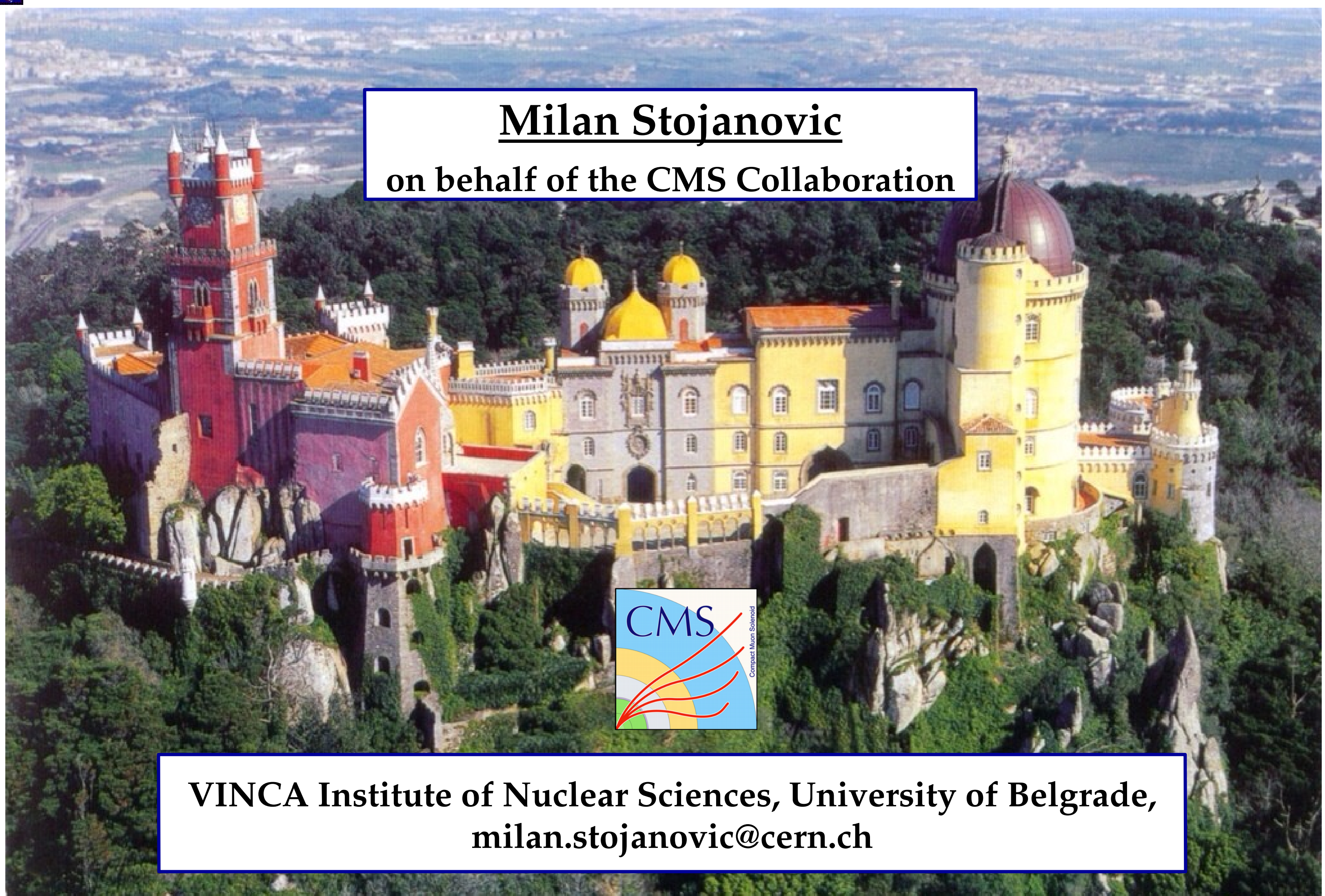
Azimuthal correlations and mixed higher order flow harmonics from CMS at the LHC

Excited QCD, Sintra, 2017



Milan Stojanovic

on behalf of the CMS Collaboration

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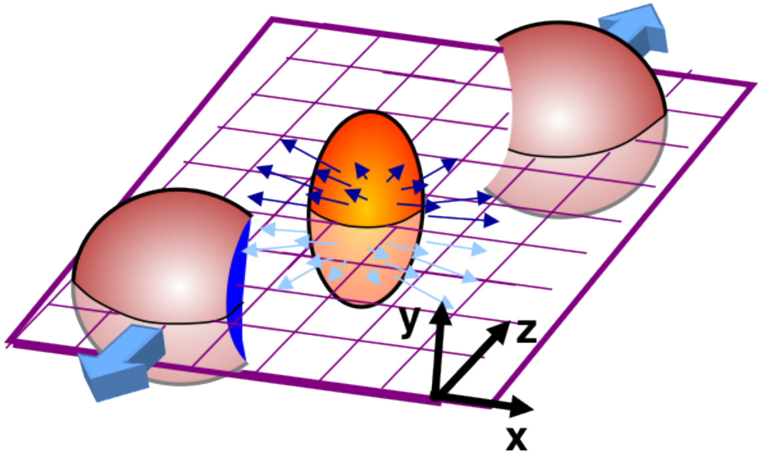
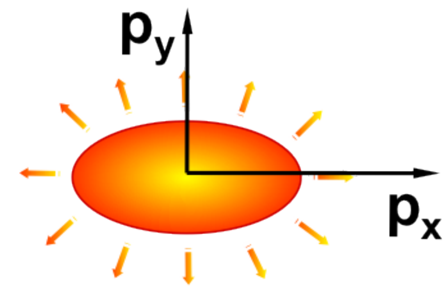
Motivation





Lenticular overlapping region → space anisotropy → momentum space anisotropy

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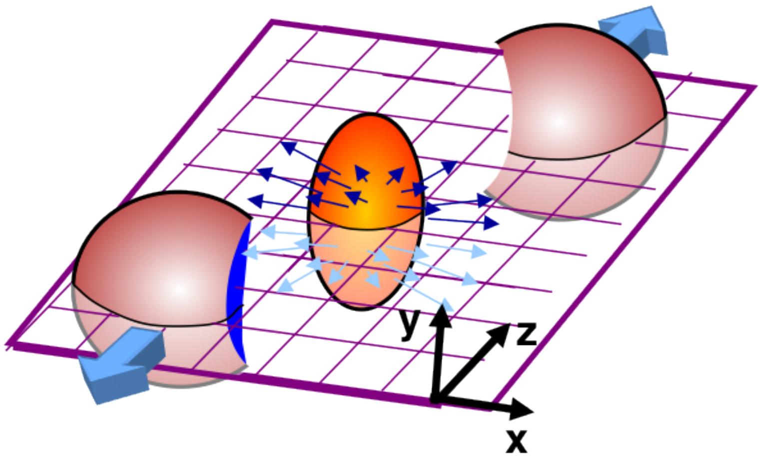

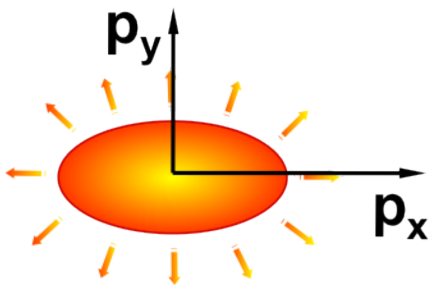

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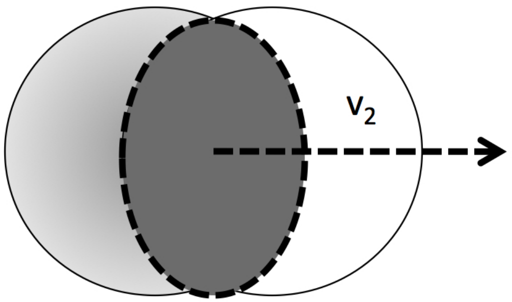

System symmetry → elliptic flow

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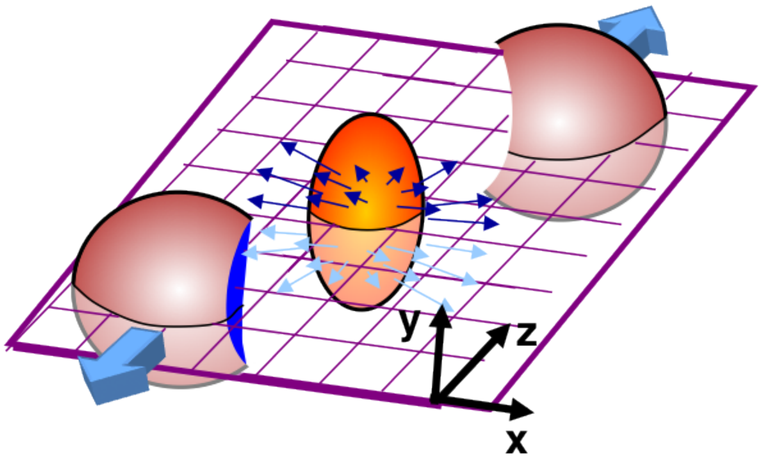

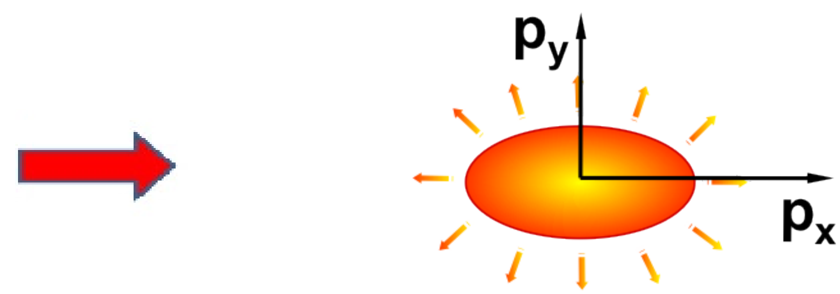

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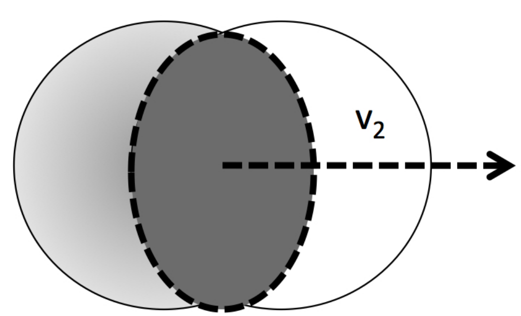

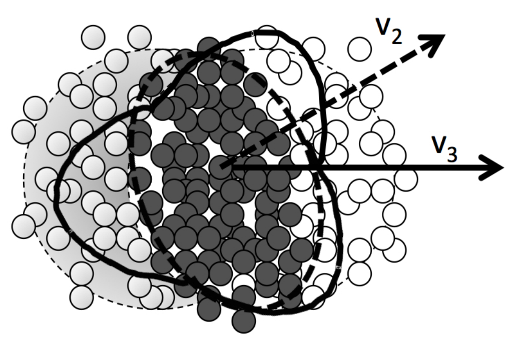

System symmetry → elliptic flow

Fluctuations → non-zero higher order flow

Motivation

- Particle distribution over azimuthal angle: $$\frac{dN}{d\phi} \propto 1 + \sum_n 2v_n \cos[n(\phi - \Psi_n)]$$
- v_n coefficients driven by:
  - Initial geometry;
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- Two methods:
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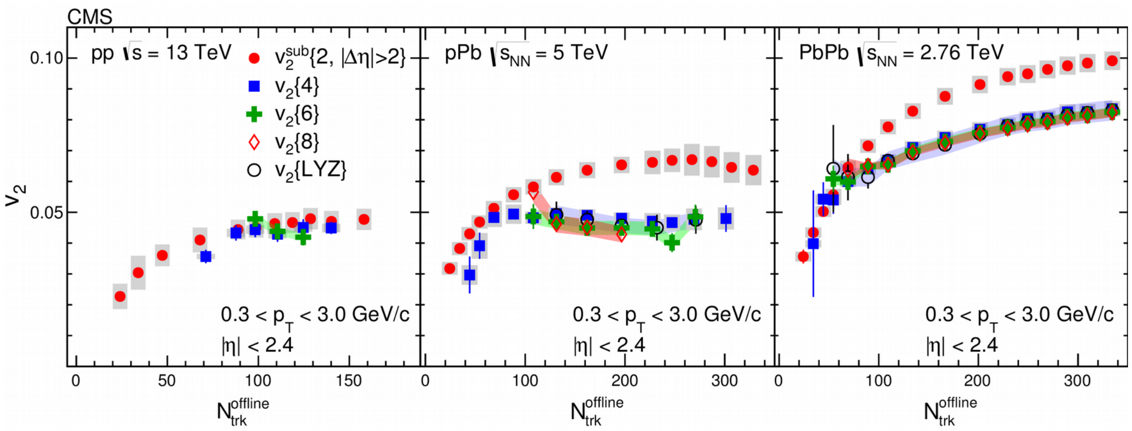

- What about small systems?
  - Long range correlations observed in both pp & pPb collisions.

