PINNING DOWN THE ORIGIN OF COLLECTIVITY IN SMALL SYSTEMS WITH ALICE

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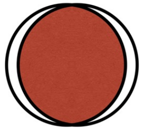
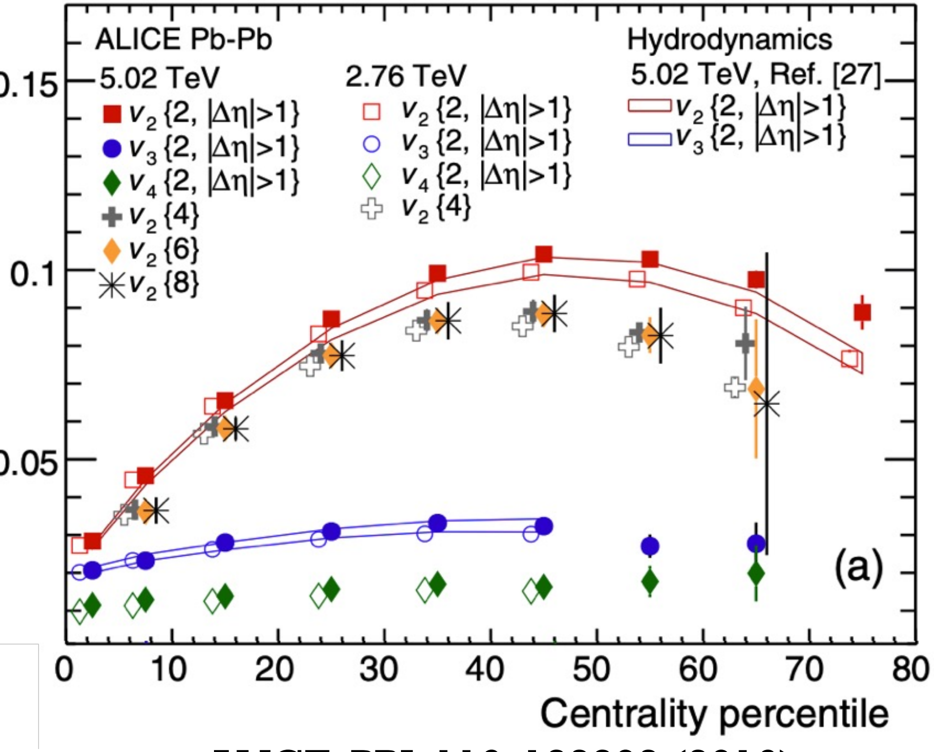
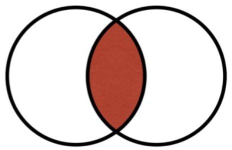
ANISOTROPIC FLOW IN HEAVY-ION COLLISIONS

Anisotropy in azimuthal distribution of final-state particles:

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

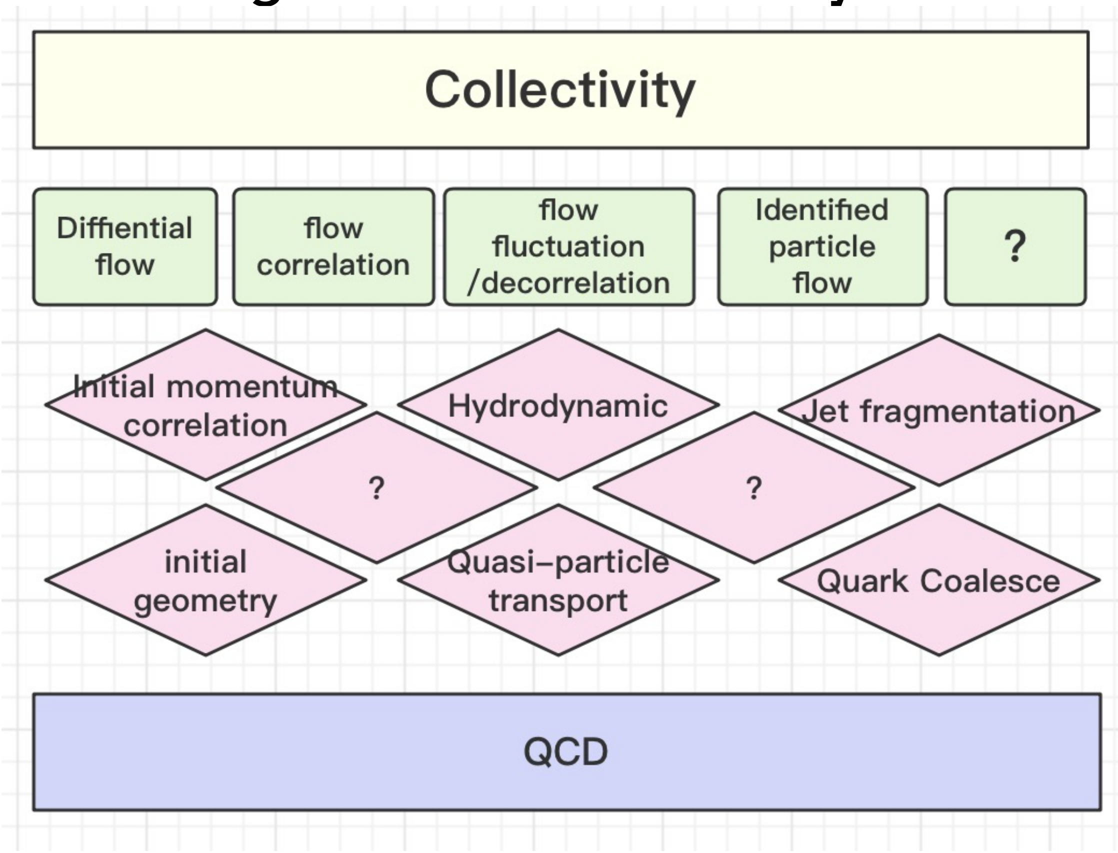






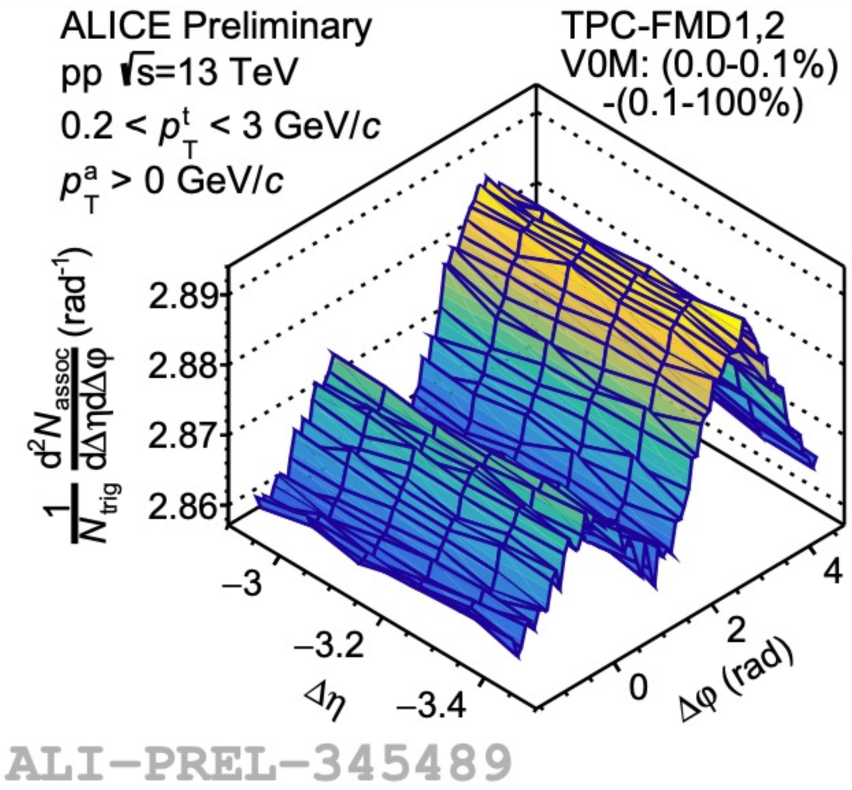
ALICE, PRL 116, 132302 (2016)

