13th International workshop on Multiple Partonic Interactions at the LHC

Flow of identified hadrons in p-Pb and pp collisions with ALICE

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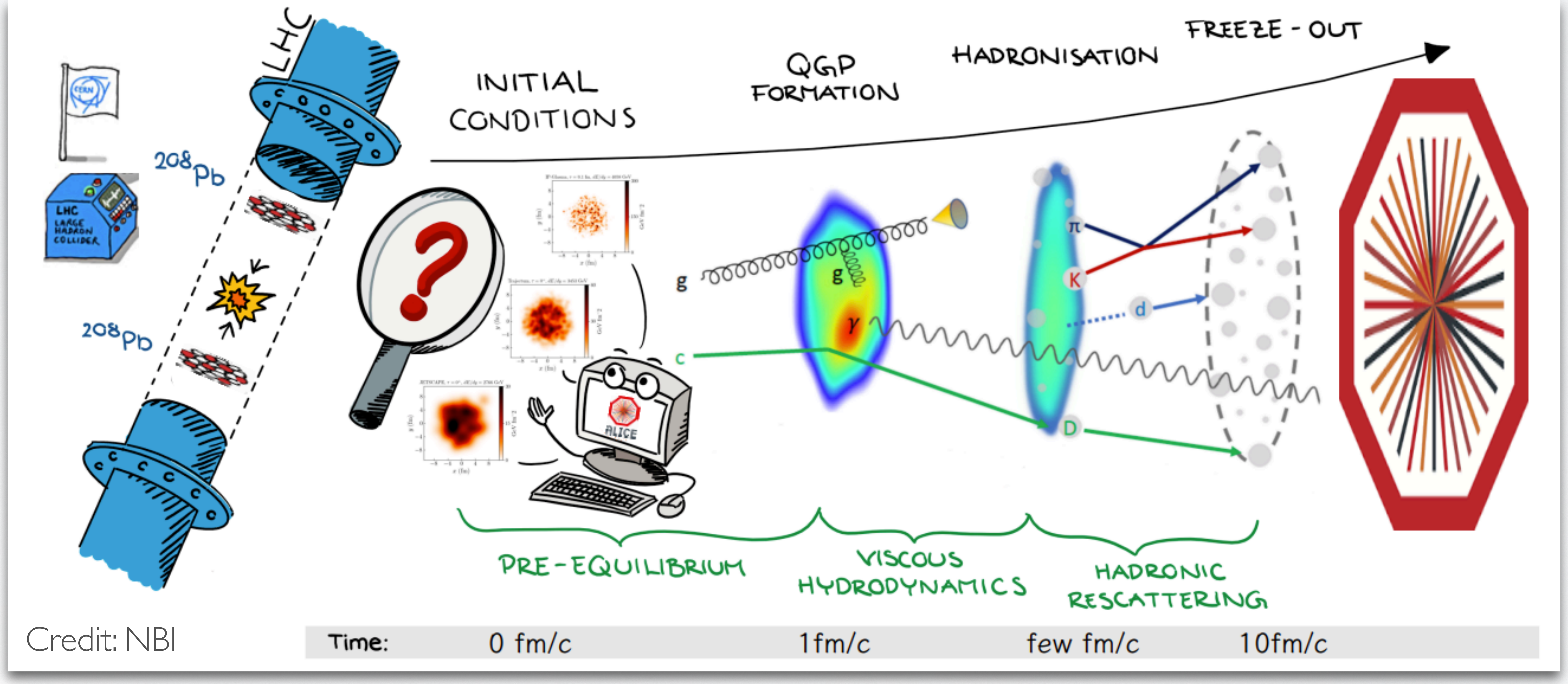
Quark-gluon plasma and its evolution

- **Quark-gluon plasma (QGP)**
  - Hot and dense nuclear matter of deconfined quarks and gluons
  - Strongly interacting liquid
  - Existed right after the Big Bang
  - Created in ultrarelativistic heavy-ion collision



Credit: NBI

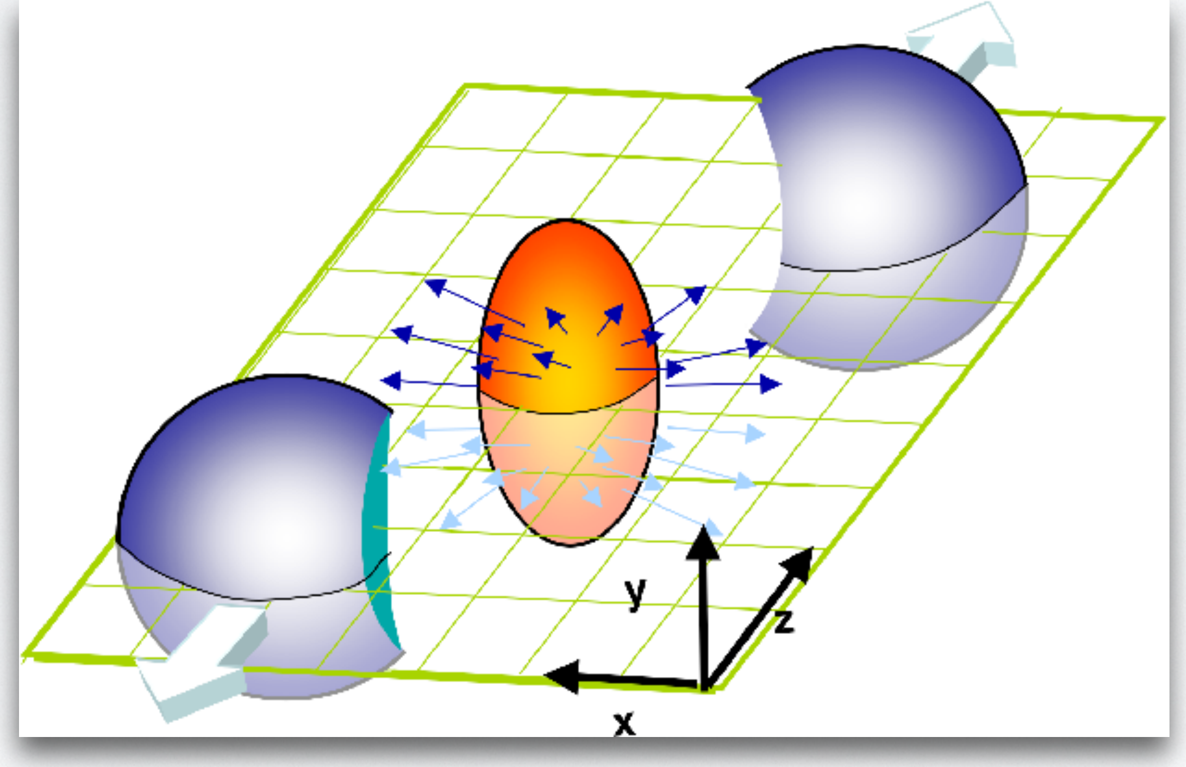
Initial conditions

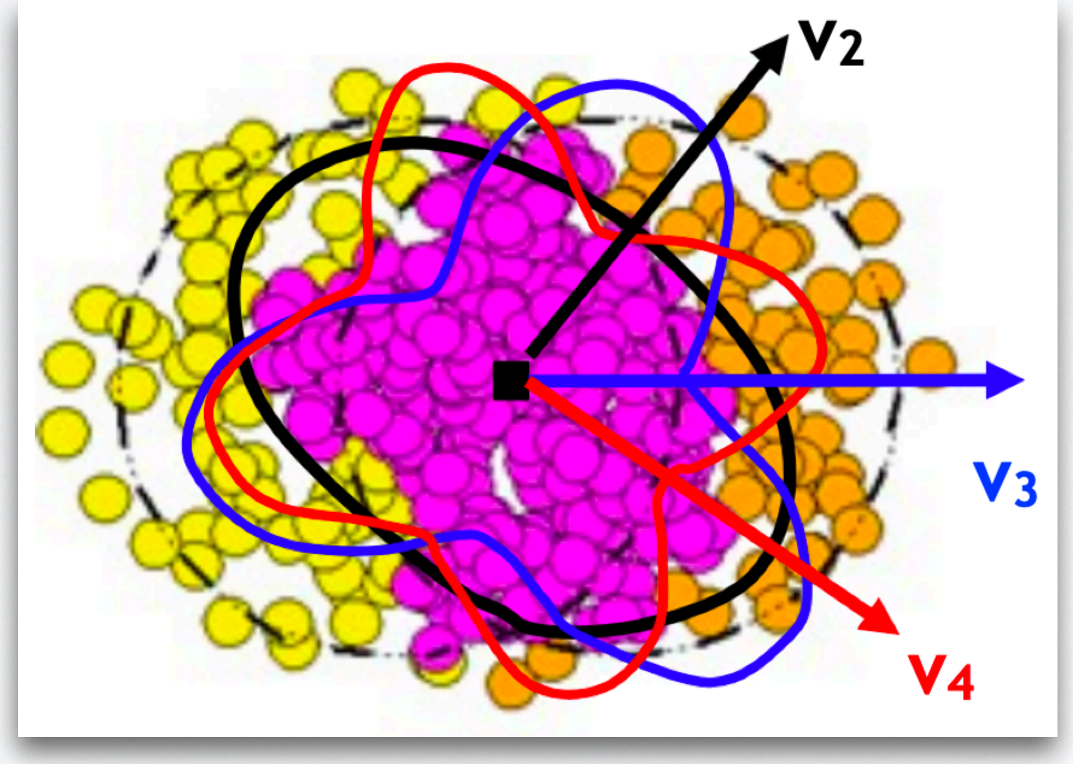
- Geometry of the nuclei overlap and its fluctuations

