Two-particle correlation and flow of identified hadrons in small systems at LHC energies

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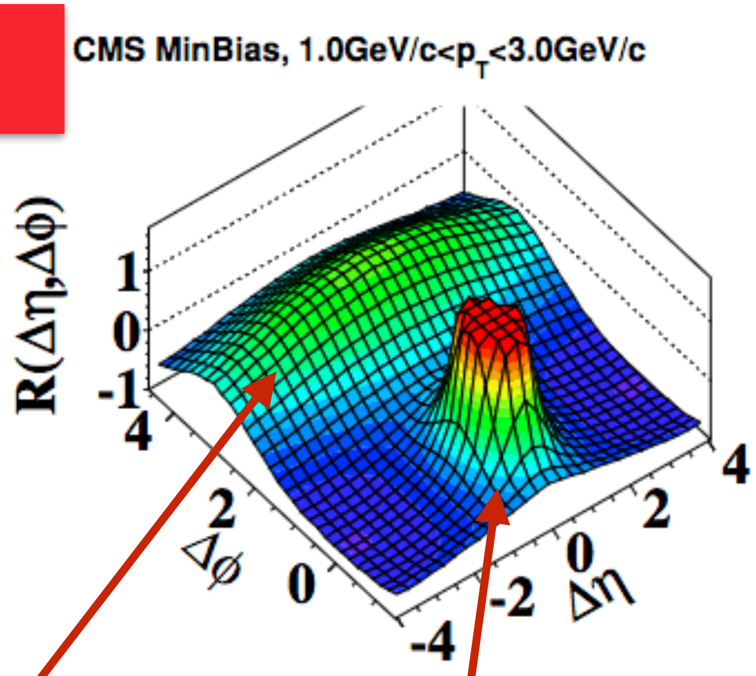
9th International Workshop on Multiple Partonic Interactions at the LHC, Shimla, India

Di-Hadron ridge structures

pp

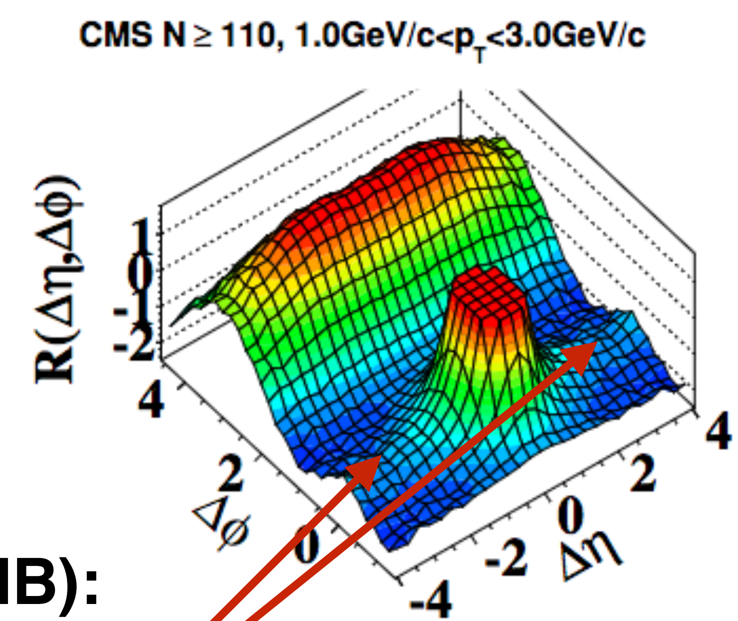


Away side
(Δφ≈π)

Near side
(Δφ≈0, Δη≈0)

Minimum-bias pp:

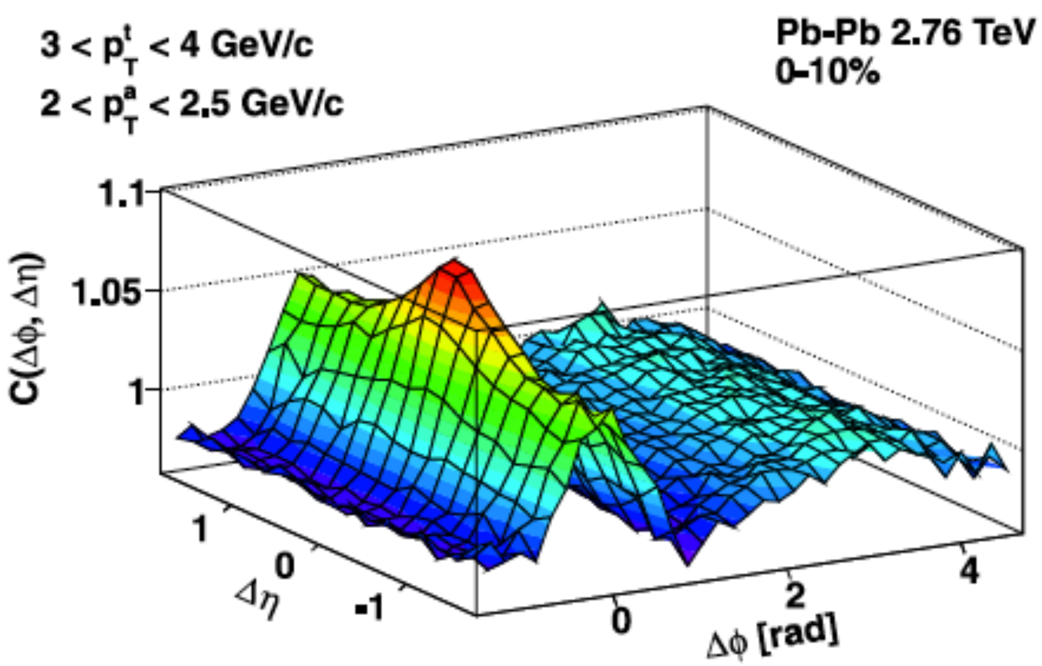
- ❖ Jet peak on the near side + resonances, *etc.*
- ❖ Recoil jet on the away side



High multiplicity (0.0005% of MB):

- ❖ Near side ridge
- ❖ Origin still to be fully understood!

Pb-Pb



Central (0-10%) Pb-Pb:

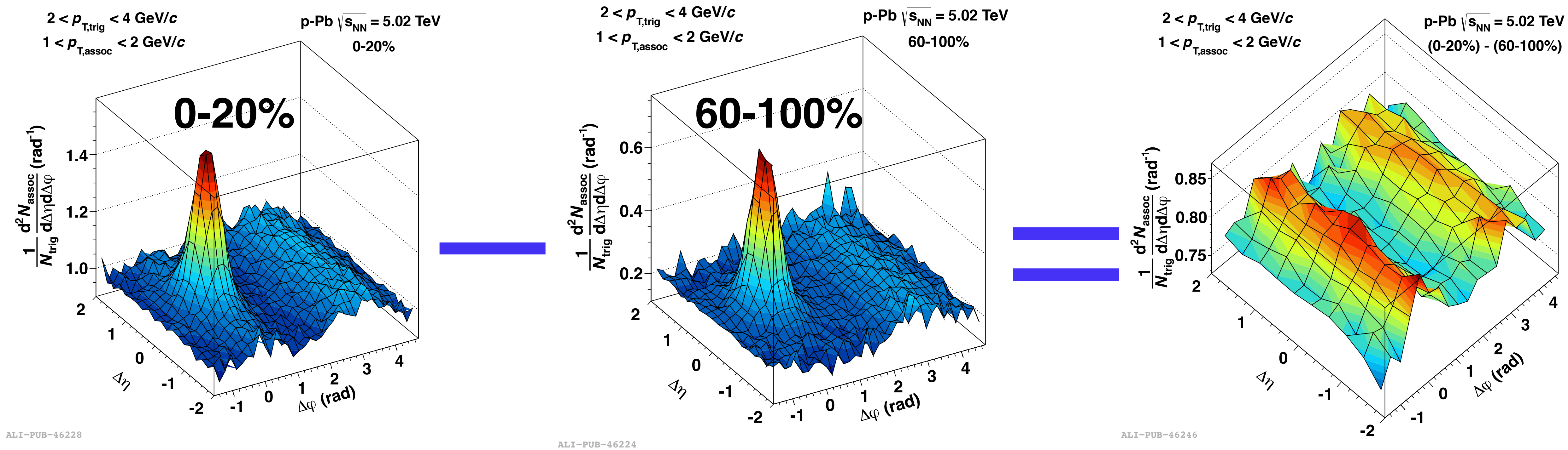
- ❖ Near side ridge structure
- ❖ Long range correlation in Δη

ALICE Phys. Lett. B 708, 249-264 (2012)
ATLAS Phys. Rev. C 86, 014907 (2012)
CMS JHEP 09, 091 (2010)
B. Schenke *et al.*, Phys. Rev. Lett. 106, 042301 (2011)

Di-Hadron ridge structures

p-Pb

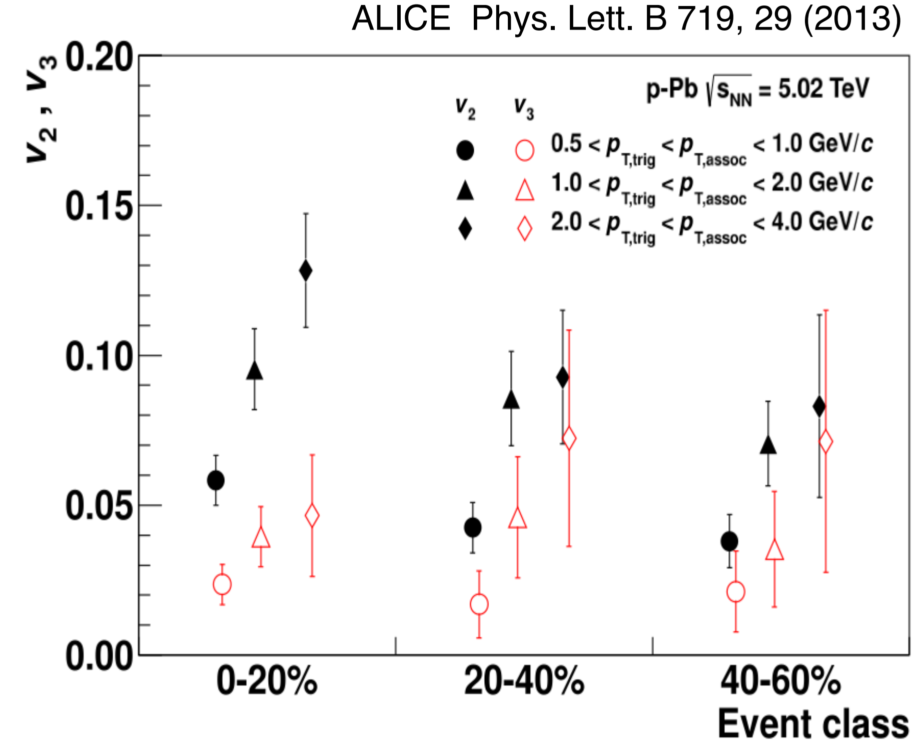
Jet contribution reduced by subtracting low multiplicity event classes



High multiplicity p-Pb events:

- Long range structure on both the near and away side
- Double ridge in p-Pb
- Quantified using Fourier decomposition

