Latest CMS results on flow in pPb and PbPb

Shengquan Tuo
(Vanderbilt University)
for the CMS Collaboration

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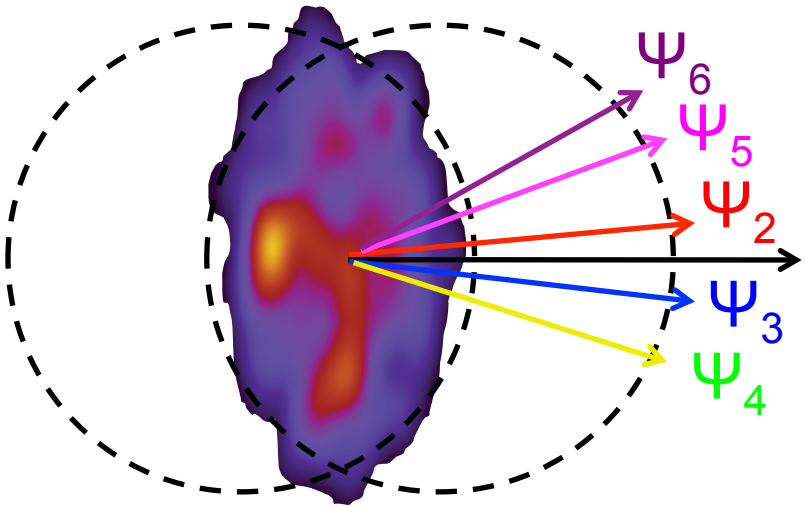
Outline

Studying the role of geometry fluctuations

(I): New results of higher-order flow in PbPb collisions

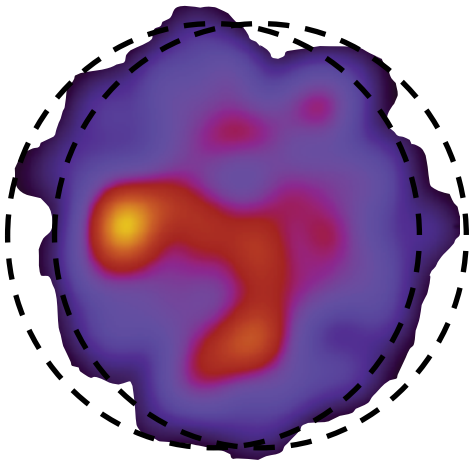
(arXiv:1310.8651)



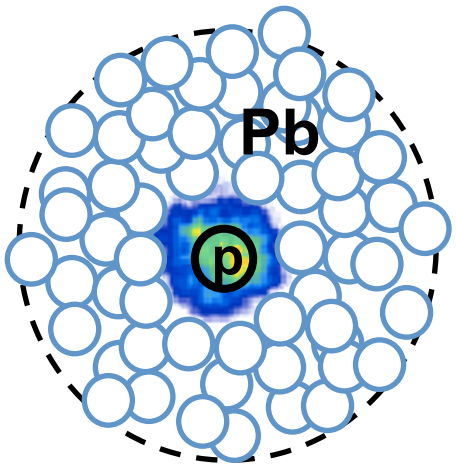
v_2, v_3, v_4, v_5 and v_6 using multiple methods

Flow phenomena in the most violent collisions at the LHC:

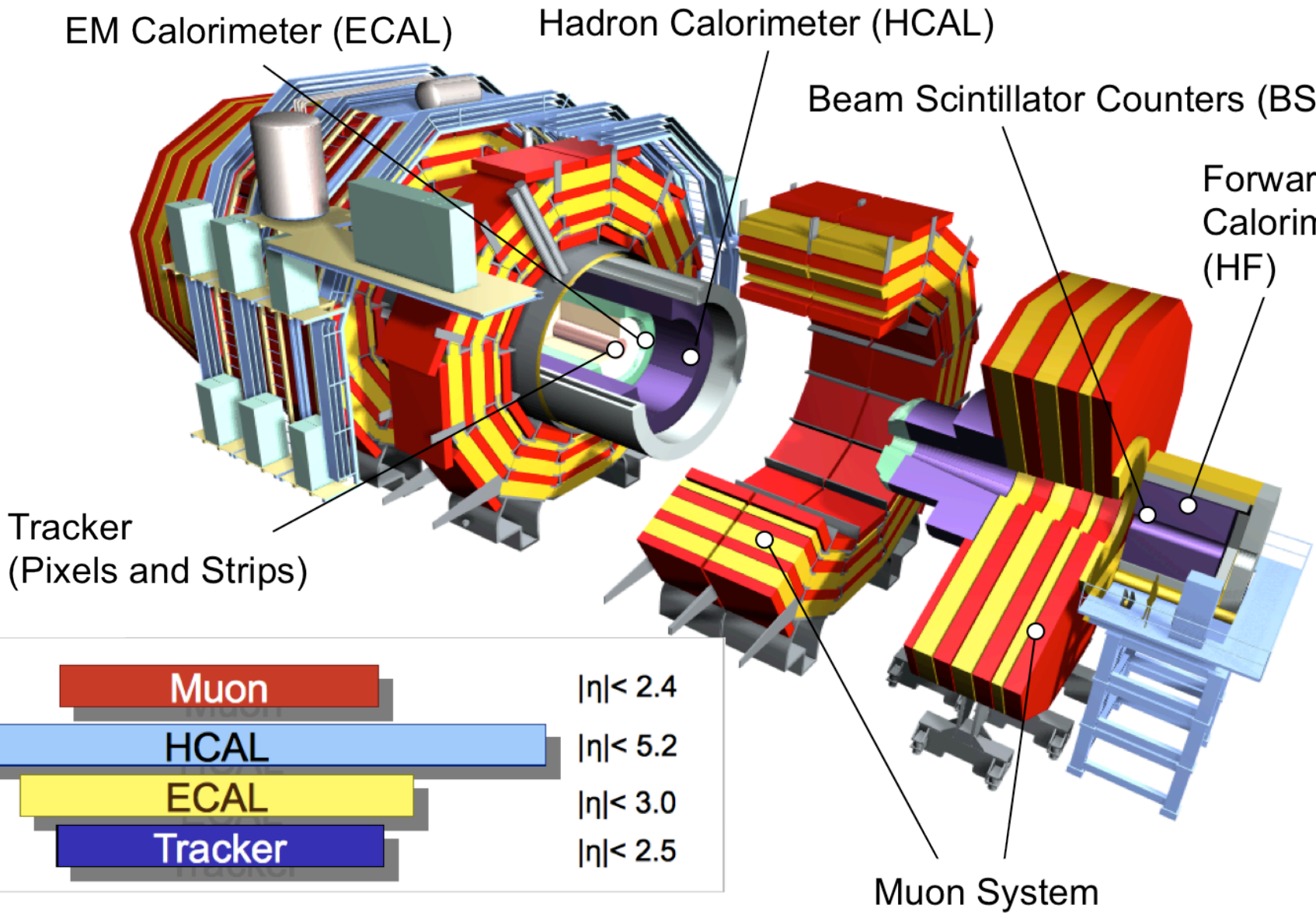
(II): Ultra-central PbPb



(III): High-multiplicity pPb (and pp)



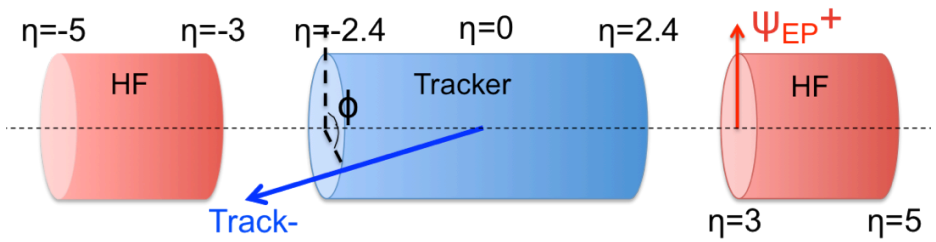
CMS Detector



Large acceptance and wide kinematic coverage!

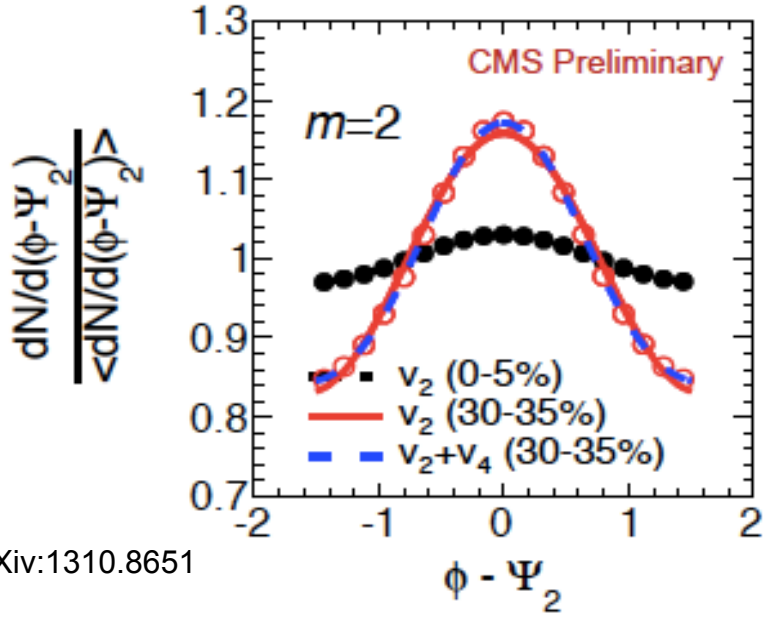
Studies of flow phenomena in CMS

➢ Event plane method:



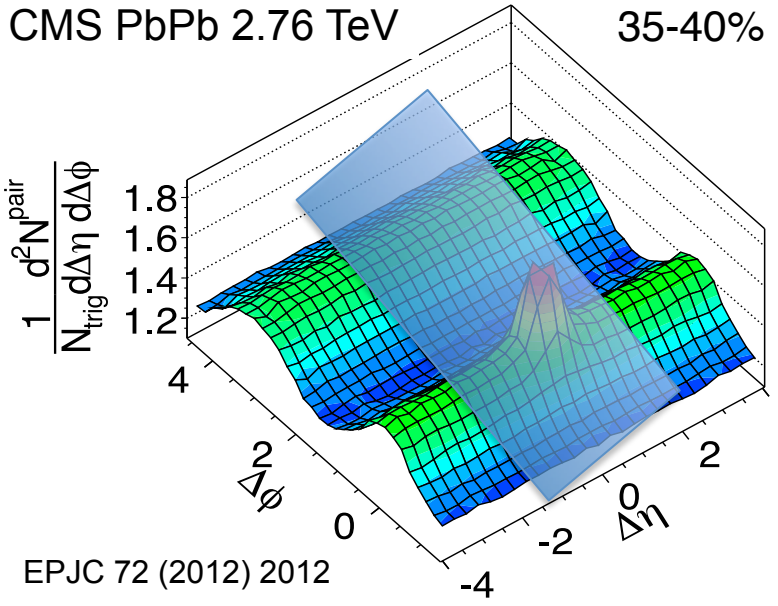
$$\frac{1}{N}\frac{dN}{d\varphi} \sim 1 + 2\sum_{n=1}^{\infty} v_n \cos\left[n(\varphi - \Psi)\right]$$

event plane angle



arXiv:1310.8651

➢ Two-particle Δη-Δϕ correlation:



EPJC 72 (2012) 2012

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

Factorization assumption:

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

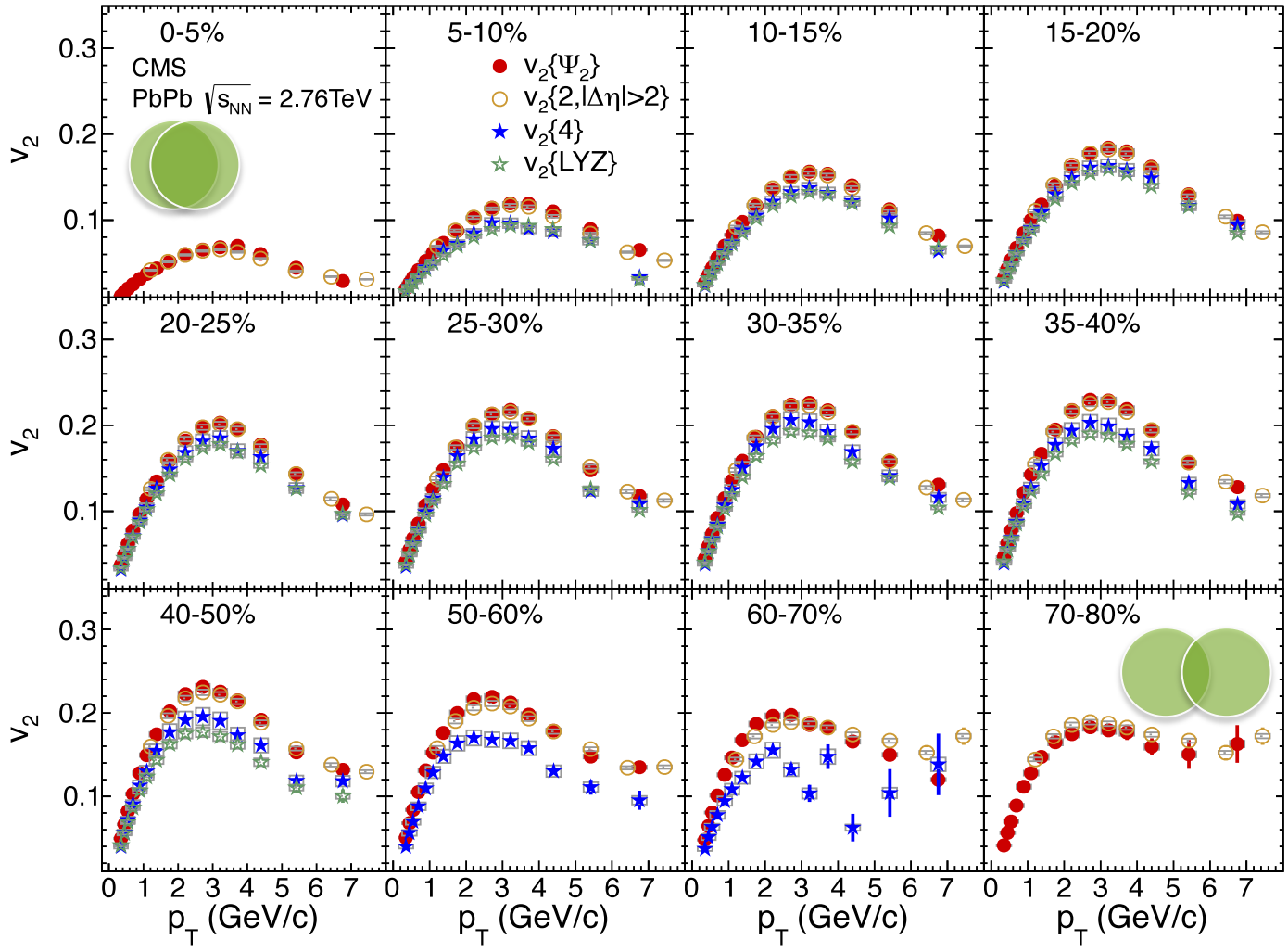
➢ **Multiparticle correlations:** multi-particle cumulants and LYZ

Elliptic flow (v_2) in PbPb at CMS

v_2 vs centrality and p_T

PRC 87(2013) 014902
EPJC 72 (2012) 2012

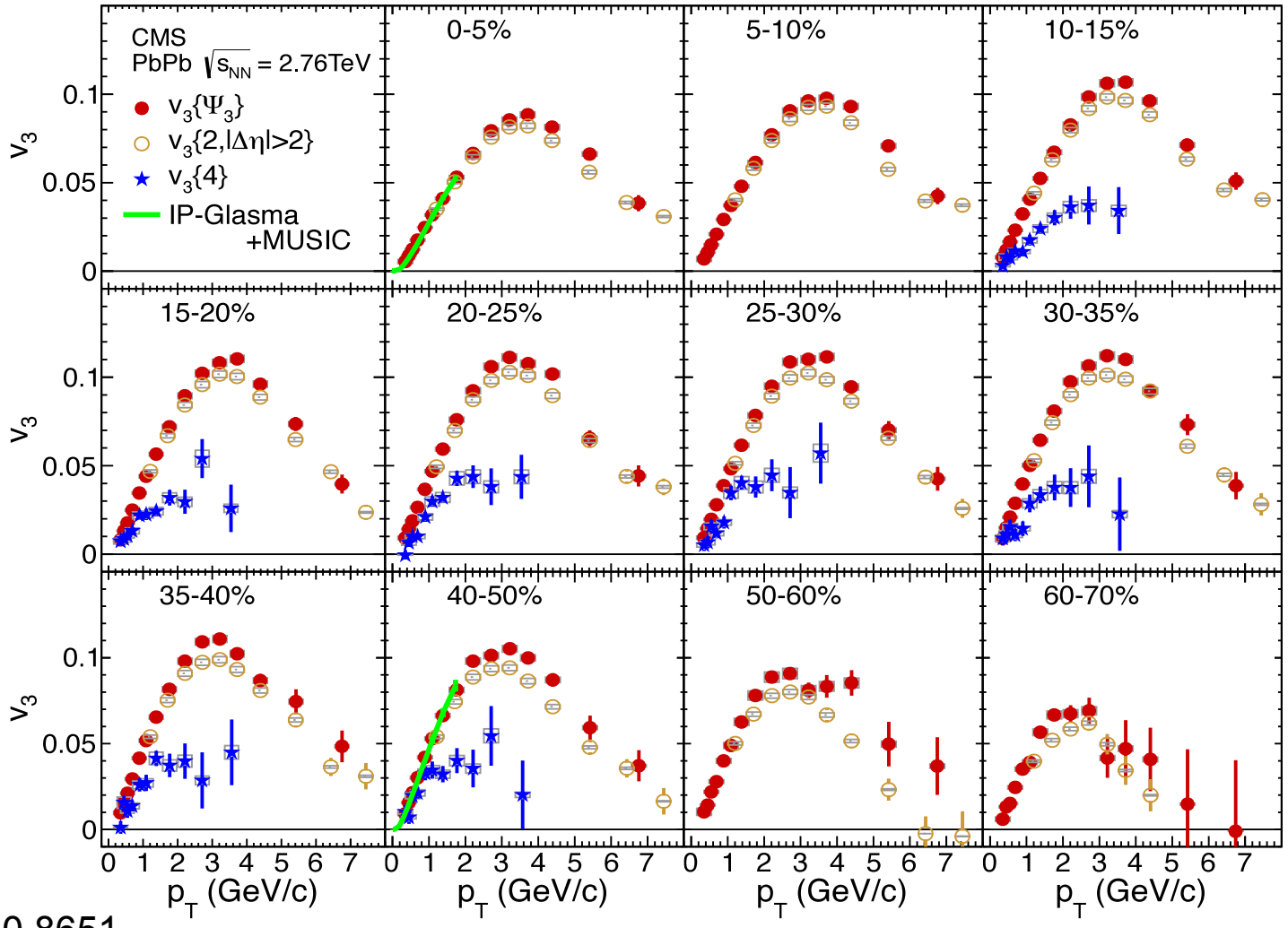
v_2



- **Four methods** with different sensitivities to flow fluctuations and non-flow

