“Long-range collectivity” in small systems

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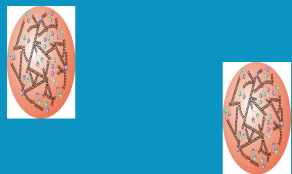
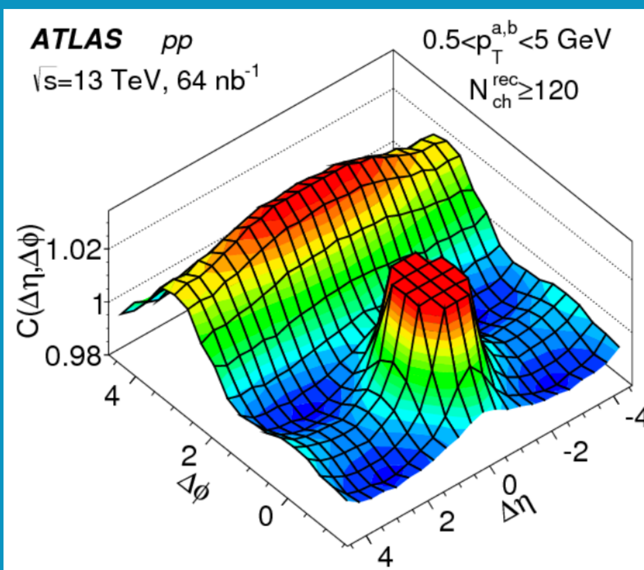
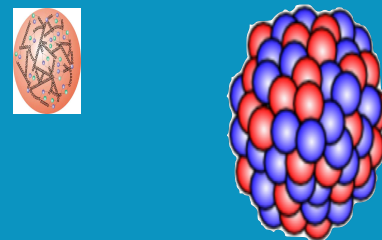
- What is collectivity?
- How to distinguish initial vs final state effects ?

Long-range collectivity in different systems

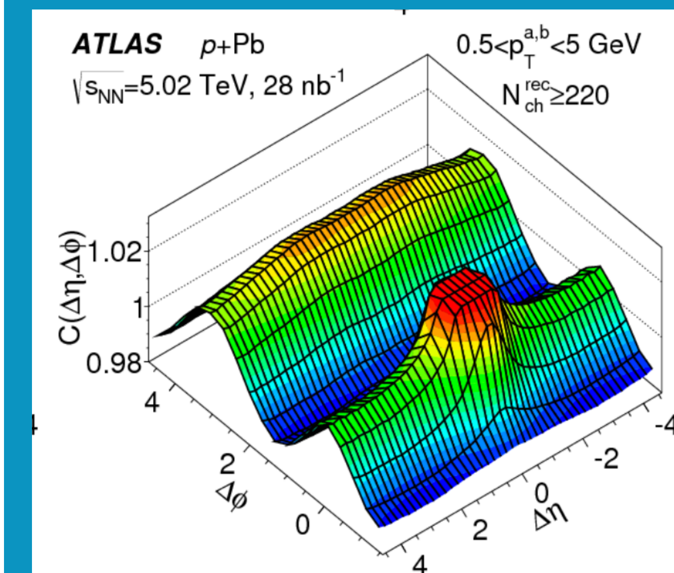


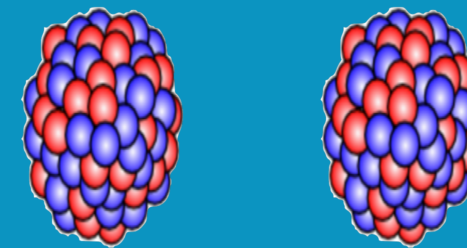
p+p



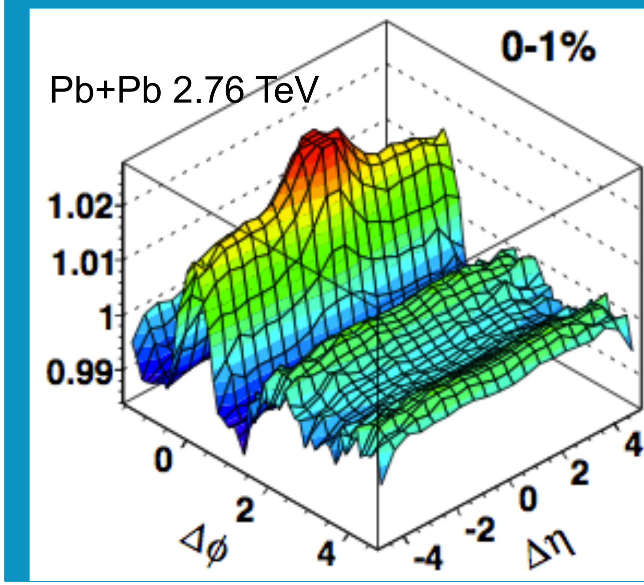


p+Pb





Pb+Pb

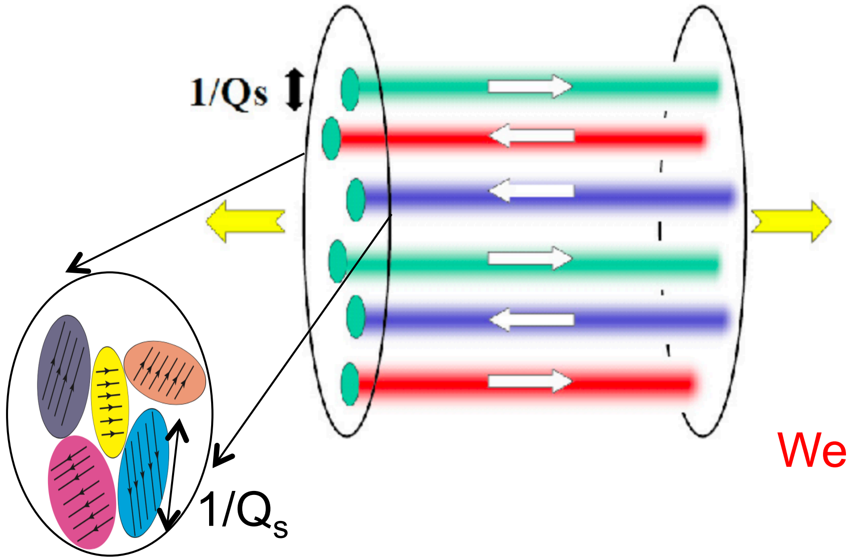


- Long-range correlation in momentum space comes
  - directly from early time t~0 (CGC)
  - or it is a final state response to spatial fluctuation at t=0 (hydro).

What is the timescale for emergence of collectivity?

Examples of initial vs final state scenarios

CGC



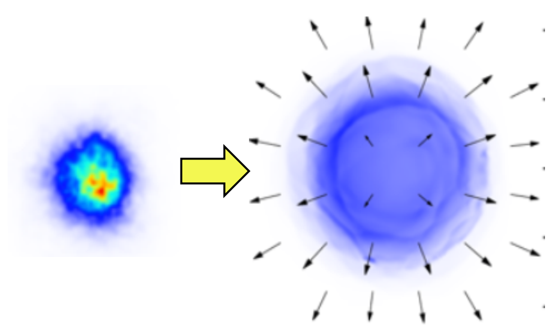
Domain of color fields of size $1/Q_s$, each produce multi-particles correlated across full η.

Uncorr. between domains, strong fluct. in Q_s

More domains, smaller v_n, more Q_s fluct, stronger v_n

Well motivated model framework, lack systematic treatment

Hydro



Hot spots (domains) in transverse plane e.g IP-plasma, boost-invariant geometry shape

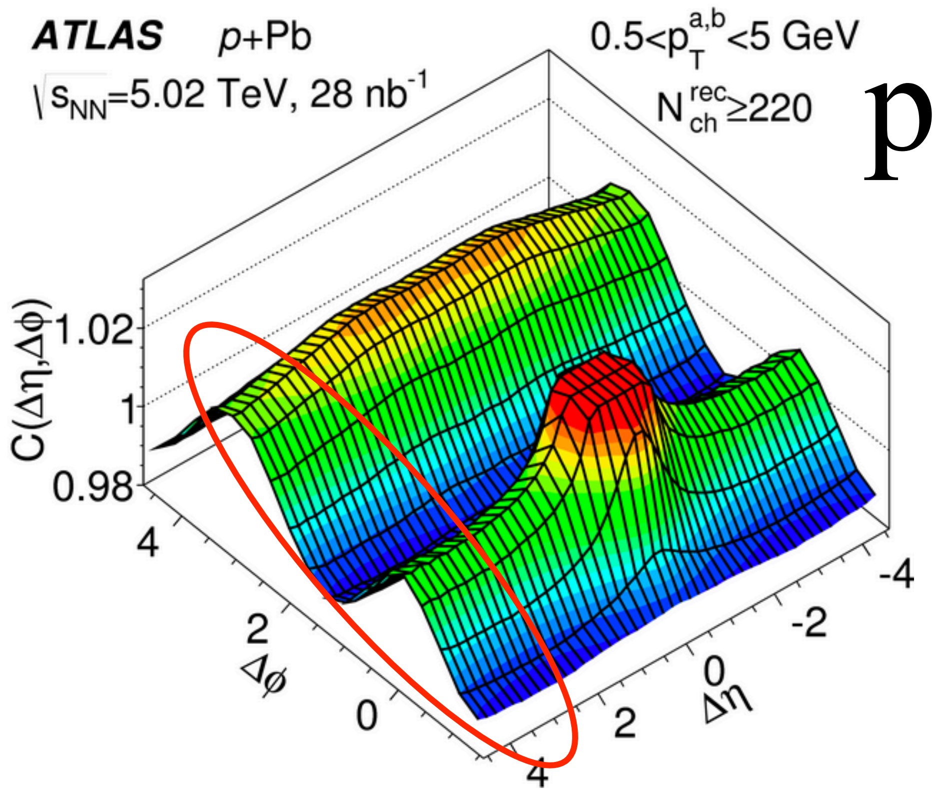
Expansion and interaction of hot spots generate collectivity

v_n depends on distribution of hot spots (ε_n) and transport properties.

