

Collectivity of soft probes in small systems

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2021.06.09



LHCP2021
The Ninth Annual Conference on Large Hadron Collider Physics

Online

7-12 June 2021 ~~Paris (France), Sorbonne Université~~ (IN2P3/CNRS, IRFU/CEA)

D. Longieras IJClab 2021

Before the LHC

- The observation of collective behaviour in ion-ion collisions was one of key signatures of QGP at RHIC
- The fact that hydrodynamic models described the behaviour was determinant to hadron-gas model and proof of a new state of matter: QCD liquid
- Following: the hydrodynamic modelling was tried on pp collisions with somewhat surprising predictions

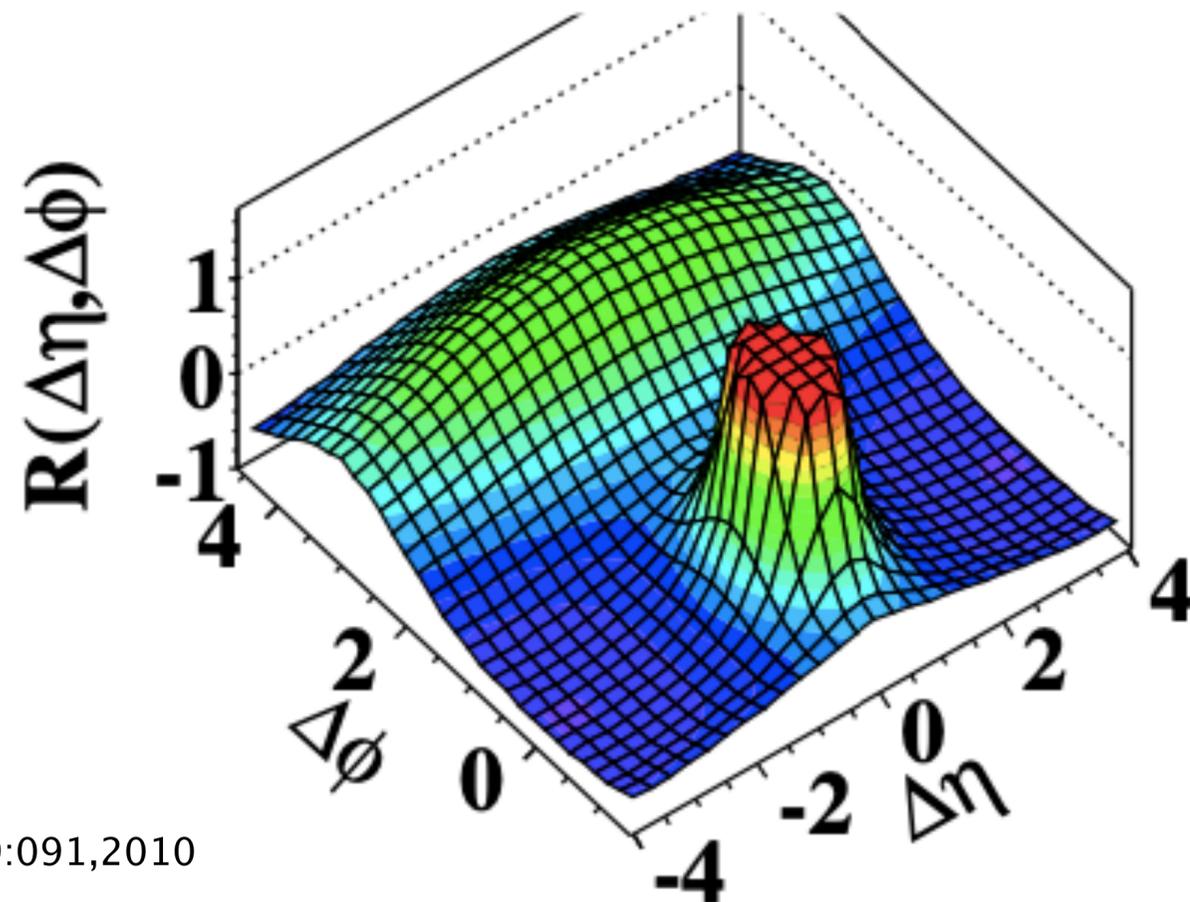
If high multiplicity events originate from azimuthally asymmetric events containing two flux tubes, an observable signal above the statistical fluctuations in the measured elliptic flow could appear.

