Azimuthal Anisotropy of Charged Particles from Multiparticle Correlations in pPb and PbPb Collisions

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for the CMS Collaboration

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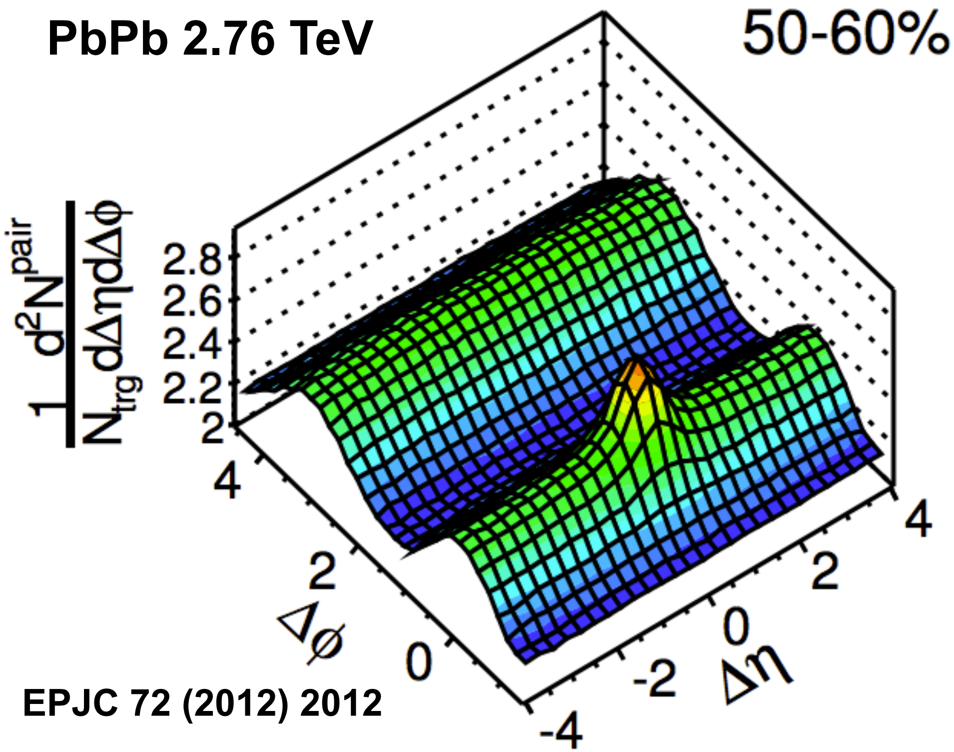
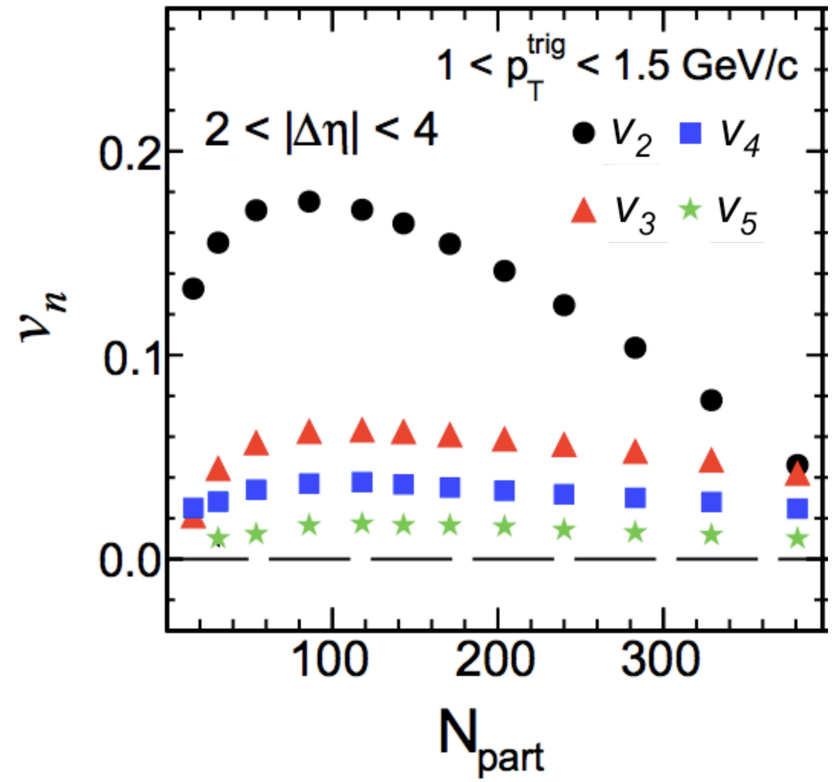
Outline

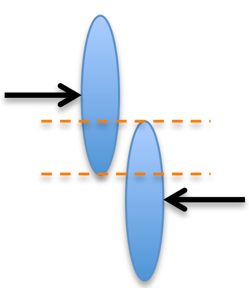
- Motivation
- Experiment
- Analysis Techniques
- Results
- Summary

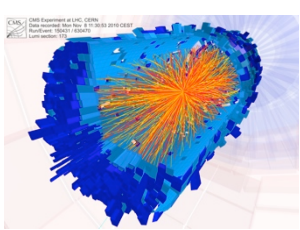
Motivation





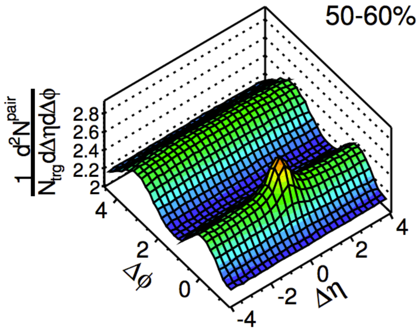
- In PbPb at 2.76 TeV collisions, well known ridge-like structure
- Collective flow



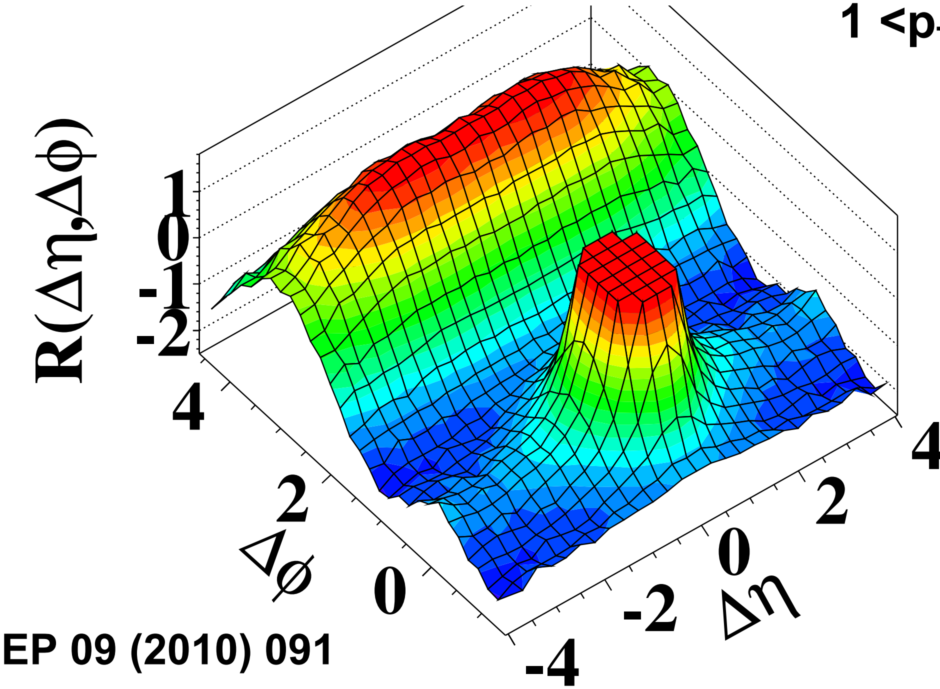


Motivation

PbPb 2.76 TeV

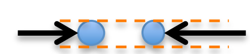


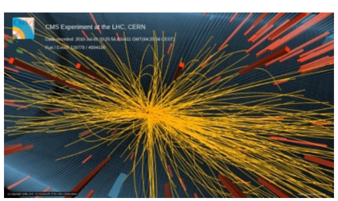
pp 7 TeV, $N_{trk}^{offline} \geq 110$
$1 < p_T < 3$ GeV/c



