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Correlations of azimuthal anisotropy Fourier harmonics with subevent cumulants in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16\,\mathrm{TeV}$

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Abstract

Event-by-event long-range correlations of azimuthal anisotropy Fourier coefficients (v_n) in 8.16 TeV pPb data, collected by the CMS experiment at the LHC, are extracted using a subevent four-particle cumulant technique applied to very low multiplicity events. Each combination of four charged particles are selected from either two, three, or four distinct subevent regions of a pseudorapidity range from -2.4 to 2.4 of the CMS tracker, and with transverse momentum between 0.3 and 3.0 GeV. Using the subevent cumulant technique, correlations between v_n of different orders are measured as functions of particle multiplicity and compared to the standard cumulant method without subevents over a wide event multiplicity range. At high multiplicities, the v_2 and v_3 coefficients exhibit an anticorrelation; this behavior is observed consistently using various methods. The v_2 and v_4 correlation strength is found to depend on the number of subevents used in the calculation. As the event multiplicity decreases, the results from different subevent methods diverge because of different contributions of non-collective or few-particle correlations. Correlations extracted with the four-subevent method exhibit a tendency to diminish monotonically toward the lowest multiplicity region (about 20 charged tracks) investigated. These findings extend previous studies to a significantly lower event multiplicity range and establish the evidence for the onset of long-range collective multiparticle correlations in small system collisions.

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*See Appendix A for the list of collaboration members

1 Introduction

In high-energy ultrarelativistic nucleus-nucleus (AA) collisions, a dense and hot state of matter called the quark gluon plasma (QGP) is produced [1, 2]. Studies of multiparticle correlations provide important insights into the underlying mechanism of particle production in this strongly coupled, non-perturbative regime. A key feature of such multiparticle correlations in AA collisions is a pronounced structure on the near side relative azimuthal angle ($|\Delta\phi| \approx 0$) that extends over a large range in relative pseudorapidity ($|\Delta\eta|$ up to 4 units or more). This feature, known as the "ridge", has been found over a wide range of center-of-mass energies and system sizes in AA collisions at both the BNL RHIC [3–6] and the CERN LHC [7–11]. It is interpreted as arising primarily from the initial anisotropic geometry and its fluctuations coupled with the collective hydrodynamic flow of a strongly interacting, expanding medium [12, 13]. The azimuthal correlations of emitted particle pairs are typically characterized by their Fourier components as:

$$\frac{\mathrm{d}N^{\mathrm{pair}}}{\mathrm{d}\Delta\phi} \propto 1 + \sum_{n} 2V_{n\Delta}\cos(n\Delta\phi), \tag{1}$$

where $V_{n\Delta}$ are the two-particle Fourier coefficients. If factorization is assumed, $v_n = \sqrt{V_{n\Delta}}$ denote the single-particle anisotropy harmonics [14]. In particular, the second, third, and fourth Fourier components are known as elliptic (v_2), triangular (v_3), and quadrangular (v_4) flow, respectively [13].

In order to constrain the effects of the geometry and its fluctuations in the initial conditions, and the transport properties of the produced medium in AA collisions, new studies were carried out looking at correlations between different orders of v_n harmonics. In particular, event-by-event fluctuations of v_n harmonic amplitudes in PbPb collisions at the LHC were studied using the event shape engineering technique [15], and the four-particle symmetric cumulant (SC) method [16, 17], where the SC method for two different harmonic orders n and m is defined as:

$$\begin{aligned} \mathrm{SC}(n,m) &= \langle\langle\cos(n\phi_1 + m\phi_2 - n\phi_3 - m\phi_4)\rangle\rangle - \langle\langle\cos(n\phi_1 - n\phi_2)\rangle\rangle\langle\langle\cos(m\phi_3 - m\phi_4)\rangle\rangle, \\ &= \langle v_n^2 v_m^2\rangle - \langle v_n^2\rangle\langle v_m^2\rangle. \end{aligned} \tag{2}$$

Here, the double angular brackets indicate that the averaging procedure is done first on all distinct particle quadruplets in an event, and then over all the events, by weighting each single event average with its number of quadruplets. Over the full range of impact parameters in PbPb collisions, it was found that the v_2 harmonic exhibits a negative event-by-event correlation with the v_3 harmonic, while the correlation is positive between the v_2 and v_4 harmonics. These correlations are shown to be sensitive probes of initial-state fluctuations (v_2 *vs.* v_3) and medium transport coefficients (v_2 *vs.* v_4) [16, 18–21].

In high-multiplicity pp and pA collisions, the "ridge" has been observed [22–28] and detailed studies have highlighted its collective nature [29–32]. Event-by-event correlations among the v_2, v_3 and v_4 Fourier harmonics have also been measured for both systems using the SC method [33]. The correlation data reveal features similar to those observed in PbPb collisions, where a negative correlation is found between the v_2 and v_3 harmonics, while the correlation is positive between the v_2 and v_4 harmonics. These observations may further support the hydrodynamic origin of collective correlations in high-multiplicity events for these small systems [16].

