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Flow and Correlations in PbPb and pPb Collisions from CMS Experiment

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Abstract. Measurements of two- and four-particle angular correlations for inclusive charged particles in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV are presented over a wide pseudorapidity range, $|\eta| < 2.5$ and full azimuth from the CMS experiment. Results from 31 nb^{-1} of pPb data, collected during the 2013 LHC running are compared to 2.76 TeV semi peripheral PbPb collision data, from 2011 PbPb run, having similar range of particle multiplicities. The second-order (v_2) and third-order (v_3) anisotropy harmonics are extracted using the two-particle azimuthal correlation technique. v_2 is also extracted using a four-particle cumulant method to further explore the multi-particle nature of correlations in pPb collisions. We observe a remarkable similarity in the v_3 signal as a function of multiplicity between pPb and PbPb systems.

1 Introduction

Studies of multi-particle correlations play a major role in characterizing the underlying mechanism of particle production in high-energy collisions of protons and nuclei. Long-range (large $|\Delta\eta|$) correlations observed in two-dimensional (2D) $\Delta\eta$-$\Delta\phi$ co-ordinates are of particular interest in nucleus-nucleus (AA) collisions. Where $\Delta\eta$ and $\Delta\phi$ are the relative pseudorapidity and azimuthal differences between two particles. The second harmonic in the Fourier expansion of the azimuthal anisotropy of the produced particle, known as the "elliptic flow" (v_2) is a major source of such long-range correlations [1]. v_2 contributes a $\cos(2\Delta\phi)$ type structure to the two-particle correlation function over a broad range in $\Delta\eta$ [2]. Higher-order anisotropic flow components arising due to initial-state geometry fluctuations also play a major role in contributing to these long-range correlations, in particular the "triangular flow" which contributes a $\cos(3\Delta\phi)$ component [3, 4]. Recently, a similar long-range near-side ($\Delta\phi \sim 0$) correlation structure was observed in the highest multiplicity proton-proton (pp) [5] and proton-lead (pPb) [6] collisions at the LHC. Evidence of such correlations was also found recently in 200 GeV deuteron-gold collisions at RHIC [7]. Since hydrodynamic flow is intrinsically a multi-particle phenomenon, it can be probed more directly using multi-particle correlation (or cumulant) techniques [8] besides two-particle correlations.

This paper presents a detailed analysis of two- and four particle angular correlations in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, to provide further constraints on the theoretical understanding of the particle production mechanisms in different colliding systems. The results presented here are based on dedicated high-multiplicity triggers, which enabled access to very high multiplicity pPb events.

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Therefore, correlation results from pPb collisions can be compared up to mid-central (~ 55% centrality) PbPb collisions, where centrality is defined as a percentage of hadronic PbPb cross-section. The two-particle long-range correlation data are presented in terms of anisotropy harmonics (v_2 and v_3), which provide a measure of relative correlation magnitude w.r.t. the uncorrelated background. Results from a four-particle cumulant method are also presented here to investigate the multi-particle nature of the correlation further.

2 Selections of Events and Tracks

The data set corresponds to an integrated luminosity of about 31 nb^{-1}, assuming a pPb interaction cross section of 2.1 barns. Because of the asymmetric collision system and the requirement of the LHC to have identical magnetic rigidity of both particle beams, the nucleon-nucleon center-of-mass in pPb collisions is not at rest with respect to the laboratory frame. Massless particles emitted at η_{cm} = 0 in the nucleon-nucleon center-of-mass frame with be detected at η = -0.465 (clockwise proton beam) or 0.465 (counterclockwise proton beam) in the laboratory frame. These results are compared to PbPb collisions at 2.76 TeV corresponding to an integrated luminosity of 2.3 $\mu\mathrm{b}^{-1}$. Hadronic collisions were selected by requiring a coincidence of at least one HF (Hadron Forward, having an acceptance of $2.9 < |\eta| < 5.2$) calorimeter tower with more than 3 GeV of total energy in each of the HF detectors. Events were also required to contain at least one reconstructed primary vertex within 15 cm of the nominal interaction point along the beam axis and within 0.15 cm transverse to the beam trajectory. At least two reconstructed tracks were required to be associated with the primary vertex. For more details, please refer to the CMS publication [9]. The events were divided into classes of reconstructed track multiplicity, $\mathrm{N}_{\mathrm{trk}}^{\mathrm{offline}}$, where primary tracks with $|\eta| < 2.4$ and $p_{\mathrm{T}} > 0.4$ GeV/c were counted. Data from the track multiplicity triggers with online track thresholds of 100, 130, 160, and 190 where used for $120 \leq \mathrm{N}_{\mathrm{trk}}^{\mathrm{offline}} < 150$, $150 \leq \mathrm{N}_{\mathrm{trk}}^{\mathrm{offline}} < 185$, $185 \leq \mathrm{N}_{\mathrm{trk}}^{\mathrm{offline}} < 220$, and $\mathrm{N}_{\mathrm{trk}}^{\mathrm{offline}} \geq 220$, respectively.

