Parallel Session 2.2: QCD in Small Systems

Charge Asymmetry Dependence of Anisotropic Flow in pPb and PbPb collisions with CMS

- and its implication to the Chiral Magnetic Wave

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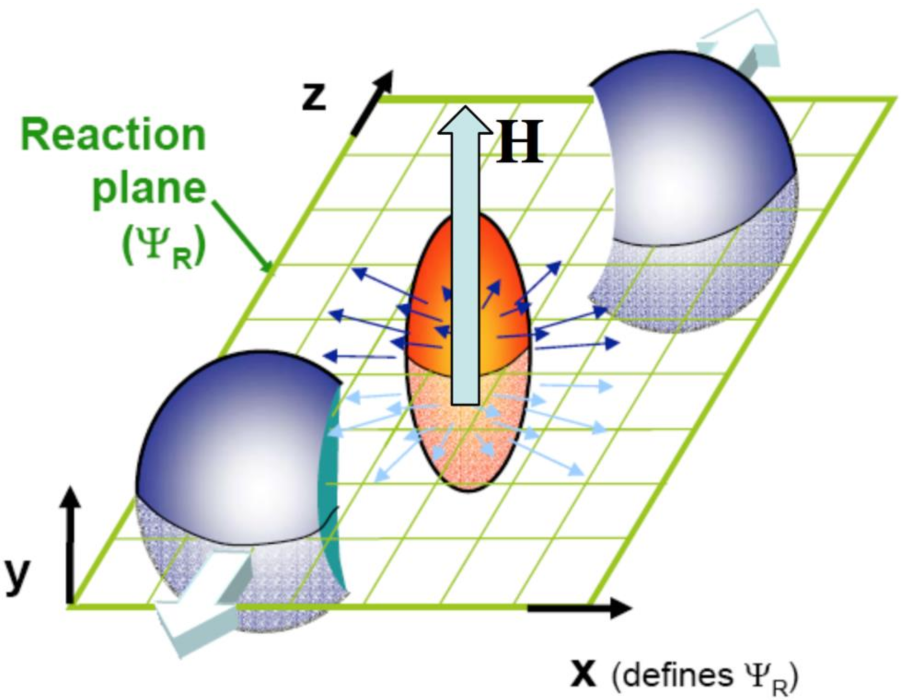
Rice University, Houston TX
On behalf of CMS collaboration

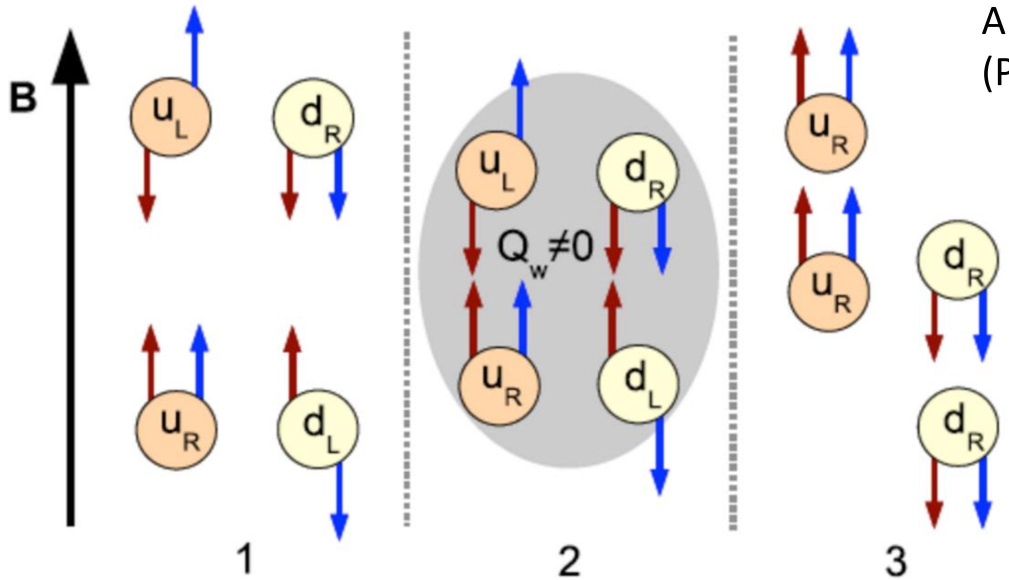
Quark Matter Conference, Chicago- Feb. 7 (2017)

Strong Magnetic Field in heavy-ion collisions



- Strong B field in non-central collisions
  - RHIC - 10^19 Gauss
  - LHC – 14 ✕ RHIC
  - Induces number of novel quantum phenomena in QGP
- Chiral anomaly in QCD

Chiral Magnetic Effect



Arxiv: 1312.3348
(Prog. Part.Nucl.Phys'14)

Blue: Spin
Red : Momentum

- Imbalance in left/right handed quarks + Magnetic Field

$$\vec{J} = \frac{e^2}{2\pi^2}\mu_5 \vec{B}$$

Anomalous Chiral Effects

Analogous to Ohm's law $\vec{J} = \sigma \vec{E}$

$$\vec{j}_V = \frac{N_c\, e}{2\pi^2} \mu_A \vec{B}$$

- Chiral Magnetic Effect (CME)
  - Vector charge separation along B (electric)

$$\vec{j}_A = \frac{N_c\, e}{2\pi^2} \mu_V \vec{B}$$

- Chiral Separation Effect (CSE)
  - Axial charge separation along B

Chiral Magnetic Wave

$$j_A = \frac{N_c e}{2\pi^2}\mu_V B \qquad j_V = \frac{N_c e}{2\pi^2}\mu_A B$$

Coupling of electric and axial charge densities

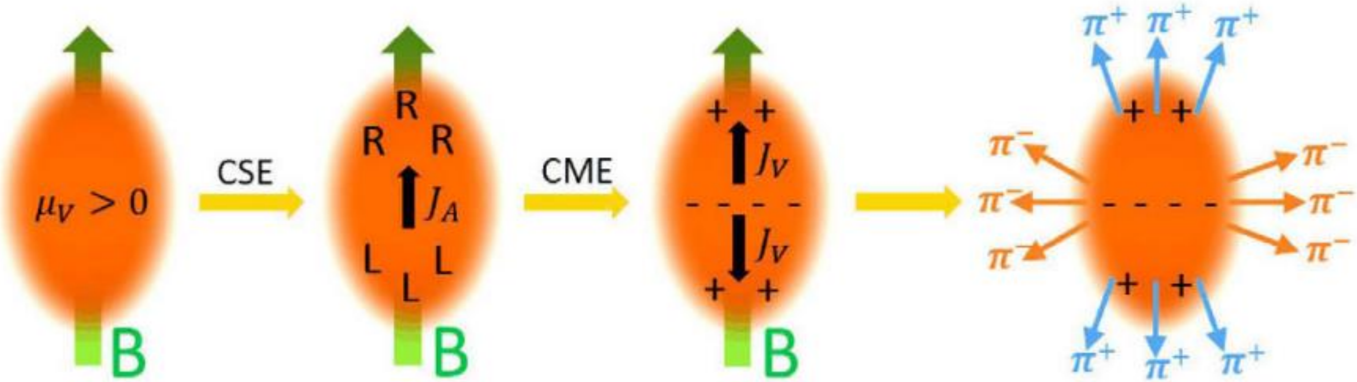
$$\left(\partial_0 \mp \partial_1 v_\chi - D_L \partial_1^2\right) j^0_{L,R} = 0$$

Chiral Magnetic Wave

$$j_A = \frac{N_c e}{2\pi^2}\mu_V B \qquad j_V = \frac{N_c e}{2\pi^2}\mu_A B$$

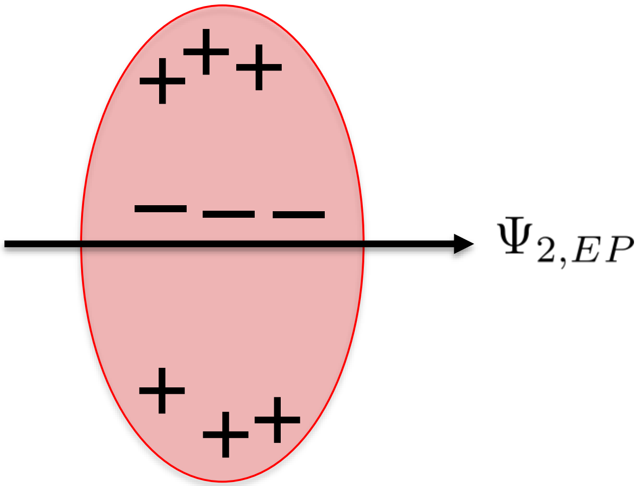
Coupling of electric and axial charge densities

$$\left(\partial_0 \mp \partial_1 v_\chi - D_L \partial_1^2\right) j^0_{L,R} = 0$$



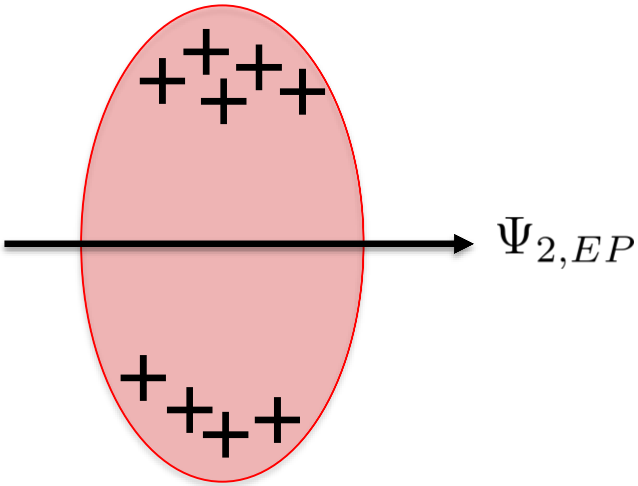
Experimental Prediction of CMW Mechanism