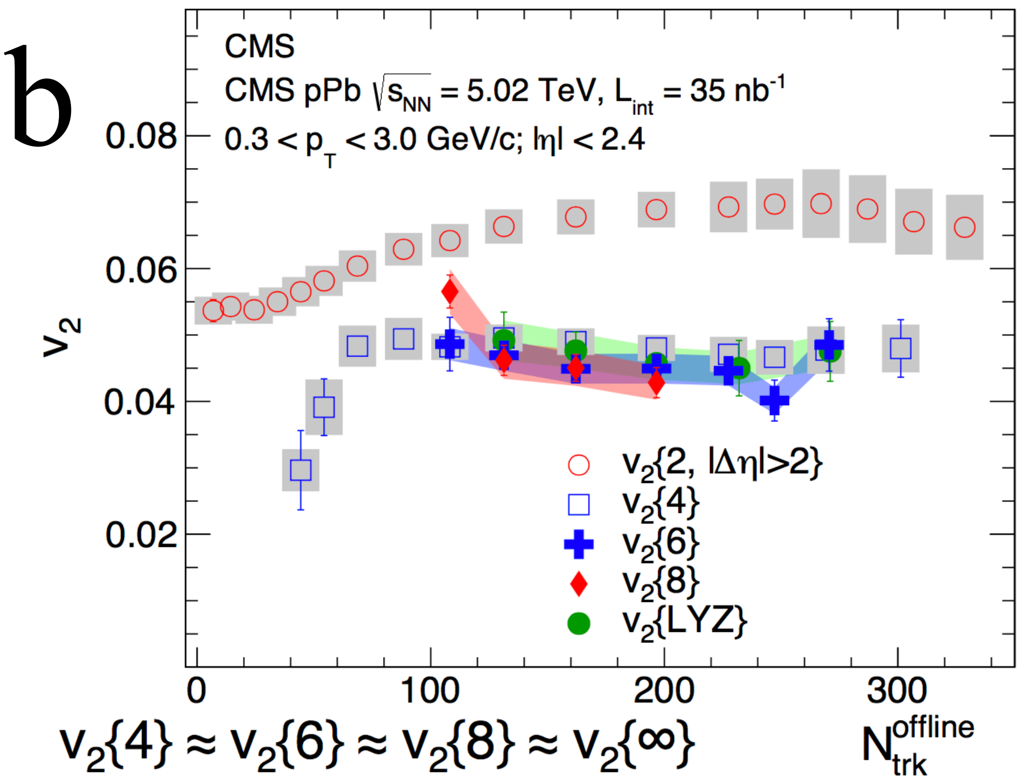
Ongoing debate whether hydro is applicable in small systems

Features of collectivity in HM pPb

pPb



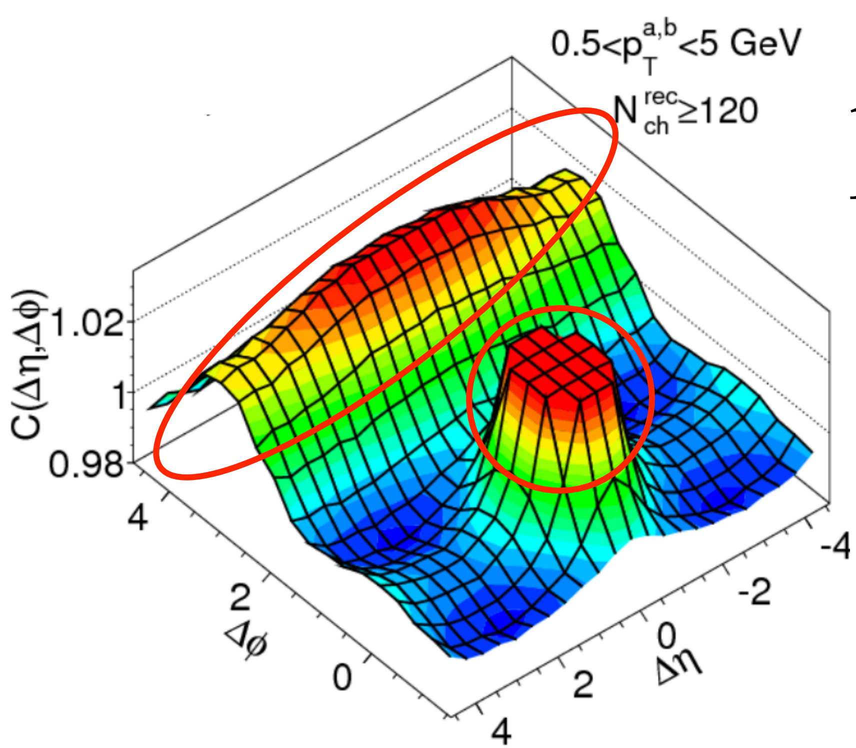
Long-range in η



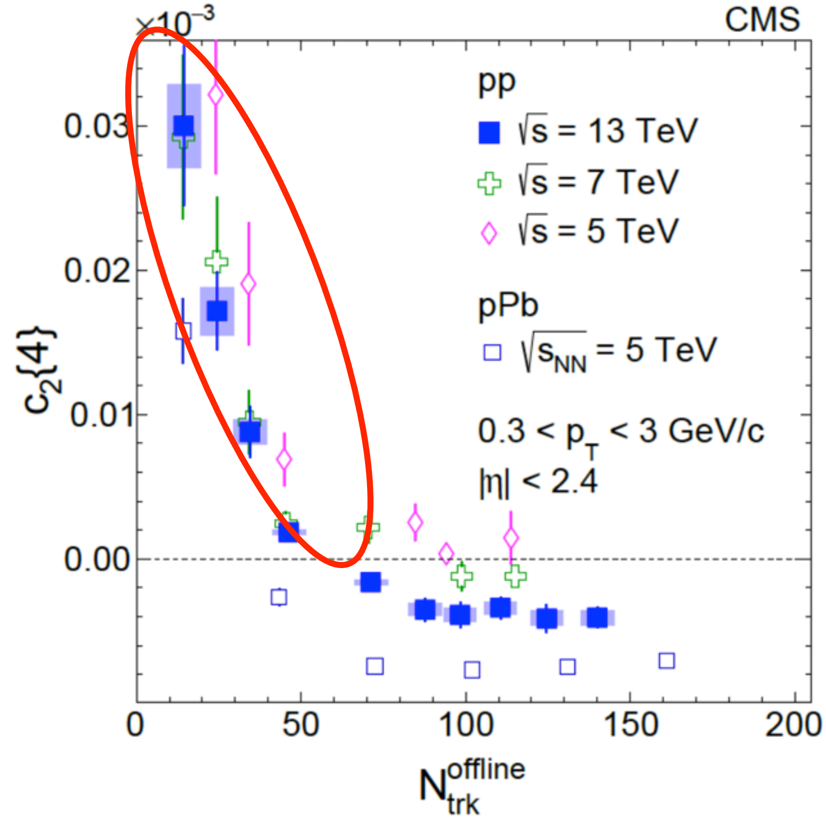
$v_2\{4\} \approx v_2\{6\} \approx v_2\{8\} \approx v_2\{\infty\}$

Multi-particle signals

Features of collectivity in HM pp



pp



Long-range in η

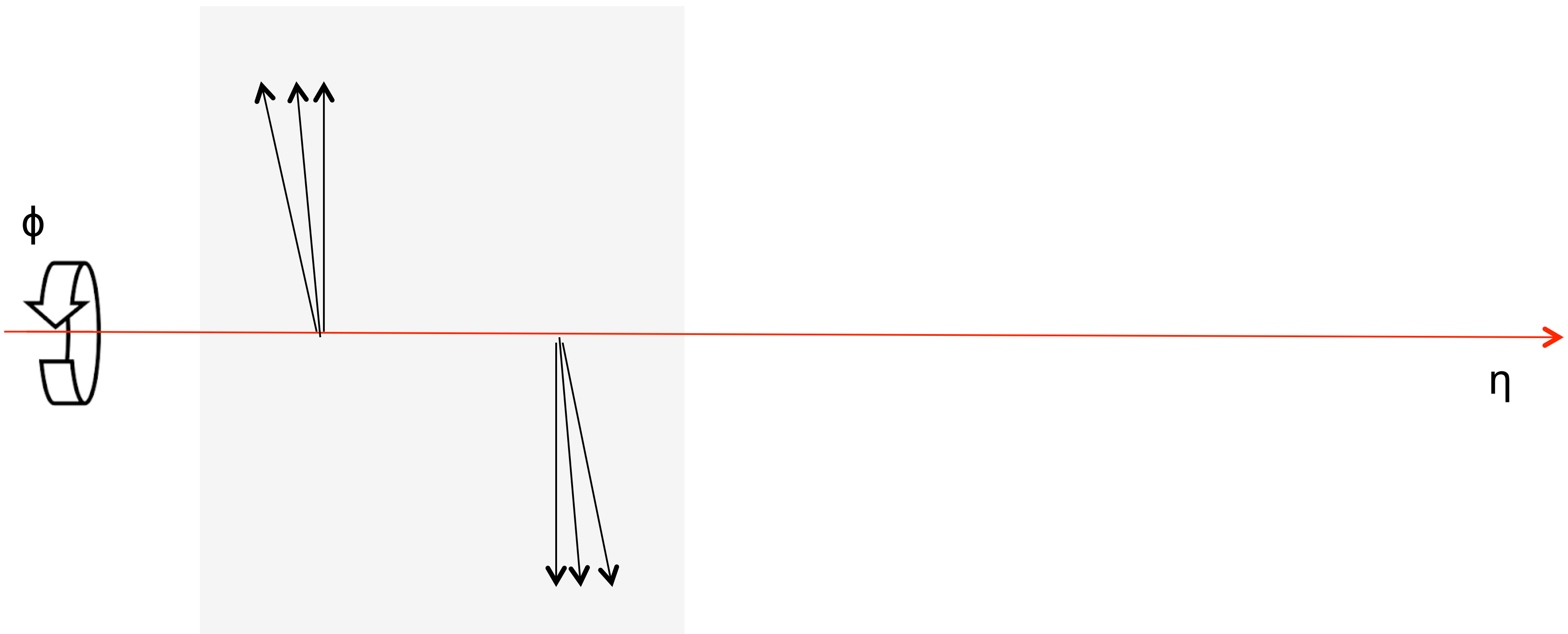
Multi-particle signals

Non-flow can generate long-range (away-jet) or multi-particle correlation (fragmentation) but not both

