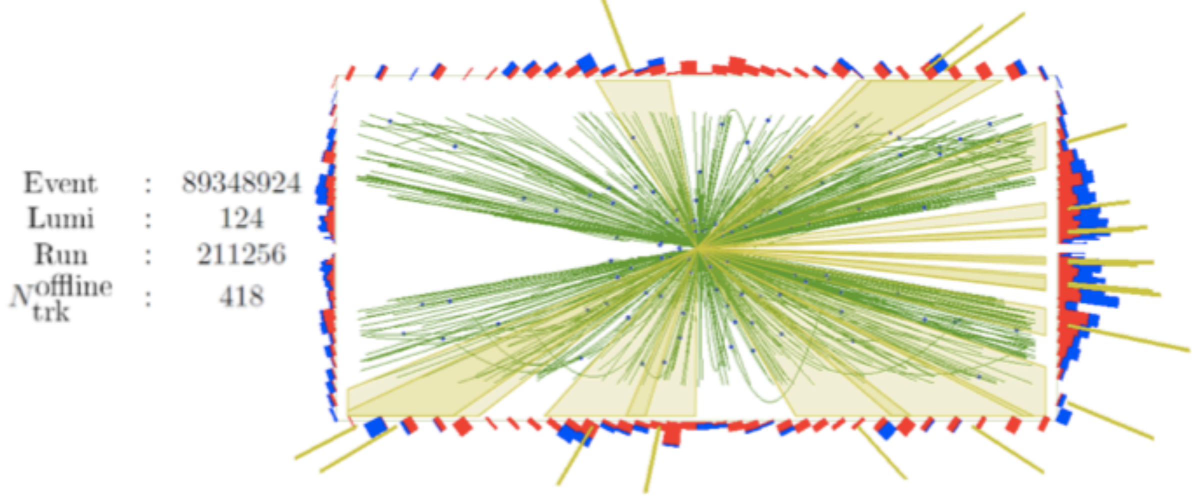


CMS high multiplicity proton-lead collisions

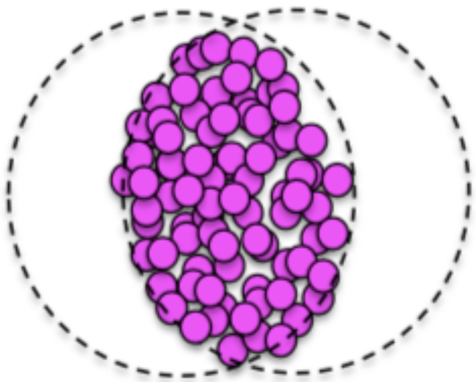
Measurement of elliptic and triangular flow with multiparticle correlations in pPb collisions at 8.16 TeV

Shengquan Tuo
for the CMS Collaboration

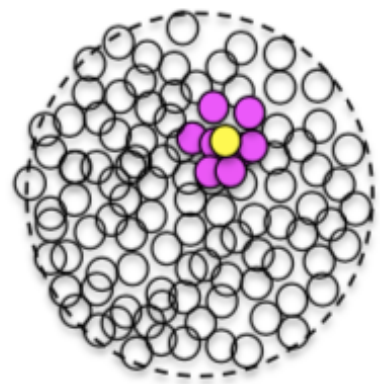
Motivation

- Fourier harmonics v_n

$$\frac{dN}{d\phi} \propto 1 + \sum 2v_n \cos[n(\phi - \Psi_n)]$$

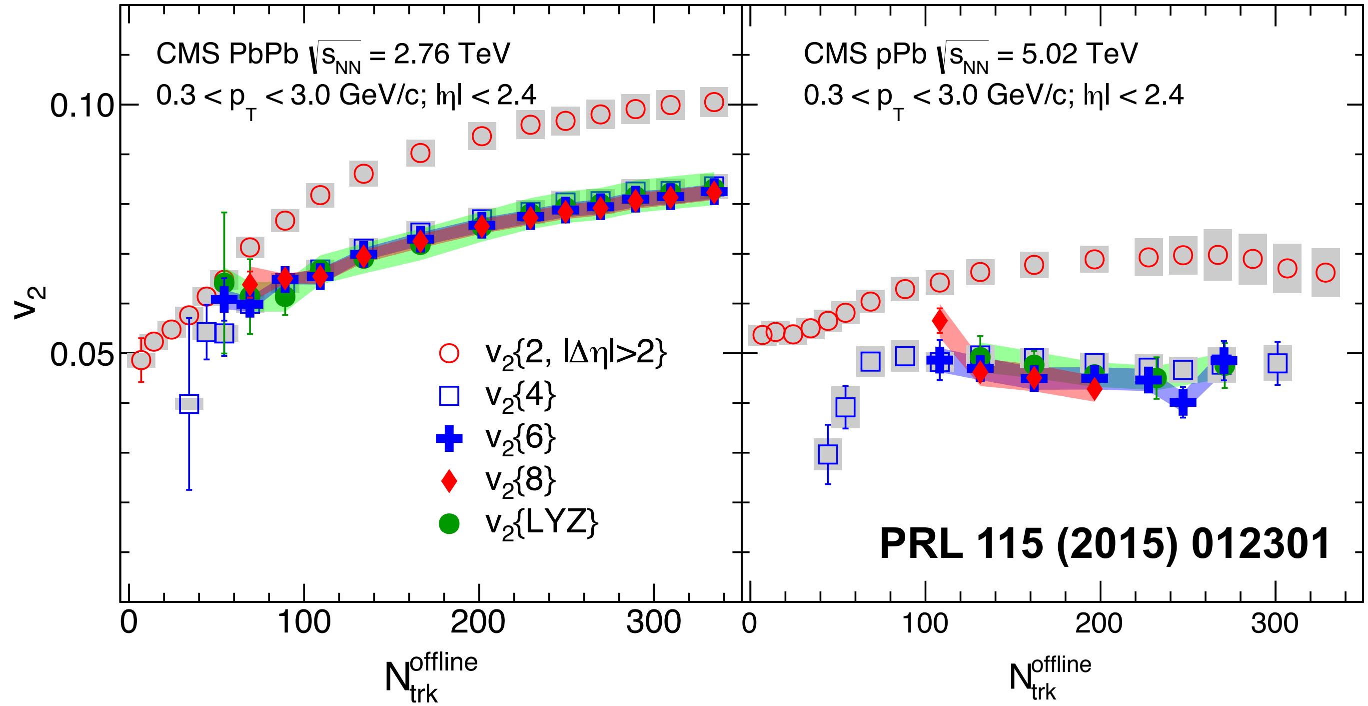


- Initial state ε_n → final state v_n
- PbPb – collectivity
  - Global geometry → Elliptic flow v_2
  - Fluctuation → Triangular flow v_3 and …
- pPb
  - Pure fluctuation → v_2 and v_3?
  - What is the distribution? Gaussian?



