Search for Chiral Magnetic Wave in Pb-Pb collisions with the ALICE detector

Wenya Wu (for the ALICE Collaboration)
Fudan University, Shanghai, China

Outline:
- ✓ Motivation
- ✓ Experimental observable
- ✓ ESE constrains CMW fraction
- ✓ Centrality dependence of CMW fraction
- ✓ Summary

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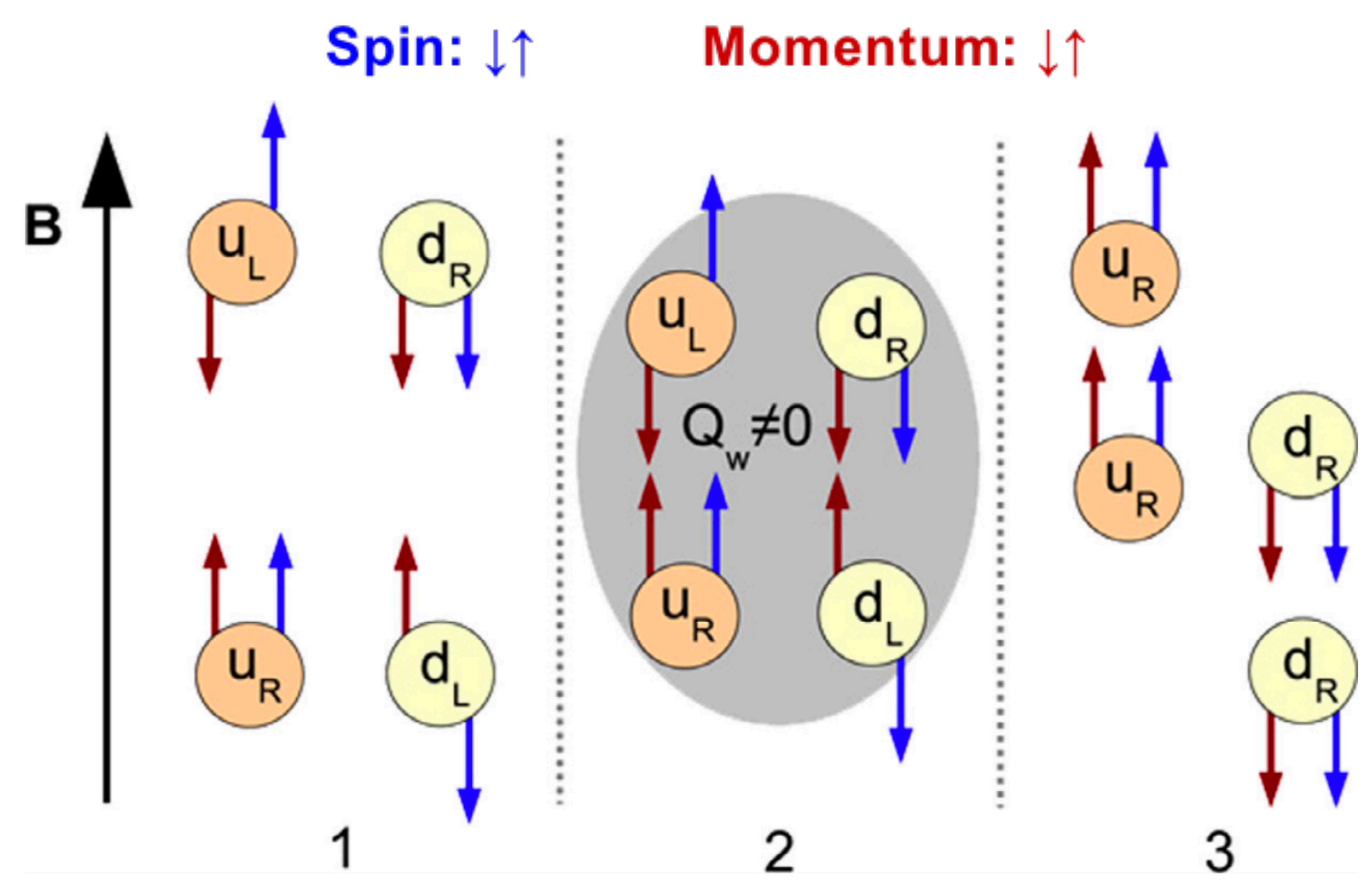
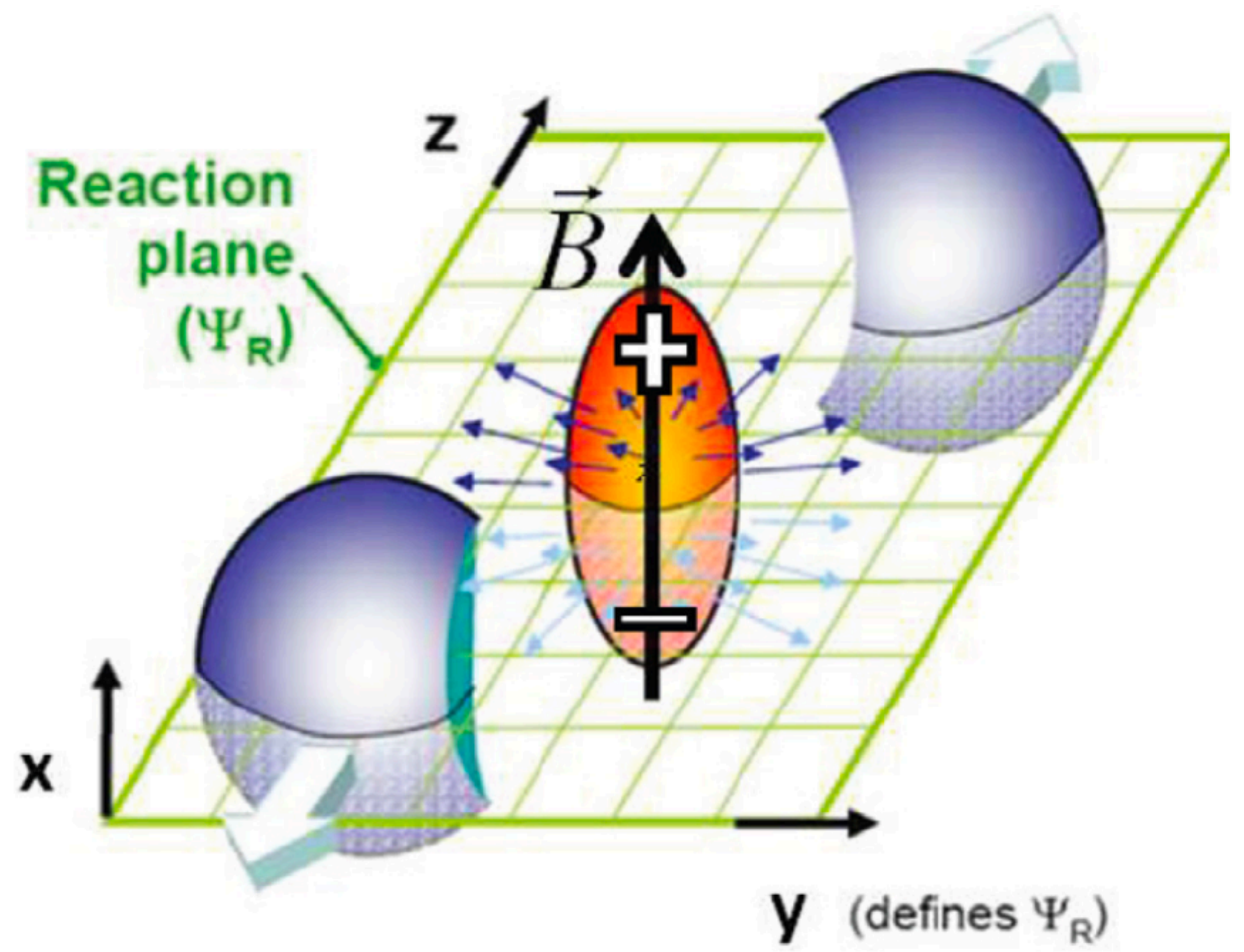
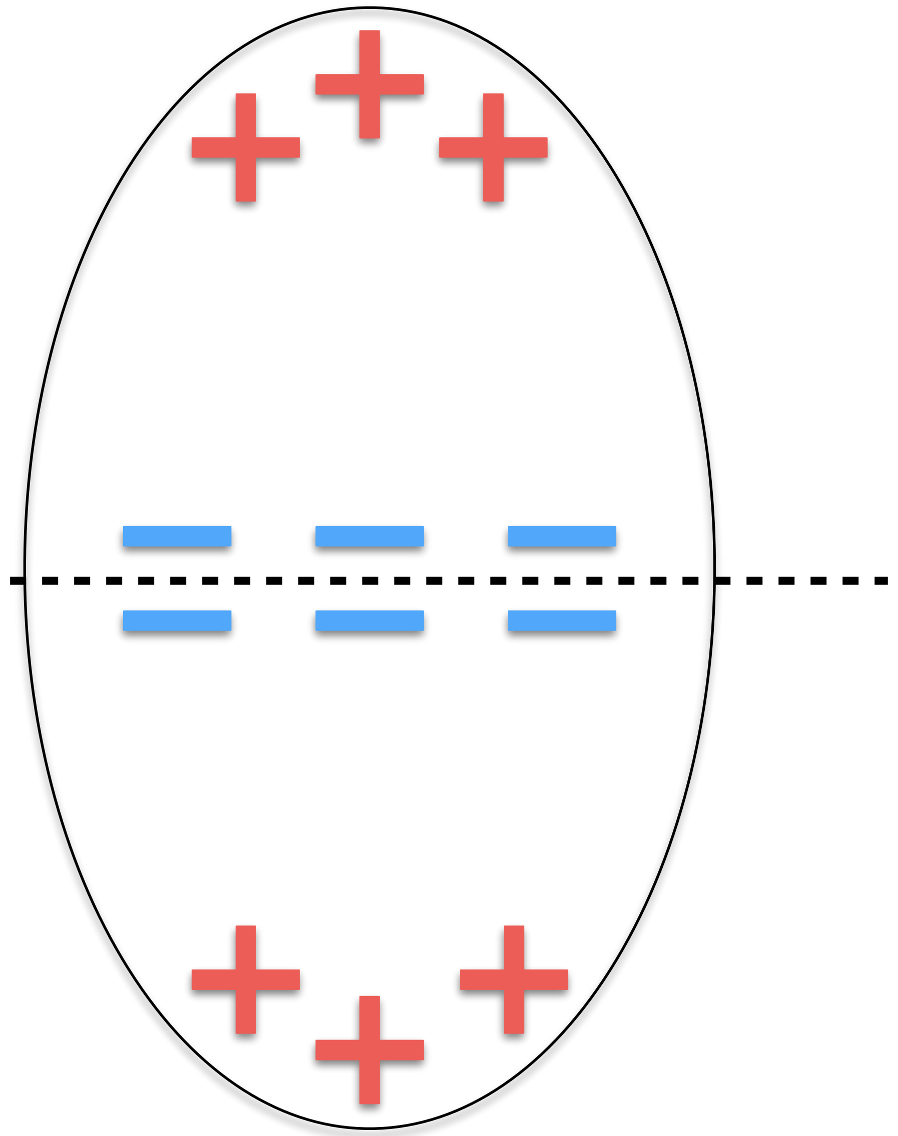
Motivation



