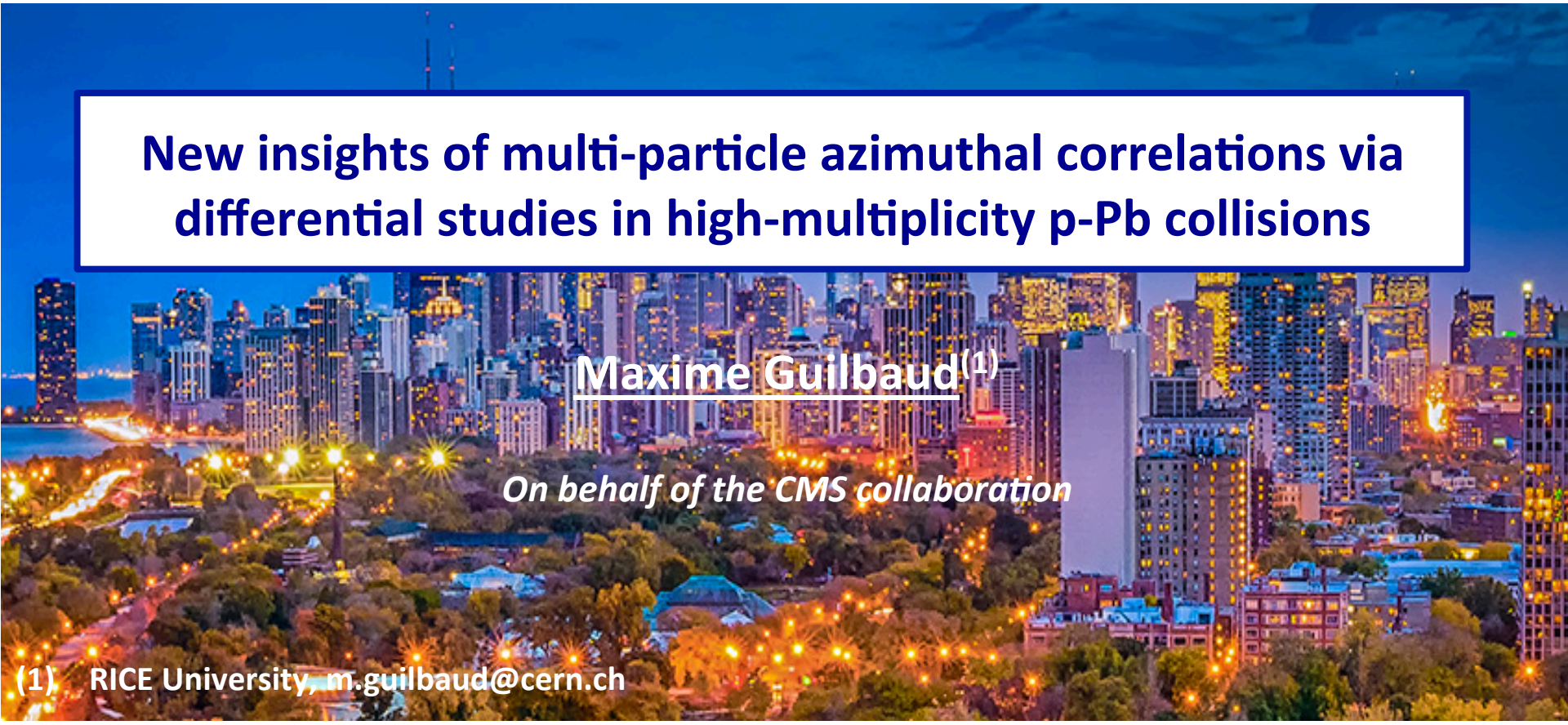


New insights of multi-particle azimuthal correlations via differential studies in high-multiplicity p-Pb collisions

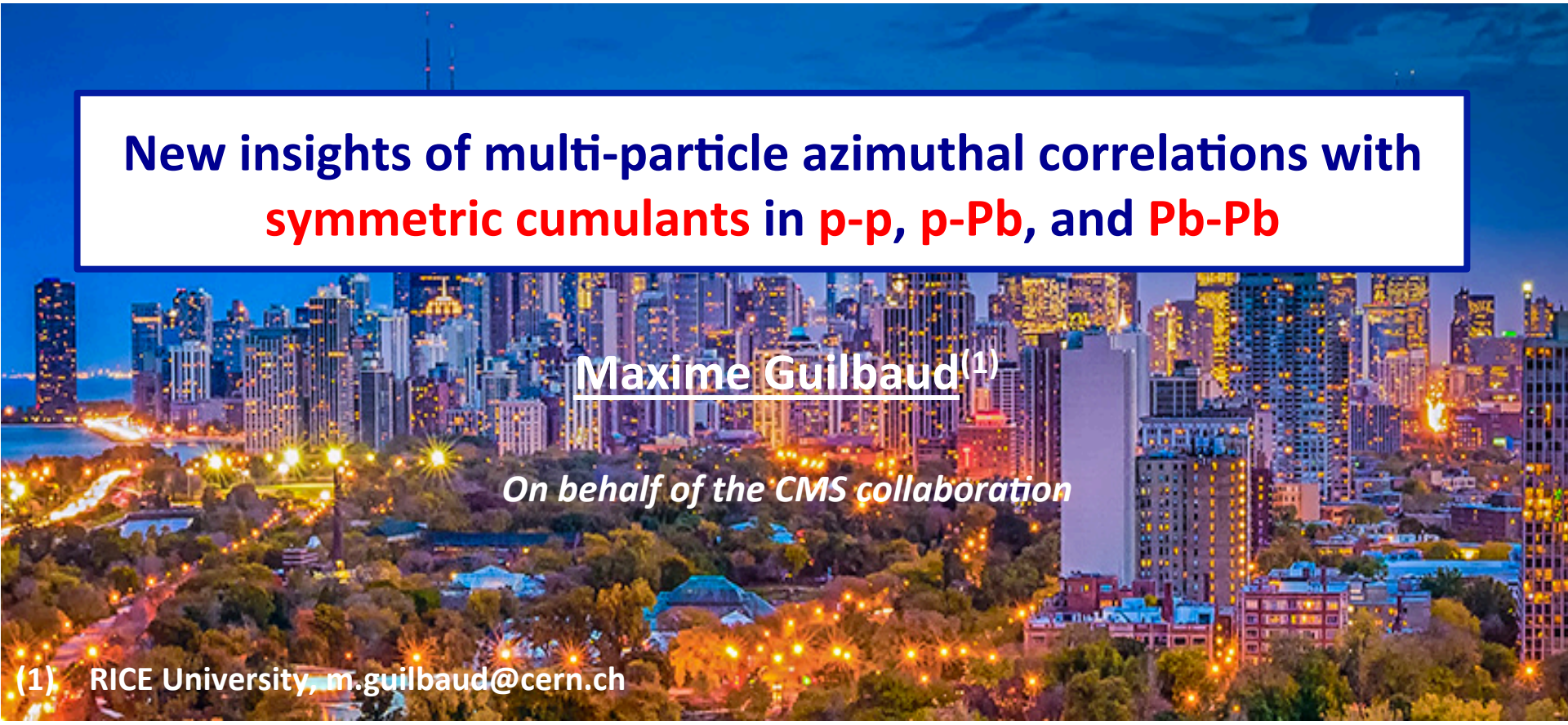
Maxime Guilbaud[(1)]

On behalf of the CMS collaboration

(1) RICE University, m.guilbaud@cern.ch

Parallel session: QCD in small systems

7/2/17



New insights of multi-particle azimuthal correlations with symmetric cumulants in p-p, p-Pb, and Pb-Pb

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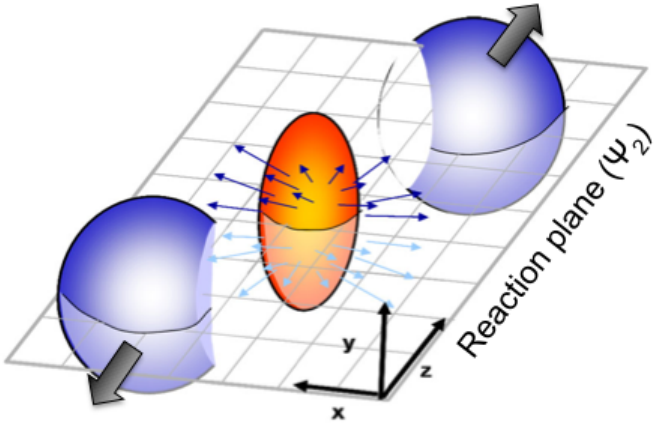
Parallel session: QCD in small systems

7/2/17

Hydrodynamic flow in A-A collisions



$$f(p_T, \phi, \eta) \sim 1 + 2 \cdot \sum_n v_n(p_T, \eta) \cdot \cos[\mathrm{n}(\phi - \Psi_\mathrm{n})]$$

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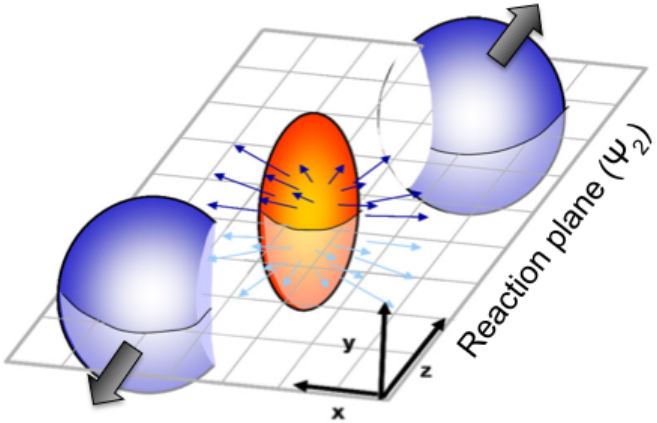

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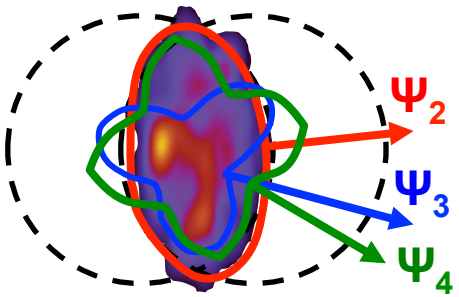

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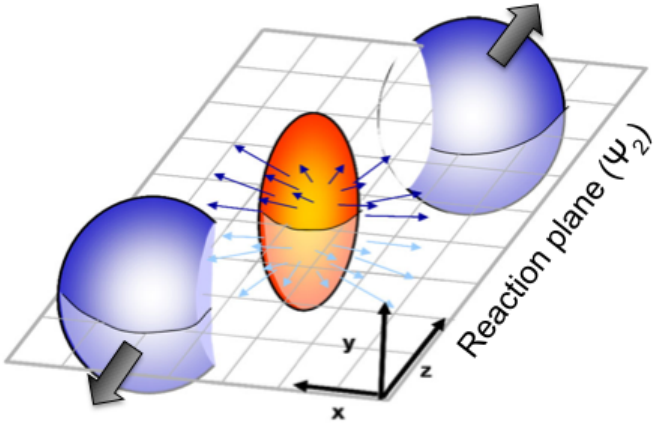

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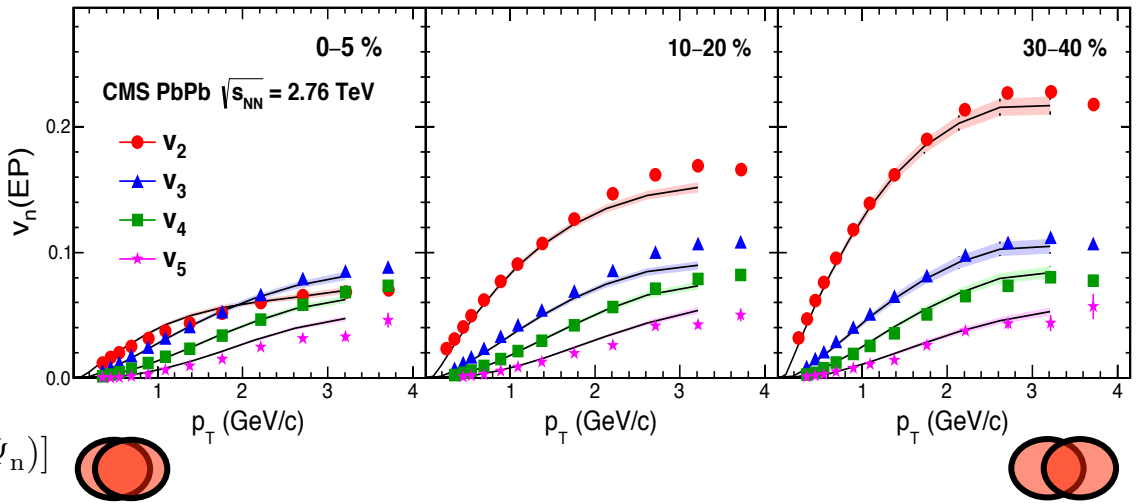
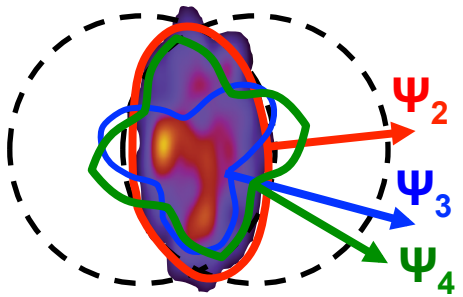


Phys. Rev. C 89, 0449076 **CMS results**

Phys. Rev. Lett. 110, 012302 **IP glasma + MUSIC**

- v_n depends on:
  - Initial state geometry and its fluctuations
  - Medium transport coefficients (η/s, …)
- v_n well understood in A-A collisions with hydro.
  - Diagonal terms (v_n^2)



v_n coefficient correlations

Can we do better?

- Correlations between flow harmonics access details about:
  - Medium response (η/s, …)
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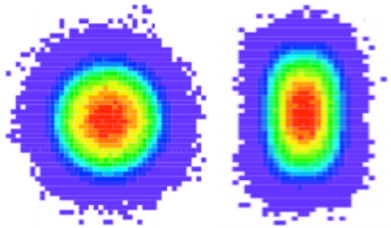
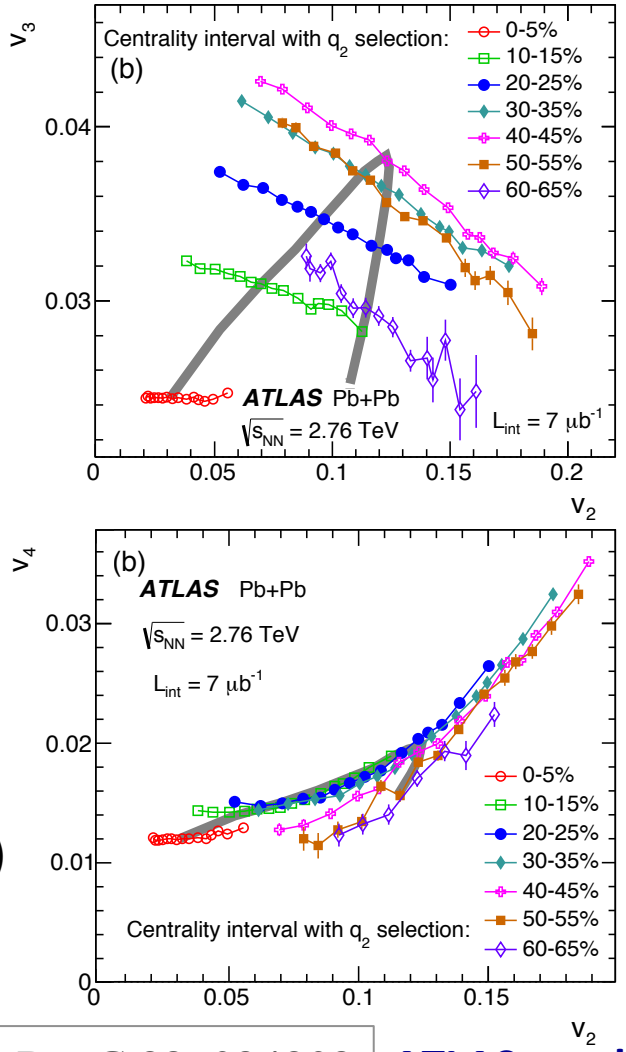


small q_2 **large q_2**

q_2 cut:

- Same centrality (initial geometry)
- Different ellipticity



PhysRevC.92, 034903 **ATLAS results**

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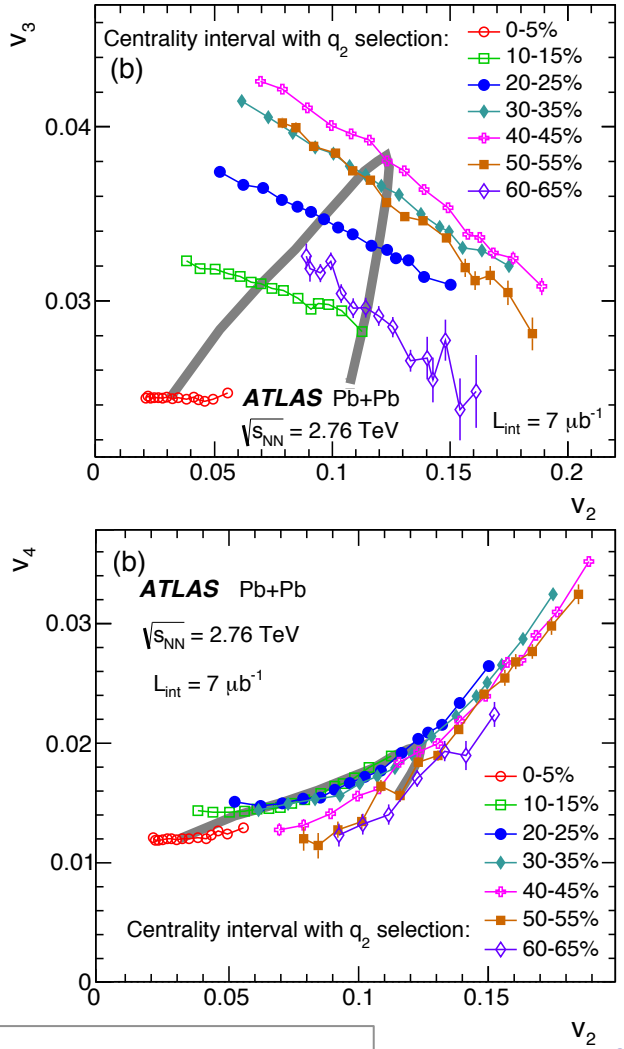
Something else?