Motivation

- Collectivity in small collision systems



- Higher order v_3 harmonics from multiparticle correlations?
  - Origin of collectivity – Comparing to PbPb
- Gauge the fluctuation effect
  - Transport properties (η/s)

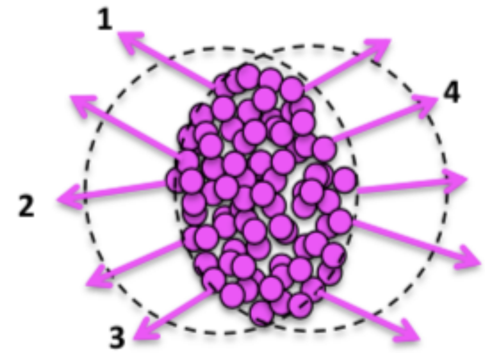
Cumulant method

- 4-particle correlator, per event → $\langle 4\rangle = \left\langle e^{-in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)}\right\rangle$
- 4-particle cumulant, all events → $c_n\{4\} = \langle\langle 4\rangle\rangle - 2\langle\langle 2\rangle\rangle^2$
- Cumulant v_n →

$$v_n\{4\} = \sqrt[4]{-c_n\{4\}}$$

$$v_n\{6\} = \sqrt[6]{\frac{1}{4}c_n\{6\}}$$

$$v_n\{8\} = \sqrt[8]{-\frac{1}{33}c_n\{8\}}$$



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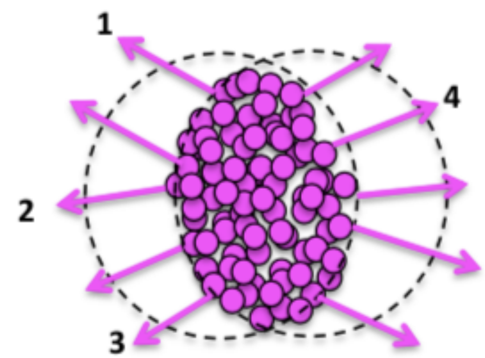


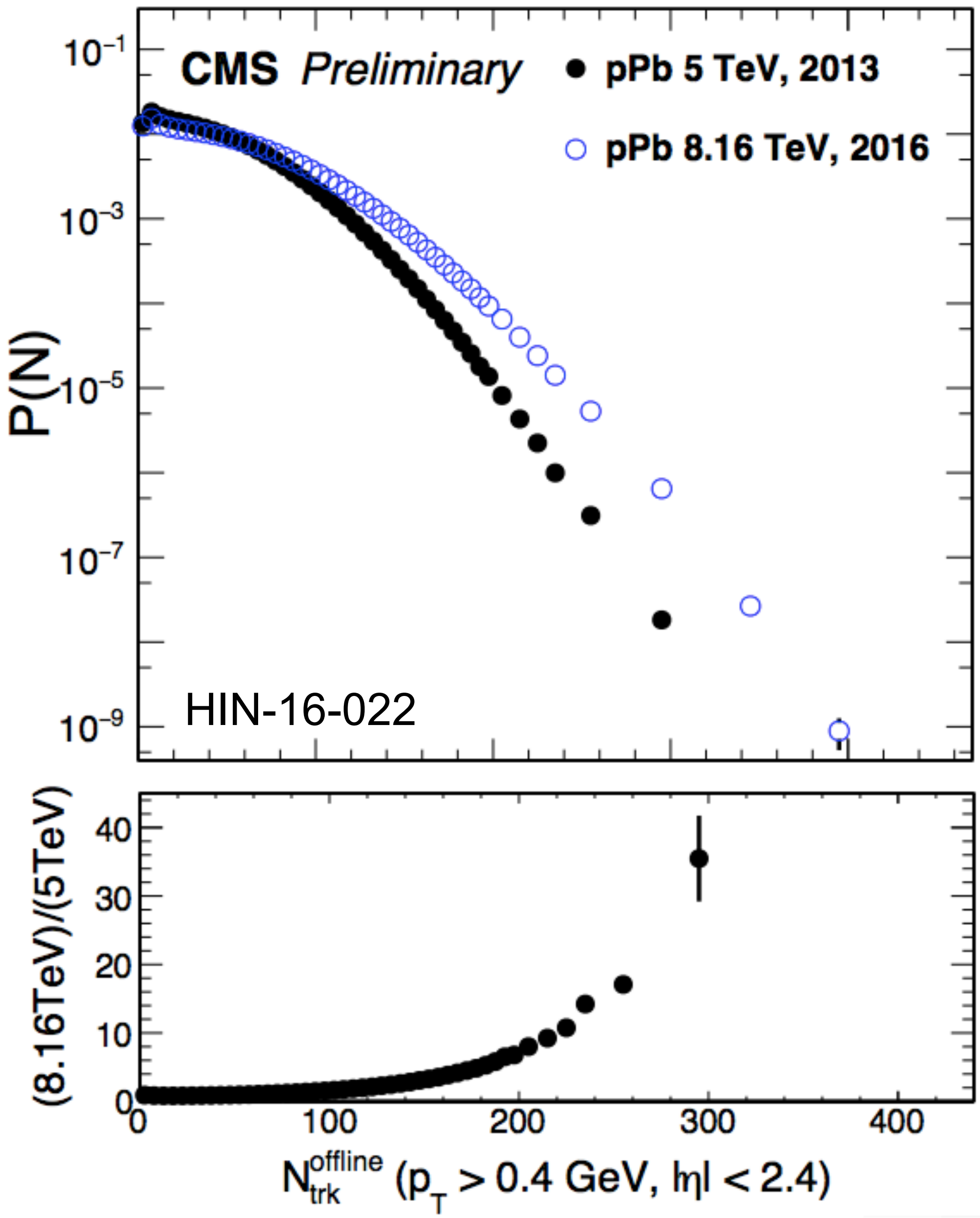
- Flow fluctuations →

$$v_n\{2\}^2 = \langle v_n\rangle^2 + \sigma_n^2$$
$$v_n\{4\}^2 = \langle v_n\rangle^2 - \sigma_n^2$$

