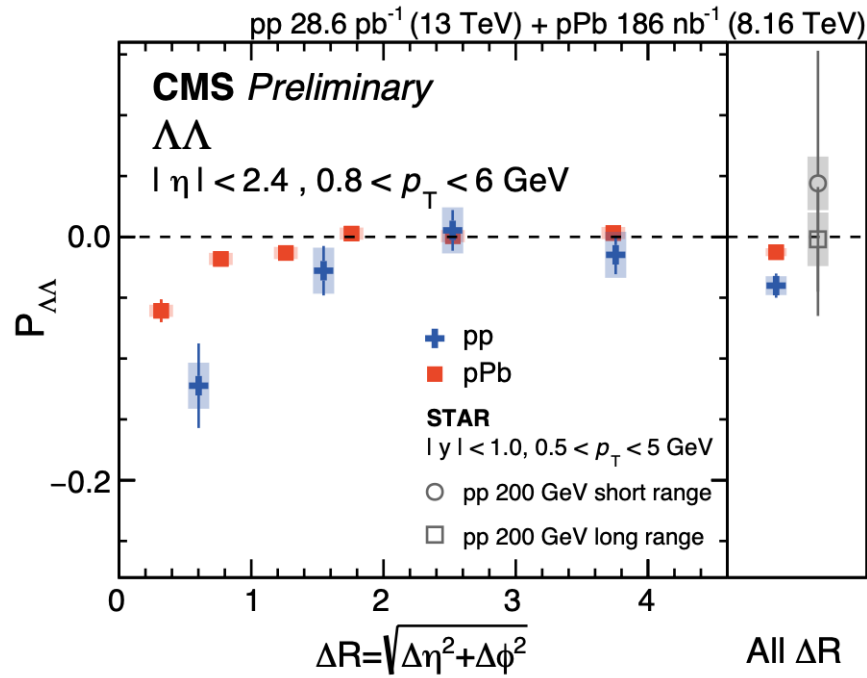


Does $P_{z,s2}$ change with v_2 ?

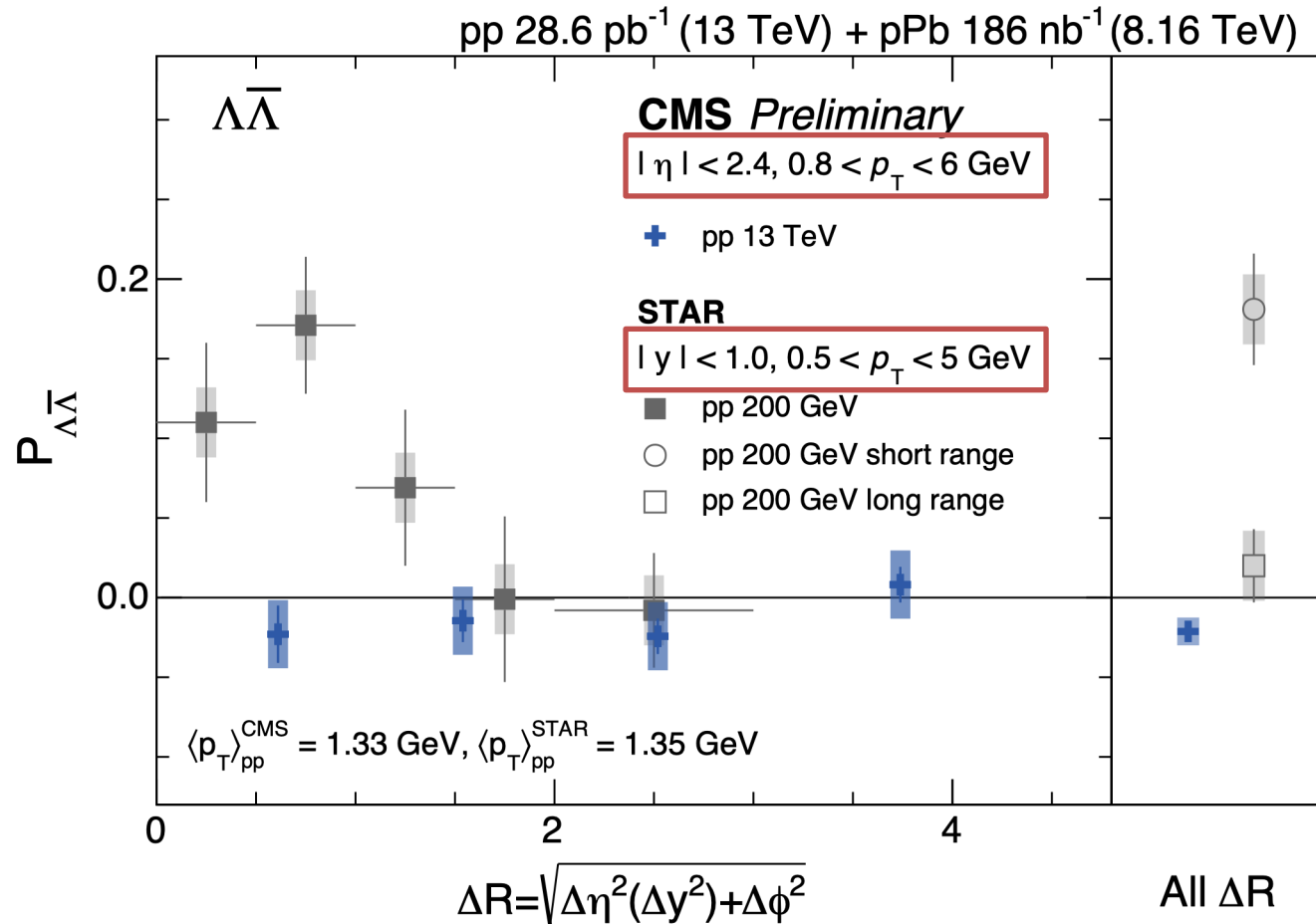
The results in 19.6 GeV AuAu shows a hint

