自旋关联实验测量进展

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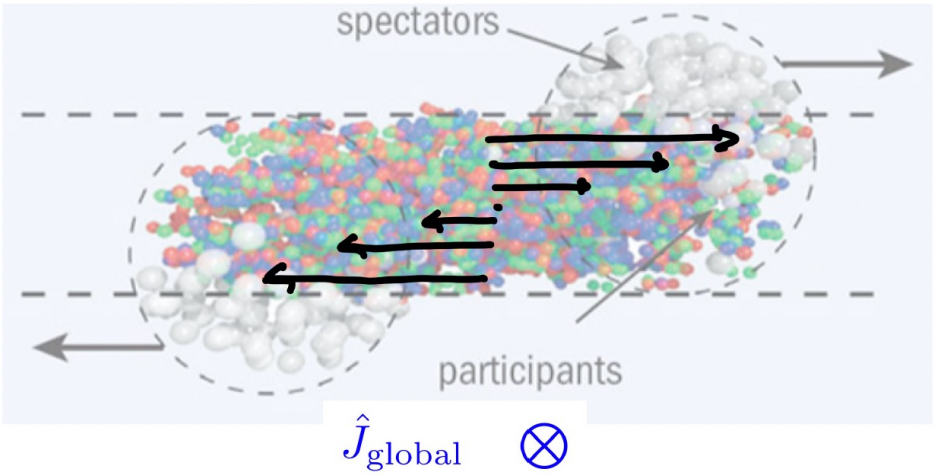
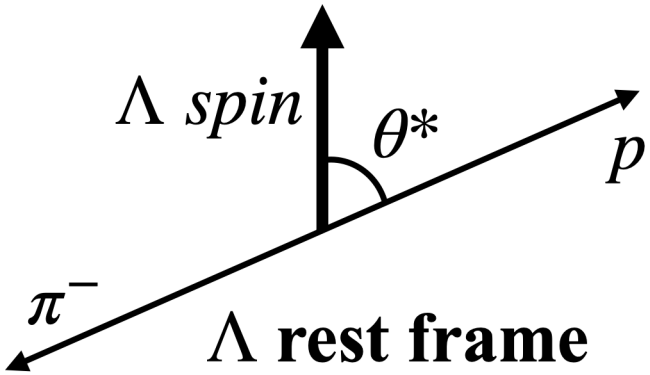
Shandong University 山东大学

第一届强相互作用自旋物理会议

"The most vortical fluid"



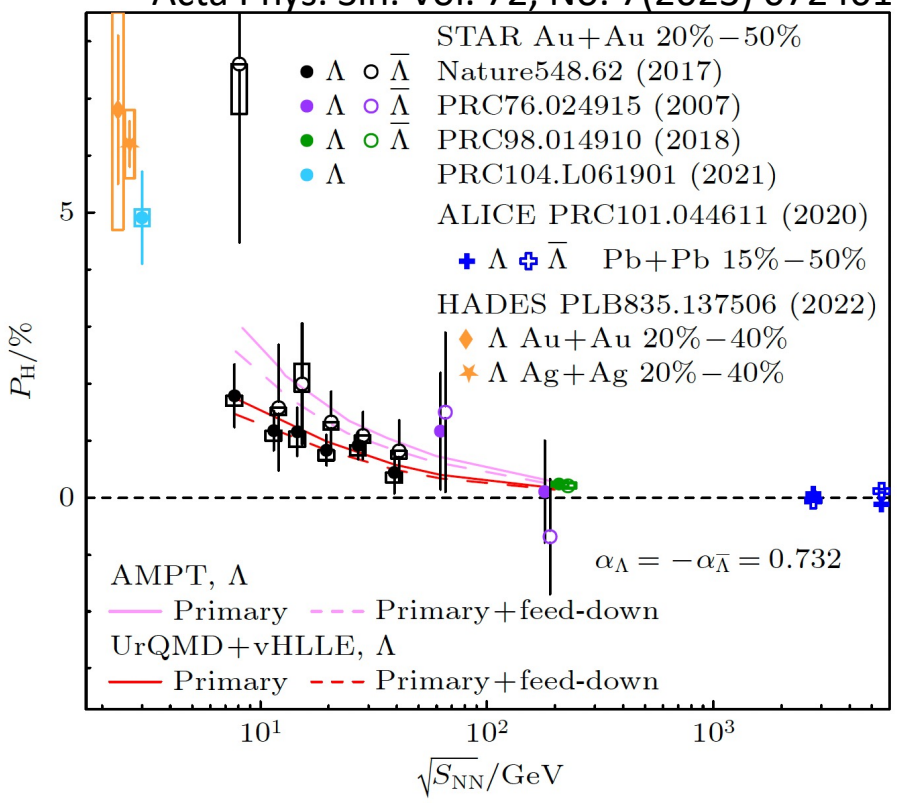


Large initial orbital angular momentum
Can polarize particles through spin-orbit coupling

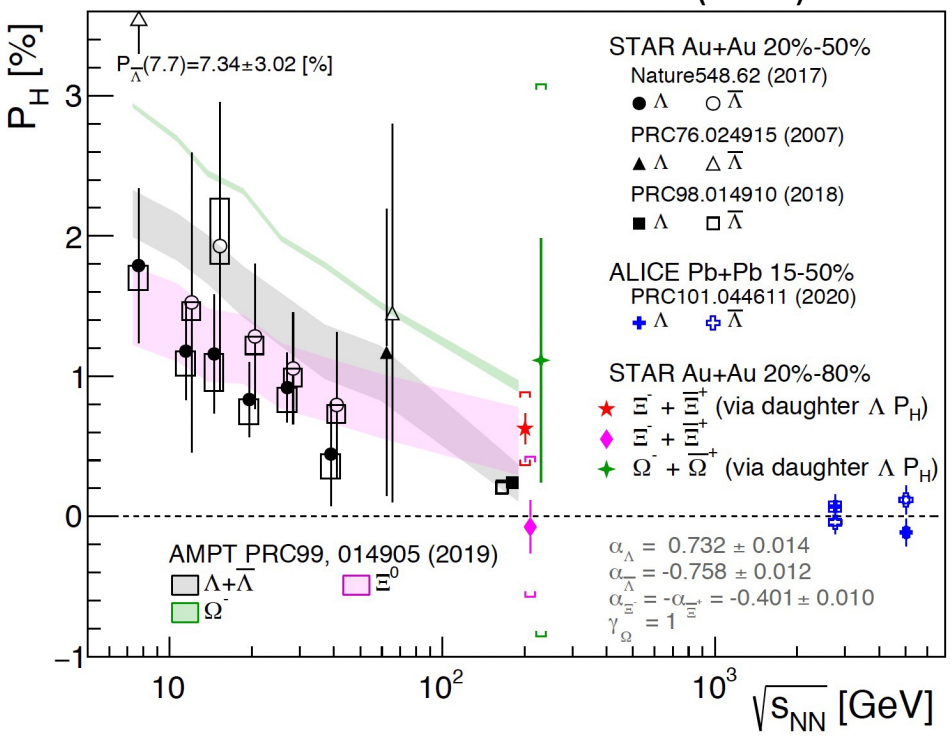
Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)

"The most vortical fluid"

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



PRL 126 (2021) 162301



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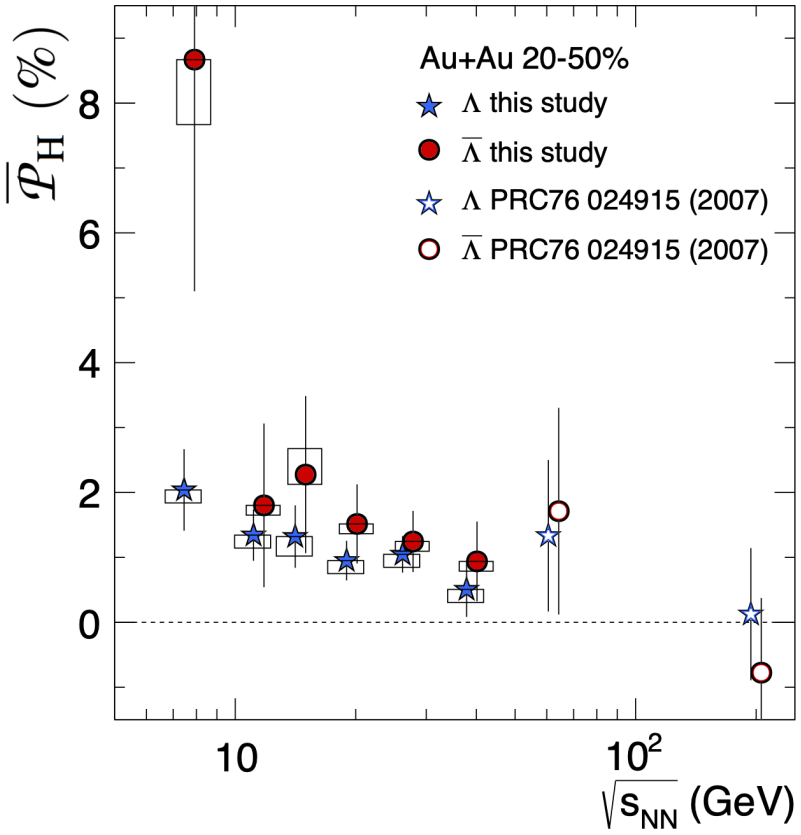
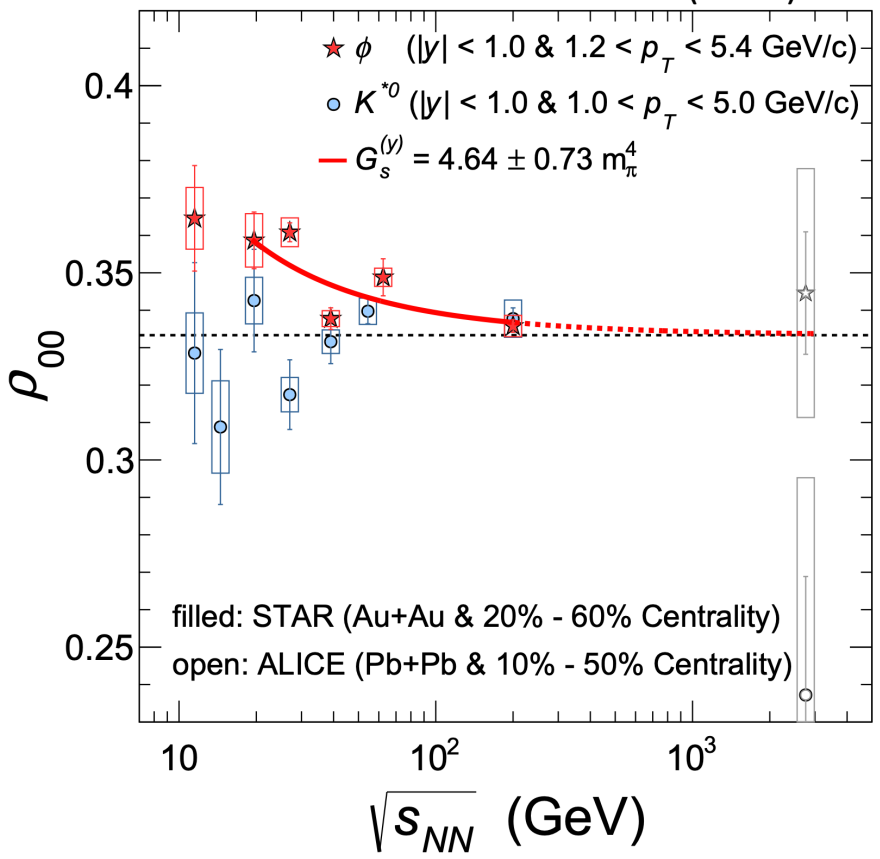
Largest vorticity ever seen $\boldsymbol{\omega} \approx (9 \pm 1) \times 10^{21}\ \mathrm{s}^{-1}$

Global polarization vs spin alignment

Nature 548 (2017) 62



Nature 614 (2023) 244

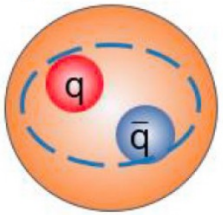


Global polarization and spin alignment in HI post a question why

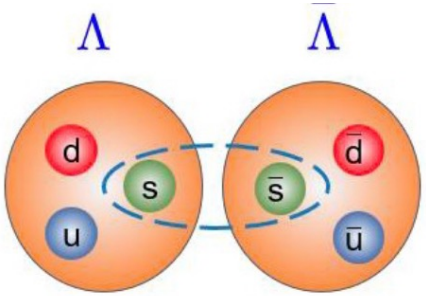
$$\left|\rho_{00}^{V} - \frac{1}{3}\right| \gg P_{\Lambda}^{2} \sim P_{q}^{2}$$

Spin correlation

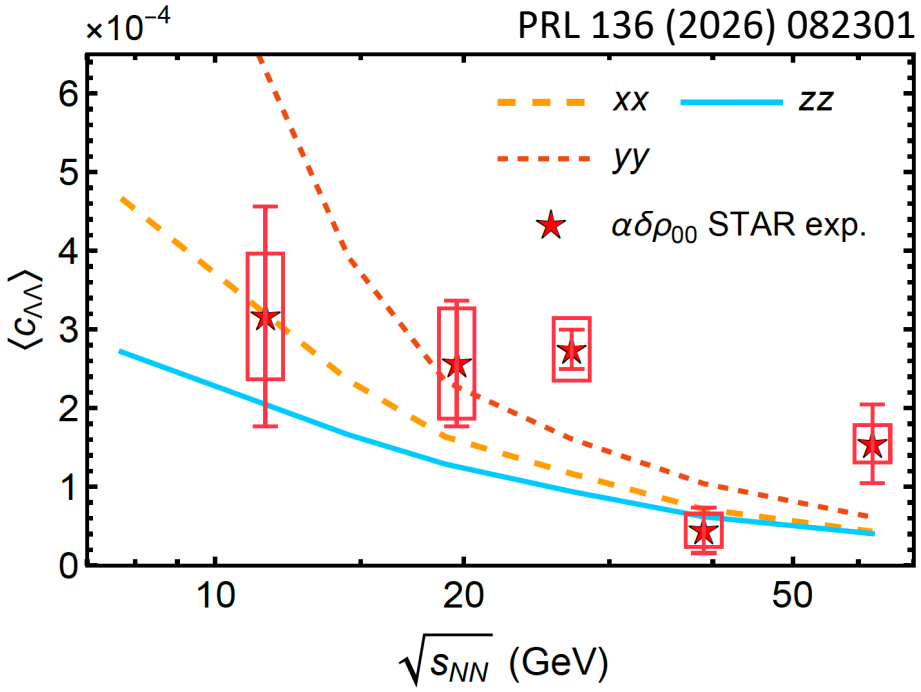
PRD 109 (2024) 114003



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



PRL 136 (2026) 082301



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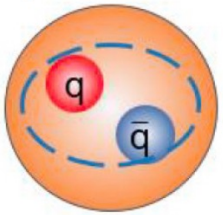
Spin-spin correlation proposed as a solution

