Measurement of charge-dependent fluctuations and correlations at CMS

Sayan Chatterjee for the CMS collaboration

Indian Institute Of Technology, Madras

WPCF 2023 - XVI Workshop on Particle Correlations and Femtoscopy & IV Resonance Workshop 2023

6-10 Nov 2023, Catania (Italy)

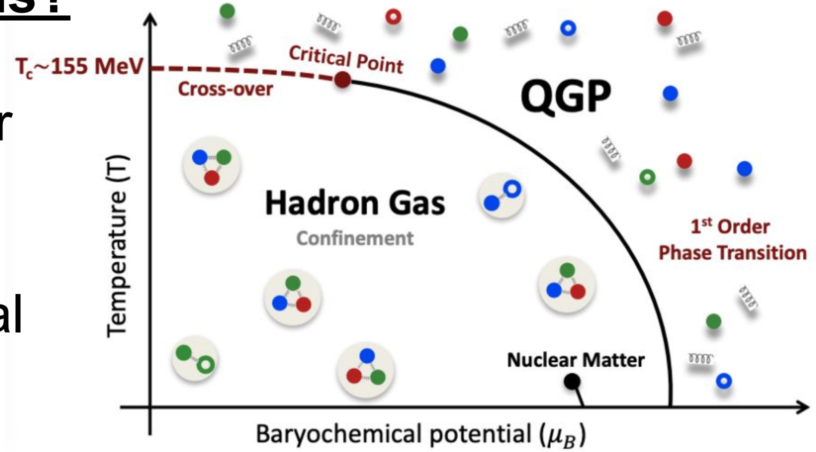
Outline

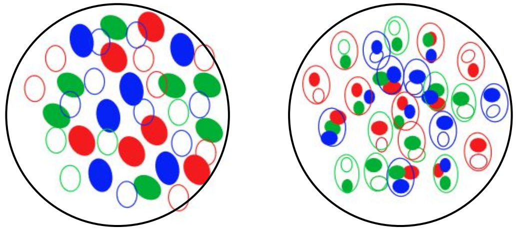
- Introduction & Motivation
  - Charge fluctuations
  - Charge correlations
- Observables
- Results
- Summary

Charge Fluctuations

Why EbyE fluctuations?

- ❖ To study the proper -ties of the phase transitions.
- ❖ To locate the critical end point





QGP | Hadron Gas (HG)

$$q = \pm\frac{1}{3}, \pm\frac{2}{3}, \qquad q = \pm 1, \pm 2,$$

$$q^2 = \frac{1}{9}, \frac{4}{9} \qquad q^2 = 1, 4$$

- ❖ Net-charge fluctuations are proportional to the square of charges in the system
- ❖ Net-charge fluctuations in the HG phase are larger than in QGP

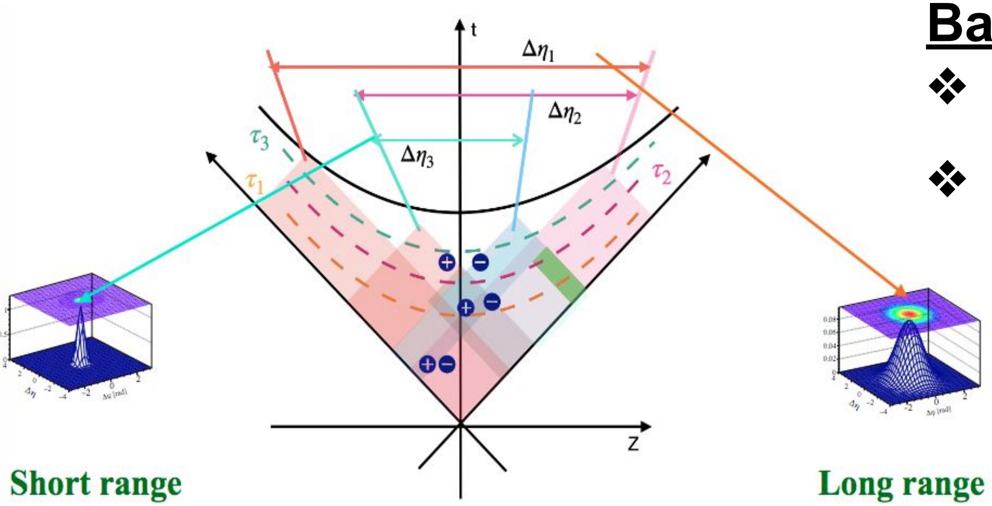
$$\nu_{(+-,dyn)} = \frac{\langle N_+(N_+-1)\rangle}{\langle N_+\rangle^2} + \frac{\langle N_-(N_--1)\rangle}{\langle N_-\rangle^2} - 2\frac{\langle N_+N_-\rangle}{\langle N_+\rangle\langle N_-\rangle}$$

$$D = 4\frac{\langle(\delta Q)^2\rangle}{\langle N_{ch}\rangle} = \langle N_{ch}\rangle\langle\nu_{+-,dyn}\rangle + 4$$

$$D = \begin{cases} 4\text{ , HG} \\ 3\text{ , HRG} \\ 1\text{ - }1.5\text{ , QGP} \end{cases}$$

Phys. Rev. Lett. 85, 2076 (2000)