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



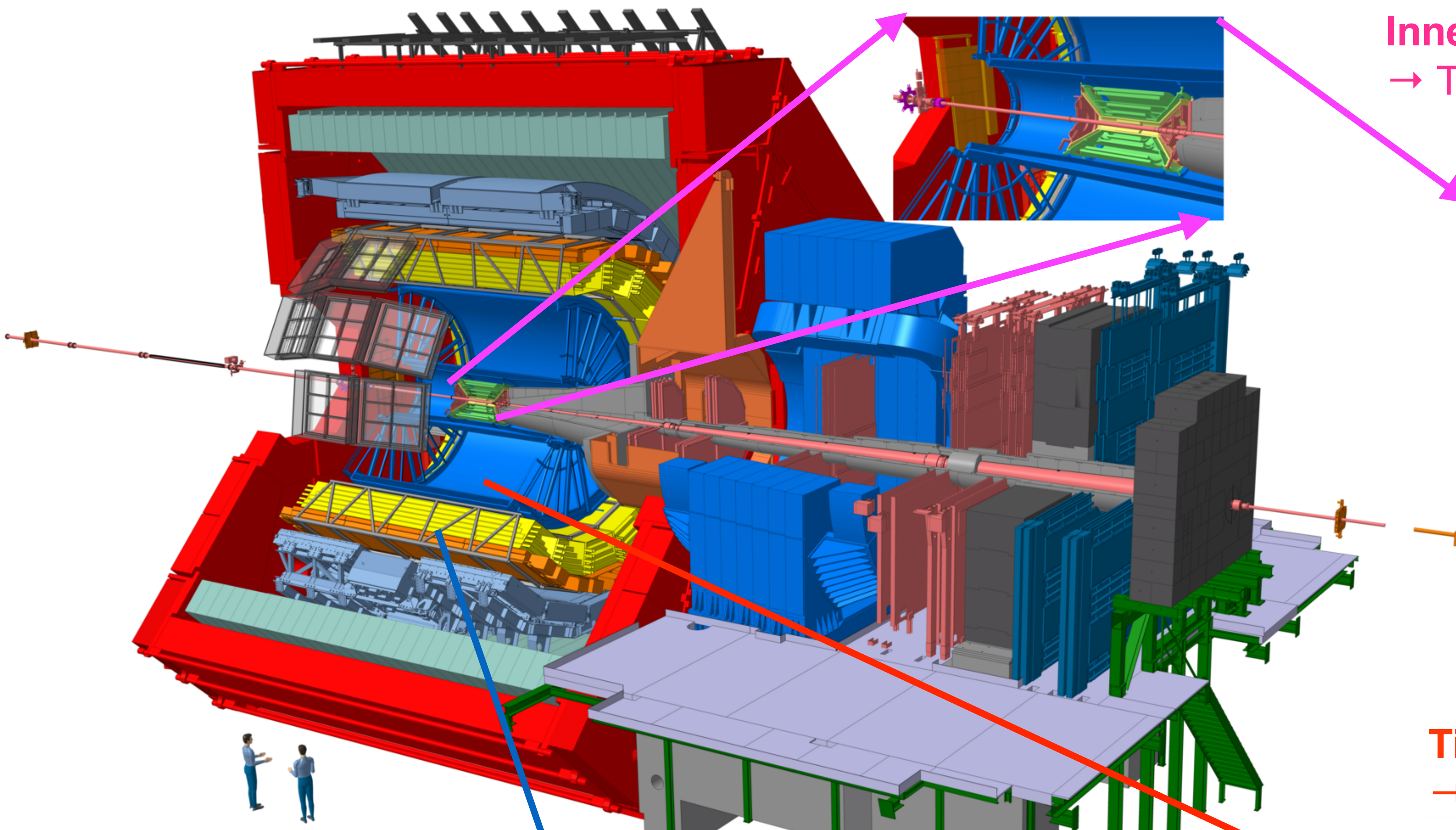
Final state effects:

Multiparticle interaction, Collective effects

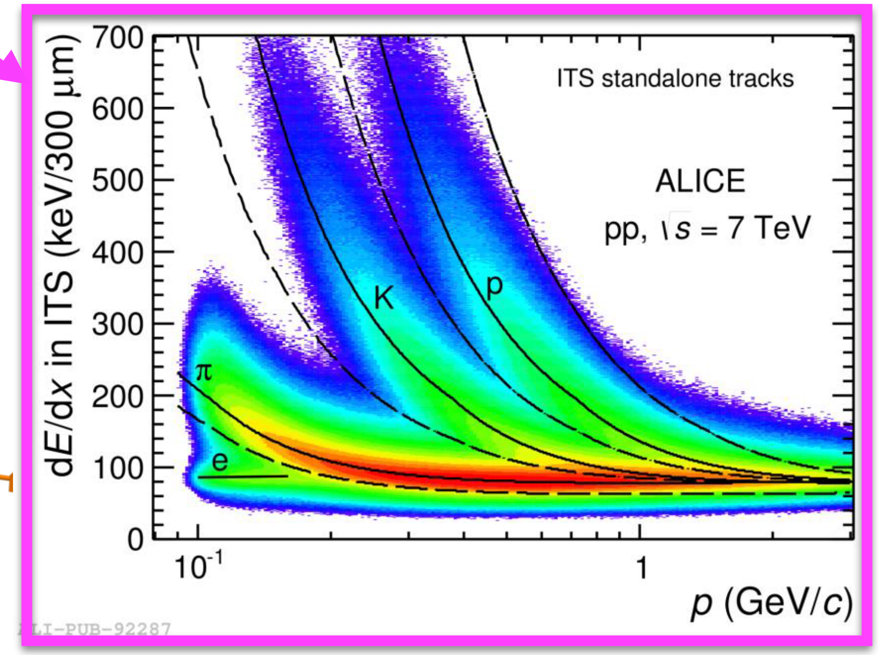
Small system: Does it flow or not?

-Particle identification might shed light

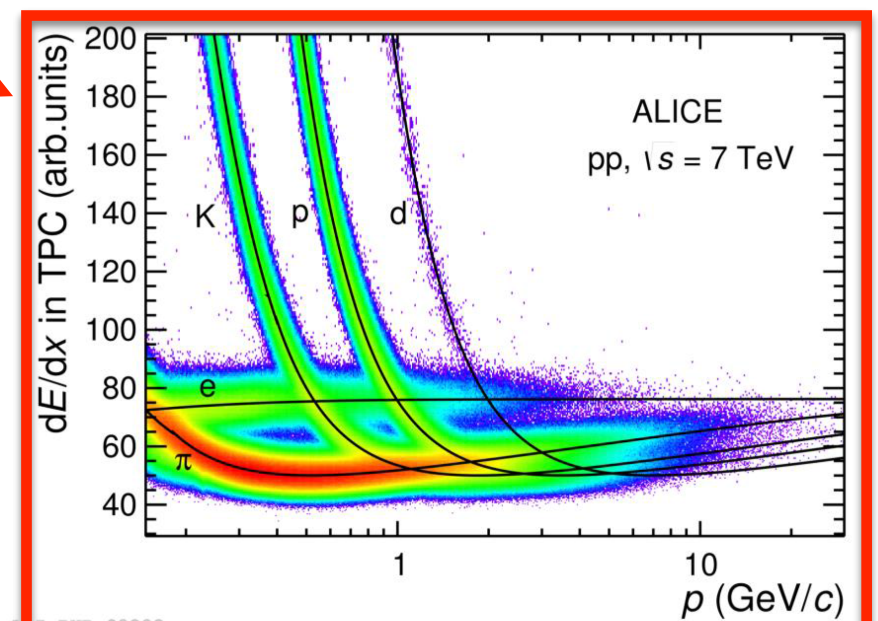
Particle identification in ALICE



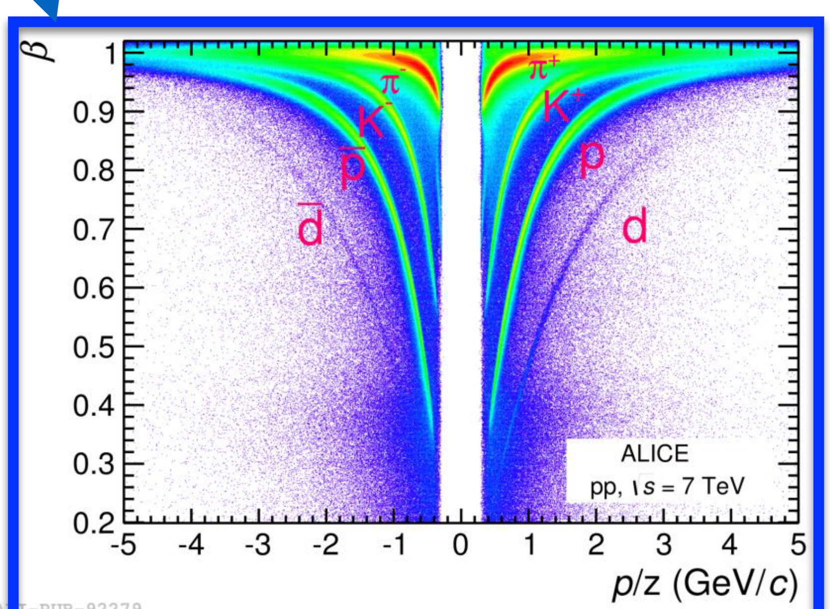
Inner Tracking System (ITS) : (|η| < 0.9)
→ Tracking, vertex, PID (dE/dx)



Time Projection Chamber (TPC): (|η| < 0.9)
→ Tracking, vertex, PID (dE/dx)



Time of Flight (TOF)
(|η| < 0.9)
→ PID



More details:
Int. J. Mod. Phys. A 29, 1430044 (2014)

