# Measurement of charge dependent correlations and fluctuations at CMS


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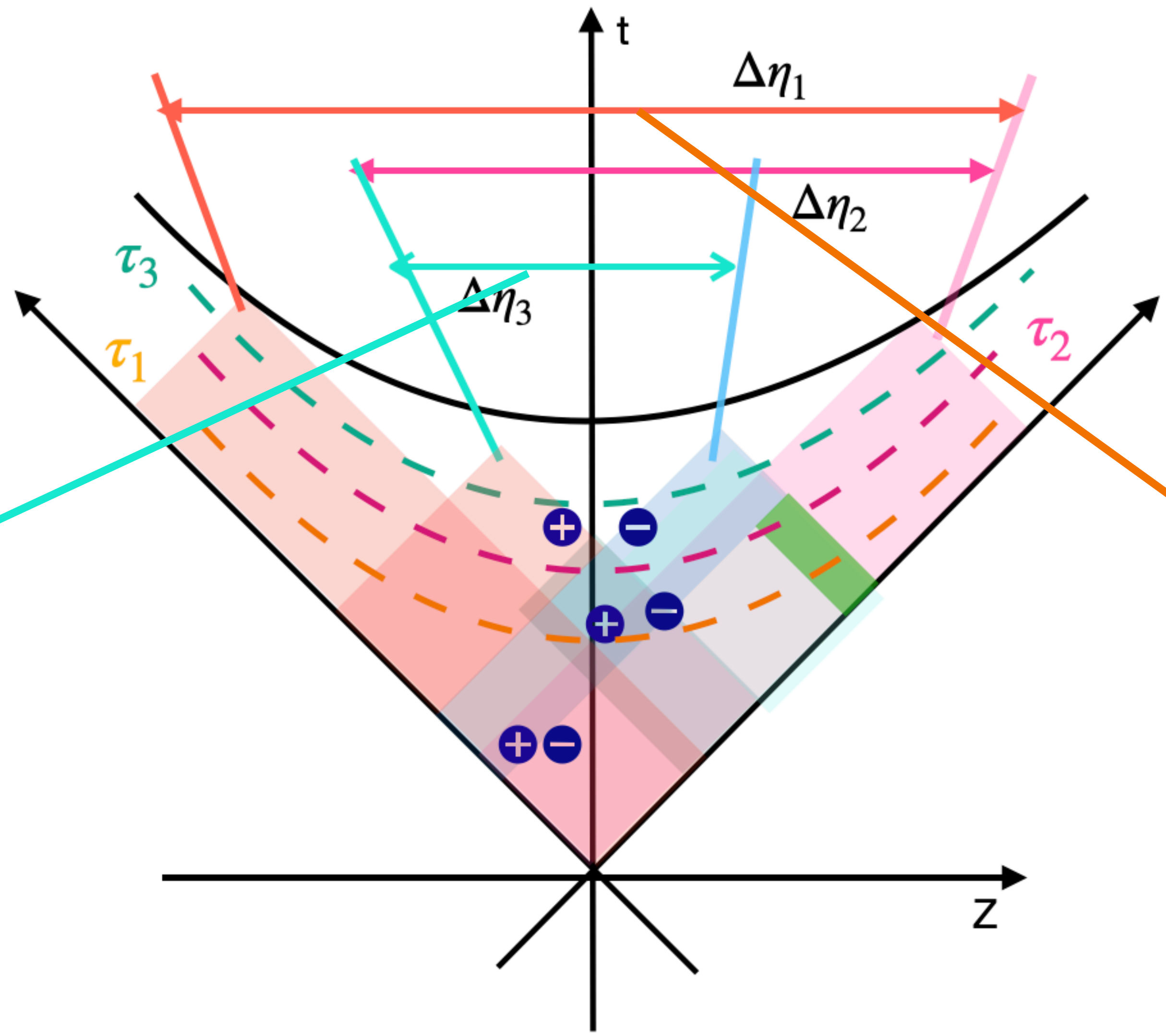
# Outline

- Introduction & motivation
- Observables
- CMS detector
- Results & discussions
- Summary

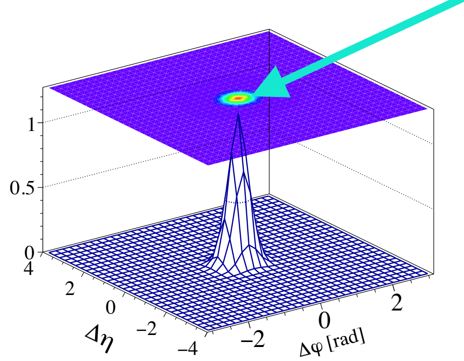
# Balancing charge separation

- Law of nature "charge is conserved"
- The longitudinal width of the correlation is related to time the correlation is established.

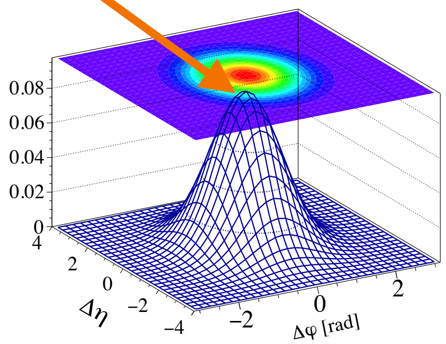



What is the hadronization time?

**Short range**




**Long range**




- Early time charge separation $\longrightarrow$ should be long range in $\Delta\eta$

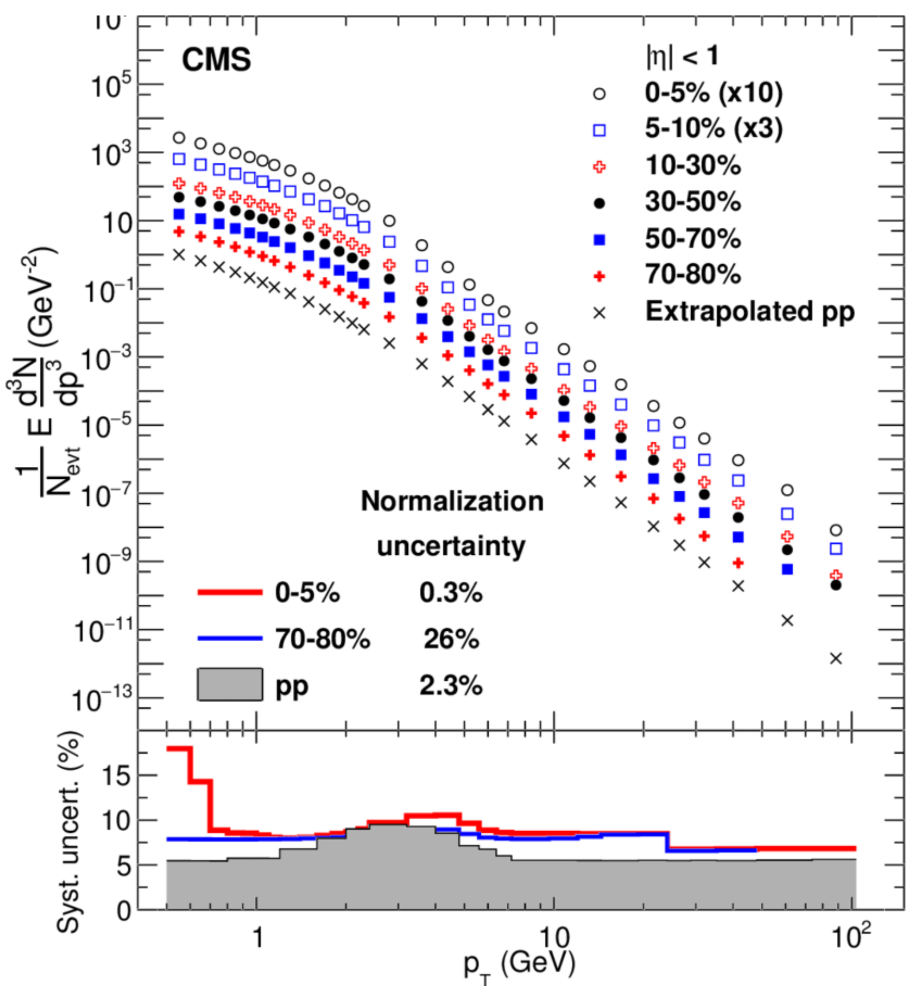
*Phys.Rev.Lett.85,(2000)2689 [Scott Pratt]*