JHEP 09 (2010) 091

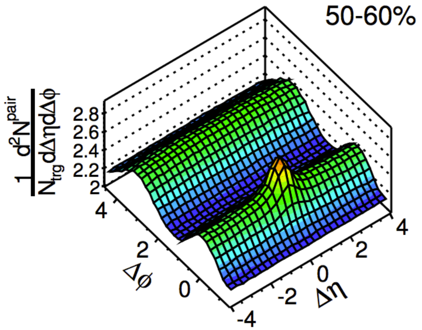
- In pp at 7 TeV, long-range ridge correlation observed
- Origin unclear



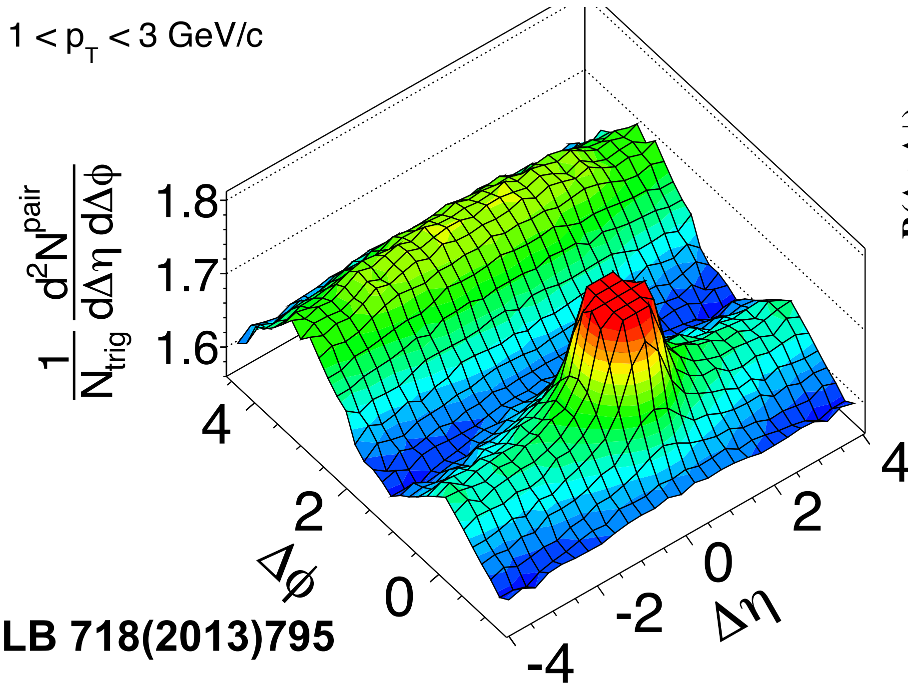


Motivation

PbPb 2.76 TeV

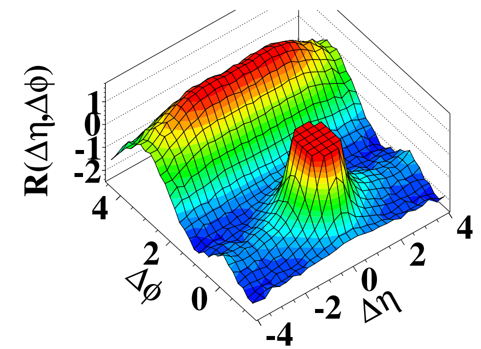


pPb 5.02 TeV $N_{trk}^{offline} \geq 110$

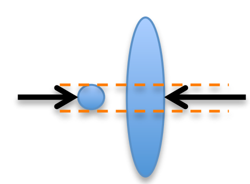


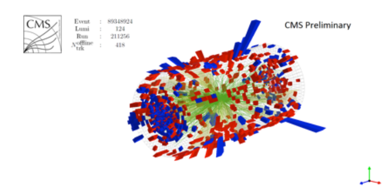
PLB 718(2013)795

pp 7 TeV, $N_{trk}^{offline} \geq 110$
$1 < p_T < 3$ GeV/c

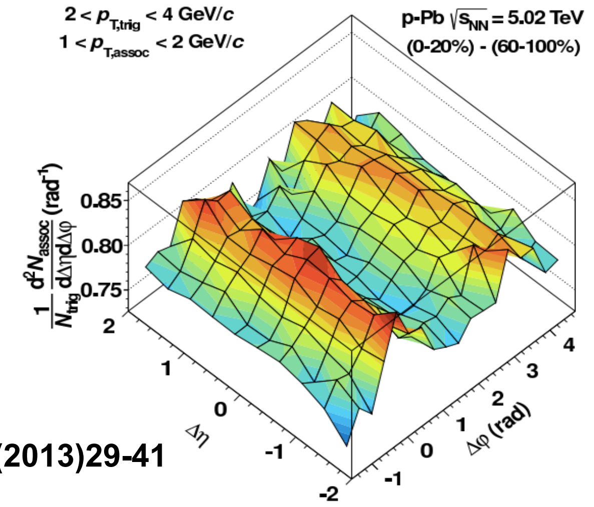


- In pPb 5.02 TeV, long-range ridge correlation expected
- Strongly enhanced
- Collective flow?



