Exploring Collective Dynamics in Small Collision Systems at the LHC

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In collaboration with You Zhou (NBI, Copenhagen), Wenya Wu (Fudan University (Shanghai), TUM (Munich)), Qiye Shou (Fudan University), Mingrui Zhao (CIAE)

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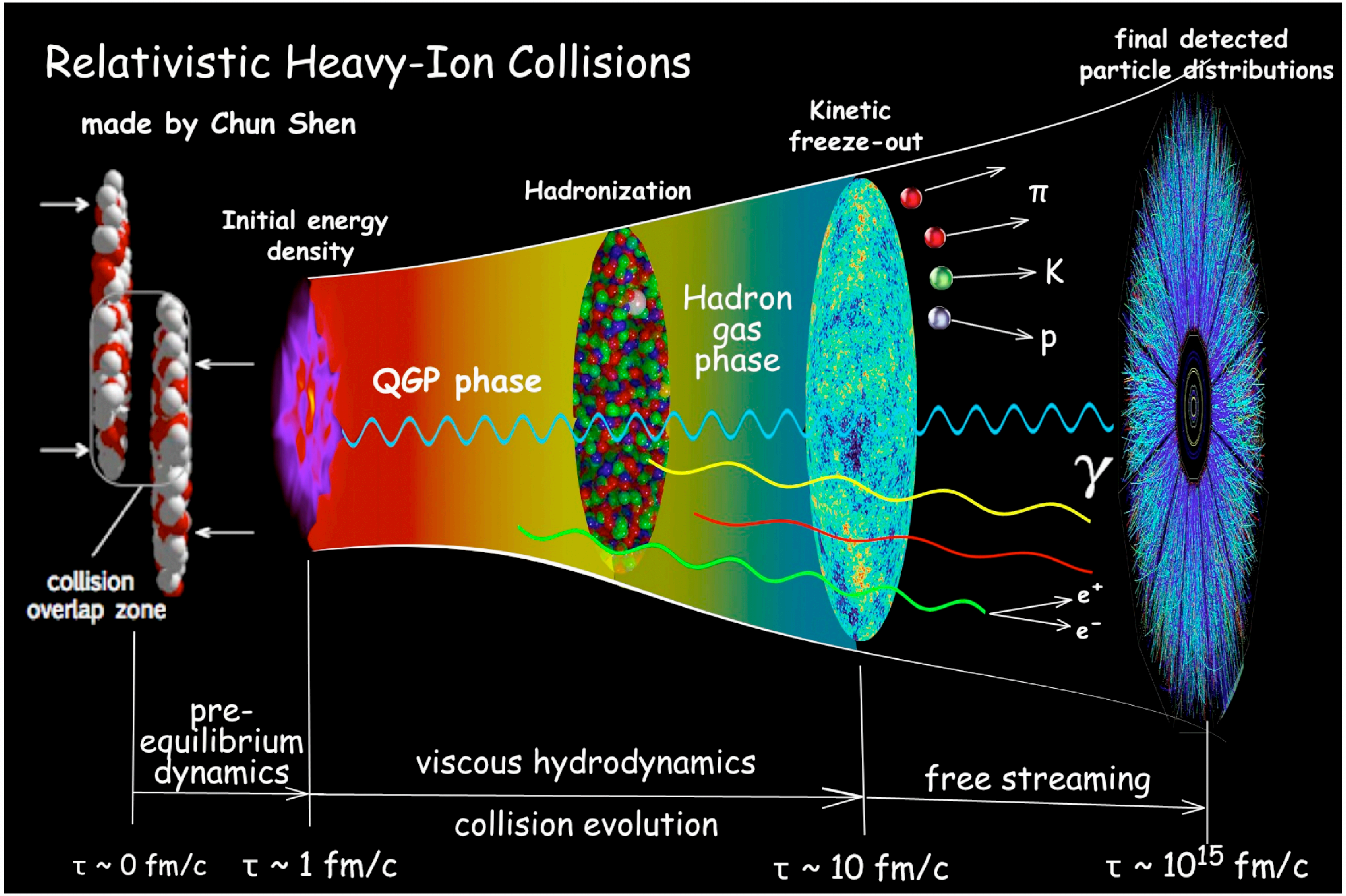
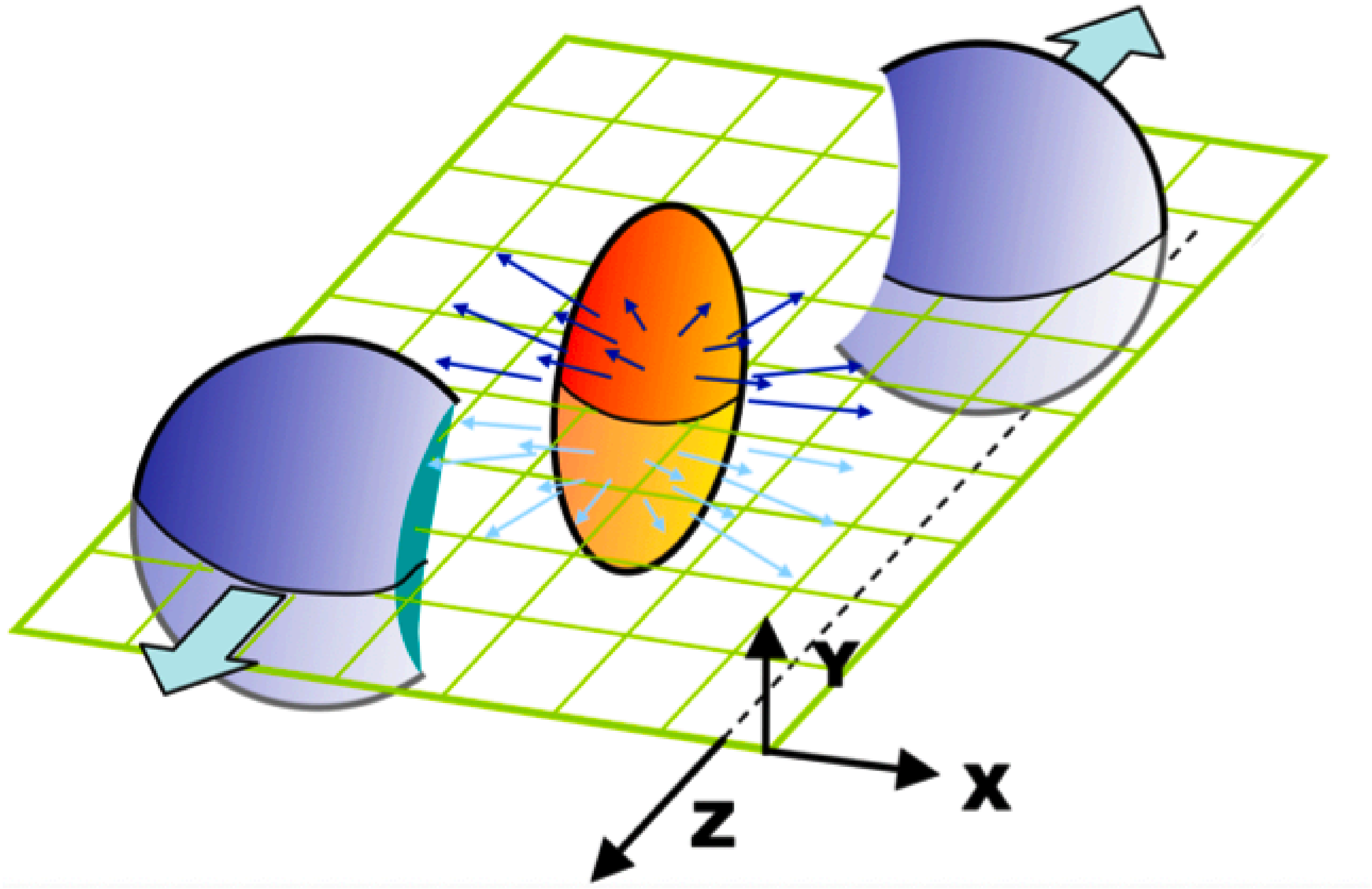
Outline

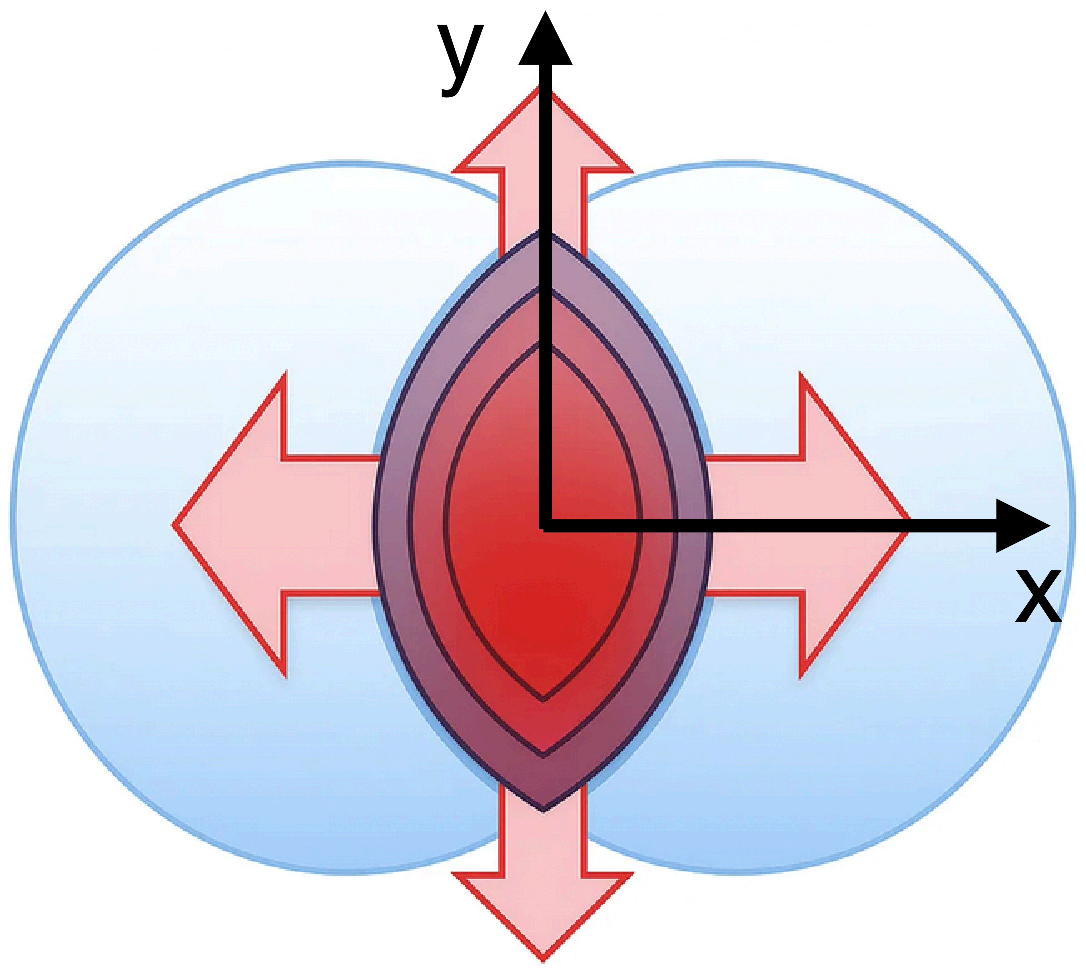


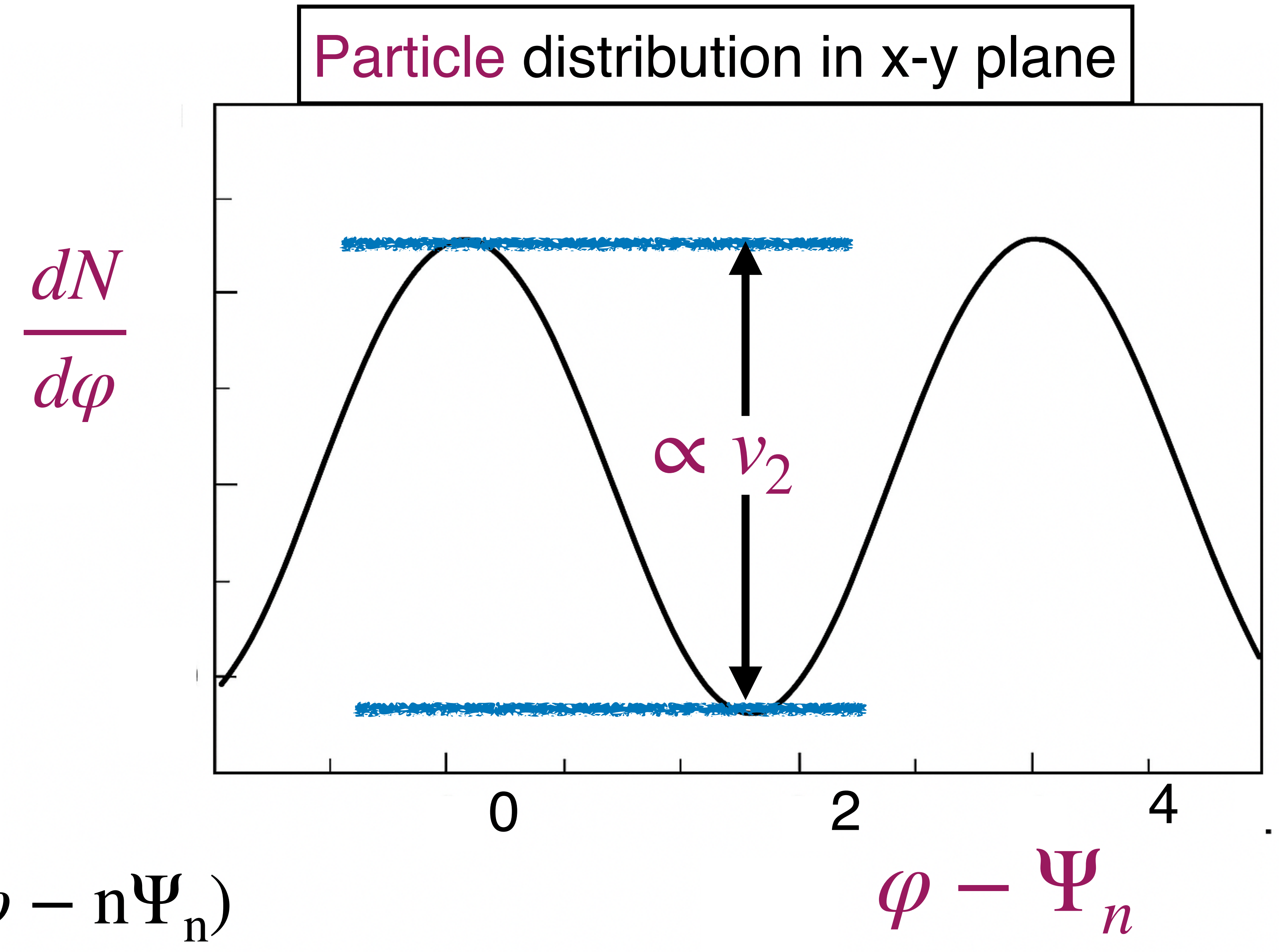
- Baseline: Heavy-ion collisions— collective phenomena are well established and widely studied.
- Explore similarities and differences between small systems and heavy-ion collisions.

Anatomy: Collectivity in heavy-ion collisions

Initial state geometry + Final state interaction (Hydrodynamics description)







Azimuthal distribution of particles: $P(\varphi) \equiv \frac{dN^{singles}}{d\varphi} \propto 1 + 2\sum_n v_n \cos(n\varphi - n\Psi_n)$

Second Fourier Coefficient ⟶ $v_2 = \langle\langle \cos 2(\varphi - \Psi_2) \rangle\rangle$

Hydro prediction ($v_n \propto \epsilon_n$)

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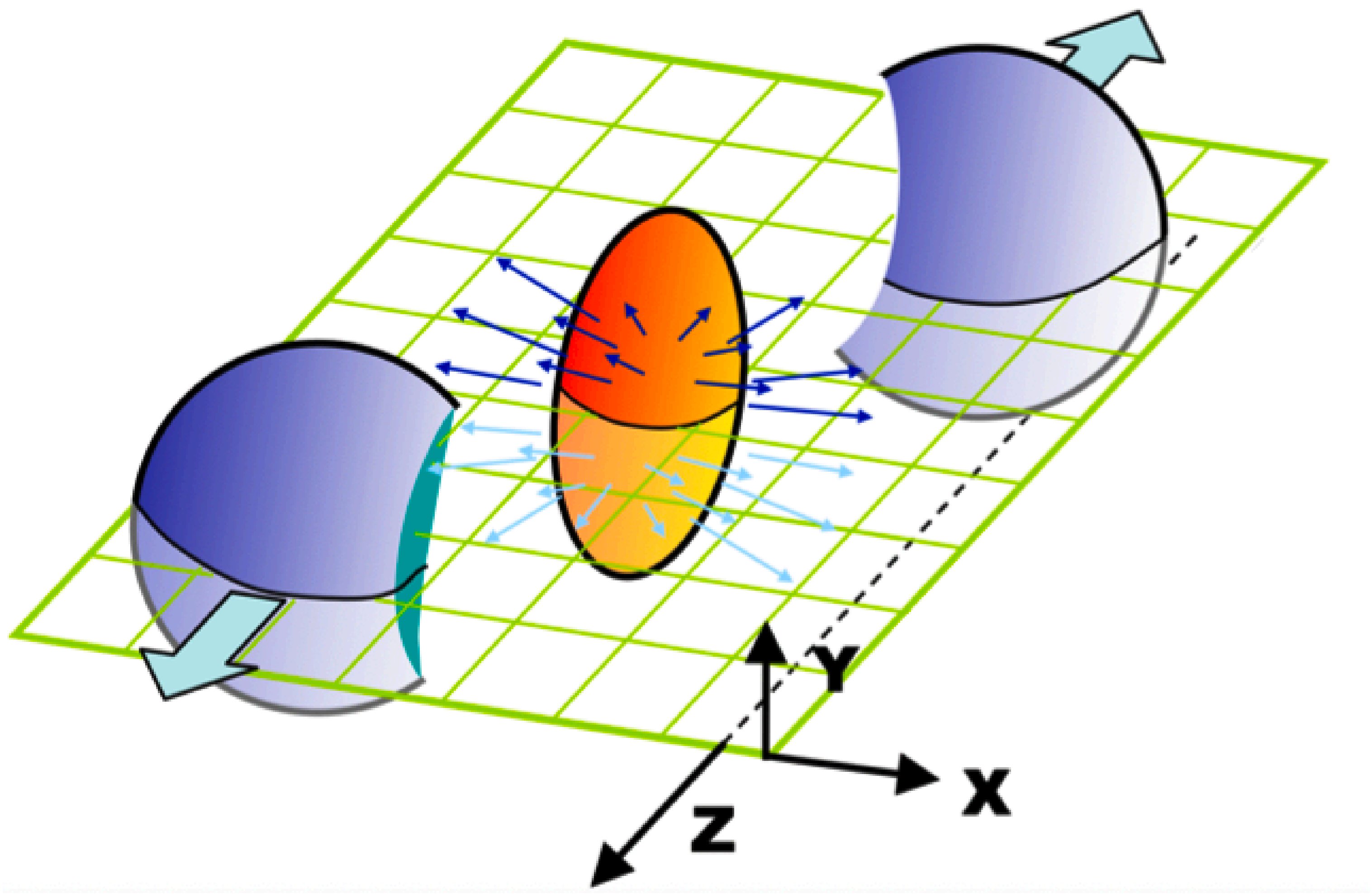

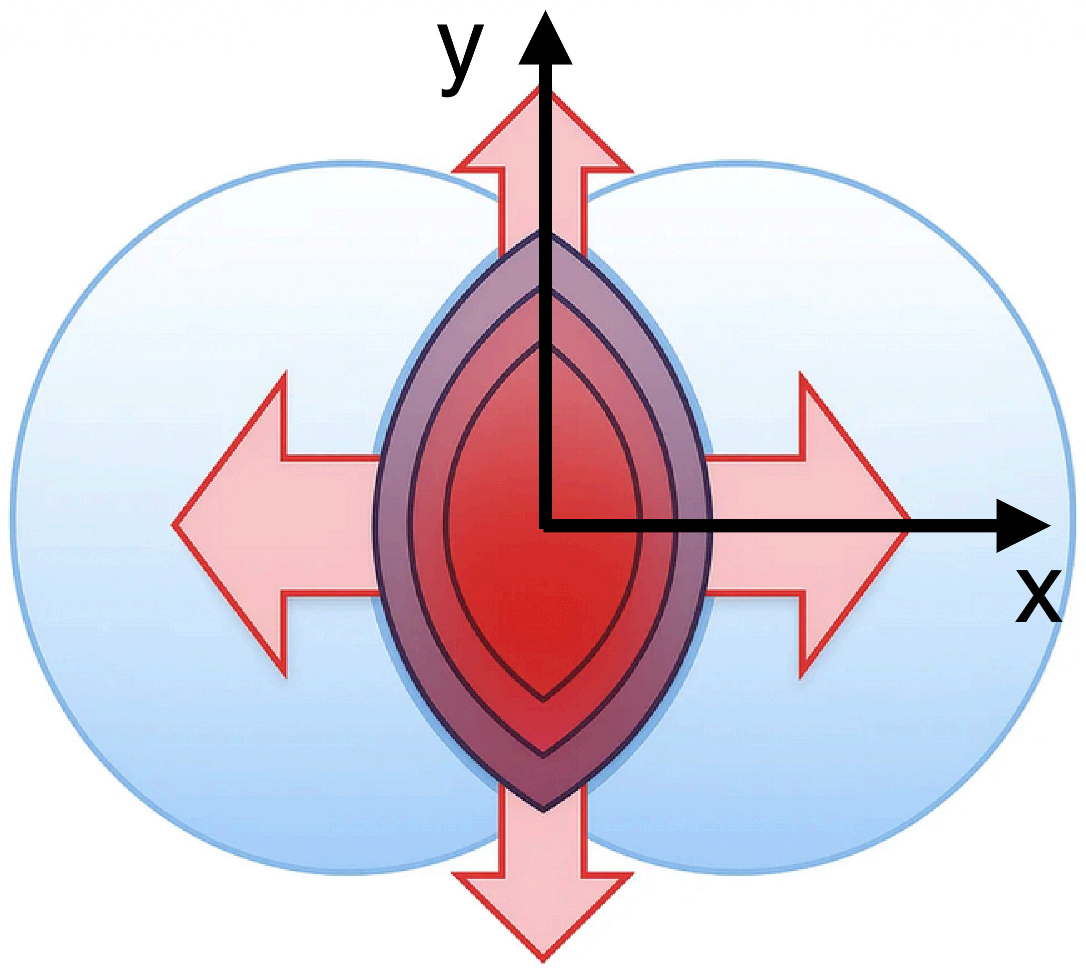

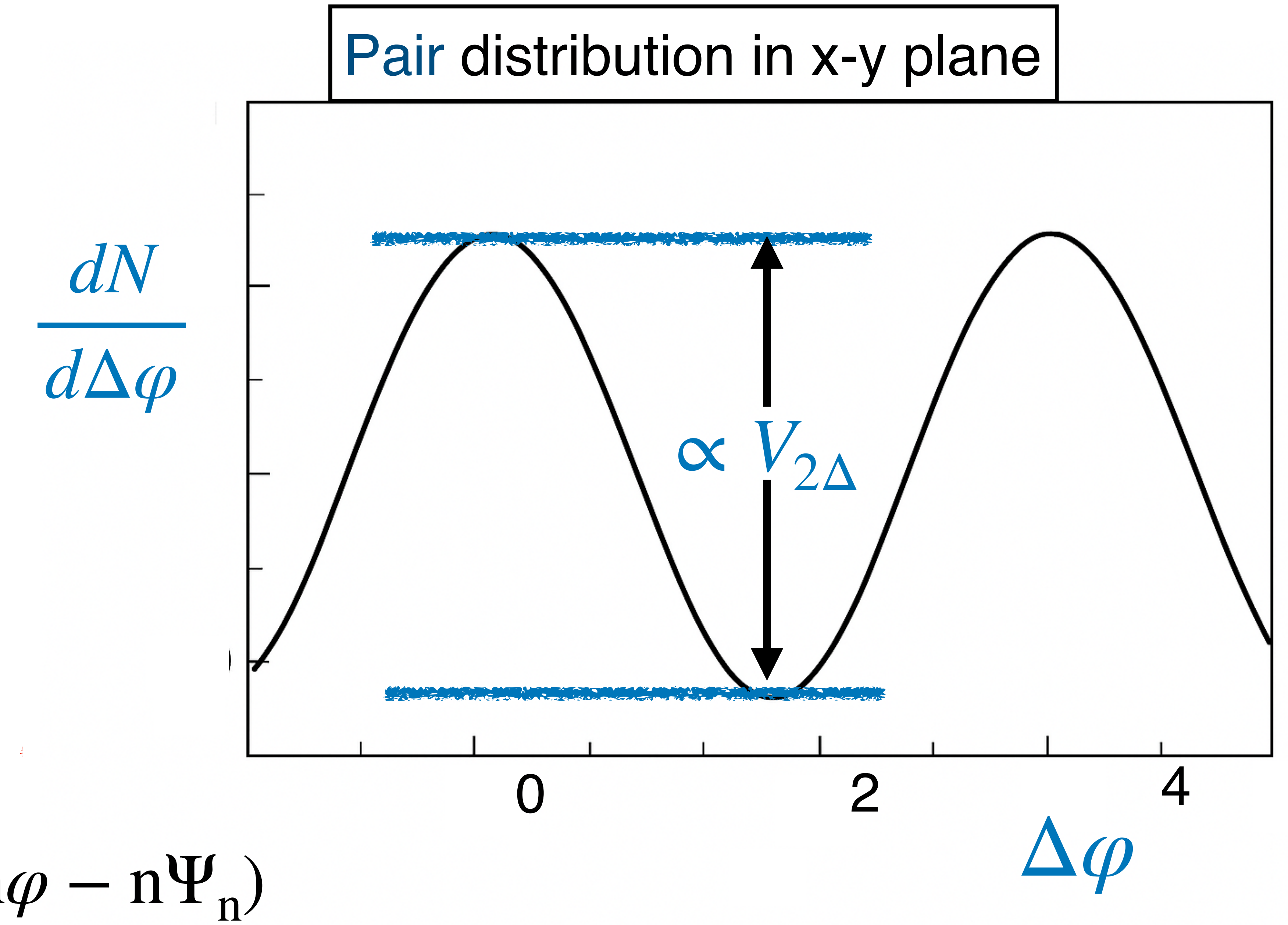

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Hydro prediction ($v_n \propto \epsilon_n$)

Azimuthal distribution of pairs: $P(\varphi_1) * P(\varphi_2) \equiv \frac{dN^{pairs}}{d\Delta\varphi} \propto 1 + 2\sum_n V_{n\Delta} \cos(\mathrm{n}\Delta\varphi)$

$$V_{n\Delta} = \langle\langle \cos n(\varphi_1 - \Psi_n) \cdot \cos n(\varphi_2 - \Psi_n)\rangle\rangle = \langle\langle \cos n\,[(\varphi_1 - \Psi_n) - (\varphi_2 - \Psi_n)]\rangle\rangle = \langle\langle \cos n(\varphi_1 - \varphi_2)\rangle\rangle$$

The pair distribution gets rid of the event plane Ψ_n (difficult to determine experimentally)

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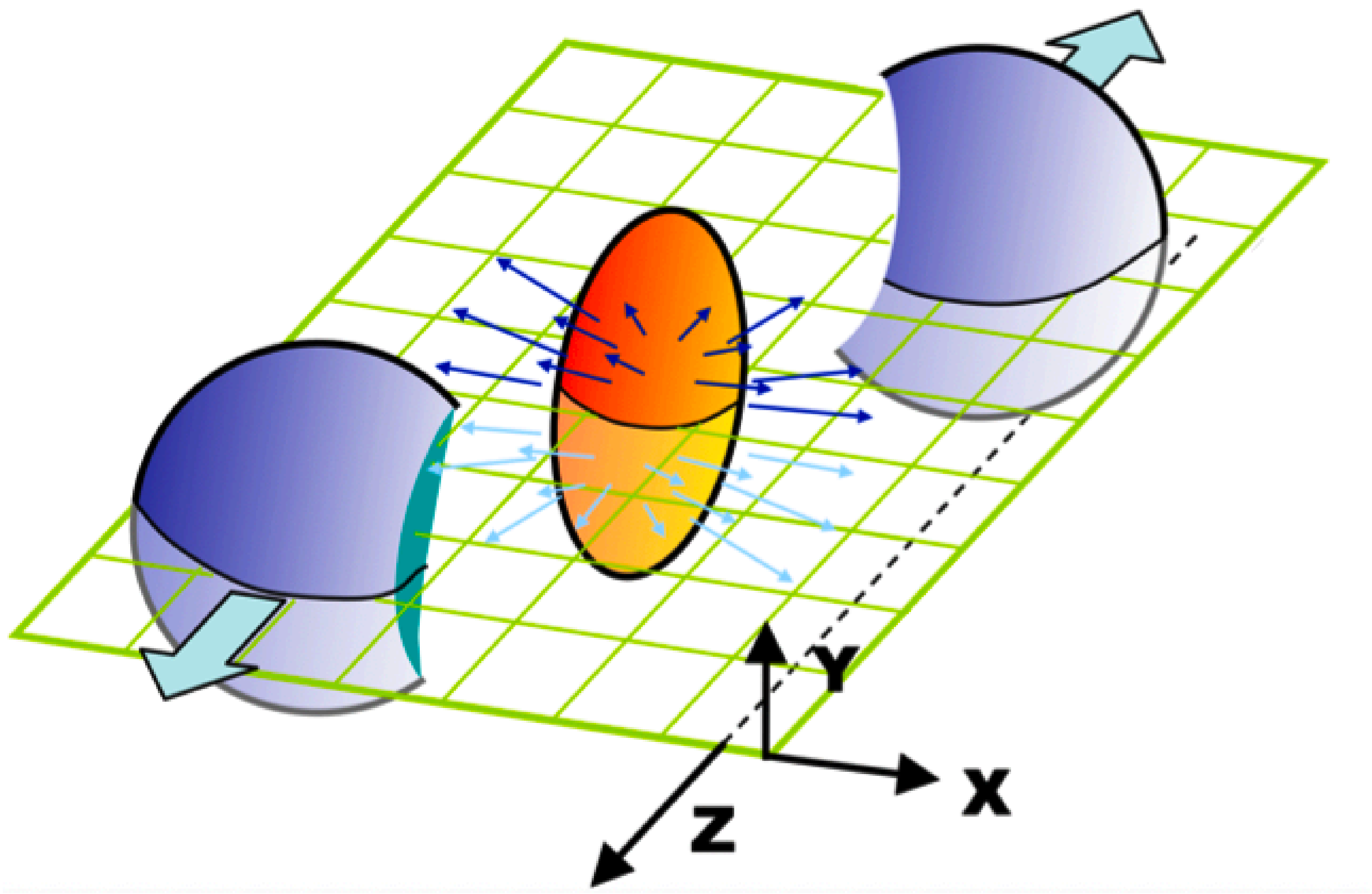
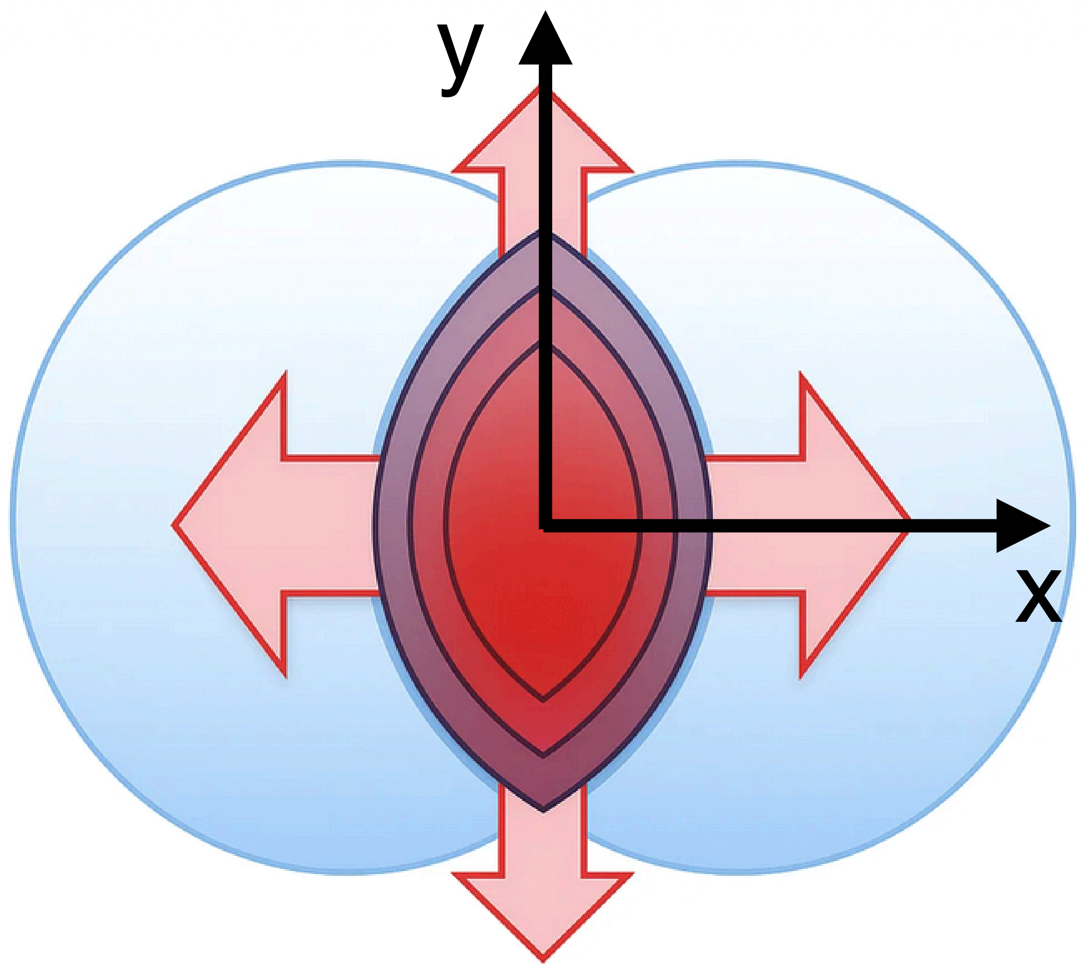
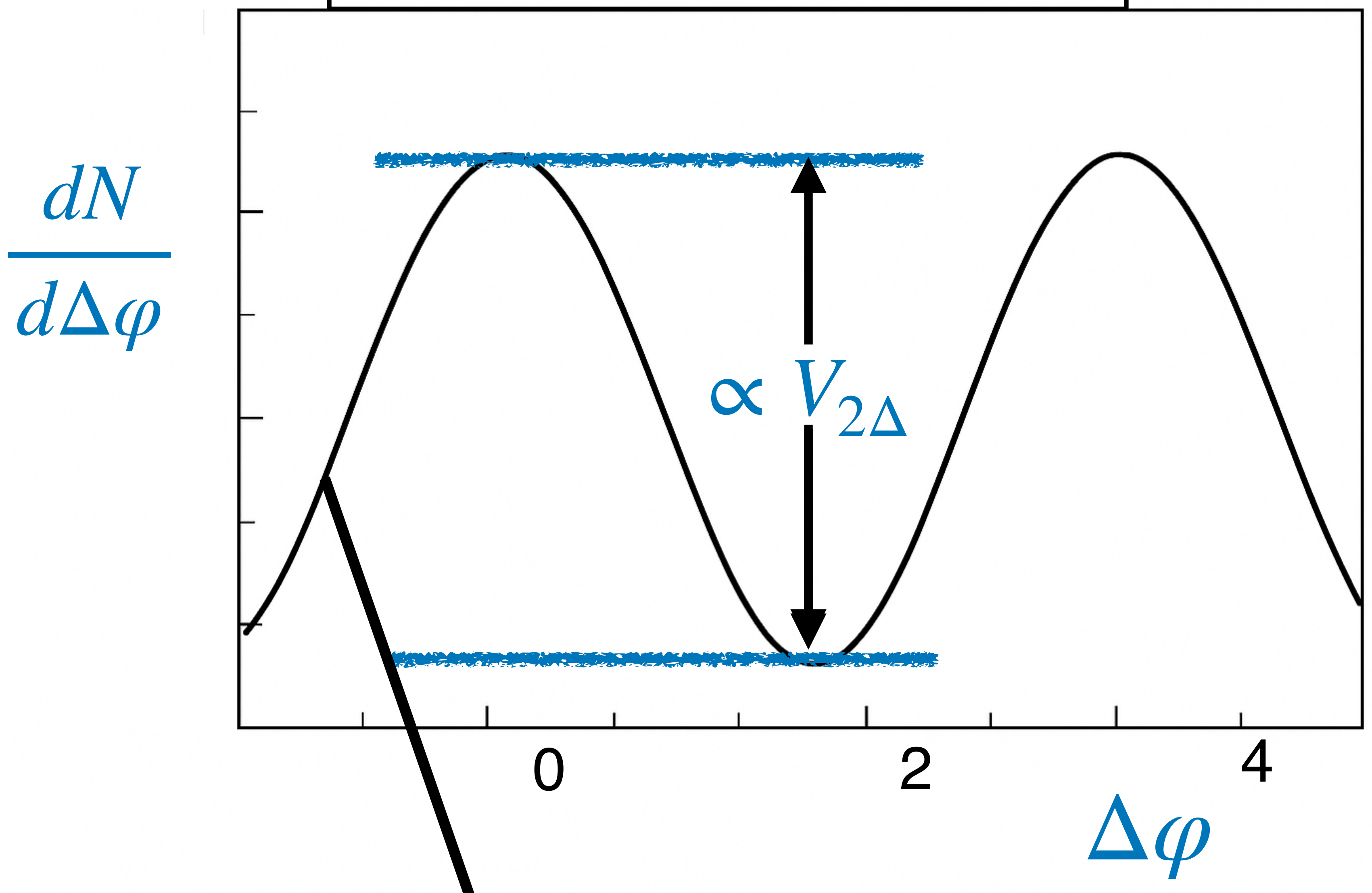




Pair distribution in x-y plane



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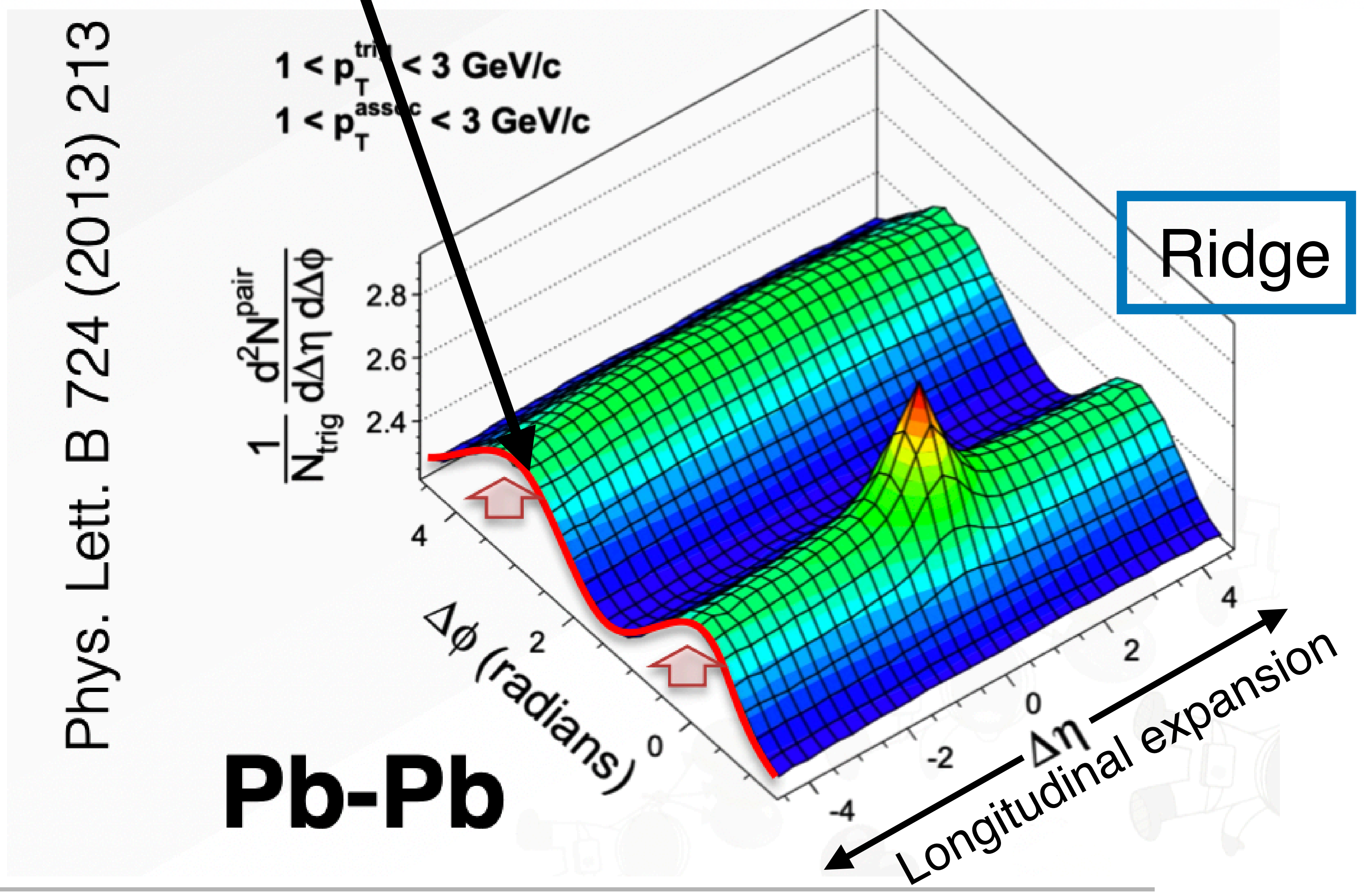

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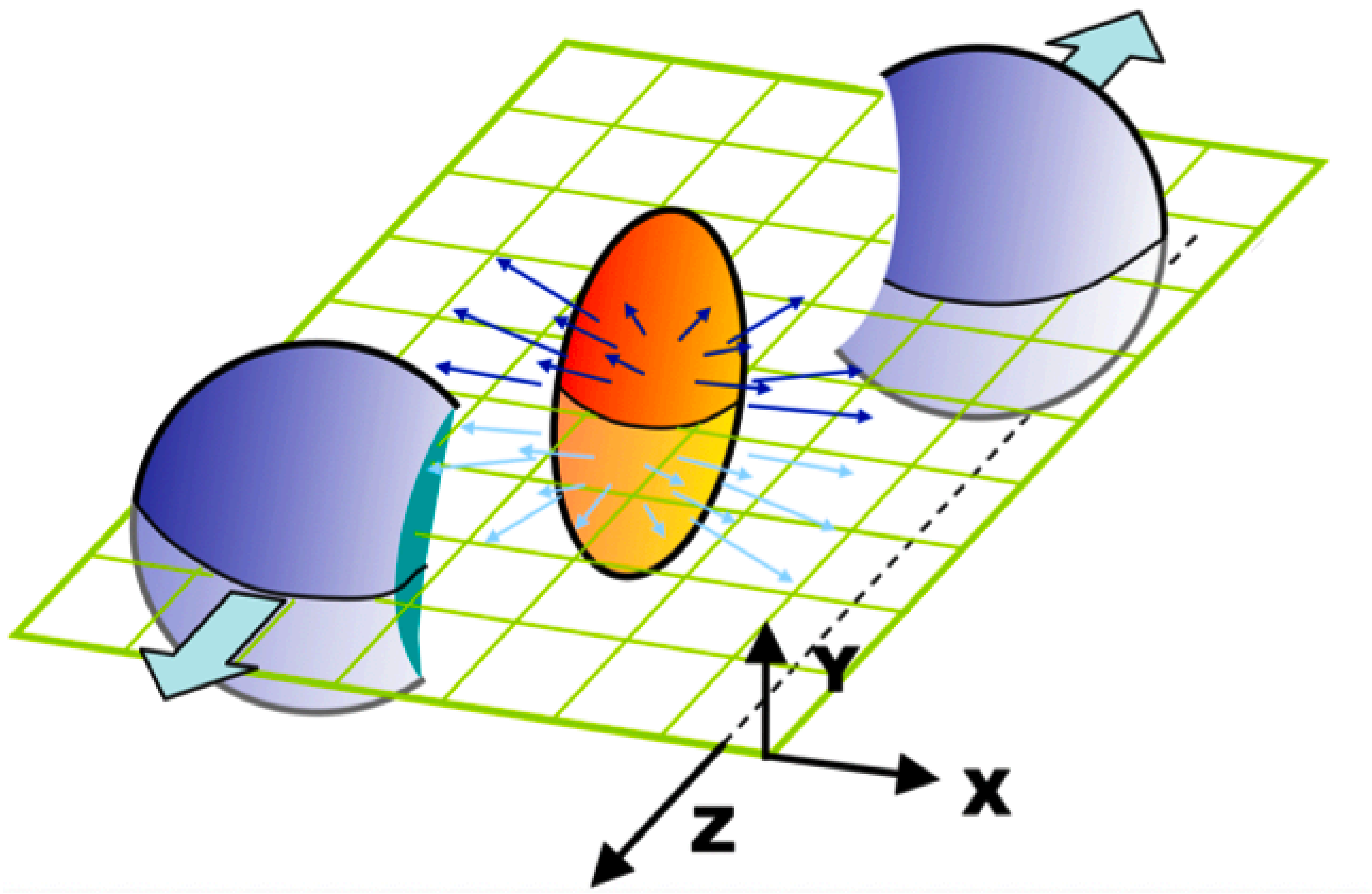