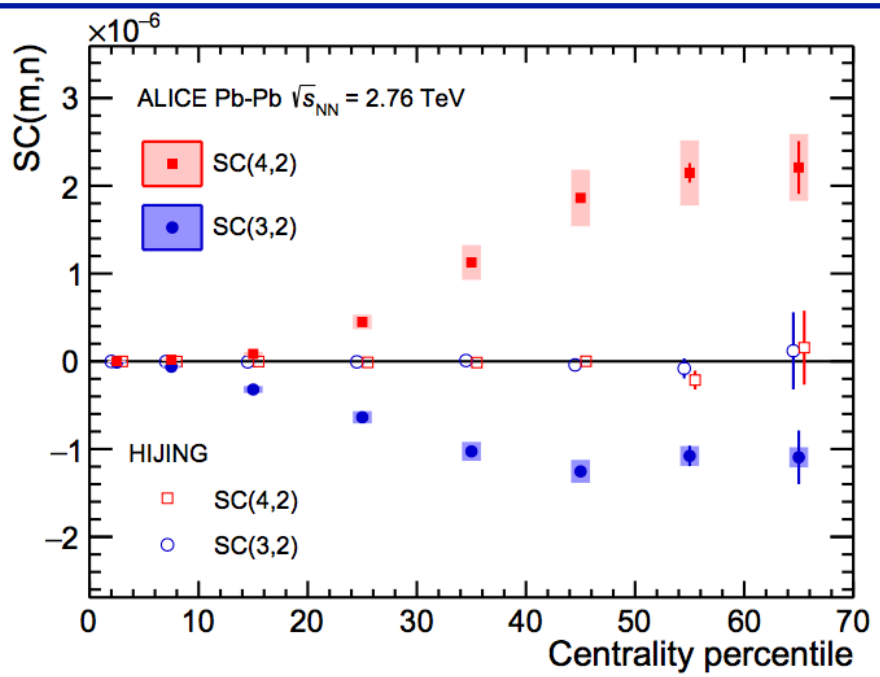


PhysRevC.92, 034903 **ATLAS results**

Symmetric Cumulants (SC) in A-A

- Correlation between harmonics:

$$SC(n,m) = \left\langle v_n^2 v_m^2 \right\rangle - \left\langle v_n^2 \right\rangle \left\langle v_m^2 \right\rangle$$



PhysRevLett.117, 182301 **ALICE results**

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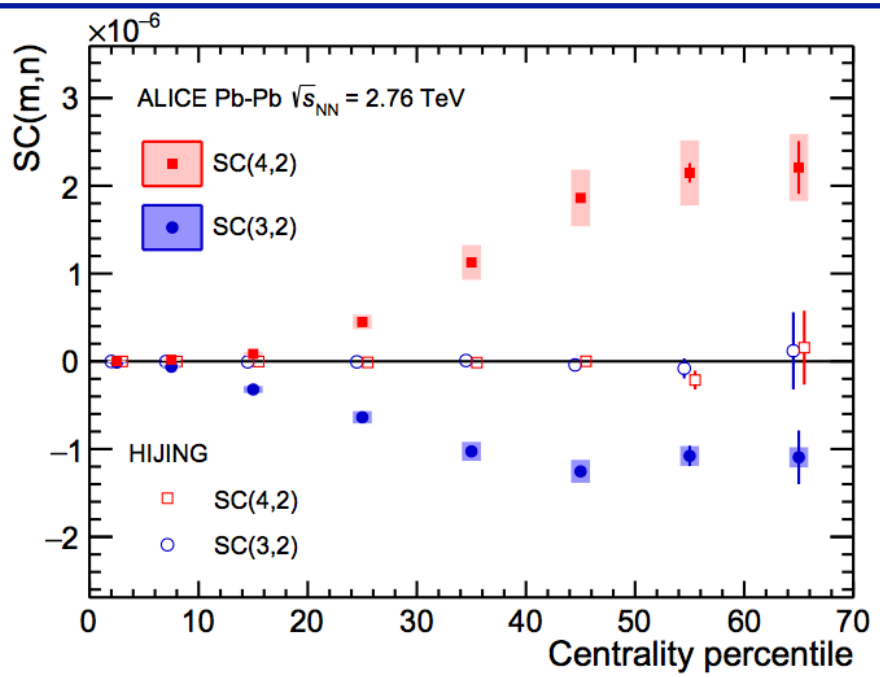
- Symmetric Cumulant (SC) developed by ALICE
  - New observable
  - **Base on 4-particle cumulant technique**
  - Non-flow free at first order



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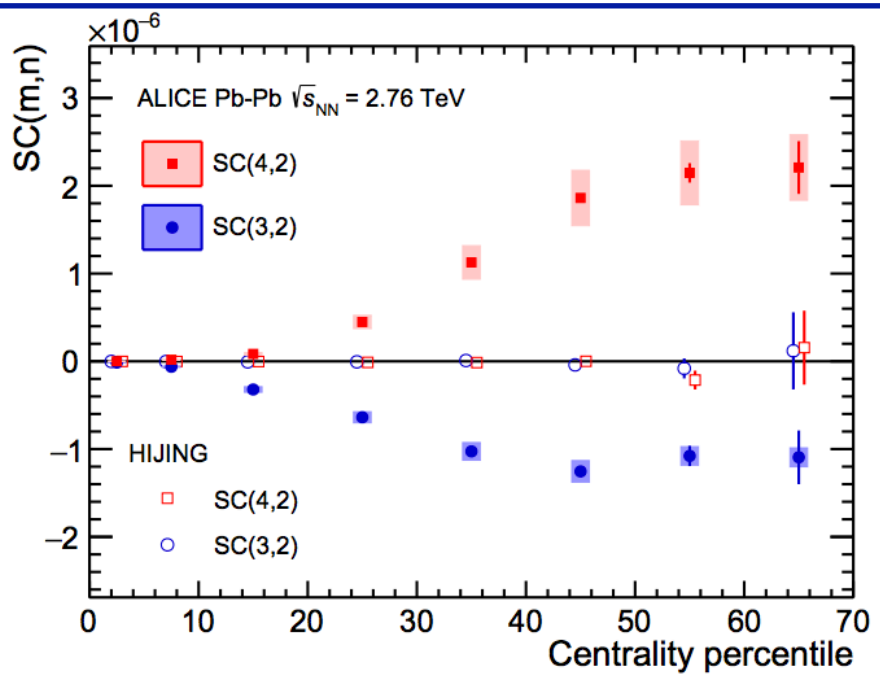
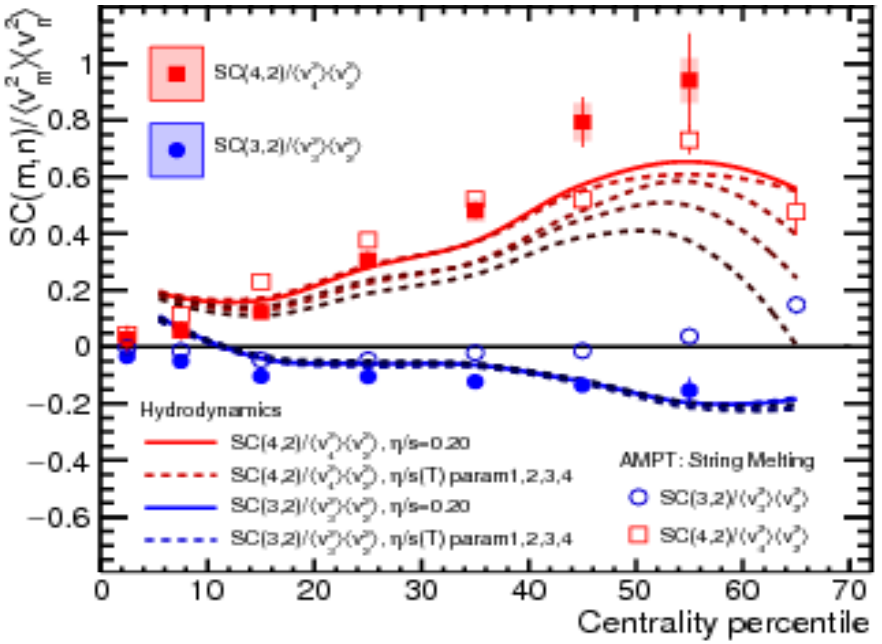


PhysRevLett.117, 182301 **ALICE results**

SC(2,3) < 0 ➔ v_2 and v_3 are **anti-correlated**
SC(2,4) > 0 ➔ v_2 and v_4 are **correlated**

Normalized SC in A-A

- SC normalized by $\langle\varepsilon_n^2\rangle.\langle\varepsilon_m^2\rangle$
  - Only $\langle v_n^2\rangle.\langle v_m^2\rangle$ accessible experimentally
  - Normalized by v_n magnitude



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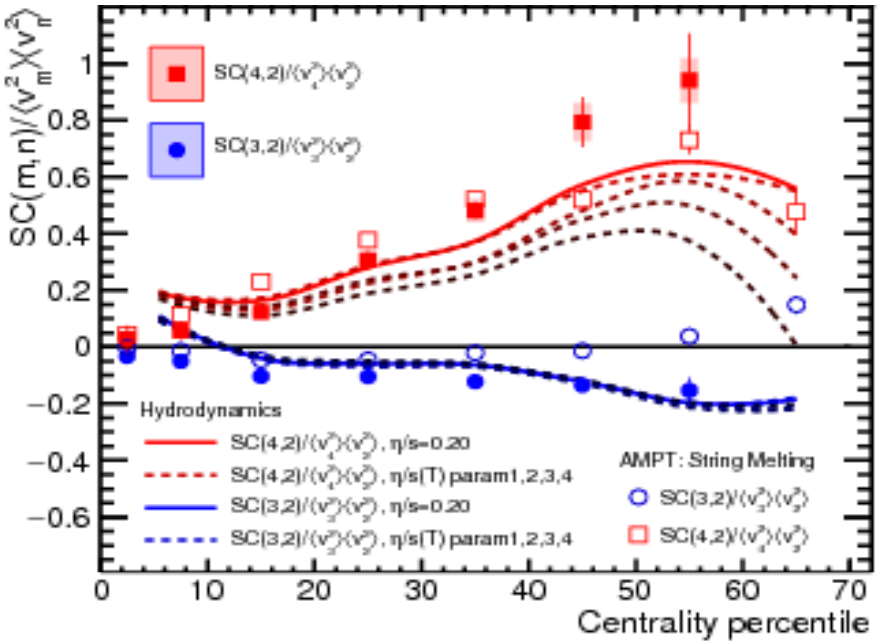

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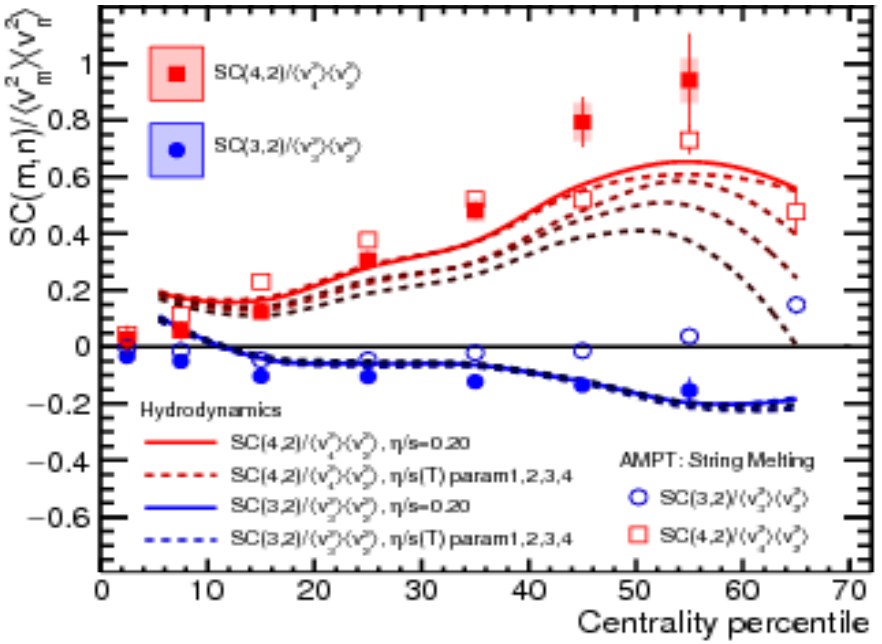

PhysRevLett.117, 182301 **ALICE results**

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- **Stringent constraints on models!**
  - Giacalone et al. **arXiv 1605.08303**
  - Gardim et al. **arXiv 1608.02982**
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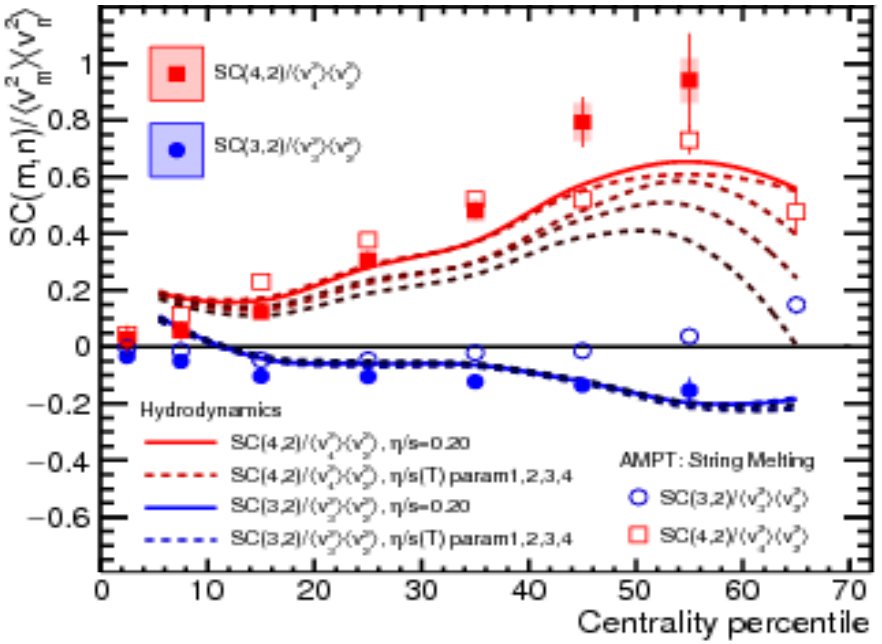

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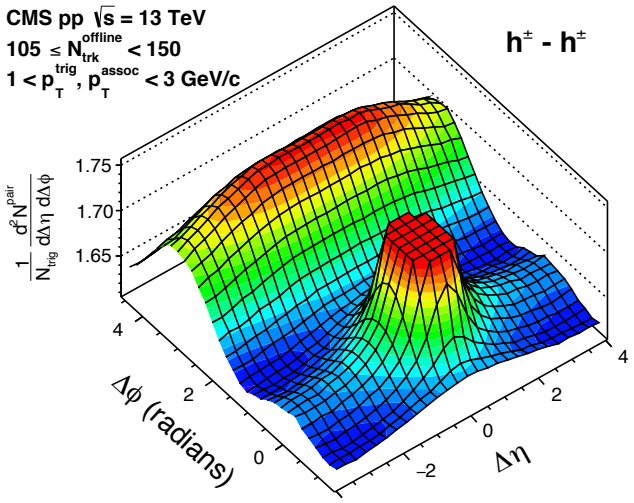
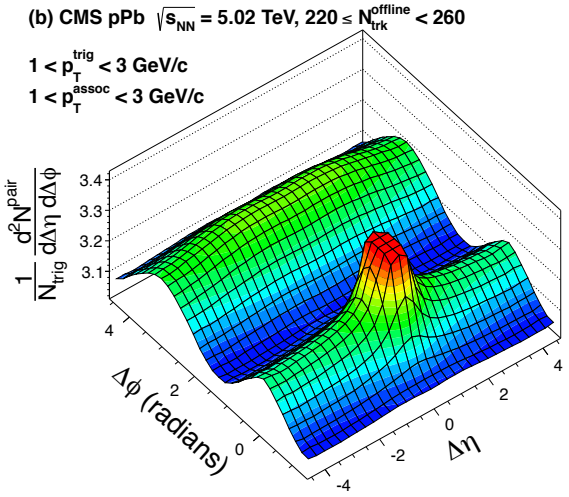
What about small colliding systems?

