Measurement of Long-Range Near-Side Two-Particle Angular Correlations in pp Collisions at $\sqrt{s} = 13$ TeV

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Results on two-particle angular correlations for charged particles produced in pp collisions at a center-of-mass energy of 13 TeV are presented. The data were taken with the CMS detector at the LHC and correspond to an integrated luminosity of about 270 nb^{-1}. The correlations are studied over a broad range of pseudorapidity ($|\eta| < 2.4$) and over the full azimuth (ϕ) as a function of charged particle multiplicity and transverse momentum (p_T). In high-multiplicity events, a long-range ($|\Delta\eta| > 2.0$), near-side ($\Delta\phi \approx 0$) structure emerges in the two-particle $\Delta\eta$–$\Delta\phi$ correlation functions. The magnitude of the correlation exhibits a pronounced maximum in the range $1.0 < p_T < 2.0$ GeV/c and an approximately linear increase with the charged particle multiplicity, with an overall correlation strength similar to that found in earlier pp data at $\sqrt{s} = 7$ TeV. The present measurement extends the study of near-side long-range correlations up to charged particle multiplicities $N_{ch} \sim 180$, a region so far unexplored in pp collisions. The observed long-range correlations are compared to those seen in pp, pPb, and PbPb collisions at lower collision energies.

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Studies of particle correlations in high-energy hadron-hadron collisions provide valuable information on the underlying quantum chromodynamics processes leading to particle production. Measurements of two-particle angular correlations are typically performed in terms of two-dimensional $\Delta\eta$-$\Delta\phi$ correlation functions, where η is the pseudorapidity and ϕ is the azimuthal angle. Of particular interest in studies of possible novel partonic collective effects is the long-range (e.g., $|\Delta\eta| > 2.0$) structure of two-particle correlation functions, in which the effects of known sources such as resonance decays and fragmentation of high-momentum partons are known to be small. In most Monte Carlo (MC) event generators for proton-proton (pp) collisions, the typical sources of such long-range correlations are momentum conservation and away-side ($\Delta\phi \approx \pi$) jet correlations. Measurements in high-energy nucleus-nucleus collisions have shown a long-range structure in the two-particle angular correlations functions, which has been attributed to the presence of the hot and dense matter formed [1]. Several novel features were observed in azimuthal correlations over large $\Delta\eta$ for intermediate particle transverse momenta, $p_T \approx 1$–5 GeV/c [2,3]. These correlations are thought to arise from the response of a hydrodynamically expanding partonic medium to fluctuations of the initial collision geometry [4–9]. Measurements in pp collisions at a center-of-mass energy of $\sqrt{s} = 7$ TeV have also revealed the presence of long-range, near-side ($\Delta\phi \approx 0$) correlations in events with very large final-state particle multiplicity [10]. Similar phenomena have also been observed in high-multiplicity proton-lead (pPb) collisions [11–13], where they have been studied extensively [14–21].

A wide range of models have been suggested to explain the emergence of these correlations in pp [22] and pPb [23–27] collisions. While models based on a hydrodynamic approach can describe many aspects of the observed correlations [23,24], it has been proposed that initial-state correlations of gluon fields could also lead to similar effects [25–27].

The LHC at CERN has recently started to deliver pp collisions at a new energy regime at $\sqrt{s} = 13$ TeV, and there is renewed interest in investigating this phenomenon, especially its energy dependence. The first measurement of long-range two-particle correlations in pp collisions at $\sqrt{s} = 13$ TeV has been reported by the ATLAS collaboration [28]. In this Letter, studies of long-range correlations in pp collisions at $\sqrt{s} = 13$ TeV with the CMS detector are presented. The measurements are performed over a wide range in charged particle multiplicity and p_T. The strength of long-range near-side correlations is quantified, and results for pp, pPb, and PbPb systems at various collision energies are compared.

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

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forward calorimetry (HF, $3 < |\eta| < 5$) complements the coverage provided by the barrel and endcap detectors. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. The silicon tracker measures charged particles within the pseudorapidity range $|\eta| < 2.5$. It consists of 1440 silicon pixel and 15 148 silicon strip detector modules. For nonisolated particles of $1 < p_T < 10$ GeV/c and $|\eta| < 1.4$, the track resolutions are typically 1.5% in p_T and 25–90 (45–150) μm in the transverse (longitudinal) impact parameter [29]. The first level (L1) of the CMS trigger system, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select the most interesting events in a fixed time interval of less than 4 μs. The high-level trigger (HLT) processor farm further decreases the event rate from around 100 kHz to less than 1 kHz, before data storage. 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 Ref. [30]. The MC simulation of the CMS detector response is based on GEANT4 [31].

