Search for Chiral Magnetic Wave in heavy-ion collisions

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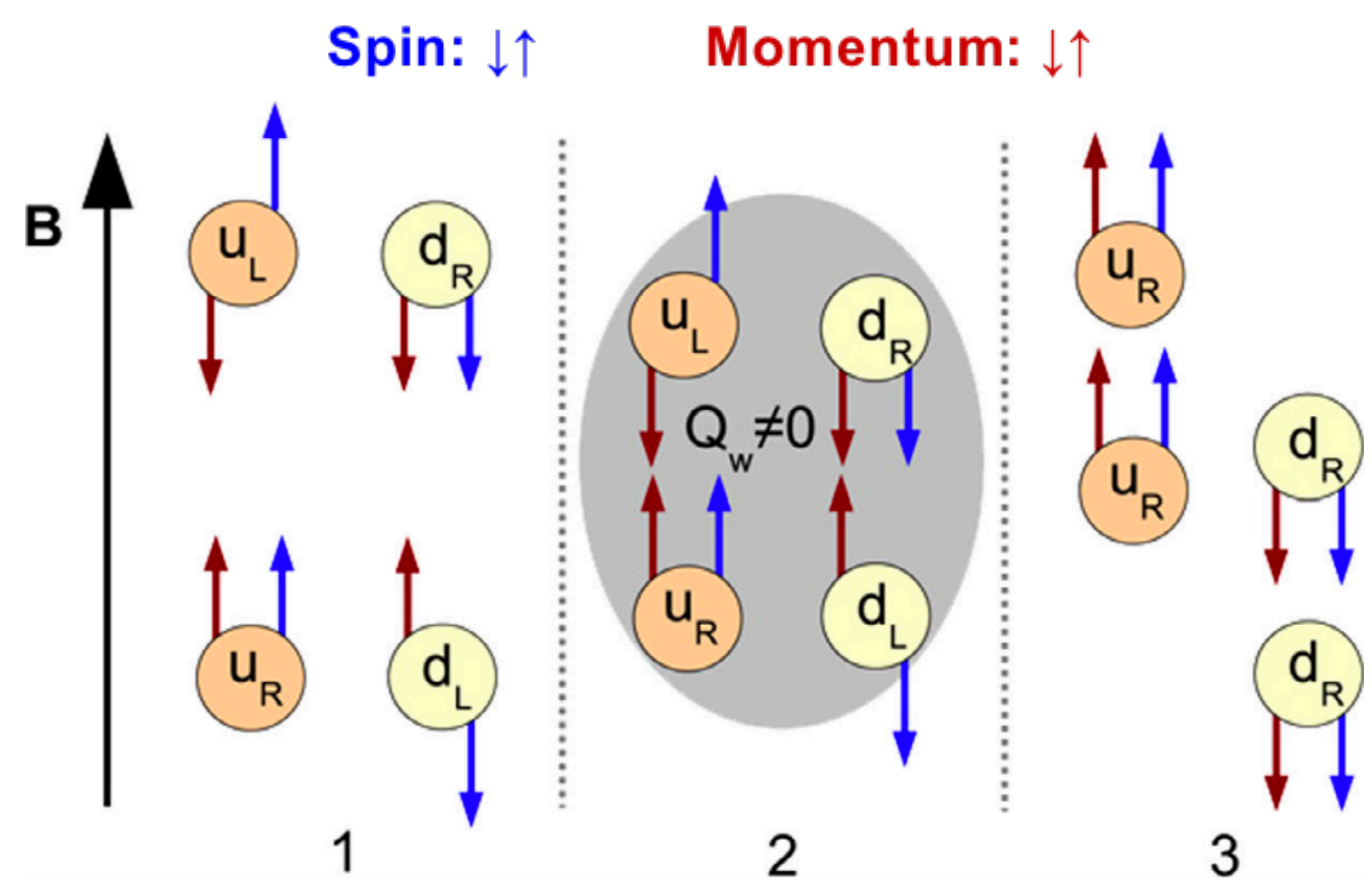
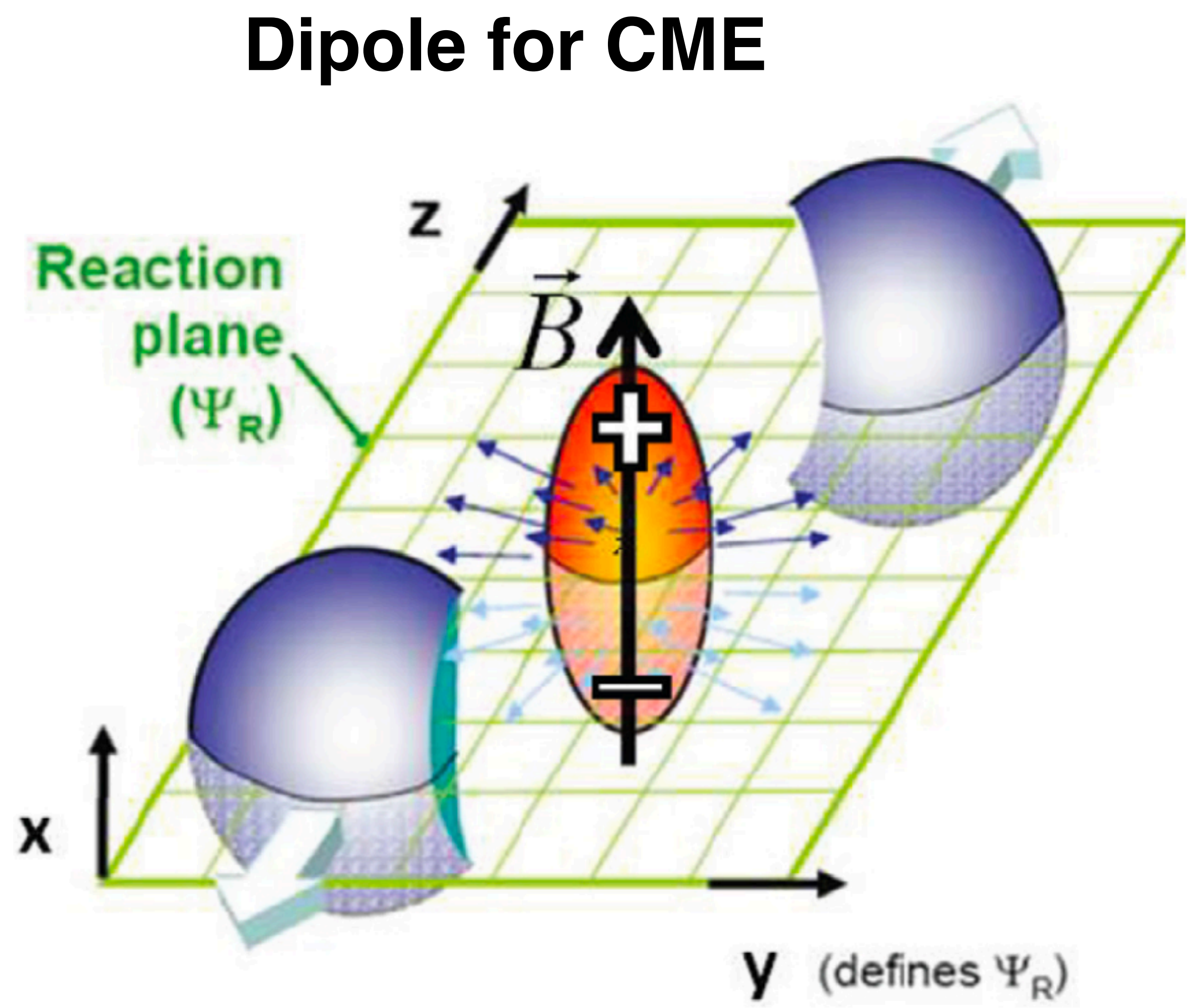
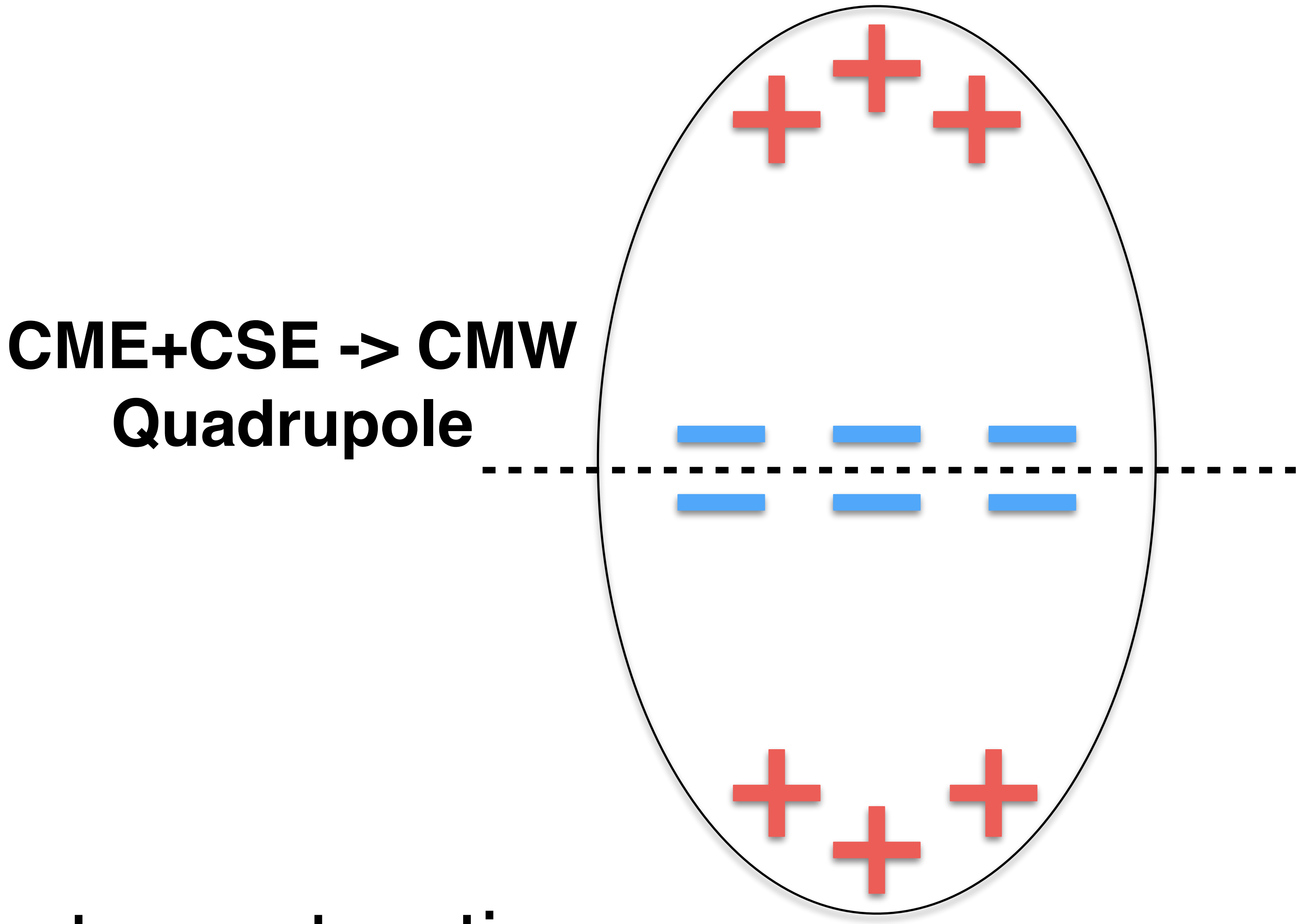
Outline