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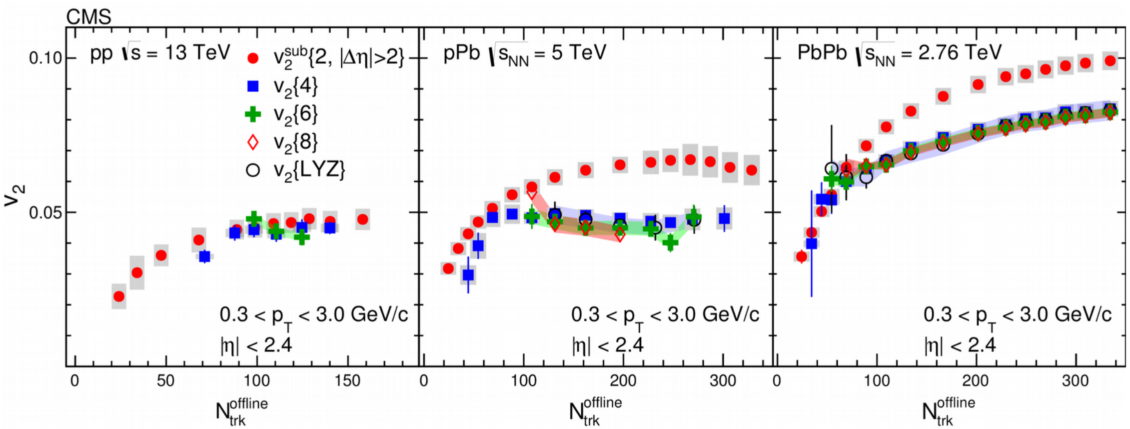

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2. Do the flow correlations can give us better understanding of collectivity in small systems?

Mixed order harmonics

- Azimuthal distribution one can write: $P(\phi) = \frac{1}{2\pi} \sum_{n=-\infty}^{+\infty} V_n e^{-in\phi}$ where $V_n \equiv v_n e^{in\Psi_n}$
- The response is <u>linear</u> ($v_n = k_n * \varepsilon_n$) for n=2,3.
- For higher harmonics (n > 3) there are both, linear and <u>nonlinear</u> part:

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\begin{aligned}
V_4 &= V_{4L} + \chi_{422}(V_2)^2 \\
V_5 &= V_{5L} + \chi_{523} V_2 V_3 \\
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Nonlinear response (from $\varepsilon_2, \varepsilon_3$)

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Linear response (from ε_n)   Nonlinear response (from $\varepsilon_2,\varepsilon_3$)

- Non linear part can be studied from flow harmonics measured with respect to the lower order event planes (mixed order harmonics):
  $v_4\{\Psi_{22}\}$, $v_5\{\Psi_{23}\}$, $v_6\{\Psi_{33}\}$, $v_6\{\Psi_{222}\}$, $v_7\{\Psi_{223}\}$, where, for example, $v_5\{\Psi_{23}\}$ is:

$$v_5\{\Psi_{23}\} \equiv \frac{Re\langle V_5 V_2^* V_3^*\rangle}{\sqrt{\langle |V_2|^2 |V_3|^2\rangle}}$$, and nonlinear response coefficient: $$\chi_{523} = \frac{v_5\{\Psi_{23}\}}{\sqrt{\langle v_2^2 v_3^2\rangle}}$$

Mixed order harmonics

- Standard scalar product approach (linear + nonlinear part):

$$v_n\{\Psi_n\} \equiv \frac{Re\langle V_n V_n^* \rangle}{\sqrt{\langle |V_n|^2 \rangle}} = \frac{\langle v_n v_n \cos(n\Psi_n - n\Psi_n) \rangle}{\sqrt{\langle v_n^2 \rangle}} = \sqrt{\langle v_n^2 \rangle}$$

v_n measured with respect to their own event plane (Ψ_n)

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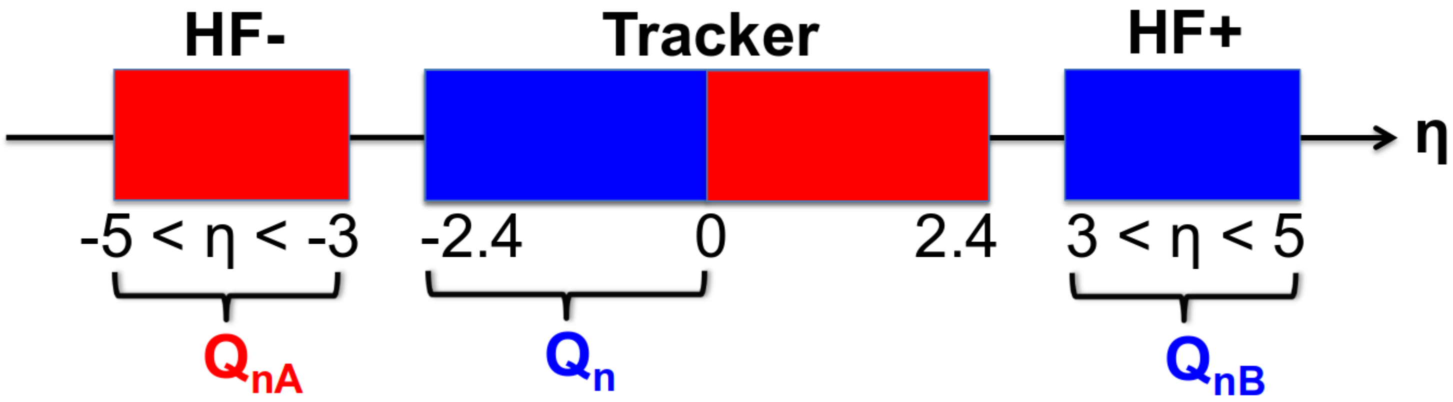
- Nonlinear response coefficient:

$$\chi_{523} = \frac{Re\langle V_5 V_2^* V_3^*\rangle}{\langle |V_2|^2|V_3|^2\rangle} = \frac{\langle v_5 v_2 v_3 \cos(5\Psi_5 - 2\Psi_2 - 3\Psi_3)\rangle}{\langle v_2^2 v_3^2\rangle} = \frac{v_5\{\Psi_{23}\}}{\sqrt{\langle v_2^2 v_3^2\rangle}}$$

Mixed order harmonics

Sub-events, divided by pseudorapidity range,
with |Δη|> 3.0 gap to avoid short-range correlations.



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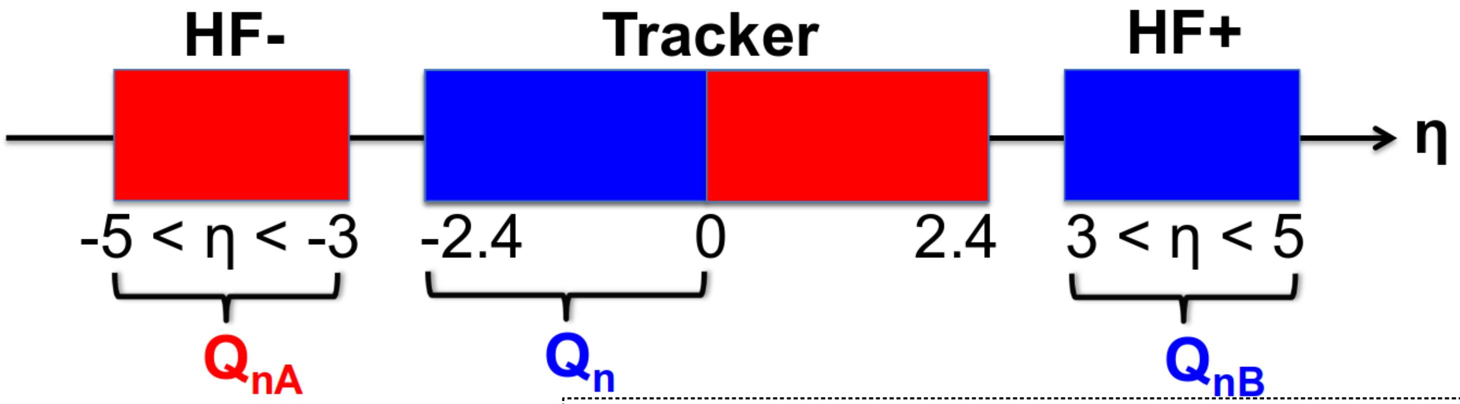

Deriving procedure:

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- Flow vector:

$$Q_n = \frac{1}{\sum w_j} \sum_j w_j e^{in\phi_j} = |Q_n| \, e^{in\Psi_n}$$

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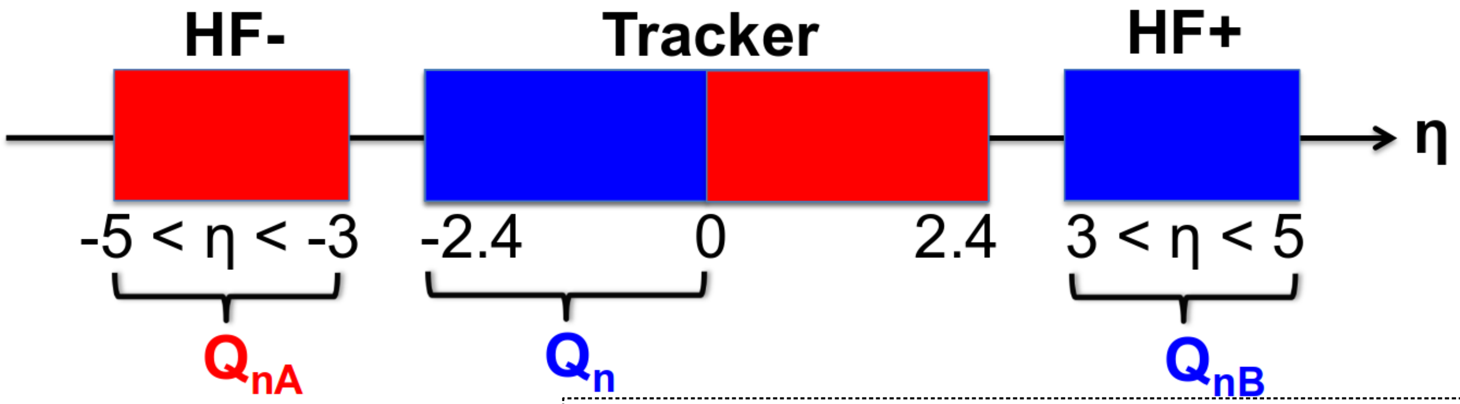

