

Angular correlation studies in p-Pb with ALICE

ZIMÁNYI SCHOOL'13



13. Zimányi

**WINTER SCHOOL ON
HEAVY ION PHYSICS**

**Dec. 2. - Dec. 6.,
Budapest, Hungary**



M. M.: Women with Brushwood

József Zimányi (1931 - 2006)

Panos Christakoglou (Nikhef)

On behalf of the ALICE Collaboration



- ...a baseline measurement for heavy-ion collisions...



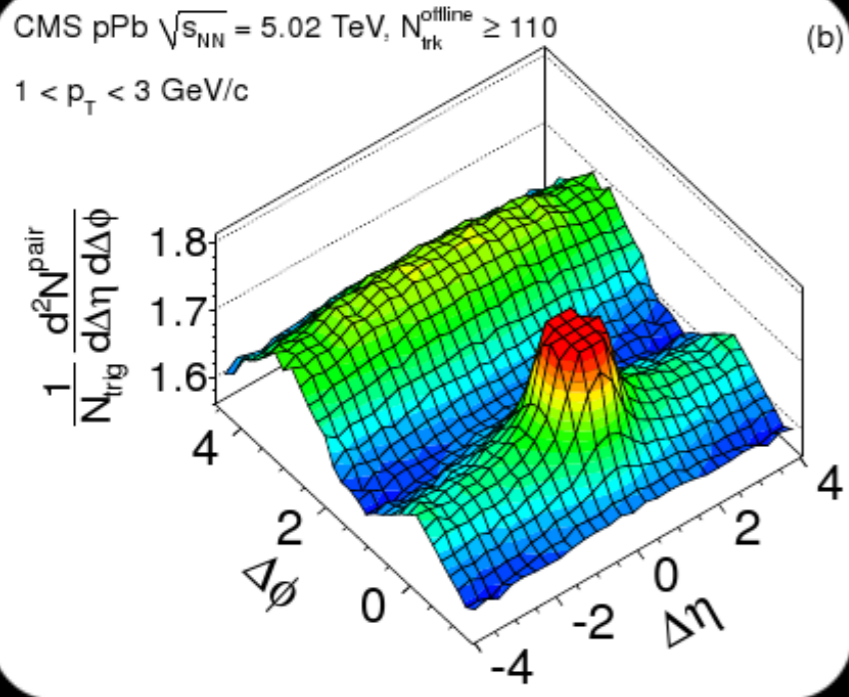
- ...a baseline measurement for heavy-ion collisions...
- To a crucial test of cold nuclear matter effects...
-



- ...a baseline measurement for heavy-ion collisions...
- To a crucial test of cold nuclear matter effects...
- Reaching the level of producing astonishing new results



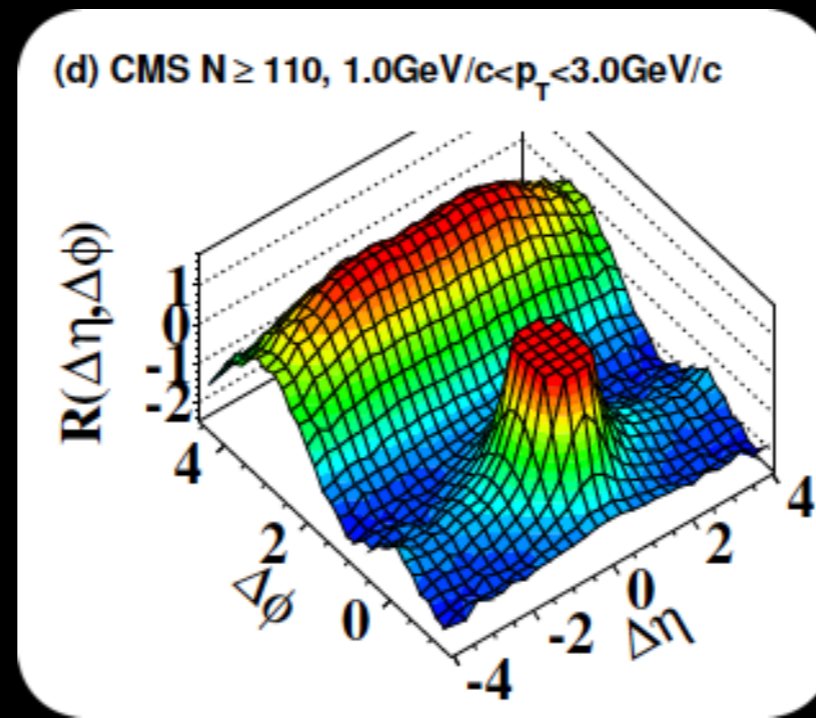
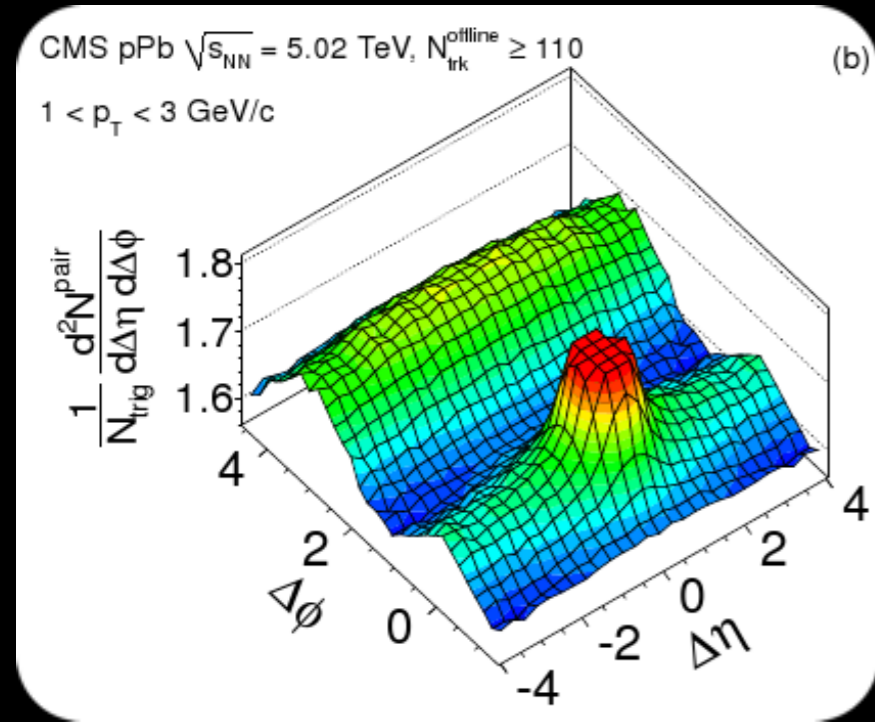
(CMS Collaboration) Phys. Lett. **B718**, (2013) 795



Near side ridge in p-Pb

(CMS Collaboration) Phys. Lett. **B718**, (2013) 795

(CMS Collaboration) JHEP 09, (2010) 091

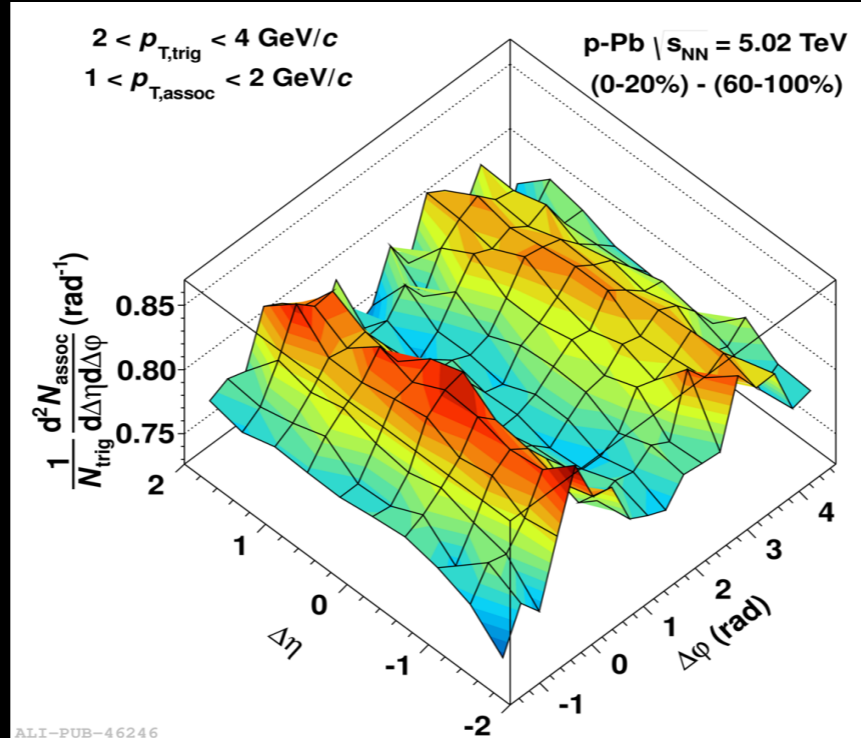
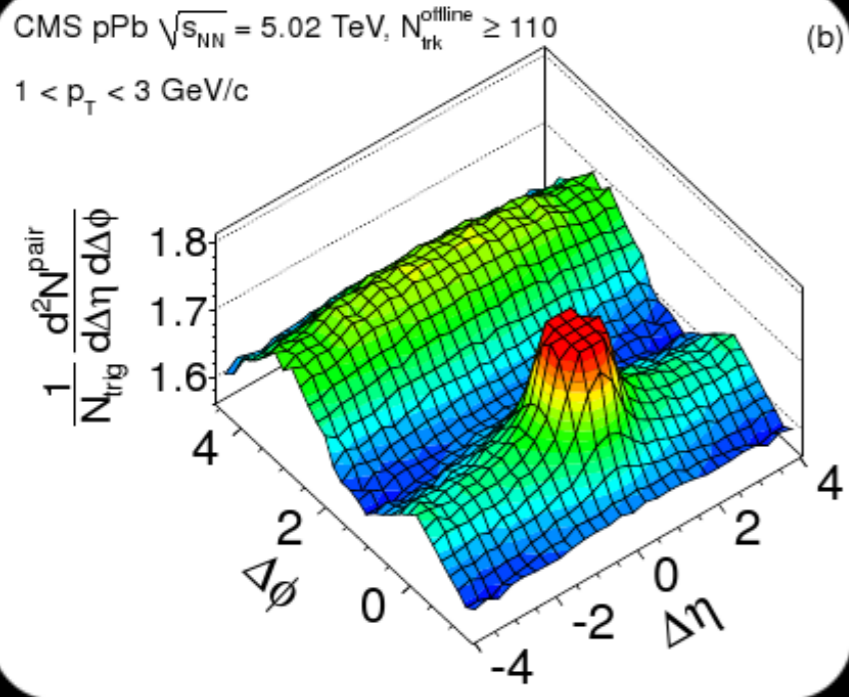


Near side ridge in p-Pb

Near side ridge in pp

(CMS Collaboration) Phys. Lett. **B718**, (2013) 795

ALICE Collaboration: Phys. Lett. **B719**, (2013) 29



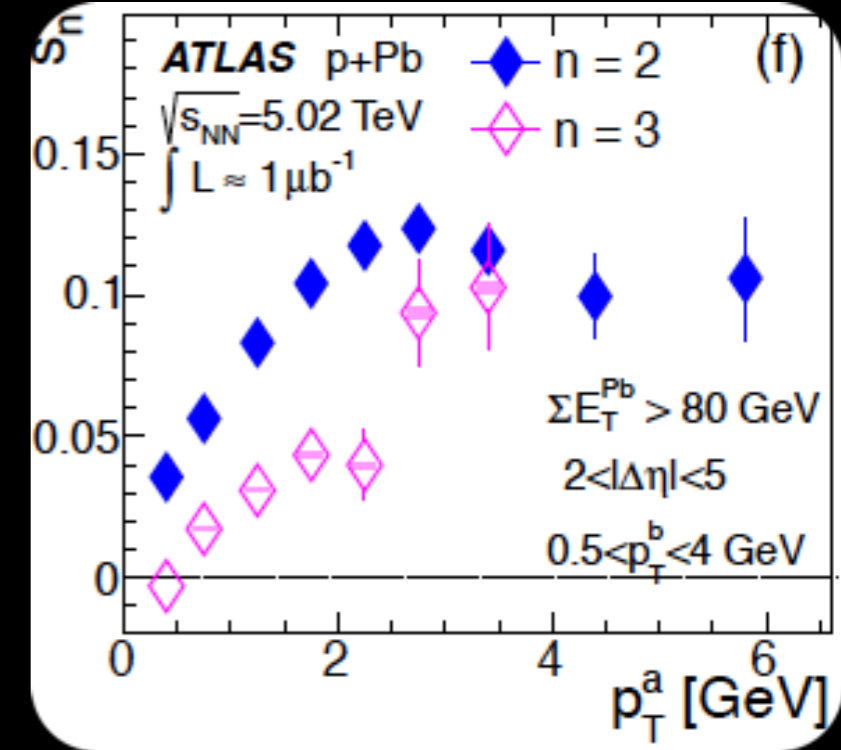
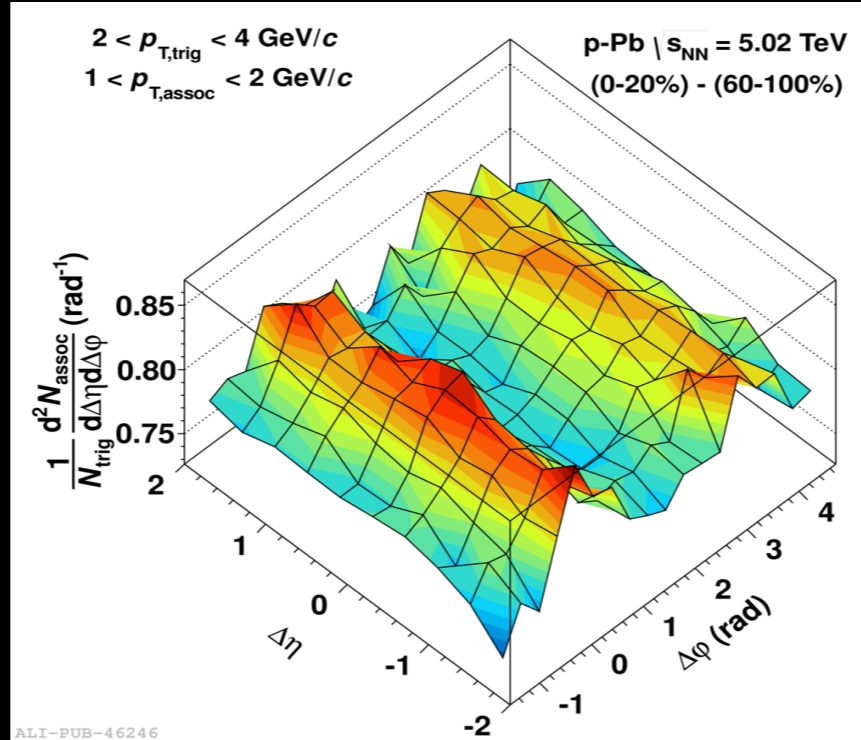
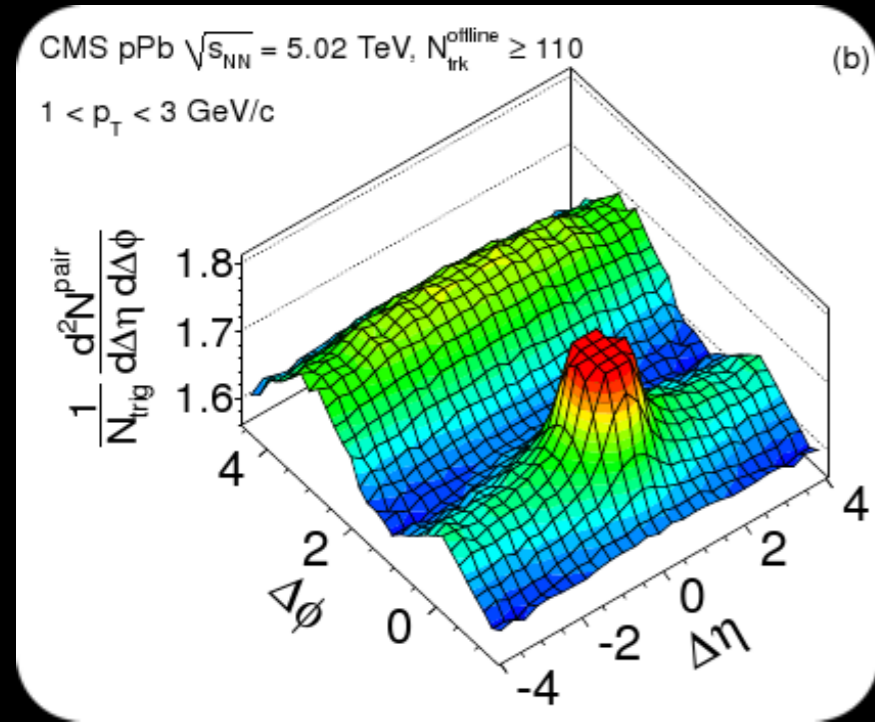
Near side ridge in p-Pb

Double ridge in p-Pb

(CMS Collaboration) Phys. Lett. **B718**, (2013) 795

ALICE Collaboration: Phys. Lett. **B719**, (2013) 29

ATLAS Collaboration, Phys. Rev. Lett. **110**, (2013) 182302



Near side ridge in p-Pb

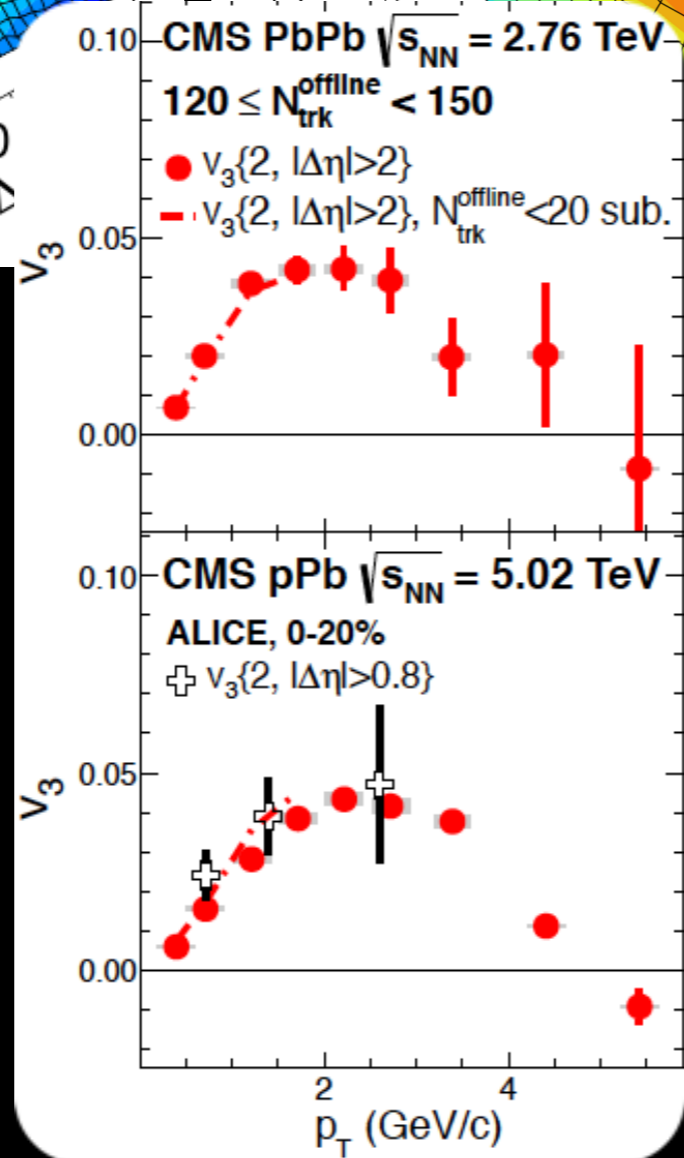
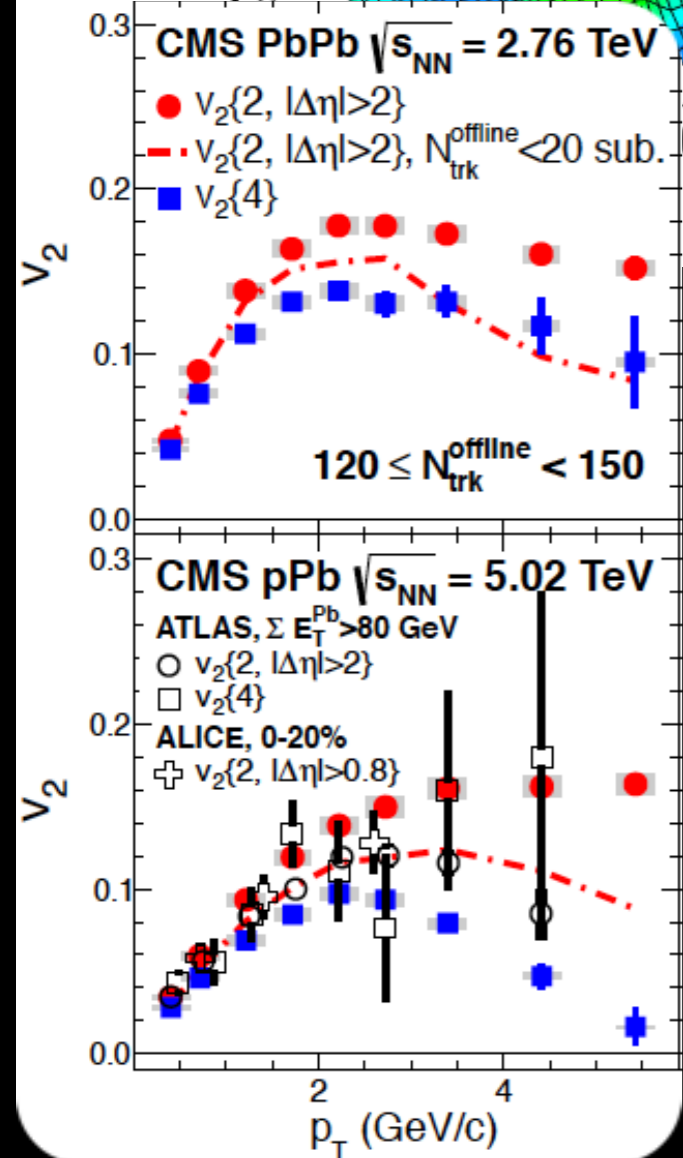
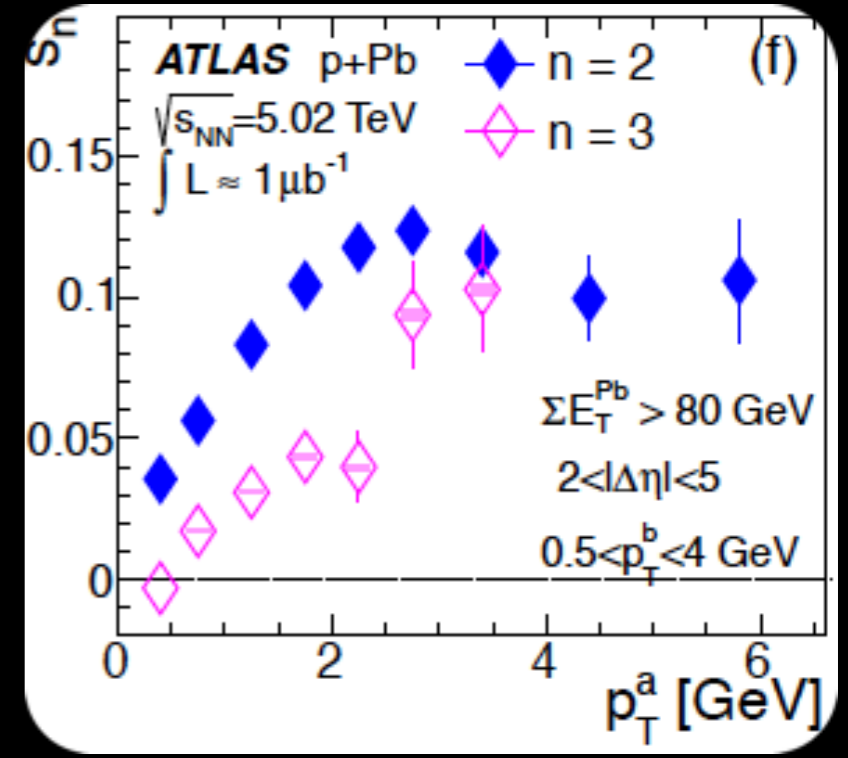
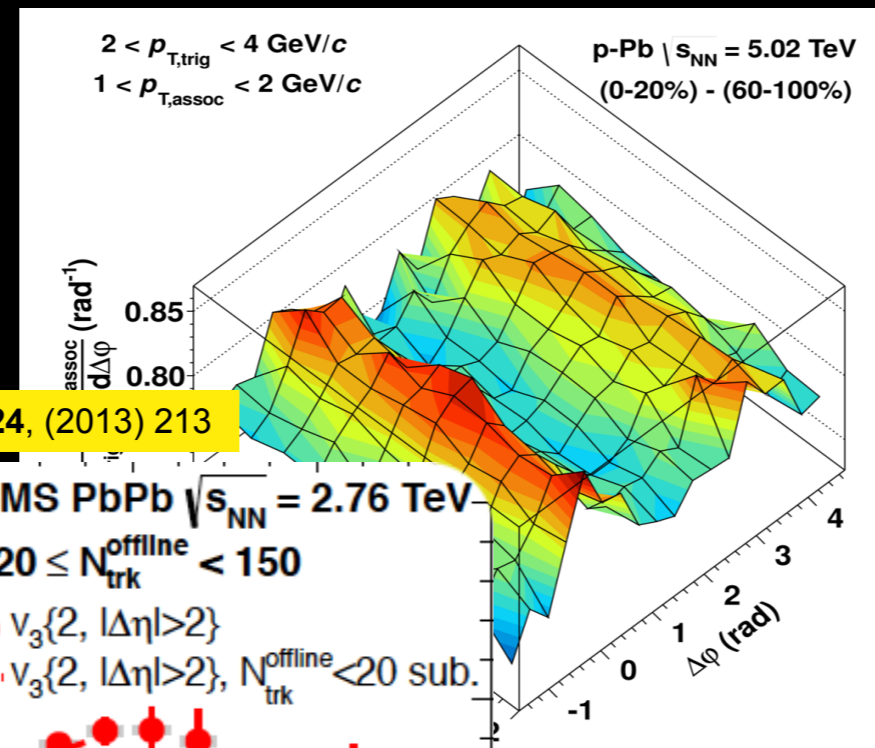
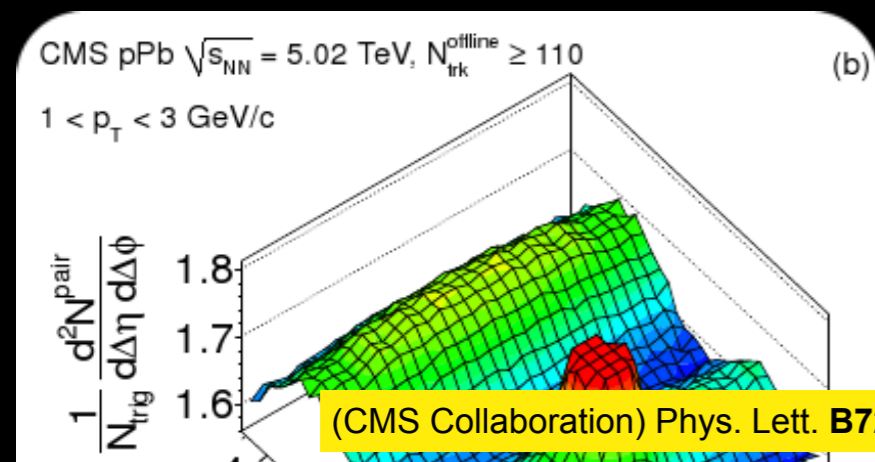
Double ridge in p-Pb