Spin correlation

PRD 109 (2024) 114003



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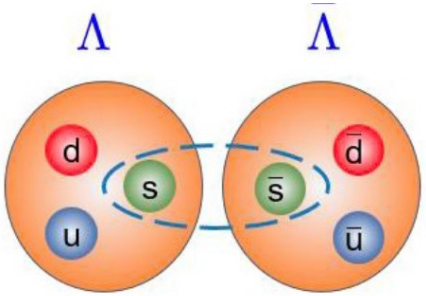

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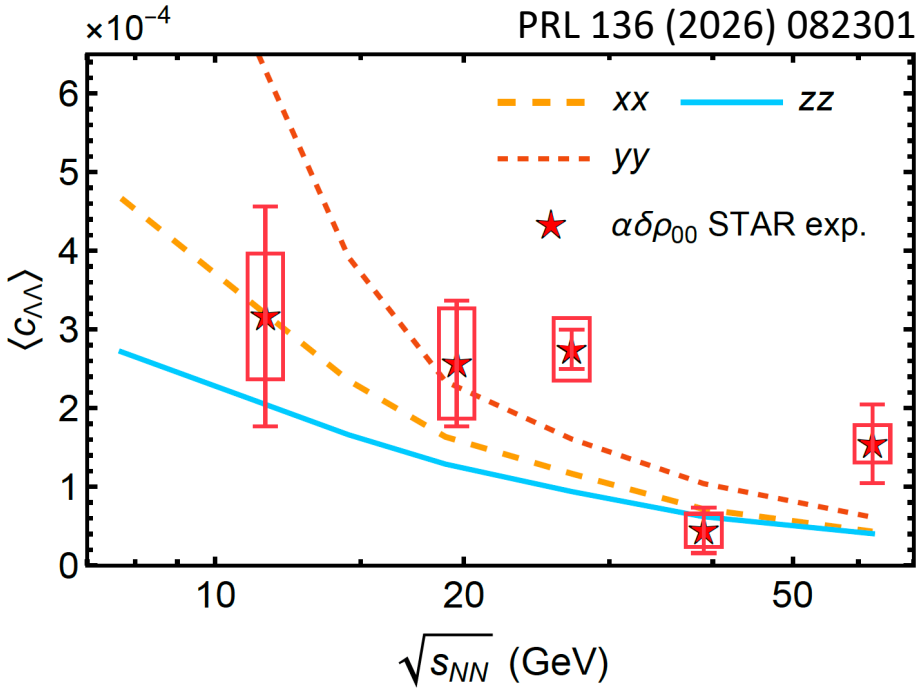


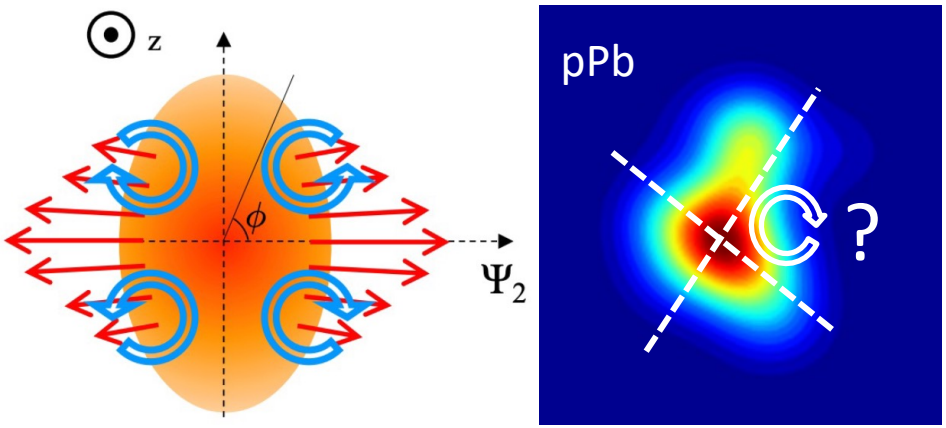
Global polarization and spin alignment in HI post a question why

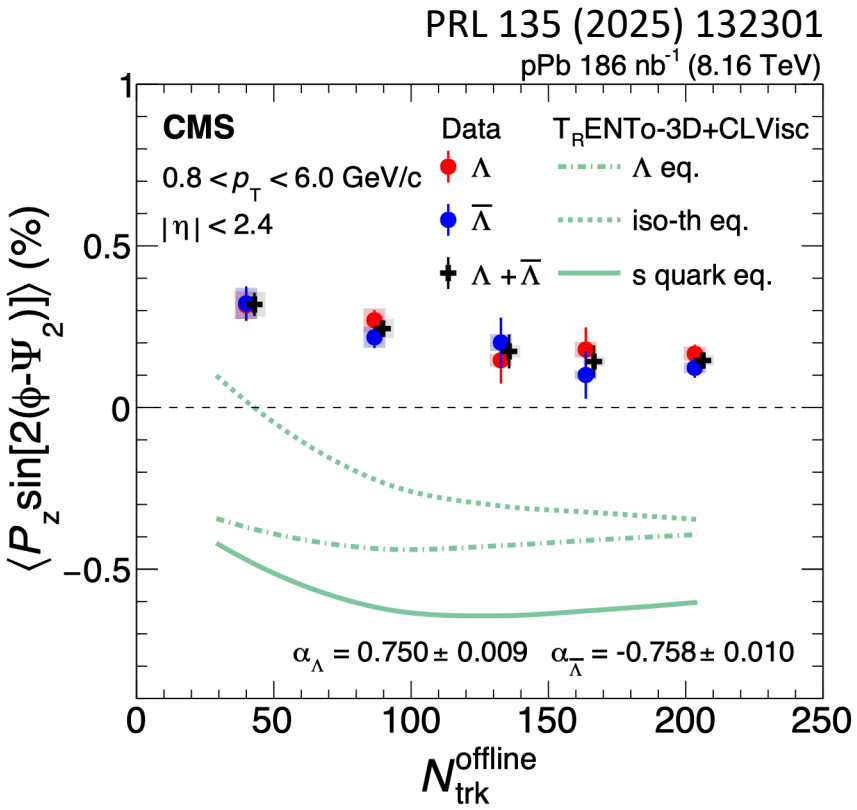
$$\left|\rho_{00}^{V} - \frac{1}{3}\right| \gg P_{\Lambda}^{2} \sim P_{q}^{2}$$

Spin-spin correlation proposed as a solution

Every HI-QGP observable needs a 'vacuum' reference

Surprises when go small





Current models in AA collisions cannot reproduce the pPb Pz sign

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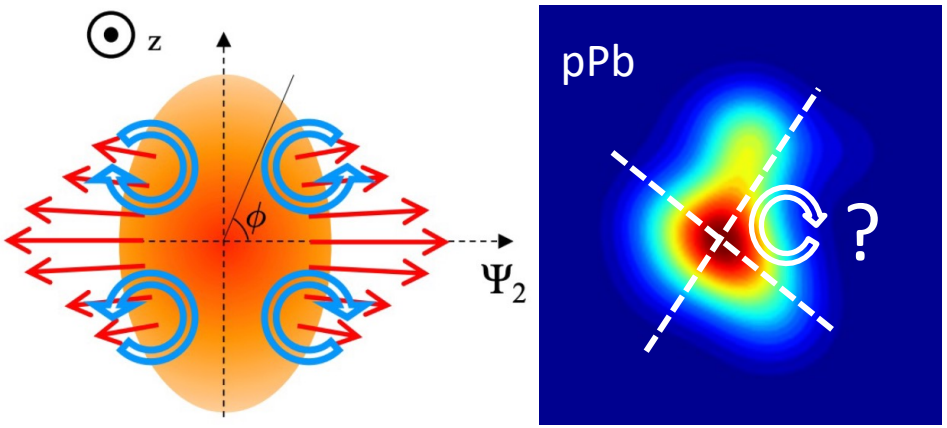

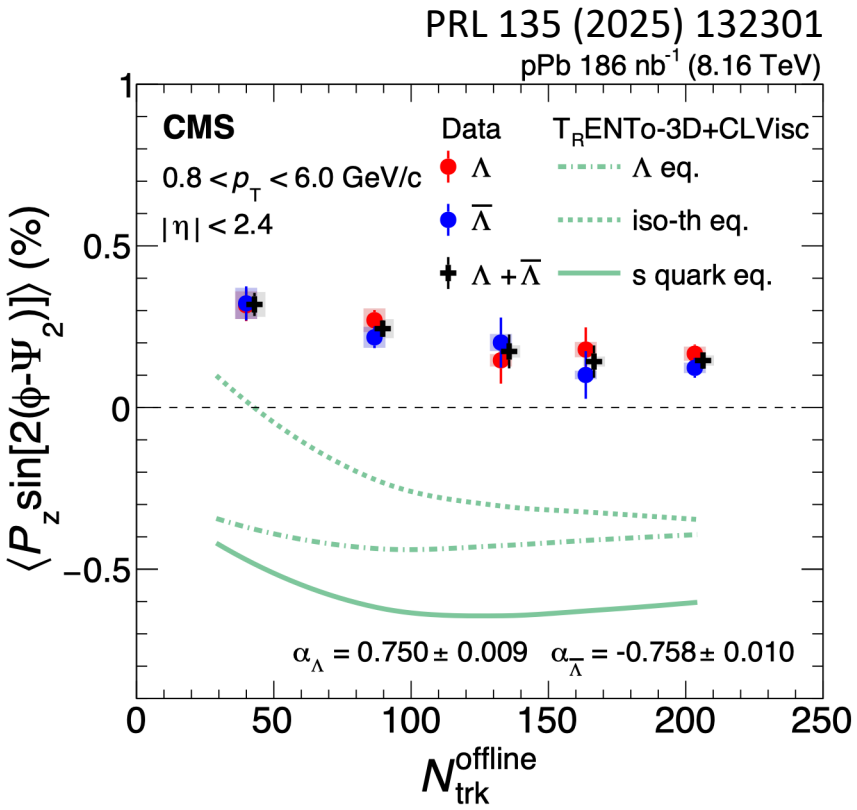

Current models in AA collisions cannot reproduce the pPb Pz sign

Indication of non-QGP/collective effects?

Revealed the importance of 'vacuum' reference

$P_{\Lambda,\Lambda}$ 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

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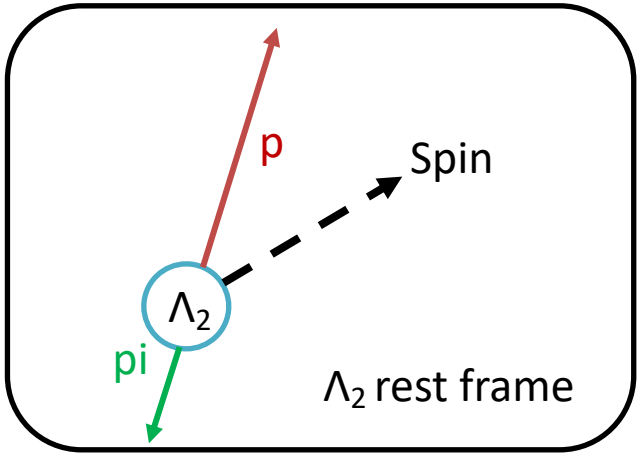

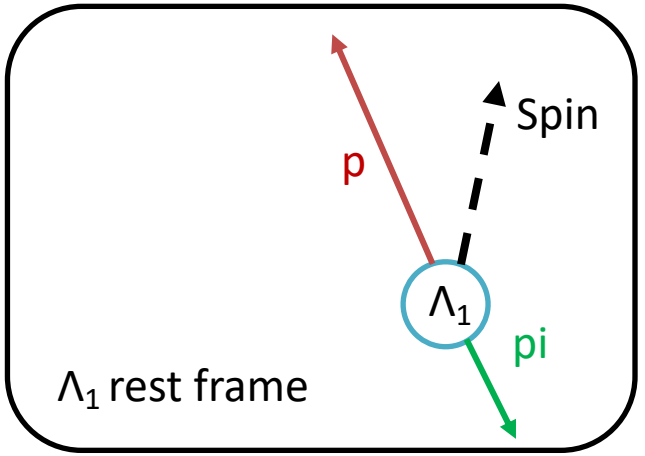

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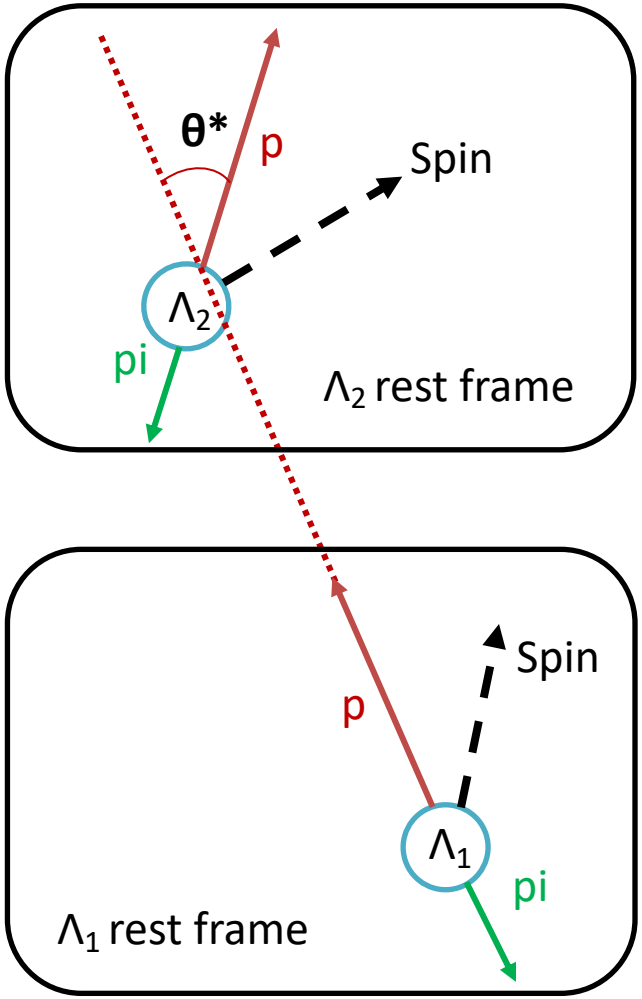