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

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



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



From
kinematics
difference?

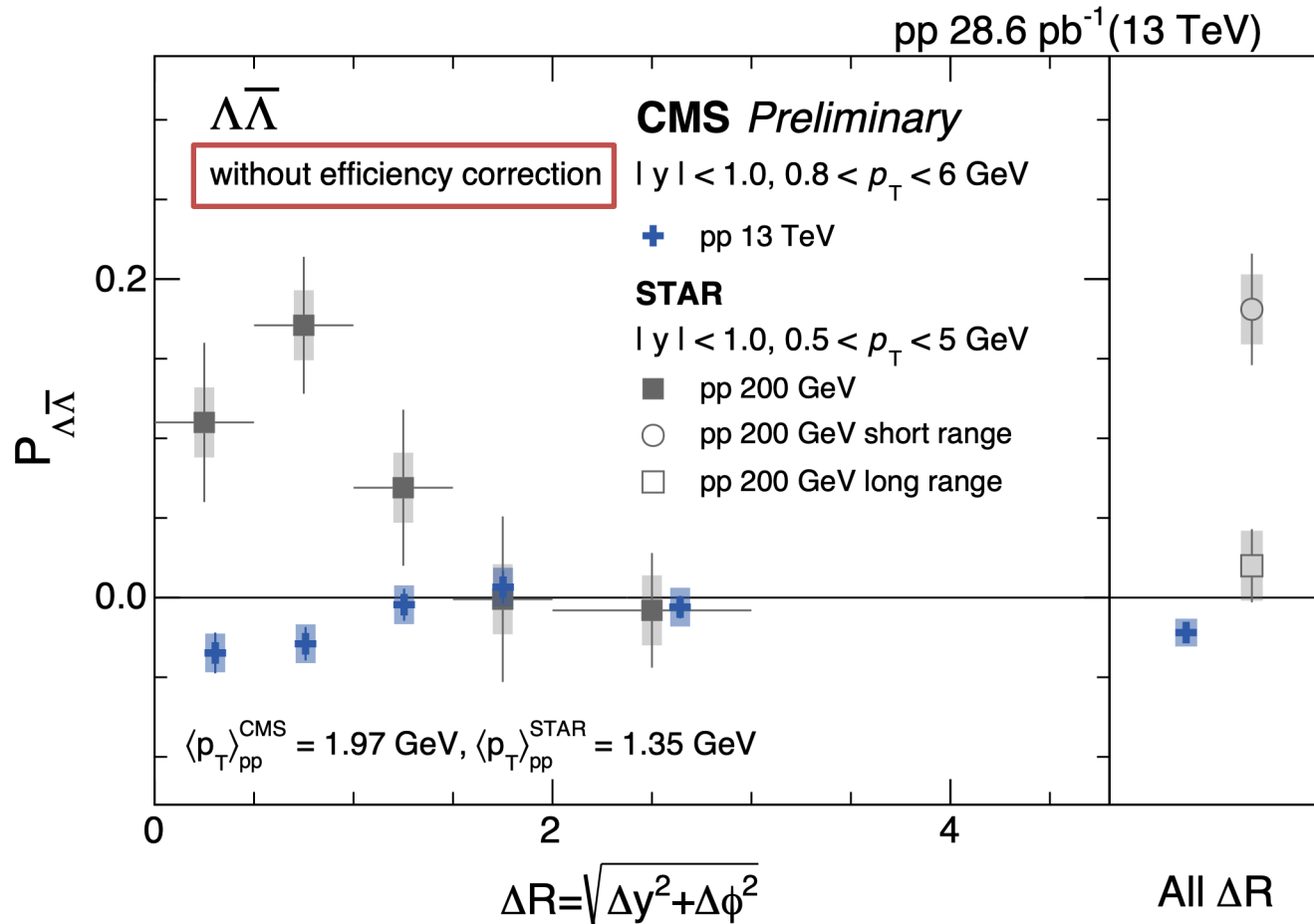
ΔR differential results consistent with zero within uncertainties

The integrated result hints a negative value

Different behavior from STAR results at 200 GeV

Might be due to different production mechanism?

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



Results with $|y| < 1$ not flip to positive values
 Small ΔR region shows more prominent negative values
 CAVEAT: No efficiency correction