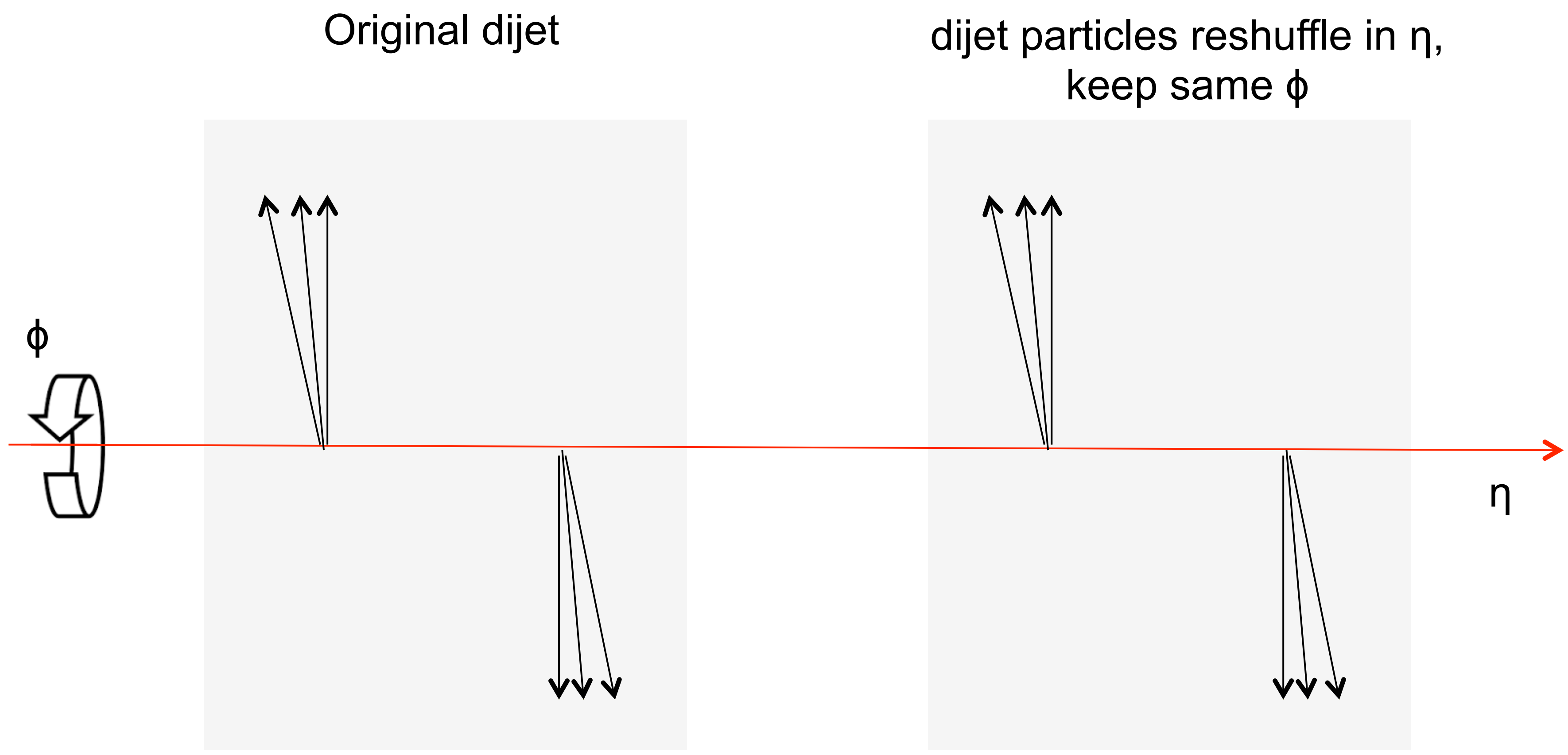
Collectivity must mean both

Azimuthal correlation from collectivity

Original dijet



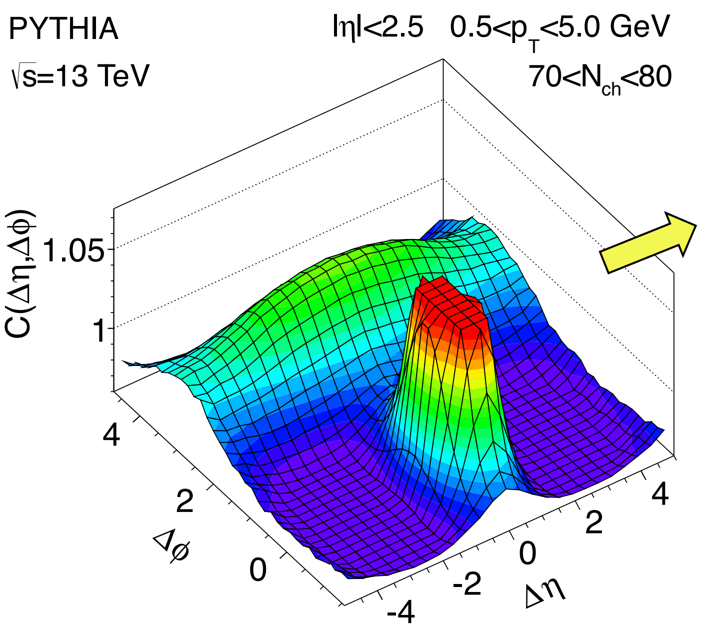
Azimuthal correlation from collectivity

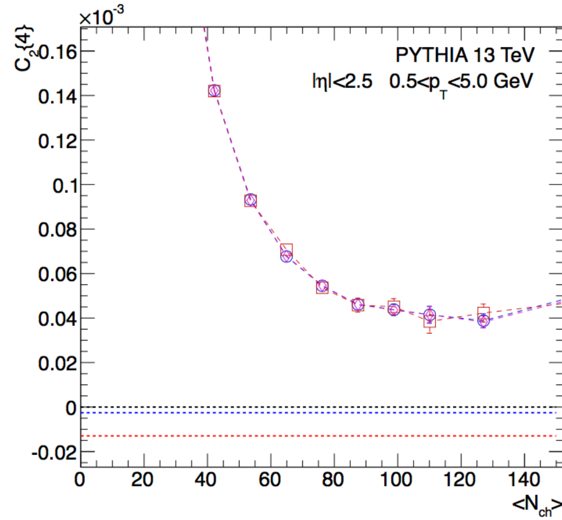


They give the same flow coefficient $c_n\{4\}$ and $v_n\{4\}$, although clearly the first case is non-flow and the second case would be classified as flow

Azimuthal correlation from collectivity

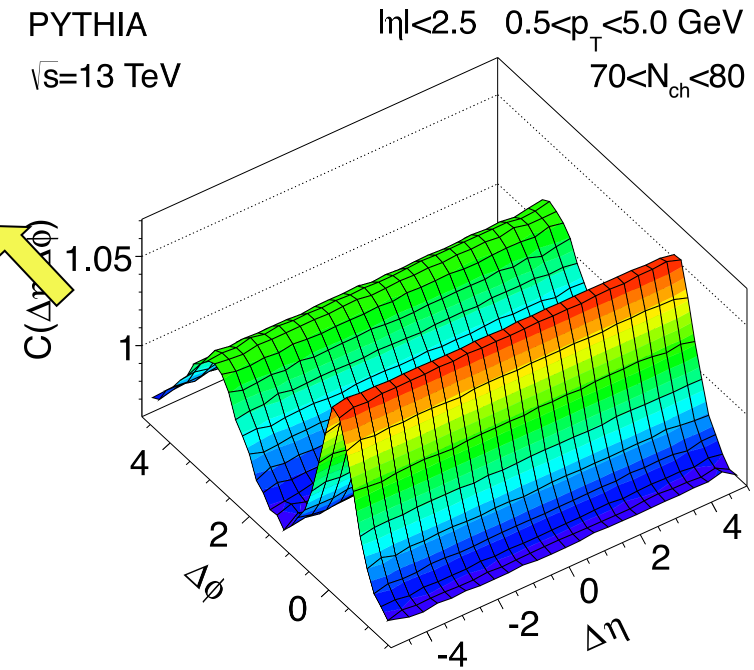
original





By mingliang Zhou

η reshuffled



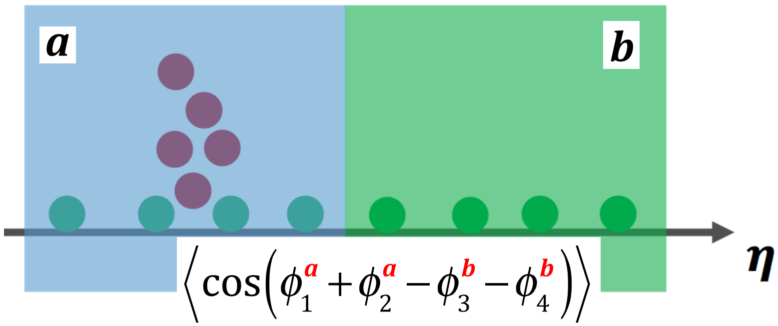
They give the same flow coefficient $c_n\{4\}$ and $v_n\{4\}$, although clearly the first case is non-flow and the second case would be classified as flow

Azumuthal corr. alone can’t distinguish flow & non-flow.

