Study of Modified Near-side Jet Peak Structure in a Longitudinally Boosted Flowing Medium in PbPb Collisions with CMS

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Introduction & Motivation

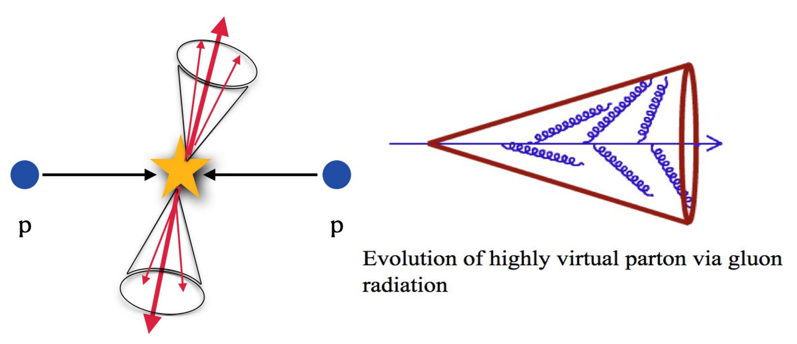
The particles produced in a heavy-ion collision can be broadly classified as:

- Particles originating from hard QCD processes (pre-equilibrium stage),
- Particles originating from a thermal bath of partons undergoing hydrodynamical evolution (equilibrium stage),
- Particles coming from hard-soft interactions.

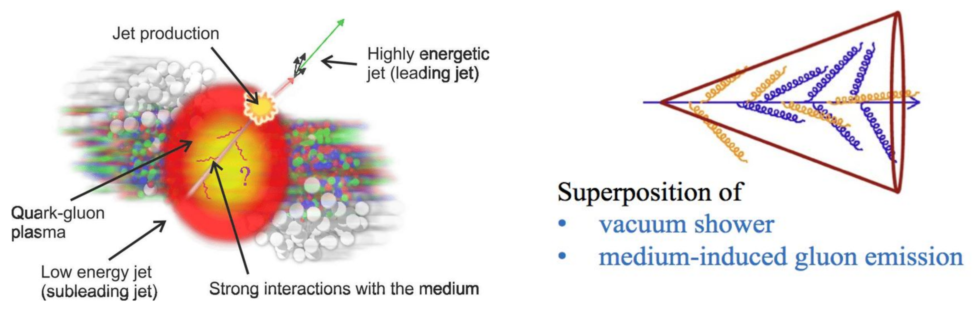
Particles from same source are correlated with each other, creating specific correlation structure in phase space, useful to characterize the system produced in such ultra-relativistic high energetic collisions.

Studying jet-like short-range correlations in heavy-ion collisions provides insights into the early-stage dynamics and spatial structure of the collision system.

Jet shower in vacuum



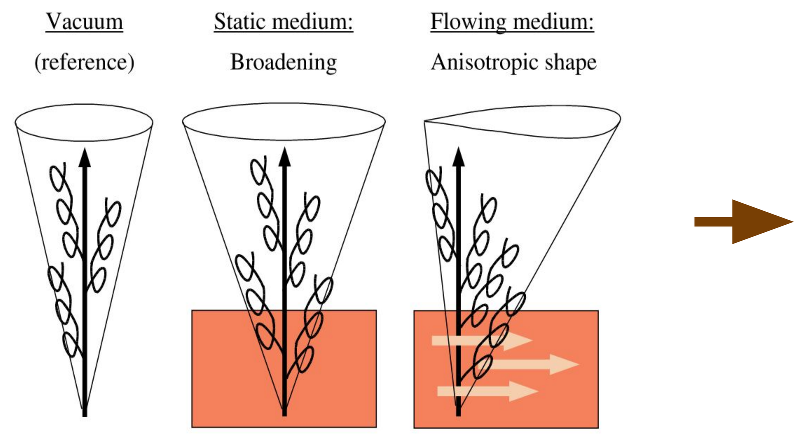
Jet shower in medium



- These processes happen simultaneously and interfere.
- Angle ordering is modified or destroyed.