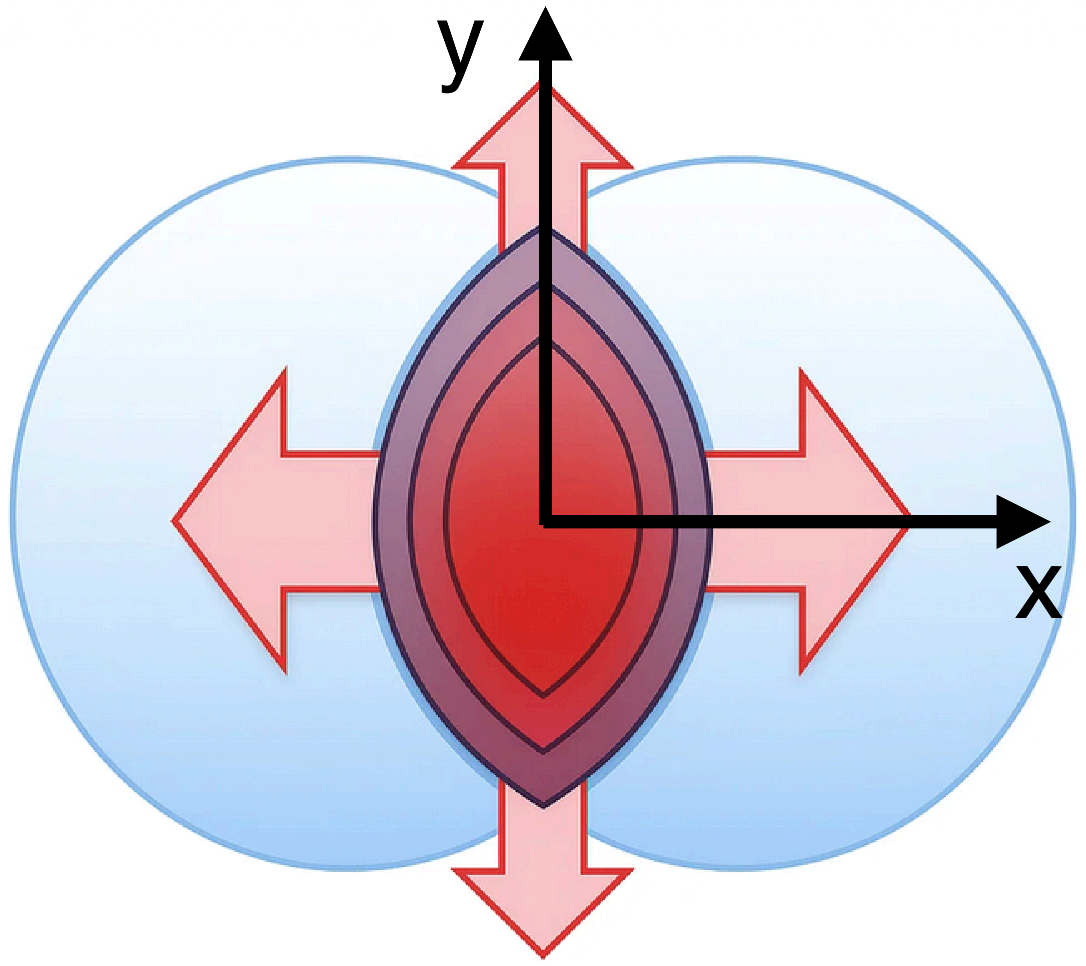

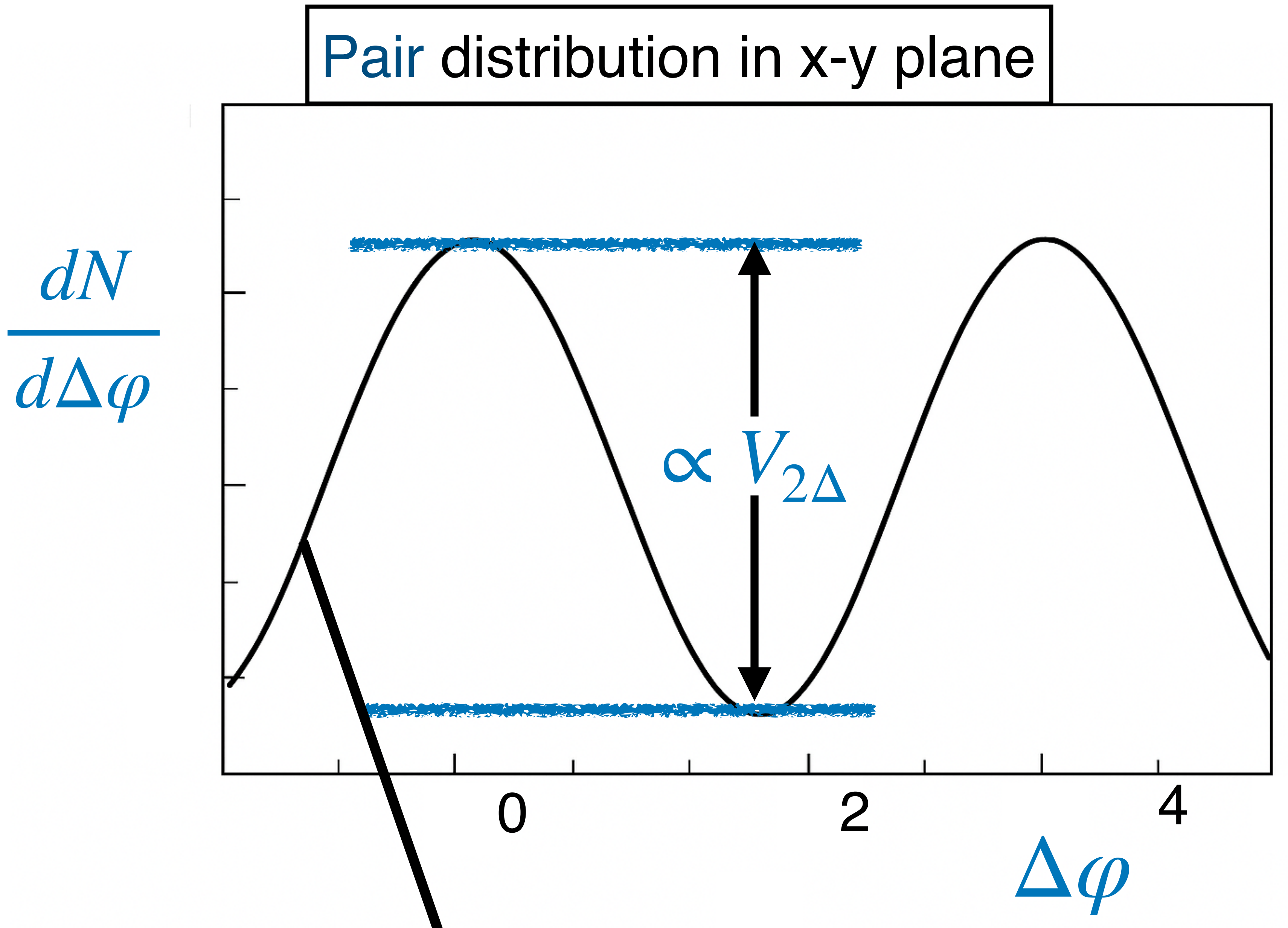

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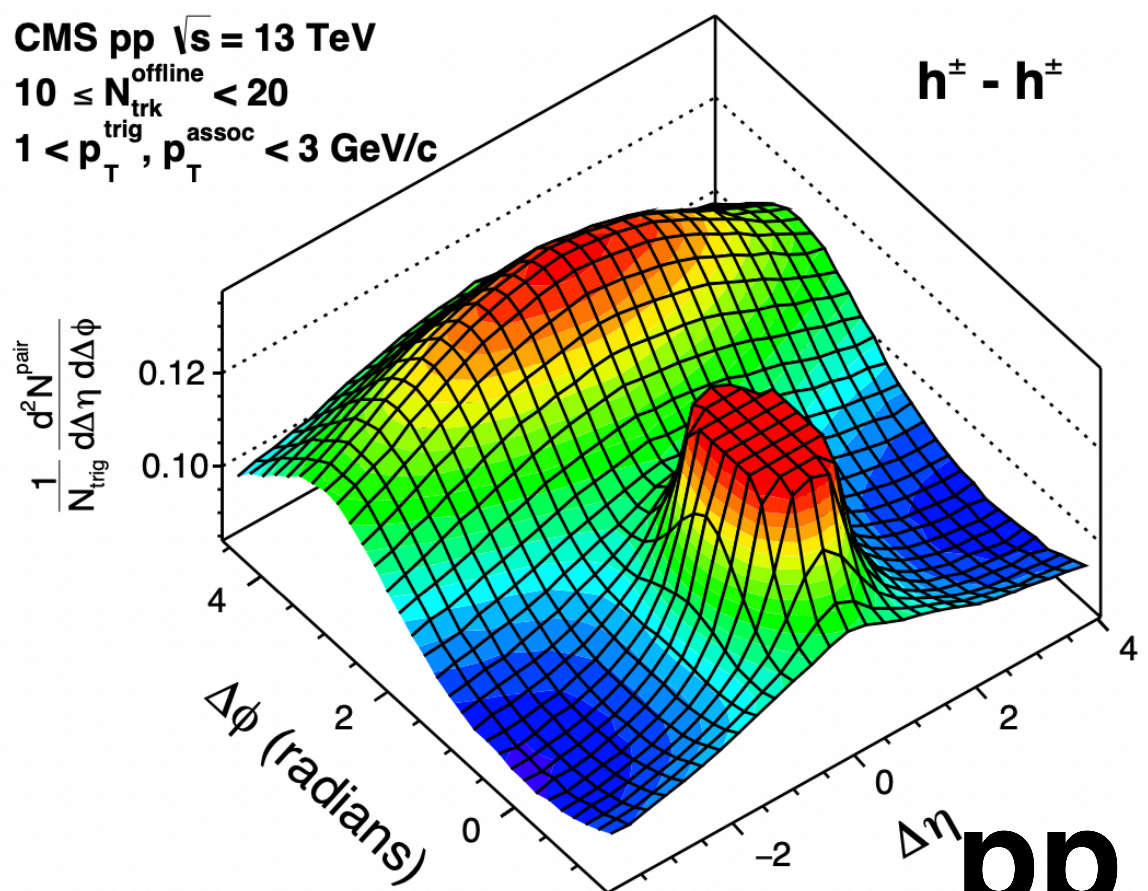
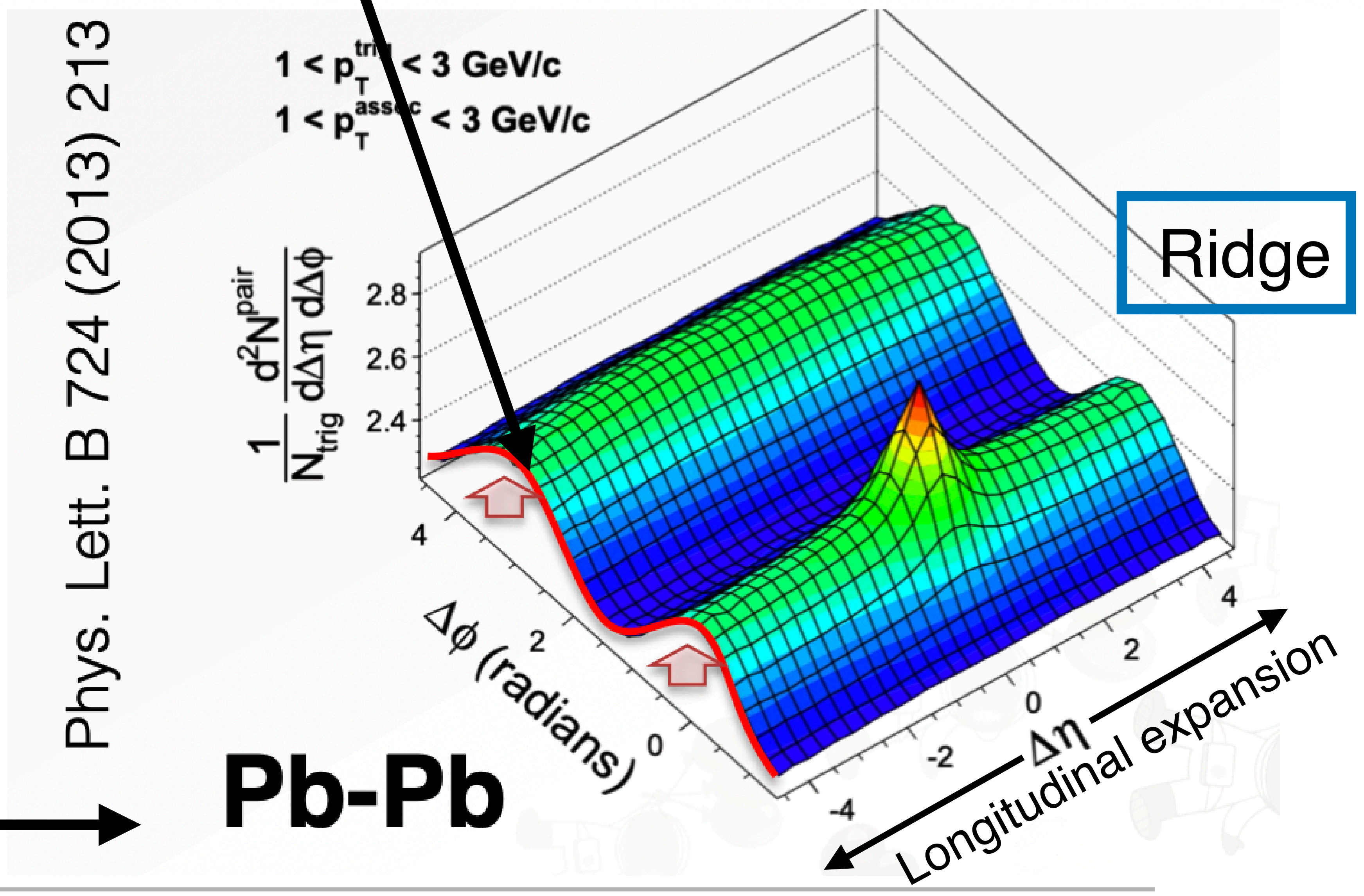
Hydro prediction ($v_n \propto \epsilon_n$)

No Ridge

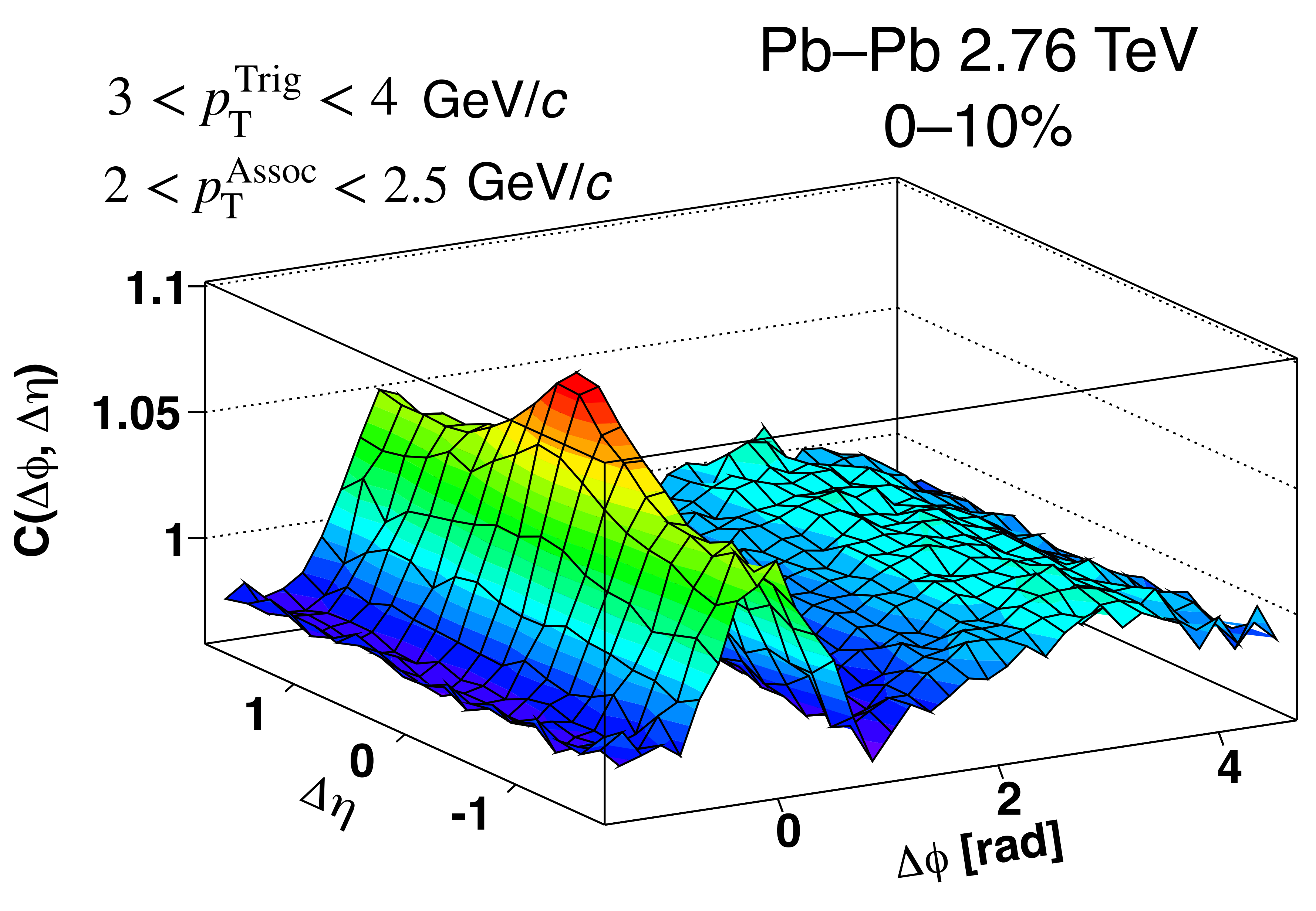


CMS, Phys.Lett. B 765 (2017) 193

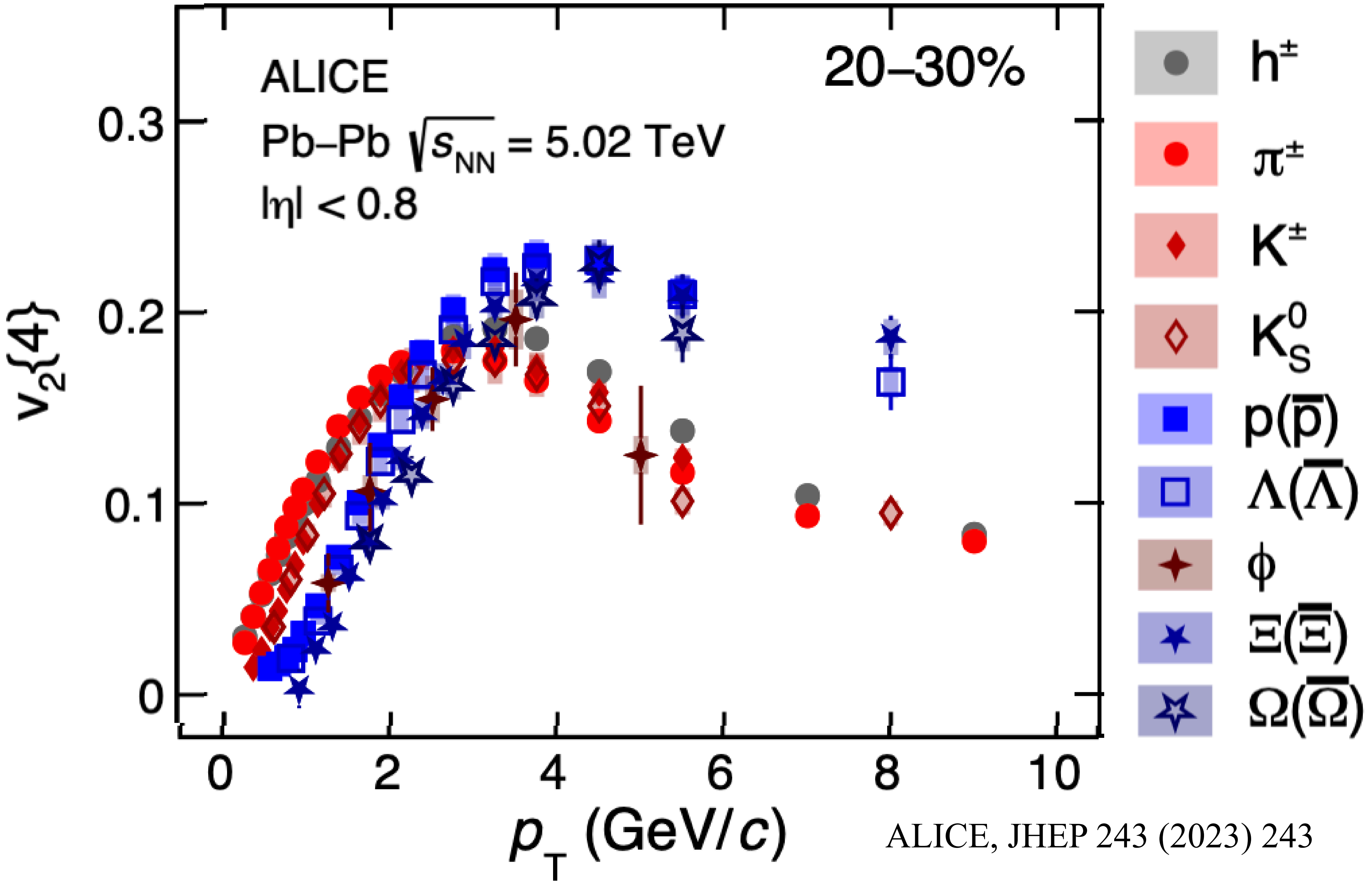
pp ⟶ Collectivity emerges! ⟶ Pb-Pb



Baseline: Collective features in heavy-ion collisions



ALICE, PLB 708 (2012) 249-264



ALICE, JHEP 243 (2023) 243

PID v_2 measurements in Pb-Pb (CCNU, Wuhan)

- Low p_T ($p_T \lesssim 3$ GeV/c) — Mass ordering —Interplay between radial and elliptic flow (hydrodynamics).

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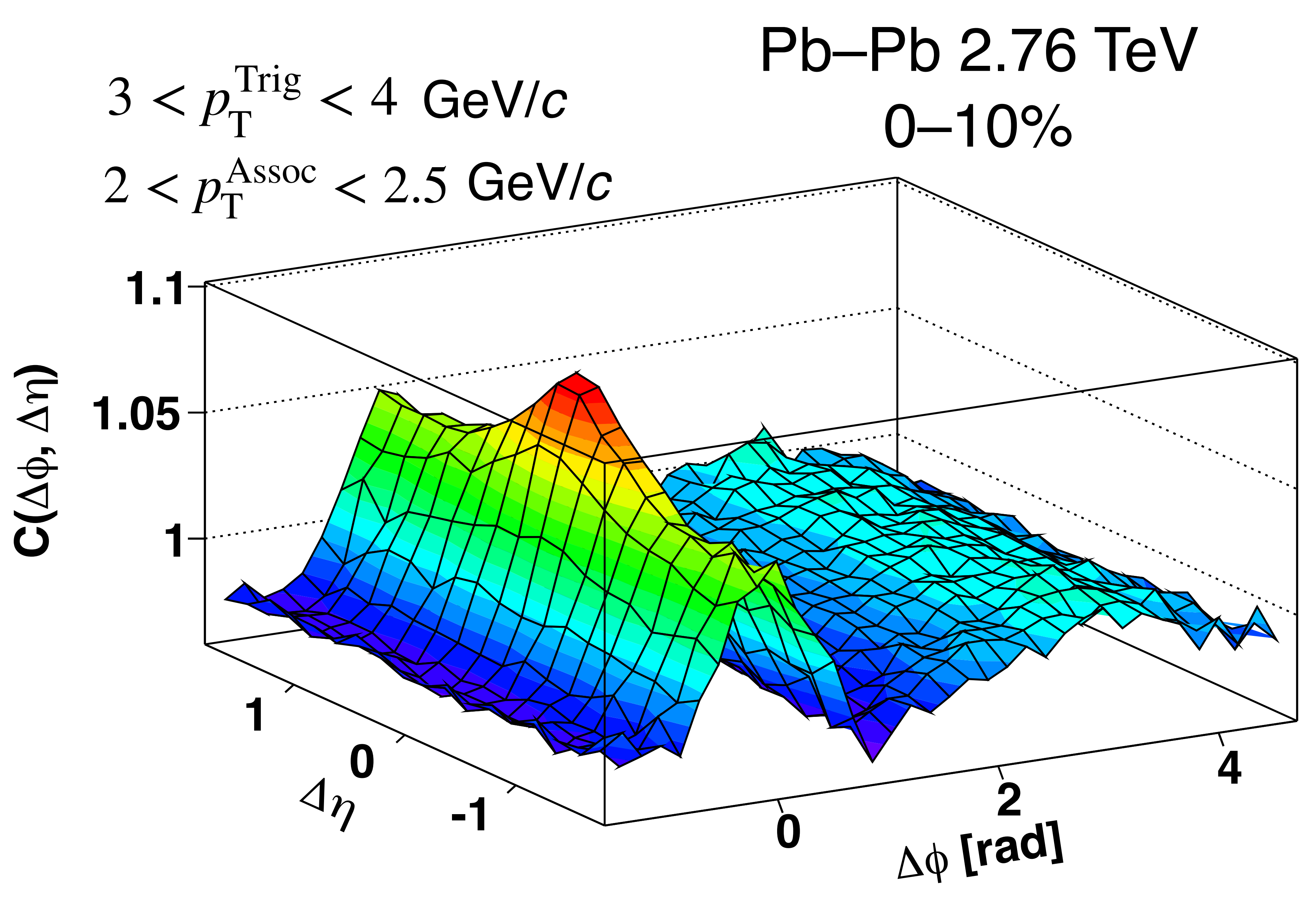

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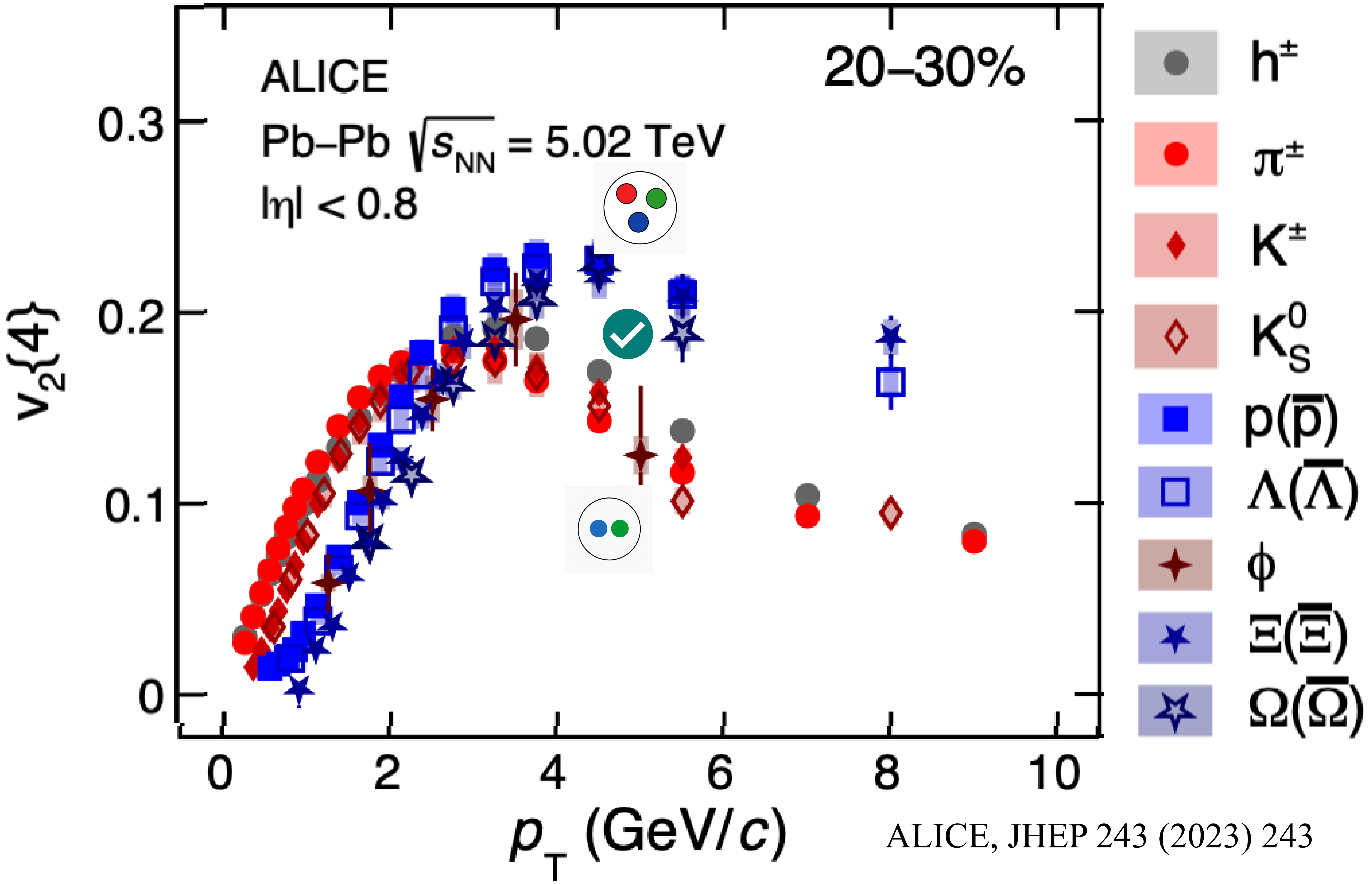

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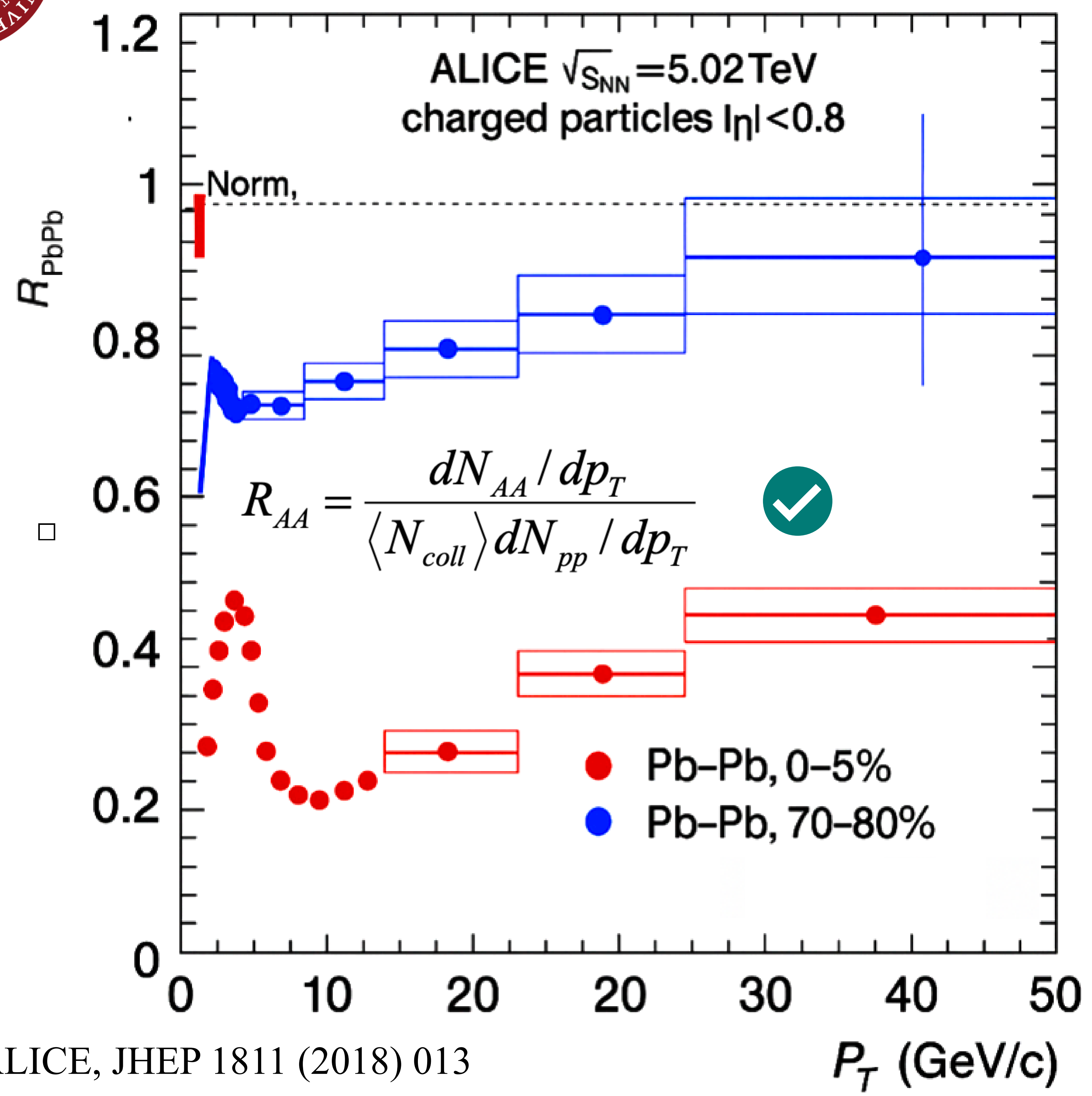
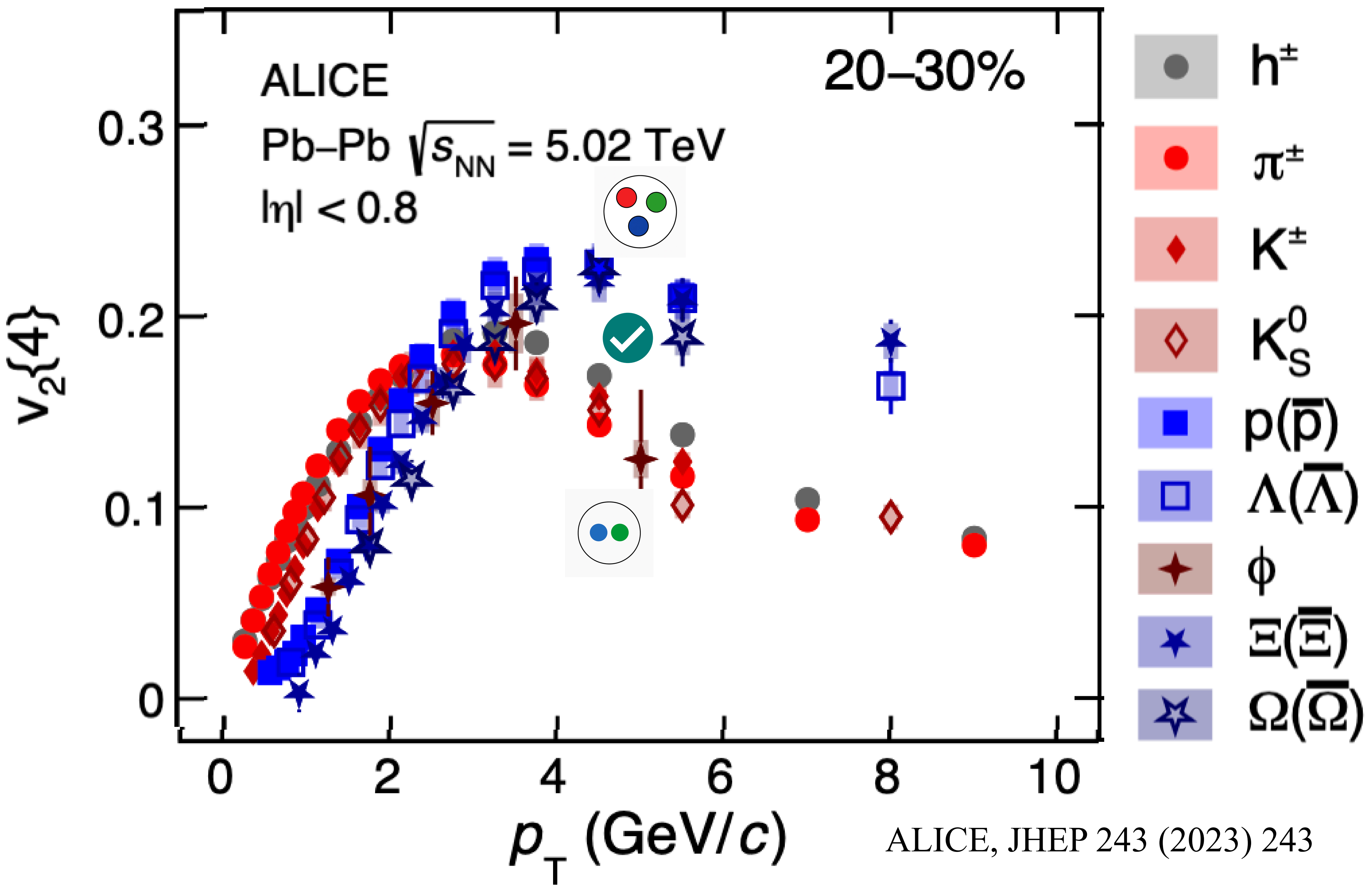


ALICE, JHEP 1811 (2018) 013



ALICE, JHEP 243 (2023) 243

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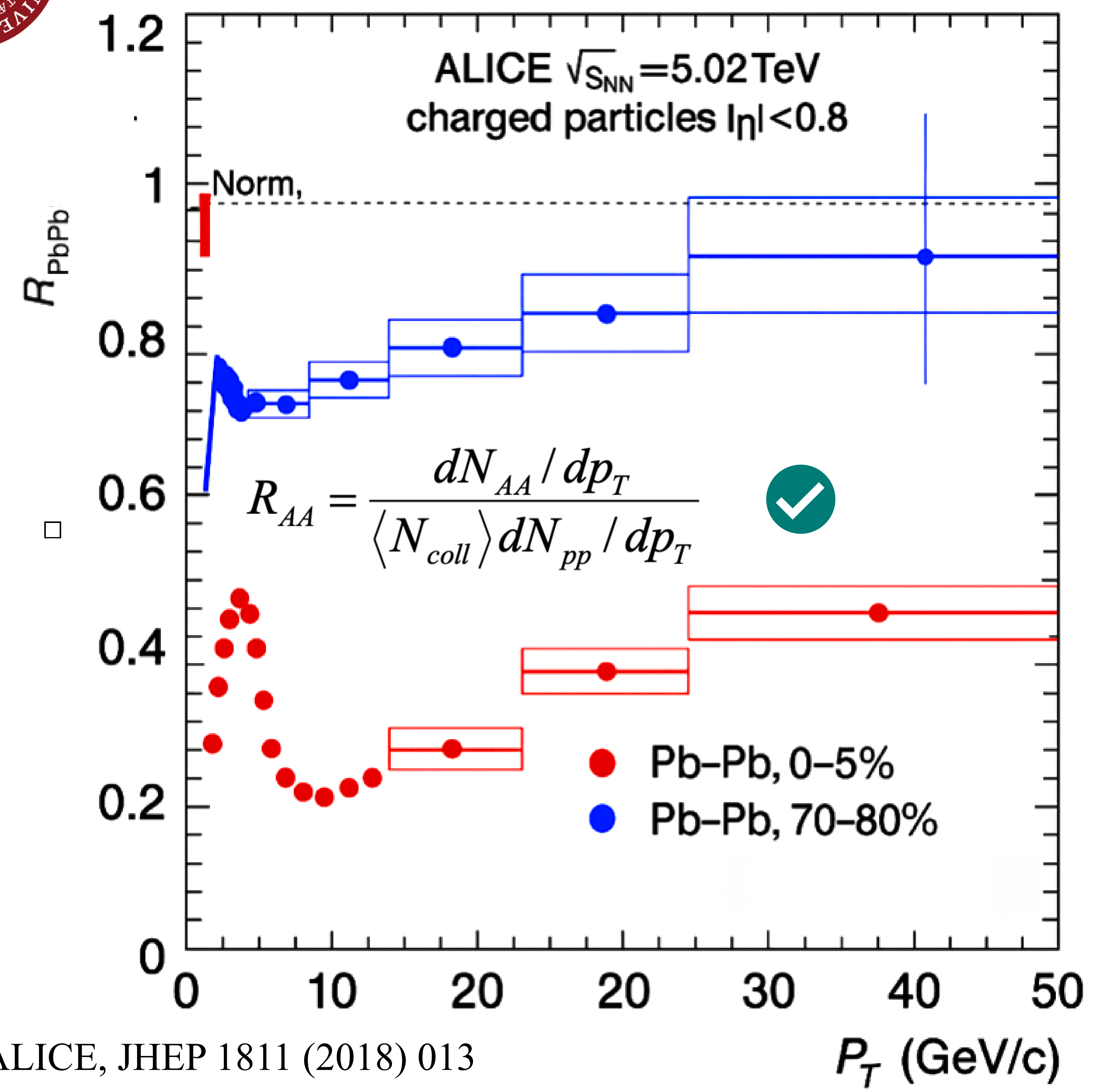

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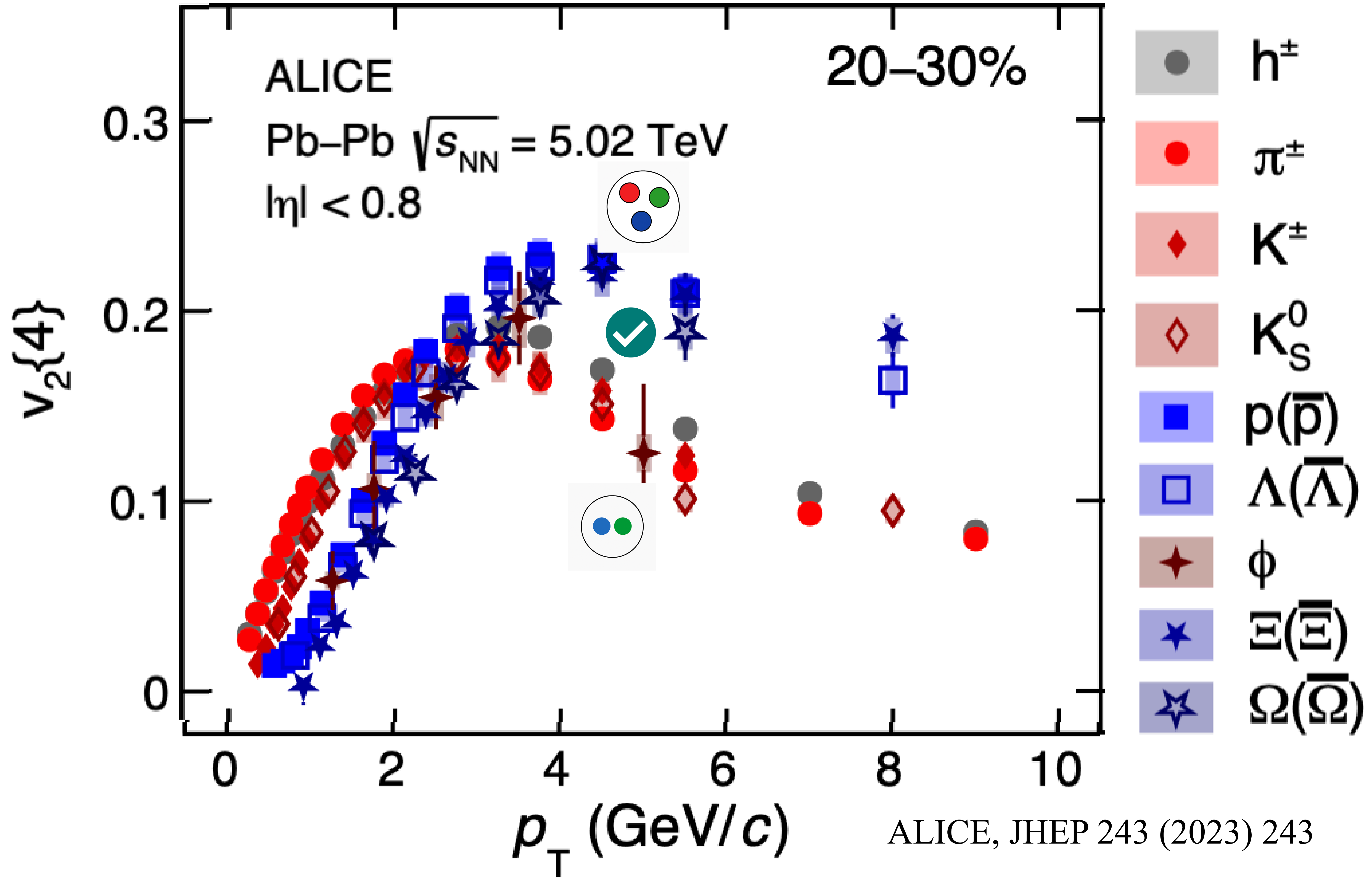

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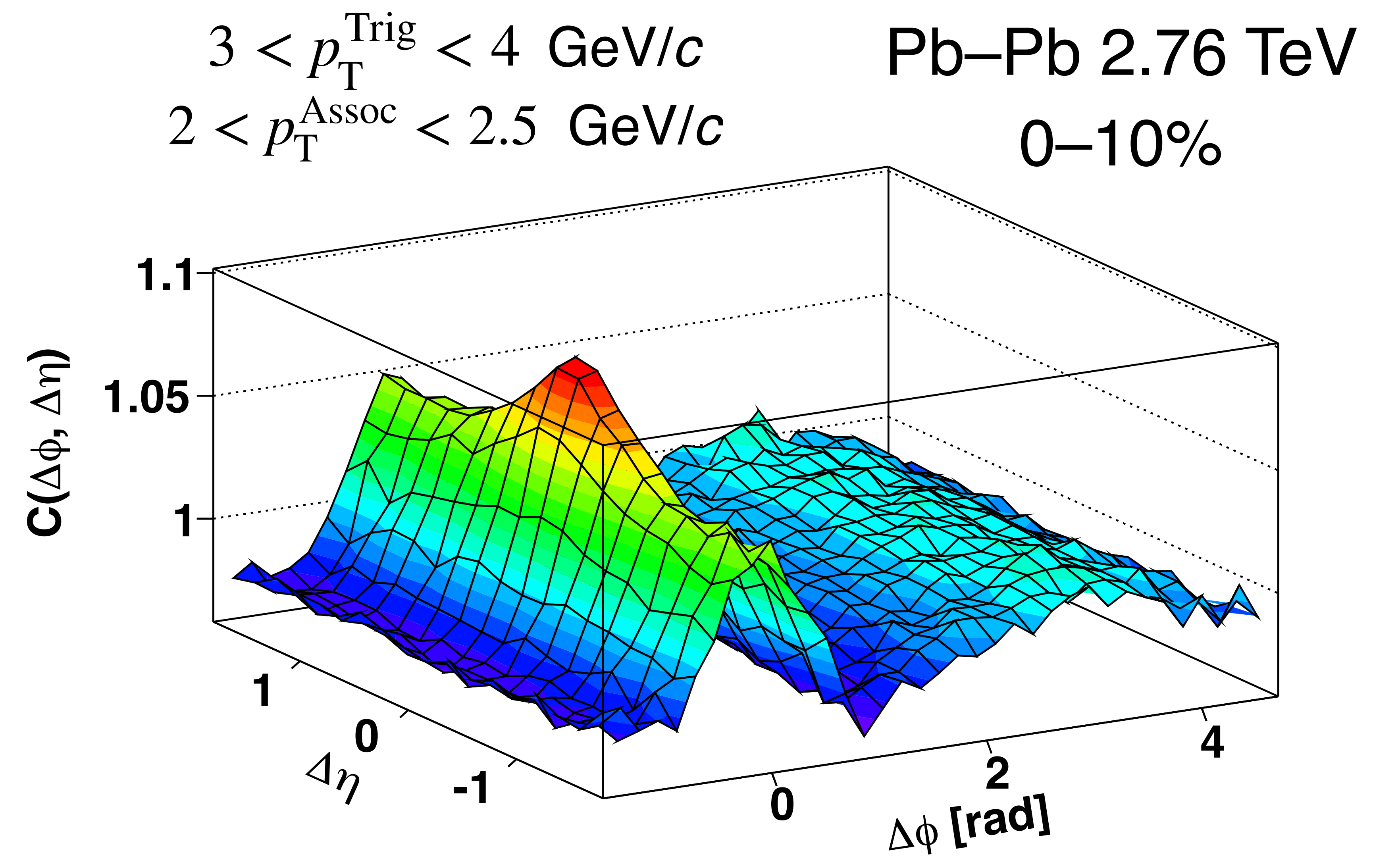
What about small collision systems?

Collectivity in small systems?