# Effect from radial flow

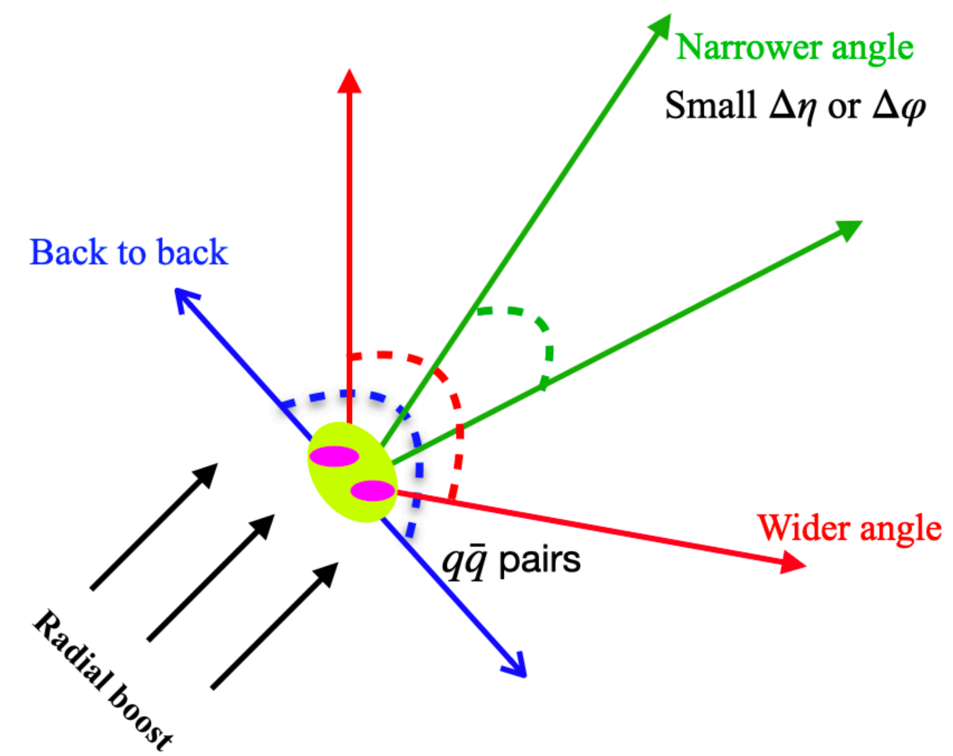
- Radial flow : $\Delta p_z = m_T \,.\, sinh(\Delta y) \approx m_T \,.\, \Delta y$

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

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




*JHEP 10 (2018)138*




Kinematic lensing due to the radial boost

- Balance functions (BFs) is constructed from four possible charge combinations

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

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

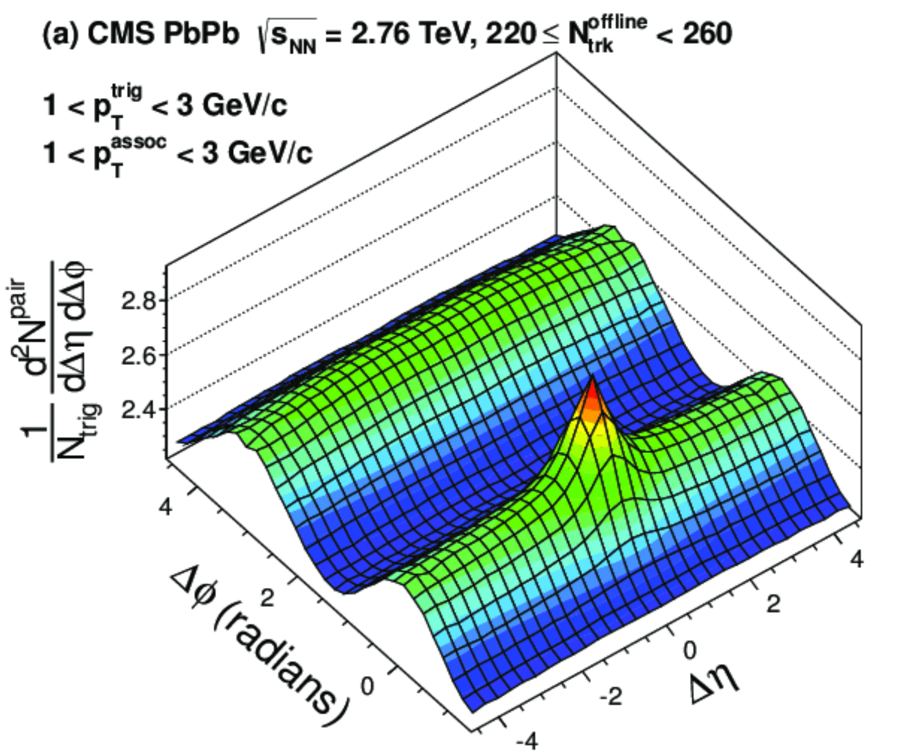
$US = C(+,-), C(-,+)$ $\quad LS = C(+,+), C(-,-)$

BFs are sensitive to Physics

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

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

*Phys. Lett. B 724 (2013) 213*




Charge hadron correlation functions

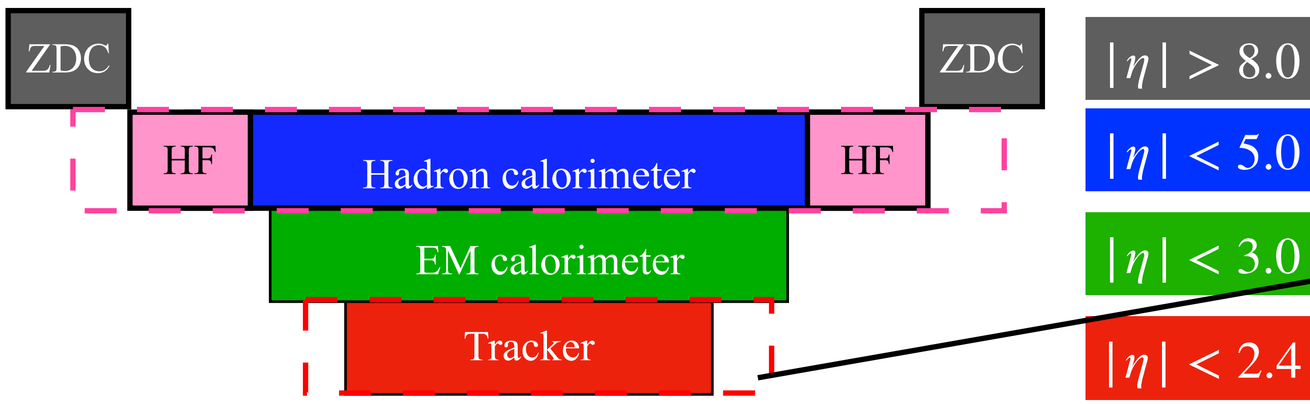
- The width of the BFs can be characterised by the $\langle|\Delta\eta|\rangle$ and $\langle|\Delta\varphi|\rangle$ calculations.

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

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

# CMS detector

- Datasets: PbPb 2018 at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV & pPb 2016 at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV



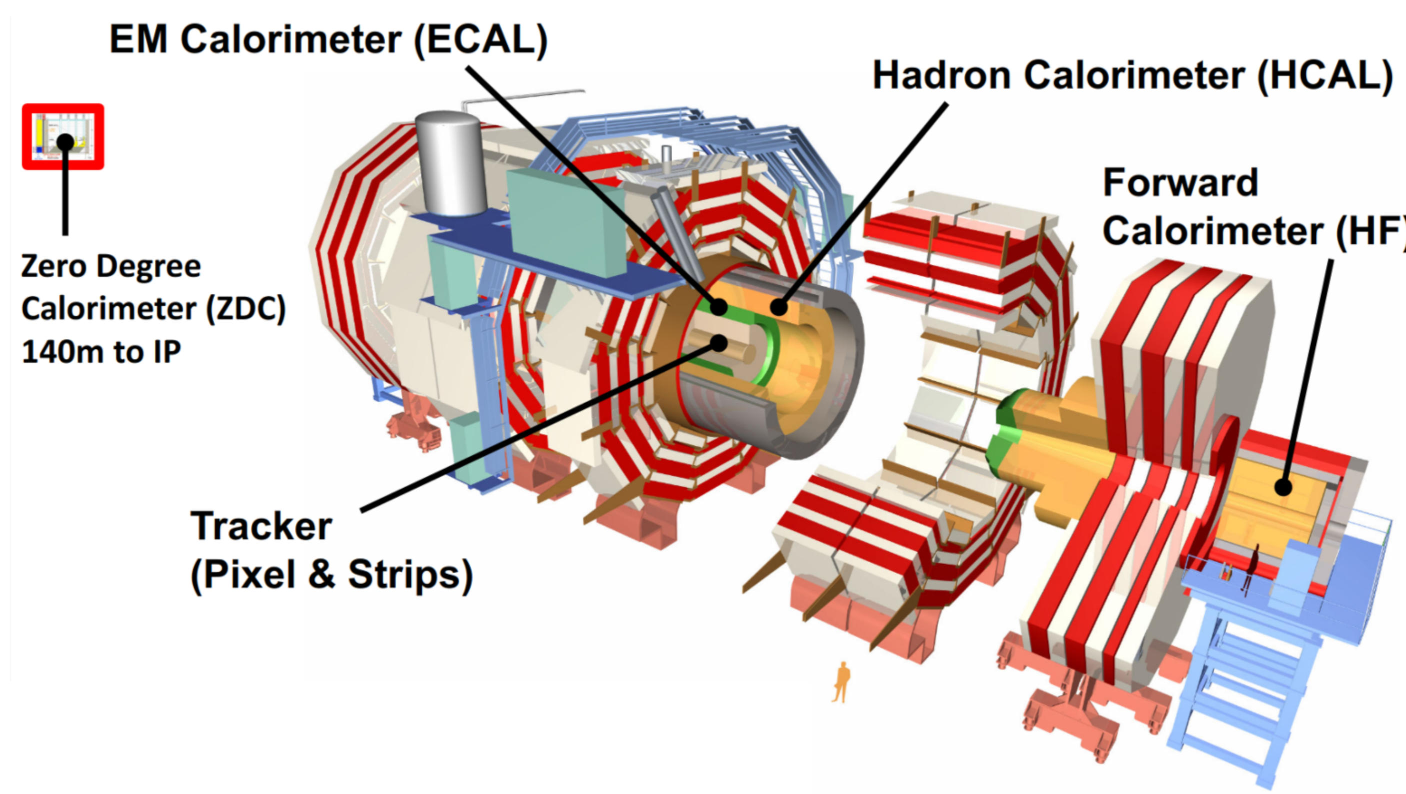

Kinematic selections used

- $p_{\mathrm{T}} > 0.5$ GeV, $|\eta| < 2.4$

**Why CMS Detector?**

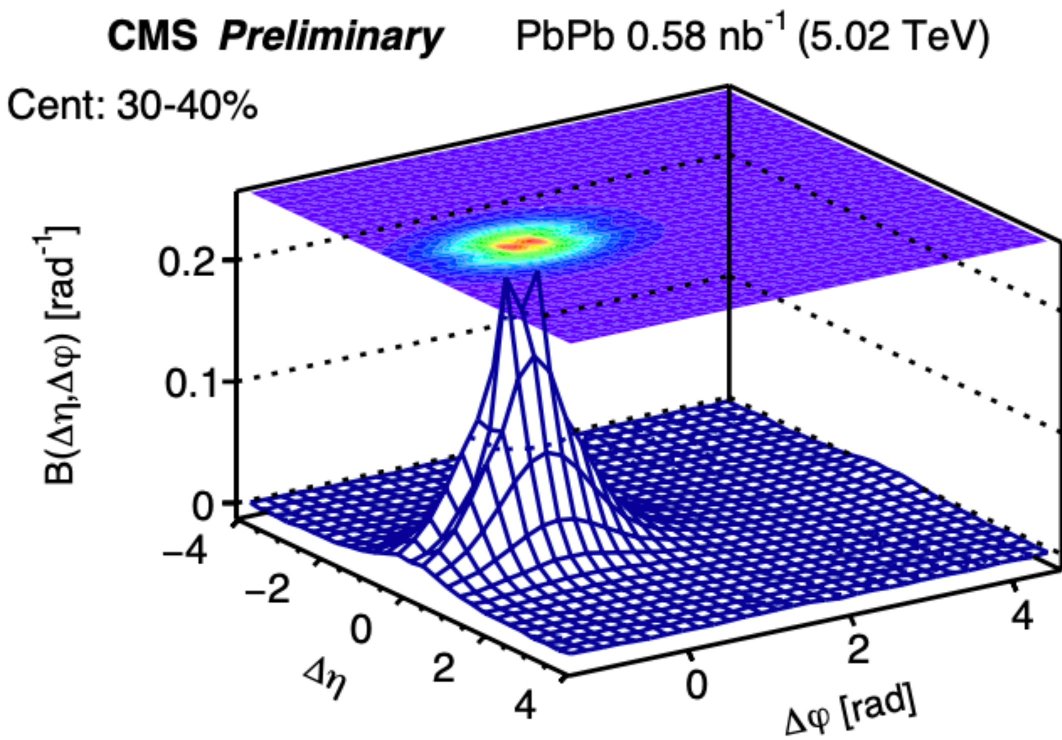
- Good precision
- Large rapidity coverage

Ideal for capturing balancing partners and initial fluctuations

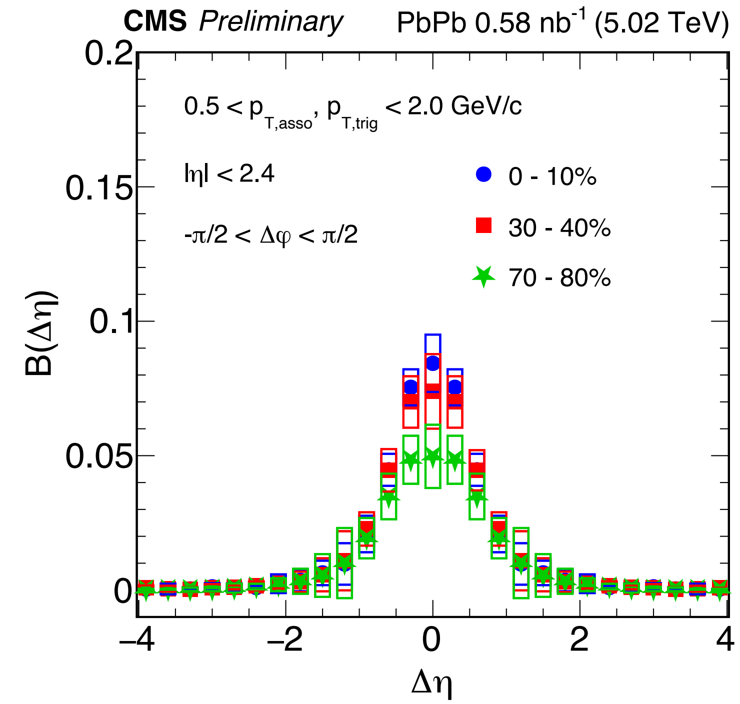


# Multiplicity dependence of BFs

CMS-PAS-HIN-21-017



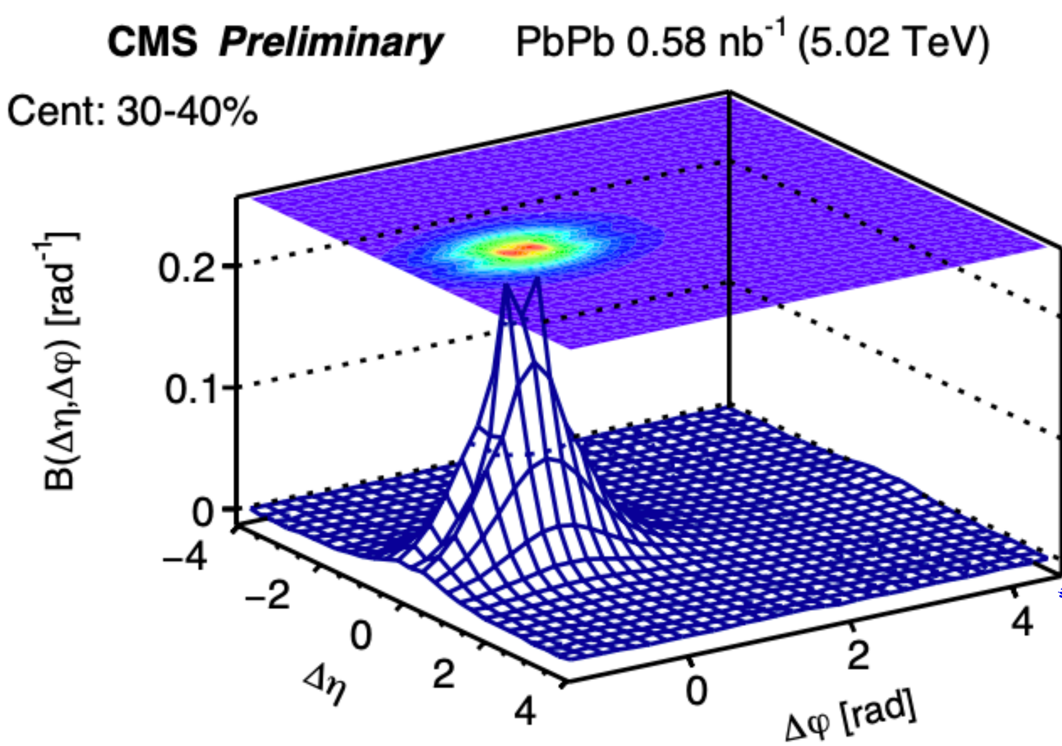

Projection in $\Delta\eta$



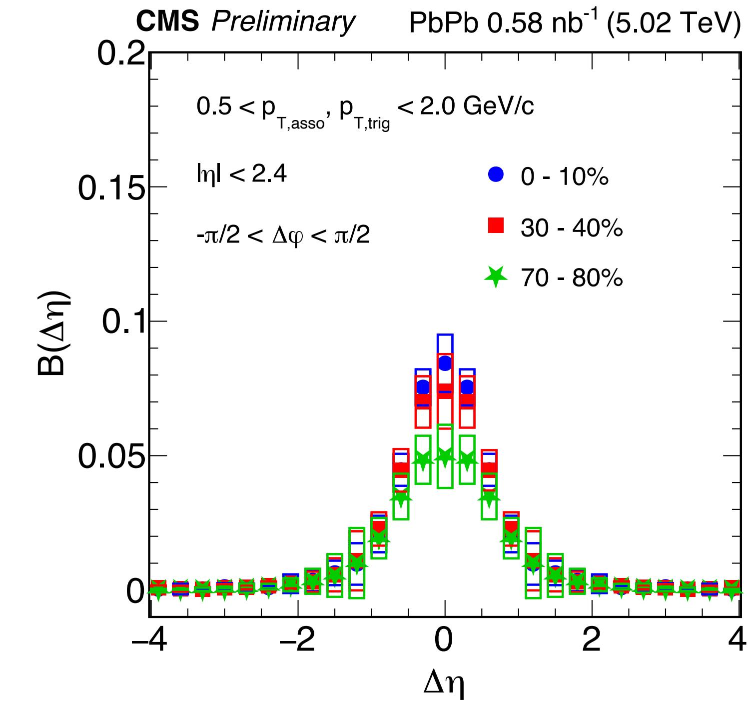

$$B(\Delta\eta, \Delta\varphi) = \frac{1}{2}[C(+,-) + C)-,+) - C(-,-) - C(+,+)]$$