- ✓ Motivation
- ✓ Experimental meaurements
- ✓ Backgrounds
- ✓ Model simulation
- ✓ Summary







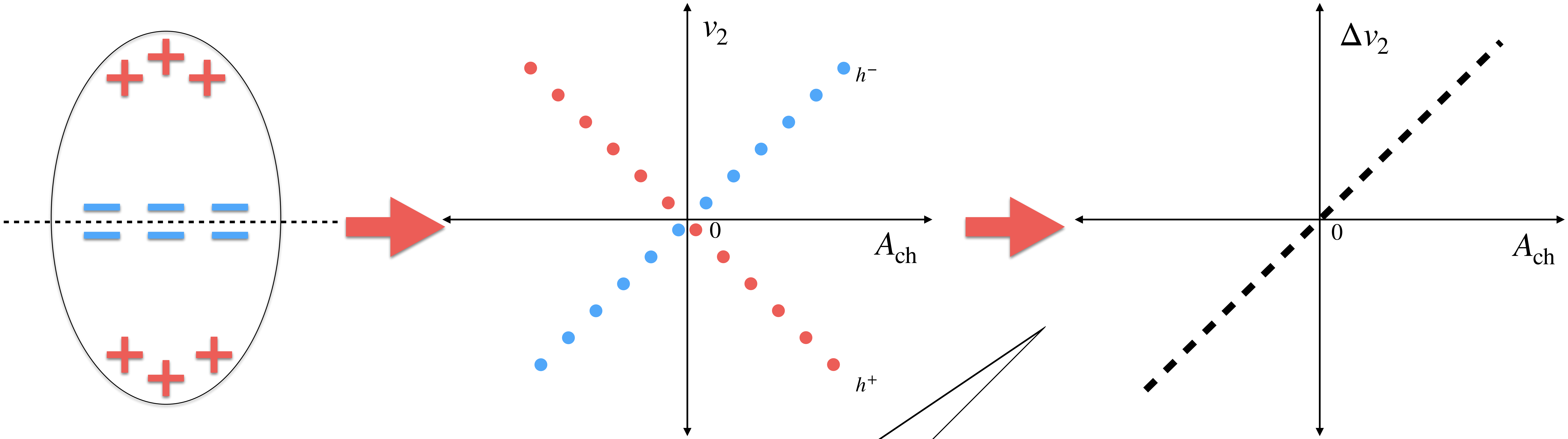
- ✓ **Chiral Magnetic Effect (CME)**: $j_\nu = \frac{N_c e}{2\pi^2}\mu_A B$
- ✓ **Chiral Separation Effect (CSE)**: $j_A = \frac{N_c e}{2\pi^2}\mu_\nu B$
- ✓ **Chiral Magnetic Wave (CMW)**: CME+CSE

✓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)

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

Experimental observable — covariance

Integral covariance :

$$\langle v_2^{\pm} A_{ch} \rangle - \langle A_{ch} \rangle \langle v_2^{\pm} \rangle \approx \mp r \sigma^2_{A_{ch}} / 2$$

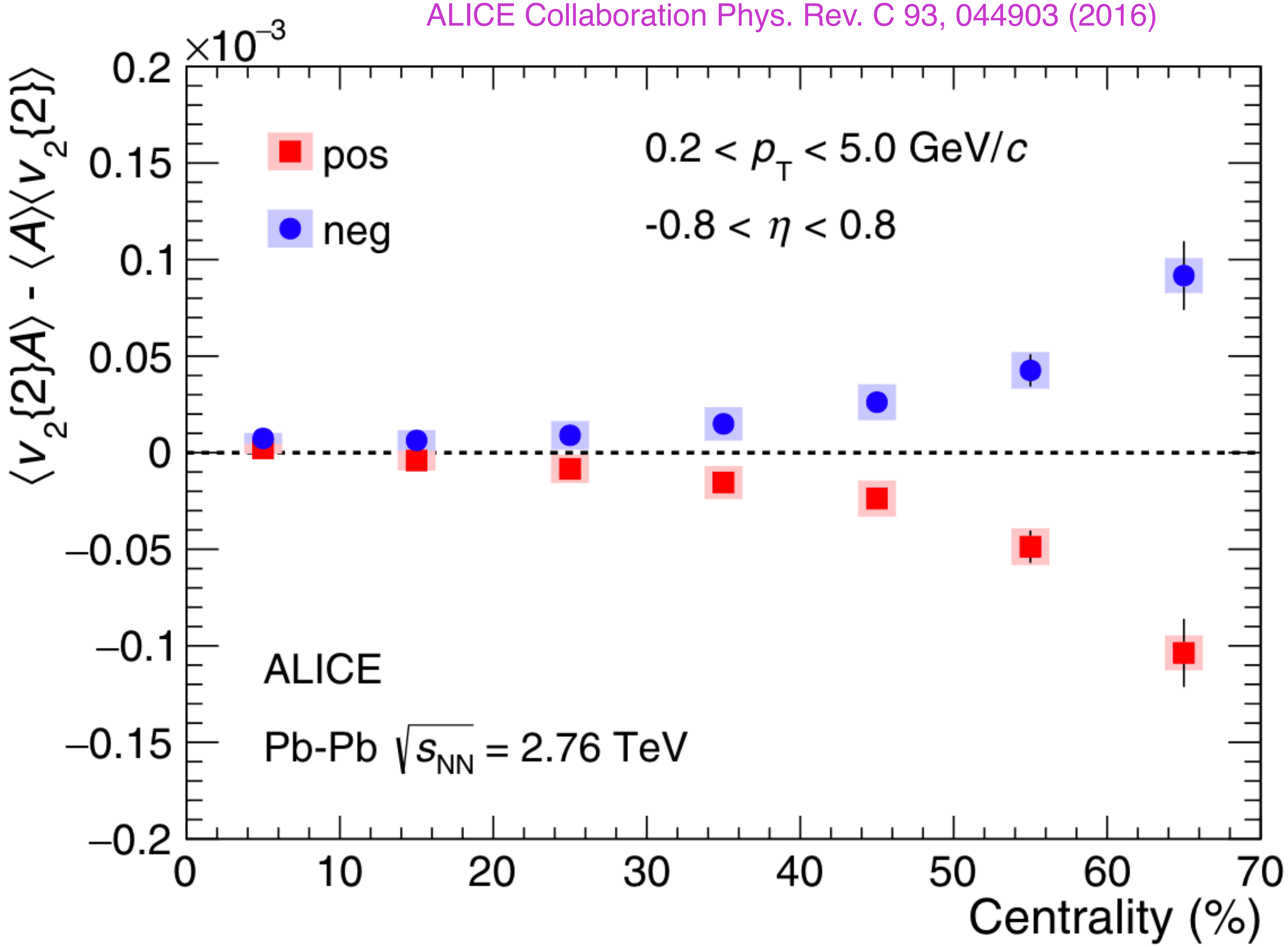
$$dN_{ch}/d\eta \left(\langle v_2^{\pm} A_{ch} \rangle - \langle A_{ch} \rangle \langle v_2^{\pm} \rangle \right)_{neg-pos}$$

Covariance observable:

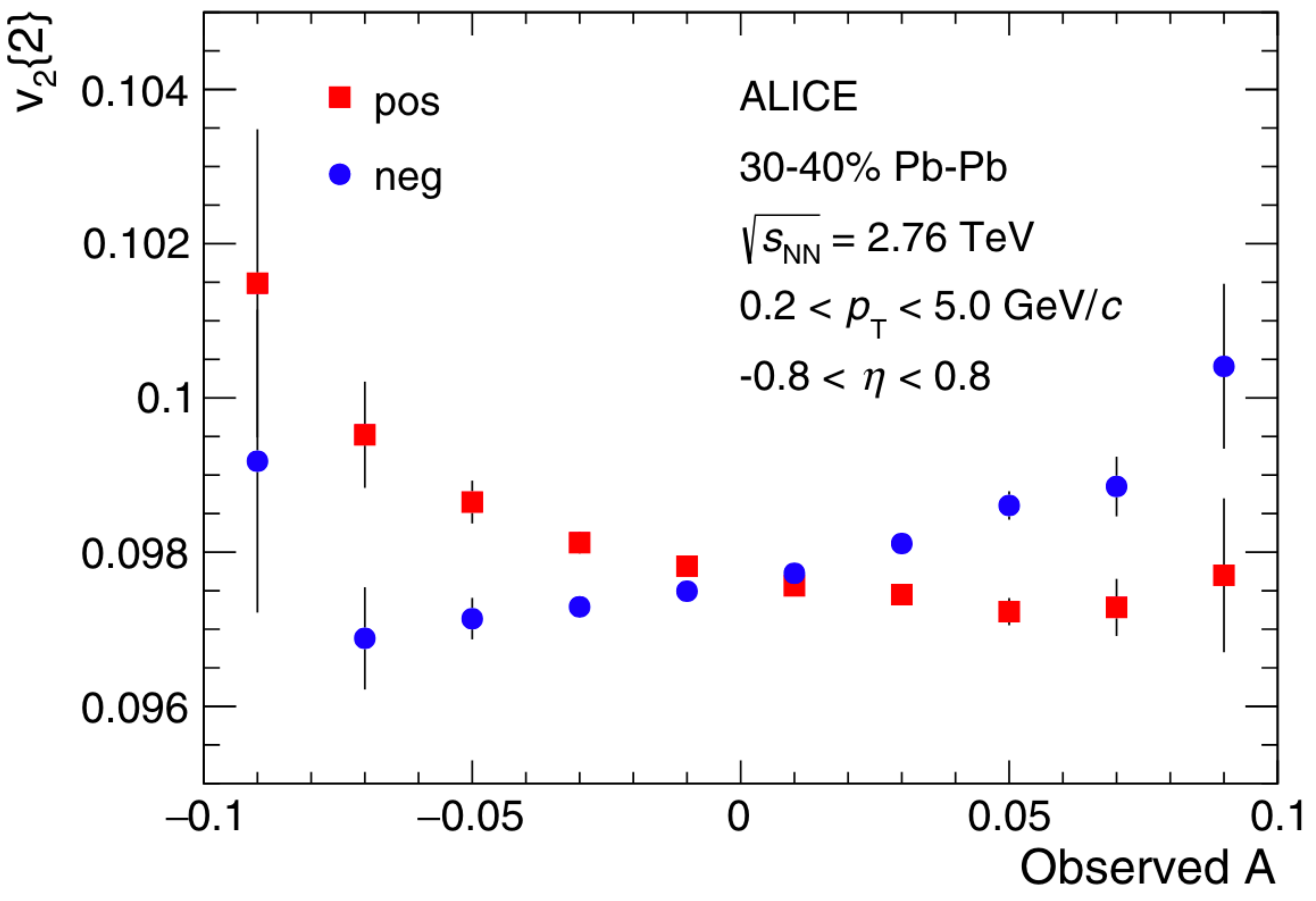
(proposed in S. A. Voloshin et al. Nucl.Phys.A 931 992-996 (2014))

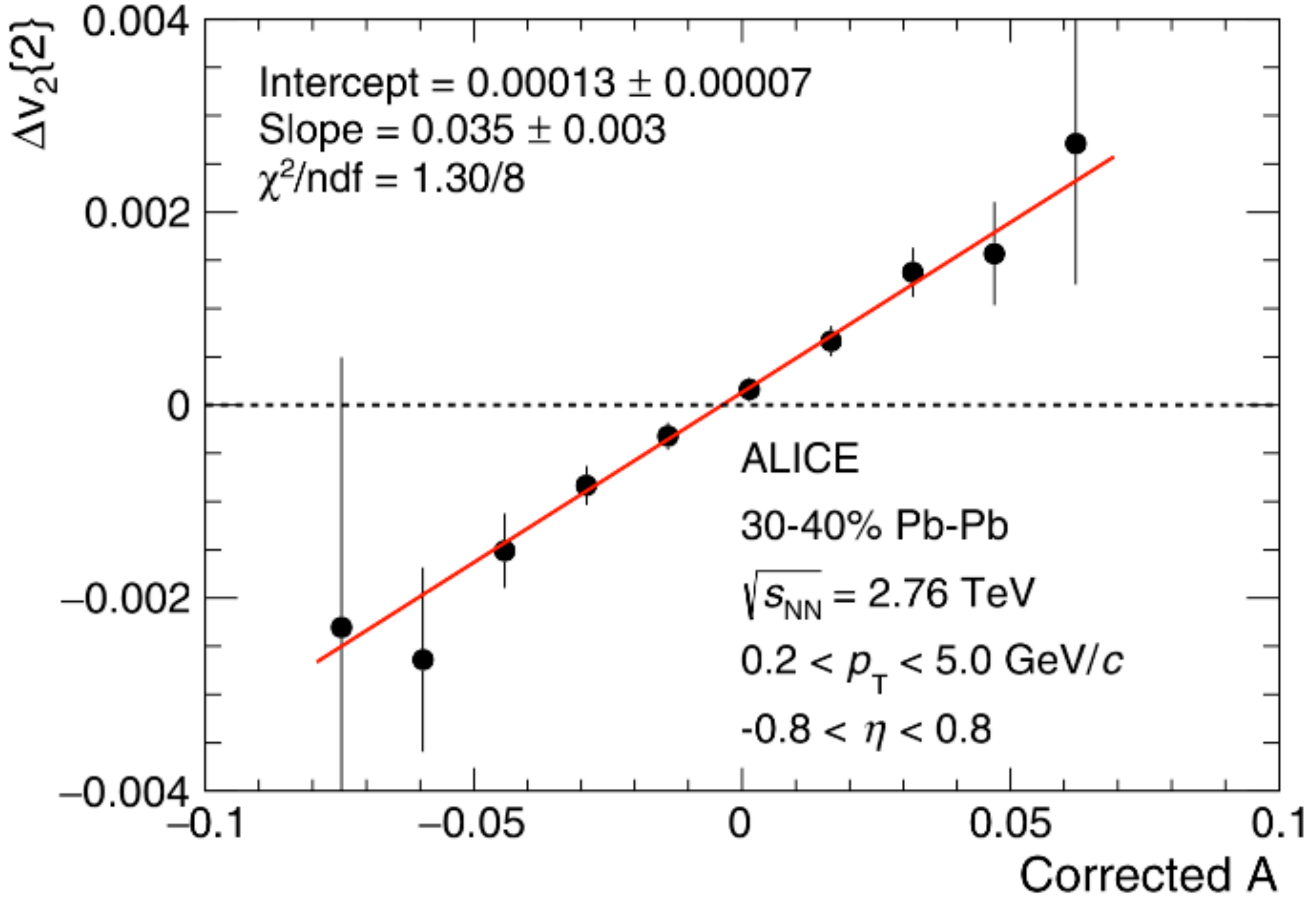
✓ Proportional to slope parameter
✓ Saves statistics
✓ Has differential form (see backup)

