

Collectivity of high transverse momentum particles in small collision systems at CMS

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Abstract. Studies at the LHC have revealed signatures of collective dynamics in high-multiplicity proton–lead (pPb) collisions through multiparticle correlation techniques. However, no clear evidence of jet quenching has been established in pPb events. This discrepancy raises the fundamental question: How can a medium that reproduces hydrodynamic-like collective behavior and strongly influences the distribution of soft hadrons show little to no modification of high- p_T particles? To address this puzzle, we present a detailed measurement of transverse momentum and multiplicity-dependent Fourier coefficients (v_n) in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV with the CMS detector. In particular, we extend p_T -differential multiparticle cumulant measurements with the subevent technique to high transverse momentum. A comparison with PbPb collisions in similar multiplicity ranges is also performed.

1 Introduction

Collective azimuthal anisotropies observed in relativistic nucleus–nucleus (AA) collisions at RHIC [1, 2] and the LHC [3, 4] are generally regarded as strong evidence for the formation of a quark–gluon plasma (QGP), a state of matter that behaves like a nearly perfect fluid [5]. The particle emission patterns in such systems are typically described through a Fourier decomposition, where the second (v_2) and third (v_3) coefficients capture the medium’s response to the collision geometry and initial-state fluctuations, thereby constraining the QGP’s transport properties [6]. Similar correlation structures have also been measured in high-multiplicity pPb events [7], raising the possibility that a short-lived QGP-like medium may also emerge in smaller systems.

This work focuses on the azimuthal anisotropy of particles at high transverse momentum. In this regime, energetic partons are not expected to thermalize within the medium, so hydrodynamic flow does not apply. Instead, the dominant source of anisotropy at high p_T is attributed to parton energy loss, which depends on the path length through the medium [9]. In AA collisions, the elliptic overlap geometry in non-central events naturally introduces such path-length-dependent quenching [10, 11]. Motivated by the observation of flow-like signatures in pPb [12, 13], it is important to test whether high- p_T partons are similarly affected in these smaller systems. To this end, we employ the multiparticle Q -cumulant technique [14], incorporating the subevent method [15] to suppress nonflow contributions. We present the first subevent-based cumulant measurement of v_2 extended to $p_T \sim 20$ GeV in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV, with comparisons to PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV recorded with CMS.

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2 Subevent cumulants

The multiparticle Q -cumulant approach is used to determine v_2 values for charged hadrons within $|\eta| < 2.4$, implemented via the *mcorrelations* framework [16]. This formalism, widely applied in previous CMS analyses [17], extracts 4-, 6-, and 8-particle cumulants that are less sensitive to nonflow sources such as jets and dijet correlations. In this scheme, each particle of interest (POI) is correlated with a reference set of $m - 1$ charged hadrons (RFPs). For this study, RFPs are chosen as tracks with $0.3 < p_T < 3.0$ GeV in pPb and $0.5 < p_T < 3.0$ GeV in PbPb, within $|\eta| < 2.4$, ensuring suppression of minijet-related contributions above 3 GeV.

Conventional cumulants allow POIs and RFPs to overlap in pseudorapidity. To further reduce short-range nonflow, we adopt the subevent method, where particles are separated into distinct η intervals prior to correlation building, enforcing a pseudorapidity gap by construction. For two-subevent method we use $-2.4 < \eta < 0$ and $0 < \eta < 2.4$. The three-subevent method uses three η ranges ($-2.4 < \eta < -0.8$, $-0.8 < \eta < 0.8$ and $0.8 < \eta < 2.4$), while the four-subevent method minimizes nonflow effects by assigning each particle to a distinct η range ($-2.4 < \eta < -1.2$, $-1.2 < \eta < 0$, $0 < \eta < 1.2$ and $1.2 < \eta < 2.4$).

Differential cumulants $d_n\{4\}$ are defined as

$$d_n\{4\} = \langle\langle 4' \rangle\rangle - 2\langle\langle 2' \rangle\rangle\langle\langle 2 \rangle\rangle, \quad (1)$$

where $\langle\langle 4' \rangle\rangle$ represents a 4-particle correlator involving one POI and three RFPs, while $\langle\langle 2' \rangle\rangle$ corresponds to a POI-RFP two-particle correlator.

Explicit formulations for 2-, 3-, and 4-subevent cases follow standard definitions [15], with pseudorapidity partitions ensuring non-overlap between POI and RFPs. For example, in the two-subevent configuration, particles from subevent a' are correlated against those from b^* , while higher-order (three- or four-subevent) cases provide stricter suppression of short-range jetlike correlations.