The data used in this study were recorded under special running conditions in which the beams were separated at the CMS interaction point, resulting in an average of 1.3 pp interactions per bunch crossing. The integrated luminosity recorded was about 270 nb^{-1}. As the average number of pp interactions per bunch crossing is small in the present data, minimum bias (MB) pp events were selected online by simply requiring that two proton bunches collide near the center of the CMS detector. Only a small fraction ($\sim 10^{-3}$) of all MB pp events were recorded (i.e., the trigger was prescaled). In order to enhance the fraction of high-multiplicity events, additional samples were collected with a dedicated selection procedure that combined the CMS L1 and HLT systems. At L1, the total transverse energy summed over ECAL and HCAL was required to be greater than a given threshold (both 15 and 40 GeV thresholds were used). Only the lowest threshold trigger was prescaled. Track reconstruction for the HLT was based on the three layers of the pixel detectors, and required that the track originates within a cylindrical region centered on the nominal interaction point. This region has a length of 30 cm along the beam direction and a radius of 0.2 cm perpendicular to it. For each event, the vertex reconstructed with the highest number of tracks was selected. The number of tracks ($N_{\rm trk}^{\rm online}$) with $|\eta| < 2.4$, $p_T > 0.4$ GeV/c, and a distance of closest approach of 0.12 cm or less from this vertex was determined for each event. Data were taken with thresholds $N_{\rm trk}^{\rm online} > 60$ or 85 (based on events selected with a L1 total energy larger than 15 GeV), and 110 (based on events selected with a L1 total energy larger than 40 GeV).

In the off-line analysis, hadronic collisions are selected by requiring at least one tower in each of the two HF calorimeters with more than 3 GeV energy to suppress diffractive interactions [32]. Events are also required to contain at least one reconstructed primary vertex with a position along the beam axis, $z_{\rm vtx}$, within 15 cm of the nominal interaction point and within 0.15 cm of the beams in the transverse plane. In addition, at least two tracks must be associated with this vertex. As the data have an average of 1.3 pp interactions per bunch crossing, a substantial fraction of events have at least one additional interaction (pile-up). A procedure similar to that described in Ref. [14] is used for identifying and rejecting pile-up events. It is based on the number of tracks associated with each reconstructed vertex and the distance between multiple vertices. If the distance between the highest-multiplicity vertex and the closest additional vertex along the z direction is larger than 1 cm, the event is accepted. This is because the tracks used for the correlation analysis are always selected with respect to the highest-multiplicity vertex in the event. An additional vertex sufficiently far from the highest-multiplicity vertex has a negligible effect on the analysis. The MC studies carried out with the EPOS [33] and PYTHIA8 v208 [34] generators (with the CMS underlying event tune CUETP8M1 [35]) indicate that 94%–96% of the events satisfy the analysis selections; i.e., they have at least one stable particle from the pp interaction with energy $E > 3$ GeV in each of the η regions $-5 < \eta < -3$ and $3 < \eta < 5$.

The present analysis is based on a sample of events with high-purity primary tracks [29] originating from the pp interaction. To obtain this sample, additional requirements are applied. The significance of the distance between the track and the primary vertex along the beam axis, d_z/σ_{d_z}, and the significance of the impact parameter relative to the best resolution of the vertex coordinates transverse to the beam, d_T/σ_{d_T}, must both be less than 3 in absolute value, and the relative p_T uncertainty, $\sigma(p_T)/p_T$, must be less than 10%. To ensure high tracking efficiency and to reduce the rate of misreconstructed tracks, primary tracks with $|\eta| < 2.4$ and $p_T > 0.1$ GeV/c are used in the analysis (a p_T cutoff of 0.4 GeV/c is used in the track multiplicity determination to match the HLT requirement). Simulation studies based on PYTHIA8 are used to obtain the geometrical acceptance and efficiency for primary track reconstruction as well as the rate of misreconstructed tracks. The combined acceptance and efficiency is better than 60% for $p_T > 0.4$ GeV/c and $|\eta| < 2.4$ and better than 90% in the $|\eta| < 1$ region for $p_T > 0.6$ GeV/c. For the track multiplicity range studied in this Letter, no dependence of the tracking efficiency on track multiplicity is found and the rate of misreconstructed tracks is 1%–2% according to simulations.