Long-range collectivity via subevent cumulants

arXiv:1701.03830

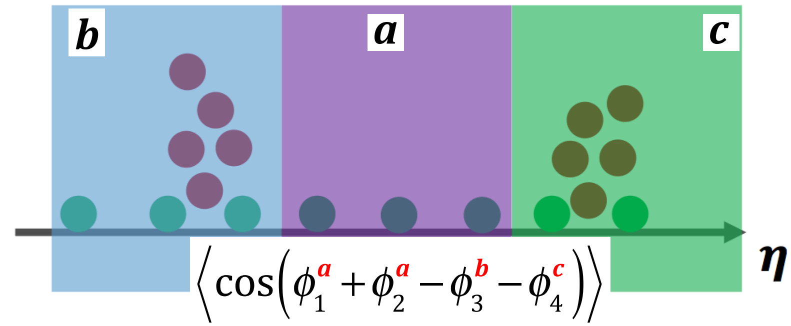
Event with jet



2 sub-event

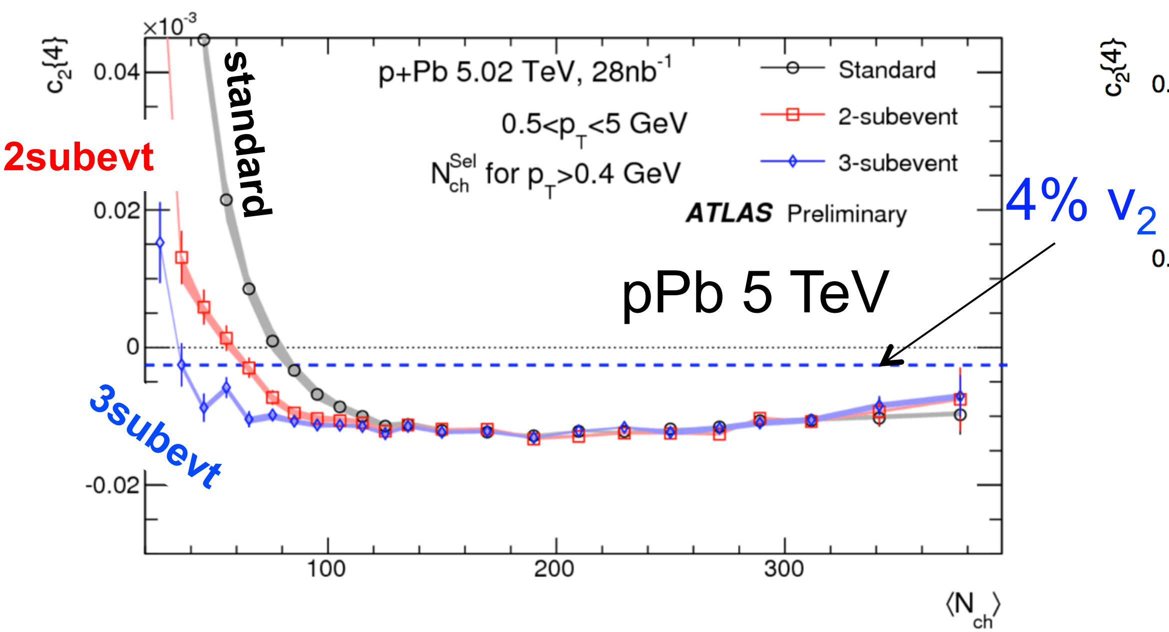
removes intra-jet correlations

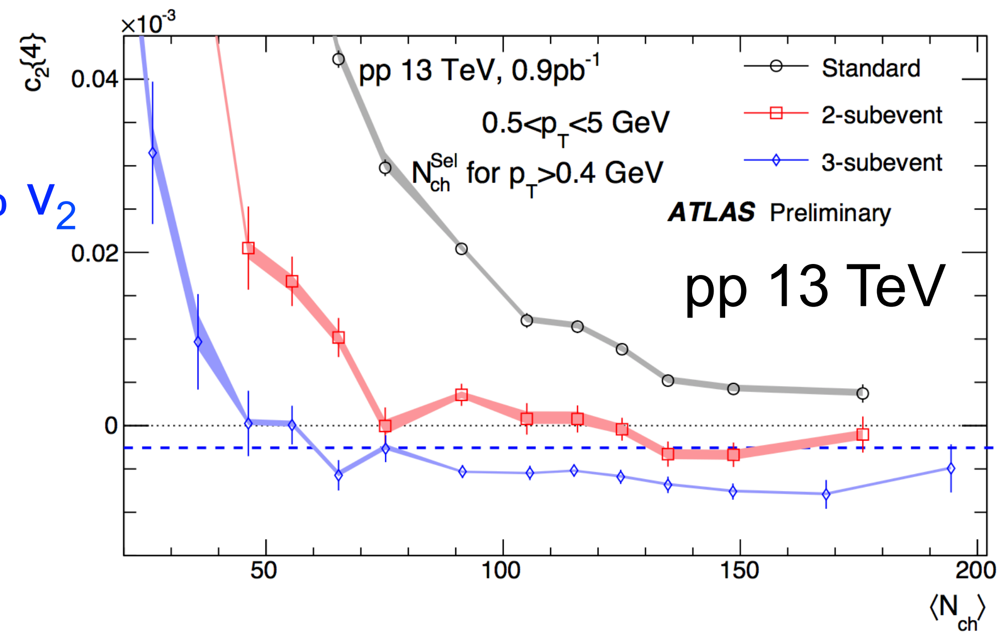
Event with dijet



3 sub-event

removes inter-jet correlations





pPb: methods consistent for N_{ch}>100, but split below that

pp: Only subevent method gives reliable negative $c_2\{4\}$ in broad range of N_{ch}

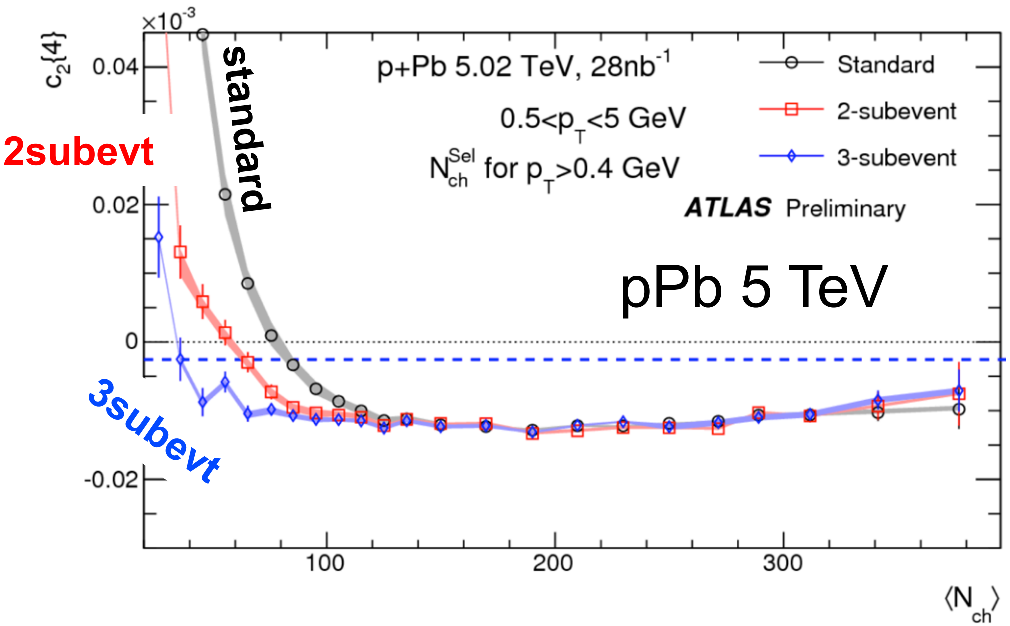
Sign-change of $c_2\{4\}$

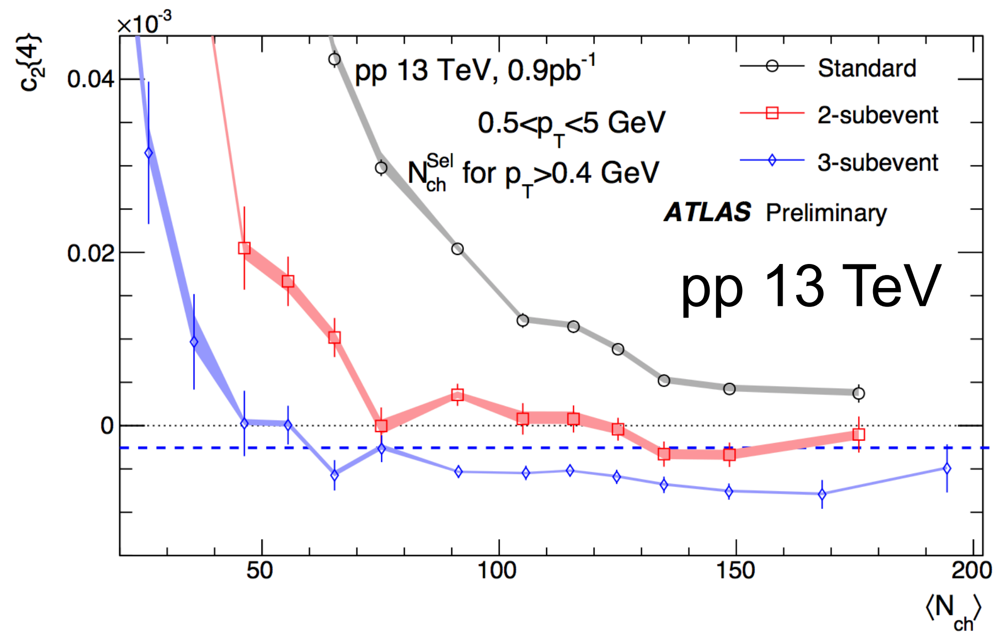
- Most positive $c_2\{4\}$ in standard cumulants are jets and dijets.
  - Remaining positive $c_2\{4\}$ in 3-subevent due to residual dijets.

