

Measurement of charge-dependent fluctuations and correlations at CMS

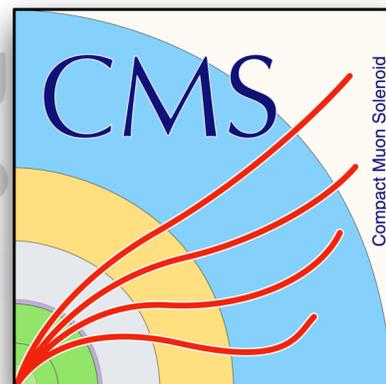
Subash Behera for the CMS Collaboration

Indian Institute of Technology, Madras

7th edition of the International Conference on the Initial Stages in High-Energy Nuclear Collisions

The VII-th International Conference on the
Initial Stages of High-Energy
Collisions (IS2023)

19–23 Jun 2023, Copenhagen



Outline

Experiment at the LHC, CERN

2018-Nov-08 20:47:53.005743 GMT

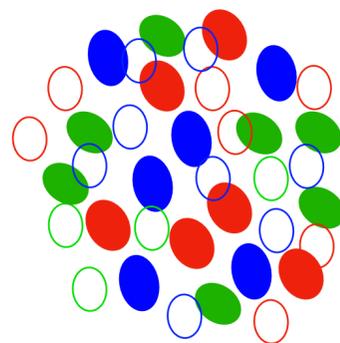
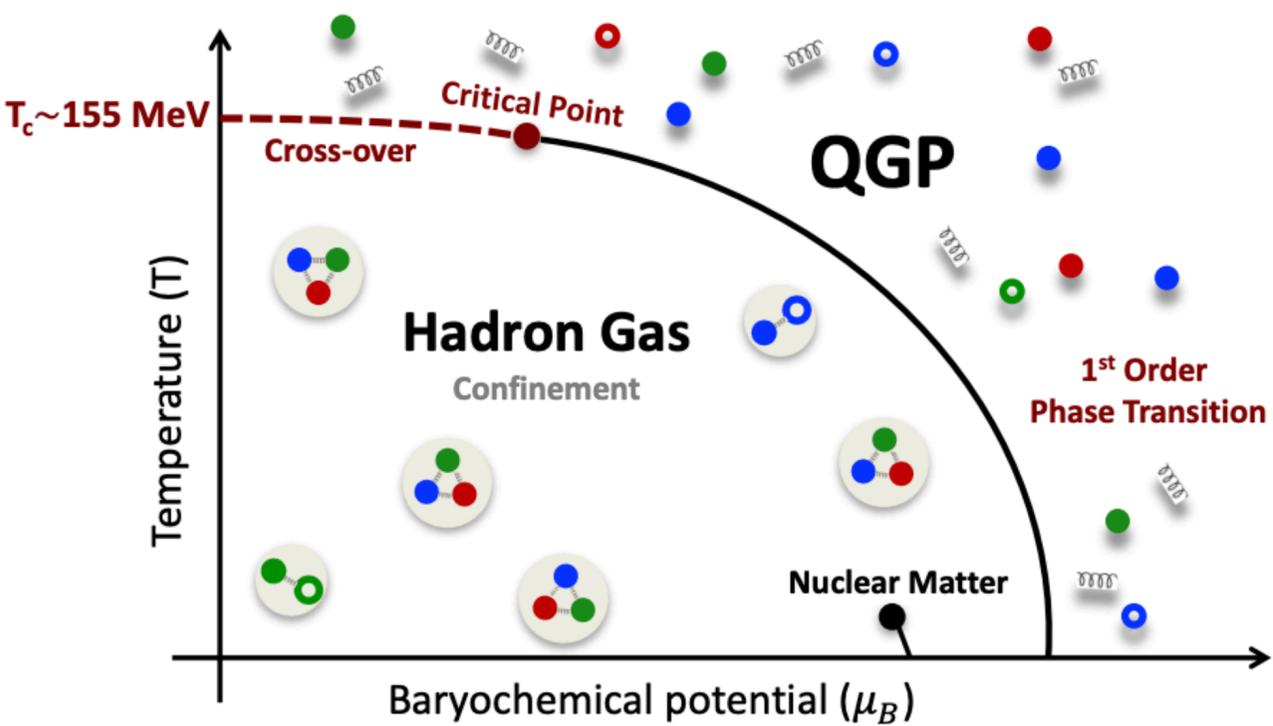
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- Introduction
- Motivation
- CMS detector
- Results
- Summary

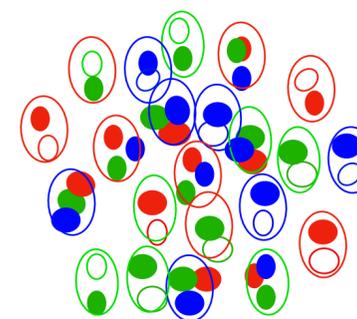


Motivation: QGP properties

Relevant charge carriers



QGP



Hadron gas (HG)

$$q = \pm \frac{1}{3}, \pm \frac{2}{3}, \quad q^2 = \frac{1}{9}, \frac{4}{9}$$

$$q = \pm 1, \pm 2, \quad q^2 = 1, 4$$

► Fluctuations in hadron gas is higher than in QGP medium.

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

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

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

[Phys. Rev. Lett. 85, 2076](#)

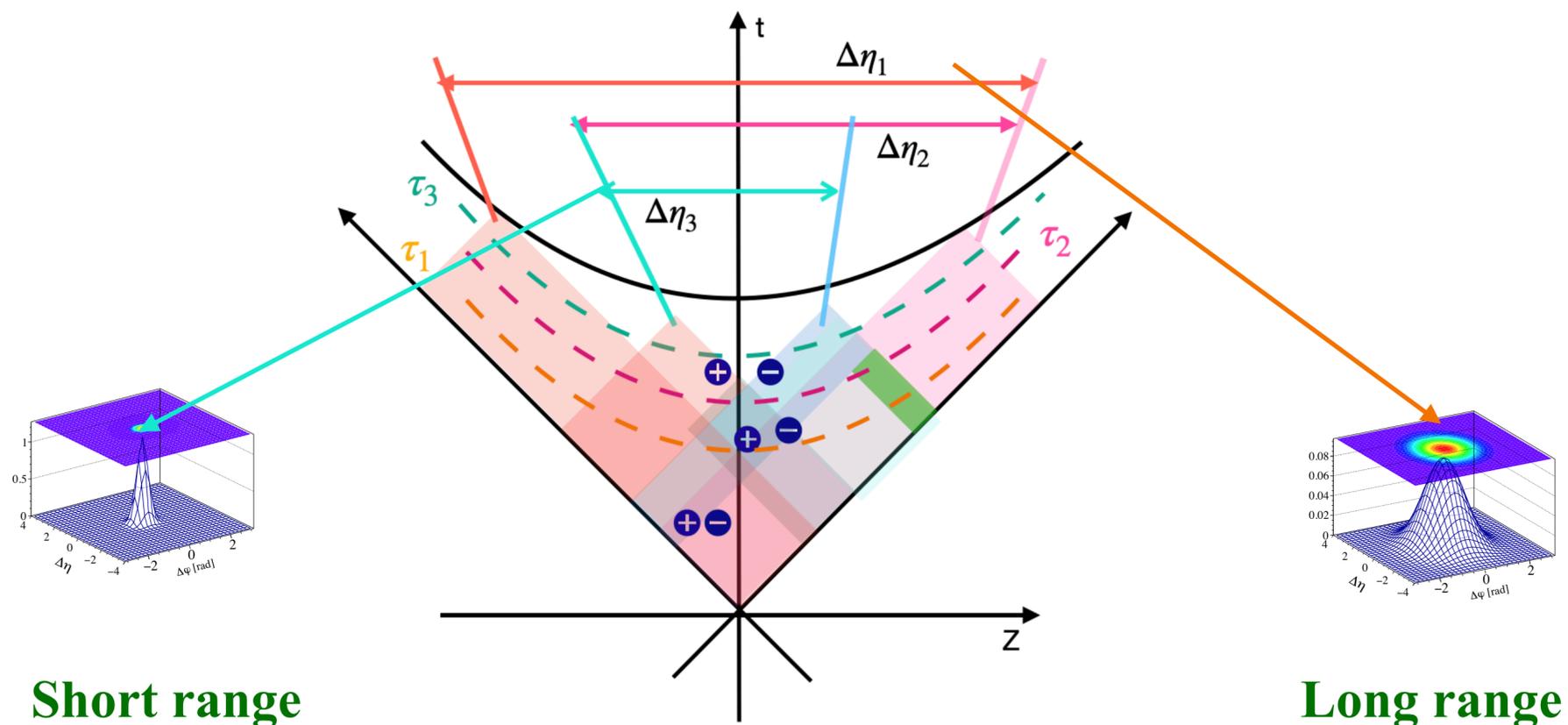
Why EbyE fluctuations?

- To study the properties of the phase transition.
- To locate the critical end point.

Motivation: QGP properties

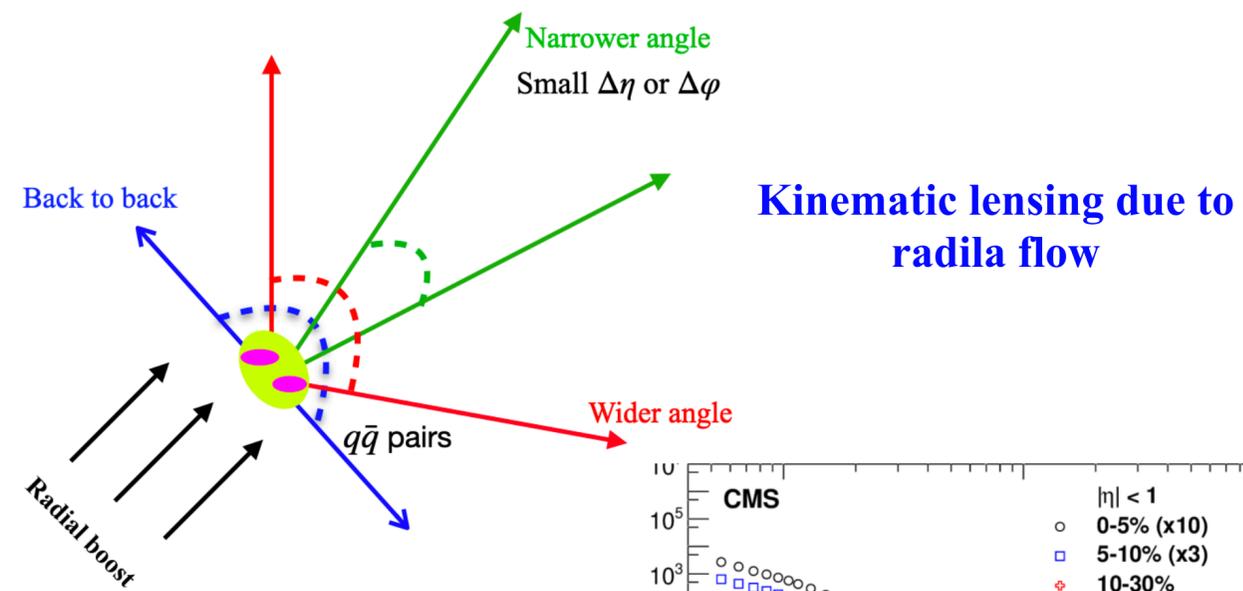
Balancing charge separation

- ▶ Law of nature “charge is conserved”
- ▶ Longitudinal width of the correlation is related to time the correlation is established.

