Unraveling the origin of collectivity in high and low multiplicity pp and p–Pb collisions in ALICE at the LHC

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- On behalf of the ALICE Collaboration

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THE VELUX FOUNDATIONS

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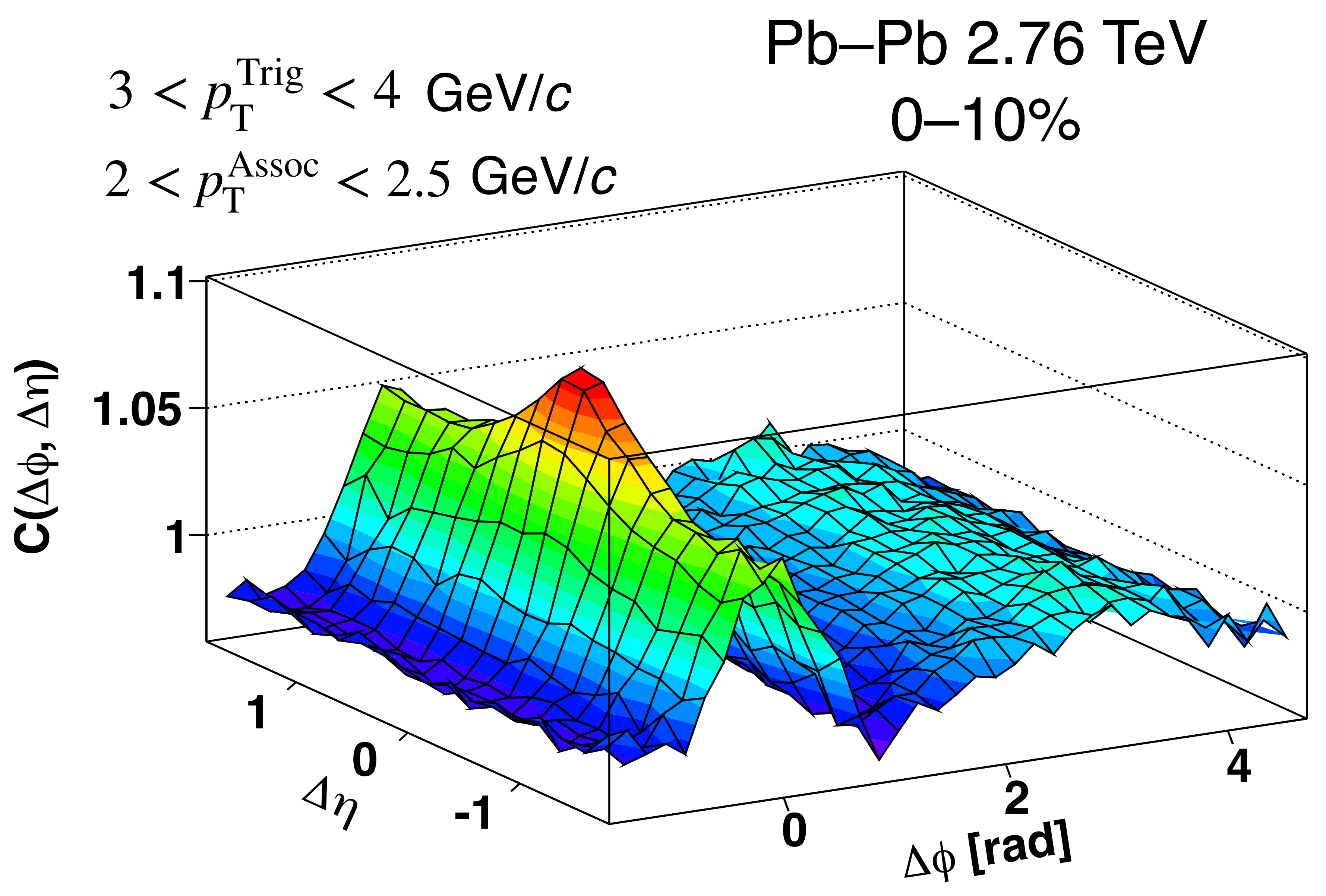
Outline

Studying collective phenomena in pp and p–Pb collisions in ALICE:

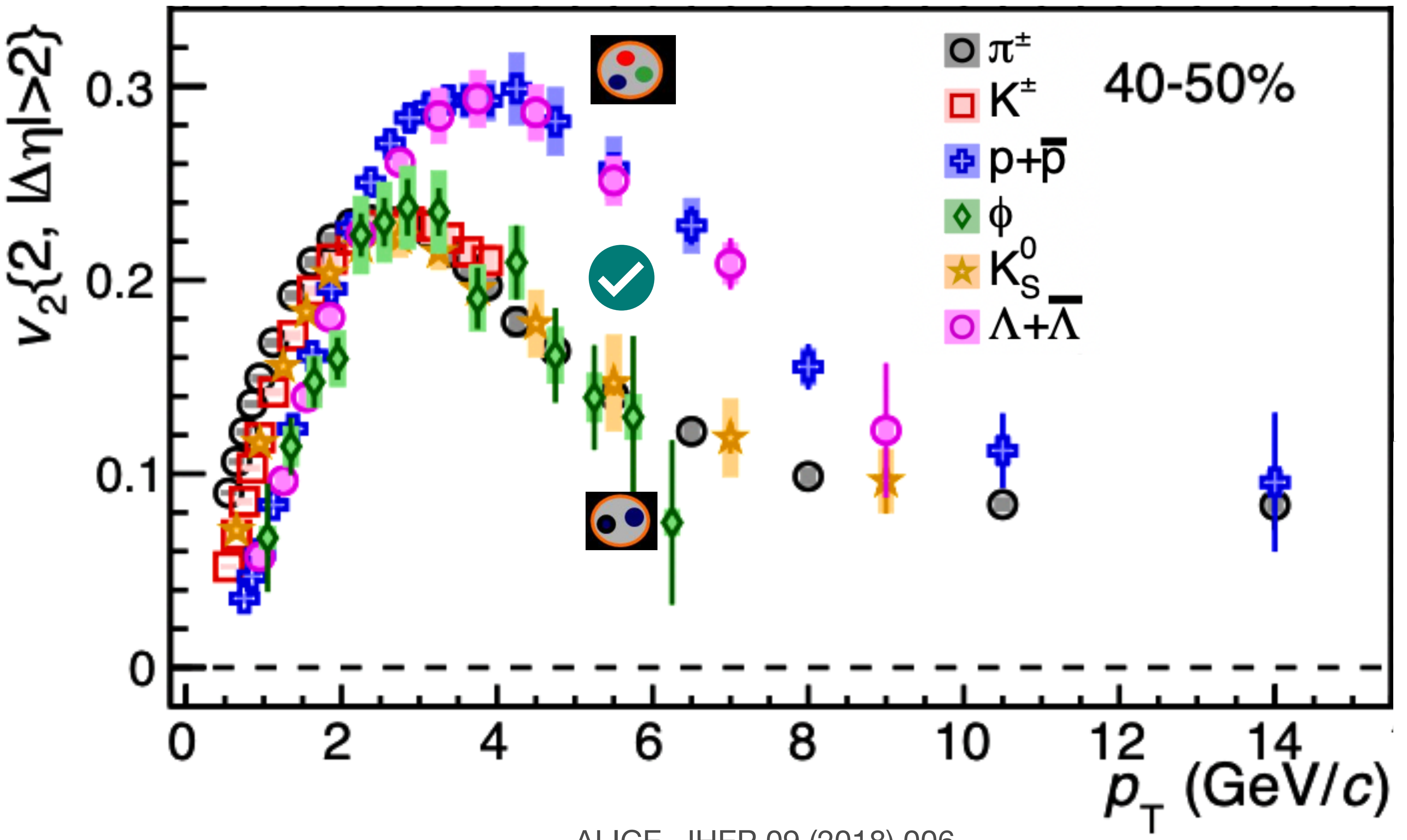
- Investigating the multiplicity dependence of v_2 of baryons and mesons at intermediate p_{T}.

- Exploring the ultra long-range correlation ($|\Delta\eta| > 5.0$) down to low multiplicity in pp and p–Pb collisions.

Baseline: Collective features in heavy-ion collisions



ALICE, PLB 708 (2012) 249-264



ALICE, JHEP 09 (2018) 006

- Long-range correlation, anisotropic flow of identified particles, multi-particle correlations…
- Low p_T ($p_T \lesssim 3$ GeV/c) — Mass ordering of v_2.
- Intermediate p_T ($3 < p_T \lesssim 8$ GeV/c) —Baryon-meson grouping and splitting of v_2 — quark coalescence, sign of partonic collectivity (✓).

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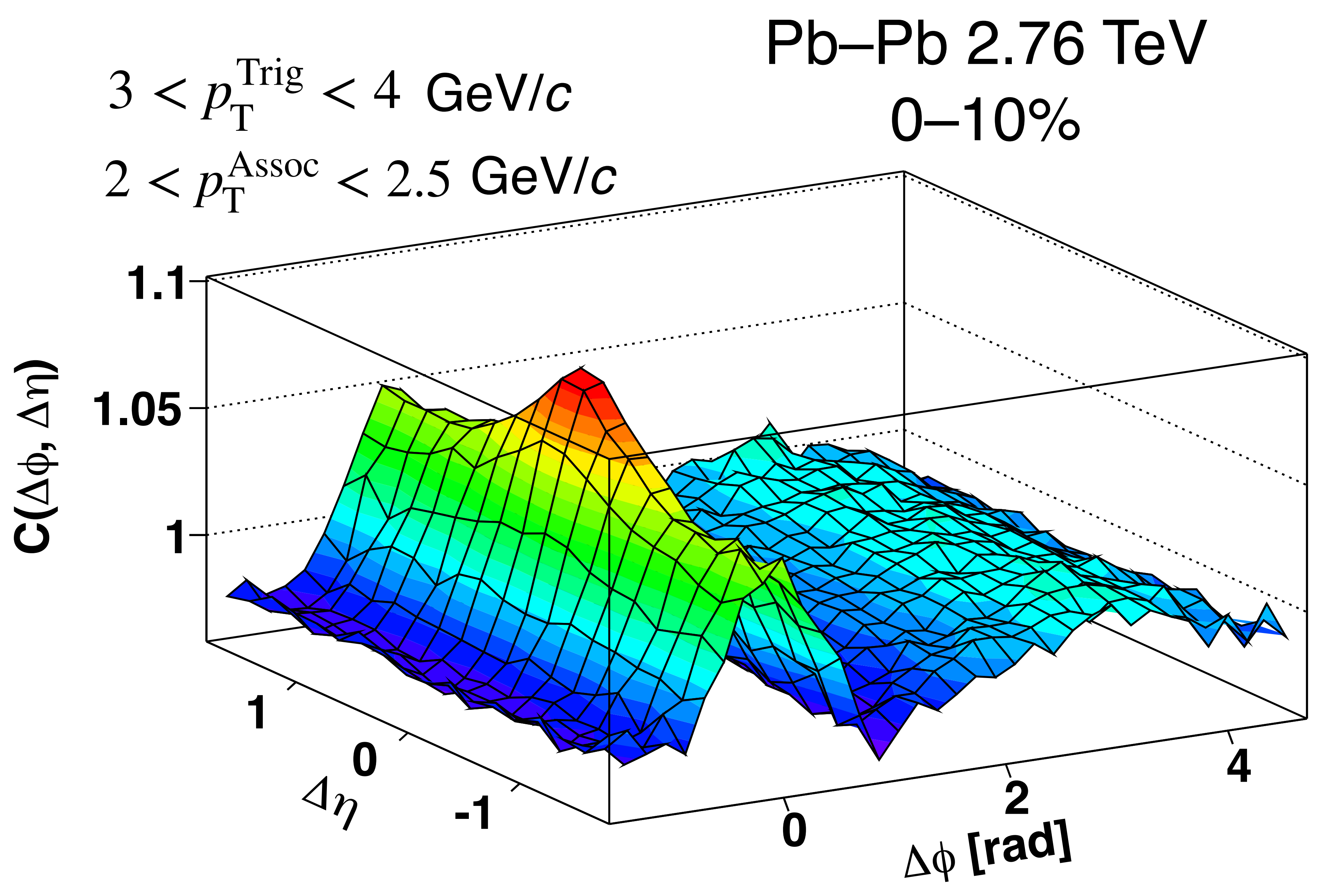

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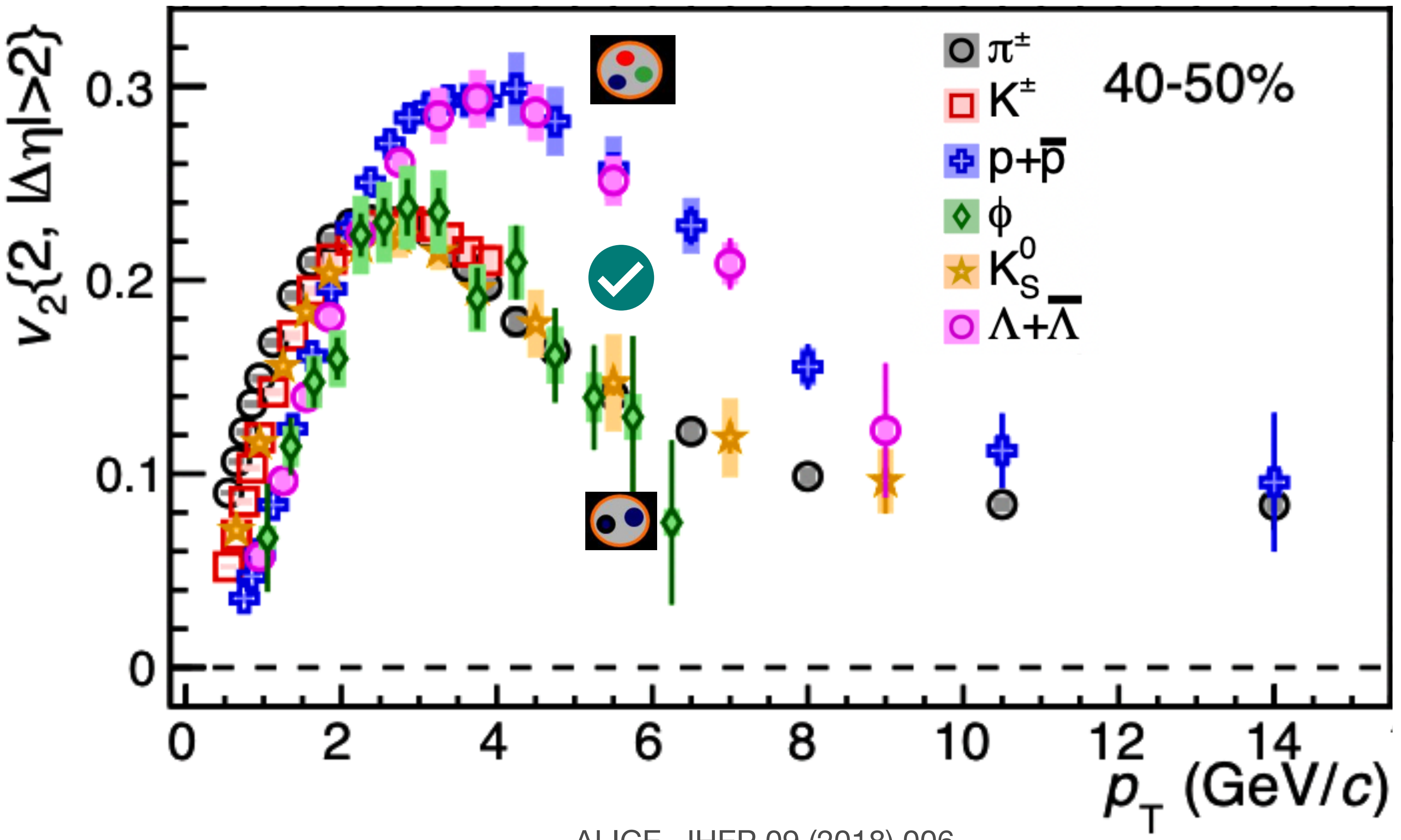

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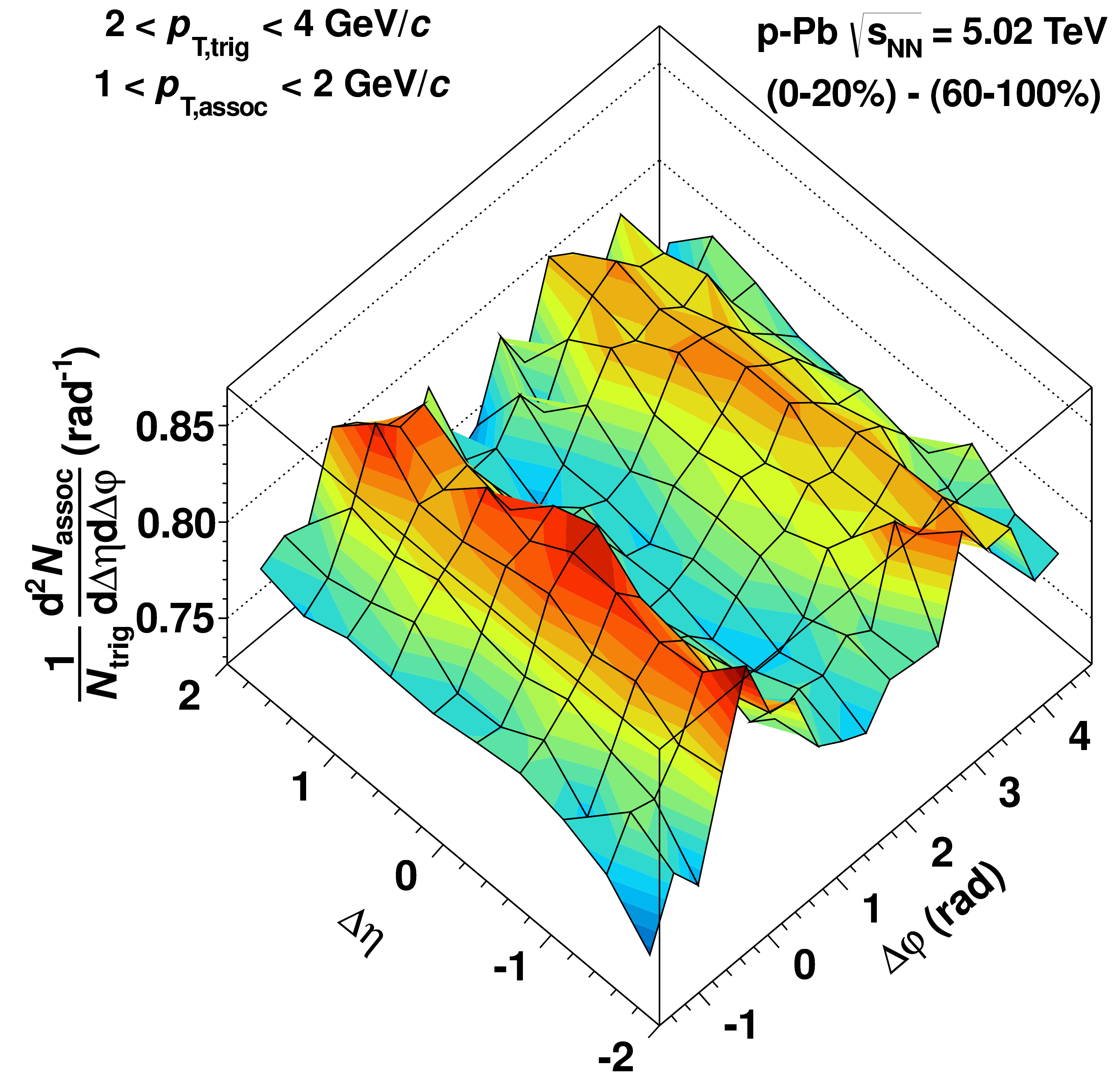
What about small systems?

Similar collective beahvior in small systems?



