Polarization measurements from CMS

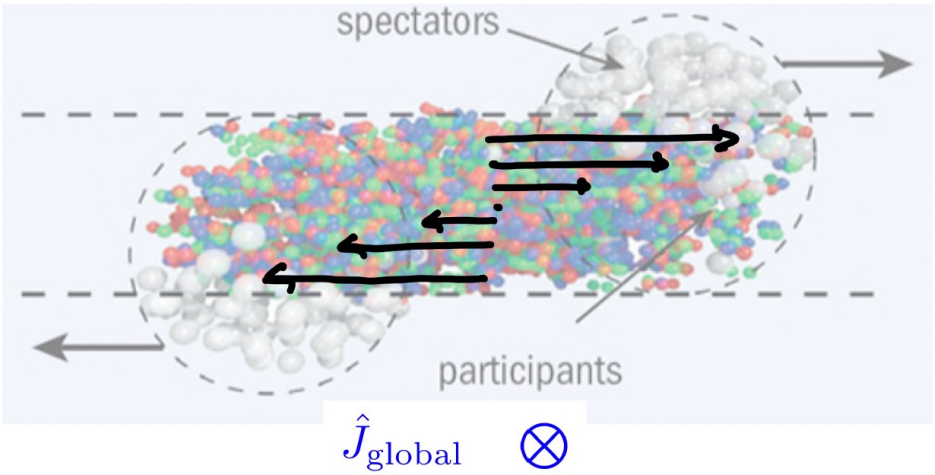
Zhenyu Chen 陈震宇
Shandong University 山东大学

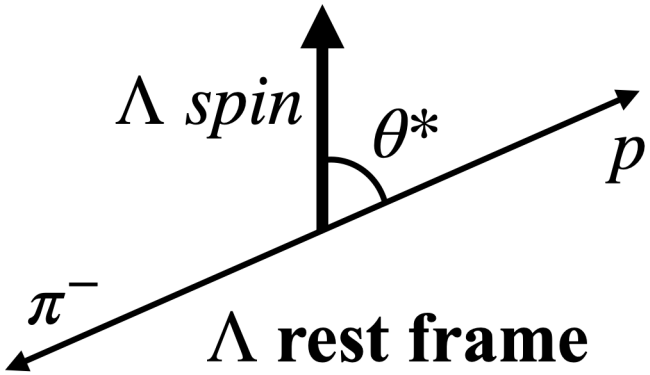
PacificSPIN 2026, Taipei



山东大学
SHANDONG UNIVERSITY

Polarization as unique probe of QCD matter





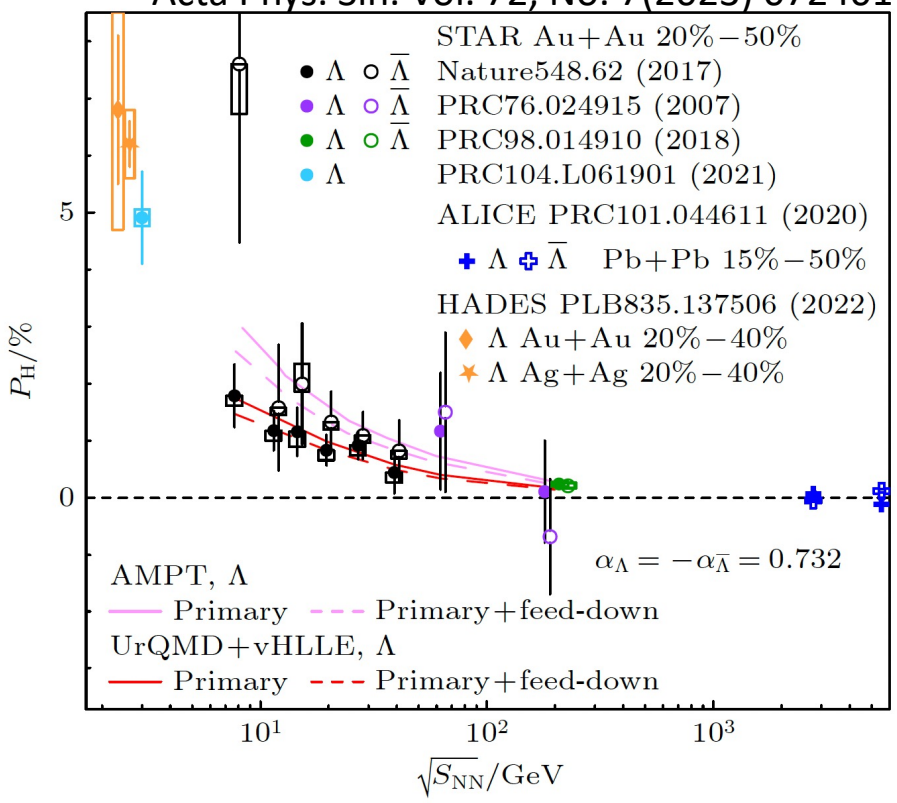
Large initial orbital angular momentum

Can polarize particles through spin-orbit coupling

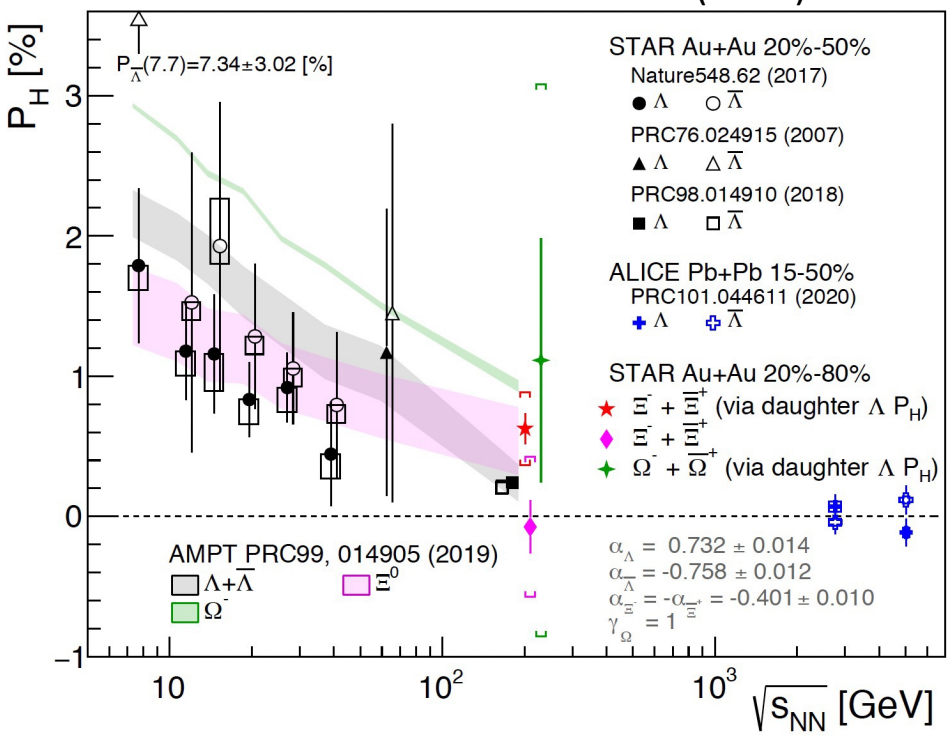
Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)

“The most vortical fluid”

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



PRL 126 (2021) 162301



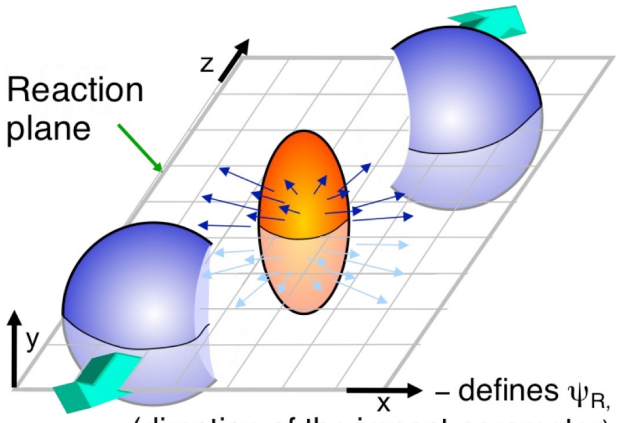
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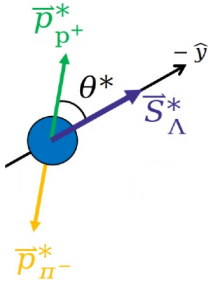
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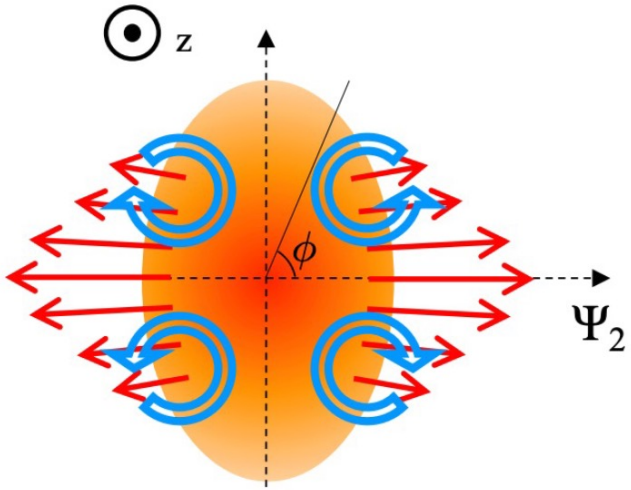
Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)

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

Hyperon polarization along beam direction

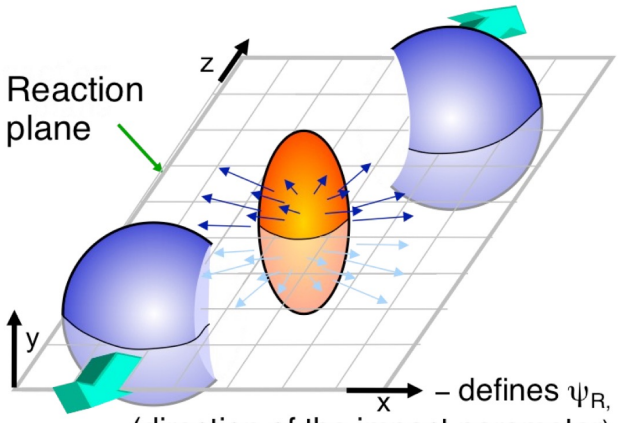


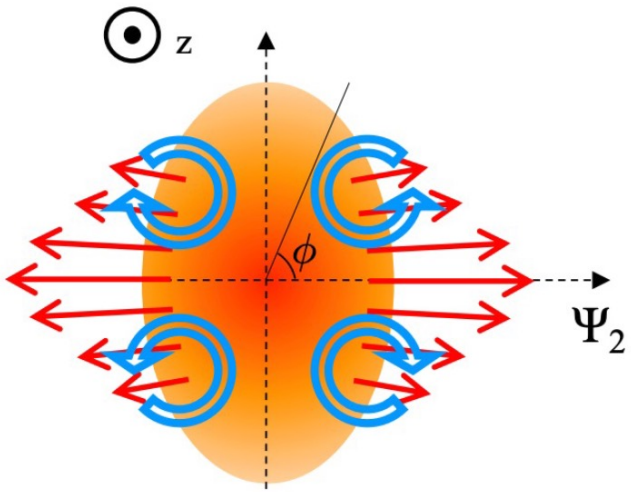


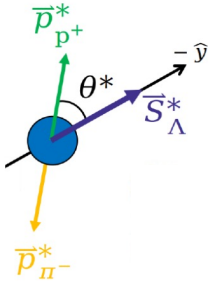


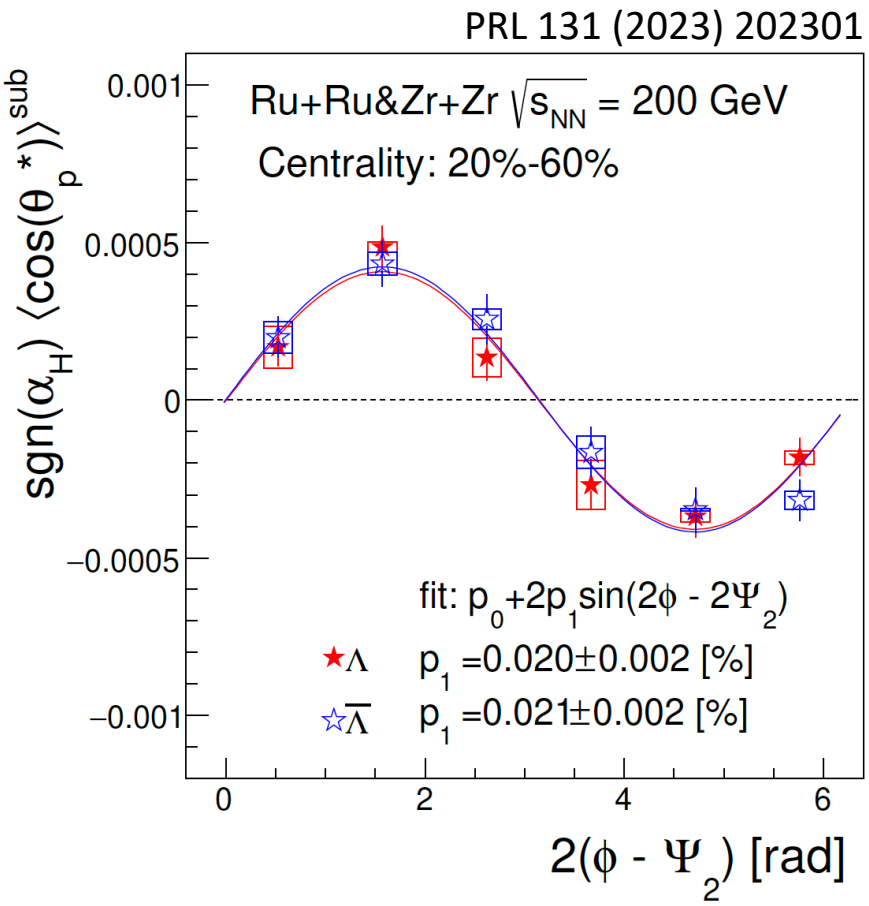
Simple expectation of vorticity from the anisotropic expansion of QGP

Hyperon polarization along beam direction





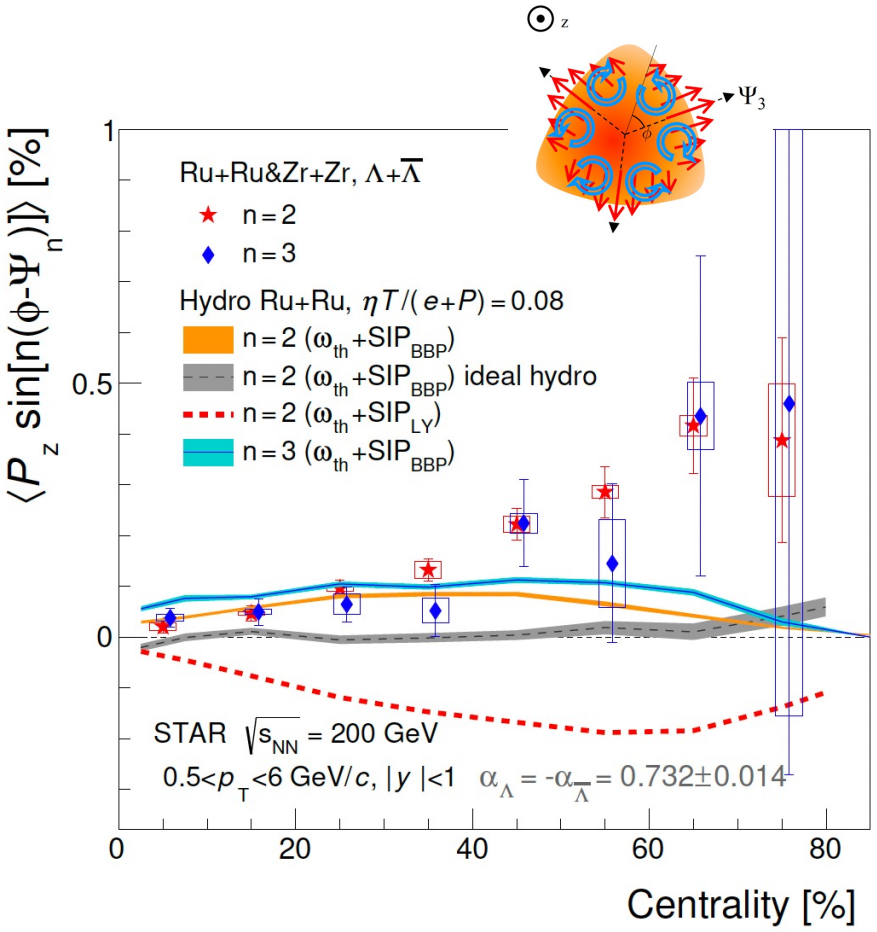


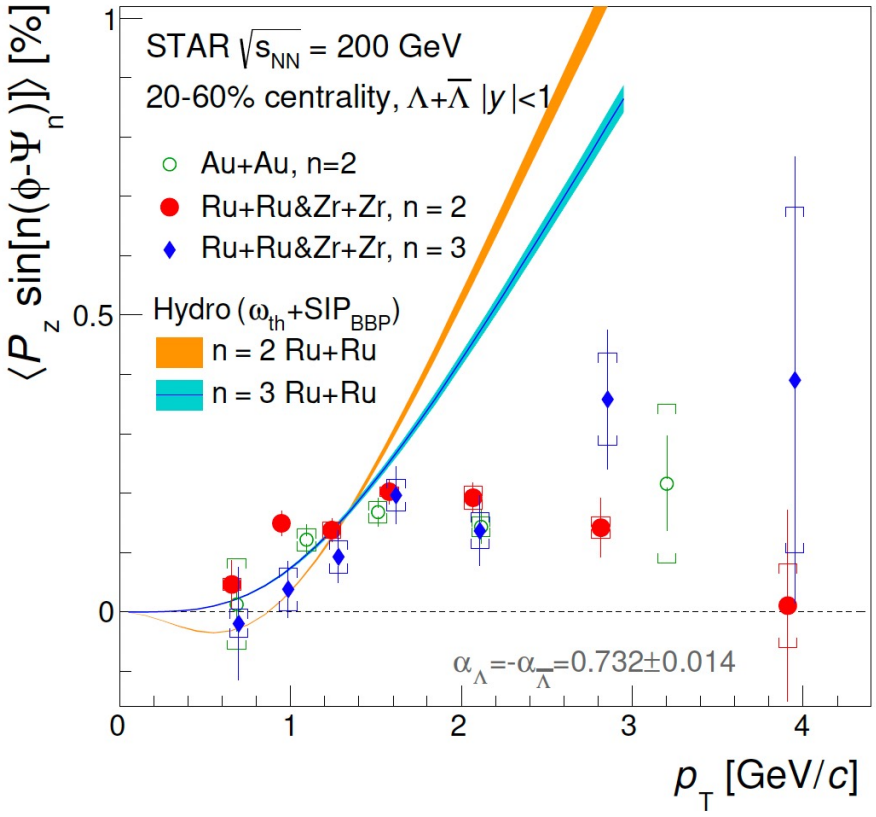


Simple expectation of vorticity from the anisotropic expansion of QGP
Confirmed by experimental measurements

Hyperon polarization linked to collective flow(?)

PRL 131 (2023) 202301



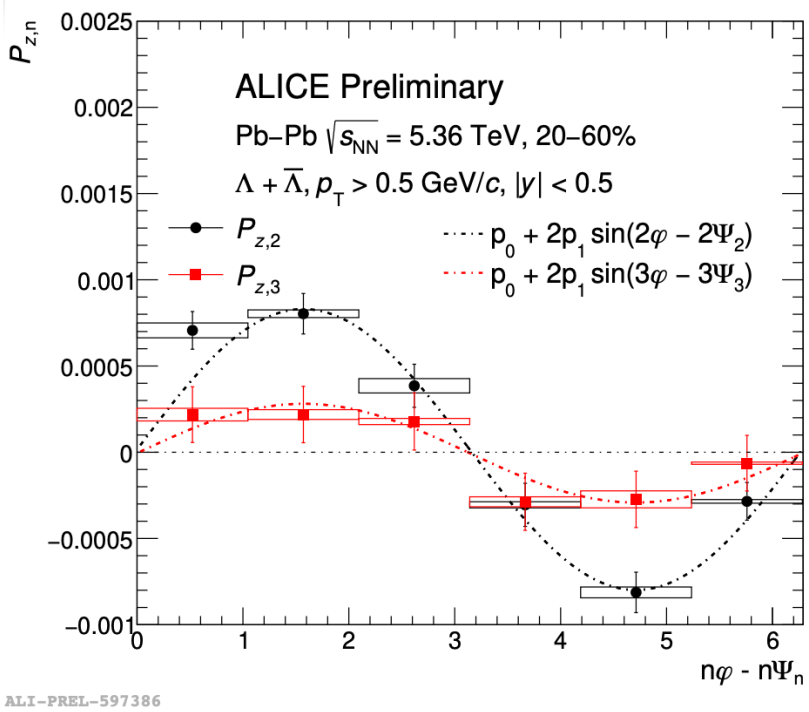


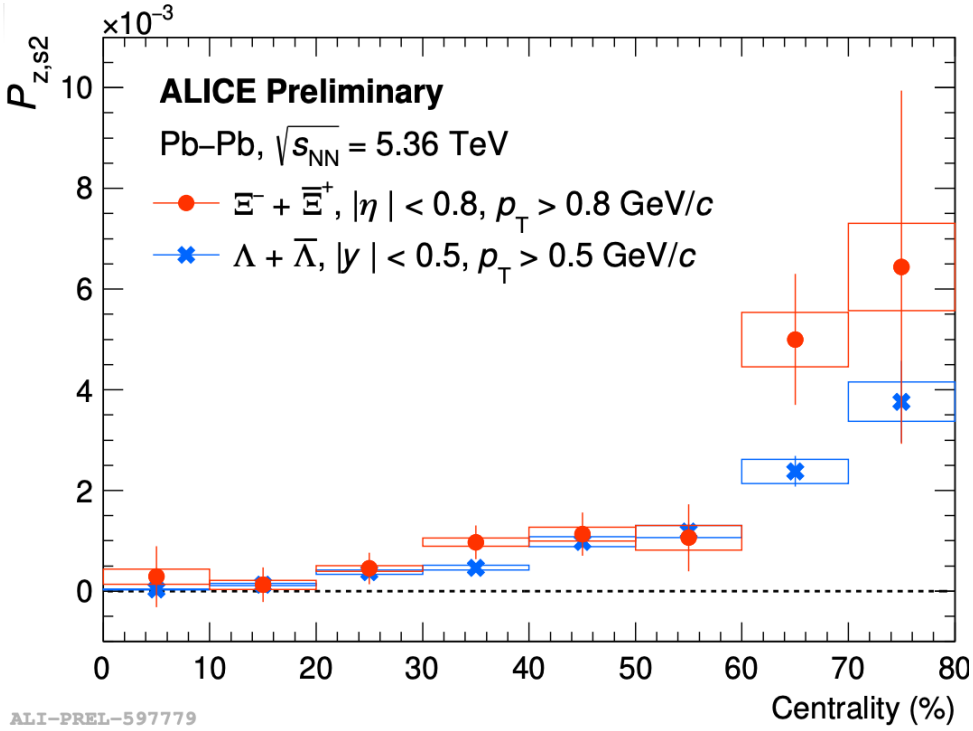
Same expectation of vorticity from higher order flow observed

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(?)