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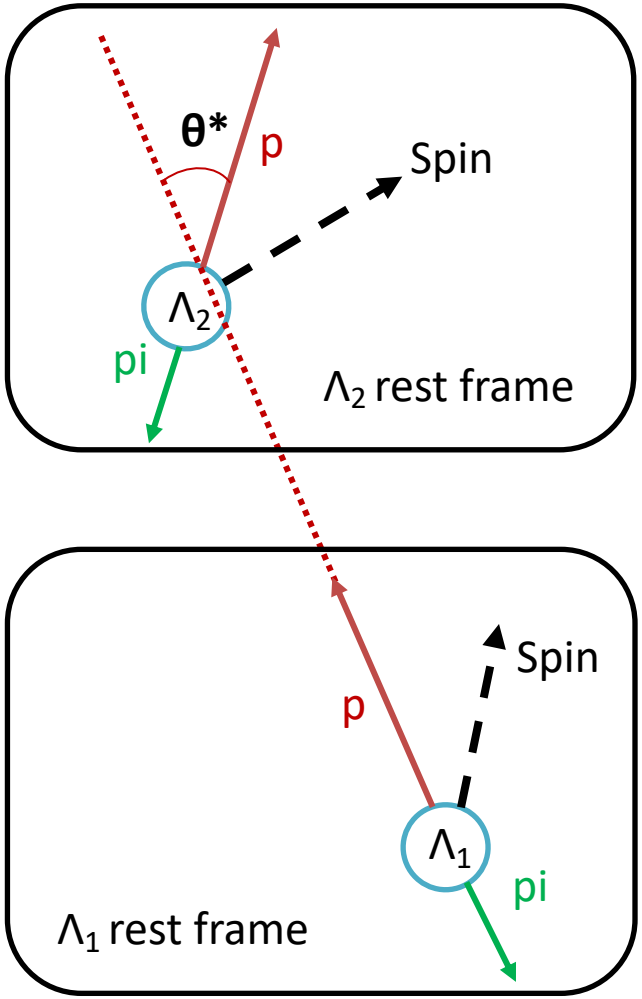


Hyperon pair cosθ* distribution extraction

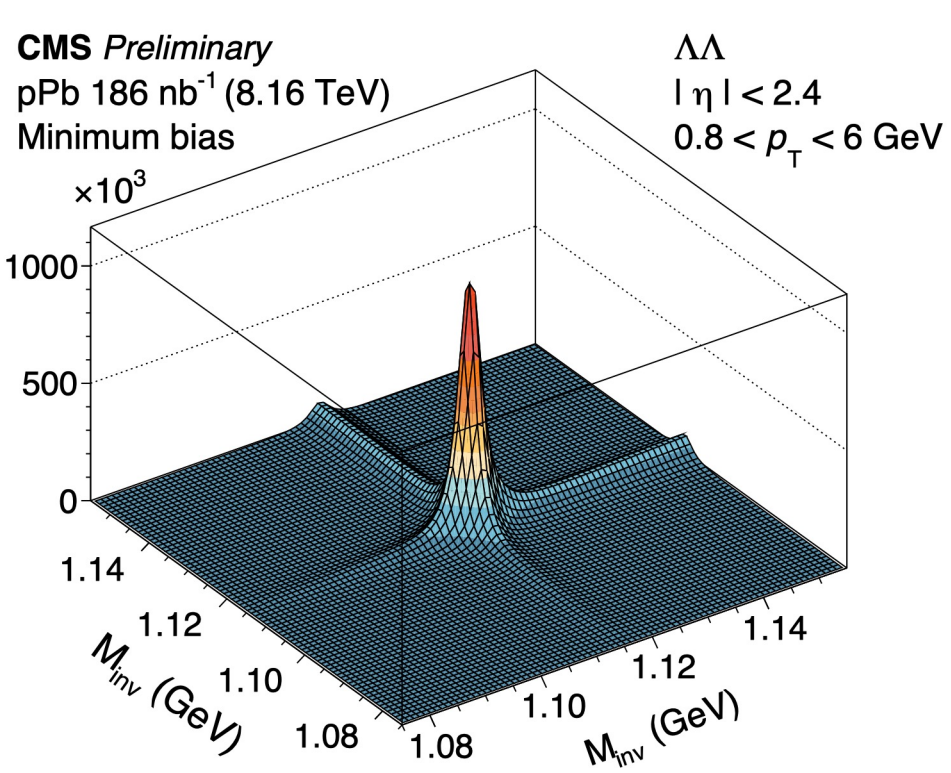
↓

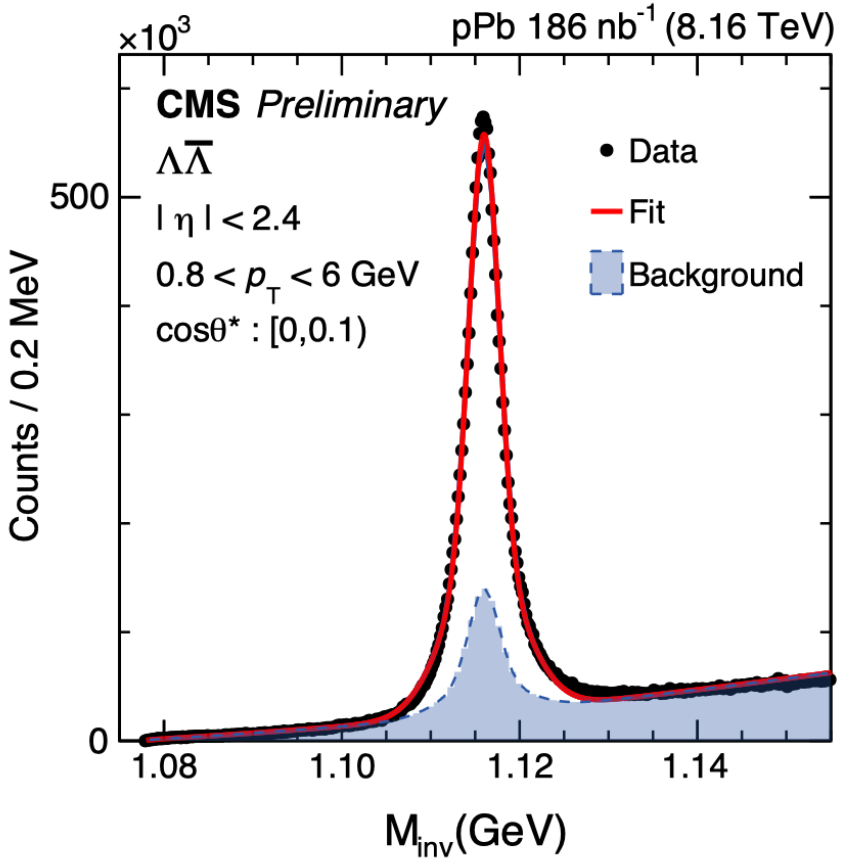
Acceptance correction

↓

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

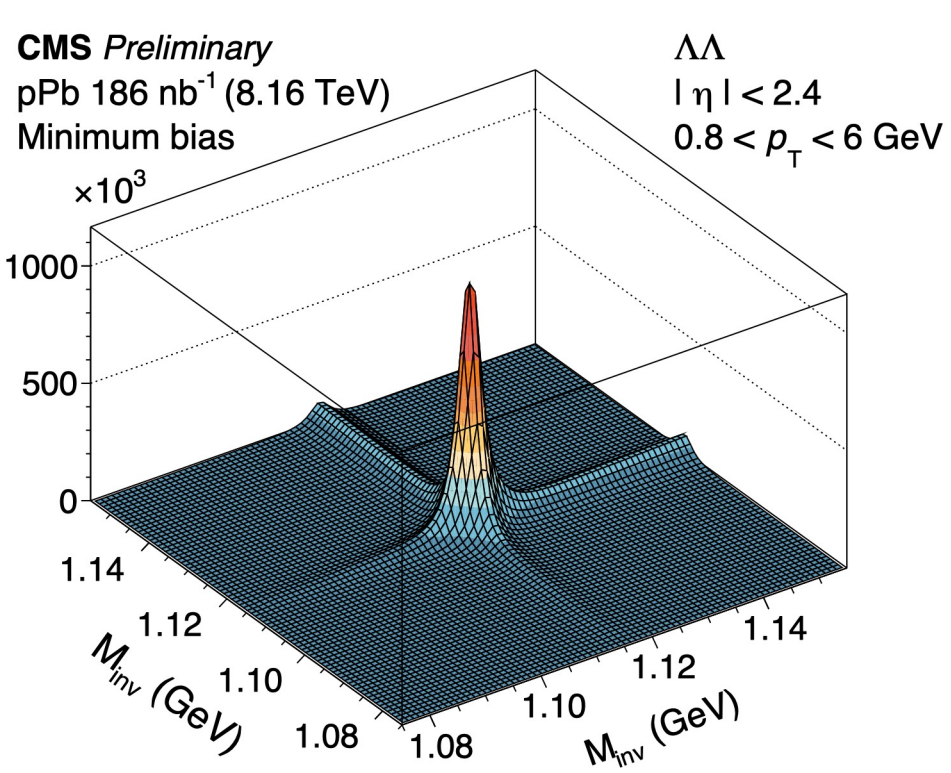
$P_{\Lambda,\Lambda}$ extraction - cosθ* distributions