- Event-by-Event fluctuating charge asymmetry parameter



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

- Event-by-Event fluctuating charge asymmetry parameter

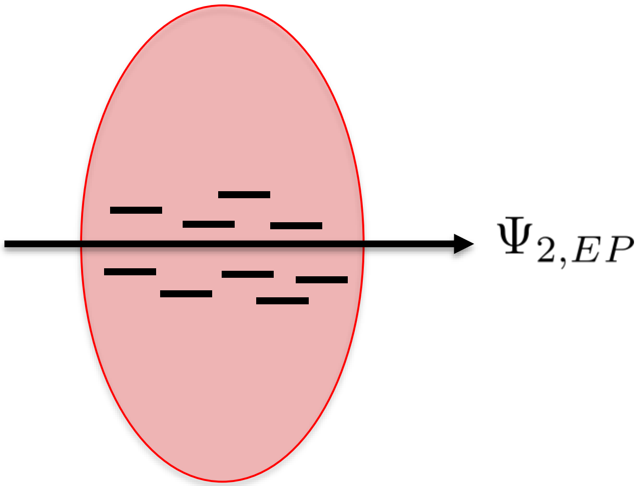


$$A_{ch} = \frac{N^+ - N^-}{N^+ + N^-}$$

Ach ↑ v_2^+ ↓

Experimental Prediction of CMW Mechanism

- Event-by-Event fluctuating charge asymmetry parameter

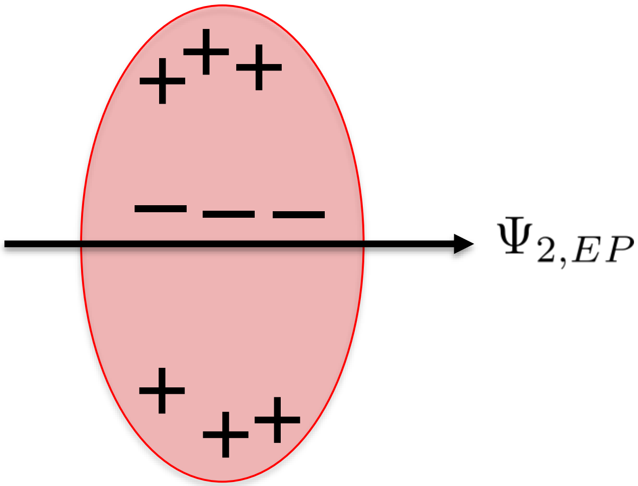


$$A_{ch} = \frac{N^+ - N^-}{N^+ + N^-}$$

$A_{ch} \downarrow \quad v_2^- \uparrow$

Experimental Prediction of CMW Mechanism

- Event-by-Event fluctuating charge asymmetry parameter



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

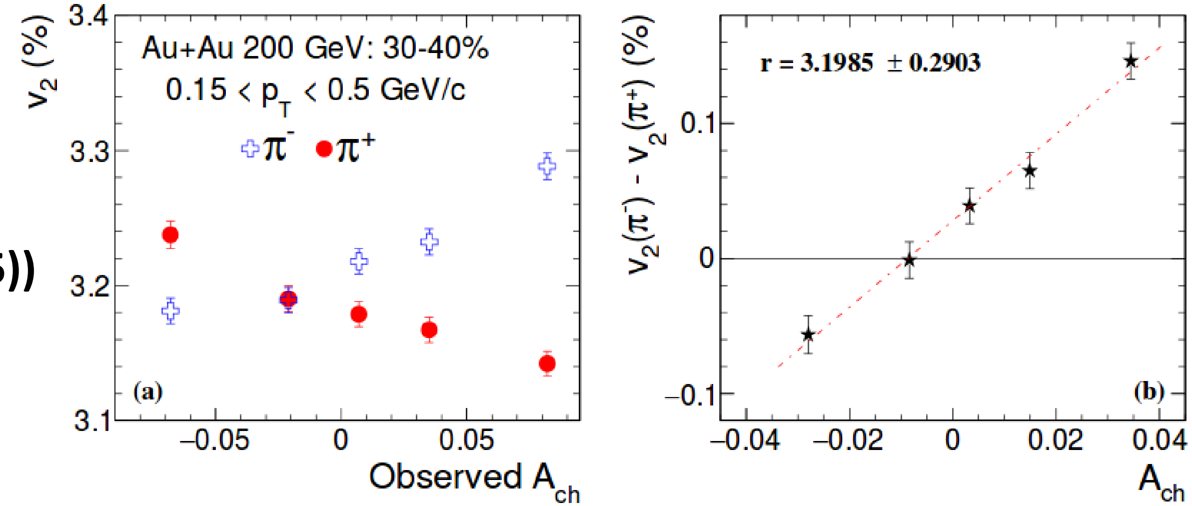
$$\frac{d(N_+ - N_-)}{d\phi} = (\bar{N}_+ - \bar{N}_-)[1 - r_e \cos(2\phi)]$$

$$\frac{dN_\pm}{d\phi} = \bar{N}_\pm \left[1 + (2v_2 \mp r_e\, A)\cos(2\phi)\right]$$

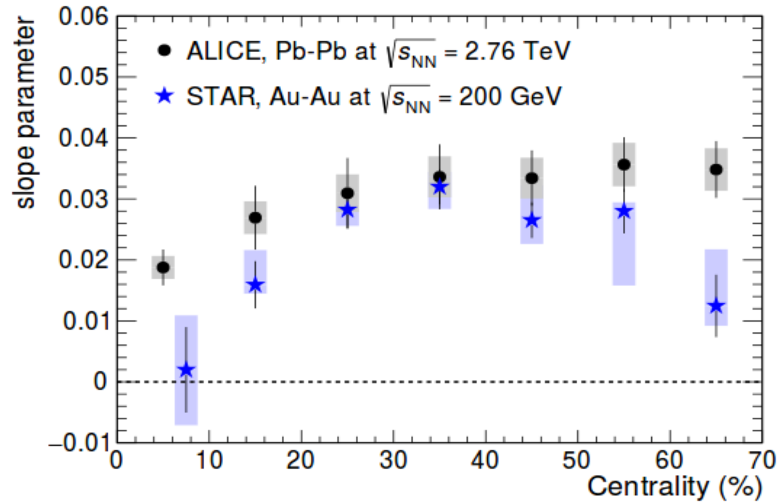
$$v_2^\pm \simeq v_{2,\pm}^{base} \mp r_e A_{ch}/2$$

Previous Measurements

STAR
(Phys.Rev.Lett. 114 (2015))



ALICE
(Phys.Rev. C93 (2016))



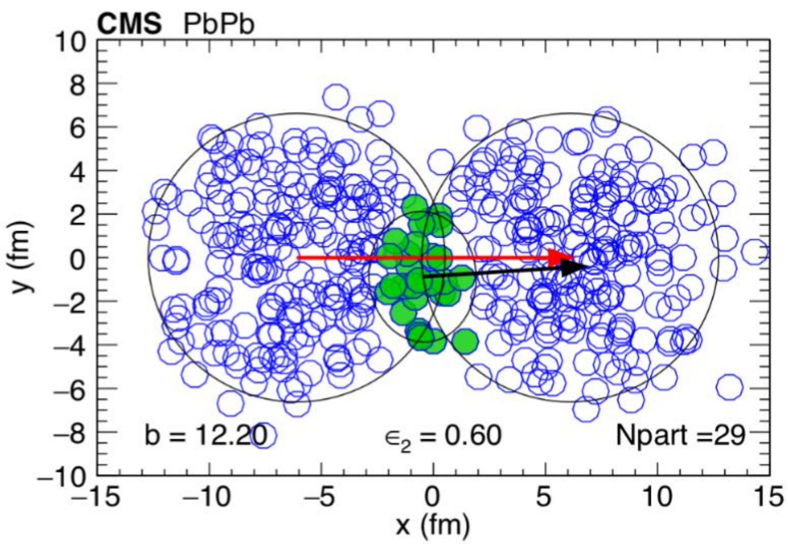
$$v_2^{\pm} \simeq v_{2,\pm}^{base} \mp r_e A_{ch}/2$$

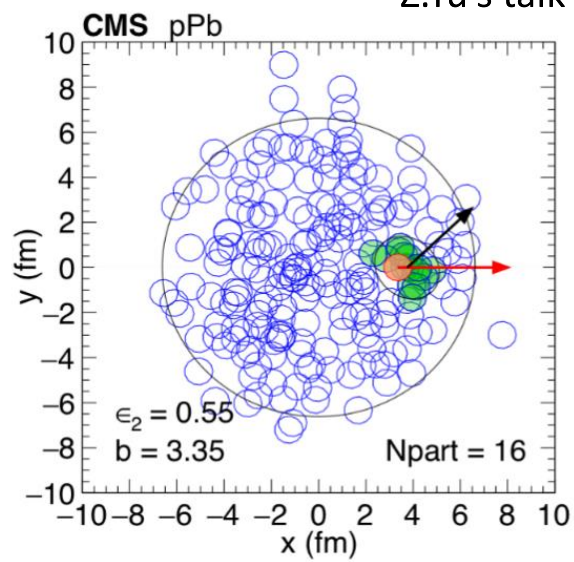
$$v_2^{-} - v_2^{+} = r_e\, A$$

What's new about CMS measurement?