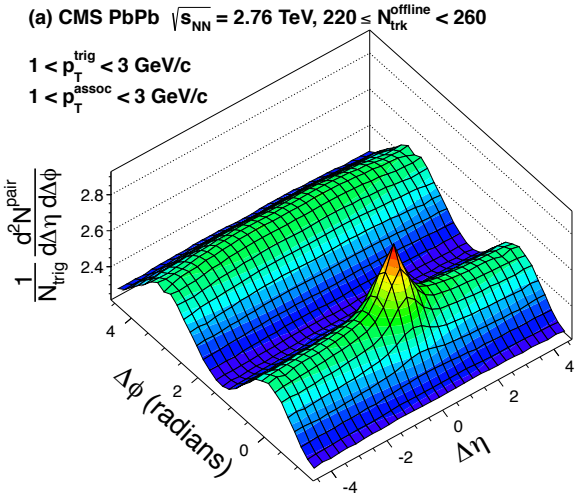
Ridge in small systems

- Ridge observed in all systems
  - **See Z.Chen's talk tomorrow 11.40 am**

PhysLettB.2013.06, 028, PhysLettB.2016.12, 009 **CMS results**







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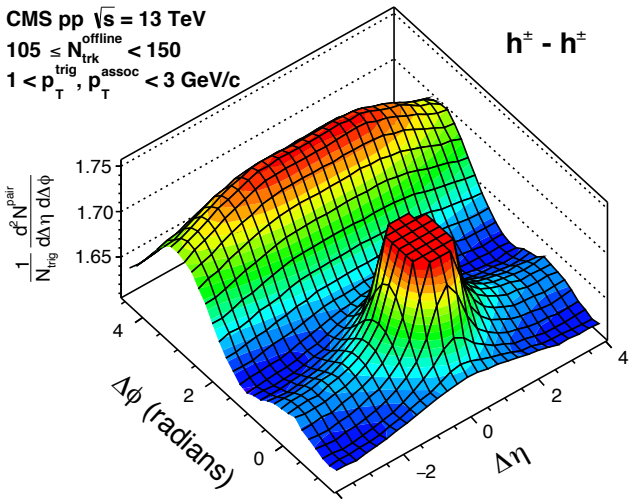

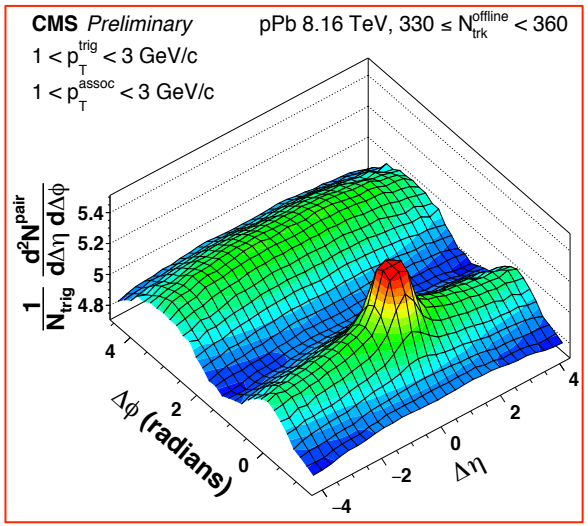

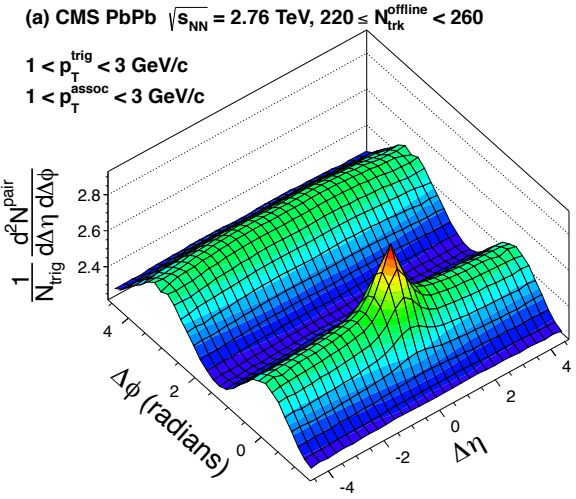

NEW!!!

- Fourier coefficients (v_n) extracted with:
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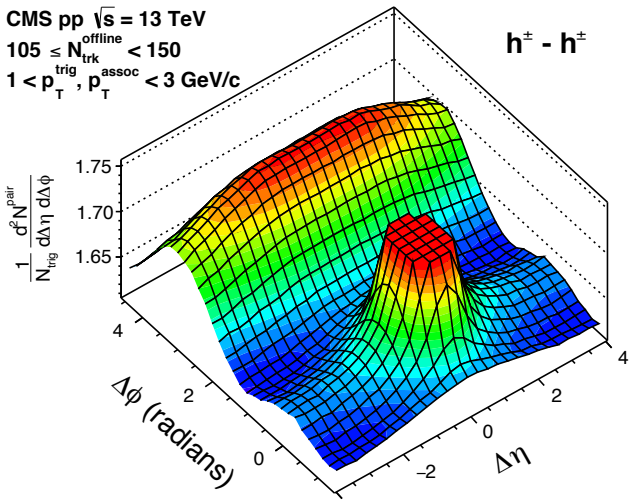

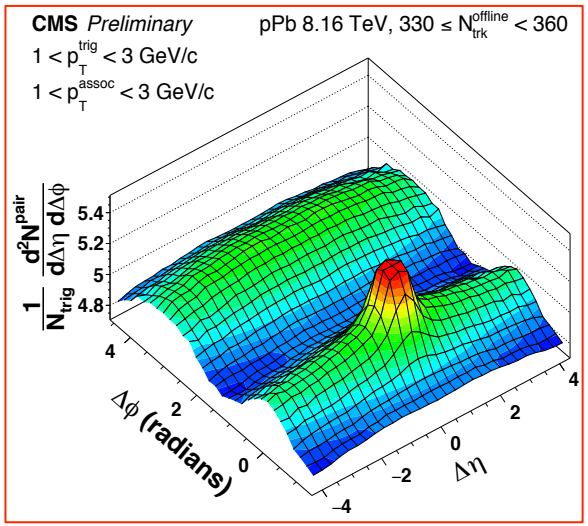

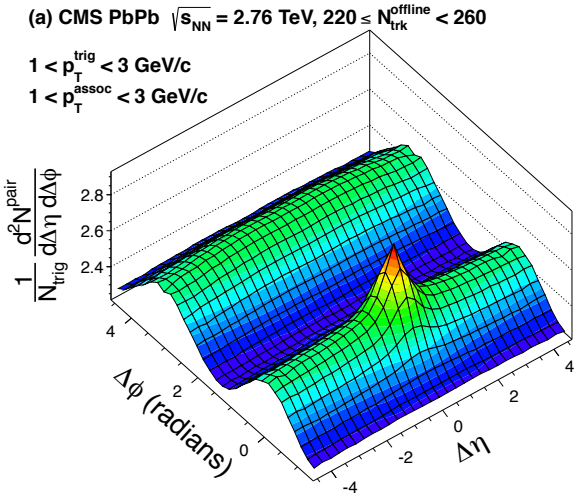

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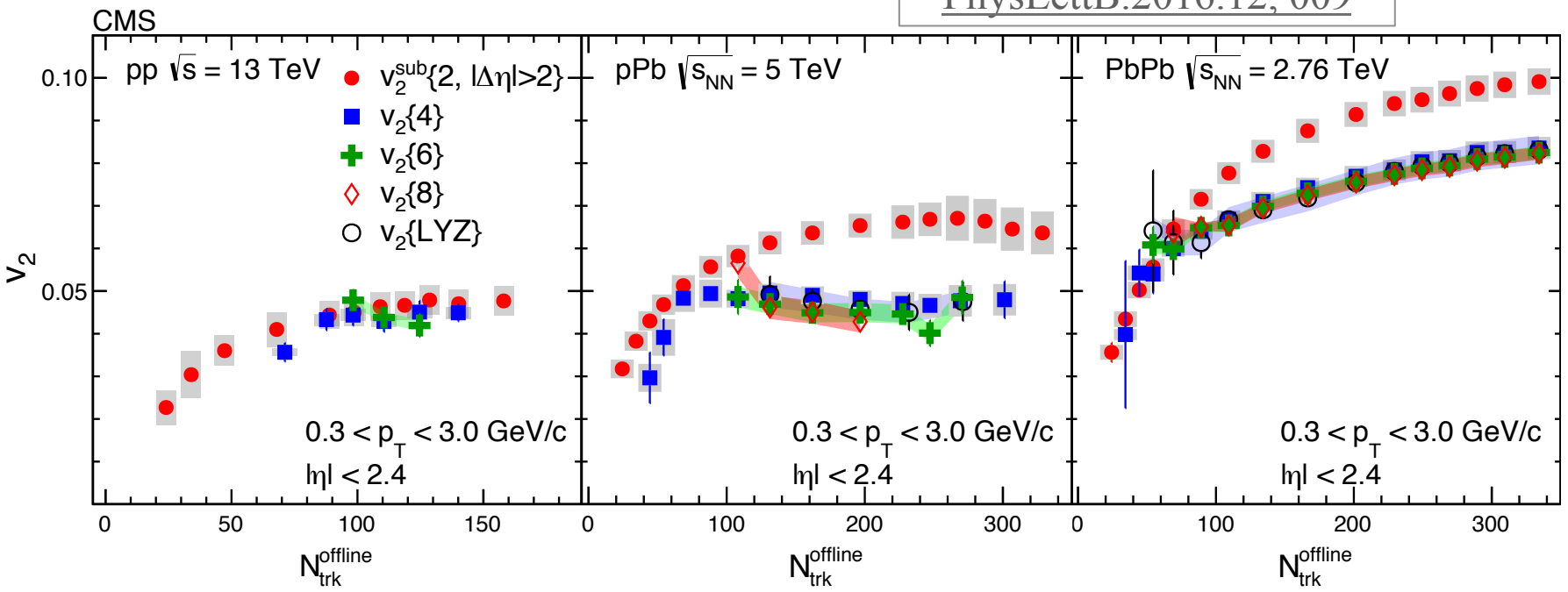
What about correlations?
More insights on the Ridge nature with SCs

Fourier harmonics and multi-particle cumulants in small systems

- Measurement of Fourier harmonics with multi-particle cumulants
  - **See Z.Chen's talk tomorrow 11.40 am**

PhysLettB.2016.12, 009



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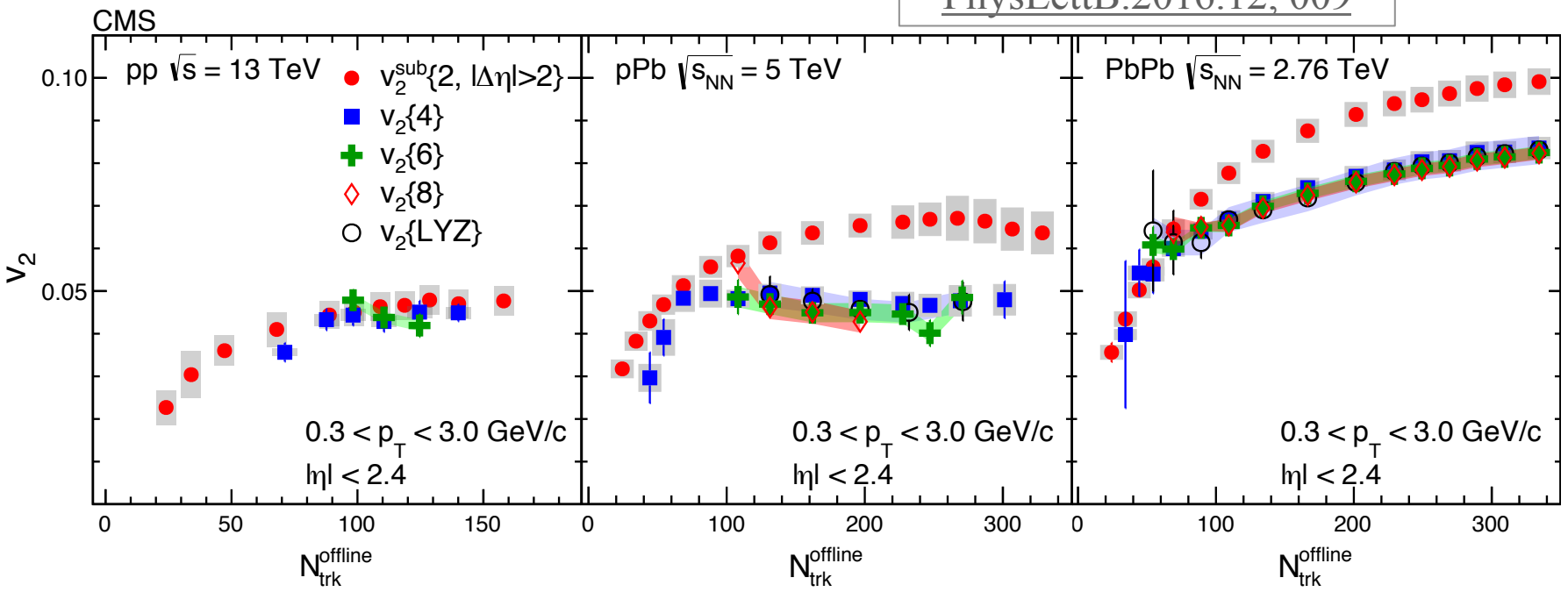

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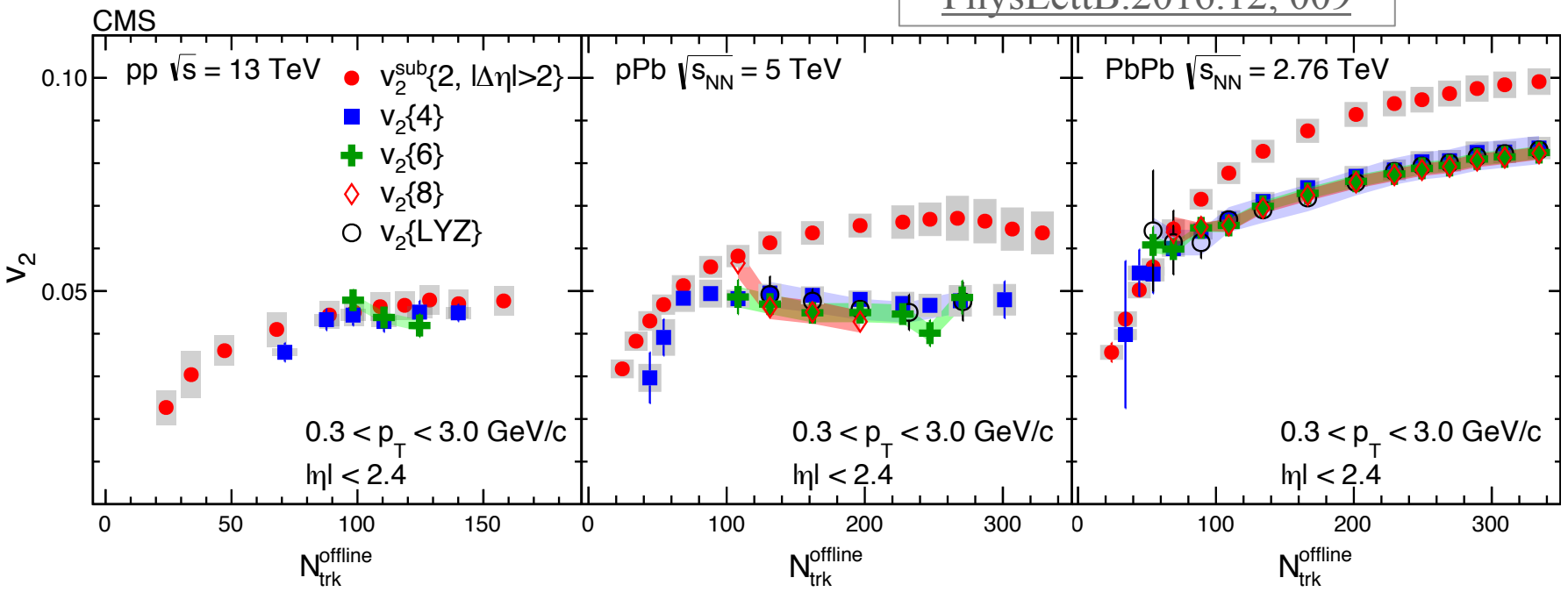

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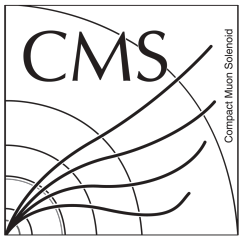
What about correlations between harmonics?

