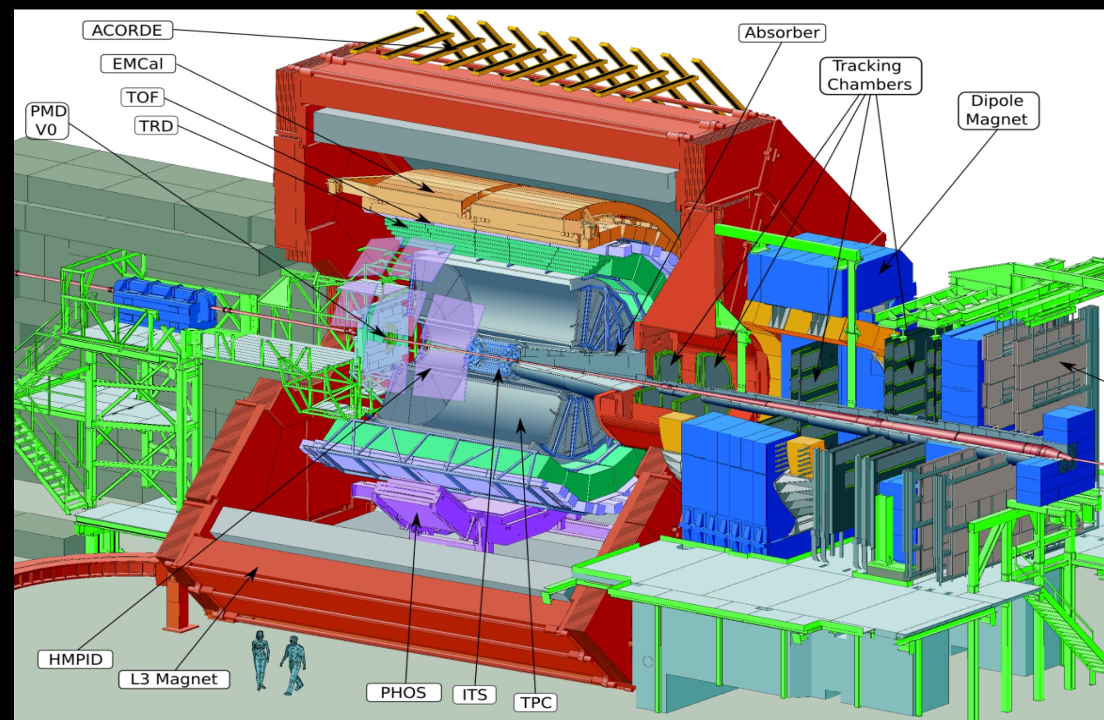
NIKHEF

ALICE

Results based on: ALICE Collaboration, arXiv:1509.07255 (submitted to EPJC)

Multiplicity and transverse momentum dependence of electric charge balance functions



Panos Christakoglou[1] (in place of Alis Rodriguez Manso[1,2]) for the ALICE Collaboration

[1]Nikhef
[2]Utrecht University

QUARK MATTER 2015

The XXVth International Conference on Ultrarelativistic Nucleus-Nucleus Collisions

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Charge dependent correlations (balance functions)

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

$$B(\Delta\eta,\Delta\varphi)=\frac{1}{2}\left[c_{(+,-)}+c_{(-,+)}-c_{(+,+)}-c_{(-,-)}\right]$$

$$c_{(+,-)}=\frac{1}{N_{trig,+}}\frac{d^2N_{assoc,-}}{d\Delta\eta d\Delta\varphi}=\frac{S_{(+,-)}}{f_{(+,-)}}$$

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→ particle pair density normalised to the number of trigger particles

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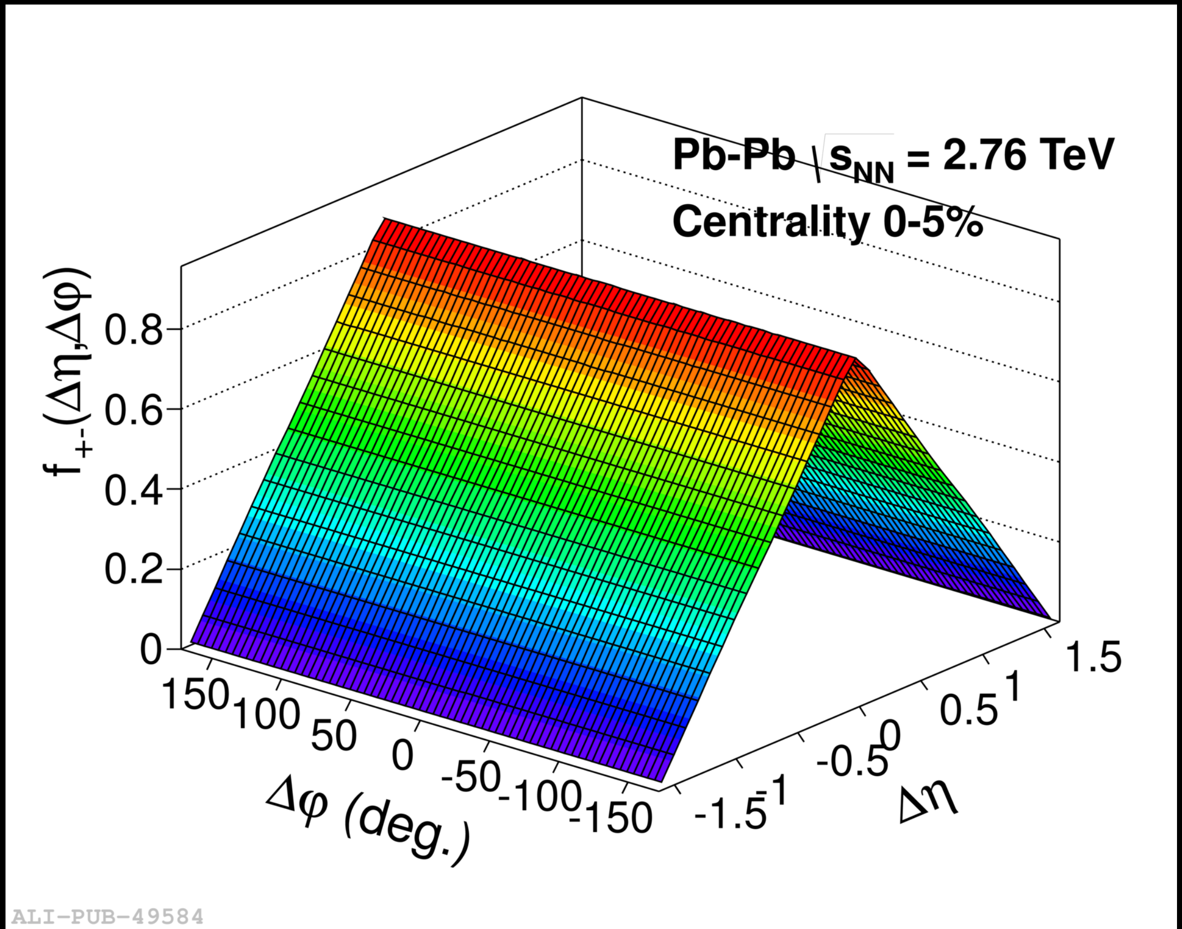
particle pair density normalised to the number of trigger particles

$$f_{(+,-)}=\alpha\frac{d^2N_{mixed,(+,-)}}{d\Delta\eta d\Delta\varphi}$$

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



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

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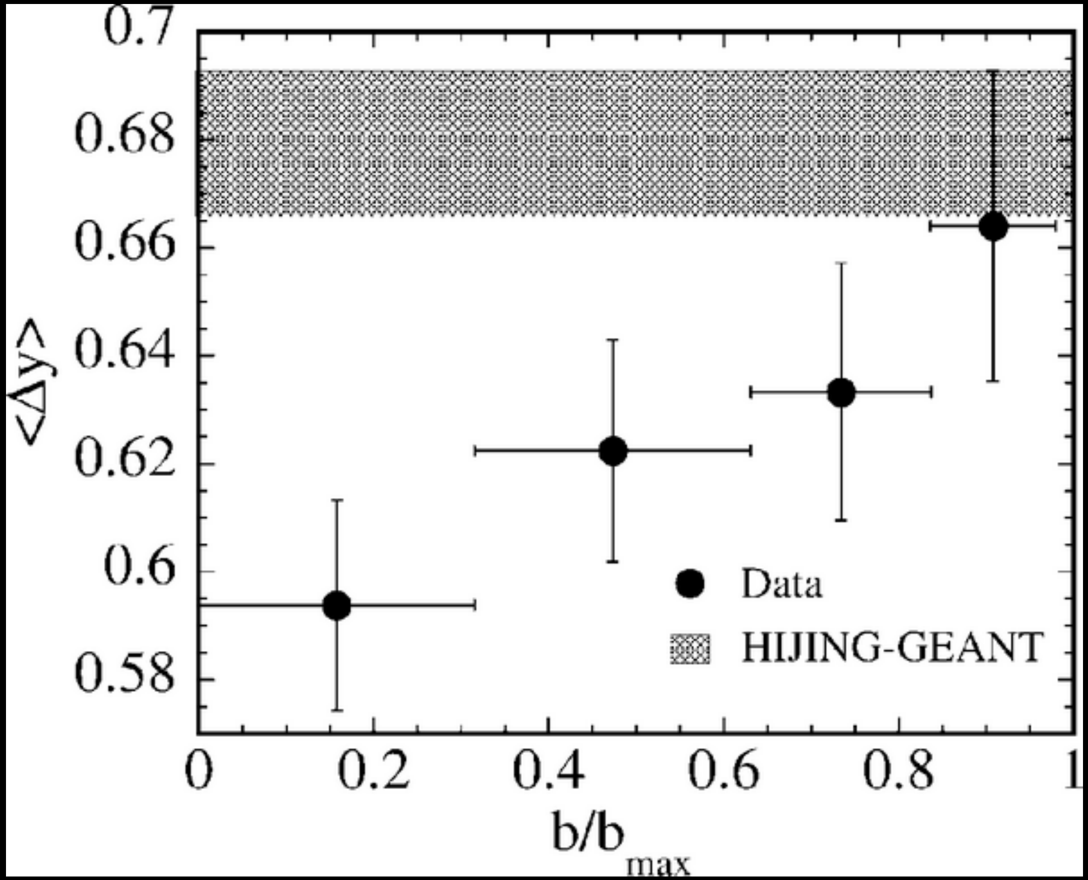
Detector acceptance and inefficiencies (mixed events or from convolution of single particle distributions)

- “Balancing charges” affected (focused) by
  - the collective motion of the system
  - when the particles are produced (early vs delayed hadronization)
- Narrower balance functions if collectivity is developed and particles are produced at a late stage

Previous results

STAR Collaboration, Phys. Rev. Lett. **90,** (2003) 172301

Au-Au $\sqrt{s_{NN}}$ = 130 GeV



charged particles in |η| < 1.3
Acceptance not corrected for

Weighted average:

$$\langle \Delta y \rangle = \frac{\sum_{i=1}^{n} B_i \Delta y_i}{\sum_{i=1}^{n} B_i}$$

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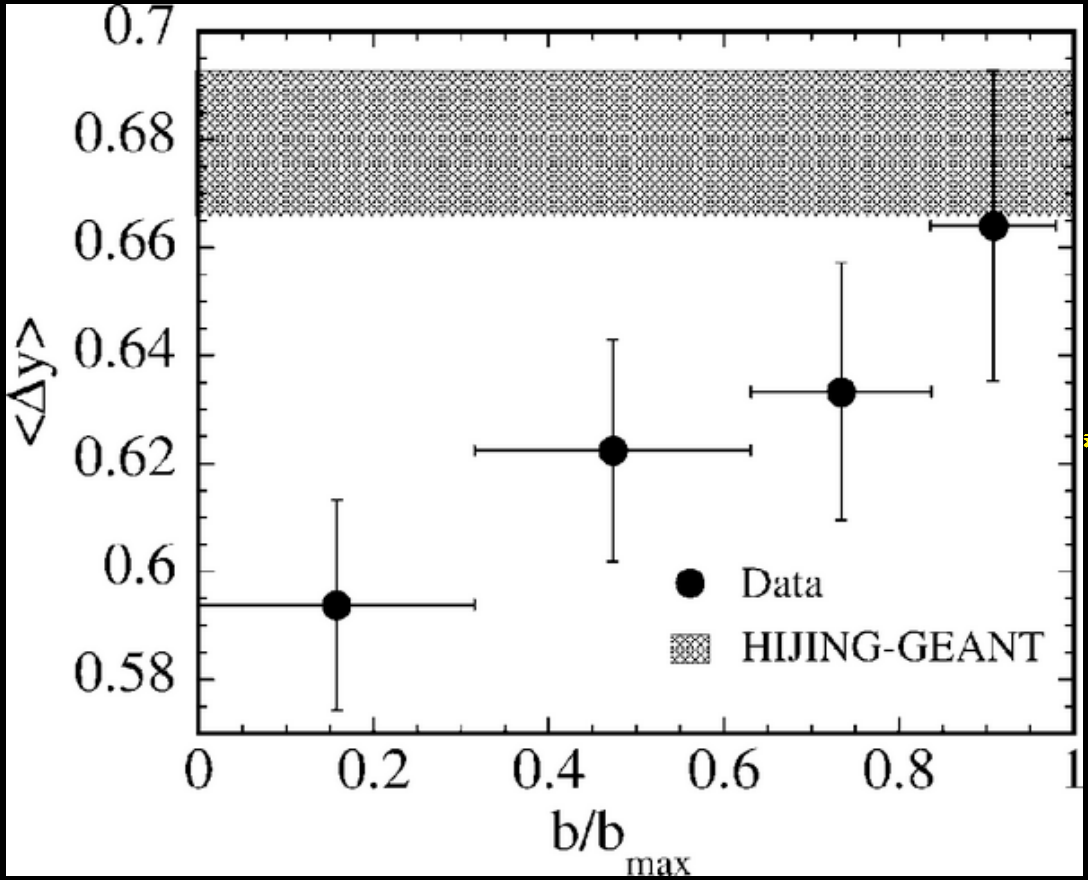

Considered as the "**smoking gun**" of QGP creation

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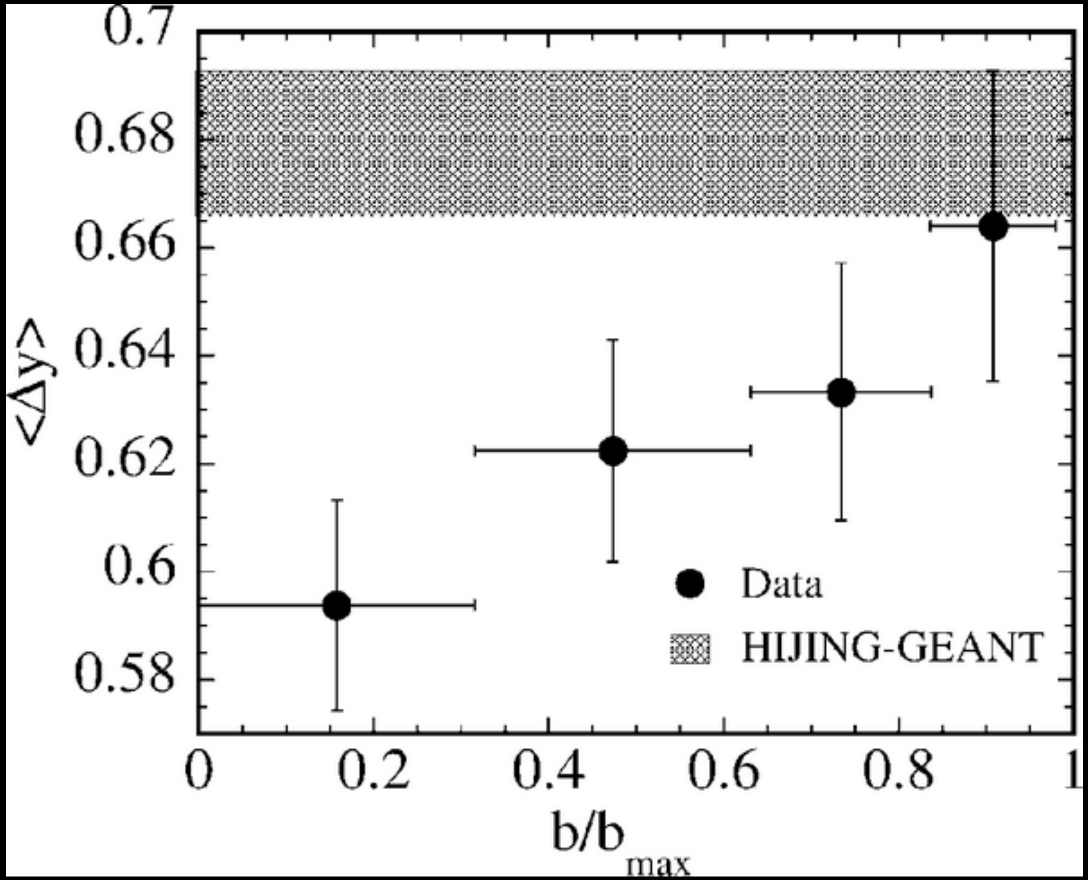
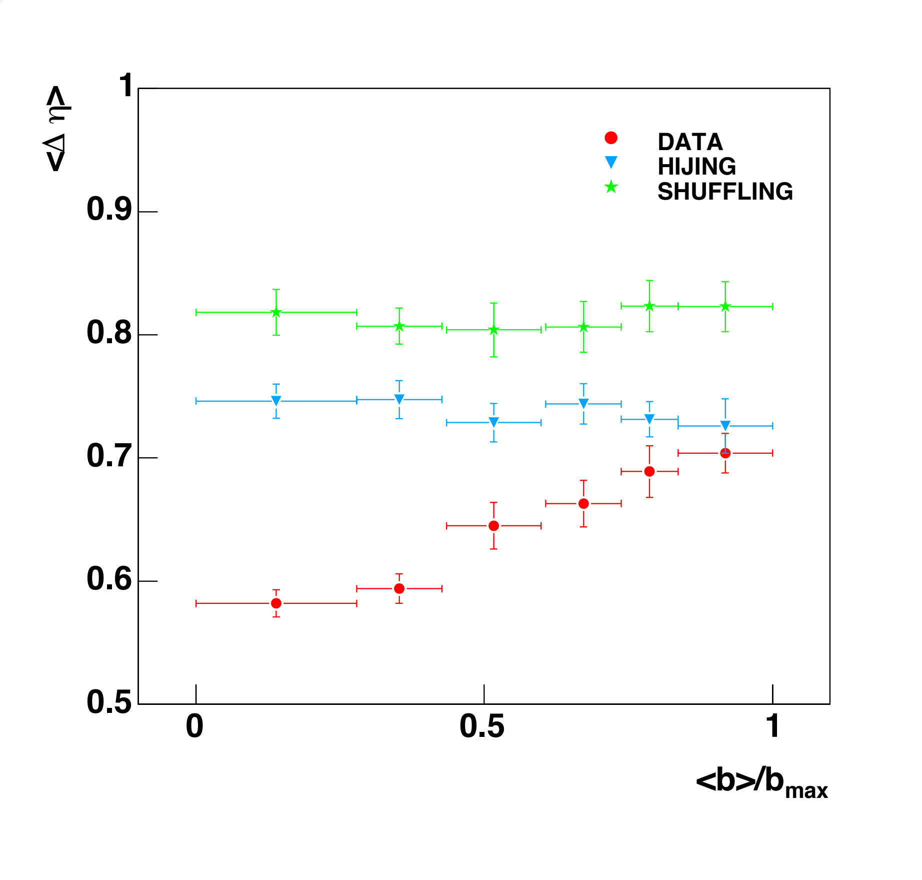


charged particles in |η| < 1.3
Acceptance not corrected for

NA49 Collaboration, Phys. Rev. Lett. **90,** (2003) 172301

Pb-Pb $\sqrt{s_{NN}}$ = 17.2 GeV



charged particles in 2.6 < η < 5.0
Acceptance not corrected for

Weighted average:

$$\langle \Delta y \rangle = \frac{\sum_{i=1}^{n} B_i \Delta y_i}{\sum_{i=1}^{n} B_i}$$

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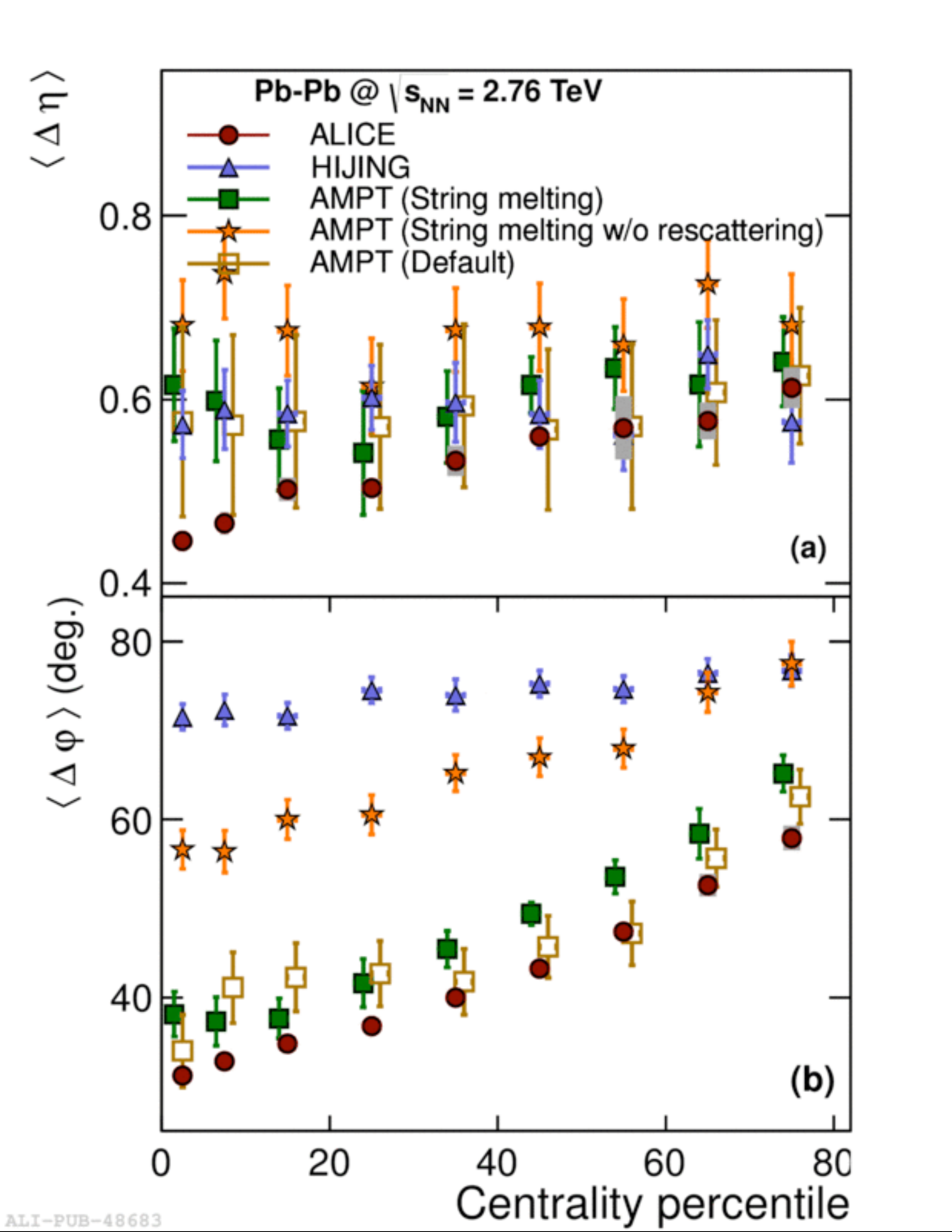
Previous results

ALICE Collaboration, Phys. Lett. B**723,** (2013) 267



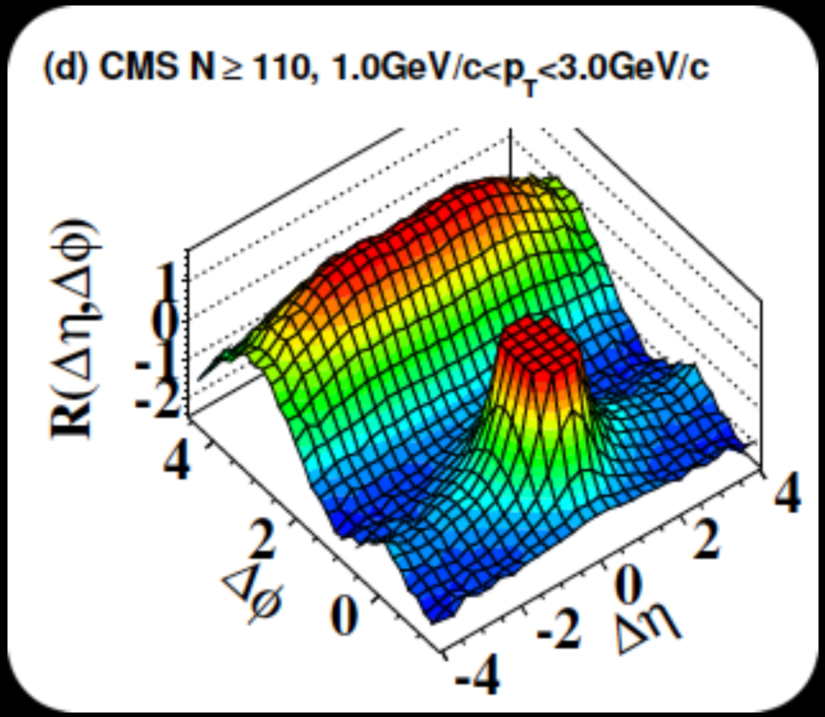
charged particles in |η| < 0.8
Acceptance and efficiency corrected