Following the procedure established in Refs. [11,14,15,36,37], the data set is divided into classes of events with different track multiplicity, $N_{\rm trk}^{\rm off\text{-}line}$, which is evaluated by counting primary tracks with $|\eta| < 2.4$ and $p_T > 0.4$ GeV/c. Details of the multiplicity classification in this analysis are provided in Table I, which also gives

TABLE I. Multiplicity classes used in the analysis, corresponding fraction of the full event sample, observed and corrected average charged particle multiplicities for $|\eta| < 2.4$ and $p_T > 0.4$ GeV/c. Systematic uncertainties are given for the corrected multiplicities.

Multiplicity class ($N_{trk}^{off\text{-}line}$)	Fraction	$\langle N_{trk}^{off\text{-}line} \rangle$	$\langle N_{trk}^{corrected} \rangle$
Minimum bias	1.0	20	23 ± 1
[2, 34]	0.82	13	16 ± 1
[35, 79]	0.15	47	58 ± 2
[80, 104]	0.02	88	107 ± 4
[105, 134]	3.3×10^{-4}	113	131 ± 5
≥135	1.4×10^{-5}	145	168 ± 7

the fraction with respect to the full multiplicity distribution and the average number of primary tracks before and after correcting for detector effects. The minimum bias sample is used for the range $N_{trk}^{off\text{-}line} < 80$, while various high-multiplicity samples are used for $N_{trk}^{off\text{-}line}$ ranges above 80.

For each track multiplicity class, "trigger" particles are defined as charged particles originating from the primary vertex within a given p_T range. The number of trigger particles for each p_T range in the event is denoted by N_{trig}. In this analysis, particle pairs are formed by associating every trigger particle with the remaining charged primary particles (associated particles) from the same p_T interval as the trigger particle. The per-trigger-particle associated yield is defined as

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

where $\Delta\eta$ and $\Delta\phi$ are the differences in η and ϕ of the pair. The symbol N^{pair} denotes the number of particle pairs. The signal distribution, $S(\Delta\eta, \Delta\phi)$, is the per-trigger-particle yield of particle pairs from the same event,

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

The symbol N^{same} denotes the number of pairs taken from the same event. The mixed-event background distribution, used to account for random combinatorial background and pair acceptance effects,

$$B(\Delta\eta, \Delta\phi) = \frac{1}{N_{trig}} \frac{d^2 N^{mix}}{d\Delta\eta d\Delta\phi}, \quad (3)$$

is constructed by pairing the trigger particles in each event with the particles from 10 different random events within a 0.2 cm wide z_{vtx} range. The symbol N^{mix} denotes the number of pairs taken from the mixed event, while $B(0,0)$ represents the mixed-event associated yield for both particles of the pair going in approximately the same direction and thus having full pair acceptance (with a bin width of 0.3 in $\Delta\eta$ and $\pi/16$ in $\Delta\phi$). Therefore, the ratio $B(0,0)/B(\Delta\eta, \Delta\phi)$ is the pair-acceptance correction factor used to derive the corrected per-trigger-particle associated yield distribution. The signal and background distributions are first calculated for each event, and then averaged over all the events within the track multiplicity class for each p_T range.

Each reconstructed track is weighted by the inverse of an efficiency factor, which accounts for the detector acceptance, the reconstruction efficiency, and the fraction of misreconstructed tracks (the same factor as used for correcting the average multiplicity in Table I).