Sizable v_2 and v_3 components in p-Pb

(CMS Collaboration) Phys. Lett. **B718**, (2013) 795

ALICE Collaboration: Phys. Lett. **B719**, (2013) 29

ATLAS Collaboration, Phys. Rev. Lett. **110**, (2013) 182302



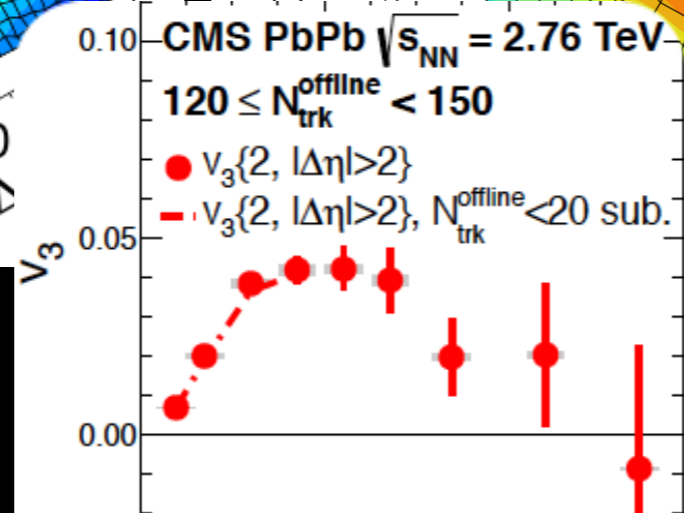
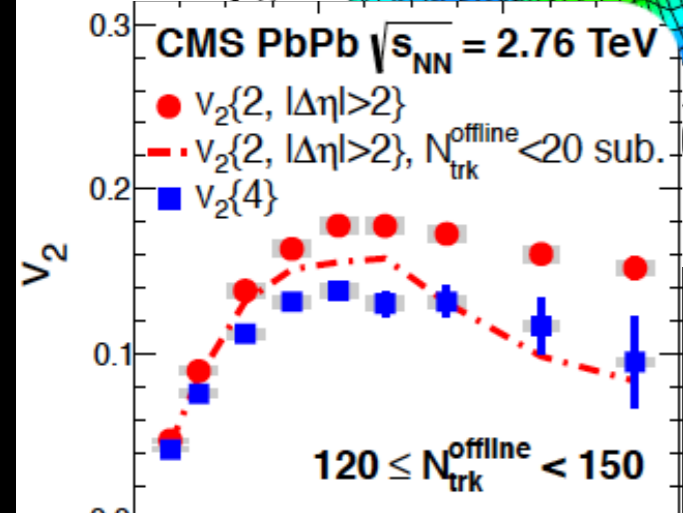
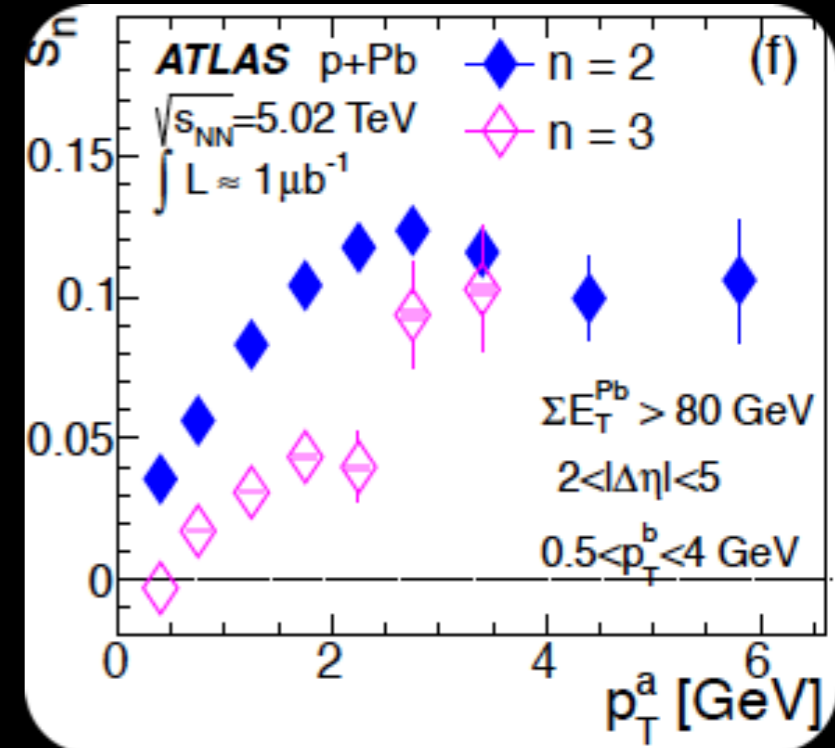
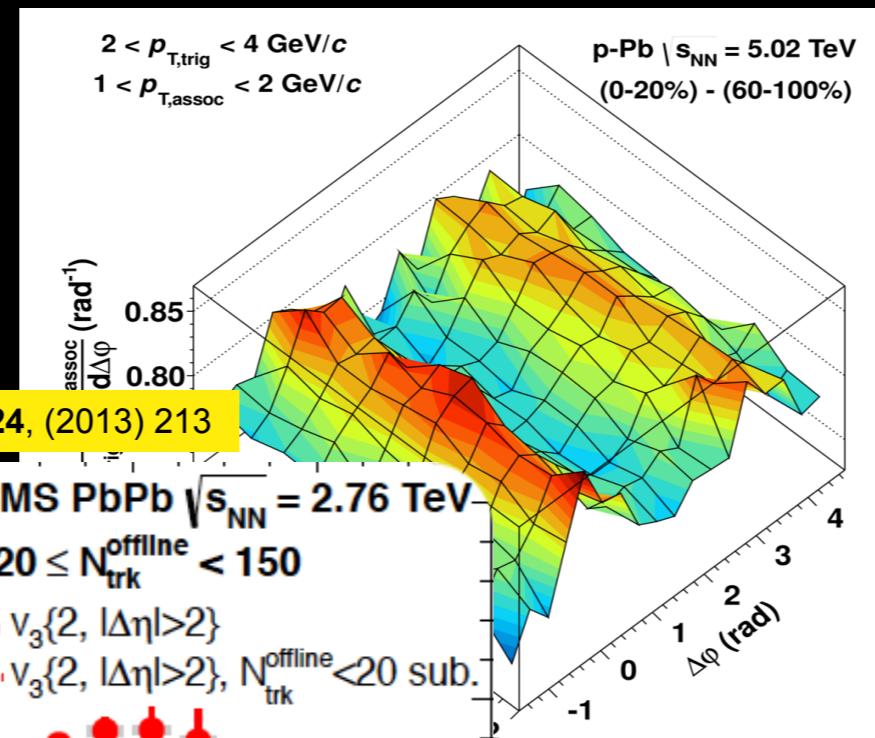
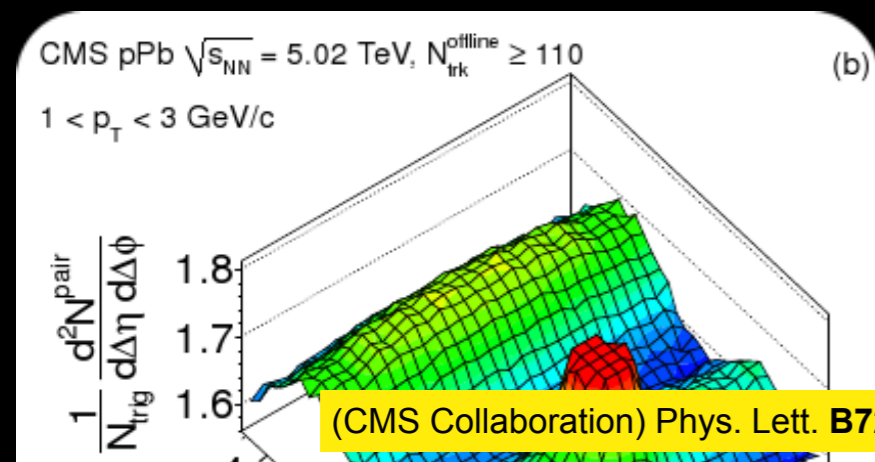
Sizable v_2 and v_3 components in p-Pb

Sizable v_2 and v_3 components in p-Pb with similar evolution vs p_T as in Pb-Pb

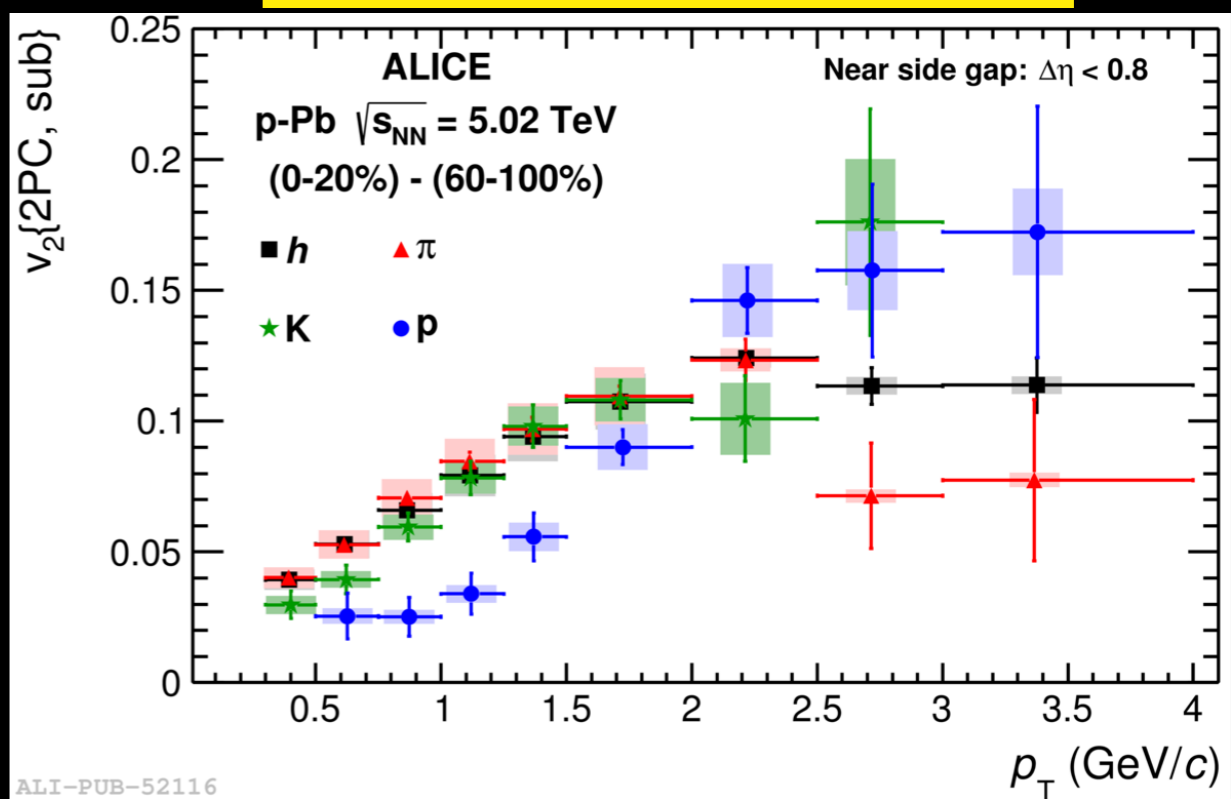
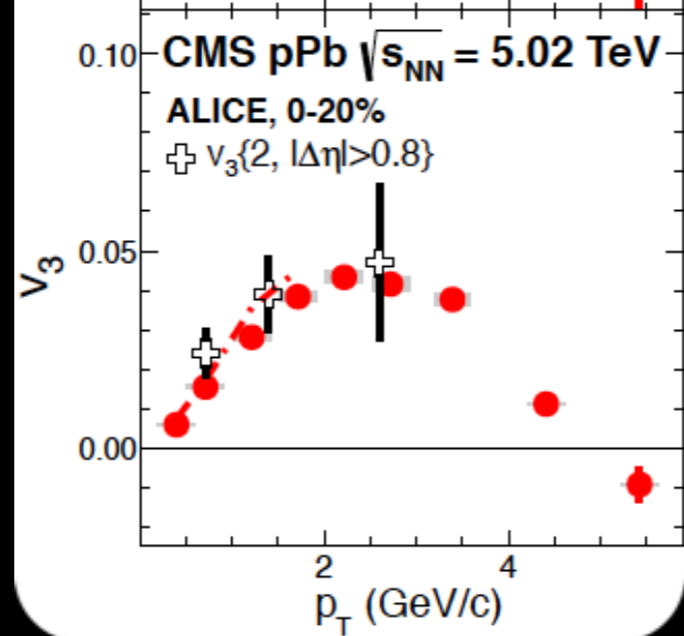
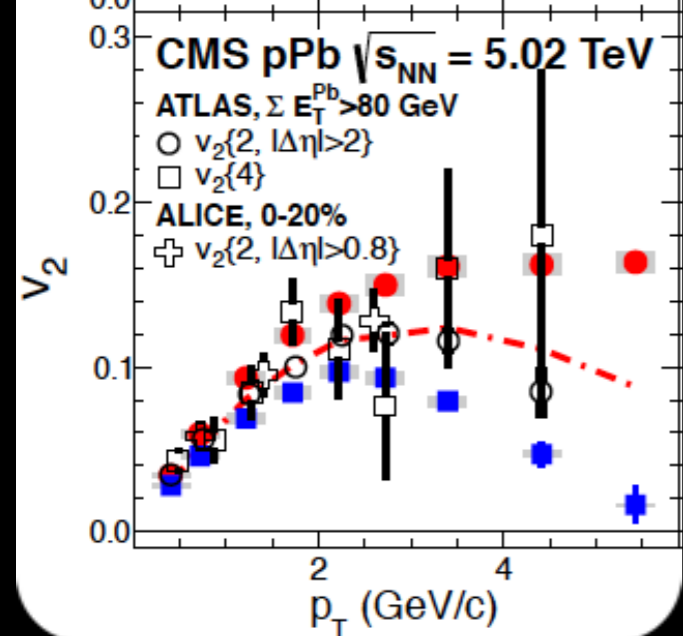
(CMS Collaboration) Phys. Lett. **B718**, (2013) 795

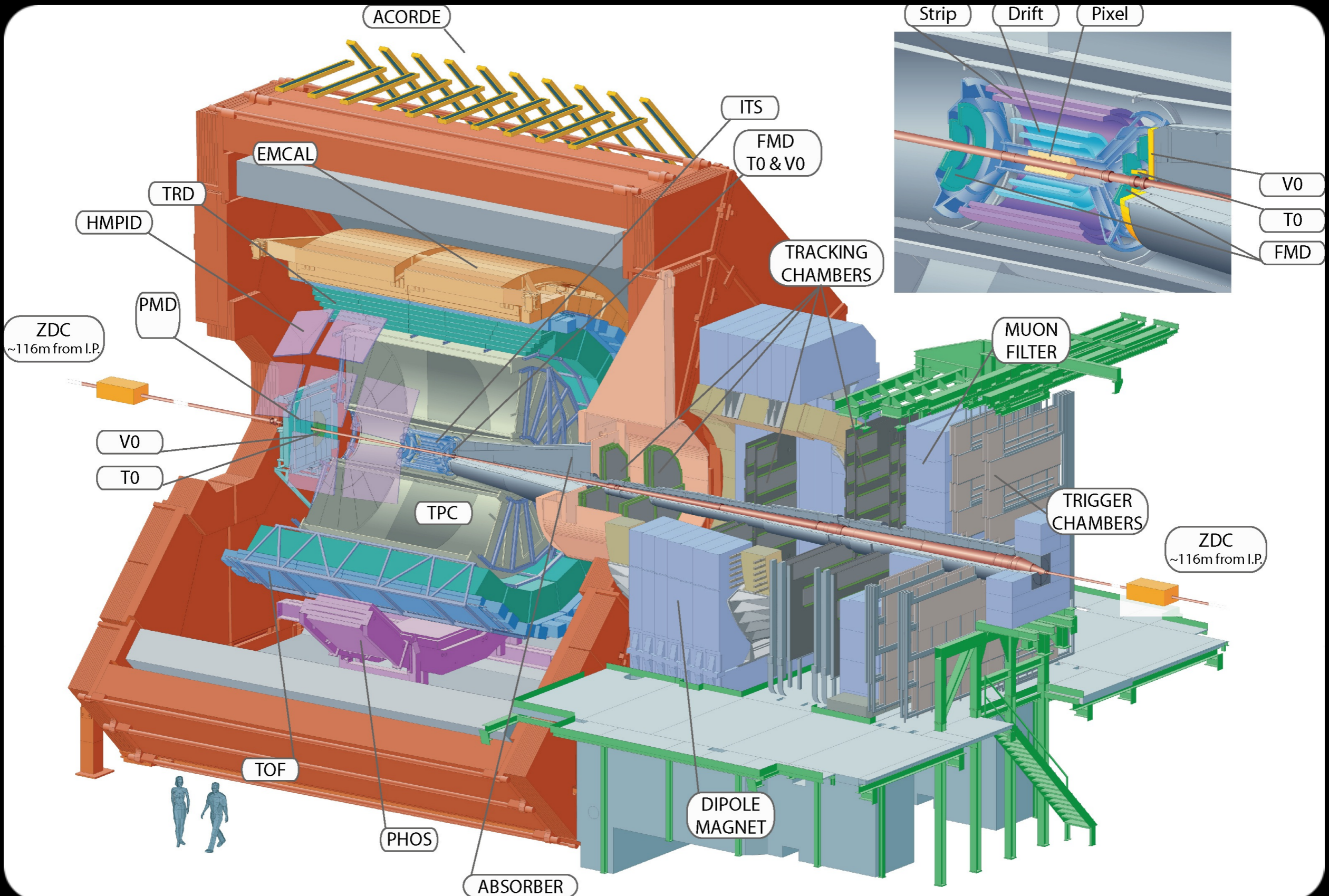
ALICE Collaboration: Phys. Lett. **B719**, (2013) 29