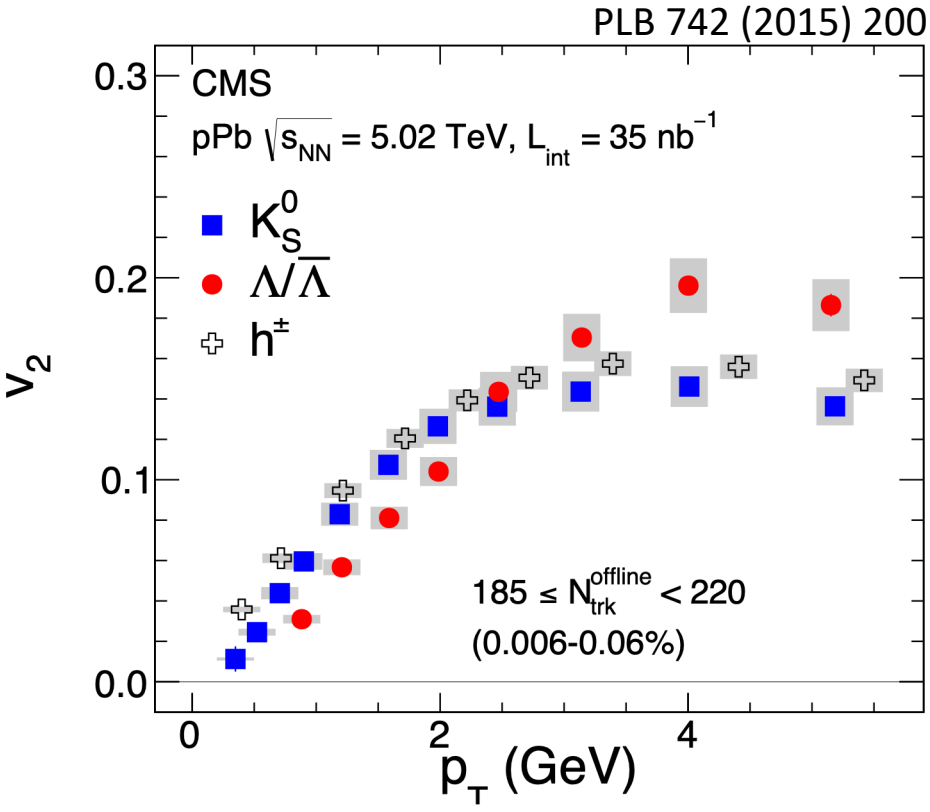
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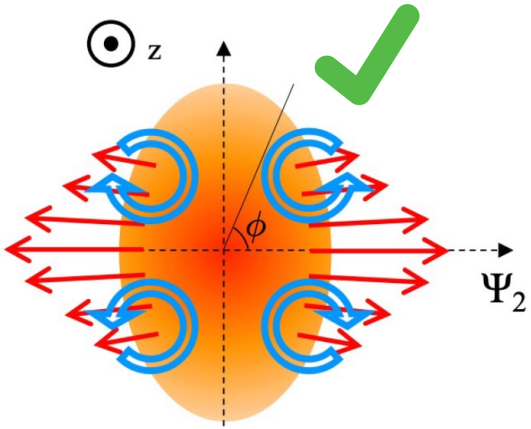
Details of model calculations need to be investigated

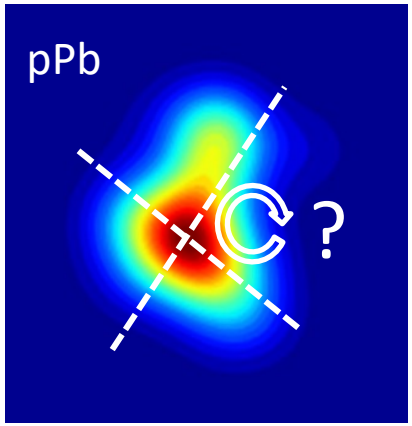
The observation of $P_{z,s3}$ indicates the link of vorticity to geometry

Recently extended to multi-strange hyperons

A test in small system





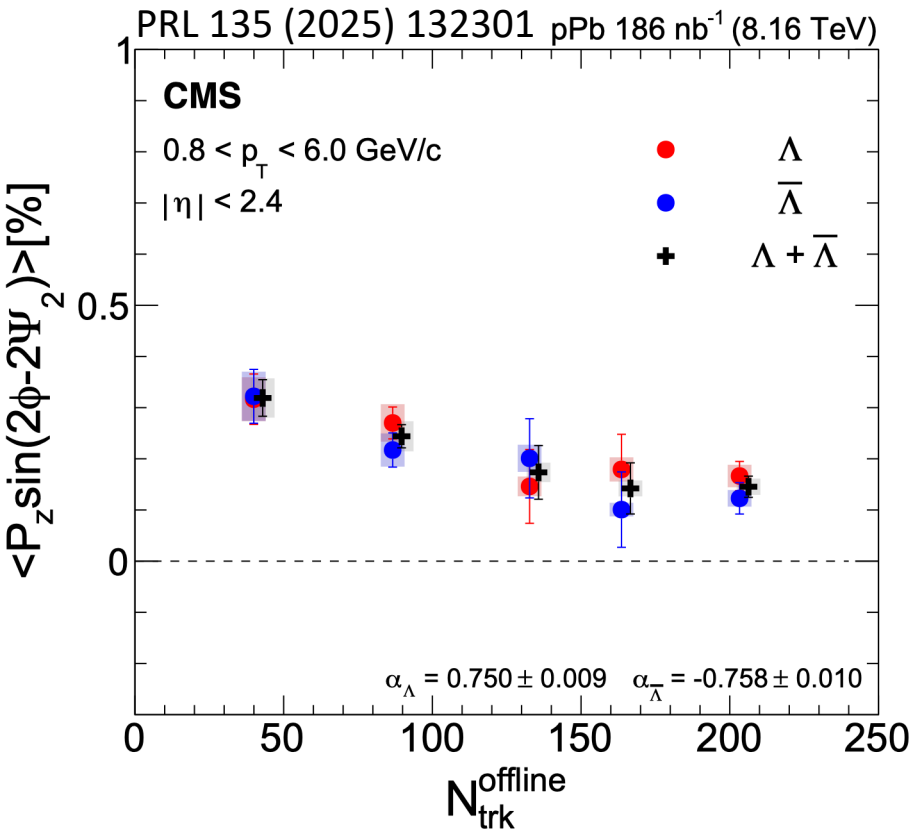


Features of QGP droplets observed in small but dense systems

Can we see hyperon polarization P_z there?

A test of QGP formation & different mechanisms of P_z

$P_{z,s2}$ in pPb collision

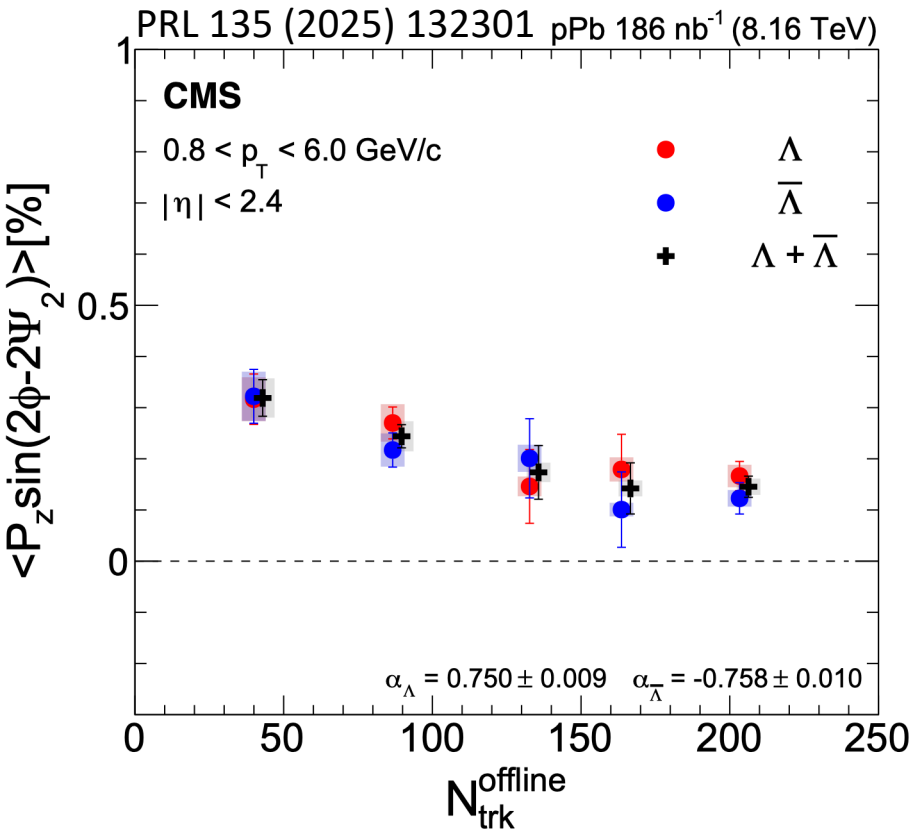


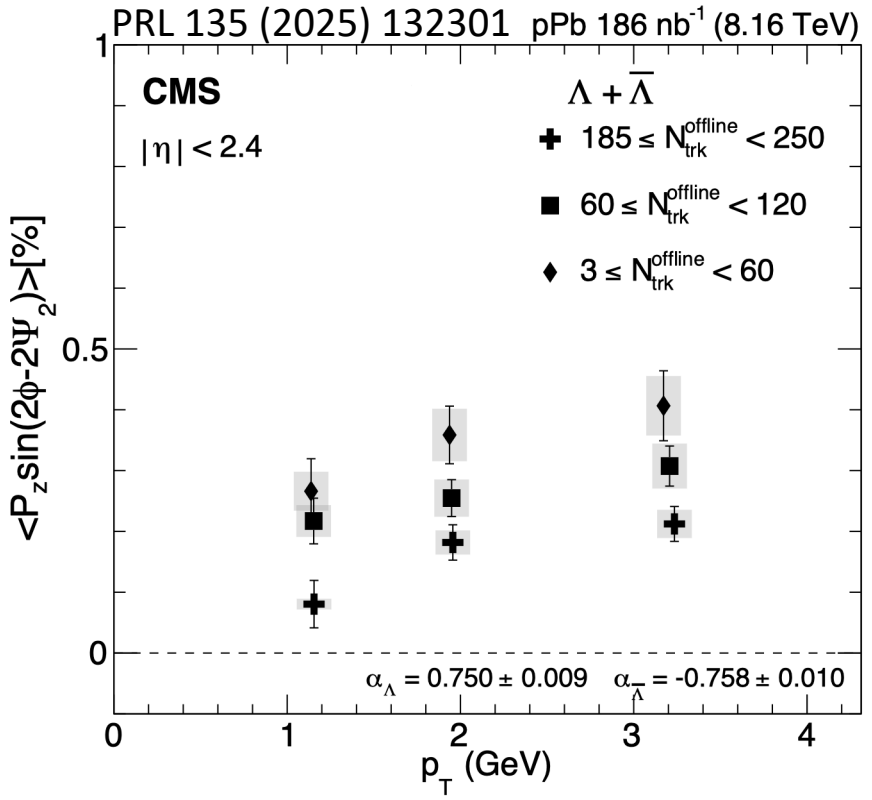
Significant positive $P_{z,s2}$ observed over entire multiplicity range

Consistent results for Λ and anti-Λ

Decrease towards high multiplicity

$P_{z,s2}$ in pPb collision





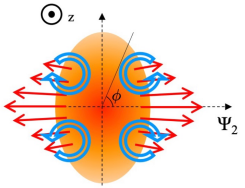
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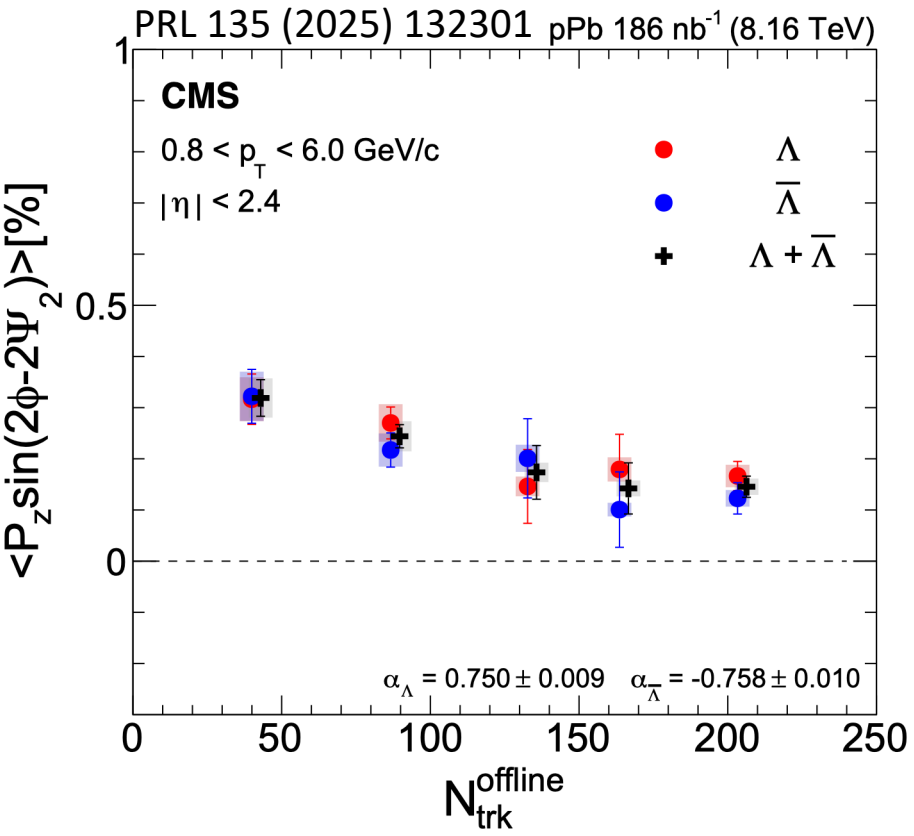
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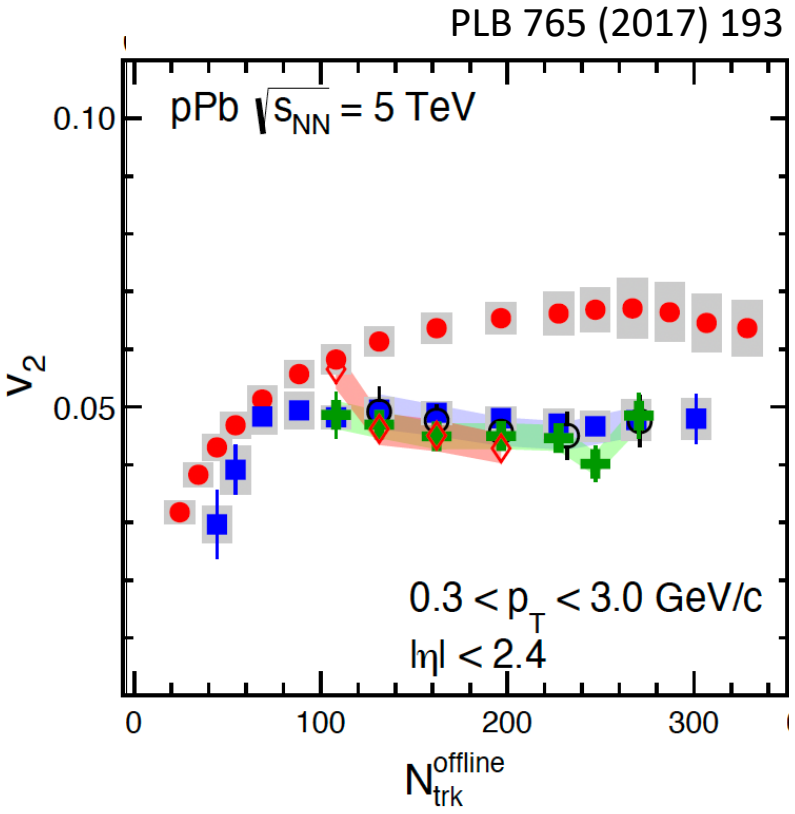
Decrease towards high multiplicity

Increase towards higher p_T – becomes flat at higher p_T?