Pb–Pb | **High multiplicity p–Pb** | **High multiplicity pp**



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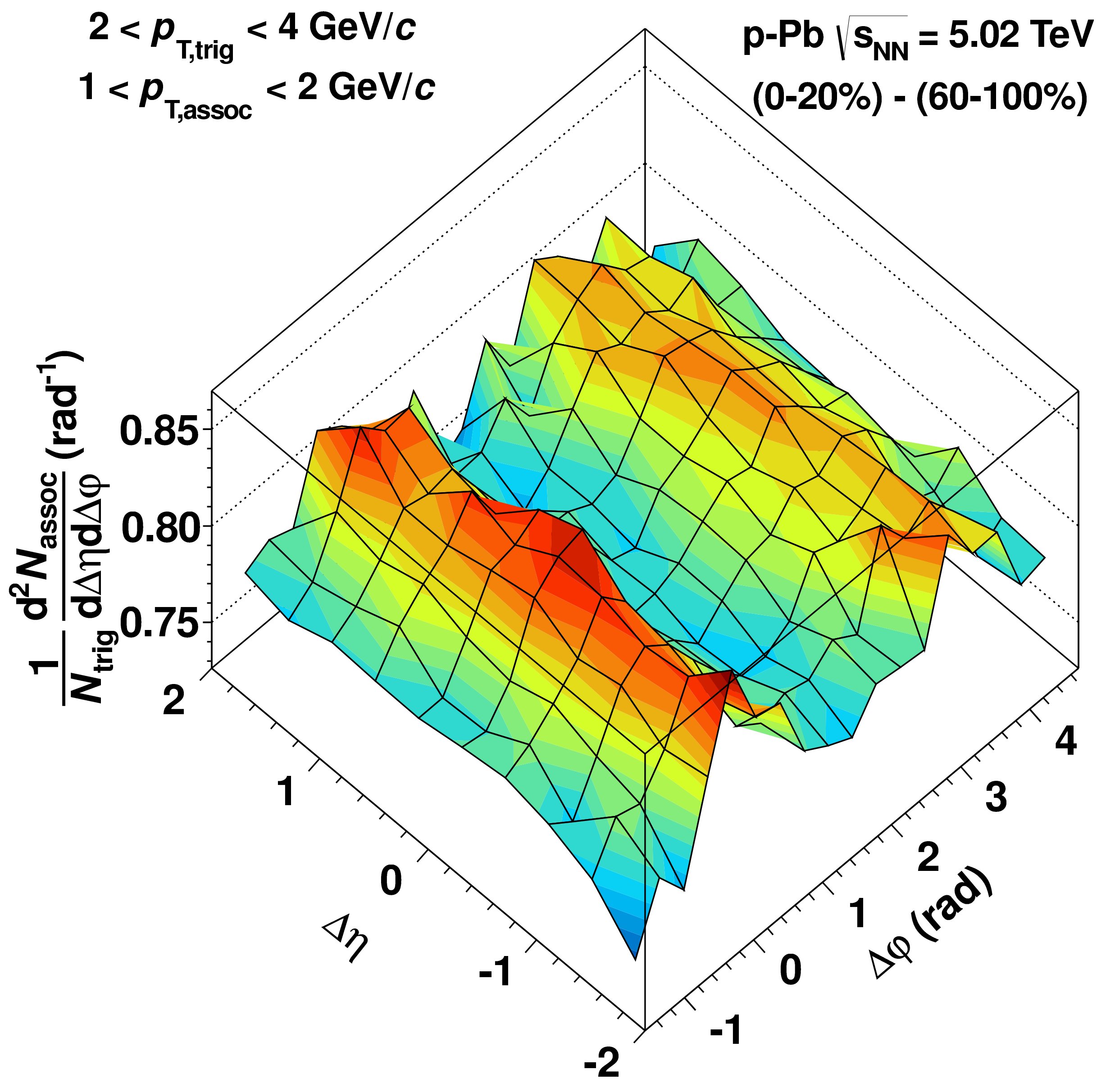
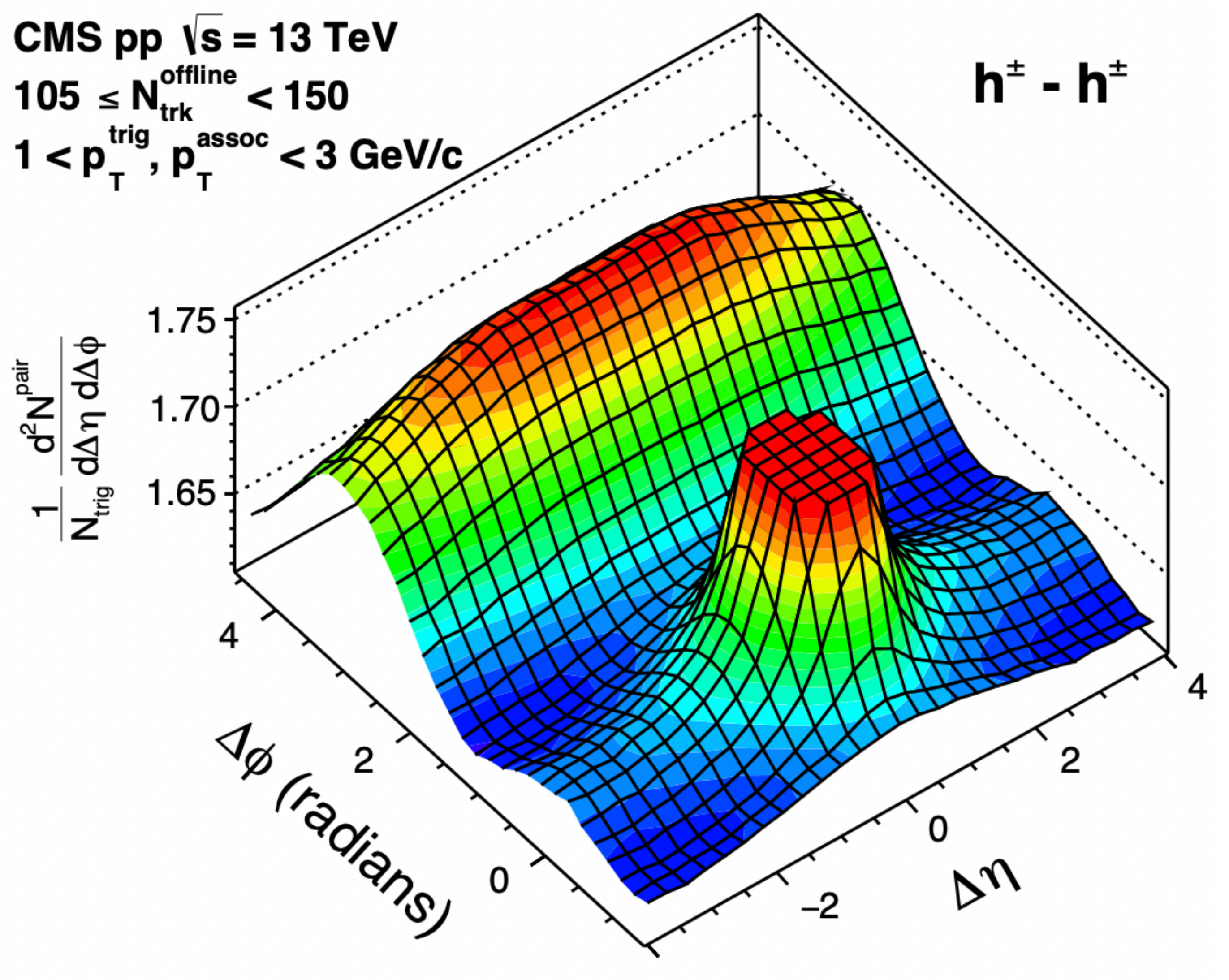
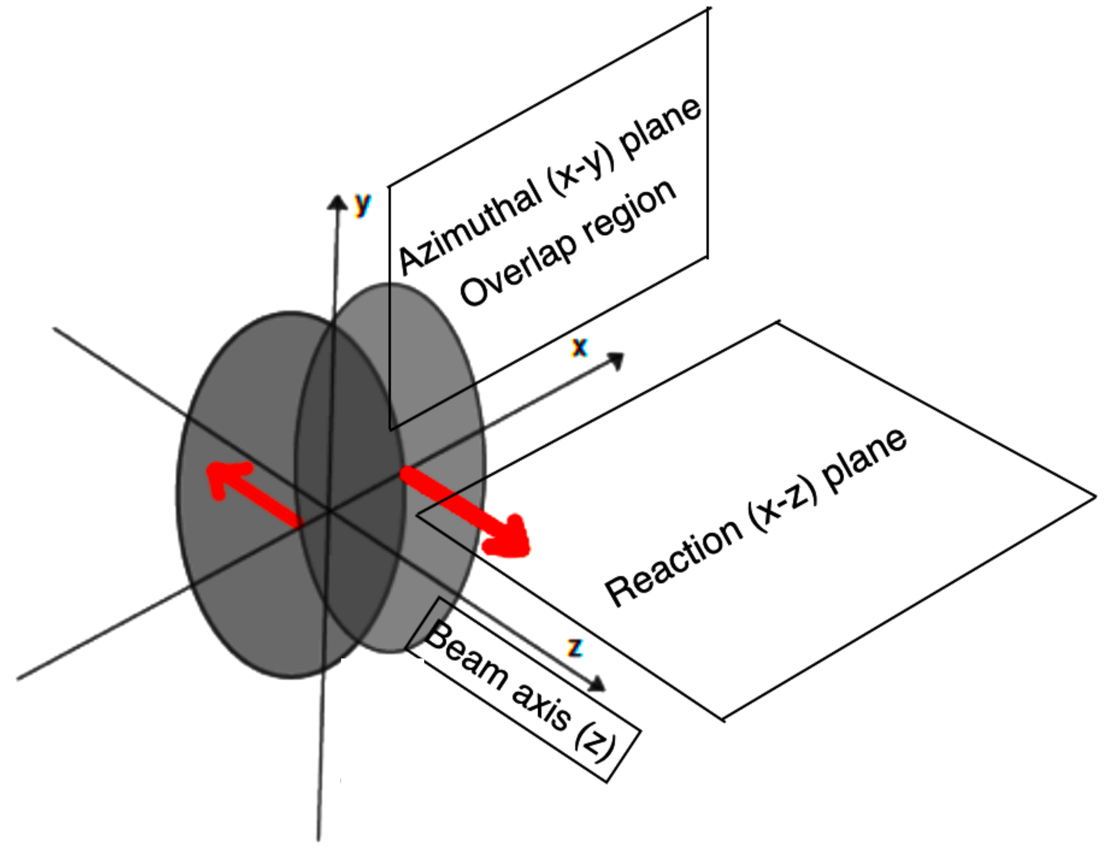


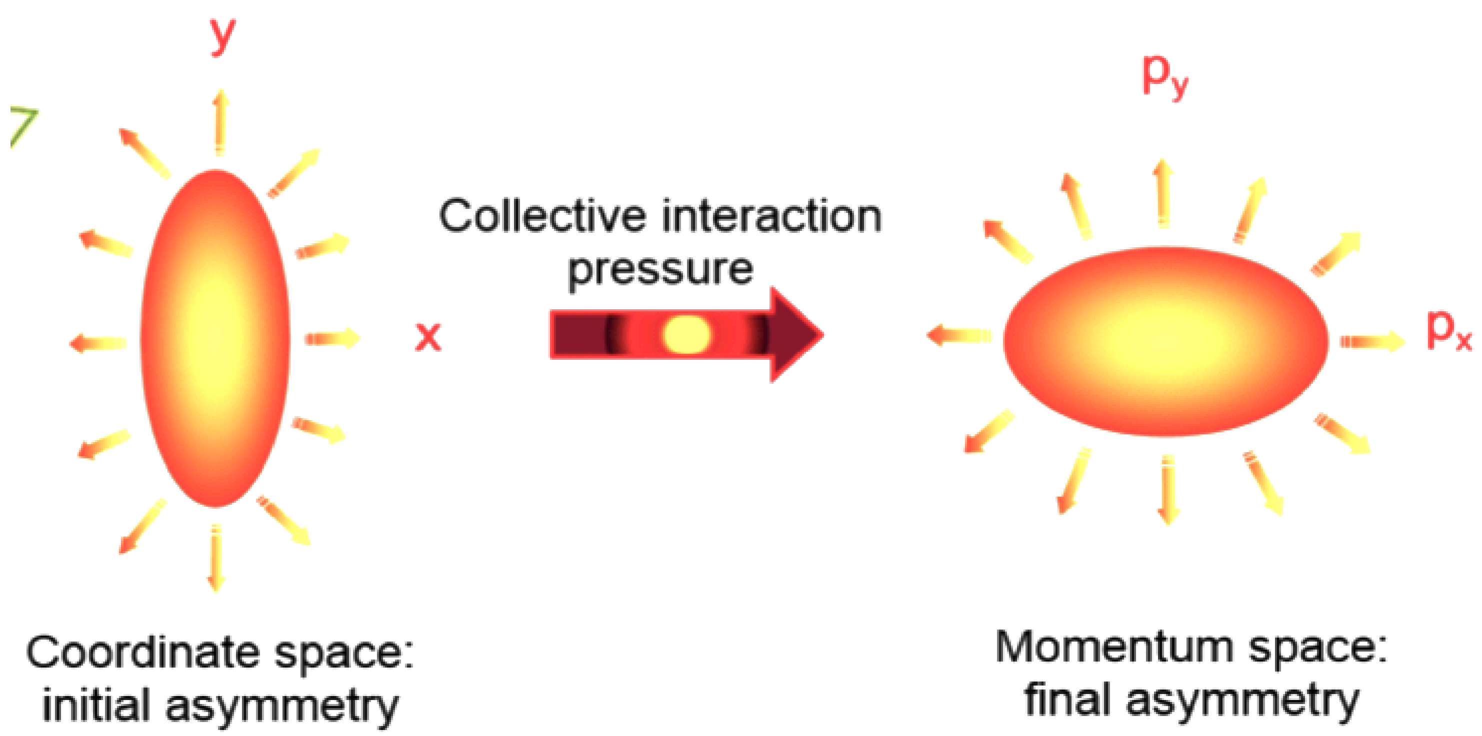
ALICE, Phys.Lett. B 719 (2013) 29-41

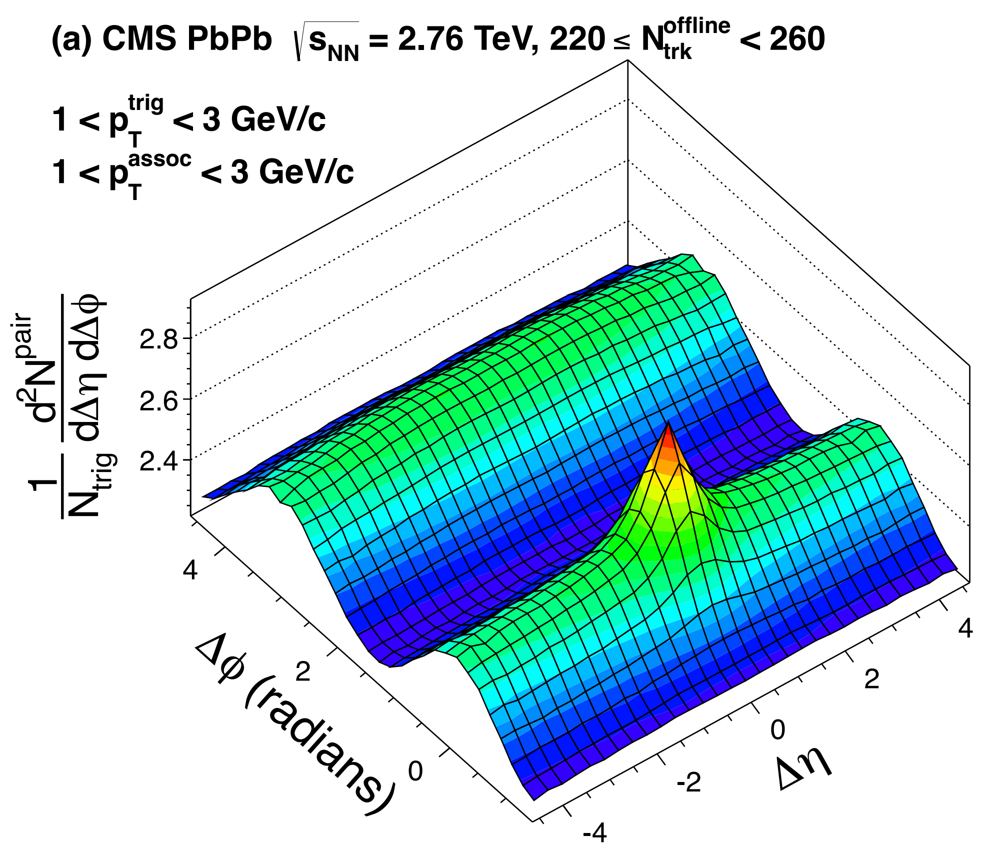


CMS, Phys.Lett. B 765 (2017) 193

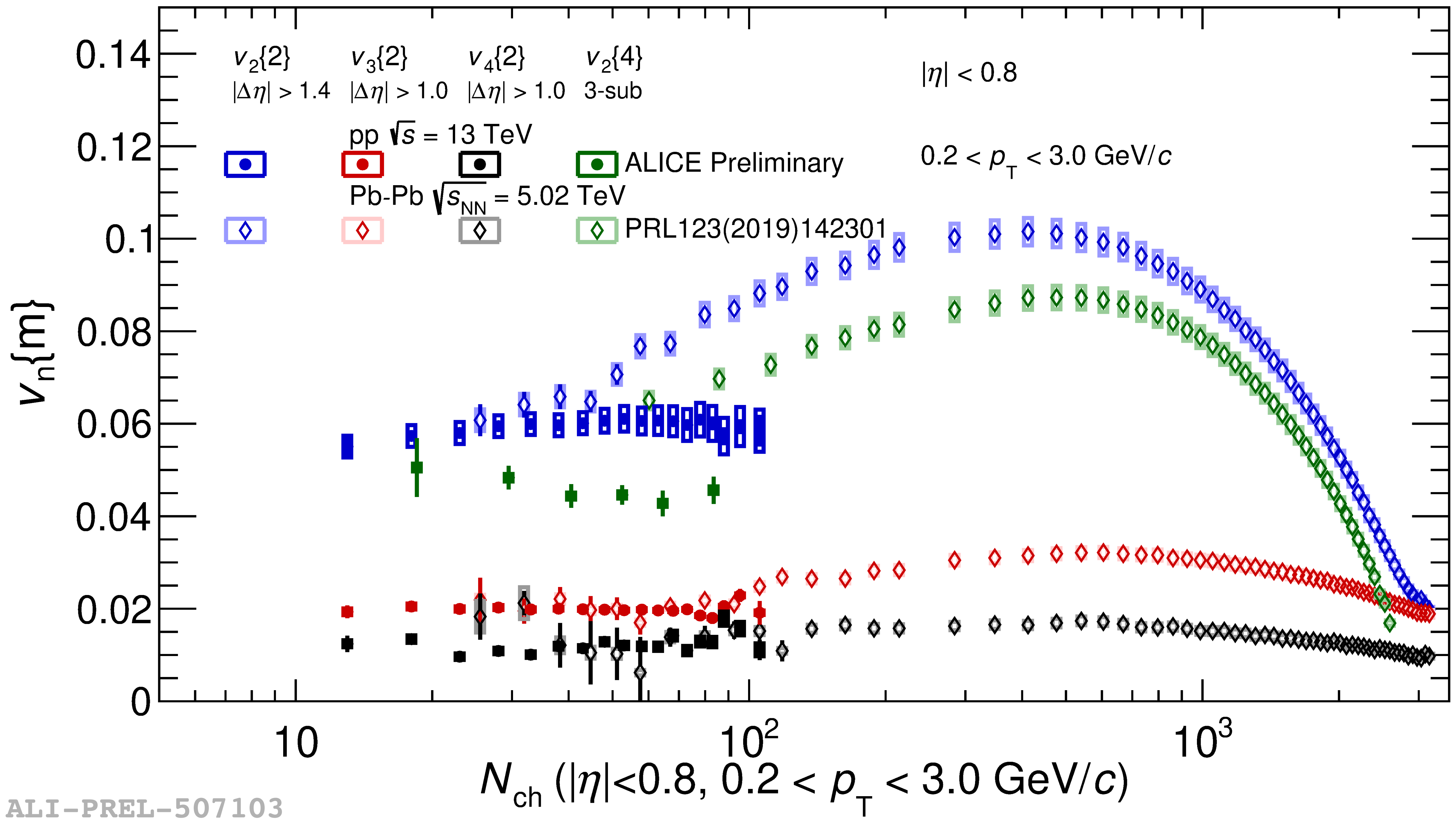
Everything flows (?) - Initial state geometry + Final state interaction (hydro description?)





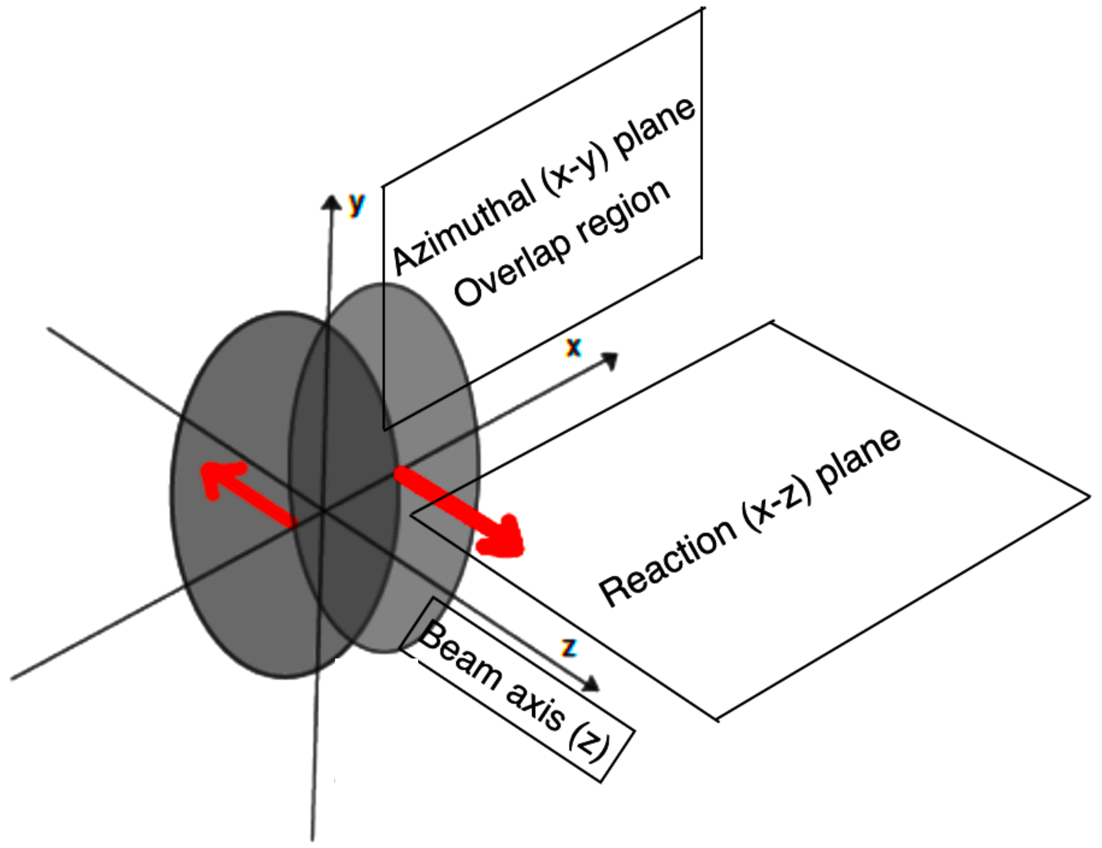


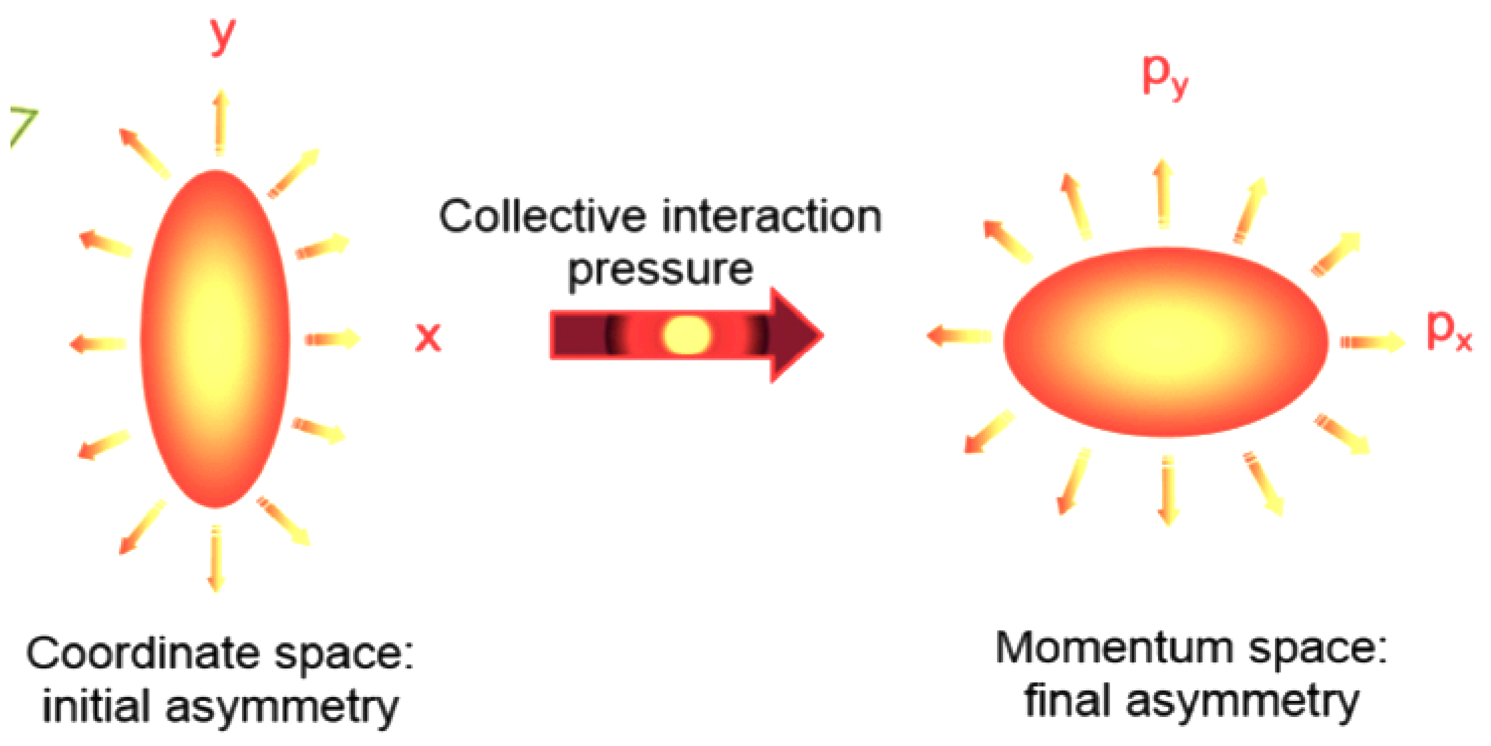
Collectivity in small systems?

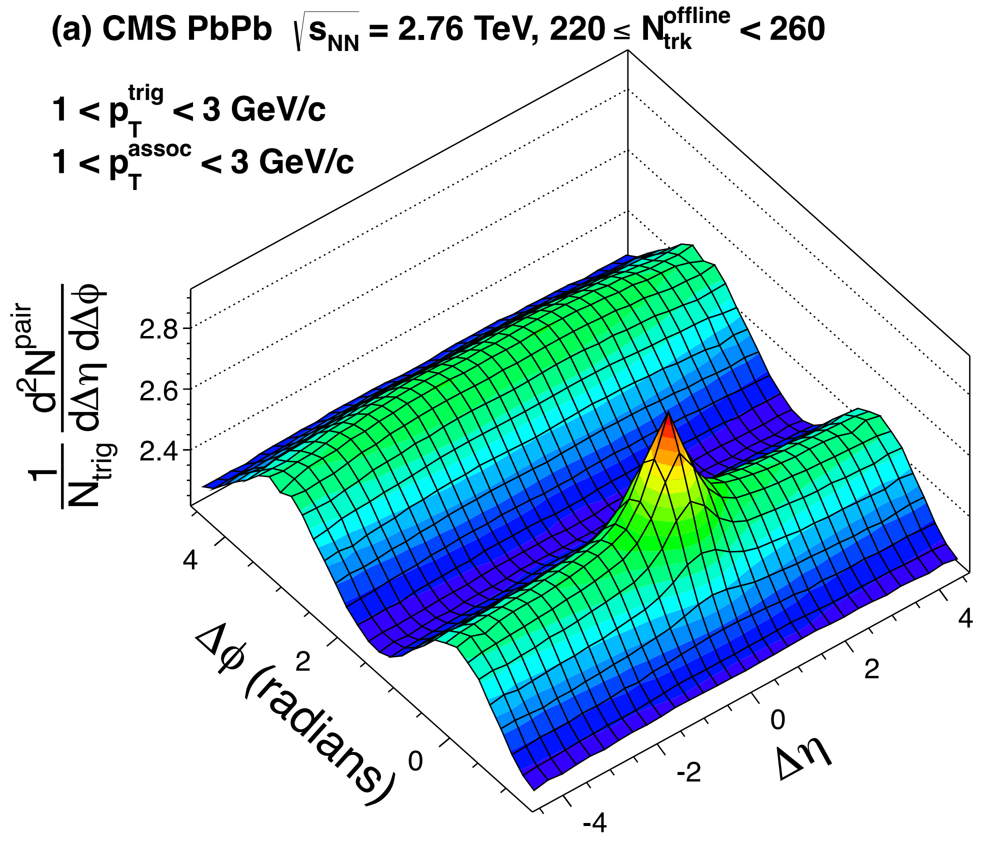


Mingrui Zhao (CIAE)

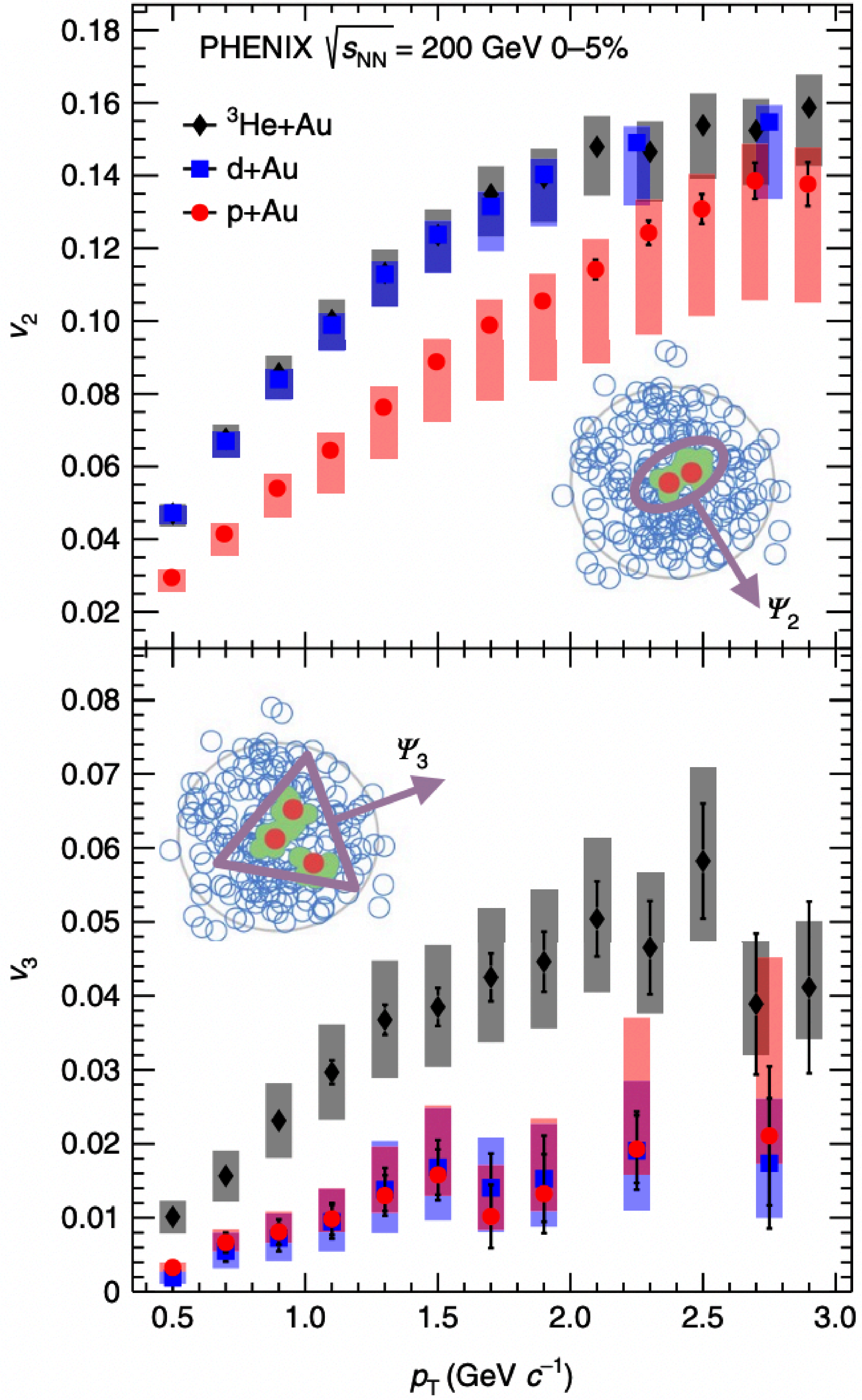
Everything flows (?) - Initial state geometry + Final state interaction (hydro description? Geometry driven?)





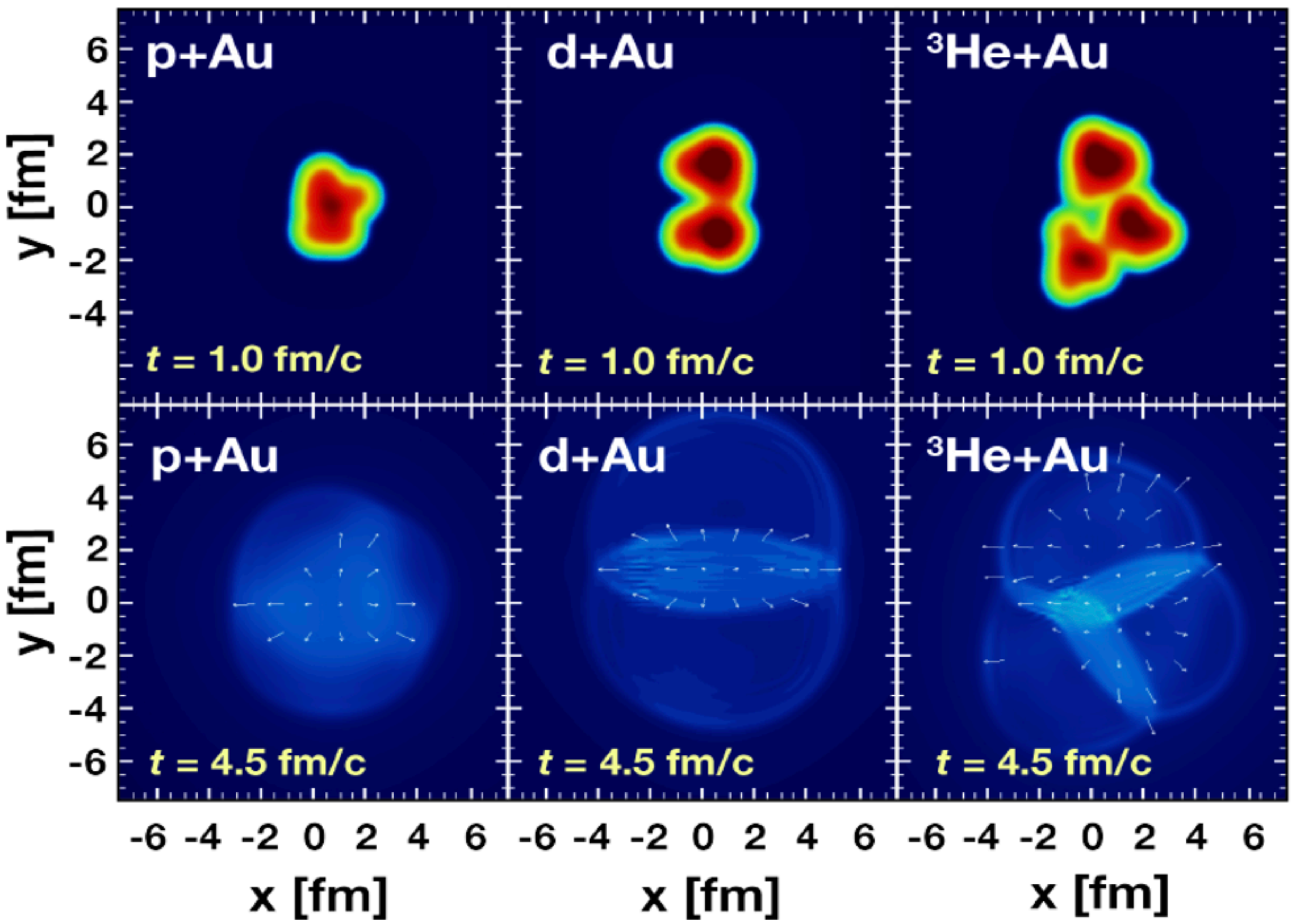


Initial geometry driven…



PHENIX, Nature Physics 15, 214-219 (2019)
Consistent with latest results: PHENIX: PRC 107 (2023) 024907

Hydro prediction ($v_n \propto \epsilon_n$)

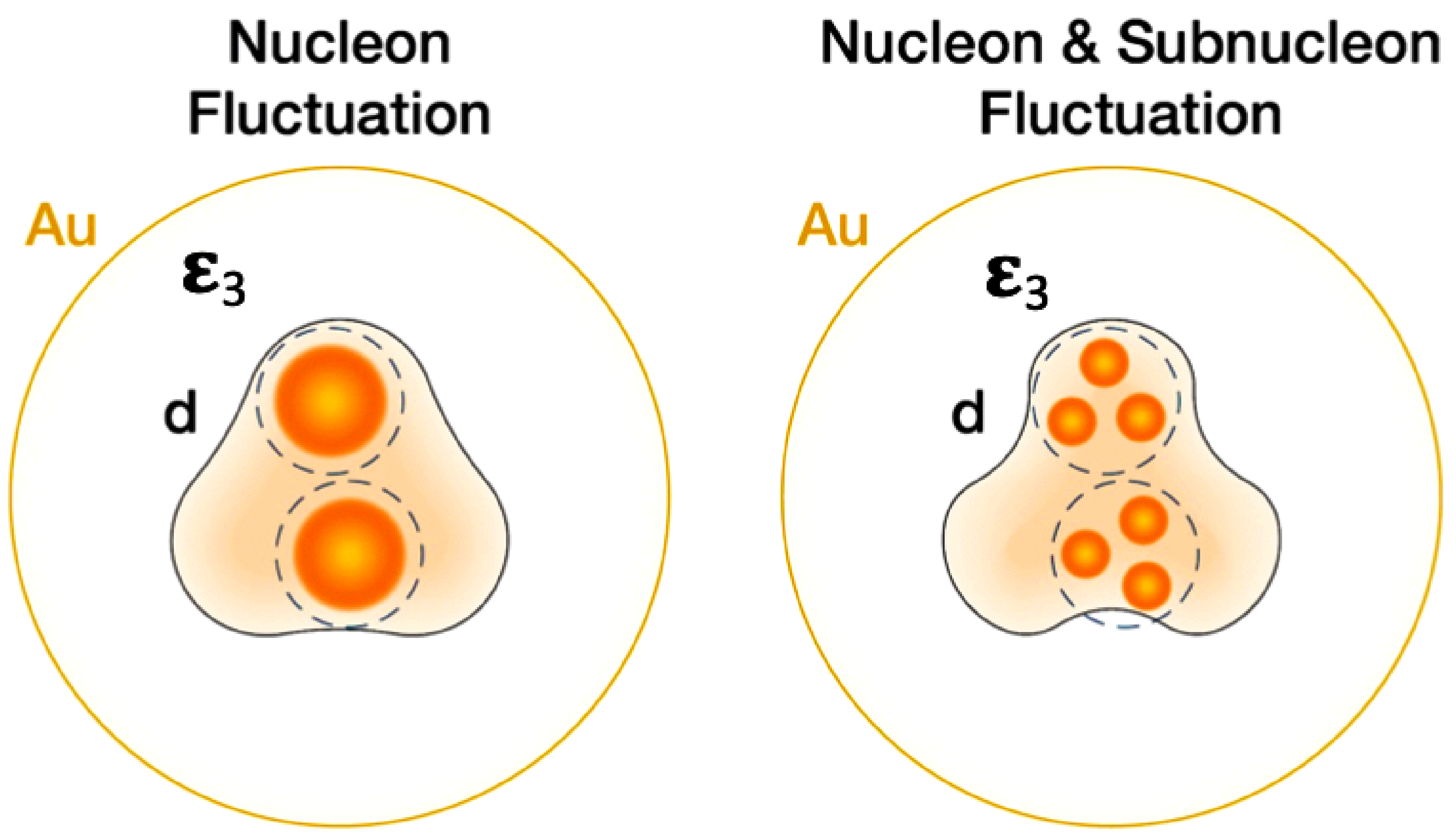


- Geometry scan results: consistent with hydro prediction:

$$v_2^{p+Au} < v_2^{d+Au} \approx v_2^{^3He+Au}$$
$$v_3^{p+Au} \approx v_3^{d+Au} < v_3^{^3He+Au}$$

Hydrodynamics applicable **(initial conditions?)**

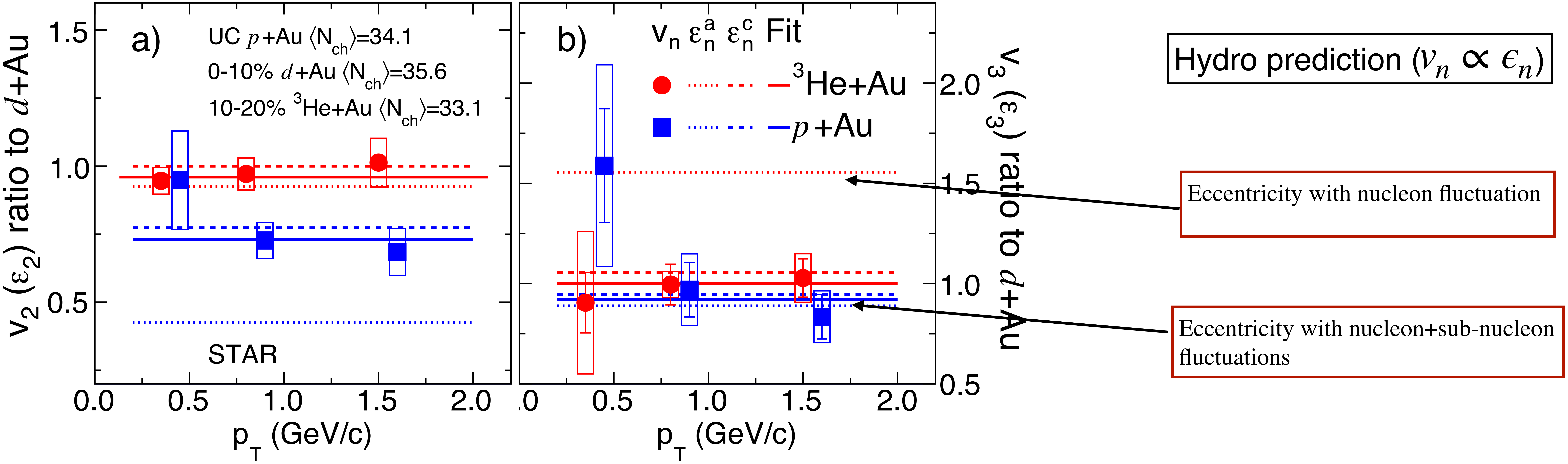
Initial State — still a mystery!



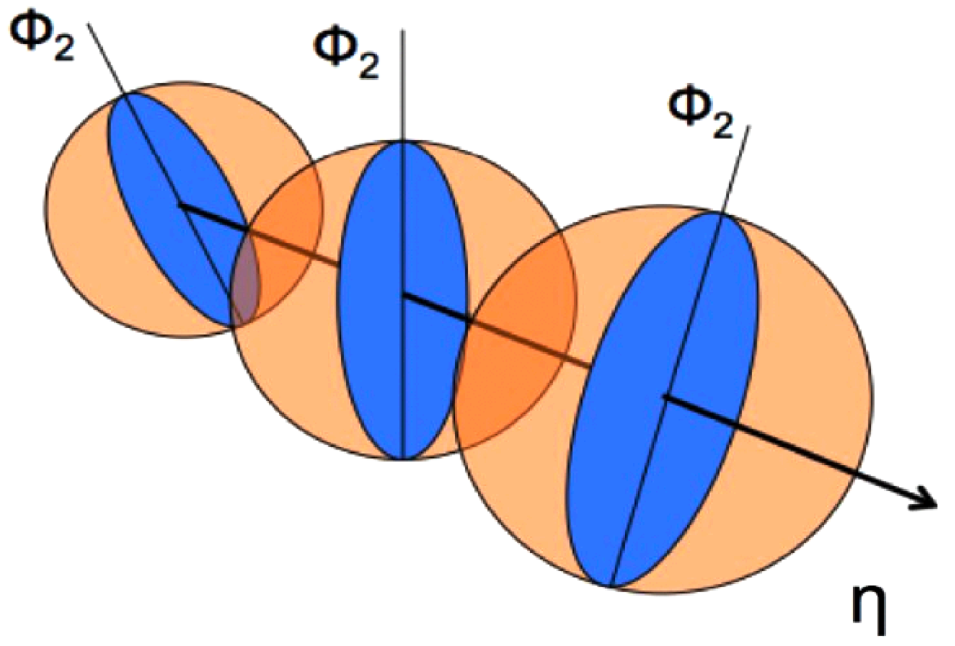
- Possible contributions: (nucleonic + sub-nucleonic) fluctuations / CGC / clustering / ? —any universal recipe?

- Boost invariant approaches are inadequate!

STAR, Phys. Rev. Lett. 130, 242301 (2023)

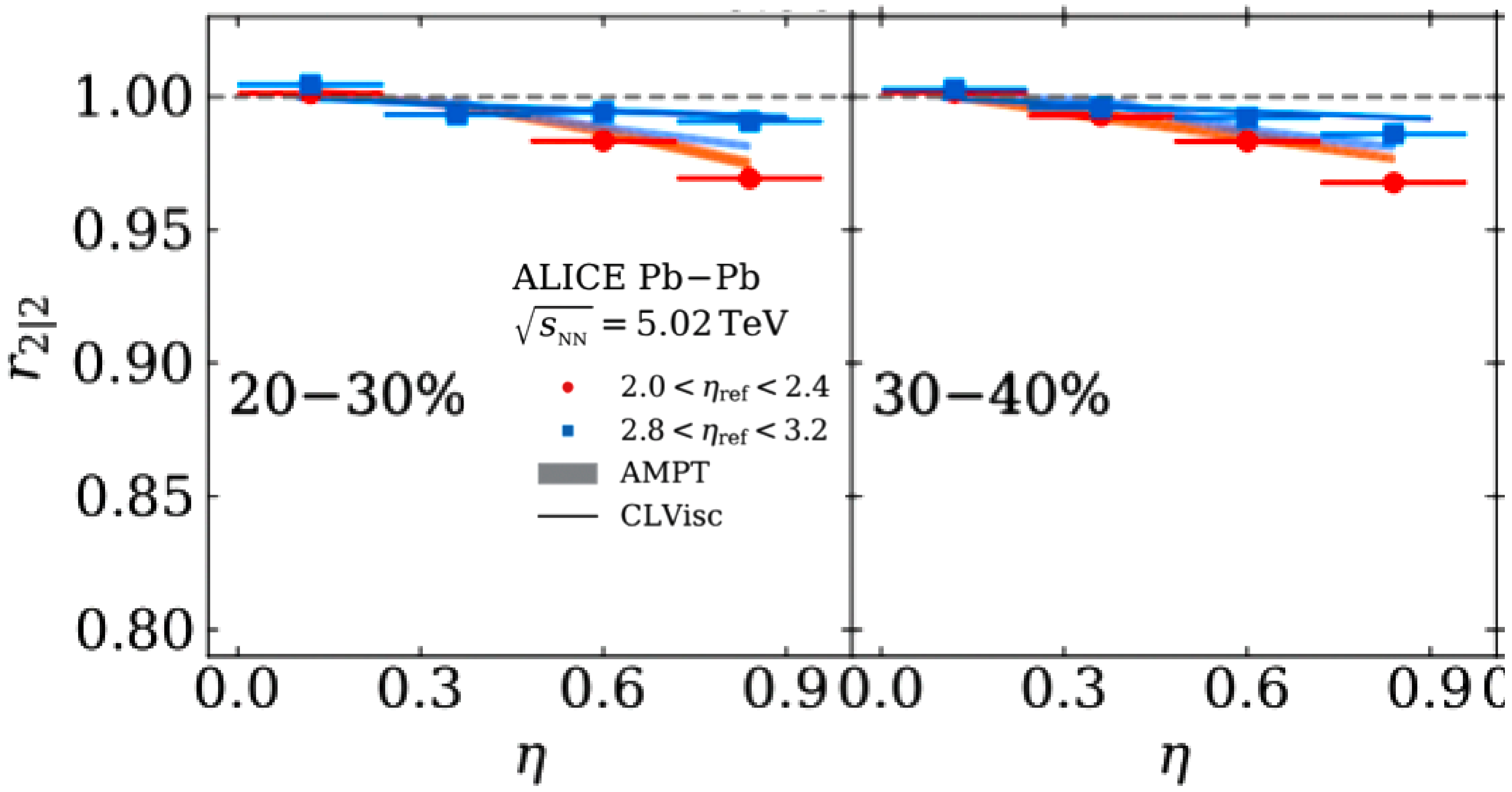


Flow vector fluctutates in both small and large systems!



