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Pseudorapidity dependence of near-side and away-side long-range correlations in pPb collisions with CMS

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Abstract

Two-particle long-range pseudorapidity ($\Delta\eta$) correlations are observed in pPb collisions at the LHC. Previous correlation measurements have been averaged over both the trigger and associated particle η . In order to explore the possible pseudorapidity dependence of the long-range correlations in asymmetric pPb collisions, a new analysis of two-particle correlations with trigger particles at various fixed eta locations is presented. The data were collected during the 2013 LHC pPb run at a nucleon-nucleon center-of-mass energy of 5.02 TeV by the CMS experiment, with a wide eta coverage of $-2.4 \leq \eta \leq 2.4$. The near-side $\Delta\eta$ correlations are decomposed into short-range (jet) and long-range components. The away-side long-range correlations in central collisions are also studied by subtracting back-to-back jet contributions, modeled by the away-side correlations from peripheral collisions after accounting for the biases introduced by the multiplicity classification. The long-range correlations are found to be dependent on pseudorapidity. The observed pseudo-rapidity dependence may potentially discriminate theoretical models for long-range two-particle correlations observed in pPb collisions.

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Pseudorapidity dependence of long-range two-particle correlations in pPb collisions at 5.02 TeV with CMS

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Abstract

CMS measurements of two-particle correlations of charged particles have previously been published for proton-proton (pp), proton-lead (pPb), and lead-lead (PbPb) systems. This analysis studies the pseudorapidity dependency of the two-particle correlations by restricting one of the particles in a narrow η range. The near-side ($\Delta\phi \approx 0$) correlation in high-multiplicity collisions is decomposed into a short-range jet-like component and a long-range ridge component in pseudorapidity. The jet-like correlations are subtracted, and the remaining ridge correlations are studied versus $\Delta\eta$. Furthermore, the Fourier coefficients of the two-particle correlations are extracted for high-multiplicity collisions, with and without subtraction of jet contributions approximated by the scaled low-multiplicity collision data. The η dependence of the azimuthal anisotropy parameters is reported.

1. Introduction

Studies of two-particle correlations in high energy collisions play an important role in understanding the hot and dense medium created in relativistic heavy-ion collisions. The ridge was observed in central AA collisions, after elliptic flow (second Fourier coefficient v_2) subtraction [1, 2, 3], and was primarily attributed to triangular flow in a hydrodynamic picture. The ridge was observed in high-multiplicity pp and pPb collisions after a uniform background subtraction [4, 5, 6, 7]. The similarity to the heavy ion ridge suggests a hydrodynamic origin [8, 9, 10], whether hydrodynamics can be reliably applied to pp and pA systems is however under active debate.

The two-particle ridge correlations have been measured so far with integrated trigger and associated particles η ranges and divided by mixed-event “acceptance.” The measured ridge correlations at large $\Delta\eta$ are found to be uniform in $\Delta\eta$. Any $\Delta\eta$ dependence in the ridge correlation signal could have been averaged out by the integration of the trigger and associated particle pseudorapidities [11]. To gain further insights into the long-range ridge correlation in the pPb system, in this work we perform a $\Delta\eta$ -dependent analysis by restricting the trigger particle to a narrow η range. The combinatorial background is essentially the single-particle density in such an analysis, $dN/d\Delta\eta \approx dN/d\eta$. The background in pPb collisions is therefore nonuniform in $\Delta\eta$. The measured ridge correlations, in comparison to the subtracted combinatorial background, may provide further insights into the ridge production mechanism.

In addition, The Fourier coefficients V_n is measured. V_n are determined from a Fourier decomposition of long-range ($|\Delta\eta| > 2$ to remove most of the short-range correlations) two-particle $\Delta\phi$ correlation functions. The η dependences of the azimuthal anisotropy parameter are reported.

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

Figure 1. The near-side ($|\Delta\phi| < \pi/3$) correlated yield after ZYAM subtraction in high-multiplicity $220 \leq N_{\text{trk}}^{\text{offline}} < 260$ pPb collisions at 5.02 TeV. The trigger and associated particle p_T ranges are both $0.3 < p_T < 3$ GeV/c. The trigger particles are restricted to the Pb-side ($-2.4 < \eta_{\text{trig}} < -2.0$, left panels) and the p-side ($2.0 < \eta_{\text{trig}} < 2.4$, right panels), respectively. Fit functions by Eq. 2 (black curves) are superimposed; the red curve and the blue open points are the two fit components, jet and ridge, respectively.