Dipole for CME



CME+CSE -> CMW
Quadrupole



✓ **Chiral Magnetic Effect (CME)**: $j_\nu = \frac{N_c e}{2\pi^2}\mu_A B$

✓ **Chiral Separation Effect (CSE)**: $j_A = \frac{N_c e}{2\pi^2}\mu_\nu B$

✓ **Chiral Magnetic Wave (CMW)**: CME+CSE

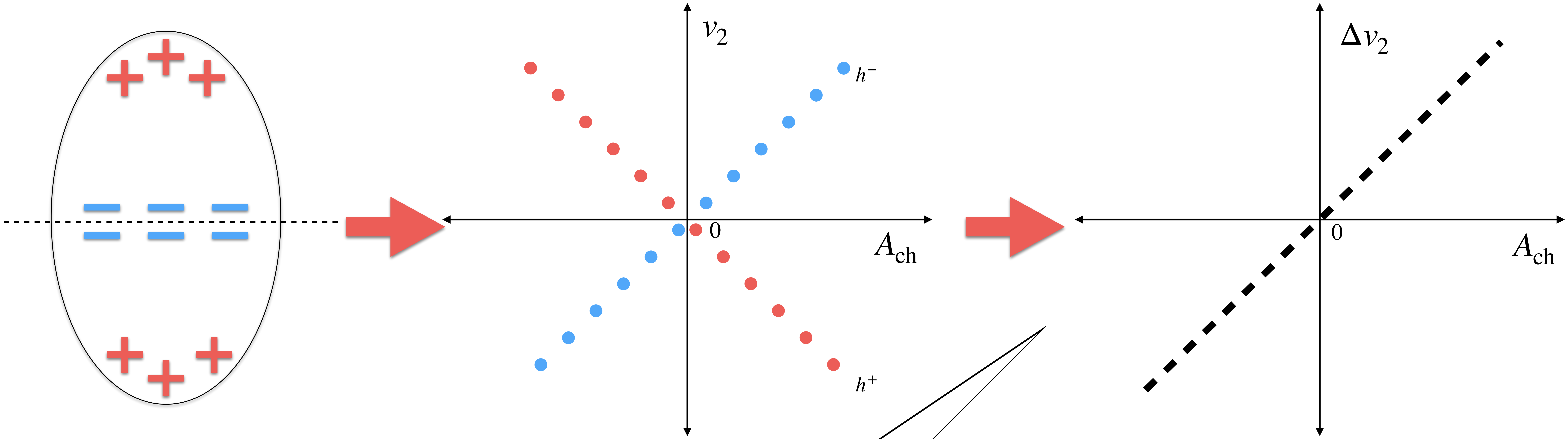
✓Chiral symmetry restoration
✓Deconfinement
✓QCD vacuum transitions
✓Extremely strong magnetic field ($\sim 10^{15}$ T)

All the necessary conditions are possible to be achieved in heavy-ion collisions

K. Dmitri et al. Phys.Rev.Lett. 81 512-515 (1998)
B. Yannis et al. Phys. Rev. Lett. 107 052303 (2011)

Experimental observable

B. Yannis et al. Phys. Rev. Lett. 107 052303 (2011)



$$A_{ch} = \frac{N^+ - N^-}{N^+ + N^-},$$

$$\Delta v_2 = v_2^- - v_2^+ = rA_{ch}$$

CMW observable: Normalized slope, $r_{\Delta v_2}^{Norm.} = \frac{d(\frac{\Delta v_2}{\langle v_2 \rangle})}{dA_{ch}}, \langle v_2 \rangle = \frac{v_2^+ + v_2^-}{2}$

Covariance observable

Integral covariance :

$$\left\langle v_2^{\pm} A_{ch} \right\rangle - \langle A_{ch} \rangle \left\langle v_2^{\pm} \right\rangle \approx \mp r\sigma_{A_{ch}}^2 / 2$$

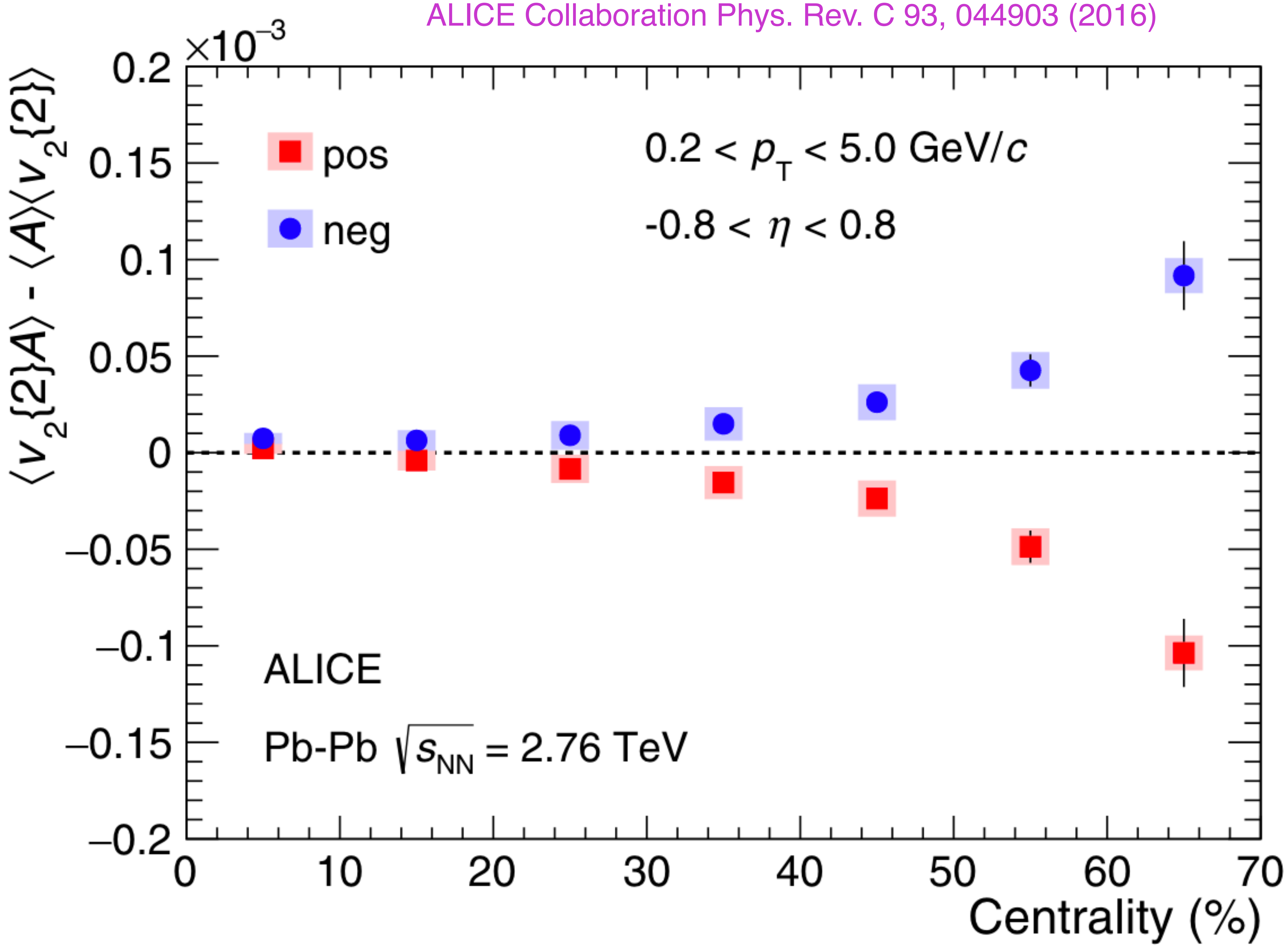
$$dN_{ch}/d\eta \left(\left\langle v_2^{\pm} A_{ch} \right\rangle - \langle A_{ch} \rangle \left\langle v_2^{\pm} \right\rangle \right)_{neg-pos}$$

Covariance observable:

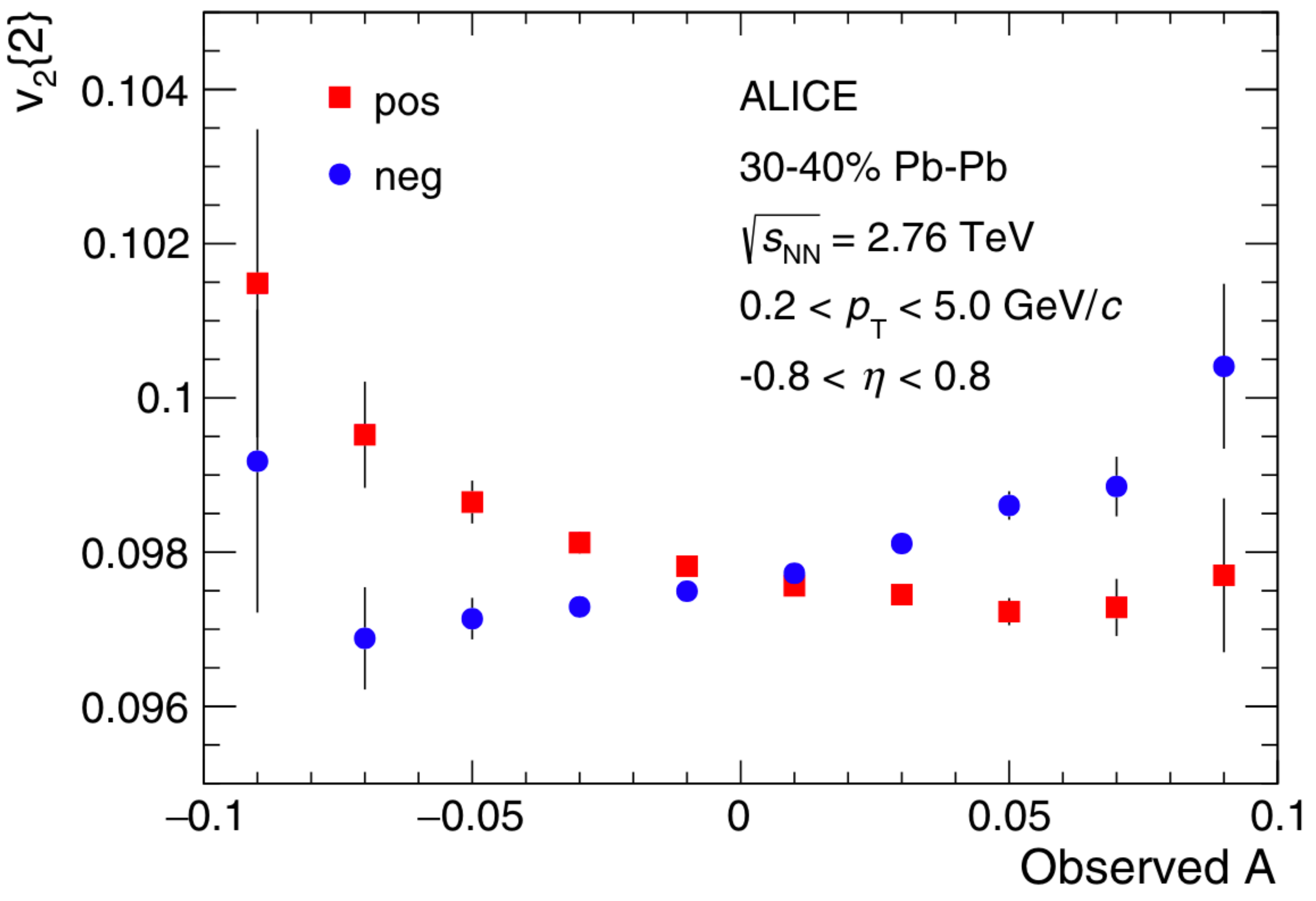
(proposed in S. A. Voloshin et al. Nucl.Phys.A 931 992-996 (2014))