- Narrowing of the balance function observed at SPS, RHIC and LHC
- Results described well by models incorporating collectivity in heavy-ion collisions

Motivation

Effects in small systems that we are normally used to see in heavy ion collisions

(CMS Collaboration) JHEP 09, (2010) 091



Near side ridge in pp

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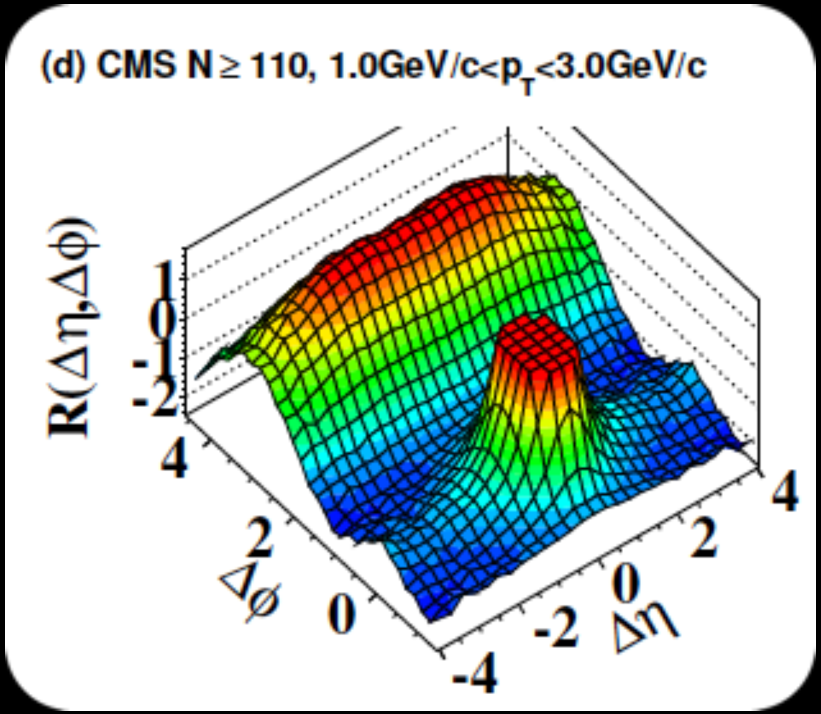
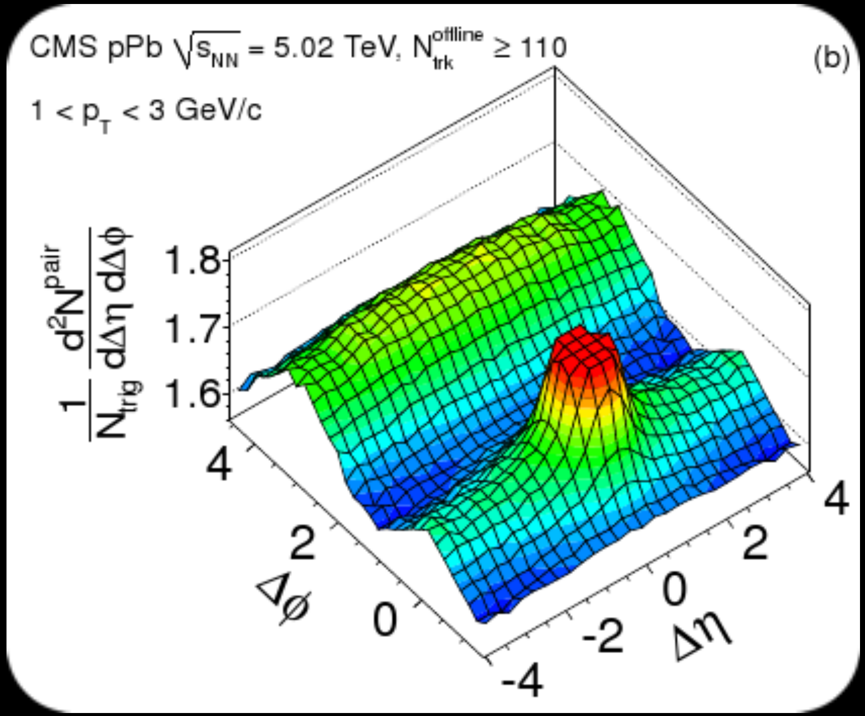
(CMS Collaboration) Phys. Lett. **B718**, (2013) 795





Near side ridge in p-Pb

Motivation

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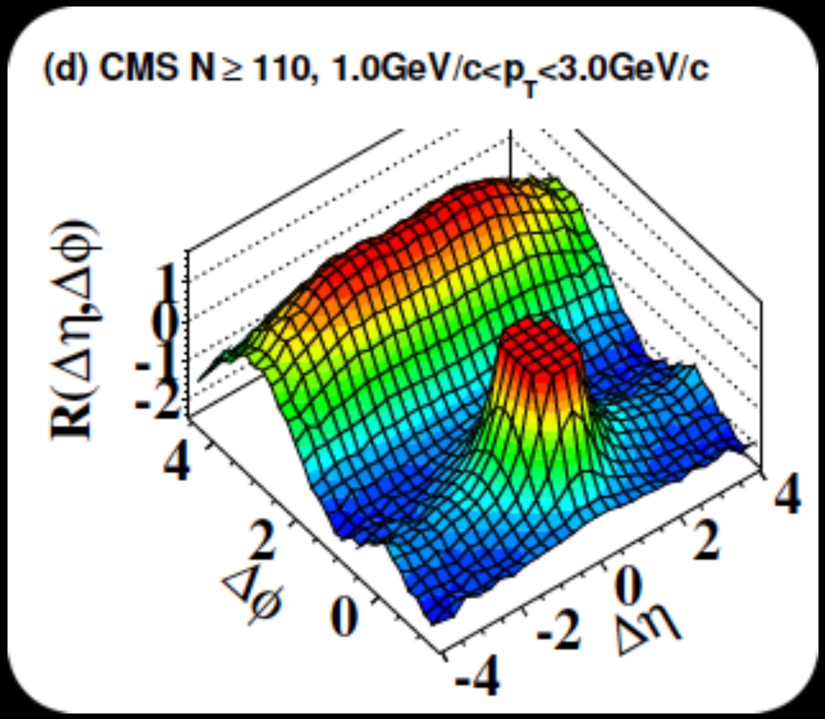
(CMS Collaboration) JHEP 09, (2010) 091



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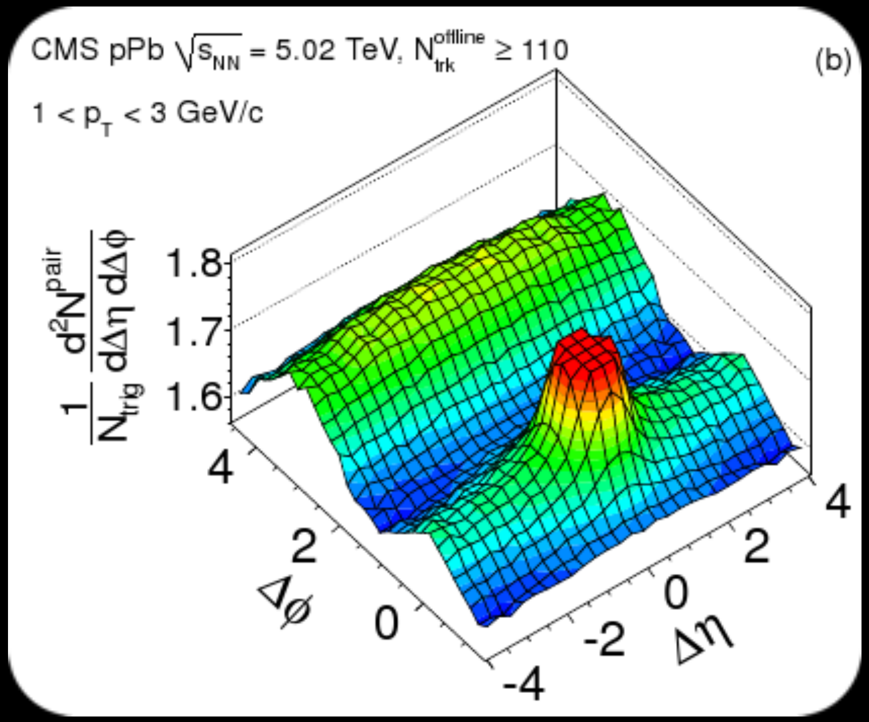
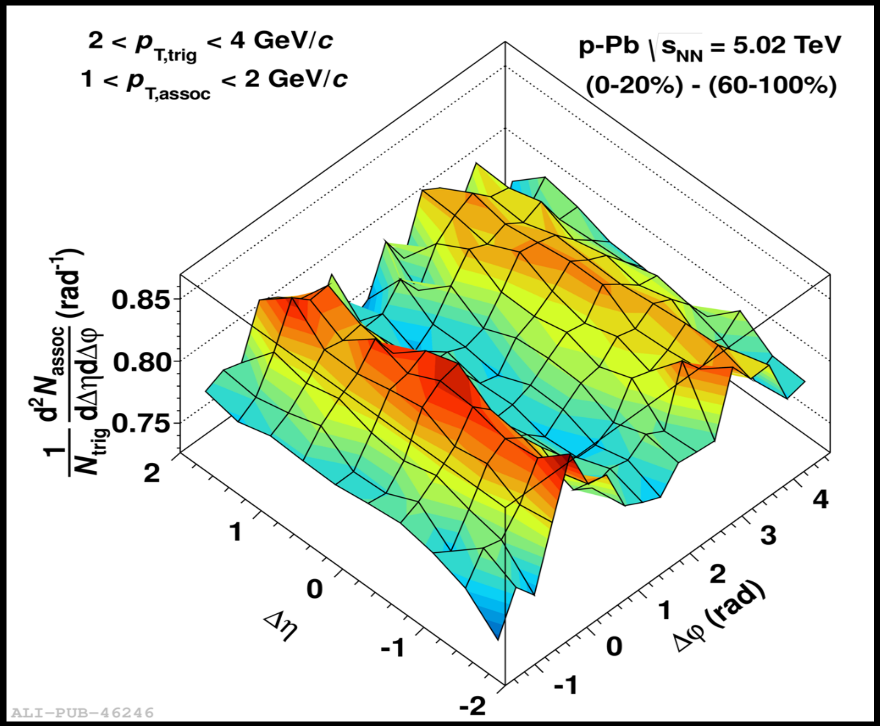


ALICE Collaboration: Phys. Lett. **B719**, (2013) 29



Double ridge in p-Pb

Motivation

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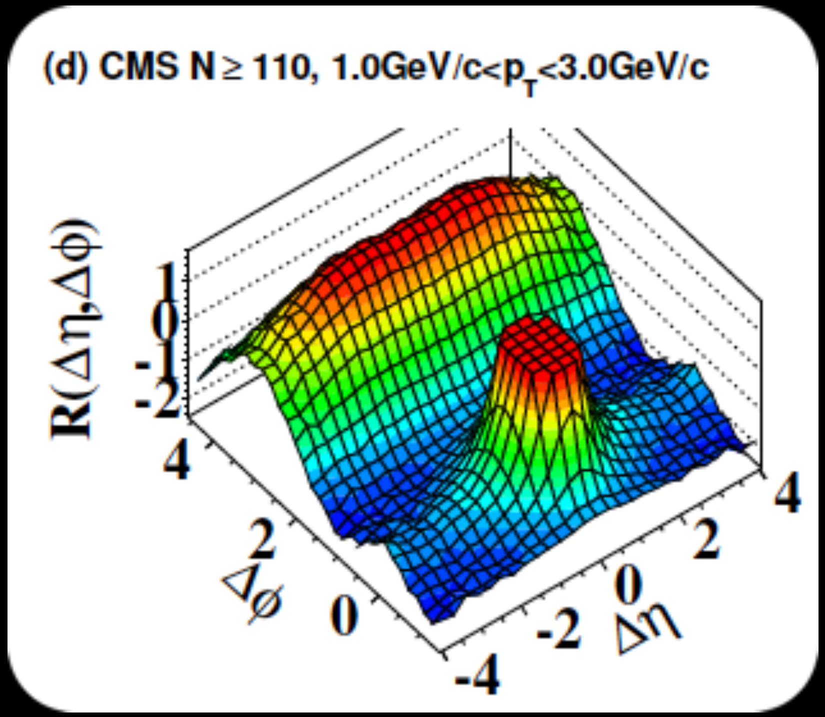
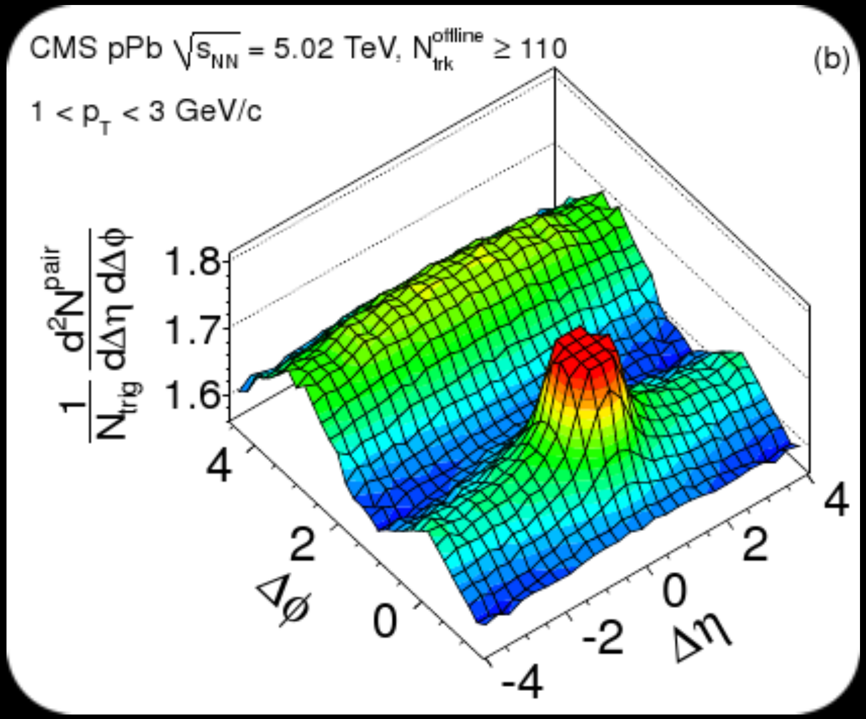
(CMS Collaboration) JHEP 09, (2010) 091



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



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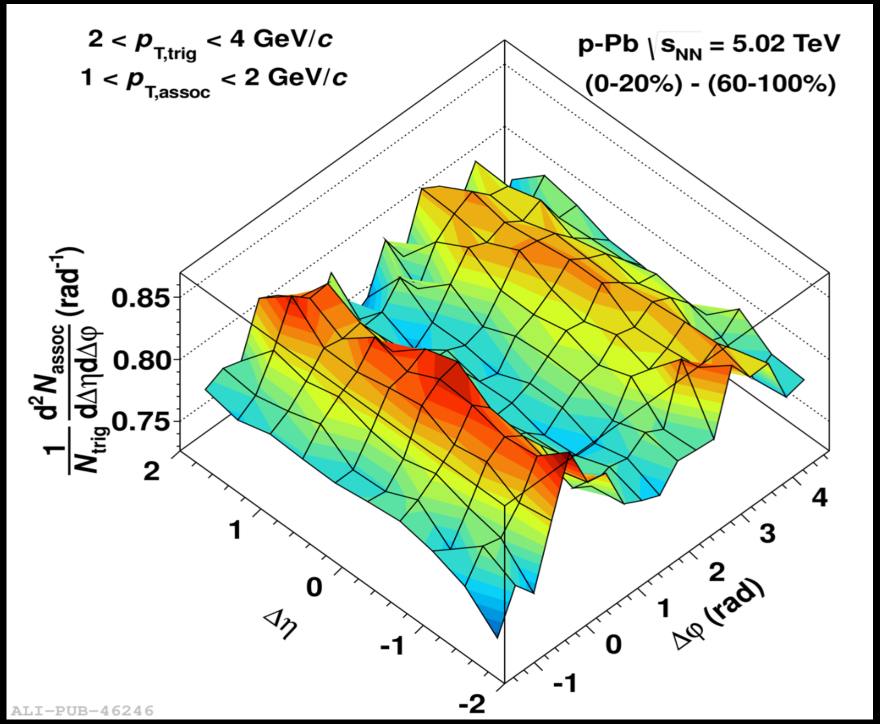
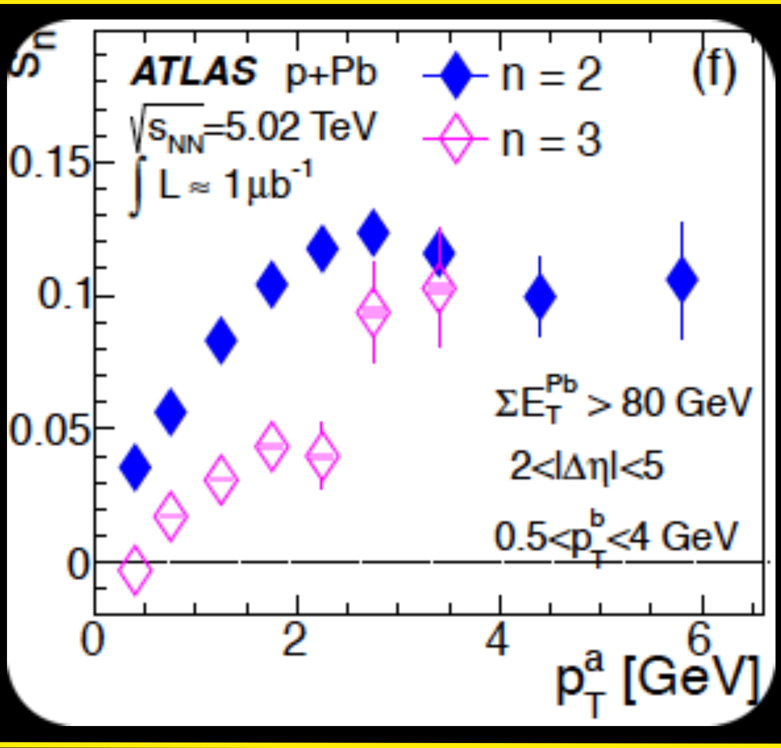


ATLAS Collaboration, Phys. Rev. Lett. **110**, (2013) 182302



Sizeable v_2 and v_3 components in p-Pb

Motivation

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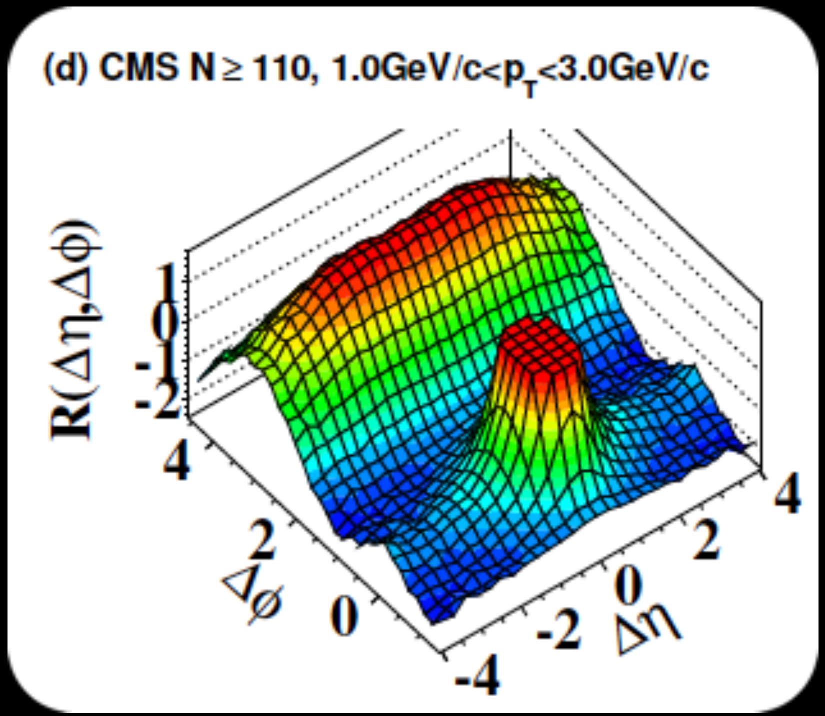
(CMS Collaboration) JHEP 09, (2010) 091



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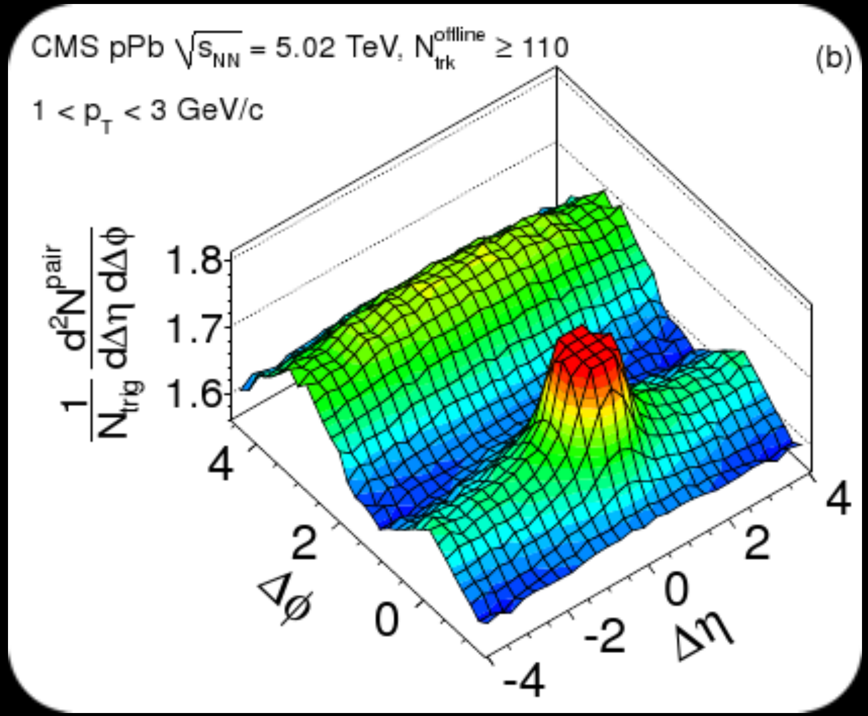

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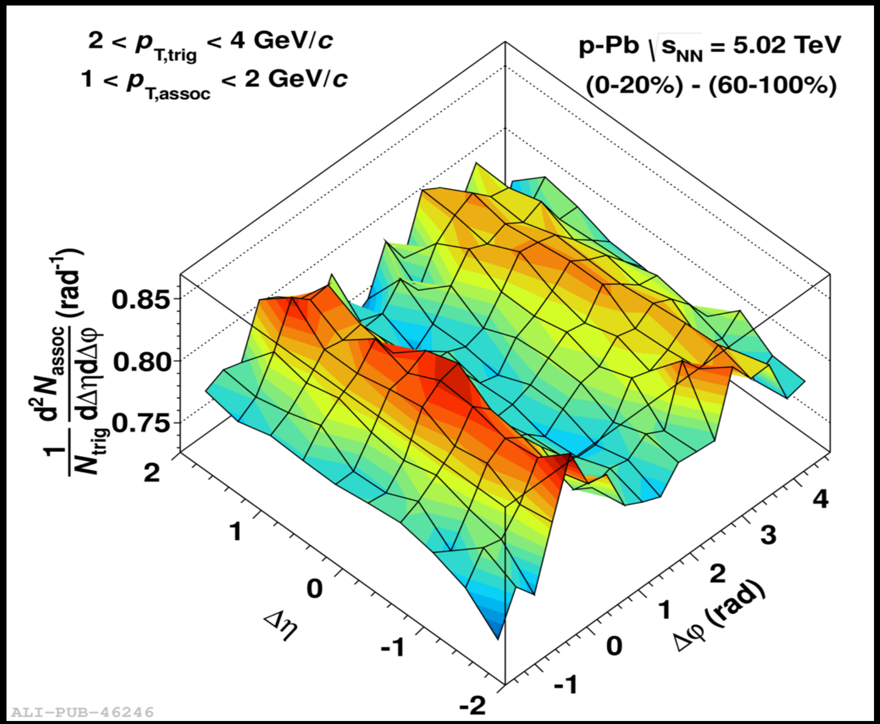