Higher-order flow (v_n) in PbPb

v_3



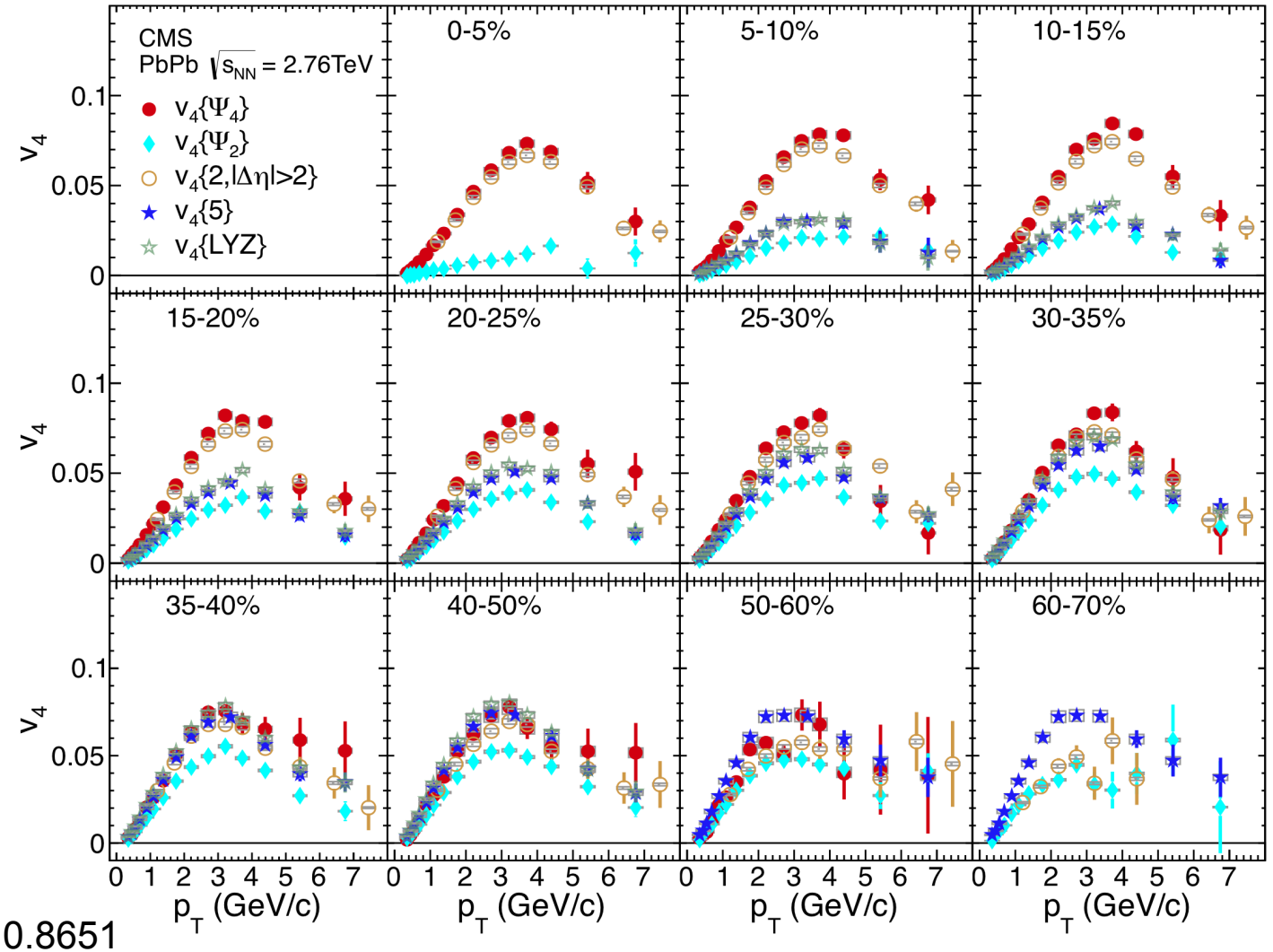
arXiv:1310.8651

$v_3\{\Psi_3\} \approx v_3\{2, |\Delta\eta| > 2\} >> v_3\{4\}$ with little centrality dependence

➔ Strong effect of fluctuations

Higher-order flow (v_n) in PbPb

v_4



arXiv:1310.8651

$v_4\{\Psi_4\}$ and $v_4\{2, |\Delta\eta| > 2\}$: Ψ_4 ref.

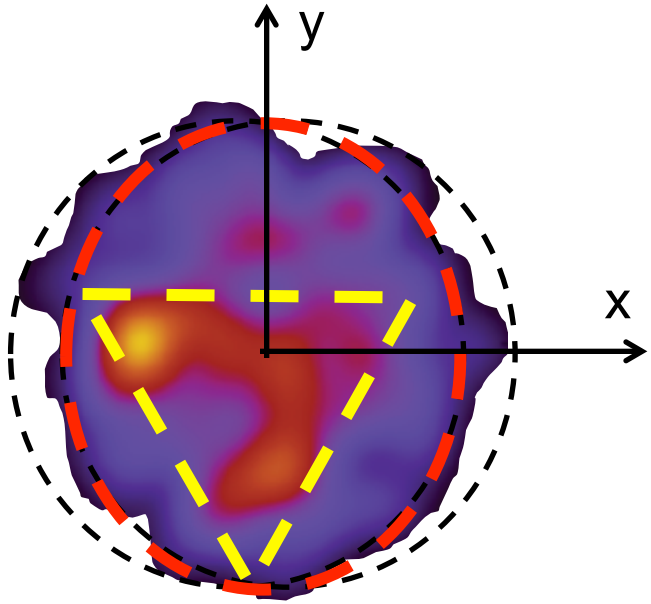
- Weak centrality dependence
- **Fluctuations dominant**

$v_4\{\Psi_2\}$, $v_4\{5\}$ and $v_4\{\mathrm{LYZ}\}$: Ψ_2 ref.

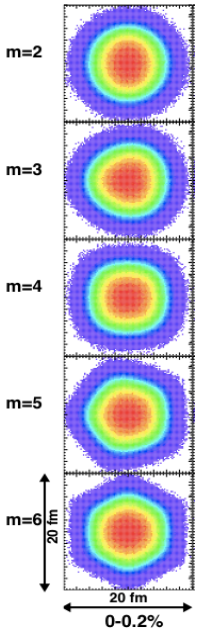
- Strong centrality dependence
- **Elliptic geometry driven**

Flow in ultra-central PbPb collisions

Moving to ultra-central events, all v_n are mostly driven by fluctuations:



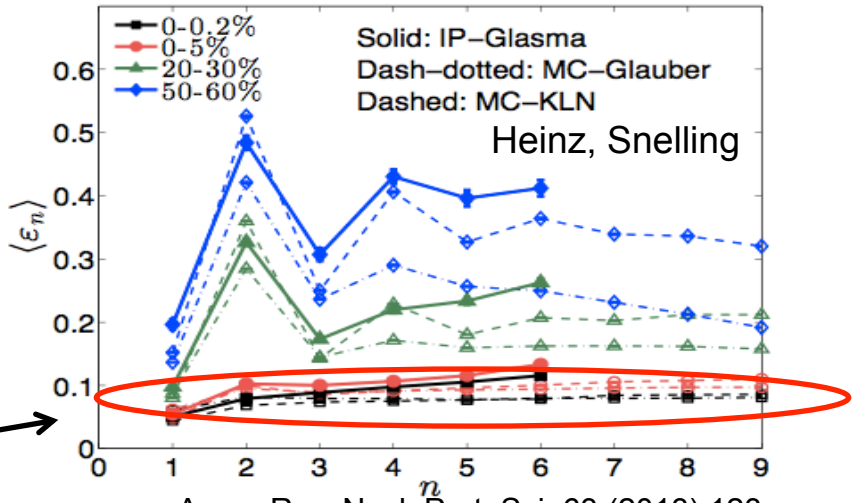
0-0.2% central



Participant distribution relative to the n^{th} order participant plane

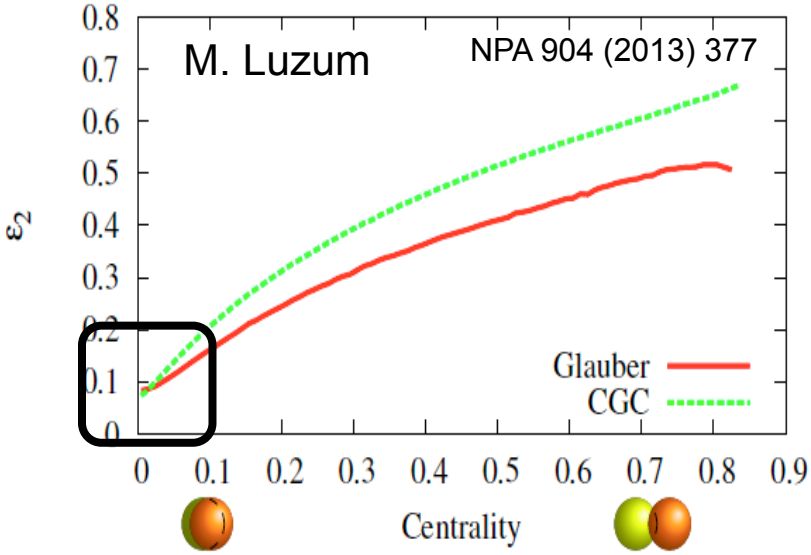
JHEP 02 (2014) 088

various order of ε_n converge as collision becomes central



Annu. Rev. Nucl. Part. Sci. 63 (2013) 123

ε_n from various models converge as collision becomes central



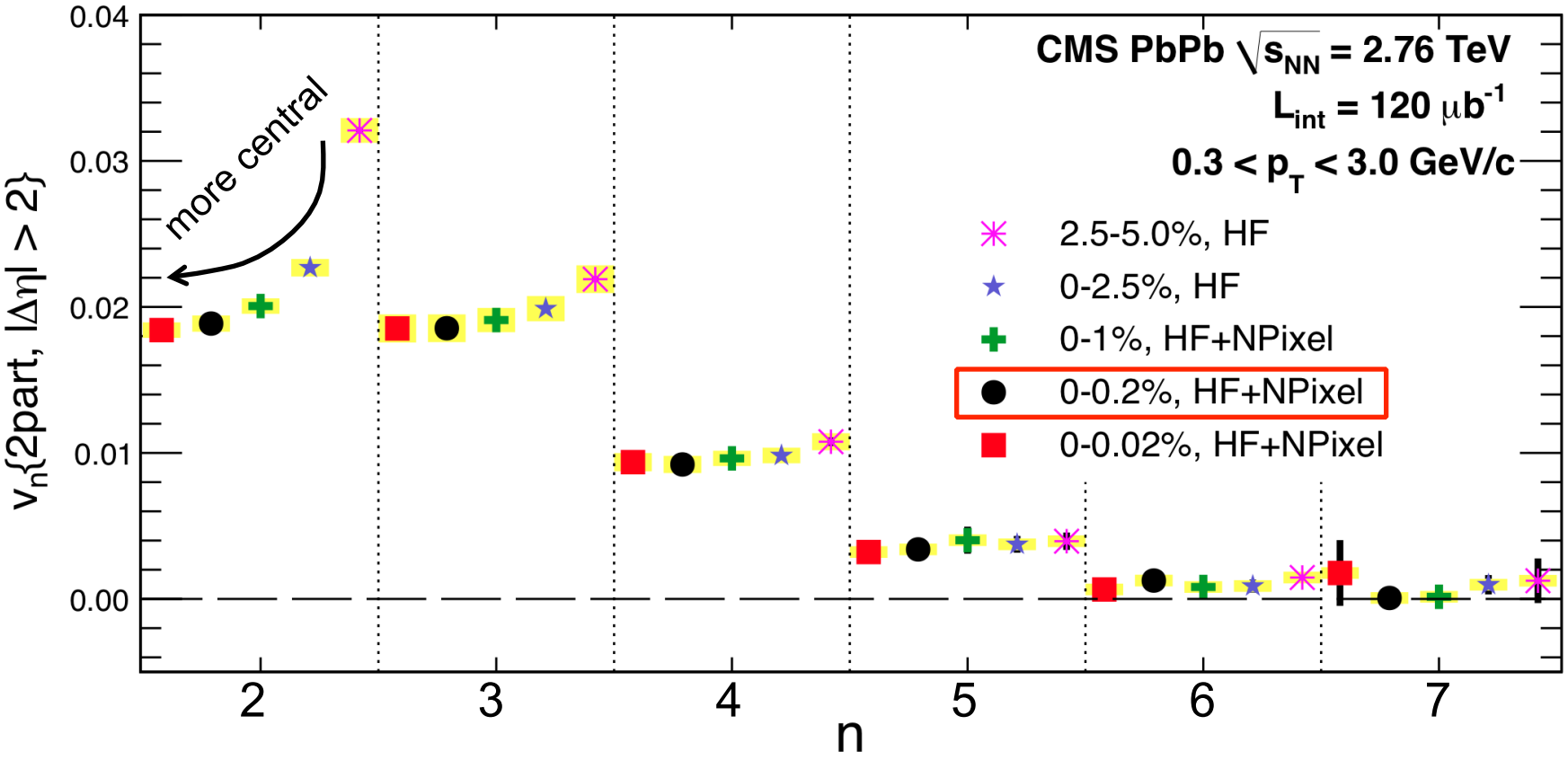
Ideal testing grounds for effects due to initial-state fluctuations

Flow in ultra-central PbPb collisions

~ 2M events for 0.0-0.2% centrality triggered events

v_n vs n from two-particle correlations

JHEP 02 (2014) 088



All orders of v_n tends to saturate around 0.0-0.2% centrality

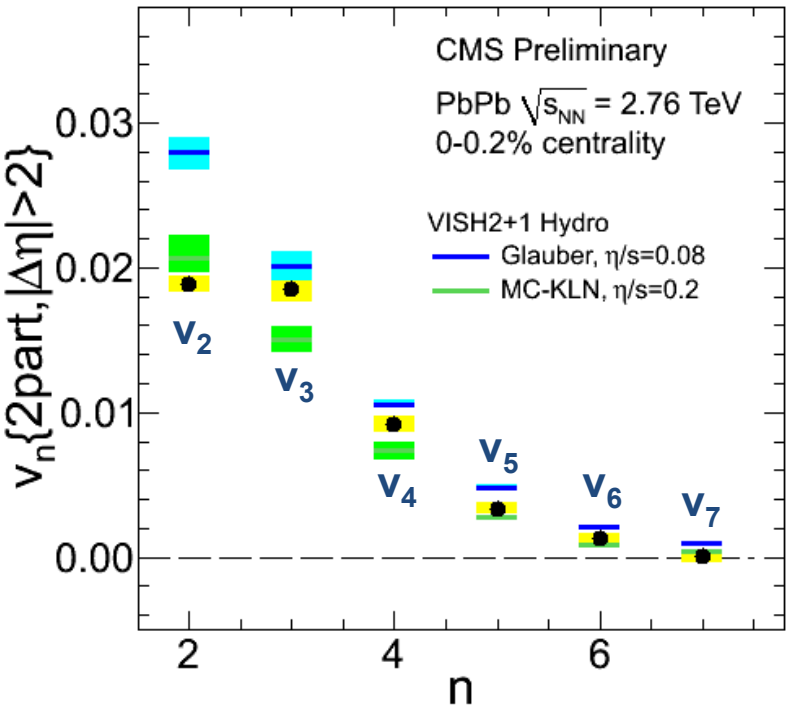
➔ Predominantly induced by initial-state fluctuations

Flow in ultra-central PbPb collisions

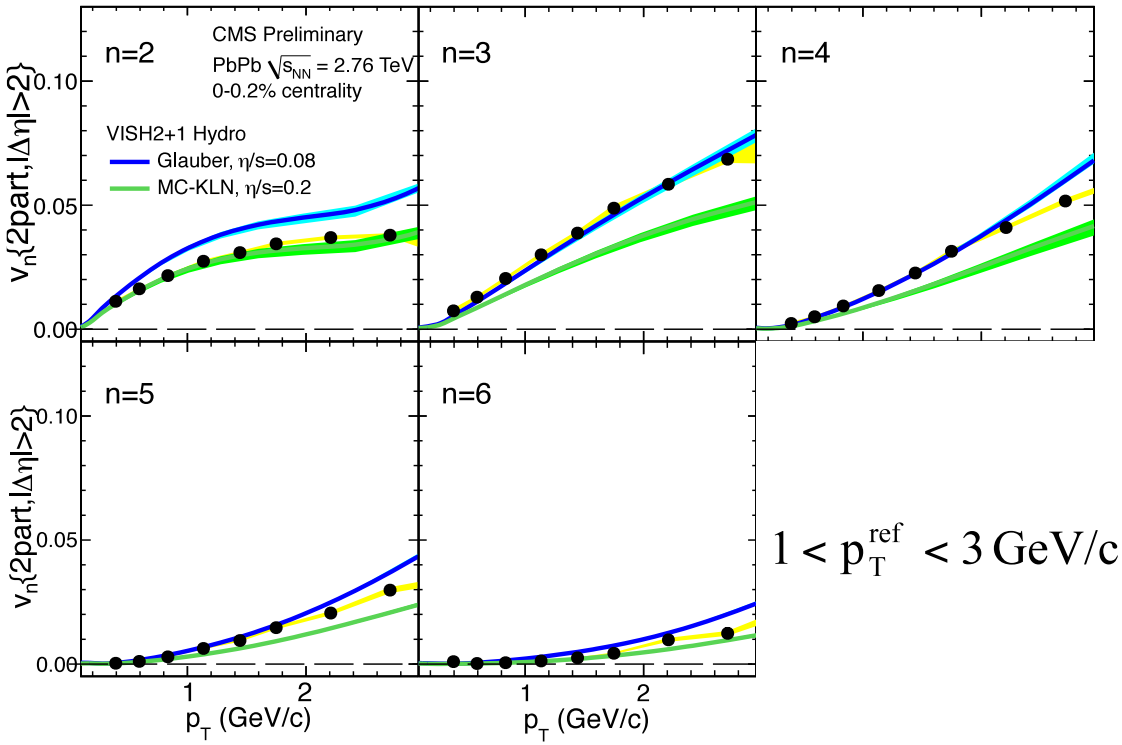
0.0-0.2% centrality

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

Calculation by Heinz et al.