From: Piotr Bożek: Acta Phys.Polon.B41:837,2010

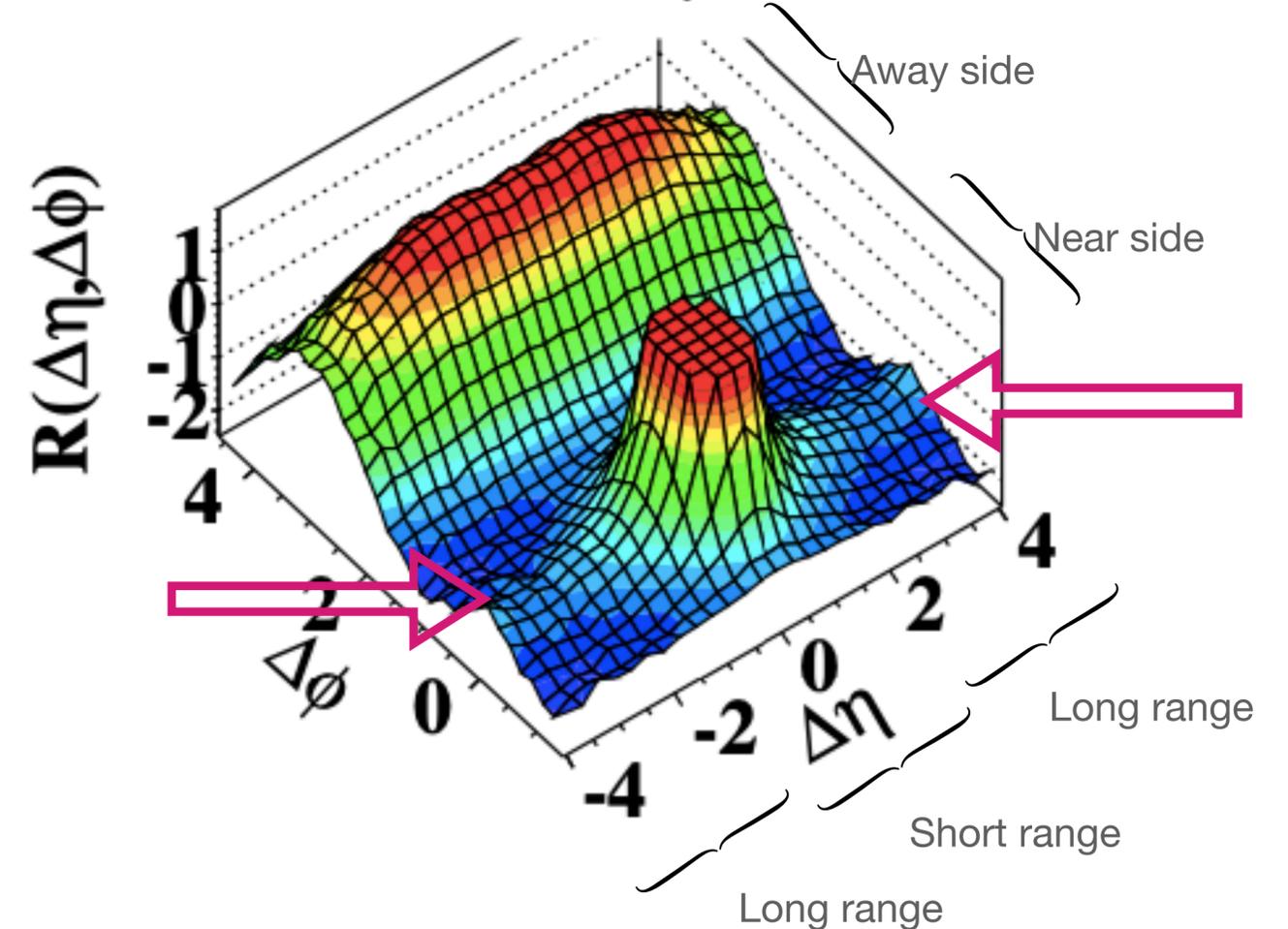
The CMS ridge

In retrospect - the first hint

(b) CMS MinBias, $1.0\text{GeV}/c < p_T < 3.0\text{GeV}/c$



(d) CMS $N \geq 110$, $1.0\text{GeV}/c < p_T < 3.0\text{GeV}/c$

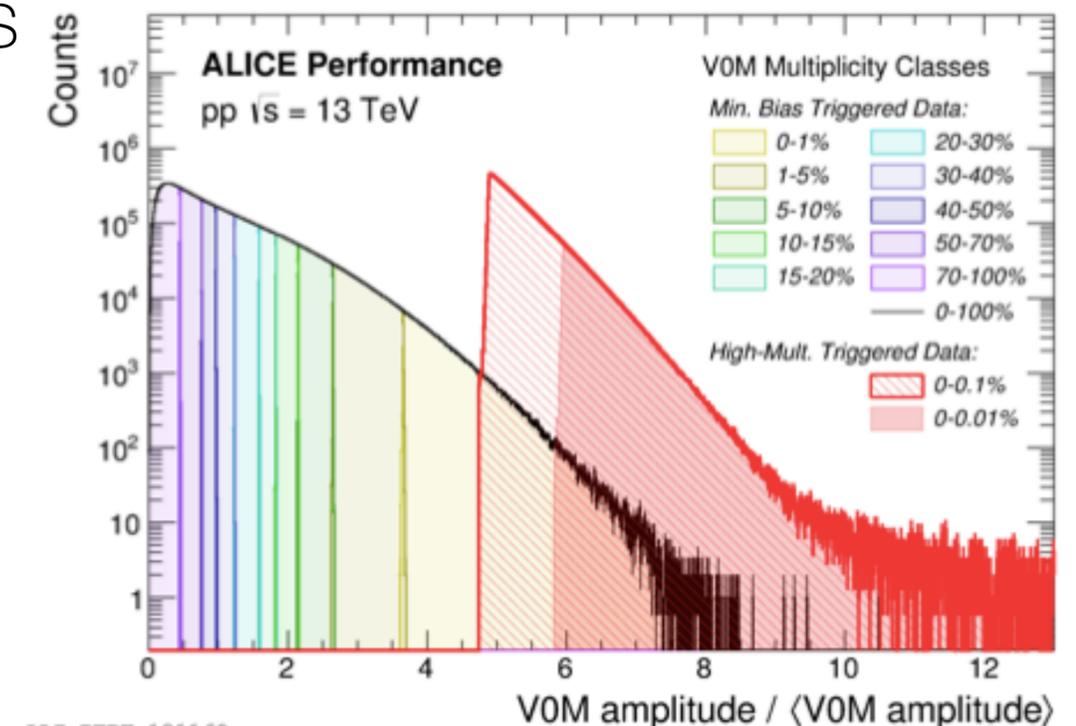


JHEP 1009:091,2010

Looking at the right kind of events (very high multiplicity) and right kinematics ($< 3\text{GeV}$) collectivity was seen in pp at 7 TeV

Development of analysis techniques

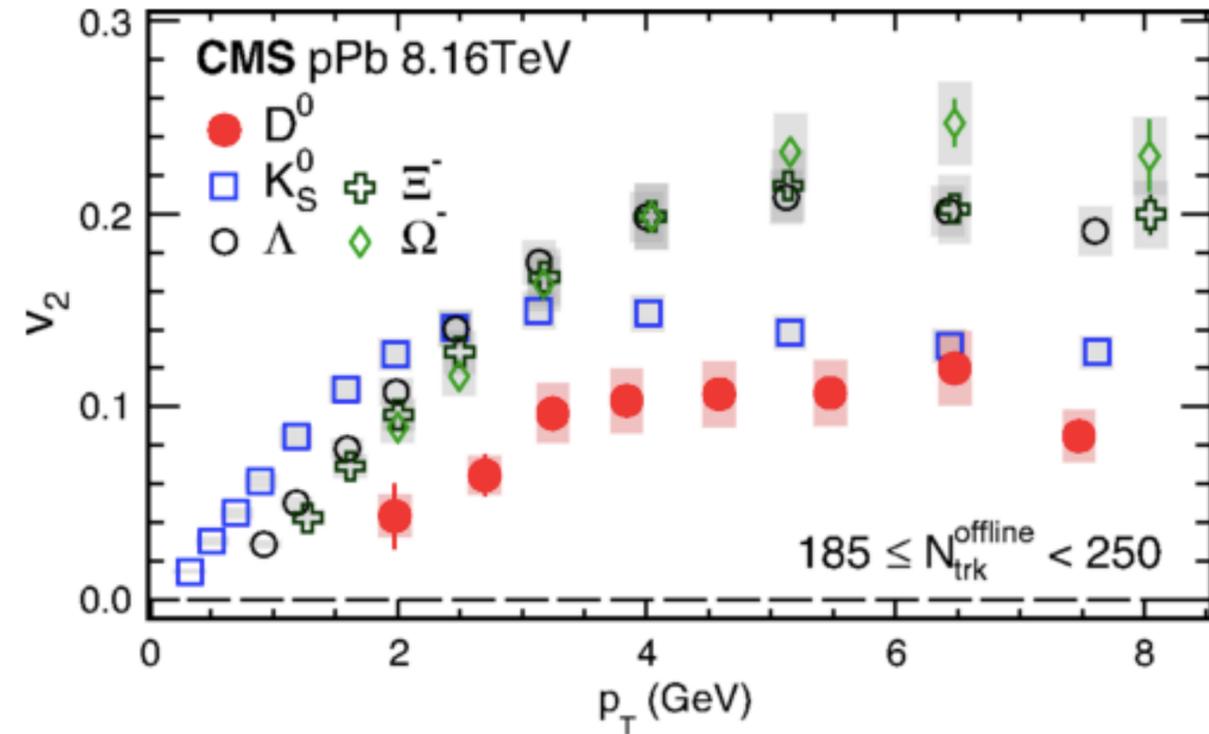
- The original technique 2-particle correlation is still a “working horse”
 - Advances in peripheral/low-mult correlation subtraction (not assuming absence of the azimuthal correlation in subtracted component)
- Multi-particle correlations (including sub-event techniques to eliminate short range component) were applied
- Collection of high multiplicity (HM) pp collisions happens routinely in all experiments and provides a rich dataset to study these phenomena