- ✓ Proportional to slope parameter
- ✓ Saves statistics
- ✓ Has differential form (see backup)

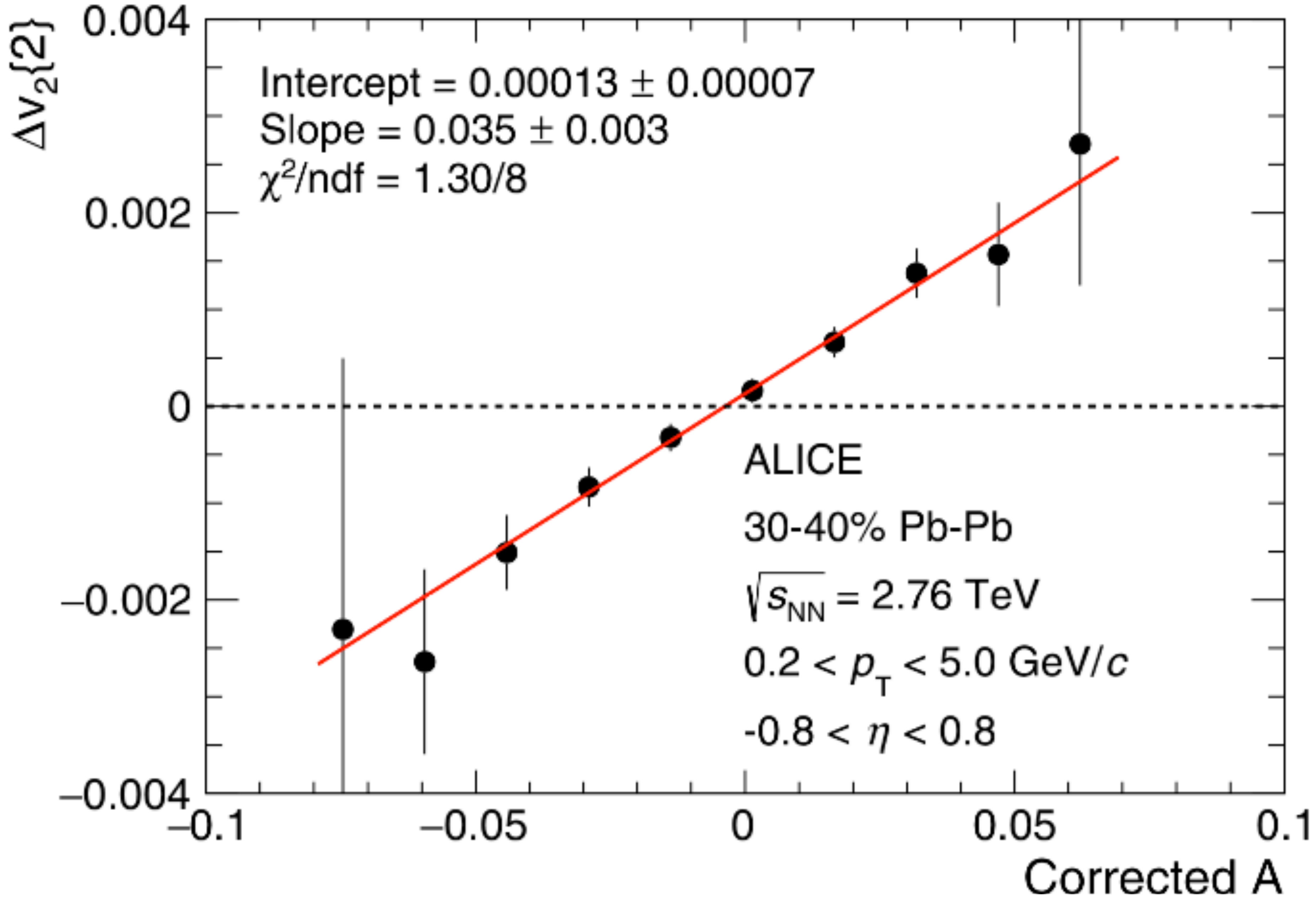
ALICE Collaboration Phys. Rev. C 93, 044903 (2016)

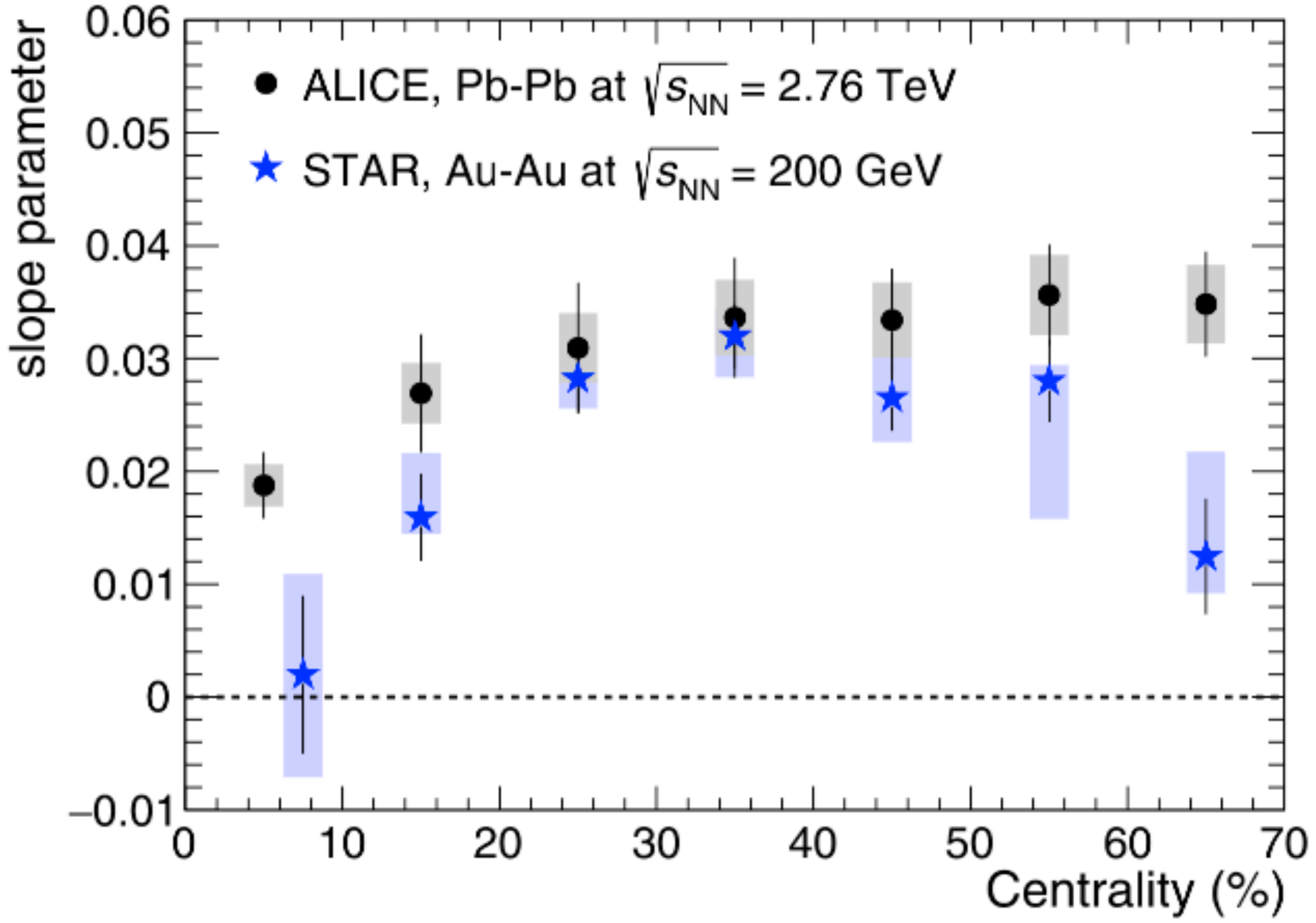


Previous experimental results



ALICE Collaboration. Phys. Rev. C 93, 044903 (2016)