$P_{z,s2}$ in pPb collision

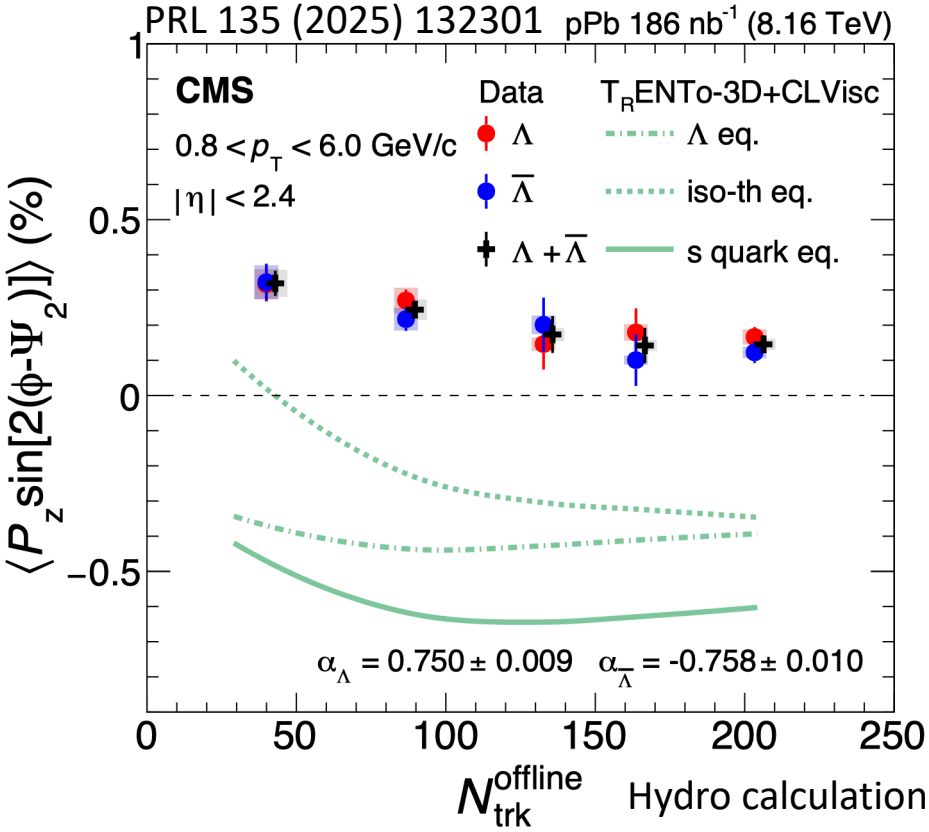






Not consistent with the trend of v_2

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

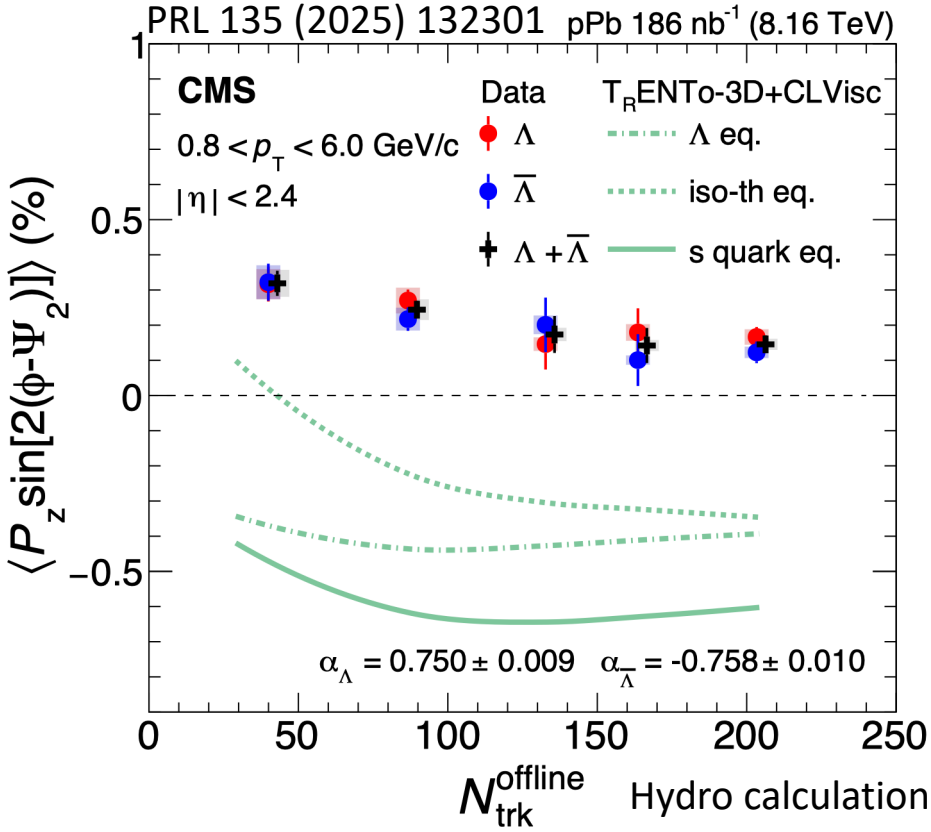


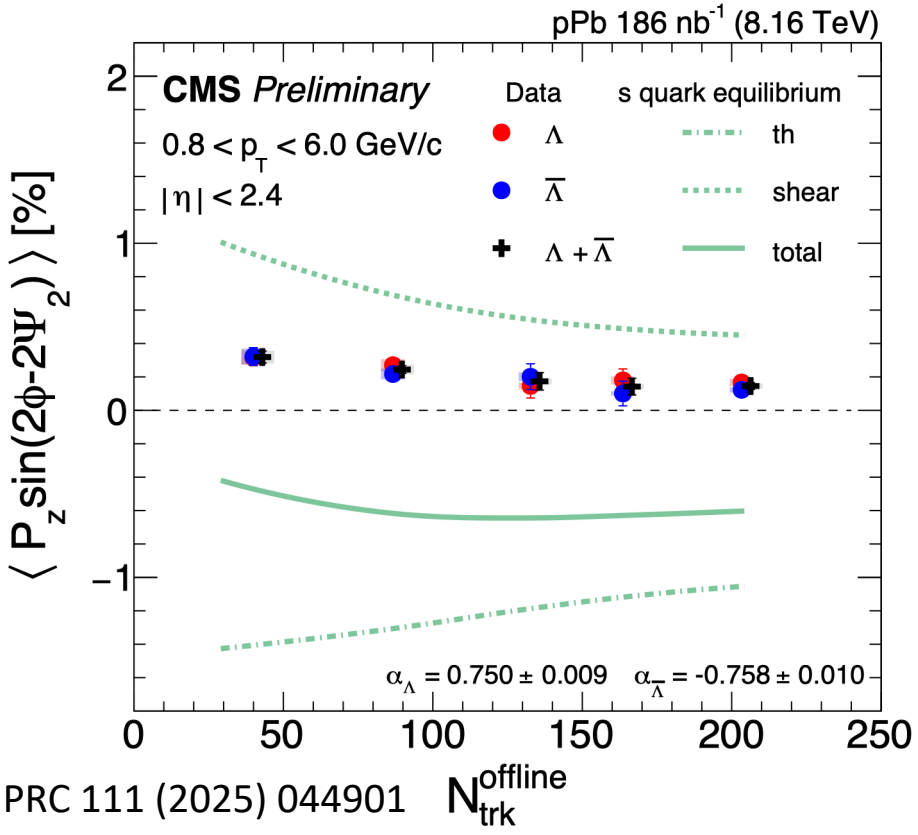
Hydro calculation PRC 111 (2025) 044901

Hydro calculations result in negative Pz

Post challenge to current theoretical framework

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





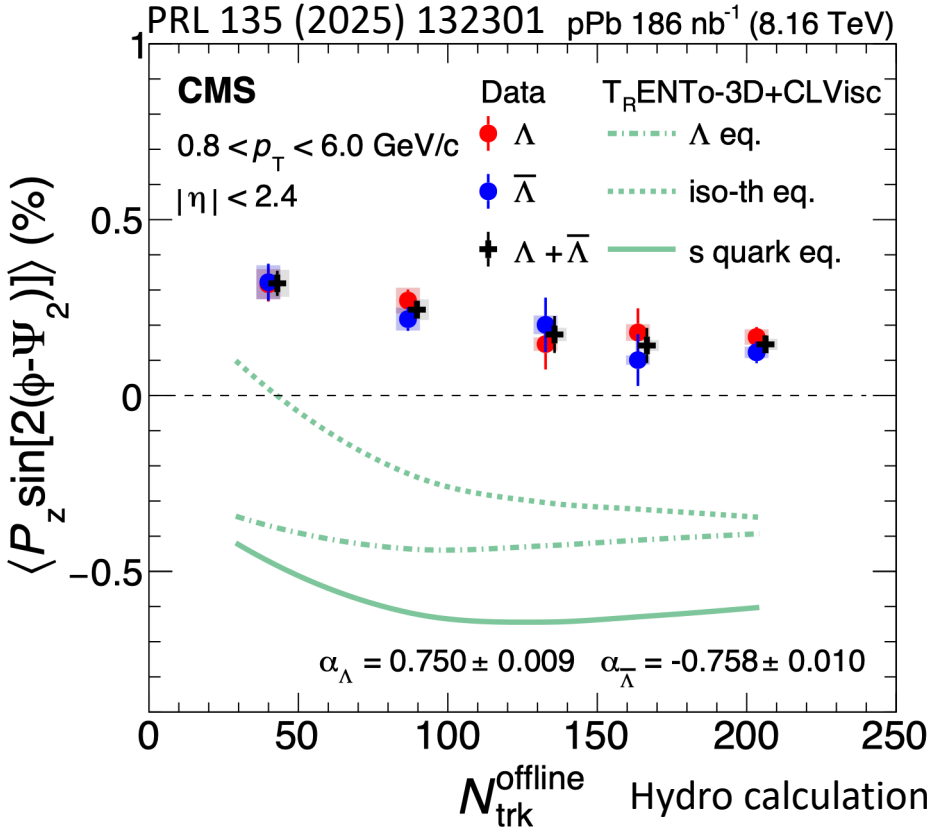
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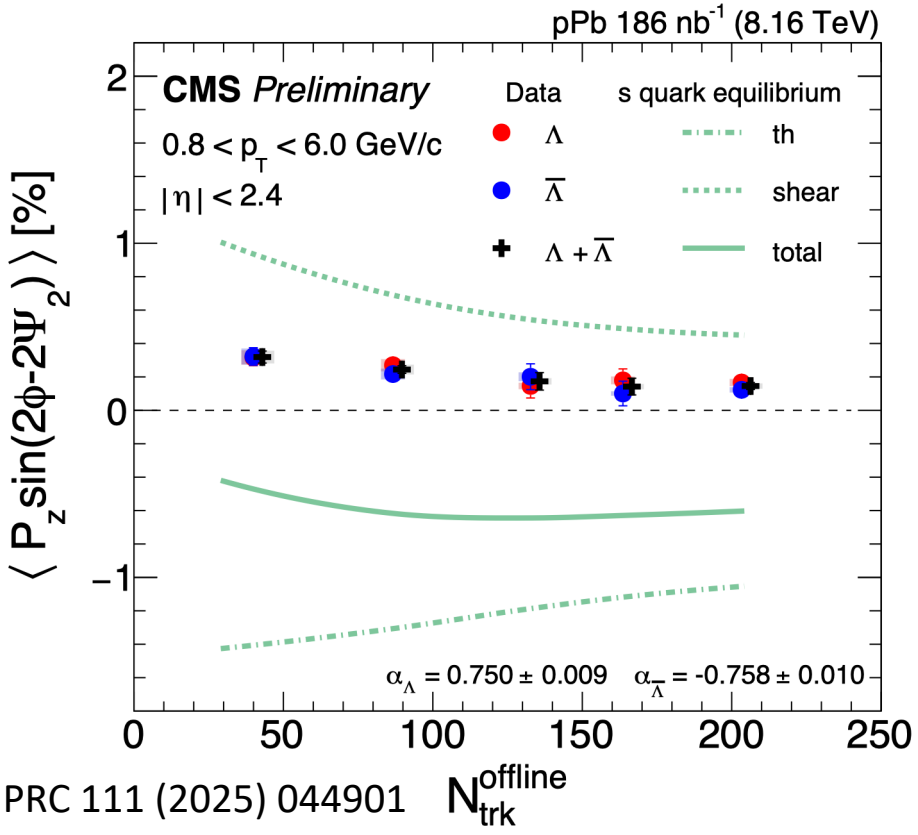
Hydro calculations result in negative Pz

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 calculation PRC 111 (2025) 044901

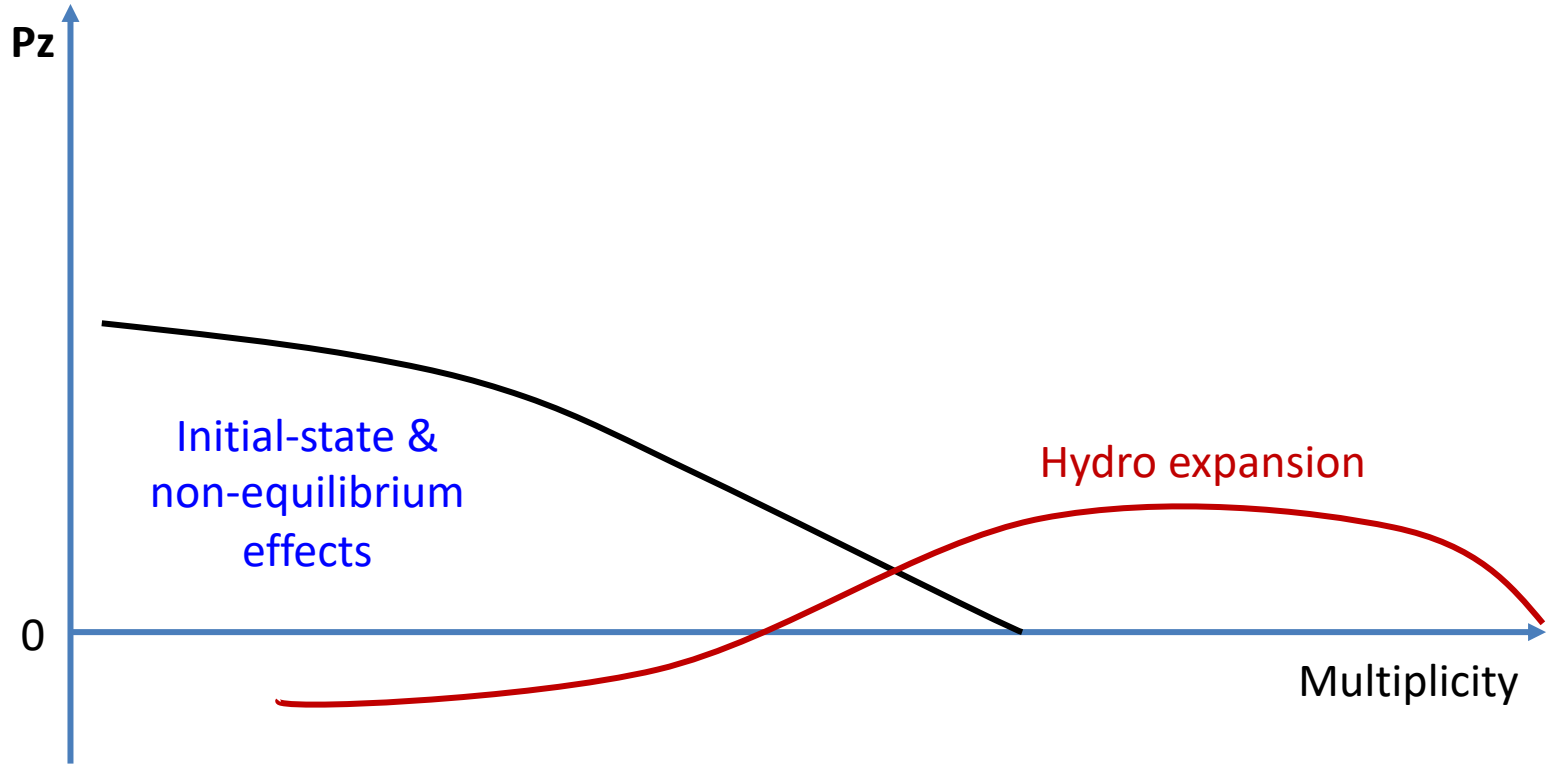
Hydro calculations result in negative Pz

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

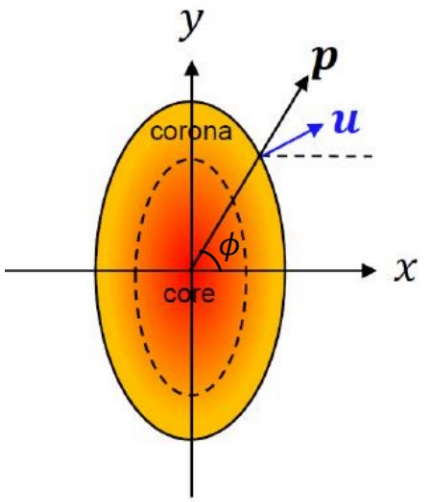


A naïve guess of contributions to hyperon local polarization

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) :



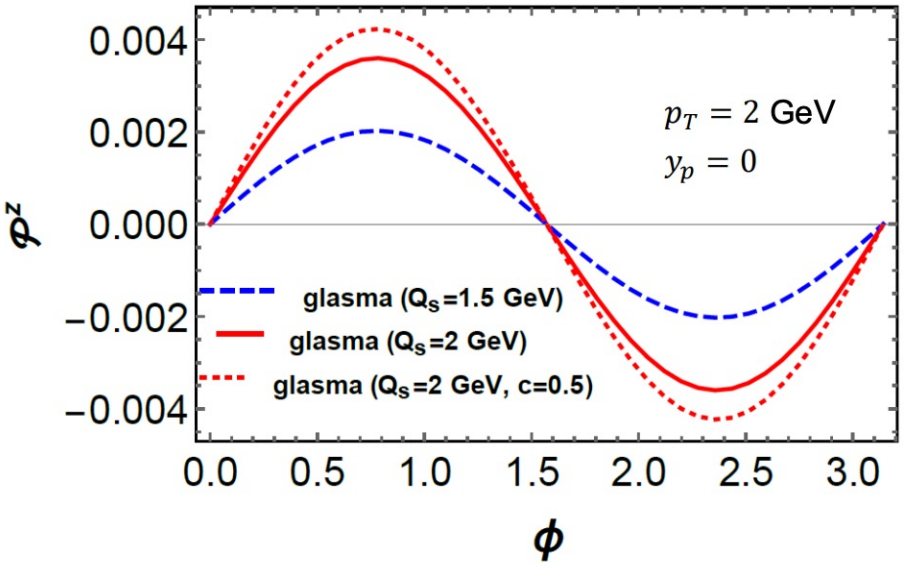
weak initial anisotropic flow from pressure gradient

traveling time in corona

$\boldsymbol{p} \times \boldsymbol{u}$ structure

$$\mathcal{P}^z \approx \frac{\hbar(N_c^2-1)Q_s^2\Delta t}{16M_\Lambda N_c^2\epsilon_{\boldsymbol{p}}\int d\Sigma\cdot p f_V^{\rm s}}\int d\Sigma\cdot p(p^x u^y - p^y u^x)$$
$$\times f_V^{\rm s}(1-f_V^{\rm s})\big((1-2f_V^{\rm s})u^0 + Q_s/\epsilon_{\boldsymbol{p}}\big), \quad f_V^{\rm s} = \frac{1}{e^{p\cdot u/Q_s}+c}.$$

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

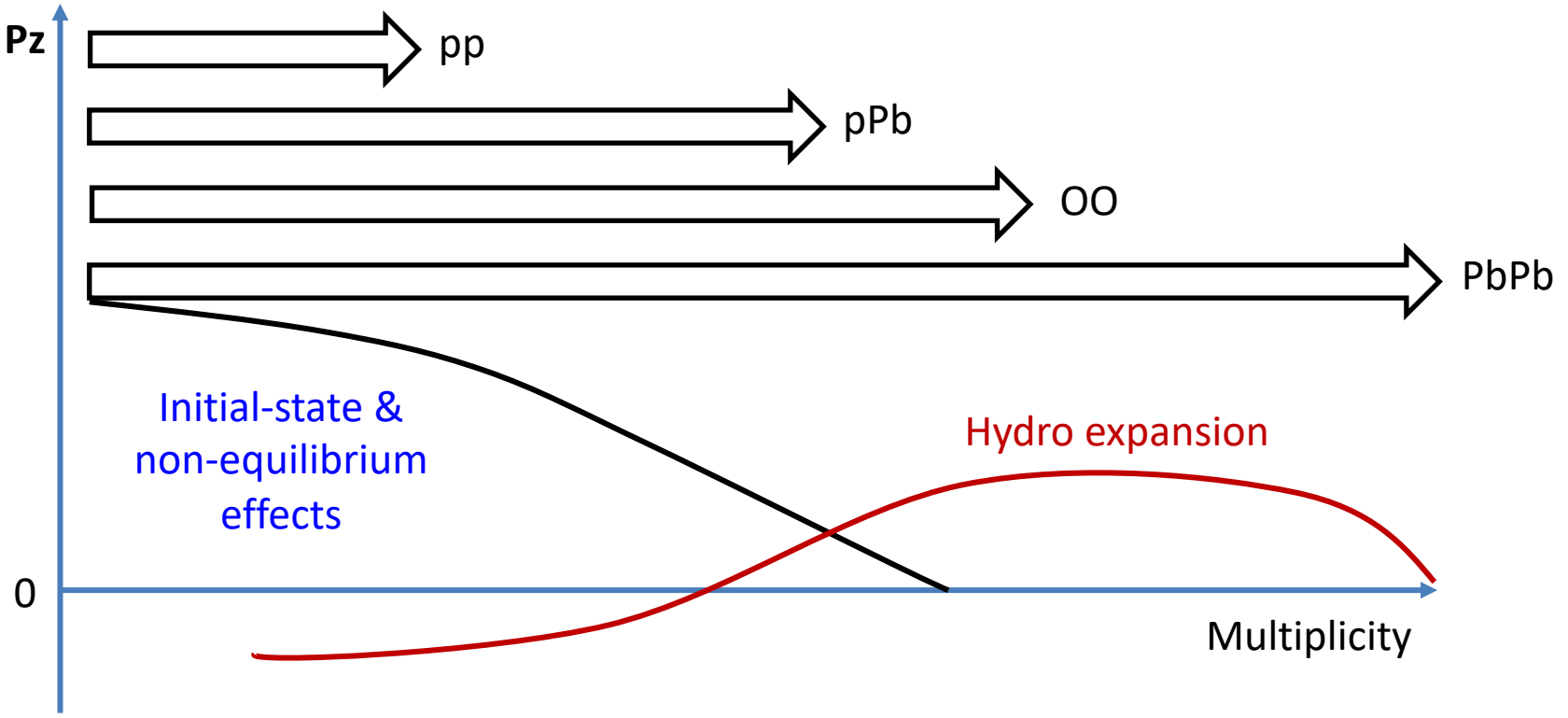


H. Sung, B. Müller, DY, arXiv: 2507.23210

✓ consistent sign & comparable order of magnitude with observations

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

Hyperon polarization across systems

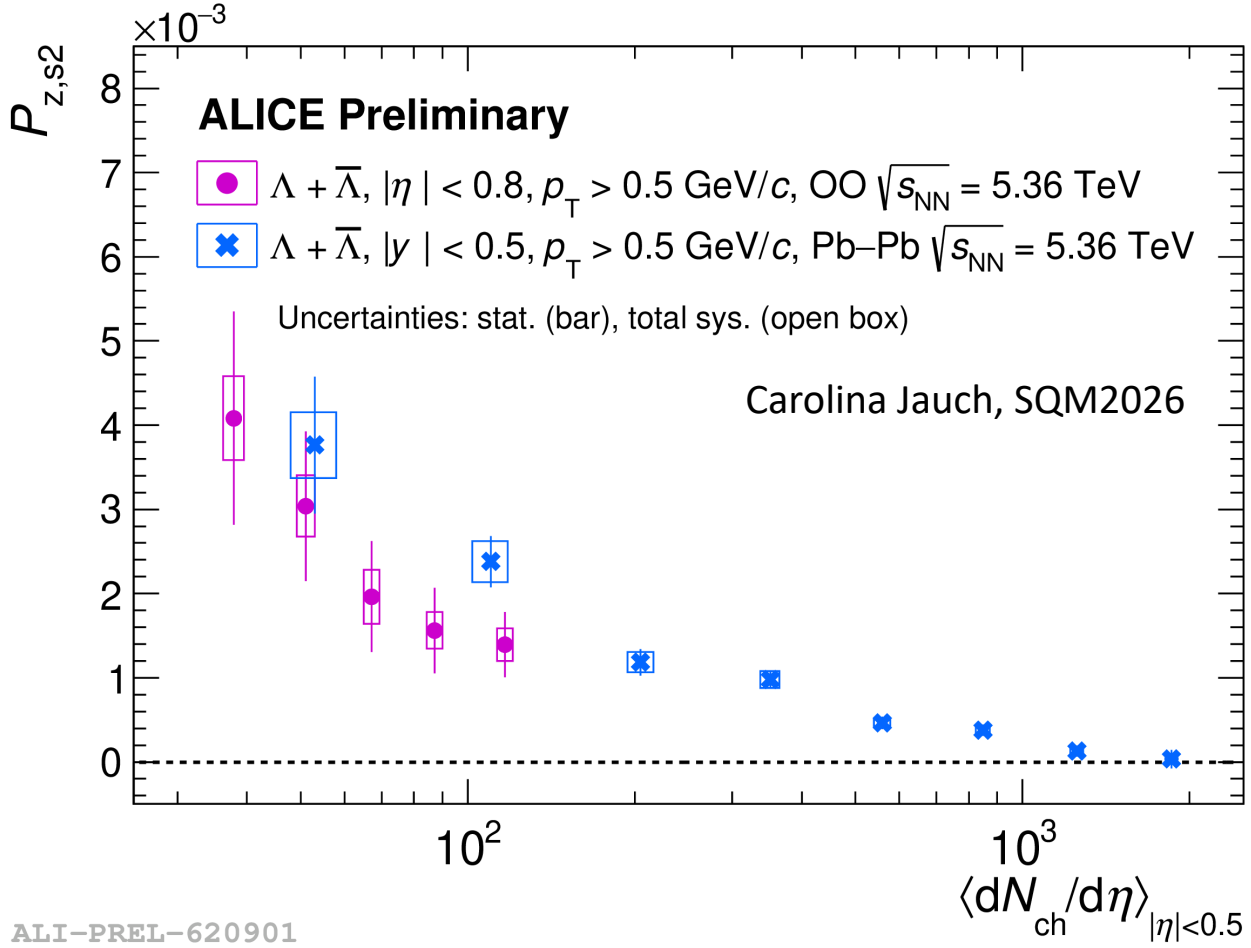


A naïve guess of contributions to hyperon local polarization

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



Significant local polarization observed in OO

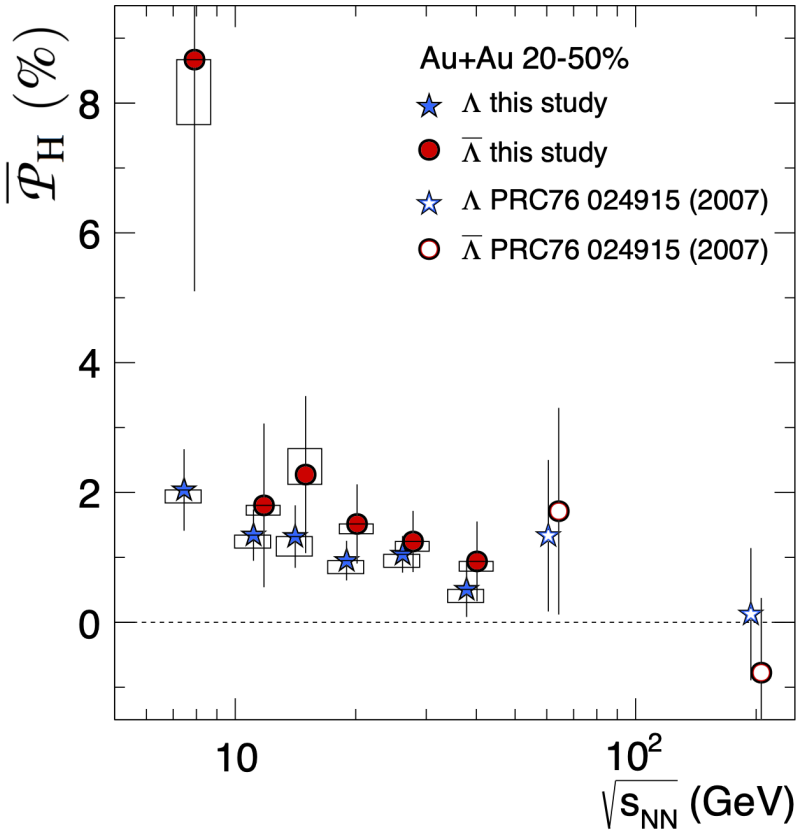
Similar behavior as in PbPb

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

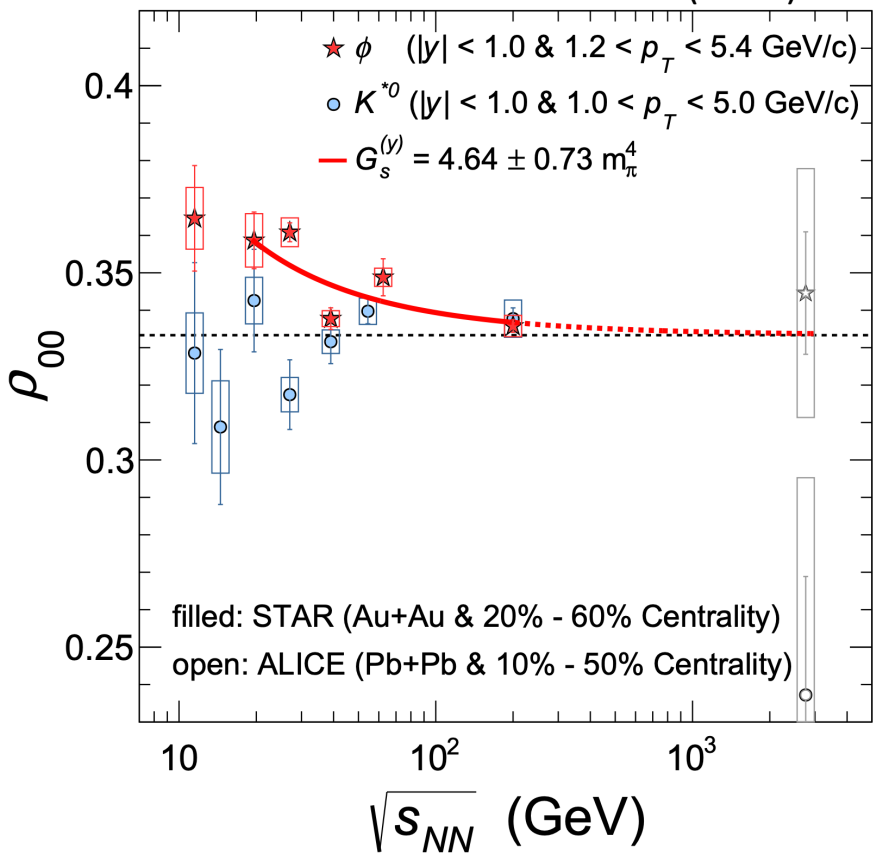
Looking forward to more results & theory comparison