Hydrodynamic expansion

- Sensitive to initial state
- Sensitive to QGP properties $(\eta/s, \xi/s)$

Flow measurements in **heavy-ion collisions**

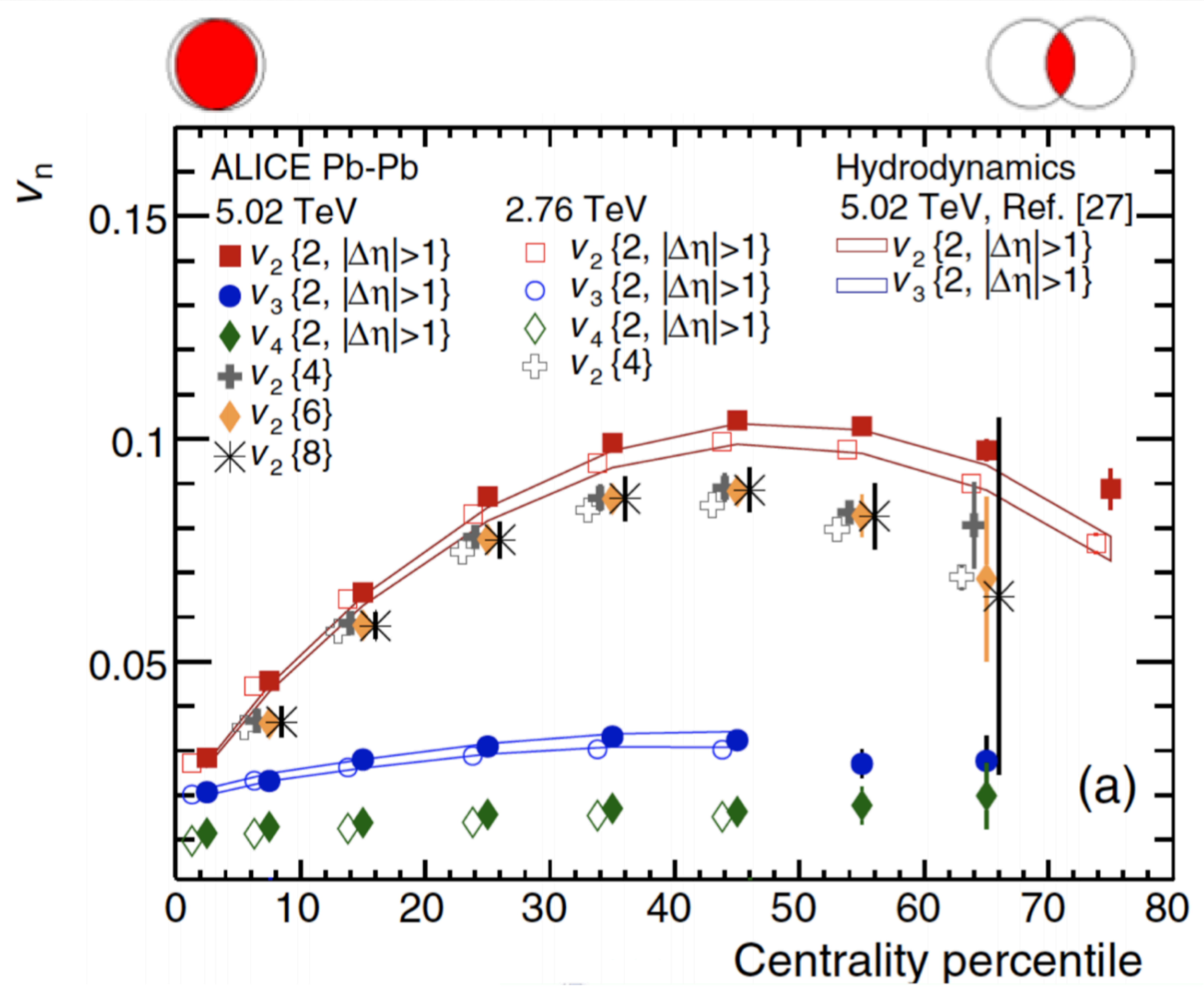




- Partial nuclei overlap ⇨ Spatial anisotropy ⇨ Different pressure gradients ⇨ Particles flow anisotropically in transverse plane
- Quantified using flow coefficients v_n obtained from the Fourier expansion of final-state particles:

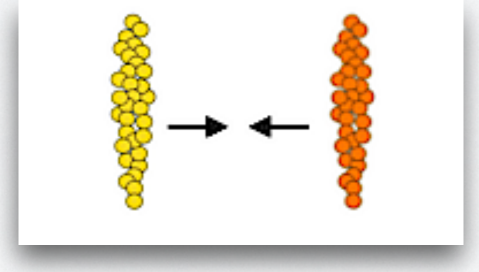
$$\frac{\mathrm{d}N}{\mathrm{d}\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos n(\varphi - \Psi_n)$$

- Flow coefficients v_n provide detailed information on the **initial conditions and transport properties of the created medium**
- Well described by hydrodynamic models

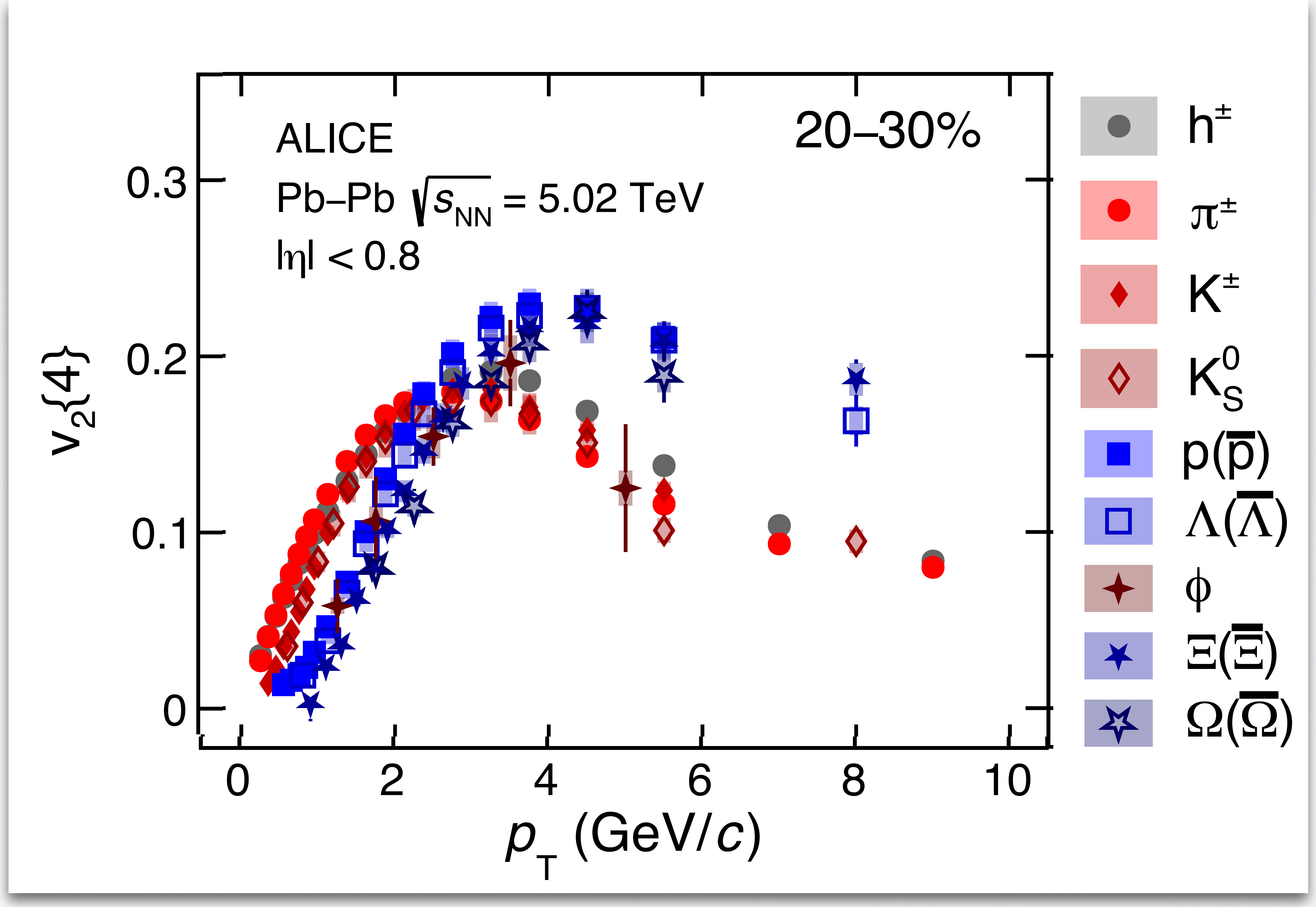


ALICE, Phys. Rev. Lett. 116, 132302 (2016)

Flow of identified particles in Pb-Pb collisions

Pb-Pb 

- Low p_T region: **mass ordering**
  - Common boost from the medium
  - Described by hydrodynamics
- Intermediate p_T region: **baryon-meson grouping**
  - Partonic collectivity