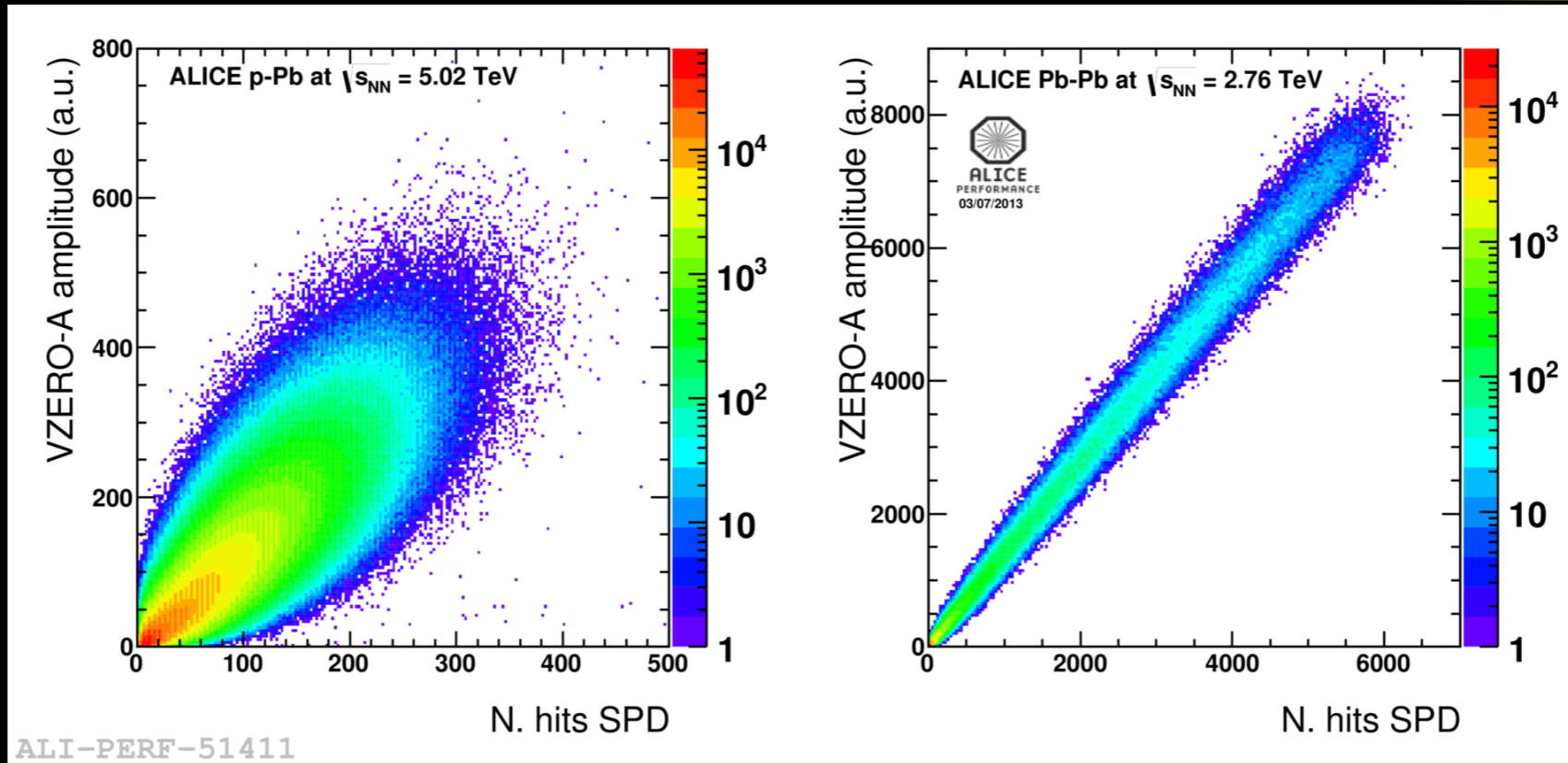
ATLAS Collaboration, Phys. Rev. Lett. **110**, (2013) 182302



ALICE Collaboration: Phys. Lett. **B726**, (2013) 164





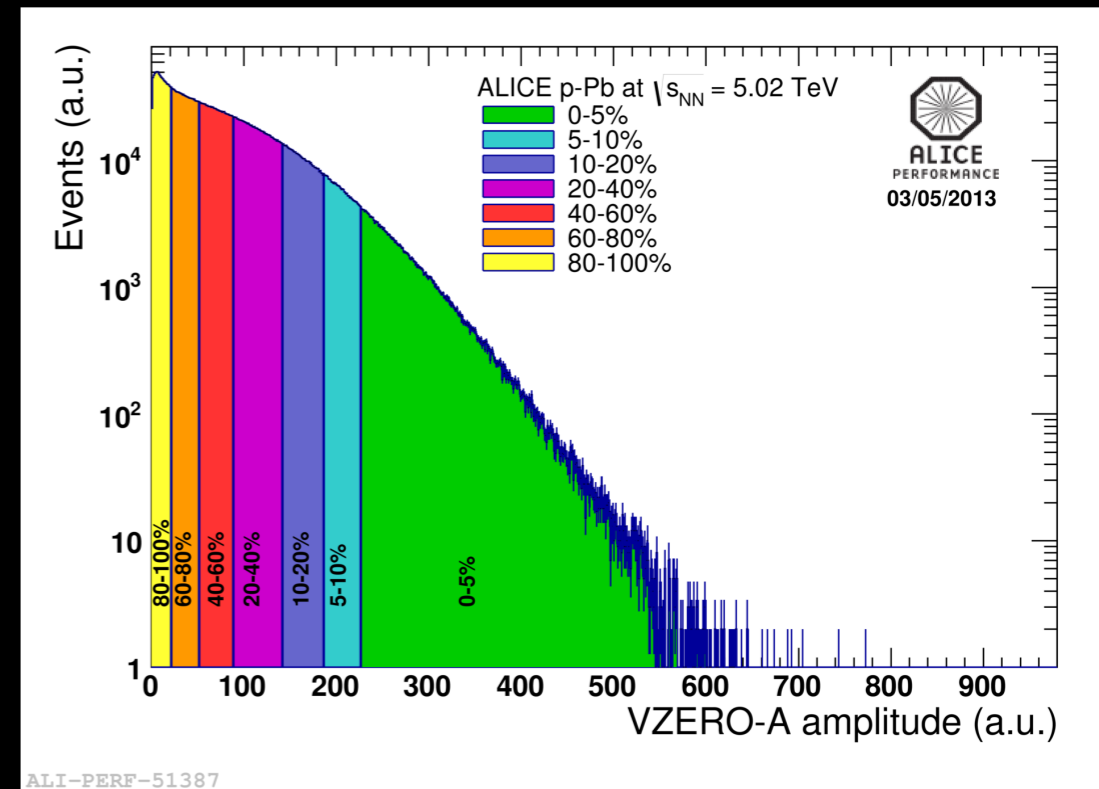


Centrality determination in p-Pb is not as straightforward as in Pb-Pb

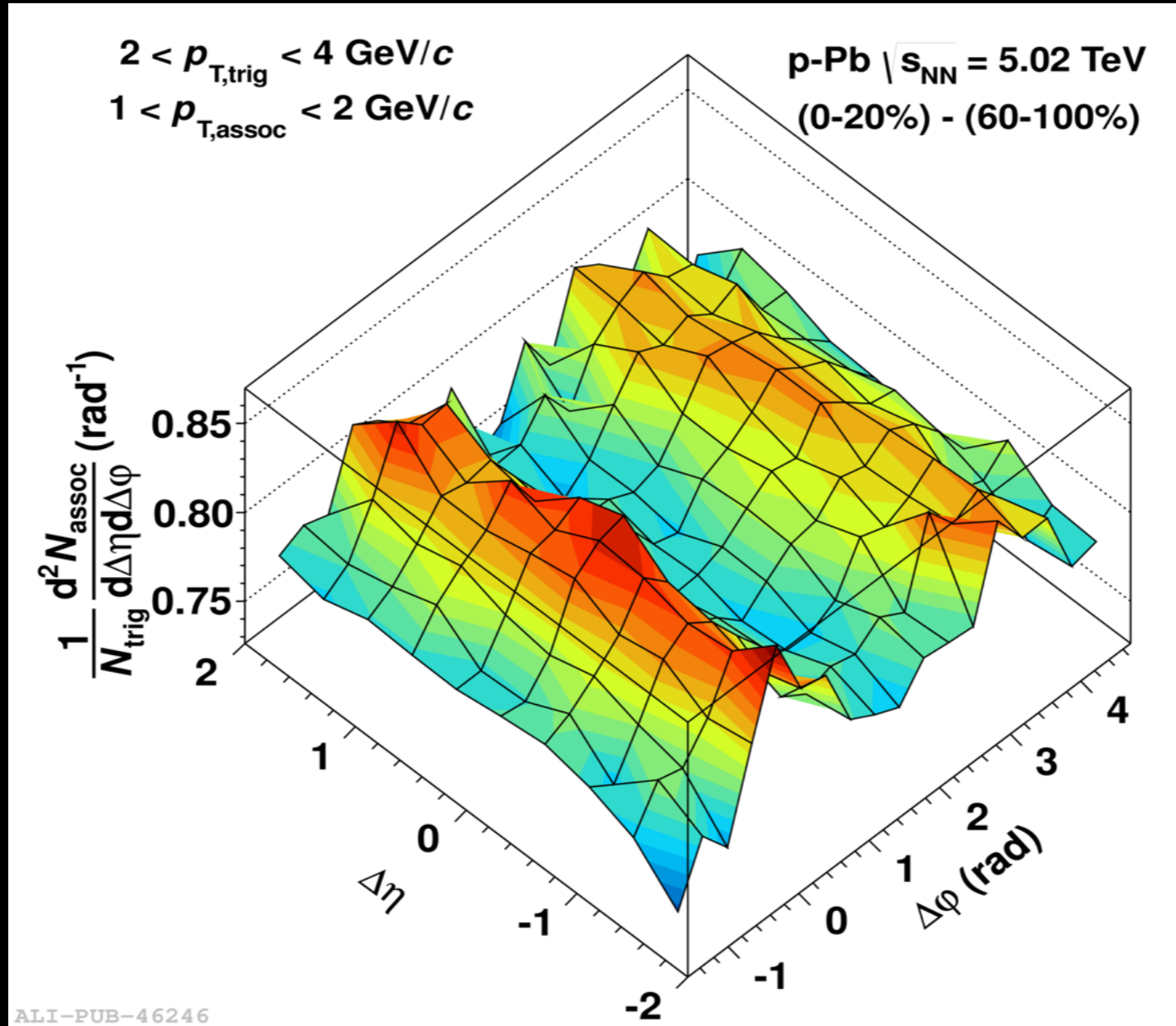
- ★ Weak correlation between parameters like
 - impact parameter and number of participants
 - number of participants and multiplicity

Define event classes based on

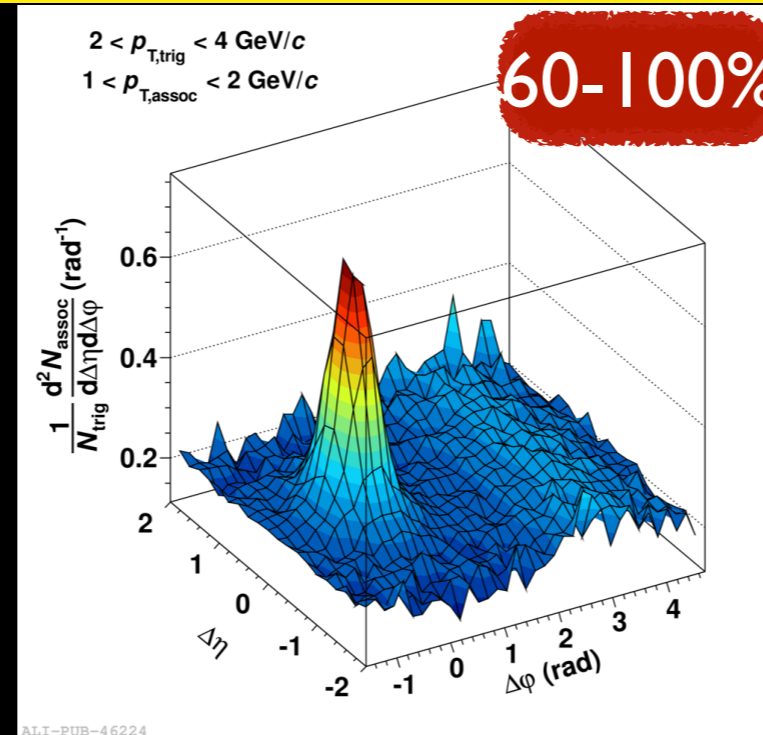
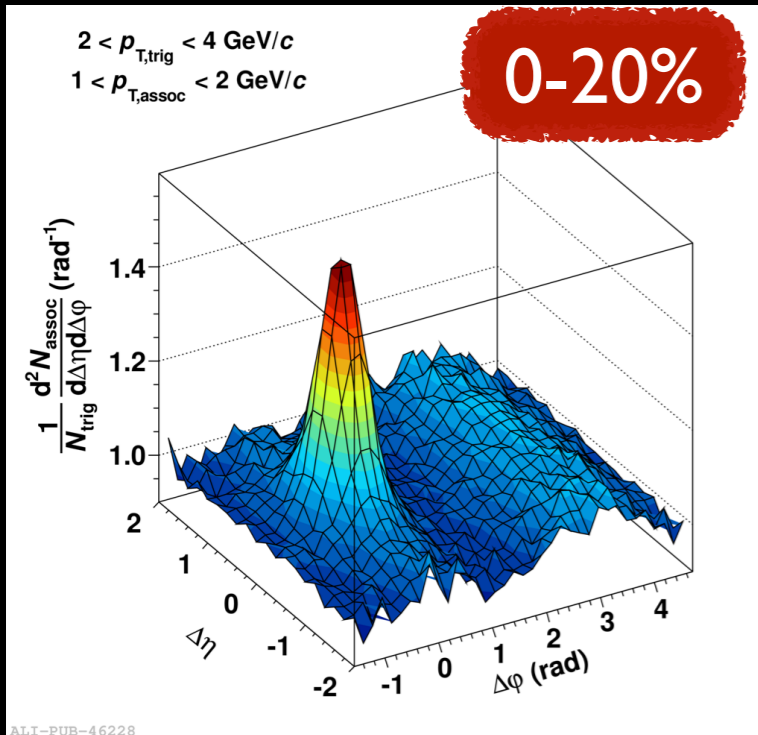
- ★ multiplicity measurement from central detectors (e.g. CMS)
- ★ multiplicity measurement from forward detectors (e.g. ALICE)
- ★ calorimetry (e.g. ATLAS)



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$$\frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{assoc}}}{d\Delta\eta d\Delta\phi} \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}$$

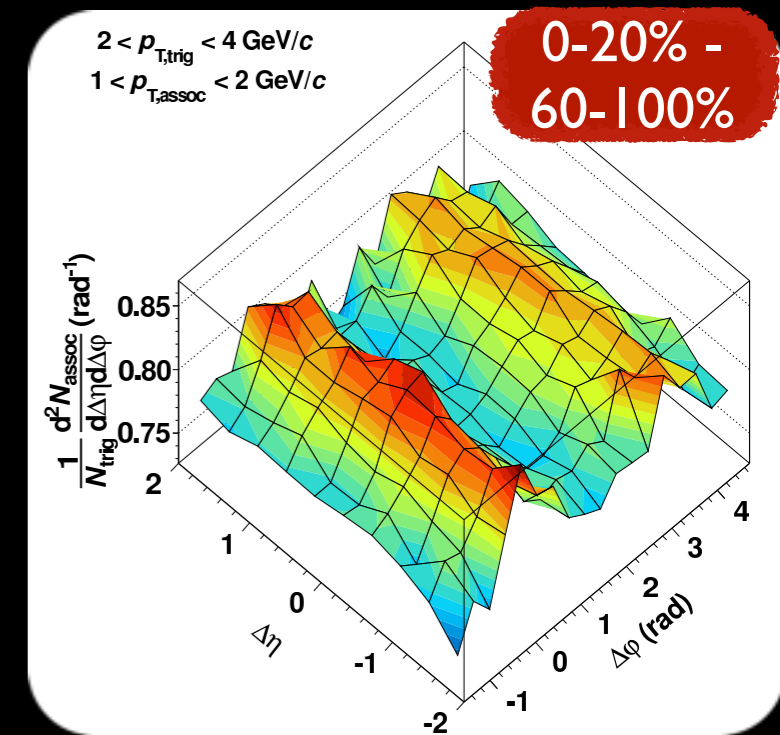
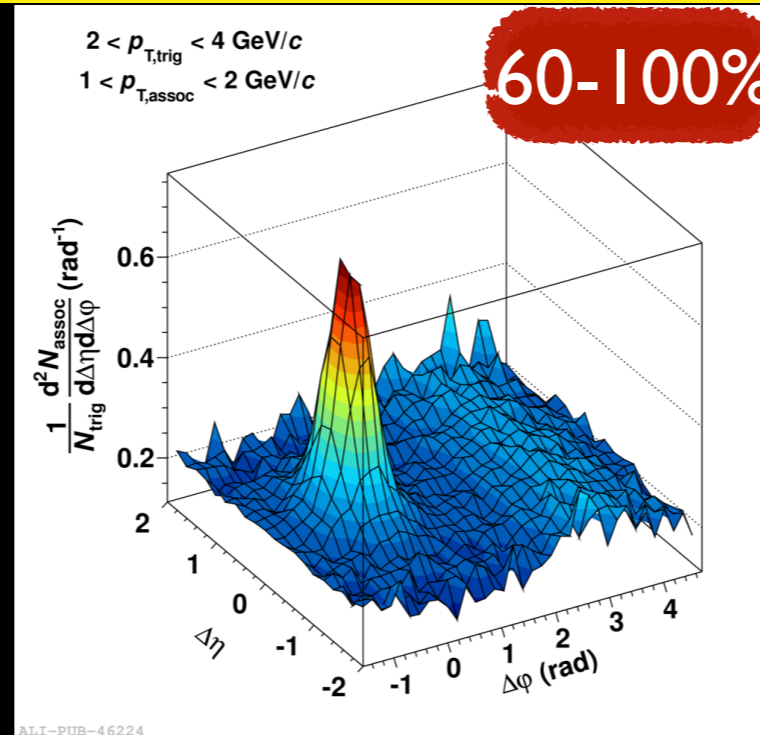
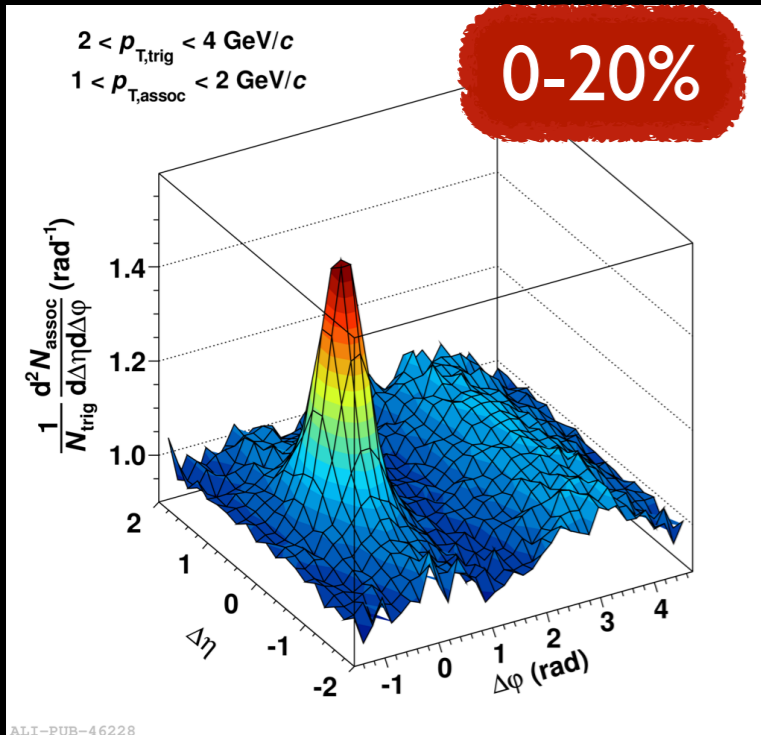
$$S(\Delta\eta, \Delta\phi) = \left(\frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{assoc}}}{d\Delta\eta d\Delta\phi} \right)_{\text{same}}$$

$$B(\Delta\eta, \Delta\phi) = a \left(\frac{d^2 N_{\text{assoc}}}{d\Delta\eta d\Delta\phi} \right)_{\text{mixed}}$$



Near side ridge is observed in high multiplicity p-Pb collisions

ALICE Collaboration: Phys. Lett. B719, (2013) 29



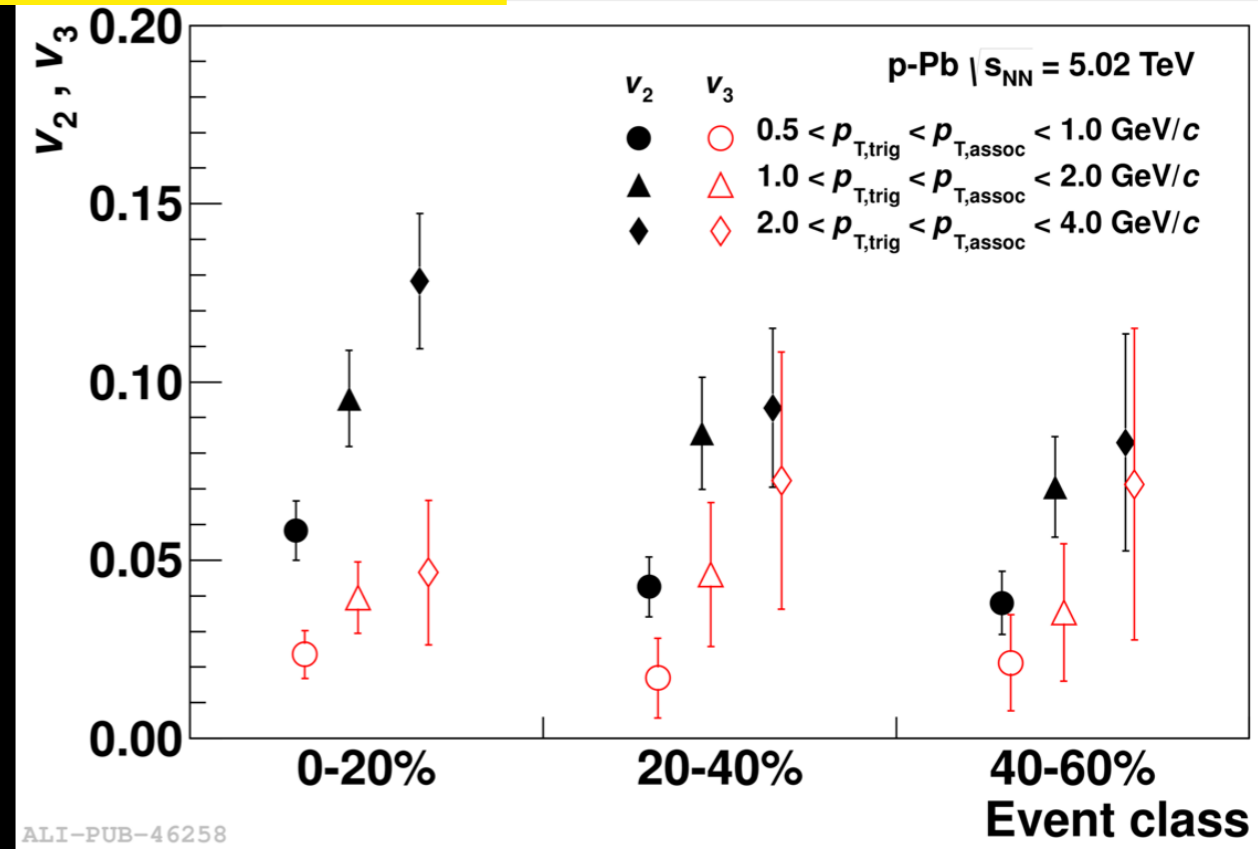
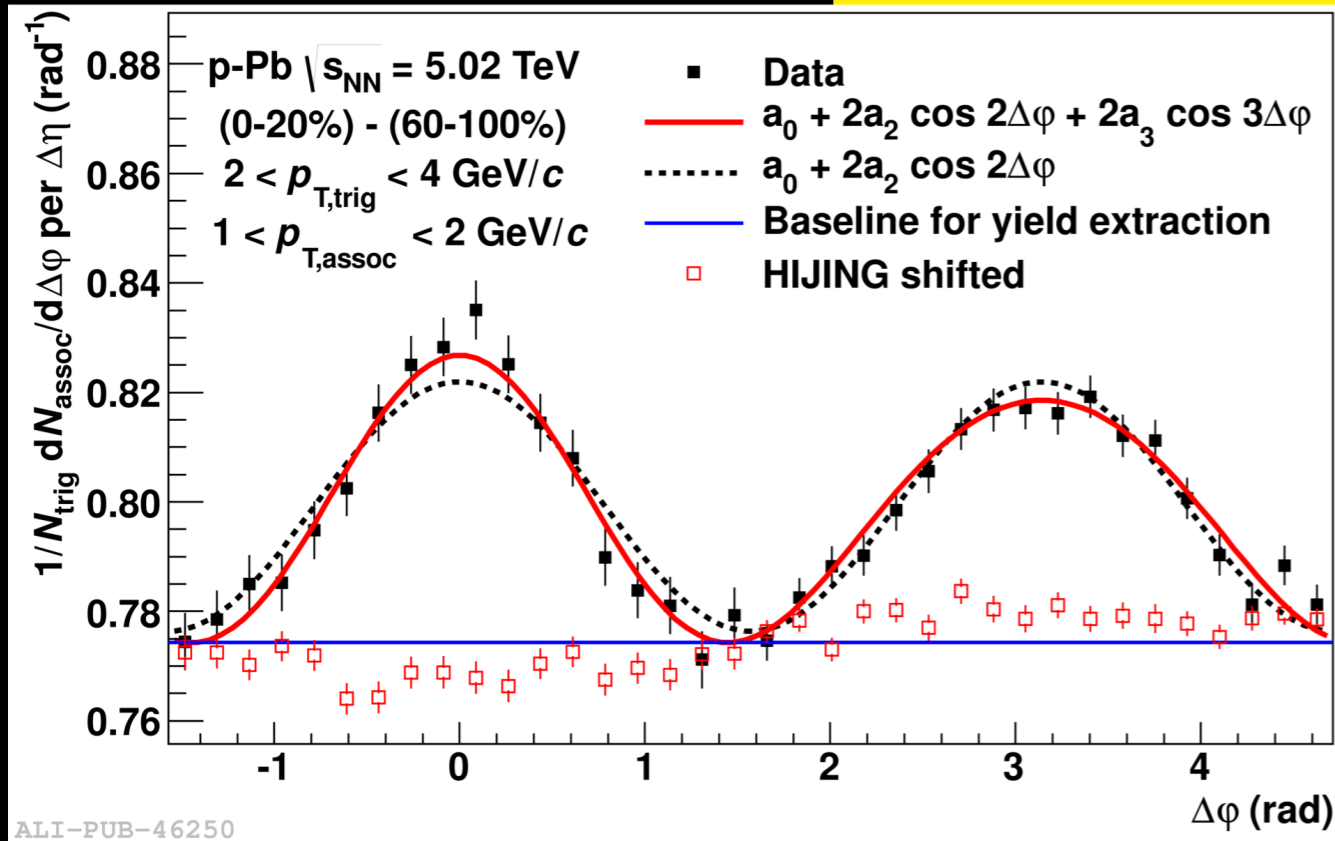
$$\frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{assoc}}}{d\Delta\eta d\Delta\phi} \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}$$