Dumitru,McLerran,Skokov

- CGC expect sign-change at low N_{ch} $$c_2\{4\} = \frac{1}{N_D^3}\left(\frac{1}{4(N_c^2-1)^3} - A^4\right)$$

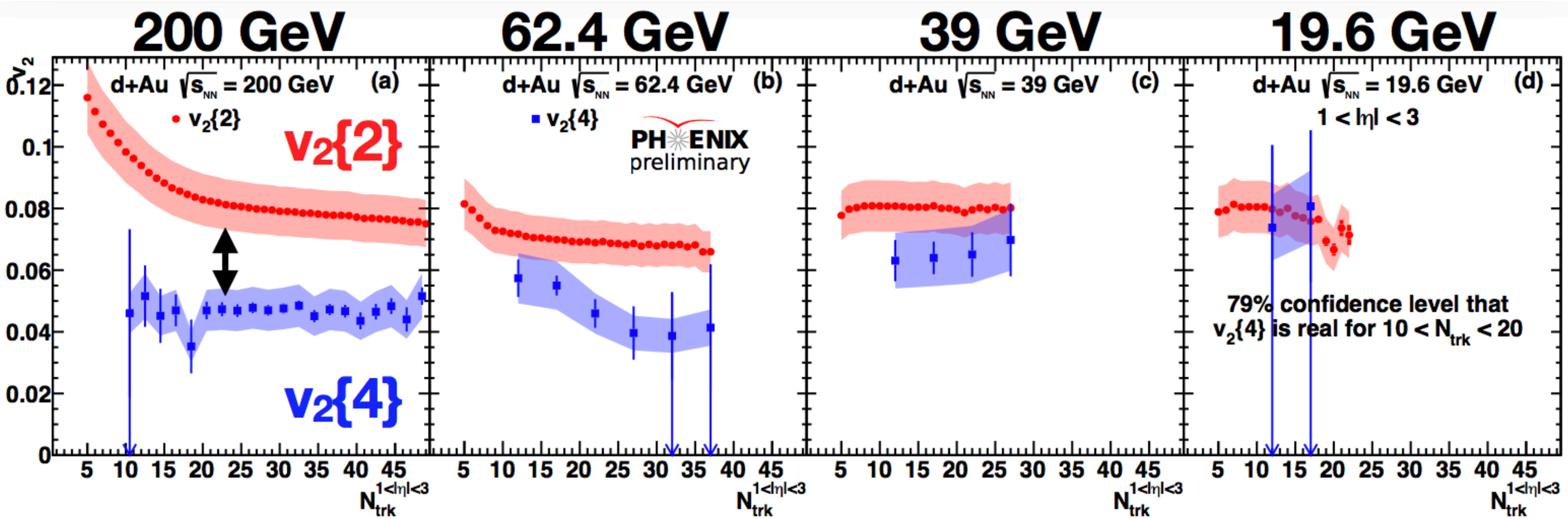
Glasma diagram non-linear/non-Gaussian effects





Glasma diagram contribution is small?

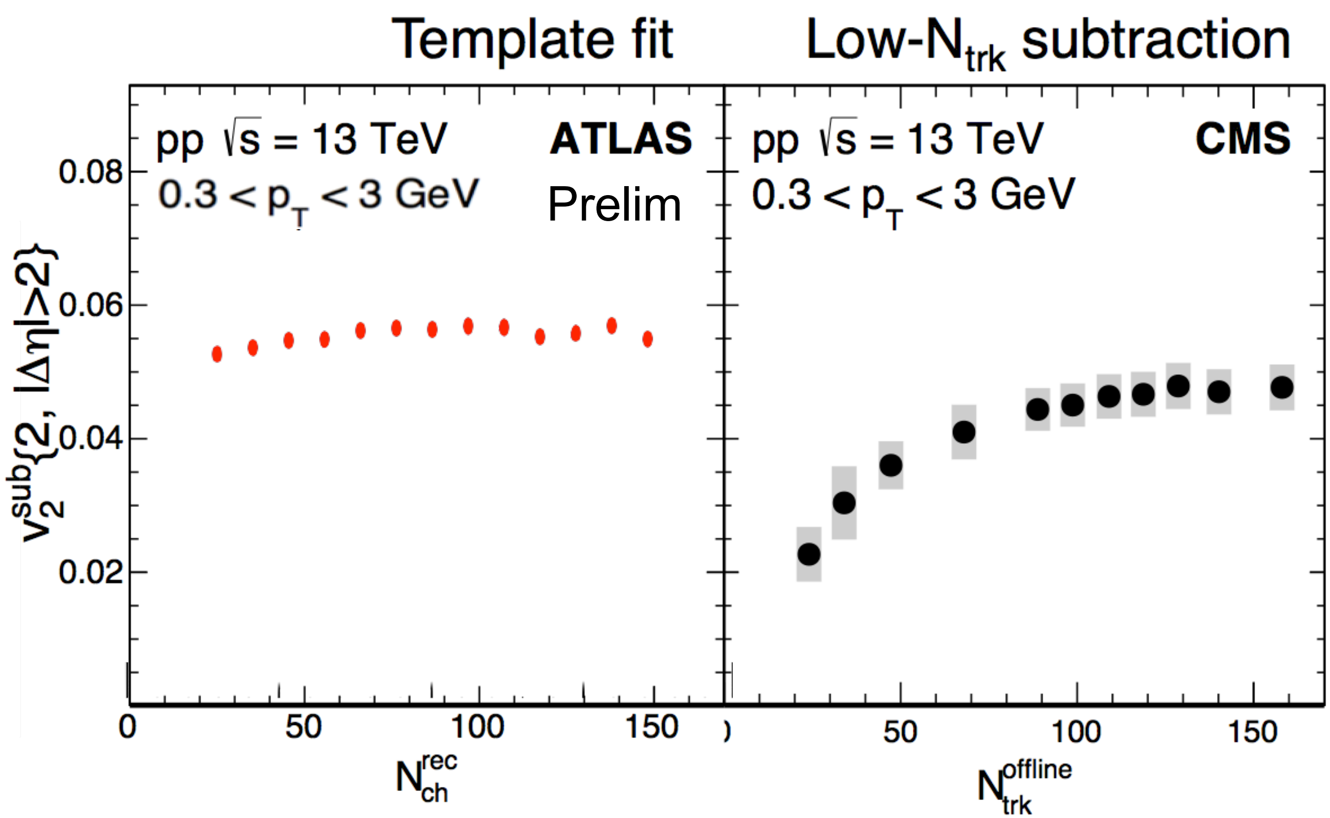
$\sqrt{s}$ dependence of $c_2\{4\}$ at RHIC



- Surprising features: $v_2\{4\}$ larger at lower $\sqrt{s}$, reaching $v_2\{2\}$.
- Difficult to describe in both CGC and hydro

Important to understand non-flow in standard cumulant method

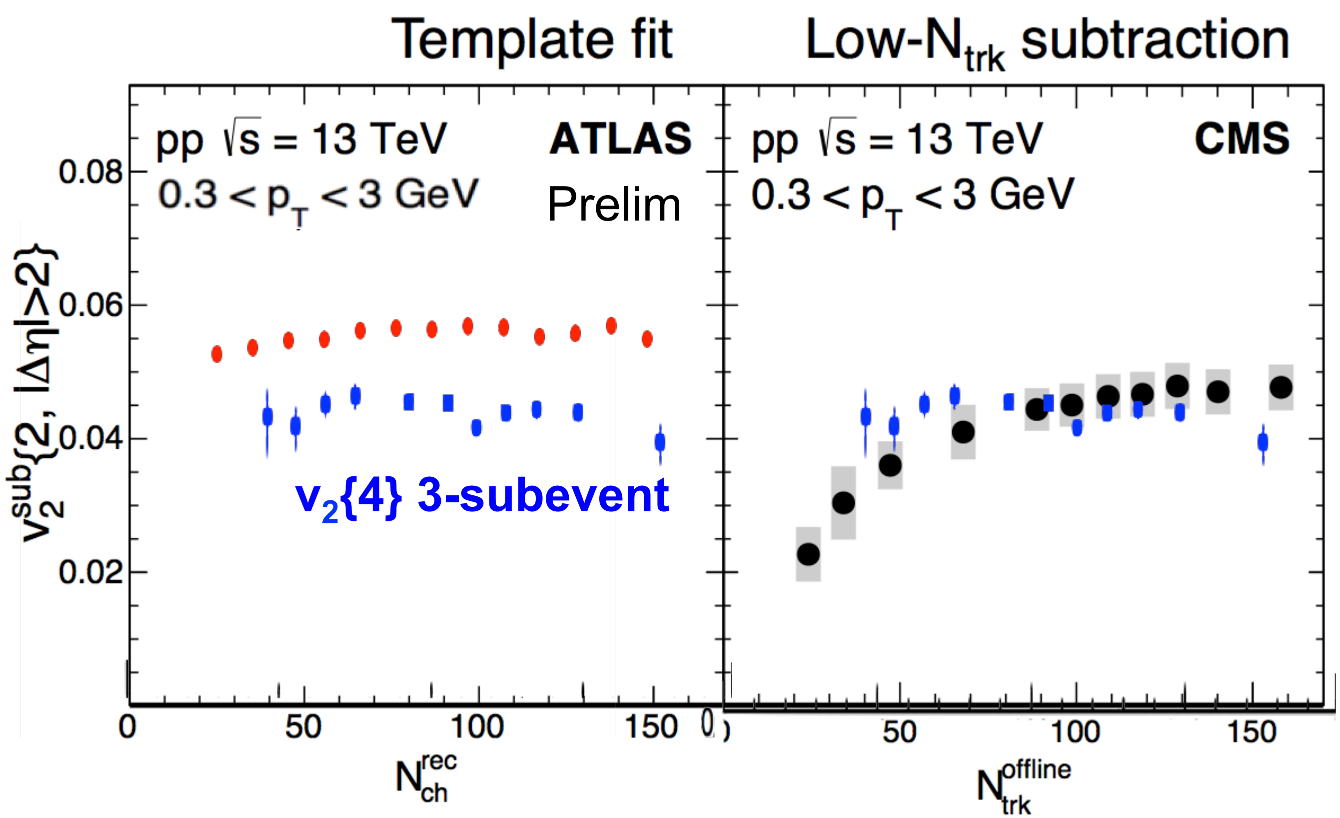
Does collectivity turn off at low N_{ch}?



peripheral subtraction including peripheral pedestal (assuming the peripheral also has flow)
→so called template fit

peripheral subtraction not including peripheral pedestal (assuming the peripheral has no flow)
→ so call peripheral sub.

Does collectivity turn off at low N_{ch}?



- $v_2\{4\}$ from 3-subevent show no dependence on N_{ch}.
  - NO hint of collectivity turning-off at low N_{ch}!

  Challenge both CGC and standard hydro?

