Measurements of charge-dependent correlations with CMS

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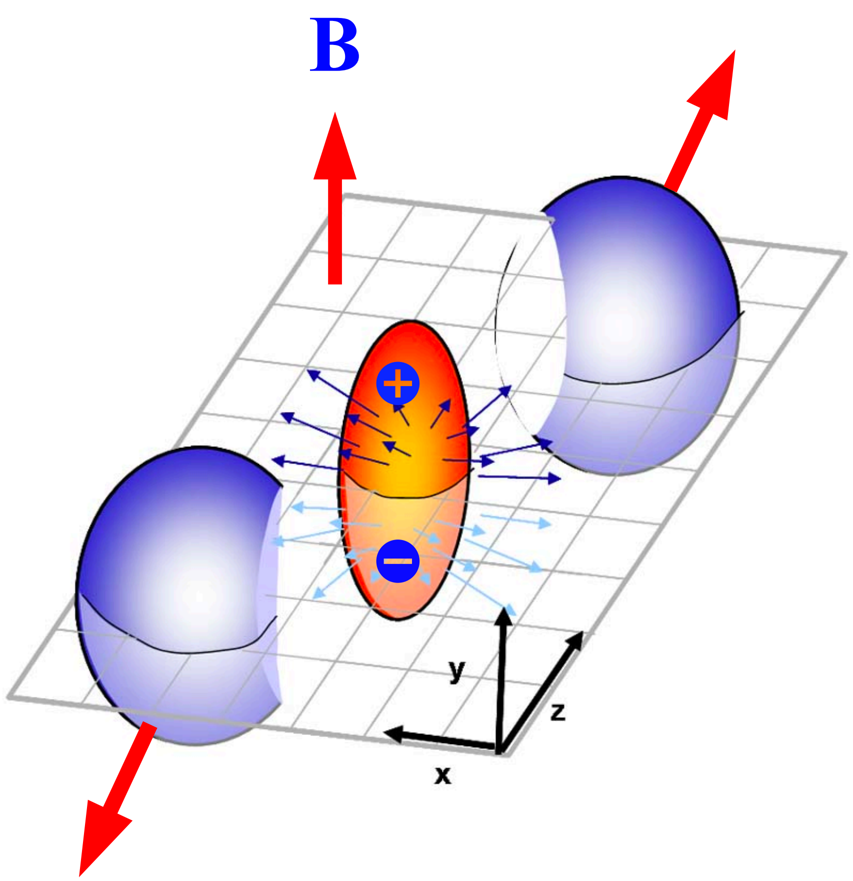
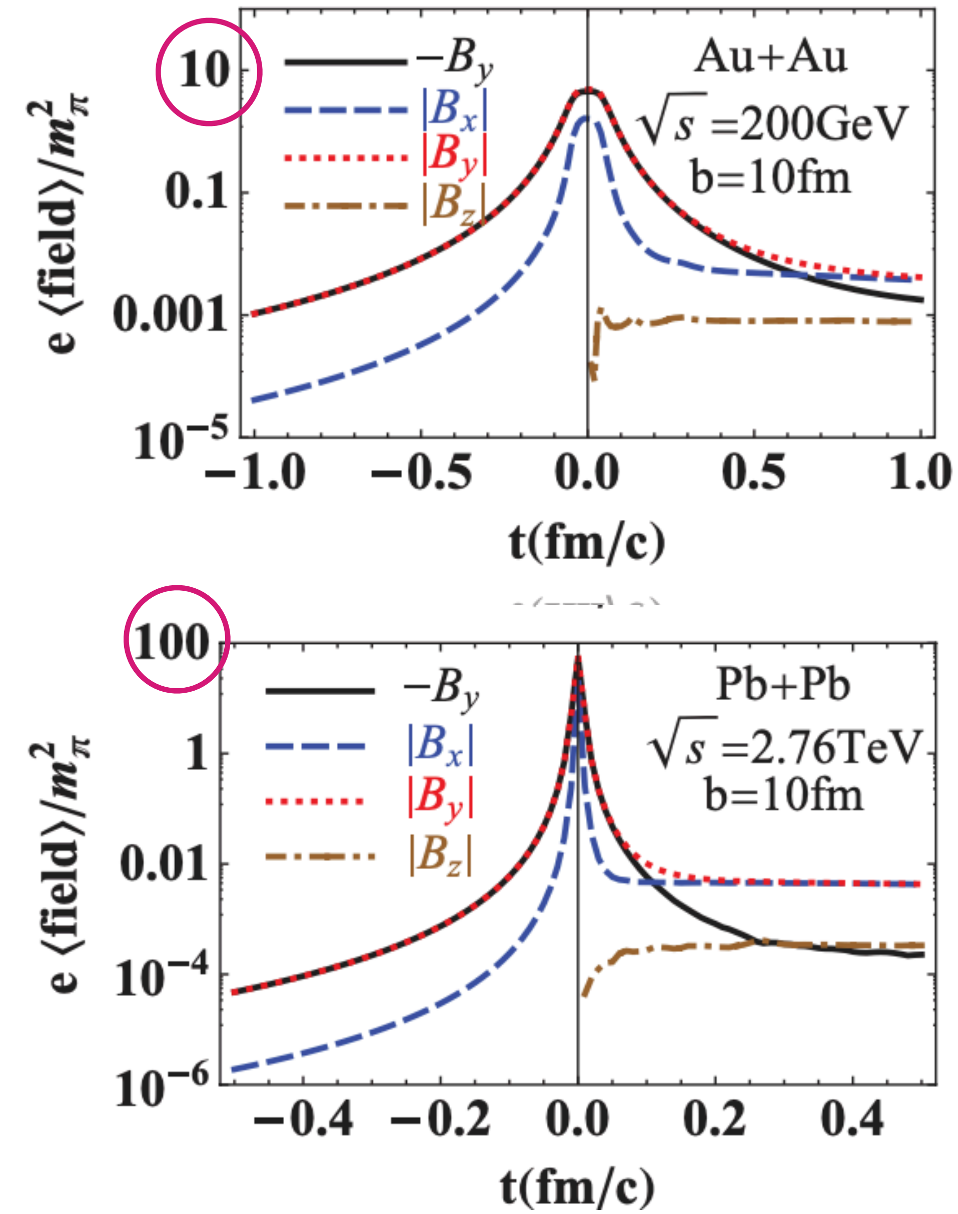
The magnetic field in heavy-ion collisions



PRC 85, 044907 (2012)

Au+Au

Pb+Pb

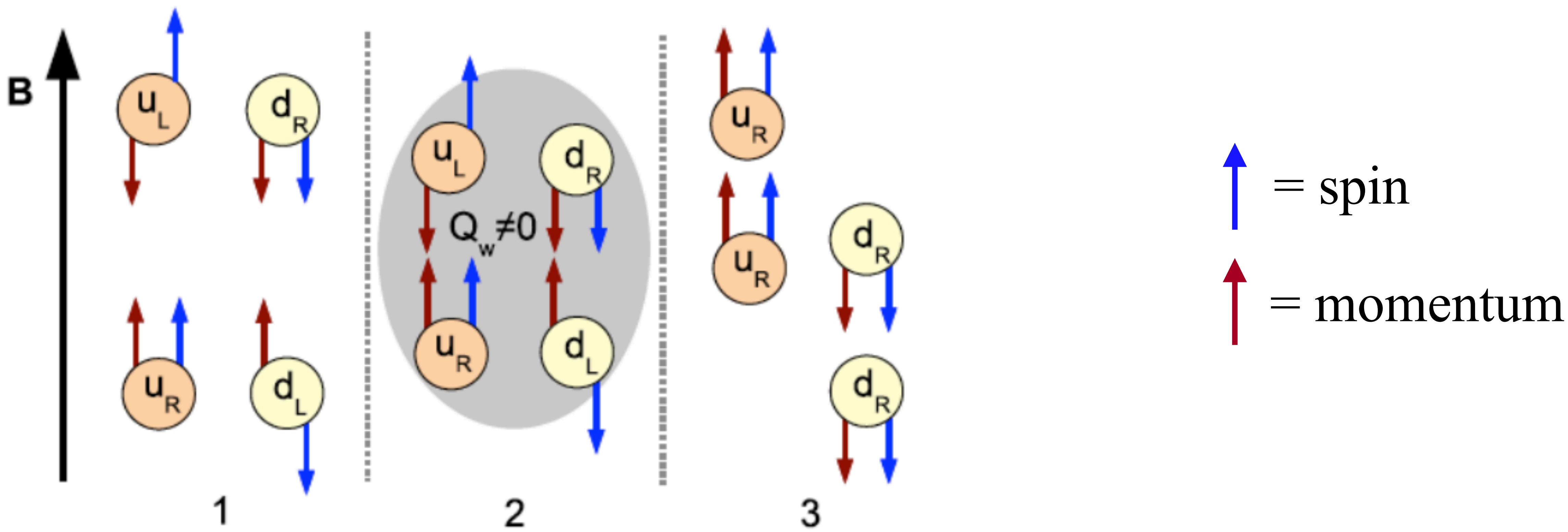


- The spectators define both the magnetic field and the geometry.

  ⟶ A very strong magnetic field in nuclear overlap region.