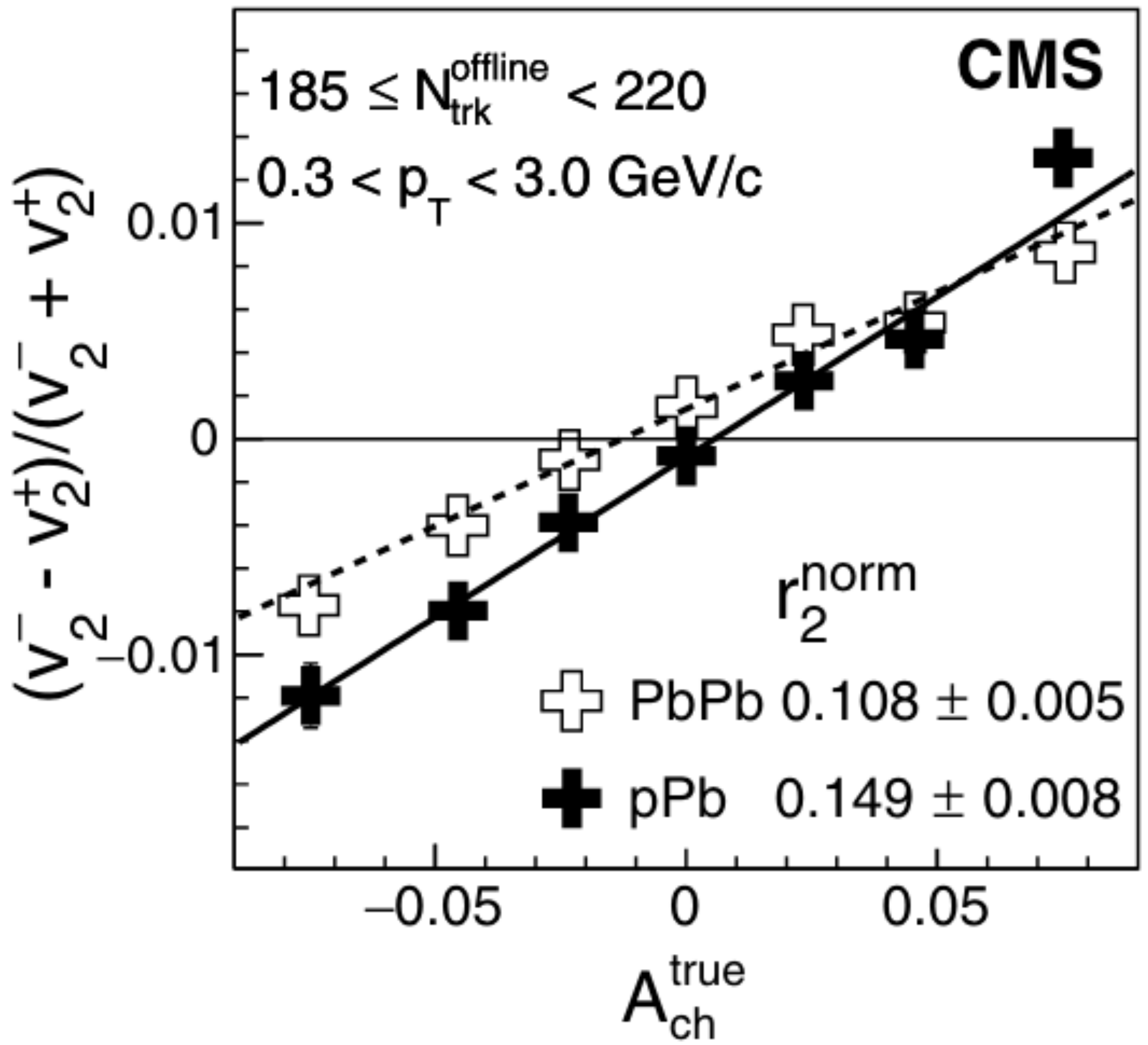


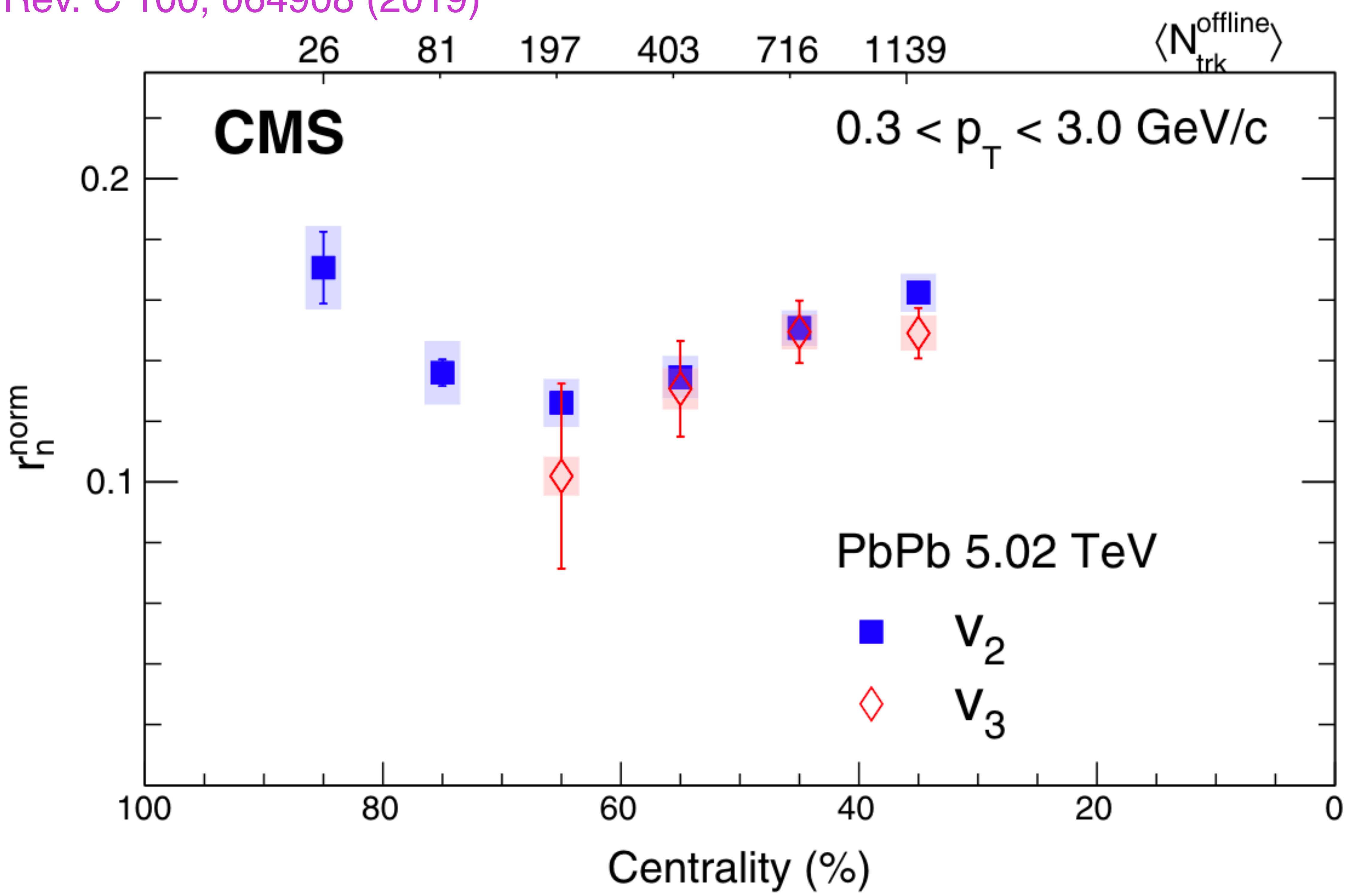


- ✓ Linear relationship for $\Delta v_2(h^{\pm})$ vs. A_{ch}
- ✓ Significant positive signals (around 3%) in ALICE and STAR match theoretical prediction

Previous experimental results and LCC backgrounds

CMS Collaboration Phys. Rev. C 100, 064908 (2019)





Most possible background: **local charge conservation (LCC)**

✓ The observable in p-Pb collision is in line with the one in Pb-Pb collisions

✓ Higher harmonic (v_3) observable with nonzero signal

How to separate the signal/background?

A. Bzdak et al. Phys. Lett. B 726 239–243 (2013)

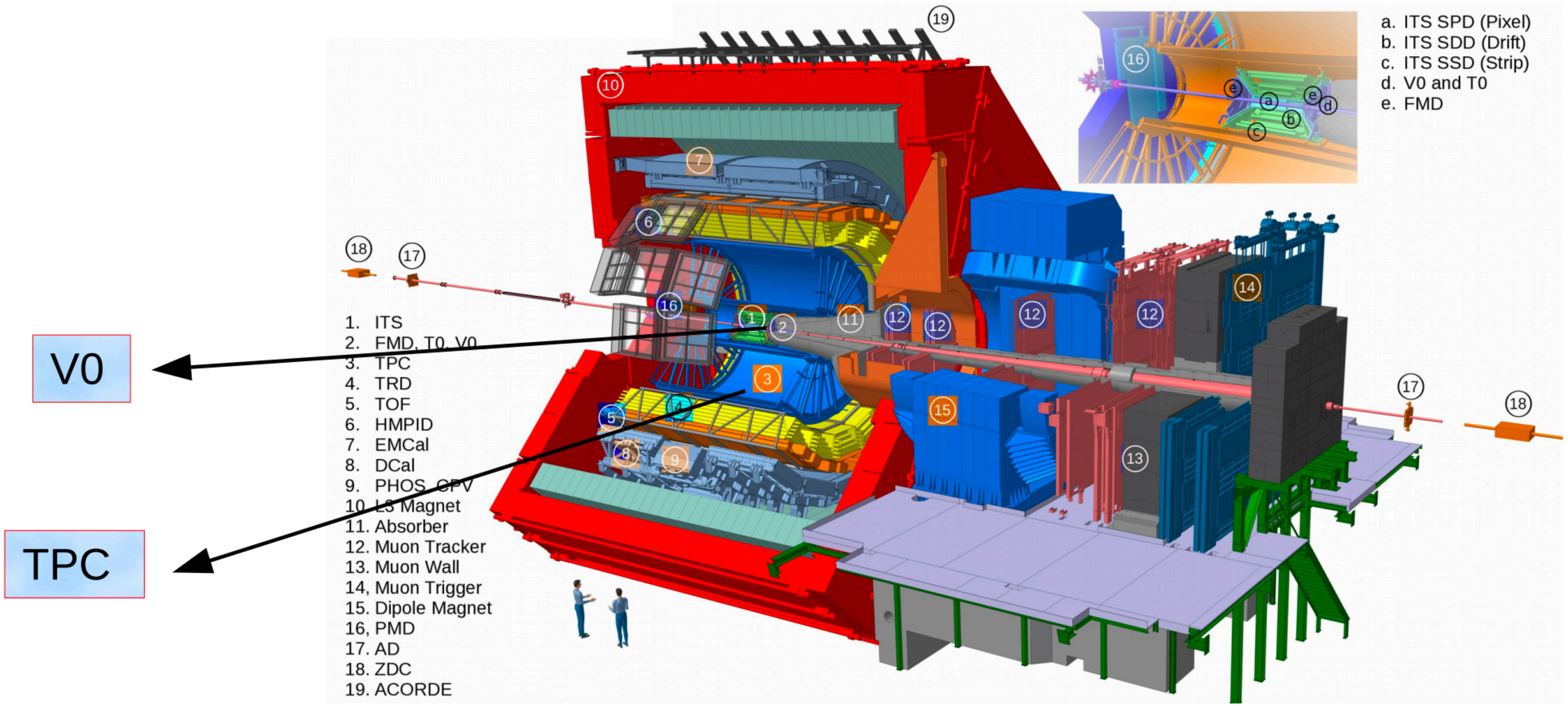
S. A. Voloshin et al. Nucl.Phys.A 931 992-996 (2014)