The two-dimensional (2D) $\Delta\eta$-$\Delta\phi$ two-particle correlation functions for events with low and high multiplicities are shown in Fig. 1. As in our earlier papers, pairs of

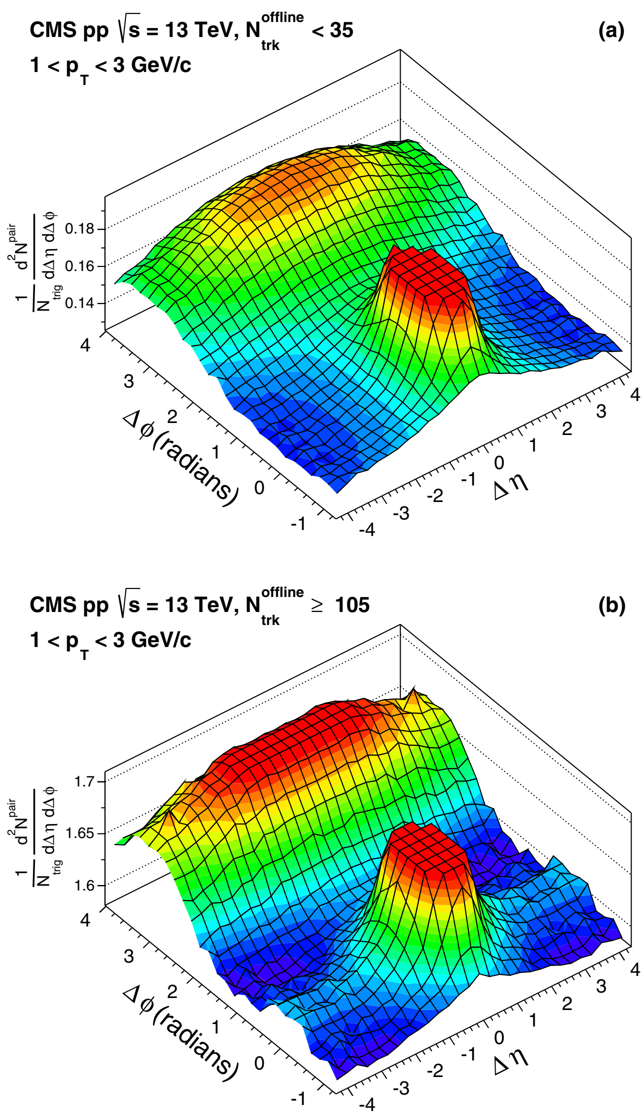

FIG. 1. The 2D $(\Delta\eta, \Delta\phi)$ two-particle correlation functions in pp collisions at $\sqrt{s} = 13$ TeV for pairs of charged particles both in the range $1 < p_T < 3$ GeV/c. Results are shown for (a) low-multiplicity events ($N_{trk}^{off\text{-}line} < 35$) and for (b) a high-multiplicity sample ($N_{trk}^{off\text{-}line} \geq 105$). The sharp peaks from jet correlations around $(\Delta\eta, \Delta\phi) = (0, 0)$ are truncated to better illustrate the long-range correlations.

charged particles both in the range $1 < p_T < 3$ GeV/c are used in this analysis. For the low-multiplicity sample ($N_{trk}^{off\text{-}line} < 35$), the dominant features are the peak near $(\Delta\eta, \Delta\phi) = (0, 0)$ (truncated for better illustration of the long-range structures) for pairs of particles originating from the same jet. The elongated structure at $\Delta\phi \approx \pi$ corresponds to pairs of particles from back-to-back jets. In high-multiplicity pp events ($N_{trk}^{off\text{-}line} \geq 105$), in addition to these jetlike correlation structures, a "ridge"-like structure is clearly visible at $\Delta\phi \approx 0$, extending over a range of at least 4 units in $|\Delta\eta|$. No such long-range correlations are predicted by PYTHIA.

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 Refs. [10,11,14]. The correlated portion of the associated yield is estimated by using an implementation of the zero-yield-at-minimum (ZYAM) procedure [38]. The 1D $\Delta\phi$ correlation function is fitted with a truncated Fourier series up to the fifth term. The minimum value of the fit function, C_{ZYAM}, is then subtracted from the 1D $\Delta\phi$ correlation function as a constant background (containing no information about correlations) so that the minimum of the correlation function is zero. The location of the minimum of the function in this region is denoted as $\Delta\phi_{ZYAM}$. The ZYAM procedure is a straightforward way to quantify the magnitude of long-range near-side yield. However, it does not take into account potential biases introduced by away-side jet correlations leading to a nonflat distribution on the near side. Therefore, when performing data-theory comparisons, other sources of correlations, such as jets, should be included in the model calculation.