However, the nature of the long-range collectivity in small systems, especially for the low-multiplicity region (e.g., less than about 50–60 charged particles), still remains inconclusive

and much debated (e.g., see reviews in Refs. [34, 35]). It has been argued that the contribution of initial momentum space collectivity from the gluon saturation model may become dominant as the event multiplicity decreases [36]. Understanding the multiplicity dependence of the observed long-range collectivity is the key to disentangle contributions from various physical origins. Experimental investigation of collective multiparticle correlations for low-multiplicity events is largely hindered by the presence of significant noncollective correlations (nonflow), such as few-particle correlations from jets. The observed trend for the v_2–v_3 correlation (SC(n,m)) to become positive is likely related to the nonflow effect [33]. In order to suppress these few-particle correlations and to explore possible collective correlation signals, subevent cumulant techniques have been proposed to require rapidity gaps among particles [37, 38]. As detailed in Refs. [38–40], each combination of four particles is required to fall into two, three or four distinct subevents within the full η range. There are already studies highlighting the importance of the nonflow contribution in cumulant calculations and the effectiveness of the subevent techniques to strongly suppress it [39, 40].

Using a large data sample collected using the CMS detector, this paper presents the first measurement of event-by-event correlations of v_2 *vs.* v_3 and v_2 *vs.* v_4 using the SC method with subevents in pPb collisions at a nucleon-nucleon center-of mass energy $\sqrt{s_{\mathrm{NN}}} = 8.16\,\mathrm{TeV}$ covering a wide multiplicity range. The correlation measurements are performed using 2, 3, and 4 subevents, where the impact of few-particle correlations is systematically reduced in a data-driven way as the number of subevents increases. The results are also compared to previous measurements without the subevent technique.

2 The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume, there are four primary subdetectors including a silicon pixel and strip tracker detector, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections. The iron and quartz-fiber Cherenkov hadron forward (HF) calorimeters cover the range $3 < |\eta| < 5$. The silicon tracker measures charged particles within the range $|\eta| < 2.5$. For charged particles with transverse momentum $1 < p_{\mathrm{T}} < 10\,\mathrm{GeV}/c$ and $|\eta| < 1.4$, the track resolutions are typically 1.5% in p_{T} and 25–90 (45–150) μm in the transverse (longitudinal) impact parameter [41]. The Monte Carlo (MC) simulation of the full CMS detector response is based on GEANT4 [42]. The detailed description of the CMS detector can be found in Ref. [43].

3 Event and track selections

The measurements presented in this paper use the 8.16 TeV pPb data set with an integrated luminosity of $186\,\mathrm{nb}^{-1}$, where the beam directions were reversed during the run after collecting the first $62.6\,\mathrm{nb}^{-1}$. The beam energies were 6.5 TeV for protons and 2.56 TeV per nucleon for lead nuclei [44]. The results from both beam directions are combined using the convention that the proton-going direction defines positive pseudorapidity. As a result of the energy difference between the colliding beams, the nucleon-nucleon center-of-mass frame in the pPb collisions is not at rest with respect to the laboratory frame. Massless particles emitted at $\eta_{\mathrm{CM}} = 0$ in the nucleon-nucleon center-of-mass frame will be detected at $\eta_{\mathrm{lab}} = 0.465$ in the laboratory frame. All pseudorapidities reported in this paper are given with respect to the laboratory frame. During the data taking, the average number of collisions per bunch crossing (pileup) varied

from 0.10 to 0.25. A procedure similar to that described in Ref. [45] is used for identifying and rejecting events with pileup.

The minimum bias (MB) 8.16 TeV pPb events are triggered by requiring energy deposits in at least one of the two HF calorimeters above 1 GeV and the presence of at least one track with $p_{\mathrm{T}} > 0.4\,\mathrm{GeV}/c$ reconstructed using hits from the pixel tracker only. In order to collect a large sample of high-multiplicity pPb collisions, a dedicated trigger is implemented using the CMS level-1 (L1) and high-level trigger (HLT) systems [46]. At L1, the total number of ECAL+HCAL towers having deposited energy above an energy threshold of 0.5 GeV in transverse energy (E_{T}) is required to be greater than a given threshold (120 and 150 towers depending on the targeted multiplicity range). As part of the HLT trigger, the track reconstruction is performed online with the identical reconstruction algorithm used offline [41]. For each event selected at L1, the reconstructed vertex with the highest number of associated tracks is selected as the primary vertex at the HLT. The number of tracks with $|\eta| < 2.4$, $p_{\mathrm{T}} > 0.4\,\mathrm{GeV}/c$, and a distance of closest approach less than 0.12 cm along the beam axis to the primary vertex is determined for each event and is required to exceed 120, 185 and 250 to enrich the sample with high-multiplicity (HM) events in the ranges 120–185, 185–250 and 250–∞, respectively. The events are required to contain a primary vertex within 15 cm of the nominal interaction point along the beam axis and 0.2 cm in the transverse direction. Finally, for high-multiplicity events, the trigger efficiency is required to be greater than 95%. In the multiplicity region where this requirement is not met ($N_{\mathrm{trk}}^{\mathrm{offline}} < 120$), MB triggered events are used.