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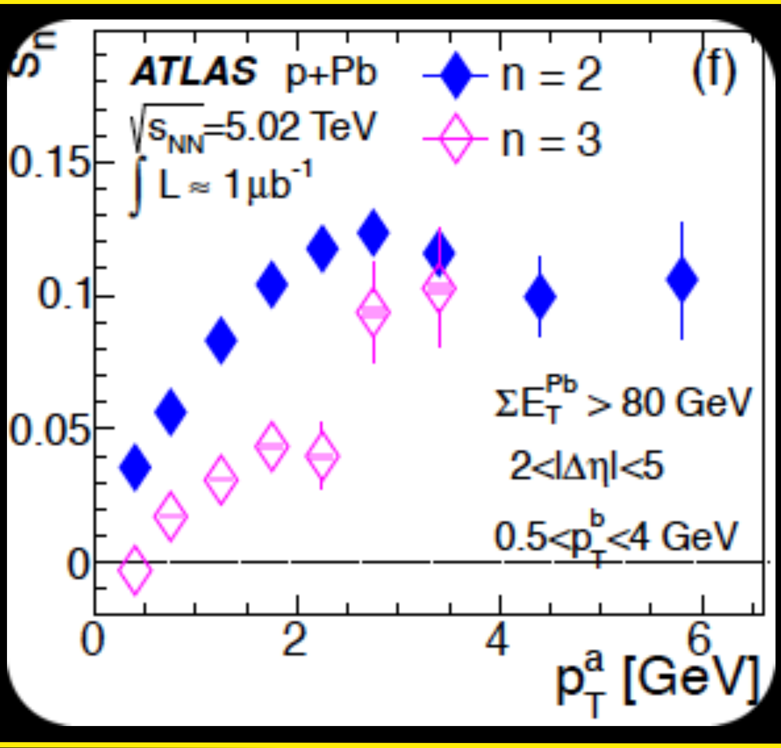
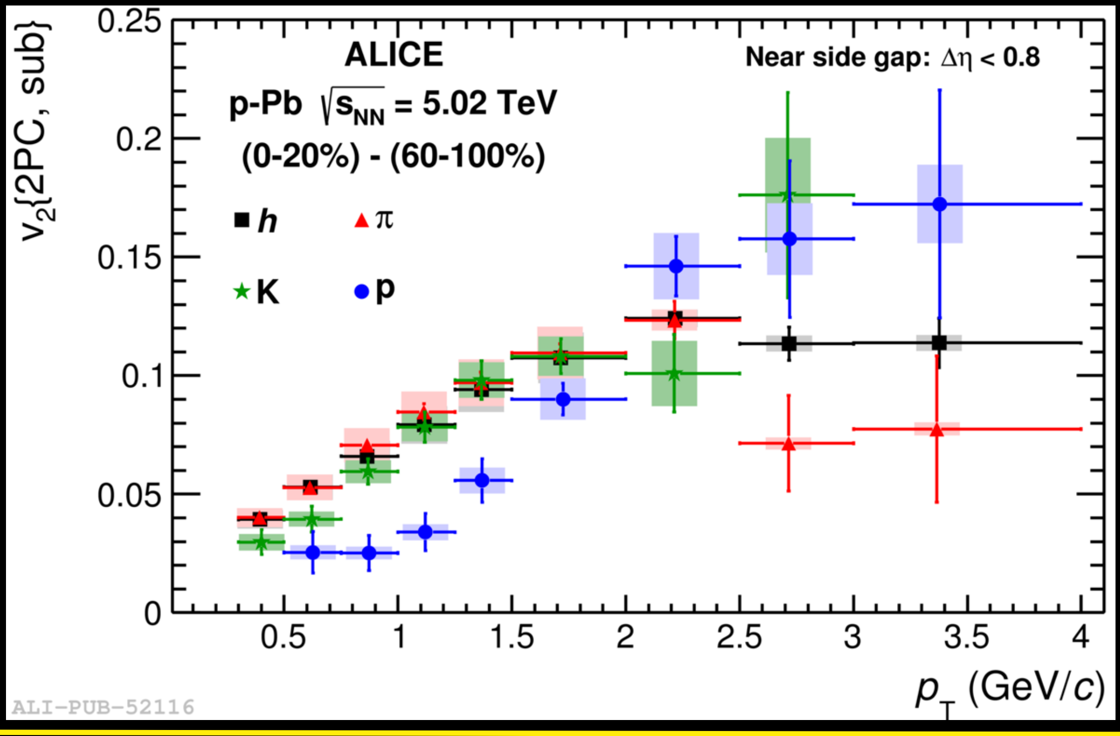


ALICE Collaboration: Phys. Lett. **B726**, (2013) 164



Mass ordering in v_2 in p-Pb

Motivation

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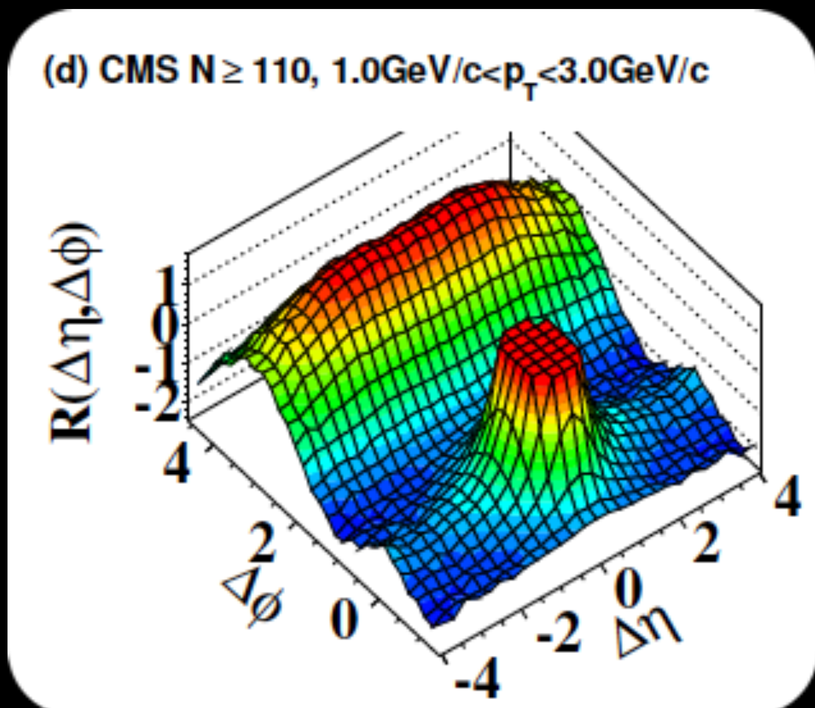
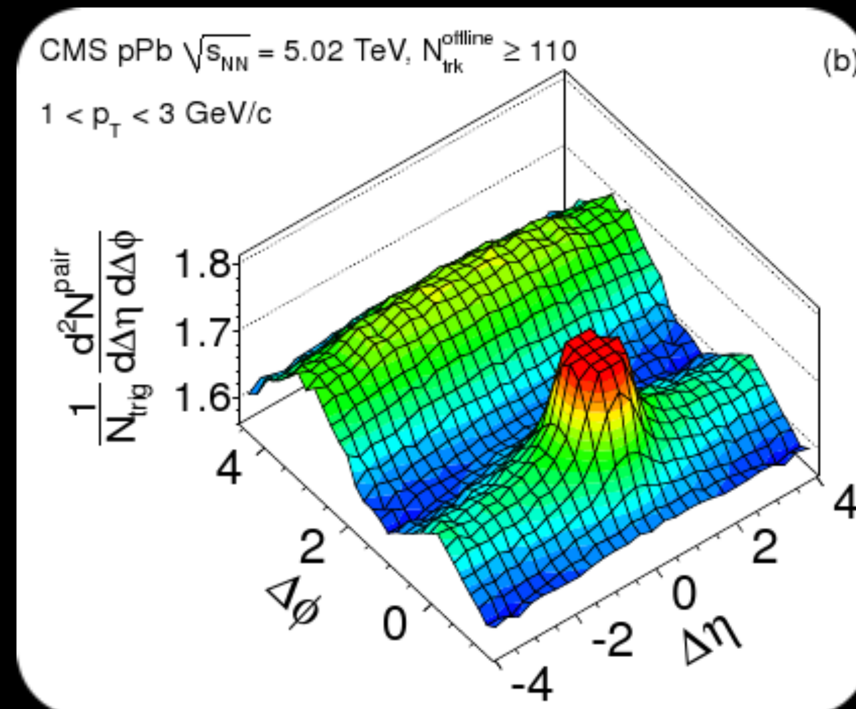
(CMS Collaboration) JHEP 09, (2010) 091



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



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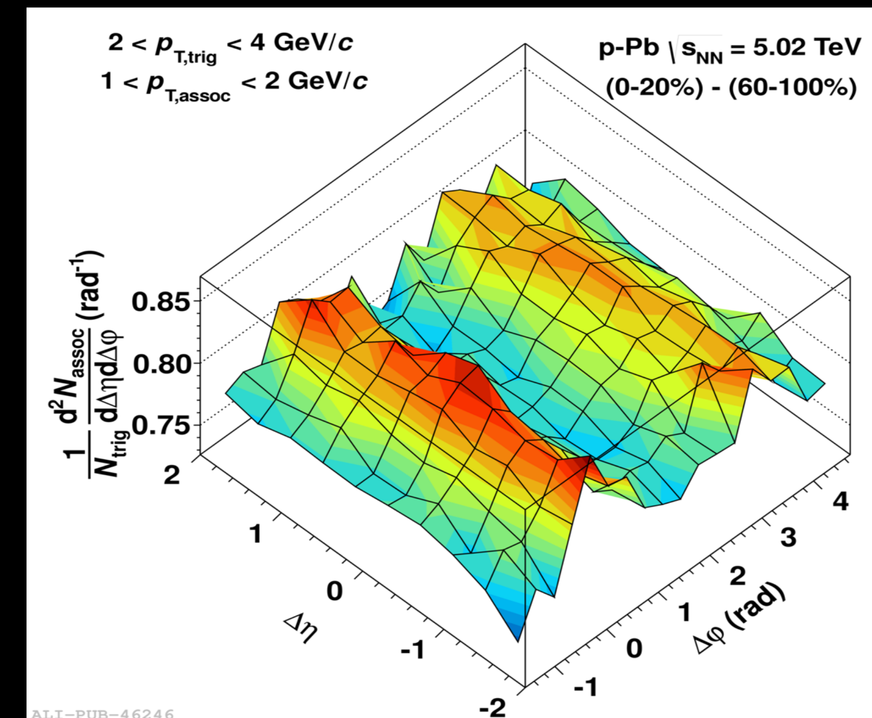

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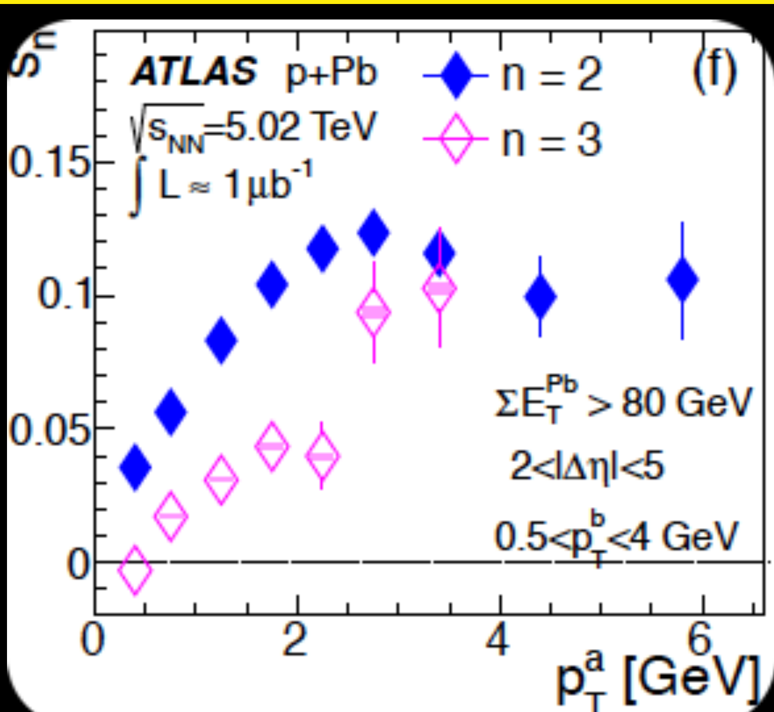

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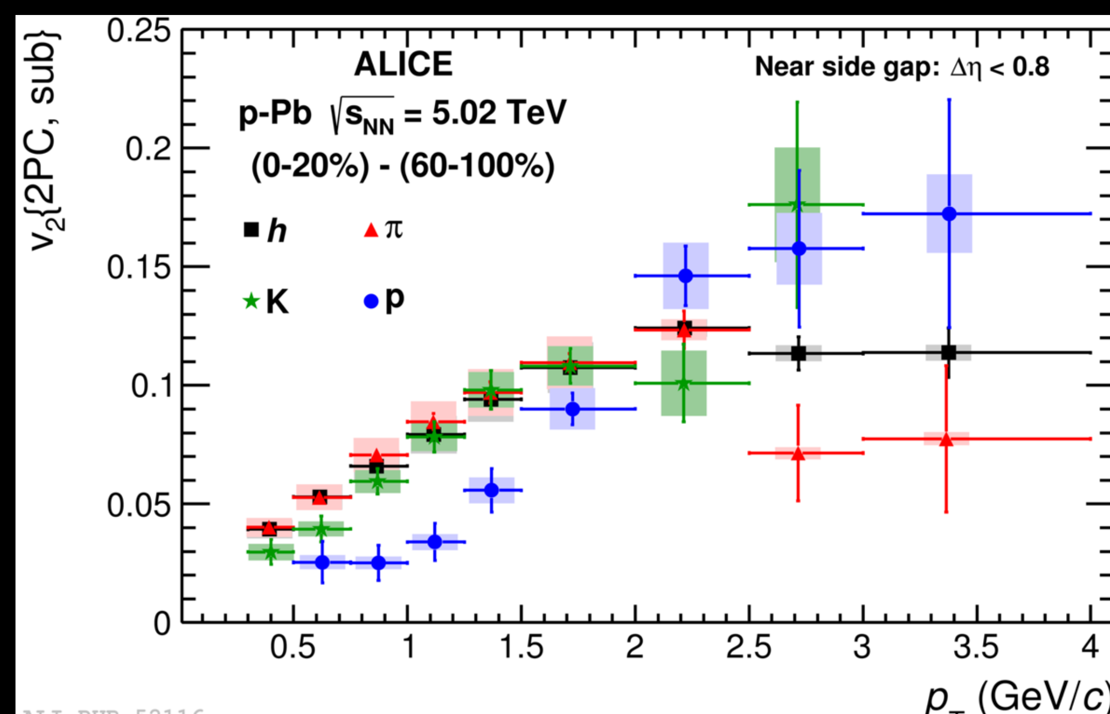

- Do we see with the balance function similar effects in small systems as in heavy-ions?
- If yes, can we get a handle on their origin?

Analysis details

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

- 35M events
- 2010 + 2011 runs
- Central + semi-central+ min. bias trigger

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pp $\sqrt{s}$ = 7 TeV

- 240M min. bias events
- 2010 run
- Low pile-up

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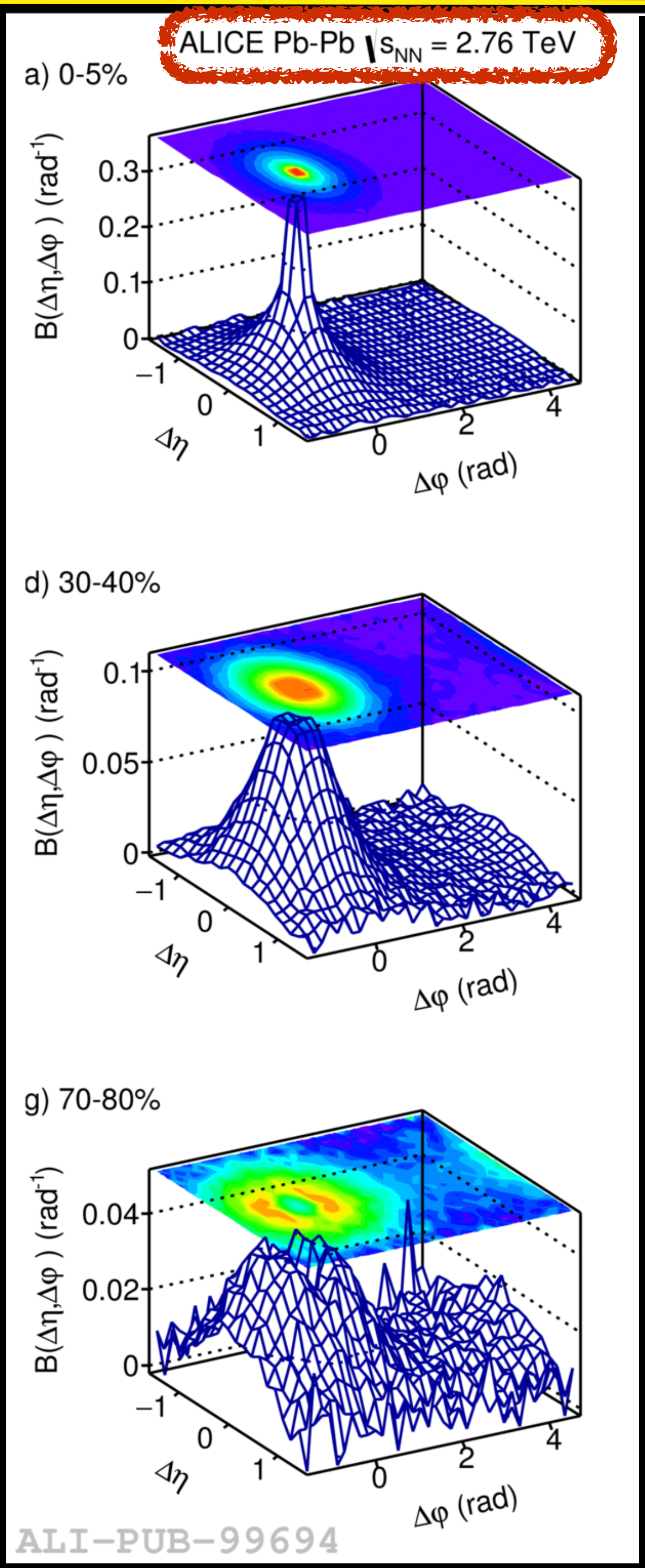
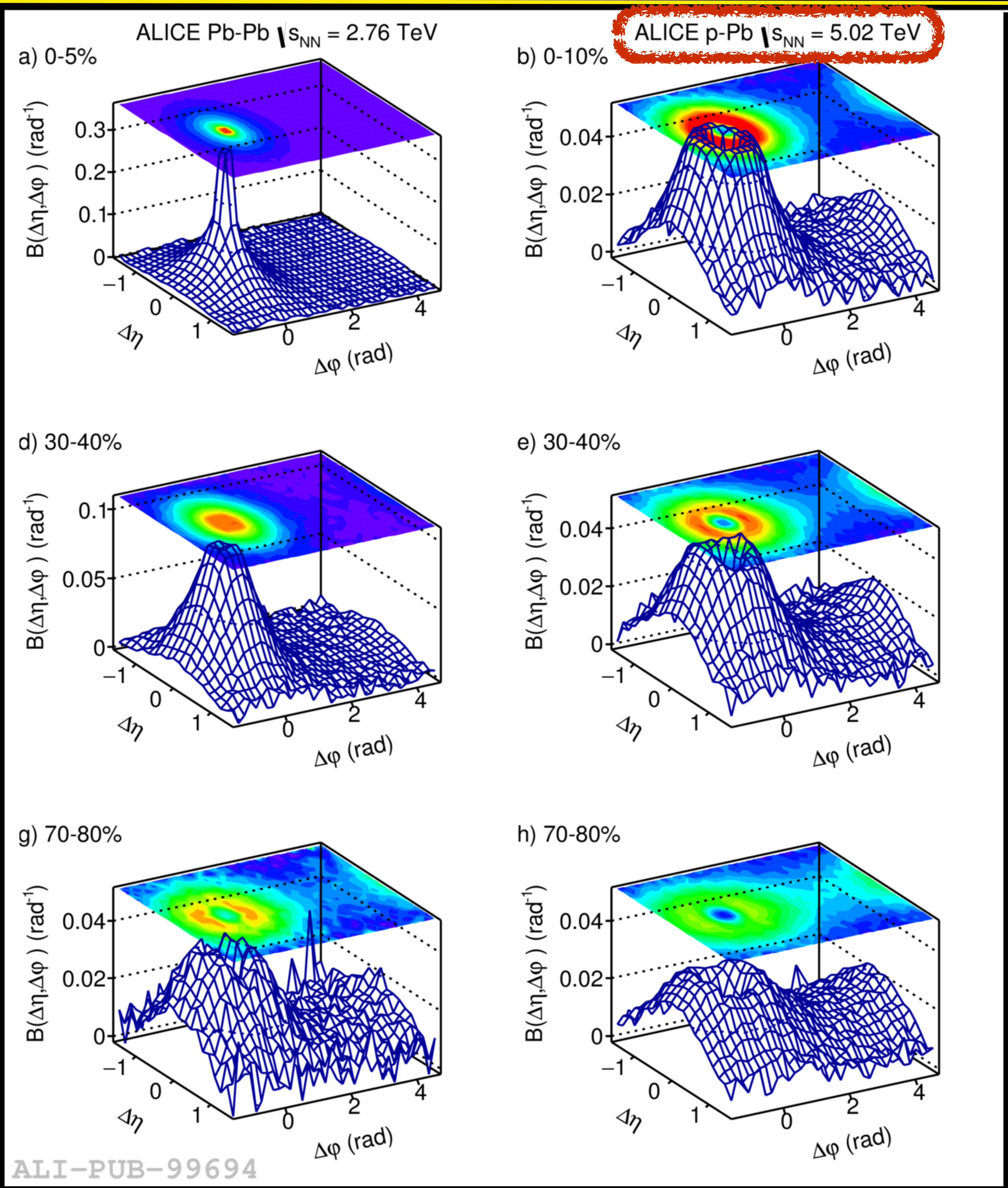
- Multiplicity classes estimated using the V0A detector (direction of Pb-beam in p-Pb collisions)
- Charged particles (corrected for pair acceptance and single particle efficiency/contamination)
- $|\eta| < 0.8$
- $0.2 < p_T < 15$ GeV/c
  - **Low p_T region:** $0.2 < p_{T,assoc} < p_{T,trig} < 2.0$ GeV/c
  - **Intermediate p_T region:** $2.0 < p_{T,assoc} < 3.0$ GeV/c, $3.0 < p_{T,trig} < 4.0$ GeV/c
  - **High p_T region:** $3.0 < p_{T,assoc} < 8.0$ GeV/c, $8.0 < p_{T,trig} < 15.0$ GeV/c


ALICE Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
a) 0-5%
d) 30-40%
g) 70-80%
B(Δη,Δφ) (rad⁻¹)
Δη
Δφ (rad)
ALI-PUB-99694

Balance functions in Δη-Δφ: low p_T



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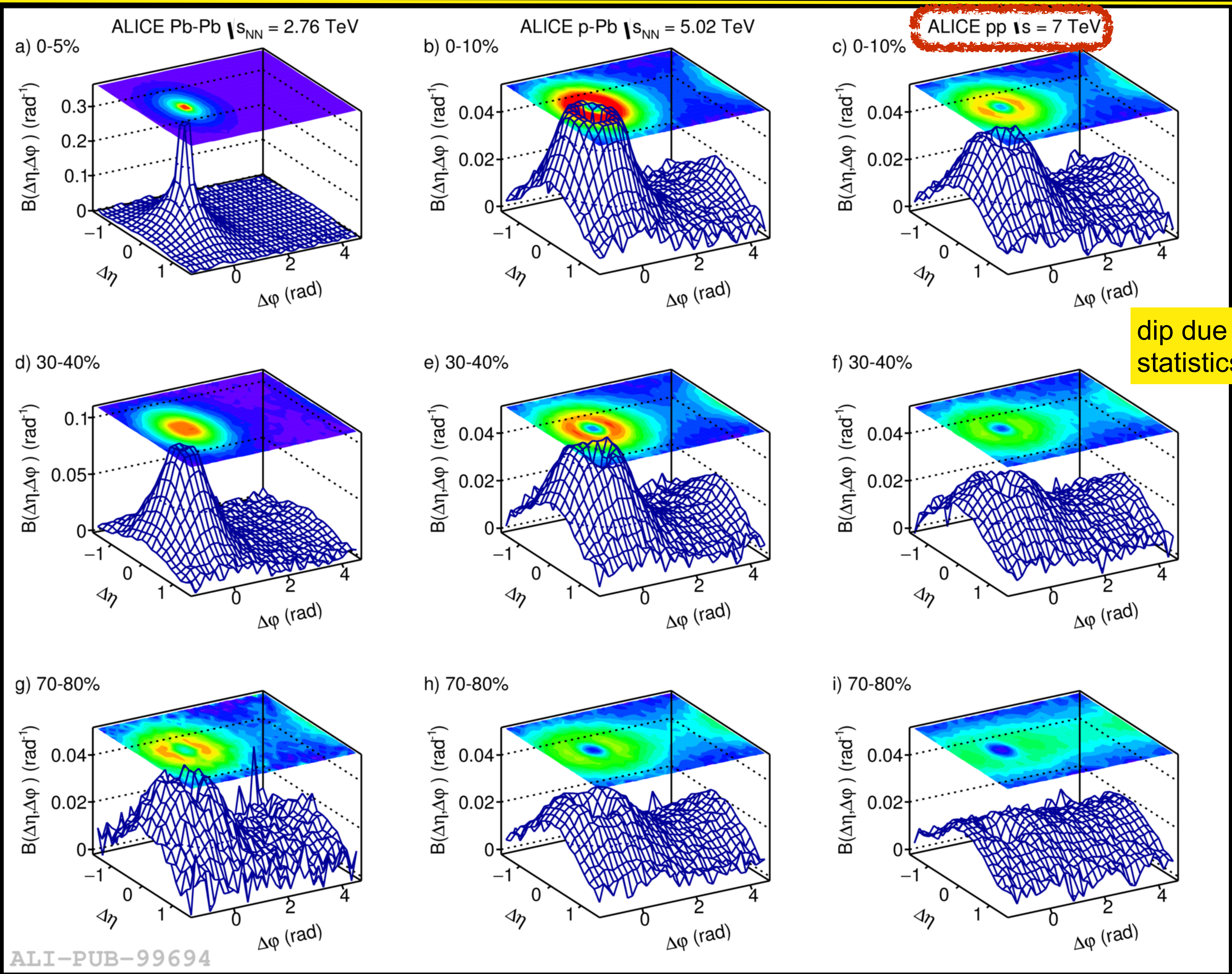
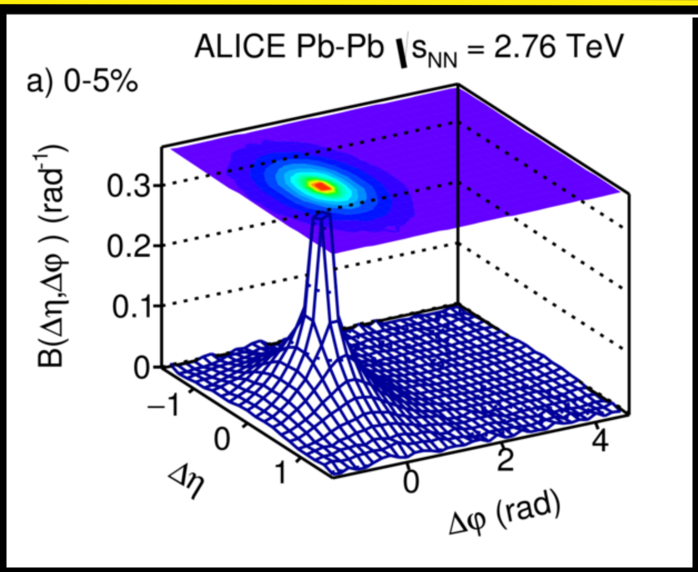
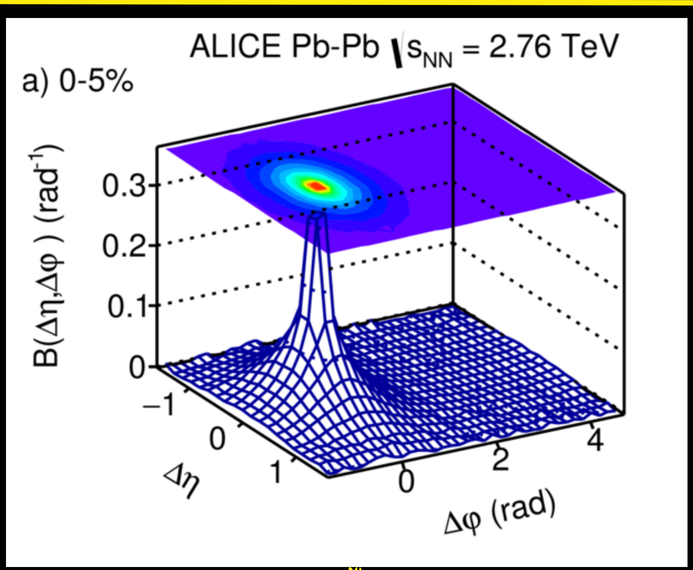


