What have we learned from angular correlation studies in p-Pb collisions?

Panos Christakoglou (Nikhef)

On behalf of the ALICE Collaboration

Another version of David vs Goliath…

p(d)-A collisions: a field that developed from…

- …a baseline measurement for heavy-ion collisions…

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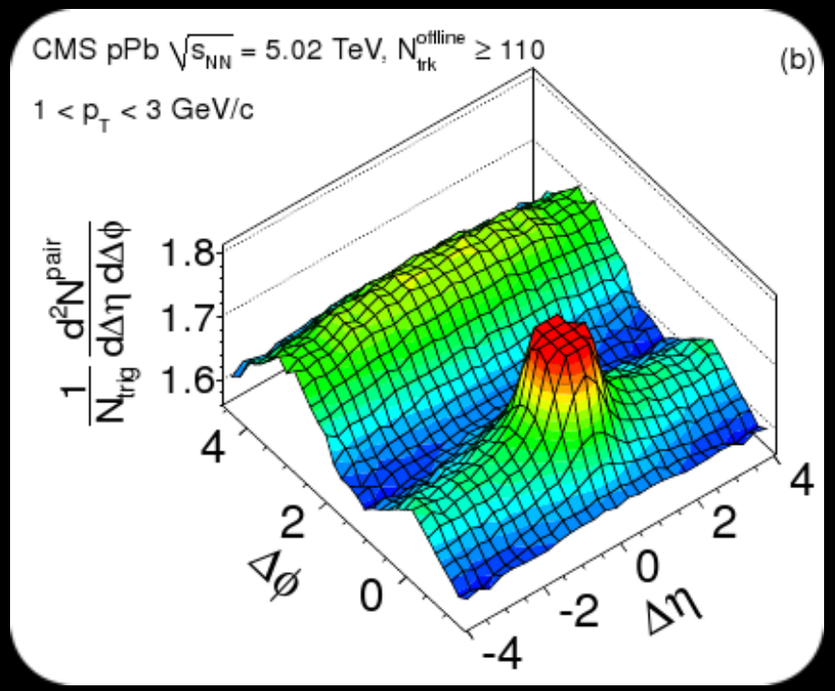
p(d)-A collisions: a field that developed from…

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

p(d)-A collisions: a field that developed from…

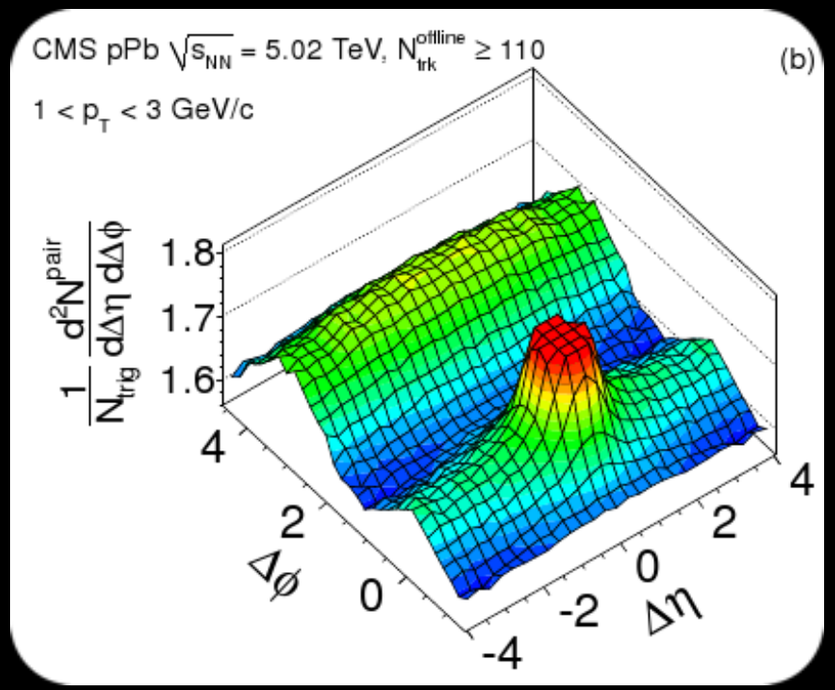
(CMS Collaboration) Phys. Lett. **B718**, (2013) 795



Near side ridge in p-Pb

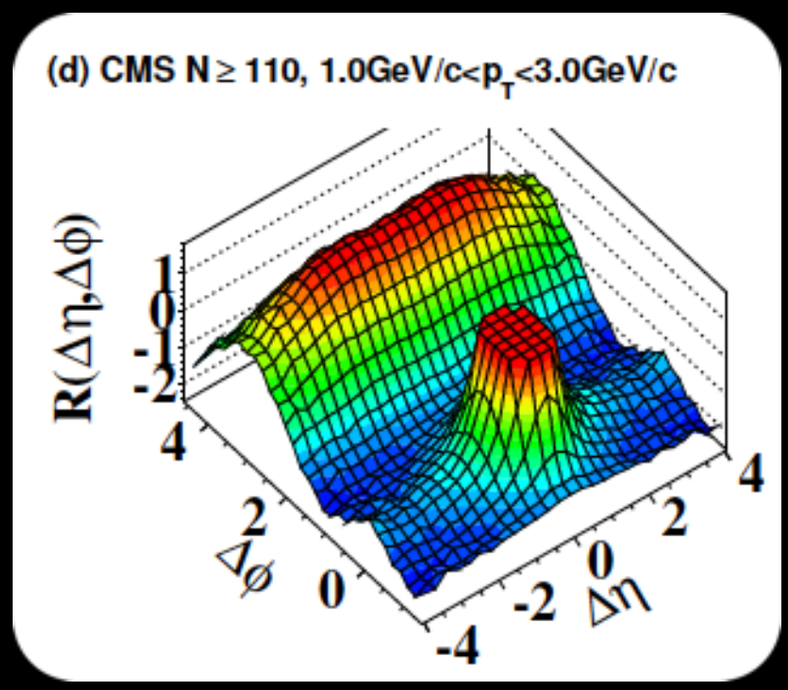
p(d)-A collisions: a field that developed from…

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



Near side ridge in p-Pb

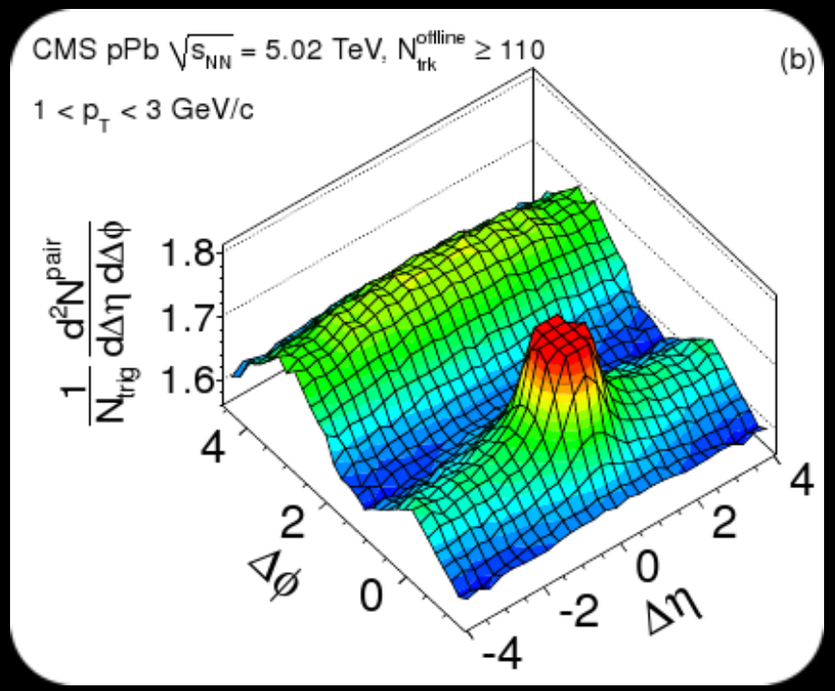
(CMS Collaboration) JHEP 09, (2010) 091



Near side ridge in pp

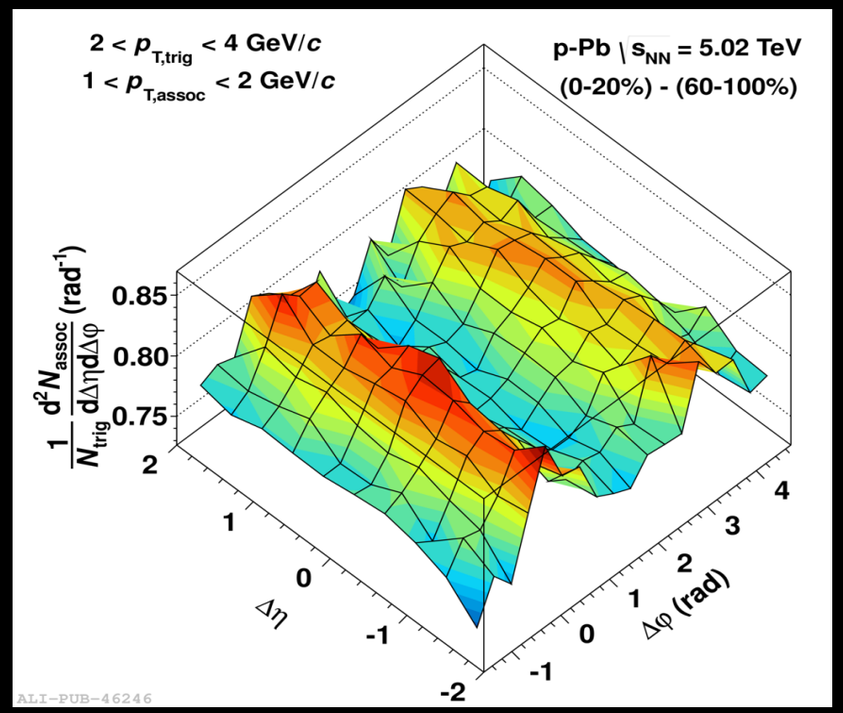
p(d)-A collisions: a field that developed from…

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



Near side ridge in p-Pb

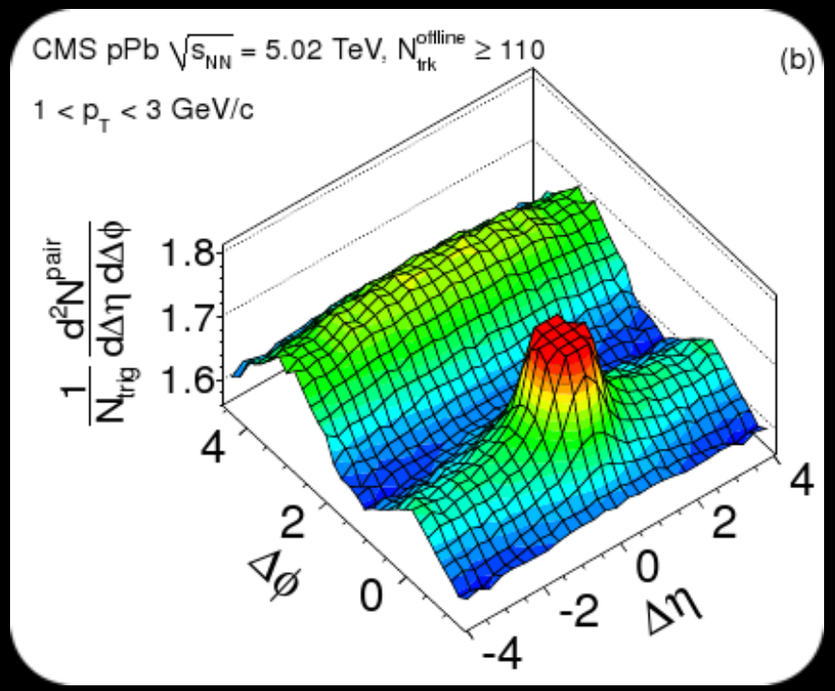
ALICE Collaboration: Phys. Lett. **B719**, (2013) 29



Double ridge in p-Pb

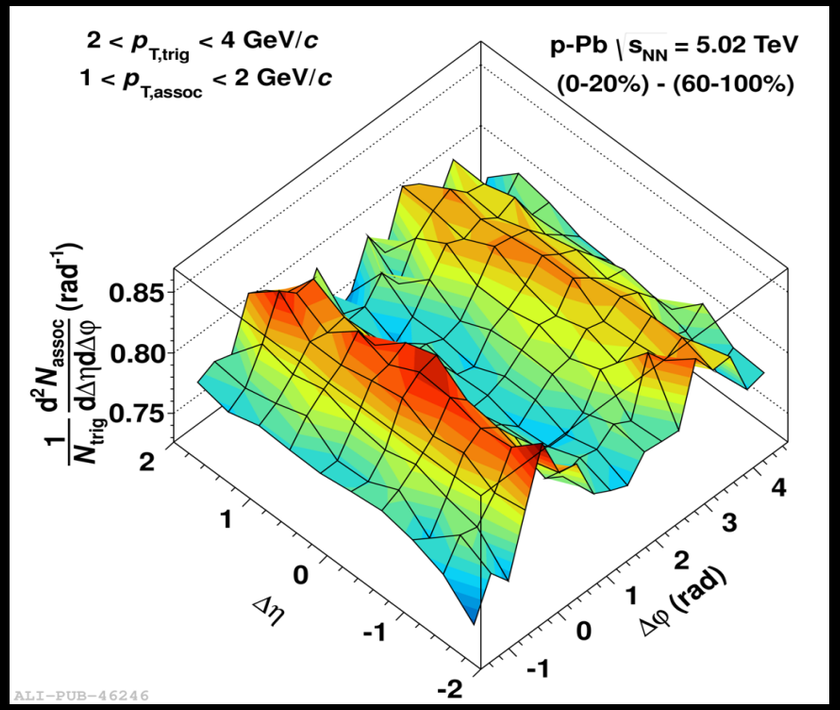
p(d)-A collisions: a field that developed from…

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



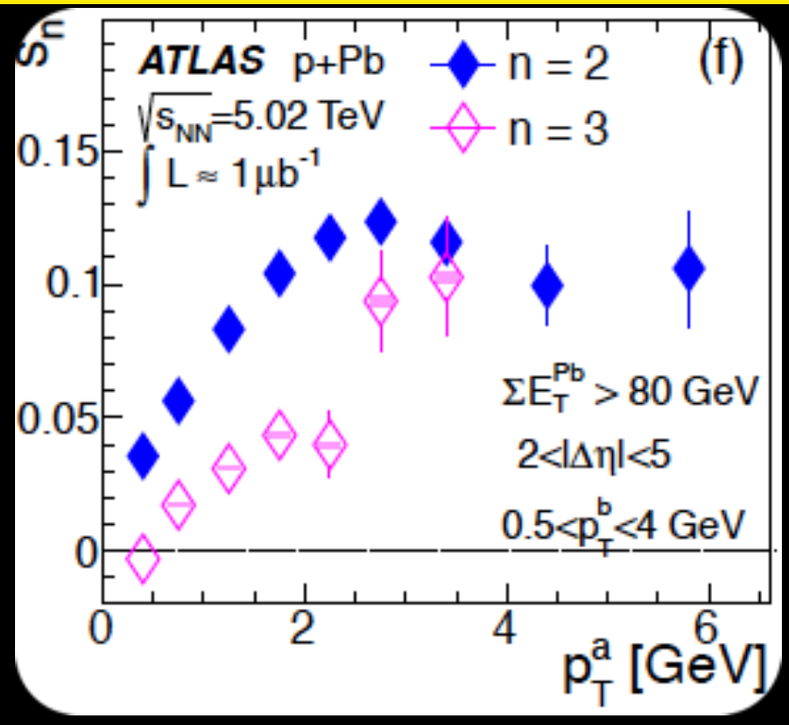
Near side ridge in p-Pb

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



Double ridge in p-Pb

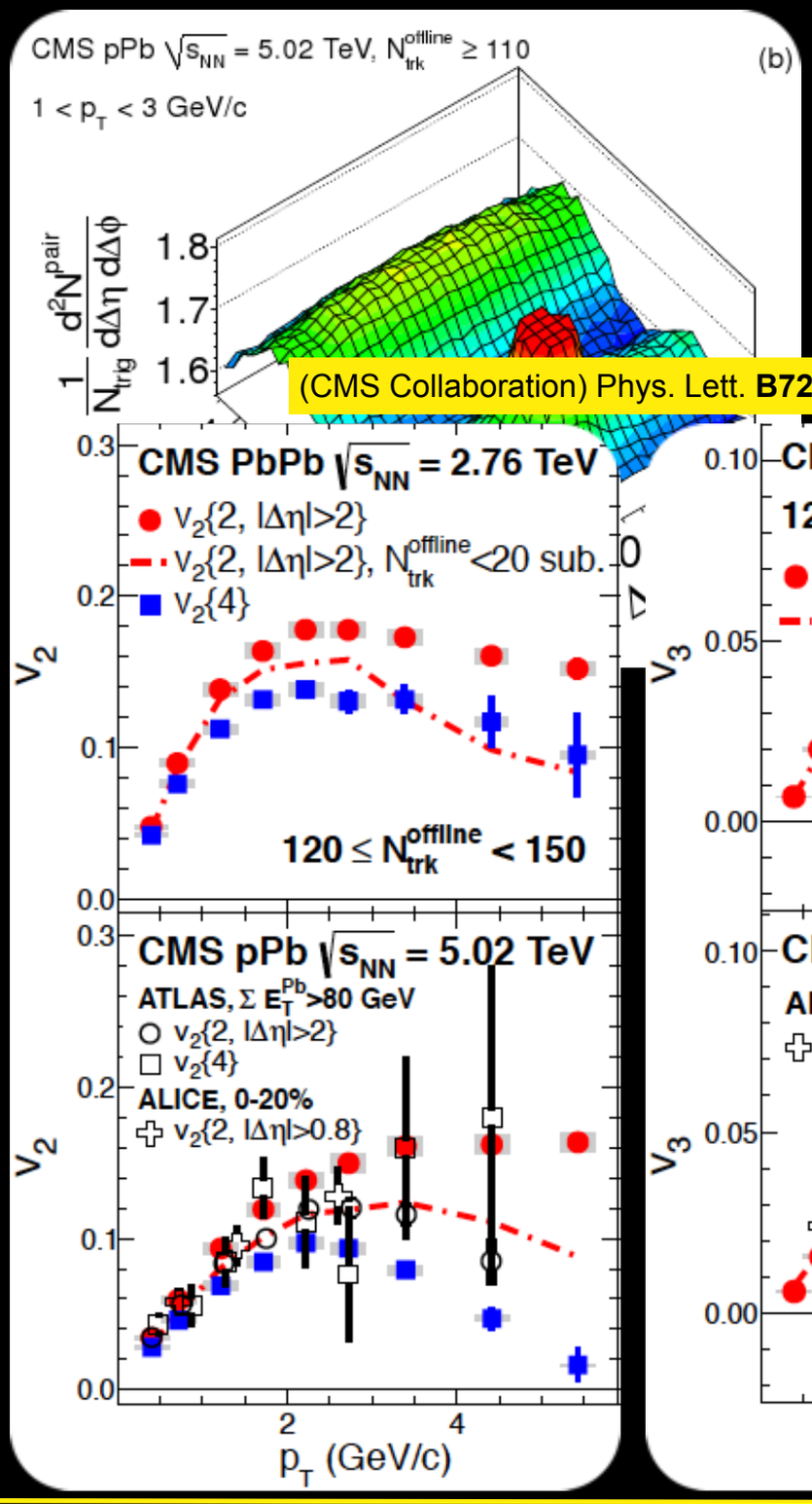
ATLAS Collaboration, Phys. Rev. Lett. **110**, (2013) 182302



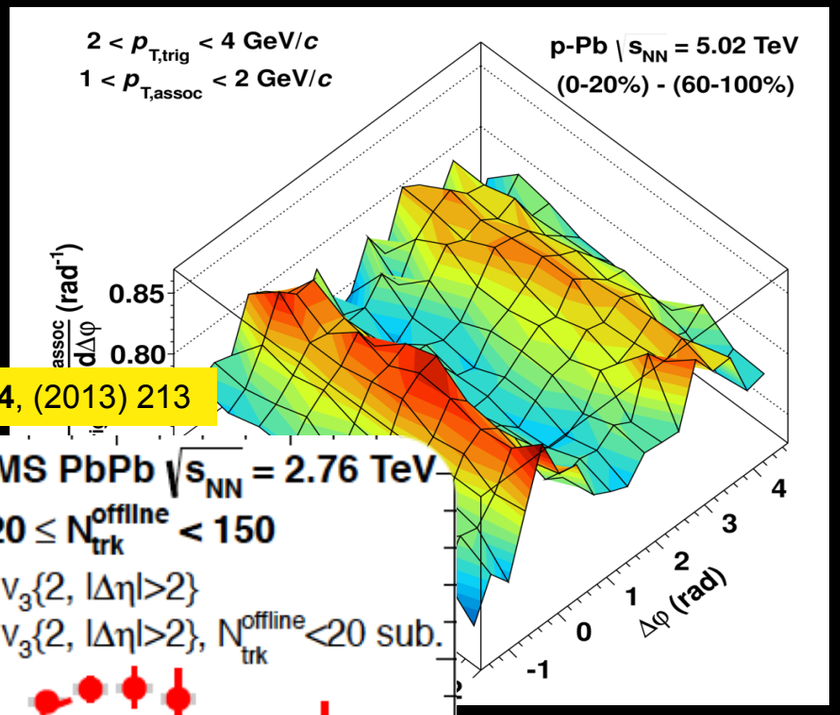
Sizable v_2 and v_3 components in p-Pb

p(d)-A collisions: a field that developed from…

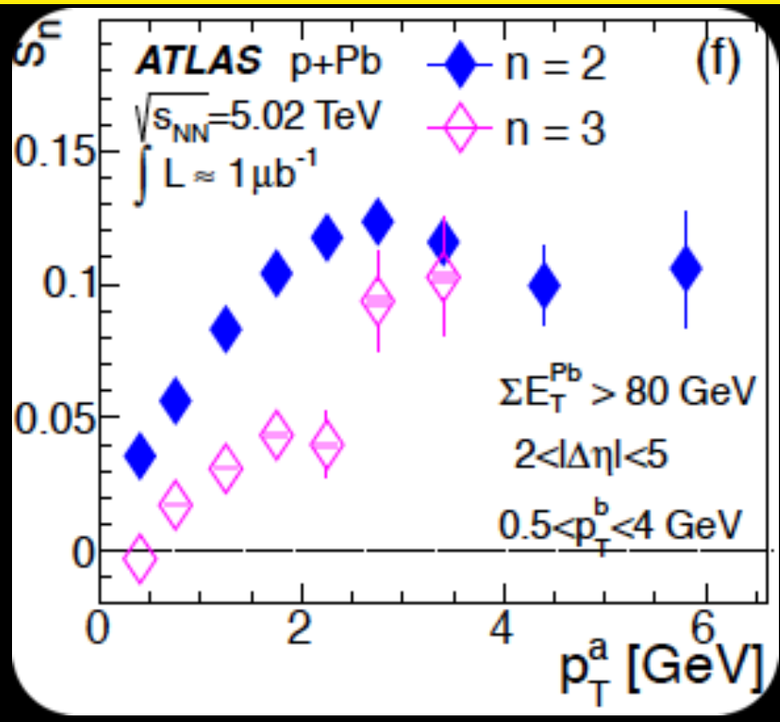
(CMS Collaboration) Phys. Lett. **B718**, (2013) 795