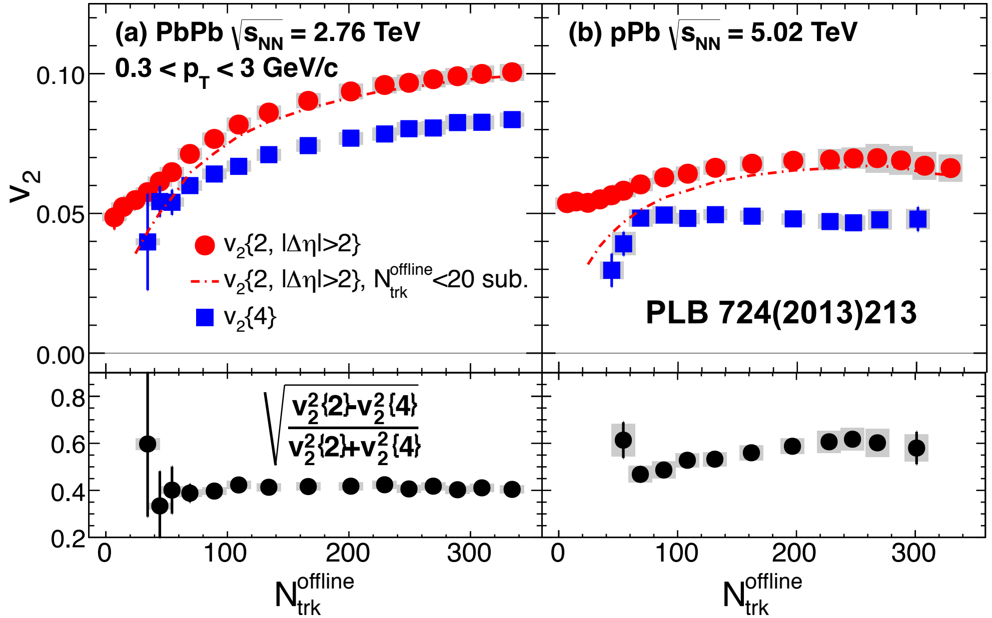


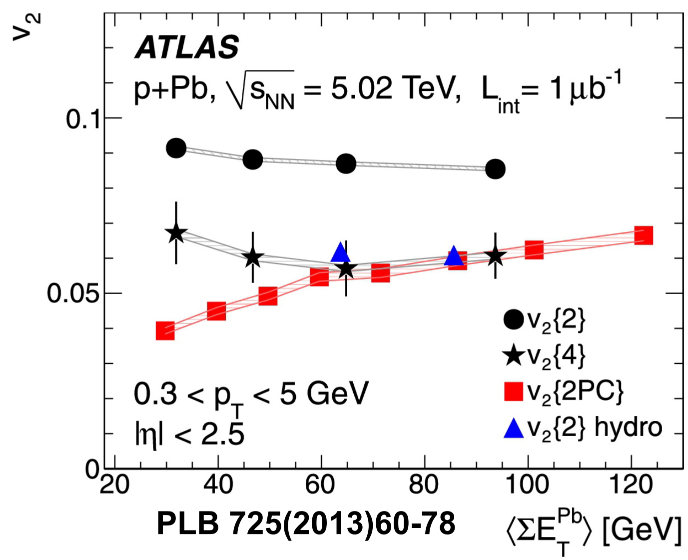
Motivation



PLB 719(2013)29-41

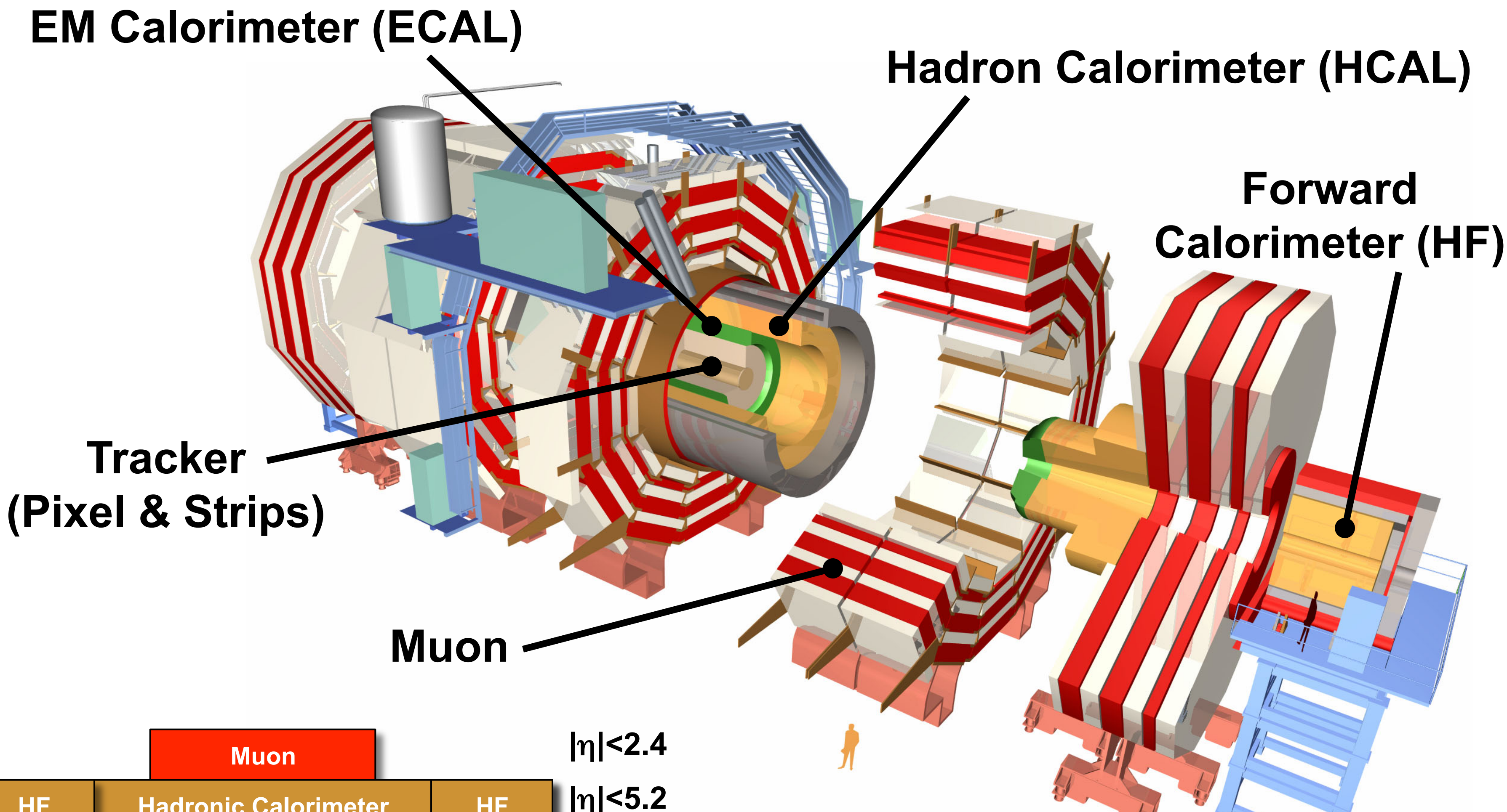
- Intensive studies on ridge
  - ALICE: PLB 719 (2013) 29-41
  - CMS: PLB 724 (2013) 213
  - ATLAS: PLB 725 (2013) 60-78
- Great interest of correlations involving even more particles
  - arXiv:1311.7325 (Bzdak, Bozek & McLerran)
  - PRL 112(2014)082301 (Yan & Ollitrault)