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



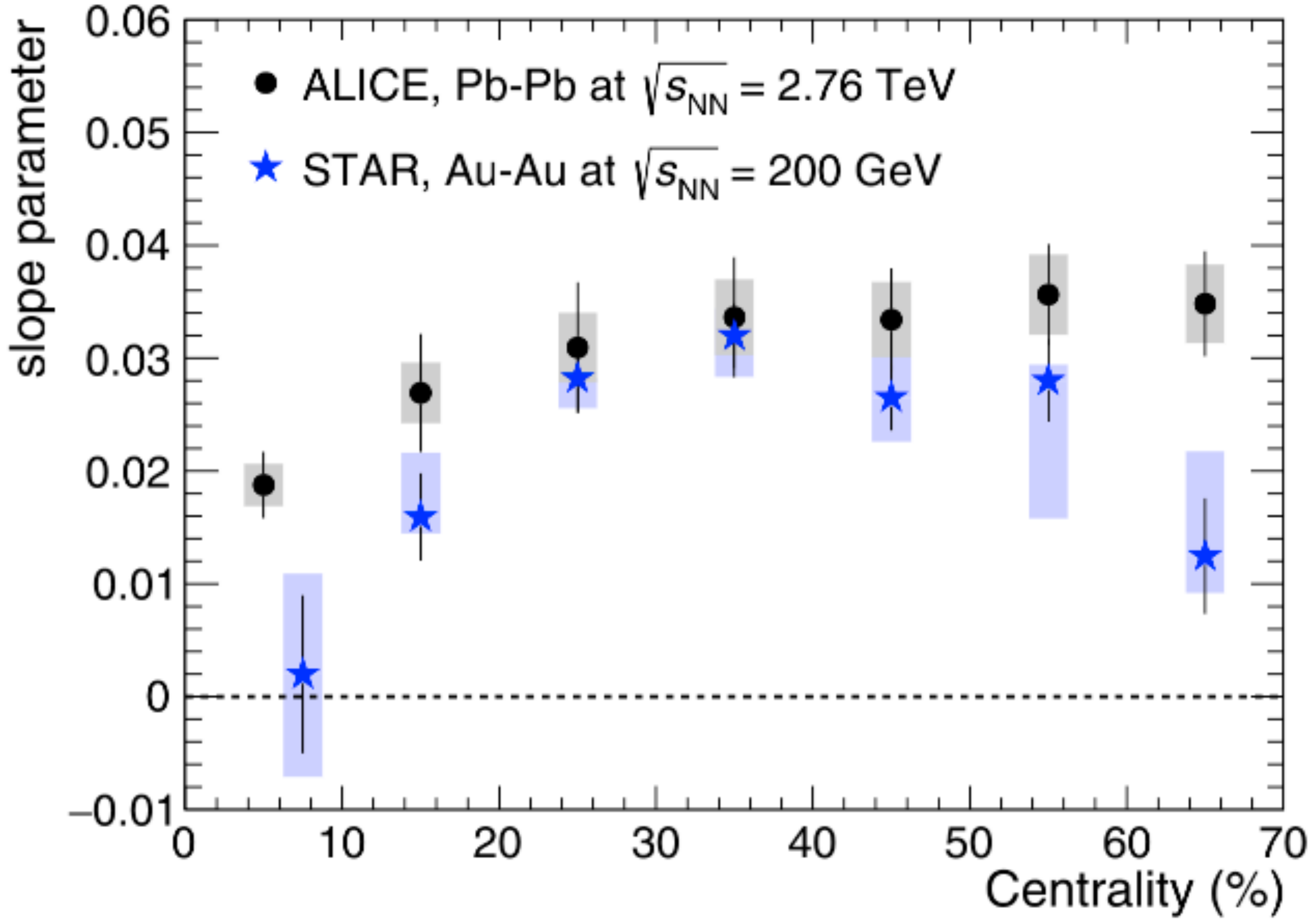
Previous experimental measurements — ALICE & STAR



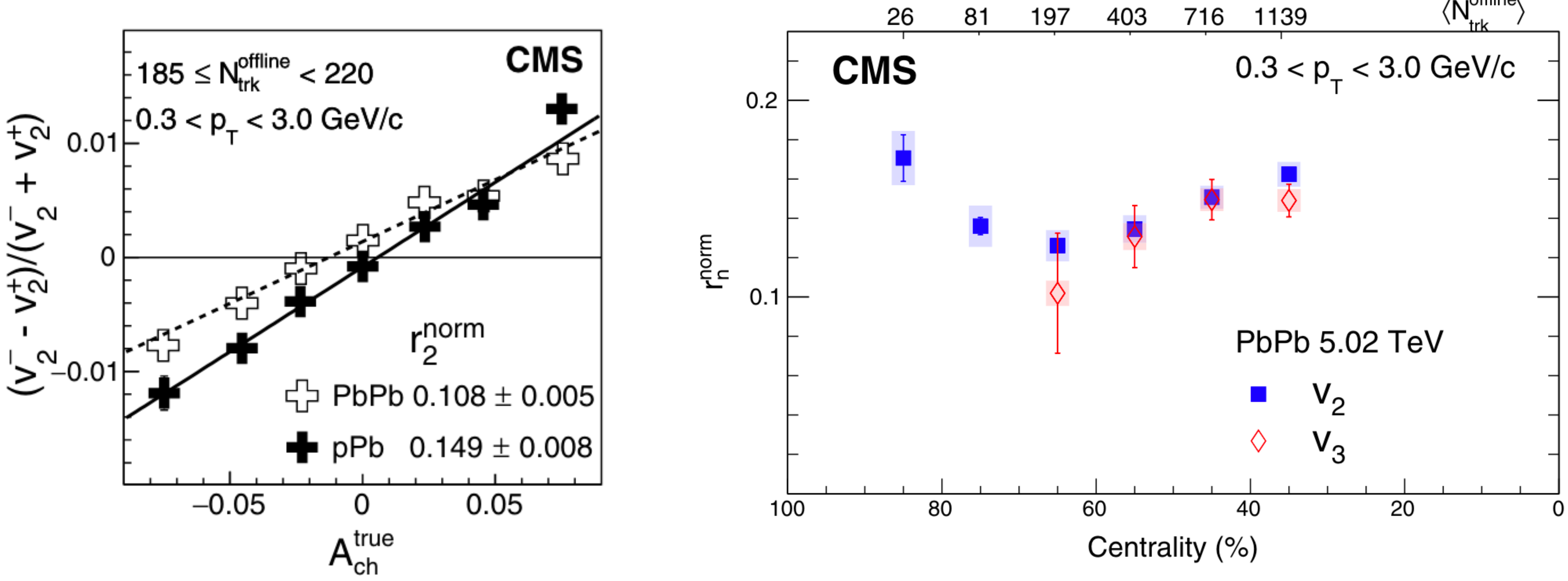


ALICE Collaboration. Phys. Rev. C 93, 044903 (2016)