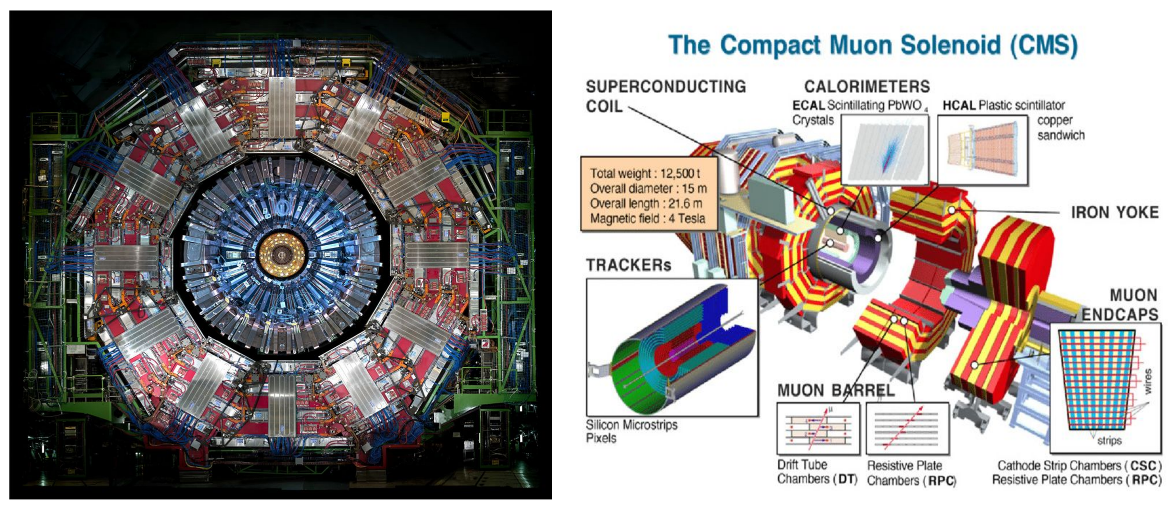
Jet shape in Flowing medium

PhysRevLett.93.242301



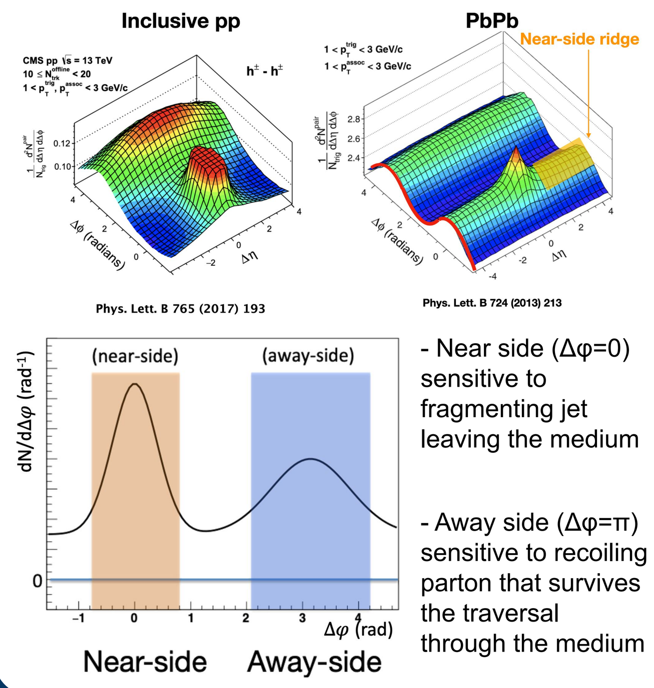
- Left one: Jet fragmenting in the **vacuum**, say **pp system**.
- Middle one: Jet fragmenting in a medium that is **longitudinally comoving** with the rest frame of the jet **(static medium).**
- Right one: Jet fragmenting in a medium that is **longitudinally boosted** with respect to the rest frame of the jet.