Collectivity in Small Systems

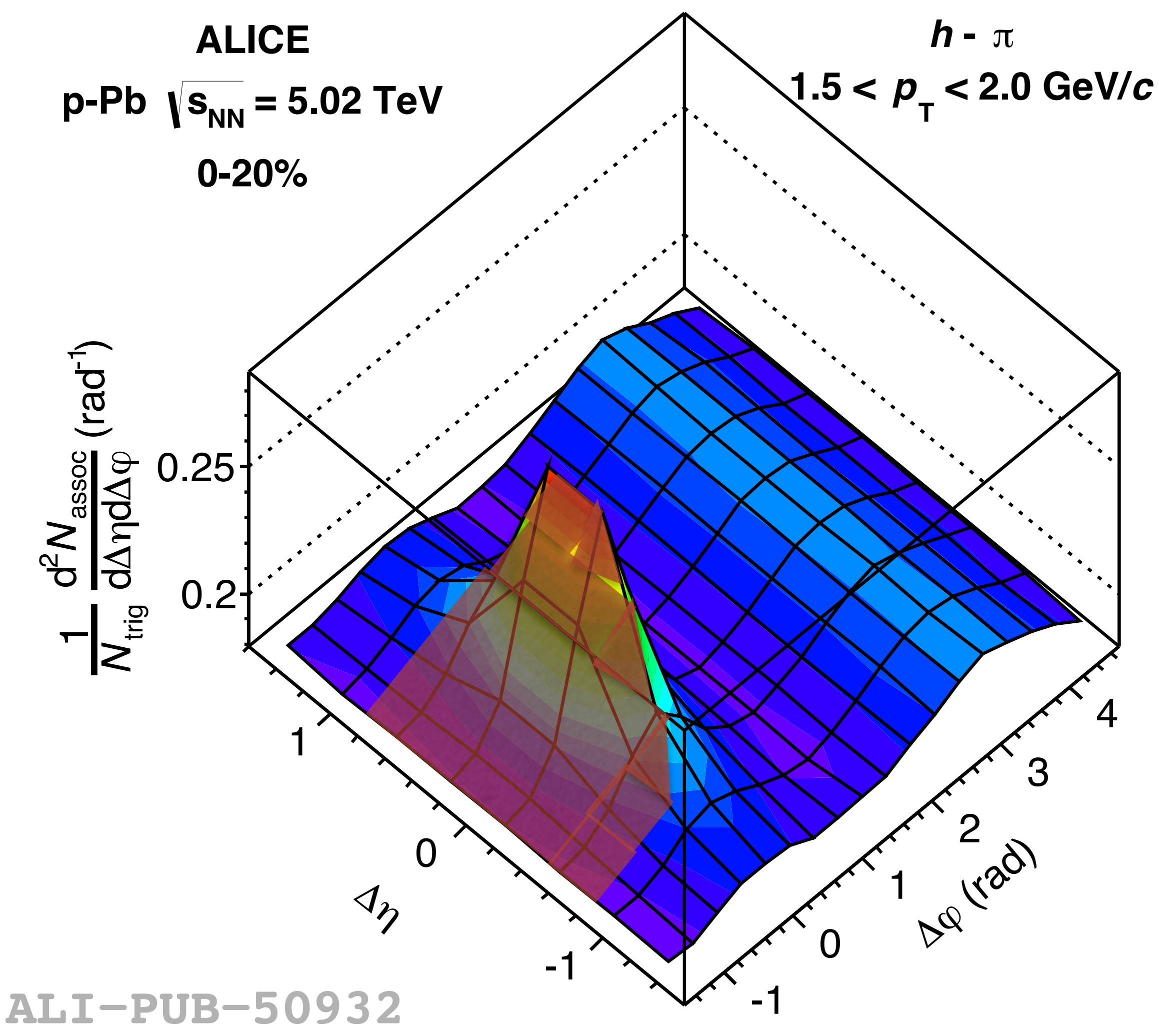
Part-I : Di-Hadron Correlations

Associated yield per trigger particle

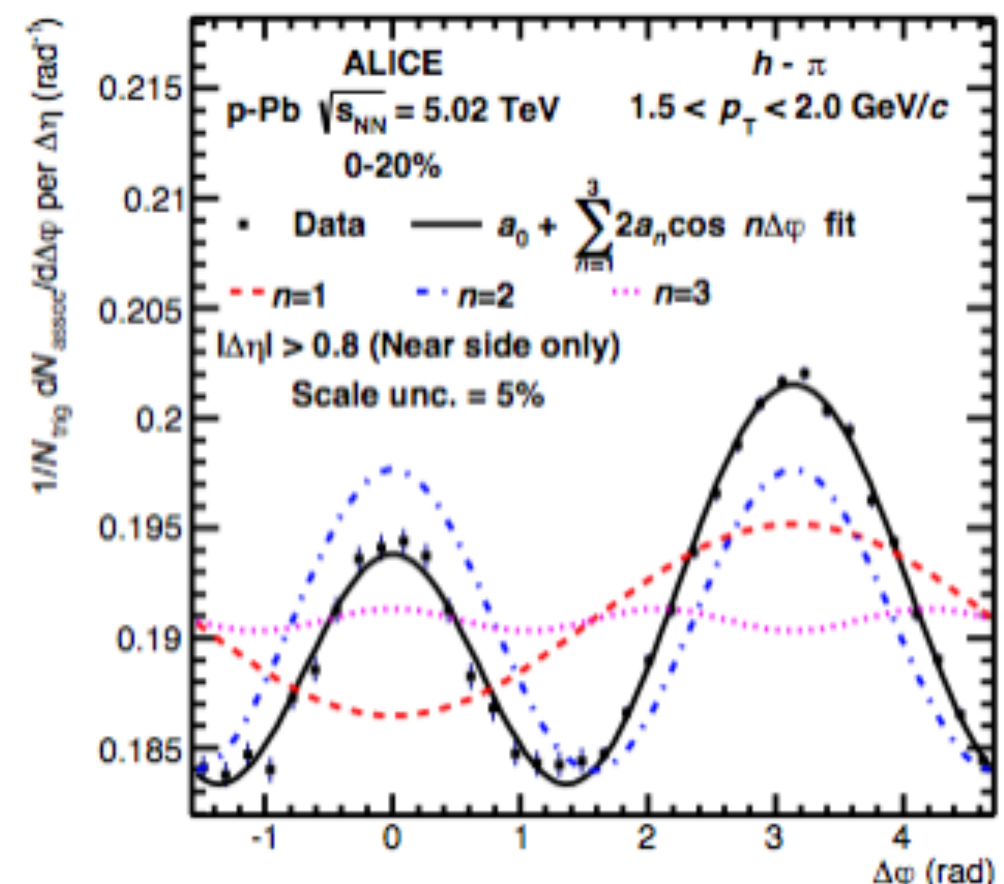
$$\frac{1}{N_{\rm trig}}\frac{d^2N_{\rm assoc}}{d\Delta\eta d\Delta\varphi} = \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)}$$

$$S(\Delta\eta,\Delta\varphi) = 1/N_{\rm trig}\ d^2N_{\rm same}/d\Delta\eta d\Delta\varphi$$

$$B(\Delta\eta,\Delta\varphi) = \alpha\, d^2N_{\rm mixed}/d\Delta\eta\, d\Delta\varphi$$



Near side jet peak excluded (|Δη|<0.8)

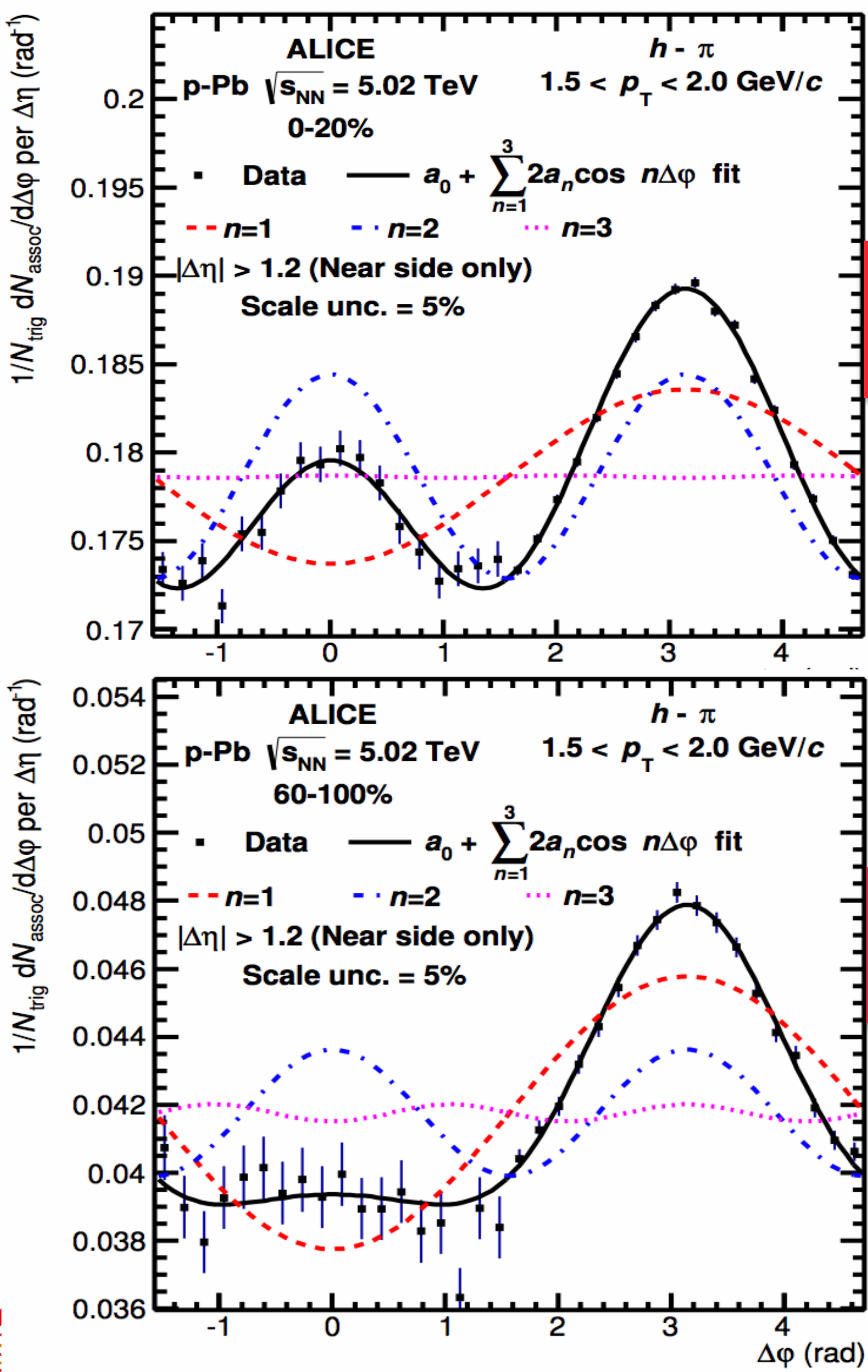


Good fit with 3 components:
- First component large due to recoil jet
- a_2 given by jet + ridge
- a_3 much smaller than the other components