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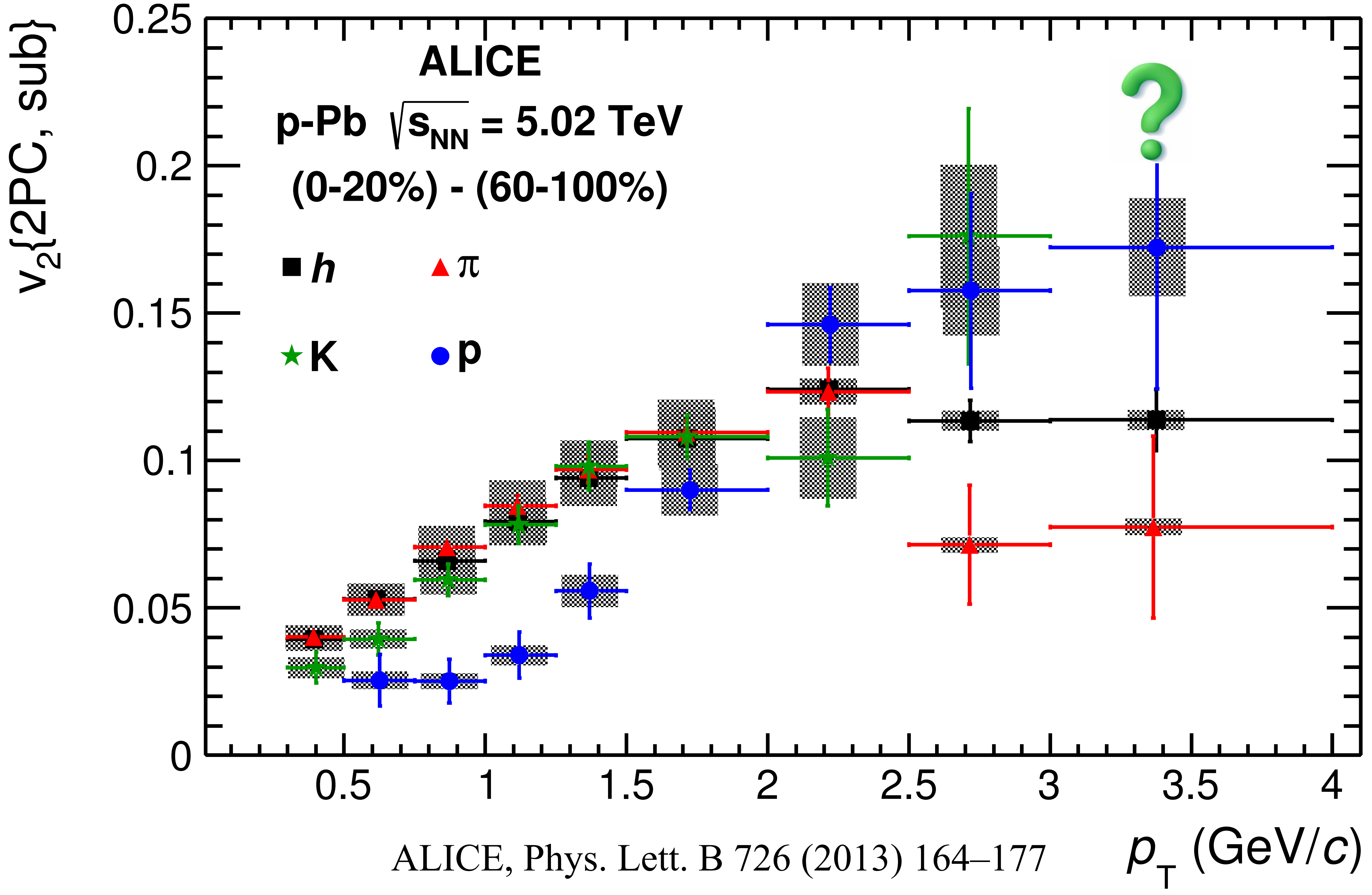

ALICE, Phys. Lett. B 726 (2013) 164–177

Major issue— non-flow removal.

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- Low p_T ($p_T \lesssim 3$ GeV/c) — Mass ordering of v_2.
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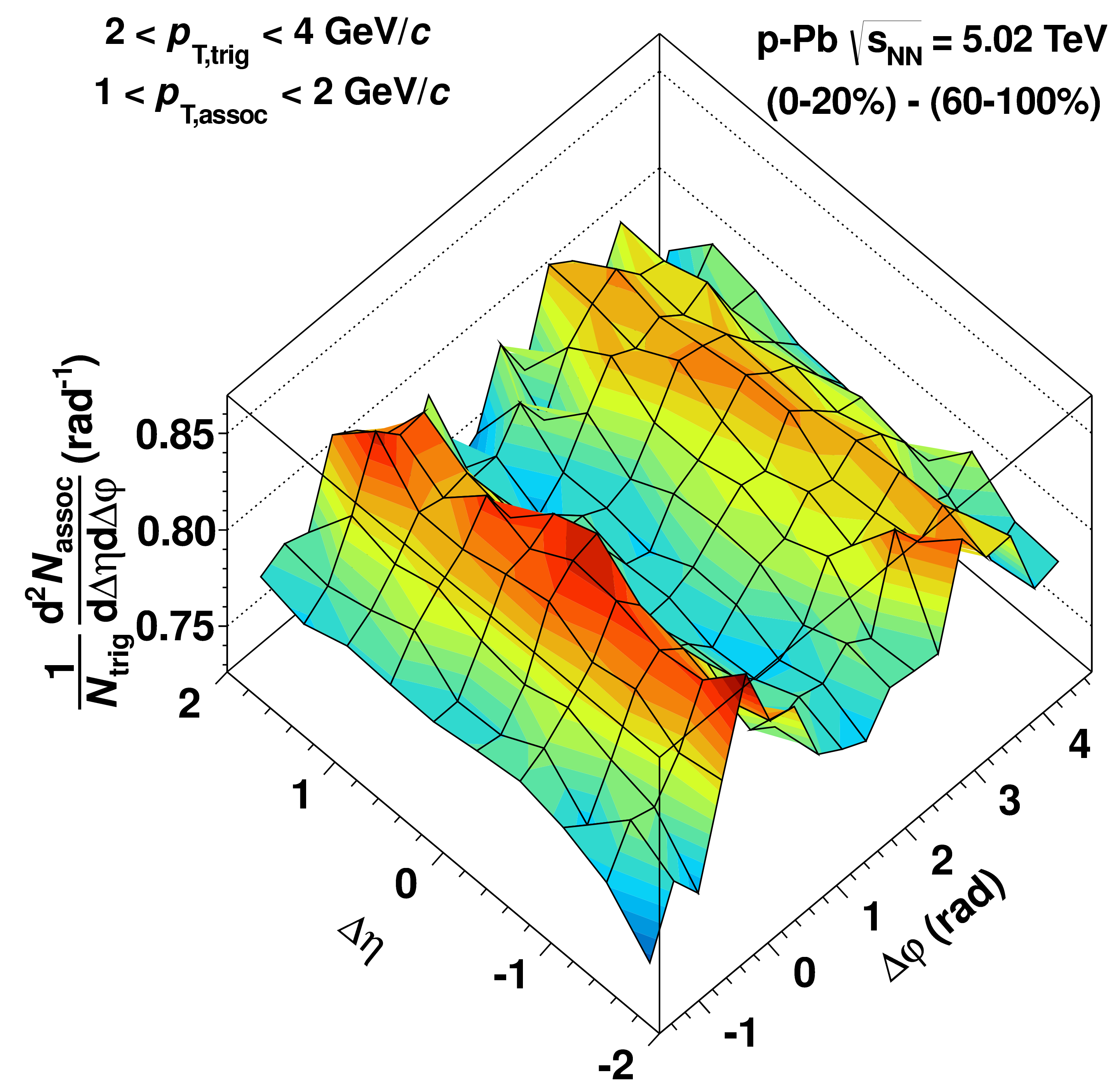

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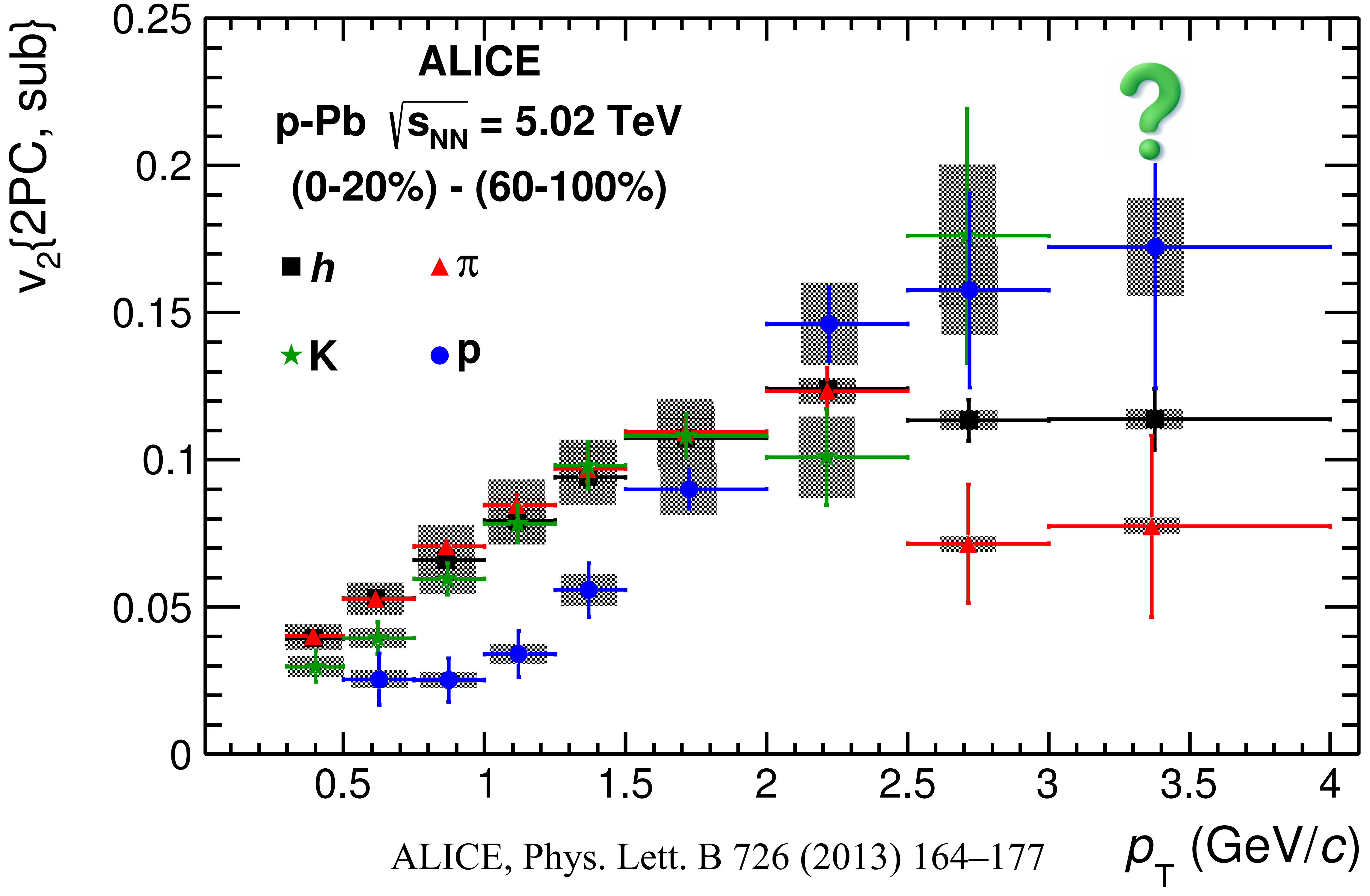

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Focus: Baryon and meson $v_2(p_T)$ at intermediate p_T

The ALICE Detector

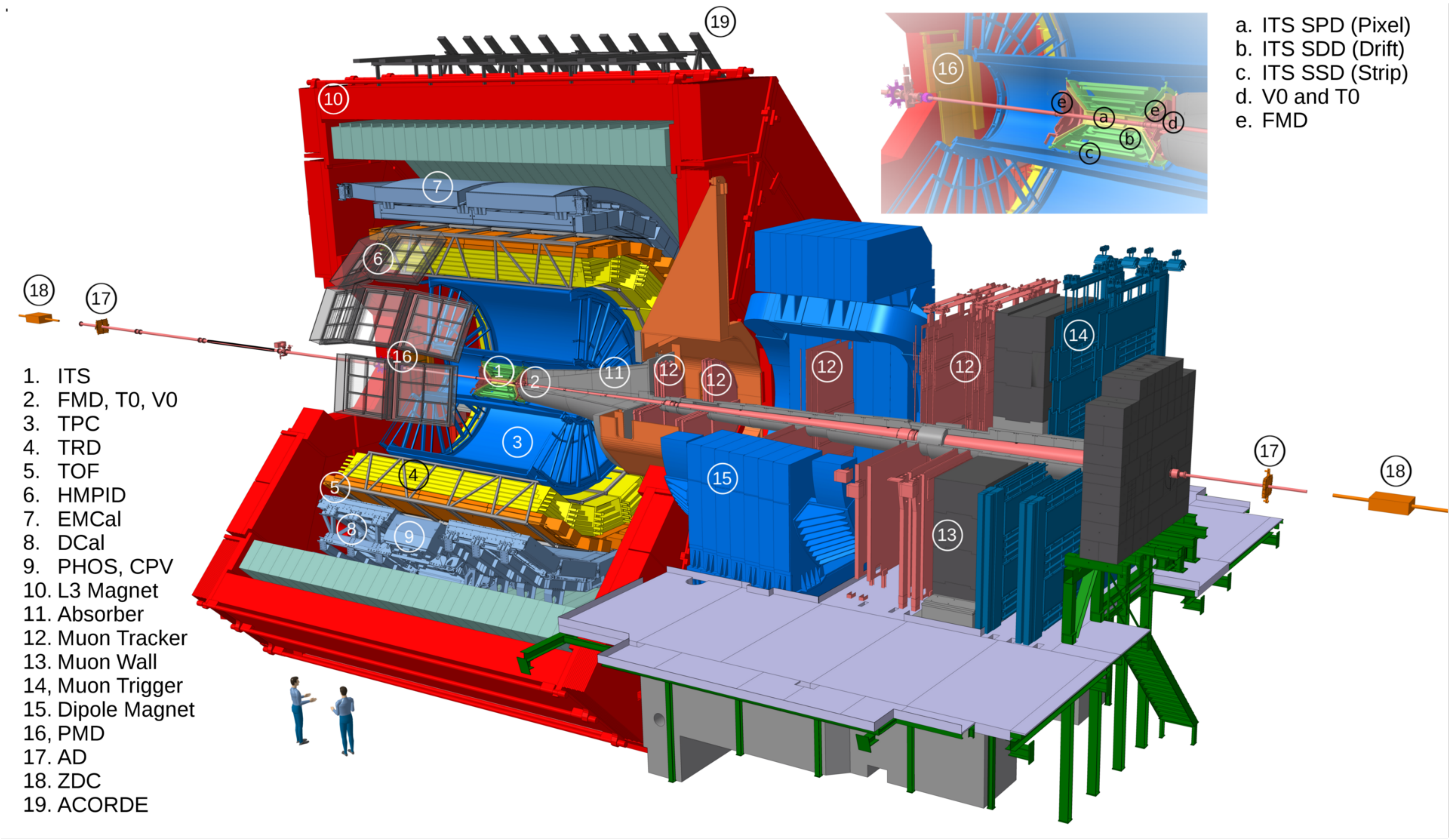
- Detectors primarily used in this analysis:

1. **V0 Detector**
Triggering and event classification.

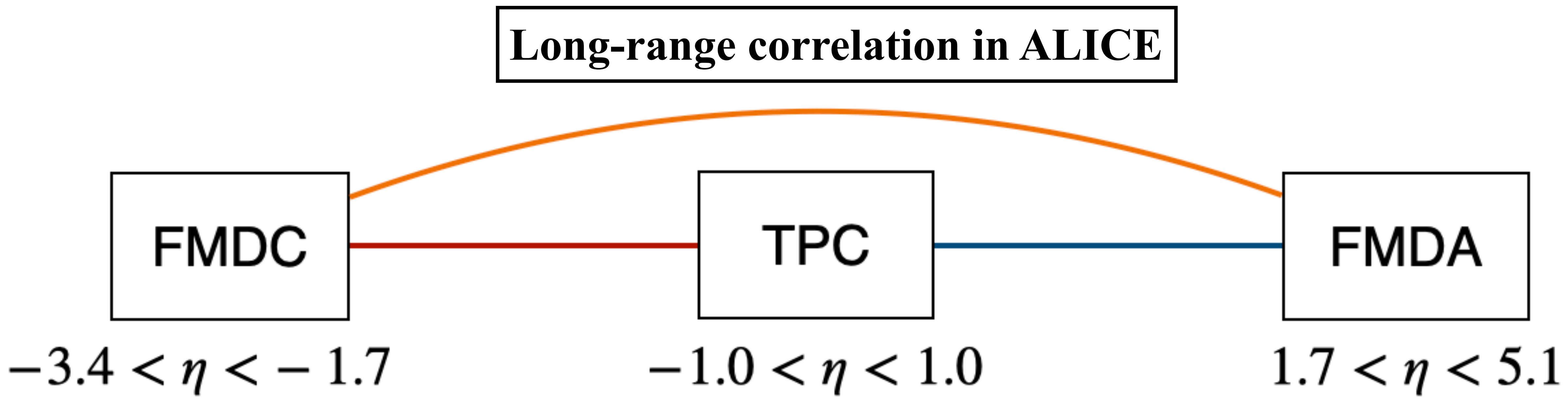
2. **Forward Multiplicity Detector (FMD)**
Unique coverage for long range correlation in ALICE.

3. **Time-of-Flight (TOF)**
Particle identification.

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

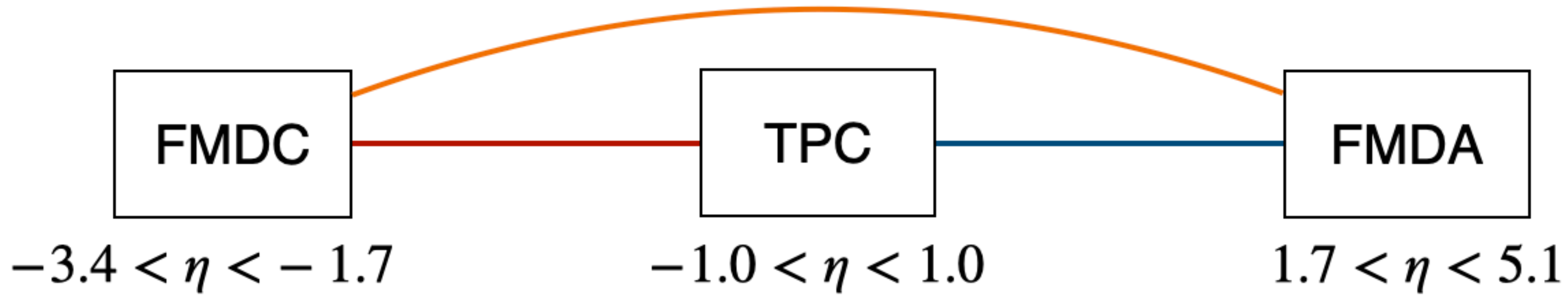


- N_{ch}: Number of tracks in TPC with ($|\eta| < 0.8$, and $p_{\mathrm{T}} > 0.2$ GeV/c). Used as event classifier.