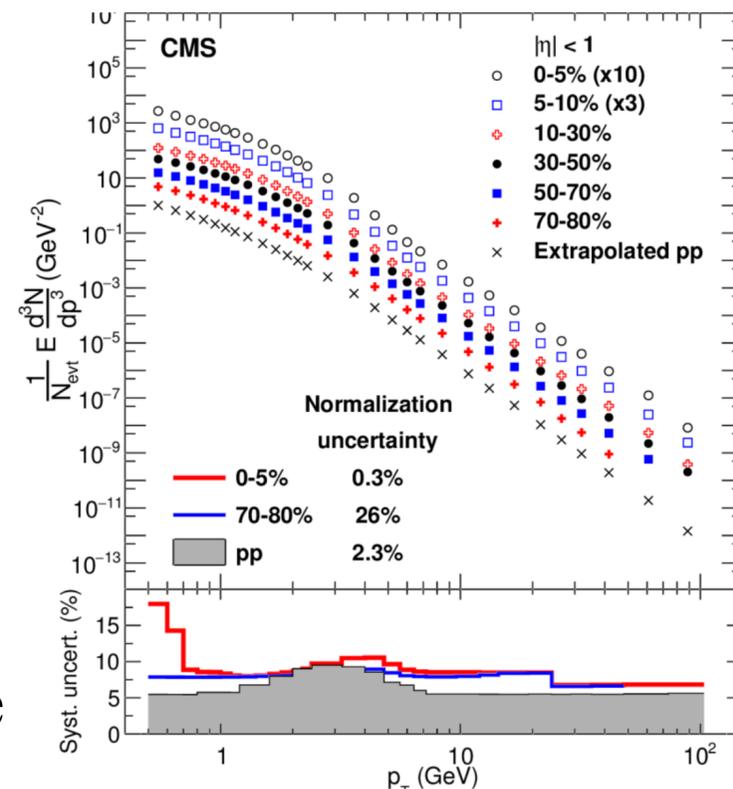


Radial flow

$$\Delta p_z = m_T \cdot \sinh(\Delta y) \approx m_T \cdot \Delta y$$



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



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- ▶ Increasing the centrality and the transverse momentum decreases the width of balance function due to the **radial flow**

Observables

► Balance functions are constructed from four possible charge combinations

Phys. Lett. B 724 (2013) 213

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

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

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

Balance functions are sensitive to Physics

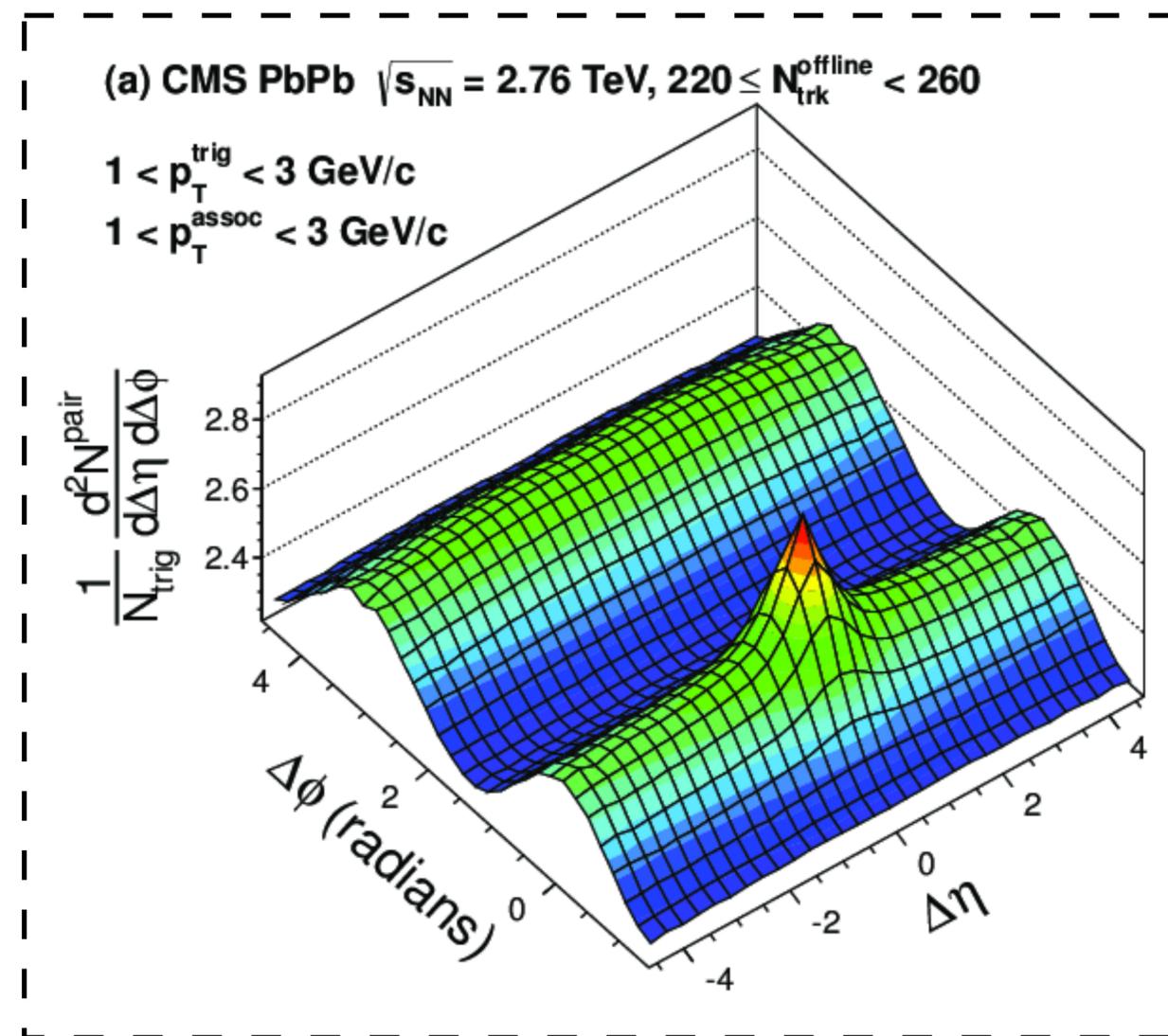
● Late or early hadronization

● Collision dynamics: radial flow

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

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

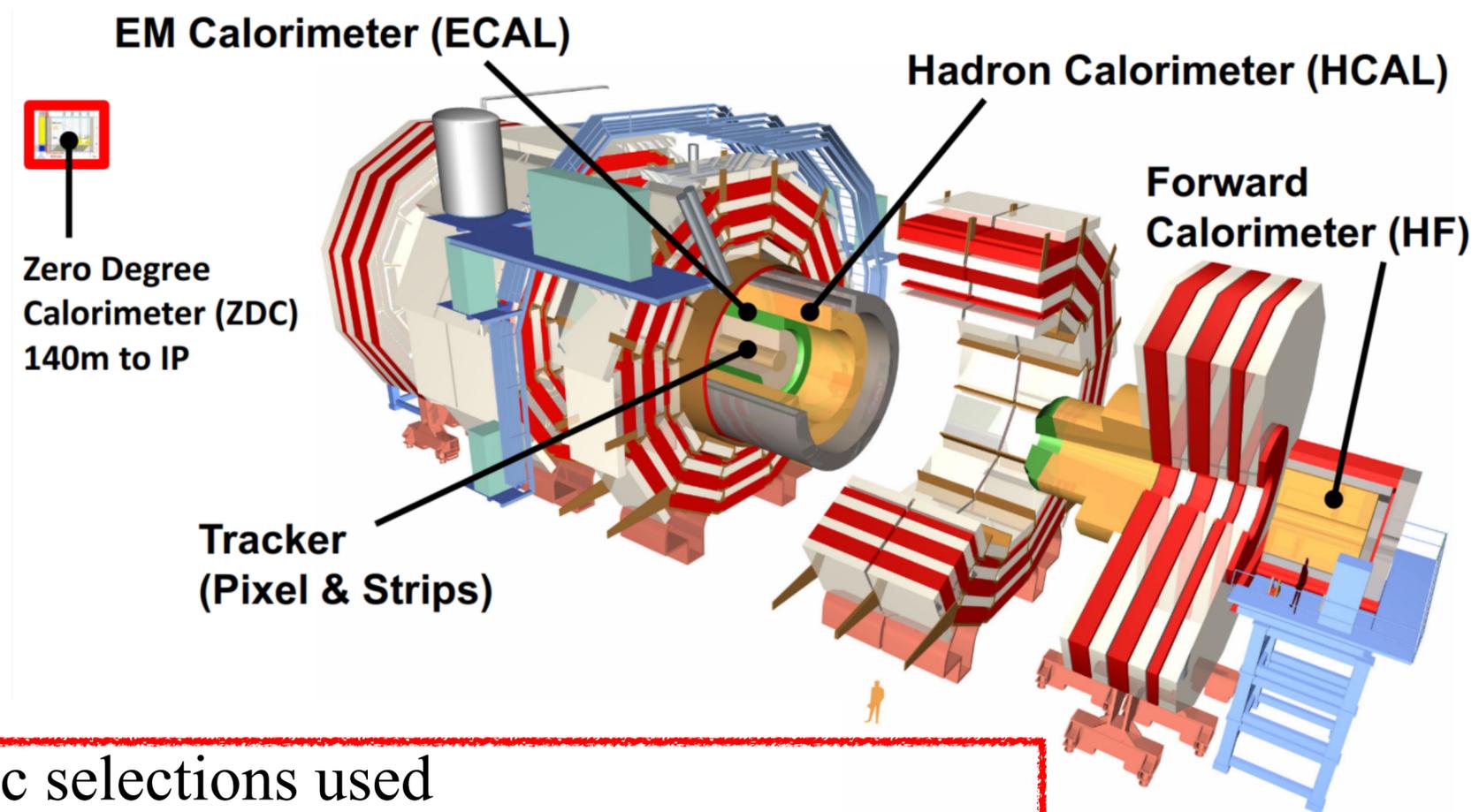
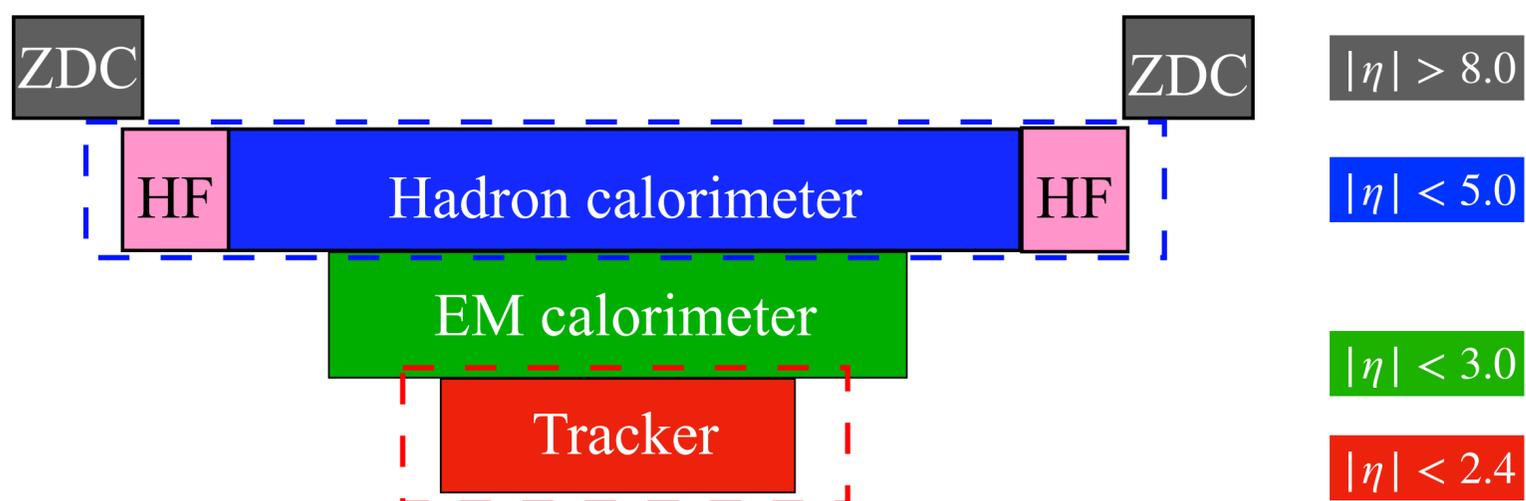
$$\langle |\Delta\phi| \rangle = \frac{\sum_i B(\Delta\phi_i) |\Delta\phi_i|}{\sum_i B(\Delta\phi_i)}$$



Charge hadron correlation functions

CMS detector

► Datasets: PbPb 2018 data at $\sqrt{s_{NN}} = 5.02$ TeV, pPb 2016 at $\sqrt{s_{NN}} = 8.16$ TeV and 2017 pp at 5.02 TeV.



Why CMS Detector?