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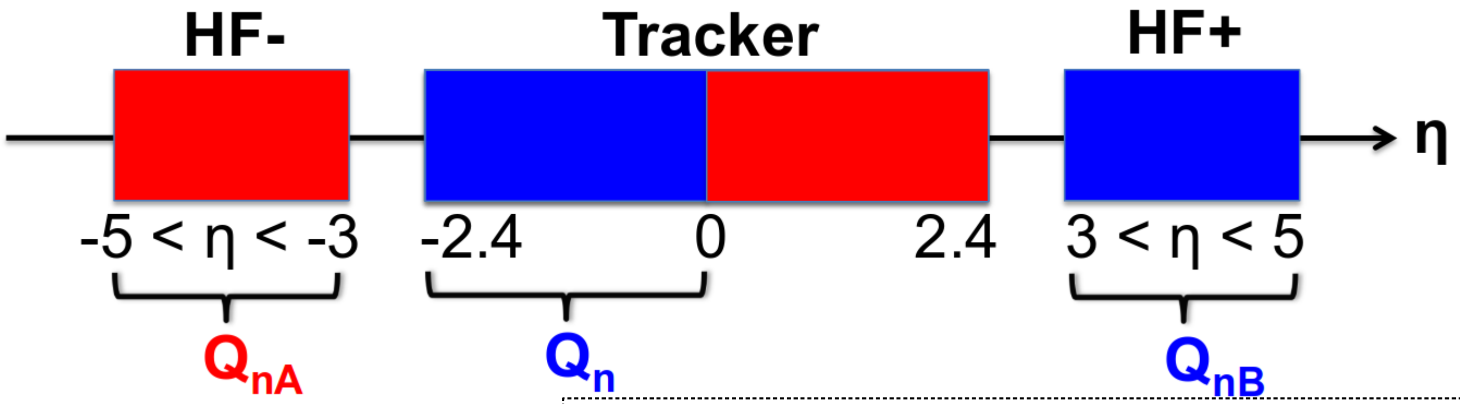

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- Nonlinear response coefficient: $$\chi_{523} = \frac{Re\langle Q_5 Q^*_{2B} Q^*_{3B}\rangle}{Re\langle Q_2 Q_3 Q^*_{2B} Q^*_{3B}\rangle}$$

Two-particle correlations

- For $v_n\{\Psi_n\}$ measurement two-particle correlation method has been used.

1. Signal distribution:

$$S(\Delta\eta, \Delta\phi) = \frac{1}{N_{trig}} \frac{d^2 N^{same}}{\Delta\eta\Delta\phi}$$

2. Background distribution:

$$B(\Delta\eta, \Delta\phi) = \frac{1}{N_{trig}} \frac{d^2 N^{mix}}{\Delta\eta\Delta\phi}$$

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$$\frac{1}{N_{trig}} \frac{d^2 N^{pair}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}$$

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1D correlation function - $|\Delta\phi|$ projection for $2 < |\Delta\eta| < 4$.

Fourier fit:

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Flow harmonics extraction: $$v_n(p_T)=\frac{V_{n\Delta}(p_T,p_T^{reff})}{\sqrt{V_{n\Delta}(p_T^{reff},p_T^{reff})}}$$

Mixed order harmonics vs centrality

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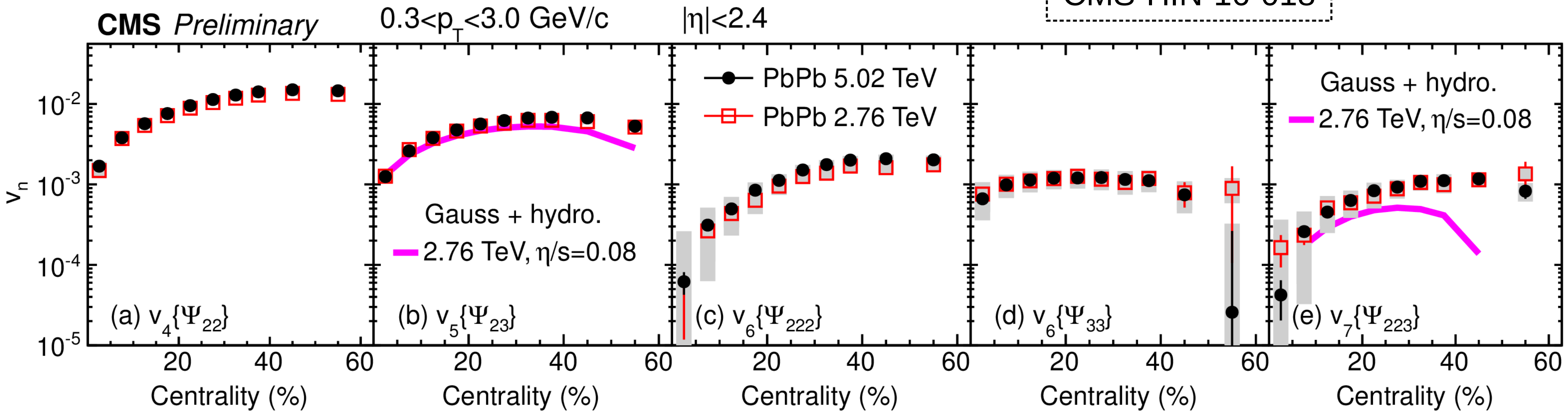

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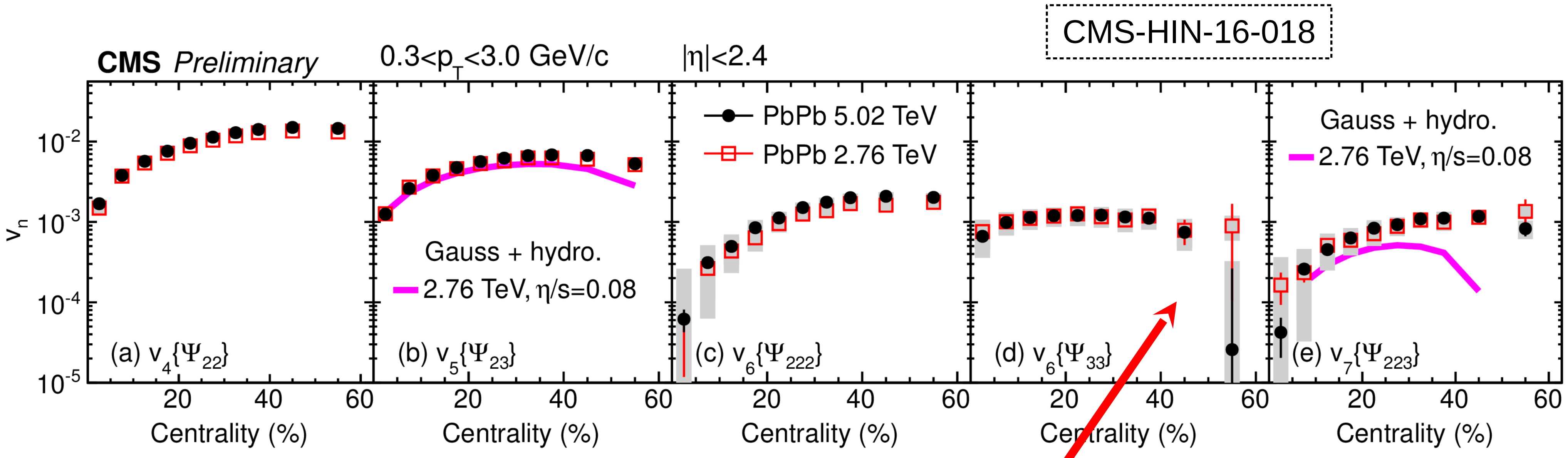

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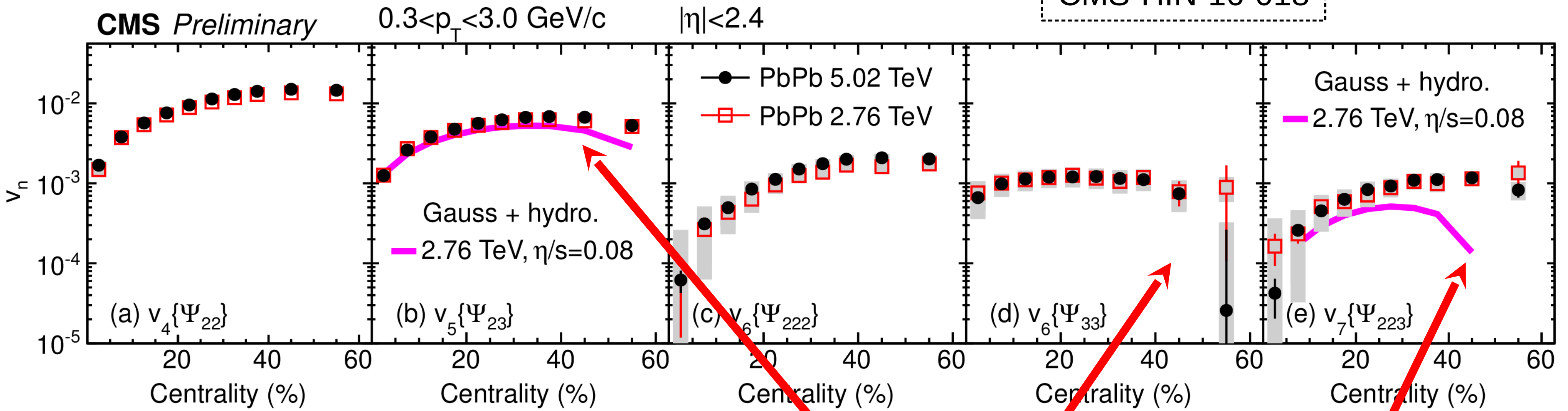

- Strong centrality dependence, except for $v_6\{\Psi_{33}\}$.
- Hydro. with η/s=0.08 describes the shape of $v_5\{\psi_{23}\}$, but not $v_7\{\psi_{223}\}$