- **Datasets**:
1. p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
2. pp collisions at $\sqrt{s} = 13$ TeV

$V_{2\Delta}$ and v_2 measurement from long-range correlation in ALICE



- Long-range correlations: TPC—FMDA/C and FMDA—FMDC corelations.

$$v_n\{2\} = \sqrt{\frac{V_{n\Delta}^{\text{TPC-FMDA}} V_{n\Delta}^{\text{TPC-FMDC}}}{V_{n\Delta}^{\text{FMDA-FMDC}}}}$$

$$V_{2\Delta}^{\text{TPC-FMD}} \approx v_2^{\text{TPC}} v_2^{\text{FMD}}$$

- $V_{2\Delta}$ estimated from Template Fit method:

Higher multiplicity event = Scaled baseline event (non-flow) + Additional flow

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

Probed — Baseline — Flow expansion

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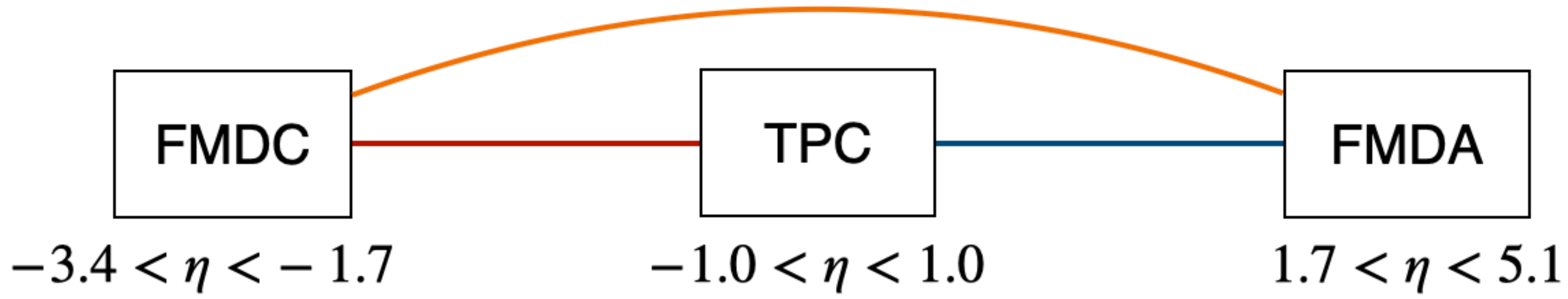

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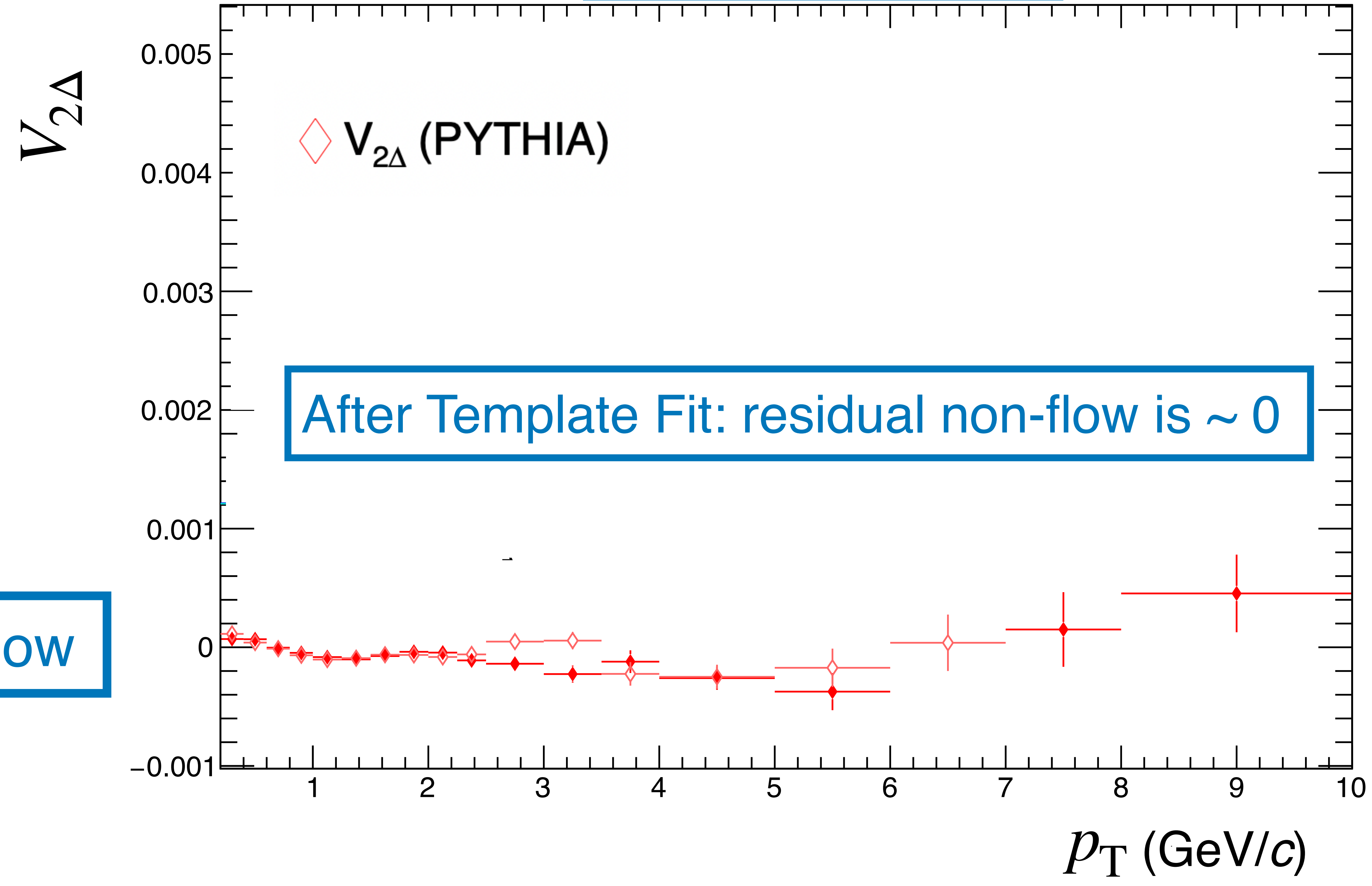
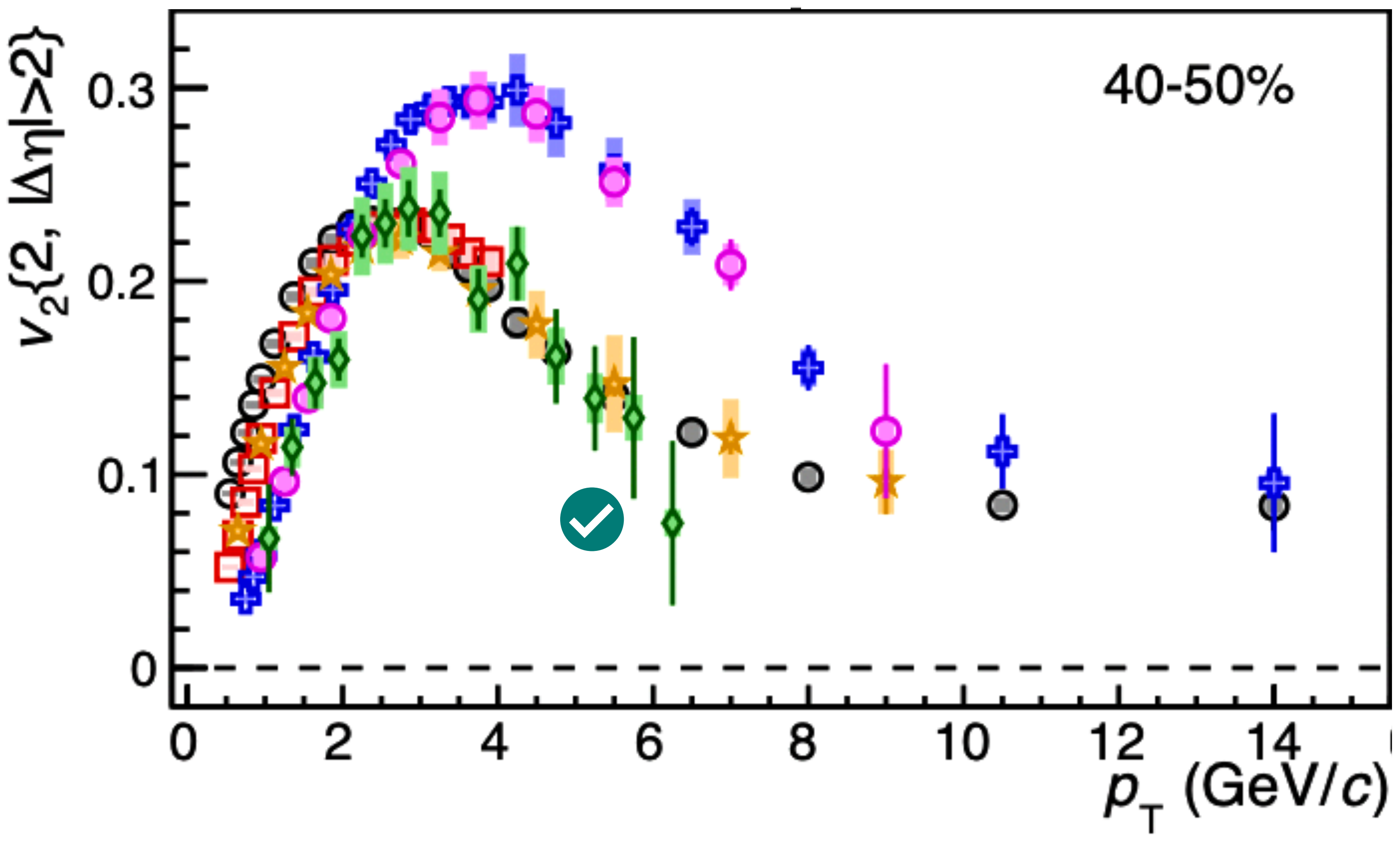
Non-flow removal



Everything flows, everywhere…

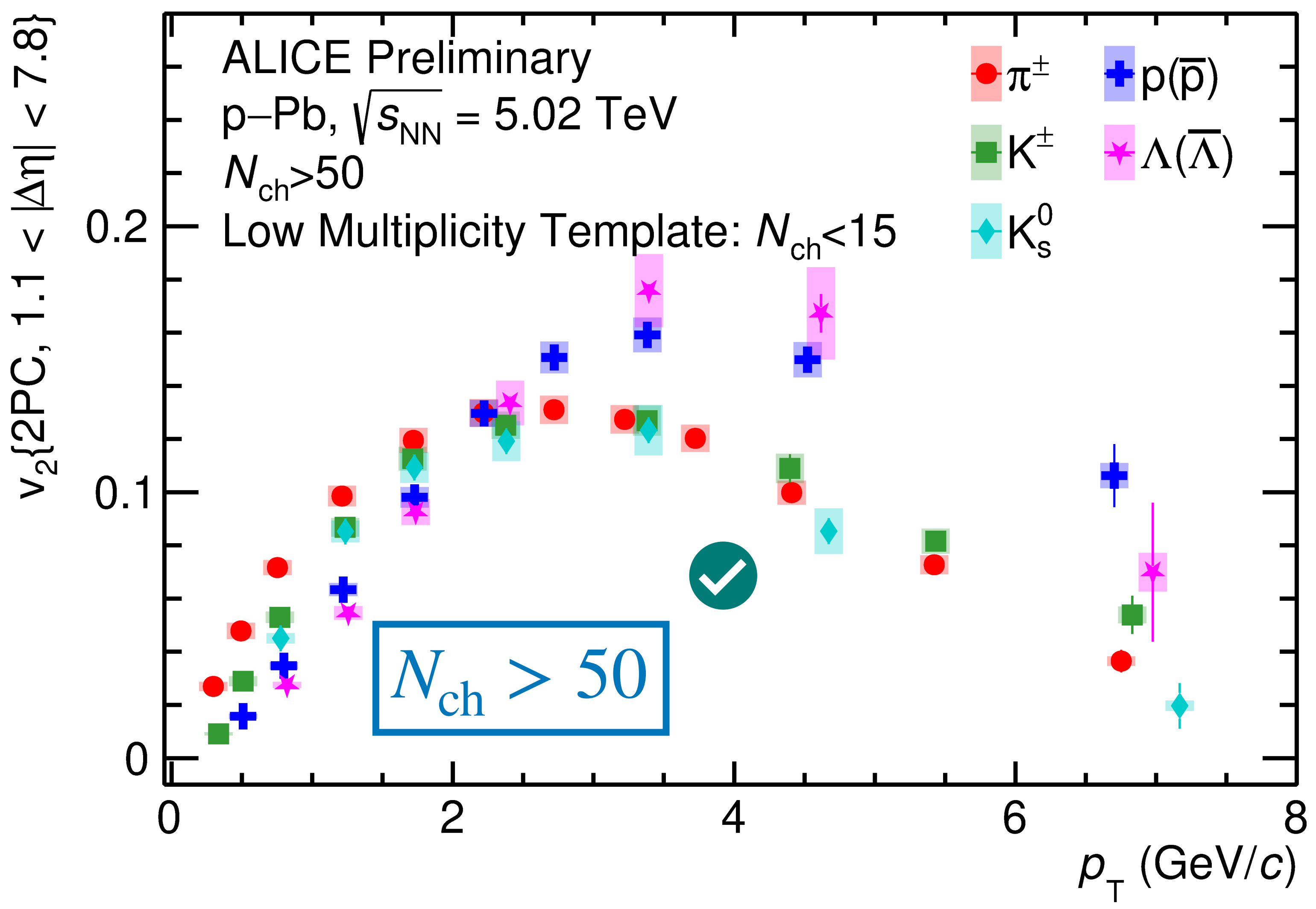
Semi-central Pb–Pb



ALICE, JHEP 243 (2023) 243

New

High multiplicity p–Pb



ALI-PREL-573065

High multiplicity events in small systems: Qualitatively similar to the heavy-ion results!

- Low p_T ($p_T \lesssim 3$ GeV$/c$) — Mass ordering of v_2.
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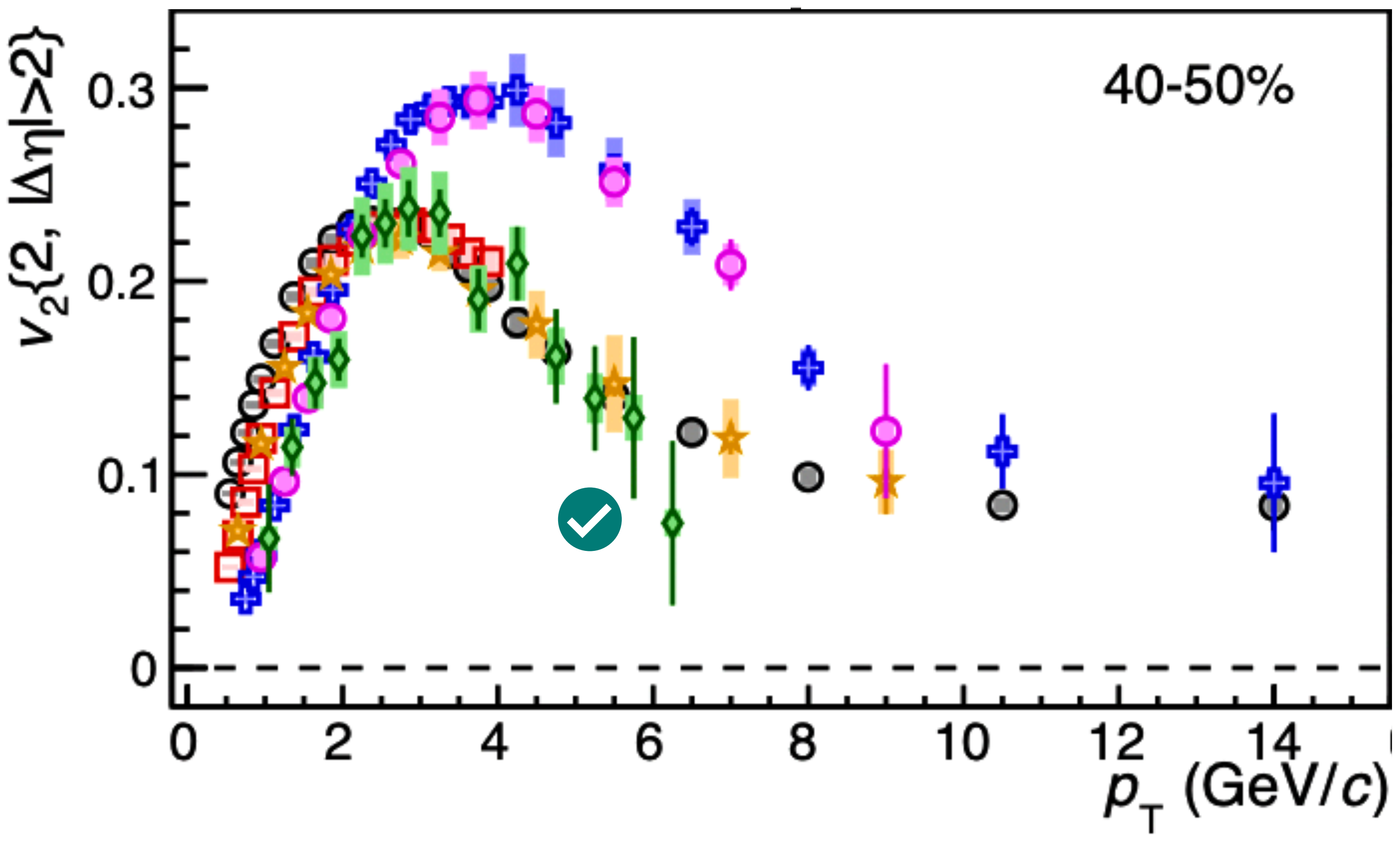

ALICE, JHEP 243 (2023) 243

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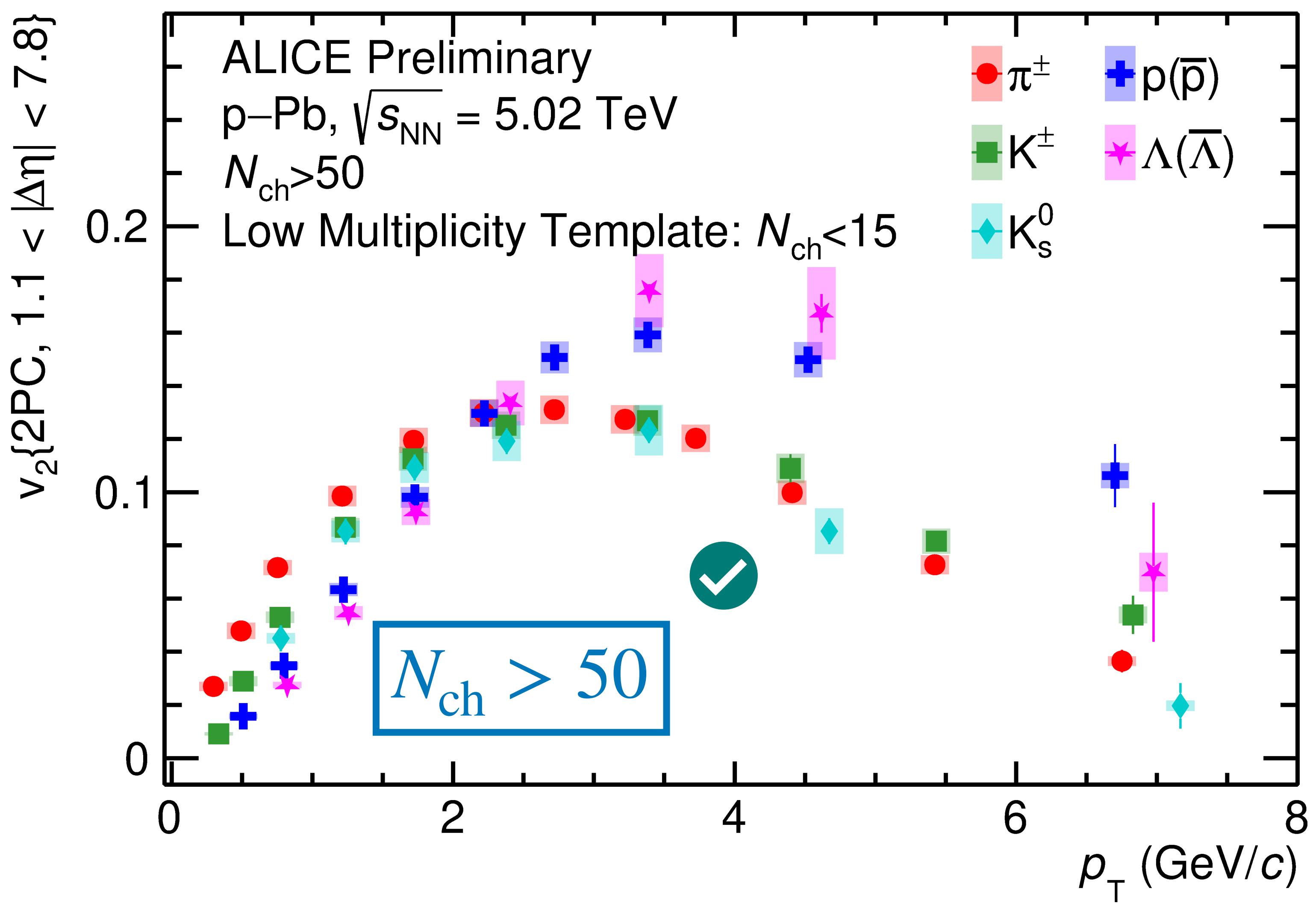
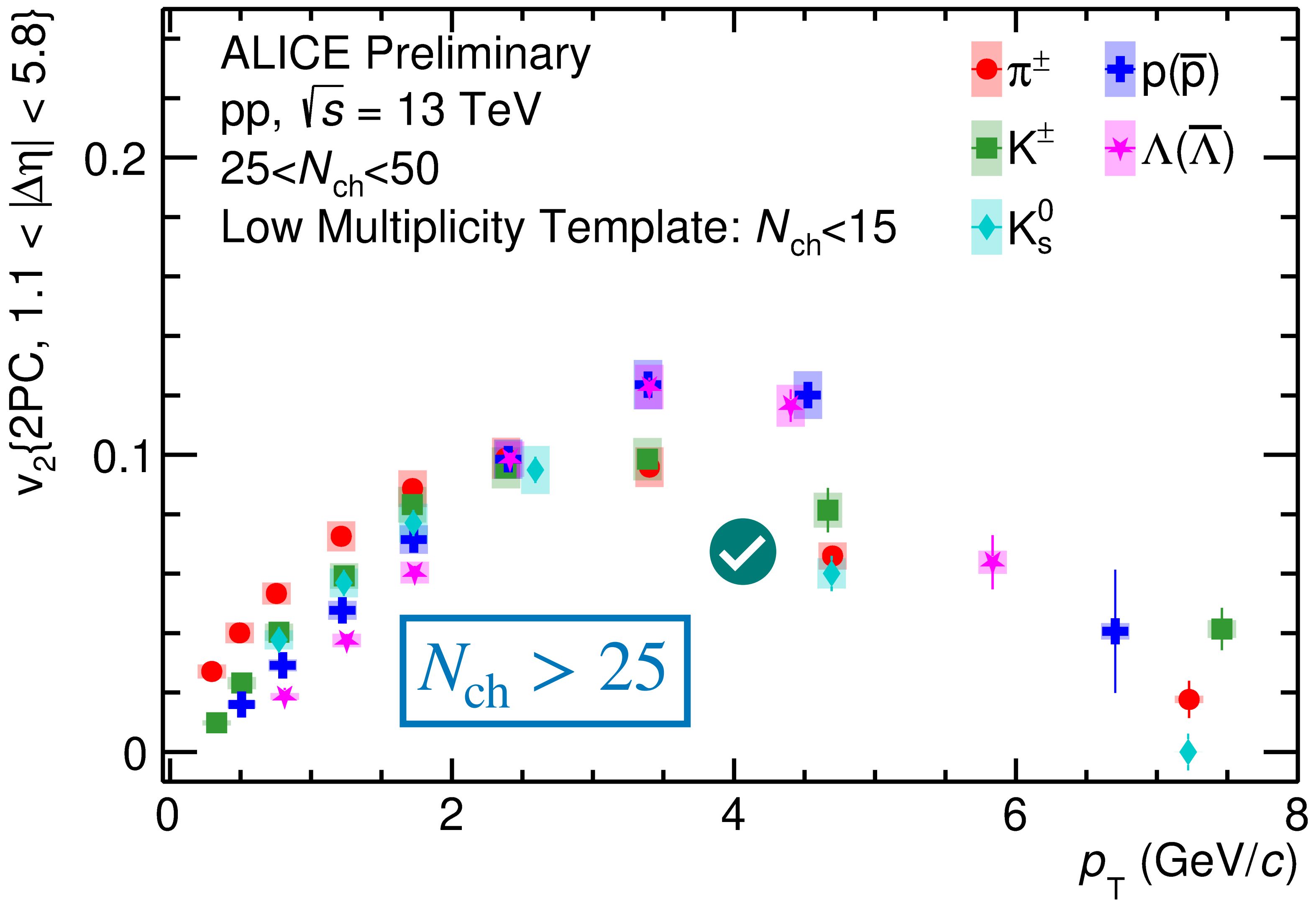


