TWO-PARTICLE CORRELATIONS IN pp COLLISIONS AT 13 TeV MEASURED WITH CMS*

S.M. Dogra

for the CMS Collaboration

Instituto Física Teórica, Unidade Complementar da UNESP
01140-070 São Paulo, SP, Brazil

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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.

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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-

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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_S and $\Lambda/\bar{\Lambda}$ are also discussed. The anisotropy harmonics v_2 are extracted at 7 TeV from long-range ($|\Delta\eta| > 2$) two-particle correlations by associating either an unidentified charged particle, or an identified V0 particle (K^0_S, $\Lambda/\bar{\Lambda}$) with another unidentified charged particle and are expressed as a function of particle p_T and event multiplicity.

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, $\frac{1}{N_{\text{trig}}} \frac{\mathrm{d}^2 N}{\mathrm{d}\Delta\phi \mathrm{d}\Delta\eta}$. Figure 1 shows the 2D $\Delta\eta$–$\Delta\phi$ 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 of $N^{\text{offline}}_{\text{trk}}$ is the same as in [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].

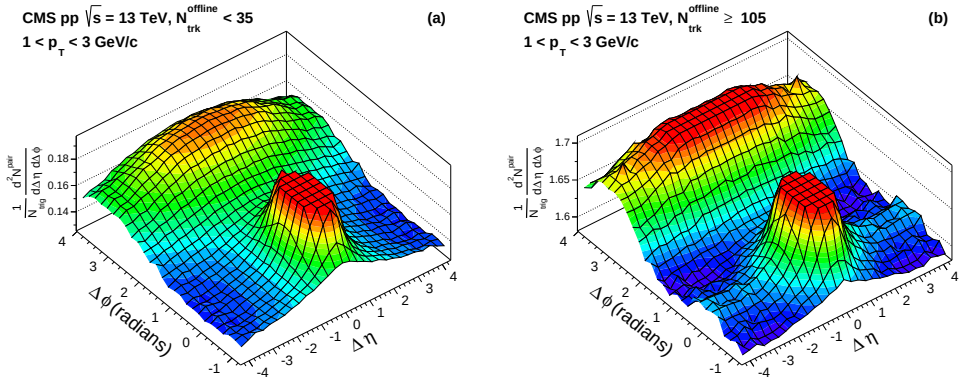

Fig. 1. The 2D $(\Delta\eta, \Delta\phi)$ two-particle correlation functions in pp collisions at 13 TeV for the pairs of charged particles in the range of $1 < p_{\mathrm{T}} < 3$ GeV/c.

3. Results

Figure 2 (a) shows that the associated yield of long-range near-side correlations for events with $N_{\mathrm{trk}}^{\mathrm{offline}} \geq 105$ for 13 TeV, and $N_{\mathrm{trk}}^{\mathrm{offline}} \geq 110$ for 7 TeV, peaks at the region of $1 < p_{\mathrm{T}} < 2$ GeV/c for both center-of-mass energies. The yield reaches a maximum around $p_{\mathrm{T}} \approx 1$ GeV/c and decreases with increasing p_{T} and has no center-of-mass energy dependence. The multiplicity dependence of the associated yield for $1 < p_{\mathrm{T}} < 2$ 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 $N_{\mathrm{trk}}^{\mathrm{offline}} \gtrsim 40$, 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 $\sqrt{s} = 13$ 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 $1 < p_{\mathrm{T}} < 2$ GeV/c as a function of the $N_{\mathrm{trk}}^{\mathrm{offline}}$. 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.

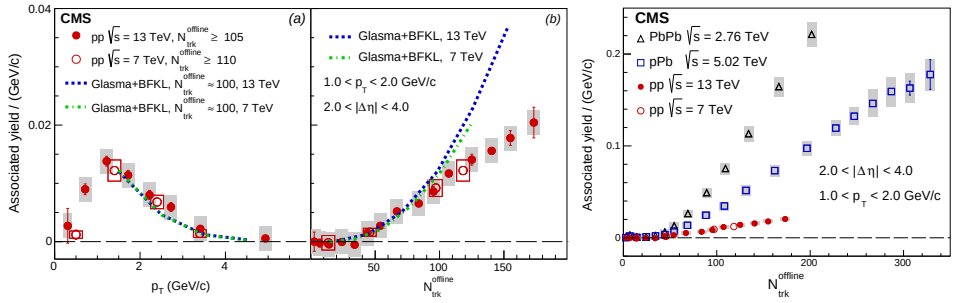

Fig. 2. Left: Associated yield for the near side of the correlation function for pp data at 7 TeV and 13 TeV, (a) averaged over $2 < \Delta\eta < 4$ as a function of p_{T}, (b) for $1 < p_{\mathrm{T}} < 2$ GeV/c as a function of $N_{\mathrm{trk}}^{\mathrm{offline}}$ and compared with gluon saturation 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.