In the offline analysis, the primary tracks, i.e. reconstructed tracks that originate from the primary vertex and satisfy the high-quality criteria of Ref. [41], are used to perform the correlation measurements, as well as to evaluate the charged-particle multiplicity ($N_{\mathrm{trk}}^{\mathrm{offline}}$) for each event. In addition, the significances of the track impact parameter with respect to the primary vertex in the transverse and longitudinal direction divided by their uncertainties are required to be less than 3. The relative p_{T} uncertainty must be less than 10%. To ensure high tracking efficiency, only tracks with $|\eta| < 2.4$ and $p_{\mathrm{T}} > 0.3\,\mathrm{GeV}/c$ are used in this analysis [41].

In this analysis, about 8 billion MB and 500 million HM events are selected. Following the convention established in previous analyses [33, 47, 48], the pPb data are shown in classes of $N_{\mathrm{trk}}^{\mathrm{offline}}$, which is the number of primary tracks with $|\eta| < 2.4$ and $p_{\mathrm{T}} > 0.4\,\mathrm{GeV}/c$, without corrections for acceptance and efficiency. The $N_{\mathrm{trk}}^{\mathrm{offline}}$ boundaries used for the results of this paper are: 10, 20, 40, 80, 120, 150, 185, 250, and 350. These boundaries are chosen to minimize the statistical uncertainty in each bin. The average $N_{\mathrm{trk}}^{\mathrm{offline}}$ for MB pPb events is about 40. The overall CMS acceptance and tracking efficiency is about 85%.

4 Analysis technique

The SC technique, first introduced in Ref. [16], is based on four-particle correlations using cumulants. The four-particle cumulant technique, by simultaneously correlating four particles, is known to have the advantage of suppressing nonflow quite efficiently compared to other methods [17, 30]. To study the correlation between the Fourier coefficients n and m, one can build, for each event, a 2-particle correlator ($\langle\cos(n\phi_1 - n\phi_2)\rangle$) and a 4-particle correlator ($\langle\cos(n\phi_1 + m\phi_2 - n\phi_3 - m\phi_4)\rangle$) with a complex notation average over all the events as:

$$\begin{aligned} \langle\langle 2_{n,-n}\rangle\rangle &\equiv \left\langle\left\langle e^{i(n\phi_1 - n\phi_2)}\right\rangle\right\rangle, \\ \langle\langle 4_{n,m,-n,-m}\rangle\rangle &\equiv \left\langle\left\langle e^{i(n\phi_1 + m\phi_2 - n\phi_3 - m\phi_4)}\right\rangle\right\rangle. \end{aligned} \tag{3}$$

In the above equations, the real part of the 2- and 4-particle correlators are the cosine terms presented in Eq. (2.) The final observable, the *SC*, is defined as follows:

$$\mathrm{SC}(n,m) = \langle\langle 4_{n,m,-n,-m}\rangle\rangle - \langle\langle 2_{n,-n}\rangle\rangle \langle\langle 2_{m,-m}\rangle\rangle. \tag{4}$$

Nevertheless, it was shown in previous studies [33] that the standard four-particle cumulant technique does not suppress all of the short-range correlation contribution. In particular, the increasing trend of SC toward low multiplicities, following a power law, is characteristic of remaining nonflow contaminations [49]. In that paper, to further suppress nonflow, the subevent technique is used based on the calculation published in Ref. [37]. In the two-subevent case, the first and second subevents are defined as $-2.4 < \eta < 0$ and $0 < \eta < 2.4$. The bounds for three subevents are -2.4, -0.8, 0.8, 2.4, and for four subevents are -2.4, -1.2, 0, 1.2, 2.4. The formula of the SC calculation can be derived from Eq. (4):

$$\mathrm{SC}_{2\mathrm{sub}}(n,m) = \langle\langle 4\rangle^{aa|bb}_{n,m|-n,-m}\rangle - \langle\langle 2\rangle^{a|b}_{n|-n}\rangle\langle\langle 2\rangle^{a|b}_{m|-m}\rangle, \tag{5}$$

$$\mathrm{SC}_{3\mathrm{sub}}(n,m) = \langle\langle 4\rangle^{a|bb|c}_{-n|m,n|-m}\rangle - \langle\langle 2\rangle^{a|b}_{-n|n}\rangle\langle\langle 2\rangle^{b|c}_{m|-m}\rangle, \tag{6}$$

$$\mathrm{SC}_{4\mathrm{sub}}(n,m) = \langle\langle 4\rangle^{a|b|c|d}_{n|m|-n|-m}\rangle - \langle\langle 2\rangle^{a|c}_{n|-n}\rangle\langle\langle 2\rangle^{b|d}_{m|-m}\rangle. \tag{7}$$

where a, b, c, and d denote the particles chosen in each subevent for the calculation and n, m the corresponding harmonic attributed to this subevent. In Eq. (5), the notation $aa|bb$ in the 4-particle correlator means that two particles are required to be in the first subevent (aa) while the other two are required to be in the second subevent (bb). Similarly, for the 2-particle correlator, one particle in each subevent is required ($a|b$). A similar reasoning is applied in Eqs. (6) and (7).