Global polarization vs spin alignment

Nature 548 (2017) 62



Nature 614 (2023) 244

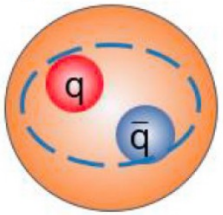


Global polarization and spin alignment in HI post a question why

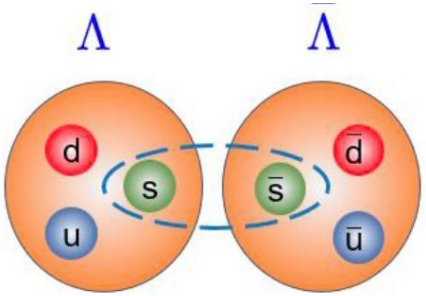
$$\left|\rho_{00}^{V} - \frac{1}{3}\right| \gg P_{\Lambda}^{2} \sim P_{q}^{2}$$

Spin correlation

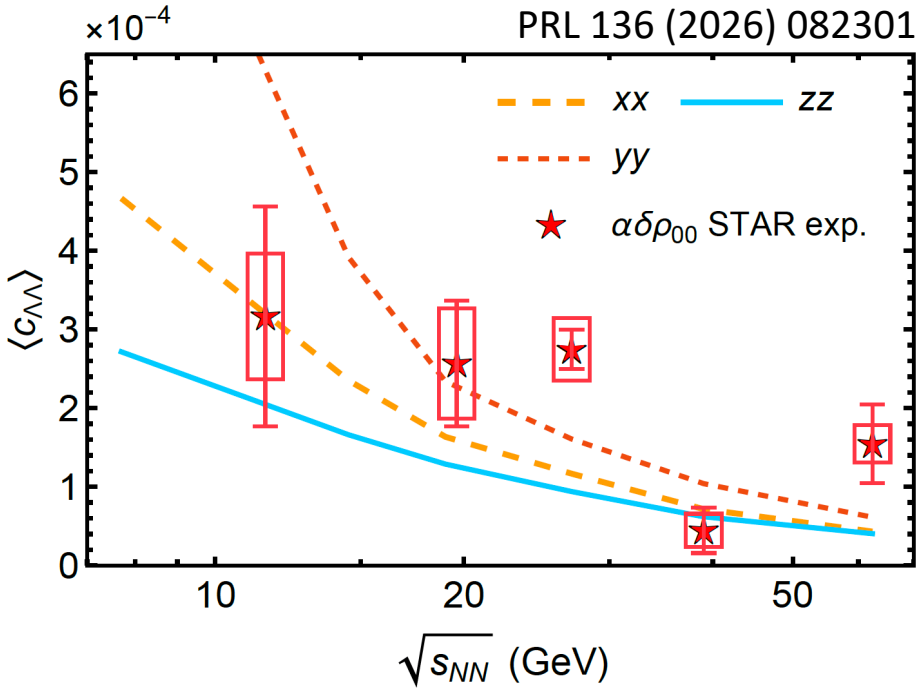
PRD 109 (2024) 114003



$$\langle p_q p_{\bar{q}} \rangle \neq \langle p_q \rangle \langle p_{\bar{q}} \rangle$$



PRL 136 (2026) 082301



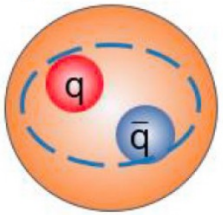
Global polarization and spin alignment in HI post a question why

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

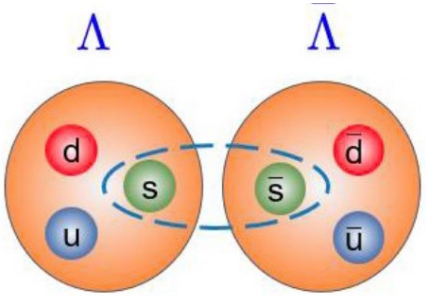
Spin-spin correlation proposed as a solution

Spin correlation

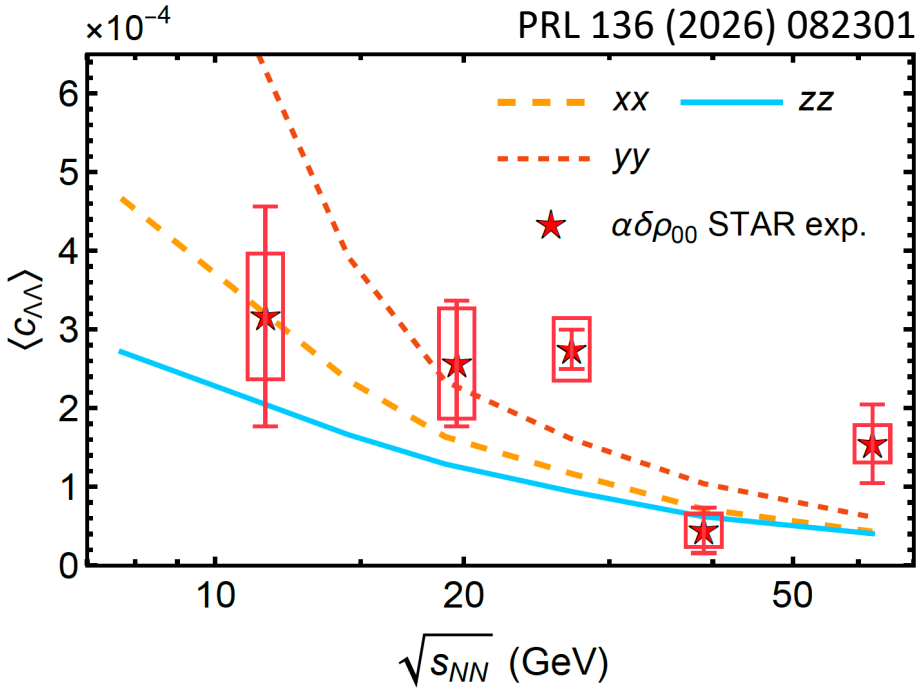
PRD 109 (2024) 114003



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PRL 136 (2026) 082301



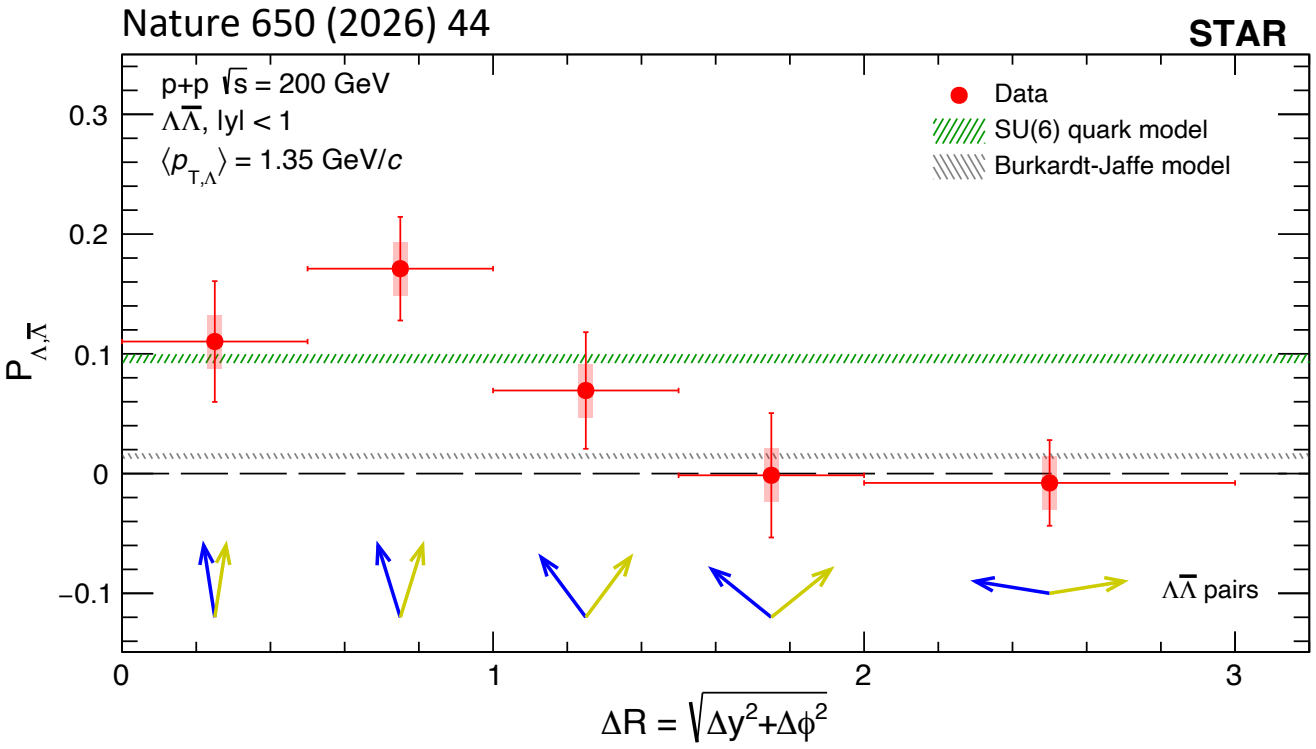
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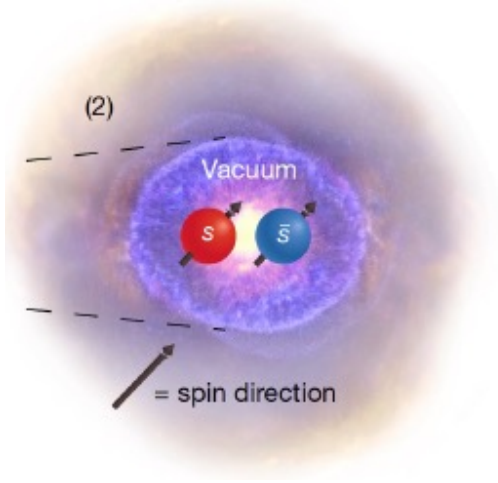
$$\left|\rho_{00}^{V} - \frac{1}{3}\right| \gg P_{\Lambda}^{2} \sim P_{q}^{2}$$

Spin-spin correlation proposed as a solution

Every HI-QGP observable needs a 'vacuum' reference

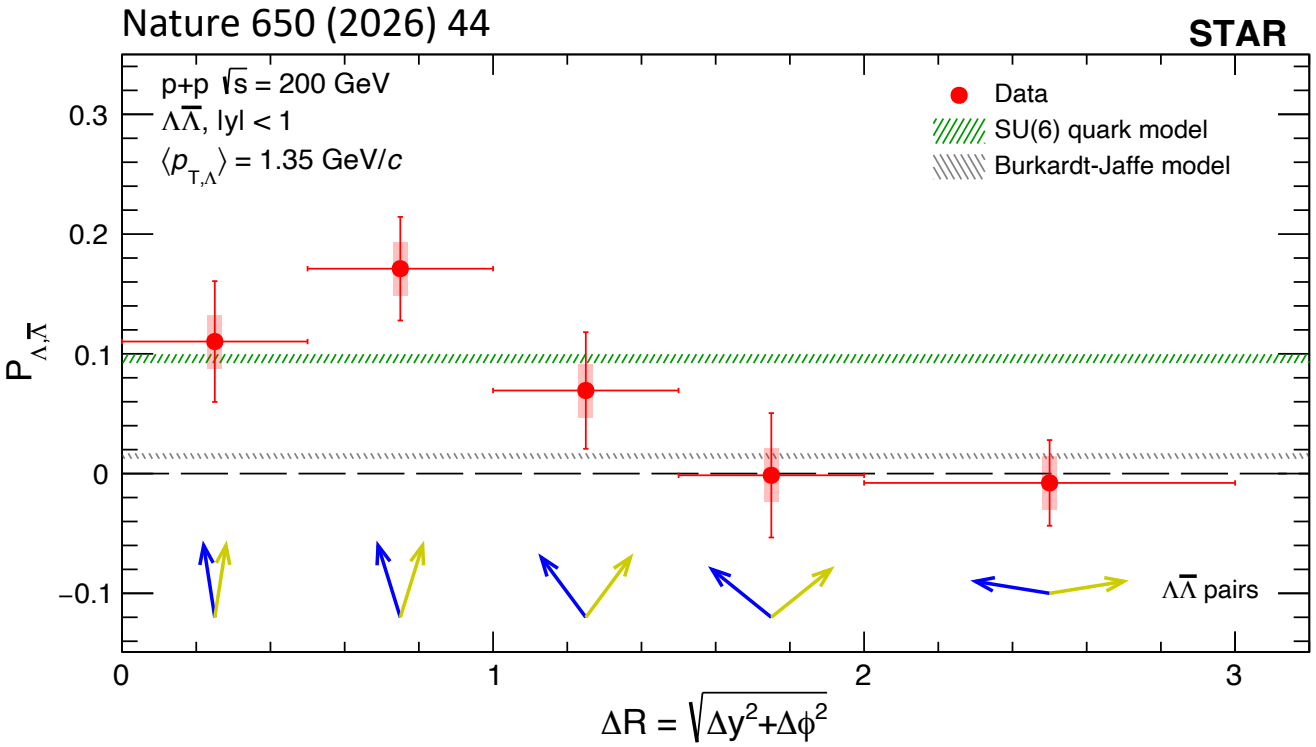
Spin correlation in pp at RHIC

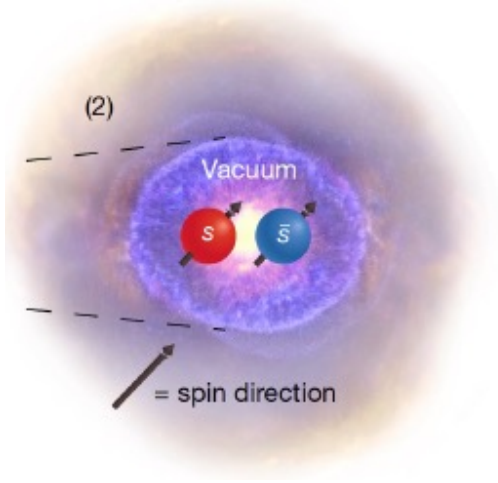




Evidence of positive signal observed by STAR for Lambda + anti-Lambda
Interpreted as reflecting the spin structure of ssbar from QCD vacuum

Spin correlation in pp at RHIC





Evidence of positive signal observed by STAR for Lambda + anti-Lambda

Interpreted as reflecting the spin structure of ssbar 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

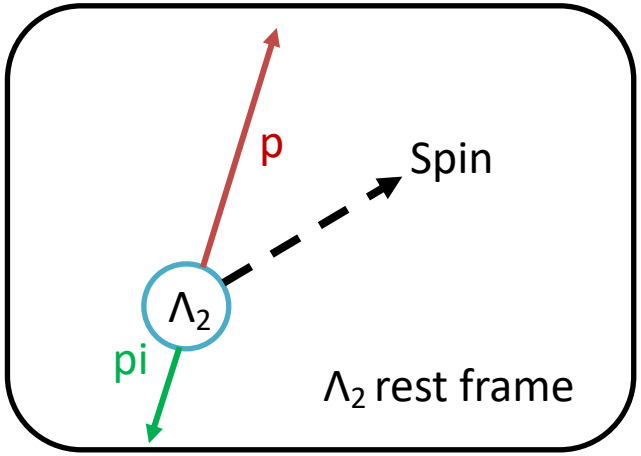
$P_{\Lambda,\Lambda}$ extraction

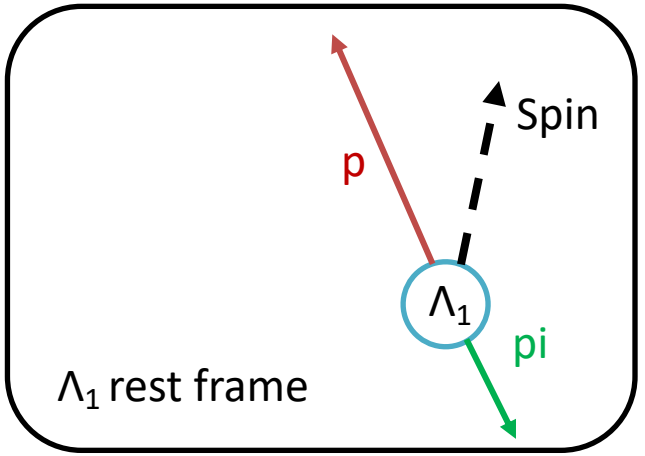
Spin correlation extracted from θ* distributions:

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

Phys.Rev.A 69 (2004) 034102

Spin correlation magnitude





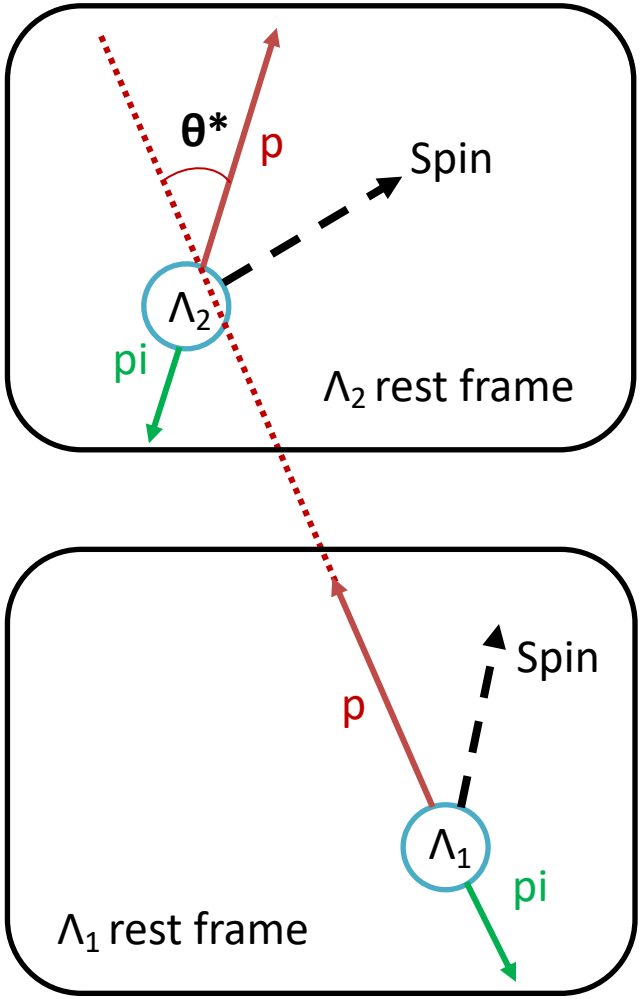
$P_{\Lambda,\Lambda}$ extraction

Spin correlation extracted from θ* distributions:

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

Phys.Rev.A 69 (2004) 034102

Spin correlation magnitude



Hyperon pair cosθ* distribution extraction

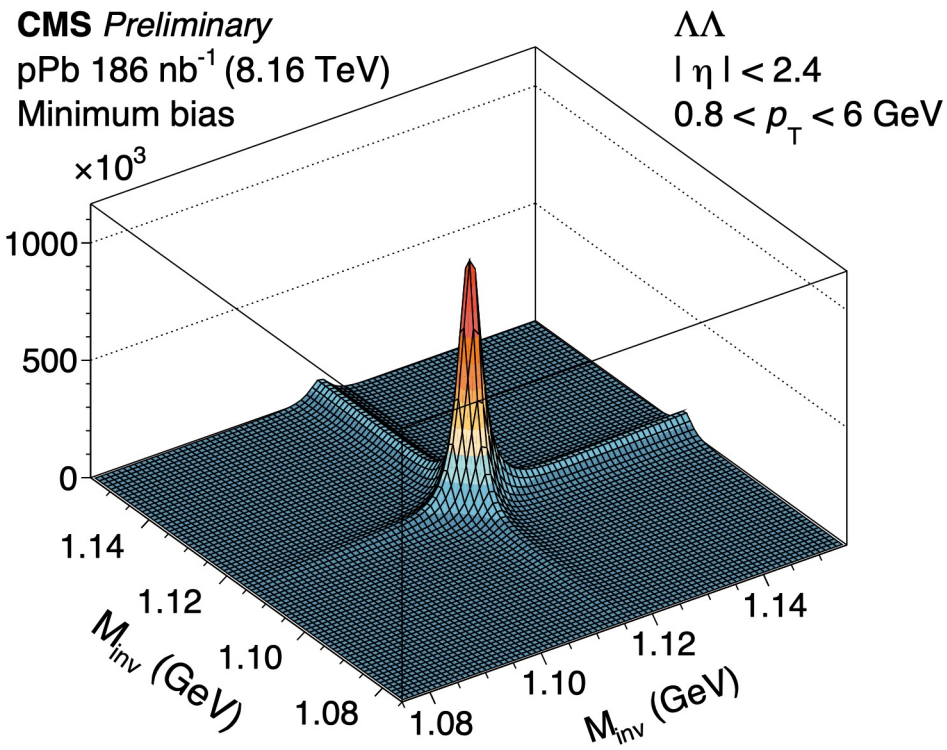
↓

Acceptance correction

↓

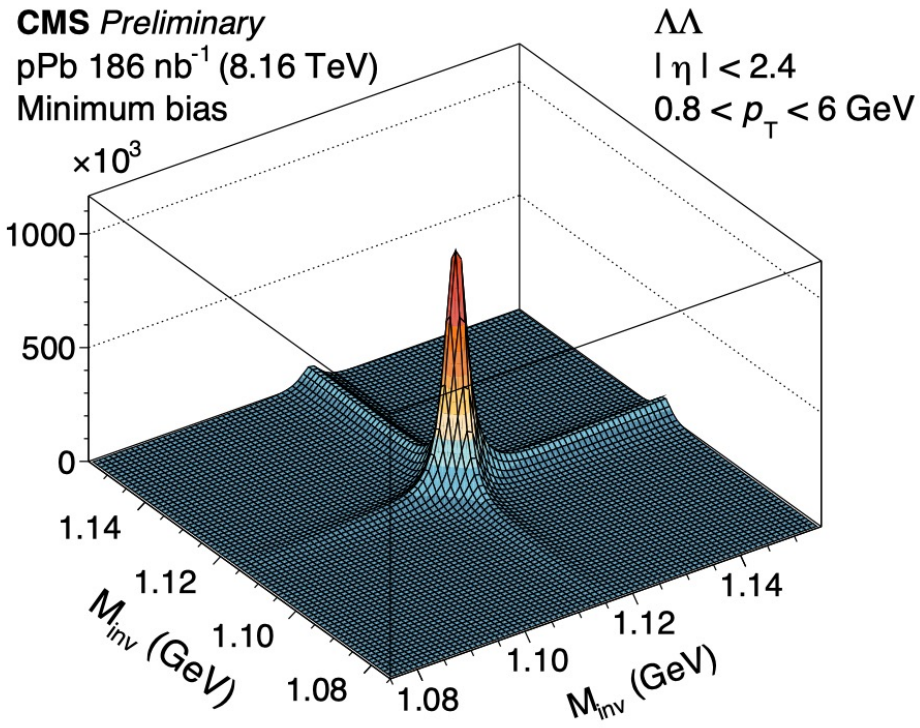
Fit for slope $P_{\Lambda,\Lambda}$

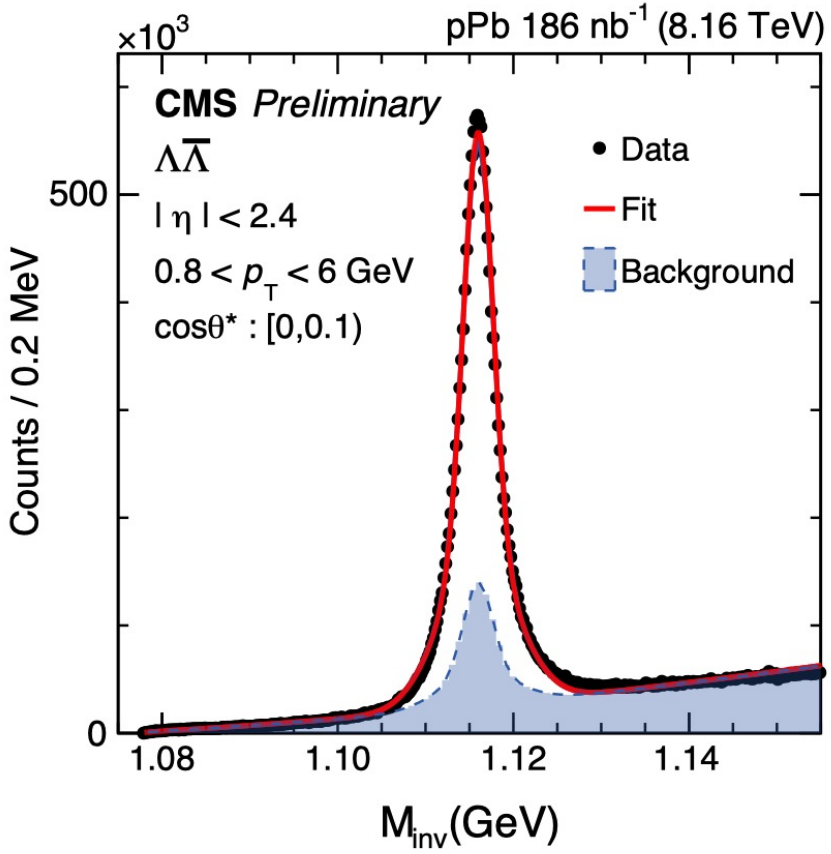
$P_{\Lambda,\Lambda}$ extraction - cosθ* distributions