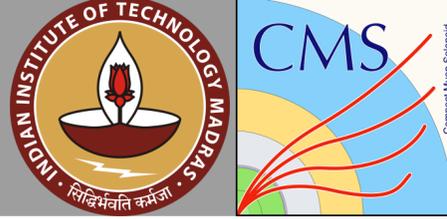
- Good precision
- Large rapidity coverage

Ideal for capturing balancing partners and initial state fluctuations

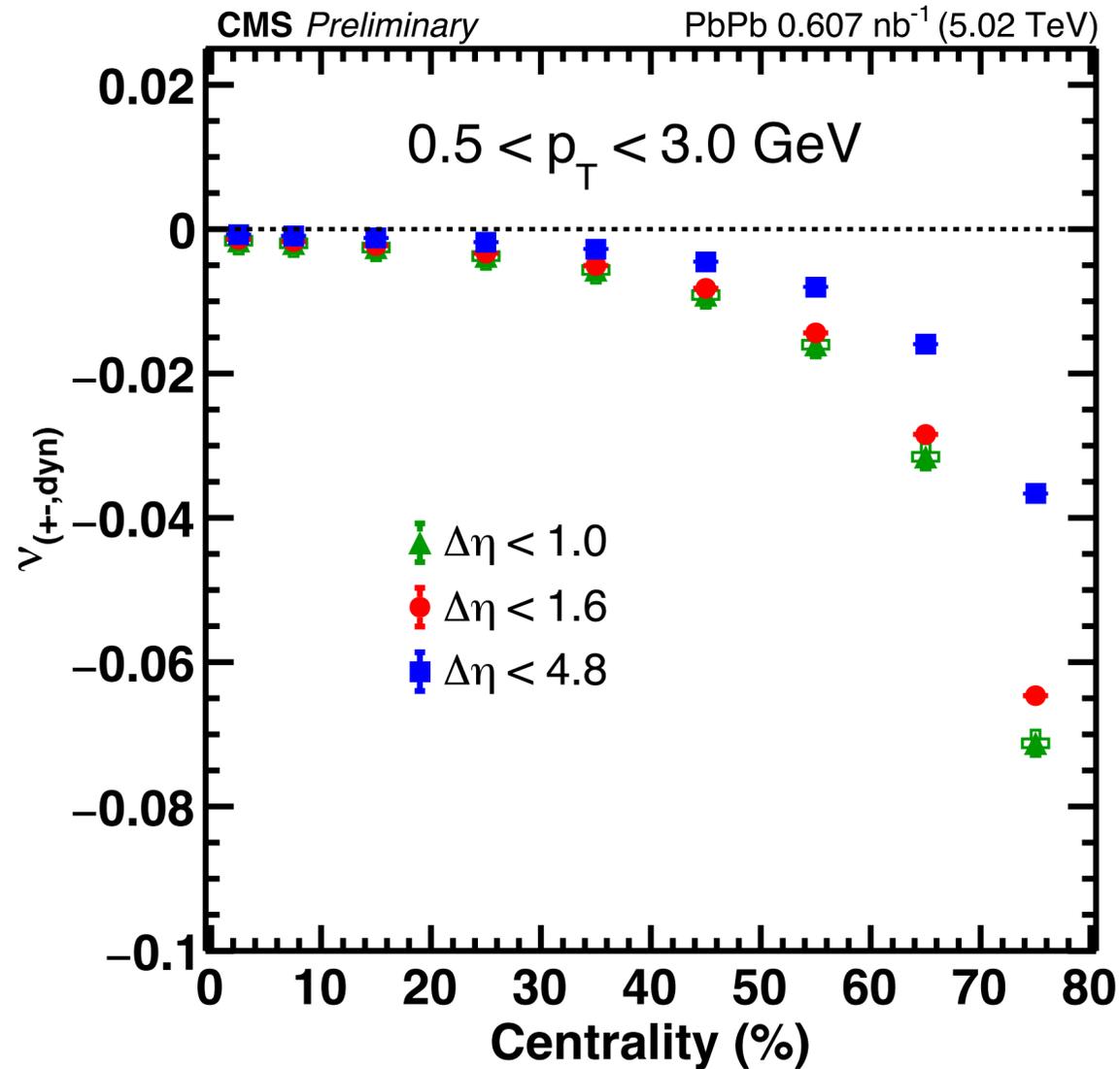
Kinematic selections used

- ◉ $p_T > 0.4$ GeV and 0.5 GeV (pPb, pp and PbPb)
- $|\eta| < 2.4$

Centrality dependence



CMS-PAS-HIN-22-005



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

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

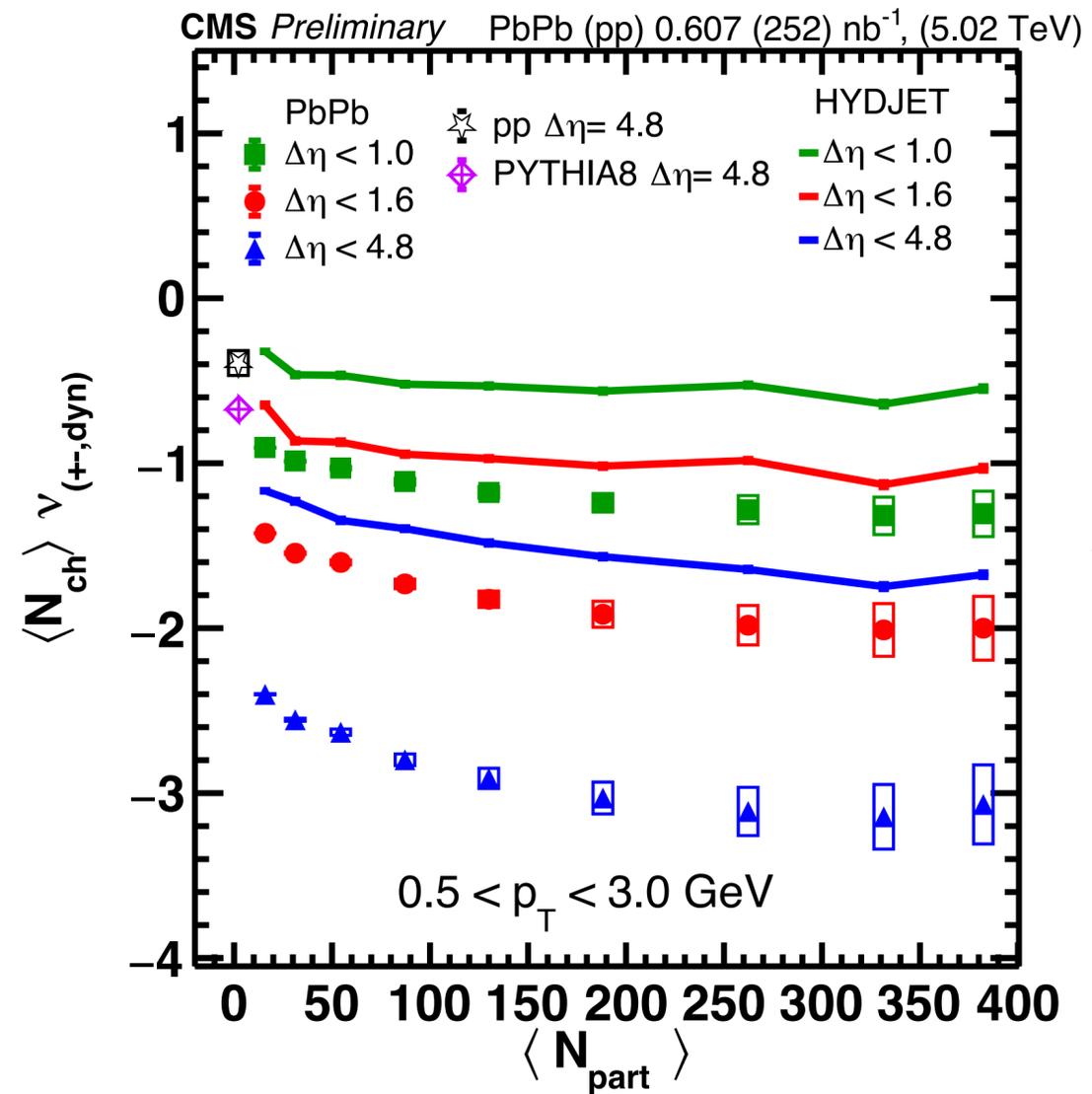
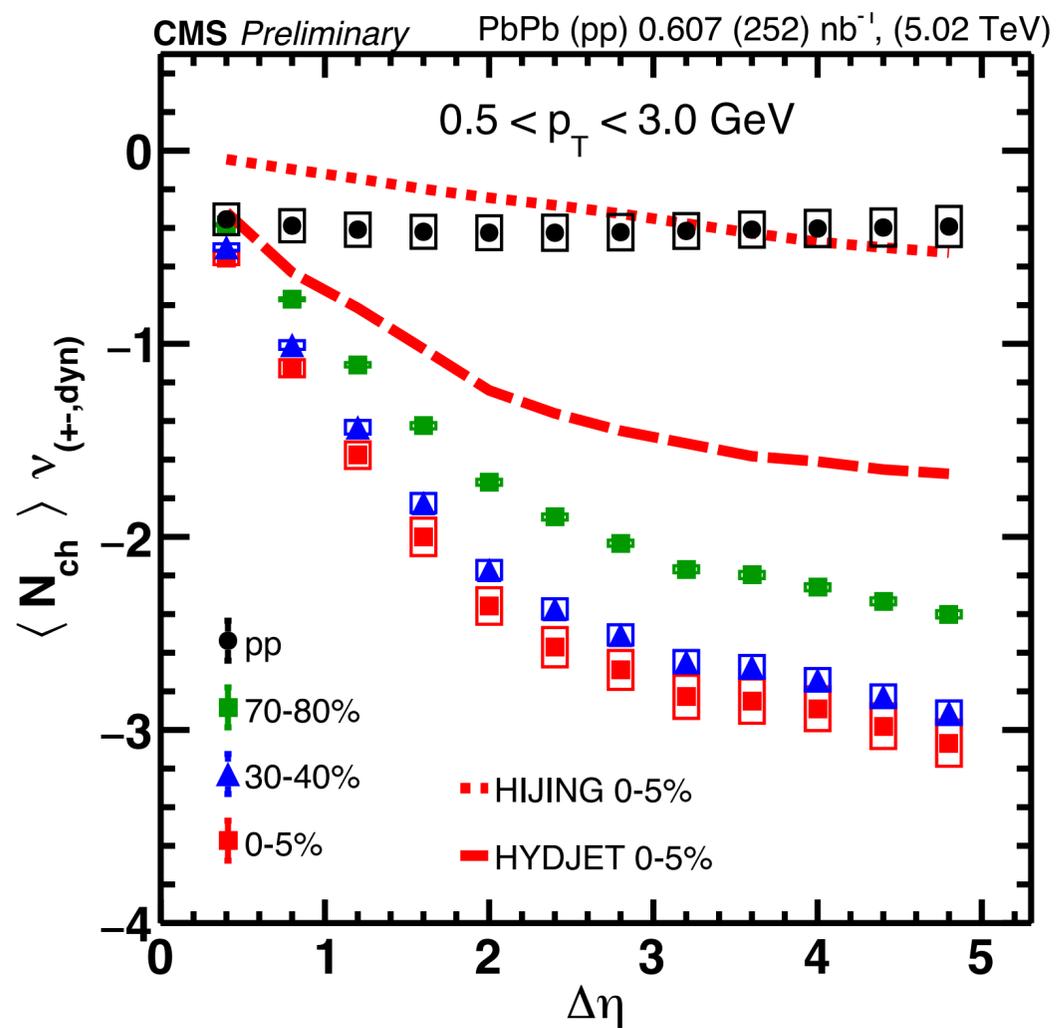
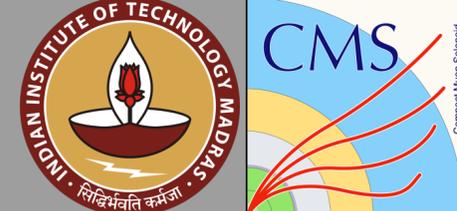
- ⊙ $\nu_{(+-,dyn)} = 0$; no dynamical fluctuations
- ⊙ $\nu_{(+-,dyn)} > 0$; same sign correlations dominates
- ⊙ $\nu_{(+-,dyn)} < 0$; significance of opposite sign correlations dominates

✓ $\nu_{(+-,dyn)}$ value decreases with the increase of η window

✓ Smaller $|\nu_{(+-,dyn)}|$ value towards the central collision signifies the equilibration of + and - charges