p_T dependence of v_n



$1 < p_T^{ref} < 3$ GeV/c

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12011

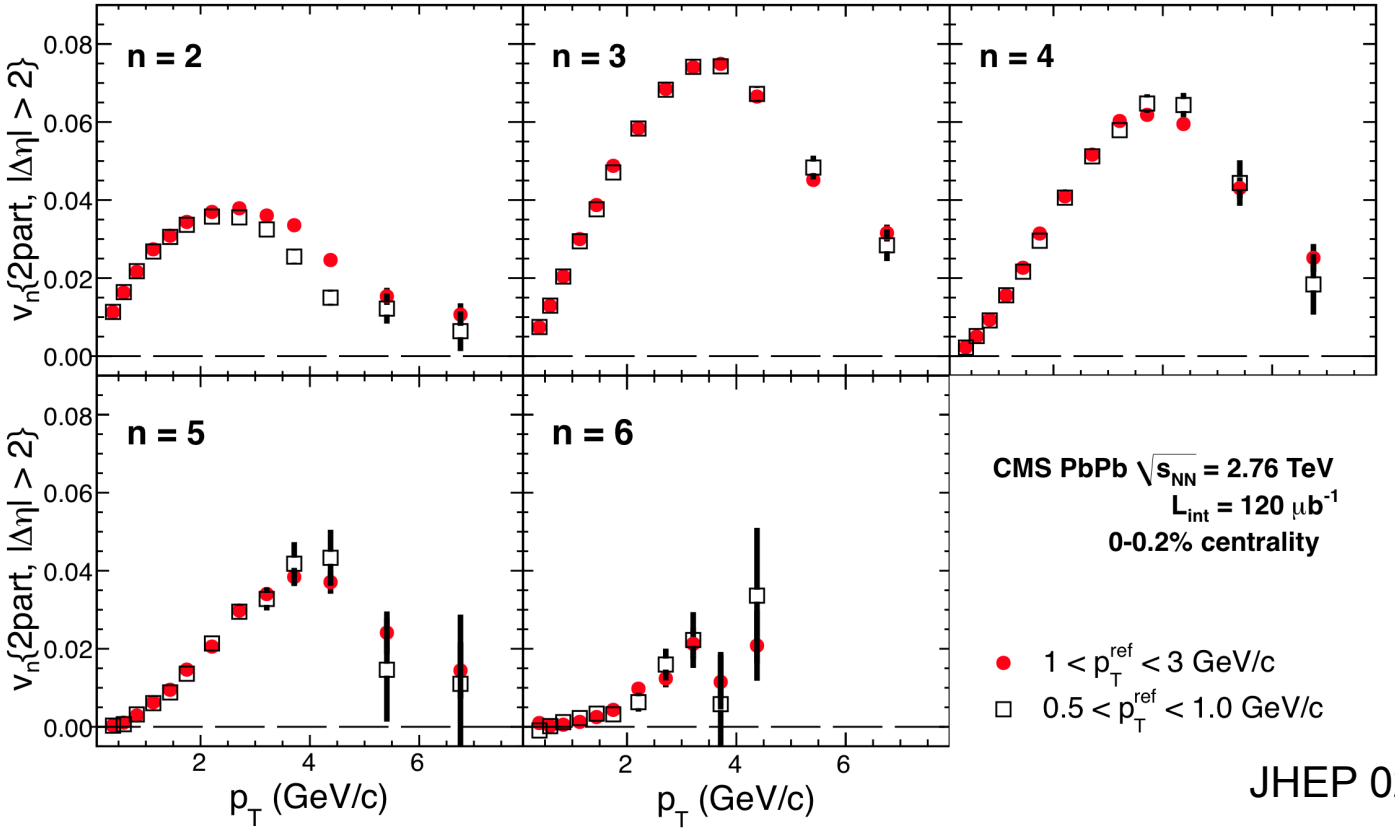
Shape and magnitude of v_n qualitatively reproduced by viscous hydrodynamics with fluctuating initial conditions

Factorization of $V_{n\Delta}(p_T^{trig}, p_T^{assoc})$

For pure flow-driven correlations,

$$V_{n\Delta}(p_T^{trig}, p_T^{assoc}) \stackrel{?}{=} v_n(p_T^{trig}) \times v_n(p_T^{assoc}) \quad \text{(factorization)}$$

Factorization test: $v_n(p_T)$ derived from different p_T^{ref}



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Factorization breakdown for v_2 at high p_T ➔ ***onset of non-flow?***

Factorization breakdown in hydrodynamics

Is factorization breakdown really inconsistent with hydro?

$$\frac{2\pi}{N}\frac{dN}{d\varphi} \sim 1 + 2\sum_{n=1}^{\infty} v_n(p_T)\cos\left[n\left(\varphi - \Psi_n(p_T)\right)\right]$$

- It is known that v_n is a function of p_T (also η, PID etc.)
- **Same is true for event plane angle Ψ_n (determined by final-state particles) due to event-by-event fluctuating initial-state geometry**

Gardim et al., PRC 87, 031901(R) (2013), Heinz et al., PRC 87, 034913 (2013)

Proposed to study the ratio:

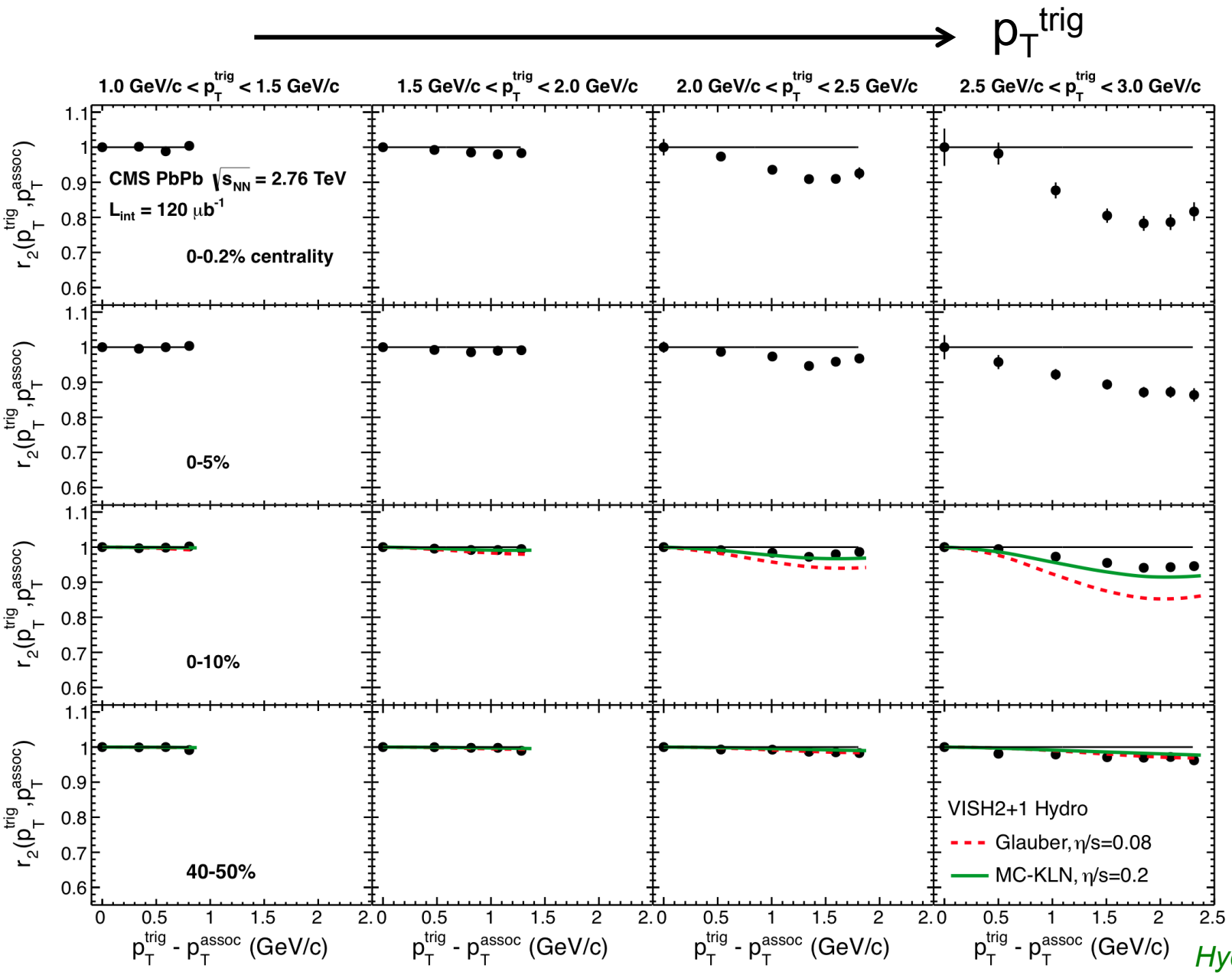
$$r_n \equiv \frac{V_{n\Delta}(p_T^{trig}, p_T^{assoc})}{\sqrt{V_{n\Delta}(p_T^{trig}, p_T^{trig})}\sqrt{V_{n\Delta}(p_T^{assoc}, p_T^{assoc})}}$$

$r_n = 1$ ➔ factorization holds

$$= \frac{\left\langle v_n(p_T^{trig}) v_n(p_T^{assoc}) \cos[n(\Psi_n(p_T^{trig}) - \Psi_n(p_T^{assoc}))]\right\rangle}{\sqrt{v_n^2(p_T^{trig}) v_n^2(p_T^{assoc})}}$$

In general, $r_n \leq 1$, if event-by-event Ψ_n depends on p_T

Factorization breakdown in data and hydrodynamics



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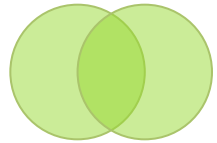
0-0.2%

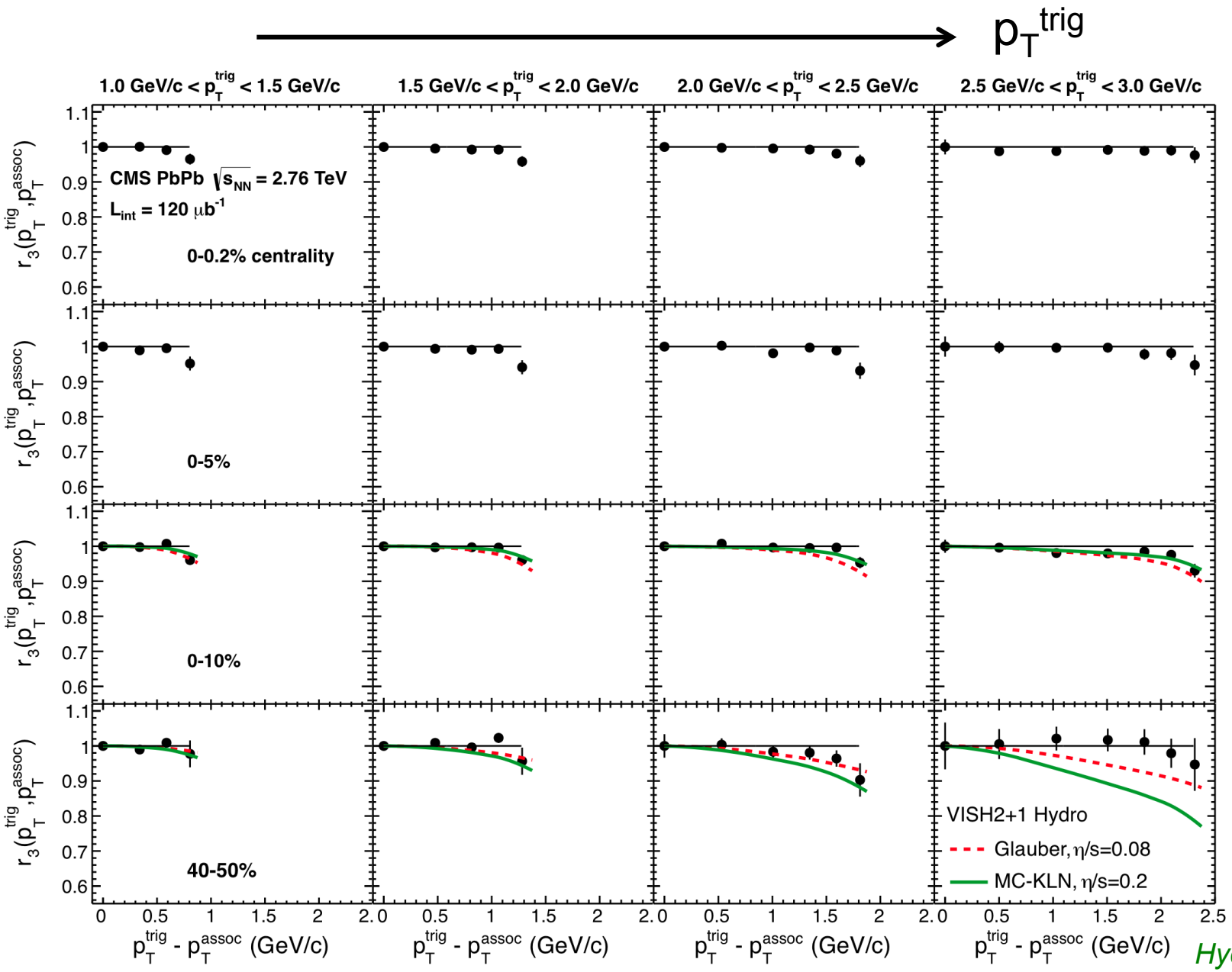
40-50%



Hydro from Heinz and Shen PRC 87, 034913 (2013)

Sizable effect for v_2 in ultra-central events

Factorization breakdown in data and hydrodynamics



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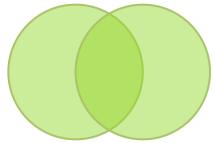
0-0.2%

40-50%

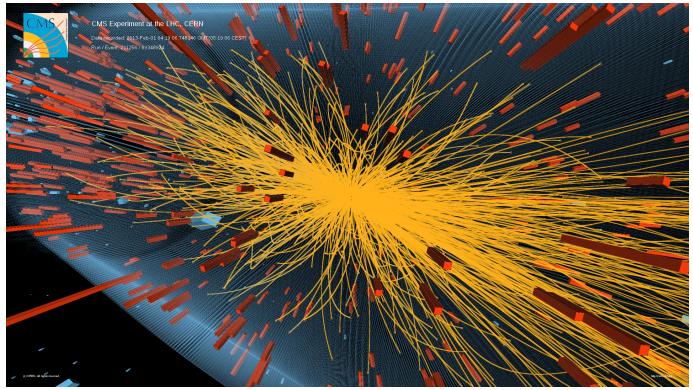


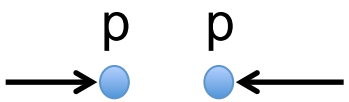
Hydro from Heinz and Shen PRC 87, 034913 (2013)

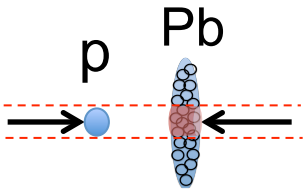
The effect is smaller for v_3

“Flow” in small collison systems?

High-multiplicity
pPb event
(418 tracks)

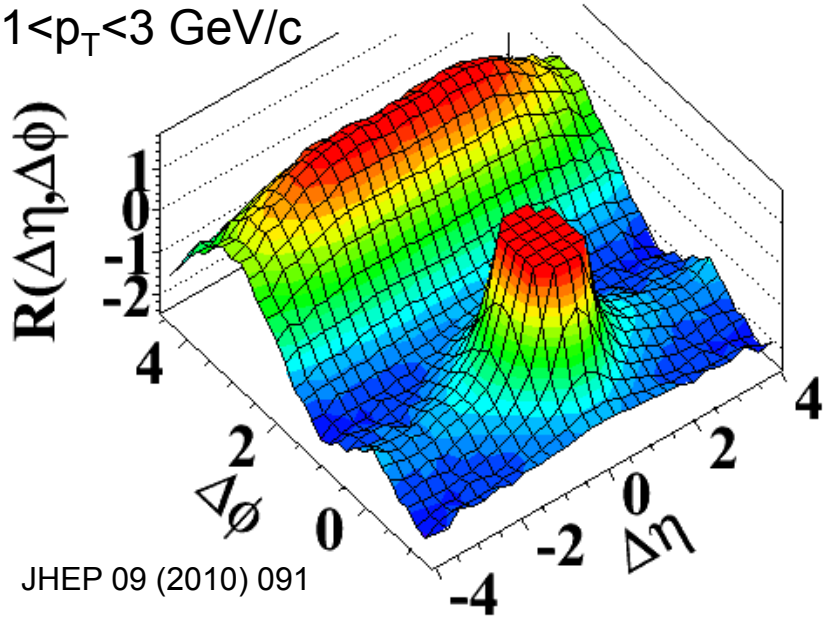






pp 7 TeV, N>=110 **0.0007% central**

1<p_T<3 GeV/c

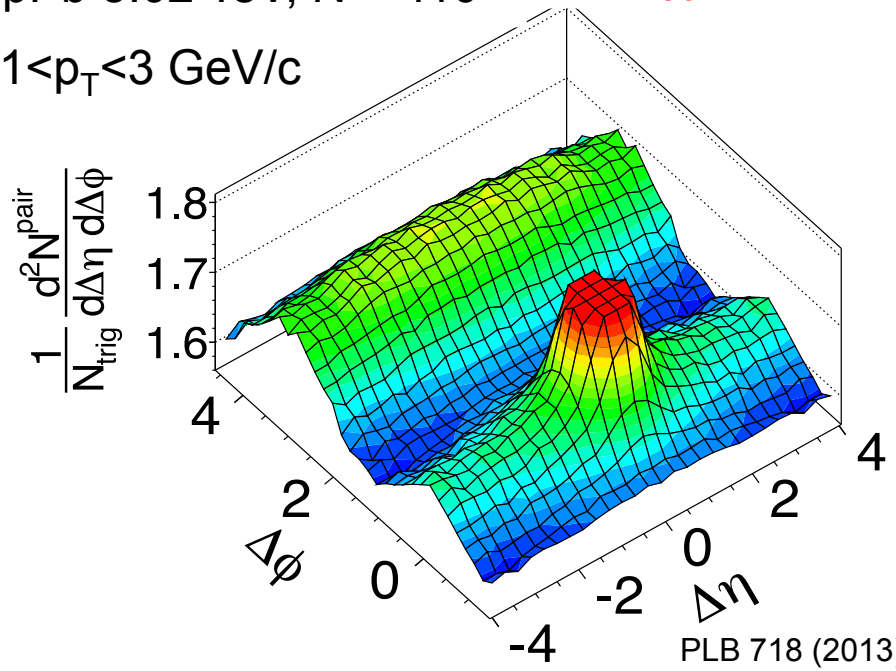


JHEP 09 (2010) 091

Sensitive to fluctuations
inside a nucleon!

pPb 5.02 TeV, N>=110 **0-3% central**

1<p_T<3 GeV/c



PLB 718 (2013) 795

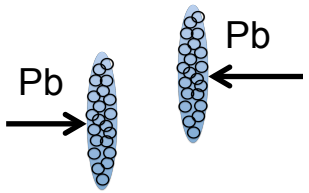
2 million MB events from 2012 pilot run

Flow (or QGP) manifests also in pp and pPb?
Or quantum interference of gluon (CGC model)?