The chiral magnetic effect (CME)

Prog.Part.Nucl.Phys. 75 (2014) 133



- Chiral symmetry restoration due to quantum anomaly

$$\vec{J} = \sigma_5 \vec{B} = \left(\frac{(Qe)^2}{2\pi^2} \mu_5 \right) \vec{B} \longrightarrow \text{Charge separation}$$

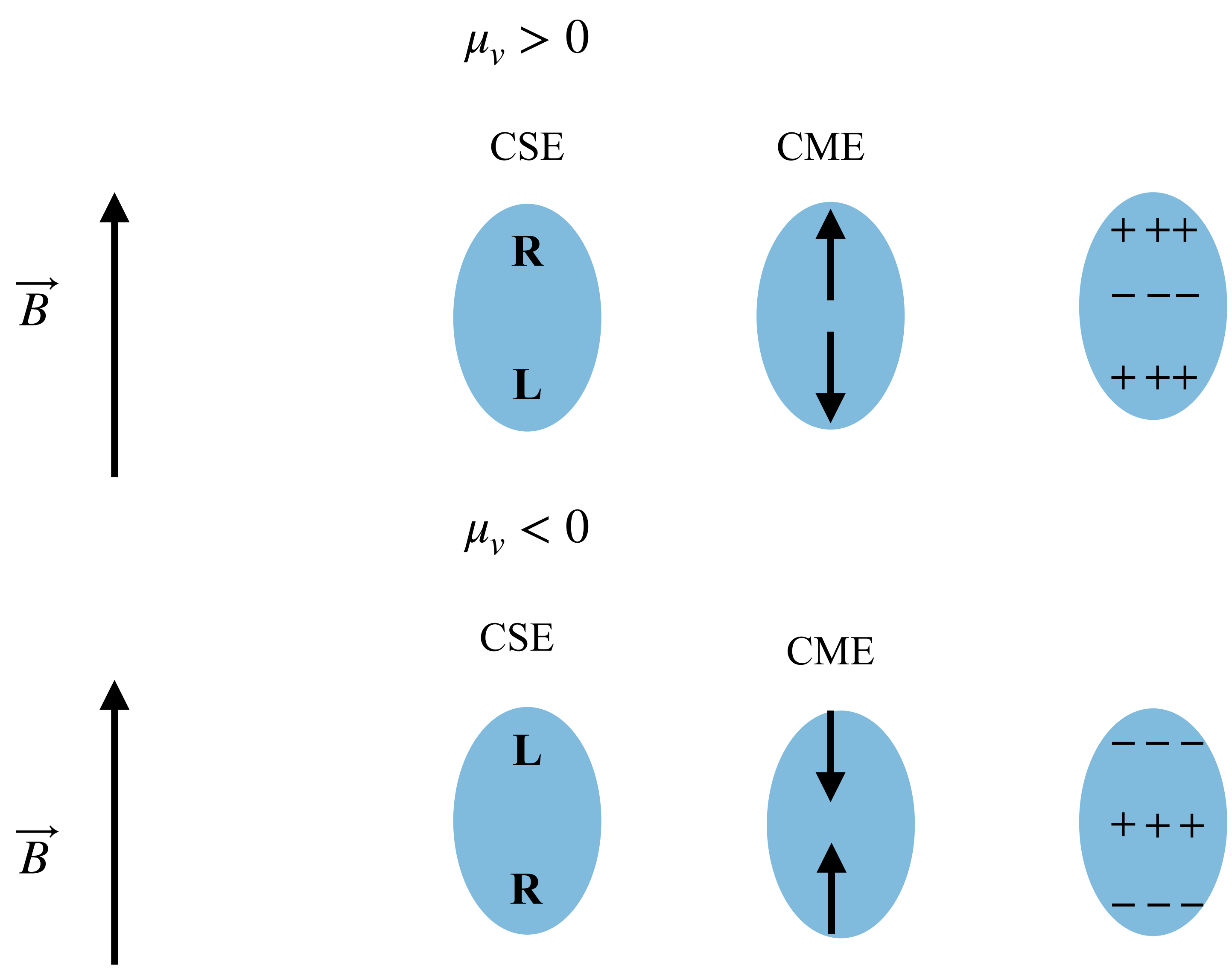
Anomalous chiral effects

Chiral separation effects

$$\overrightarrow{J}_A = \frac{N_c e}{2\pi^2}\mu_V \overrightarrow{B}$$

Chiral magnetic effects

$$\overrightarrow{J}_\nu = \frac{N_c e}{2\pi^2}\mu_A \overrightarrow{B}$$



- Separation of chiralities in the opposite pole by chiral separation effect (CSE)
- CME currents in opposite directions, leading to electric quadrupole

Chiral magnetic wave (CMW)

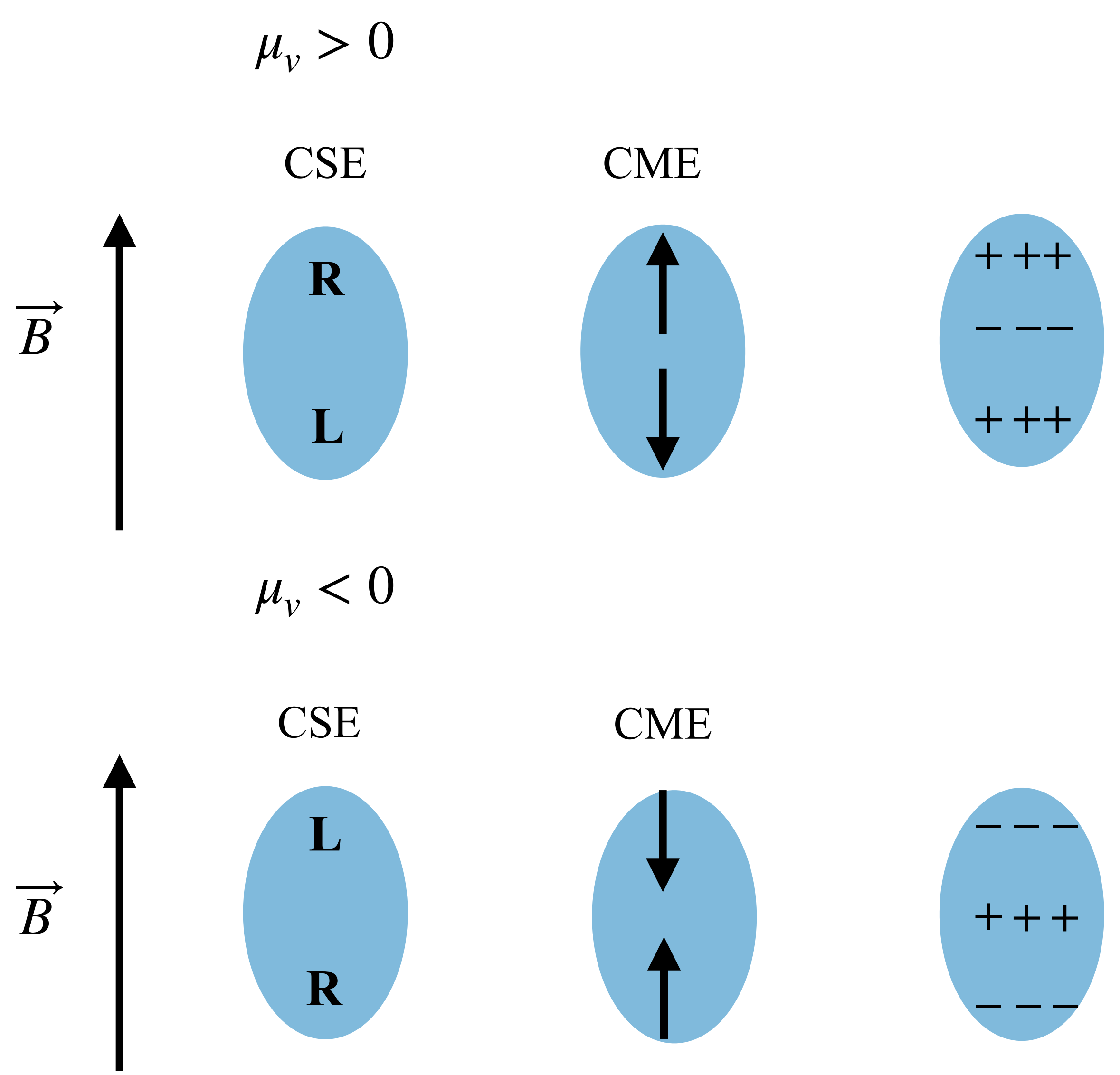
Experimental prediction

Definition of charge asymmetry

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

Azimuthal distribution of particles

$$\frac{dN_\pm}{d\varphi} = \bar{N} \pm [1 + (2v_2 \mp r_e A)cos(2\varphi)]$$



$$v_2^\pm = v_2 \mp \frac{r_e A}{2}$$

$$\Delta v_2 = v_2^- - v_2^+ = r_e A$$

Previous measurements

STAR, Phys. Rev. Lett. 114, 252302 (2015)