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



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

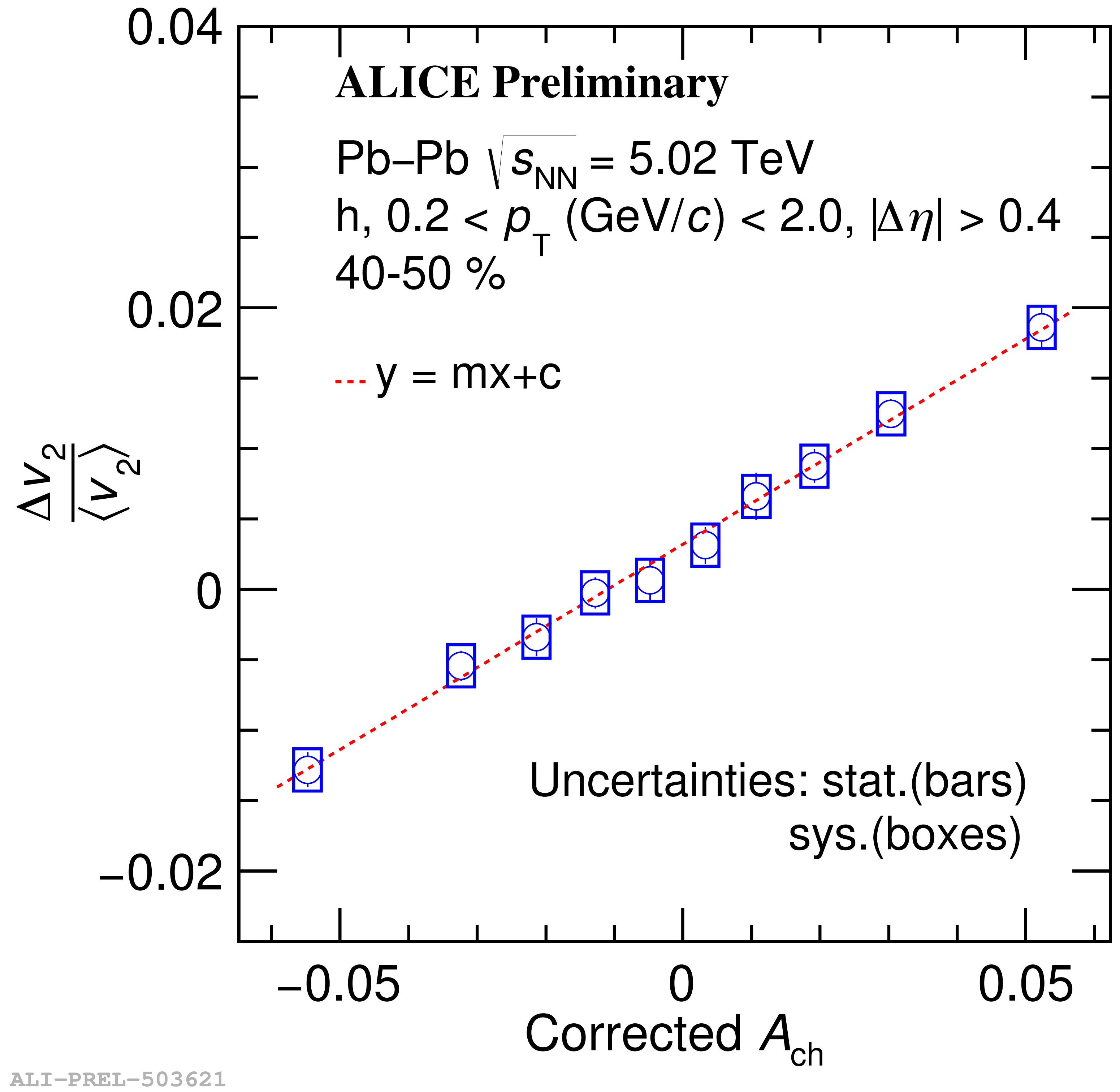


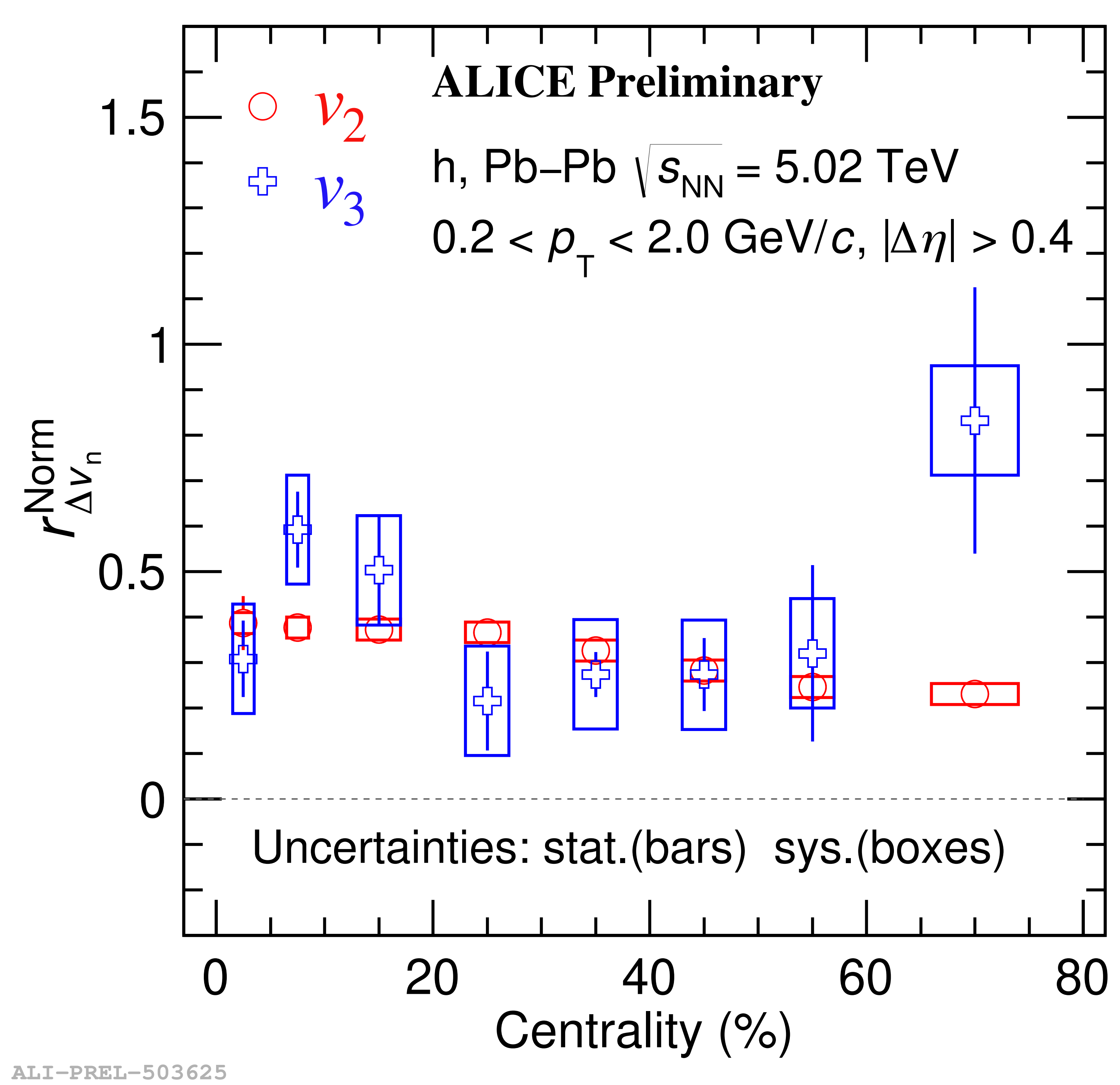
Most possible background: **local charge conservation (LCC) convoluted with v_2**

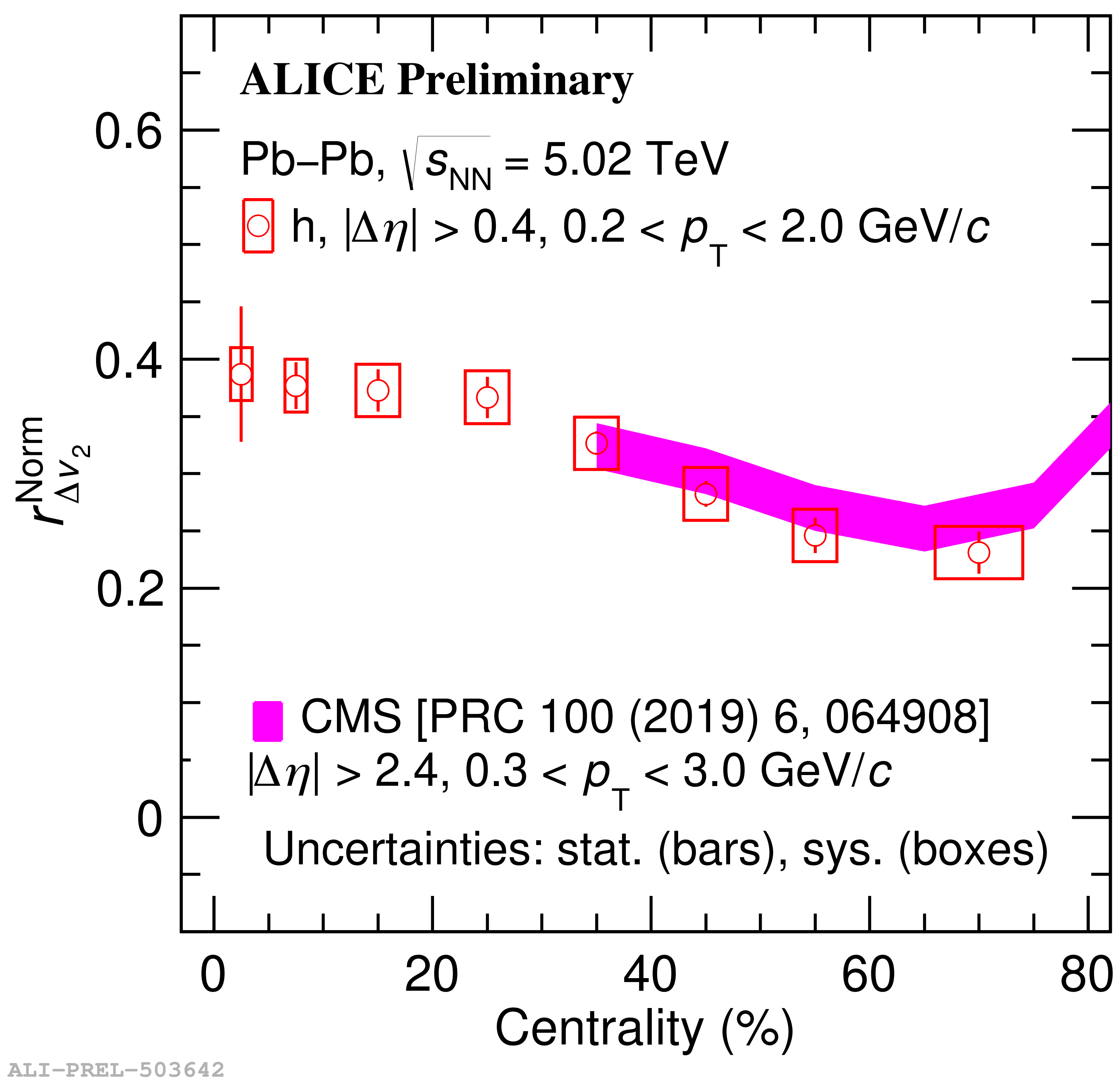
- ✓ The observable in p-Pb collision is in line with the one in Pb-Pb collisions
- ✓ Higher harmonic (v_3) observable with nonzero signal

A. Bzdak et al. Phys. Lett. B 726 239243 (2013)
S. A. Voloshin et al. Nucl.Phys.A 931 992996 (2014)
W. Wu et al. Phys. Rev. C 103, 034906 (2021)

How to separate the signal/background?