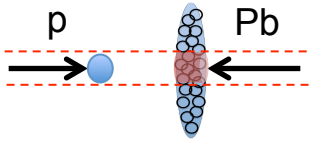
pPb data from 2013 run

Pushing into very high multiplicity region for pPb

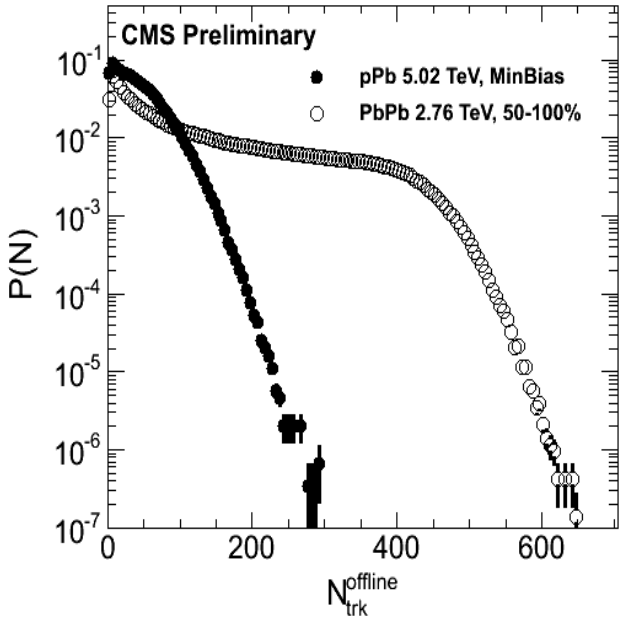
60 billion sampled pPb events at 5.02 TeV from 2013 run



~ 55-60% centrality



0-0.0003% most central



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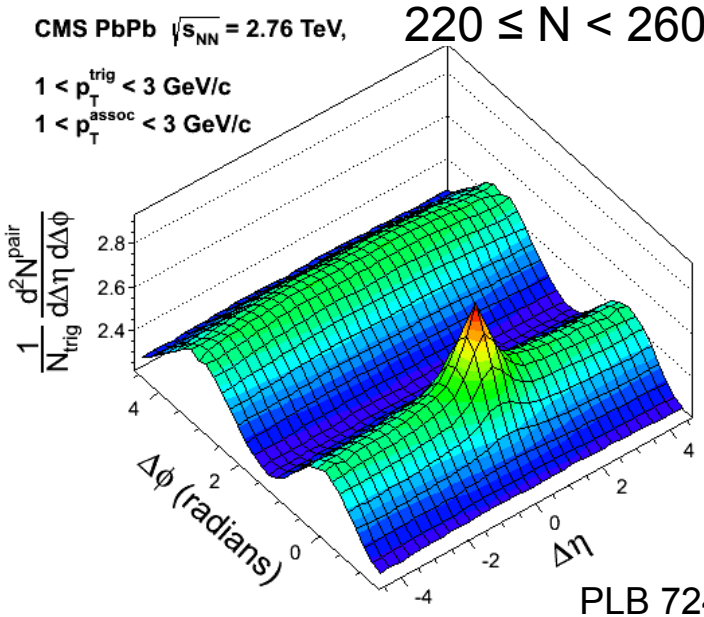
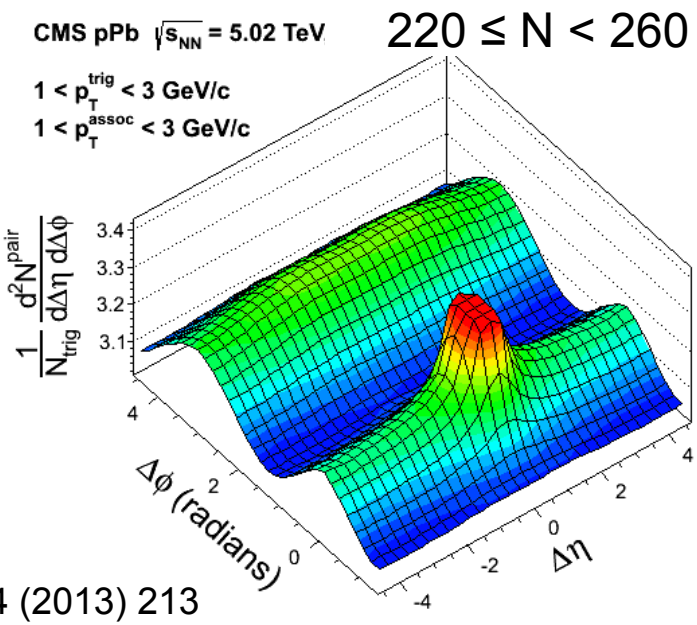




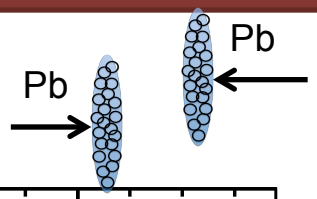
PLB 724 (2013) 213

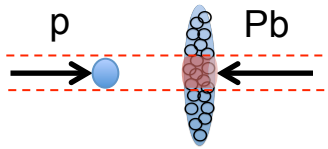
Hydrodynamics well established

The phenomena is very similar in pPb

p_T dependence of flow (v_n) in PbPb and pPb

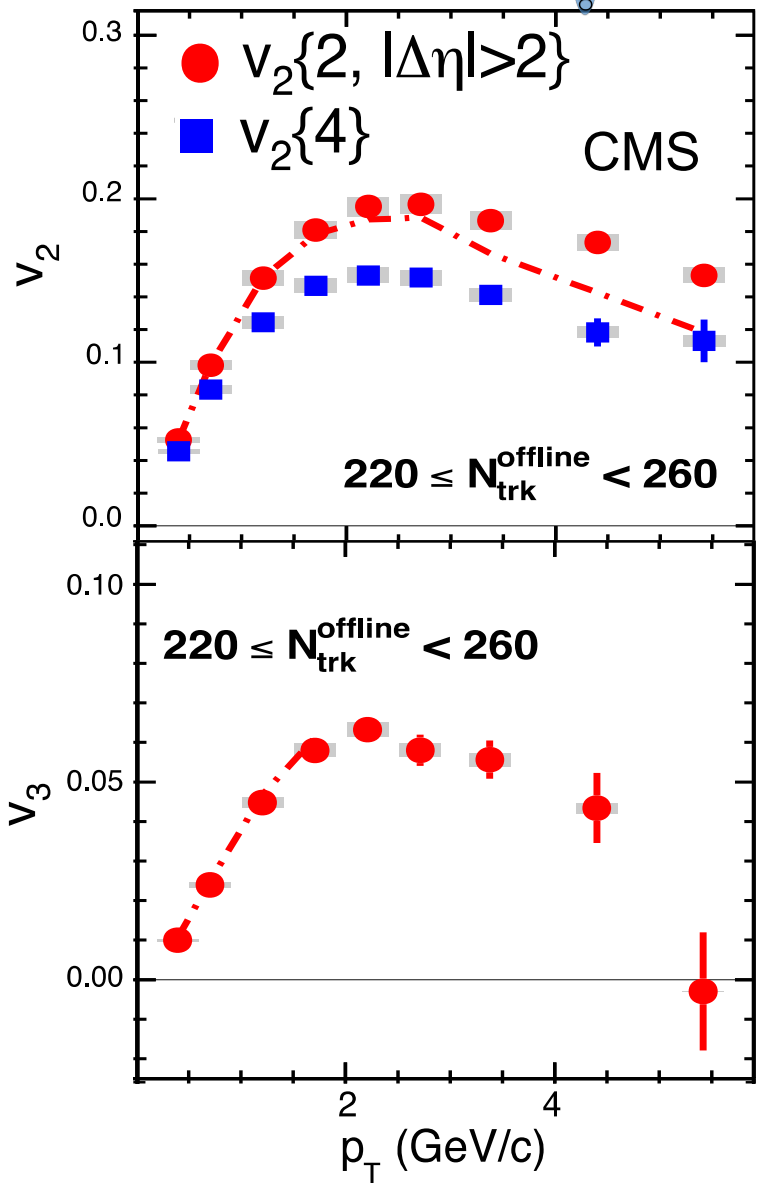
Dash-dotted curves:
peripheral N<20 subtracted

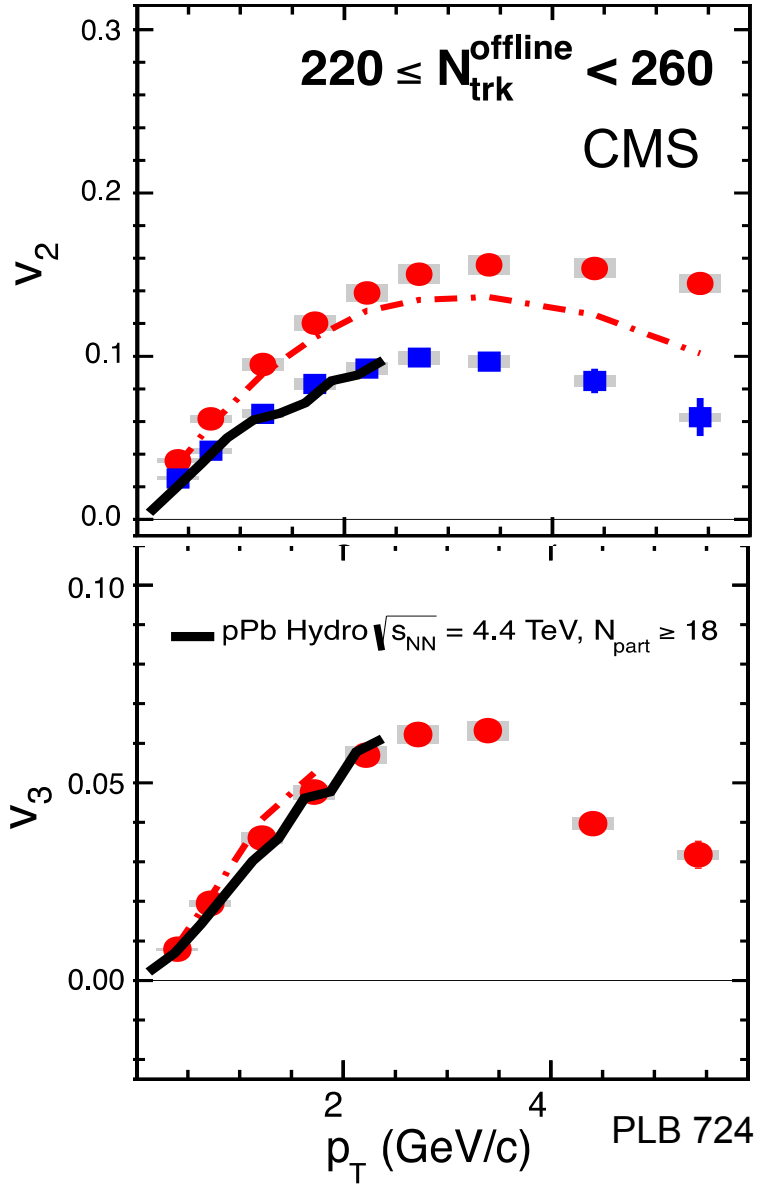




Elliptic flow

Triangular flow





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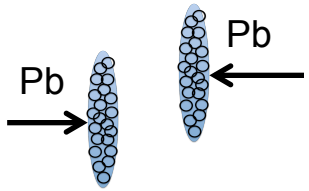
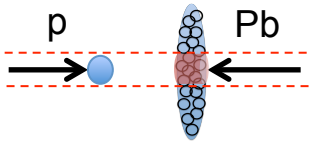
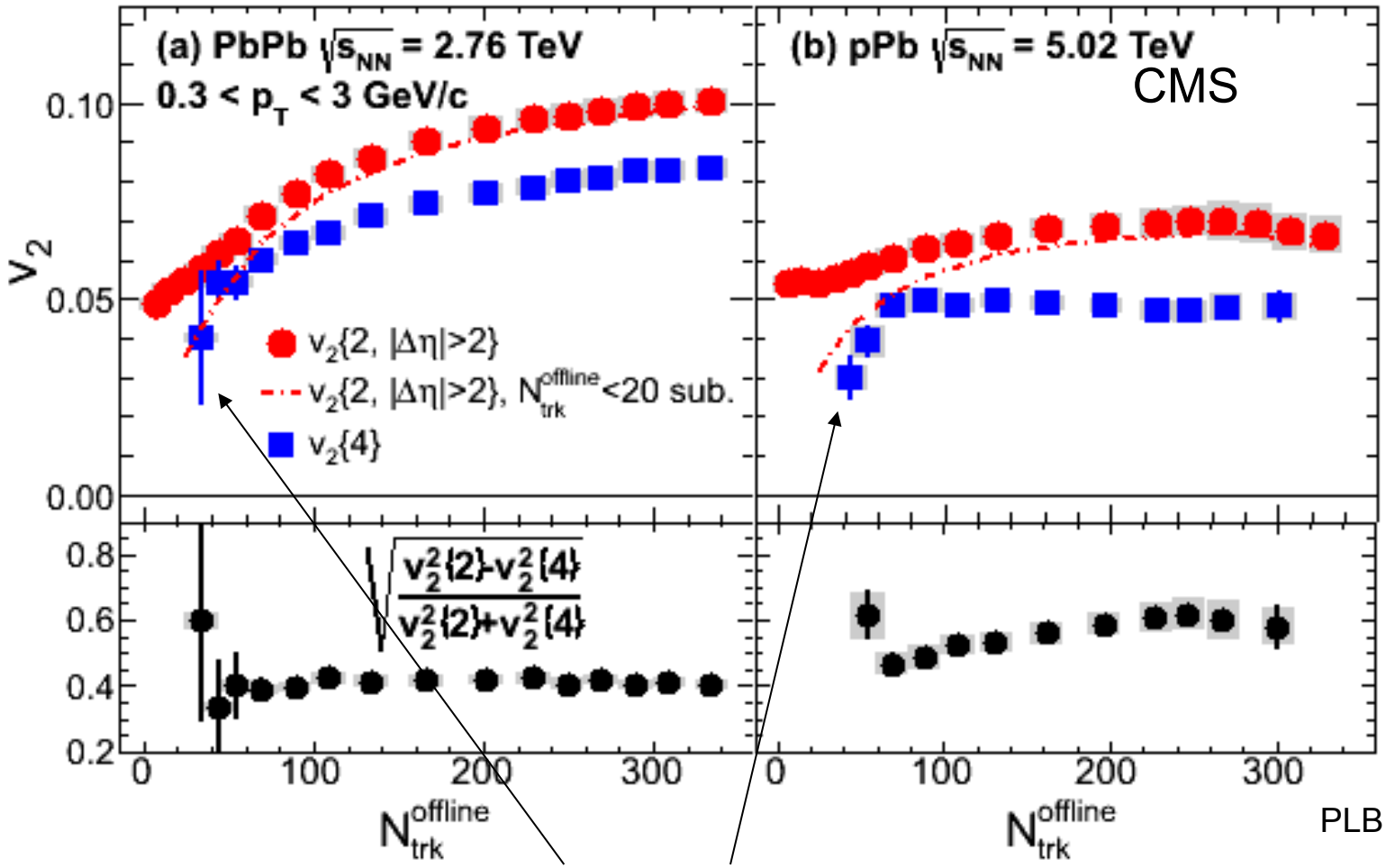
Remarkable similarity of v_n for PbPb and pPb

Multiplicity dependence of elliptic flow (v_2)

Dash-dotted curves:
peripheral N<20 subtracted







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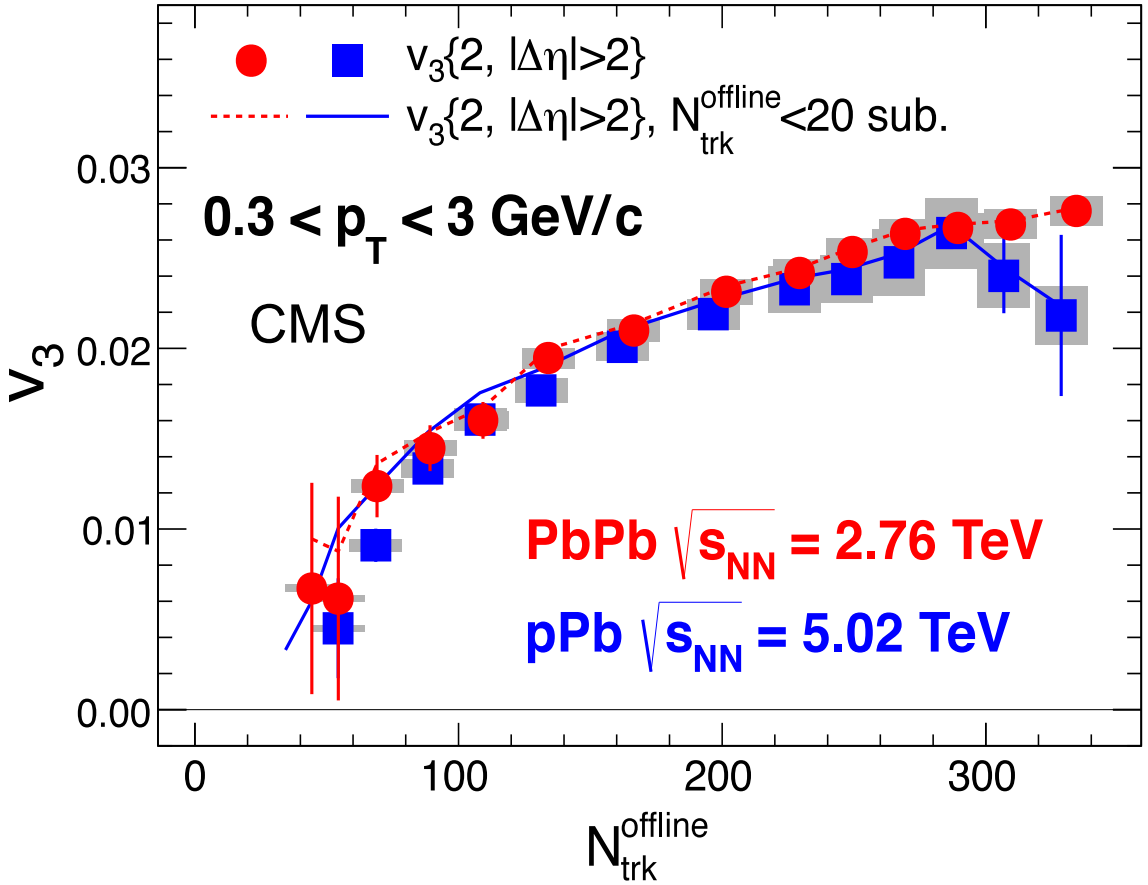
$v_2\{4\}$ becomes significant at N ~ 40

Multiplicity dependence of triangular flow (v_3)



