ANISOTROPIC FLOW MEASUREMENTS IN SMALL SYSTEM

Mingrui Zhao

China Institute of Atomic Energy

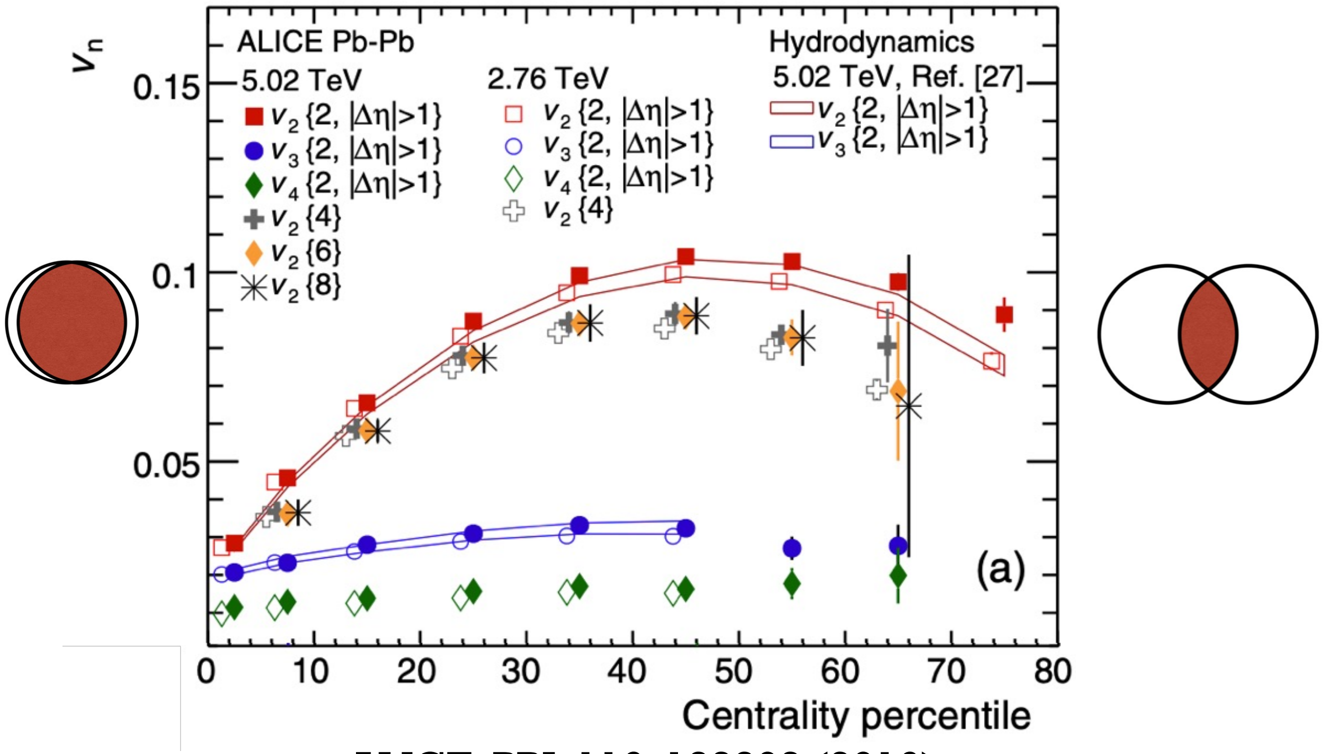
Workshop on Advances, Innovations, and Future Perspectives in High-Energy Nuclear Physics

23 Oct 2024

Anisotropic flow in heavy-ion collisions

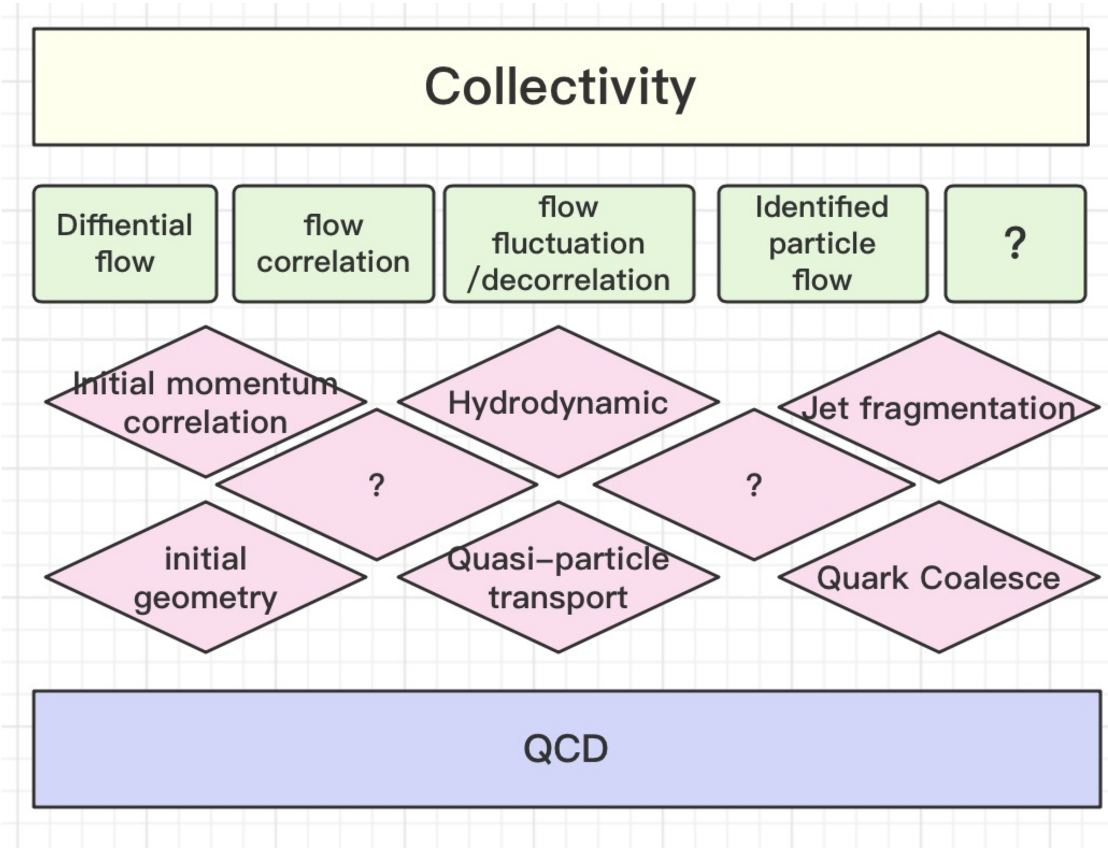
Anisotropy in azimuthal distribution of final-state particles:

$$\frac{dN}{d\phi} \approx 1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\phi - \psi_n))$$

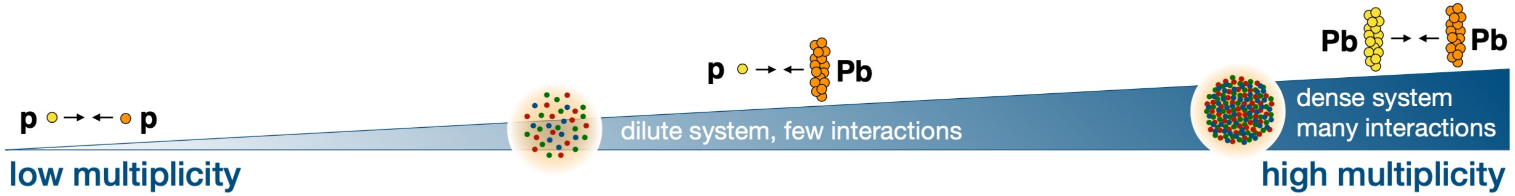


ALICE, PRL 116, 132302 (2016)

- Origin of the collectivity

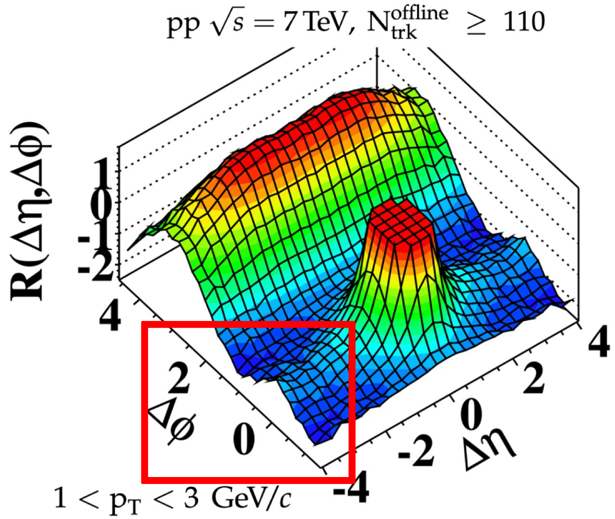


Collectivity in small systems

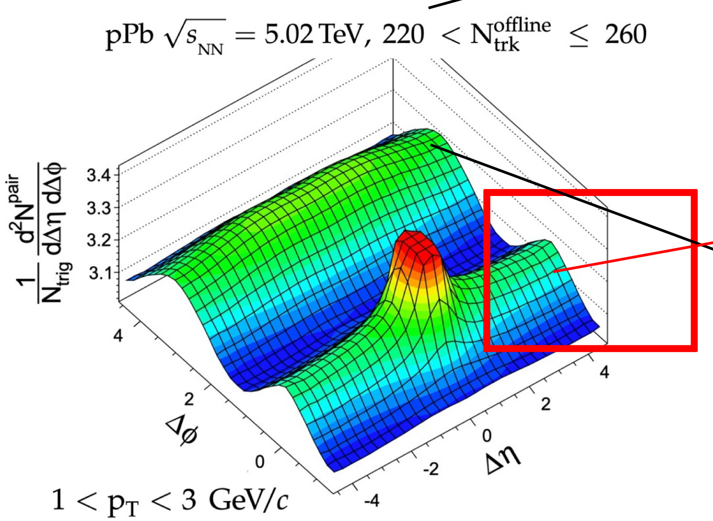


- A (more than) ten-year puzzle:
- Still one of the **most surprising discovery at LHC** !

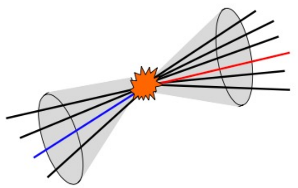
[JHEP 09 (2010) 091]



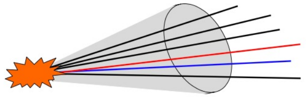
[Phys.Lett.B 718 (2013)]



Back-to-back jet + lorentz boost



Particles from different η region are correlated, **why?**



Single jet

Flow in small systems

- People want to measure flow in small systems, but, what is flow?

- Flow: **single particle** distribution:

$$\frac{dN}{d\phi} \approx 1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\phi - \psi_n))$$

- Requirement:
  - Given a single event, particles within the event are uncorrelated
  - Hard to be satisfied in pp and pPb collisions

- Typical methods:
  - **Multi-particle correlations with gap**
  - **Template fit**

Different method = Different physics

Flow is only a name?
Why not just construct some observable and compare with model?