The systematic uncertainties in the experimental procedure are evaluated by varying the conditions in extracting SC. The systematic uncertainties due to tracking inefficiency and misreconstructed track rate are studied by varying the track quality requirements. The selection thresholds on the significance of the transverse and longitudinal track impact parameter divided by their uncertainties are varied from 2 to 5. In addition, the relative p_{T} uncertainty is varied from 5 to 10%. The sensitivity of the results to the primary vertex position along the beam axis (z_{vtx}) is quantified by comparing results with different z_{vtx} selection: $|z_{\mathrm{vtx}}| < 3\,\mathrm{cm}$ and $3 < |z_{\mathrm{vtx}}| < 15\,\mathrm{cm}$, and the possible contamination by residual pileup interactions is studied by varying the pileup rejection criteria from no pileup rejection at all to selecting events with only one reconstructed vertex. Finally, to study potential trigger biases, a comparison to high-multiplicity pPb data for a given multiplicity range that were collected by a lower-threshold trigger with 100% efficiency is performed. This uncertainty is found to be negligible, while the other systematic uncertainty sources have contributions of 1% each, independent of $N^{\mathrm{offline}}_{\mathrm{trk}}$. The total systematic uncertainties are estimated to be 1.8% for SC.

5 Results

The results of symmetric cumulants $\mathrm{SC}(2,3)$ and $\mathrm{SC}(2,4)$ obtained with the 2-, 3-, and 4-subevent methods for $0.3 < p_{\mathrm{T}} < 3\,\mathrm{GeV}/c$ are shown in Fig. 1, as functions of multiplicity in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16\,\mathrm{TeV}$. For comparison, the results with no subevents from Ref. [33] are also shown for the range $40 < N^{\mathrm{offline}}_{\mathrm{trk}} < 350$ (the SC with no subevents for lower multiplicities are out of range because of the choice of the y-axis scale). The systematic uncertainties are the same for no and n-subevents ($n = 2, 3, 4$).

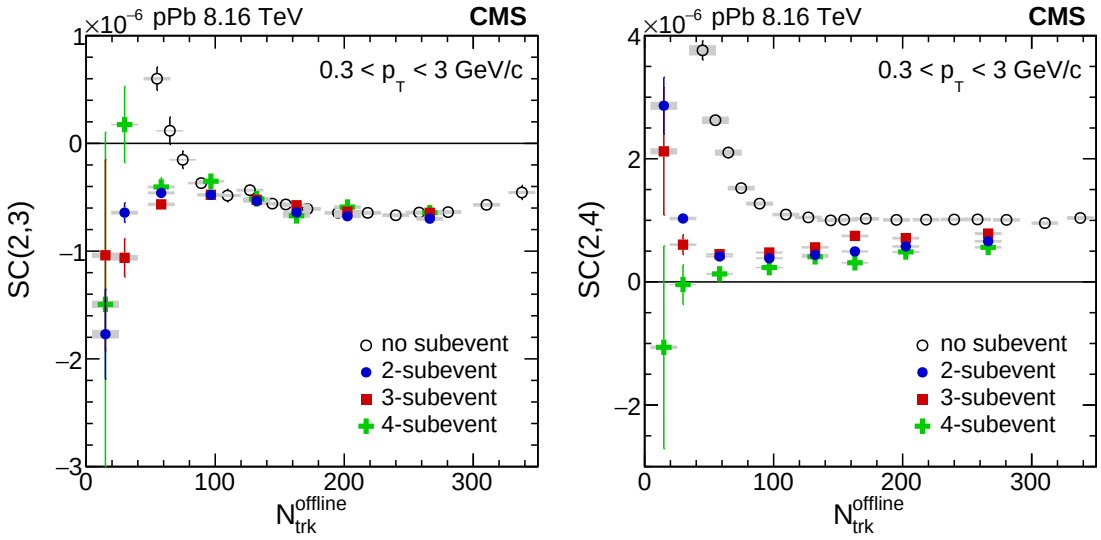

Figure 1: The $\mathrm{SC}(2,3)$ (left) and $\mathrm{SC}(2,4)$ (right) distributions as functions of $N_{\mathrm{trk}}^{\mathrm{offline}}$ from 2 subevents (full blue circles), 3 subevents (red squares), and 4 subevents (green crosses). For comparison, published results from Ref. [33] with no subevents (open black circles), are also shown. Bars represent statistical uncertainties while grey areas represent the systematic uncertainties.

