Recent results in small systems from CMS

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on behalf of the CMS experiment

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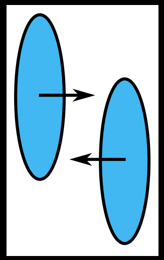
SQM 2019

The 18th International Conference on Strangeness in Quark Matter, 10-15 June

Large vs. small at the LHC

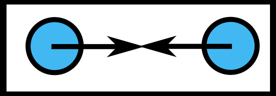
p-Pb
$\sqrt{s_{NN}}$ = 5.02 TeV
$\sqrt{s_{NN}}$ = 8 TeV



Pb-Pb
$\sqrt{s_{NN}}$ = 2.76 TeV
$\sqrt{s_{NN}}$ = 5.02 TeV

Xe-Xe
$\sqrt{s_{NN}}$ = 5.44 TeV

pp
$\sqrt{s}$ = 2.76 TeV
$\sqrt{s}$ = 5.02 TeV
$\sqrt{s}$ = 7 TeV
$\sqrt{s}$ = 8 TeV
$\sqrt{s}$ = 13 TeV

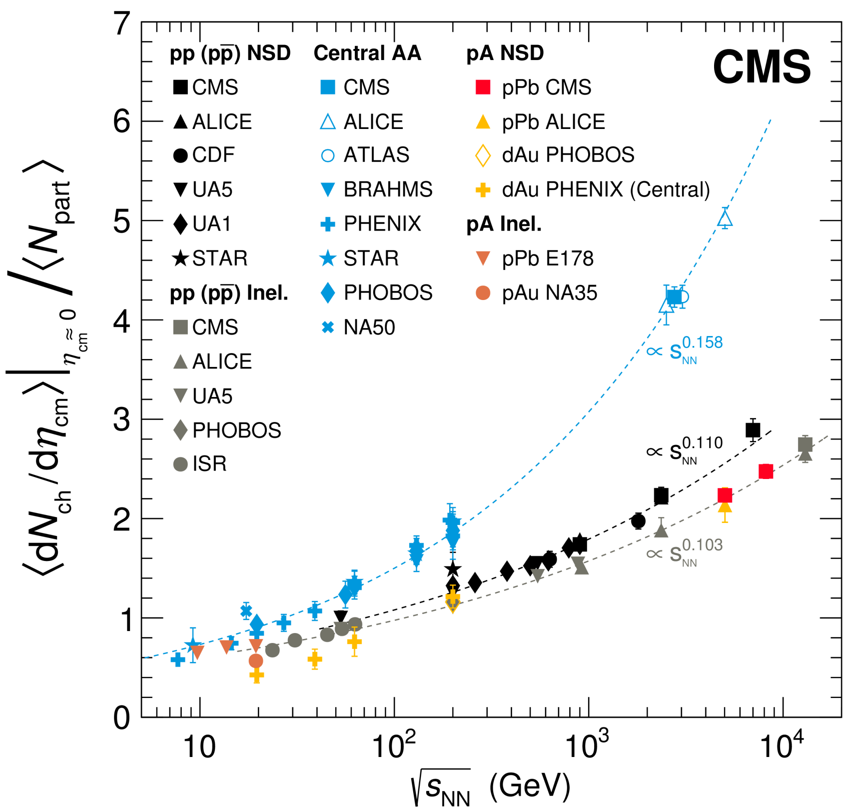


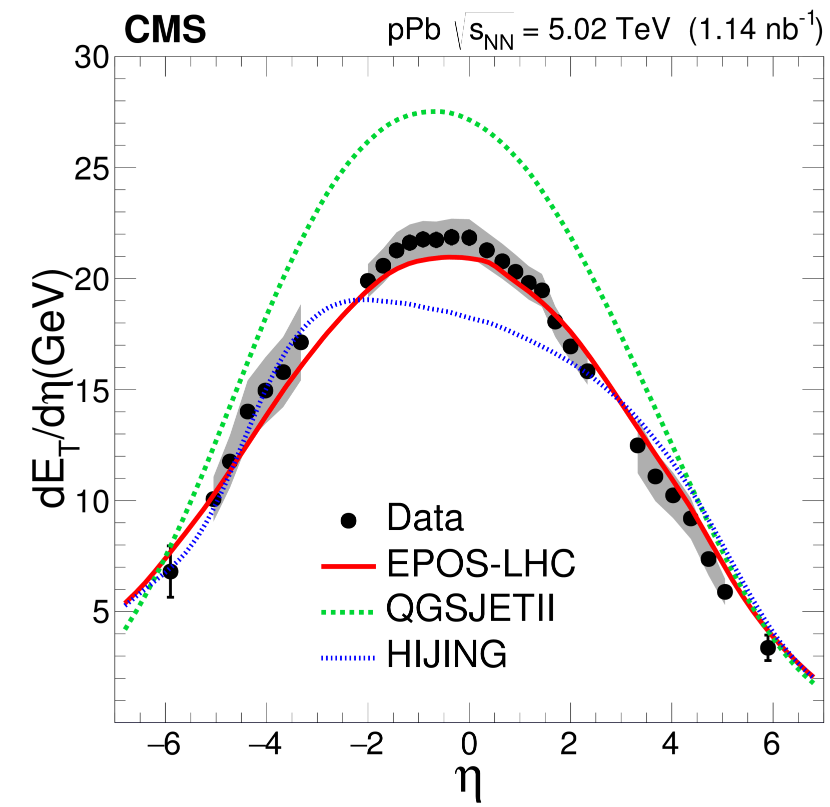
What are ‘small’ systems?

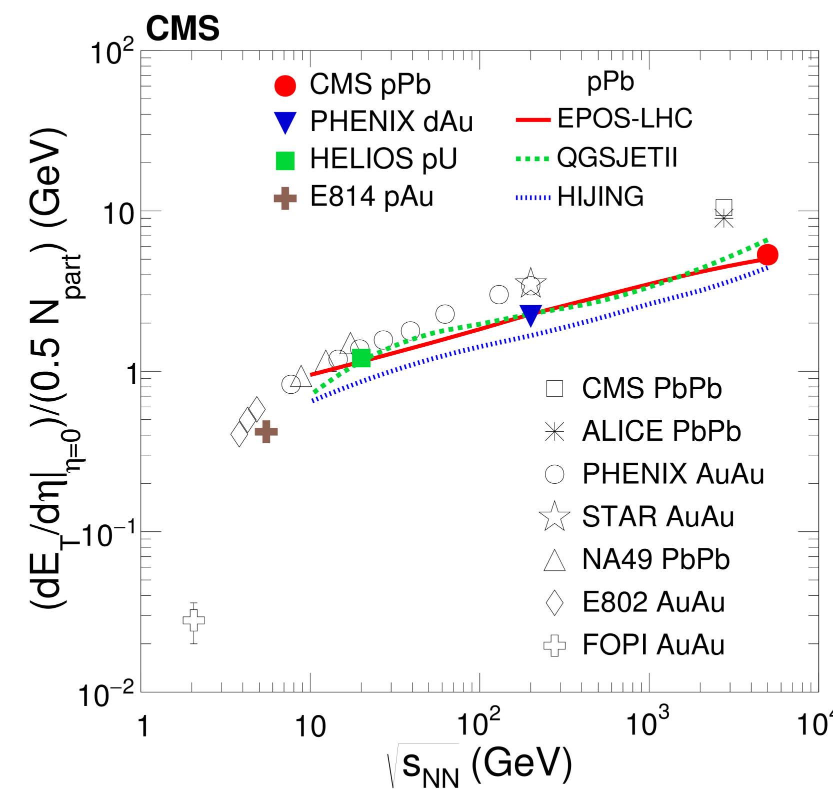
JHEP 01 (2018) 045

arXiv:1810.0574

Accepted for publication in PRC







‘Small’ qualifies the size of the colliding systems and/or the created medium

- **Traditional POV:** a priori too small to show characteristics of QGP physics
- **Alternative POV:** individual events show high particle multiplicity, energy density, etc

Main topics discussed in this talk:

Looking at the observables (there might be a personal bias!):

- Collective phenomena:
  - p_T spectra, Fourier harmonics, event by event fluctuations,…
- Quarkonia and more hints for final state effects
- Cross section & Nuclear modification factors

Flavours in CMS:-

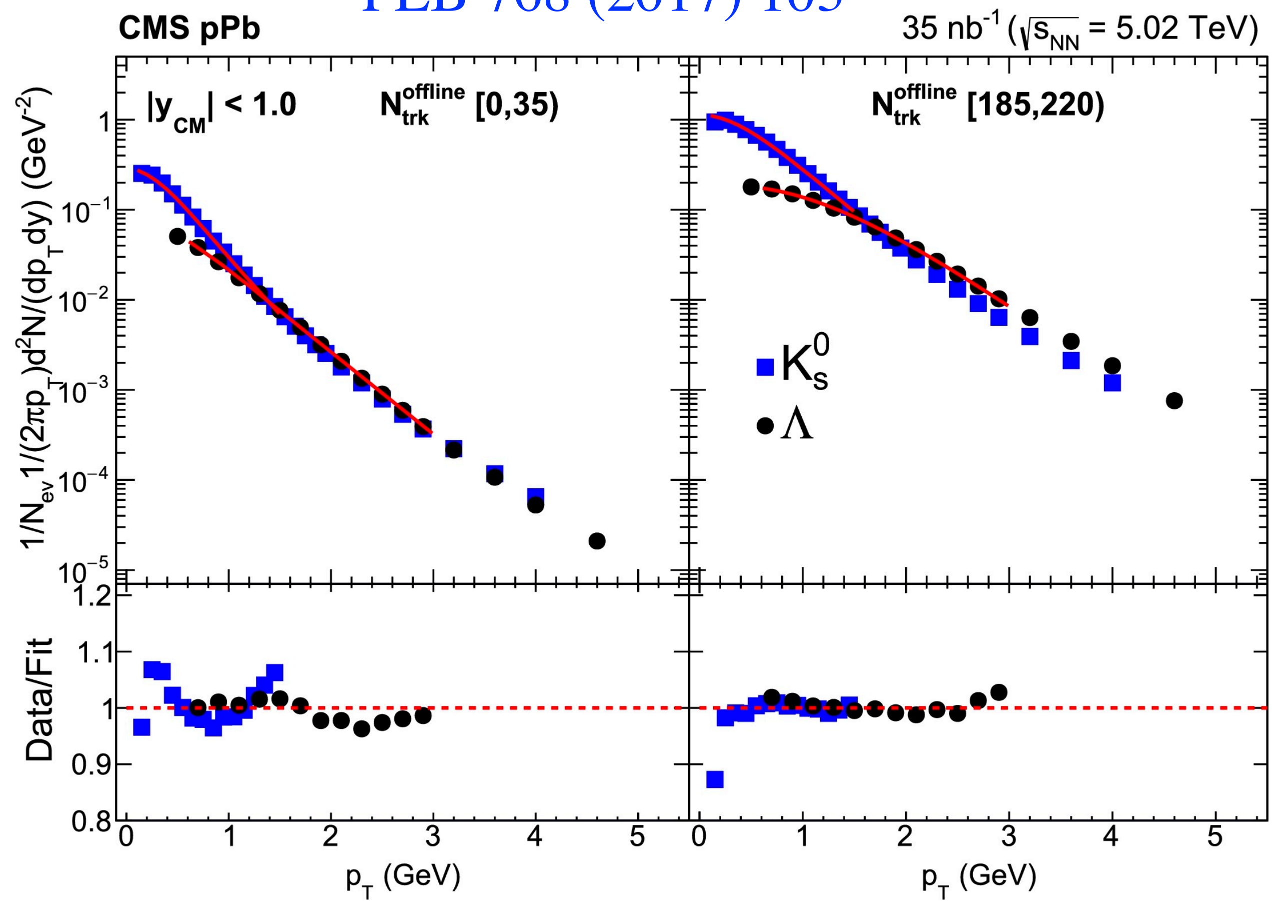
- Light flavours, strange and multi-strange hadrons
- Heavy flavours, charm and beauty: quarkonia, open HF

☞ Probing collectivity with multiplicity

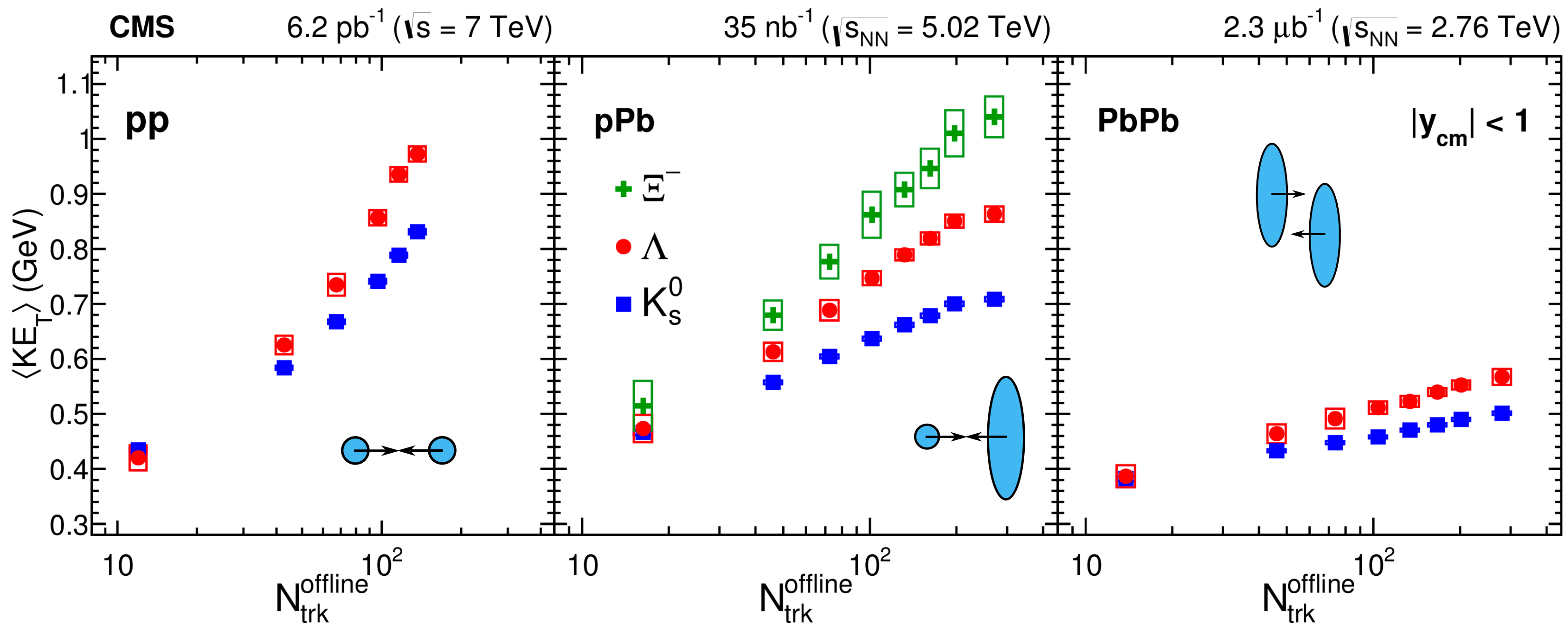
PLB 768 (2017) 103

Hydrodynamic Blast-Wave model:

- Characterize spectral shapes and test collective radial flow
- Spectra from thermal sources T_{kin} expanding with common velocity $<\beta_T>$



- Higher $<KE_T>$ at higher multiplicities for all systems
- Faster increase for heavier particles
- Particle species dependence of $<KE_T>$ is larger in small systems compared to Pb-Pb



Puzzle:

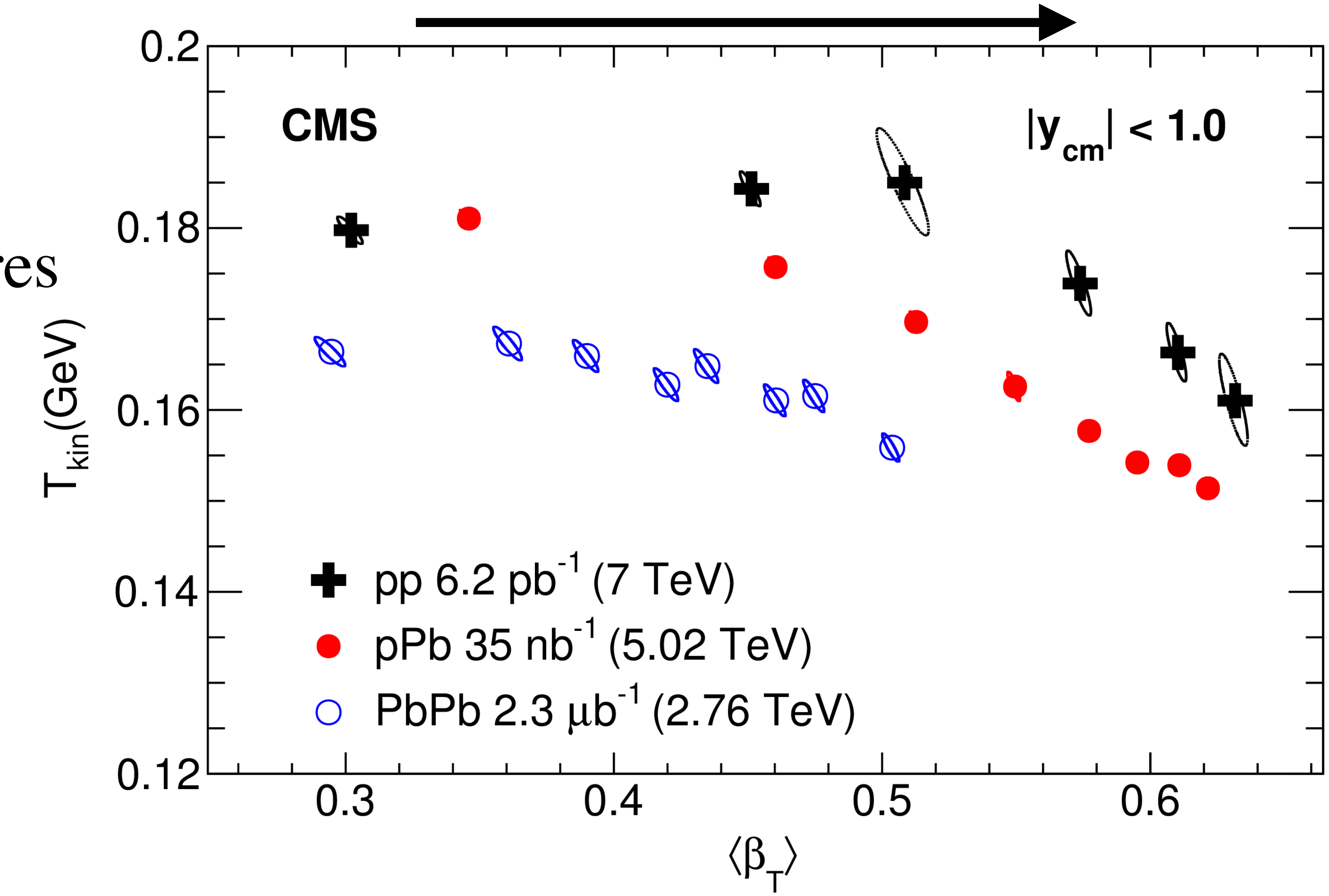
Onset of collectivity !

Blast-Wave fit parameters:

- Model dependent meaning of T_{kin} and $\langle\beta_T\rangle$
- p-p and p-Pb show similar features as of Pb-Pb
- Large radial flow velocity in small systems:

$$\langle\beta_T\rangle_{pp} > \langle\beta_T\rangle_{pPb} > \langle\beta_T\rangle_{PbPb}$$

Multiplicity increases



PLB 768 (2017) 103

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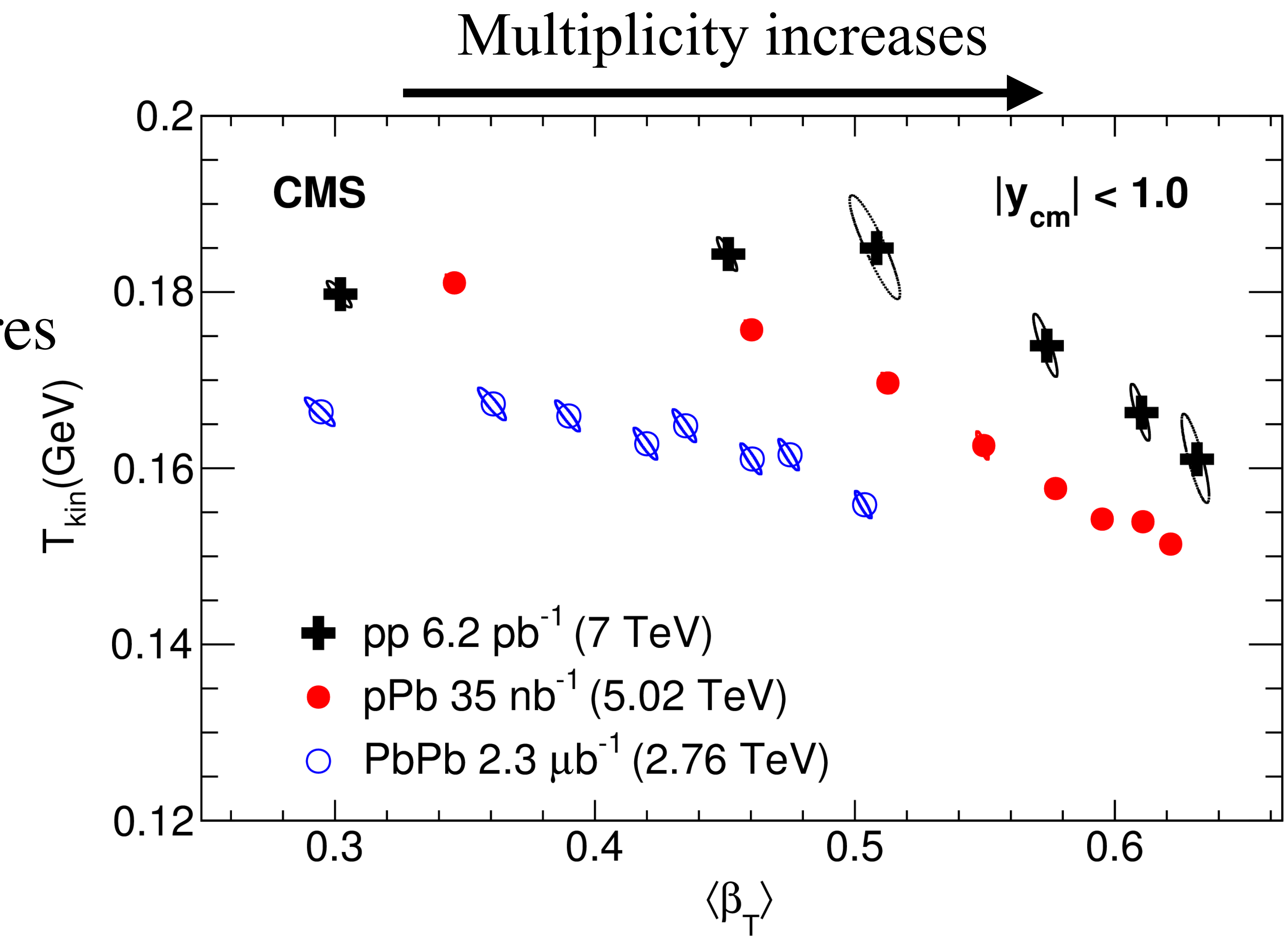
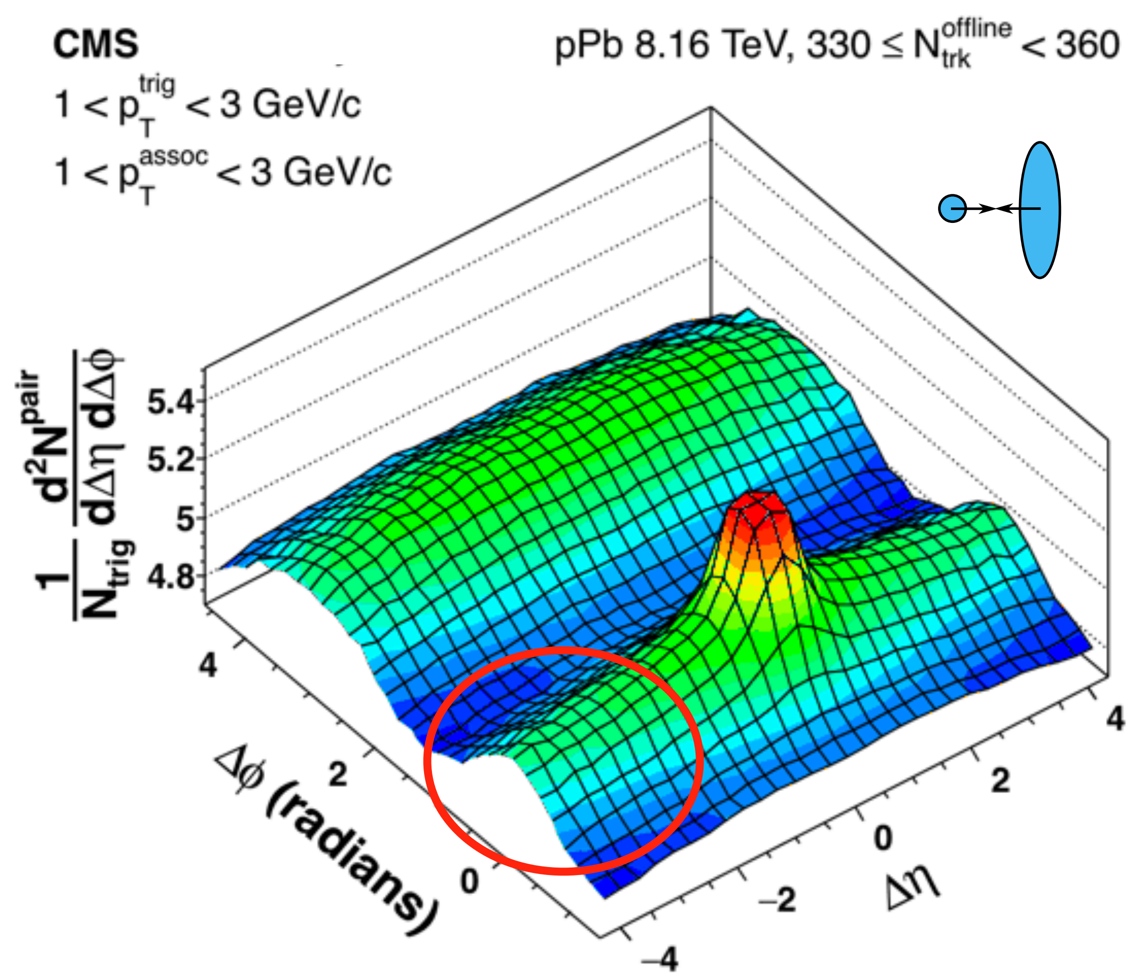


PLB 768 (2017) 103

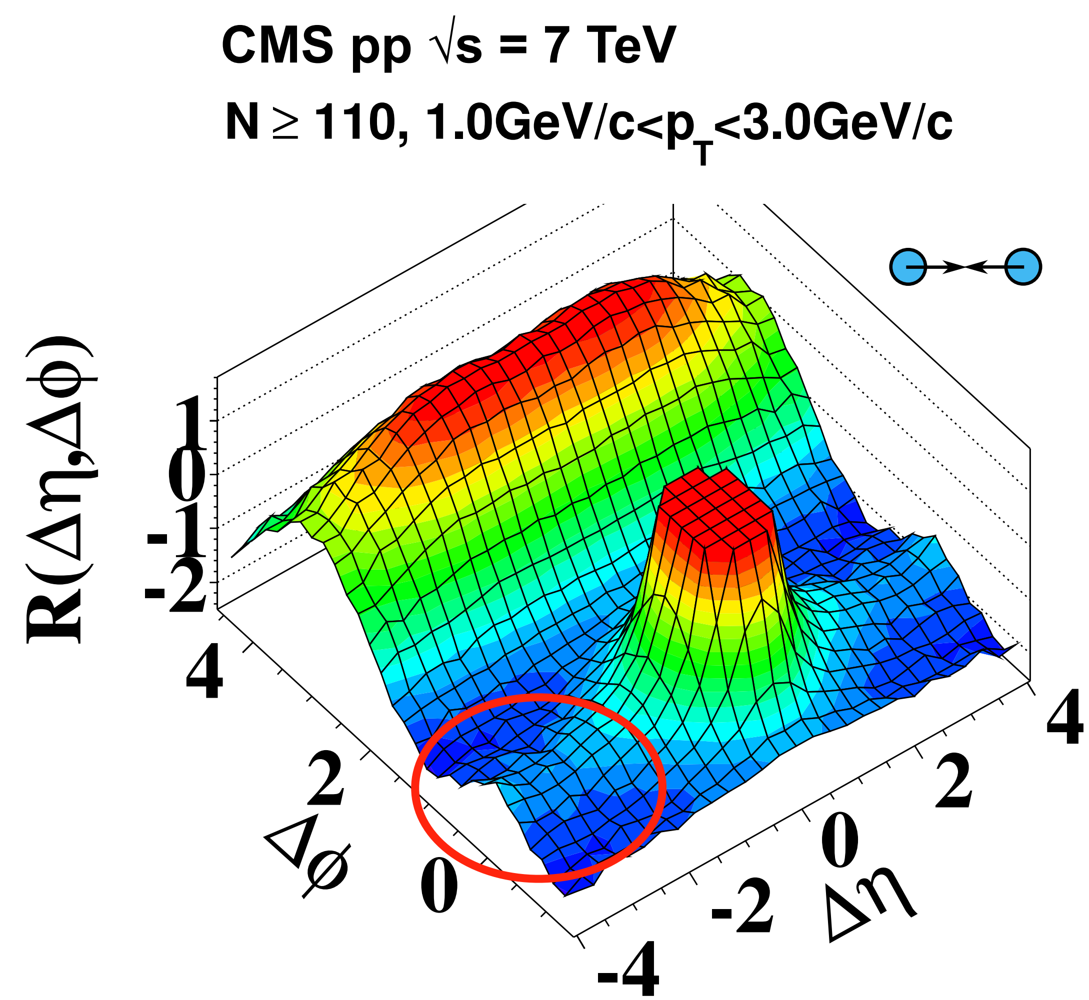
Several hints for collectivity from single particle spectra