- Gaussian fluctuations → $v_n\{4\} = v_n\{6\} = v_n\{8\}$

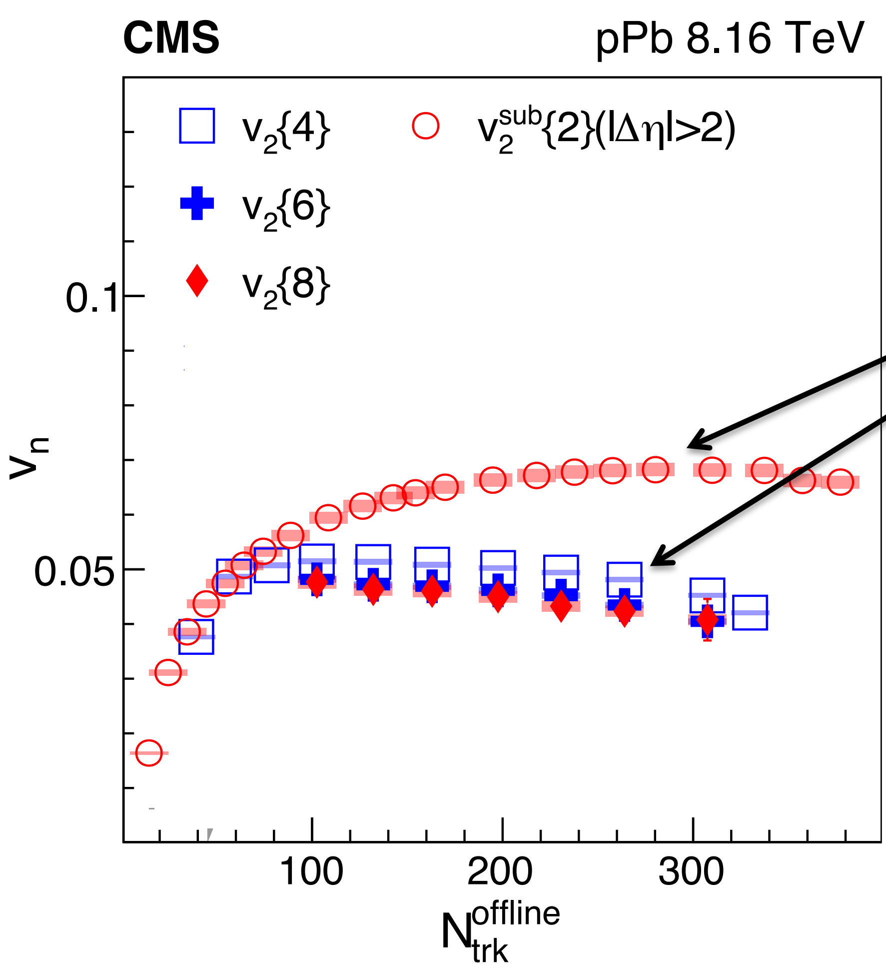
Experiment setup

- pPb 8.16 TeV
  - High Multiplicity trigger
- PbPb 5.02 TeV
  - Minimum Bias trigger
- $N_{trk}^{offline}$ definition:
  - $p_T > 0.4$ GeV/c, $|\eta| < 2.4$



Results: v_n in pPb

arXiv:1904.11519



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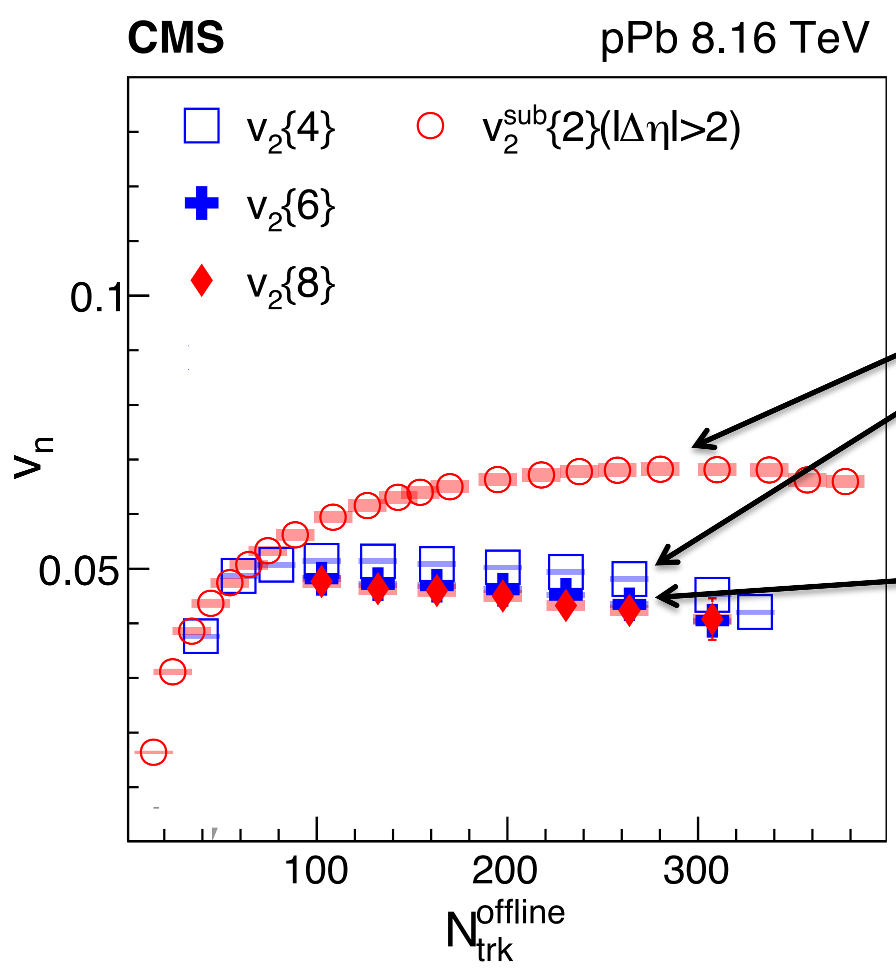
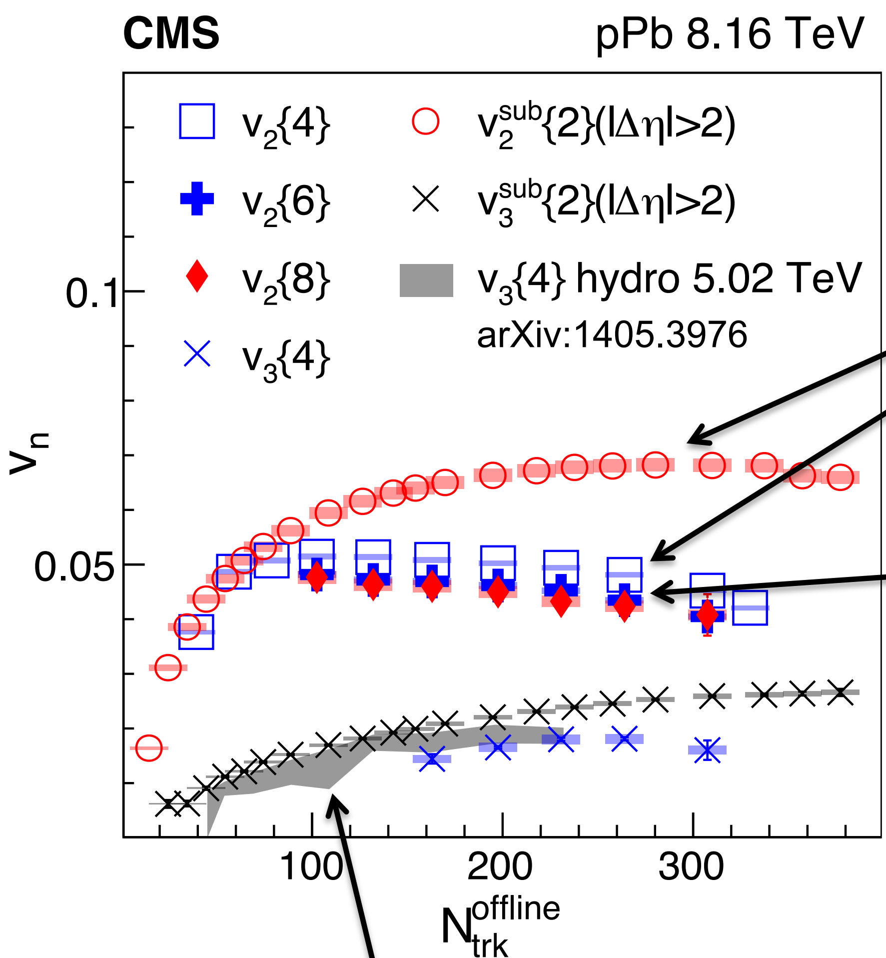


