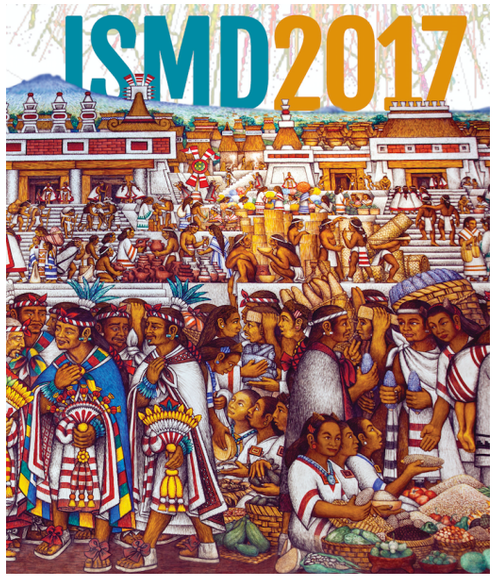
Searches for collectivity in small systems using multi-particle azimuthal correlations with ALICE

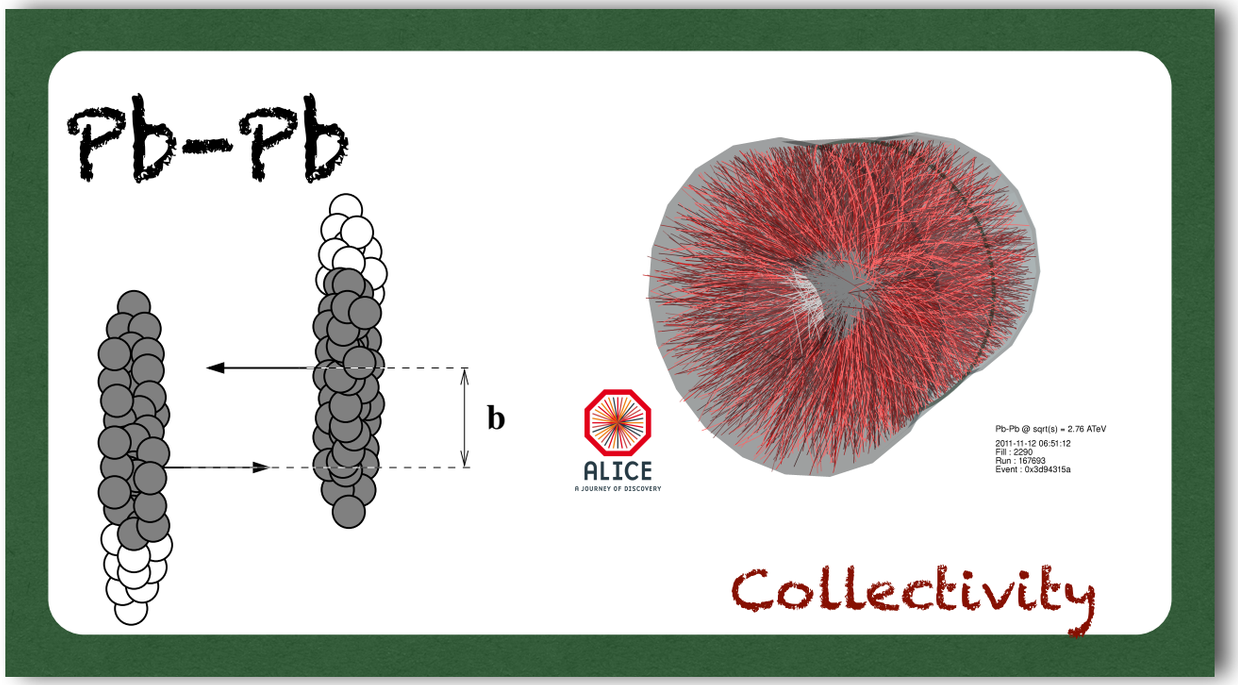


Katarina Gajdosova
Niels Bohr Institute, University of Copenhagen

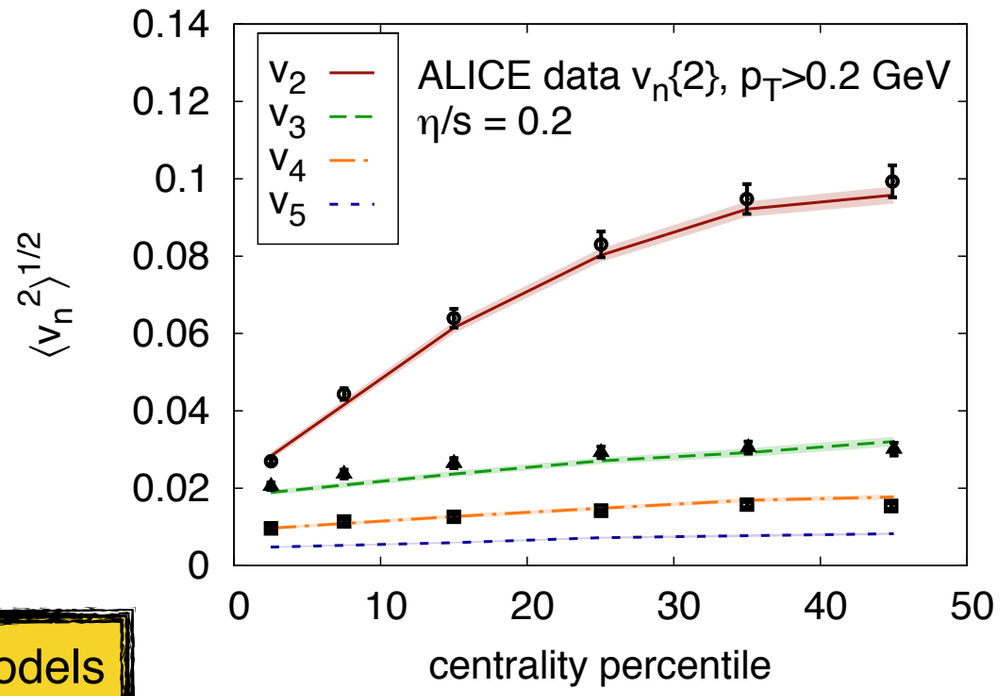
on behalf of the ALICE Collaboration

ISMD 2017, Tlaxcala, Mexico
September 12, 2017

Collectivity in Pb-Pb and p-Pb

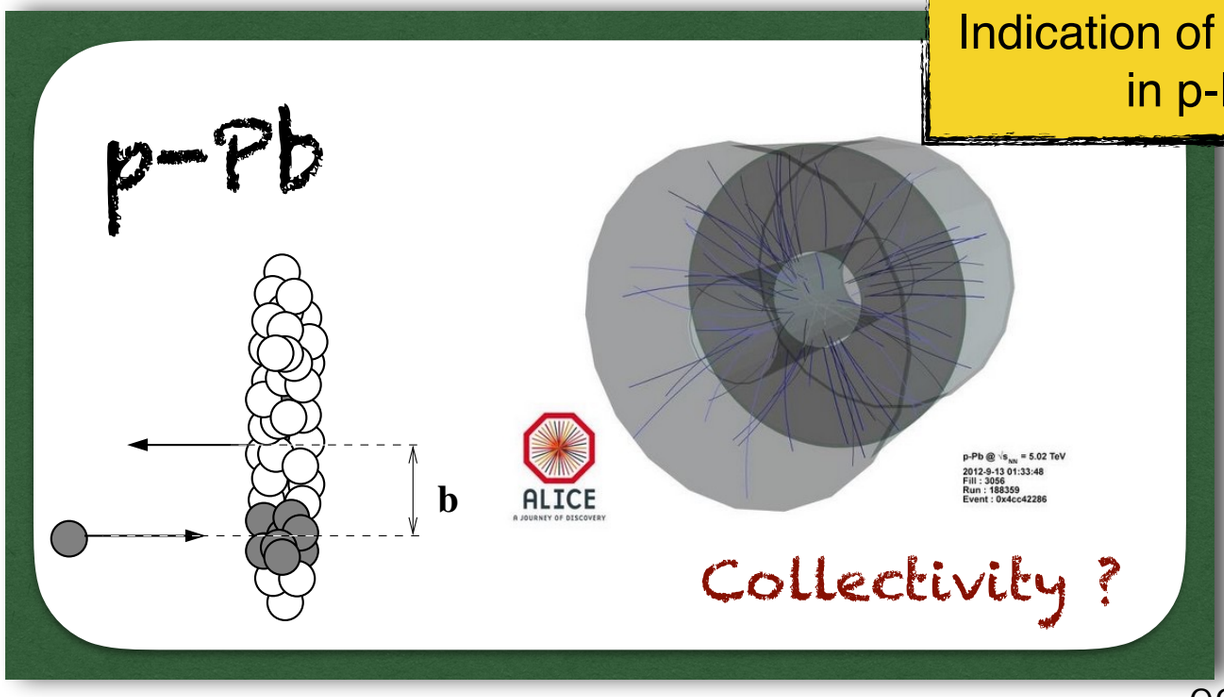


ALICE, PRL 107, 032301 (2011) C. Gale *et al* PRL 110, 012302 (2013)

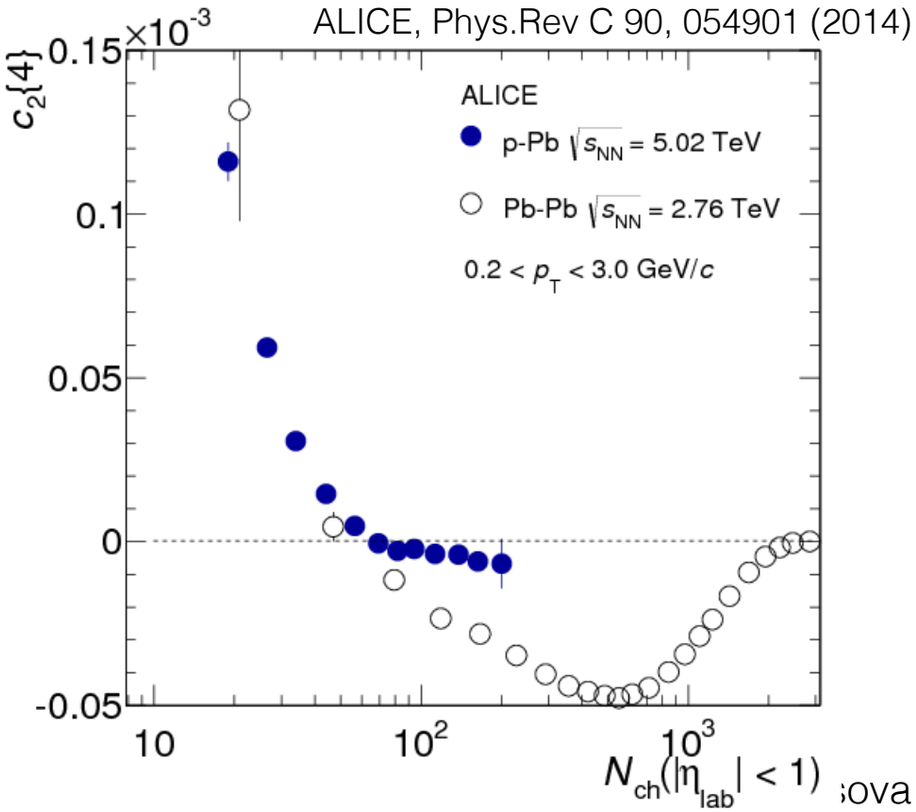


Flow results compatible with hydro models

Indication of collectivity in p-Pb



ALICE, Phys.Rev C 90, 054901 (2014)



;ova

Is flow produced in pp collisions?