$$S(\Delta\eta, \Delta\phi) = \left(\frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{assoc}}}{d\Delta\eta d\Delta\phi} \right)_{\text{same}}$$

$$B(\Delta\eta, \Delta\phi) = a \left(\frac{d^2 N_{\text{assoc}}}{d\Delta\eta d\Delta\phi} \right)_{\text{mixed}}$$

- Near side ridge is observed in high multiplicity p-Pb collisions
- Subtraction of the jet component i.e. as measured in the 60-100% multiplicity class reveals
 - ★ a double symmetric ridge on the near and the away side!

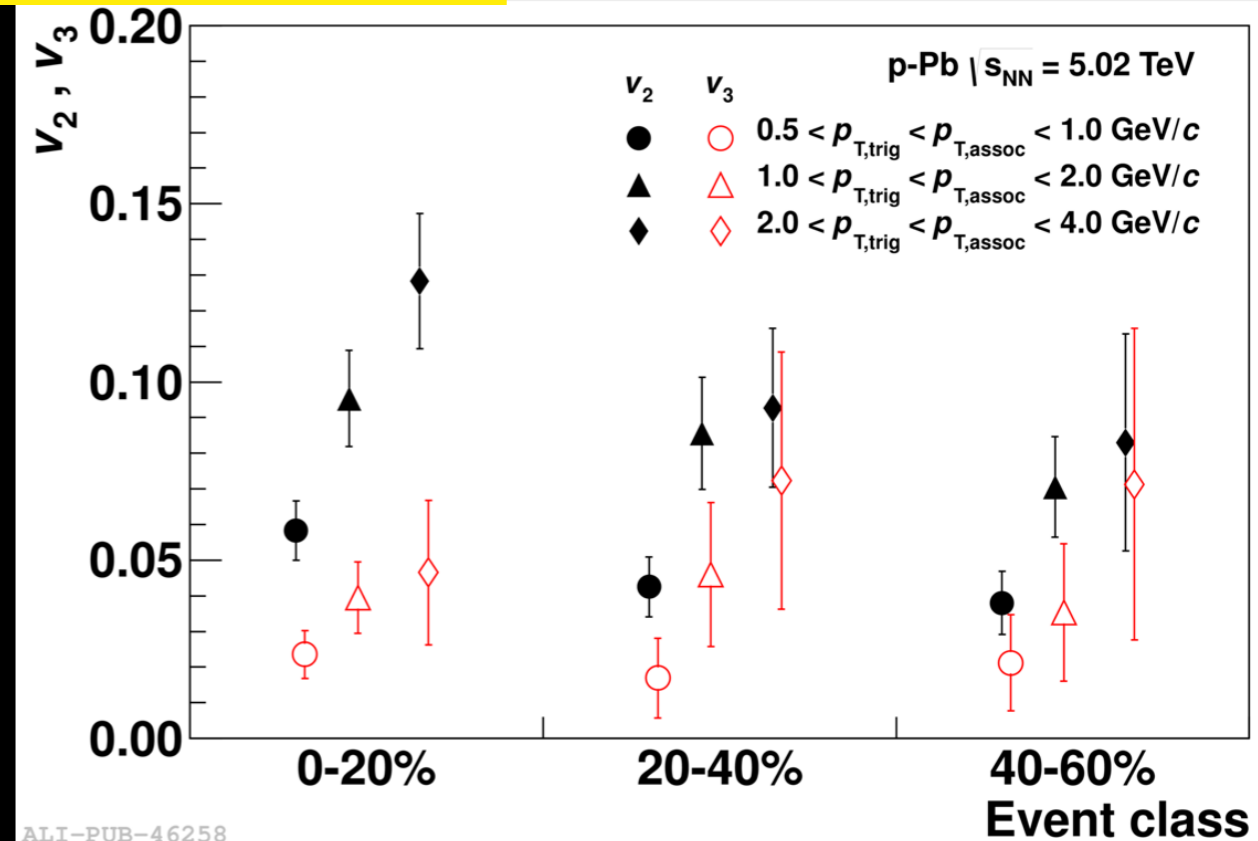
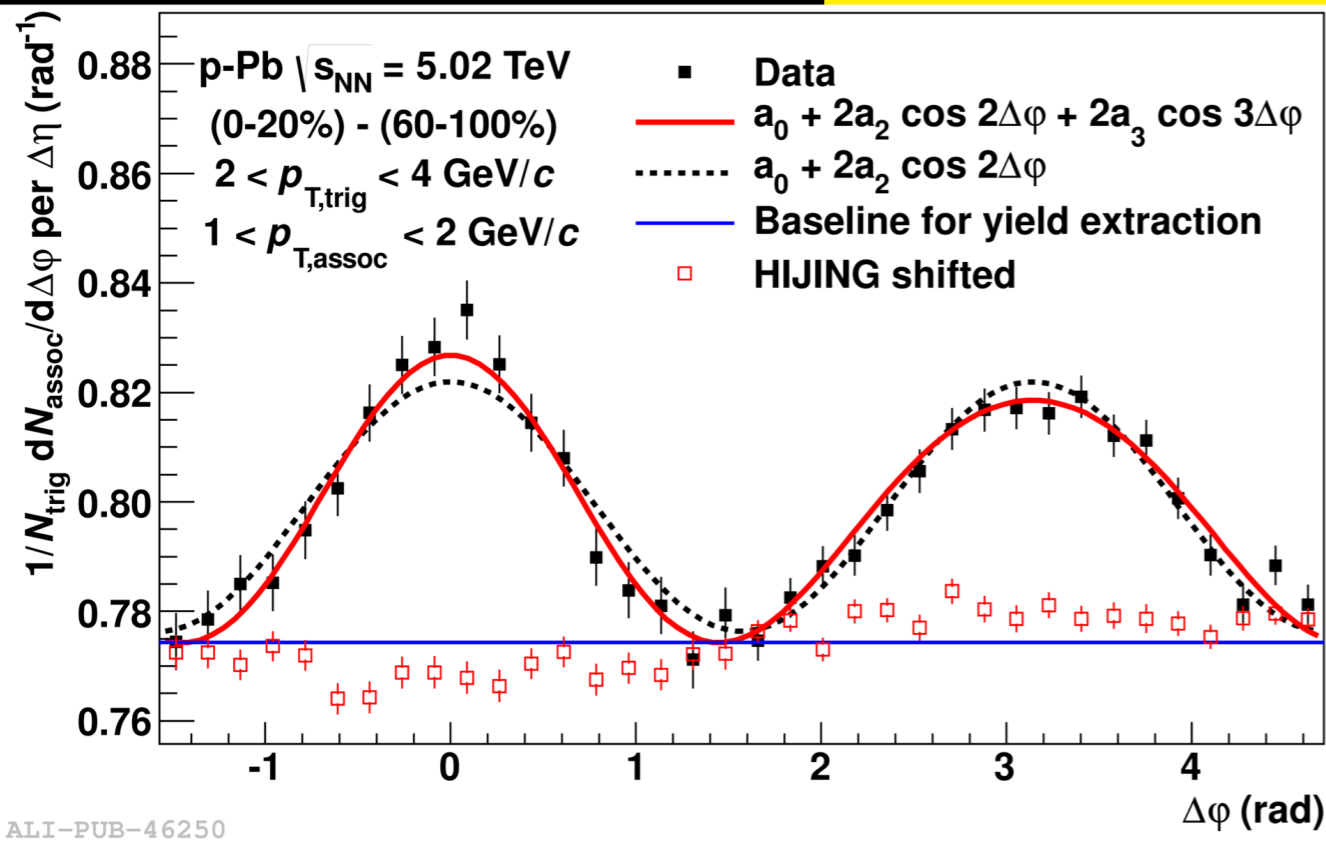
ALICE Collaboration: Phys. Lett. B719, (2013) 29



$$\frac{1}{N_{trig.}} \frac{dN_{assoc}}{d\Delta\phi} = a_0 + 2a_2 \cos(2\Delta\phi) + 2a_3 \cos(3\Delta\phi)$$

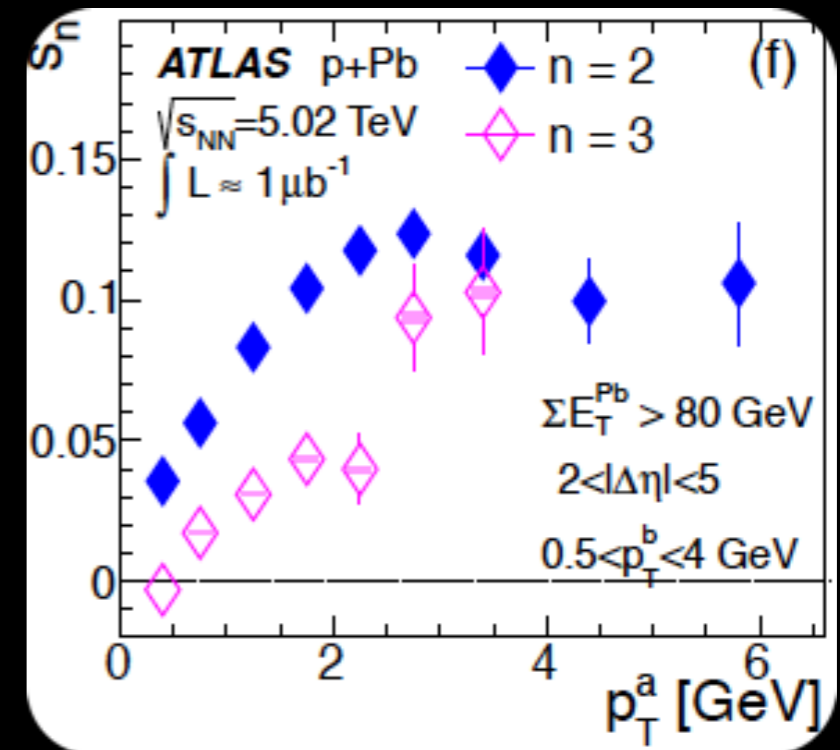
- Fourier decomposition using the 2nd and the 3rd harmonic
- v_2 and v_3 increase with increasing p_T , while exhibiting a mild multiplicity dependence

ALICE Collaboration: Phys. Lett. B719, (2013) 29



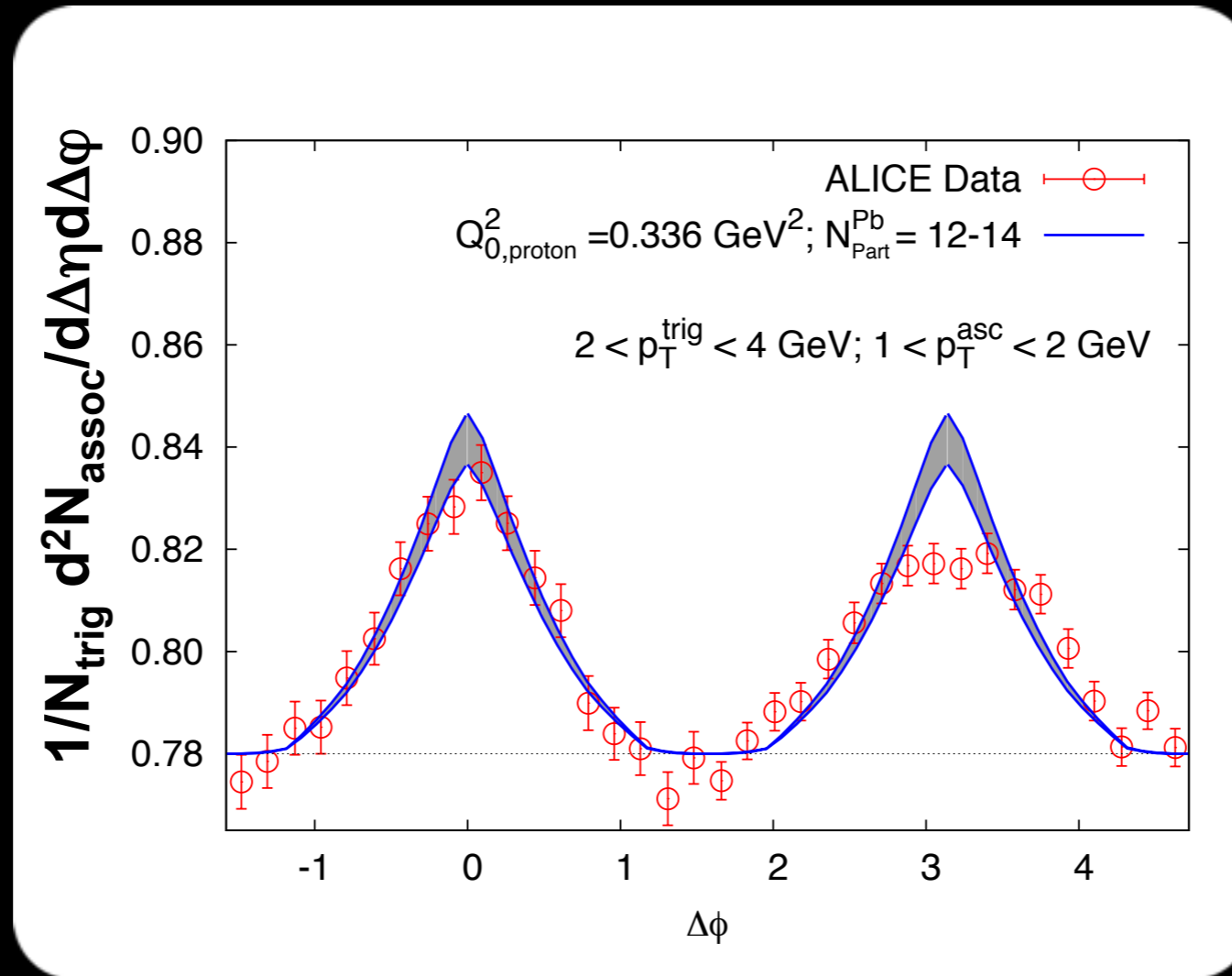
Similar observation by ATLAS slightly later

ATLAS Collaboration, Phys. Rev. Lett. 110, (2013) 182302



- In qualitative agreement with hydro (P. Bozek and W. Broniowski, Phys.Lett. **B718**, (2013) 1557) and CGC calculations

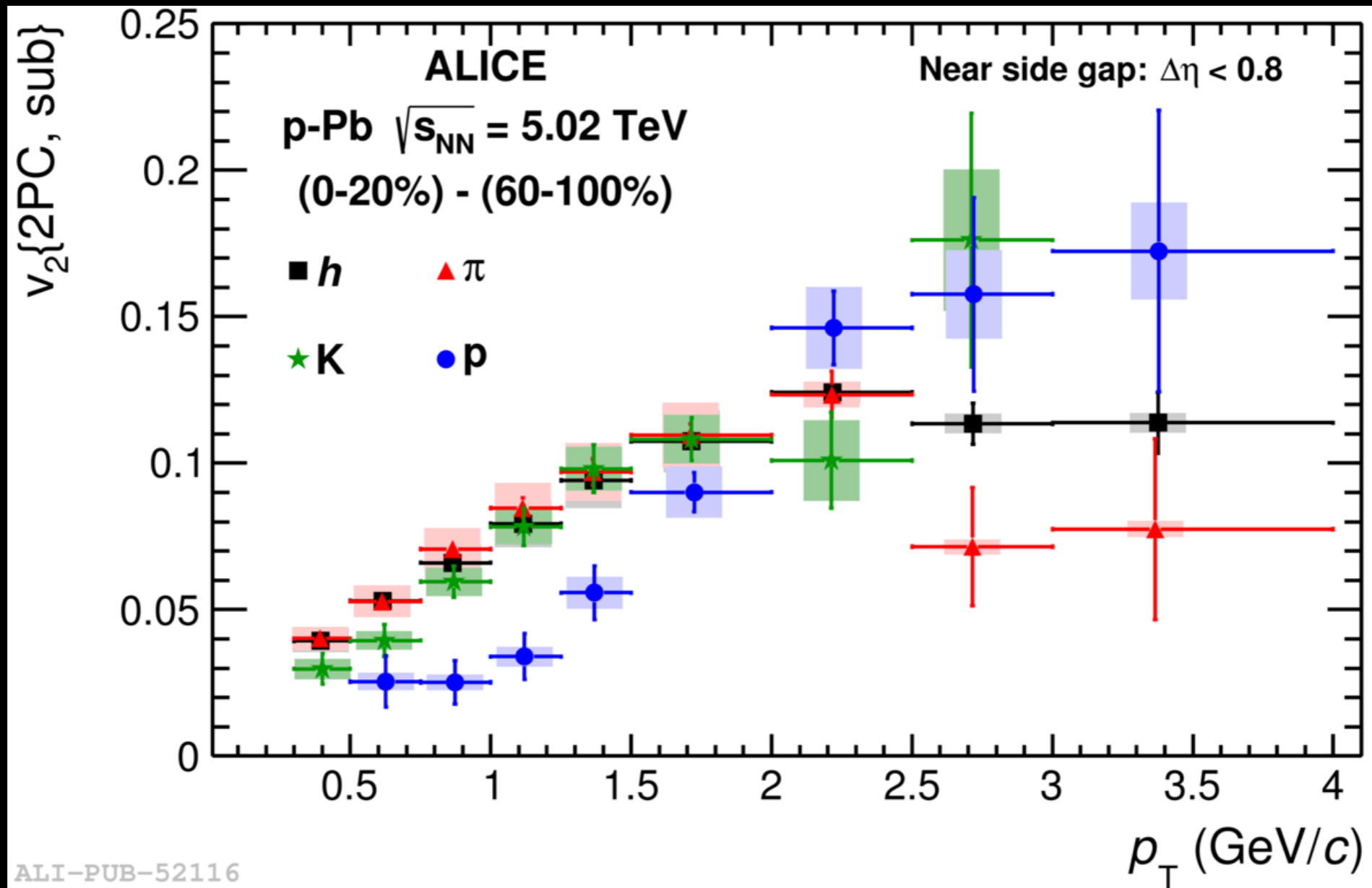
K.Dusling and R. Venugopalan, Phys.Rev. **D87**, (2013) 094034