dip due to quantum statistics correlations

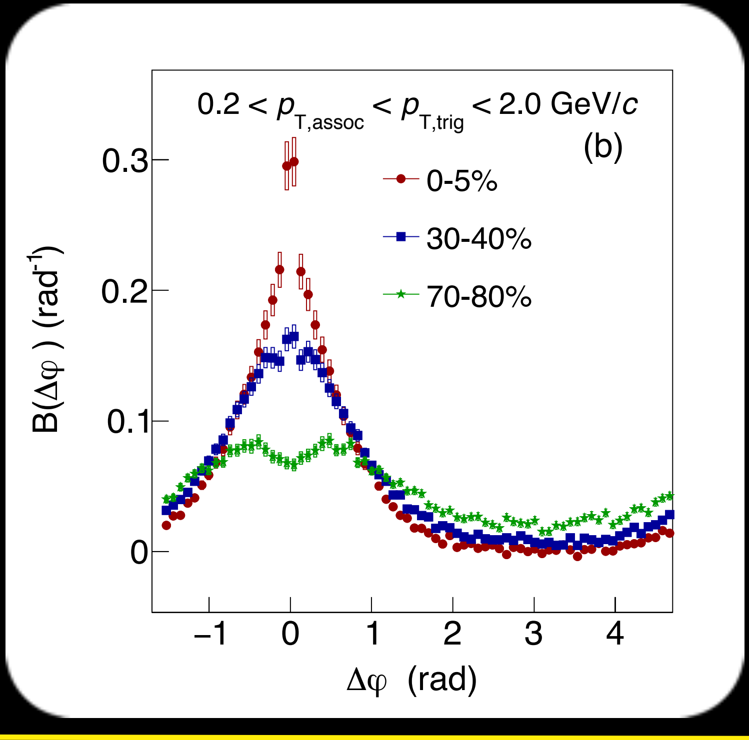
Projections in Δη and Δφ



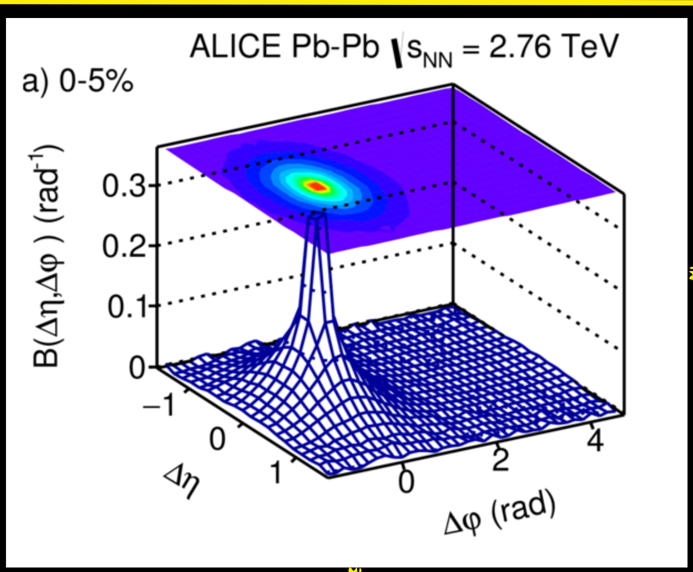
Projections in Δη and Δφ



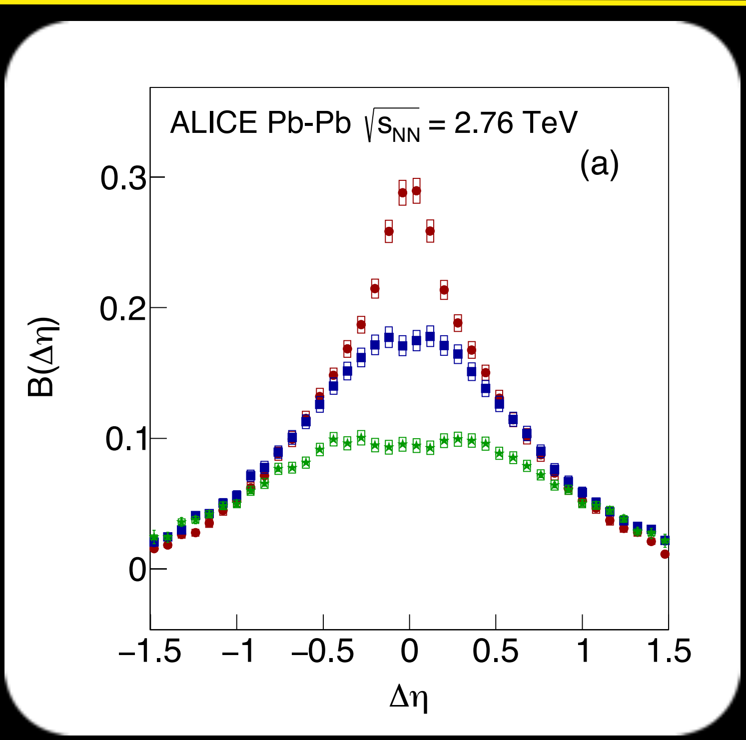
Project in Δφ



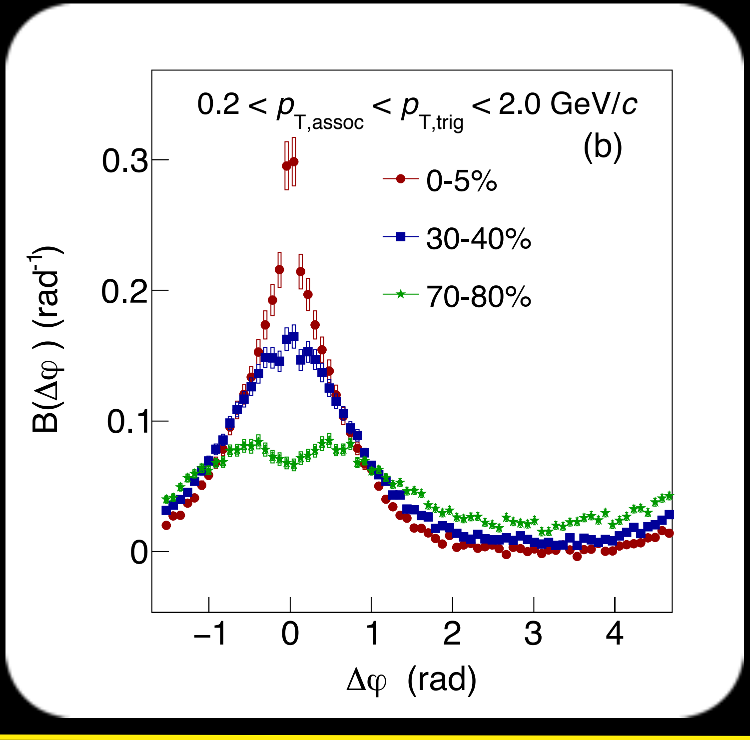
Projections in Δη and Δφ



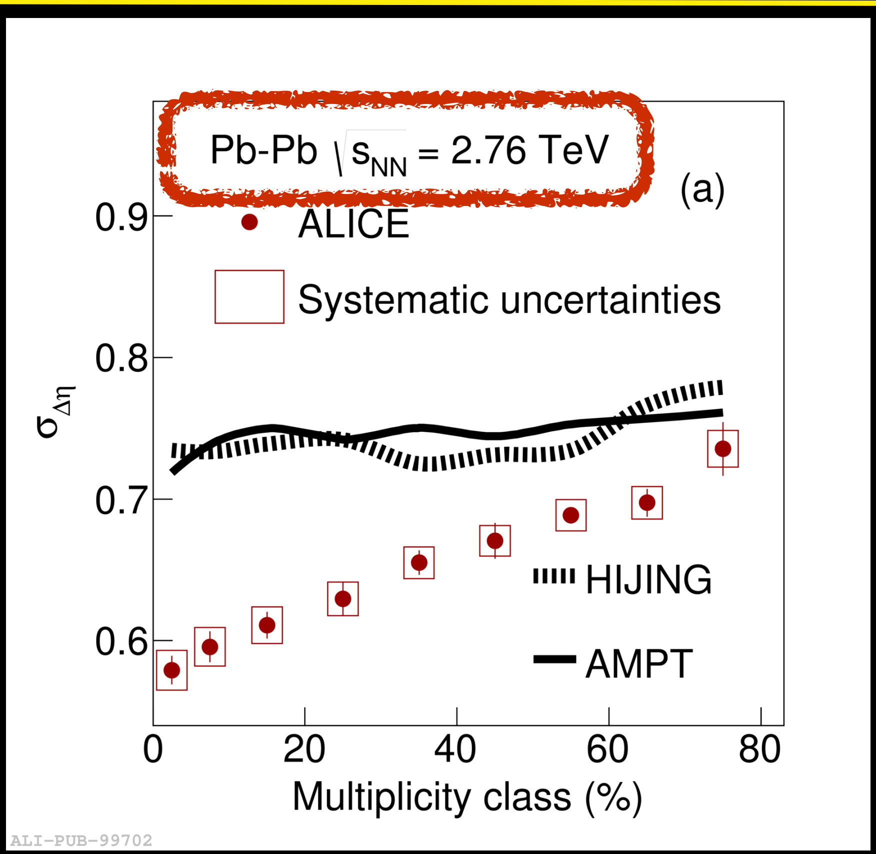
Project the near side in Δη



Project in Δφ



$\sigma_{\Delta\eta}$ vs multiplicity class: low p_T



- Narrowing of the balance function with increasing multiplicity in Pb-Pb in $\Delta\eta$
  - Data not described by either AMPT or HIJING

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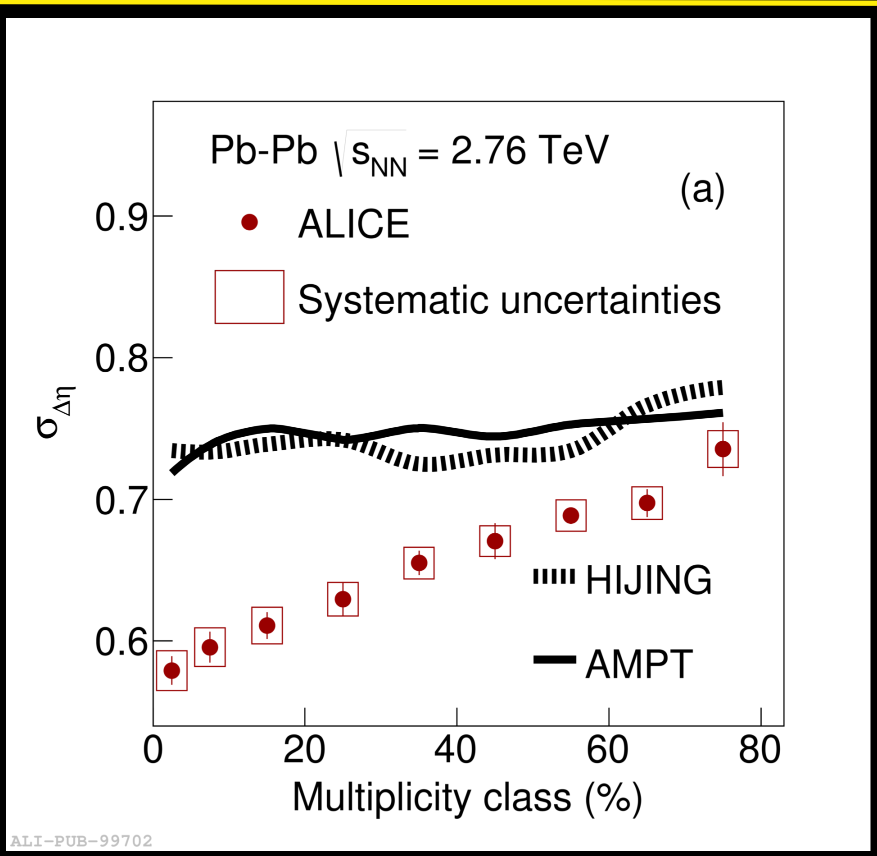

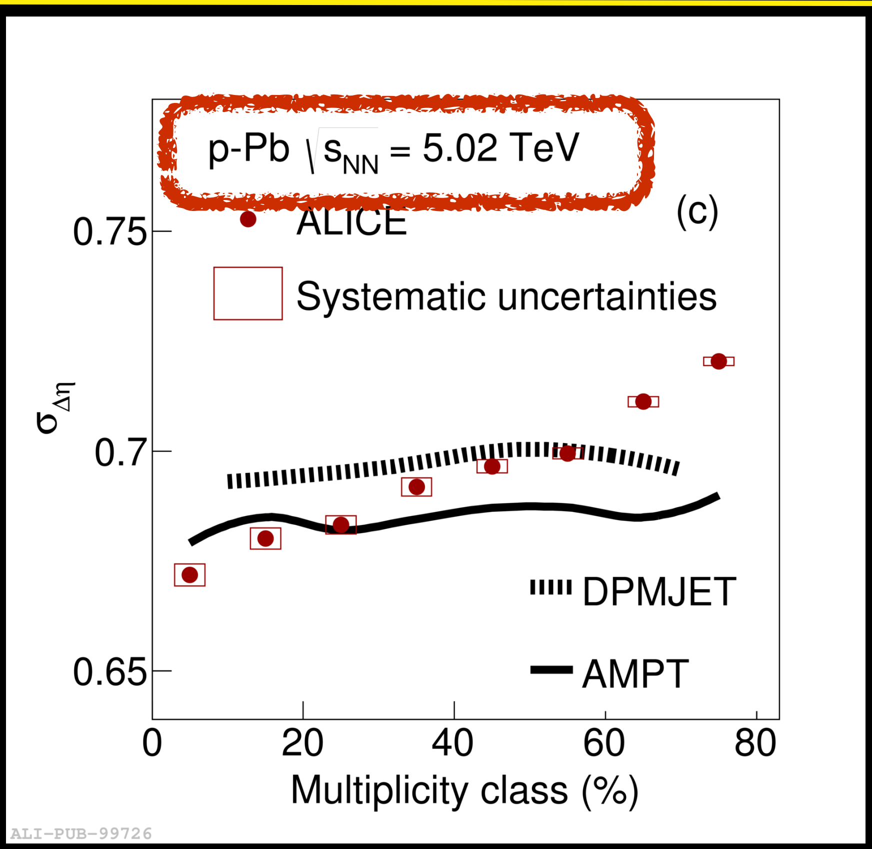

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- Narrowing of the balance function with increasing multiplicity in p-Pb in $\Delta\eta$
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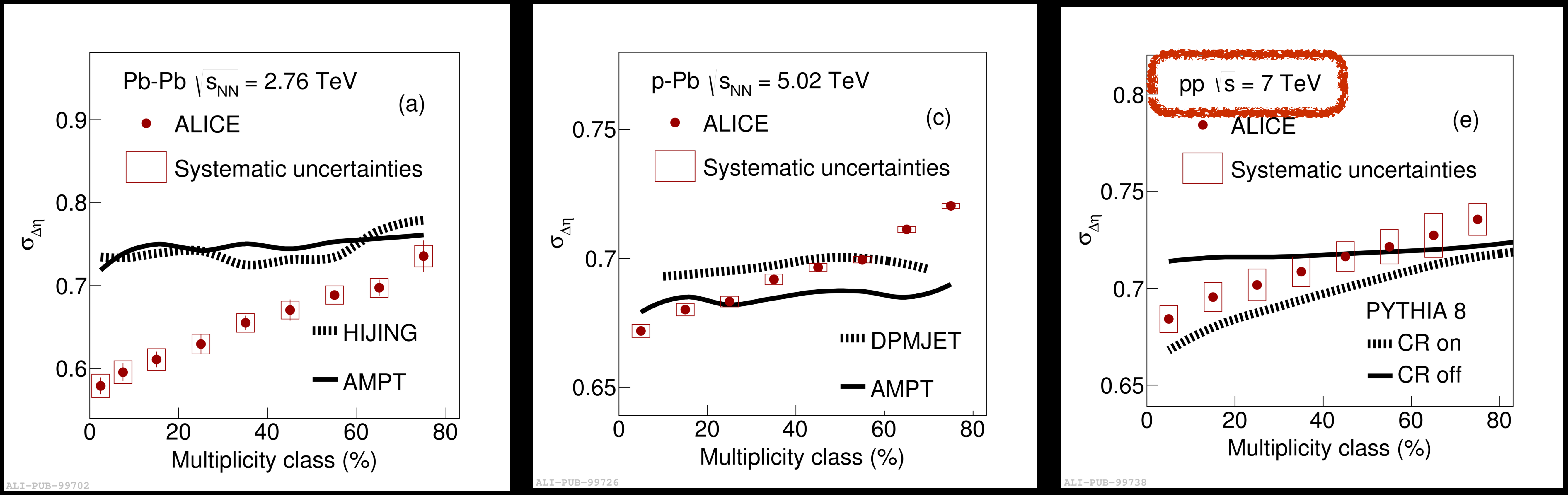

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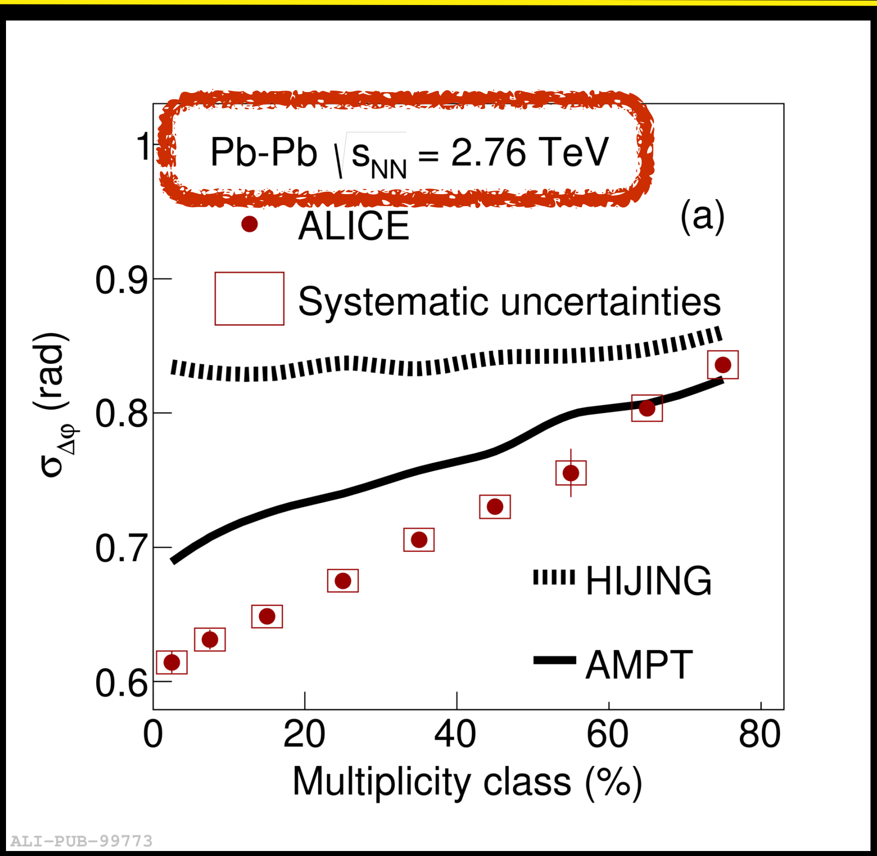
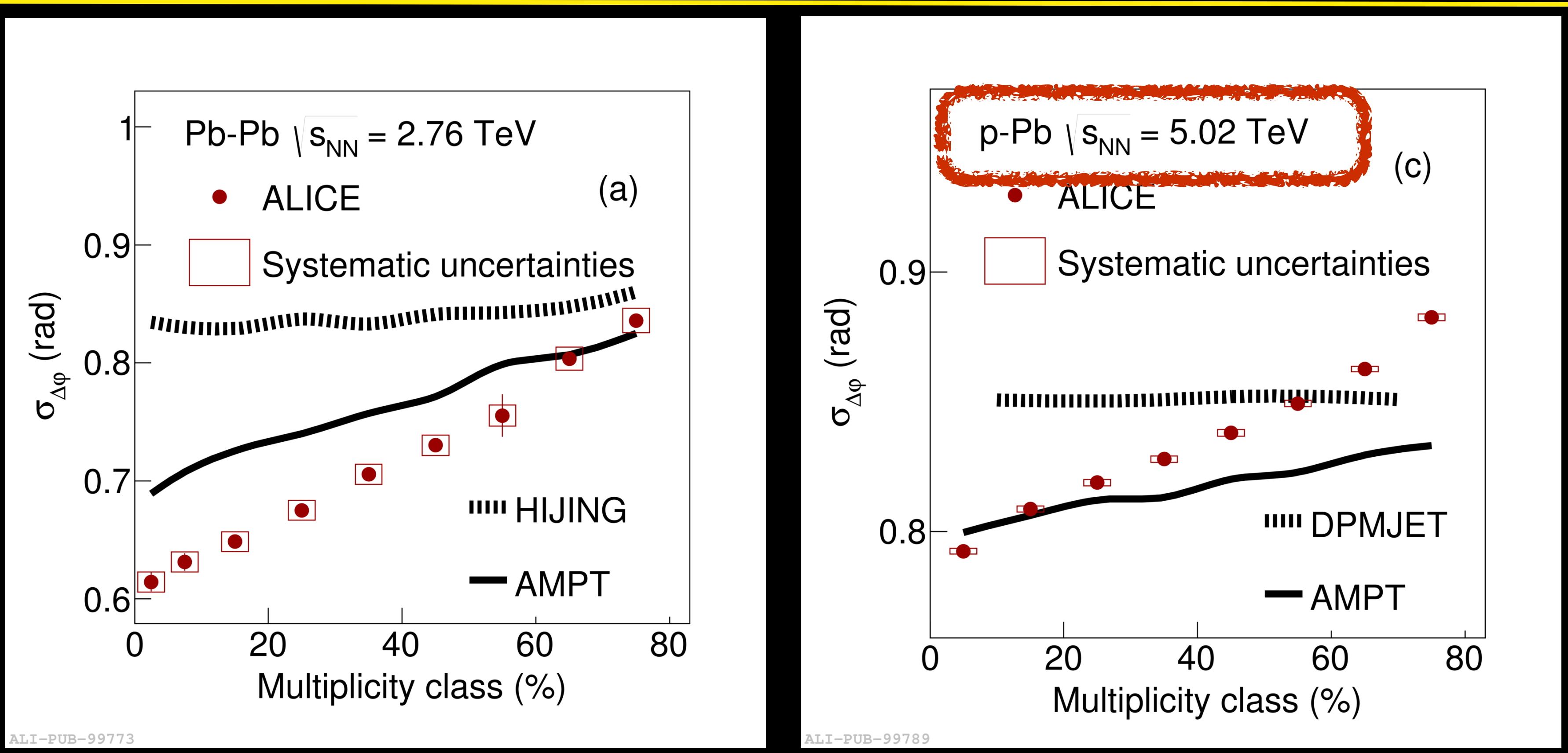
- Narrowing of the balance function with increasing multiplicity in p-Pb in $\Delta\eta$
  - Data not described by either AMPT or DPMJET
- Narrowing of the balance function with increasing multiplicity in pp in $\Delta\eta$
  - Colour reconnection seems to be the ingredient in PYTHIA8 that allows for the qualitative description of the experimental trend ➡ connection to MPIs

$\sigma_{\Delta\varphi}$ vs multiplicity class: low p_T



- Narrowing of the balance function with increasing multiplicity in Pb-Pb in Δφ
  - ★ Narrowing described by qualitatively by AMPT but not by HIJING ➡ connection to radial flow