D as a function of $\langle N_{\text{part}} \rangle$ and $\Delta\eta$



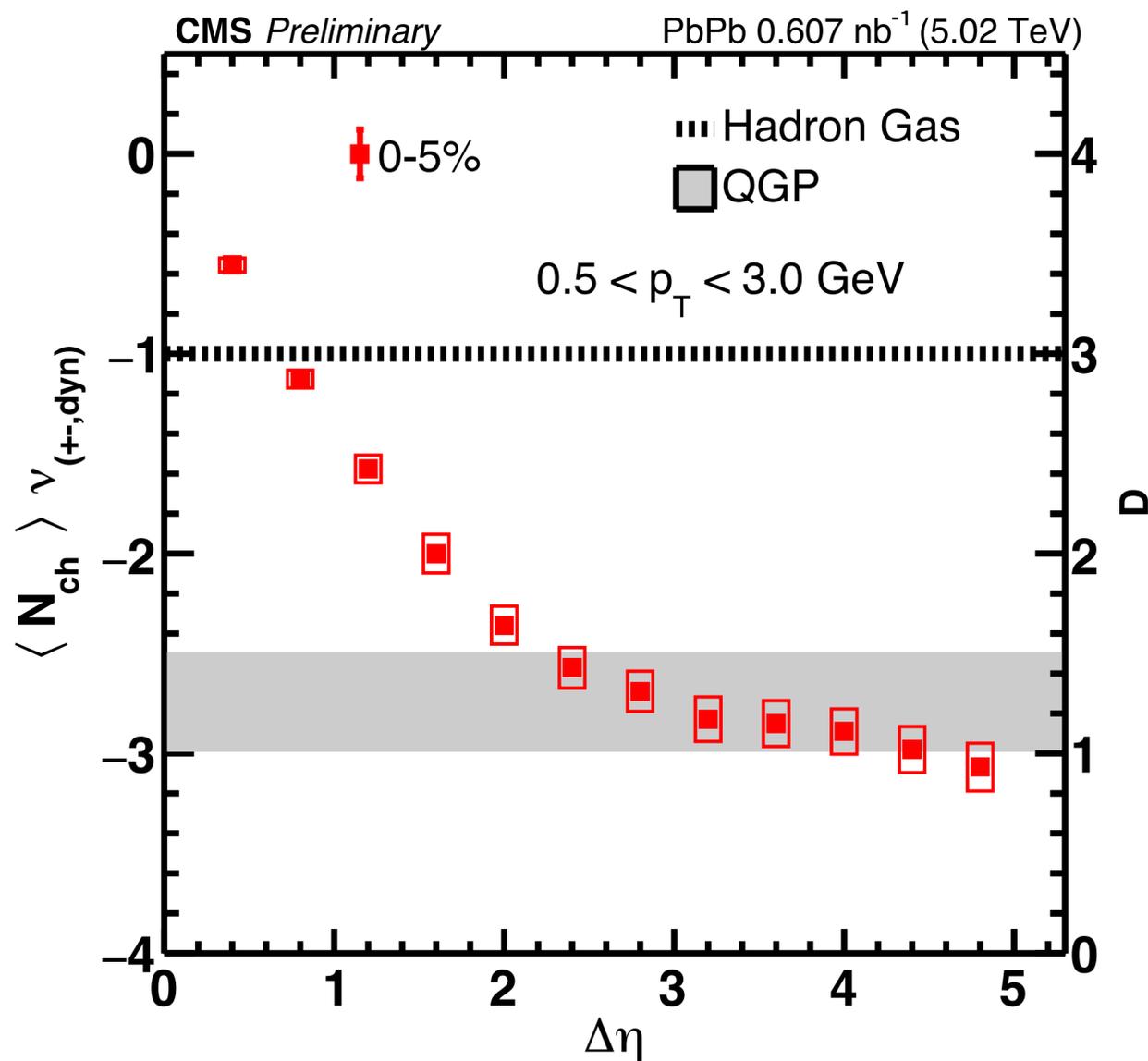
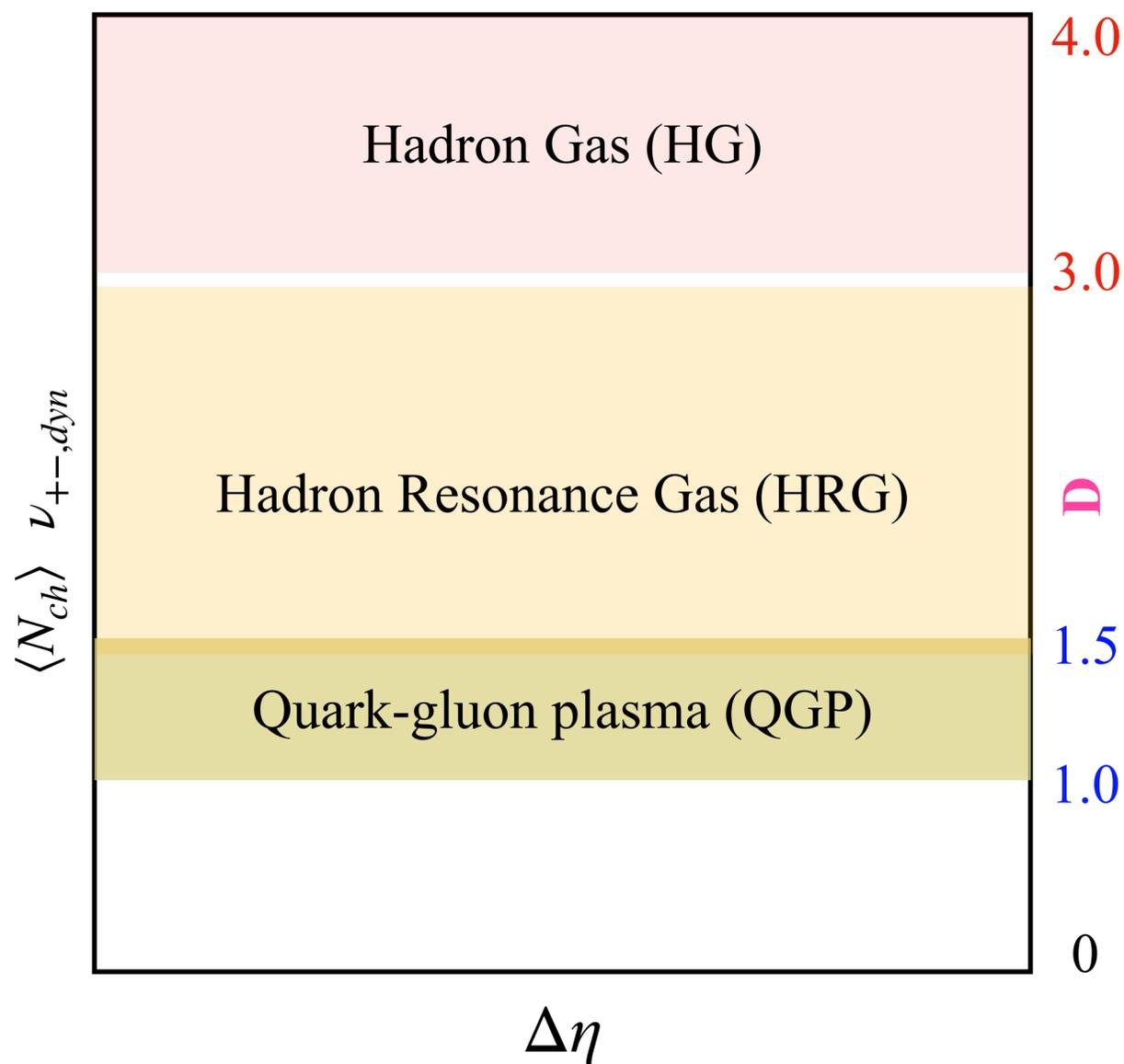
✓ Fluctuations decreases with the increase of $\Delta\eta$ windows.

✓ HIJING and HYDJET can not explain the experimental data results properly.

✓ Measured fluctuations may diluted due to diffusion of charged hadrons in rapidity during the evolution of the system.

CMS-PAS-HIN-22-005

$\Delta\eta$ dependence



[Phys. Rev. C 79, 024906](#)

$$D = \langle N_{ch} \rangle \langle \nu_{+-,dyn} \rangle + 4$$

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

[Phys. Rev. Lett. 85, 2076](#)

[Phys. Rev. Lett. 110, 152301](#)

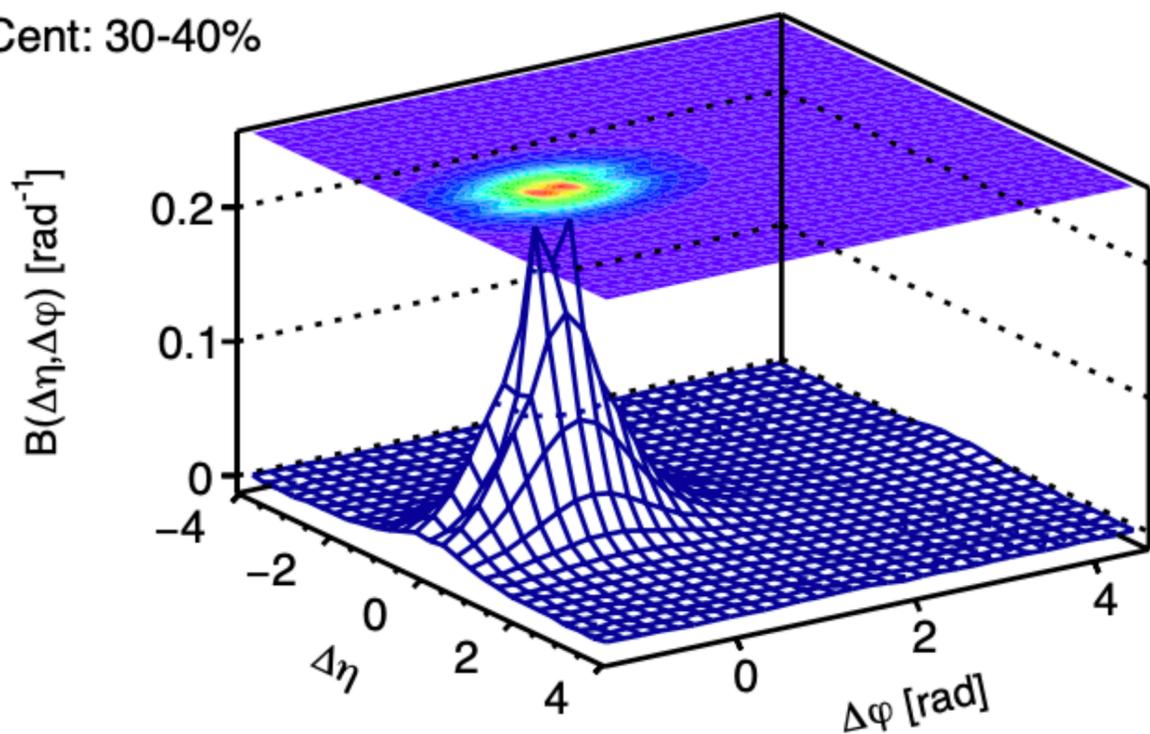
CMS results consistent with QGP prediction for larger $\Delta\eta$

CMS-PAS-HIN-22-005

Balance function

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

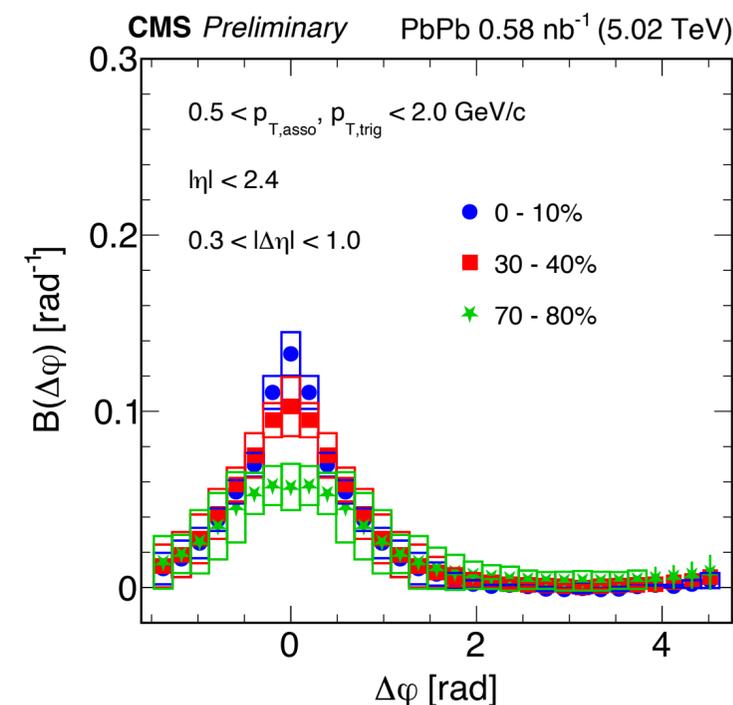
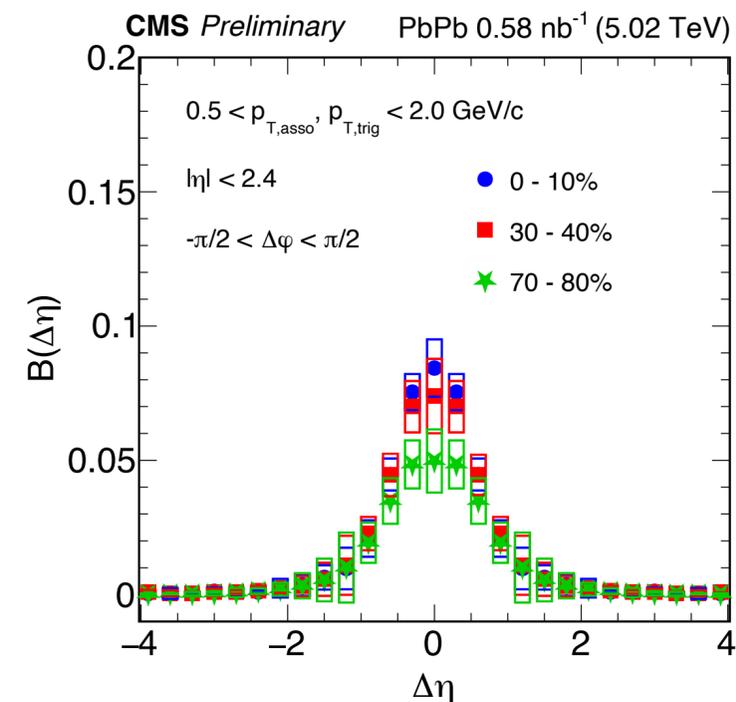
CMS Preliminary PbPb 0.58 nb⁻¹ (5.02 TeV)
Cent: 30-40%