- 1. CMW in a smaller system (pPb)

arXiv:1610.00263
Z.Tu's talk at 3pm !





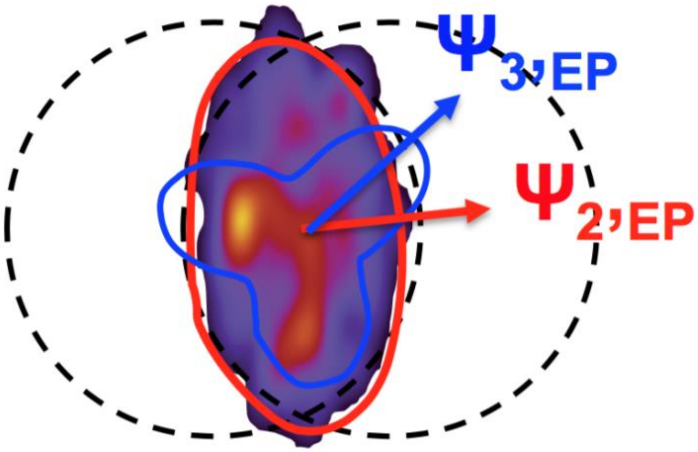
$$\langle (eB)^2 \cos[2(\psi_B - \Psi_{RP})] \rangle$$

Smaller B field

B field direction ≠ Reaction Plane

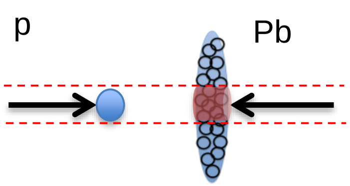
What's new about CMS measurement?

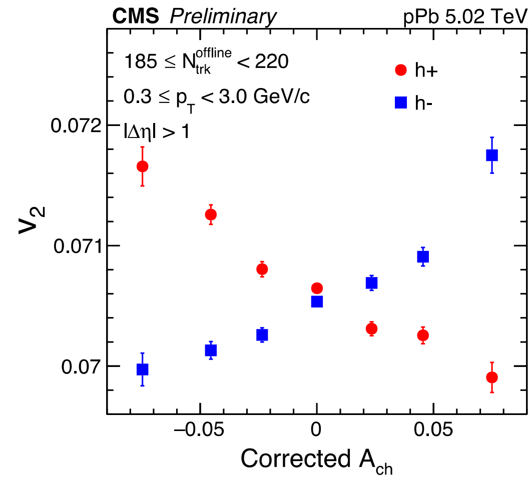
❖ 2. Third Order Harmonics

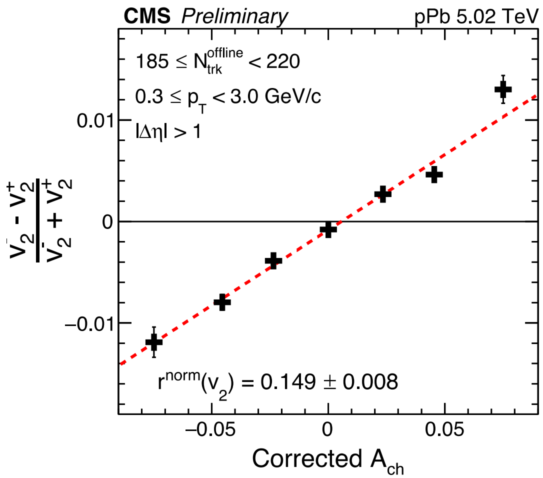


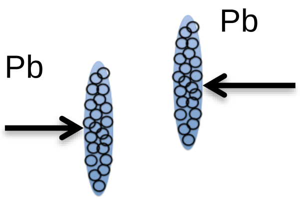
- CMW mechanism predicts the slope of the third harmonic to be zero
- Orientation of the triangular flow has no correlation with RP
- Measurement of v3 slope in PbPb - crucial in testing CMW

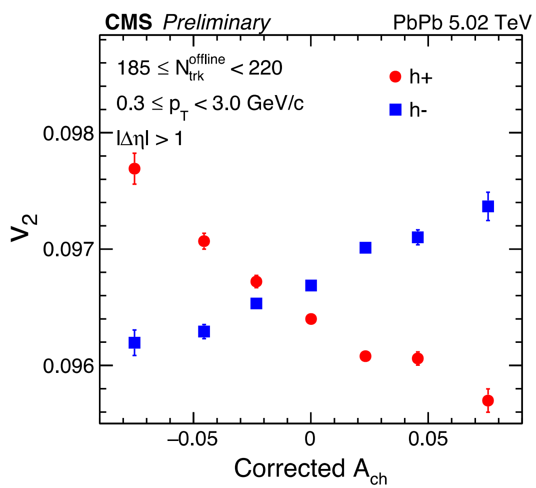
1. CMW in pPb and PbPb

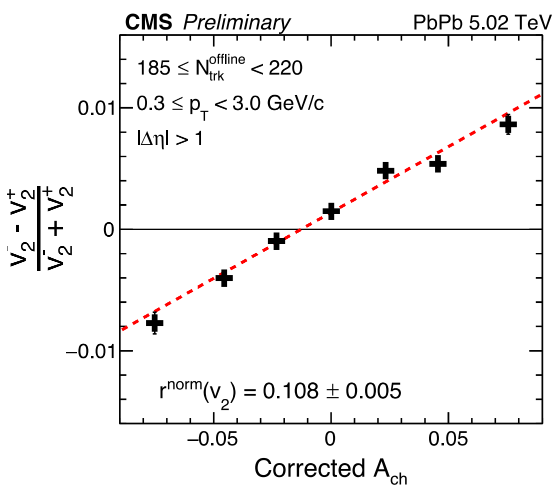








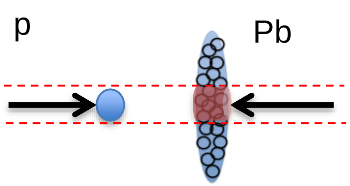


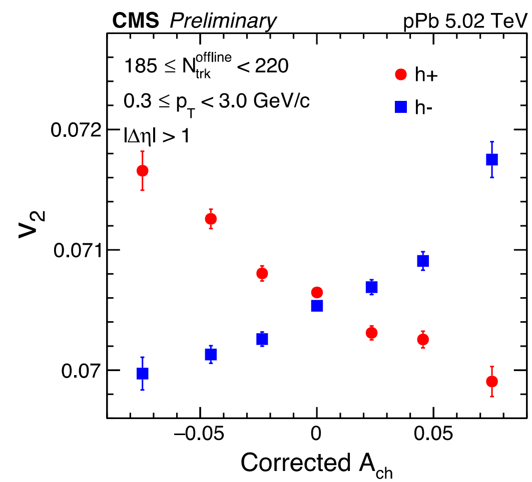


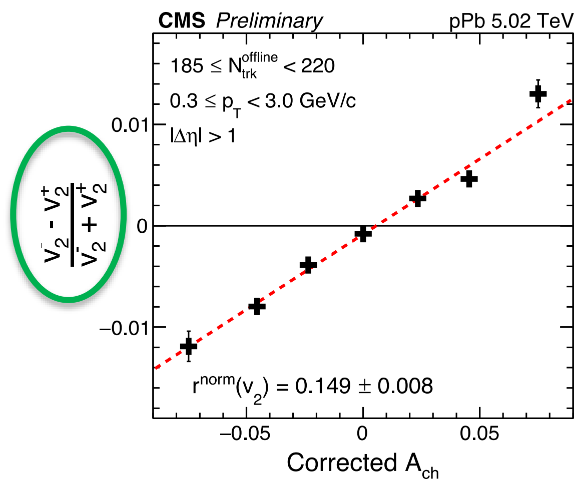
CMS NEW RESULT CMS

Significant nonzero slope observed in pPb : Challenges CMW!