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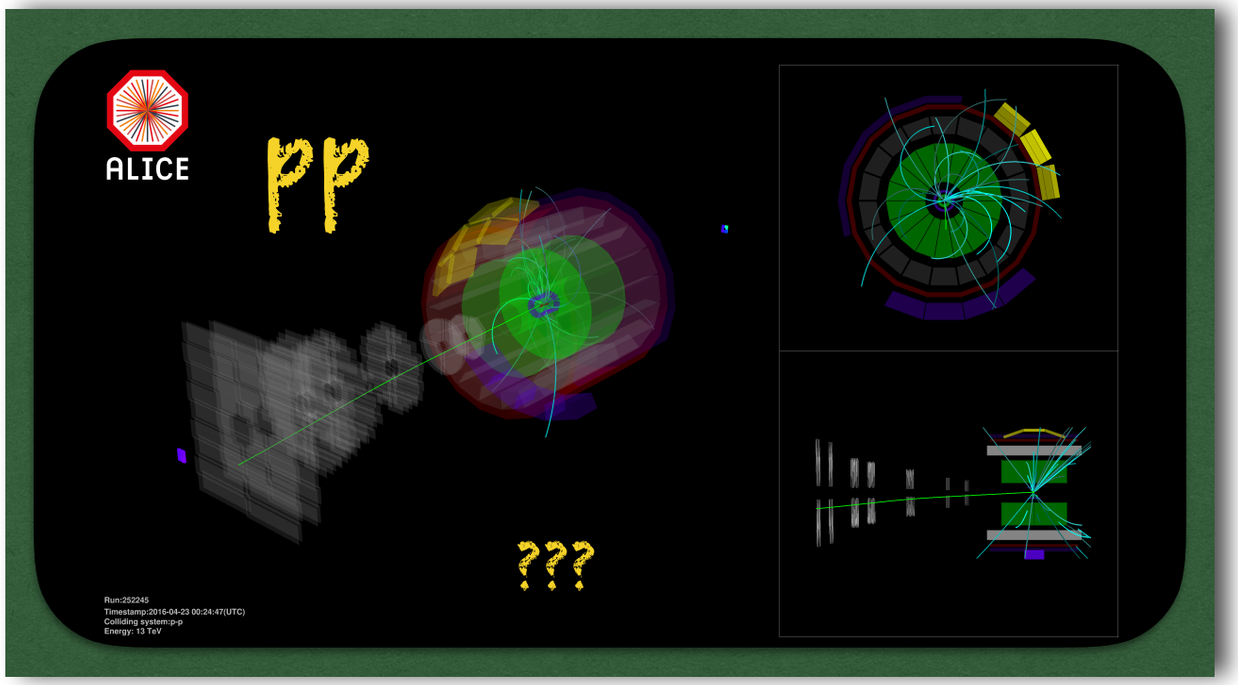
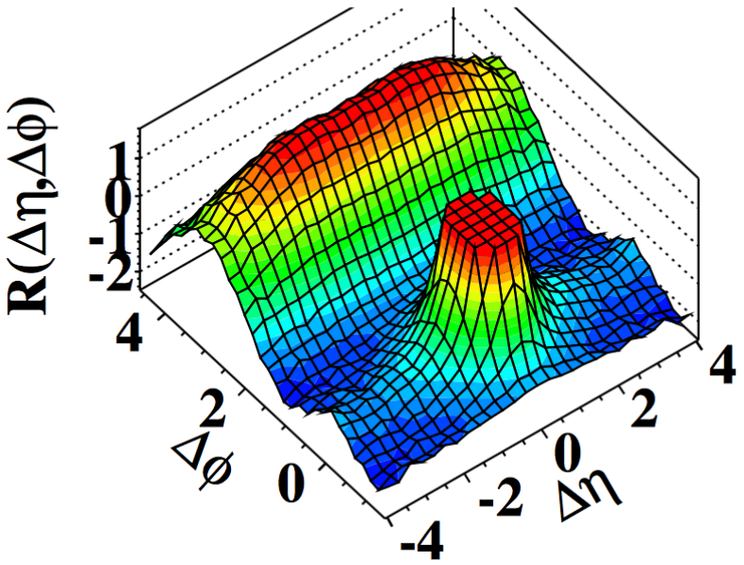


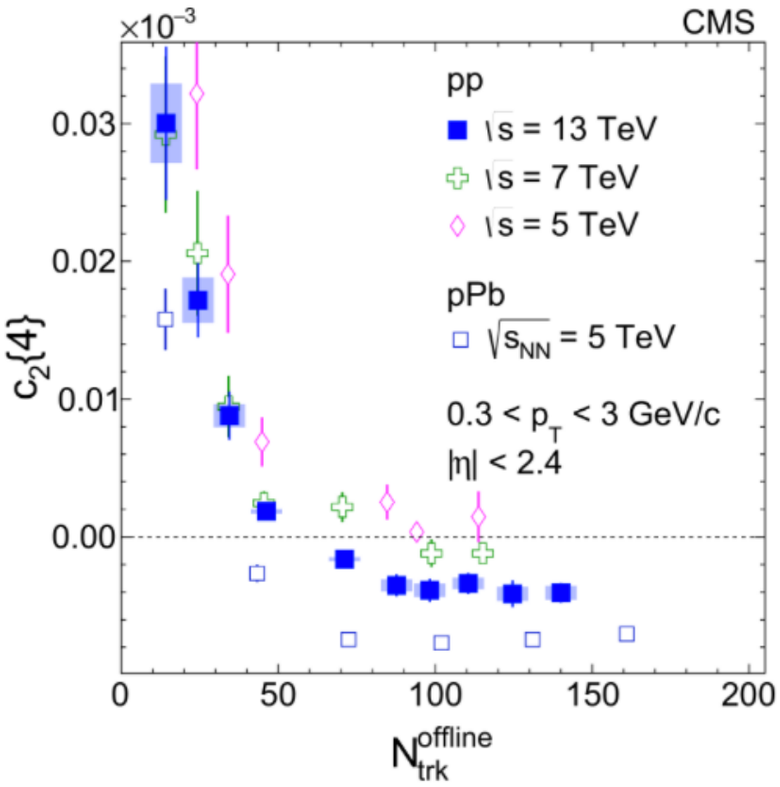
- Do we have an indication of collectivity?
  - Ridge observed in high multiplicity pp collisions at $\sqrt{s}$ = 7 TeV and 13 TeV
  - Negative $c_2\{4\}$ in high multiplicity pp collisions at $\sqrt{s}$ = 13 TeV measured by CMS and ATLAS
- What does ALICE observe?

CMS, JHEP 1009:091 (2010)

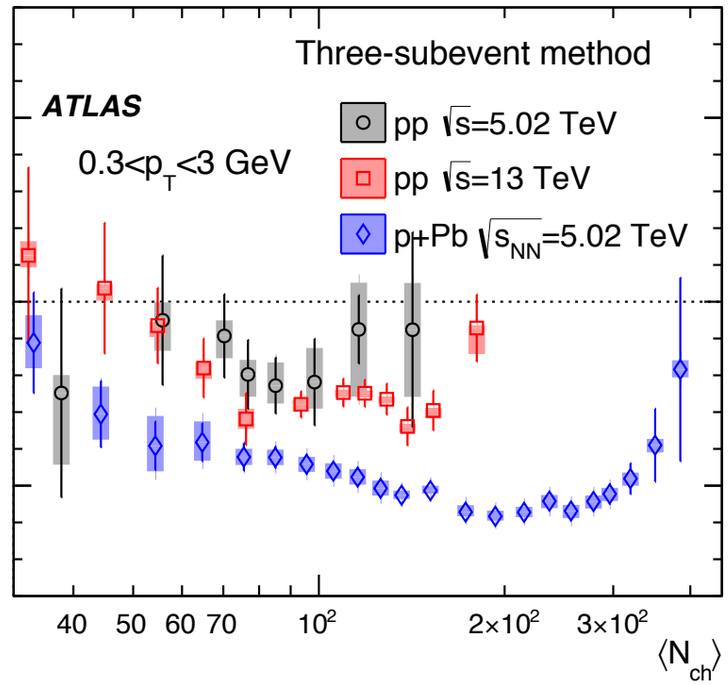
(d) CMS N ≥ 110, 1.0GeV/c<p_T<3.0GeV/c



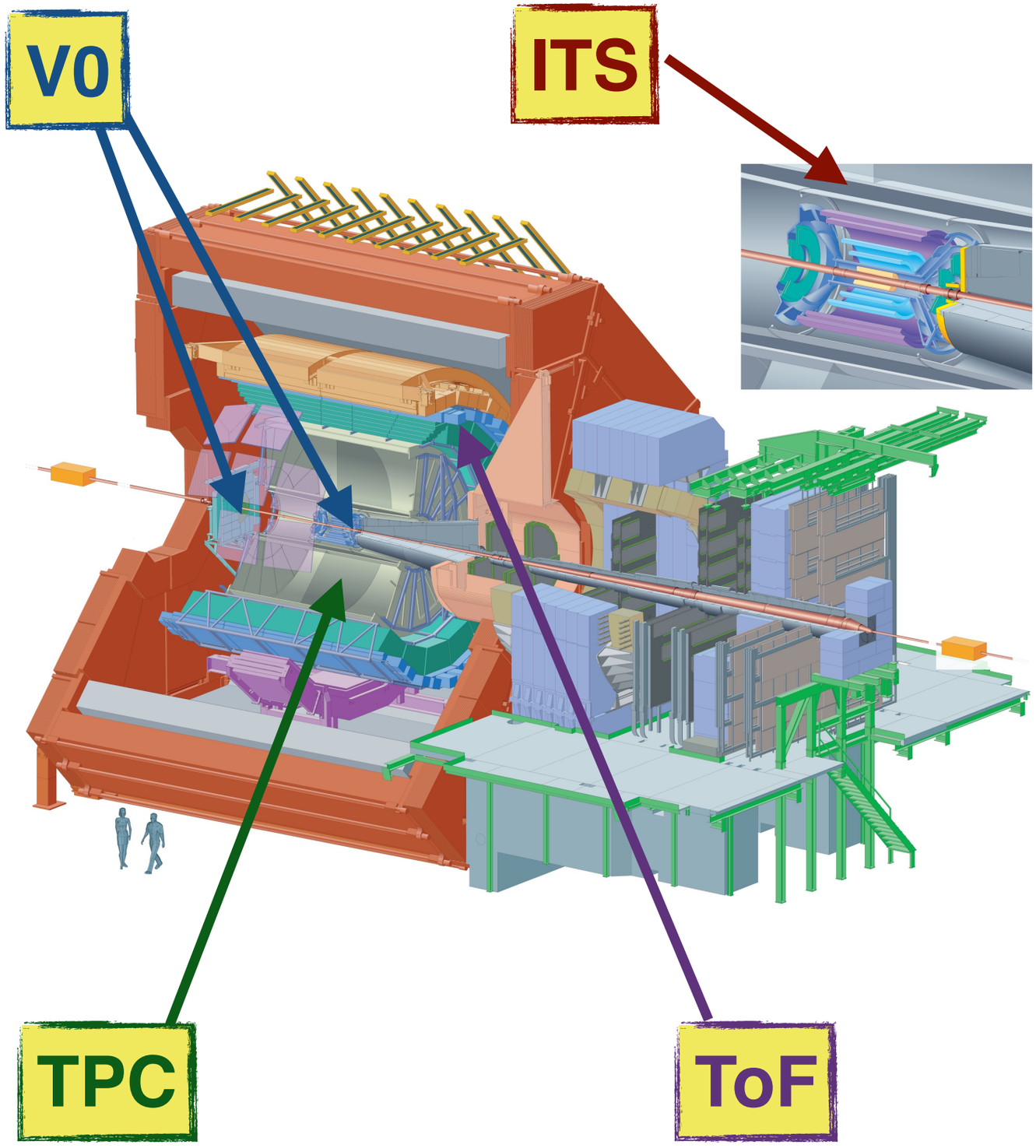
CMS, PLB 765 (2017) 193-200



ATLAS, arXiv:1708.03559 [hep-ex] (2017)