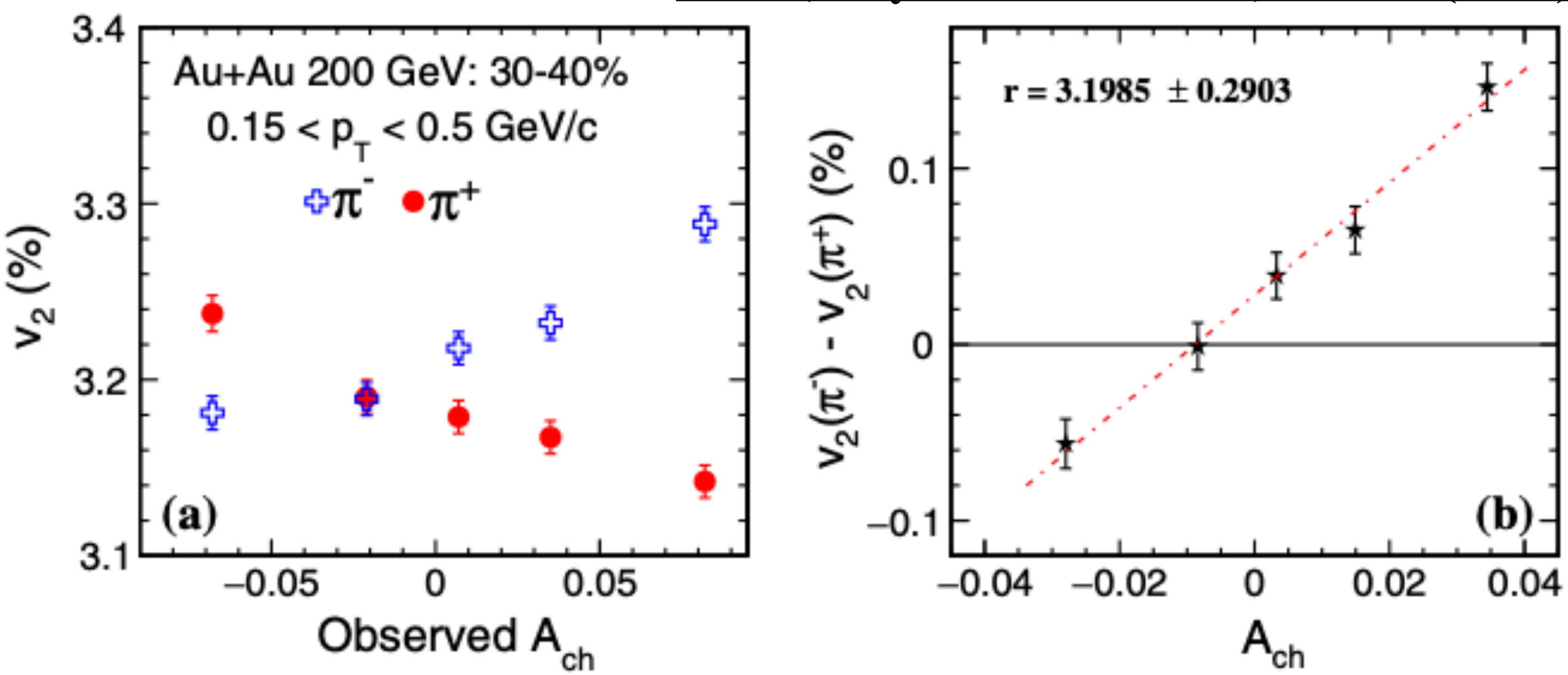
v_2 of the charged particles

$$v_2^{\pm} = v_2 \mp \frac{r_e A}{2}$$

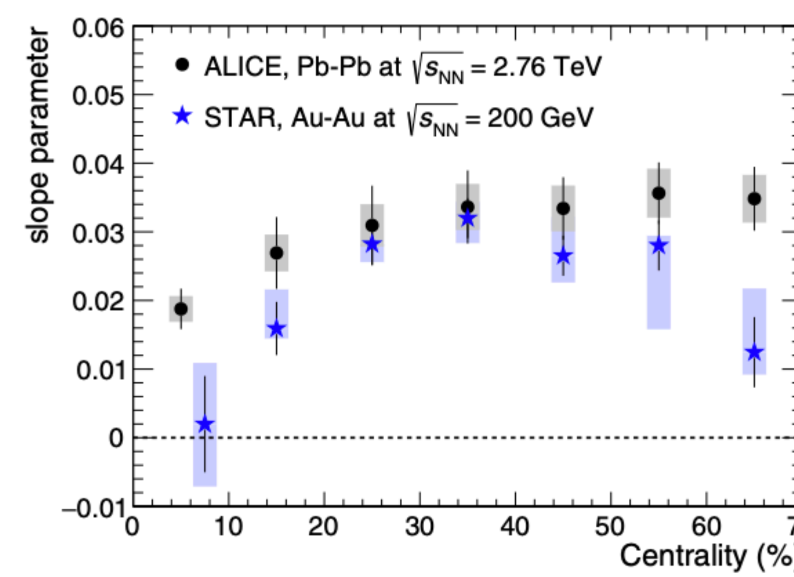
Definition of Δv_2

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

r_e is the slope parameter



ALICE , Phys.Rev. C93 (2016)

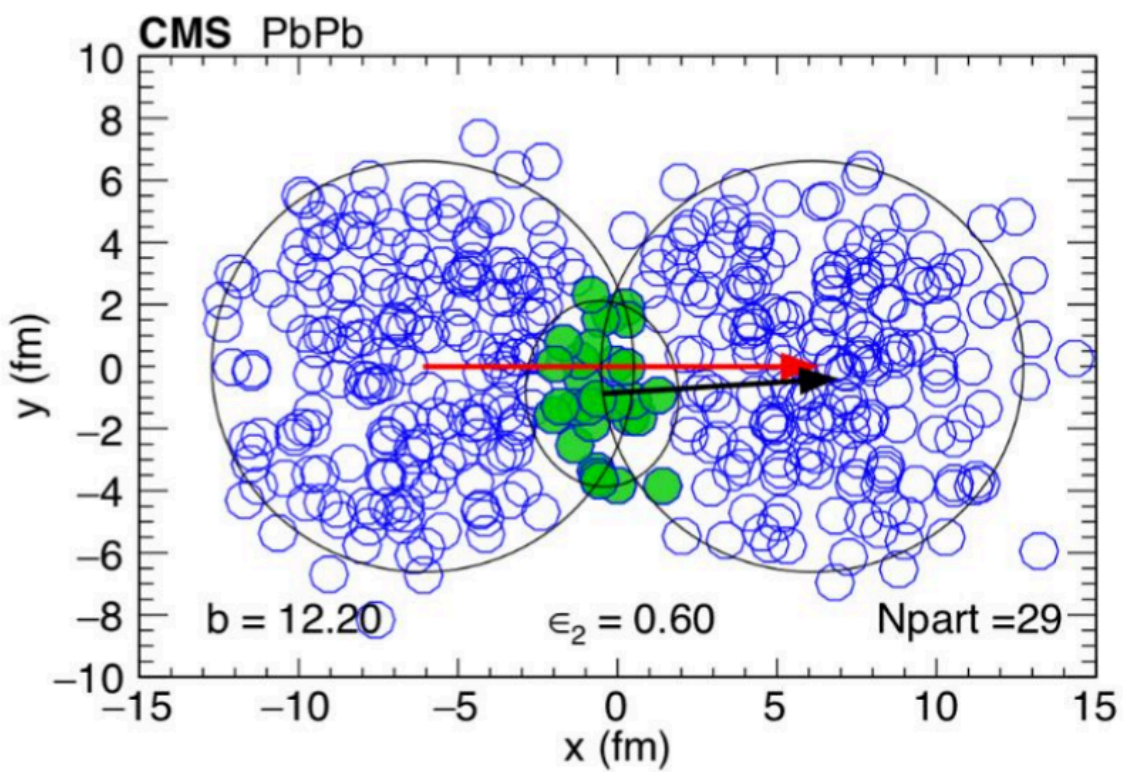


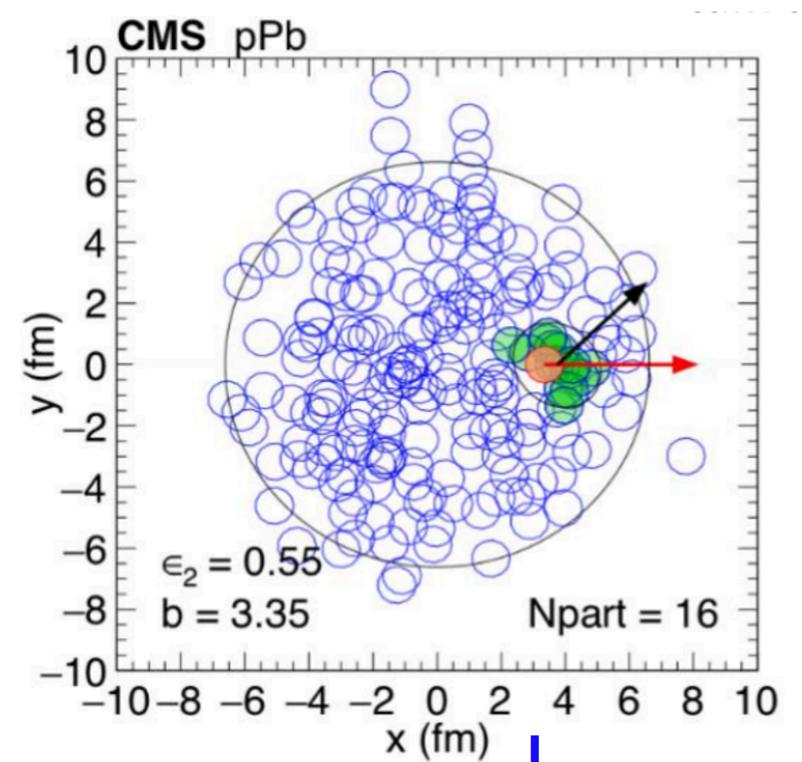
- A clear and strong signal
- Similar with the STAR results
- Qualitatively consistent with the expectations of the CMW picture

What is new in CMS?

- CMW in pPb collision system.

PhysRevLett.118.122301 (2017)





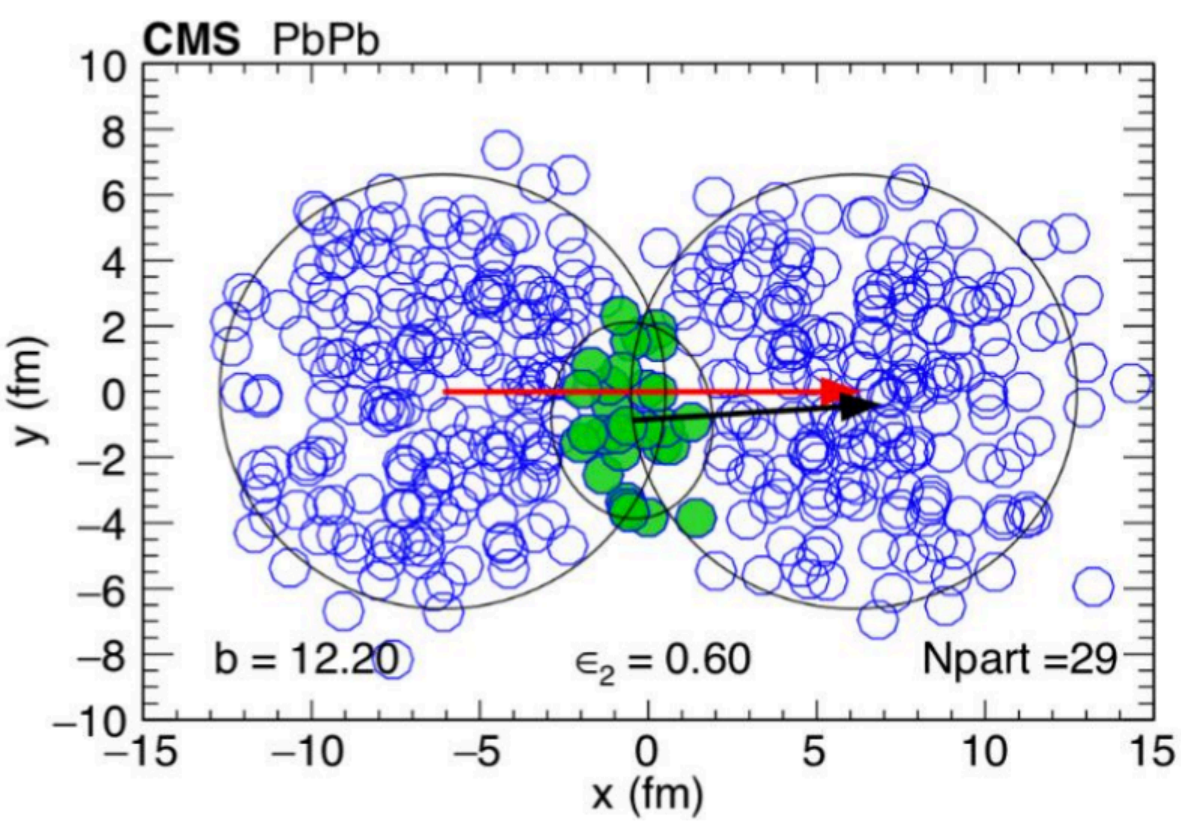
Reaction plane ≠ **B** field direction → $\langle (eB)^2 cos[2(\psi_B - \psi_{RP})] \rangle$

