New studies of CME using charge-dependent azimuthal correlations at the LHC

Submitted to PRC and arXiv:1708.01602

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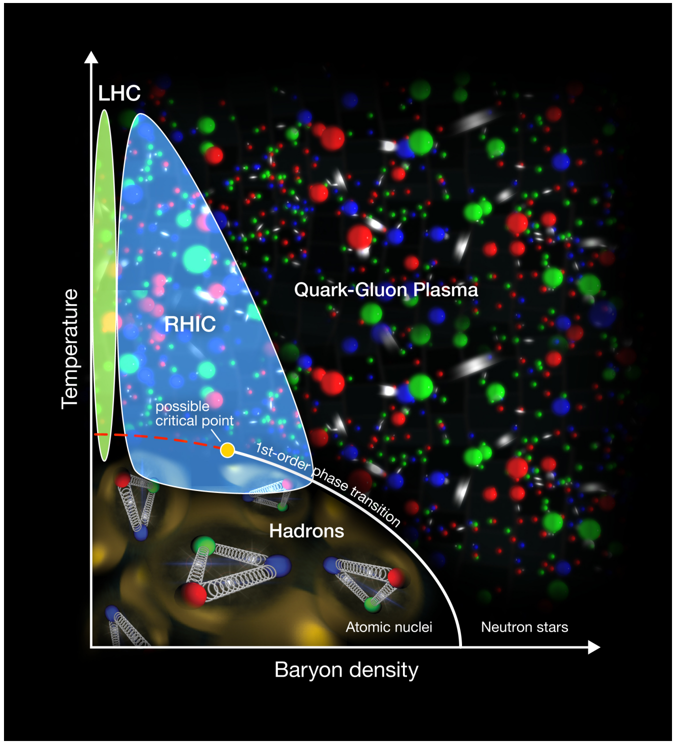
On behalf of CMS collaboration

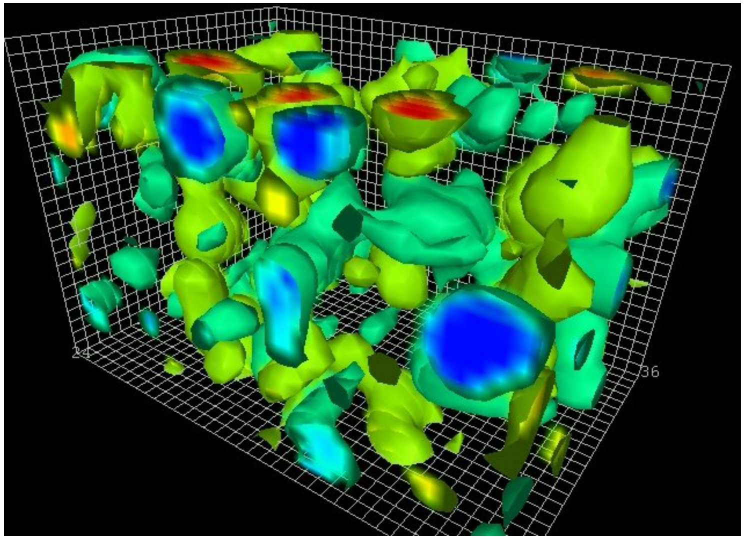
CPOD, Stony Brook University, US 2017

Chiral magnetic effect (CME) in HIC

Deconfinement + Chiral symmetry restoration



Fluctuations of topological charge in QCD vacuum → P and CP odd domains



Derek Leinweber, University of Adelaide

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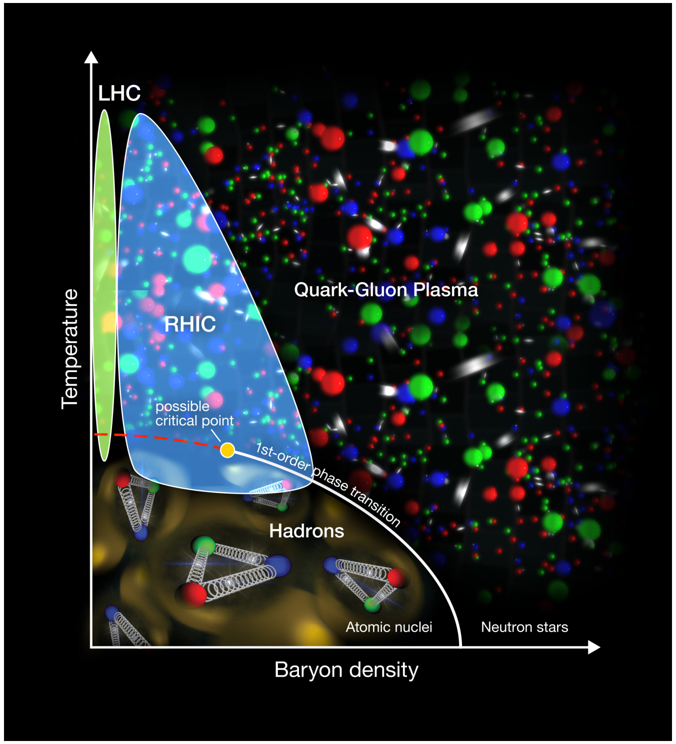
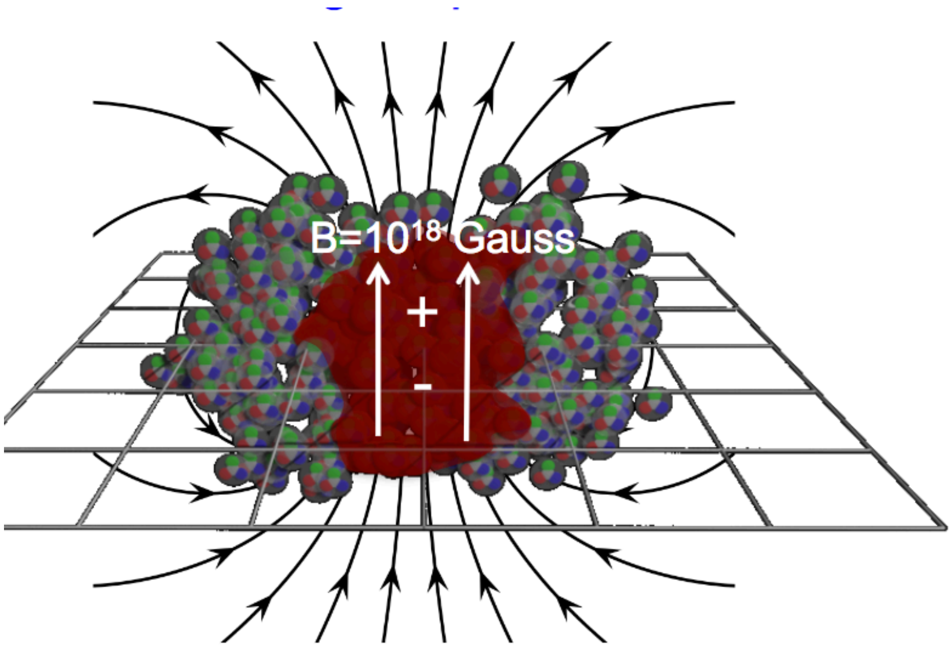


Strong magnetic field



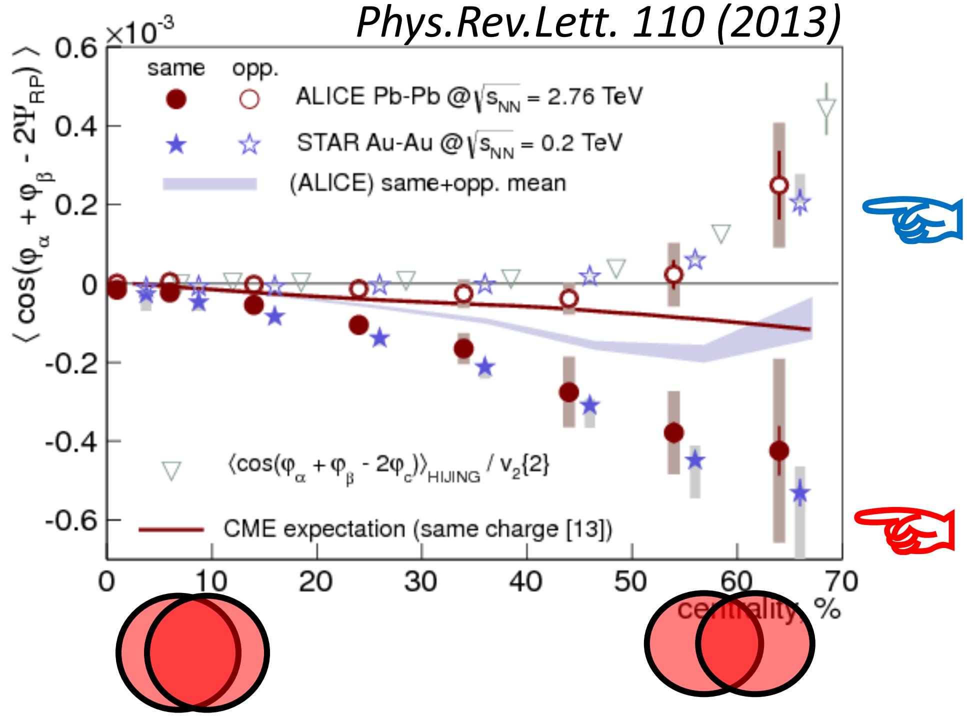
❖ Chirality imbalance inside of the QGP phase with **a strong magnetic field** can generate charge separation, known as the CME

If CME is observed, evidence for chiral symmetry restoration!

Status of CME in previous studies

with $\gamma \equiv \left\langle \cos\left(\phi_\alpha + \phi_\beta - 2\psi_{RP}\right)\right\rangle$ *arXiv: hep-ph/0406311*

Phys.Rev.Lett. 110 (2013)



❖ Charged-dependent correlation observed

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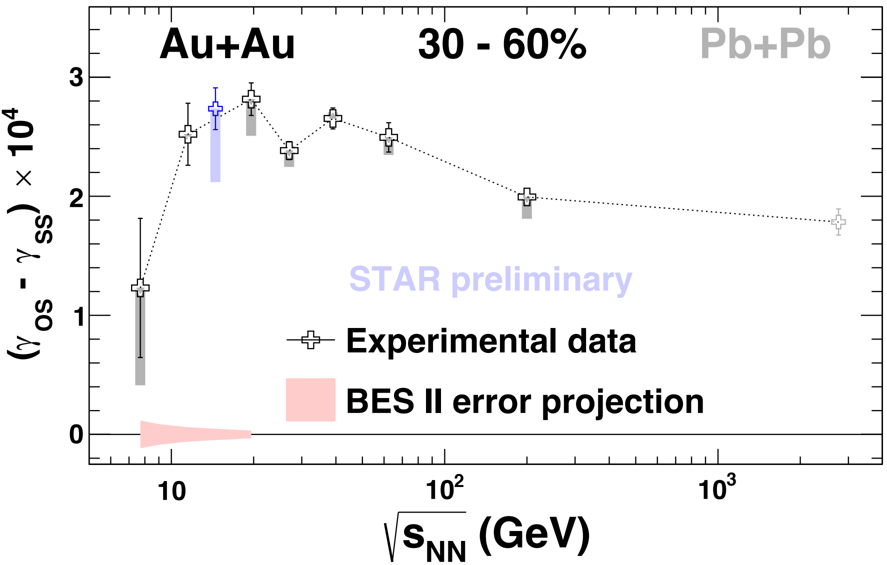

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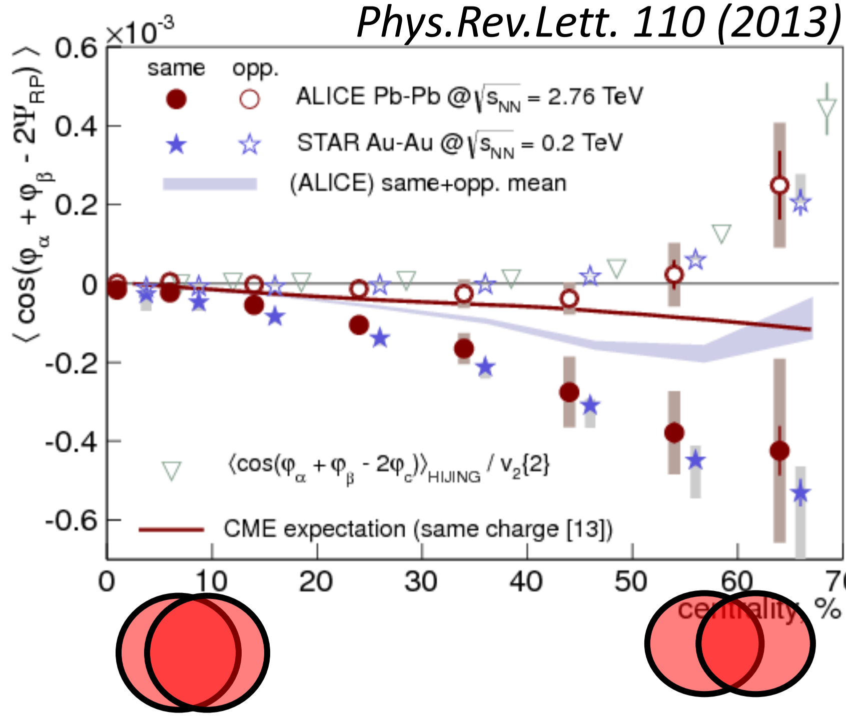

- ❖ $\gamma_{os\text{-}ss}$ drops at low energy (?)
- ❖ Important for BES program

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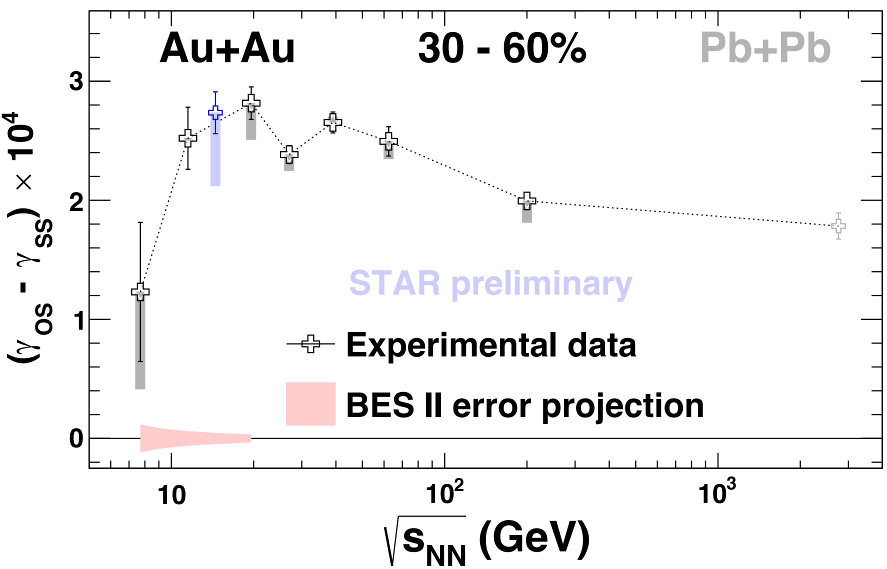

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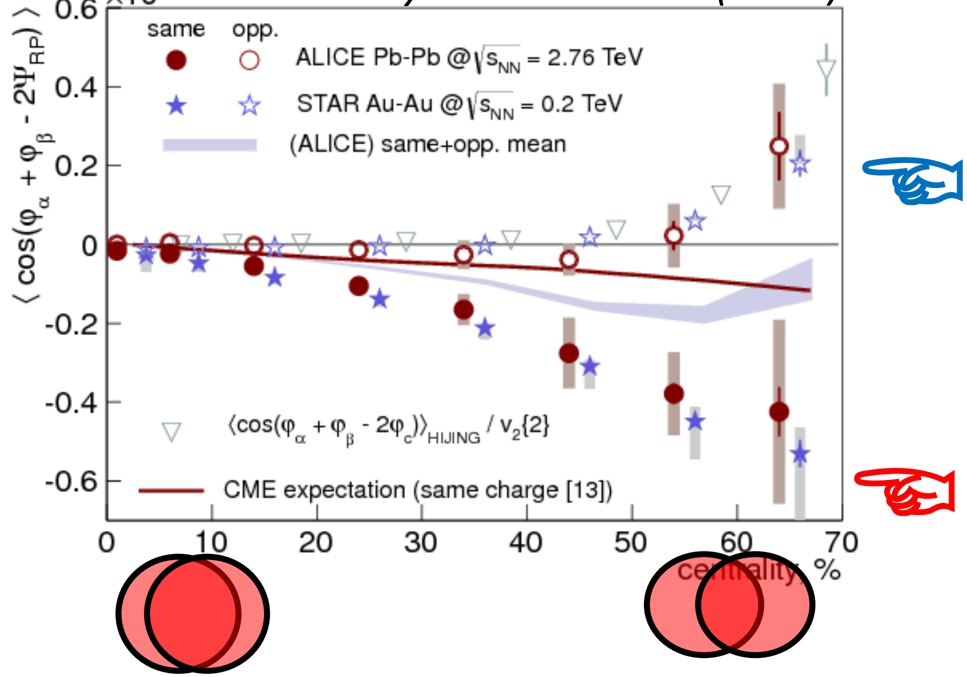
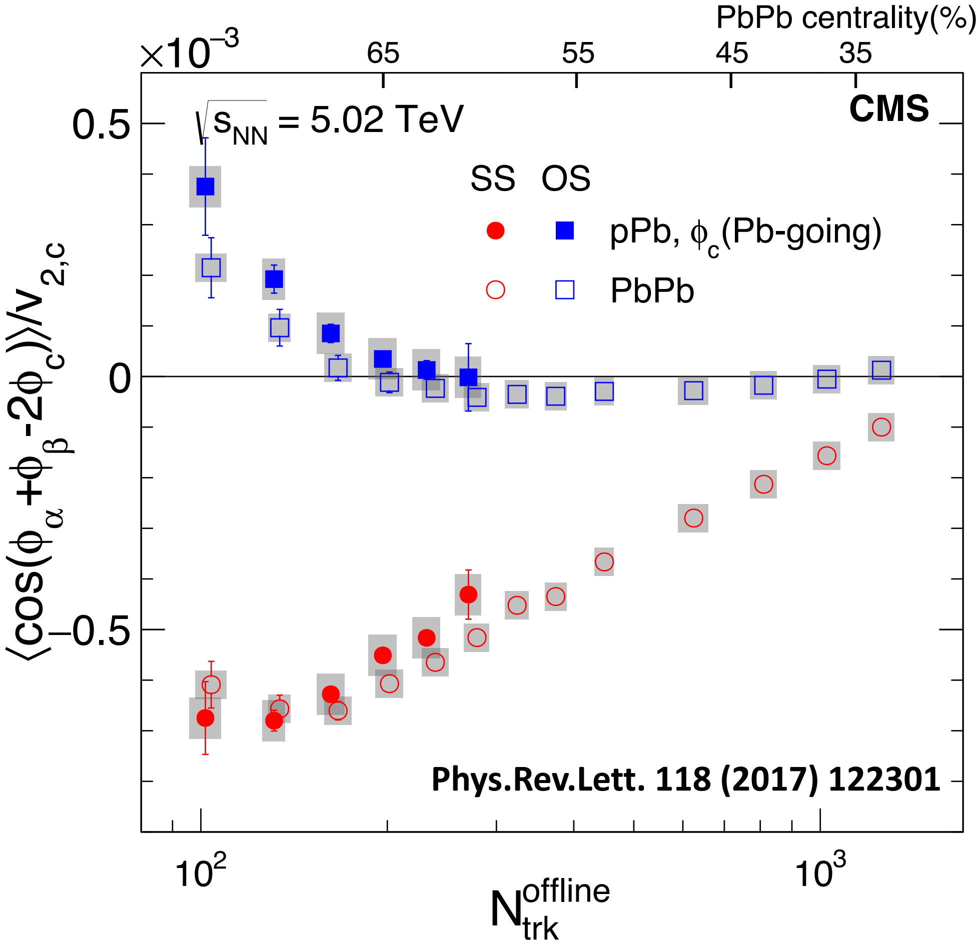


- $\gamma_{os\text{-}ss}$ drops at low energy (?)
- Important for BES program
- Charged-dependent correlation observed

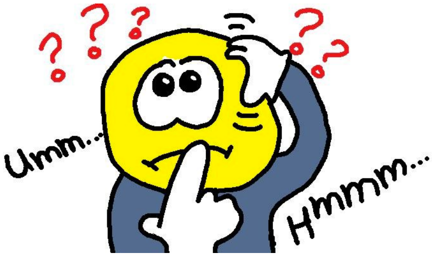
Agree with CME expectation

Status of CME in recent studies



Non negligible background has been long speculated.

Question is about "how much"?