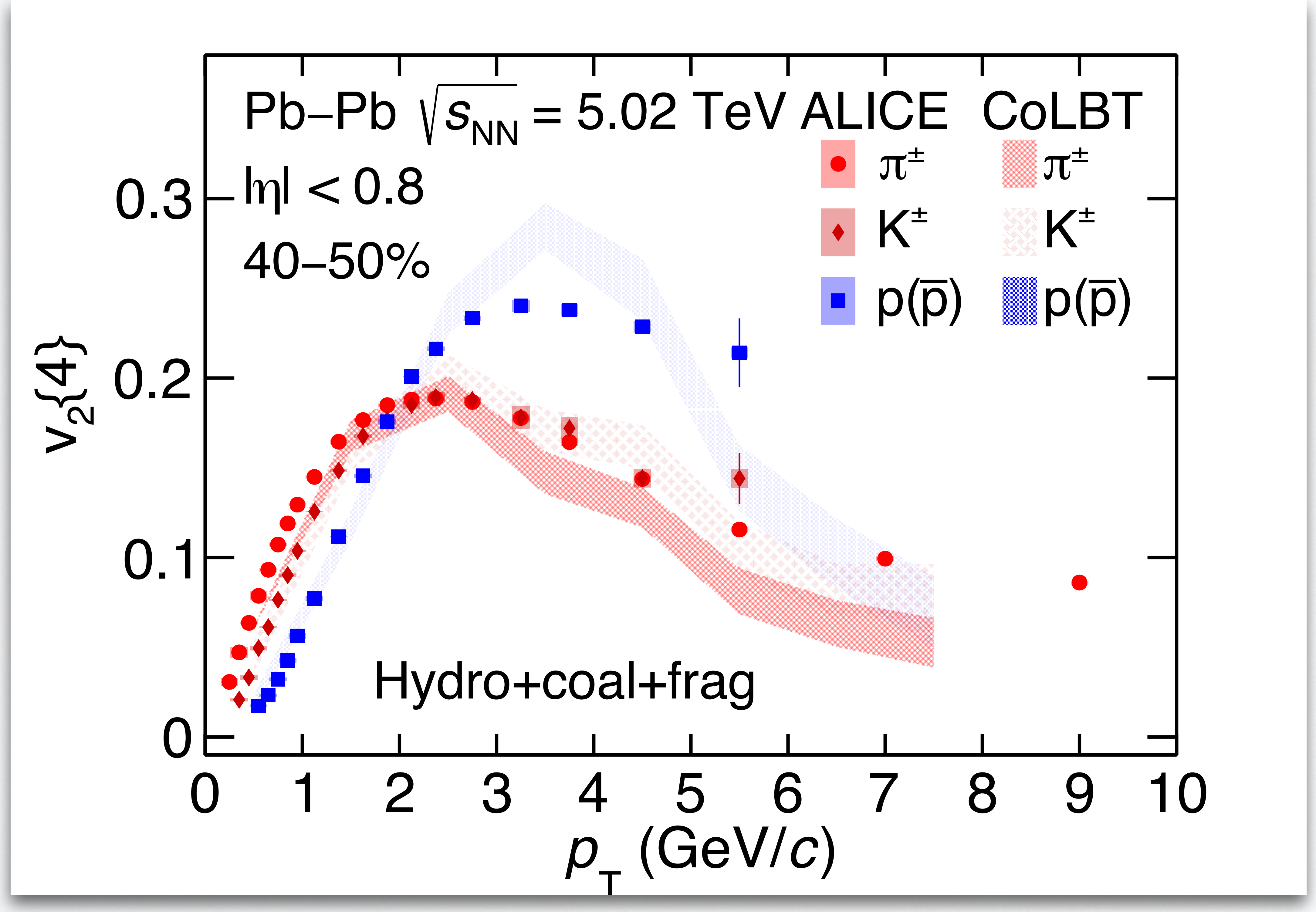


ALICE, arXiv: 2206.04587, accepted by *JHEP*

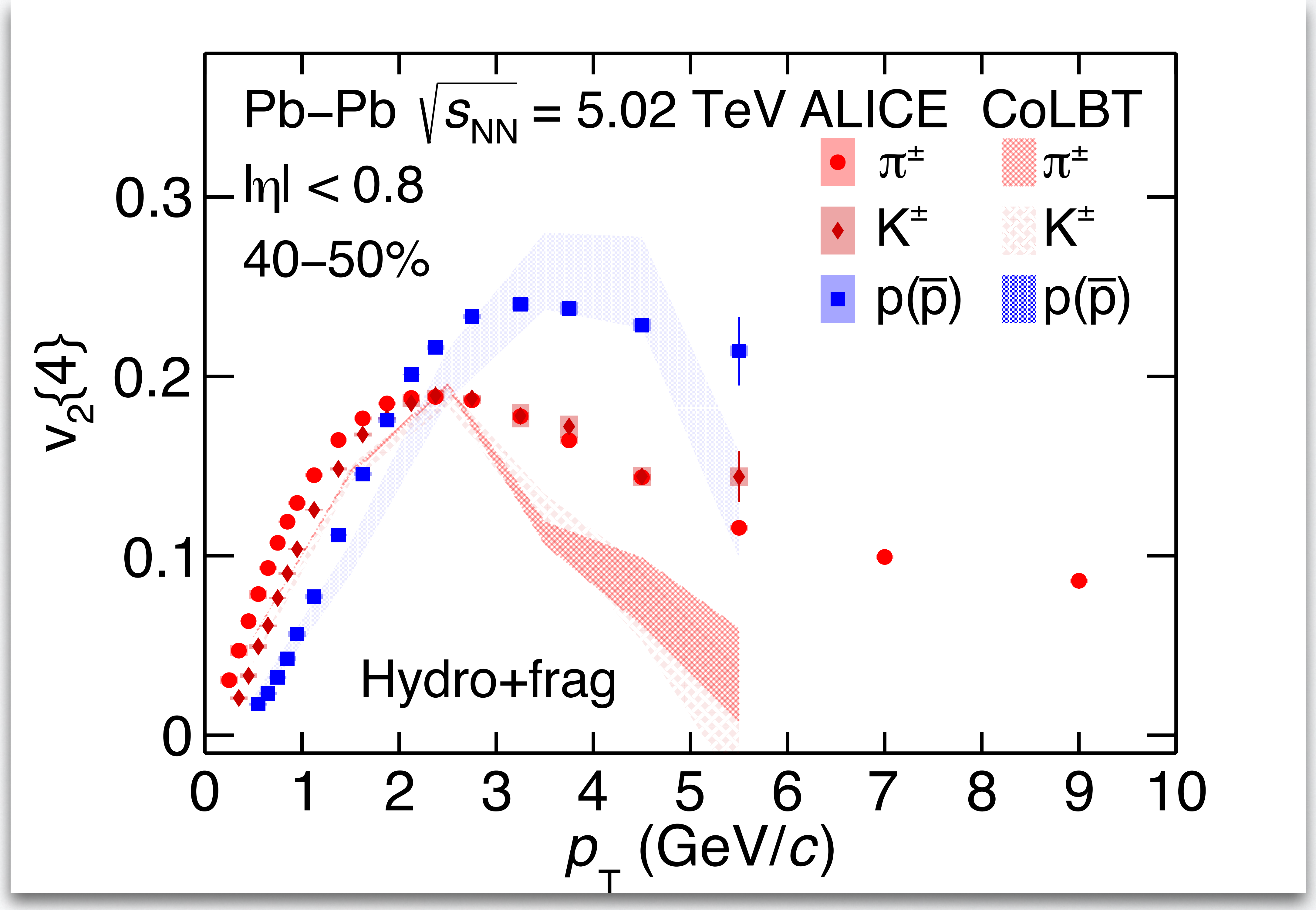
Contribution of the **quark coalescence**

- Hybrid CoLBT model:
  - **Hydro+coal+frag:** Contributions from hydrodynamics, quark coalescence, and jet fragmentation
  - **Hydro+frag:** Contributions from hydrodynamics and jet fragmentation

- The model with quark coalescence **describes the data better**
- Baryon-meson crossing is **not unique** for the model with quark coalescence