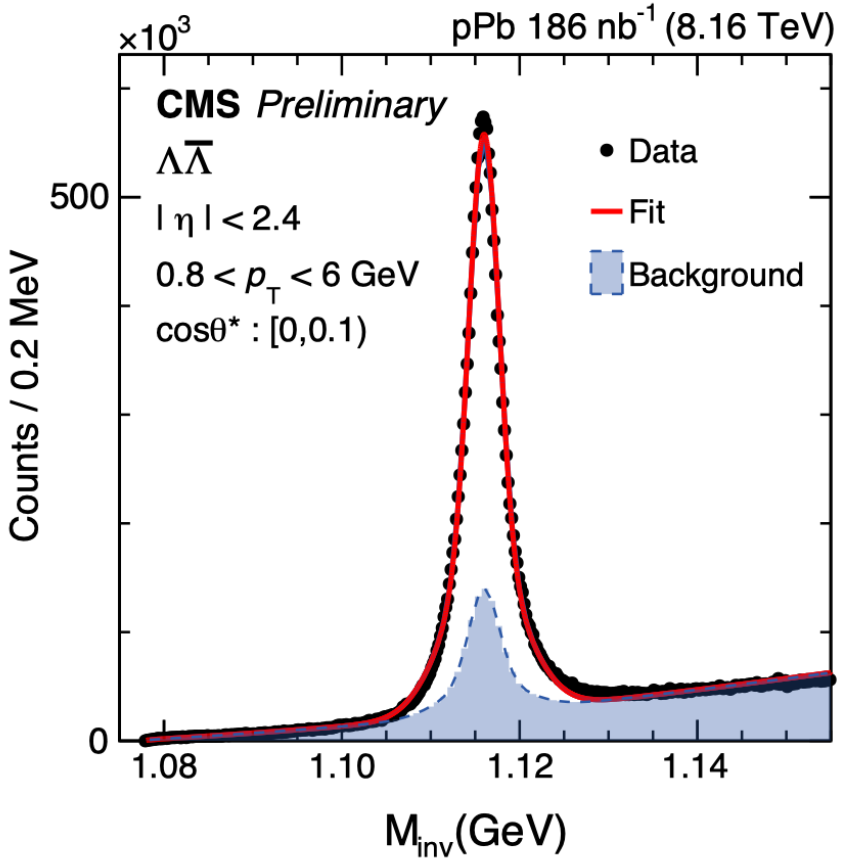




Yield of Λ pairs measured in cosθ* intervals

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

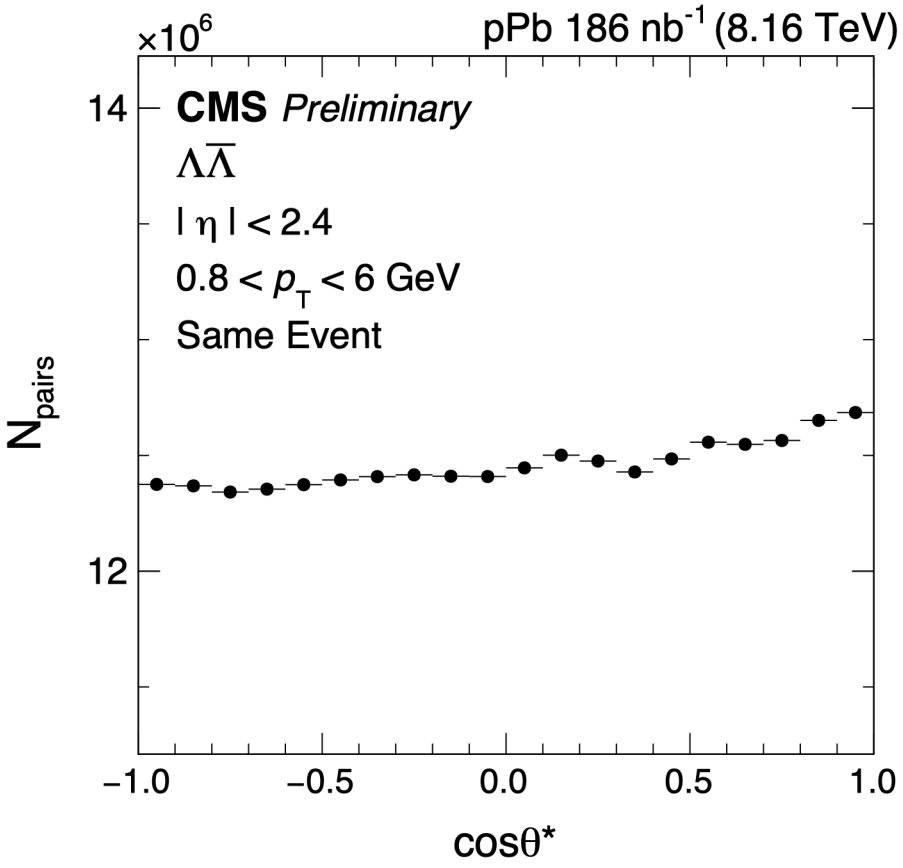




Yield of Λ pairs measured in cosθ* intervals

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

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



Yield of Λ pairs measured in cosθ* intervals

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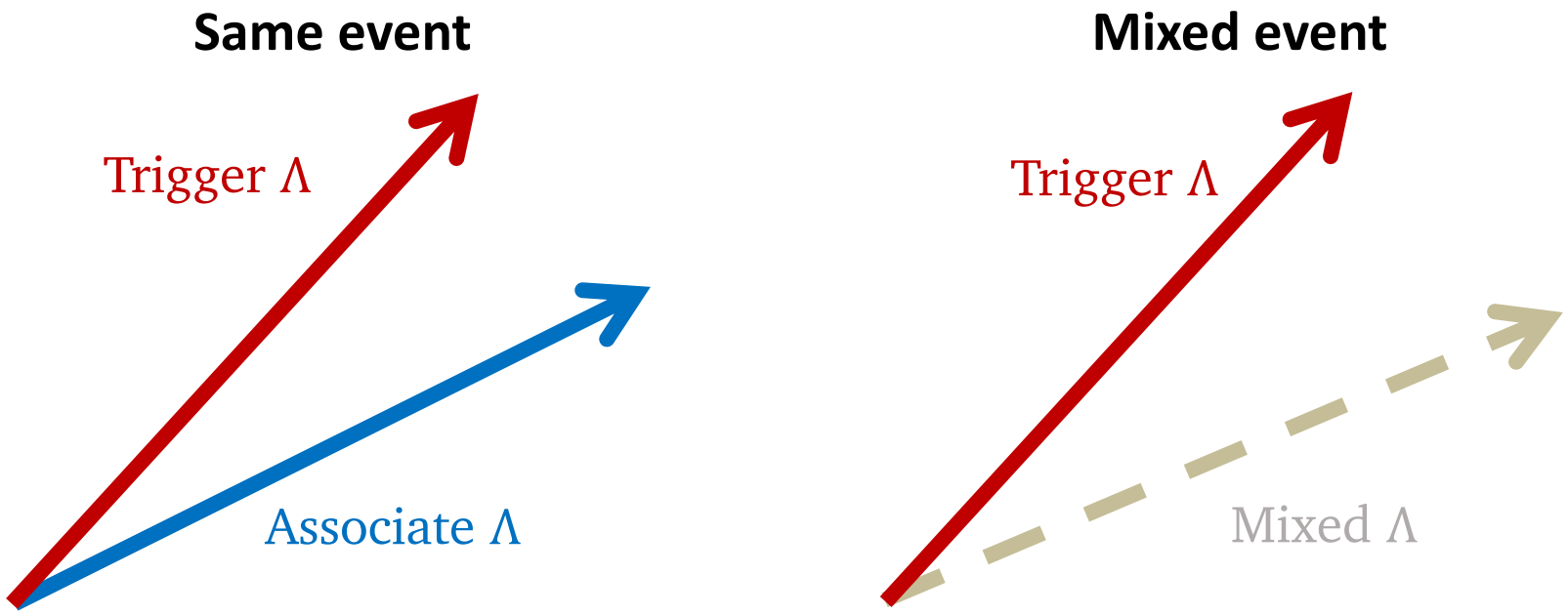
The cosθ* distribution is determined

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



A mixed event correction is implemented with requirements

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

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

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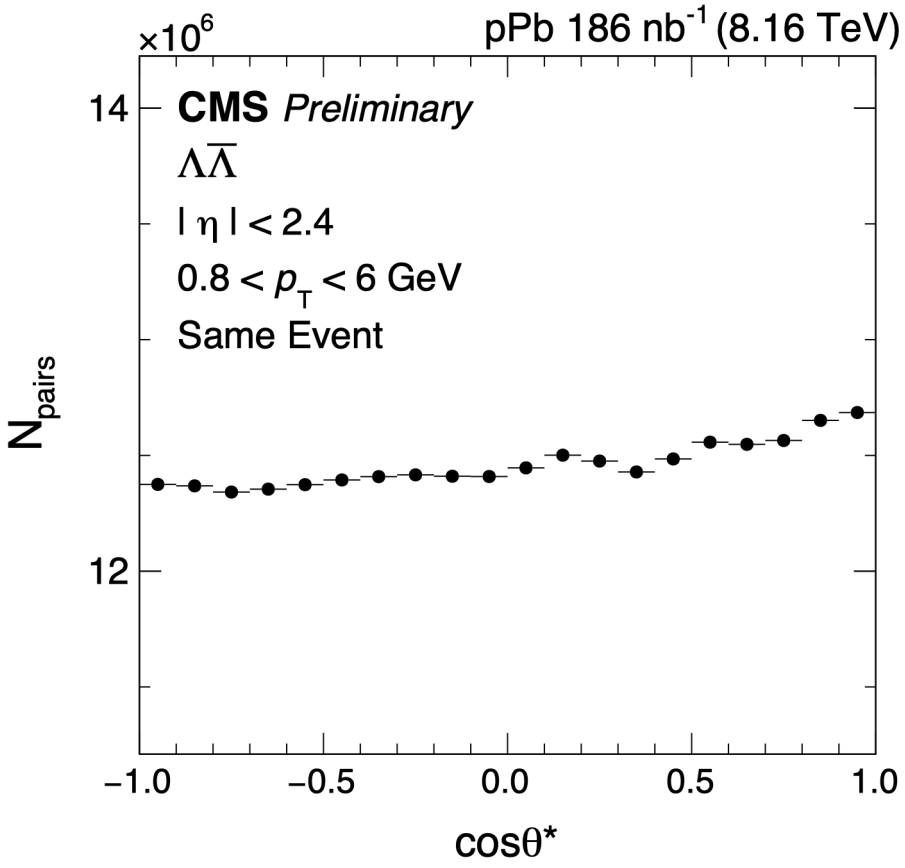

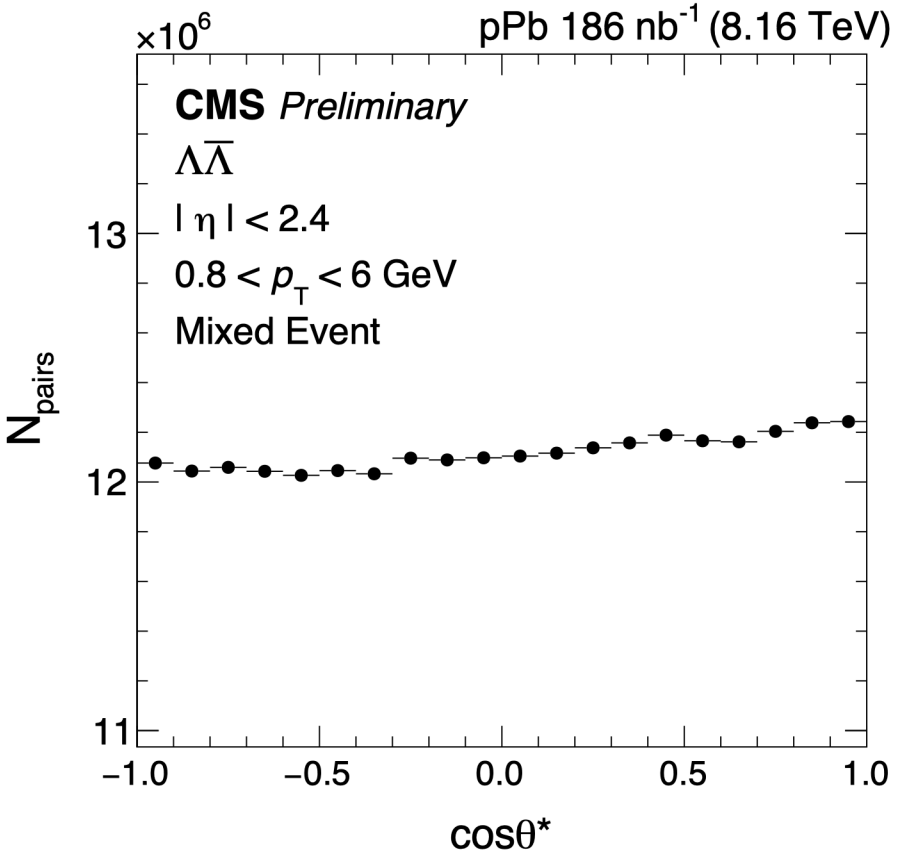

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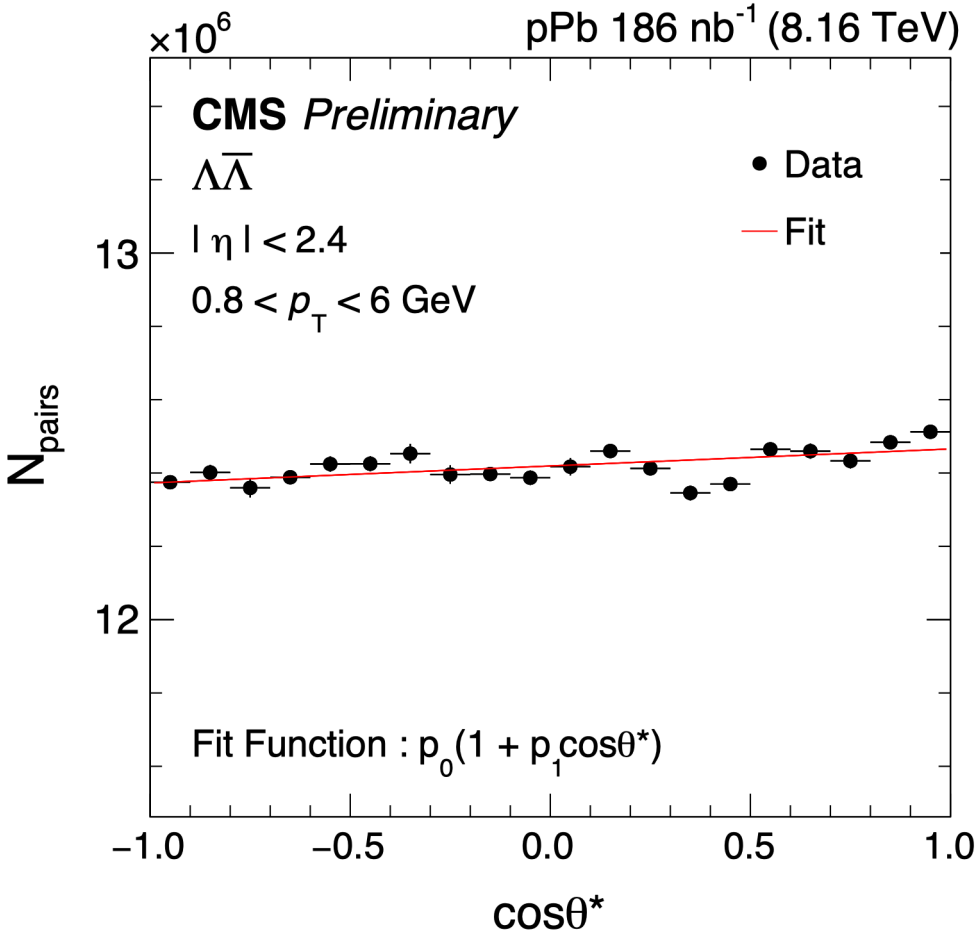
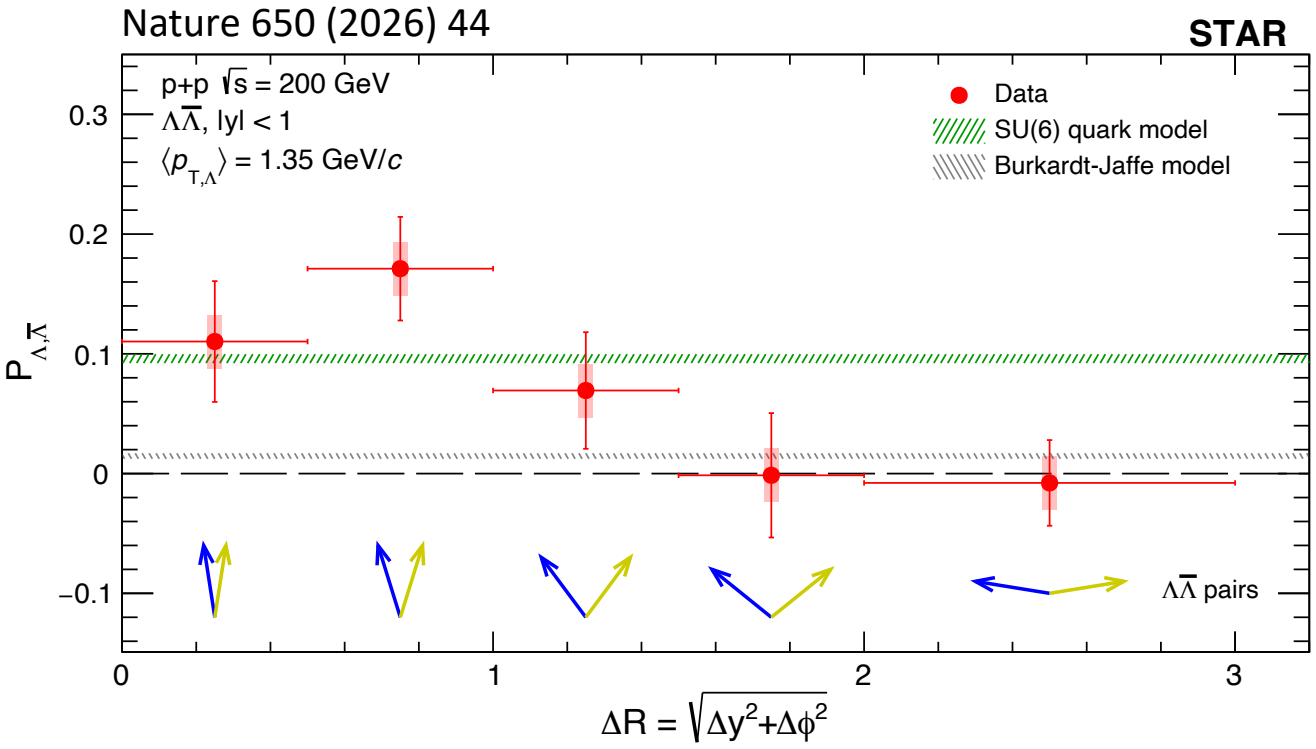


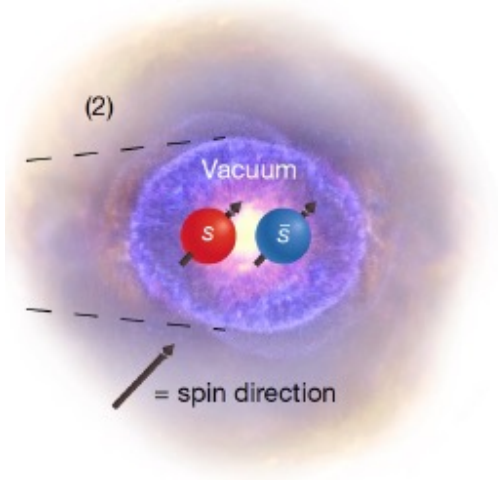
Same event divided by mixed event to correct acceptance

