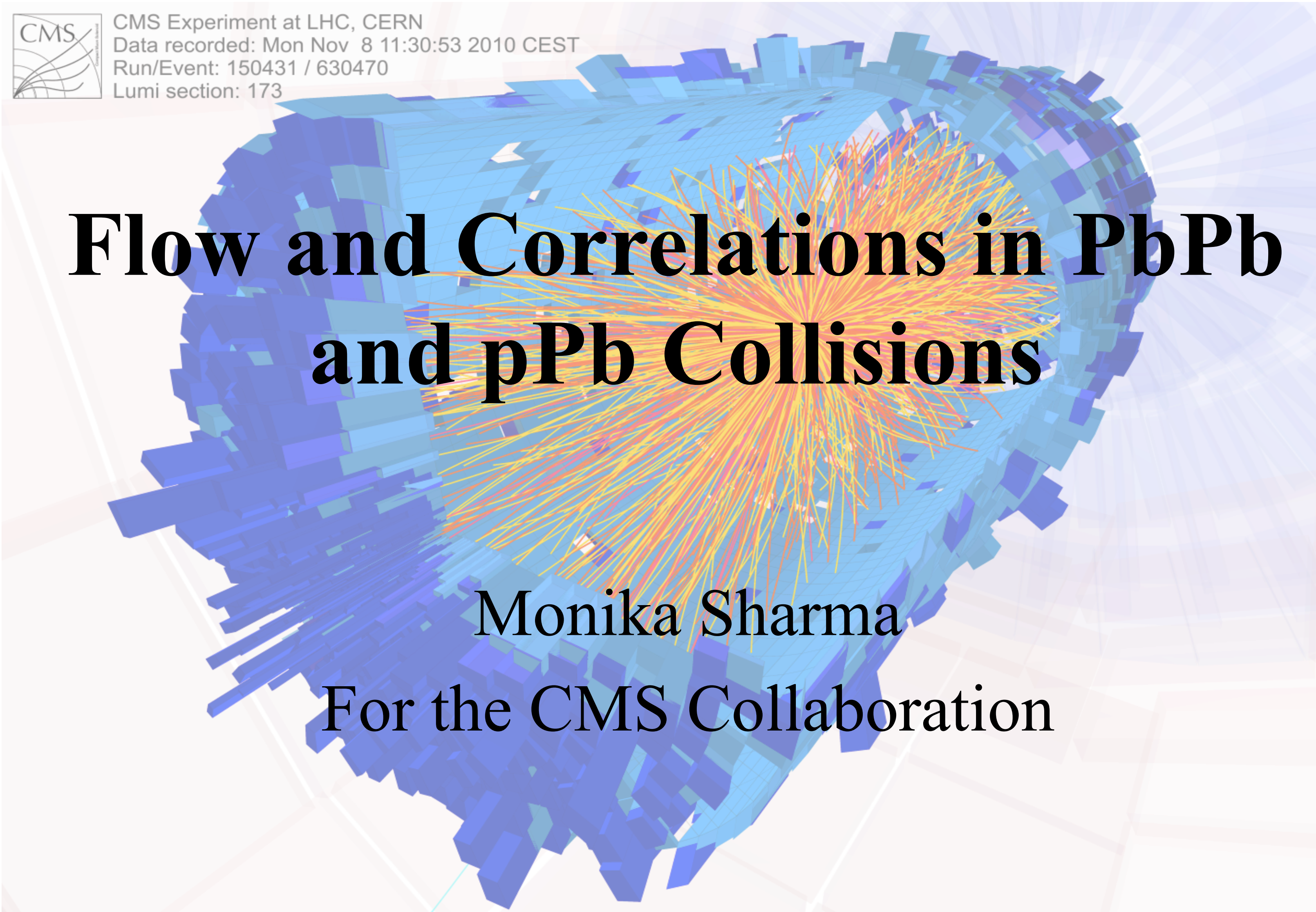
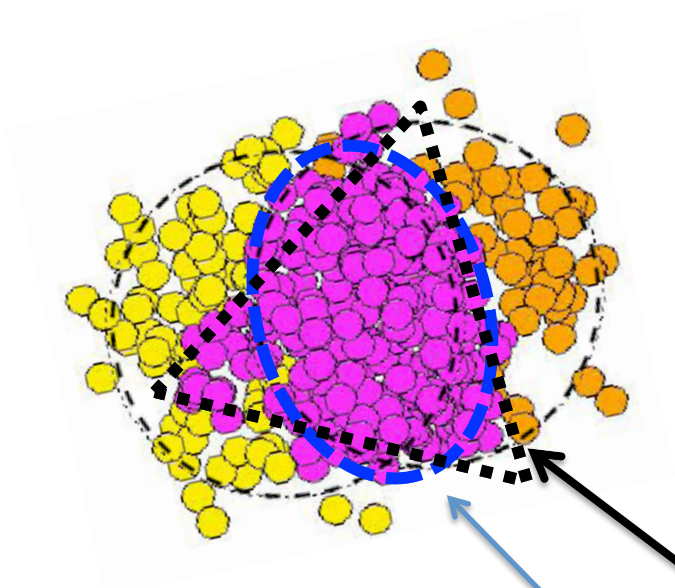