Correlations in p-Pb collisions

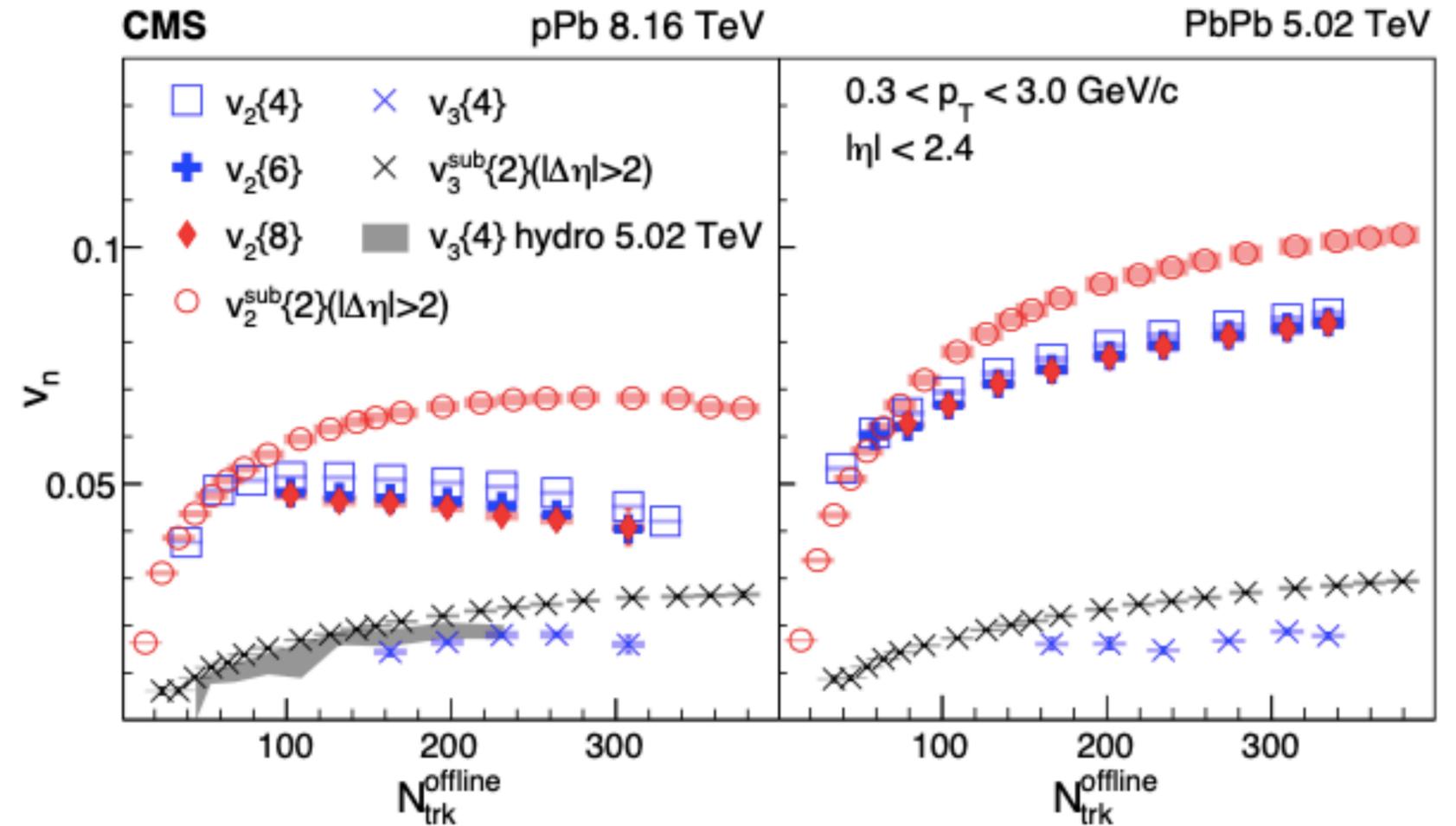
Intermediate system size offers a window to observe transition from large to small

Phys. Rev. Lett. **121**, 082301



A typical mass ordering of the flow observed in p-Pb collisions (as in Pb-Pb)

Phys. Rev. C **101**, 014912 (2020)



Second flow harmonic in Pb-Pb boosted additionally by initial oblate collision shape, third harmonic (fluctuations driven) are the same