Figure 2 shows the resulting $\Delta\phi$ correlation functions for various selections in p_T and multiplicity $N_{trk}^{off\text{-}line}$. The results for pp data at $\sqrt{s} = 7$ TeV are also shown for comparison. The selected $N_{trk}^{off\text{-}line}$ ranges in the 7 and 13 TeV data do not match precisely because of slight

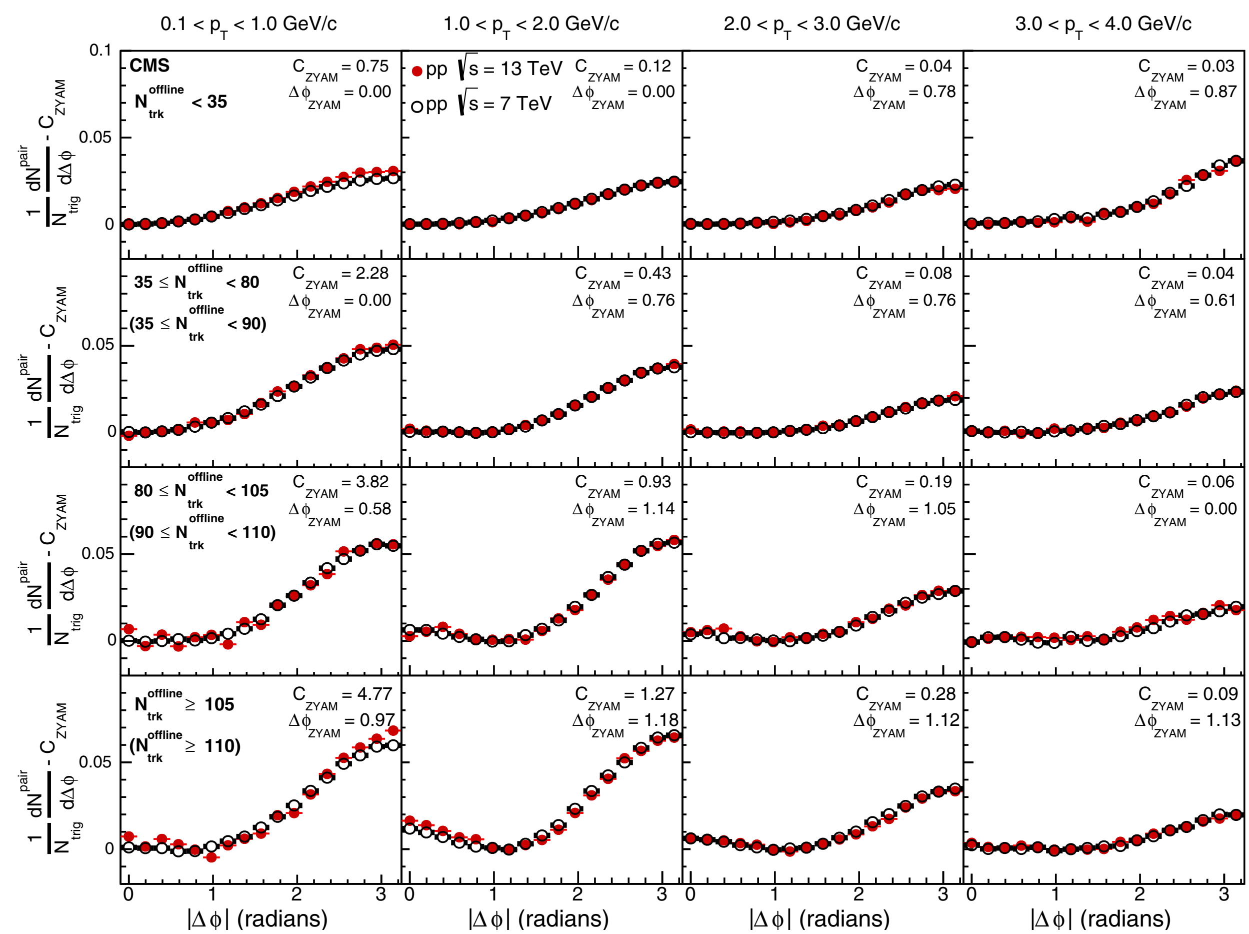

FIG. 2. Correlated yield obtained with the ZYAM procedure as a function of $|\Delta\phi|$, averaged over $2 < |\Delta\eta| < 4$ in different p_T and multiplicity bins for pp data at $\sqrt{s} = 13$ TeV (filled circles) and 7 TeV (open circles). The p_T selection applies to both particles in the pair. Numbers in brackets indicate the multiplicity range of the 7 TeV data when different from that at 13 TeV. The statistical uncertainties are smaller than the marker size. The subtracted ZYAM constant is given in each panel (C_{ZYAM}).

