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Measurement of long-range near-side two-particle angular correlations in pp collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration*

Abstract

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 $1.0 < p_T < 2.0 \text{ GeV}/c$ and an approximately linear increase with the charged particle multiplicity. The overall correlation strength at $\sqrt{s} = 13$ TeV is similar to that found in earlier pp data at $\sqrt{s} = 7$ TeV, but is measured up to much higher multiplicity values. 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 ($2.0 < |\Delta\eta| < 4.0$) 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, $p_T \approx 1\text{--}5\text{ GeV}/c$ [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 $\sqrt{s} = 7\text{ TeV}$ 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 $\sqrt{s} = 13\text{ TeV}$, 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 $\sqrt{s} = 13\text{ TeV}$ has been reported by the ATLAS collaboration [28]. In this Letter, studies of long-range correlations in pp collisions at $\sqrt{s} = 13\text{ TeV}$ 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), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections. Extensive forward calorimetry (HF) 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 non-isolated particles of $1 < p_T < 10\text{ GeV}/c$ 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 so as to reach a low average number of 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 ($N_{\text{trk}}^{\text{online}}$) with $|\eta| < 2.4$, $p_T > 0.4 \text{ GeV}/c$, 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 $N_{\text{trk}}^{\text{online}} > 60$ 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 offline analysis, hadronic collisions are selected by requiring at least one tower in each of the two HF calorimeters ($3 < |\eta| < 5$) 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_{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 to 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 [35]: CUETP8M1) 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 $E > 3 \text{ GeV}$ in each of the η regions $-5 < \eta < -3$ and $3 < \eta < 5$.

The present analysis is based on a sample of 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 $p_T > 0.1 \text{ GeV}/c$ are used in the analysis (a p_T cutoff of $0.4 \text{ GeV}/c$ 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 $p_T > 0.4 \text{ GeV}/c$ and $|\eta| < 2.4$ and better than 90% in the $|\eta| < 1$ region for $p_T > 0.6 \text{ GeV}/c$. For the track multiplicity range studied in this paper, 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, $N_{\text{trk}}^{\text{offline}}$, which is evaluated by counting primary tracks with $|\eta| < 2.4$ and $p_T > 0.4 \text{ GeV}/c$. Details of the multiplicity classification in this analysis are provided in Table 1, which also gives 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 triggered sample is used for the range $N_{\text{trk}}^{\text{offline}} < 80$, while various high-multiplicity triggered samples are used for $N_{\text{trk}}^{\text{offline}}$ ranges above 80.

Table 1: 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 $p_T > 0.4 \text{ GeV}/c$. Systematic uncertainties are given for the corrected multiplicities.

Multiplicity class ($N_{\text{trk}}^{\text{offline}}$)	Fraction	$\langle N_{\text{trk}}^{\text{offline}} \rangle$	$\langle N_{\text{trk}}^{\text{corrected}} \rangle$
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

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

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

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,

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

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,

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

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. The definition of the two-particle correlation function in this Letter is the same as that used for pPb and PbPb data [14], and is somewhat different from that used in Ref. [10] for pp collisions at $\sqrt{s} = 7$ TeV. This explains the discrepancy in correlation data between the two collision energies in the low-multiplicity and high- p_T region, as discussed later.

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 1).

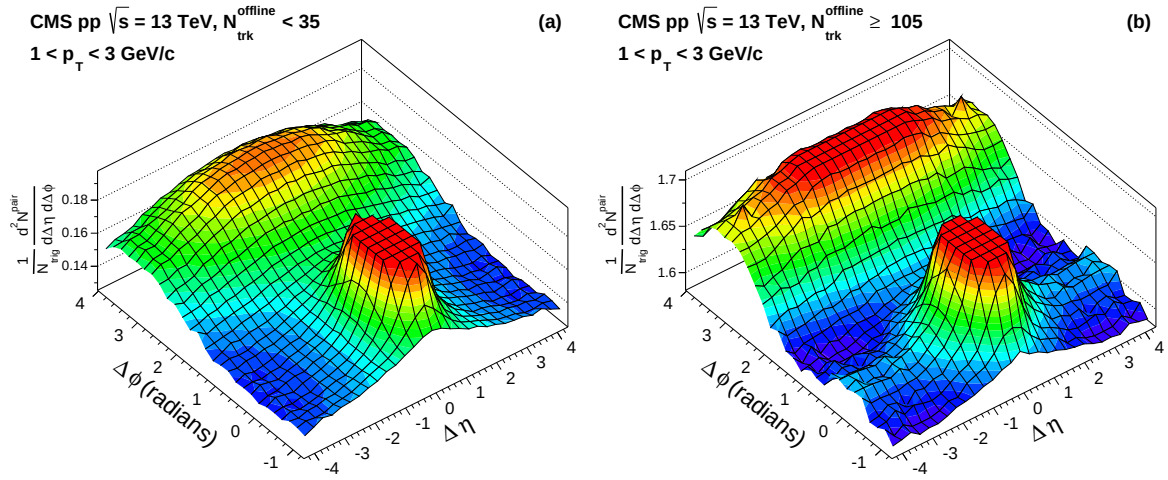


Figure 1: The 2D $(\Delta\eta, \Delta\phi)$ two-particle correlation functions in pp collisions at $\sqrt{s} = 13$ TeV for pairs of charged particles both in the range $1 < p_T < 3$ GeV/c. Results are shown for (a) low-multiplicity events ($N_{\text{trk}}^{\text{offline}} < 35$) and for (b) a high-multiplicity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

The two-dimensional (2D) $\Delta\eta$ – $\Delta\phi$ two-particle correlation functions for events with low and high multiplicities are shown in Fig. 1, for pairs of charged particles both in the range $1 < p_T < 3$ GeV/c. For the low-multiplicity sample ($N_{\text{trk}}^{\text{offline}} < 35$), 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 ($N_{\text{trk}}^{\text{offline}} \geq 105$), in addition to these jet-like correlation structures, a “ridge”-like structure emerges 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, 36, 37]. 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

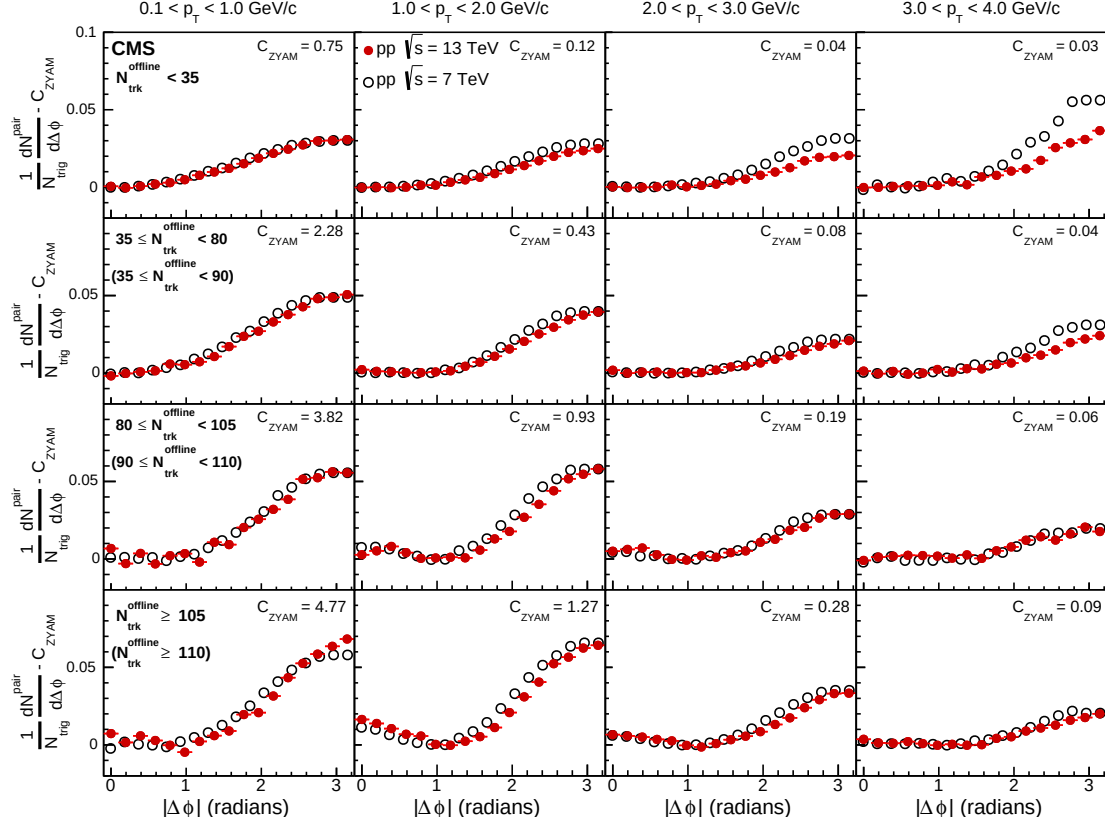


Figure 2: Correlated yield obtained with the ZYAM procedure as a function of $|\Delta\phi|$, averaged over $2 < |\Delta\eta| < 4$ in different p_T and multiplicity bins for pp data at $\sqrt{s} = 13$ TeV (filled circles) and 7 TeV (open circles). The p_T selection applies to both particles in the pair. 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}).

denoted as $\Delta\phi_{ZYAM}$.