Projection in $\Delta\eta$

CMS-PAS-HIN-21-017

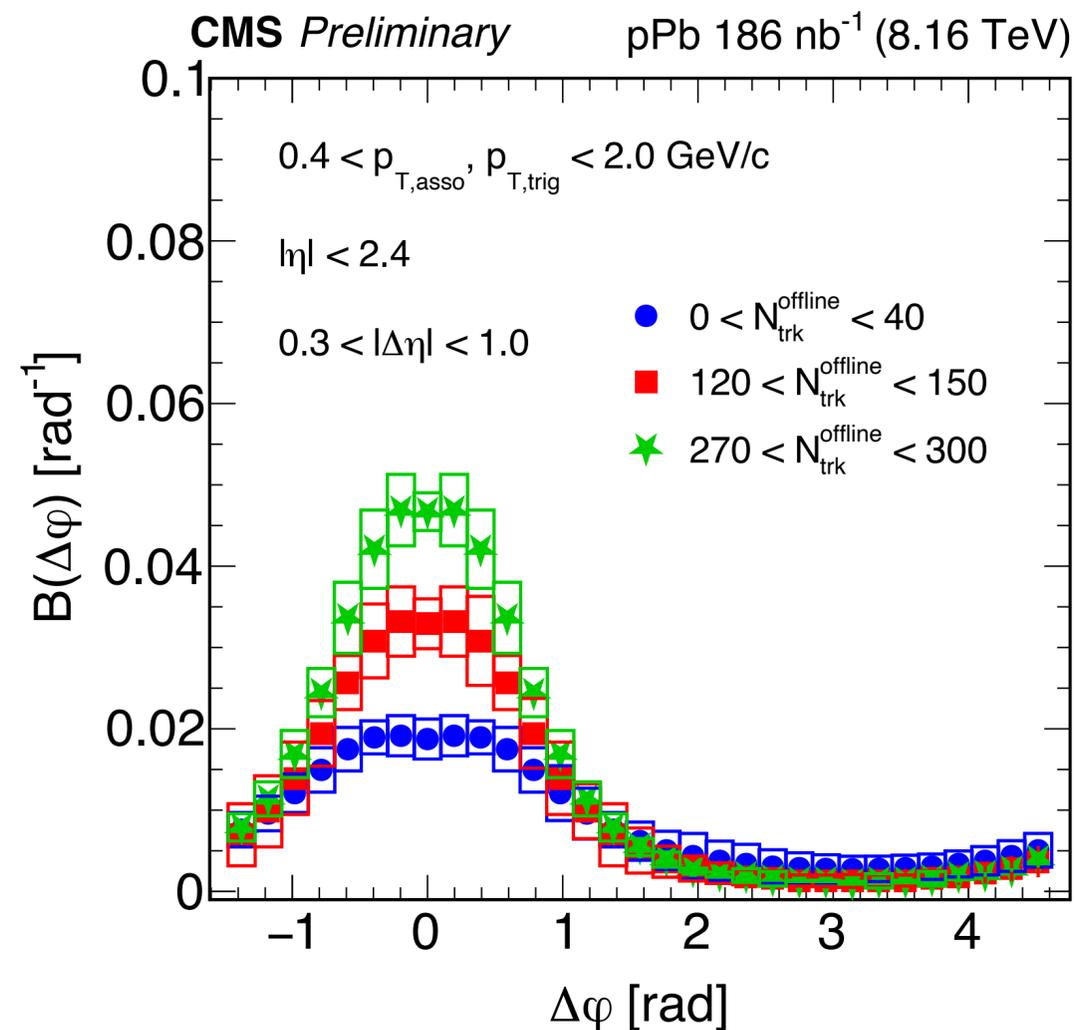
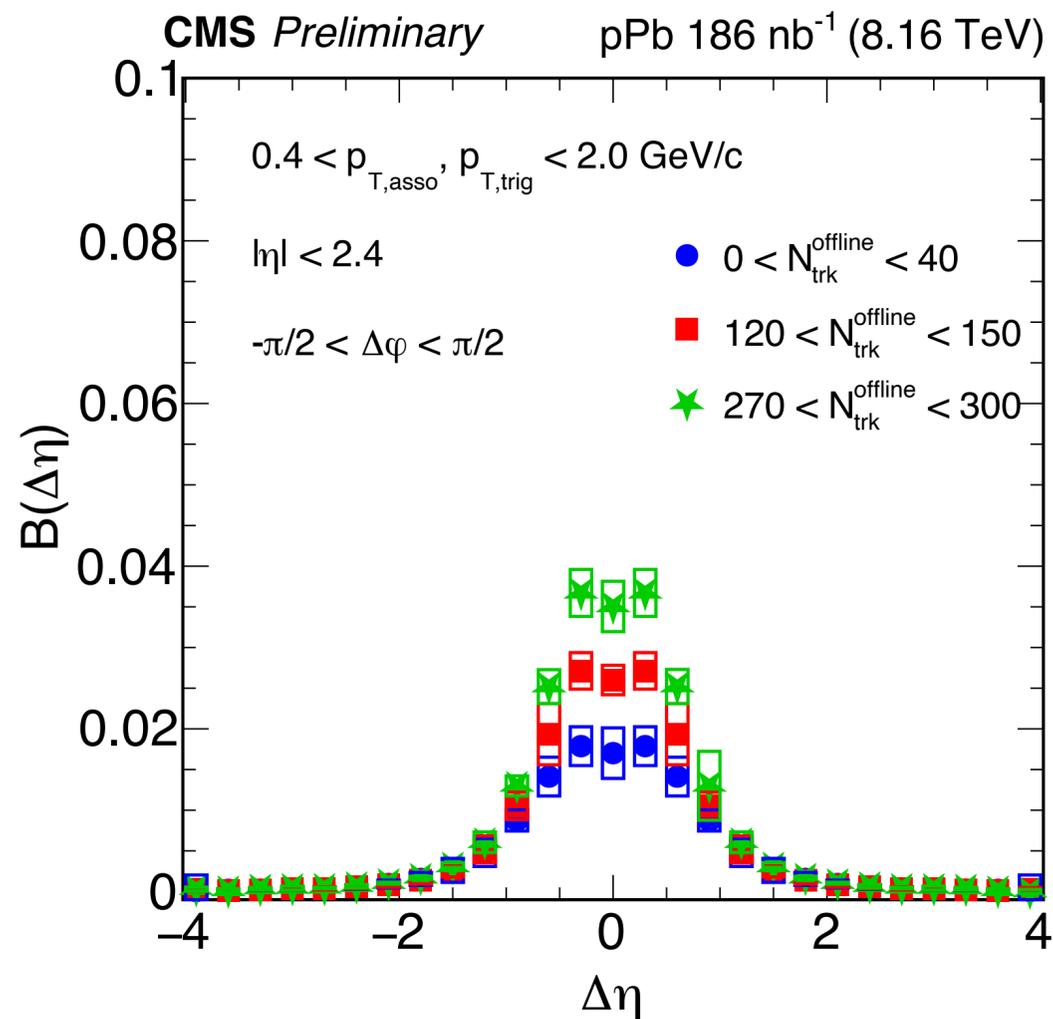
Projection in $\Delta\phi$



► Narrowing of the balance function is observed from high to low track multiplicity collisions.

Balance function

CMS-PAS-HIN-21-017

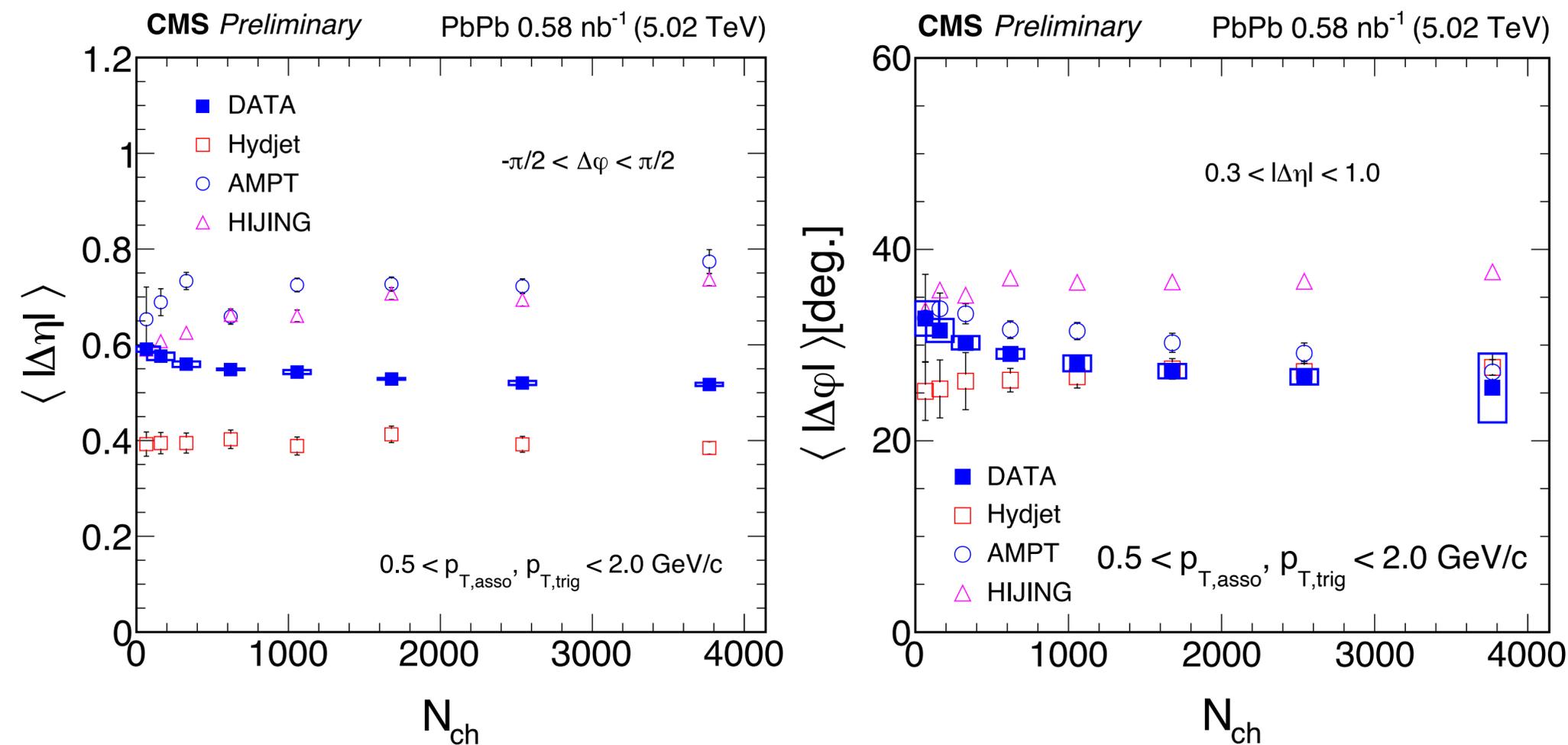


Similar trend observed in pPb collisions

► Narrowing of the balance function is observed from high to low track multiplicity collisions.

$\langle |\Delta\eta| \rangle$ and $\langle |\Delta\phi| \rangle$ Vs multiplicity class

■ Data ○ AMPT △ HIJING □ HYDJET



● Narrowing of the balance function with increasing multiplicity in $\Delta\eta$ and $\Delta\phi$.