differences in the multiplicity domains for which the high-multiplicity triggers used in 2010 and 2015 are fully efficient. Note that the previously published pp data at $\sqrt{s} = 7$ TeV in Ref. [10] are obtained by means of a slightly different definition of the two-particle correlation functions and the 7 TeV data shown in Fig. 2 have therefore been reanalyzed. The difference has no impact on the associated yields for high-multiplicity events, and is only noticeable at very low multiplicity and high p_{T}, where most of the particle pairs are localized around $(\Delta\eta, \Delta\phi) \sim (0, 0)$ due to jetlike correlations.

Nearly no center-of-mass energy dependence is observed for the correlations in any p_{T} or multiplicity range, as shown in Fig. 2. A clear evolution of the $\Delta\phi$ correlation function with both p_{T} and $N_{\mathrm{trk}}^{\text{off-line}}$ is observed at both collision energies. For the lowest multiplicity sample, the correlation functions have a minimum at $\Delta\phi = 0$ and a maximum at $\Delta\phi = \pi$, reflecting the correlations from momentum conservation and the increasing contribution from back-to-back jetlike correlations at higher p_{T}. For high-multiplicity pp events ($N_{\mathrm{trk}}^{\text{off-line}} \geq 80$), a second local maximum near $|\Delta\phi| \approx 0$ becomes visible, reflecting near-side, long-range correlations that appear as a ridgelike structure. This near-side correlation signal is strongest in the $1 < p_{\mathrm{T}} < 2\,\mathrm{GeV}/c$ range and increases with multiplicity.

Based on the studies in Ref. [29], the total systematic uncertainty of the tracking efficiency is 3.9%, which translates into a 3.9% systematic uncertainty of the associated yields. The systematic uncertainties related to the track quality requirements are studied by varying the track selections on d_z/σ_{d_z} and $d_{\mathrm{T}}/\sigma_{d_{\mathrm{T}}}$ between 2 and 5. These changes produce effects on the associated yields smaller than 0.0006 in absolute value. In order to evaluate the uncertainty of the trigger efficiency, results from high-multiplicity data collected with two different triggers are compared. The results agree to better than 0.0015; this is taken as an estimate of the trigger efficiency contribution to the systematic uncertainty. The possible contamination of residual pile-up events is investigated by comparing the nominal results to those obtained without any pile-up rejection or with the requirement of only one reconstructed vertex. The corresponding effect on the associated yield is less than 0.0006 in absolute value. The sensitivity of the results to the vertex position along the beam direction (z_{vtx}) is quantified by comparing results for $|z_{\mathrm{vtx}}| < 3$ cm and $3 < |z_{\mathrm{vtx}}| < 15$ cm, which yields a contribution to the systematic uncertainty of less than 0.0010. Finally, an alternative choice of a second-order polynomial fit function for estimating C_{ZYAM} in the region $0.1 < |\Delta\phi| < 2.0$ gives an absolute systematic uncertainty of 0.0007 in the total correlated yield from the ZYAM procedure. The event multiplicity classification is not varied in the systematic studies. All the systematic effects studied yield contributions that are independent of p_{T} and multiplicity; their values are summarized in Table II.

TABLE II. Summary of systematic uncertainties on the long-range, near-side associated yields in pp collisions at $\sqrt{s} = 13$ TeV.