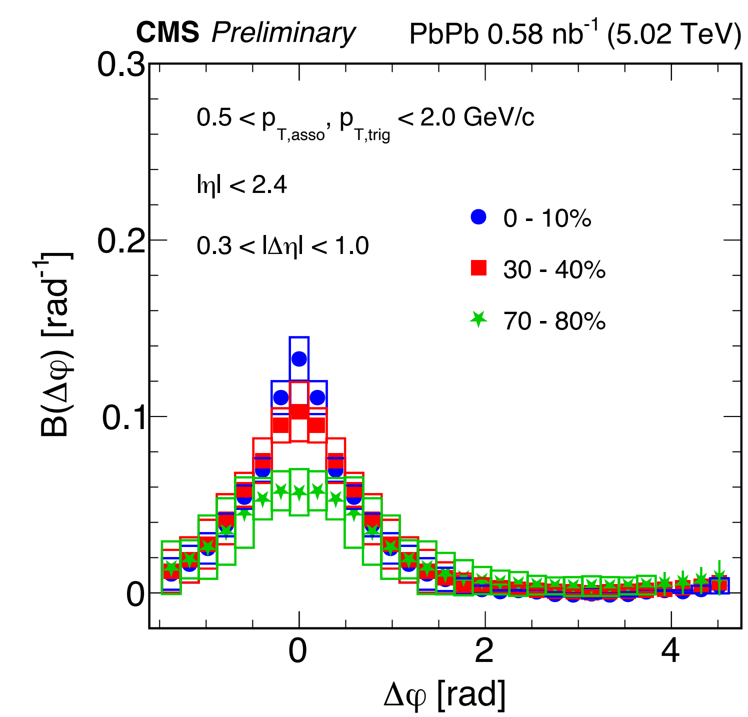
# Multiplicity dependence of BFs

CMS-PAS-HIN-21-017




Projection in $\Delta\eta$

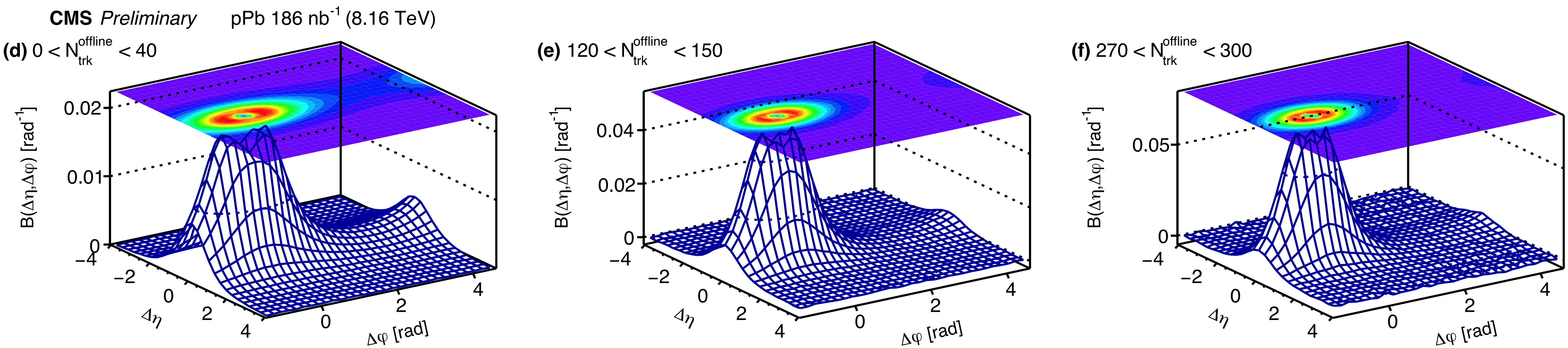


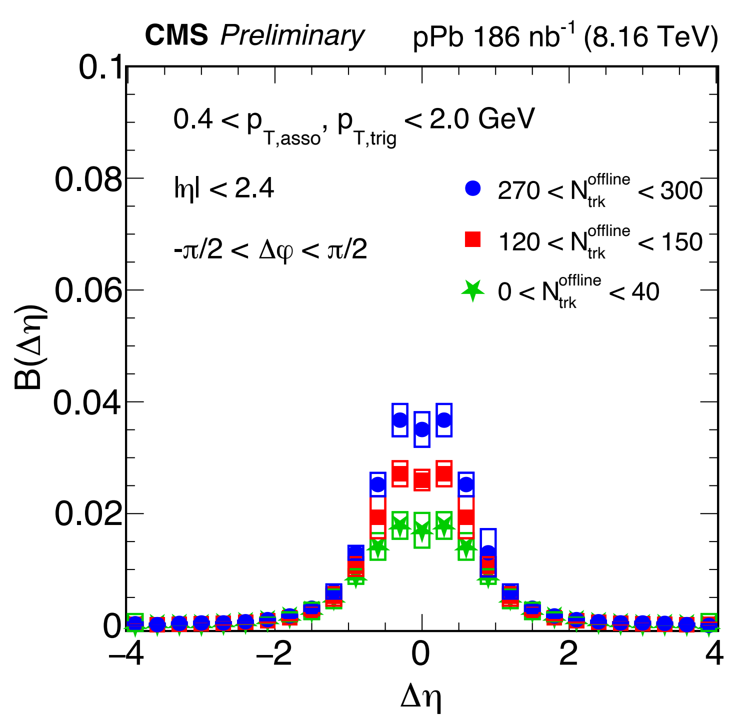



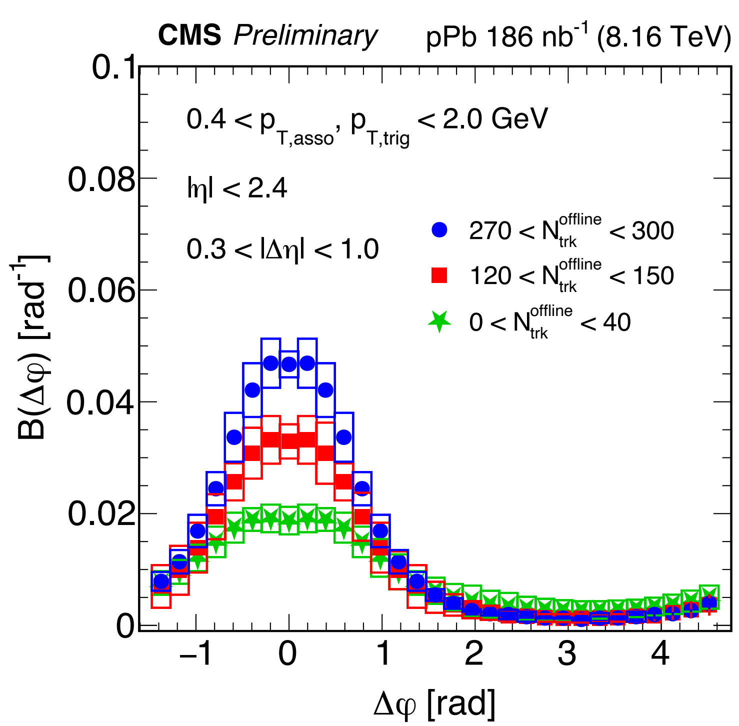

Projection in $\Delta\varphi$

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

# Multiplicity dependence of BFs



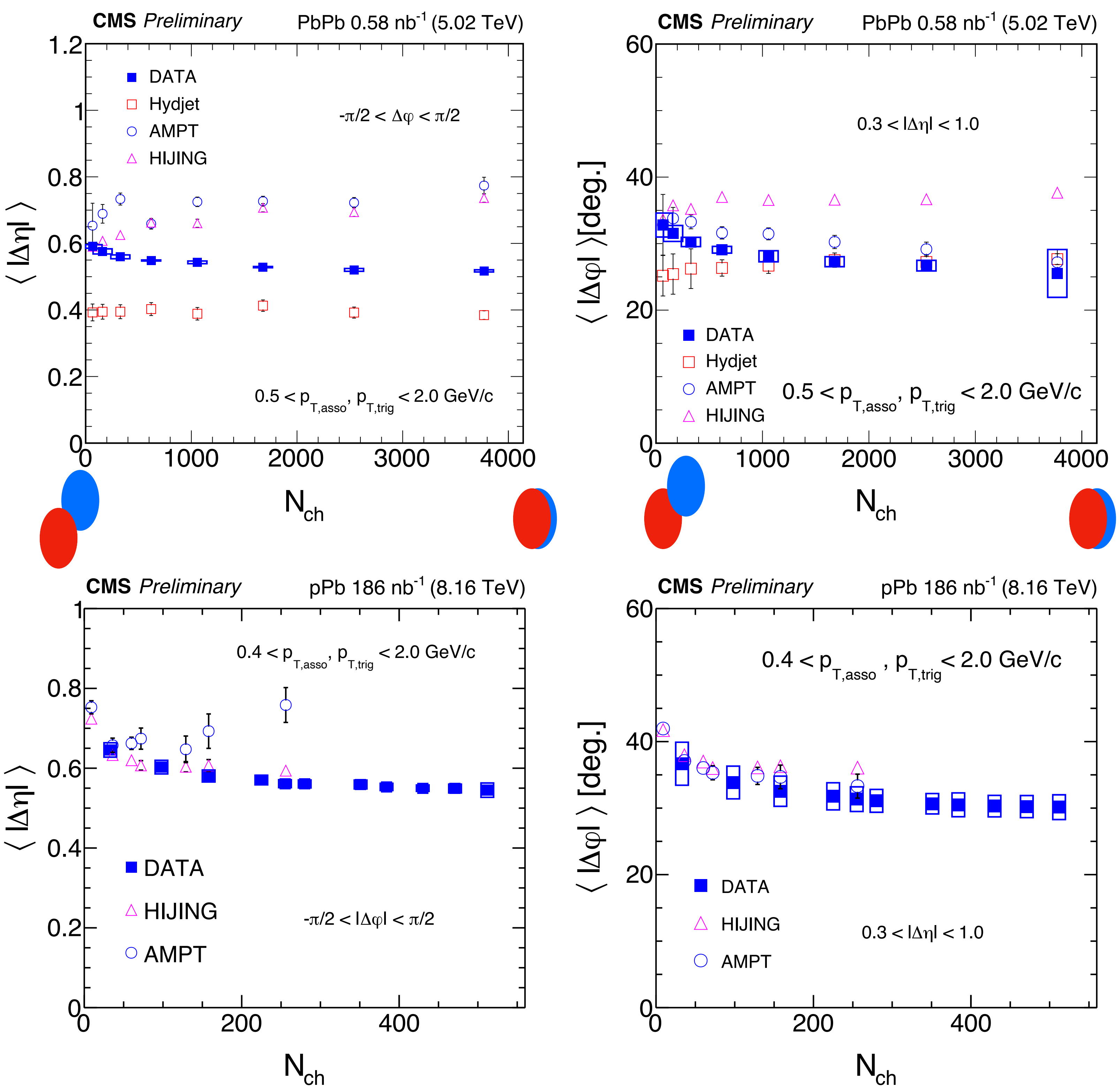




- Narrowing of the balance function is observed from high to low track multiplicity collisions.