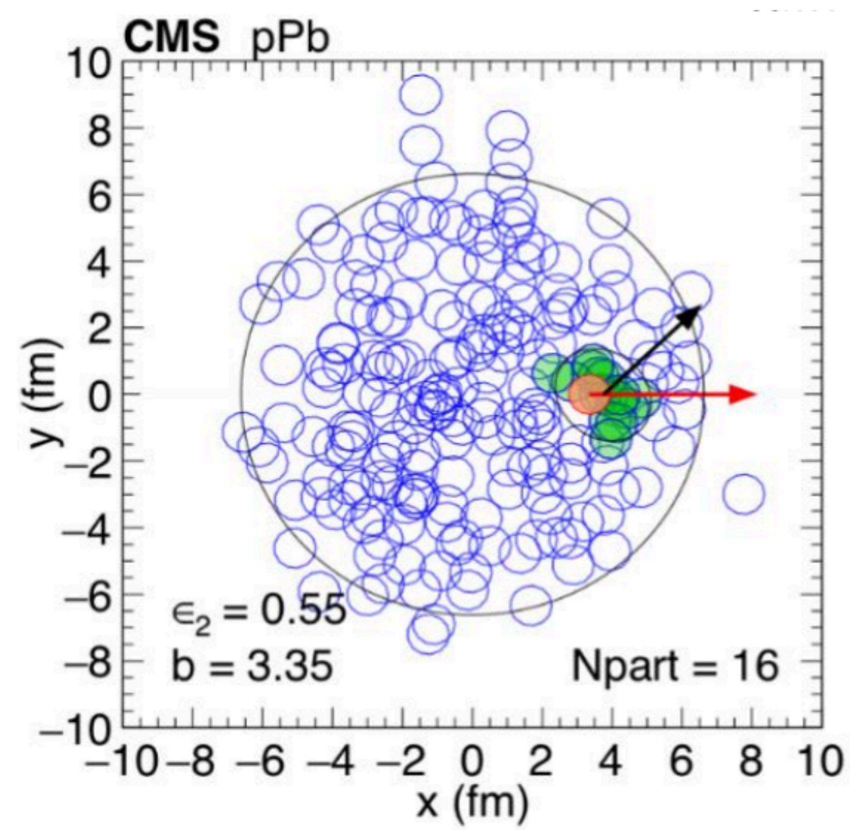
- Can we expect a similar charge asymmetry dependence for v_2 in pPb as the **B** field is comparatively smaller than PbPb?

What is new in CMS?

- CMW in pPb collision system.

PhysRevLett.118.122301 (2017)





- CMW predicts slope of the third order harmonics to be zero
- The measurement of v_3 slope parameter is crucial testing for CMW.

The calculation of v_2 and v_3

- Q-cumulant method is used to calculate the 2-particle correlations

$$Q_{n,k} \equiv \sum_{i=1}^{M} w_i^k e^{in\varphi_i} \qquad w_i = \text{ inverse of tracking efficiency}$$

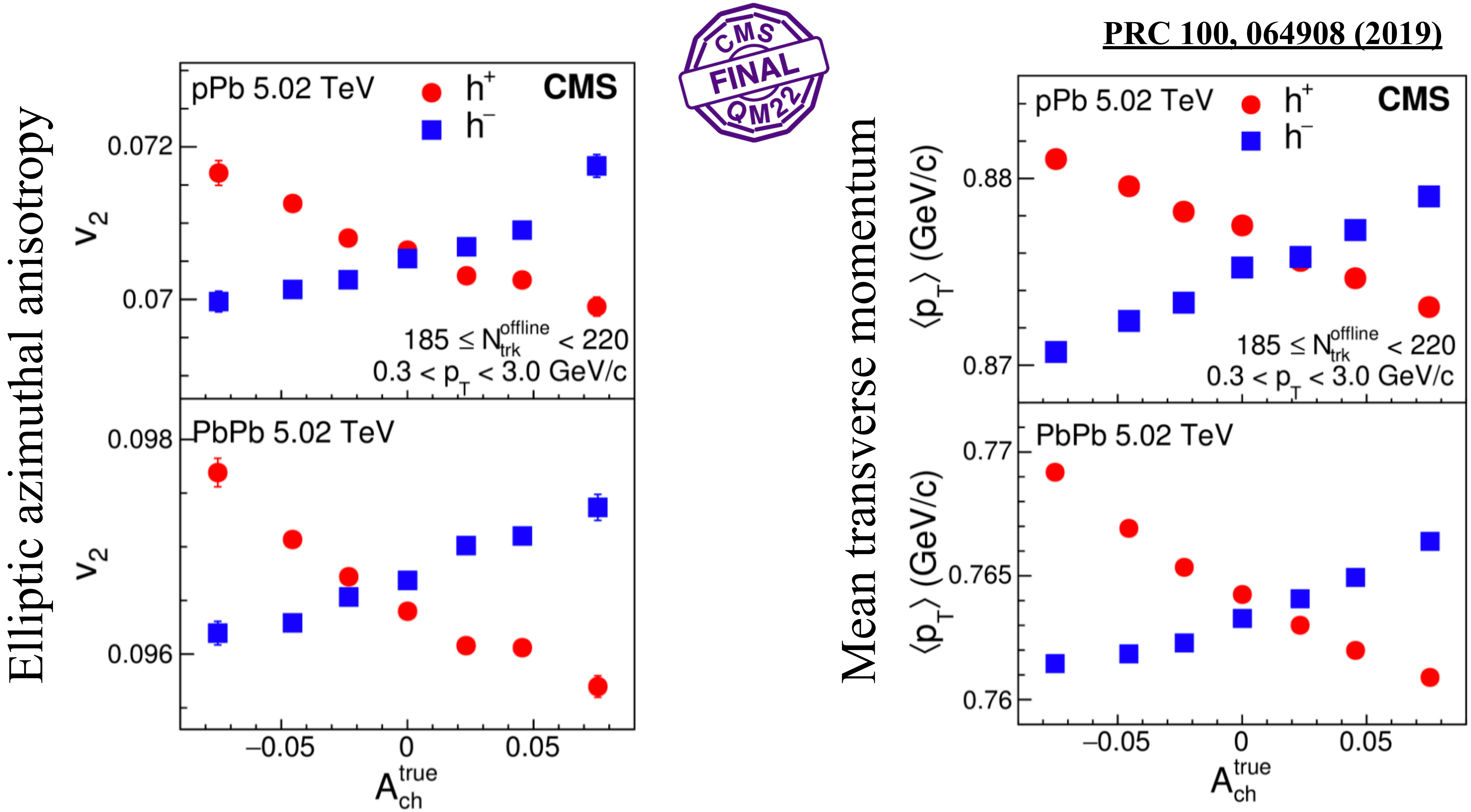
$$\langle 2 \rangle \equiv \frac{1}{M_{11}} \sum_{i,j=1}^{M}{}' w_i w_j e^{in(\varphi_i - \varphi_j)} \qquad M_{11} \equiv \sum_{i,j=1}^{N}{}' w_i w_j$$

$$\langle\langle 2 \rangle\rangle = \frac{\sum_{i=1}^{N} (M_{11})_i \langle 2 \rangle_i}{\sum_{i=1}^{N} (M_{11})_i} \qquad c_n\{2\} = \langle\langle 2 \rangle\rangle \qquad v_n\{2\} = \sqrt{c_n\{2\}}$$

- Eta gap one unit is applied to suppress the non-flow effect like short range correlations
- v_2 of positive and negative particles calculated separately

v_2 and $\langle p_T \rangle$ as a function of A_{ch}

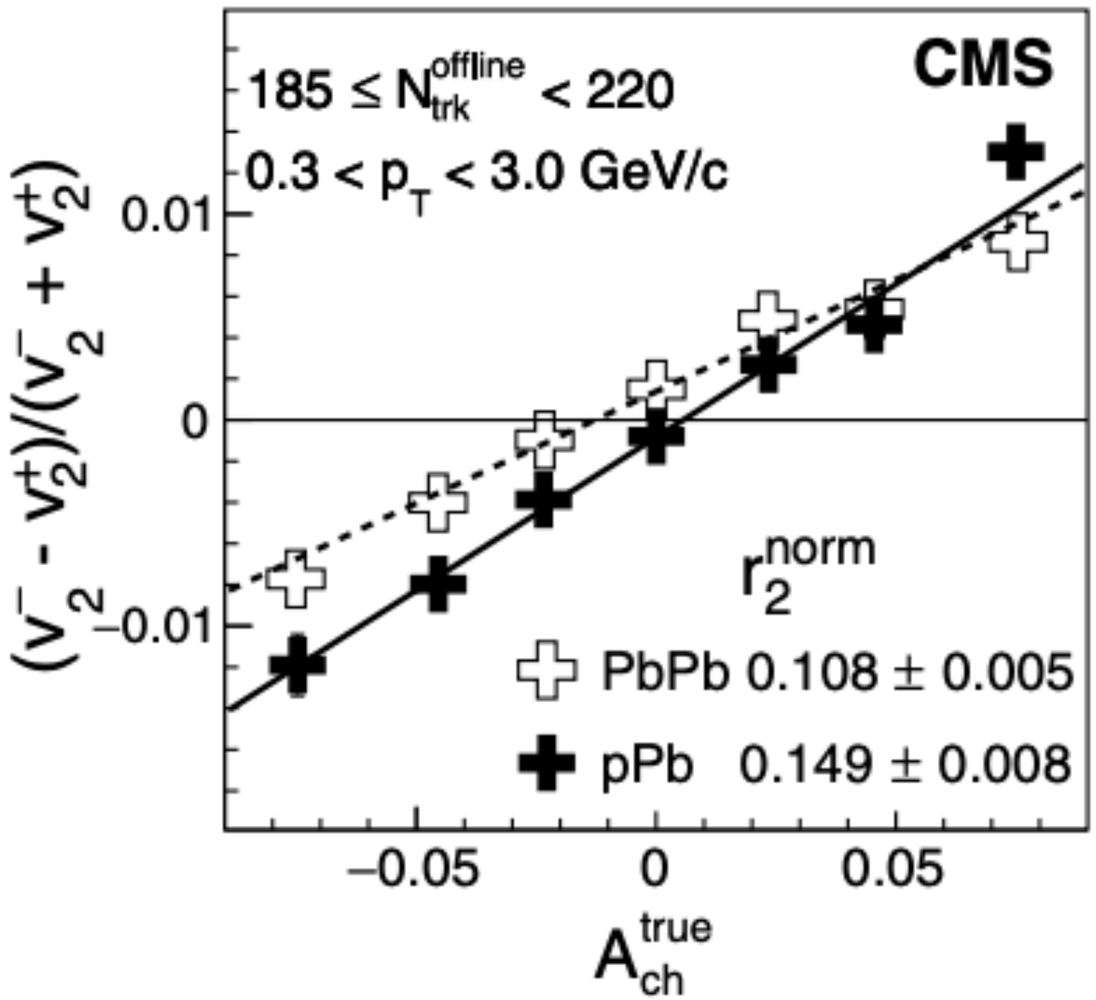
PRC 100, 064908 (2019)