$$v_n\{2\}^2 = \langle v_n \rangle^2 + \sigma_n^2$$
$$v_n\{4\}^2 = \langle v_n \rangle^2 - \sigma_n^2$$

$$v_2\{2\} > v_2\{4\} \gtrsim v_2\{6\} \gtrsim v_2\{8\}$$

- Non-Gaussian fluctuation

Results: v_n in pPb



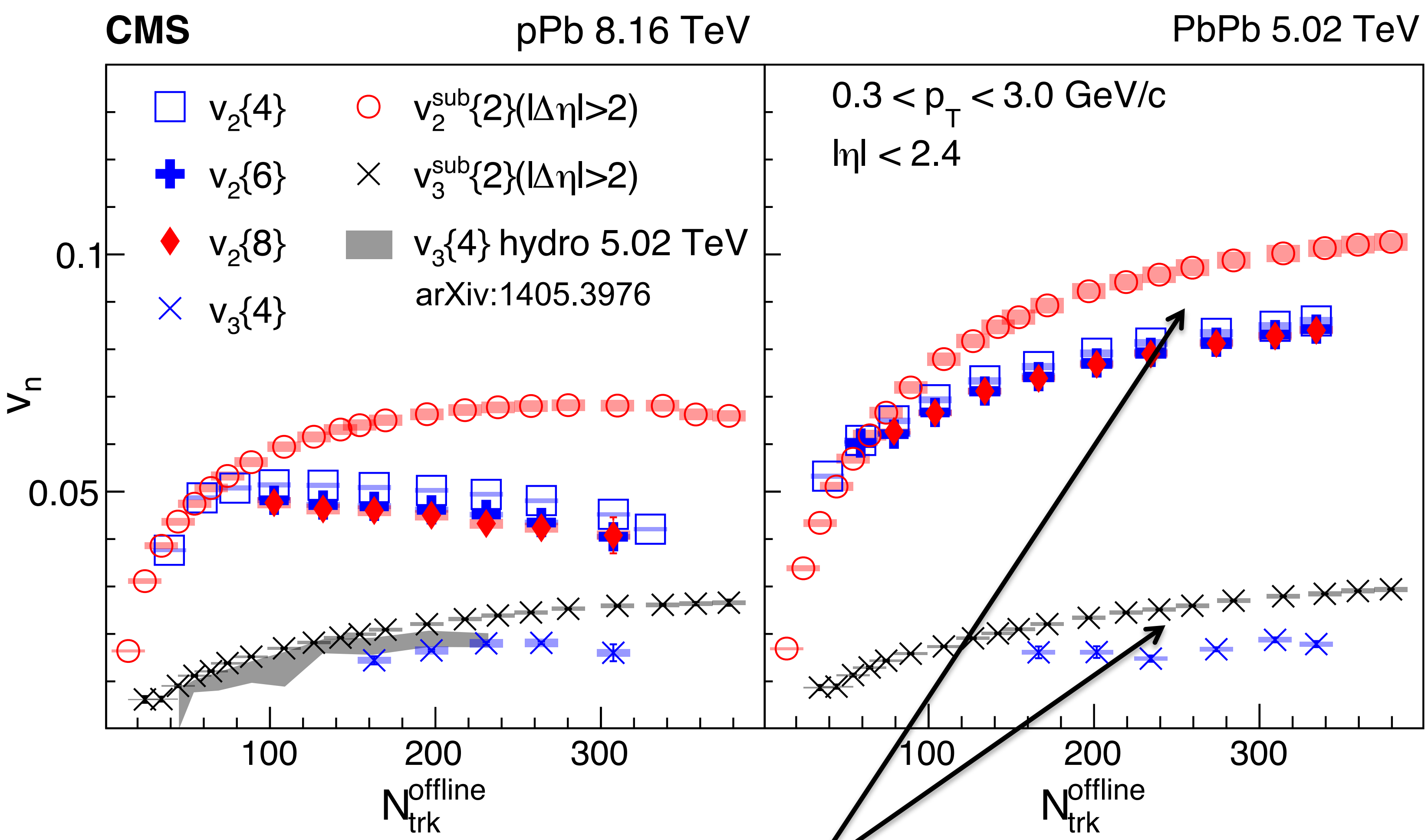
$$v_n\{2\}^2 = \langle v_n \rangle^2 + \sigma_n^2$$
$$v_n\{4\}^2 = \langle v_n \rangle^2 - \sigma_n^2$$

$$v_2\{2\} > v_2\{4\} \gtrsim v_2\{6\} \gtrsim v_2\{8\}$$

- Non-Gaussian fluctuation

- Hydrodynamic calculation of pPb 5.02 TeV
  - σ = 0.4 fm, η/s = 0.08
- Consistent with data