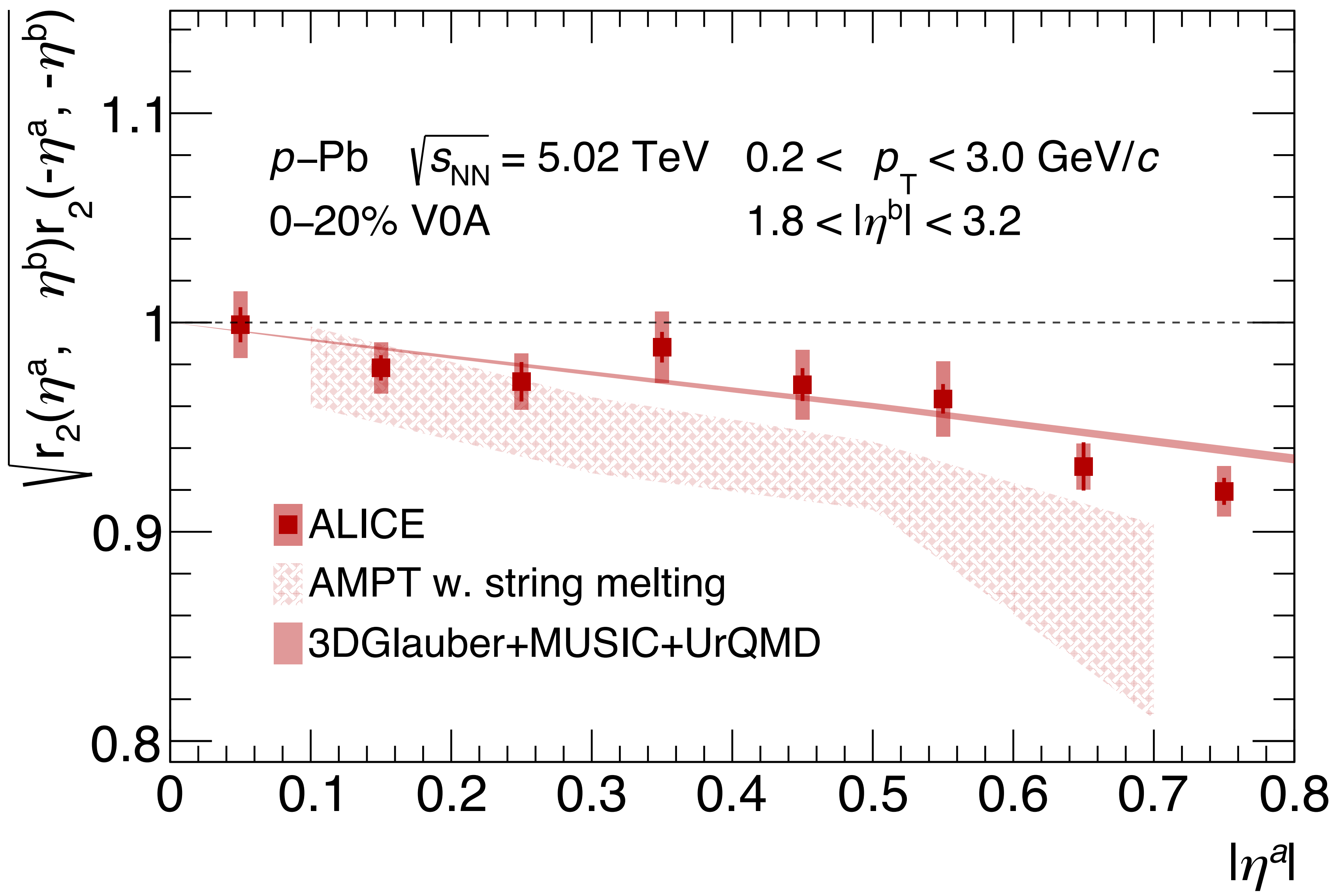
$V_n(\eta_1) \neq V_n(\eta_2)$

Pb-Pb



ALICE, Physics Letters B, Volume 850, 2024, 138477

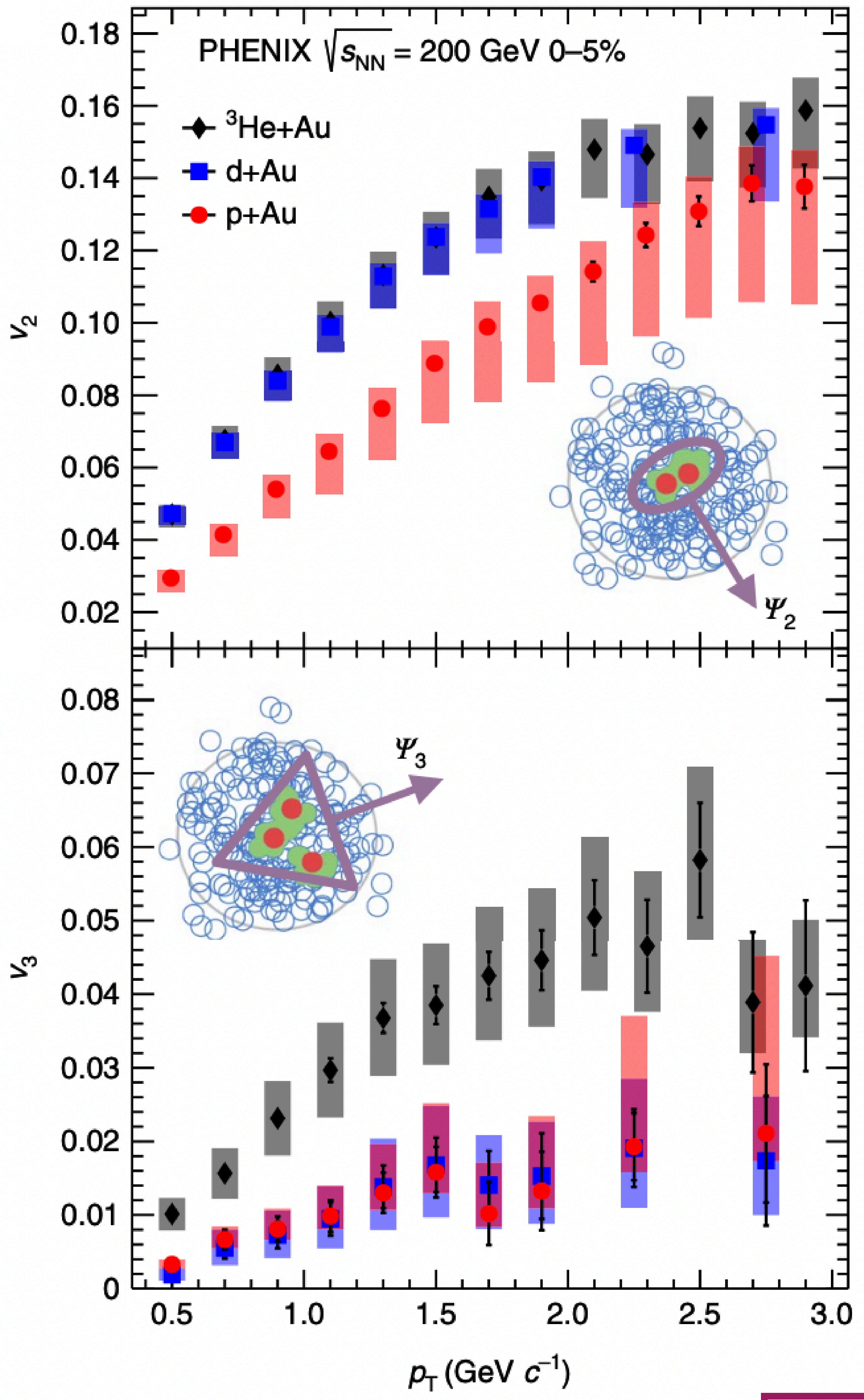
p-Pb



- Evidence of flow vector decorrelations in p_T and η in p-Pb collisions (Similar to Pb-Pb).
- Small systems results can not be explained by nonflow.

Similarities in transverse and longitudinal expansion dynamics small and large systems!

Overall, Hydrodynamics applicable…



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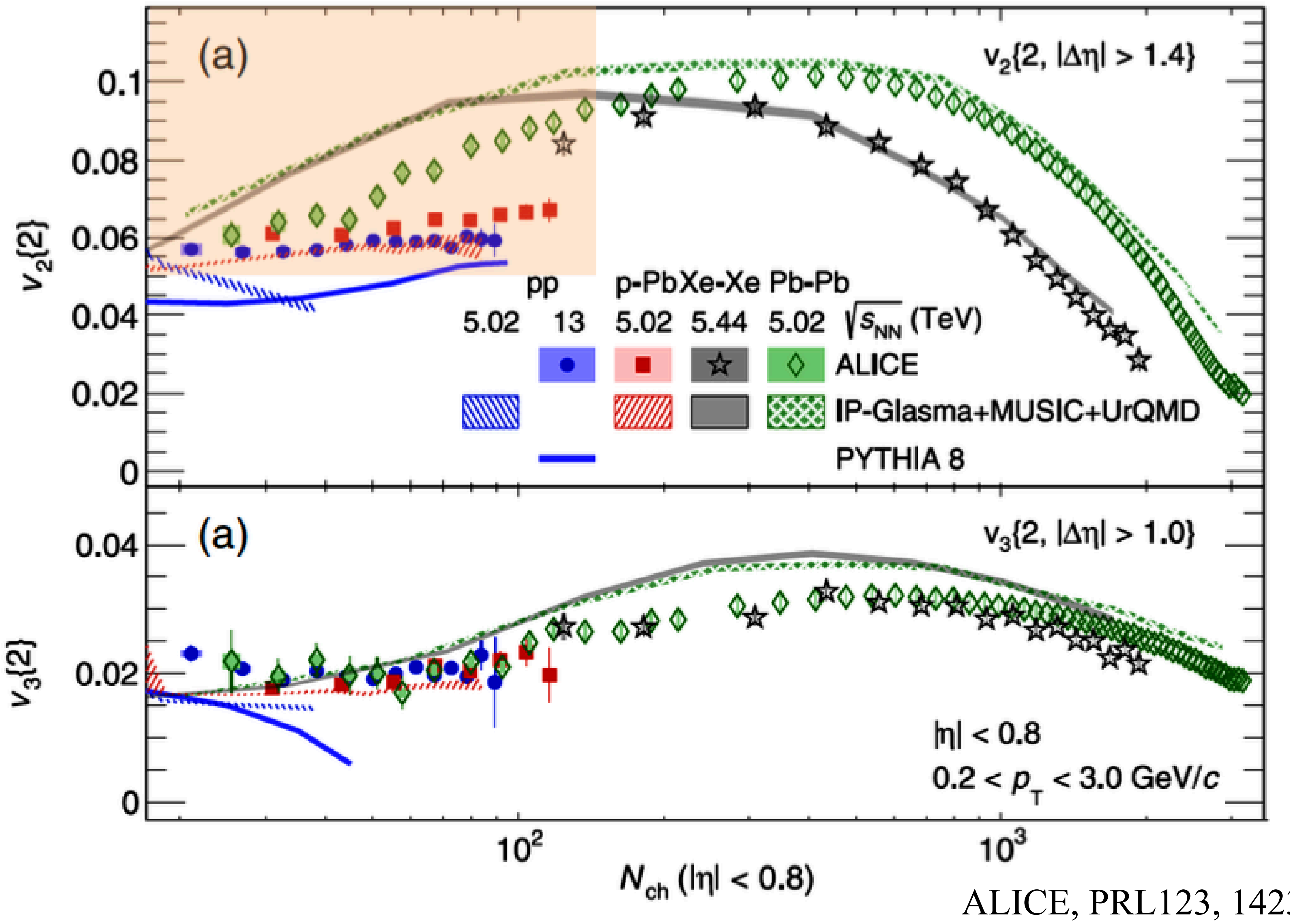


ALICE, PRL123, 142301 (2019)

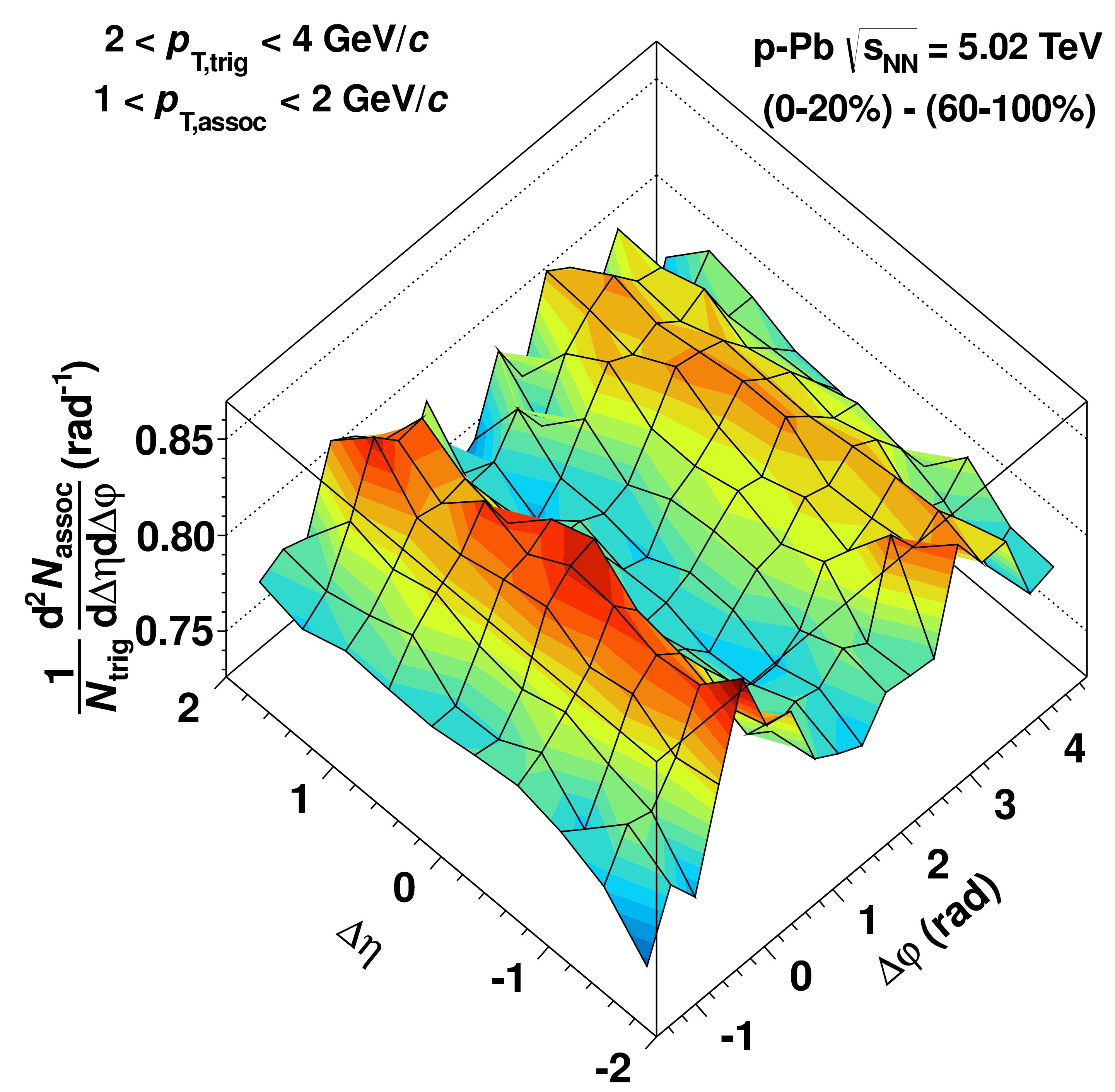
- Geometry scan results: consistent with hydro prediction:

$$v_2^{pp} < v_2^{p-Pb} < v_2^{Pb-Pb}$$

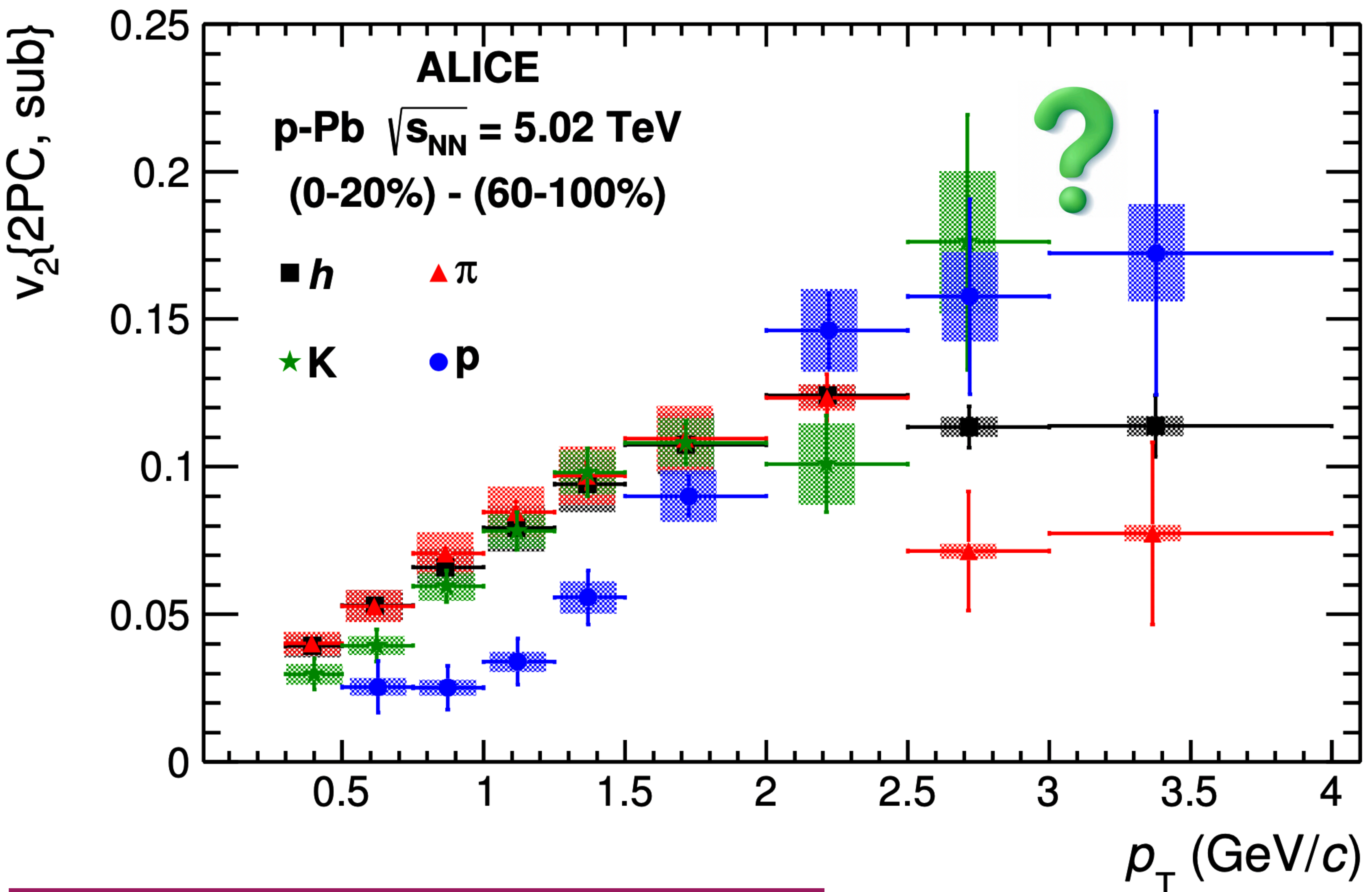
$$v_3^{pp} \approx v_3^{p-Pb} \approx v_3^{Pb-Pb}$$

Hydrodynamics applicable **(initial conditions?)**. How to confirm a partonic medium??

Similar collective behavior in small systems?



ALICE, Phys.Lett. B719 (2013) 29-41



Major issue— non-flow removal.

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

- Low p_T ($p_T \lesssim 3$ GeV/c) — Mass ordering of v_2.
- Intermediate p_T ($3 < p_T \lesssim 6$ GeV/c) — No evidence of baryon-meson grouping and splitting of v_2 — no concrete evidence of partonic collectivity (insufficient 2013 statistics to confirm baryon-meson v_2 grouping/splitting).

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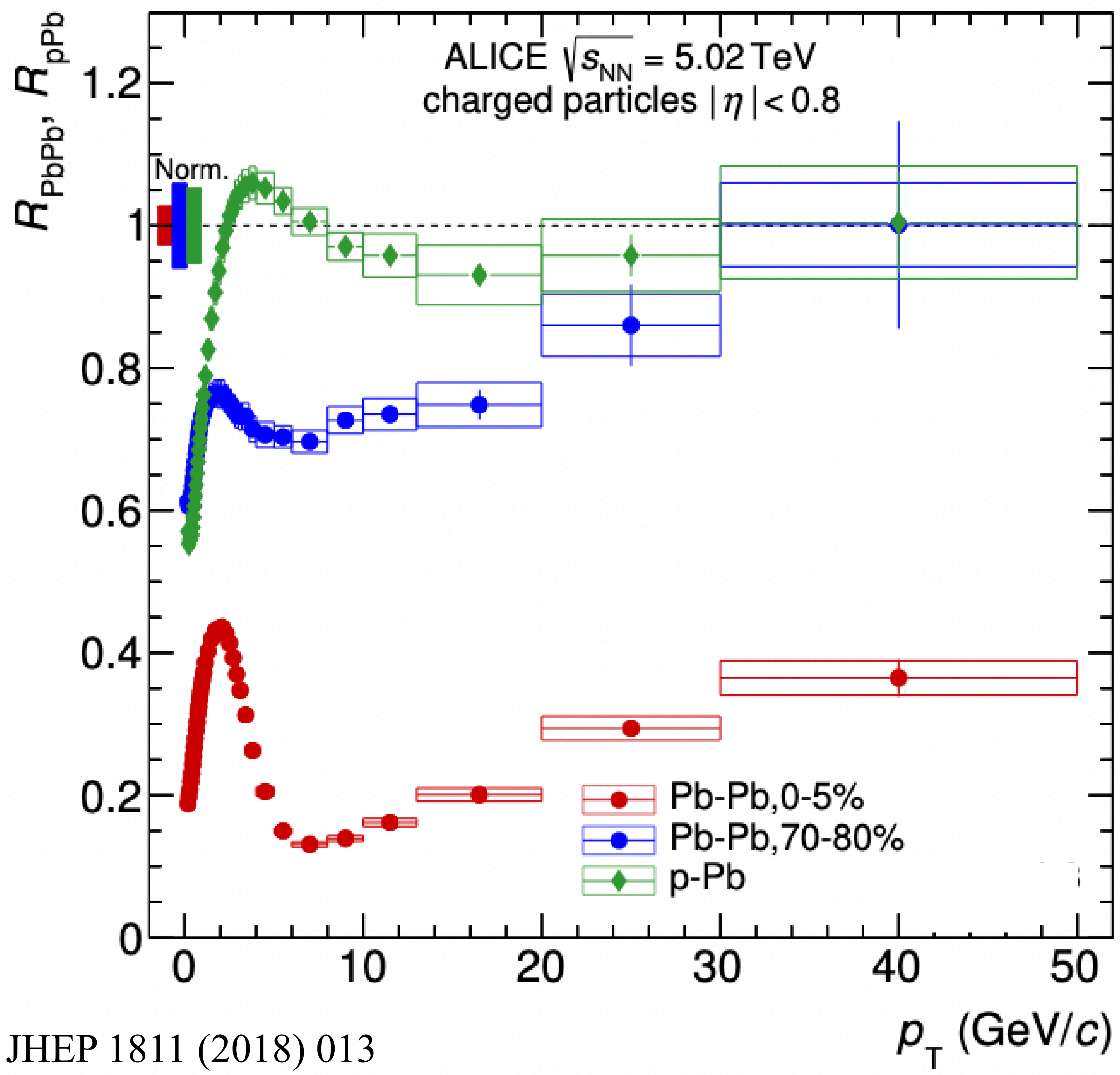
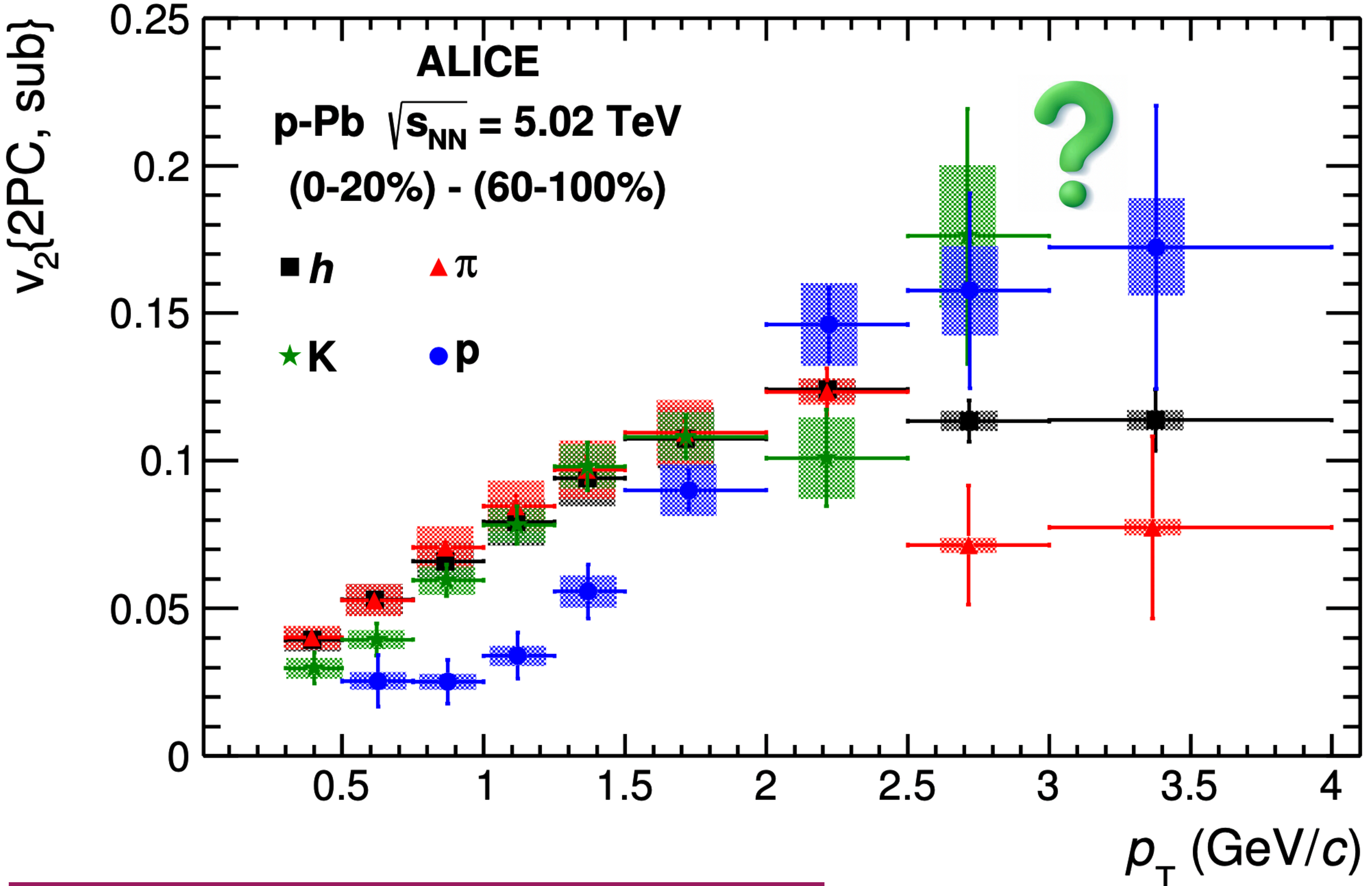


ALICE, JHEP 1811 (2018) 013



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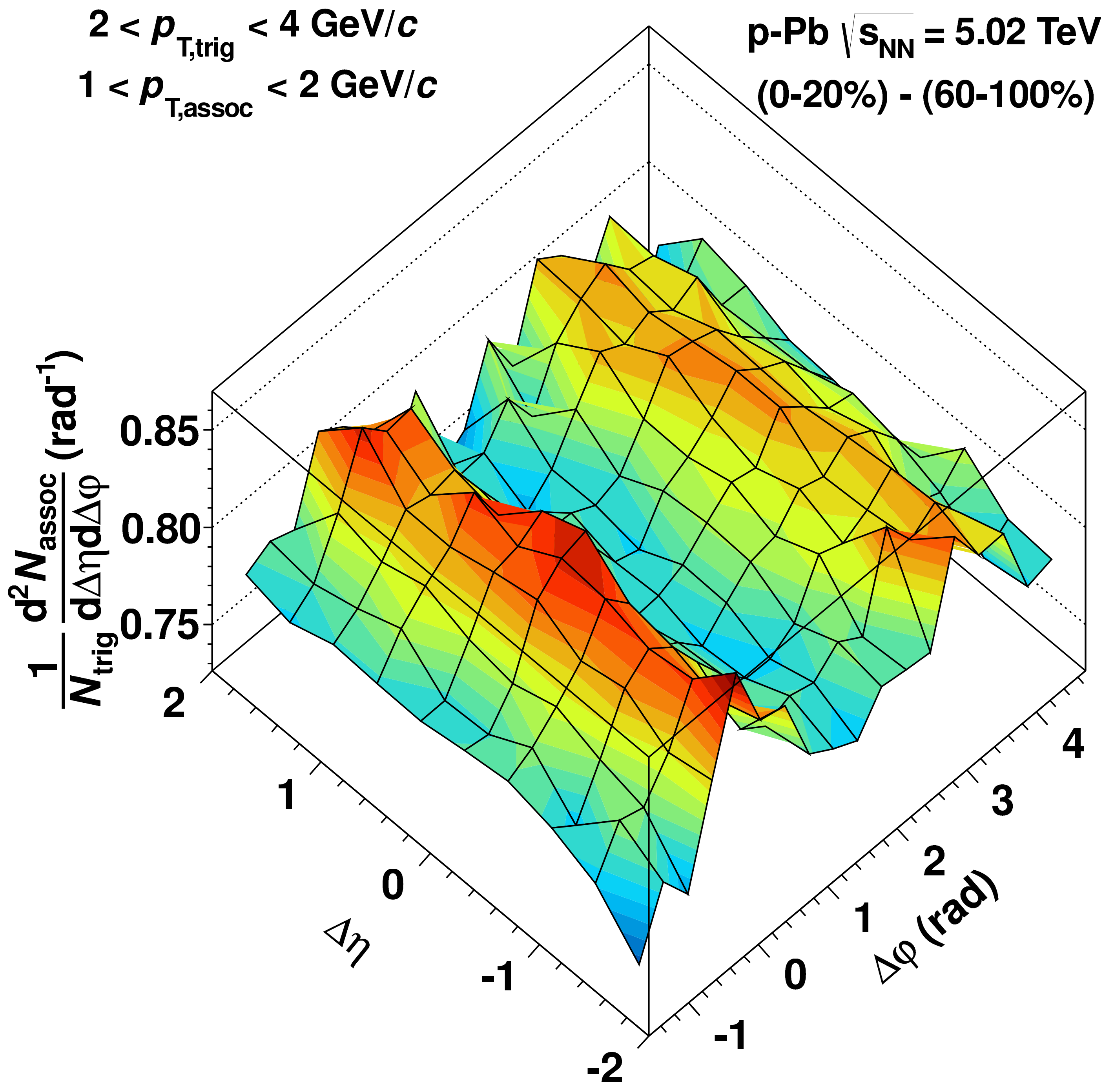

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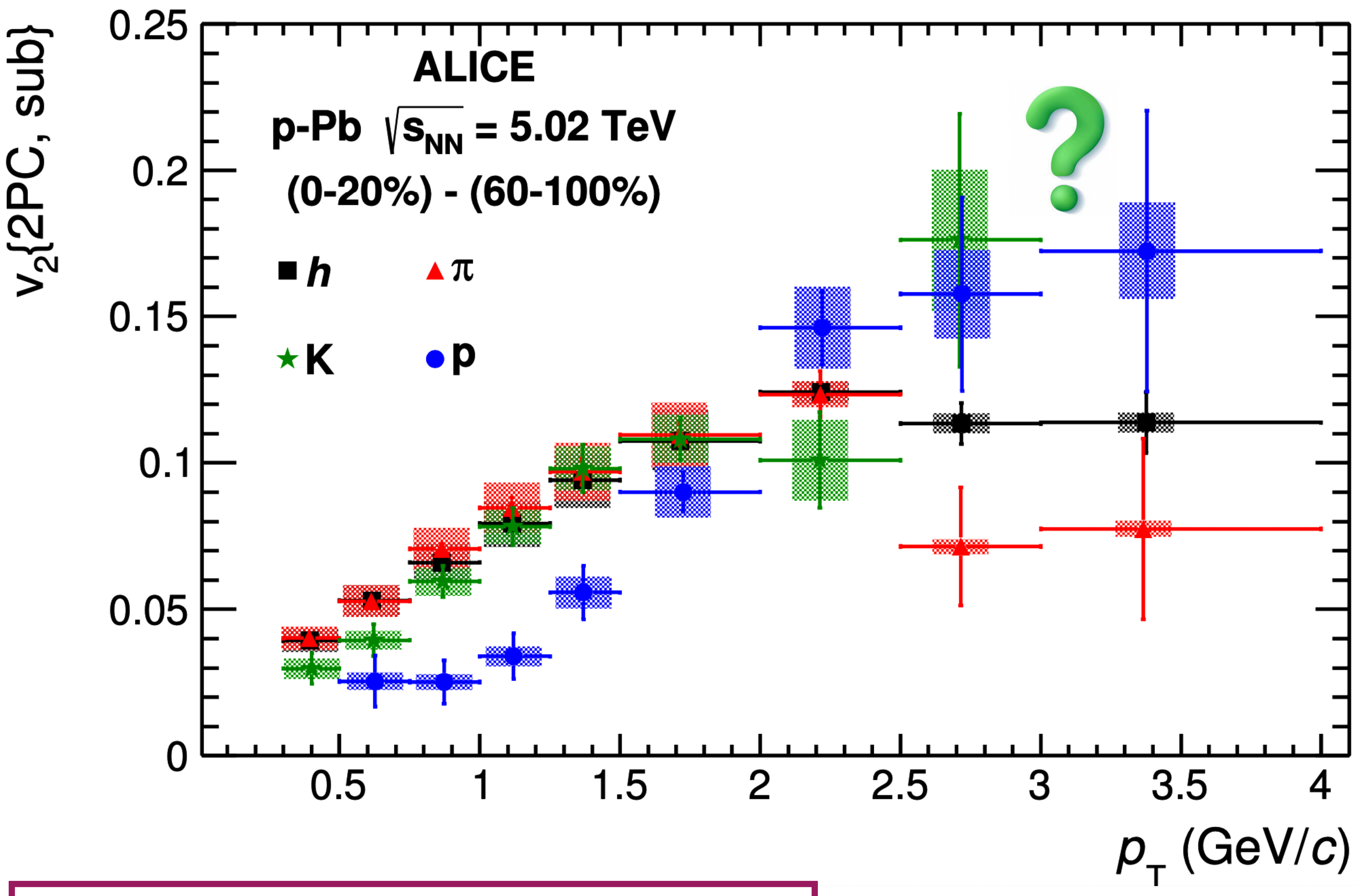

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Focus: Baryon and meson $v_2(p_T)$ at intermediate p_T

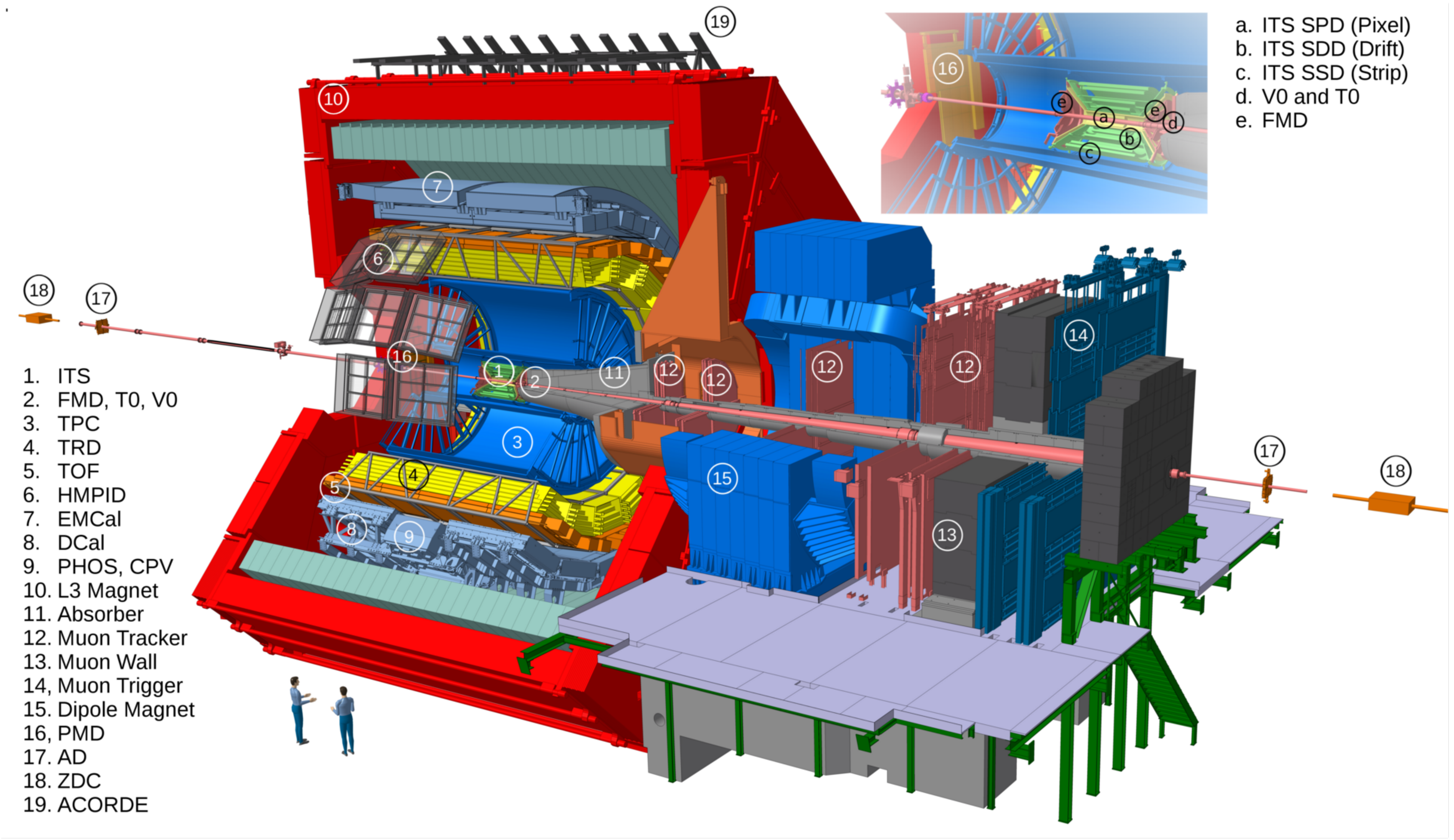
Detectors primarily used in this analysis:

1. V0 Detector
Triggering and event classification.

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

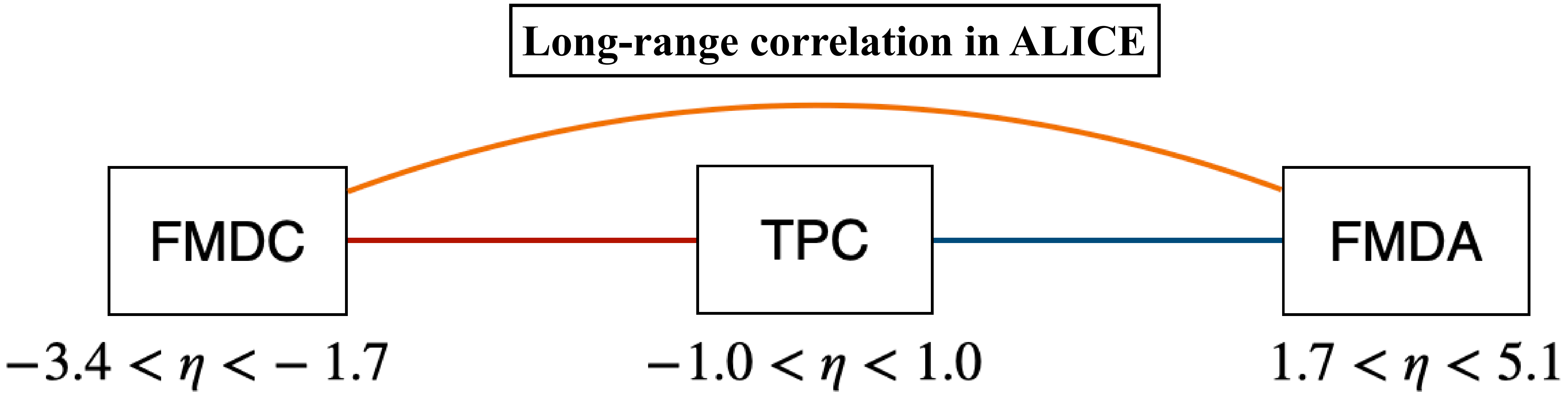
3. Time-of-Flight (TOF)
Particle identification.

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

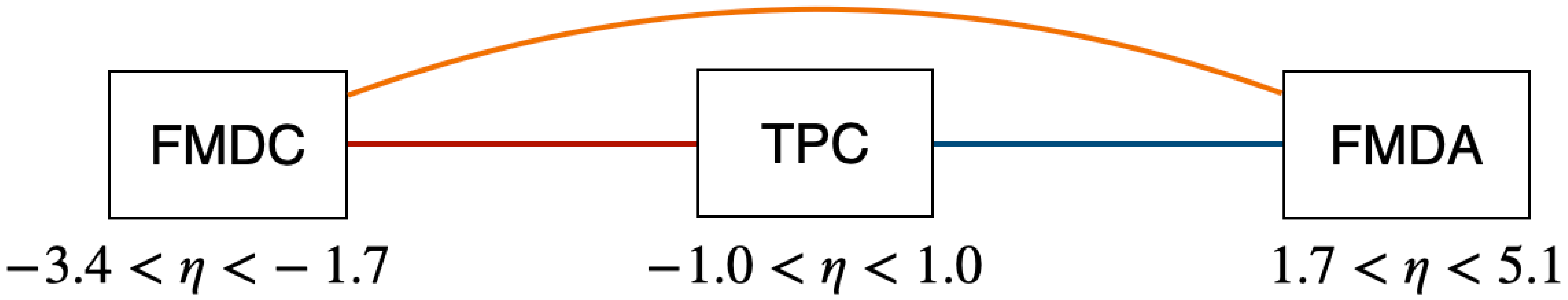


- N_{ch}: Number of tracks in TPC with ($|\eta| < 0.8$, and $p_{\mathrm{T}} > 0.2$ GeV/c). Used as event classifier.

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



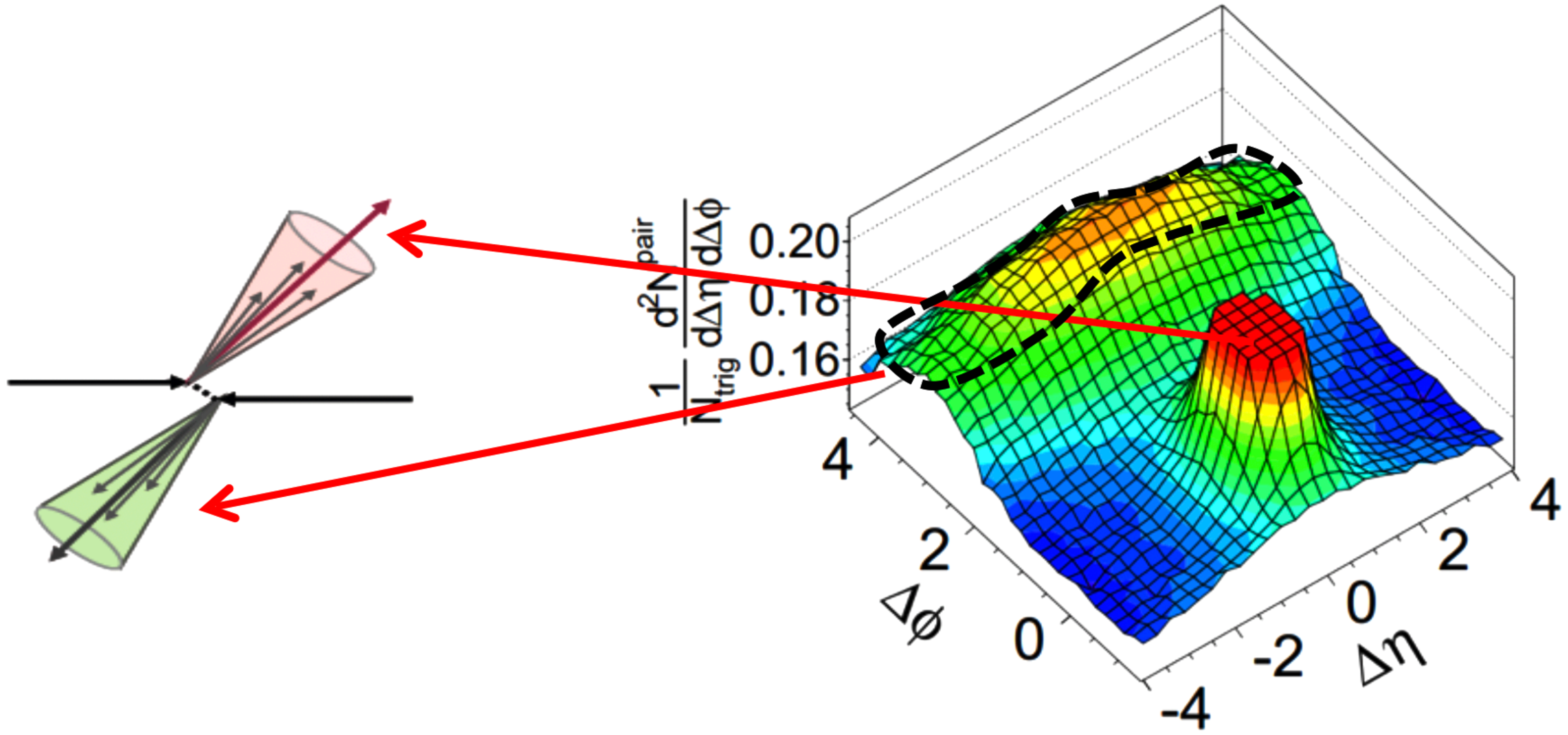
$V_{2\Delta}$ and v_2 measurement from long-range correlation in ALICE



- Long-range correlations: TPC—FMDA, TPC—FMDC and FMDA—FMDC correlations.

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

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



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

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

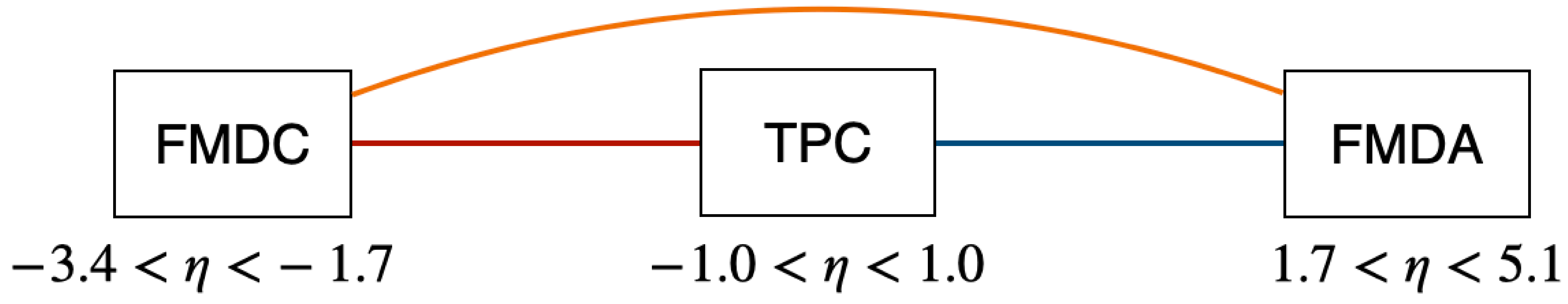
$$Y(\Delta\varphi) = FY(\Delta\varphi)^{\mathrm{peri}} + G\left[1 + \sum_{n=2}^{\infty} 2V_{n\Delta}\cos(n\Delta\varphi)\right]$$

Probed — Baseline — Flow expansion

ALICE, arXiv:2411.09323

Major issue— non-flow removal.