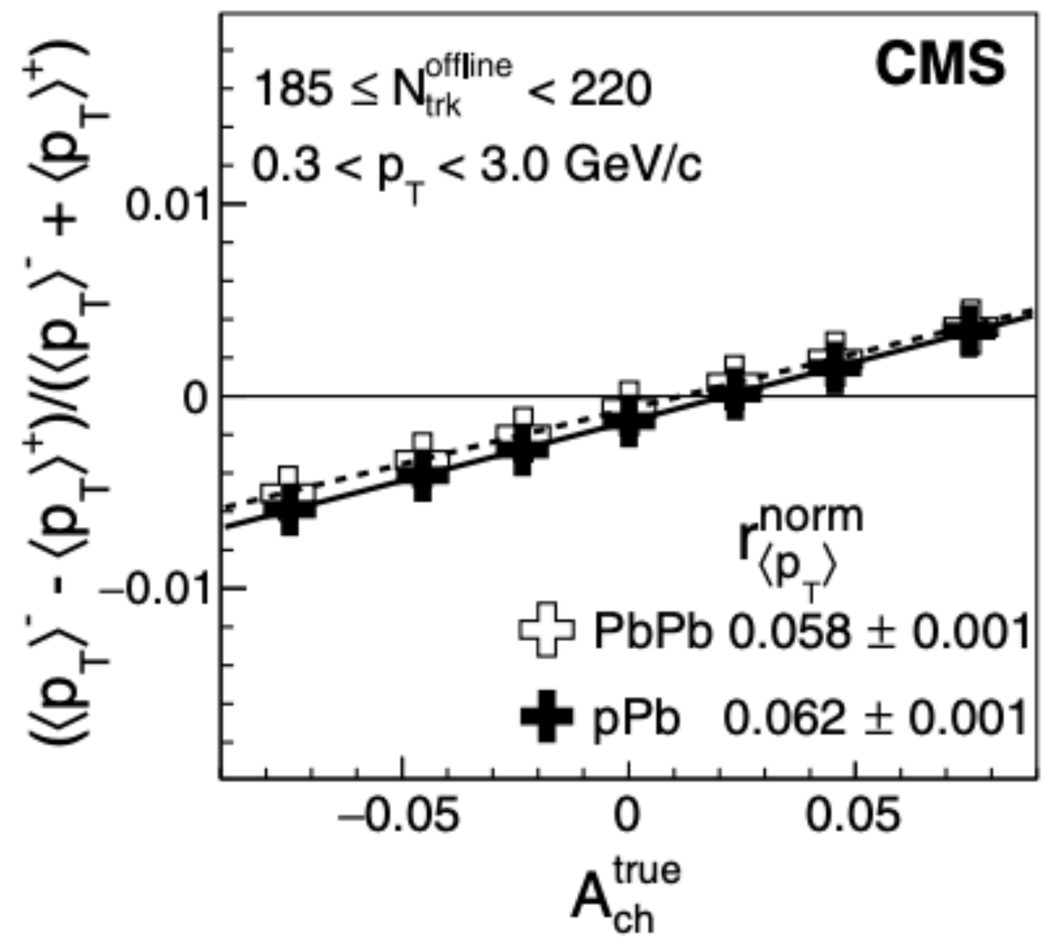


- A significant non-zero v_2 with A_{ch}^{true} is observed in pPb collisions.
- $\langle p_T \rangle$ Vs A_{ch}^{true} shows similar increasing or decreasing trend.

Slope parameter in PbPb and pPb

PRC 100, 064908 (2019)



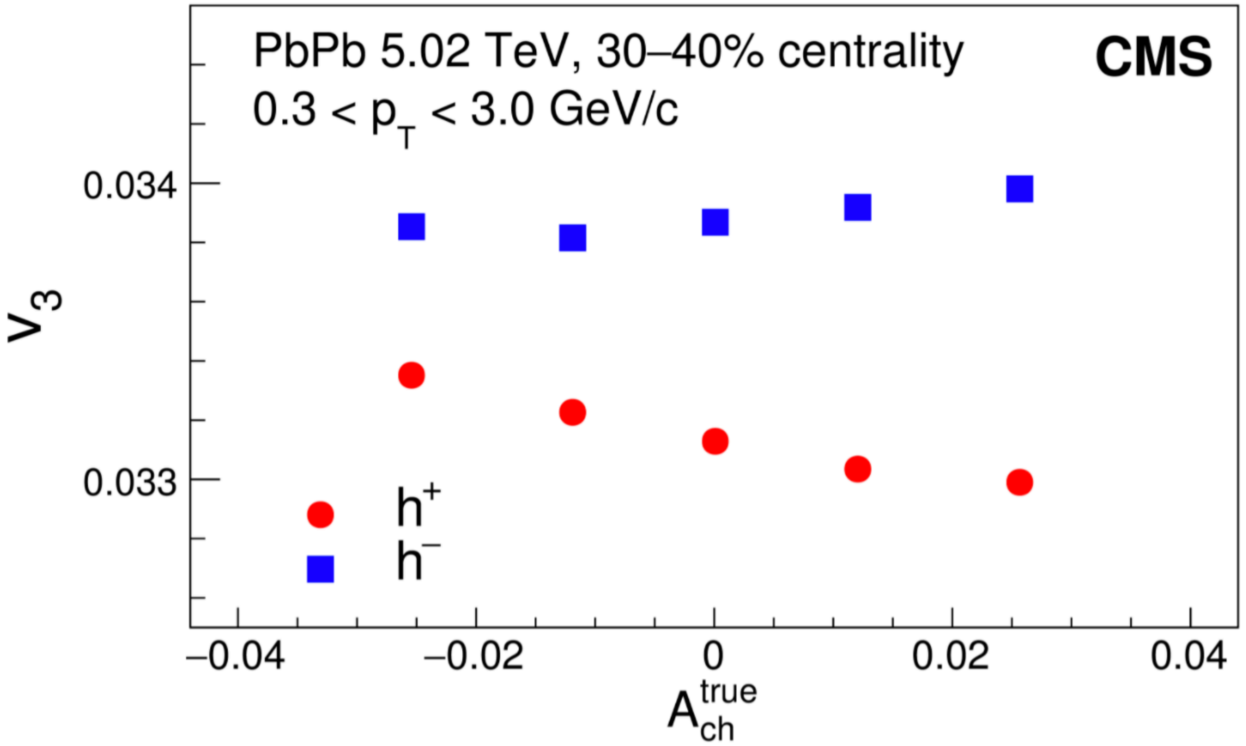


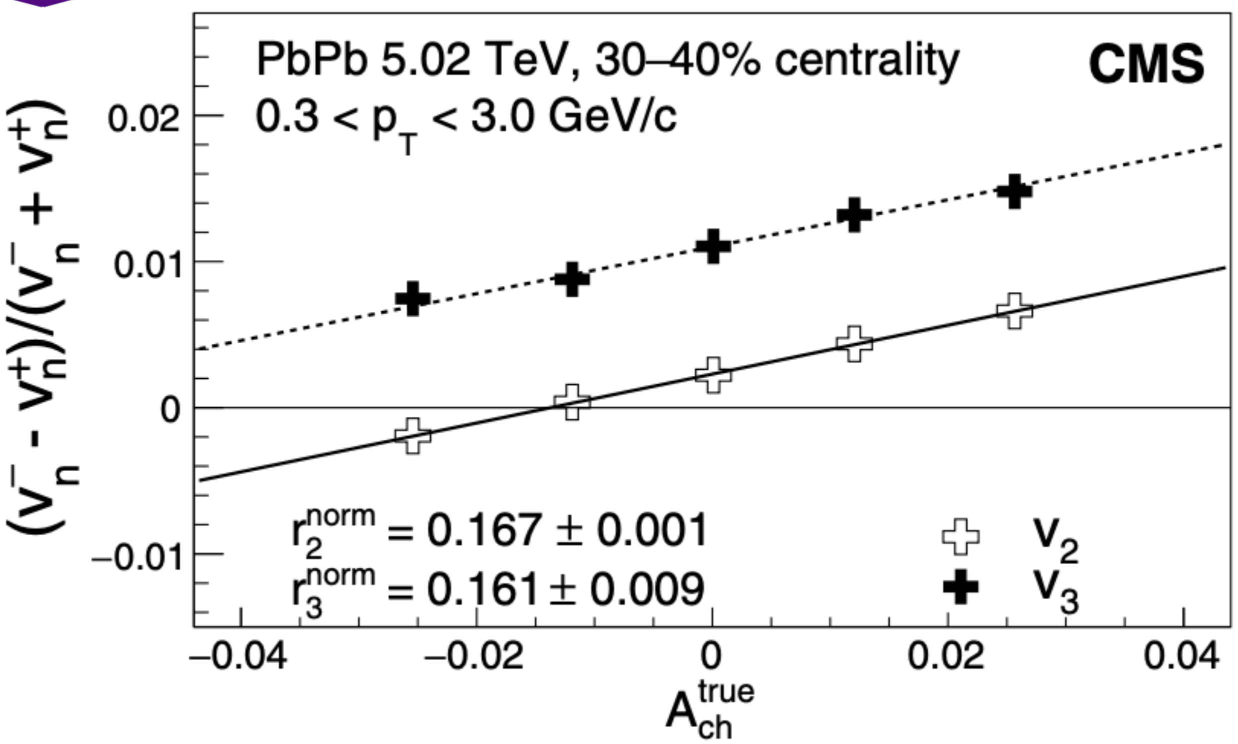
- Slope from normalized mean p_T $r_{\langle p_T\rangle}^{norm}$show similar patterns when fitting v_2 r_2^{norm}.
- Support for the local charge conservation (LCC) interpretation.

