Editors' Suggestion

Observation of Enhanced Long-Range Elliptic Anisotropies Inside High-Multiplicity Jets in pp Collisions at $\sqrt{s} = 13$ TeV

A. Hayrapetyan *et al.*[*]
(CMS Collaboration)

(Received 28 December 2023; revised 20 June 2024; accepted 27 August 2024; published 30 September 2024)

A search for collective effects inside jets produced in proton-proton collisions is performed via correlation measurements of charged particles using the CMS detector at the CERN LHC. The analysis uses data collected at a center-of-mass energy of $\sqrt{s} = 13$ TeV, corresponding to an integrated luminosity of 138 fb^{-1}. Jets are reconstructed with the anti-k_T algorithm with a distance parameter of 0.8 and are required to have transverse momentum greater than 550 GeV and pseudorapidity $|\eta^\mathrm{jet}| < 1.6$. Two-particle correlations among the charged particles within the jets are studied as functions of the particles' azimuthal angle and pseudorapidity separations ($\Delta\phi^*$ and $\Delta\eta^*$) in a jet coordinate basis, where particles' η^*, ϕ^* are defined relative to the direction of the jet. The correlation functions are studied in classes of in-jet charged-particle multiplicity up to $N_\mathrm{ch}^\mathrm{j} \approx 100$. Fourier harmonics are extracted from long-range azimuthal correlation functions to characterize azimuthal anisotropy for $|\Delta\eta^*| > 2$. For low-N_ch^j jets, the long-range elliptic anisotropic harmonic, v_2^*, is observed to decrease with N_ch^j. This trend is well described by Monte Carlo event generators. However, a rising trend for v_2^* emerges at $N_\mathrm{ch}^\mathrm{j} \gtrsim 80$, hinting at a possible onset of collective behavior, which is not reproduced by the models tested. This observation yields new insights into the dynamics of jet evolution in the vacuum.

DOI: 10.1103/PhysRevLett.133.142301

The theory of quantum chromodynamics (QCD) describes the strong interaction among partons (quarks and gluons) carrying color charges. At low energies, the color force is very strong and partons are confined in color-neutral objects (hadrons)—a property that results from the nonperturbative nature of QCD in this regime. In high-energy proton collisions, large momentum transfers between partons inside the colliding protons can result in a collimated spray of hadrons originating from the fragmentation and hadronization of an outgoing parton. This collimated spray is called a "jet." [1,2]. Energetic jets are produced abundantly at LHC collision energies and can generate large final-state hadron multiplicities (e.g., > 100 charged particles) resulting from a single parton.

Final states containing thousands of hadrons are routinely produced in high-energy nucleus-nucleus (AA) collisions, where a hot medium of deconfined partons known as a quark-gluon plasma is formed [3–9]. The extreme parton densities realized in these collisions result in strong partonic rescatterings that quickly drive the system toward a nearly ideal hydrodynamic limit. As a result, long-range collective flow effects have been observed at the BNL RHIC [3–6] and the CERN LHC [10–14].

It was originally thought that small collision systems such as electron-positron (e^+e^-), electron-proton (ep), and proton-proton (pp) collisions would produce final states that were too small and dilute for secondary partonic rescatterings to drive the system toward thermal equilibrium. Collective hydrodynamic behavior was not expected to play an important role in these final states, notwithstanding some early studies [15,16]. Surprisingly, strong long-range collective correlations, similar to those observed in AA collisions, were discovered in the azimuthal distributions of charged particles in the laboratory reference frame of pp collisions having a large final-state multiplicity in the entire event [17–20]. This raised the question of whether a tiny quark-gluon plasma droplet is created in such conditions [21]. Subsequently, similar collective phenomena were observed in proton-nucleus (pA) collisions [22–32], and lighter AA systems [32–35]. Correlation studies in e^+e^- [36–38], ep [39,40], photon-proton (γp) [41], and photonuclear (γA) [42] systems have been limited to relatively low-multiplicity events (less than a total of 30–40 charged particles per event) and have not unambiguously demonstrated such behavior.

It is natural to ask what minimum system size is needed for QCD collective effects to develop. Although the

---

[*] Full author list given at the end of the Letter.