CMS-PAS-HIN-21-017

Similar trend observed in pPb collisions

# $\langle |\Delta\eta| \rangle$ and $\langle |\Delta\varphi| \rangle$ Vs multiplicity class




- Narrowing of the balance function with increasing multiplicity in $\Delta\eta$ and $\Delta\varphi$.

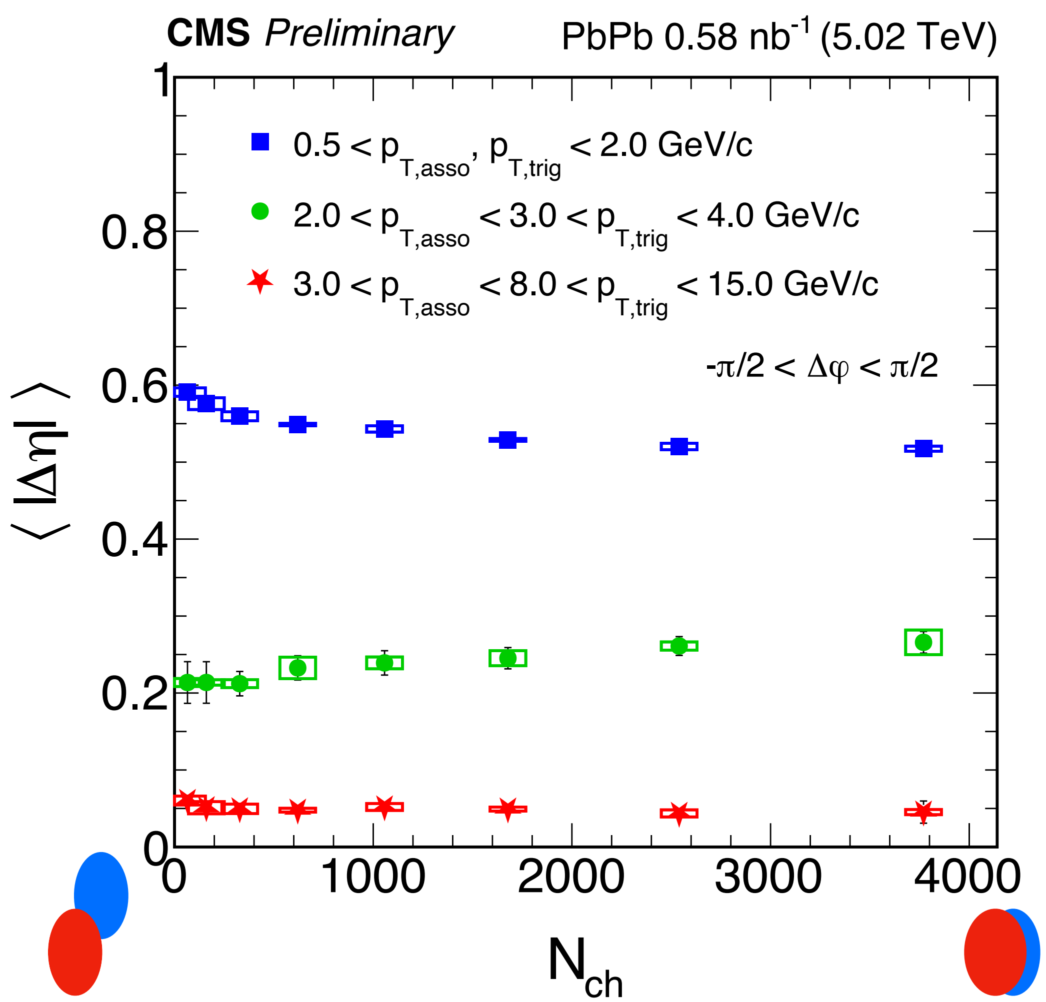
- Data not described by either HYDJET , HIJING or APMT in $\Delta\eta$.

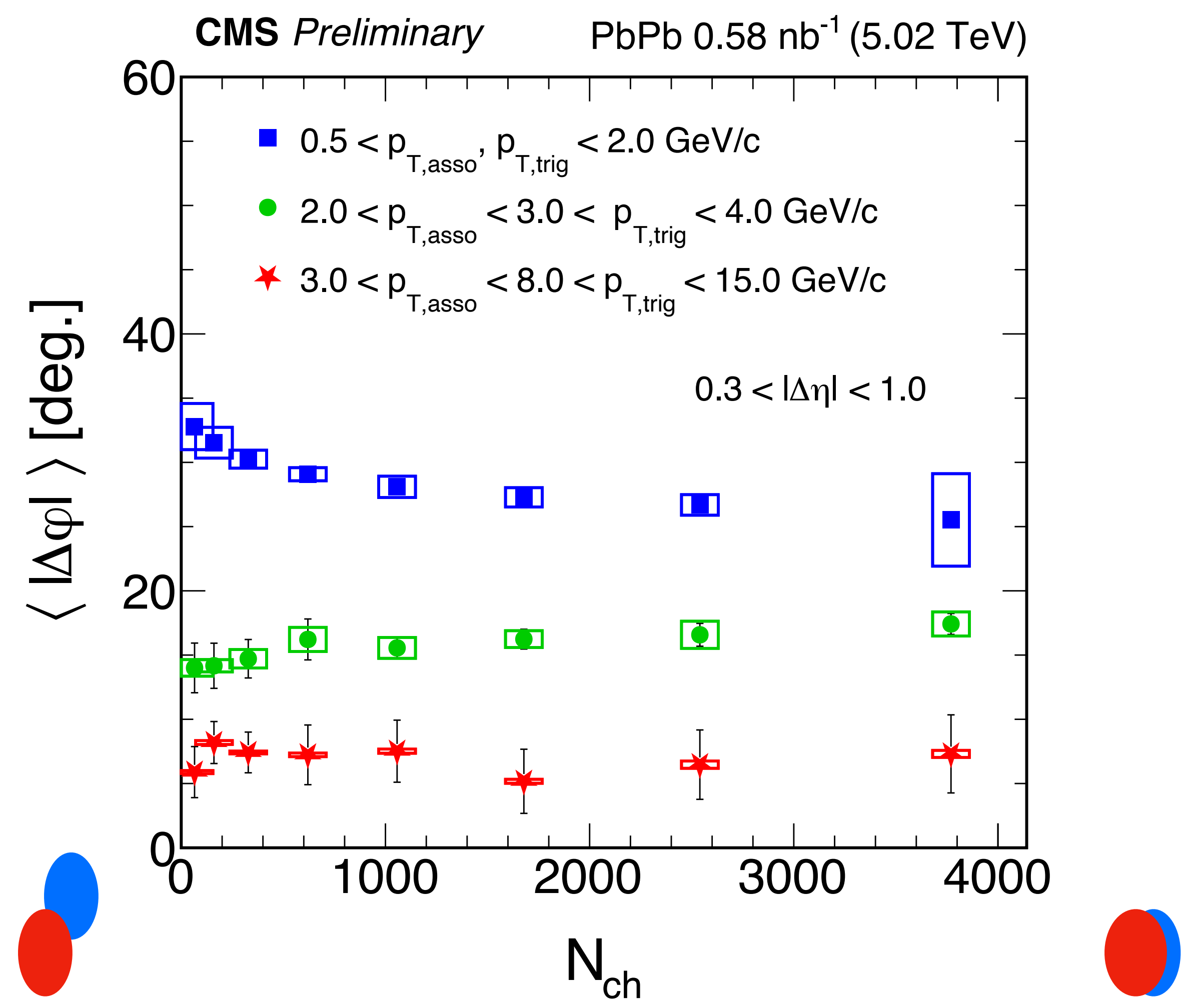
- Narrowing in $\Delta\varphi$ described by AMPT $\longrightarrow$ connection to radial flow.