2. Data samples and quality cuts

This analysis is performed using the data recorded by CMS during the LHC pPb run in January and February, 2013. The data correspond to an integrated luminosity of 35 ± 1 nb $^{-1}$. The beam energies were 4 TeV for protons and 1.58 TeV per nucleon for lead nuclei, resulting in a center-of-mass energy per nucleon pair of 5.02 TeV.

Charged particles are reconstructed in the silicon tracking system. The events are classified by $N_{\text{trk}}^{\text{offline}}$, the measured number of tracks within $|\eta| < 2.4$ and $p_T > 0.4$ GeV/c after track quality selections. The high- and low-multiplicity events in this analysis are defined by $220 \leq N_{\text{trk}}^{\text{offline}} < 260$ and $2 \leq N_{\text{trk}}^{\text{offline}} < 20$, respectively. The high-multiplicity cut $220 \leq N_{\text{trk}}^{\text{offline}} < 260$ corresponds to a event fraction of top 0.00034%. Data from the HLT minimum bias trigger were used for low-multiplicity event selection, while the high-multiplicity triggers with online multiplicity thresholds of 100, 130, 160, and 190 were used for the high-multiplicity event selection [10].

3. Analysis procedure

The dihadron correlation is quantified by the azimuthal angle ϕ and pseudorapidity η differences between the two particles (called trigger and associated particle). The per-trigger normalized associated particle yield is defined by:

$$S(\Delta\eta, \Delta\phi) = \frac{1}{N_{\text{trig}}} \frac{d^2N}{d\Delta\eta d\Delta\phi}. \quad (1)$$

Unlike in previous analysis [1, 2, 3, 4, 5, 6, 7], the trigger particles in this analysis are restricted to two narrow η windows: $-2.4 < \eta_{\text{trig}} < -2.0$ (Pb-side) and $2.0 < \eta_{\text{trig}} < 2.4$ (p-side). The associated particles are from the entire measured η range of $-2.4 < \eta_{\text{assoc}} < 2.4$. The correlation is studied in the range of $0 < |\Delta\eta| < 4.4$ where the two-particle acceptance is 100%. The single particle efficiencies are corrected.

The $\Delta\phi$ distribution of associated yield is projected within each $\Delta\eta$ bin. The Zero-Yield-At-Minimum (ZYAM) description [13] is used to subtract a uniform background in $\Delta\phi$. What remains is the correlated yield integrated on the near side ($|\Delta\phi| < \pi/3$) in each $\Delta\eta$ bin. The near-side correlated yield, is shown as a function of $\Delta\eta$ in Fig. 1 for high-multiplicity events.

The yield is composed of a near-side jet-like peak and a long range $\Delta\eta$ ridge. In order to decompose the near-side yield into jet and ridge, we fit the data with a two-component functional form:

$$\frac{1}{N_{\text{trig}}} \frac{dN_{\text{near}}(\Delta\eta)}{d\Delta\eta} = \frac{Y\beta}{\sqrt{2}\sigma\Gamma(1/2\beta)} \exp\left[-\left(\frac{\Delta\eta^2}{2\sigma^2}\right)^\beta\right] + (C + k\Delta\eta) \times \text{ZYAM}(\Delta\eta). \quad (2)$$

The first term represents the near-side jet; Y is the correlated yield, and σ and β describe the correlation shape. A generalized Gaussian form as in Eq. 2 was found to describe the data well. The second term represents the ridge structure. Since the ridge is wide in $\Delta\eta$ and may be related to the bulk medium, we model its shape as dominated by the underlying background event, ZYAM($\Delta\eta$). We found, however, that the background shape multiplied by a constant was inadequate to describe the data. Instead, the background shape multiplied by a linear function in $\Delta\eta$, as in Eq. 2, can fit the data well, with reasonable χ^2/ndf (see Fig. 1).

4. Results

To get the ridge yield, we subtract the fitted jet from the correlated yield shown in Fig. 1. The subtracted results are shown in Fig. 2 for both trigger η windows. The results are plotted as a function of the associated particle η , which is simply taken as $\eta_{\text{assoc}} = \Delta\eta + \langle\eta_{\text{trig}}\rangle$. The systematic uncertainties are shown by the shaded bands; they are the quadratic sum of the ZYAM uncertainty and that due to the choice of fit function. The near-side ridge depends on η_{assoc} (and $\Delta\eta$). The near-side ridge for the p-side trigger particles appears smaller than that for the Pb-side one.