Flow and Correlations in PbPb and pPb Collisions

Monika Sharma
For the CMS Collaboration

Motivation: hydrodynamics

Azimuthal particle correlations in AA collisions



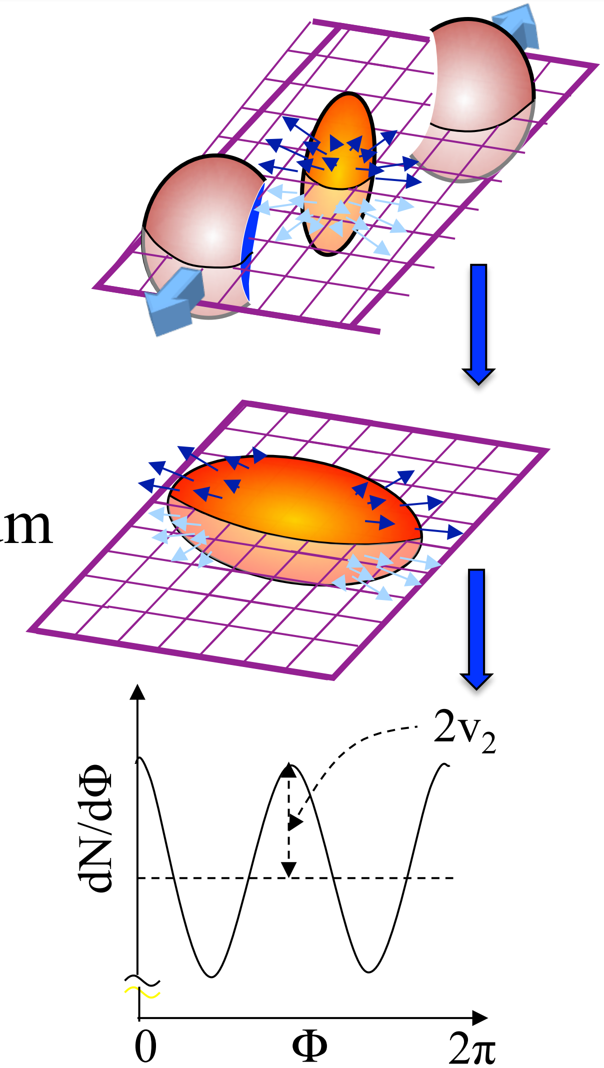
Elliptic, v_2

Triangular, v_3

Initial spatial anisotropy

↓

Final momentum anisotropy

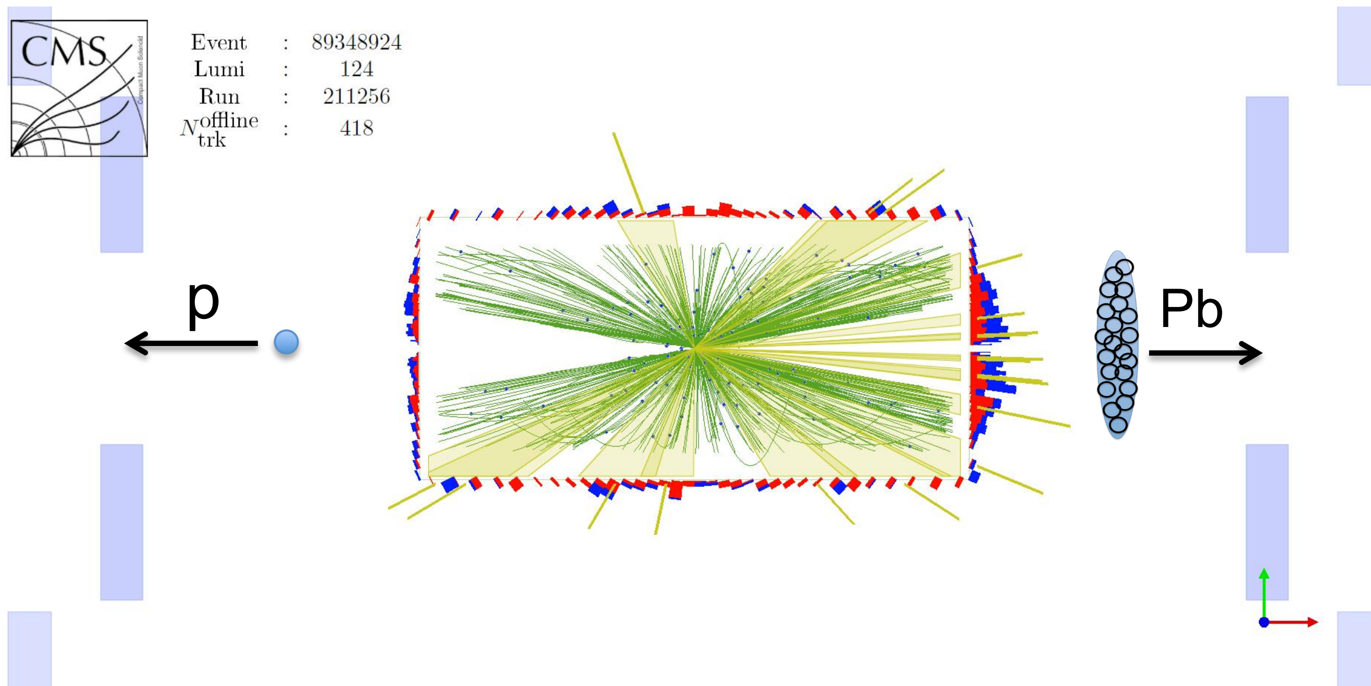


Quantified by coefficients of a Fourier series

Fourier series: $dN/d\phi = 1 + 2v_1\cos(\phi) + 2\,v_2\cos(2\phi) + 2v_3\cos(3\phi) + \ldots$

Motivation: establishing baseline of PbPb collisions

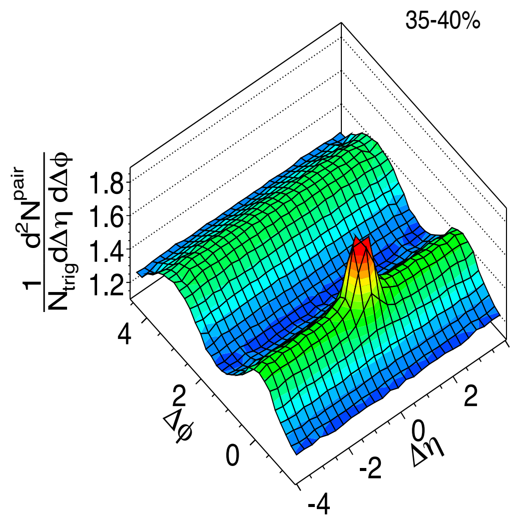
Controlled environment? pPb collisions



- ✓ No deconfined medium is expected to be formed?
- ✓ What about azimuthal anisotropy in pPb collisions?

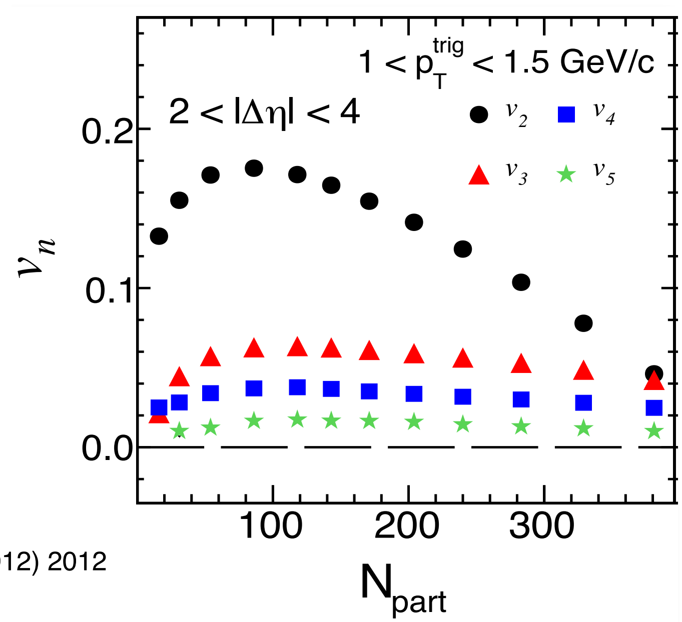
Motivation

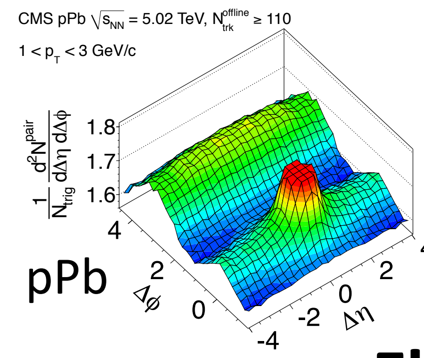
Long range correlations ⟷ Flow, v_n



PbPb

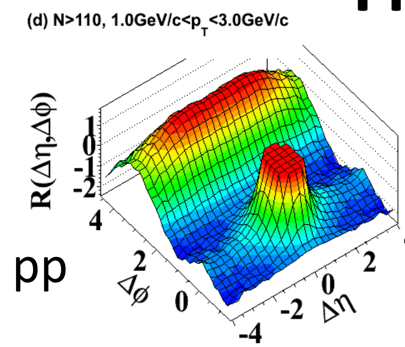
EPJC 72 (2012) 2012





pPb

Flow?



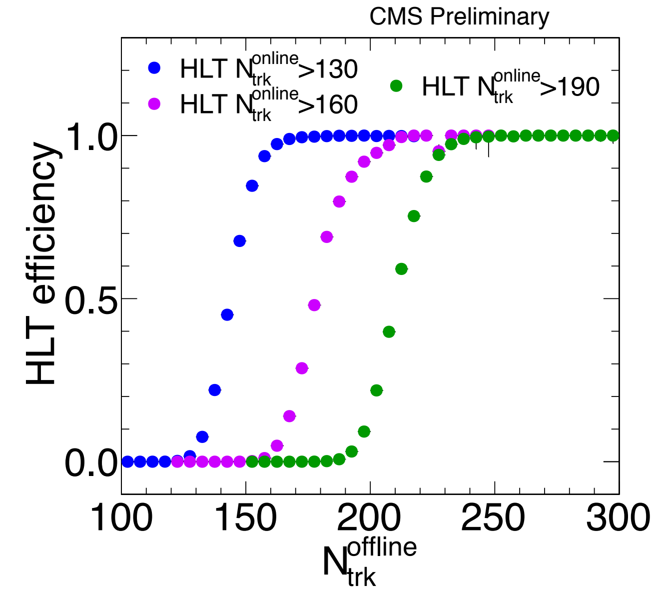
pp

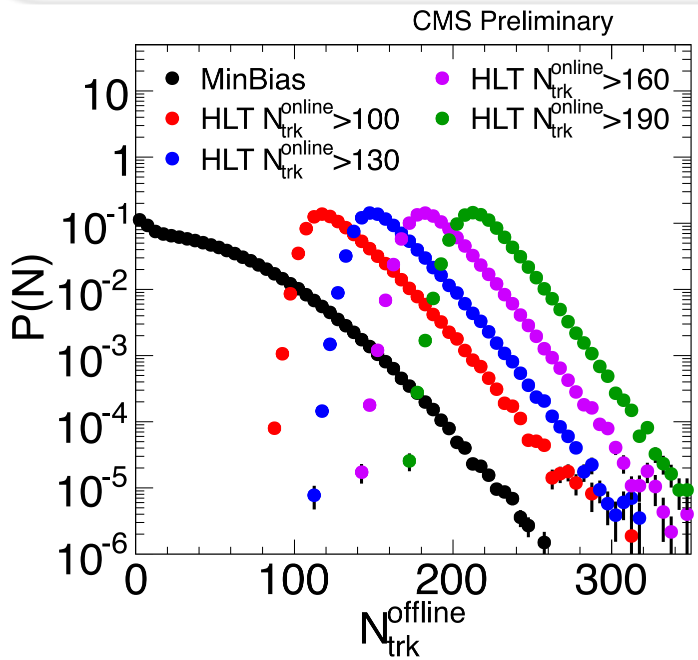
JHEP 09 (2010) 091

- Long range correlations can be explained by flow harmonics in PbPb
- Are these correlations in pPb also related to hydrodynamic flow?
- Or CGC?

Data sets, trigger selection and multiplicity distribution

- **Data sets**
  - 2013 pPb + Pbp, 31 nb^{-1}
  - 2011 PbPb, 2.3μb^{-1} (50-100%)
- **Triggers**
  - Minimum bias trigger
  - High multiplicity triggers in 2013





Track (p_T>0.4 GeV/c, |η|<2.4) multiplicity distribution in pPb for different triggers

The fraction of events in 300 ≤ $N_{trk}^{offline}$ < 350 is about 10^{-7} with respect to all MinBias events.