CMS-PAS-HIN-21-017

# $\langle|\Delta\eta|\rangle$ and $\langle|\Delta\varphi|\rangle$ Vs multiplicity class and $p_T$

CMS-PAS-HIN-21-017

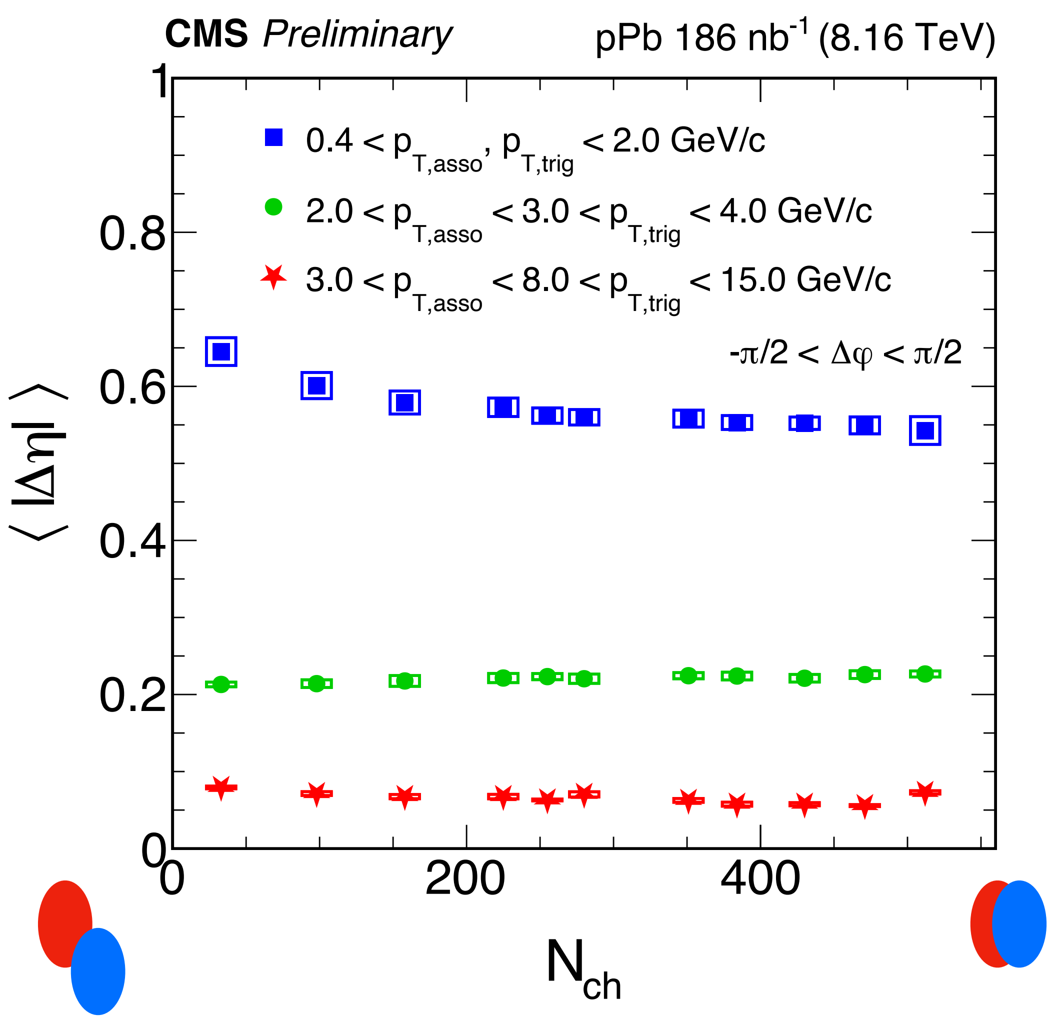


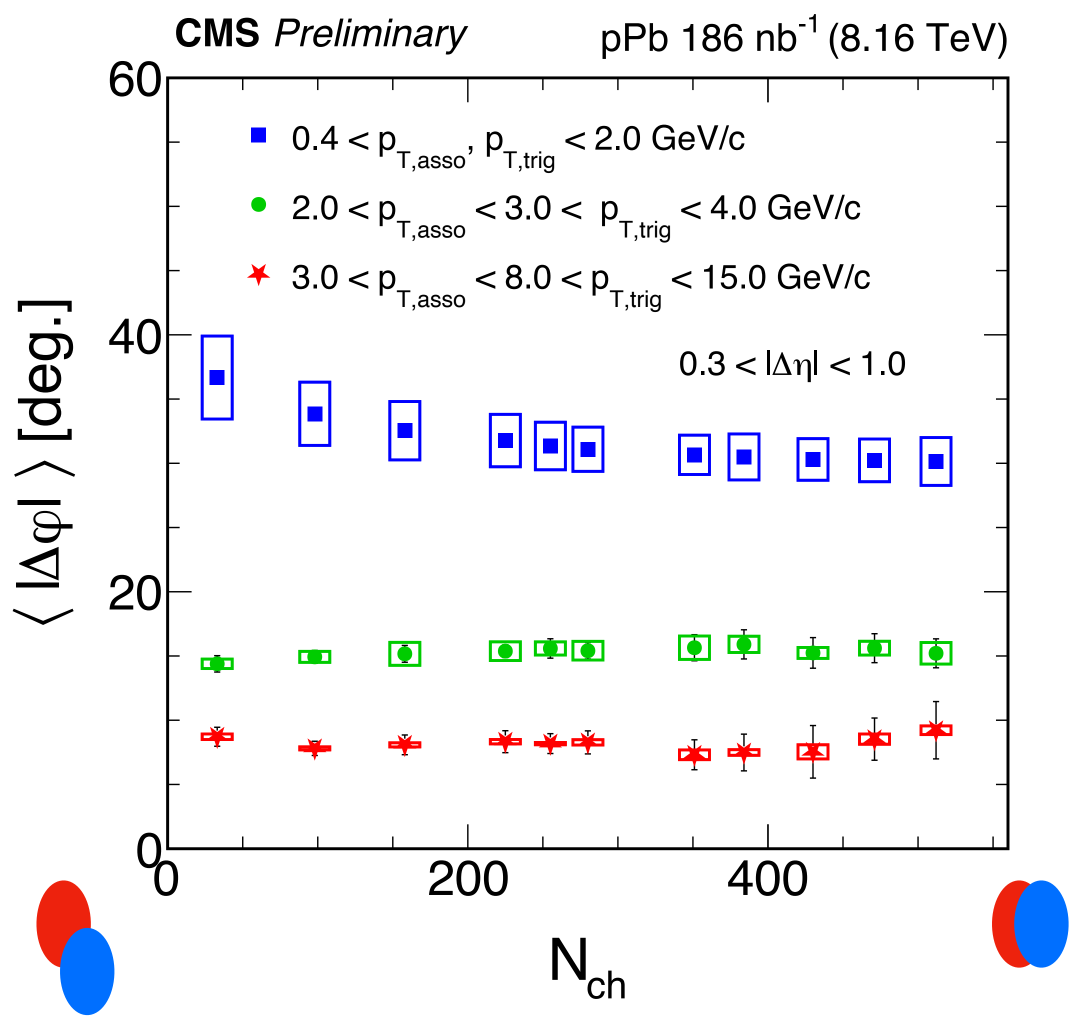




- Balance function become narrower with increasing in $p_T$.
- Less multiplicity dependence is observed for higher-$p_T$.
- Narrowing of the balance functions in low-$p_T$ region is the effect from the bulk.