- **Why is pPb and PbPb so similar? Background dominated**

- The fact that γ(pPb) ≈ γ(PbPb) not only challenges the CME but also the background mechanism (e.g., ~v2/N)

Motivation of a detail analysis

- **Two major questions to be answered:**
  i. What is the background exactly?
  ii. Is there any real CME signal, if BKG is removed?

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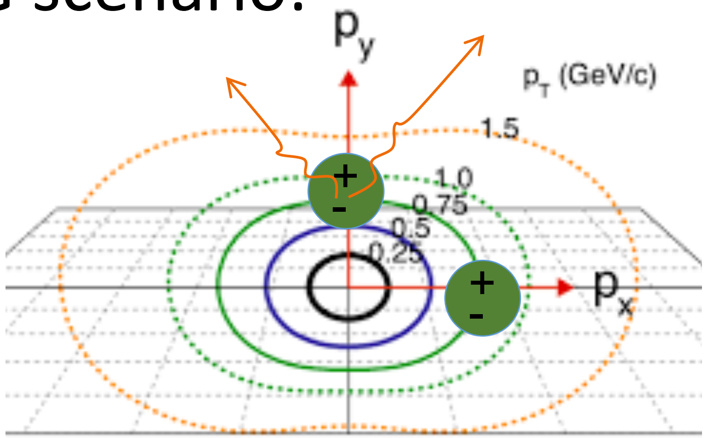
Commonly suspected BKG scenario:

Lect.Notes Phys. 871 (2013) 503-536

$$\gamma = \kappa \cdot v_2 \cdot \delta - H$$

where $\delta \equiv \left\langle \cos\left(\phi_\alpha - \phi_\beta\right)\right\rangle$



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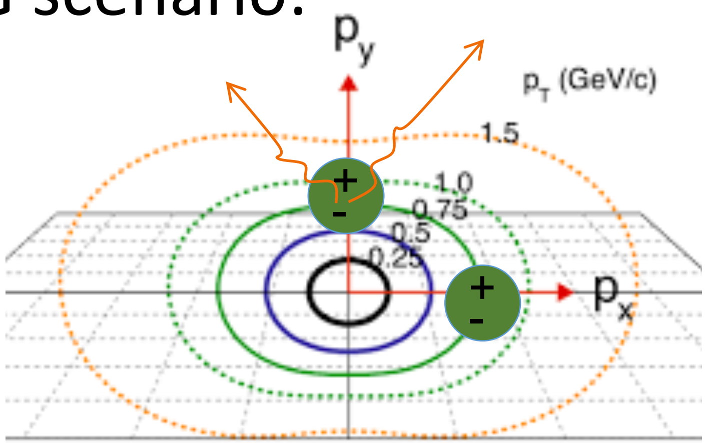

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  i. κ parameter is hard to constrain

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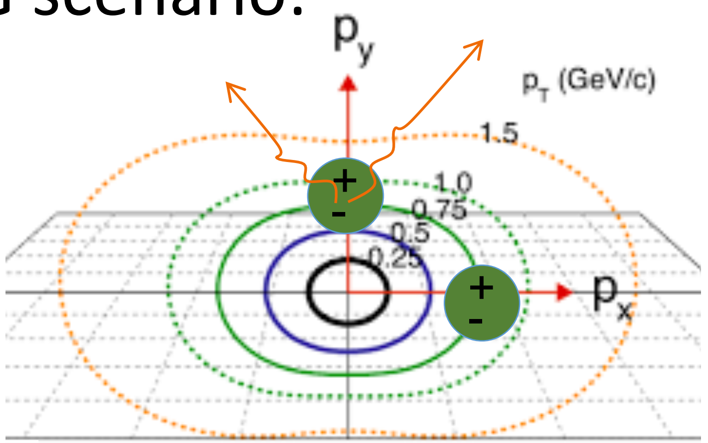

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- **Two major difficulties:**
  i. κ parameter is hard to constrain
  ii. BKG is hard to control, need an independent handle on v_2 without changing the B field

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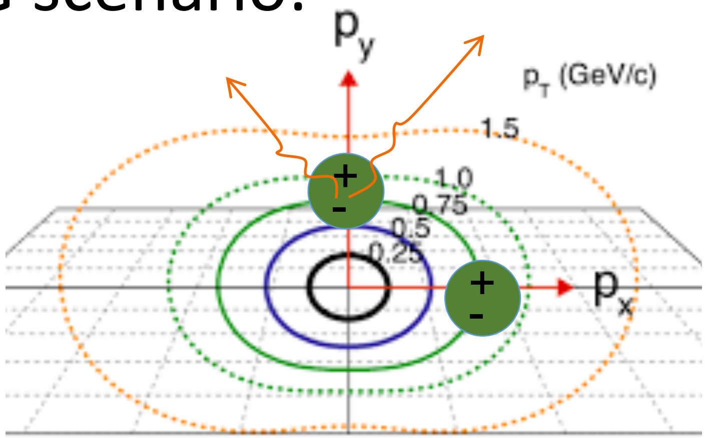

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New experimental strategy is needed!

Analysis strategy

1: Higher-harmonic correlator

$$\gamma_{123} \equiv \left\langle \cos\left(\phi_\alpha + 2\phi_\beta - 3\Psi_3\right)\right\rangle$$

- CME free as no charge separation w.r.t. Ψ_3
- For BKG-only source,

$$\gamma_{123} = \kappa \cdot v_3 \cdot \delta \; \cancel{- H}$$

An independent constraint to $\boldsymbol{\kappa}$!

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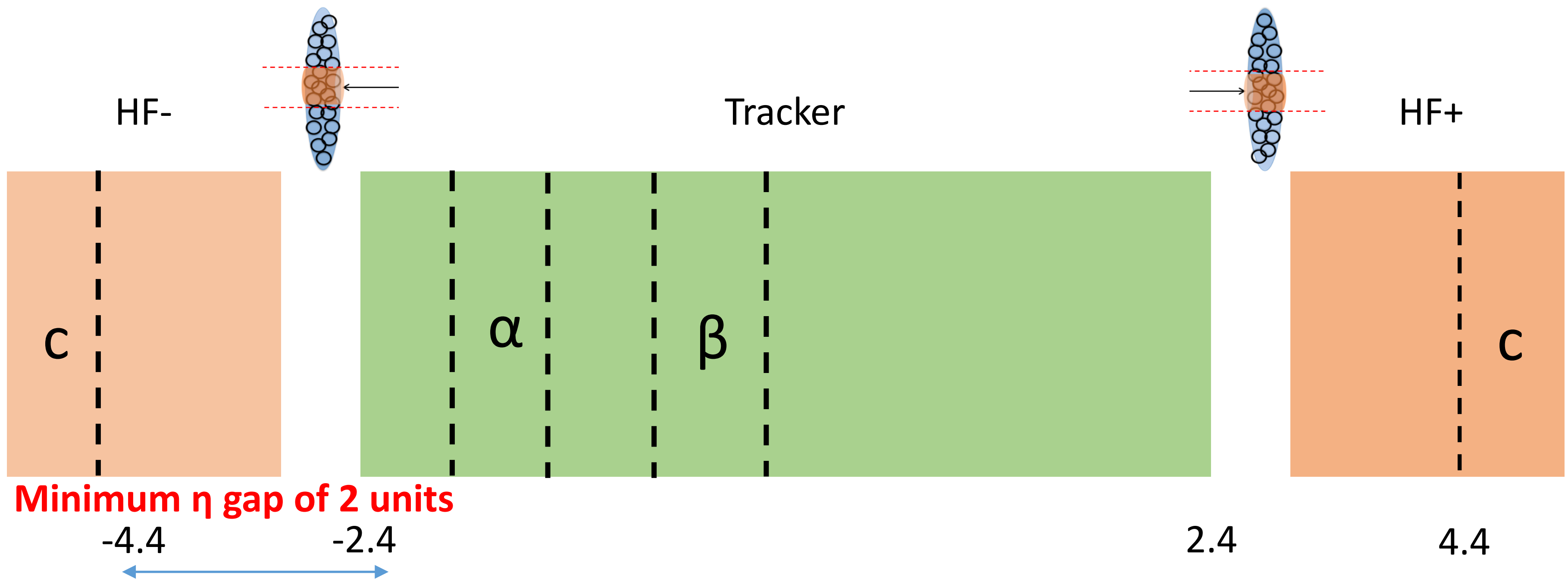
An independent constraint to κ!

- **2: Event Shape Engineering (ESE)** arXiv:1608.03205v2

To directly observe the relation between γ and v_2

(Is it consistent with a v_2-linear BKG-only scenario?)

Measurement with CMS detectors



- γ_{112} is γ, measured in the same way as before: Phys.Rev.Lett. 118 (2017) no.12, 122301

$$\gamma_{112} = \left\langle \cos\left(\phi_\alpha + \phi_\beta - 2\Psi_{EP}\right)\right\rangle \cong \left\langle \cos\left(\phi_\alpha + \phi_\beta - 2\phi_c\right)\right\rangle / v_{2,c}$$

- Similarly, $\gamma_{123} = \left\langle \cos\left(\phi_\alpha + 2\phi_\beta - 3\Psi_3\right)\right\rangle \cong \left\langle \cos\left(\phi_\alpha + 2\phi_\beta - 3\phi_c\right)\right\rangle / v_{3,c}$ $\quad \delta \equiv \left\langle \cos\left(\phi_\alpha - \phi_\beta\right)\right\rangle$

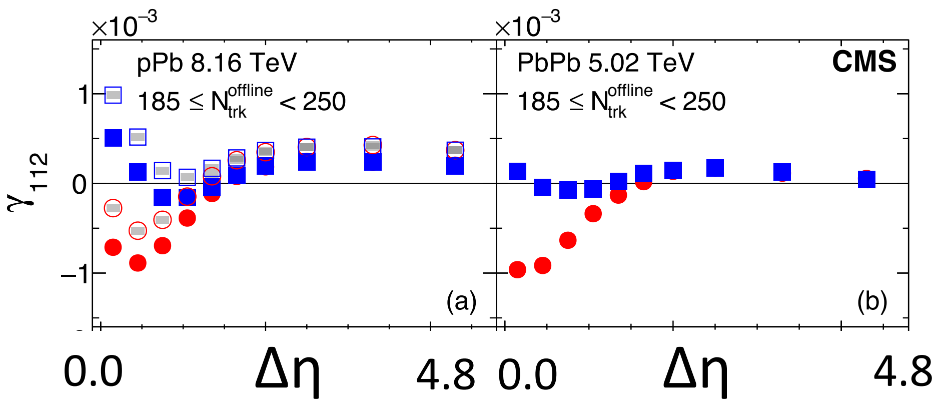
- Large gap between particle α,β and c, to reduce short range correlation. Valid for factorization.

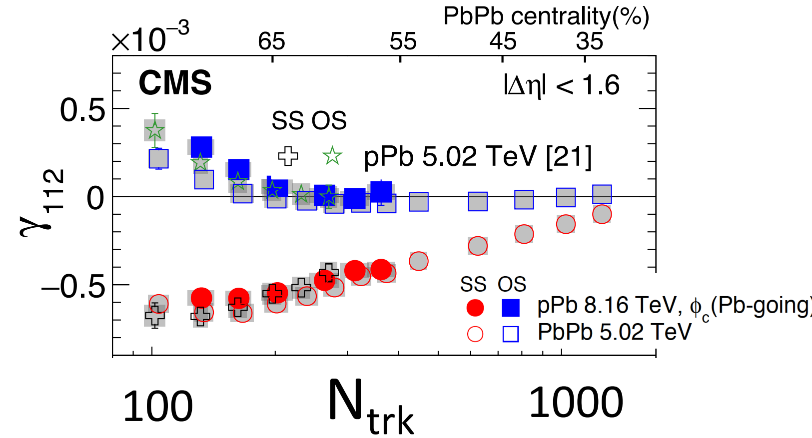
arXiv:1708.01602

Results: OS and SS

Similar data is seen btw 8 and 5 TeV pPb

pPb PbPb





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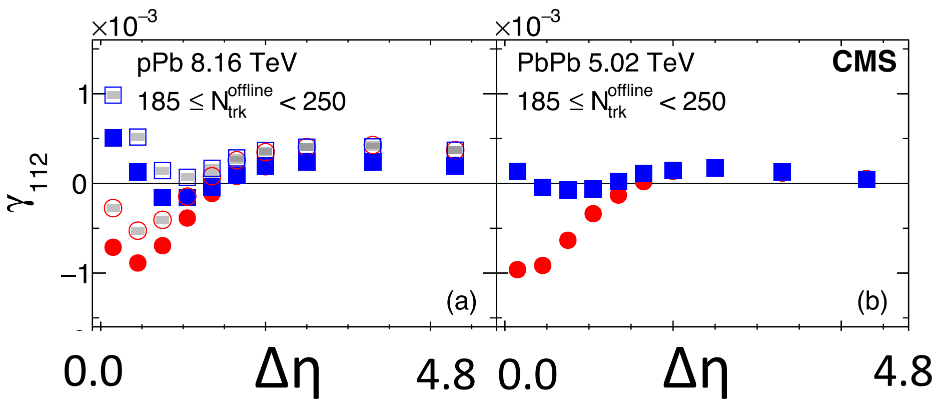

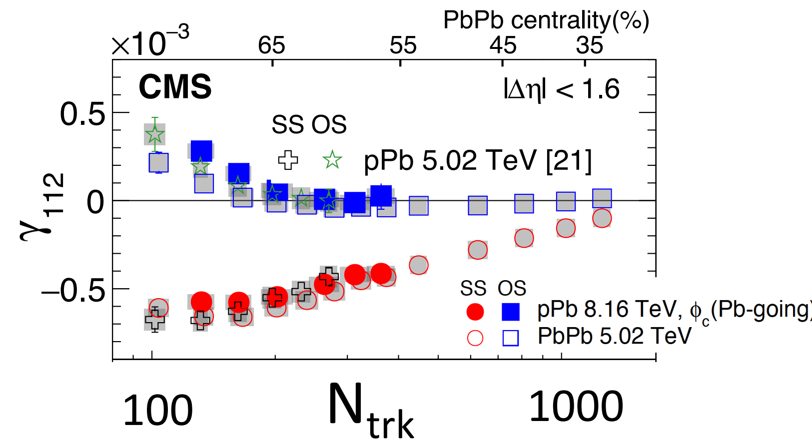

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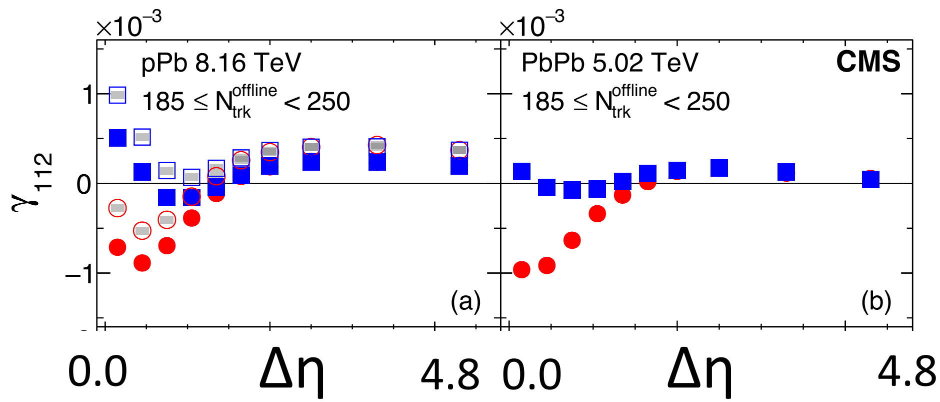
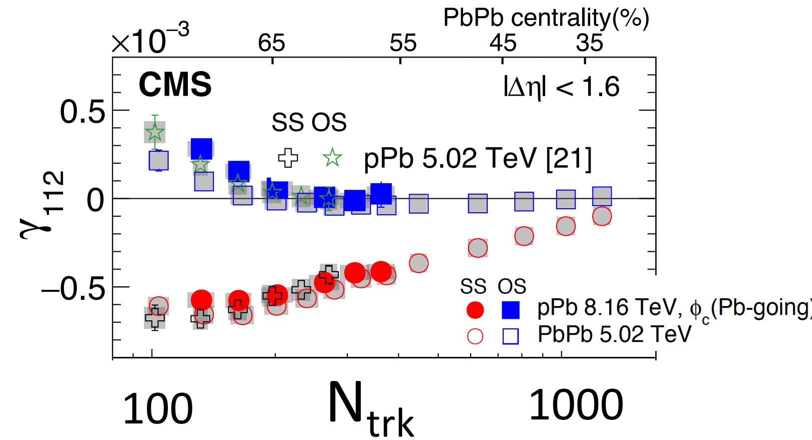
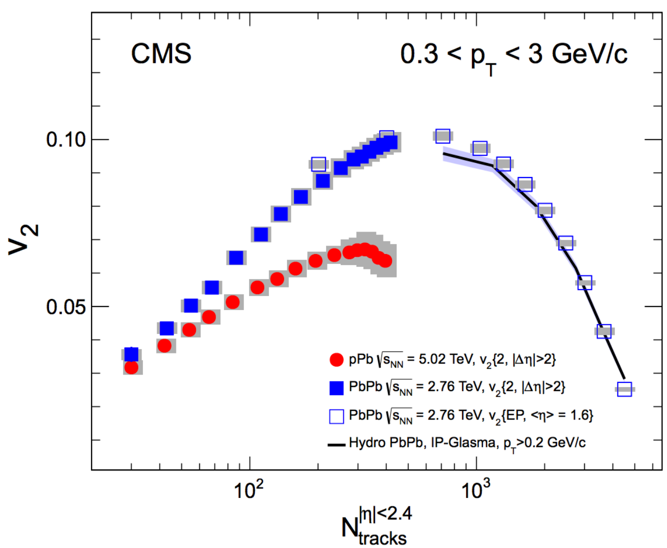




❖ **Why is γ_{112} pPb and PbPb so similar?**

V_2 (pPb) < V_2 (PbPb)



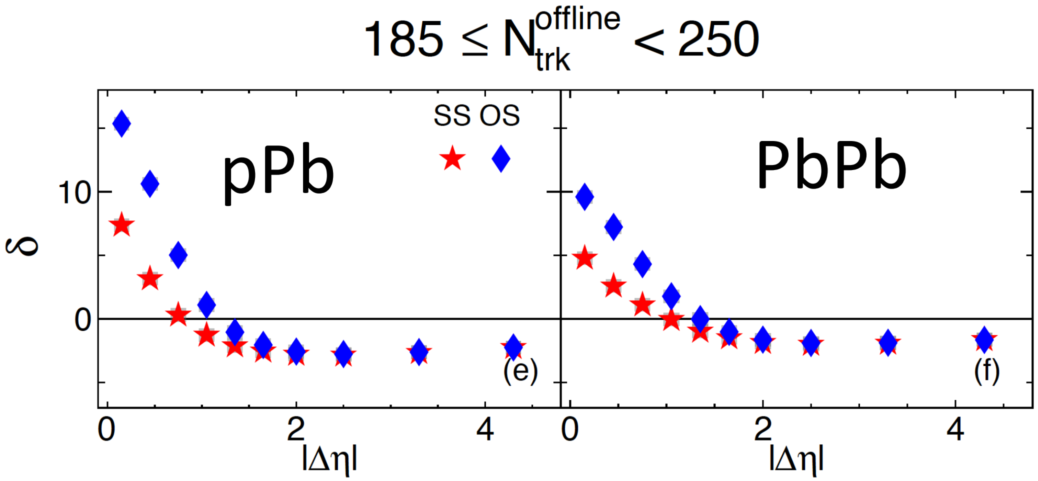
BKG scenario:

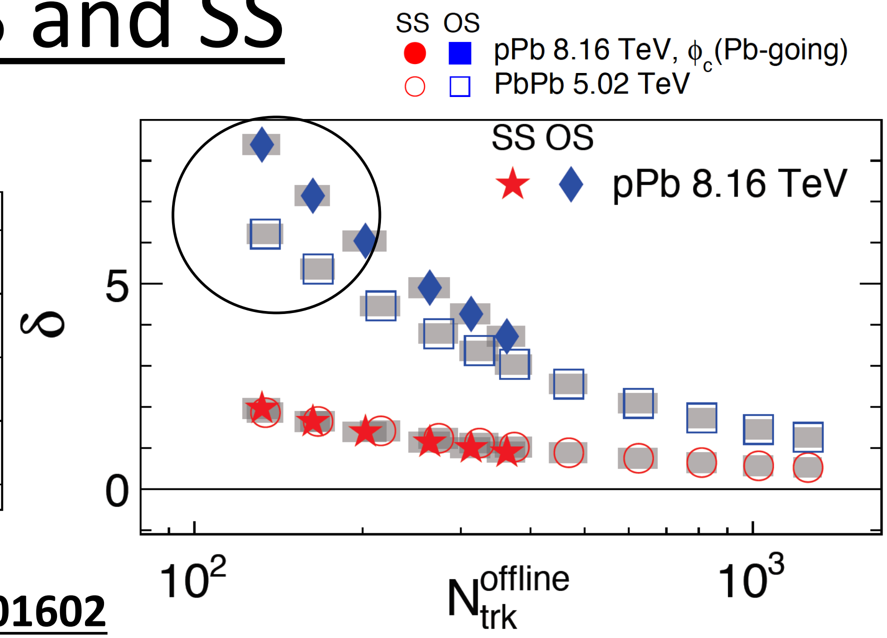
$$\gamma_{112} = \kappa \cdot v_2 \cdot \delta$$

How about δ btw pPb and PbPb?

