Two-particle correlations in pp collisions at 13 TeV measured with CMS

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Abstract

Results on two-particle angular correlations for charged particles emitted in pp collisions at a center-of-mass energy of 13 TeV are presented as a function of charged-particle multiplicity and transverse momentum ($p_T$). In high-multiplicity events, a long-range ($|\eta| > 2.0$), near-side ($\Delta\phi = 0$) structure emerges in the two-particle $\Delta\eta - \Delta\phi$ correlation functions. The overall correlation strength is similar to that found in earlier pp data at 7 TeV, but is measured up to much higher multiplicity values. A detailed study in pp collisions at 7 TeV of the second-order ($v_2$) azimuthal anisotropy harmonics of charged particles, $K^0_S$ and $\Lambda/\bar{\Lambda}$ particles are extracted from long-range two-particle correlations as a function of particle multiplicity and transverse momentum and are also compared with values obtained in pPb and PbPb collisions at similar multiplicities.

Presented at WPCF-2015 XI Workshop on Particle Correlations and Femtoscopy
Two-Particle Correlations in $pp$ Collisions at 13 TeV Measured with CMS

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1. Introduction

The discovery of long-range two-particle azimuthal correlations at large relative pseudorapidity in high-multiplicity proton-proton [1] and proton-lead [2] collisions at CMS has opened up new opportunities of studying novel dynamics of particle production in small but high-density Quantum Chromodynamic (QCD) systems. Similar long-range correlation structures at small relative azimuthal angle $\Delta \phi \approx 0$ were first observed in relativistic nucleus-nucleus ($AA$) collisions. Such correlations have been extensively studied and it has been suggested that the hydrodynamic collective flow of a strongly interacting and expanding medium is responsible for these long-range correlations in large heavy-ion collision systems. A wide range of models have been suggested to explain the emergence of these correlations in $pp$ and pPb collisions, while models based on a hydrodynamic approach can describe many aspects of the observed correlations [3], it has been proposed that initial-state correlations of gluon fields could also lead to similar effects [4]. To provide new insights on understanding the long-range correlation phenomenon in high-multiplicity $pp$ collisions, the results of two-particle azimuthal correlations with unidentified charged particles and identified particles of $K_0^0$ and $\Lambda/\bar{\Lambda}$ are also discussed. The anisotropy harmonics $v_2$ and $v_3$ are extracted at 7 TeV from long-range ($\mid \Delta \eta \mid > 2$) two-particle correlations by associating either an unidentified charged particle, or an identified V0 particle ($K_0^0$, $\Lambda/\bar{\Lambda}$) with another unidentified charged particle and are expressed as a function of particle $p_T$ and event multiplicity.

* Presented at WPCF2015
2. The CMS experiment and two particle correlations

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 are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL, $|\eta| < 3$), and a brass and scintillator hadron calorimeter (HCAL, $|\eta| < 3$), each composed of a barrel and two endcap sections. Extensive forward calorimetry (HF, $3 < |\eta| < 5$) complements the coverage provided by the barrel and endcap detectors. The silicon tracker measures charged particles within the pseudorapidity range $|\eta| < 2.5$. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in [5]. The distributions in relative azimuthal angle ($\Delta \phi = \phi_{\text{trig}} - \phi_{\text{assoc}}$) and relative pseudorapidity ($\Delta \eta = \eta_{\text{trig}} - \eta_{\text{assoc}}$) between trigger and associated particles are constructed to obtain the per-trigger yield, $\frac{1}{N_{\text{trig}}} \frac{d^2N}{d\Delta \phi d\Delta \eta}$. The Fig. 1 shows the 2-D $\Delta \eta - \Delta \phi$ correlation functions, for pairs of a charged trigger particles and a charged associated particle, in low ($N_{\text{offline}}^{\text{trk}} < 35$) and high-multiplicity $N_{\text{offline}}^{\text{trk}} \geq 105$. The definition $N_{\text{offline}}^{\text{trk}}$ is in the same way as [1, 2]. The dominant correlation peak near $(\Delta \eta, \Delta \phi) = (0, 0)$ due to jet fragmentation, a long-range ridge structure is seen at $\Delta \phi \approx 0$ extending at least 4 units in $|\Delta \eta|$, while such structure is not observed at low multiplicity. On the away side ($\Delta \phi \approx \pi$) of the correlation functions, a long-range structure is also seen and found to exhibit a larger magnitude compared to that on the near side. To quantitatively investigate these long-range near-side correlations, and to provide a direct comparison to pp results at lower collision energy, one-dimensional (1D) distributions in $\Delta \phi$ are constructed by averaging the signal and background 2D distributions over $2 < |\Delta \eta| < 4$, as done in [1, 2]. The correlated portion of the associated yield is estimated by using an implementation of the zero-yield-at-minimum (ZYAM) procedure [6]. The details of the analysis are mentioned in [7].