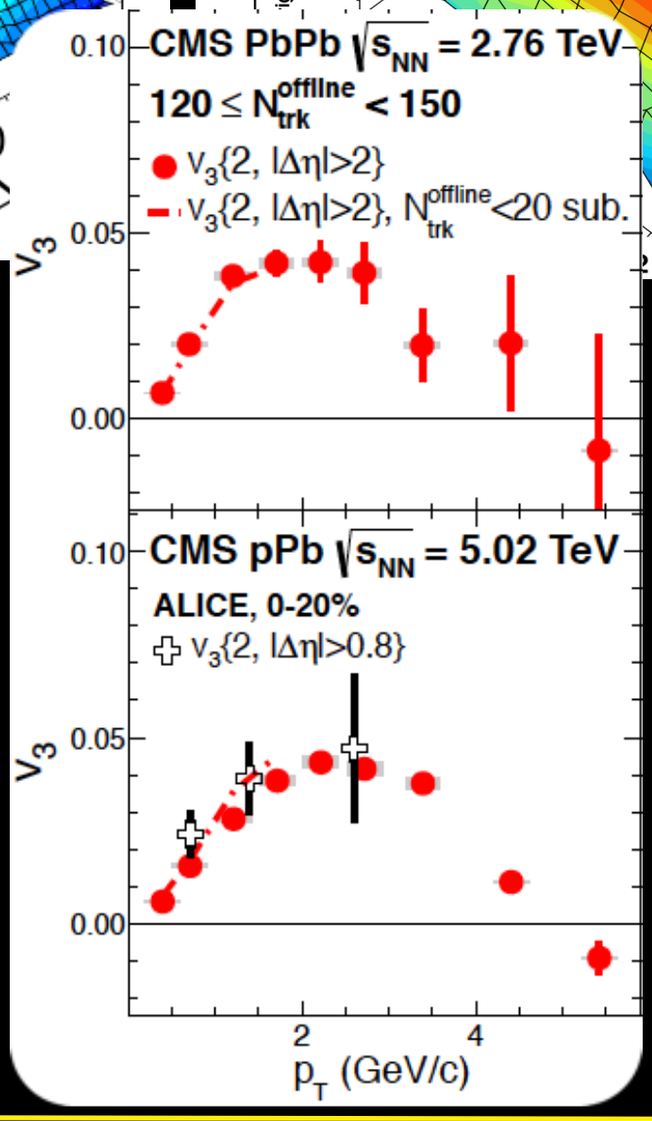
ALICE Collaboration: Phys. Lett. **B719**, (2013) 29



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



(CMS Collaboration) Phys. Lett. **B724**, (2013) 213

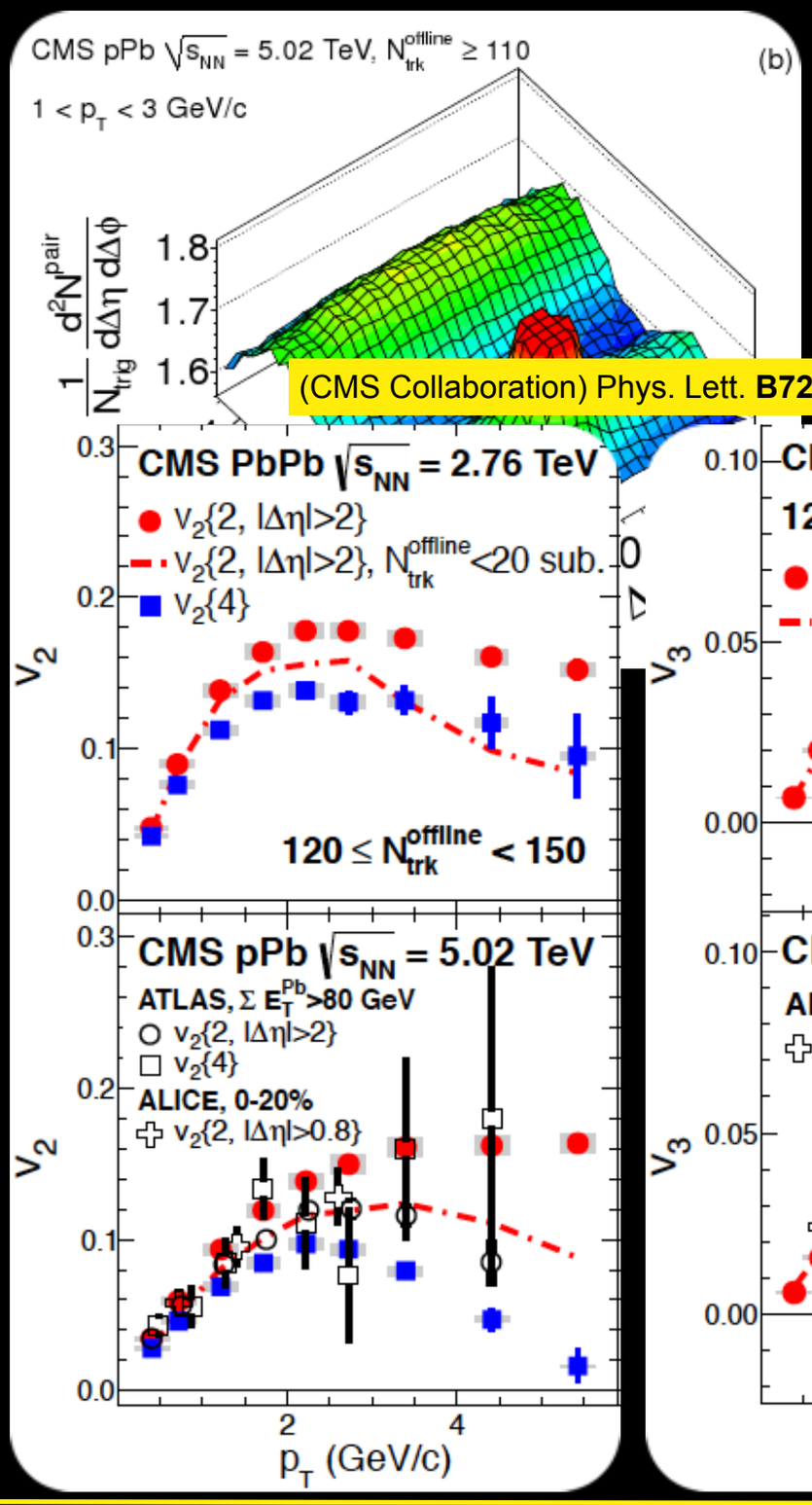


Sizable v_2 and v_3 components in p-Pb

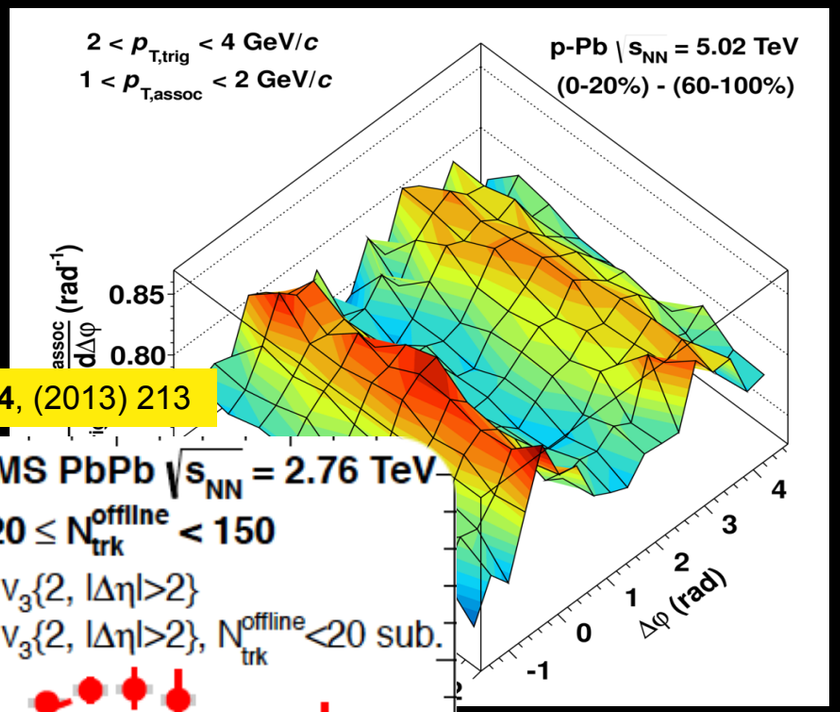
Sizable v_2 and v_3 components in p-Pb with similar evolution vs p_T as in Pb-Pb

p(d)-A collisions: a field that developed from…

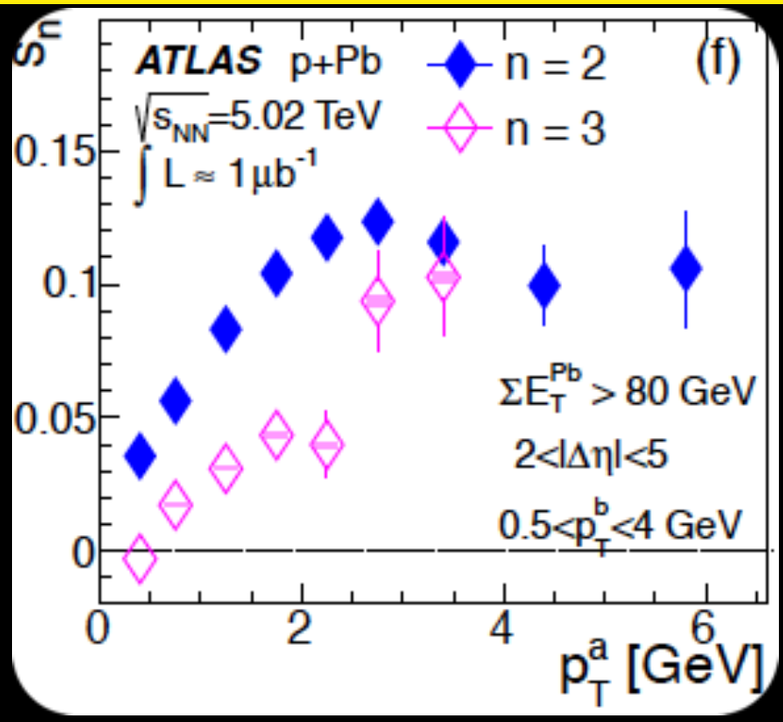
(CMS Collaboration) Phys. Lett. **B718**, (2013) 795



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

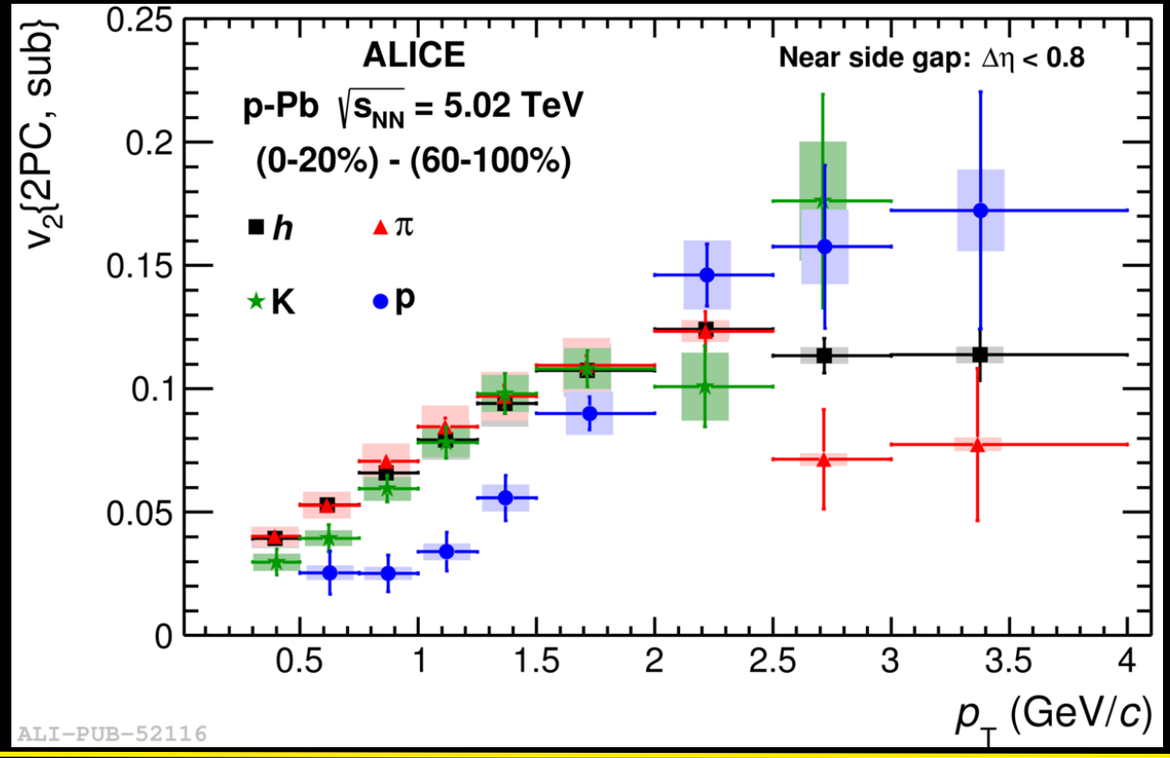


ATLAS Collaboration, Phys. Rev. Lett. **110**, (2013) 182302

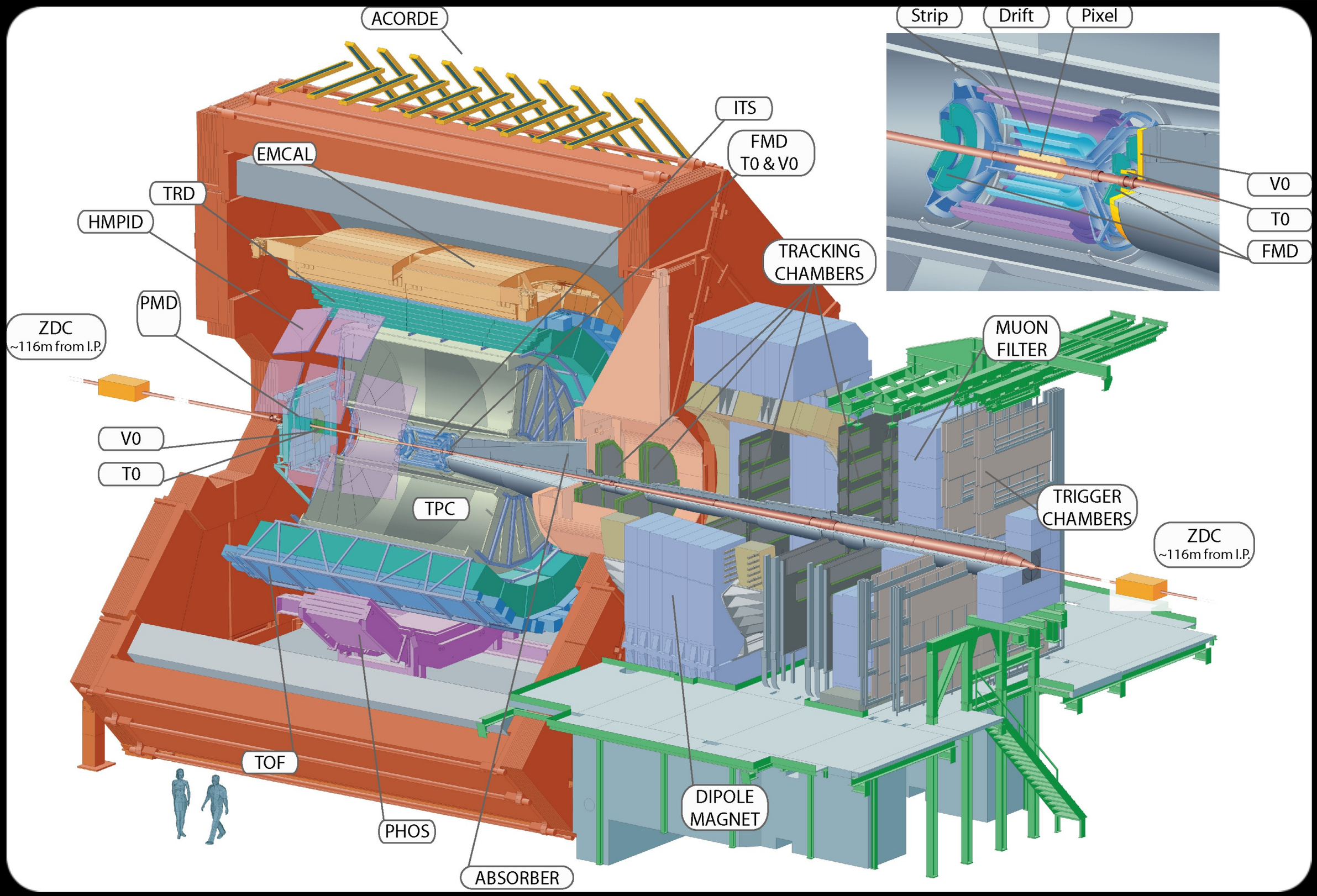


(CMS Collaboration) Phys. Lett. **B724**, (2013) 213

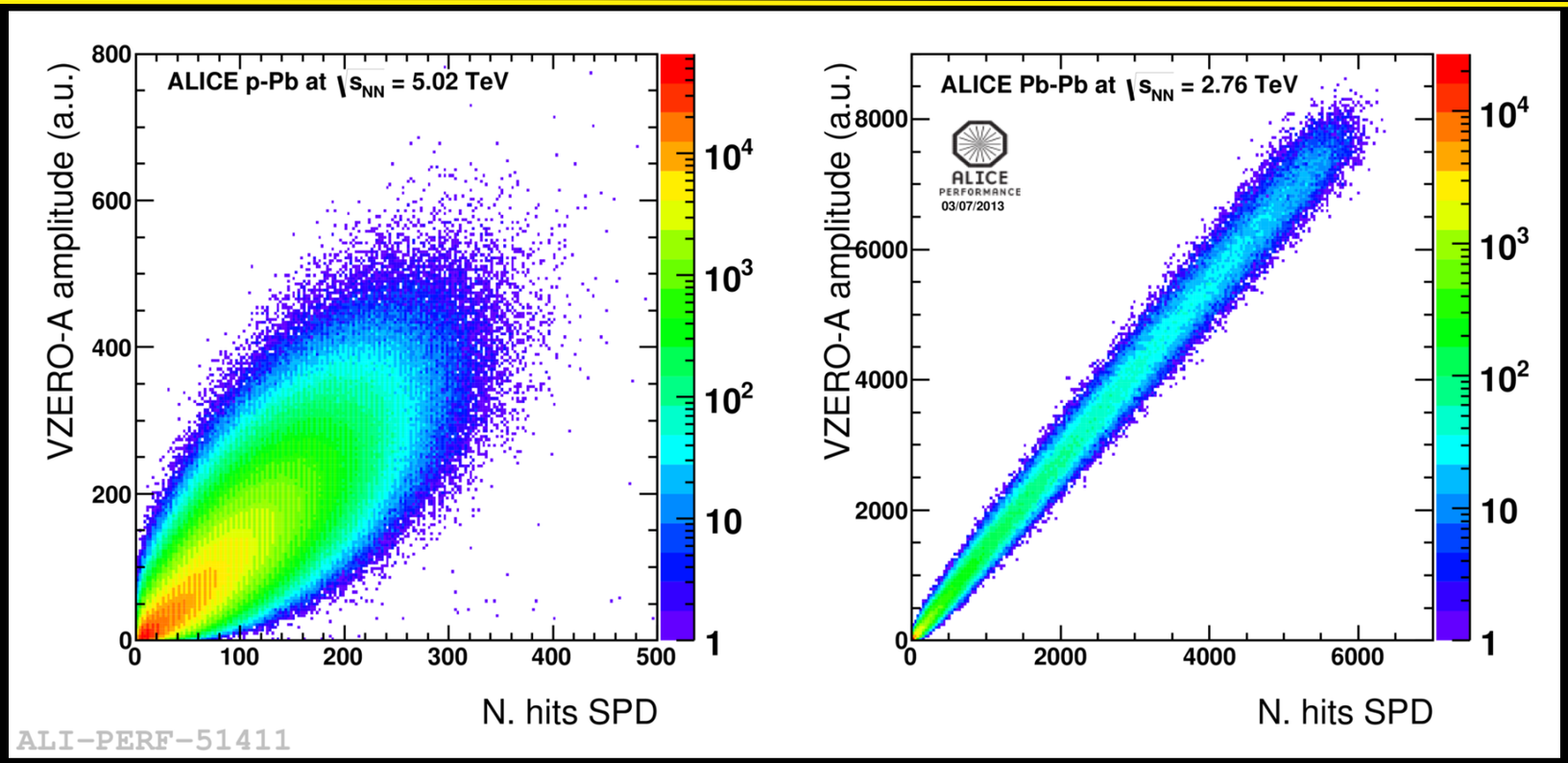
ALICE Collaboration: Phys. Lett. **B726**, (2013) 164