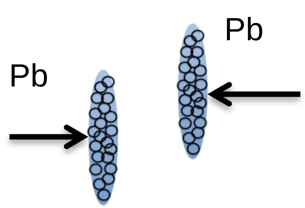
1. CMW in pPb and PbPb

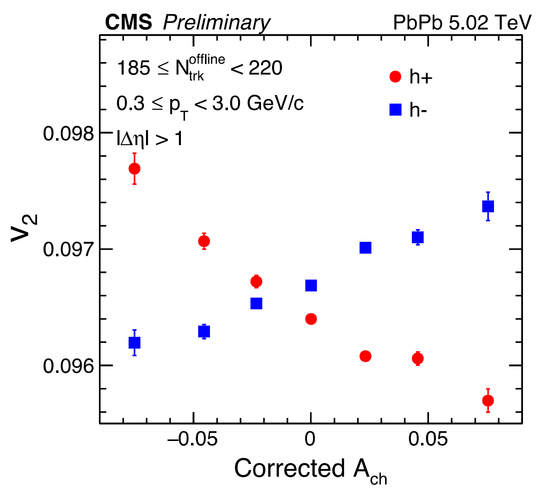


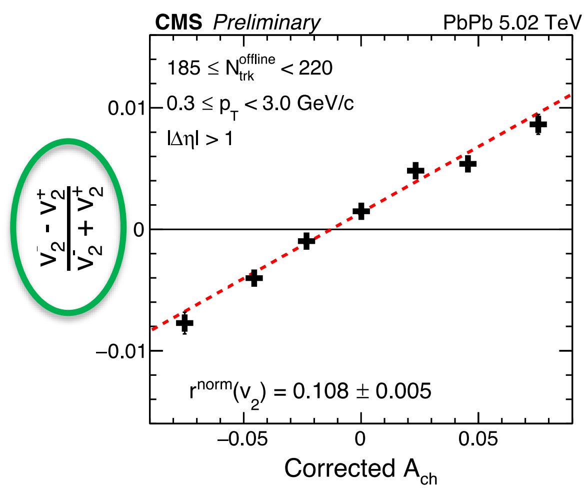




CMS NEW RESULT CMS

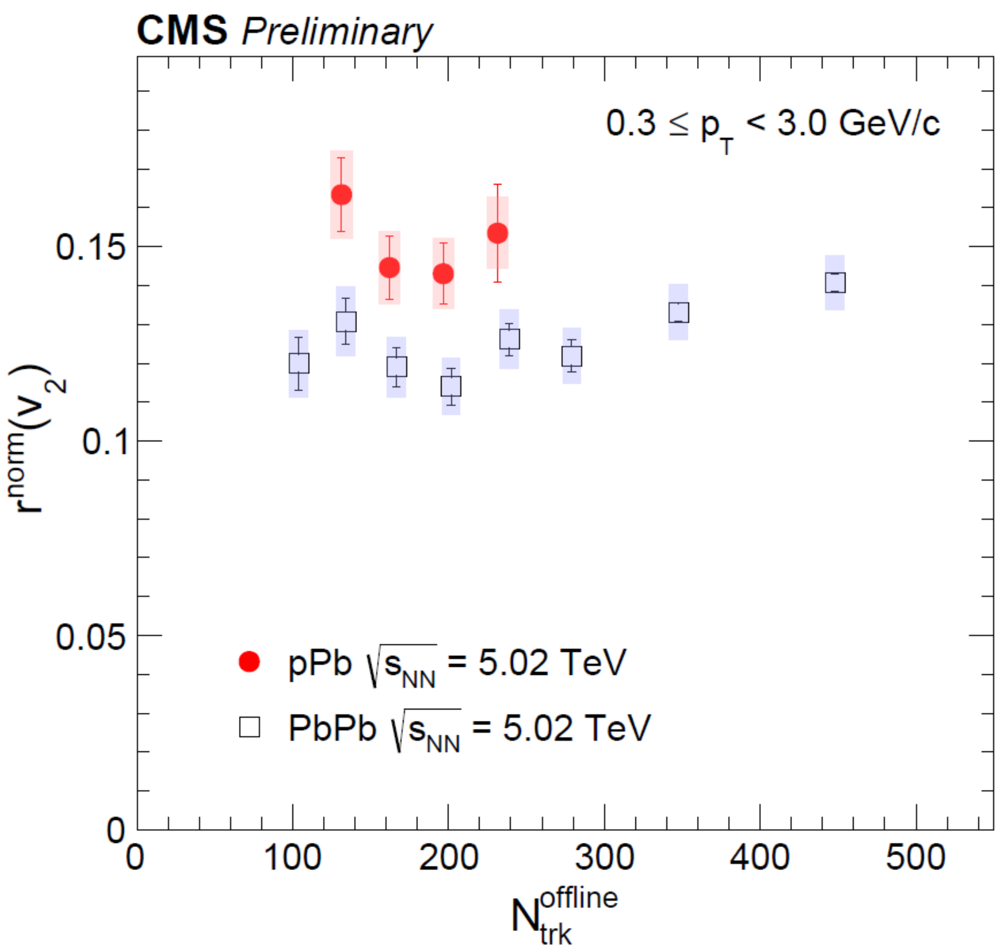






Significant nonzero slope observed in pPb : Challenges CMW!

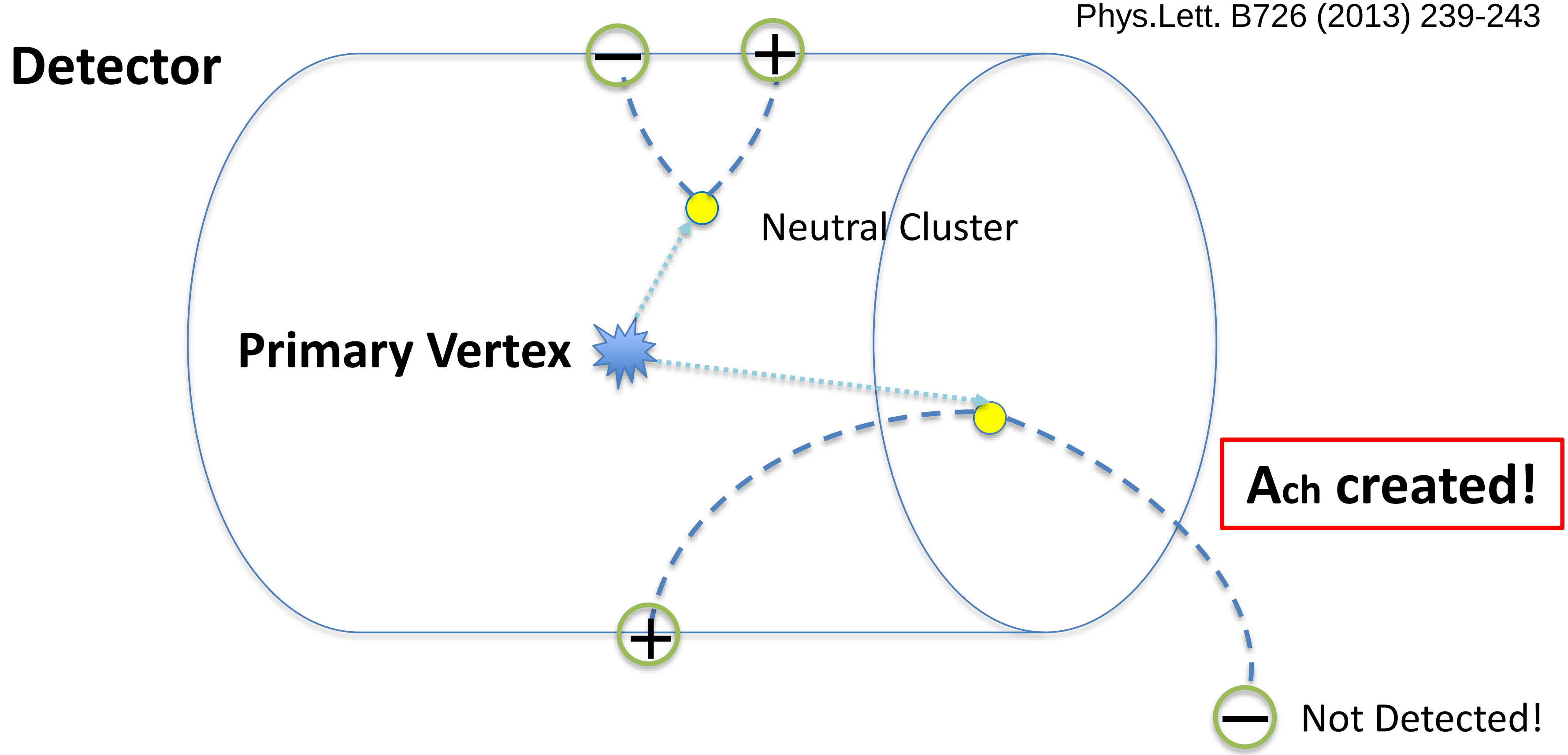
1. CMW in pPb and PbPb



Similar normalized
pPb and PbPb Slope
In all multiplicity ranges
: Challenges CMW