3 Analysis Technique

Please refer to Refs. [10] for details on constructing a correlation function. The per-trigger-particle associated yield is defined as

$$\frac{1}{N_{trig}} \frac{d^2 N^{pair}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}, \tag{1}$$

where $\Delta\eta$ and $\Delta\phi$ are the differences in η and ϕ of the pair. The signal pair distribution, $S(\Delta\eta, \Delta\phi)$, represents the yield of particle pairs normalized by $\mathrm{N}_{\mathrm{trig}}$ from the same event, $S(\Delta\eta, \Delta\phi) = \frac{1}{N_{\mathrm{trig}}} \frac{d^2 N^{same}}{d\Delta\eta d\Delta\phi}$ and the mixed-event pair distribution defined as, $B(\Delta\eta, \Delta\phi) = \frac{1}{N_{\mathrm{trig}}} \frac{d^2 N^{Mix}}{d\Delta\eta d\Delta\phi}$, is constructed by pairing the trigger particles in each event with the associated particles from 10 different random events in the same 2 cm wide $\mathrm{z}_{\mathrm{vtx}}$ range and from the same track multiplicity class.

4 Results

Figure 1 shows the 2D two-particle correlation functions measured in 2.76 TeV PbPb (a) and 5.02 TeV pPb (b) collisions, for pairs of charged particles with $1 \leq \mathrm{p}_{\mathrm{T}}^{\mathrm{trig}} < 3$ GeV/c and $1 \leq \mathrm{p}_{\mathrm{T}}^{\mathrm{assoc}} < 3$ GeV/c, and with the track multiplicity in the range $220 \leq \mathrm{N}_{\mathrm{trk}}^{\mathrm{offline}} < 260$. For both colliding systems, in addition to the correlation peak near $(\Delta\eta, \Delta\phi) = (0,0)$ due to jet fragmentation, a pronounced long-range structure is seen at $\Delta\phi \approx 0$ extending at least 4.8 units in $|\Delta\eta|$. This structure has been widely reported in AA collisions also [10–13]. To compare with hydrodynamic predictions of the long-range correlations in pPb collisions, the elliptic (v_2) and triangular (v_3) flow harmonics are extracted from a Fourier decomposition of 1D $\Delta\phi$ correlation functions, $v_2\{2\}$ and $v_3\{2\}$ for long-range region, $|\Delta\eta| > 2$ as shown in Figs. 2 and 3. A four particle cumulant method is also used to extract the $v_2\{4\}$ signal. Figure 2 shows the magnitude of the v_2 signal is found to be larger in PbPb than in pPb by about 30% for $p_T < 2$ GeV/c both for $v_2\{2, |\Delta\eta| > 2\}$ and $v_2\{4\}$ in the same multiplicity range. The differences between the $v_2\{2, |\Delta\eta| > 2\}$ and $v_2\{4\}$ could attributed to different sensitivity to nonflow effects of these observables. It is argued that with the large $\Delta\eta$ gap the nonflow is minimized. The main difference is due to fluctuations that increase $v_2\{2\}$ and decrease $v_2\{4\}$. The multiplicity dependence of v_3 for