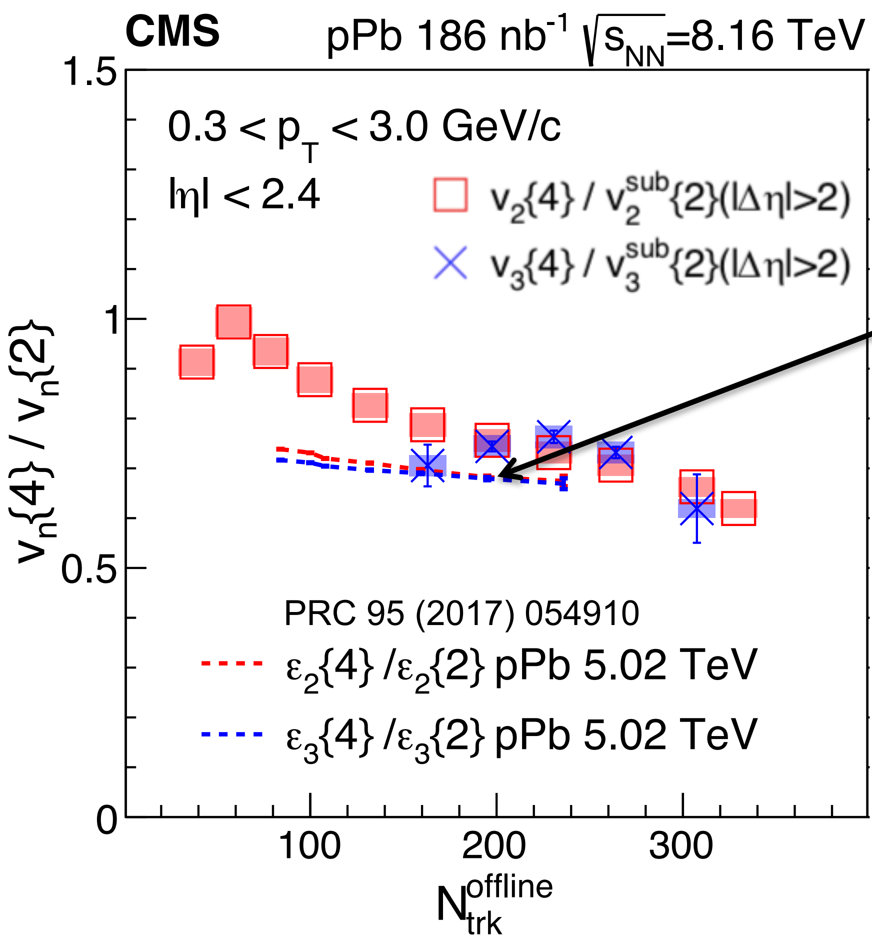
Results: v_n in pPb and PbPb



$$v_n\{2\}^2 = \langle v_n\rangle^2 + \sigma_n^2$$
$$v_n\{4\}^2 = \langle v_n\rangle^2 - \sigma_n^2$$

Result: $v_n\{4\}/v_n\{2\}$ in pPb

arXiv:1904.11519

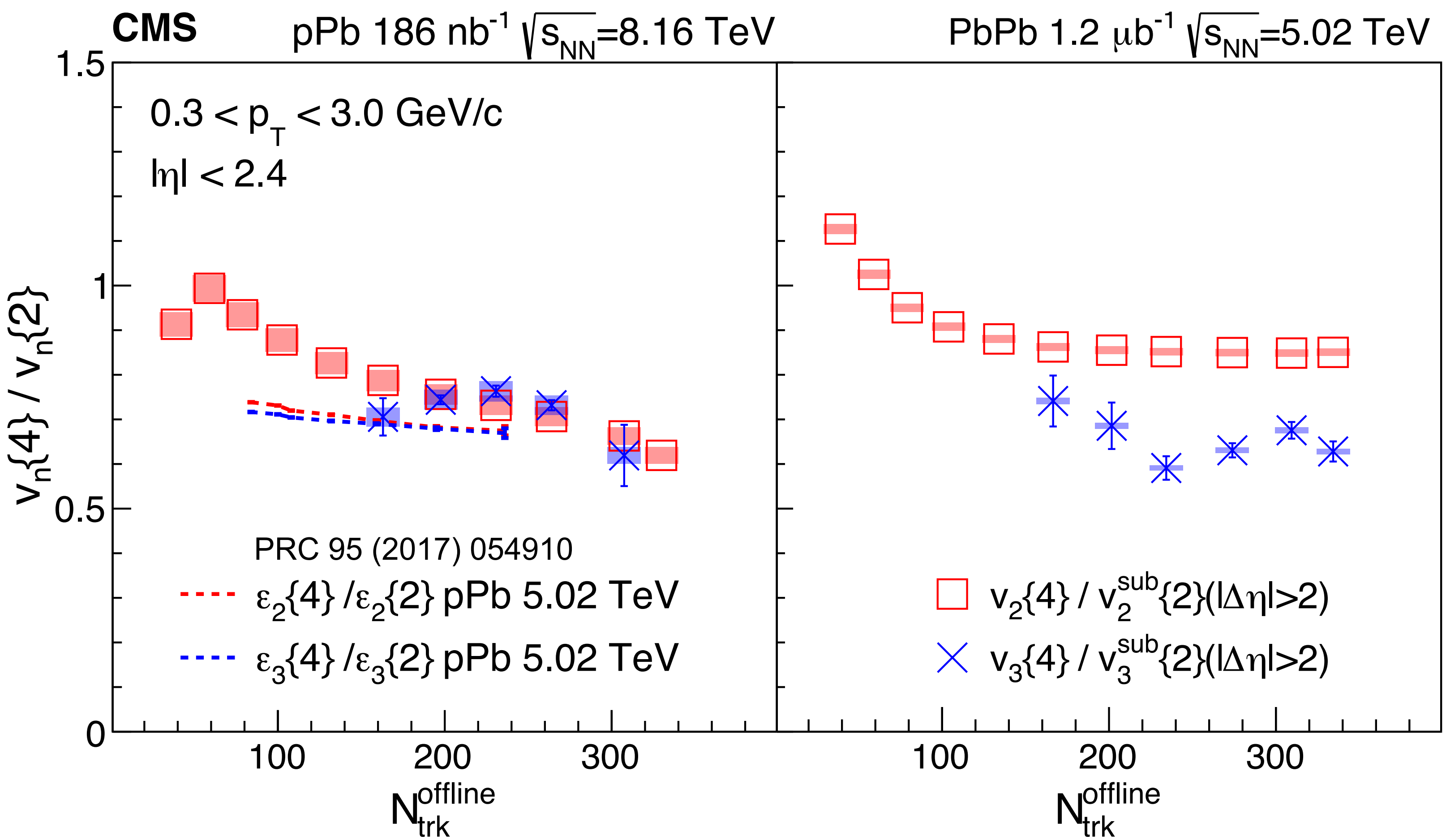


- TRENTo $\varepsilon_n\{4\}/\varepsilon_n\{2\}$ for 5.02 TeV pPb with Glauber and σ = 0.3 fm
- Insensitive to other model parameters
- Consistent with data

$$\frac{v_n\{4\}}{v_n\{2\}} = \sqrt{\frac{\langle v_n \rangle^2 - \sigma_n^2}{\langle v_n \rangle^2 + \sigma_n^2}}$$

- v_2 and v_3 fluctuation driven

Result: $v_n\{4\}/v_n\{2\}$ in pPb and PbPb



$$\frac{v_n\{4\}}{v_n\{2\}} = \sqrt{\frac{\langle v_n \rangle^2 - \sigma_n^2}{\langle v_n \rangle^2 + \sigma_n^2}}$$