No significant ridge and energy loss

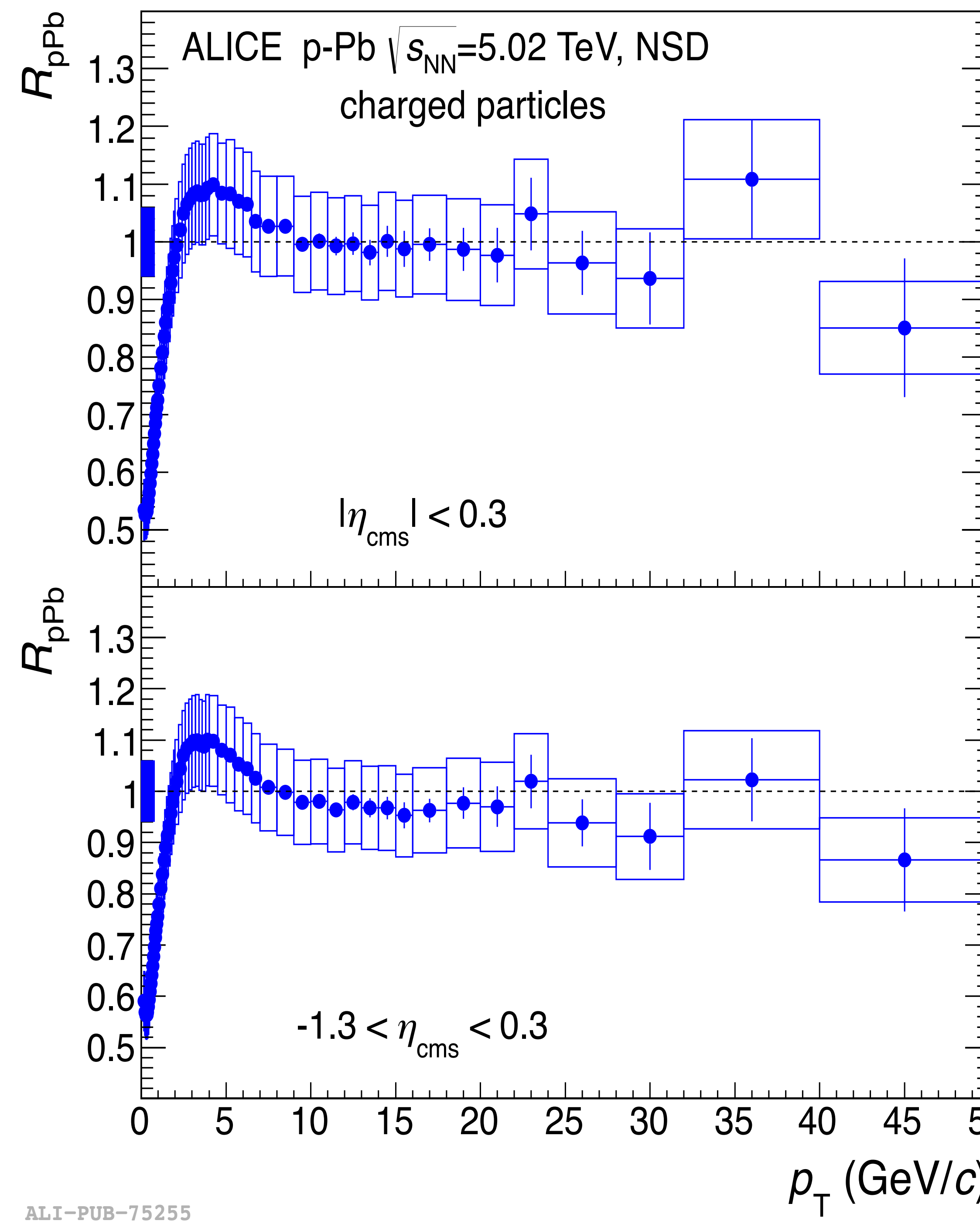
Jet contribution reduced assuming:

- Mostly jet contribution (i.e. no significant ridge) in low multiplicity p-Pb events
- No significant medium effect in the energy loss / jet fragmentation

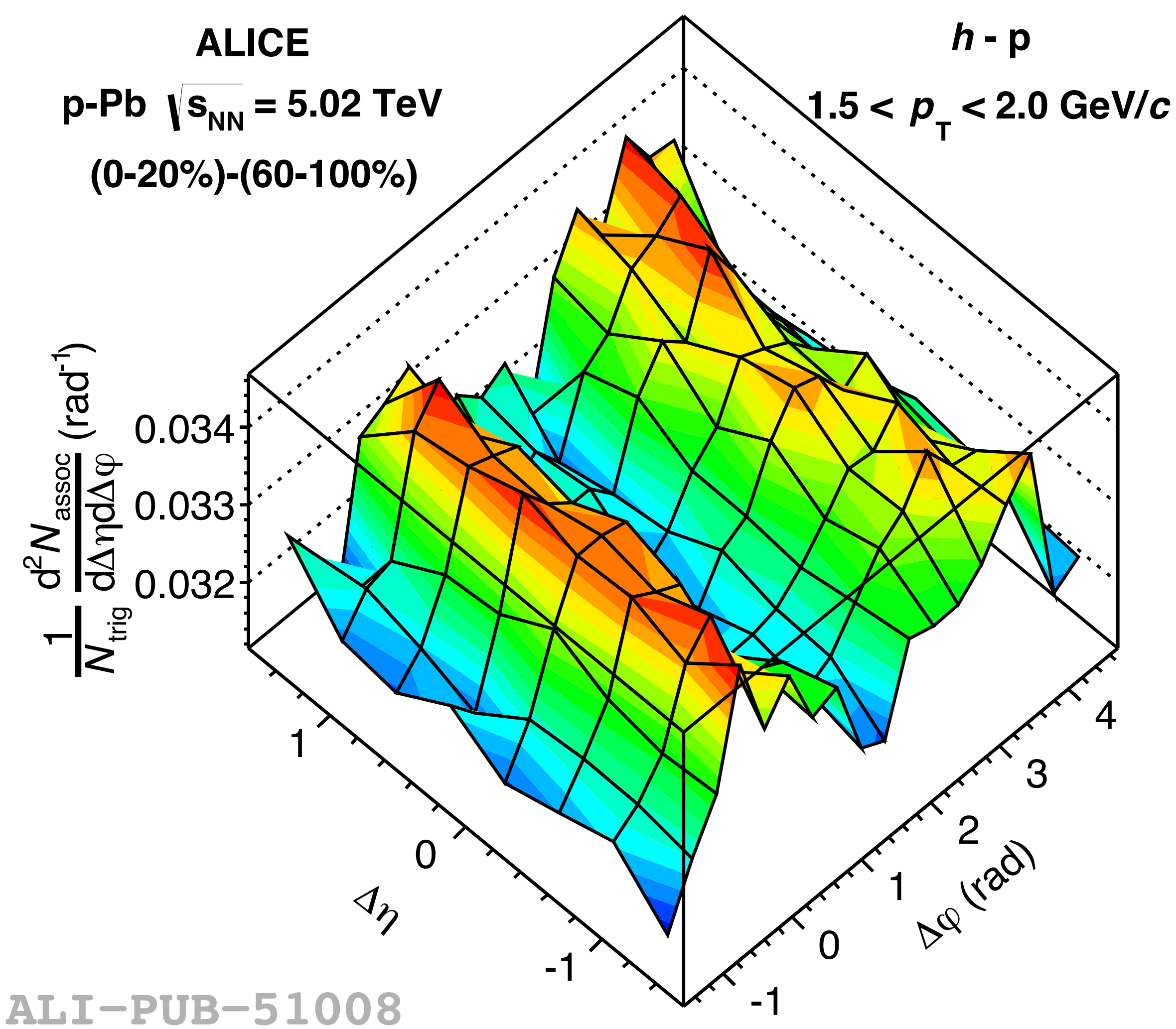


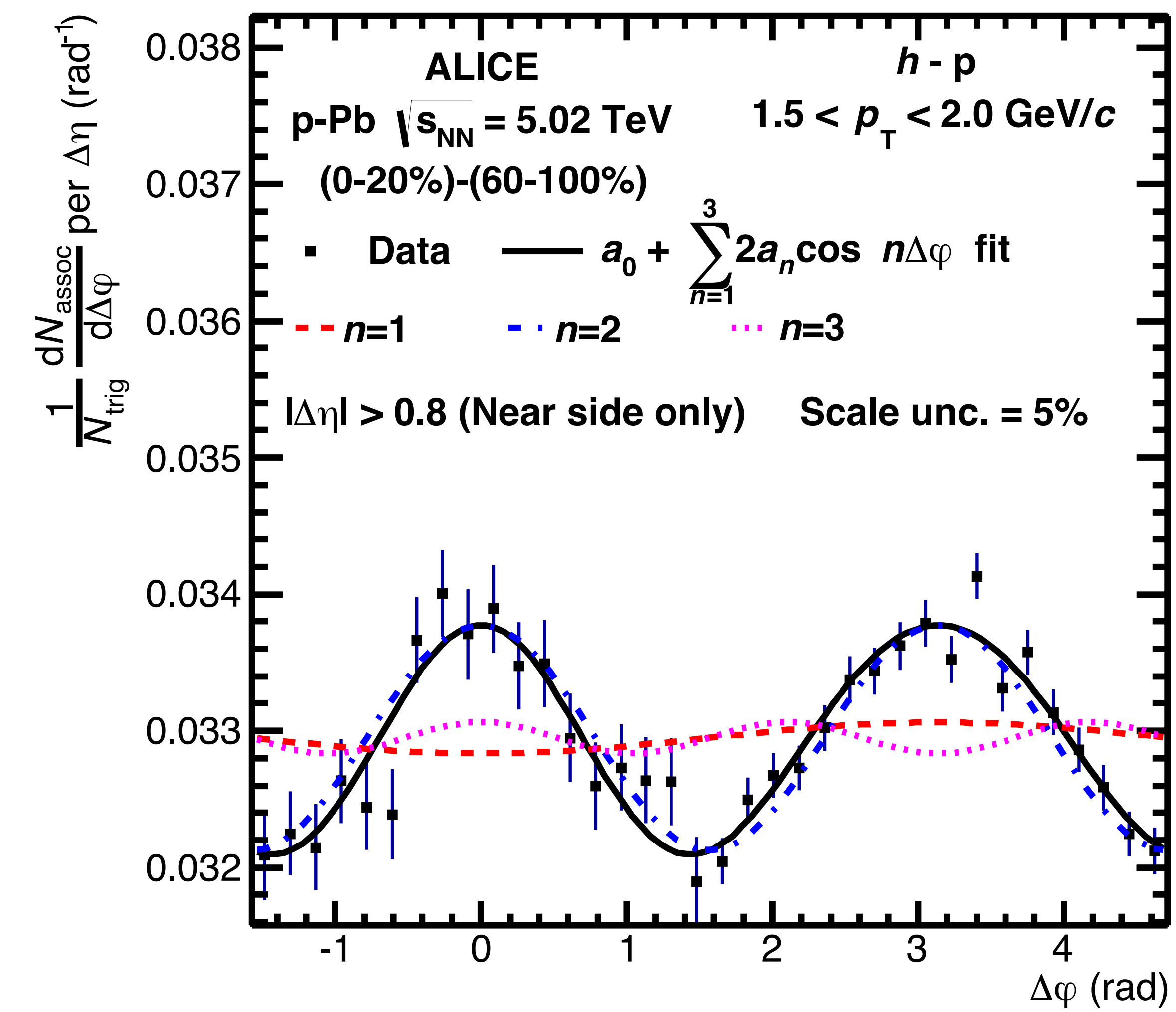
High Mult.

Low Mult.