Data sets, trigger selection and multiplicity distribution

- **Data sets**
  - 2013 pPb + Pbp, 31 nb^{-1}
  - 2011 PbPb, 2.3μb^{-1} (50-100%)
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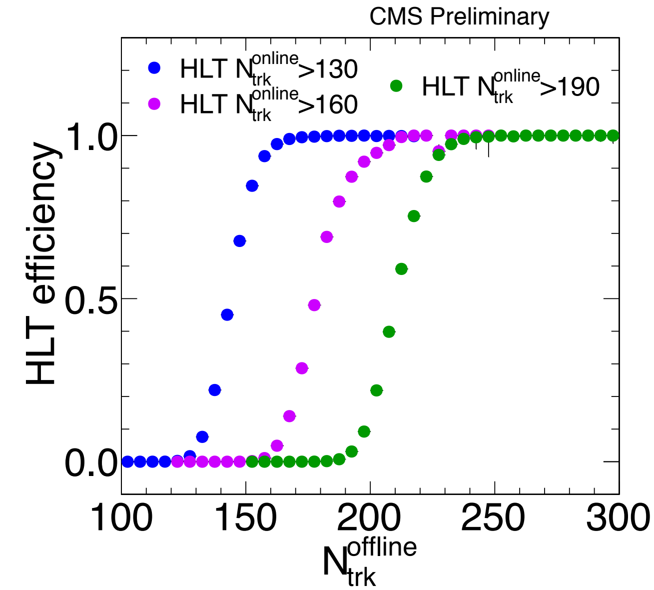
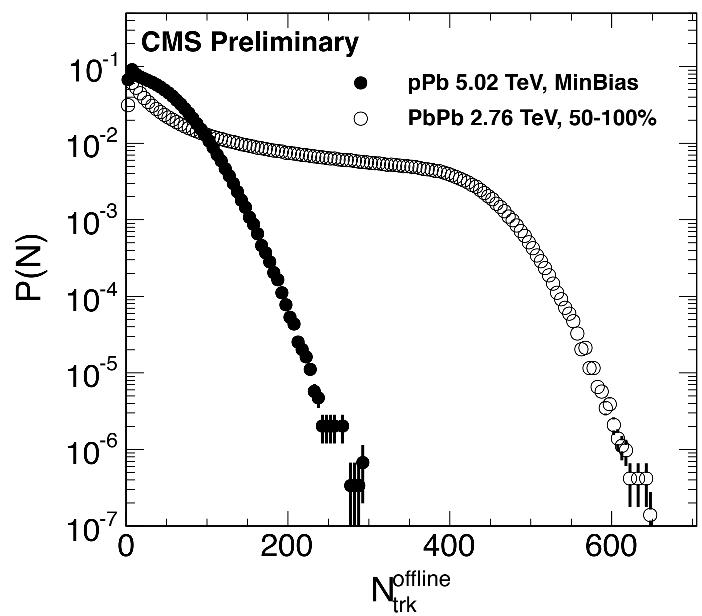
  - Minimum bias trigger
  - High multiplicity triggers in 2013

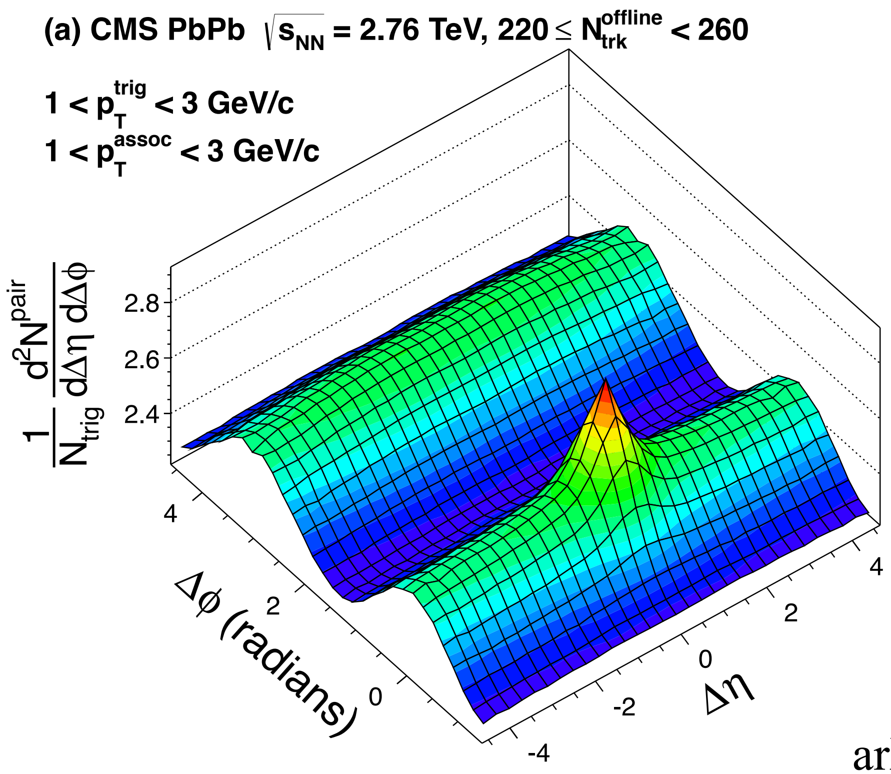




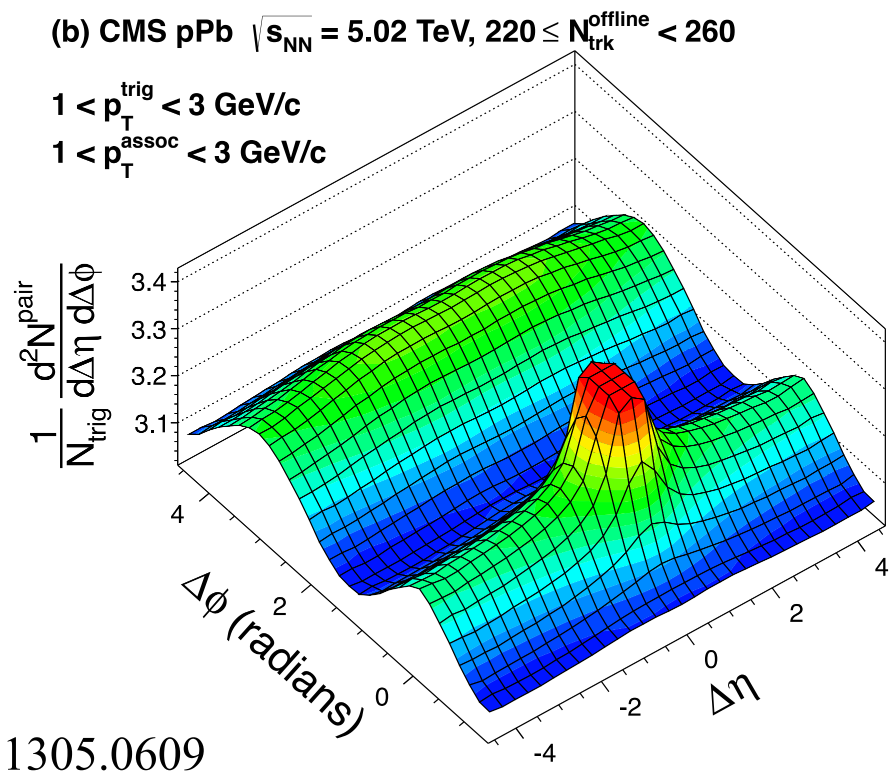
Track multiplicity distribution in MinBias pPb and PbPb 50-100%

Results: Two-particle correlations in PbPb and pPb

PbPb



pPb

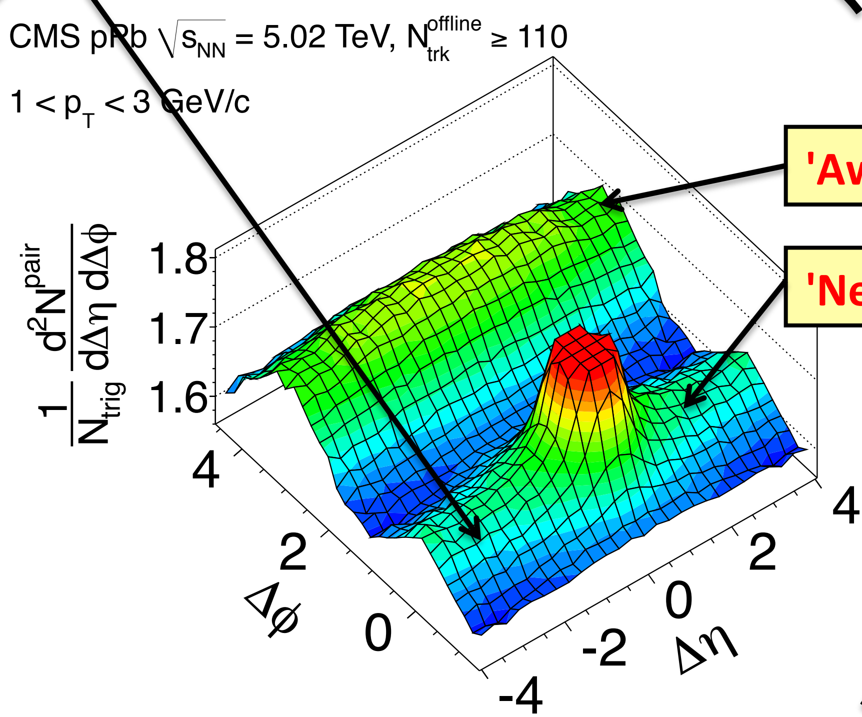


arXiv:1305.0609

- PbPb and pPb use the same multiplicity selection, 220 =< $N_{trk}^{offline}$ <260
- Very strong long-range correlations in pPb