ALI-PREL-573065

New

High multiplicity pp



ALI-PREL-573050

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ALICE, JHEP 243 (2023) 243

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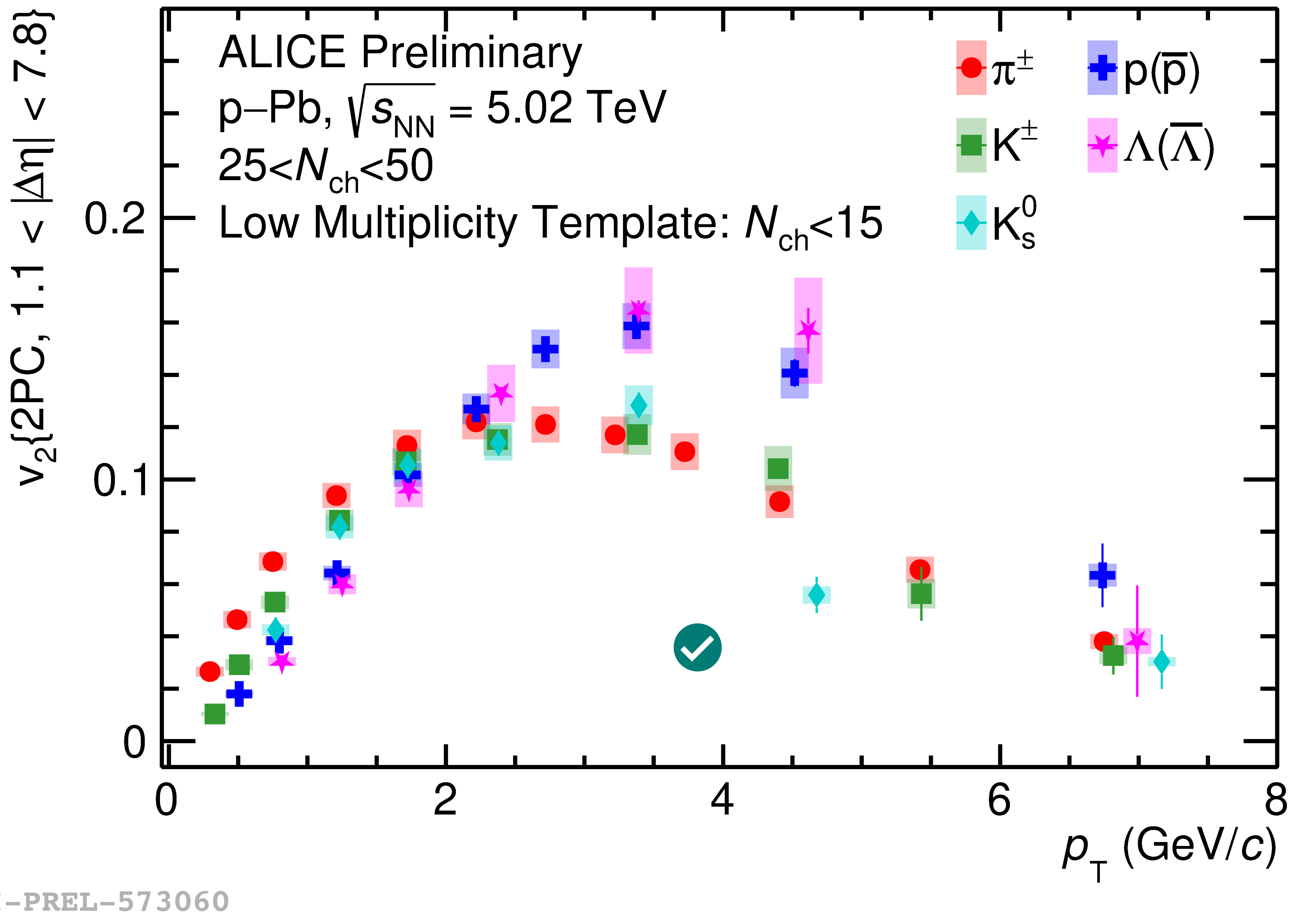
What about lower multiplicity classes of small systems?

p–Pb : N_{ch} dependence of v_2 of identified particles

New $25 < N_{ch} < 50$

p–Pb



- $N_{ch} > 25$: Baryon-meson grouping (~1σ) + splitting (> 5σ) of v_2 at intermediate p_T.

p–Pb : N_{ch} dependence of v_2 of identified particles

p–Pb

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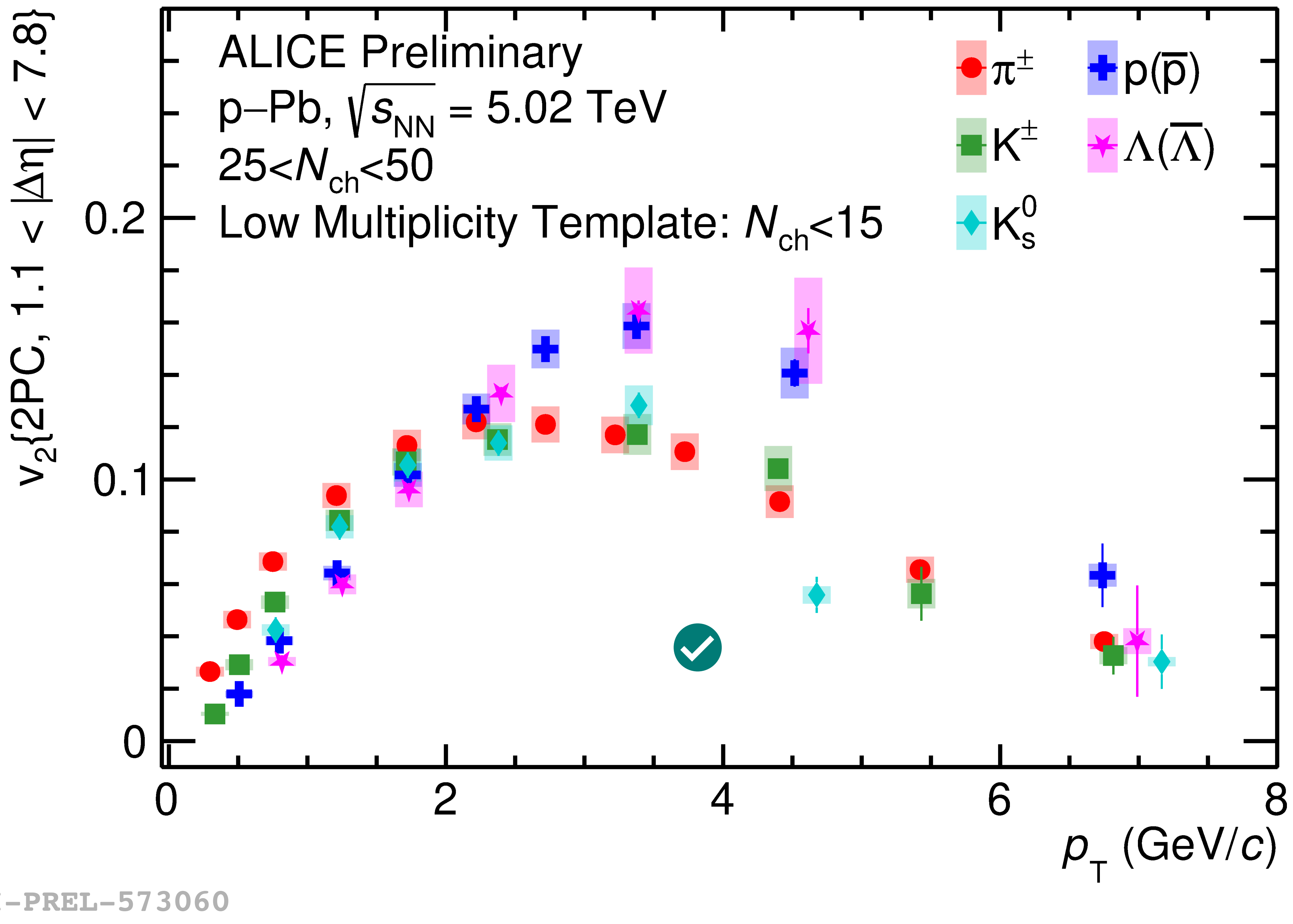
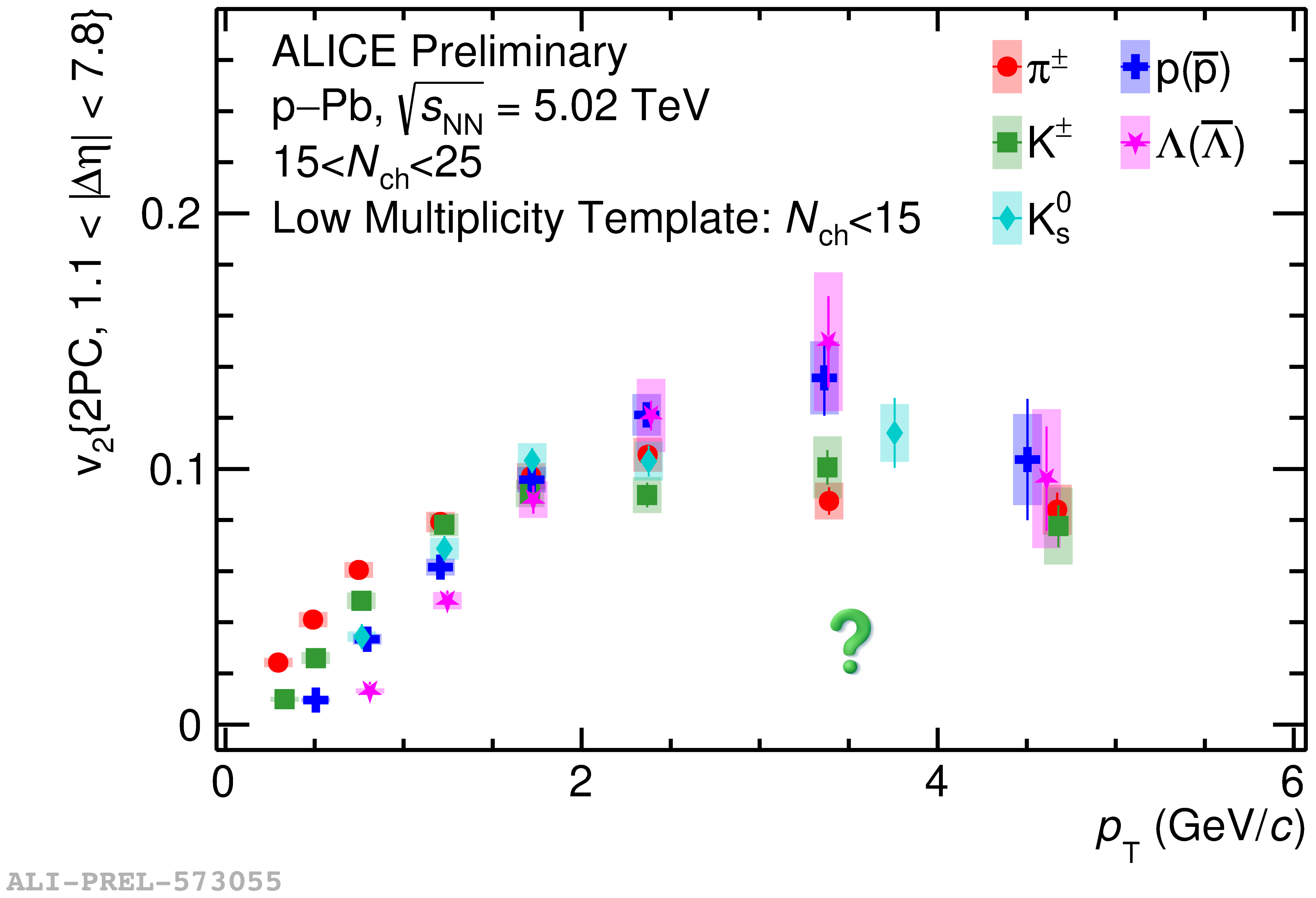


New $15 < N_{ch} < 25$



- $N_{ch} > 25$: Baryon-meson grouping ($\sim 1\sigma$) + splitting ($> 5\sigma$) of v_2 at intermediate p_T.
- $N_{ch} < 25$: grouping and splitting (within 2σ) diluted.

pp : N_{ch} dependence of v_2 of identified particles

pp

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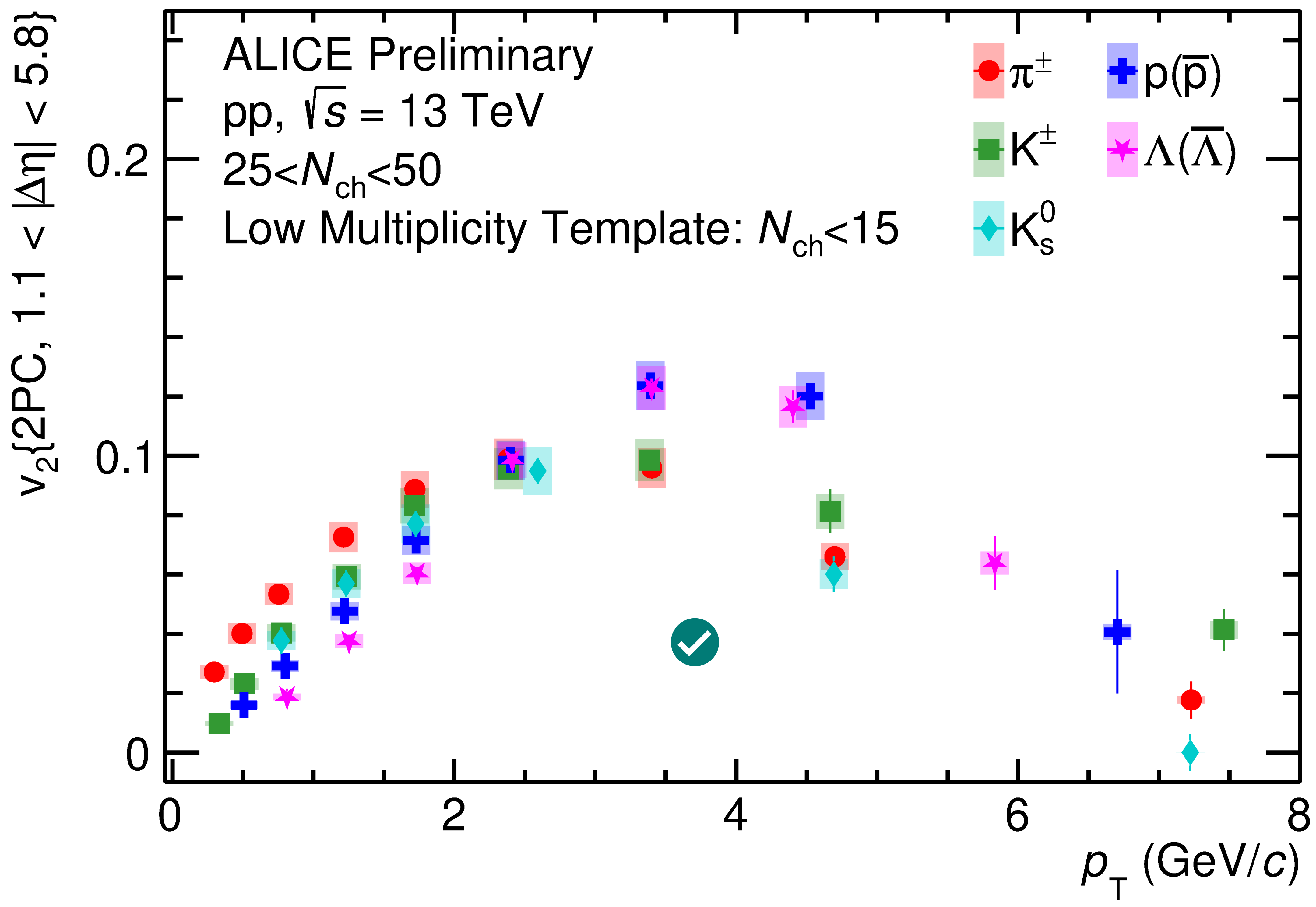

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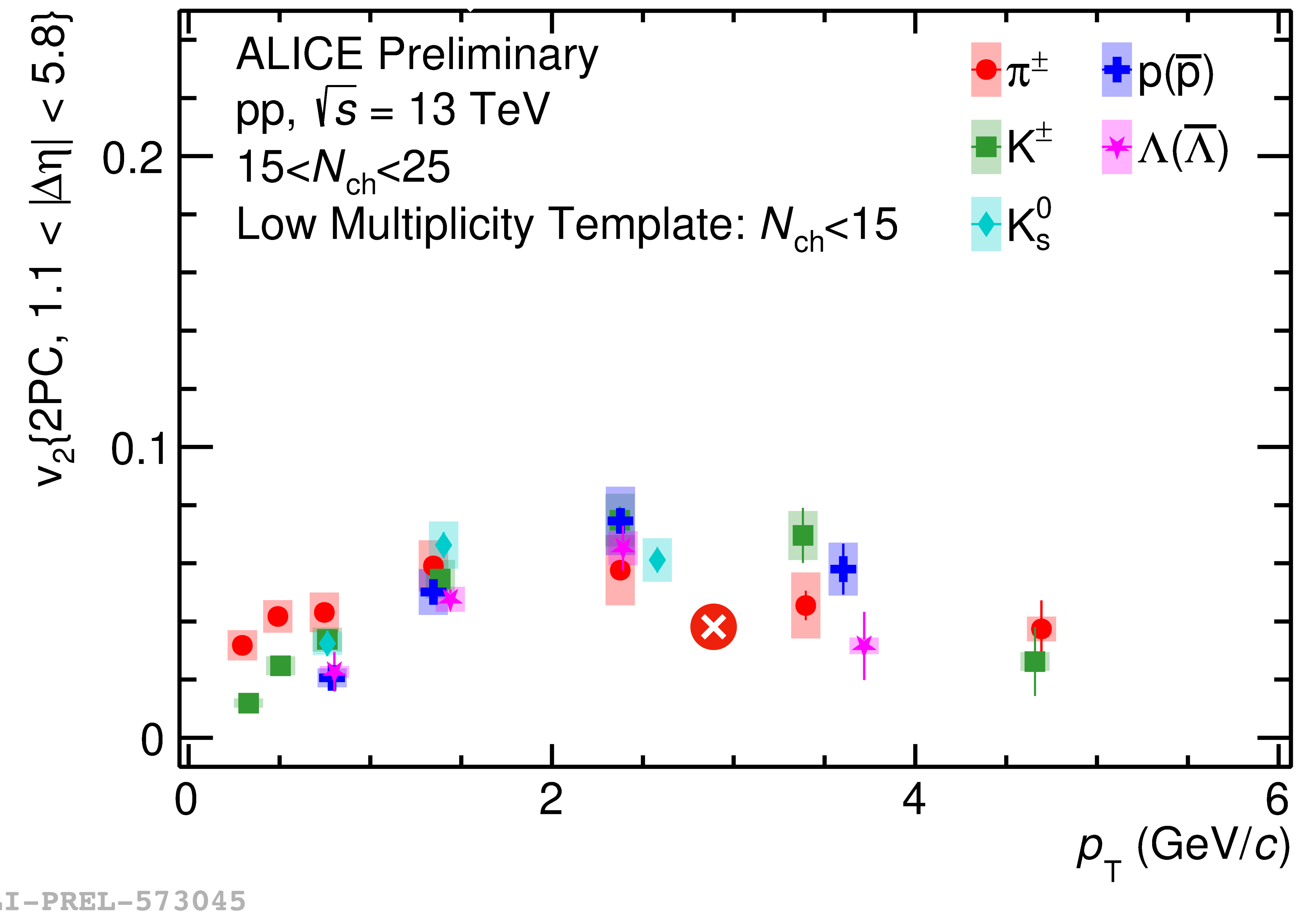
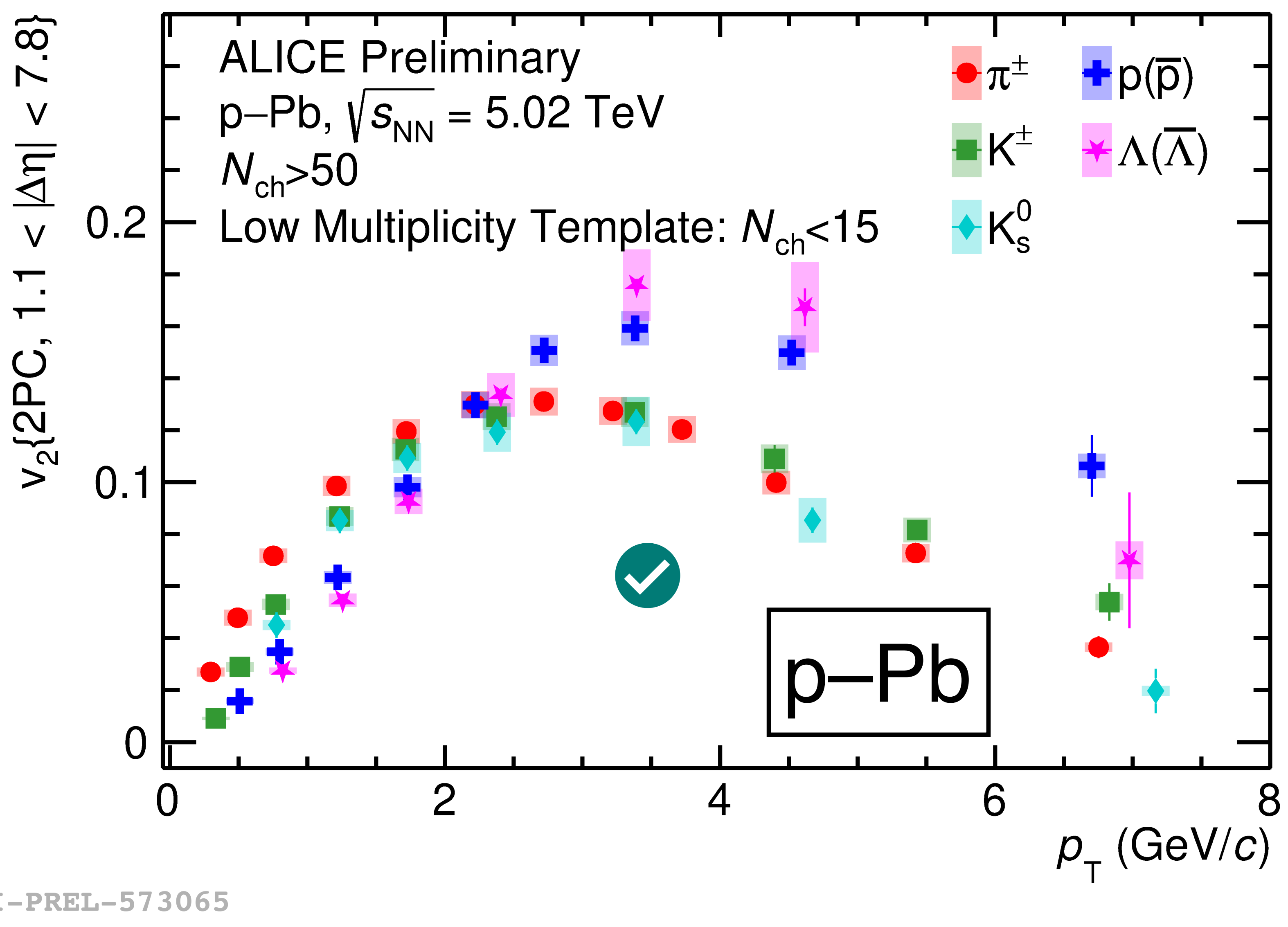