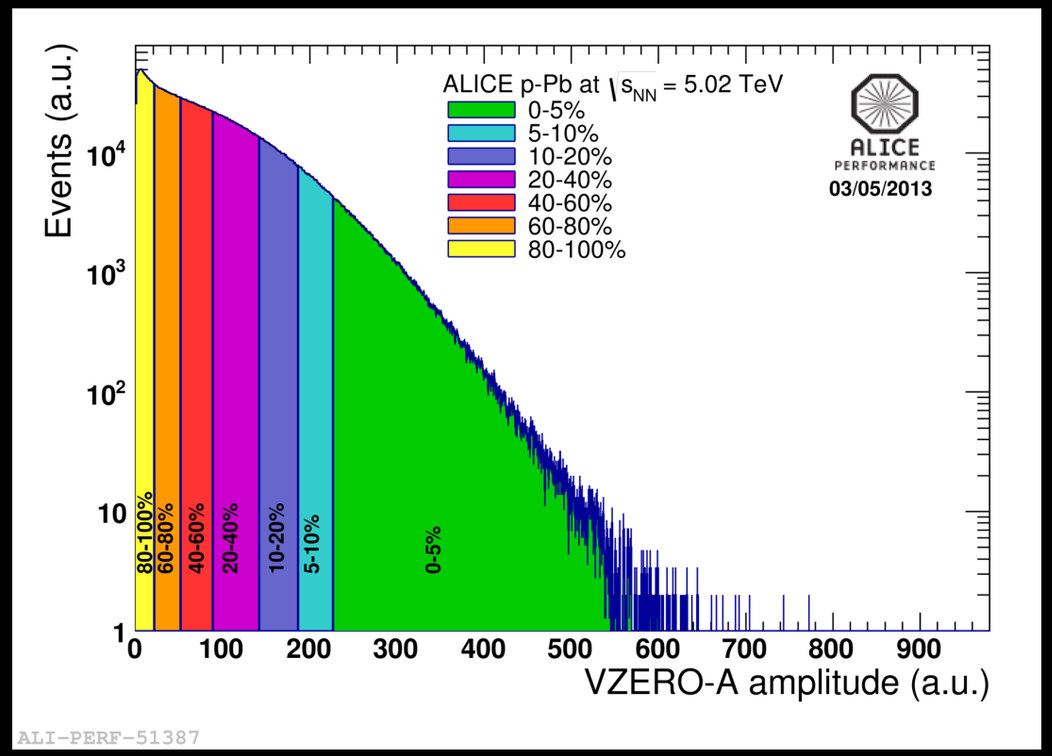
Experimental setup



Multiplicity classes in p-Pb

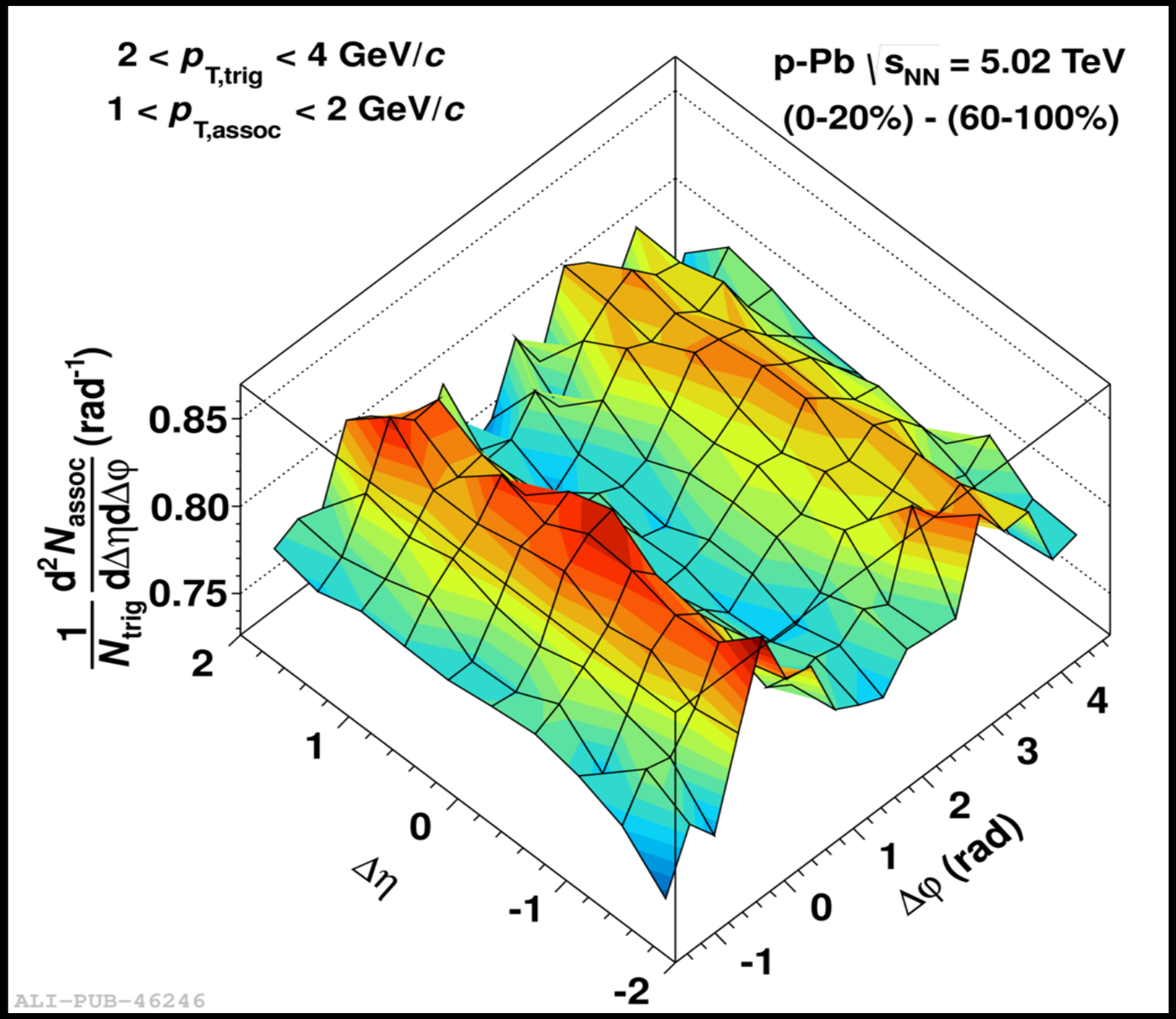


- Centrality determination in p-Pb is not as straightforward as in Pb-Pb
  - ★ Weak correlation between parameters like
    - impact parameter and number of participants
    - number of participants and multiplicity
- Define event classes based on
  - ★ multiplicity measurement from central detectors (e.g. CMS)
  - ★ multiplicity measurement from forward detectors (e.g. ALICE)
  - ★ calorimetry (e.g. ATLAS)



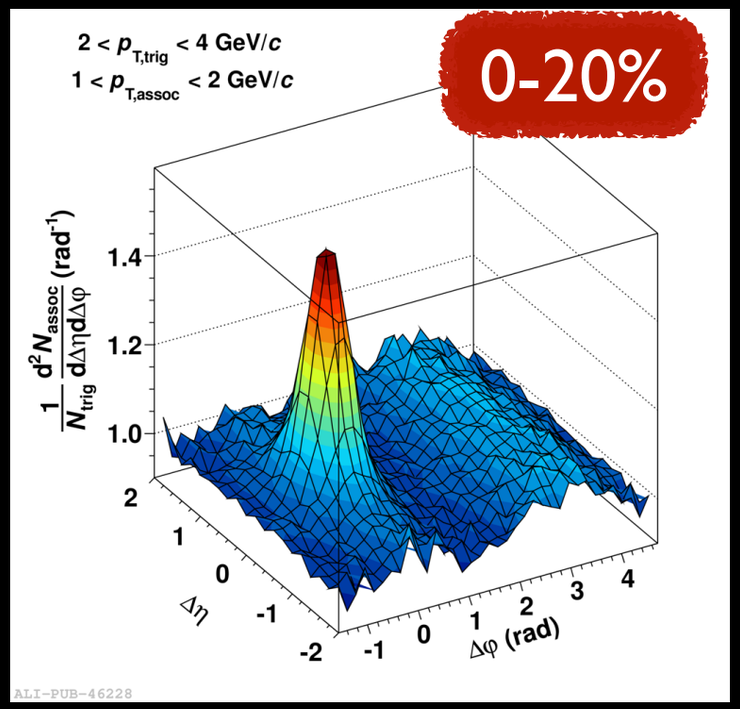
Double ridge in p-Pb collisions

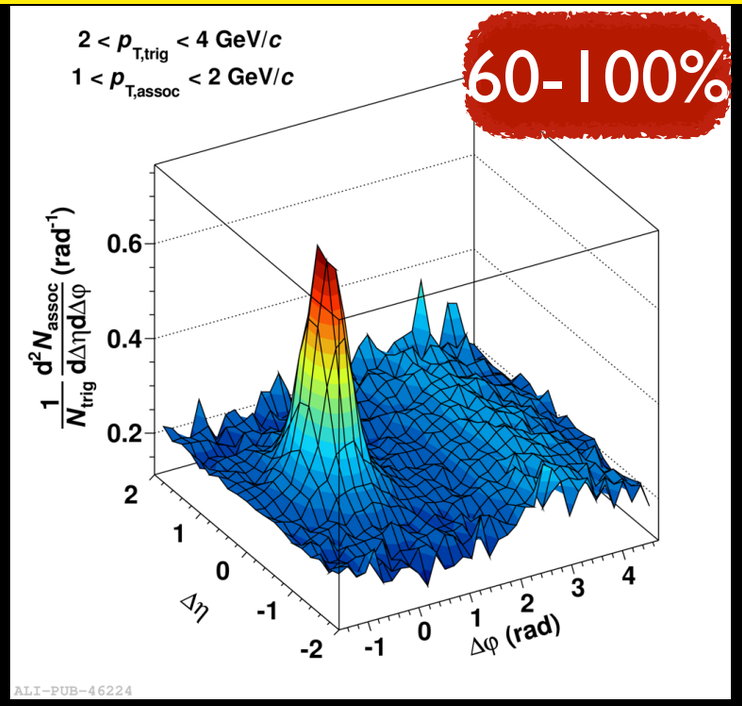
ALICE Collaboration: Phys. Lett. **B719**, (2013) 29



Double ridge in p-Pb: Charged particles

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





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

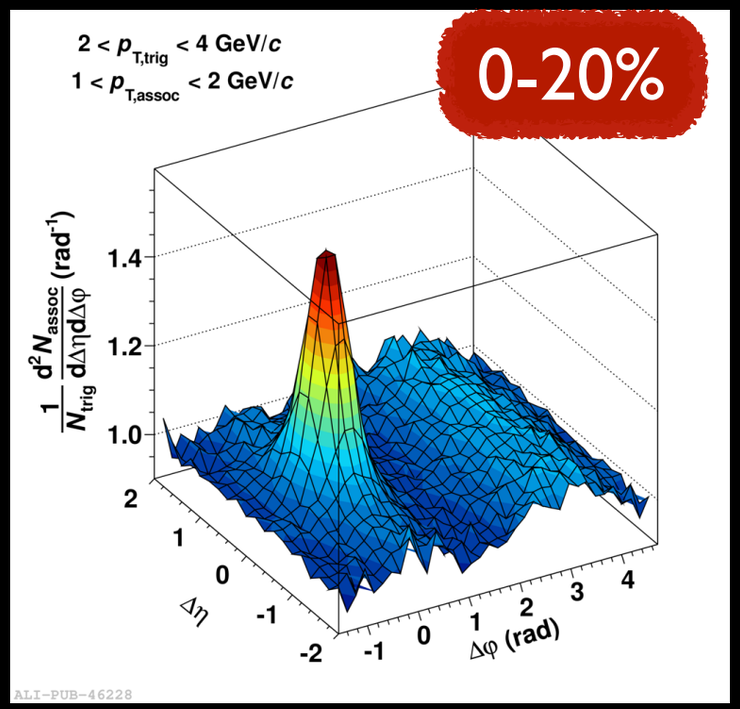
$$S(\Delta\eta,\Delta\varphi)=\left(\frac{1}{N_{trig}}\frac{d^2N_{assoc}}{d\Delta\eta d\Delta\varphi}\right)_{same}$$

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

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

Double ridge in p-Pb: Charged particles

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



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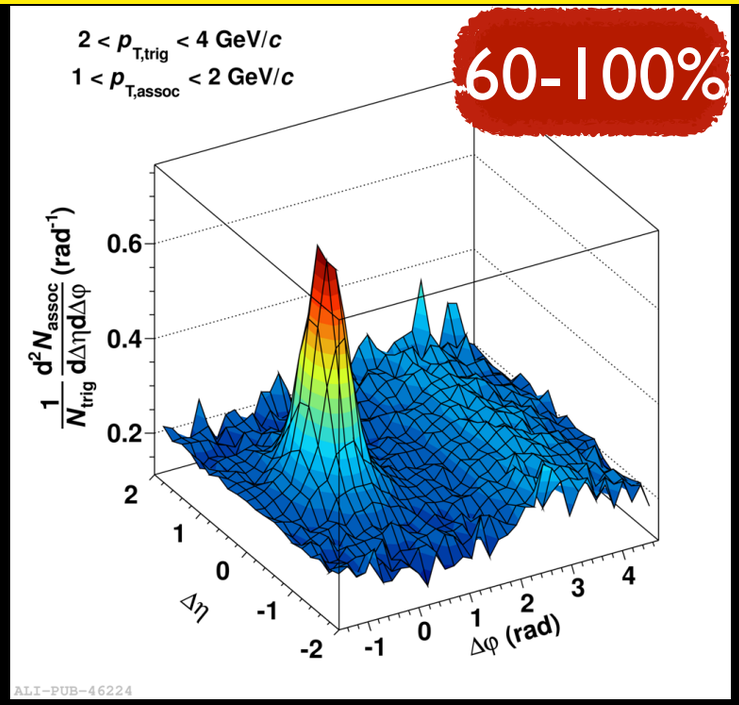

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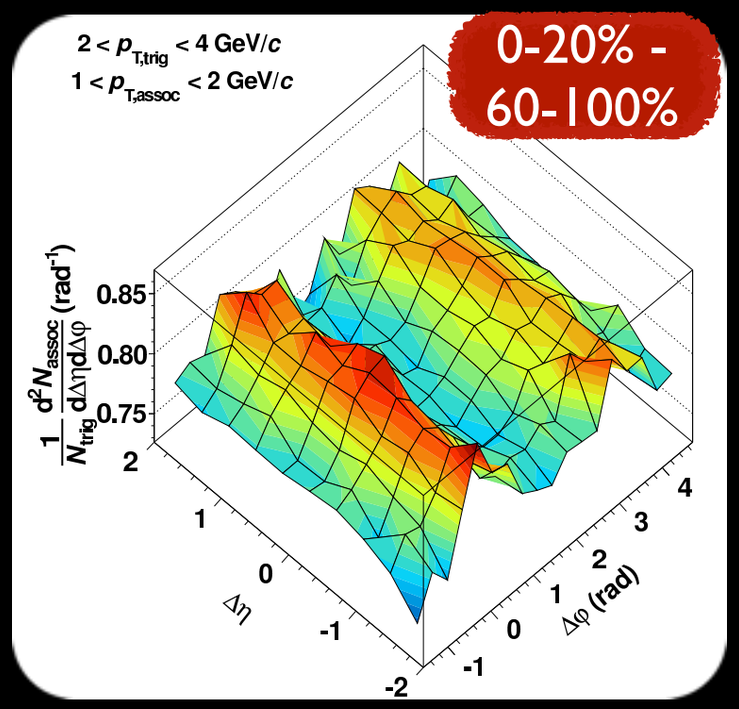


$$\frac{1}{N_{trig}}\frac{d^2N_{assoc}}{d\Delta\eta d\Delta\varphi}\frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)}$$

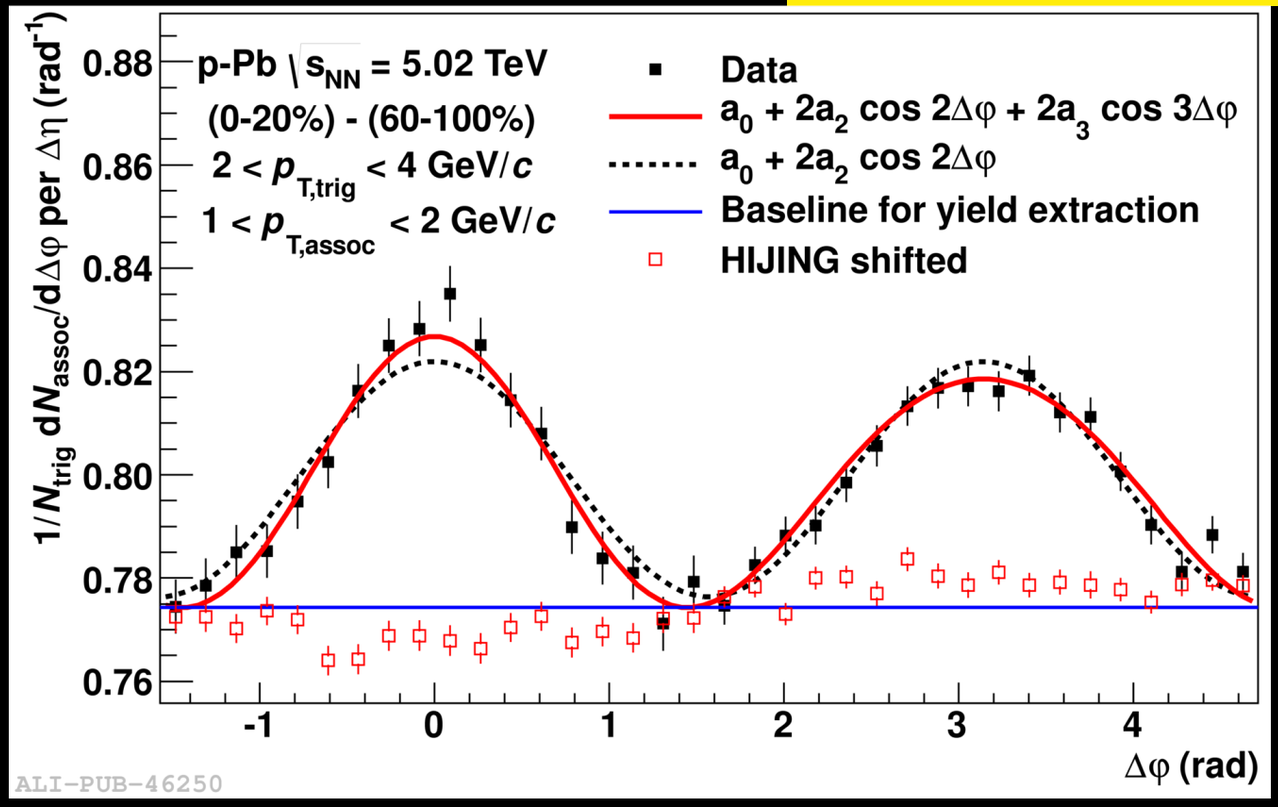
$$S(\Delta\eta,\Delta\varphi)=\left(\frac{1}{N_{trig}}\frac{d^2N_{assoc}}{d\Delta\eta d\Delta\varphi}\right)_{same}$$

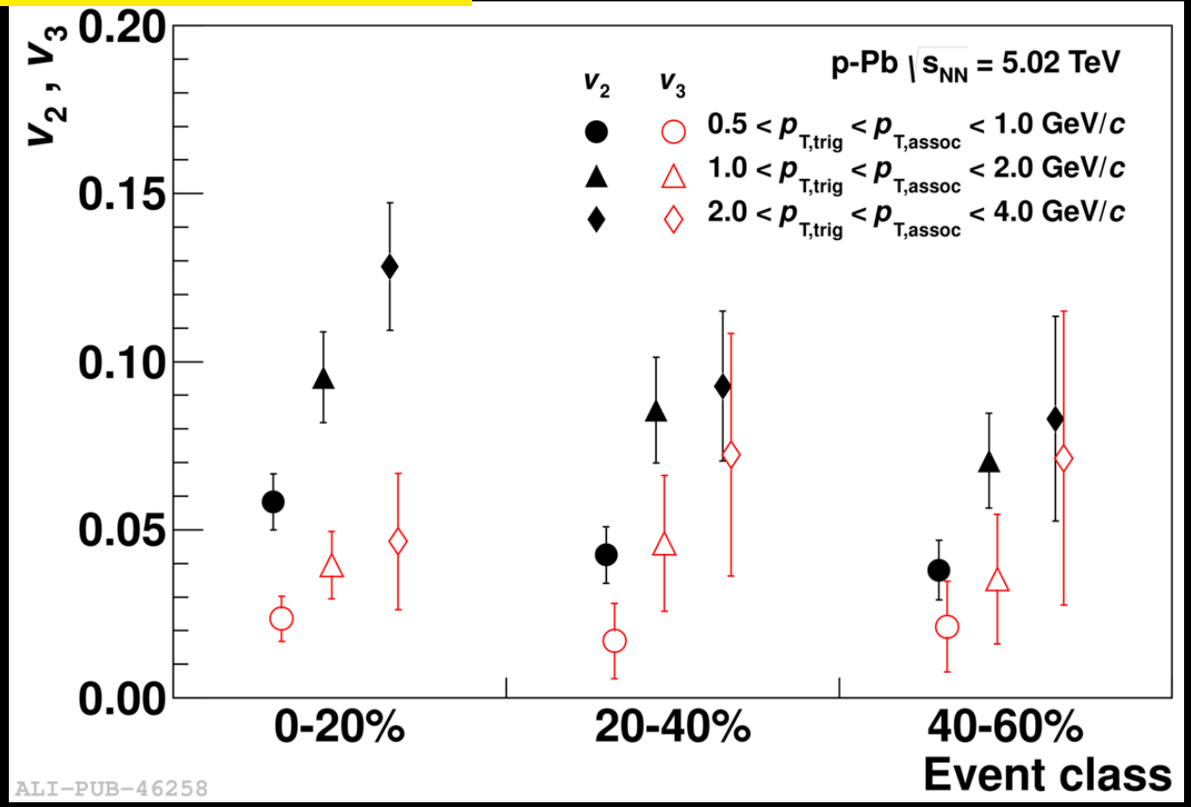
$$B(\Delta\eta,\Delta\varphi)=a\left(\frac{d^2N_{assoc}}{d\Delta\eta d\Delta\varphi}\right)_{mixed}$$

- 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!