Local Charge Conservation Mechanism

A. Bzdak, P. Bozek
Phys.Lett. B726 (2013) 239-243



- Neutral cluster decays locally into charged pairs with a certain η separation

Local Charge Conservation Mechanism

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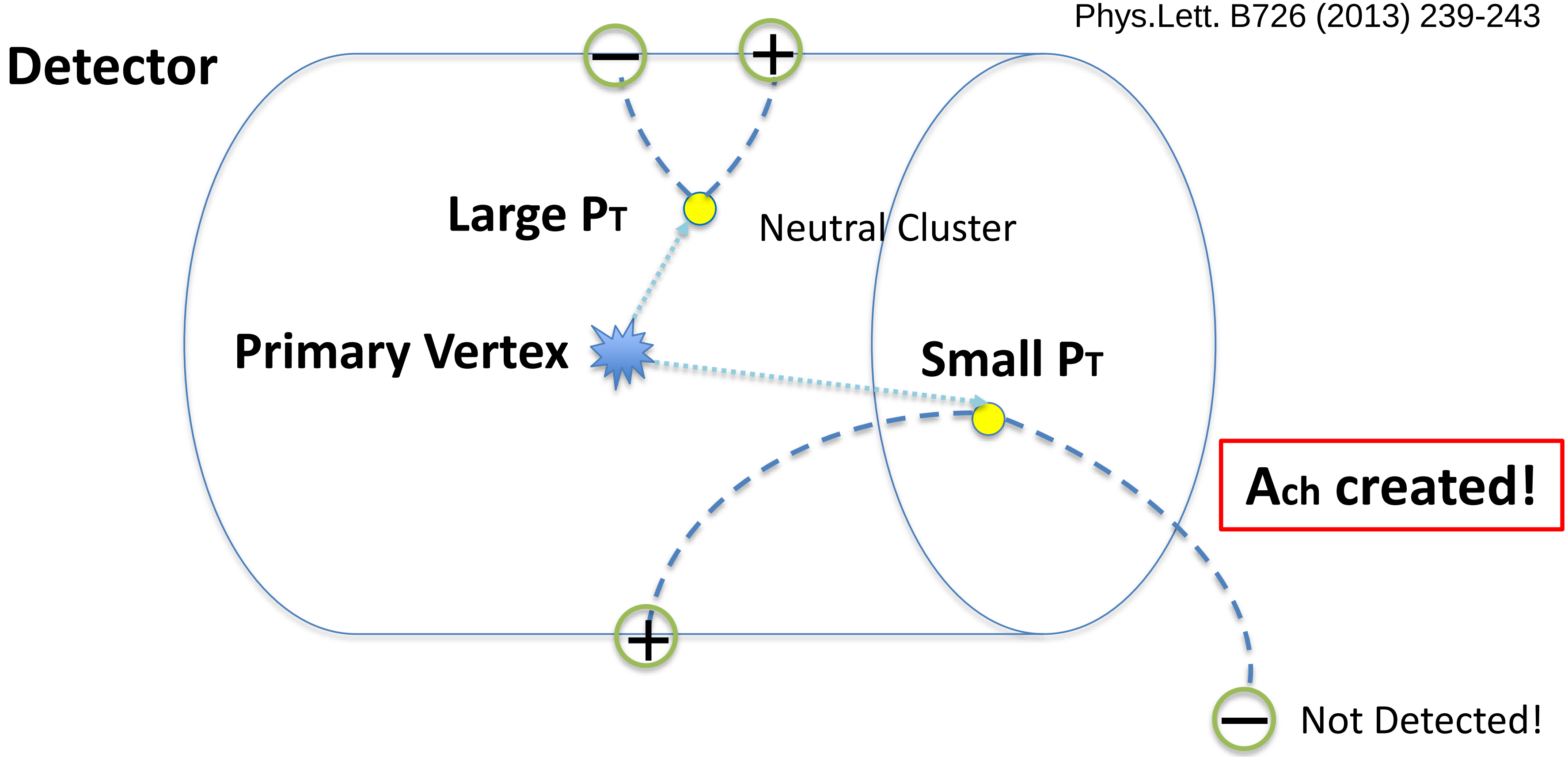
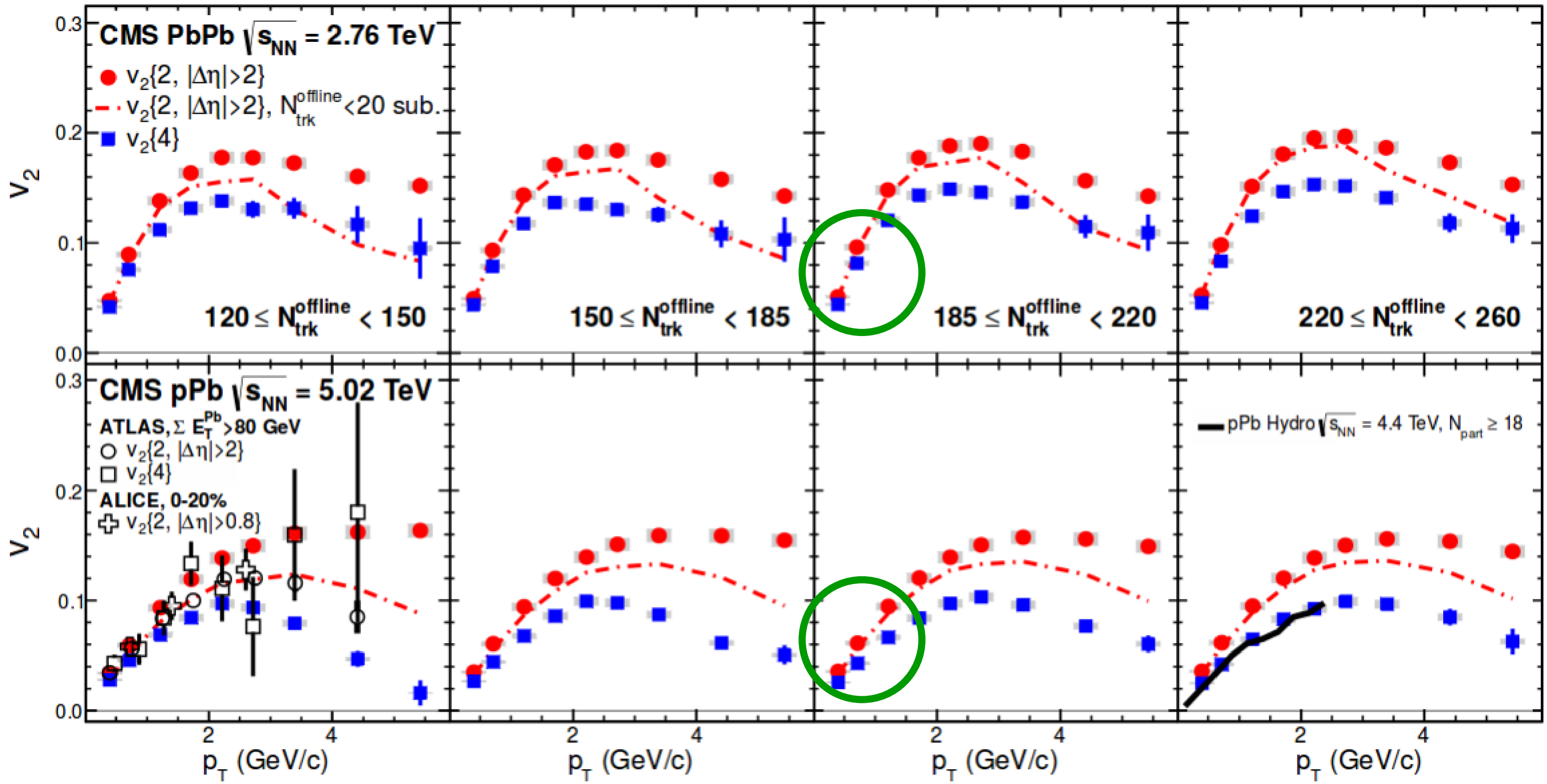