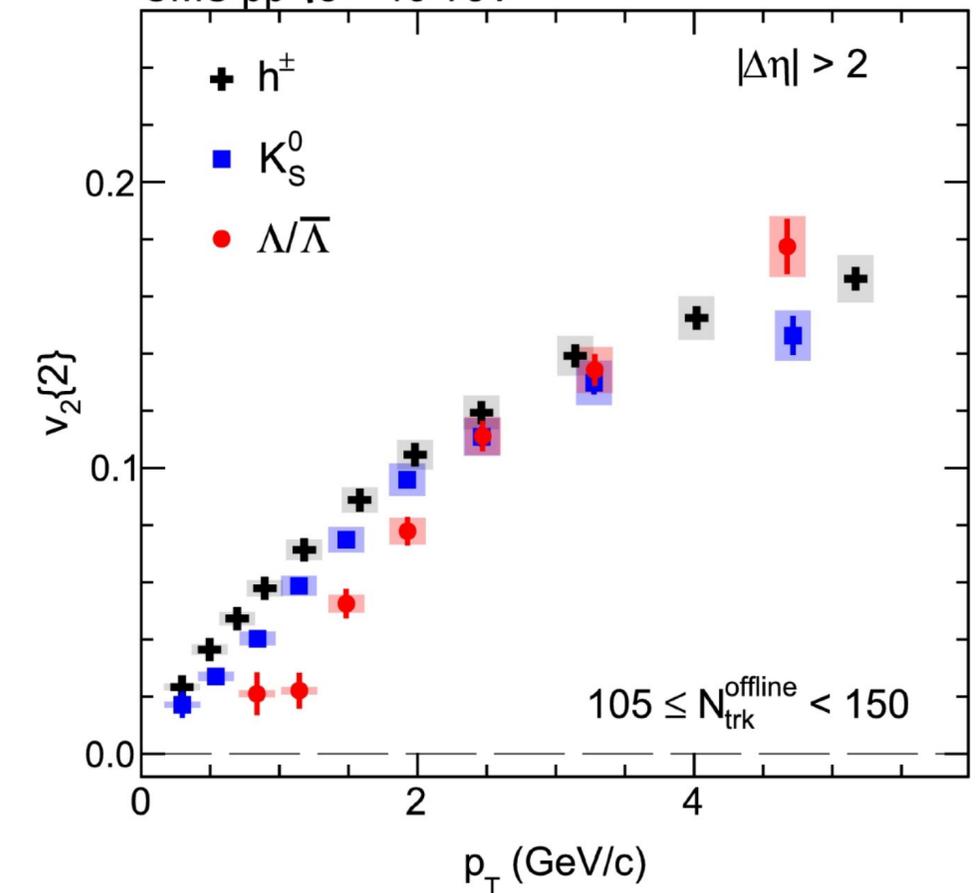
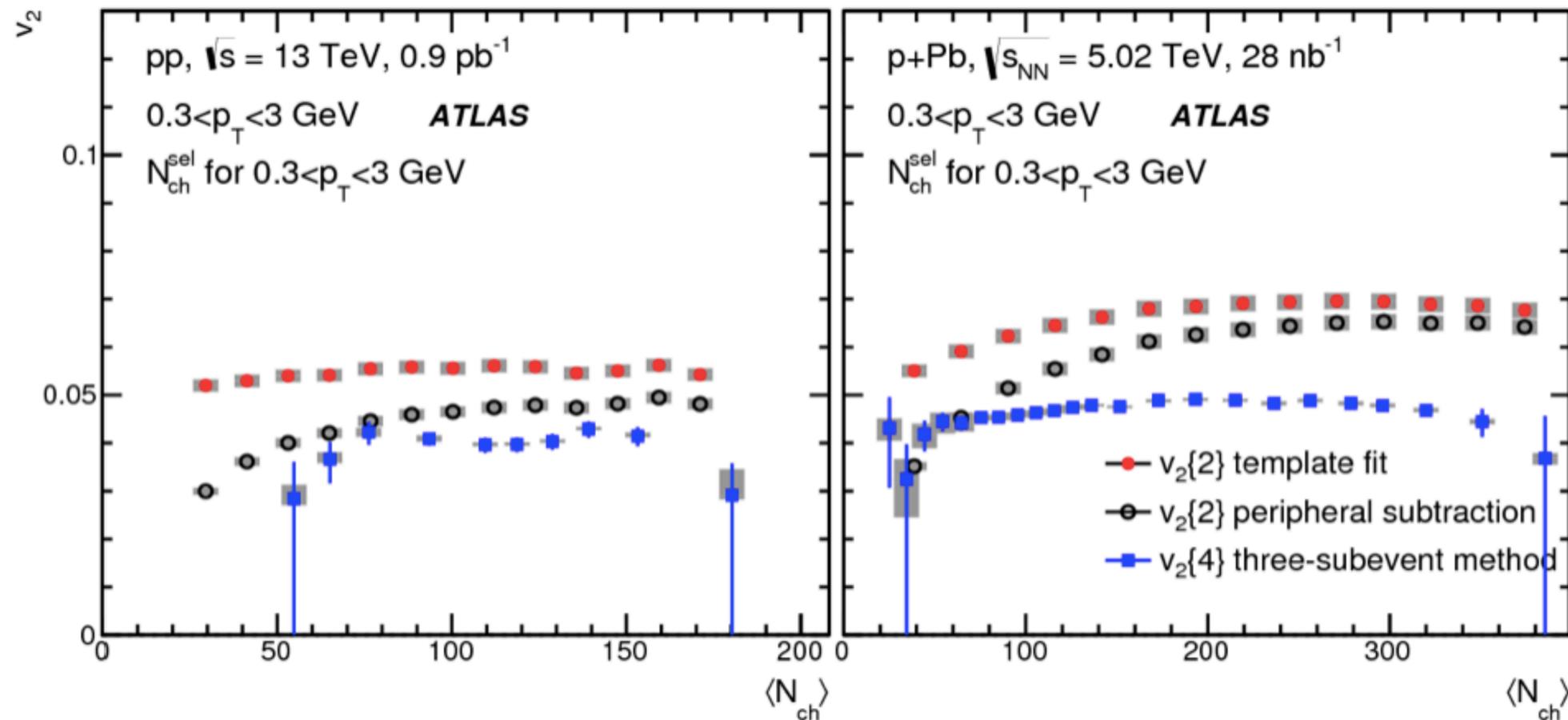
Correlations in p-p

Examples from ATLAS & CMS

Phys. Rev. C 97 (2018) 024904

Physics Letters B 765 (2017) 193-220

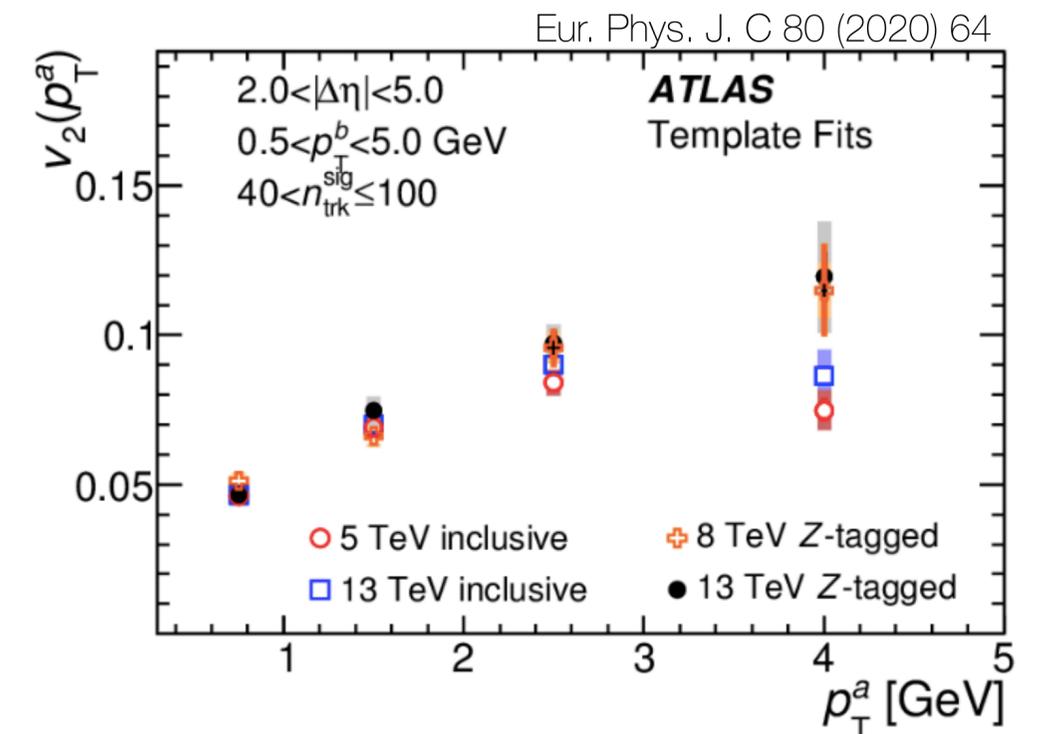
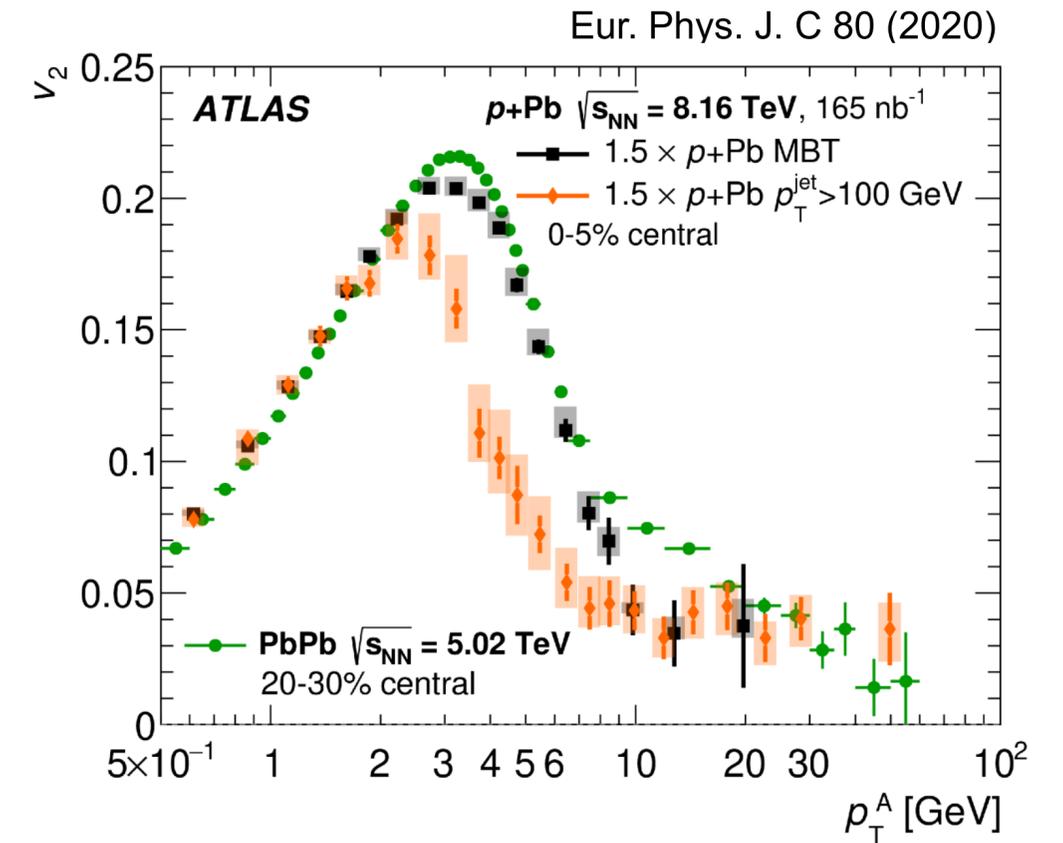
CMS pp $\sqrt{s} = 13$ TeV