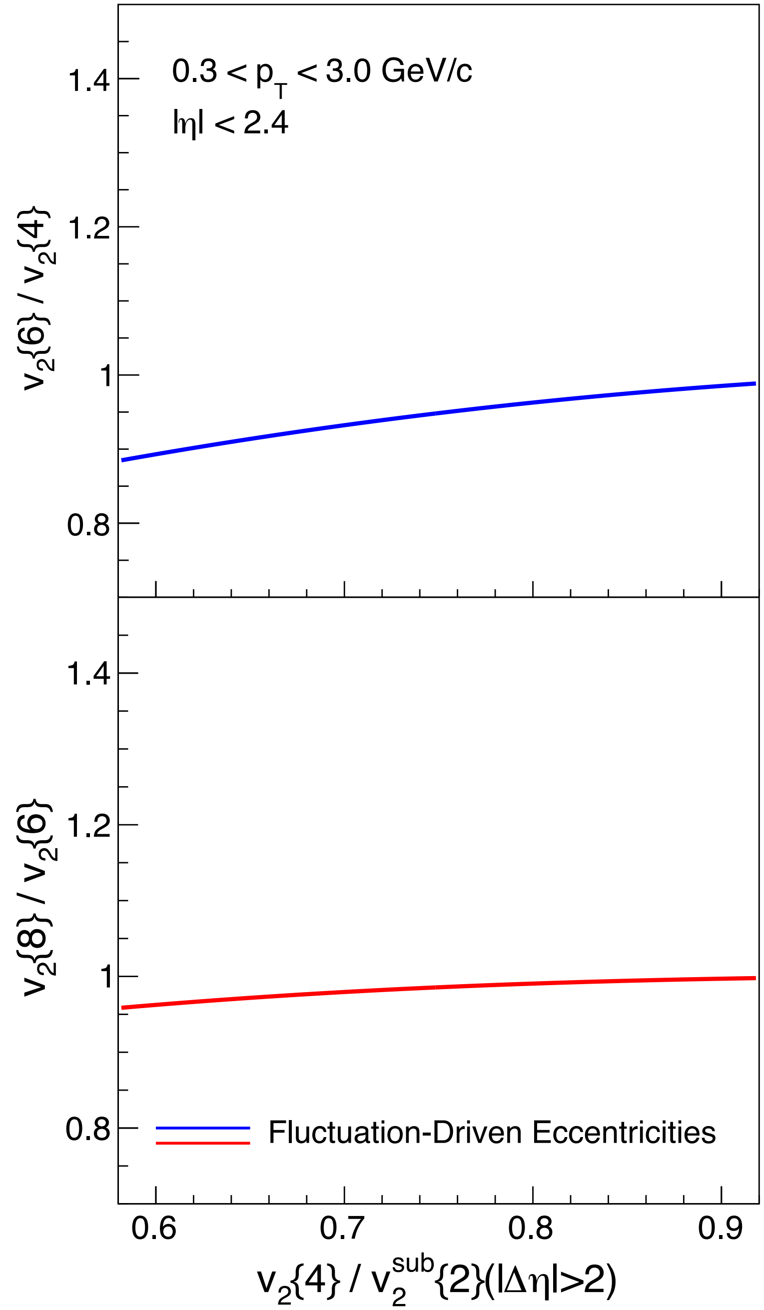
- v_2 and v_3 fluctuation driven

PbPb:

- v_2 global shape dependent
- v_3 fluctuation driven

Results: fluctuation of eccentricity

- Fluctuation driven eccentricity
  - Non-Gaussian fluctuation
    $v_2\{4\} \gtrsim v_2\{6\} \gtrsim v_2\{8\}$
  - Power law distribution ε_2
    (PRL 112, (2014) 082301)