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



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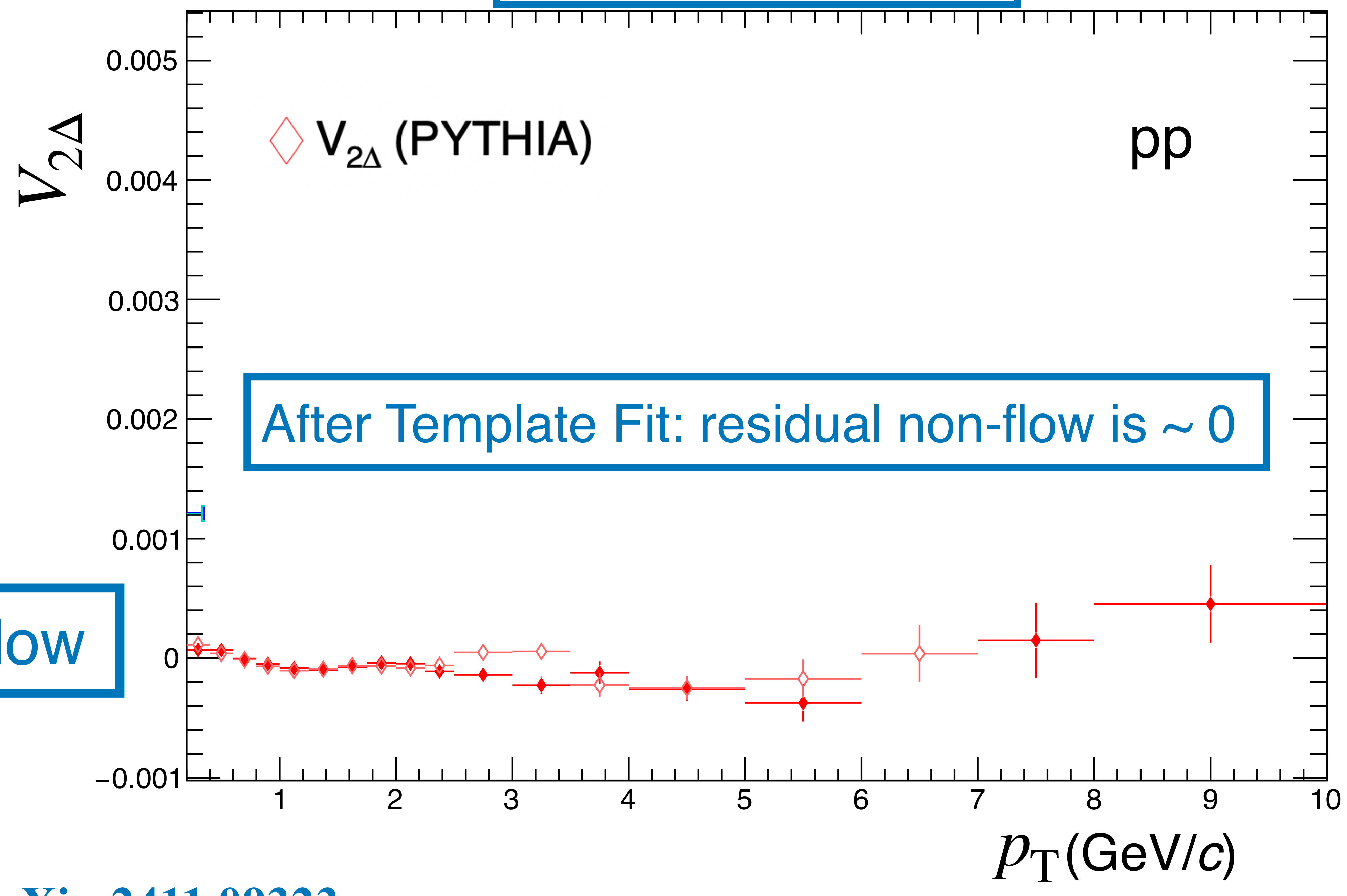
Probed ↙ Baseline ↙ Flow expansion ↘

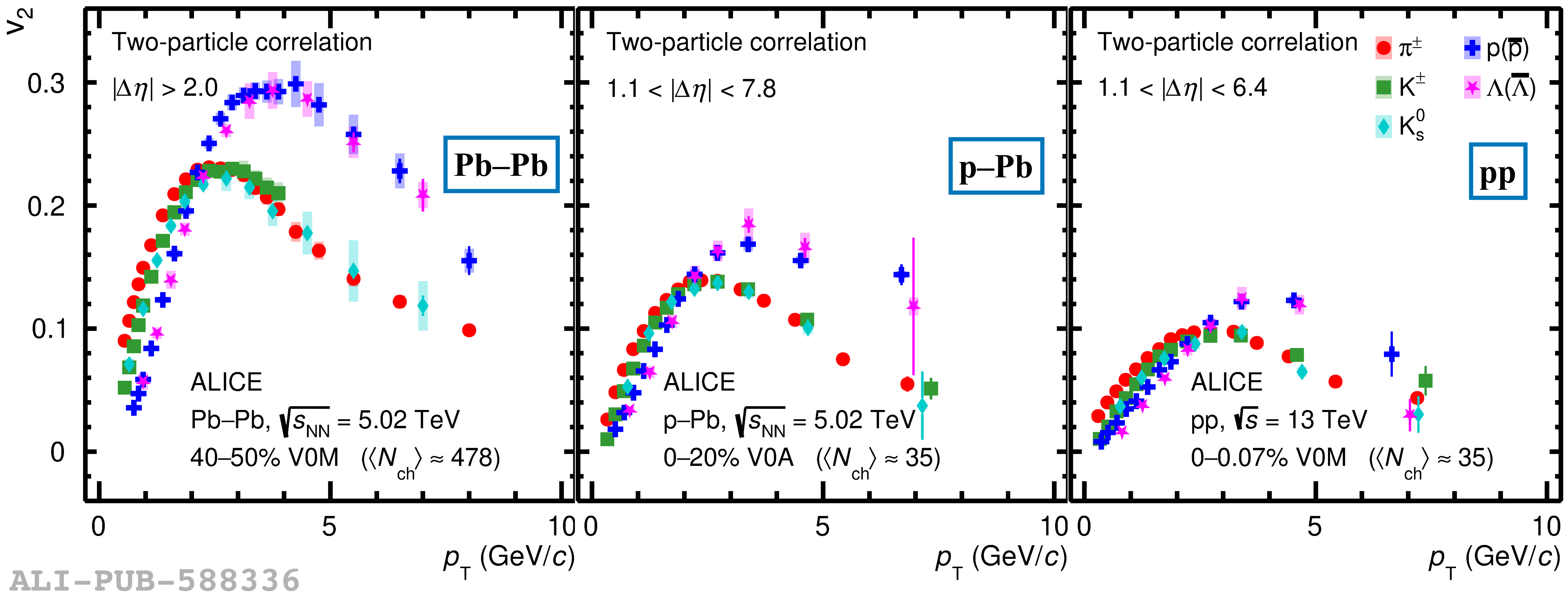
Non-flow removal



ALICE, arXiv:2411.09323

Everything flows, everywhere…

ALICE, arXiv:2411.09323



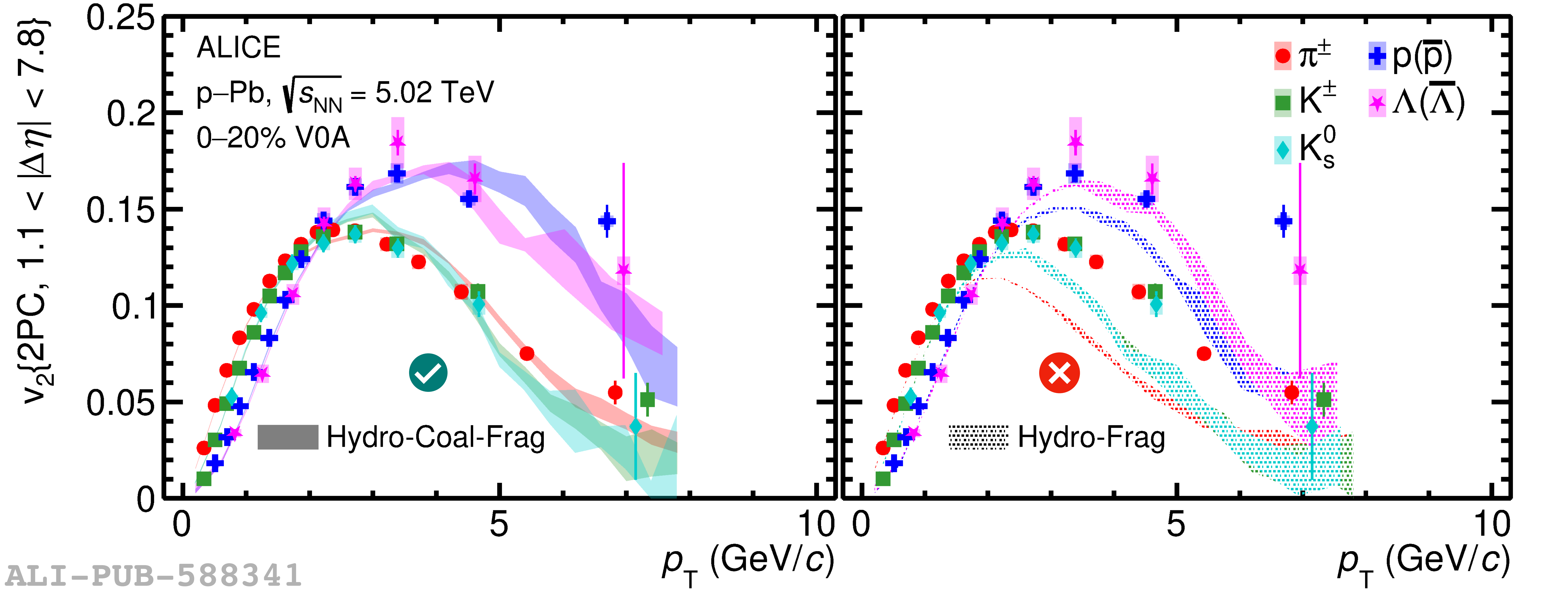
High multiplicity events in small systems: Qualitatively similar to the heavy-ion results!

- Low p_T ($p_T \lesssim 3$ GeV$/c$) — Mass ordering of v_2.
- Intermediate p_T ($3 \lesssim p_T \lesssim 6$ GeV$/c$) — Baryon-meson grouping (~1σ confidence) + splitting (> 5σ confidence) of v_2 — quark coalescence, evidence of partonic collectivity (✓).

Partonic collectivity in small collision systems!

High multiplicity p–Pb

ALICE, arXiv:2411.09323



Hydro: Hydrodynamics

Coal: Coalescence model of hadronization

Frag: Jet fragmentation

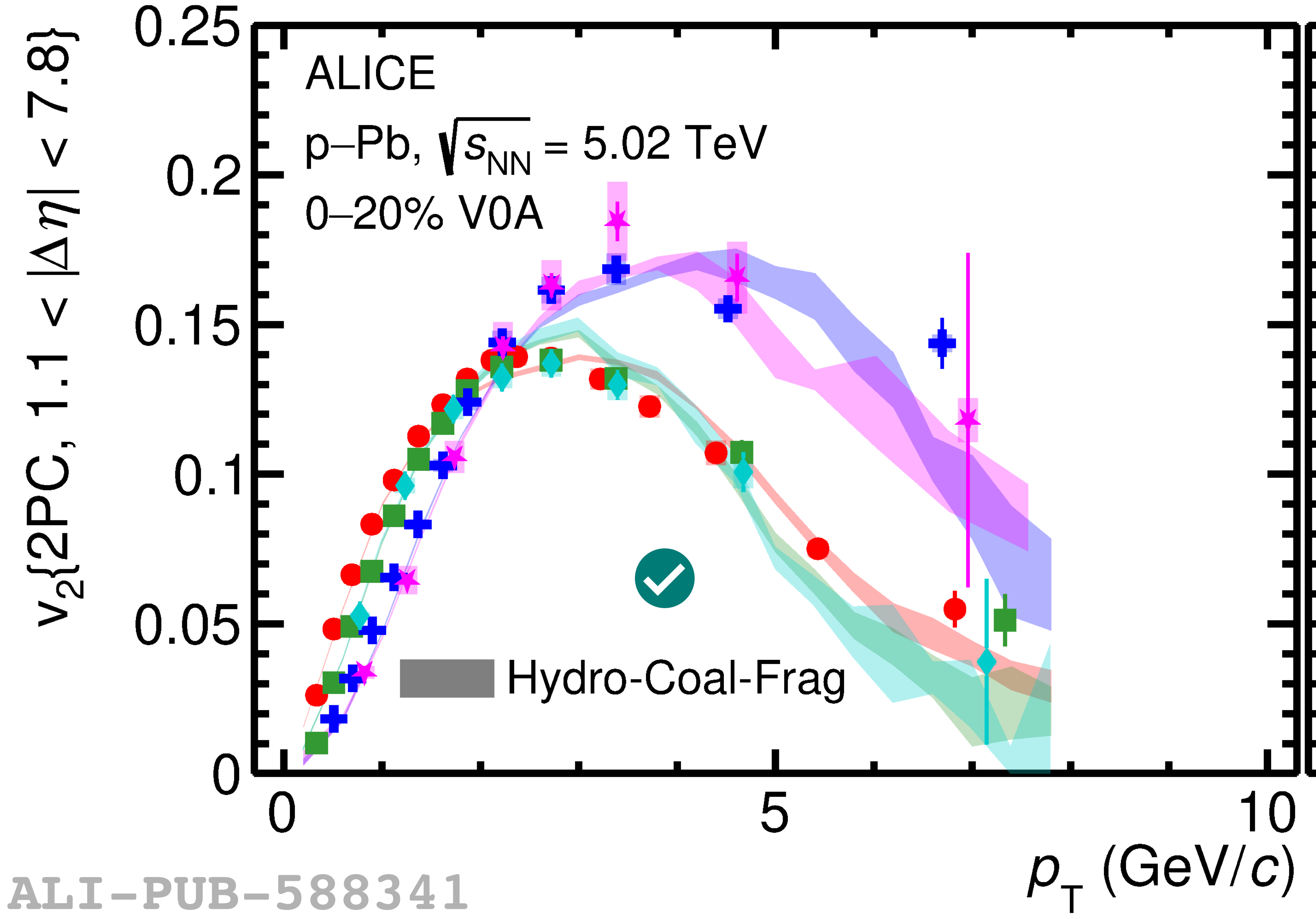
W. Zhao et al., Phys. Rev. Lett. 125, 072301 (2020)

- Baryon-meson grouping (~1σ) + splitting (> 5σ) 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). ✗

Partonic collectivity in small collision systems!

High multiplicity p–Pb

ALICE, arXiv:2411.09323



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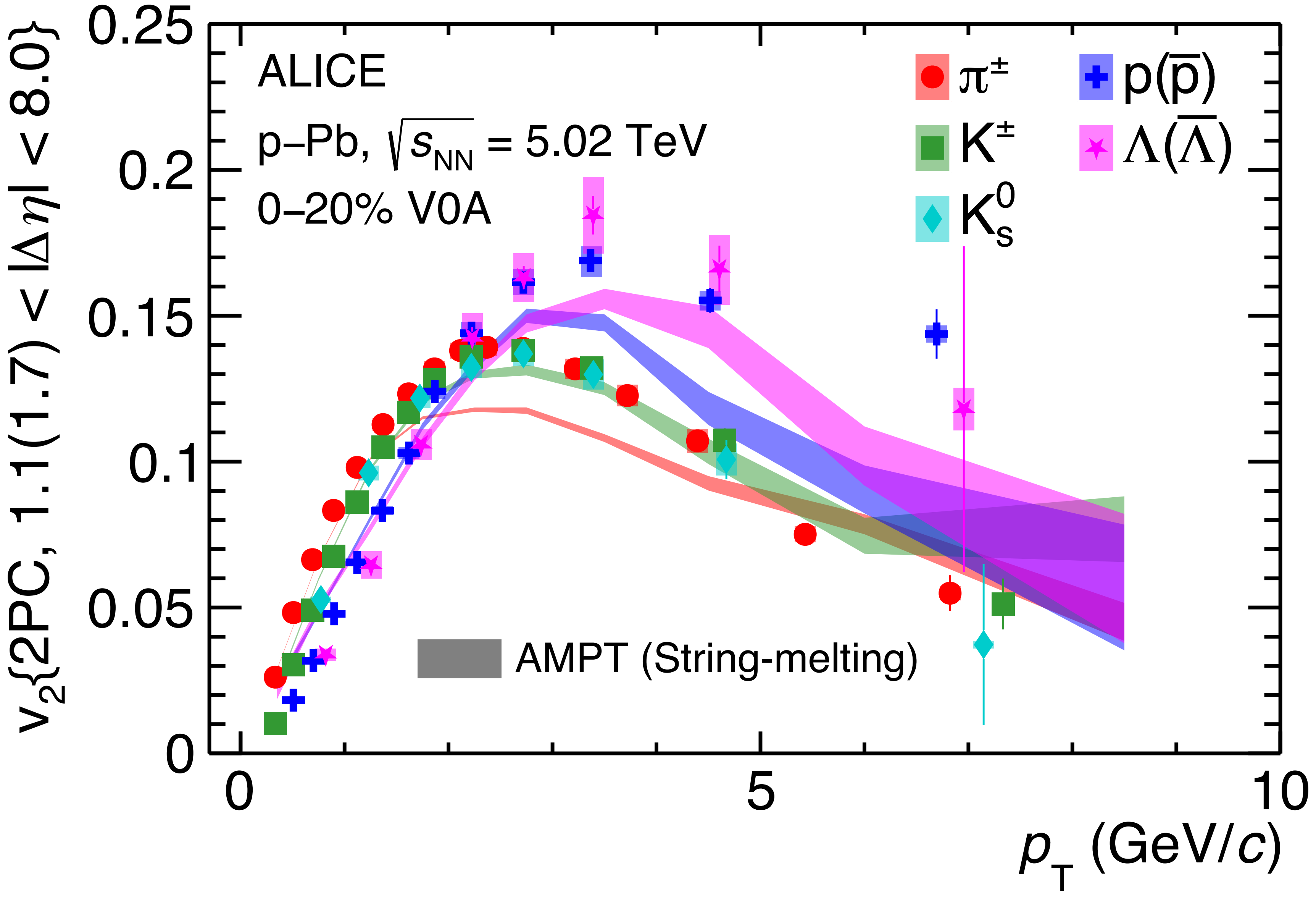


AMPT: S. Tang et al; NUCL SCI TECH 35, 32 (2024)

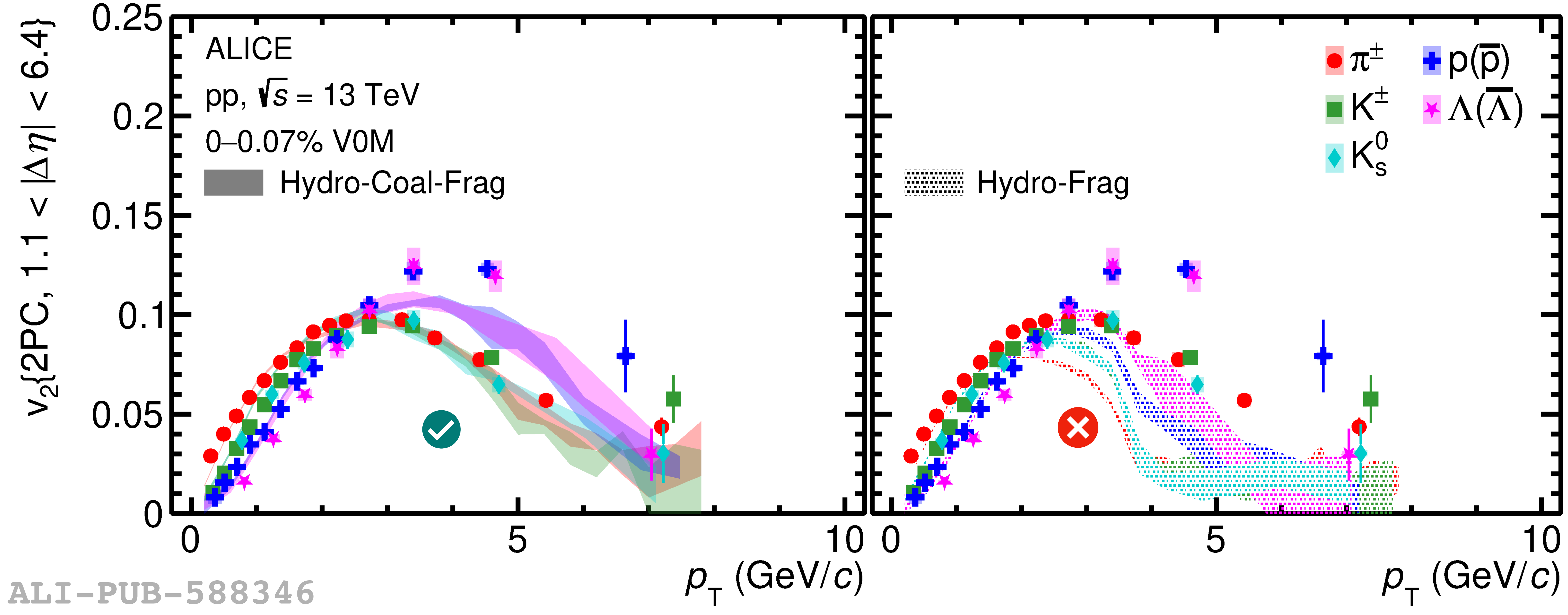
- Baryon-meson grouping (~1σ) + splitting ($> 5\sigma$) of v_2 at intermediate p_T. ✔
- Hydro+Coal+Frag explains the baryon-meson v_2 grouping and splitting. ✔
- Hydro+Frag fails to describe the pattern (despite parameters adjustments). ✖
- Transport model with coalescence model of hadronization (AMPT) fails to describe the data. ✖

Coalescence of flowing partons necessary to describe the pattern

Partonic collectivity in small collision systems!

High multiplicity pp

ALICE, arXiv:2411.09323



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

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- Hydro+Coal+Frag explains the baryon-meson v_2 grouping and splitting. ✓
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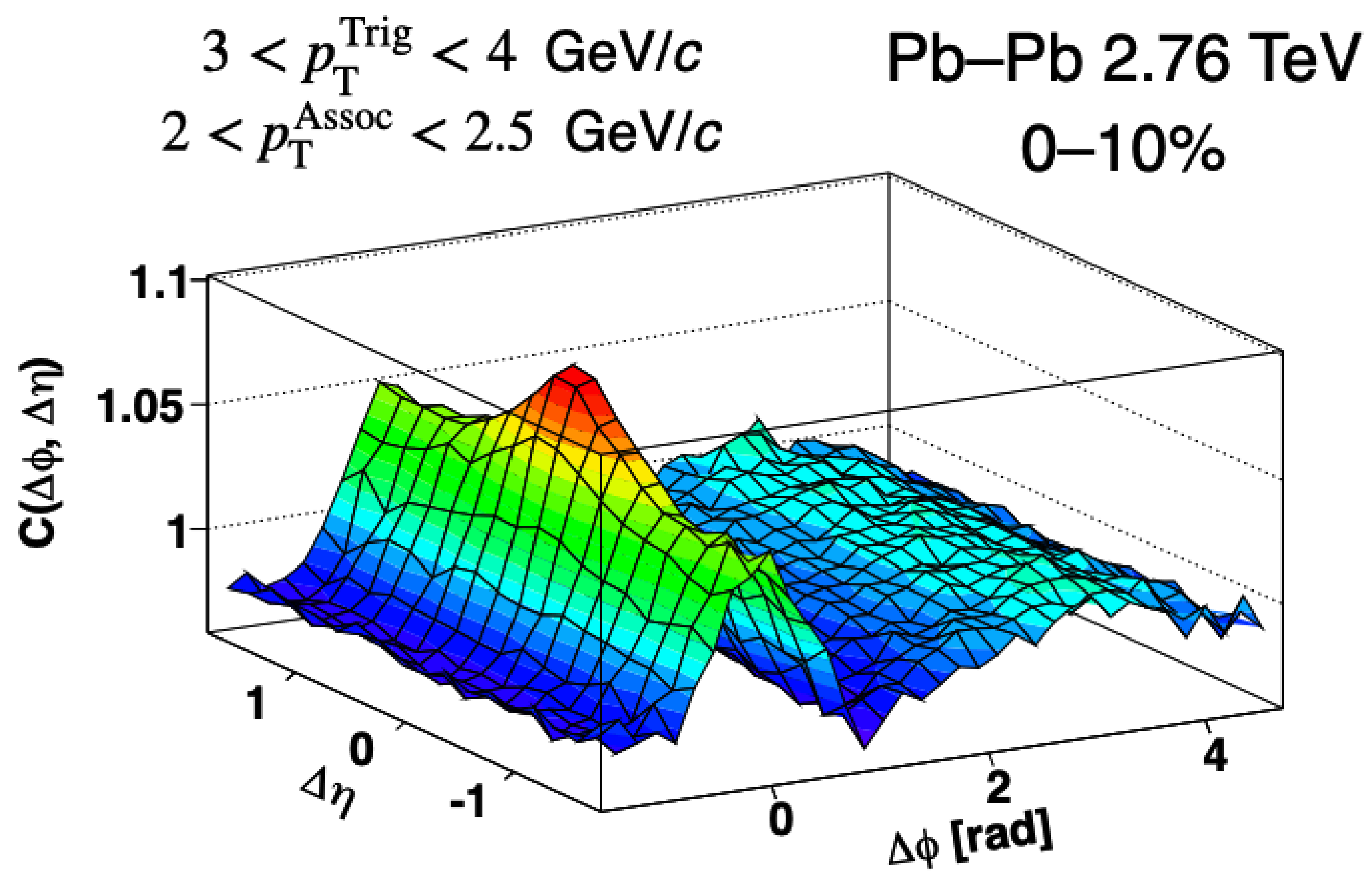
- PYTHIA String-Shoving doesn't describe the data. ✗

Coalescence of flowing partons necessary to describe the pattern

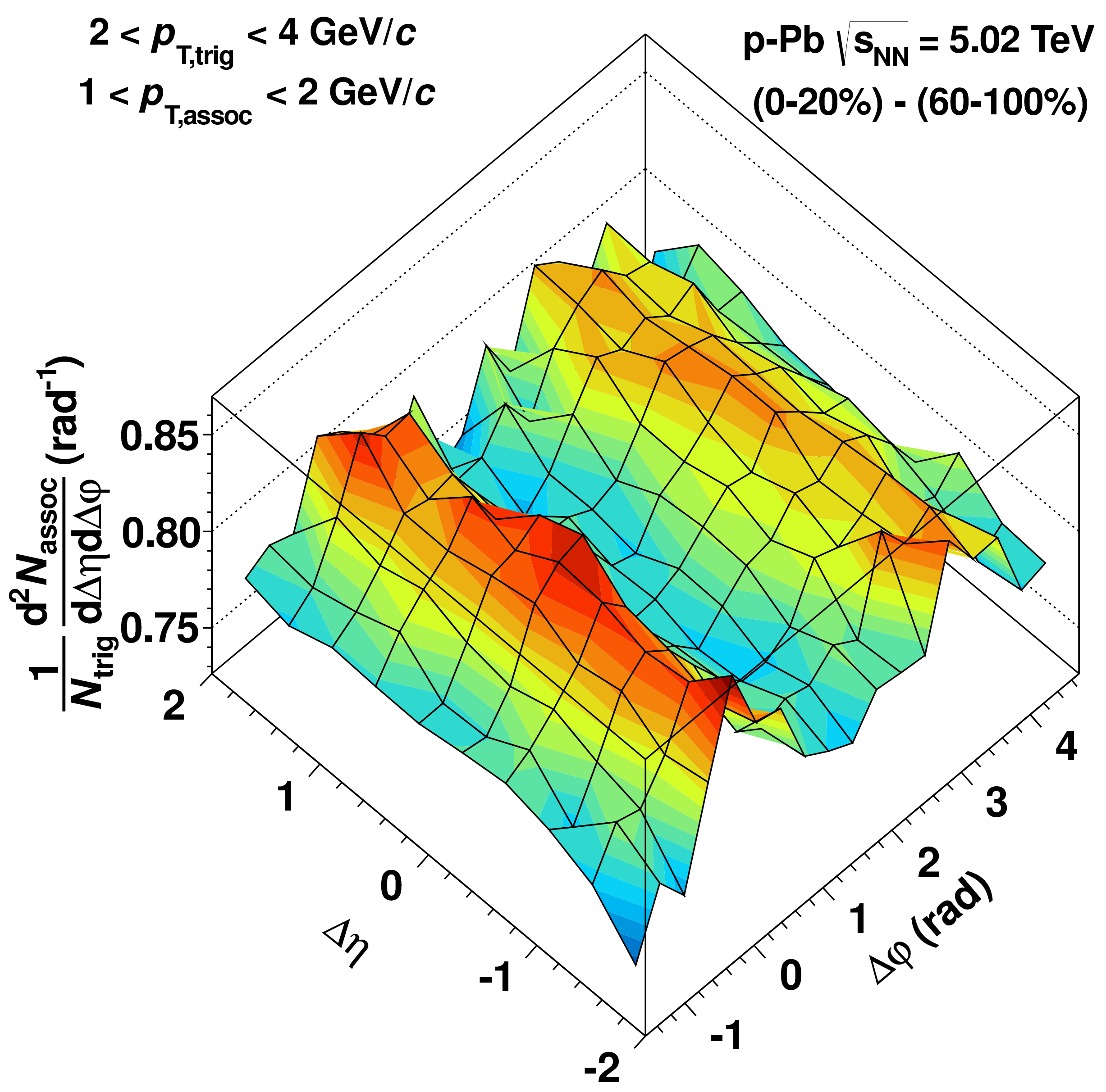
The Old Milestone

Pb–Pb



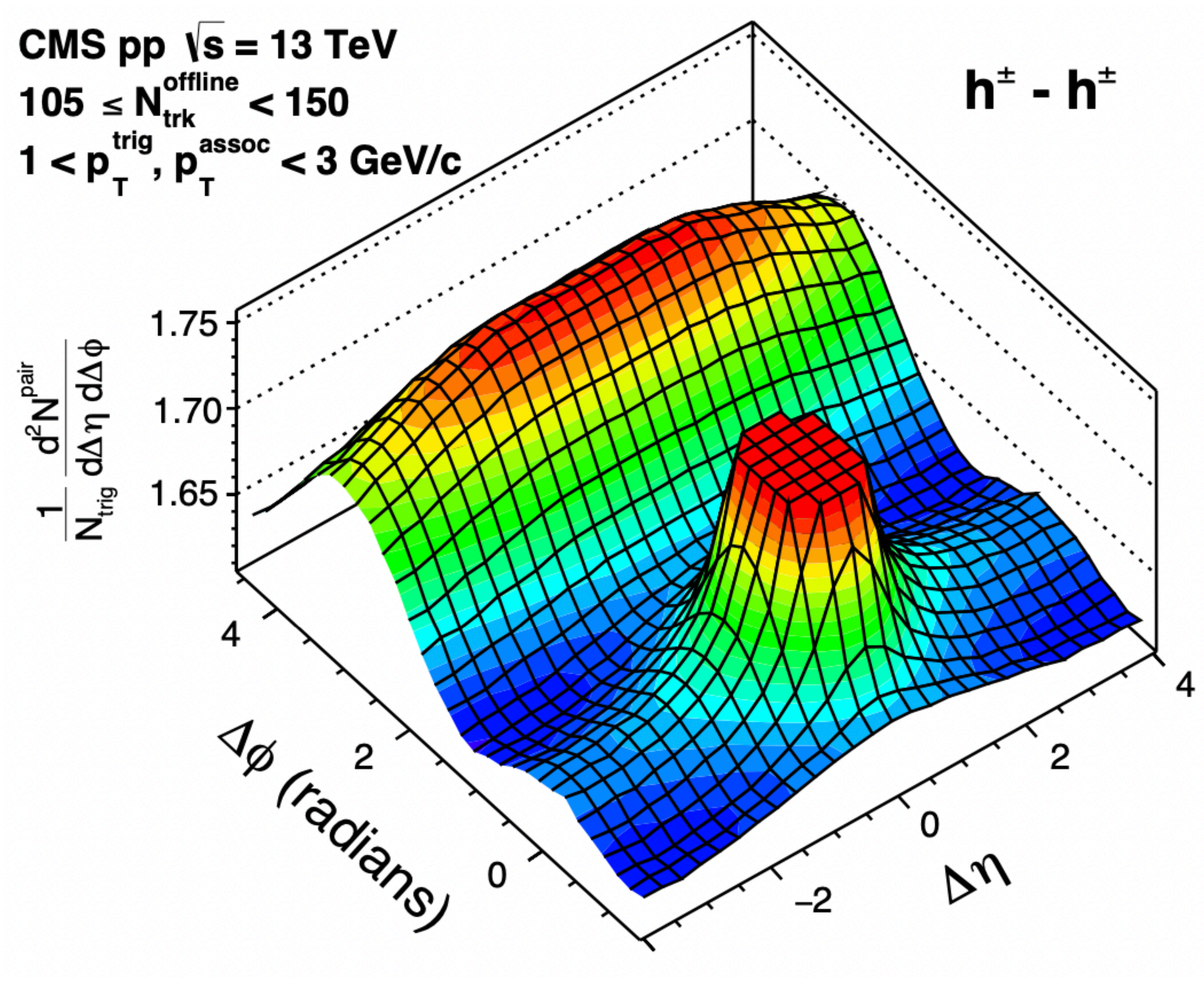
ALICE, PLB 708 (2012) 249-264

High multiplicity p–Pb



ALICE, Phys.Lett. B 719 (2013) 29-41

High multiplicity pp



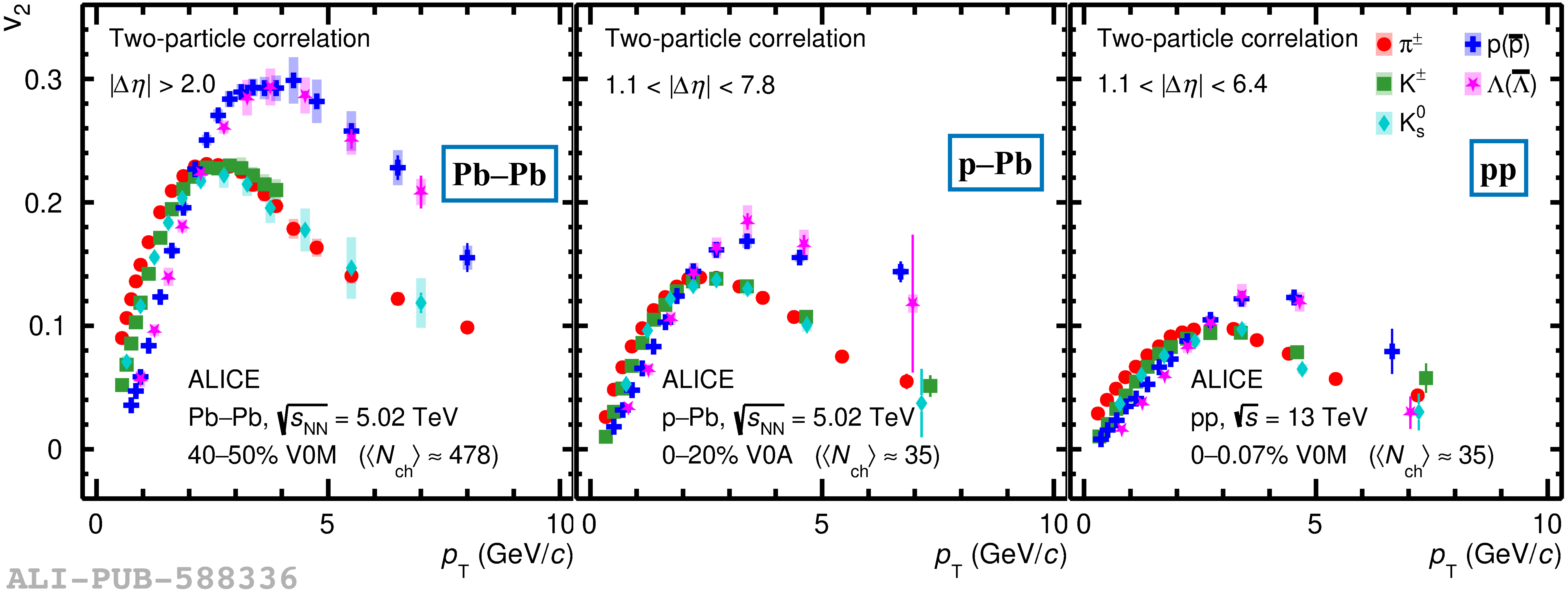
CMS, Phys.Lett. B 765 (2017) 193

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

Is it partonic collectivity?

The New Milestone...And

ALICE, arXiv:2411.09323



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

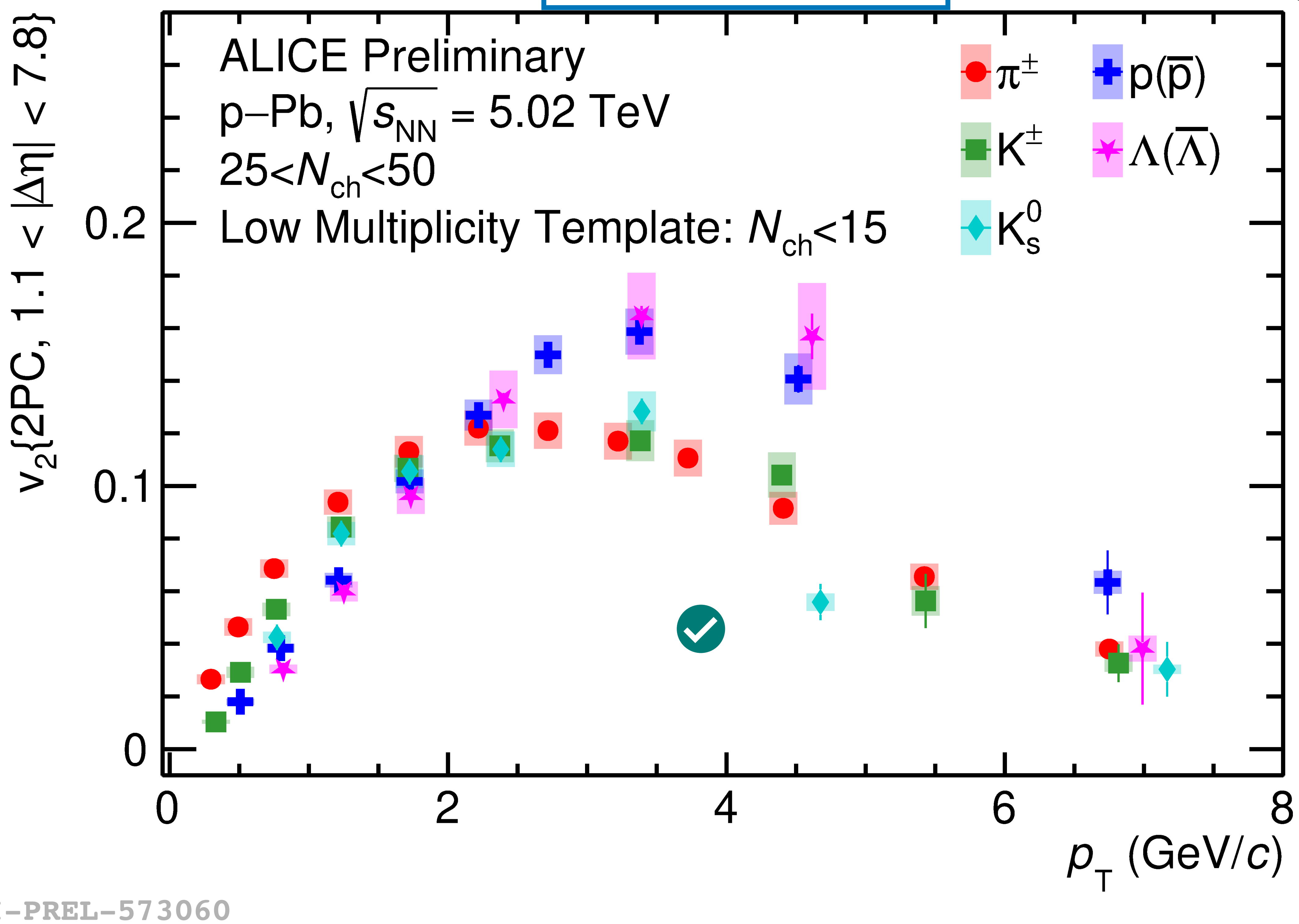
- Intermediate p_T ($3 \lesssim p_T \lesssim 6$ GeV/c) — Baryon-meson grouping (~1σ confidence) + splitting ($> 5\sigma$ confidence) of v_2 — quark coalescence, evidence of partonic collectivity (✔).

Where does it switch off? At which multiplicity? ← New open question

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

$25 < N_{ch} < 50$

p–Pb

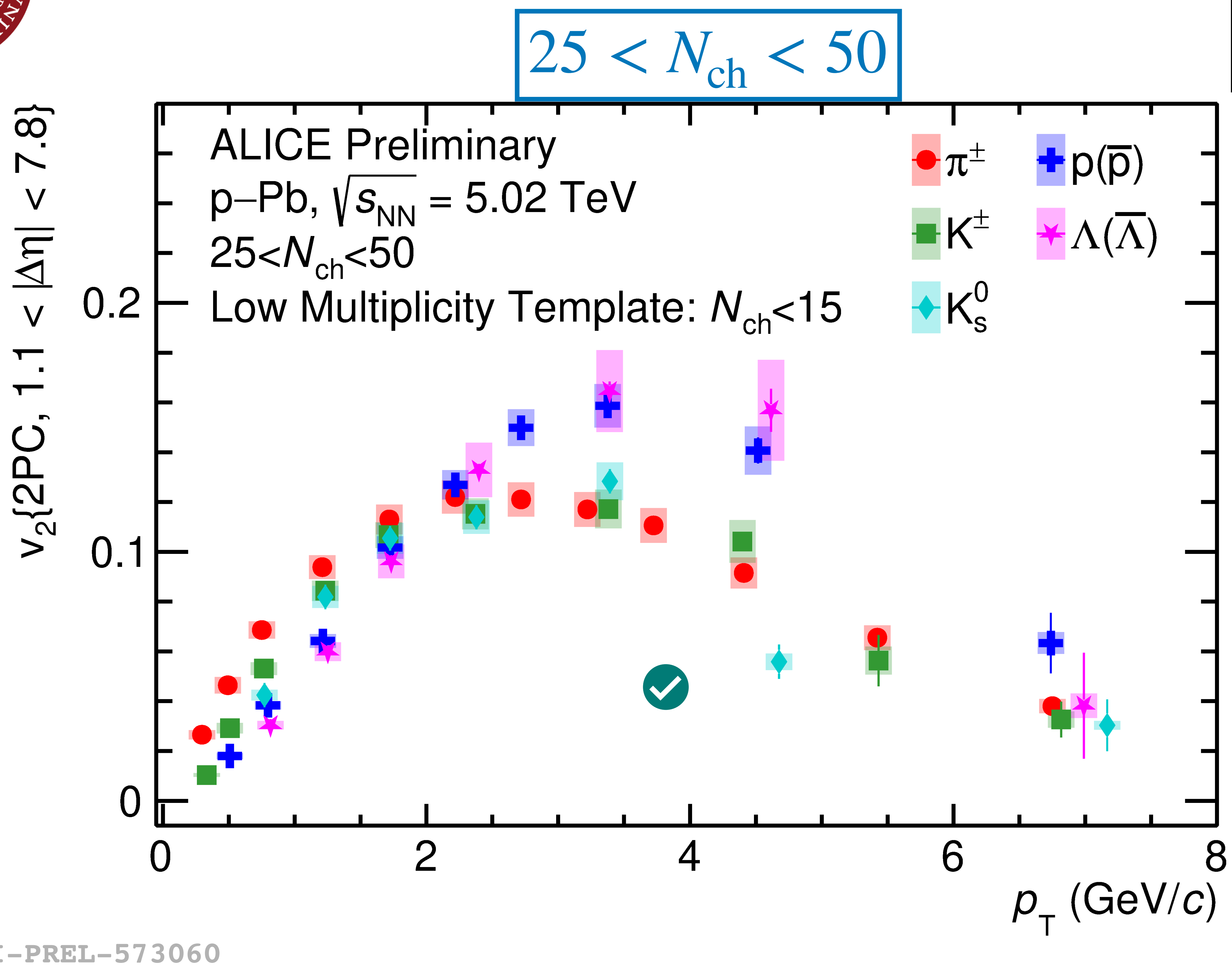


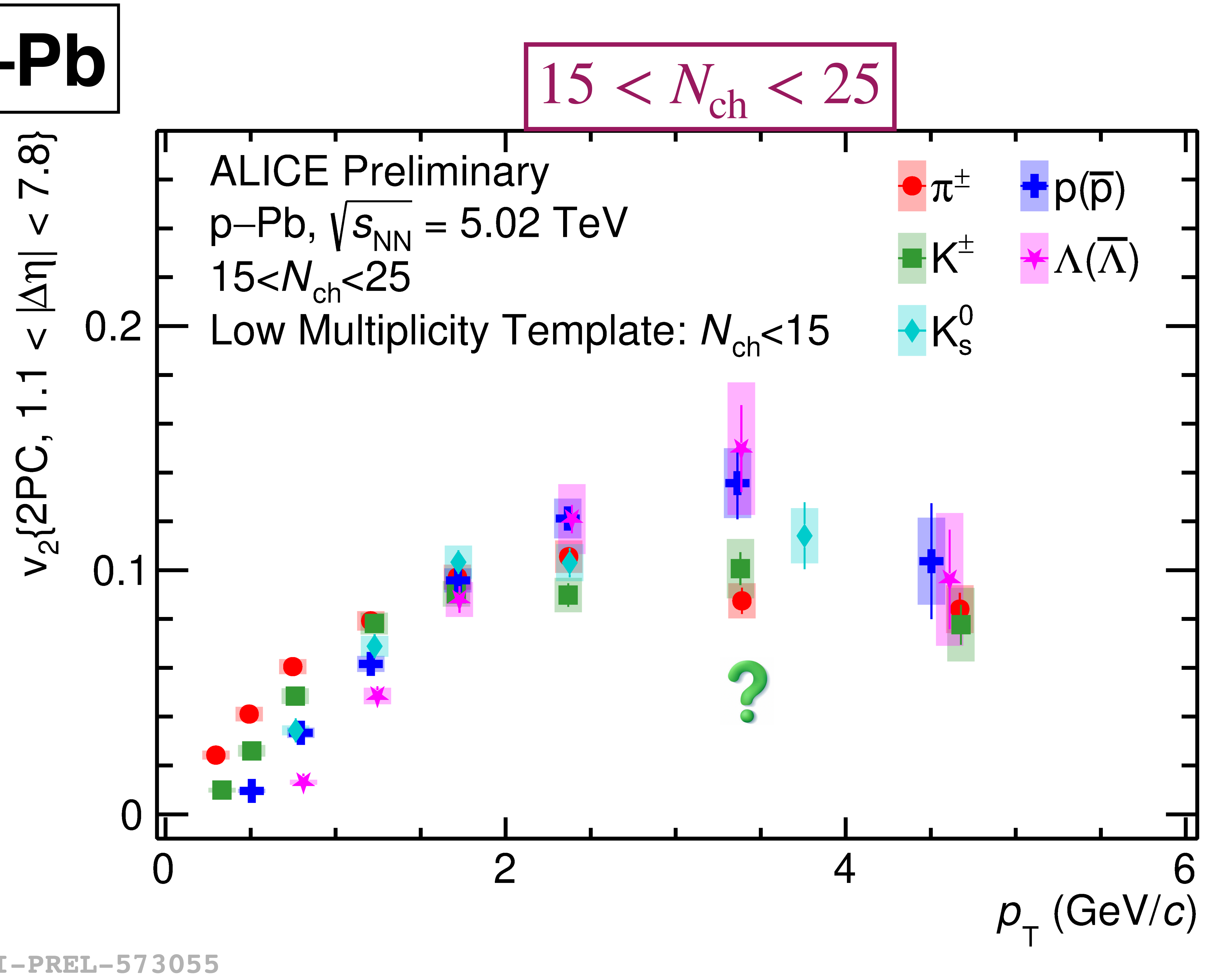
Wenya Wu, Qiye Shou (Fudan University)

N_{ch} : Number of tracks in TPC with ($|\eta| < 0.8$, and $p_T > 0.2$ GeV/c)

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

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





Wenya Wu, Qiye Shou (Fudan University)

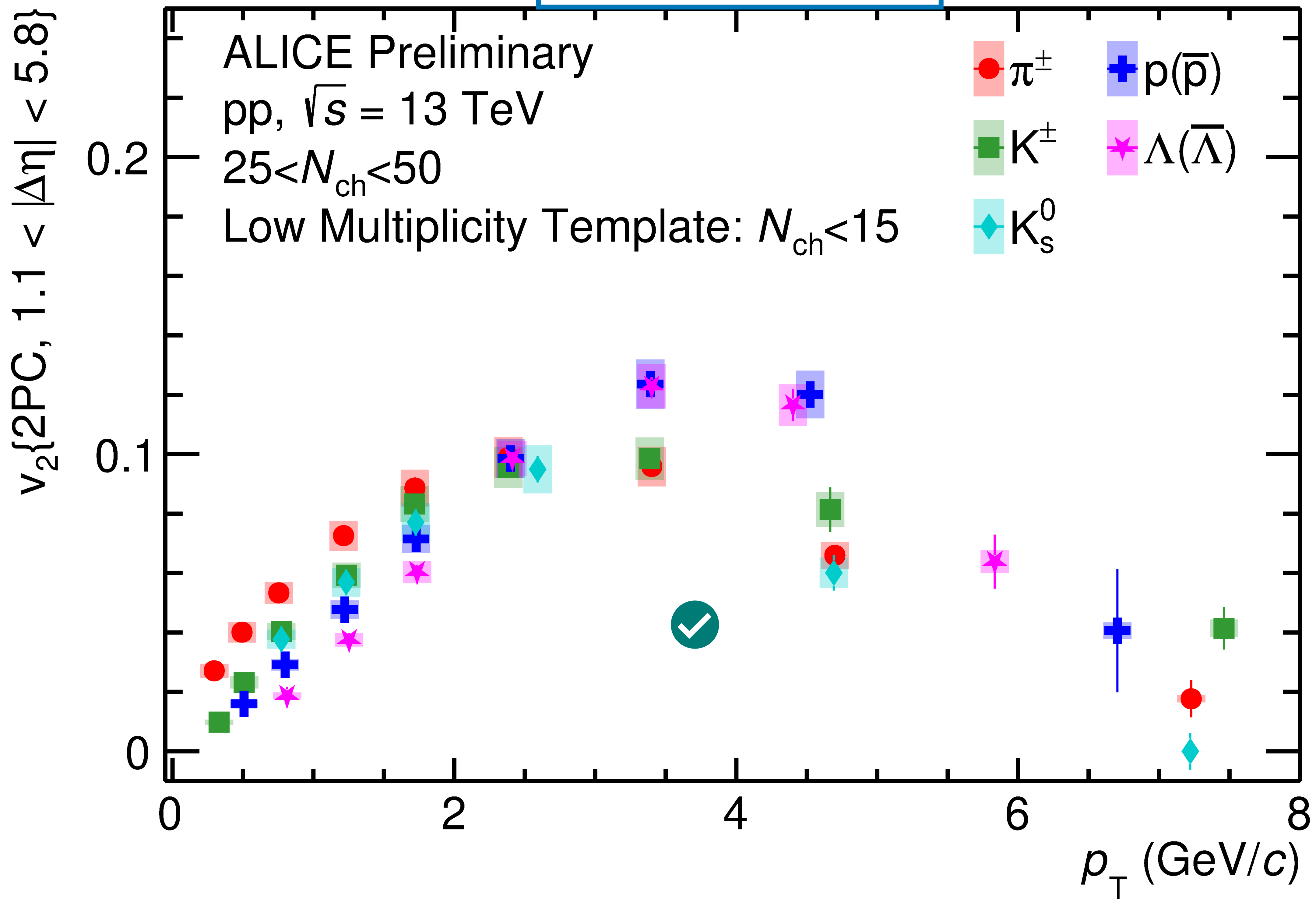
N_{ch} : Number of tracks in TPC with ($|\eta| < 0.8$, and $p_T > 0.2$ GeV/c)

- $N_{ch} > 25$: 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.