Discovery: pPb pilot run

'Near Side long range correlations'



'Away Side JET', $\Delta\phi \sim \pi$

'Near Side JET', $\Delta\phi \sim 0$

Long range rapidity correlations

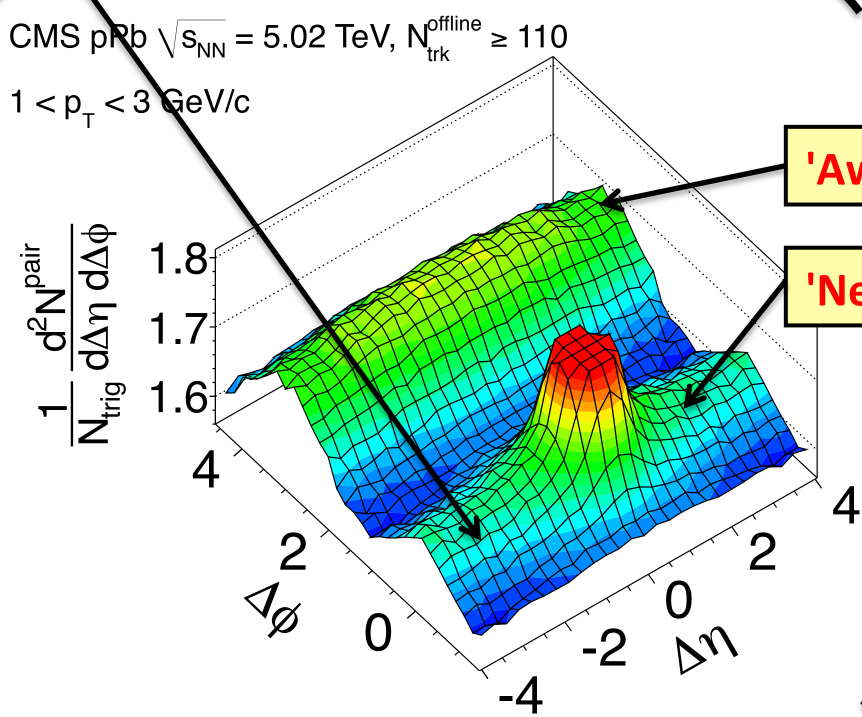
→ Seen only for high multiplicity pp and pPb collisions

[PLB 718 (2013) 795]

- Explore in detail the multiplicity and p_T dependence of the 2-particle correlations
- New observable: 4-particle correlations add greater sensitivity to collective effects

Discovery: pPb pilot run

'Near Side long range correlations'



'Away Side JET', $\Delta\phi \sim \pi$

'Near Side JET', $\Delta\phi \sim 0$

➡ Long range rapidity correlations

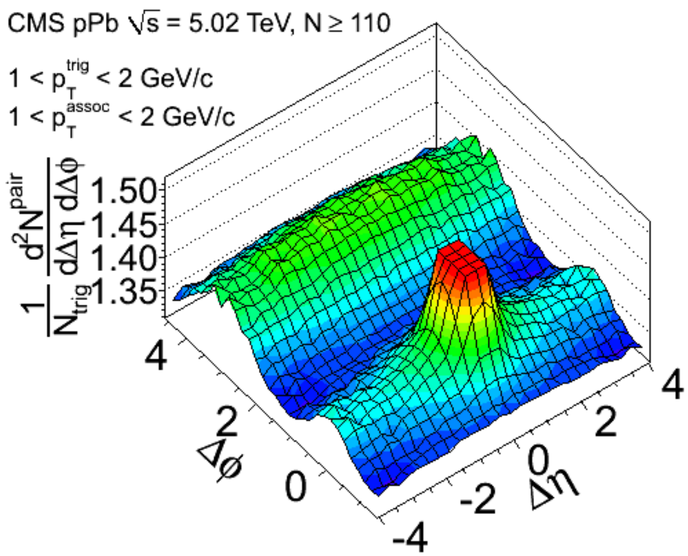
⟶ Seen only for high multiplicity pp and pPb collisions

What is new from the latest pPb run?

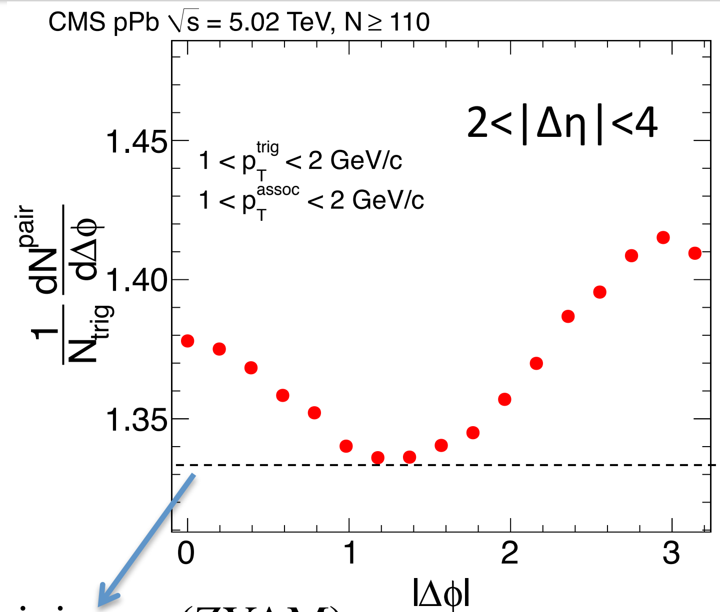
PLB 718 (2013) 795

- Explore in detail the multiplicity and p_T dependence of the 2-particle correlations
- New observable: 4-particle correlations add greater sensitivity to collective effects

2-particle correlation method



Average over ridge region (2<|Δη|<4)



Shift the distribution to zero yield at minimum (ZYAM) and extract the associated yield

Physics Letters B 718 (2013) 795–814

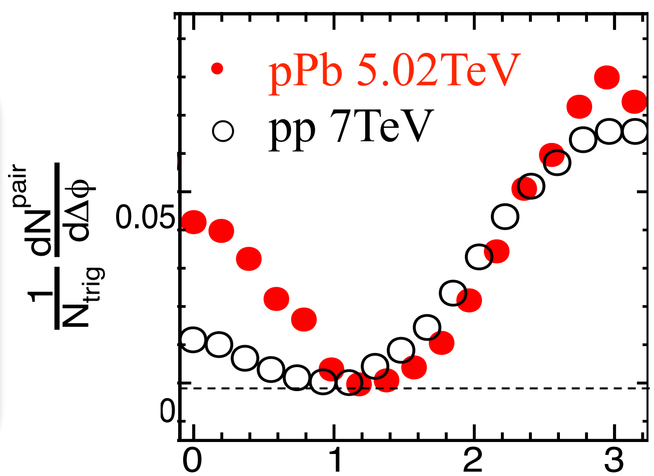
$$v_n\{2, |\Delta\eta| > 2\}(p_T) = \frac{V_{n\Delta}(p_T, p_T^{ref})}{\sqrt{V_{n\Delta}(p_T^{ref}, p_T^{ref})}}$$

Fourier decomposition:

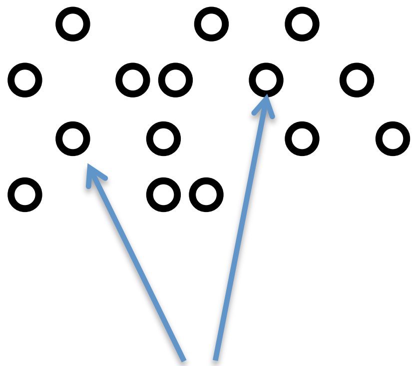
$$\frac{dN^{pair}}{d\Delta\phi} \sim 1 + 2\sum_{n=1} V_{n\Delta} \cos(n\Delta\phi)$$

Assuming factorization:

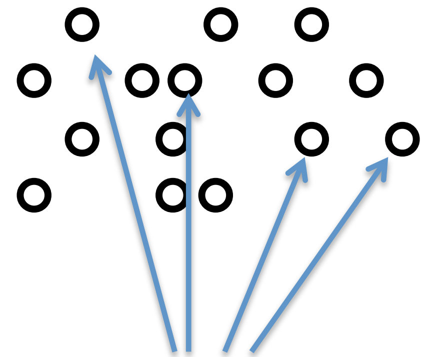
$$V_{n\Delta} = v_n(p_T^{trig}) \times v_n(p_T^{assoc})$$



