

Dihadron Correlations in pp and PbPb Collisions

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Measurements of charged dihadron angular correlations are presented in proton-proton (pp) and Lead-Lead (PbPb) collisions, over a broad range of pseudorapidity and azimuthal angle, using the CMS detector at the LHC. A new and striking “ridge”-like structure emerges in the two-dimensional correlation function for particle pairs with intermediate p_T of 1-3 GeV/c, in the kinematic region $2.0 < |\Delta\eta| < 4.8$ and small $\Delta\phi$ in very high multiplicity pp collisions at $\sqrt{s} = 7$ TeV. Studies of the long-range and short-range dihadron correlations in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV are presented as well.

§1. Dihadron correlations in high multiplicity pp at $\sqrt{s} = 7$ TeV

Measurements of dihadron azimuthal correlations^{1)–6)} have provided a powerful tool to study the properties of the strongly interacting medium created in ultrarelativistic nuclear collisions. For the first time, long-range, near-side ($\Delta\phi \approx 0$) ridge-like azimuthal correlations for $2.0 < |\Delta\eta| < 4.8$ have recently been observed in high multiplicity proton-proton (pp) events at $\sqrt{s} = 7$ TeV at the LHC by the CMS Collaboration.⁷⁾ The nearly 4π solid-angle acceptance of the CMS detector⁸⁾ is ideally suited for studies of both short- and long-range particle correlations. A detailed description of dihadron correlations analysis technique can be found in Ref. 9).

This novel structure resembles similar features observed in relativistic heavy-ion experiments and is most evident in the intermediate transverse momentum range of both $1 < p_T^{\text{trig}} < 3$ GeV/c and $1 < p_T^{\text{assoc}} < 3$ GeV/c. Following up the first observation of the ridge correlation structure in high multiplicity pp collisions at $\sqrt{s} = 7$ TeV,⁷⁾ new results are presented using the full statistics data collected in 2010. Figure 1 shows the per-trigger-particle associated yield distribution of charged hadrons as a function of $\Delta\eta$ and $\Delta\phi$ in high multiplicity ($N \geq 110$) pp collisions at $\sqrt{s} = 7$ TeV with trigger particles both for $2 < p_T^{\text{trig}} < 3$ GeV/c (left) and $5 < p_T^{\text{trig}} < 6$ GeV/c (right), respectively. Associated particle p_T ranges are $1 < p_T^{\text{assoc}} < 2$ GeV/c for both. The ridge-like structure is clearly visible at $\Delta\phi \approx 0$ extending to $|\Delta\eta|$ of at least 4 units as previously observed in Ref. 7). However, at higher p_T^{trig} of 5–6 GeV/c as presented in Fig. 1 (right), the ridge almost disappears.

In order to fully explore dependence on event multiplicity and transverse momentum of short- and long-range correlations, 1-D $\Delta\phi$ azimuthal correlation functions are calculated by integrating over the $0.0 < |\Delta\eta| < 1.0$ and $2.0 < |\Delta\eta| < 4.0$ region, defined as the jet region and ridge region, respectively. In the next step, the near-side (small $\Delta\phi$ region) integrated associated yield is calculated for both jet and ridge regions relative to the minimum of the distribution by using “zero-yield-at-minimum (ZYAM)” procedure.⁹⁾ Top panel of Fig. 2 shows the integrated near-side associated yield for both the jet and ridge regions with $1 < p_T^{\text{assoc}} < 2$ GeV/c (the p_T range

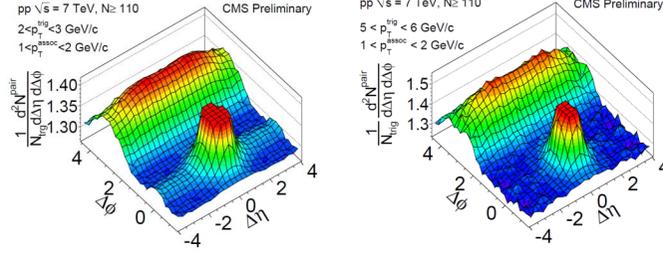


Fig. 1. (color online) Two-dimensional (2-D) per-trigger-particle associated yield of charged hadrons as a function of $\Delta\eta$ and $\Delta\phi$ for $2 < p_T^{\text{trig}} < 3$ GeV/c and $1 < p_T^{\text{assoc}} < 2$ GeV/c (left) and $5 < p_T^{\text{trig}} < 6$ GeV/c and $1 < p_T^{\text{assoc}} < 2$ GeV/c (right) from high multiplicity ($N \geq 110$) pp collisions at $\sqrt{s} = 7$ TeV with jet peak cutoff for better demonstration of the ridge.