$\sigma_{\Delta\varphi}$ vs multiplicity class: low p_T



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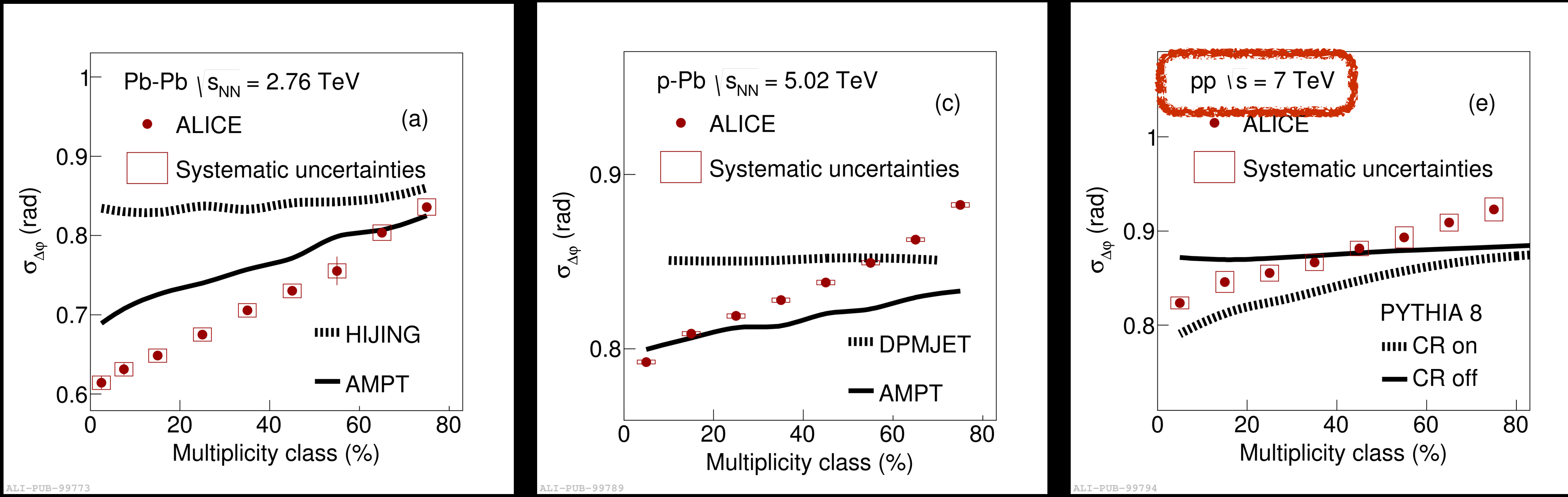
  - Narrowing partially described by AMPT but not by DPMJET

$\sigma_{\Delta\varphi}$ vs multiplicity class: low p_T



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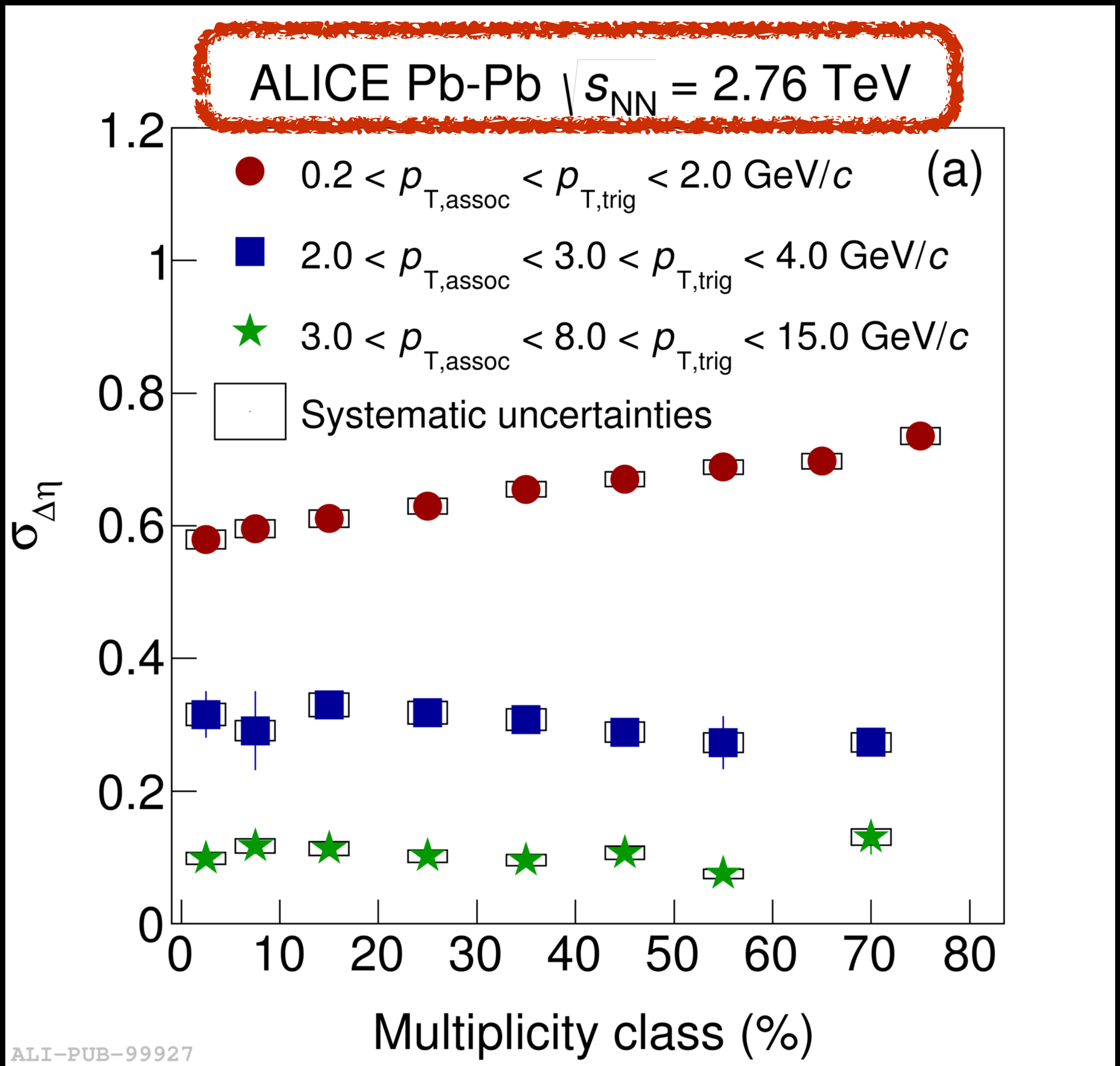
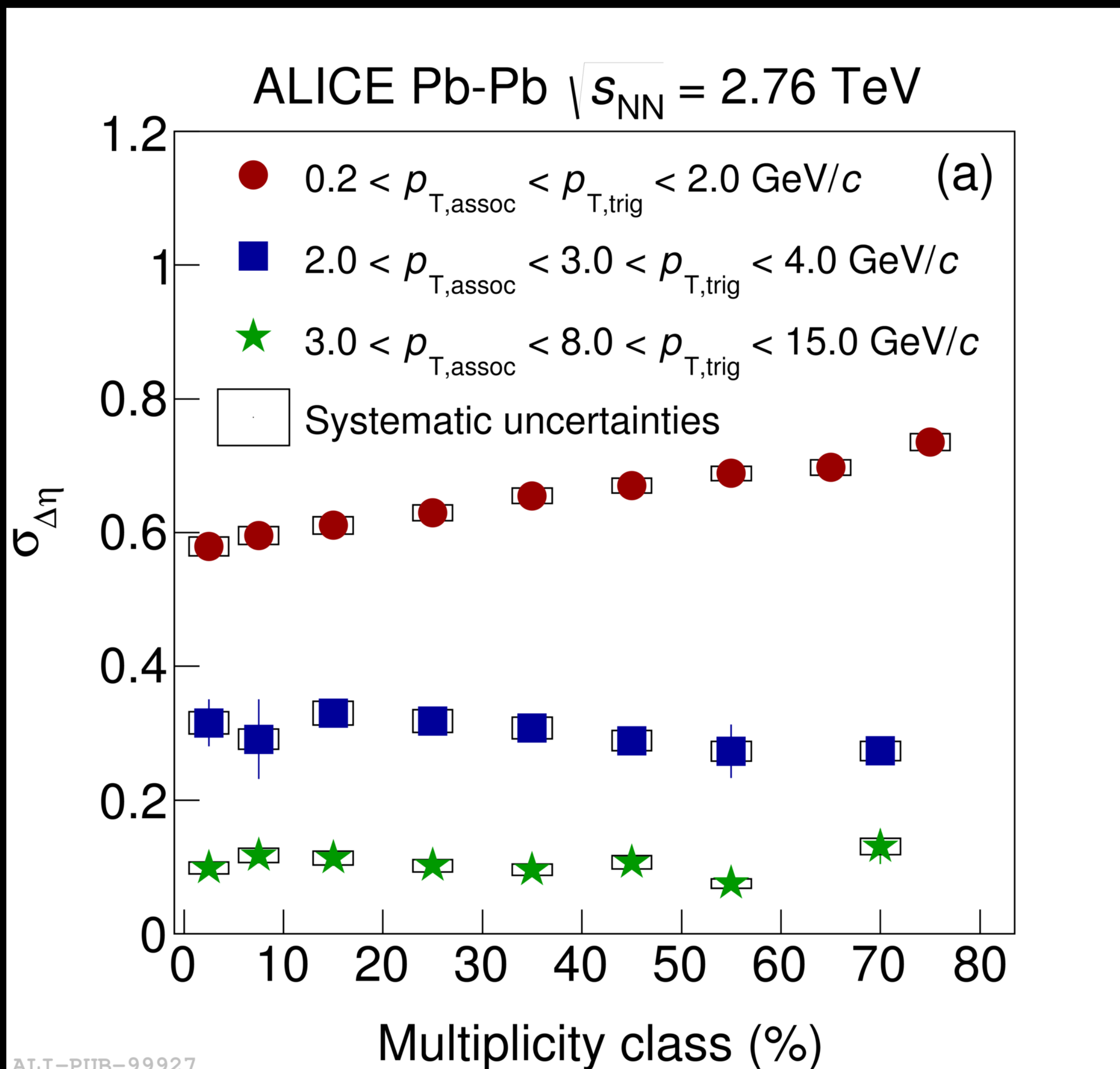
  - ★ Colour reconnection seems to be the ingredient in PYTHIA8 that allows for the qualitative description of the experimental trend ➡ connection to MPIs

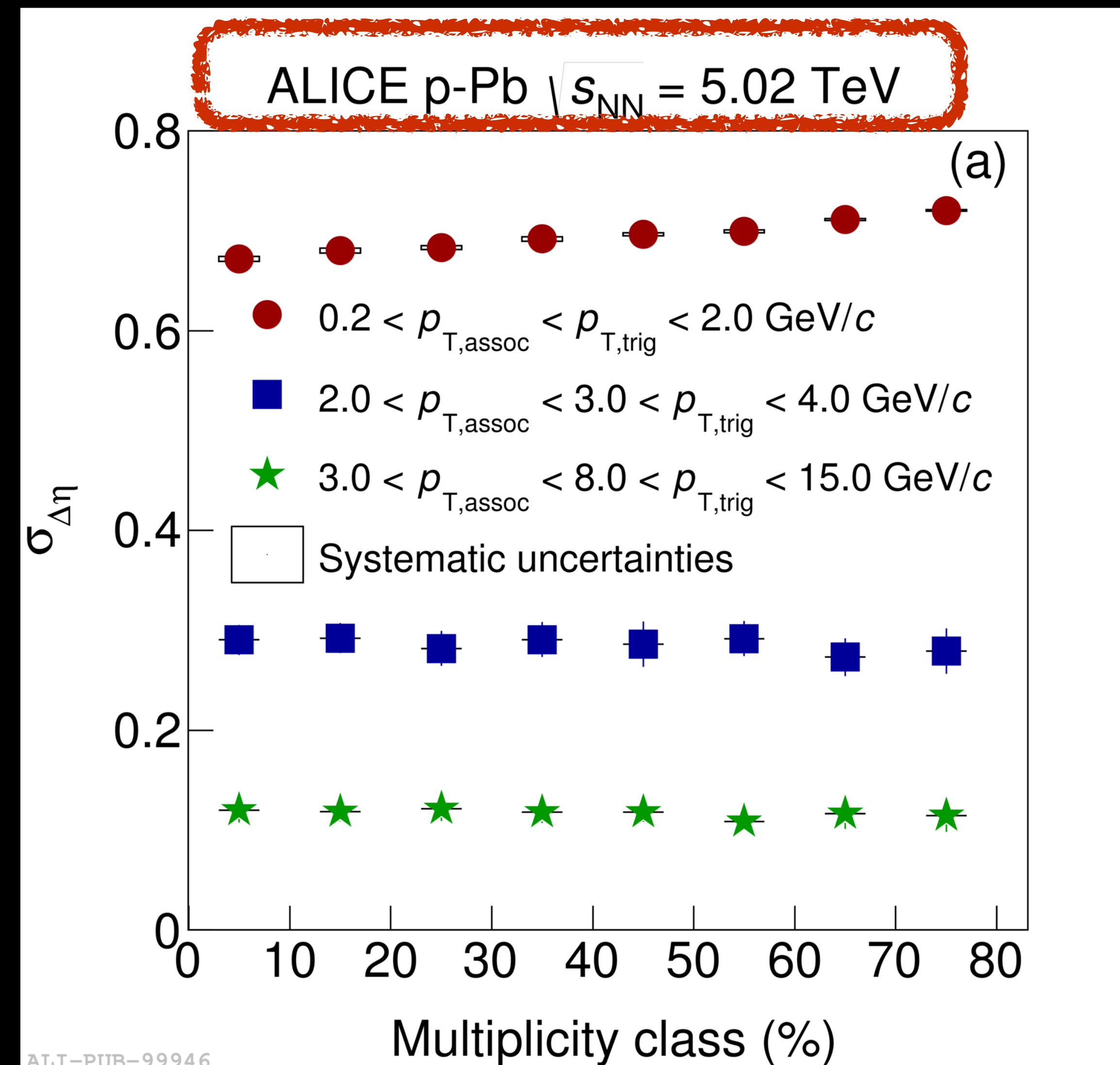
$\sigma_{\Delta\eta}$ vs multiplicity class vs p_T



- Narrowing with increasing multiplicity ➡ effect of the bulk
  - Width does not depend on multiplicity for higher values of p_T
- Balance functions get narrower with increasing p_T for a given multiplicity

$\sigma_{\Delta\eta}$ vs multiplicity class vs p_T

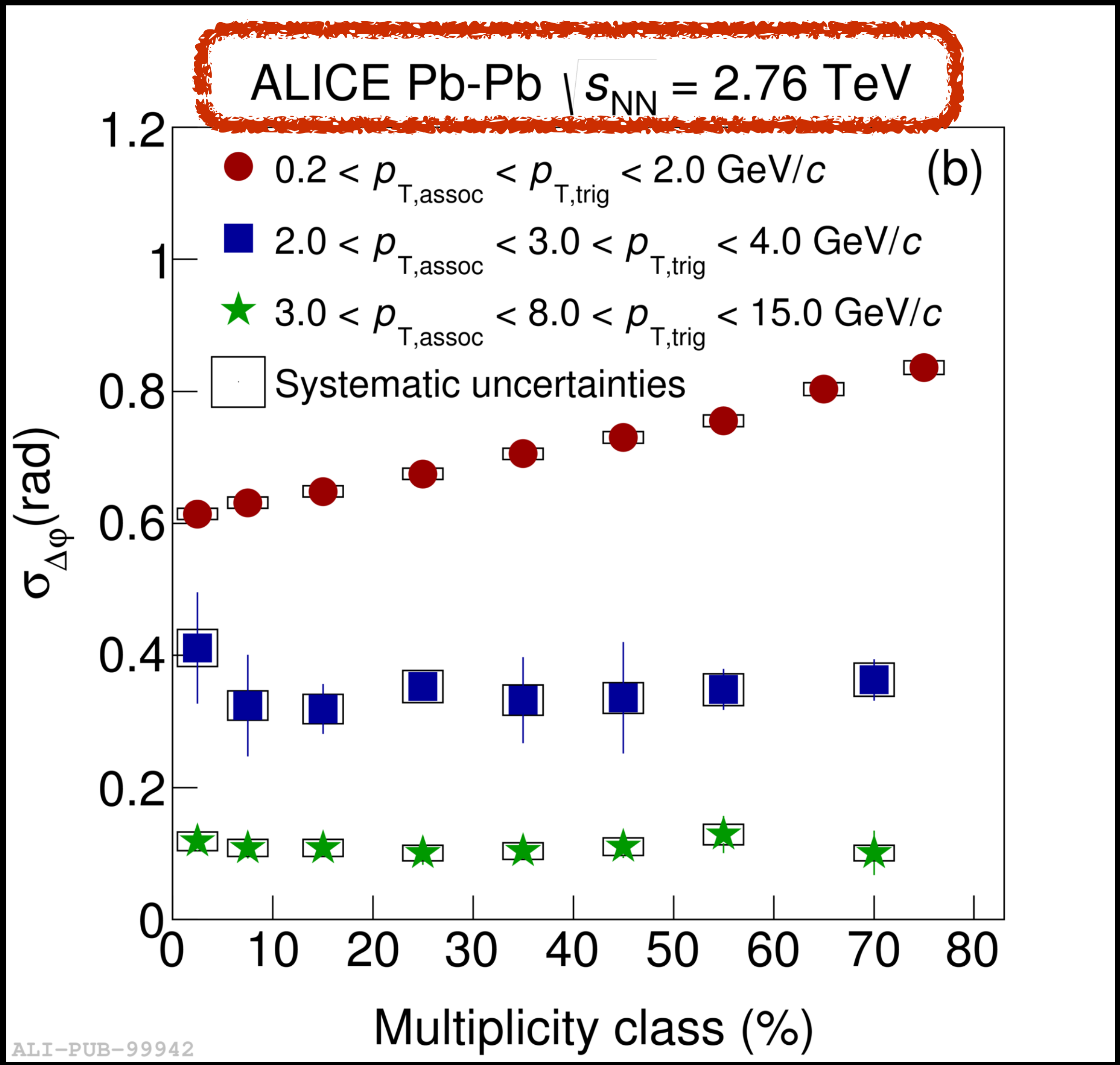




- Narrowing with increasing multiplicity ➡ effect of the bulk
  - Width does not depend on multiplicity for higher values of p_T
- Balance functions get narrower with increasing p_T for a given multiplicity

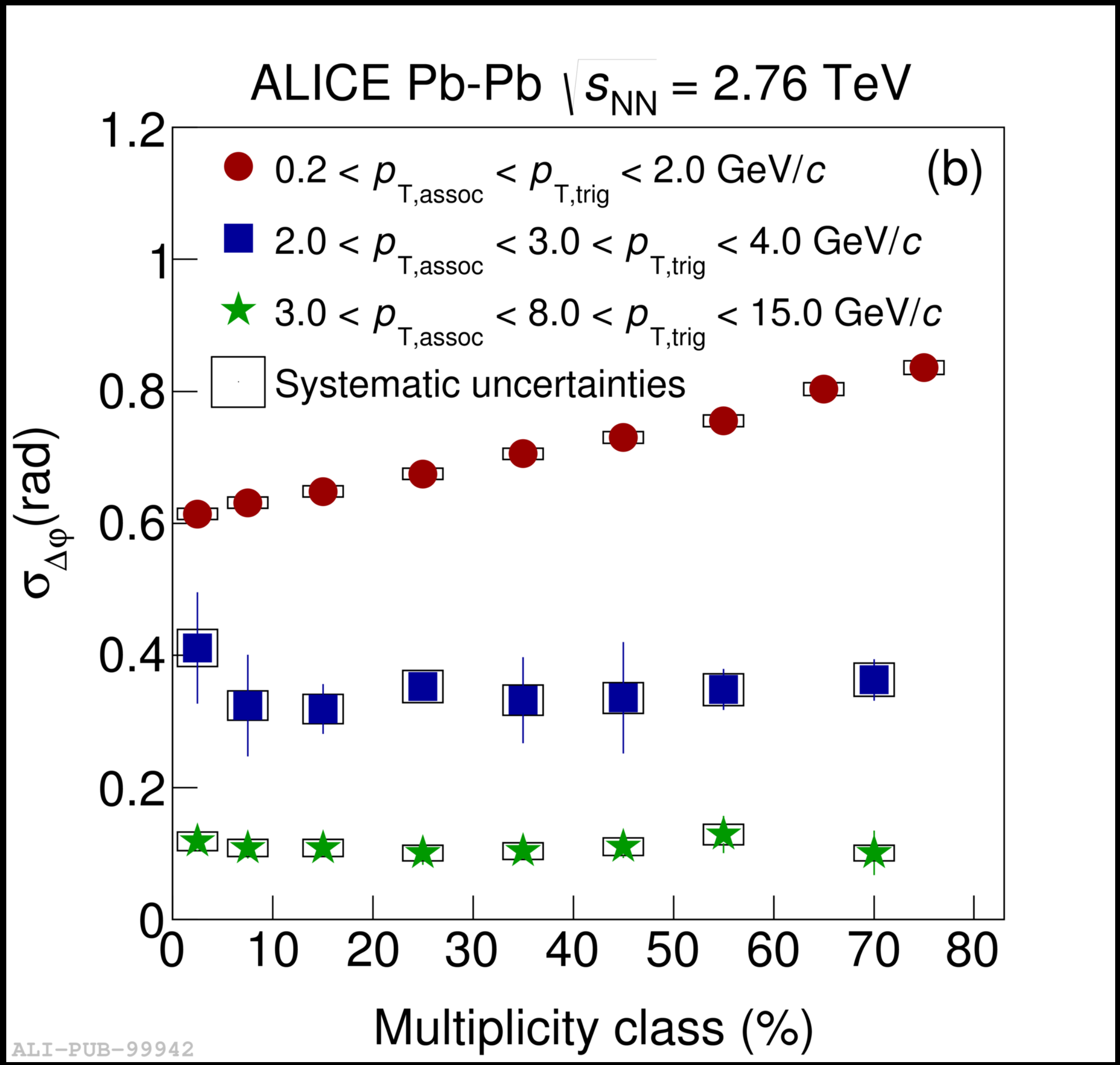
in both Pb-Pb and p-Pb

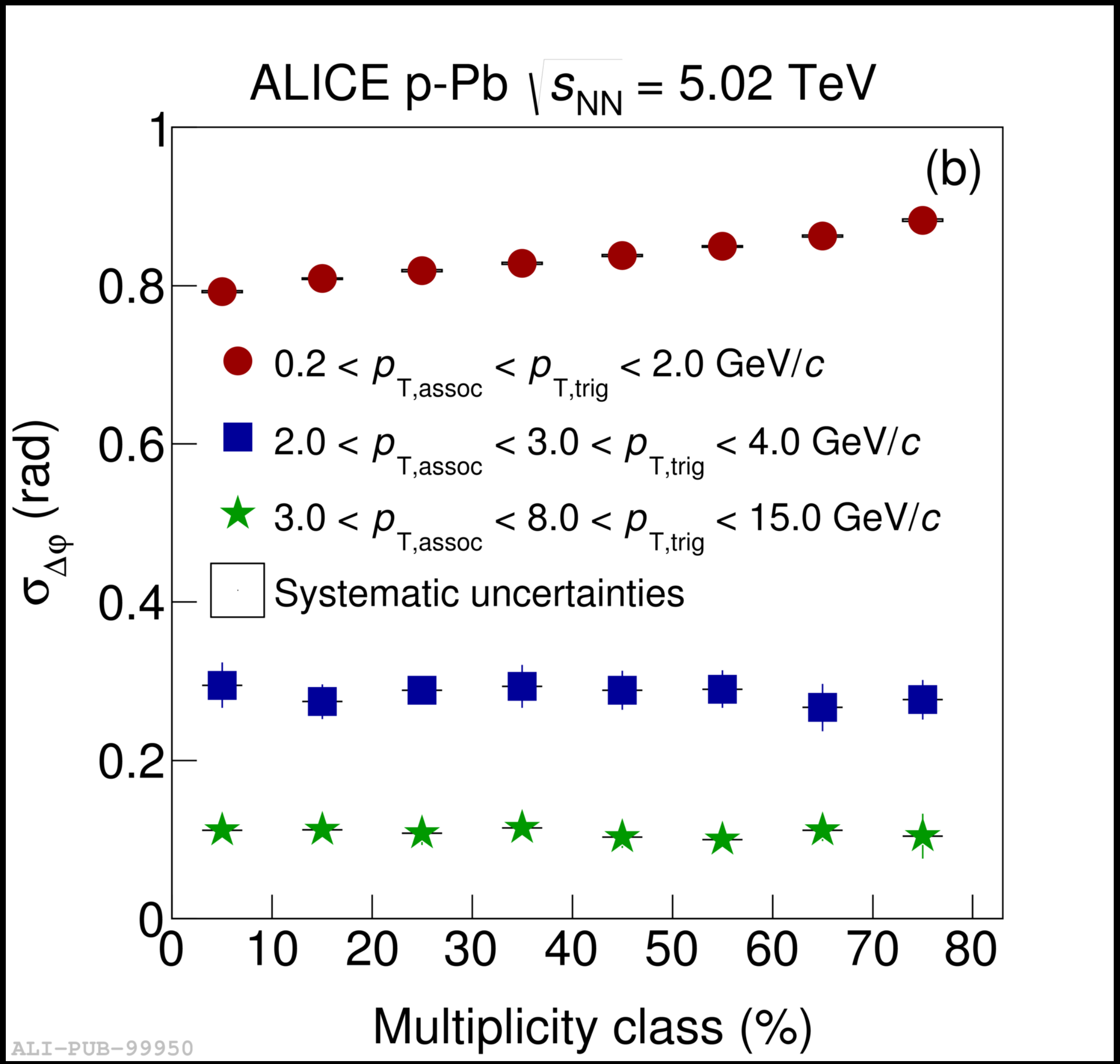
$\sigma_{\Delta\varphi}$ vs multiplicity class vs p_T