Complementary information from two-particle correlations

Long-range ($2 < |\Delta\eta| < 4$), near-side ($\Delta\phi \approx 0$) angular correlations in high multiplicity p-p and p-Pb collisions



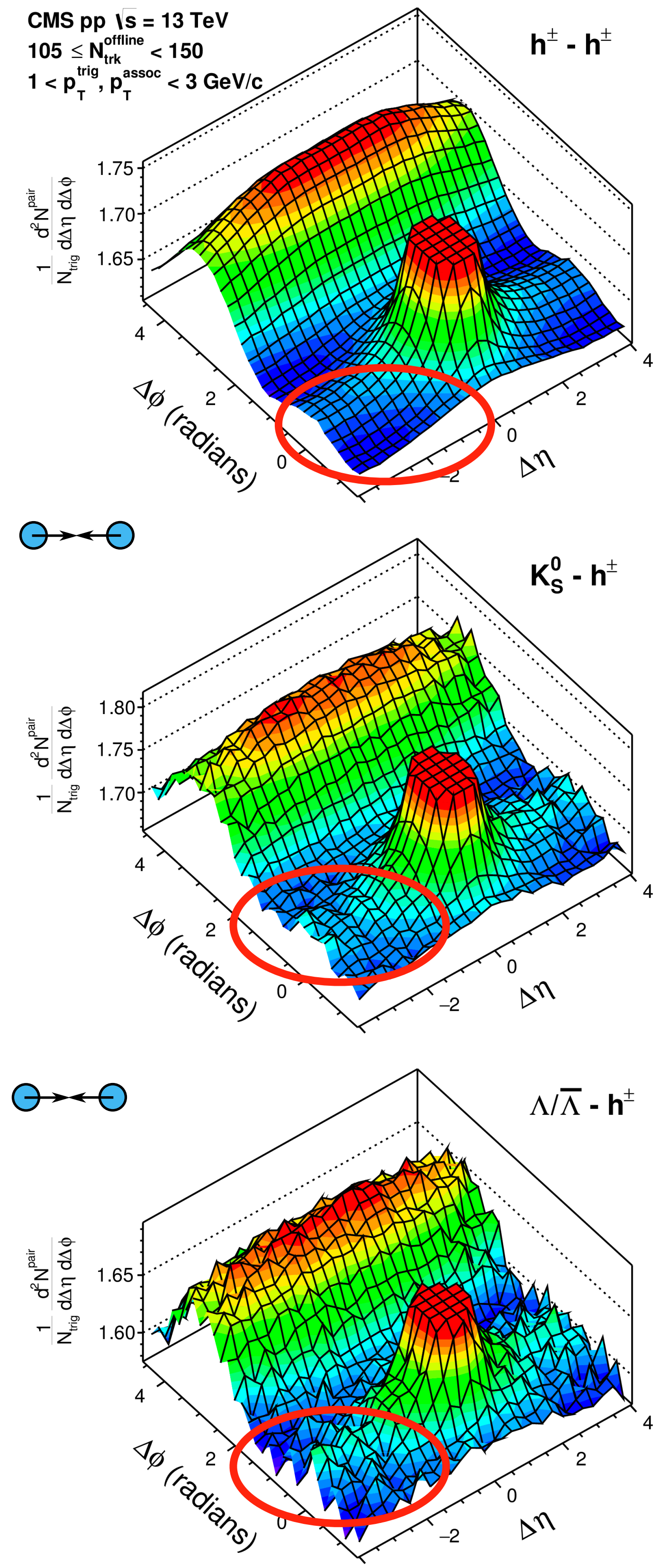
PRL 120 (2018) 092301



PRL 116 (2016) 172302

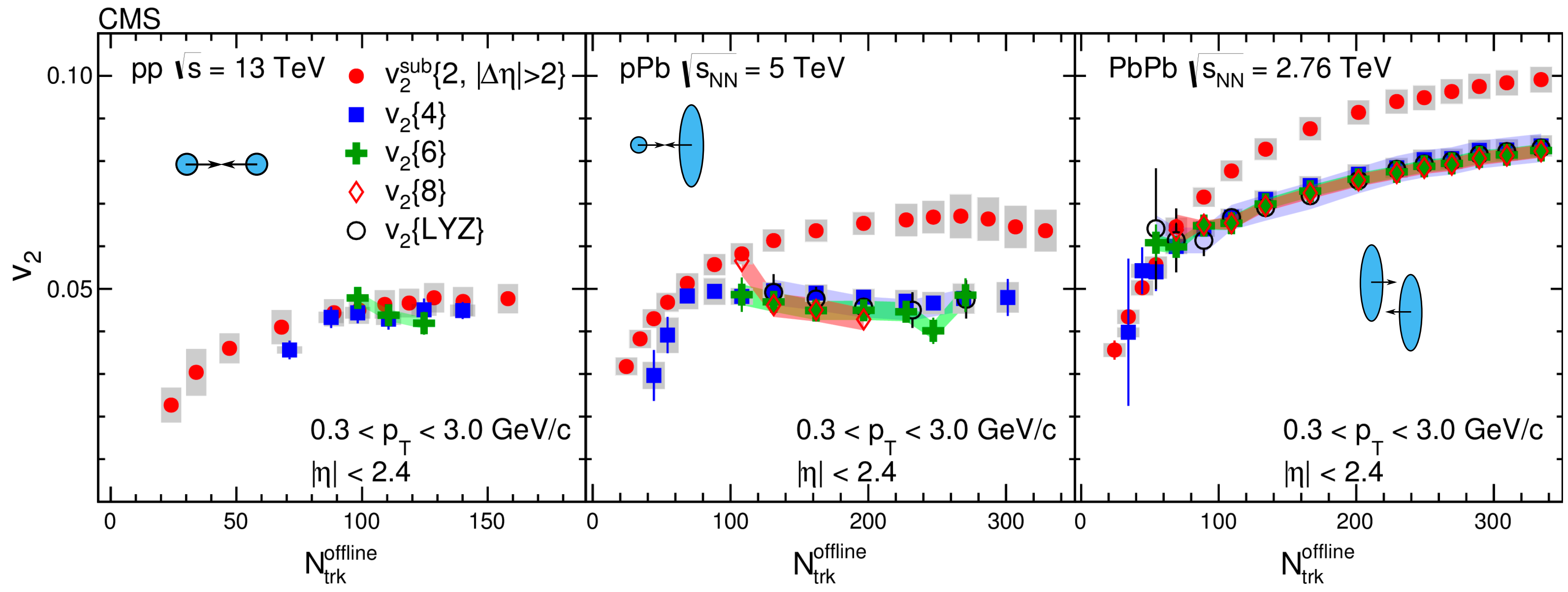
Is this a sign of hydro in small systems?
Is it collective in small systems?

Nature of the Ridge



PLB 765 (2017) 193

Collectivity from large to small systems



v_2 {4, 6, 8}:

- Similar for p-p and p-Pb: fluctuation-driven geometry
- Pb-Pb larger: accounted by average elliptic geometry

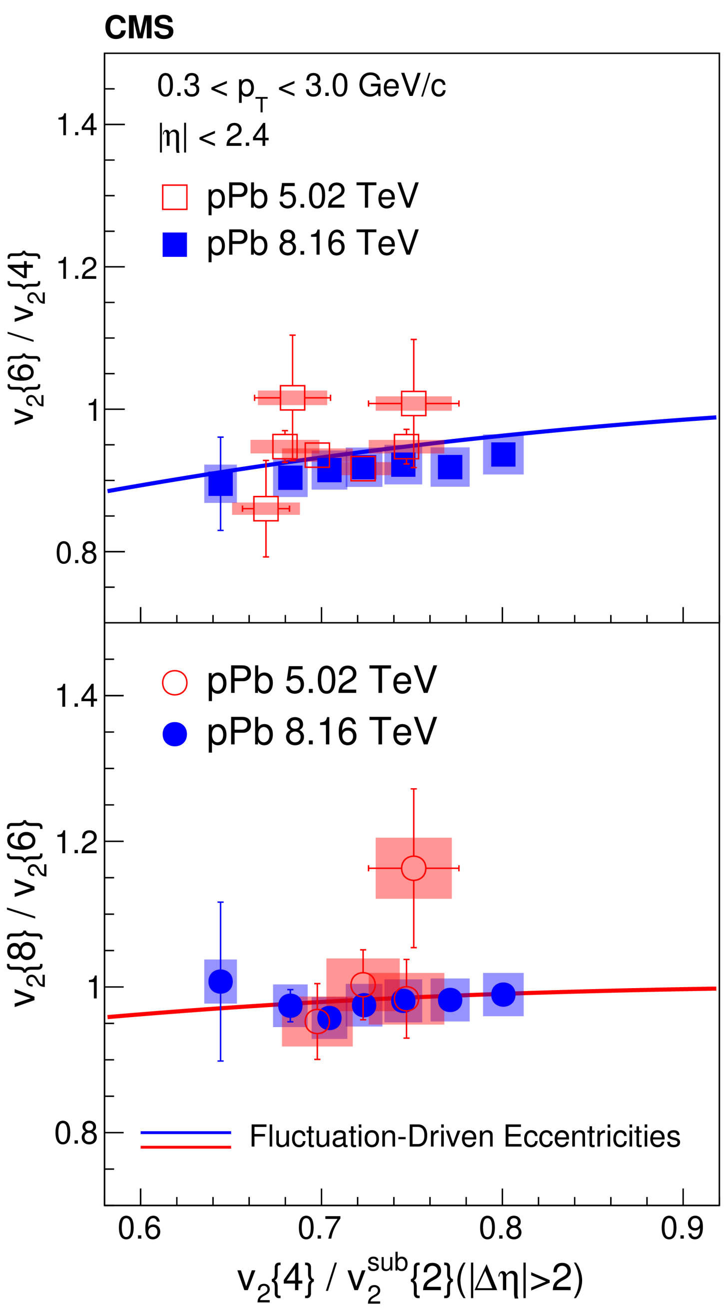
Basar, Teeny, arXiv:1408.3411

☞Multi-particle correlation

☞Similar patterns for all systems

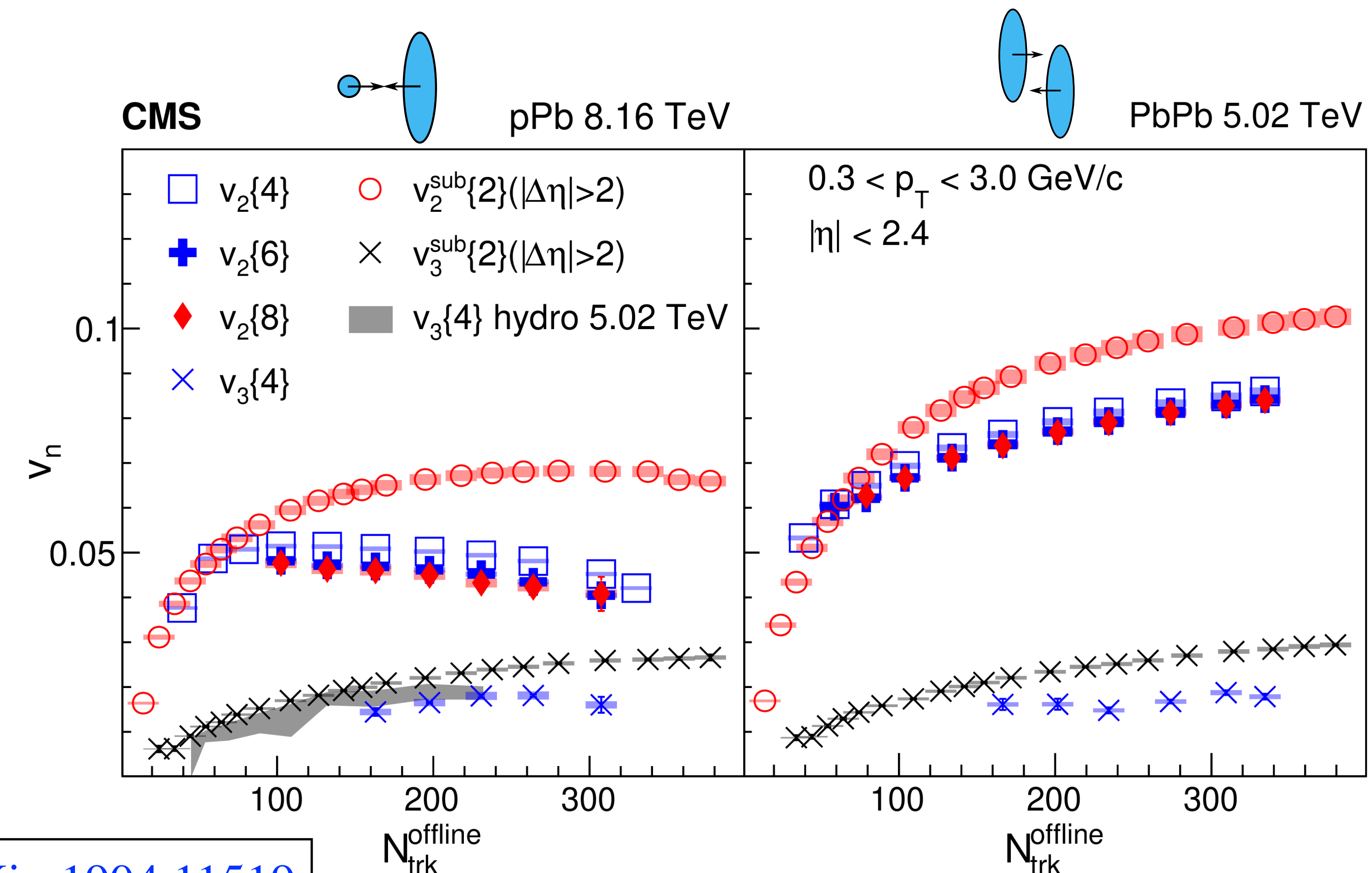
☞Evidence of collectivity in p-Pb system!