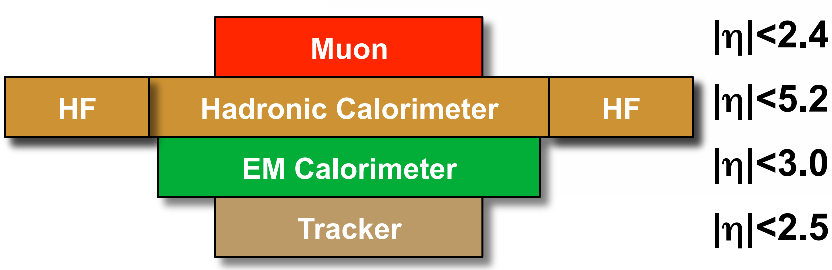




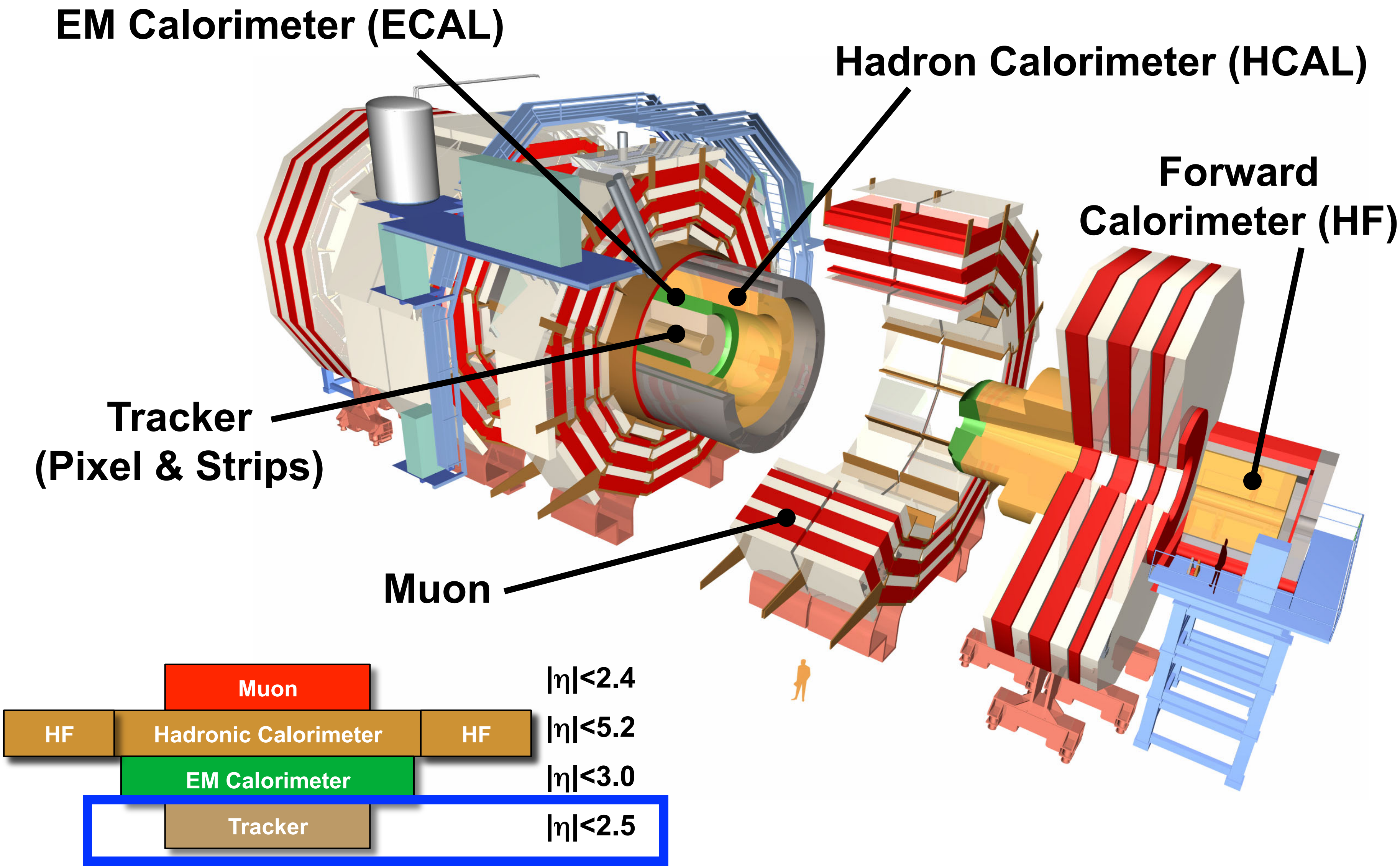
PLB 725(2013)60-78

CMS Detector



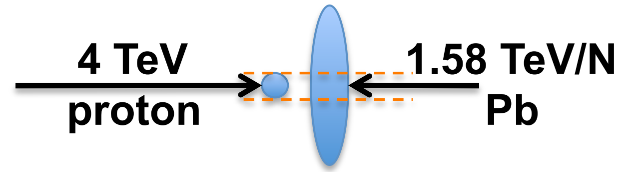


CMS Detector

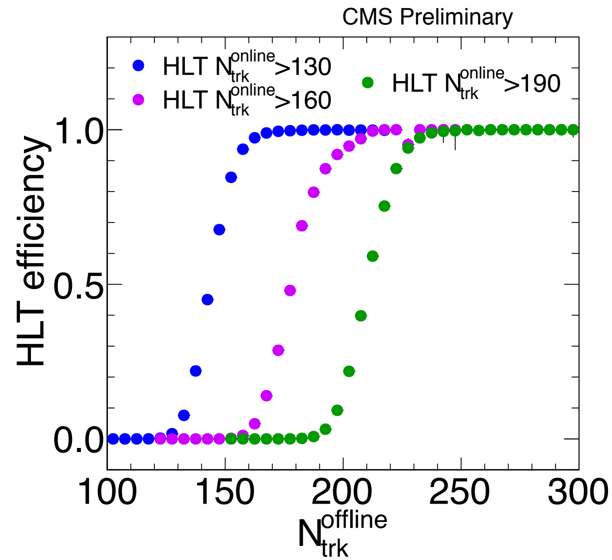


Experiment

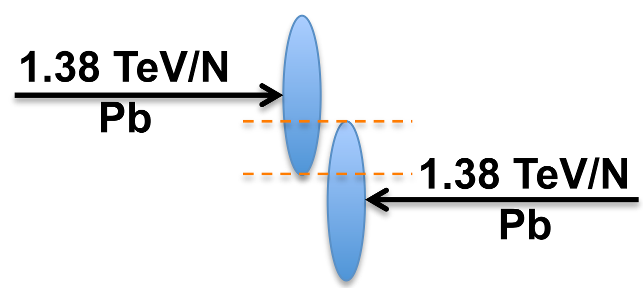
- pPb Run at LHC
  - $\sqrt{s_{NN}}$ = 5.02 TeV, 35 nb^{-1}



- Triggers
  - Minimum Bias
  - High Multiplicity



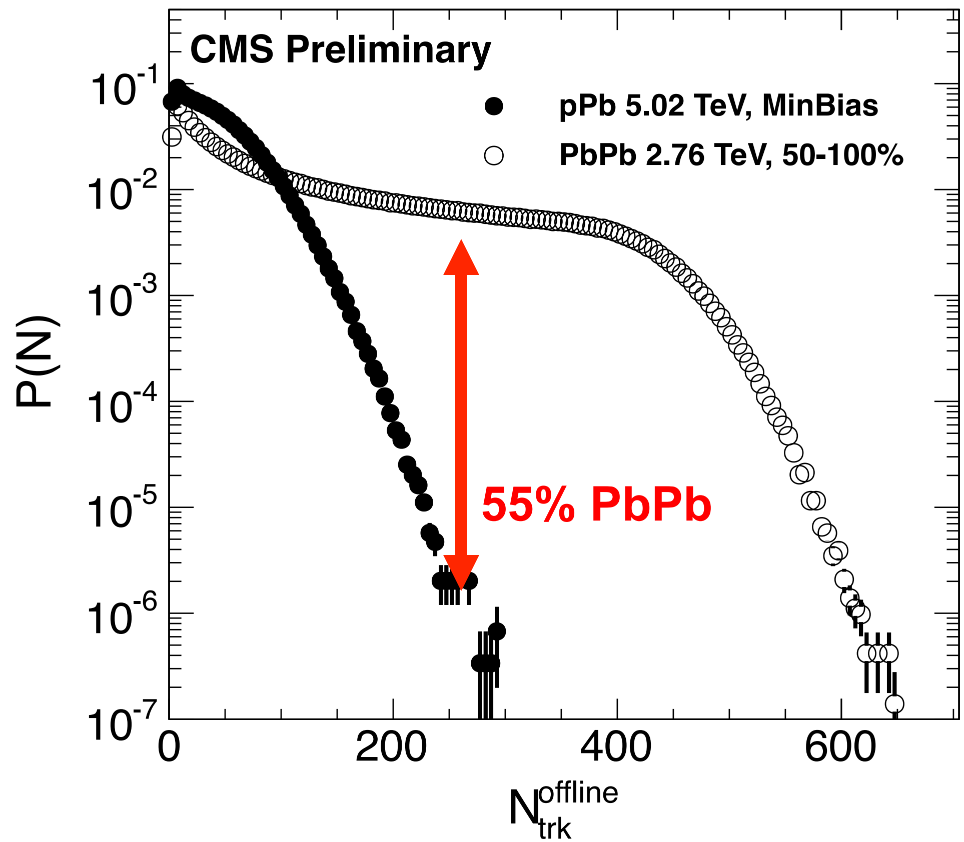
- PbPb
  - $\sqrt{s_{NN}}$ = 2.76 TeV (50-100%)
  - Same reconstruction as pPb



Multiplicity Distribution

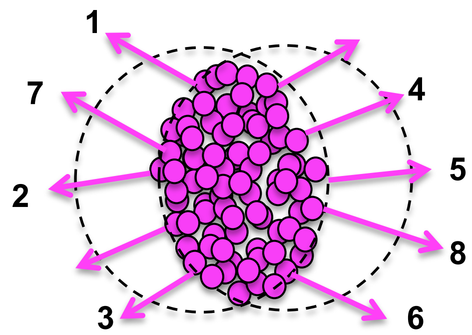
Offline track multiplicity $N_{trk}^{offline}$, p_T > 0.4 GeV/c, |η| < 2.4

- High multiplicity comparable to 55% PbPb
- 1 out 10M events

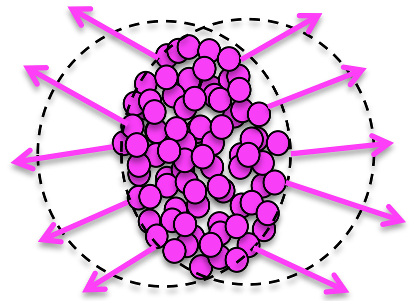


Analysis Techniques

6- and 8-particle cumulant



Lee-Yang Zeros



- **Genuine 6- and 8-particle correlations**
- **Insensitive to non-flow contributions from < 6 and 8 particles**

- **Genuine all-particle correlation**
- **Built-in correction for non-uniform distribution**

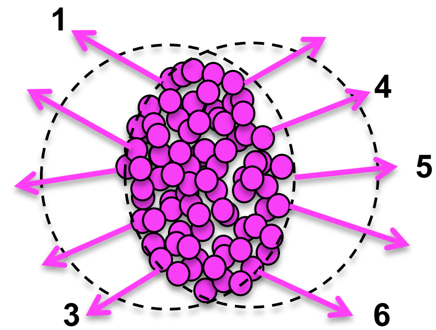
Multiparticle Cumulant

- 6-particle correlator, per event

$$\langle 6 \rangle \equiv \left\langle e^{in(\phi_1+\phi_2+\phi_3-\phi_4-\phi_5-\phi_6)} \right\rangle$$

$$\equiv \frac{1}{P_{M,6}} \sum_{\substack{i\neq j\neq k \\ \neq l\neq m\neq n}}^{M} e^{in(\phi_i+\phi_j+\phi_k-\phi_l-\phi_m-\phi_n)}$$

Distinctive 6-particle combinations



- 6-particle cumulant, all events

$$c_n\{6\} = \langle\langle 6 \rangle\rangle - 9 \bullet \langle\langle 4 \rangle\rangle \langle\langle 2 \rangle\rangle + 12 \bullet \langle\langle 2 \rangle\rangle^3$$