- Narrowing with increasing multiplicity ➡ effect of the bulk
  - Width does not depend on multiplicity for higher values of p_T
- Balance functions get narrower with increasing p_T for a given multiplicity

$\sigma_{\Delta\varphi}$ vs multiplicity class vs p_T

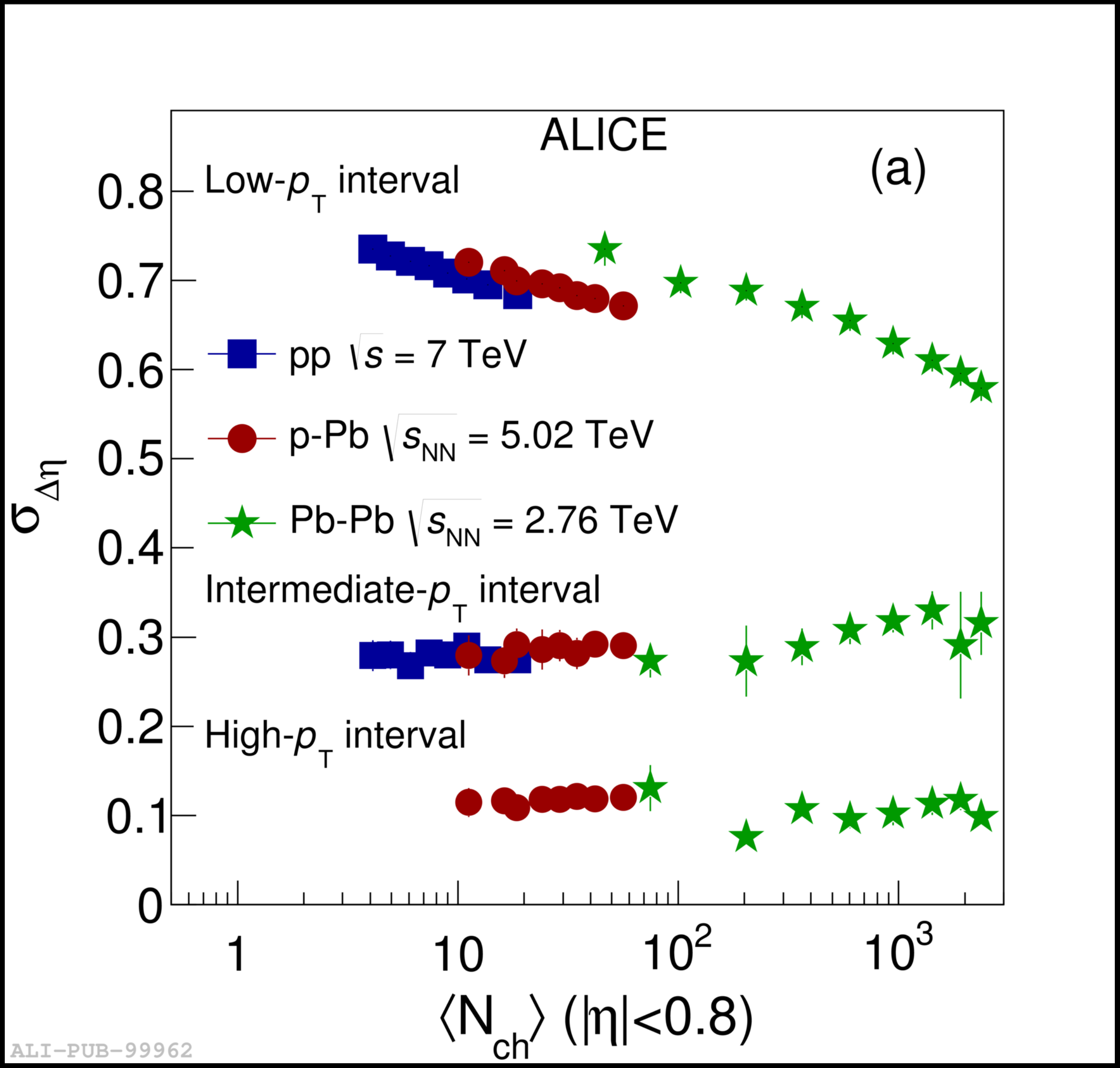




- Narrowing with increasing multiplicity ➡ effect of the bulk
- ★ Width does not depend on multiplicity for higher values of p_T
- Balance functions get narrower with increasing p_T for a given multiplicity

in both Pb-Pb and p-Pb and in both Δη and Δφ

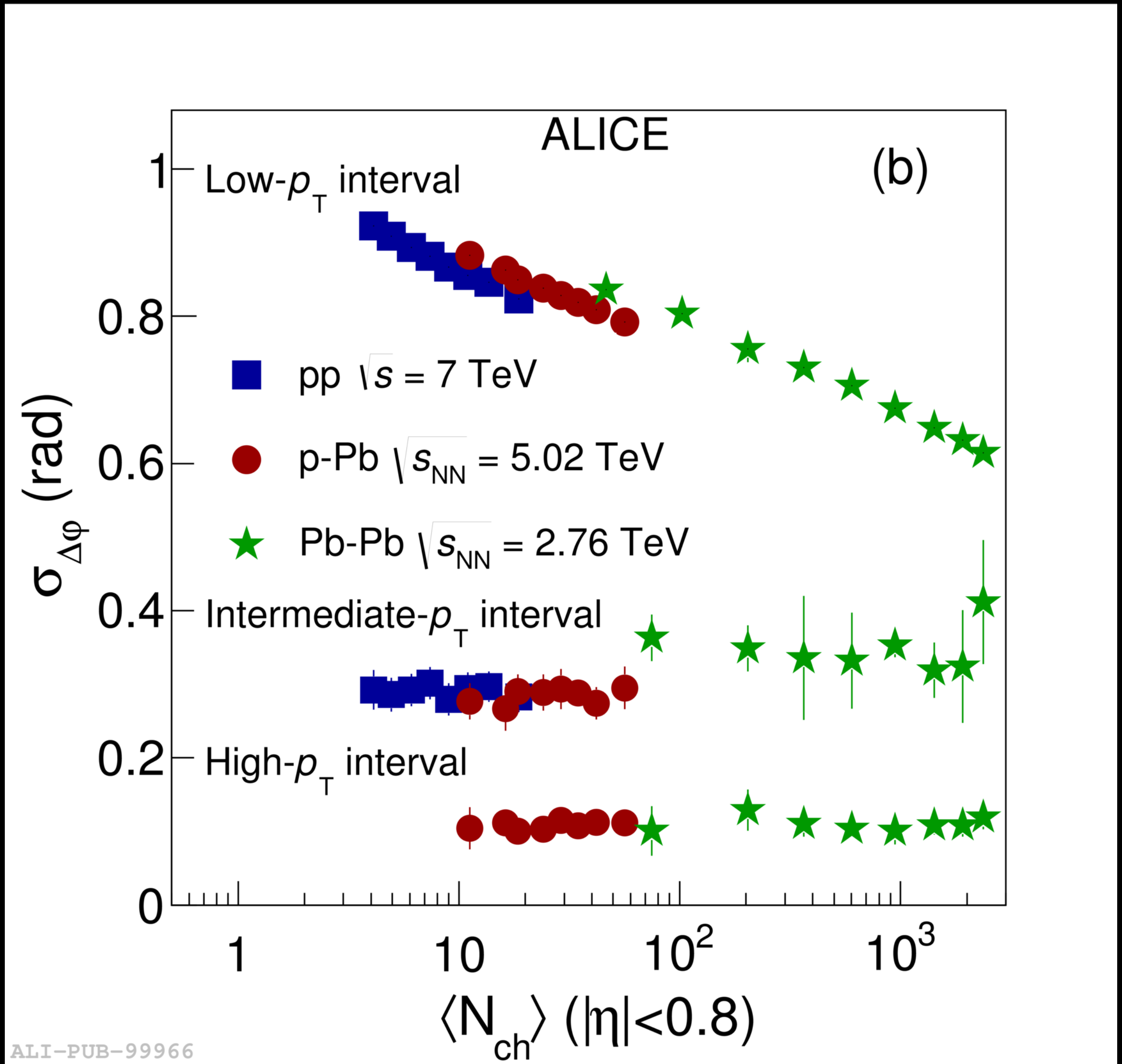
System comparison: $\sigma_{\Delta\eta}$ vs multiplicity vs p_T



- At low p_T in $\Delta\eta$:
  - pp similar to p-Pb at the same multiplicity
  - Pb-Pb different than p-Pb at the same multiplicity

- At intermediate and high p_T in $\Delta\eta$:
  - no significant difference between the three systems

System comparison: $\sigma_{\Delta\varphi}$ vs multiplicity vs p_T

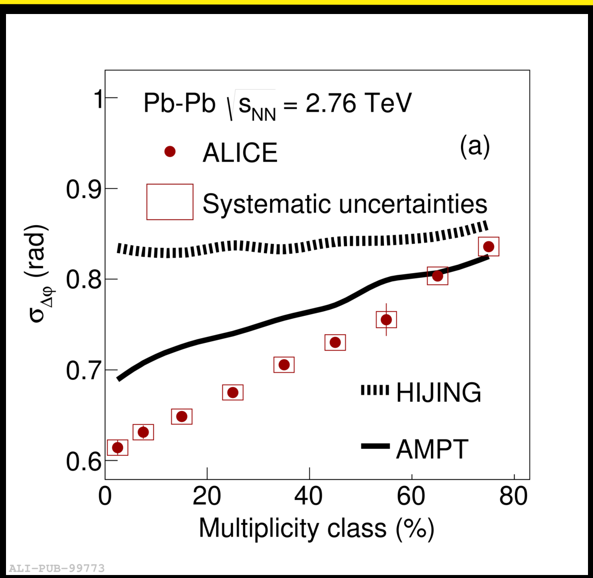


- At low p_T in Δφ:
  - pp similar to p-Pb at the same multiplicity
  - Pb-Pb different than p-Pb at the same multiplicity

- At intermediate and high p_T in Δφ:
  - no significant difference between the three systems

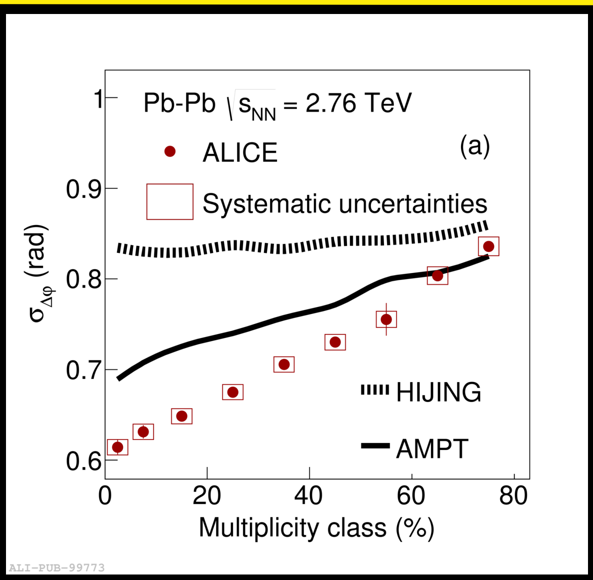
Summary

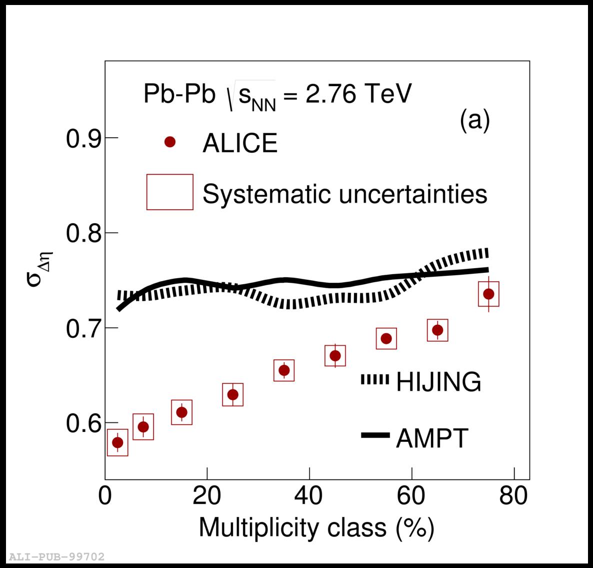
Summary



Narrowing in Δφ for heavy-ion collisions, qualitatively described by AMPT

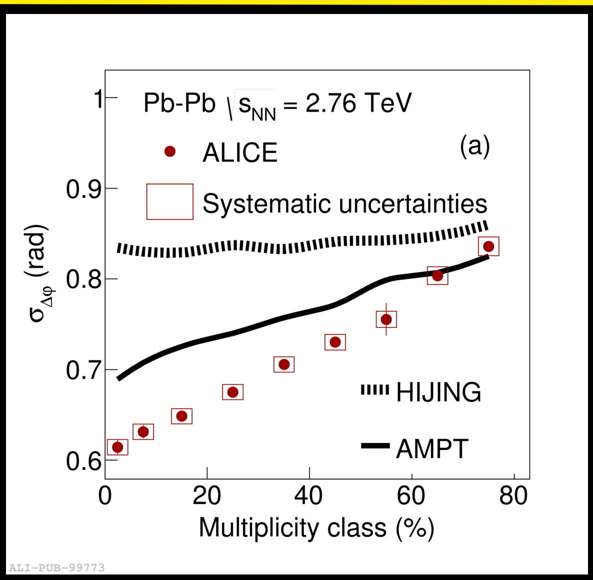
Summary

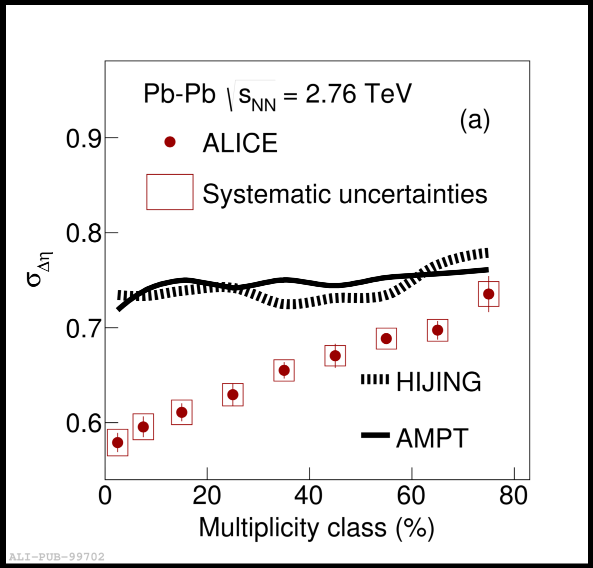


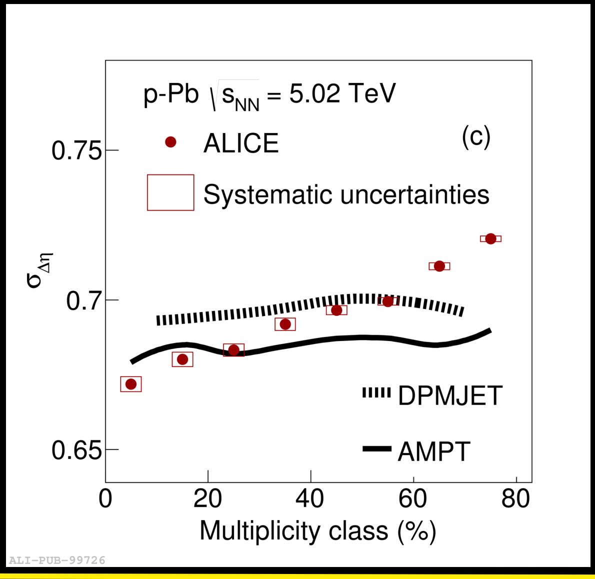


Narrowing in Δη for heavy-ion collisions, can not be described by either AMPT or HIJING

Summary

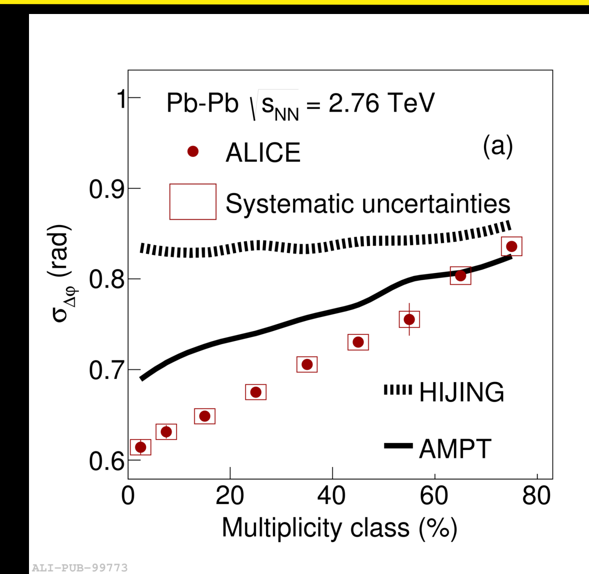


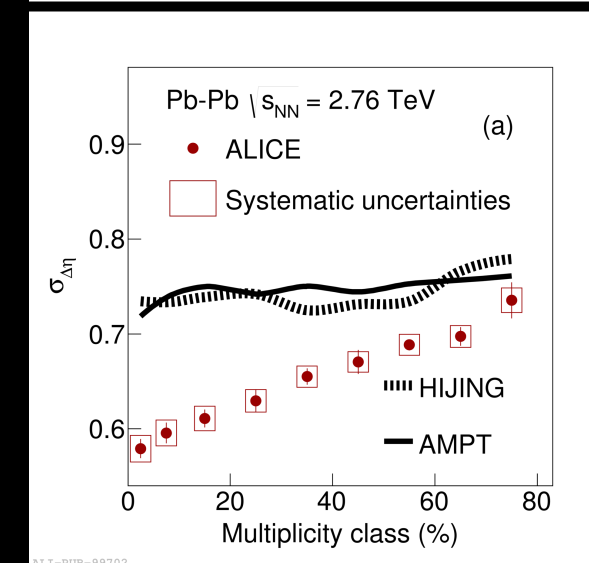


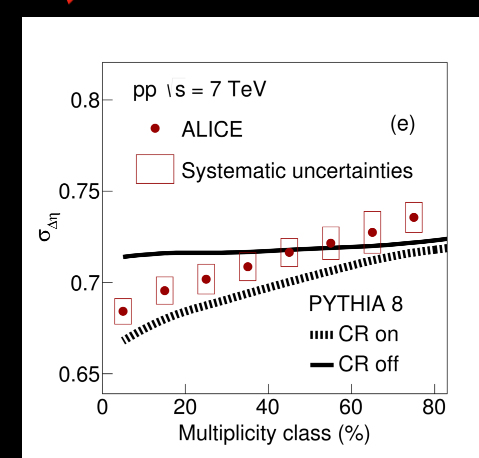


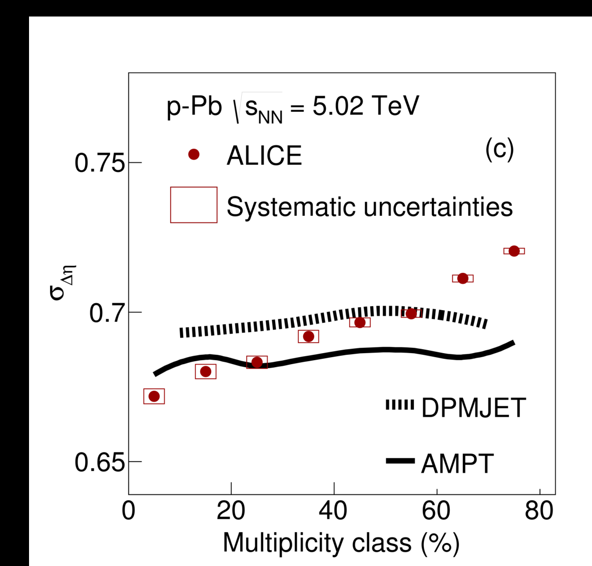
Narrowing in Δη and Δφ persists also in small systems

Summary



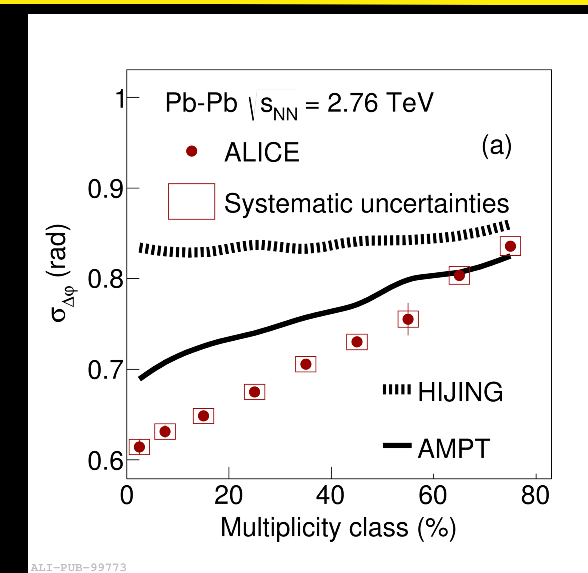




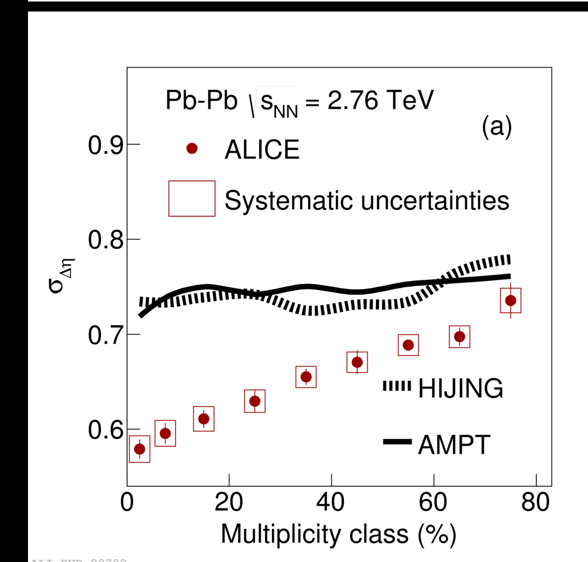


Colour reconnection needed to describe the effect in pp

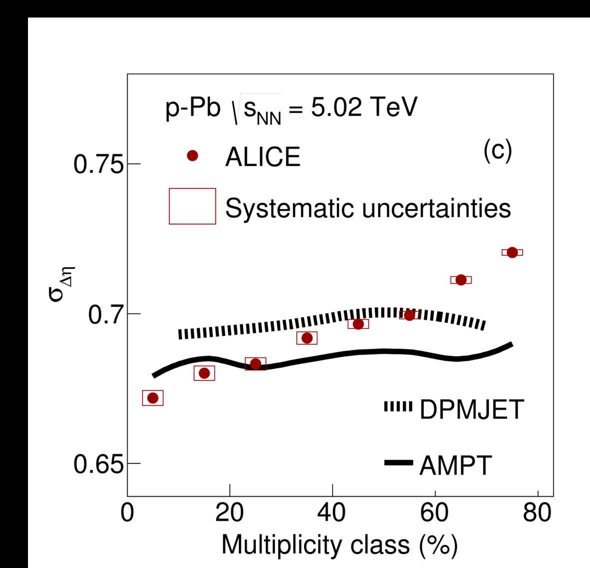
Summary



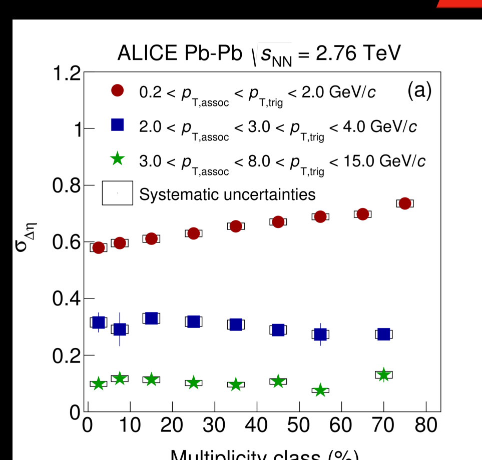
Pb-Pb √sNN = 2.76 TeV
ALICE
(a)
Systematic uncertainties
HIJING
AMPT
σΔφ (rad)
Multiplicity class (%)



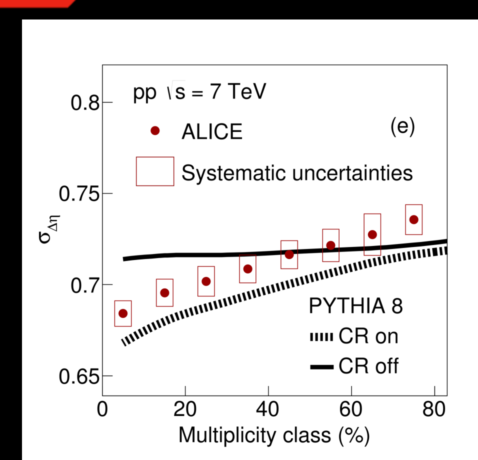
Pb-Pb √sNN = 2.76 TeV
ALICE
(a)
Systematic uncertainties
HIJING
AMPT
σΔη
Multiplicity class (%)



p-Pb √sNN = 5.02 TeV
ALICE
(c)
Systematic uncertainties
DPMJET
AMPT
σΔη
Multiplicity class (%)