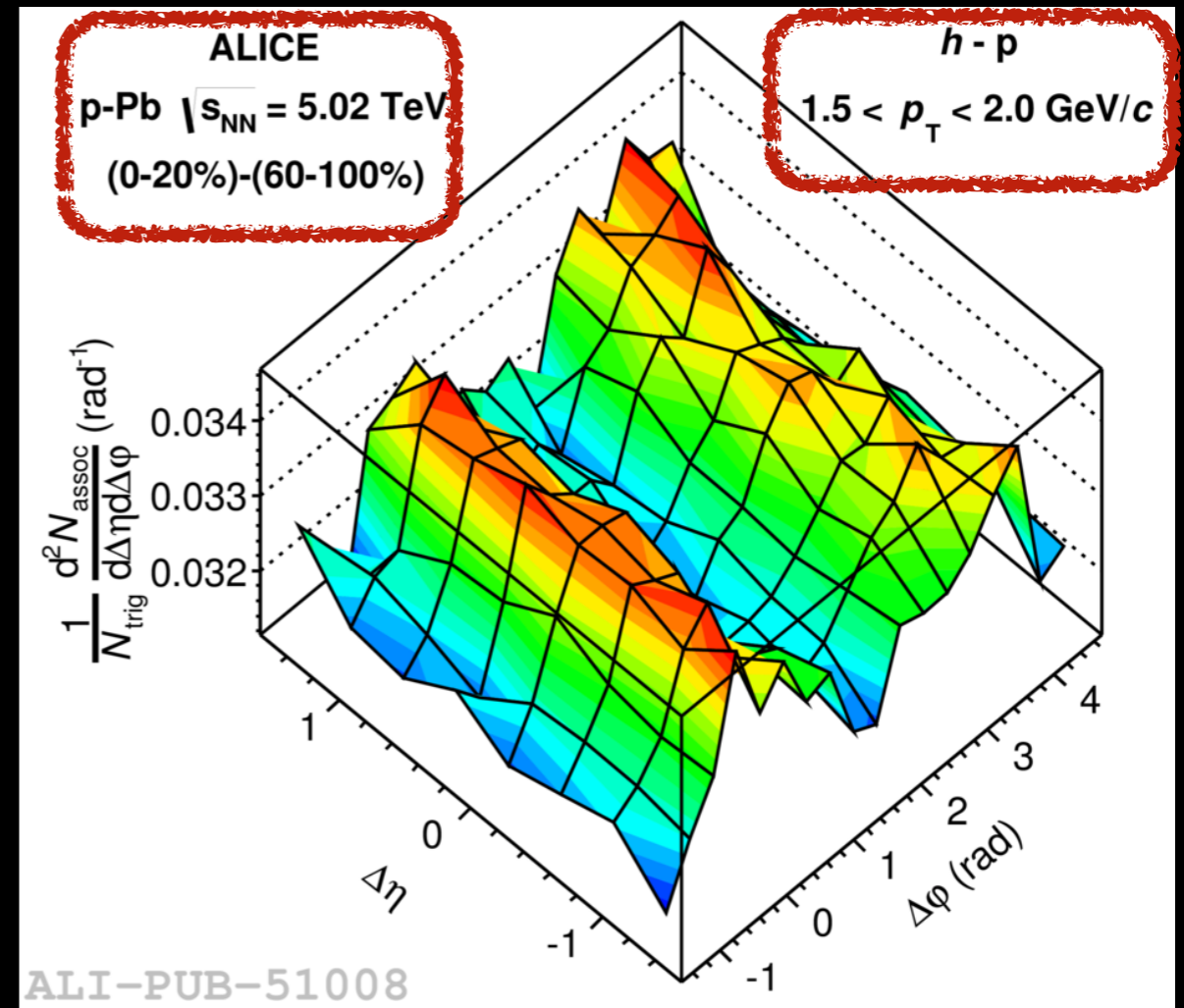
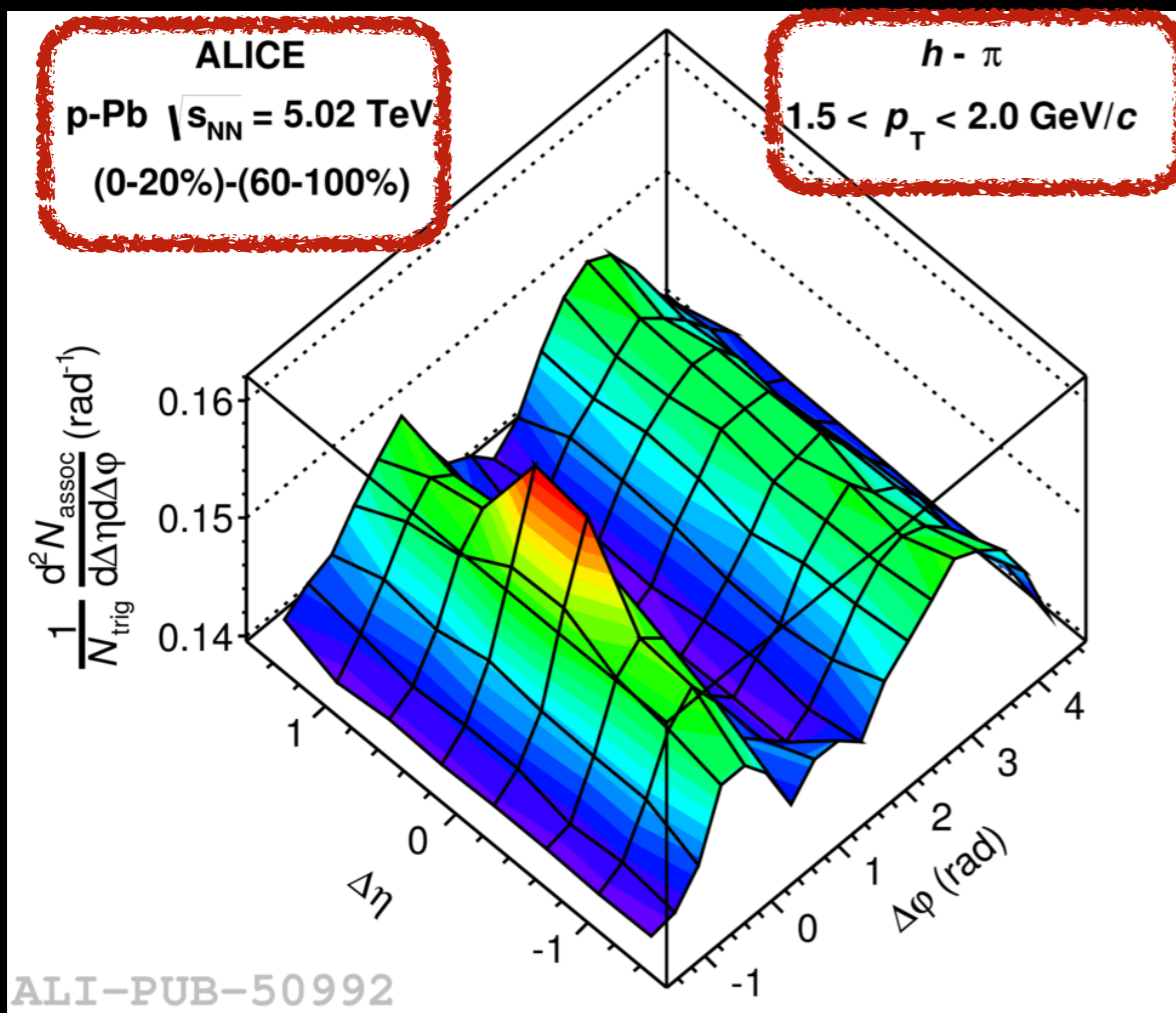


Relative good agreement, however no v_3 component

Can we learn more from data?

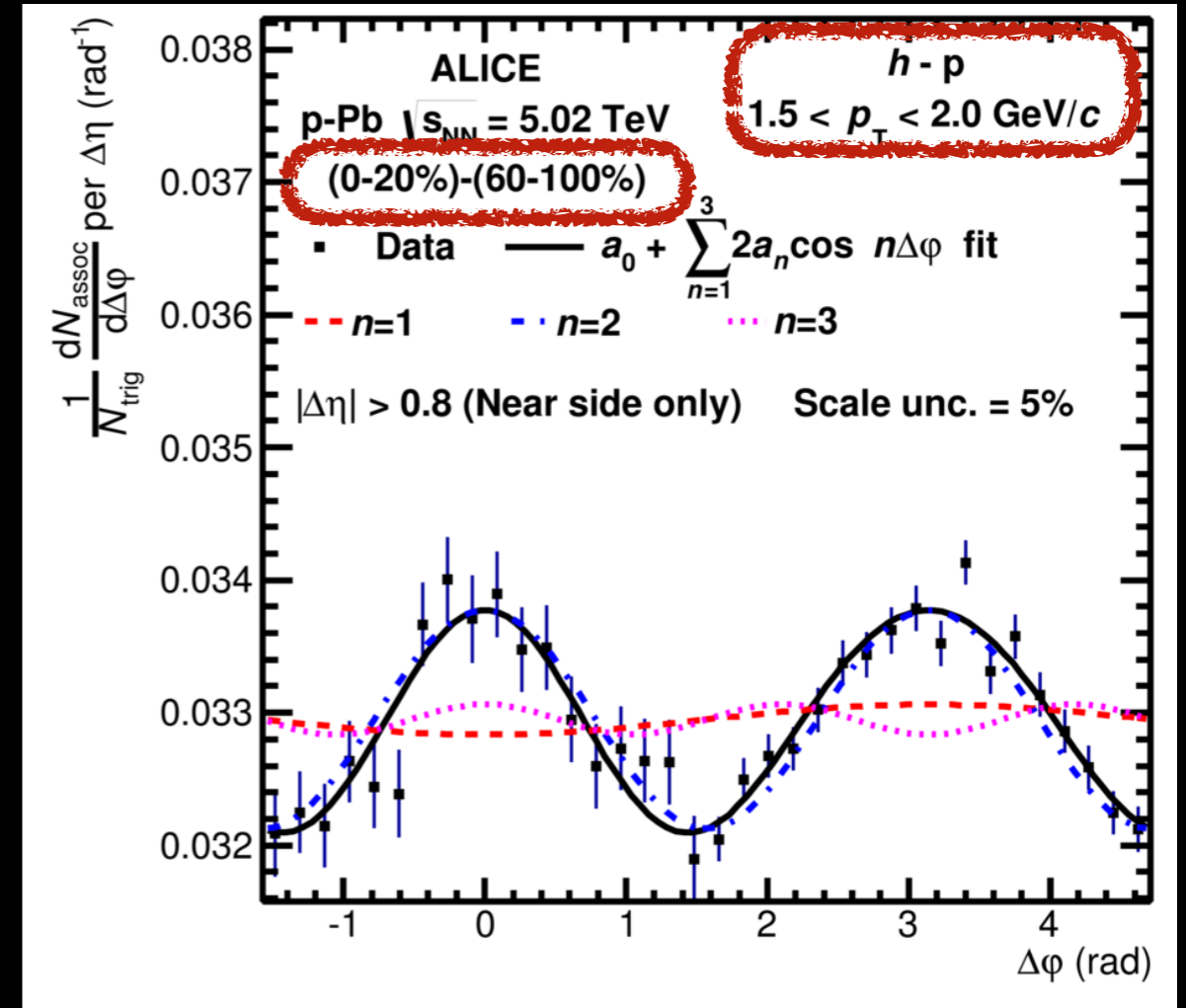
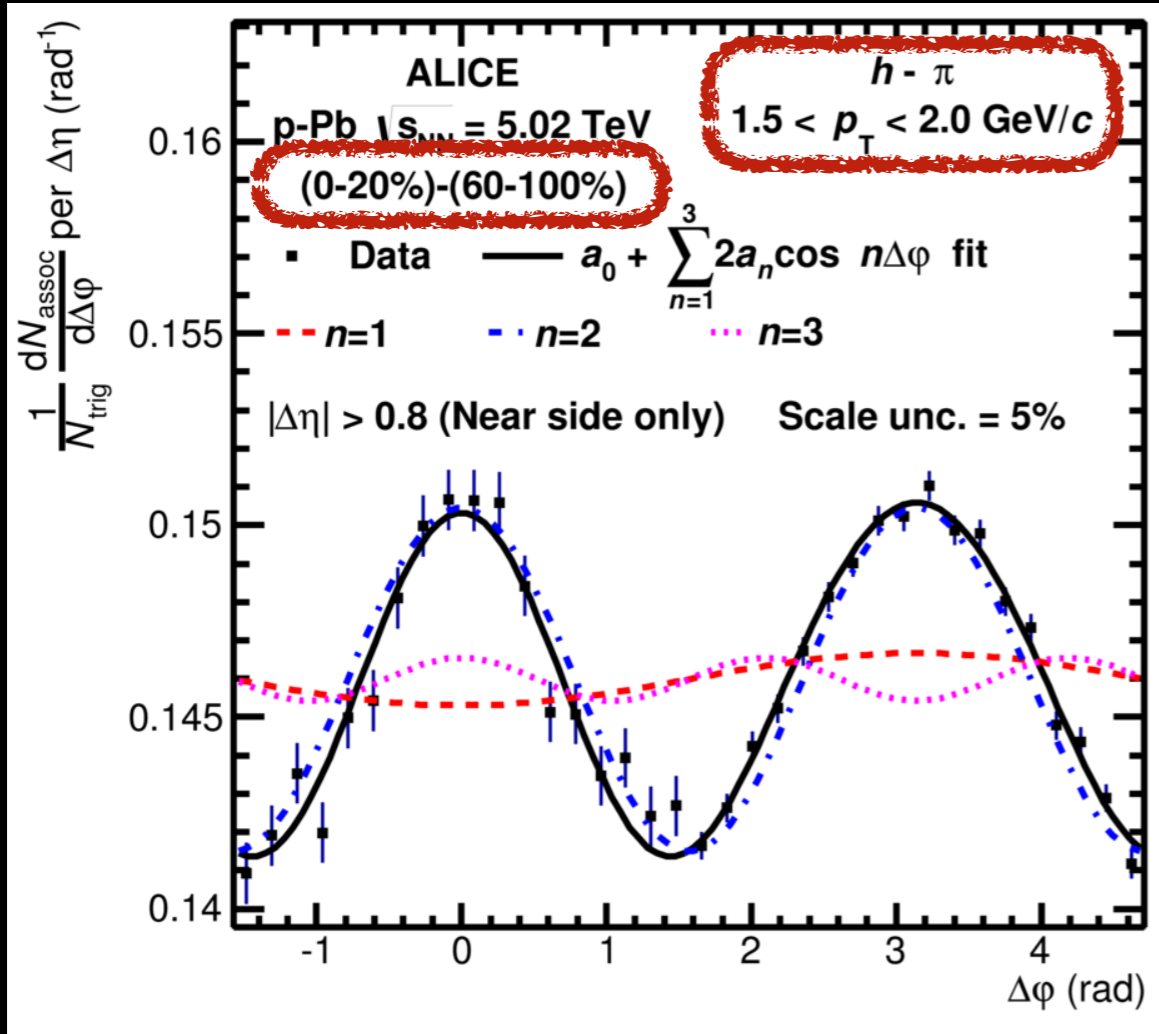
ALICE Collaboration: Phys. Lett. **B726**, (2013) 164





- Similar analysis: charged particle \Rightarrow “trigger”, (π, K, p) \Rightarrow “associated”
- Jet component reduction: (0-20)% - (60-100)%
- Symmetric ridges in all cases i.e. π -h, K-h, p-h
- ★ Residual near side jet peak for π -h and to a smaller extent K-h

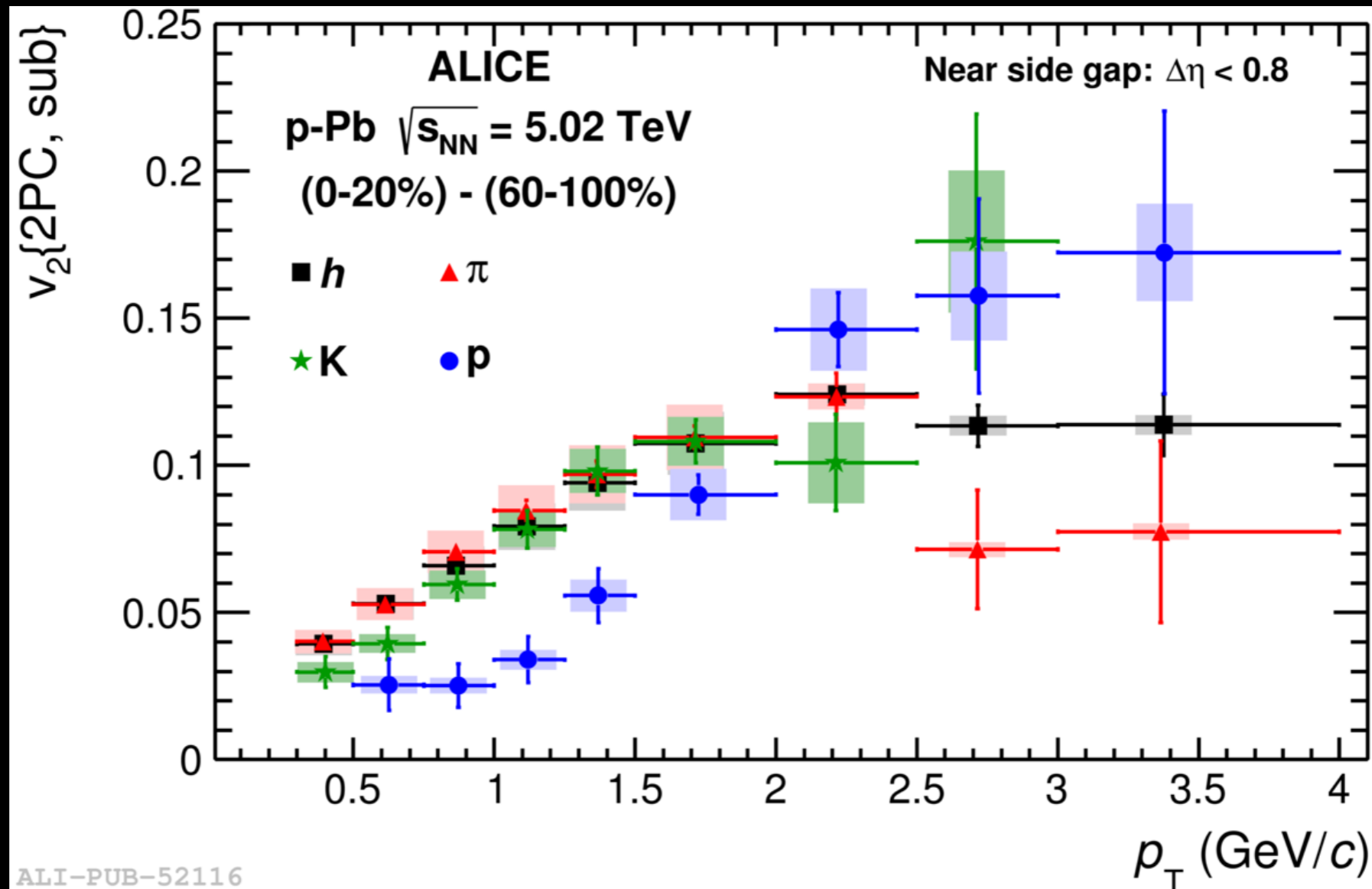
ALICE Collaboration: Phys. Lett. **B726**, (2013) 164



$$\frac{1}{N_{trig.}} \frac{dN_{assoc}}{d\Delta\phi} = a_0 + 2a_1 \cos(\Delta\phi) + 2a_2 \cos(2\Delta\phi) + 2a_3 \cos(3\Delta\phi)$$

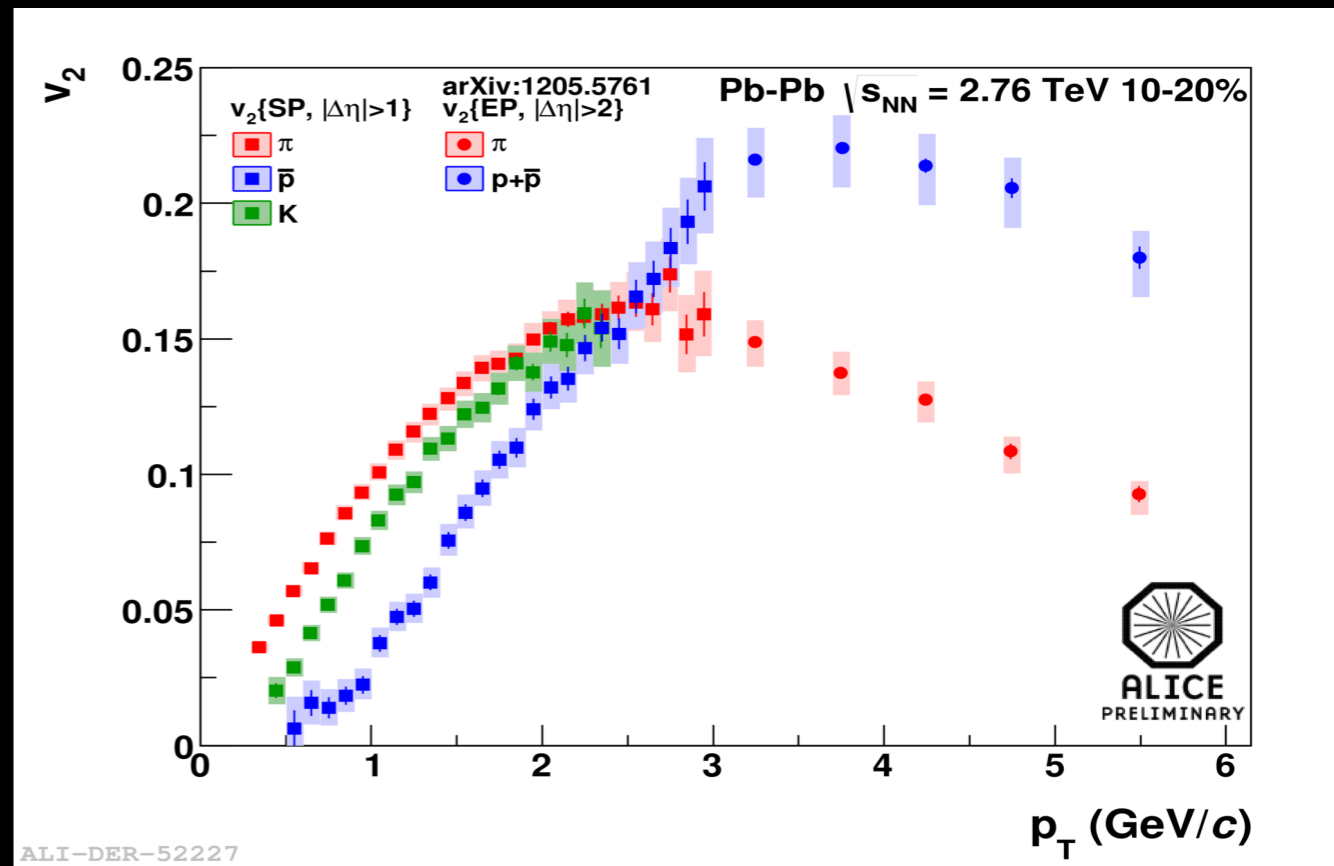
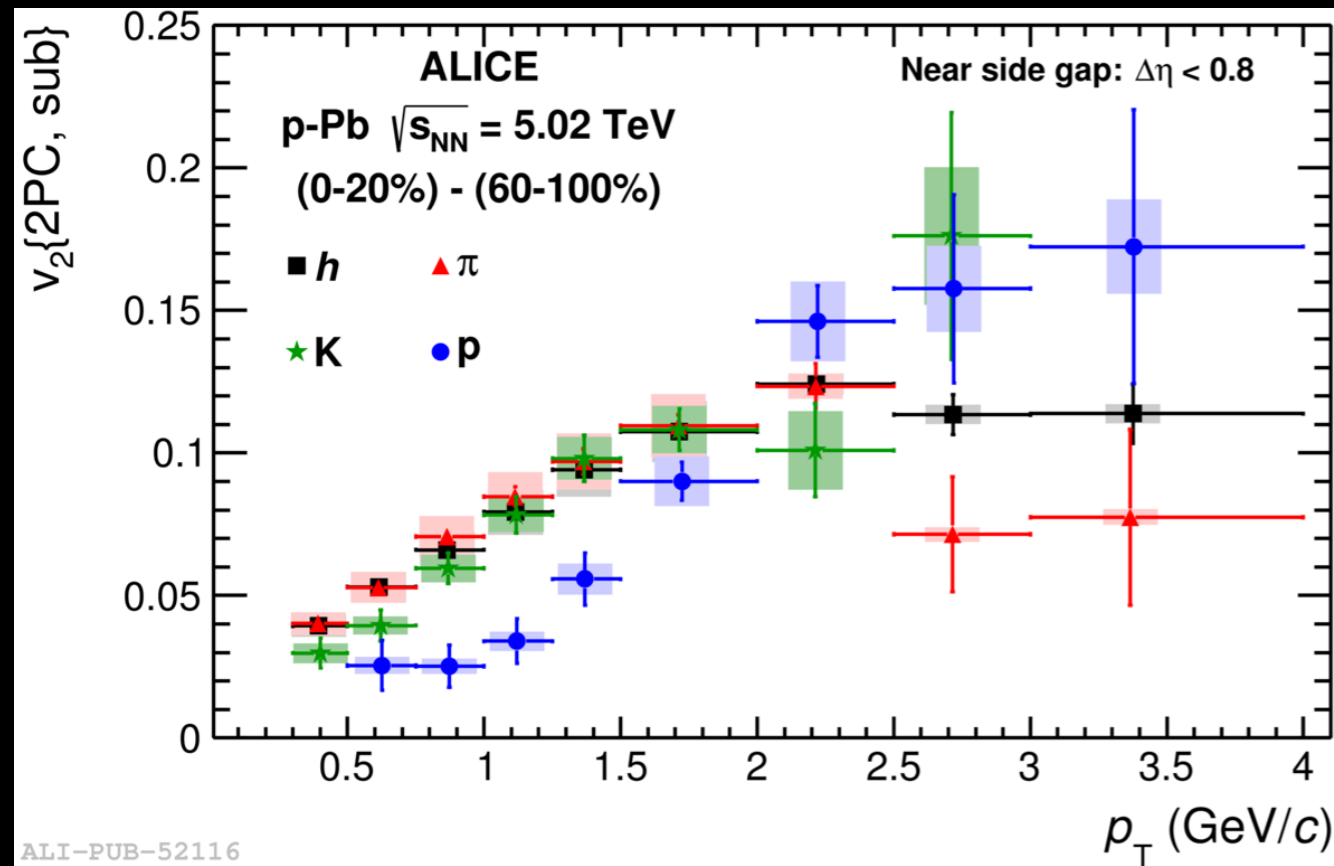
- After subtraction: symmetric double ridges for h- π , h-K, h-p
- Small contribution from the odd coefficients