Charge Correlations



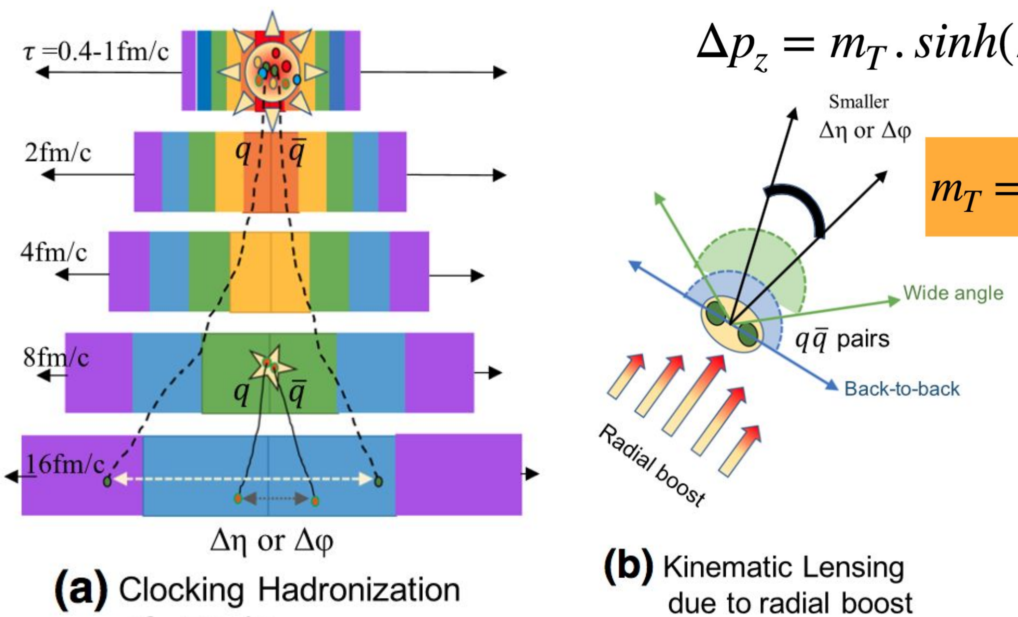
Balancing charge separations

- Law of Nature "charge is conserved"
- Longitudinal width of the correlation is related to time the correlation is established
    - The width is also affected by the radial flow effect

Radial flow

$$\Delta p_z = m_T \,.\, sinh(\Delta y) \approx m_T \,.\, \Delta y$$

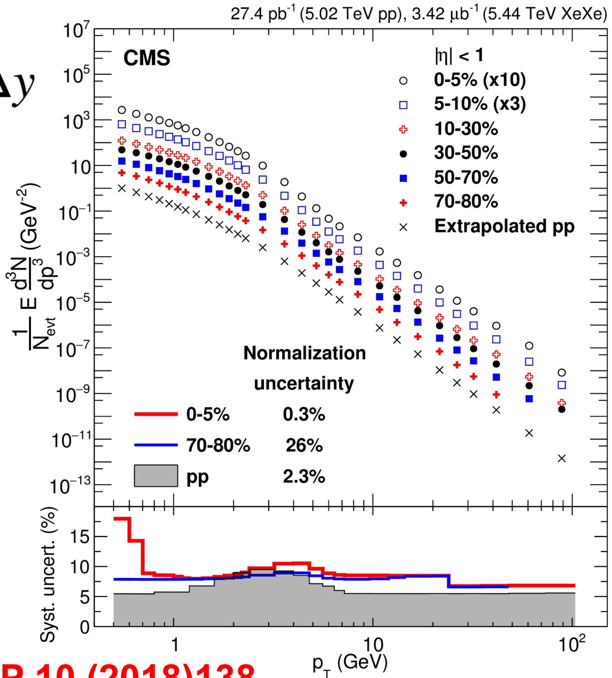
$$m_T = \sqrt{m_0^2 + p_T^2}$$



(a) Clocking Hadronization of $q\bar{q}$ pairs

(b) Kinematic Lensing due to radial boost

Eur. Phys. J. C (2021) 81:1024



JHEP 10 (2018)138

Observables

Balance functions are constructed from four possible charge combinations

$$\frac{1}{N_{trig}}\frac{d^2N^{pair}}{d\Delta\eta\, d\Delta\phi} = C_2(\Delta\eta, \Delta\varphi) = C_2(1, 2) \quad \Delta\eta = \eta_1 - \eta_2 \quad \Delta\varphi = \varphi_1 - \varphi_2$$

refers two particles

1 ⇒ Trigger particle; 2 ⇒ Associate particle

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

$$B(\Delta\eta, \Delta\varphi) = \frac{1}{2}[US - LS]$$

$$US = C(+,-) + C(-,+) \qquad LS = C(+,+) + C(-,-)$$

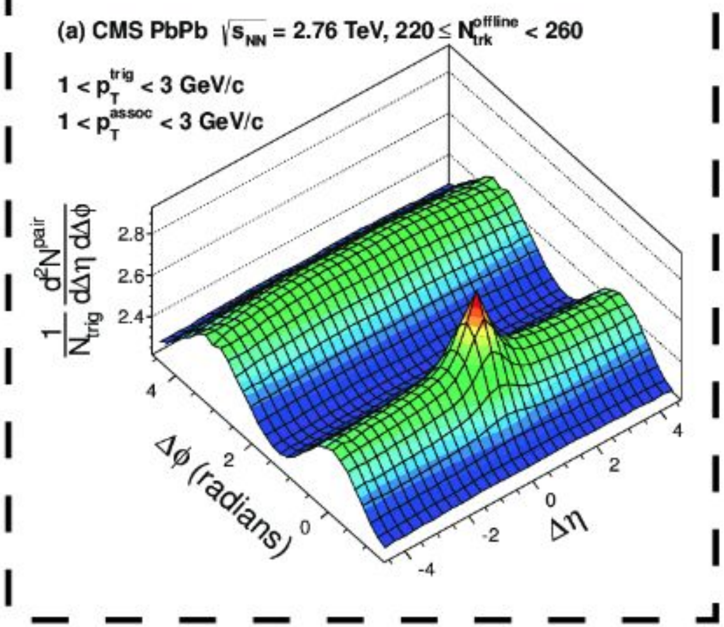
Balance functions are sensitive to Physics

- ❖ Late or early hadronization
- ❖ Collision dynamics: radial flow

Scott Pratt, Phys. Rev. Lett. 85, 2689

$$\langle|\Delta\eta|\rangle = \frac{\sum_i B(\Delta\eta_i)|\Delta\eta_i|}{\sum_i B(\Delta\eta_i)} \qquad \langle|\Delta\varphi|\rangle = \frac{\sum_i B(\Delta\varphi_i)|\Delta\varphi_i|}{\sum_i B(\Delta\varphi_i)}$$