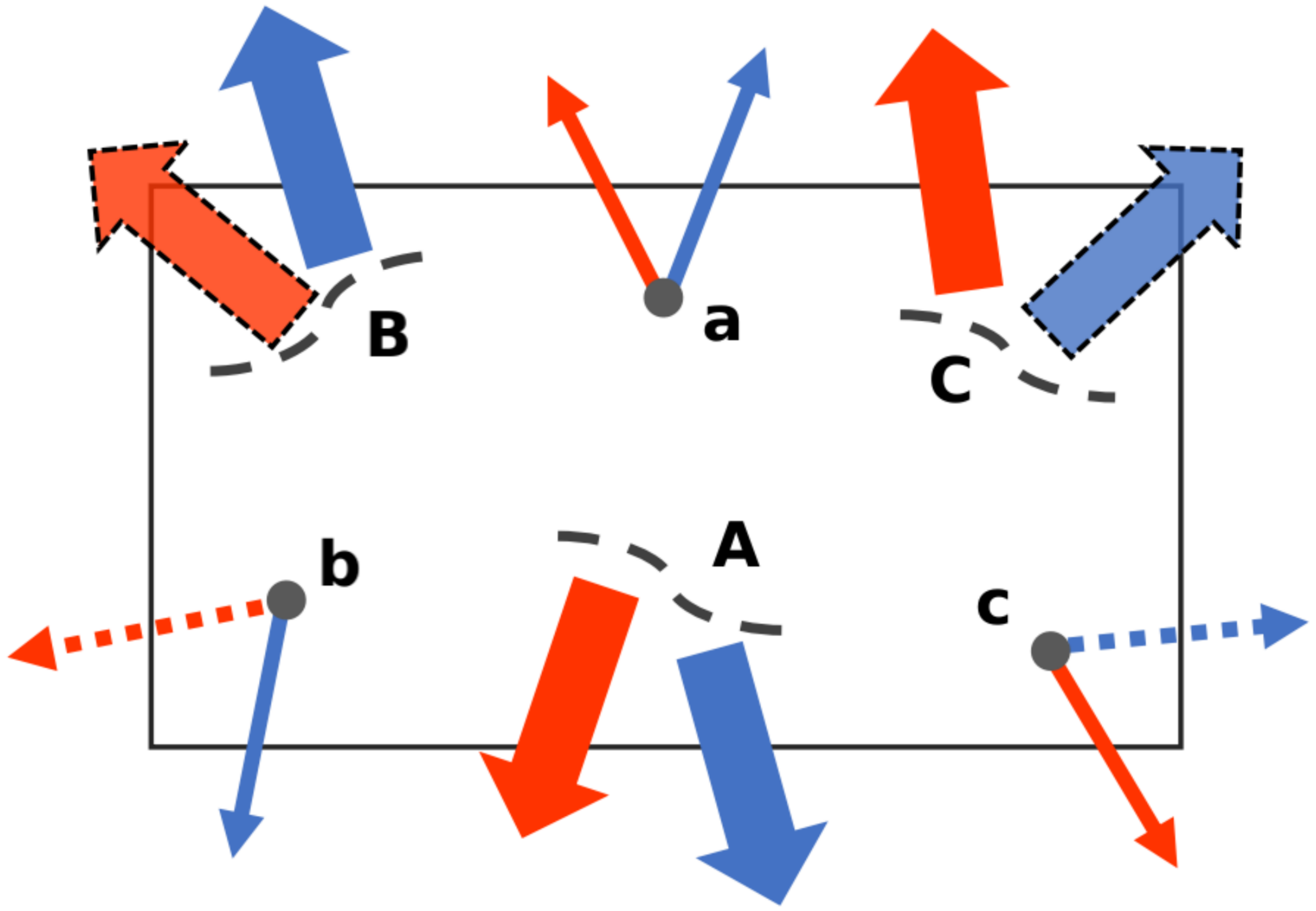






- ✓ Linear dependences between $\Delta v_2/\langle v_2 \rangle$ and A_{ch} in the left figure
- ✓ In the middle figure , $r_{\Delta v_2}^{Norm.}$ is consistent with $r_{\Delta v_3}^{Norm.}$ within uncertainties
- ✓ $r_{\Delta v_2}^{\mathrm{Norm(ALICE)}} \approx r_{\Delta v_2}^{\mathrm{Norm(CMS)}}$

W. Wu arXiv:2212.04137



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 $\|\eta\|$	1.17	0.53	2.15	2.12
Daughter p_T	0.59	0.64	0.68	0.74
Daughter $\|\eta\|$	0.41	0.39	0.41	0.40
Daughter $\|\Delta\eta\|$	1.27	0.48	1.03	0.69

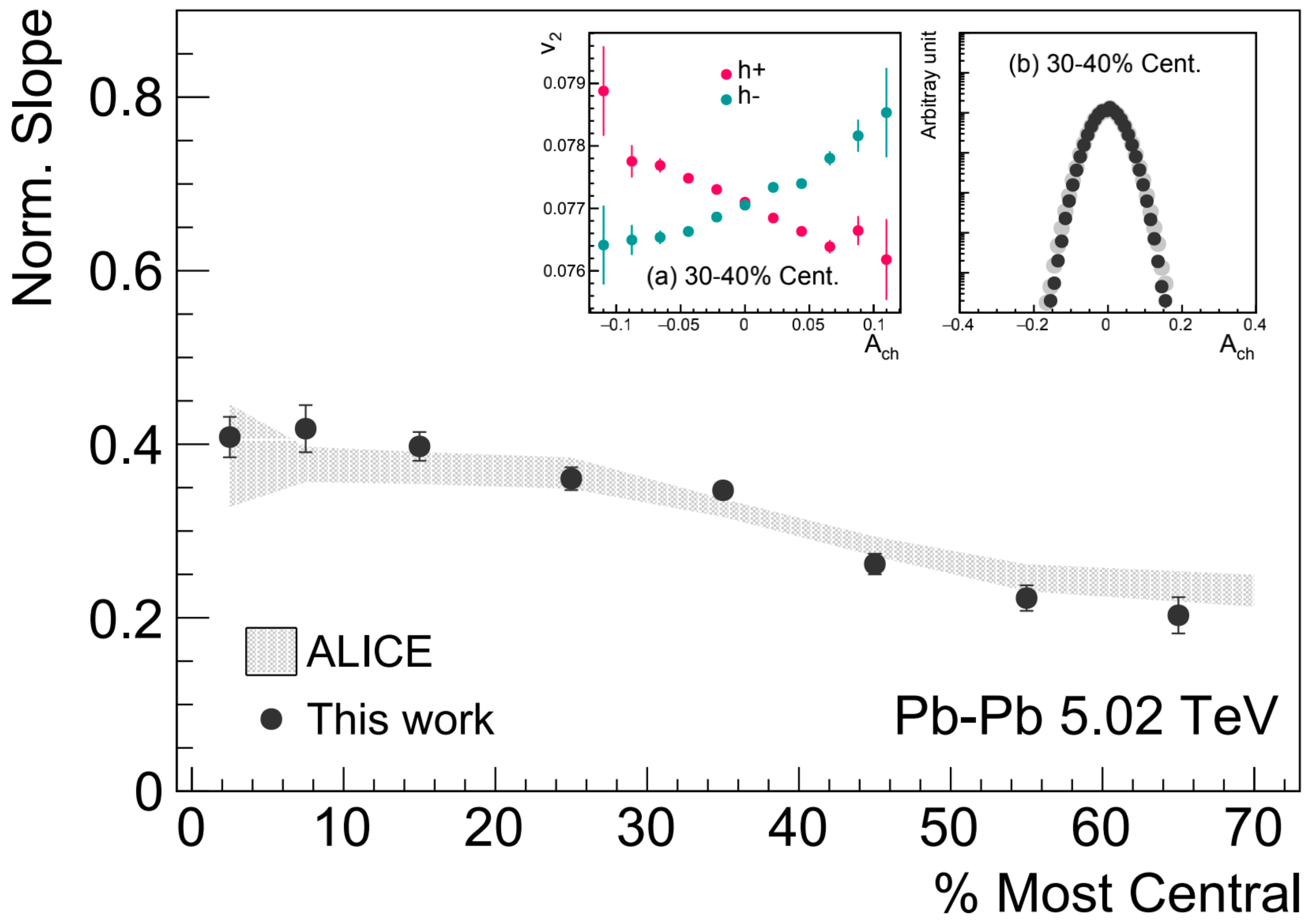
$A_{ch} < 0(>0) \to$ B(C) and b(c) ↑ → unpaired neg(pos) particles ↑ $\to \langle p_T^- \rangle < \langle p_T^+ \rangle (\langle p_T^- \rangle > \langle p_T^+ \rangle)$

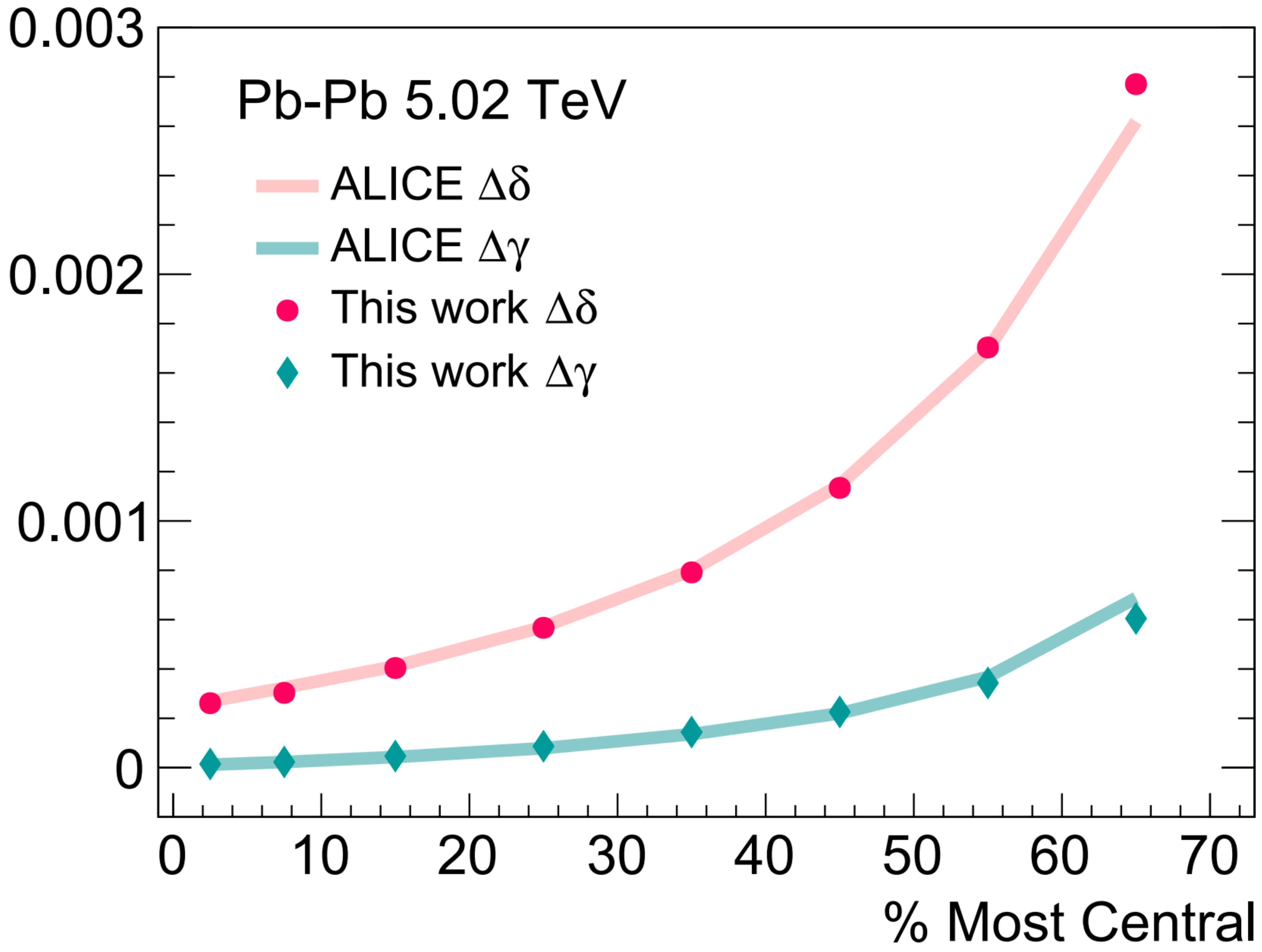
- **Resonance decay** (a,b,c): paired particle emitted at the same point
- **String fragmentation model** (A,B,C): hadronization process with a string consisting of q and $\bar{q}$ endpoints