Clusters with small P_T → More likely to contribute to A_{ch}

Local Charge Conservation

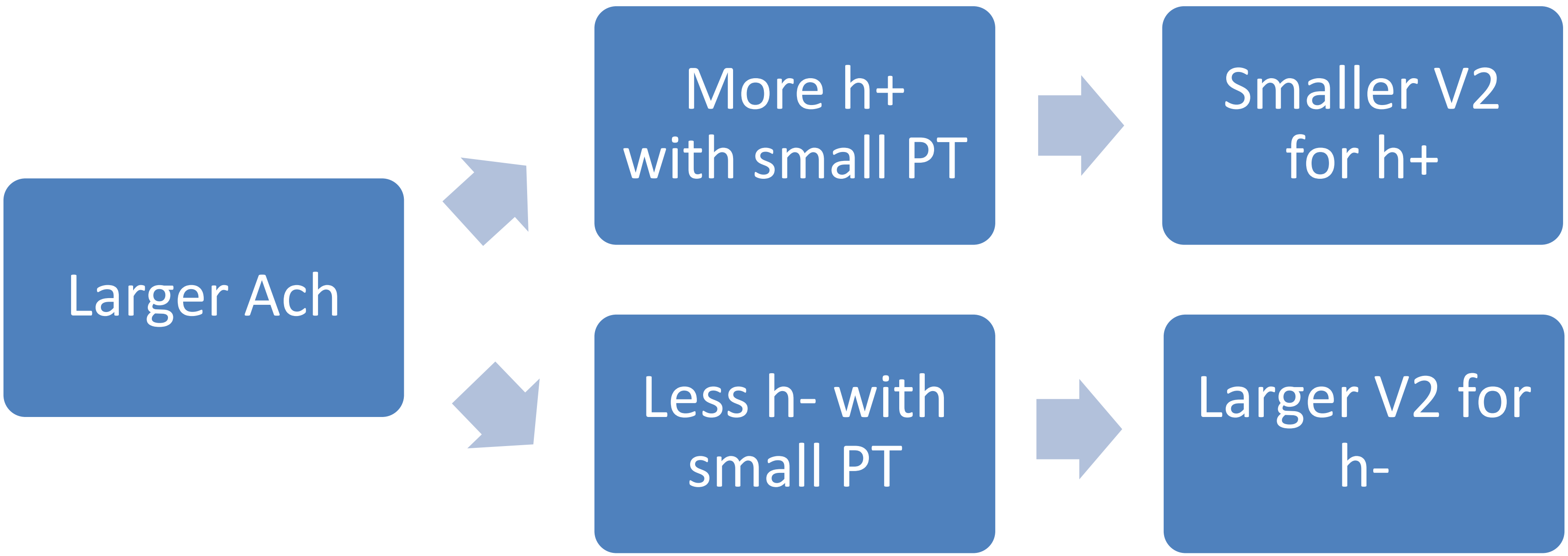
Phys.Lett. B724 (2013) 213-240

When P_T is small, V_2 is proportional to P_T



Local Charge Conservation

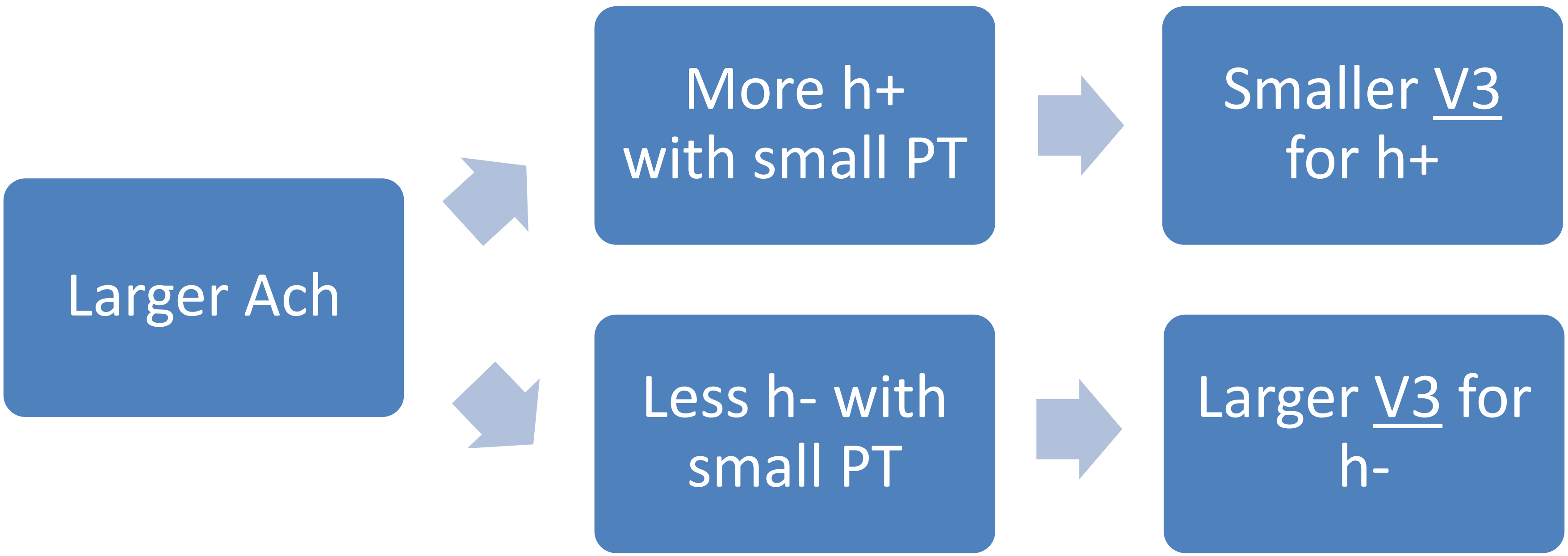
1. Clusters with small P_T → More likely to contribute to A_{ch}
2. When P_T is small, V2 is proportional to P_T



$$v_2^{\pm} \simeq v_{2,\pm}^{base} \mp r_e A_{ch}/2$$

Local Charge Conservation

1. **Clusters with small P_T → More likely to contribute to A_{ch}**
2. **When P_T is small, V3 is proportional to P_T**



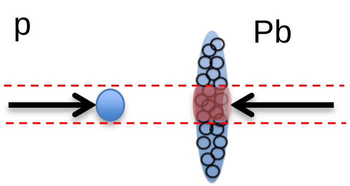
V3 has same Ach depdence as V2

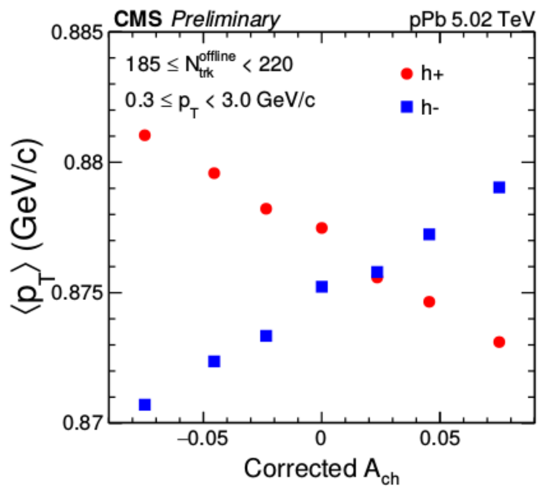
Prediction of LCC

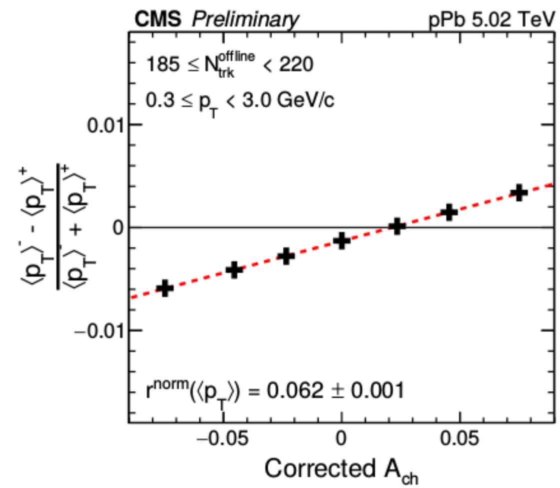
- LCC predicts the same pattern as in V_2 vs A_{ch} for P_T as a function of A_{ch}

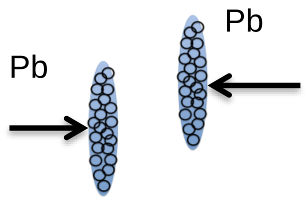
- (V_3 slope)/(V_2 slope) ~ V_3/V_2 - Same after normalizing
  - CMW predicted no V3 slope