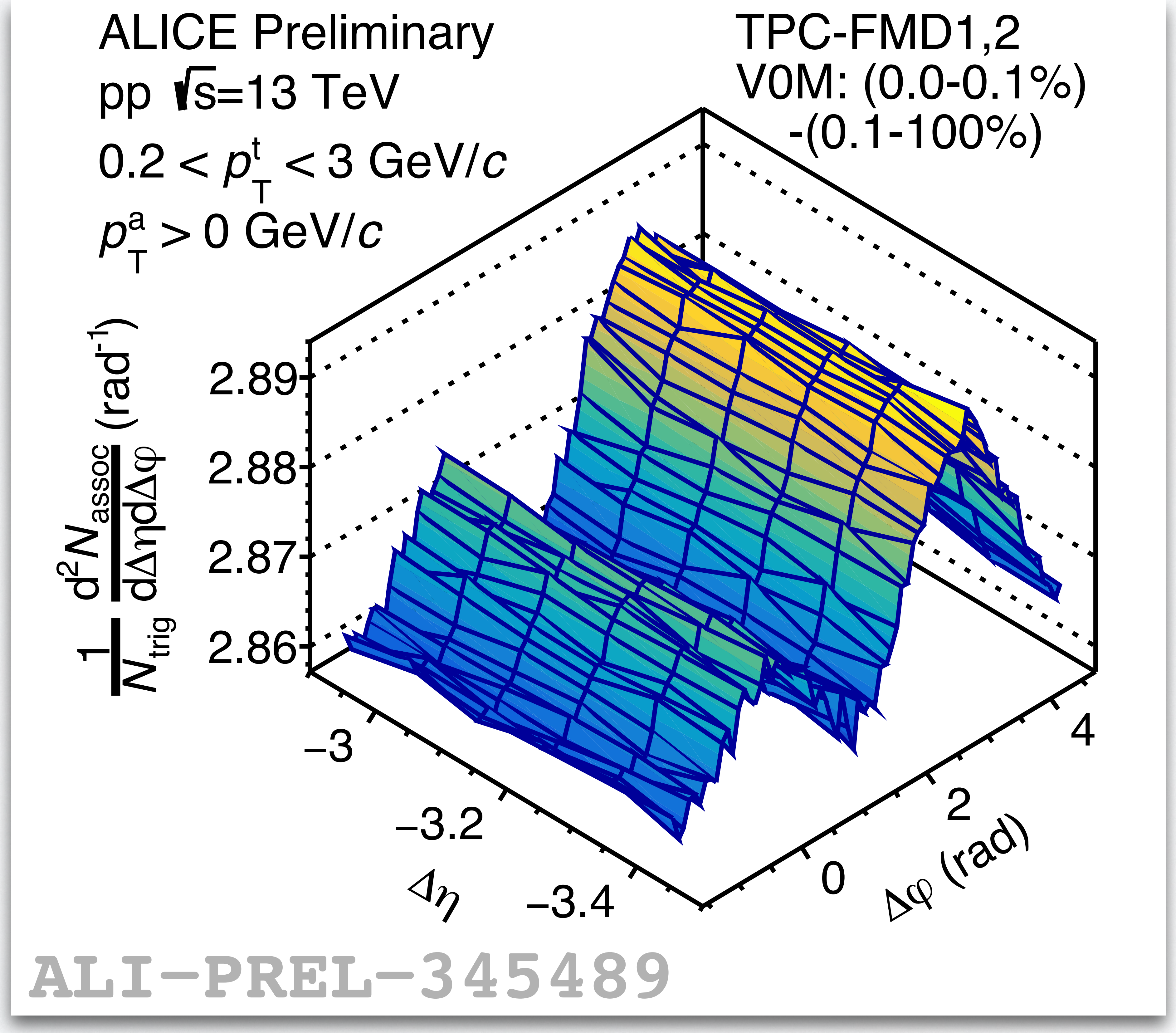
ALICE, arXiv: 2206.04587, accepted by *JHEP*



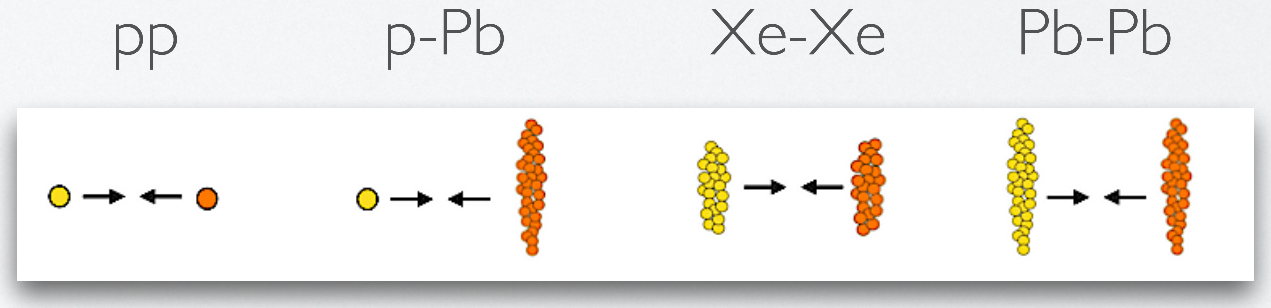
CoLBT, W. Zhao *et al.*, Phys. Rev. Lett. 128, 022302 (2022)

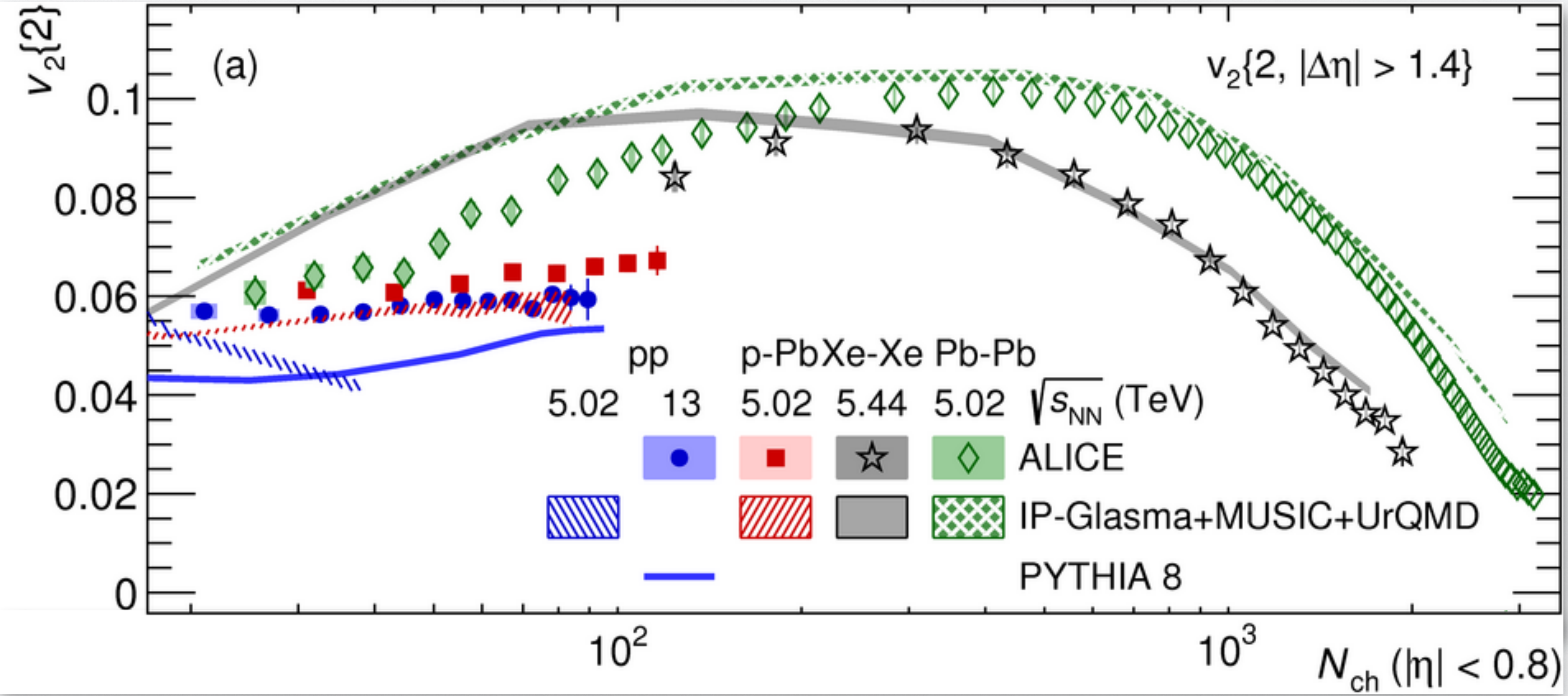
Collectivity in small collision systems

- Double ridge, a sign of collectivity, observed in **both pp and p-Pb collisions**
- Before that, small systems were considered only a baseline for heavy-ion collisions



- Sizeable flow observed across all collision systems
- Together with multi-particle long-range correlations confirmed **collectivity in small systems**