- Origin of the collectivity



COLLECTIVITY IN SMALL SYSTEMS

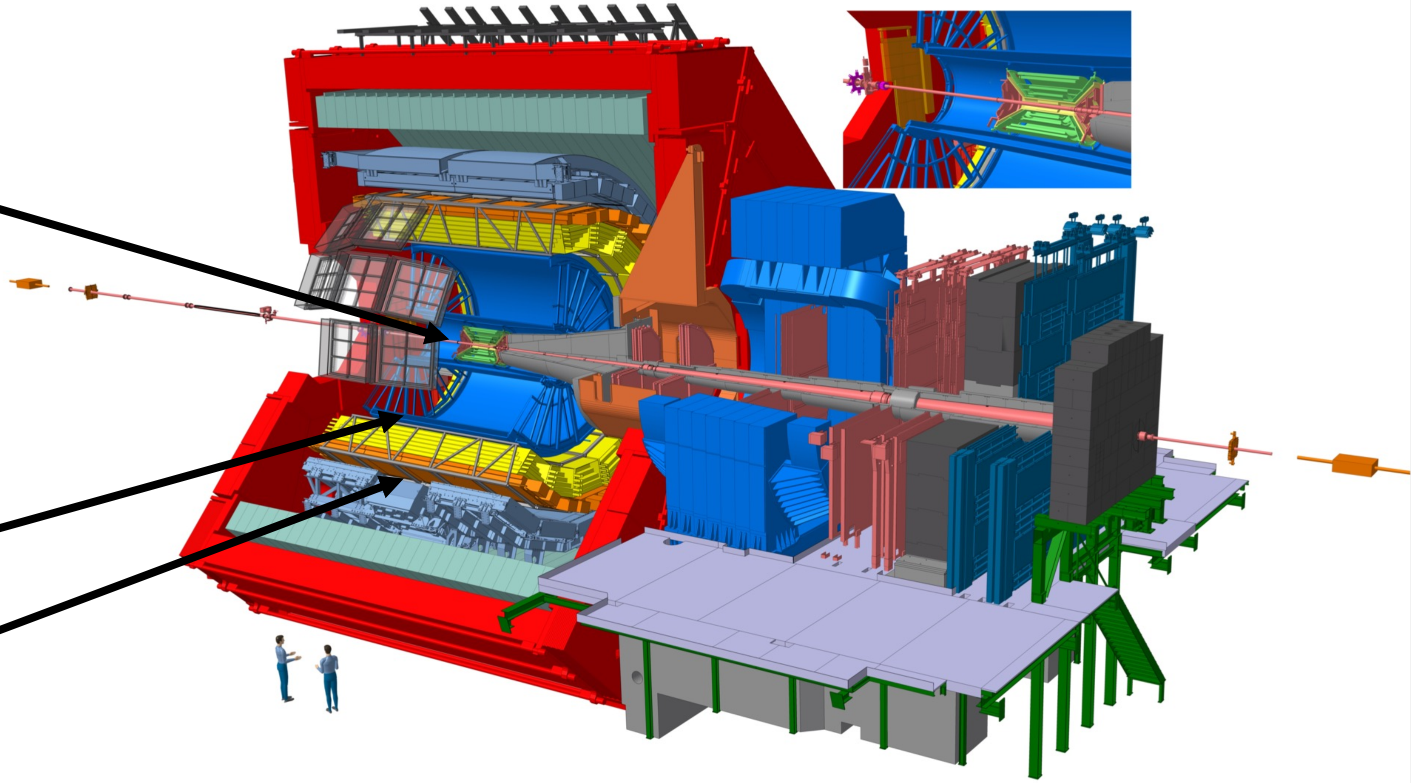
- Double ridge structure, a **sign of collectivity** in heavy-ion collisions, also observed in **pp and p–Pb collisions**



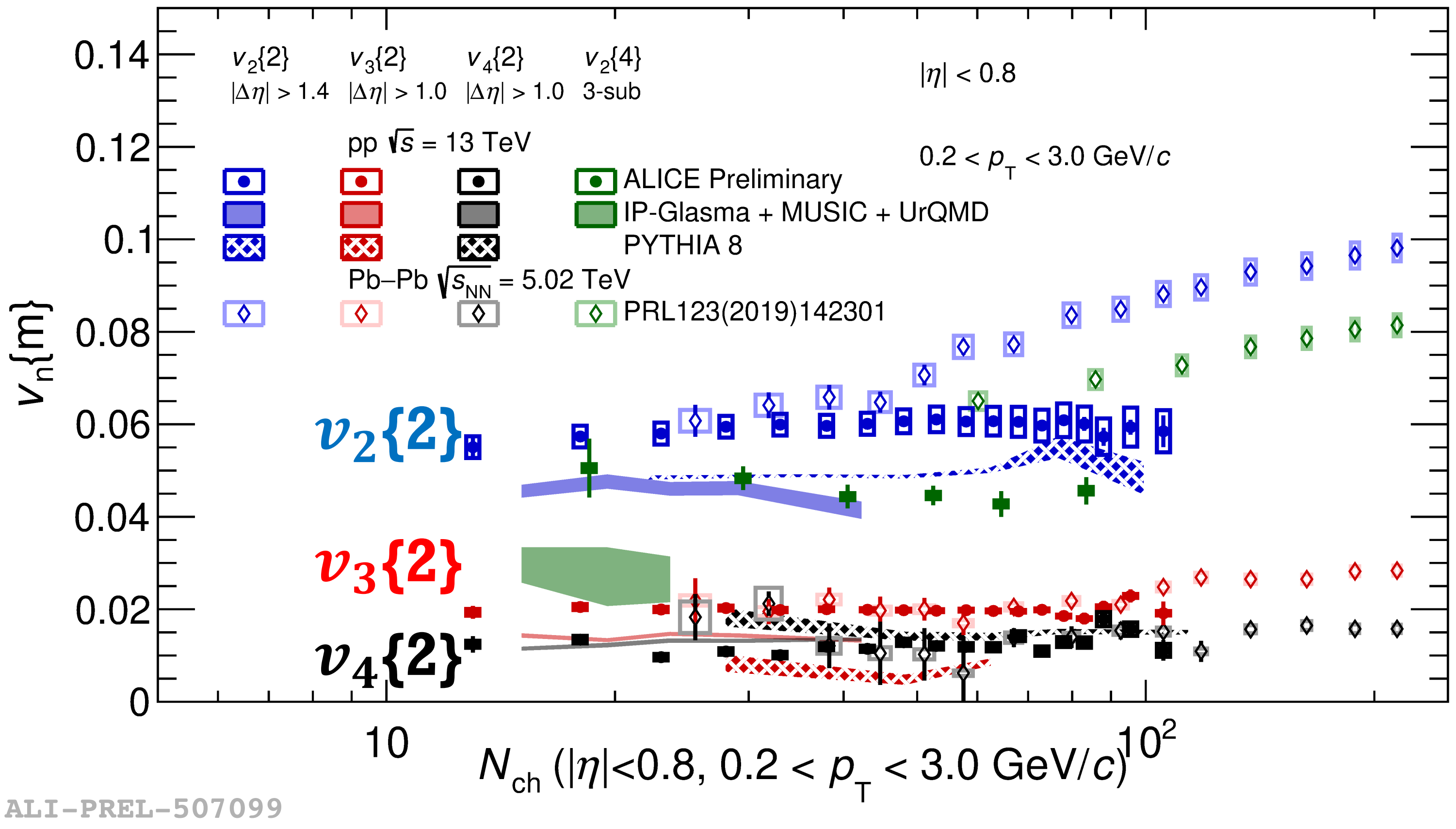
- **Methodology:**
  - Measure the **same** observables in **large and small systems**
  - Compare the results in large and small systems and see if they can be explained in a **coherent way**

ALICE EXPERIMENT

- **Inner Tracking System (ITS)**
  - Tracking, triggering and vertexing
- **V0 Detector (V0A/V0C)**
  - Triggering and event classification
- **Forward Multiplicity Detector (FMD)**
  - Unique pseudorapidity coverage
  - $-3.4 < \eta < -1.7$
  - $1.7 < \eta < 5.0$
- **Time Projection Chamber (TPC)**
  - Tracking and particle identification
- **Time-of-Flight detector (TOF)**
  - Particle identification