If what is measured is similar to flow -> indicate the underlying mechanism is similar to QGP

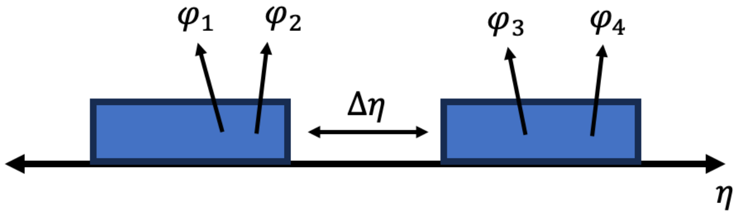
Multi-particle correlations with gaps

$\mathrm{SC}(m,n) = \mathrm{cov}(v_m^2, v_n^2)$: correlation of **event-by-event** v_n

$$\mathrm{SC}(3,2) = \langle\langle\cos(3\varphi_1 + 2\varphi_2 - 3\varphi_3 - 2\varphi_4)\rangle\rangle - \langle\langle\cos(3\varphi_1 - 3\varphi_3)\rangle\rangle\langle\langle\cos(2\varphi_2 - 2\varphi_4)\rangle\rangle$$

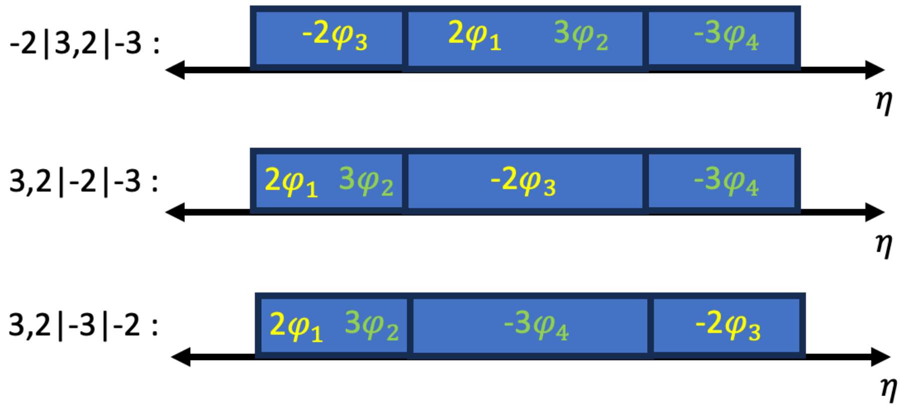
$$\langle\cos(3\varphi_1 + 2\varphi_2 - 3\varphi_3 - 2\varphi_4)\rangle = \left(\frac{1}{N_{\mathrm{comb}}}\sum_{i\neq j\neq k\neq l}\cos(3\varphi_i + 2\varphi_j - 3\varphi_k - 2\varphi_l)\right)$$

|Δη| separation method



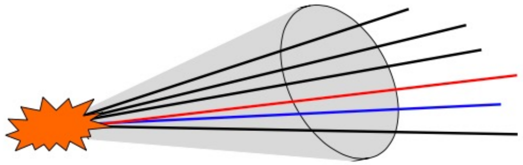
$$\langle\langle\cos(3\varphi_1 + 2\varphi_2 - 3\varphi_3 - 2\varphi_4)\rangle\rangle$$

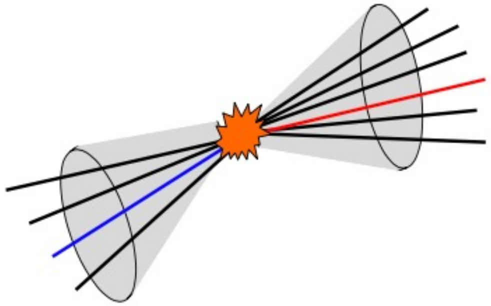
Three subevent method



- -3|3,2|-2 : **two short** range correlations
- 3,2|-2|-3 : **short** range correlation of $n = 2$ and **long** range correlation of $n = 3$
- 3,2|-3|-2 : **long** range correlation of $n = 2$ and **short** range correlation of $n = 3$