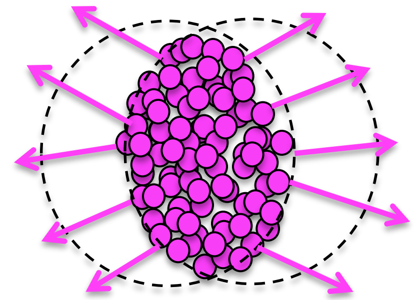
- Q-Cumulant: decompose → flow vector $Q_n \equiv \sum_{i=1}^{M} w_i e^{in\varphi_i}$

- Cumulant v_n → $v_n\{4\} = \sqrt[4]{-c_n\{4\}}, v_n\{6\} = \sqrt[6]{\frac{1}{4}c_n\{6\}}, v_n\{8\} = \sqrt[8]{-\frac{1}{33}c_n\{8\}}$

Lee-Yang Zeros Method

- All-particle correlation, per event

$$g(ir) \equiv \prod_{j=1}^{M} \left[1 + i \cdot r \cdot w_j \cos\left(n(\phi_j - \theta)\right)\right]$$



- Generating function, all events

$$G(ir) = \langle g(ir) \rangle = \frac{1}{N_{evt}} \sum_{events} g(ir)$$

Decompose

Flow vector:

$$Q_n = (Q_{nx}, Q_{ny})$$

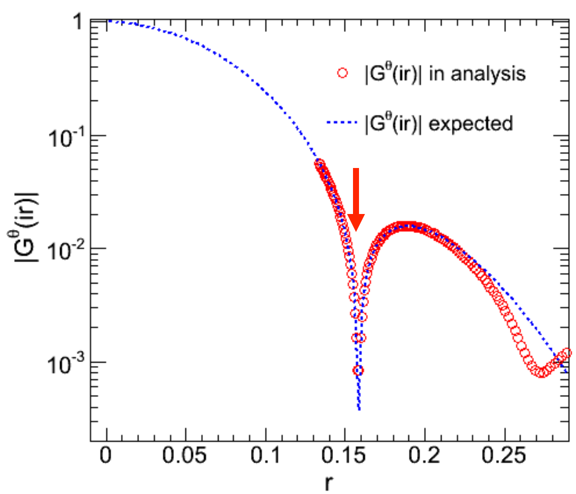
$$Q_{nx} = \sum_{j=1}^{M} w_j \cos(n\phi_j)$$