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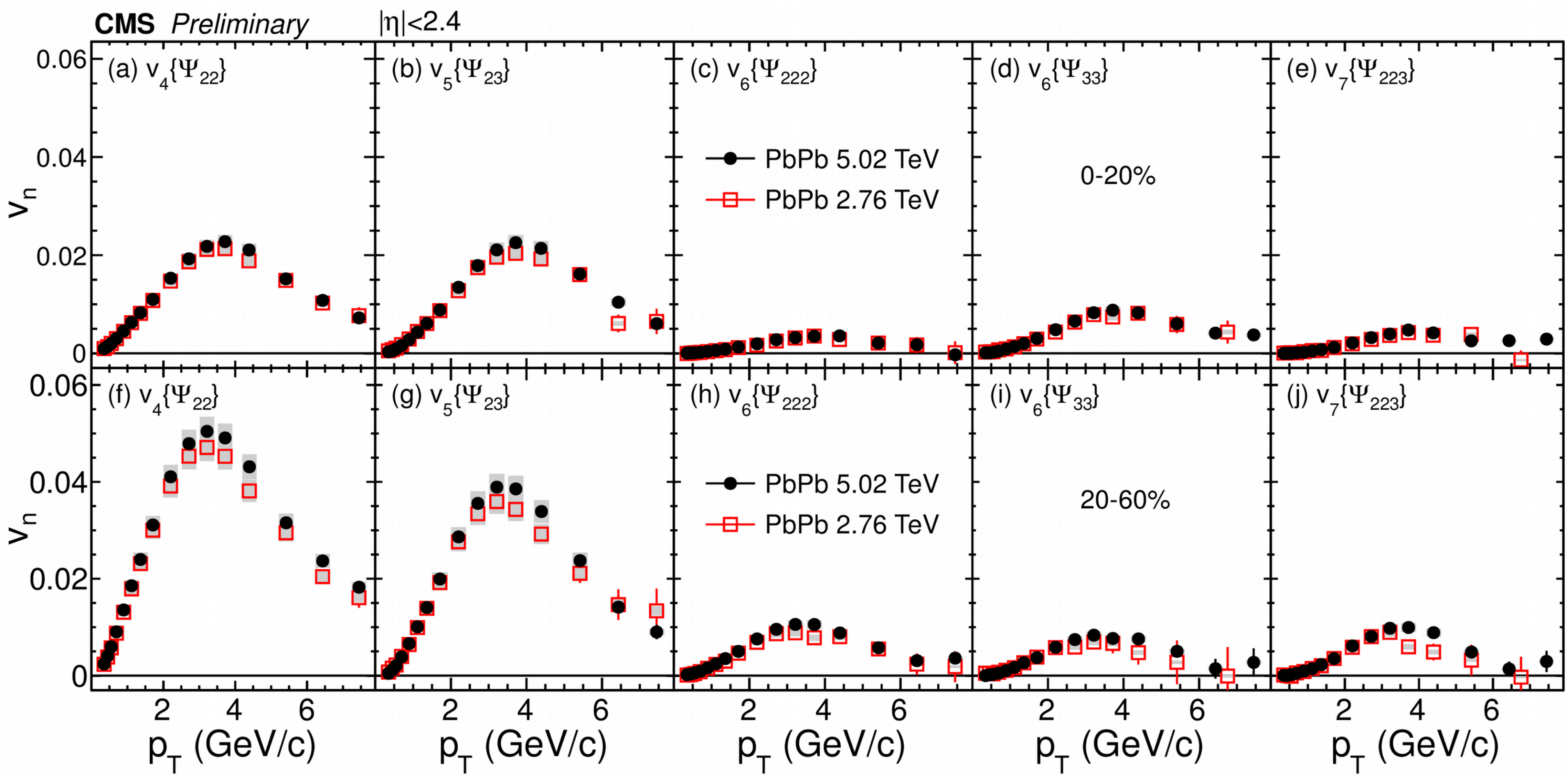
Mixed order harmonics vs p_T



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- No strong energy dependence.

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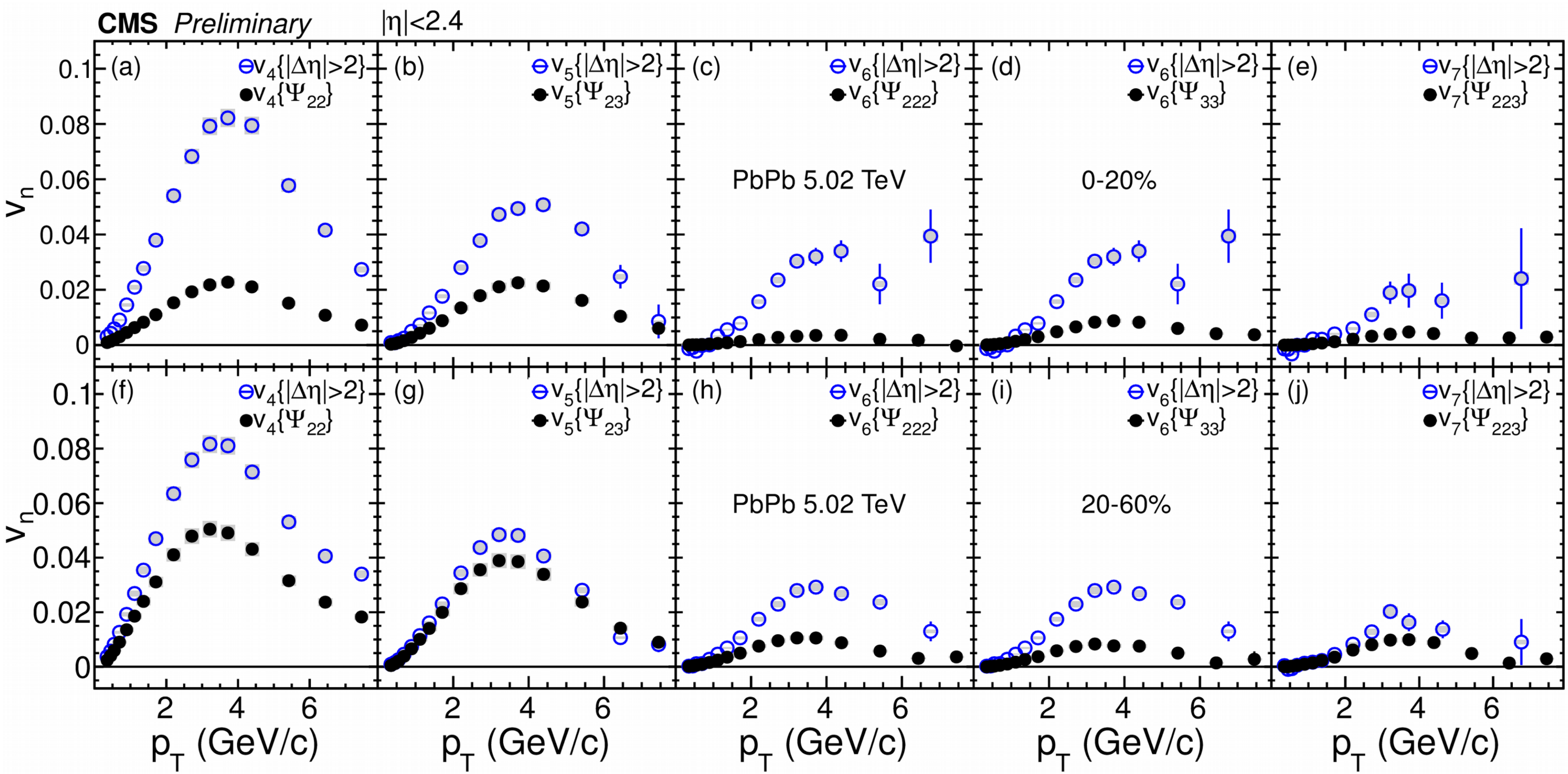

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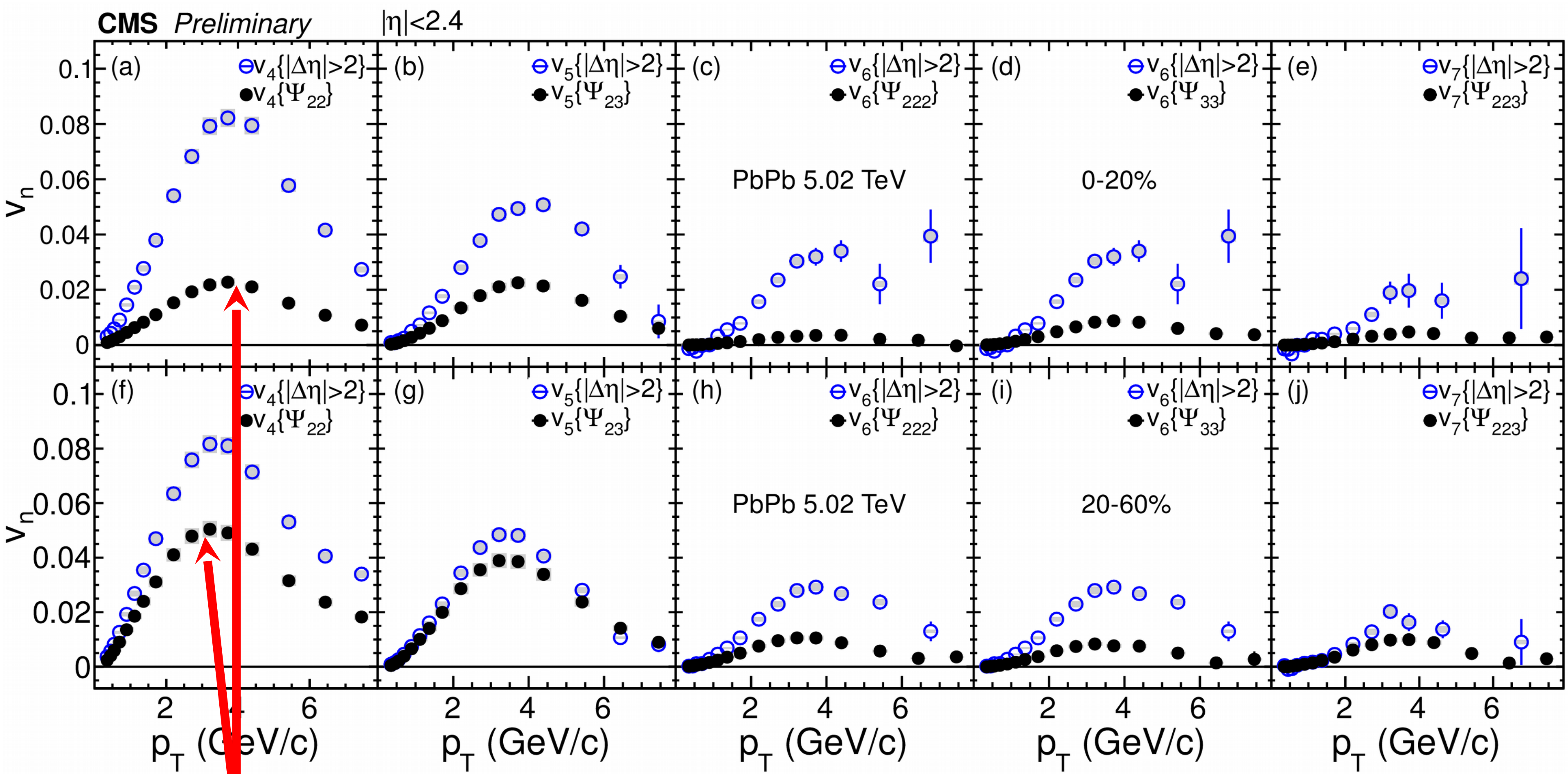