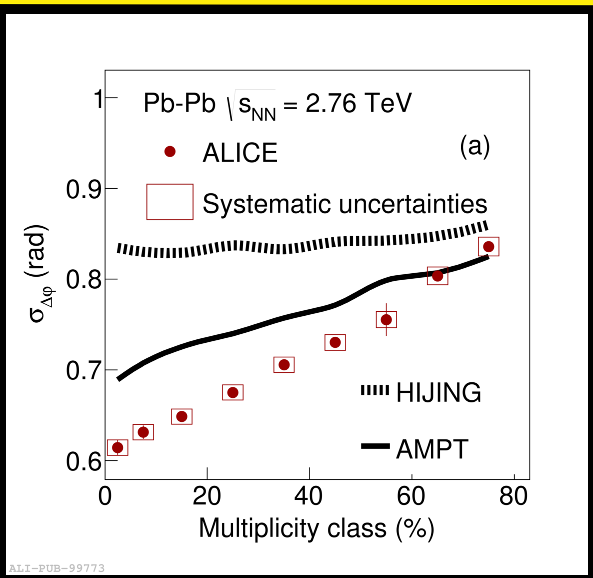


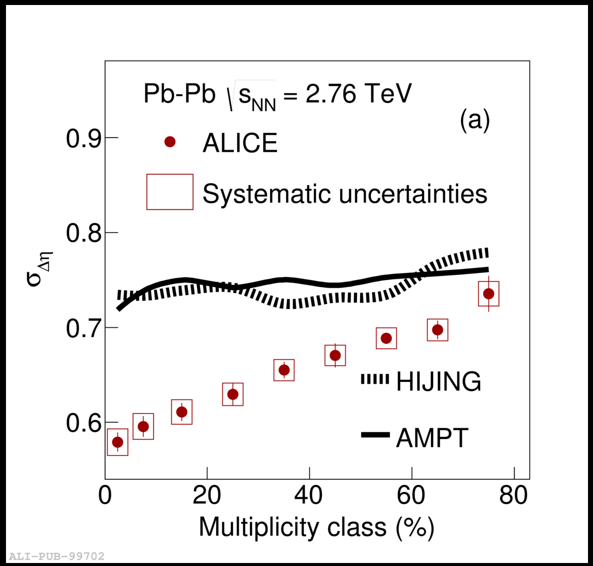
ALICE Pb-Pb √sNN = 2.76 TeV
0.2 < pT,assoc < pT,trig < 2.0 GeV/c
(a)
2.0 < pT,assoc < 3.0 < pT,trig < 4.0 GeV/c
3.0 < pT,assoc < 8.0 < pT,trig < 15.0 GeV/c
Systematic uncertainties
σΔη
Multiplicity class (%)



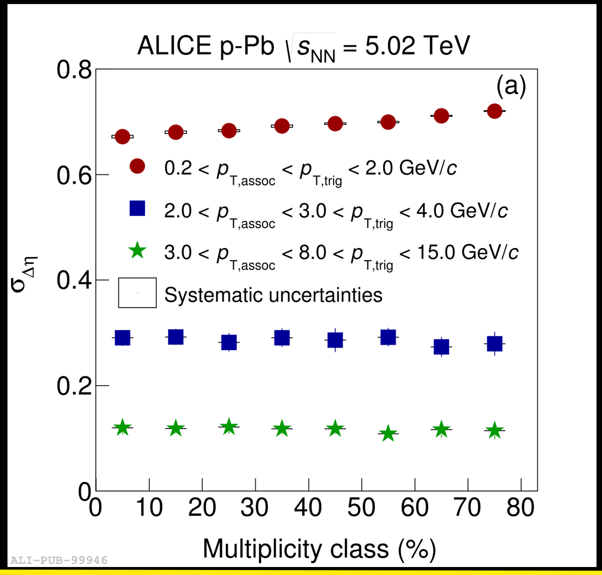
pp √s = 7 TeV
ALICE
(e)
Systematic uncertainties
PYTHIA 8
CR on
CR off
σΔη
Multiplicity class (%)

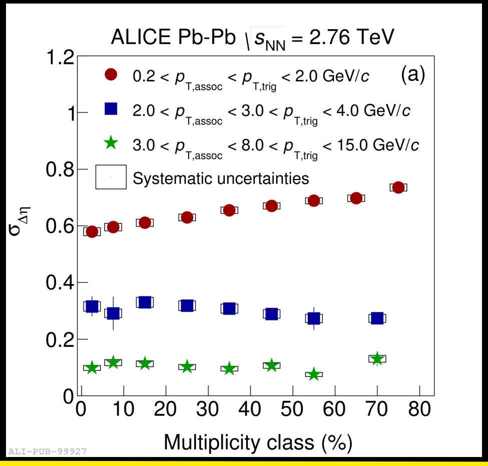
Summary

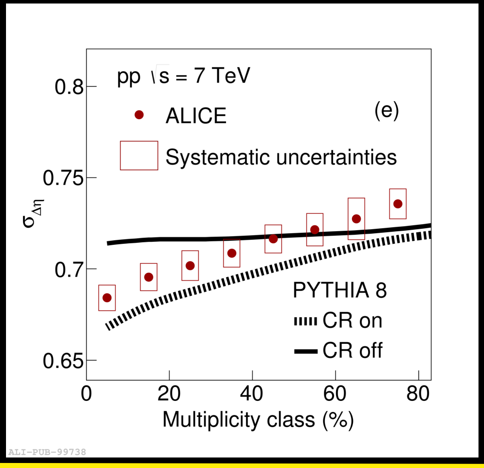


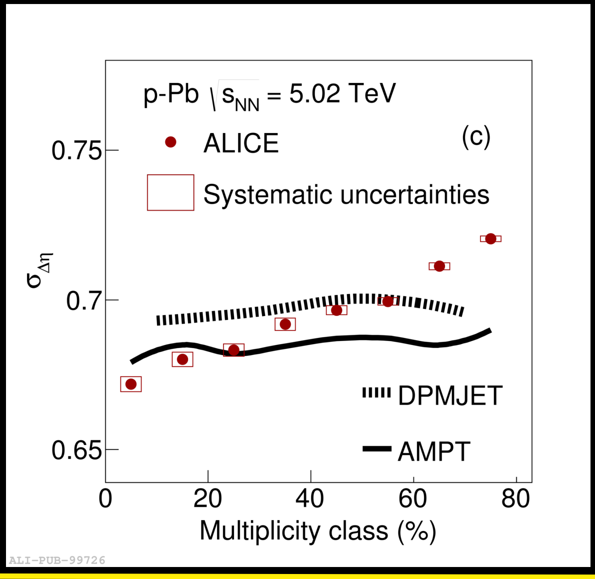


Narrowing only in the low p_T region, balance functions narrower with increasing p_T

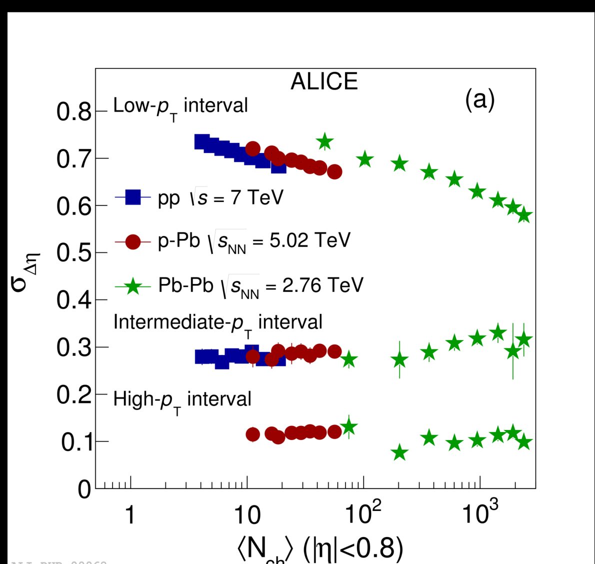


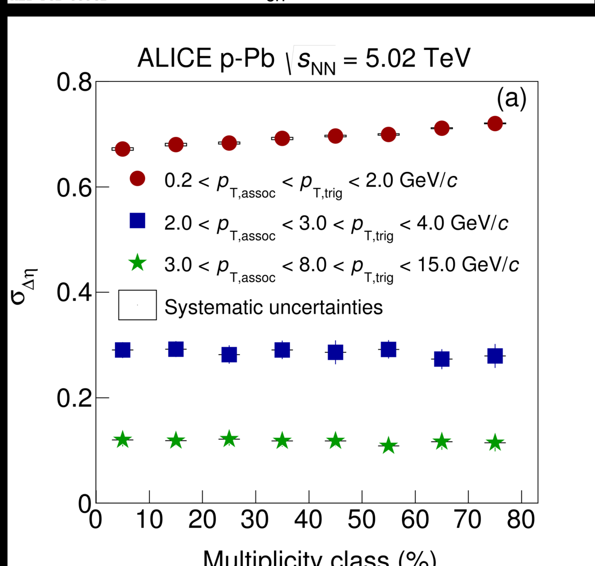


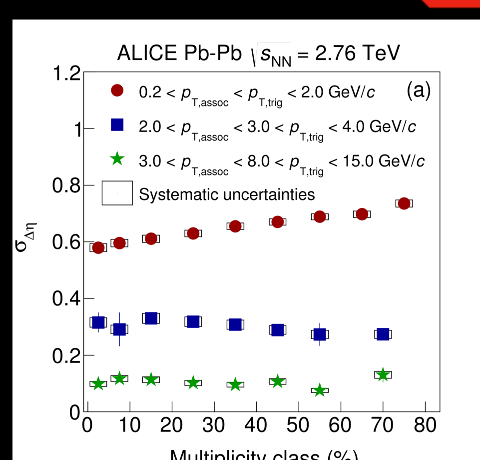


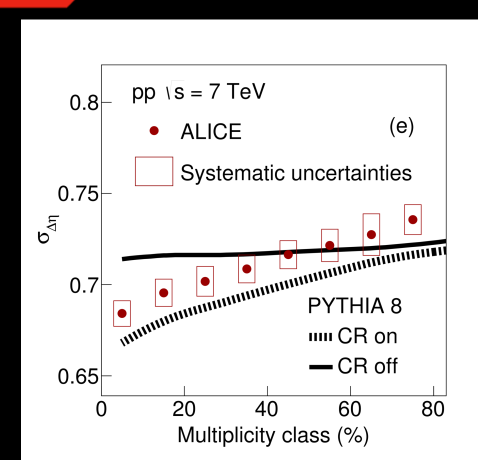


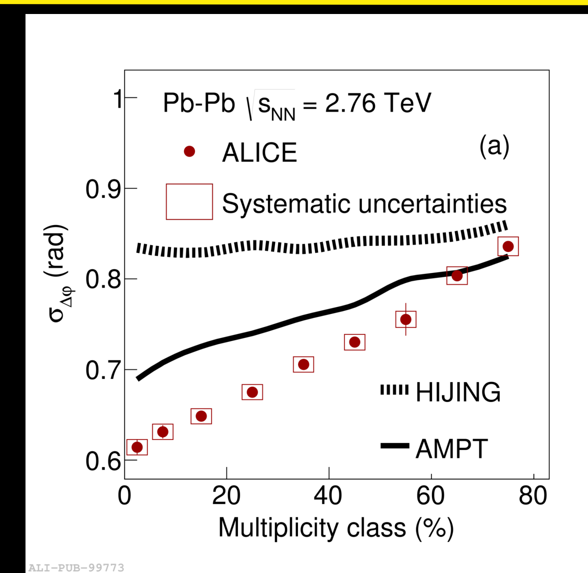
Summary

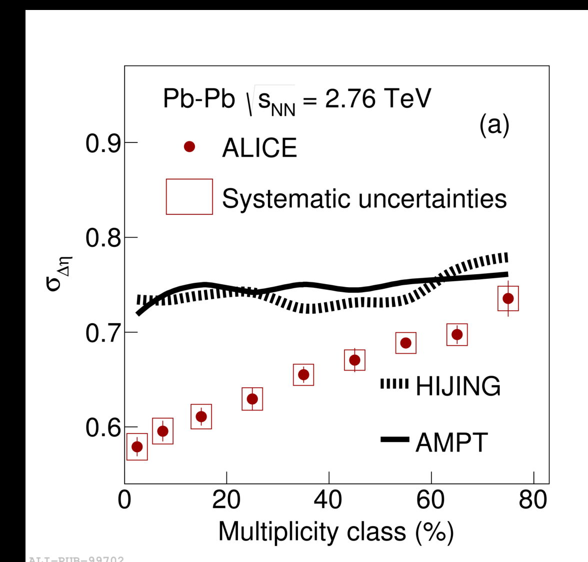

ALICE
(a)
Low-p_T interval
pp $\sqrt{s}$ = 7 TeV
p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
Intermediate-p_T interval
High-p_T interval
$\sigma_{\Delta\eta}$
$\langle N_{ch} \rangle$ ($|\eta|$<0.8)
ALI-PUB-99962

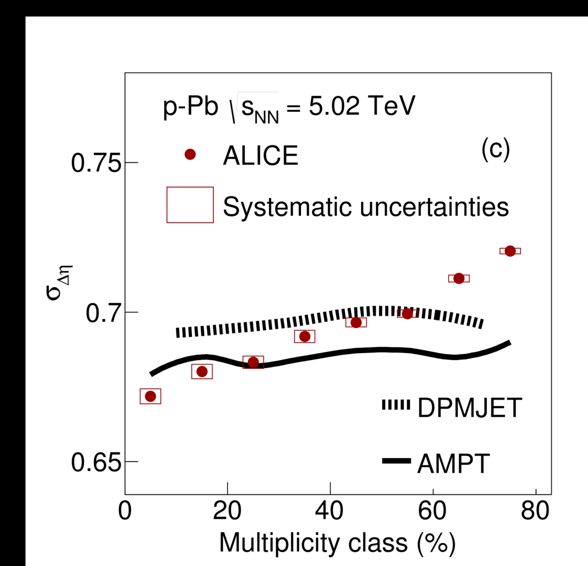

ALICE p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
(a)
0.2 < $p_{T,assoc}$ < $p_{T,trig}$ < 2.0 GeV/c
2.0 < $p_{T,assoc}$ < 3.0 < $p_{T,trig}$ < 4.0 GeV/c
3.0 < $p_{T,assoc}$ < 8.0 < $p_{T,trig}$ < 15.0 GeV/c
Systematic uncertainties
$\sigma_{\Delta\eta}$
Multiplicity class (%)
ALI-PUB-99946


ALICE Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
(a)
0.2 < $p_{T,assoc}$ < $p_{T,trig}$ < 2.0 GeV/c
2.0 < $p_{T,assoc}$ < 3.0 < $p_{T,trig}$ < 4.0 GeV/c
3.0 < $p_{T,assoc}$ < 8.0 < $p_{T,trig}$ < 15.0 GeV/c
Systematic uncertainties
$\sigma_{\Delta\eta}$
Multiplicity class (%)


pp $\sqrt{s}$ = 7 TeV
ALICE
(e)
Systematic uncertainties
PYTHIA 8
CR on
CR off
$\sigma_{\Delta\eta}$
Multiplicity class (%)

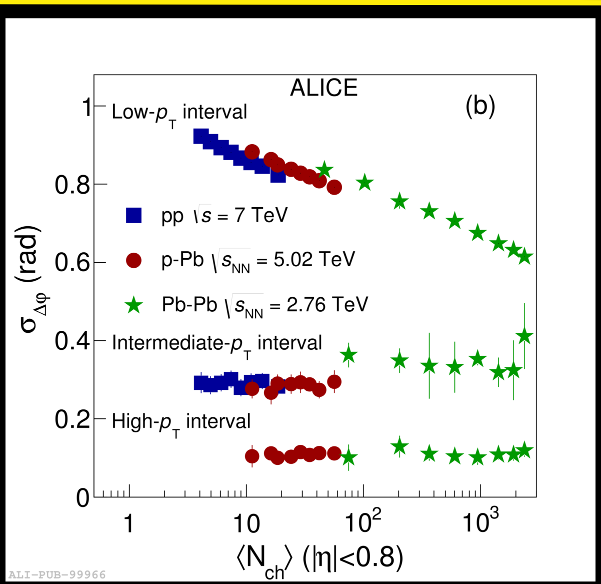

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE
(a)
Systematic uncertainties
HIJING
AMPT
$\sigma_{\Delta\varphi}$ (rad)
Multiplicity class (%)
ALI-PUB-99773

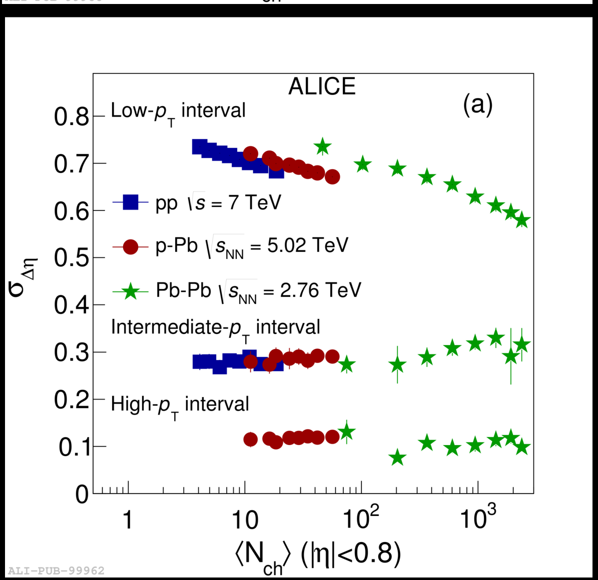

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE
(a)
Systematic uncertainties
HIJING
AMPT
$\sigma_{\Delta\eta}$
Multiplicity class (%)
ALI-PUB-99702

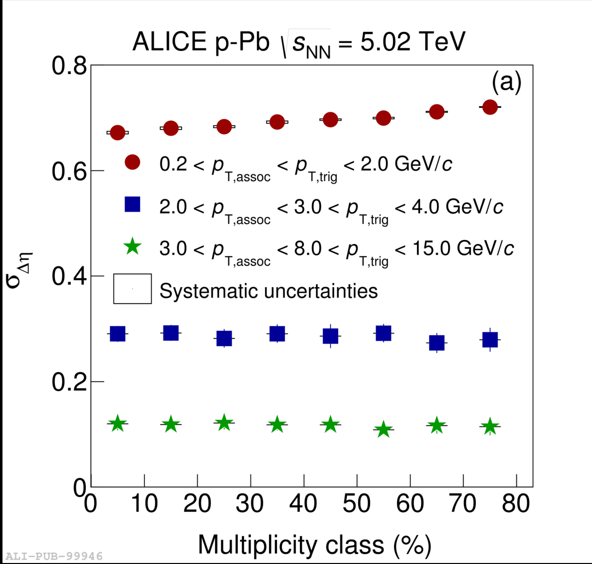

p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
ALICE
(c)
Systematic uncertainties
DPMJET
AMPT
$\sigma_{\Delta\eta}$
Multiplicity class (%)
ALI-PUB-99726

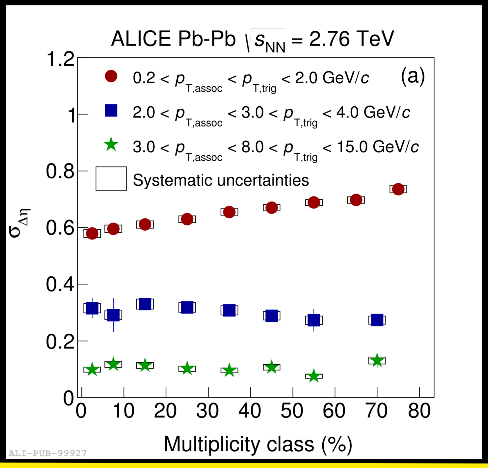
Summary

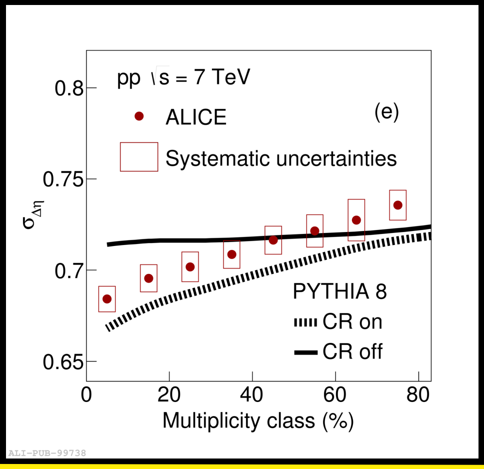
- Small systems similar at low p_T but different wrt heavy-ions
- Similar results for all systems with increasing p_T