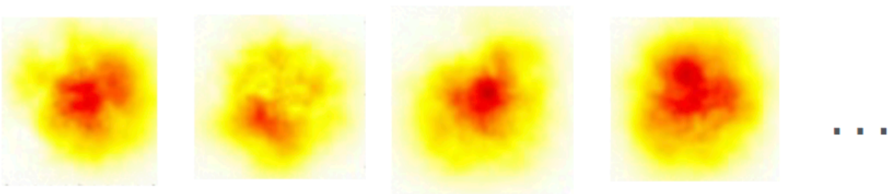
- Why $v_2\{2\}_{\text{peri. sub}} \approx v_2\{4\}$ in pp? surprising because:

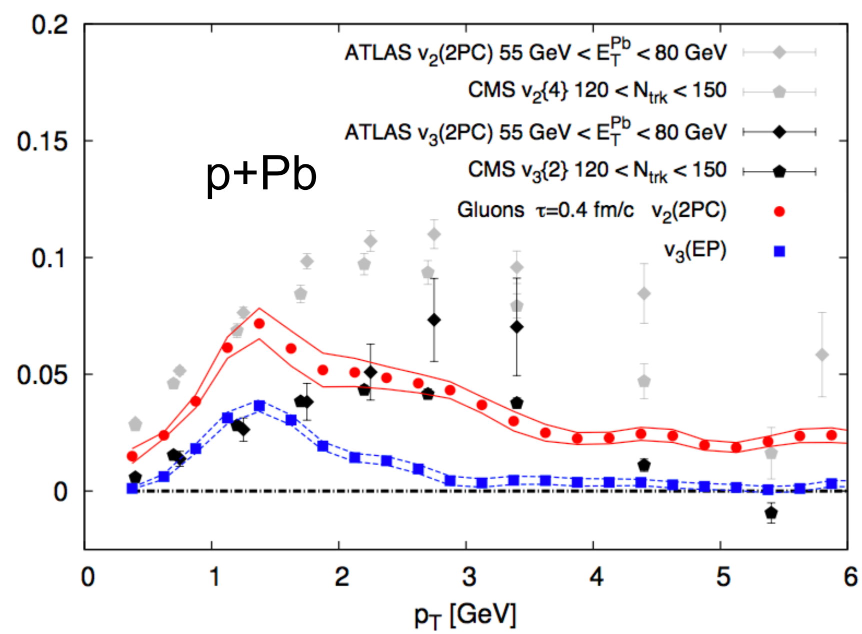
$$v_n\{2\}^4 - v_n\{4\}^4 = \left\langle \left(v_n^2 - \left\langle v_n^2 \right\rangle\right)^2 \right\rangle \geq 0$$

Role of initial geometry is very different

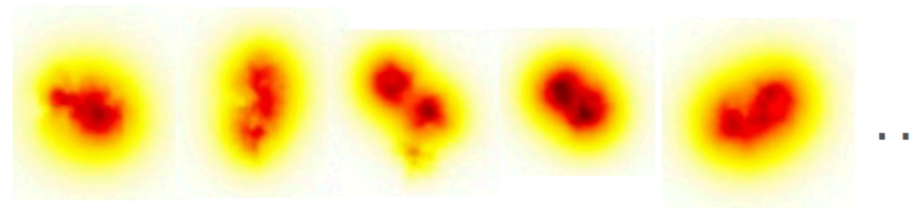
From Schenke, Schlichting, Venugopalan,

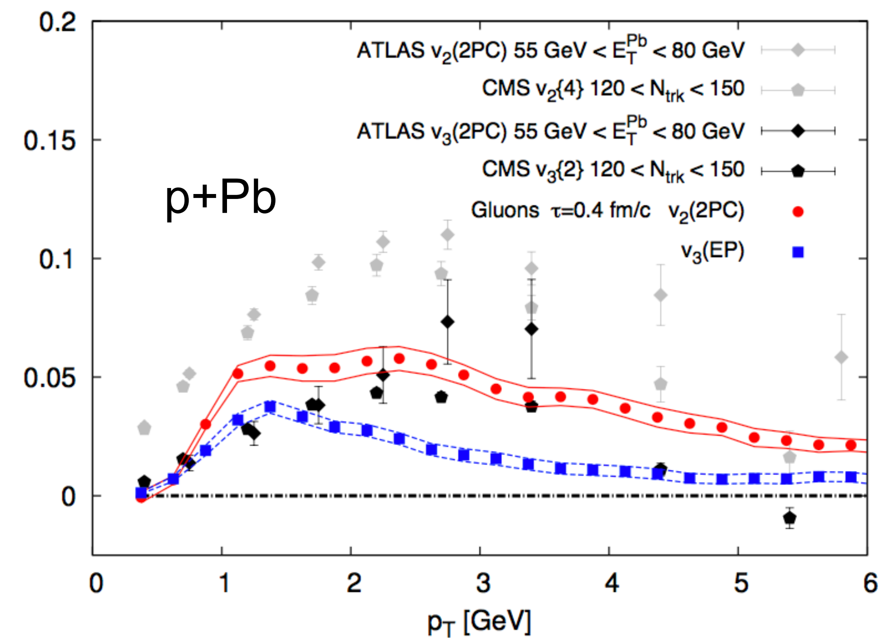
‘Spherical’ proton





‘Eccentric’ proton



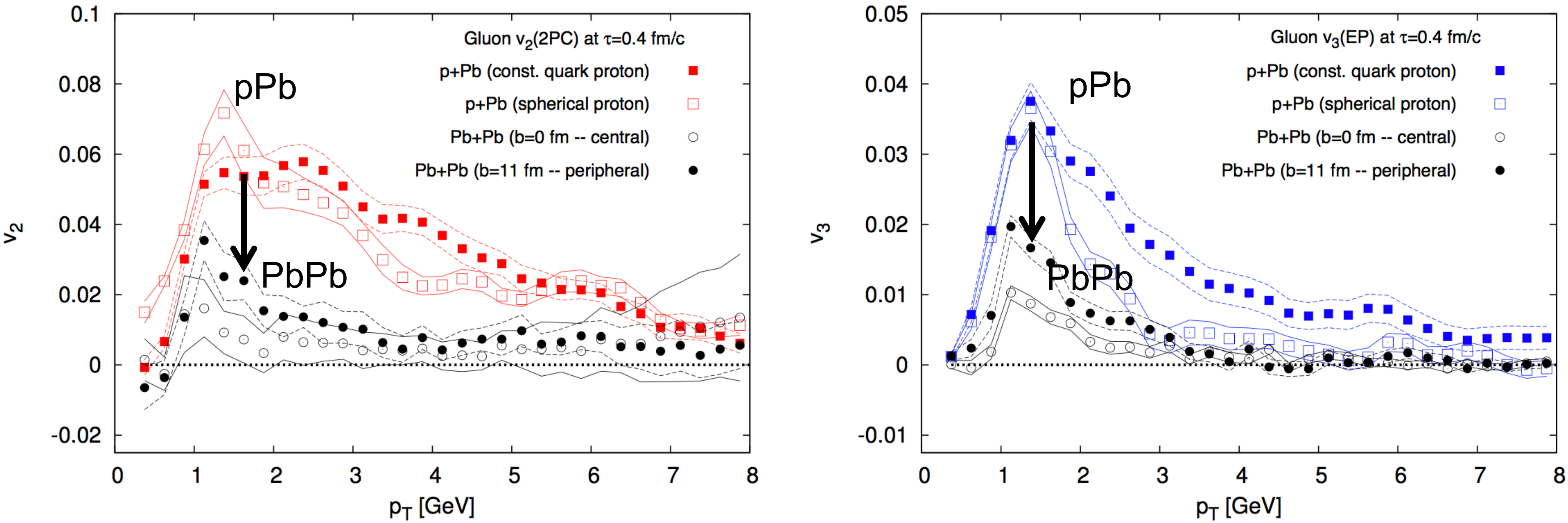


The orientation of collectivity is unrelated to initial eccentricity

→Very different from hydrodynamics

Role of initial geometry is very different

From Schenke, Schlichting, Venugopalan,



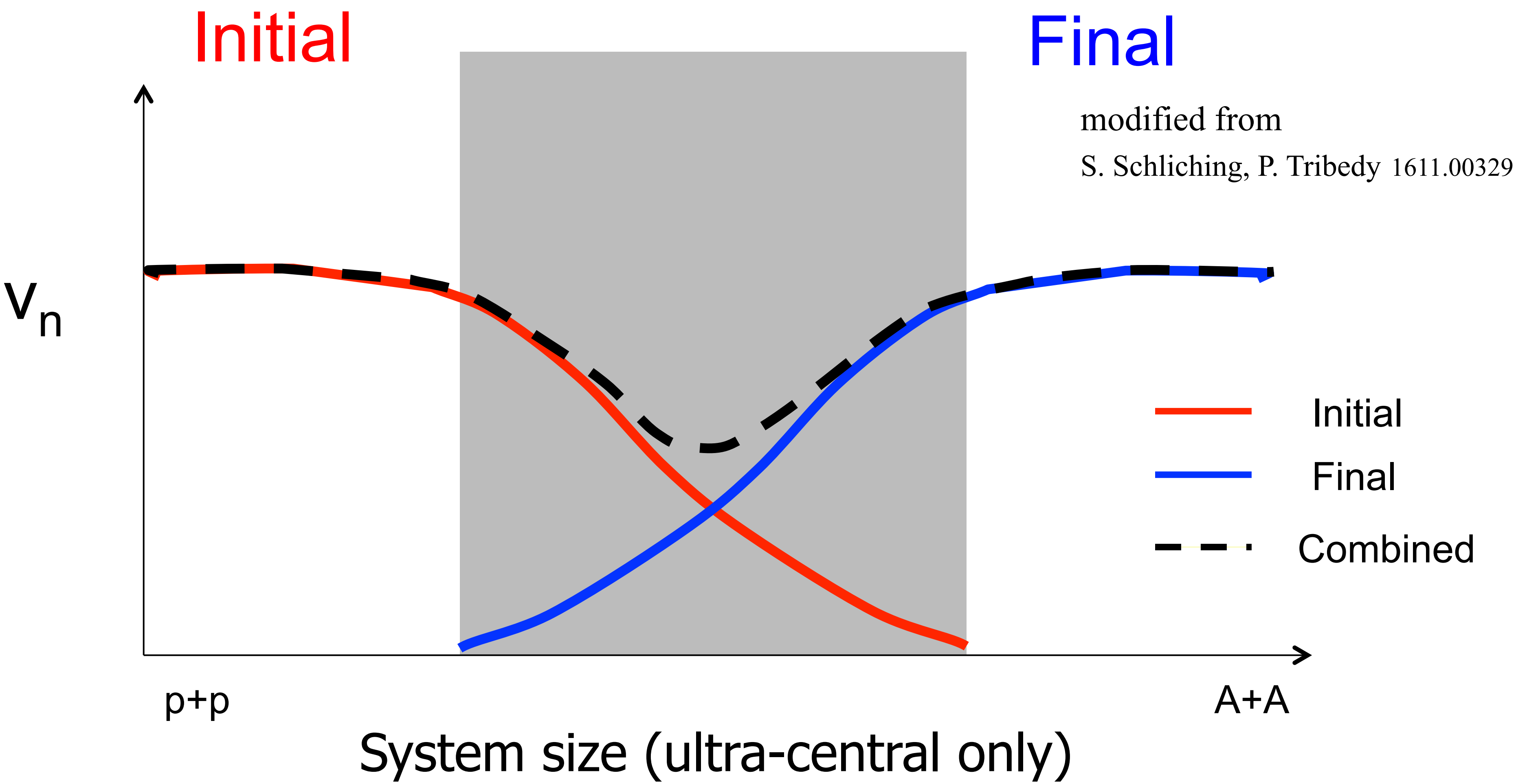
$$c_2\{4\} = \frac{1}{N_D^3}\left(\frac{1}{4(N_c^2-1)^3} - \mathcal{A}^4\right)$$