- $N_{ch} > 25$: Baryon-meson grouping ($\sim 1\sigma$) + splitting ($> 5\sigma$) of v_2 at intermediate p_T. ✓
- $N_{ch} < 25$: grouping and splitting (within 1σ) diminished in pp. ✗

Where is the onset of collectivity? Will get back to this in a moment…

Data—Model Comparison

High multiplicity p–Pb

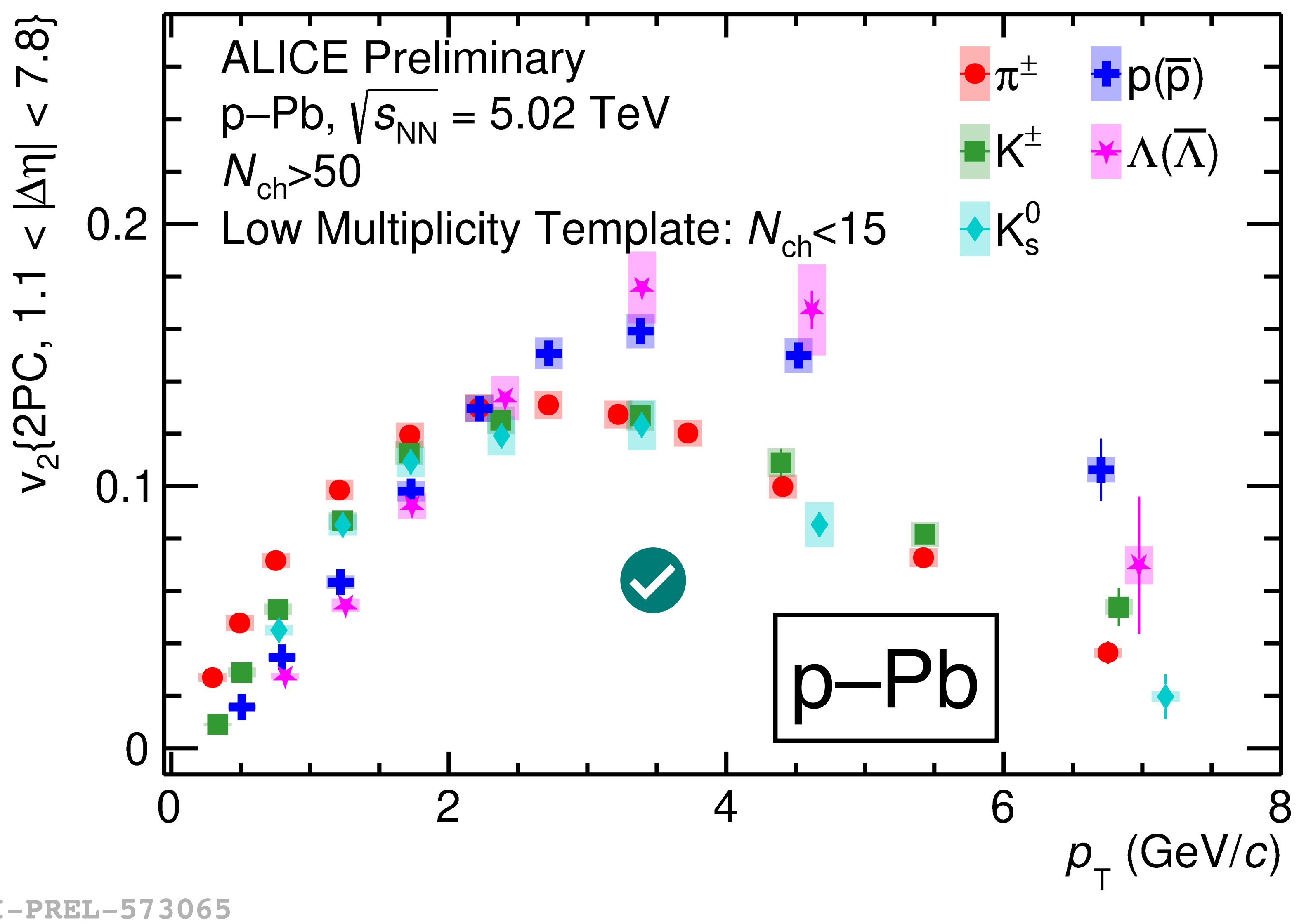


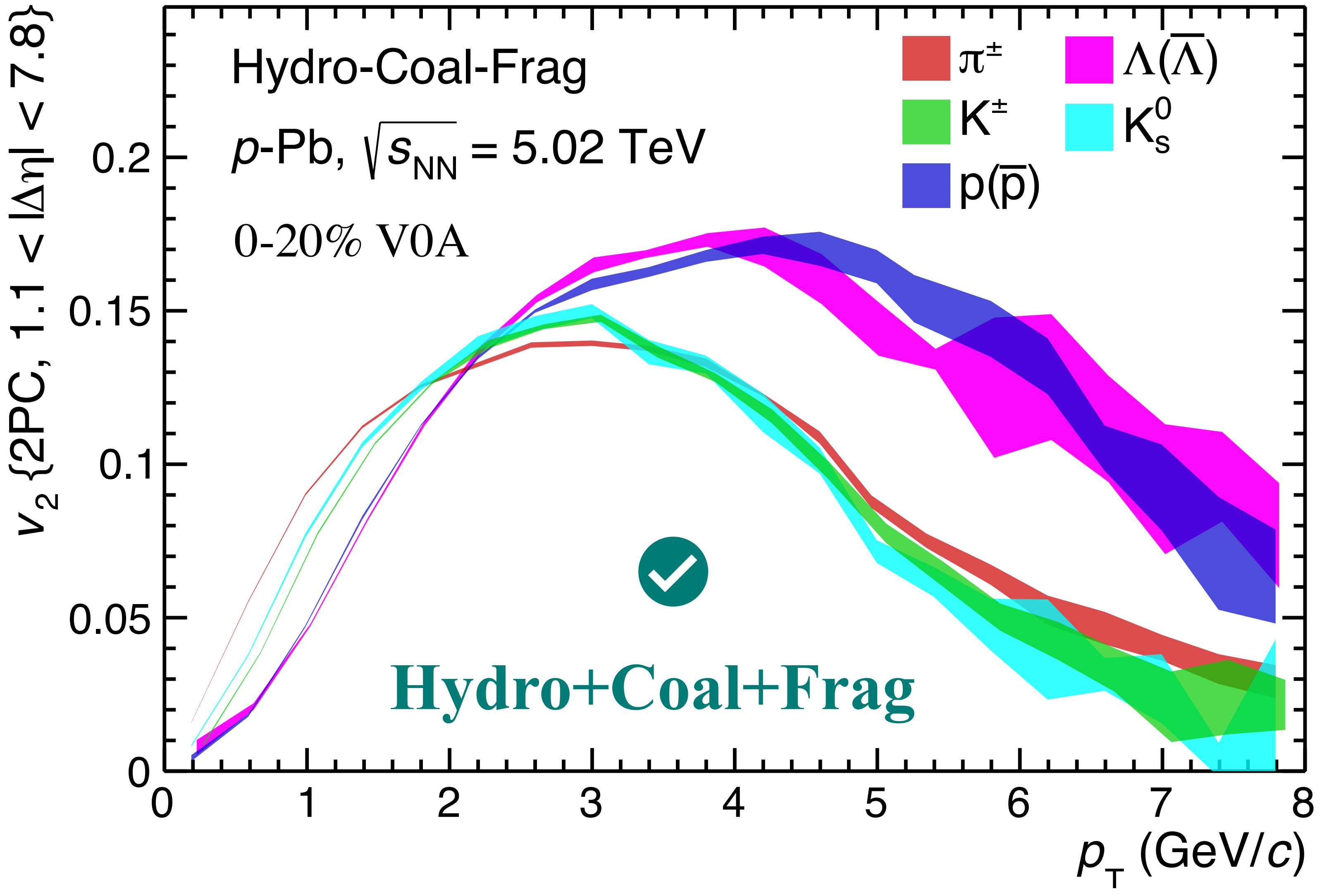
- Baryon-meson grouping and splitting of v_2 at intermediate p_T. ✓

Any model comparison?

Partonic collectivity in small collision systems!

High multiplicity p–Pb





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

Hydro: Hydrodynamics

Coal: Coalescence model of hadronization

Frag: Jet fragmentation

High multiplicity p–Pb: data and model have different N_{ch} / centrality cuts

- Baryon-meson grouping and splitting of v_2 at intermediate p_T. ✓
- Hydro+Coal+Frag explains the baryon-meson v_2 grouping and splitting. ✓

Partonic collectivity in small collision systems!

High multiplicity p–Pb

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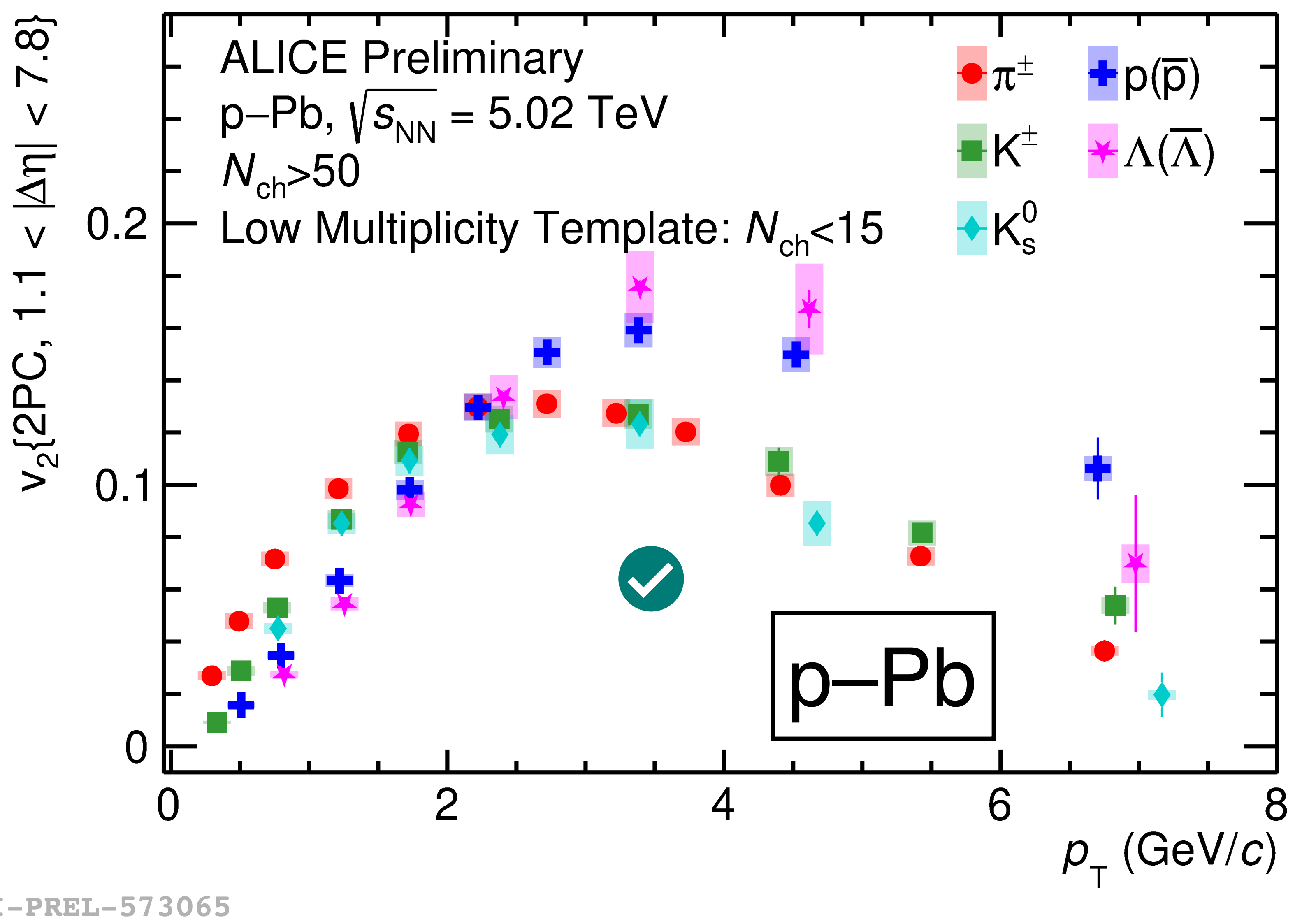

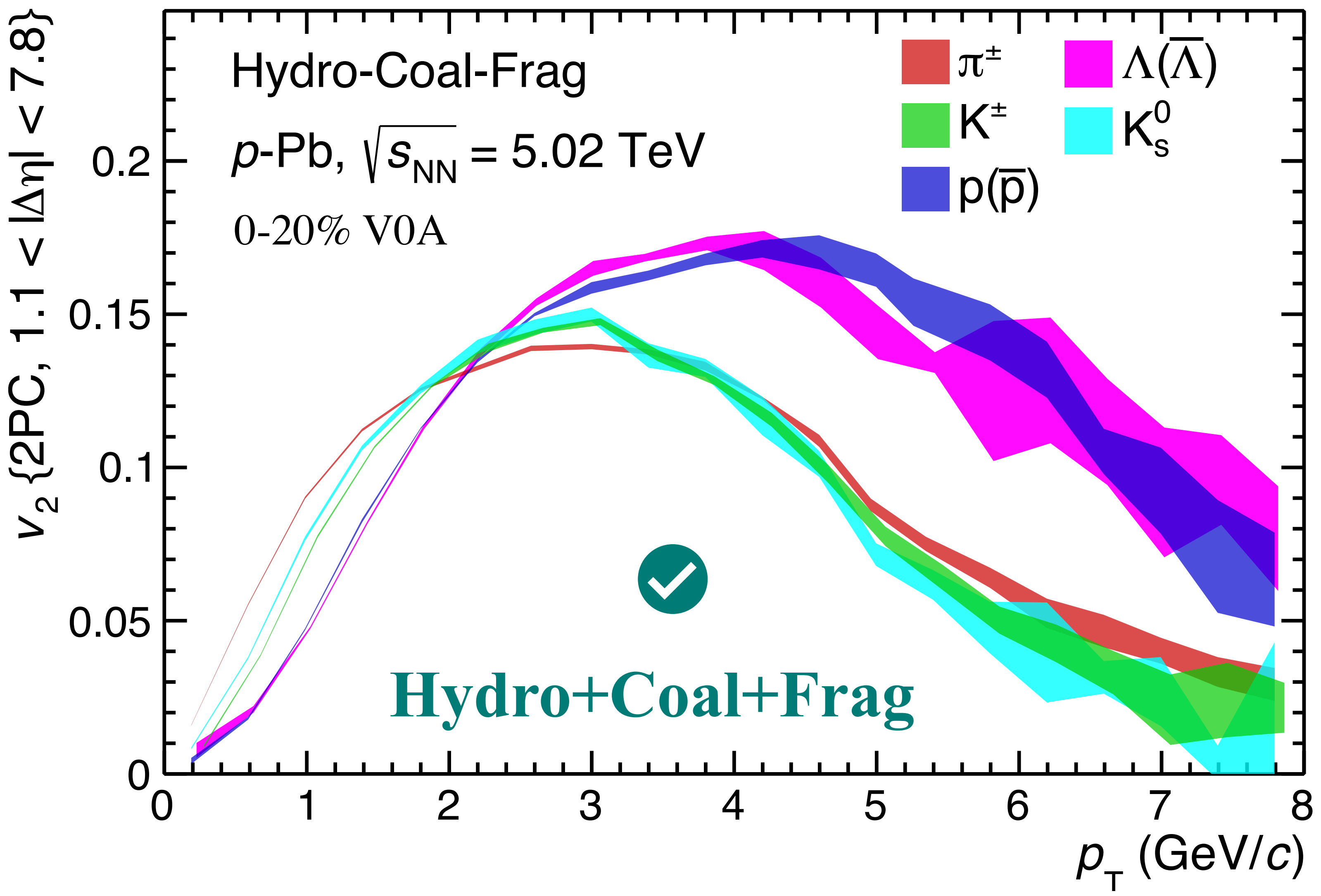

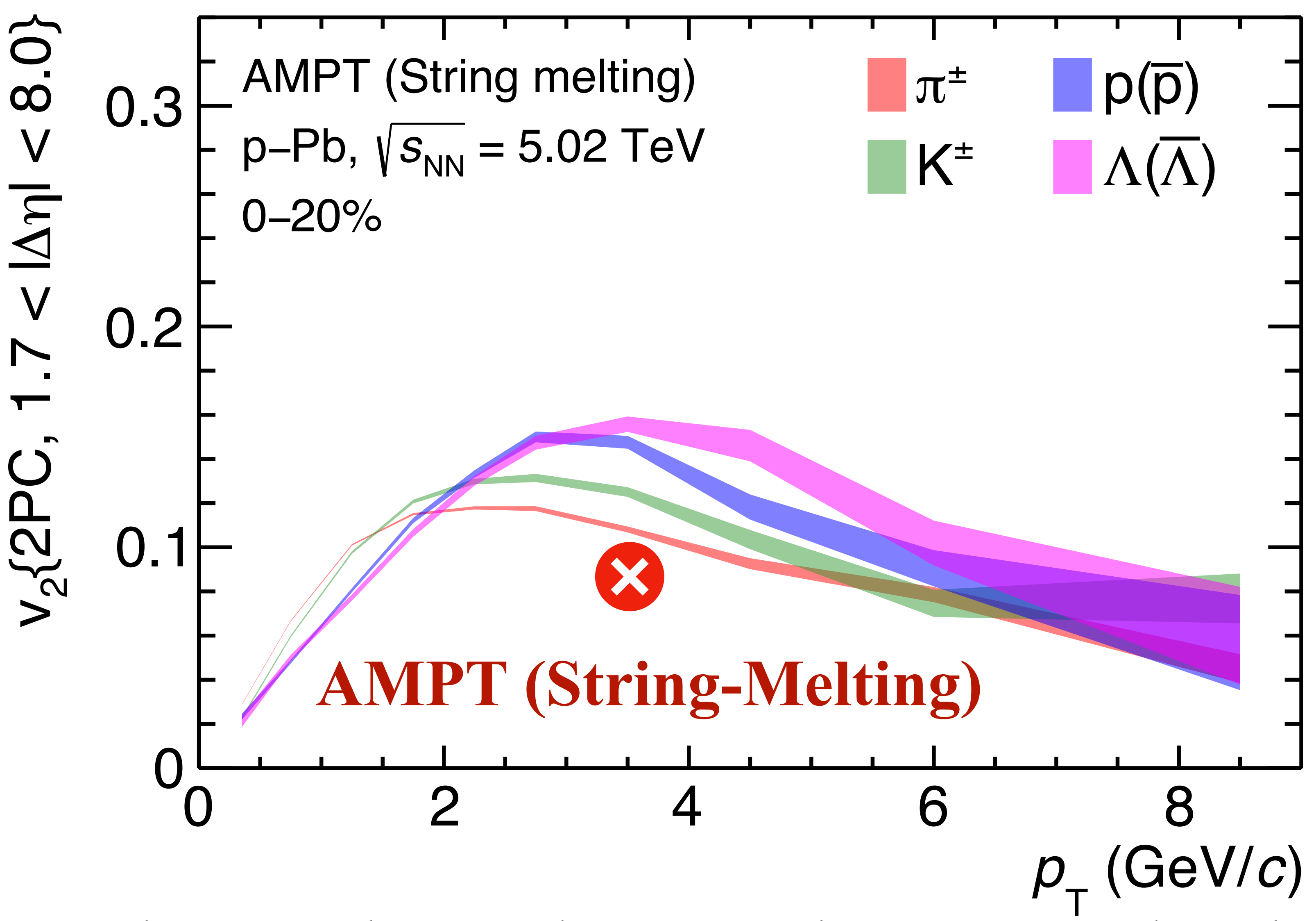

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High multiplicity p–Pb: data and model have different N_{ch} / centrality cuts

- Baryon-meson grouping and splitting of v_2 at intermediate p_T. ✓
- Hydro+Coal+Frag explains the baryon-meson v_2 grouping and splitting. ✓
- Hydro+Frag fails to describe the pattern (despite parameters adjustments). ✗
- Transport model with coalescence model of hadronization (AMPT) fails to describe the data. ✗

Partonic collectivity in small collision systems!