W. Wu et al. Phys. Rev. C 103, 034906 (2021)

THE ALICE detector

Time Projection Chamber (TPC): ($|\eta| < 0.9$)

- ✓ Primary vertex and tracking
- ✓ Momentum measurement
- ✓ Particle identification

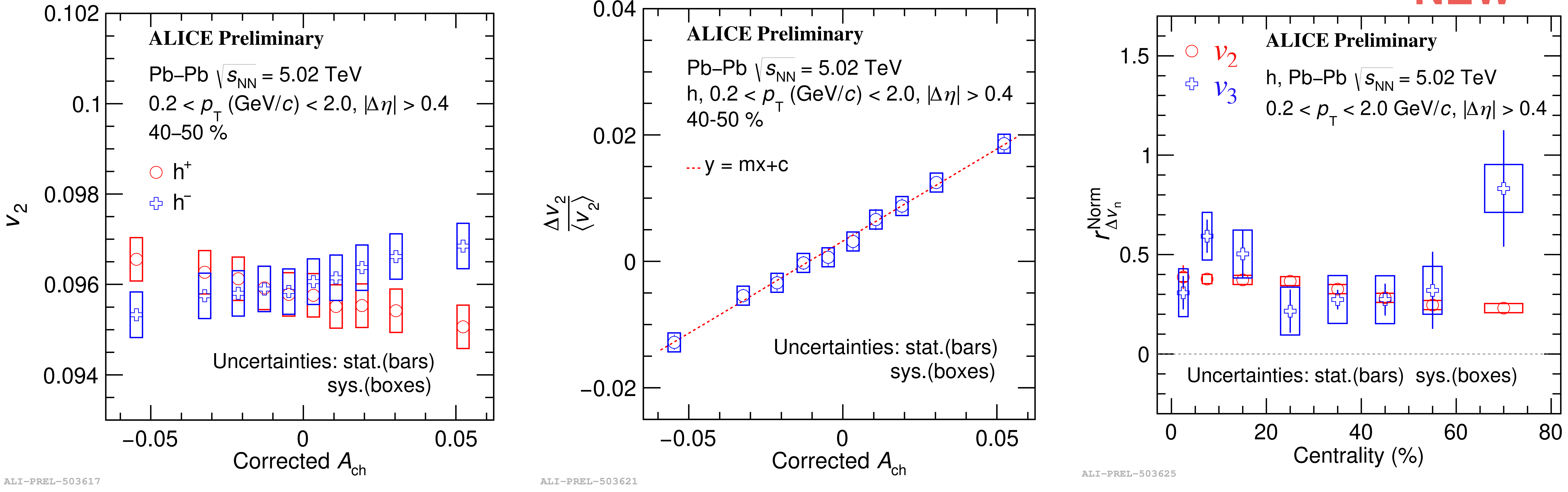


V0: V0A ($2.8 < \eta < 5.1$) V0C ($-3.7 < \eta < -1.7$)

✓ Trigger and centrality (also used for event-shape engineering / event-plane)

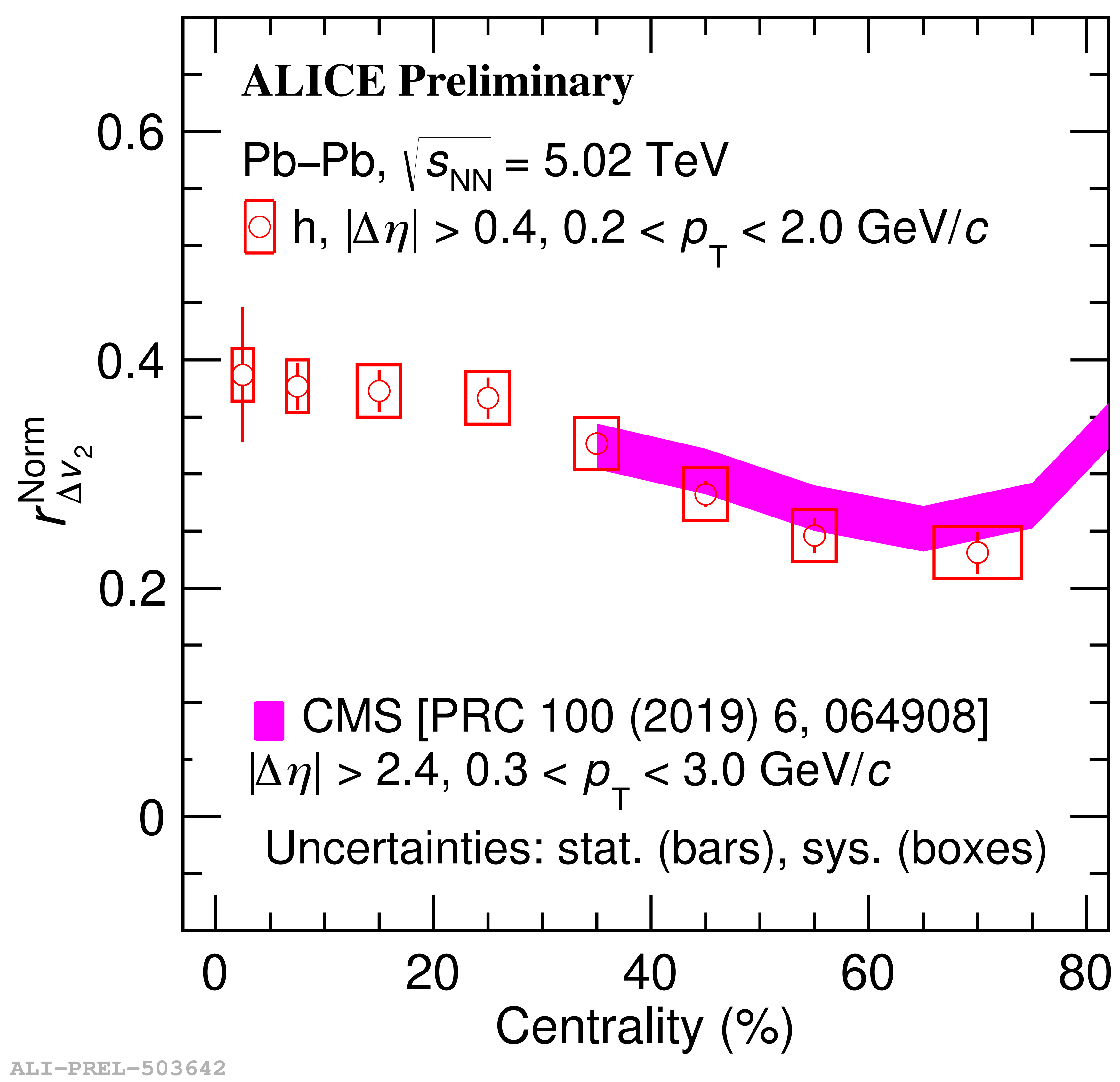
Slope in Pb-Pb collision at 5.02 TeV

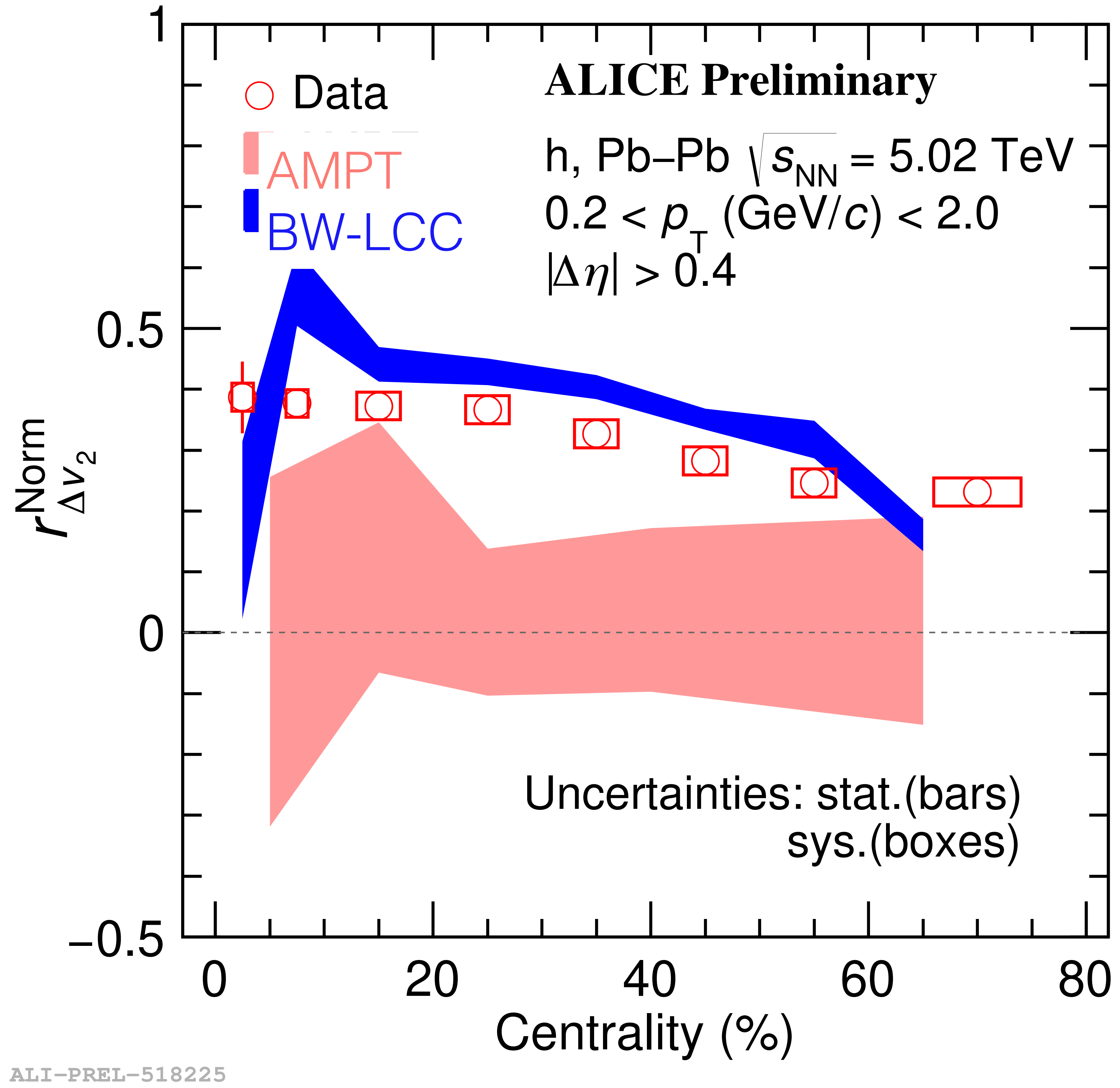
NEW



- ✓ Linear dependences between $v_2^{\pm}$ ($\frac{\Delta v_2}{\langle v_2 \rangle}$) and A_{ch} in the left (middle) figure
- ✓ In the right figure , $r^{Norm.}_{\Delta v_2}$ is consistent with $r^{Norm.}_{\Delta v_3}$ within uncertainties