Further proof of collectivity: geometry driven phenomena



First measurement of $v_3\{4\}$ in p-Pb collisions

☞ More sensitive to initial state fluctuations



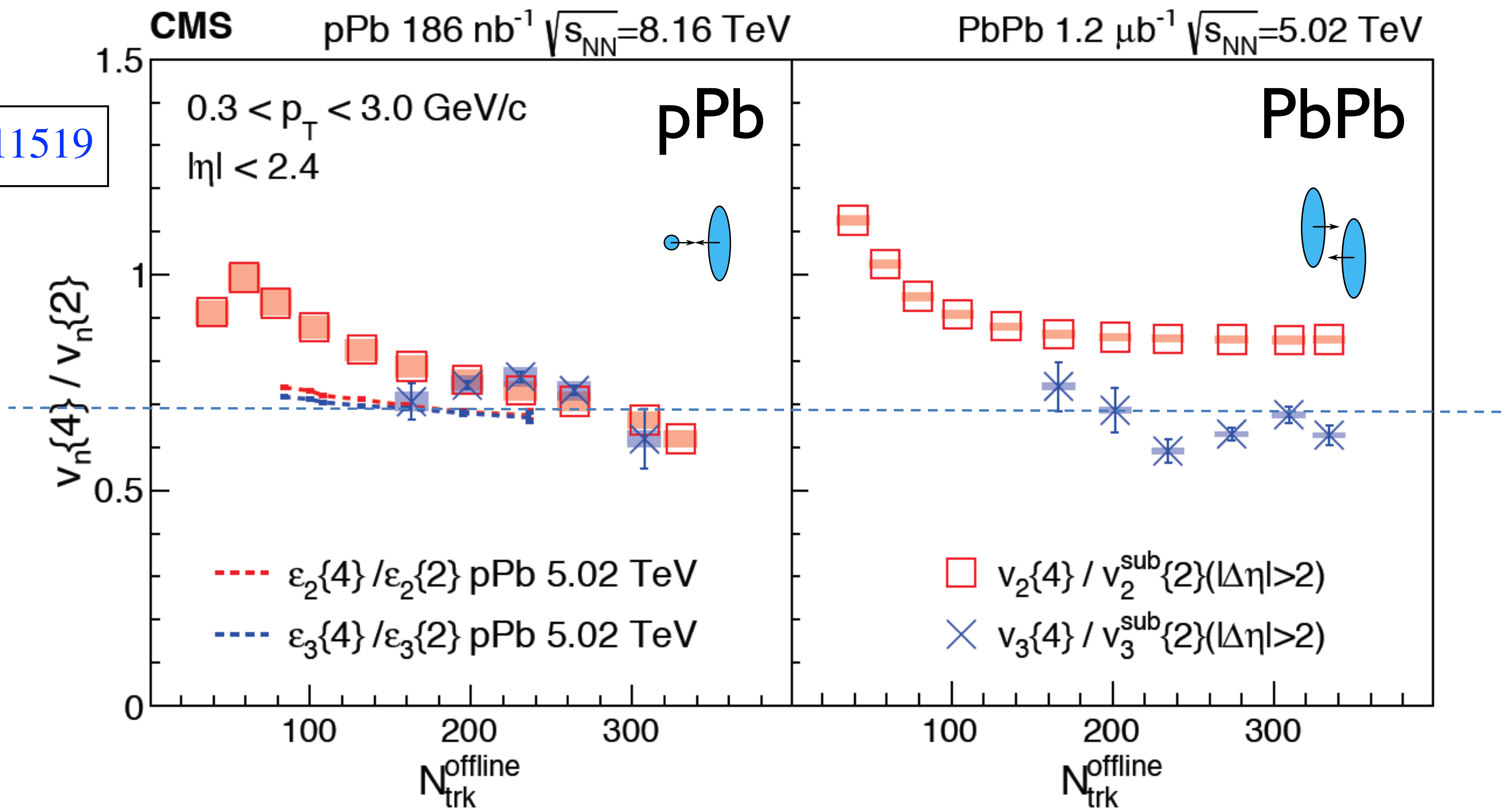
arXiv:1904.11519

Prediction: $\frac{v_2\{4\}}{v_2\{2\}} = \frac{v_3\{4\}}{v_3\{2\}}$

- Data & hydrodynamics-motivated fluctuation-driven IS calculations are in agreement

Evidence for geometry driven

arXiv:1904.11519



Prediction confirmed in p-Pb!

$$\frac{v_2\{4\}}{v_2\{2\}} = \frac{v_3\{4\}}{v_3\{2\}}$$

$\frac{v_3\{4\}}{v_3\{2\}}$ similar in p-Pb and PbPb

Small systems: evidence for fluctuation-driven initial state geometry

Study correlation between harmonics (n, m):

- Via Symmetric Cumulant:

$$SC(n,m) = \langle v_n^2 v_m^2 \rangle - \langle v_n^2 \rangle \langle v_m^2 \rangle$$

- Based on 4-particle cumulant calculations

PRL 117 (2016) 182301

PRL 120 (2018) 092301

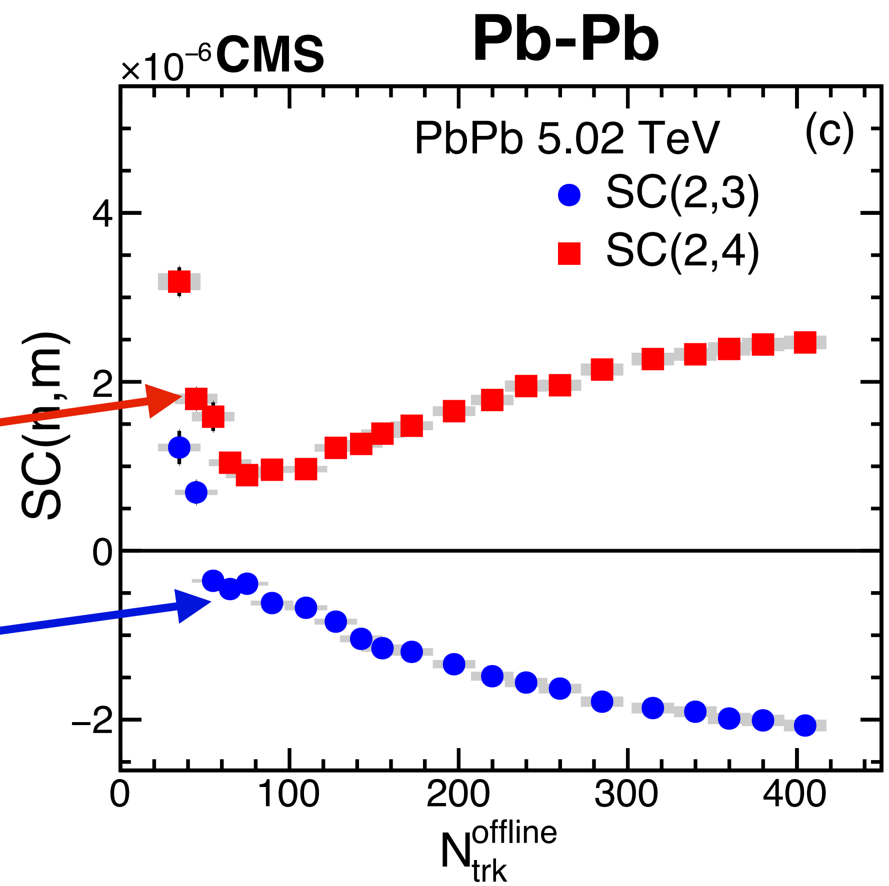
Sensitive to:

- Initial State fluctuations (v_2 vs. v_3)
- Medium transport coefficient (v_2 vs. v_4)

Results from Pb-Pb:

v_2, v_4 correlated

v_2, v_3 anti-correlated



Correlation between harmonics: the small system case

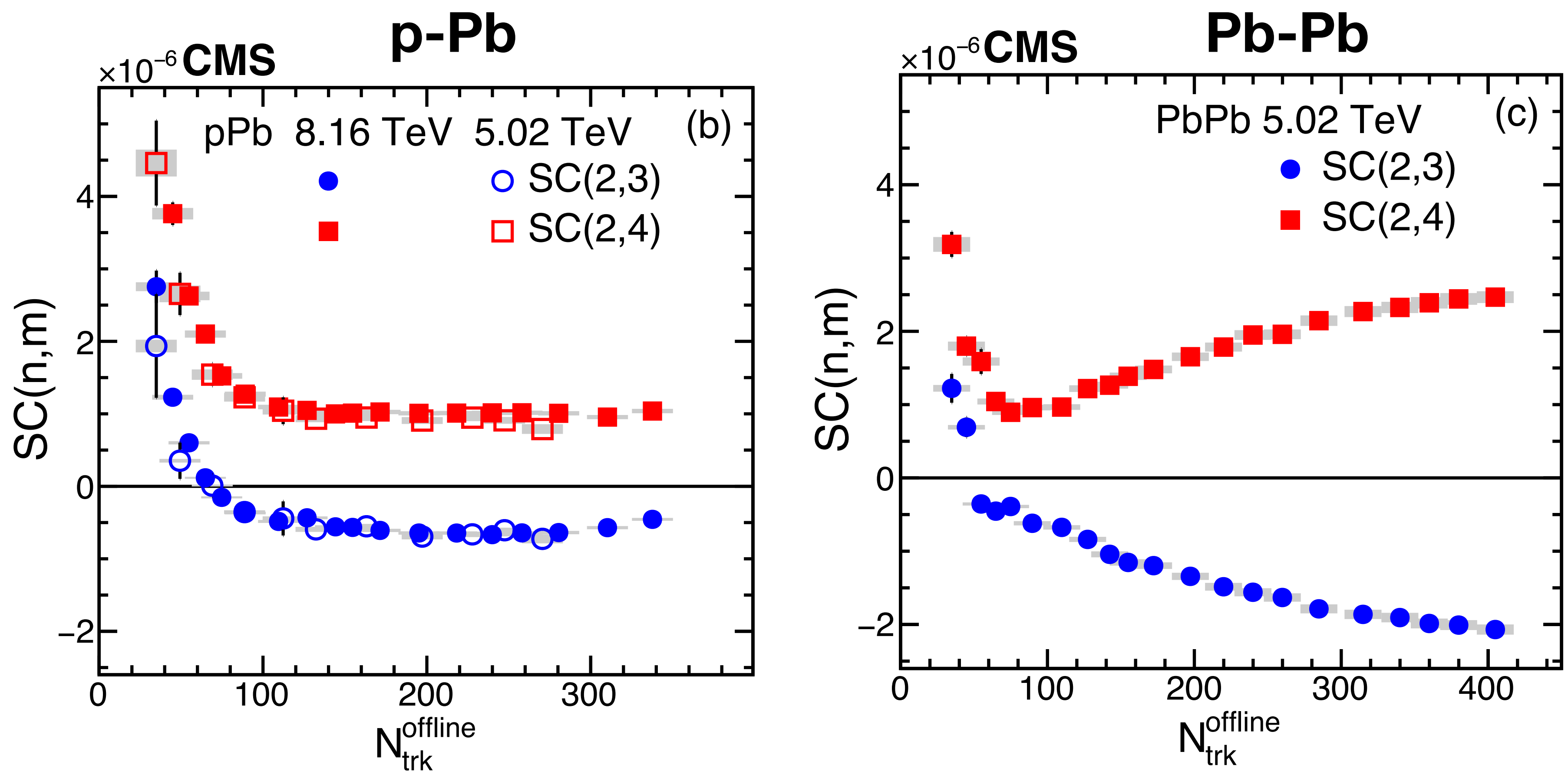
Similarities observed for SCs in all systems

☞ (v_2 , v_3) anti-correlated

☞ (v_2, v_4) correlated

☞ Small energy dependence (see p-Pb results)

PRL 120 (2018) 092301



Correlation between harmonics: the small system case

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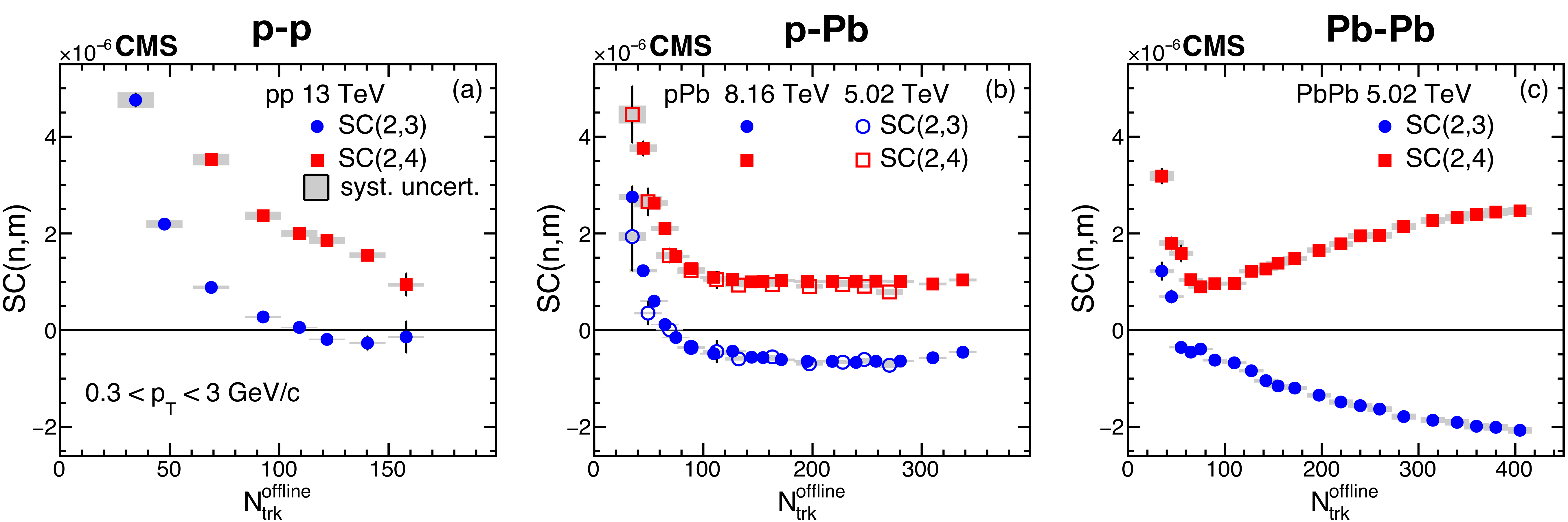
- ☞ (v_2, v_4) correlated
- ☞ Small energy dependence (see p-Pb results)