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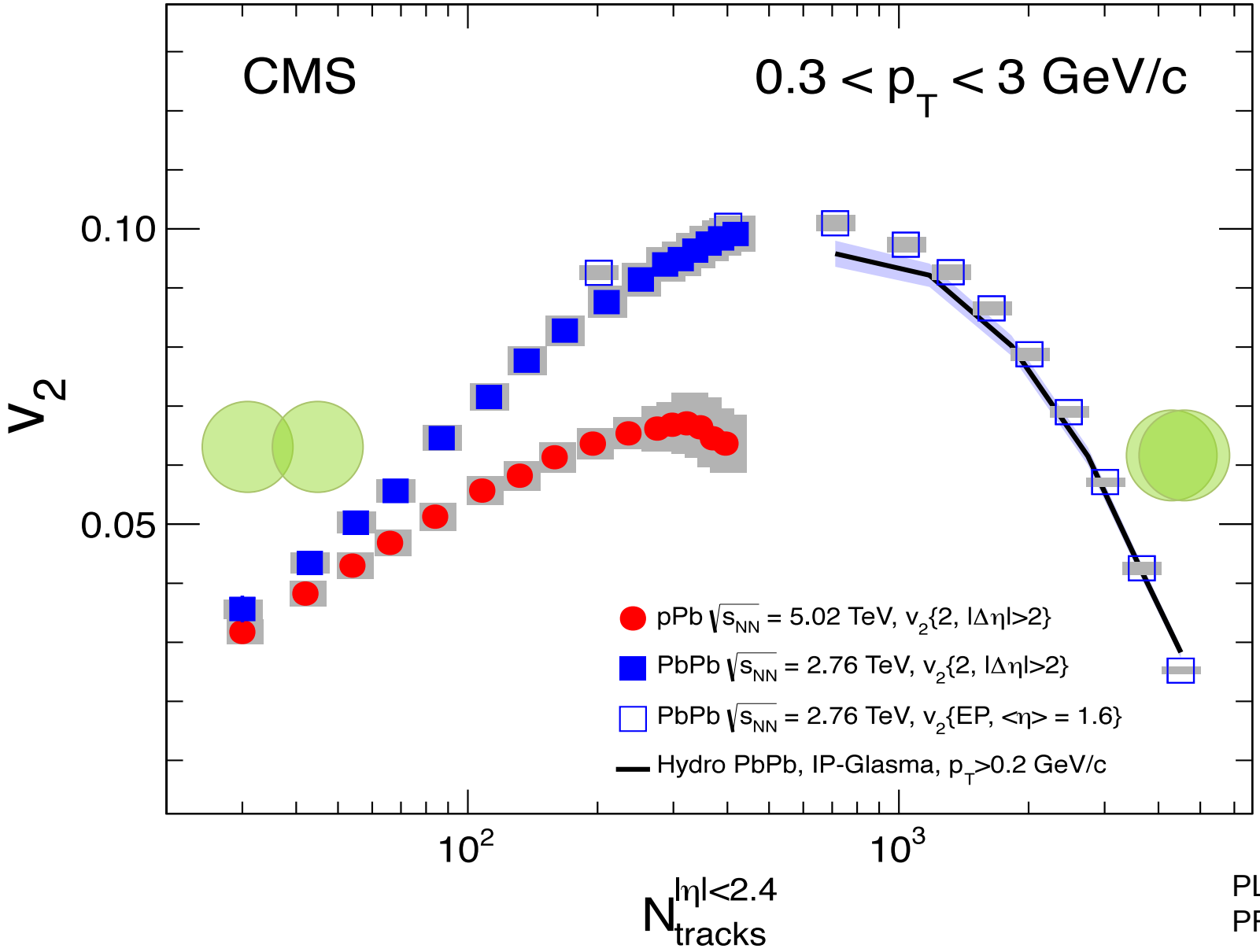
Striking similarity of v_3 for PbPb and pPb systems, although drastically different collision geometry and its fluctuations

- *Can this be understood in hydrodynamics?*
- *How about CGC?*

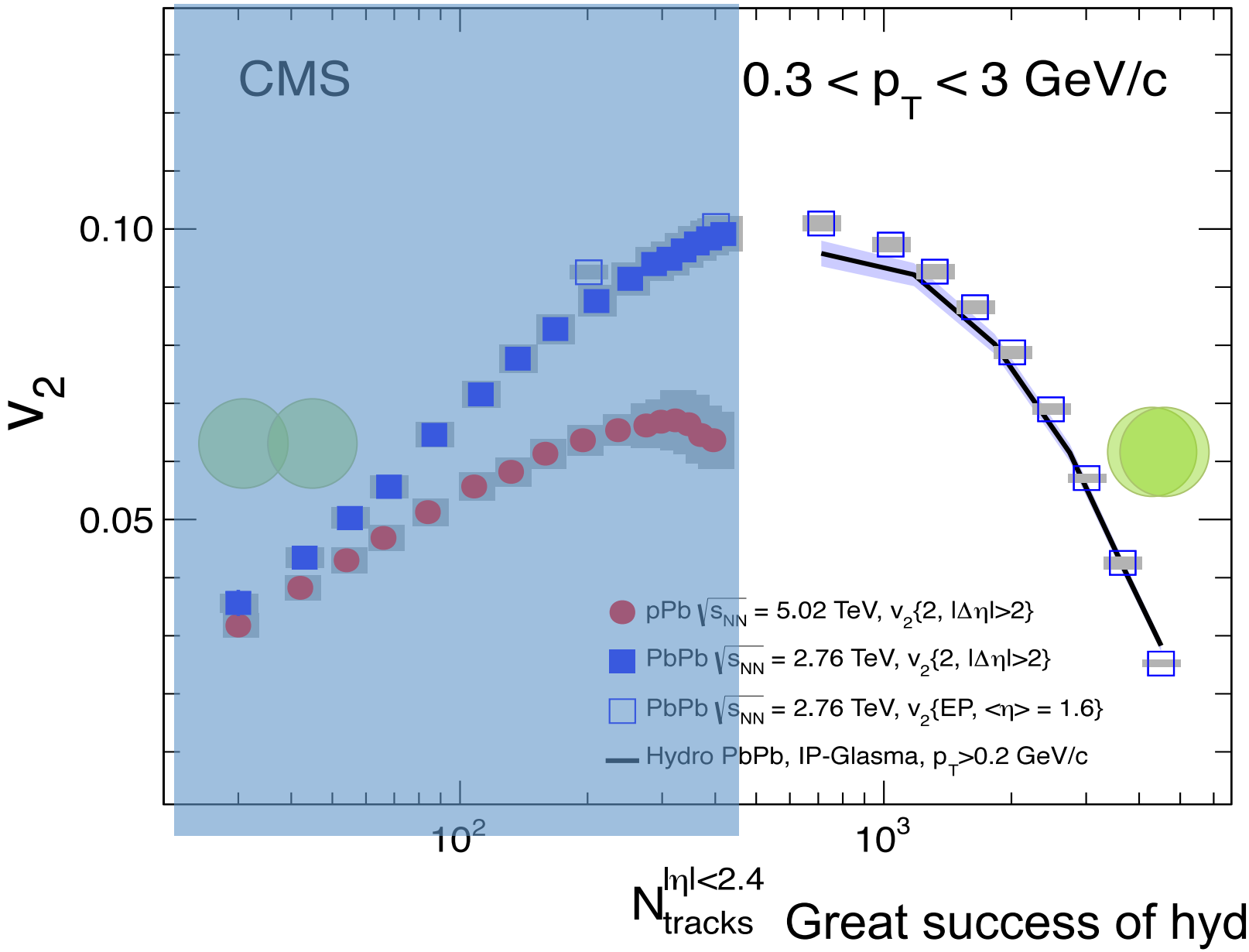
v_3 may be a critical challenge to both models

Quest for a coherent picture of flow phenomena



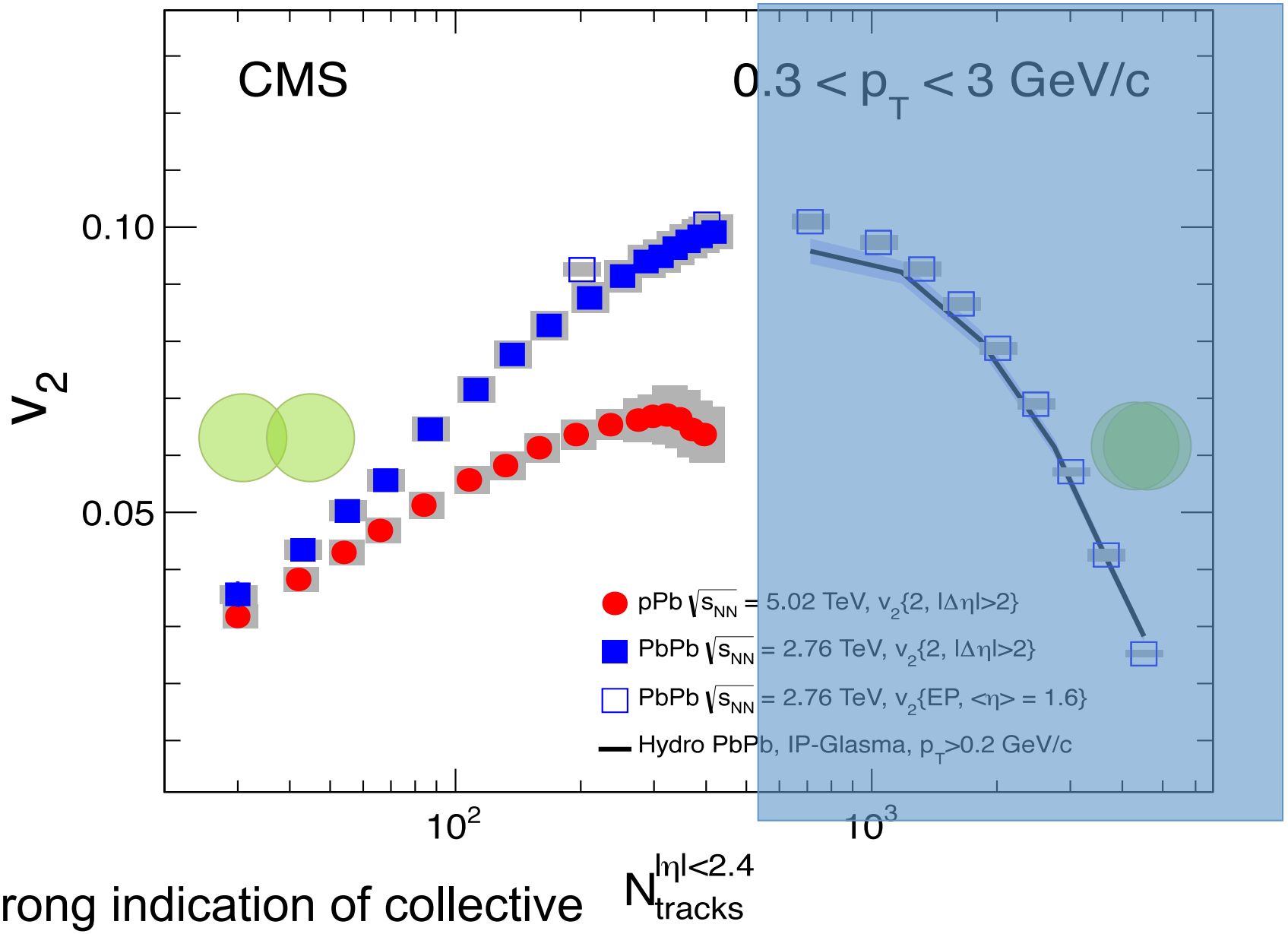
PLB 724 (2013) 213
PRC 87(2013) 014902

Quest for a coherent picture of flow phenomena



Great success of hydrodynamics in central AA collisions

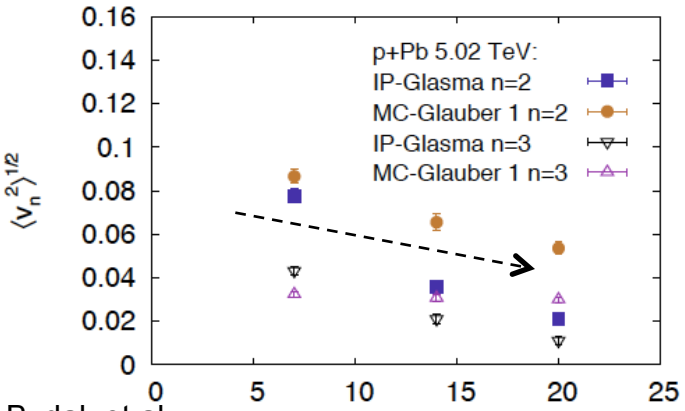
Quest for a coherent picture of flow phenomena



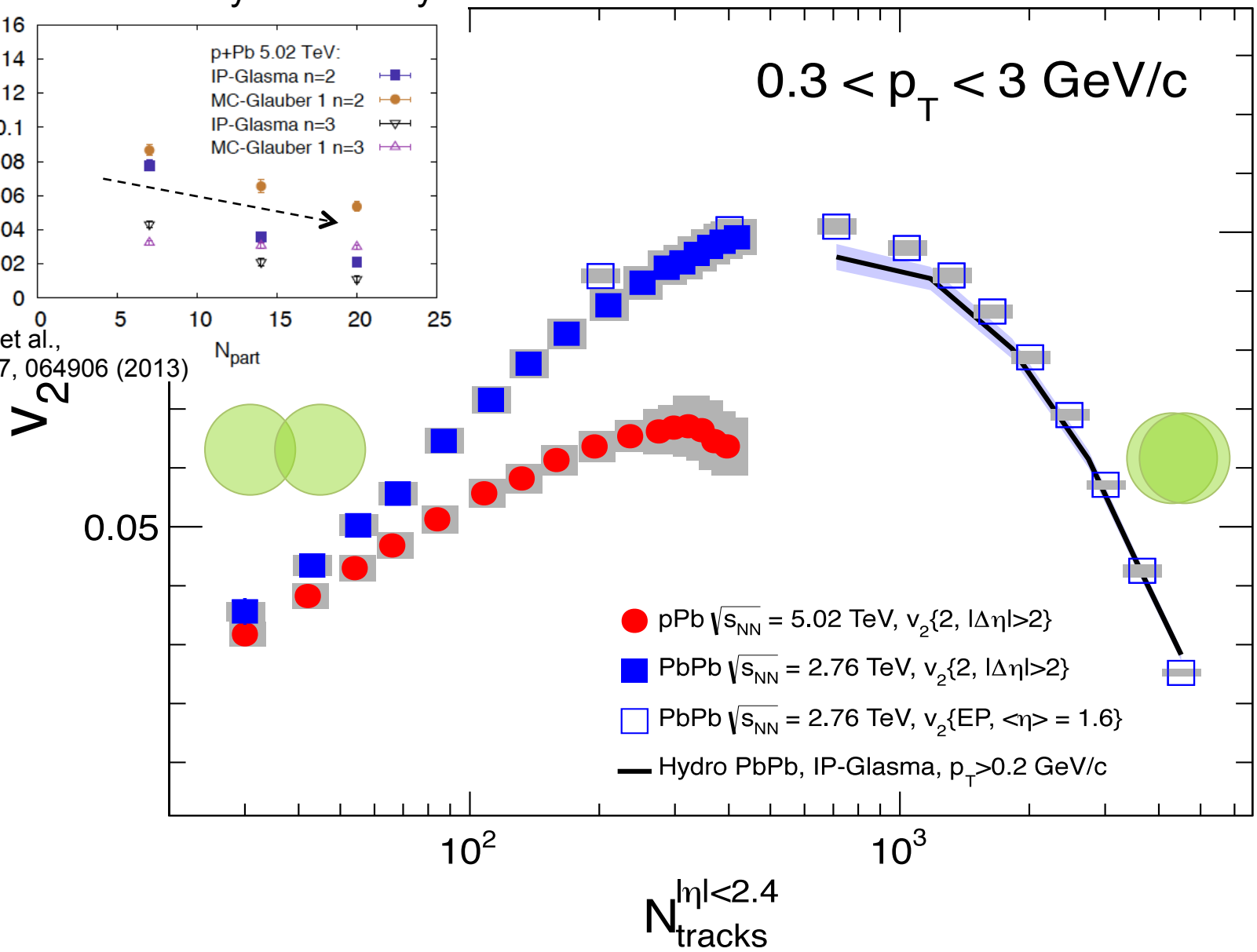
Strong indication of collective behavior in very small systems

Quest for a coherent picture of flow phenomena

"Incorrect" centrality trend in hydro

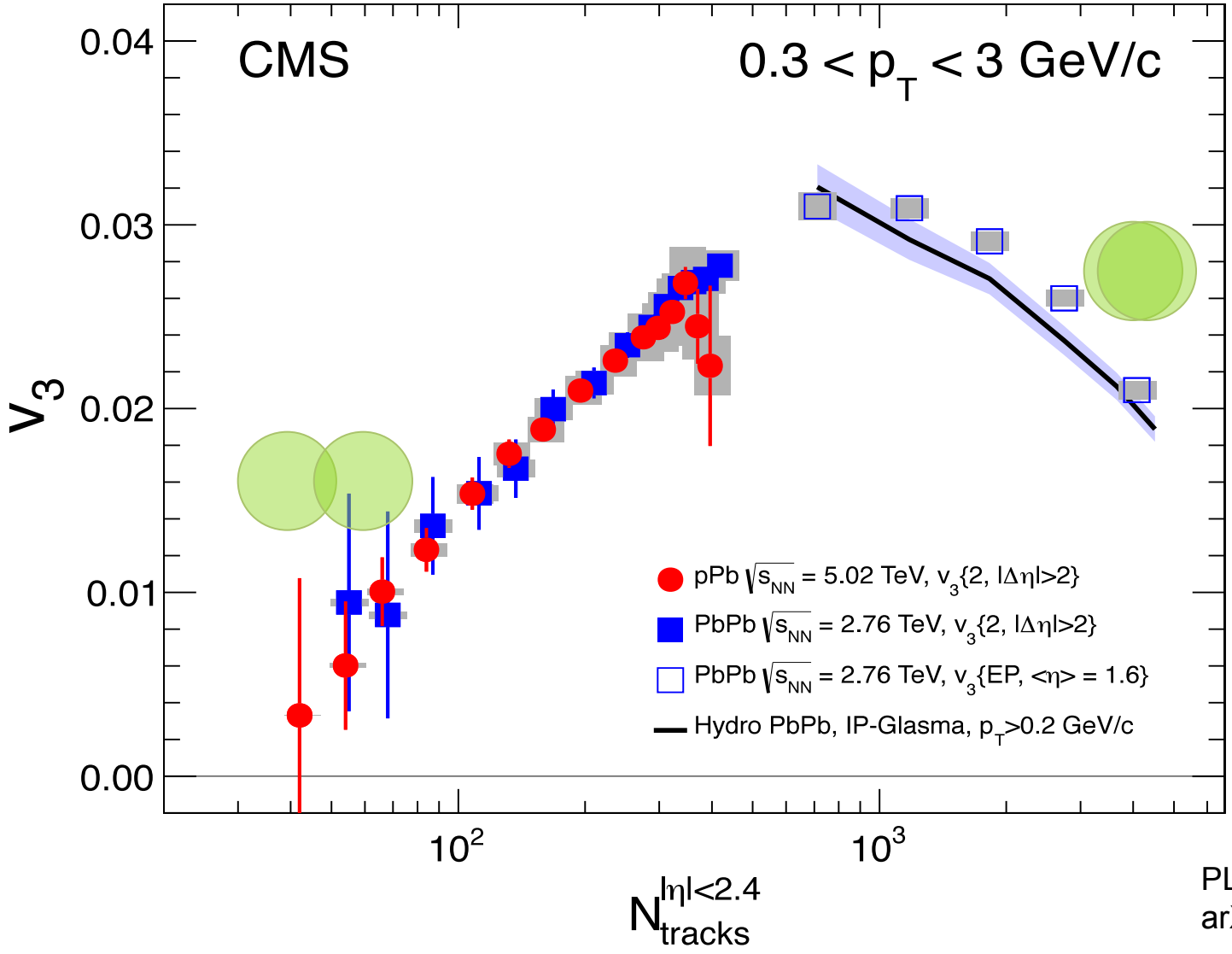


Bzdak et al.,
PRC 87, 064906 (2013)



It is imperative to achieve a coherent picture of flow phenomena among various systems

Quest for a coherent picture of flow phenomena



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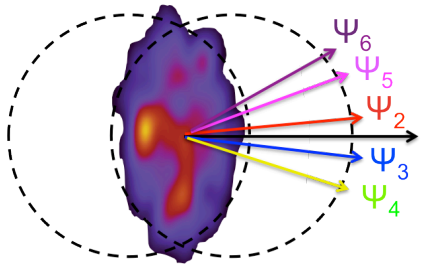
arXiv:1310.8651

How to understand the almost identical v_3 in pPb and PbPb?
And will this trend continue for more central pPb ?