Comparison with CMS results and the model





NEW

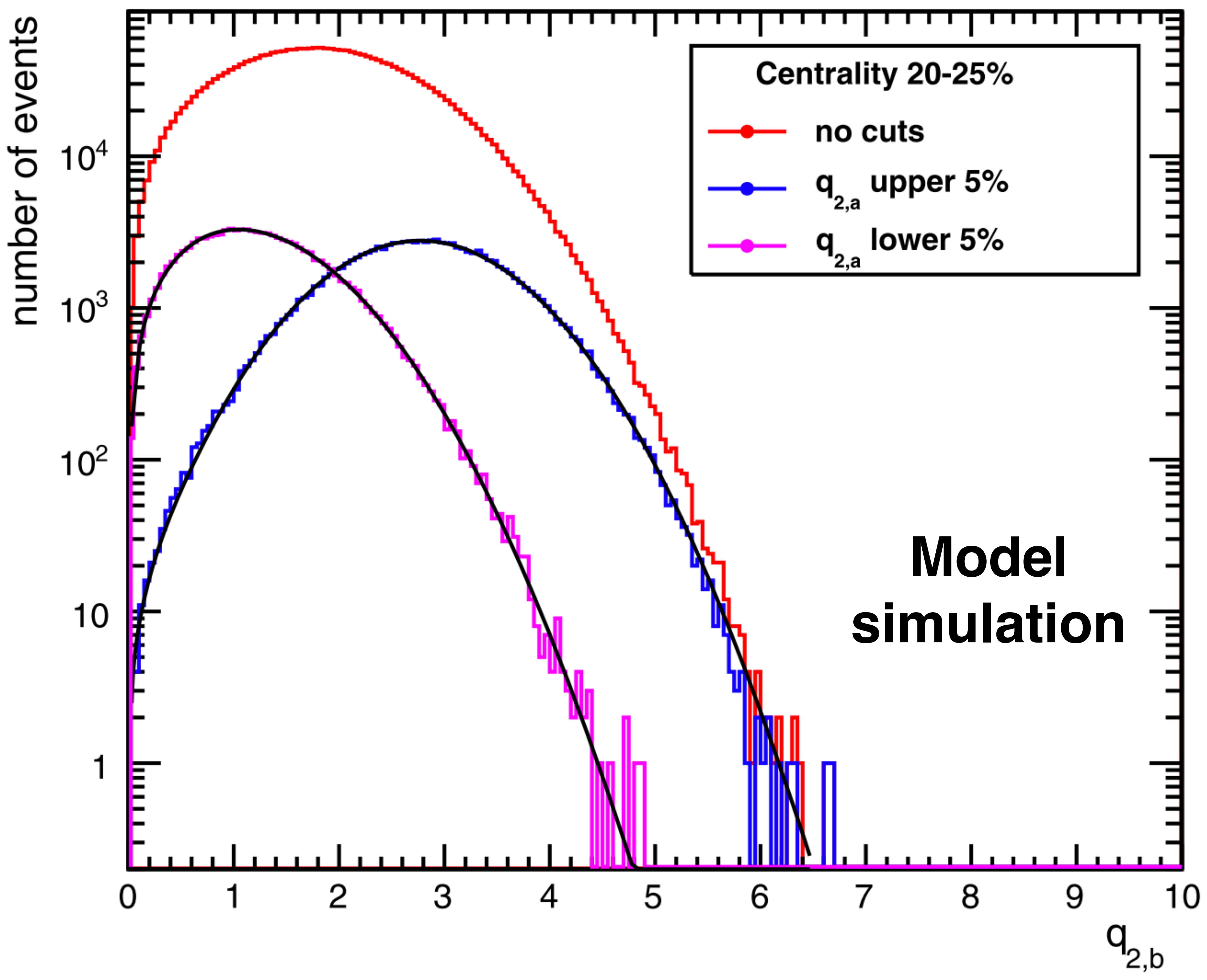
CMS Collaboration Phys. Rev. C 100, 064908 (2019)

$$r^{\text{Norm(ALICE)}}_{\Delta v_2} \approx r^{\text{Norm(CMS)}}_{\Delta v_2}$$

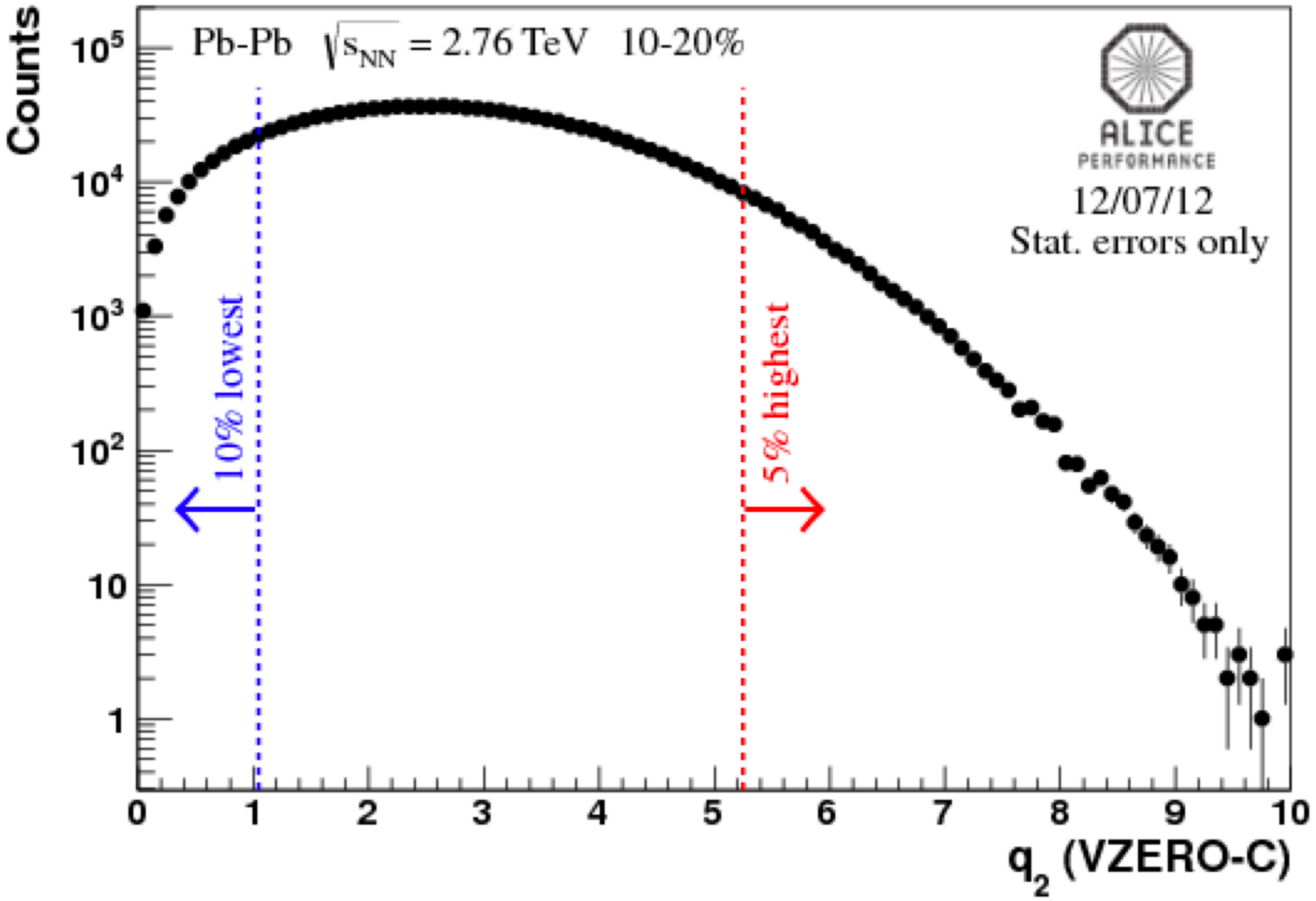
- ✓ BW-LCC model (engaging 100% local charge conservation) over-predicts the experimental measurements
- ✓ AMPT model (no CMW and violation of charge conservation) shows slope consistent with zero

Event Shape Engineering (ESE) method

J. Schukraft et al. Phys. Lett. B 719 394–398 (2013)



A. Dobrin et al. Nucl.Phys.A 904-905 455c-458c (2013)



- ✓ Select events corresponding to initial geometry
- ✓ Sensitive to anisotropy of collision
- ✓ Successfully used for CME