In general: v_n(p-p) ≠ v_n(p-Pb) ≠ v_n(Pb-Pb)

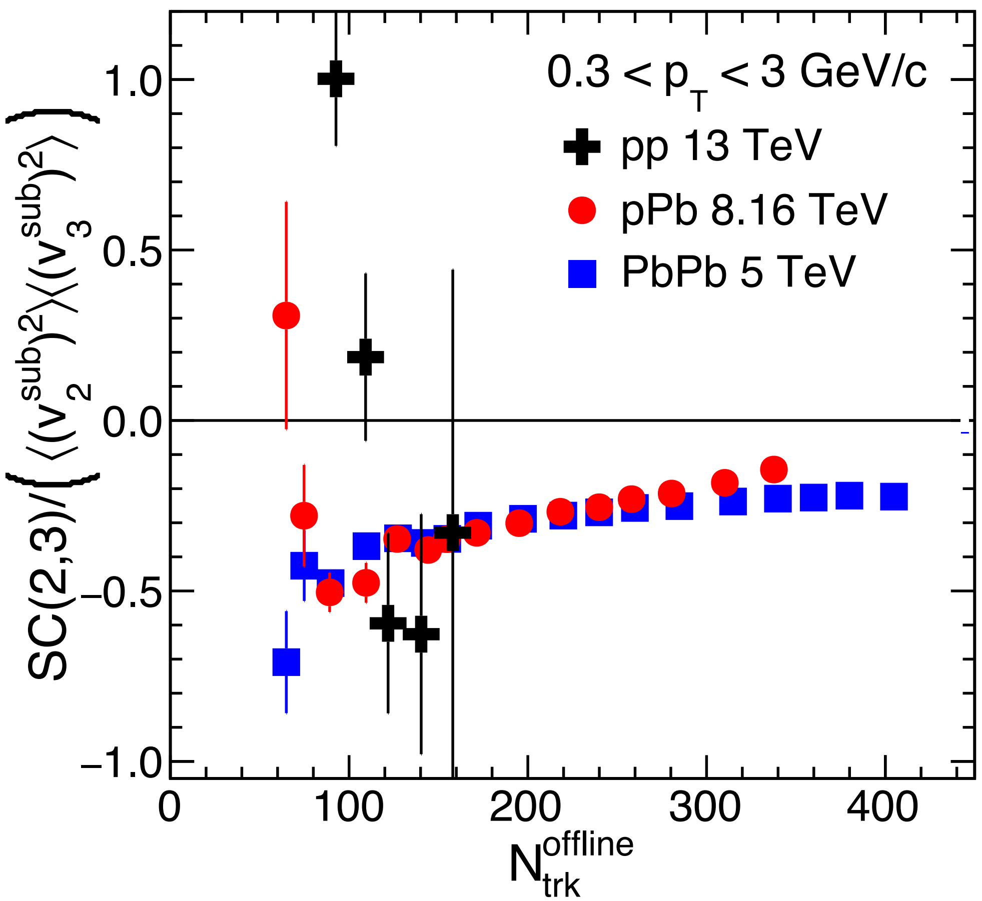
⇒ Normalization needed for comparison

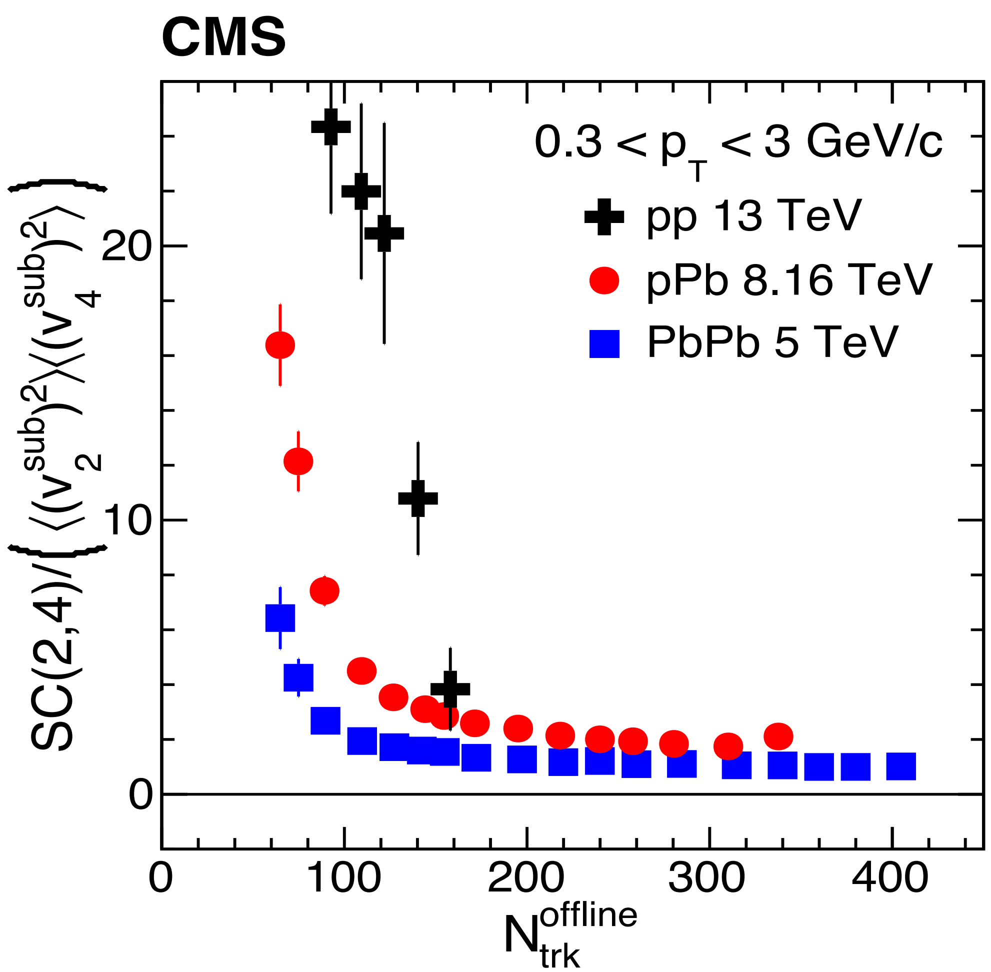
PRL 120 (2018) 092301



Normalized SCs (NSCs)

arXiv: 1905.09935
PRL 120 (2018) 092301





- Similar behaviour in p-Pb and Pb-Pb
- Points to similar IS fluctuations

Common paradigm?

- Ordering observed:

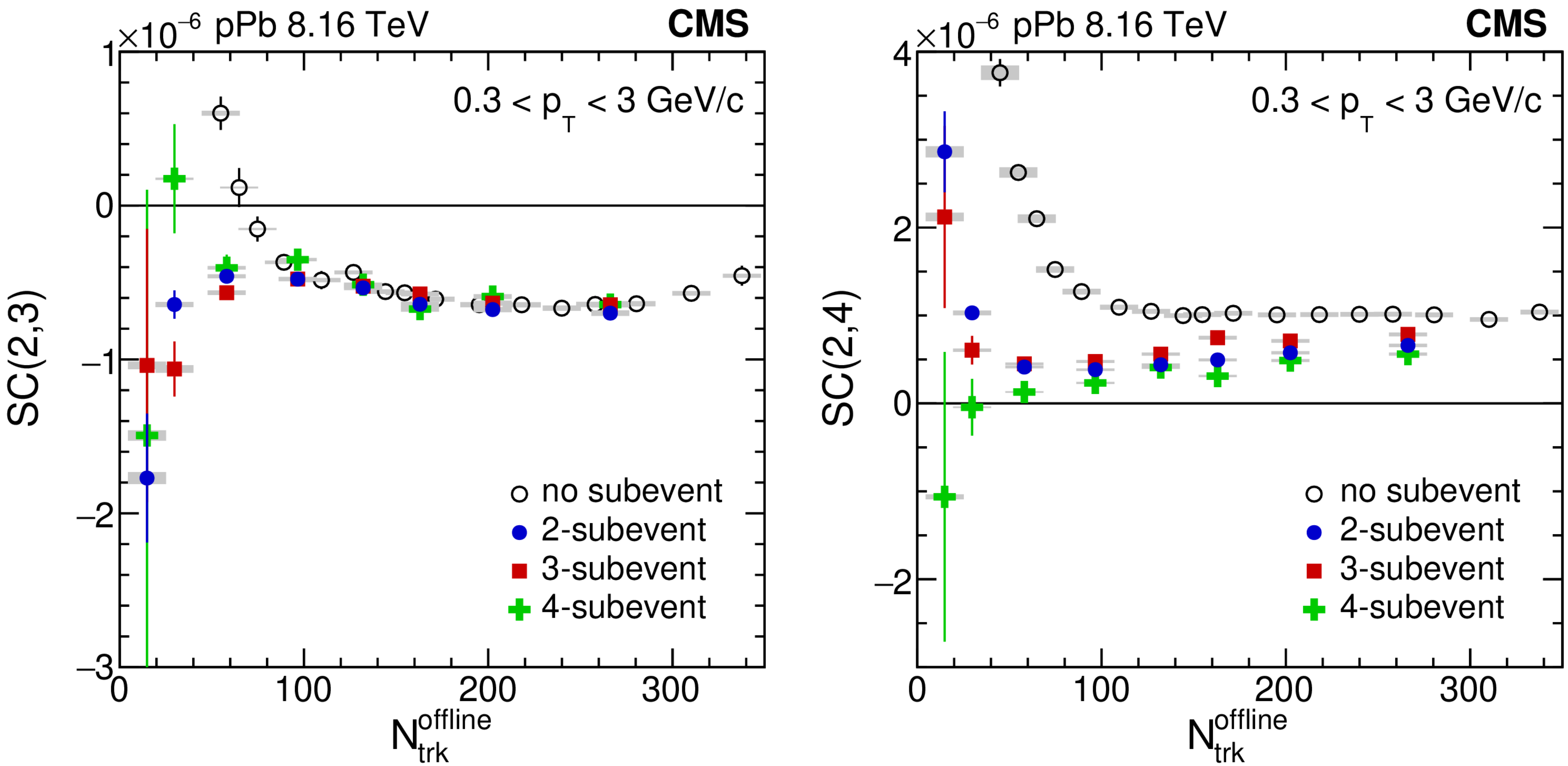
p-p > p-Pb > Pb-Pb

What is the origin?

Need of further non-flow suppression !

SCs with sub-events

arXiv: 1905.09935



☞Non-flow suppressed at low multiplicities

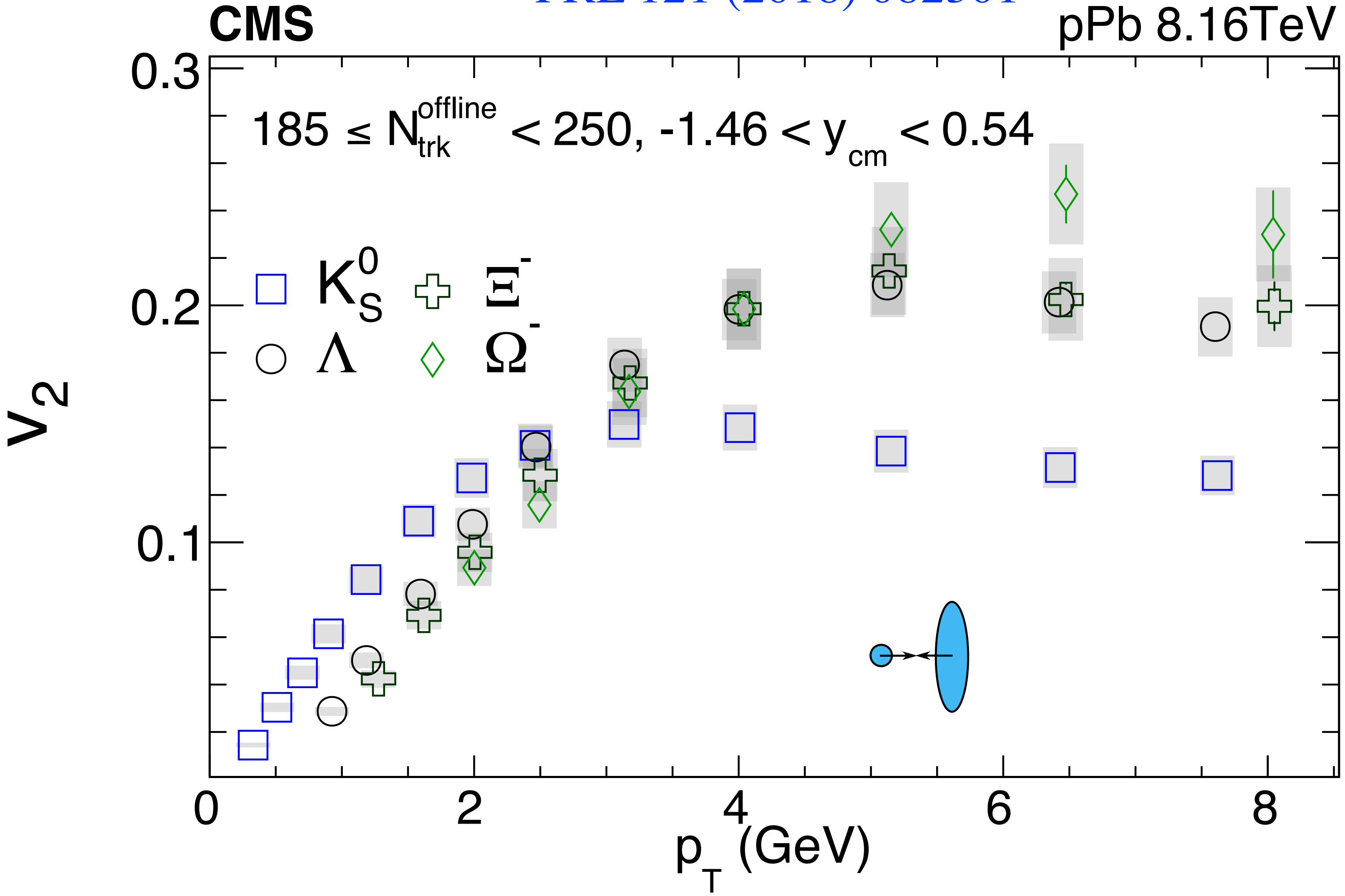
☞Similar results at high multiplicities for SC(2,3)