Figure 2. The near-side ridge yield in high-multiplicity pPb collisions ($220 \leq N_{\text{trk}}^{\text{offline}} < 260$) at 5.02 TeV. The trigger and associated particle ranges are both $0.3 < p_T < 3$ GeV/c. The trigger particle η ranges are $-2.4 < \eta_{\text{trig}} < -2.0$ (Pb-side, red) and $2.0 < \eta_{\text{trig}} < 2.4$ (p-side, blue). The data are plotted as a function of $\eta_{\text{assoc}} = \Delta\eta + \langle\eta_{\text{trig}}\rangle$, where $\langle\eta_{\text{trig}}\rangle$ is taken to be -2.2 and 2.2 for Pb-side and p-side trigger particles, respectively. Error bars are statistical; the shaded areas are systematic uncertainty, quadratic sum of the ZYAM uncertainty and the fit function uncertainty.

If the ridge is of hydrodynamic origin, where all pairs are responsible for enhanced/depleted emission at certain azimuthal angles, the more natural observable would be the azimuthal Fourier harmonics, V_n . We study V_2 and V_3 in high-multiplicity collisions for Pb-side and p-side trigger particles both with and without subtracting the low multiplicity V_n . The jet contributions may be significantly reduced or eliminated by subtracting the low-multiplicity collision data,

$$V_n^{\text{sub}} = V_n^{220 \leq N_{\text{trk}}^{\text{offline}} < 260} - V_n^{N_{\text{trk}}^{\text{offline}} < 20} \cdot \frac{N_{\text{assoc}}^{N_{\text{trk}}^{\text{offline}} < 20}}{N_{\text{assoc}}^{220 \leq N_{\text{trk}}^{\text{offline}} < 260}} \cdot \alpha. \quad (3)$$

The scaling factor α is the ratio of the jet correlated yields in high-multiplicity data to low-multiplicity data as obtained from fits by Eq. 2.

In order to study the η_{assoc} dependence of the anisotropy parameter, the V_n is self-normalized by dividing its value at $\eta_{\text{assoc}} = 0$. The result would be the relative anisotropy parameter, $v_n(\eta_{\text{assoc}})/v_n(0)$, if the Fourier coefficient is the product of the single particle anisotropies, v_n . The systematic errors on the can be directly derived from the beam direction systematics because other systematic errors are cancelled in the way it is defined. The systematic uncertainty of $\pm 5\%$ is estimated for $v_2(\eta)/v_2(0)$, and $\pm 15\%$ is for $v_3(\eta)/v_3(0)$. Figure 3 shows the $v_n(\eta)/v_n(0)$ results. Significant η dependence of v_2 is observed for the anisotropy parameter; it decreases by about $20 \pm 4\%$ from $\eta = 0$ to $\eta = 2$ in the p-direction; the decrease towards to the Pb-side rapidity is not as large. The v_2 appears to be asymmetric about $\eta = 0$

or the c.m.s. frame mid-rapidity ($\eta = 0.465$). Finite v_3 is observed; the statistical errors are presently too large for v_3 to draw conclusions regarding its η dependence.

Figure 3. Self-normalized anisotropy parameters, $v_2(\eta)/v_2(0)$ (left panel) and $v_3(\eta)/v_3(0)$ (right panel), as a function of η . Data points are results from V_n^{sub} with low-multiplicity data subtracted; closed points are from the Pb-side trigger data and open points from the p-side. Error bars are statistical; for v_2 , the statistical errors are smaller than the symbols. Bands show systematic uncertainty of $\pm 5\%$ for v_2 and $\pm 15\%$ for v_3 . The curves show the results obtained from the high-multiplicity data without subtraction of the low-multiplicity data. The systematic uncertainties (not shown) are of the same magnitude as shown by the bands.

5. Conclusion

Two-particle correlations as function of $\Delta\eta$ are reported in pPb collisions at 5.02 TeV by the CMS experiment. The trigger particle is restricted to narrow η windows of $-2.4 < \eta_{\text{trig}} < -2$ (Pb-side) and $2 < \eta_{\text{trig}} < 2.4$ (p-side). After jet subtraction, the remaining near-side ridge is found to be dependent on $\Delta\eta$.

The self-normalized anisotropy parameter, $v_n(\eta_{\text{assoc}})/v_n(0)$, is obtained from the Fourier coefficients of the azimuthal correlations. A significant η dependence is observed for the second harmonic anisotropy parameter v_2 .

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