Systematic uncertainty sources	Abs. uncertainty ($\times 10^{-3}$)
Track quality requirements	0.6
Trigger efficiency	1.5
Correction for tracking efficiency	<0.08
Effect of pile-up events	0.6
Vertex selection	1.0
ZYAM procedure	0.7
Total	2.1

The strength of the long-range, near-side correlations can be further quantified by integrating the correlated yields from Fig. 2 over $|\Delta\phi| < \Delta\phi_{\mathrm{ZYAM}}$ for each p_{T} range and event multiplicity class. The resulting integrated near-side yield, divided by the width of the p_{T} interval, is plotted as a function of the particle p_{T} and the event multiplicity in Fig. 3 for the present data. Finer p_{T} and $N_{\mathrm{trk}}^{\text{off-line}}$ ranges than in Fig. 2 are used for better illustrating the trend of the data. The previous results from $\sqrt{s} = 7$ TeV in wider p_{T} and $N_{\mathrm{trk}}^{\text{off-line}}$ ranges are also shown for comparison. The 7 TeV data obtained from Ref. [11] are multiplied by two, as their range in $\Delta\phi$ is 0–$\Delta\phi_{\mathrm{ZYAM}}$, half of the full near-side structure range.

Figure 3(a) shows that the associated yield of long-range near-side correlations for events with $N_{\mathrm{trk}}^{\text{off-line}} \geq 105$ ($N_{\mathrm{trk}}^{\text{off-line}} \geq 110$ for the 7 TeV data) peaks in the region $1 < p_{\mathrm{T}} < 2$ 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}. No center-of-mass energy dependence is visible. The multiplicity dependence of the associated yield for $1 < p_{\mathrm{T}} < 2$ GeV$/c$ particle pairs is shown in Fig. 3(b). For low-multiplicity events, the associated yield determined with the ZYAM procedure is consistent with zero. This indicates that ridgelike correlations are absent or smaller than the negative correlations expected because of, for example, momentum conservation. At higher multiplicity the ridgelike correlation emerges, with an approximately linear rise of the associated yield with multiplicity for $N_{\mathrm{trk}}^{\text{off-line}} \gtrsim 40$.

In the framework of gluon saturation models, a long-range correlation structure is predicted to arise from initial collimated gluon emissions [40–42]. The energy dependence of associated yields observed in the data is qualitatively in agreement with this model at $\sqrt{s} = 13$ TeV [39], as shown in Fig. 3(b). However, although the model calculation quantitatively describes the associated yields over the multiplicity range covered by the previous 7 TeV data, significant deviations are observed at the higher multiplicities probed by the present 13 TeV data. The associated yields predicted by this model exhibit a much faster increase with $N_{\mathrm{trk}}^{\text{off-line}}$ than that seen in the data,

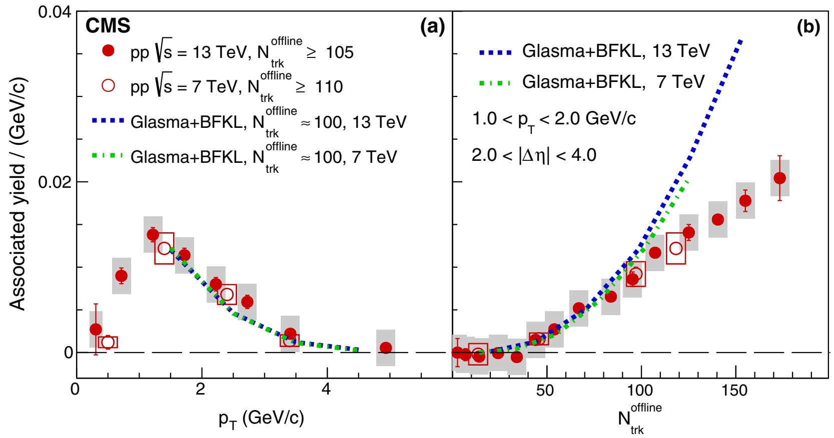

FIG. 3. Associated yield for the near side of the correlation function averaged over $2 < |\Delta\eta| < 4$ and integrated over the region $|\Delta\phi| < \Delta\phi_{\mathrm{ZYAM}}$ for pp data at $\sqrt{s} = 13$ TeV (filled circles) and 7 TeV (open circles). Panel (a) shows the associated yield as a function of p_{T} for events with $N_{\mathrm{trk}}^{\text{off-line}} \geq 105$. The p_{T} value for each p_{T} bin is the average p_{T} value. In panel (b) the associated yield for $1 < p_{\mathrm{T}} < 2$ GeV/c is shown as a function of the multiplicity, $N_{\mathrm{trk}}^{\text{off-line}}$. The $N_{\mathrm{trk}}^{\text{off-line}}$ value at which the yield is plotted is the average $N_{\mathrm{trk}}^{\text{off-line}}$ value in the bin. The p_{T} selection applies to both particles in each pair. The error bars correspond to the statistical uncertainties, while the shaded areas and boxes denote the systematic uncertainties. Curves represent the predictions of the gluon saturation model [39].