Both $\mathrm{SC}(2,3)$ and $\mathrm{SC}(2,4)$ diverge toward large positive values for low-$N_{\mathrm{trk}}^{\mathrm{offline}}$ ranges ($N_{\mathrm{trk}}^{\mathrm{offline}} < 80$) using the no-subevent method, likely because of a dominant contribution from few-particle short-range correlations, as discussed in Ref. [33]. Using the subevent method, the contributions from short-range correlations are significantly suppressed [39, 40]. No significant positive $\mathrm{SC}(2,3)$ values with subevent methods are observed over the entire event multiplicity range. The 2- and 3-subevent $\mathrm{SC}(2,3)$ preserve significant negative signals down to $N_{\mathrm{trk}}^{\mathrm{offline}} \sim 20$, while the 4-subevent $\mathrm{SC}(2,3)$ tends to show a monotonic trend gradually converging to zero at $N_{\mathrm{trk}}^{\mathrm{offline}} \sim 20$. Similar behavior is also observed for $\mathrm{SC}(2,4)$, where 2- and 3-subevent $\mathrm{SC}(2,4)$ values remain positive but the 4-subevent $\mathrm{SC}(2,4)$ decreases to zero toward $N_{\mathrm{trk}}^{\mathrm{offline}} \sim 20$. As the 4-subevent method is the most powerful in eliminating nonflow effects, the observed trends in 4-subevent $\mathrm{SC}(2,3)$ and $\mathrm{SC}(2,4)$ provide evidence for the onset of long-range collective particle correlations from low to high multiplicities in pPb collisions.

For $N_{\mathrm{trk}}^{\mathrm{offline}} > 80$, the no-subevent and n-subevent methods give consistent results for $\mathrm{SC}(2,3)$, suggesting that the contribution from nonflow effects is negligible. For $\mathrm{SC}(2,4)$, there is a difference clearly observed between no-subevent and n-subevent results even up to the highest multiplicities investigated. This observation is illustrated more clearly in Fig. 2, which shows the $\mathrm{SC}(2,3)$ and $\mathrm{SC}(2,4)$ relative differences between 2 subevents and 3 or 4 subevents. The $\mathrm{SC}(2,3)$ results (Fig. 2, left) are consistent among the 2-, 3- and 4-subevent methods, while there is an approximately 10–40% difference for $\mathrm{SC}(2,4)$ (Fig. 2, right) between the 2-subevent and 3- or 4-subevent methods. The 3-subevent $\mathrm{SC}(2,4)$ values are greater than the 2-subevent values, contrary to what is typically expected from non-flow contributions. This behavior may suggest the sensitivity of $\mathrm{SC}(2,4)$ to other effects. In particular, the event-plane decorrelation [50] could be an important contribution to the observed behavior as also observed in Ref. [32]. The impact of event-plane decorrelation and how it may be different for $\mathrm{SC}(2,3)$ and $\mathrm{SC}(2,4)$ remains to be understood in future work.

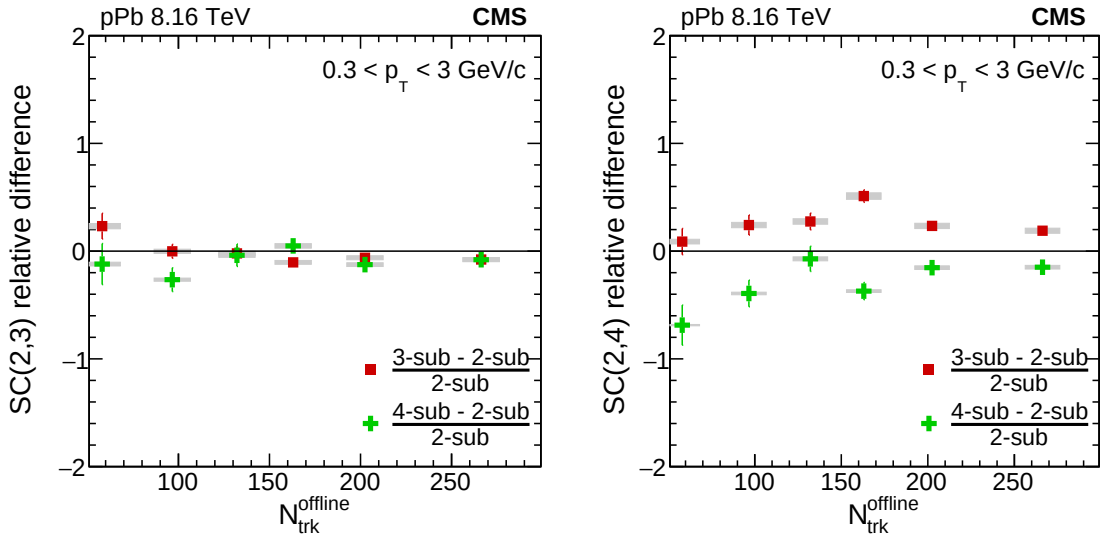

Figure 2: The relative difference of $\mathrm{SC}(2,3)$ (left) and $\mathrm{SC}(2,4)$ (right) between 2 and 3 subevents (red squares) as well as between 2 and 4 subevents (green crosses) as a function of $N_{\mathrm{trk}}^{\mathrm{offline}}$. Bars represent statistical uncertainties while shaded areas represent the systematic uncertainties.