SC in small systems



- SC can be measured in small system (p-p and p-Pb)
  - **Never measured**
  - Little knowledge

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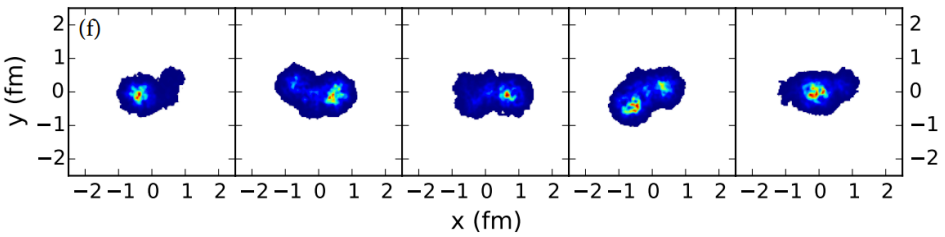
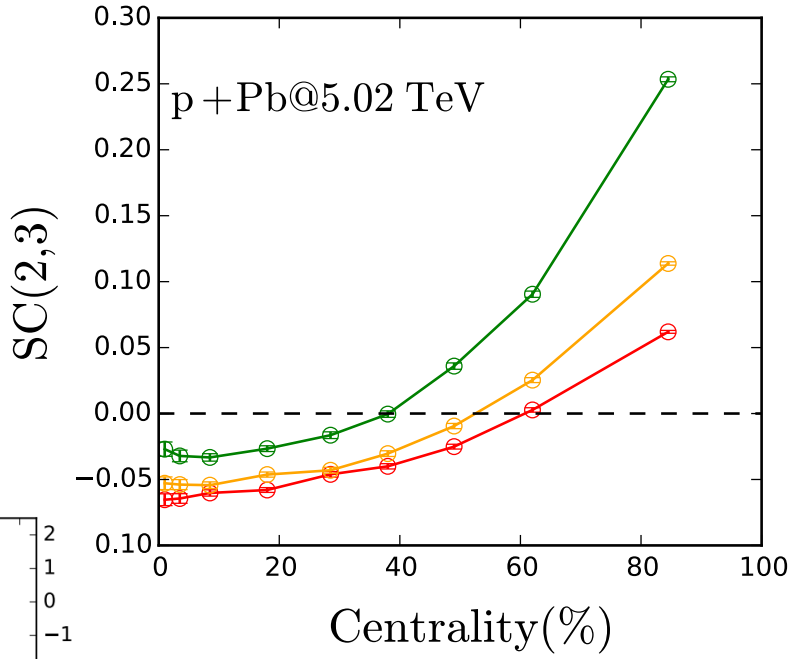
J. Quian, U. Heinz **(eccentricity correlation only)** arXiv 1605.09418

$\sigma_g = 0.25$fm
$\sigma_g = 0.3$fm
$\sigma_g = 0.3$fm, $\theta = 0.75$
$\sigma_g = 0.4$fm

quark width

multiplicity fluctuations





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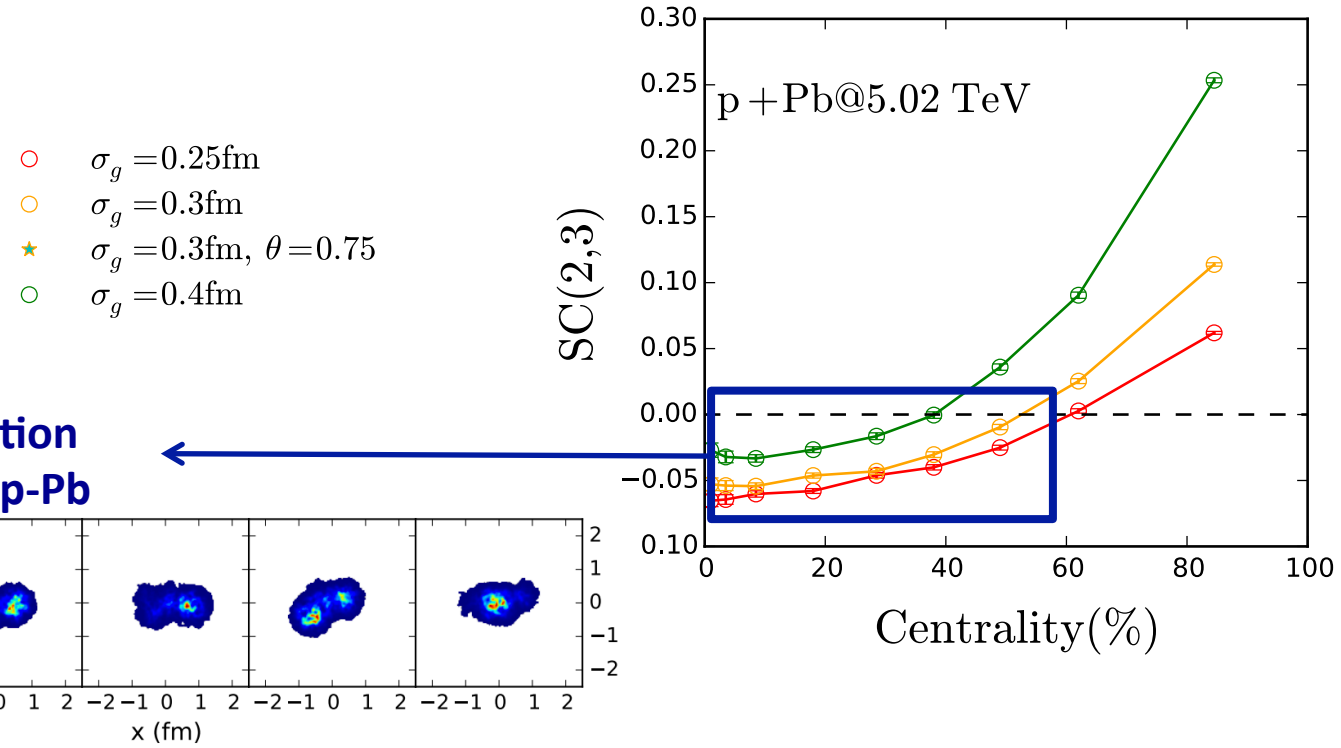
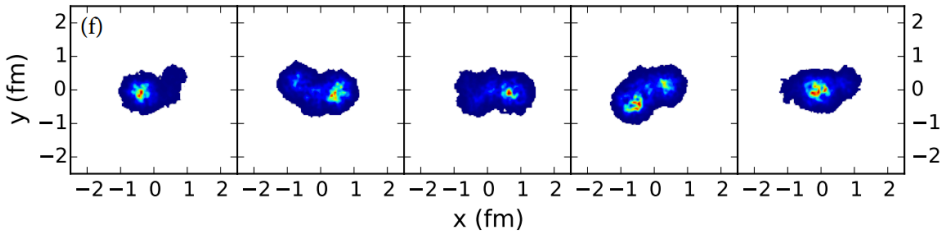


Anti-correlation predicted in p-Pb



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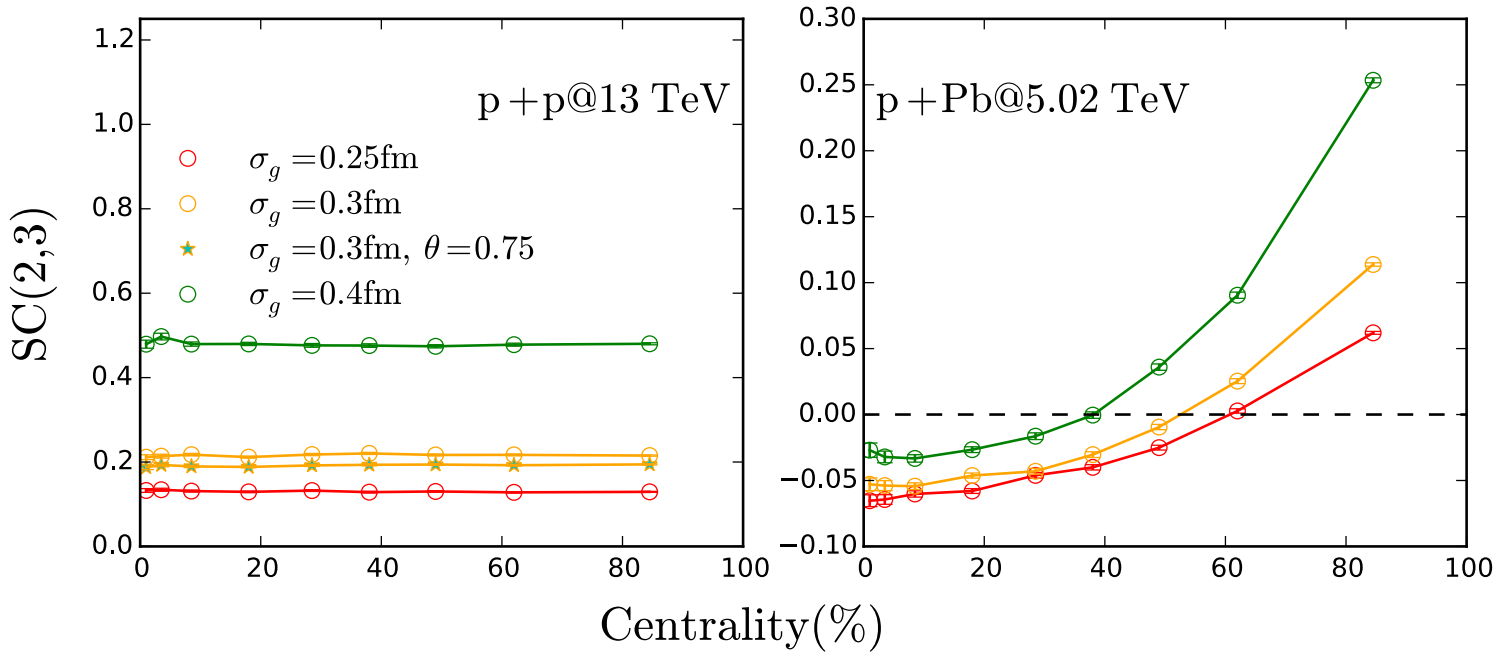

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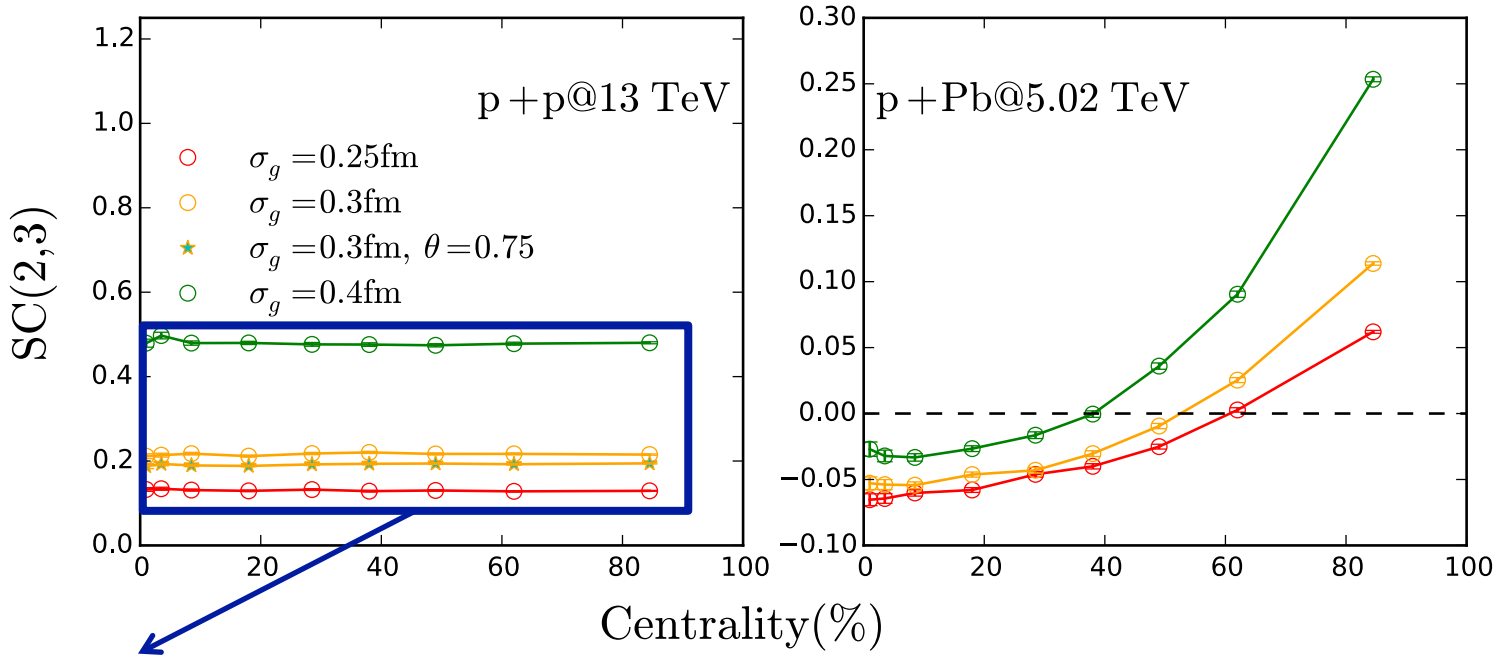

Correlation predicted in p-p → **Related to the number of fluctuating sources**

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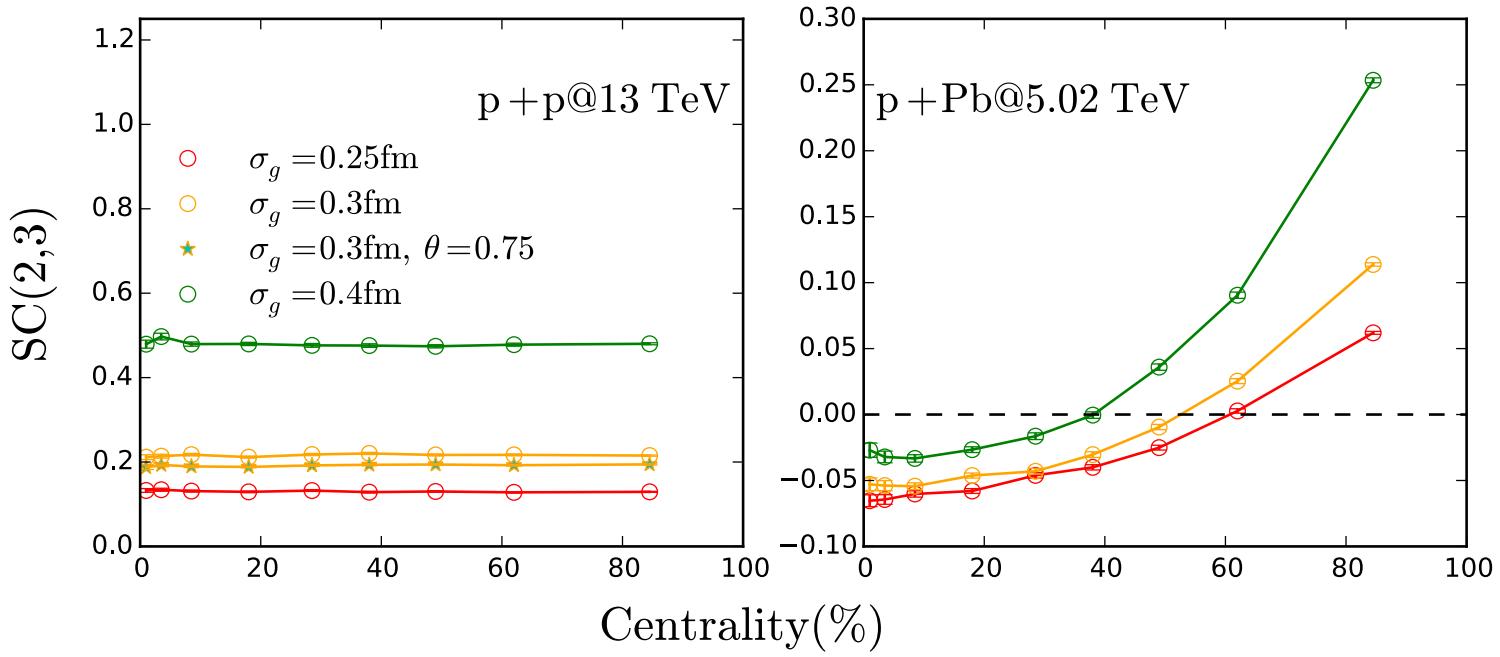
  - Little knowledge