Multi-particle correlations with gaps



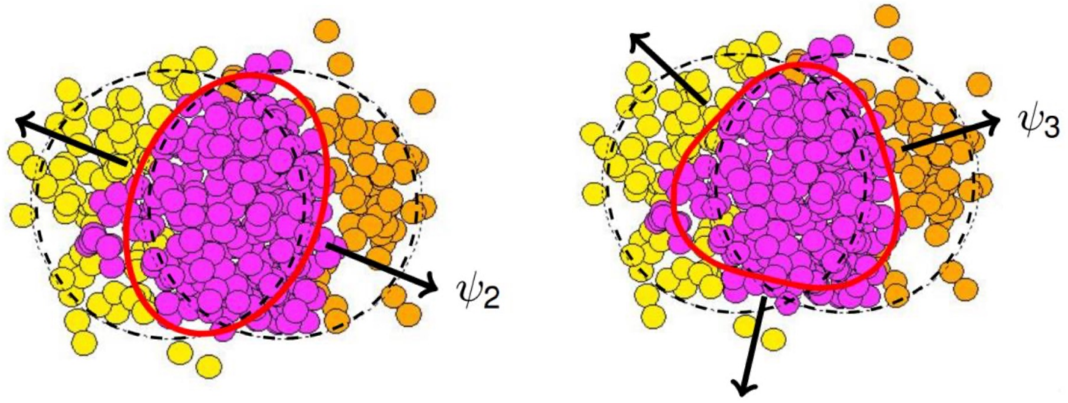


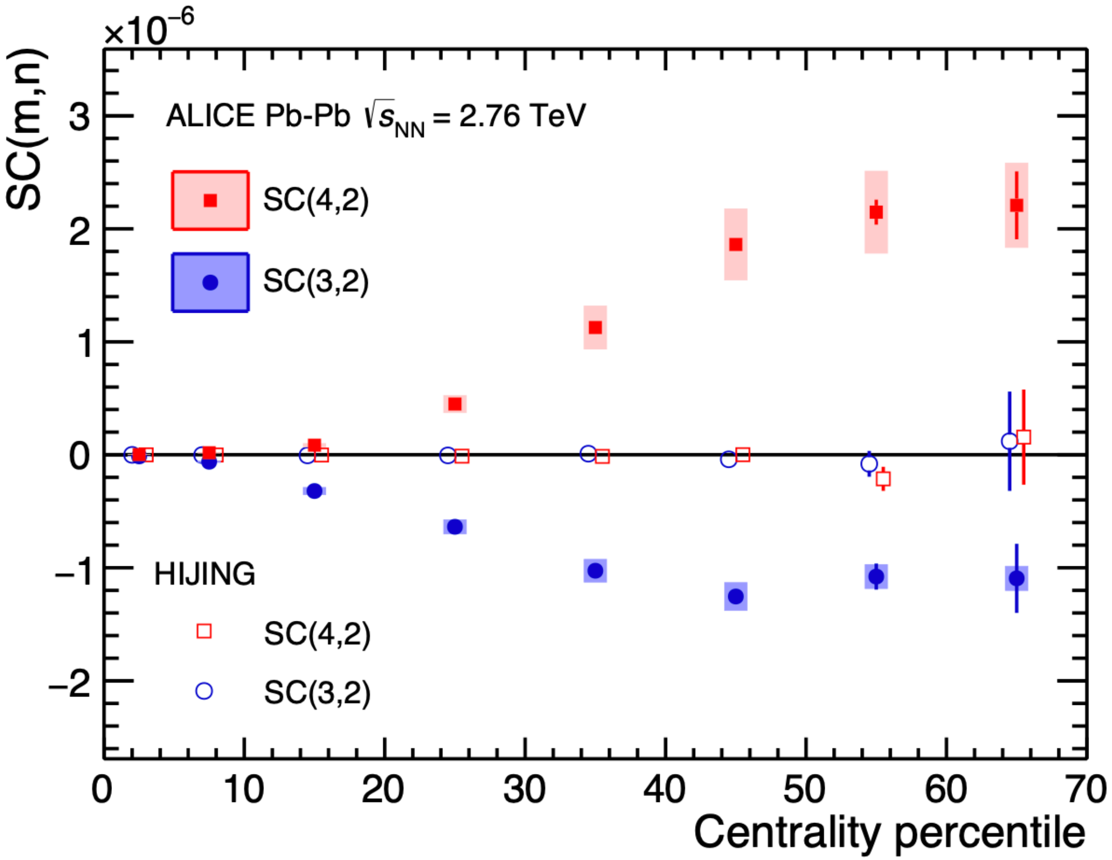
- What is measured including contributions from many sources:
  - Remnant of the jets and cascade decay
  - Back-to-back jets (intrinsic non-removable)

- To isolate the **non-trivial correlations** are highly depends on theory
- The **conclusions draw from data** only should be very **weak** considering the complex sources that causes the correlations
- The method it self is **simple,** so robust for apple-to-apple comparison with model calculations

Flow correlations

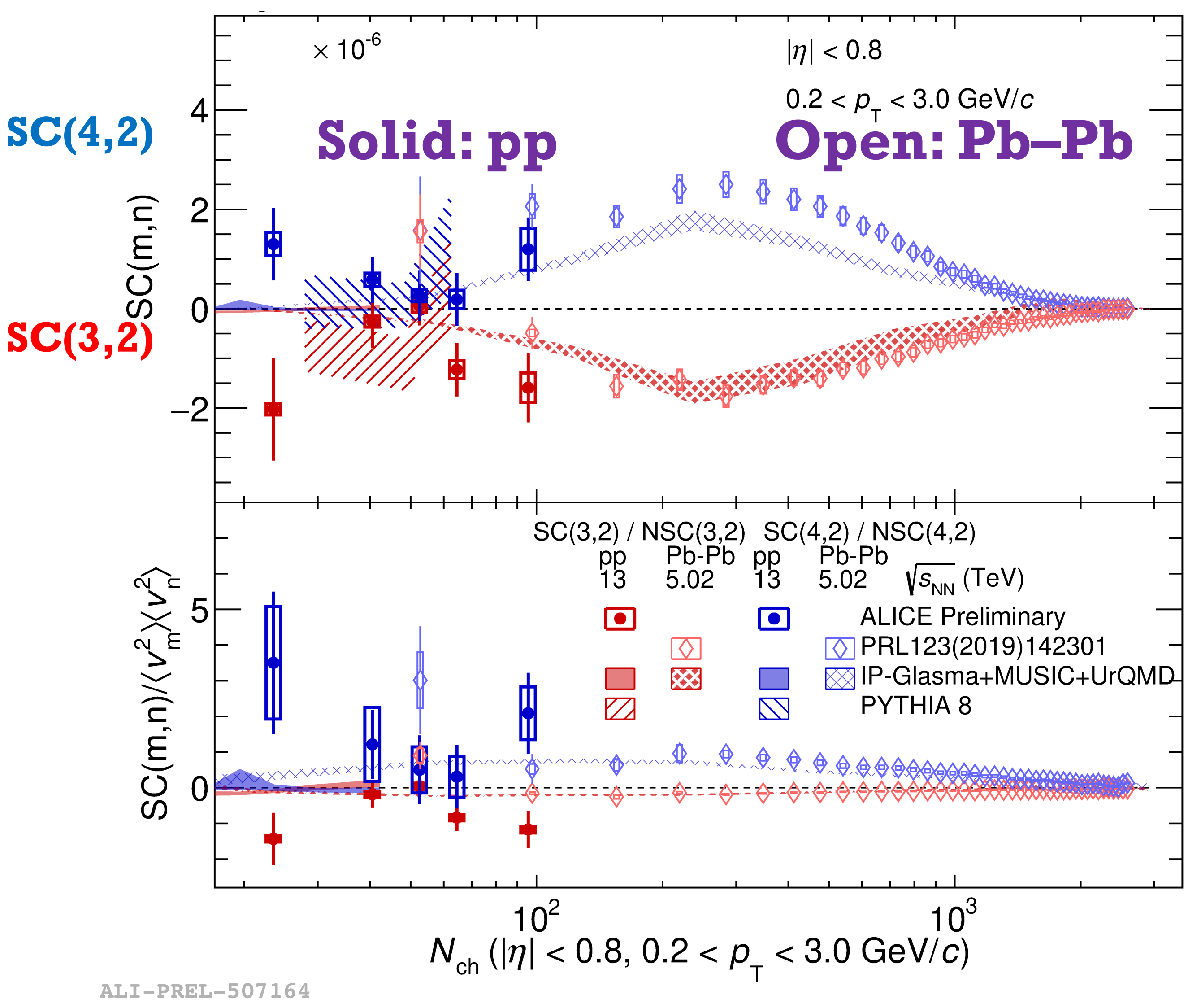
- $\mathrm{SC}(m,n) = \mathrm{cov}(v_m^2, v_n^2)$: correlation of **event-by-event** v_n
- At **non-central** region:
  - **Positive** SC(4,2)
  - **Negative** SC(3,2)