FLOW HARMONICS

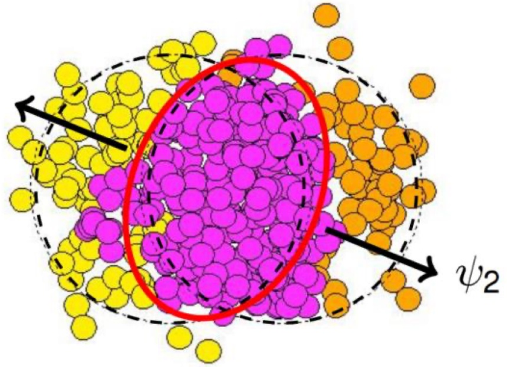


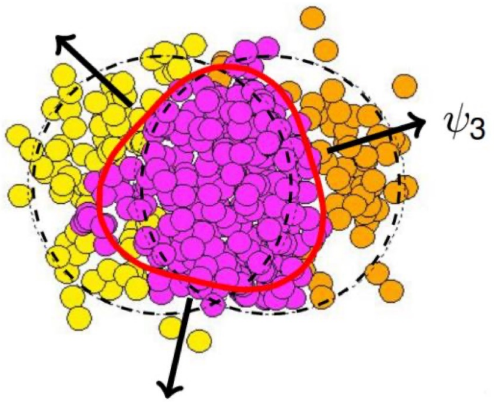
Solid: pp **Open: Pb–Pb**

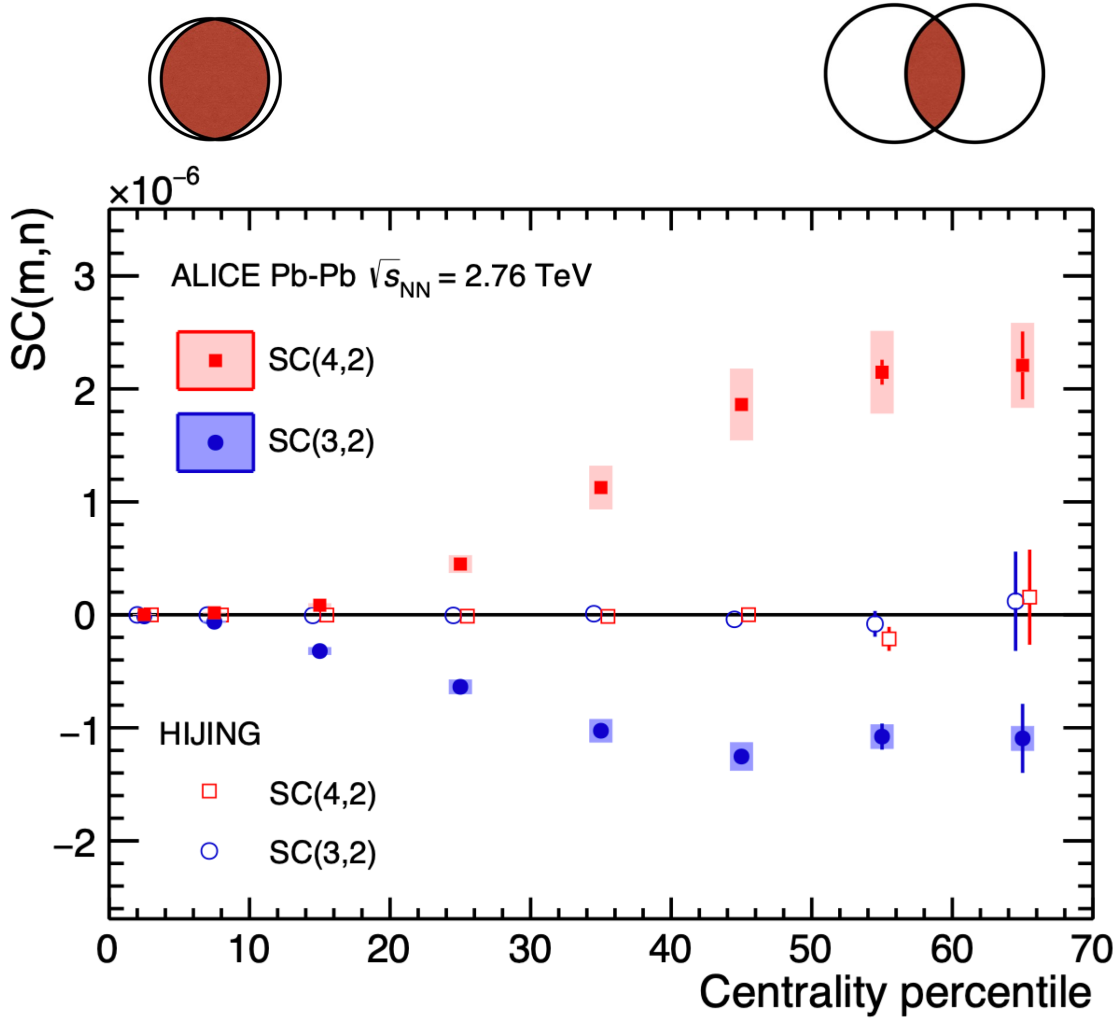
- The magnitudes of v_n in pp are similar as in Pb–Pb at low multiplicities (**flow fluctuation dominates region**)
- Flow harmonics provide constraints for modeling of the **initial geometry and its fluctuations**, as well as **the transport parameters**

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)







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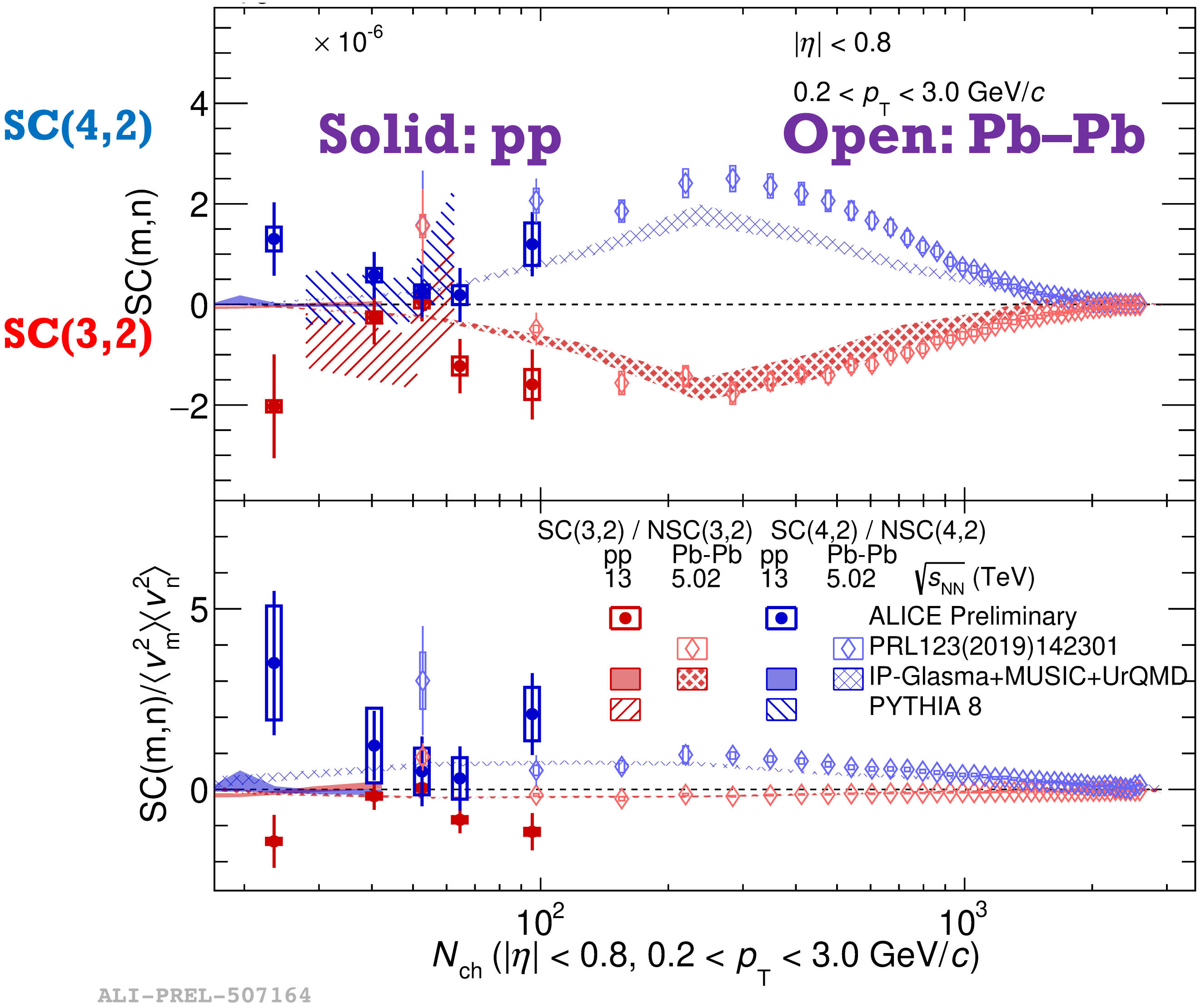
FLOW CORRELATIONS IN SMALL SYSTEMS



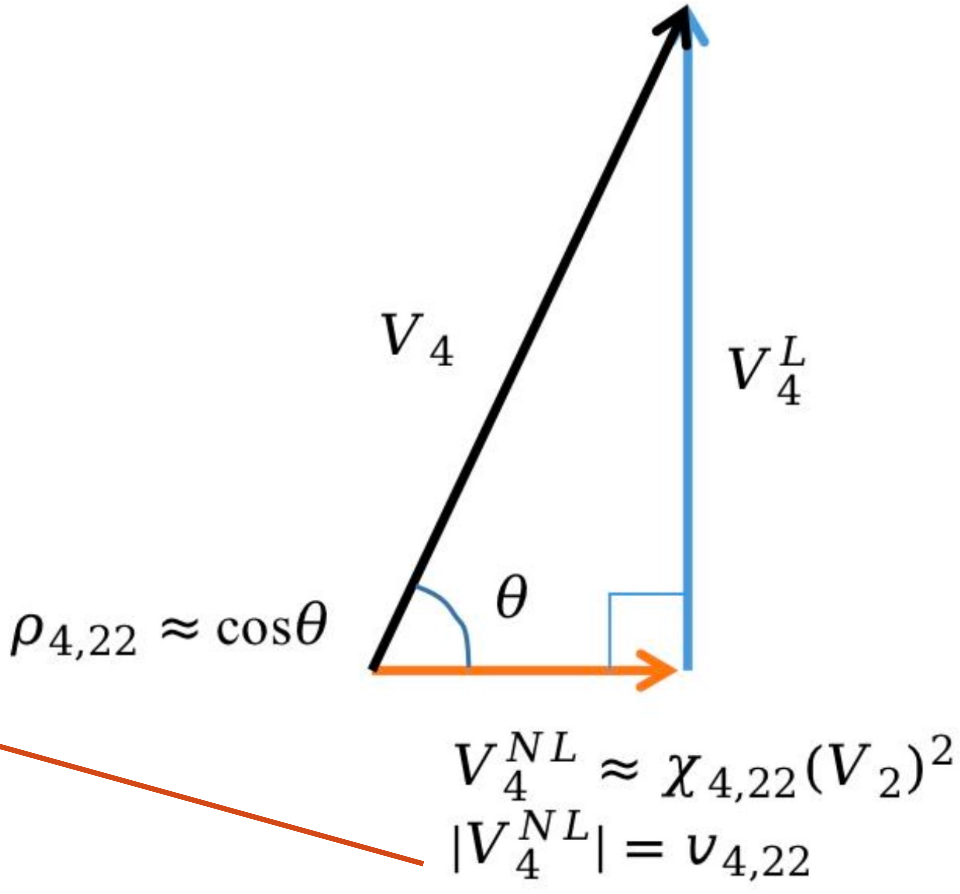
- Hint of **negative SC(3,2)** (2.1σ significance) and **positive SC(4,2)** (1.9σ significance) in pp collisions, having the **same sign** as Pb–Pb collisions
- Constraints on **initial geometry fluctuations**