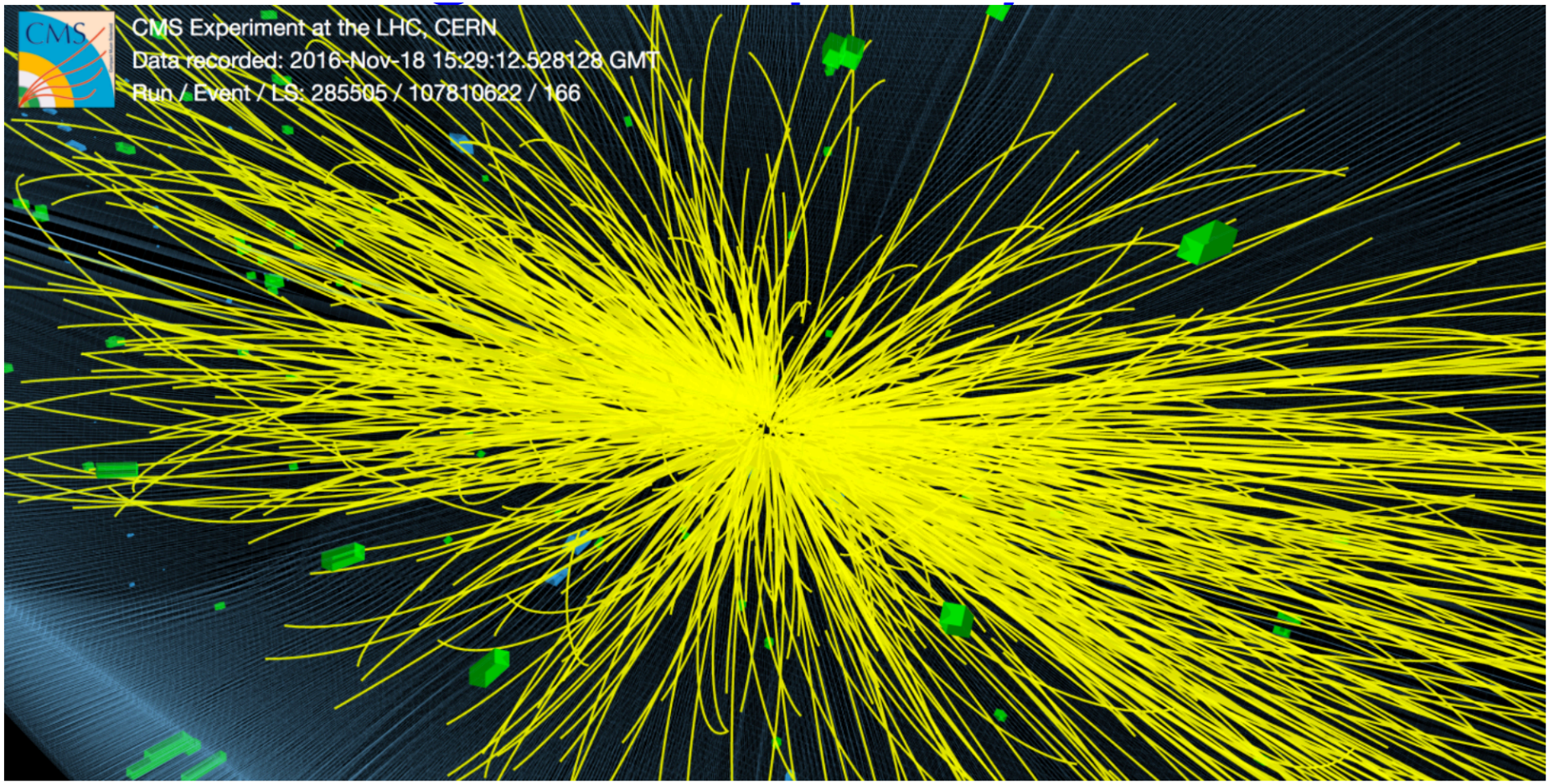
J. Quian, U. Heinz **(eccentricity correlation only)** arXiv 1605.09418



High multiplicity data in small system needed!!!

New p-Pb data at 8.16 TeV

Large sample of high-multiplicity events collected for p-p (13 TeV: 2.2 pb^{-1}) and p-Pb (5.02 & 8.16 TeV: 35 nb^{-1}/186 nb^{-1}) so far!!!



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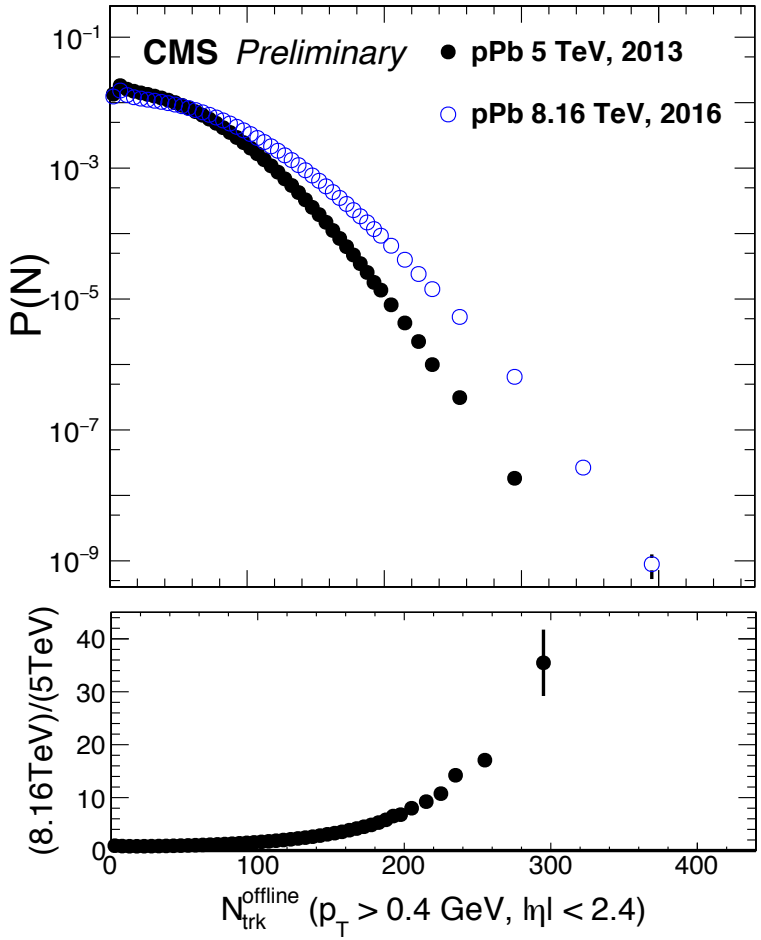
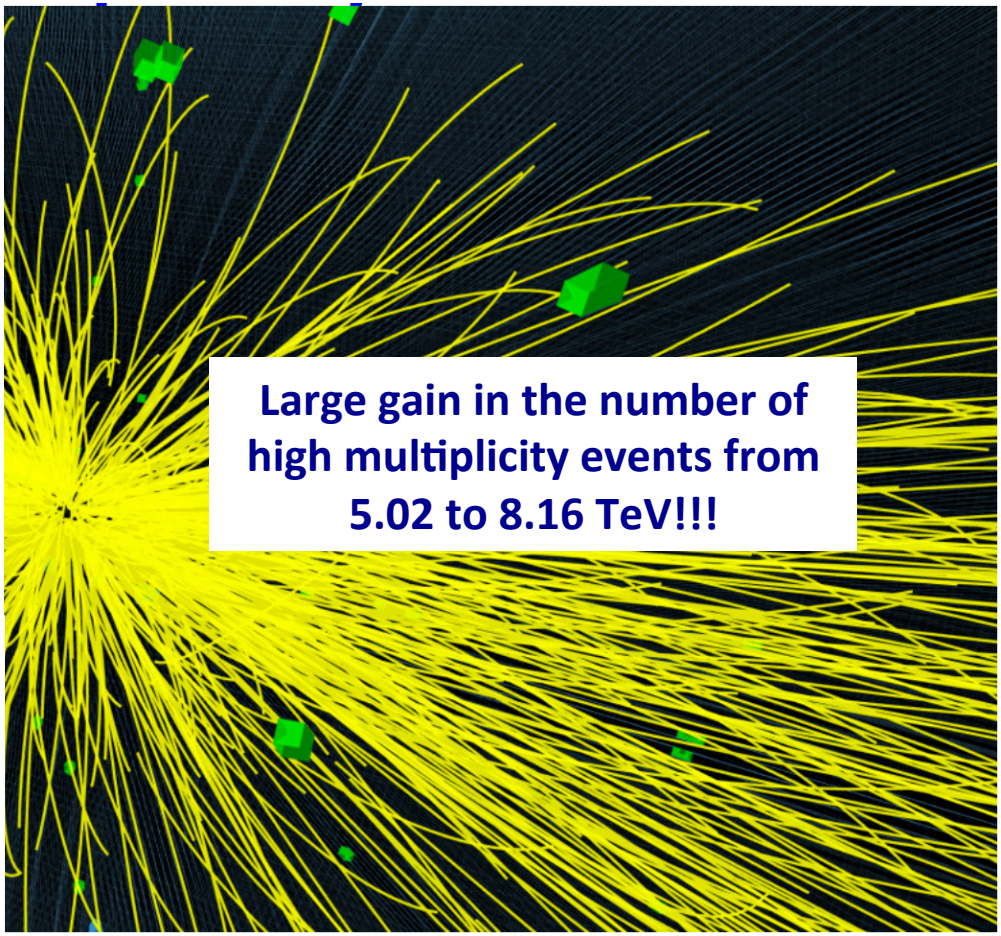
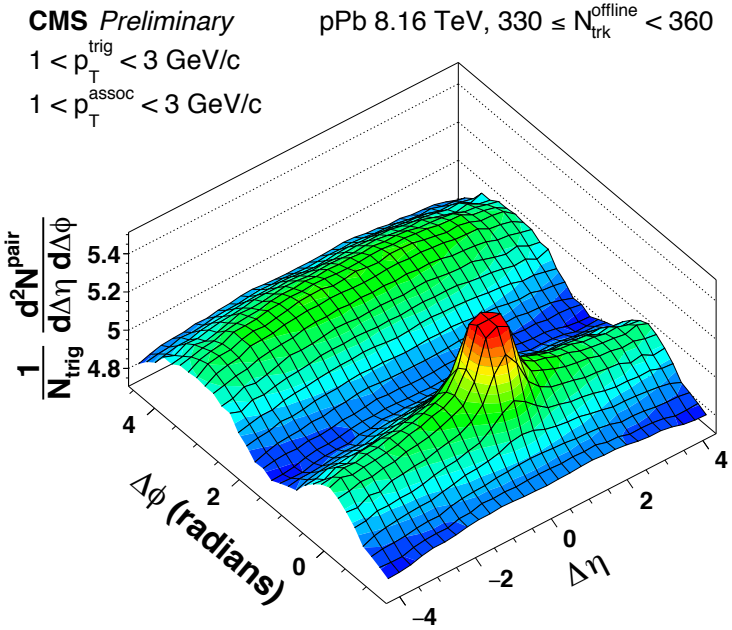




2-particle correlation technique

2D correlation function



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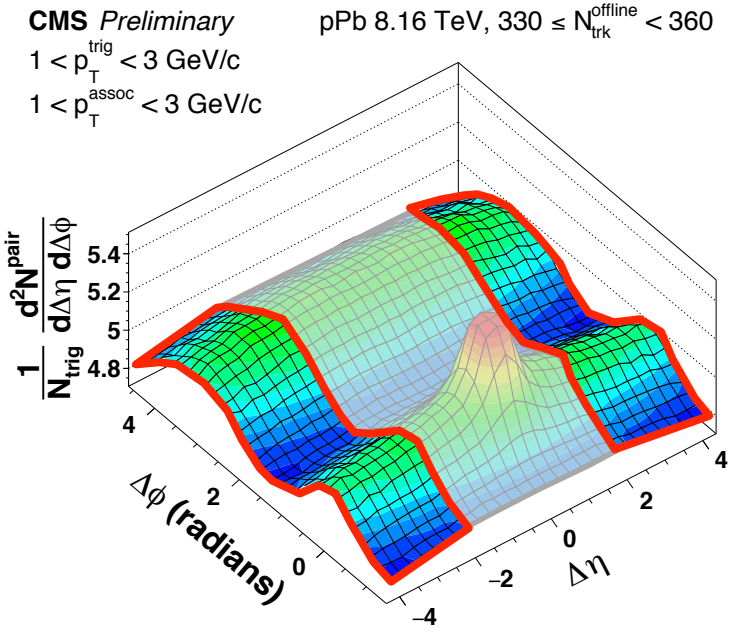
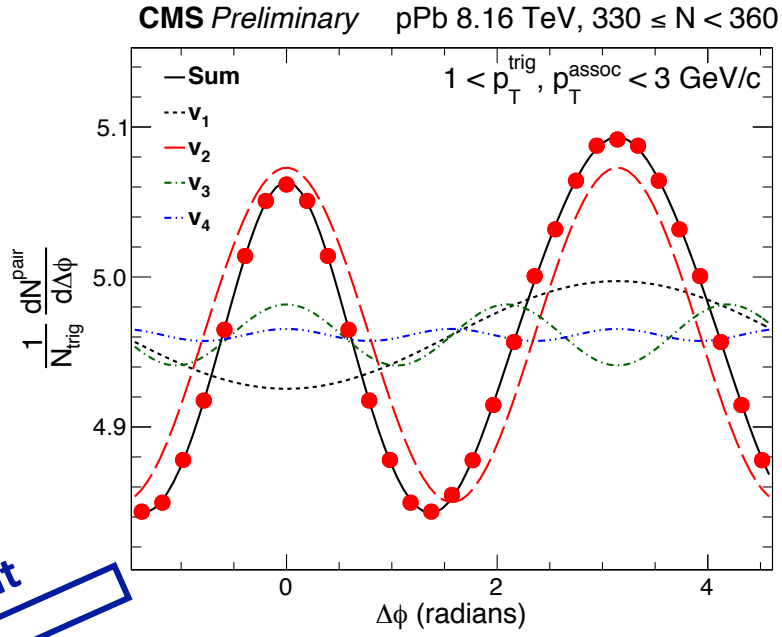


Projection on ΔΦ

1D correlation function



Fourier fit

$$\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}N^{\mathrm{pair}}}{\mathrm{d}\Delta\phi} = \frac{N_{\mathrm{assoc}}}{2\pi}\left[1+\sum_{n} 2V_{n\Delta}\cos(n\Delta\phi)\right]$$

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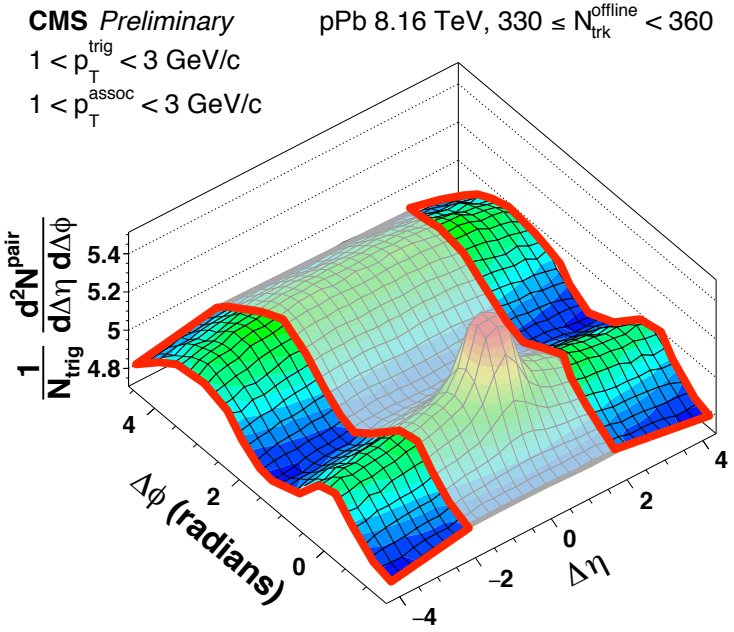