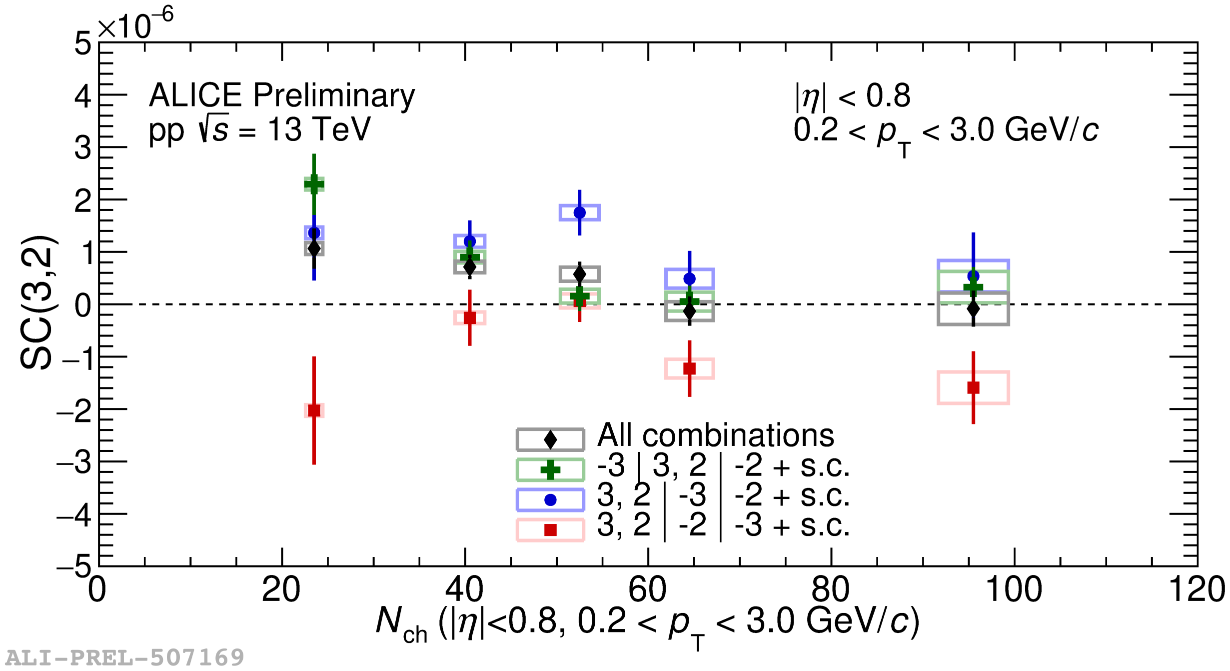
ALICE, PRL 117 (2016) 182301

Flow correlations in small systems

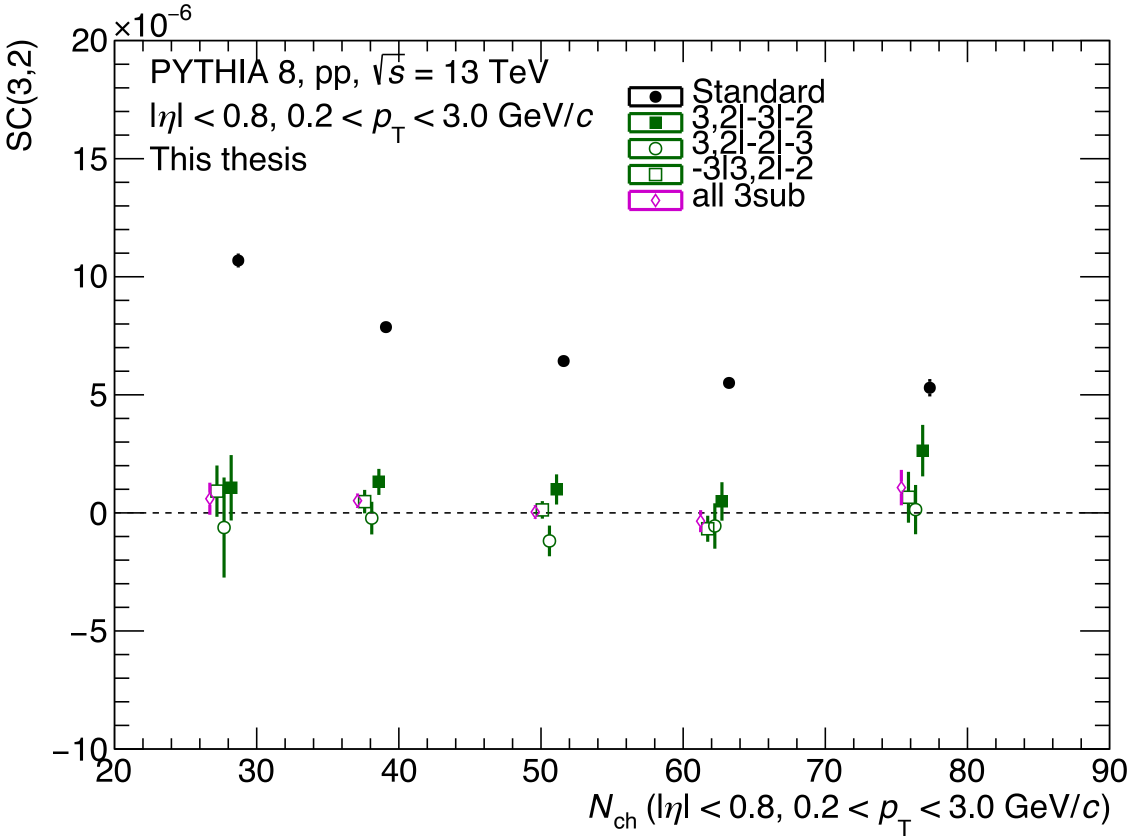


- Hint of **negative SC(3,2)** (2.1σ significance) and **positive SC(4,2)** (1.9σ significance) in pp collisions, having the **same sign** as Pb–Pb collisions