Same techniques as in p-Pb used to prove the signal to be due to the collectivity rather than a short range correlations

So we have collectivity due to the QGP droplet being produced?

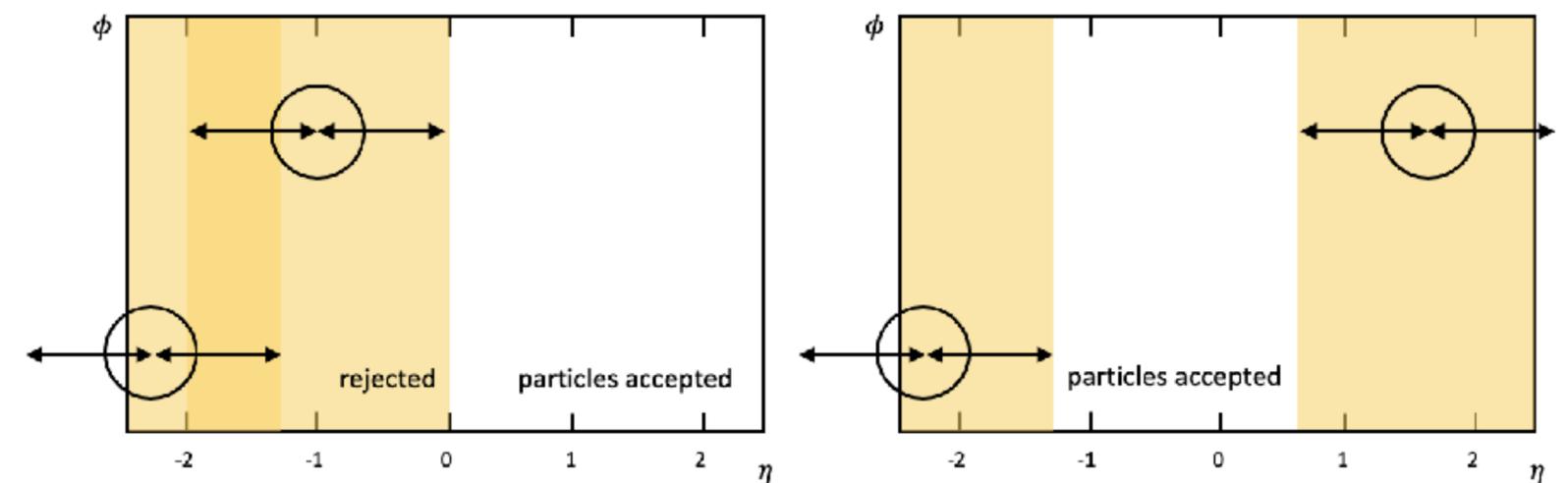
- The jets shapes modification (i.e. quenching) is another key signature of QGP, yet it is not observed in p+Pb collisions, despite a clear observation of anisotropy of high p_T particles in p-Pb
- Several approaches to modeling
 - Purely initial state effects (saturation)
 - Hybrid approaches: EPOS combine IS/FS (incl. hydro)
 - PYTHIA String shoving model - strings repelling in longitudinal direction
- Current trend in the field is to study collectivity in pp collisions that are tagged by the hard probes to enhance a particular type of events (e.g. large momentum transfer, proton shape fluctuation) initiated by ATLAS v_n in pp events tagged with Z boson



Measurement of the sensitivity of two particle correlations in pp collisions at $\sqrt{s} = 13$ TeV to the presence of jets with the ATLAS