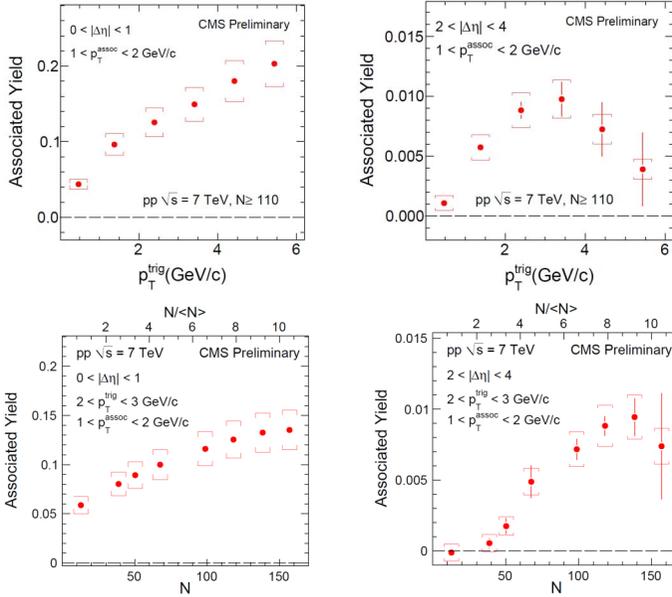


Fig. 2. (color online) Top: Integrated near-side associated yields for jet ($0 < |\Delta\eta| < 1$) and the ridge ($2 < |\Delta\eta| < 4$) region, with $1 < p_T^{\text{assoc}} < 2$ GeV/c, calculated by the ZYAM procedure, as a function of p_T^{trig} for $N \geq 110$ of pp collisions at $\sqrt{s} = 7$ TeV. Bottom: Integrated near-side associated yields for jet ($0 < |\Delta\eta| < 1$) and ridge ($2 < |\Delta\eta| < 4$) region, with $2 < p_T^{\text{trig}} < 3$ GeV/c and $1 < p_T^{\text{assoc}} < 2$ GeV/c, calculated by the ZYAM procedure, as a function of event multiplicity from pp collisions at $\sqrt{s} = 7$ TeV. The statistical uncertainties are shown as bars, while the brackets denote the systematic uncertainties.

where the ridge effect appears to be strongest) as a function of p_T^{trig} for $N \geq 110$. The jet yield increases with p_T^{trig} as expected due to the increasing contributions from high p_T jets. The ridge yield first increases with p_T^{trig} , reaches a maximum around $p_T^{\text{trig}} \sim 2-3$ GeV/c and drops at higher p_T^{trig} . The multiplicity dependence of the near-side associated yield in the jet and ridge region is also illustrated in Fig. 2 (bottom panel) for one transverse momentum bin of $2 < p_T^{\text{trig}} < 3$ GeV/c and $1 < p_T^{\text{assoc}} < 2$ GeV/c, the p_T bin where the ridge effect appears to be strongest. The

ridge effect gradually turns on with event multiplicity around $N \sim 50$ – 60 (about four times of the average multiplicity in minimum bias events) and smoothly increases toward high multiplicity region.

§2. Dihadron correlations in $PbPb$ at $\sqrt{s_{NN}} = 2.76$ TeV

For $PbPb$ collisions at $\sqrt{s_{NN}} = 2.76$ TeV, two-dimensional (2-D) per-trigger-particle associated yield as a function of $\Delta\eta$ and $\Delta\phi$ for trigger particles with $4 < p_T^{\text{trig}} < 6$ GeV/ c and associated particles with $2 < p_T^{\text{assoc}} < 4$ GeV/ c is shown in Fig. 3 for two selected centrality classes. In the 0–5% most central $PbPb$ collisions, a clear and significant ridge-like structure is observed at $\Delta\phi \approx 0$, which extends all the way to the limit of the measurement of $|\Delta\eta| = 4$. In mid-peripheral collisions, a $\cos(2\Delta\phi)$ component becomes prominent, which is attributed to the elliptic flow effects (v_2).

In the same manner of pp dihadron correlation studies, one-dimensional (1-D) $\Delta\phi$ correlation functions and near-side integrated associated yields in short-range jet and long-range ridge regions are calculated. Strong centrality dependence is observed in the associated yields that comes primarily from the long-range ridge region. By subtracting off the ridge region yield from the jet region yield, the residual jet region associated yield is found to be largely independent of centrality, a general feature of the data that is similar to that seen at RHIC.^{(10),(11)} See Ref. 12) for more details.