Figure 2 shows the resulting $\Delta\phi$ correlation functions for various selections in p_T and multiplicity $N_{trk}^{offline}$. The results for pp data at $\sqrt{s} = 7$ TeV [10], obtained by means of a similar procedure, are also plotted. The selected $N_{trk}^{offline}$ ranges in the 7 and 13 TeV data do not match precisely because of slight differences in the multiplicity domains for which the high-multiplicity triggers used in 2010 and 2015 are fully efficient. A difference between the 7 and 13 TeV away-side yields is observed at low multiplicity and high- p_T , which reflects the different definitions of the two-particle correlation functions in this Letter and in Ref. [10]. This difference is only noticeable when the signal pair distribution is dominated by jet correlations (low multiplicity and high- p_T), where most of the particle pairs are localized around $(\Delta\eta, \Delta\phi) \sim (0, 0)$. Indeed, in this case, the normalization procedure applied in the 7 TeV analysis enhances the away-side jet yield. If the procedure used for the 13 TeV data is applied to the 7 TeV data, no significant center-of-mass energy dependence is observed for the correlations in any p_T or multiplicity ranges.

A clear evolution of the $\Delta\phi$ correlation function as a function of both p_T and $N_{trk}^{offline}$ 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 jet-like correlations at higher

p_T . For high-multiplicity pp events ($N_{\text{trk}}^{\text{offline}} \geq 80$), a second local maximum near $|\Delta\phi| \approx 0$ becomes visible, reflecting near-side, long-range correlations that appear as a ridge-like structure. This near-side correlation signal is strongest in the $1 < p_T < 2 \text{ GeV}/c$ 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_T/σ_{d_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 $|z_{\text{vtx}}| < 3 \text{ cm}$ and $3 < |z_{\text{vtx}}| < 15 \text{ cm}$, 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 during all systematic studies. All the systematic effects studied yield contributions that are independent of p_T and multiplicity; their values are summarized in Table 2.

Table 2: Summary of systematic uncertainties on the long-range, near-side associated yields in pp collisions at $\sqrt{s} = 13 \text{ TeV}$.

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 yield from Fig. 2 over $|\Delta\phi| < \Delta\phi_{\text{ZYAM}}$ 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 particle p_T and event multiplicity in Fig. 3 for the present data. Finer p_T and $N_{\text{trk}}^{\text{offline}}$ ranges than in Fig. 2 are used for better illustrating the detailed trend of the data. The previous results from $\sqrt{s} = 7 \text{ TeV}$ in wider p_T and $N_{\text{trk}}^{\text{offline}}$ ranges are also shown for comparison. The original 7 TeV data from Ref. [10] are multiplied by two, as their range in $\Delta\phi$ is $0 - \Delta\phi_{\text{ZYAM}}$, 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 $N_{\text{trk}}^{\text{offline}} \geq 105$ ($N_{\text{trk}}^{\text{offline}} \geq 110$ for the 7 TeV data) peaks in the region $1 < p_T < 2 \text{ GeV}/c$ for both center-of-mass energies. The yield reaches a maximum around $p_T \approx 1 \text{ GeV}/c$ and decreases with increasing p_T . No center-of-mass energy dependence is visible. The multiplicity dependence of the associated yield for $1 < p_T < 2 \text{ GeV}/c$ particle pairs is shown in Fig. 3 (b). For low-multiplicity events, the associated yield determined with the ZYAM procedure is consis-

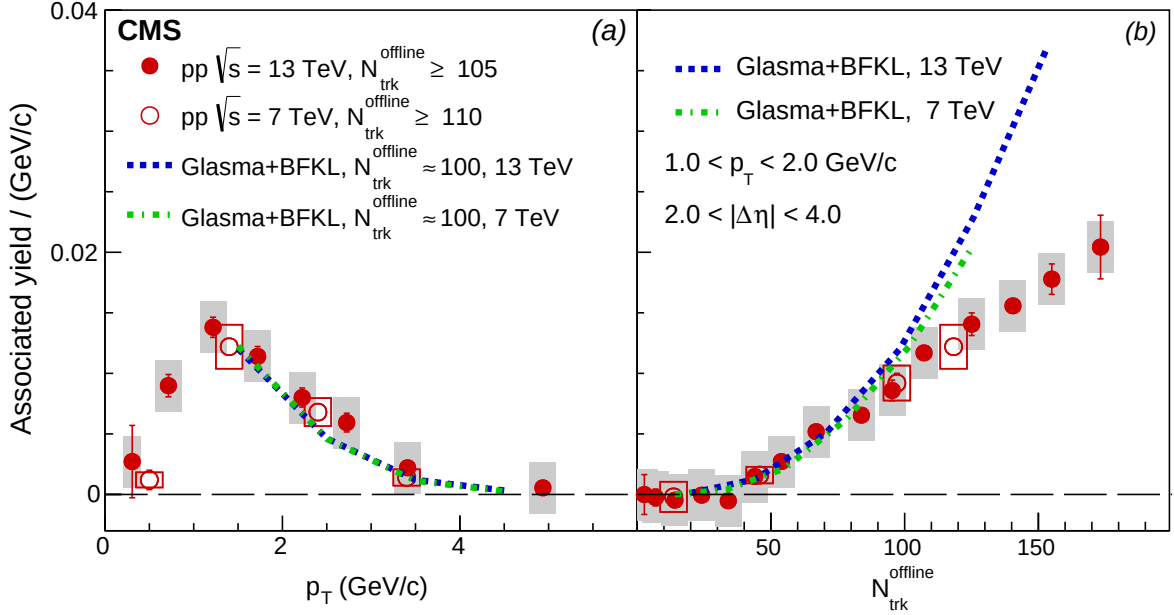


Figure 3: Associated yield for the near side of the correlation function averaged over $2 < |\Delta\eta| < 4$ and integrated over the region $|\Delta\phi| < \Delta\phi_{\text{ZYAM}}$ for pp data at $\sqrt{s} = 13$ TeV (filled circles) and 7 TeV (open circles). Panel (a) shows the associated yield as a function of p_T for events with $N_{\text{trk}}^{\text{offline}} \geq 105$. The p_T value for each p_T bin is the average p_T value. In panel (b) the associated yield for $1 < p_T < 2$ GeV/c is shown as a function of multiplicity $N_{\text{trk}}^{\text{offline}}$. The $N_{\text{trk}}^{\text{offline}}$ value for each $N_{\text{trk}}^{\text{offline}}$ bin is the average $N_{\text{trk}}^{\text{offline}}$ value. 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 calculations from the gluon saturation model [39].

tent 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 the ridge-like correlation emerges, with an approximately linear rise of the associated yield with multiplicity for $N_{\text{trk}}^{\text{offline}} \gtrsim 40$.