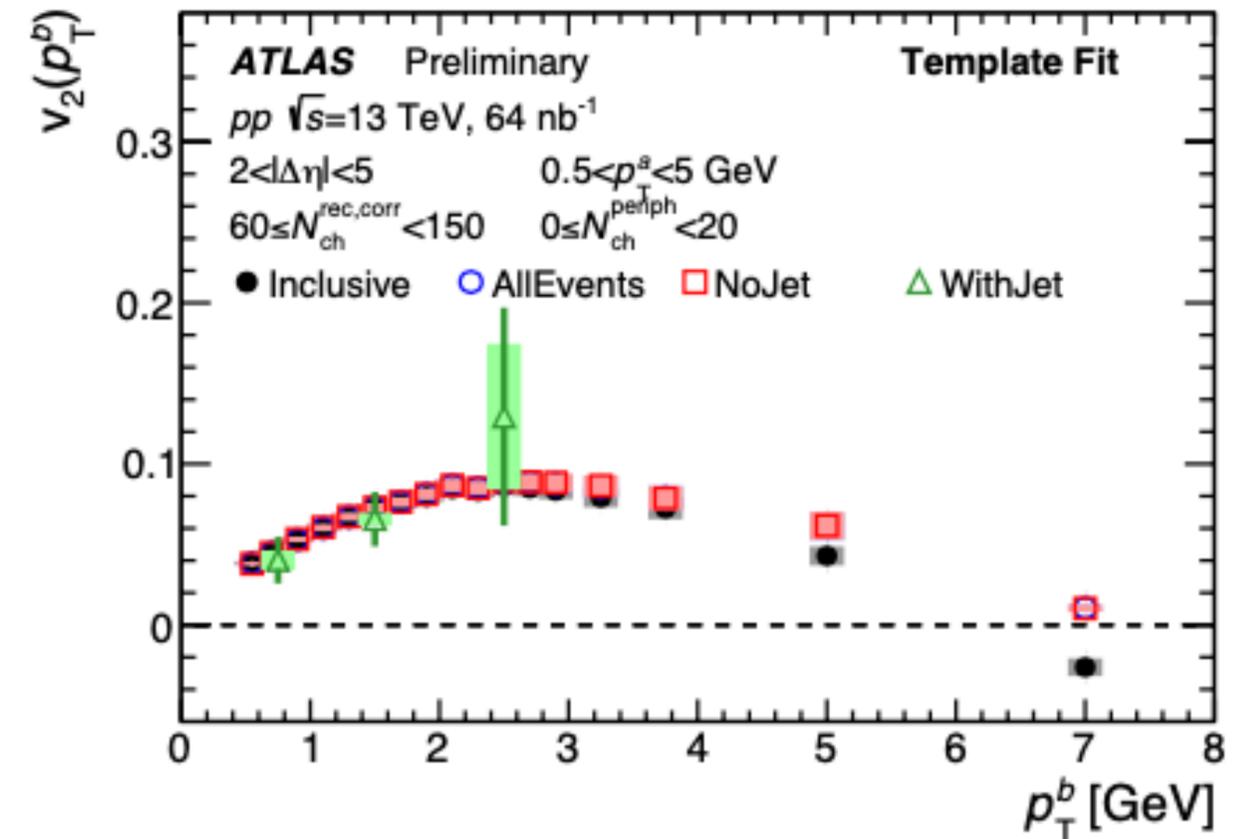
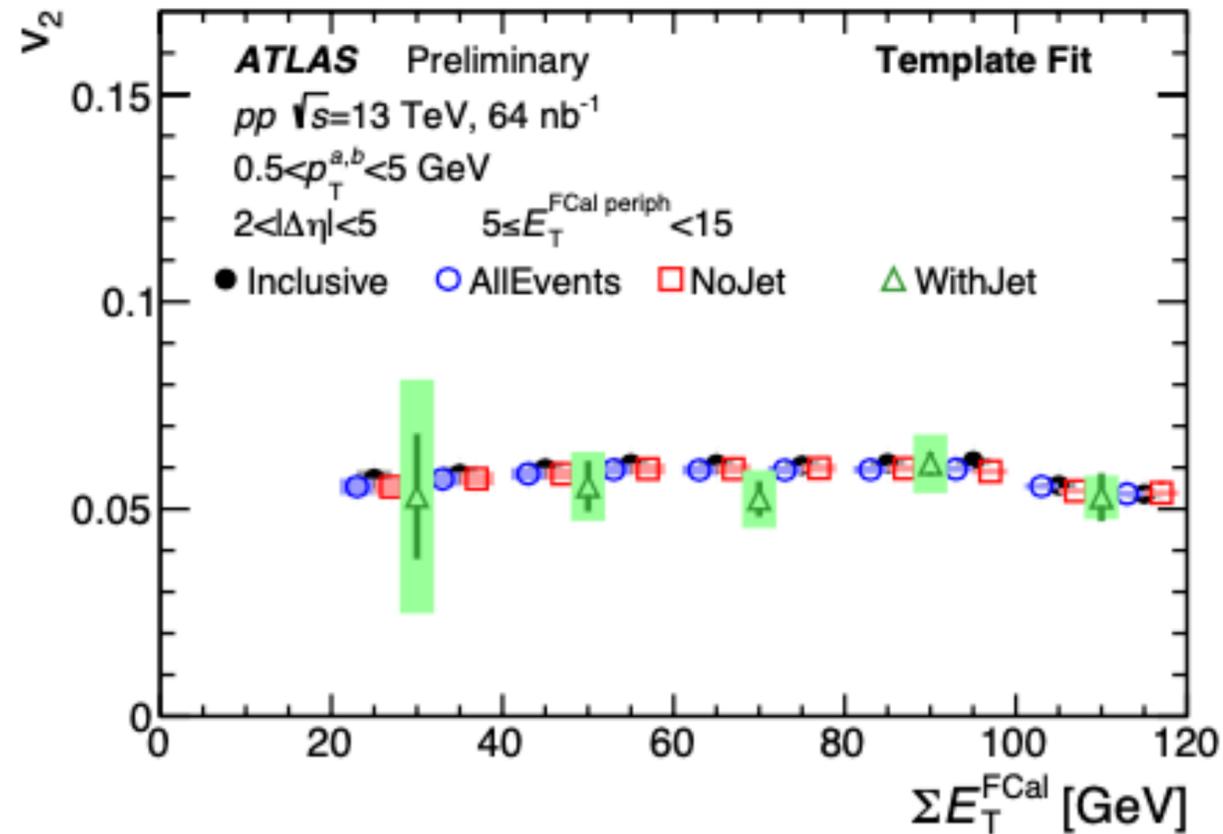
ATLAS Collaboration result: ATLAS-CONF-2020-018

- Idea to remove events with track-jet $p_T > 10$ GeV and/or charged particles close ($|\Delta\eta| < 1$) to such a jet



- Four categories:
 - Inclusive - all events, all particles
 - AllEvents - all events, no particles near jet
 - NoJet - subset of events w/o jet
 - WithJet - events w/ jet but no particles close by to jet

Results



Charged particles from jets do not contribute to the observed correlation

No significant difference of v_2 due to the presence of the jet in the event is observed (scanned over the jet p_T^{jet} thresholds (6-12 GeV))

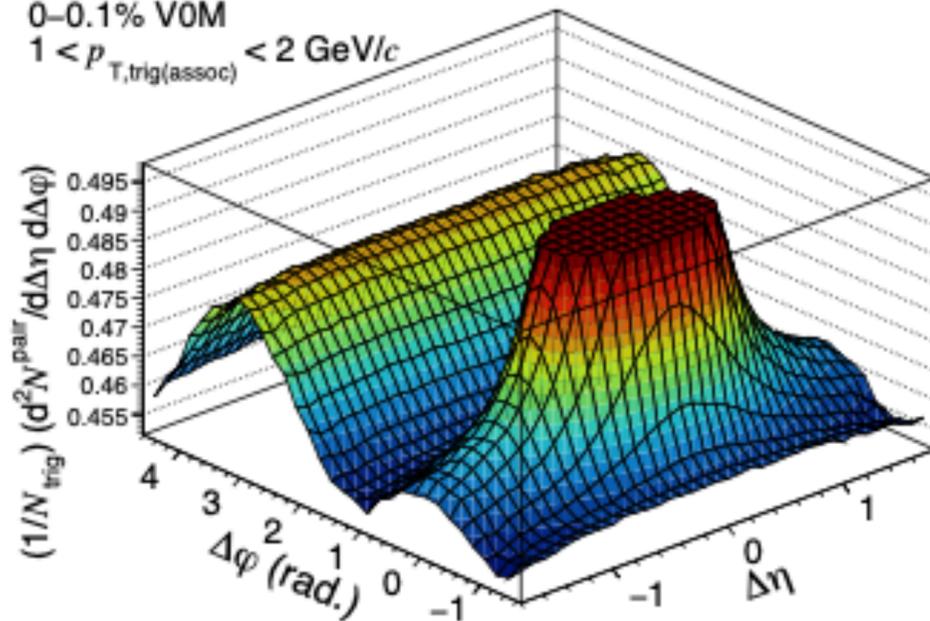
The strength of correlations are the same, also p_T dependence, higher harmonics