Results: OS and SS

$$\gamma_{112} = \kappa \cdot v_2 \cdot \delta$$





arXiv:1708.01602

Results: (OS-SS)

$\gamma_{112} = \kappa \cdot v_2 \cdot \delta$

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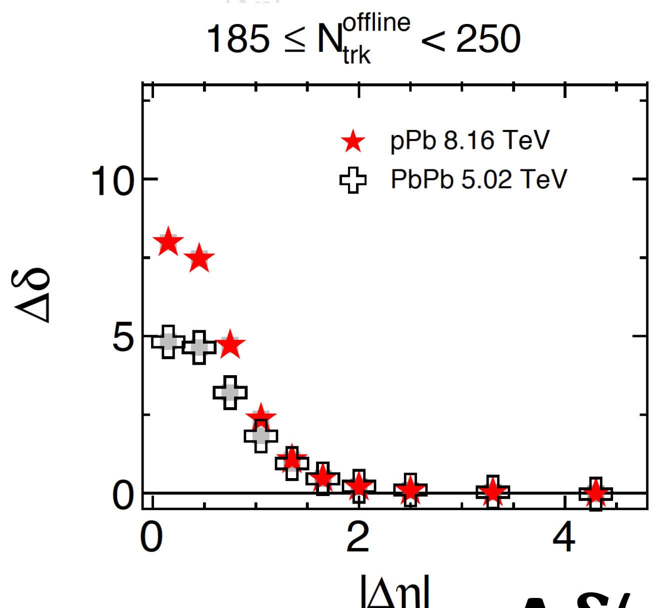
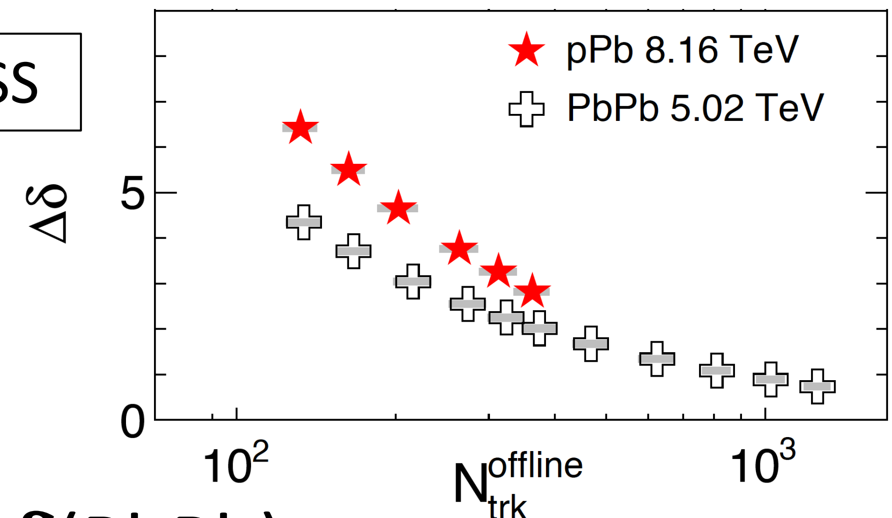


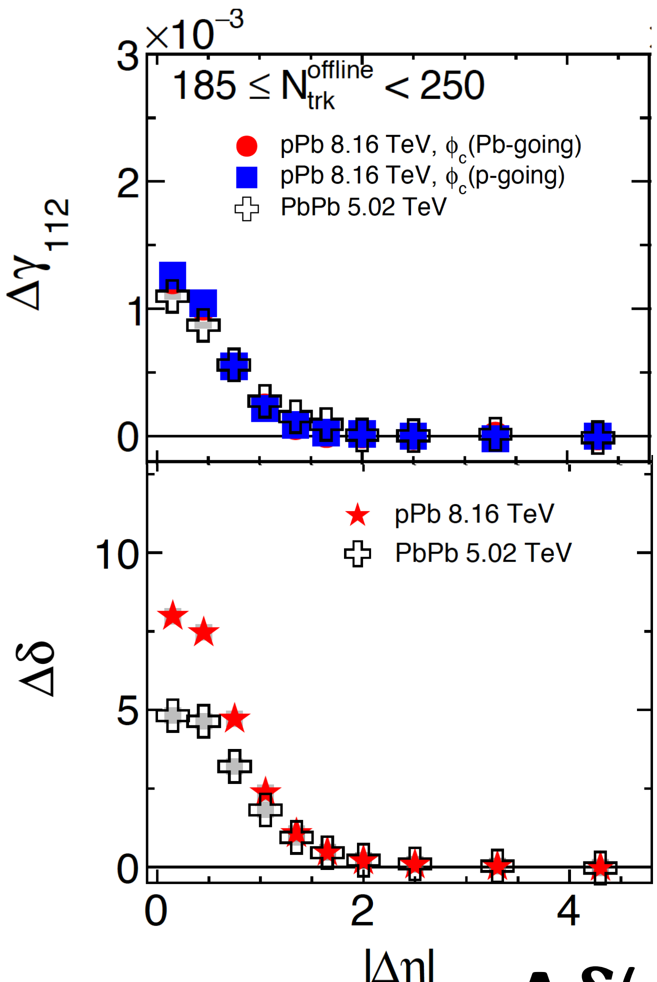
Δ = OS-SS



$\boldsymbol{\Delta\delta}$(pPb) > $\boldsymbol{\Delta\delta}$(PbPb)

Results: (OS-SS)

arXiv:1708.01602



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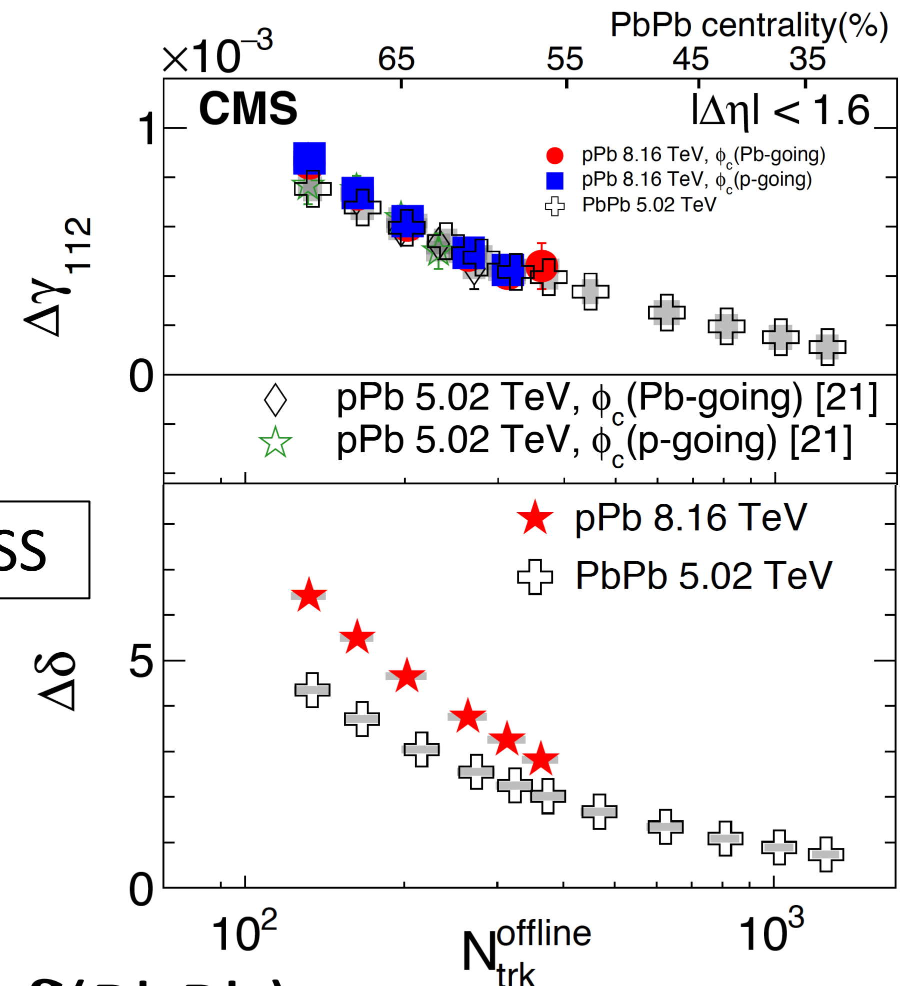

$$\Delta\delta(\mathrm{pPb}) > \Delta\delta(\mathrm{PbPb})$$

This can explain γ(pPb) ≈ γ(PbPb), if $\gamma = \kappa \cdot v_2 \cdot \delta$

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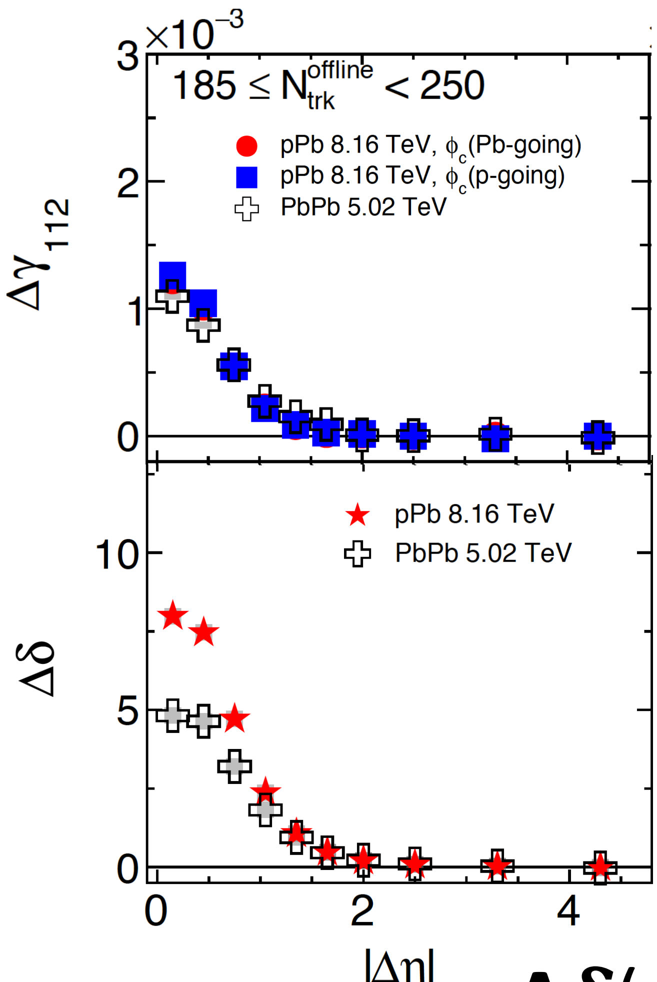

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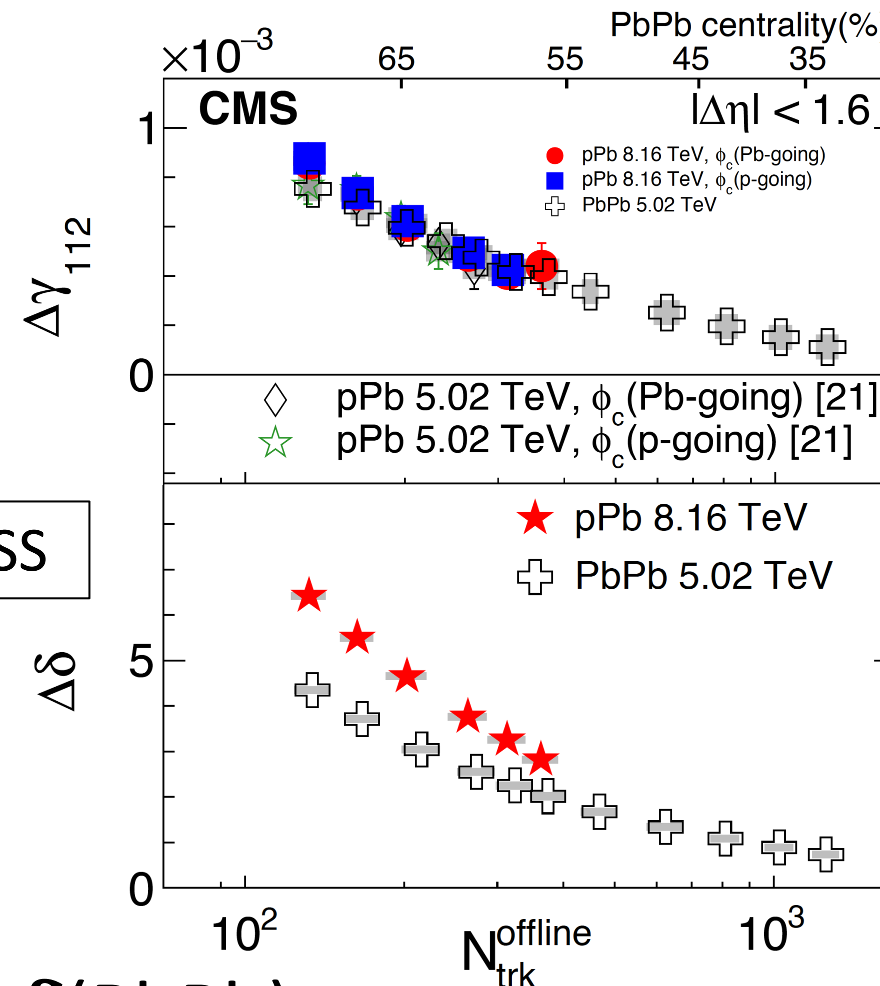

$\boldsymbol{\Delta\delta}$(pPb) > $\boldsymbol{\Delta\delta}$(PbPb)

Still unconstrained

This can explain γ(pPb) ≈ γ(PbPb), if $\gamma = \kappa \cdot v_2 \cdot \delta$

Results: higher-order correlator

- CME free correlator

$$\gamma_{123} \equiv \left\langle \cos\left(\phi_{\alpha} + 2\phi_{\beta} - 3\Psi_{3}\right)\right\rangle$$

Charge-dependent signal has to be BKG

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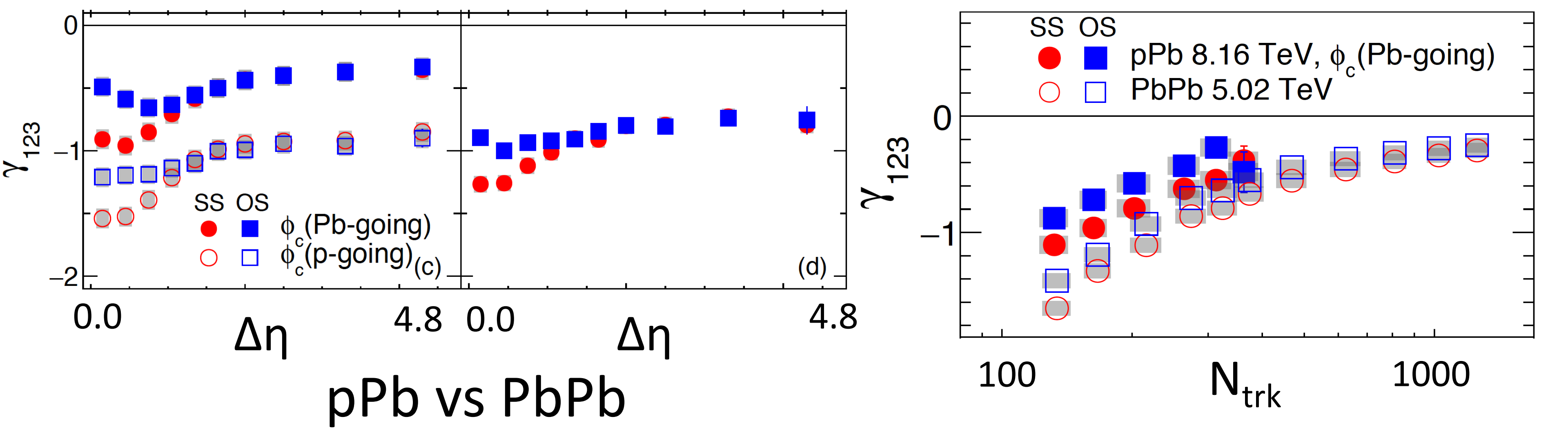


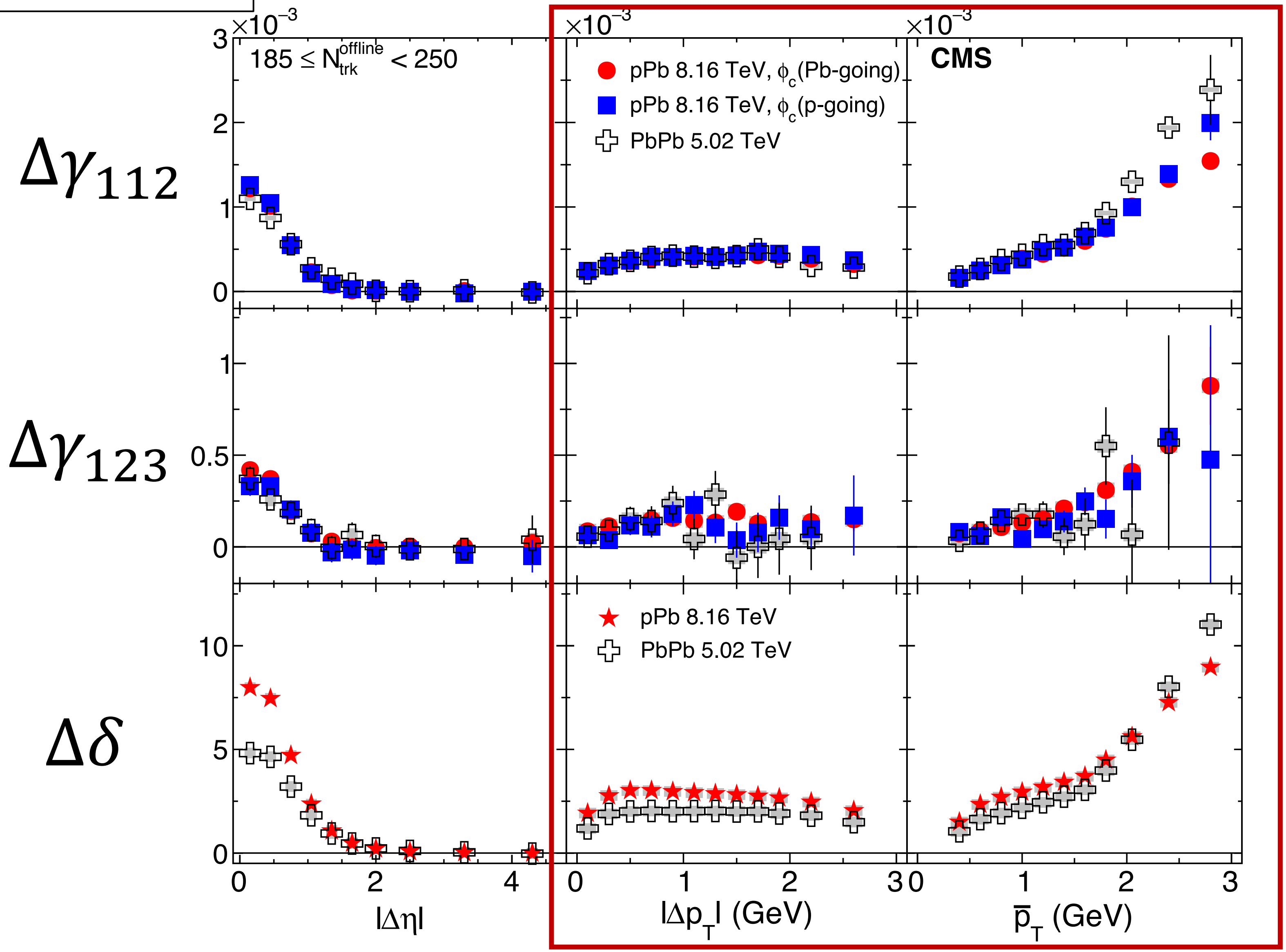
➢ Correlation is still short-range and charge-dependent.

➢ Can this be compatible with the suspected BKG?