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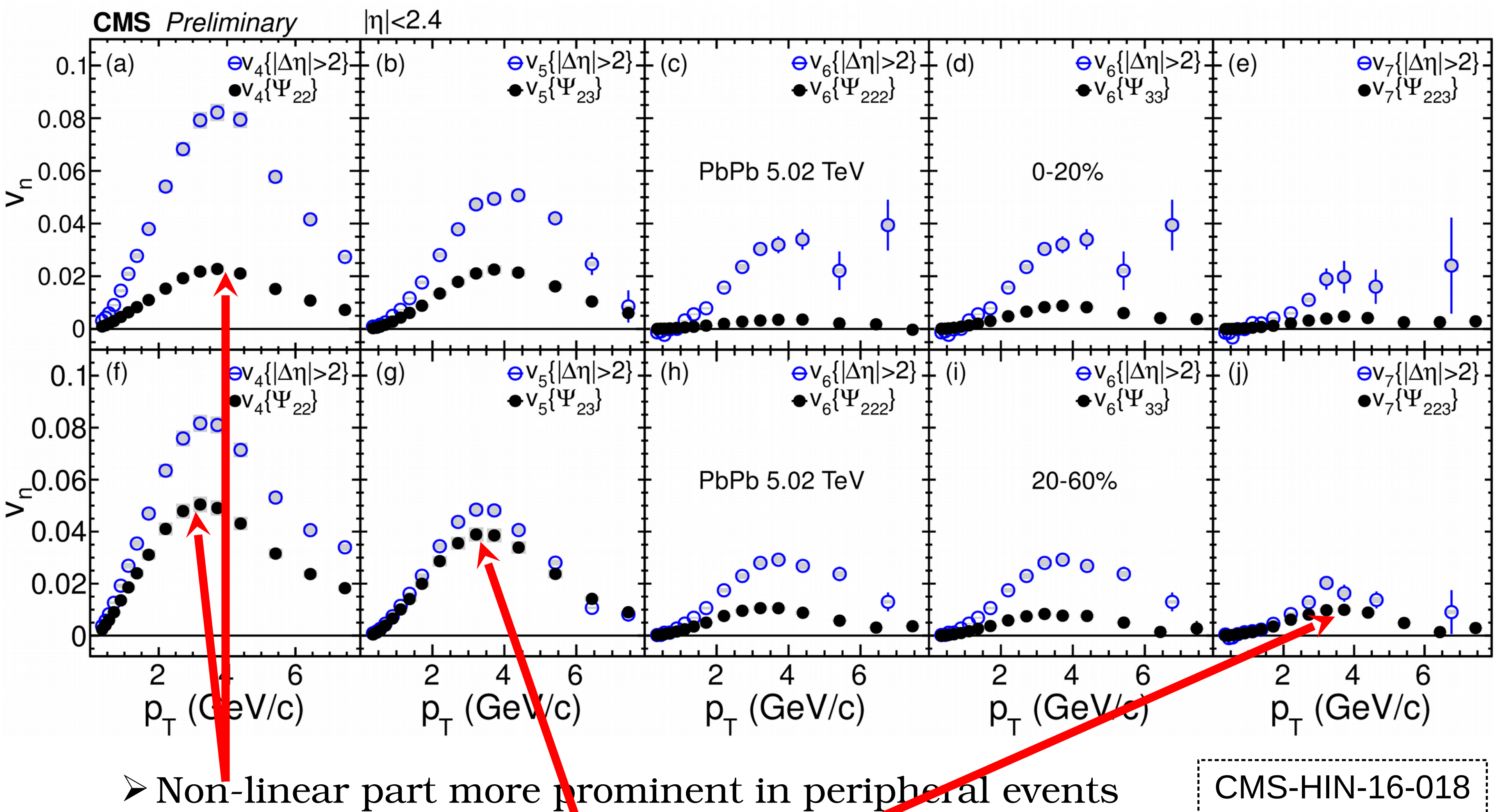
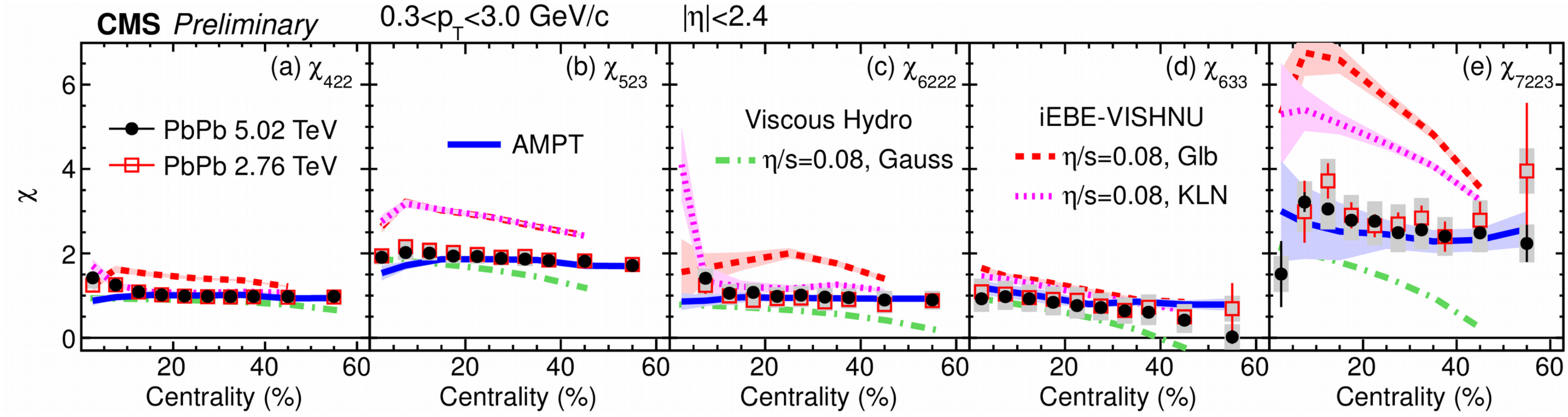


- Non-linear part more prominent in peripheral events
- And for odd harmonics!

Non-linear response coefficient vs centrality



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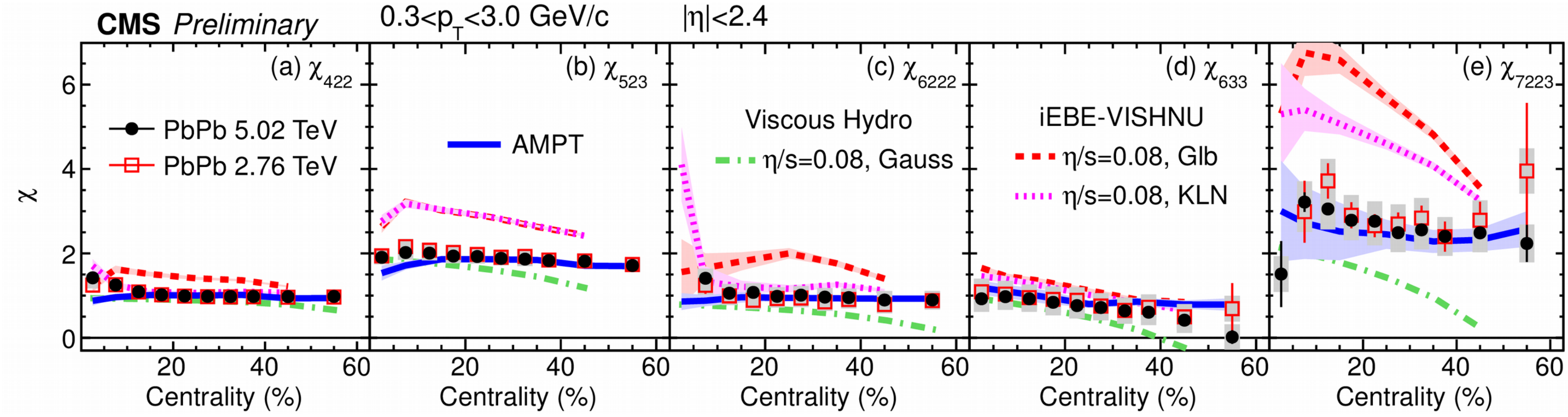

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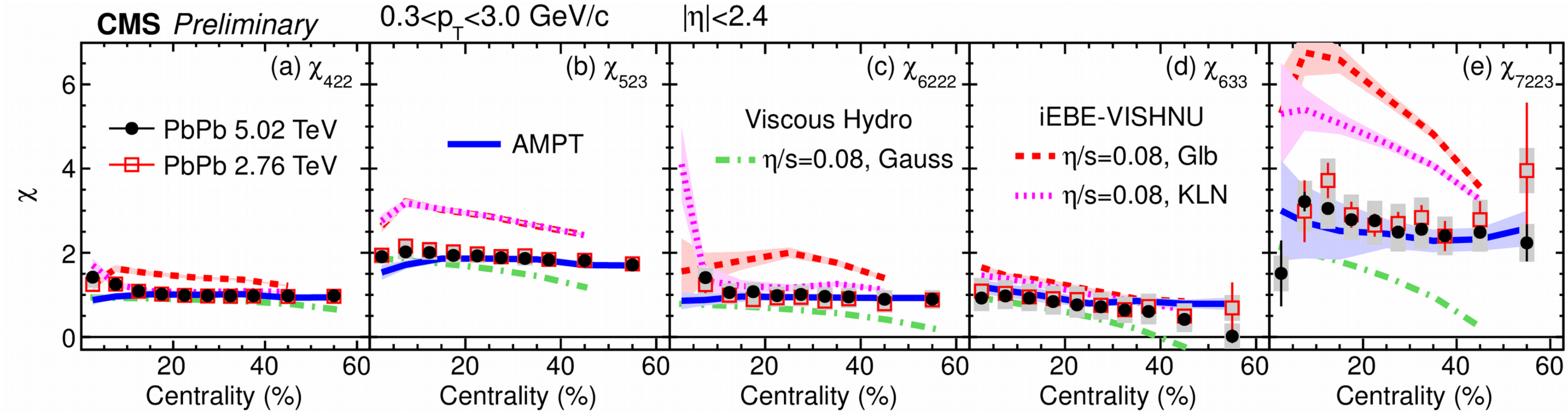

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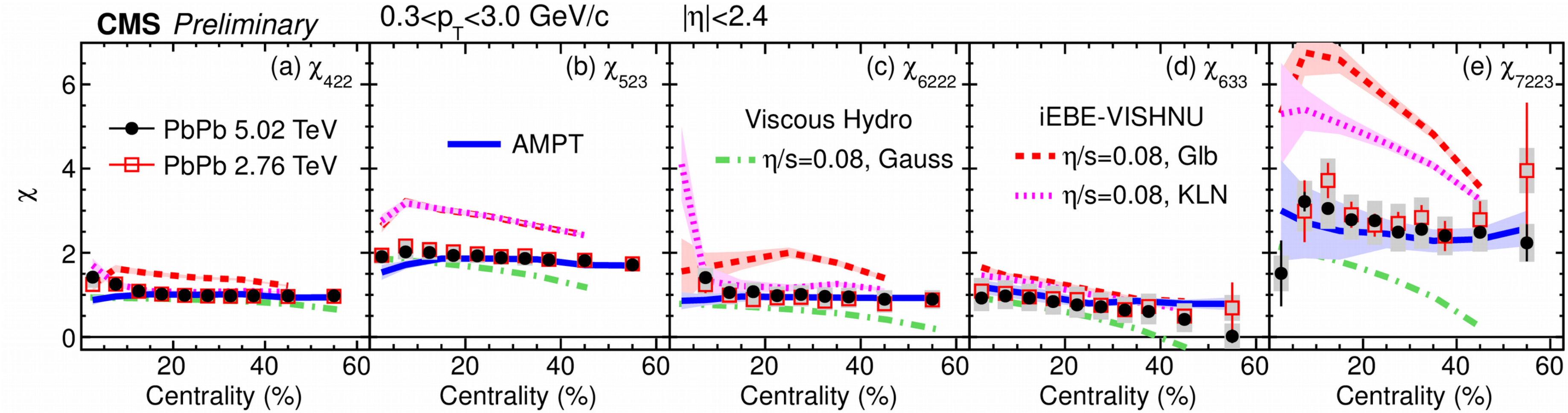