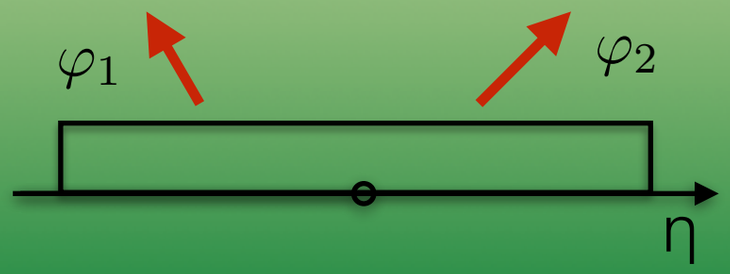
ALICE detector



- **ITS**
  - trigger, tracking, vertexing
- **TPC**
  - tracking, PID
- **V0**
  - trigger
- **ToF**
  - PID

- **Data samples**:
  - Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV
  - p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
    - minimum-bias and high-multiplicity trigger
  - pp at $\sqrt{s}$ = 13 TeV
    - minimum-bias and high-multiplicity trigger

2-particle cumulant $c_n\{2\}$

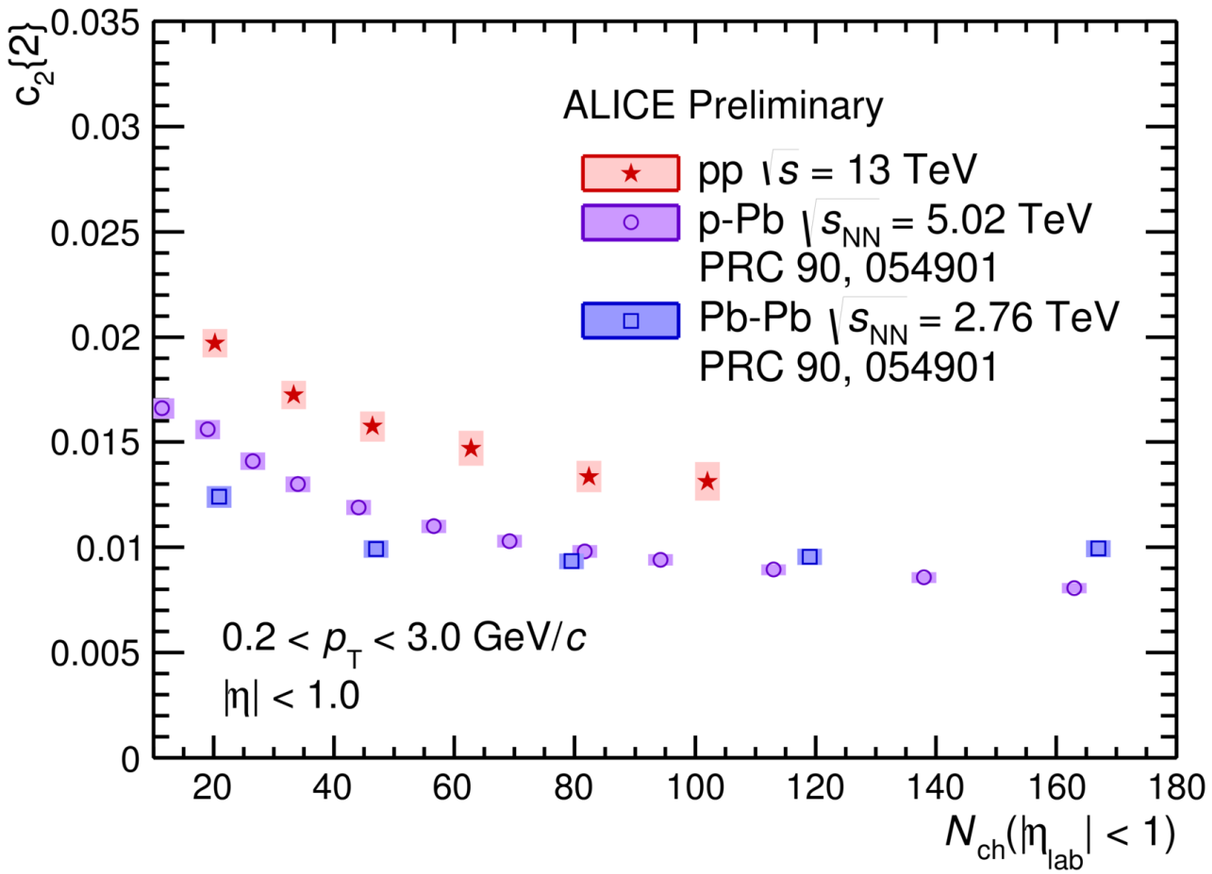


cumulant

$$c_n\{2\} = \langle\langle 2 \rangle\rangle = \langle\langle \cos n(\varphi_1 - \varphi_2) \rangle\rangle$$

flow coefficient

$$v_n\{2\} = \sqrt{c_n\{2\}}$$

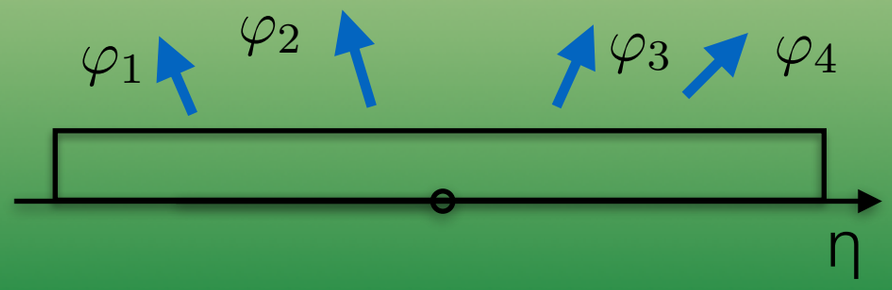


ALI-PREL-119544

- All systems show decreasing dependence on multiplicity
- $c_2\{2\}$ is clearly higher in **pp** collisions than in **p-Pb** or **Pb-Pb**
- However, 2-particle correlations measurements are affected by **non-flow effects** (e.g. contributions from jets and resonances), especially in small collision systems

Are there observables less sensitive to non-flow?

4-particle cumulant $c_n\{4\}$



cumulant

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

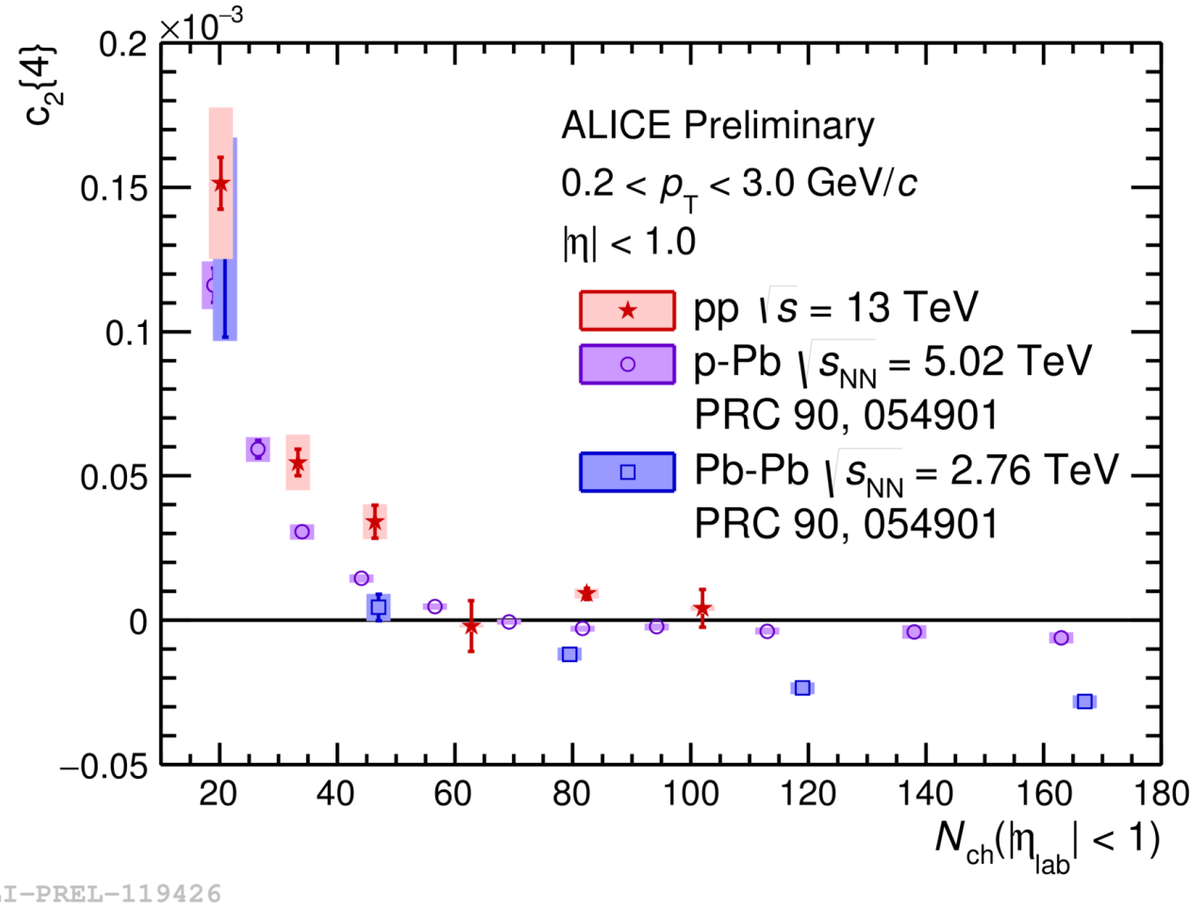
flow coefficient

$$v_n\{4\} = \sqrt[4]{-c_n\{4\}}$$

- 2-particle correlations (including non-flow) are subtracted from $c_n\{4\}$
- Negative $c_n\{4\}$ is considered to be a hint of collectivity
- Clear negative sign of $c_2\{4\}$ in high multiplicity p-Pb and Pb-Pb collisions is observed
- **No evident negative signal** of $c_2\{4\}$ in pp collisions

Any possible flow signal is probably significantly smaller than non-flow effects in small systems.

How can we suppress such effects in the measurements?



ALI-PREL-119426

Looking for flow in small systems

Niels Bohr Institutet

- How can we find the flow signal?