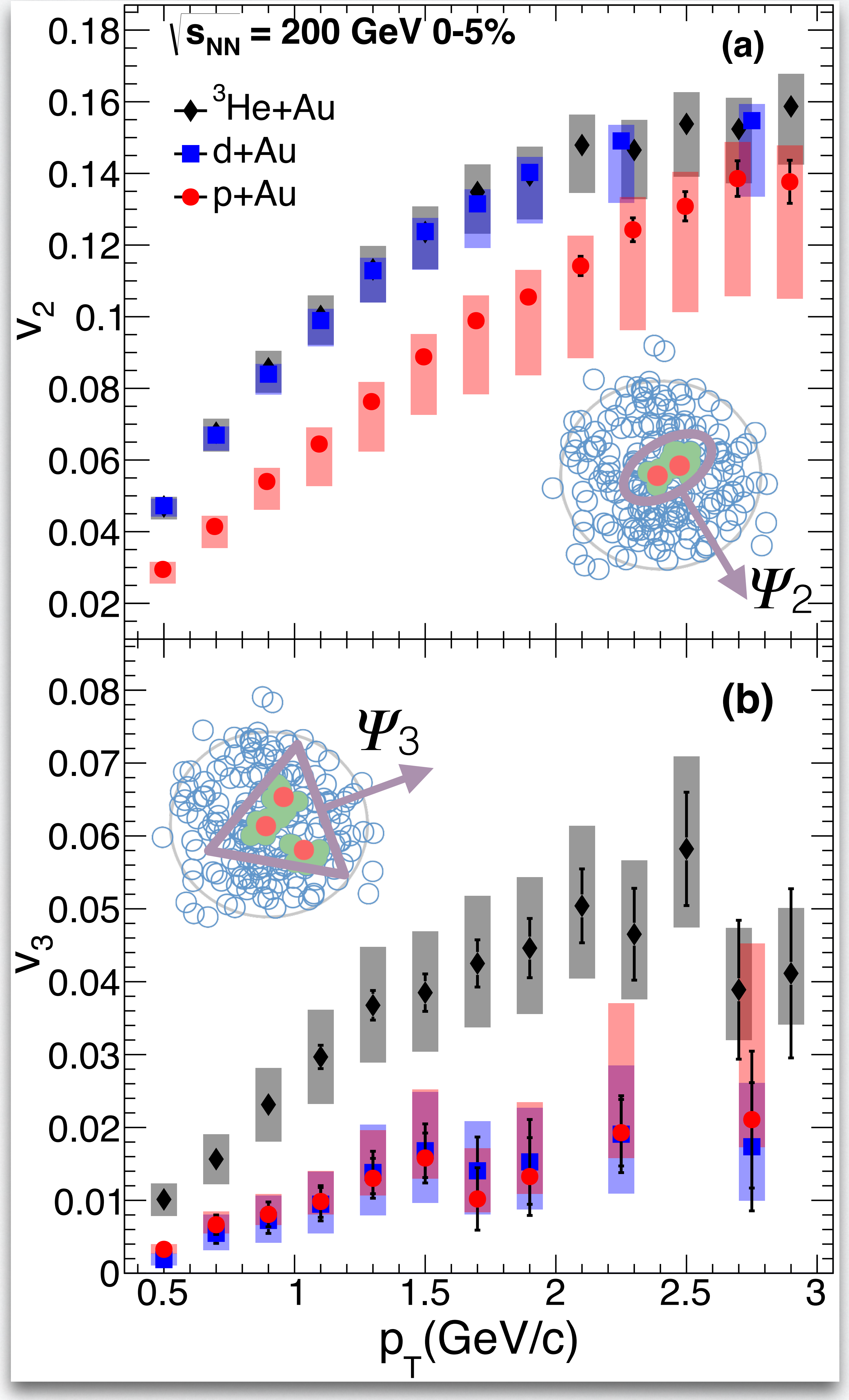




ALICE, Phys. Rev. Lett. 123, 142301 (2019)

The **origin of collectivity** in small collision systems

- Based on the current understanding, the collectivity in small systems is **driven by the initial geometry** via system dynamic evolution
- But **we do NOT know:**
  - Can there be partonic interaction with the quark-gluon plasma?
  - Are there any potential contributions from colour glass condensate?
  - Or parton escape?
  - Or hadronic interactions?
  - Or...?



PHENIX, Nature Physics 15, 2019

ALICE detector — A Large Ion Collider Experiment

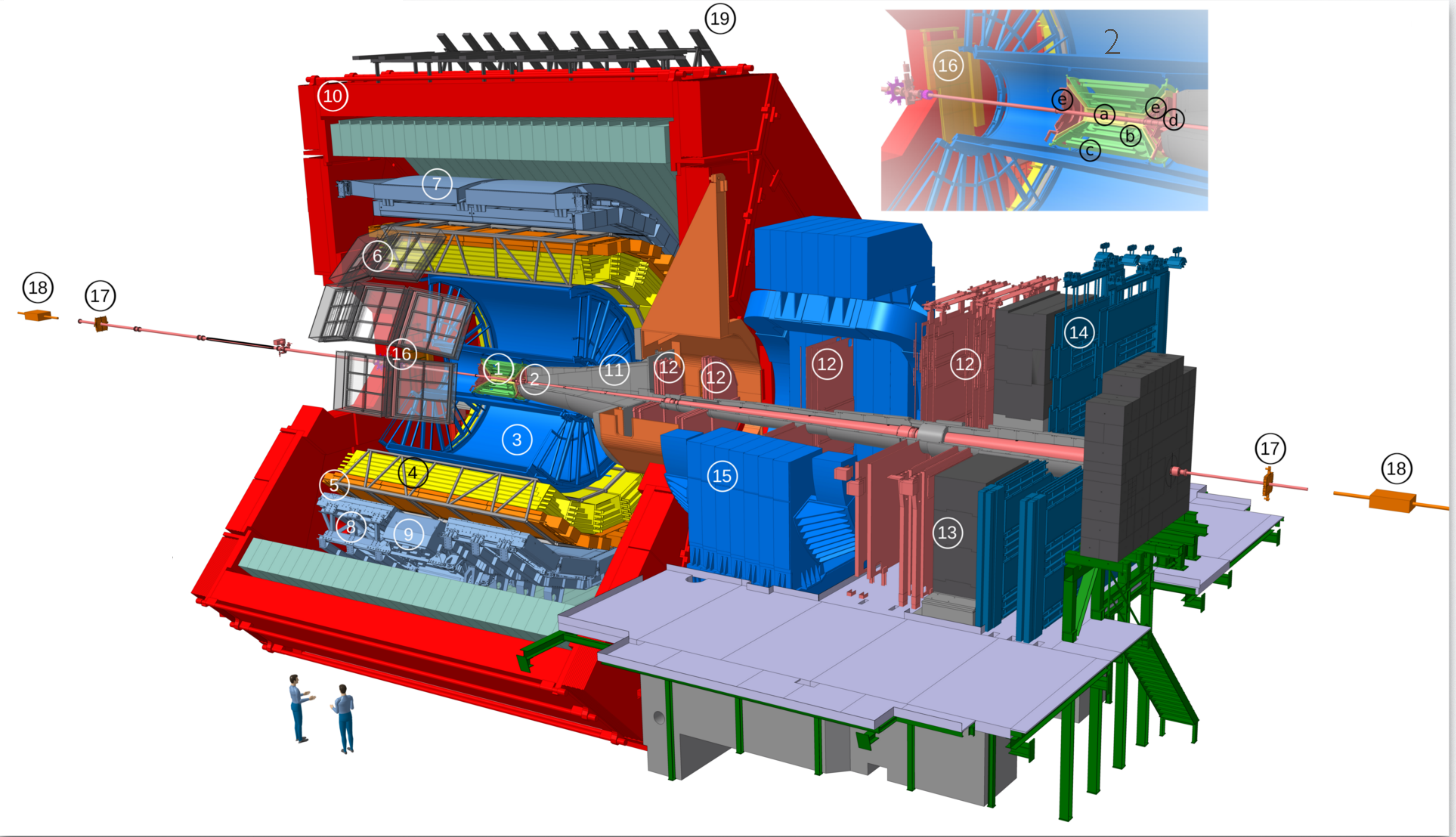
1. **Inner Tracking System** (ITS)
   - Tracking and triggering

2d. **V0 detector**
   - Triggering and event multiplicity determination

2e. **Forward Multiplicity Detector** (FMD)
   - Unique pseudorapidity coverage
   - $-3.4 \leq \eta \leq -1.7$
   - $1.7 \leq \eta \leq 5.0$

3. **Time Projection Chamber** (TPC)
   - Tracking and particle identification

5. **Time-of-Flight detector** (TOF)
   - Particle identification

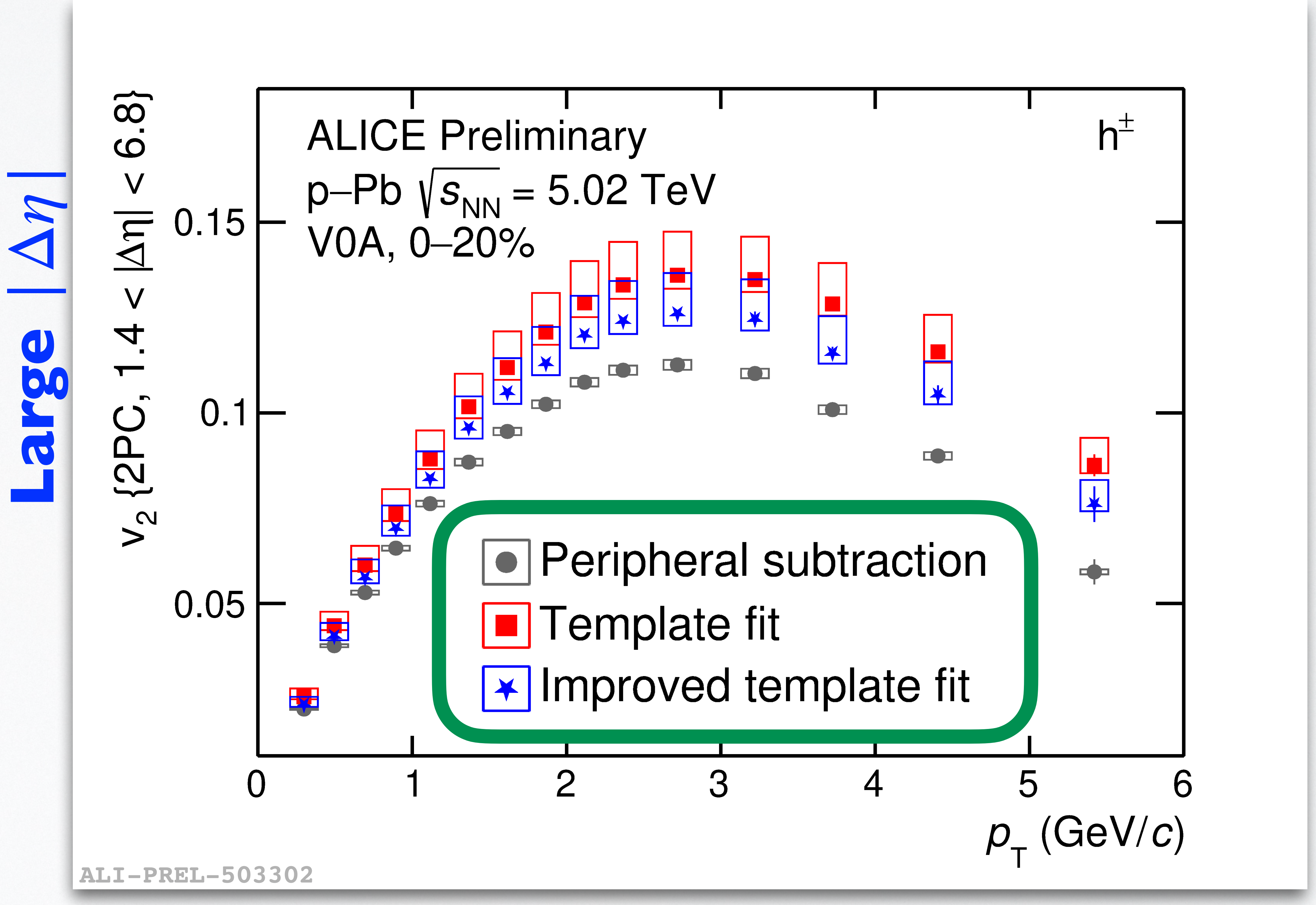


Non-flow treatment

- Small systems dominated by non-flow, correlations not associated with the common symmetry plane
- Different methods of non-flow suppression:
  - **Pseudorapidity separation** $(|\Delta\eta| > \varepsilon)$
  - Higher order correlations
  - **Subtraction** of low multiplicity (peripheral) collisions:
    - Peripheral subtraction method
    - Template fit, where