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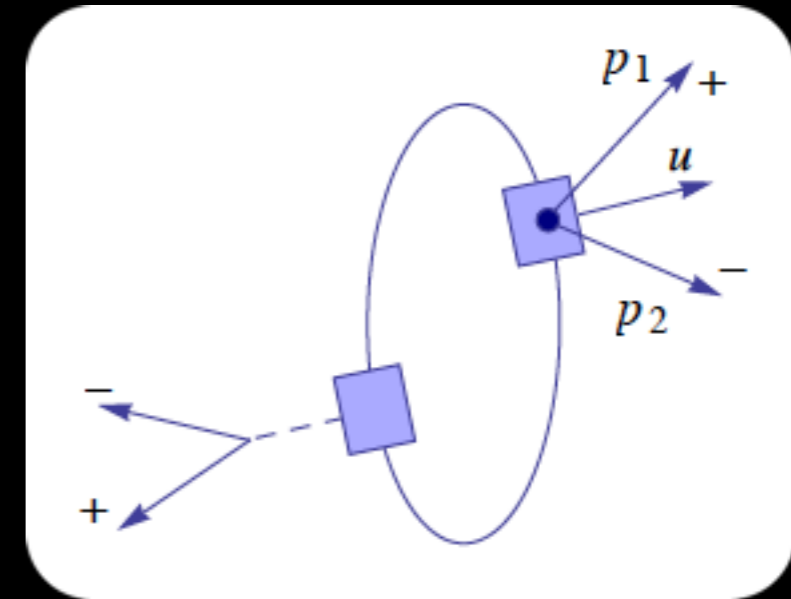
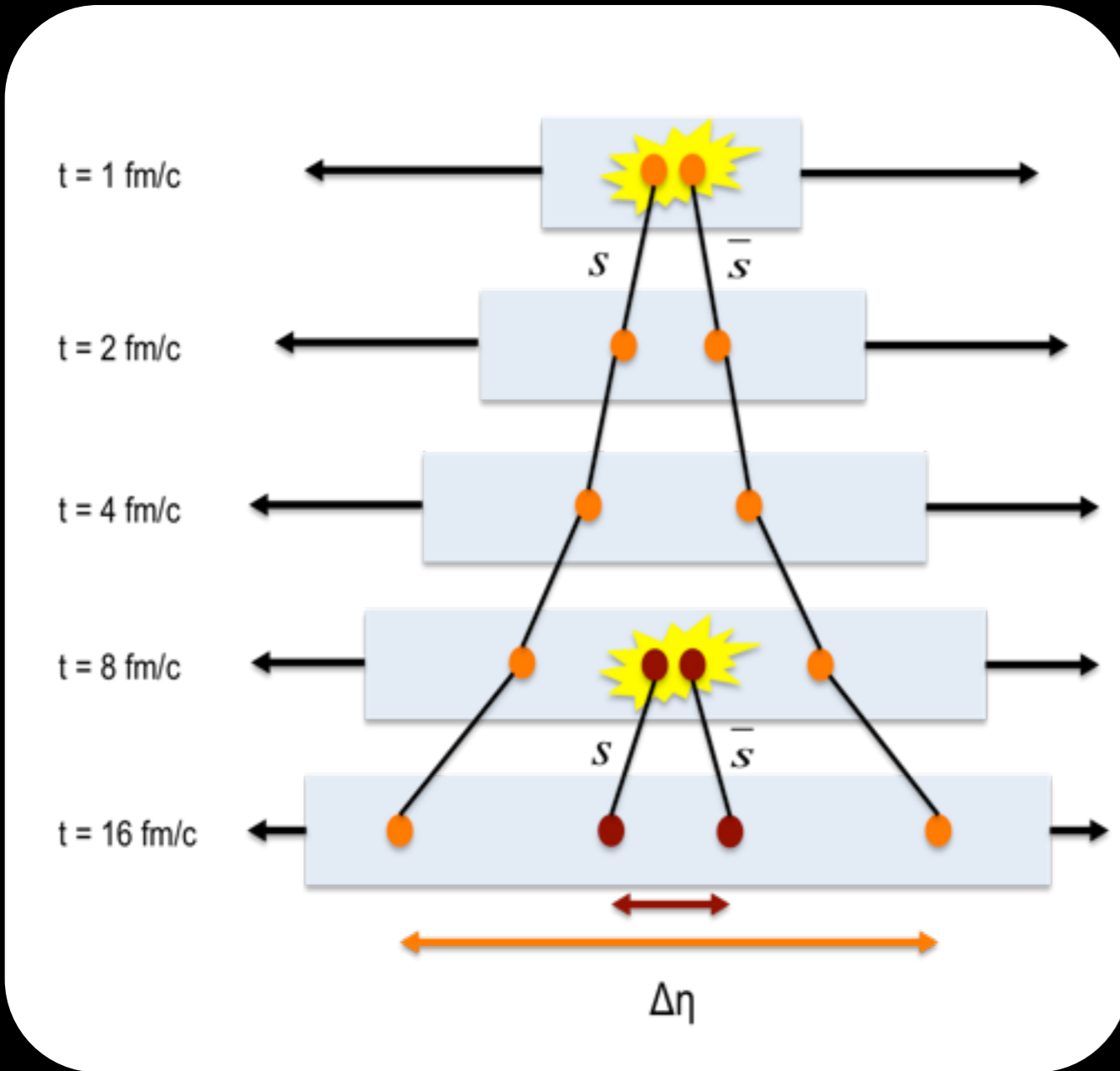
📌 Mass splitting observed in p-Pb collisions!

ALICE Collaboration: Phys. Lett. **B726**, (2013) 164



- 📍 Mass splitting observed in p-Pb collisions!
- 📍 Qualitatively similar picture as in Pb-Pb
- ★ Qualitatively consistent with a system that develops some degree of collective behaviour

ALICE Collaboration: Phys. Lett. **B726**, (2013) 164



S. Bass, P. Danielewicz and S. Pratt, Phys. Rev. Lett. **85**, (2000) 2689

$$B_{+-}(\Delta\eta, \Delta\phi, P_{T, trig}, P_{T, assoc}) = \frac{1}{2} (C_{US} - C_{LS})$$

$$C_{US}: C_{+-}, C_{-+}$$

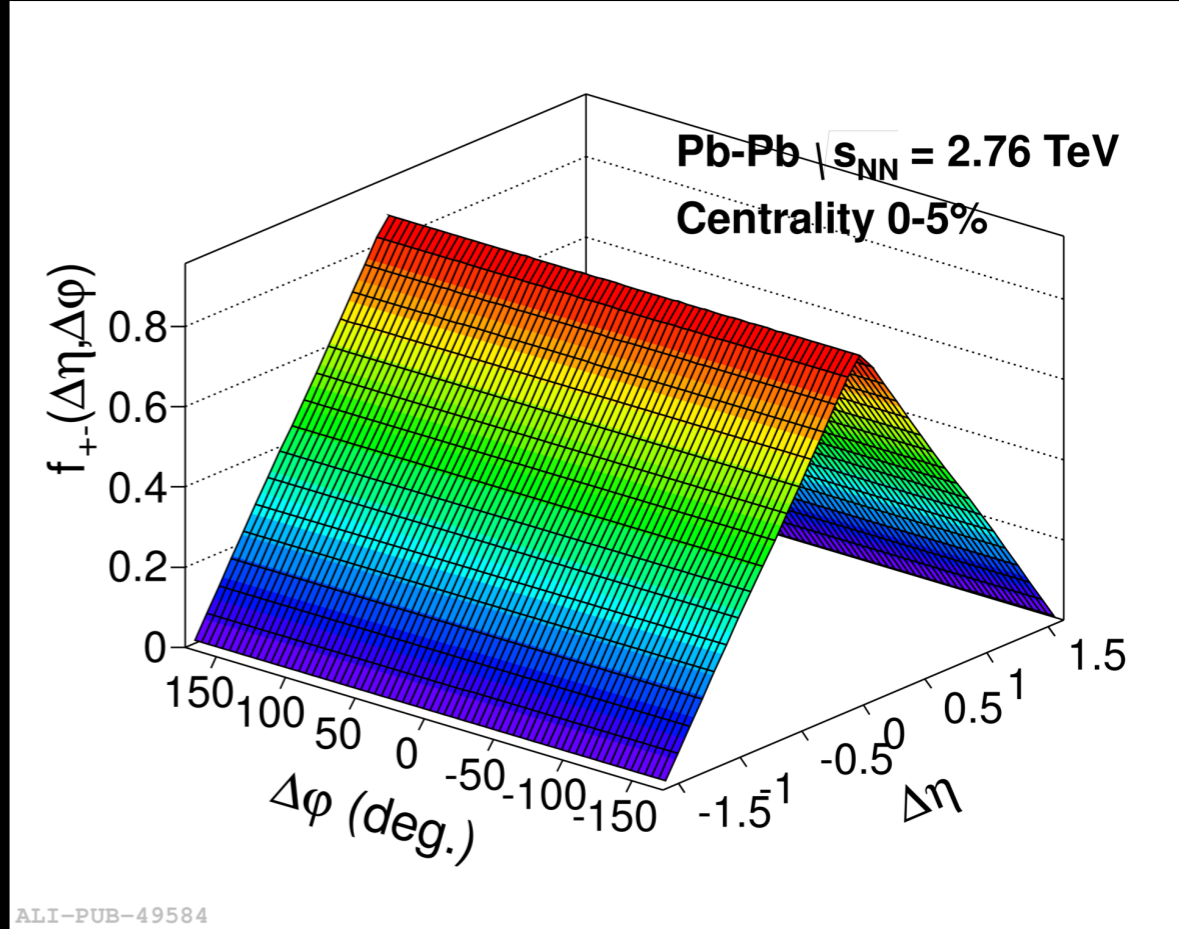
$$C_{LS}: C_{++}, C_{--}$$

Can be extended to any conserved quantum number e.g. baryon number, strangeness

$$C_{+-} = \left(\frac{N_{+-}}{N_+} \right) / f_{+-}$$

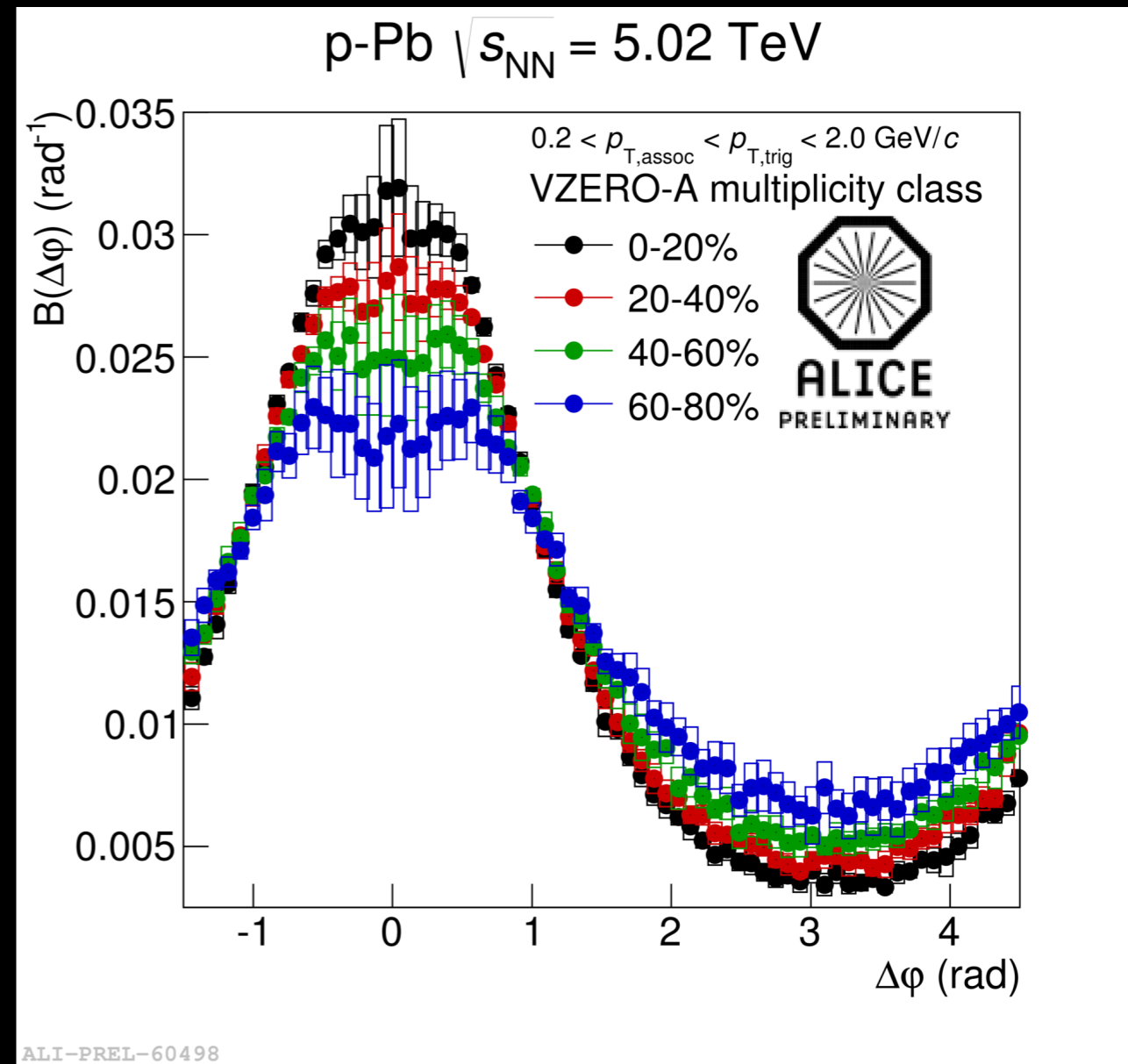
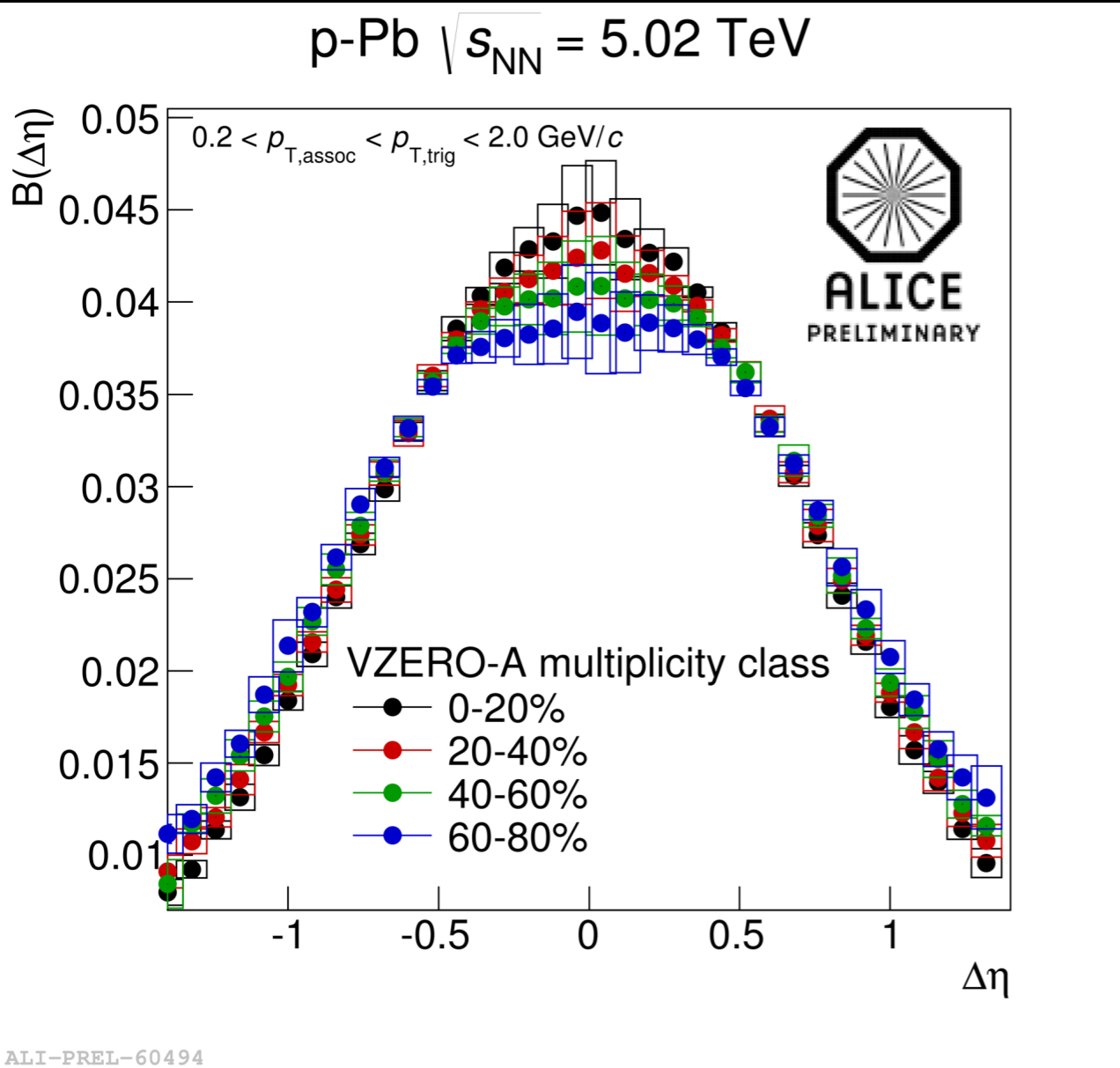
Detector acceptance and inefficiencies (mixed events or from convolution of single particle distributions)

particle pair density normalized to the number of trigger particles

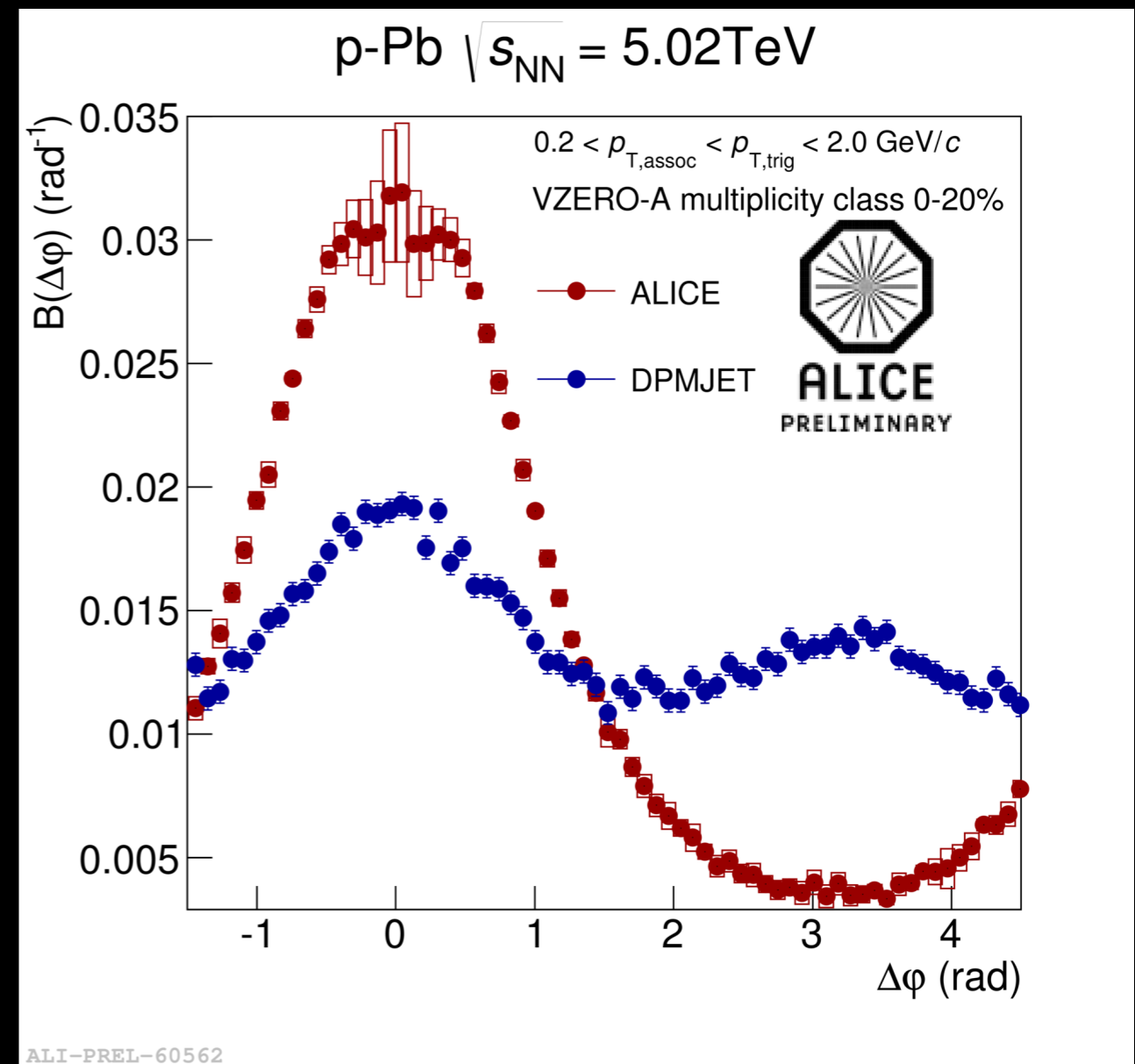
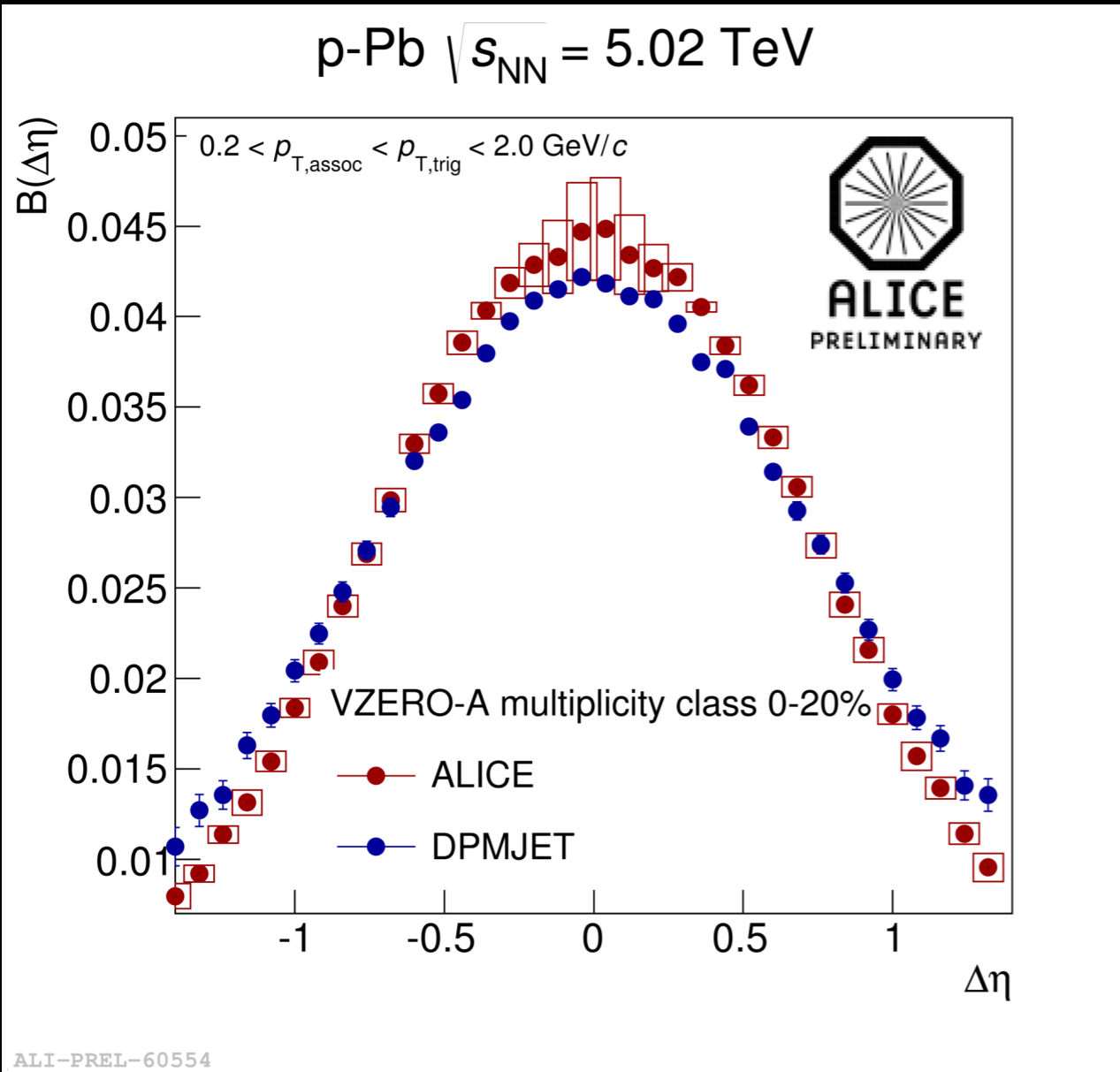