    1. Enhance flow by increasing the transverse momentum threshold

    2. Suppress non-flow by introducing |Δη| gap

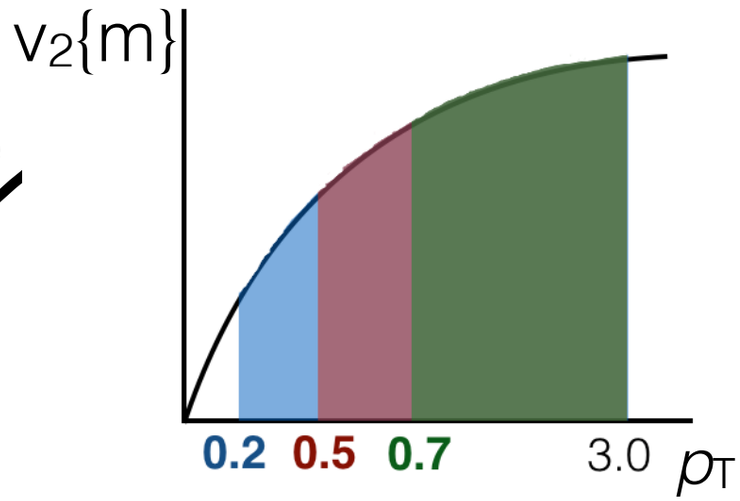
Looking for flow in large systems

Niels Bohr Institutet

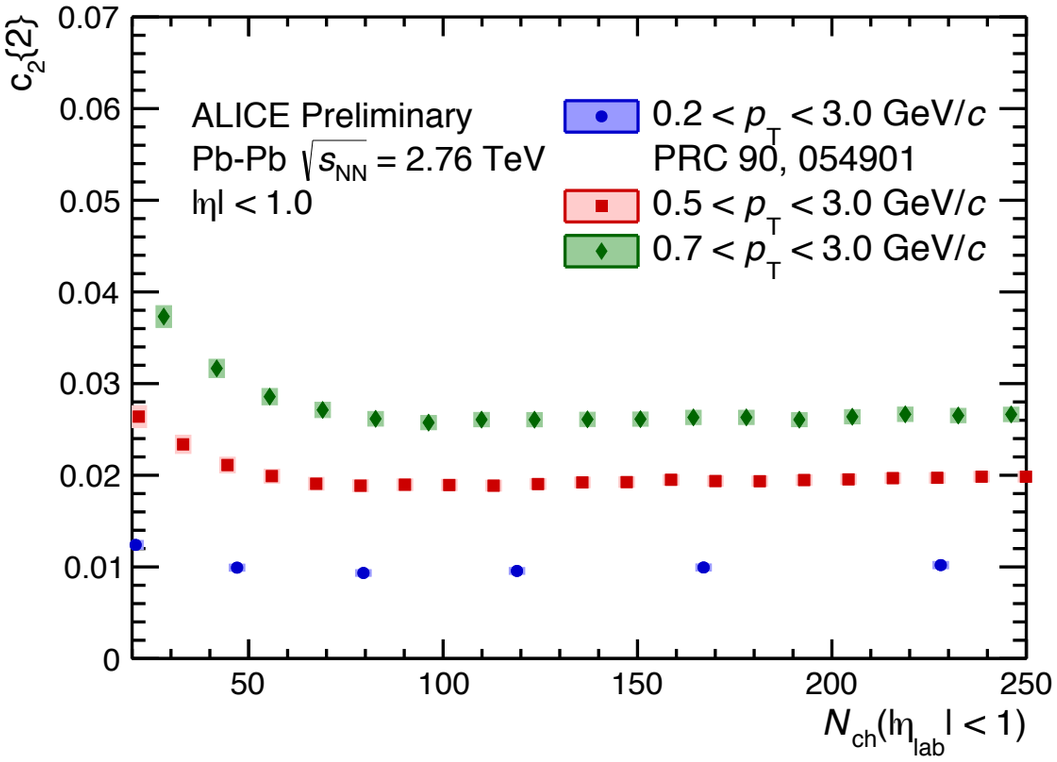
- How can we find the flow signal?

1. Enhance flow by increasing the transverse momentum threshold

Both flow and non-flow increase the measurements vs. N_{ch}



Flow decreases the measurement vs. N_{ch}, while non-flow increases it

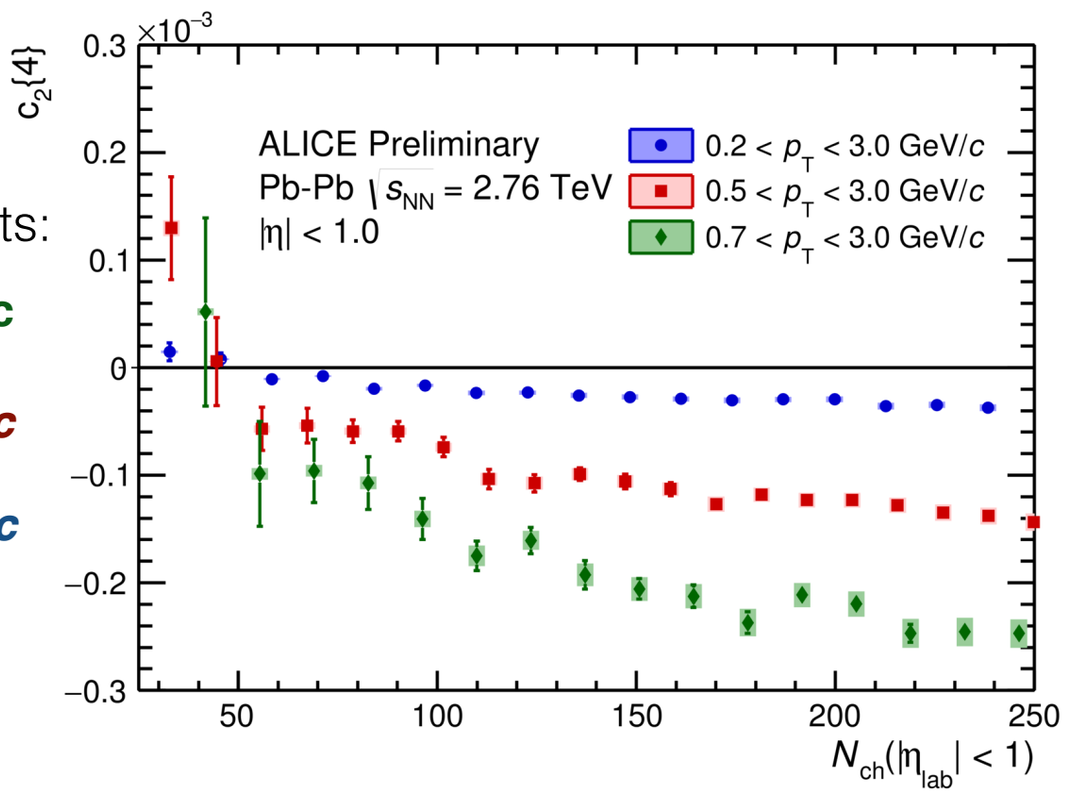


different low p_T cuts:

$0.7 < p_T < 3.0$ GeV/c

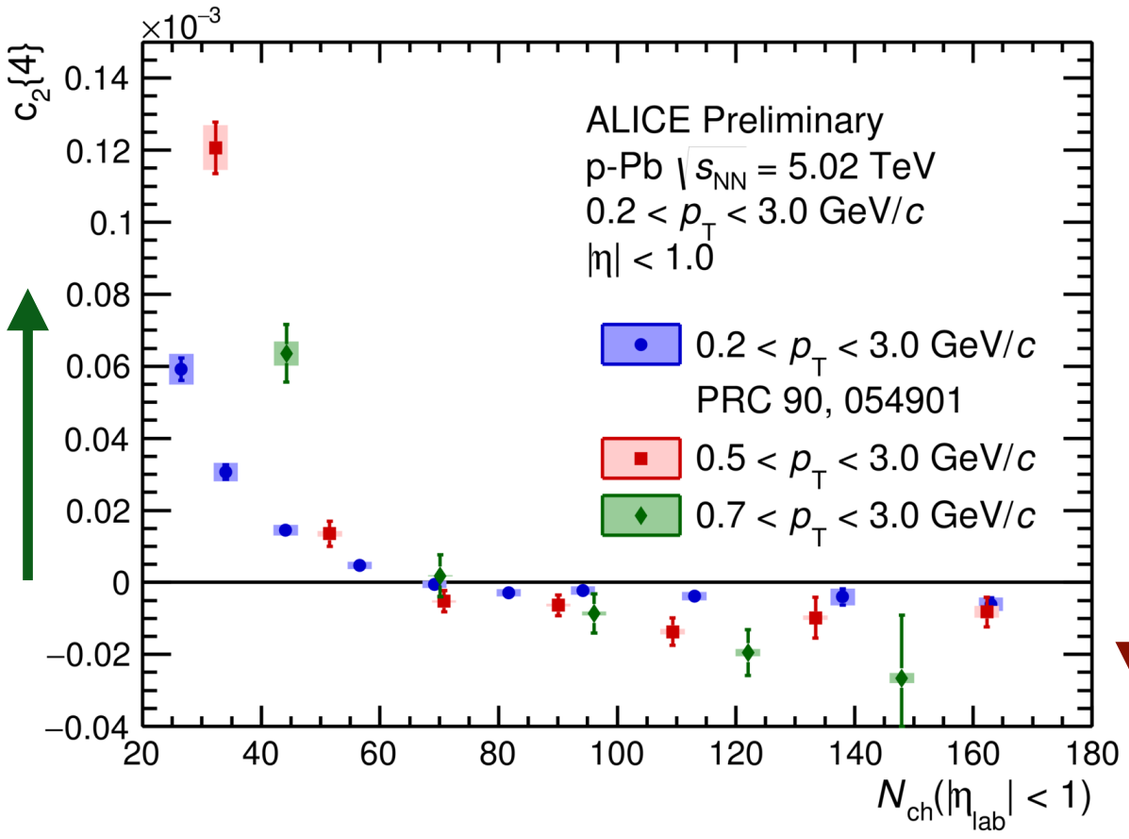
$0.5 < p_T < 3.0$ GeV/c

$0.2 < p_T < 3.0$ GeV/c

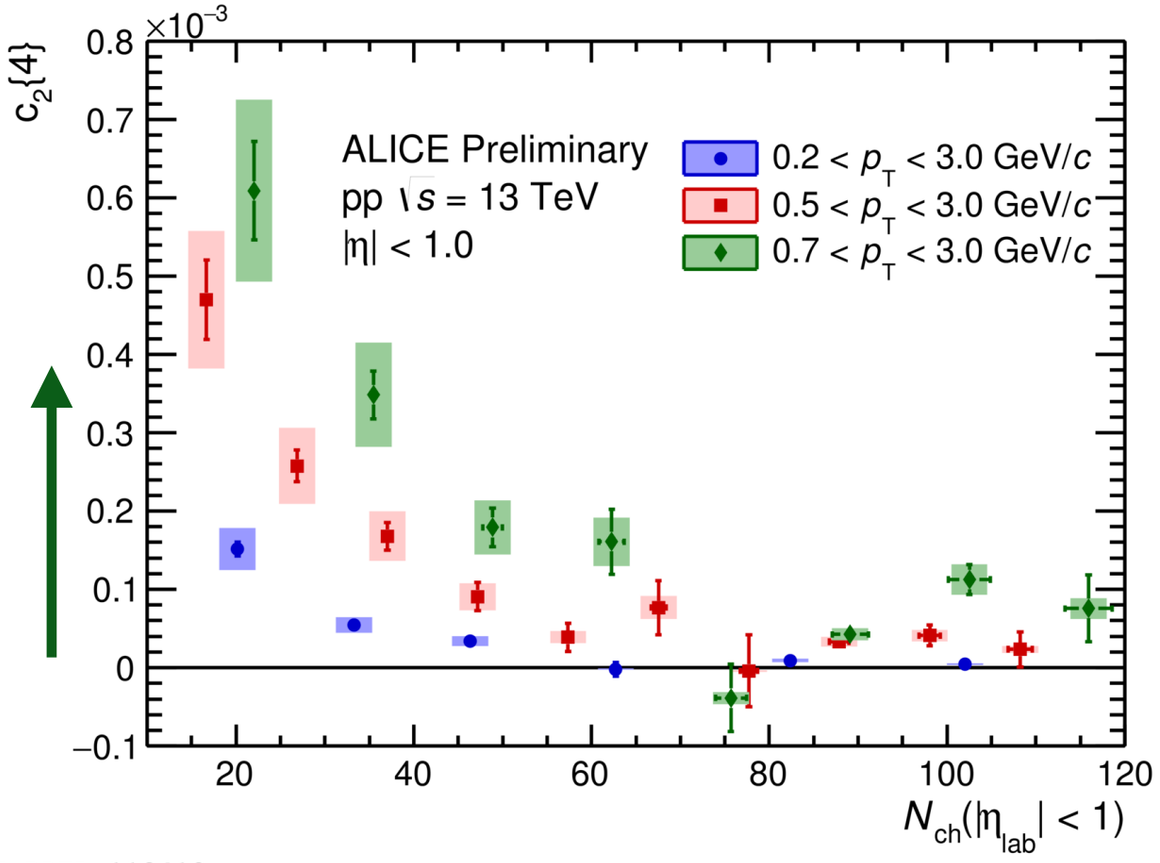


ALI-PREL-119535

Enhancing “flow” in small systems



ALI-PREL-119515



ALI-PREL-119410

- Measurements in p-Pb collisions exhibit similar behaviour as in Pb-Pb collisions:
  - $c_2\{4\}$ **increases** with increasing minimum p_T cut at low multiplicity
  - $c_2\{4\}$ seems to **decrease** with increasing minimum p_T cut at high multiplicity