Double ridge in p-Pb: Fourier decomposition

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



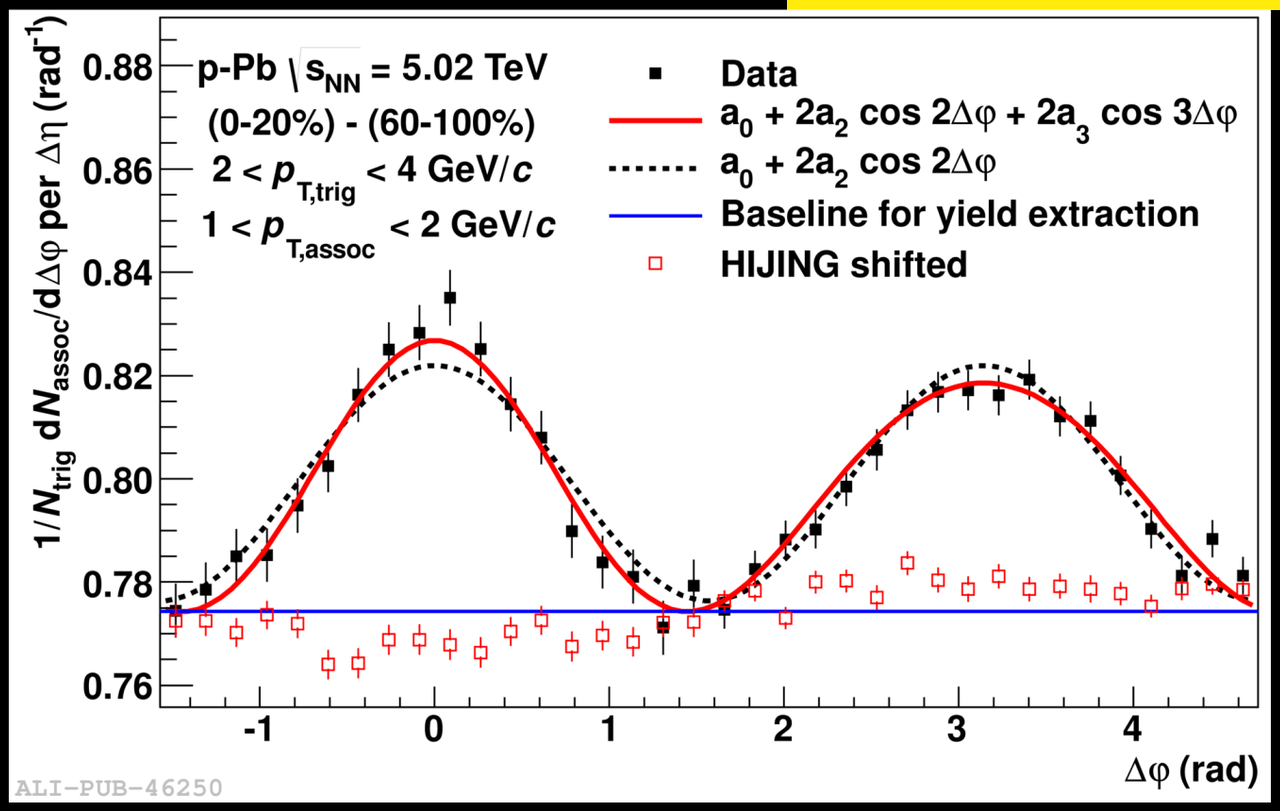


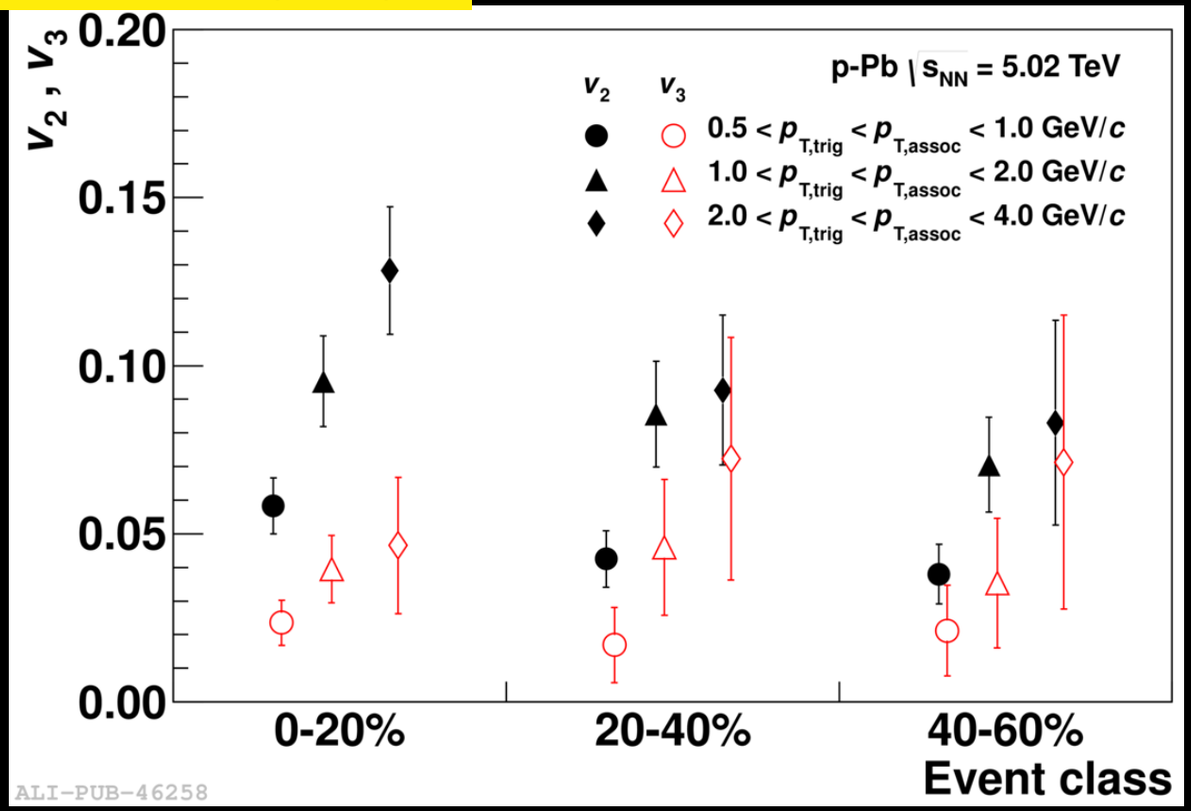
$$\frac{1}{N_{trig.}}\frac{dN_{assoc}}{d\Delta\varphi} = a_0 + 2a_2\cos(2\Delta\varphi) + 2a_3\cos(3\Delta\varphi)$$

- 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

Double ridge in p-Pb: Fourier decomposition

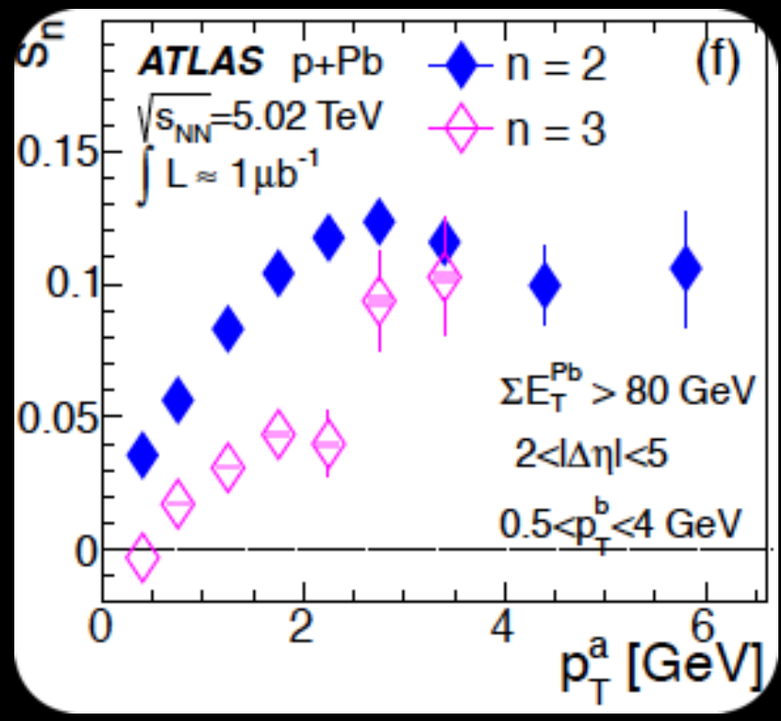
ALICE Collaboration: Phys. Lett. **B719**, (2013) 29





- Similar observation by ATLAS slightly later

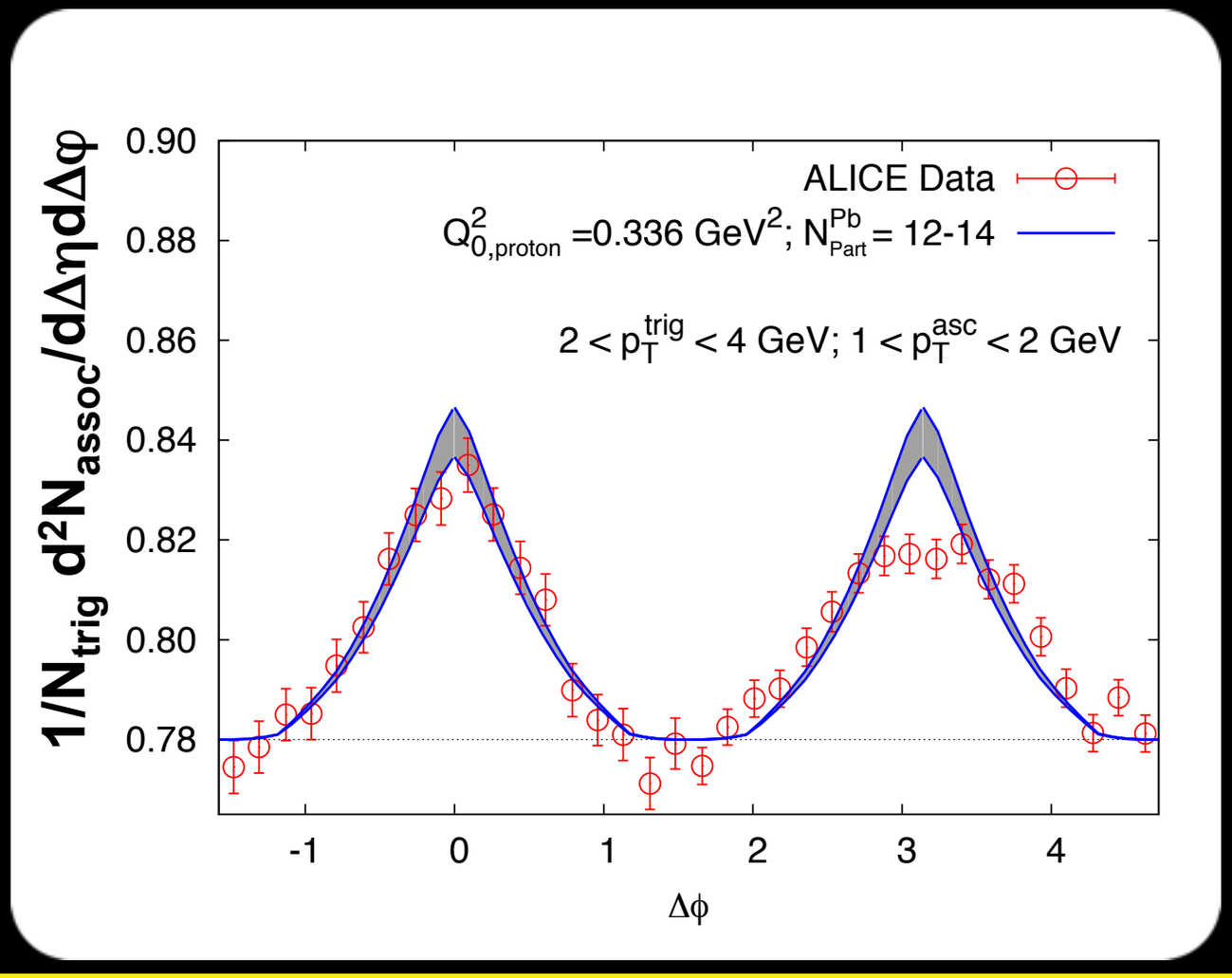
ATLAS Collaboration, Phys. Rev. Lett. **110**, (2013) 182302



Collectivity vs initial state (CGC)

- 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

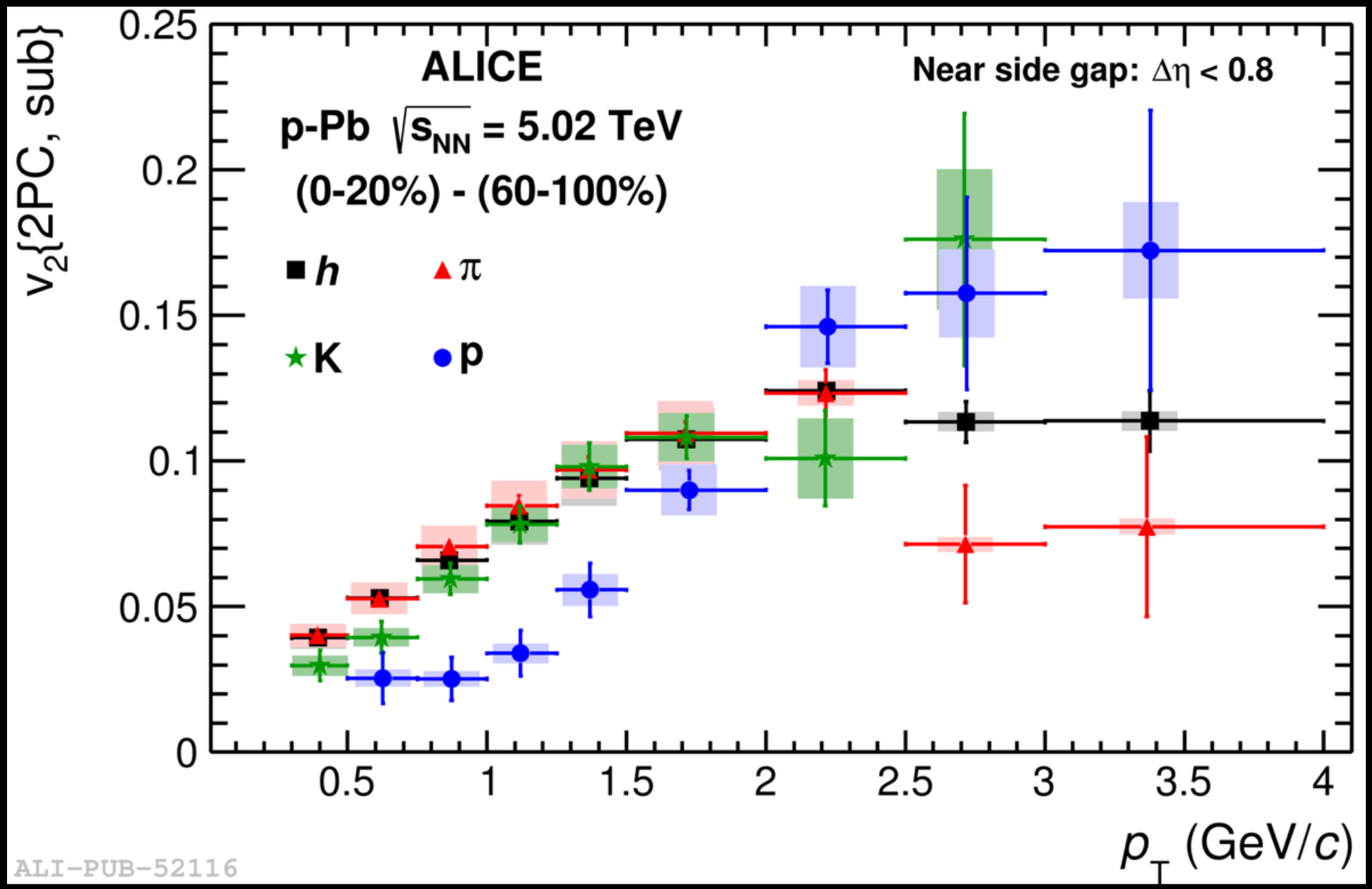


Relative good agreement, however no v_3 component

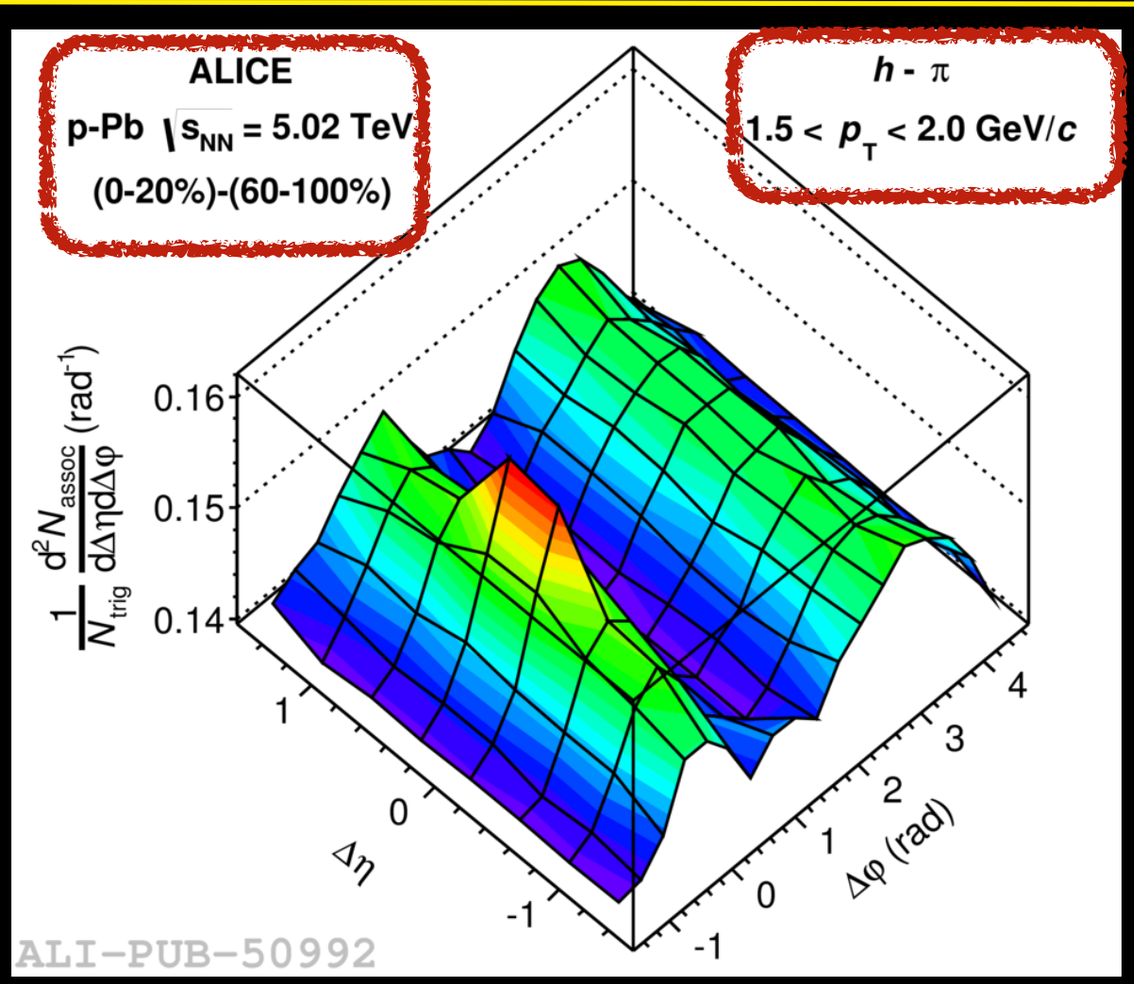
Can we learn more from data?