☞Different results between *no-* and *n-subevents* for SC(2,4) at high multiplicities

- SC(2,4) has a greater sensitivity to non-flow

Strange hadrons flow in small systems

PRL 121 (2018) 082301



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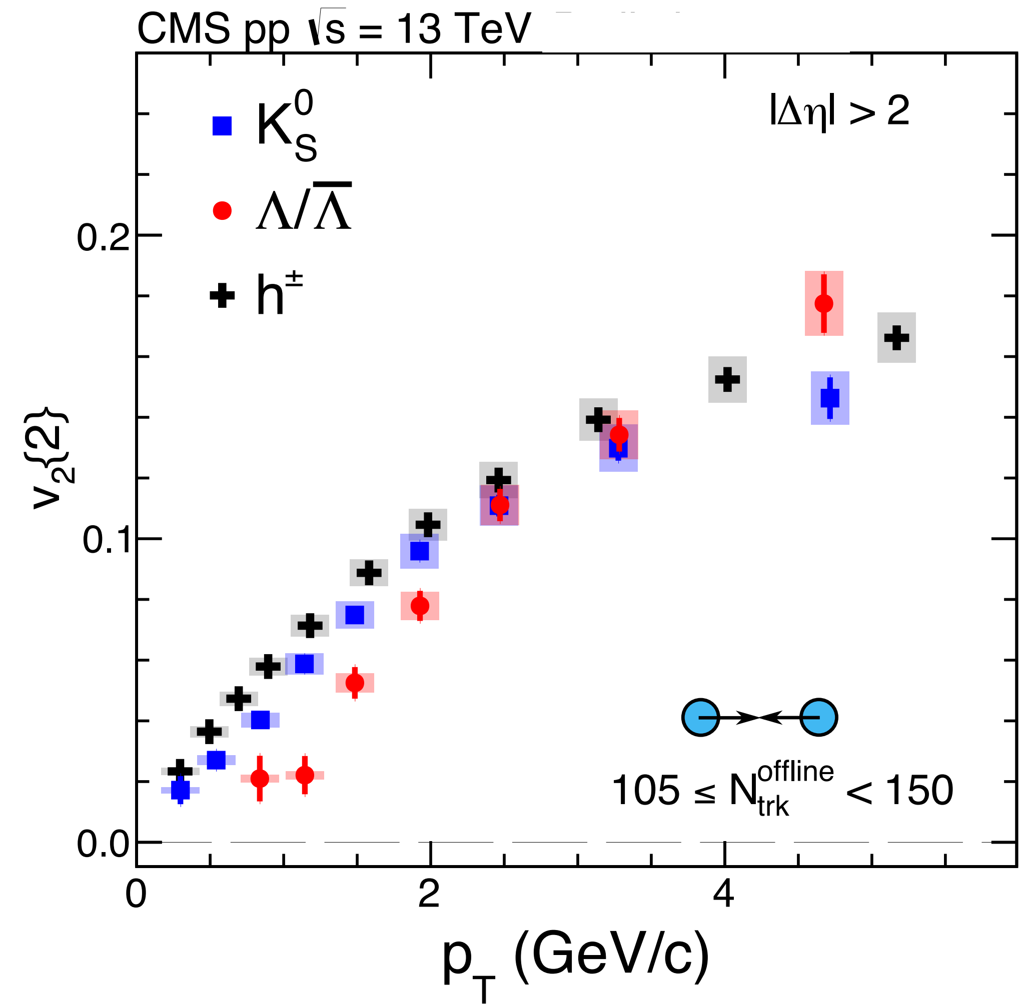
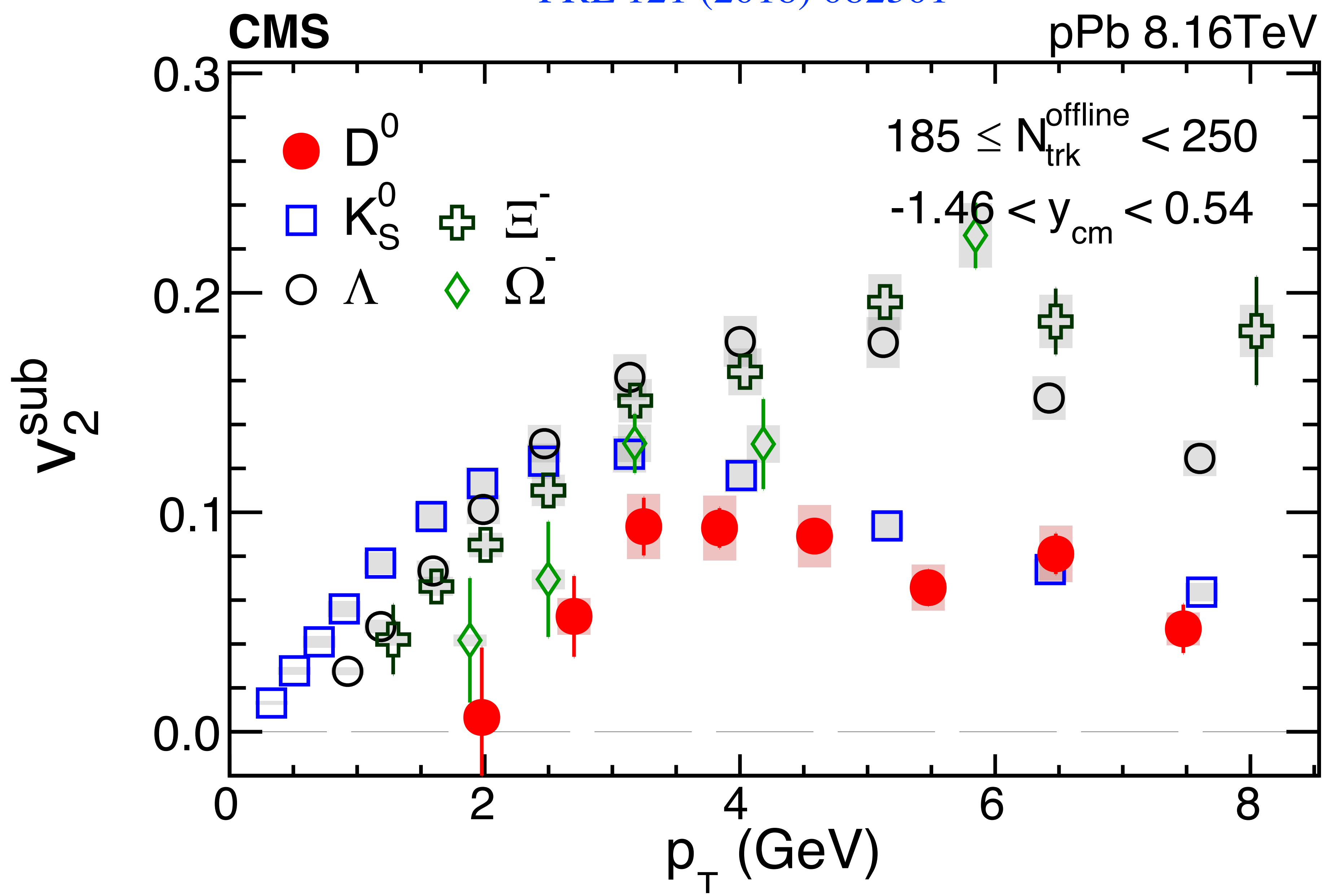


- Significant v_2 signal. Follow mass ordering at low p_T (radial flow)
- Similar pattern for all systems ? Similar origin?

Reminiscent of A-A observation !

Heavy quark collectivity in small systems

PRL 121 (2018) 082301

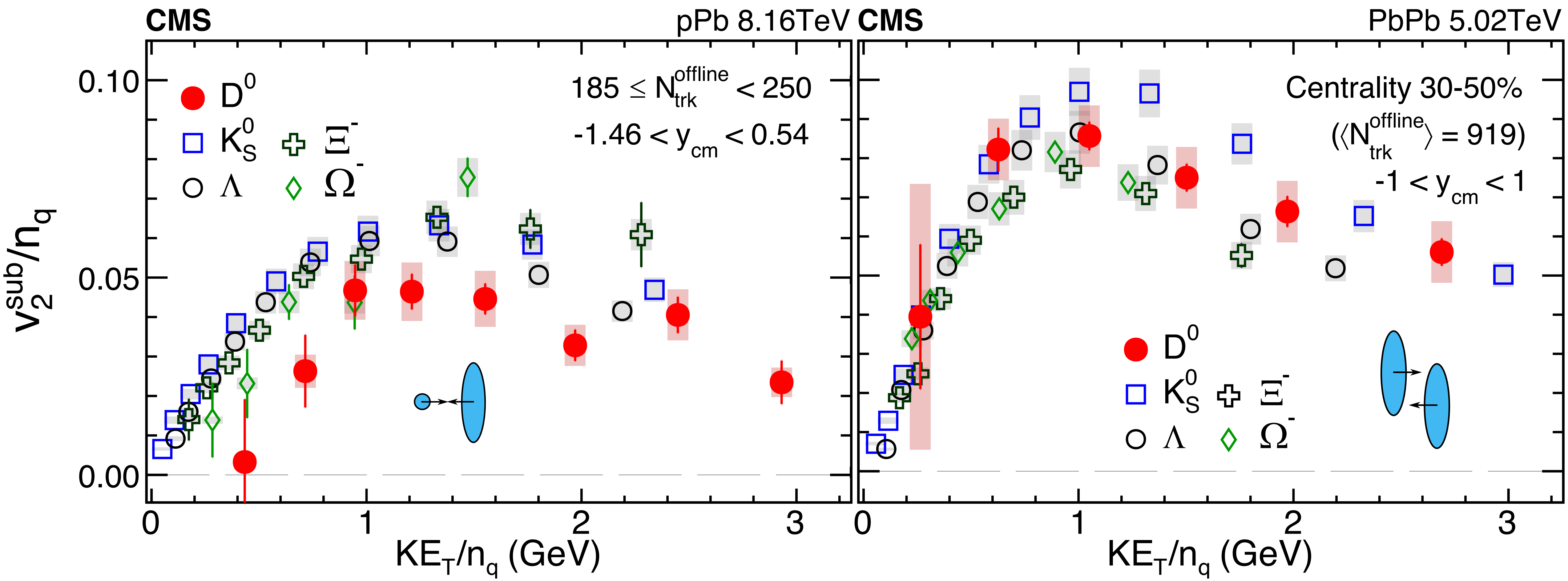


Strong D^0 flow:

- D^0 v_2 is similar to K_s^0 at higher p_T
- May be some indication of $v_2(c) < v_2(u,d,s)$?

What does NCQ scaling tell us?

Constituent quark number scaling: PRL 121 (2018) 082301



Small system:

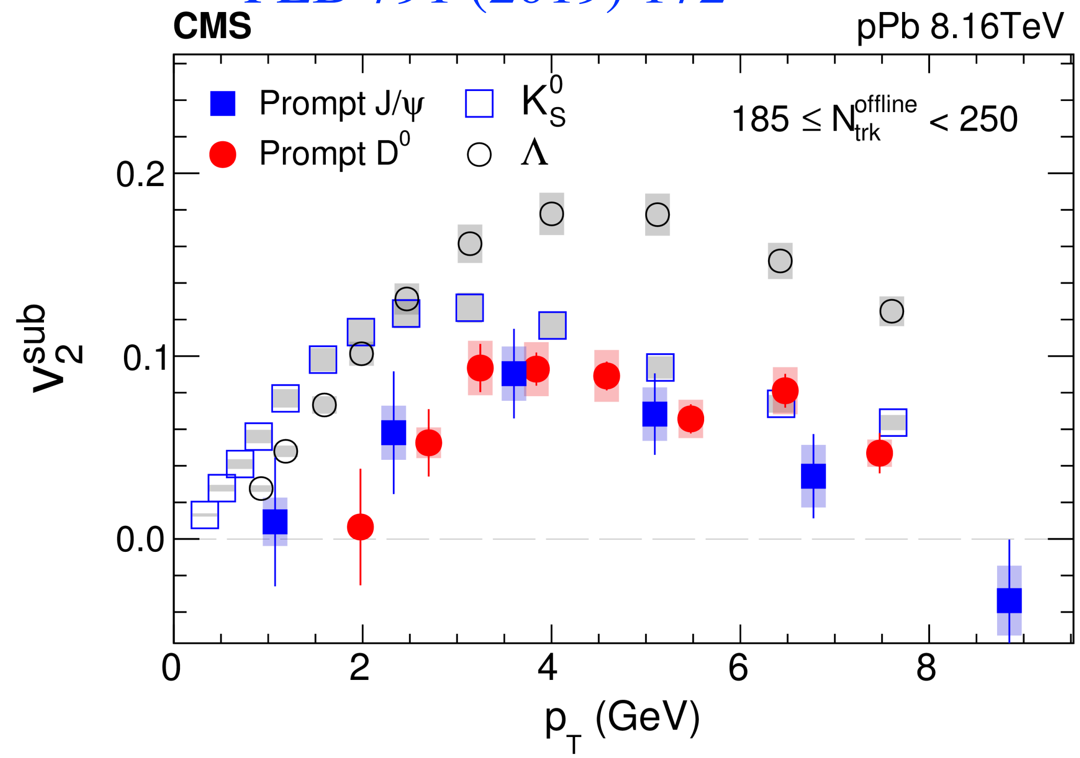
☞Shrink system size: **N_{trk} ~ 900 ⟶ N_{trk} ~ 200**

☞D^0 v_2 consistently lower: $v_2(c) < v_2(u,d,s)$

- Hydro like: less flow/thermalization for charm quarks in p-Pb due to a much reduced small system size?