- Constraints on **initial geometry fluctuations**

Flow correlations in small systems



ALICE



PYTHIA

- Configurations matter in pp collisions!
- Apple-to-apple comparison is possible
- Suggesting the conclusions from last slides are only **indications**

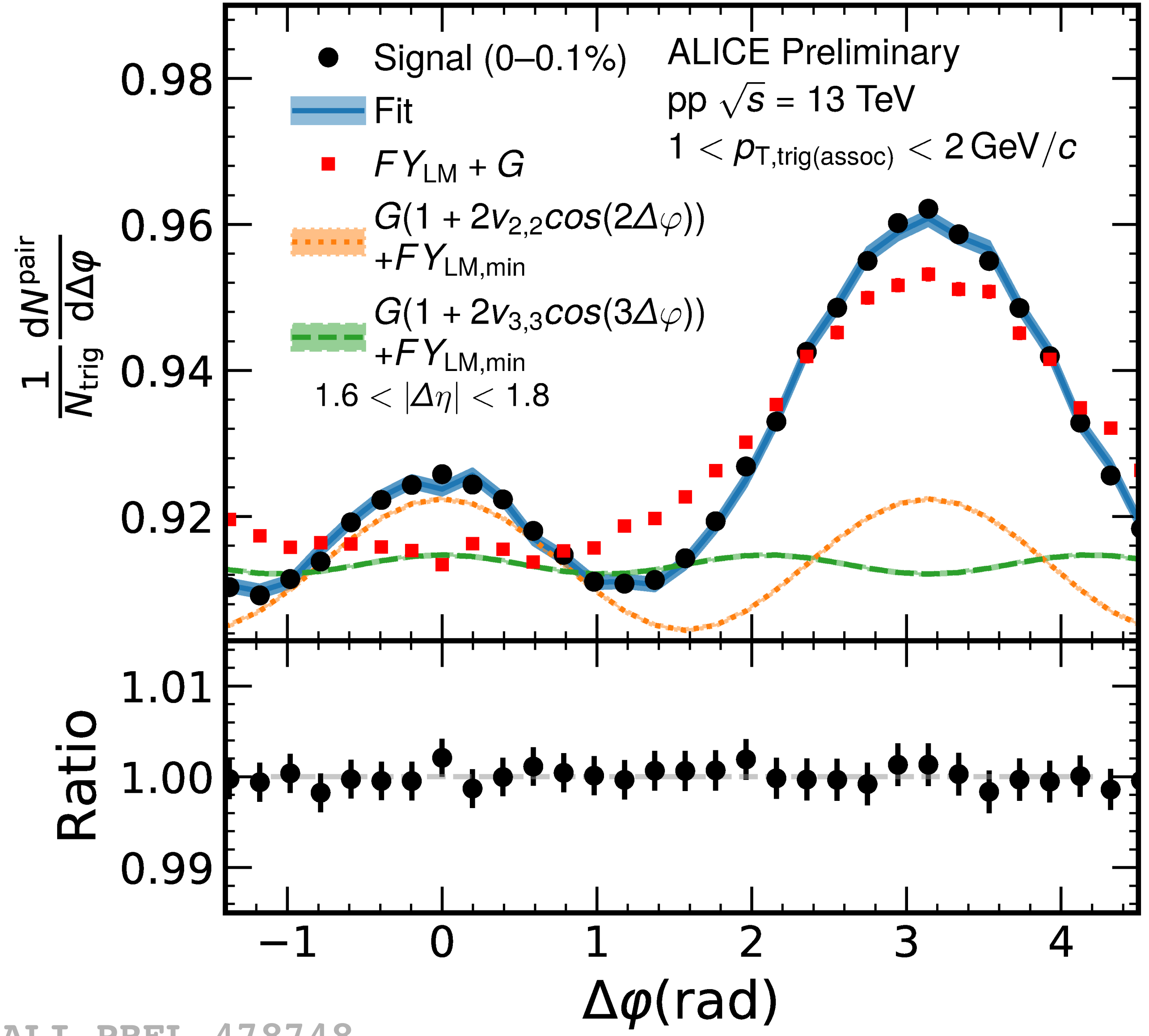
Template fit

Procedure:

1. Select high Multiplicity and low multiplicity event classes
2. Construct $\Delta\phi$ distribution for high-multiplicity and low multiplicity events
3. Use Low multiplicity events as template + flow harmonics to fit the high multiplicity distributions

Measurement = **High Mult** ⊖ **Low Mult**

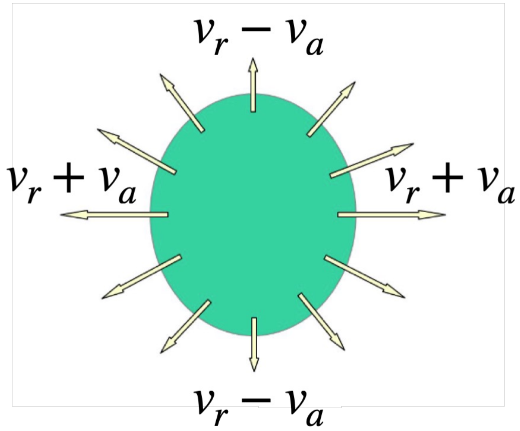
- Difficult in model comparison
  - The differences between low and high multiplicity could be too hard to be considered by the models

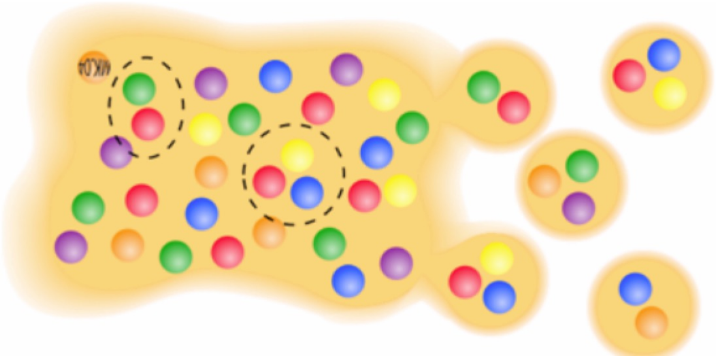


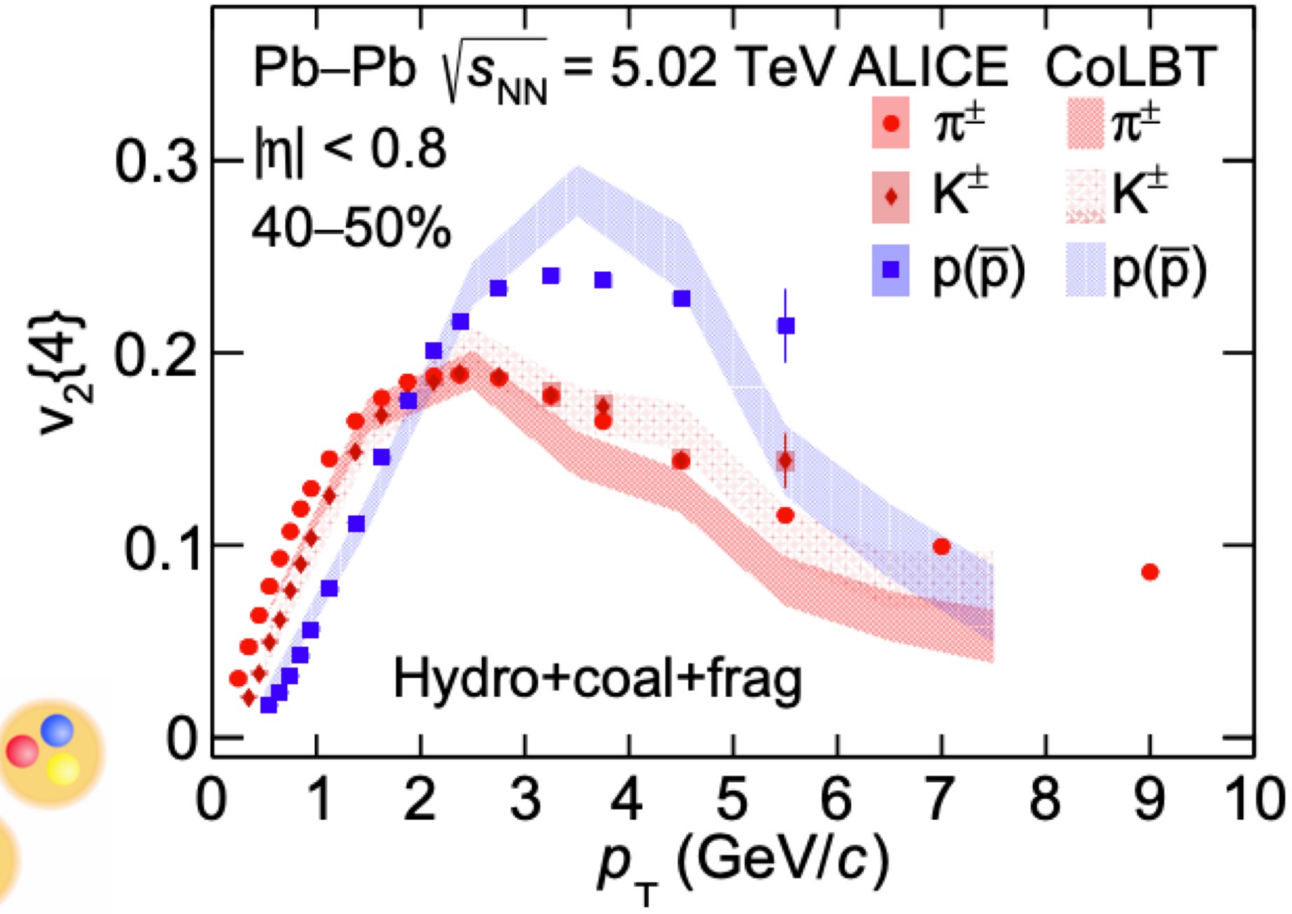
ALI-PREL-478748

Flow of identified particles

- Low-p_T region: **mass ordering** (anisotropic boost in the medium)
- Intermediate-p_T region: **baryon-meson grouping** (partonic collectivity)