6 Summary

The first measurement of event-by-event correlations of different Fourier harmonic orders in symmetric cumulants $\mathrm{SC}(2,3)$ and $\mathrm{SC}(2,4)$ with 2, 3, and 4 subevents in proton-lead (pPb) collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16\,\mathrm{TeV}$ is presented using a large data sample collected by the CMS experiment. The pPb data analyzed with the subevent method are compared to previously published results using the technique without subevents. In all cases, an anticorrelation is observed between the single-particle anisotropy harmonics v_2 and v_3, while v_2 and v_4 are positively correlated. For charged-particle multiplicity $N_{\mathrm{trk}}^{\mathrm{offline}} > 100$, both standard and n-subevent methods give similar results for $\mathrm{SC}(2,3)$, suggesting that nonflow effects have negligible contributions in this region. The $\mathrm{SC}(2,4)$ results show a somewhat different behavior, which depends on the number of subevents in the same multiplicity region. By significantly suppressing the nonflow contribution, the 4-subevent results for both $\mathrm{SC}(2,3)$ and $\mathrm{SC}(2,4)$ show a monotonically decreasing magnitude toward zero at $N_{\mathrm{trk}}^{\mathrm{offline}} \sim 20$. These new results presented in this paper provide evidence for the onset of long-range collective particle correlations from low to high multiplicity events in pPb collisions. The observed multiplicity dependence of multiparticle azimuthal correlations may further constrain the physical origin of the collectivity observed in small system collisions.

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References

[1] E. V. Shuryak, "What RHIC experiments and theory tell us about properties of quark-gluon plasma?", *Nucl. Phys. A* **750** (2005) 64, doi:10.1016/j.nuclphysa.2004.10.022, arXiv:hep-ph/0405066.

[2] W. Busza, K. Rajagopal, and W. van der Schee, "Heavy ion collisions: The big picture, and the big questions", *Ann. Rev. Nucl. Part. Sci.* **68** (2018) 339, doi:10.1146/annurev-nucl-101917-020852, arXiv:1802.04801.

[3] STAR Collaboration, "Long range rapidity correlations and jet production in high energy nuclear collisions", *Phys. Rev. C* **80** (2009) 064912, doi:10.1103/PhysRevC.80.064912, arXiv:0909.0191.

[4] PHOBOS Collaboration, "System size dependence of cluster properties from two-particle angular correlations in Cu+Cu and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV", *Phys. Rev. C* **81** (2010) 024904, doi:10.1103/PhysRevC.81.024904, arXiv:0812.1172.

[5] PHOBOS Collaboration, "High transverse momentum triggered correlations over a large pseudorapidity acceptance in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV", *Phys. Rev. Lett.* **104** (2010) 062301, doi:10.1103/PhysRevLett.104.062301, arXiv:0903.2811.

[6] STAR Collaboration, "Three-particle coincidence of the long range pseudorapidity correlation in high energy nucleus-nucleus collisions", *Phys. Rev. Lett.* **105** (2010) 022301, doi:10.1103/PhysRevLett.105.022301, arXiv:0912.3977.

[7] CMS Collaboration, "Long-range and short-range dihadron angular correlations in central PbPb collisions at a nucleon-nucleon center of mass energy of 2.76 TeV", *JHEP* **07** (2011) 076, doi:10.1007/JHEP07(2011)076, arXiv:1105.2438.

[8] CMS Collaboration, "Centrality dependence of dihadron correlations and azimuthal anisotropy harmonics in PbPb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *Eur. Phys. J. C* **72** (2012) 2012, doi:10.1140/epjc/s10052-012-2012-3, arXiv:1201.3158.

[9] ALICE Collaboration, "Harmonic decomposition of two-particle angular correlations in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *Phys. Lett. B* **708** (2012) 249, doi:10.1016/j.physletb.2012.01.060, arXiv:1109.2501.

[10] ATLAS Collaboration, "Measurement of the azimuthal anisotropy for charged particle production in $\sqrt{s_{\rm NN}}$ = 2.76 TeV lead-lead collisions with the ATLAS detector", *Phys. Rev. C* **86** (2012) 014907, doi:10.1103/PhysRevC.86.014907, arXiv:1203.3087.

[11] CMS Collaboration, "Studies of azimuthal dihadron correlations in ultra-central PbPb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *JHEP* **02** (2014) 088, doi:10.1007/JHEP02(2014)088, arXiv:1312.1845.

[12] J.-Y. Ollitrault, "Anisotropy as a signature of transverse collective flow", *Phys. Rev. D* **46** (1992) 229, doi:10.1103/PhysRevD.46.229.

[13] B. Alver and G. Roland, "Collision geometry fluctuations and triangular flow in heavy-ion collisions", *Phys. Rev. C* **81** (2010) 054905, doi:10.1103/PhysRevC.81.054905, arXiv:1003.0194. [Erratum: doi:10.1103/PhysRevC.82.039903].