The orientation of collectivity is unrelated to initial eccentricity

→Very different from hydrodynamics

Expect contribution diminish as system size is increased

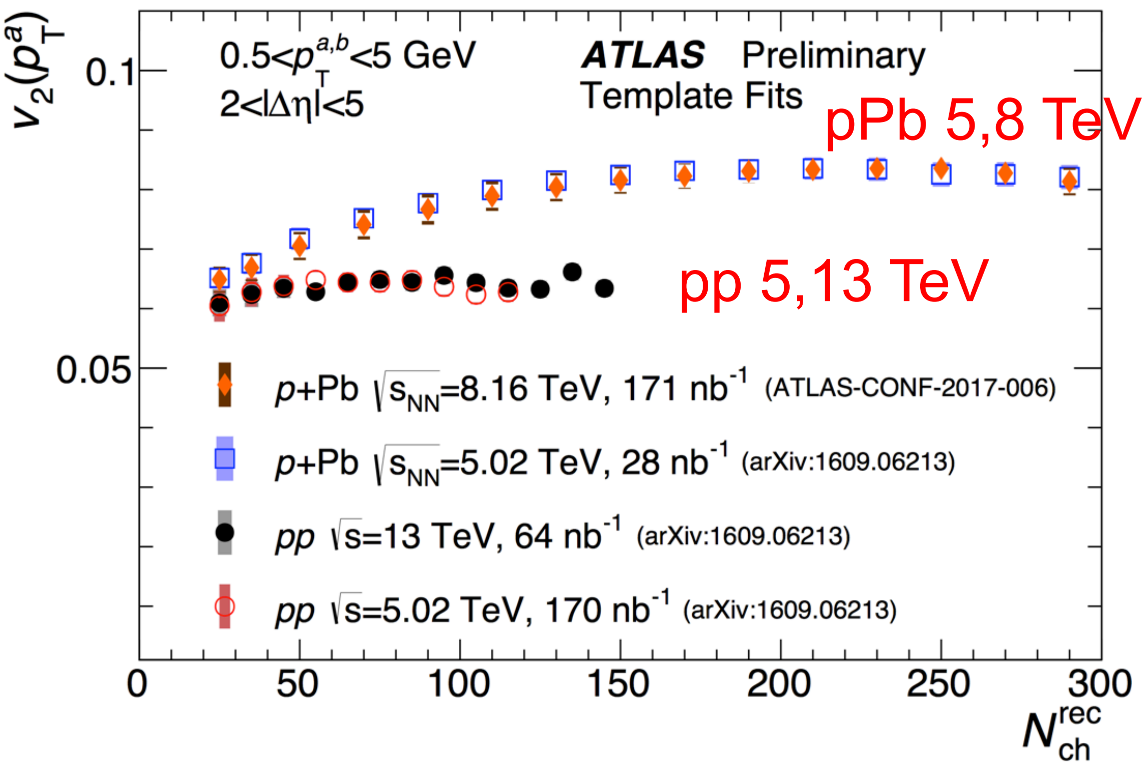
Presence of both initial and final state scenarios?

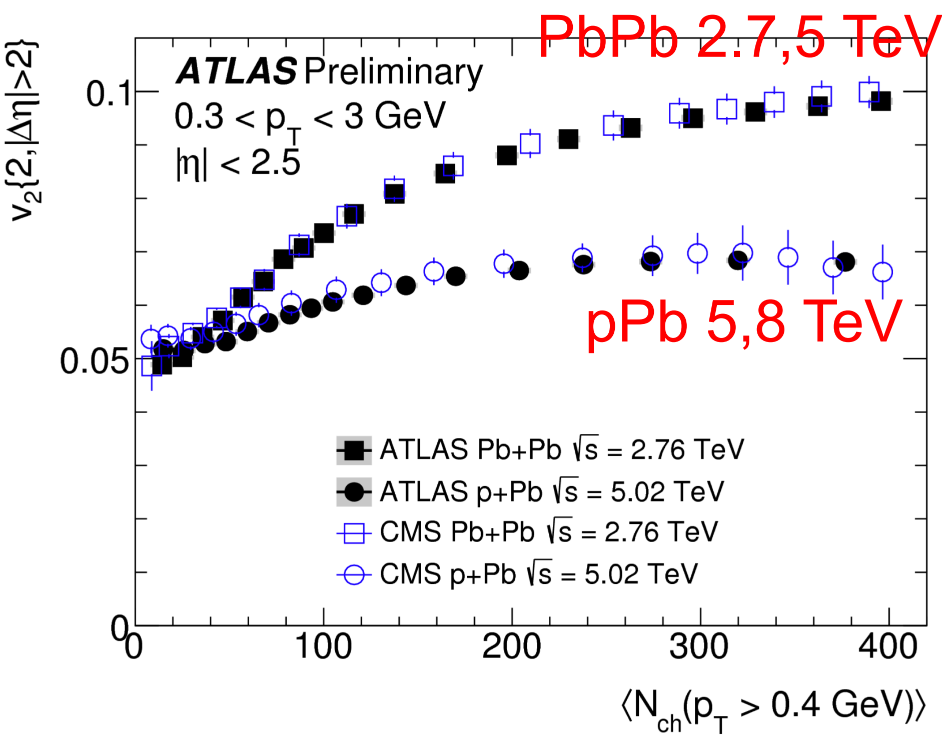


Phases of collectivity from CGC and hydro are unrelated

→ a minimum of total v_n at certain system size?

System size dependence





Clear dependence on collision systems but ~no dependence on √s

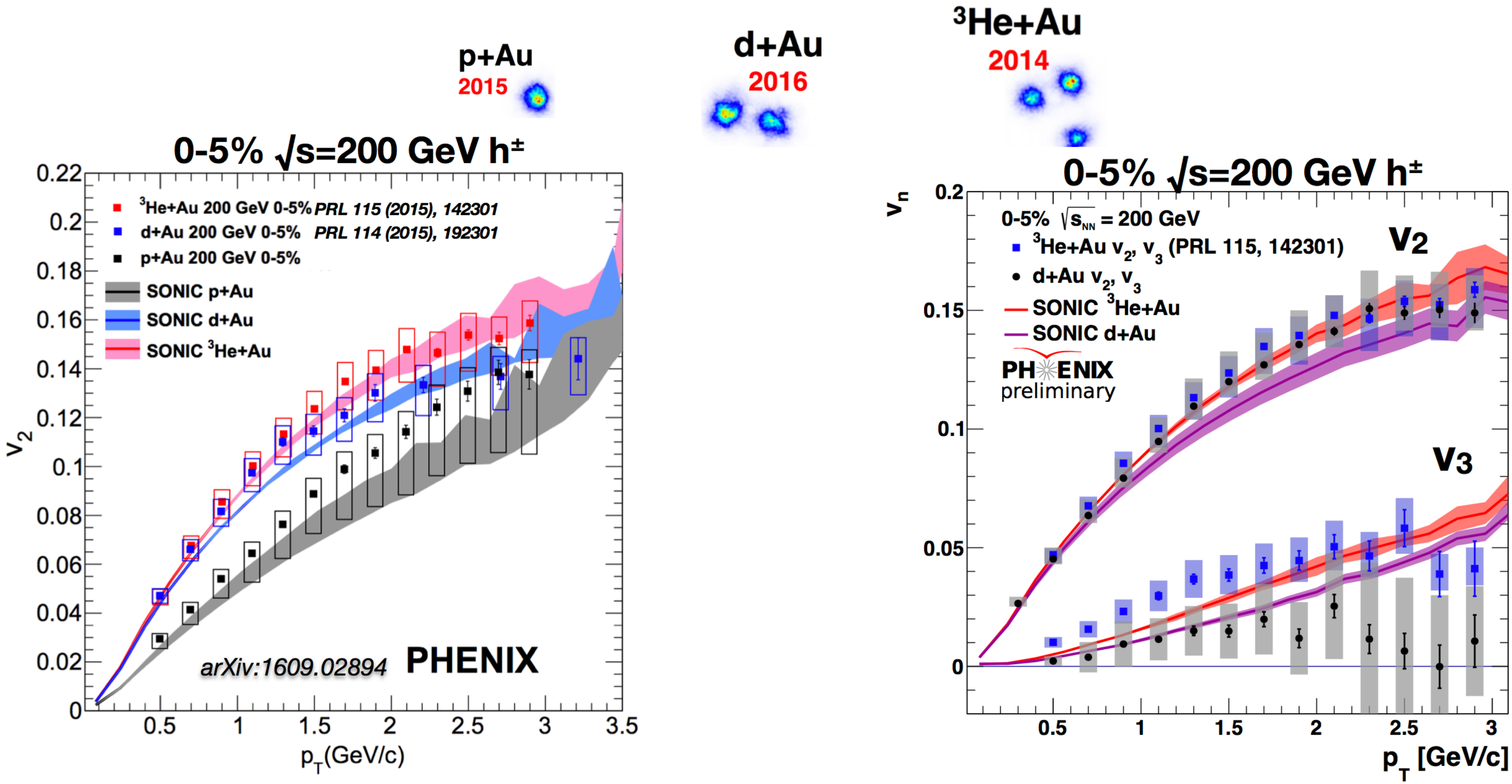
v_2^{pp} (high-mul)<v_2^{pPb}(low-mul)!