Flow of identified hadrons in p-Pb



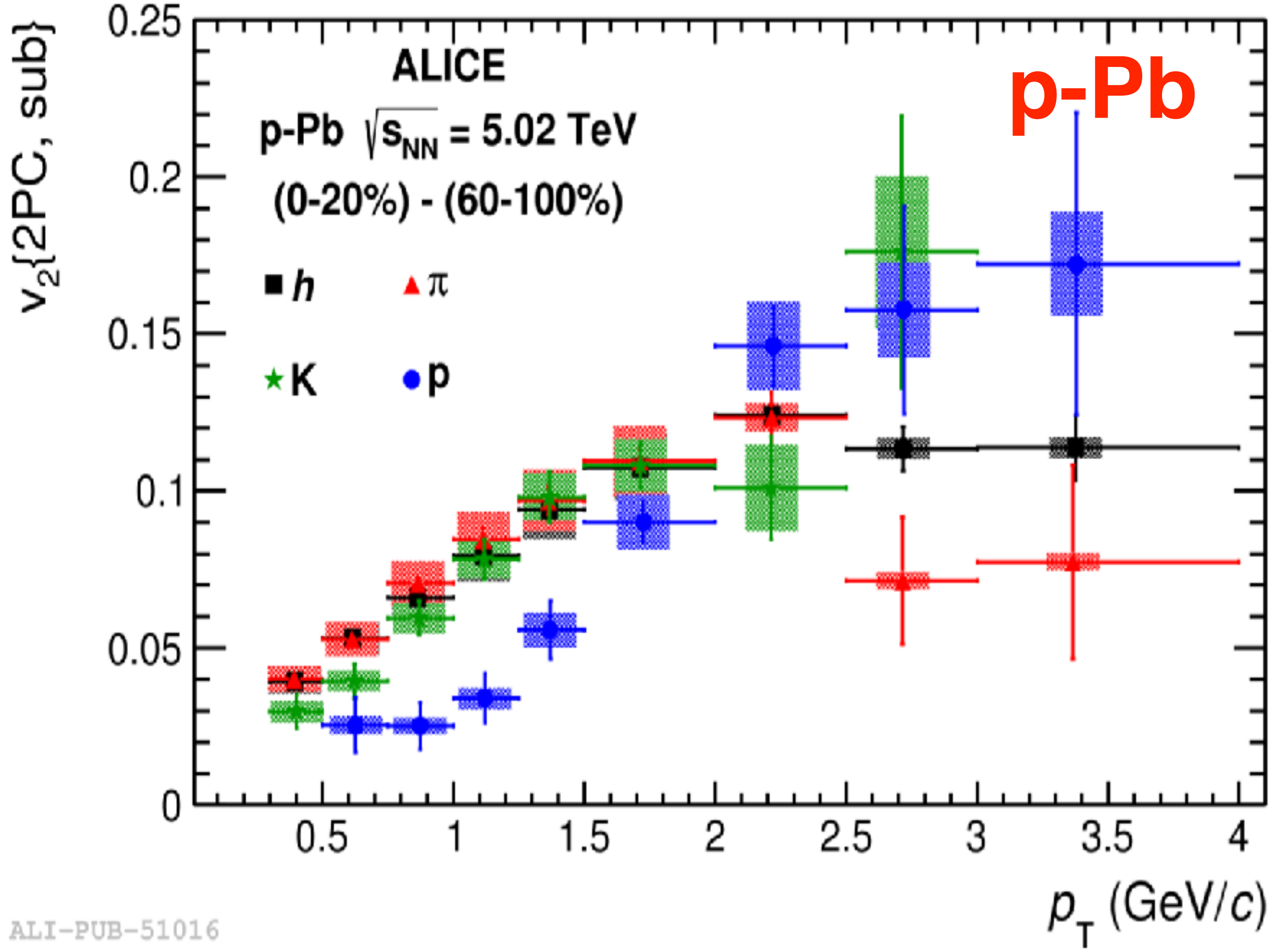


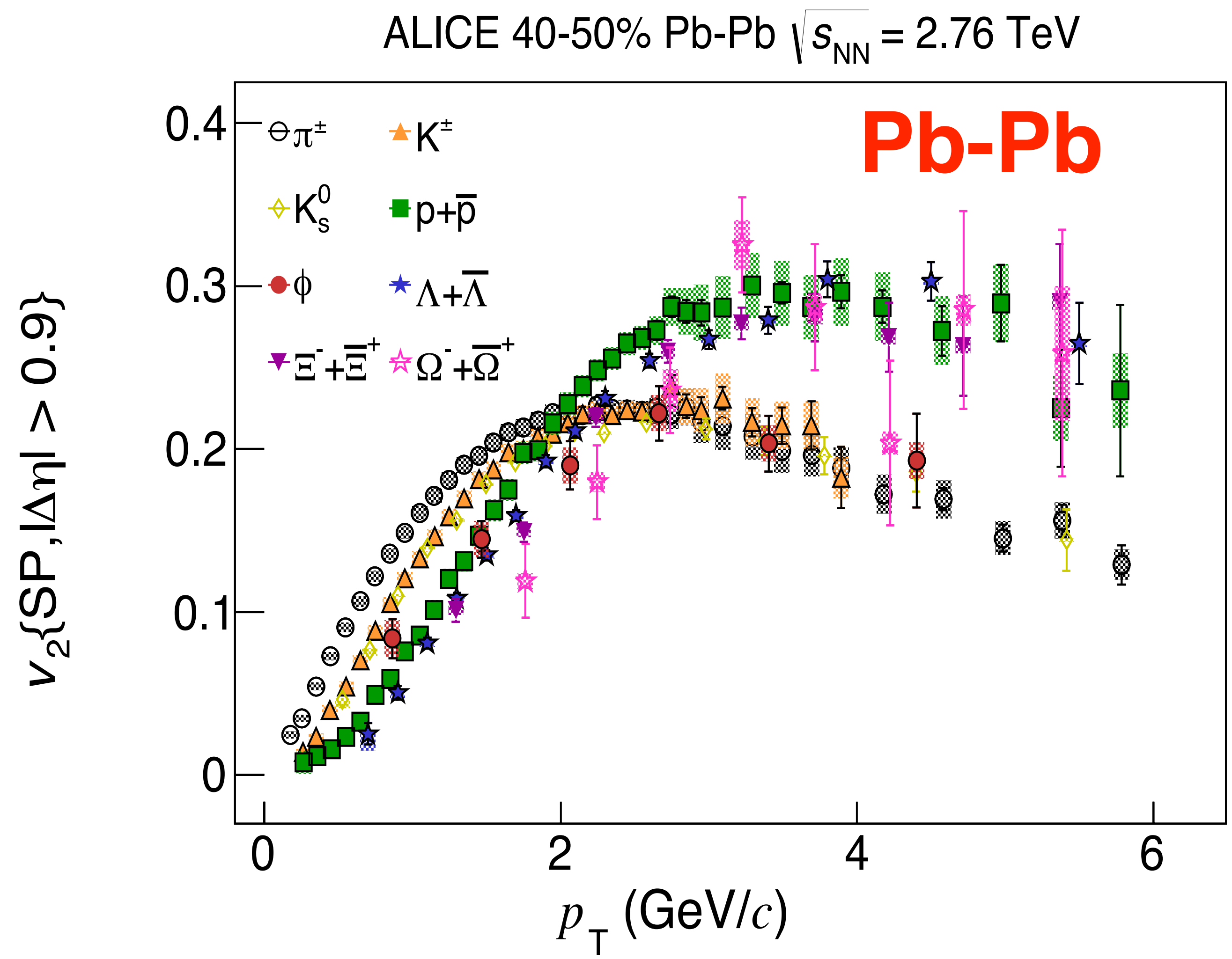
$$V_{n\Delta}^{h-i}\{2PC\} = a_n^{h-i}/a_0^{h-i}$$

$$v_n^h\{2PC\} = \sqrt{V_{n\Delta}^{h-h}}$$

$$v_n^i\{2PC\} = V_{n\Delta}^{h-i}/\sqrt{V_{n\Delta}^{h-h}}$$

Flow of identified hadrons in p-Pb





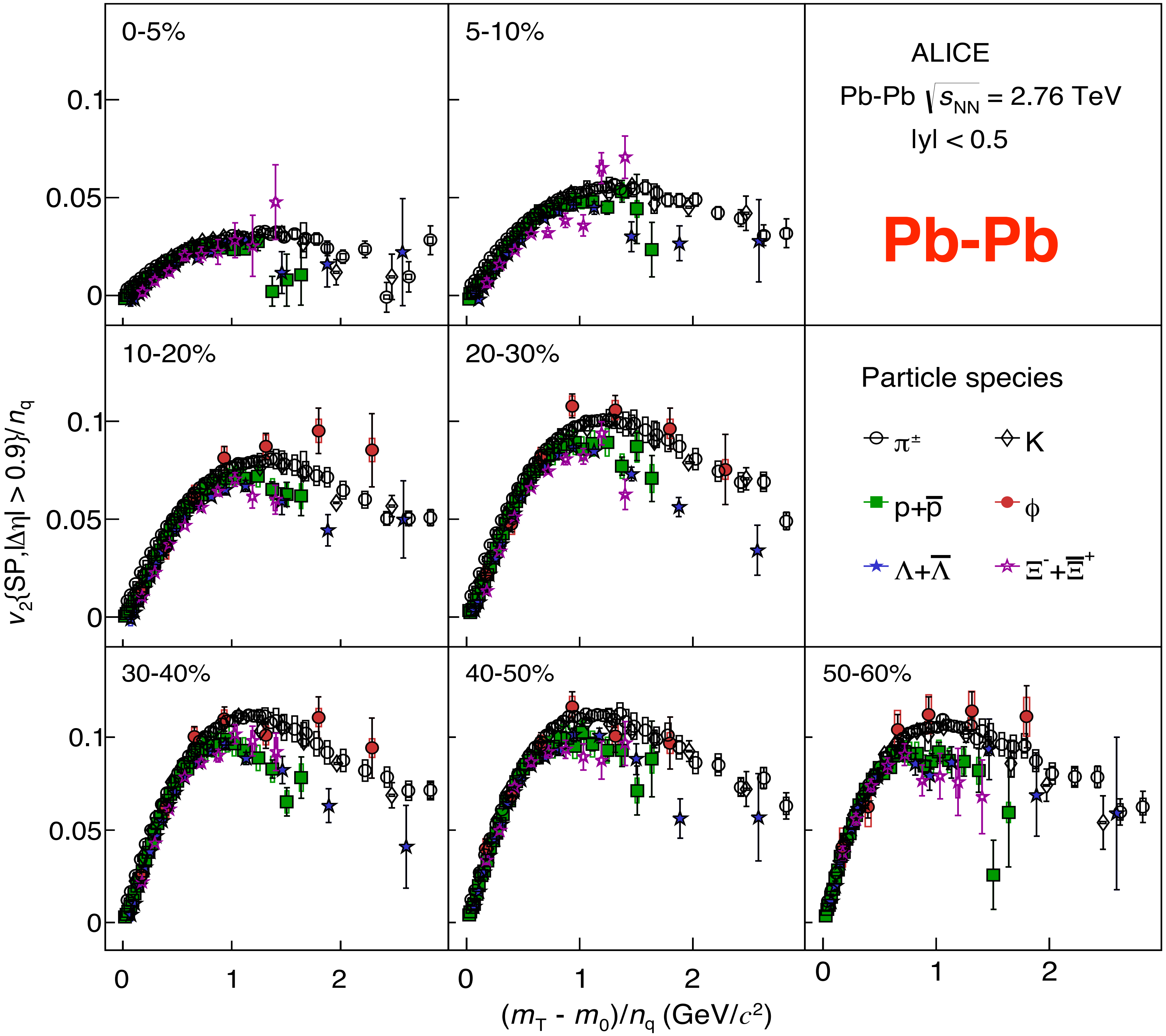
For p-Pb:

ALICE: JHEP 06, 190 (2015)