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

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

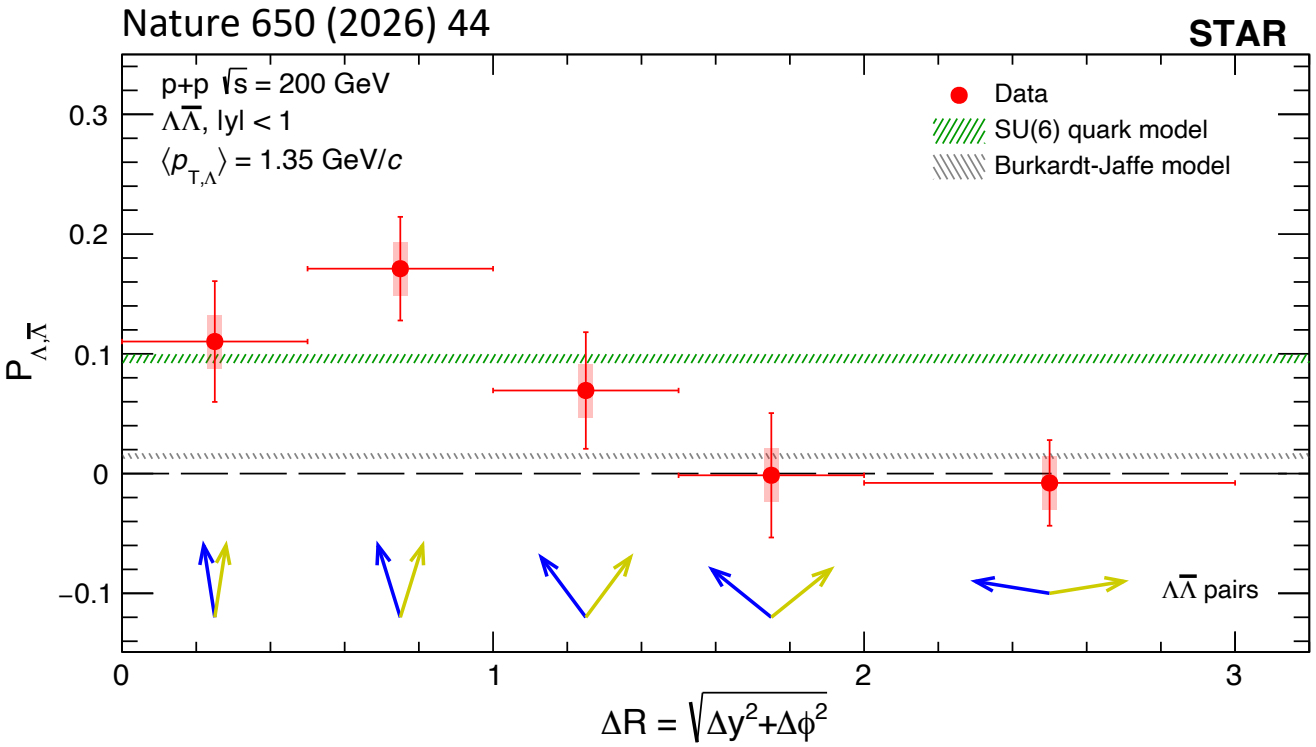
Spin correlation of $\Lambda\bar{\Lambda}$ in pp

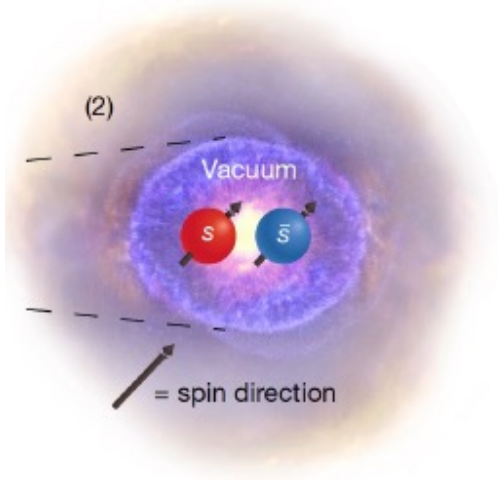




Evidence of positive signal observed by STAR for Lambda + anti-Lambda
Interpreted as reflecting the spin structure of ssbar from QCD vacuum

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





Evidence of positive signal observed by STAR for Lambda + anti-Lambda
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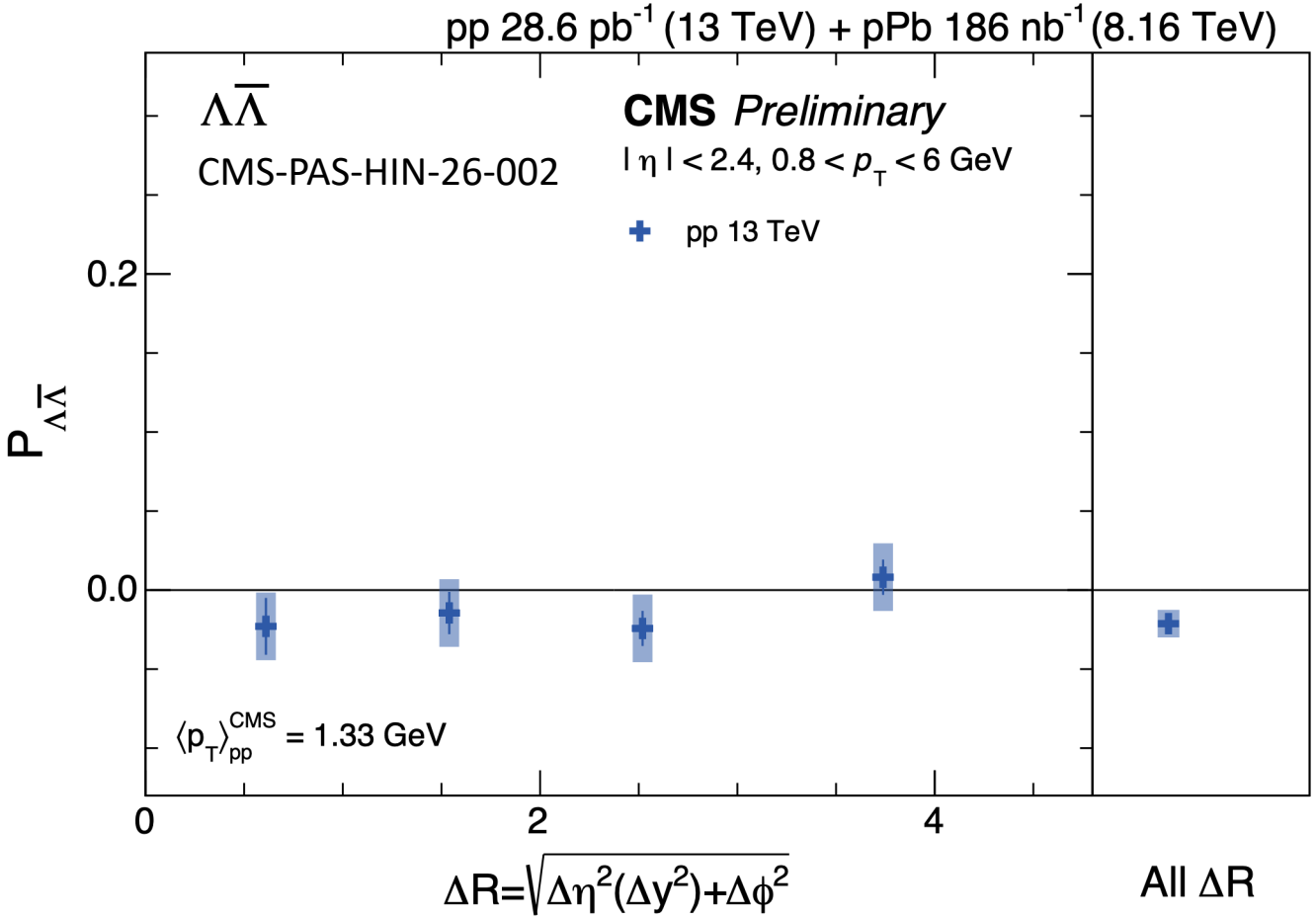
Spin correlation measurement at LHC is important

1. Energy and system dependence of proposed interpretation
2. Test of underlying mechanism with different type of pairs

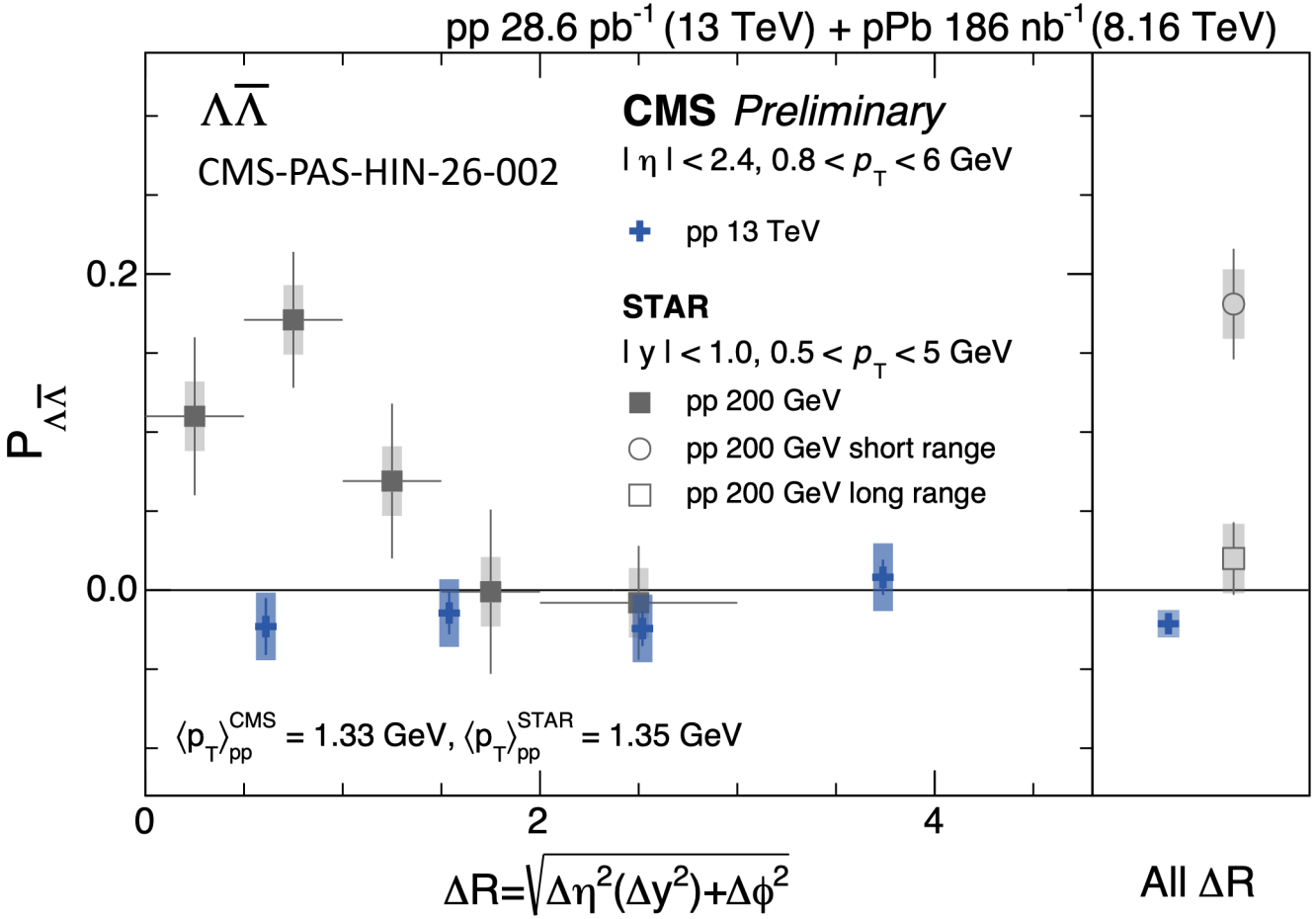
Spin correlation of $\Lambda\bar{\Lambda}$ in pp



ΔR differential results consistent with zero within uncertainties

The integrated result hints a negative value

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



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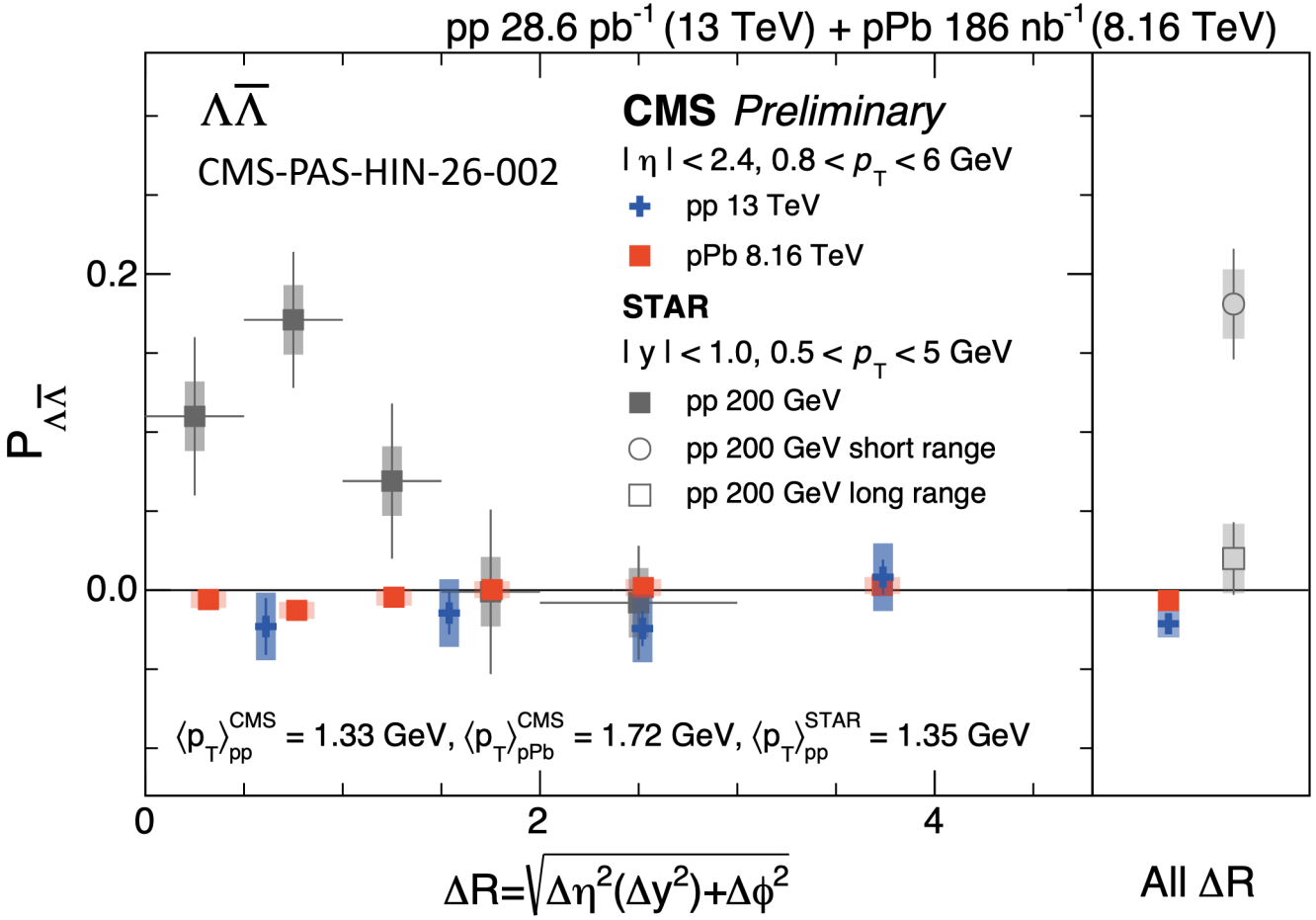
Different behavior from STAR results at 200 GeV

Might be due to different production mechanism?