Δ = OS-SS

Results: (OS-SS)

arXiv:1708.01602



❖ **Suspected BKG should also describe other differential variables**

Results: Test BKG

(Δ = OS-SS)

To test this background only scenario, we compare $\boldsymbol{\kappa}_2$ and $\boldsymbol{\kappa}_3$

$$\Delta\gamma_{112} = \kappa_2 \cdot v_2 \cdot \Delta\delta$$
$$\Delta\gamma_{123} = \kappa_3 \cdot v_3 \cdot \Delta\delta$$

If $\boldsymbol{\kappa}_2 = \boldsymbol{\kappa}_3$, the data is compatible with ~100% background

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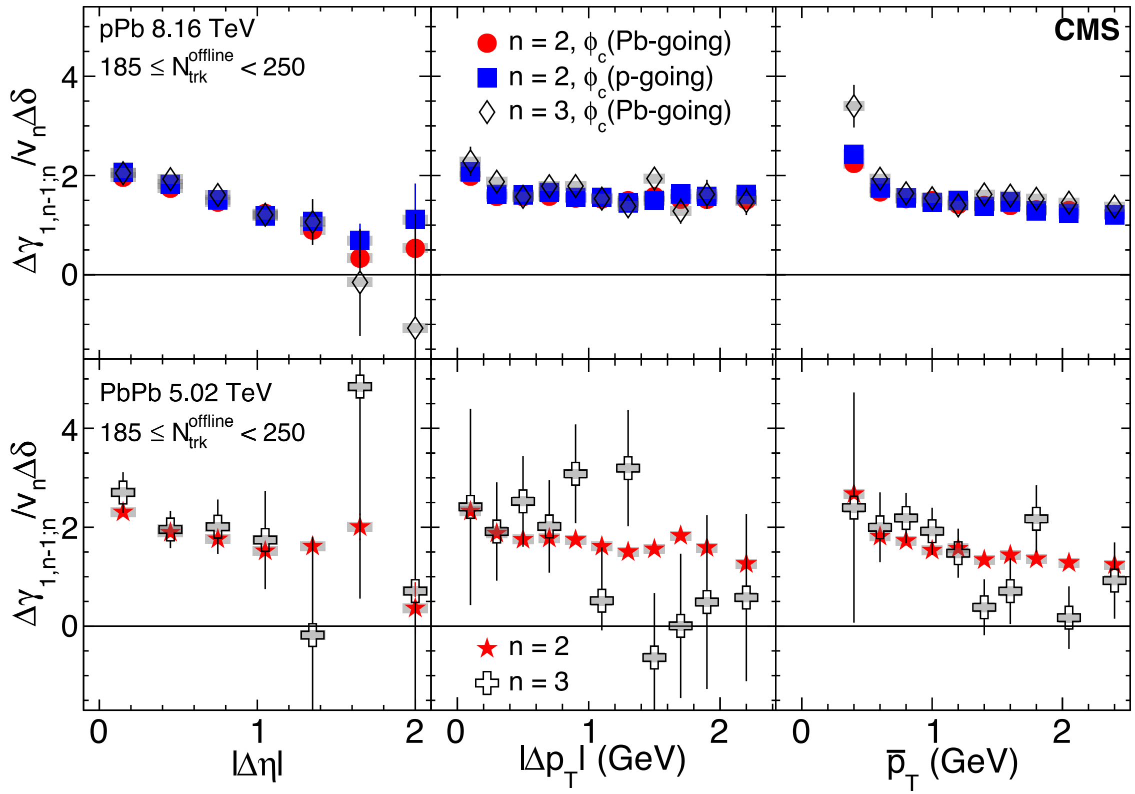

arXiv:1708.01602

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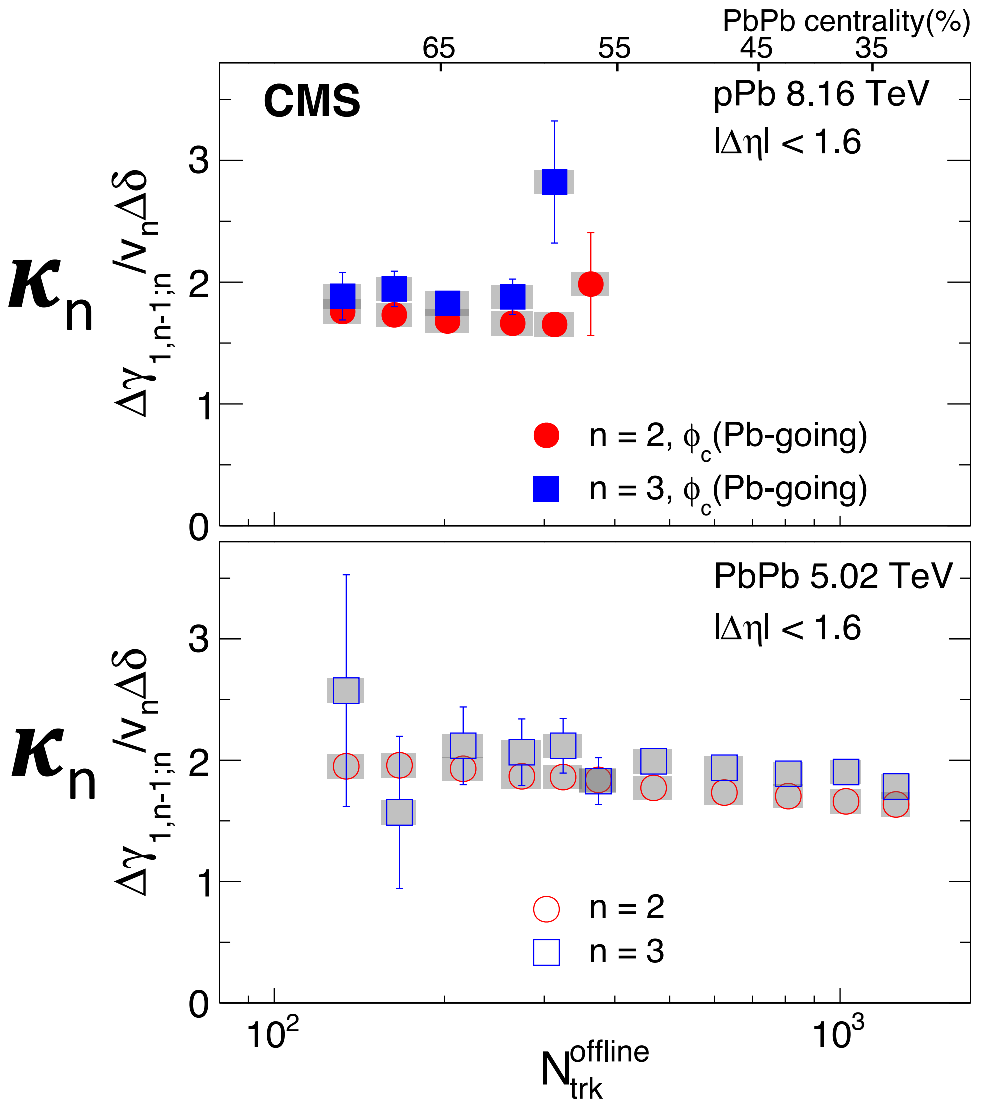
✓ $\kappa_2 = \kappa_3$, the data is compatible with ~100% background scenario throughout **the entire multiplicity or centrality range**



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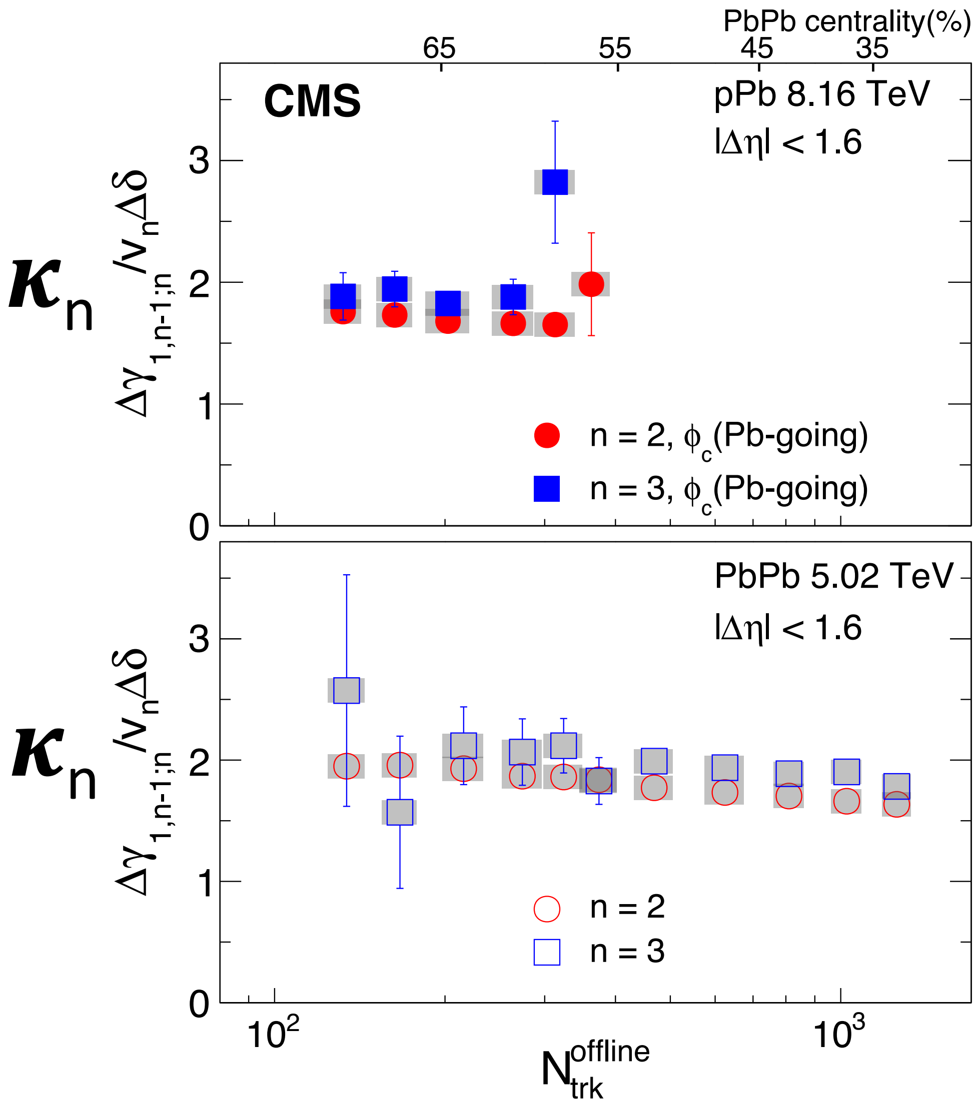
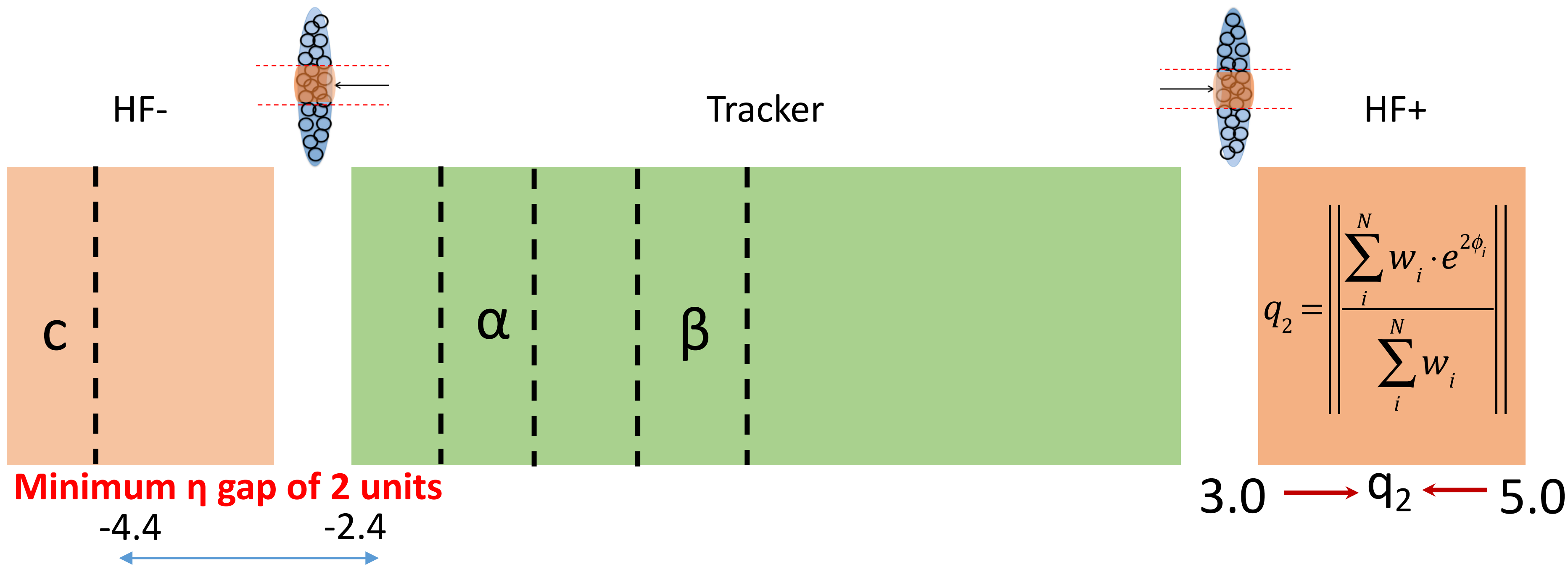


- Now, can we observe the linear dependence on v2 and see if there is any room for CME?

ESE with CMS detectors



- ❖ The ESE uses q_2, magnitude of q vector, in one side of the HF (3-5 units) to select events with very different v2
- ❖ In pPb collision, q_2 is calculated from the Pb-going side. Particle c from both p- and Pb-going side are studied.

- ❖ Particle c in γ_{112} is from the other side of the q_2 region in PbPb.

ESE with CMS detectors

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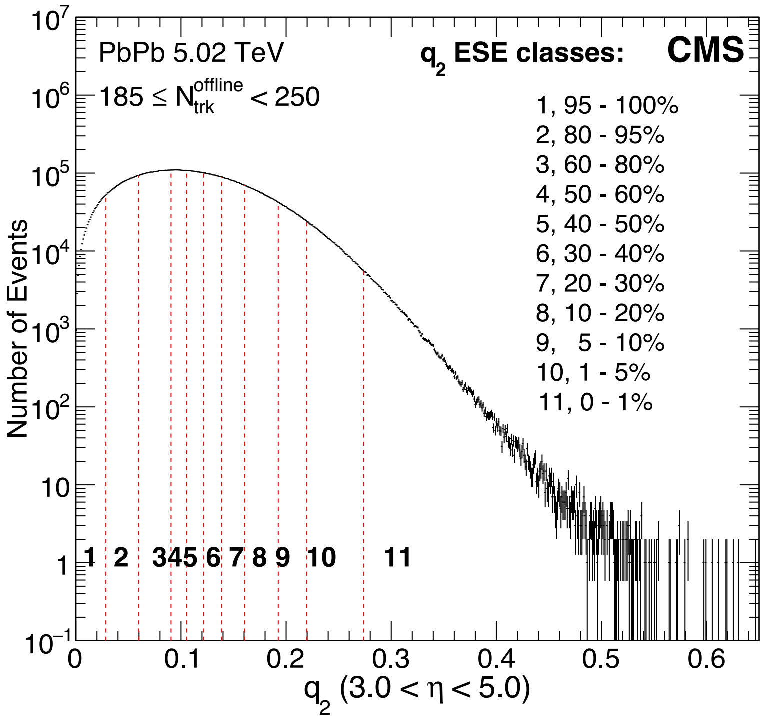
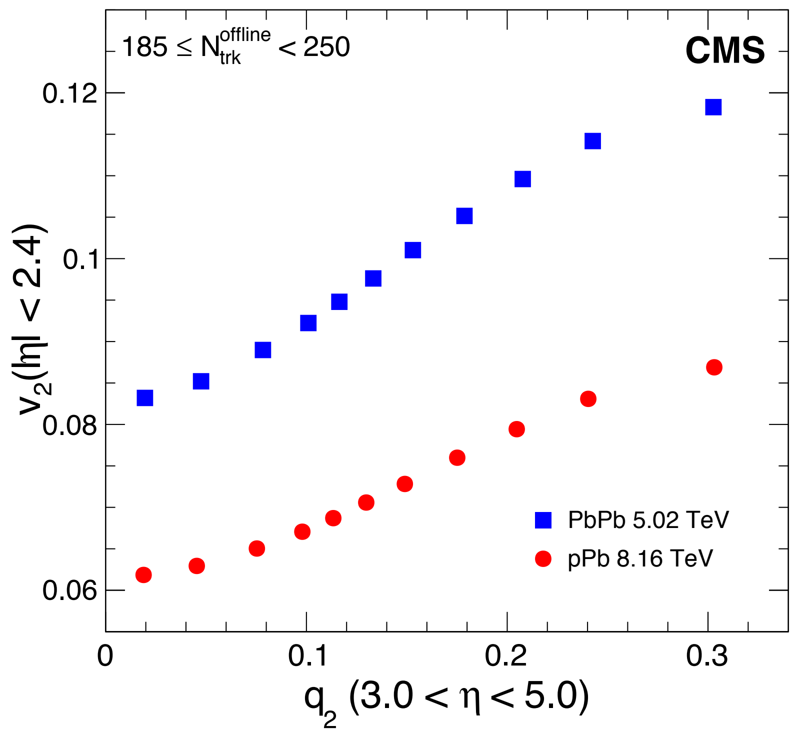
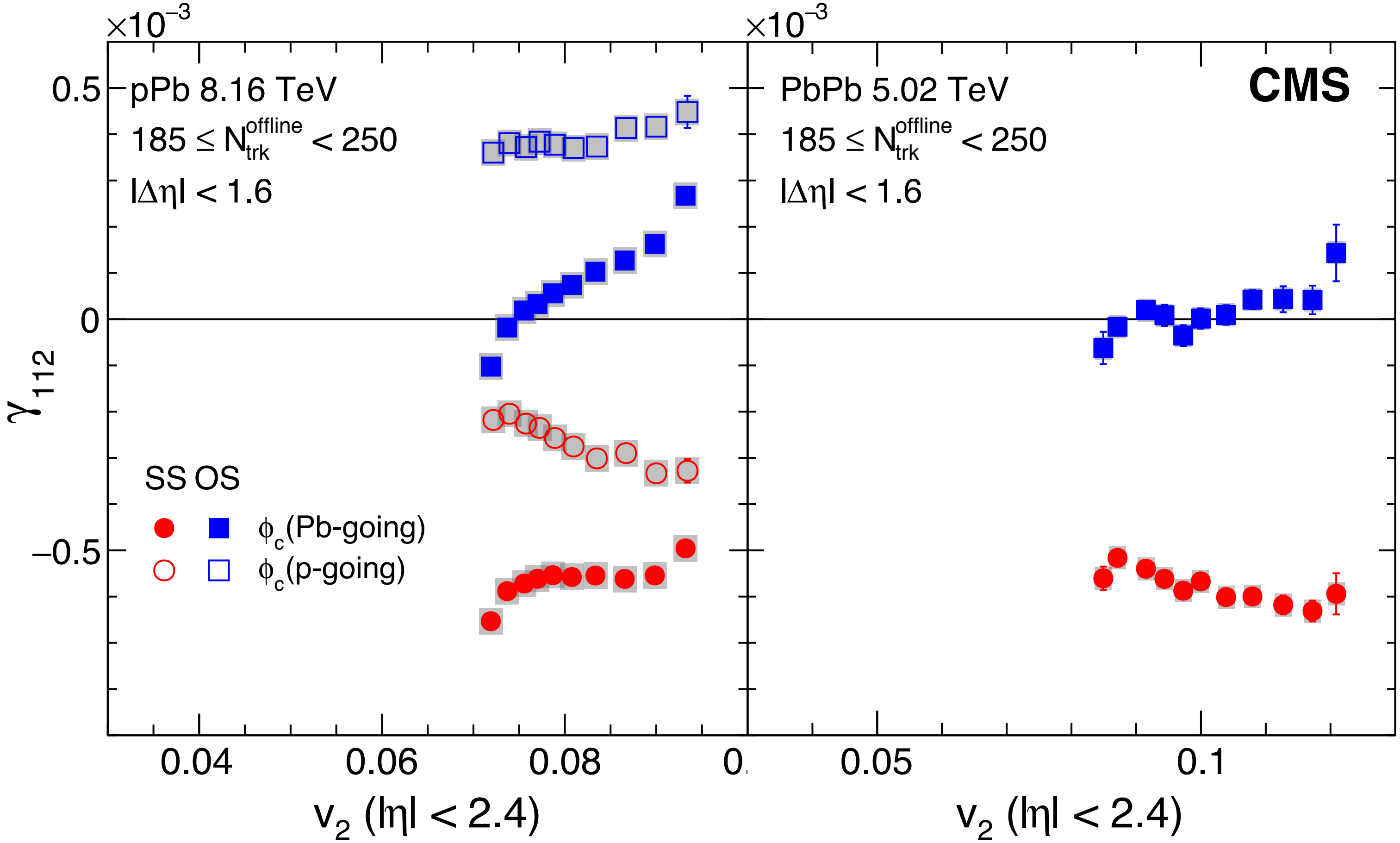




- q_2 is monotonically correlated with v2, expected from the initial-state geometry;
- γ_{112} can be studied as a function of v2 within a single multiplicity or centrality class.