In the framework of gluon saturation models, a long-range correlation structure is predicted to arise from initial collimated gluon emissions [39–41]. The associated yields as well as their energy dependence are qualitatively in agreement with this model, as shown in Fig. 3 (b), although the increase of yields as a function of multiplicity is predicted to be faster than that observed in the data for the very high-multiplicity region. A similar conclusion on the energy dependence may be drawn in hydrodynamic models, since the collective flow effect in heavy-ion collisions is nearly unchanged from the RHIC to the LHC center-of-mass energies, which differ by more than an order of magnitude [42–44]. However, it remains to be seen whether hydrodynamic models can quantitatively describe the exact 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 $1 < p_T < 2$ 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 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

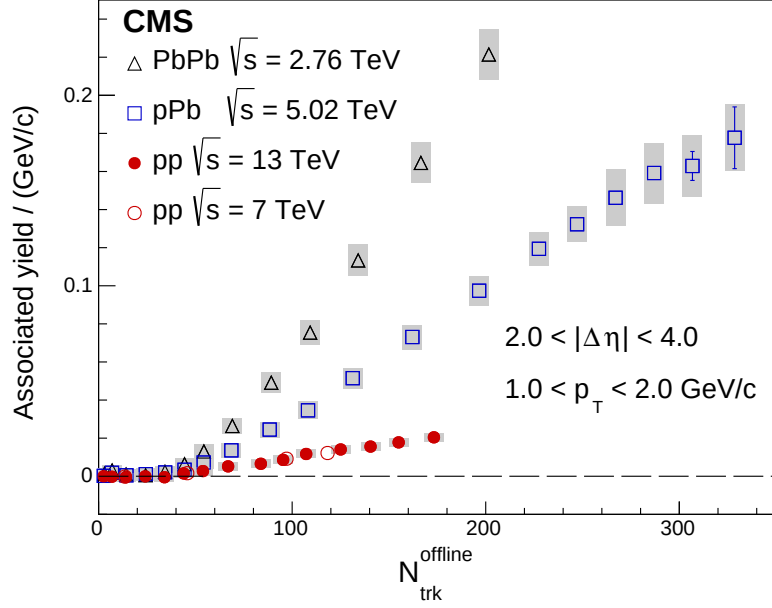


Figure 4: Associated yield of long-range near-side two-particle correlations for $1 < p_T < 2 \text{ GeV}/c$ in pp collisions at $\sqrt{s} = 13$ and 7 TeV , pPb collisions at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$, and PbPb collisions at $\sqrt{s_{NN}} = 2.76 \text{ TeV}$. Associated yield for the near-side of the correlation function is averaged over $2 < |\Delta\eta| < 4$ and integrated over the region $|\Delta\phi| < \Delta\phi_{\text{ZYAM}}$. The $N_{\text{trk}}^{\text{offline}}$ value for each $N_{\text{trk}}^{\text{offline}}$ bin is the average $N_{\text{trk}}^{\text{offline}}$ 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.

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 $\sqrt{s} = 13 \text{ TeV}$ have been measured by the CMS experiment at the LHC. The amount of data recorded corresponds to an integrated luminosity of about 270 nb^{-1} . As it was first observed in pp collisions at $\sqrt{s} = 7 \text{ TeV}$, 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 $2 \text{ GeV}/c$. 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 $N_{\text{trk}}^{\text{offline}} \gtrsim 40$. A strong collision system size dependence is observed when comparing data from pp, pPb, and PbPb collisions. Comparing the pp data at $\sqrt{s} = 7 \text{ TeV}$ and 13 TeV , no collision energy dependence of the near-side associated yields is observed over the overlapping event multiplicity and p_T ranges.

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A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia

V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth¹, V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler¹, V. Knünz, A. König, M. Krammer¹, I. Krätschmer, D. Liko, T. Matsushita, I. Mikulec, D. Rabady², B. Rahbaran, H. Rohringer, J. Schieck¹, R. Schöfbeck, J. Strauss, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz¹

National Centre for Particle and High Energy Physics, Minsk, Belarus

V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium

S. Alderweireldt, T. Cornelis, E.A. De Wolf, X. Janssen, A. Knutsson, J. Lauwers, S. Luyckx, M. Van De Klundert, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium

S. Abu Zeid, F. Blekman, J. D'Hondt, N. Daci, I. De Bruyn, K. Deroover, N. Heracleous, J. Keaveney, S. Lowette, L. Moreels, A. Olbrechts, Q. Python, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Van Parijs

Université Libre de Bruxelles, Bruxelles, Belgium

P. Barria, H. Brun, C. Caillol, B. Clerbaux, G. De Lentdecker, G. Fasanella, L. Favart, A. Grebenyuk, G. Karapostoli, T. Lenzi, A. Léonard, T. Maerschalk, A. Marinov, L. Perniè, A. Randle-conde, T. Seva, C. Vander Velde, P. Vanlaer, R. Yonamine, F. Zenoni, F. Zhang³

Ghent University, Ghent, Belgium

K. Beernaert, L. Benucci, A. Cimmino, S. Crucy, D. Dobur, A. Fagot, G. Garcia, M. Gul, J. Mccartin, A.A. Ocampo Rios, D. Poyraz, D. Ryckbosch, S. Salva, M. Sigamani, M. Tytgat, W. Van Driessche, E. Yazgan, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium

S. Basegmez, C. Beluffi⁴, O. Bondu, S. Brochet, G. Bruno, A. Caudron, L. Ceard, G.G. Da Silveira, C. Delaere, D. Favart, L. Forthomme, A. Giammanco⁵, J. Hollar, A. Jafari, P. Jez, M. Komm, V. Lemaître, A. Mertens, M. Musich, C. Nuttens, L. Perrini, A. Pin, K. Piotrkowski, A. Popov⁶, L. Quertenmont, M. Selvaggi, M. Vidal Marono

Université de Mons, Mons, Belgium

N. Beliy, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

W.L. Aldá Júnior, F.L. Alves, G.A. Alves, L. Brito, M. Correa Martins Junior, M. Hamer, C. Hensel, A. Moraes, M.E. Pol, P. Rebello Teles

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato⁷, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, L.M. Huertas Guativa, H. Malbouisson, D. Matos Figueiredo, C. Mora Herrera, L. Mundim, H. Nogima, W.L. Prado Da Silva, A. Santoro, A. Sznajder, E.J. Tonelli Manganote⁷, A. Vilela Pereira

Universidade Estadual Paulista ^a, Universidade Federal do ABC ^b, São Paulo, Brazil

S. Ahuja^a, C.A. Bernardes^b, A. De Souza Santos^b, S. Dogra^a, T.R. Fernandez Perez Tomei^a,

E.M. Gregores^b, P.G. Mercadante^b, C.S. Moon^{a,8}, S.F. Novaes^a, Sandra S. Padula^a, D. Romero Abad, J.C. Ruiz Vargas

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

A. Aleksandrov, R. Hadjiiska, P. Iaydjiev, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

University of Sofia, Sofia, Bulgaria

A. Dimitrov, I. Glushkov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China

M. Ahmad, J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, T. Cheng, R. Du, C.H. Jiang, R. Plestina⁹, F. Romeo, S.M. Shaheen, A. Spiezia, J. Tao, C. Wang, Z. Wang, H. Zhang

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

C. Asawatangtrakuldee, Y. Ban, Q. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, Z. Xu

Universidad de Los Andes, Bogota, Colombia

C. Avila, A. Cabrera, L.F. Chaparro Sierra, C. Florez, J.P. Gomez, B. Gomez Moreno, J.C. Sanabria

University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia

N. Godinovic, D. Lelas, I. Puljak, P.M. Ribeiro Cipriano

University of Split, Faculty of Science, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

V. Brigljevic, K. Kadija, J. Luetic, S. Micanovic, L. Sudic

University of Cyprus, Nicosia, Cyprus

A. Attikis, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis, H. Rykaczewski

Charles University, Prague, Czech Republic

M. Bodlak, M. Finger¹⁰, M. Finger Jr.¹⁰

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt

E. El-khateeb^{11,11}, T. Elkafrawy¹¹, A. Mohamed¹², E. Salama^{13,11}

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

B. Calpas, M. Kadastik, M. Murumaa, M. Raidal, A. Tiko, C. Veelken

Department of Physics, University of Helsinki, Helsinki, Finland

P. Eerola, J. Pekkanen, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

J. Härkönen, V. Karimäki, R. Kinnunen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, L. Wendland

Lappeenranta University of Technology, Lappeenranta, Finland

J. Talvitie, T. Tuuva

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France

M. Besancon, F. Couderc, M. DeJardin, D. Denegri, B. Fabbro, J.L. Faure, C. Favaro, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, M. Machet, J. Malcles, J. Rander, A. Rosowsky, M. Titov, A. Zghiche