CMS Detector



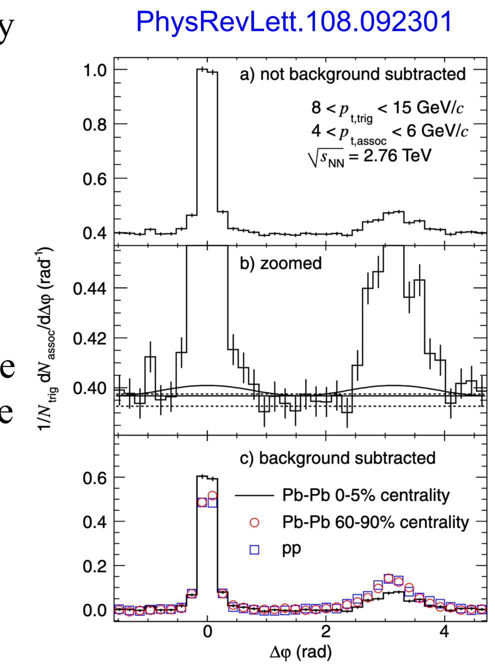
- **Tracking -** High magnetic field and high-granularity silicon detectors
- **Trigger -** The two-tier CMS trigger system efficiently reduces the collision event rate from millions per second to around 1,000
- **Pseudorapidity -** Wide pseudorapidity coverage ($|\eta| < 2.4$)

Di-hadron Correlation & Near-side Peak



- **Two-Particle Correlations**: A key tool to study short-range jet-like correlations statistically.
- The modification of the internal structure of jet-like would be reflected in the near-side peak.
- We can study how the near-side peak width is modified in presence of medium by comparing the same from vacuum.
- We can study the longitudinal boost invariance in forward rapidity because of wide acceptance in eta.

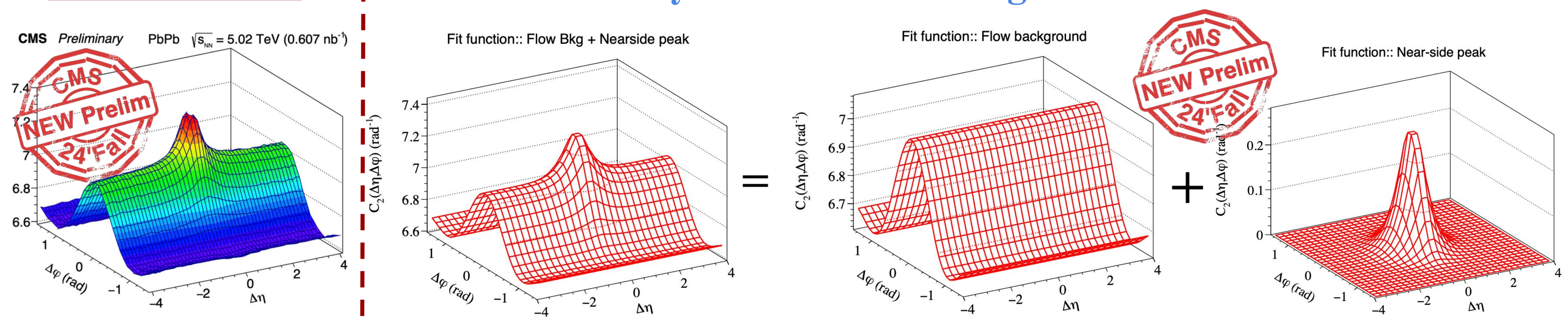
PhysRevLett.108.092301



Part I: Longitudinal & Transverse Width of the Near-side Peak

CMS PAS-HIN-24-008

Analysis method : Fitting functions



We want to extract the width of the near-side peak by fitting the distribution with this function.