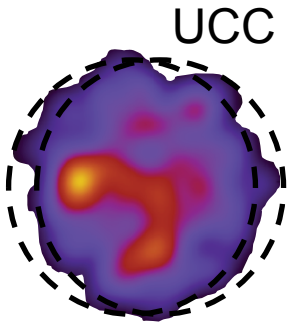
Summary

CMS have performed comprehensive measurements of flow phenomena over various collision systems of ***pp***, ***pPb*** and ***PbPb***

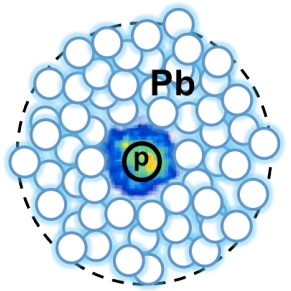
- Measurements of higher-order v_n provide insight on initial-state fluctuations



- Ultra-central PbPb collisions are new testing grounds of initial-state fluctuations and provide stringent constraints to η/s of the QGP
- Factorization breakdown of two-particle correlations is consistent with hydrodynamics with initial-state fluctuations



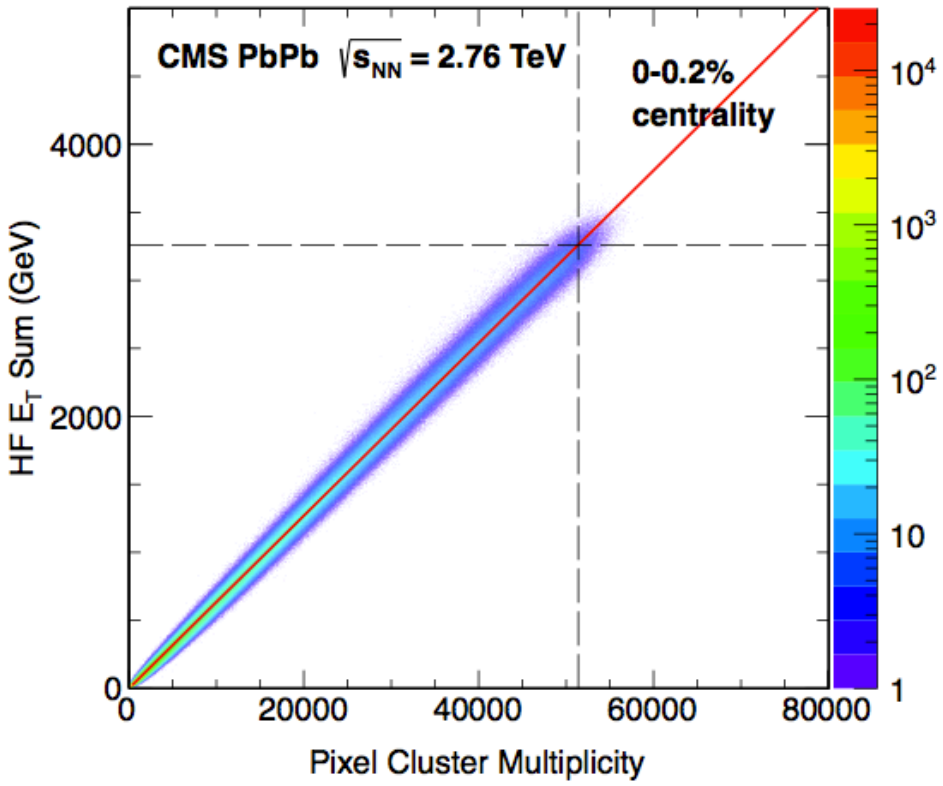
- Observation of strong collective behavior in pPb (pp) that is remarkably similar to PbPb: *manifestation of tiny QGP droplet?*



Backup

Flow phenomena in UCC events

UCC selection



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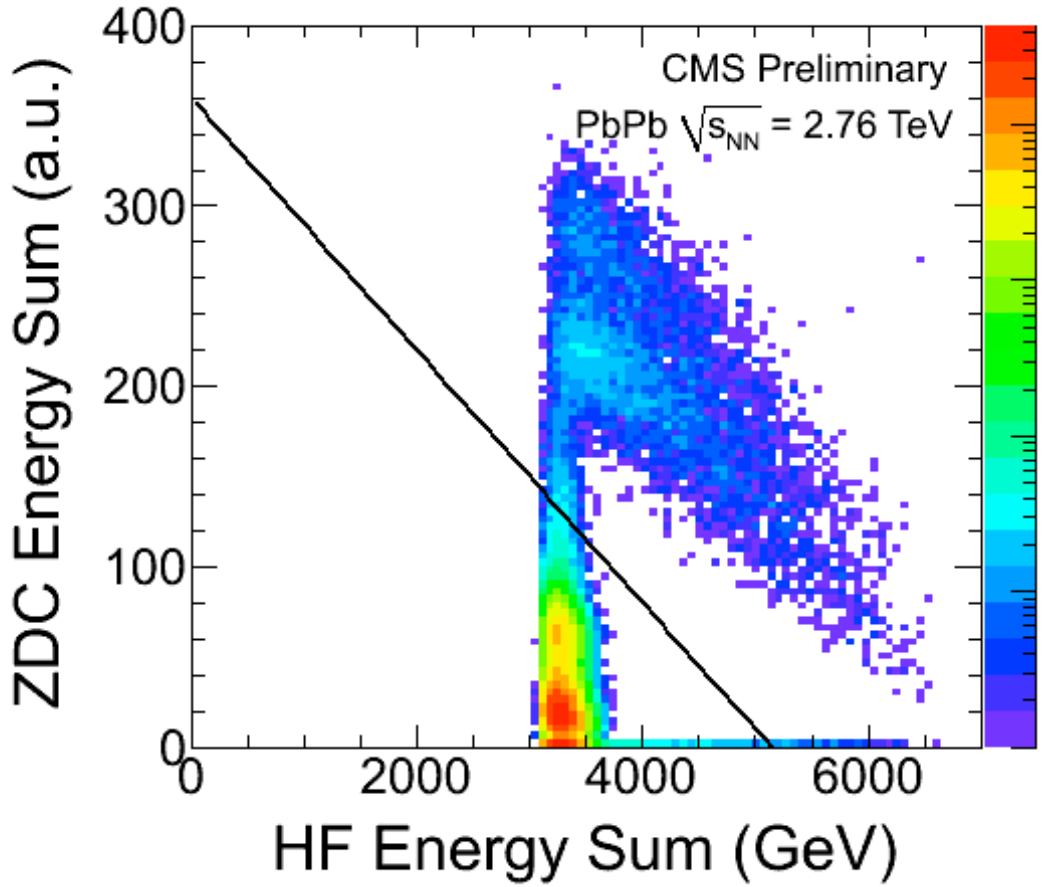
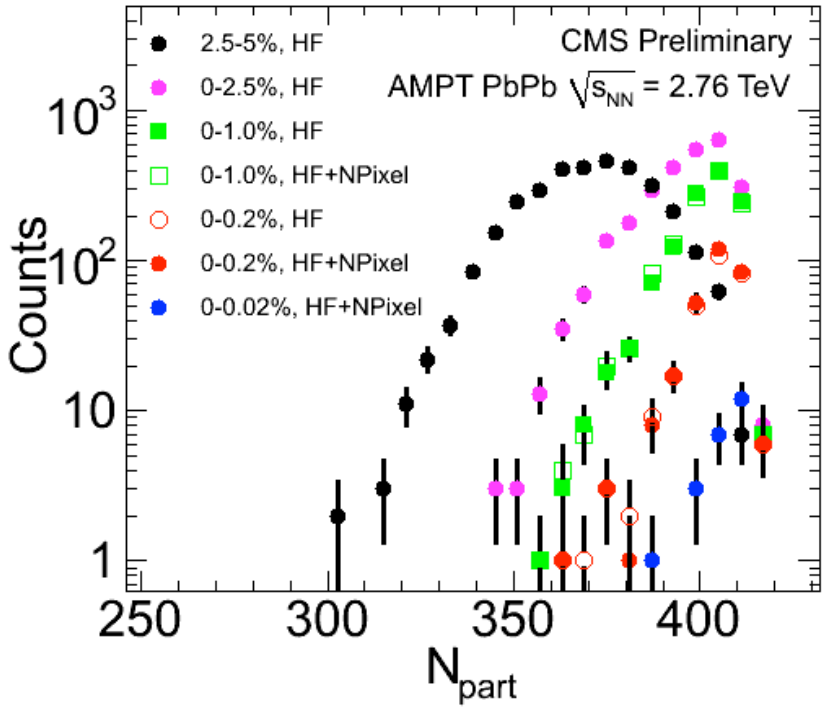
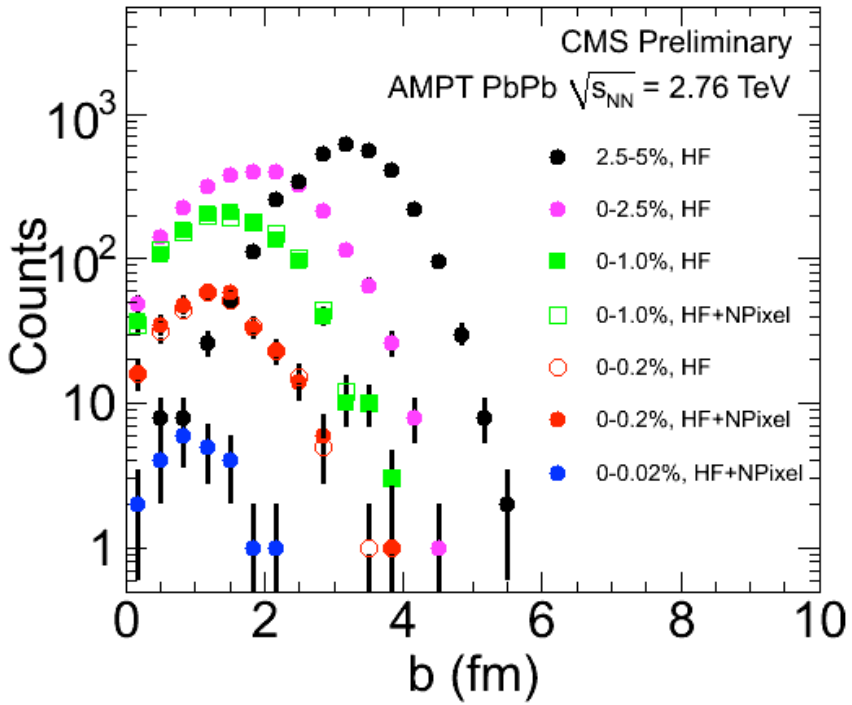
Pileup rejection



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12011

Flow phenomena in UCC events





https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12011

Centrality	N_{part}	RMS
0.00–0.02%	406.2	3.6
0.0–0.2%	404.0	6.9
0.0–1.0%	401.1	8.3
0.0–2.5%	395.8	11.3
2.5–5.0%	381.3	19.5

Flow phenomena in UCC events

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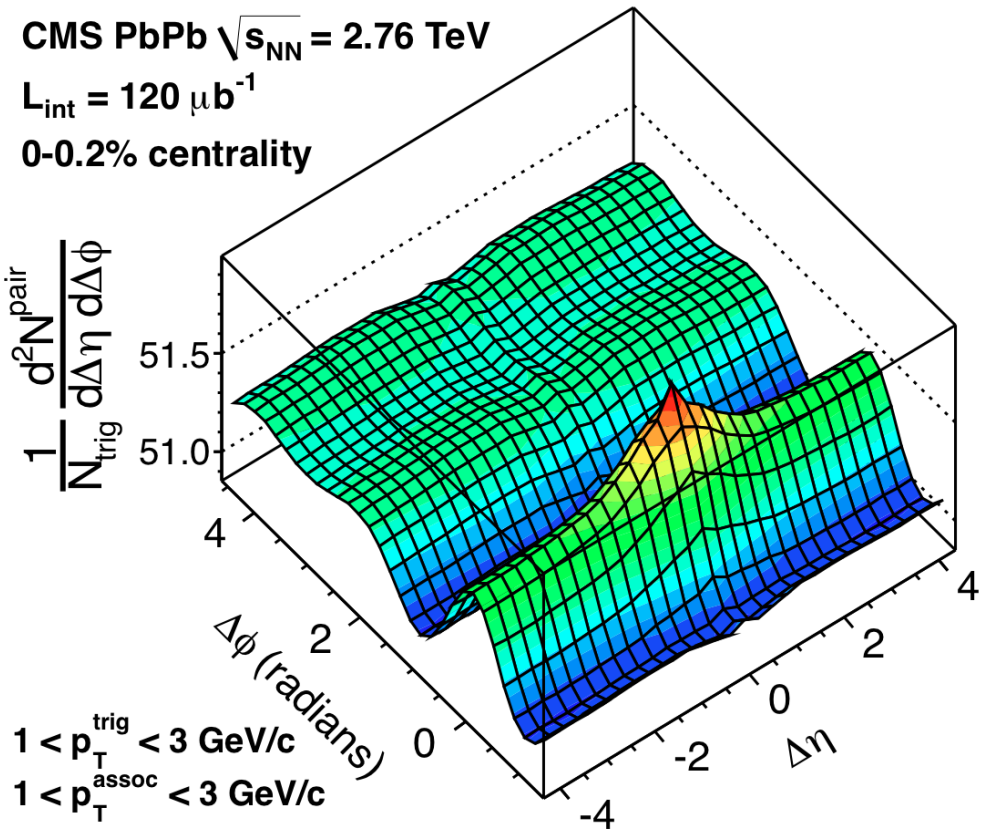