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France

I. Antropov, S. Baffioni, F. Beaudette, P. Busson, L. Cadamuro, E. Chapon, C. Charlot, O. Davignon, N. Filipovic, R. Granier de Cassagnac, M. Jo, S. Lisniak, L. Mastrolorenzo, P. Miné, I.N. Naranjo, M. Nguyen, C. Ochando, G. Ortona, P. Paganini, P. Pigard, S. Regnard, R. Salerno, J.B. Sauvan, Y. Sirois, T. Strebler, Y. Yilmaz, A. Zabi

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

J.-L. Agram¹⁴, J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, M. Buttignol, E.C. Chabert, N. Chanon, C. Collard, E. Conte¹⁴, X. Coubez, J.-C. Fontaine¹⁴, D. Gelé, U. Goerlach, C. Goetzmann, A.-C. Le Bihan, J.A. Merlin², K. Skovpen, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France

S. Gadrat

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France

S. Beauceron, C. Bernet, G. Boudoul, E. Bouvier, C.A. Carrillo Montoya, R. Chierici, D. Contardo, B. Courbon, P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, F. Lagarde, I.B. Laktineh, M. Lethuillier, L. Mirabito, A.L. Pequegnot, S. Perries, J.D. Ruiz Alvarez, D. Sabes, L. Sgandurra, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret

Georgian Technical University, Tbilisi, Georgia

T. Toriashvili¹⁵

Tbilisi State University, Tbilisi, Georgia

Z. Tsamalaidze¹⁰

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany

C. Autermann, S. Beranek, L. Feld, A. Heister, M.K. Kiesel, K. Klein, M. Lipinski, A. Ostapchuk, M. Preuten, F. Raupach, S. Schael, J.F. Schulte, T. Verlage, H. Weber, V. Zhukov⁶

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany

M. Ata, M. Brodski, E. Dietz-Laursonn, D. Duchardt, M. Endres, M. Erdmann, S. Erdweg, T. Esch, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, P. Millet, S. Mukherjee, M. Olschewski, K. Padeken, P. Papacz, T. Pook, M. Radziej, H. Reithler, M. Rieger, F. Scheuch, L. Sonnenschein, D. Teyssier, S. Thüer

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Künsken, J. Lingemann, A. Nehr Korn, A. Nowack, I.M. Nugent, C. Pistone, O. Pooth, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, I. Asin, N. Bartosik, O. Behnke, U. Behrens, A.J. Bell, K. Borras¹⁶, A. Burgmeier, A. Campbell, F. Costanza, C. Diez Pardos, G. Dolinska, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, E. Gallo¹⁷, J. Garay Garcia, A. Geiser, A. Gizhko, P. Gunnellini, J. Hauk, M. Hempel¹⁸, H. Jung, A. Kalogeropoulos, O. Karacheban¹⁸, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, I. Korol, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann¹⁸, R. Mankel, I. Marfin¹⁸, I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, S. Naumann-Emme, A. Nayak, E. Ntomari, H. Perrey, D. Pitzl, R. Placakyte, A. Raspereza, B. Roland, M.Ö. Sahin, P. Saxena, T. Schoerner-Sadenius, C. Seitz, S. Spannagel, K.D. Trippkewitz, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

V. Blobel, M. Centis Vignali, A.R. Draeger, J. Erfle, E. Garutti, K. Goebel, D. Gonzalez, M. Görner, J. Haller, M. Hoffmann, R.S. Höing, A. Junkes, R. Klanner, R. Kogler, N. Kovalchuk, T. Lapsien, T. Lenz, I. Marchesini, D. Marconi, M. Meyer, D. Nowatschin, J. Ott, F. Pantaleo², T. Peiffer, A. Perieanu, N. Pietsch, J. Poehlsen, D. Rathjens, C. Sander, C. Scharf, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, J. Schwandt, V. Sola, H. Stadie, G. Steinbrück, H. Tholen, D. Troendle, E. Usai, L. Vanelderen, A. Vanhoefer, B. Vormwald

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, S. Baur, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, F. Colombo, W. De Boer, A. Descroix, A. Dierlamm, S. Fink, F. Frensch, R. Friese, M. Giffels, A. Gilbert, D. Haitz, F. Hartmann², S.M. Heindl, U. Husemann, I. Katkov⁶, A. Kornmayer², P. Lobelle Pardo, B. Maier, H. Mildner, M.U. Mozer, T. Müller, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, S. Röcker, F. Roscher, M. Schröder, G. Sieber, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, M. Weber, T. Weiler, S. Williamson, C. Wöhrmann, R. Wolf

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece

G. Anagnostou, G. Daskalakis, T. Gerasis, V.A. Giakoumopoulou, A. Kyriakis, D. Loukas, A. Psallidas, I. Topsis-Giotis

University of Athens, Athens, Greece

A. Agapitos, S. Kesisoglou, A. Panagiotou, N. Saoulidou, E. Tziaferi

University of Ioánnina, Ioánnina, Greece

I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Loukas, N. Manthos, I. Papadopoulos, E. Paradas, J. Strologas

Wigner Research Centre for Physics, Budapest, Hungary

G. Bencze, C. Hajdu, A. Hazi, P. Hidas, D. Horvath¹⁹, F. Sikler, V. Veszpremi, G. Vesztergombi²⁰, A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, S. Czellar, J. Karancsi²¹, J. Molnar, Z. Szillasi²

University of Debrecen, Debrecen, Hungary

M. Bartók²², A. Makovec, P. Raics, Z.L. Trocsanyi, B. Ujvari

National Institute of Science Education and Research, Bhubaneswar, India

S. Choudhury²³, P. Mal, K. Mandal, D.K. Sahoo, N. Sahoo, S.K. Swain

Panjab University, Chandigarh, India

S. Bansal, S.B. Beri, V. Bhatnagar, R. Chawla, R. Gupta, U. Bhawandeep, A.K. Kalsi, A. Kaur, M. Kaur, R. Kumar, A. Mehta, M. Mittal, J.B. Singh, G. Walia

University of Delhi, Delhi, India

Ashok Kumar, A. Bhardwaj, B.C. Choudhary, R.B. Garg, S. Malhotra, M. Naimuddin, N. Nishu, K. Ranjan, R. Sharma, V. Sharma

Saha Institute of Nuclear Physics, Kolkata, India

S. Bhattacharya, K. Chatterjee, S. Dey, S. Dutta, Sa. Jain, N. Majumdar, A. Modak, K. Mondal, S. Mukhopadhyay, A. Roy, D. Roy, S. Roy Chowdhury, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India

A. Abdulsalam, R. Chudasama, D. Dutta, V. Jha, V. Kumar, A.K. Mohanty², L.M. Pant, P. Shukla, A. Topkar

Tata Institute of Fundamental Research, Mumbai, India

T. Aziz, S. Banerjee, S. Bhowmik²⁴, R.M. Chatterjee, R.K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu²⁵, G. Kole, S. Kumar, B. Mahakud, M. Maity²⁴, G. Majumder, K. Mazumdar, S. Mitra, G.B. Mohanty, B. Parida, T. Sarkar²⁴, N. Sur, B. Sutar, N. Wickramage²⁶

Indian Institute of Science Education and Research (IISER), Pune, India

S. Chauhan, S. Dube, A. Kapoor, K. Kothekar, S. Sharma

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran

H. Bakhshiansohi, H. Behnamian, S.M. Etesami²⁷, A. Fahim²⁸, R. Goldouzian, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, F. Rezaei Hosseinabadi, B. Safarzadeh²⁹, M. Zeinali

University College Dublin, Dublin, Ireland

M. Felcini, M. Grunewald

INFN Sezione di Bari ^a, Università di Bari ^b, Politecnico di Bari ^c, Bari, Italy

M. Abbrescia^{a,b}, C. Calabria^{a,b}, C. Caputo^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, L. Cristella^{a,b}, N. De Filippis^{a,c}, M. De Palma^{a,b}, L. Fiore^a, G. Iaselli^{a,c}, G. Maggi^{a,c}, M. Maggi^a, G. Miniello^{a,b}, S. My^{a,c}, S. Nuzzo^{a,b}, A. Pompili^{a,b}, G. Pugliese^{a,c}, R. Radogna^{a,b}, A. Ranieri^a, G. Selvaggi^{a,b}, L. Silvestris^{a,2}, R. Venditti^{a,b}