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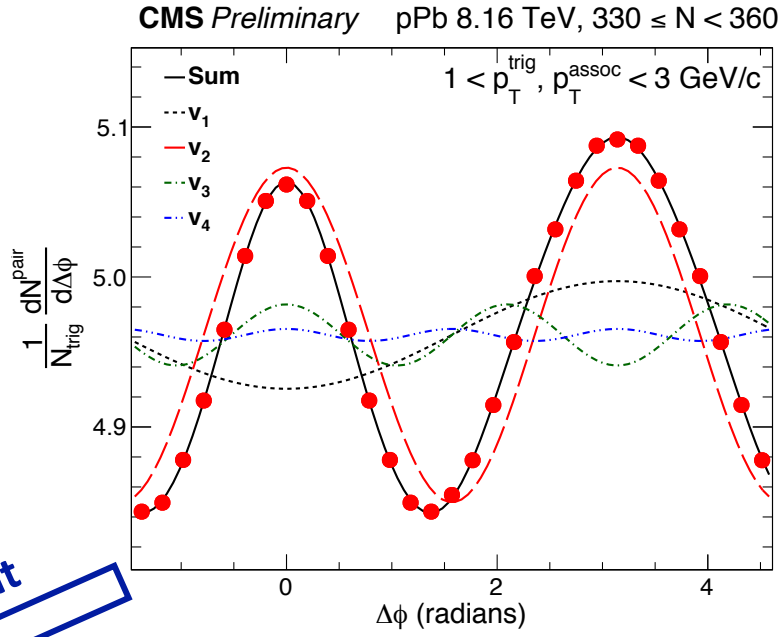

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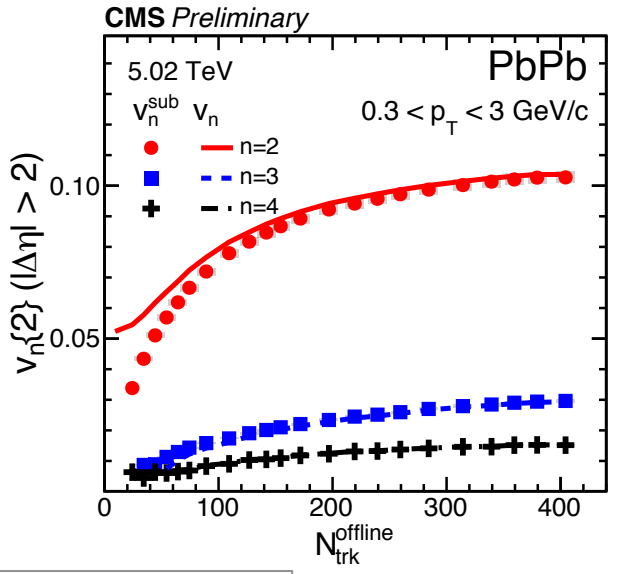
$$v_n = \sqrt{V_{n\Delta}}$$

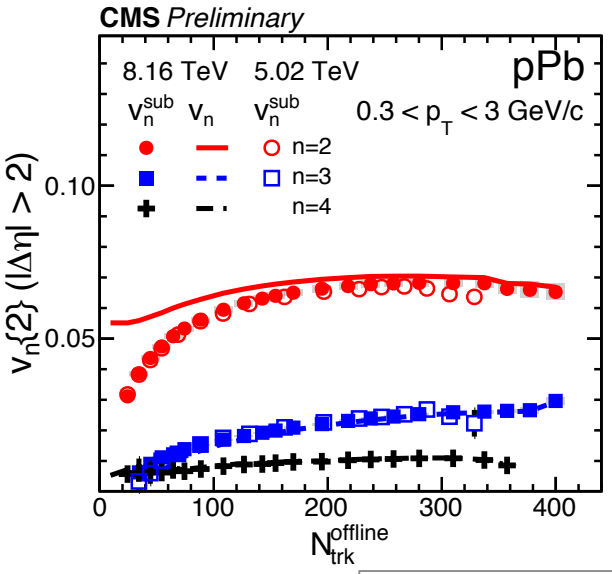
Extract single particle v_n

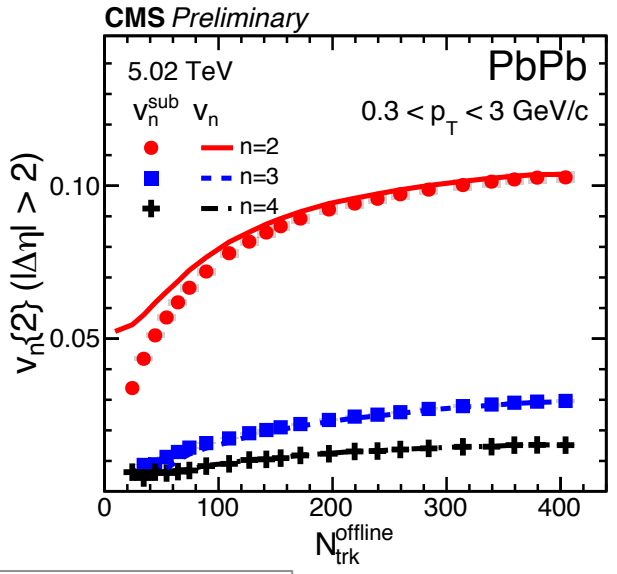
v_n as a function of multiplicity



CMS-PAS-HIN-16-022

v_n as a function of multiplicity





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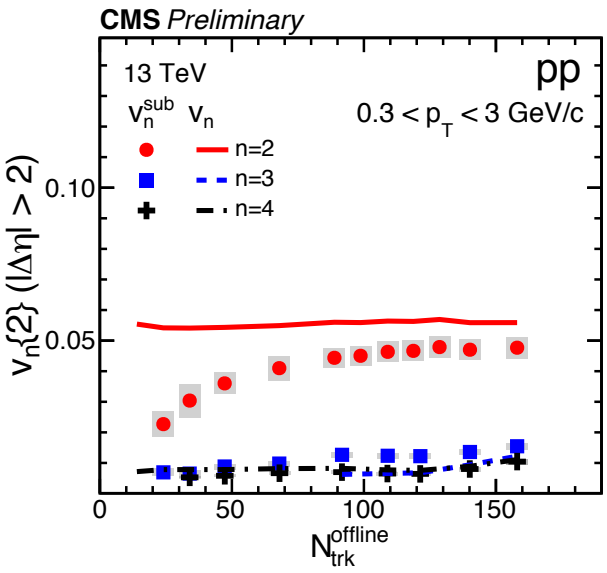
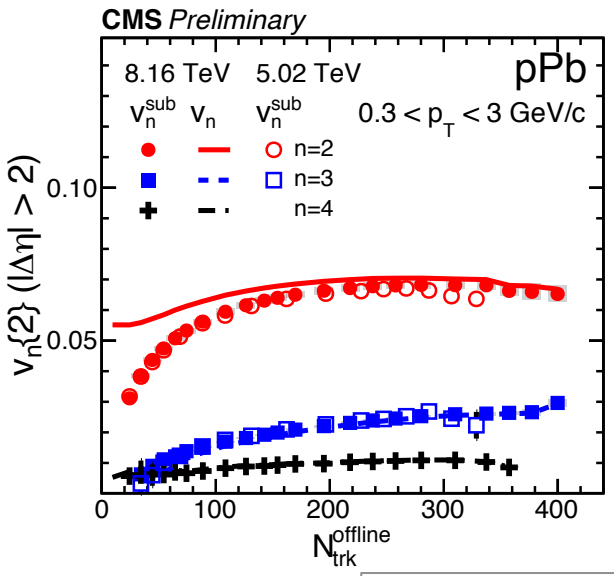
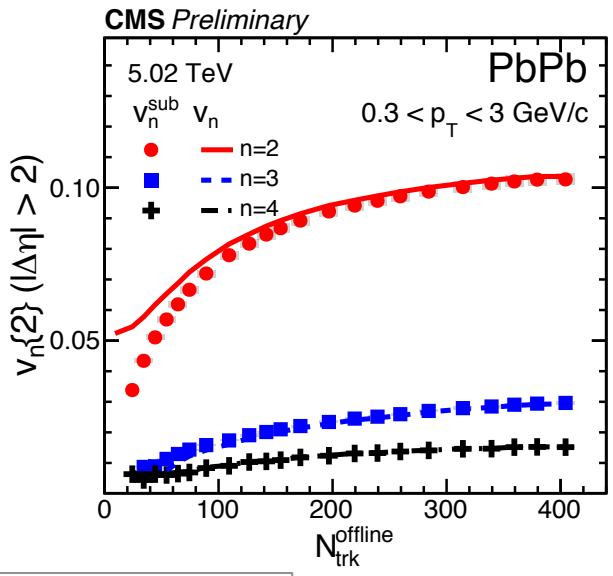


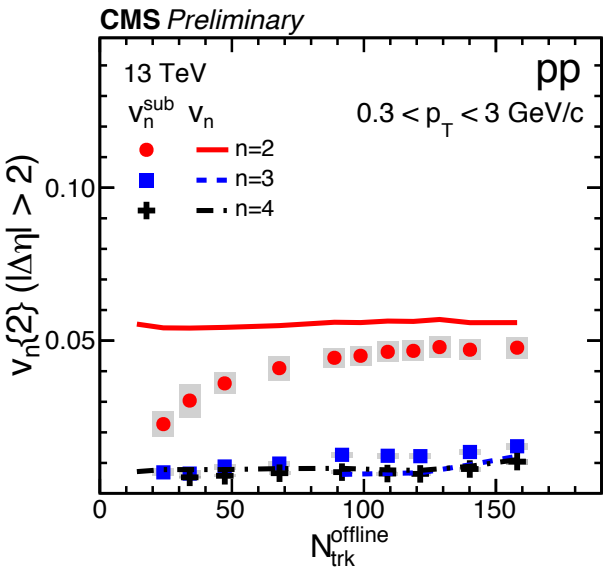


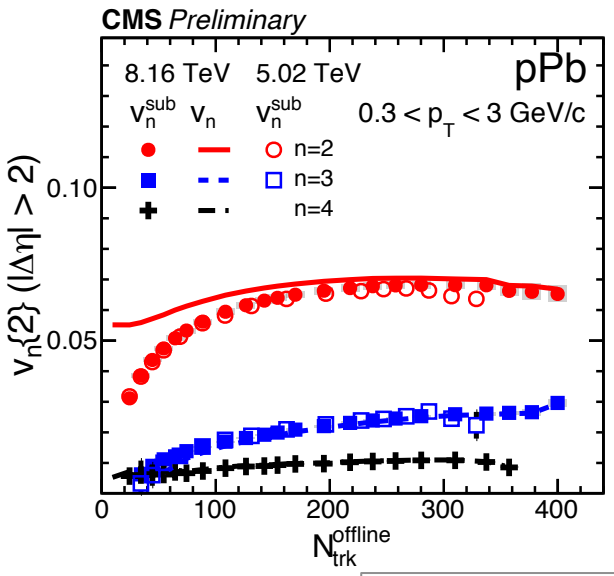


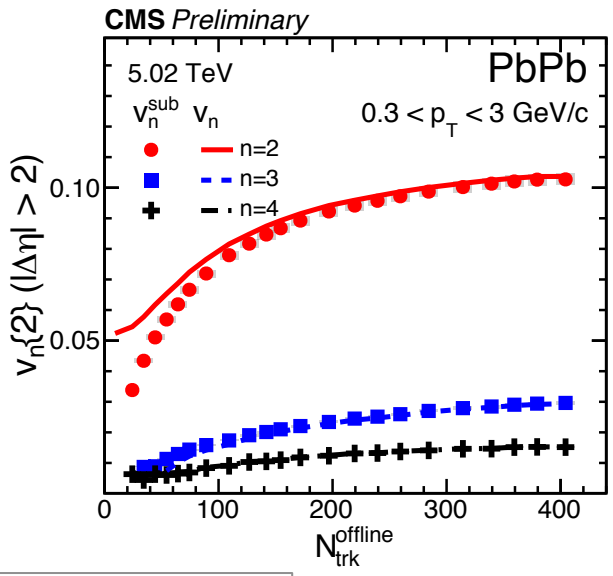
CMS-PAS-HIN-16-022

- Similar pattern observed across systems for v_n

v_n as a function of multiplicity



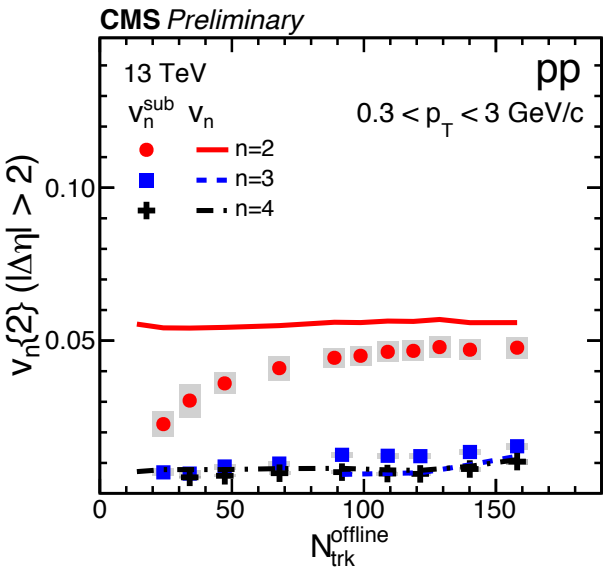


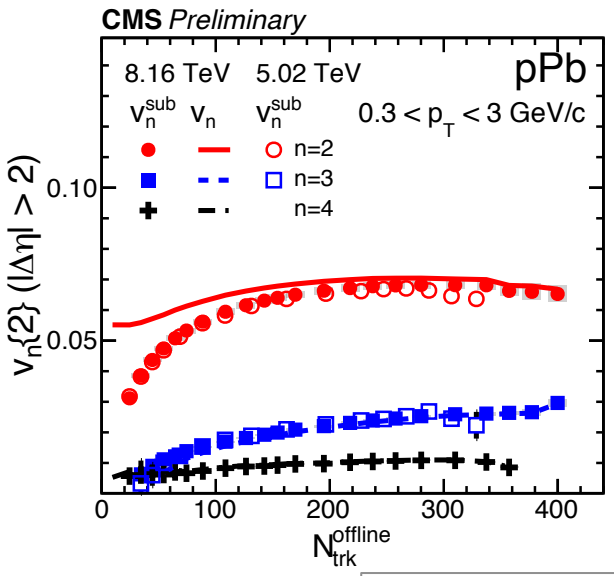


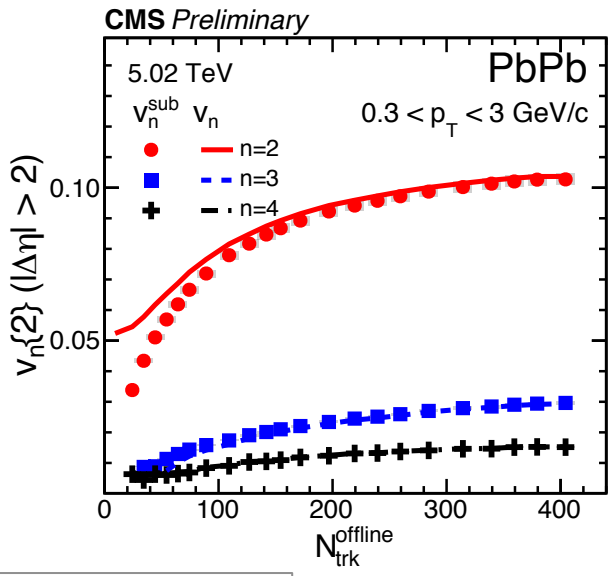
CMS-PAS-HIN-16-022

- Similar pattern observed across systems for v_n
- Very small energy dependence observed for p-Pb results

v_n as a function of multiplicity







CMS-PAS-HIN-16-022

- Similar pattern observed across systems for v_n
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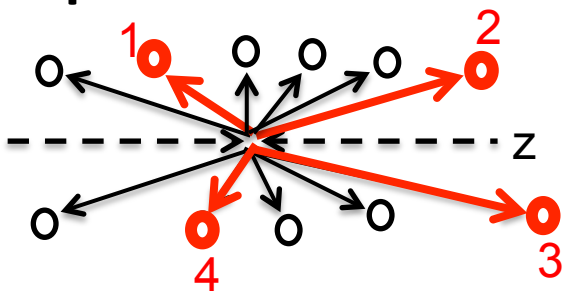
These results will be used to normalize SCs

Symmetric cumulant

Based on 4-particle cumulant technique



- **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**

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

Symmetric cumulant

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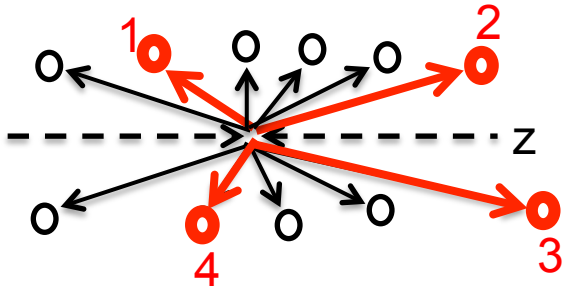