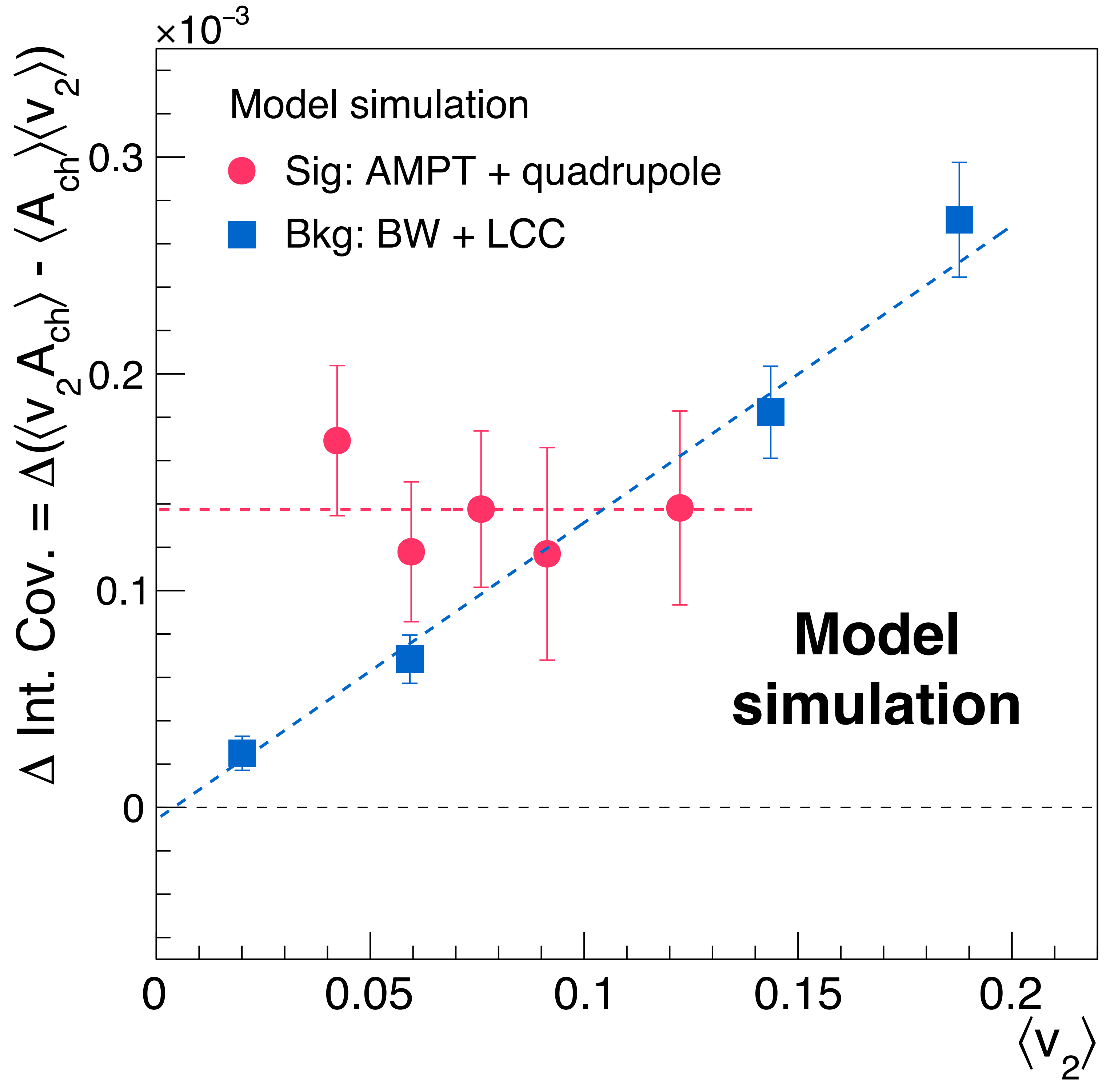
ALICE Collaboration Phys. Lett. B 777, 151162 (2018)
CMS Collaboration Phys. Rev. C 100, 064908 (2019)

- ✓ Applying ESE technique to constrain CME
- ✓ Selects events with equivalent event numbers
- ✓ Estimates observables in each q_2 interval

ESE constrains CMW fraction

NEW

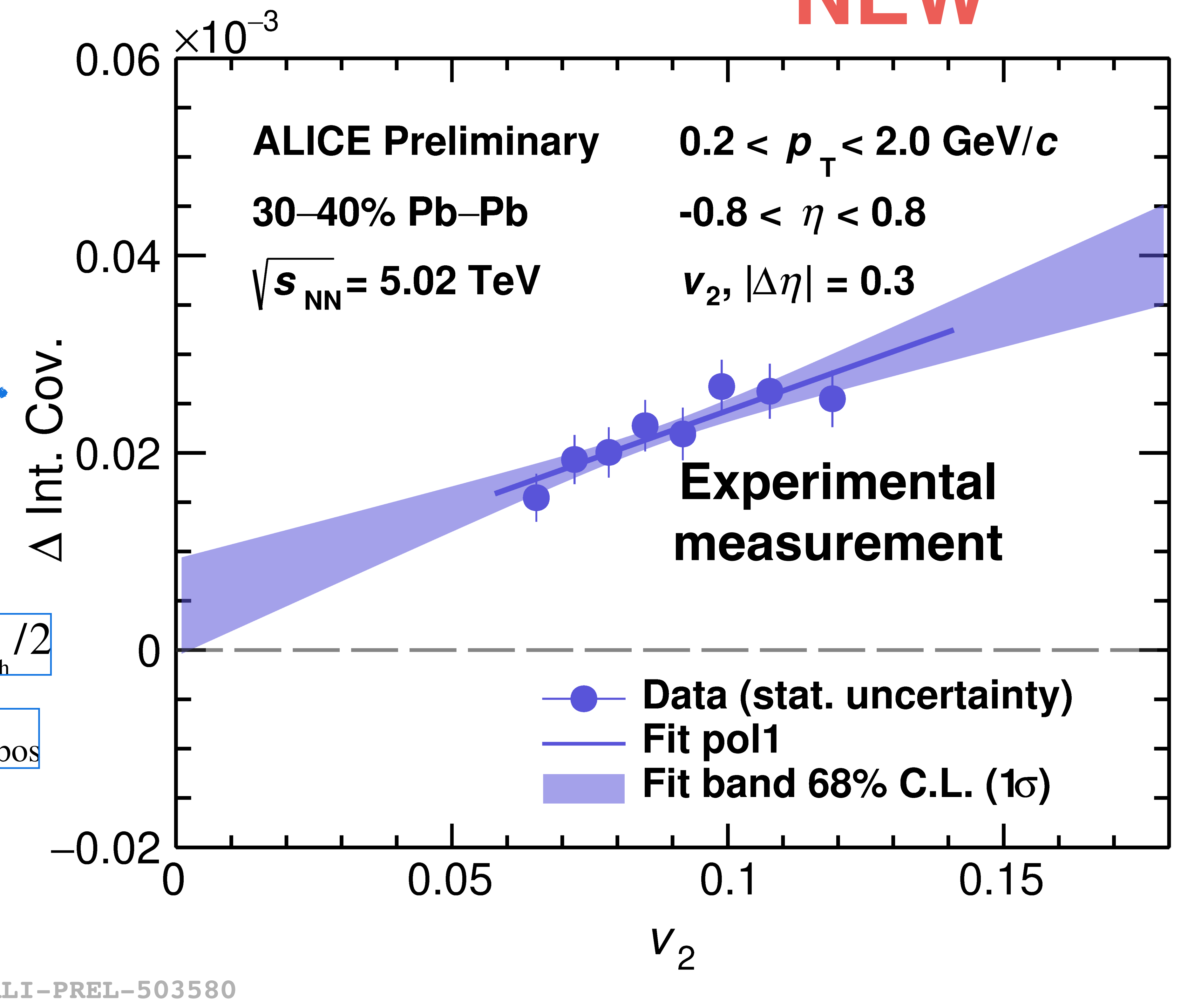
C. Wang et al. Phys. Lett. B 820 136580 (2021)



Integral covariance (Int. Cov.) is the covariance between $v_2^{\pm}$ and A_{ch}

$$\mathrm{Int.Cov.} \equiv \langle v_2^{\pm} A_{ch} \rangle - \langle A_{ch} \rangle \langle v_2^{\pm} \rangle \approx \mp r\sigma^2_{A_{ch}}/2$$

$$\Delta\mathrm{Int.Cov.} \equiv (\langle v_2^{\pm} A_{ch} \rangle - \langle A_{ch} \rangle \langle v_2^{\pm} \rangle)_{neg-pos}$$



- ✓ CMW signal (AMPT+quadrupole)
  ΔInt. Cov. vs. v_2 : finite intercept
- ✓ Background (BW+LCC)
  ΔInt. Cov. vs. v_2 : zero intercept

- ✓ In most centralities, the proportionality of ΔInt. Cov. changes with v_2 → indication of a large background
- ✓ Linear fit: $F(v_2) = a \times v_2 + b$

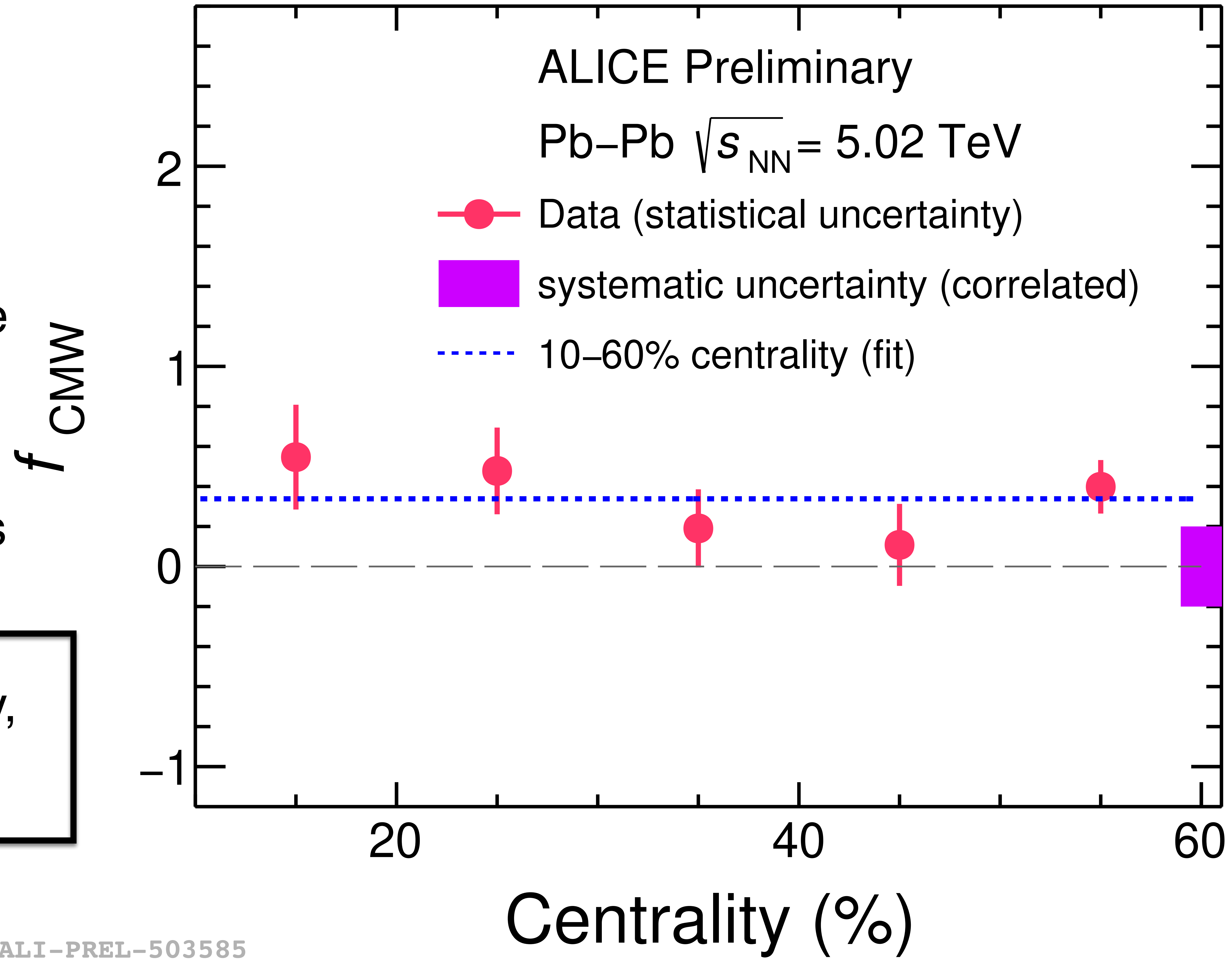
Centrality dependence of CMW fraction f_{CMW}