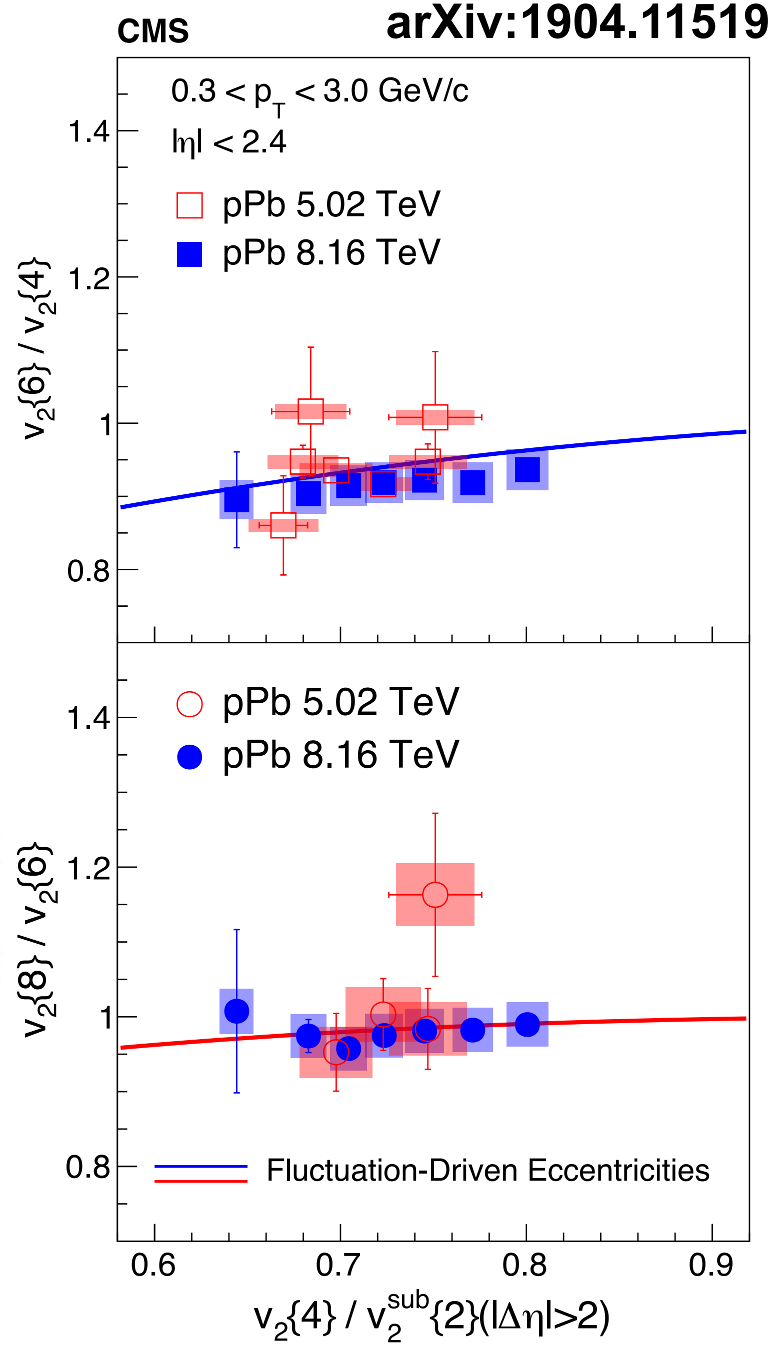


Results: fluctuation of eccentricity

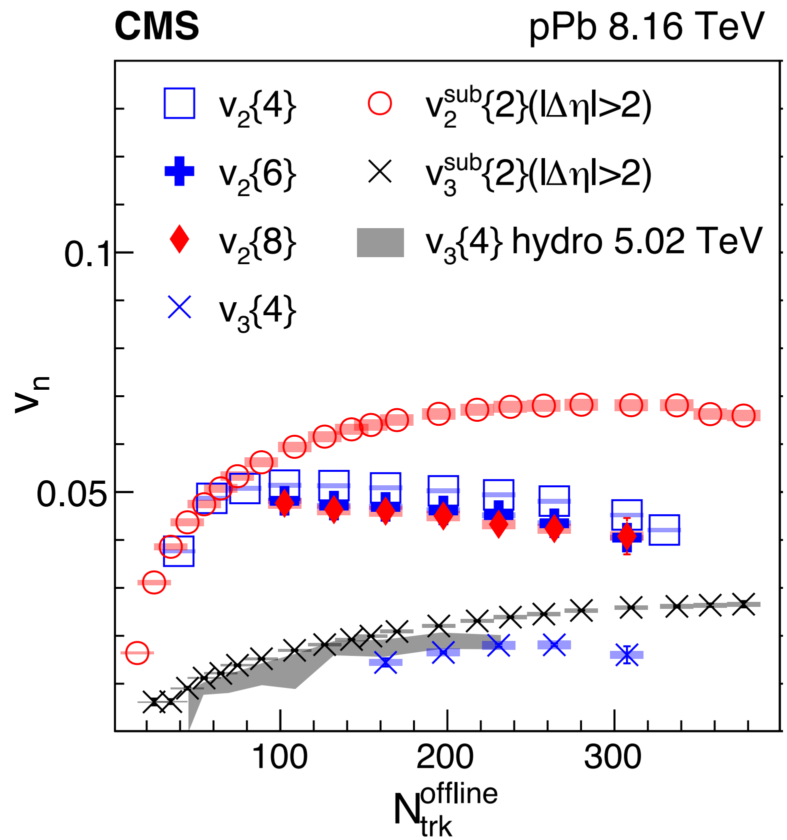
- Fluctuation driven eccentricity
  - Non-Gaussian fluctuation
    $v_2\{4\} \gtrsim v_2\{6\} \gtrsim v_2\{8\}$
  - Power law distribution ε_2
    (PRL 112, (2014) 082301)

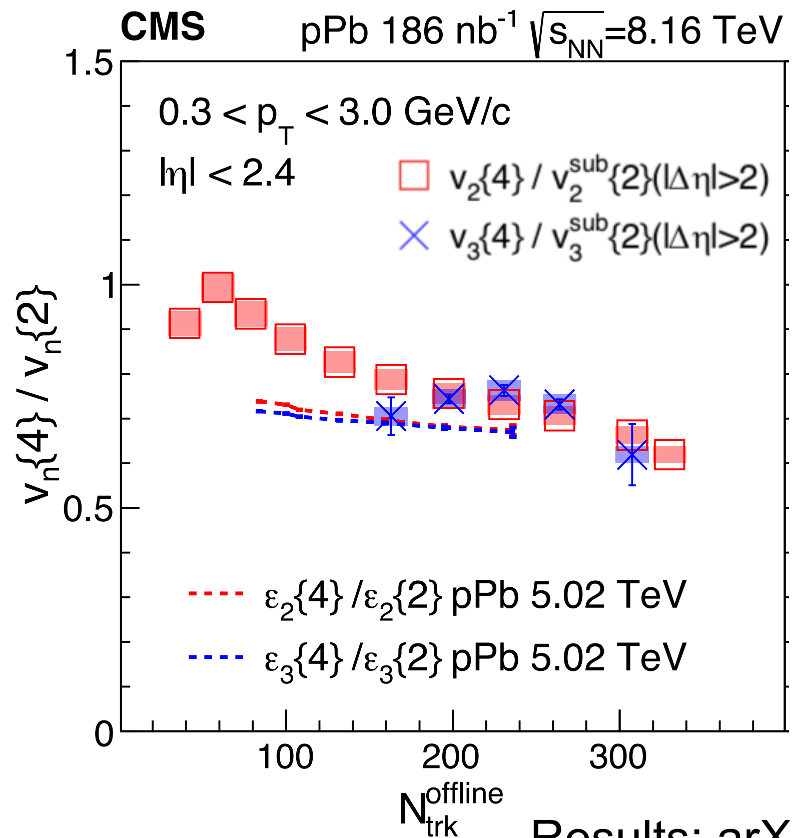
- pPb 5.02 TeV
  - PRL 115 (2015) 012301
- pPb 8.16 TeV
  - Improved statistics
  - Good agreement with predictions

arXiv:1904.11519



Summary





Results: arXiv:1904.11519

- Measurement of $v_3\{4\}$ in small systems
- v_2, v_3 dominated by fluctuations in pPb
- Global geometry dominates PbPb v2 results
- $v_2\{4\} \gtrsim v_2\{6\} \gtrsim v_2\{8\}$ → Non-Gaussian fluctuation
- Consistent with data: Hydro, TRENTo, power distribution

Backup: Power law distribution

Phys. Rev. Lett. 112, 082301 (2014)