Results: ESE

arXiv:1708.01602

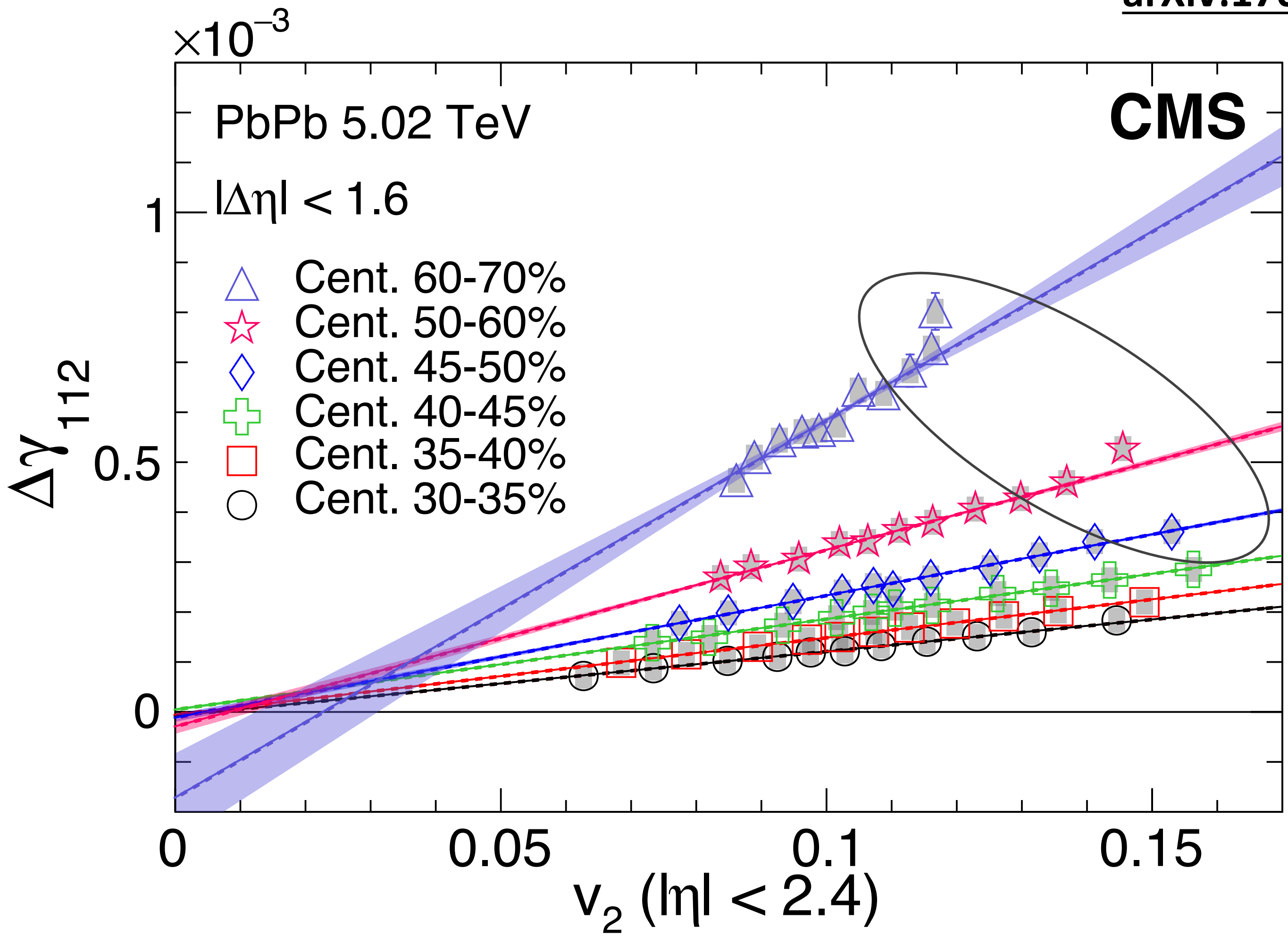


❖ Nontrivial to interpret the data, due to mixture of charge-(in)dependent correlations.

❖ How about the difference OS-SS?

Results: ESE

arXiv:1708.01602



- ❖ OS-SS vs v2, when v2 = 0 → finite intercept?
- ❖ Some nonlinear trend at high v2. Anything else other than CME?

Results: ESE

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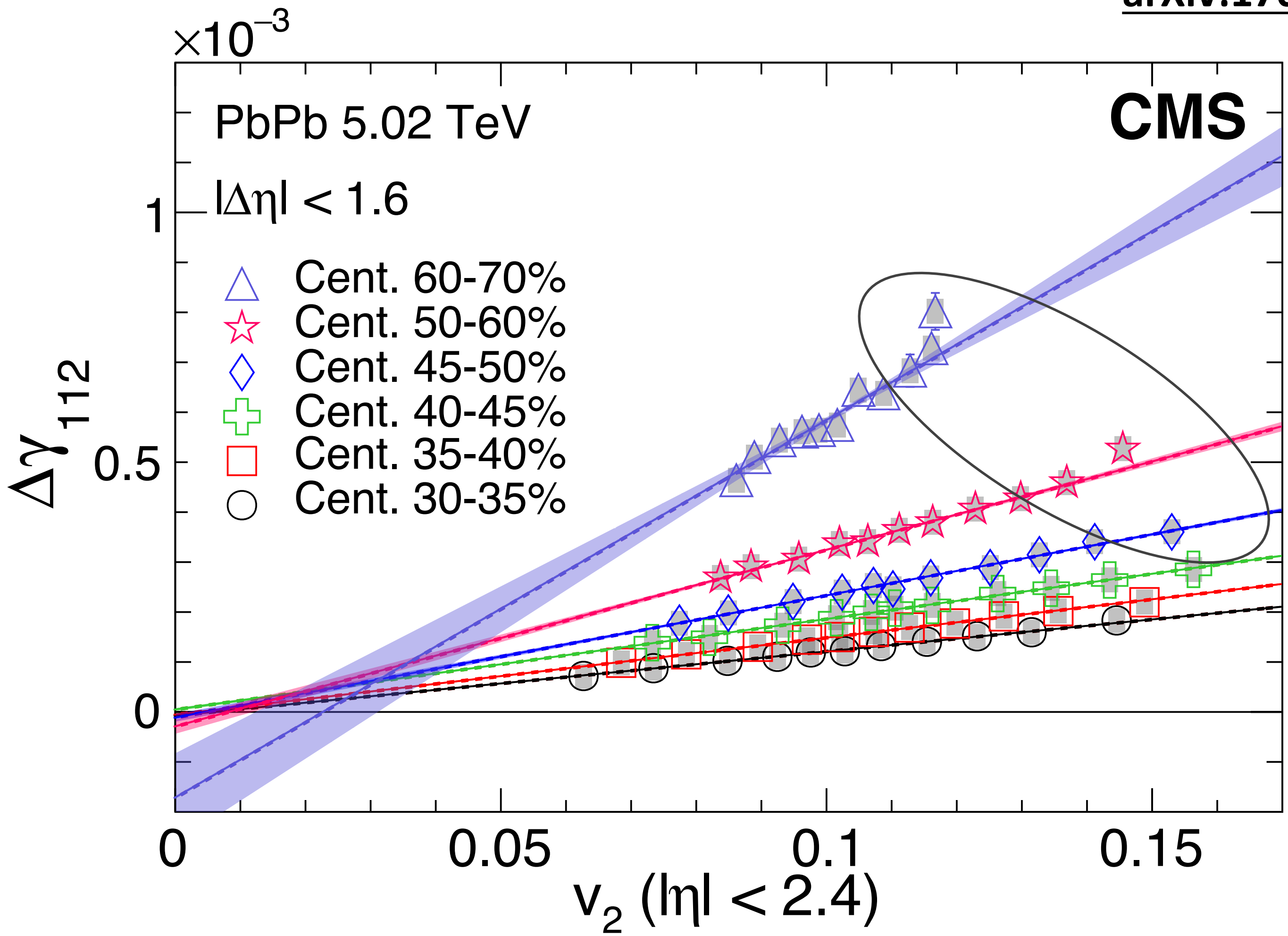

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δ-correlator? Is δ independent of v2?

Results: ESE

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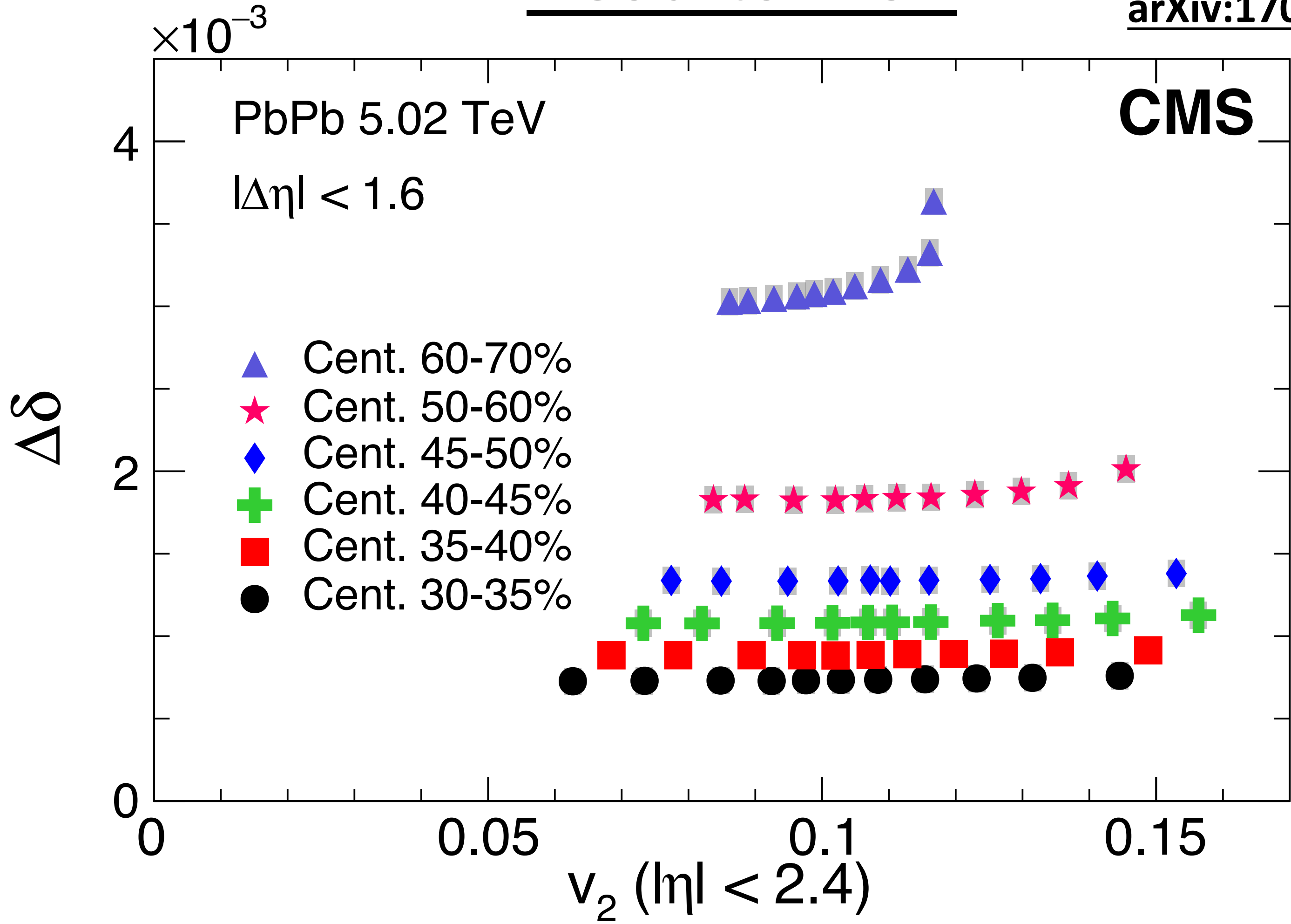

- Indeed, the Δδ is not flat vs v2, esp at low multiplicity.
- Two effects:
  1. Multiplicity dilution, multiplicity bias from q_2 selection
  2. Nonflow, η-gap is not optimal.

Results: ESE

❖ Background-only scenario:

$$\Delta\gamma_{112} = \kappa_2 \cdot v_2 \cdot \Delta\delta$$

➡

$$\Delta\gamma_{112}/\Delta\delta = \kappa_2 \cdot v_2$$

→ Goes thru ZERO!

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- Background + signal scenario:

$$\Delta\gamma_{112} = \kappa_2 \cdot v_2 \cdot \Delta\delta \text{ - b}$$

➡

$$\Delta\gamma_{112}/\Delta\delta = \kappa_2 \cdot v_2 \text{ - b/ } \Delta\delta$$

→ Finite intercept!

Results: ESE

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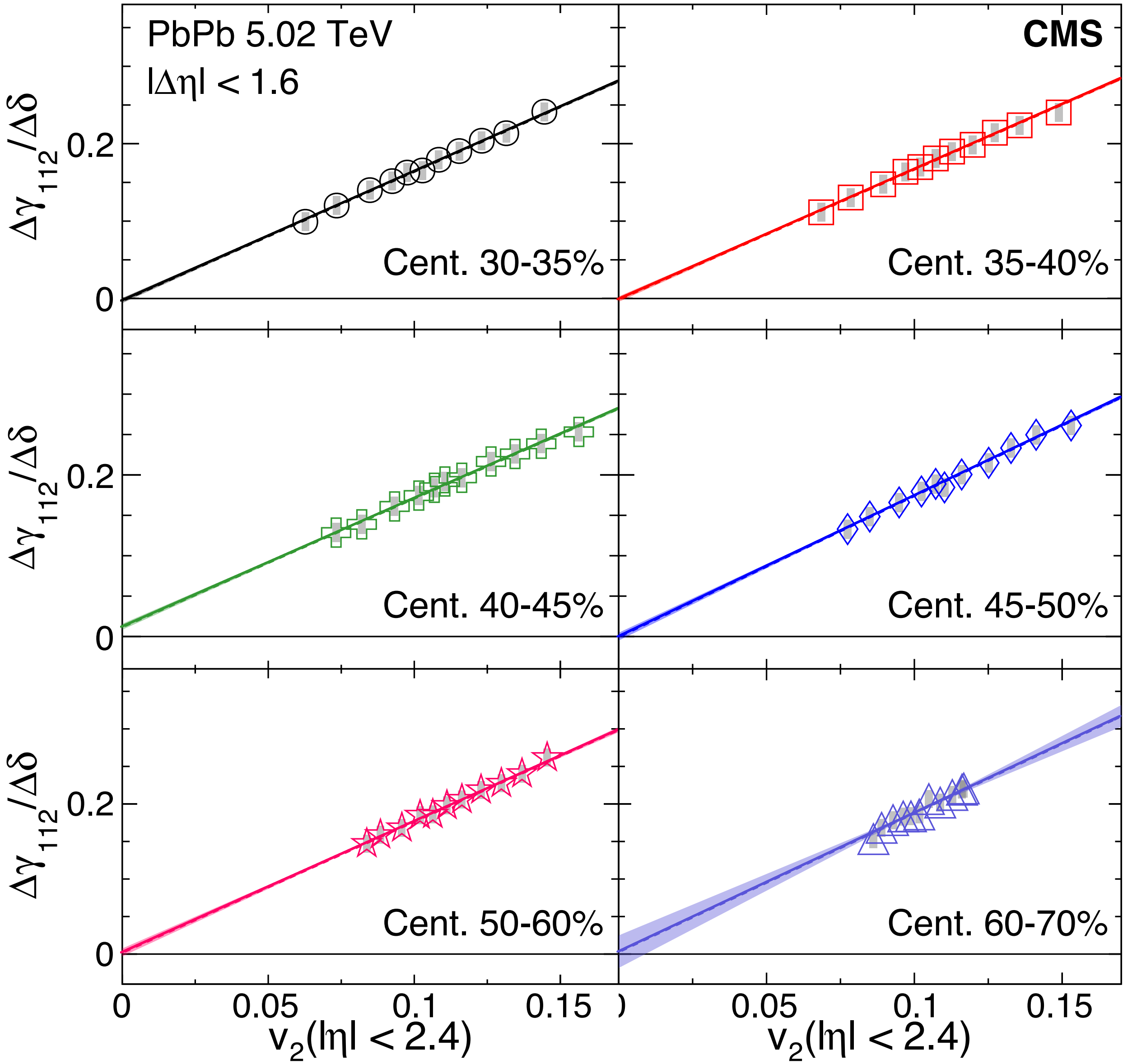
→ Goes thru ZERO! ✓



Results: ESE

pPb vs PbPb

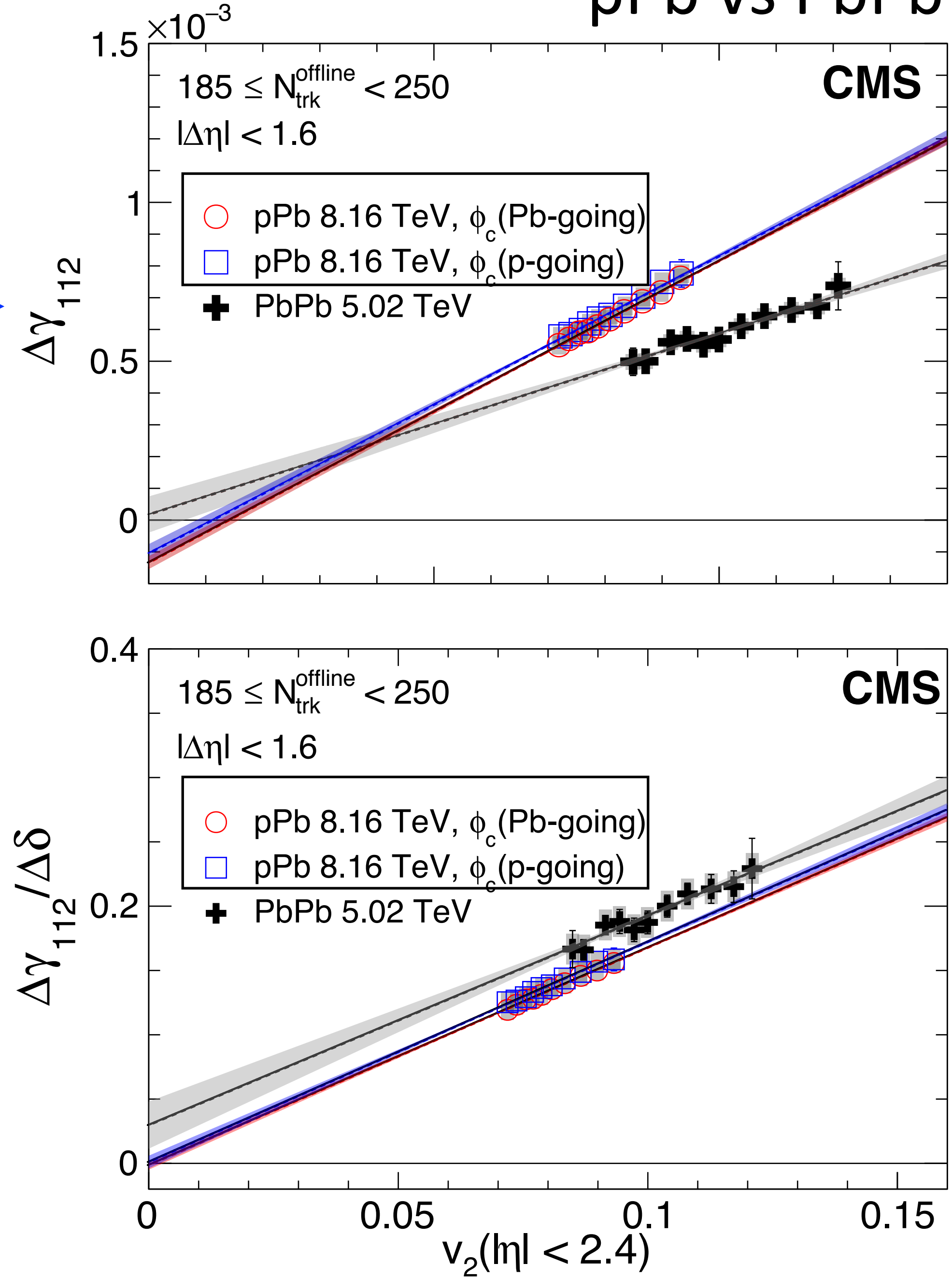
- Background-only scenario:

$$\Delta\gamma_{112} = \kappa_2 \cdot v_2 \cdot \Delta\delta$$

➡

$$\Delta\gamma_{112}/\Delta\delta = \kappa_2 \cdot v_2$$

→ Goes thru ZERO! ✓



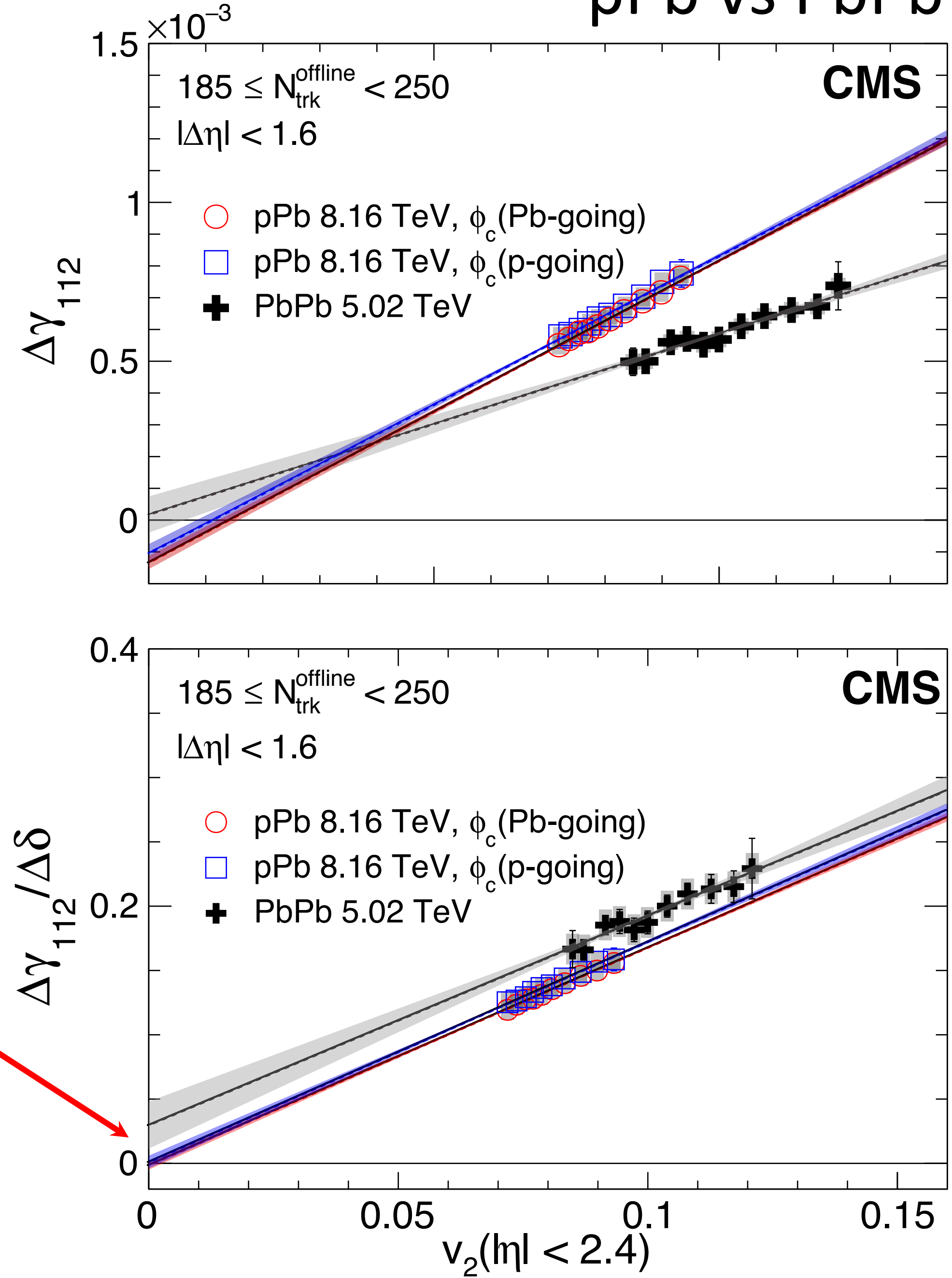
arXiv:1708.01602

Results: ESE

pPb vs PbPb

- Background-only scenario:
  $\Delta\gamma_{112} = \kappa_2 \cdot v_2 \cdot \Delta\delta$
  ➡
  $\Delta\gamma_{112}/\Delta\delta = \kappa_2 \cdot v_2$
  → Goes thru ZERO! ✓

- The remaining intercept can be quantitatively constrained with uncertainty



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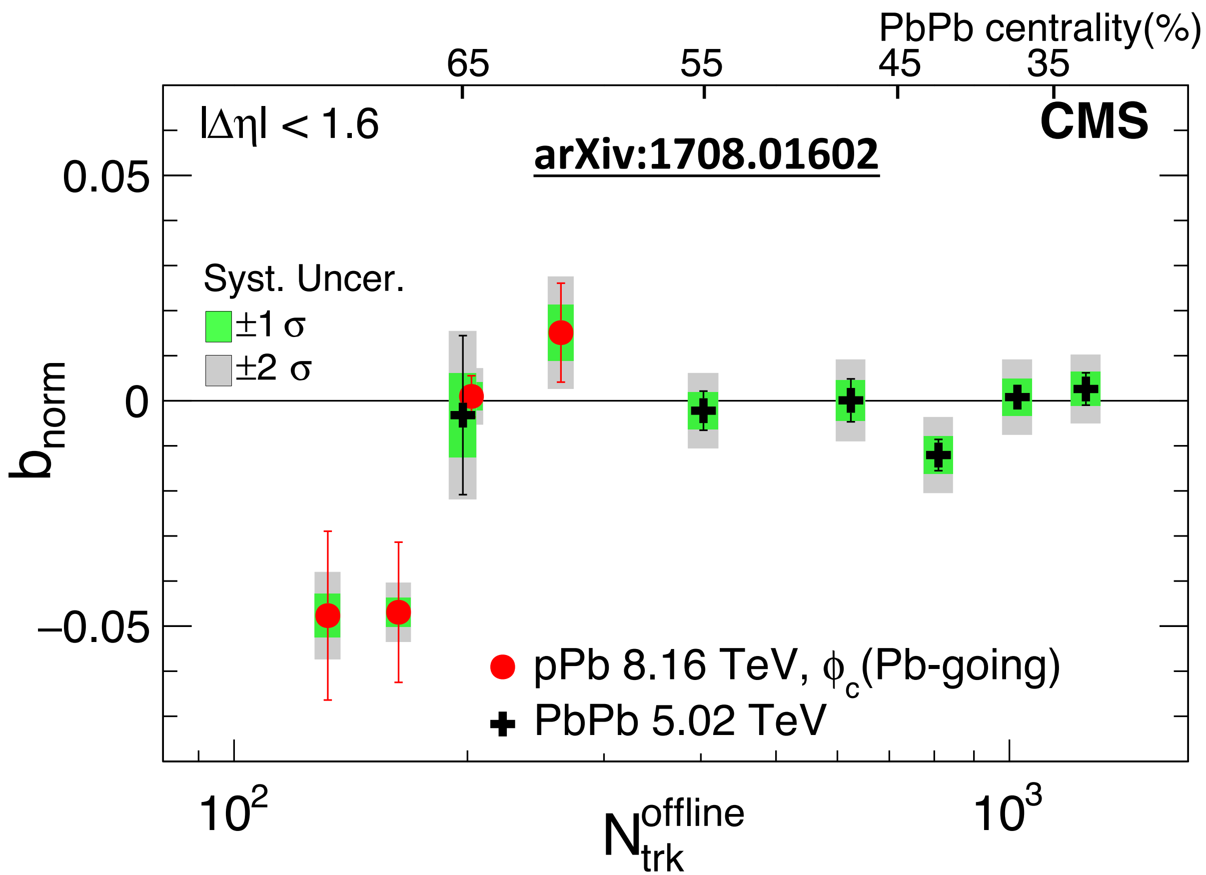
Results: ESE

- Normalized intercept vs multiplicity:

$$\Delta\gamma_{112}/\Delta\delta = \kappa_2 \cdot v_2 - b/\Delta\delta \quad (b_{norm})$$



No significant positive intercept!

Results: ESE

$f_{norm} = b_{norm} / (\Delta\gamma_{112}/\Delta\delta) \approx b/\Delta\gamma_{112}$ (v2-indep-comp)

Upper limit @ 95% Confidence level
6.6% and **3.8%** for pPb and PbPb, if combined all multiplicities

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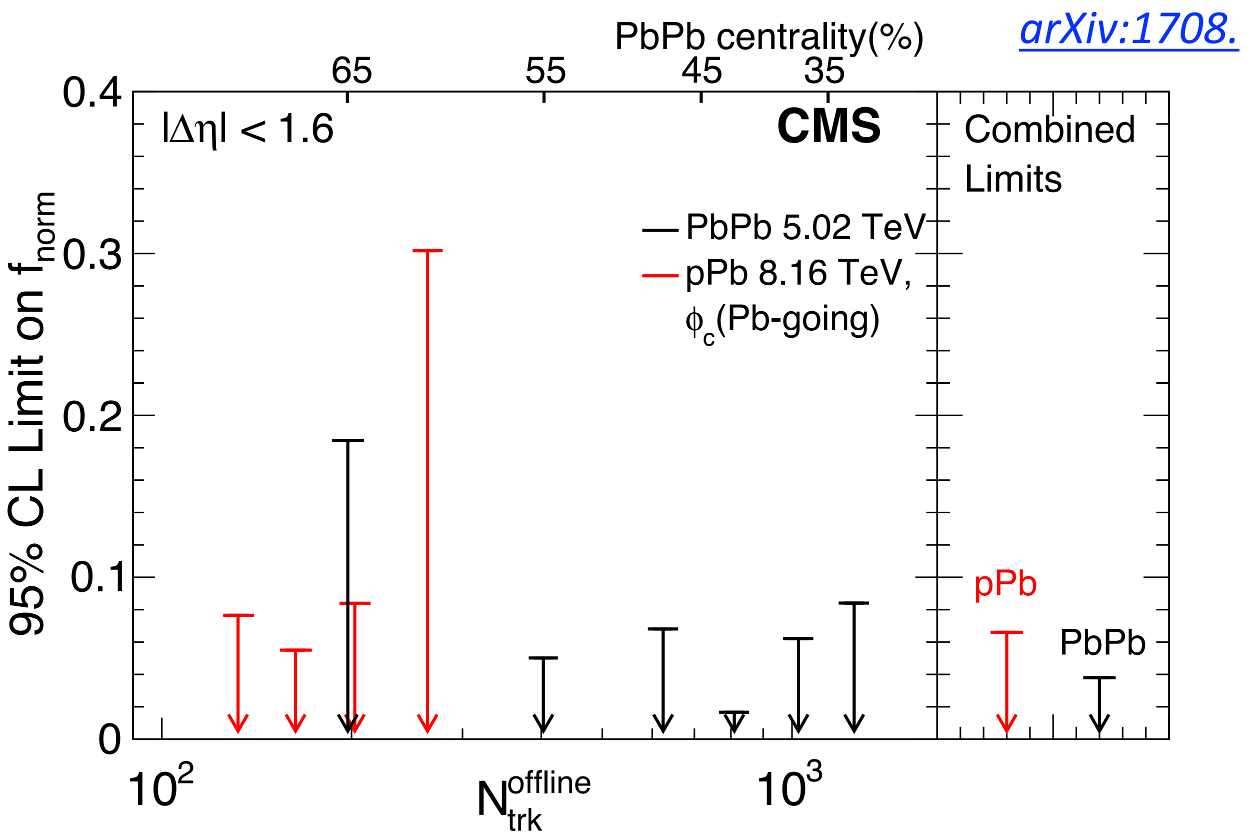


Summary and outlook

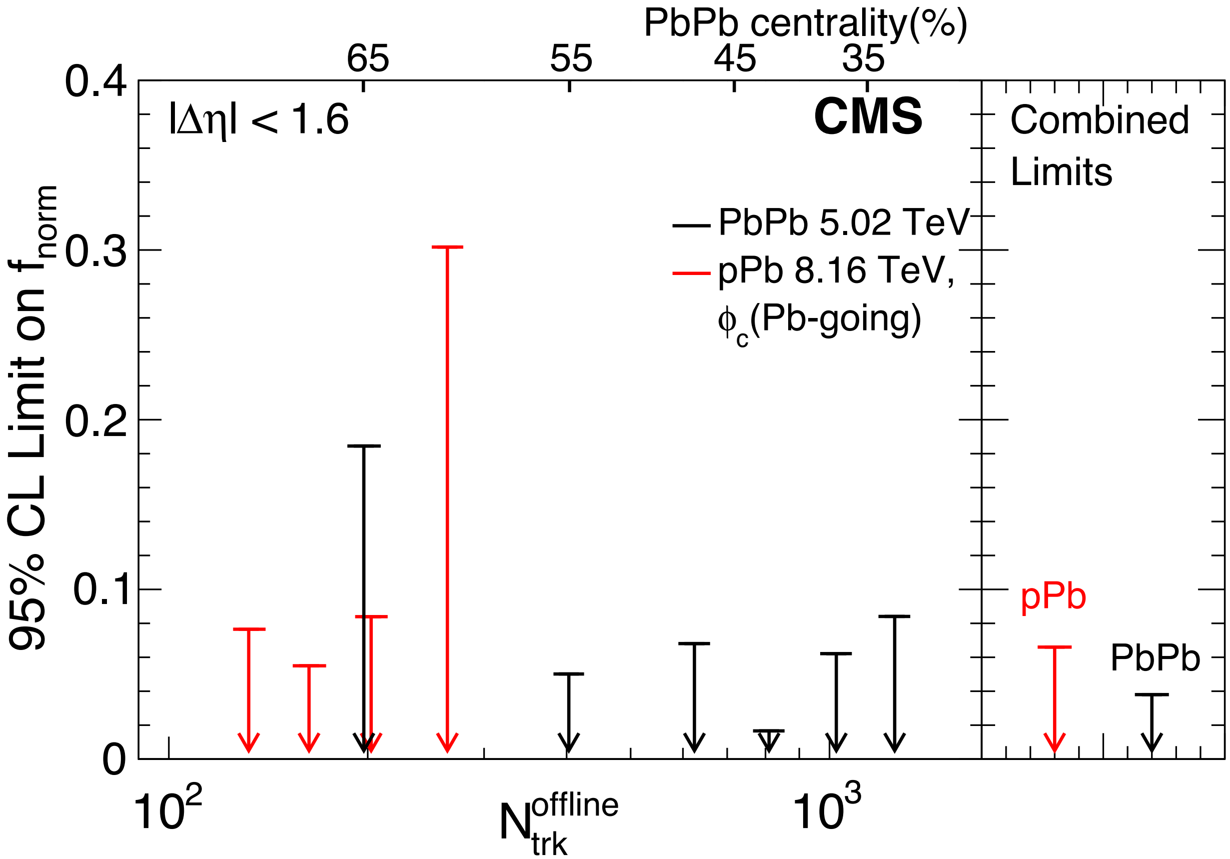
- Experimental achievements:
  - ✓ First time measurement of γ_{123}, and δ in pA collisions
  - ✓ First time Event-Shape-Engineering in pA collisions

- Major conclusions and implications:
  - ✓ γ dominated by background, i.e., $\gamma = \kappa \cdot v_n \cdot \delta$
  - ✓ Possible CME signal (at LHC energies) is less than 6.6% for pPb and 3.8% for PbPb collisions @95% CL.

  - ✓ Significant improvement on constraining the CME signal.

Provide more insights for lower energy CME search

Thank you!



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Backup

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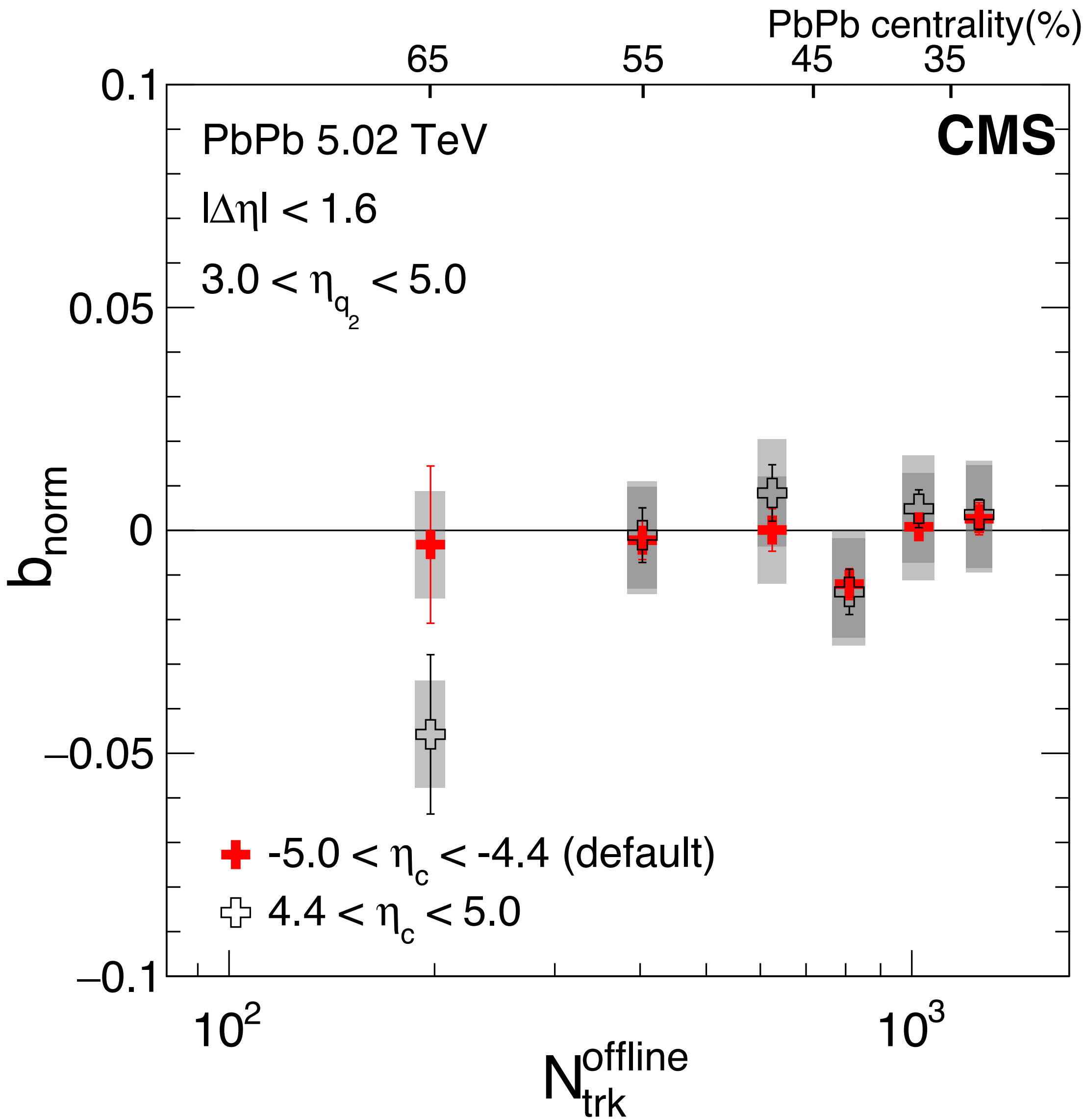