Phys. Lett. B 724 (2013) 213



Charge hadron correlation functions

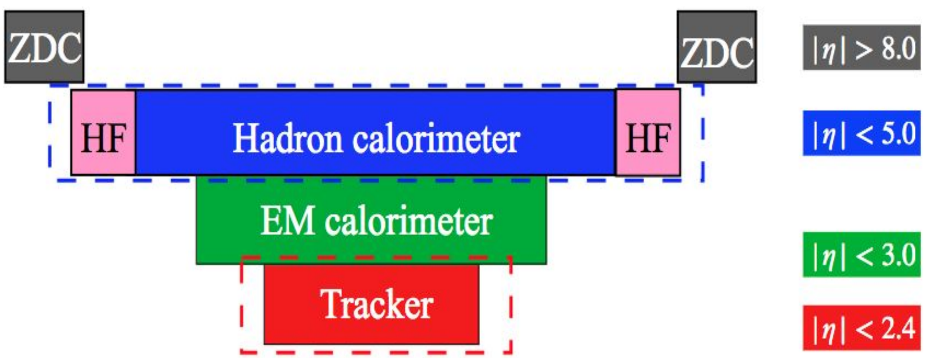
CMS Results

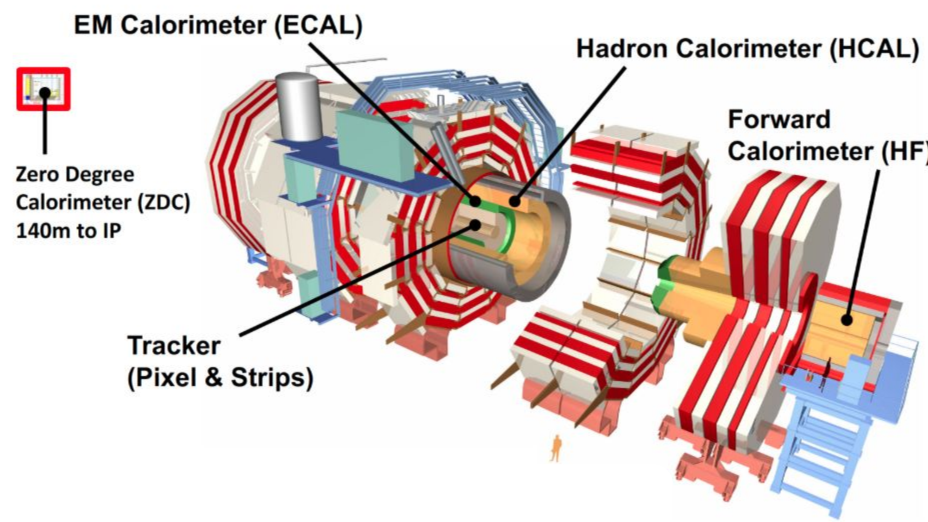
Datasets:

- ❖ 2018 PbPb at $\sqrt{s_{NN}}$ = 5.02 TeV
- ❖ 2016 pPb at $\sqrt{s_{NN}}$ = 8.16 TeV
- ❖ 2017 pp at $\sqrt{s_{NN}}$ = 5.02 TeV

Kinematic selections used

- ❖ pT > 0.4 GeV and 0.5 GeV (pPb, pp and PbPb)
- ❖ | η | < 2.4

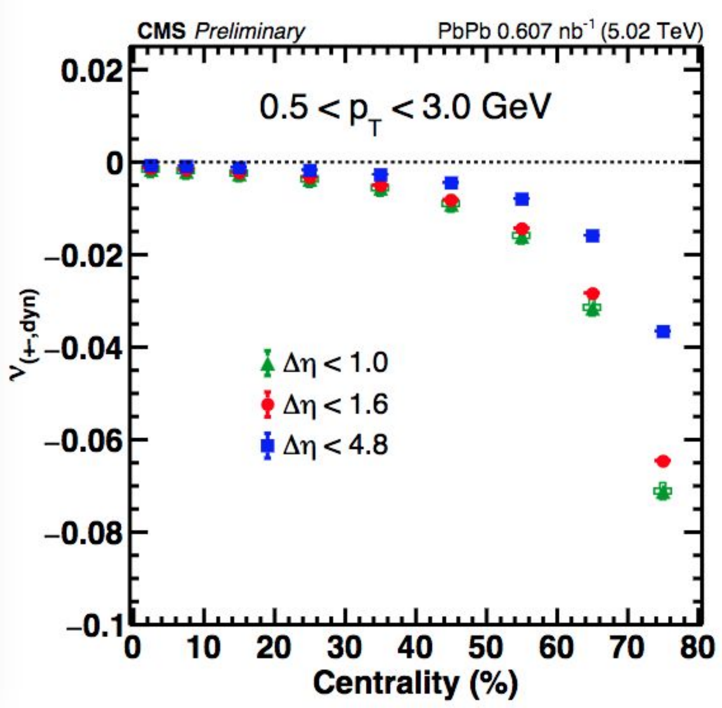




Why CMS Detector?

- ❖ Good precision
- ❖ Wide rapidity coverage

Net charge Fluctuations: Centrality



CMS-PAS-HIN-22-005

$$\nu_{(+-,\mathrm{dyn})} = \nu_{+-} - \nu_{\mathrm{stat}} = \left\langle \left(\frac{N_+}{\langle N_+ \rangle} - \frac{N_-}{\langle N_- \rangle} \right)^2 \right\rangle - \frac{1}{\langle N_+ \rangle} - \frac{1}{\langle N_- \rangle}$$

$$\nu_{(+-,dyn)} = \frac{\langle N_+(N_+ - 1)\rangle}{\langle N_+ \rangle^2} + \frac{\langle N_-(N_- - 1)\rangle}{\langle N_- \rangle^2} - 2\frac{\langle N_+ N_- \rangle}{\langle N_+ \rangle \langle N_- \rangle}$$