CMW LCC:
W. Wu et al. Phys. Rev. C 103, 034906 (2021)
A. Bzdak et al. Phys. Lett. B 726 239243 (2013)
C. Wang, W. Wu et al. Phys. Lett. B 820 136580 (2021)

CME LCC:
S. Schlichting et al. Phys. Rev. C 83, 014913 (2011)

Blast wave with LCC reproduces experiemntal results of CMW/E



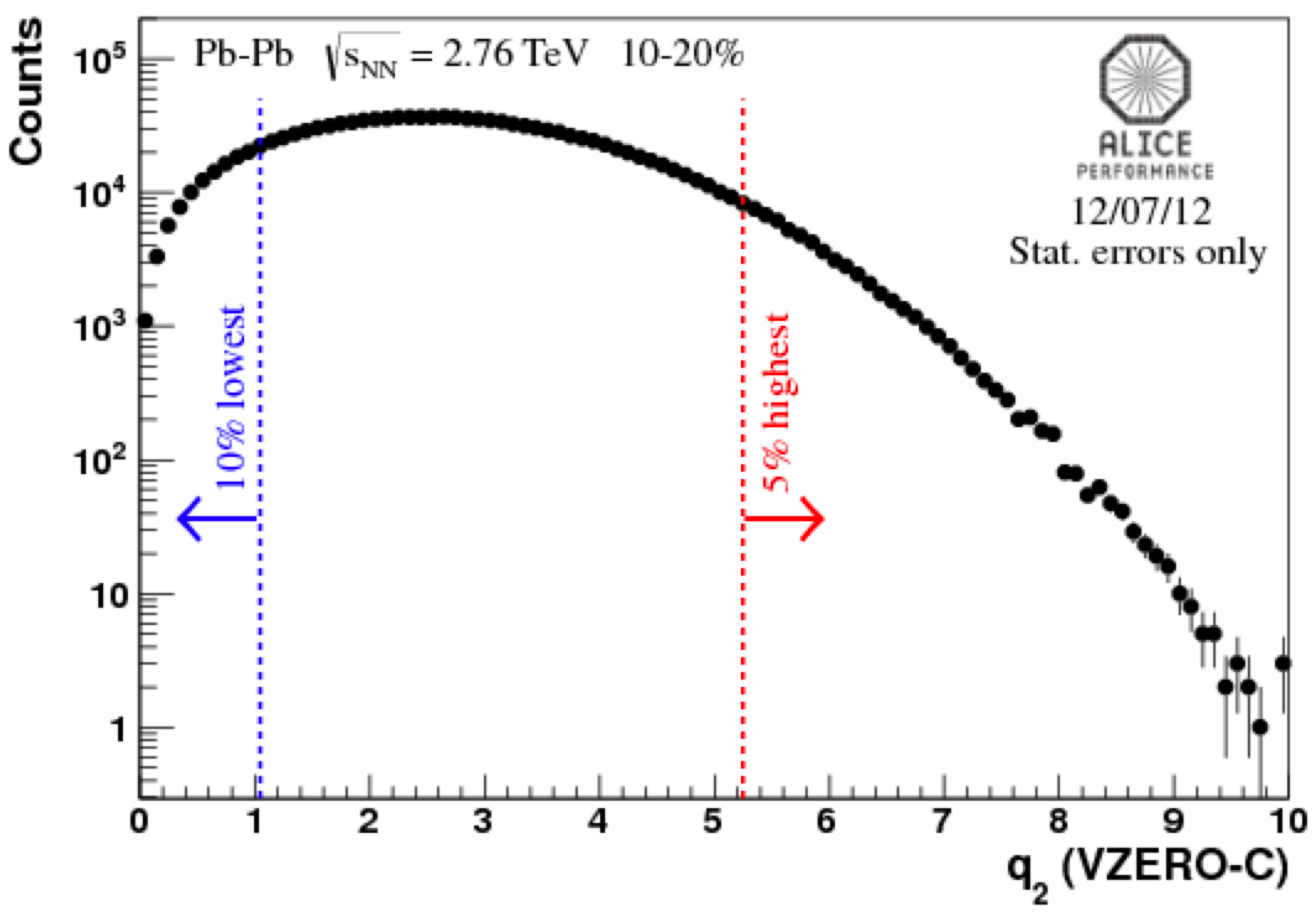


- BW+LCC —> boost paired particles at a same point
- Blast wave model (thermal expansion) adding **finite** LCC effect can reproduce the ALICE experimantal measurements of CMW(left) and CME(right) together —> measurements on both CMW and CME are dominated by the LCC background
- Observables are very sensitive to CMW/CME signal as BW+LCC (adding signal) simulation

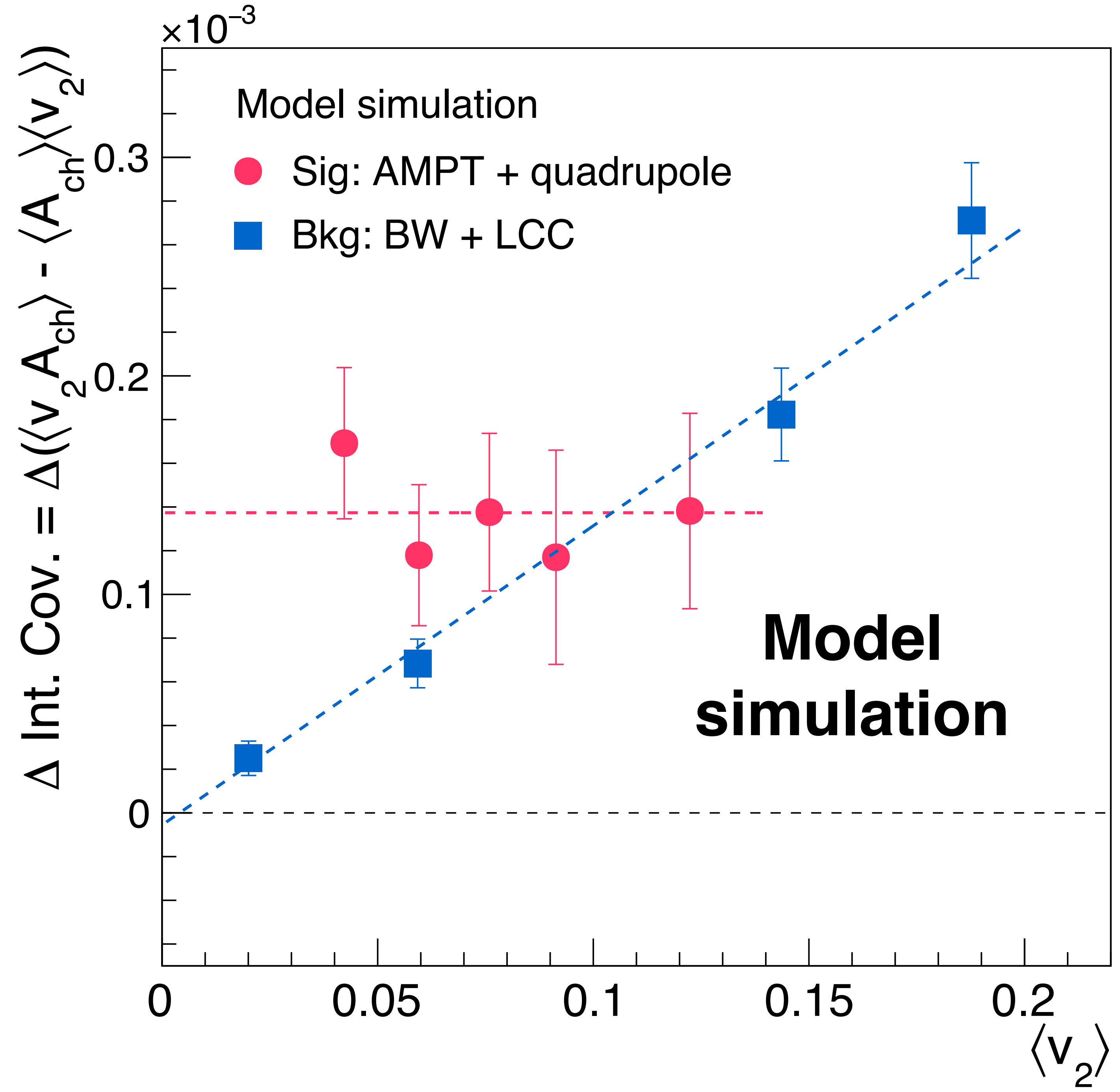
WY. WU et al. arXiv:2211.15446 (2022)