- $c_2\{4\}$ in pp collisions **increases** with increasing minimum p_T cut through the whole multiplicity region
- **Opposite** behaviour to p-Pb or Pb-Pb measurements **at similar multiplicities**

Looking for flow in small systems

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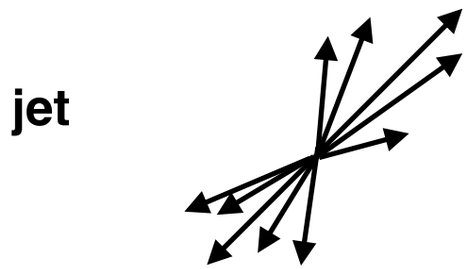
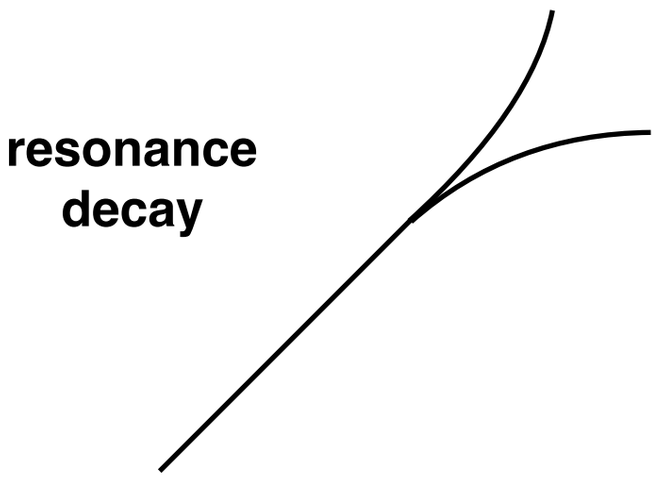
- How can we find the flow signal?

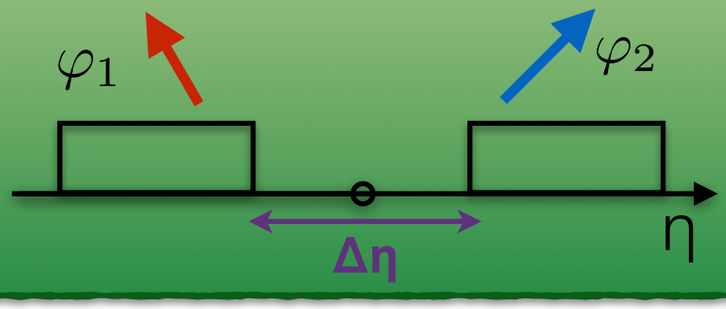
1. Enhance flow by increasing the transverse momentum threshold
2. **Suppress non-flow by introducing |Δη| gap**





- Particles from jets or resonance decays are strongly correlated, therefore they contaminate the measurements
- Angle between these particles is usually small
- Applying a |Δη| gap between sub-events suppresses correlations from particles with small opening angles

2-particle cumulant $c_n\{2, |\Delta\eta|\}$

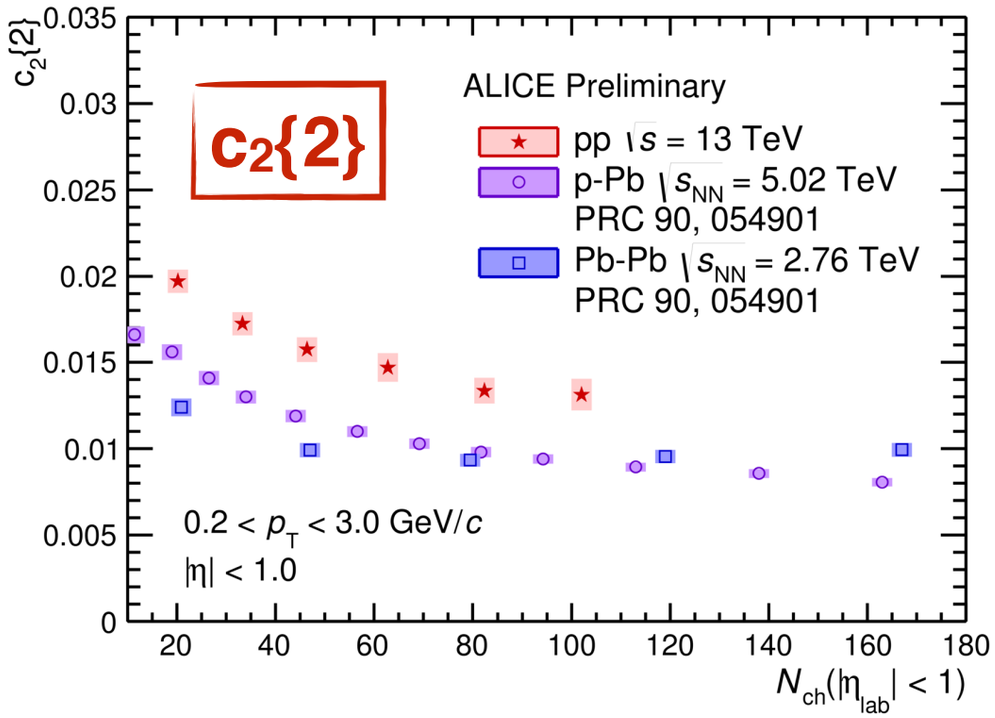


cumulant

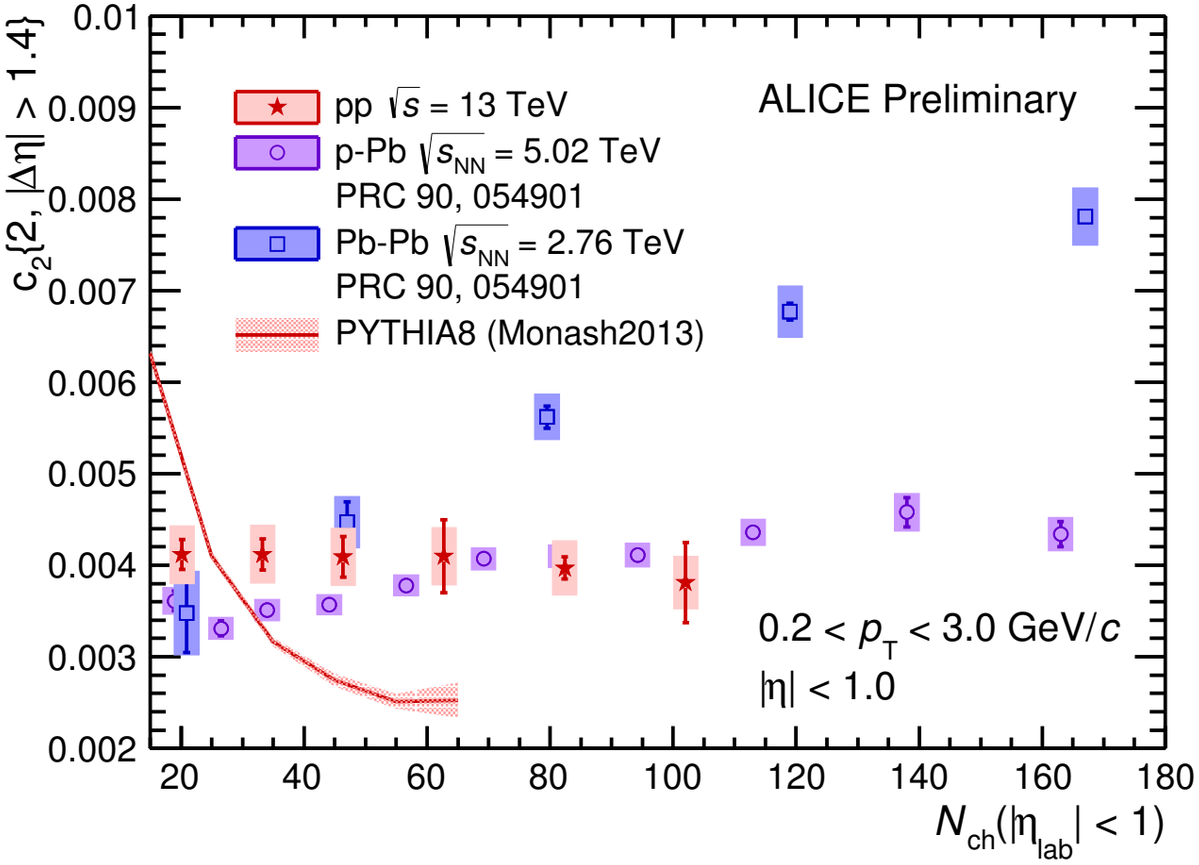
$$c_n\{2, |\Delta\eta|\} = \langle\langle \cos n(\varphi_1 - \varphi_2)\rangle\rangle$$

flow coefficient

$$v_n\{2, |\Delta\eta|\} = \sqrt{c_n\{2, |\Delta\eta|\}}$$



ALI-PREL-119544

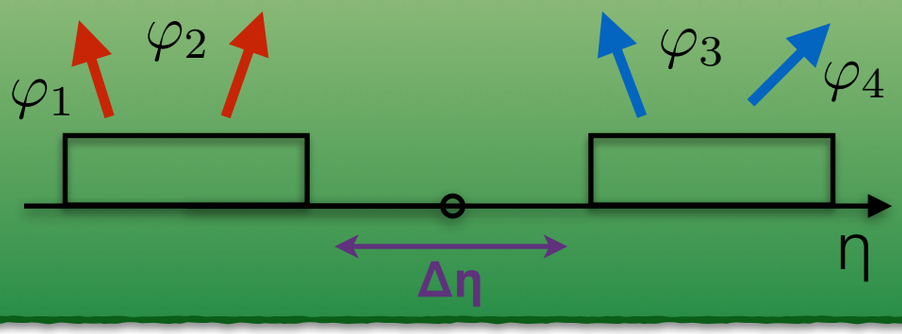


ALI-DER-129673

- $c_2\{2, |\Delta\eta| > 1.4\}$ is significantly smaller than $c_2\{2\}$ in all collision systems
  - **Suppresses non-flow effects** from short-range correlations