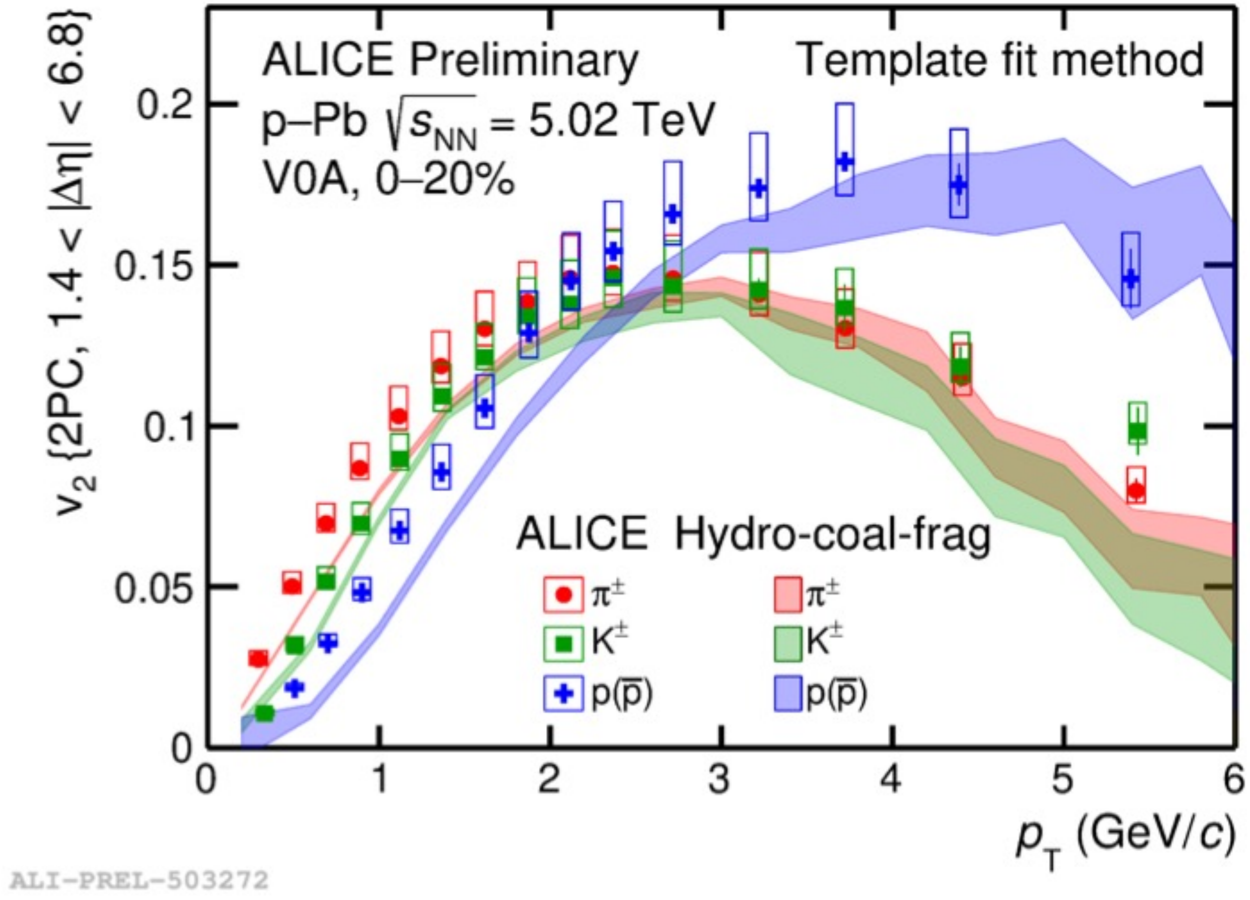


ALICE, JHEP 05 (2023) 243

Flow of identified particles in small systems

Measurement = High Mult ⊖ Low Mult

p–Pb



- Similar observations of **mass ordering and baryon-meson grouping** as in Pb–Pb collisions
- **Parton degree of freedom**

The **coincident** emergency of mass ordering and grouping are **highly impossible**

Summary

- What the flow measurements measured could be “not-flow”
- The **methods difference** is important
  - Each one has advantages and disadvantages
- Keep in mind that results with different methods should be interpreted in different ways
- Should be **more careful** about “everywhere flow”

Thank you for your attention