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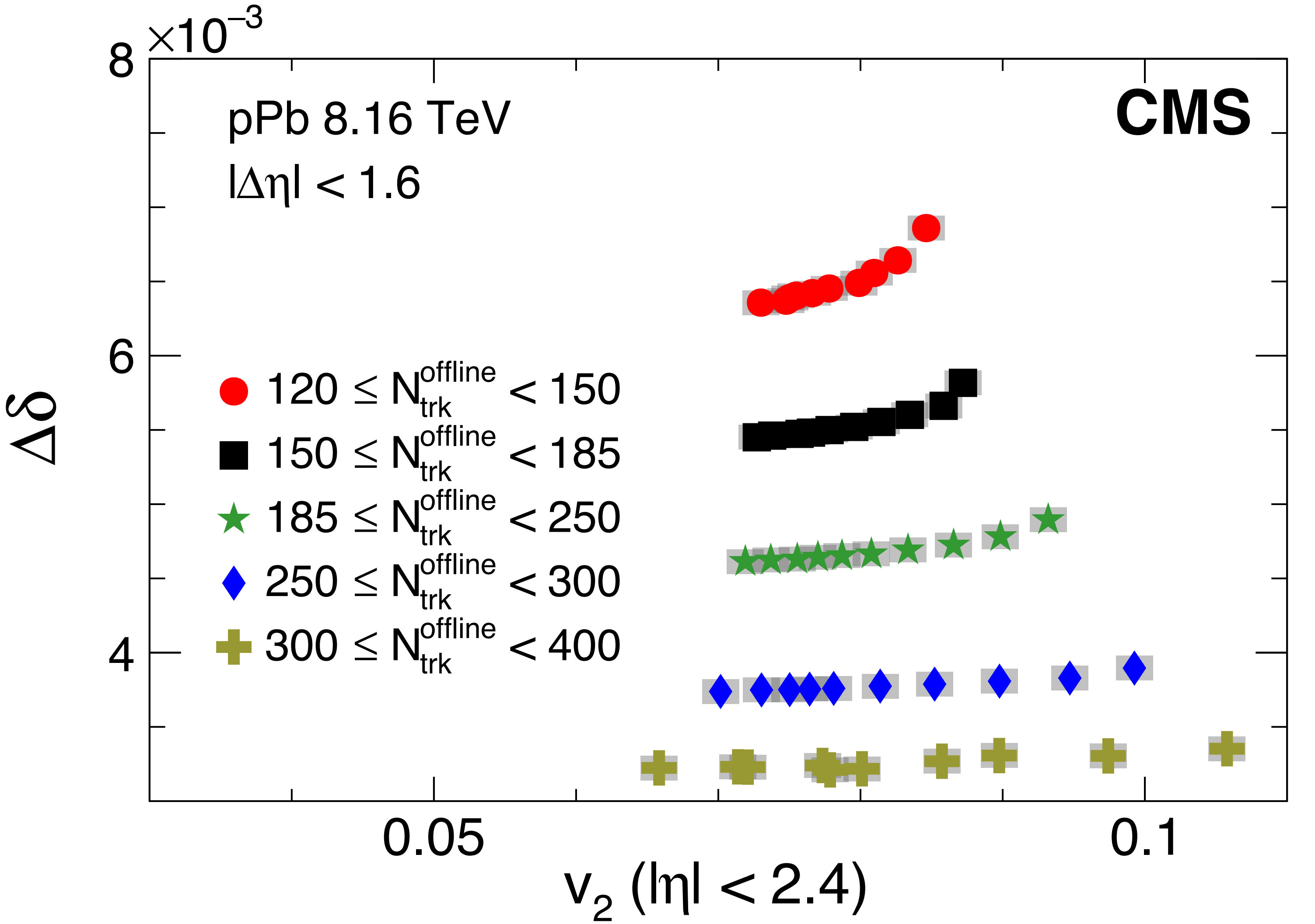

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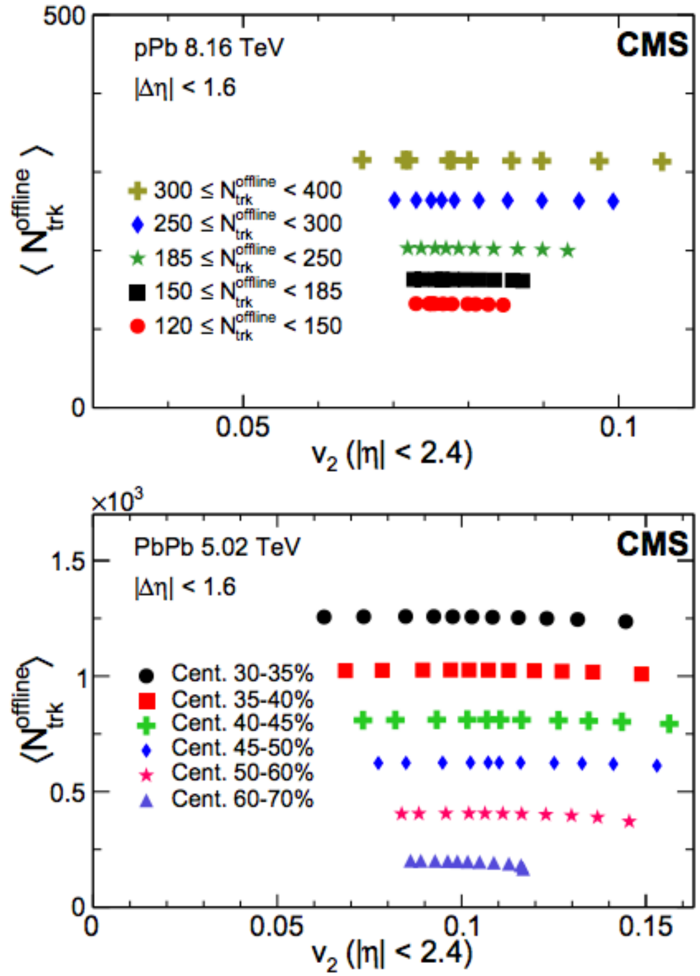

Figure 19: The average multiplicity $N_{trk}^{offline}$ as a function of v_2 evaluated in each q_2 class, for different multiplicity ranges in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV (upper), and for different centrality classes in PbPb collisions at 5.02 TeV (lower). Statistical uncertainties are invisible on the current scale.

Backup

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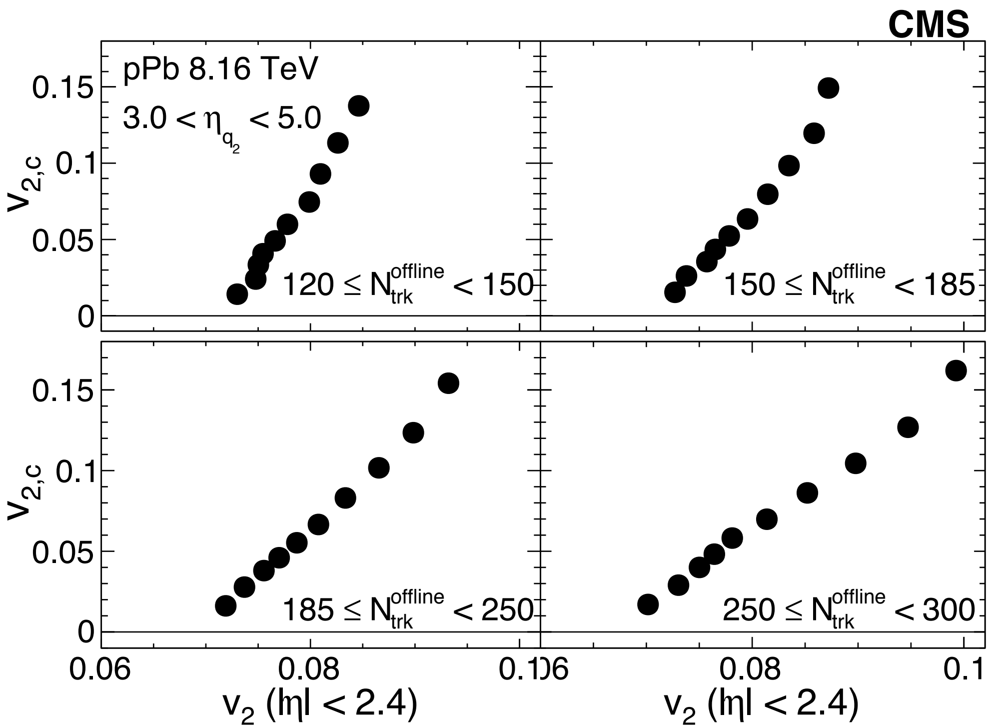

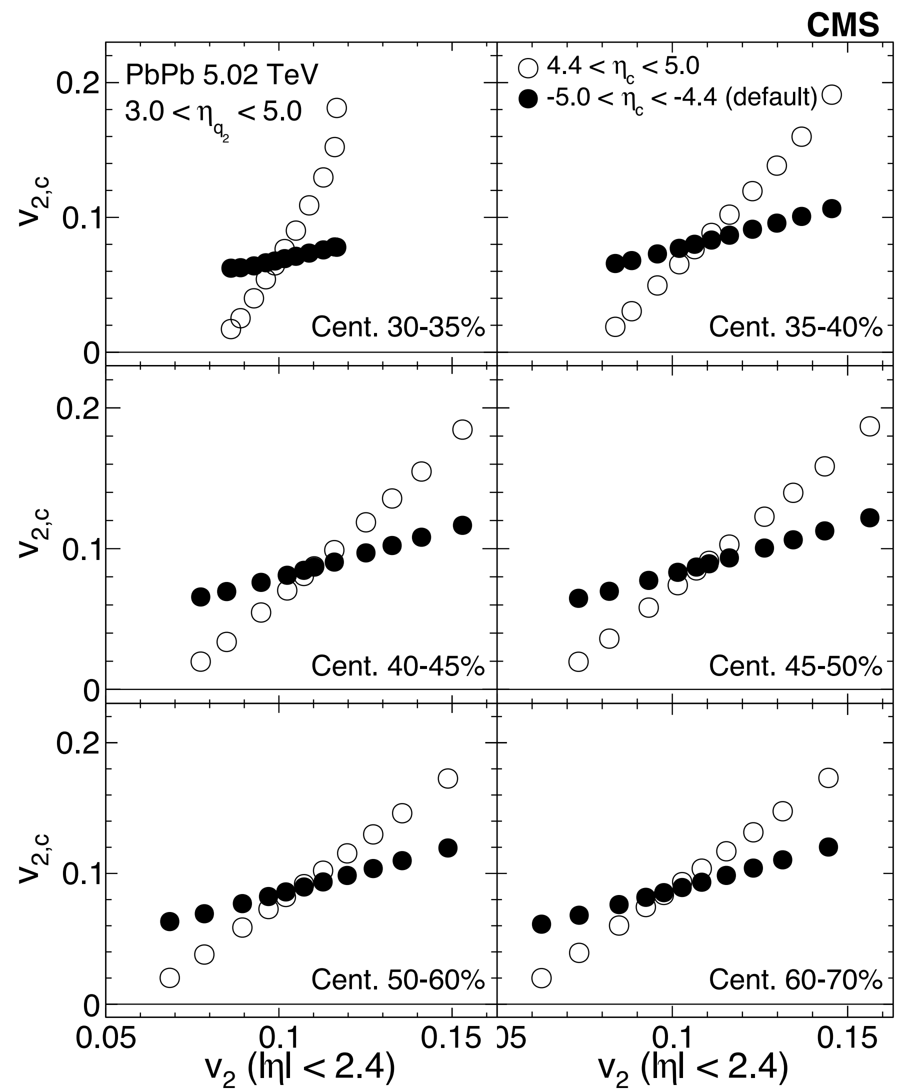

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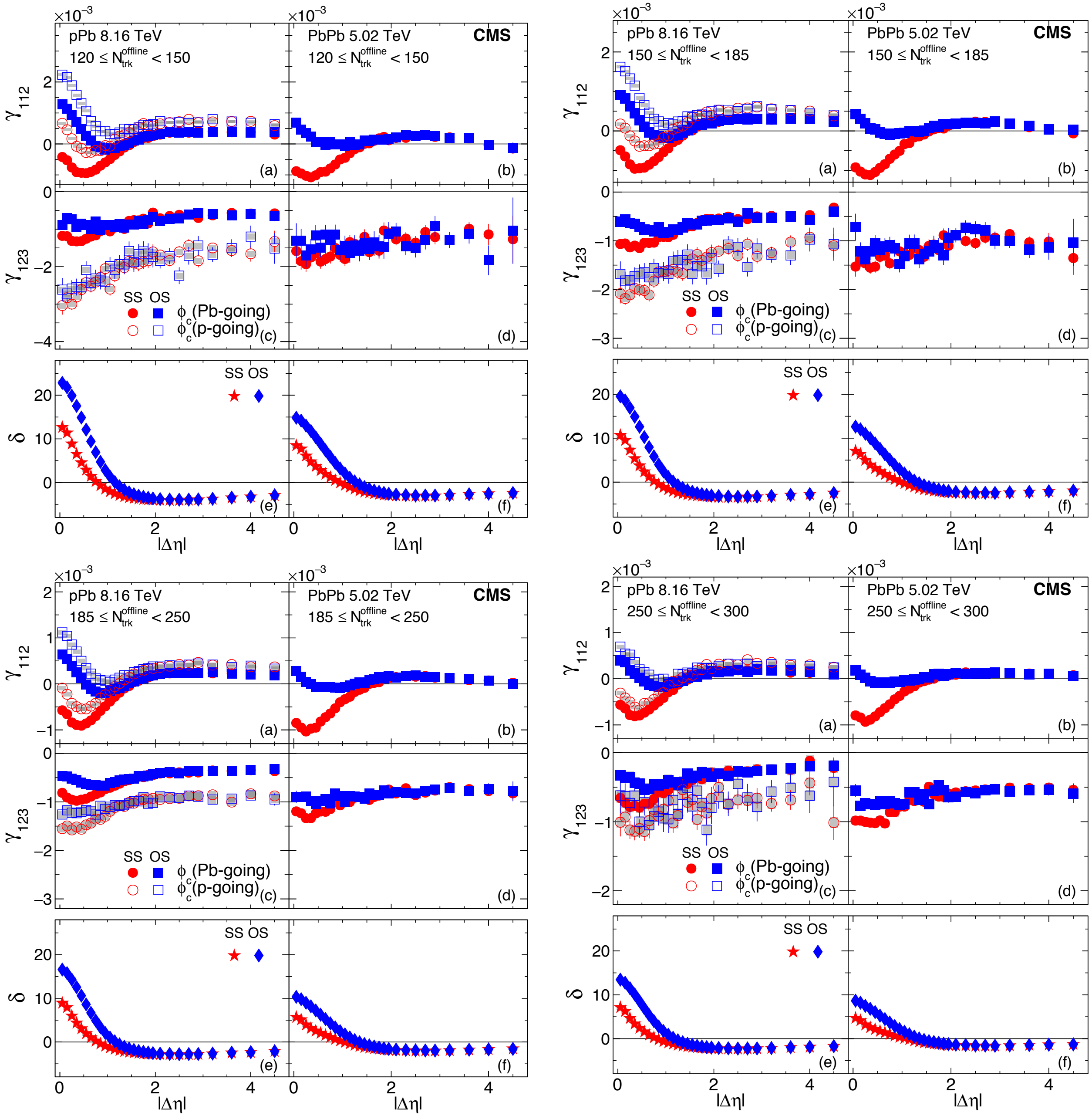

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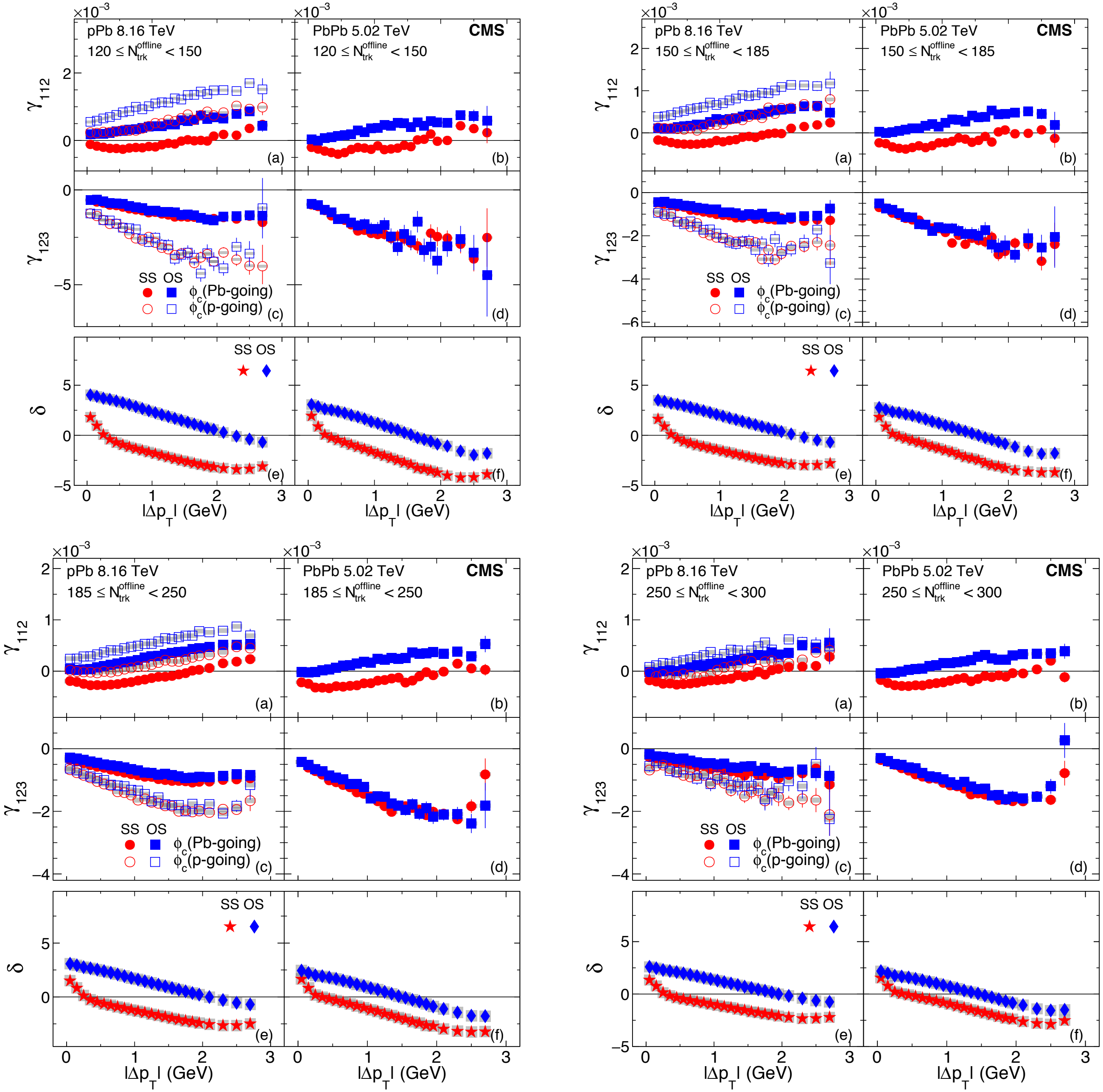

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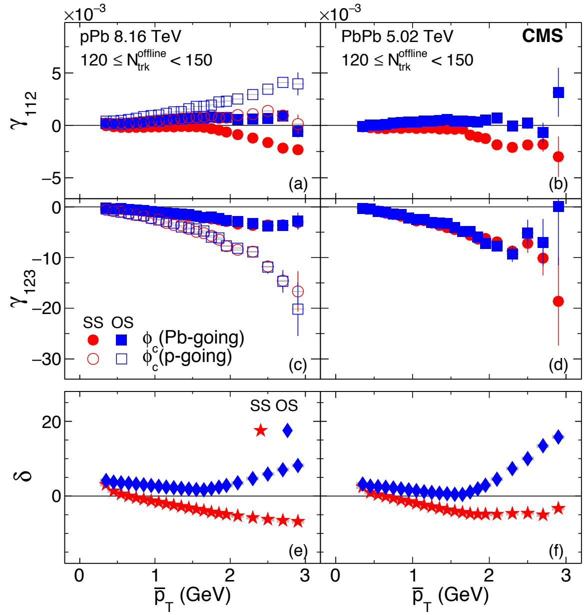