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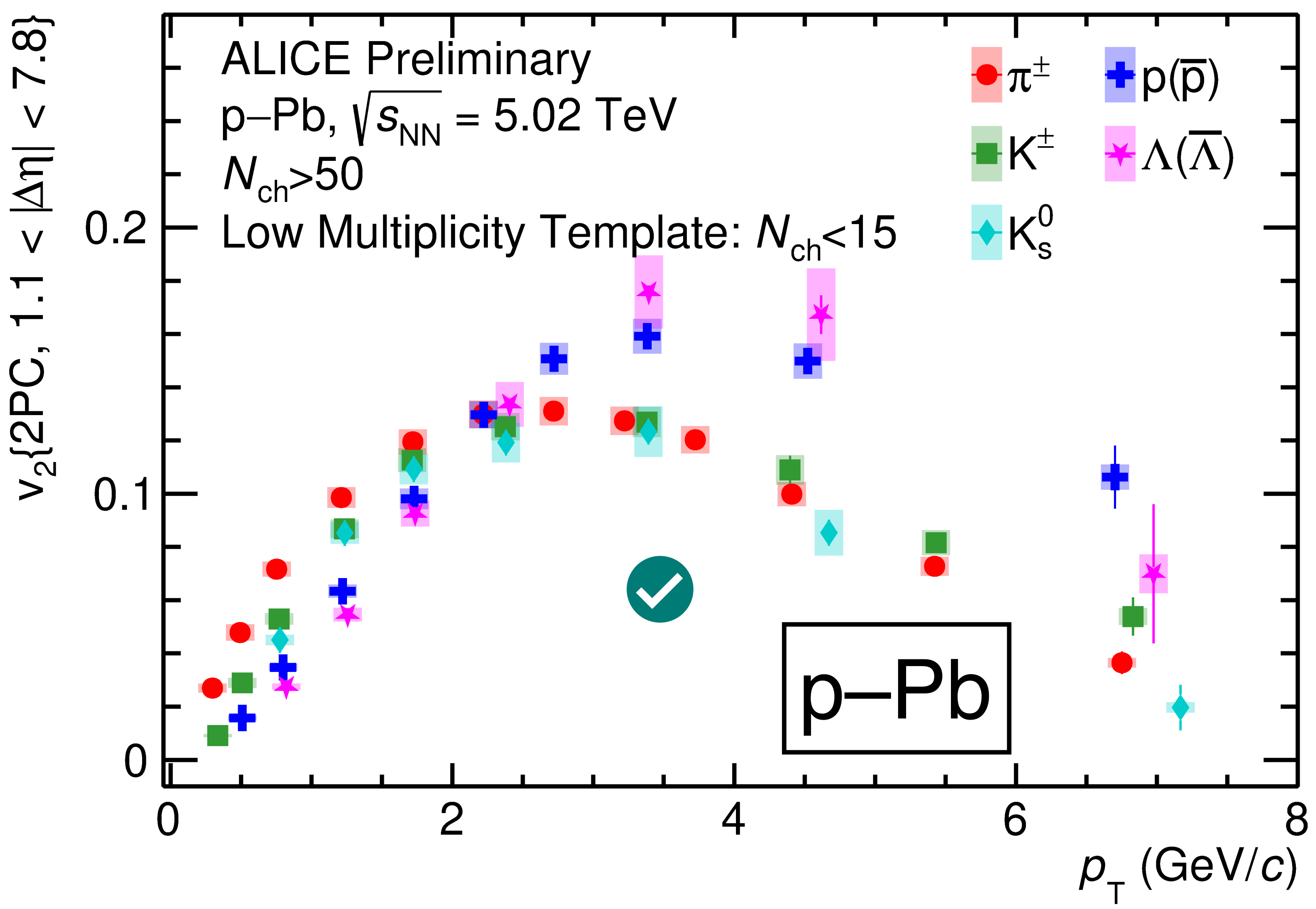

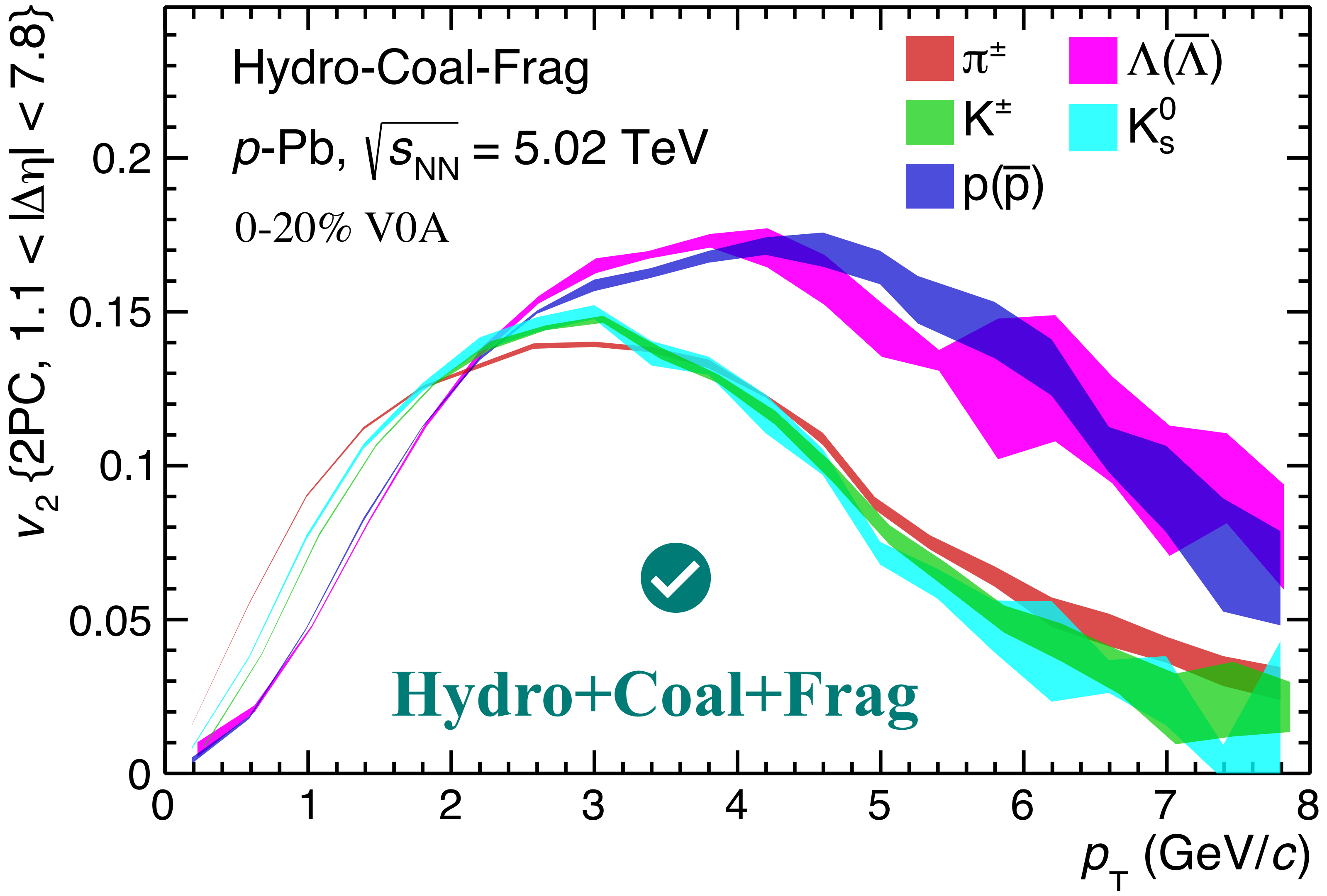

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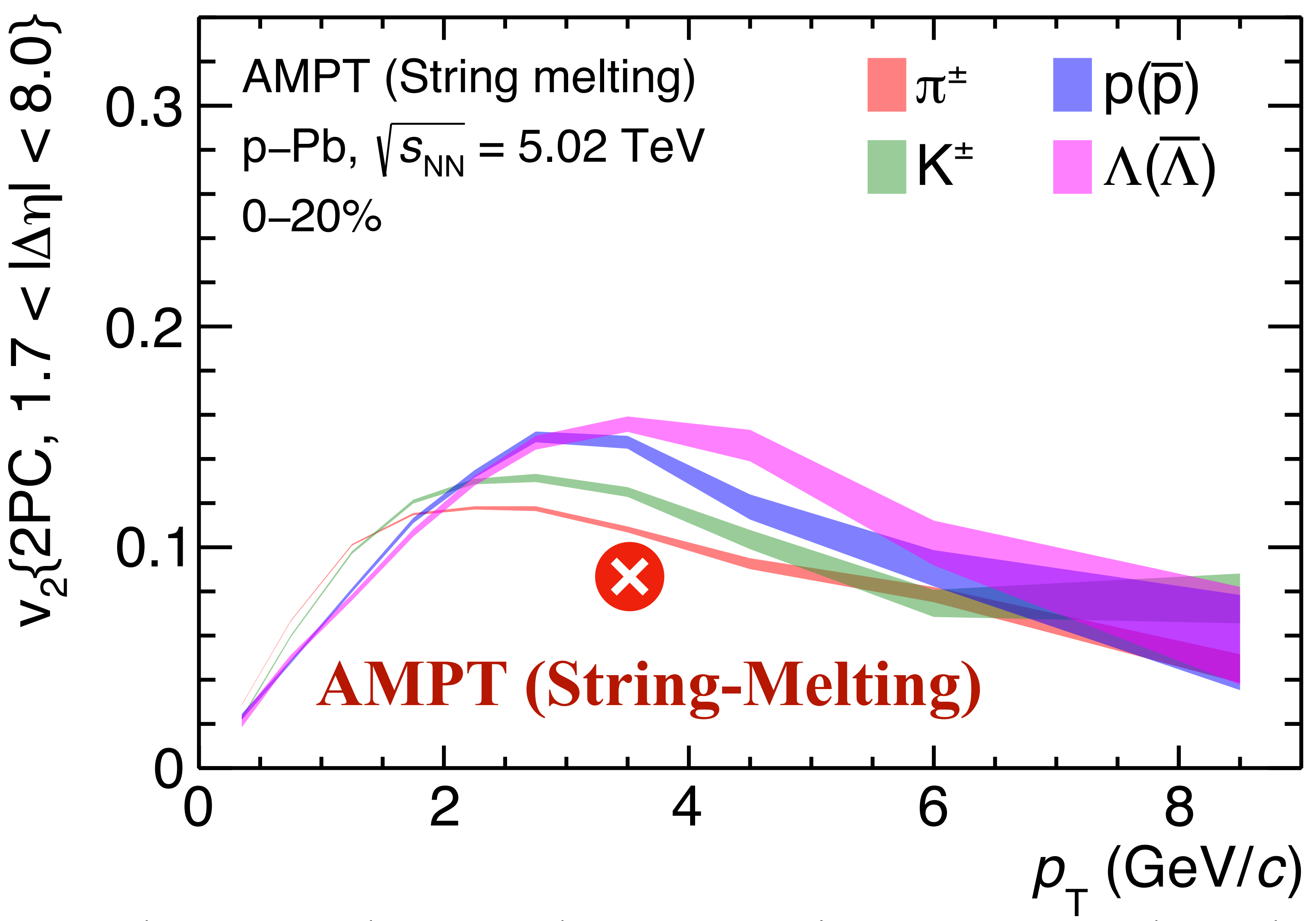

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High multiplicity p–Pb: data and model have different N_{ch} / centrality cuts

- Baryon-meson grouping and splitting of v_2 at intermediate p_T. ✔
- Hydro+Coal+Frag explains the baryon-meson v_2 grouping and splitting. ✔
- Hydro+Frag fails to describe the pattern (despite parameters adjustments). ✖
- Transport model with coalescence model of hadronization (AMPT) fails to describe the data. ✖

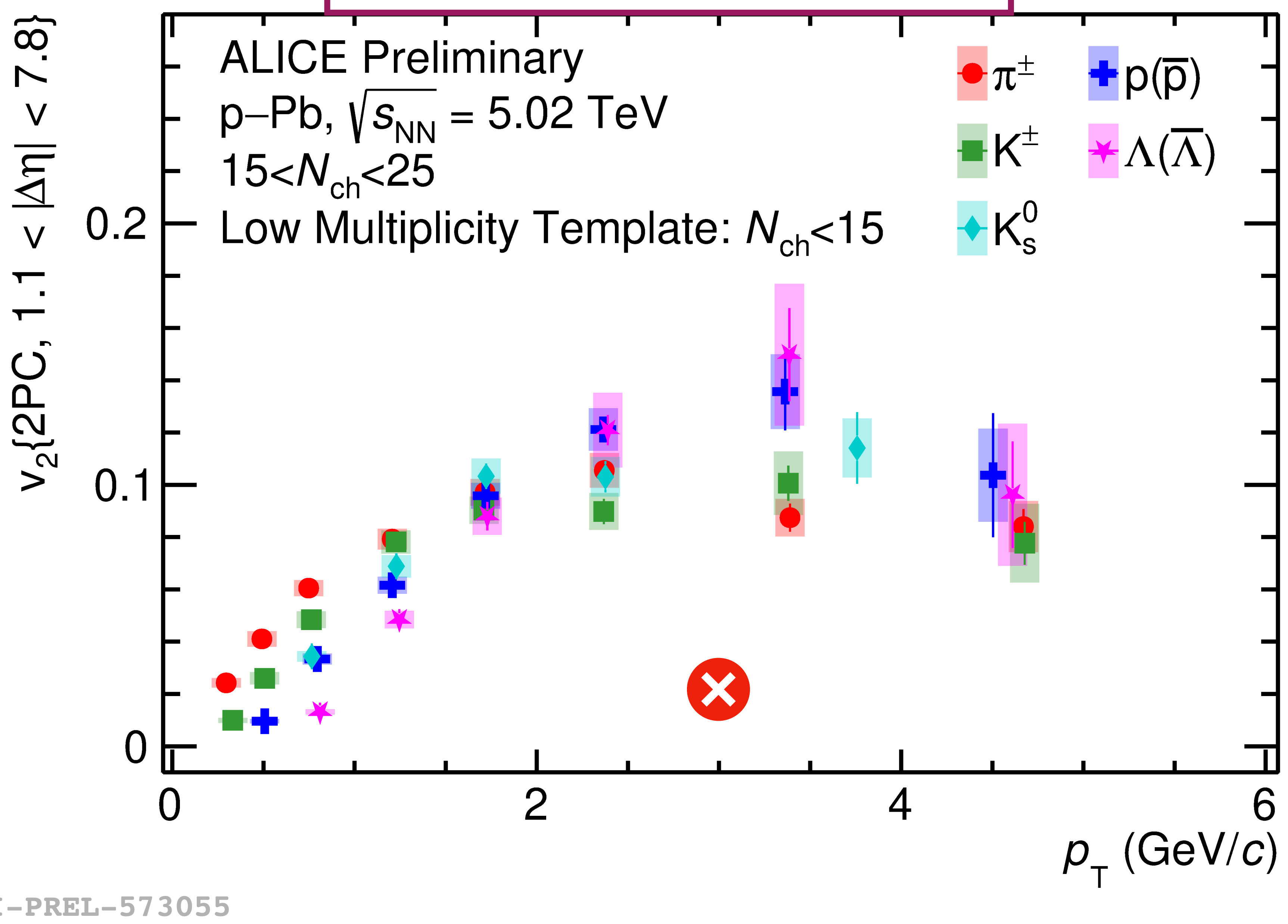
Model estimations at low multiplicity missing. Data provides good constraints for the models!

What is the low multiplicity limit for collectivity?

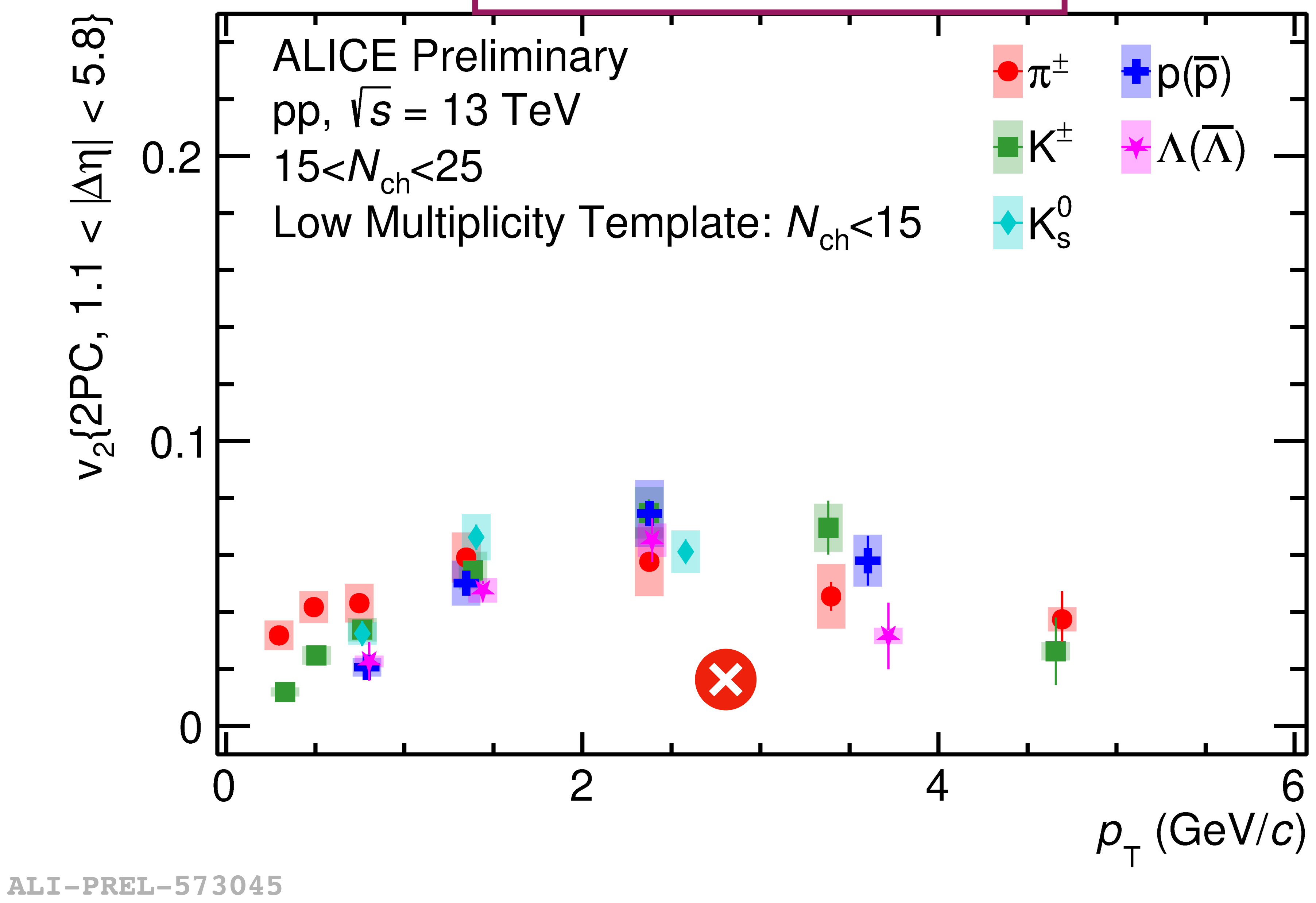
Reminder: For low multiplicity p–Pb and pp collisions