suggesting that other mechanisms may be active in this region. Hydrodynamic models also predict no energy dependence: they reproduce the collective flow effect in heavy-ion collisions, which is nearly unchanged from the RHIC to the LHC center-of-mass energies, although they differ by more than an order of magnitude [43–45]. However, it remains to be seen whether hydrodynamic models can quantitatively describe the behavior of the observables presented here.

Long-range near-side yields have also been measured for pPb and PbPb collisions by CMS [14]. Figure 4 compares the associated yields in pp, pPb, and PbPb collisions for $1 < p_{\mathrm{T}} < 2$ GeV/c as a function of the track multiplicity. The various data sets were collected at different center-of-mass energies, but this should have negligible effect on the results, as discussed above. In all three systems, the ridgelike 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. Clearly, there is a strong collision system size dependence of the long-range near-side correlations.

In summary, two-particle angular correlations in pp collisions at $\sqrt{s} = 13$ TeV have been measured by the CMS experiment at the LHC. The data correspond to an integrated luminosity of about 270 nb^{-1}. As first observed in pp collisions at $\sqrt{s} = 7$ TeV, two-particle azimuthal correlations in high-multiplicity pp collisions exhibit a long-range structure in the near side ($\Delta\phi \approx 0$) extending over at least 4 units in pseudorapidity separation. The effect is most evident in the intermediate transverse momentum region between 1 and 2 GeV/c. The near-side long-range yield obtained with the ZYAM procedure is found to be consistent with zero in the low-multiplicity region, with an approximately linear increase with multiplicity for $N_{\mathrm{trk}}^{\text{off-line}} \gtrsim 40$. The new 13 TeV data presented in this Letter significantly extends the multiplicity coverage achieved by previously data at $\sqrt{s} = 7$ TeV. Finally, a

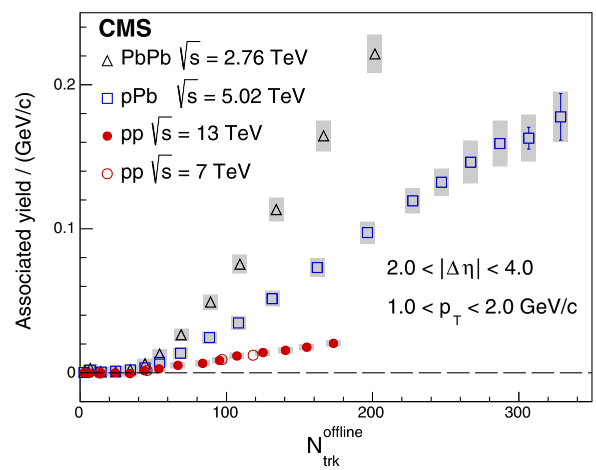

FIG. 4. Associated yield of long-range near-side two-particle correlations for $1 < p_{\mathrm{T}} < 2$ GeV/c in pp collisions at $\sqrt{s} = 13$ and 7 TeV, pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, and PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV. Associated yield for the near side of the correlation function is averaged over $2 < |\Delta\eta| < 4$ and integrated over the region $|\Delta\phi| < \Delta\phi_{\mathrm{ZYAM}}$. The $N_{\mathrm{trk}}^{\text{off-line}}$ value for each $N_{\mathrm{trk}}^{\text{off-line}}$ bin is the average $N_{\mathrm{trk}}^{\text{off-line}}$ value. The error bars correspond to the statistical uncertainties, while the shaded areas denote the systematic uncertainties. Note that there are PbPb points above the upper vertical scale, which are not shown for clarity.

strong collision system size dependence is observed when comparing data from pp, pPb, and PbPb collisions. Comparing the pp data at $\sqrt{s} = 7$ TeV and 13 TeV, no collision energy dependence of the near-side associated yields is observed.

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