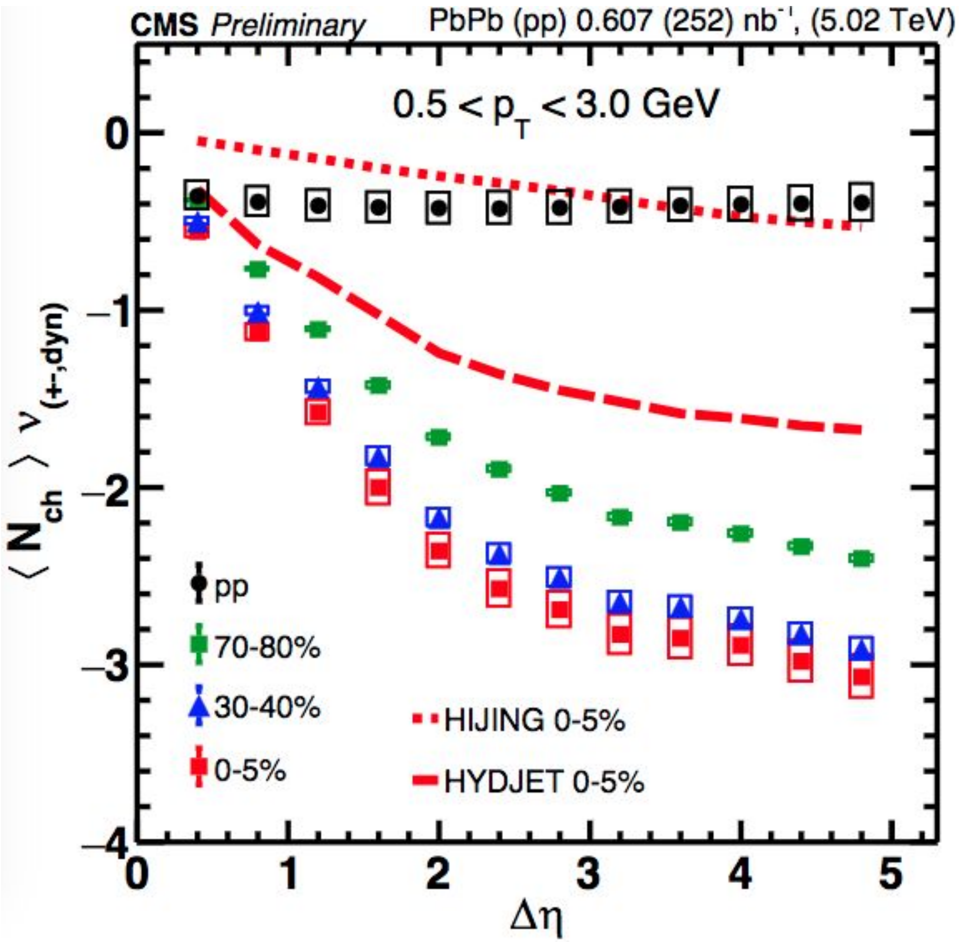
- ❖ ν_{dyn} = 0; no dynamical fluctuation
- ❖ ν_{dyn} > 0; same sign correlations dominates
- ❖ ν_{dyn} < 0; significance of opposite sign correlations dominates

✓ | ν_{dyn} | value decreases with the increase of η window

✓ Smaller | ν_{dyn} | value towards the central collision signifies the equilibration of + and - charges

Net charge Fluctuations: Δη

CMS-PAS-HIN-22-005

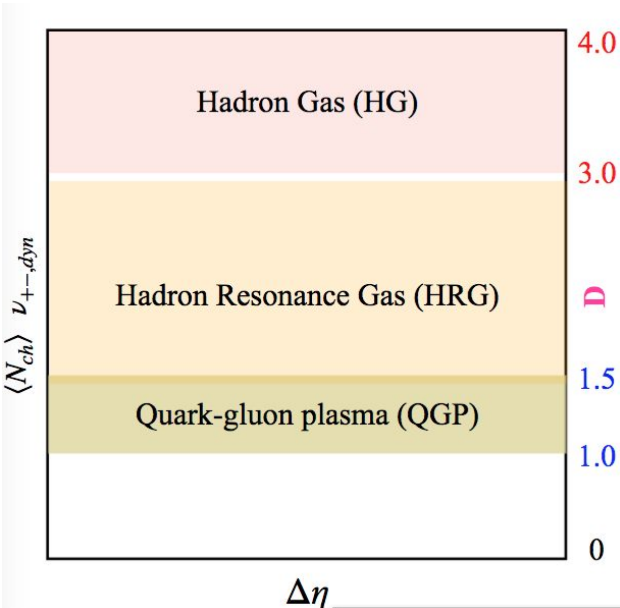


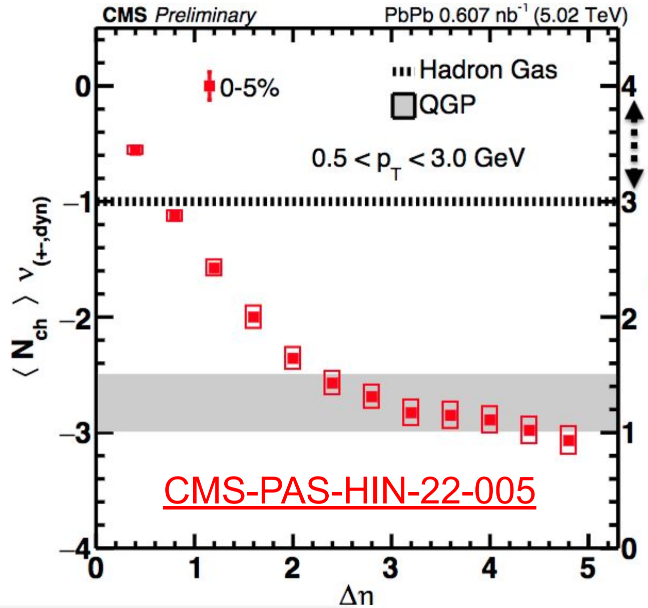
✓ Fluctuations decrease with the increase of Δη windows

✓ HIJING and HYDJET could not explain the experimental data results properly

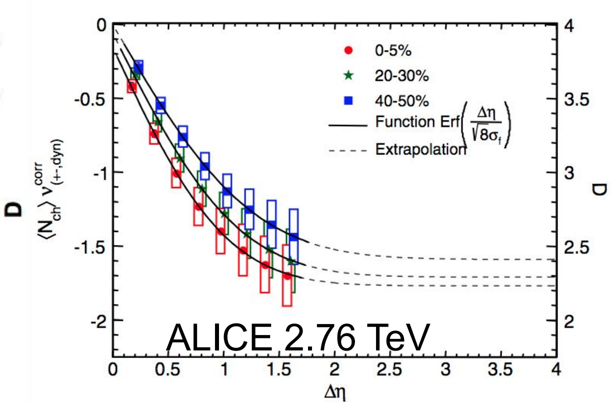
✓ Fluctuations diluted due to diffusion of charged hadrons in rapidity during the evolution of the system

Net charge Fluctuations: D measure





Phys. Rev. Lett. 110, 152301 (2013)



Phys. Rev. Lett. 85, 2076 (2000)