$$Q_{ny} = \sum_{j=1}^{M} w_j \sin(n\phi_j)$$

- Integrated $v_n\{LYZ\}$

$$V_2\{LYZ\} = \frac{j_{01}}{r_0}$$

j_{01}=2.40483
r_0 is the first zero of |G(ir)|



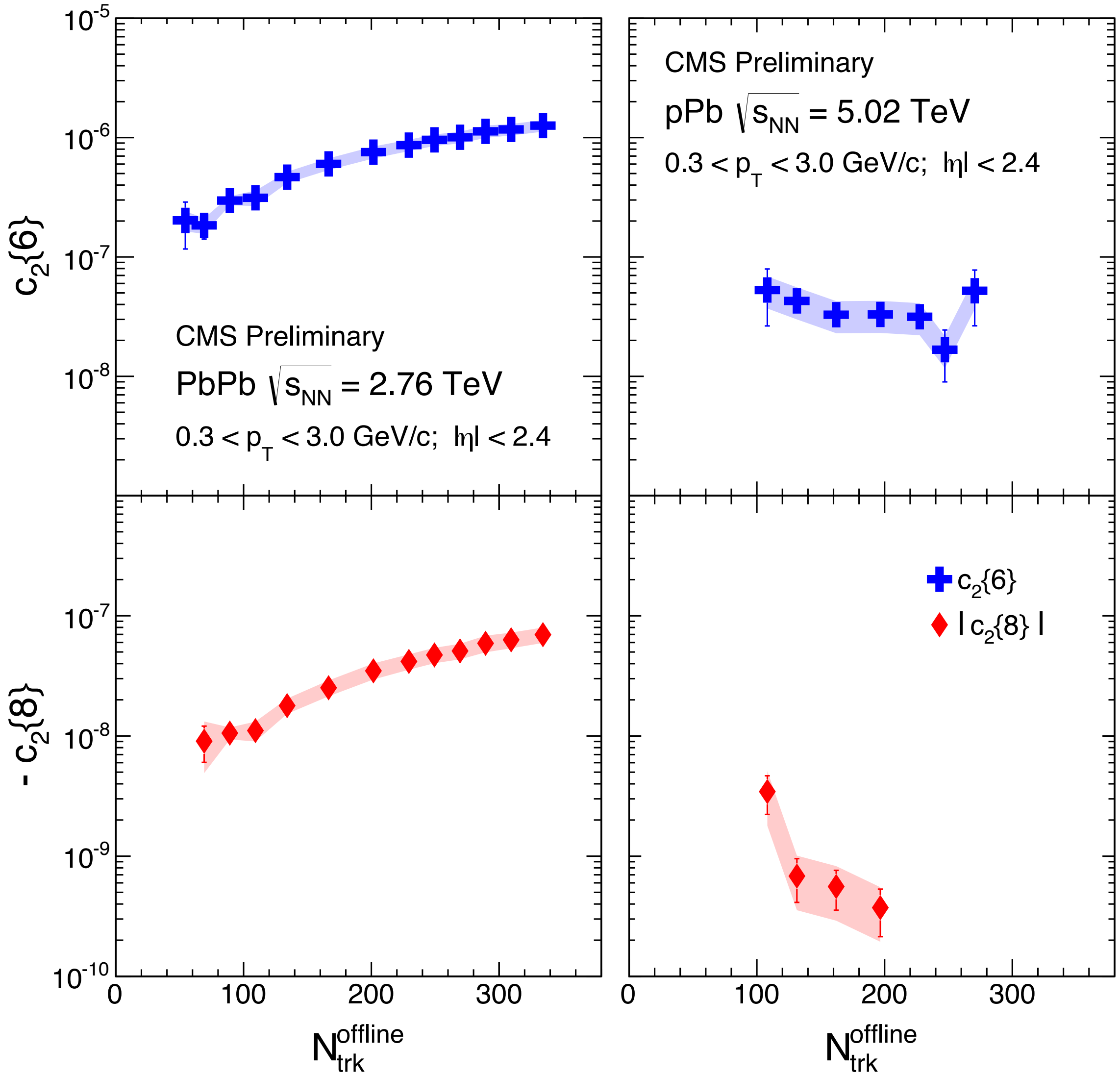
Results – Cumulant

- True 6- and 8-particle correlations in pPb and PbPb collisions

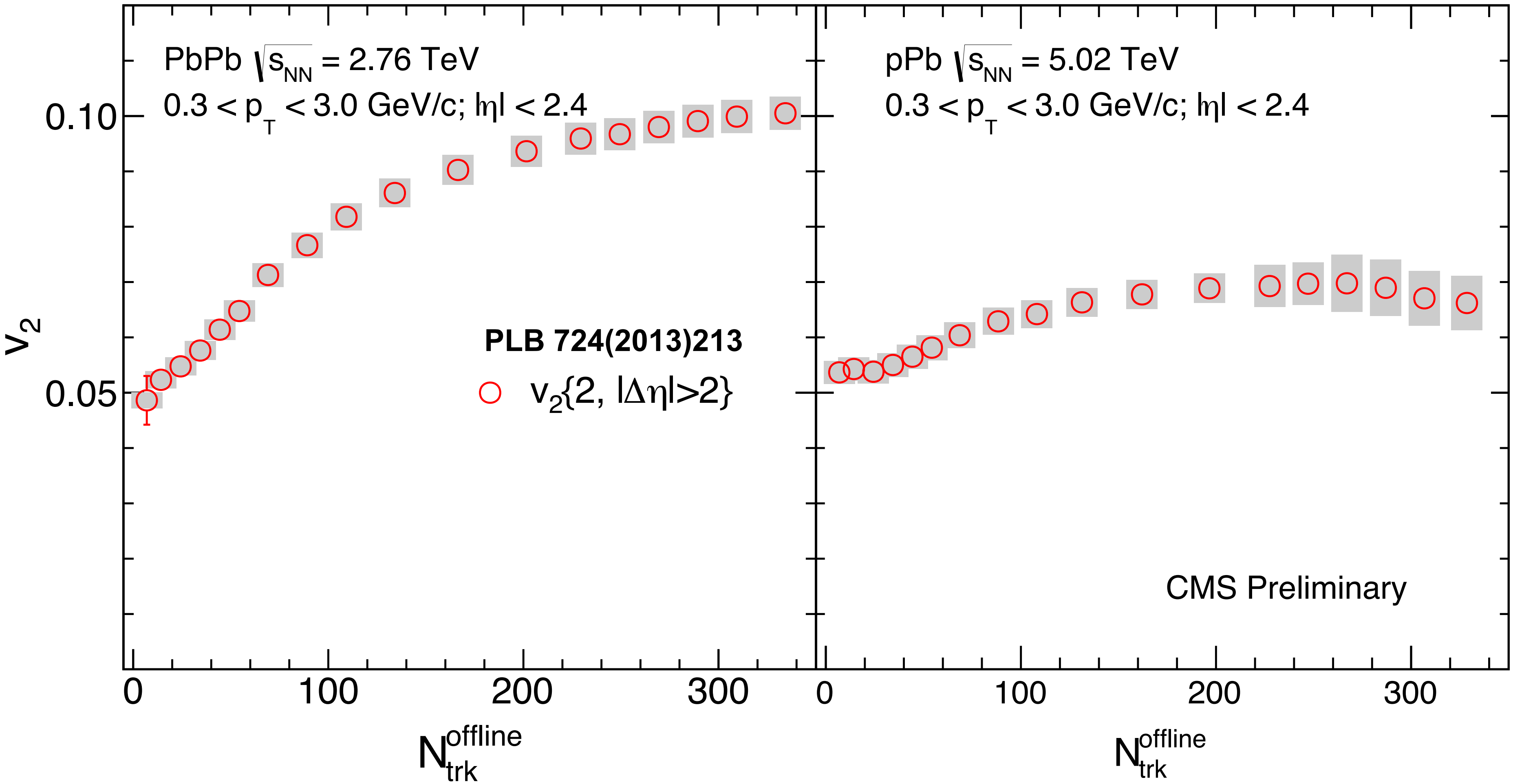
$$v_n\{4\} = \sqrt[4]{-c_n\{4\}}$$

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

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

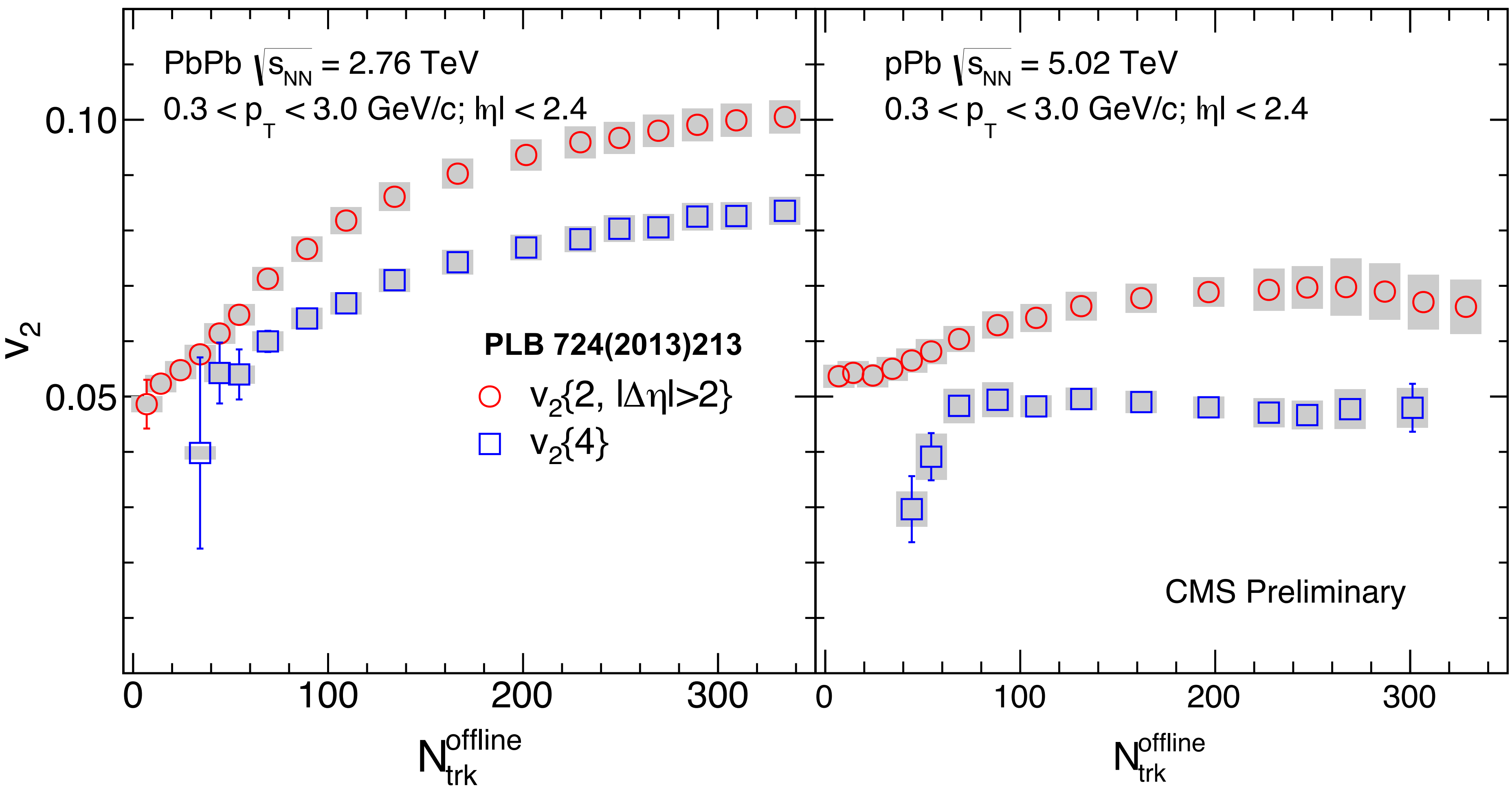


Results – v_2



PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
0.3 < p_T < 3.0 GeV/c; |η| < 2.4
PLB 724(2013)213
$v_2\{2, |\Delta\eta|>2\}$
pPb $\sqrt{s_{NN}}$ = 5.02 TeV
0.3 < p_T < 3.0 GeV/c; |η| < 2.4
CMS Preliminary
v_2
0.10
0.05
0
100
200
300
$N_{trk}^{offline}$