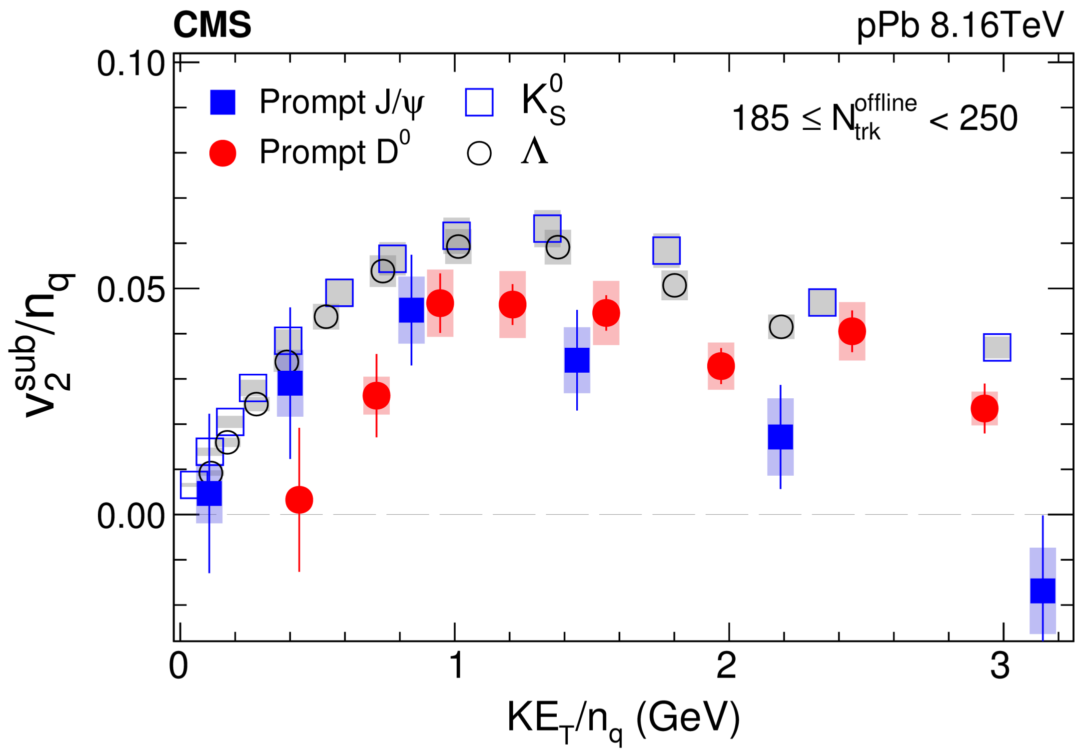
- Charmonia can be sensitive to additional effects:
  - Recombination of cc pairs
  - Initial correlation from Plasma

PRL 121 (2018) 082301
PLB 791 (2019) 172

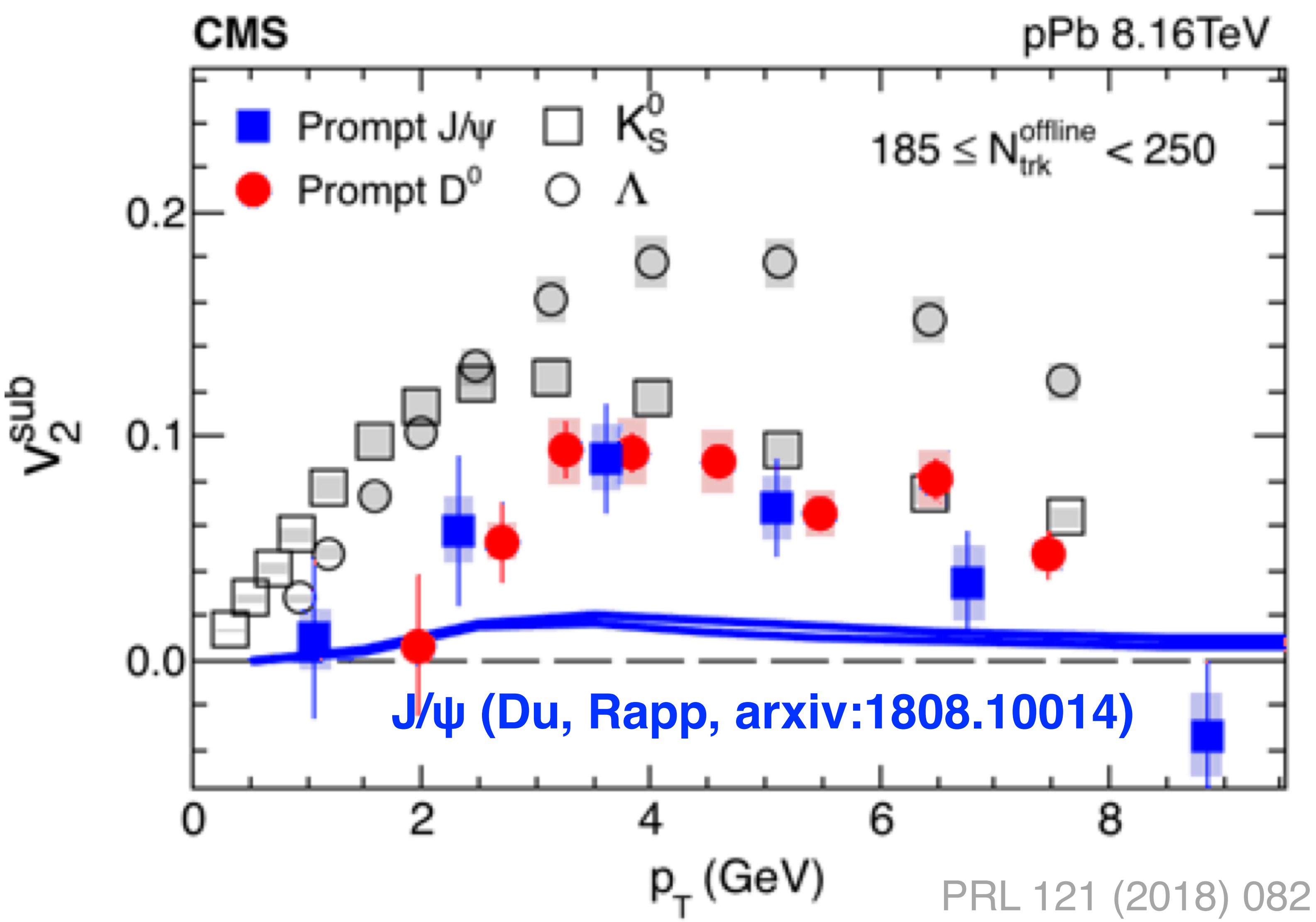


Small systems:

v_2 (c) < v_2 (u,d,s) ⇛ v_2 (J/ψ) < $v_2(D^0)$?



- Large v_2 observed for charm quark
- Similar magnitude for (J/ψ) and D^0
- Smaller than light flavour hadrons at low p_T
- The observed pattern is similar to A-A
- Uncertainties are still large



OK… what's the problem?

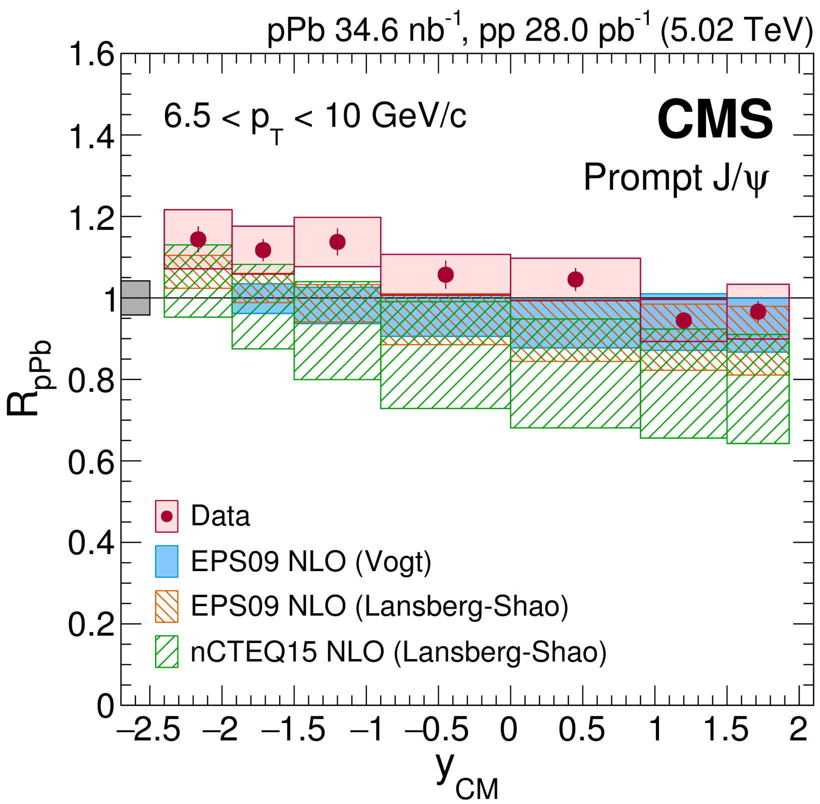
(Surprisingly!?) large (J/ψ) v_2 signal

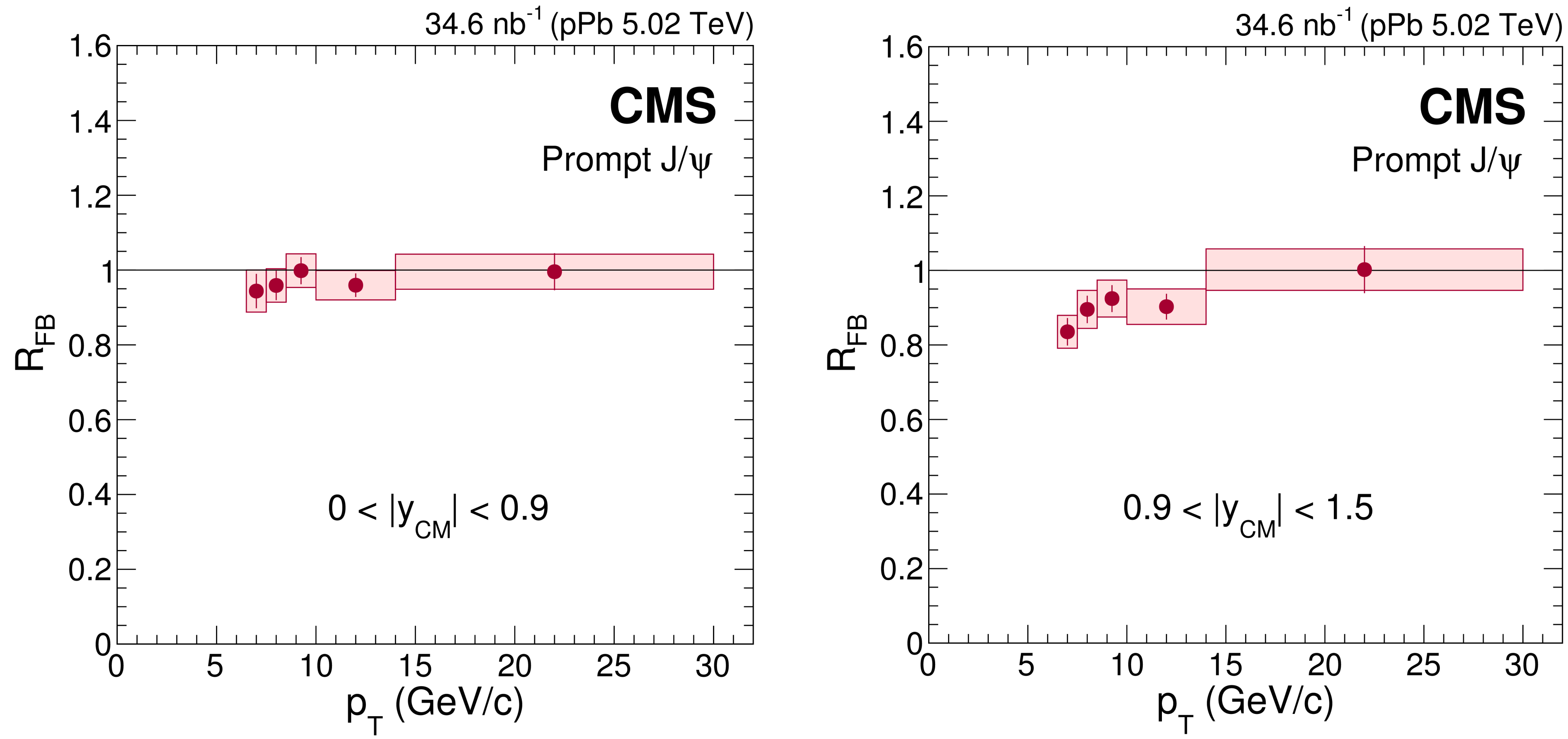
☞**Final state interaction alone cannot explain this**

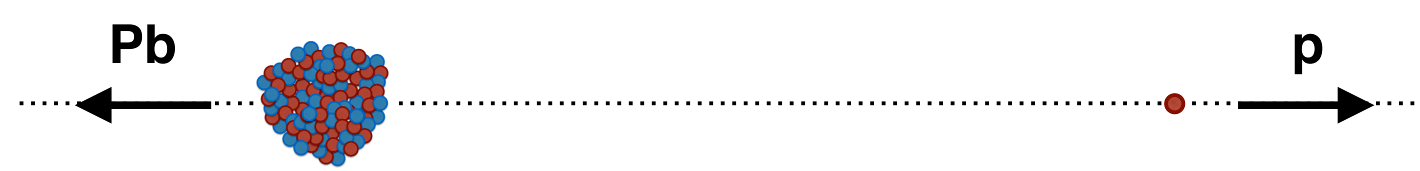
LHC data. We are therefore forced to conclude that this signal must be in large part due to initial-state (or pre-equilibrium) effects not included in our approach. This situation

Prompt J/ψ in pp and pPb:

EPJC 77 (2017) 269





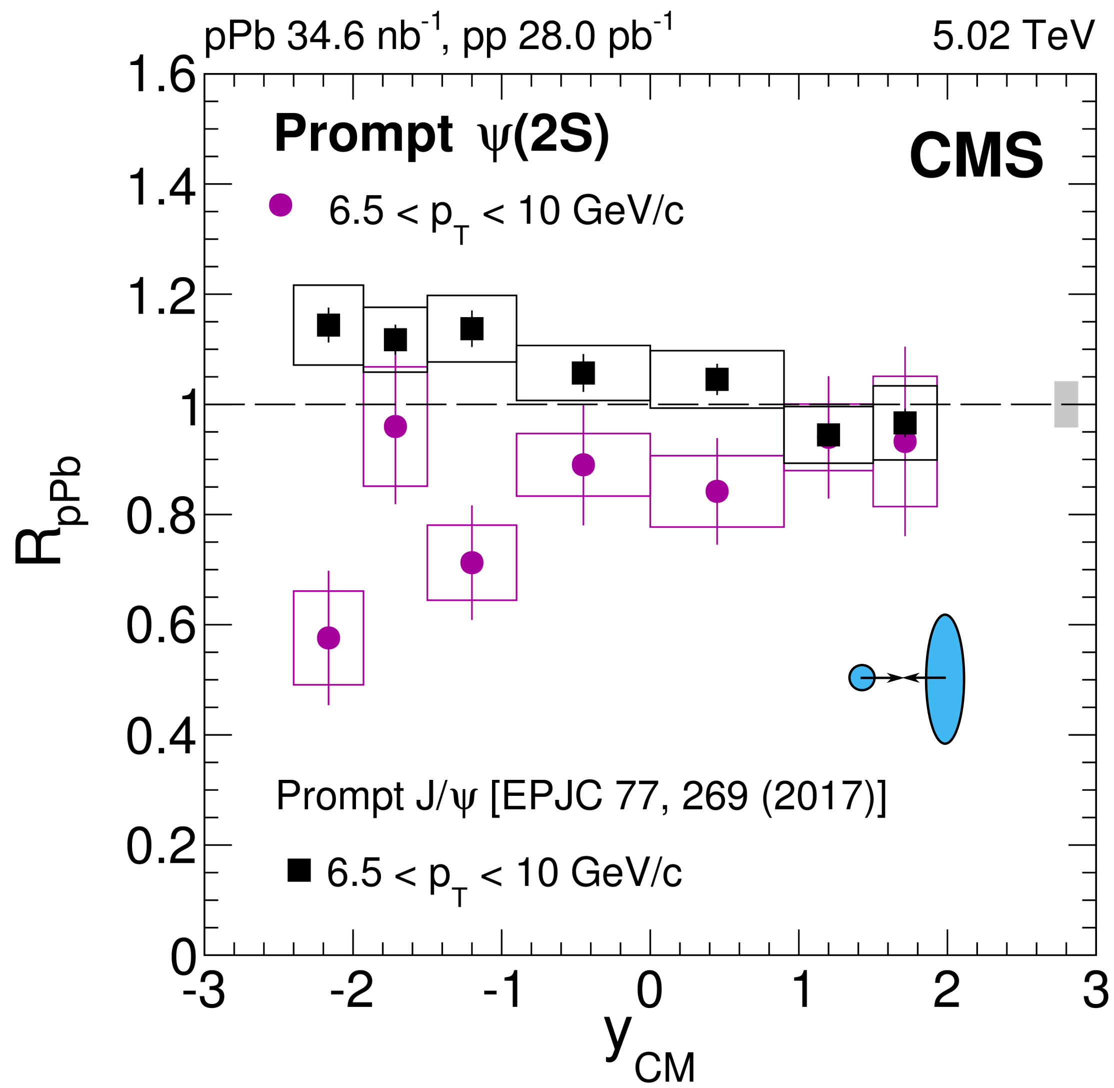


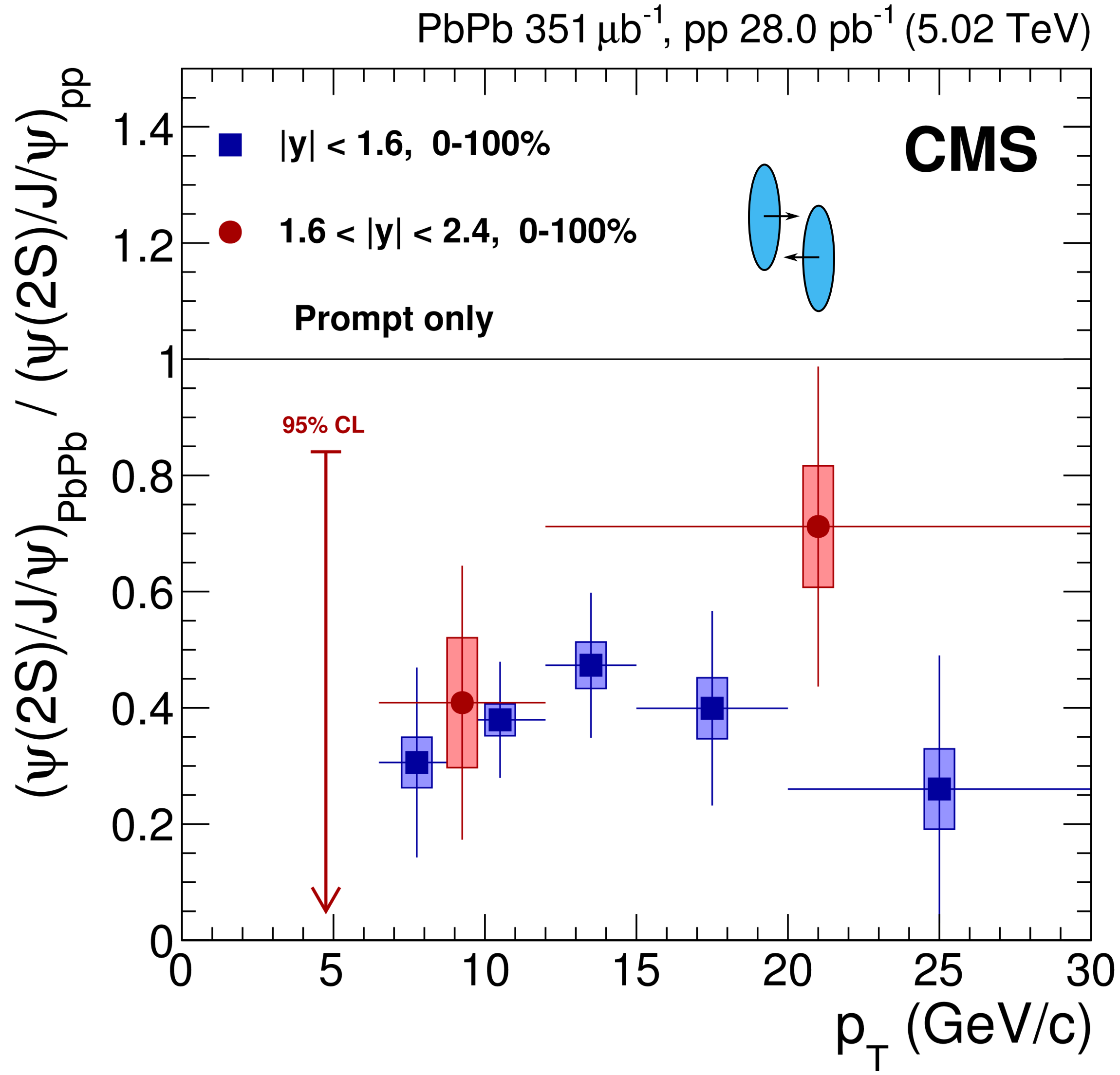
- Small modification in p-Pb collisions
- R_{FB} shows a significant decrease for increasing y_{CM}

- Role of Cold Nuclear Matter (CNM) effects!

Prompt J/ψ vs. prompt ψ(2s)

PLB 790 (2019) 509

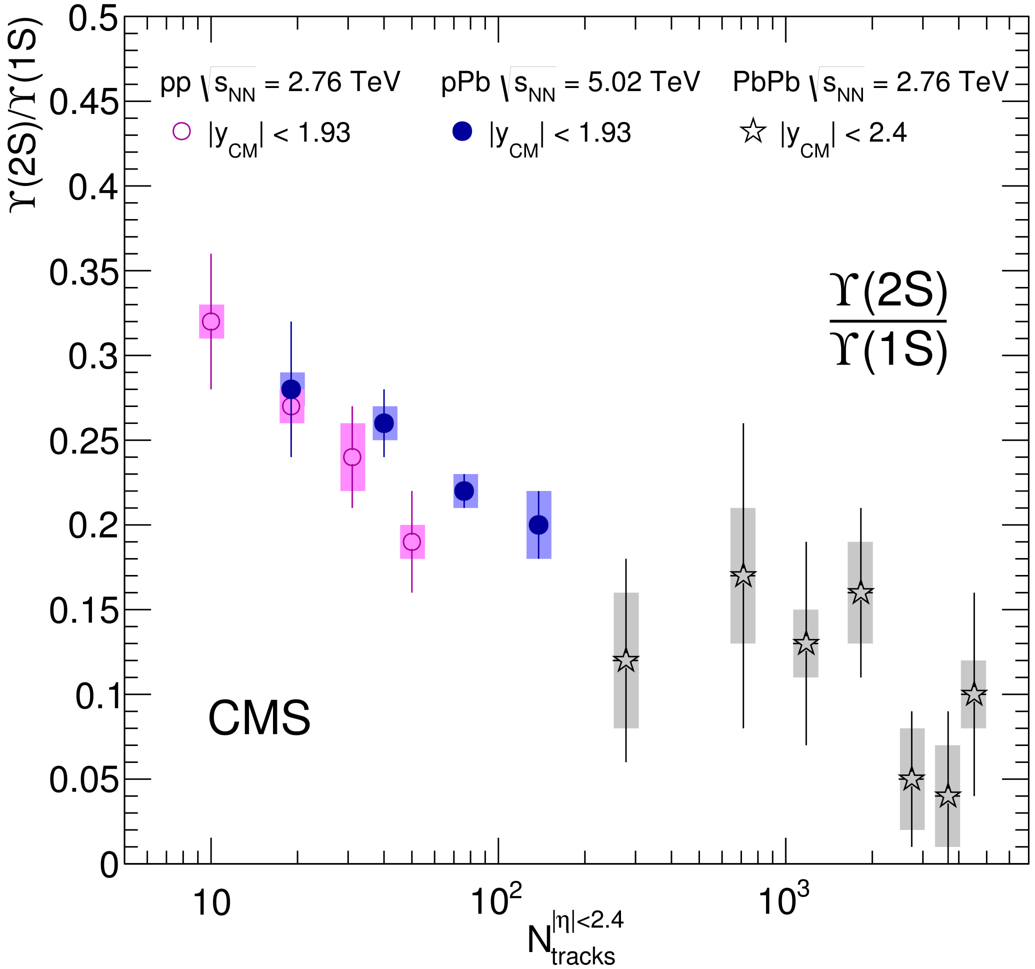


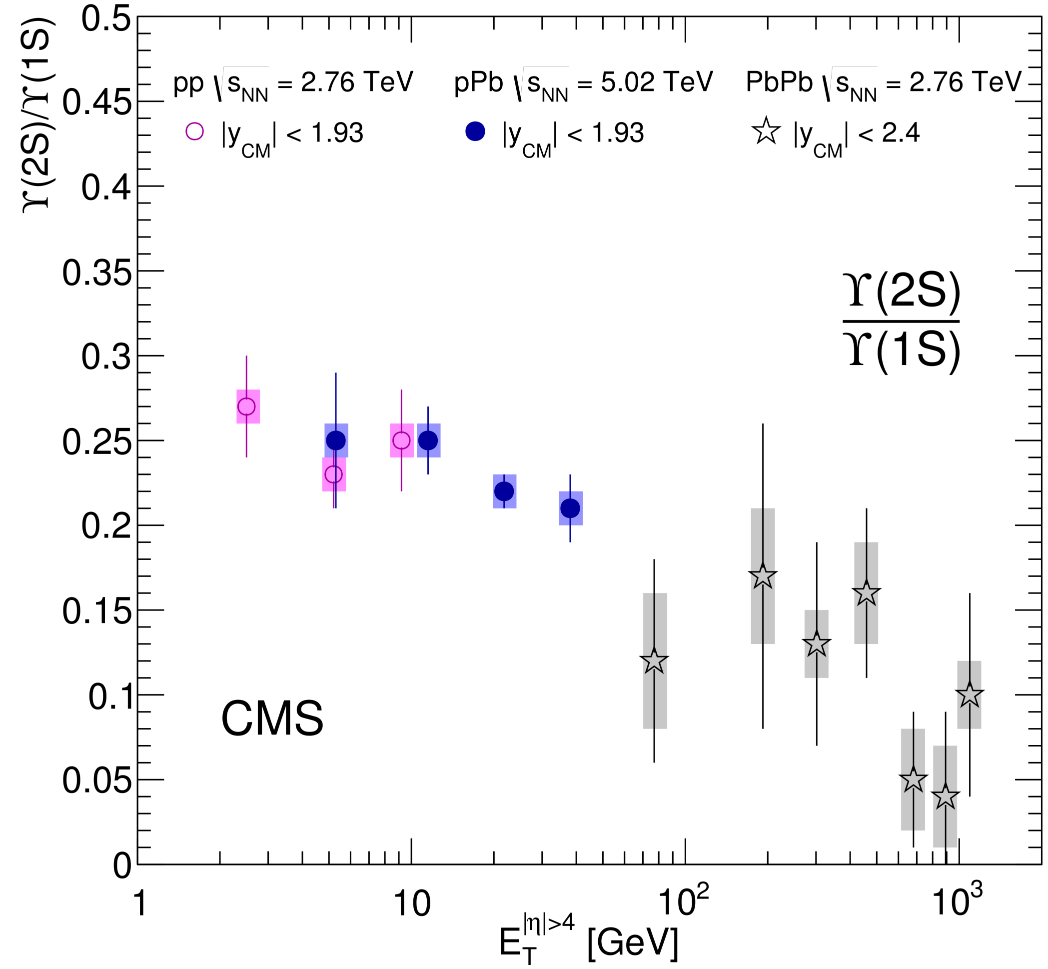


- Higher suppression of the excited state (ψ(2s)) than the ground state (J/ψ) both in p-Pb and Pb-Pb collisions
- Points to different nuclear effects in the production of ψ(2s) compared to J/ψ

Modification of quarkonia in small systems

JHEP 04 (2014) 103





- The excited ϒ states are suppressed but any bias? — normalise to Z^0
- J/ψ to ϒ(1S) ratio vs. N_{trk} — suppress or enhance?

Collectivity in small systems

☞ Particle mass dependence of p_T spectra
☞ Non-zero collective flow from multi-particle correlations
☞ Strong evidence for initial-geometry driven flow harmonics in HM ($N_{trk} > 100$) via high precision measurements

Heavy flavour

☞ Significant D^0 and J/ψ elliptic flow measured in small system
☞ QGP hypothesis: D^0 results indicates less thermalized charm
☞ Intriguing results for J/ψ

New opportunity ahead from higher statistics, more ion species and better instrumentations

– Stay tuned!

Topics I couldn't cover in this talk

- Jets and their modifications
- Open heavy flavour observables
- Vector bosons and constraints on nPDF
- Exclusive vector-meson photo production
- … and many more

CMS representation @ SQM2019

- ‘Recent results on heavy flavour from CMS’

  — Russian Chistov
- ‘Recent results in small systems from CMS’

  — Prabhat Pujahari
- ‘CMS upgrade plan for high-luminosity era and outlook on heavy-quark production in nuclear collisions’

  — Byungsik Hong
- ‘Λ_c production in pp and PbPb collisions with the CMS detector’

  — Rui Xiao
- ‘Strange and non-strange charm production in pp and PbPb collisions’

  — Cheng-Chieh Peng
- ‘Measurement of strange and non-strange beauty production in PbPb collisions’

  — Fuqiang Wang
- ‘Bottomonium production in pp, pPb and PbPb collisions’

  — Daniele Fasanella
- ‘Study of jet fragmentation in J/ψ and D mesons with CMS’

  — Xiao Wang

Don’t miss all the fun & excitement ! ☺️