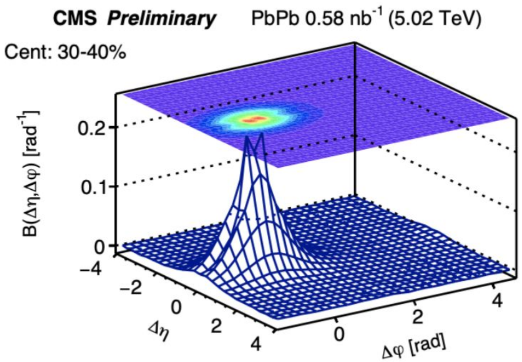
$$D = 4\frac{\langle(\delta Q)^2\rangle}{\langle N_{ch}\rangle} = \langle N_{ch}\rangle\langle \nu_{+-,dyn}\rangle + 4$$

$$D = \begin{cases} 4\text{ , HG} \\ 3\text{ , HRG} \\ 1\text{ - }1.5\text{ , QGP} \end{cases}$$

- ❖ **GCC correction needs to be applied with full phase space using MC. In Data we will not get the full phase space.**
- ❖ Comparing to ALICE, CMS results reach lower values of D-measure at larger Δη
- ❖ With larger Δη, D-measure reaches the fluctuations predicted with QGP

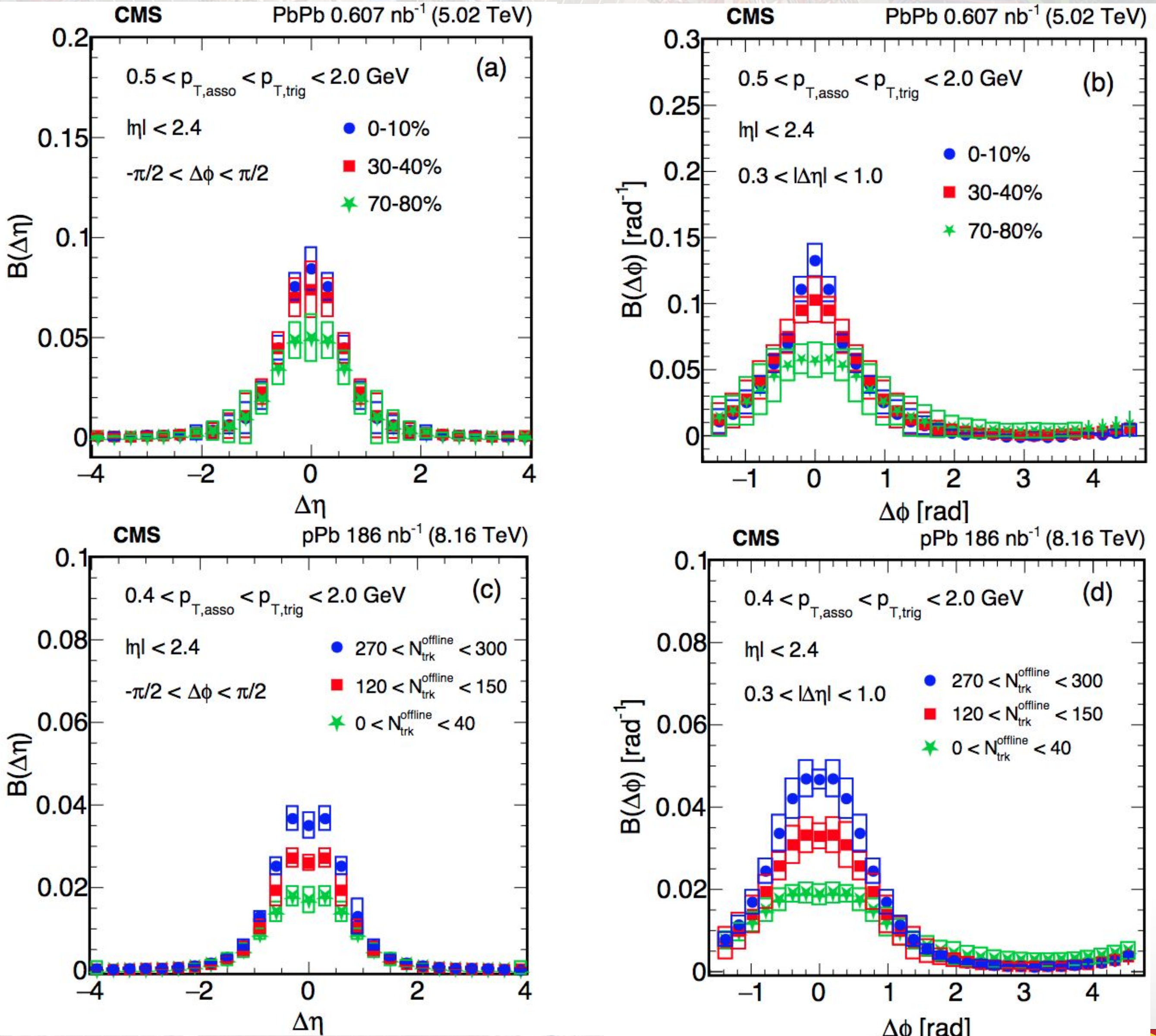
Balance Functions: PbPb & pPb

$$\frac{1}{N_{trig}} \frac{d^2 N^{pair}}{d\Delta\eta\, d\Delta\phi} = C(1,2)$$



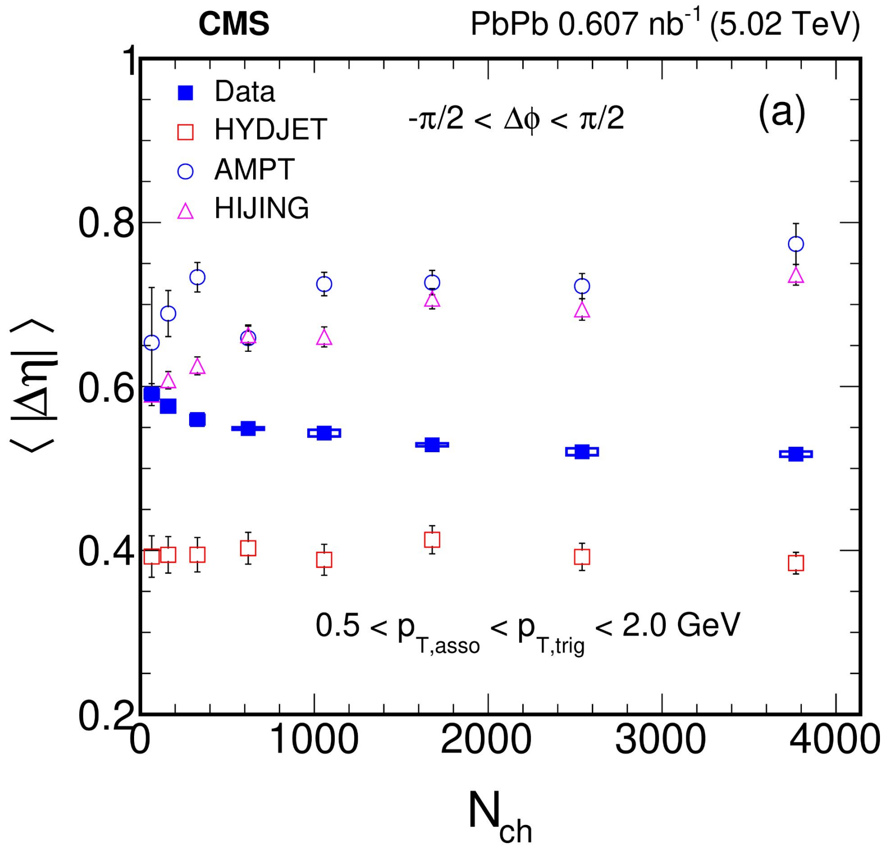
B = 1/2 [*C*(+ , −) + *C*(− , +) − *C*(− , −) − *C*(+ , +)]