Multi-particle correlations

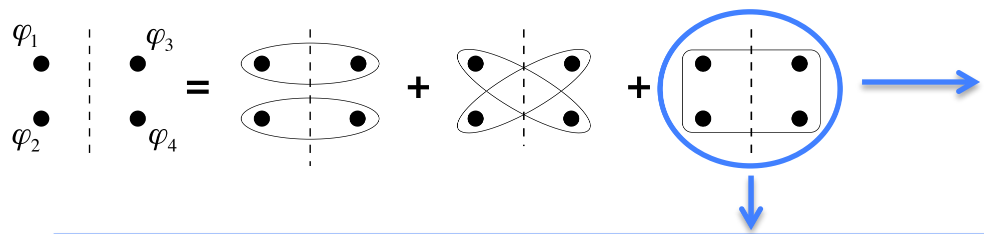


$$\left\langle e^{in(\varphi_1-\varphi_2)} \right\rangle$$



$$\left\langle e^{in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)} \right\rangle$$

Four particle correlations (Q-cumulant method): remove 2 and 3 particle correlations



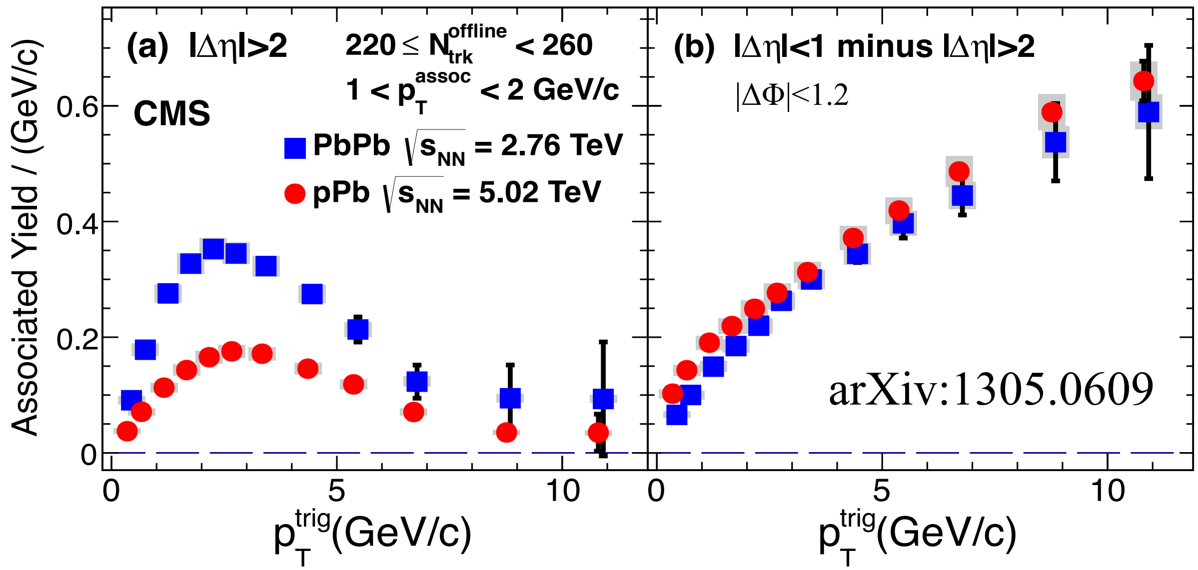
$$c_n\{4\} = \langle\langle 4\rangle\rangle - 2\cdot\langle\langle 2\rangle\rangle^2$$

$$\left\langle e^{in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)} \right\rangle - \left\langle e^{in(\varphi_1-\varphi_3)} \right\rangle \left\langle e^{in(\varphi_2-\varphi_4)} \right\rangle - \left\langle e^{in(\varphi_1-\varphi_4)} \right\rangle \left\langle e^{in(\varphi_2-\varphi_3)} \right\rangle$$

Associated yield

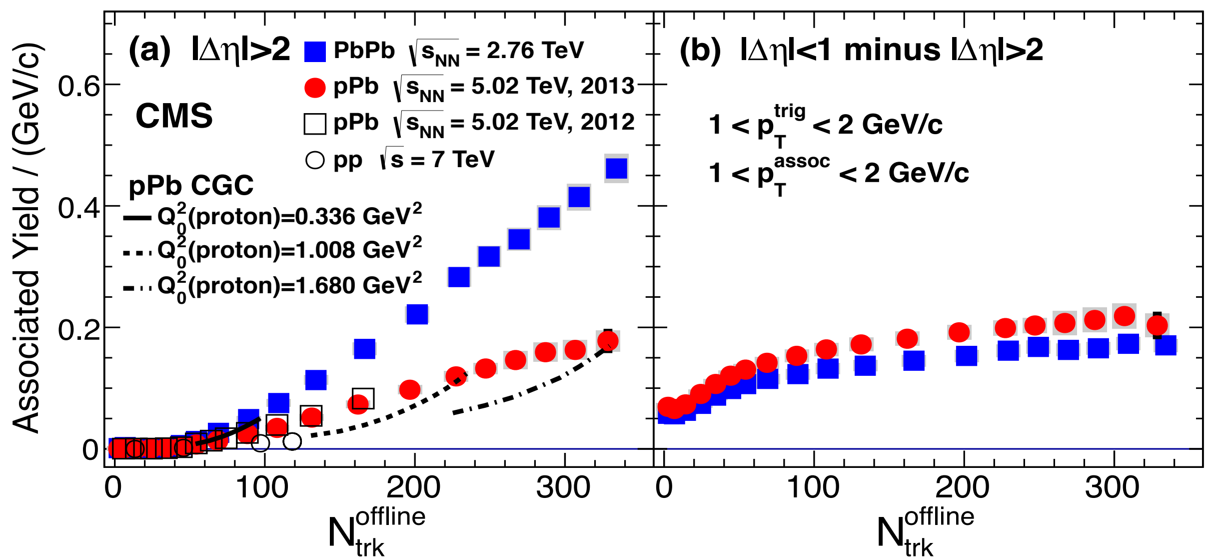
Yield vs p_T

- Similar p_T dependence for PbPb and pPb
- Larger in PbPb (|Δη|>2)
- Expected behavior due to jets (Fig. b)



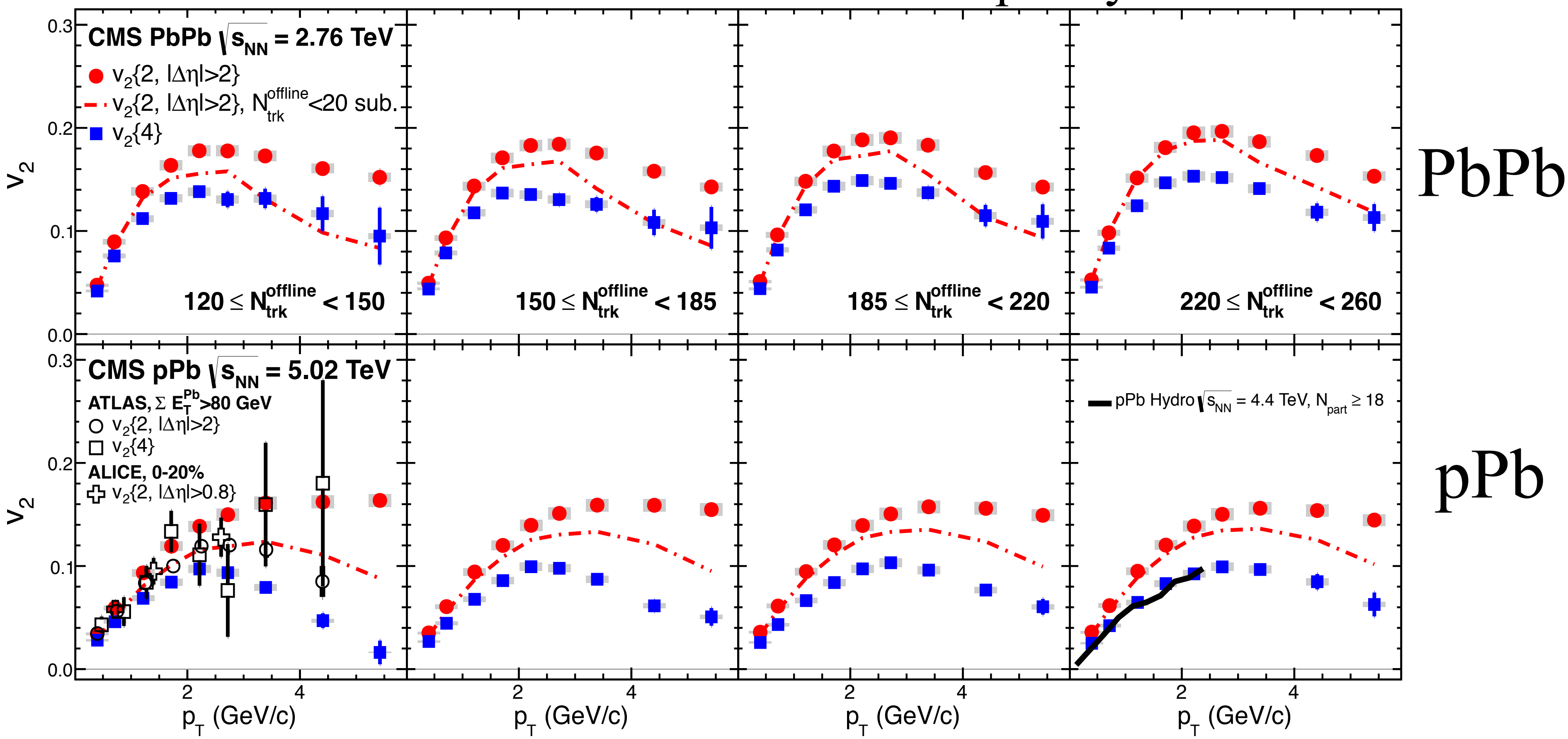
Yield vs multiplicity

- Yield becomes significant at N~40-50, followed by a monotonic rise
- Larger in PbPb (|Δη|>2)