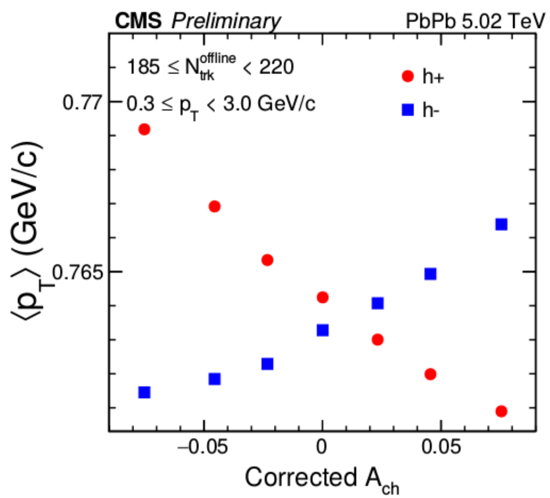
PT as a function of Ach

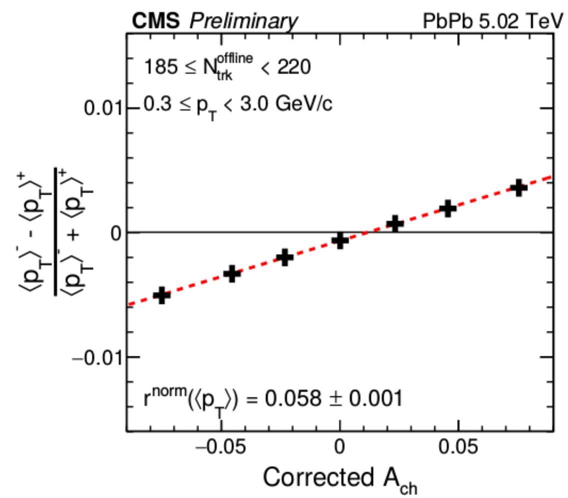








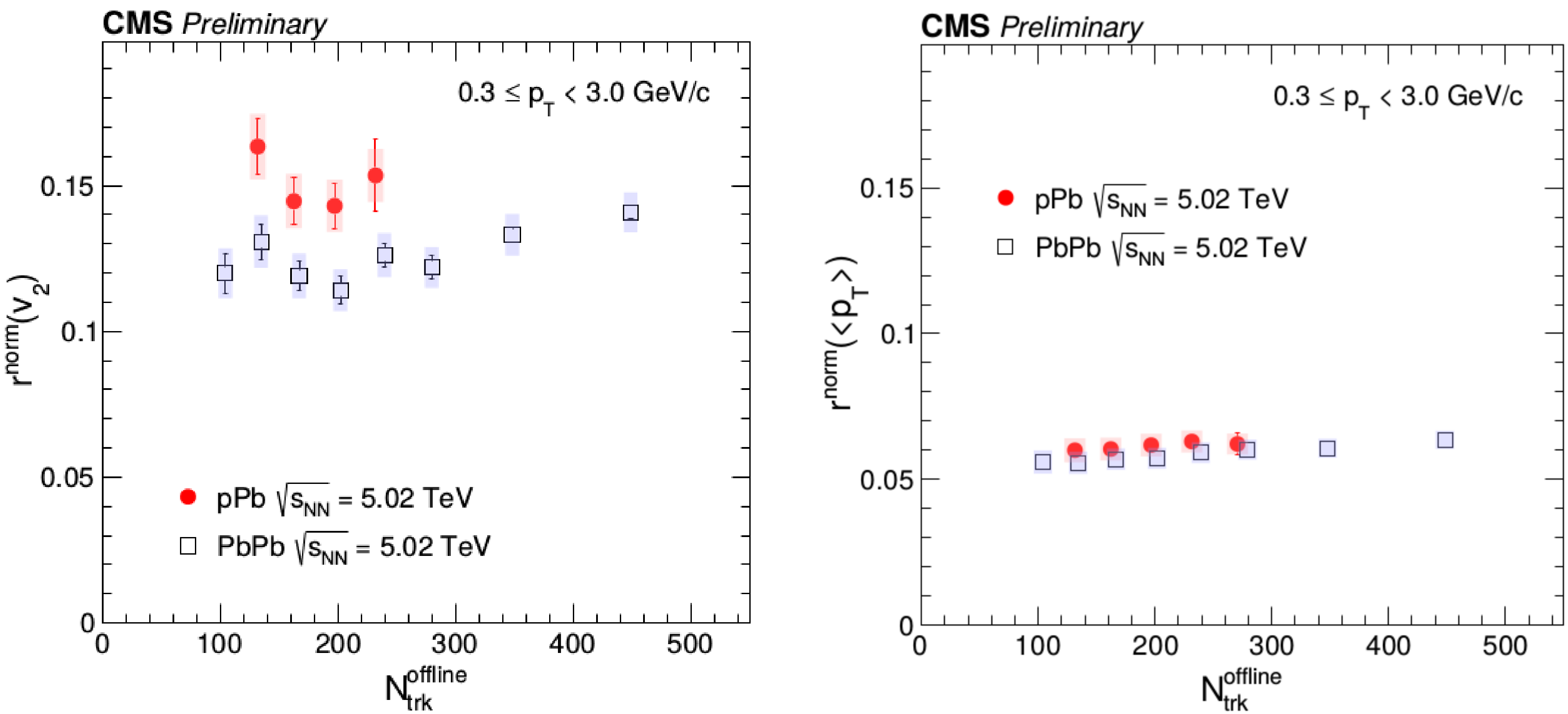




CMS NEW RESULT

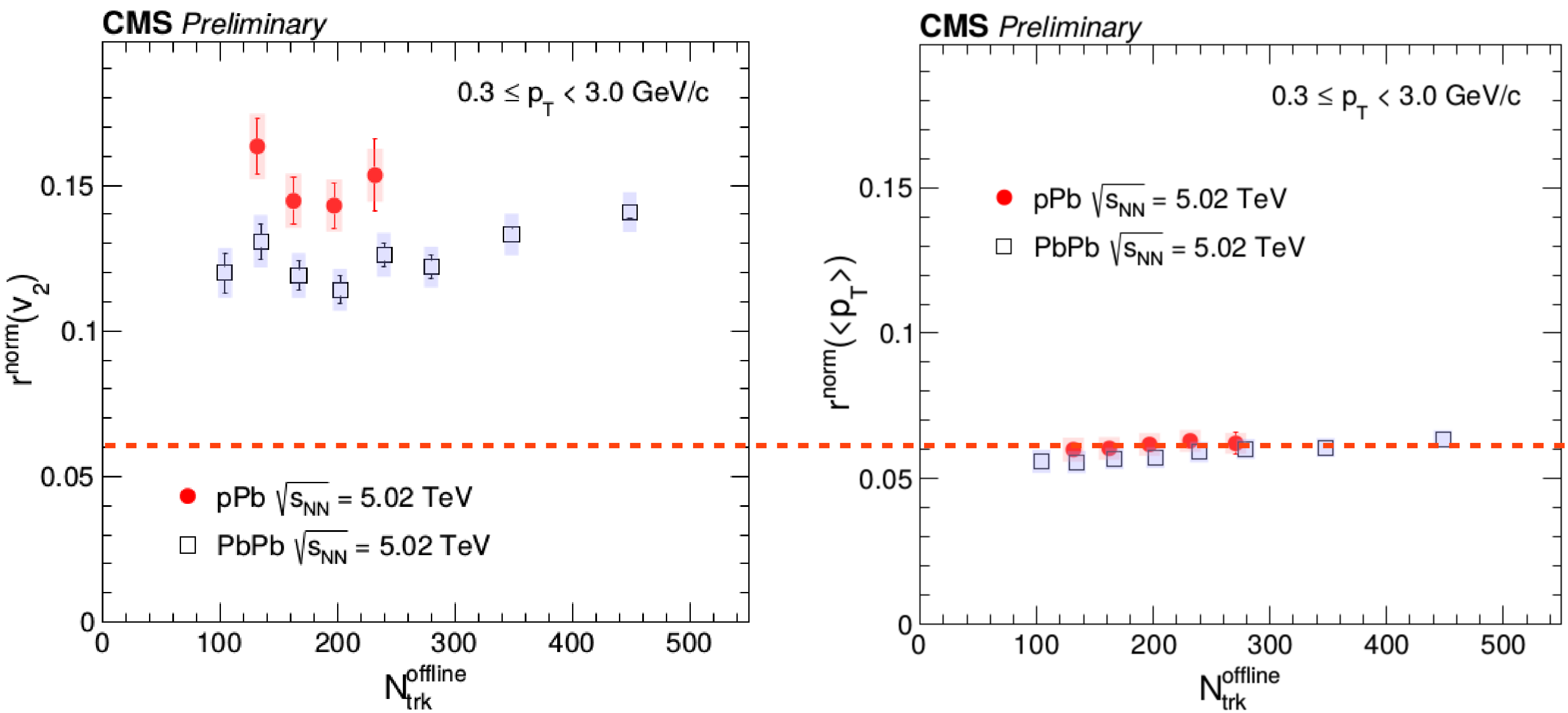
Mean PT show the same pattern as V2 : Supports LCC interpretation!

PT as a function of Ach



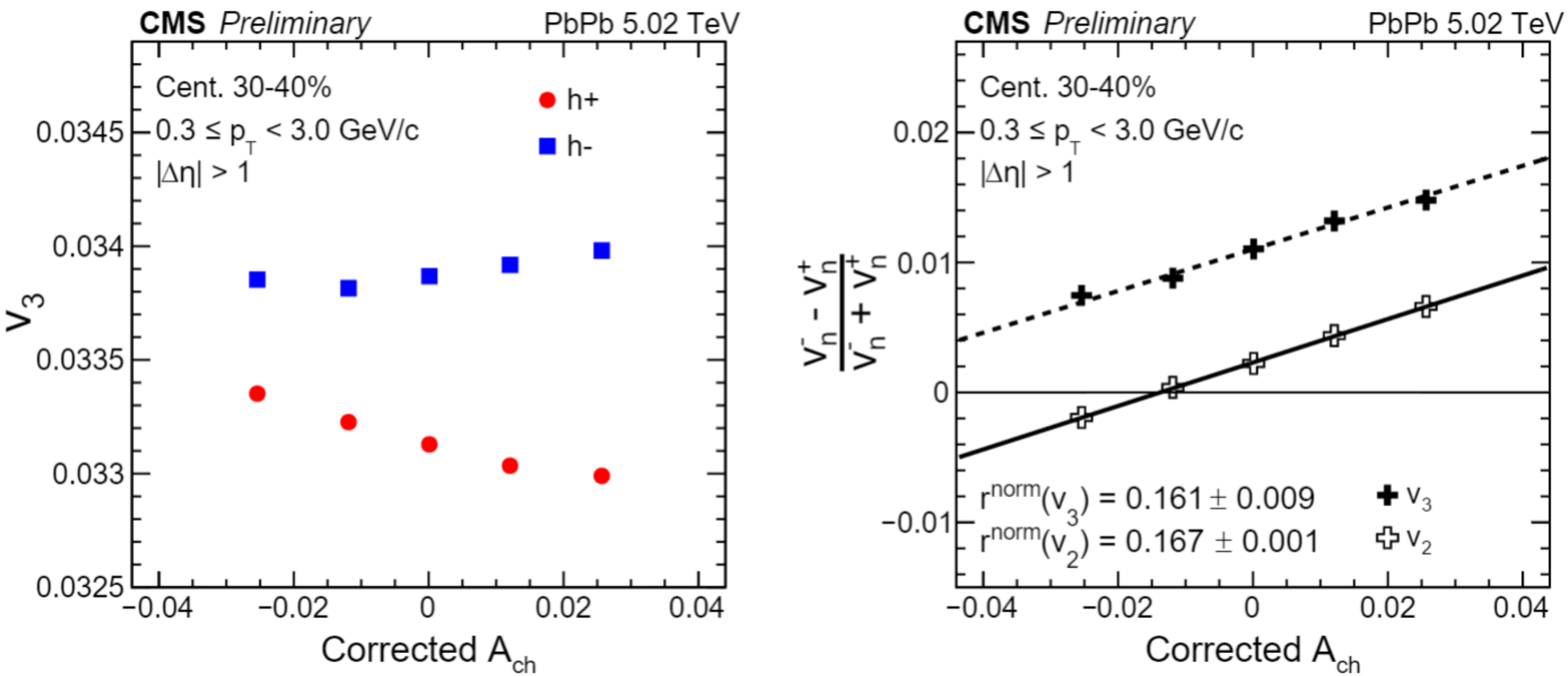
- The normalized PT slope of pPb and PbPb are similar