3. Results

Figure 2(a) shows that the associated yield of long-range near-side correlations for events with $N_{\text{trk}}^{\text{offline}} \geq 105$ for 13 TeV, and $N_{\text{trk}}^{\text{offline}} \geq 110$ for 7 TeV, peaks at the region $1 < p_T < 2$ GeV/c for both center-of-mass energies. The yield reaches a maximum around $p_T$
Figure 2. Left: Associated yield for the near side of the correlation function for \( pp \) data at 7 TeV and 13 TeV, (a) averaged over \( 2 < \Delta \eta < 4 \) as a function of \( p_T \), (b) for \( 1 < p_T < 2 \text{ GeV/c} \) as a function of \( N_{\text{trk}} \) and compared with gluon saturation model \([4]\). Right: Comparison of associated yield in \( pp \) collisions at 13 and 7 TeV, with \( pPb \) collisions at 5.02 TeV, and \( PbPb \) collisions at 2.76 TeV.

\( \approx 1 \text{ GeV/c} \) and decreases with increasing \( p_T \) and has no center-of-mass energy dependence. The multiplicity dependence of the associated yield for \( 1 < p_T < 2 \text{ GeV/c} \) particle pairs is shown in Fig. 2(b). For low-multiplicity events, the associated yield determined with the ZYAM procedure is consistent with zero. This indicates that ridge-like correlations are absent or smaller than the negative correlations expected because of, for example, momentum conservation. At higher multiplicity for \( N_{\text{trk}} \geq 40 \) the ridge-like correlation emerges as shown in Fig. 2(b), with an approximately linear rise of the associated yield and compared with gluon saturation model \( \sqrt{s} = 13 \text{ TeV} \) \([4]\), which predicts a faster rise than that observed in the data for the very high-multiplicity region. Right plot of Fig. 2 compares the associated yields in \( pp \), \( pPb \), and \( PbPb \) collisions for \( 1 < p_T < 2 \text{ GeV/c} \) as a function of the \( N_{\text{trk}} \). In all three systems, the ridge-like correlations become significant at a multiplicity value of about 40, and exhibit a nearly linear increase for higher values. For a given track multiplicity, the associated yield in \( pp \) collisions is roughly 10% and 25% of those observed in \( PbPb \) and \( pPb \) collisions, respectively which clearly suggests a strong collision system size dependence of the long-range near-side correlations.

To investigate more about the origin of long-range correlations, the \( v_2 \) measurements for \( pp \) collisions at 7 TeV are also studied as a function of \( p_T \) for inclusive charged particles as well as \( K_S^0 \) and \( \Lambda \) as a function of \( p_T \) for low and high multiplicity event as shown in Fig. 3. The extracted \( v_2 \) values mainly reflects back-to-back jet correlations on the away side as there is no evidence of long-range near-side correlation being seen in these low-multiplicity events. However, for the high multiplicity events with \( 110 \leq N_{\text{trk}} < 150 \), a deviation of \( v_2 \) between particle species is observed. In the lower \( p_T \) region of 2.5 GeV/c, the \( v_2 \) of \( K_S^0 \) is bigger than that of \( \Lambda/\bar{\Lambda} \) at a given \( p_T \) value. Both are consistently below the inclusive charged particle \( v_2 \) values. Since most charged particles are pions in this \( p_T \) range, this indicates that lighter particle species exhibit a stronger azimuthal anisotropy signal similar to the observed in \( AA \) collisions \([8]\) and \( pPb \) collisions \([9]\). This behavior is found to be qualitatively consistent with hydrodynamic models. The \( v_2^{sub} \) results as a function of \( p_T \) for \( 110 \leq N_{\text{trk}} < 150 \) is shown in the right panel after subtracting the contribution of the back-to-back jet correlations from low multiplicity events as explained in \([10]\). The amount of \( v_2 \) being subtracted increases as
Figure 3. The $v_2$ results of inclusive charged particles, $K^0_S$ and $\Lambda$ as a function of $p_T$ in $pp$ collisions at 7 TeV, for $10 \leq N_{\text{trk}}^{\text{offline}} < 20$ (left), and $110 \leq N_{\text{trk}}^{\text{offline}} < 150$ (middle). The $v_2^{\text{sub}}$ results as a function of $p_T$ for $110 \leq N_{\text{trk}}^{\text{offline}} < 150$ is shown in the right panel. The systematic uncertainties are indicated by the shaded areas.

a function of $p_T$ for all particle species, which is consistent with the observation of stronger jet-like correlation at higher $p_T$ observed from $v_2$ results for $10 \leq N_{\text{trk}}^{\text{offline}} < 20$. The $v_2^{\text{sub}}$ values for all three types of particle are found to increase with $p_T$, reaching 8% at $2 < p_T < 3$ GeV/c, and then converges to zero at higher $p_T$ values. The particle species dependence of $v_2^{\text{sub}}$ at lower $p_T$ region is also observed after applying jet correction, while at higher $p_T$, $v_2^{\text{sub}}$ become identical within uncertainties for all three types of particles.

4. Summary

The results of two particle correlation for $pp$ collisions at center-of-mass energy of 13 TeV are presented. The associated yields for $pp$ collisions at 13 TeV has similar values compared to 7 TeV as a function of $p_T$ and multiplicity and are compared with the models. The results for $v_2$ and $v_3$ are also presented at 7 TeV for charged particle as well as $K^0_S$ and $\Lambda$ as a function of $p_T$ and multiplicity. The data presented in this paper not only provide important insights to understand the origin of long-range correlations in $pp$ collision, but also shed light on the subnucleonic structure of the proton.

References