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- **Symmetric cumulant**

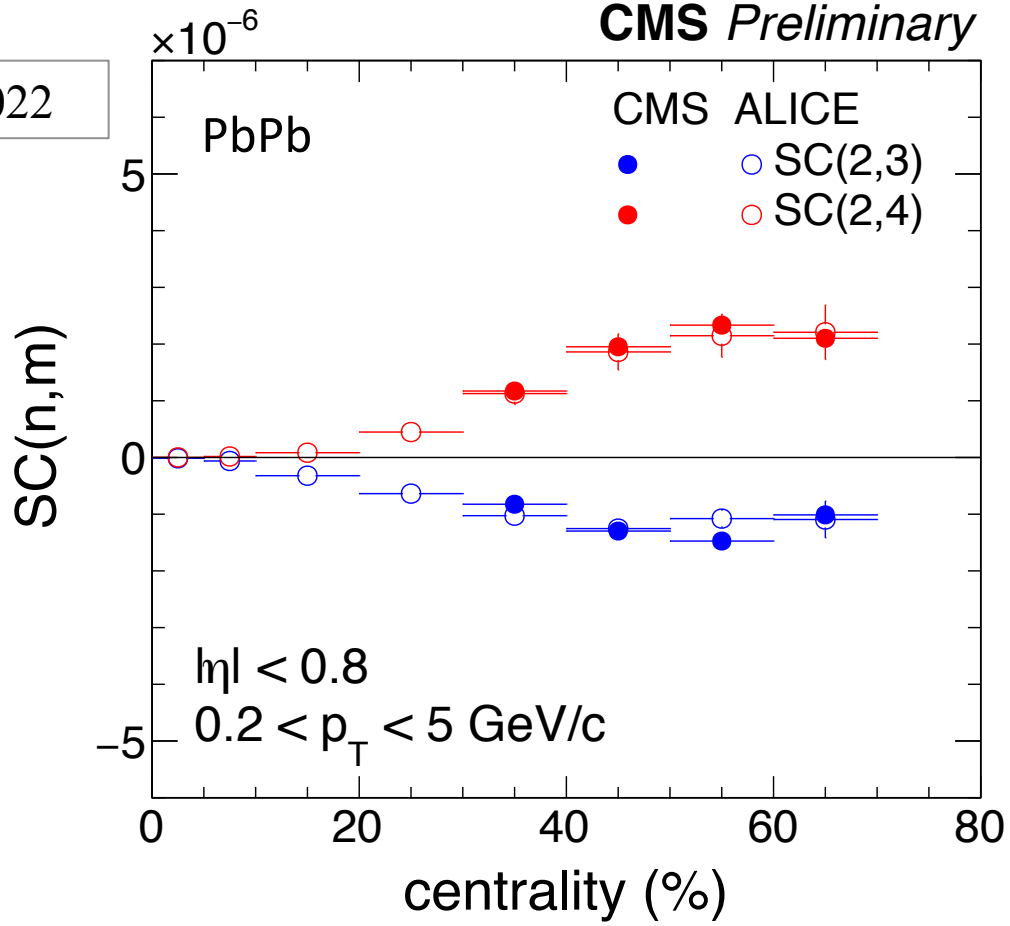
$$SC(n,m) = \langle\langle 4\rangle\rangle_{n,m} - \langle\langle 2\rangle\rangle_n \cdot \langle\langle 2\rangle\rangle_m = \left\langle v_n^2 v_m^2 \right\rangle - \left\langle v_n^2 \right\rangle \left\langle v_m^2 \right\rangle$$

Correlators are expressed in terms of Q-vectors $Q_n \equiv \sum_{i=1}^{M} e^{in\phi_i}$

SC comparison with ALICE

Very good agreement with ALICE using the same cuts

CMS-PAS-HIN-16-022



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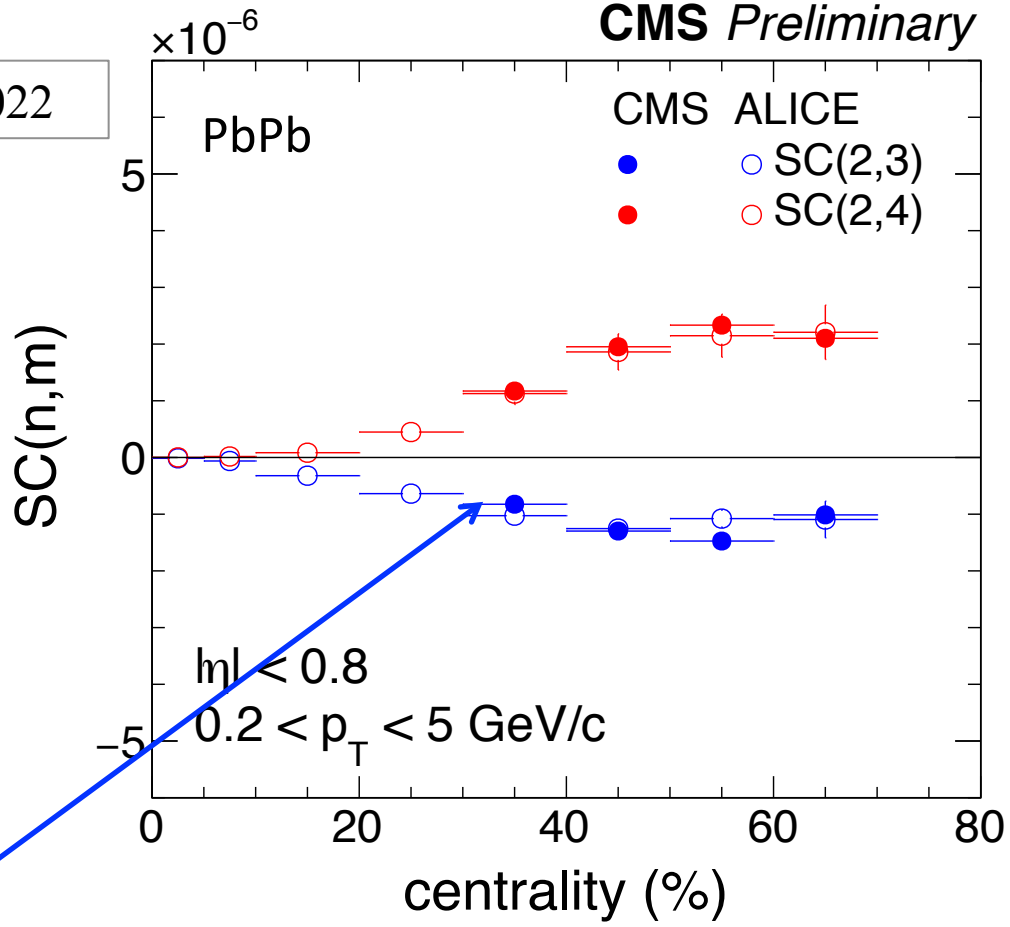

SC(2,3): v_2, v_3 anti-correlated

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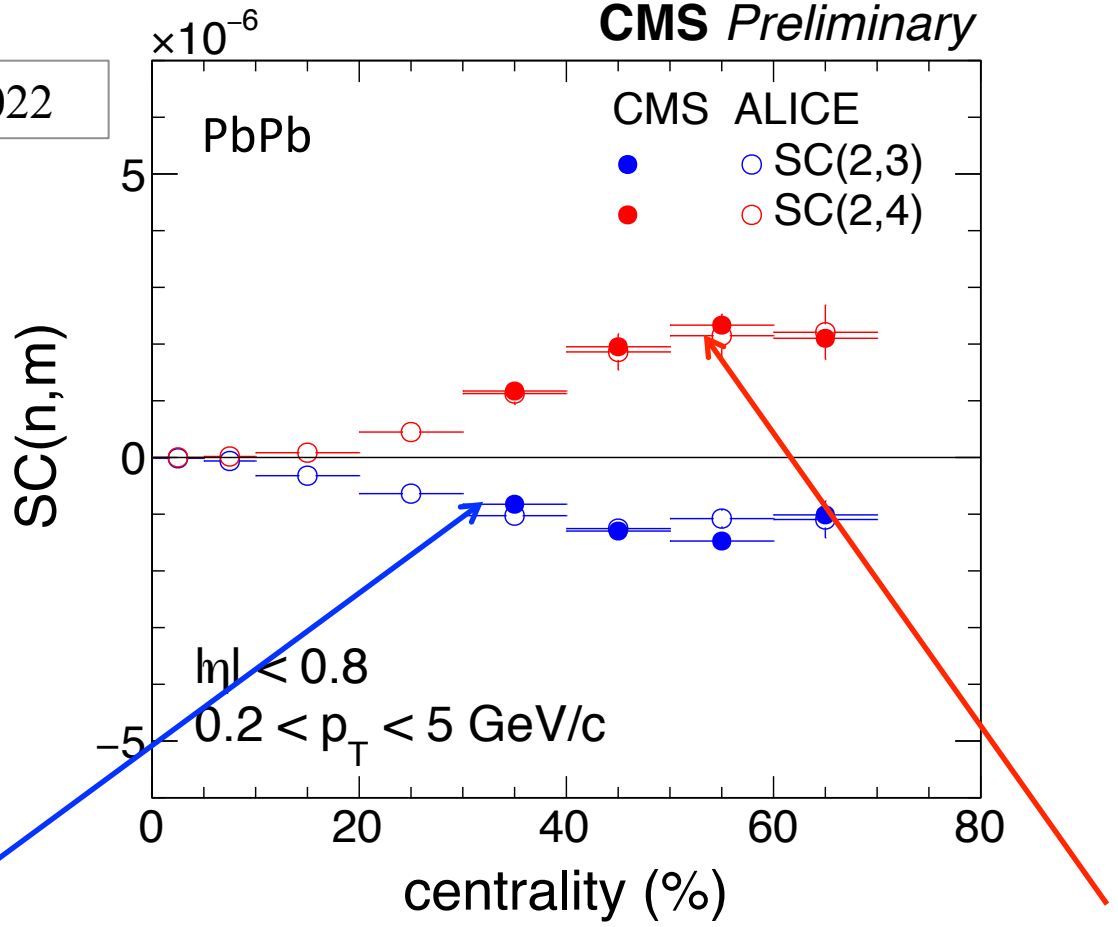
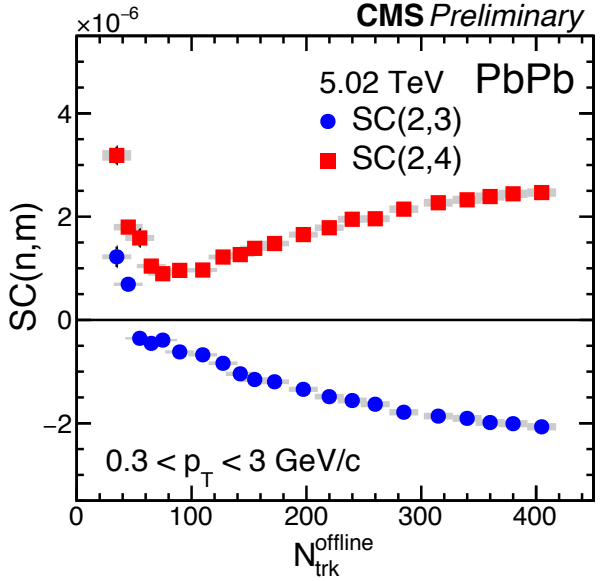


SC(2,3): v_2, v_3 anti-correlated

SC(2,4): v_2, v_4 correlated

SC as a function of multiplicity



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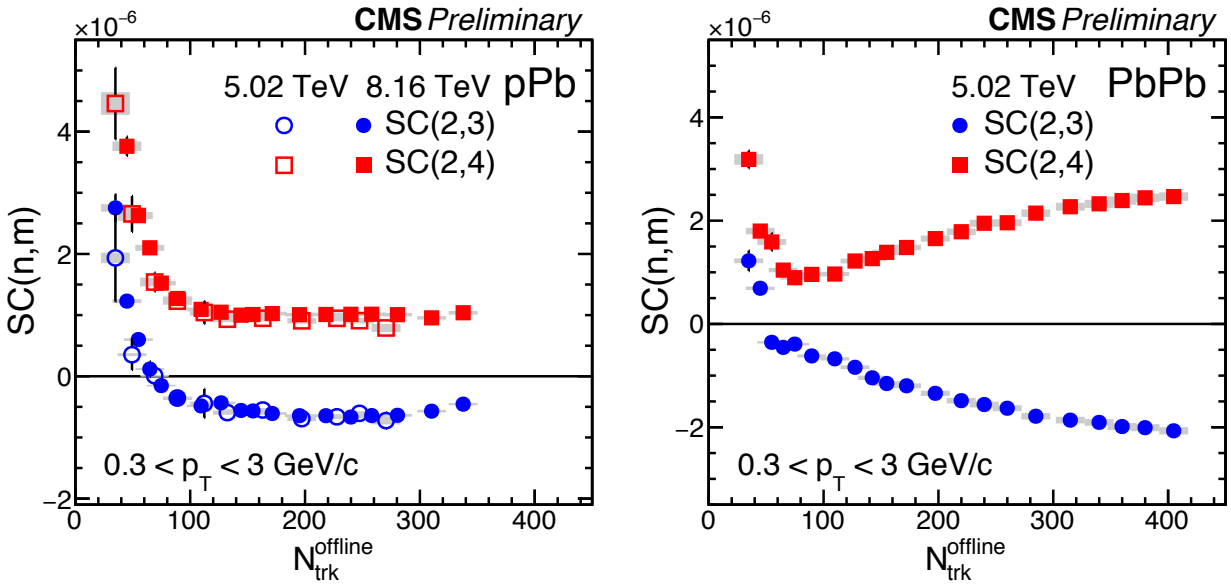
SC as a function of multiplicity



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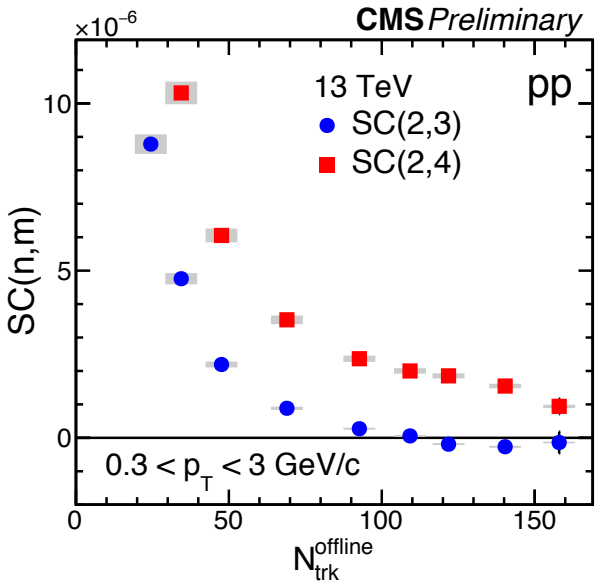