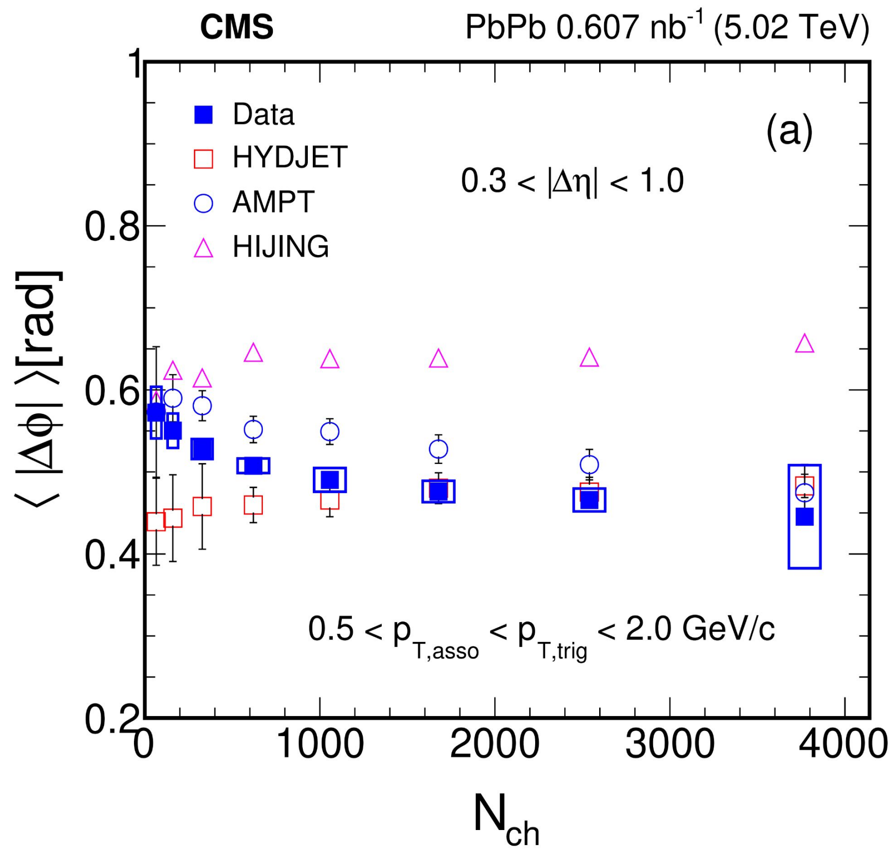
arXiv:2307.11185



⟨|Δη|⟩ and ⟨|Δφ|⟩ vs. multiplicity – PbPb

arXiv:2307.11185

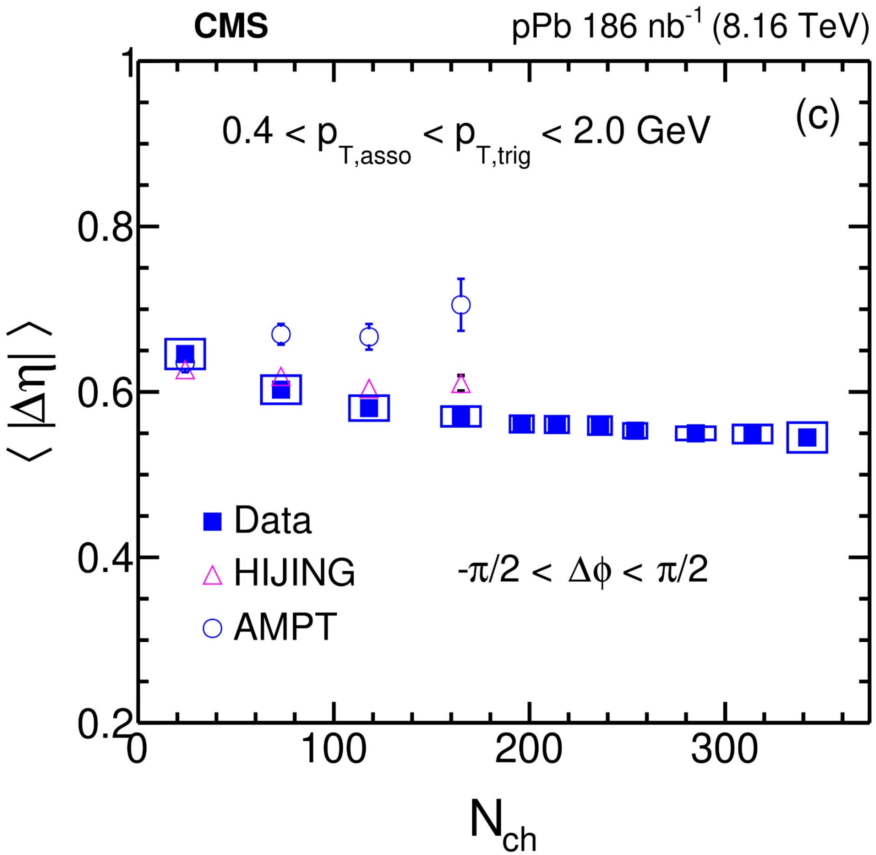


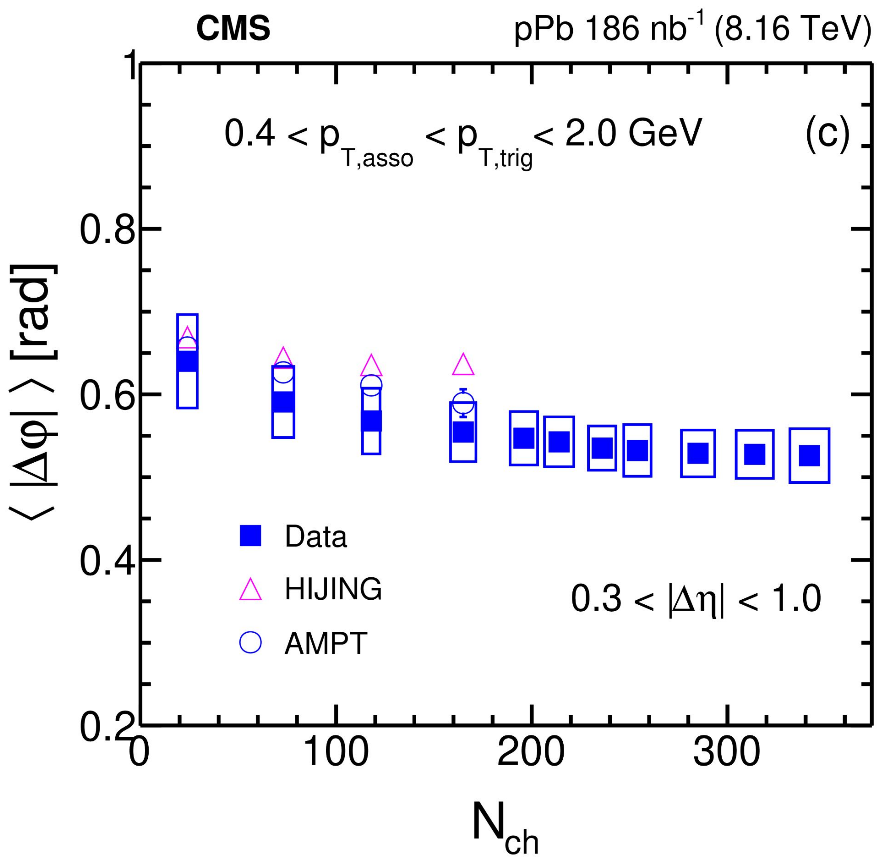


- ❖ Narrowing of the balance function with increasing multiplicity in Δη and Δφ.
- ❖ Data not described by either HYDJET , HIJING or APMT in Δη.