The final anisotropy coefficients are extracted as

$$v_n\{4\} = -d_n\{4\}/(-c_n\{4\})^{3/4}, \quad (2)$$

with $c_n\{4\}$ denoting the integrated 4-particle cumulant. Additional details on detector performance and analysis procedures are available in Ref. [18].

3 Results

Figure 1 shows $v_2\{4\}$ for the multiplicity class $185 \leq N_{\text{trk}}^{\text{offline}} < 250$. In pPb, the standard cumulant analysis yields negative $v_2\{4\}$ values at $p_T > 10$ GeV, reflecting the dominance of nonflow from hard jets in these rare high-multiplicity events. Applying the subevent technique preserves positive $v_2\{4\}$ values up to $p_T \sim 17$ GeV, and the agreement between three- and four-subevent methods demonstrates robust suppression of jet-related biases.

In Fig. 2, the left panel shows that the $v_2\{4\}$ magnitudes in pPb closely match those observed in PbPb at high p_T . The right panel illustrates $v_2\{4\}$ as a function of multiplicity for $p_T > 6$ GeV, revealing consistent values between the two systems except at the lowest multiplicities, where the pPb results are compatible with zero within uncertainties.

4 Summary

We have presented measurements of $v_2\{4\}$ using the subevent cumulant approach in pPb and PbPb collisions at $\sqrt{s_{\text{NN}}} = 8.16$ and 5.02 TeV, respectively. These results extend azimuthal

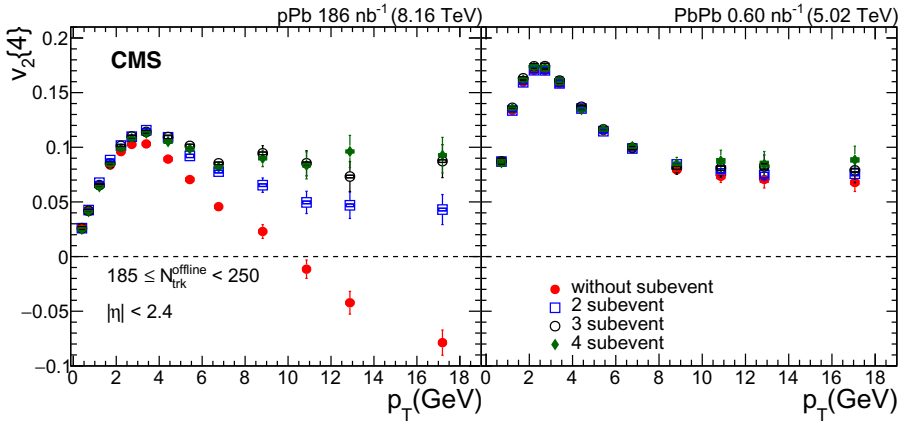


Figure 1. $v_2\{4\}$ versus p_T for $185 \leq N_{\text{trk}}^{\text{offline}} < 250$ in pPb (left) and PbPb (right) collisions. Statistical (lines) and systematic (boxes) uncertainties are shown.

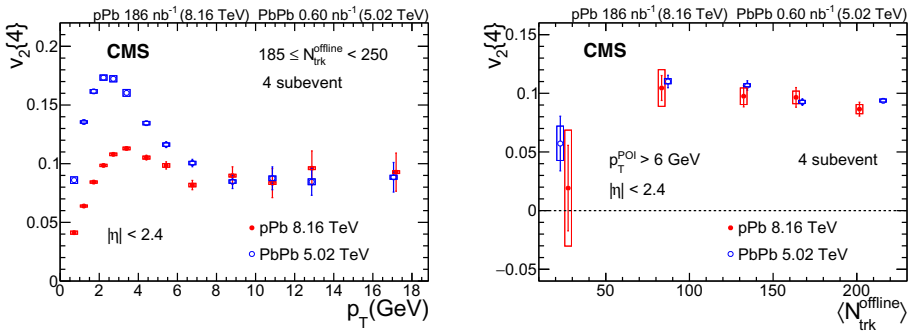


Figure 2. Left: $v_2\{4\}$ versus p_T from the 4-subevent method. Right: $v_2\{4\}$ as a function of $\langle N_{\text{trk}}^{\text{offline}} \rangle$ for POI with $p_T > 6$ GeV.

anisotropy studies into the high- p_T regime in small collision systems. After nonflow suppression, significant positive $v_2\{4\}$ values are observed in high-multiplicity pPb events up to $p_T \sim 17$ GeV. The striking similarity between pPb and PbPb high- p_T v_2 suggests a common underlying mechanism driving parton anisotropy across small and large systems, offering new constraints on the interplay between parton energy loss and collective dynamics.

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