INFN Sezione di Bologna ^a, Università di Bologna ^b, Bologna, Italy

G. Abbiendi^a, C. Battilana², A.C. Benvenuti^a, D. Bonacorsi^{a,b}, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^{a,b}, R. Campanini^{a,b}, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, S.S. Chhibra^{a,b}, G. Codispoti^{a,b}, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, D. Fasanella^{a,b}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^a, A. Montanari^a, F.L. Navarria^{a,b}, A. Perrotta^a, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G.P. Siroli^{a,b}, N. Tosi^{a,b,2}, R. Travaglini^{a,b}

INFN Sezione di Catania ^a, Università di Catania ^b, Catania, Italy

G. Cappello^a, M. Chiorboli^{a,b}, S. Costa^{a,b}, A. Di Mattia^a, F. Giordano^{a,b}, R. Potenza^{a,b}, A. Tricomi^{a,b}, C. Tuve^{a,b}

INFN Sezione di Firenze ^a, Università di Firenze ^b, Firenze, Italy

G. Barbagli^a, V. Ciulli^{a,b}, C. Civinini^a, R. D'Alessandro^{a,b}, E. Focardi^{a,b}, V. Gori^{a,b}, P. Lenzi^{a,b}, M. Meschini^a, S. Paoletti^a, G. Sguazzoni^a, L. Viliani^{a,b,2}

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, F. Fabbri, D. Piccolo, F. Primavera²

INFN Sezione di Genova ^a, Università di Genova ^b, Genova, Italy

V. Calvelli^{a,b}, F. Ferro^a, M. Lo Vetere^{a,b}, M.R. Monge^{a,b}, E. Robutti^a, S. Tosi^{a,b}

INFN Sezione di Milano-Bicocca ^a, Università di Milano-Bicocca ^b, Milano, Italy

L. Brianza, M.E. Dinardo^{a,b}, S. Fiorendi^{a,b}, S. Gennai^a, R. Gerosa^{a,b}, A. Ghezzi^{a,b}, P. Govoni^{a,b}, S. Malvezzi^a, R.A. Manzoni^{a,b,2}, B. Marzocchi^{a,b}, D. Menasce^a, L. Moroni^a, M. Paganoni^{a,b}, D. Pedrini^a, S. Ragazzi^{a,b}, N. Redaelli^a, T. Tabarelli de Fatis^{a,b}

INFN Sezione di Napoli ^a, Università di Napoli 'Federico II' ^b, Napoli, Italy, Università della Basilicata ^c, Potenza, Italy, Università G. Marconi ^d, Roma, Italy

S. Buontempo^a, N. Cavallo^{a,c}, S. Di Guida^{a,d,2}, M. Esposito^{a,b}, F. Fabozzi^{a,c}, A.O.M. Iorio^{a,b}, G. Lanza^a, L. Lista^a, S. Meola^{a,d,2}, M. Merola^a, P. Paolucci^{a,2}, C. Sciacca^{a,b}, F. Thyssen

INFN Sezione di Padova ^a, Università di Padova ^b, Padova, Italy, Università di Trento ^c, Trento, Italy

P. Azzi^{a,2}, N. Bacchetta^a, L. Benato^{a,b}, D. Bisello^{a,b}, A. Boletti^{a,b}, A. Branca^{a,b}, R. Carlin^{a,b}, P. Checchia^a, M. Dall'Osso^{a,b,2}, T. Dorigo^a, U. Dosselli^a, F. Gasparini^{a,b}, U. Gasparini^{a,b}, F. Gonella^a, A. Gozzelino^a, K. Kanishchev^{a,c}, S. Lacaprara^a, M. Margoni^{a,b}, A.T. Meneguzzo^{a,b}, J. Pazzini^{a,b,2}, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b}, M. Zanetti, P. Zotto^{a,b}, A. Zucchetta^{a,b,2}, G. Zumerle^{a,b}

INFN Sezione di Pavia ^a, Università di Pavia ^b, Pavia, Italy

A. Braghieri^a, A. Magnani^{a,b}, P. Montagna^{a,b}, S.P. Ratti^{a,b}, V. Re^a, C. Riccardi^{a,b}, P. Salvini^a, I. Vai^{a,b}, P. Vitulo^{a,b}

INFN Sezione di Perugia ^a, Università di Perugia ^b, Perugia, Italy

L. Alunni Solestizi^{a,b}, G.M. Bilei^a, D. Ciangottini^{a,b,2}, L. Fanò^{a,b}, P. Lariccia^{a,b}, G. Mantovani^{a,b}, M. Menichelli^a, A. Saha^a, A. Santocchia^{a,b}

INFN Sezione di Pisa ^a, Università di Pisa ^b, Scuola Normale Superiore di Pisa ^c, Pisa, Italy

K. Androsov^{a,30}, P. Azzurri^{a,2}, G. Bagliesi^a, J. Bernardini^a, T. Boccali^a, R. Castaldi^a, M.A. Ciocci^{a,30}, R. Dell'Orso^a, S. Donato^{a,c,2}, G. Fedi, L. Foà^{a,c†}, A. Giassi^a, M.T. Grippo^{a,30}, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,b}, A. Messineo^{a,b}, F. Palla^a, A. Rizzi^{a,b}, A. Savoy-Navarro^{a,31}, A.T. Serban^a, P. Spagnolo^a, R. Tenchini^a, G. Tonelli^{a,b}, A. Venturi^a, P.G. Verdini^a

INFN Sezione di Roma ^a, Università di Roma ^b, Roma, Italy

L. Barone^{a,b}, F. Cavallari^a, G. D'imperio^{a,b,2}, D. Del Re^{a,b,2}, M. Diemoz^a, S. Gelli^{a,b}, C. Jorda^a, E. Longo^{a,b}, F. Margaroli^{a,b}, P. Meridiani^a, G. Organtini^{a,b}, R. Paramatti^a, F. Preiato^{a,b}, S. Rahatlou^{a,b}, C. Rovelli^a, F. Santanastasio^{a,b}, P. Traczyk^{a,b,2}

INFN Sezione di Torino ^a, Università di Torino ^b, Torino, Italy, Università del Piemonte Orientale ^c, Novara, Italy

N. Amapane^{a,b}, R. Arcidiacono^{a,c,2}, S. Argiro^{a,b}, M. Arneodo^{a,c}, R. Bellan^{a,b}, C. Biino^a, N. Cartiglia^a, M. Costa^{a,b}, R. Covarelli^{a,b}, A. Degano^{a,b}, N. Demaria^a, L. Finco^{a,b,2}, B. Kiani^{a,b}, C. Mariotti^a, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, E. Monteil^{a,b}, M.M. Obertino^{a,b}, L. Pacher^{a,b}, N. Pastrone^a, M. Pelliccioni^a, G.L. Pinna Angioni^{a,b}, F. Ravera^{a,b}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Sacchi^{a,b}, A. Solano^{a,b}, A. Staiano^a

INFN Sezione di Trieste ^a, Università di Trieste ^b, Trieste, Italy

S. Belforte^a, V. Candelise^{a,b}, M. Casarsa^a, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a, C. La Licata^{a,b}, M. Marone^{a,b}, A. Schizzi^{a,b}, A. Zanetti^a

Kangwon National University, Chunchon, Korea

A. Kropivnitskaya, S.K. Nam

Kyungpook National University, Daegu, Korea

D.H. Kim, G.N. Kim, M.S. Kim, D.J. Kong, S. Lee, Y.D. Oh, A. Sakharov, D.C. Son

Chonbuk National University, Jeonju, Korea

J.A. Brochero Cifuentes, H. Kim, T.J. Kim

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea

S. Song

Korea University, Seoul, Korea

S. Choi, Y. Go, D. Gyun, B. Hong, H. Kim, Y. Kim, B. Lee, K. Lee, K.S. Lee, S. Lee, S.K. Park, Y. Roh

Seoul National University, Seoul, Korea

H.D. Yoo

University of Seoul, Seoul, Korea

M. Choi, H. Kim, J.H. Kim, J.S.H. Lee, I.C. Park, G. Ryu, M.S. Ryu

Sungkyunkwan University, Suwon, Korea

Y. Choi, J. Goh, D. Kim, E. Kwon, J. Lee, I. Yu

Vilnius University, Vilnius, Lithuania

V. Dudenas, A. Juodagalvis, J. Vaitkus

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia

I. Ahmed, Z.A. Ibrahim, J.R. Komaragiri, M.A.B. Md Ali³², F. Mohamad Idris³³, W.A.T. Wan Abdullah, M.N. Yusli

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico

E. Casimiro Linares, H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz³⁴, A. Hernandez-Almada, R. Lopez-Fernandez, A. Sanchez-Hernandez