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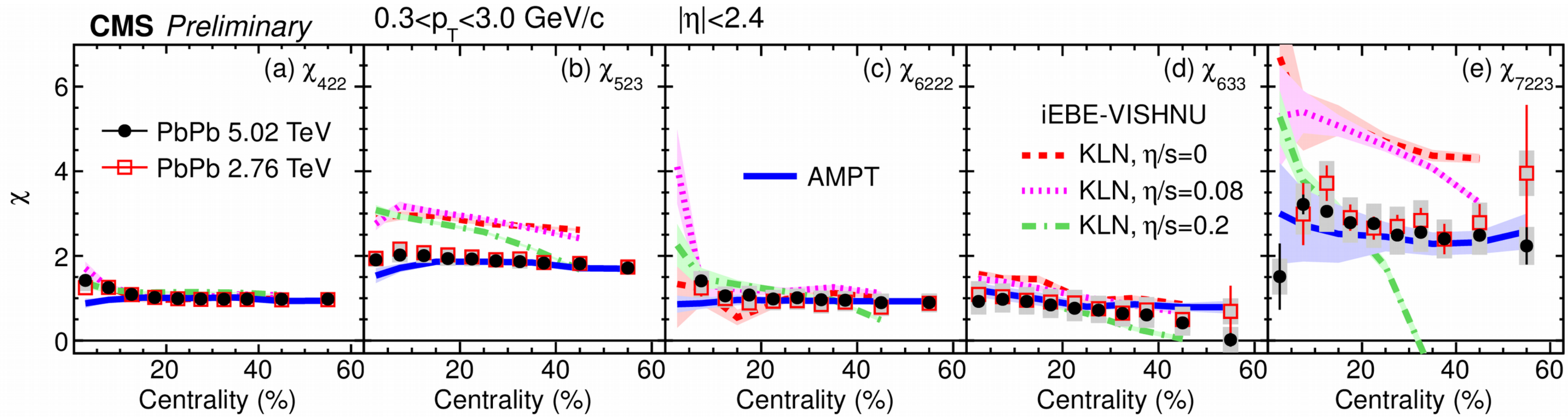

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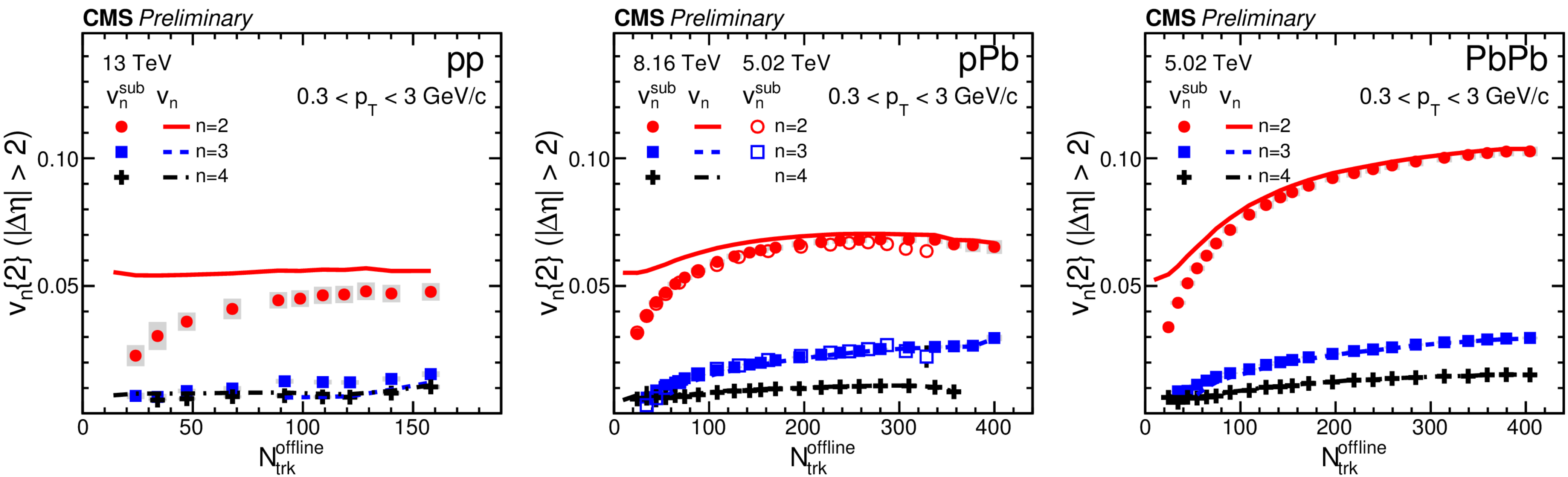
Flow in small systems

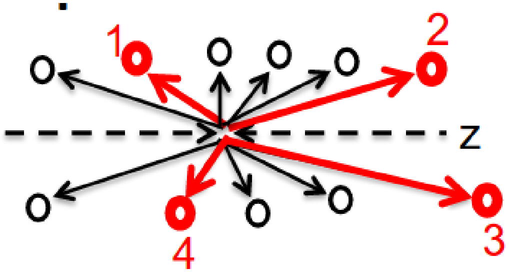
CMS-HIN-16-022



- Similar pattern in all systems.
- Weak energy dependence in pPb collisions.

Symmetric cumulant

New observable, based on 4-particle cumulant technique, developed by ALICE.



Diagonal terms:

$$\langle\langle 4\rangle\rangle_{n,n} \equiv \left\langle\left\langle \cos\left[n\left(\phi_1+\phi_2-\phi_3-\phi_4\right)\right]\right\rangle\right\rangle$$

Non-diagonal terms:

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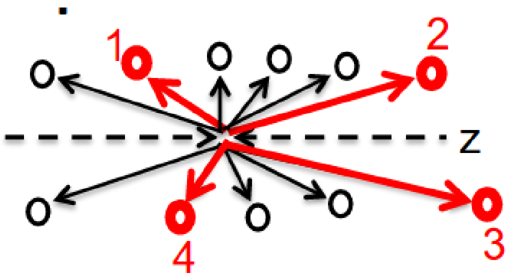

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➢

Symmetric cumulant:

$$SC(n,m) \equiv \langle\langle 4\rangle\rangle_{n,m} - \langle\langle 2\rangle\rangle_n \langle\langle 2\rangle\rangle_m = \langle v_n^2 v_m^2\rangle - \langle v_n^2\rangle\langle v_m^2\rangle$$

- SC (n,m) > 0 → n,m correlated
- SC (n,m) < 0 → n,m anti-correlated
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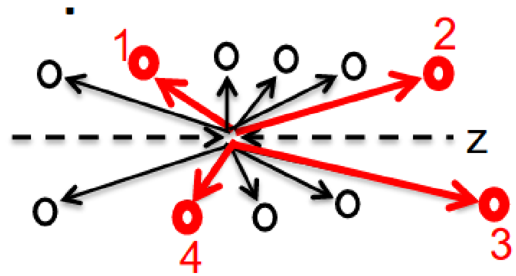

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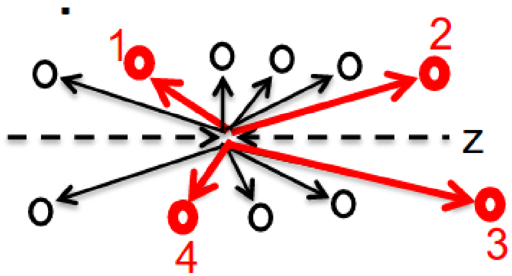

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Extracted from two-particle correlations

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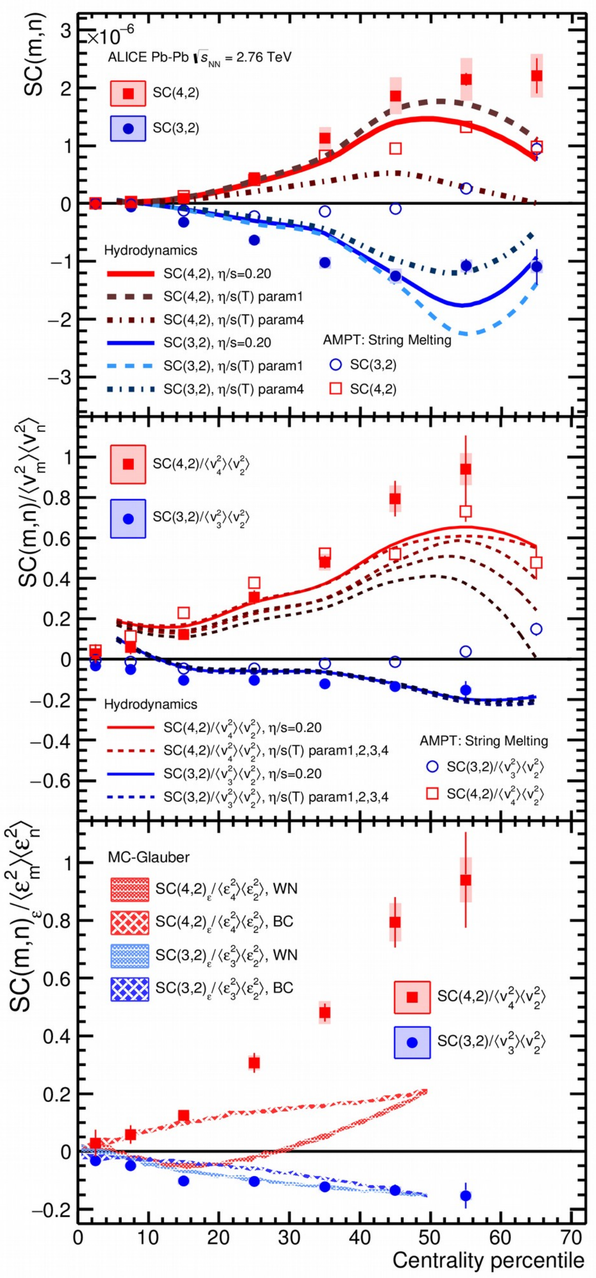
Symmetric cumulant

PhysRevLett.117, 182301 (2016)

➢ Flow harmonics correlations:

✗ SC(4,2) < 0 → v_2 & v_4 correlated!

✗ SC(3,2) < 0 → v_2 & v_3 anticorrelated!



Symmetric cumulant

PhysRevLett.117, 182301 (2016)

- Flow harmonics correlations:
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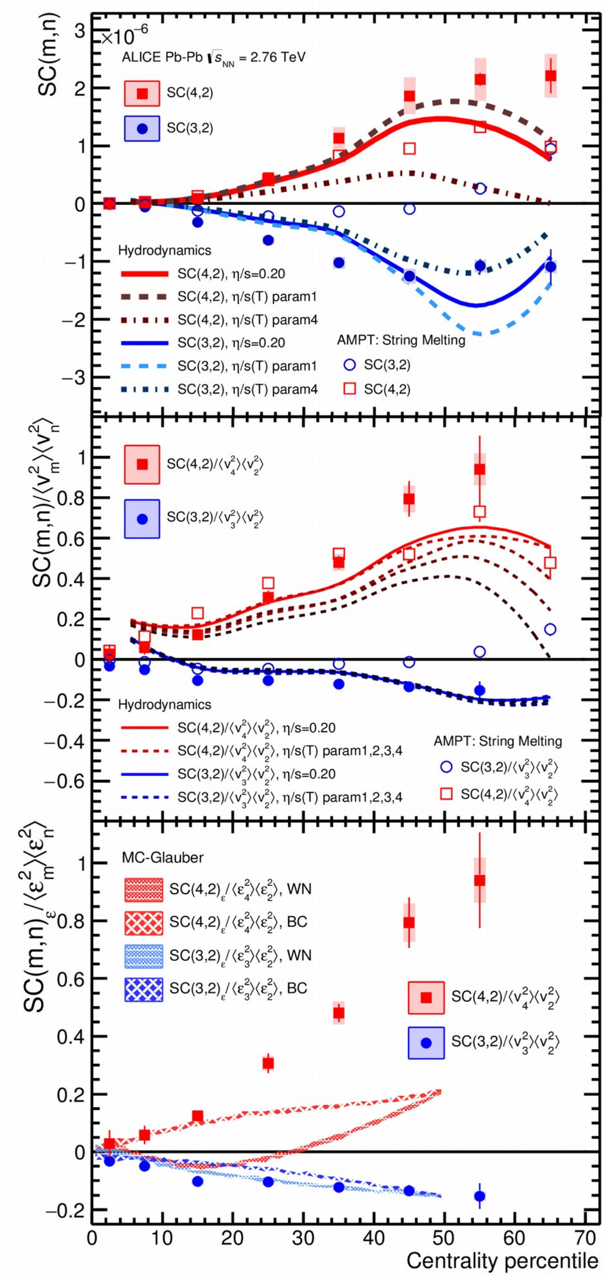
- SC(n,m) normalized by <v_2><v_m>:
  - ✗ Normalized SC(4,2) depends on both IS and medium response;
  - ✗ Normalized SC(3,2) depends only on initial state (IS) fluctuations!