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



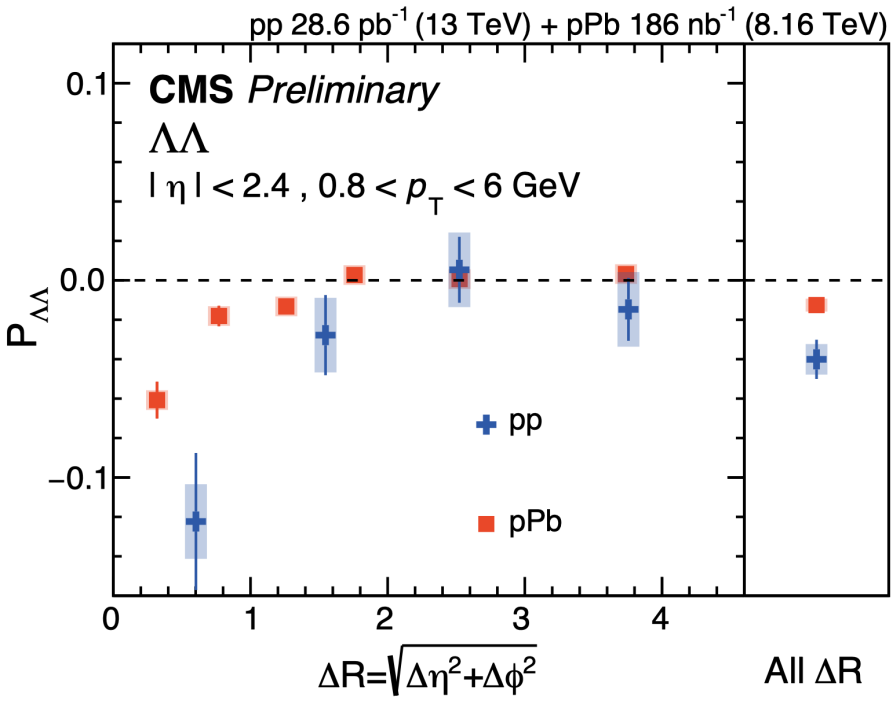
pPb results similar to pp

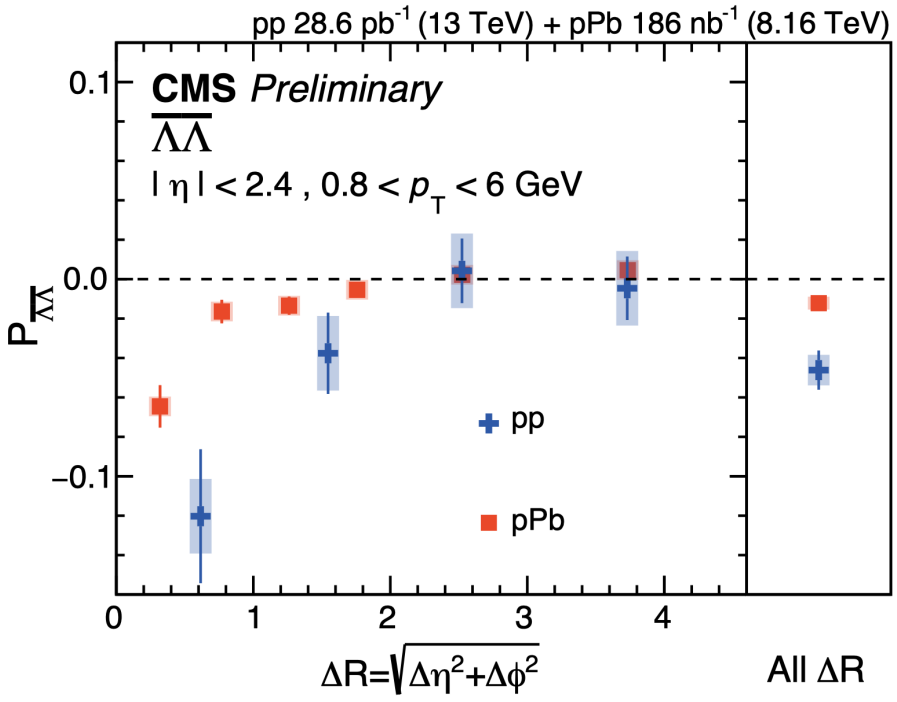
Hint of smaller integrated value in pPb than pp

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

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

CMS-PAS-HIN-26-002





Negative spin correlation observed at small ΔR

Converge to 0 at large ΔR

A hint of larger magnitude in pp than pPb

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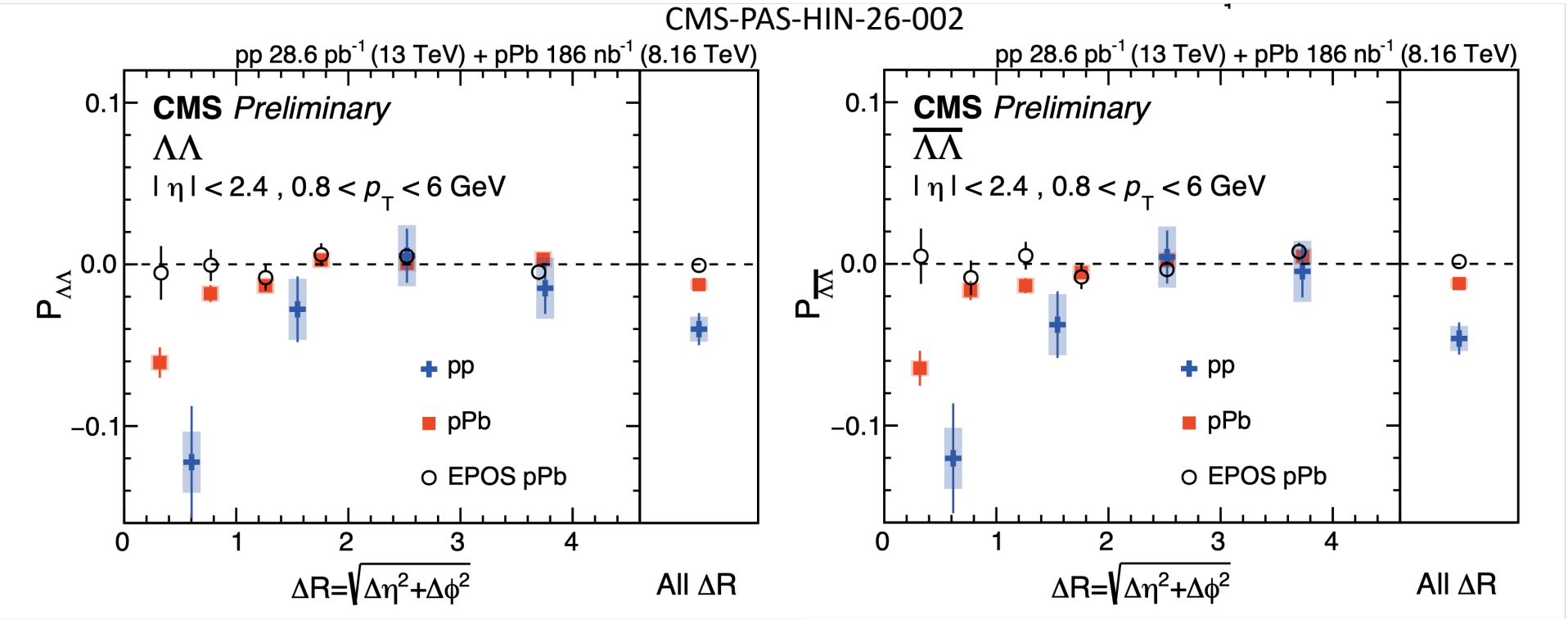

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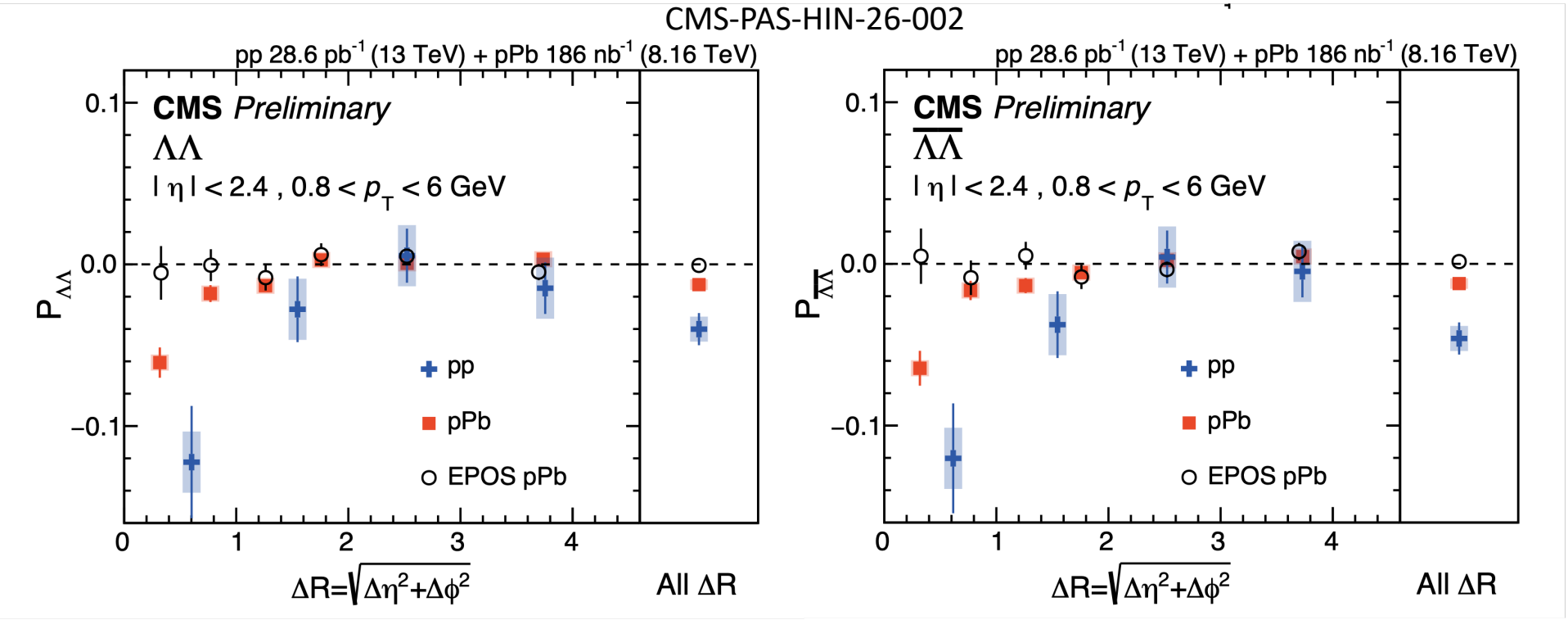
Same analysis in EPOS yield 0 as expected

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

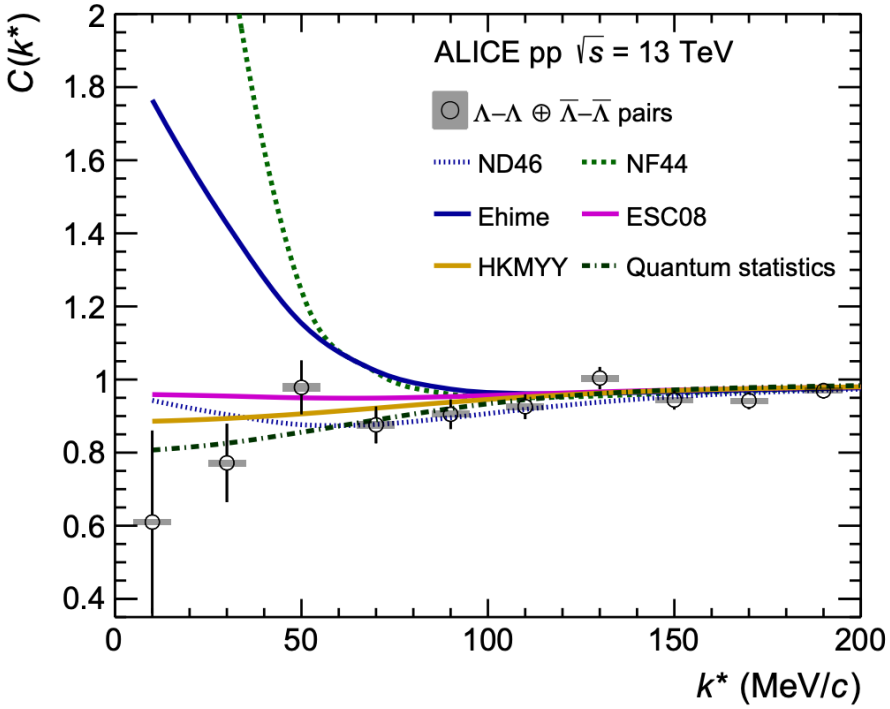


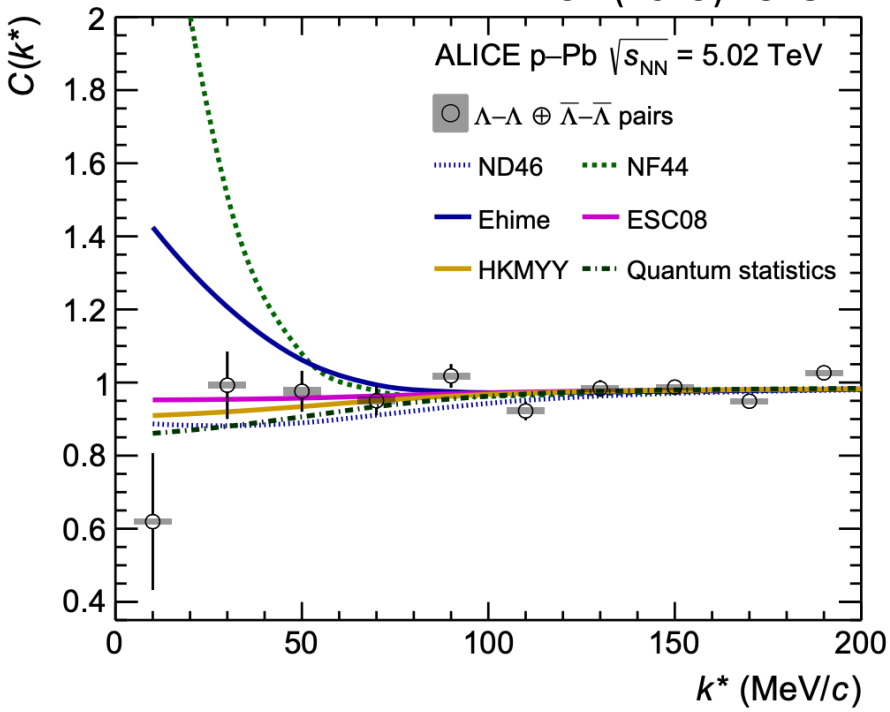
A signal for identical particles when close in space?