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

I. Pedraza, H.A. Salazar Ibarguen

Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico

A. Morelos Pineda

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

P.H. Butler

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan

A. Ahmad, M. Ahmad, Q. Hassan, H.R. Hoorani, W.A. Khan, T. Khurshid, M. Shoaib

National Centre for Nuclear Research, Swierk, Poland

H. Bialkowska, M. Bluj, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, P. Zalewski

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland

G. Brona, K. Bunkowski, A. Byszuk³⁵, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, M. Walczak

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal

P. Bargassa, C. Beirão Da Cruz E Silva, A. Di Francesco, P. Faccioli, P.G. Ferreira Parracho,

M. Gallinaro, N. Leonardo, L. Lloret Iglesias, F. Nguyen, J. Rodrigues Antunes, J. Seixas, O. Toldaiev, D. Vadrucio, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia

S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, A. Lanev, A. Malakhov, V. Matveev^{36,37}, P. Moiseenz, V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia

V. Golovtsov, Y. Ivanov, V. Kim³⁸, E. Kuznetsova, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia

Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, A. Karneyeu, M. Kirsanov, N. Krasnikov, A. Pashenkov, D. Tlisov, A. Toropin

Institute for Theoretical and Experimental Physics, Moscow, Russia

V. Epshteyn, V. Gavrillov, N. Lychkovskaya, V. Popov, I. Pozdnyakov, G. Safronov, A. Spiridonov, E. Vlasov, A. Zhokin

National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia

A. Bylinkin

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin³⁷, I. Dremin³⁷, M. Kirakosyan, A. Leonidov³⁷, G. Mesyats, S.V. Rusakov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

A. Baskakov, A. Belyaev, E. Boos, A. Ershov, A. Gribushin, L. Khein, V. Klyukhin, O. Kodolova, I. Lokhtin, O. Lukina, I. Myagkov, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia

P. Adzic³⁹, P. Cirkovic, J. Milosevic, V. Rekovic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

J. Alcaraz Maestre, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, A. Escalante Del Valle, C. Fernandez Bedoya, J.P. Fernández Ramos, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, E. Navarro De Martino, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares

Universidad Autónoma de Madrid, Madrid, Spain

C. Albajar, J.F. de Trocóniz, M. Missiroli, D. Moran

Universidad de Oviedo, Oviedo, Spain

J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, E. Palencia Cortezon, J.M. Vizan Garcia

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain

I.J. Cabrillo, A. Calderon, J.R. Castiñeiras De Saa, P. De Castro Manzano, M. Fernandez, J. Garcia-Ferrero, G. Gomez, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, J. Piedra Gomez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, N. Trevisani, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, A. Benaglia, J. Bendavid, L. Benhabib, J.F. Benitez, G.M. Berruti, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, R. Castello, G. Cerminara, M. D'Alfonso, D. d'Enterria, A. Dabrowski, V. Daponte, A. David, M. De Gruttola, F. De Guio, A. De Roeck, S. De Visscher, E. Di Marco⁴⁰, M. Dobson, M. Dordevic, B. Dorney, T. du Pree, D. Duggan, M. Dünser, N. Dupont, A. Elliott-Peisert, G. Franzoni, J. Fulcher, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer, P. Harris, J. Hegeman, V. Innocente, P. Janot, H. Kirschenmann, M.J. Kortelainen, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, M.T. Lucchini, N. Magini, L. Malgeri, M. Mannelli, A. Martelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, M.V. Nemallapudi, H. Neugebauer, S. Orfanelli⁴¹, L. Orsini, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, D. Piparo, A. Racz, T. Reis, G. Rolandi⁴², M. Rovere, M. Ruan, H. Sakulin, C. Schäfer, C. Schwick, M. Seidel, A. Sharma, P. Silva, M. Simon, P. Sphicas⁴³, J. Steggemann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Triossi, A. Tsiros, G.I. Veres²⁰, N. Wardle, H.K. Wöhri, A. Zagozdinska³⁵, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

W. Bertl, K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, U. Langenegger, D. Renker, T. Rohe

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, P. Eller, C. Grab, C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, W. Lustermann, B. Mangano, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, D. Meister, F. Micheli, P. Musella, F. Nessi-Tedaldi, F. Pandolfi, J. Pata, F. Pauss, L. Perrozzi, M. Quittnat, M. Rossini, M. Schönenberger, A. Starodumov⁴⁴, M. Takahashi, V.R. Tavolaro, K. Theofilatos, R. Wallny

Universität Zürich, Zurich, Switzerland

T.K. Aarrestad, C. Amsler⁴⁵, L. Caminada, M.F. Canelli, V. Chiochia, A. De Cosa, C. Galloni, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, J. Ngadiuba, D. Pinna, G. Rauco, P. Robmann, F.J. Ronga, D. Salerno, Y. Yang

National Central University, Chung-Li, Taiwan

M. Cardaci, K.H. Chen, T.H. Doan, Sh. Jain, R. Khurana, M. Konyushikhin, C.M. Kuo, W. Lin, Y.J. Lu, A. Pozdnyakov, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

Arun Kumar, R. Bartek, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, P.H. Chen, C. Dietz, F. Fiori, U. Grundler, W.-S. Hou, Y. Hsiung, Y.F. Liu, R.-S. Lu, M. Miñano Moya, E. Petrakou, J.f. Tsai, Y.M. Tzeng

Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand

B. Asavapibhop, K. Kovitanggoon, G. Singh, N. Srimanobhas, N. Suwonjandee

Cukurova University, Adana, Turkey

A. Adiguzel, S. Cerci⁴⁶, Z.S. Demiroglu, C. Dozen, I. Dumanoglu, F.H. Gecit, S. Girgis,

G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal⁴⁷, A. Kayis Topaksu, G. Onengut⁴⁸, M. Ozcan, K. Ozdemir⁴⁹, S. Ozturk⁵⁰, B. Tali⁴⁶, H. Topakli⁵⁰, M. Vergili, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey

I.V. Akin, B. Bilin, S. Bilmis, B. Isildak⁵¹, G. Karapinar⁵², M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey

E. Gülmez, M. Kaya⁵³, O. Kaya⁵⁴, E.A. Yetkin⁵⁵, T. Yetkin⁵⁶

Istanbul Technical University, Istanbul, Turkey

A. Cakir, K. Cankocak, S. Sen⁵⁷, F.I. Vardarli

Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine

B. Grynyov

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine

L. Levchuk, P. Sorokin

University of Bristol, Bristol, United Kingdom

R. Aggleton, F. Ball, L. Beck, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold⁵⁸, S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, S. Senkin, D. Smith, V.J. Smith

Rutherford Appleton Laboratory, Didcot, United Kingdom

K.W. Bell, A. Belyaev⁵⁹, C. Brew, R.M. Brown, L. Calligaris, D. Cieri, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams, S.D. Worm

Imperial College, London, United Kingdom

M. Baber, R. Bainbridge, O. Buchmuller, A. Bundock, D. Burton, S. Casasso, M. Citron, D. Colling, L. Corpe, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, P. Dunne, A. Elwood, D. Futyan, G. Hall, G. Iles, R. Lane, R. Lucas⁵⁸, L. Lyons, A.-M. Magnan, S. Malik, J. Nash, A. Nikitenko⁴⁴, J. Pela, M. Pesaresi, K. Petridis, D.M. Raymond, A. Richards, A. Rose, C. Seez, A. Tapper, K. Uchida, M. Vazquez Acosta⁶⁰, T. Virdee, S.C. Zenz

Brunel University, Uxbridge, United Kingdom

J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Baylor University, Waco, USA