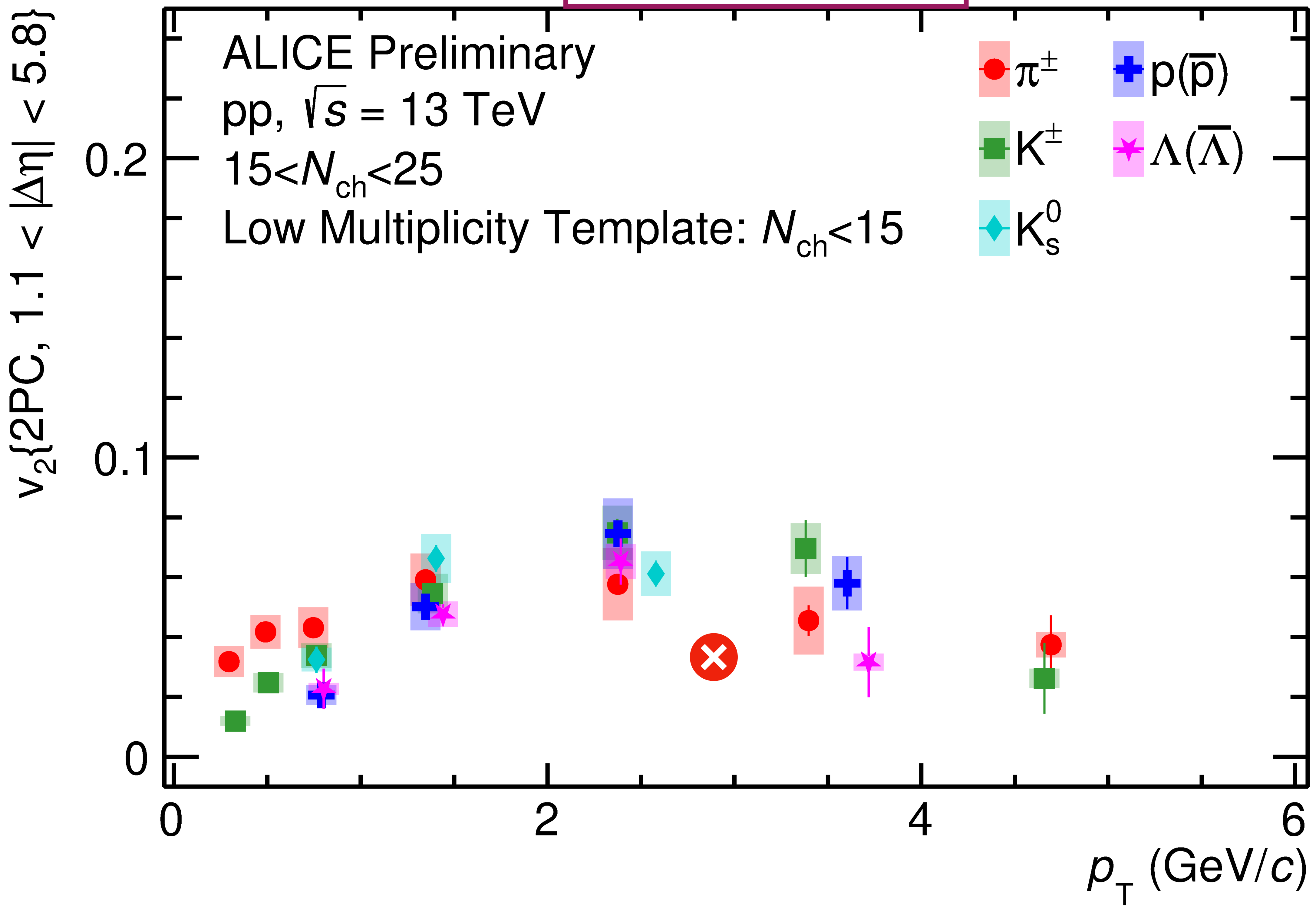
pp: N_{ch} dependence of v_2 of identified particles

pp

$25 < N_{ch} < 50$



$15 < N_{ch} < 25$



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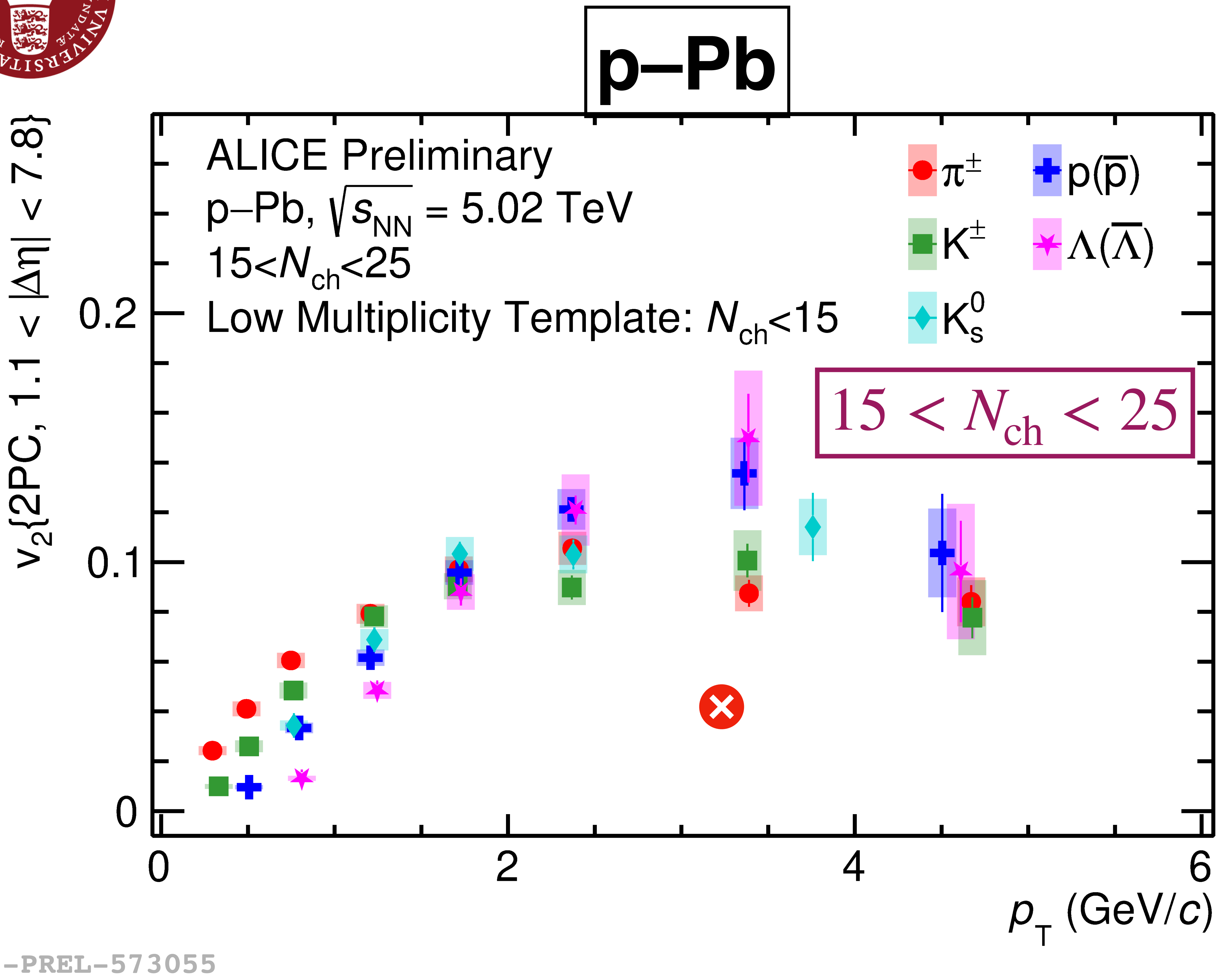
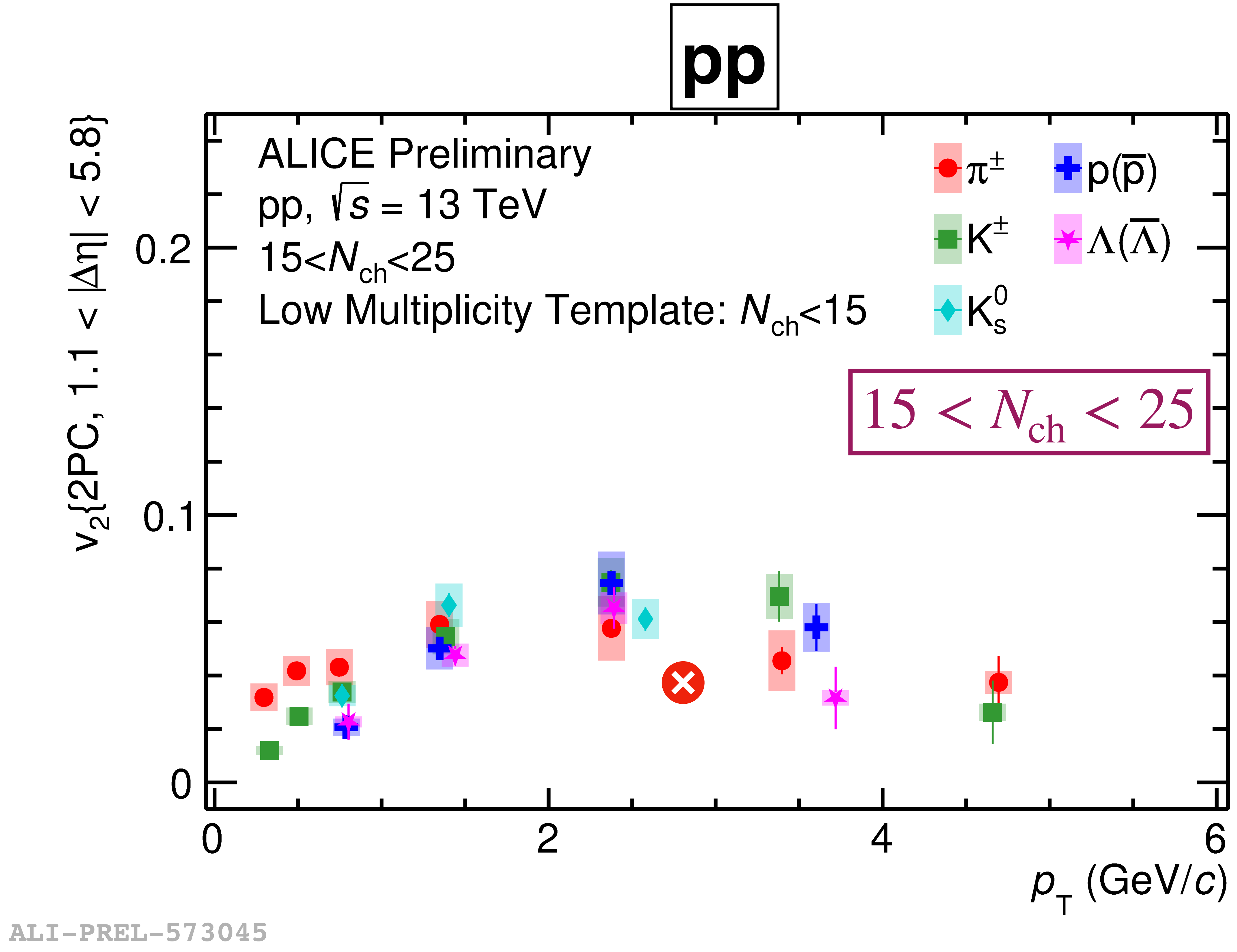
N_{ch} : Number of tracks in TPC with ($|\eta| < 0.8$, and $p_T > 0.2$ GeV/c)

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

Finite v_2 at low multiplicity!



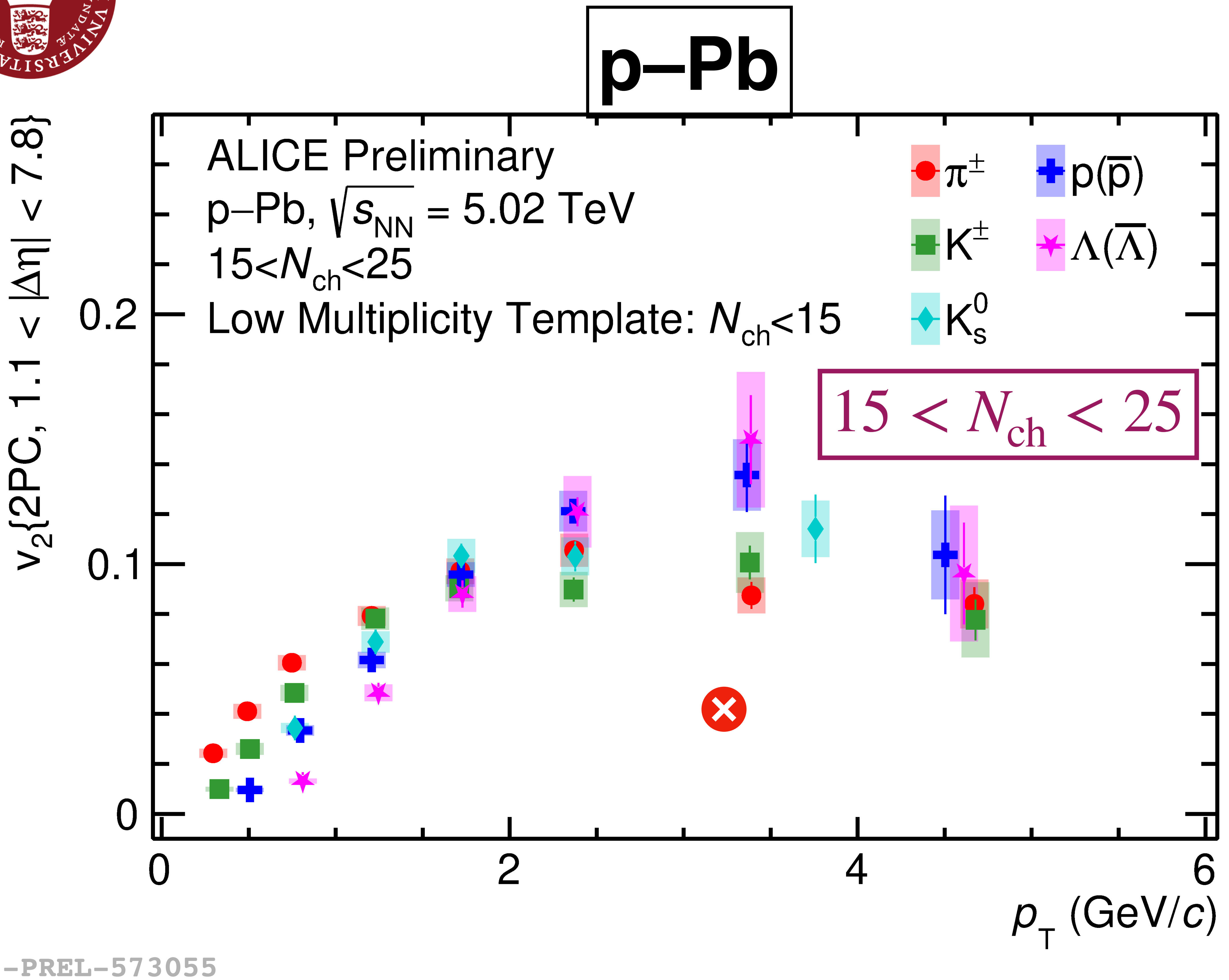


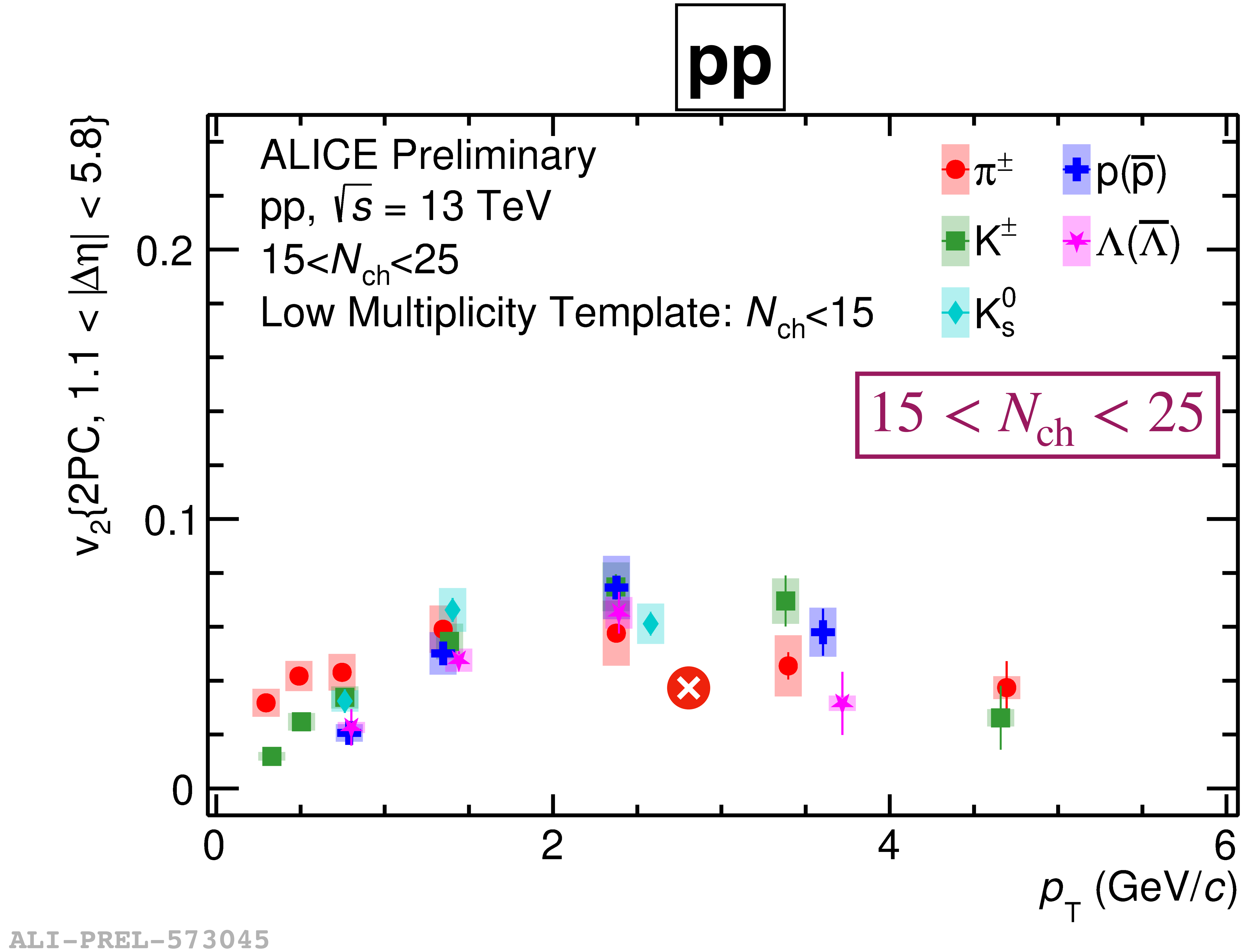
N_{ch} : Number of tracks in TPC with ($|\eta| < 0.8$, and $p_T > 0.2$ GeV/c)

- $N_{ch} < 25$: Baryon-meson v_2 grouping and splitting diminished in both pp and p–Pb collisions!

Finite v_2 at low multiplicity! Cannot be explained by pure non-flow effects.

Finite v_2 at low multiplicity!





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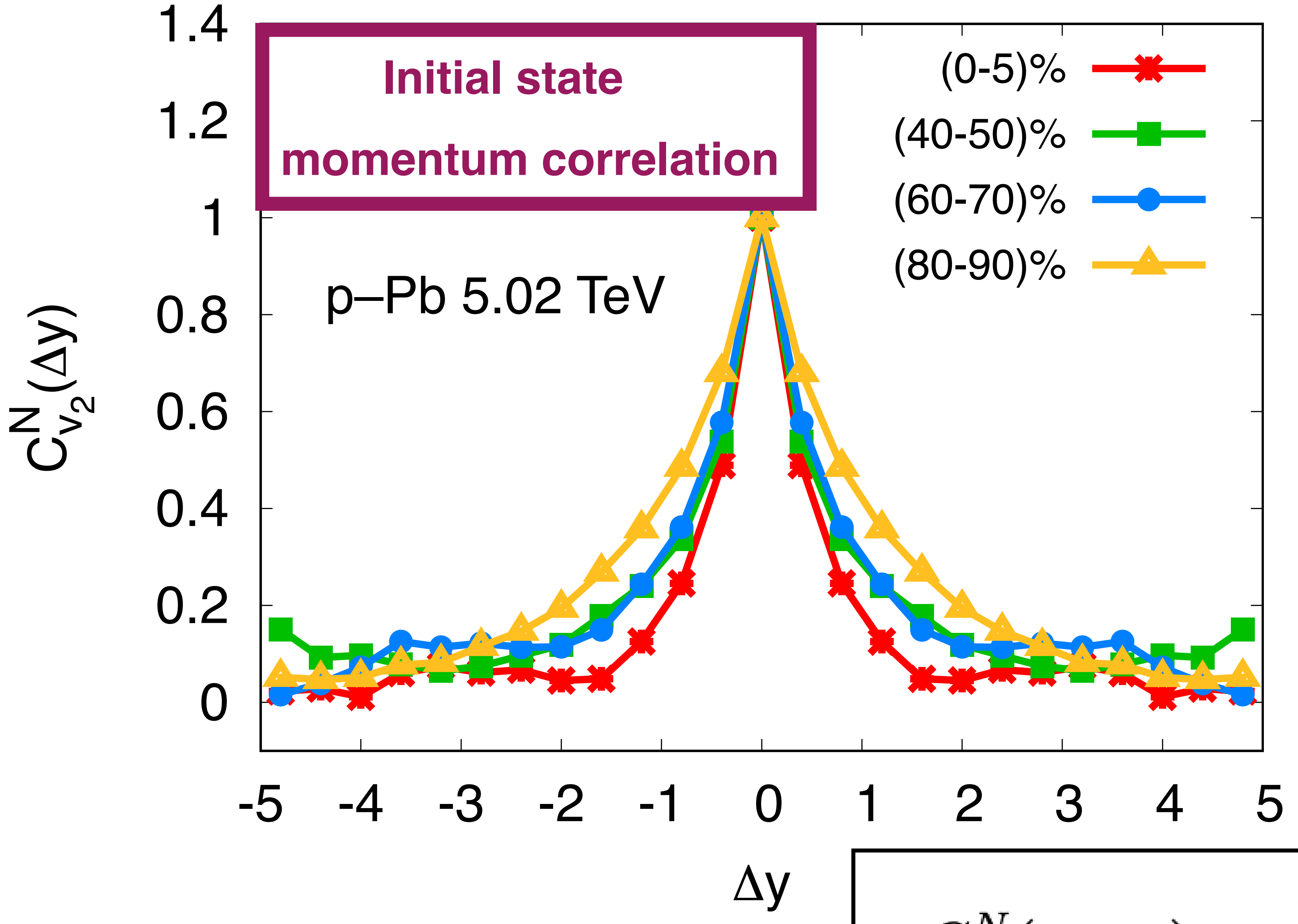
- $N_{ch} < 25$: Baryon-meson v_2 grouping and splitting diminished in both pp and p–Pb collisions!

Finite v_2 at low multiplicity! Initial state effects play an important role in low multiplicity small systems?

Initial state effects might be short range…

THE 3D IP-GLASMA MODEL



$$C^N_{\mathcal{O}}(y_1, y_2) = \frac{C_{\mathcal{O}}(y_1, y_2)}{\sqrt{\langle|\mathcal{O}(y_1)|^2\rangle\langle|\mathcal{O}(y_2)|^2\rangle}} .$$

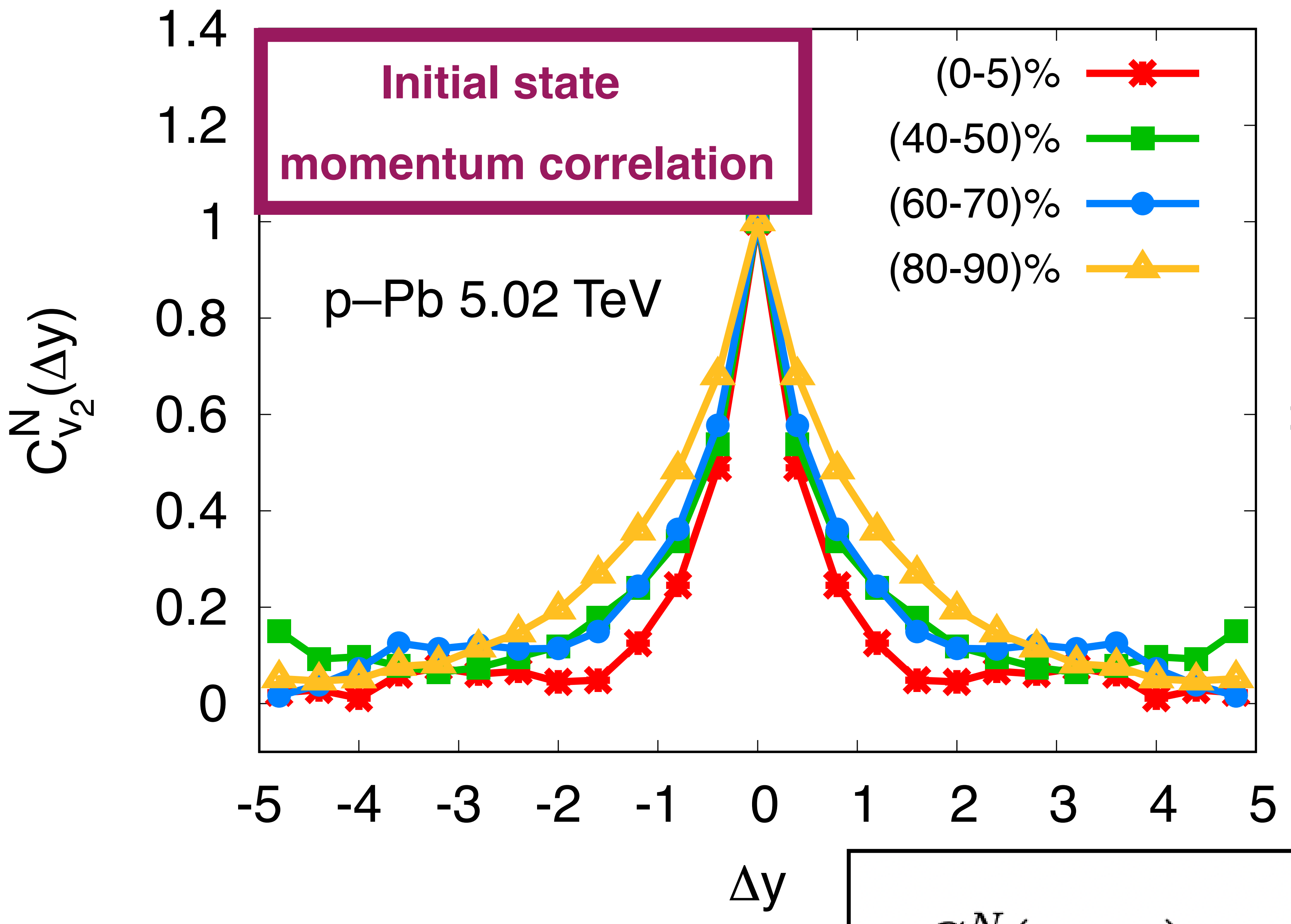
B. Schenke, S. Schlichting, P. Singh; Phys. Rev. D 105, 094023 (2022)

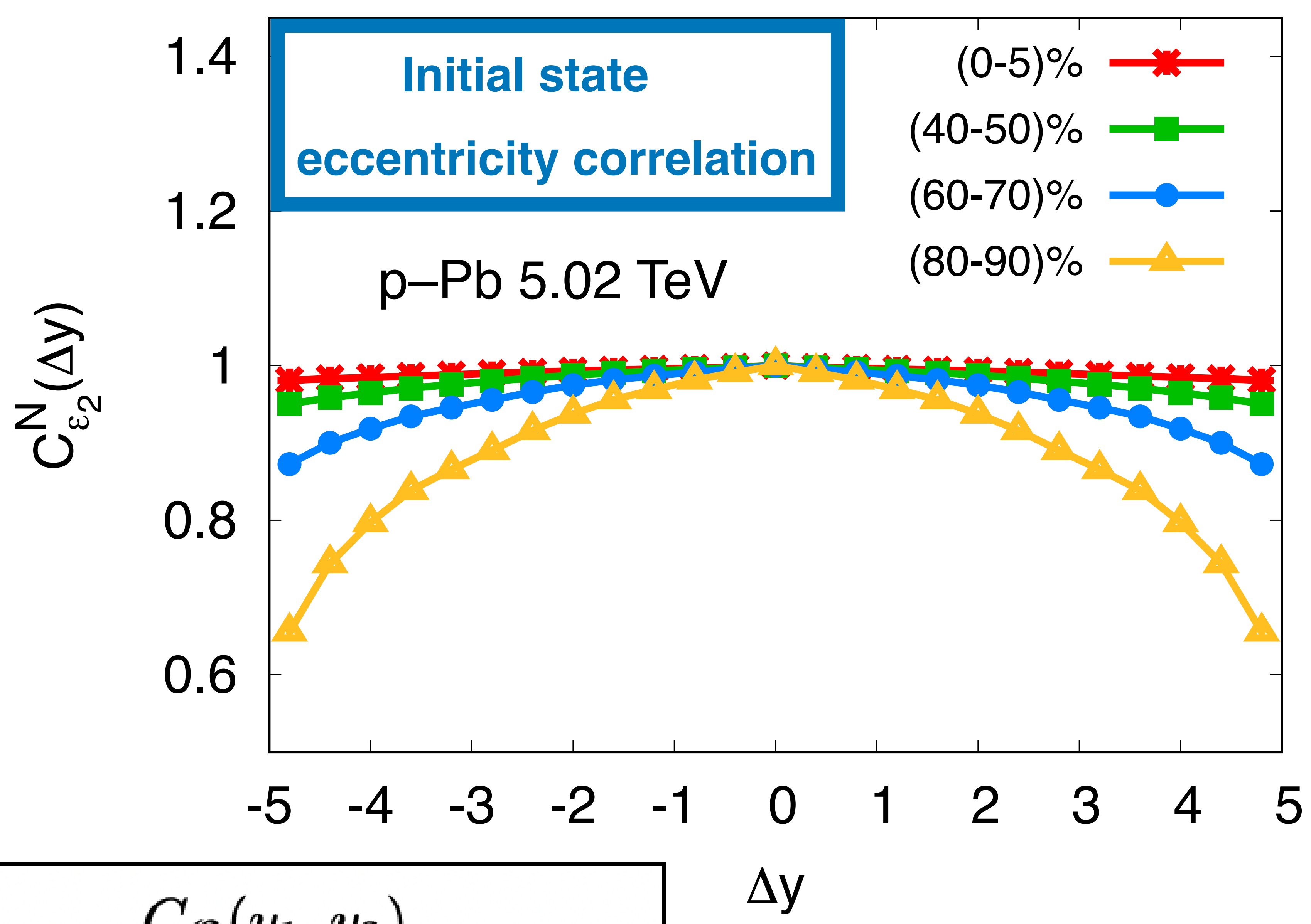
- Initial state momentum correlations — relatively short-range (finite contribution for $|\Delta\eta| \lesssim 3.0$).

How to disentangle **initial** and **final** state effects?

Initial state effects might be short range…

THE 3D IP-GLASMA MODEL





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

- Initial state momentum correlations — relatively short-range (finite contribution for $|\Delta\eta| \lesssim 3.0$).
- Event geometry (transverse) — correlated across large rapidity intervals.

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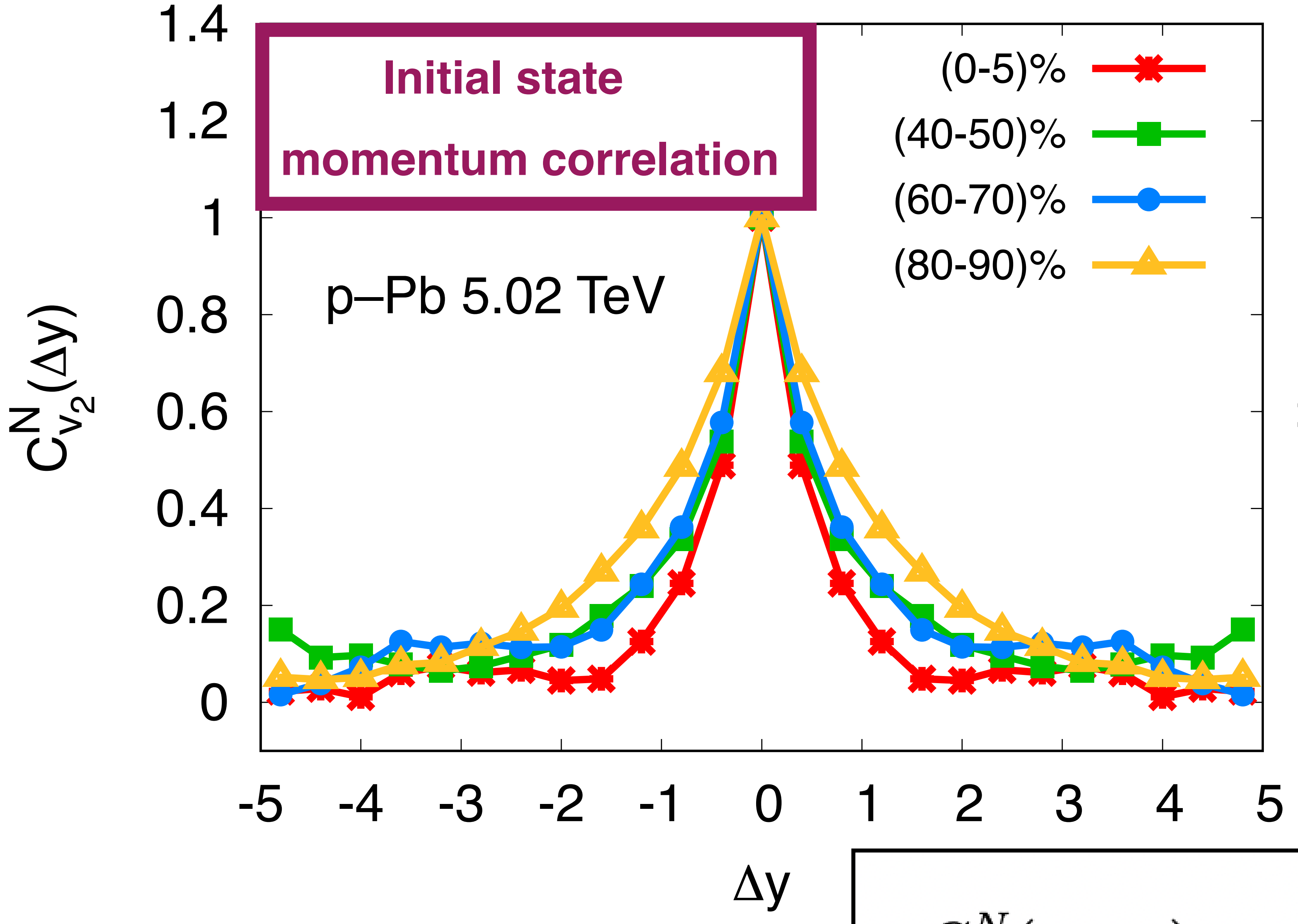
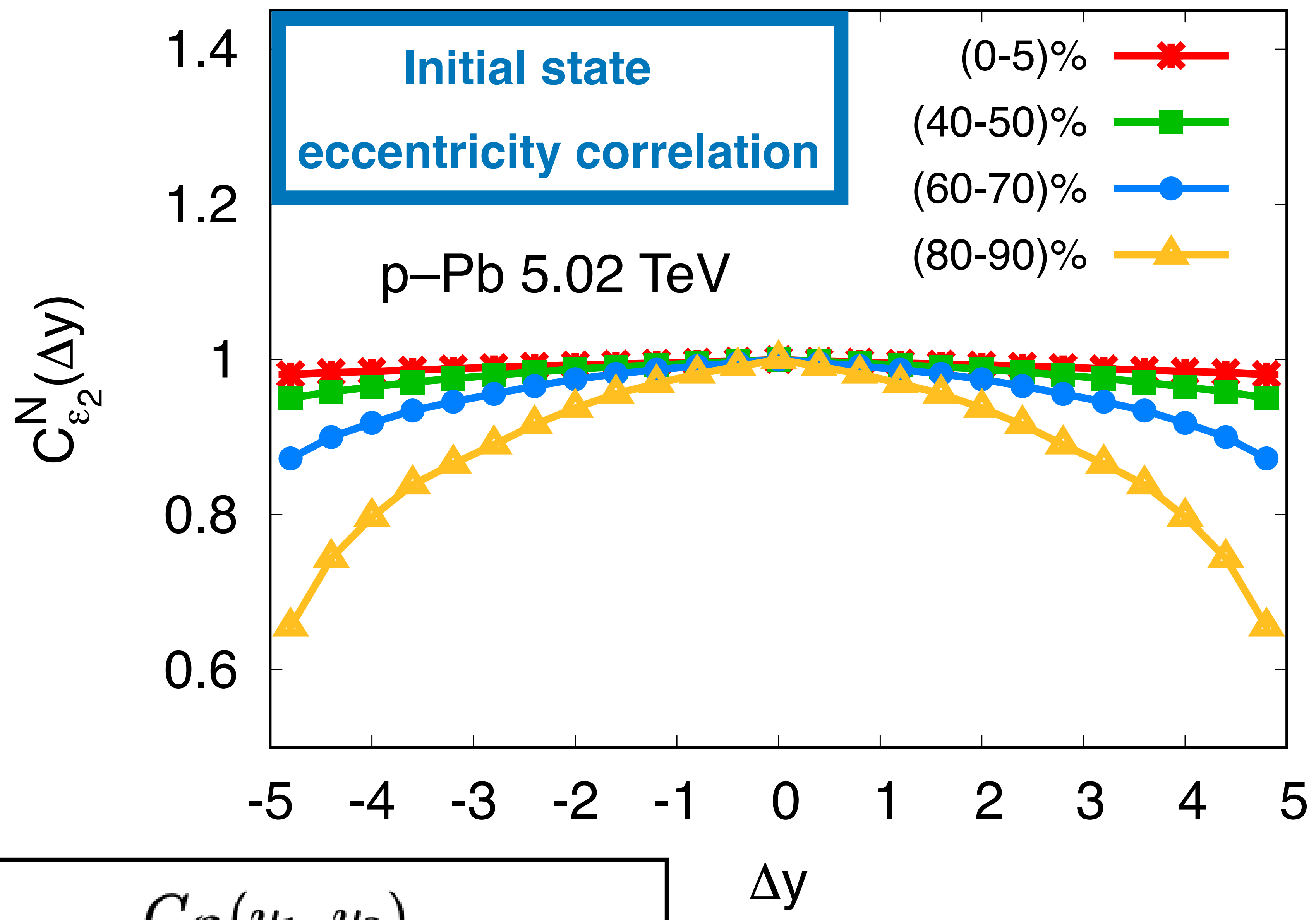
THE 3D IP-GLASMA MODEL





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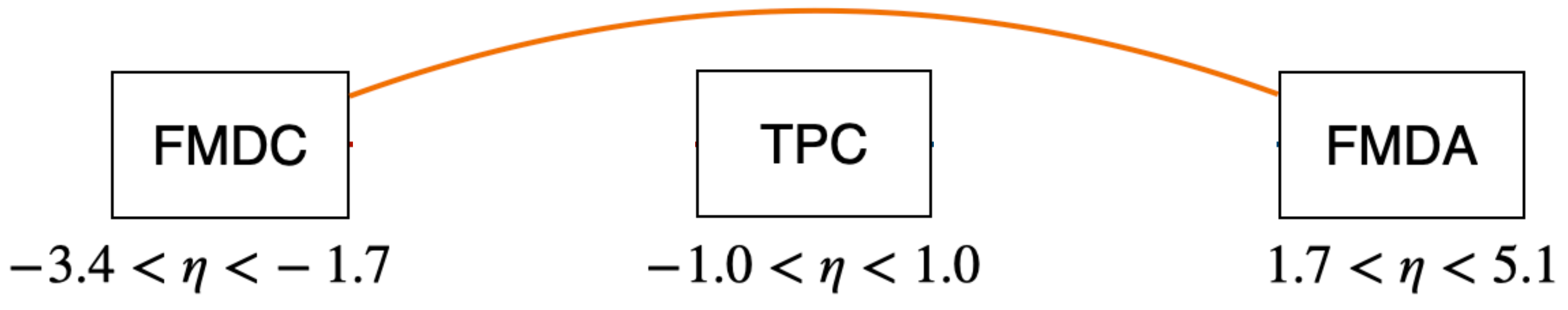
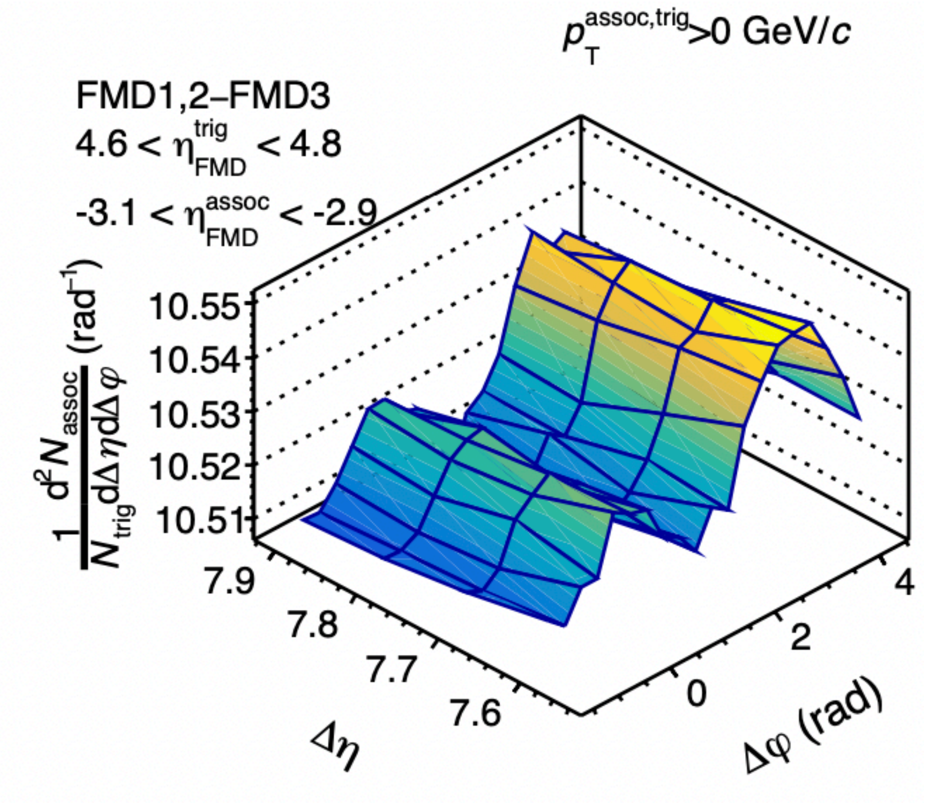
B. Schenke, S. Schlichting, P. Singh; Phys. Rev. D 105, 094023 (2022)

Ultra Long-range correlation in ALICE



FMDA—FMDC correlation
$(|\Delta\eta > 5.0|)$

$V_{n\Delta}^{\mathrm{FMDA-FMDC}}$



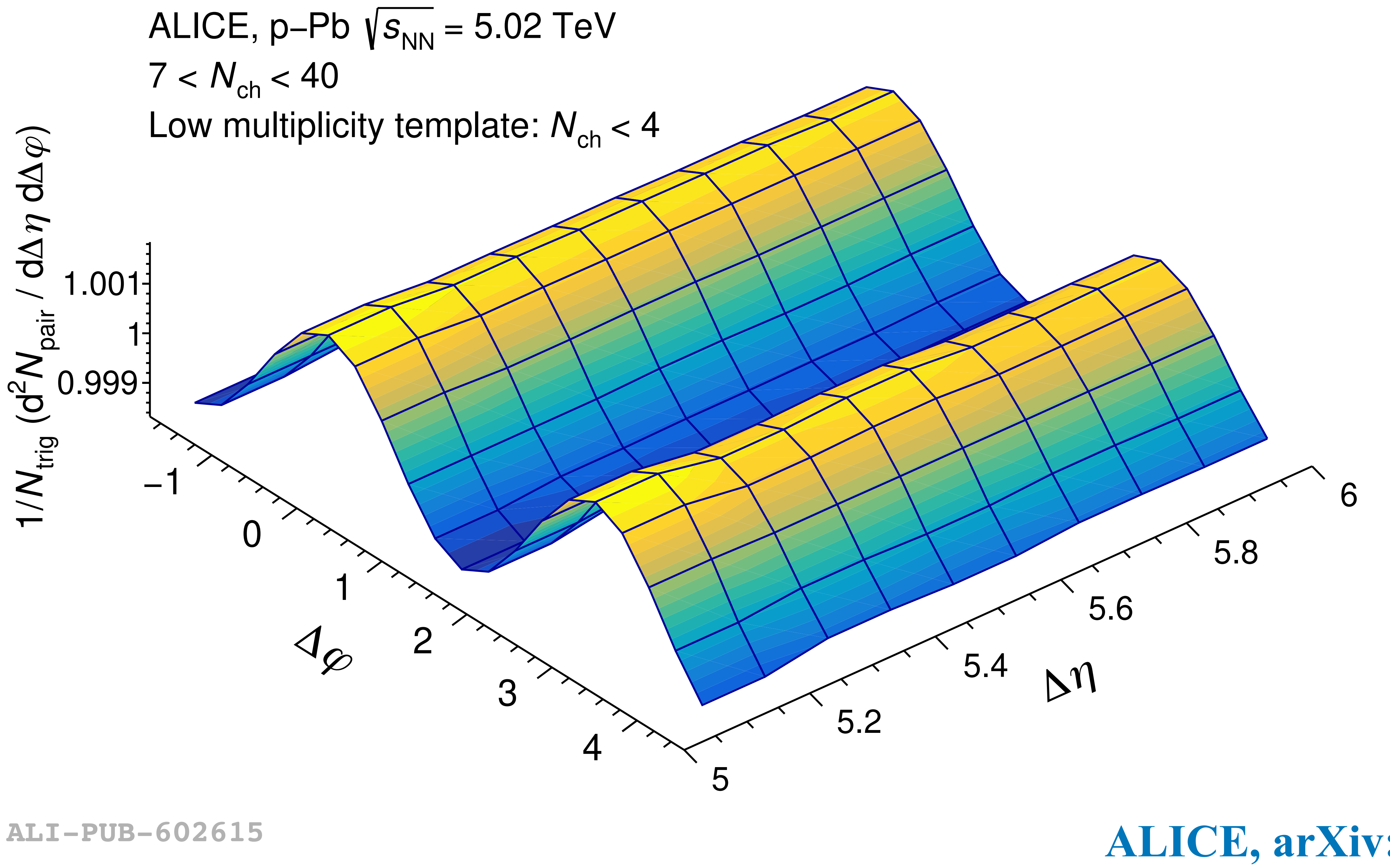
ALICE, JHEP 01 (2024) 199

- Initial state momentum correlations — relatively short-range (finite contribution for $|\Delta\eta| \lesssim 3.0$).
- Event geometry (transverse) — correlated across large rapidity intervals.

