The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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Azimuthal anisotropy of charged particles from multiparticle correlations in pPb and PbPb collisions with CMS

Quan Wang for the CMS Collaboration

Abstract

Motivated by two- and four-particle azimuthal correlation measurements that suggest possible collective flow for charged particles emitted in pPb collisions at $\sqrt{s_{NN}}=5.02$ TeV, we extend the correlation results for these collisions using the six- and eight-particle cumulant methods, and the Lee-Yang Zeros method. CMS has an extensive program studying azimuthal harmonic coefficients for both PbPb and pPb collisions using various methods. The current pPb results will be presented in this context. The data were collected by the CMS experiment at the LHC using both minimum bias and high-multiplicity collision triggers over a wide range in pseudorapidity. The results are compared to 2.76 TeV semi-peripheral PbPb collision data collected in 2011 covering a similar range of particle multiplicities. The second-order azimuthal anisotropy Fourier harmonic (v_2) is shown for the different methods. A comparison of the six- and greater particle correlations to the previously published two- and four-particle correlation results sheds light on the multiparticle nature of the azimuthal anisotropy. The results are also discussed in terms of recent calculations that explore the role of participant fluctuations on measurements of higher-order particle correlations in pPb collisions.

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Quan Wang (for the CMS Collaboration)¹

CERN Building 42-1-22, Geneva 23, Switzerland CH-1211

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Motivated by two- and four-particle azimuthal correlation measurements that suggest possible collective flow for charged particles emitted in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, we extend the correlation results for these collisions using the six- and eight-particle cumulant methods, and the Lee-Yang Zeros method. CMS has an extensive program studying azimuthal harmonic coefficients for both PbPb and pPb collisions using various methods. The current pPb results will be presented in this context. The data were collected by the CMS experiment at the LHC using both minimum bias and high-multiplicity collision triggers over a wide range in pseudorapidity. The results are compared to 2.76 TeV semi-peripheral PbPb collision data collected in 2011 covering a similar range of particle multiplicities. The second-order azimuthal anisotropy Fourier harmonic (v_2) is shown for the different methods. A comparison of the six- and greater particle correlations to the previously published two- and four-particle correlation results sheds light on the multiparticle nature of the azimuthal anisotropy. The results are also discussed in terms of recent calculations that explore the role of participant fluctuations on measurements of higher-order particle correlations in pPb collisions.

Keywords: Flow, Multiparticle Cumulant, Lee-Yang Zeros

1. Introduction

Studies of the collective behavior of the emitted particles provide an important insight of the hot and dense matter created in the heavy-ion collisions. In two-particle correlations, a pronounced near-side (small relative azimuthal angle $|\Delta\phi| \sim 0$) long-range (large relative pseudorapidity $\Delta\eta$) structure, also known as the “ridge-like” structure, has been observed and extensively explored in relativistic high energy nucleus-nucleus (AA) collisions at both the Relative Heavy Ion Collider (RHIC) [1, 2, 3, 4, 5] and the Large Hadron Collider (LHC) [6, 7, 8, 9, 10], over a wide range of energies and system sizes. These long-range correlations can be interpreted as hydrodynamic collective flow of the strongly interacting and expanding medium. However, such long-range correlations have also been reported in proton-proton (pp) [11] and proton-lead (pPb) [12, 13, 14] collisions with very high final-state particle multiplicity at the LHC. Also, evidence of such correlations was also found in 200 GeV deuteron-gold (dAu) at RHIC [15]. The origin of such correlations is still not clear in small systems. It is important to investigate whether the long-range correlations are due to particle pairs, or are multiparticle nature. The first attempts to address this question in pPb collisions were presented in Ref. [16] by directly measuring four-particle azimuthal correlations, where the elliptic flow signal (v_2) was obtained in the context of hydrodynamic models using the cumulant method.

To further investigate the multiparticle nature of the observed long-range correlations, we present measurements for pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV of multiparticle correlations using six- and eight-particle cumulant methods [17, 18] and also results based on the Lee-Yang Zeros (LYZ) method [19, 20] involving correlations among all

¹ A list of members of the CMS Collaboration and acknowledgements can be found at the end of this issue.

particles. The pPb data are obtained by the CMS experiment during the 2013 pPb run at the LHC. With a large sample of very high multiplicity triggered pPb collisions, the correlation data have been studied in a regime that is comparable to the particle multiplicity in mid-central (50–60% centrality) PbPb collisions. For comparison, a sample of semi-peripheral (50–100% centrality) PbPb data at $\sqrt{s_{NN}} = 2.76$ TeV collected during 2011 run is reprocessed using the same reconstruction algorithm as the pPb data to cover the similar multiplicity range.

2. Results

Figure 1. The cumulant $c_2\{6\}$ (top) and $c_2\{8\}$ (bottom) results as a function of the number of offline tracks $N_{\text{trk}}^{\text{offline}}$ for pPb (right) and PbPb (left) reactions. The absolute values of the otherwise negative $c_2\{8\}$ values are shown. Shaded areas denote systematic uncertainties.