NONLINEAR FLOW RESPONSE

- **Linear response** of flow coefficients on the initial eccentricity $v_n \propto \varepsilon_n$ holds up to n = 3

$$V_4 = V_4^{L} + V_4^{NL} = V_4^{L} + \chi_{4,22}(V_2)^2$$

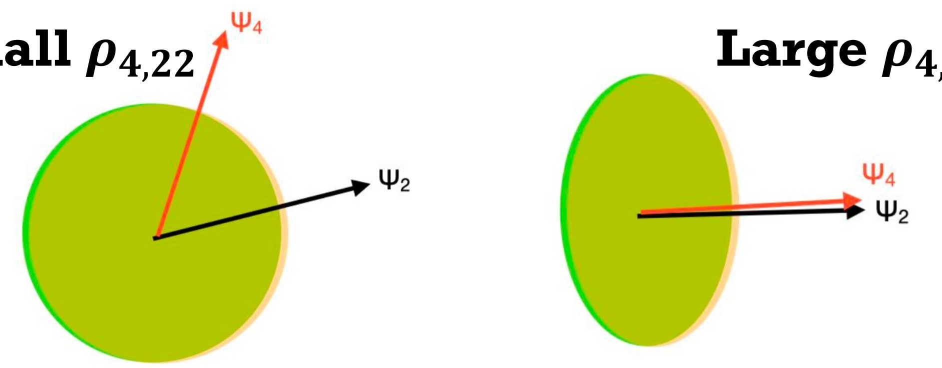
$$\rho_{4,22} = v_{4,22}/v_4\{2\} = \langle\cos(4\Psi_4 - 4\Psi_2)\rangle$$

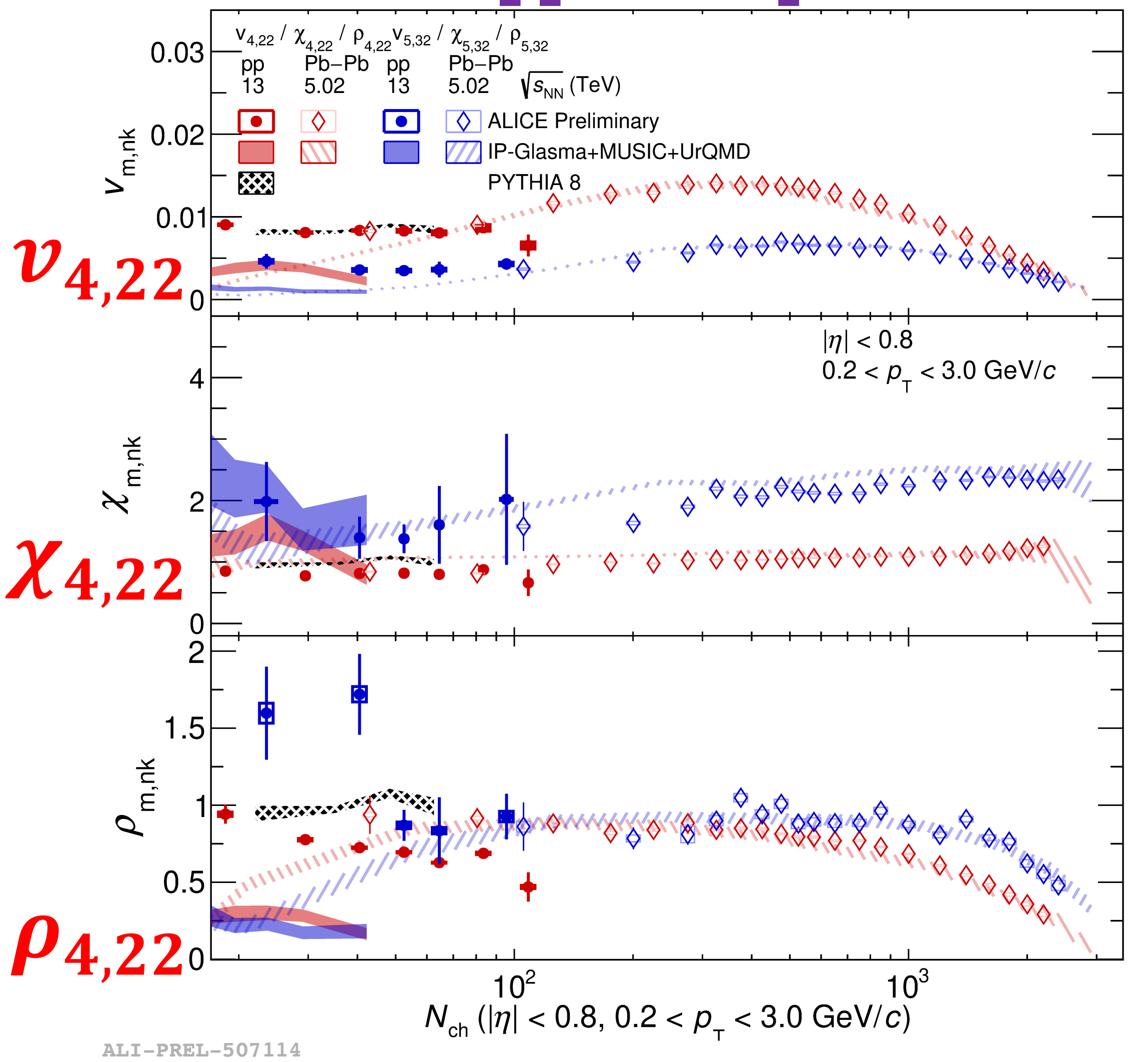


- $v_{4,22}, \chi_{4,22}, \rho_{4,22}$ have different sensitivity to the **initial geometry** and **transport parameters**

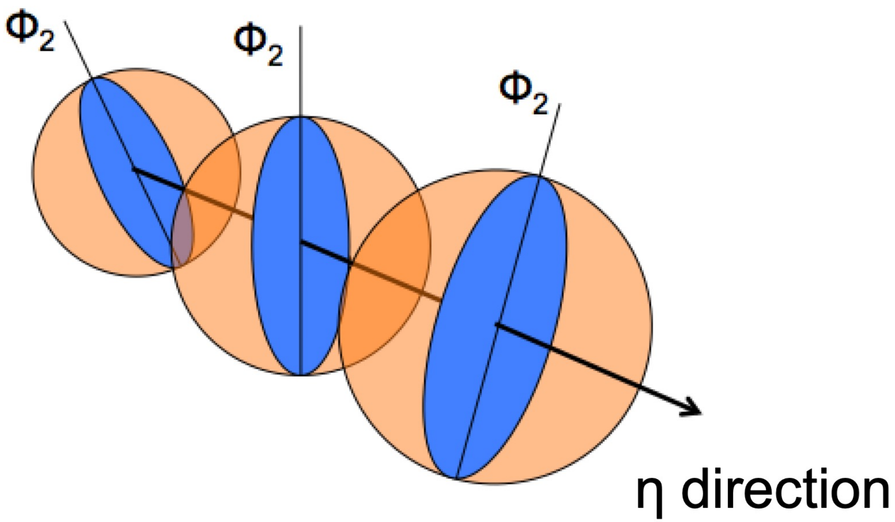
NONLINEAR FLOW RESPONSE IN SMALL SYSTEMS

- Indication for a **smooth transition** between peripheral Pb–Pb and high multiplicity pp collisions for $v_{4,22}$
- In pp collisions, $\rho_{4,22}$ shows a **decreasing trend**, which indicates the **sub-nucleon structure** of proton