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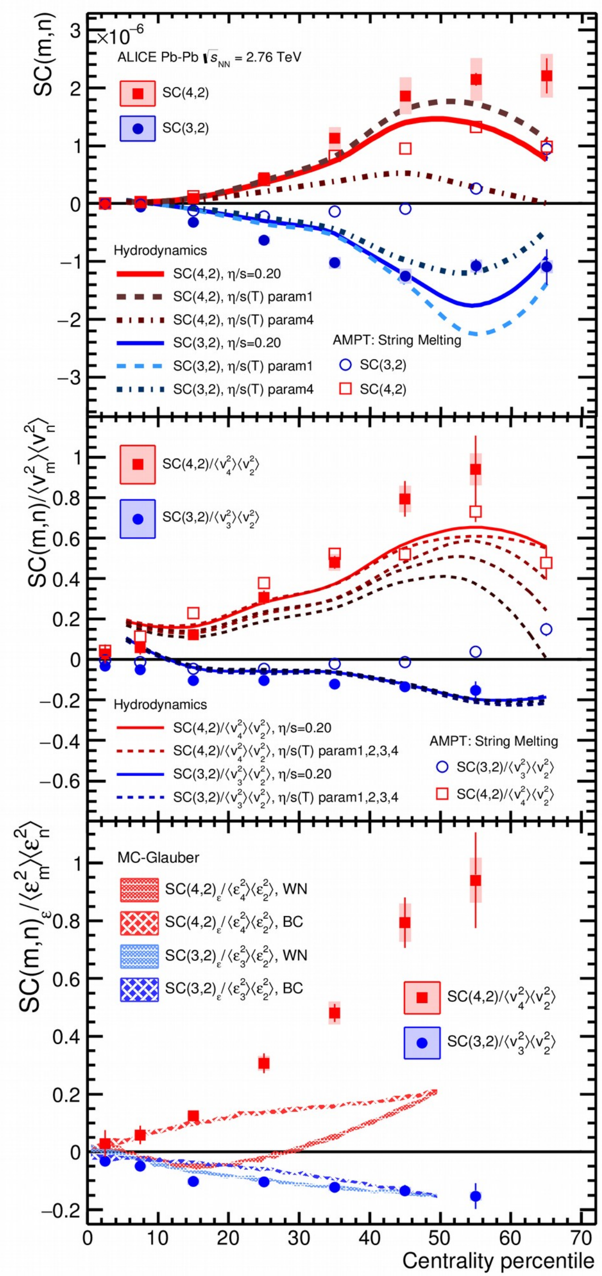
What about small systems?



SC – results

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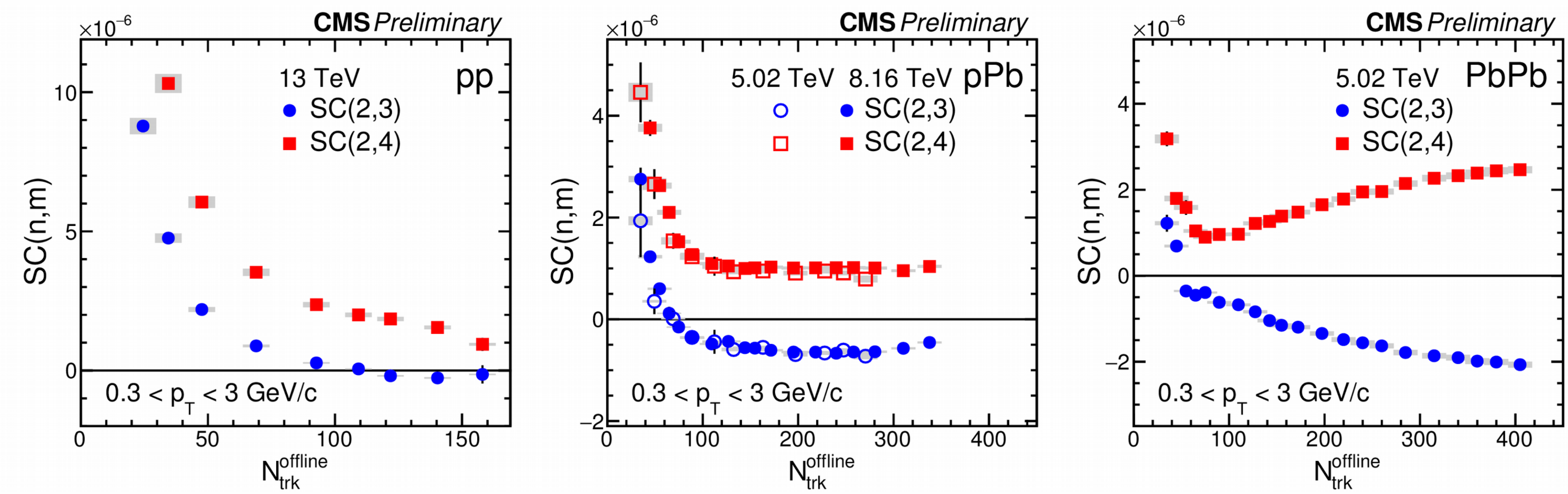

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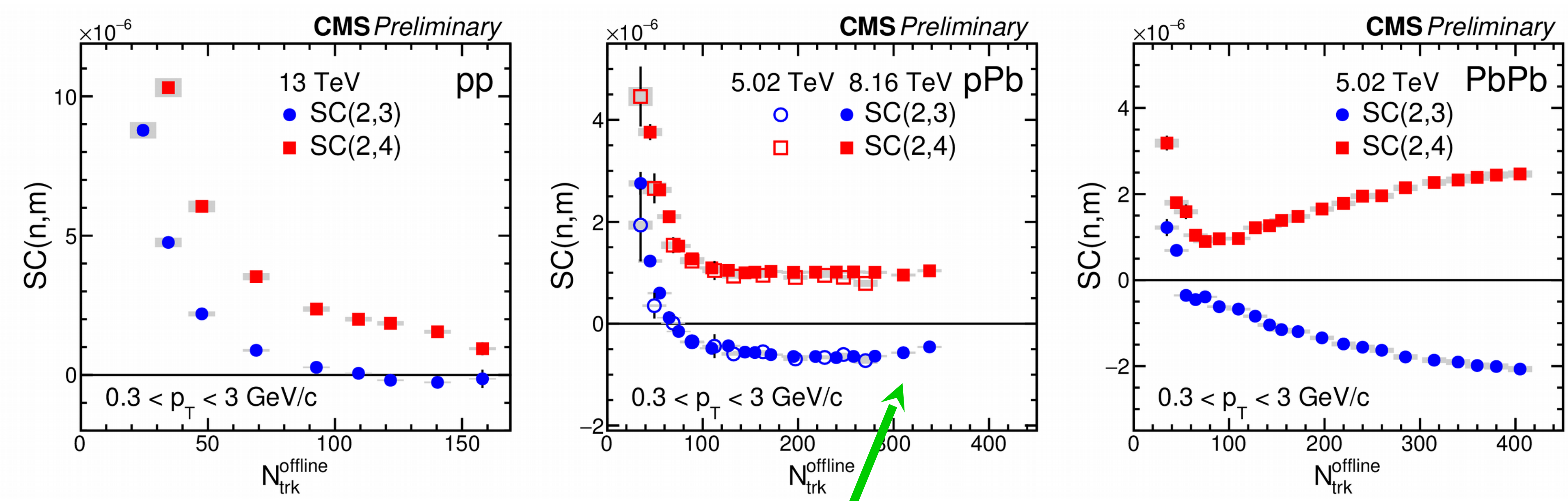

➢ Weak energy dependence (pPb).

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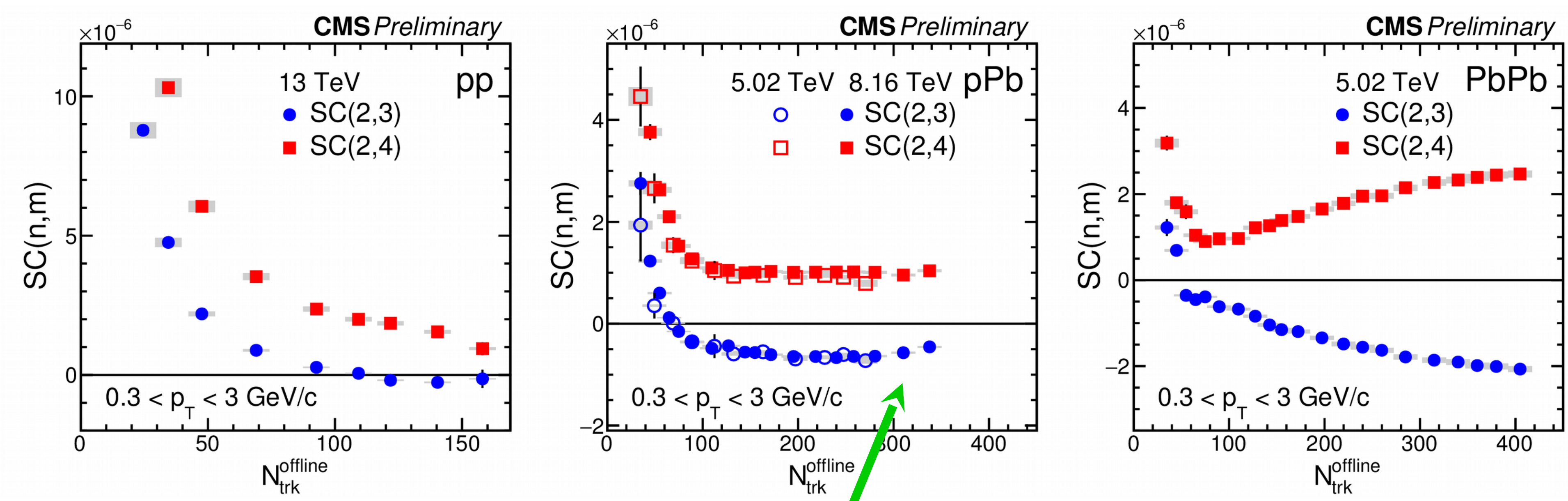