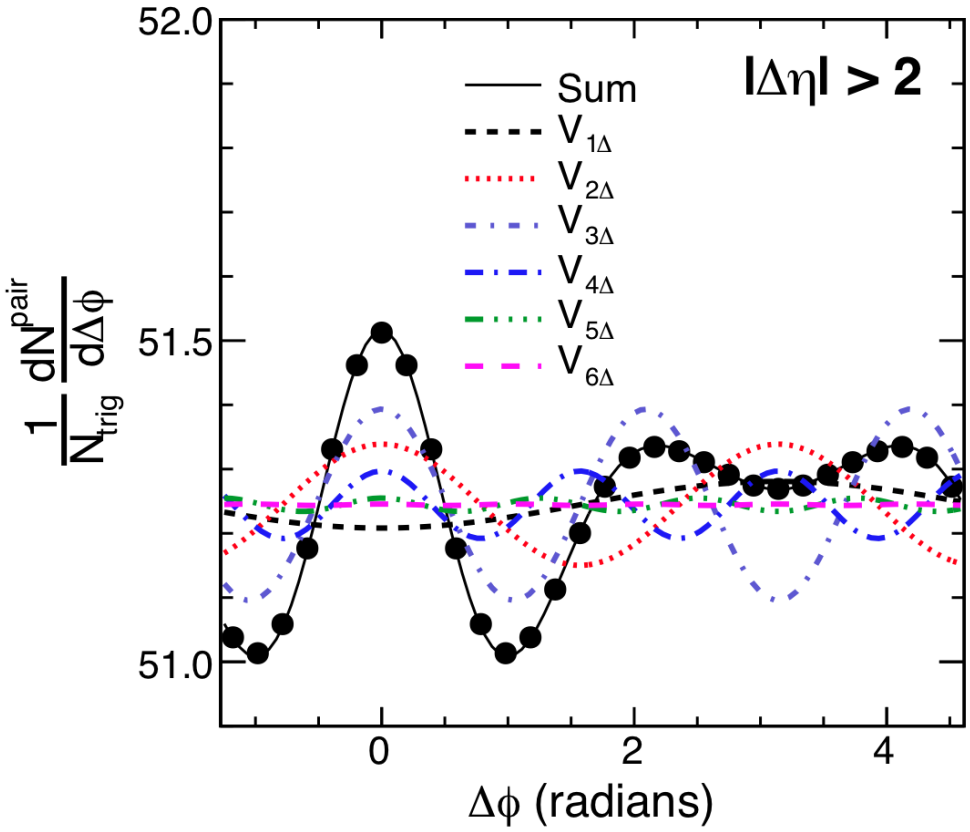

Flow phenomena in UCC events

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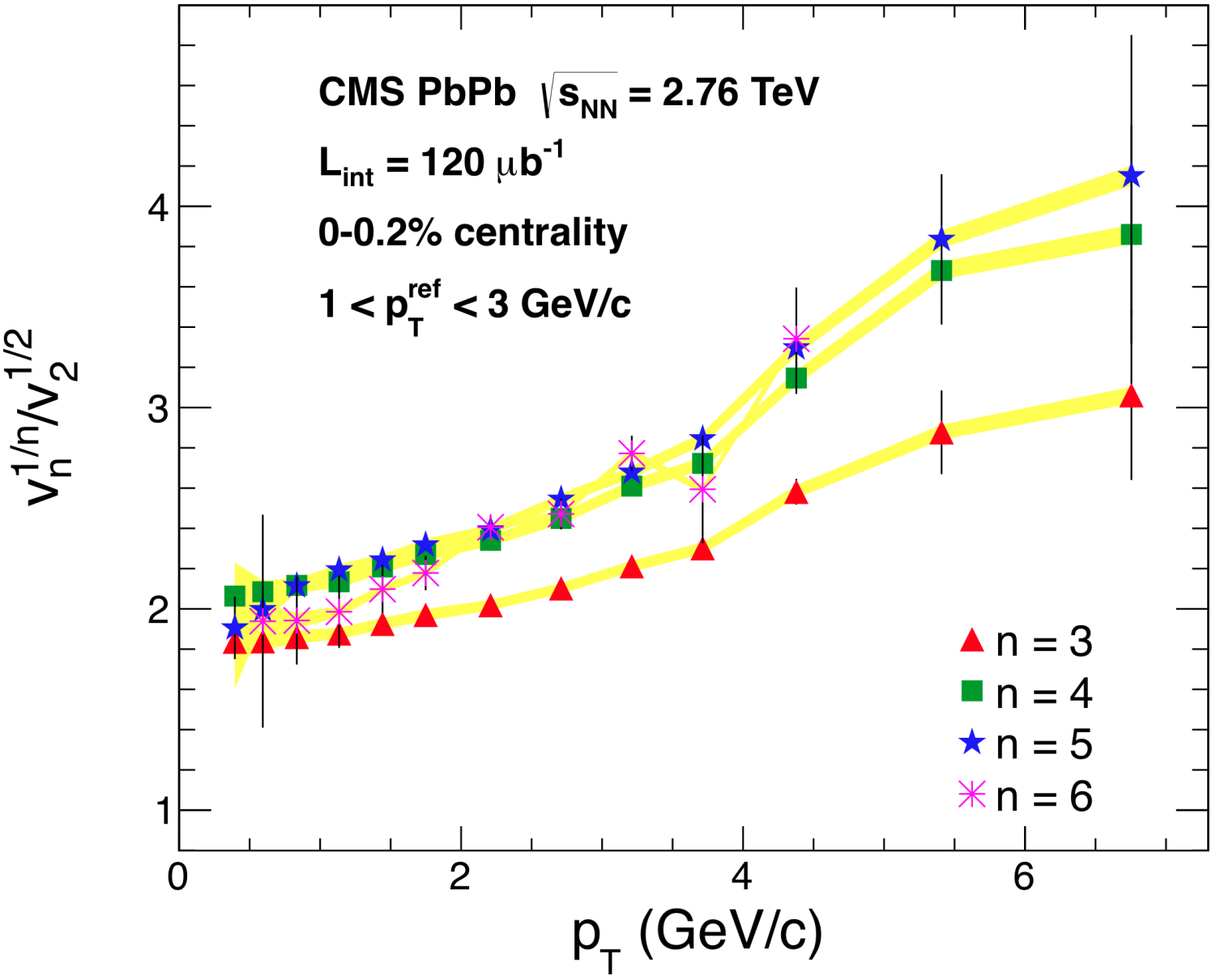
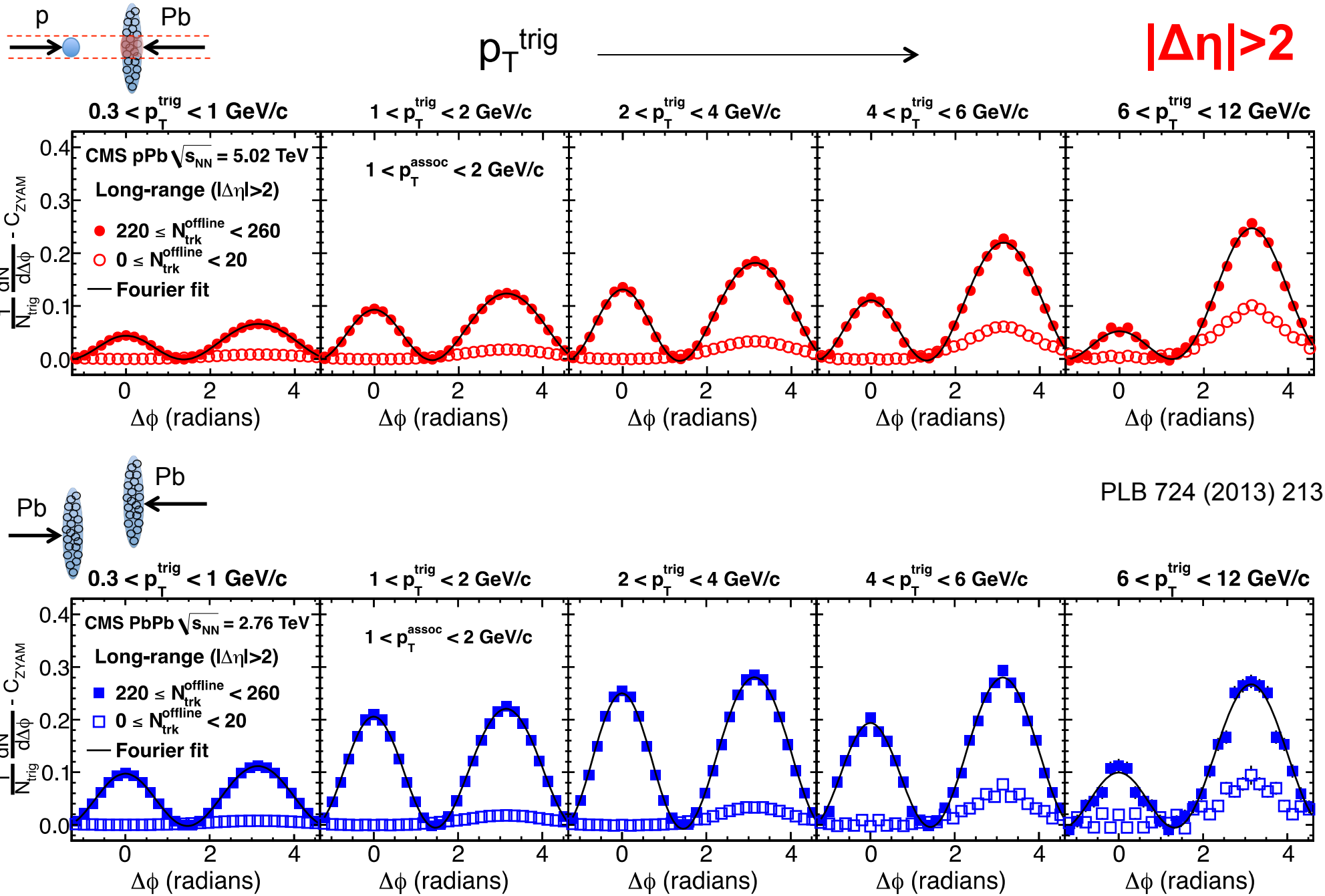


New pPb data from 2013 run



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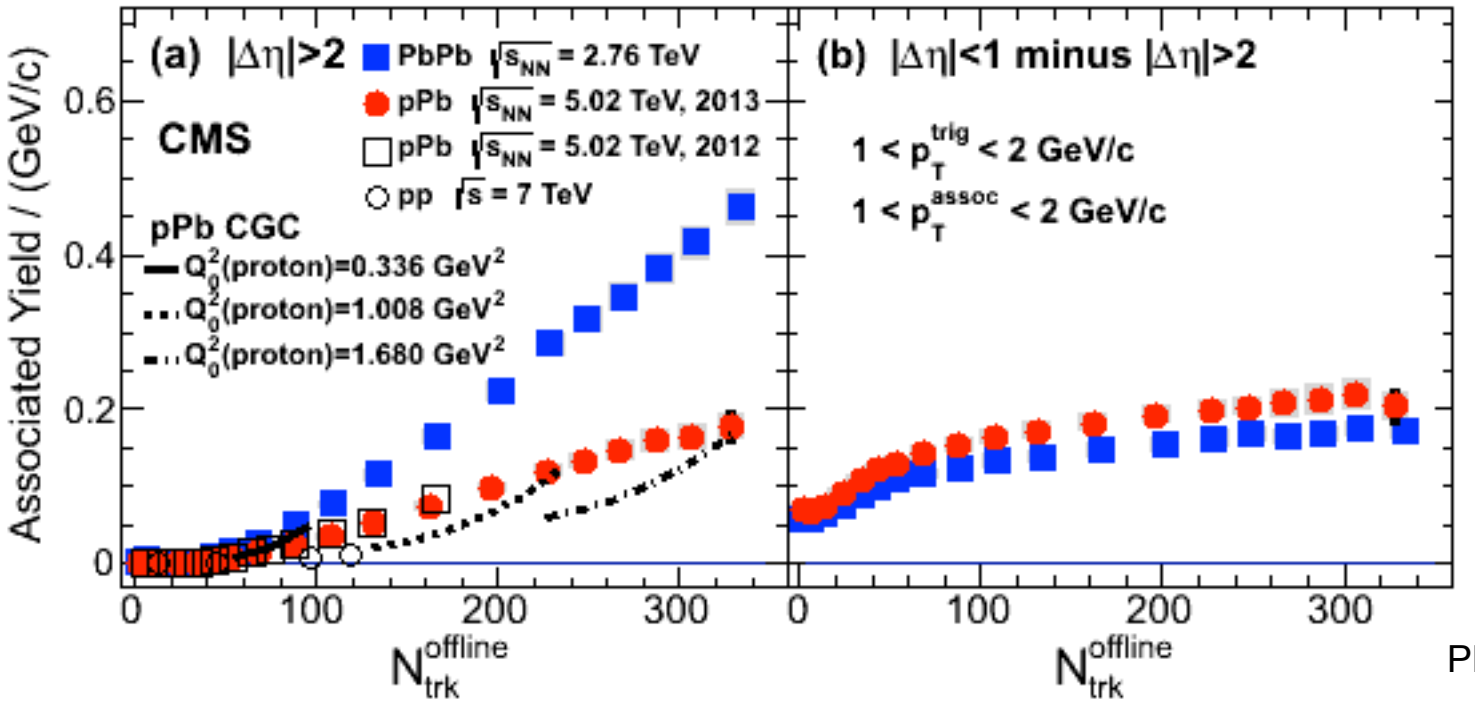
Flow phenomena in pPb



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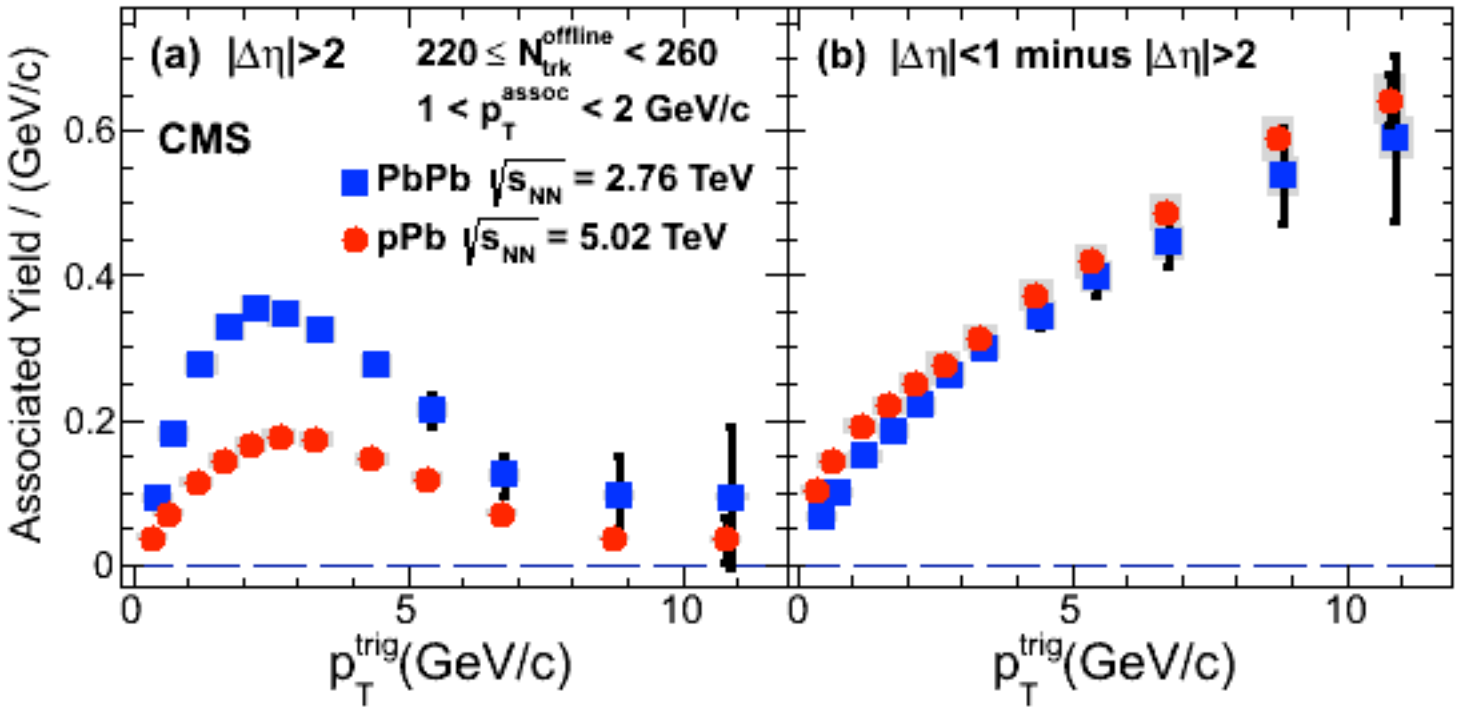
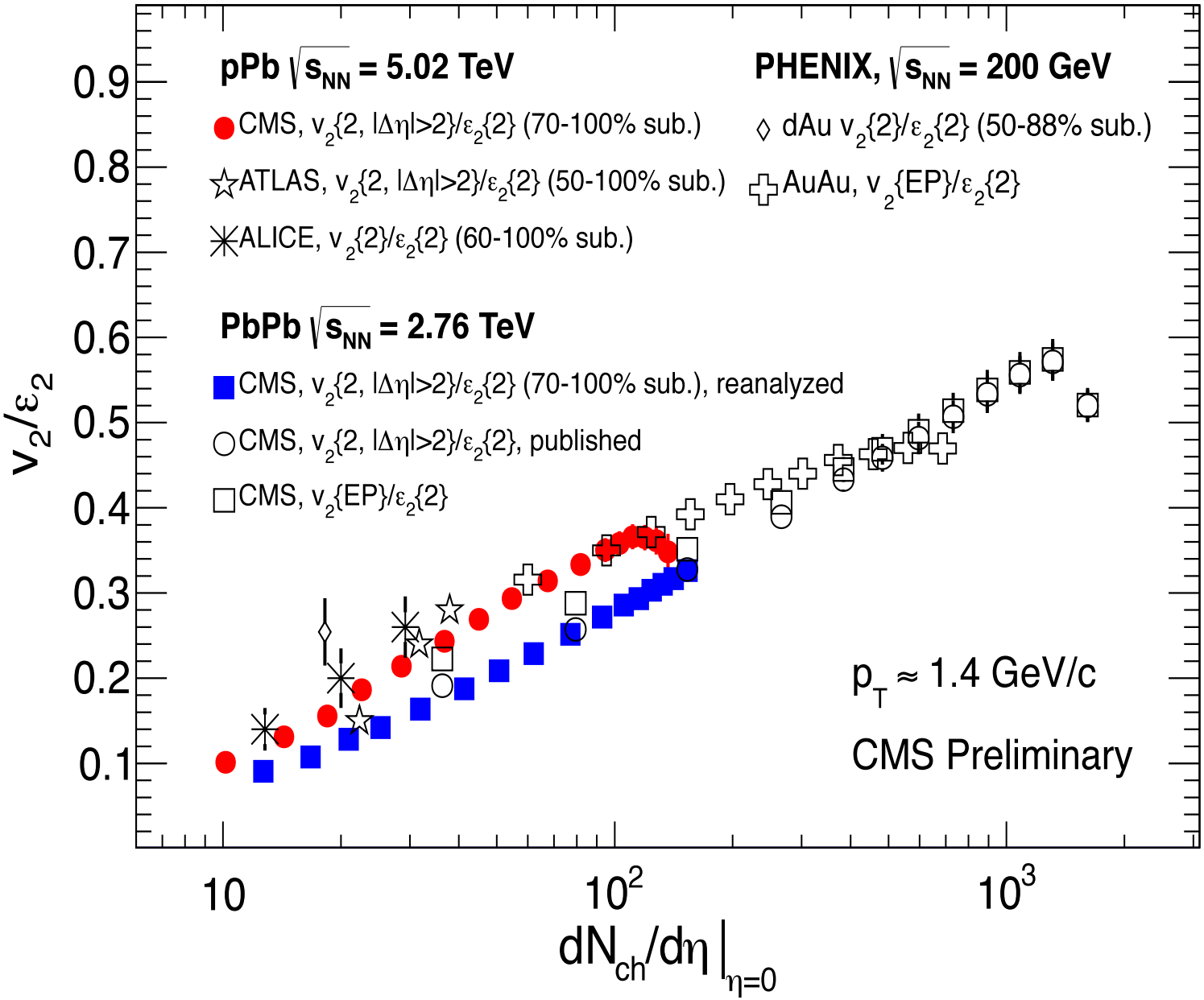


Flow phenomena in pPb



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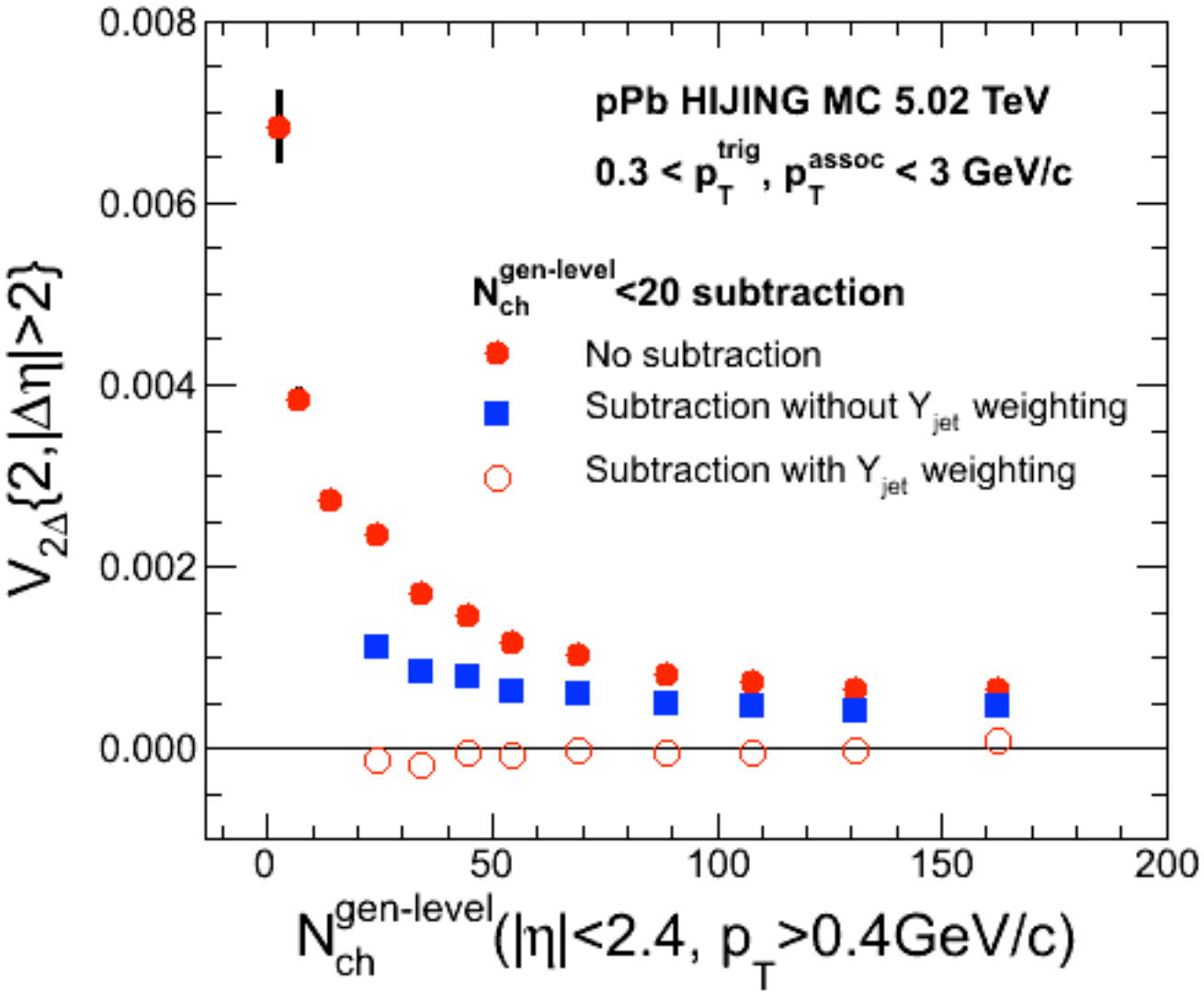
Flow phenomena in pPb