η-DECORRELATION

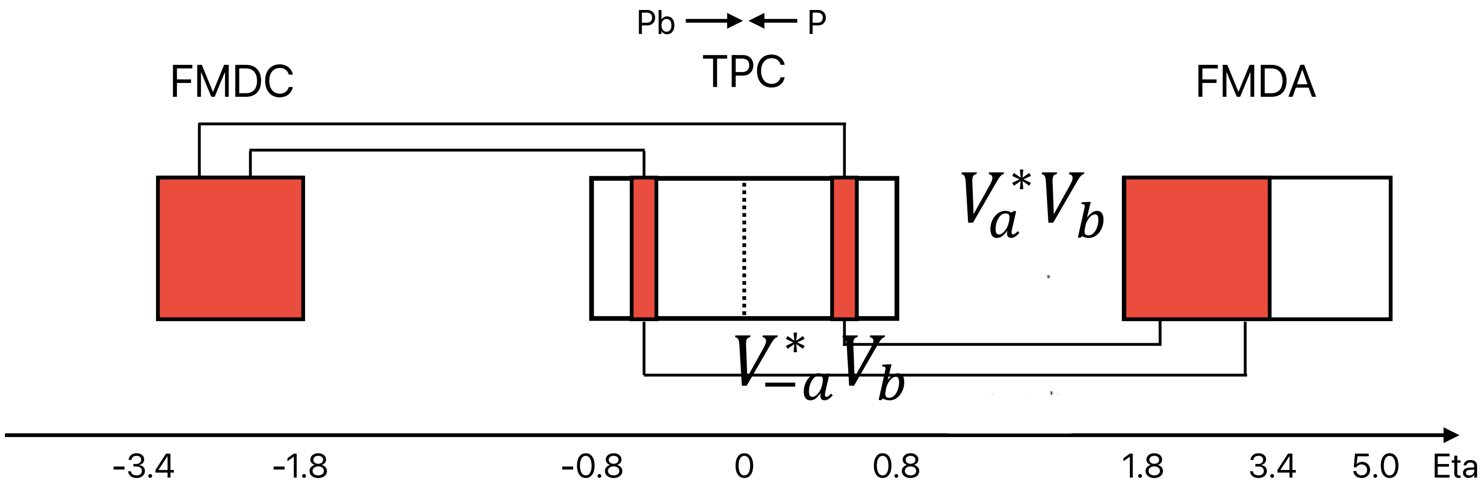


$$V_n(\eta_1) \neq V_n(\eta_2)$$

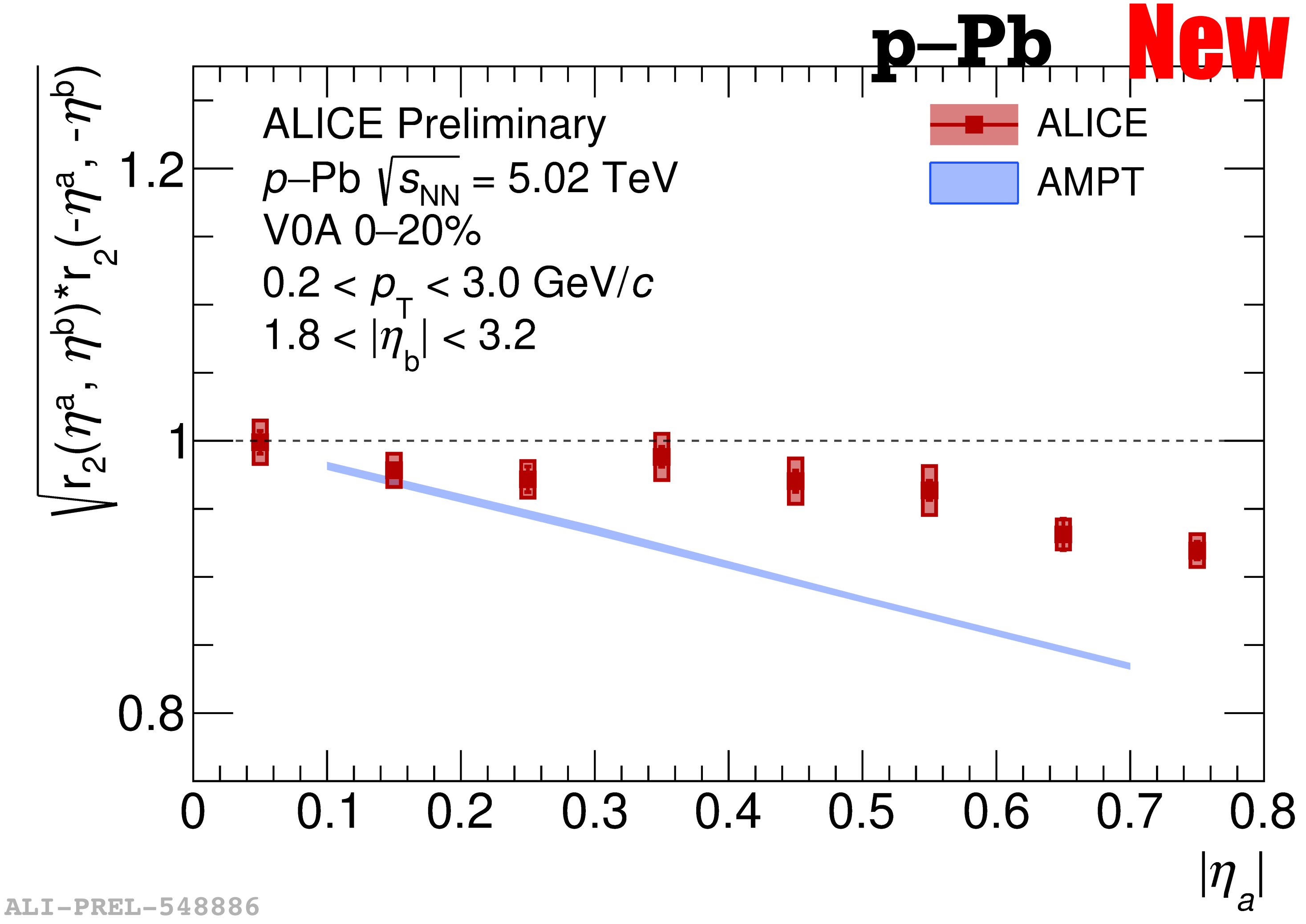
$$\langle V_a^* V_b \rangle \neq \sqrt{\langle V_a^* V_a \rangle \langle V_b^* V_b \rangle}$$

- Probe the **3D initial geometry**

$$r_n(\eta^a, \eta^b) = \frac{V_{-a}^* V_b}{V_a^* V_b}$$



η-DECORRELATION IN SMALL SYSTEMS

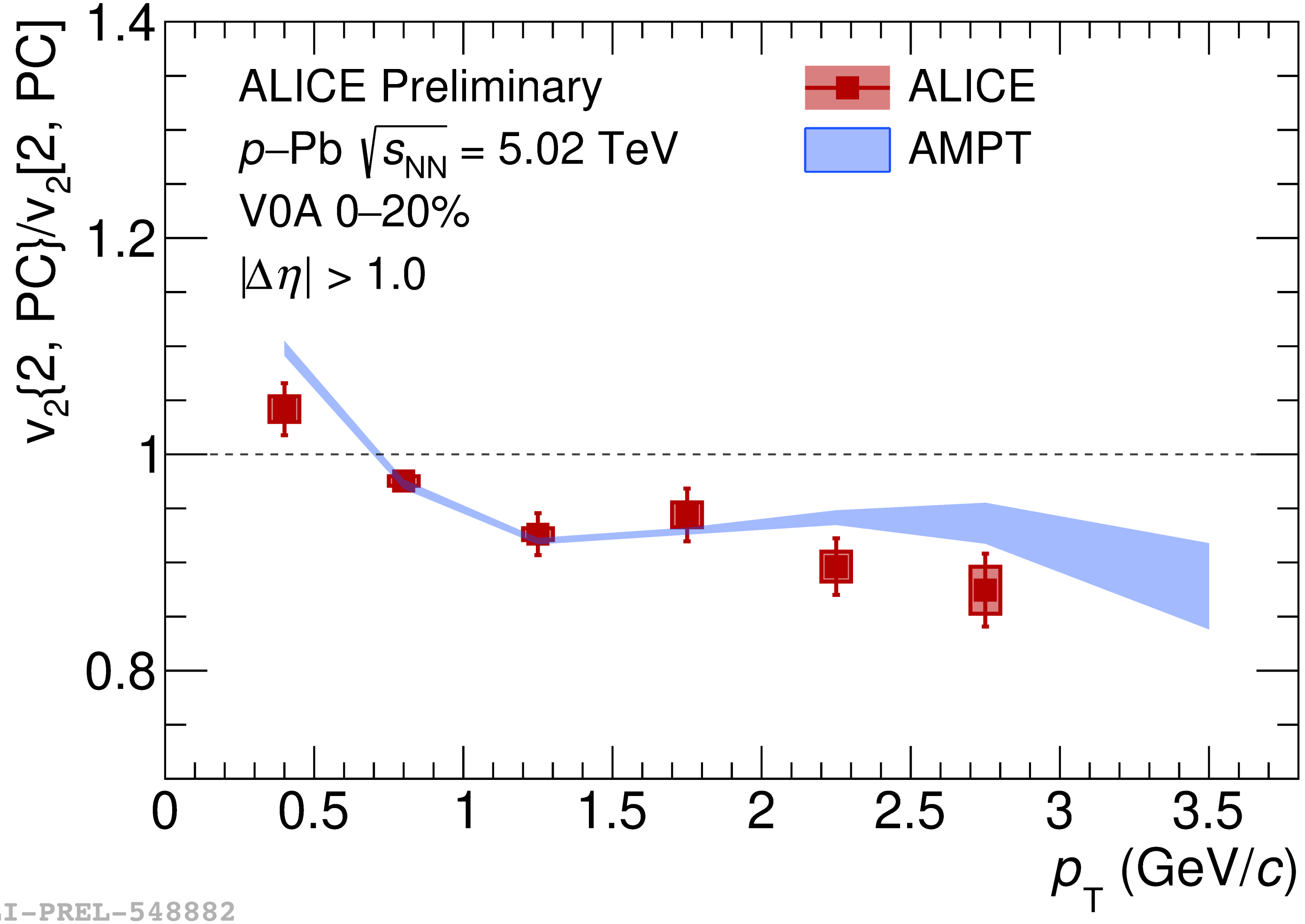


- Deviation from unity in data indicates η-decorrelations
- **First measurement** of pseudorapidity-dependent flow vector fluctuations in ALICE for p–Pb collisions

p_T-DECORRELATION

- $v_2\{2\}/v_2[2] = \frac{V^*(p_T^a)V_{ref}}{\sqrt{|V(p_T^a)|}\sqrt{V_{ref}}}$
- $r_2 = \frac{V^*(p_T^a)V(p_T^b)}{\sqrt{|V(p_T^a)||V(p_T^b)|}}$
- Constraining **initial conditions in transverse momenta phase space**
- $v_2\{2\}/v_2[2]$: **Decrease** with p_T, deviation from unity is observed