- v_2 of π is similar to v_2 of unidentified hadrons (h)
- Hint of kaon v_2 smaller than π v_2 at low-p_T
- Proton v_2 is smaller than π v_2 at low-p_T (< 2 GeV/c) and larger above
- Consistent with Hydrodynamics prediction : P. Bozek, *et al.* Phys. Rev. Lett. 111, 172303 (2013)

v_2 of identified hadrons in high multiplicity p-Pb resembles to v_2 in Pb-Pb

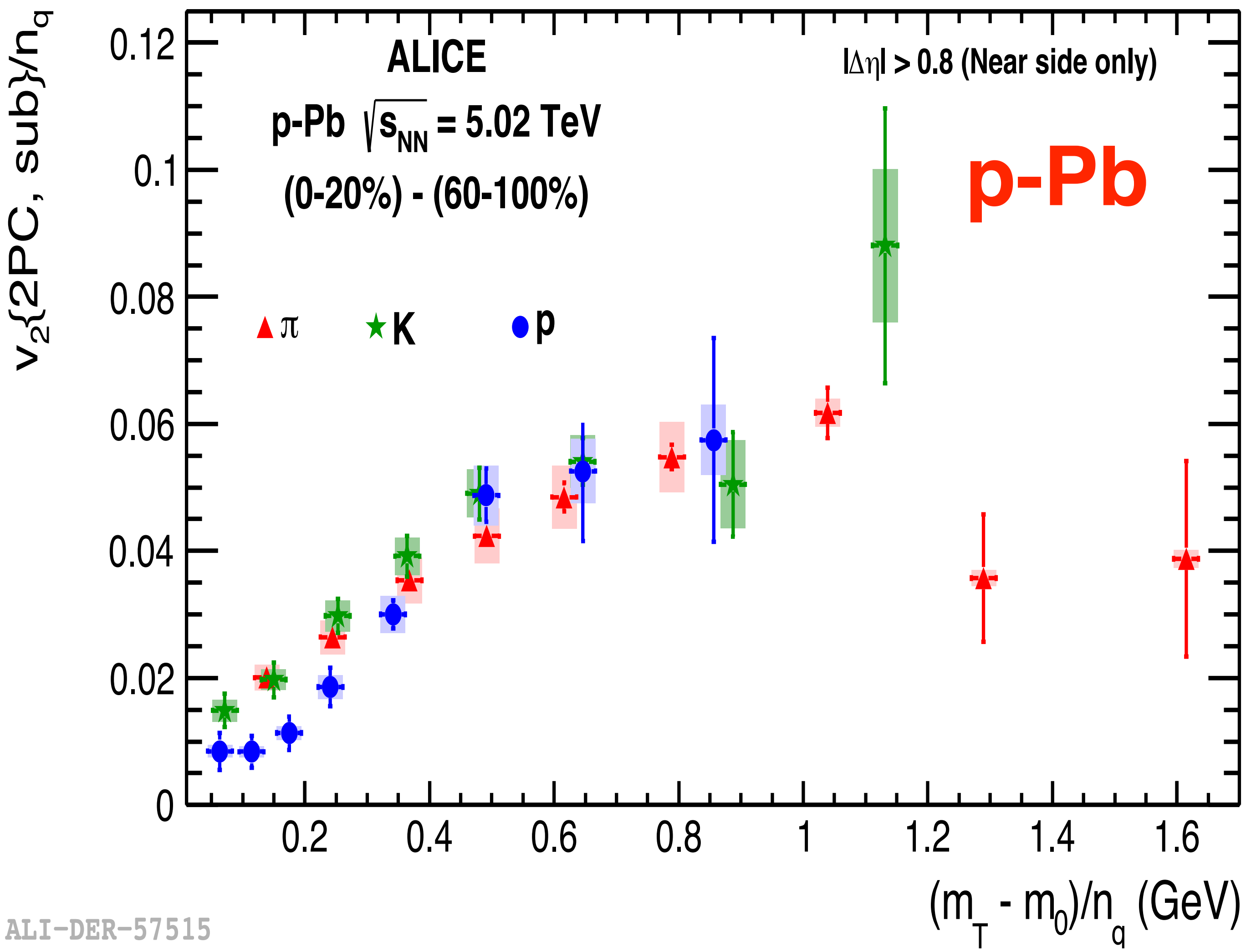
NCQ scaling of identified hadrons in Pb-Pb

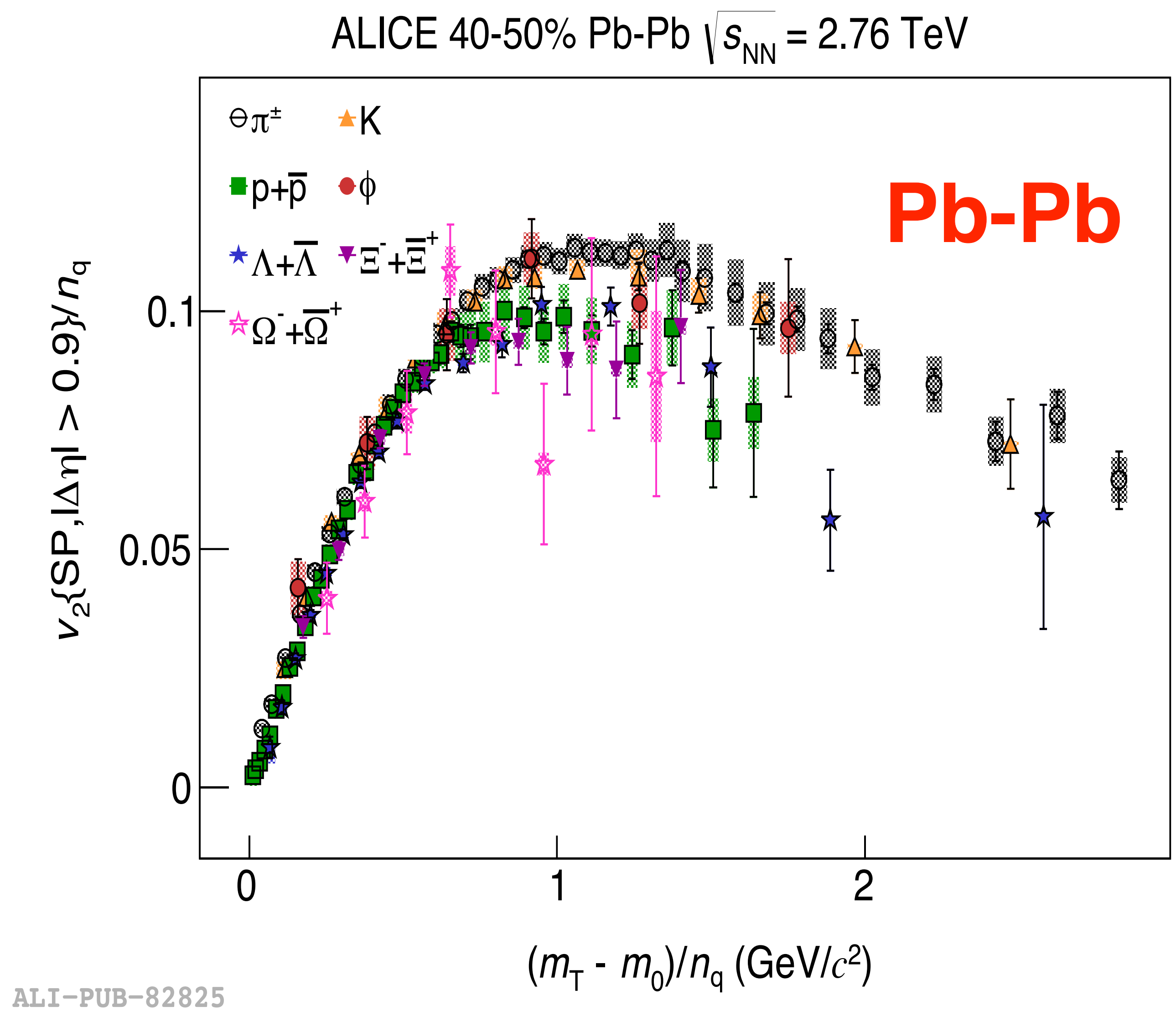


- NCQ scaling is approximate in Pb-Pb collisions

ALICE: JHEP 06, 190 (2015)

NCQ scaling in p-Pb





❖ Number of constituent quark (NCQ) scaling is approximate in high multiplicity p-Pb similar to Pb-Pb collisions

ALICE: JHEP 06, 190 (2015)