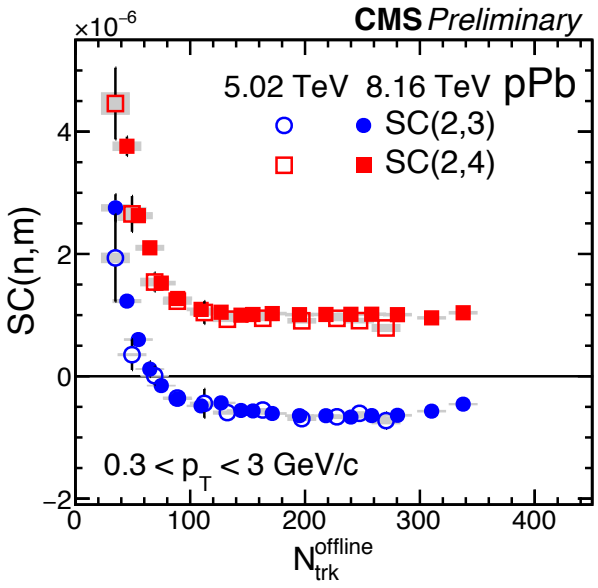

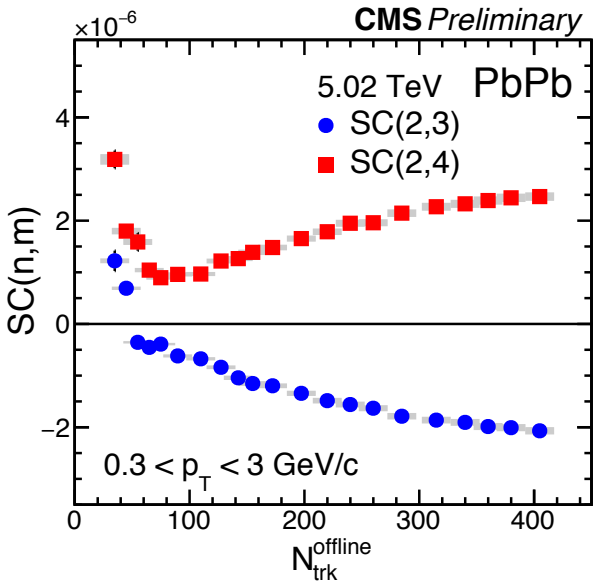

CMS-PAS-HIN-16-022

- Similar pattern observed across systems for SC

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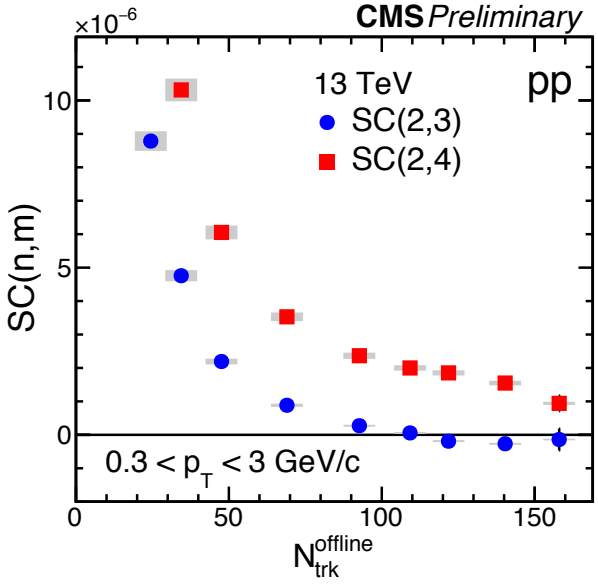
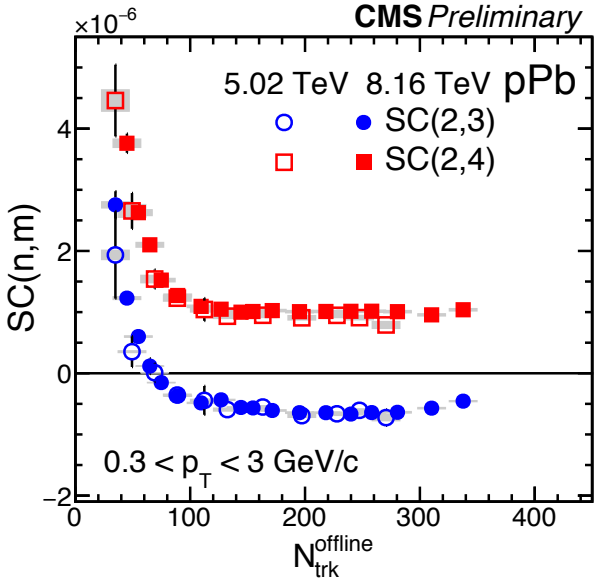
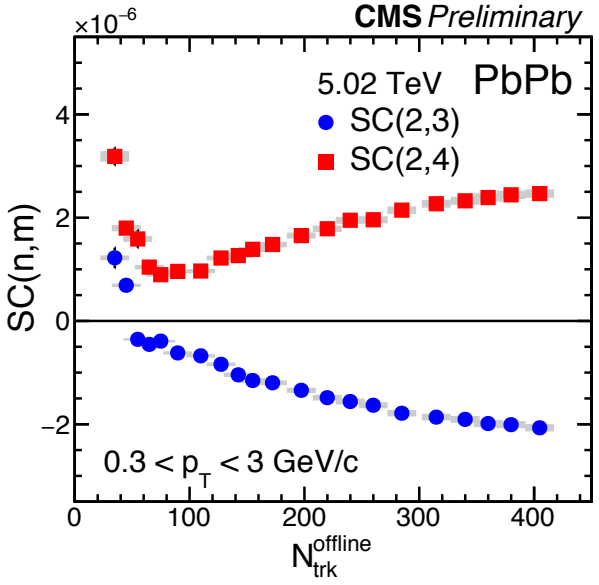






CMS-PAS-HIN-16-022

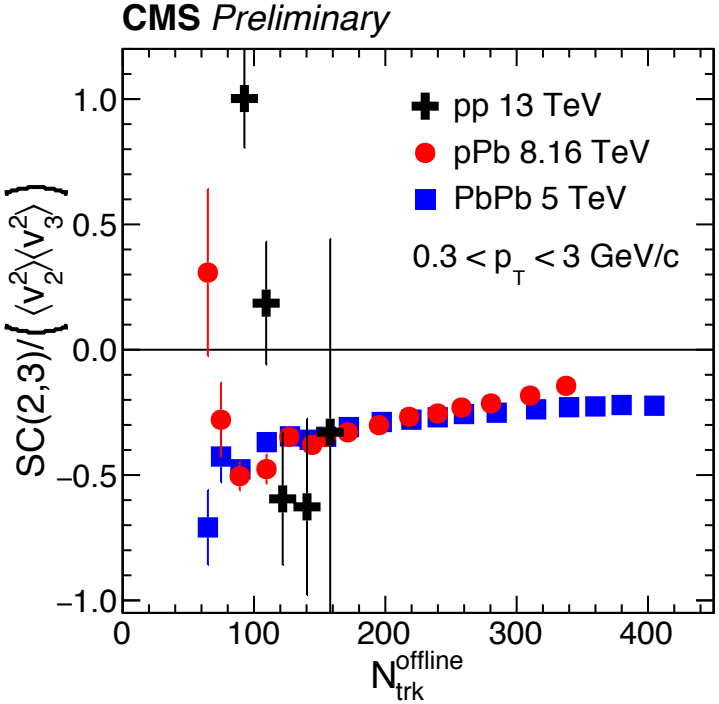
- Similar pattern observed across systems for SC
- Very small energy dependence observed for p-Pb results

Normalization needed for a fair comparison

SC normalized

CMS-PAS-HIN-16-022

SC normalized by $\langle v_n^2 \rangle . \langle v_m^2 \rangle$

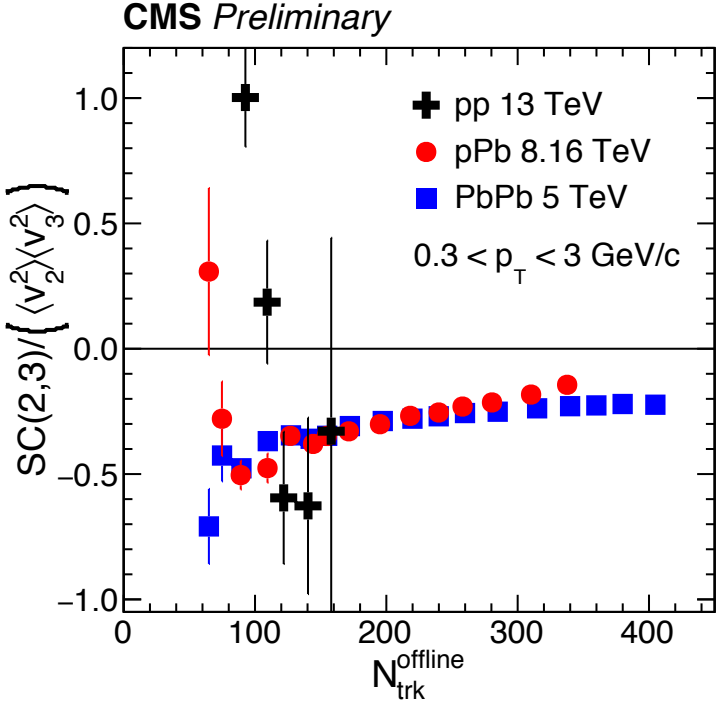


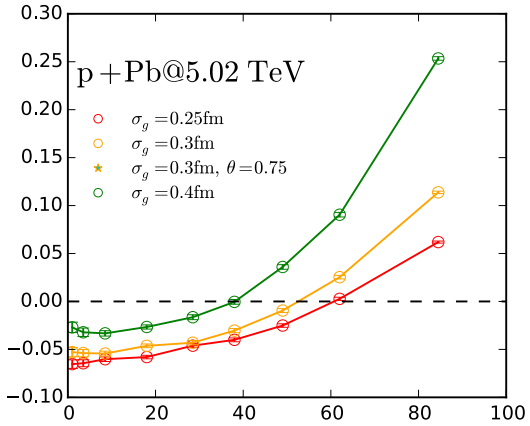
- Similar behavior in p-Pb and PbPb
- Points to similar IS fluctuations

SC normalized

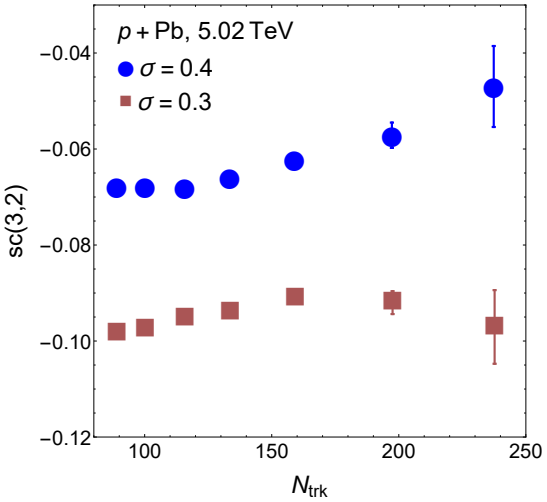
CMS-PAS-HIN-16-022

SC normalized by $\langle v_n^2 \rangle . \langle v_m^2 \rangle$





arXiv 1605.09418



Wounded nucleon model

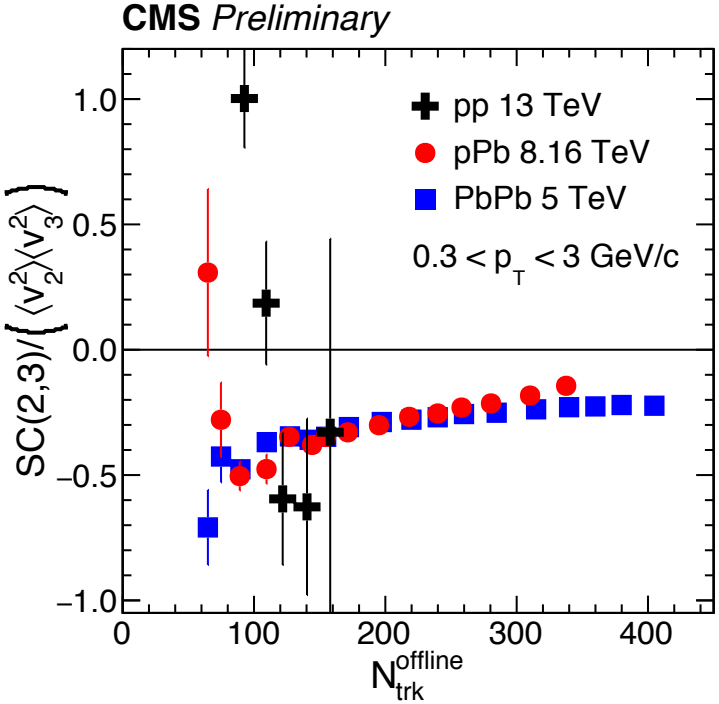
arXiv 1609.05171

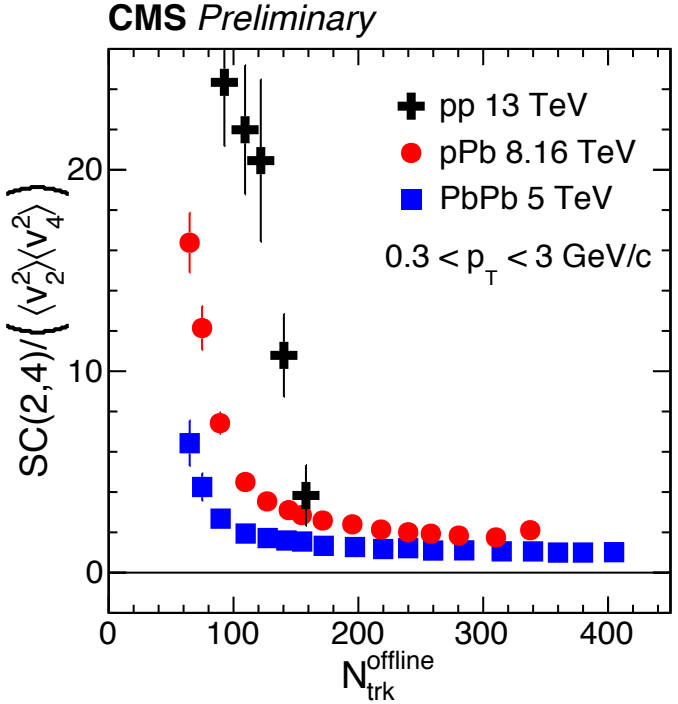
- Similar behavior in p-Pb and PbPb
- Points to similar IS fluctuations
- First calculations (ε_n correlations only)
  - Right sign
  - Magnitude is off

SC normalized

CMS-PAS-HIN-16-022

SC normalized by $\langle v_n^2 \rangle . \langle v_m^2 \rangle$





- Similar behavior in p-Pb and PbPb
- Points to similar IS fluctuations
- First calculations (ε_n correlations only)
  - Right sign
  - Magnitude is off

- Ordering observed:

  p-p > p-Pb > Pb-Pb

- May point to different transport properties

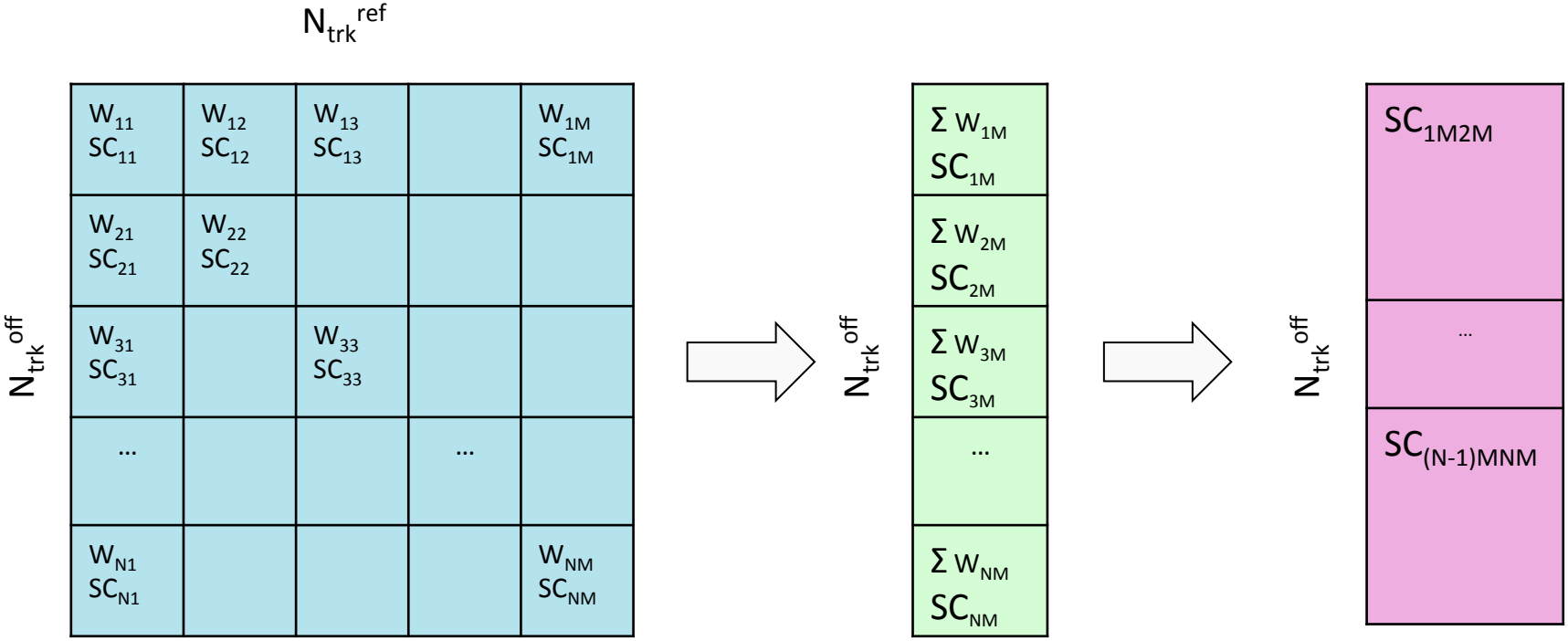
Summary

- The new p-Pb 8.16 TeV results reach a multiplicity regime never explored so far
- Symmetric cumulants were measured in p-p, p-Pb and Pb-Pb as a function of multiplicity
  - v_2 & v_3
    - Similar behavior observed across systems
    - Points to similar IS fluctuation contribution
  - v_2 & v_4
    - p-p > p-Pb > PbPb
    - May point to different transport properties
- Stringent constraints on the model calculations

backup

Symmetric Cumulant (SC): multiplicity fluctuation and normalization

- To avoid multiplicity fluctuation we follow this procedure:



- To insure an apple-to-apple comparison across system, SCs are usually normalized by $\langle v_n^2 \rangle \langle v_m^2 \rangle$ from 2-particle correlation analysis.
  - Large gap needed to get as close as possible to $\langle \varepsilon_n^2 \rangle \langle \varepsilon_m^2 \rangle$