Results – v_2



PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
0.3 < p_T < 3.0 GeV/c; |η| < 2.4
PLB 724(2013)213
$v_2\{2, |\Delta\eta|>2\}$
$v_2\{4\}$
pPb $\sqrt{s_{NN}}$ = 5.02 TeV
0.3 < p_T < 3.0 GeV/c; |η| < 2.4
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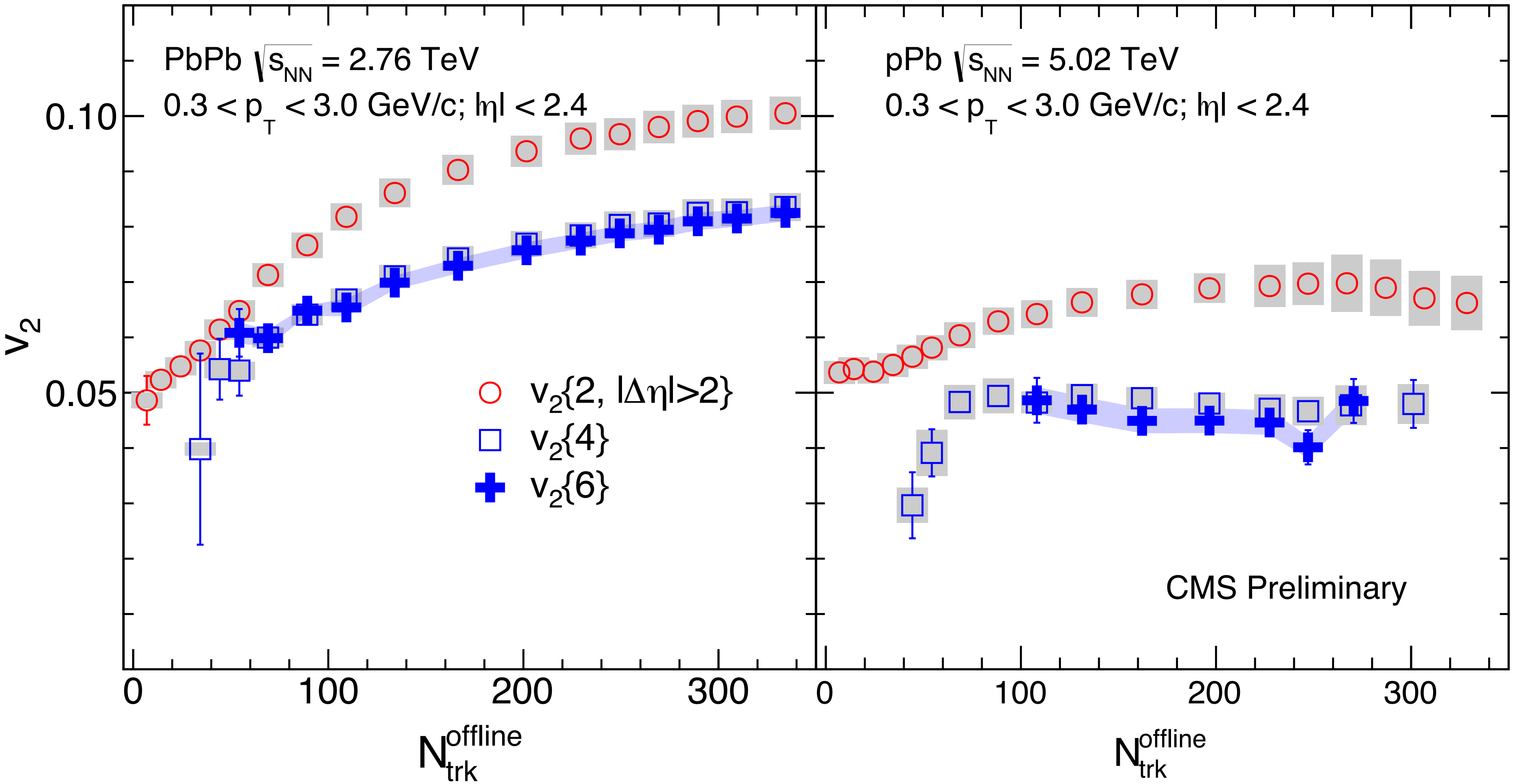
Results – v_2



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0.3 < p_T < 3.0 GeV/c; |η| < 2.4
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$v_2\{2, |\Delta\eta|>2\}$
$v_2\{4\}$
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CMS Preliminary
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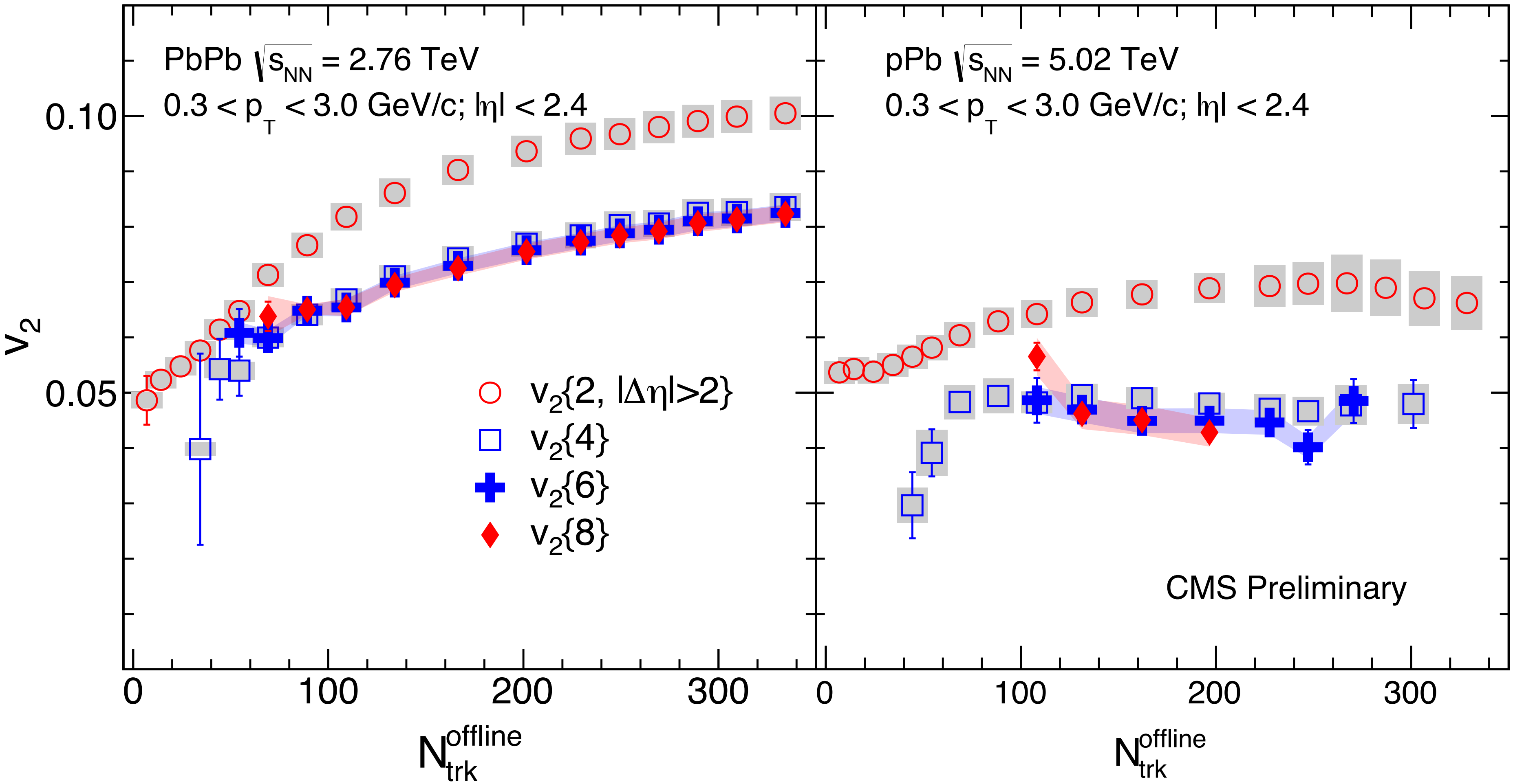
Results – v_2



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CMS Preliminary
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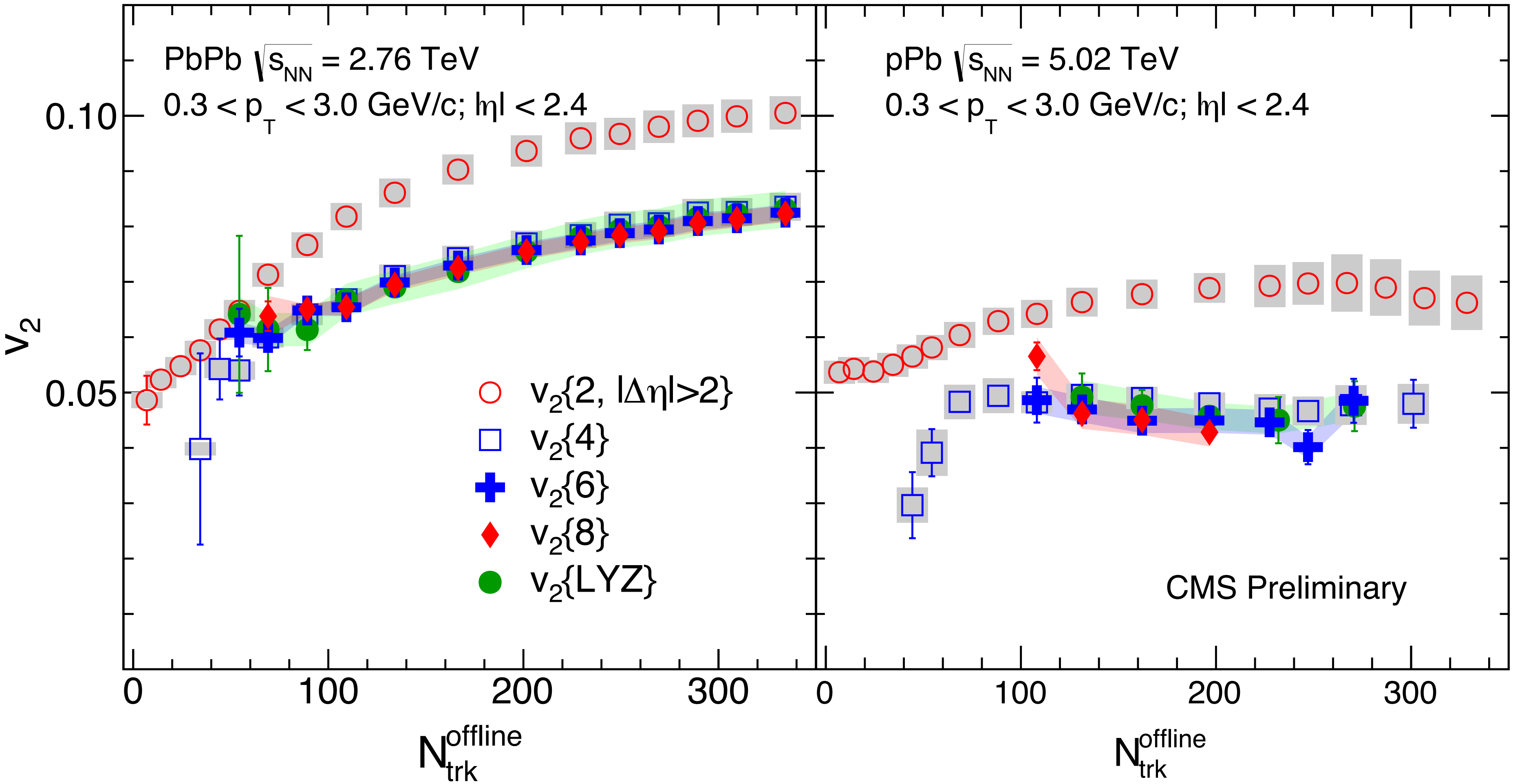
Results – v_2