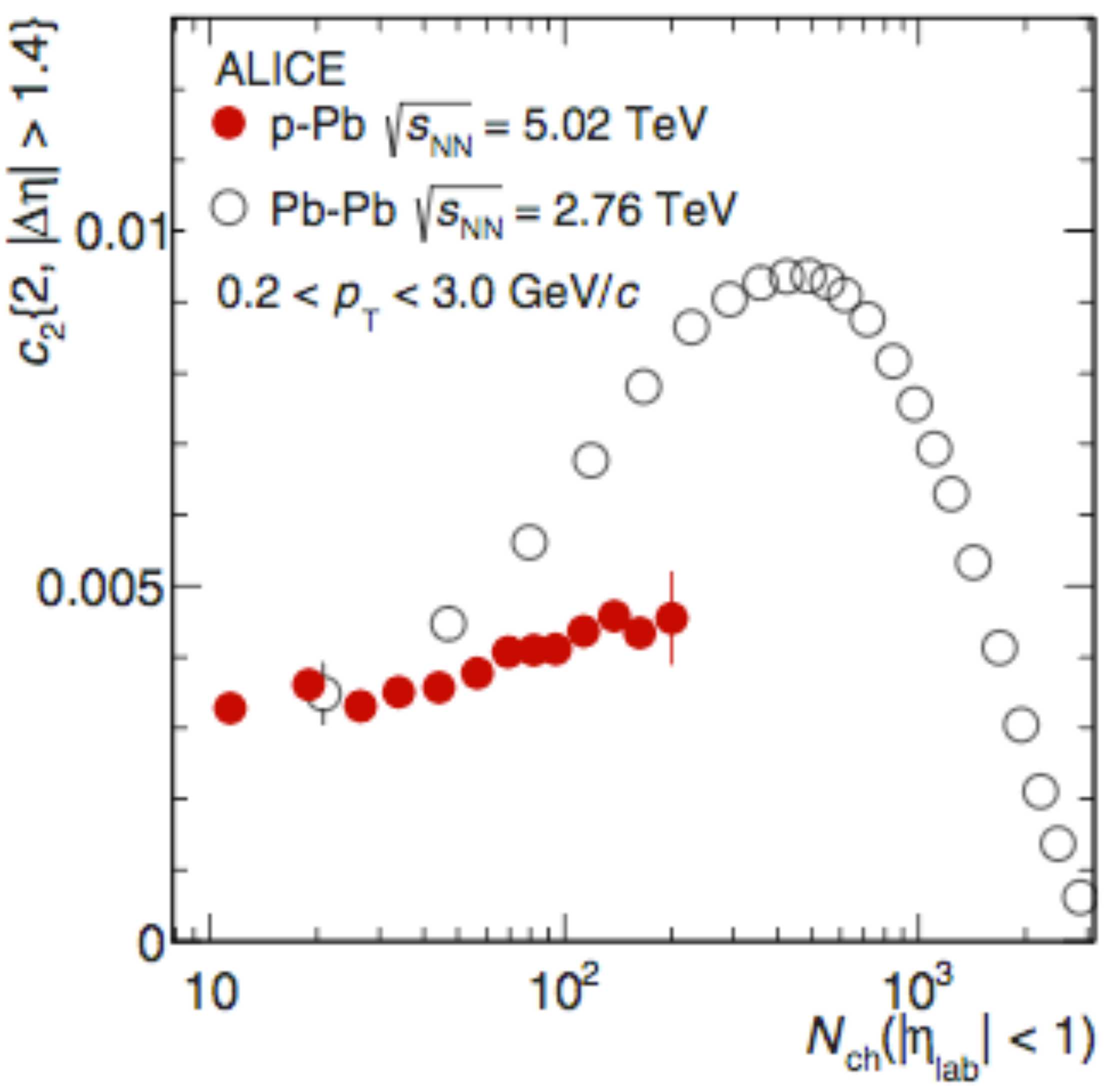
Collectivity in Small Systems

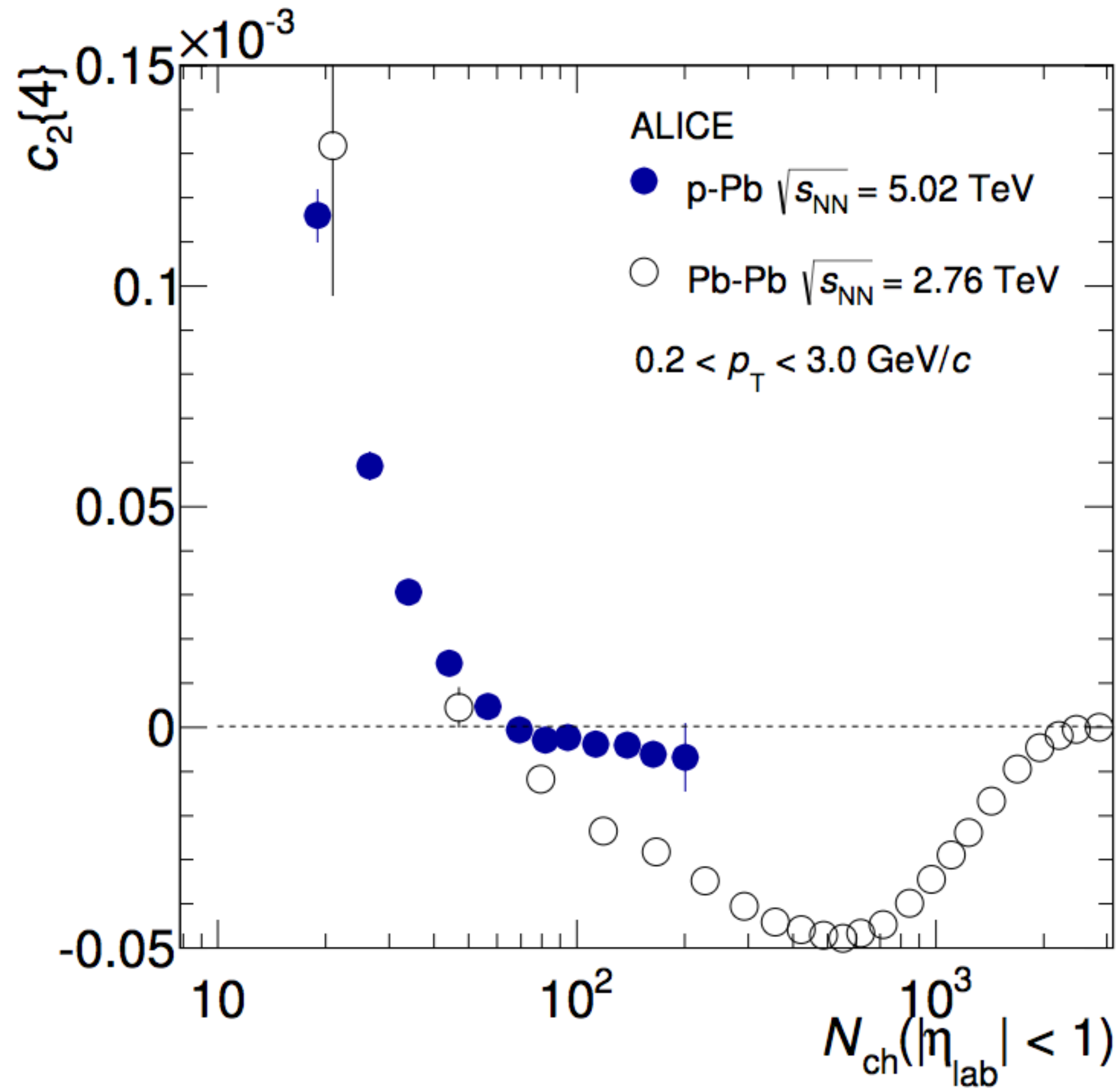
Part-II : Multi Particle Cumulants

Two and four particles cumulants

$$\langle\langle 2\rangle\rangle \equiv \langle\langle e^{in(\phi_1-\phi_2)}\rangle\rangle \qquad c_n\{4\} = \langle\langle 4\rangle\rangle - 2\cdot\langle\langle 2\rangle\rangle^2. \qquad v_n\{2\} = \sqrt{c_n\{2\}}$$

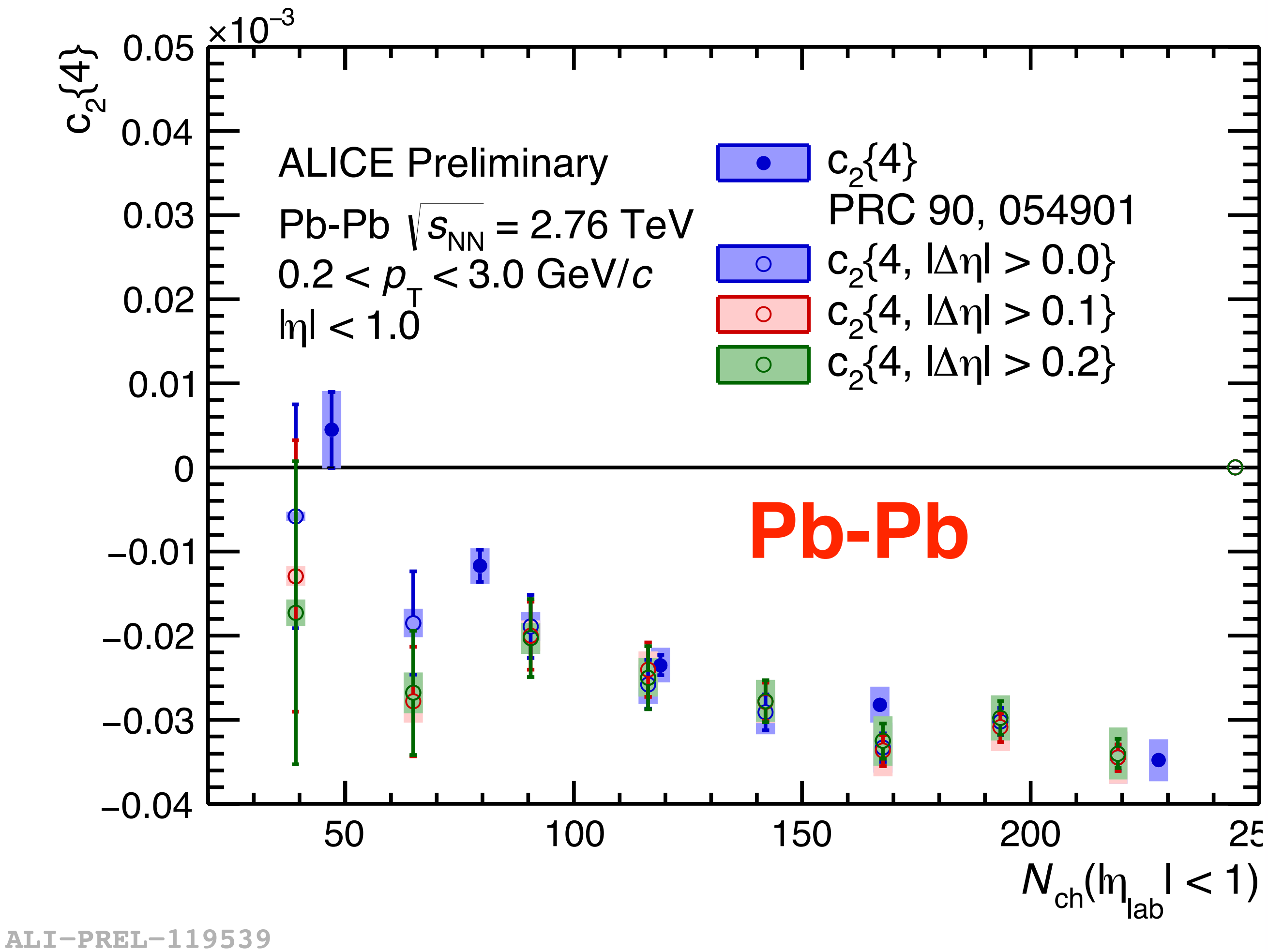
$$\langle\langle 4\rangle\rangle \equiv \langle\langle e^{in(\phi_1+\phi_2-\phi_3-\phi_4)}\rangle\rangle \qquad c_n\{2\} = \langle\langle 2\rangle\rangle \qquad v_n\{4\} = \sqrt[4]{-c_n\{4\}},$$