Long- and short-range correlations and their event-scale dependence in high-multiplicity pp collisions at $\sqrt{s} = 13$ TeV

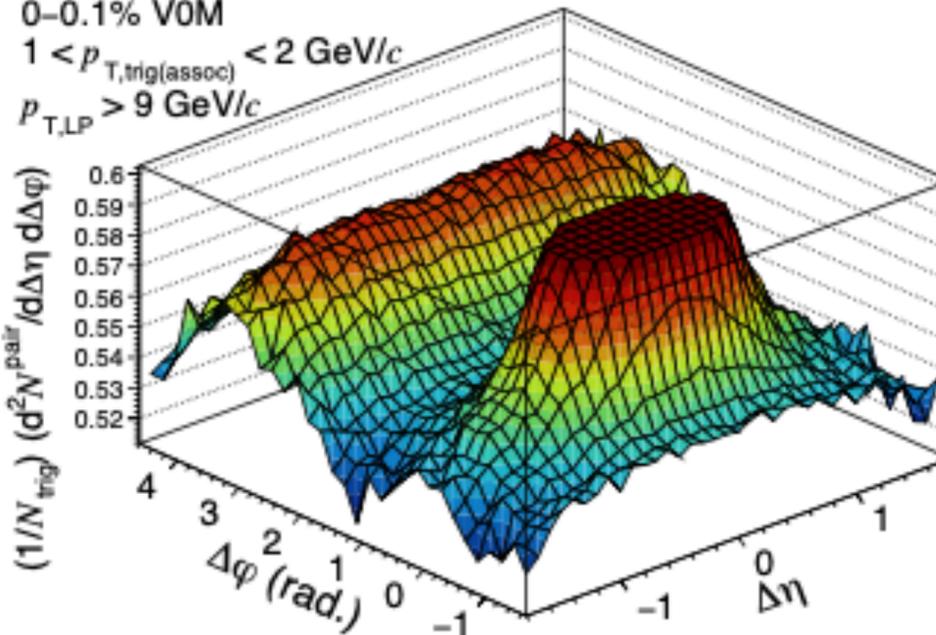
ALICE Collaboration result: [CERN-EP-2021-006/arXiv:2101.03110](https://arxiv.org/abs/2101.03110)

- The essential goal - observe an effect on the ridge depending on the p-p impact parameter by selecting HM events with an additional hard hadron or jet
- Regular ridge analysis with additional event selection + analysis of the short range peak

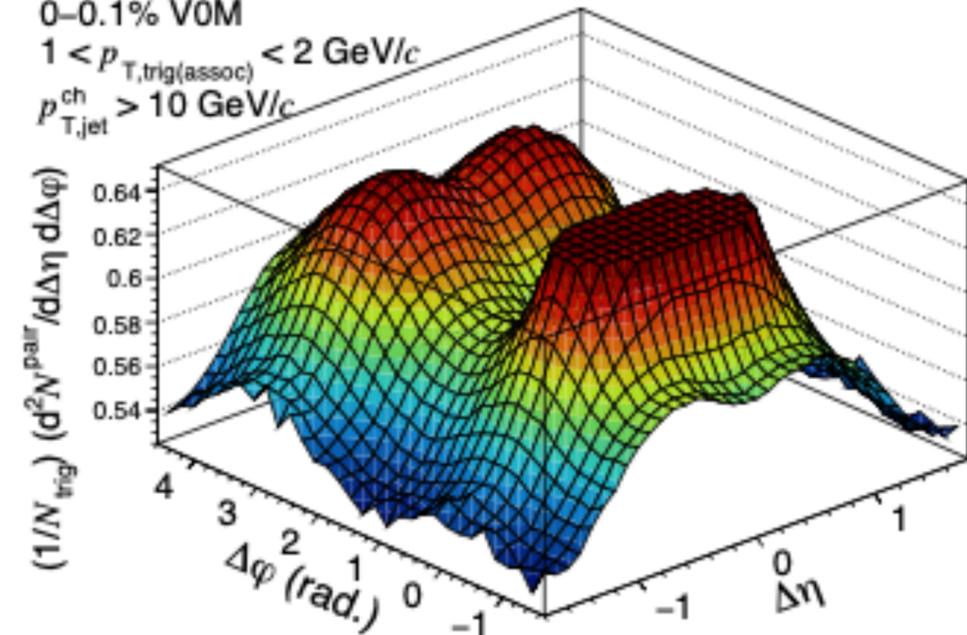
ALICE, pp $\sqrt{s} = 13$ TeV
0–0.1% V0M
 $1 < p_{T,\text{trig(assoc)}} < 2$ GeV/c