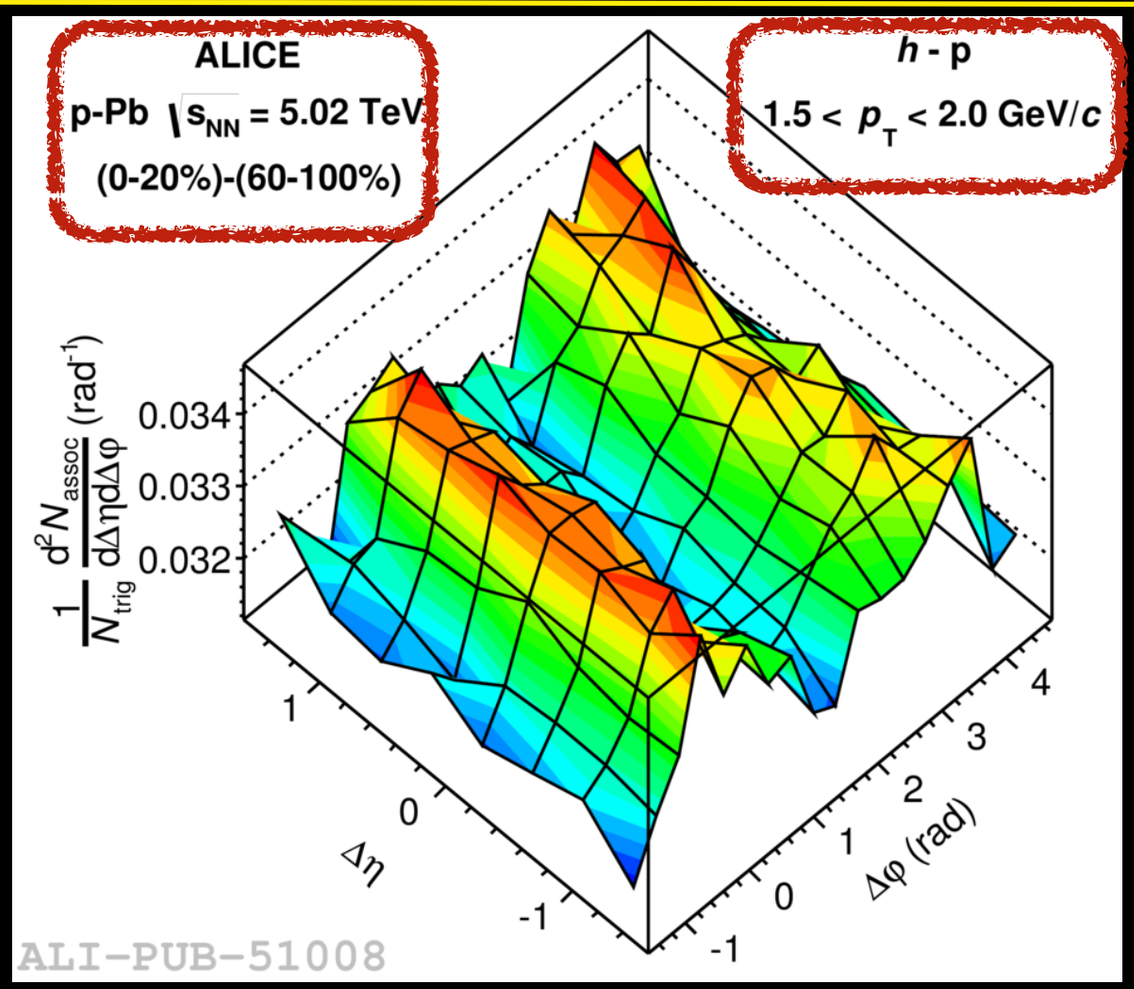
Identified particle correlations in p-Pb

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



Associated yield per trigger: π-h, K-h, p-h

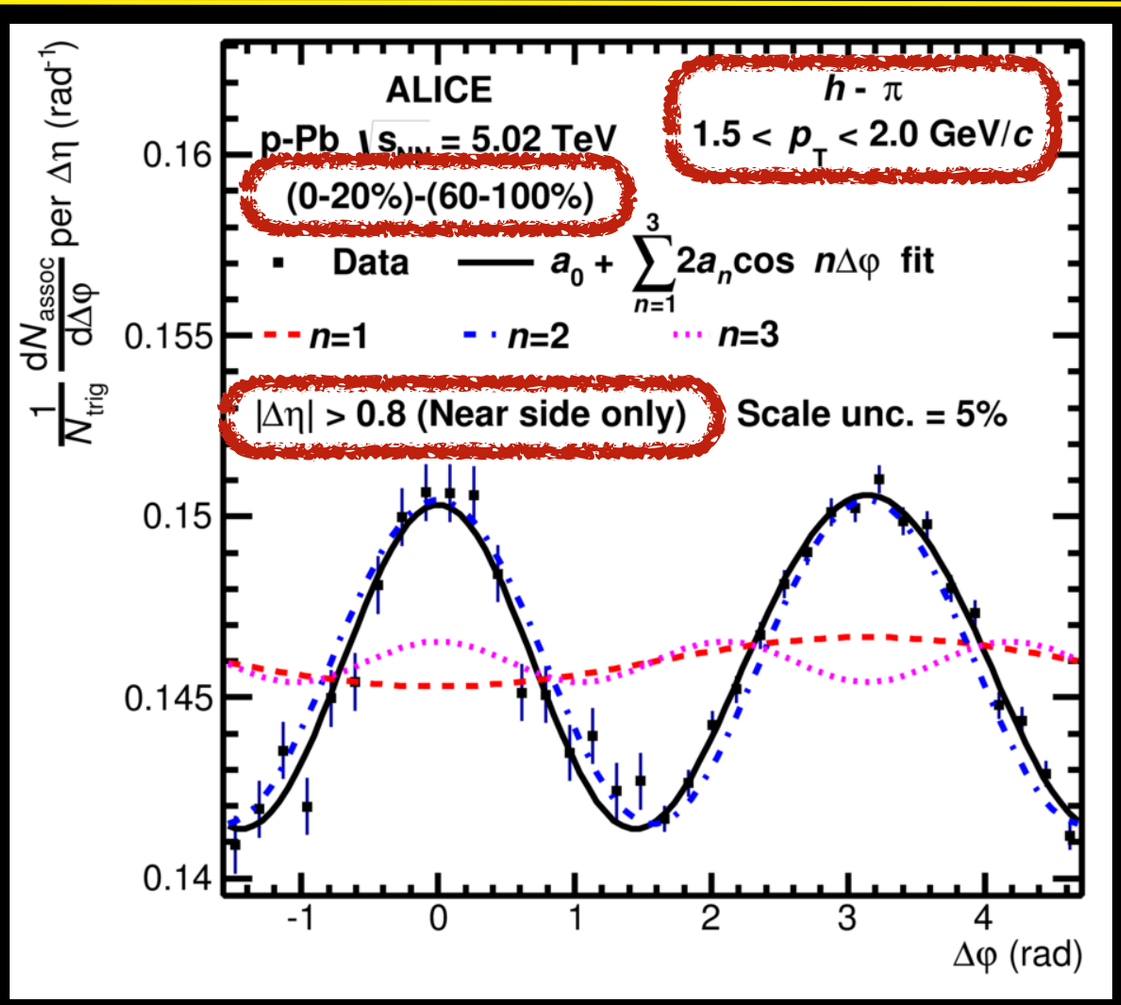


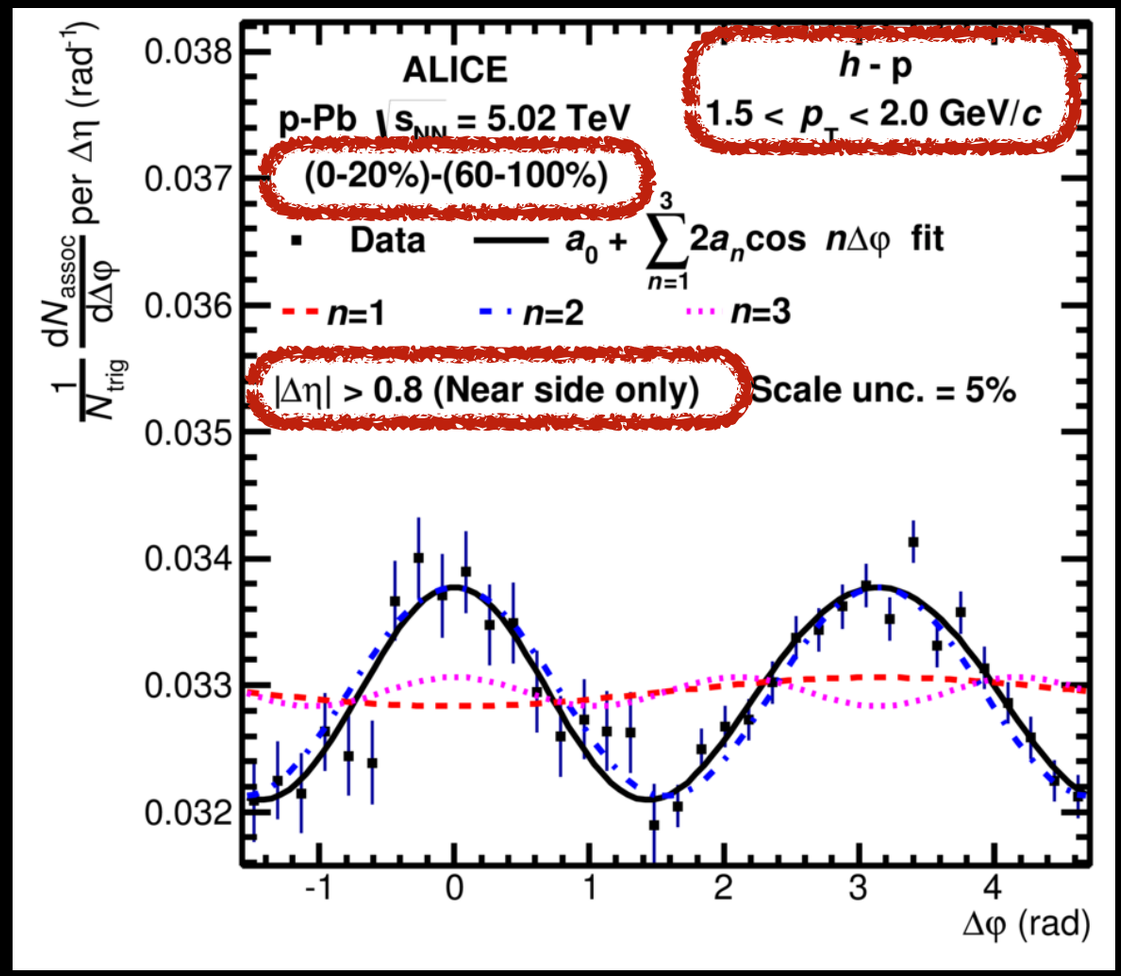


- Similar analysis: charged particle ⇒ “trigger”, (π,K,p) ⇒ “associated”
- Jet component reduction: (0-20)% - (60-100)%
- Symmetric ridges in all cases i.e. π-h, K-h, p-h
- ★ Residual near side jet peak for π-h and to a smaller extent K-h

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

Fourier decomposition



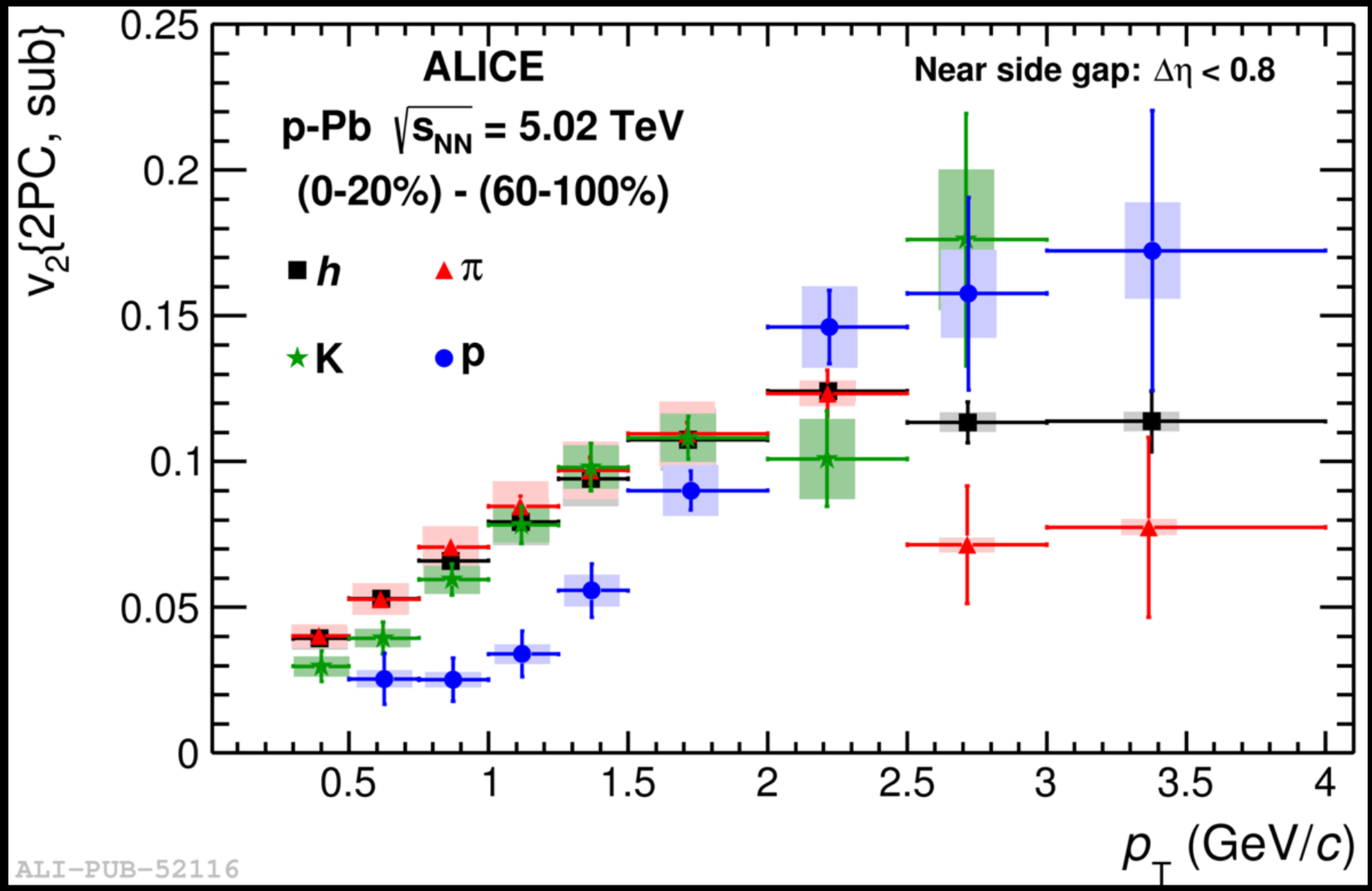


$$\frac{1}{N_{trig.}} \frac{dN_{assoc}}{d\Delta\varphi} = a_0 + 2a_1\cos(\Delta\varphi) + 2a_2\cos(2\Delta\varphi) + 2a_3\cos(3\Delta\varphi)$$

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

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

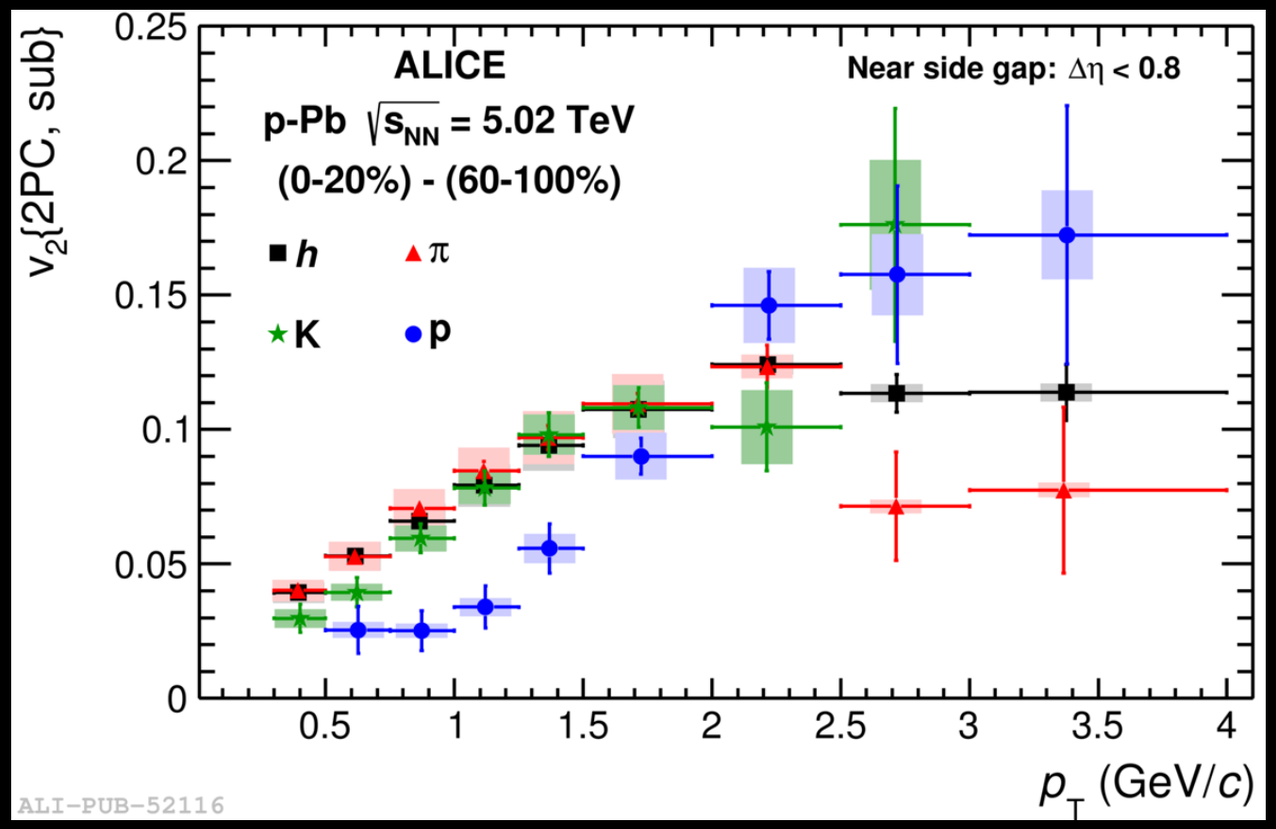
Results on p_T-differential v_2

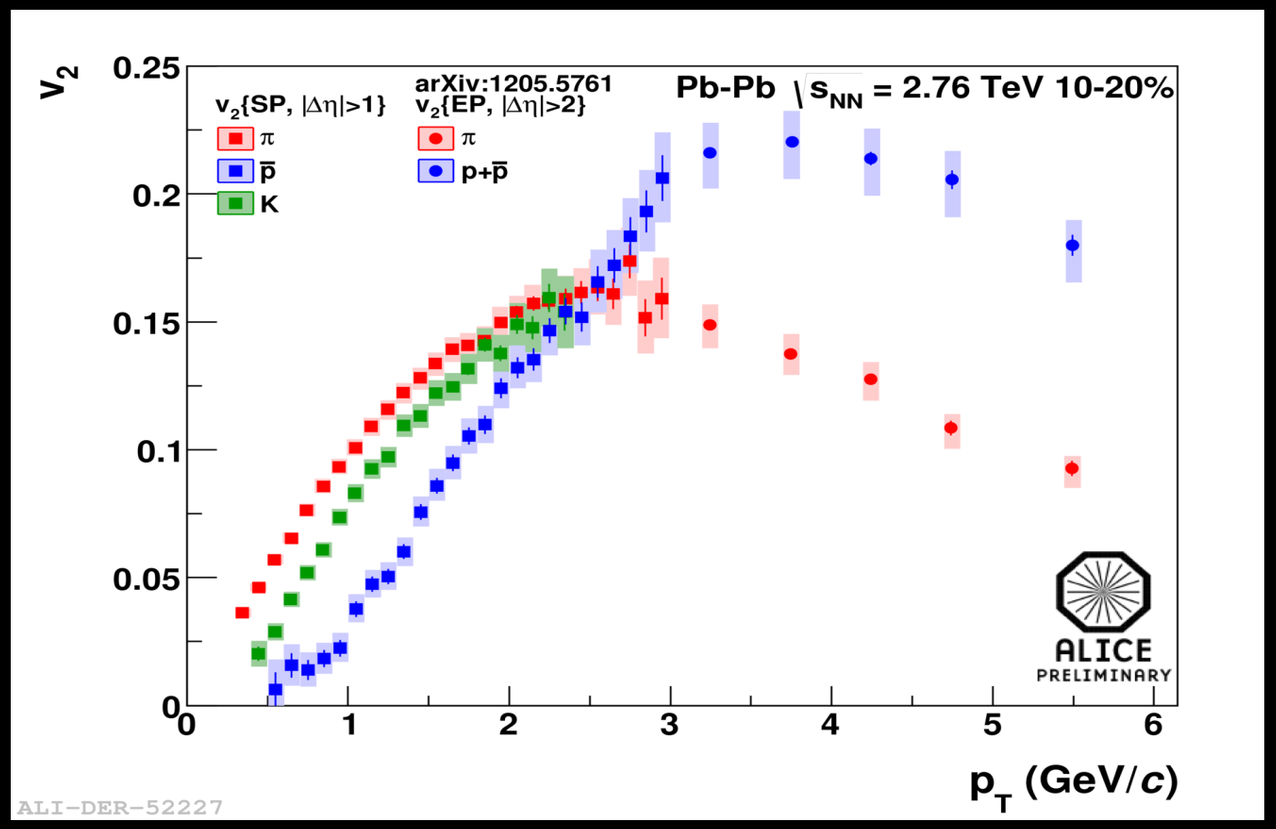


- Mass splitting observed in p-Pb collisions!