# $\langle|\Delta\eta|\rangle$ and $\langle|\Delta\varphi|\rangle$ Vs multiplicity class and $p_T$

CMS-PAS-HIN-21-017

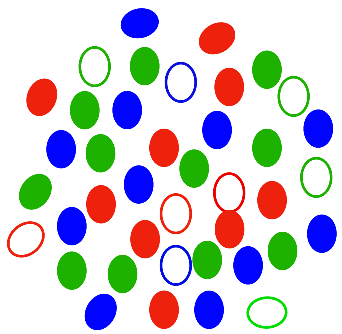


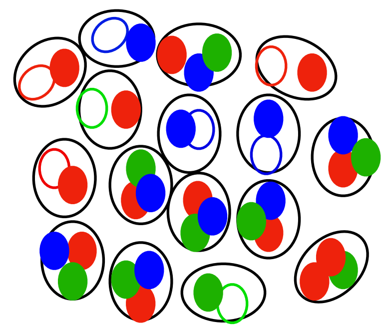

**Similar trend is observed in pPb and PbPb collisions**

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

# Dynamical net-charge fluctuations: $\nu_{\mathrm{dyn}}$



QGP



Hadron gas (HG)

HG : $q = \pm 1, \pm 2, \;\; q^2 = 1, 4$

QGP : $q = \pm \frac{1}{3}, \pm \frac{2}{3}, \;\; q^2 = \frac{1}{9}, \frac{4}{9}$

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

***Poster from Vaibhavi***

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

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

$$\frac{(\langle Q - \langle Q\rangle)^2\rangle}{\langle N_{ch}\rangle} = 1 - \int_0^Y d\Delta y \;\; B(\Delta y\,|\,Y) + O\left(\frac{\langle Q\rangle)}{\langle N_{ch}\rangle}\right)$$

Where, $Q = N_+ - N_-$ and $\;N_{ch} = N_+ + N_-$

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

*S. Jeon, V. Koch. Phys. Rev. Lett. 85, 2076 (2000)*

- To identify the relevant charge carriers and disentangle between the statistical and dynamical components.

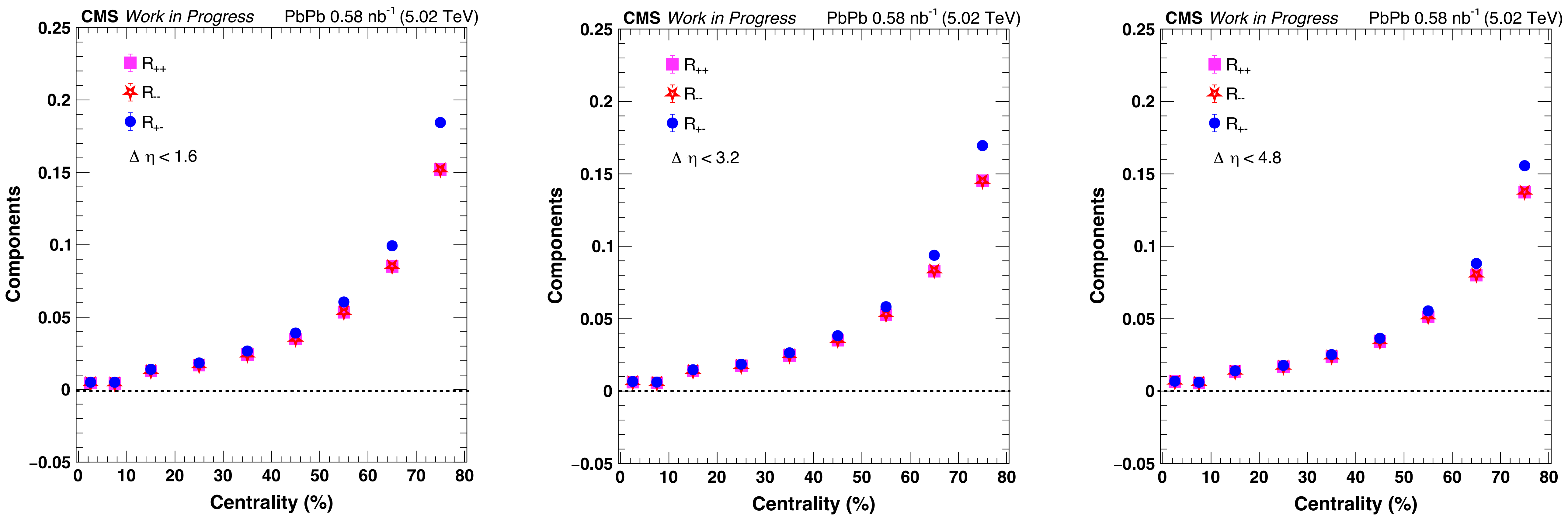
# Centrality and $\Delta\eta$ dependence of $v_{\mathrm{dyn}}$