Figure 1 shows the six- and eight-particle cumulant results $c_2\{6\}$ (top) and $c_2\{8\}$ (bottom) for charged particles with $0.3 < p_T < 3.0$ GeV/c at 2.76 TeV PbPb (left) and 5.02 TeV pPb (right) collisions as a function of the offline event multiplicity ($N_{\text{trk}}^{\text{offline}}$). The pPb results show significant correlation signals which are comparable to the PbPb results at similar multiplicity ranges. Due to limited statistics, $c_2\{6\}$ and $c_2\{8\}$ values in pPb are obtained for a smaller range in $N_{\text{trk}}^{\text{offline}}$, and also showing larger statistical uncertainties than in PbPb collisions.

Assuming the observed multiparticle cumulant correlations are responsible for the global azimuthal anisotropy of the emitted particles, the second-order Fourier harmonic, v_2 , averaged over the p_T range of 0.3–3.0 GeV/c is shown in Figure 2 for PbPb (left) and pPb (right) as a function of $N_{\text{trk}}^{\text{offline}}$. Open symbols are published v_2 results by CMS from two- ($v_2\{2\}$) and four-particle ($v_2\{4\}$) correlations. The v_2 values obtained using Lee-Yang Zeros method involving all particle correlations are also shown. For both the PbPb and pPb systems, the v_2 values are in agreement to within $\pm 10\%$ between the four- ($v_2\{4\}$), six- ($v_2\{6\}$) and eight- ($v_2\{8\}$) particle cumulants, and the LYZ method ($v_2\{\text{LYZ}\}$). This agrees with the expectations of the multiparticle correlation nature in both systems. In PbPb collisions, the v_2 values from all methods increase with multiplicity, however, little multiplicity dependence is shown for the pPb data. The two-particle correlation results, $v_2\{2\}$ with η gap of 2 units between the two particles, are consistently above the multiparticle correlation v_2 values. This behavior can be understood in the hydrodynamic context, where the fluctuating initial participant geometry induced event-by-event v_2 fluctuations contribute positively to two-particle correlations, whereas they contribute negatively to multiparticle correlations.

Figure 2. The v_2 results obtained from 6-particle (blue cross), 8-particle (red diamond) cumulants, and LYZ (green filled circle) method, averaged over particle p_T range of 0.3–3.0 GeV/c, as a function of the number of offline tracks $N_{\text{trk}}^{\text{offline}}$ in PbPb at $\sqrt{s_{NN}} = 2.76$ TeV (left) and pPb at $\sqrt{s_{NN}} = 5.02$ TeV (right). Open data points are published two-particle and four-particle v_2 results from HIN-13-002. Shaded areas denote systematic uncertainties.

Recent theory developments of fluctuation-driven initial-state eccentricities of hydrodynamic of the interacting medium [21] and alternatively, in terms of a weakly interacting field theory [22] suggest similar four-, six- and eight-particle cumulant v_2 ($v_2\{4\} \approx v_2\{6\} \approx v_2\{8\}$) values. For fluctuation-driven initial-state conditions, the ratios of v_2 values derived from various orders of multiparticle cumulants are predicted to follow a universal behavior. In Figure 3, ratios of $v_2\{6\}/v_2\{4\}$ (top) and $v_2\{8\}/v_2\{6\}$ (bottom) as a function of $v_2\{4\}/v_2\{2\}$ are shown and compared to theory curves in pPb collisions. The ratios from PbPb collisions are also shown for completeness. The $v_2\{2\}$ and $v_2\{4\}$ data are taken from previously published CMS results [16]. The solid curves correspond to theoretical predictions based on hydrodynamics with initial-state geometry fluctuations. Note that the v_2 values extracted from peripheral PbPb collisions might be dominated by initial geometry configuration other than fluctuations. The CMS pPb data are consistent with the prediction within statistical and systematic uncertainties.

3. Conclusion

In summary, multiparticle azimuthal correlations among six and more particles have been measured for the first time in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV by the CMS experiment. The new measurements extend previous CMS two- and four-particle correlation analysis. A direct comparison of the correlation data between pPb and PbPb collisions is presented as a function of particle multiplicity. Integrated over the particle p_T range of 0.3–3.0 GeV/c, the v_2 values derived from four-, six- and eight-particle cumulant methods and LYZ method are consistent within $\pm 10\%$ for both pPb and PbPb systems. This suggests the observed correlations are collective in nature. With current statistical and systematic precision, the relative ratios of v_2 from different cumulant orders are consistent with hydrodynamic predictions for fluctuation-driven initial-state eccentricities.

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Figure 3. Cumulant ratios $v_2\{6\}/v_2\{4\}$ (top) and $v_2\{8\}/v_2\{6\}$ (bottom) as a function of $v_2\{4\}/v_2\{2\}$ in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Shaded areas denote systematic uncertainties respectively. The solid curves show the expected behavior based on hydrodynamic motivated study of the role of initial-state fluctuations [21].

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