A. Borzou, K. Call, J. Dittmann, K. Hatakeyama, H. Liu, N. Pastika

The University of Alabama, Tuscaloosa, USA

O. Charaf, S.I. Cooper, C. Henderson, P. Rumerio

Boston University, Boston, USA

D. Arcaro, A. Avetisyan, T. Bose, C. Fantasia, D. Gastler, P. Lawson, D. Rankin, C. Richardson, J. Rohlf, J. St. John, L. Sulak, D. Zou

Brown University, Providence, USA

J. Alimena, E. Berry, D. Cutts, A. Ferapontov, A. Garabedian, J. Hakala, U. Heintz, E. Laird, G. Landsberg, Z. Mao, M. Narain, S. Piperov, S. Sagir, R. Syarif

University of California, Davis, Davis, USA

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway,

R. Conway, P.T. Cox, R. Erbacher, G. Funk, M. Gardner, W. Ko, R. Lander, C. Mclean, M. Mulhearn, D. Pellett, J. Pilot, F. Ricci-Tam, S. Shalhout, J. Smith, M. Squires, D. Stolp, M. Tripathi, S. Wilbur, R. Yohay

University of California, Los Angeles, USA

R. Cousins, P. Everaerts, A. Florent, J. Hauser, M. Ignatenko, D. Saltzberg, E. Takasugi, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA

K. Burt, R. Clare, J. Ellison, J.W. Gary, G. Hanson, J. Heilman, M. Ivova PANEVA, P. Jandir, E. Kennedy, F. Lacroix, O.R. Long, A. Luthra, M. Malberti, M. Olmedo Negrete, A. Shrinivas, H. Wei, S. Wimpenny, B. R. Yates

University of California, San Diego, La Jolla, USA

J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D'Agnolo, M. Derdzinski, A. Holzner, R. Kelley, D. Klein, J. Letts, I. Macneill, D. Olivito, S. Padhi, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, A. Vartak, S. Wasserbaech⁶¹, C. Welke, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, Santa Barbara, Santa Barbara, USA

J. Bradmiller-Feld, C. Campagnari, A. Dishaw, V. Dutta, K. Flowers, M. Franco Sevilla, P. Geffert, C. George, F. Golf, L. Gouskos, J. Gran, J. Incandela, N. Mccoll, S.D. Mullin, J. Richman, D. Stuart, I. Suarez, C. West, J. Yoo

California Institute of Technology, Pasadena, USA

D. Anderson, A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, J. Duarte, A. Mott, H.B. Newman, C. Pena, M. Spiropulu, J.R. Vlimant, S. Xie, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA

M.B. Andrews, V. Azzolini, A. Calamba, B. Carlson, T. Ferguson, M. Paulini, J. Russ, M. Sun, H. Vogel, I. Vorobiev

University of Colorado Boulder, Boulder, USA

J.P. Cumalat, W.T. Ford, A. Gaz, F. Jensen, A. Johnson, M. Krohn, T. Mulholland, U. Nauenberg, K. Stenson, S.R. Wagner

Cornell University, Ithaca, USA

J. Alexander, A. Chatterjee, J. Chaves, J. Chu, S. Dittmer, N. Eggert, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Rinkevicius, A. Ryd, L. Skinnari, L. Soffi, W. Sun, S.M. Tan, W.D. Teo, J. Thom, J. Thompson, J. Tucker, Y. Weng, P. Wittich

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, G. Apollinari, S. Banerjee, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, G. Bolla, K. Burkett, J.N. Butler, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, D. Hare, R.M. Harris, S. Hasegawa, J. Hirschauer, Z. Hu, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, B. Klima, B. Kreis, S. Lammel, J. Linacre, D. Lincoln, R. Lipton, T. Liu, R. Lopes De Sá, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, P. Merkel, S. Mrenna, S. Nahn, C. Newman-Holmes[†], V. O'Dell, K. Pedro, O. Prokofyev, G. Rakness, E. Sexton-Kennedy, A. Soha, W.J. Spalding, L. Spiegel, N. Strobbe, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, C. Vernieri, M. Verzocchi, R. Vidal, H.A. Weber, A. Whitbeck

University of Florida, Gainesville, USA

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, A. Carnes, M. Carver, D. Curry, S. Das,

R.D. Field, I.K. Furic, S.V. Gleyzer, J. Konigsberg, A. Korytov, K. Kotov, P. Ma, K. Matchev, H. Mei, P. Milenovic⁶², G. Mitselmakher, D. Rank, R. Rossin, L. Shchutska, M. Snowball, D. Sperka, N. Terentyev, L. Thomas, J. Wang, S. Wang, J. Yelton

Florida International University, Miami, USA

S. Hewamanage, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA

A. Ackert, J.R. Adams, T. Adams, A. Askew, S. Bein, J. Bochenek, B. Diamond, J. Haas, S. Hagopian, V. Hagopian, K.F. Johnson, A. Khatiwada, H. Prosper, M. Weinberg

Florida Institute of Technology, Melbourne, USA

M.M. Baarmand, V. Bhopatkar, S. Colafranceschi⁶³, M. Hohlmann, H. Kalakhety, D. Noonan, T. Roy, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, USA

M.R. Adams, L. Apanasevich, D. Berry, R.R. Betts, I. Bucinskaite, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, P. Kurt, C. O'Brien, I.D. Sandoval Gonzalez, P. Turner, N. Varelas, Z. Wu, M. Zakaria

The University of Iowa, Iowa City, USA

B. Bilki⁶⁴, W. Clarida, K. Dilsiz, S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya⁶⁵, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok⁵⁵, A. Penzo, C. Snyder, E. Tiras, J. Wetzel, K. Yi

Johns Hopkins University, Baltimore, USA

I. Anderson, B.A. Barnett, B. Blumenfeld, N. Eminizer, D. Fehling, L. Feng, A.V. Gritsan, P. Maksimovic, C. Martin, M. Osherson, J. Roskes, A. Sady, U. Sarica, M. Swartz, M. Xiao, Y. Xin, C. You

The University of Kansas, Lawrence, USA

P. Baringer, A. Bean, G. Benelli, C. Bruner, R.P. Kenny III, D. Majumder, M. Malek, M. Murray, S. Sanders, R. Stringer, Q. Wang

Kansas State University, Manhattan, USA

A. Ivanov, K. Kaadze, S. Khalil, M. Makouski, Y. Maravin, A. Mohammadi, L.K. Saini, N. Skhirtladze, S. Toda

Lawrence Livermore National Laboratory, Livermore, USA

D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, USA

C. Anelli, A. Baden, O. Baron, A. Belloni, B. Calvert, S.C. Eno, C. Ferraioli, J.A. Gomez, N.J. Hadley, S. Jabeen, R.G. Kellogg, T. Kolberg, J. Kunkle, Y. Lu, A.C. Mignerey, Y.H. Shin, A. Skuja, M.B. Tonjes, S.C. Tonwar

Massachusetts Institute of Technology, Cambridge, USA

A. Apyan, R. Barbieri, A. Baty, K. Bierwagen, S. Brandt, W. Busza, I.A. Cali, Z. Demiragli, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, Y. Iiyama, G.M. Innocenti, M. Klute, D. Kovalskyi, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, A.C. Marini, C. McGinn, C. Mironov, S. Narayanan, X. Niu, C. Paus, C. Roland, G. Roland, J. Salfeld-Nebgen, G.S.F. Stephans, K. Sumorok, M. Varma, D. Velicanu, J. Veverka, J. Wang, T.W. Wang, B. Wyslouch, M. Yang, V. Zhukova

University of Minnesota, Minneapolis, USA

B. Dahmes, A. Evans, A. Finkel, A. Gude, P. Hansen, S. Kalafut, S.C. Kao, K. Klapoetke, Y. Kubota, Z. Lesko, J. Mans, S. Nourbakhsh, N. Ruckstuhl, R. Rusack, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA

J.G. Acosta, S. Oliveros

University of Nebraska-Lincoln, Lincoln, USA

E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, C. Fangmeier, R. Gonzalez Suarez, R. Kamalieddin, D. Knowlton, I. Kravchenko, F. Meier, J. Monroy, F. Ratnikov, J.E. Siado, G.R. Snow