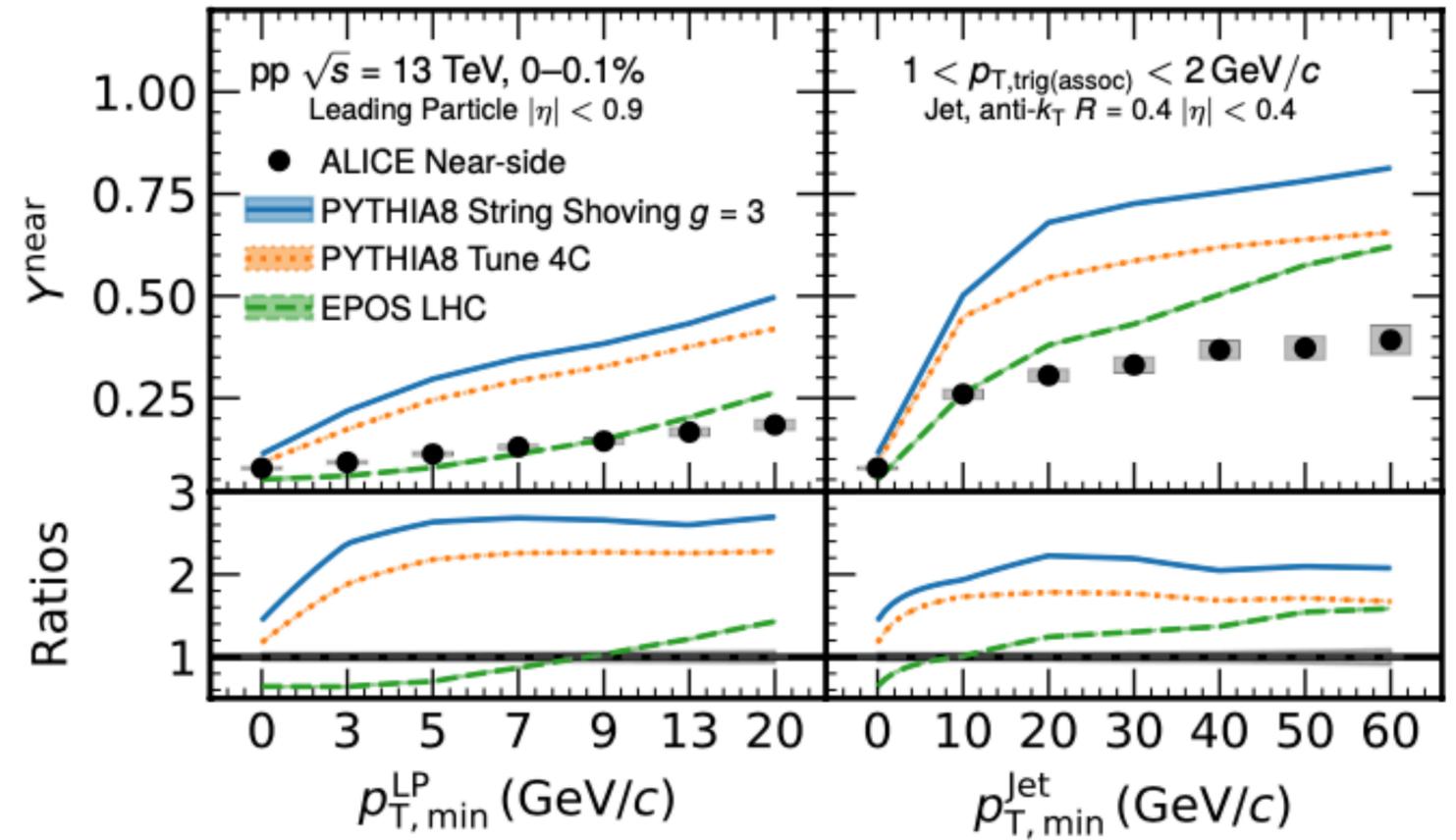
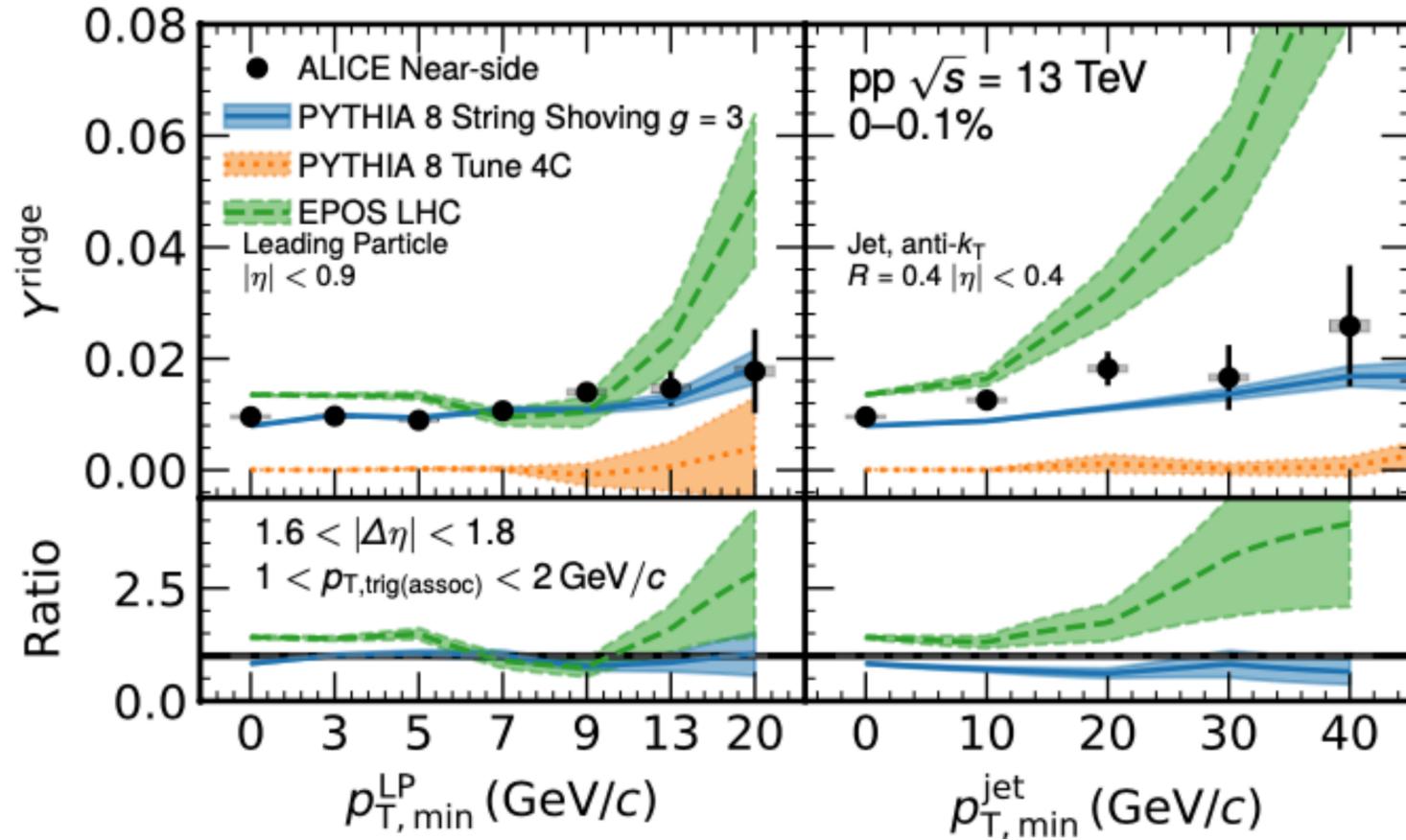
ALICE, pp $\sqrt{s} = 13$ TeV
0–0.1% V0M
 $1 < p_{T,\text{trig(assoc)}} < 2$ GeV/c
 $p_{T,\text{LP}} > 9$ GeV/c



ALICE, pp $\sqrt{s} = 13$ TeV
0–0.1% V0M
 $1 < p_{T,\text{trig(assoc)}} < 2$ GeV/c
 $p_{T,\text{jet}}^{\text{ch}} > 10$ GeV/c



Results



- The ridge persists, and maybe event slightly raises with the event scale - impact parameter dependence here?
- Modeling w/o hydro works well for ridge but fails for short range-near-side yields

Summary

- The collectivity in small systems collision is not a settled topic
- Experimental signatures similar in p-p, p-Pb and Pb-Pb
- It is certain that the collective behaviour occurs and it is only mildly related to hard processes in the event
- There are competing explanations of the observed phenomena
- Even more intriguing is the fact that a similar effects are observed in photon induced collisions (topic of the following talk by Peter Steinberg)

See also

Interesting results for which there was no time to discuss

Production of Λ and K_S^0 in jets in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and pp collisions at $\sqrt{s} = 7$ TeV

ALICE Collaboration
<https://arxiv.org/abs/2105.04890>

Azimuthal femtoscopy in central p+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ATLAS

ATLAS Collaboration
<https://cds.cern.ch/record/2244818>