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^0_{S} and $\Lambda/\bar{\Lambda}$ 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 $110 \leq N_{\mathrm{trk}}^{\mathrm{offline}} < 150$, 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^0_{S} 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.

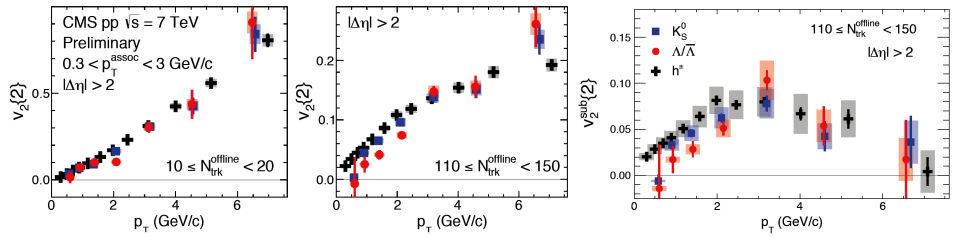

Fig. 3. The v_2 results of inclusive charged particles, K^0_{S} and $\Lambda/\bar{\Lambda}$ as a function of p_{T} in pp collisions at 7 TeV, for $10 \leq N_{\mathrm{trk}}^{\mathrm{offline}} < 20$ (left), and $110 \leq N_{\mathrm{trk}}^{\mathrm{offline}} < 150$ (middle). The v_2^{sub} results as a function of p_{T} for $110 \leq N_{\mathrm{trk}}^{\mathrm{offline}} < 150$ is shown in the right panel. The systematic uncertainties are indicated by the shaded areas.

The $v_2^{\rm sub}$ results as a function of $p_{\rm T}$ for $110 \leq N_{\rm trk}^{\rm offline} < 150$ 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 a function of $p_{\rm T}$ for all particle species, which is consistent with the observation of stronger jet-like correlation at higher $p_{\rm T}$ observed from v_2 results for $10 \leq N_{\rm trk}^{\rm offline} < 20$. The $v_2^{\rm sub}$ values for all three types of particle are found to increase with $p_{\rm T}$, reaching 8% at $2 < p_{\rm T} < 3$ GeV/c, and then converges to zero at higher $p_{\rm T}$ values. The particle species dependence of $v_2^{\rm sub}$ at lower $p_{\rm T}$ region is also observed after applying jet correction, while at higher $p_{\rm T}$, $v_2^{\rm sub}$ 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 $p_{\rm T}$ and multiplicity and are compared with the models. The results for v_2 are also presented at 7 TeV for charged particle as well as $K_{\rm S}^0$ and $\Lambda/\bar{\Lambda}$ as a function of $p_{\rm T}$ 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

[1] V. Khachatryan *et al.* [CMS Collaboration], *J. High Energy Phys.* **1009**, 091 (2010).

[2] S. Chatrchyan *et al.* [CMS Collaboration], *Phys. Lett. B* **718**, 795 (2013).

[3] P. Bozek, W. Broniowski, *Phys. Lett. B* **718**, 1557 (2013).

[4] K. Dusling, P. Tribedy, R. Venugopalan, *Phys. Rev. D* **93**, 014034 (2016).

[5] S. Chatrchyan *et al.* [CMS Collaboration], *JINST* **9**, P10009 (2014).

[6] N.N. Ajitanand *et al.*, *Phys. Rev. C* **72**, 011902 (2005).

[7] V. Khachatryan *et al.* [CMS Collaboration], submitted to *Phys. Rev. Lett.*, CMS Physics Analysis Summary FSQ-15-002, 2015.

[8] S. Chatrchyan *et al.* [CMS Collaboration], *Phys. Rev. C* **87**, 014902 (2013).

[9] V. Khachatryan *et al.* [CMS Collaboration], *Phys. Lett. B* **742**, 200 (2015).

[10] V. Khachatryan *et al.* [CMS Collaboration], Physics Analysis Summary HIN-15-009, 2015.