Phys.Lett. B726 (2013) 239-243

v_3 as a function of A_{ch}

PRC 100, 064908 (2019)





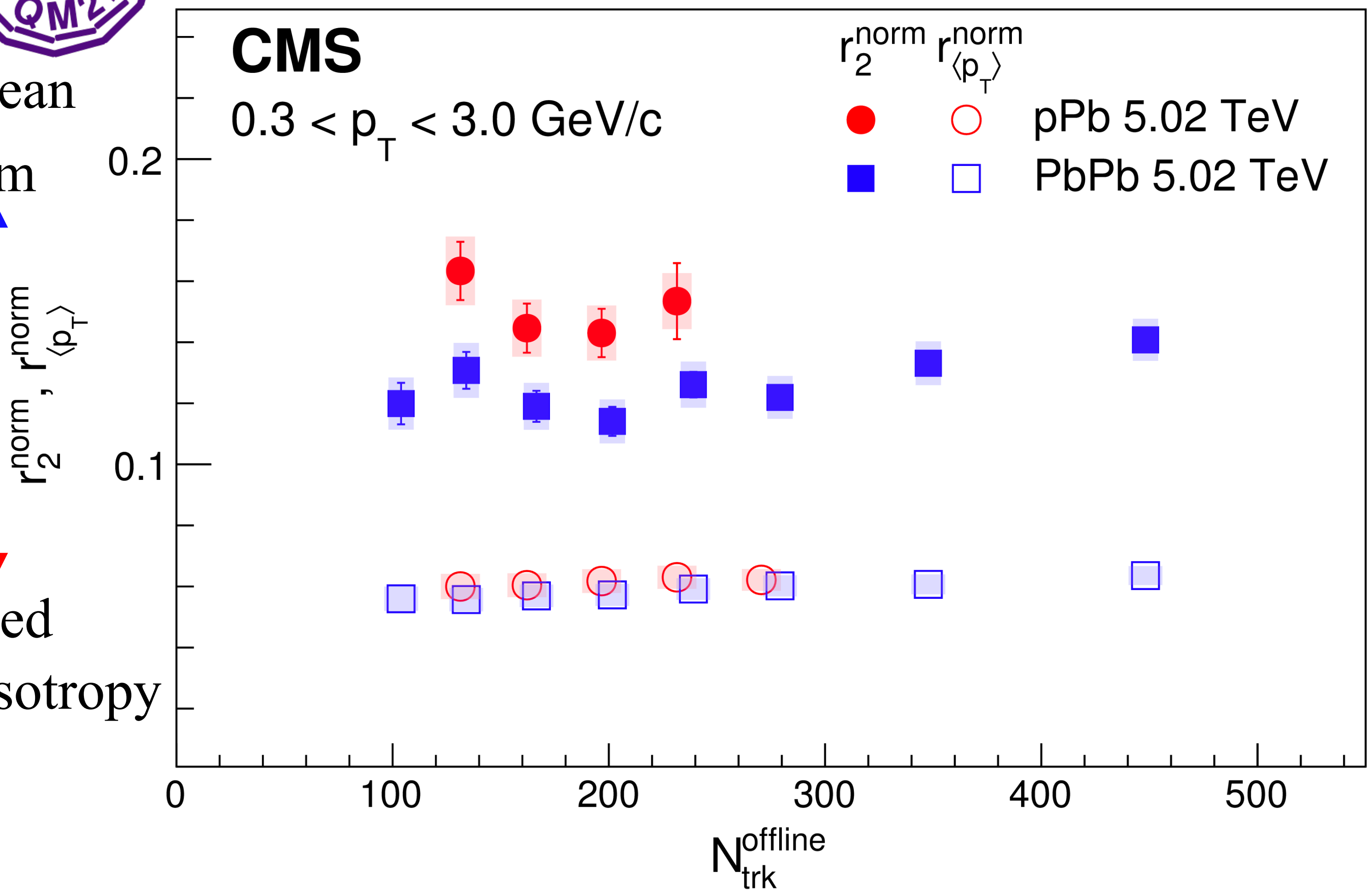
- v_3^+ (v_3^-) values decreases (increases) as A_{ch} increases.
- r_2^{norm} and r_3^{norm} slope parameter are similar in PbPb.
- Support for the LCC interpretation.

Slope parameter with centrality

PRC 100, 064908 (2019)

$r^{norm}_{p_{\langle T \rangle}}$ = Normalized mean transverse momentum

r^{norm}_{2}= Normalized elliptic azimuthal anisotropy



Red = pPb 5.02 TeV

Blue = PbPb 5.02 TeV

- r_2^{norm} are consistently same in all multiplicity
- $r_{\langle p_T \rangle}^{norm}$ for the two systems are similar
- Provides support for LCC effect
- Challenges the CMW interpretation

Bass, Danielewicz, Pratt, PRL, 85, 2689 (2000)

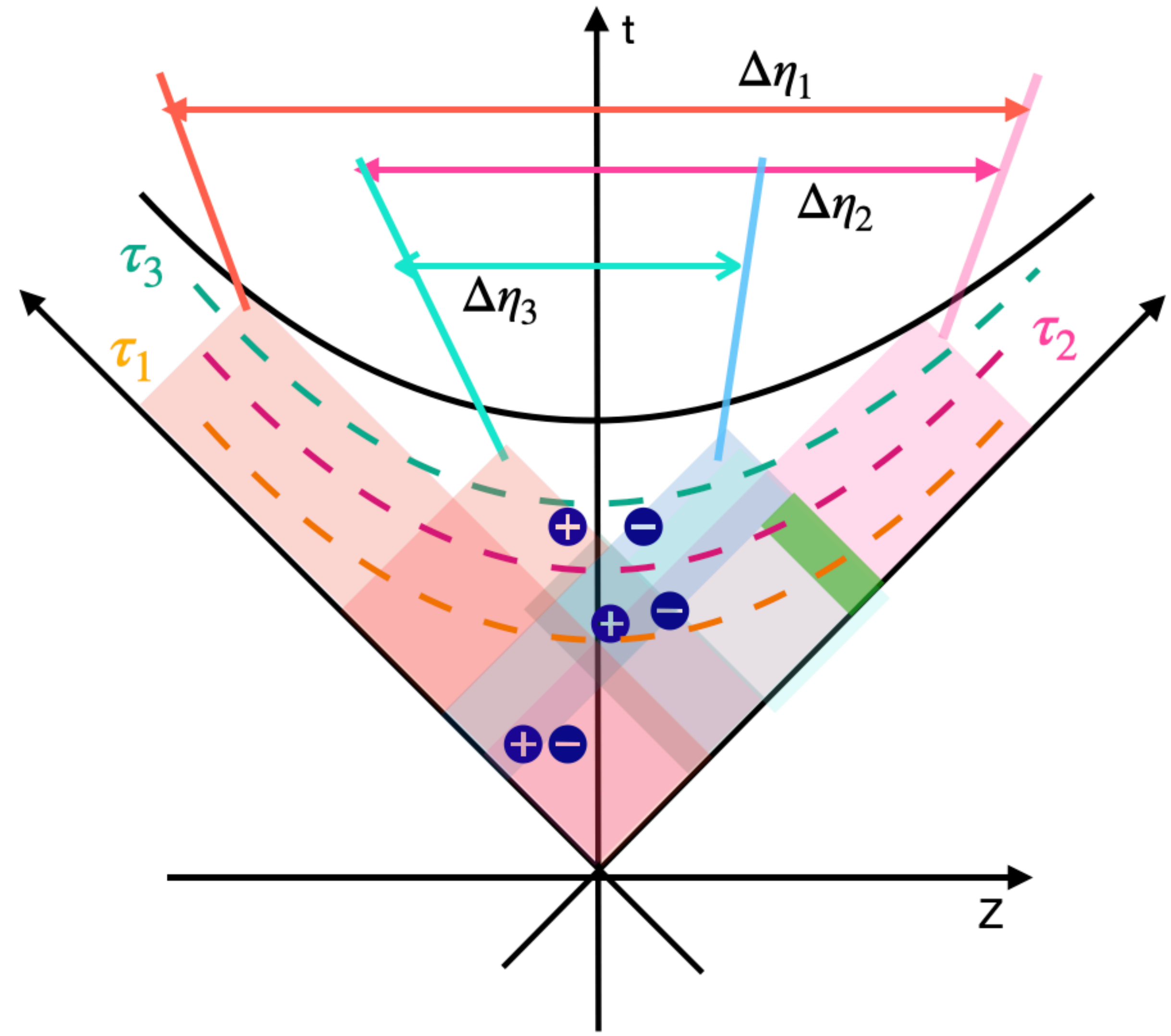
Balancing charge separation

- Correlation of balancing charge
  - Late or early hadronization
  - Collision dynamics : radial flow

$$B(\Delta\eta, \Delta\varphi) = \frac{1}{2}[c_2^{+,-} + c_2^{-,+} - c_2^{-,-} - c_2^{+,+}]$$

$$B(\Delta\eta, \Delta\varphi) = \frac{1}{2}[US - LS]$$

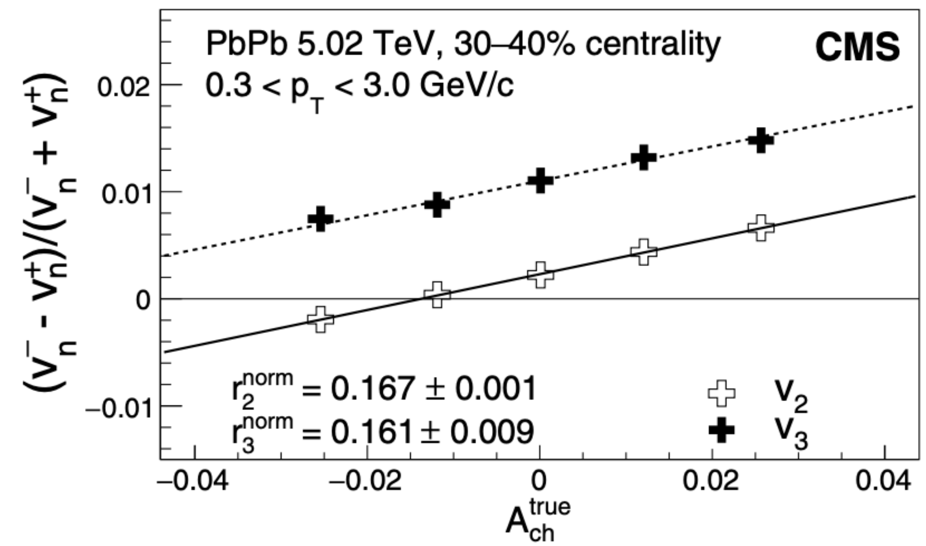
$US = c_2^{+,-}, c_2^{-,+}$ $LS = c_2^{-,-}, c_2^{+,+}$