$$F(\Delta\phi,\Delta\eta) = c_1\,[1 + \sum_{n=2}^{4} 2V_{n\Delta}\cos(n\Delta\phi)] + c_2\, G_{\gamma_{\Delta\phi},w_{\Delta\phi}} G_{\gamma_{\Delta\eta},w_{\Delta\eta}}$$

$$G_{\gamma_x,w_x}(x) = \frac{\gamma_x}{2w_x\Gamma(1/\gamma_x)}\exp\left[-\left(\frac{|x|}{w_x}\right)^{\gamma_x}\right]$$

PhysRevLett.119.102301

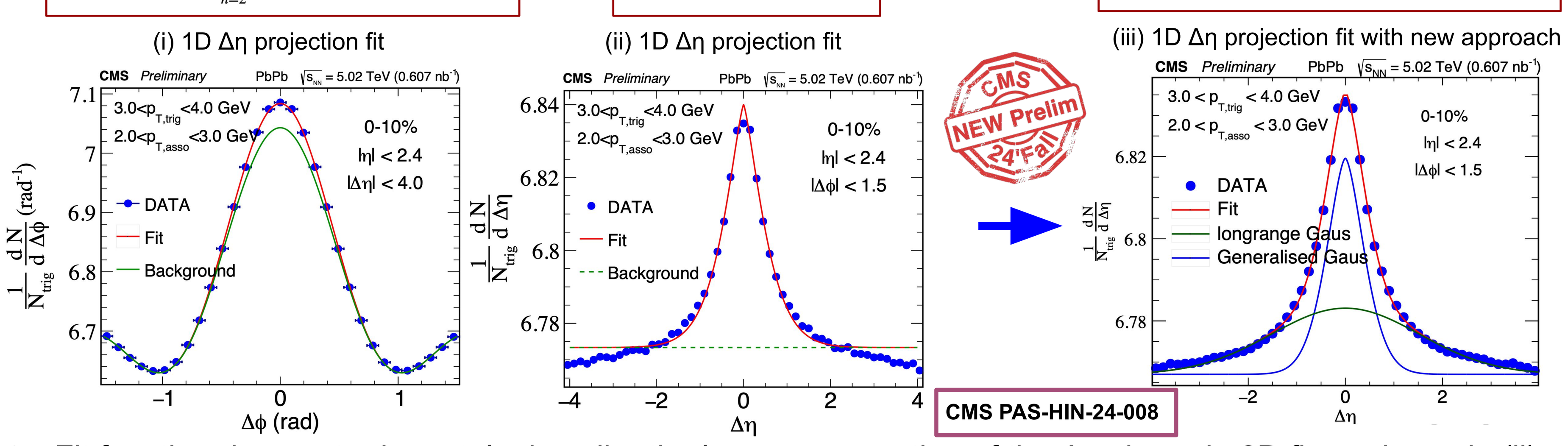
$$\text{Width, } \sigma_x = \sqrt{\frac{w_x^2\,\Gamma(3/\gamma_x)}{\Gamma(1/\gamma_x)}}$$

Analysis method : 1D projection fit

$$F(\Delta\phi) = c_1\,[1 + \sum_{n=2}^{4} 2V_{n\Delta}\cos(n\Delta\phi)] + c_2\, G_{\gamma_{\Delta\phi},w_{\Delta\phi}}$$