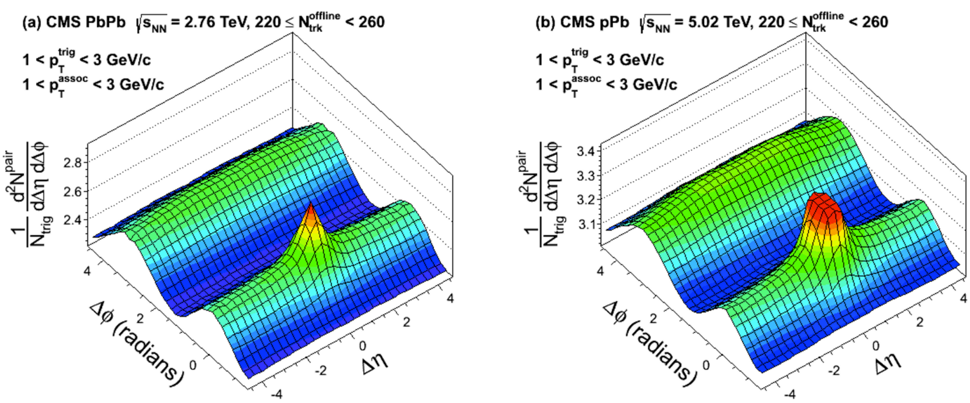

Figure 1. The 2D two-particle correlation functions for (a) 2.76 TeV PbPb and (b) 5.02 TeV pPb collisions for pairs of charged particles with $1 \le p_T^{trig} < 3$ GeV/c and $1 \le p_T^{assoc} < 3$ GeV/c within the $220 \le N_{trk}^{offline} < 260$ multiplicity bin. The sharp near-side peak at $\Delta\phi = \Delta\eta = 0$, from jet correlations is truncated to emphasize the structure outside that region.

PbPb and pPb collisions, averaged over the p_T range from 0.3 to 3.0 GeV/c, are presented in Fig. 3. We find that the values of v_3 are remarkably similar for both systems at the same event multiplicity. This similarity of the triangular flow is not trivially expected within a hydrodynamic picture since the initial-state collision geometry is very different for the pPb and PbPb systems.

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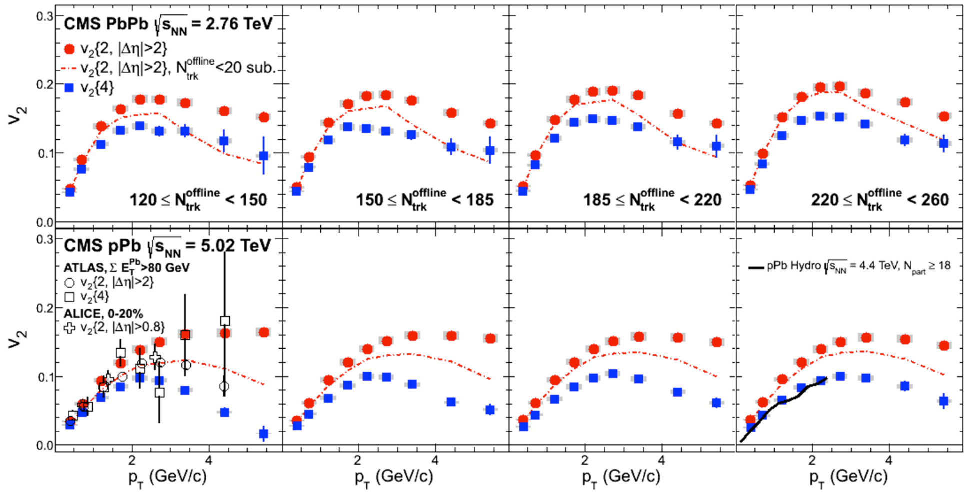

Figure 2. The differential $v_2\{2, |\Delta\eta| > 2\}$ (closed circles) and $v_2\{4\}$ (closed squares) values for four multiplicity ranges obtained with $|\eta| < 2.4$ and a p_T^{ref} range of 0.3-3 GeV/c. The results are for 2.76 TeV PbPb collisions (top) and for 5.02 TeV pPb collisions (bottom). Curves represent results obtained after subtracting the low-multiplicity data ($N_{offline}^{trk} < 20$) as well as predictions from hydrodynamic model. The open markers show results from ALICE [14] and ATLAS [15] using 2012 pPb data.

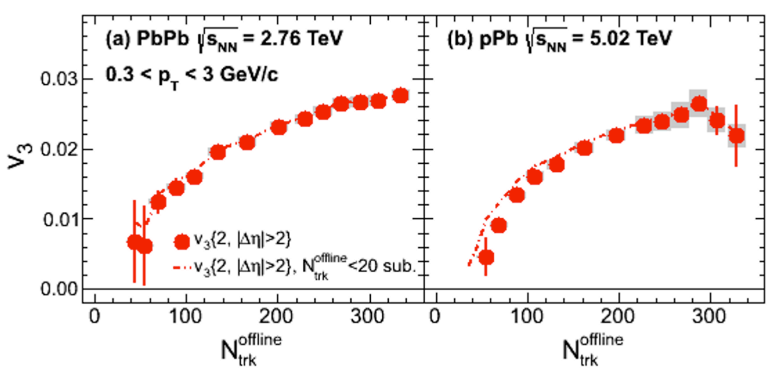

Figure 3. The $v_3\{2, |\Delta\eta| > 2\}$ values as a function of $N_{trk}^{offline}$ for $0.3 < p_T < 3$ GeV/c, in 2.76 TeV PbPb collisions (left) and 5.02 TeV pPb collisions (right).

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