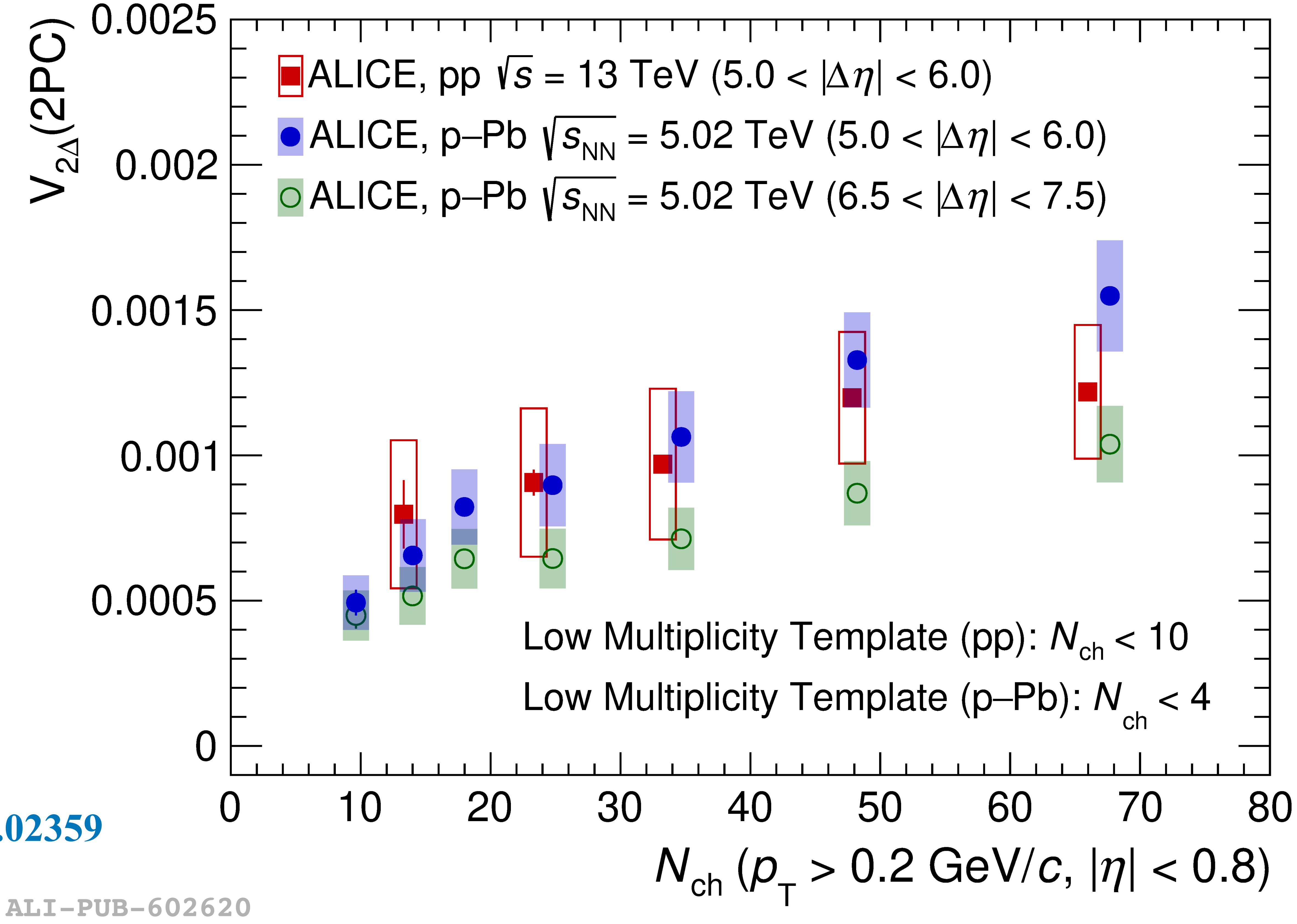
Goal: Explore the longest-range correlation down to minimum bias multiplicity

Ultra long-range correlation in ALICE

Non-flow removal by Template fit method



ALICE, arXiv:2504.02359

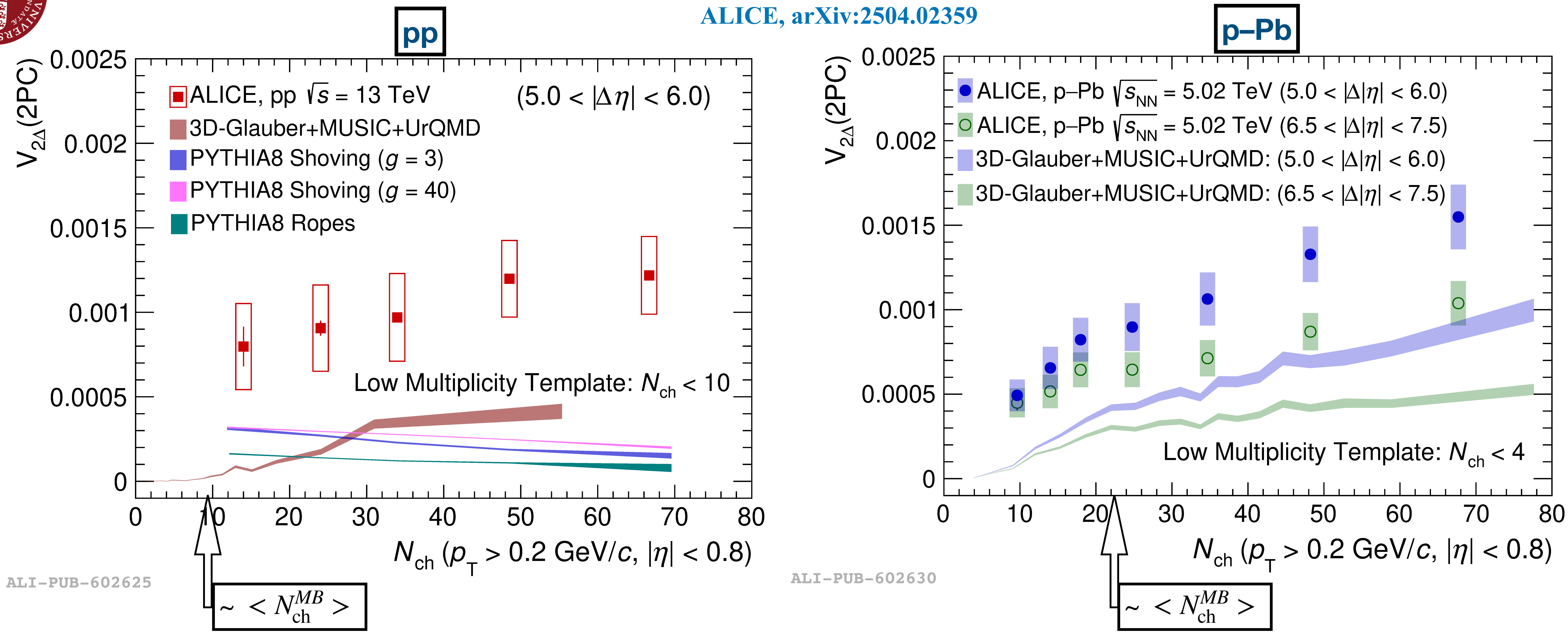


N_{ch} : Number of tracks in TPC with ($|\eta| < 0.8$, and $p_T > 0.2$ GeV/c)

- Longest-range correlation ($|\Delta\eta| >$ 5.0 (6.5)) ever measured down to or lower than minimum bias multiplicity in pp and p–Pb collisions.

Ultra long-range correlation in ALICE

ALICE, arXiv:2504.02359

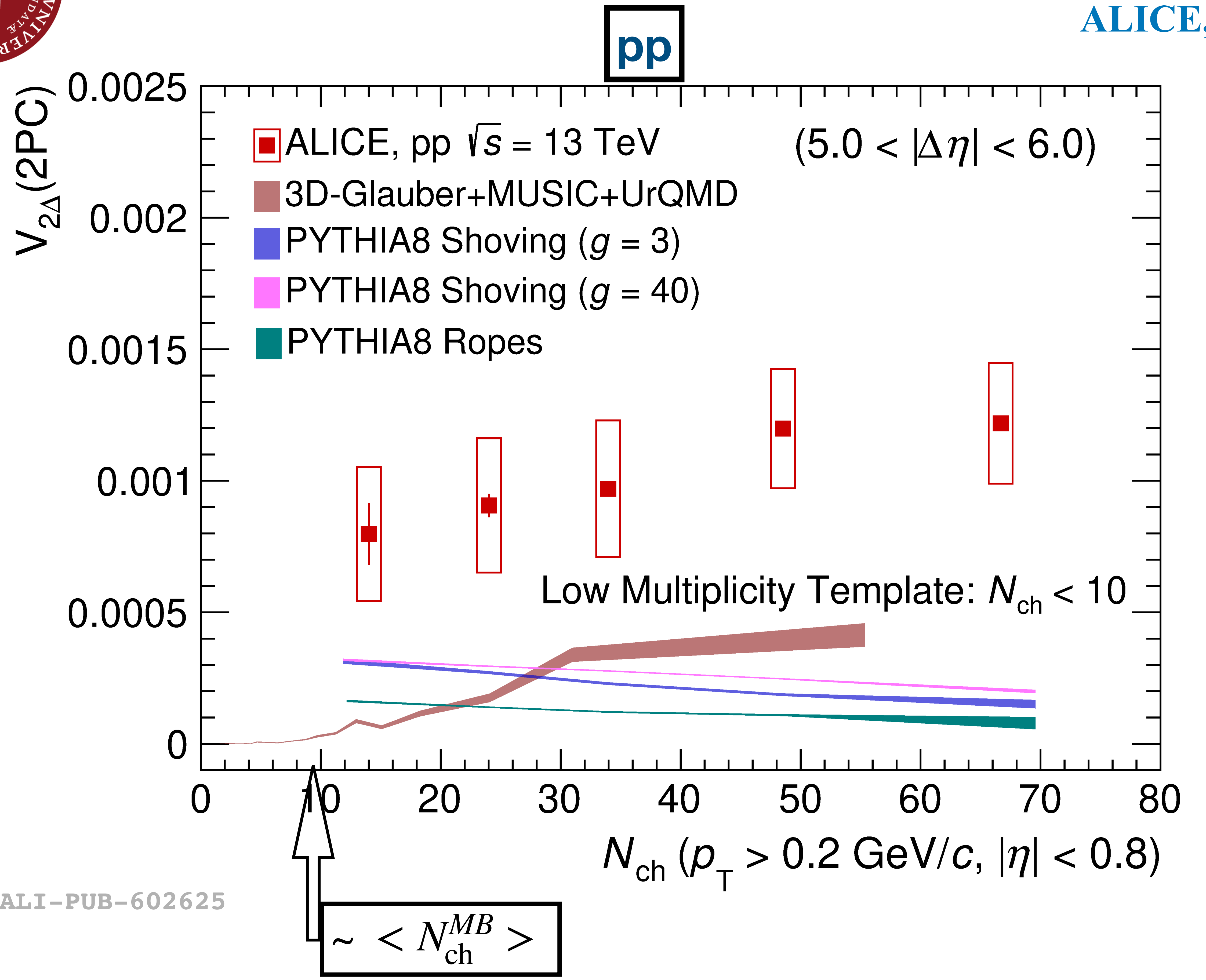


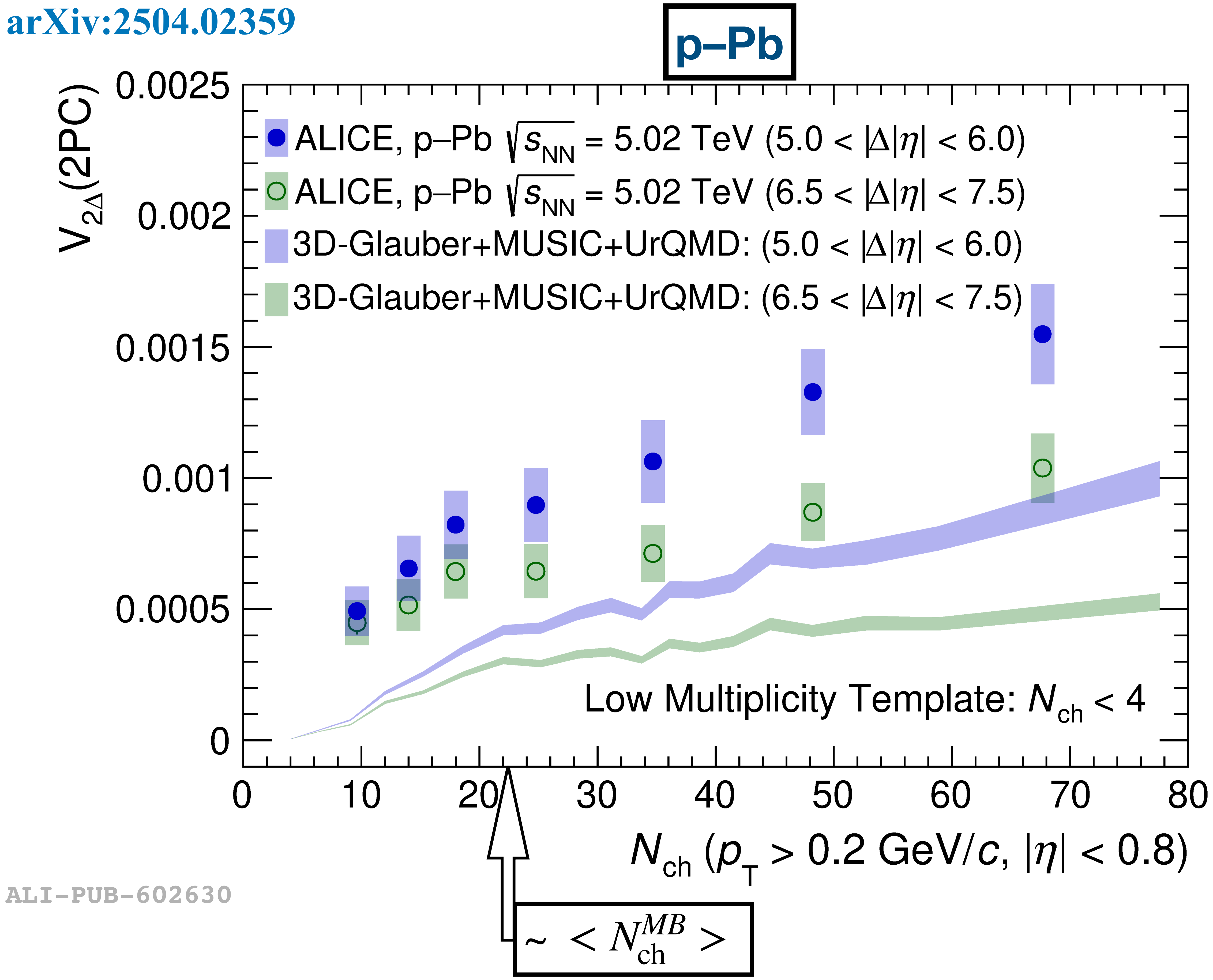
- Ultra-long-range correlation down to minimum bias multiplicity in pp and p–Pb: CGC doesn't contribute.
- 3DGlauber+MUSIC+UrQMD: (Sub-nucleonic + longitudinal fluctuation in initial state) doesn't explain the results.

W Zhao et al, Phys. Rev. C 107, 014904 (2023)

Ultra long-range correlation in ALICE

ALICE, arXiv:2504.02359





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W Zhao et al, Phys. Rev. C 107, 014904 (2023)

- PYTHIA can't explain the data. Alternative approach such as PYTHIA with Shoving/Ropes mechanism fails too!

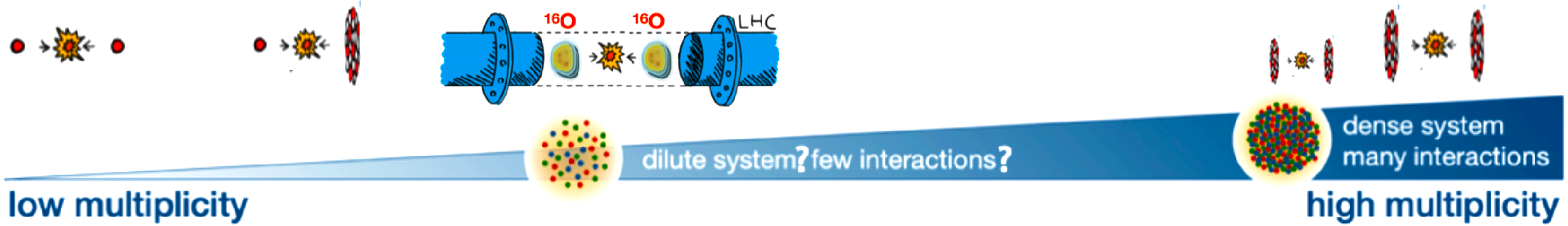
Summary

- **Identified particle flow in pp and p–Pb collisions:**
  - Baryon-meson v_2 grouping (~1σ) + splitting (> 5σ) observed at intermediate p_{T} in high multiplicity events.
  - Only model incorporating coalescence of flowing partons (Hydro+Coal+Frag) explains the pattern.
  - Evidence of collectively flowing partons, similar to the one observed in heavy-ion collisions.
  - Below certain multiplicity, the underlying dynamics changes. Partonic collectivity switches off at low multiplicity?

- **Ultra-long-range azimuthal correlation down to low multiplicity pp and p–Pb collisions:**
  - Ultra-long-range correlation ($|\Delta\eta| >$ 5.0 (6.5)) down to and lower than minimum bias multiplicity measured for the first time.
  - Hydrodynamics, CGC and PYTHIA based models can not explain the data!
  - Excellent constraint for hydrodynamic and alternative models aiming to explain collectivity in small systems.

Outlook

Upcoming Light ion collisions at the LHC



- Multiplicity overlap with pp, p–Pb, and Pb–Pb allows scanning from fluctuation-dominated to geometry-dominated regimes.

- Light-ion collisions with unique shapes (e.g., α-clustering in O and Ne) can provide important constraints on initial conditions — the shapes of light ions are well studied in low-energy nuclear structure.

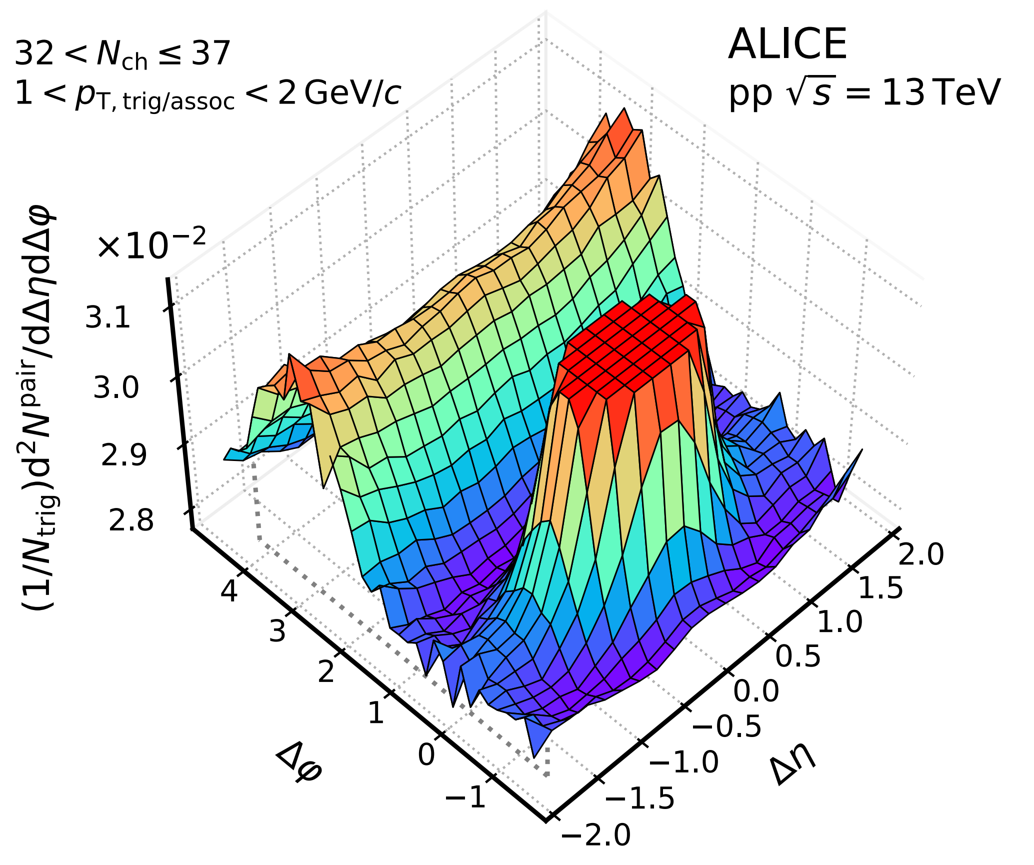
- Multiplicity-dependent precision measurements of identified particle flow and long-range correlations can offer critical input on the onset of collectivity.

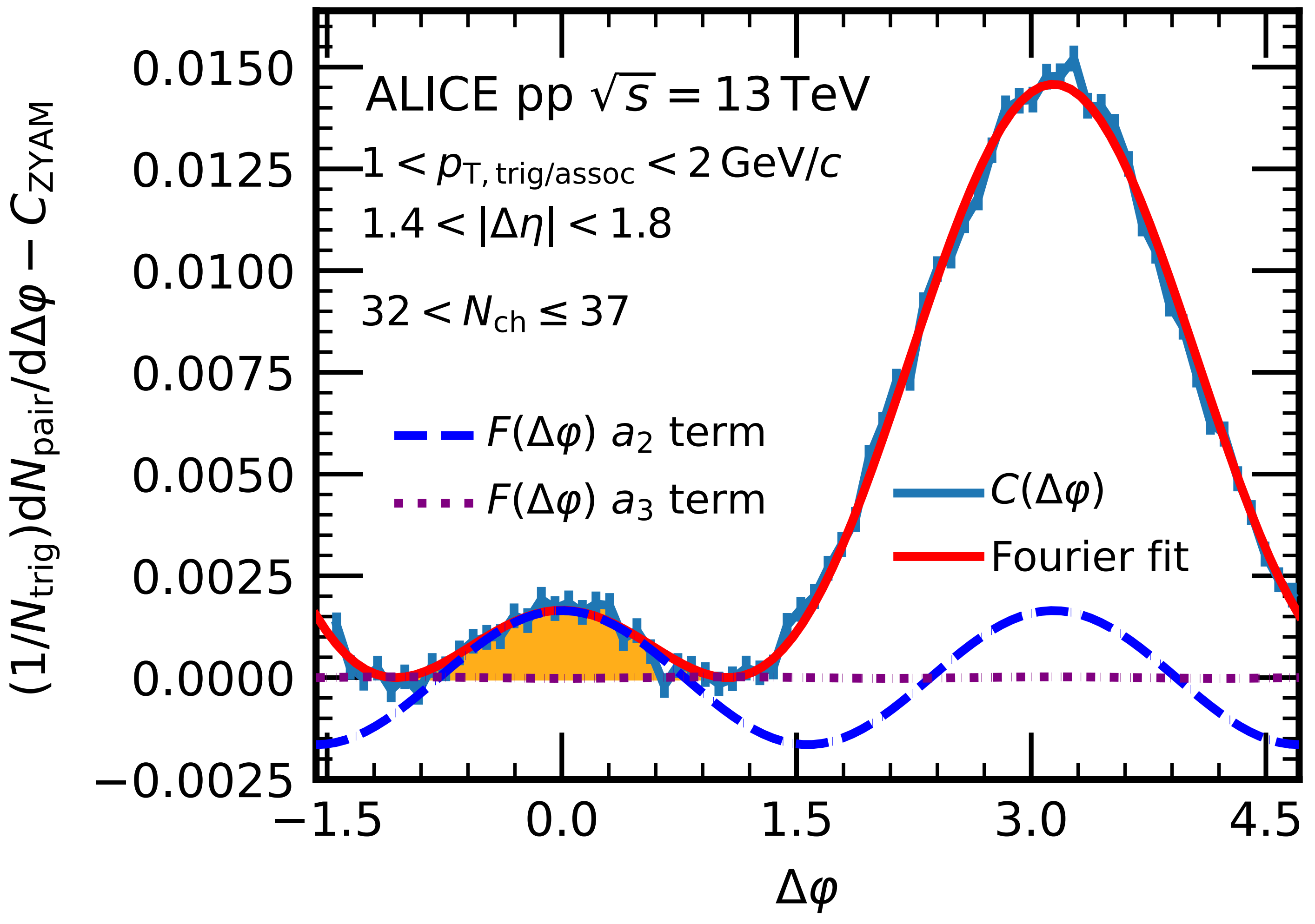
Thank You

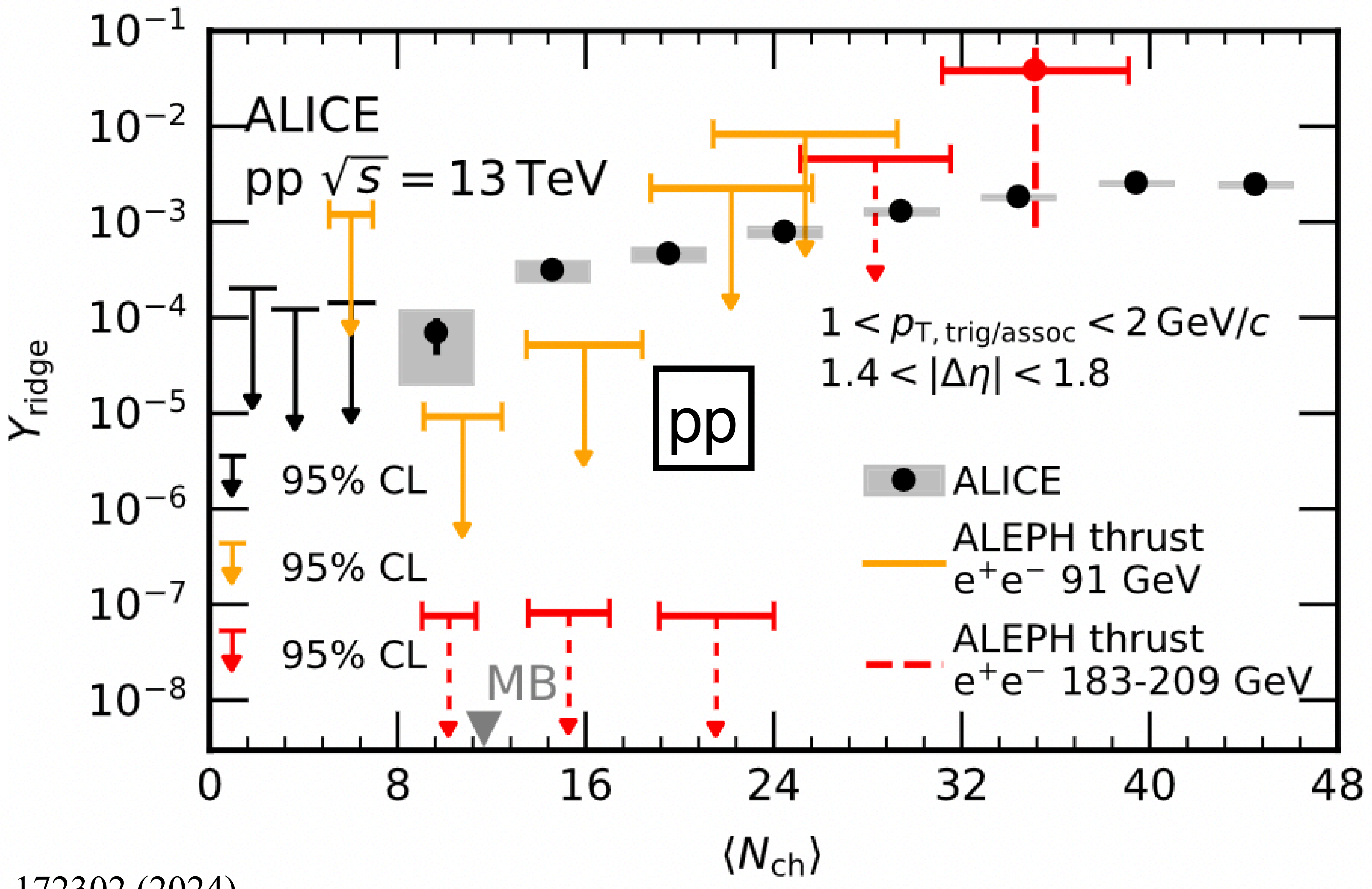
Back Up

What is the low multiplicity limit for collectivity?

Ridge yield: No non-flow subtraction





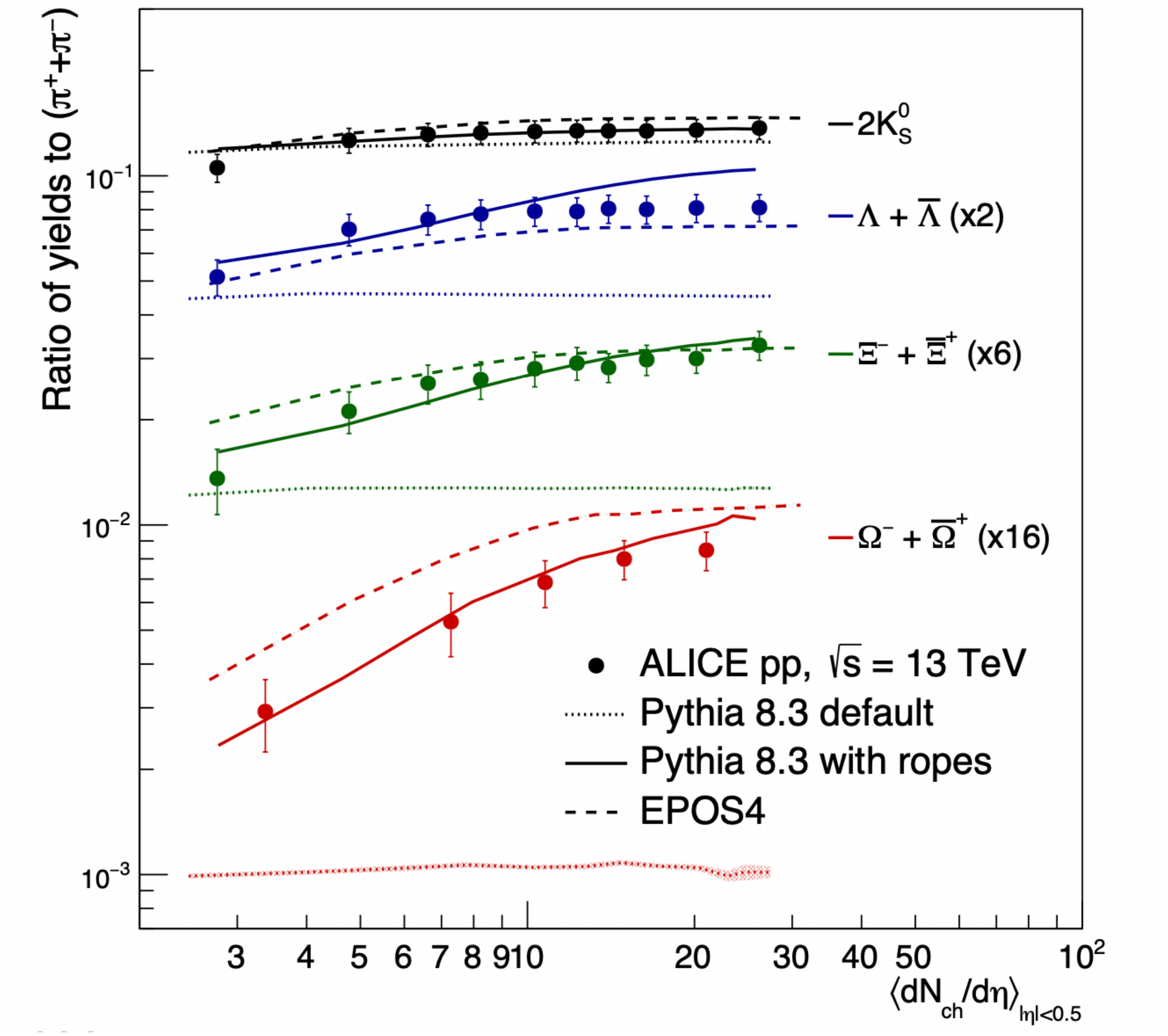


ALICE, PRL 132, 172302 (2024)

- Ridge Yield: $Y^{pp} > Y^{e^+e^-}$ 5σ (best) at 91 GeV;   6.3σ (best) at 183–209 GeV
- Correlation at mid-rapidity: relatively short range ($|\Delta\eta| < 1.8$), non-flow removal might depend on the kinematics.

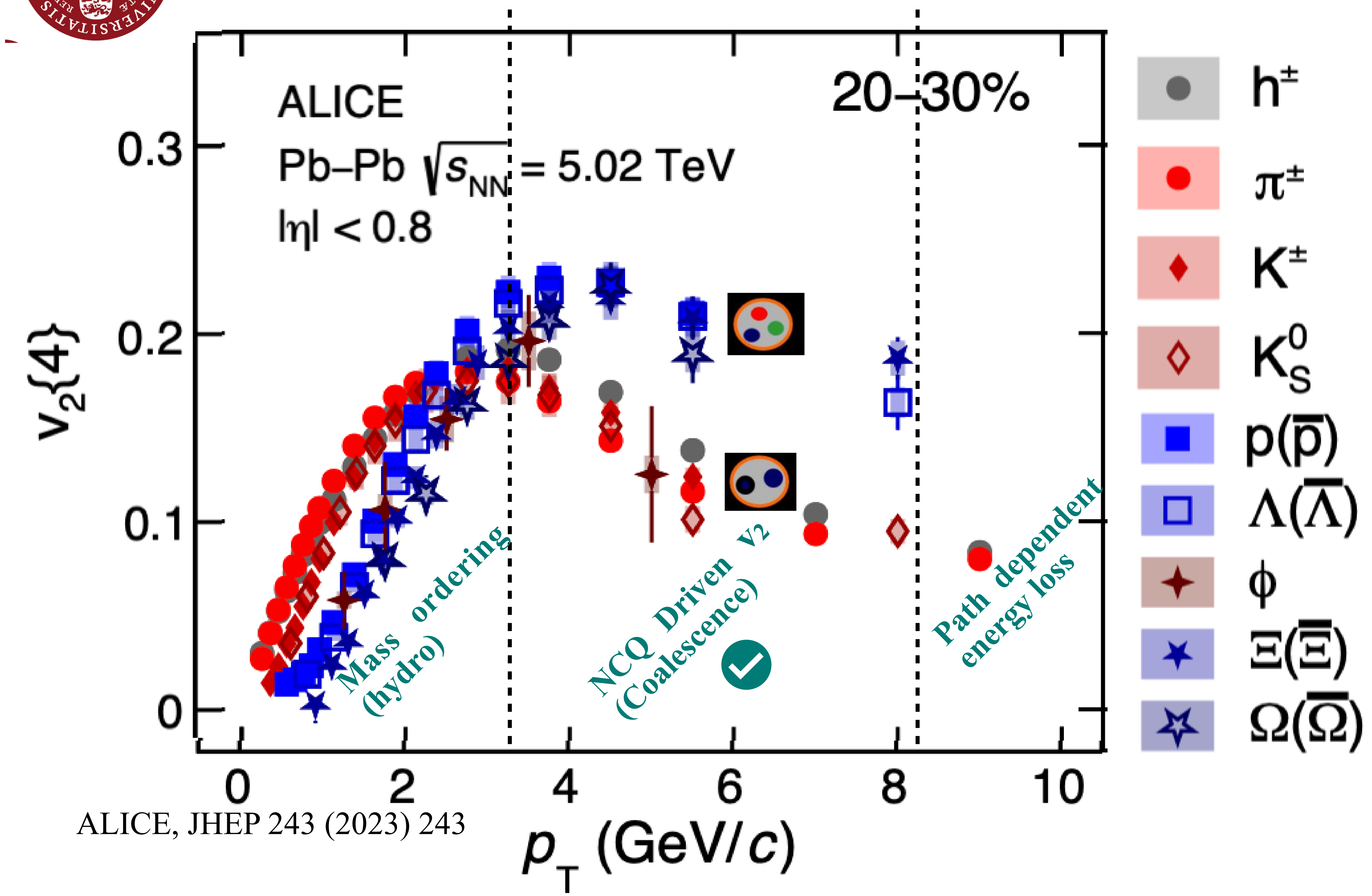
What is the origin of flow-like behavior at low multiplicity?

Initial and/or Final effects?



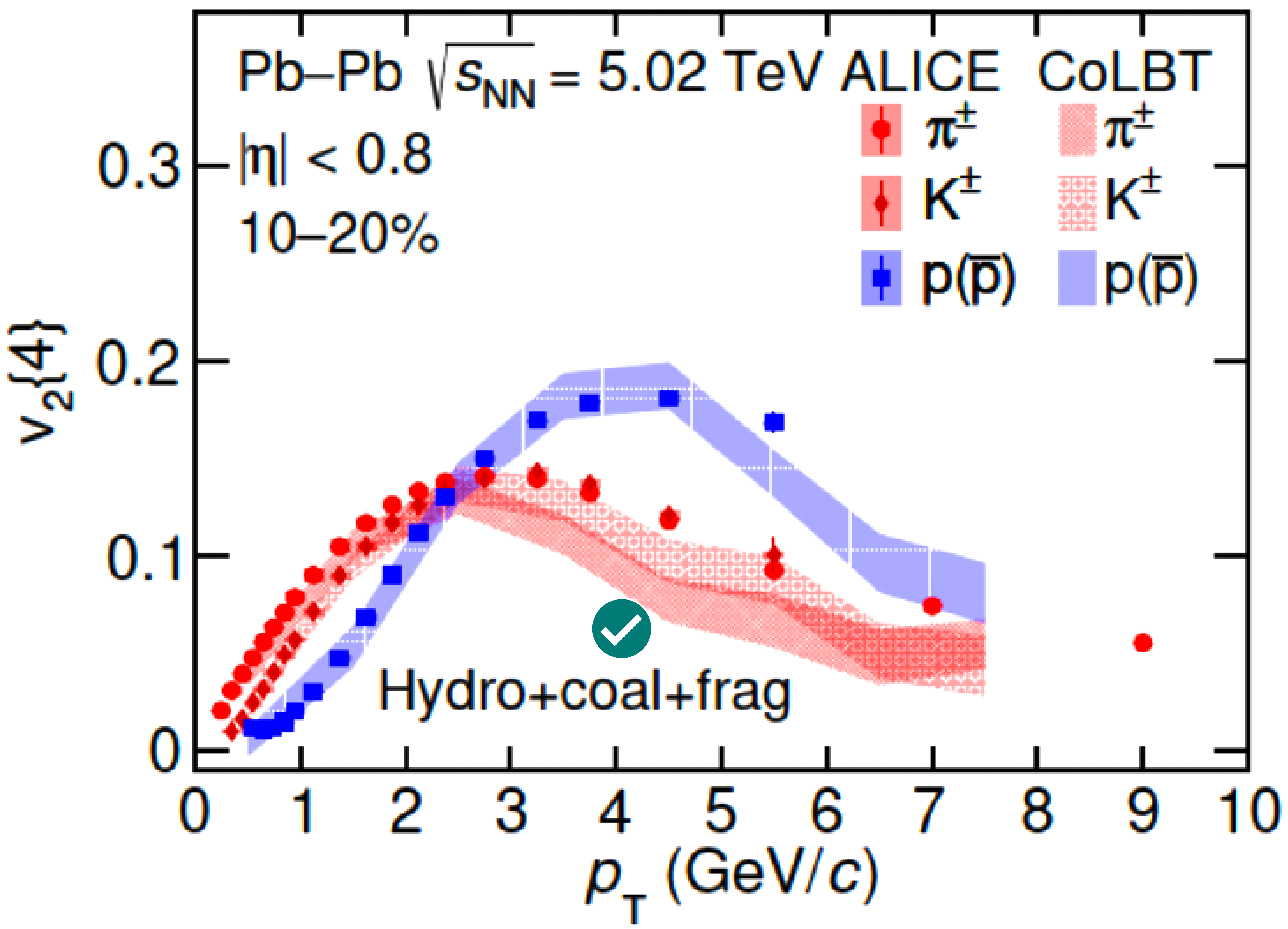
ALICE Collaboration, S.Acharya *et al.*, *Eur.Phys.J.C* 80 (2020) 8, 693

Baseline: Collective features in heavy-ion collisions



ALICE, JHEP 243 (2023) 243

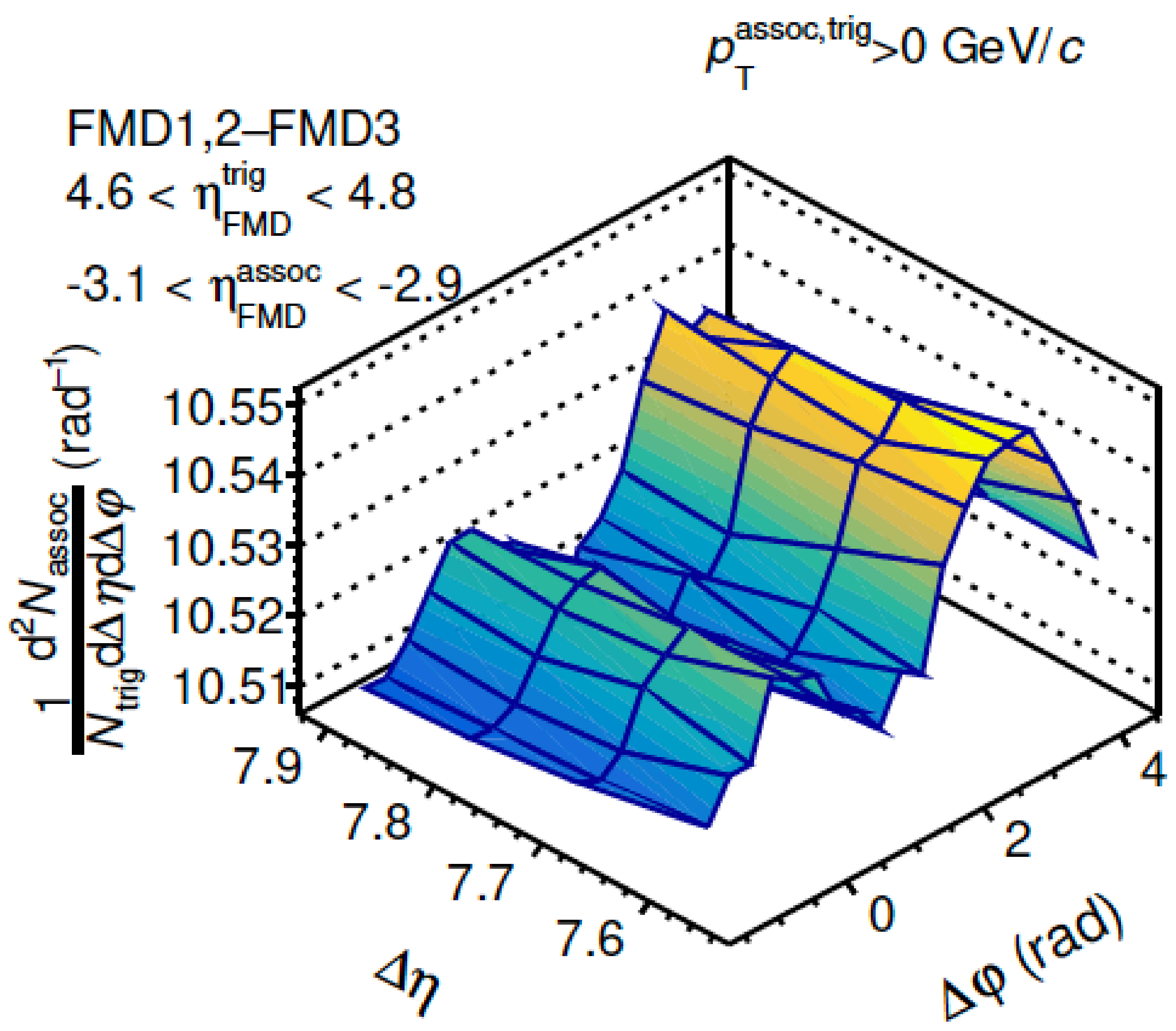
CoLBT: PRL128, 022302



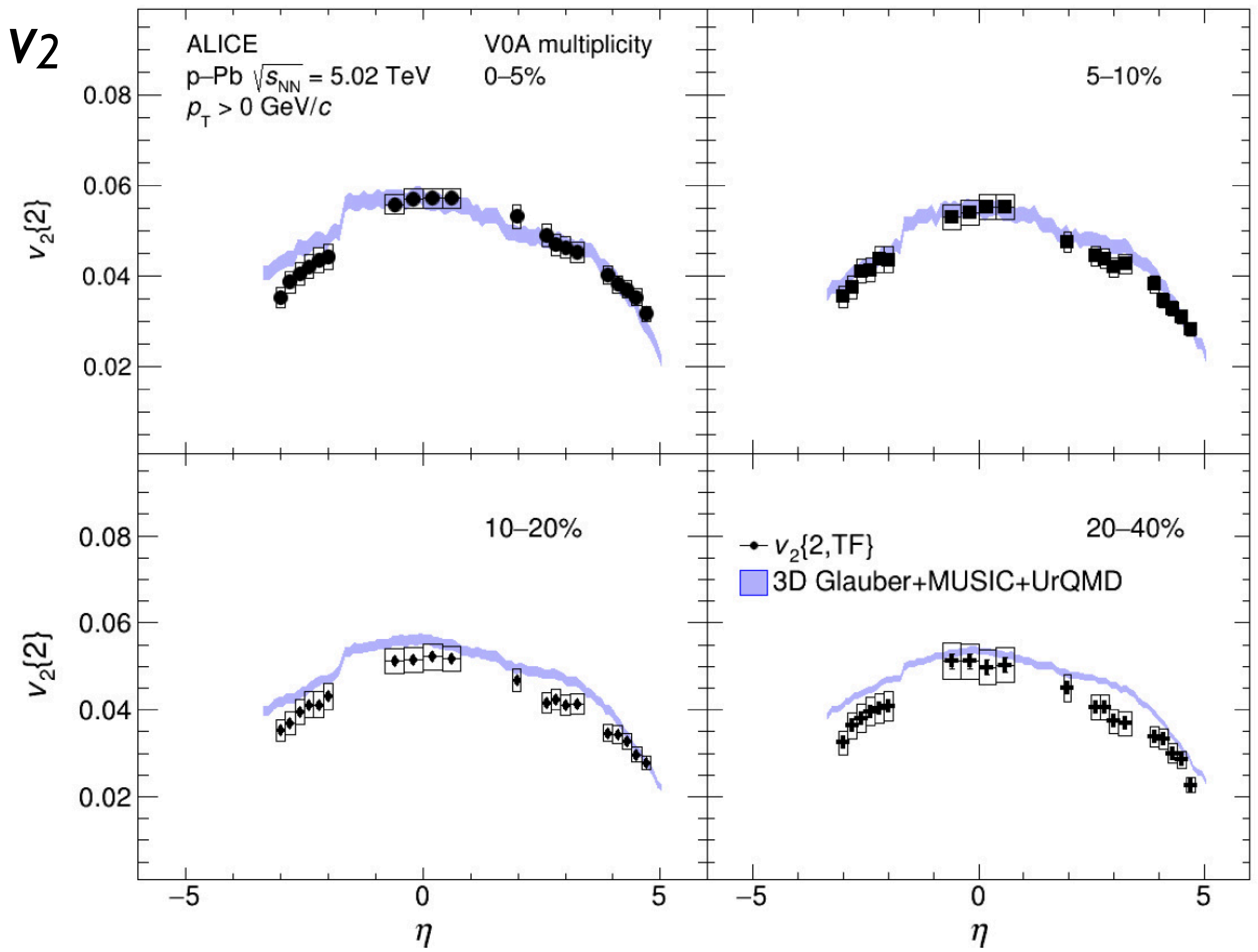
- low pT ($p_T \lesssim 3$ GeV/c) — Mass ordering —Interplay between radial and elliptic flow (hydrodynamics).
- Intermediate pT ($3 < p_T \lesssim 8$ GeV/c) —NCQ driven Baryon-meson splitting and grouping — quark coalescence, sign of partonic collectivity (✓).
- Well described by the model with hydro and quark-coalescence(✓).