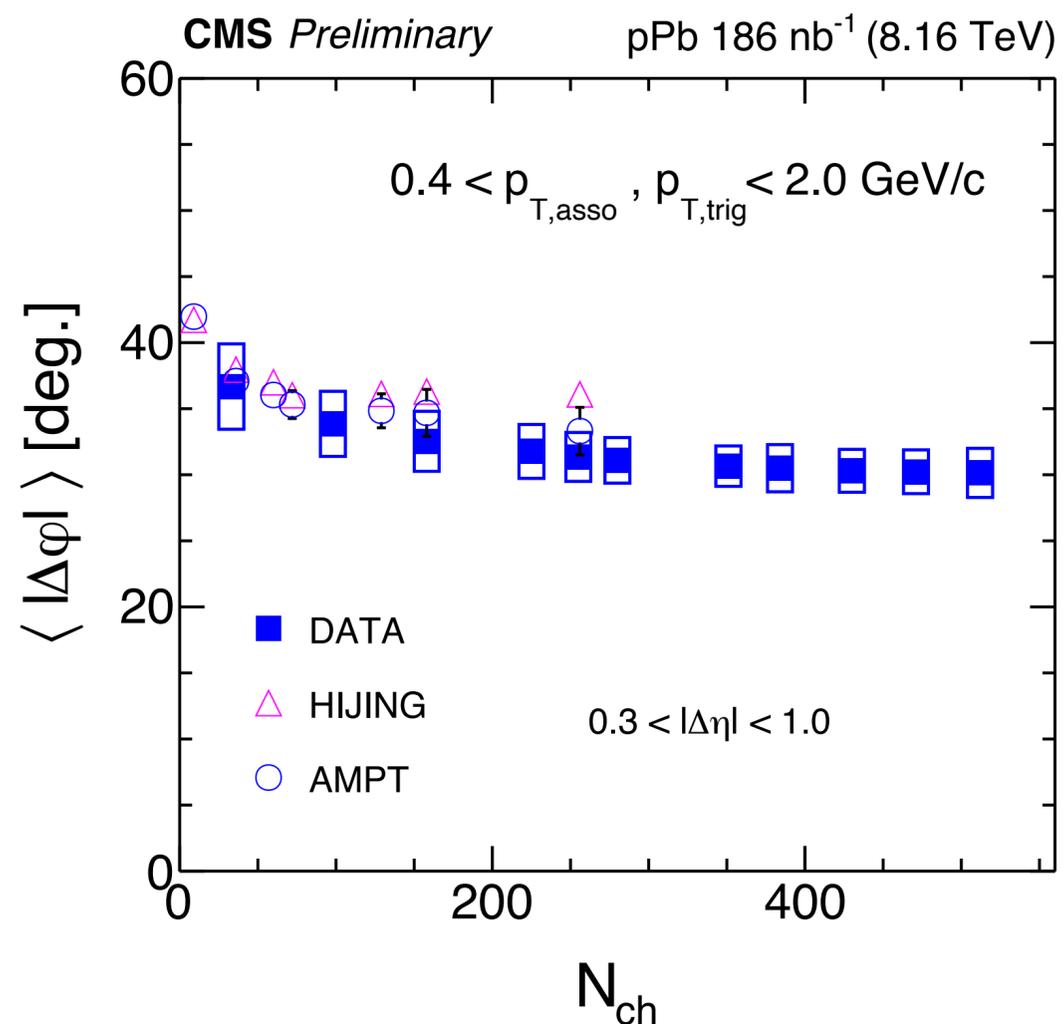
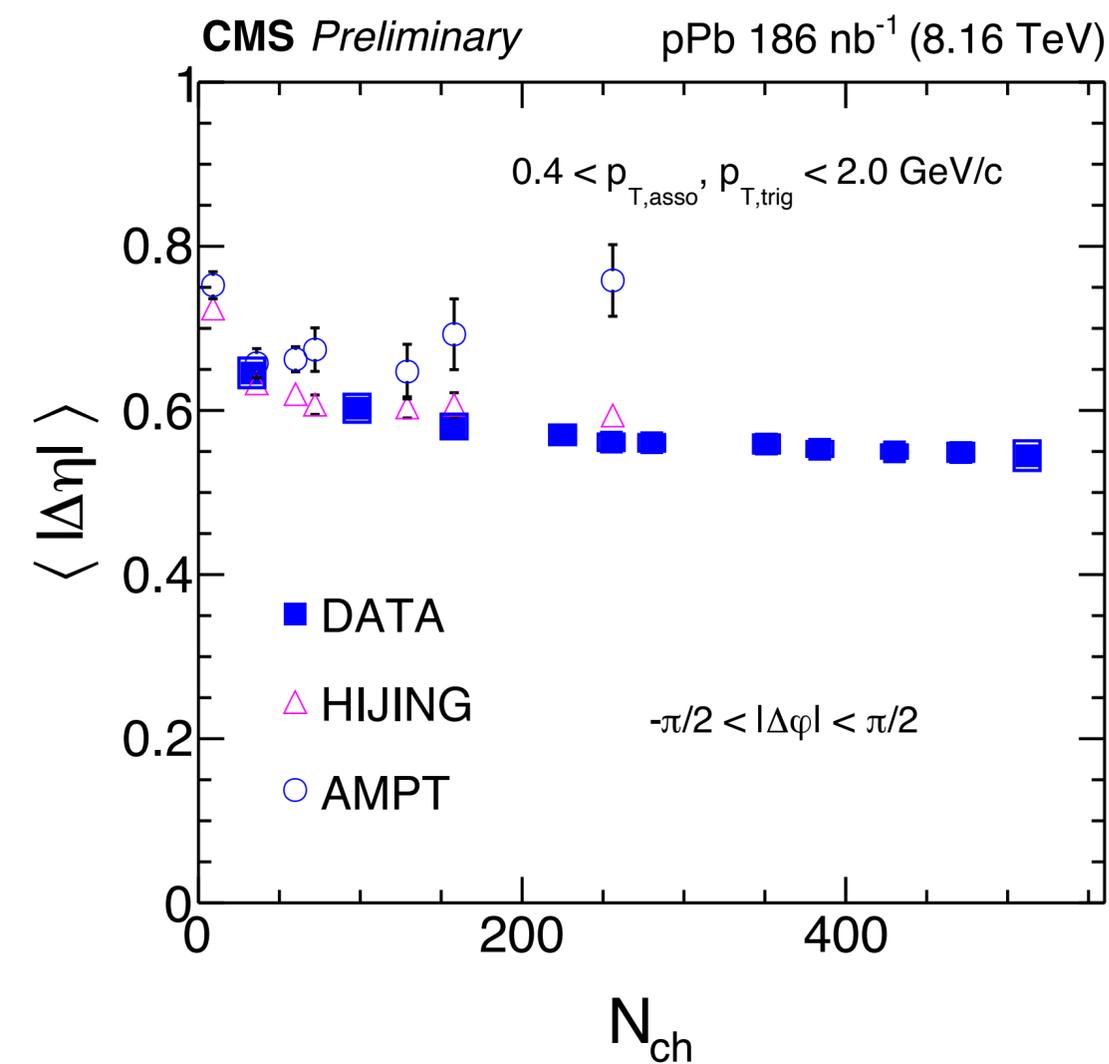
● Data not described by either HYDJET, HIJING or APMT in $\Delta\eta$.

-Narrowing in $\Delta\phi$ described by AMPT connection to radial flow.

CMS-PAS-HIN-21-017

$\langle |\Delta\eta| \rangle$ and $\langle |\Delta\phi| \rangle$ Vs multiplicity class

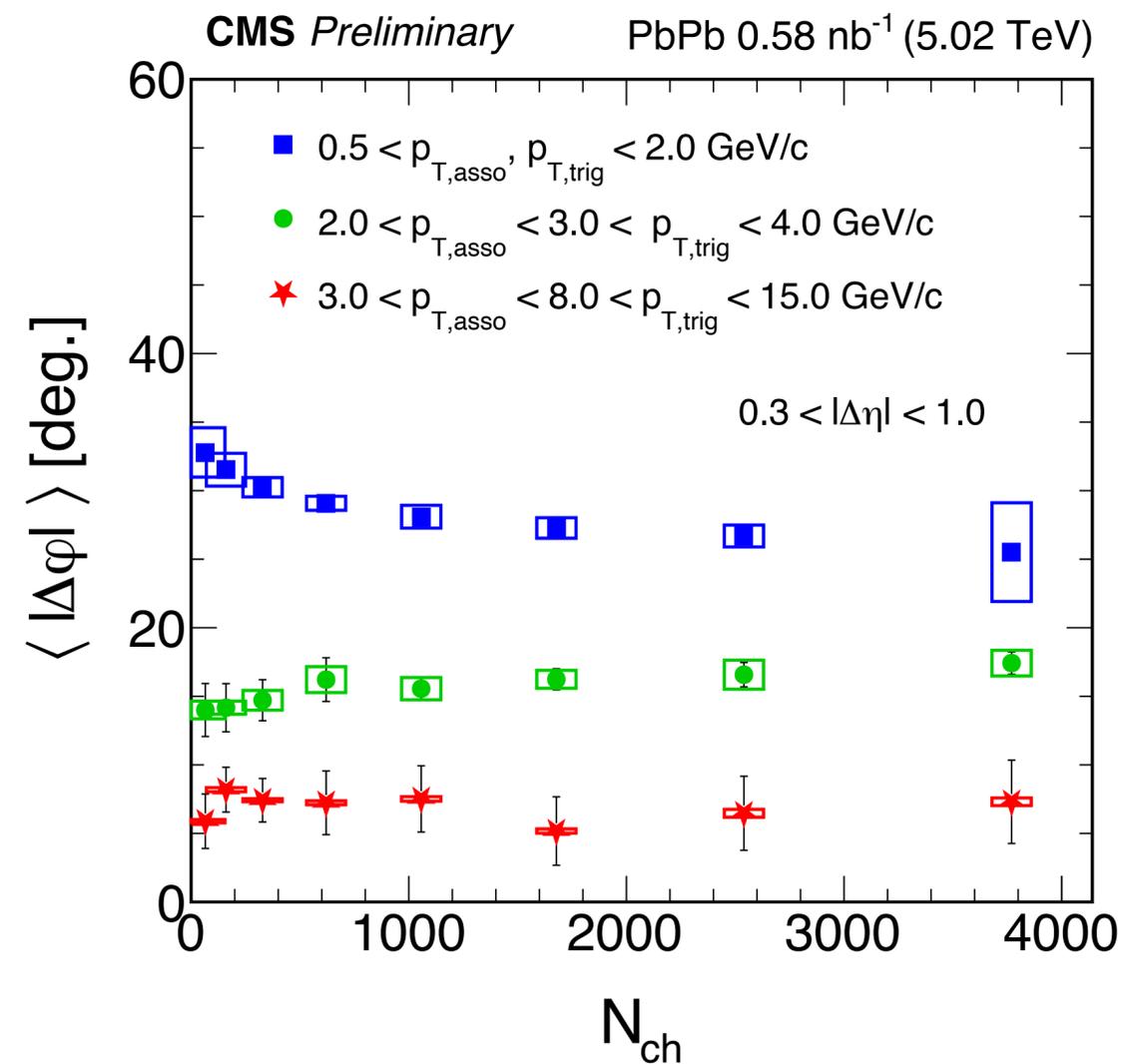
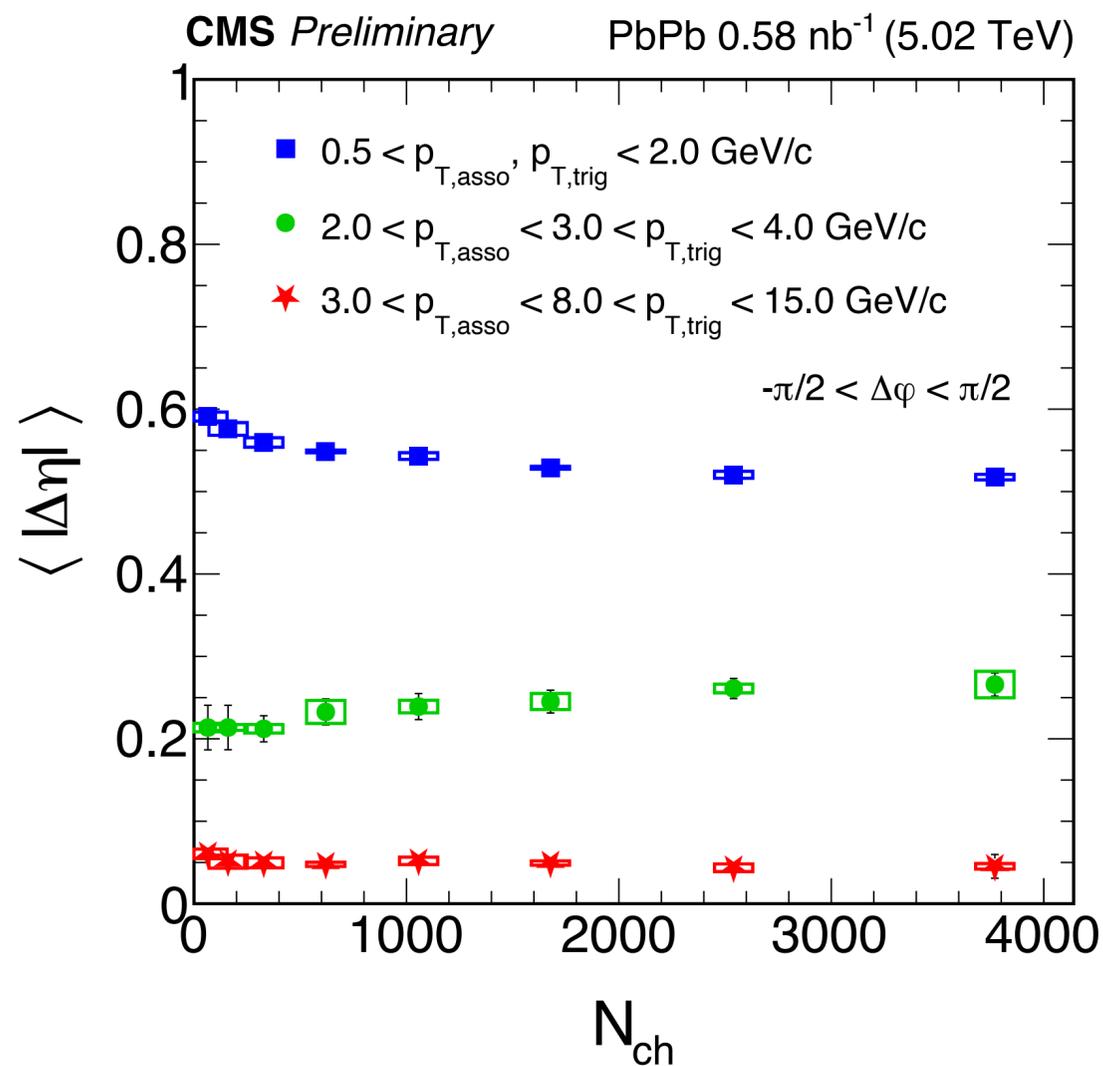
■ Data ○ AMPT △ HIJING