PT as a function of Ach



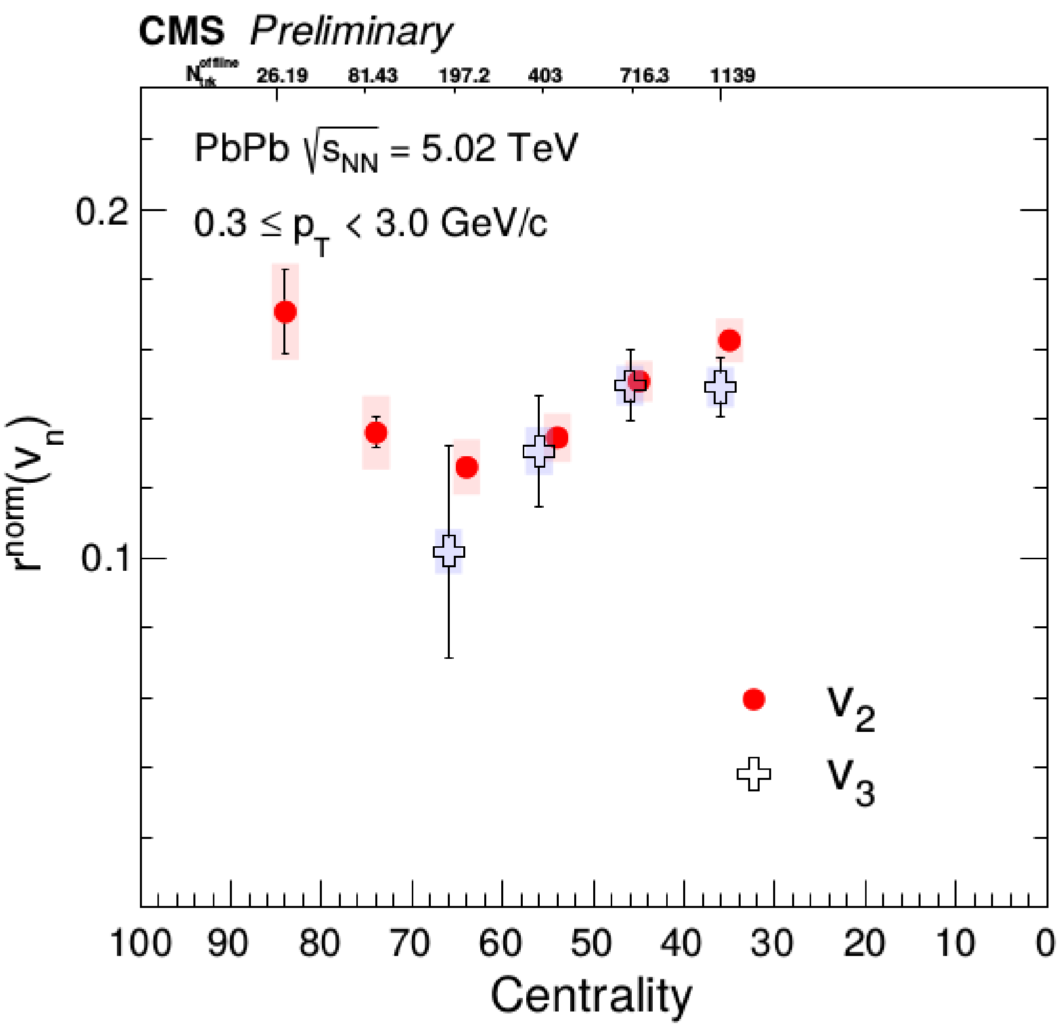
- The normalized PT slope of pPb and PbPb are similar

V_3 as a function of A_{ch}



Normalized V2 slope and V3 slope are almost identical in PbPb!
(Challeges CMW interpretation, Supports LCC interpretation)

V3 as a function of Ach



Normalized v2 and v3 are almost identical in all centrality ranges

Supports
LCC interpretation!

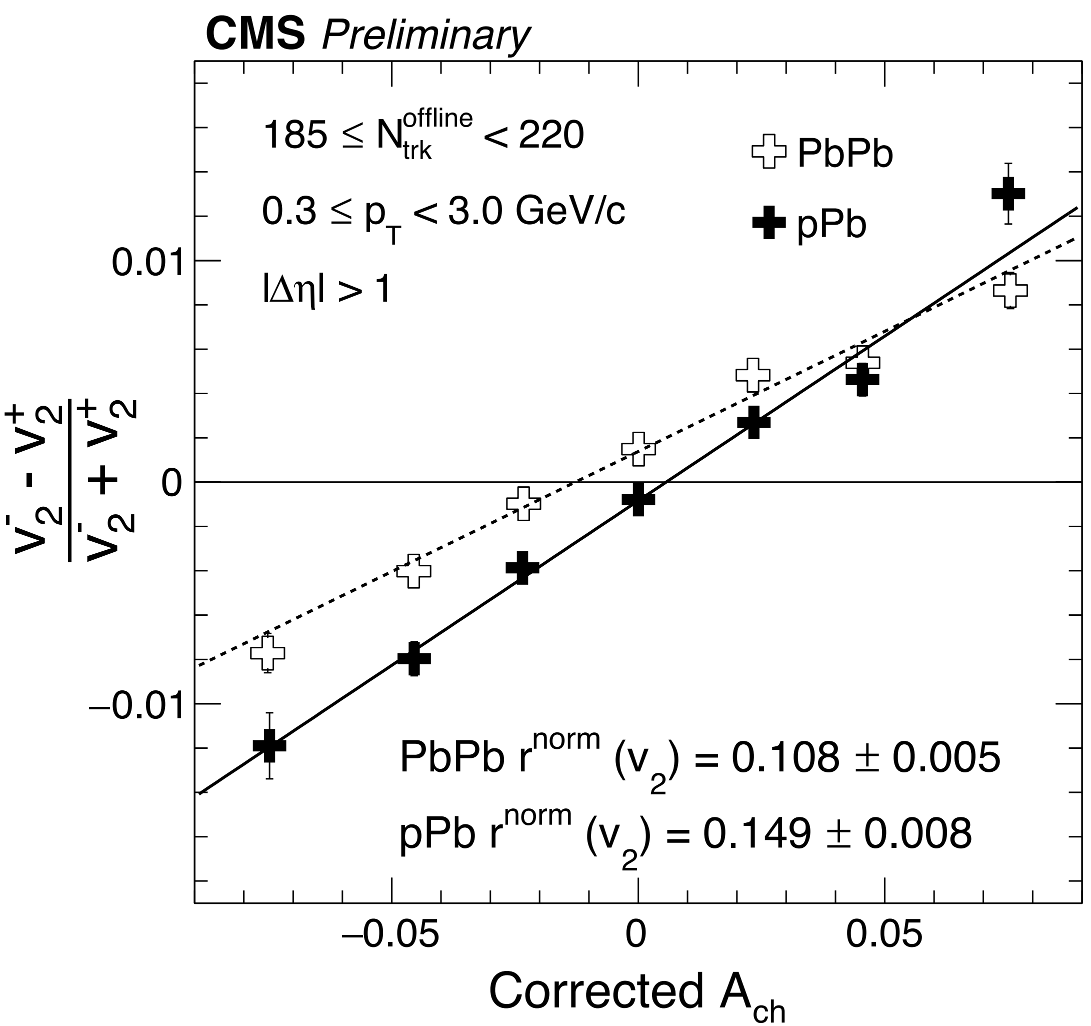
Challenges
CMW interpretation!

Summary

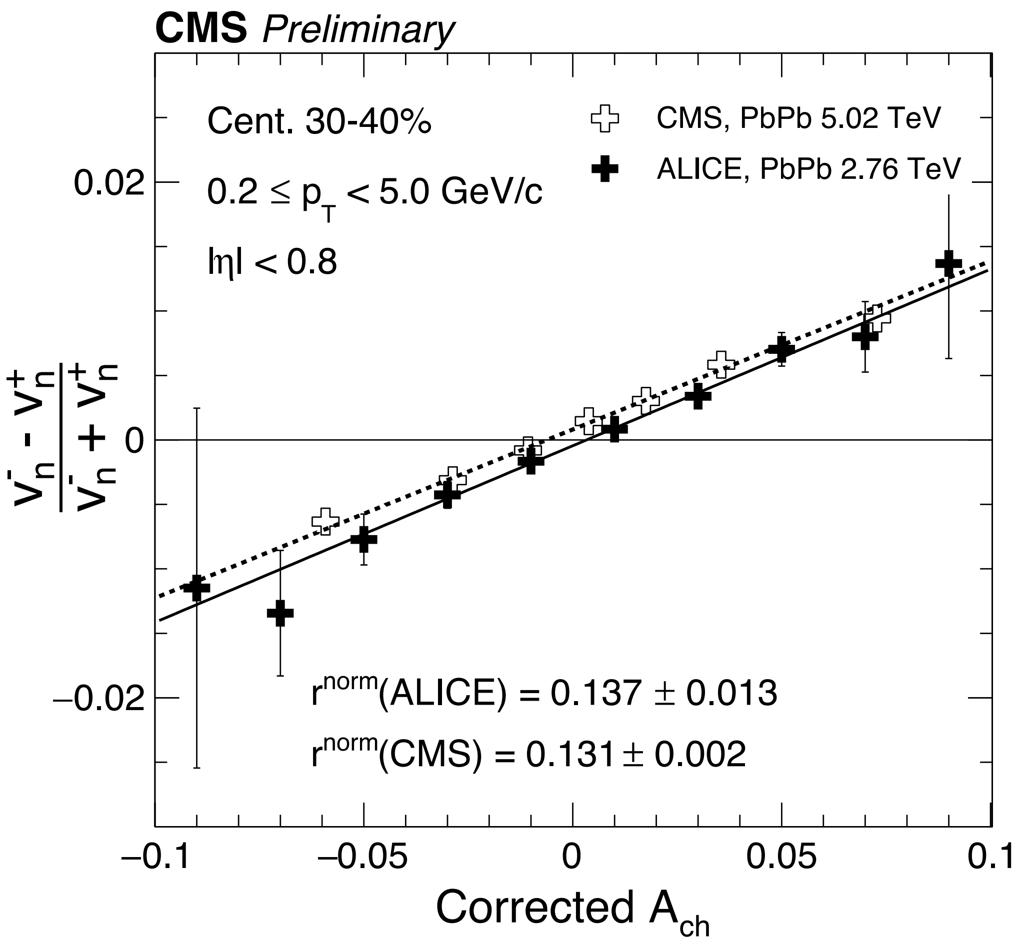
- Charge Asymmetry dep. of Vn measured in pPb and PbPb at CMS
  - 1. Significant nonzero v2 slope has been observed in pPb
  - 2. Normalized v2 slope parameters of PbPb and pPb are similar
  - 3. Normalized slope parameters of v2 and v3 are almost identical in PbPb
  - 4. Mean PT shows the same pattern when plotted vs Ach
- **The results above support Local charge conservation interpretation and challenge CMW interpretation**

Backup Slides

Comparison of pPb and PbPb v2 slope



Apple-to-apple comparison with ALICE



The distribution of Charge Asymmetry