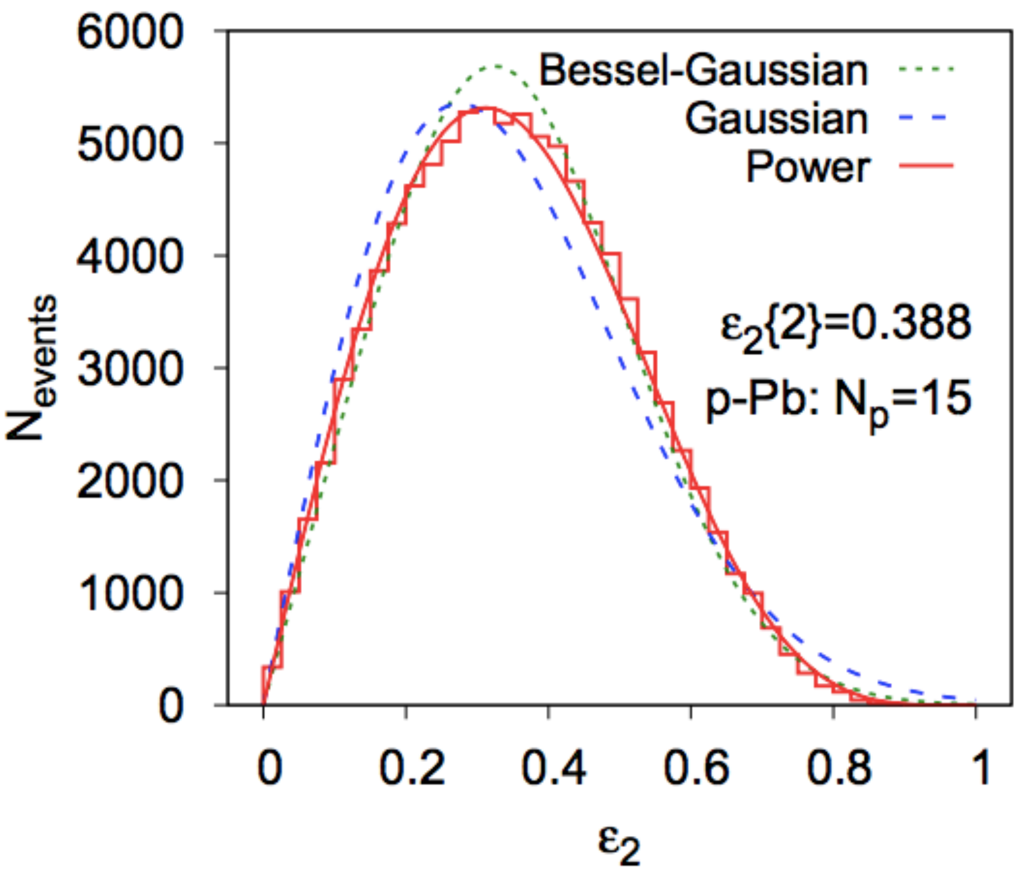


FIG. 1. (Color online) Histogram of the distribution of ε_2 obtained in a Monte-Carlo Glauber simulation of a p-Pb collision at LHC, and fits using Eqs. (2)-(4).

$$P(\varepsilon) = 2\alpha\varepsilon(1-\varepsilon^2)^{\alpha-1}$$

TABLE I. Values of the first eccentricity cumulants for the Gaussian (2), Bessel-Gaussian (3) and power law (4) distributions.

	Gauss	BG	Power
$\varepsilon\{2\}$	σ	$\sqrt{\sigma^2+\bar{\varepsilon}^2}$	$\frac{1}{\sqrt{1+\alpha}}$
$\varepsilon\{4\}$	0	$\bar{\varepsilon}$	$\left[\frac{2}{(1+\alpha)^2(2+\alpha)}\right]^{1/4}$
$\varepsilon\{6\}$	0	$\bar{\varepsilon}$	$\left[\frac{6}{(1+\alpha)^3(2+\alpha)(3+\alpha)}\right]^{1/6}$
$\varepsilon\{8\}$	0	$\bar{\varepsilon}$	$\left[\frac{48\left(1+\frac{5\alpha}{11}\right)}{(1+\alpha)^4(2+\alpha)^2(3+\alpha)(4+\alpha)}\right]^{1/8}$

Backup: quantum interference

PLB 795 (2019) 259–265

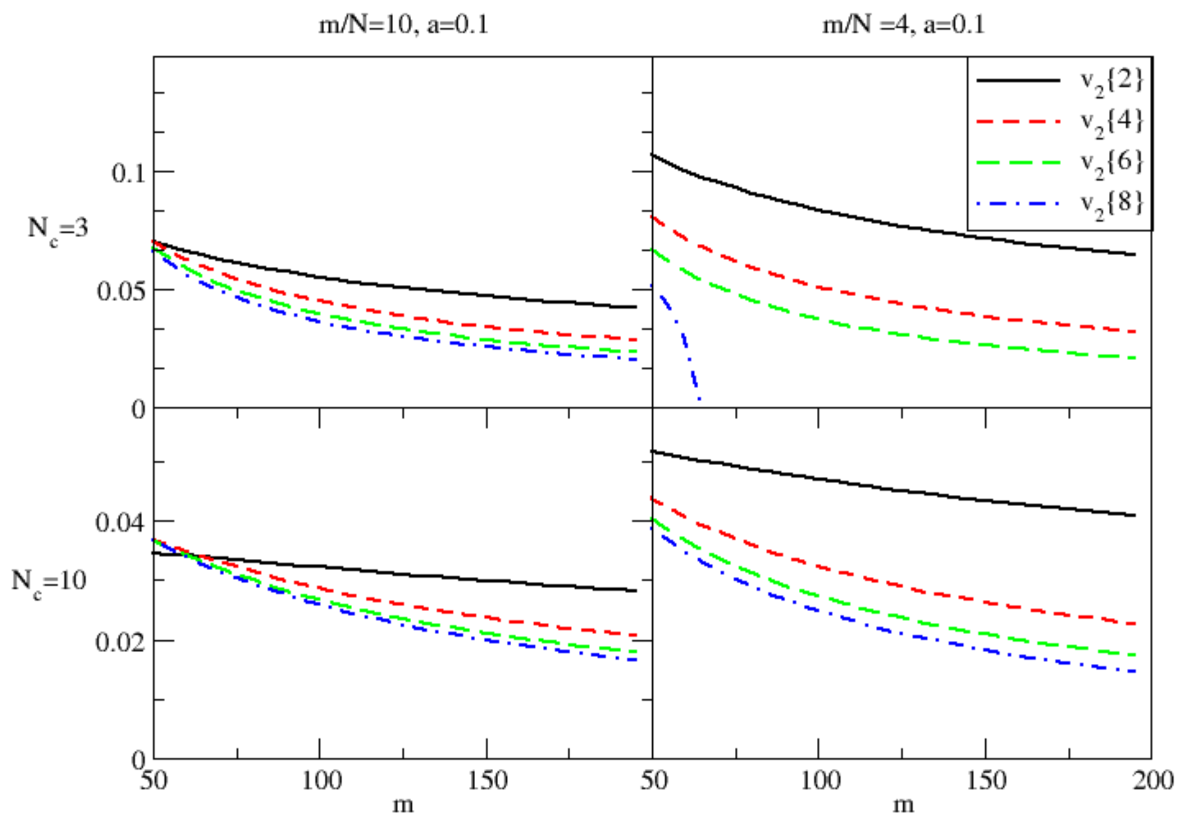


Figure 1: The elliptic flow cumulants $v_n\{2s\}(k)$ of (12), evaluated at momentum scale $B\,k^2 = 1$ from $(2s)$-particle correlations functions (10) in which all multiple dipole contributions to all orders $\left(\frac{m^2}{(N_c^2-1)}\right)^d$ are resummed.

with increasing m while the observed qualitative trend is seen in the data.[2] Our conclusion is therefore limited to the statement that the model calculation presented here provides a proof of principle that quantum interference can contribute to flow-like multi-particle correlations even if both final state rescattering effects and effects of parton saturation are absent.