p–Pb **New**



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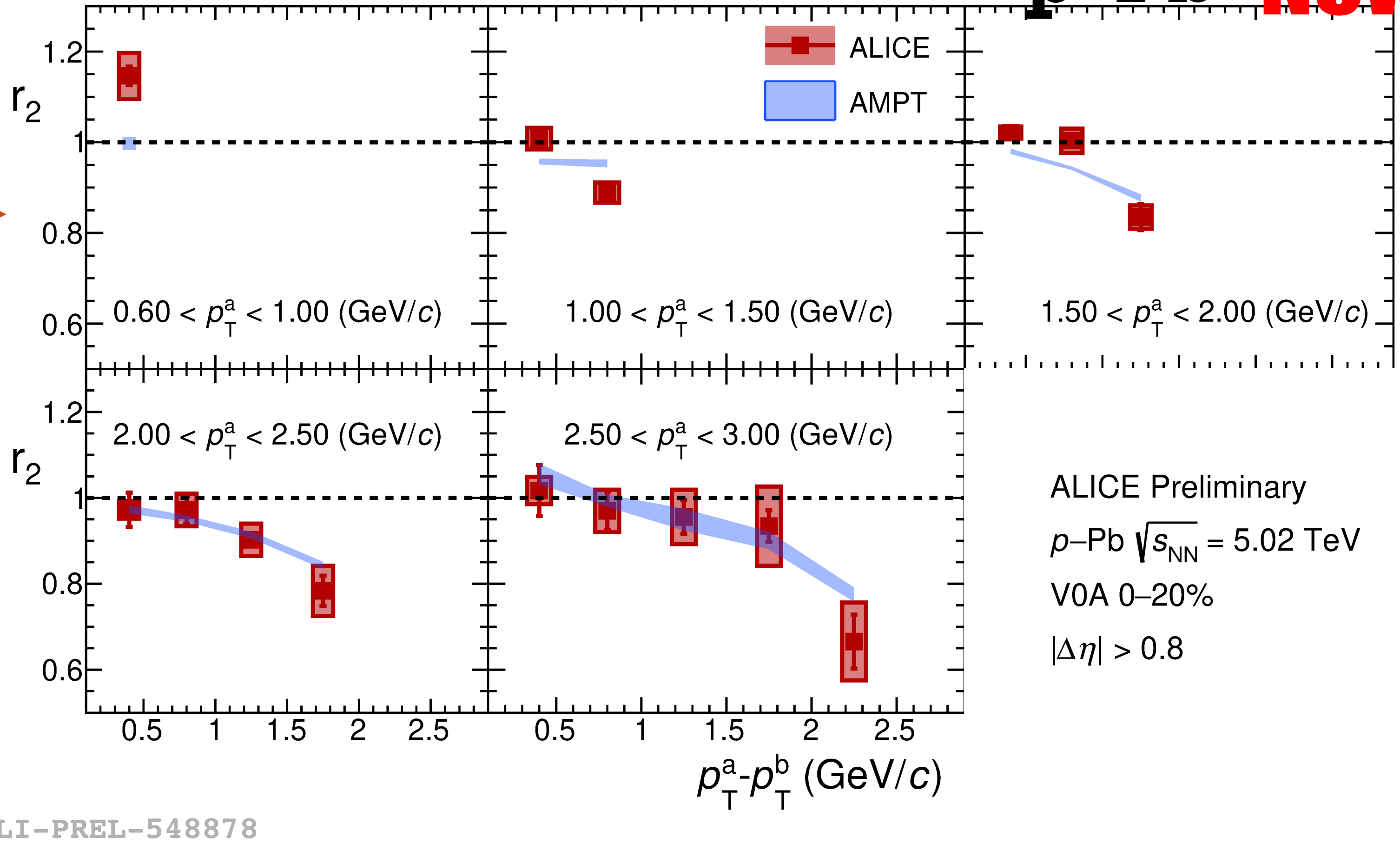
p_T-DECORRELATION

- $v_2\{2\}/v_2[2] = \frac{V^*(p_T^a)V_{ref}}{\sqrt{|V(p_T^a)|}\sqrt{V_{ref}}}$
- $r_2 = \frac{V^*(p_T^a)V(p_T^b)}{\sqrt{|V(p_T^a)||V(p_T^b)|}}$
- Constraining **initial conditions in transverse momenta phase space**
- r_2 : **Decrease** with increasing Δp_T, deviation from unity is observed

p–Pb **New**



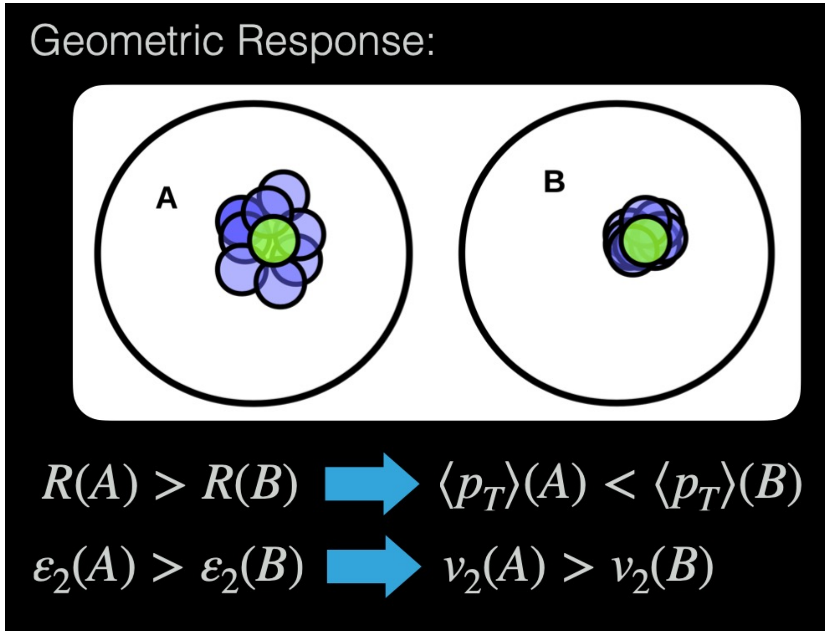
$v_2^2 - [p_\mathrm{T}]$ CORRELATION

- **Shape** of the fireball:
  - anisotropic flow, $\varepsilon_n \rightarrow v_n$
- **Size** of the fireball:
  - radial flow, $1/R \rightarrow [p_T]$

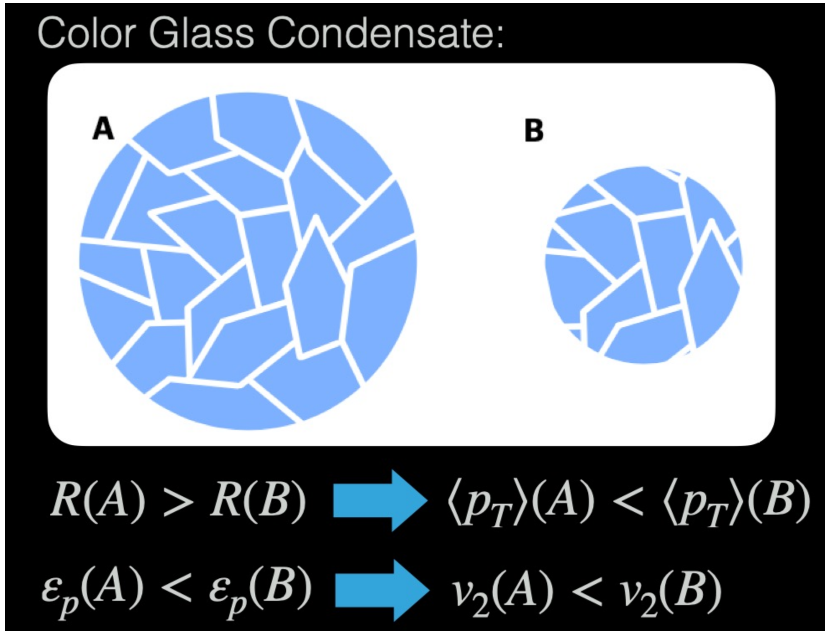
- Probe the **initial stage** of created matter in a collision

$$\rho_n\left(v_n^2, [p_T]\right) = \frac{\mathrm{cov}\left(v_n^2, [p_T]\right)}{\sqrt{\mathrm{var}\left(v_n^2\right)}\sqrt{\mathrm{var}\left([p_T]\right)}}$$