[14] S. Voloshin and Y. Zhang, "Flow study in relativistic nuclear collisions by Fourier expansion of azimuthal particle distributions", *Z. Phys. C* **70** (1996) 665, doi:10.1007/s002880050141, arXiv:hep-ph/9407282.

[15] ATLAS Collaboration, "Measurement of the correlation between flow harmonics of different order in lead-lead collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV with the ATLAS detector", *Phys. Rev. C* **92** (2015) 034903, doi:10.1103/PhysRevC.92.034903, arXiv:1504.01289.

[16] ALICE Collaboration, "Correlated event-by-event fluctuations of flow harmonics in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *Phys. Rev. Lett.* **117** (2016) 182301, doi:10.1103/PhysRevLett.117.182301, arXiv:1604.07663.

[17] A. Bilandzic et al., "Generic framework for anisotropic flow analyses with multiparticle azimuthal correlations", *Phys. Rev. C* **89** (2014) 064904, doi:10.1103/PhysRevC.89.064904, arXiv:1312.3572.

[18] B. H. Alver, C. Gombeaud, M. Luzum, and J.-Y. Ollitrault, "Triangular flow in hydrodynamics and transport theory", *Phys. Rev. C* **82** (2010) 034913, doi:10.1103/PhysRevC.82.034913, arXiv:1007.5469.

[19] B. Schenke, S. Jeon, and C. Gale, "Elliptic and triangular flow in event-by-event D=3+1 viscous hydrodynamics", *Phys. Rev. Lett.* **106** (2011) 042301, doi:10.1103/PhysRevLett.106.042301, arXiv:1009.3244.

[20] Z. Qiu, C. Shen, and U. Heinz, "Hydrodynamic elliptic and triangular flow in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *Phys. Lett. B* **707** (2012) 151, doi:10.1016/j.physletb.2011.12.041, arXiv:1110.3033.

[21] G. Giacalone, L. Yan, J. Noronha-Hostler, and J.-Y. Ollitrault, "Symmetric cumulants and event-plane correlations in Pb + Pb collisions", *Phys. Rev. C* **94** (2016) 014906, doi:10.1103/PhysRevC.94.014906, arXiv:1605.08303.

[22] CMS Collaboration, "Observation of long-range near-side angular correlations in proton-proton collisions at the LHC", *JHEP* **09** (2010) 091, doi:10.1007/JHEP09(2010)091, arXiv:1009.4122.

[23] CMS Collaboration, "Measurement of long-range near-side two-particle angular correlations in pp collisions at $\sqrt{s} = 13$ TeV", *Phys. Rev. Lett.* **116** (2016) 172302, doi:10.1103/PhysRevLett.116.172302, arXiv:1510.03068.

[24] ATLAS Collaboration, "Observation of long-range elliptic azimuthal anisotropies in $\sqrt{s} = 13$ and 2.76 TeV pp collisions with the ATLAS detector", *Phys. Rev. Lett.* **116** (2016) 172301, doi:10.1103/PhysRevLett.116.172301, arXiv:1509.04776.

[25] ATLAS Collaboration, "Measurement of long-range pseudorapidity correlations and azimuthal harmonics in $\sqrt{s_{\rm NN}}$ = 5.02 TeV proton-lead collisions with the ATLAS detector", *Phys. Rev. C* **90** (2014) 044906, doi:10.1103/PhysRevC.90.044906, arXiv:1409.1792.

[26] CMS Collaboration, "Long-range two-particle correlations of strange hadrons with charged particles in pPb and PbPb collisions at LHC energies", *Phys. Lett. B* **742** (2015) 200, doi:10.1016/j.physletb.2015.01.034, arXiv:1409.3392.

[27] LHCb Collaboration, "Measurements of long-range near-side angular correlations in $\sqrt{s_{\rm NN}}$ = 5 TeV proton-lead collisions in the forward region", *Phys. Lett. B* **762** (2016) 473, doi:10.1016/j.physletb.2016.09.064, arXiv:1512.00439.

[28] STAR Collaboration, "Long-range pseudorapidity dihadron correlations in d+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV", *Phys. Lett. B* **747** (2015) 265, doi:10.1016/j.physletb.2015.05.075, arXiv:1502.07652.

[29] CMS Collaboration, "Evidence for collective multi-particle correlations in pPb collisions", *Phys. Rev. Lett.* **115** (2015) 012301, doi:10.1103/PhysRevLett.115.012301, arXiv:1502.05382.

[30] CMS Collaboration, "Evidence for collectivity in pp collisions at the LHC", *Phys. Lett. B* **765** (2017) 193, doi:10.1016/j.physletb.2016.12.009, arXiv:1606.06198.

[31] ATLAS Collaboration, "Measurement of multi-particle azimuthal correlations in pp, p+Pb and low-multiplicity Pb+Pb collisions with the ATLAS detector", *Eur. Phys. J. C* **77** (2017) 428, doi:10.1140/epjc/s10052-017-4988-1, arXiv:1705.04176.