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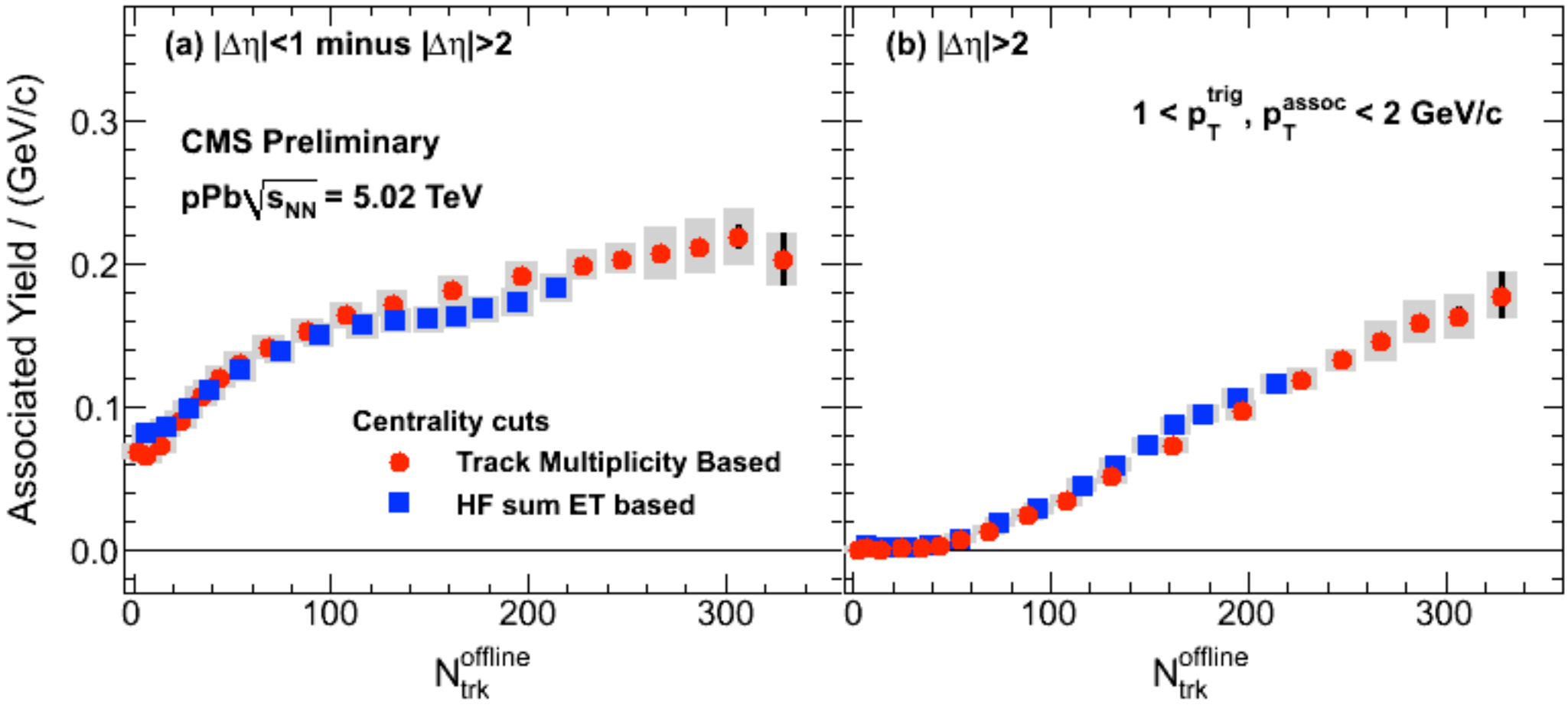
Flow phenomena in pPb



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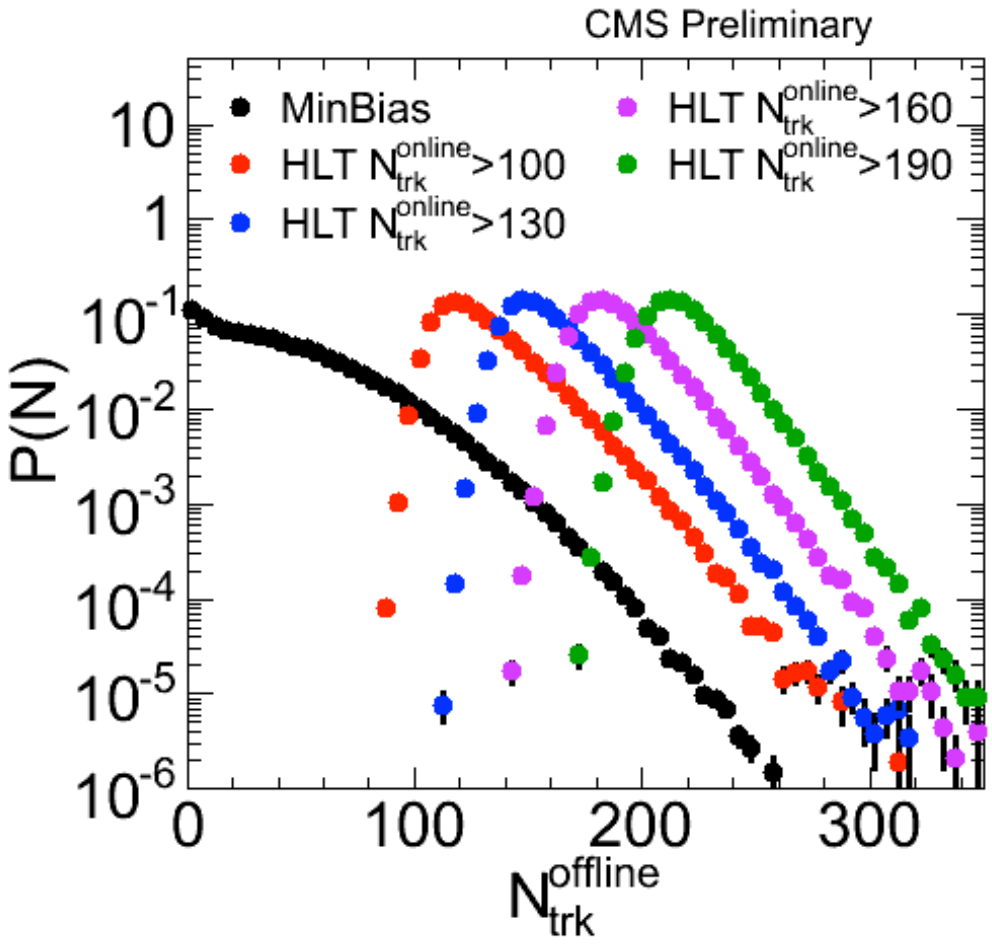
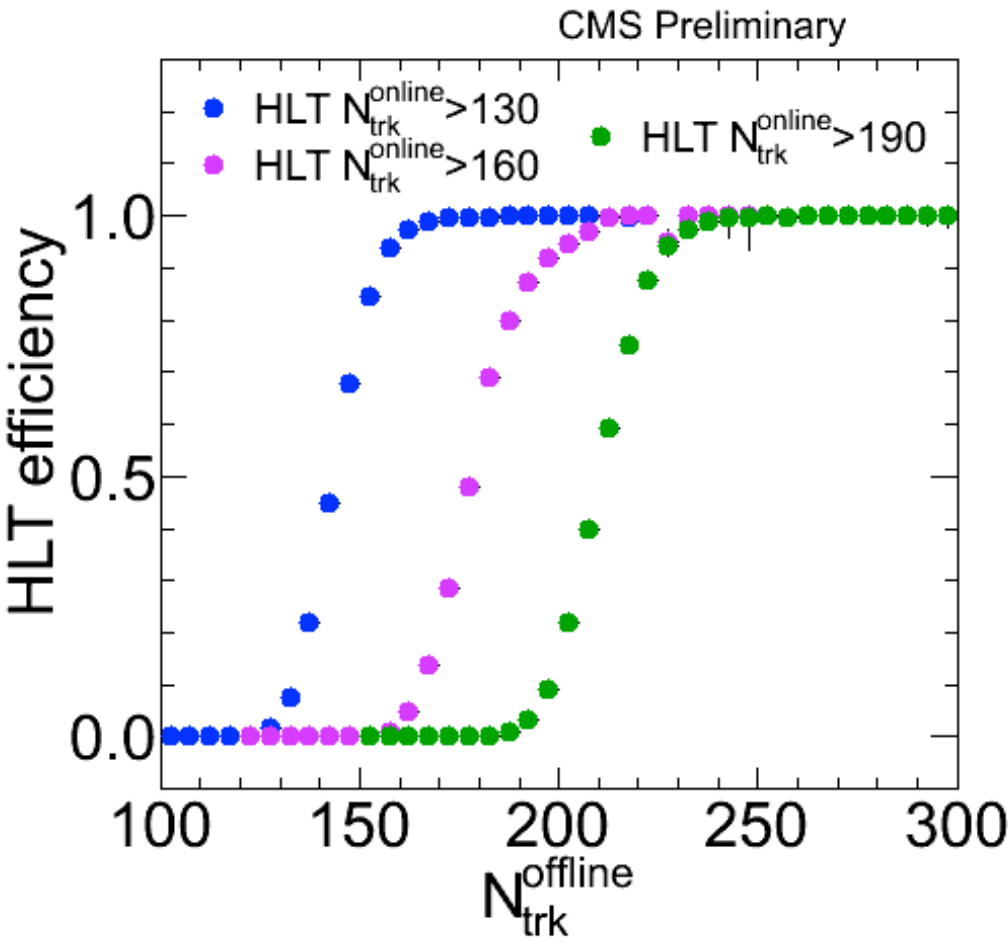
Flow phenomena in pPb





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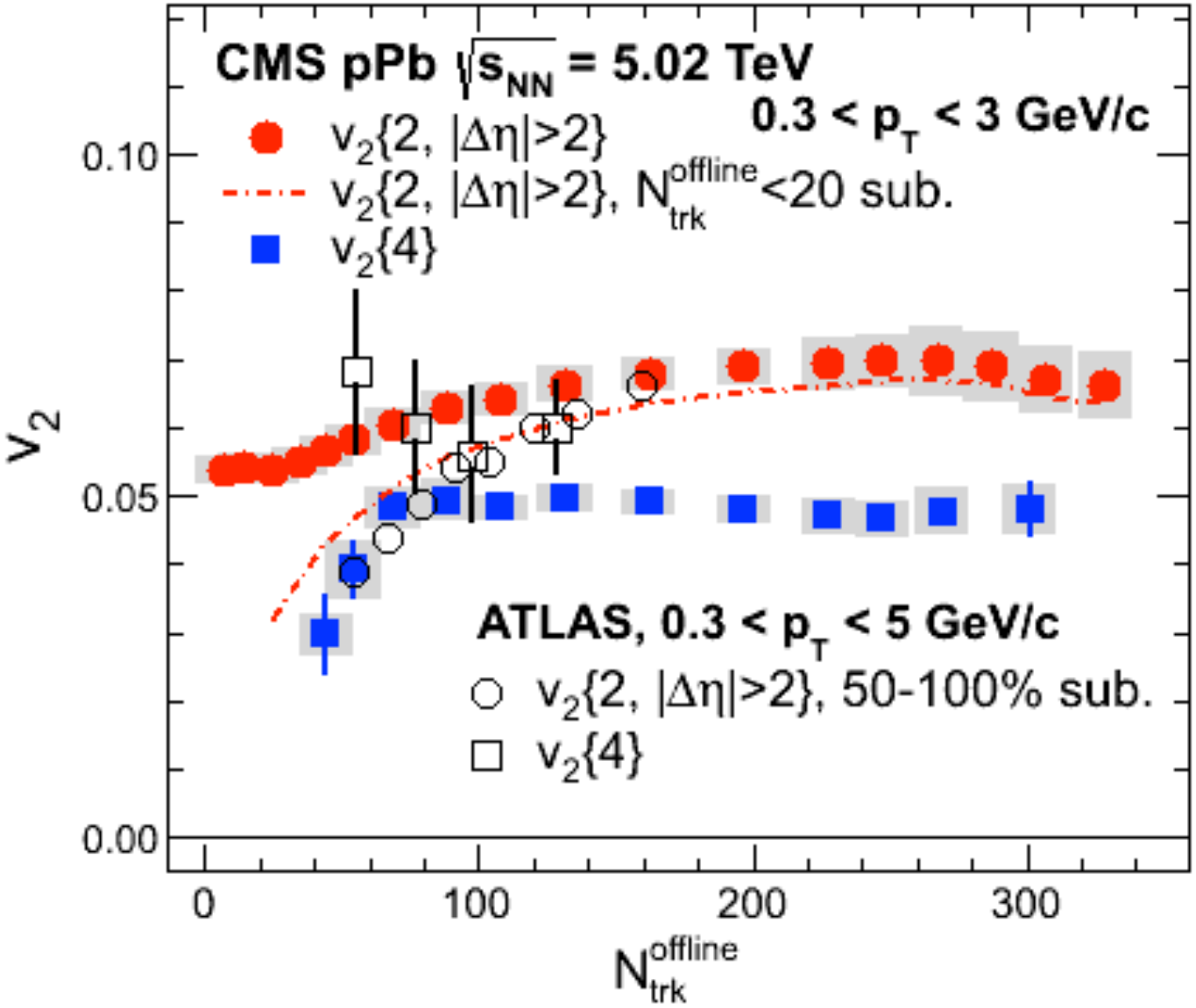
Flow phenomena in pPb



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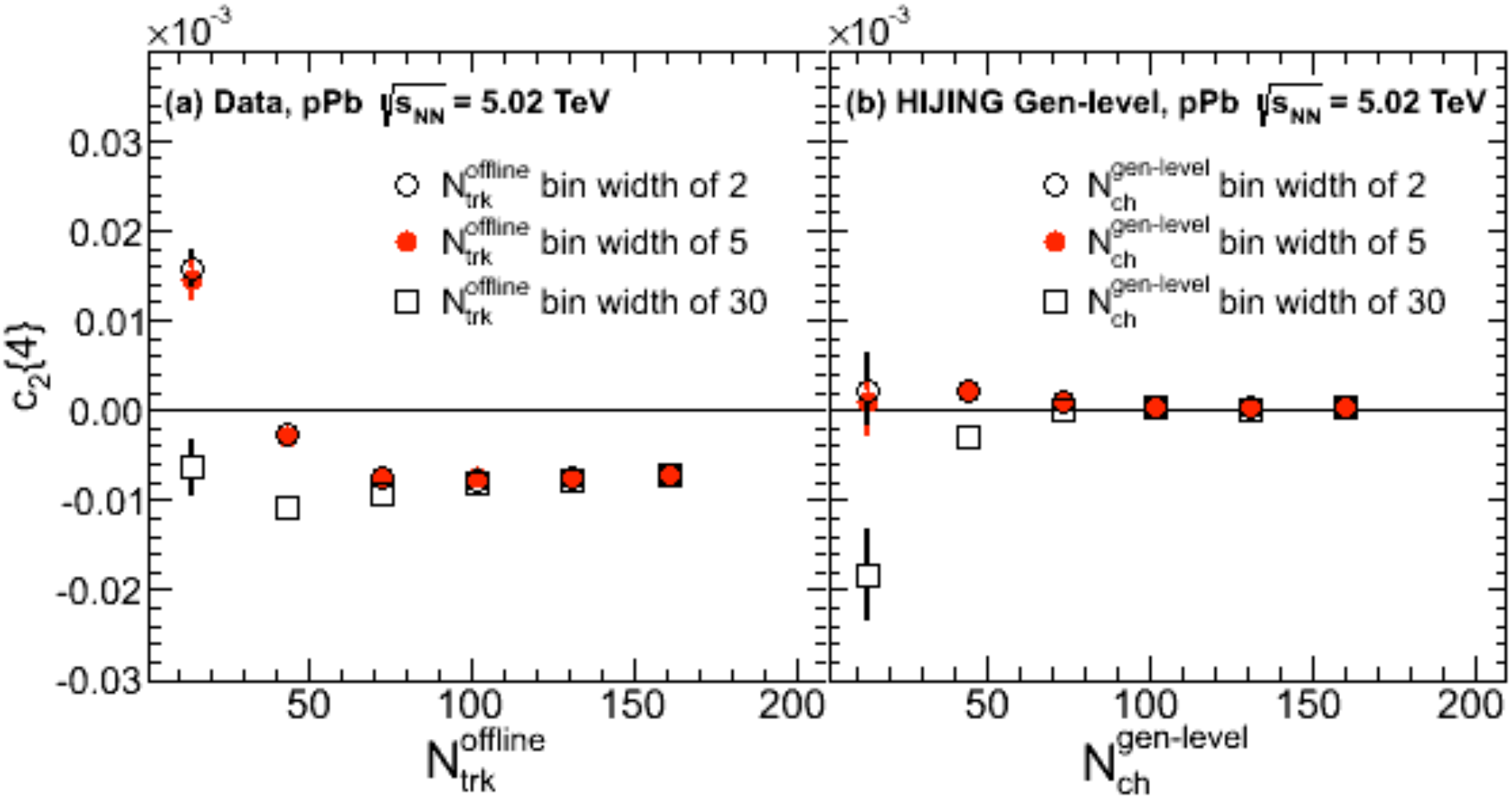
Flow phenomena in pPb

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