- ❖ Narrowing in Δφ described by AMPT connection to radial flow.

⟨|Δη|⟩ and ⟨|Δφ|⟩ vs. multiplicity – pPb

arXiv:2307.11185

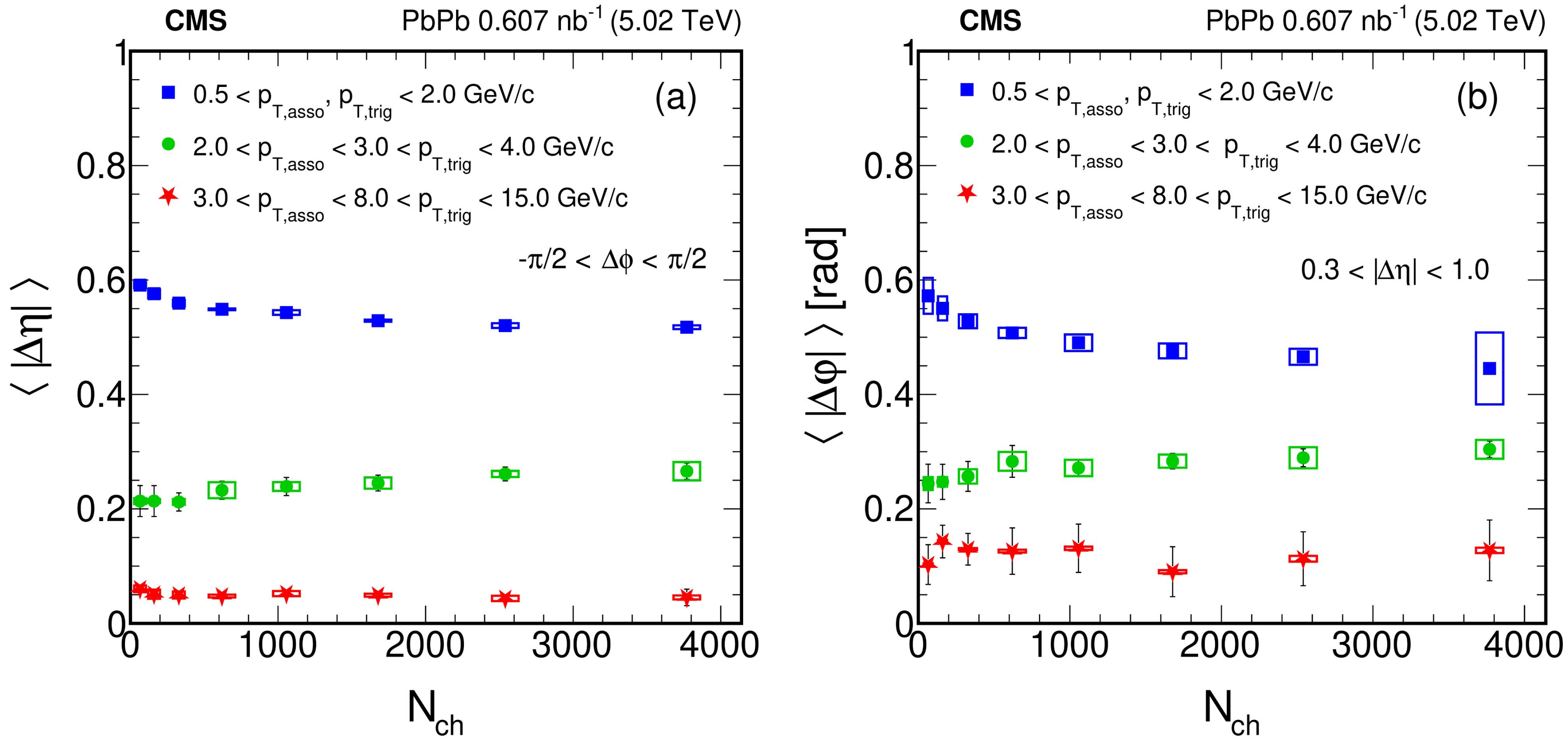




- A similar trend observed in pPb.
- Narrowing of the balance function with increasing multiplicity in $\Delta\eta$ and $\Delta\varphi$.
- Narrowing in $\Delta\varphi$ described by AMPT.