State University of New York at Buffalo, Buffalo, USA

M. Alyari, J. Dolen, J. George, A. Godshalk, C. Harrington, I. Iashvili, J. Kaisen, A. Kharchilava, A. Kumar, S. Rappoccio, B. Roozbahani

Northeastern University, Boston, USA

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, A. Hortiangtham, A. Massironi, D.M. Morse, D. Nash, T. Orimoto, R. Teixeira De Lima, D. Trocino, R.-J. Wang, D. Wood, J. Zhang

Northwestern University, Evanston, USA

S. Bhattacharya, K.A. Hahn, A. Kubik, J.F. Low, N. Mucia, N. Odell, B. Pollack, M. Schmitt, S. Stoynev, K. Sung, M. Trovato, M. Velasco

University of Notre Dame, Notre Dame, USA

A. Brinkerhoff, N. Dev, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, N. Marinelli, F. Meng, C. Mueller, Y. Musienko³⁶, M. Planer, A. Reinsvold, R. Ruchti, G. Smith, S. Taroni, N. Valls, M. Wayne, M. Wolf, A. Woodard

The Ohio State University, Columbus, USA

L. Antonelli, J. Brinson, B. Bylsma, L.S. Durkin, S. Flowers, A. Hart, C. Hill, R. Hughes, W. Ji, T.Y. Ling, B. Liu, W. Luo, D. Puigh, M. Rodenburg, B.L. Winer, H.W. Wulsin

Princeton University, Princeton, USA

O. Driga, P. Elmer, J. Hardenbrook, P. Hebda, S.A. Koay, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, C. Palmer, P. Piroué, H. Saka, D. Stickland, C. Tully, A. Zuranski

University of Puerto Rico, Mayaguez, USA

S. Malik

Purdue University, West Lafayette, USA

A. Barker, V.E. Barnes, D. Benedetti, D. Bortoletto, L. Gutay, M.K. Jha, M. Jones, A.W. Jung, K. Jung, A. Kumar, D.H. Miller, N. Neumeister, B.C. Radburn-Smith, X. Shi, I. Shipsey, D. Silvers, J. Sun, A. Svyatkovskiy, F. Wang, W. Xie, L. Xu

Purdue University Calumet, Hammond, USA

N. Parashar, J. Stupak

Rice University, Houston, USA

A. Adair, B. Akgun, Z. Chen, K.M. Ecklund, F.J.M. Geurts, M. Guilbaud, W. Li, B. Michlin, M. Northup, B.P. Padley, R. Redjimi, J. Roberts, J. Rorie, Z. Tu, J. Zabel

University of Rochester, Rochester, USA

B. Betchart, A. Bodek, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, M. Galanti, A. Garcia-Bellido, J. Han, A. Harel, O. Hindrichs, A. Khukhunaishvili, G. Petrillo, P. Tan, M. Verzetti

Rutgers, The State University of New Jersey, Piscataway, USA

S. Arora, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, E. Hughes, S. Kaplan, R. Kunnawalkam Elayavalli, A. Lath, K. Nash, S. Panwalkar, M. Park, S. Salur, S. Schnetzer, D. Sheffield, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

University of Tennessee, Knoxville, USA

M. Foerster, G. Riley, K. Rose, S. Spanier

Texas A&M University, College Station, USA

O. Bouhali⁶⁶, A. Castaneda Hernandez⁶⁶, A. Celik, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, J. Gilmore, T. Huang, T. Kamon⁶⁷, V. Krutelyov, R. Mueller, I. Osipenkov, Y. Pakhotin, R. Patel, A. Perloff, A. Rose, A. Safonov, A. Tatarinov, K.A. Ulmer²

Texas Tech University, Lubbock, USA

N. Akchurin, C. Cowden, J. Damgov, C. Dragoiu, P.R. Duerdo, J. Faulkner, S. Kunori, K. Lamichhane, S.W. Lee, T. Libeiro, S. Undleeb, I. Volobouev

Vanderbilt University, Nashville, USA

E. Appelt, A.G. Delannoy, S. Greene, A. Gurrola, R. Janjam, W. Johns, C. Maguire, Y. Mao, A. Melo, H. Ni, P. Sheldon, S. Tuo, J. Velkovska, Q. Xu

University of Virginia, Charlottesville, USA

M.W. Arenton, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, H. Li, C. Lin, C. Neu, T. Sinthuprasith, X. Sun, Y. Wang, E. Wolfe, J. Wood, F. Xia

Wayne State University, Detroit, USA

C. Clarke, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, J. Sturdy

University of Wisconsin, Madison, USA

D.A. Belknap, D. Carlsmith, M. Cepeda, S. Dasu, L. Dodd, S. Duric, B. Gomber, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, A. Lanaro, A. Levine, K. Long, R. Loveless, A. Mohapatra, I. Ojalvo, T. Perry, G.A. Pierro, G. Polese, T. Ruggles, T. Sarangi, A. Savin, A. Sharma, N. Smith, W.H. Smith, D. Taylor, P. Verwilligen, N. Woods

†: Deceased

1: Also at Vienna University of Technology, Vienna, Austria

2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland

3: Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

4: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

5: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

6: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

7: Also at Universidade Estadual de Campinas, Campinas, Brazil

8: Also at Centre National de la Recherche Scientifique (CNRS) - IN2P3, Paris, France

9: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France

10: Also at Joint Institute for Nuclear Research, Dubna, Russia

11: Also at Ain Shams University, Cairo, Egypt

12: Also at Zewail City of Science and Technology, Zewail, Egypt

13: Also at British University in Egypt, Cairo, Egypt

14: Also at Université de Haute Alsace, Mulhouse, France

-
- 15: Also at Tbilisi State University, Tbilisi, Georgia
 - 16: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
 - 17: Also at University of Hamburg, Hamburg, Germany
 - 18: Also at Brandenburg University of Technology, Cottbus, Germany
 - 19: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
 - 20: Also at Eötvös Loránd University, Budapest, Hungary
 - 21: Also at University of Debrecen, Debrecen, Hungary
 - 22: Also at Wigner Research Centre for Physics, Budapest, Hungary
 - 23: Also at Indian Institute of Science Education and Research, Bhopal, India
 - 24: Also at University of Visva-Bharati, Santiniketan, India
 - 25: Now at King Abdulaziz University, Jeddah, Saudi Arabia
 - 26: Also at University of Ruhuna, Matara, Sri Lanka
 - 27: Also at Isfahan University of Technology, Isfahan, Iran
 - 28: Also at University of Tehran, Department of Engineering Science, Tehran, Iran
 - 29: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
 - 30: Also at Università degli Studi di Siena, Siena, Italy
 - 31: Also at Purdue University, West Lafayette, USA
 - 32: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
 - 33: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
 - 34: Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico
 - 35: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
 - 36: Also at Institute for Nuclear Research, Moscow, Russia
 - 37: Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
 - 38: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
 - 39: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
 - 40: Also at INFN Sezione di Roma; Università di Roma, Roma, Italy
 - 41: Also at National Technical University of Athens, Athens, Greece
 - 42: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
 - 43: Also at University of Athens, Athens, Greece
 - 44: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
 - 45: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
 - 46: Also at Adiyaman University, Adiyaman, Turkey
 - 47: Also at Mersin University, Mersin, Turkey
 - 48: Also at Cag University, Mersin, Turkey
 - 49: Also at Piri Reis University, Istanbul, Turkey
 - 50: Also at Gaziosmanpasa University, Tokat, Turkey
 - 51: Also at Ozyegin University, Istanbul, Turkey
 - 52: Also at Izmir Institute of Technology, Izmir, Turkey
 - 53: Also at Marmara University, Istanbul, Turkey
 - 54: Also at Kafkas University, Kars, Turkey
 - 55: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
 - 56: Also at Yildiz Technical University, Istanbul, Turkey
 - 57: Also at Hacettepe University, Ankara, Turkey
 - 58: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
 - 59: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
 - 60: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain

- 61: Also at Utah Valley University, Orem, USA
- 62: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- 63: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
- 64: Also at Argonne National Laboratory, Argonne, USA
- 65: Also at Erzincan University, Erzincan, Turkey
- 66: Also at Texas A&M University at Qatar, Doha, Qatar
- 67: Also at Kyungpook National University, Daegu, Korea