v_2 in PbPb and pPb

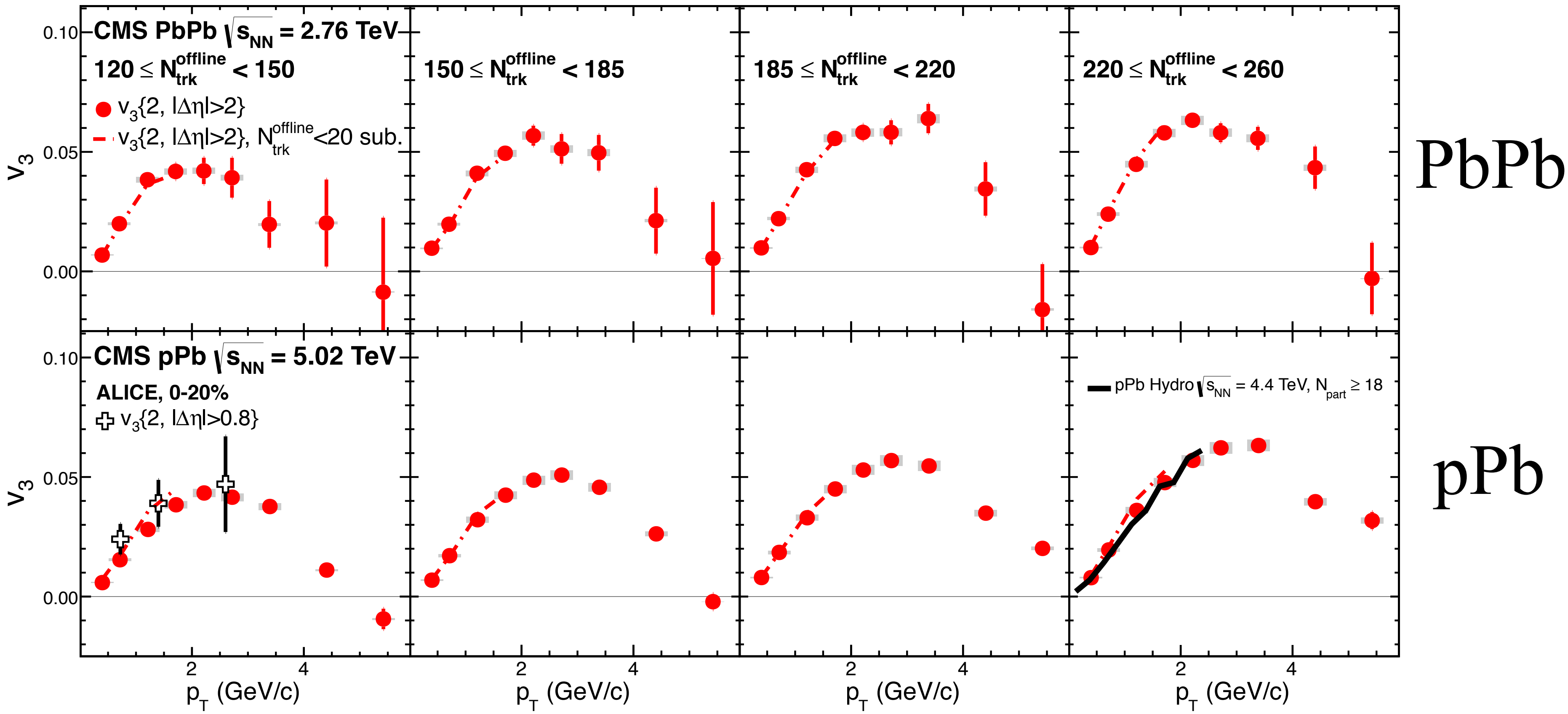
arXiv:1305.0609 Dash-dot line: peripheral subtracted multiplicity →



- v_2 shows similar shape in pPb and PbPb, but is smaller in pPb
- hydro calculation agrees with v2{4}

v_3 in PbPb and pPb

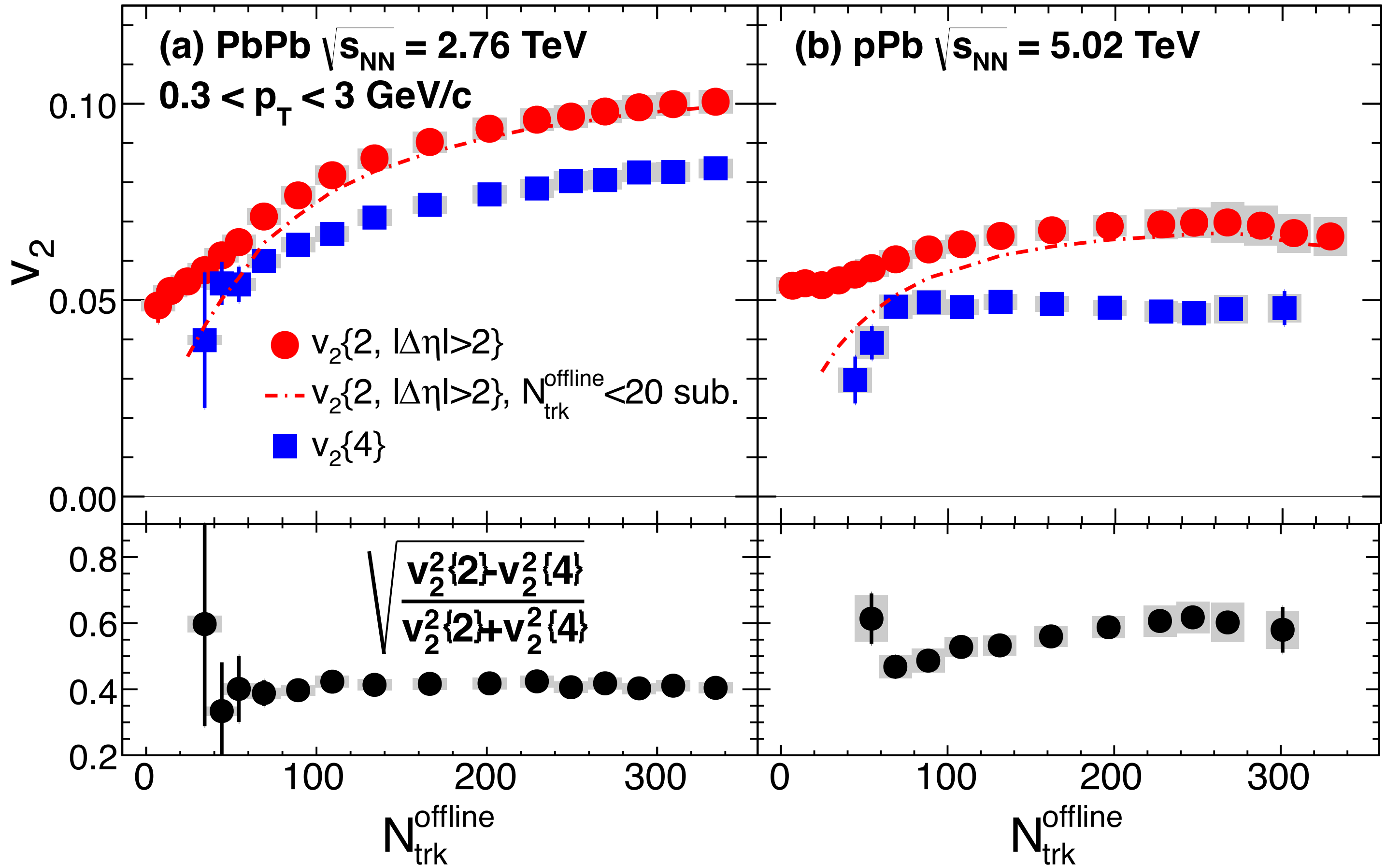
arXiv:1305.0609   Dash-dot line: peripheral subtracted   multiplicity →



- v_3 shows similar shape in pPb and PbPb; magnitude comparable
- Hydro prediction: v_3{PP}, not including fluctuations