- $c_2\{2, |\Delta\eta| > 1.4\}$ in **pp** collisions shows weak dependence on multiplicity, which is different from PYTHIA

4-particle cumulant $c_2\{4, |\Delta\eta|\}$



cumulants

$$c_n\{4,|\Delta\eta|\} = \langle\langle 4\rangle\rangle_{|\Delta\eta|} - 2\cdot\langle\langle 2\rangle\rangle^2_{|\Delta\eta|}$$

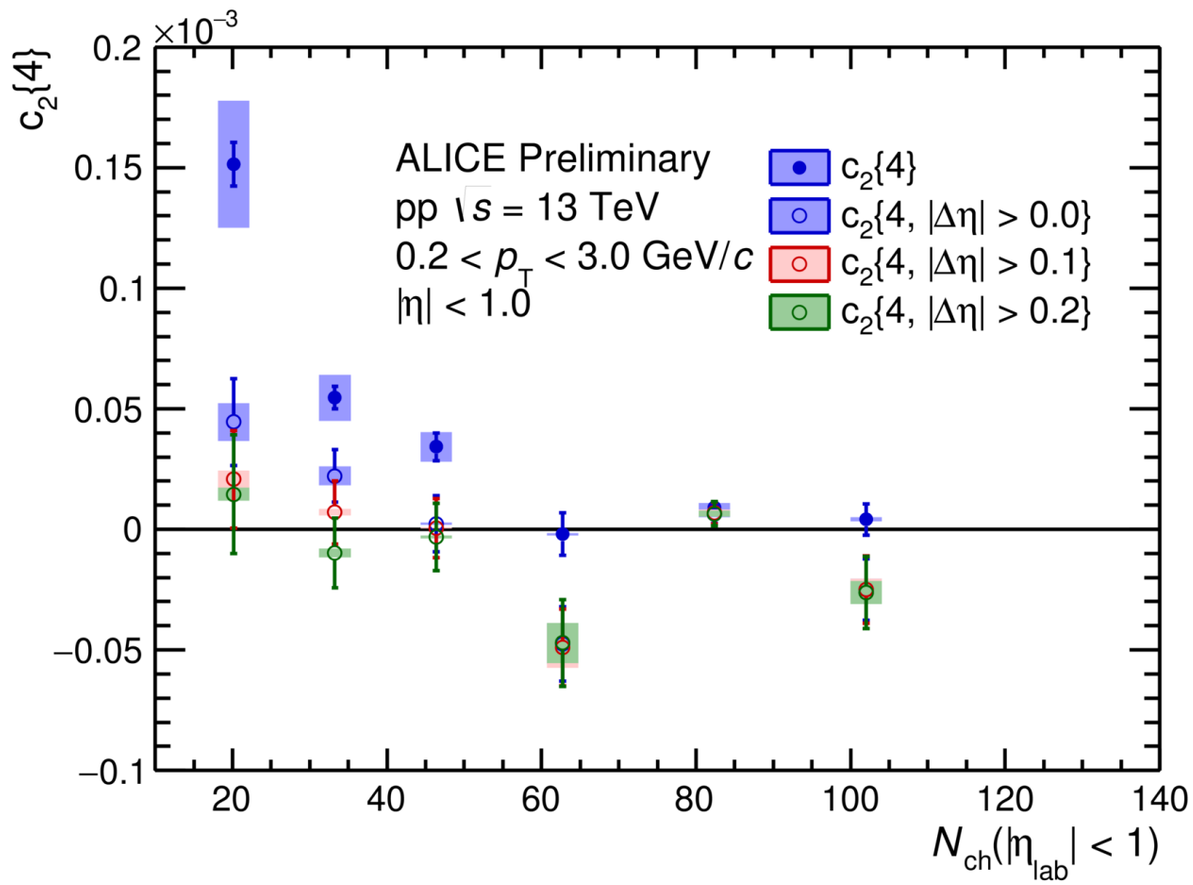
flow coefficient

$$v_n\{4,|\Delta\eta|\} = \sqrt[4]{-c_n\{4,|\Delta\eta|\}}$$

Can 4-particle correlation still be contaminated by non-flow?

- Clear decrease of $c_2\{4, |\Delta\eta|\}$ compared with $c_2\{4\}$, most significantly at low multiplicities
  - **Further suppression of non-flow** in multi-particle cumulants
- Still **no definitive flow signal**

Can we do more?



ALI-PREL-119434

Future in multi-particle cumulants

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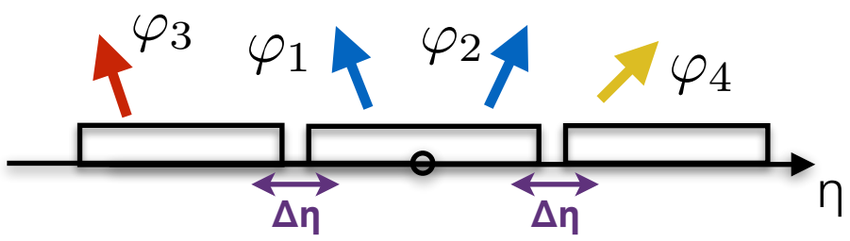
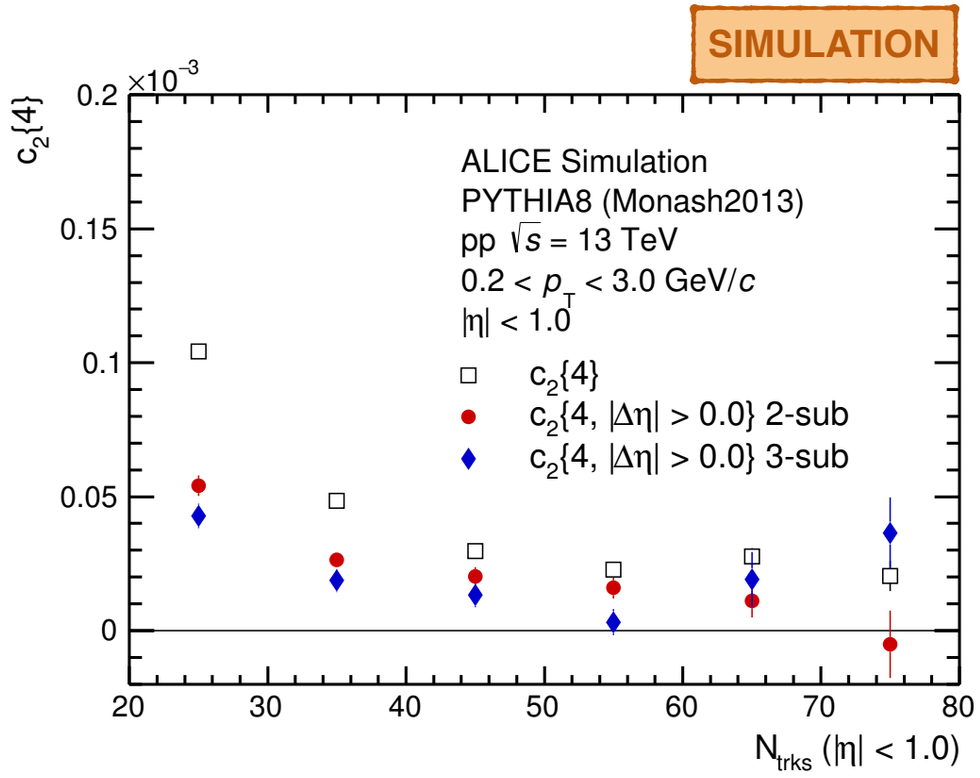
4-particle cumulant with 3-subevent method

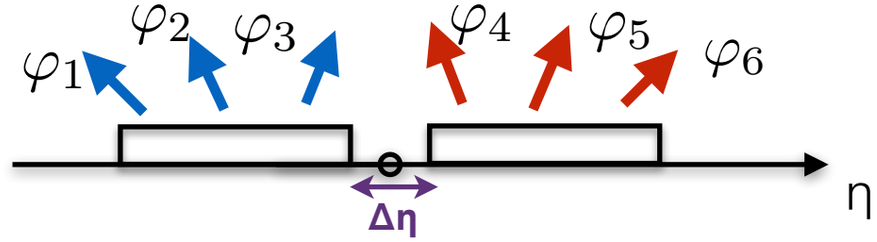


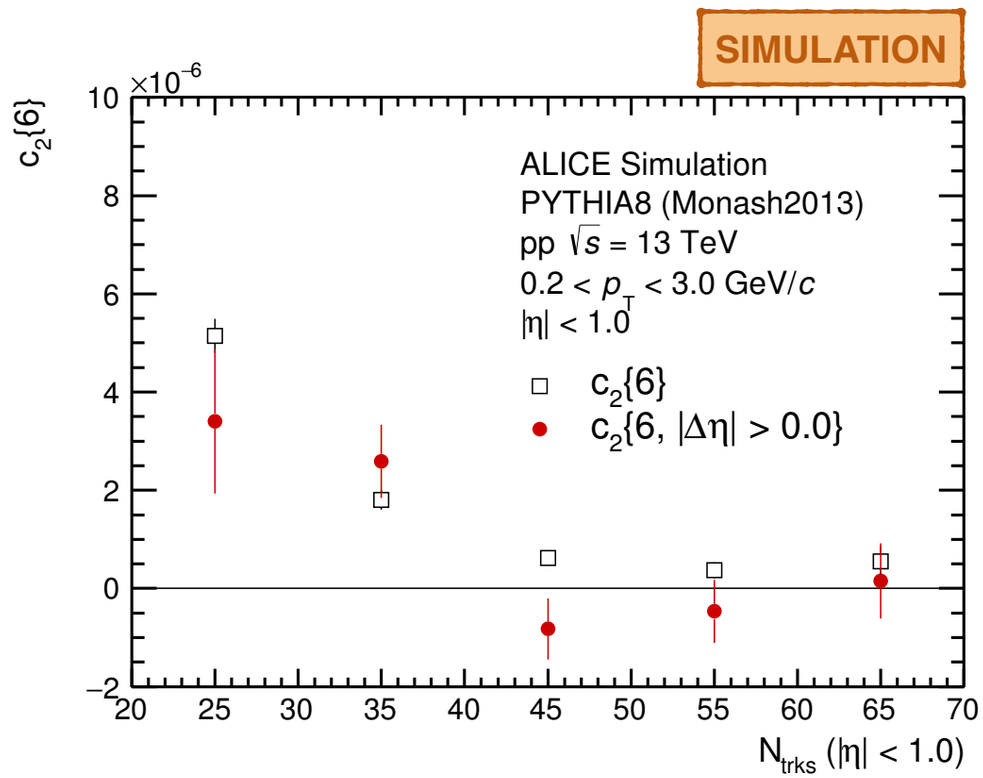


ALI-SIMUL-129367

- Measurements done with PYTHIA simulations
  - Splitting the acceptance into 3 subevents **further suppresses non-flow**