Yield of Λ pairs measured in cosθ* intervals

$P_{\Lambda,\Lambda}$ extraction - cosθ* distributions

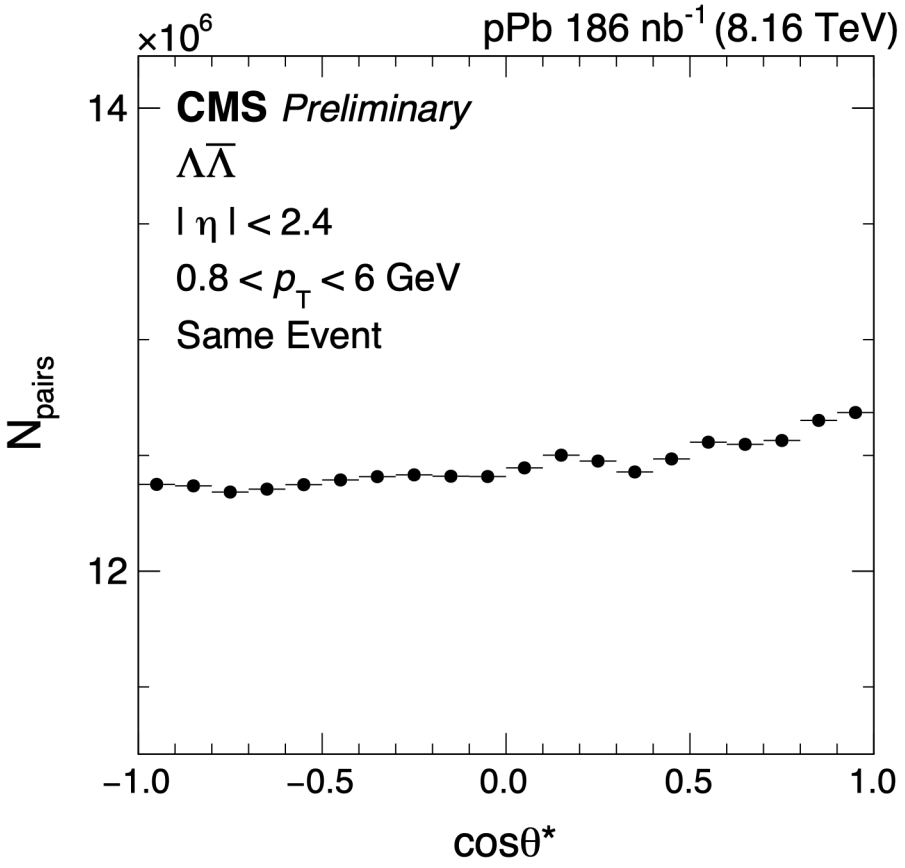


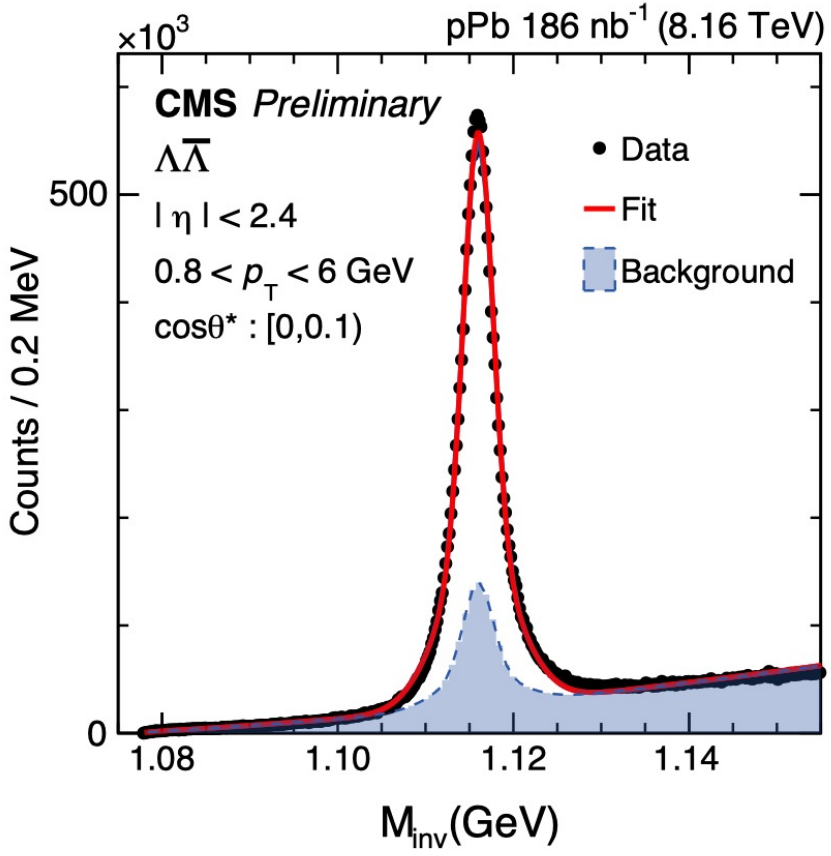


Yield of Λ pairs measured in cosθ* intervals

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

$P_{\Lambda,\Lambda}$ extraction - cosθ* distributions



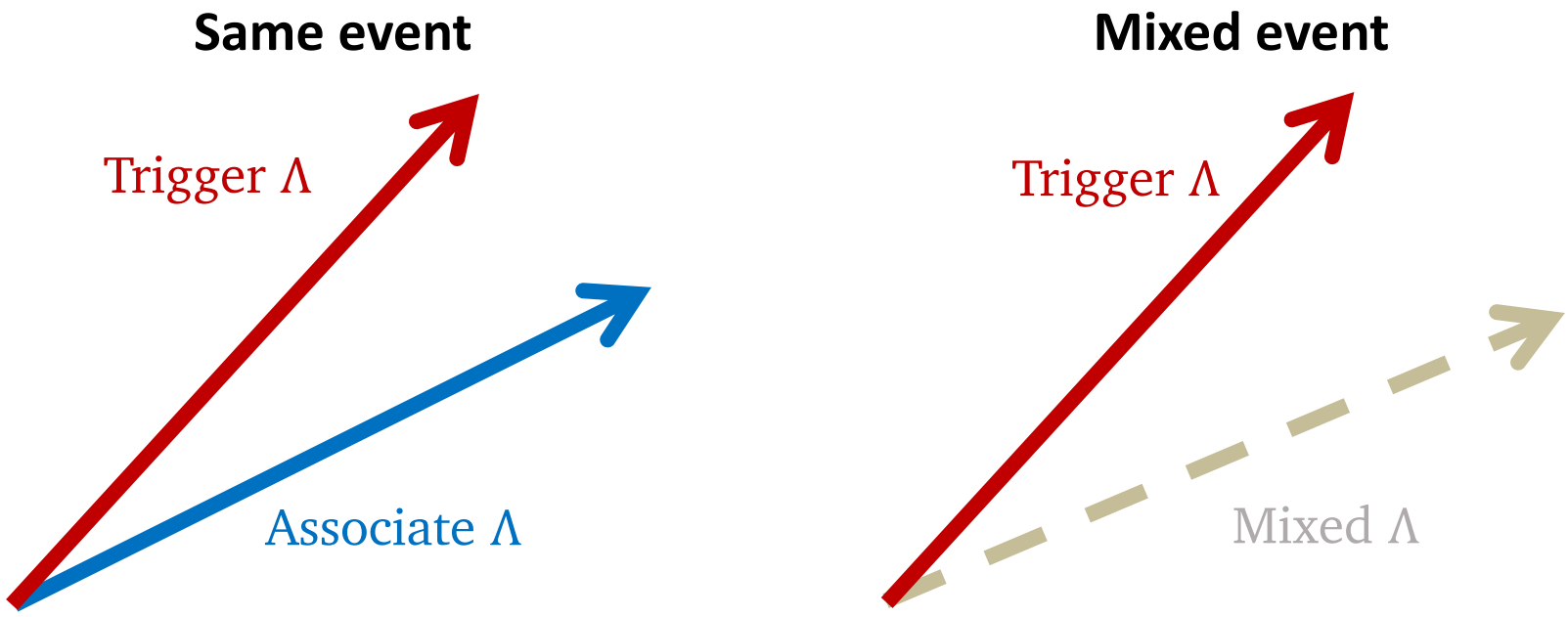


Yield of Λ pairs measured in cosθ* intervals

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

The cosθ* distribution is determined

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

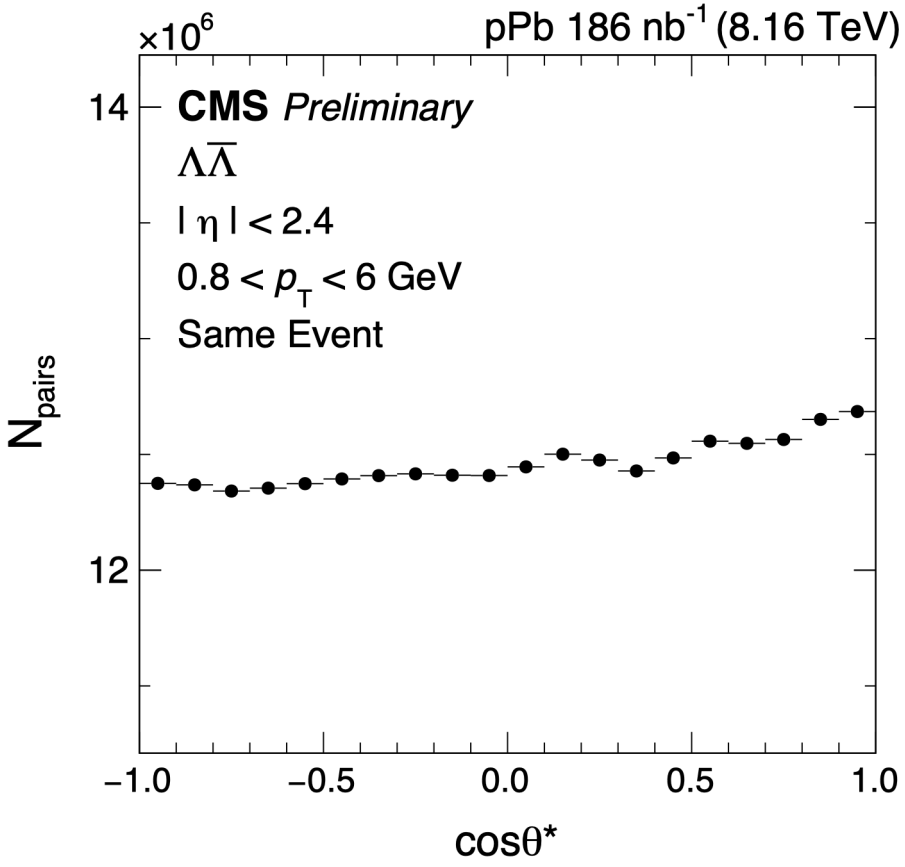


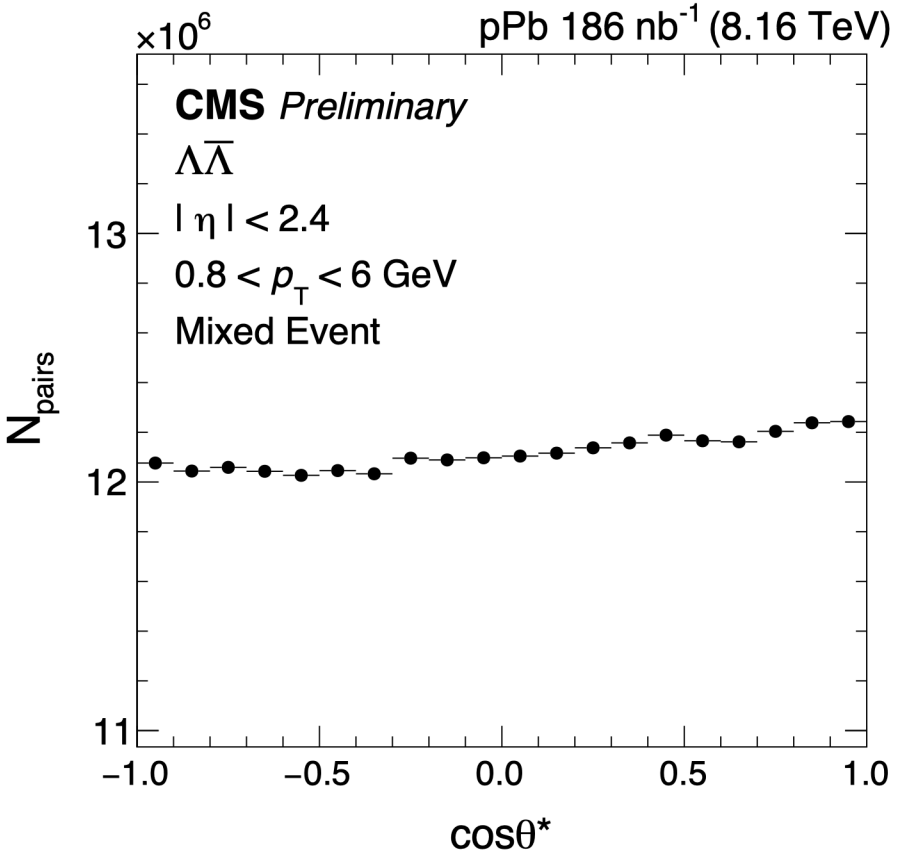
A mixed event correction is implemented with requirements

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

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

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



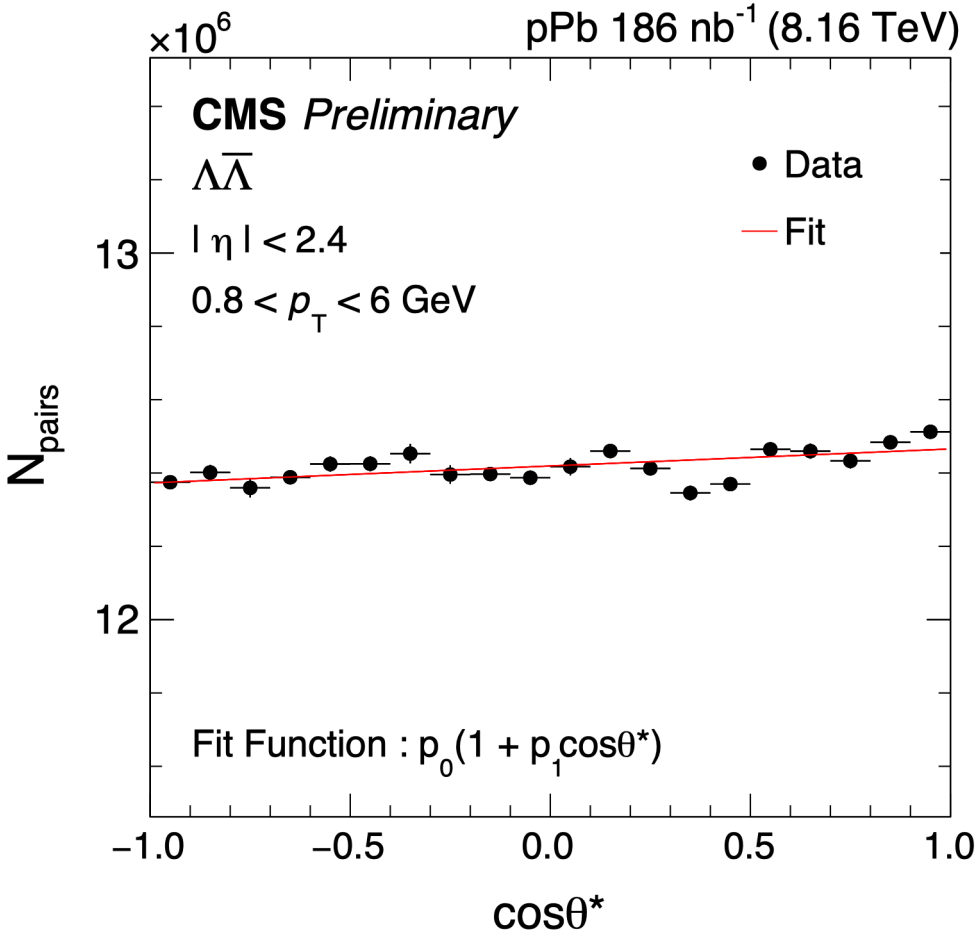


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$P_{\Lambda,\Lambda}$ extraction - acceptance correction