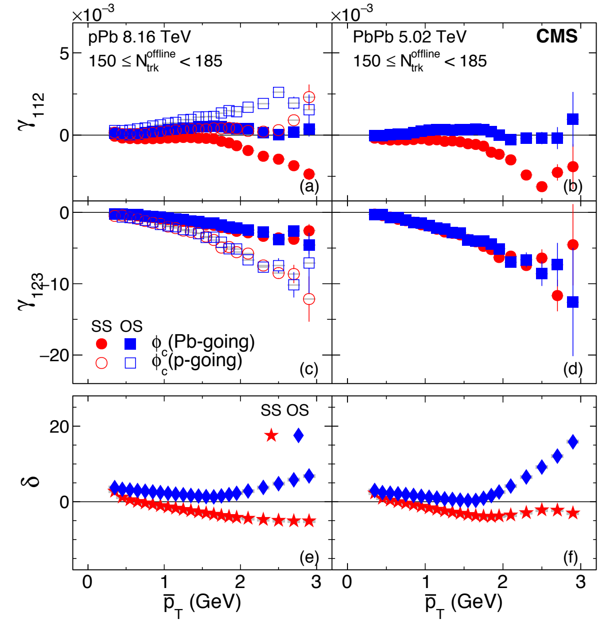

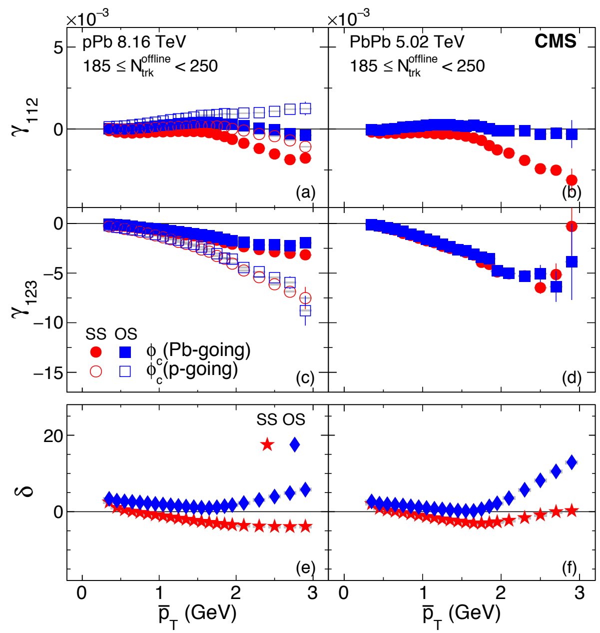

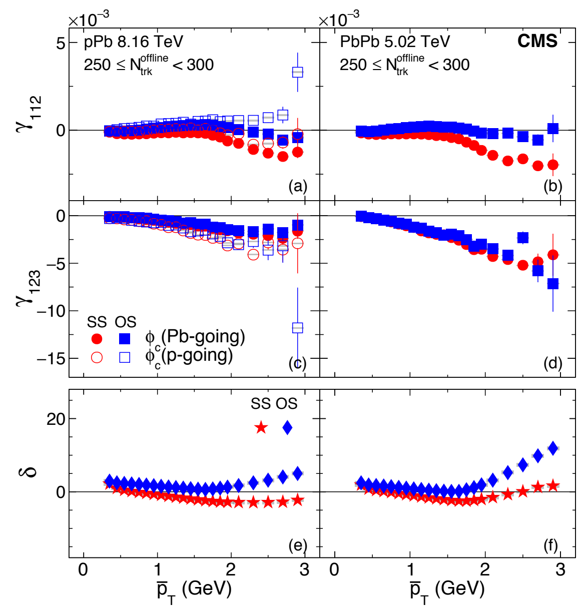

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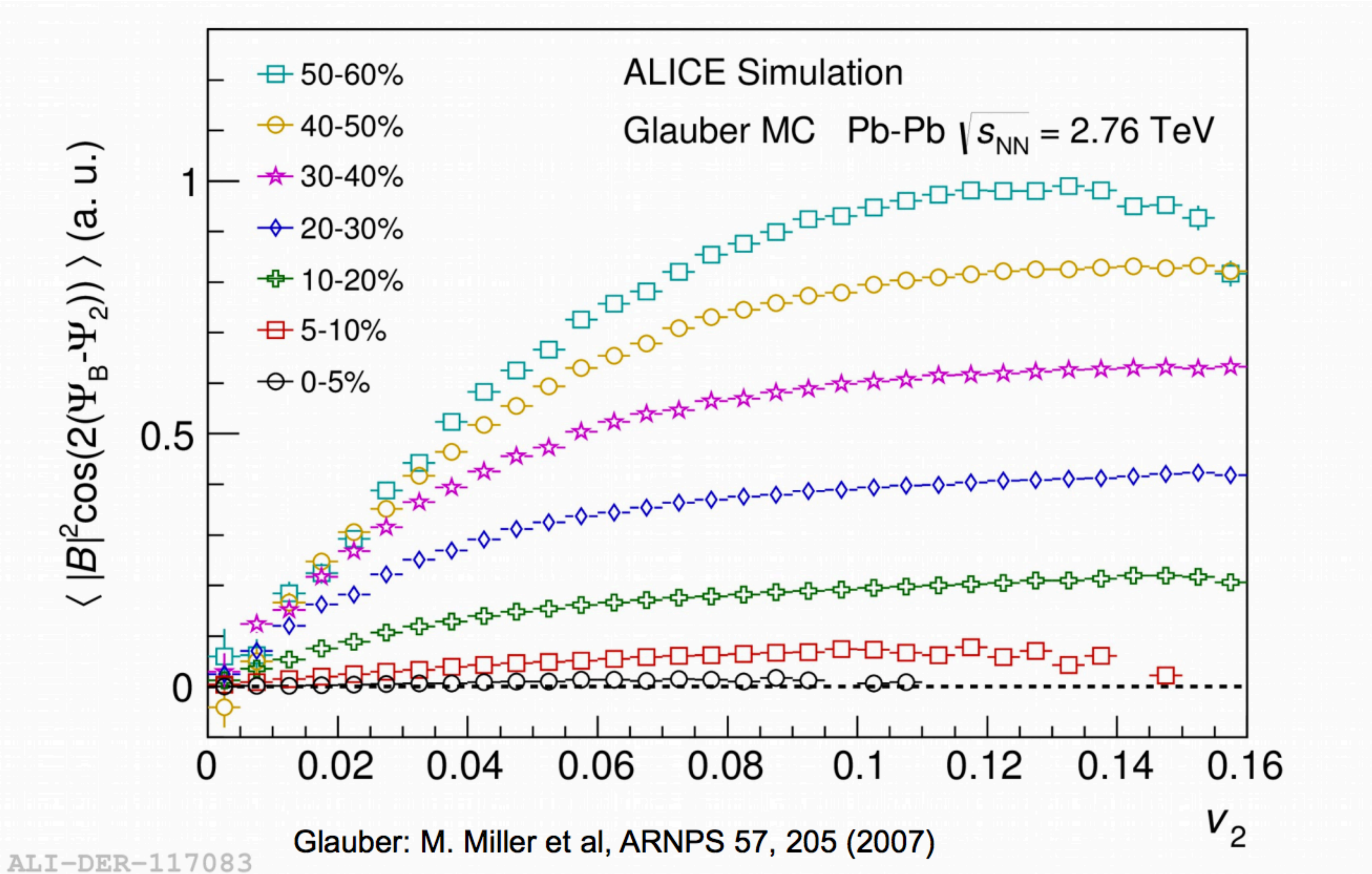
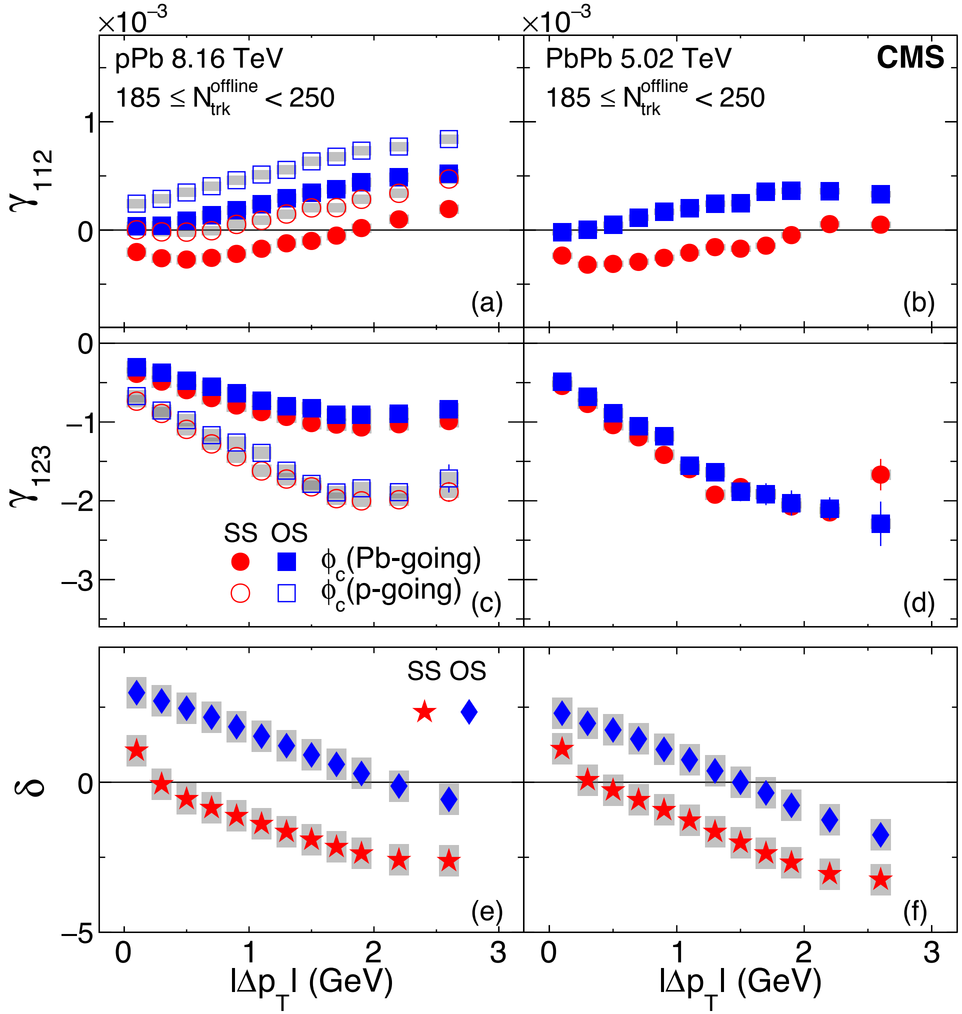


50-60%
40-50%
30-40%
20-30%
10-20%
5-10%
0-5%
ALICE Simulation
Glauber MC Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$\langle |B|^2 \cos(2(\Psi_B - \Psi_2)) \rangle$ (a. u.)
v_2
0
0.5
1
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
Glauber: M. Miller et al, ARNPS 57, 205 (2007)
ALI-DER-117083

Backup

arXiv:1708.01602

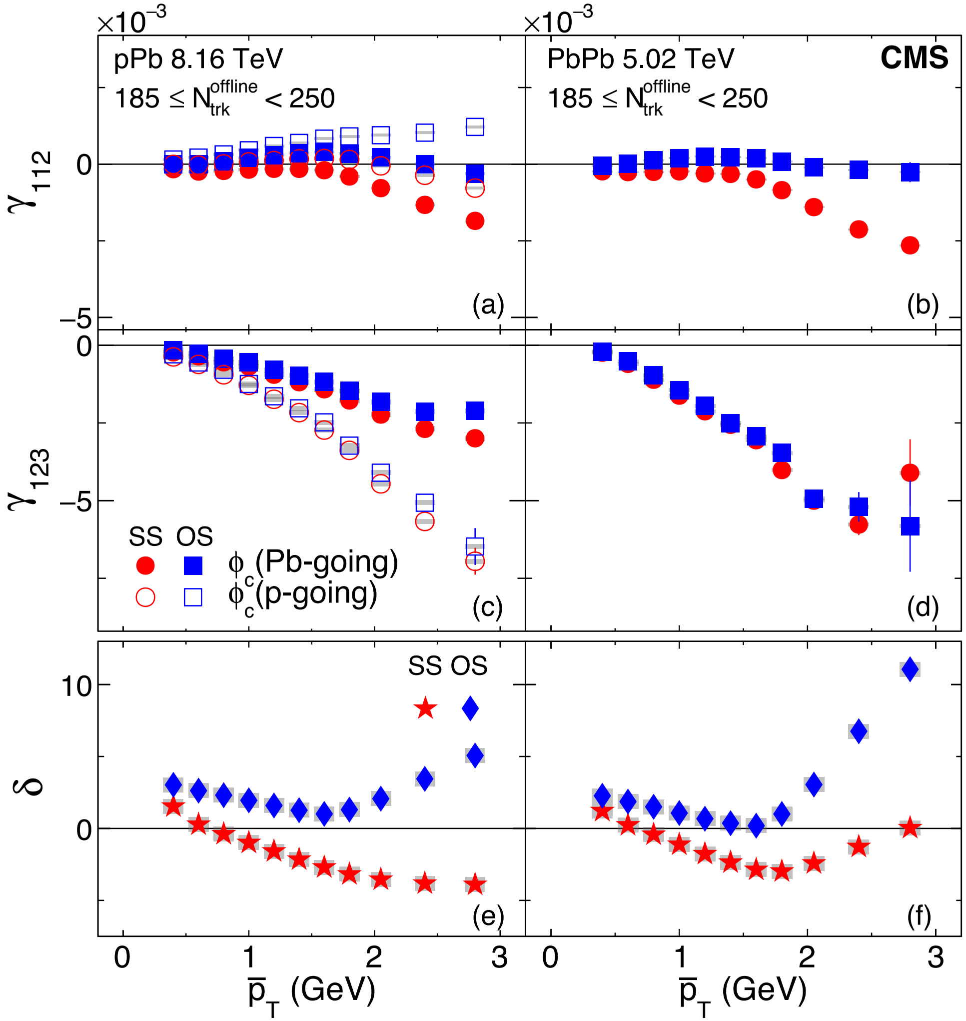
- First time measurement of γ_{123} as function of $|\Delta p_T| \equiv |p_{T,\alpha} - p_{T,\beta}|$
- Similar trend and magnitude observed between pPb and PbPb
- Not only in $|\Delta\eta|$, the similarity extends to $|\Delta p_T|$
- Observation: δ and γ_{123} are different between pPb and PbPb collisions.



Backup

arXiv:1708.01602

- First time measurement of γ_{123} as function of $\bar{p}_T \equiv (p_{T,\alpha} + p_{T,\beta})/2$
- Similar trend and magnitude observed between pPb and PbPb
- δ correlator shows more positive value towards high p_T, indicating jet-like correlation starts to be dominant.



Results: (OS-SS)

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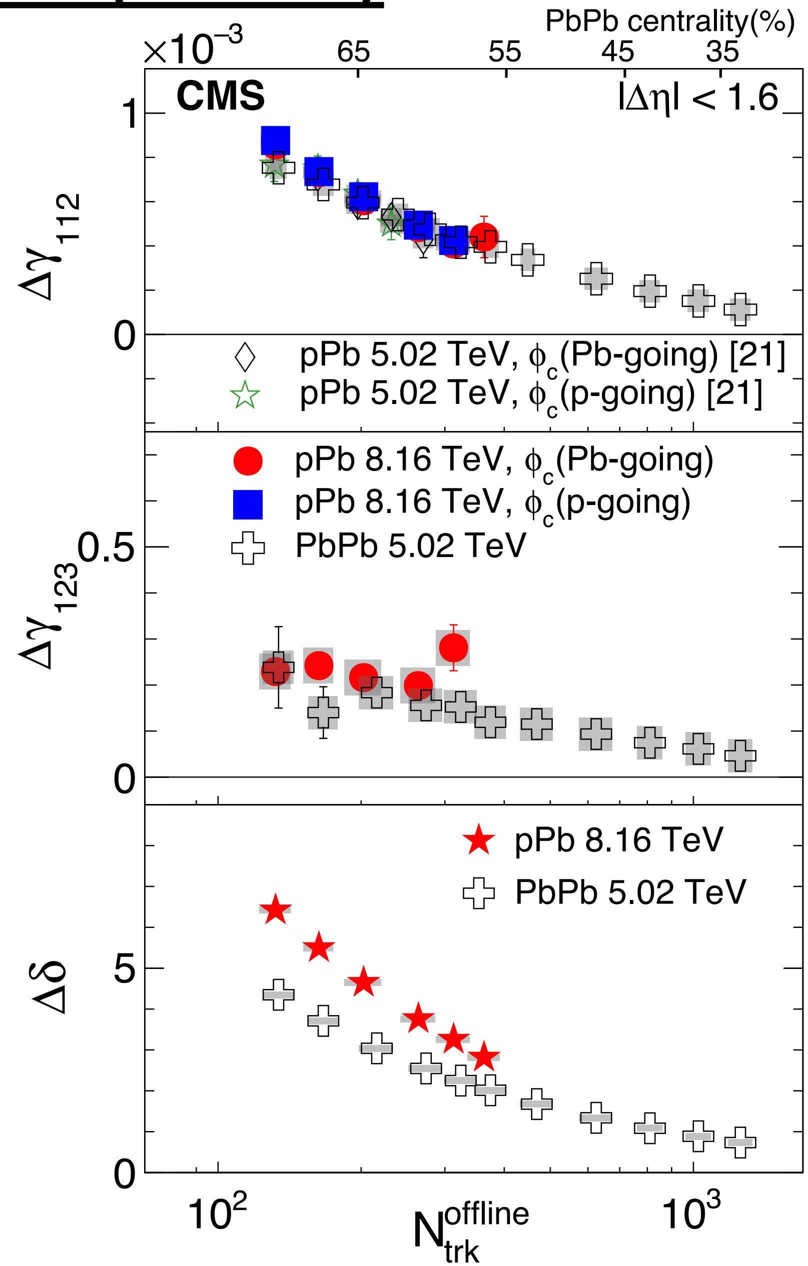
Δ = OS-SS vs Ntrk

- Is that possible the v2 and δ, these two effects add up to γ_{112}?
- If this is true, can it be compatible with the 3rd order?
- **Then it should also describe all multiplicity ranges**



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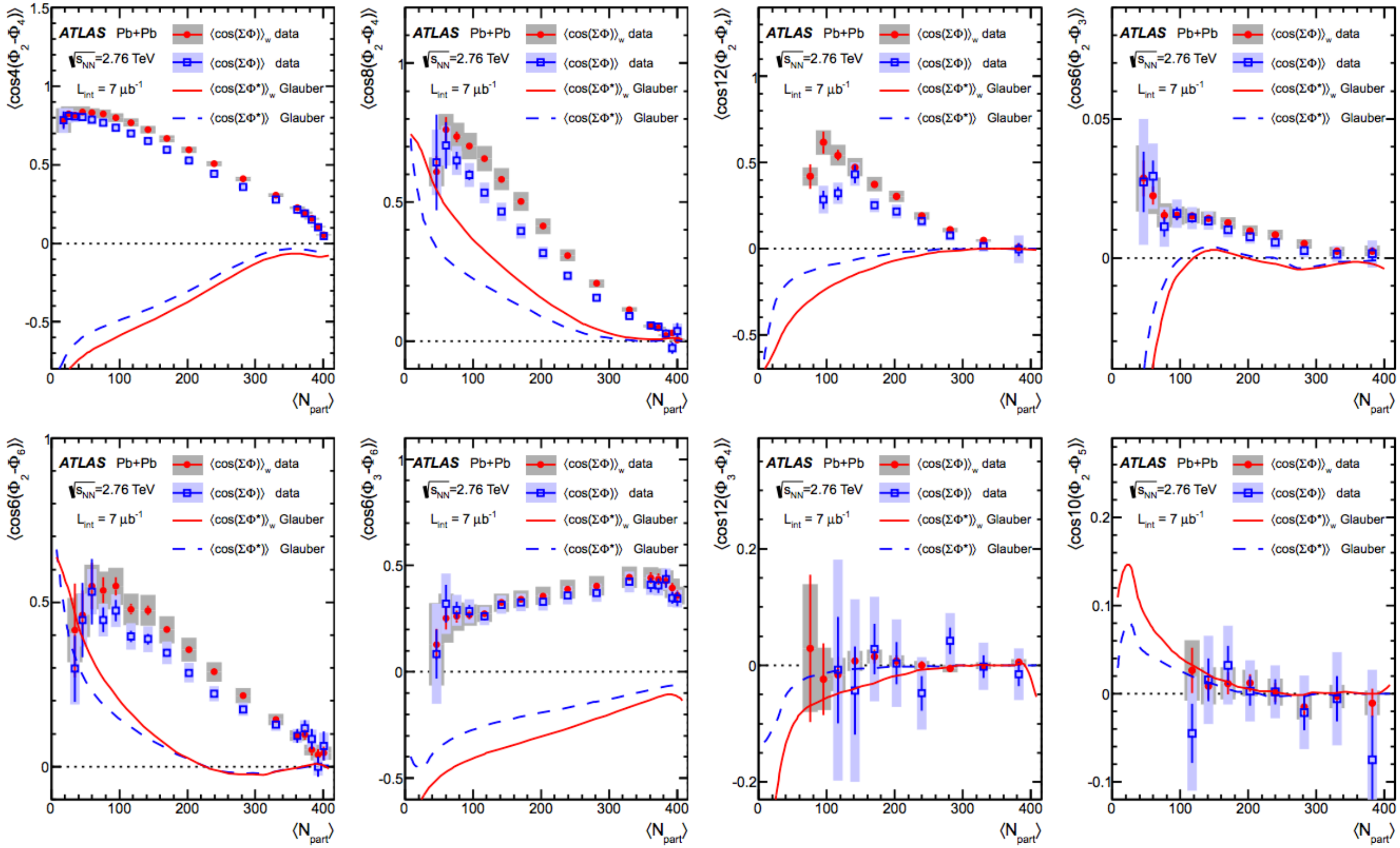

FIG. 6: (Color online) The centrality dependence of eight two-plane correlators, $\langle\cos(\Sigma\Phi)\rangle$ with $\Sigma\Phi = jk(\Phi_n - \Phi_m)$ obtained via the SP method (solid symbols) and the EP method (open symbols). The middle two panels in the top row have $j = 2$ and $j = 3$, respectively, while all other panels have $j = 1$. The error bars and shaded bands indicate the statistical uncertainties and total systematic uncertainties, respectively. The expected correlations among participant-plane angles Φ_n^* from a Glauber model are indicated by the solid curves for weighted case (Eq. (11)) and dashed lines for the unweighted case.