Searching collectivity: We have come a LONG way…

ALICE, JHEP01(2024)199



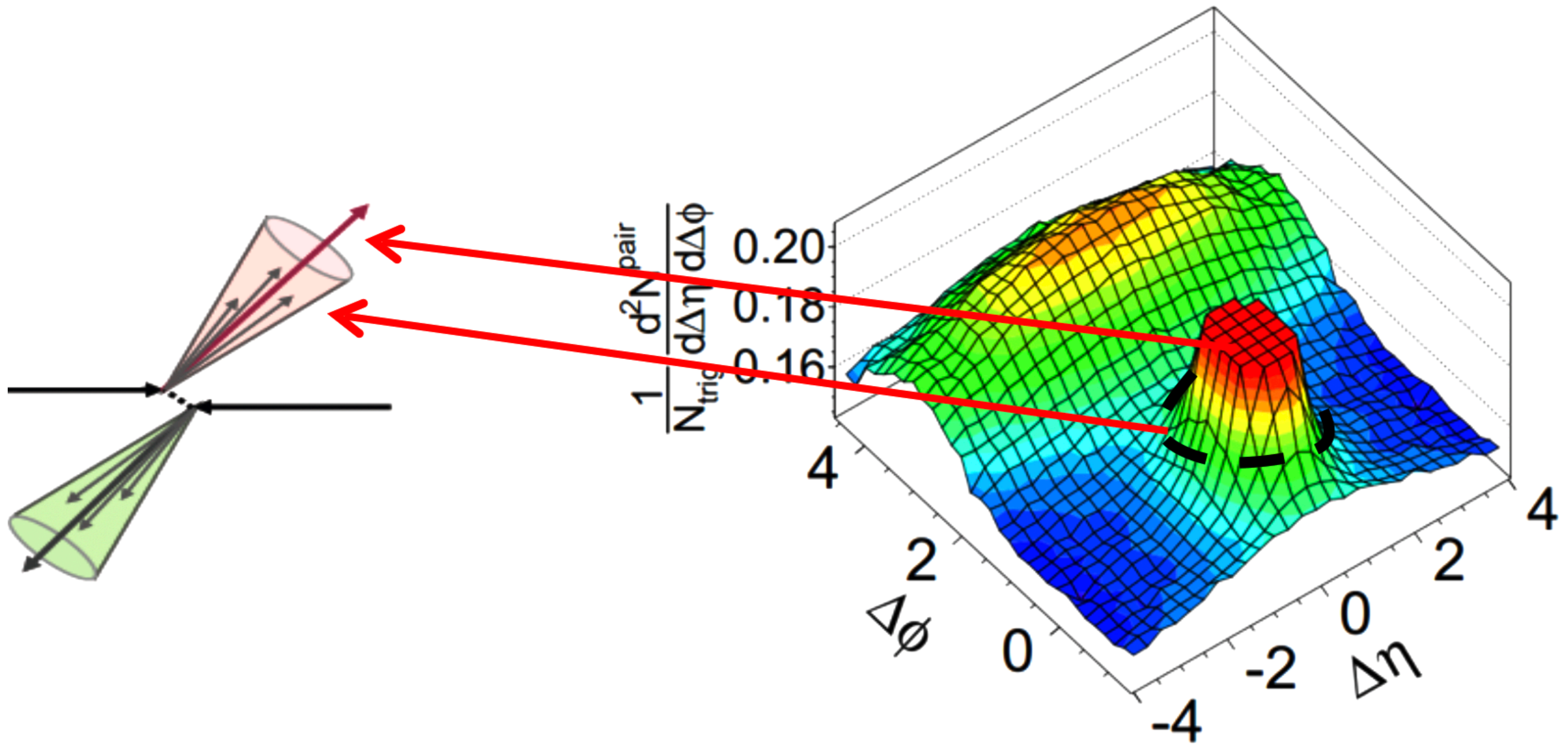
ALICE, JHEP01(2024)199



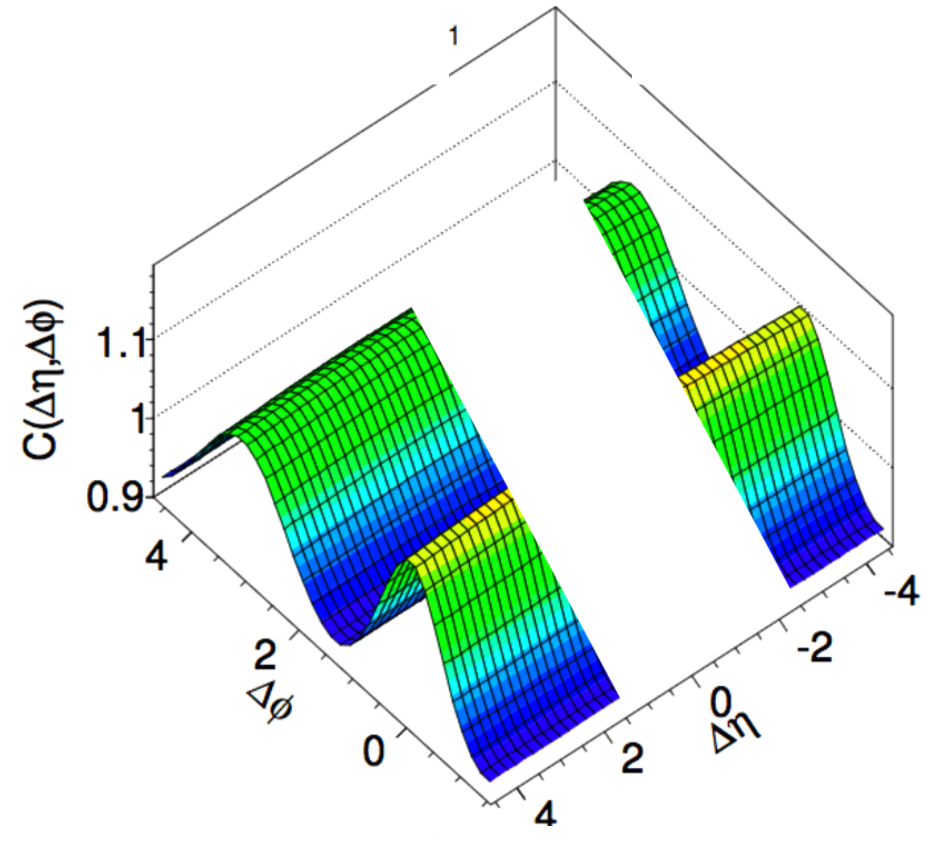
$$v_n\{2\} = \sqrt{\frac{V_{n\Delta}^{\mathrm{TPC-FMDA}} V_{n\Delta}^{\mathrm{TPC-FMDC}}}{V_{n\Delta}^{\mathrm{FMDA-FMDC}}}}$$

3 X 2 PC method

Non flow: need to be removed

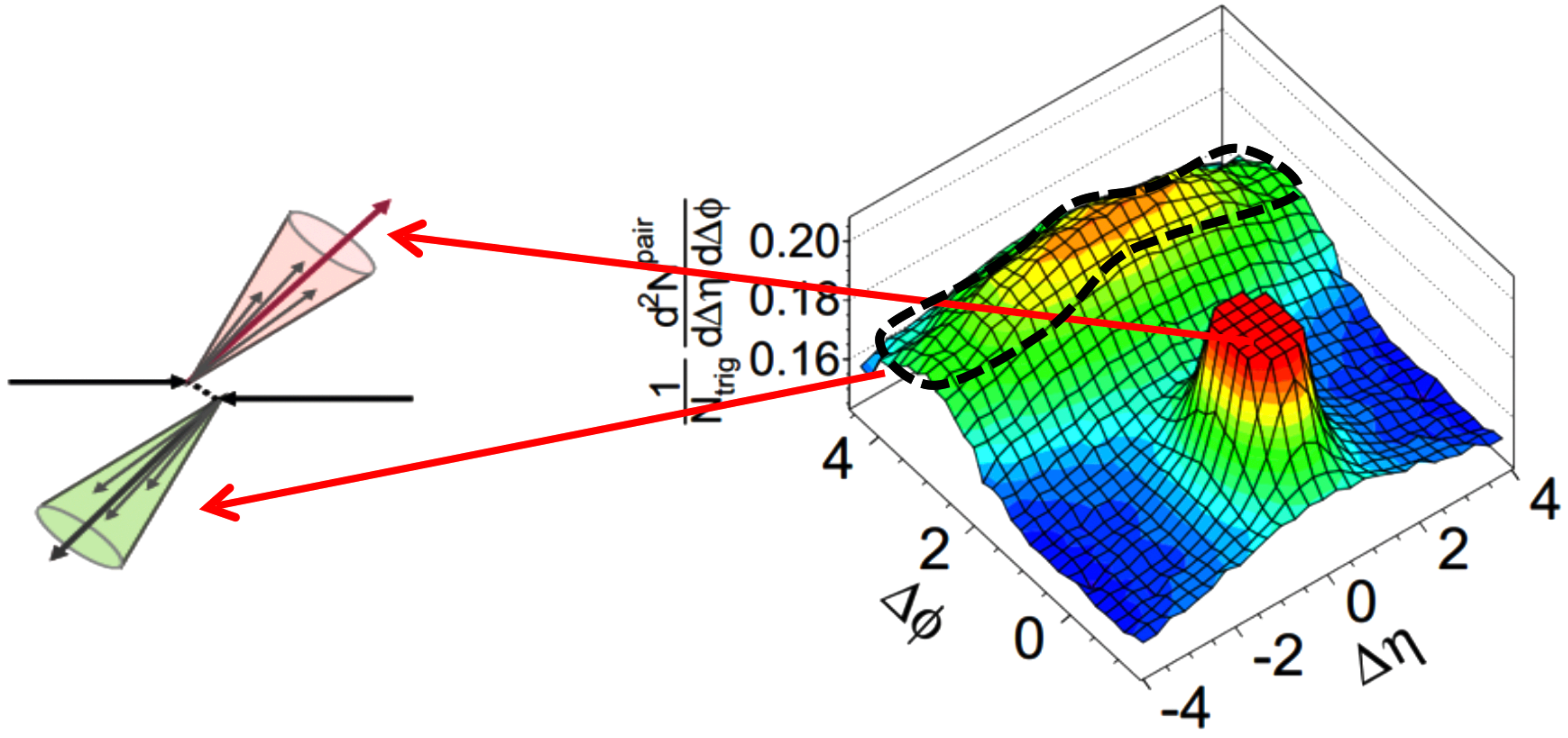


Near-side ($\Delta\eta$, $\Delta\varphi$~ 0) correlations from single jets

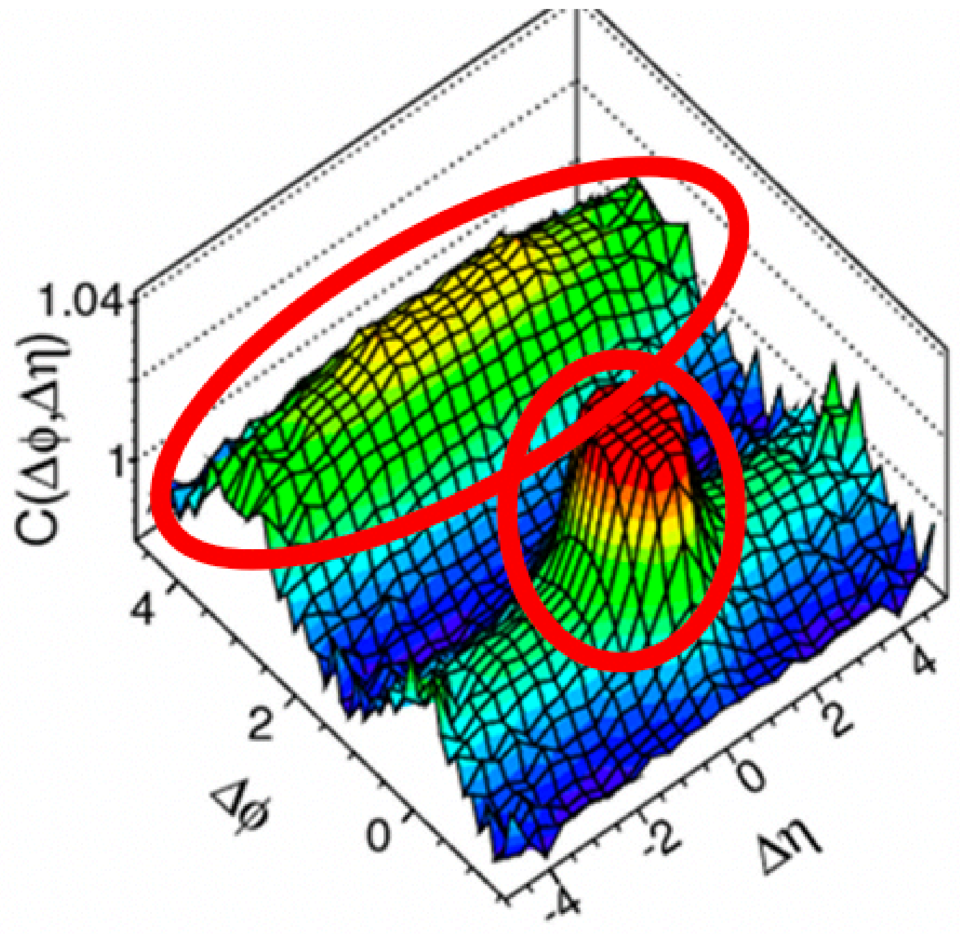


A+A

Issue— non-flow removal.



Will discuss in detail…



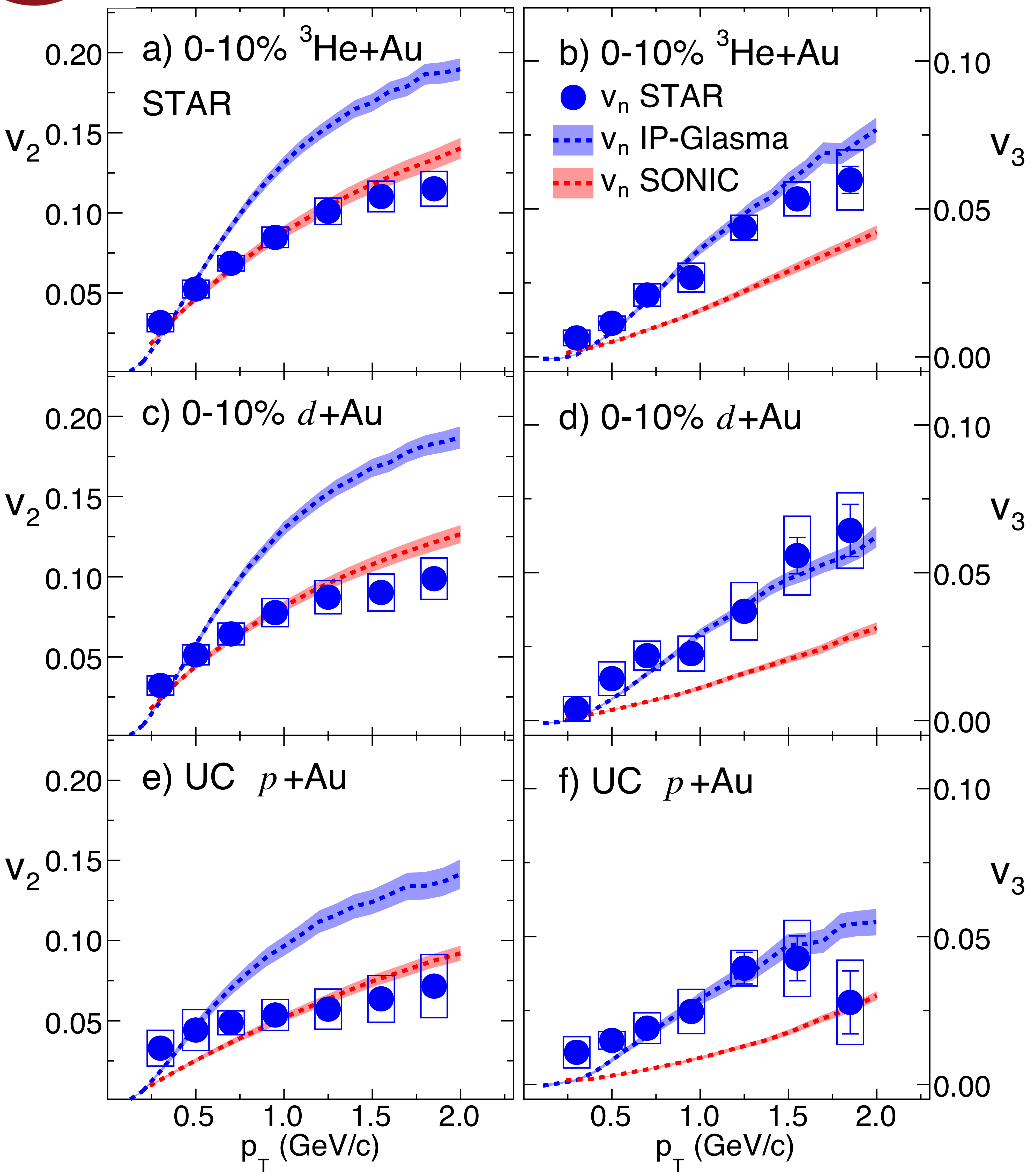
p+A

Away-side ($\Delta\varphi$ ~ π) back-to-back jet correlations:
two jets may have different rapidities: $\Delta\eta \neq 0$

Major issue— non-flow removal.

Possible Initial State effects + Hydro

STAR, Phys. Rev. Lett. 130, 242301 (2023)



$v_2^{p+Au} < v_2^{d+Au} \approx v_2^{{}^3He+Au}$ (Expected hydro ordering)

$v_3^{p+Au} \approx v_3^{d+Au} \approx v_3^{{}^3He+Au}$ (Different from PHENIX!!)

$v_3^{p+Au} \approx v_3^{d+Au} < v_3^{{}^3He+Au}$

See talk by S. Huang: Link

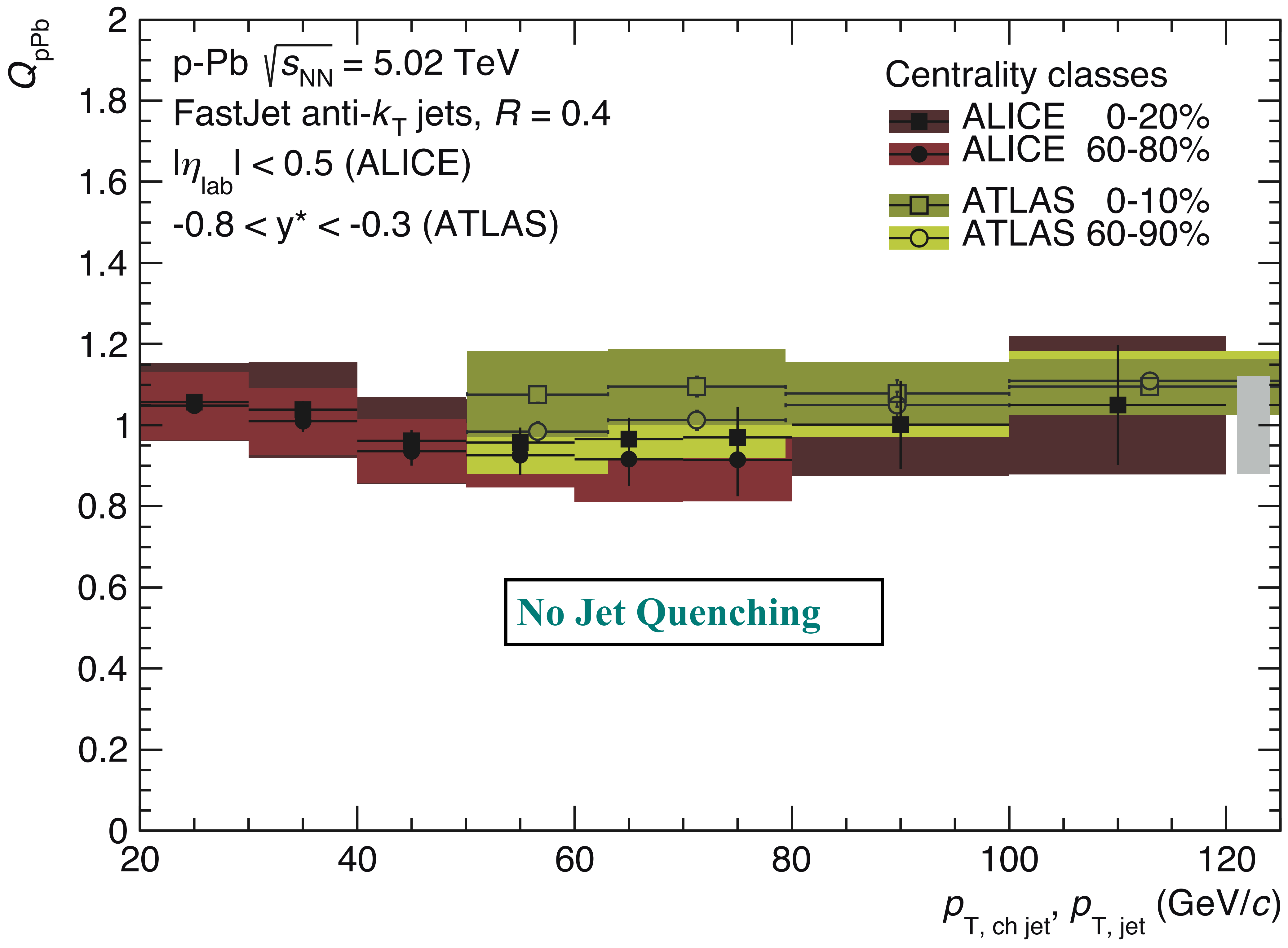
- IP-Glasma+MUSIC+URQMD (sub-nucleonic fluctuations + CGC + preflow). Describes v_3 —overestimates v_2.

Model: B Schenke, C Shen , P Tribedy; Phys. Lett. B 803, 135322 (2020)

- Possible contributions: (nucleonic + sub-nucleonic) fluctuations + Pre flow + CGC + clustering + ? —any universal recipe?

Boost invariant approaches fine?

Similarity with heavy-ions?



ALICE, EPJC, **volume 76**, 271 (2016)

- No evidence of jet-quenching in p–Pb.
- partonic collectivity can still be probed — probe the NCQ driven baryon-meson splitting and grouping of v_2 at intermadiate p_T (🔍).

- Physics Letters B 726 (2013) 164–177 :

Low statisticcs, large uncertianty. No definite baryon-meson v_2 grouping and splitting at intermediate p_{T}

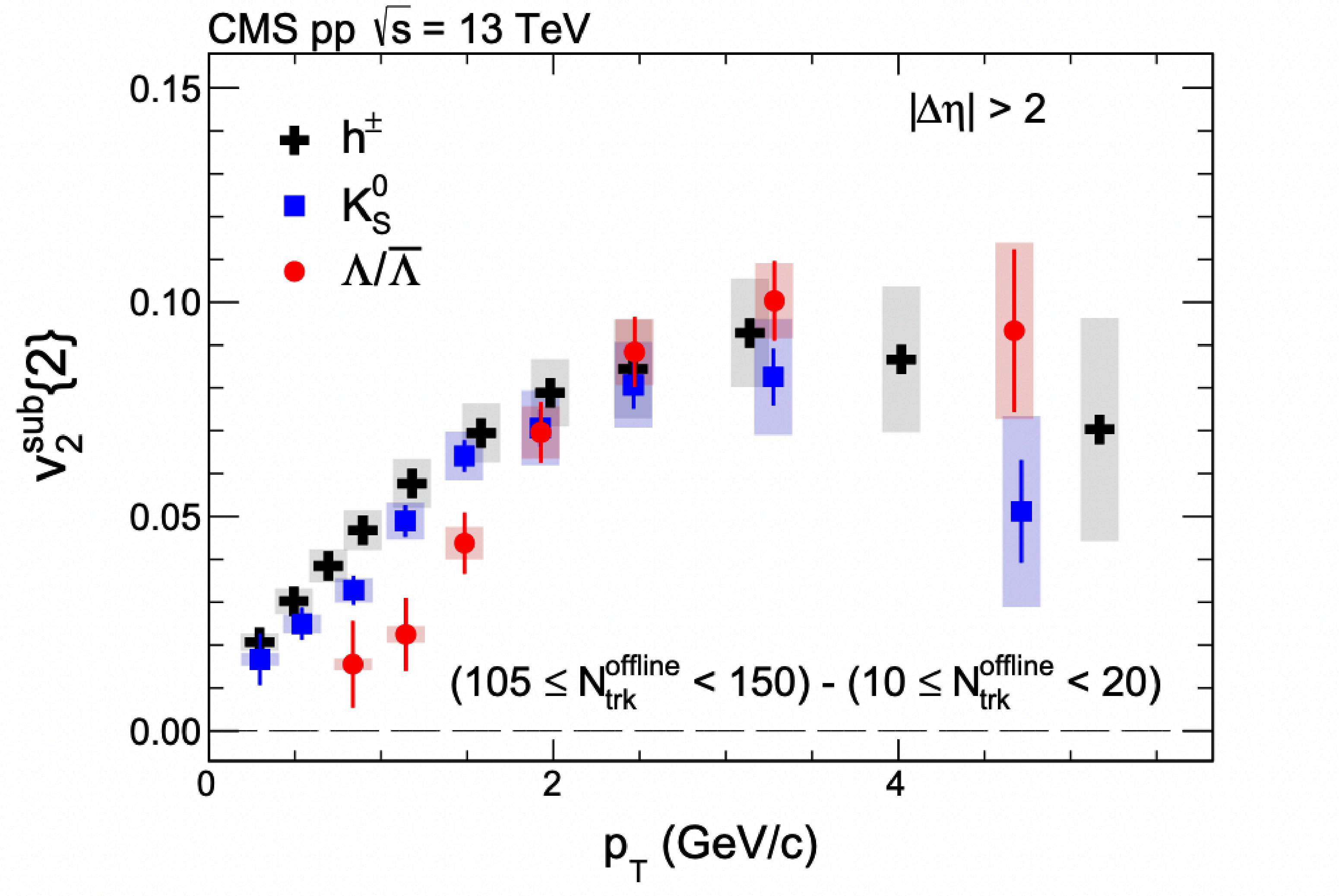
Low multiplicity subtraction without any scaling of the jet yield.

Ridge at low multiplicity can be PID dependent. So, over-subtraction can be PID dependent —may create PID depedencies in the results after subtraction.

- Phys.Lett.B 765 (2017)193

Low multiplicity subtraction without taking into account of the ridge at low multiplicity.

No splitting between baryon and meson v_2 observed at intermediate p_{T}.



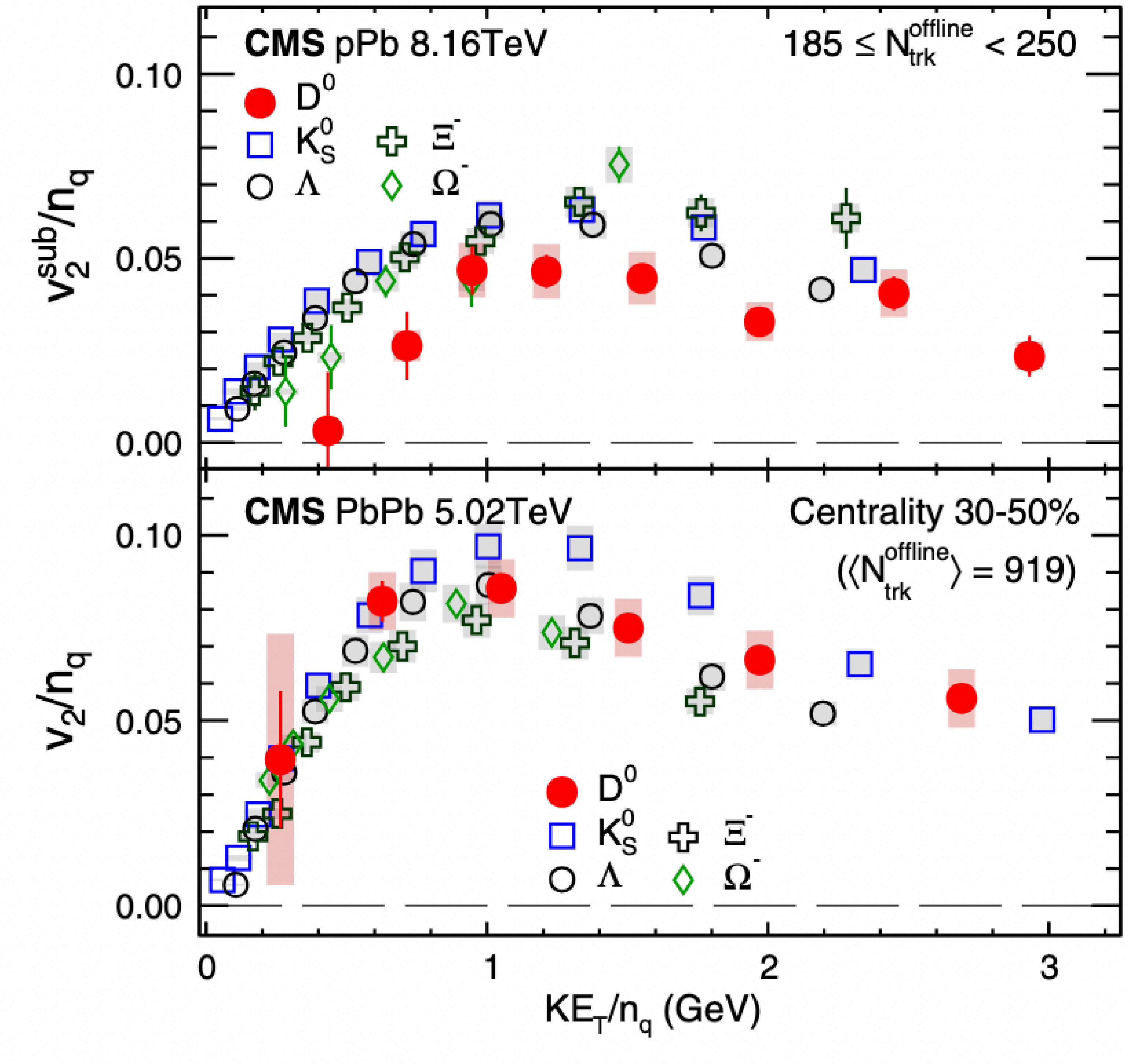
- Phys. Rev. Lett. 121, 082301 (2018):

Low multiplicity subtraction.

Ridge at low multiplicity can be PID dependent. So, over-subtraction can be PID dependent —may create PID depedencies in the results after subtraction.

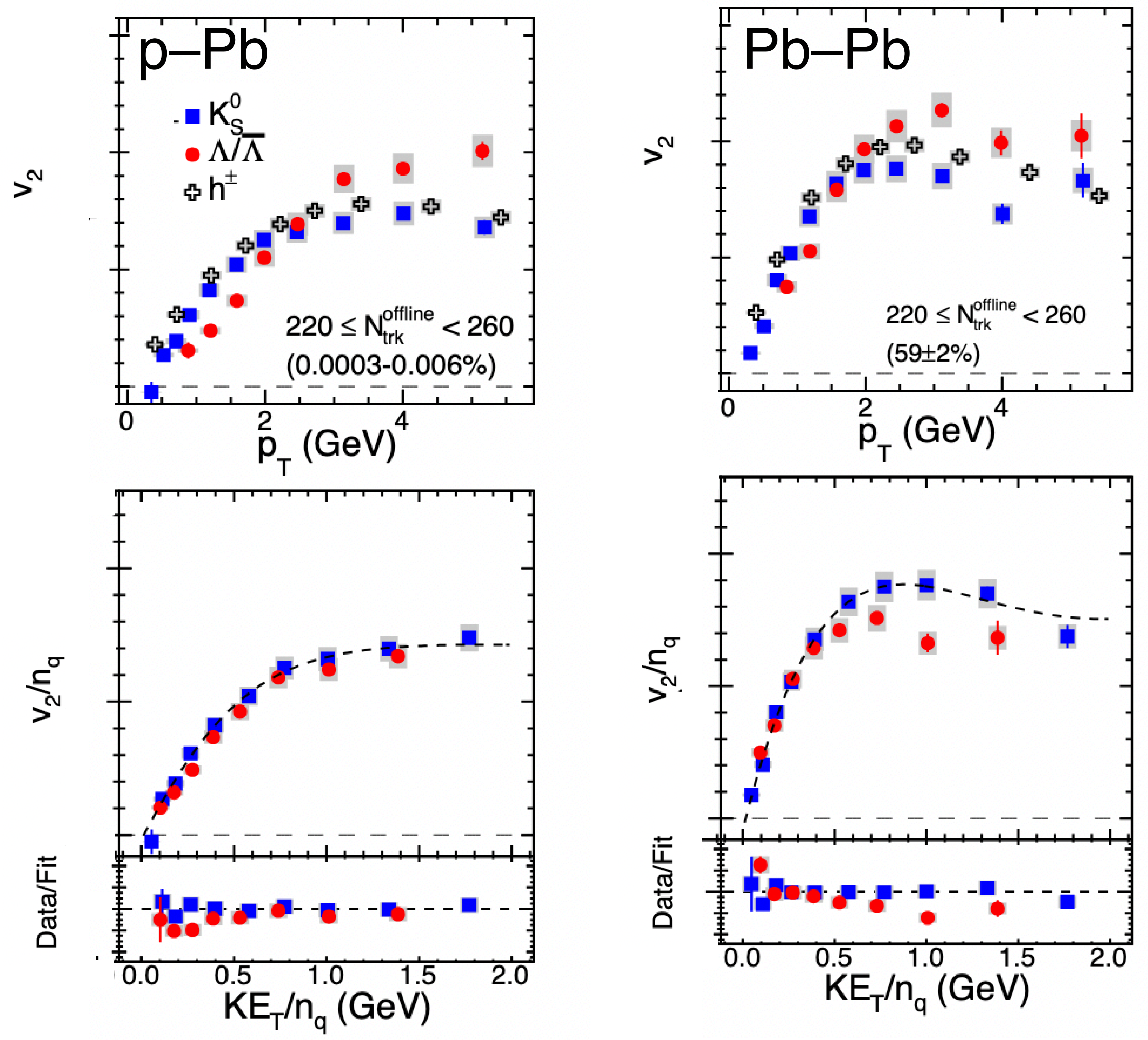
The Ω baryon v_2 is consistent with other baryons only at a single p_T point (~3.5 GeV).

The NCQ scaling holds better in p–Pb (non-flow might be an issue) compared to the Pb–Pb where QGP formation is confirmed!



- Phys. Lett. B 742 (2015) 200:

No explicit non-flow subtraction. v_2 is extracted by fitting the long-range ($|\Delta\eta| > 2$) azimuthal correlation function using a Fourier decomposition.



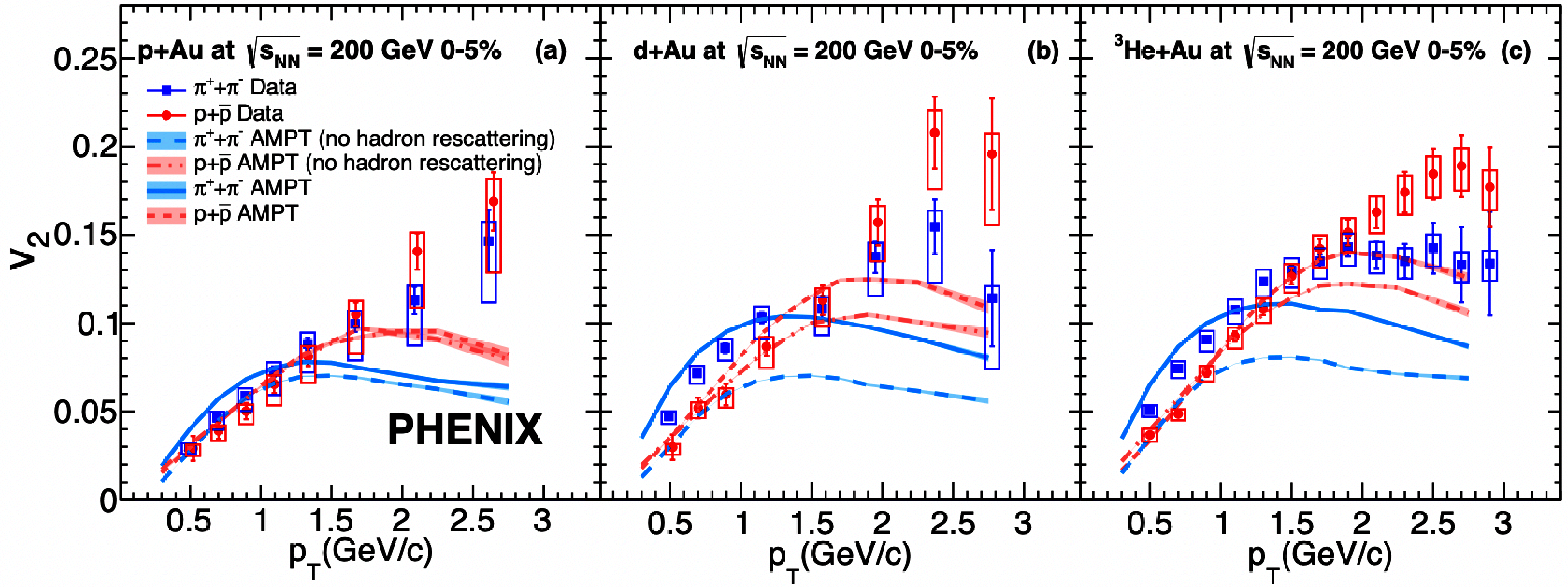
NCQ scaling is violated in Pb–Pb collisions, where QGP formation is well established.

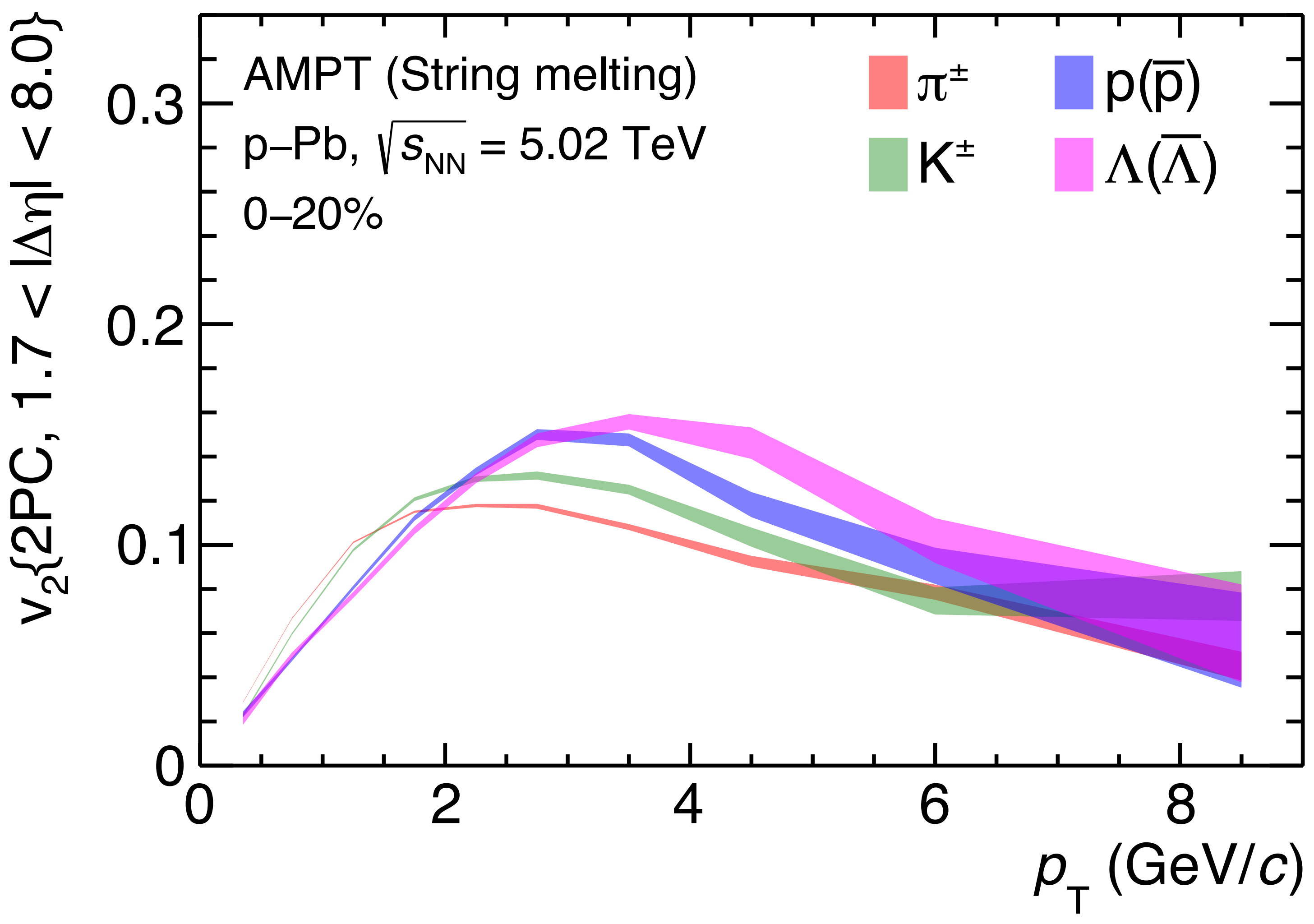
whereas the scaling appears to hold better in p–Pb collisions, despite no non-flow subtraction!

- Phys.Rev.C 97 (2018) 064904:

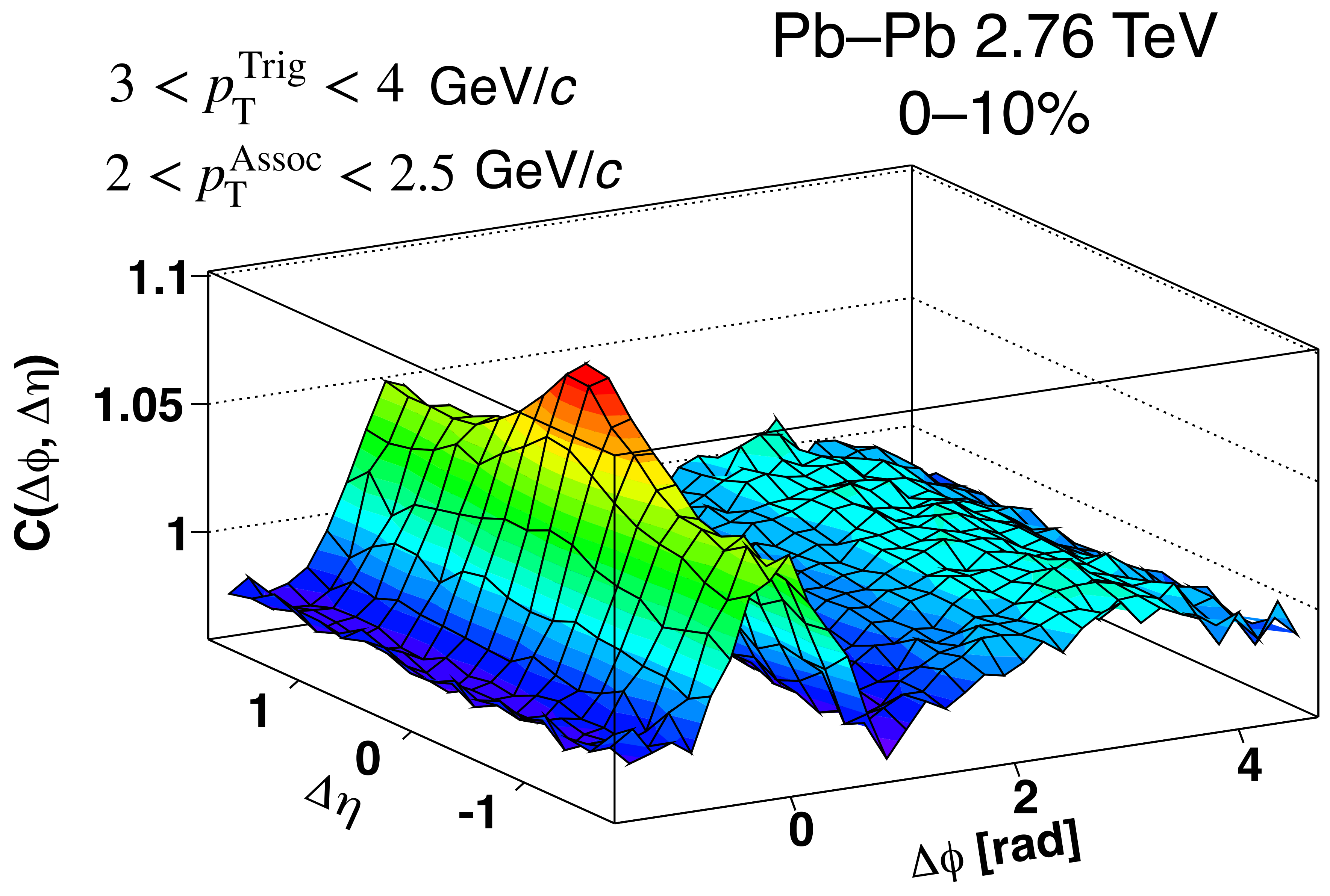
Event plane method. Susceptible to non-flow.

It includes only a single meson and baryon species, limiting the generalizability of the observed grouping.

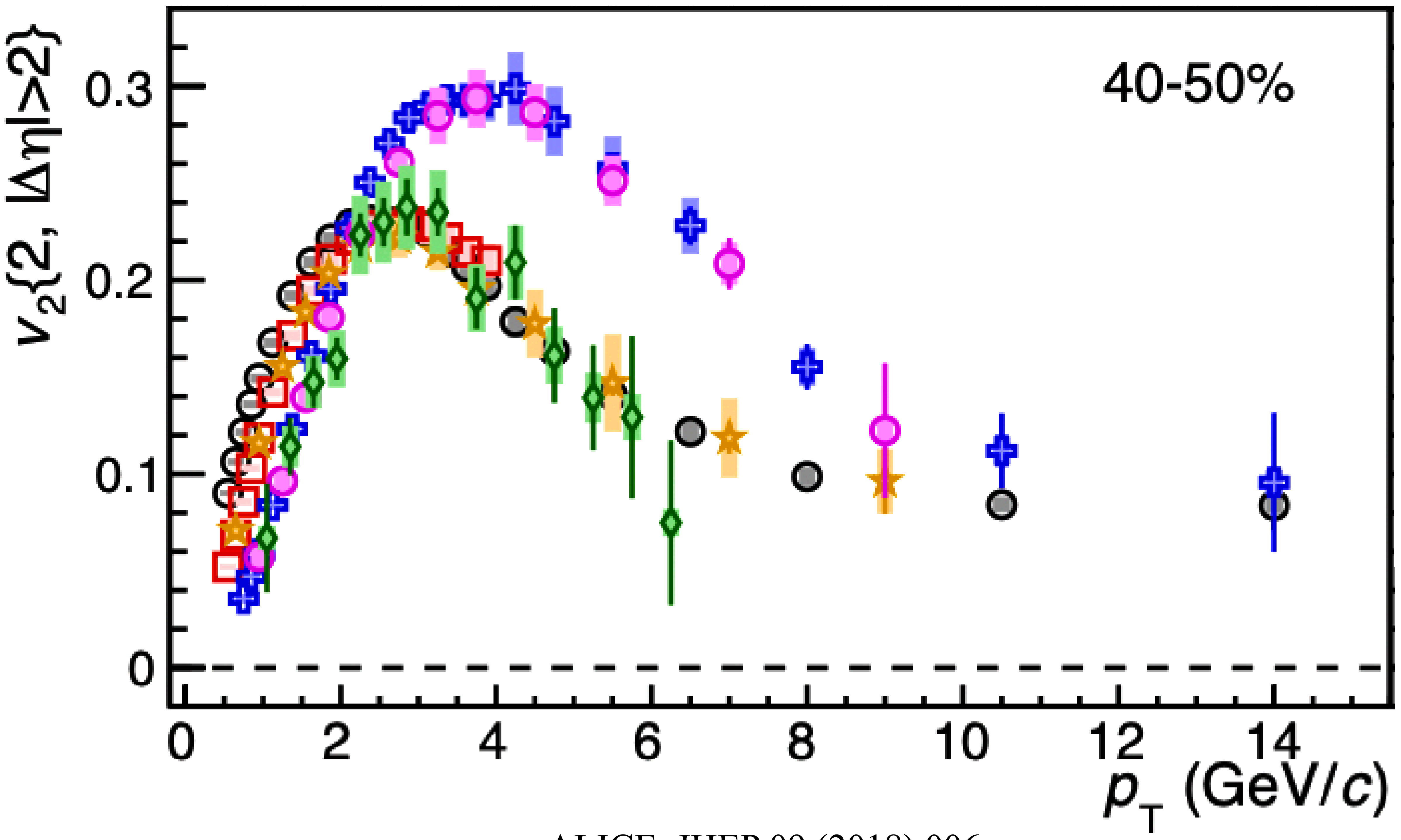




Baseline: Collective features in heavy-ion collisions



ALICE, PLB 708 (2012) 249-264



ALICE, JHEP 09 (2018) 006

- Low p_T ($p_T \lesssim 3$ GeV/c) — Mass ordering —Interplay between radial and elliptic flow (hydrodynamics).