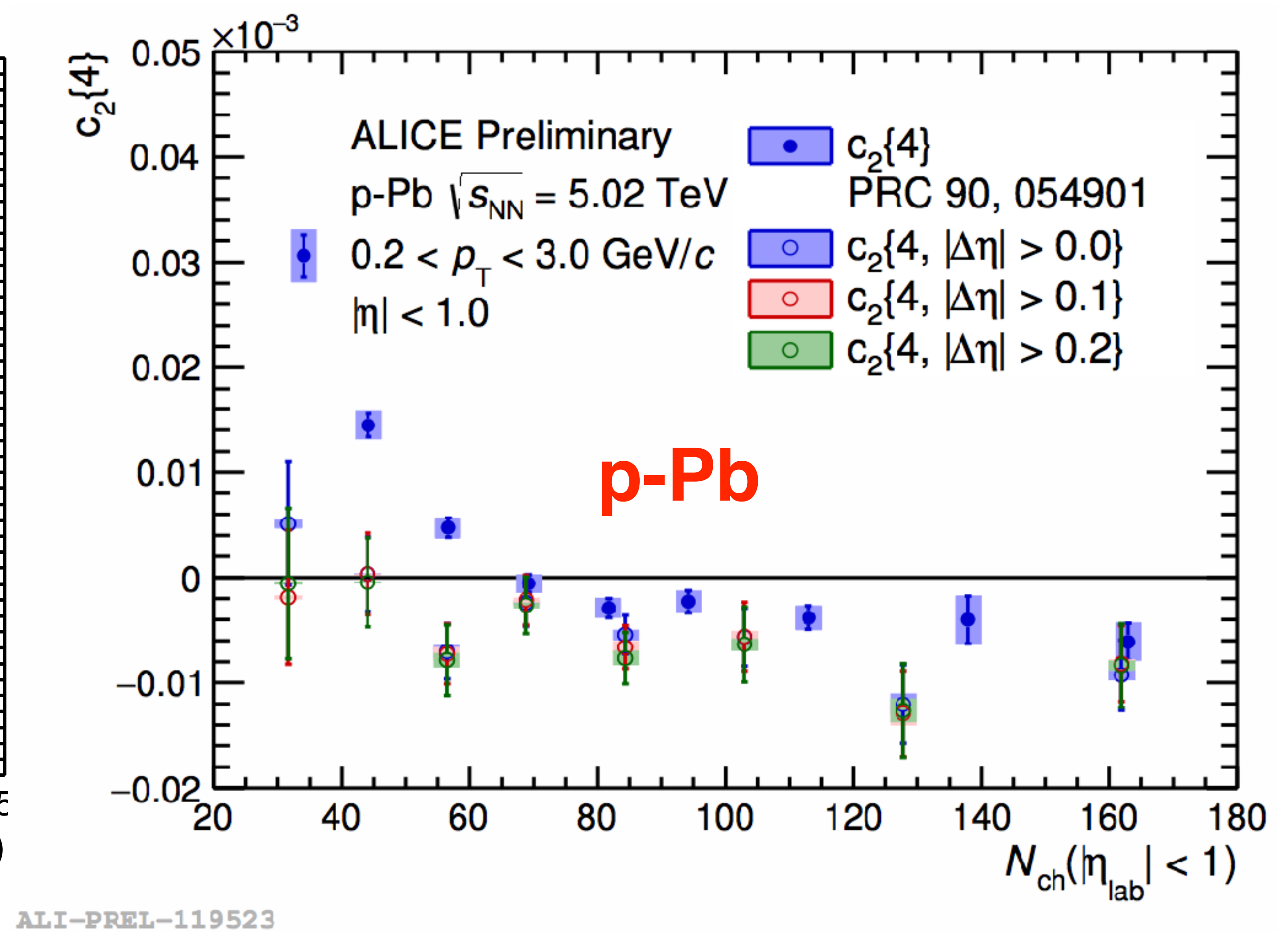




Phys. Rev. C 90, 054901 (2014)

Non flow suppression: cumulants with η-gaps



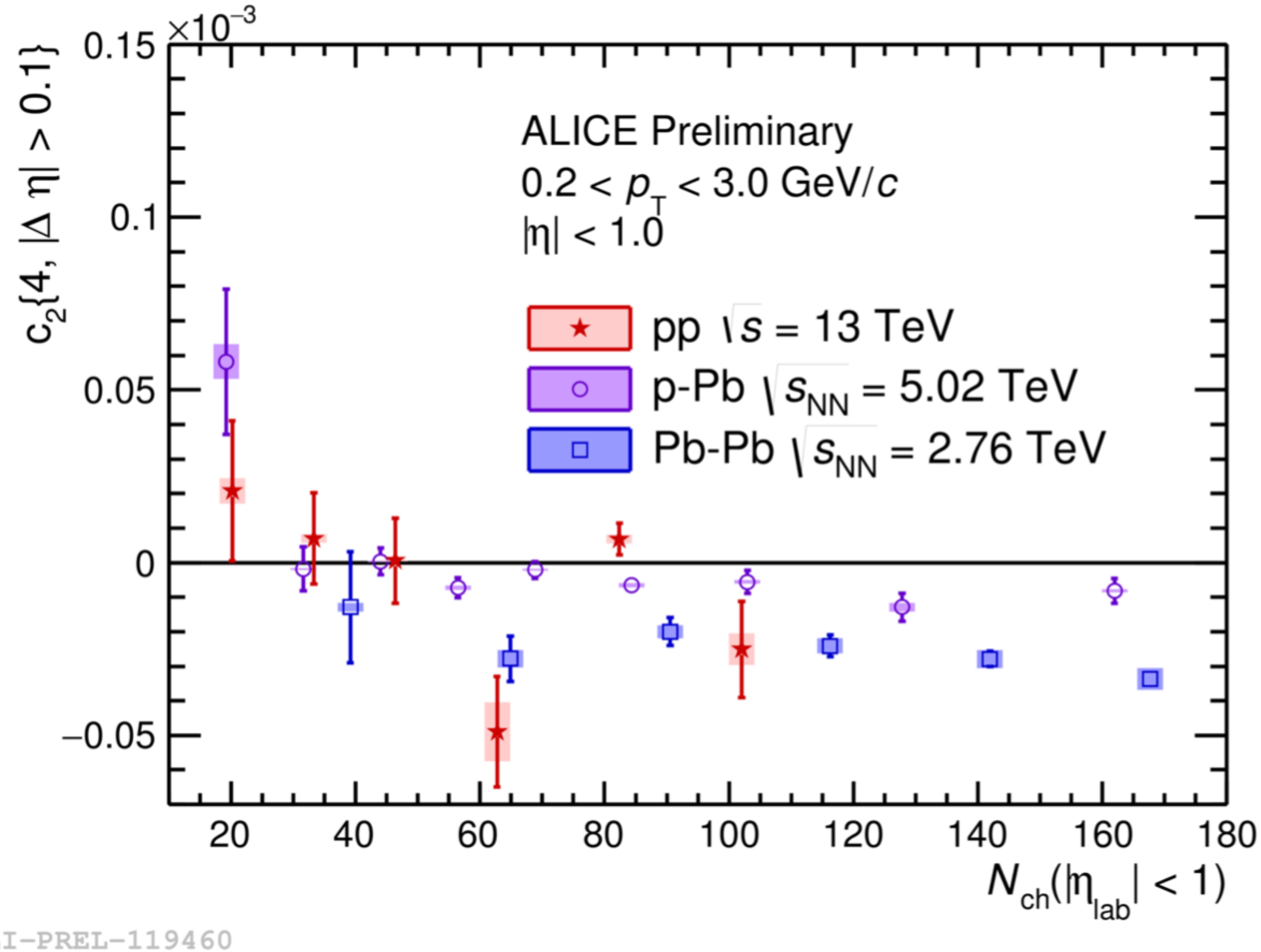


$$v_n\{4\} = \sqrt[4]{-c_n\{4\}},$$

- ❖ $c_2\{4\} > 0$ for $N_{ch} < 70$
- ❖ Results with η-gap: small non-flow effects

- ❖ $c_2\{4\} > 0$ for $N_{ch} < 70$
- ❖ Results with η-gap: strong non-flow at low multiplicity

Comparison of $c_2\{4\}$ in pp, p-Pb, and Pb-Pb



❖ Limited statistics for pp collisions: no definitive conclusion about the sign of $c_2\{4, |\Delta\eta|\}$

❖ Negative $c_2\{4, |\Delta\eta|\}$ for $N_{ch} > 40$ in Pb-Pb and p-Pb

Summary

- ❖ **Double ridge** structures are observed in **high multiplicity pp and p-Pb**

- ❖ Identified hadrons **v_2 in p-Pb** from two particle correlations:
  - ✓**Mass ordering** at low-p_T
    - ► Supported by hydrodynamic models
  - ✓Hint of **baryon and meson separation** at intermediate-p_T
  - ✓Approximate **NCQ scaling in p-Pb** resembles that in Pb-Pb

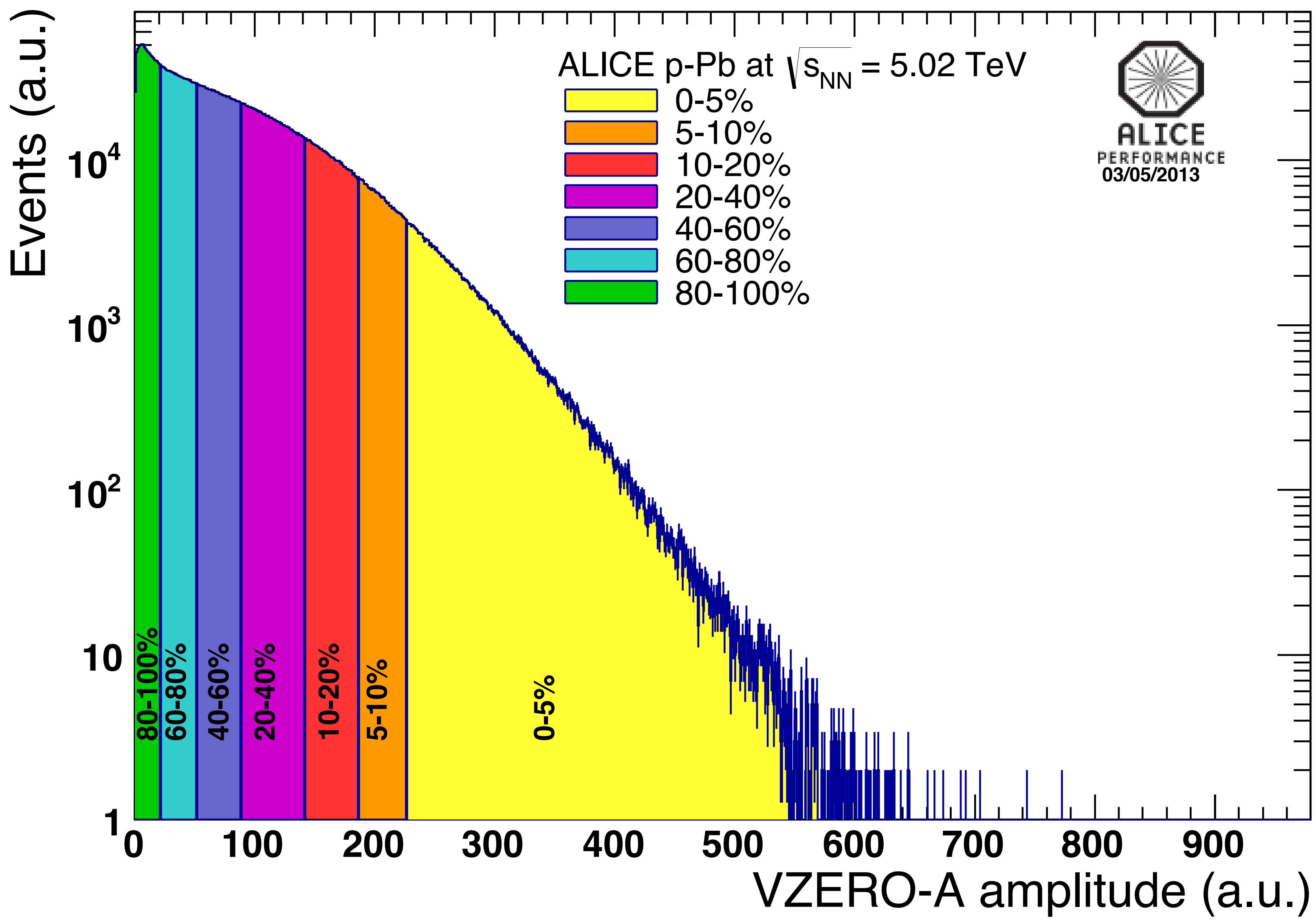
- ❖ **No definite sign of $c_2\{4\}$ in pp collisions**
  - ✓ Need high statistics data for further investigations

- ❖ ***Stay tuned for more Run 2 results***

Thank you!

Backup

Centrality selection in p-Pb



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