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

Results on p_T-differential v_2

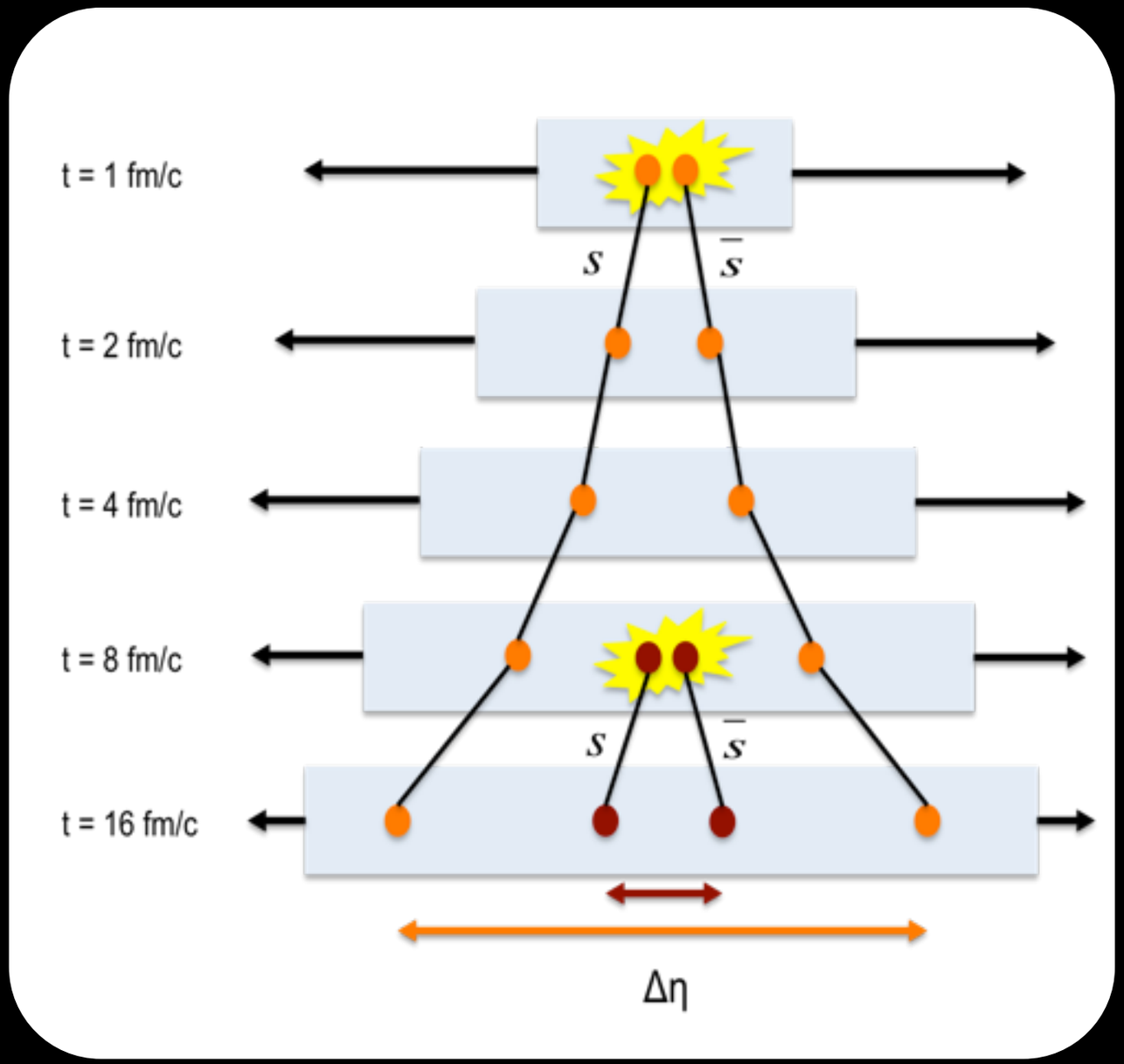


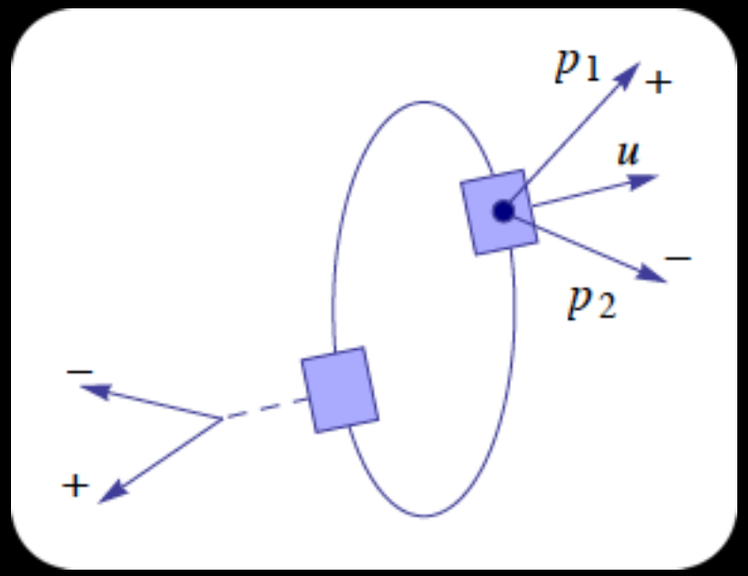


- Mass splitting observed in p-Pb collisions!
- Qualitatively similar picture as in Pb-Pb
  - ★ Qualitatively consistent with a system that develops some degree of collective behaviour

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

Charge dependent correlations (balance functions) in p-Pb





Charge dependent correlations (balance functions) in p-Pb

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

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

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

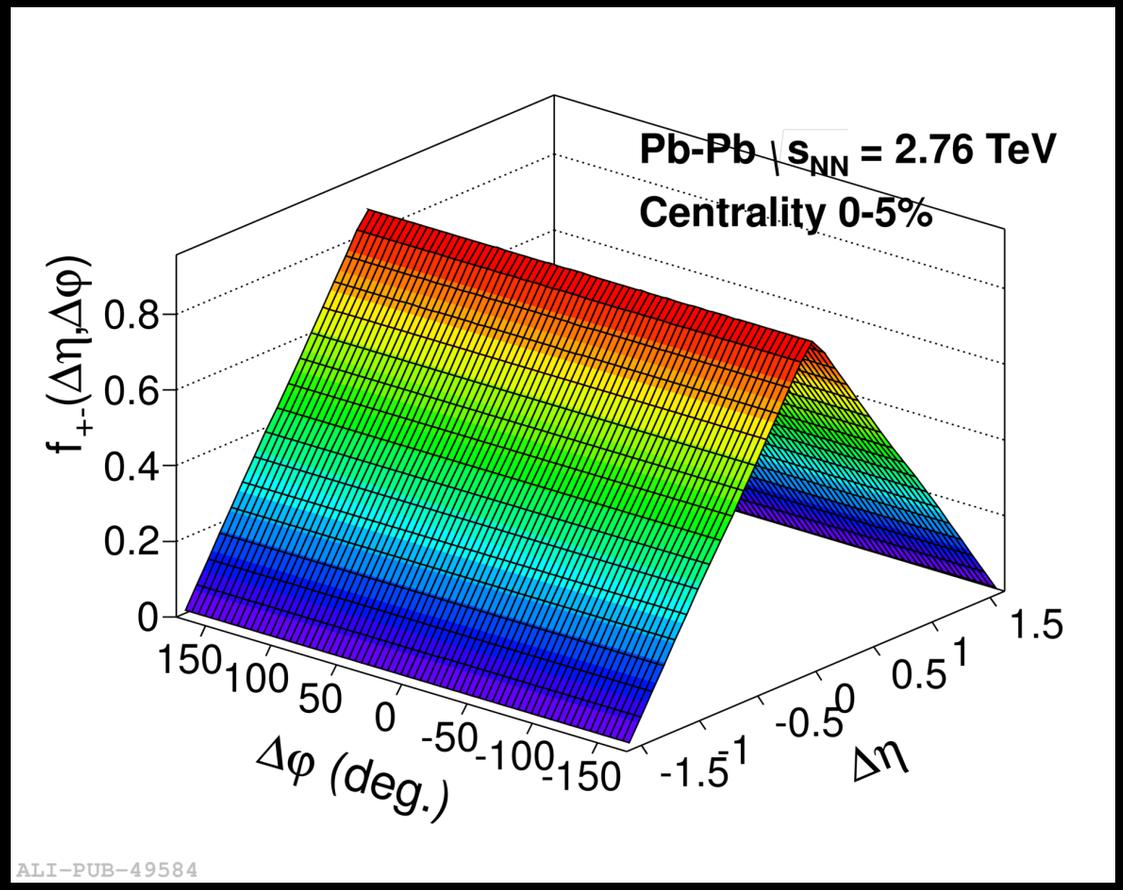
C_{LS}: C_{++}, C_{--}

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

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

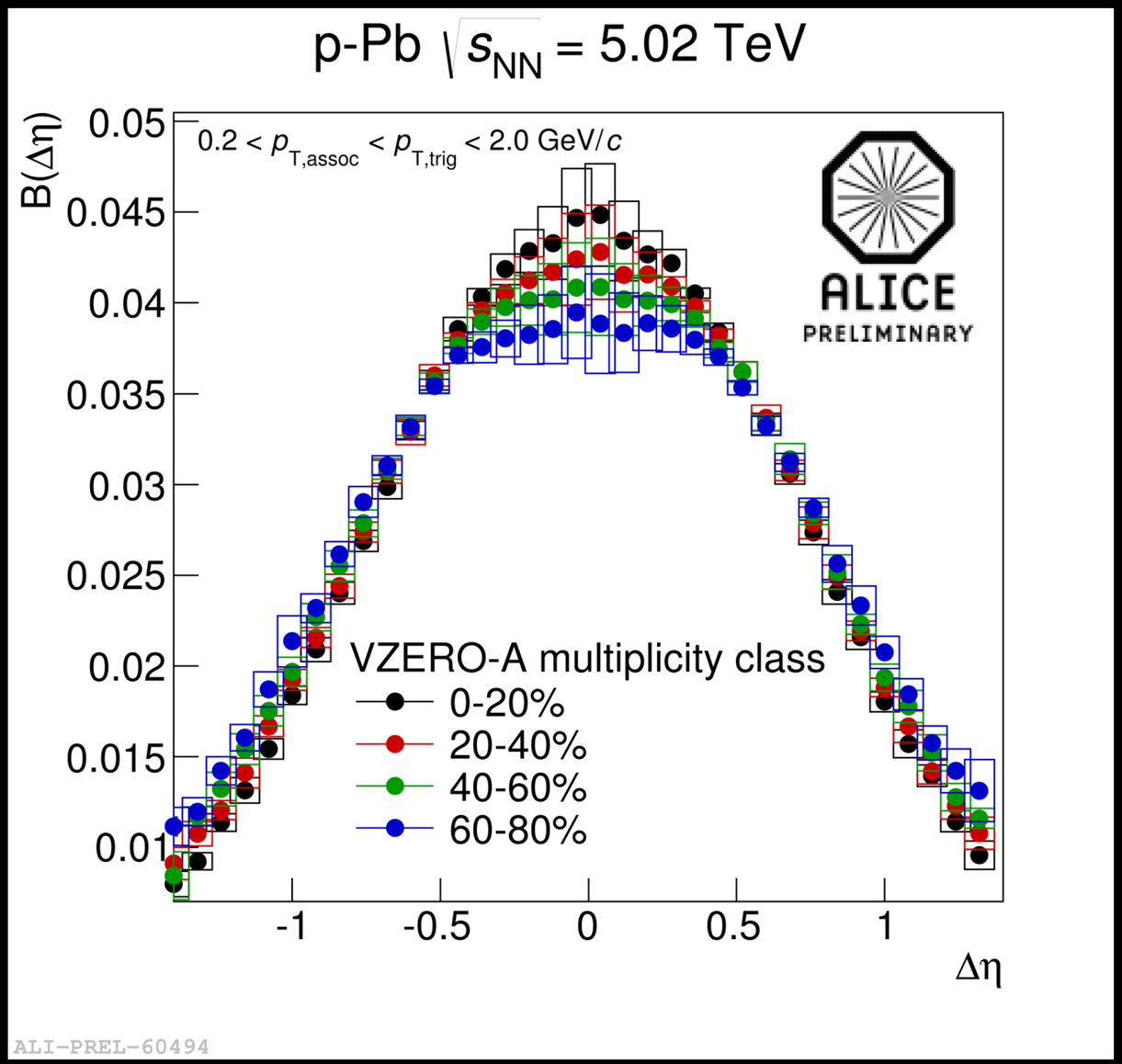
particle pair density normalized to the number of trigger particles

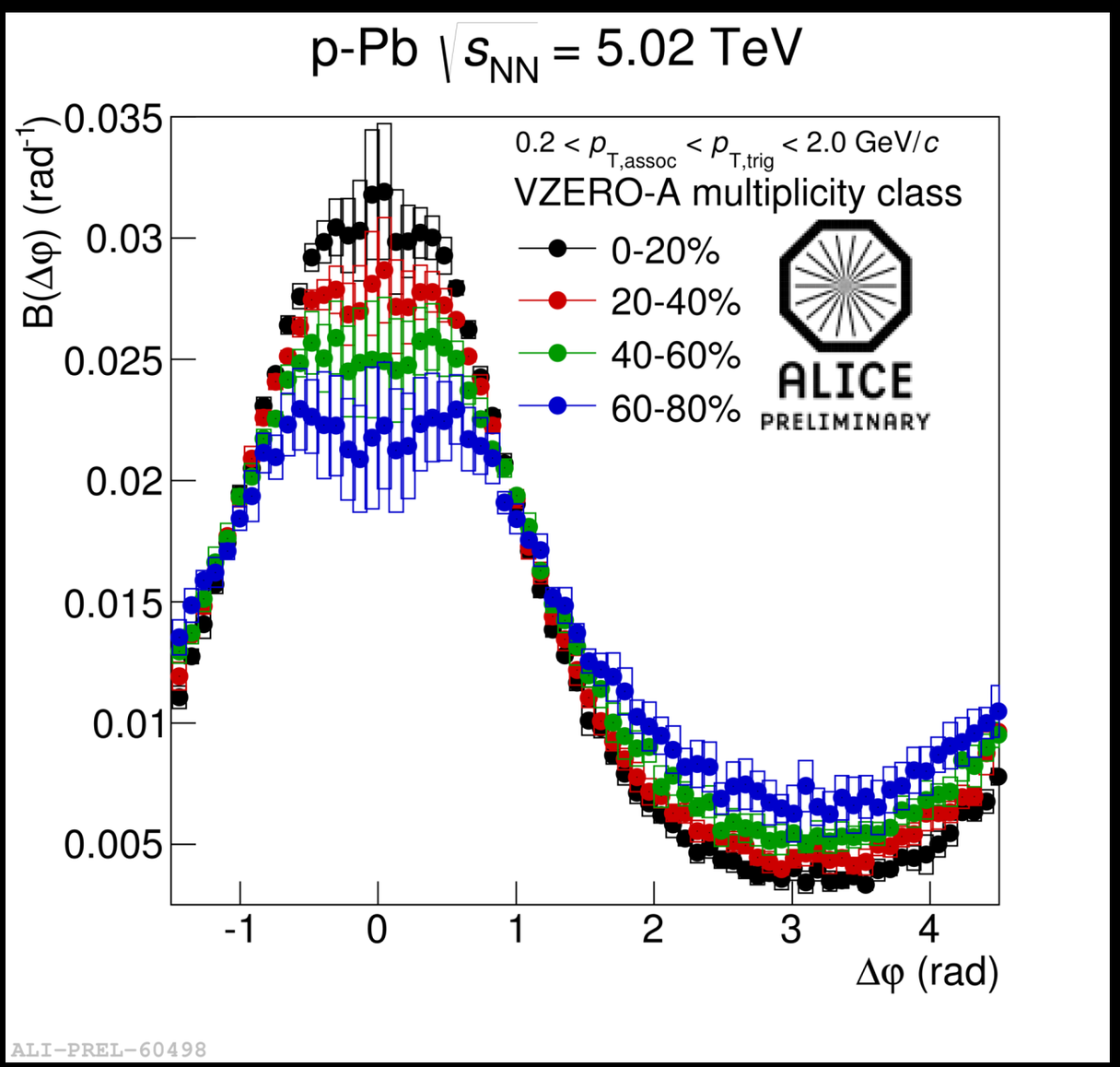
Can be extended to any conserved quantum number e.g. baryon number, strangeness



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

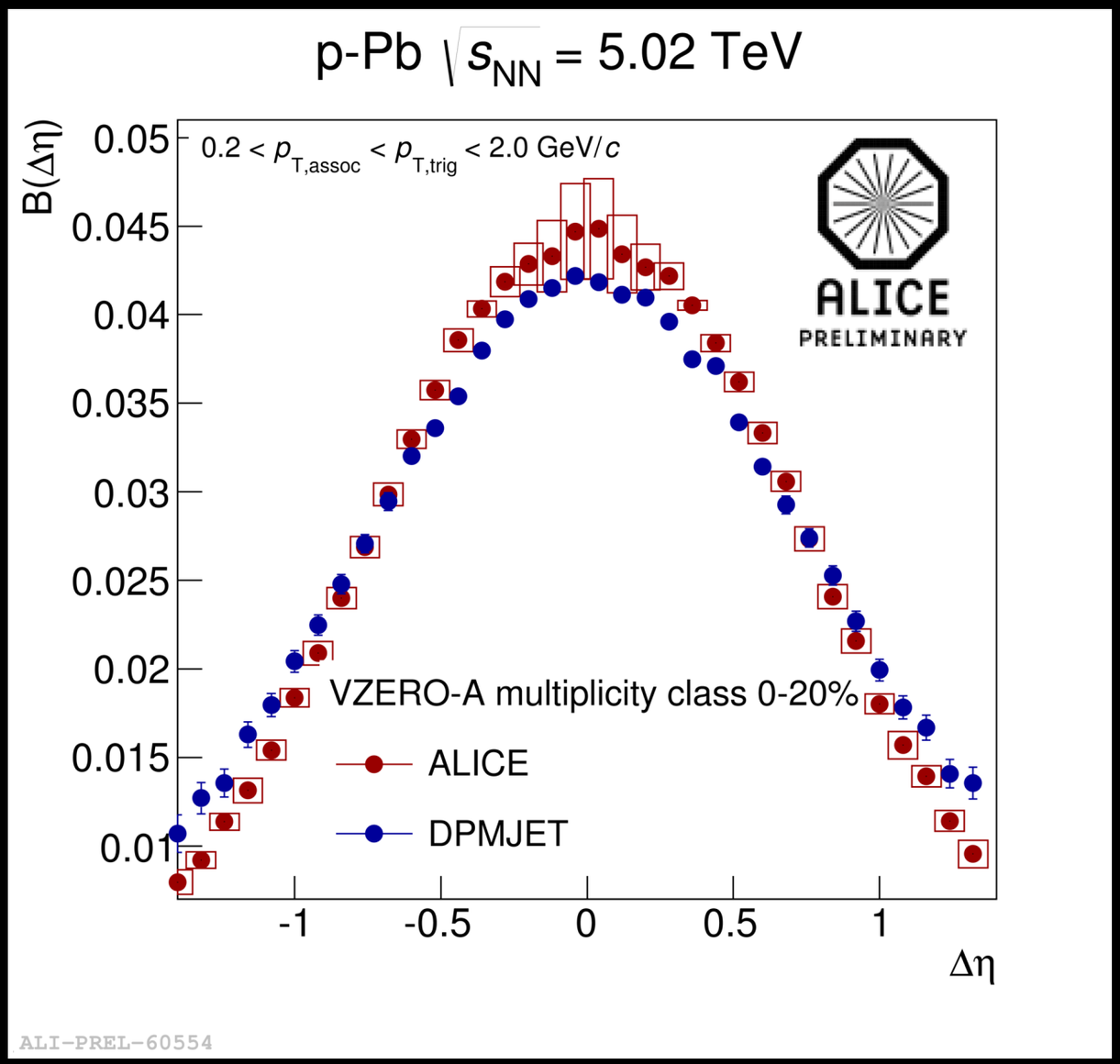
Balance functions in p-Pb: low p_T region