$$Y(\Delta\varphi) = FY(\Delta\varphi)^{peri} + G[1 + \sum_{n=2}^{\infty} 2V_{n\Delta}\cos(n\Delta\varphi)]$$

    - Improved template fit, as above with a parametrisation for the multiplicity dependence, as introduced in **ATLAS**, Phys. Lett. B 789 (2019)

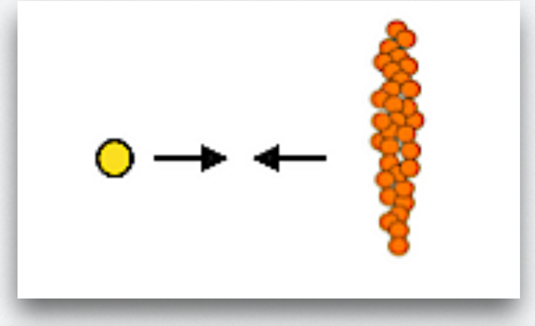


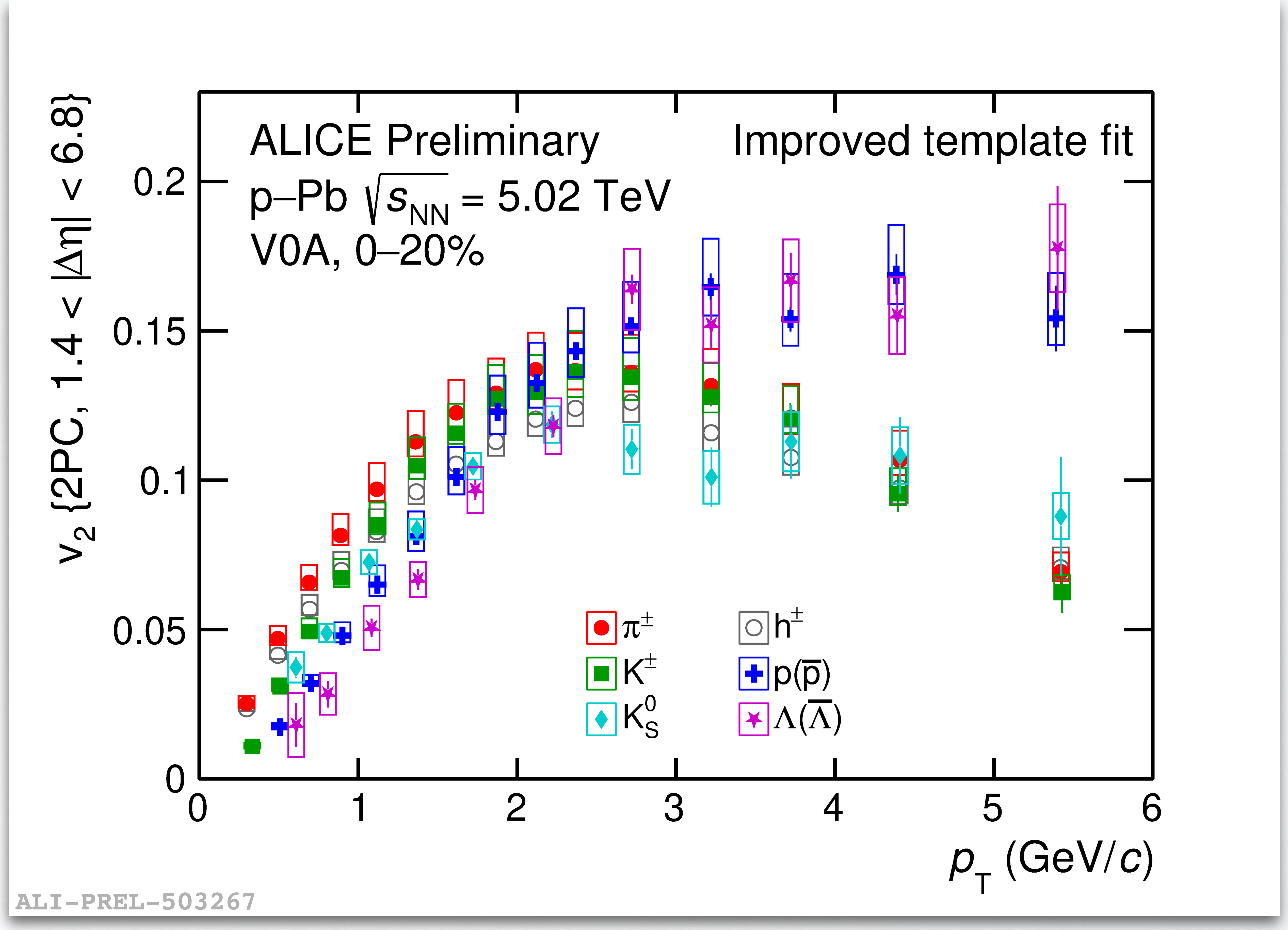
Flow of identified particles in p-Pb collisions

- p_{T} differential flow of identified particles from p-Pb collisions obtained using ultra-long-range dihadron correlations with ALICE
- Same observations as in Pb-Pb collisions
  - **Mass ordering** at low p_{T} region
  - **Baryon-meson splitting** at intermediate p_{T} region with 3σ

- Baryon-meson splitting in Pb-Pb collisions is explained by the partonic collectivity → possible presence of **partonic collectivity** is observed in p-Pb collisions

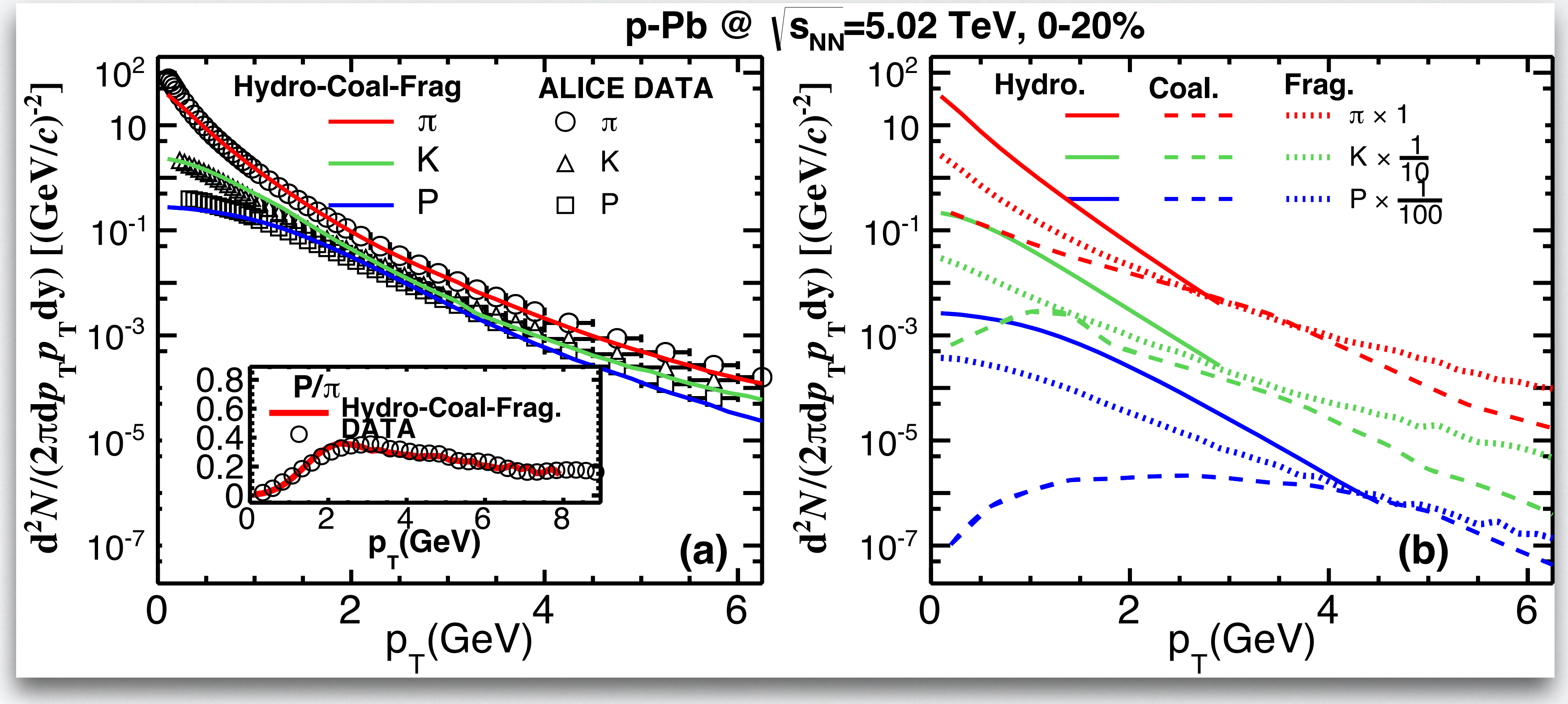
p-Pb





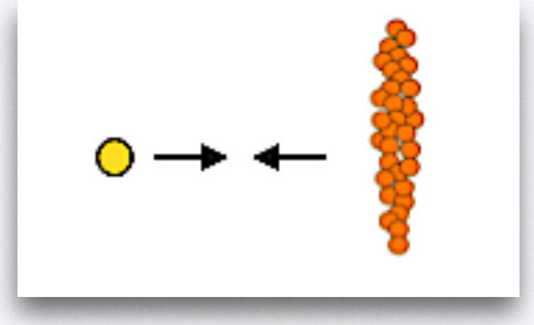
Observation of **partonic collectivity**