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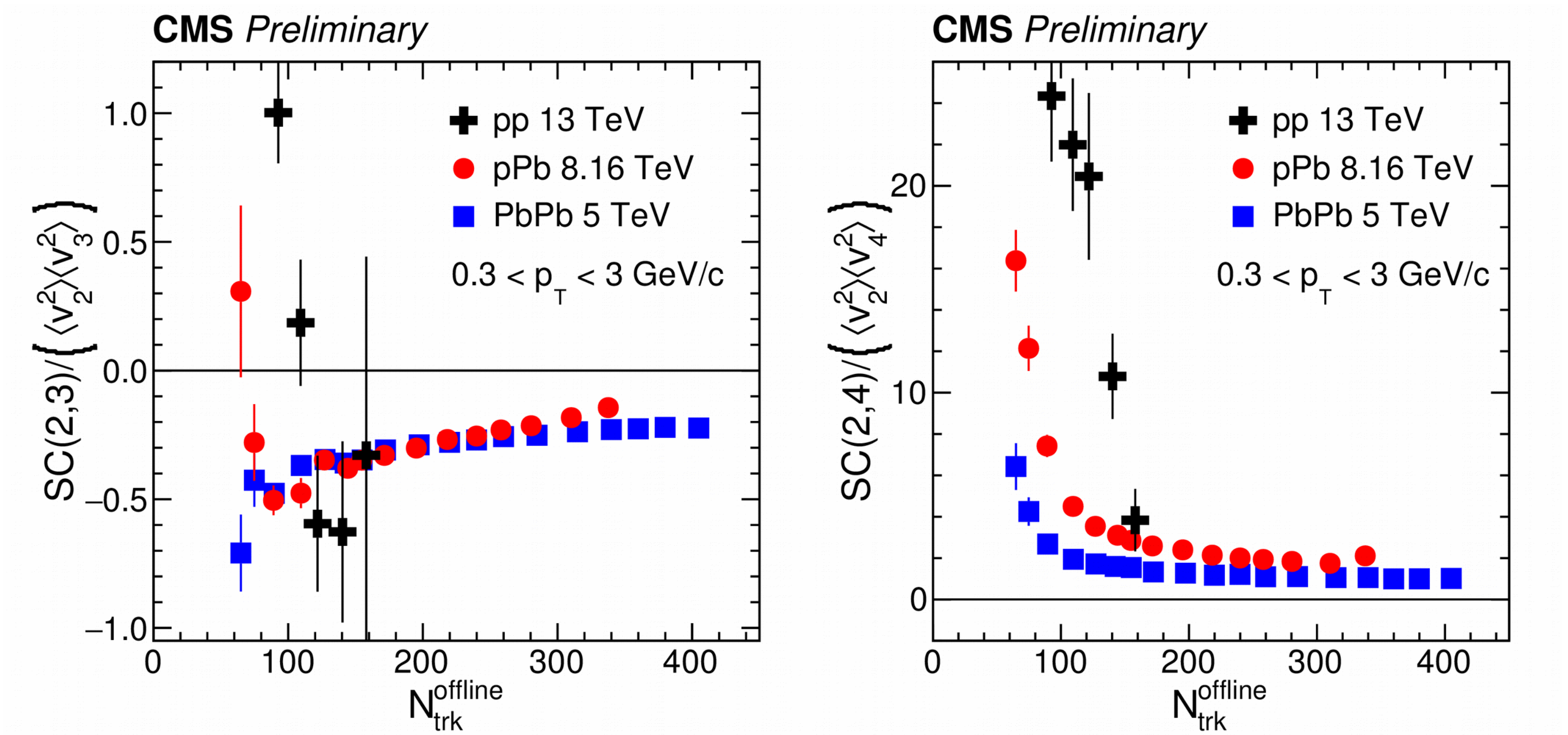
Normalized SC – results

CMS-HIN-16-022



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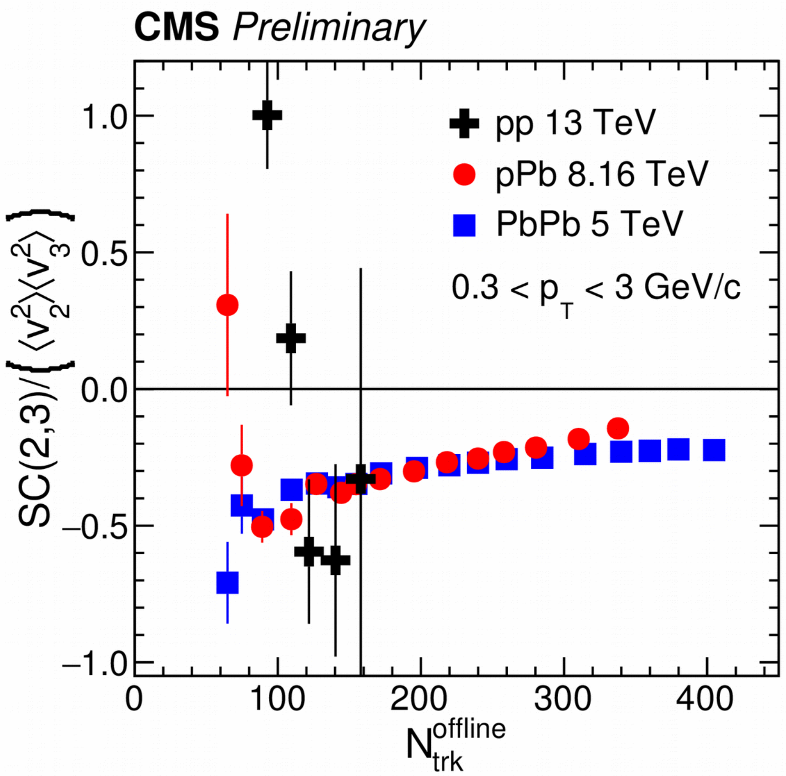

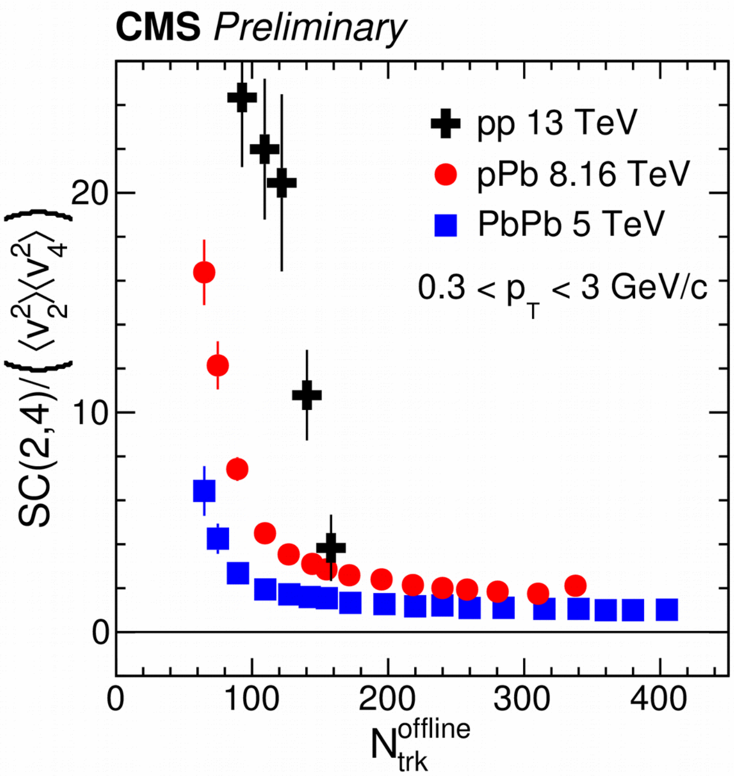

- For pPb and PbPb, similar behavior for normalized SC(2,3)
  ➔Suggests similar IS conditions.

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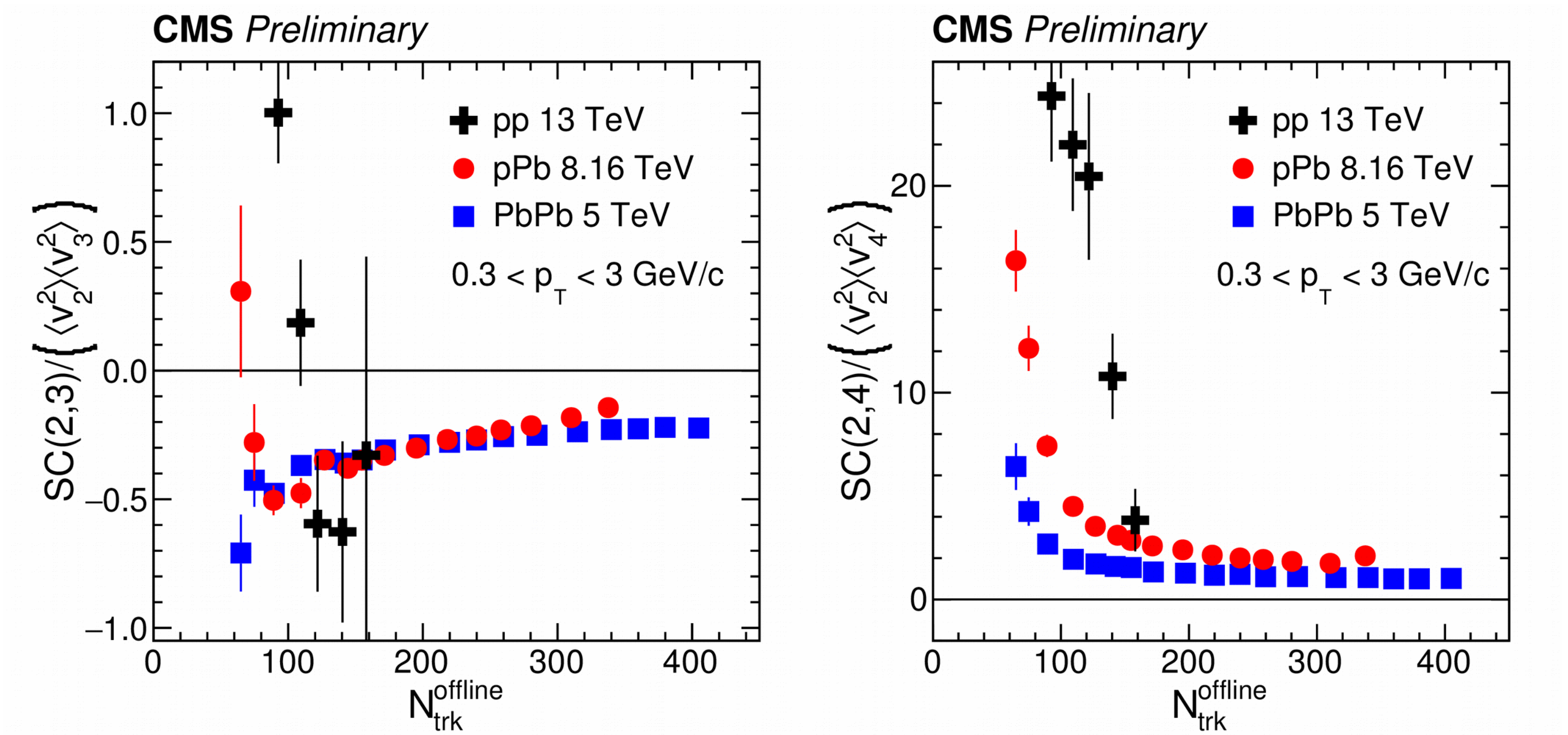

- For pPb and PbPb, similar behavior for normalized SC(2,3)
  ➔Suggests similar IS conditions.

- Ordering observed for normalized SC(2,4): pp > pPb > PbPb
  ➔May suggest different transport properties.

Summary

➢ Mixed order higher harmonics:

✔ Constraints on transport properties at the freeze-out in PbPb collisions.

➢ Symmetric cumulant in different systems (pp, pPb, PbPb):

✔ Suggests <u>similar initial state fluctuation</u> contribution;

✔ And may suggest <u>different transport properties.</u>