Motivated by the idea of understanding the long-range ridge effect in the context of higher-order hydrodynamic flow induced by initial geometric fluctuations,⁽¹³⁾ an alternative way of quantifying the observed long-range correlations using a Fourier decomposition technique is investigated. According to the methodology of Ref. 12), the 1-D $\Delta\phi$ distribution is decomposed into a Fourier series using the following expression:

$$\frac{1}{N_{\text{trig}}} \frac{dN^{\text{pair}}}{d\Delta\phi} = \frac{N_{\text{assoc}}}{2\pi} \left\{ 1 + \sum_{n=1}^{\infty} 2V_{n\Delta} \cos(n\Delta\phi) \right\}, \quad (2.1)$$

where N_{assoc} represents the total number of dihadron pairs per trigger particle for

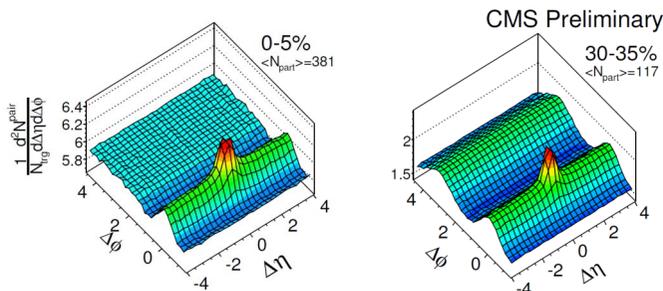


Fig. 3. (color online) Two-dimensional (2-D) per-trigger-particle associated yield of charged hadrons as a function of $\Delta\eta$ and $\Delta\phi$ for $4 < p_T^{\text{trig}} < 6$ GeV/ c and $2 < p_T^{\text{assoc}} < 4$ GeV/ c in central (left) and mid-peripheral (right) $PbPb$ collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

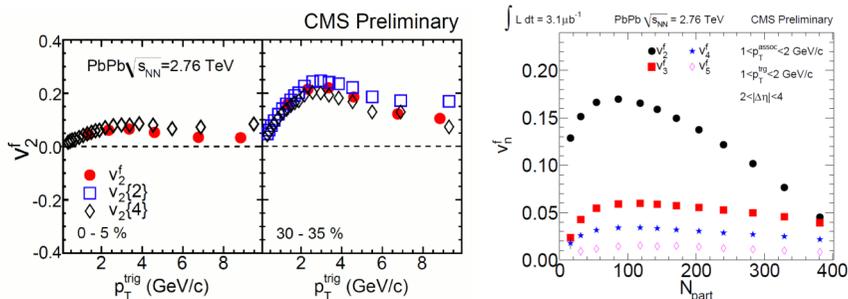


Fig. 4. (color online) v_2^f extracted as a function of p_T^{trig} for $1 < p_T^{\text{assoc}} < 2$ GeV/c for central (left) and mid-peripheral (middle) PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Comparisons to the two- and four-particle cumulant method of measuring v_2^f are also presented. The flow harmonics v_2^f , v_3^f , v_4^f and v_5^f extracted from long-range ($2 < |\Delta\eta| < 4$) azimuthal dihadron correlations for $1 < p_T^{\text{trig}} < 2$ GeV/c and $1 < p_T^{\text{assoc}} < 2$ GeV/c as a function of the number of participating nucleons (N_{part}) in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV¹⁵⁾ are also shown in the right. Statistical and systematic uncertainties are negligible.

a given $|\Delta\eta|$ and $(p_T^{\text{trig}}, p_T^{\text{assoc}})$ bin. The data are well described by this fit. If the observed correlation was purely driven by the single-particle azimuthal anisotropy arising from the hydrodynamic expansion of the medium,¹⁴⁾ the extracted Fourier components would factorize into the flow coefficients v_n (i.e., v_2 for anisotropic elliptic flow):

$$V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}}) = v_n^f(p_T^{\text{trig}}) \times v_n^f(p_T^{\text{assoc}}), \quad (2.2)$$

where $v_n^f(p_T^{\text{trig}})$ and $v_n^f(p_T^{\text{assoc}})$ are the flow coefficients for the trigger and associated particles.¹³⁾ The extracted v_2^f are shown in Fig. 4 as a function of p_T^{trig} for central (left) and mid-peripheral (middle) collisions. The results are found to be in good agreement with elliptic flow values measured by standard flow methods.¹⁵⁾ Figure 4 (right) gives the centrality dependence of the extracted flow coefficients at low p_T for the higher harmonics $n = 2$ to 5. Measurements of v_n^f up to higher orders provide essential insights to the viscosity and initial condition of the PbPb collision system according to recent theoretical progress.¹⁶⁾

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