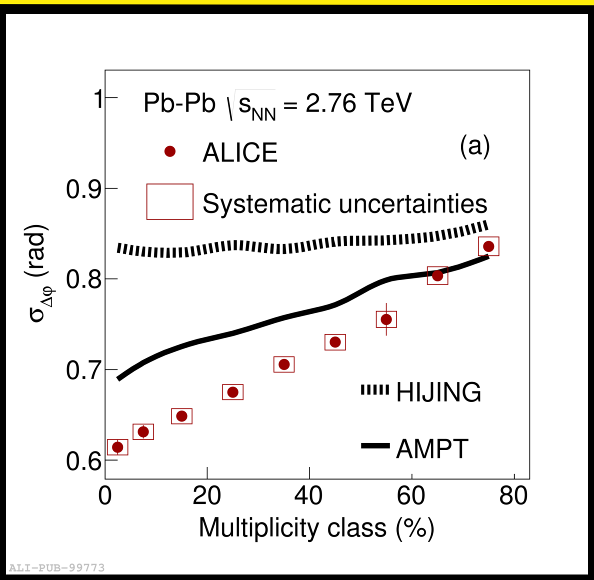


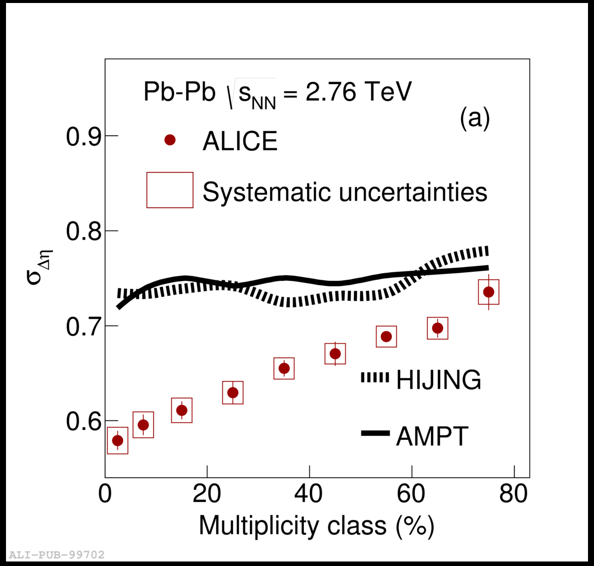


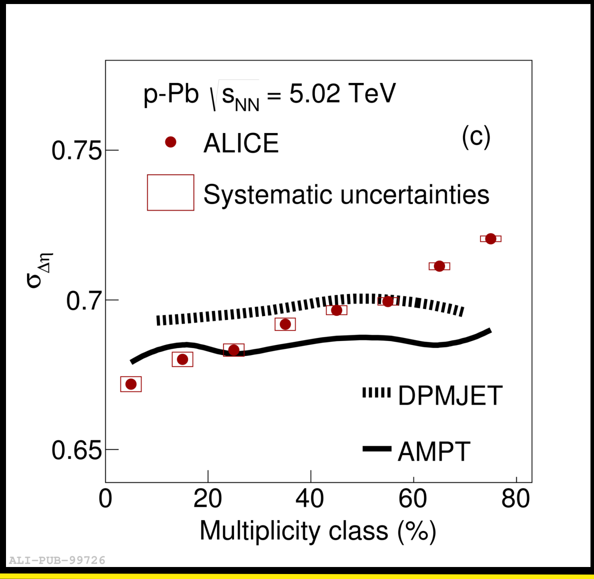










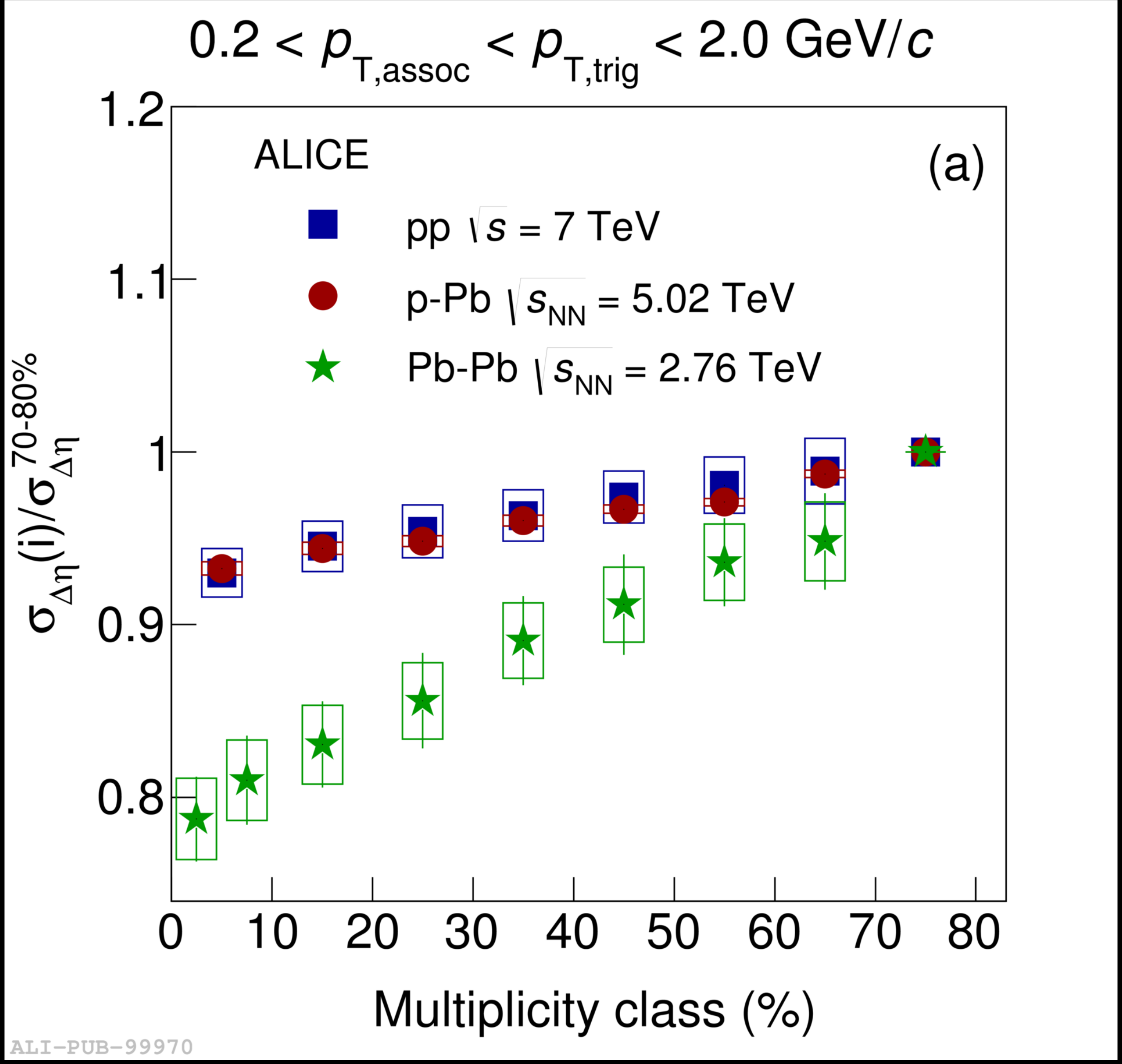


Summary

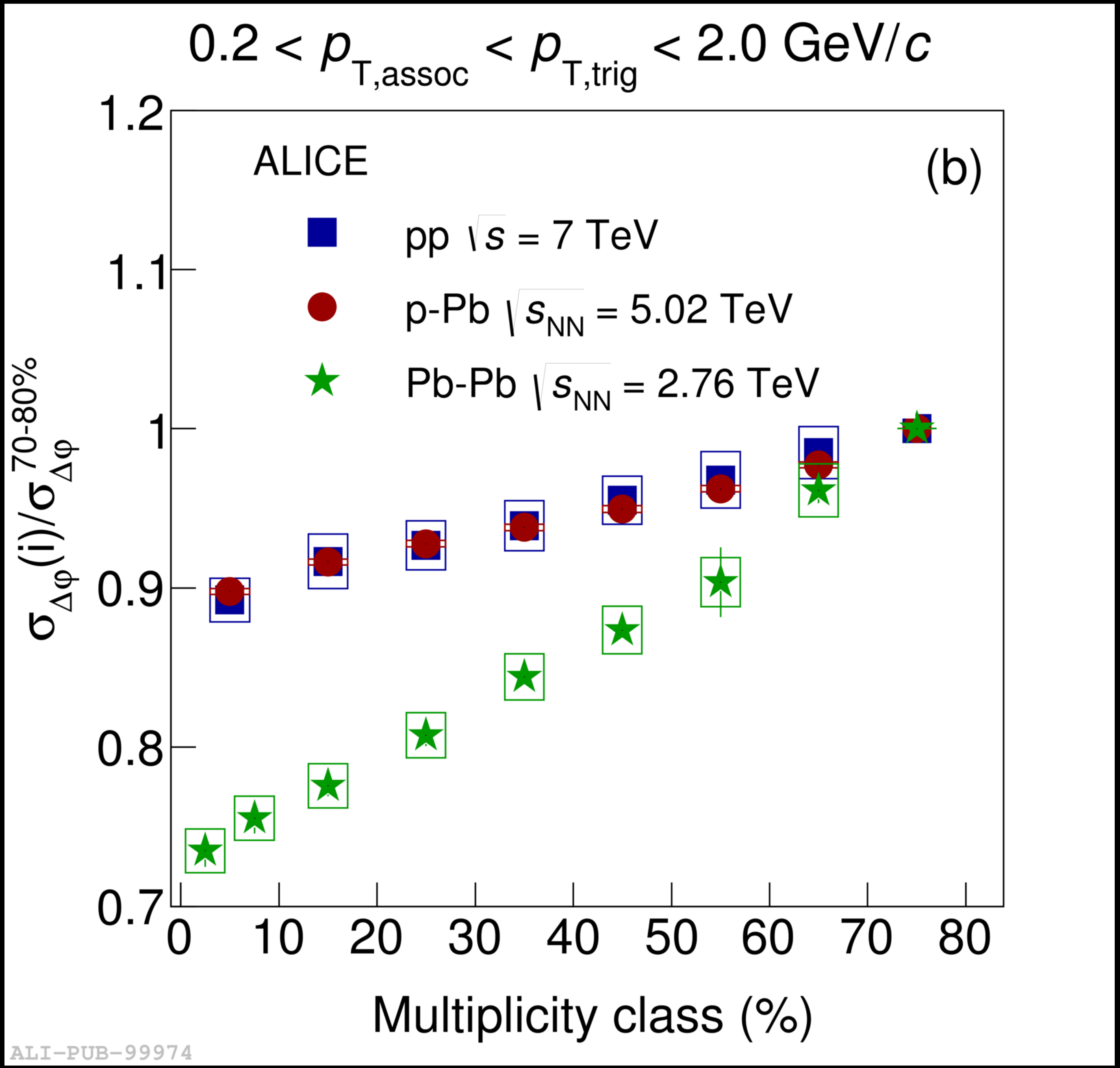
ALICE

Backup

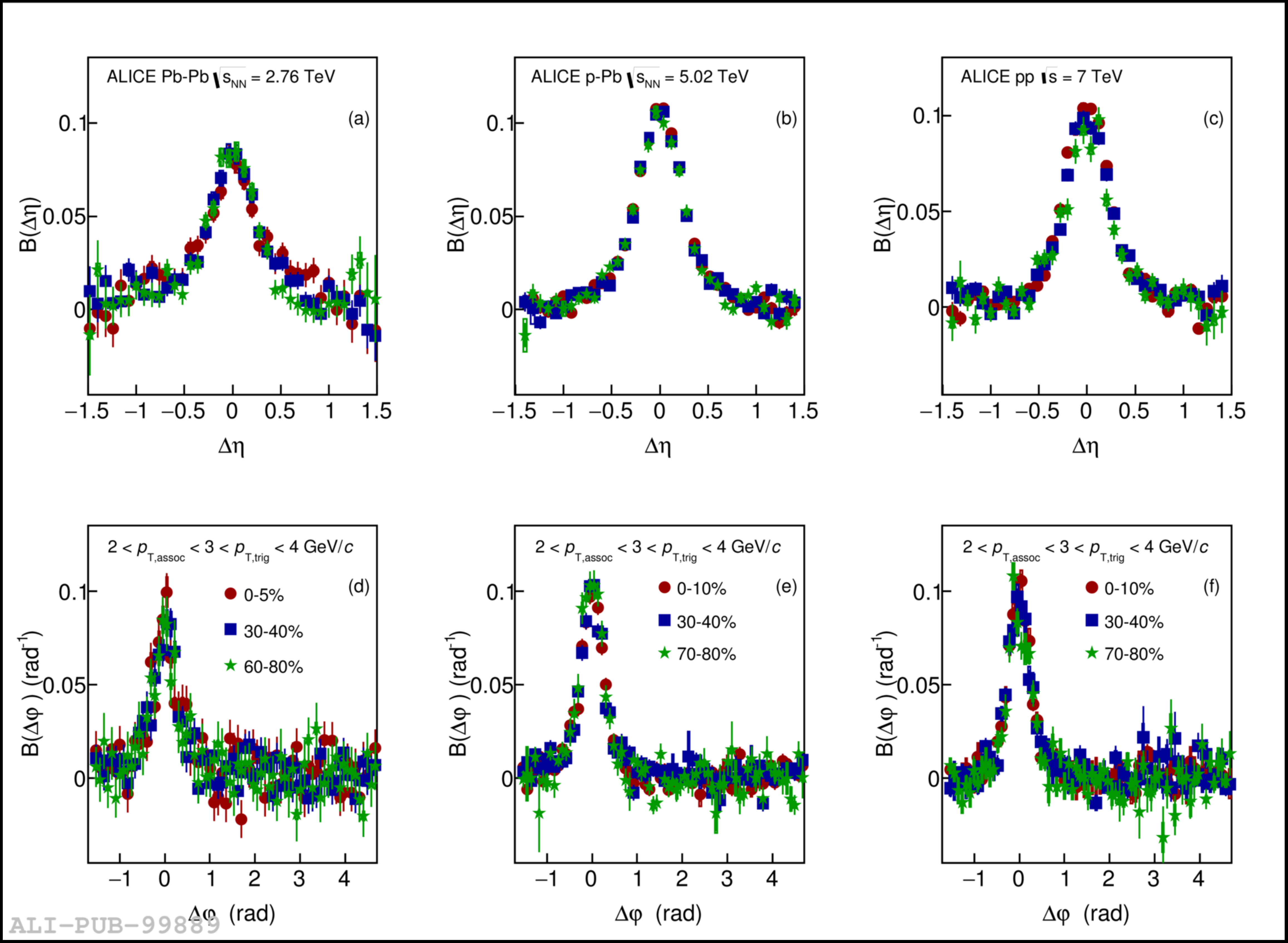
System comparison: $\sigma_{\Delta\eta}$ vs multiplicity class low p_T



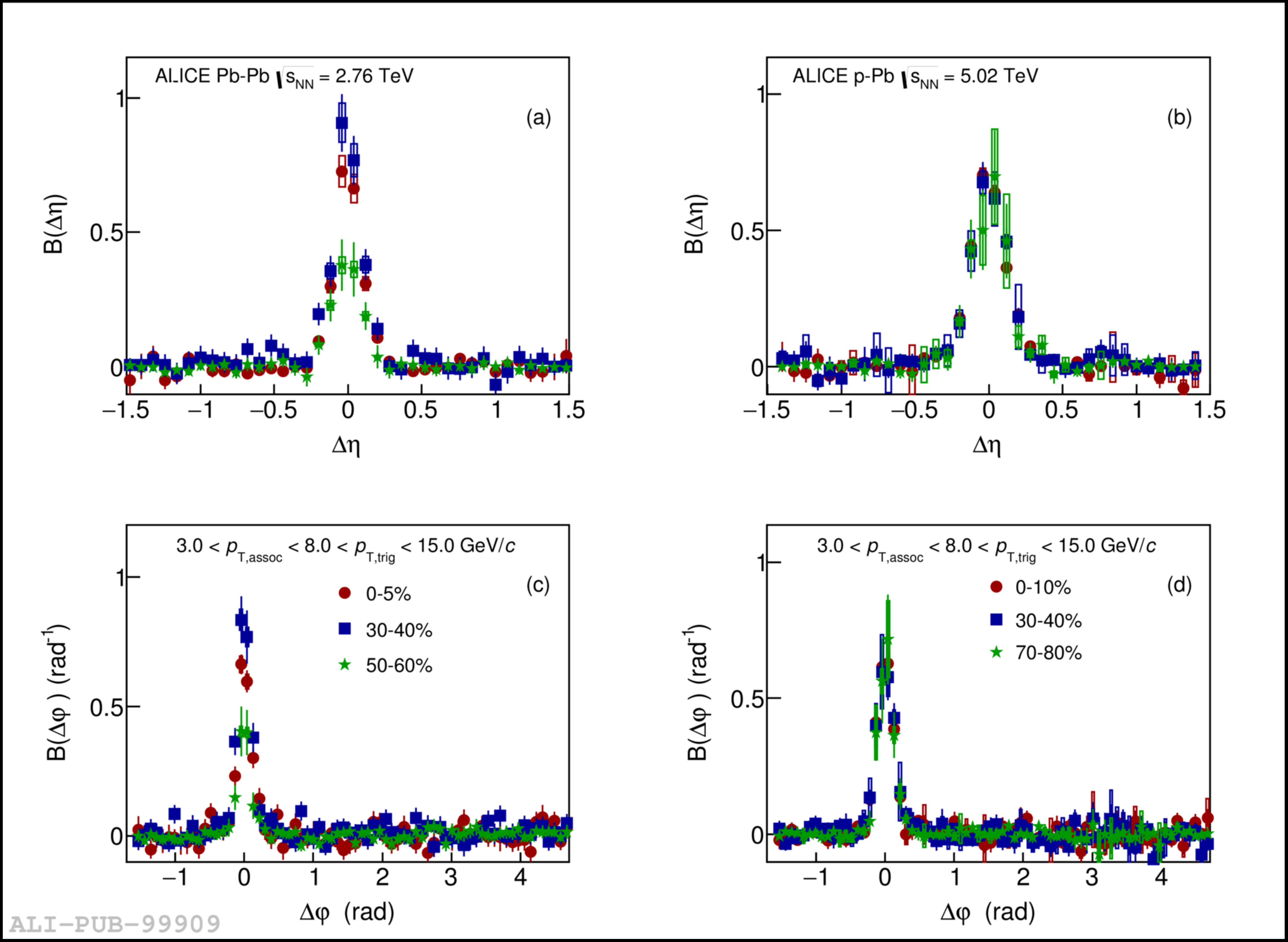
System comparison: $\sigma_{\Delta\varphi}$ vs multiplicity class low p_T



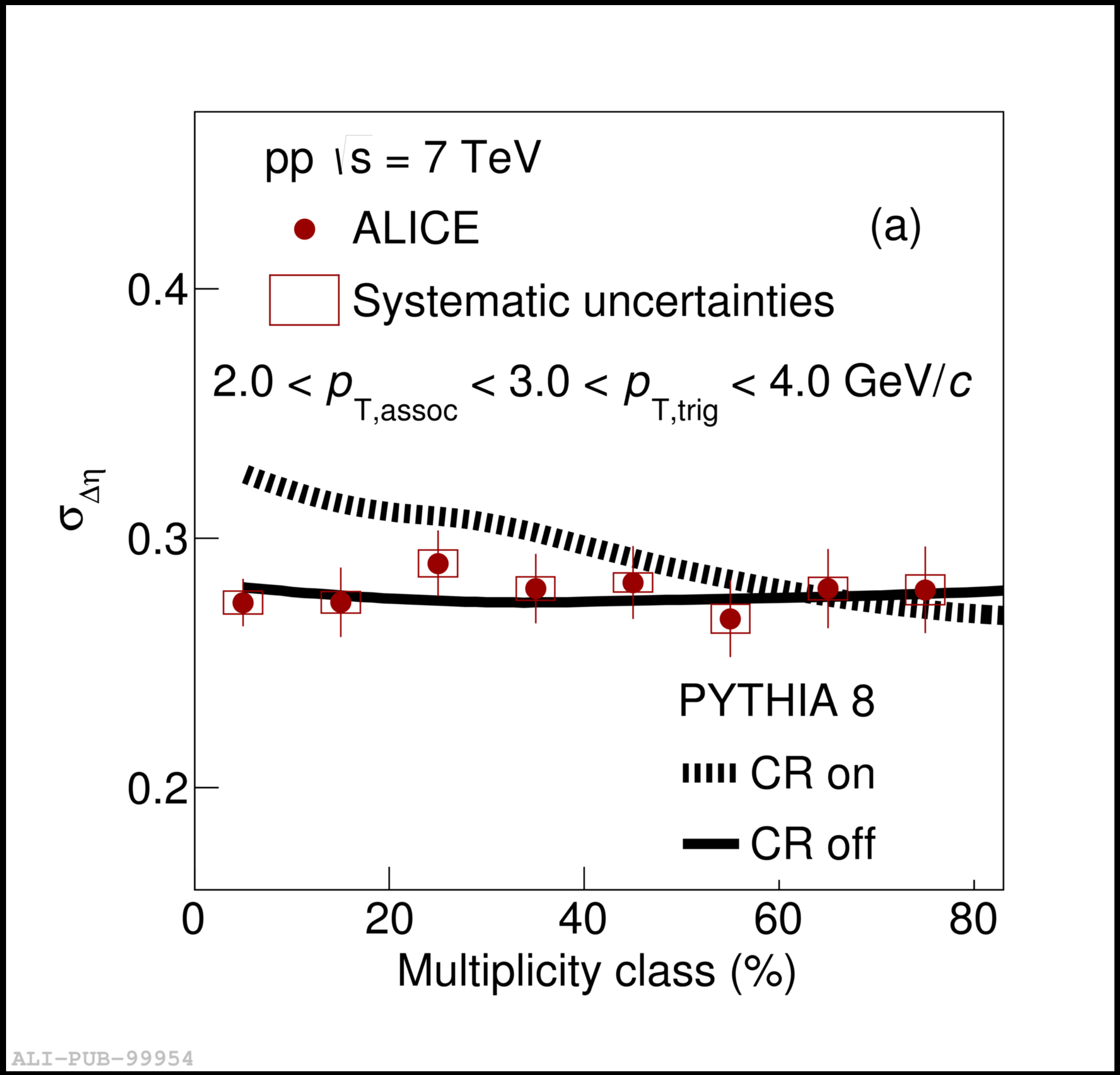
Projections in Δη and Δφ: intermediate p_T

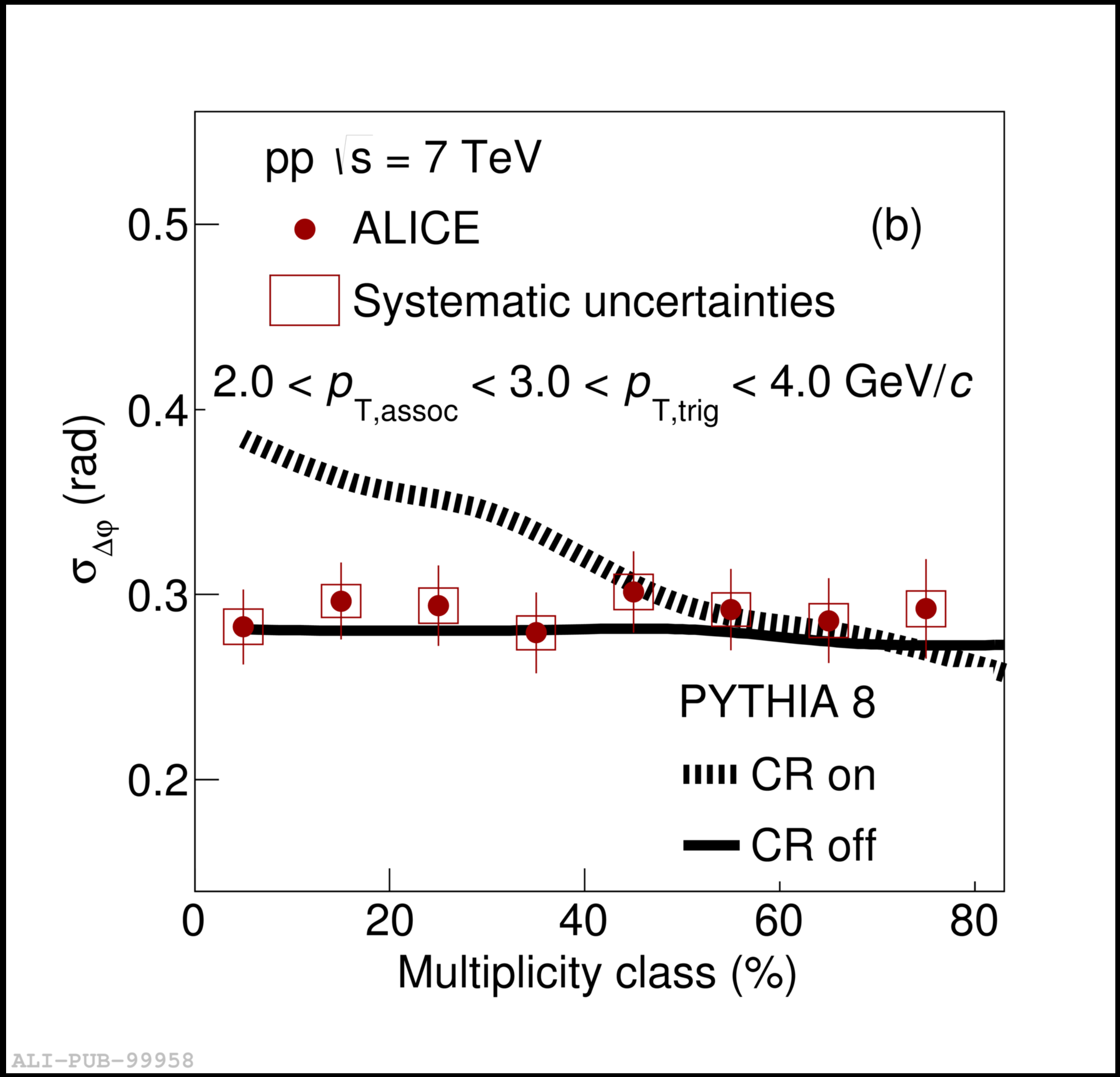


Projections in Δη and Δφ: high p_T



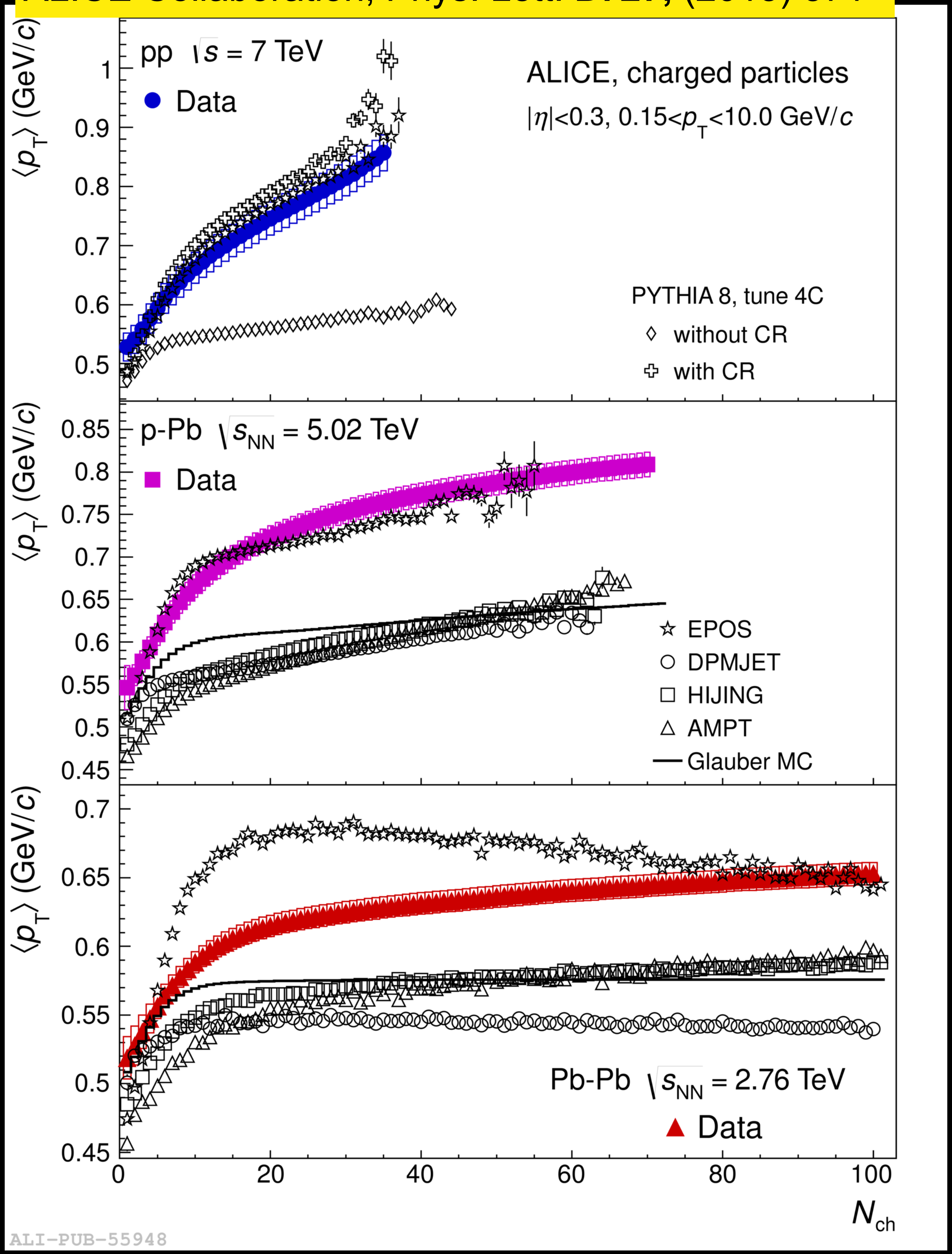
$\sigma_{\Delta\eta}$ / $\sigma_{\Delta\varphi}$ vs multiplicity class in pp collisions: intermediate p_T





Mean p_T in pp, p-Pb and Pb-Pb collisions

ALICE Collaboration, Phys. Lett. B**727,** (2013) 371



Systematic uncertainties

Category	Systematic uncertainty (max. value)		
	pp	p–Pb	Pb–Pb
Magnetic field	-	-	1.5%
LHC periods	1.1%	$< 0.1\%$	1.0%
Tracking	1.2%	0.2%	1.2%
V0 equalization	$< 0.1\%$	-	-
Electron variation	$< 0.1\%$	0.1%	0.2%
Split/merged pairs variation	$< 0.1\%$	0.2%	0.7%
Efficiency and contamination correction	0.4%	0.4%	1.1%

Table 2: The maximum value of the systematic uncertainties on the width of the balance function over all multiplicity classes for each of the sources studied for the pp, p–Pb and Pb–Pb systems.