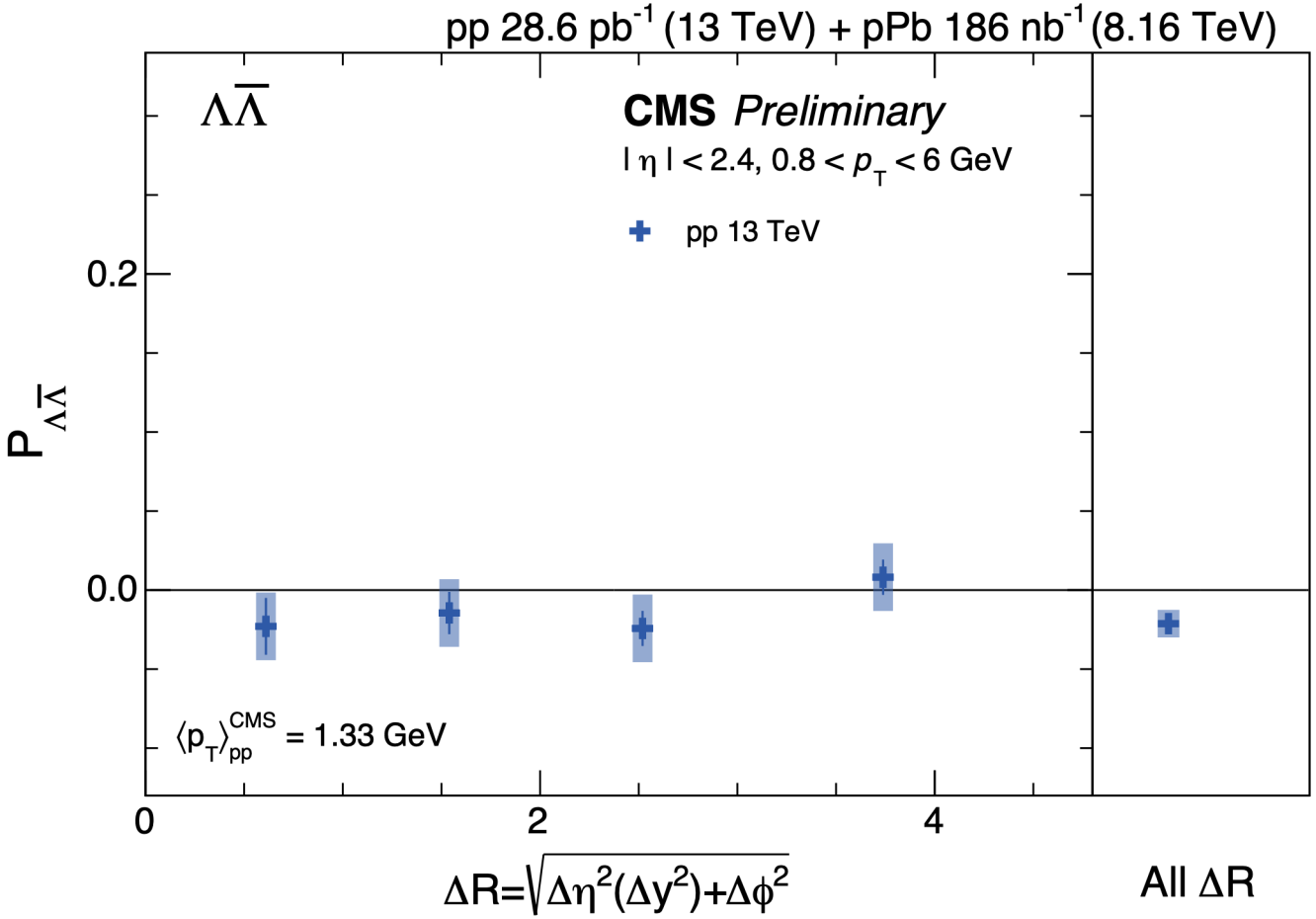


Same event divided by mixed event to correct acceptance

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

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

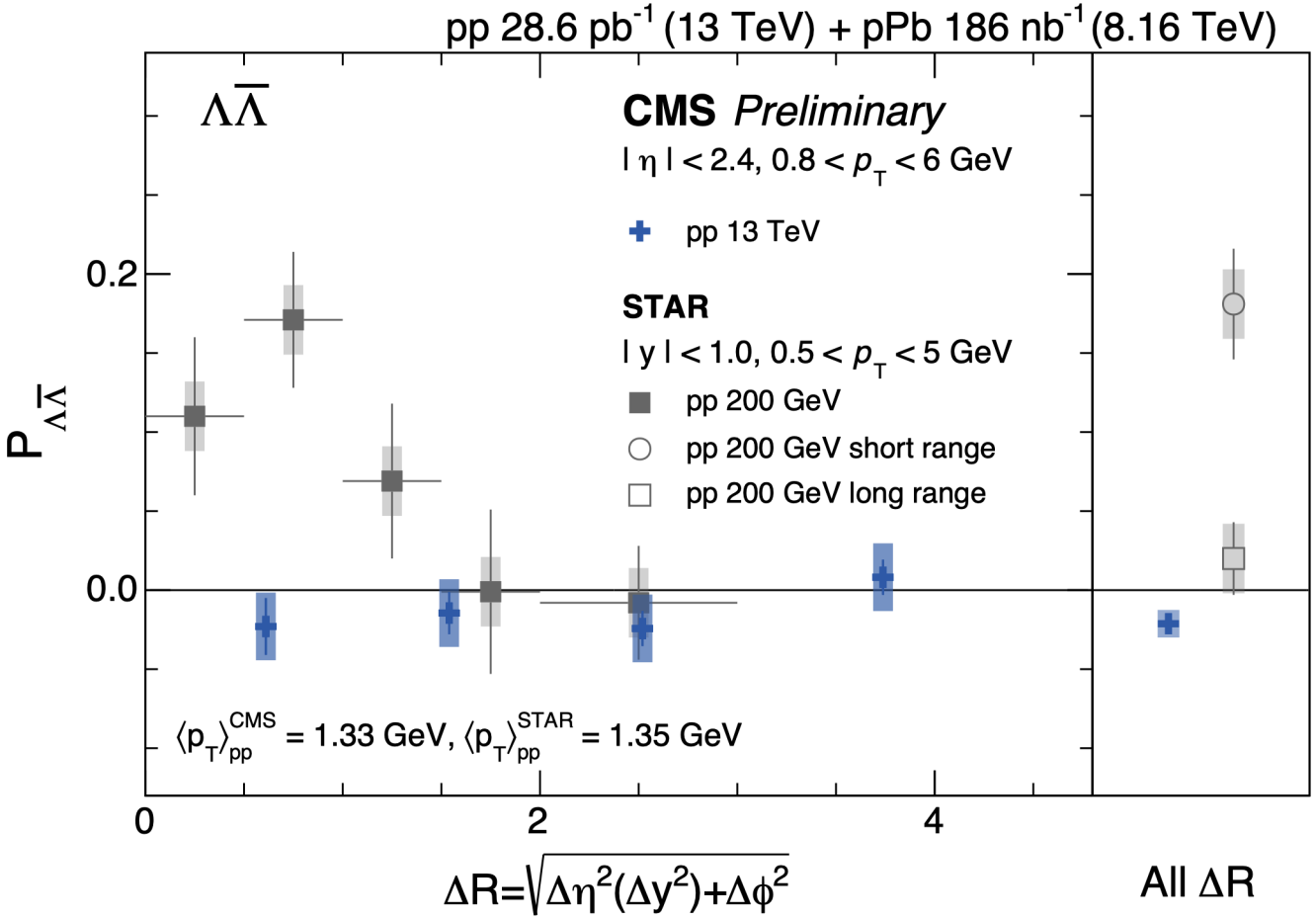
Spin correlation of $\Lambda\bar{\Lambda}$ in pp



ΔR differential results consistent with zero within uncertainties

The integrated result hints a negative value

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



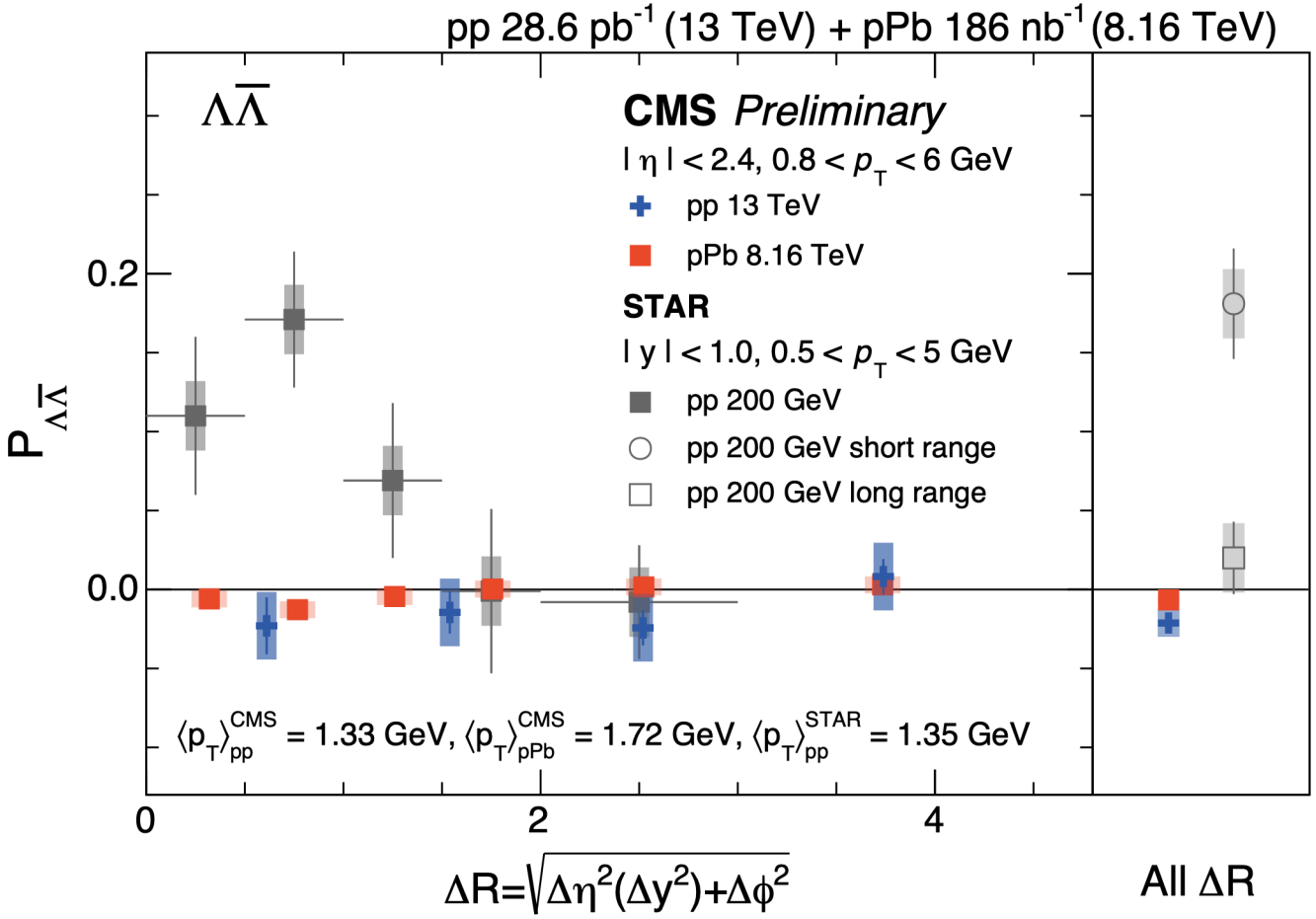
ΔR differential results consistent with zero within uncertainties

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

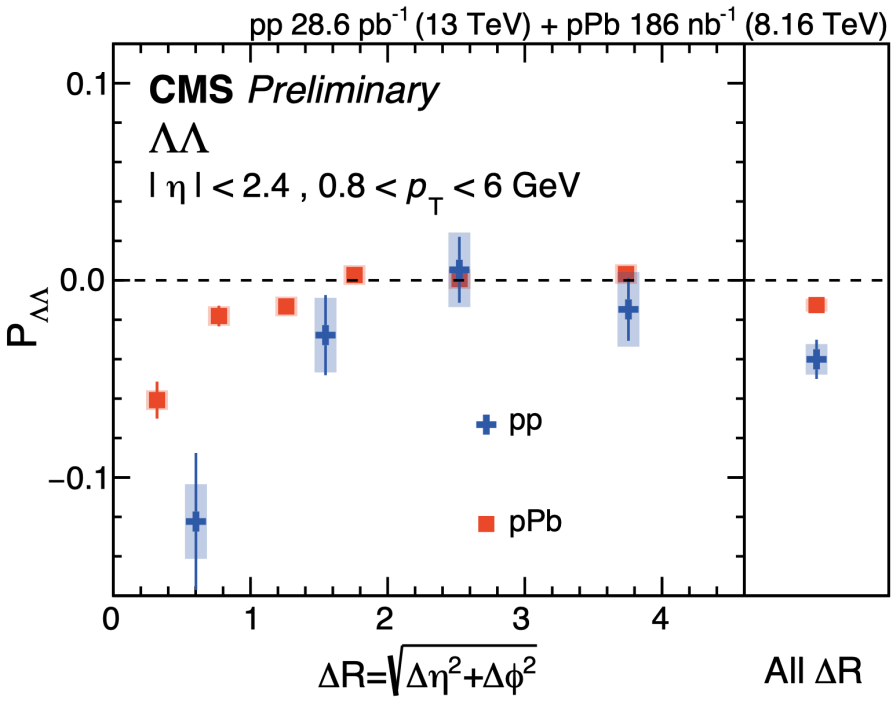


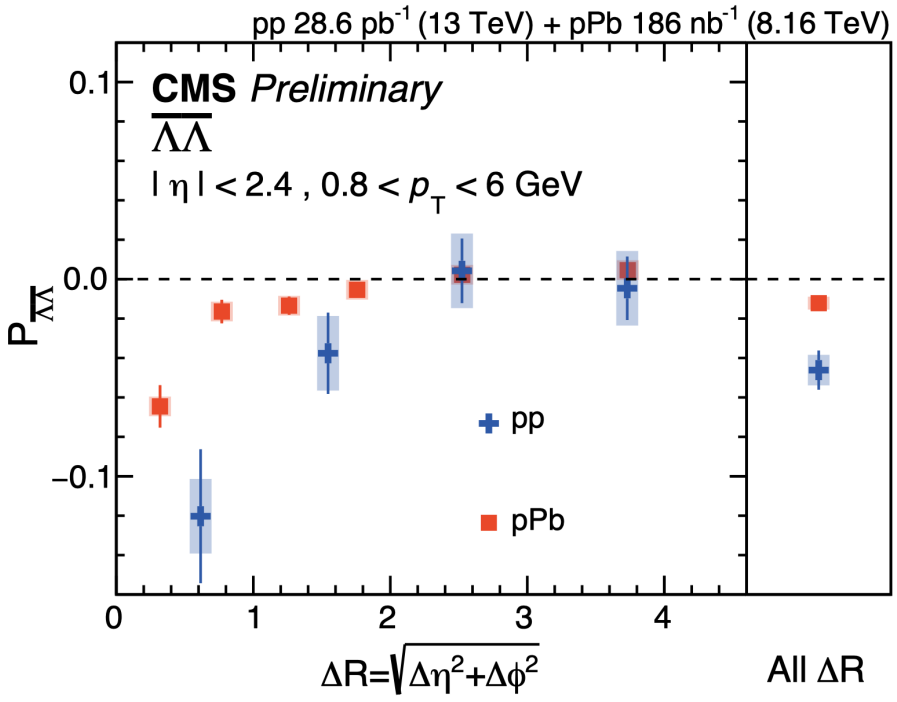
pPb results similar to pp

Hint of smaller integrated value in pPb than pp

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

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



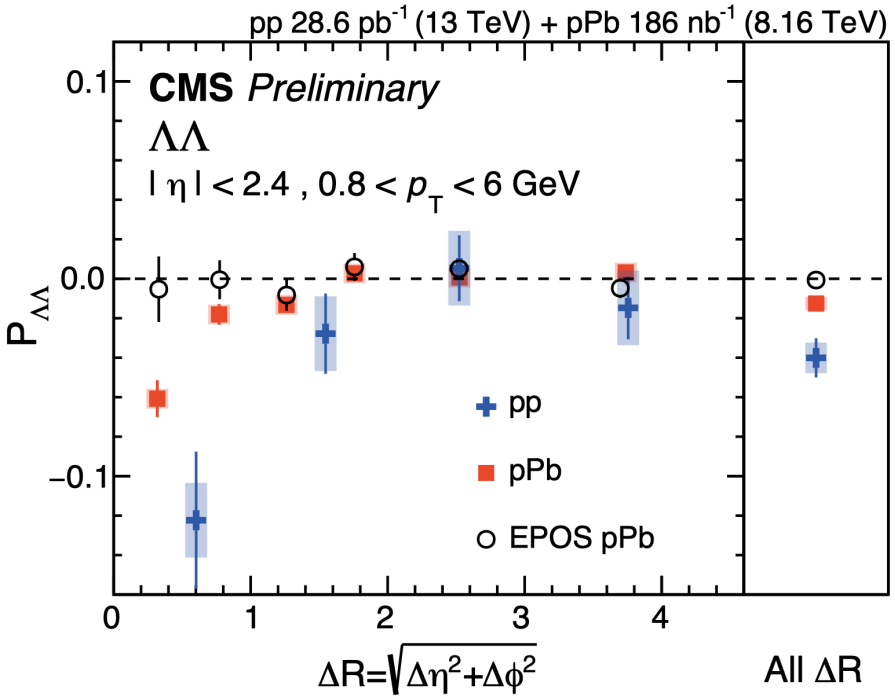


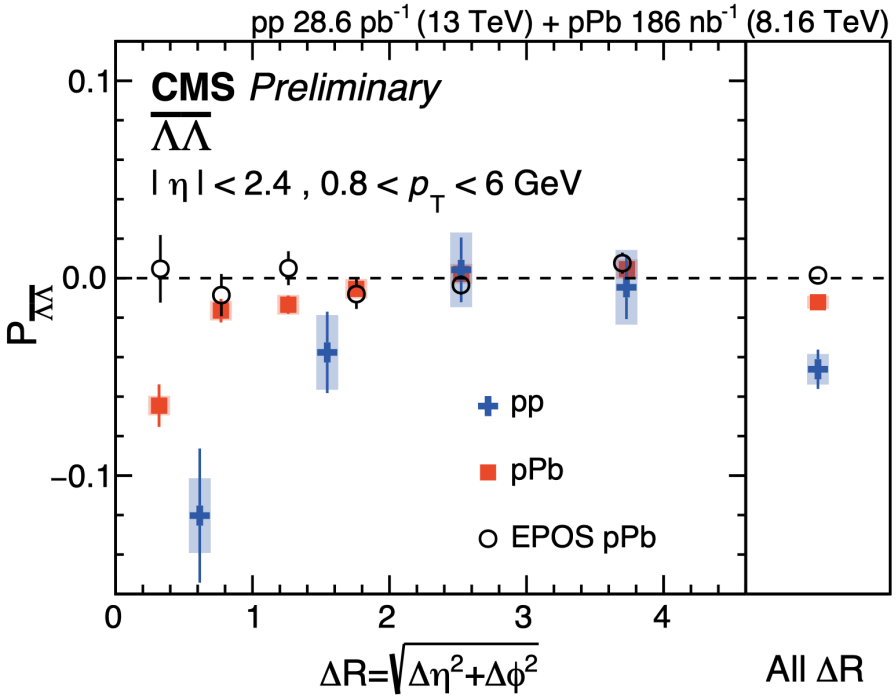
Negative spin correlation observed at small ΔR

Converge to 0 at large ΔR

A hint of larger magnitude in pp than pPb

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





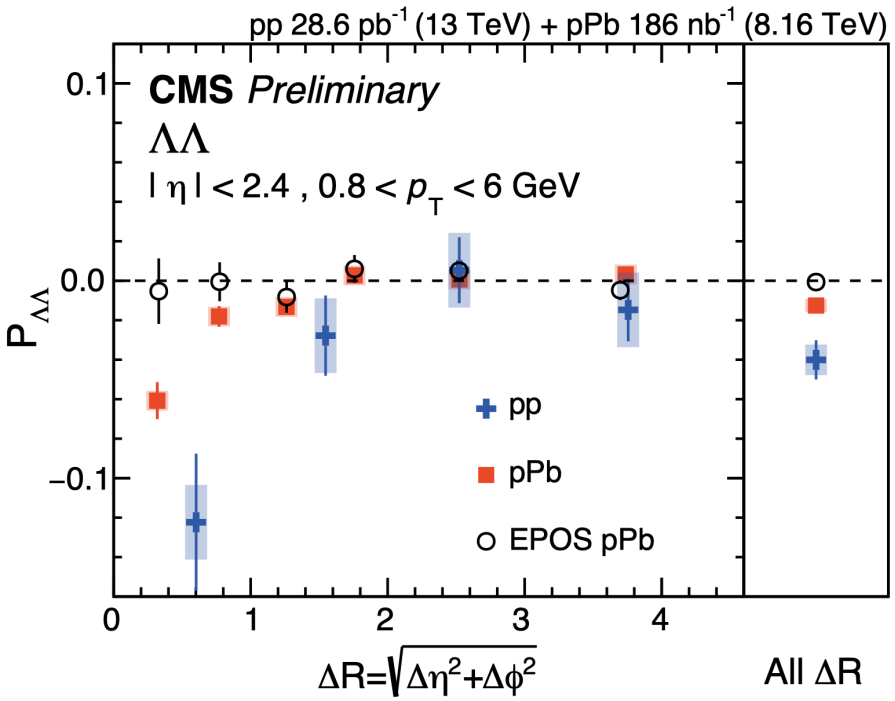
Negative spin correlation observed at small ΔR

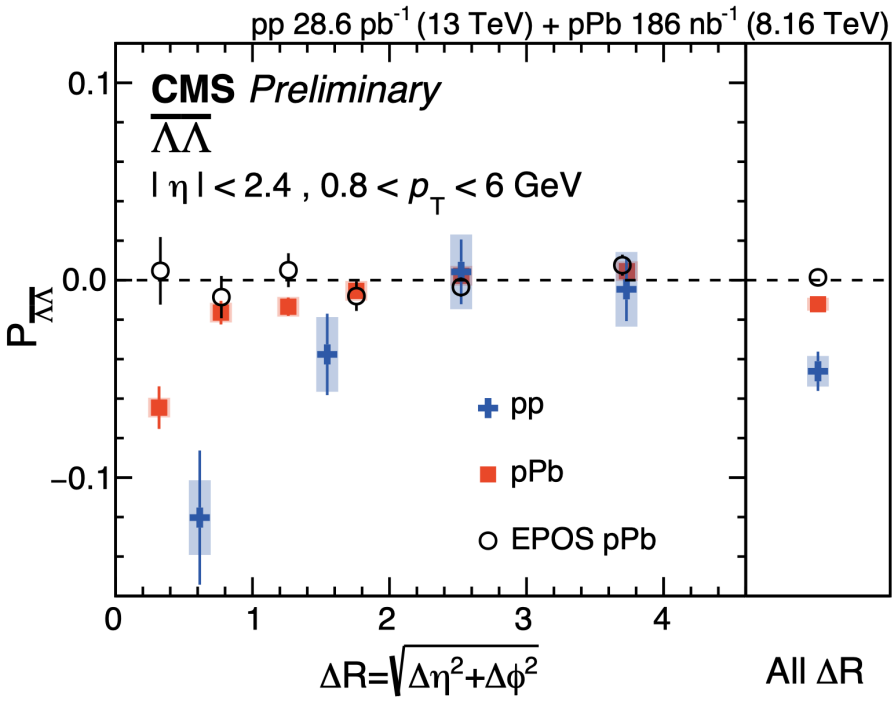
Converge to 0 at large ΔR

A hint of larger magnitude in pp than pPb

Same analysis in EPOS yield 0 as expected

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

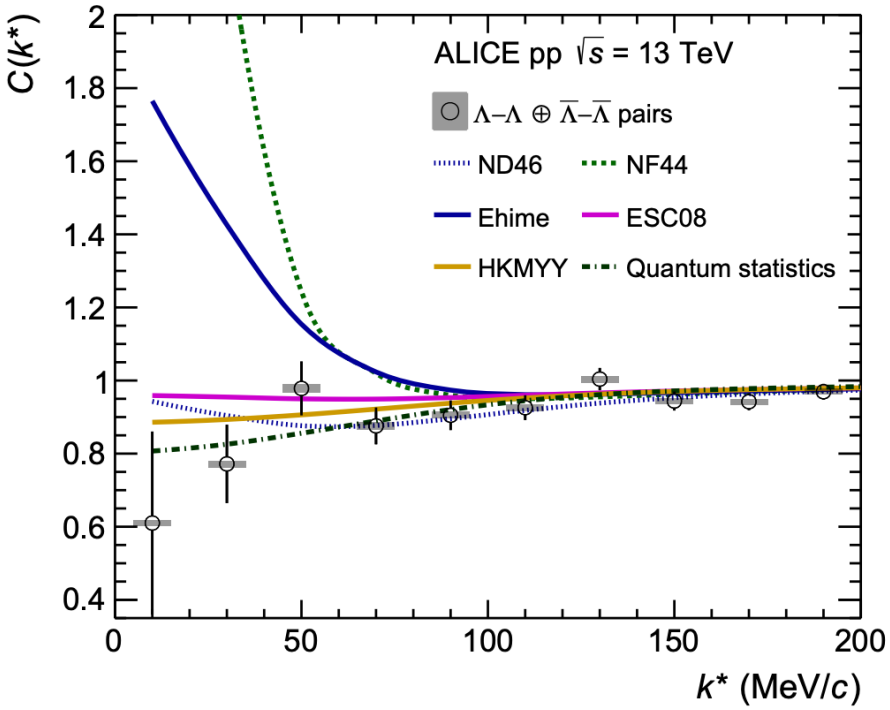


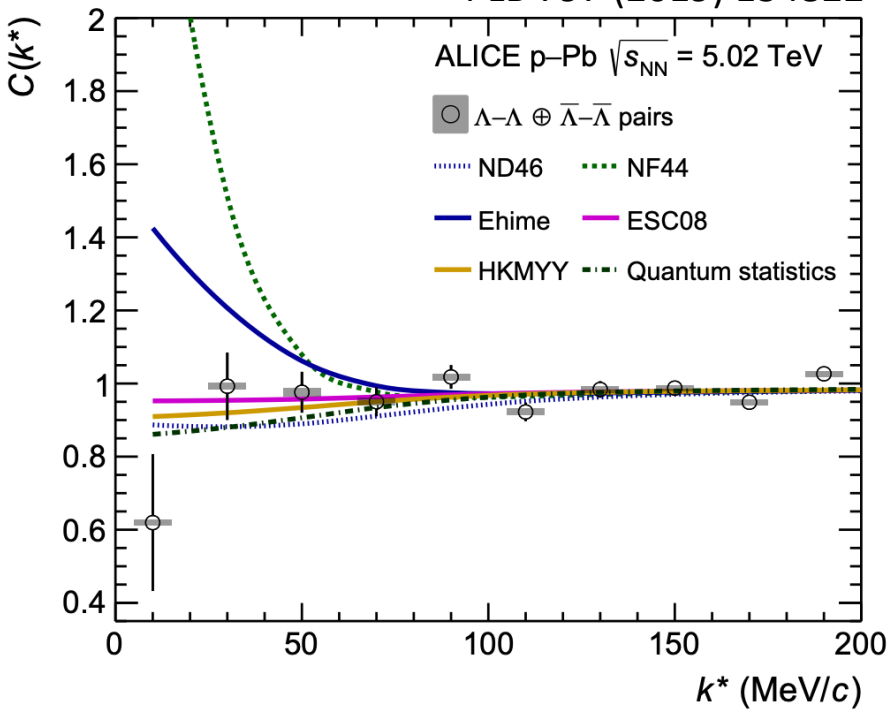


A signal for identical particles when close in space?
Hmmm… Hanbury-Brown-Twiss correlations?