- ▶ A similar trend is observed in pPb collisions
- ▶ Narrowing of the balance function with increasing multiplicity in $\Delta\eta$ and $\Delta\phi$.
- ▶ Narrowing in $\Delta\phi$ described by AMPT connection to radial flow.

CMS-PAS-HIN-21-017

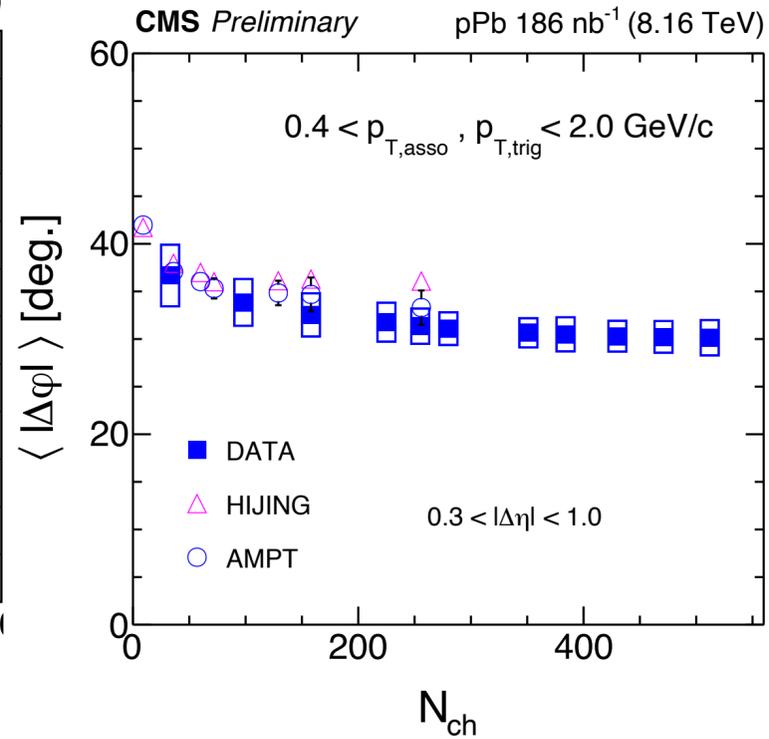
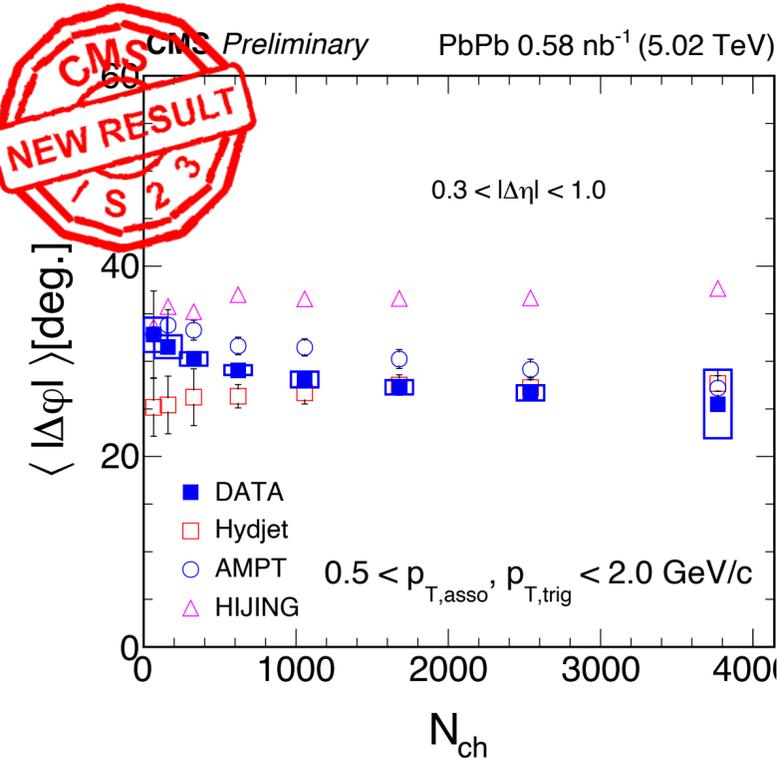
$\langle |\Delta\eta| \rangle$ and $\langle |\Delta\phi| \rangle$ Vs multiplicity and p_T



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

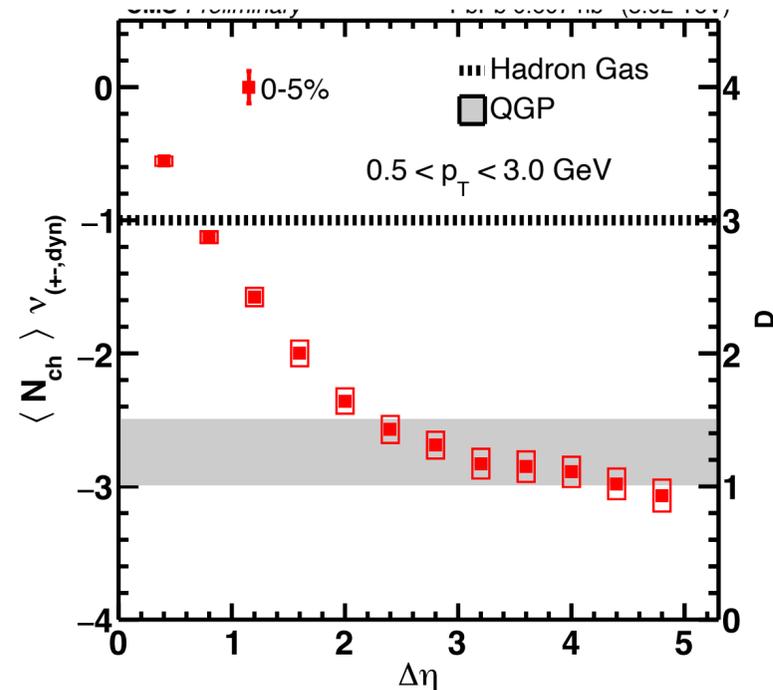
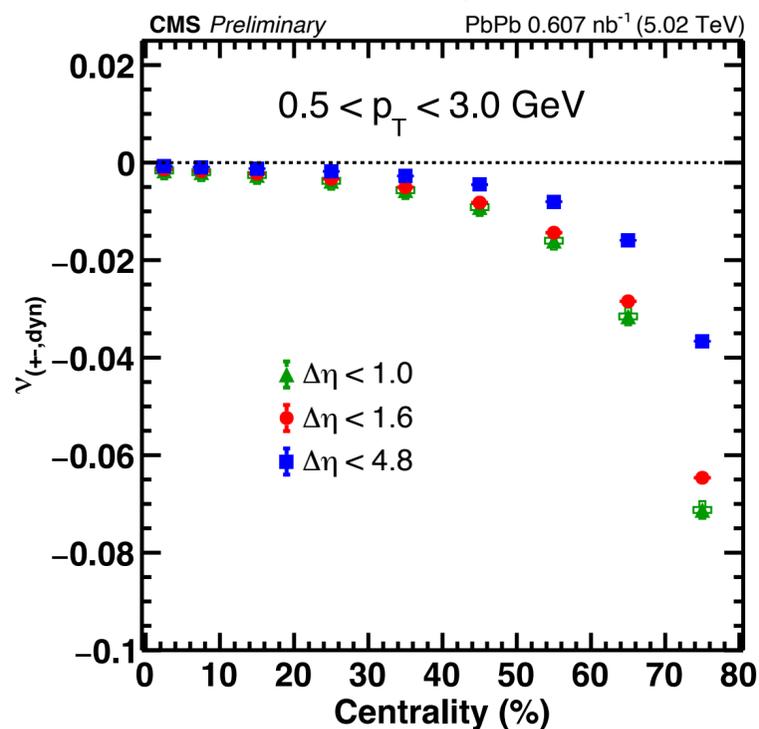
CMS-PAS-HIN-21-017

Summary



- ▶ Narrowing of the width with increasing multiplicities is consistent with the delayed hadronization.
- ▶ Narrowing in $\Delta\phi$ of the balance function from AMPT shows a similar trend observed in data.
- ▶ Width does not depend on multiplicity for higher p_T .