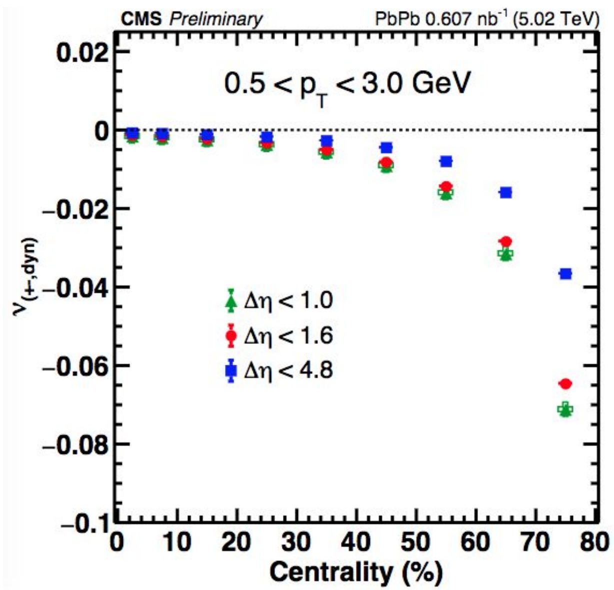
⟨|Δη|⟩ and ⟨|Δφ|⟩ vs. multiplicity and p_T

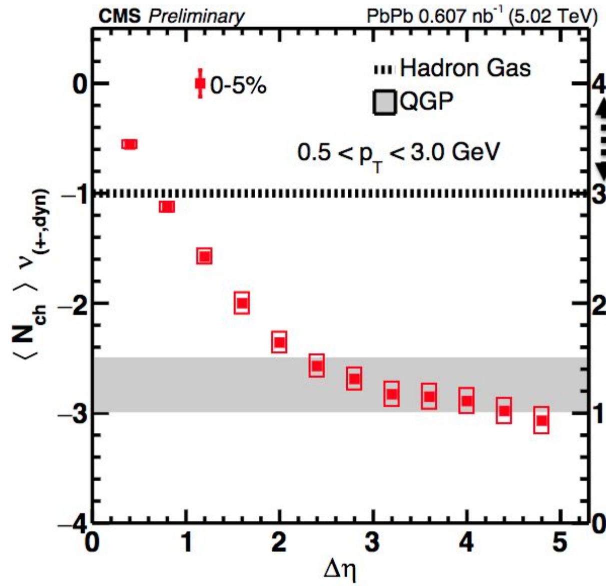
arXiv:2307.11185

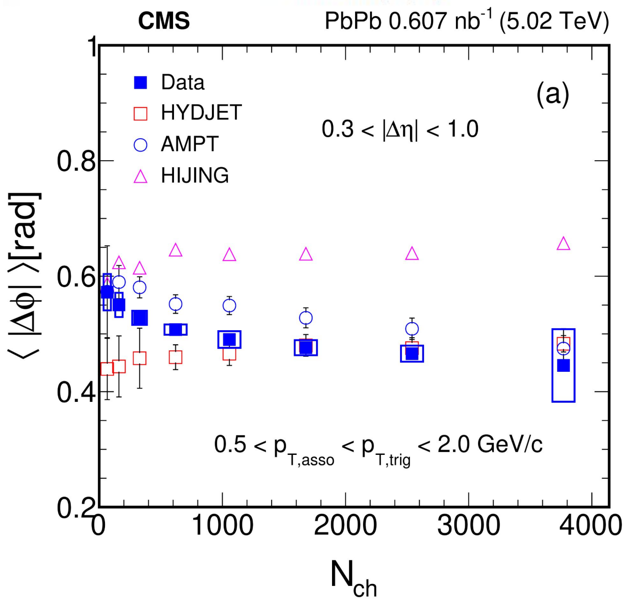


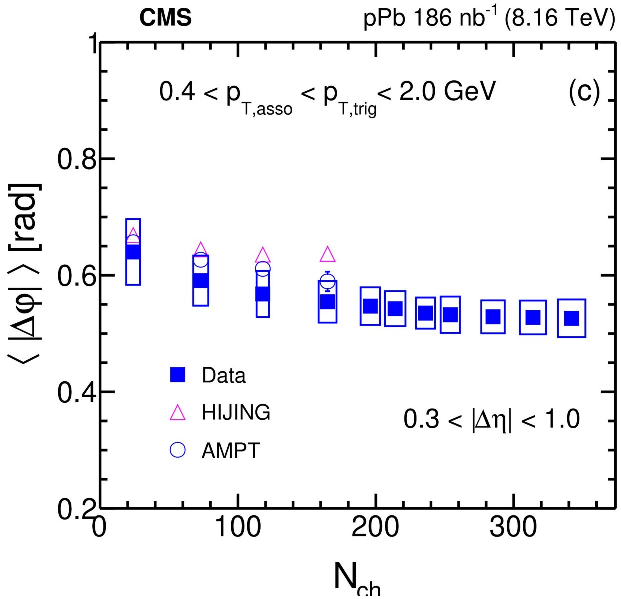
- ❖ Balance function becomes narrower with increasing in pT.
- ❖ Less multiplicity dependence is observed for higher- pT.
- ❖ Narrowing of the balance functions in low-pT region is the effect from the bulk.

Summary









- v_{dyn} value decreases with the increase of $\Delta\eta$ windows and saturating towards central collisions
- D-measure reaches the fluctuations predicted with QGP
- Narrowing of the width with increasing multiplicities is consistent with the delayed hadronization
- Narrowing in Δφ observed in AMPT as well as in Data..
- Width does not depends on multiplicity for higher pT

A similar trend is observed in pPb collisions!!