$$F(\Delta\eta) = c_1 + c_2\, G_{\gamma_{\Delta\eta},w_{\Delta\eta}}$$

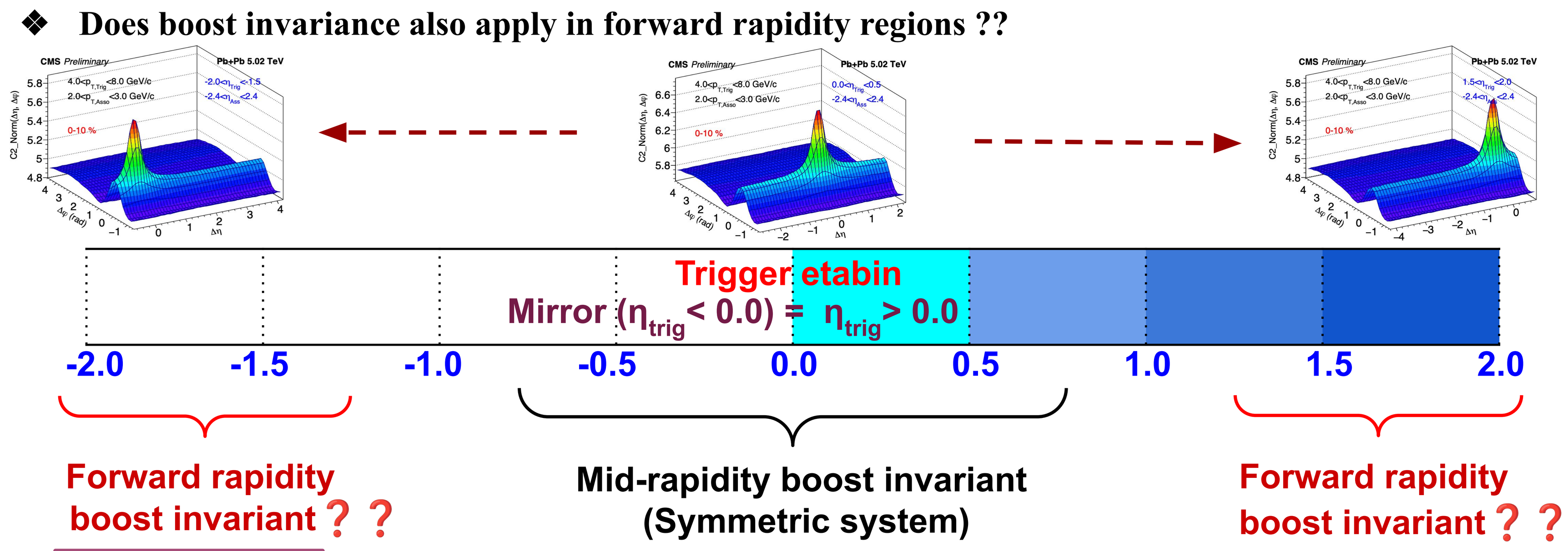
$$F_1(\Delta\eta) = c_1 + c_2\, G_{\gamma_{\Delta\eta},w_{\Delta\eta}} + c_3\, G_{\gamma_{\Delta\eta}(=2),w_{\Delta\eta}}$$



- Fit function does not adequately describe the long-range portion of the Δη shape in 2D fit as shown in (ii).
- We introduce a different approach in which we fit the full Δη region ($|\Delta\eta| < 4.0$) with two components: a generalized Gaussian function to describe the near-side peak region and a standard Gaussian function to capture the long-range Δη-dependent background. Both components are fitted simultaneously as shown in (iii)

Part II: Longitudinal Boost Invariance of the Near-side Peak

- Mid-rapidity refers to the region around zero-rapidity, notable for its observed boost invariance.
- **Does boost invariance also apply in forward rapidity regions ??**