$\rho < 0$

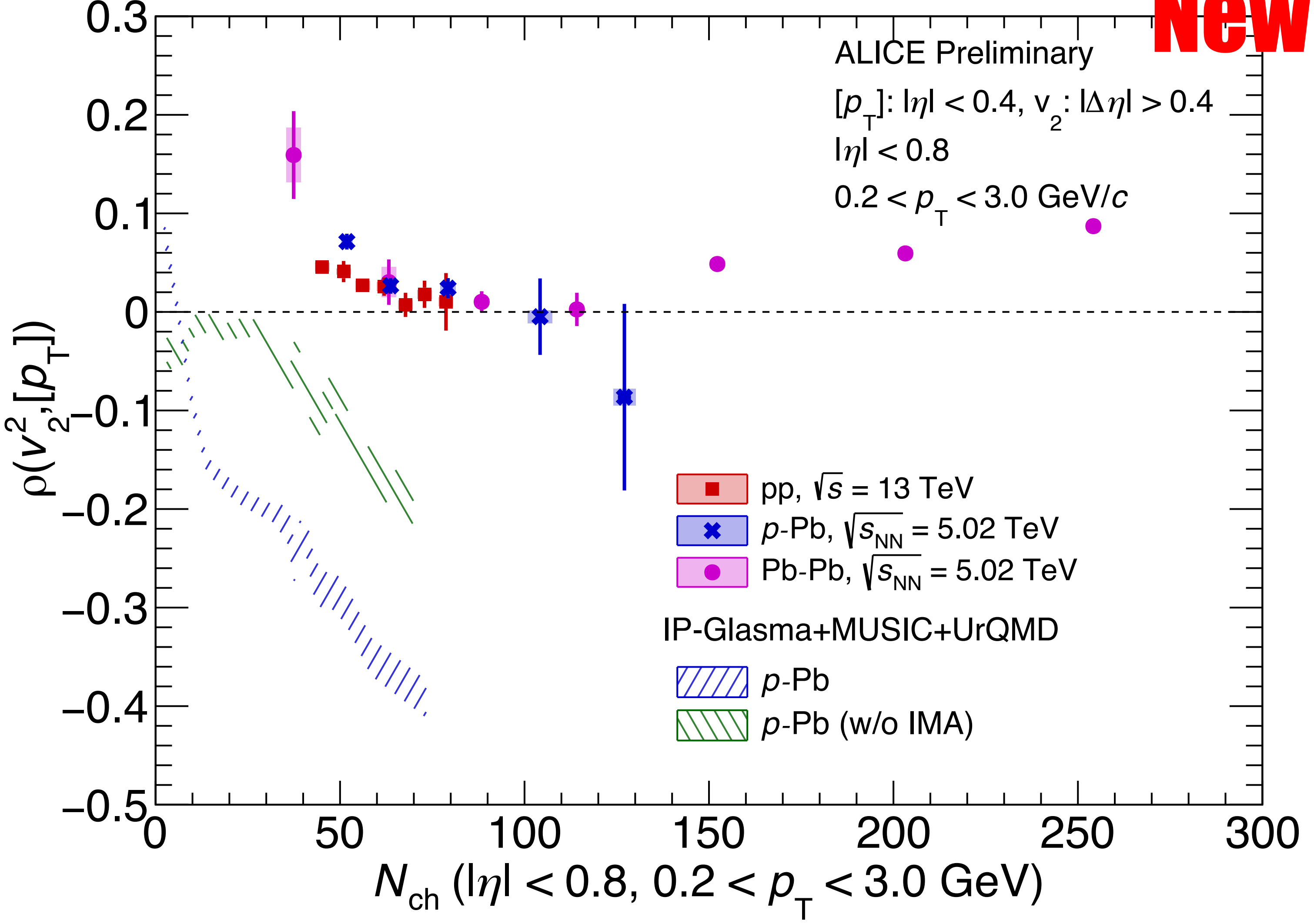


$\rho > 0$



$v_2^2 - [p_T]$ CORRELATION IN SMALL SYSTEMS

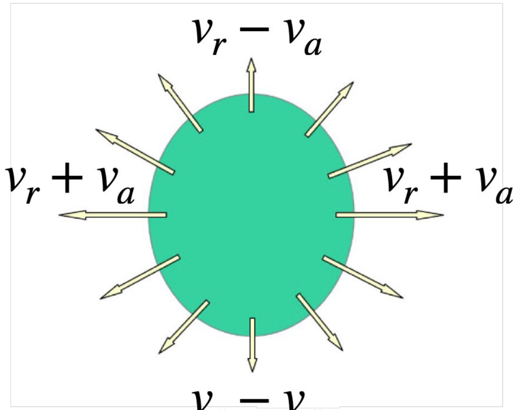
New

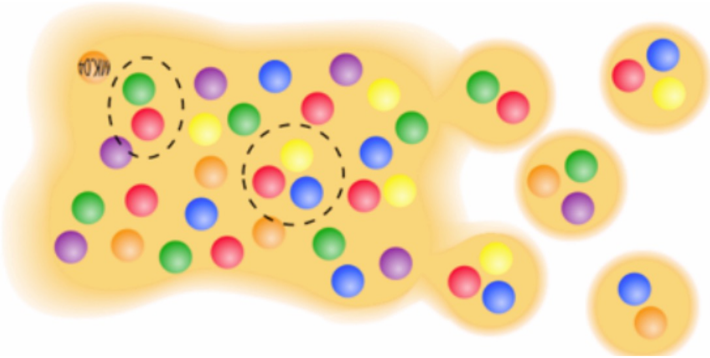


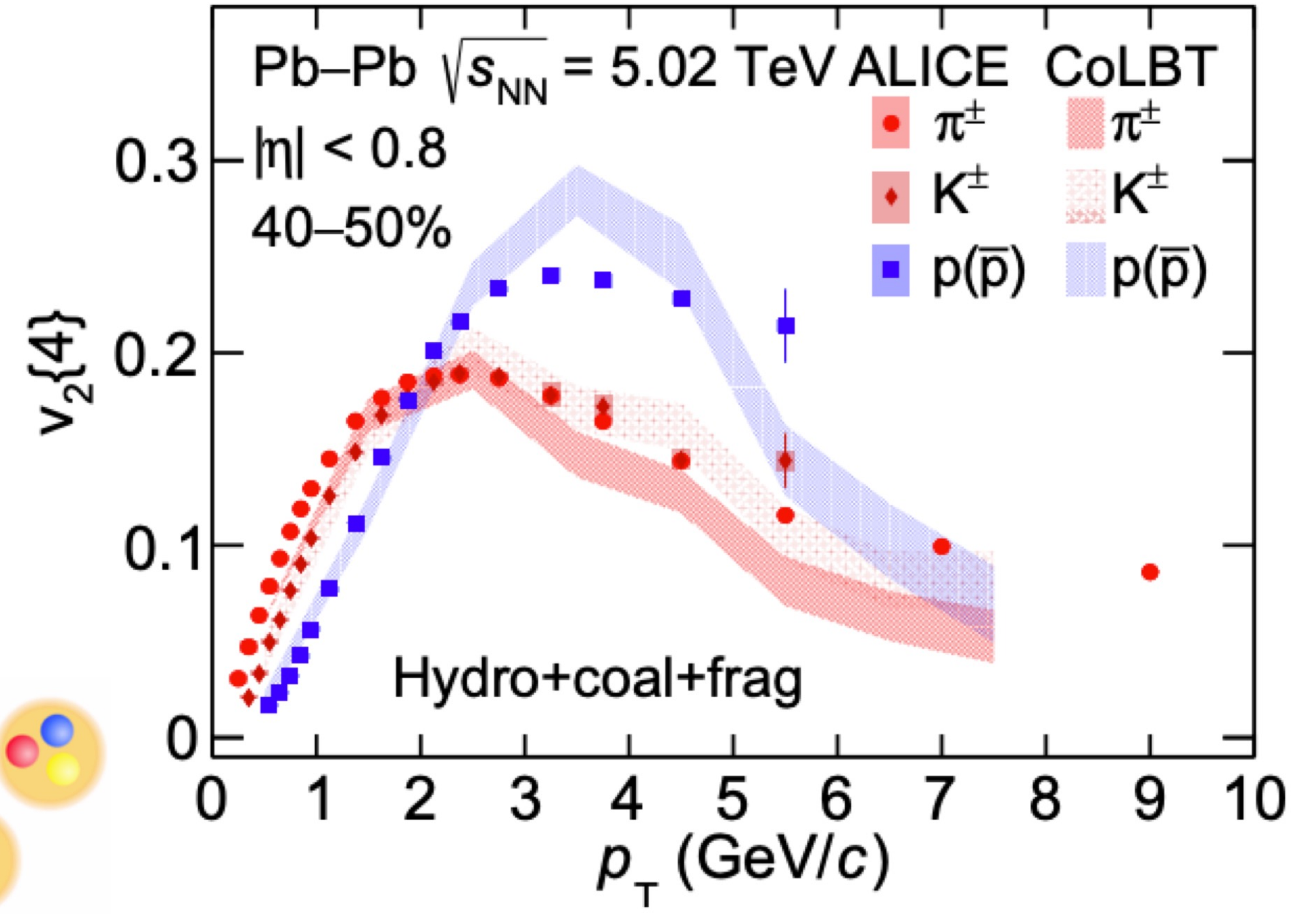
- A **decreasing trend** is observed in pp and p–Pb collisions
- Unable to be explained by simple geometry picture
- IP-Glasma + MUSIC + UrQMD fails to describe the data (with and without initial momentum anisotropy (IMA))