CGC — Unclear if the pp/pPb hierarchy is expected.

Hydro — Interplay between viscous damping and initial ε_n
pPb: may seen an average geometry effect
pp: geometry maybe poorly correlated with N_{ch}.

Kevin Welsh, Jordan Singer, and Ulrich Heinz 1605.09418

Geometry scan at RHIC



$v_2^{pAu} < v_2^{dAu} \leq v_2^{HeAu}$

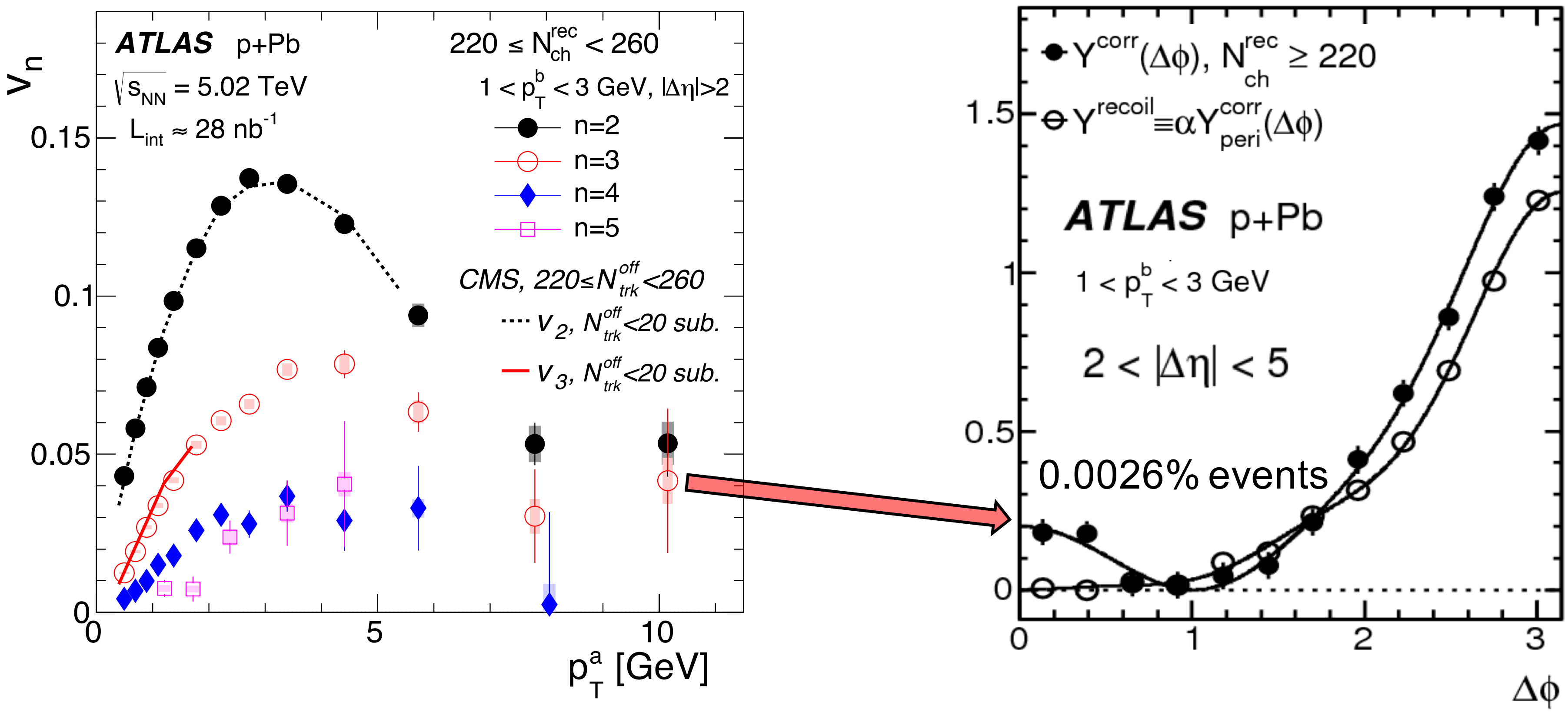
$v_3^{dAu} < v_3^{HeAu}$

Hierarchy compatible with initial geometry + final state effects

Look forward to the CGC predictions

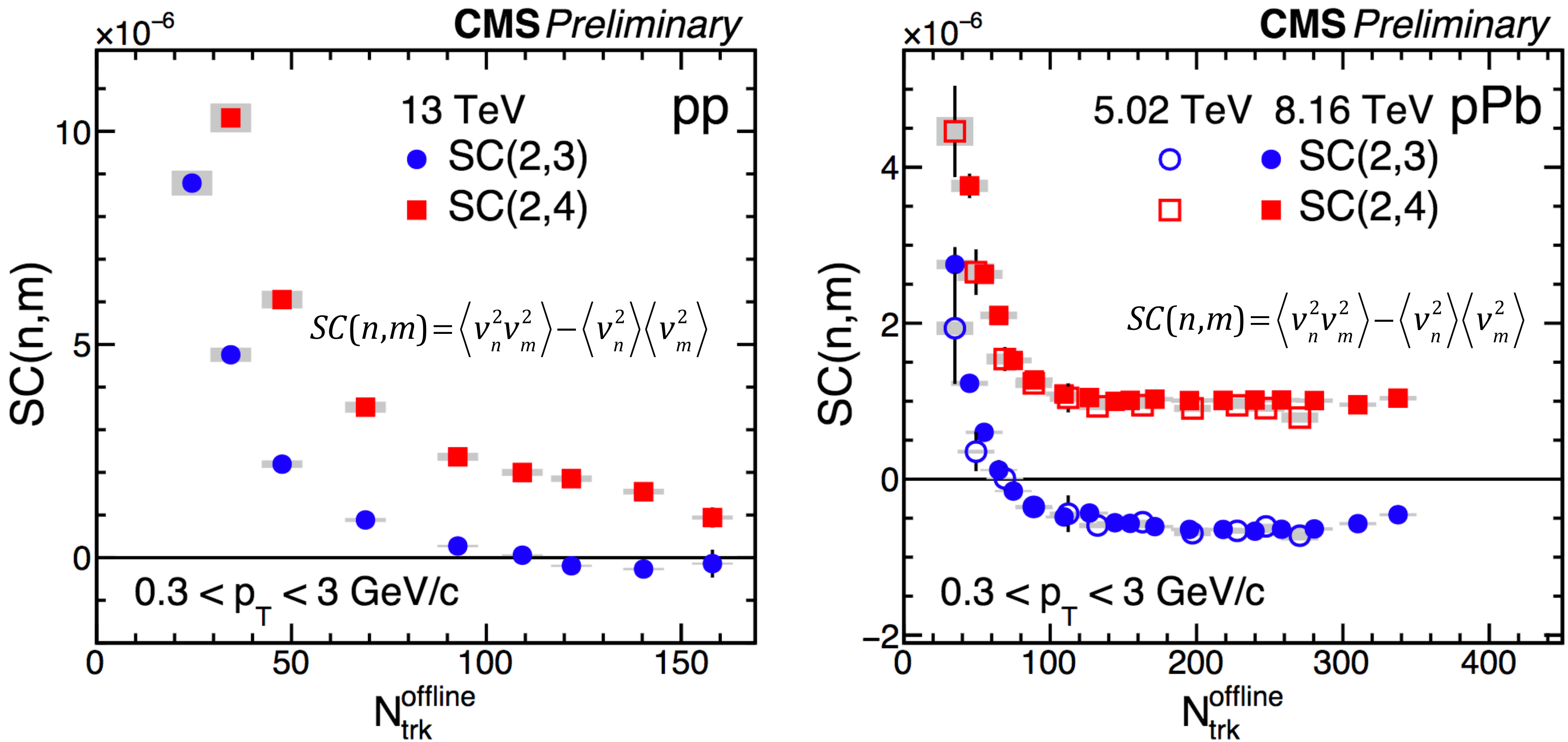
Original of high-p_T v_2?

- Ridge seen directly at 10 GeV or 5% v_2 in pPb
  - →final state effects, e.g. jet quenching (better observable than R_{AA})?
  - →initial state effects, rare Q_s fluctuation?



Outlook: more precision and higher p_T with 8 TeV pPb data

Symmetric cumulants



- Influence of non-flow need to be taken out, but see anti-correlation between v_2 v_3 and correlation between v_2 v_4.
- Naturally understood in hydrodynamics
  - v_2v_3 reflects $\varepsilon_2\varepsilon_3$ correlation, v_2v_4 correlation reflects mode-mixing effects
- In principle, some processes in CGC can also produce this 1705.00745

Summary of collectivity in small system

- Collectivity associated with ridge must involve many particles in multiple η ranges → subevent methods

Challenge for both initial & final state scenarios?

- LHC v_2 associated with ridge does not turn off at low N_{ch}.
- RHIC $v_2\{4\}$ increases and approaches $v_2\{2\}$ at lower $\sqrt{s}$

Challenge for initial state only scenarios?

- LHC $v_2^{pp} < v_2^{pPb}$ in all N_{ch} and all $\sqrt{s}$.
- LHC $c_2\{4\}$ <0 down to very low N_{ch}.
- RHIC geometry scan suggest ordering of v_n follows that of ε_n.
- LHC 5% v_2 at p_T~10 GeV, symmetric cumulants.

…

Coexistence of initial state & final state scenarios?

Key issue: How to constrain timescales for emergence of collectivity? disentangle CGC, preflow and hydro?