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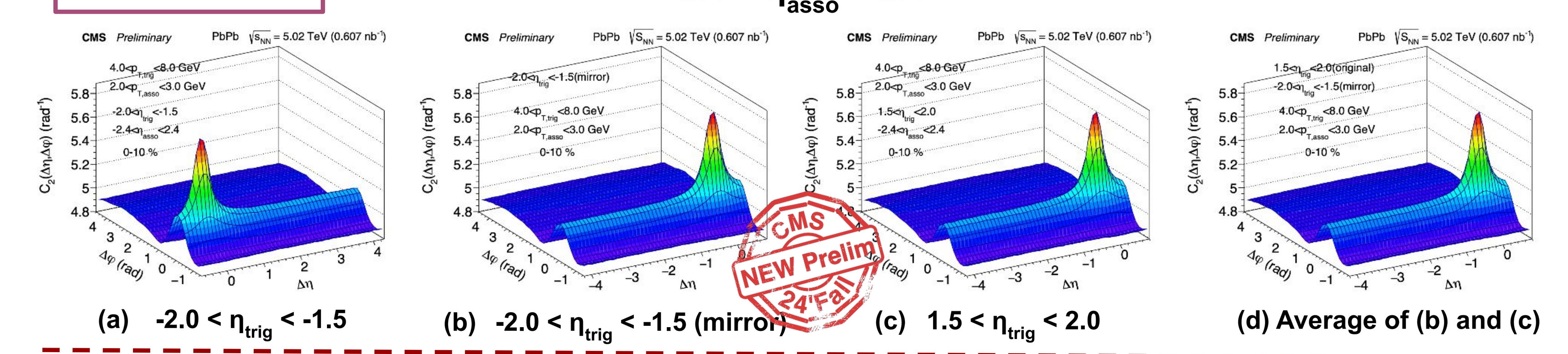

η_{trig} range	Δη range (> 0.0)	Δη range (< 0.0)	|Δη| Analysis cut
1.5 < |η_{trig}| < 2.0	0.9	-4.4	0.7
1.0 < |η_{trig}| < 1.5	1.4	-3.9	0.7
0.5 < |η_{trig}| < 1.0	1.9	-3.4	0.7
0.0 < |η_{trig}| < 0.5	2.4	-2.9	0.7

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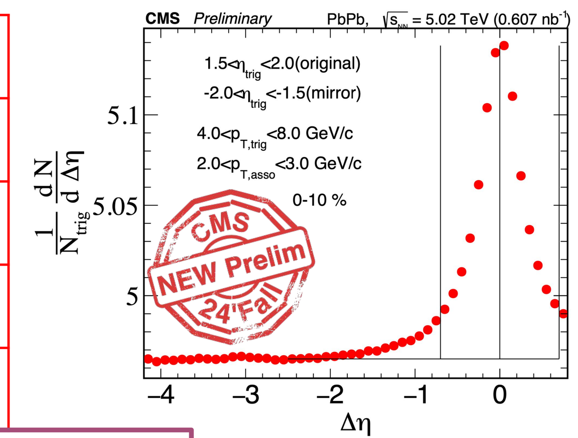

(e) 1D Δη projection of (d)

- We are studying the longitudinal boost invariance by measuring the yield ratio between Δη > 0.0 and Δη < 0.0
- Where, yield is calculated by measuring the integral for both sides of the Δη, $0.0 < |\Delta\eta| < 0.7$