Multiplicity dependence of v_2

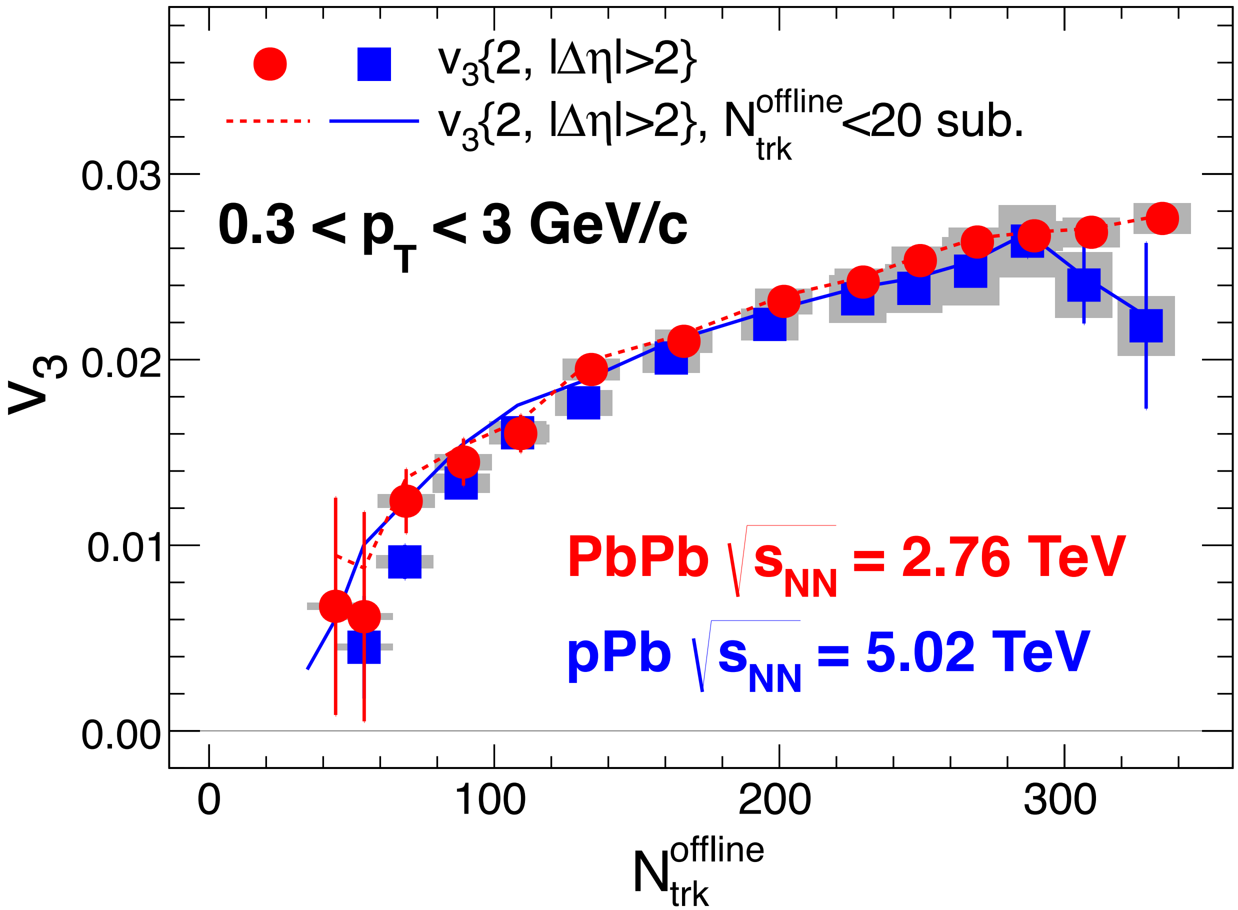
arXiv:1305.0609



- v_2 is smaller in pPb than in PbPb; turns on at N~40-50

Multiplicity dependence of v_3

arXiv:1305.0609



- v_3 is essentially the same in pPb and PbPb; turns on at N~40-50

Summary

Comparison of high statistics, high multiplicity pPb and PbPb data as a function of p_T and multiplicity

- Large $v_2\{4\}$ and $v_3\{2\}$ in pPb
- Associated yield, $v_2\{4\}$ and $v_3\{2\}$ become apparent at about the same multiplicity; N~50
- $v_3\{2\}$ is essentially the same in pPb and PbPb at the same multiplicity

Back-up

Peripheral subtraction

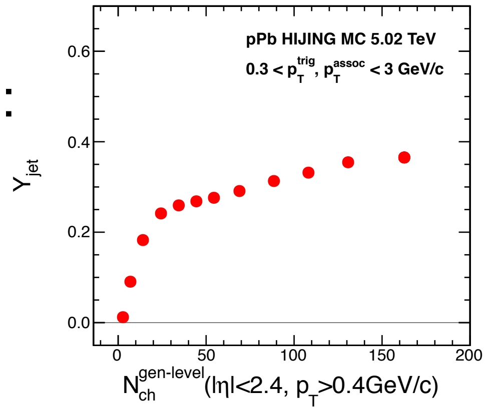
- Away-side correlations contain non-flow effects
- Subtract the data for high multiplicity by low multiplicity to correct for this

Fourier decomposition:

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

Subtracting peripheral correlations in v_2, v_3 calculations:

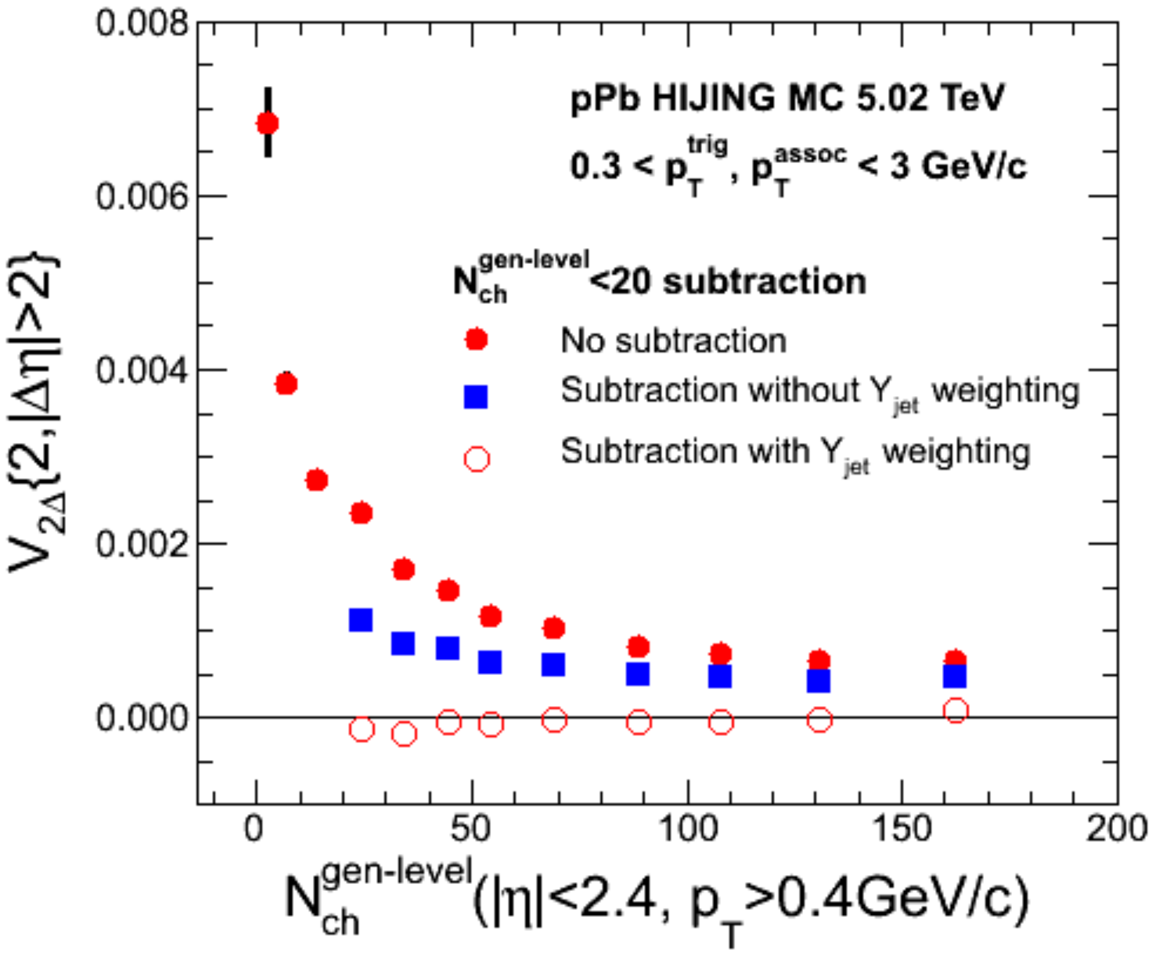
$$V_{n\Delta}(\text{cent}) - V_{n\Delta}(\text{peri}) \times \frac{N_{\rm assoc}(\text{peri})}{N_{\rm assoc}(\text{cent})} \times \frac{Y^{\rm jet}(\text{cent})}{Y^{\rm jet}(\text{peri})}$$



Subtract $N_{trk}^{offline}$<20 (70-100%) to avoid removing signal ($N_{trk}^{offline}$ ~ 40)