Hmmm… Hanbury-Brown-Twiss correlations?

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

PLB 797 (2019) 134822





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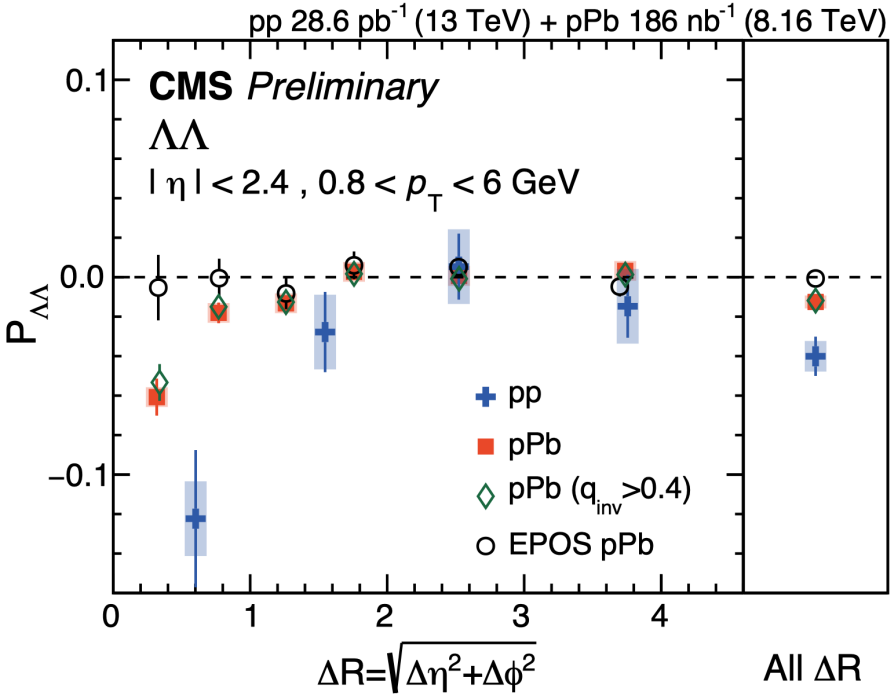
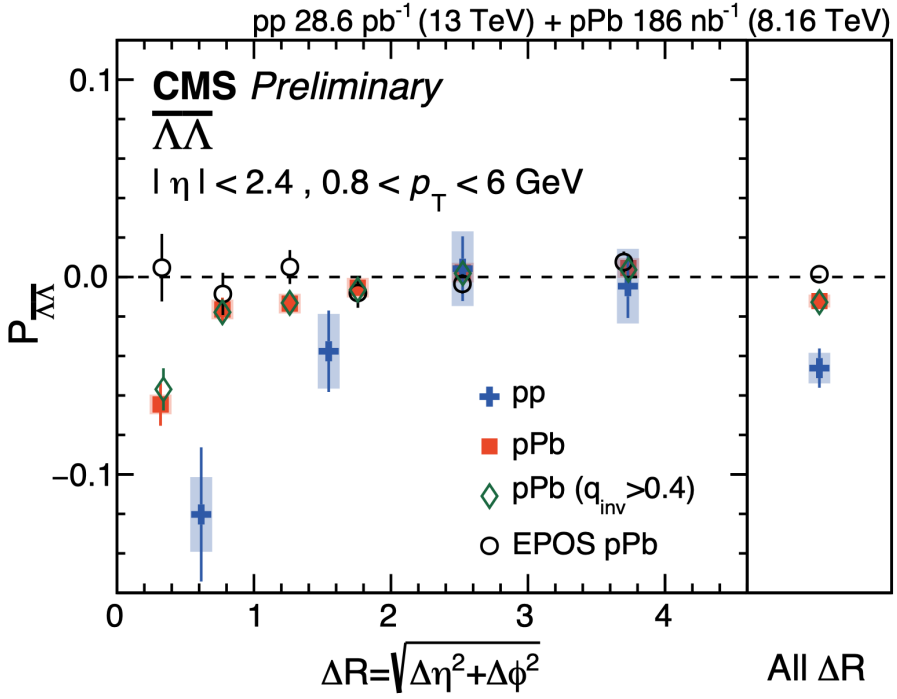
Typical HBT effects are at k* < 0.2 GeV (q_{inv} < 0.4 GeV)

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

CMS-PAS-HIN-26-002





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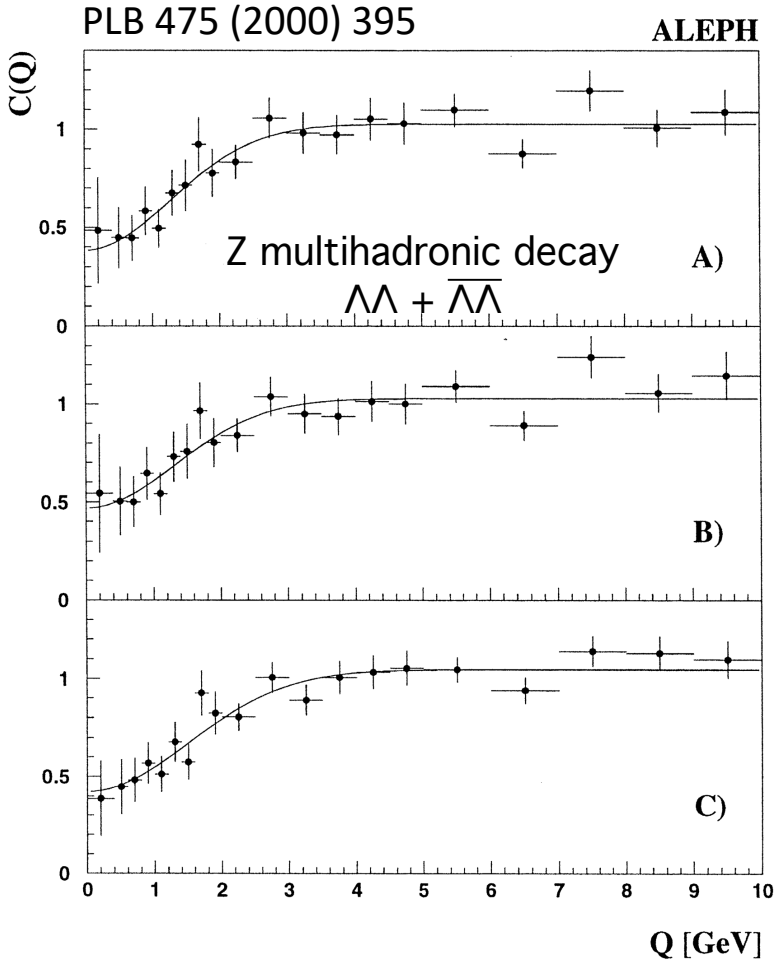
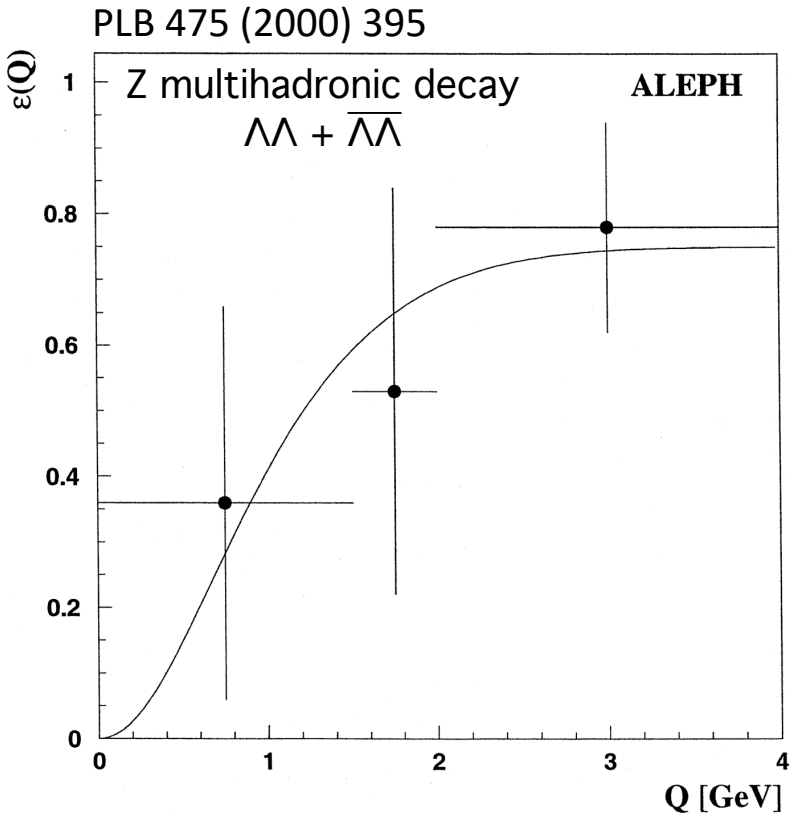
Results with q_{inv} > 0.4 GeV consistent with default
Indicate the signal is not dominated by ‘simple’ HBT effects

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





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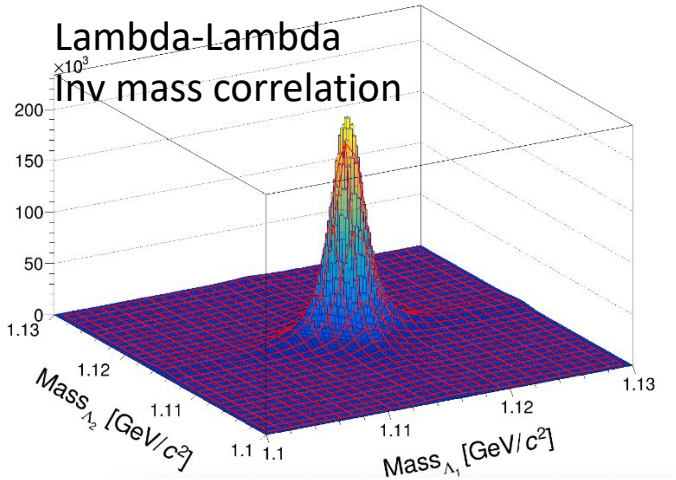
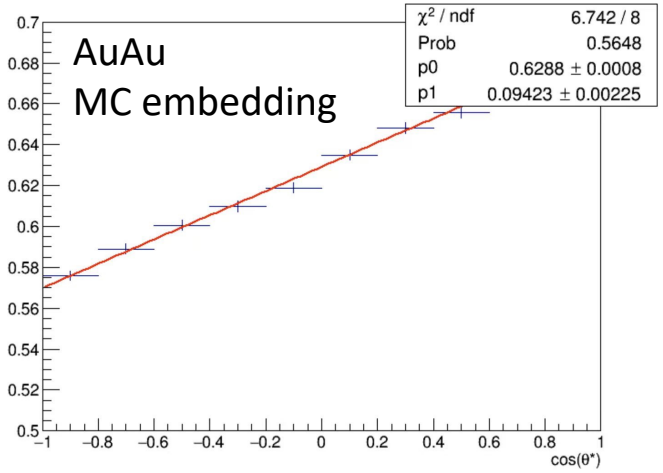
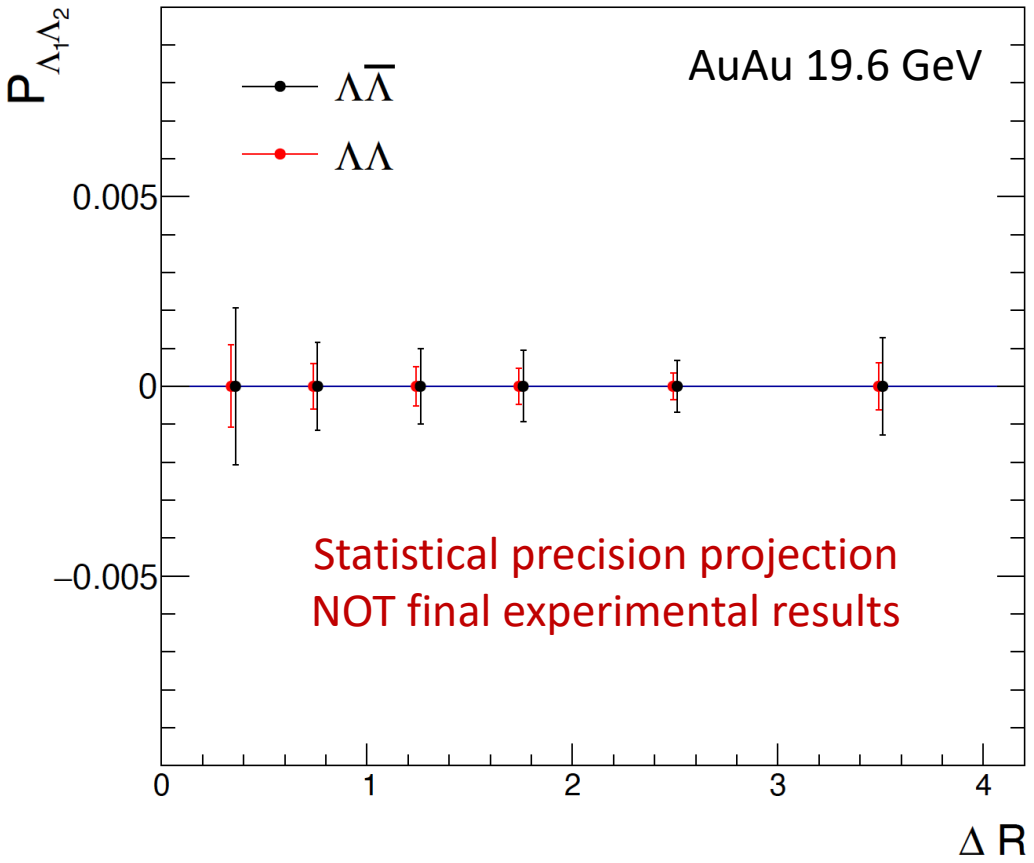
A reminder of ALEPH Z-decay results?