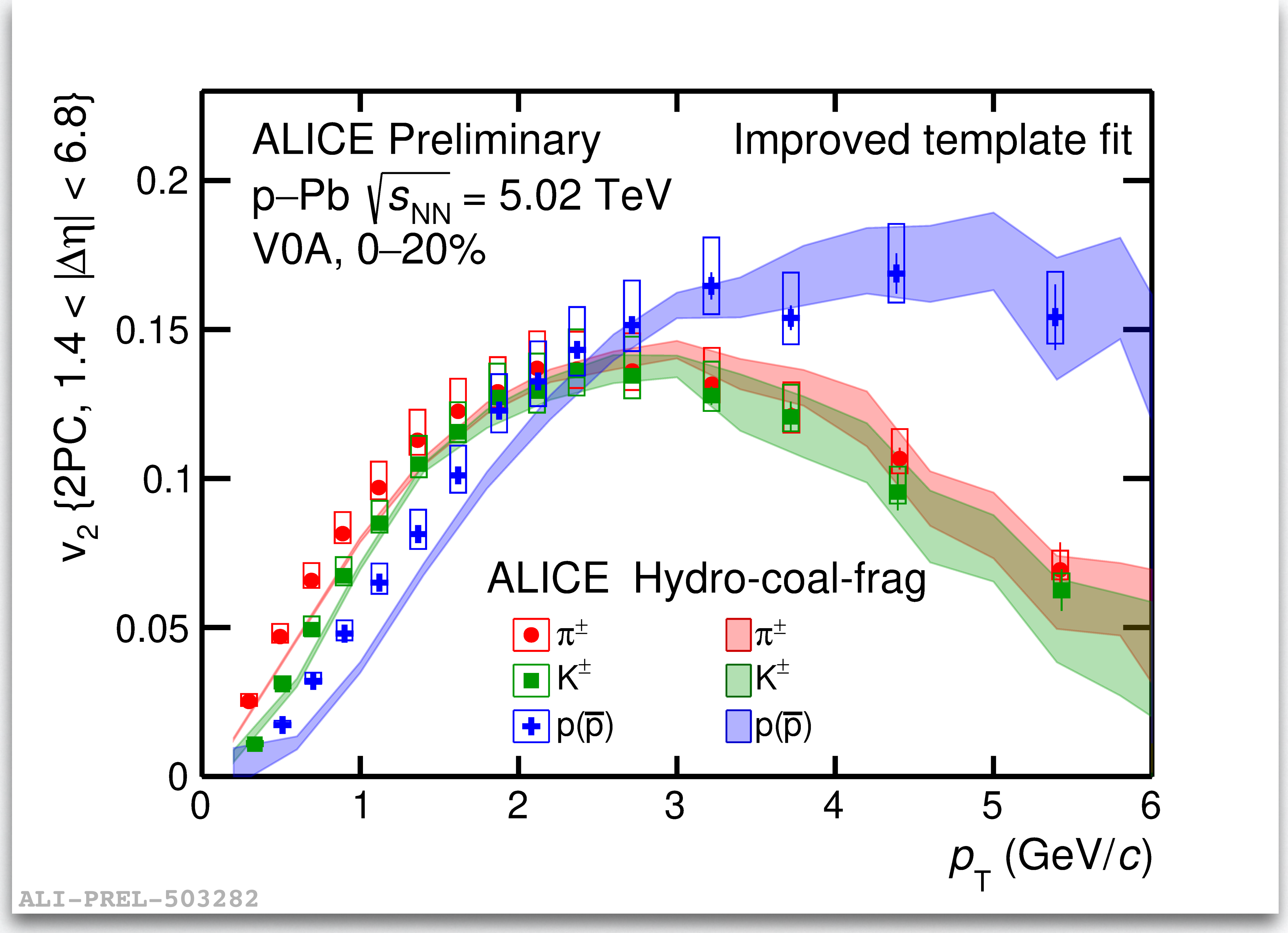
- Model from W. Zhao *et al.*, Phys. Rev. Lett. 125, 072301 (2020), combines **hydrodynamics, quark coalescence, and jet fragmentation,** with their relative contributions fixed from the fit of p_T spectra
- Model without quark coalescence cannot qualitatively describe trends seen in data
- **Partonic collectivity** further confirmed in p-Pb collisions with ALICE