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

PLB 797 (2019) 134822



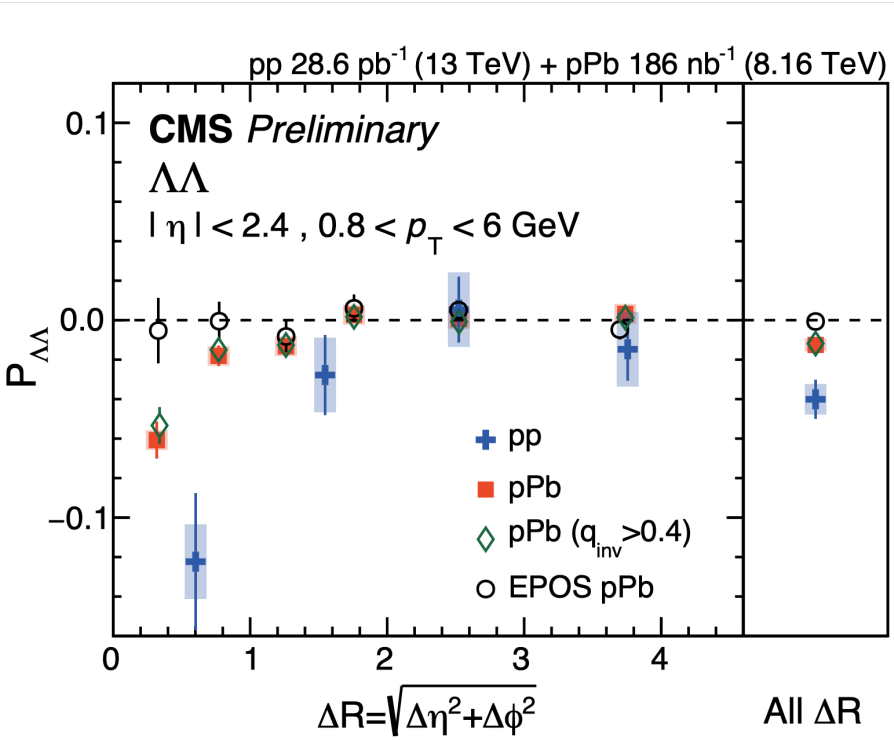


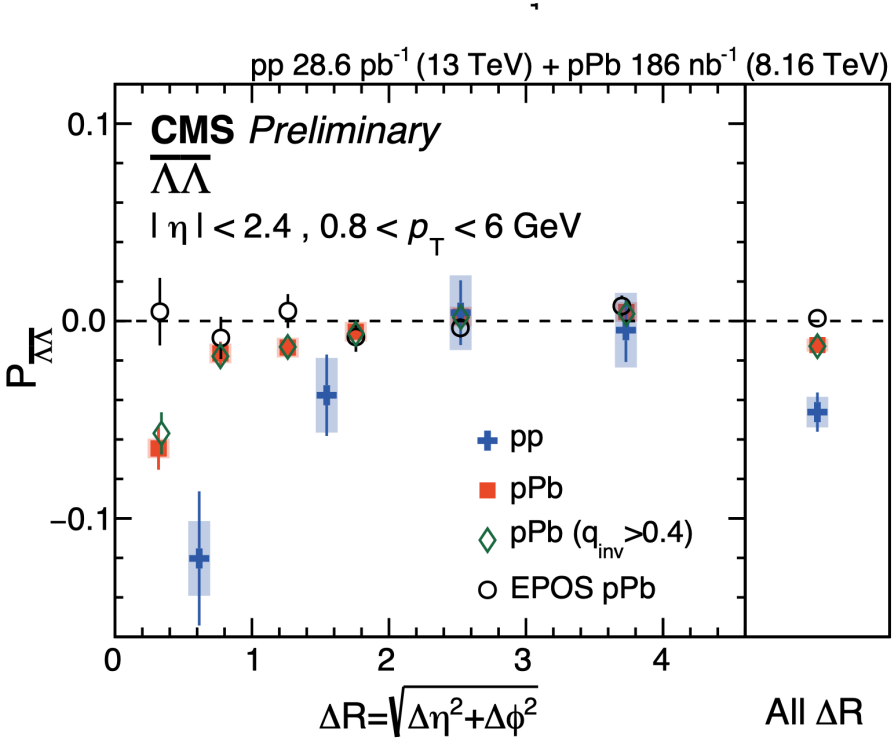
A signal for identical particles when close in space?

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

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

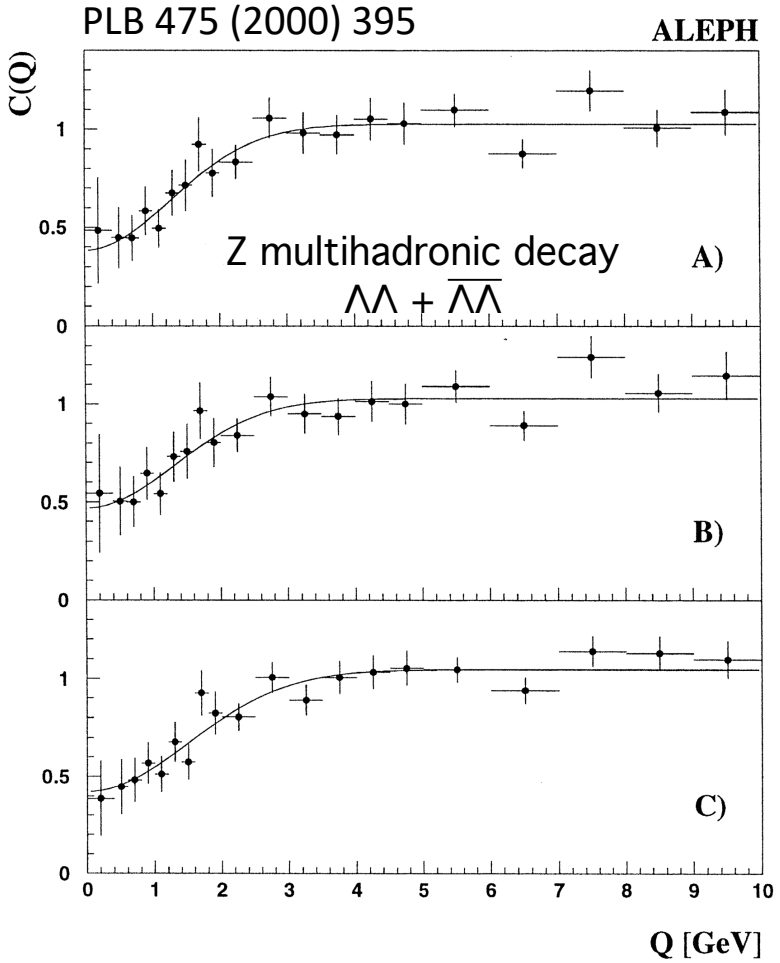


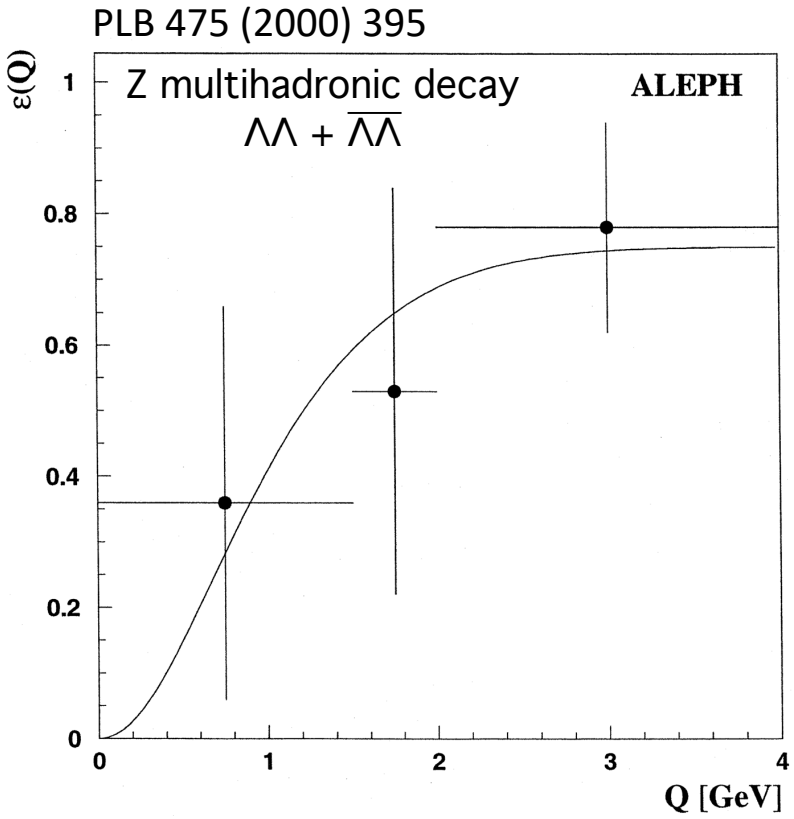


A signal for identical particles when close in space?
Hmmm… Hanbury-Brown-Twiss correlations?
Typical HBT effects are at k* < 0.2 GeV (q_{inv} < 0.4 GeV)

Results with q_{inv} > 0.4 GeV consistent with default
Indicate the signal is not dominated by simple HBT effects

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



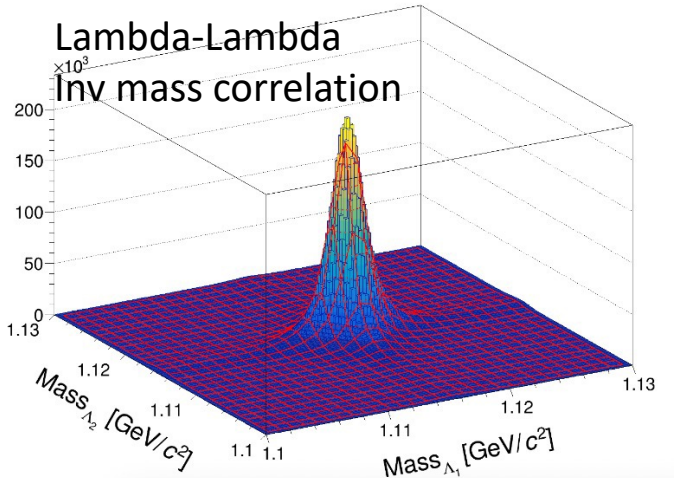


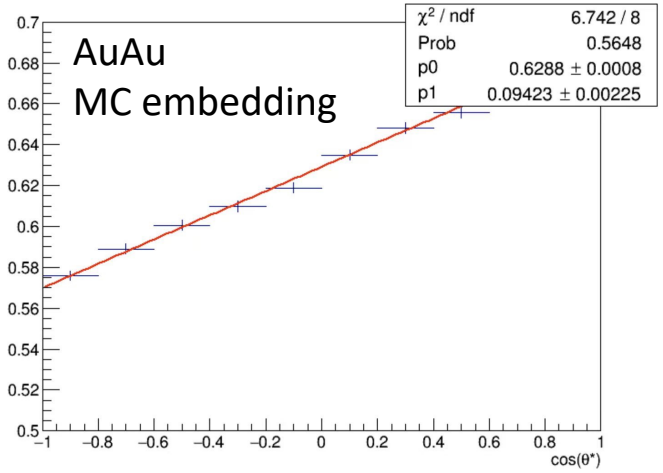
Results with q_{inv} > 0.4 GeV consistent with default

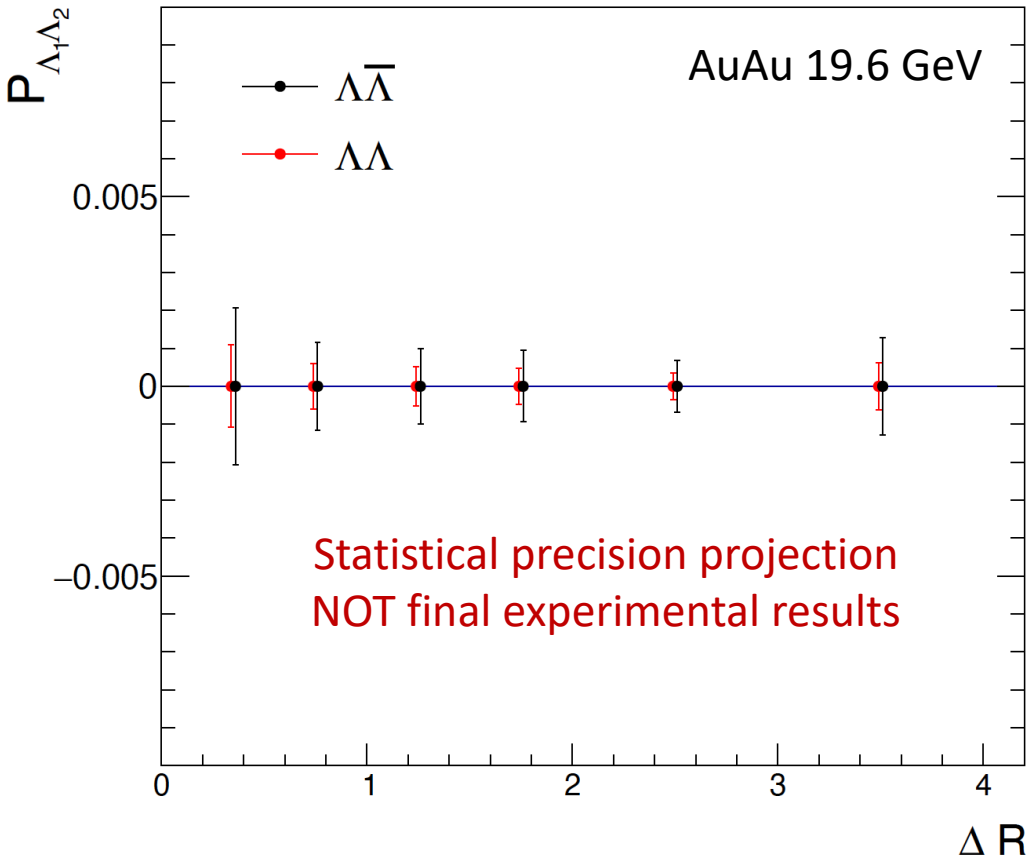
Indicate the signal is not dominated by 'simple' HBT effects

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

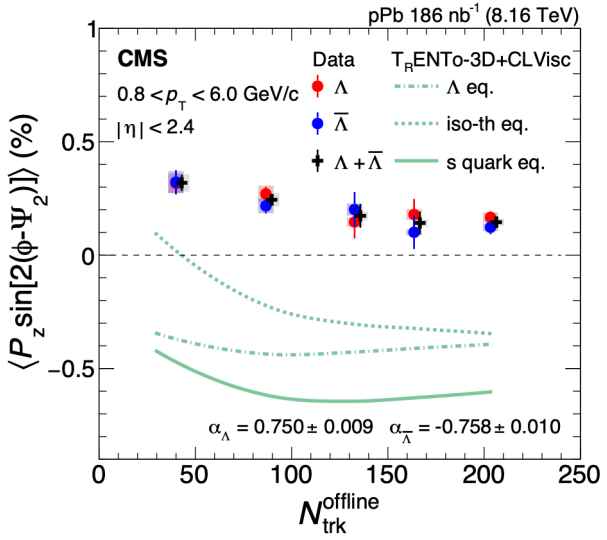
Summary

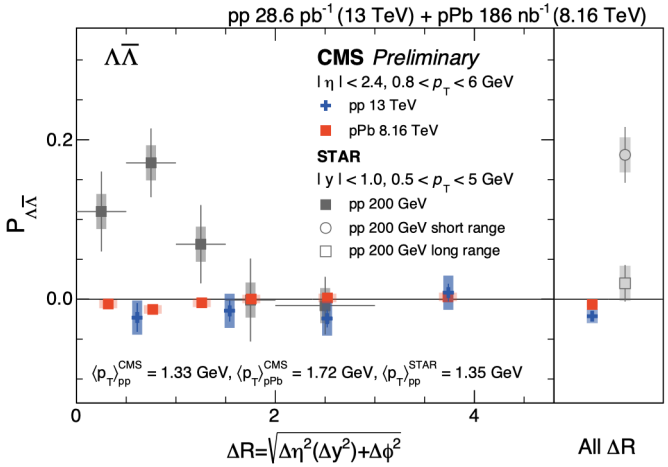
Local Polarization: The pPb results challenge a simple hydrodynamic-expansion picture, pointing to an interplay of different polarization mechanisms and/or a more complex response to the initial state

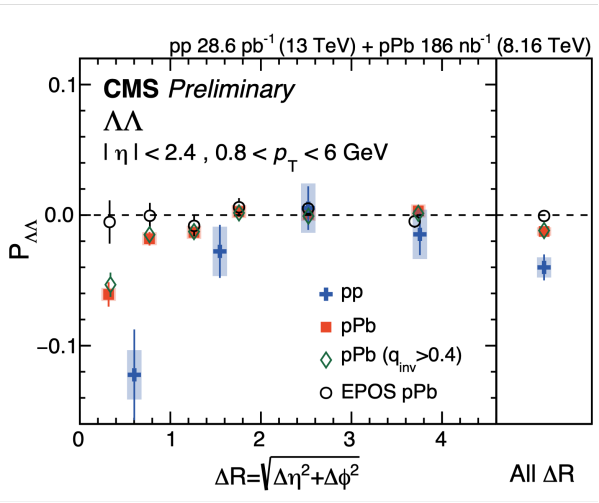
Spin correlation: The tension between RHIC and LHC results suggests a nontrivial dependence on collision conditions that is not yet understood

Systematic scans in collision system and energy can provide important clues to both open questions

As always, stay tuned for more results!



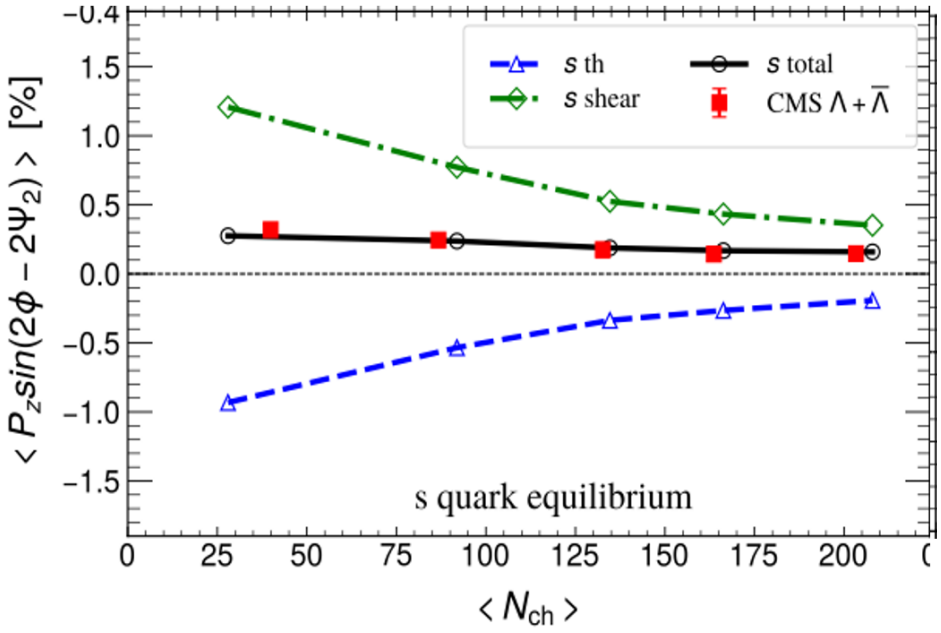




Back up

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

Taken from Shi Pu & Cong Yi

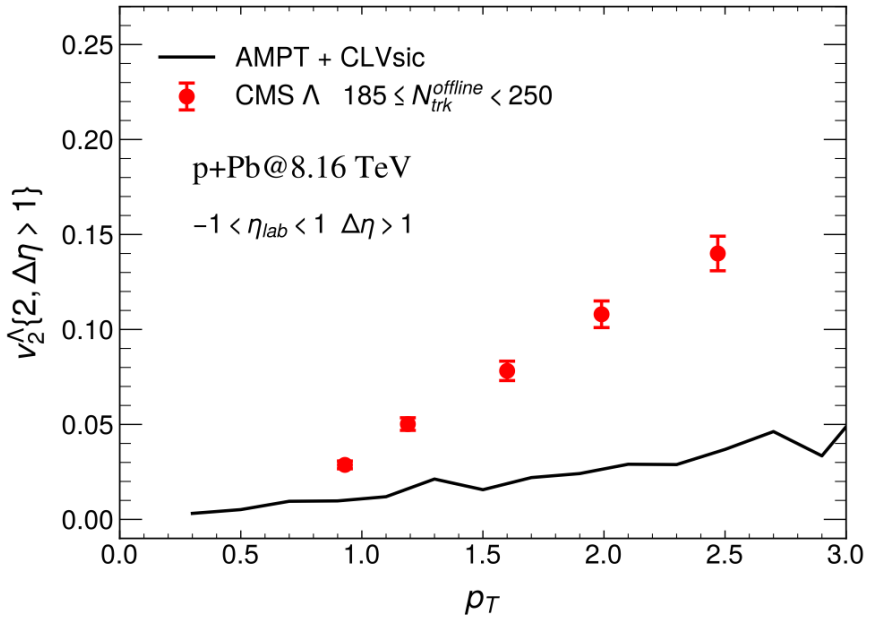


Hydro calculations result in negative Pz

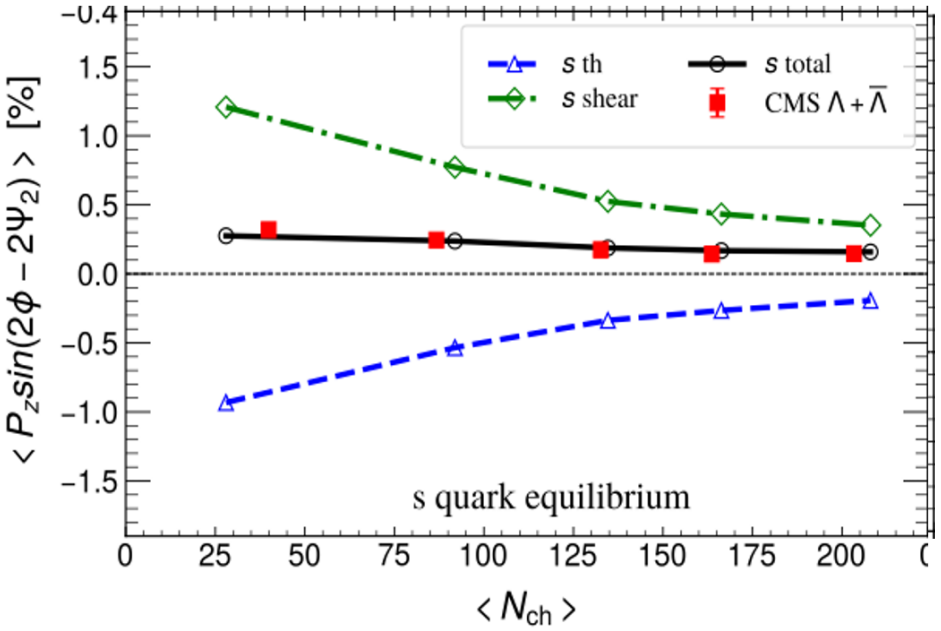
Different contributions in small systems need to be understood further