➢ $v_2\{4\}$, $v_2\{6\}$, $v_2\{8\}$ and $v_2\{LYZ\}$ are in good agreement ±10%

Result – Cumulant v_2

- In hydrodynamic picture
  - arXiv:1311.7325 (Bzdak, Bozek & McLerran)
  - PRL 112 (2014) 082301 (Yan & Ollitrault)

$$\varepsilon_2\{4\} \cong \varepsilon_2\{6\} \cong \varepsilon_2\{8\}$$

$$v_2\{4\} \cong v_2\{6\} \cong v_2\{8\}$$

Result – Cumulant v_2 ratios

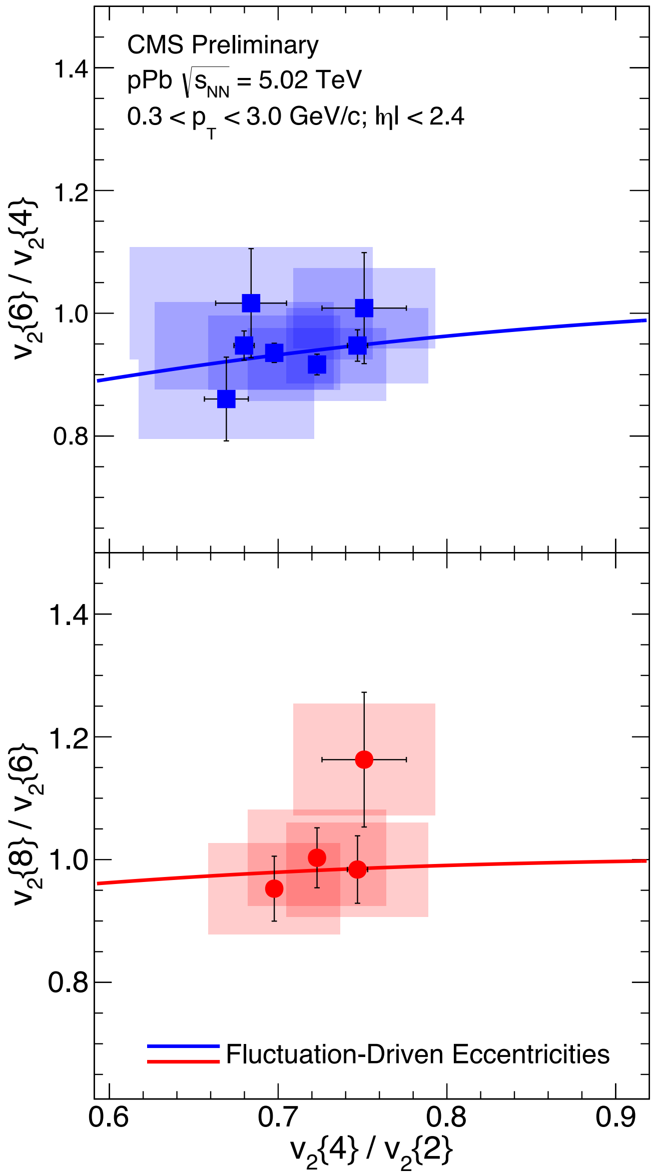
- In hydrodynamic picture
  - arXiv:1311.7325 (Bzdak, Bozek & McLerran)
  - PRL 112 (2014) 082301 (Yan & Ollitrault)

$$\varepsilon_2\{4\} \cong \varepsilon_2\{6\} \cong \varepsilon_2\{8\}$$

$$v_2\{4\} \cong v_2\{6\} \cong v_2\{8\}$$

- Fluctuation-driven initial-state eccentricities

[PRL 112 (2014) 082301 (Yan & Ollitrault)]



Result – Cumulant v_2 ratios

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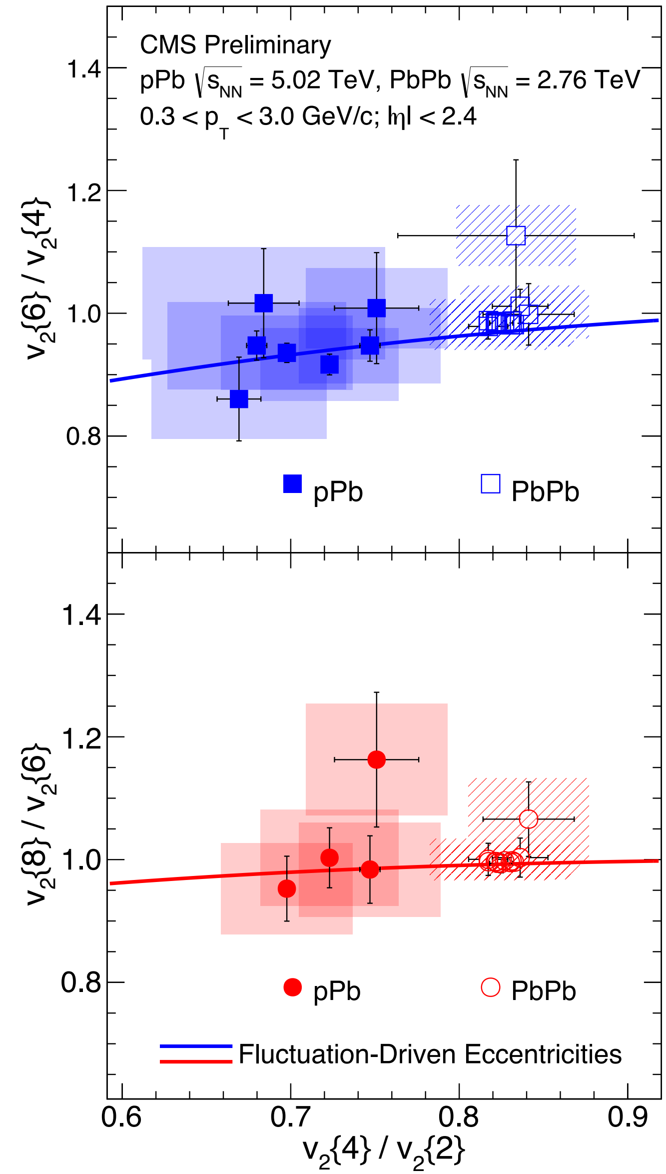
- Fluctuation-driven initial-state eccentricities

[PRL 112 (2014) 082301 (Yan & Ollitrault)]



Summary

- 6-, 8- and all-particle correlations are measured for the first time in pPb collisions at 5.02 TeV
- A direct comparison is made between pPb and PbPb as a function of multiplicity
- $v_2\{4\}$, $v_2\{6\}$, $v_2\{8\}$ and $v_2\{LYZ\}$ are consistent within 10% in pPb and PbPb, respectively
- Relative ratios of v_2 from cumulant methods are consistent with hydrodynamic predictions within current statistical precision