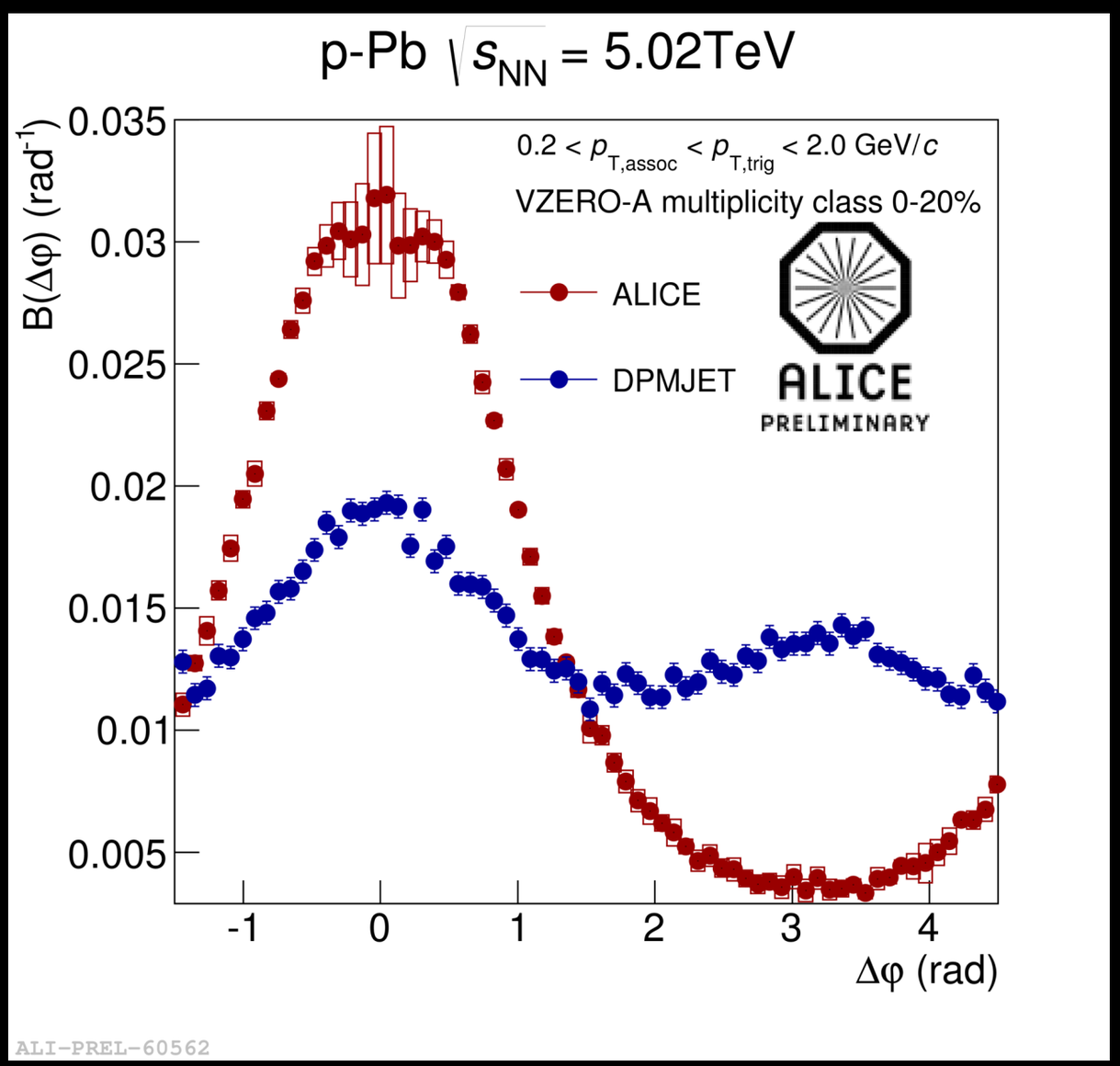




- Evident multiplicity dependence in both Δη and Δφ

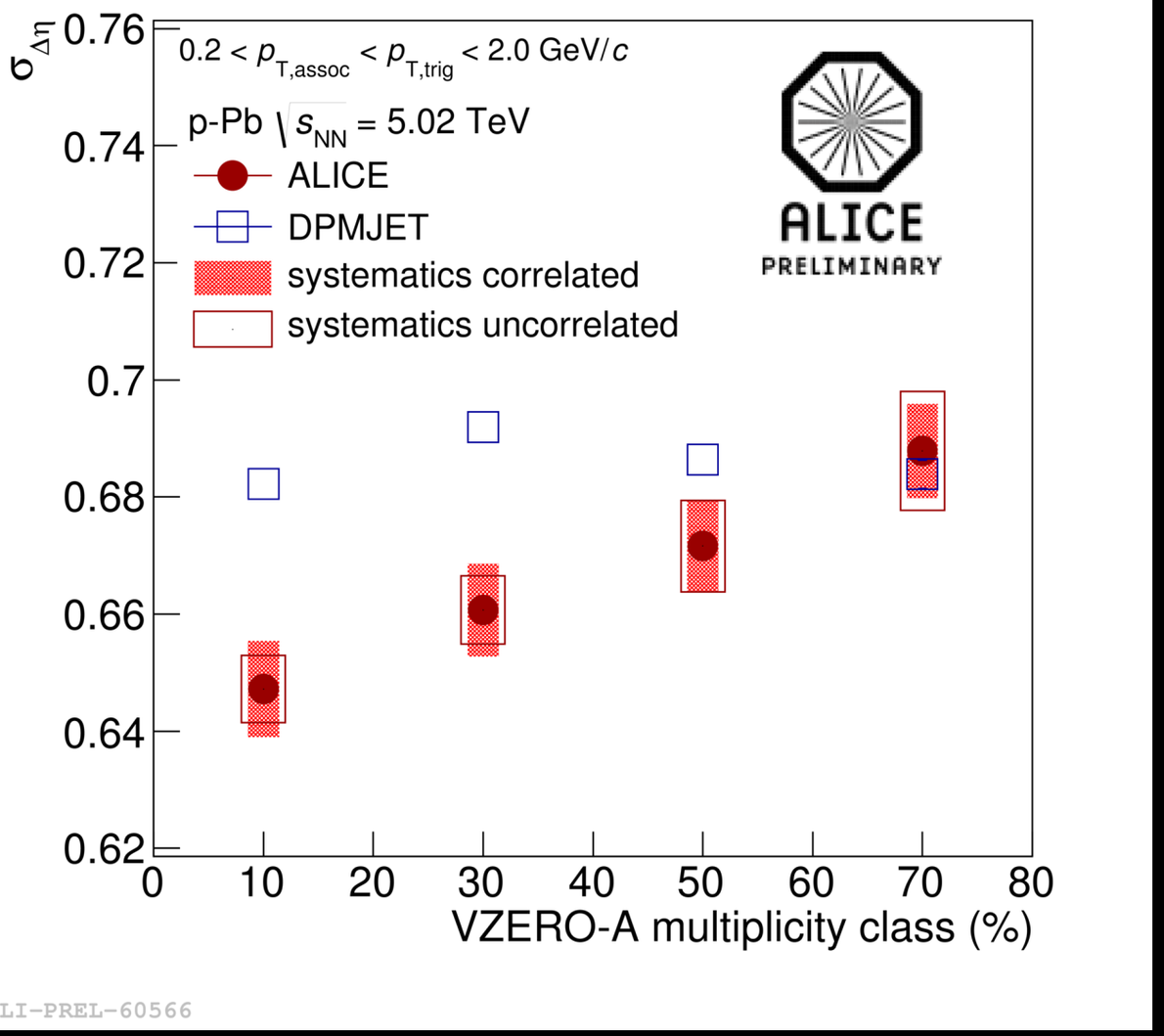
Balance functions in p-Pb: low p_T region

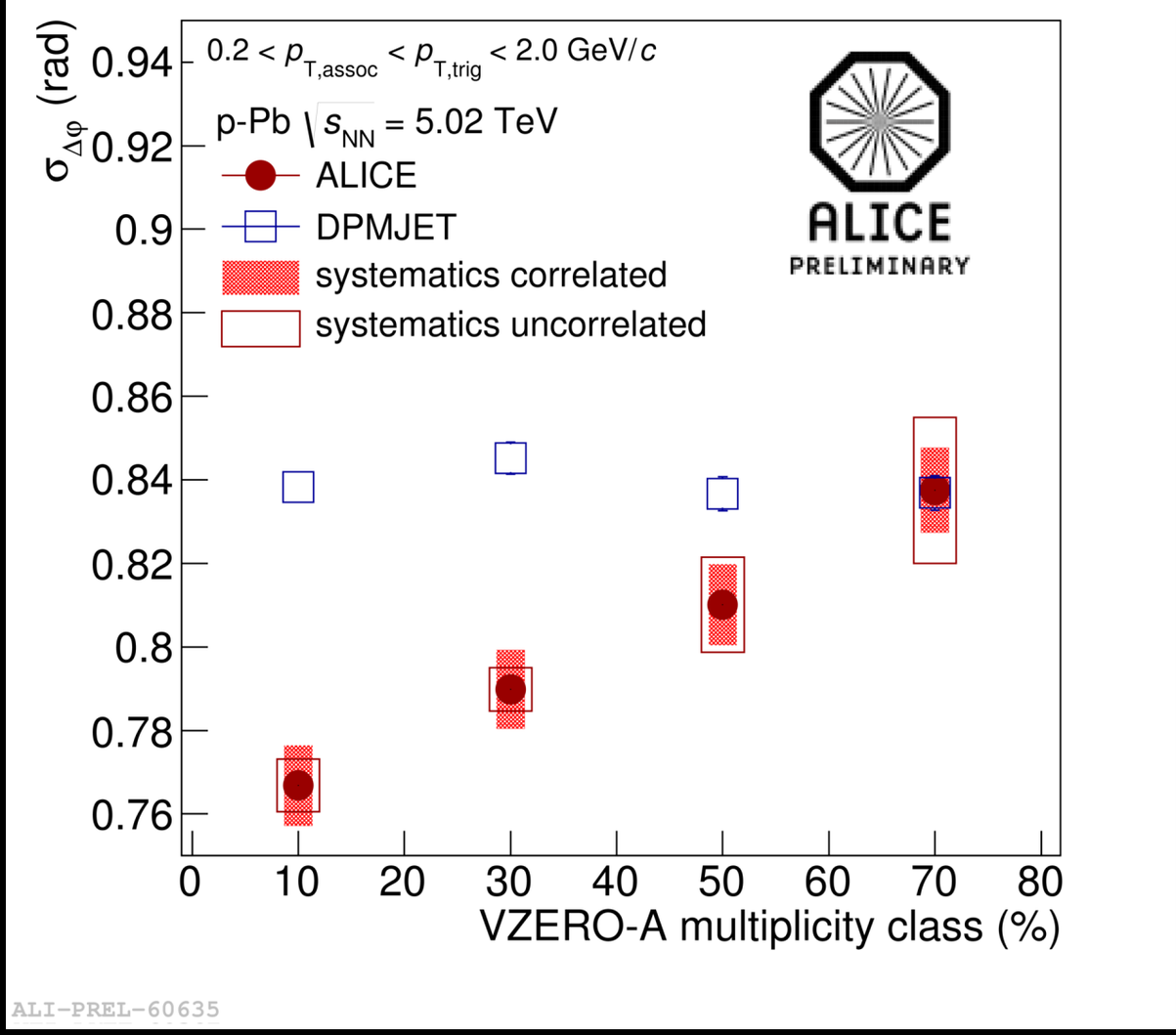




- Narrower distributions for collision data wrt DPMJET

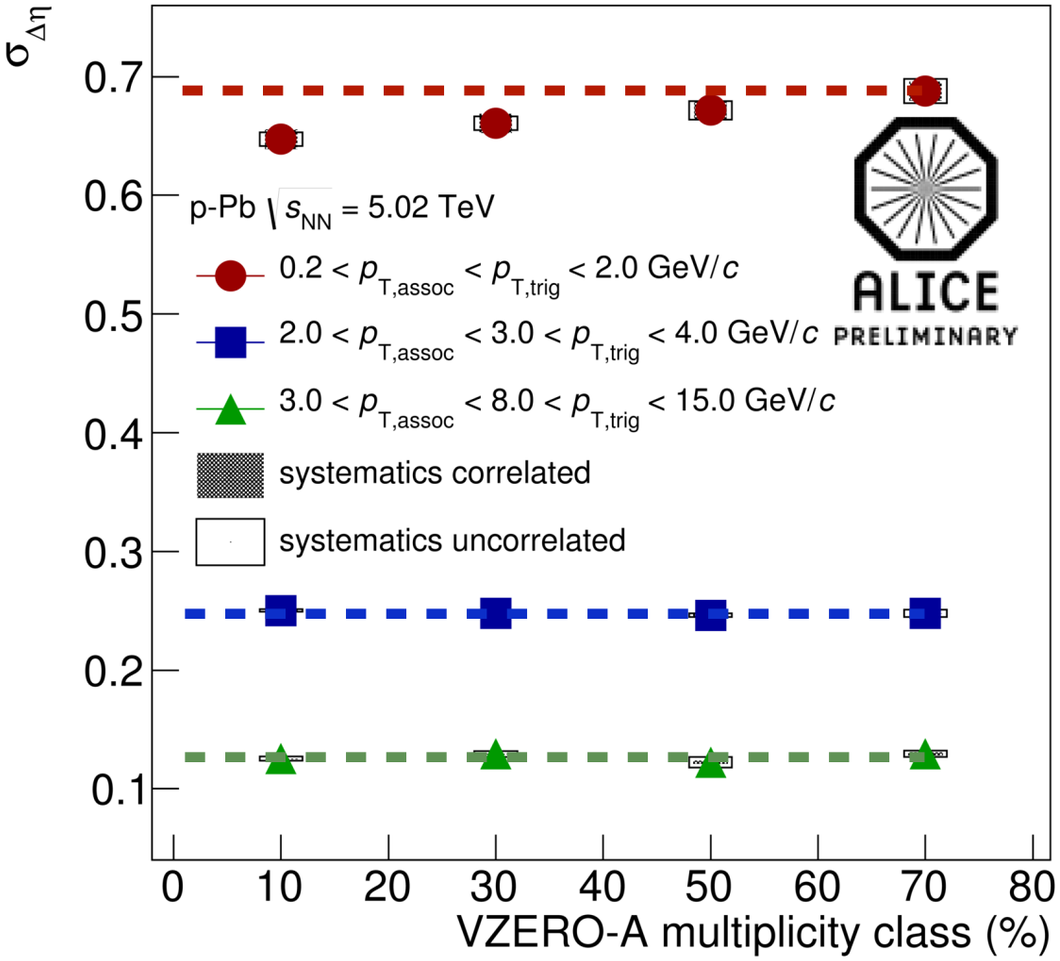
Balance functions in p-Pb: low p_T region

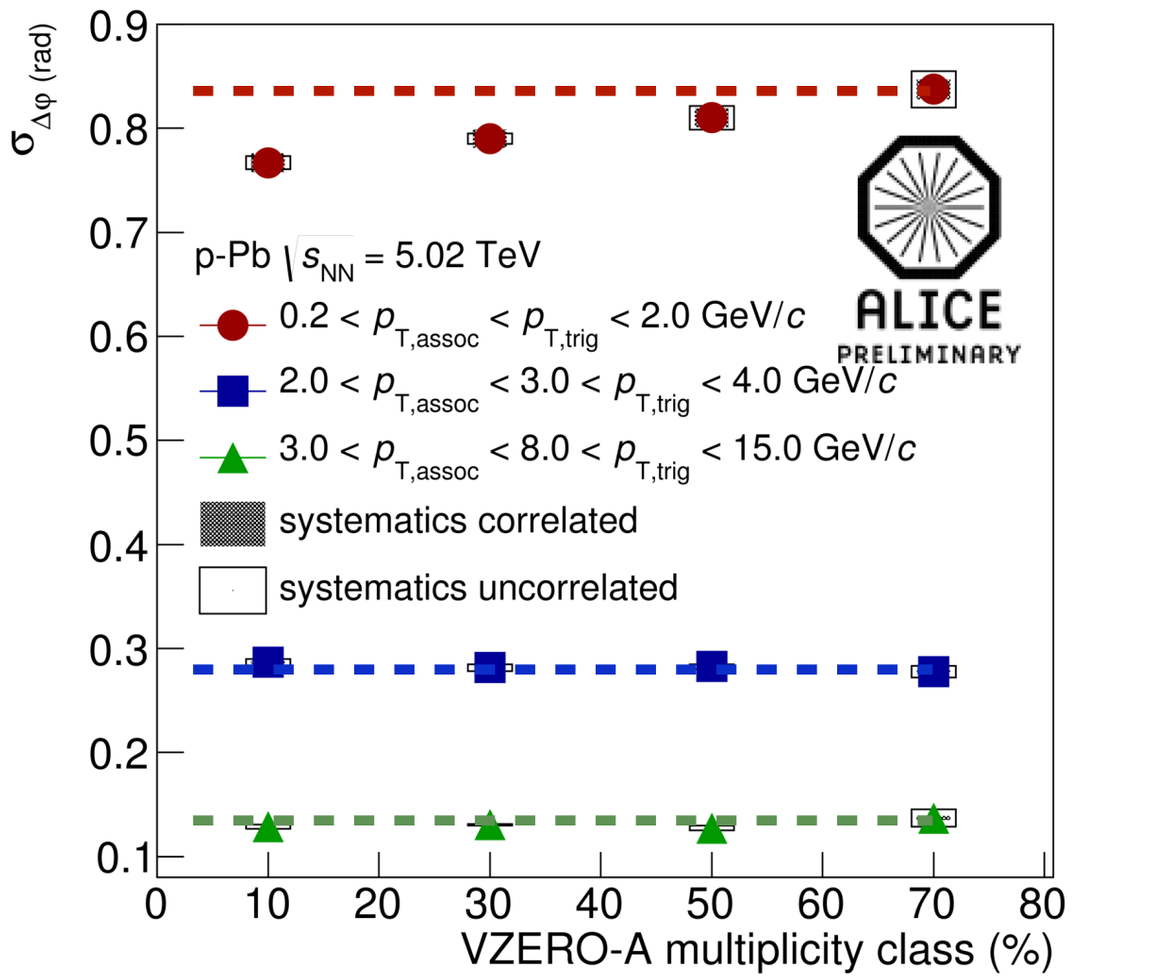




- Evident multiplicity dependence in both Δη and Δφ not reproduced by DPMJET

Balance functions in p-Pb: p_T trend

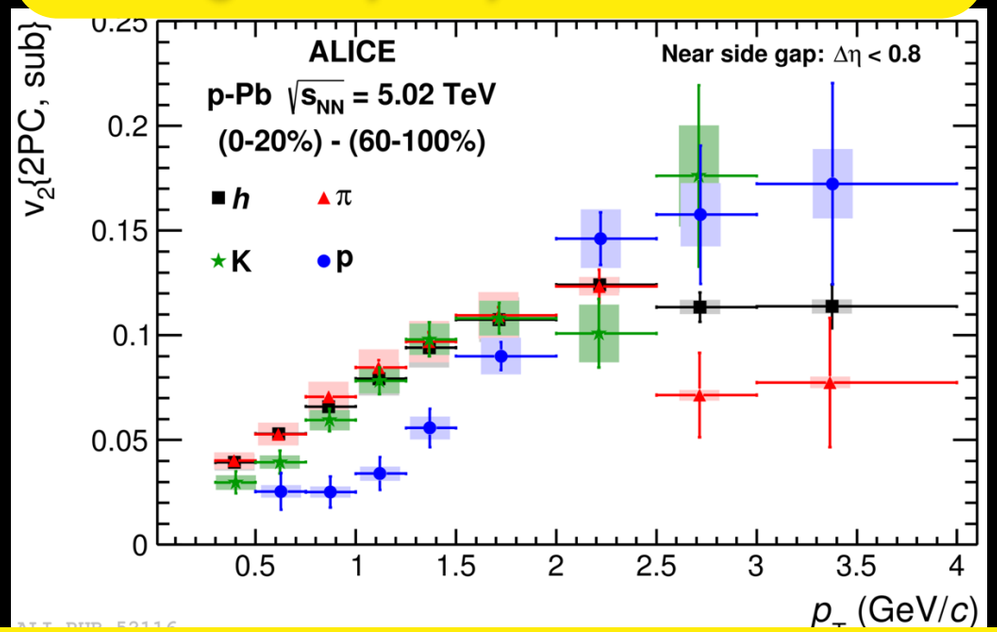




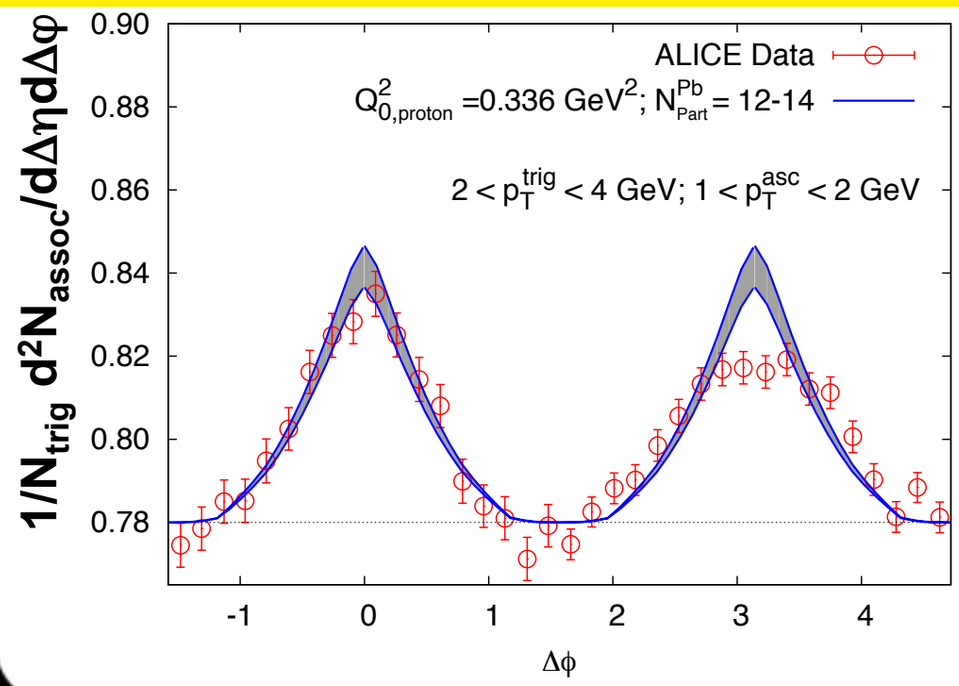
- Multiplicity dependence in both Δη and Δφ appear only in the low p_T region

Is it hydrodynamic flow…?