Event-shape engineering constrains CMW fraction

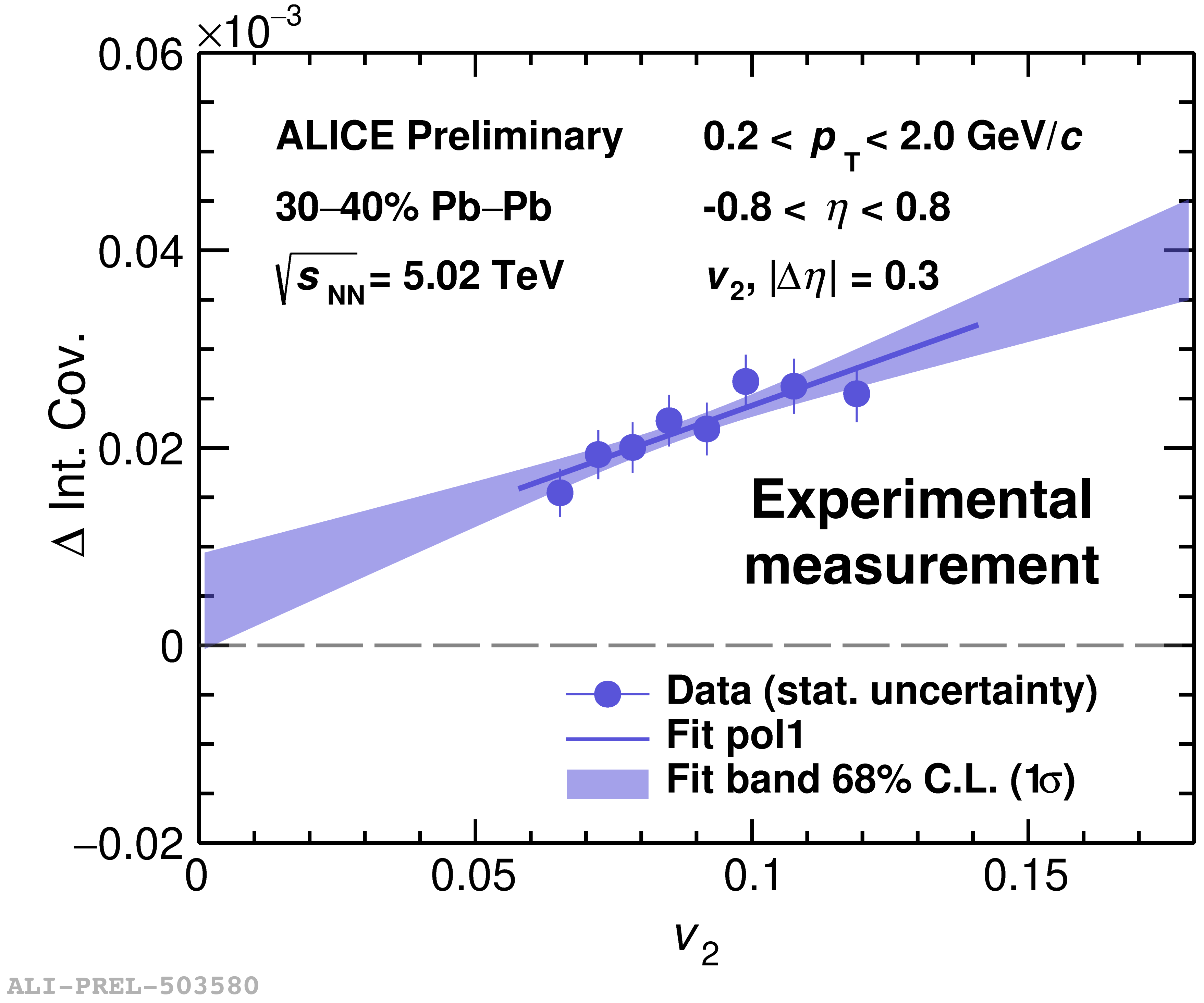
A. Dobrin et al. Nucl.Phys.A 904-905 455c-458c (2013)



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



W. Wu arXiv:2212.04137



- ✓ Classify events corresponding to q_2
- ✓ Sensitive to v_2 of collision ($q_2 \propto v_2$)
- ✓ Successfully used for CME

ESE technique
J. Schukraft et al. Phys. Lett. B 719 394398 (2013)
ALICE Collaboration Phys. Lett. B 777, 151162 (2018)
CMS Collaboration Phys. Rev. C 100, 064908 (2019)

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

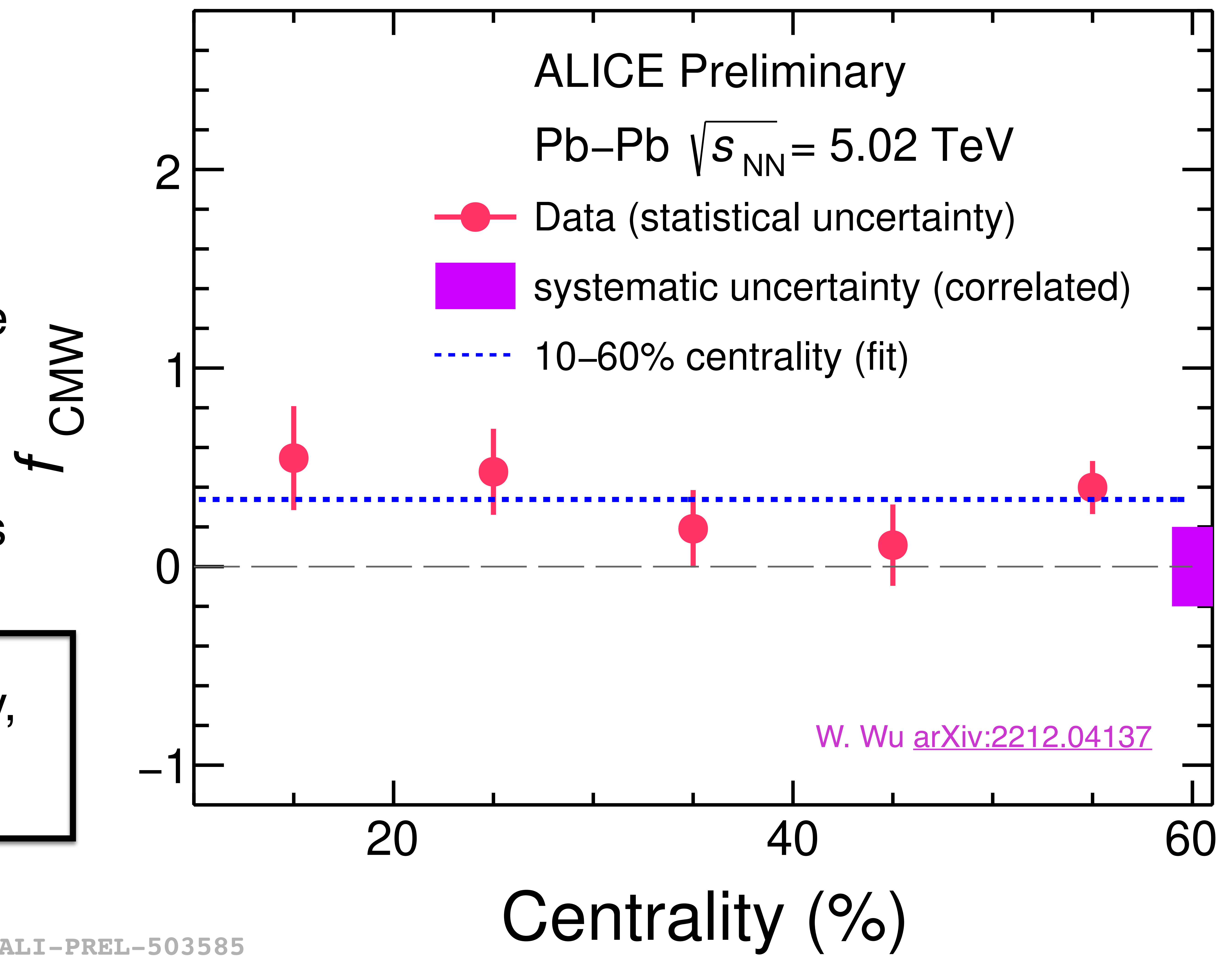
- ✓ In most centralities, the proportionality of ΔInt. Cov. changes with v_2 → indication of a large background
- ✓ Linear fit: $F(v_2) = a \times v_2 + b$

Centrality dependence of CMW fraction $f_{\rm CMW}$

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

- ✓ 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
- ✓ $f_{\rm CMW}$ consistent with 0 within uncertainties

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



ALI-PREL-503585

Summary

✓ The LCC effect is recognized as one of the most important background effect in the studies of chiral anomalous effects

✓ Δv_2-$A_{\rm ch}$ **method:** The normalized slope $r^{Norm.}_{\Delta v_2}$ is consistent with $r^{Norm.}_{\Delta v_3}$ 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 (There is no statistical significance to observe the CMW signal)

Thanks for your attention!

Back up : differential 3-particle correlator — probe LCC

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 LCC effect in CMW measurements

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