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

$$= (R_{++} - 1) + (R_{--} - 1) - 2\,(R_{+-} - 1)$$

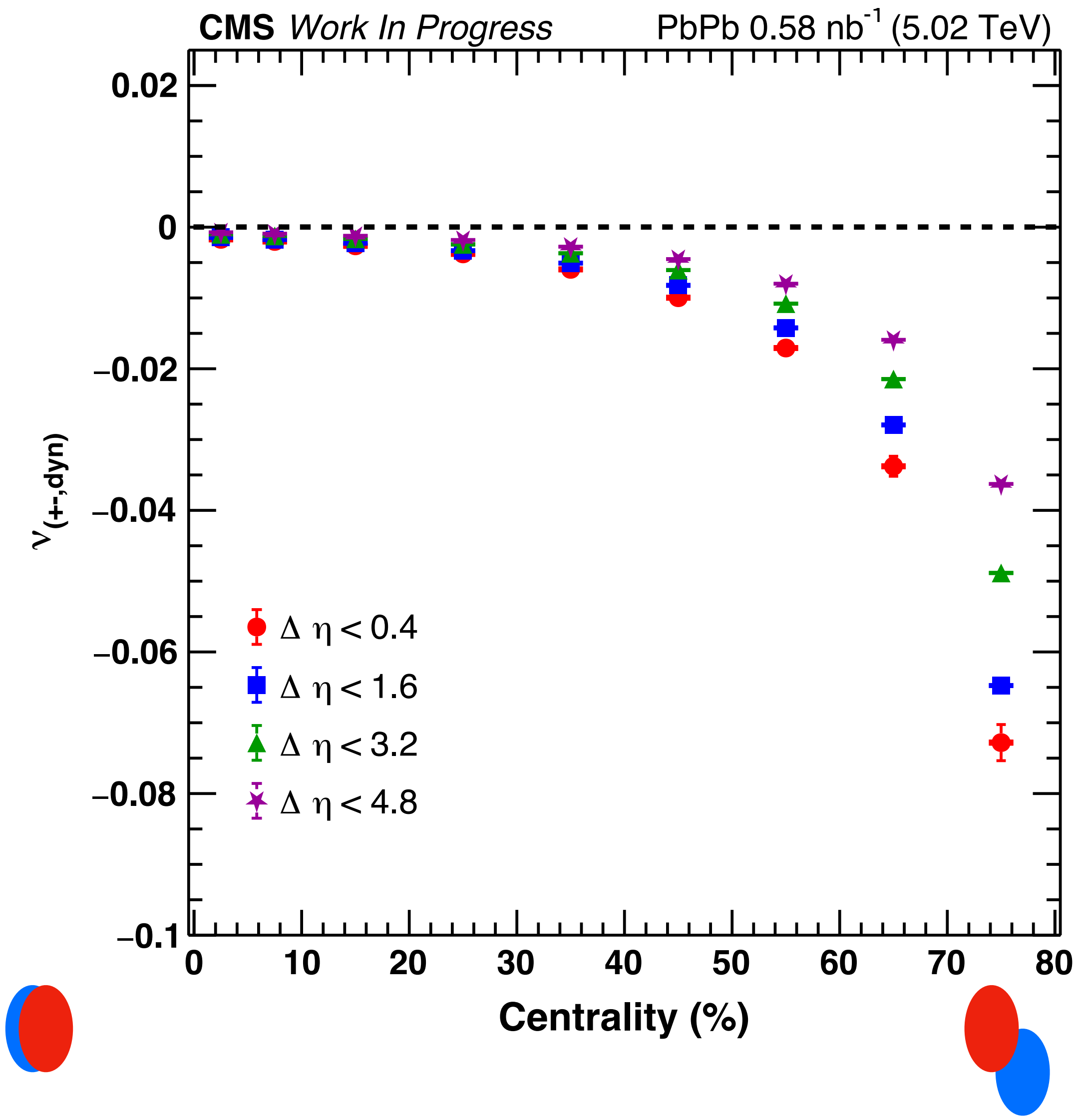
Poster from Vaibhavi

Components of $v_{+-,\mathrm{dyn}}$




- Account for the correlations of $++$ , $--$ , $+-$ charged particles

# Centrality and $\Delta\eta$ dependence of $v_{\text{dyn}}$

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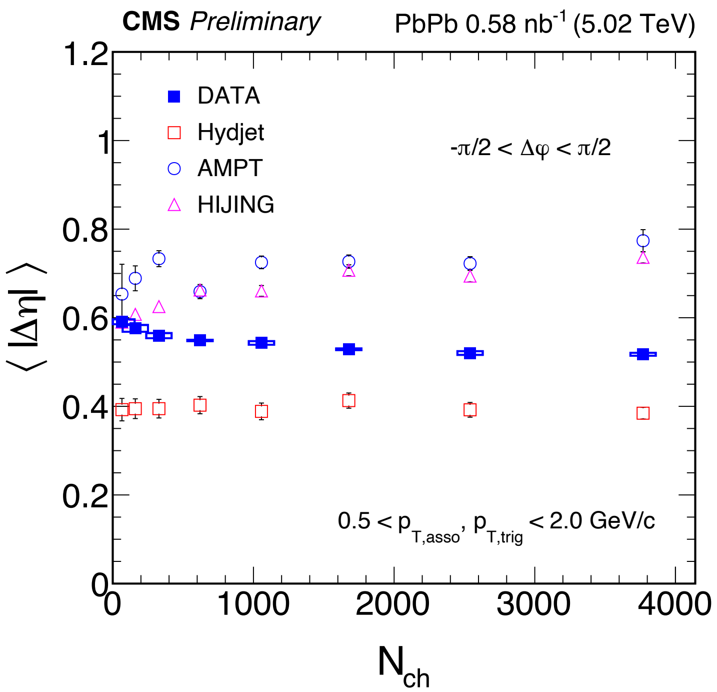
- $\nu_{(dyn)} = 0$: only statistical fluctuations
- $\nu_{(dyn)} > 0$: same sign correlations dominates
- $\nu_{(dyn)} < 0$: opposite sign correlations dominates

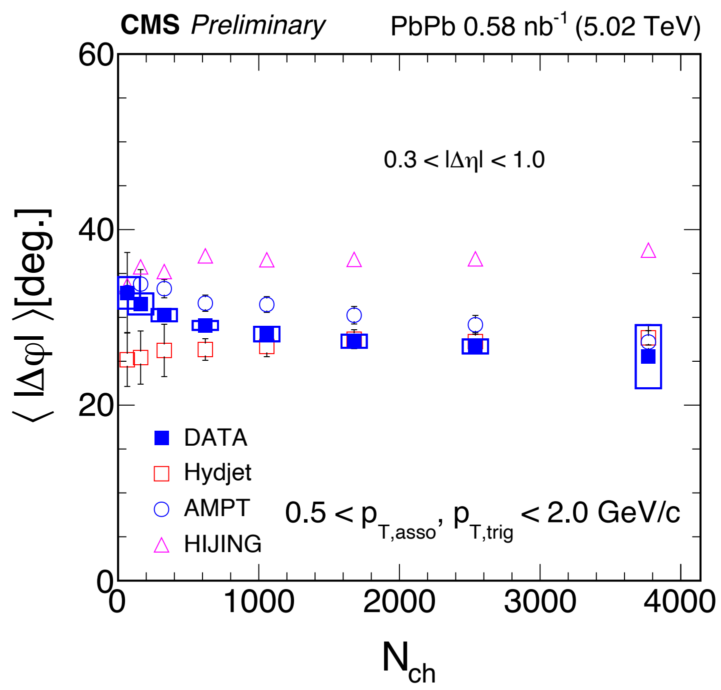
- Smaller $|\nu_{dyn}|$ value towards the central collisions
- signifies the equilibration of + and - charges

*Poster from Vaibhavi*

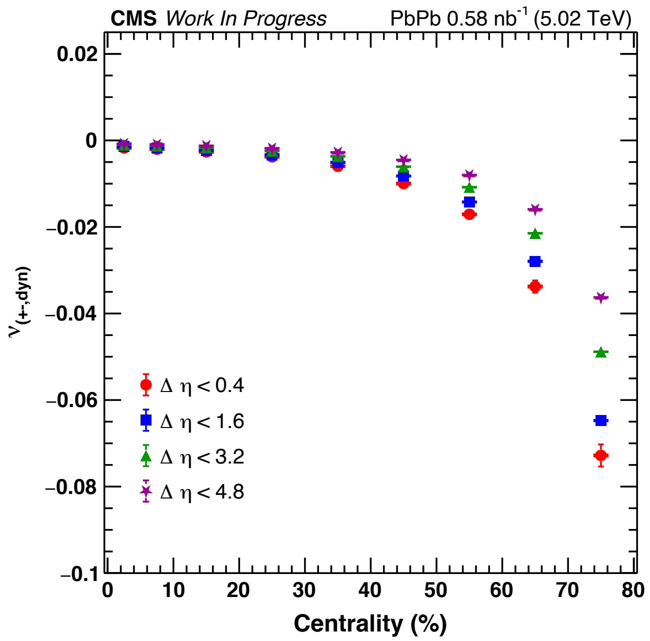
- Fluctuations strongly depends on the pseudo-rapidity window $\Delta\eta$.

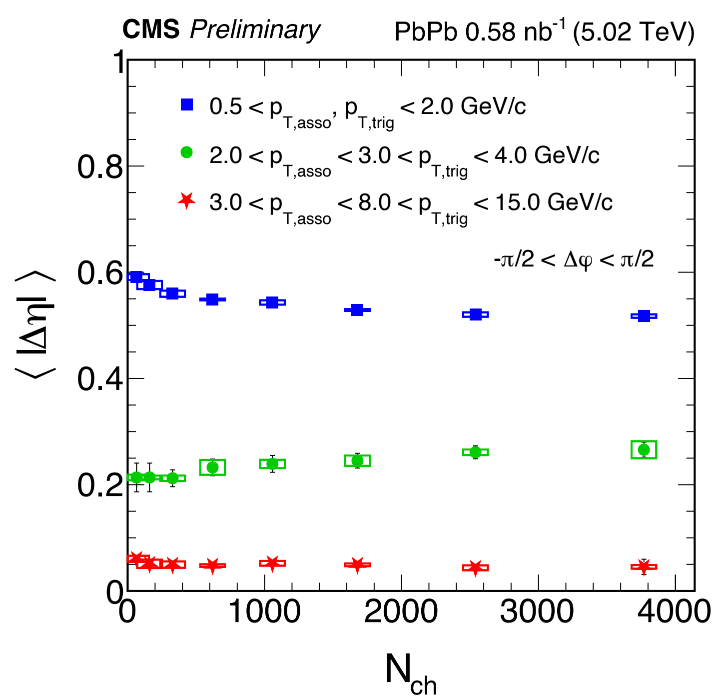
# Summary

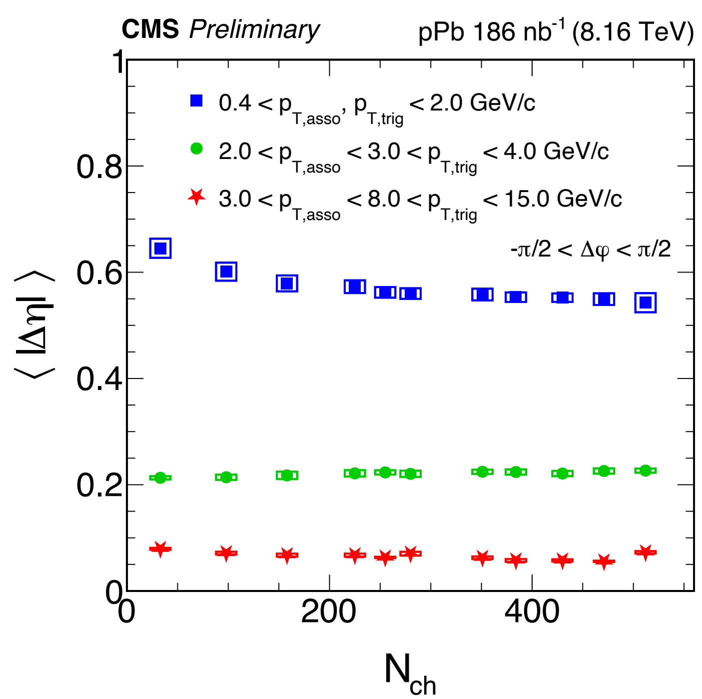



- Narrowing of the width with increasing multiplicities is consistent with the delayed hadronization.
- Narrowing in $\Delta\varphi$ of the balance function from AMPT shows a similar trend observed in data.




- Centrality and $\Delta\eta$ shows saturation of of fluctuations towards zero.
- Negative value of $v_{dyn}$ across all centrality shows correlation of opposite charges dominate.

- Width does not depends on multiplicity for higher $p_T$.