Part I: Results & Discussion

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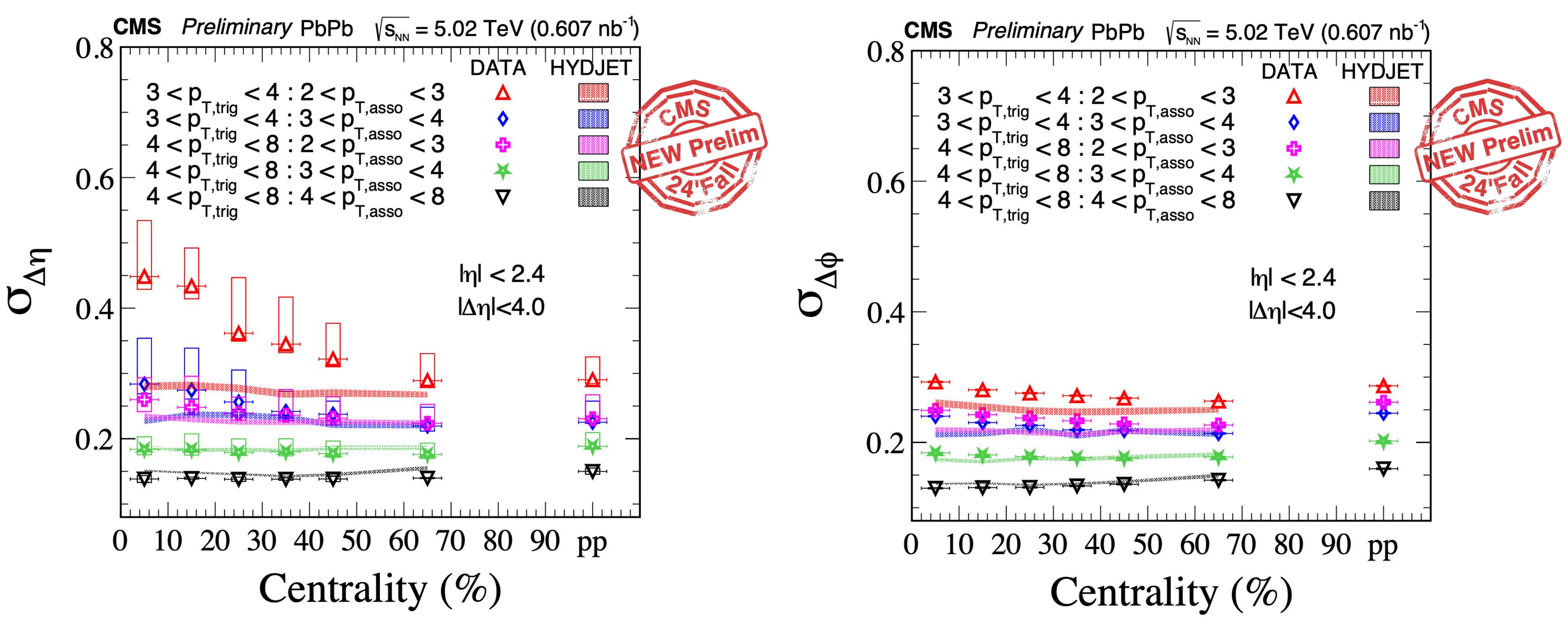