6-particle cumulant with 2-subevent method

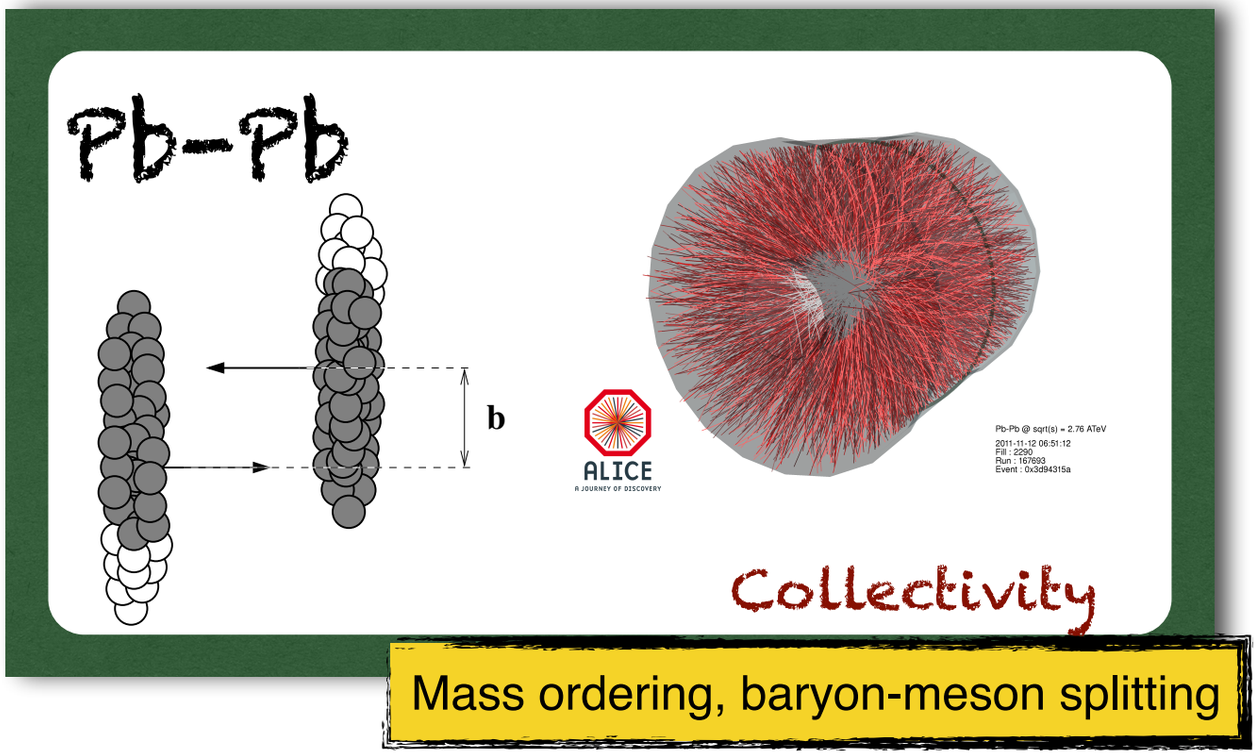




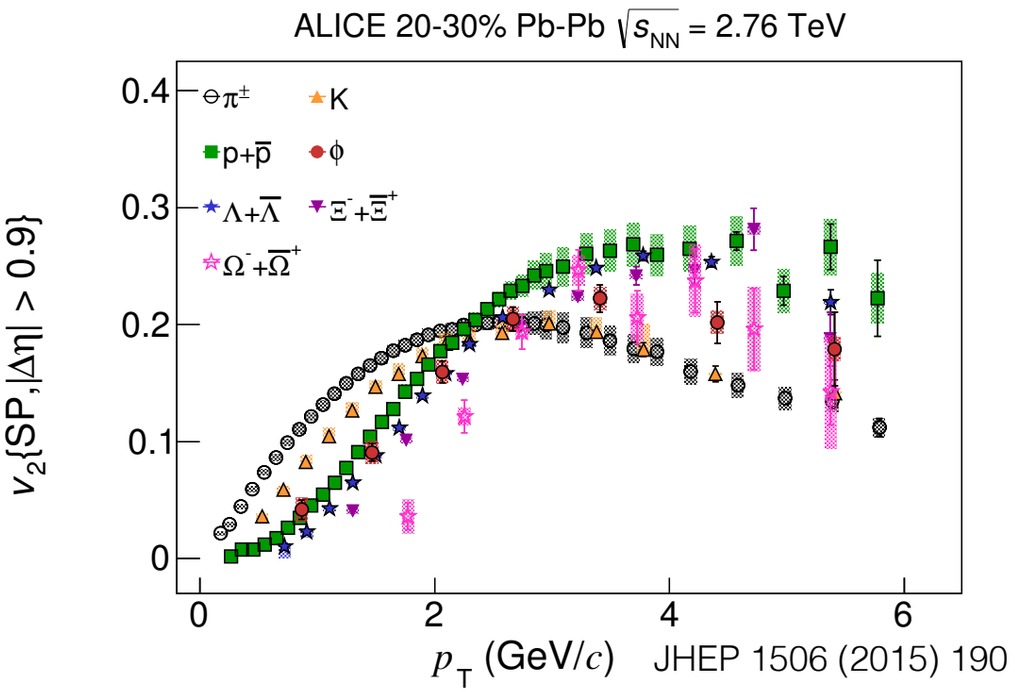
ALI-SIMUL-129375

- Measurements done with PYTHIA simulations
  - Results of $c_2\{6\}$ and $c_2\{6, |\Delta\eta| > 0.0\}$ are compatible within statistical uncertainties

Identified particle v_2

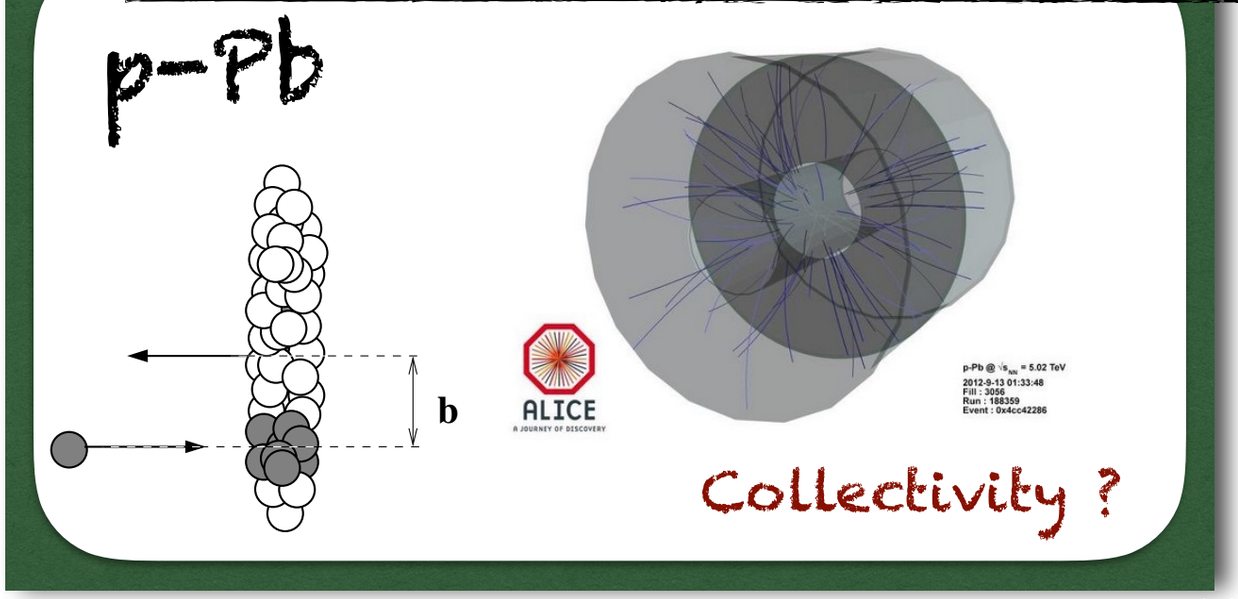


Mass ordering, baryon-meson splitting

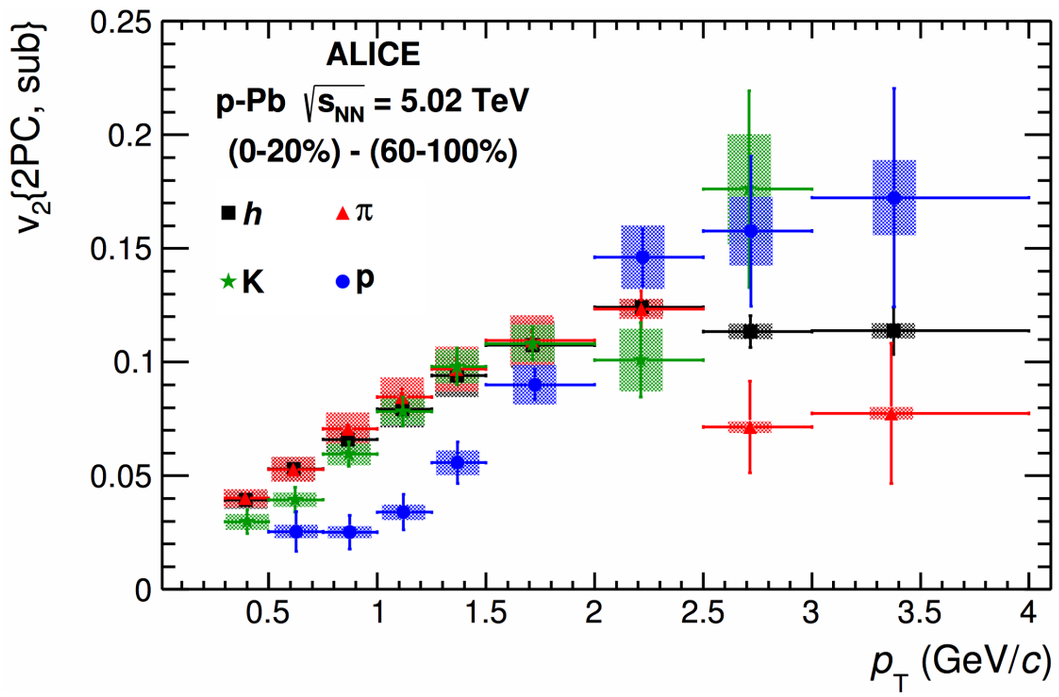


ALI-PUB-82981

Similar aspects as in Pb-Pb -> enough for collectivity?
Further investigation needed.