No evidence of baryon-meson grouping and splitting of v_2 at intermediate p_T.

p–Pb: $15 < N_{ch} < 25$



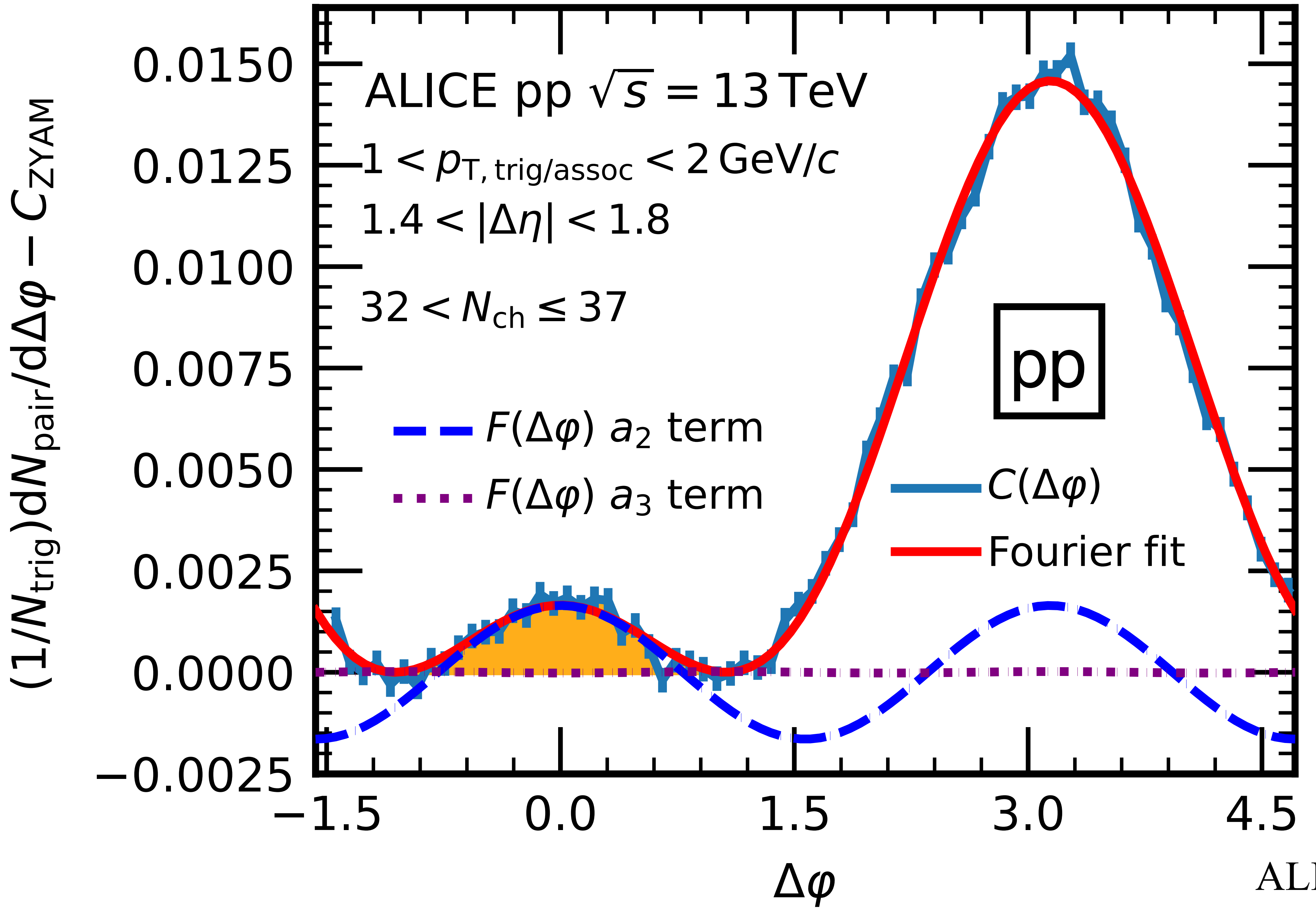
pp: $15 < N_{ch} < 25$

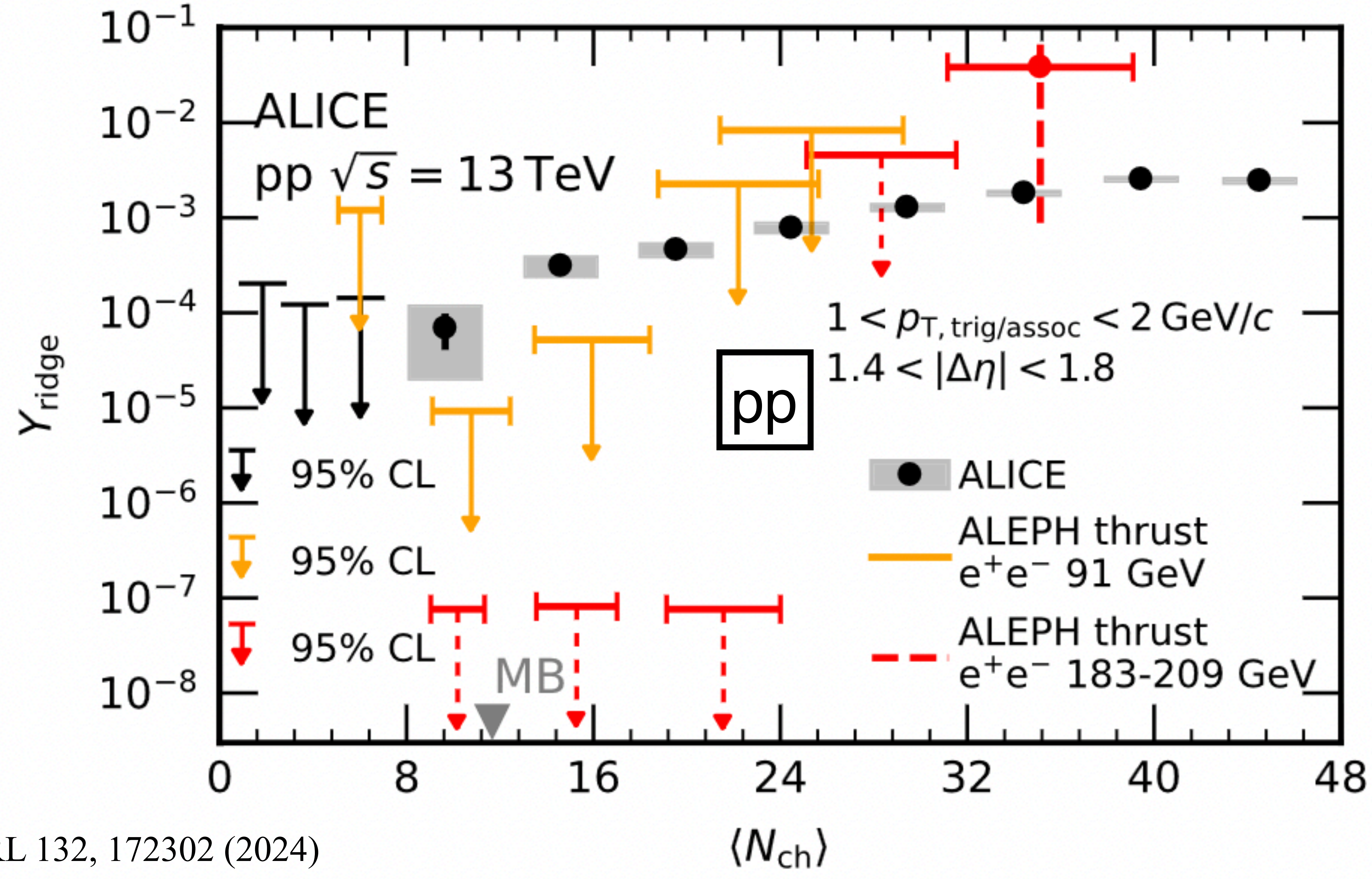


Continue the search for collectivity towards lower N_{ch} in p–Pb and pp collisions— with unidentified particles…

What is the low multiplicity limit for collectivity?

Ridge yield: No non-flow subtraction





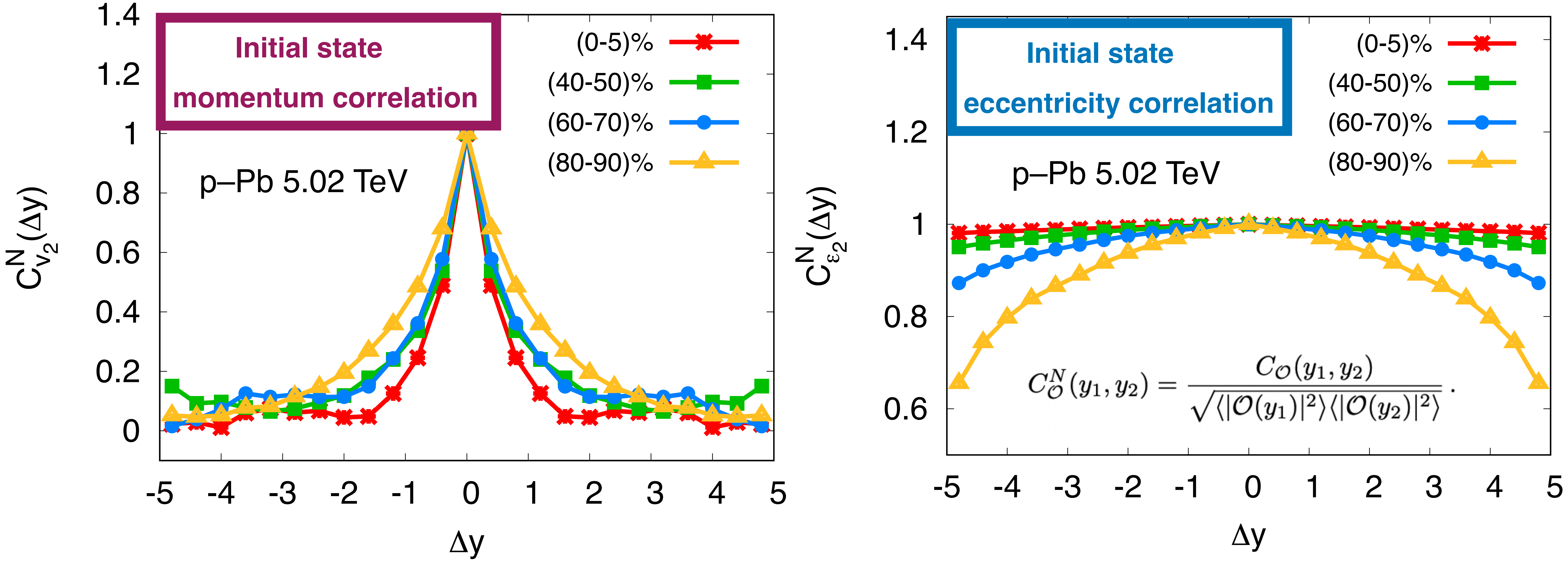
ALICE, PRL 132, 172302 (2024)

- Finite ridge-yield close to Minimum Bias (MB) multiplicity.
- Correlation at mid-rapidity: relatively short range ($|\Delta\eta| < 1.8$), non-flow removal might depend on the kinematics.

What is the origin of flow-like behavior at low multiplicity?

Initial state effects might be short range…

THE 3D IP-GLASMA MODEL



B. Schenke, S. Schlichting, P. Singh; Phys. Rev. D 105, 094023 (2022)

- Initial state momentum correlations — relatively short-range!
- Event geometry (transverse) — correlated across large rapidity intervals.

What is the origin of flow-like behavior at low multiplicity?

Initial AND/OR Final state effects?

Initial state effects might be short range…

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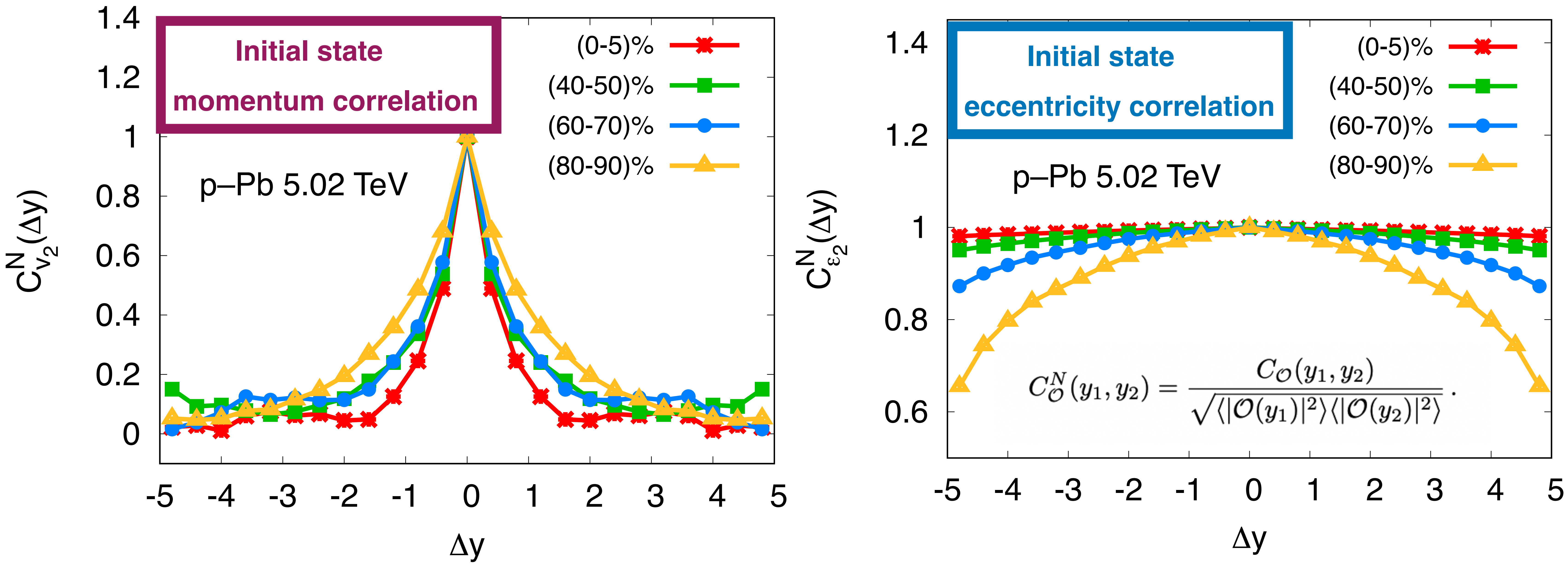

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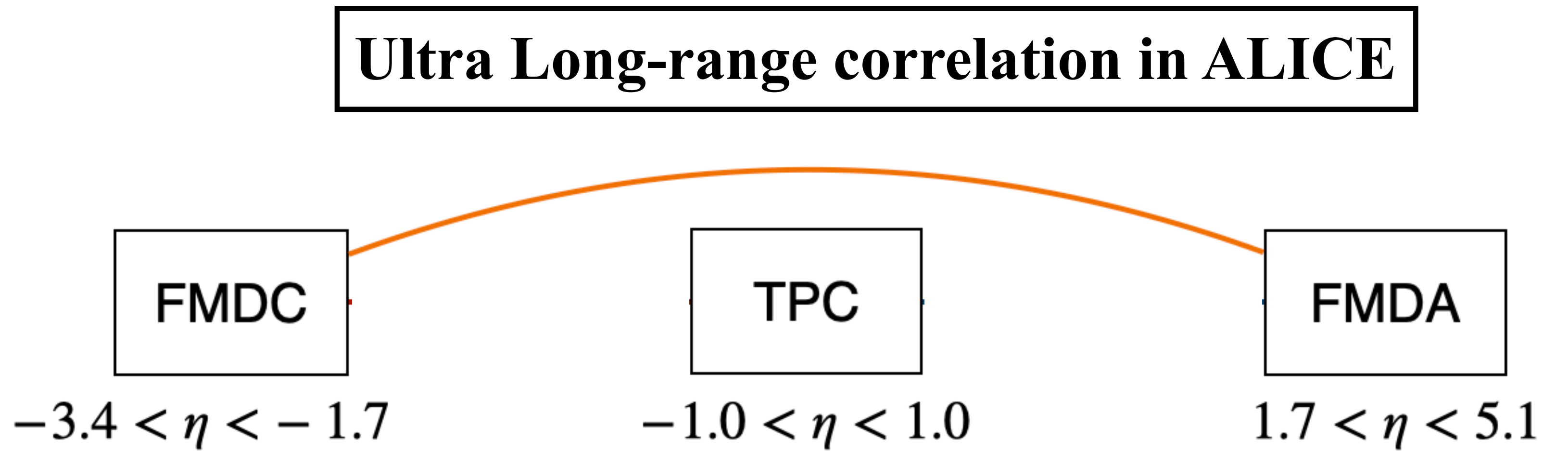
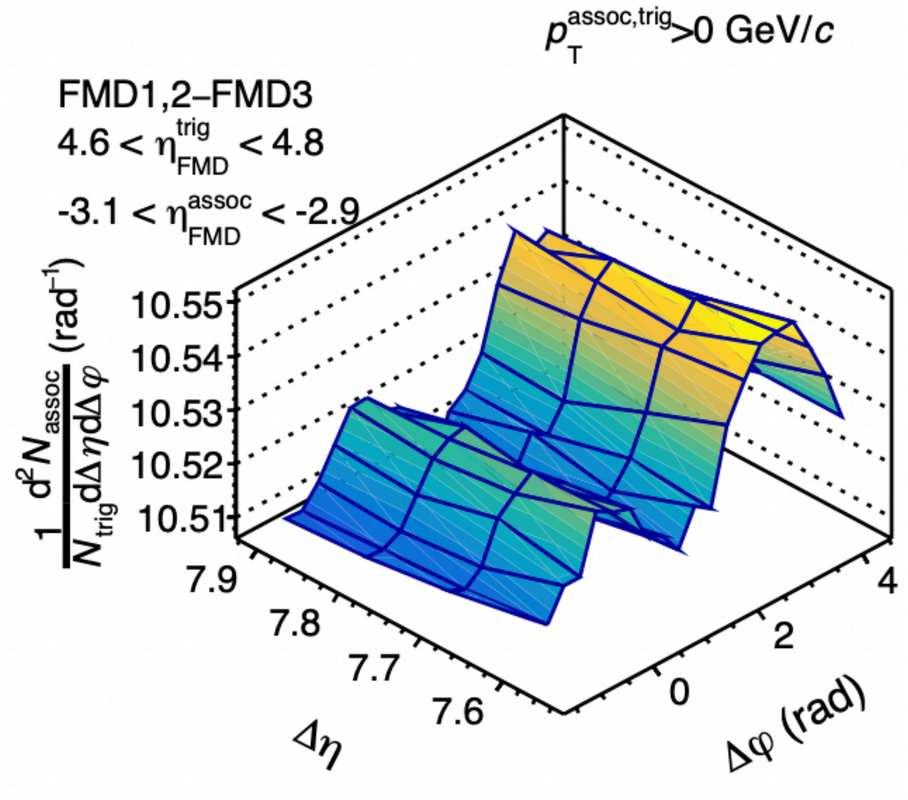