Account for the fact that jet correlation increases with multiplicity

Test our procedure in HIJING



Weighted by near-side jet yield, most of non-flow correlations are subtracted

PbPb vs pPb: p_T dependence

PbPb

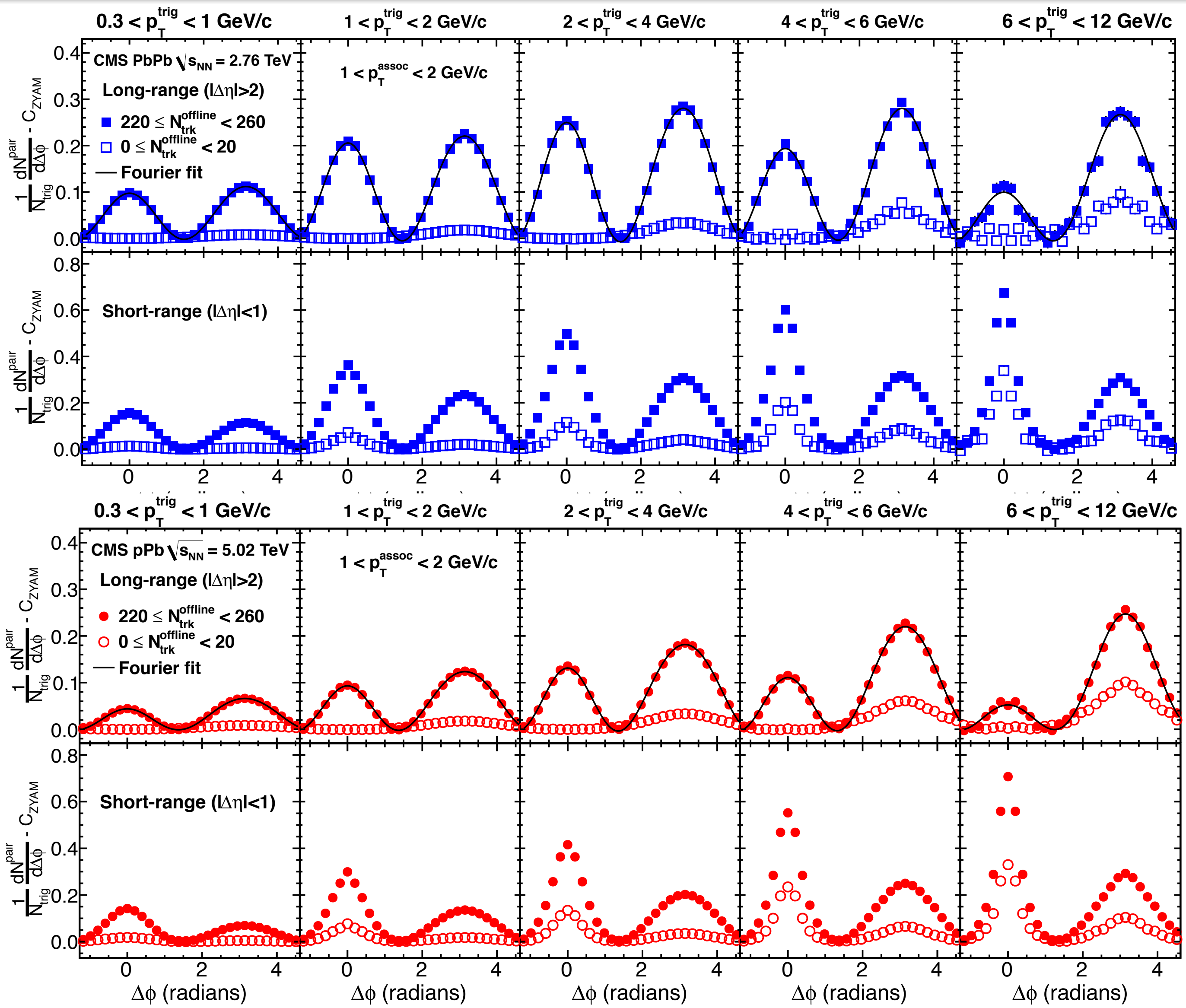
|Δη| > 2

|Δη| < 1

pPb

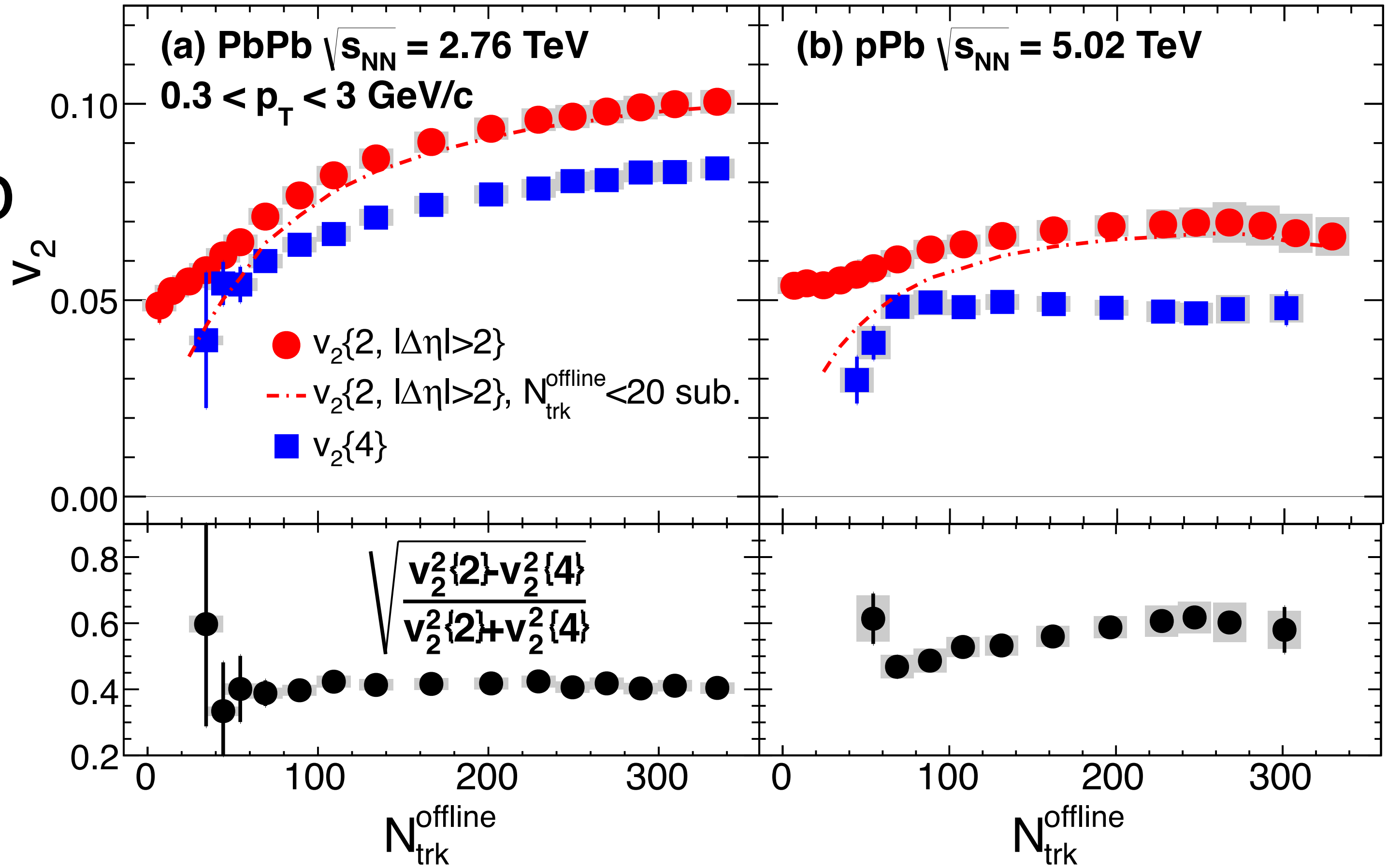
|Δη| > 2

|Δη| < 1



v_2 in PbPb and pPb

PbPb



pPb

- v_2 is smaller in pPb than in PbPb
- Peripheral subtraction has a small effect at high multiplicity

$$v_2\{2\} = \sqrt{<v_2>^2 + \sigma_{v_2}^2} \quad v_2\{4\} = \sqrt{<v_2>^2 - \sigma_{v_2}^2}, \quad \frac{\sigma_{v_2}}{v_2} = \sqrt{\frac{v_2^2\{2\} - v_2^2\{4\}}{v_2^2\{2\} + v_2^2\{4\}}}.$$

- Hydro-flow is not incorporated in the HIJING MC model – $c_2\{4\}$ consistent with zero for small bin width (2 or 5), while becomes nonzero for big bin width (30)
- The effect becomes larger going to more peripheral collisions
- In pPb data, $c_2\{4\}$ crosses zero and becomes negative at certain multiplicity. This is an indication of the onset of multi-particle correlation effect
- A bin width of 5 is chosen for the $v_2\{4\}$ analysis

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13002