ALICE, Phys.Let.B 726 (2013) 164-177



Identification of particles

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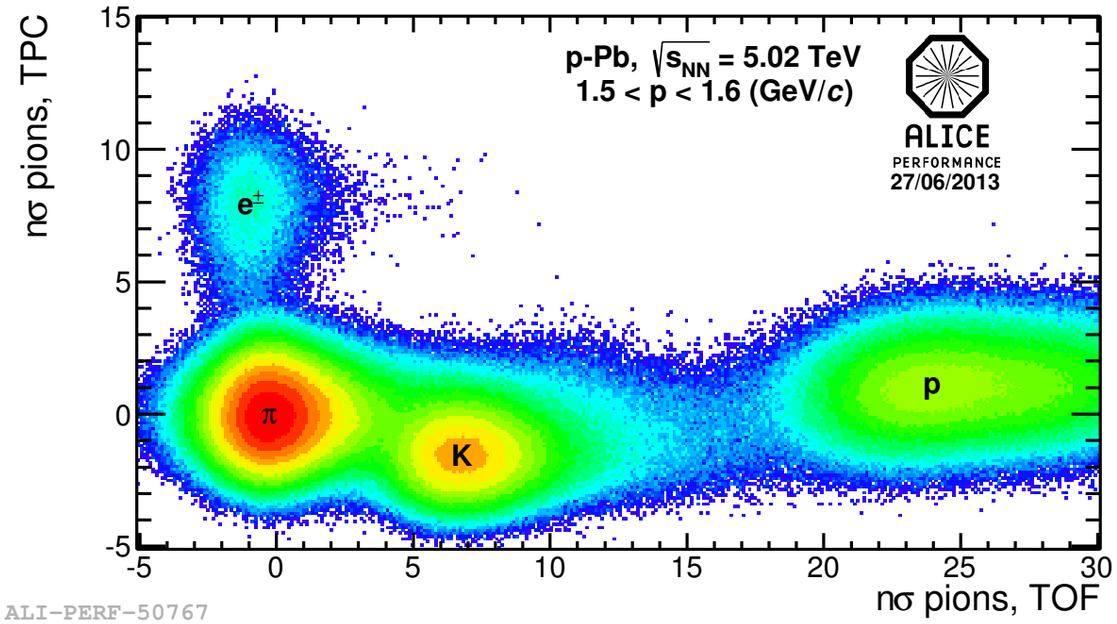
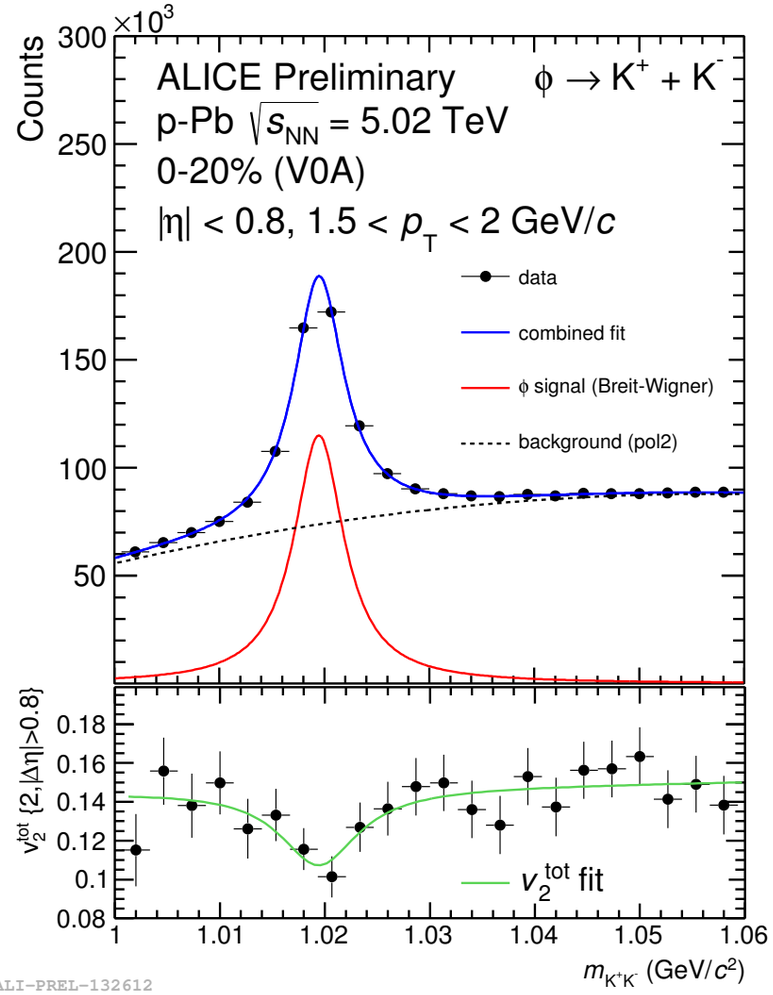
1. Particle identification using TPC&TOF detectors

- Good separation of pions, kaons, protons at low transverse momentum





2. Topological selection + invariant mass method

- Topological selection of shortly lived particles (e.g. K_S^0, Λ, ϕ) via their decay products
- v_2 vs. invariant mass method separates signal from combinatorial background based on additivity of v_2

$$v_2^{\mathrm{tot}}(m_{\mathrm{inv}}) = \frac{N^{\mathrm{sig}}}{N^{\mathrm{tot}}}(m_{\mathrm{inv}}) \cdot v_2^{\mathrm{sig}} + \frac{N^{\mathrm{bg}}}{N^{\mathrm{tot}}}(m_{\mathrm{inv}}) \cdot v_2^{\mathrm{bg}}(m_{\mathrm{inv}})$$

Identified particle v_2 in p-Pb collisions

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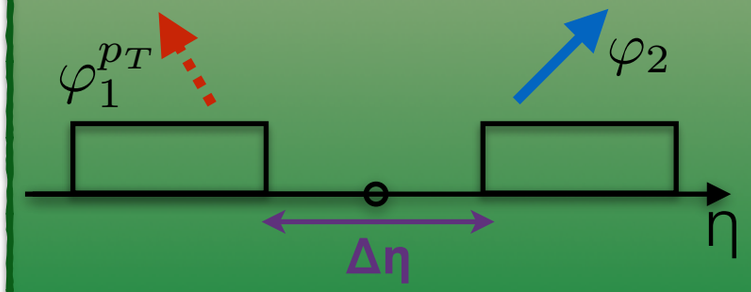
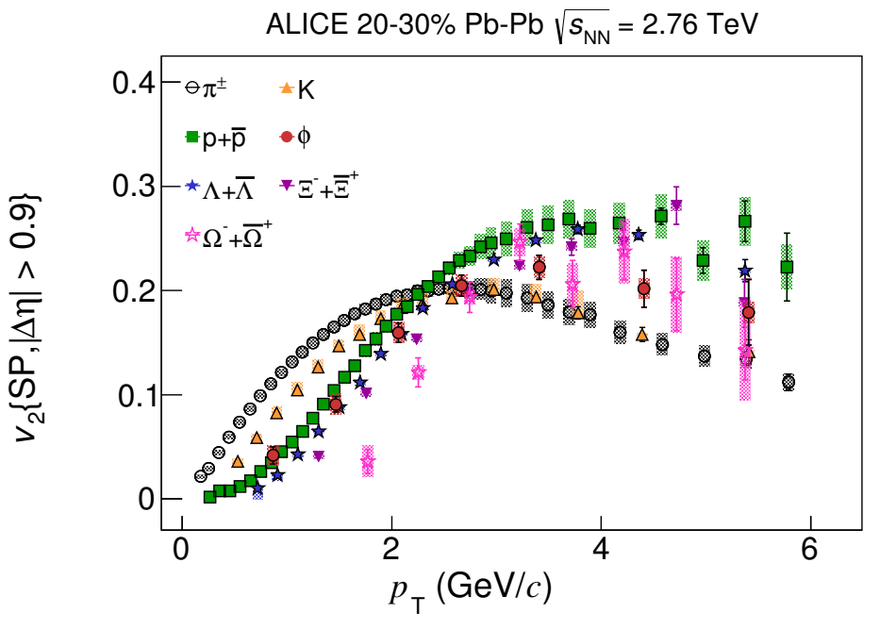


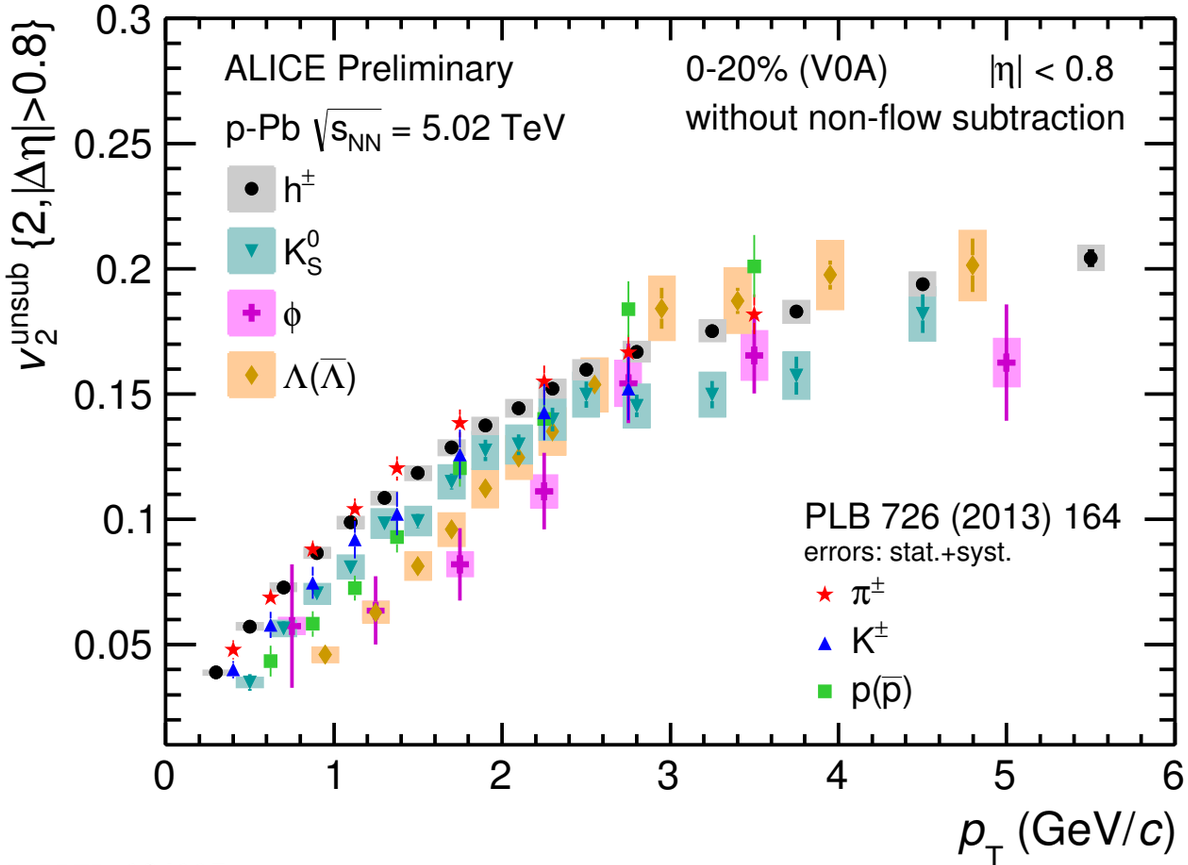
cumulant **flow coefficient**

$$d_n\{2,|\Delta\eta|\} = \langle\langle \cos n(\varphi_1^{p_T} - \varphi_2)\rangle\rangle \quad v_n\{2,|\Delta\eta|\}(p_T) = \frac{d_n\{2,|\Delta\eta|\}(p_T)}{\sqrt{c_n\{2,|\Delta\eta|\}}}$$

- Suppression of non-flow done by applying |Δη| gap
  - Non-flow subtraction method is not applied
- **Mass ordering** is observed for p_T < 2.5 GeV/c for all particles



ALI-PUB-82981



ALI-PREL-134117

Summary

- We present an investigation of anisotropic collectivity in Pb-Pb, p-Pb and pp collisions

- Clear **signs of collectivity** have been observed in high multiplicity **p-Pb** and **Pb-Pb** collisions
  - Negative $c_2\{4\}$ measurements at high multiplicities
  - Increasing the p_T cut drives the $c_2\{4\}$ to more negative values, showing dominance of flow
- ALICE has **not** measured a **definitive flow-like signature** in **pp** collisions using $c_2\{4\}$
  - Increasing the p_T cut drives the $c_2\{4\}$ to more positive values, shown dominance of non-flow
  - Further effort to suppress non-flow contributions using **$c_2\{4, |\Delta\eta|\}$** also did not reveal a definitive negative sign
- Evidence of **anisotropic collectivity is not confirmed in pp collisions** within the precision of ALICE data

(Presented results are based on data collected in 2015. Analysis of full data sample is ongoing.)

- Mass ordering reported for $p_T < 2.5$ GeV/c in **p-Pb** collisions (collectivity?)

ALICE

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Thank you for your attention!