ALI-PUB-49584

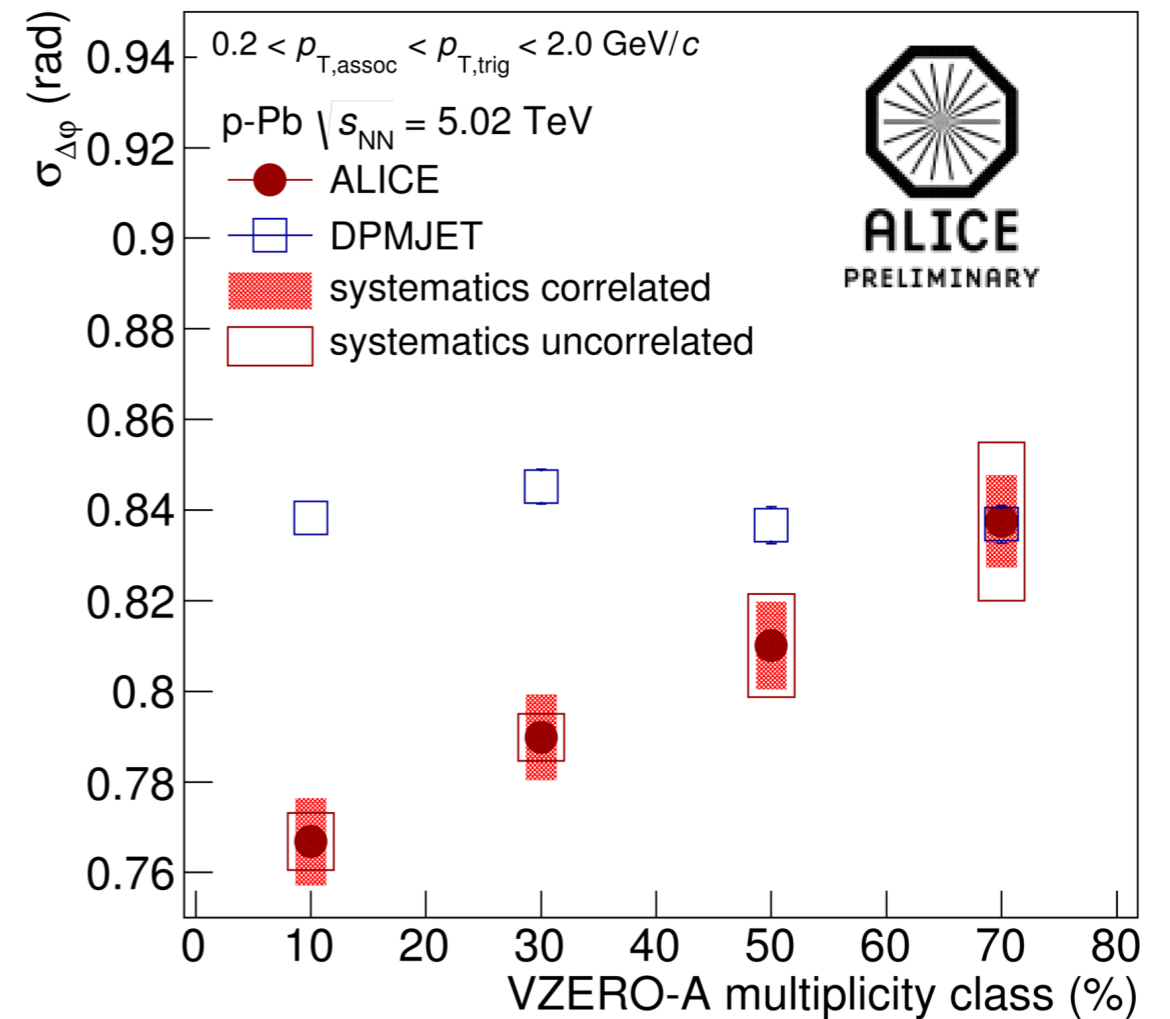
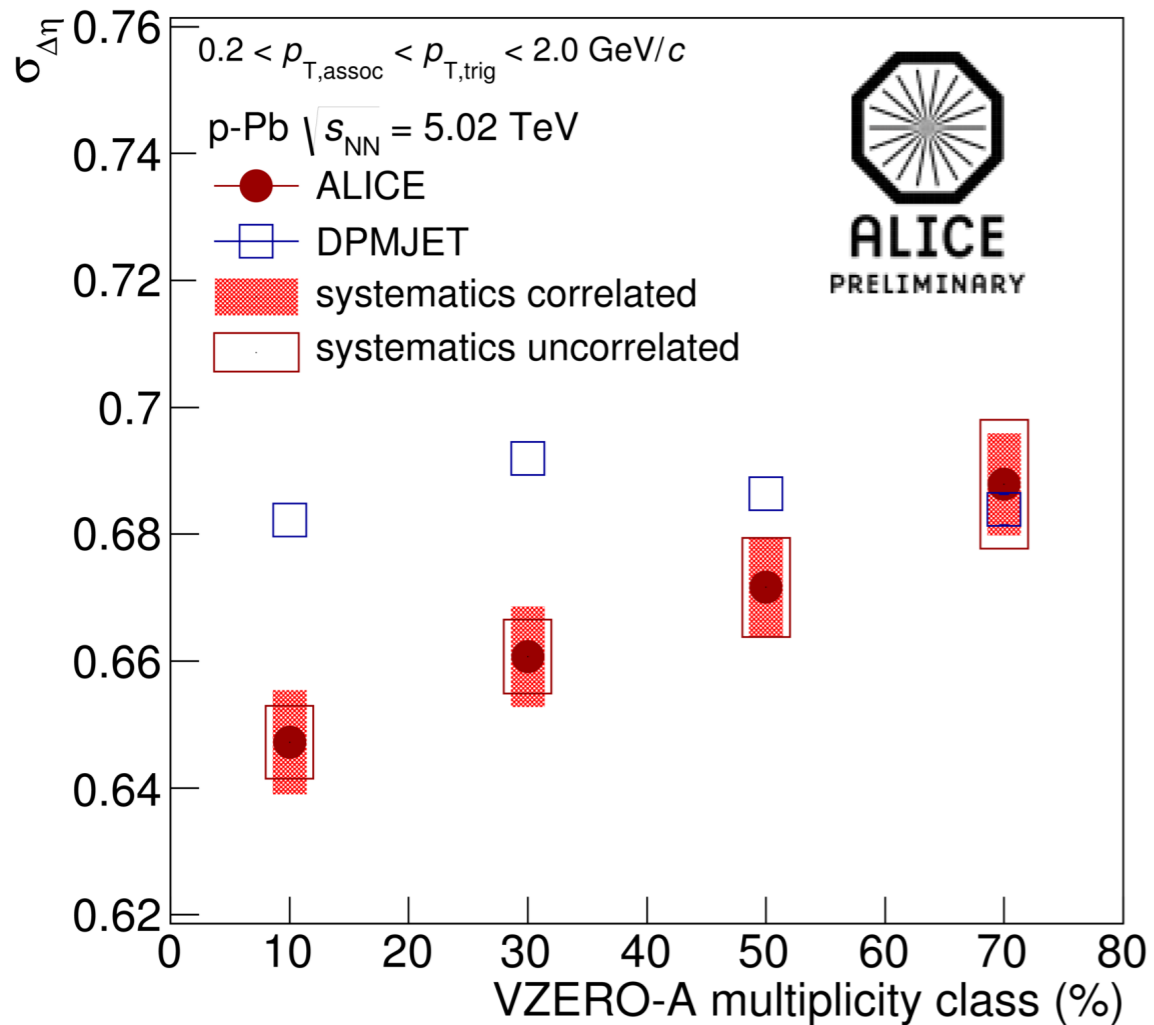
- “Balancing charges” affected (focused) by the collective motion of the system
- ★ Narrower balance functions if collectivity is developed



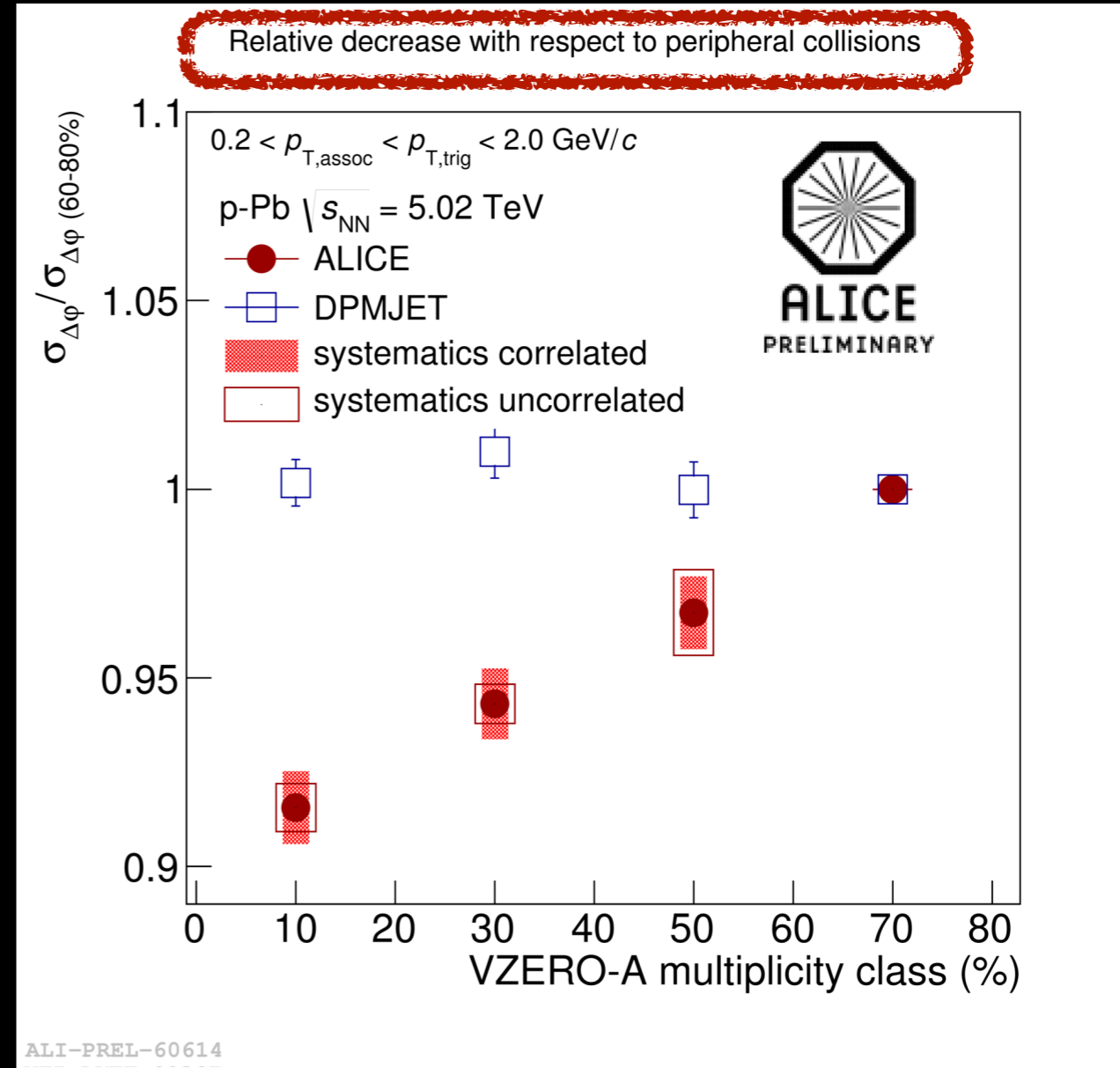
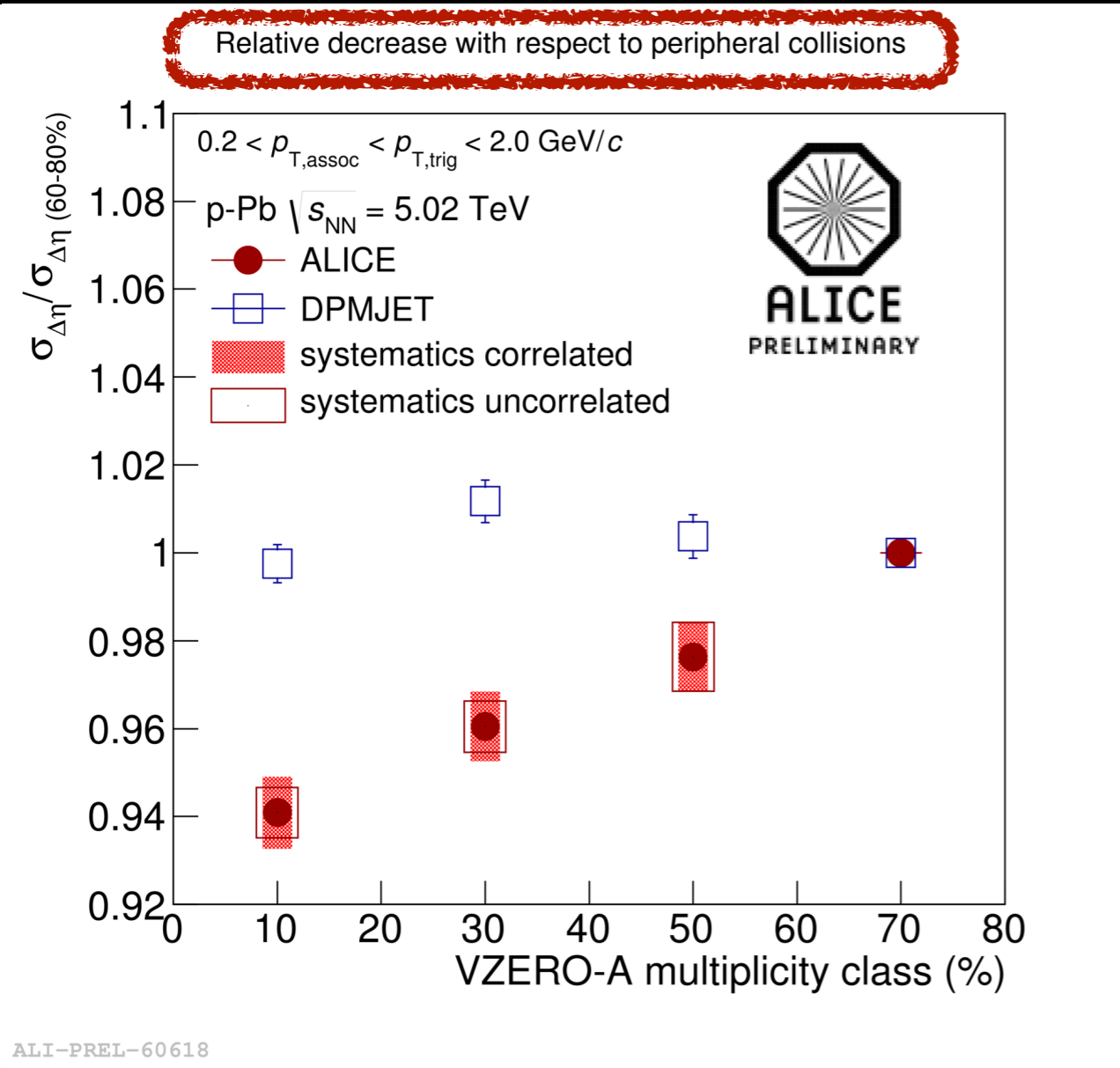
Evident multiplicity dependence in both $\Delta\eta$ and $\Delta\phi$



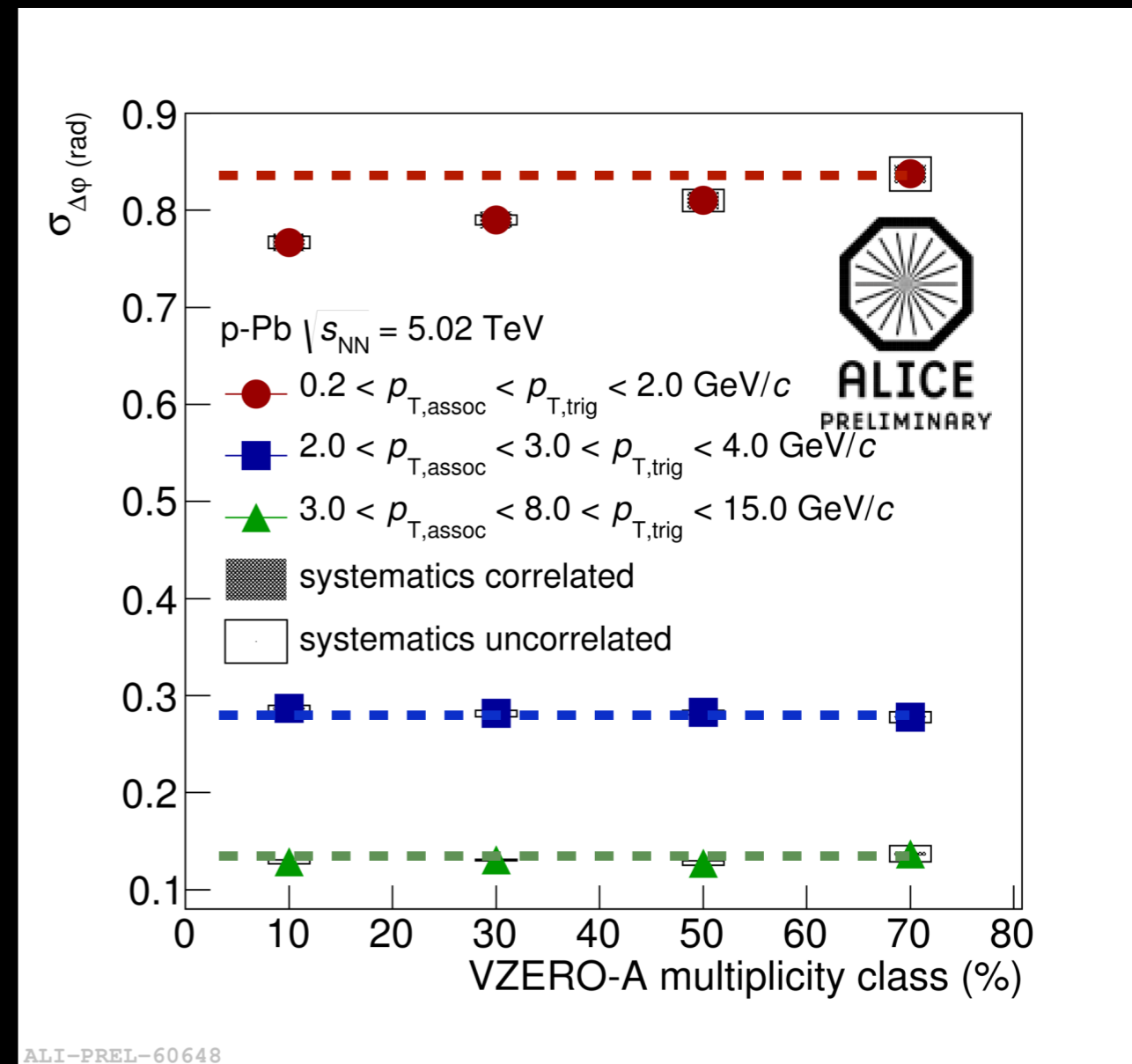
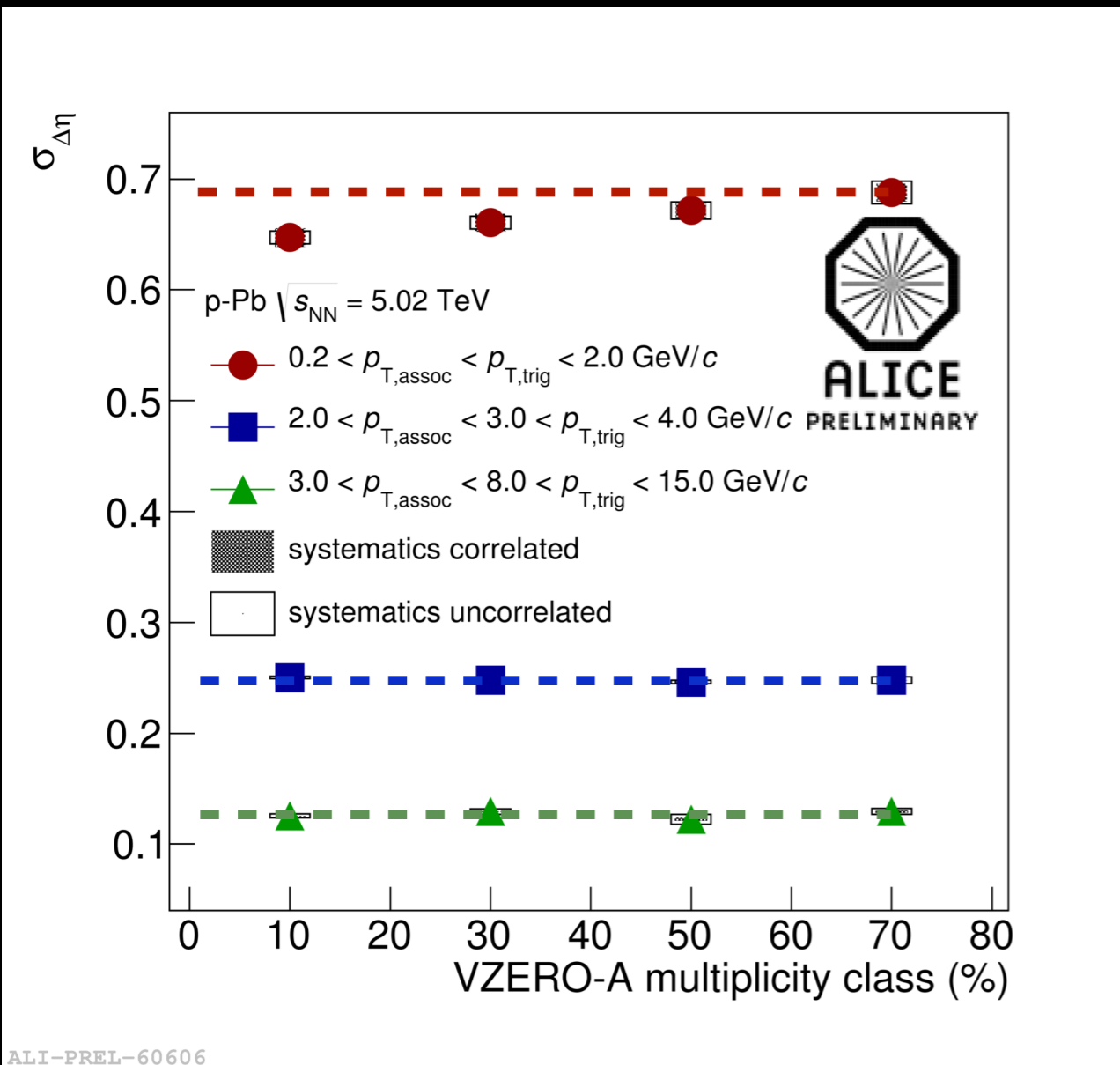
Evident multiplicity dependence in both $\Delta\eta$ and $\Delta\phi$ not reproduced by DPMJET