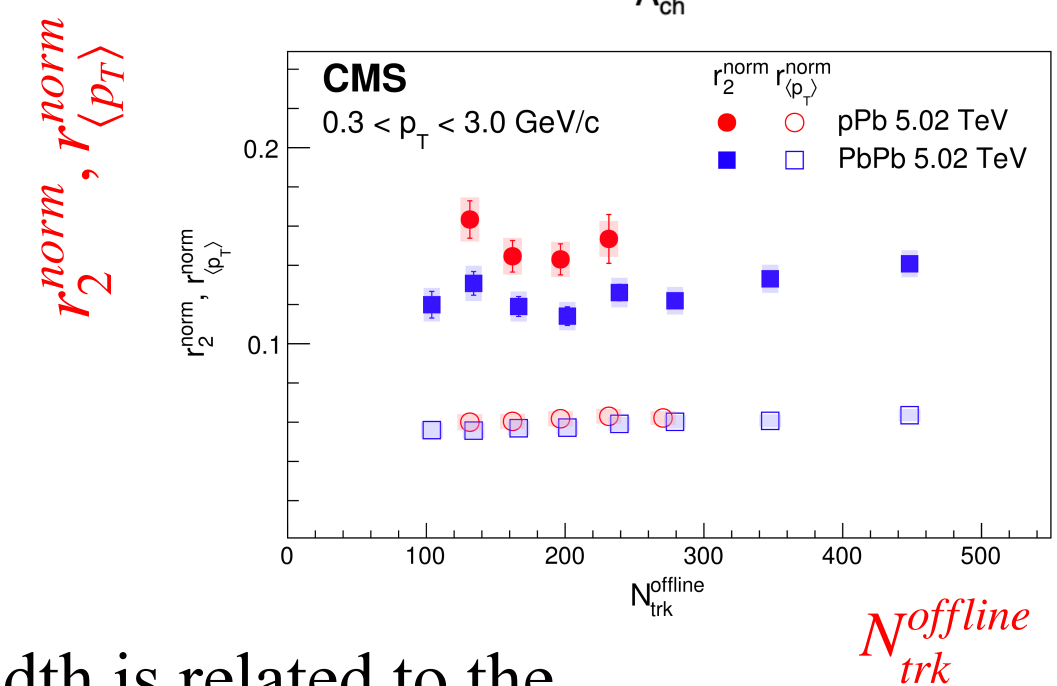
- Early charge separation ⟶ should be long range in $\Delta\eta$

Summary

- Both in PbPb and pPb collisions the charge asymmetry dependence of v_n and $\langle p_T \rangle$ is measured and quantified in terms of r_2^{norm} and $r_{\langle p_T \rangle}^{norm}$.



- r_2^{norm} and r_3^{norm} are almost identical in PbPb collisions.



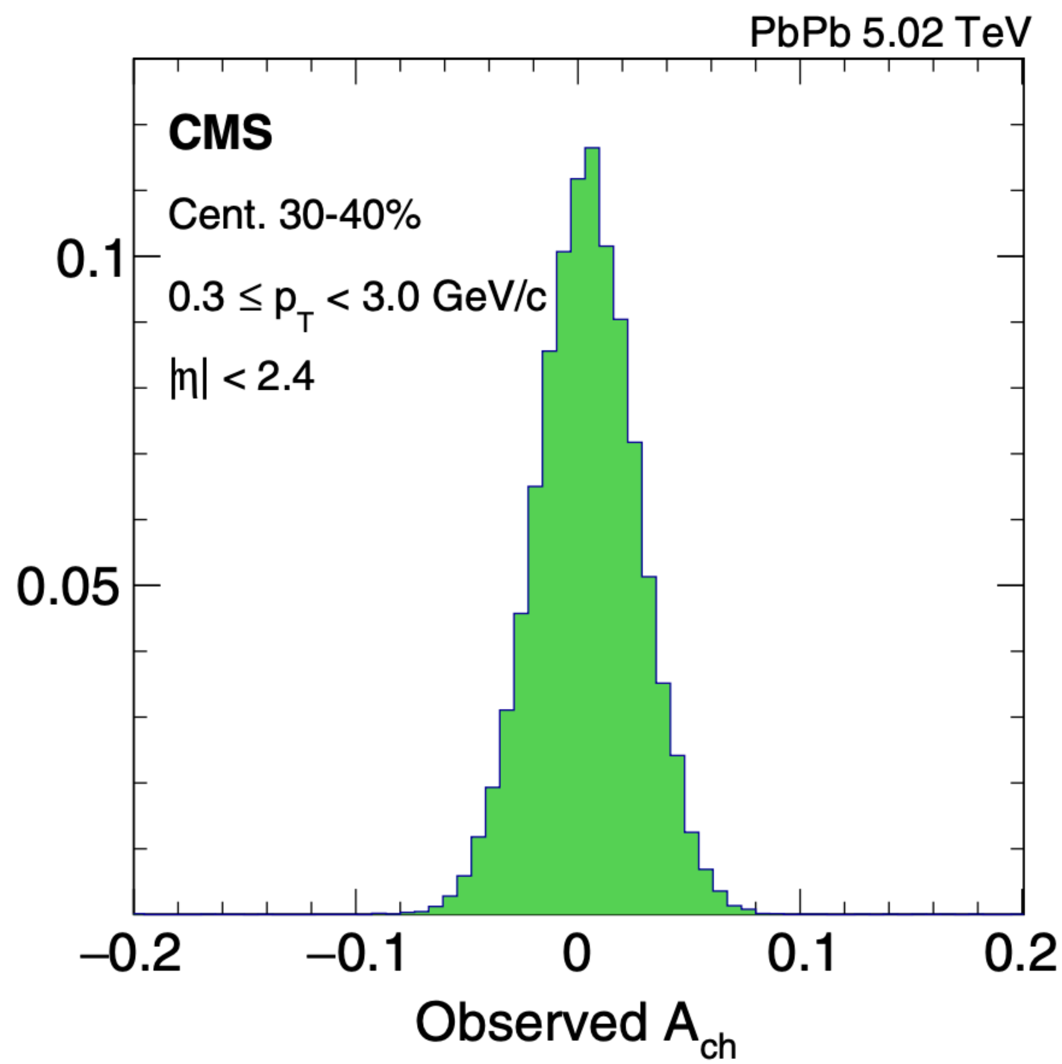
- r_2^{norm} and $r_{\langle p_T \rangle}^{norm}$ are consistent over the multiplicity in PbPb and pPb collisions.
- Support for local charge conservation interpretation and challenges to CMW.
- Narrowing and widening of the balance function width is related to the late and early hadronization.

Thank you!

Backup slides at glance

The distribution of Charge Asymmetry

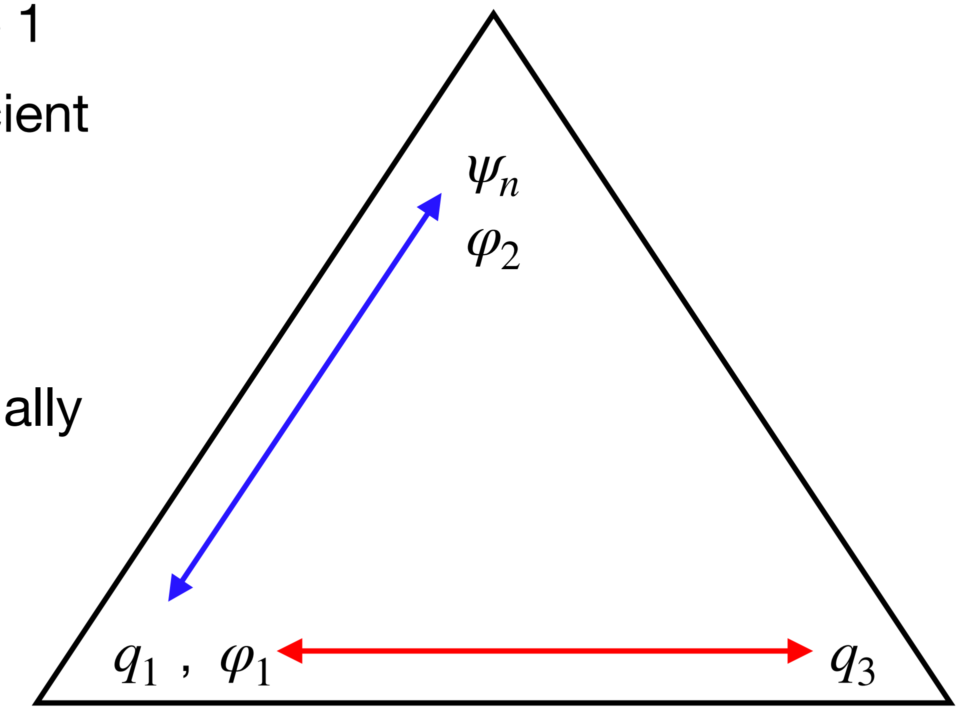
PRC 100, 064908 (2019)



- A_{ch}^{true} is obtained by correcting the observed charge A_{ch} for the detector acceptance and efficiency.