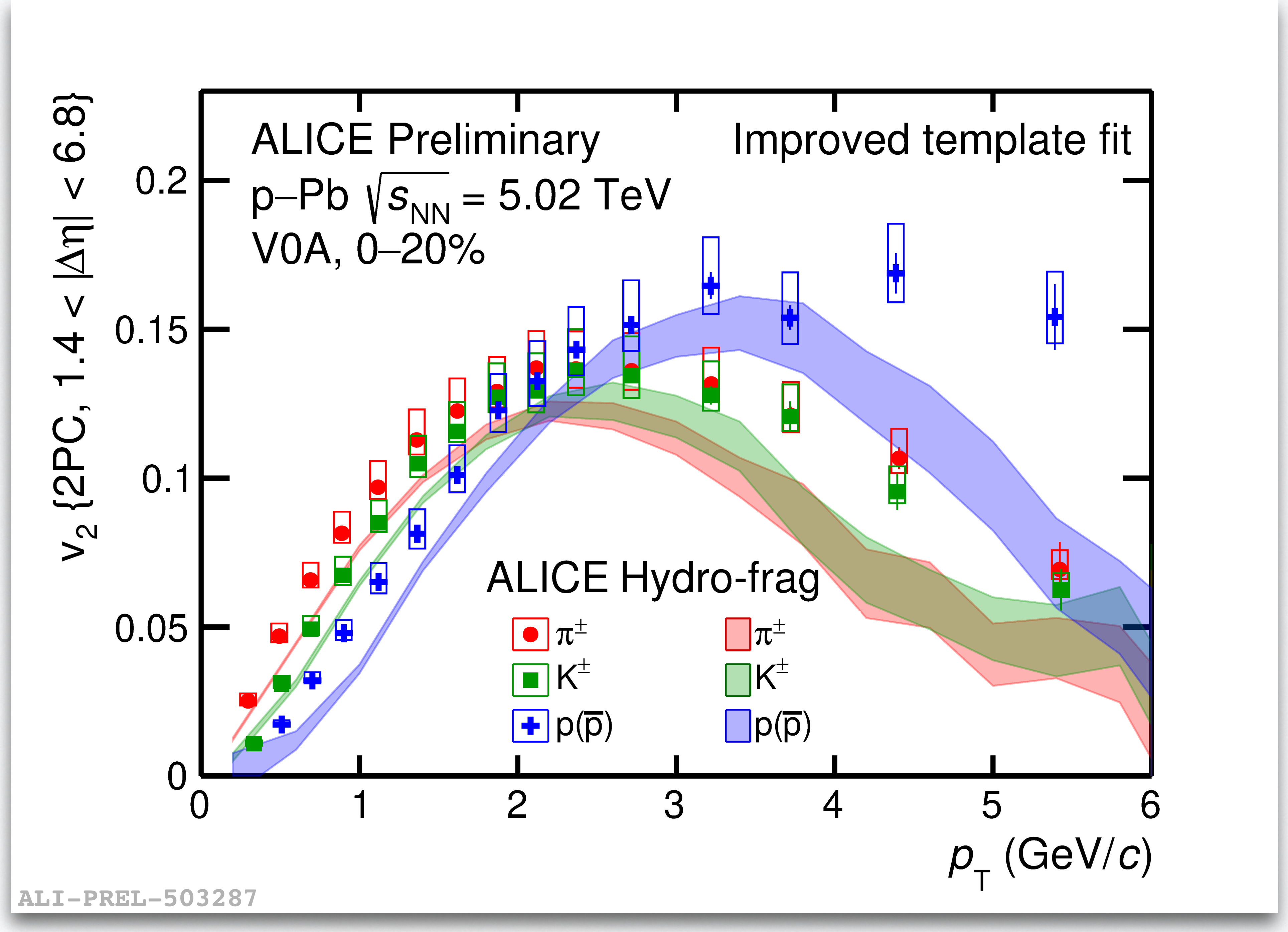


W. Zhao *et al.*, Phys. Rev. Lett. 125, 072301 (2020)

p-Pb



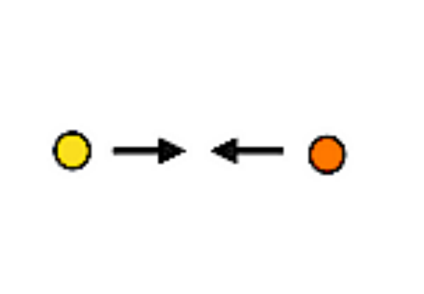


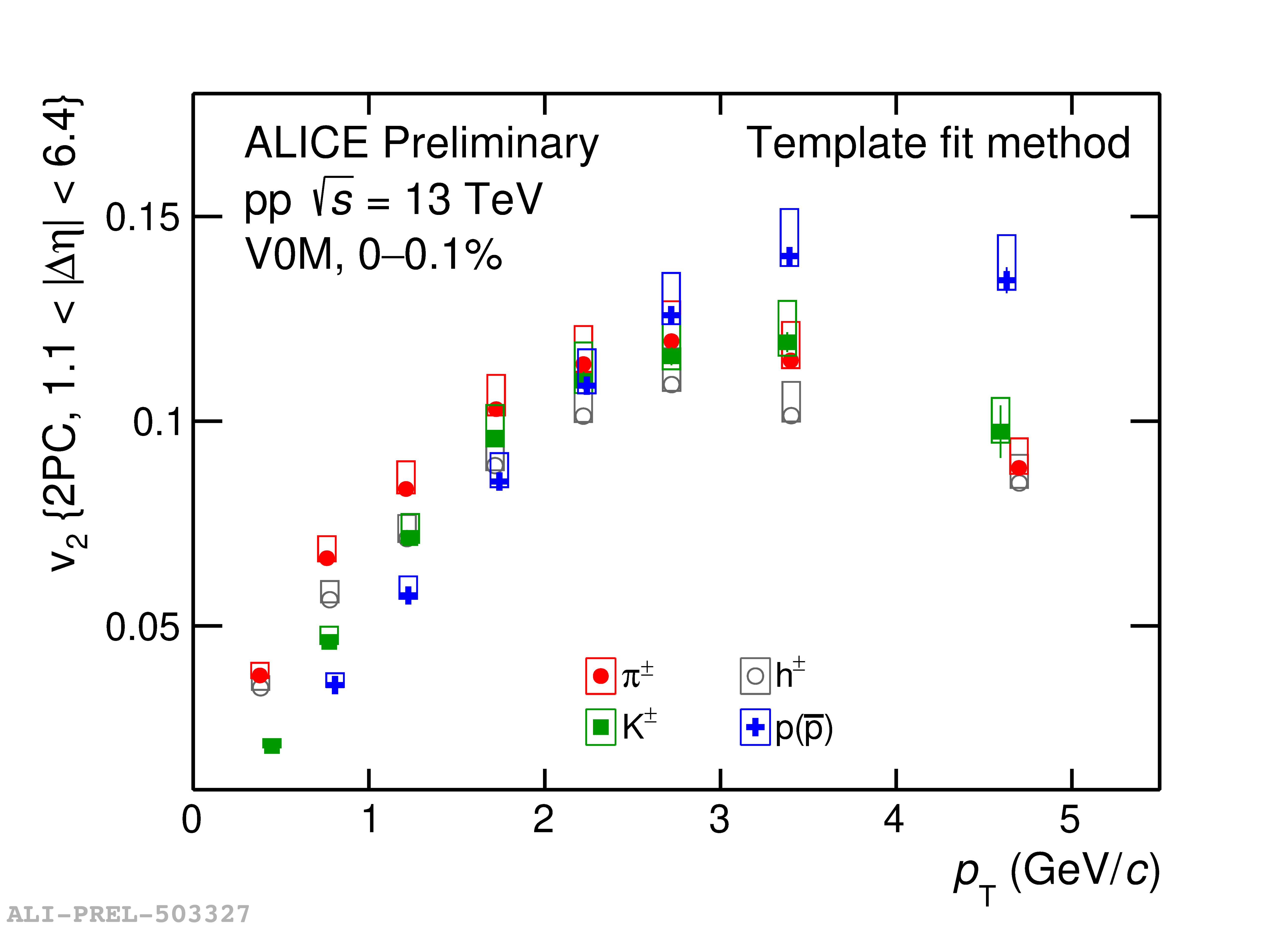


Flow of identified particles in pp collisions

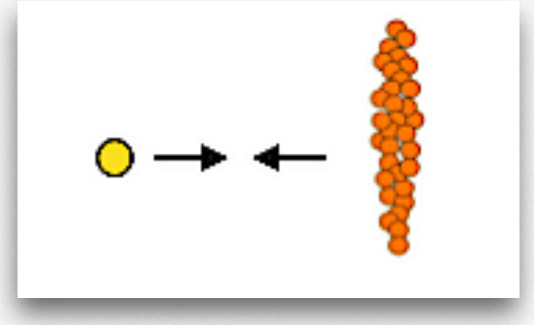
- Same observations as in p-Pb and Pb-Pb collisions
  - **Mass ordering** at low p_{T} region — presence of the radial flow in agreement with observations in the spectra of high-multiplicity collisions
  - **Baryon-meson splitting** at intermediate p_{T} region with 3σ, observed for the **first time** in pp collisions!
- Model description of pp results currently not available

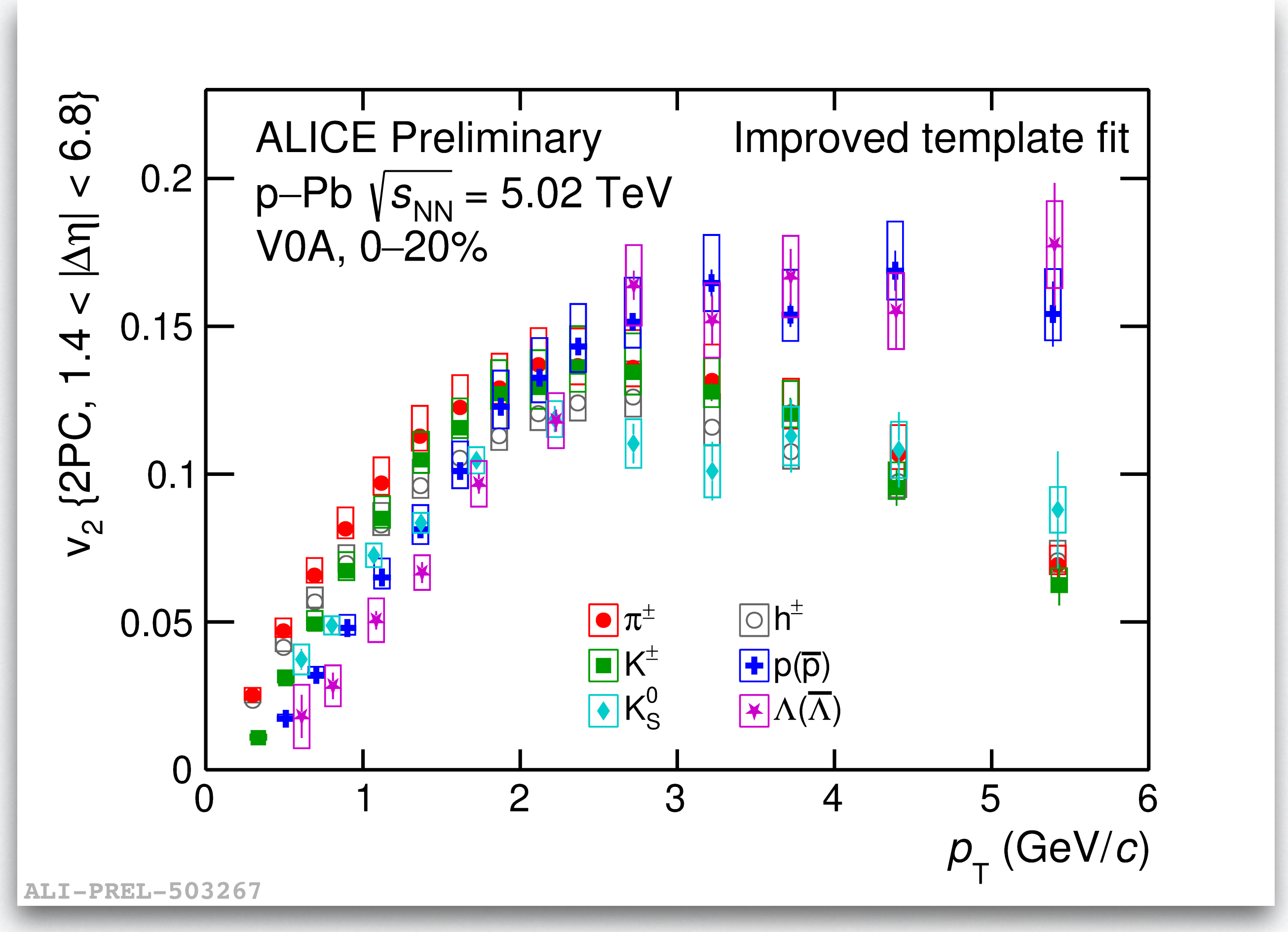
pp





p-Pb





Conclusion

- **Mass ordering** and **baryon-meson grouping,** potential QGP signals in heavy-ion collisions, are observed **in both pp and p-Pb collisions**
- The model without quark coalescence fails to describe the data in p-Pb collisions — the evidence of **partonic collectivity** in small systems is strengthened
- These results provide new insights into the **origin of collective effects in small collision systems**