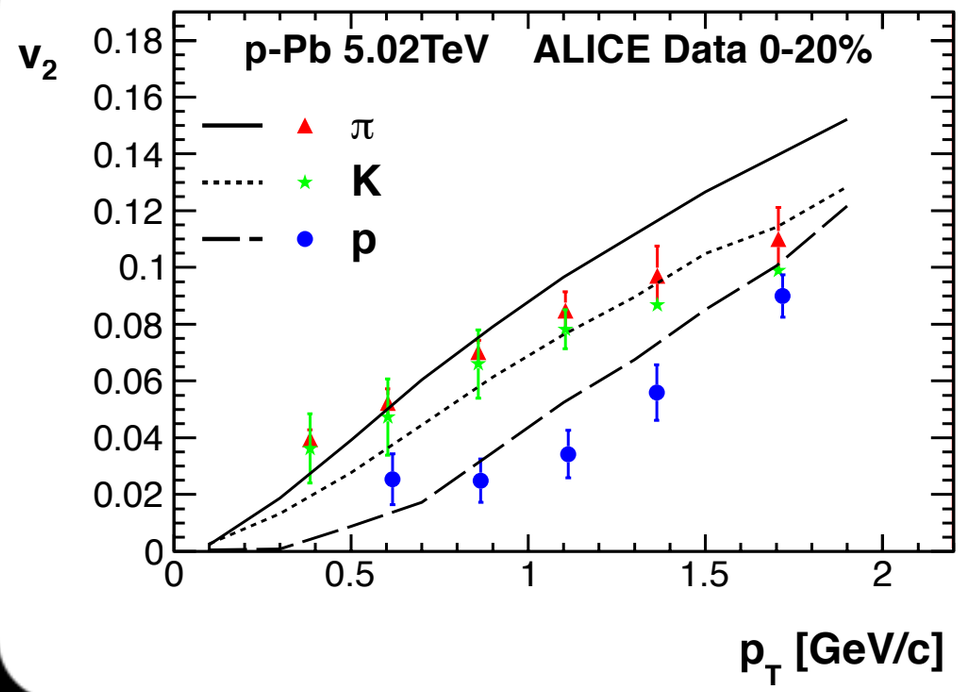
Mass ordering of v_2 in p-Pb collisions: CGC or signs of hydrodynamical evolution?



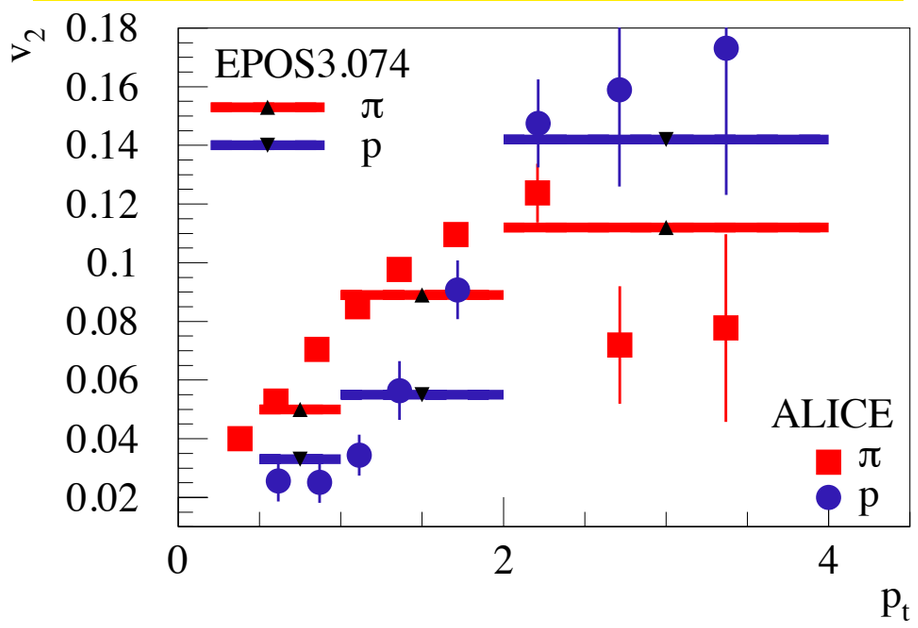
K.Dusling and R. Venugopalan, Phys.Rev. **D87**, (2013) 094034



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



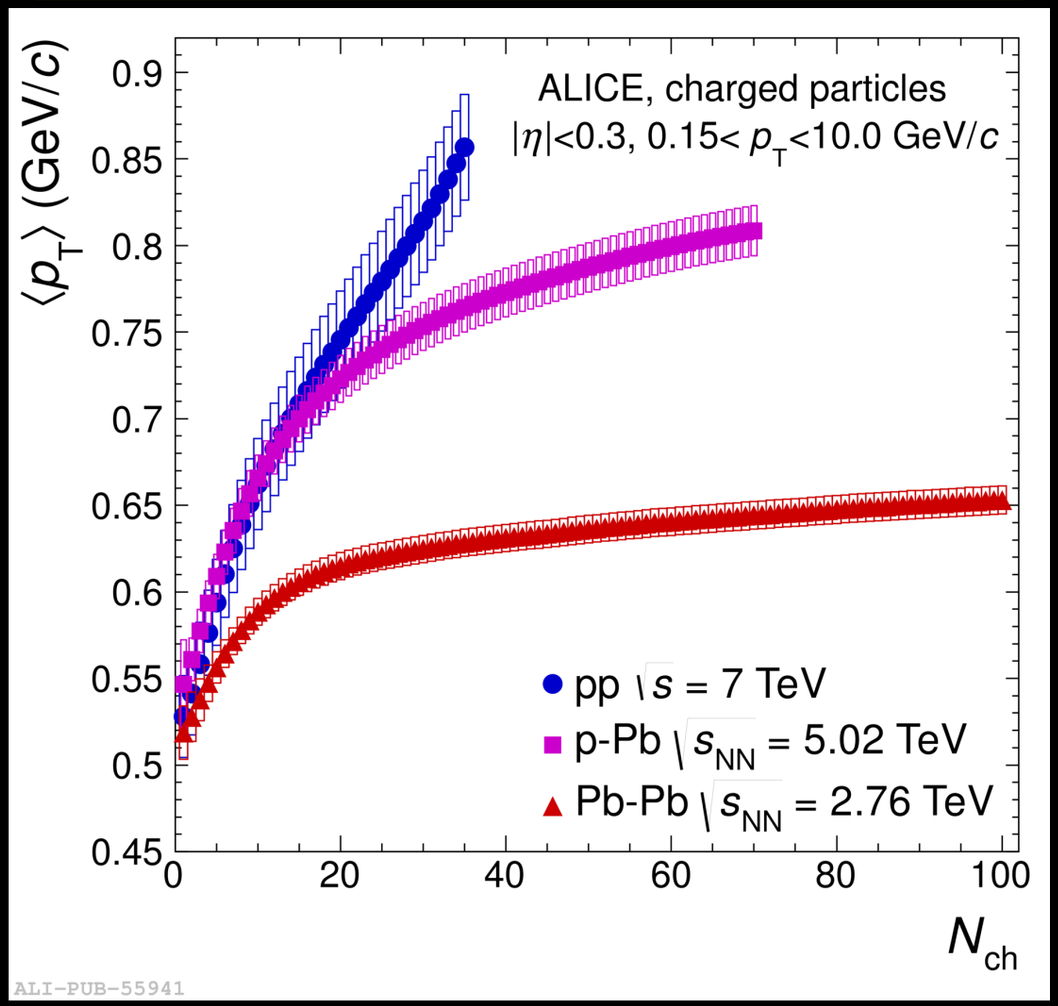
K. Werner *et al.*,arXiv:1307.4379 [nucl-th]



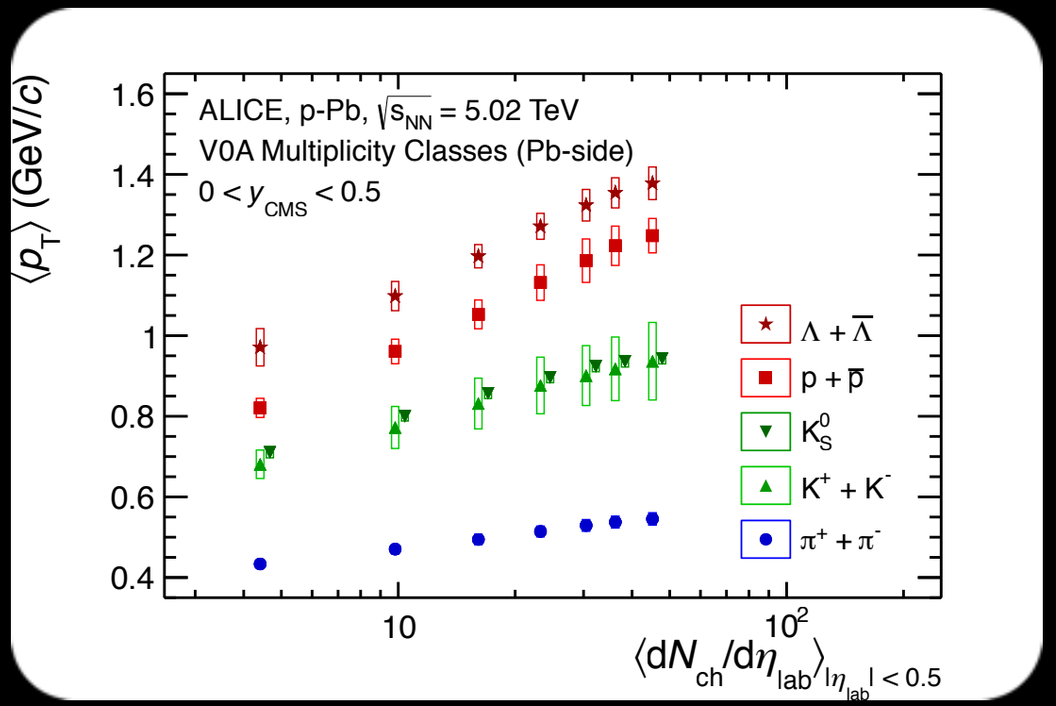
Is it hydrodynamic flow…?

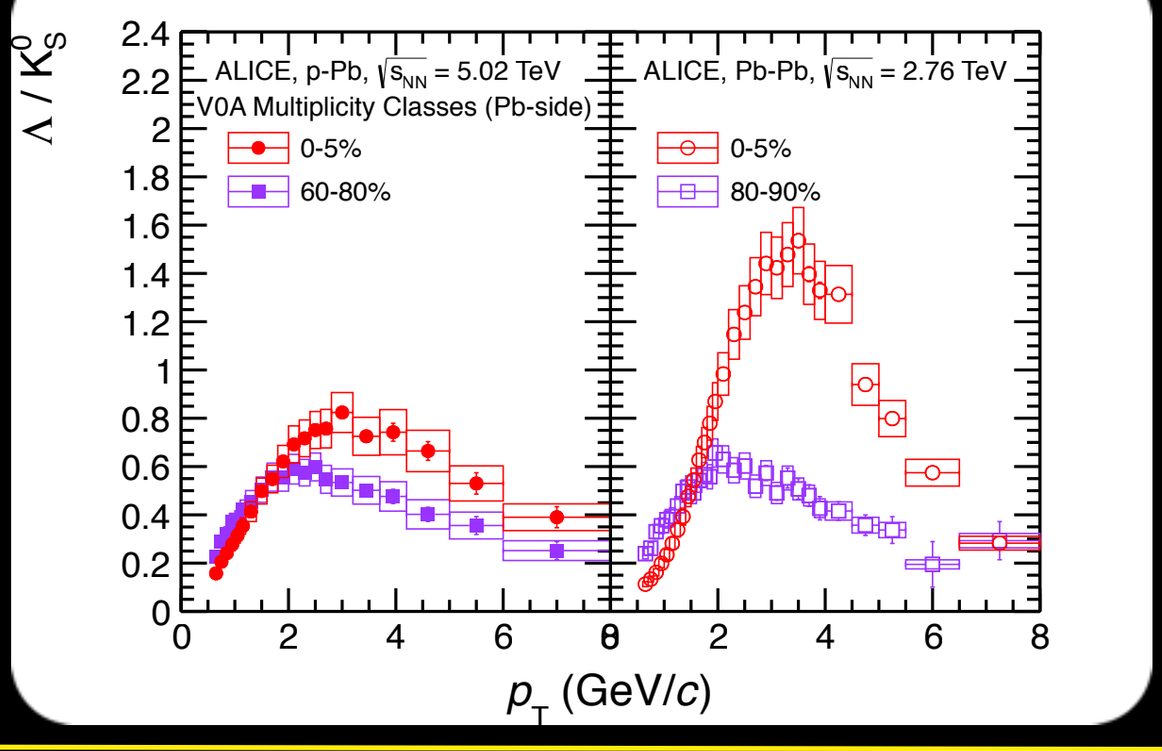
- Observations from other analyses of similar features in p-Pb as in Pb-Pb!

ALICE Collaboration arXiv: 1307.1094 [nucl-ex]



ALICE Collaboration arXiv: 1307.1094 [nucl-ex]





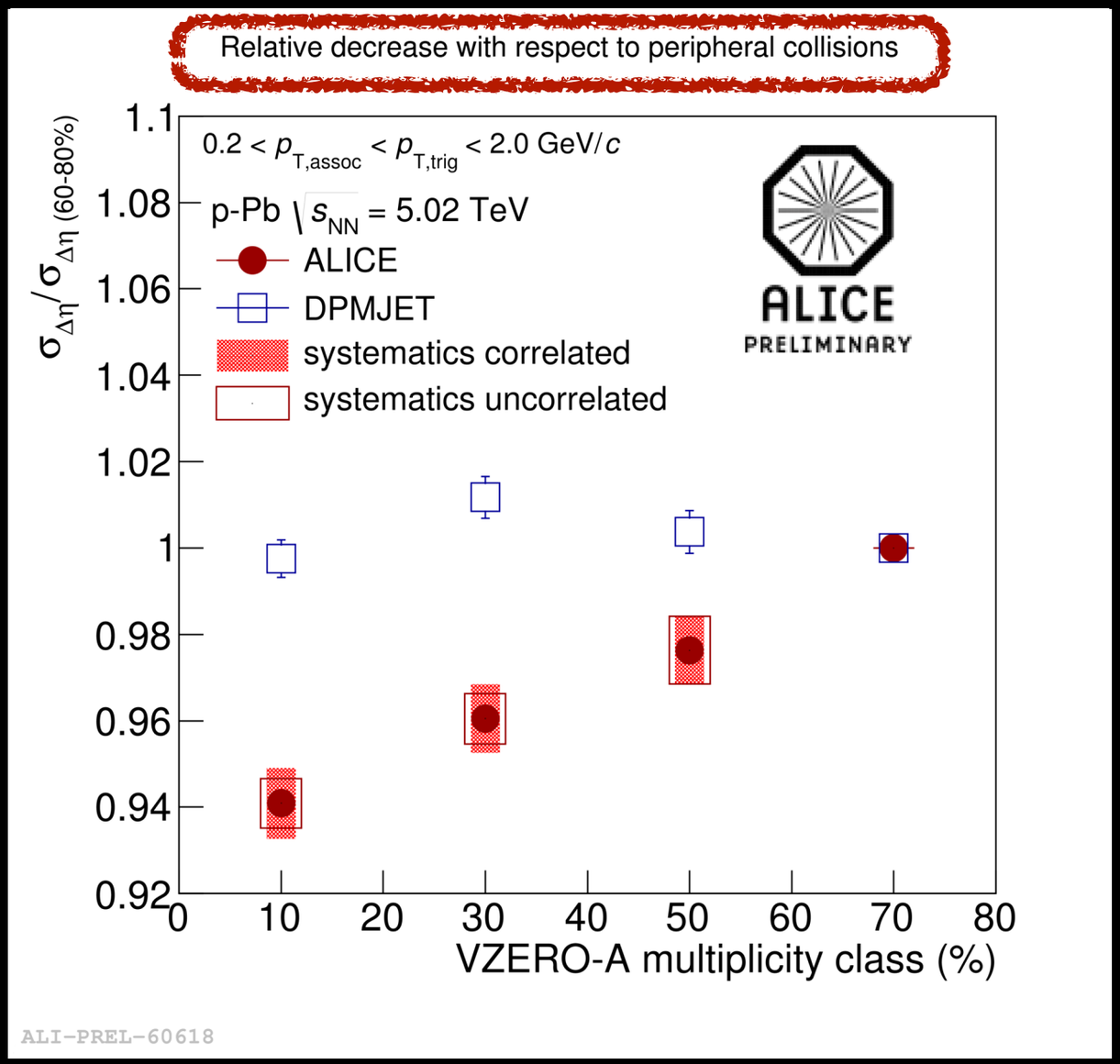
Is it hydrodynamic flow…?

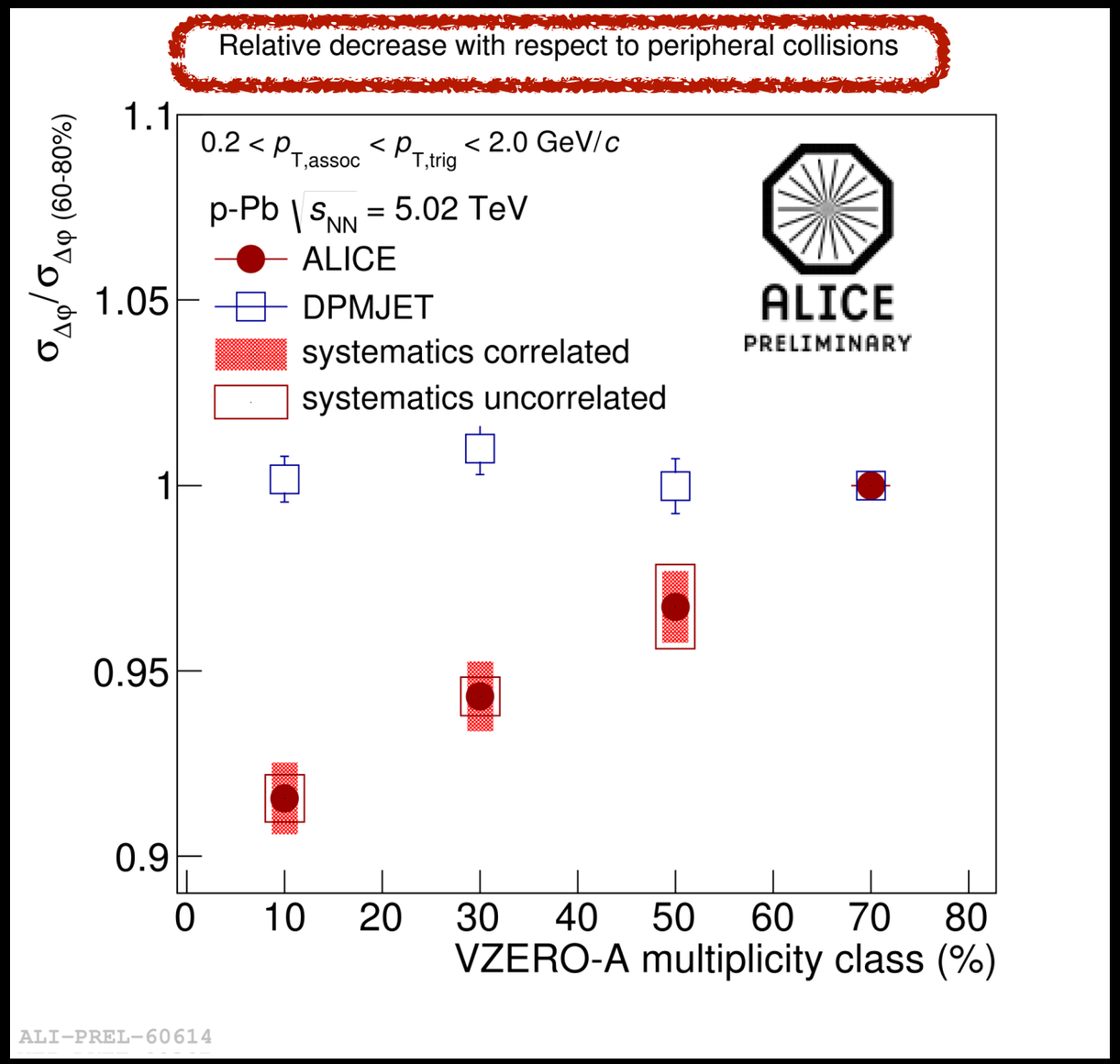
My two cents: Still I have to admit that it becomes less likely to be a cat that knows “foreign languages”

THANK YOU FOR YOUR ATTENTION

BACKUP

Balance functions in p-Pb: low p_T region





- Evident multiplicity dependence in both Δη and Δφ not reproduced by DPMJET