NEW

$$f_{CMW} \equiv \frac{b}{a \times \overline{\langle v_2 \rangle} + b}$$

- ✓ Parameters a and b are extracted from the $F(v_2)$ fit to ΔInt. Cov.
- ✓ $\overline{\langle v_2 \rangle}$ averaged over all intervals of q_2
- ✓ f_{CMW} consistent with 0 within uncertainties

Value of f_{CMW} extracted in 10-60% centrality,
f_{CMW} **~ 0.338 ± 0.084(stat.) ± 0.198(syst.)**



ALI-PREL-503585

Summary

✓ Δv_2-A_{ch} **method:** The normalized slope $r_{\Delta v_2}^{Norm.}$ is consistent with $r_{\Delta v_3}^{Norm.}$ within uncertainties implying that CMW signal is consistent with zero

✓ **ESE method:** First measurement of the CMW fraction with ESE method in Pb-Pb collisions, $f_{\rm CMW}$ is consistent with zero within uncertainties

✓ Those two methods imply the CMW signal is consistent with zero, or very small if it exists

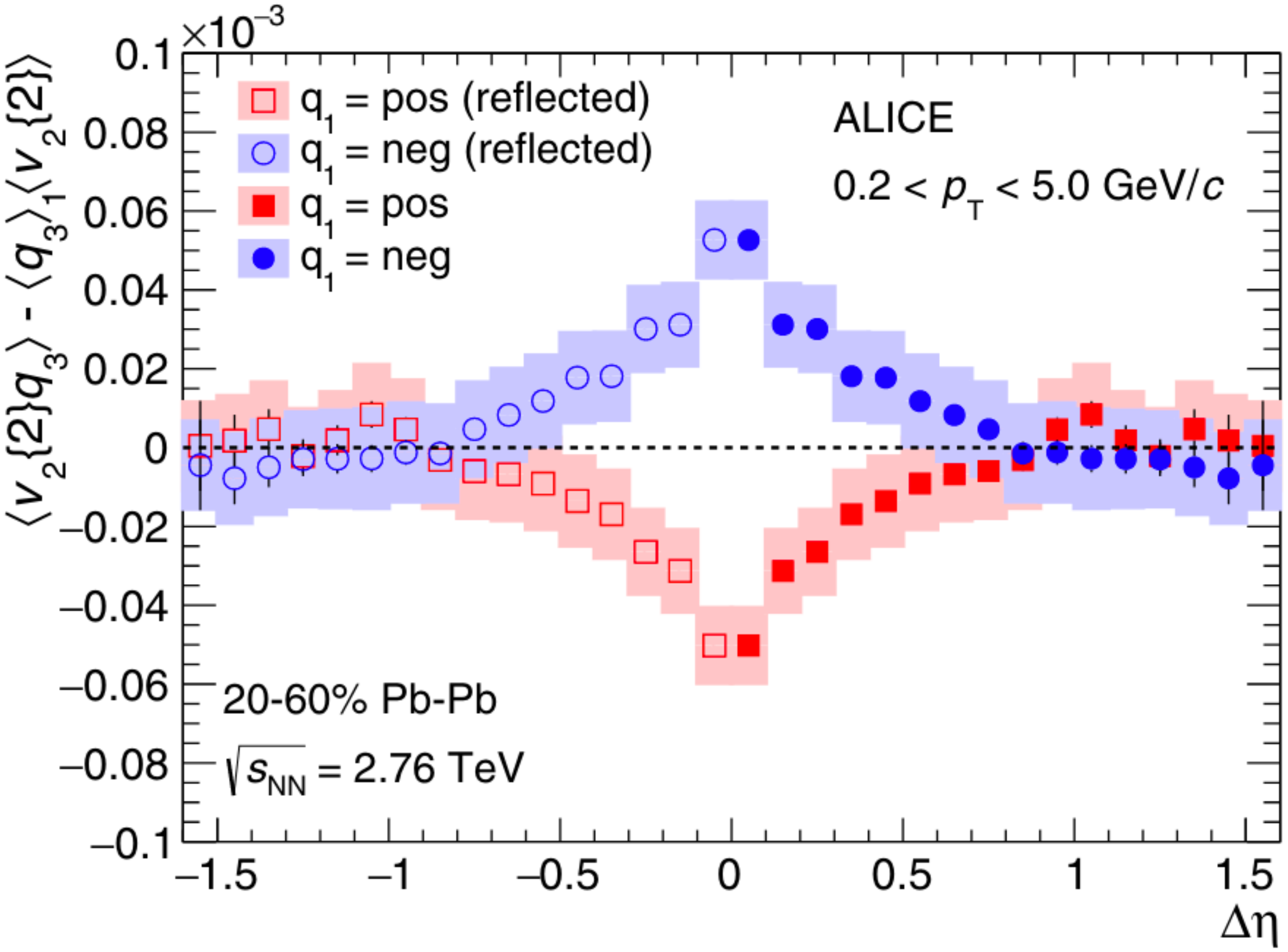
Thanks for your attention!

Backup : differential 3-particle correlator

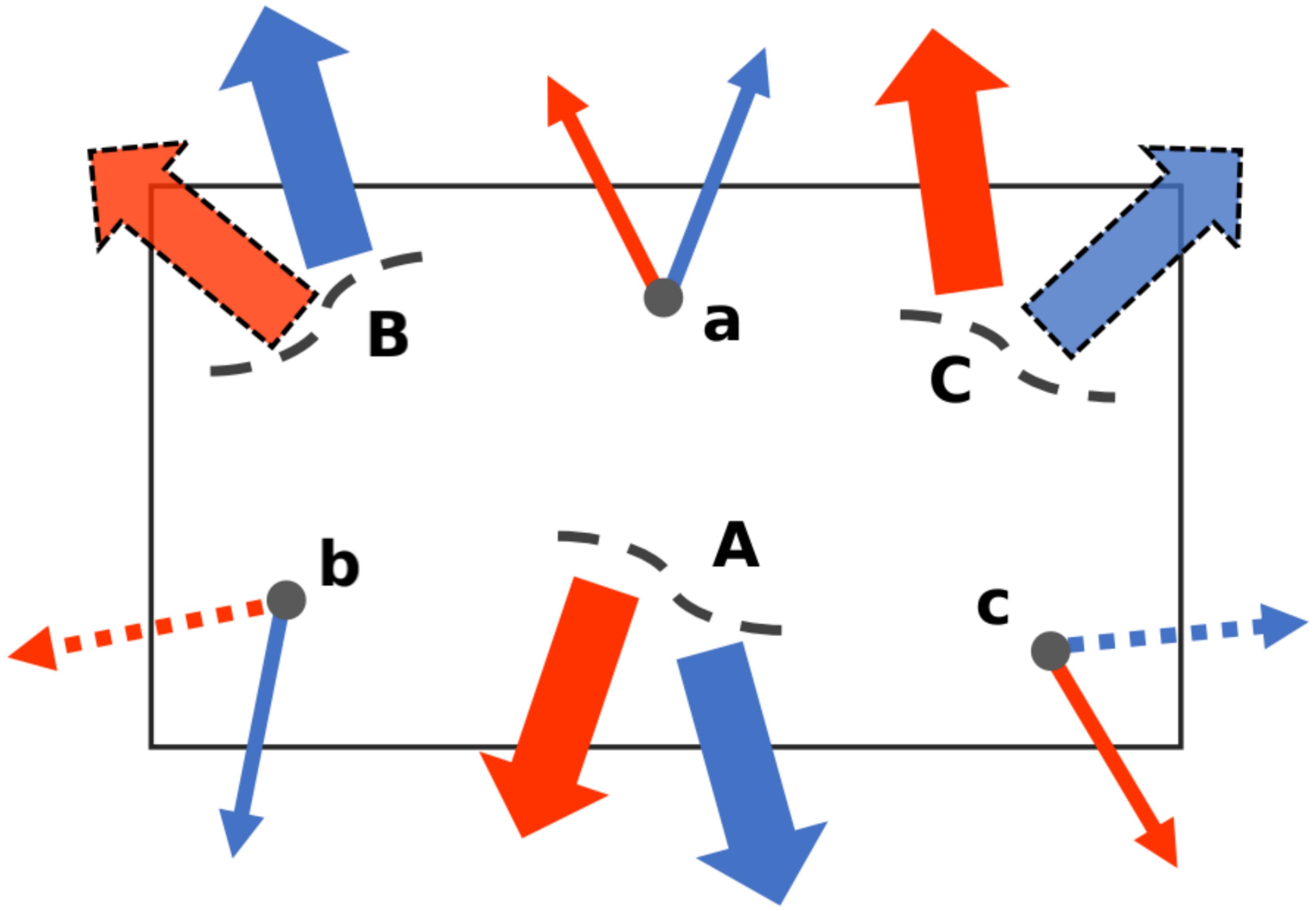
Differential covariance:

$$\langle v_2^{\pm} q_3 \rangle - \langle q_3 \rangle_1 \langle v_2^{\pm} \rangle$$

- ✓ Averaged charge around specific particle
- ✓ Reflect the local charge conservation in CMW measurements ($|\Delta\eta|$↑, covariance ↓)



Backup : local charge conservation leads to background



When selecting events with a specific A_{ch}, in practice, one preferentially applies nonuniform $p_T(\eta)$ cuts on the charged particles

A manifestation of LCC!

Type	$\rho^0 \to \pi^+\pi^-$ unpaired (case b, c)	$\rho^0 \to \pi^+\pi^-$ paired (case a)	String frag. unpaired (case B, C)	String frag. paired (case A)
Mother p_T	0.75	0.97	0.94	1.41
Mother $\lvert\eta\rvert$	1.17	0.53	2.15	2.12
Daughter p_T	0.59	0.64	0.68	0.74
Daughter $\lvert\eta\rvert$	0.41	0.39	0.41	0.40
Daughter $\lvert\Delta\eta\rvert$	1.27	0.48	1.03	0.69

$A_{ch} < 0(> 0) \to$ B(C) and b(c) $\uparrow \to$ unpaired neg(pos) particles $\uparrow \to \langle p_T^- \rangle < \langle p_T^+ \rangle \left(\langle p_T^- \rangle > \langle p_T^+ \rangle \right)$

Considering the LCC effect in an event with a specific A_{ch} value

- **Resonance decay** (a,b,c): paired particle emitted at the same point
- **String fragmentation model** (A,B,C): hadronization process with a string consisting of q and $\bar{q}$ endpoints

W. Wu et al. Phys. Rev. C 103, 034906 (2021)
C. Wang et al. Phys. Lett. B 820 136580 (2021)