FLOW OF IDENTIFIED PARTICLES

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







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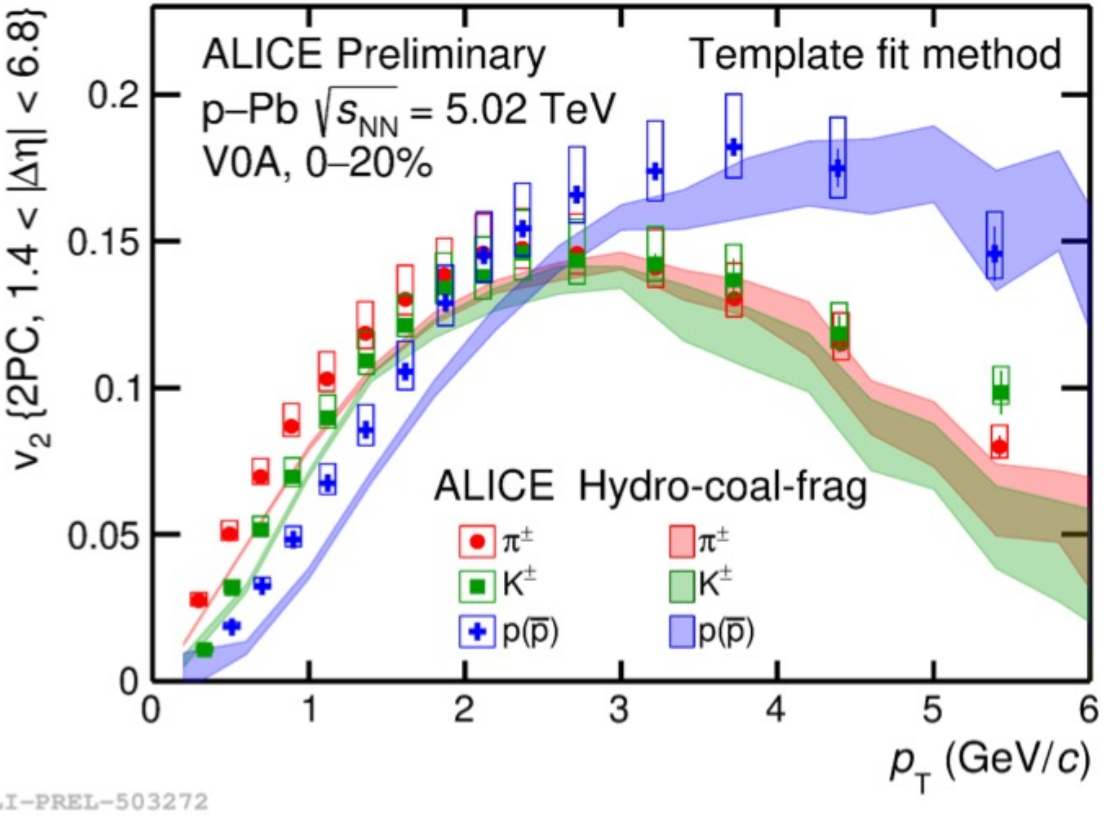
FLOW OF IDENTIFIED PARTICLES IN SMALL SYSTEMS

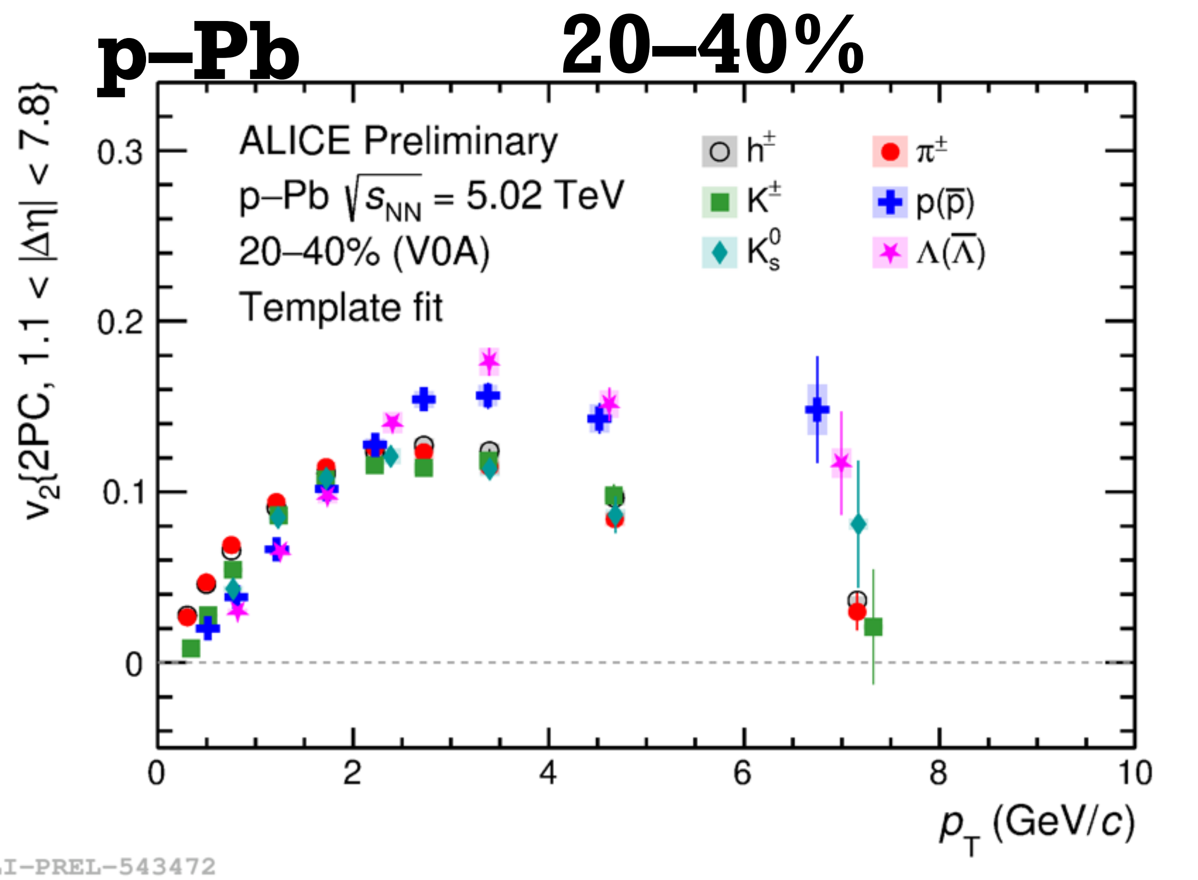
ALICE

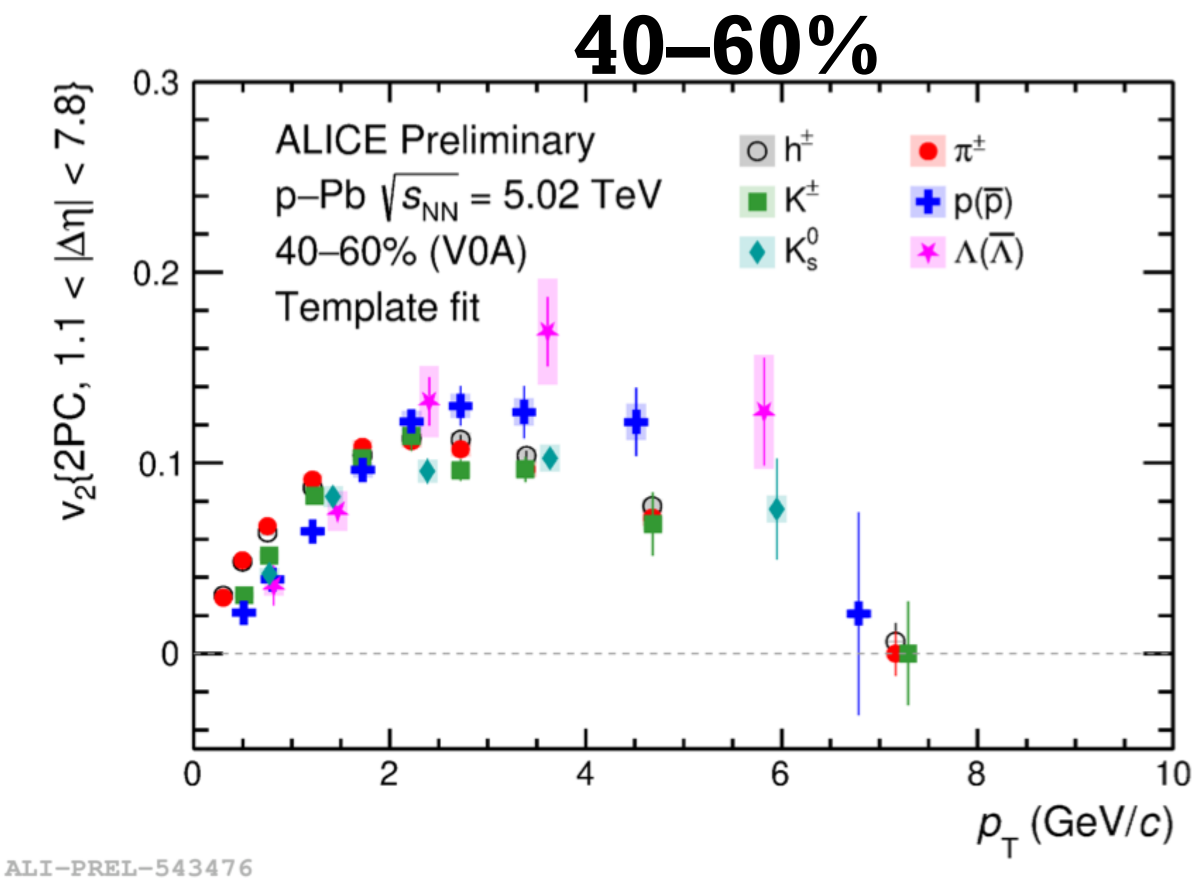
p–Pb 0–20%



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

FLOW OF IDENTIFIED PARTICLES IN SMALL SYSTEMS





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SUMMARY

- Many ALICE measurements (**flow harmonics coefficients**, **flow correlations**, **non-linear flow response**, **flow decorrelations**, **identified particles flow**) at small collision systems are presented, providing new insights into the origin of collectivity including **initial geometry (and its fluctuation)**, **development from initial geometry to final stage**, **partonic degree of freedom**, etc.
- The results cannot be explained by **a single theory** with a **single picture**
- Still challenging for both theory and experiment

Thank you for your attention