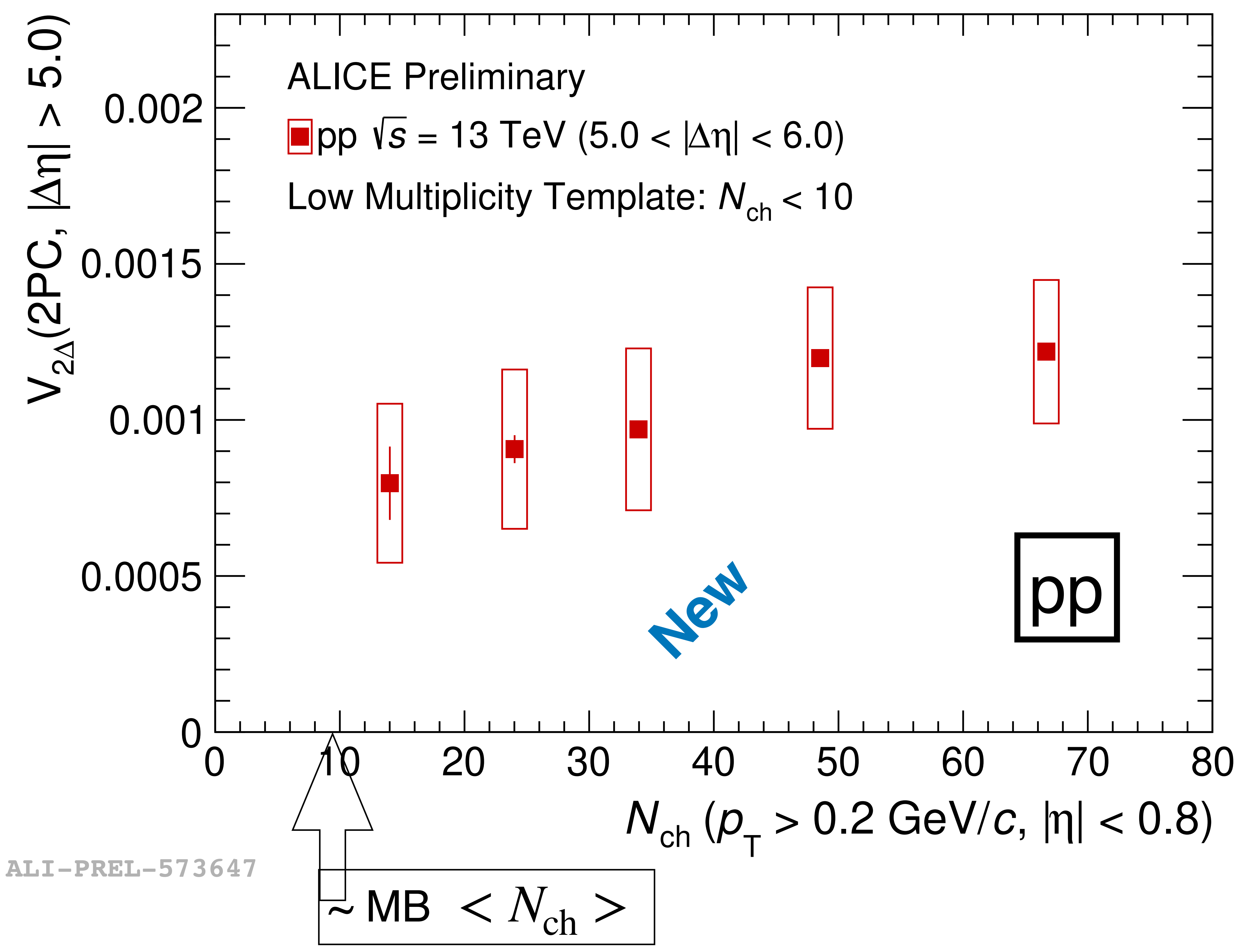
ALICE, JHEP 01 (2024) 199

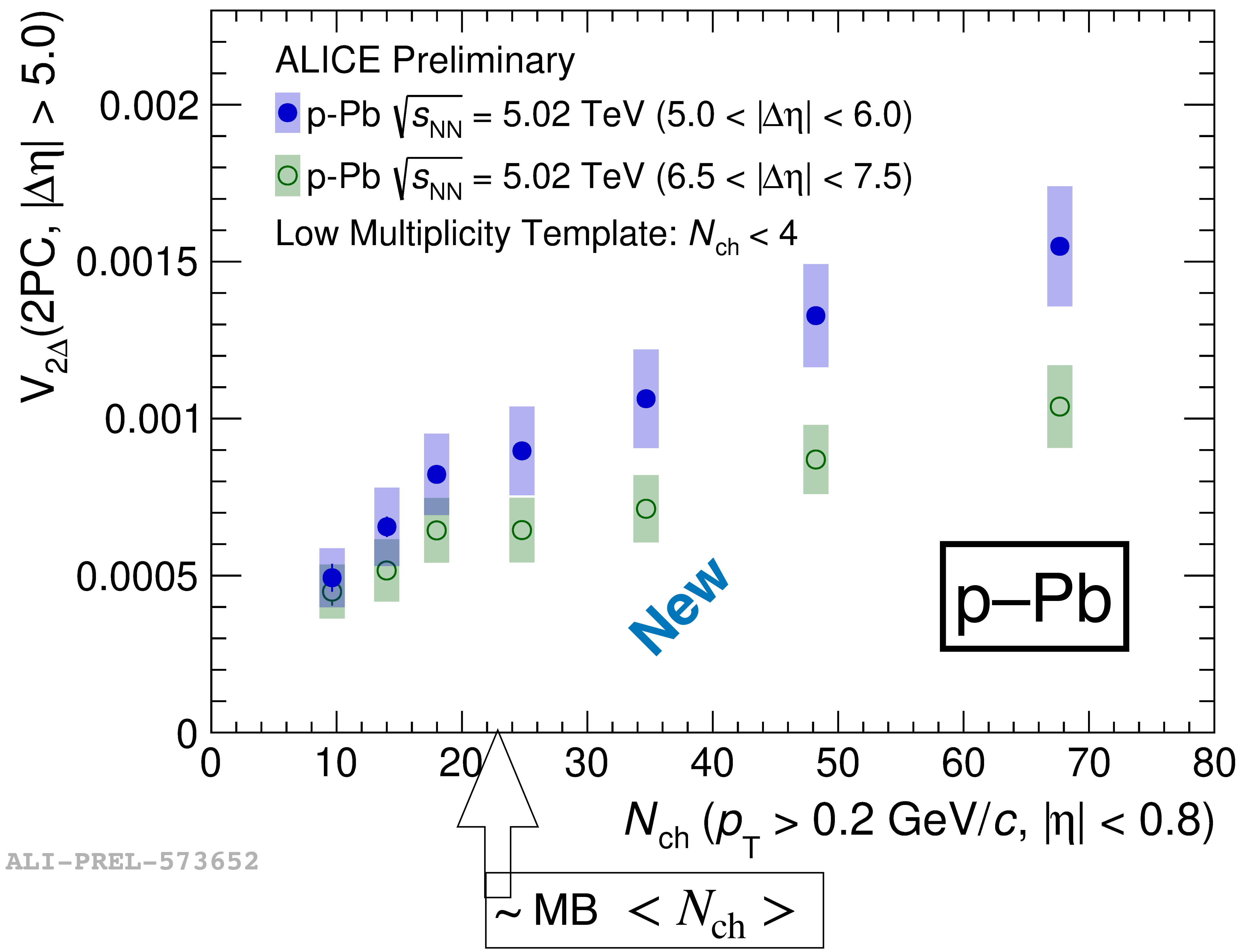
- Initial state momentum correlations — relatively short-range!
- Event geometry (transverse) — correlated across large rapidity intervals.

Goal: Explore the longest-range correlation down to minimum bias multiplicity

Ultra long-range correlation in ALICE

Non-flow removal by Template fit method

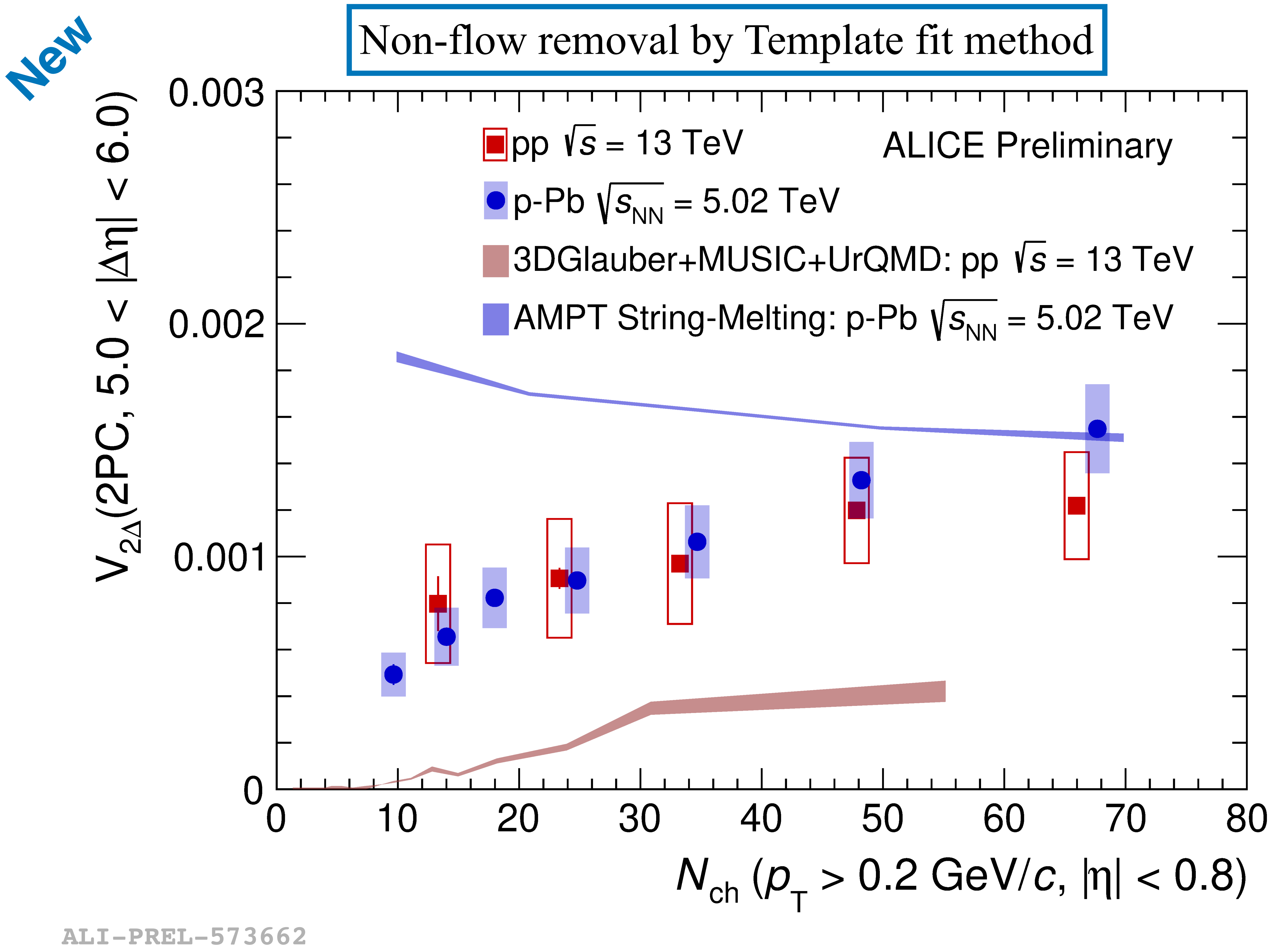




- Longest-range correlation studied close to minimum bias multiplicity in pp and p–Pb collisions.
- Initial state momentum correlation is short range. B. Schenke, S. Schlichting, P. Singh; Phys. Rev. D 105, 094023 (2022)

What is the source of ultra long-range correlation at low multiplicity pp, p–Pb collisions? Any model input?

Collective features at low multiplicity: Need more model input



- Hydrodynamics (3DGlauber + Music + UrQMD) underestimates the data. AMPT overestimates.
- Proper understanding of the initial state is missing.

Unprecedented constraint for hydrodynamic and alternative models. Need more theory/model input.

Summary and Outlook

- For pp and p–Pb: Baryon-meson grouping (~1σ) + splitting (> 5σ) of v_2 at intermediate p_{T} ($3.0 < p_{\mathrm{T}} < 5.0$ GeV/c) for N_{ch} > 25.

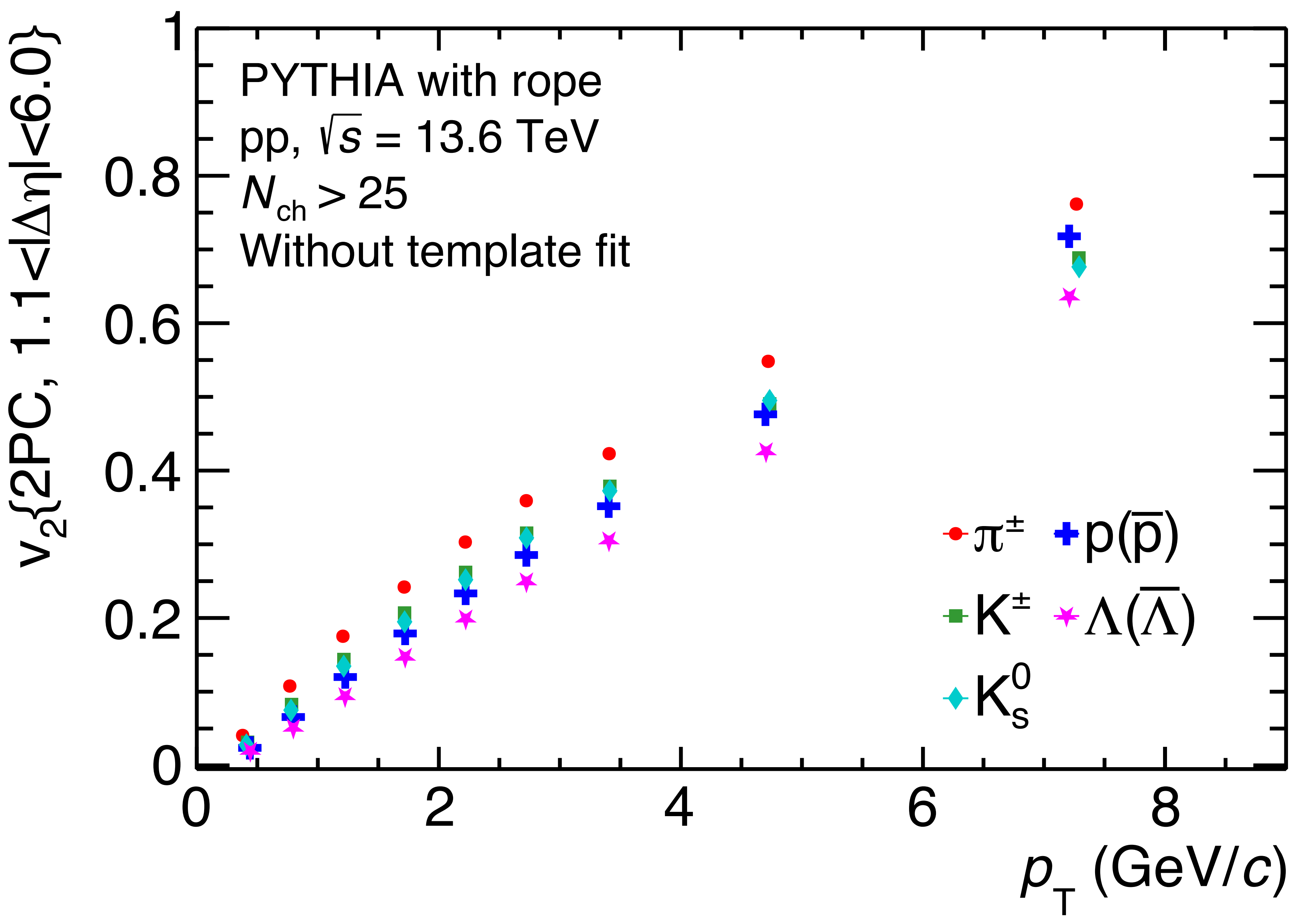
- The hydrodynamic model with the coalescence model of hadronization explains the baryon-meson grouping and splitting of v_2 in small systems.

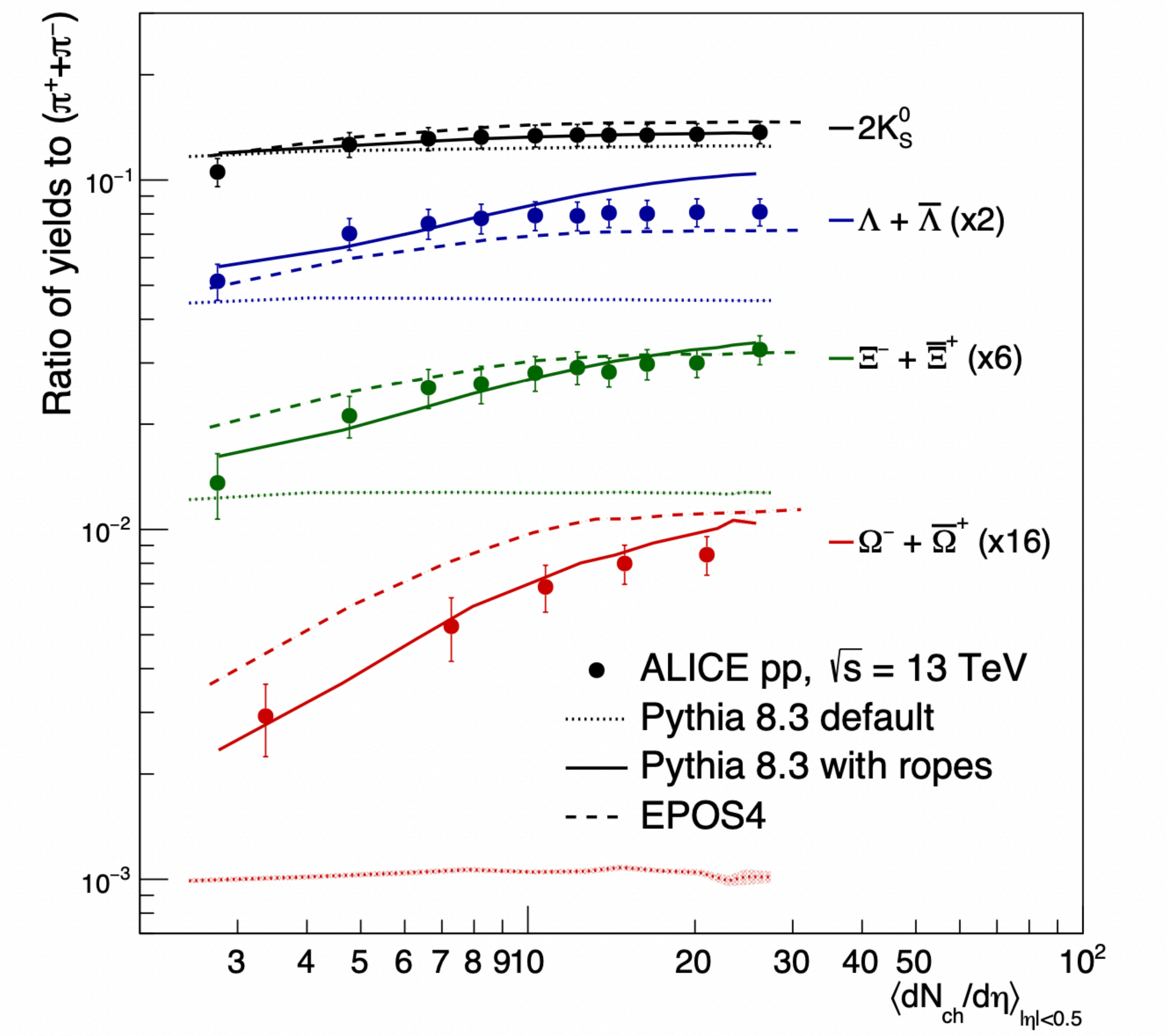
- Indication of partonic collectivity at lower multiplicity classes of pp and p–Pb collisions? High statistics Run 3 data will be useful.

- Ultra long-range correlation ($|\Delta\eta| > 5.0$) close to the minimum bias multiplicity measured in pp and p–Pb collisions for the first time.

- Unprecedented constraint for hydrodynamic and alternative models aiming to explain collectivity in small systems. Need more theory/model input.

Thank You

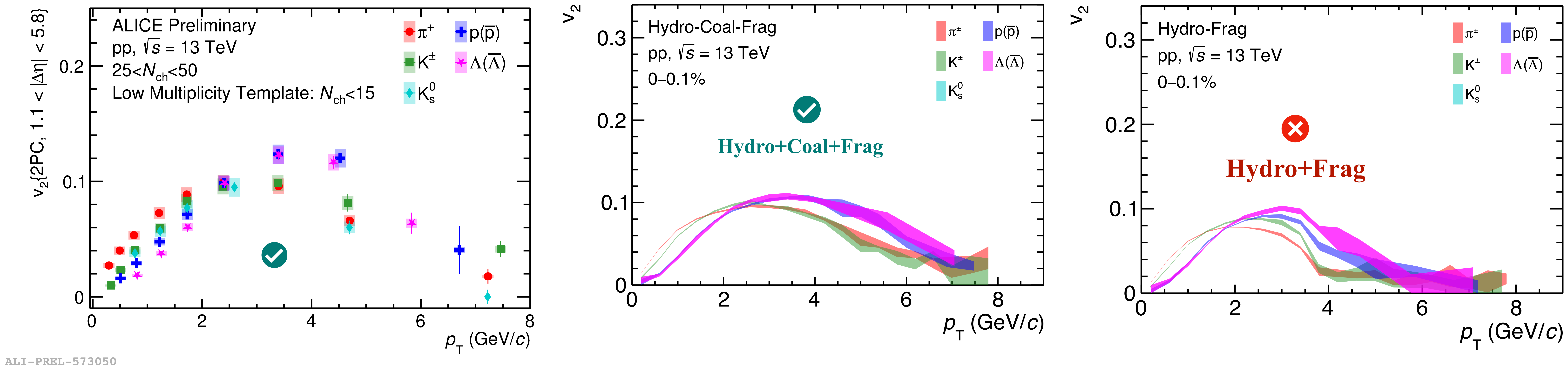




ALICE Collaboration, S.Acharya *et al.*, *Eur.Phys.J.C* 80 (2020) 8, 693

Partonic collectivity in small collision systems!

High multiplicity pp



- Both data and model results from high multiplicity pp collisions (with different N_{ch} / centrality cuts.)

- Hydro+Coal+Frag explains the grouping and splitting,
- Hydro+Frag fails to describe the pattern (despite paramters adjustments).