Tune the model to reproduce Pz

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



Taken from Shi Pu & Cong Yi

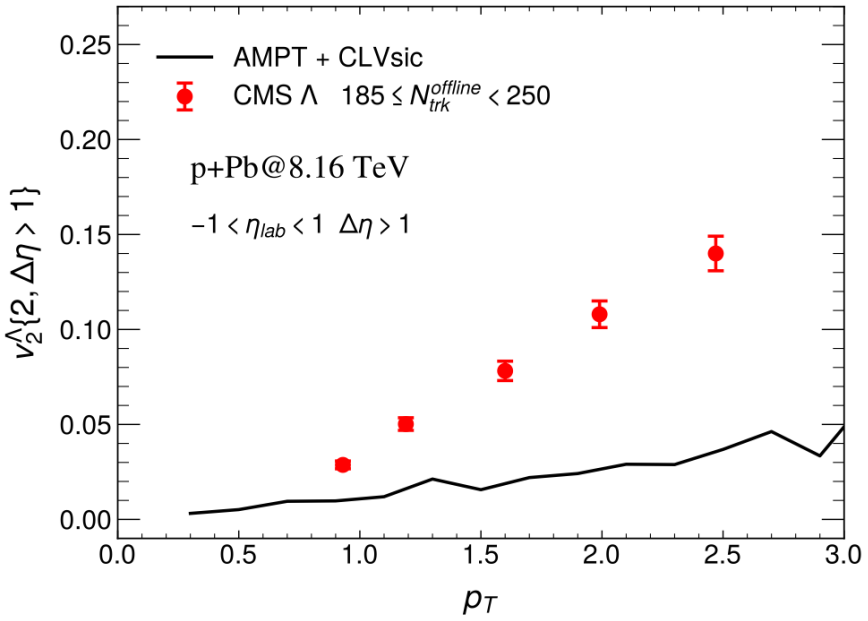


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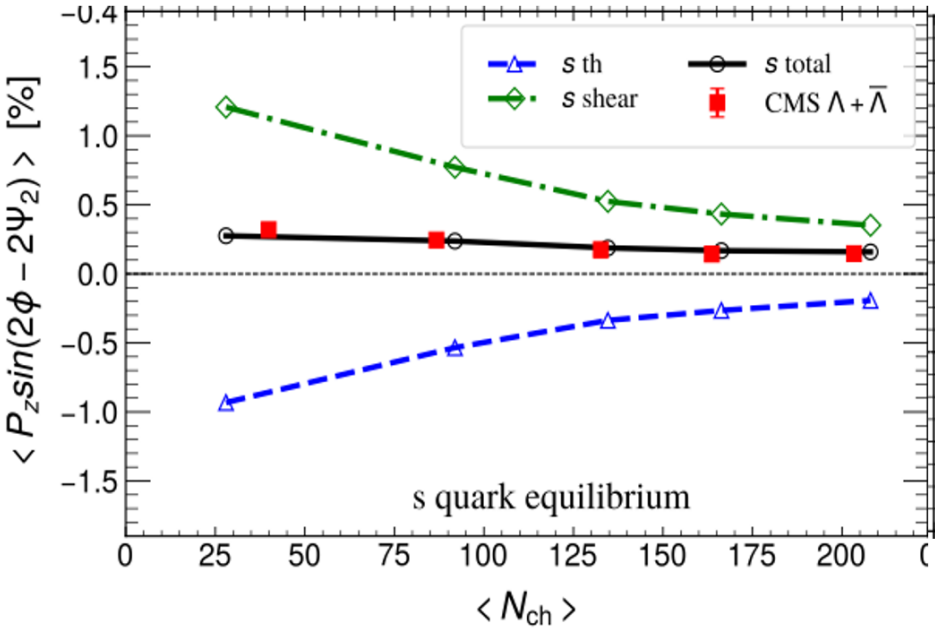
Different contributions in small systems need to be understood further

Tune the model to reproduce Pz results in too small v2

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



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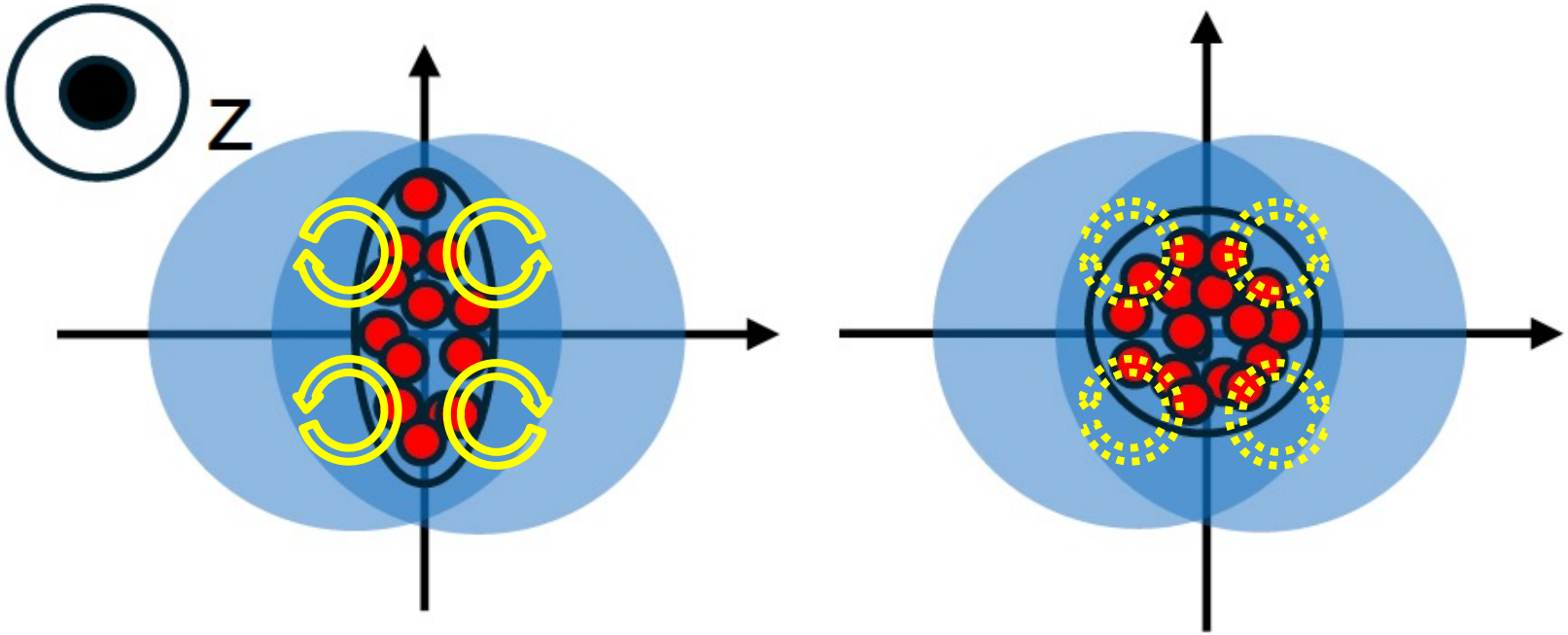
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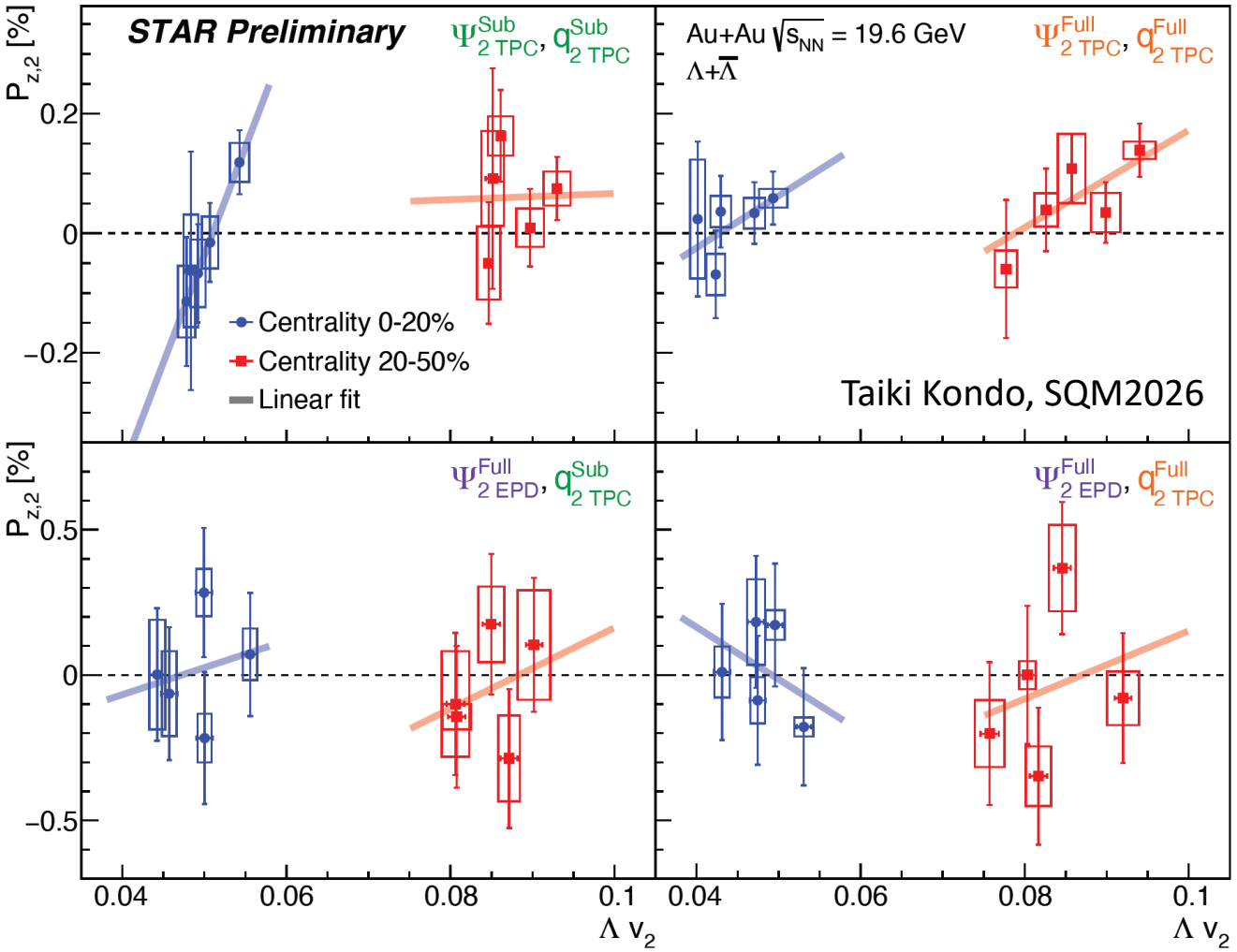
Both related to initial geometry but different response?

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



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

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

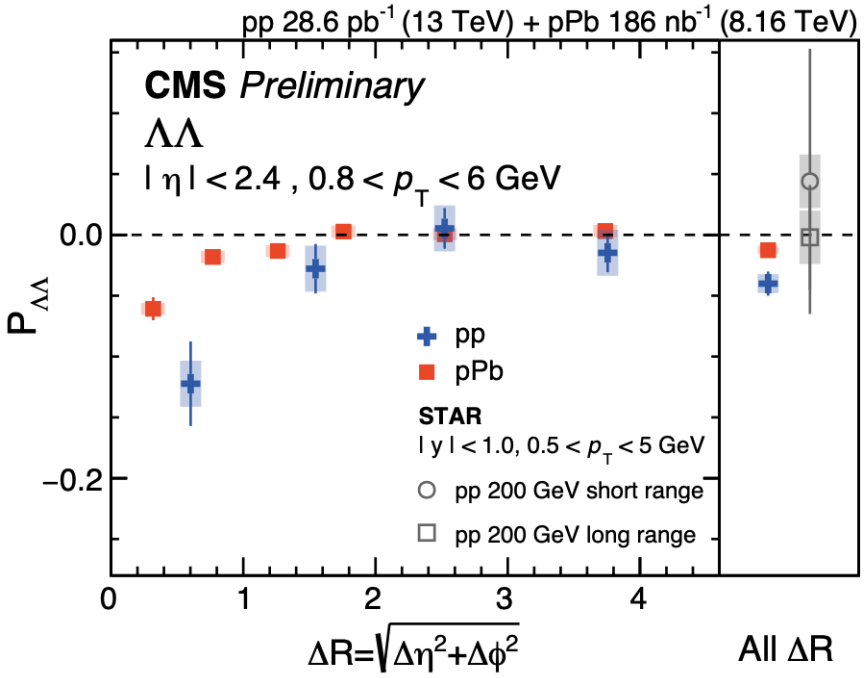


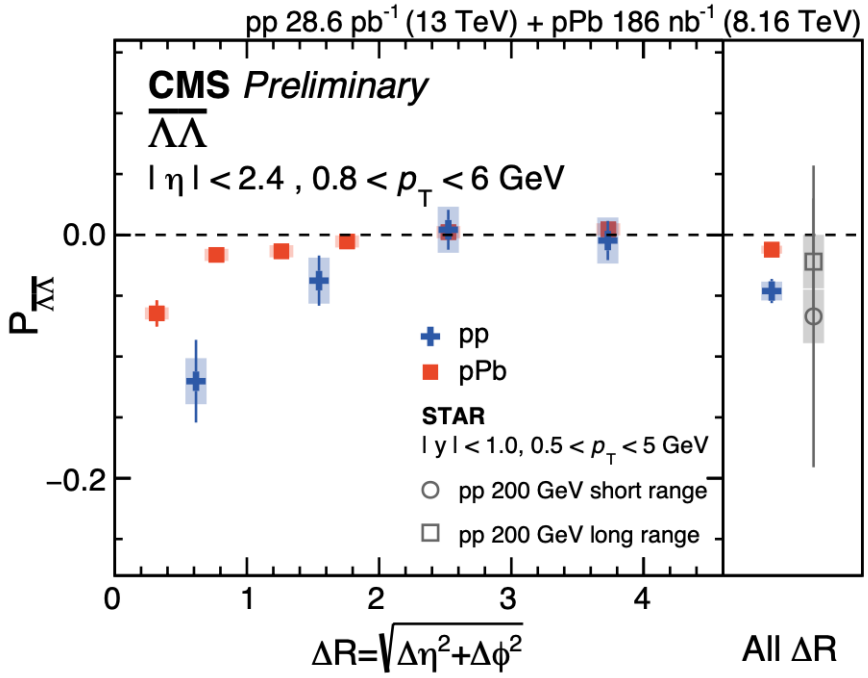
Does $P_{z,s2}$ change with v_2?

The results in 19.6 GeV AuAu shows a hint

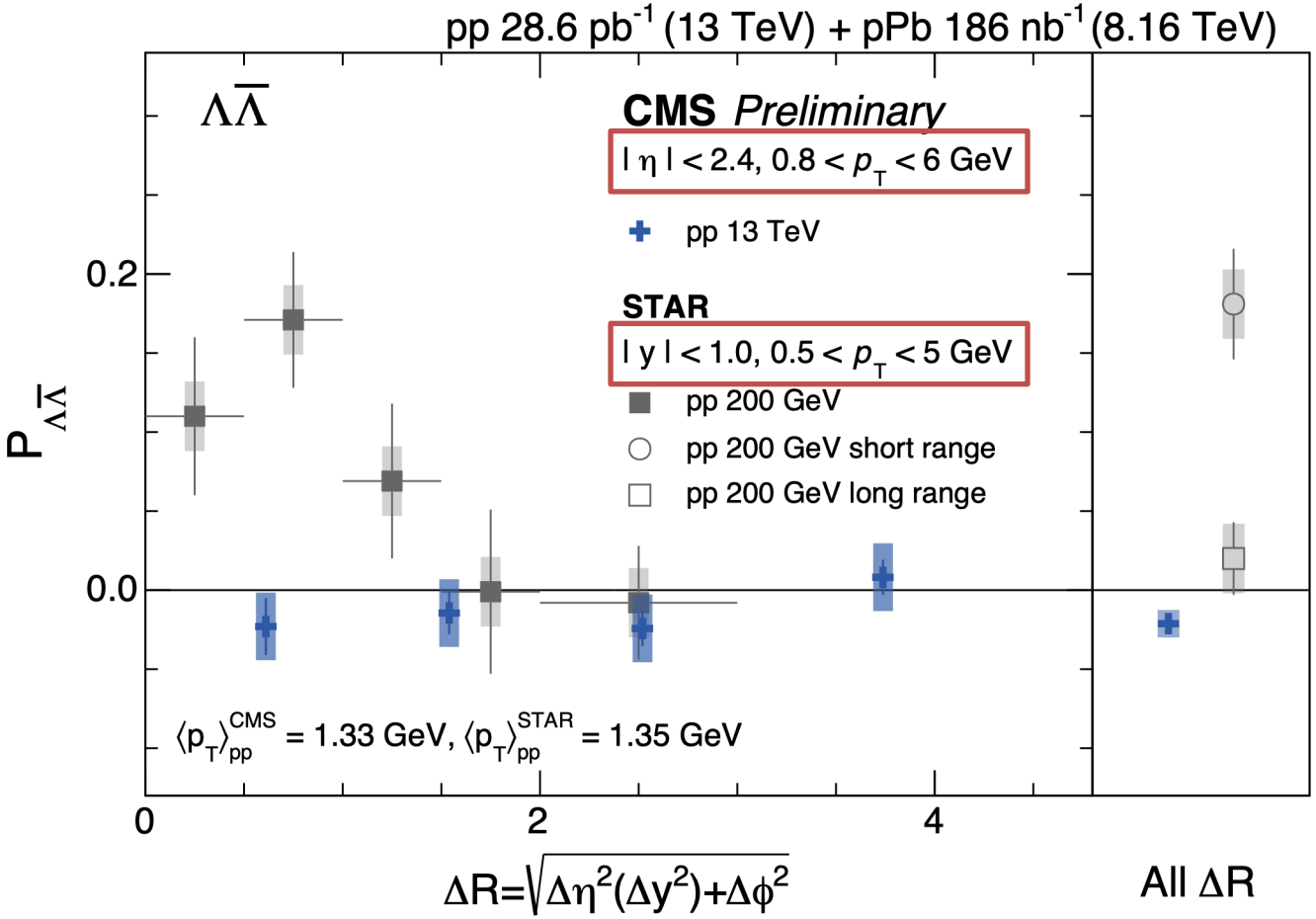
Works on-going to extend to higher energies & small system

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





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



From kinematics difference?

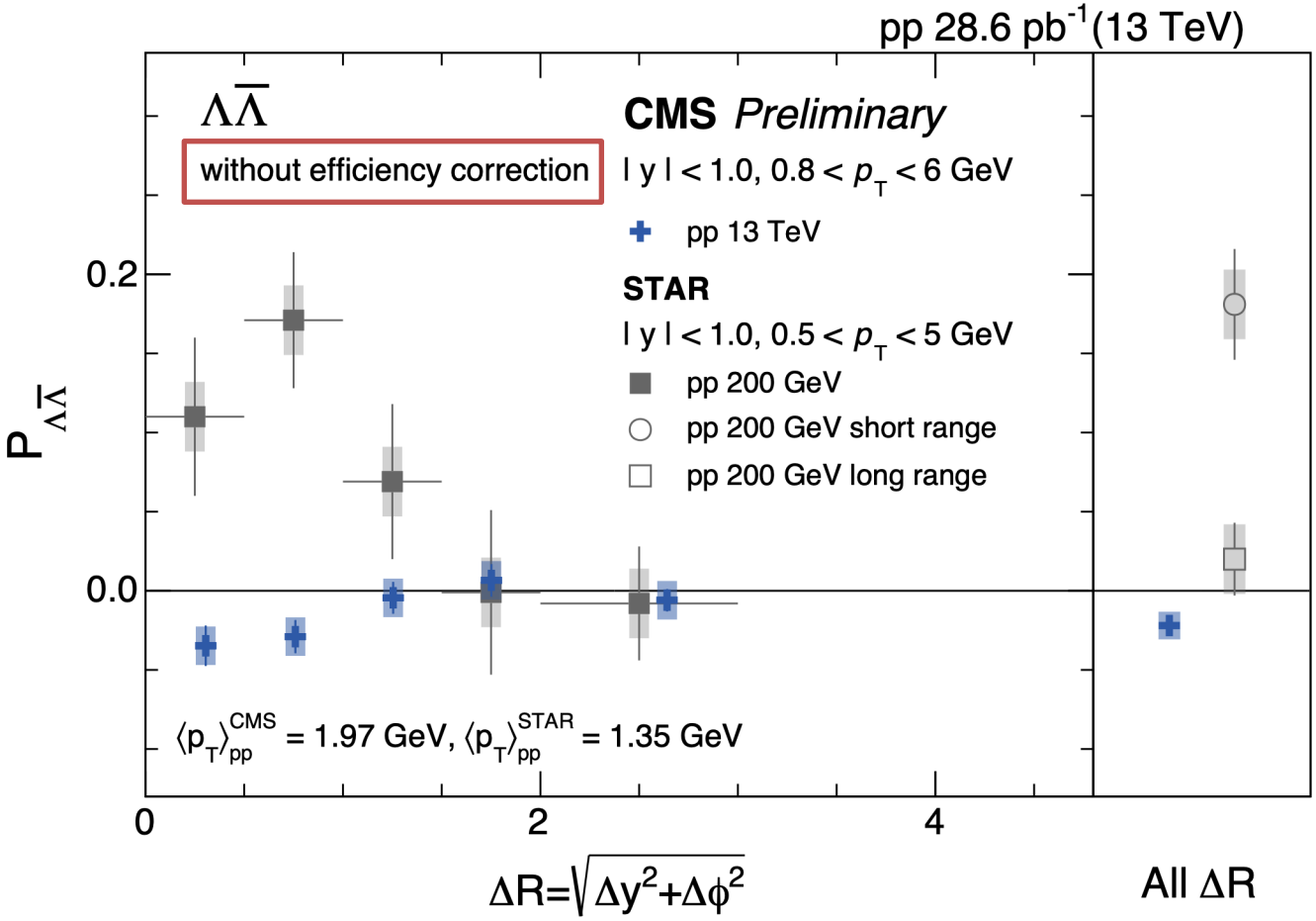
ΔR differential results consistent with zero within uncertainties

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