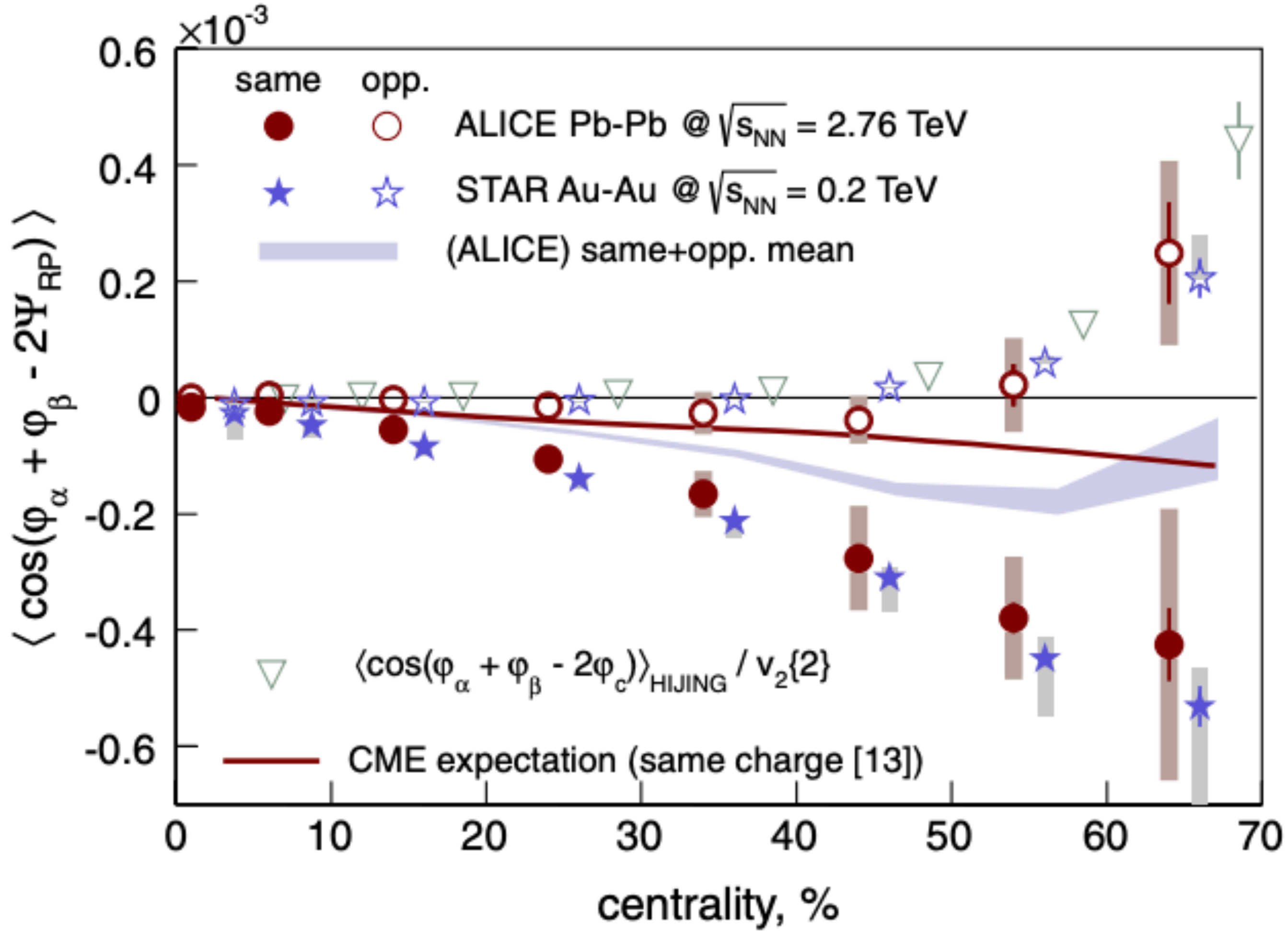
More about three particle correlator

- 1 is the particle of interest, we consider both q_1, φ_1
- 2 is the reference particle used to estimate the flow of particle 1
- Correlation between 1 and 2 is related to the harmonic coefficient
- 3 is the charge of the third particle
- Correlation between 1 and 3 is related to the balance function
- Both the correlation must be taken into account to get potentially new physics information



CME in A-A collisions

$$\gamma \equiv \left\langle cos\left(\varphi_\alpha + \varphi_\beta - 2\psi_{RP}\right)\right\rangle = \left\langle cos\left(\Delta\varphi_\alpha\right)cos\left(\Delta\varphi_\beta\right)\right\rangle - \left\langle sin\left(\Delta\varphi_\alpha\right)sin\left(\Delta\varphi_\beta\right)\right\rangle$$



$$-\left\langle a_{1,\alpha}, a_{1,\beta}\right\rangle$$

OS

SS

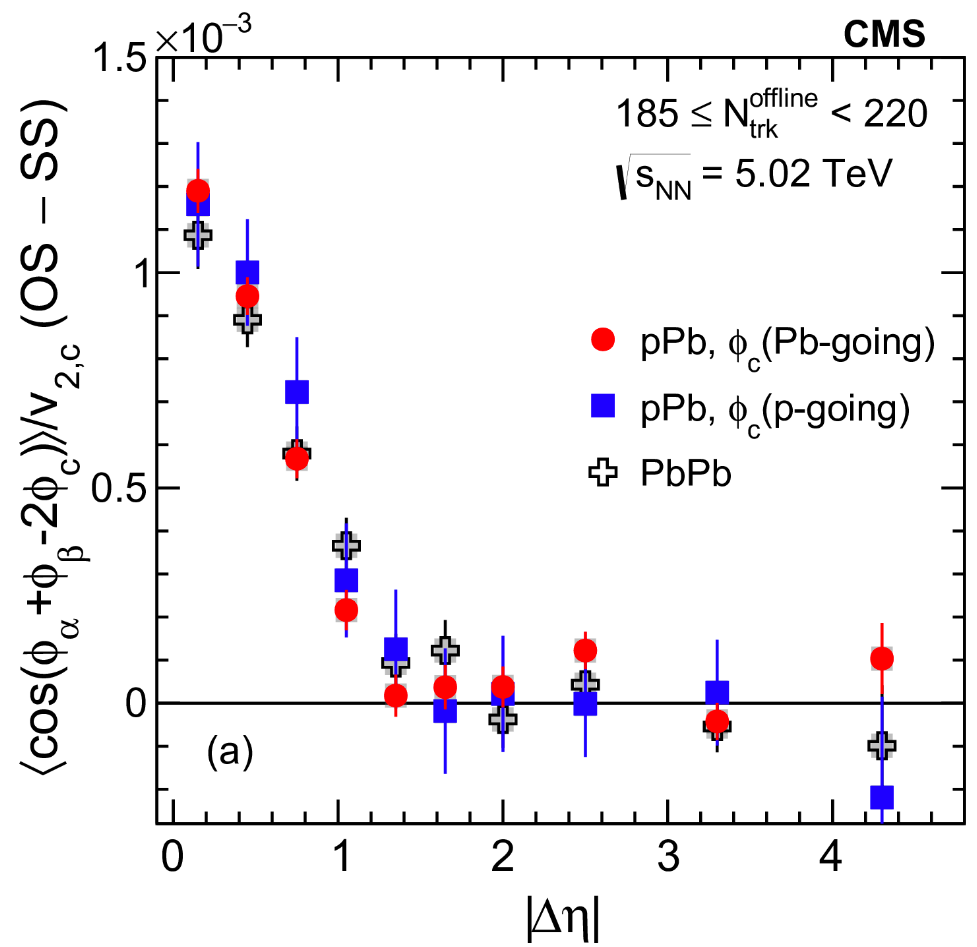
PRL 110 (2013) 012301

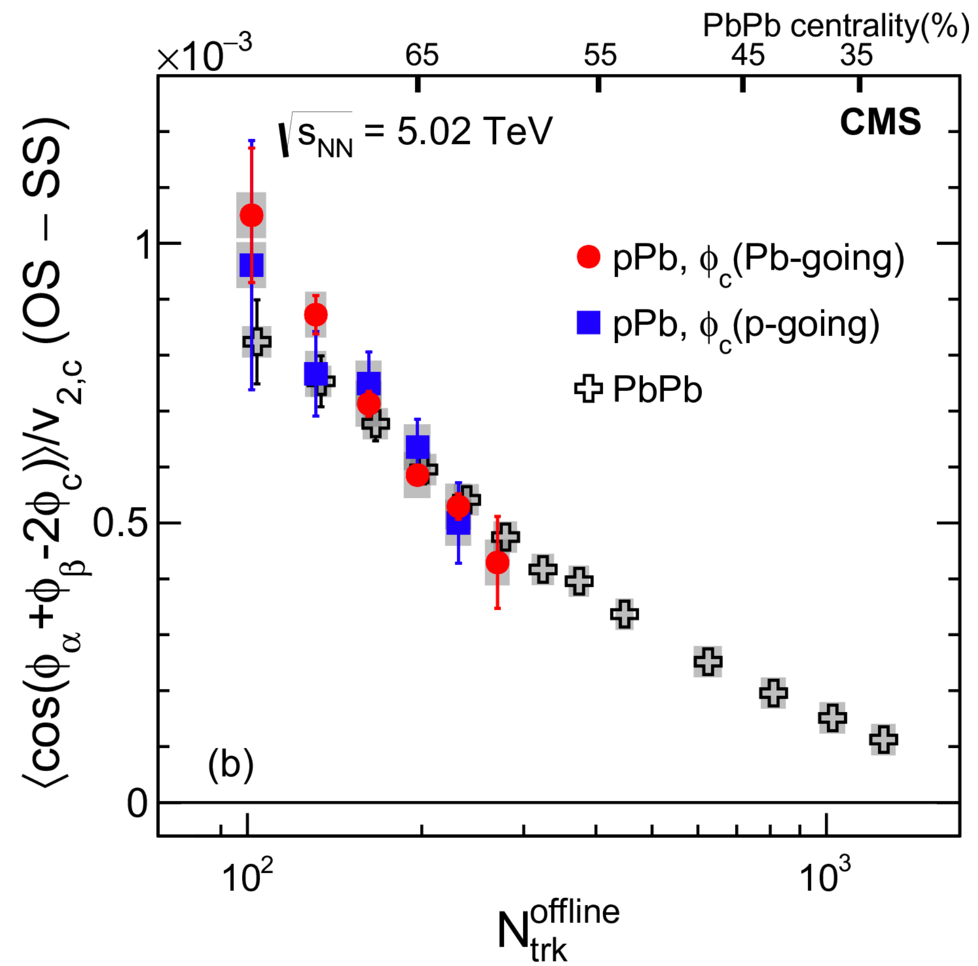
- The correlations from HIJING shows a significant increase in the magnitude for very peripheral collisions.
- Data shows a similar trend of charge separation from CME

$\Delta\gamma$ in PbPb and pPb collisions

CMS, PRL 118, 122301 (2017)

$$\Delta\gamma \sim \langle B^2 cos[2(\psi_B - \psi_{RP})]\rangle$$





- Similarity between the PbPb and pPb
- No CME signal is expected in pPb
- Correlator is highly dominated by backgrounds

CMS detector