[32] ATLAS Collaboration, "Correlated long-range mixed-harmonic fluctuations measured in pp, p+Pb and low-multiplicity Pb+Pb collisions with the ATLAS detector", *Phys. Lett. B* **789** (2019) 444, doi:10.1016/j.physletb.2018.11.065, arXiv:1807.02012.

[33] CMS Collaboration, "Observation of correlated azimuthal anisotropy Fourier harmonics in pp and p+Pb collisions at the LHC", *Phys. Rev. Lett.* **120** (2018) 092301, doi:10.1103/PhysRevLett.120.092301, arXiv:1709.09189.

[34] K. Dusling, W. Li, and B. Schenke, "Novel collective phenomena in high-energy proton-proton and proton-nucleus collisions", *Int. J. Mod. Phys. E* **25** (2016) 1630002, doi:10.1142/S0218301316300022, arXiv:1509.07939.

[35] J. L. Nagle and W. A. Zajc, "Small system collectivity in relativistic hadronic and nuclear collisions", *Ann. Rev. Nucl. Part. Sci.* **68** (2018) 211, doi:10.1146/annurev-nucl-101916-123209, arXiv:1801.03477.

[36] B. Schenke, C. Shen, and P. Tribedy, "Hybrid color glass condensate and hydrodynamic description of the Relativistic Heavy Ion Collider small system scan", *Phys. Lett. B* **803** (2020) 135322, doi:10.1016/j.physletb.2020.135322, arXiv:1908.06212.

[37] P. Di Francesco, M. Guilbaud, M. Luzum, and J.-Y. Ollitrault, "Systematic procedure for analyzing cumulants at any order", *Phys. Rev. C* **95** (2017) 044911, doi:10.1103/PhysRevC.95.044911, arXiv:1612.05634.

[38] J. Jia, M. Zhou, and A. Trzupek, "Revealing long-range multiparticle collectivity in small collision systems via subevent cumulants", *Phys. Rev. C* **96** (2017) 034906, doi:10.1103/PhysRevC.96.034906, arXiv:1701.03830.

[39] ATLAS Collaboration, "Measurement of long-range multiparticle azimuthal correlations with the subevent cumulant method in pp and p+Pb collisions with the ATLAS detector at the CERN Large Hadron Collider", *Phys. Rev. C* **97** (2018) 024904, doi:10.1103/PhysRevC.97.024904, arXiv:1708.03559.

[40] P. Huo, K. Gajdosova, J. Jia, and Y. Zhou, "Importance of non-flow in mixed-harmonic multi-particle correlations in small collision systems", *Phys. Lett. B* **777** (2018) 201, doi:10.1016/j.physletb.2017.12.035, arXiv:1710.07567.

[41] CMS Collaboration, "Description and performance of track and primary-vertex reconstruction with the CMS tracker", *JINST* **9** (2014) P10009, doi:10.1088/1748-0221/9/10/P10009, arXiv:1405.6569.

[42] Geant4 Collaboration, "Geant4 — a simulation toolkit", *Nucl. Instrum. Meth. A* **506** (2003) 250, doi:10.1016/S0168-9002(03)01368-8.

[43] CMS Collaboration, "The CMS experiment at the CERN LHC", *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

[44] E. Todesco and J. Wenninger, "Large hadron collider momentum calibration and accuracy", *Phys. Rev. Accel. Beams* **20** (Aug, 2017) 081003, doi:10.1103/PhysRevAccelBeams.20.081003.

[45] CMS Collaboration, "Multiplicity and transverse momentum dependence of two- and four-particle correlations in pPb and PbPb collisions", *Phys. Lett. B* **724** (2013) 213, doi:10.1016/j.physletb.2013.06.028, arXiv:1305.0609.

[46] CMS Collaboration, "The CMS trigger system", *JINST* **12** (2017) 01020, doi:10.1088/1748-0221/12/01/P01020, arXiv:1609.02366.

[47] CMS Collaboration, "Observation of charge-dependent azimuthal correlations in p-Pb collisions and its implication for the search for the chiral magnetic effect", *Phys. Rev. Lett.* **118** (2017) 122301, doi:10.1103/PhysRevLett.118.122301, arXiv:1610.00263.

[48] CMS Collaboration, "Constraints on the chiral magnetic effect using charge-dependent azimuthal correlations in pPb and PbPb collisions at the CERN Large Hadron Collider", *Phys. Rev. C* **97** (2018) 044912, doi:10.1103/PhysRevC.97.044912, arXiv:1708.01602.

[49] J.-Y. Ollitrault, A. M. Poskanzer, and S. A. Voloshin, "Effect of flow fluctuations and nonflow on elliptic flow methods", *Phys. Rev. C* **80** (2009) 014904, doi:10.1103/PhysRevC.80.014904, arXiv:0904.2315.

[50] CMS Collaboration, "Evidence for transverse momentum and pseudorapidity dependent event plane fluctuations in PbPb and pPb collisions", *Phys. Rev. C* **92** (2015) 034911, doi:10.1103/PhysRevC.92.034911, arXiv:1503.01692.

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