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

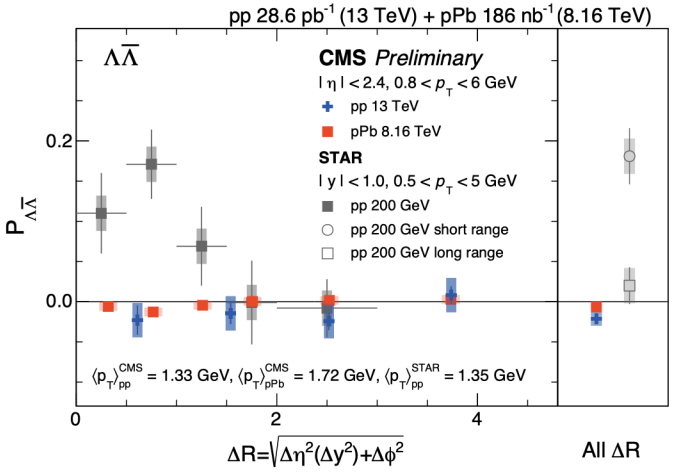
Summary

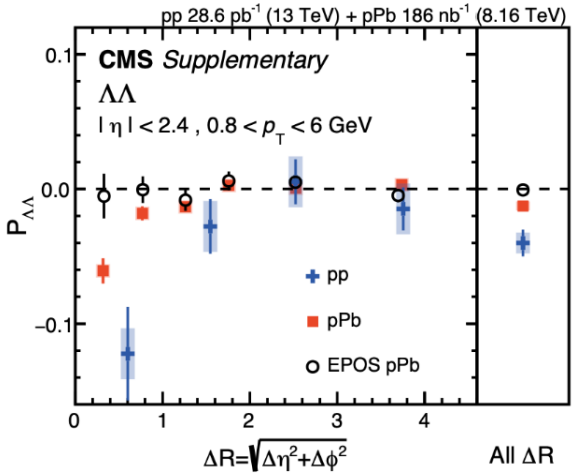
Hyperon spin correlation measured in pp & pPb at RHIC & LHC

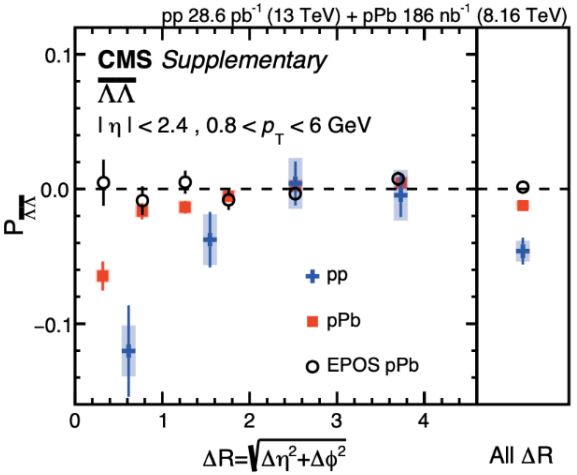
- $\Lambda\bar{\Lambda}$ results show different behavior at RHIC & LHC
  - Positive correlation at STAR
  - Consistent with 0 at CMS
- $\Lambda\Lambda$ & $\bar{\Lambda}\bar{\Lambda}$ results exhibit negative correlation at small ΔR
  - Not dominant by 'simple' HBT effects

We would like to call for more theory inputs for underlying mechanisms

A lot to be done in the future, stay tuned!!

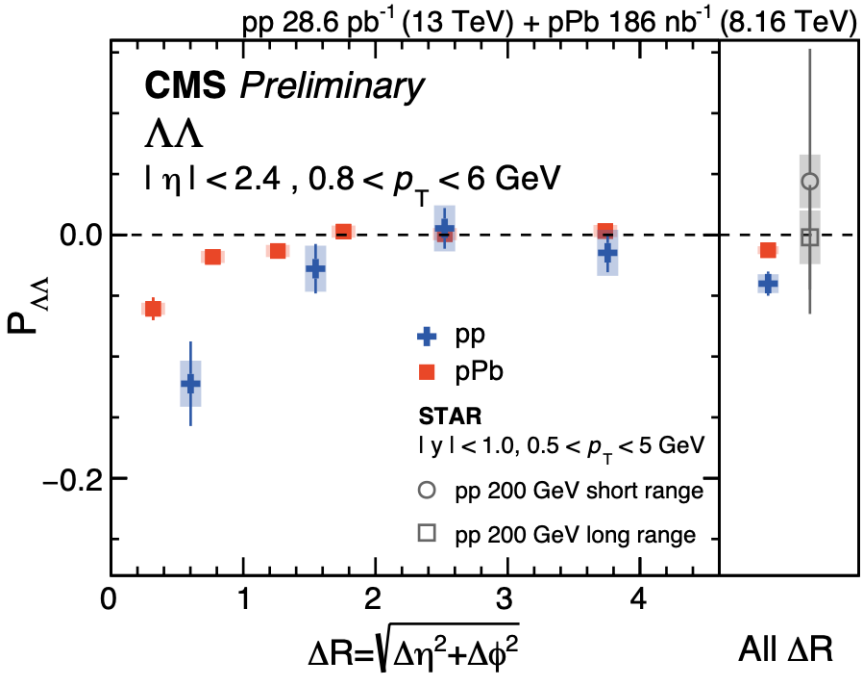


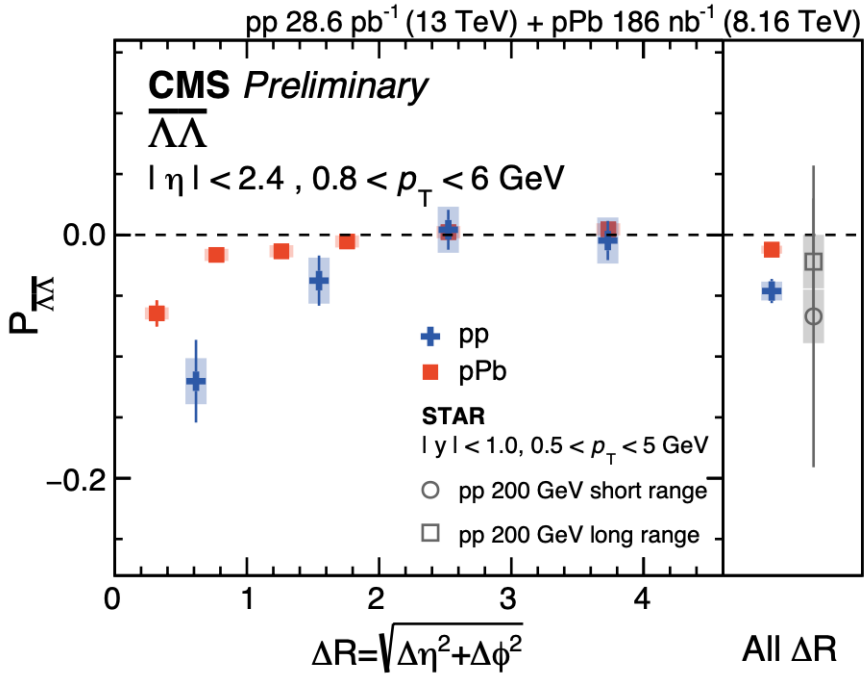




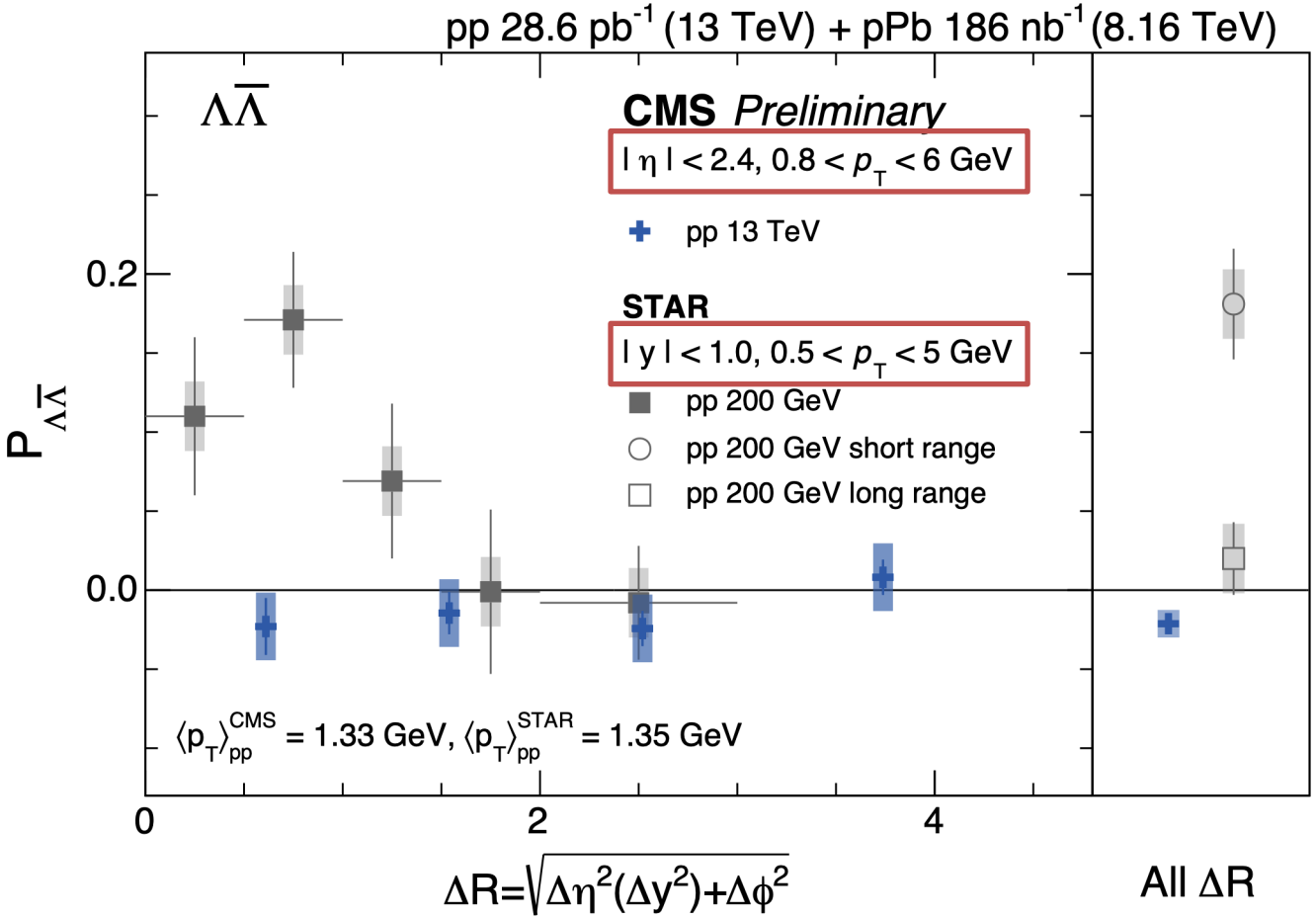
Back up

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





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



From kinematics difference?

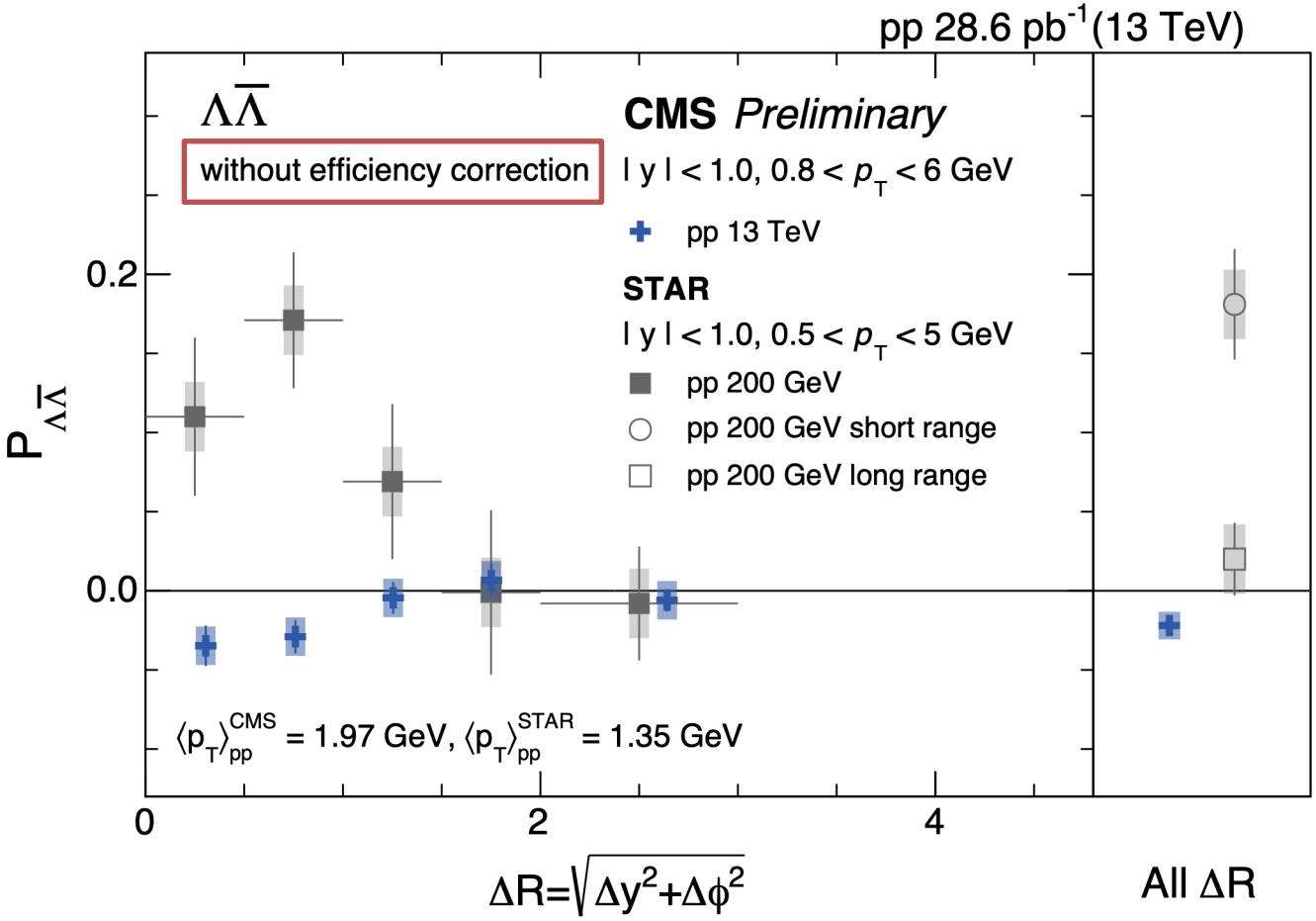
ΔR differential results consistent with zero within uncertainties

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