A similar trend is observed in pPb collisions



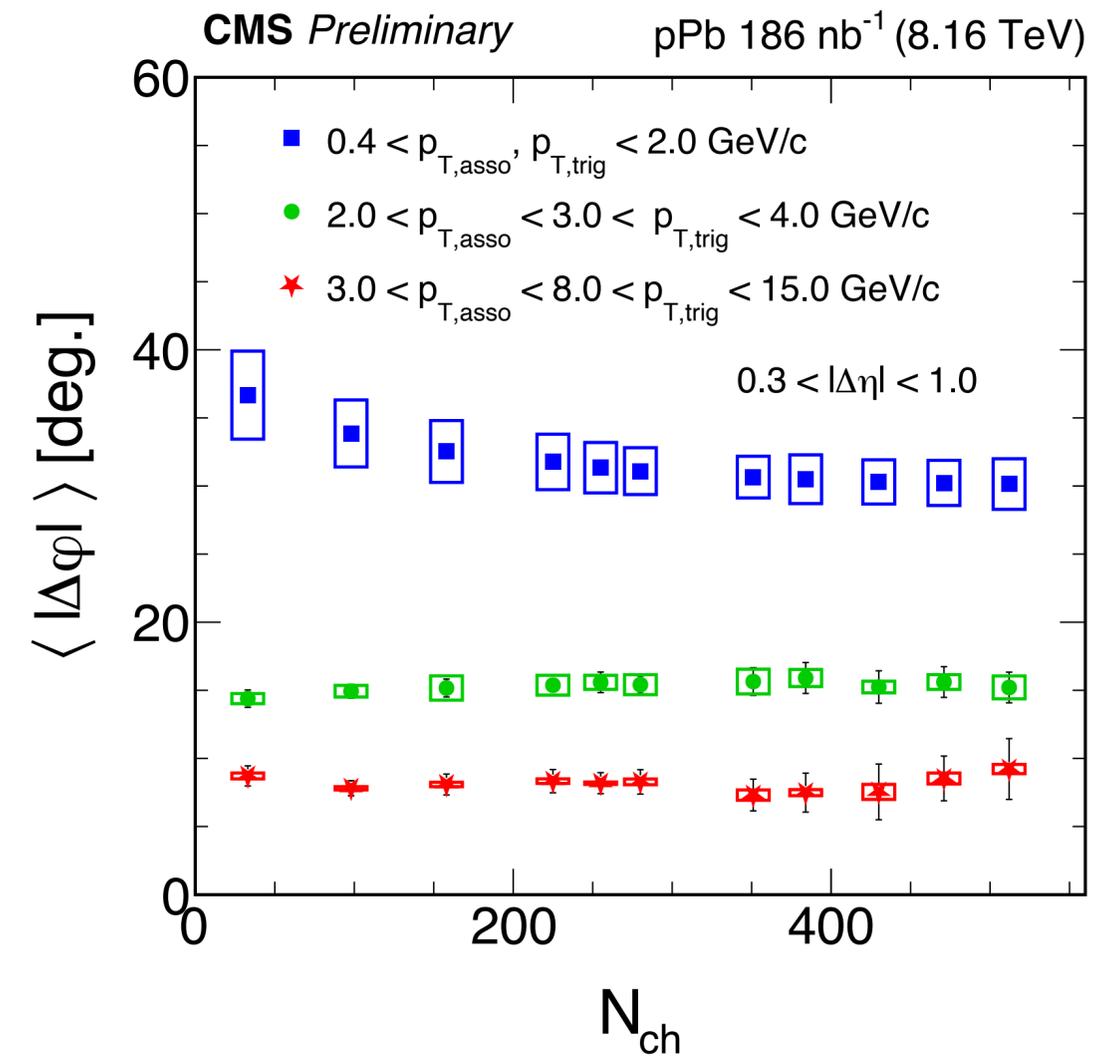
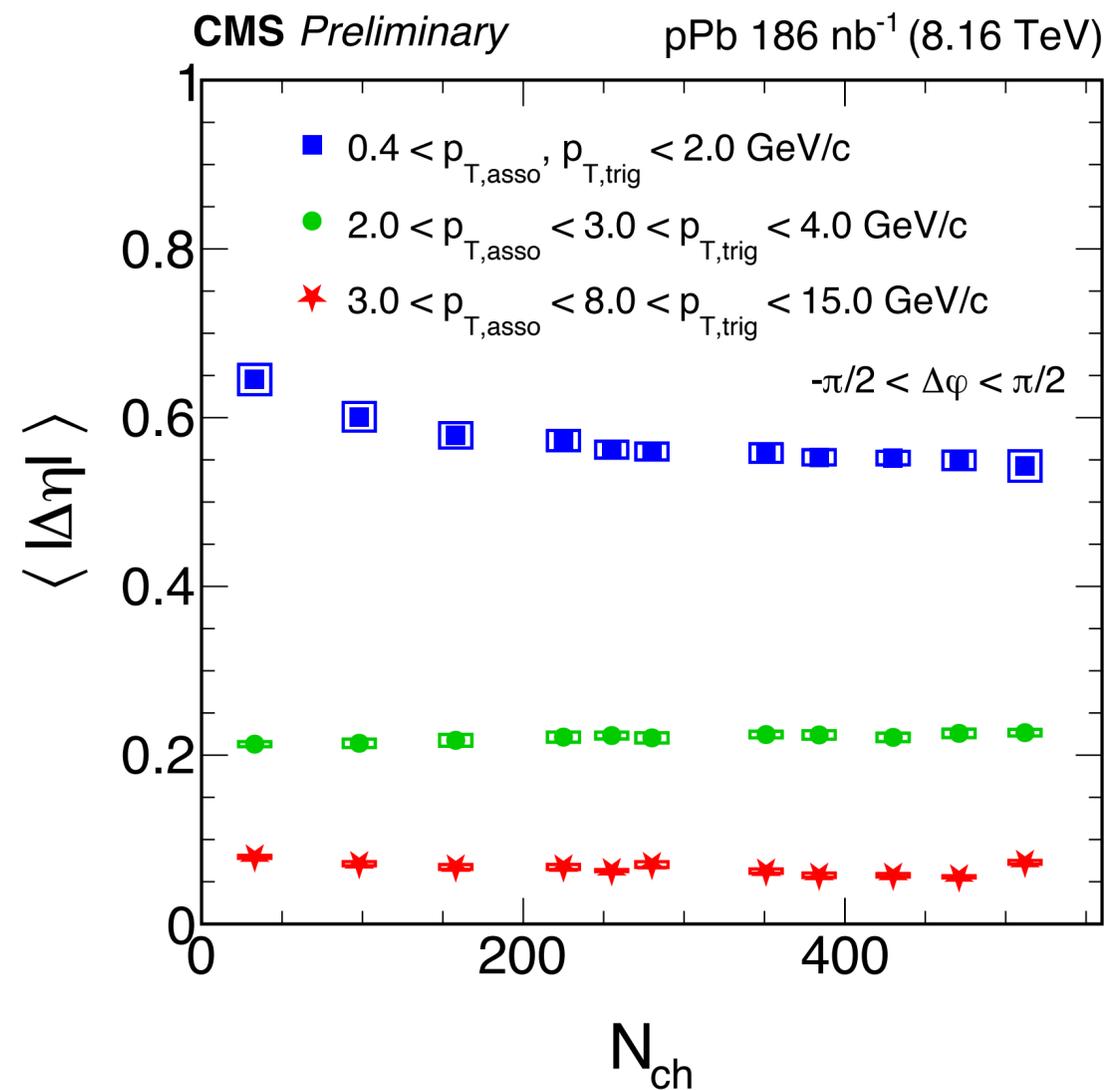
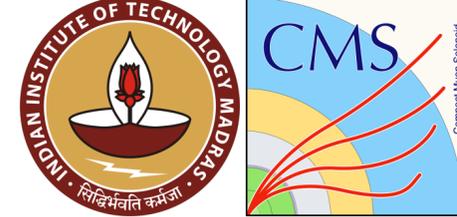
- ▶ v_{dyn} value decreases with the increase of $\Delta\eta$ windows and saturating towards central collisions.
- ▶ Negative value of v_{dyn} across all centrality shows correlation of opposite charges dominate.
- ▶ D-measure for CMS close to QGP limit and consistent with the theory prediction.

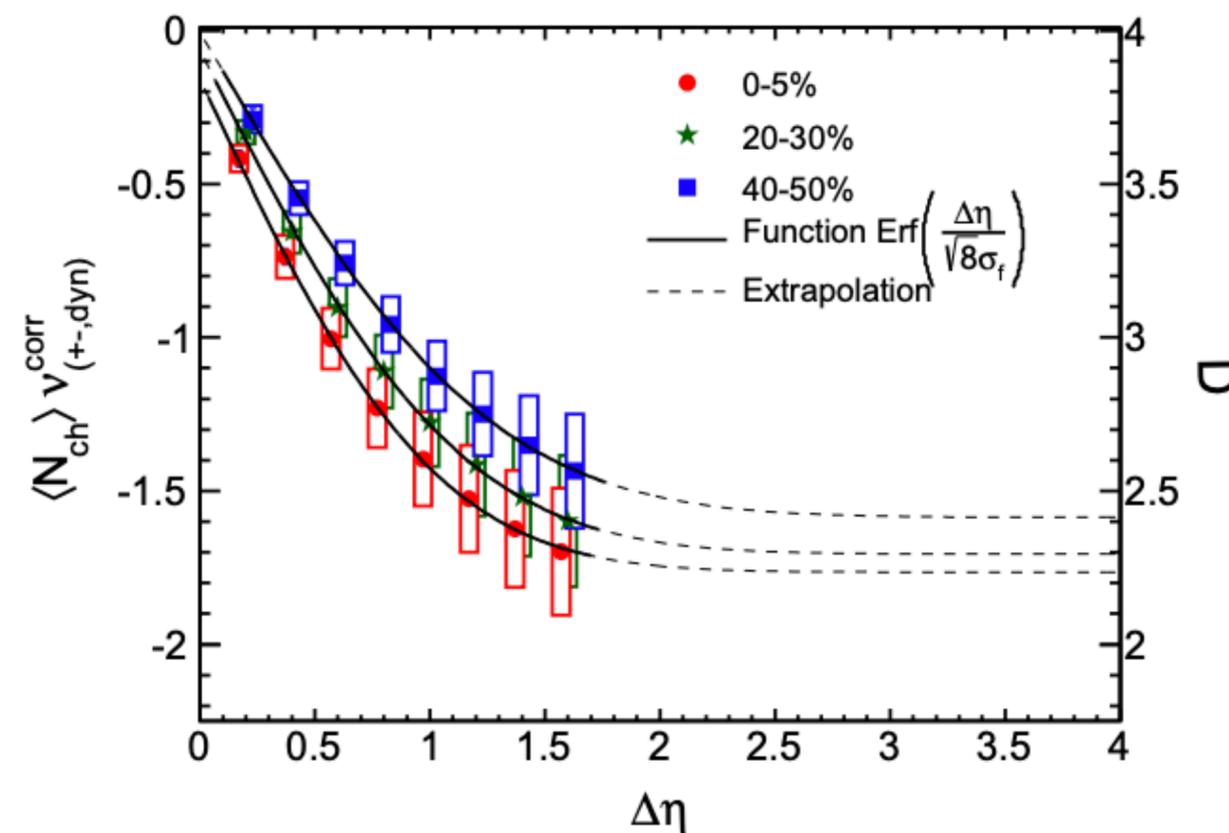
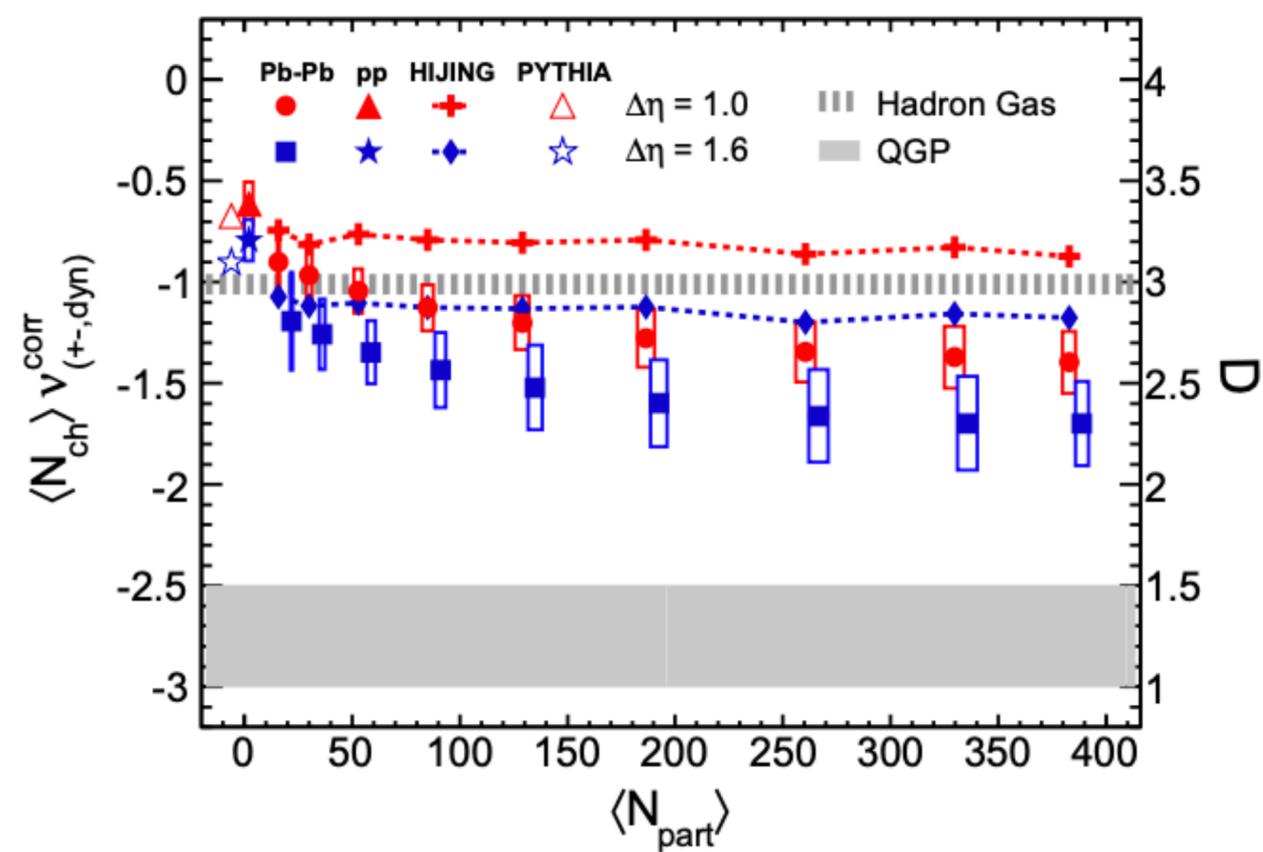


Backup slides



Balance functions vs multiplicity and high- p_T





[Phys. Rev. Lett. 110, 152301](#)