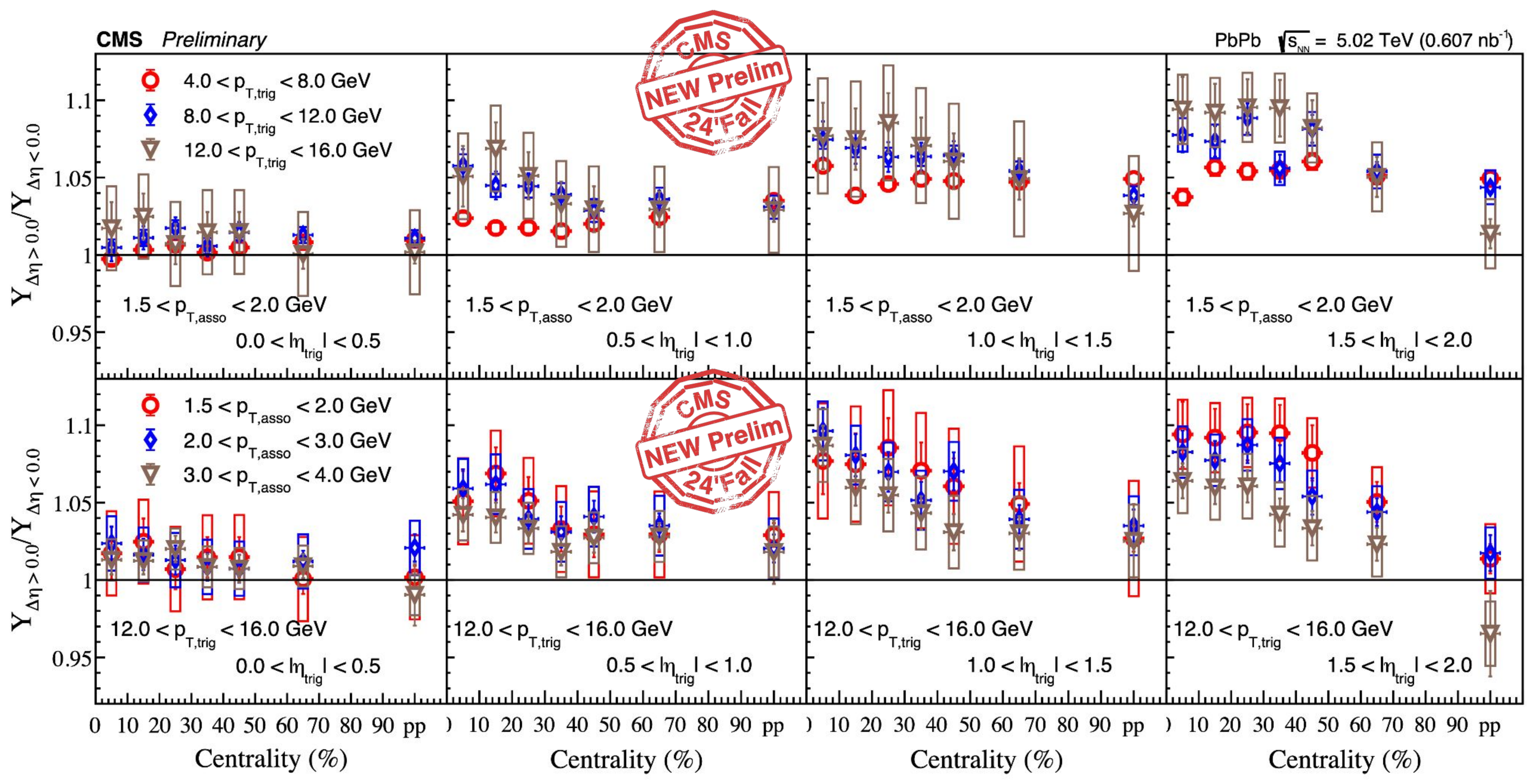
- The near-side peak has a similar shape in pp and PbPb peripheral (50-80%) collisions, where it is approximately symmetric in Δφ and Δη. This symmetric trend vanishes in longitudinal widths (Δη) towards central collisions.
- The centrality dependent longitudinal broadening is mostly effective in low-p_T regions.
- However, HYDJET behaves almost independently with centrality for both longitudinal (Δη) and transverse (Δφ) directions.

Summary

- A possible explanation is : the observed system-size dependence of the peak width may result from longitudinal hydrodynamic flow deforming initially conical jets, leading to a (Δφ – Δη) asymmetry.
- This asymmetry could also be explained by the energy loss of the progenitor parton of the trigger hadron as it interacts with the flow.
- The higher associated yield in Δη > 0, could be attributed to the longitudinally expanding medium, that might impart additional outward thrust to the trigger jet, potentially leading to more associated yields in the forward direction through the recombination process.

Part II: Results & Discussion

CMS PAS-HIN-24-008



- **Longitudinal boost invariance measurement for the first time in CMS, and even in LHC.**
- A significant increase in the associated yield ratio is observed when we move toward forward pseudorapidity (high η_{trig}).
- At mid pseudorapidity (low η_{trig}), the associated yield ratio is consistent with one and almost independent of $p_{T,trig}$ and $p_{T,asso}$ within their uncertainties.
- However, at high η_{trig} , a slight dependence of $p_{T,trig}$ is observed across centrality, where asymmetry increases towards central events.

References

1. Phys. Rev. Lett.119, 102301 (2017), ALICE collaboration, "Anomalous evolution of the near-side jet peak shape in PbPb Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV."
2. Phys. Rev. C 85, 014903 (2012), STAR collaboration, "System size and energy dependence of near-side di-hadron correlations."