Evident multiplicity dependence in both $\Delta\eta$ and $\Delta\phi$ not reproduced by DPMJET

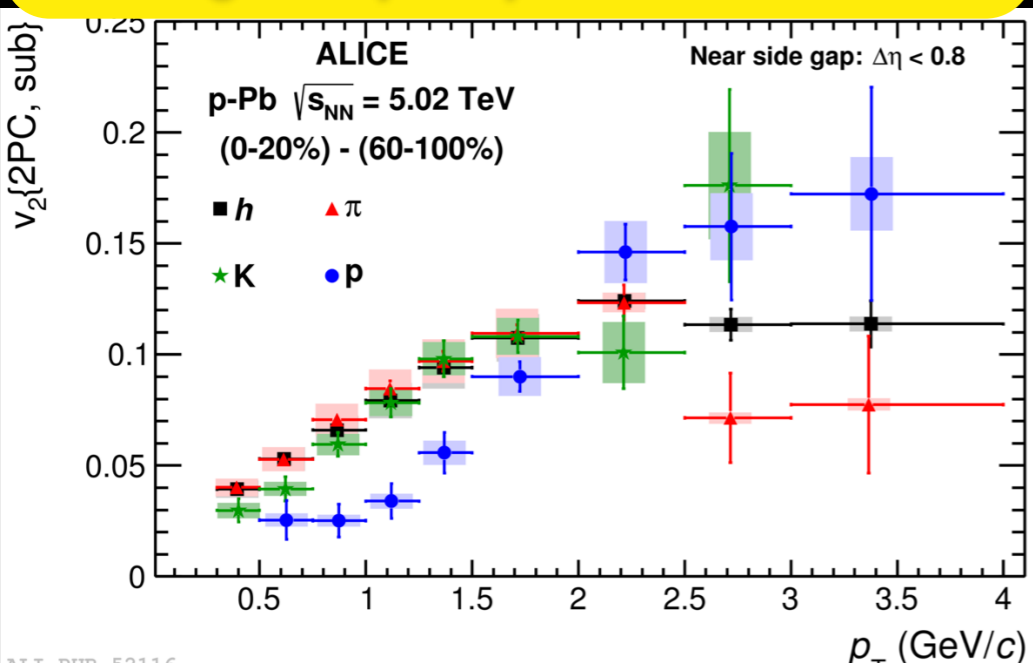


Evident multiplicity dependence in both $\Delta\eta$ and $\Delta\phi$ not reproduced by DPMJET

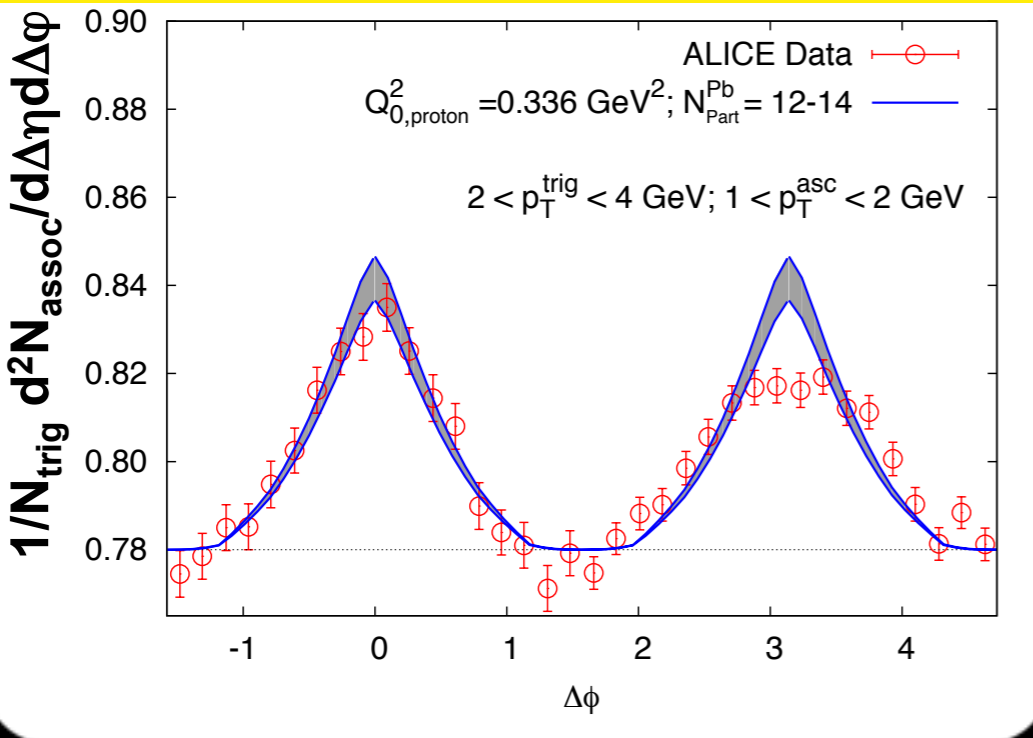


Multiplicity dependence in both $\Delta\eta$ and $\Delta\phi$ appear only in the low p_T region

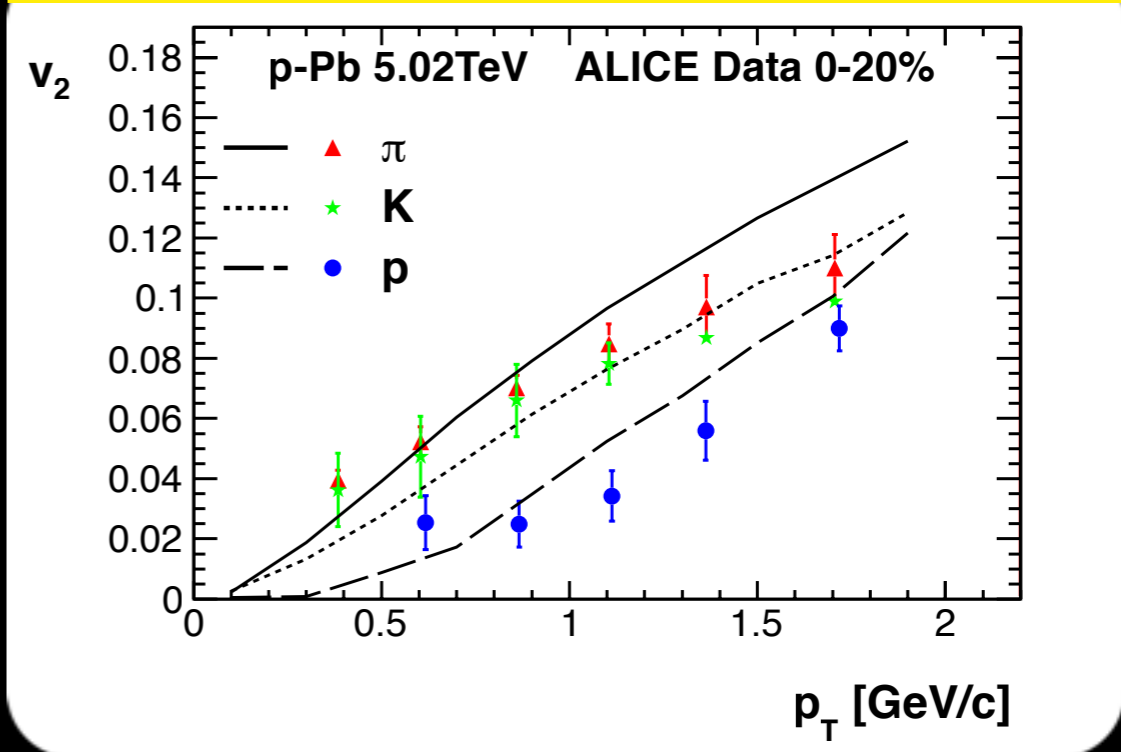
Mass ordering of v_2 in p-Pb collisions: CGC or signs of hydrodynamical evolution?



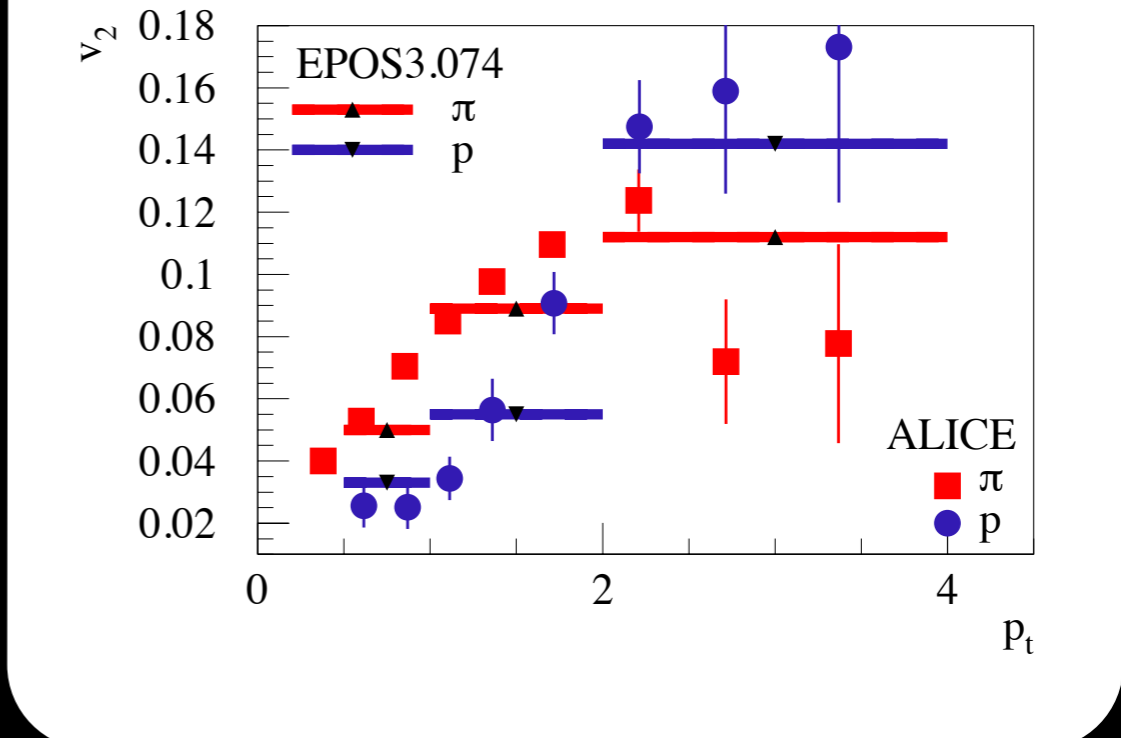
K. Dusling and R. Venugopalan, Phys. Rev. D87, (2013) 094034



P. Bozek et al., Phys. Rev. Lett. 111, (2013) 172303

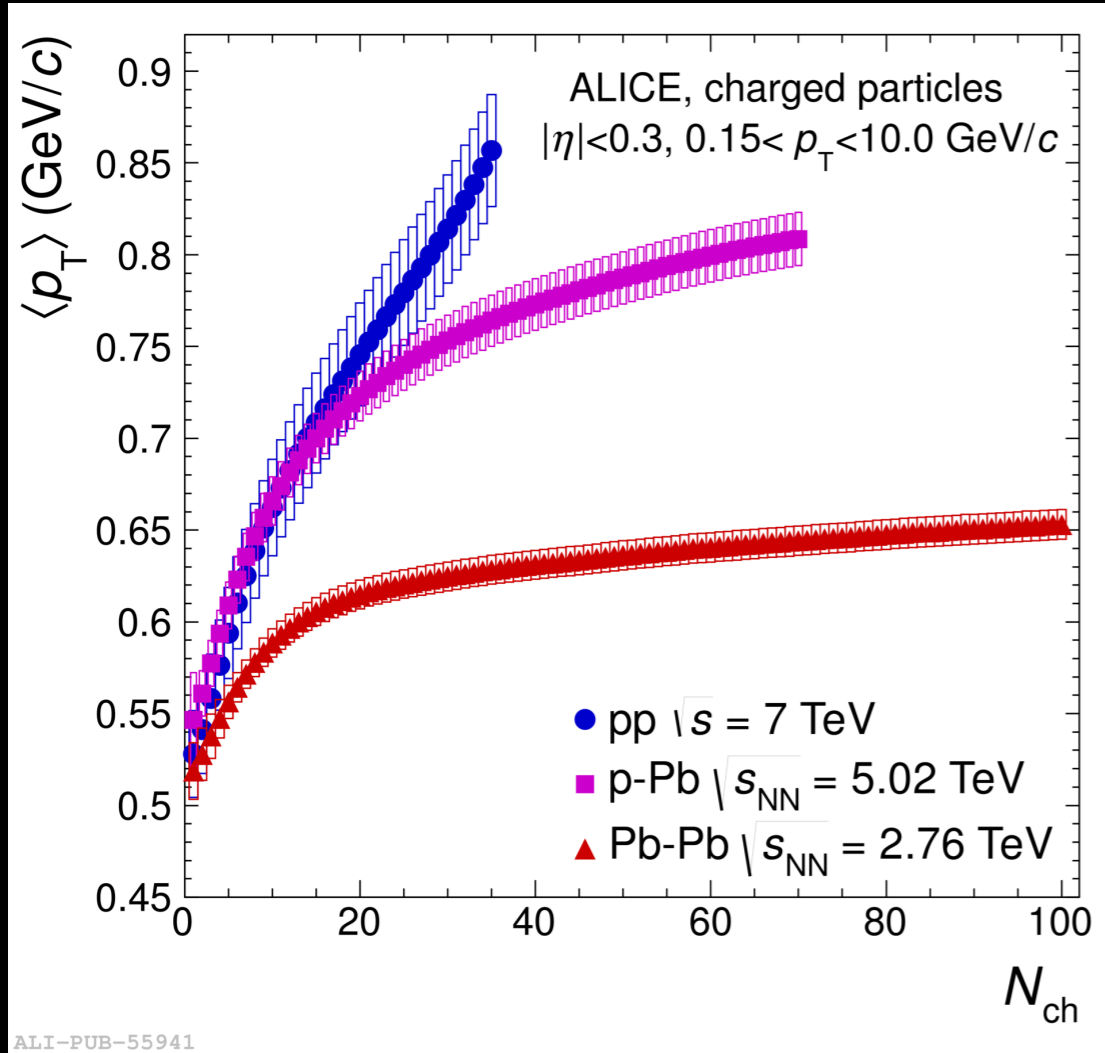


K. Werner et al., arXiv:1307.4379 [nucl-th]

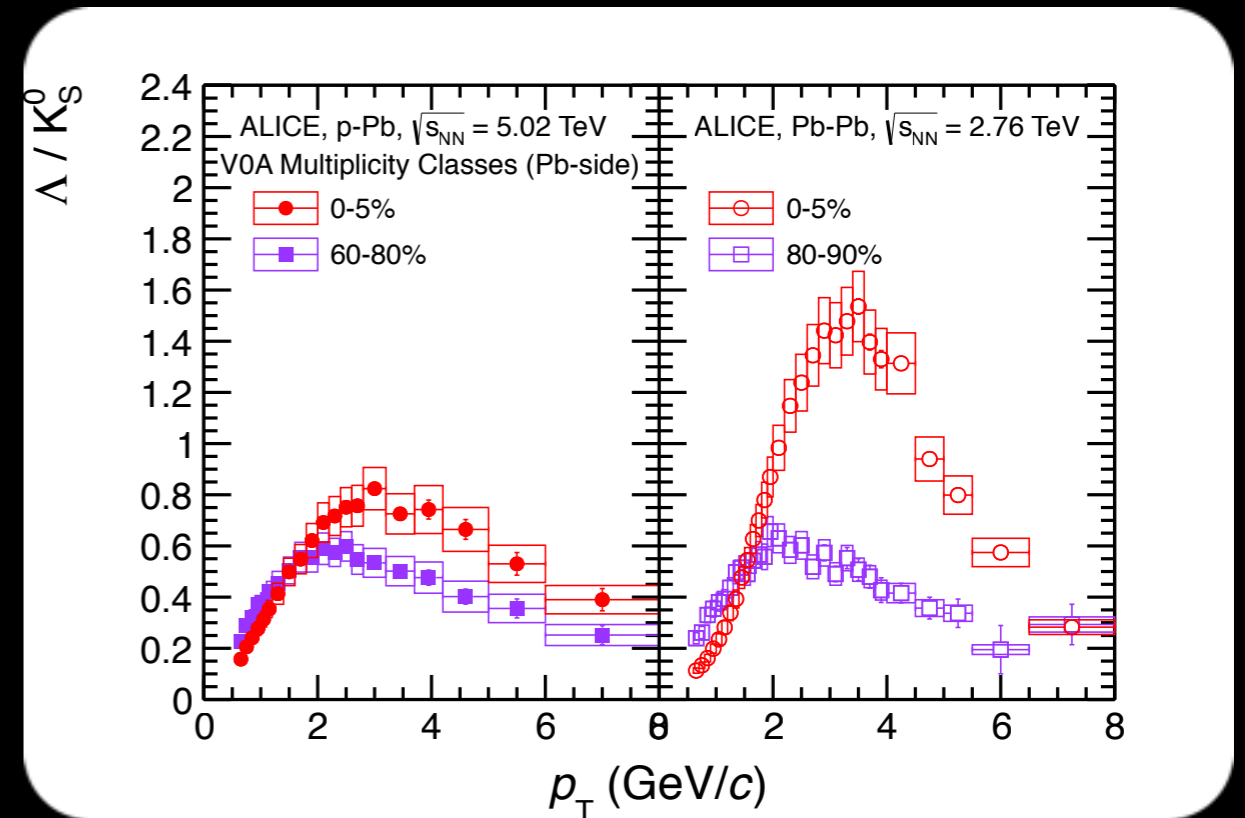
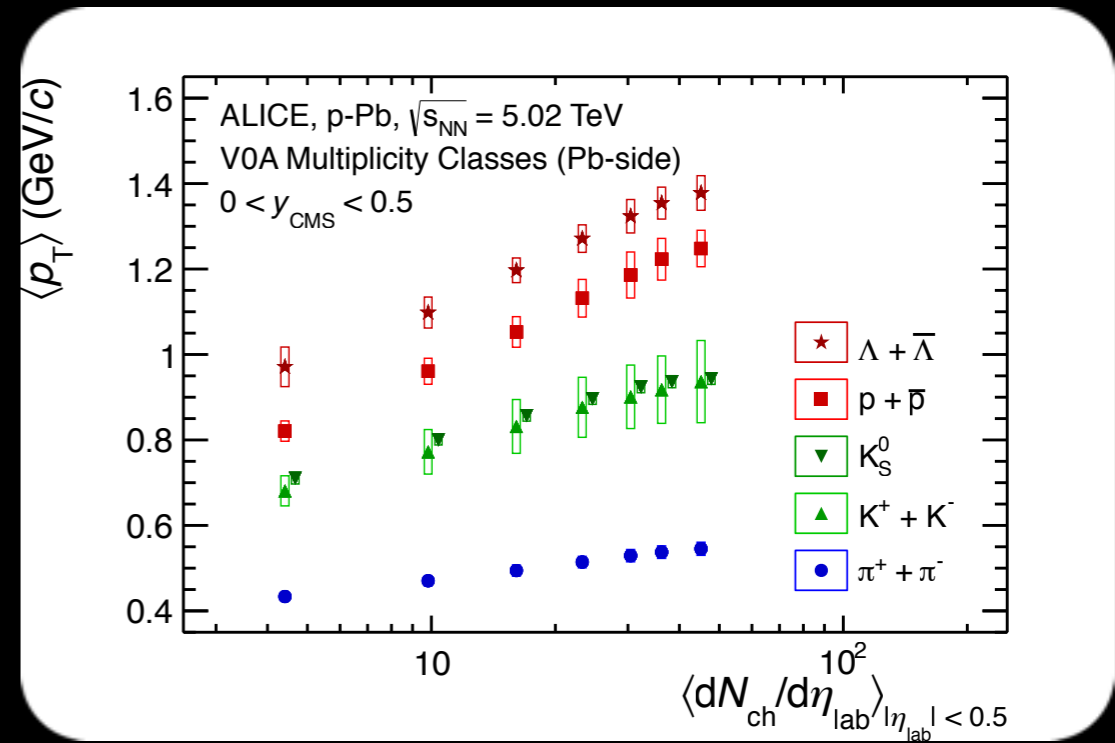


Observations from other analyses of similar features in p-Pb as in Pb-Pb!

ALICE Collaboration arXiv: 1307.1094 [nucl-ex]



ALICE Collaboration arXiv: 1307.1094 [nucl-ex]





She barks like a dog. She likes to ride in cars like a dog. But you know Fred--there's something I can't quite put my paw on.

**Woof!
Woof!**

Give it a rest Pete!

My two cents: Still I have to admit that it becomes less likely to be a cat that knows "foreign languages"



BACKUP