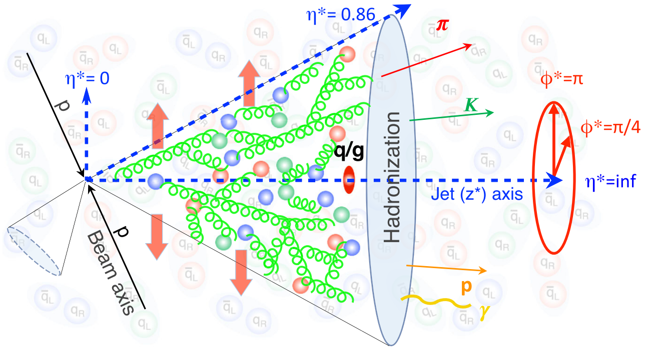

FIG. 1. An illustration showing the idea of an initially scattered parton evolving to a shower that eventually exhibits collective expansion transverse to the jet axis (represented by red arrow boxes). A jet cone (not to scale) and emerging final state particles are drawn in a coordinate system, denoted as the "jet basis," where the z axis coincides with the jet direction. The redefined pseudorapidity η^* is shown with key values in dotted blue lines, and the azimuthal angle ϕ^* is shown with key values in solid red.

dynamics of parton showering inside a jet is theoretically well described by perturbative QCD calculations [43,44], a possible buildup of collective correlations within the parton constituents of a jet had not been considered. In Ref. [45], it is postulated that collective effects can emerge from an initial system as small as an energetic parton that fragments and hadronizes in the vacuum, as illustrated in Fig. 1. Motivated by that idea, this Letter presents a search for such collective effects inside individual jets (as opposed to full events) produced in pp collisions at a center-of-mass energy of $\sqrt{s} = 13$ TeV using the CMS detector at the LHC. Using a coordinate system defined with respect to the jet axis—a proxy for the direction of the parton initiating the jet—the two-particle correlation of charged particles of a jet is measured as a function of the in-jet charged particle multiplicity, $N_{\mathrm{ch}}^{\mathrm{j}}$. Tabulated results are provided in the HEPData record for this analysis [46].

The CMS apparatus [47] is a multipurpose, nearly hermetic detector designed to trigger on [48,49] and identify electrons, muons, photons, and hadrons [50–52]. The initial triggering is done with the level-1 system, which uses customized hardware to make the rapid online decision whether or not to accept an event and deliver it to the second system, the high level trigger. This trigger uses a large CPU farm to perform optimized online event reconstruction and characterize an event. A global "particle-flow" algorithm [53] reconstructs all individual particles in an event, combining information provided by the all-silicon inner tracker and by the crystal electromagnetic and brass-scintillator hadron calorimeters, operating inside a 3.8 T superconducting solenoid, with data from the gas-ionization muon detectors embedded in the flux-return yoke outside the solenoid. The reconstructed particles are used to build more complex objects such as jets [54–57].

The $\sqrt{s} = 13$ TeV pp collisions used in this analysis were delivered from 2016–2018 and correspond to an integrated luminosity of 138 fb^{-1}. The data were collected using an online trigger searching for events containing anti-k_{T} jets [58,59] with distance parameter $R = 0.8$ having a transverse momentum ($p_{\mathrm{T}}^{\mathrm{jet}}$) above 500 GeV. In the offline analysis, jets were required to have $p_{\mathrm{T}}^{\mathrm{jet}} > 550$ GeV and pseudorapidity $|\eta^{\mathrm{jet}}| < 1.6$ in the laboratory reference frame.

The generator-level events from two Monte Carlo (MC) models, PYTHIA8.306 [60] with the CP5 tune [61] and SHERPA2.2 [62], are compared with the data. The leading order PYTHIA8 uses the Lund string fragmentation model [63], while the SHERPA generator uses a cluster fragmentation model [64]. Additionally, the PYTHIA8 events are input into GEANT4 [65] to emulate the CMS detector response for calculating correction factors for the tracking efficiency and jet energy scale. The effects of secondary pp interactions within the same or nearby bunch crossings ("pileup") are incorporated in the simulation.

This analysis is particularly interested in the charged particles of jets. These charged particles are required to have $|\eta| < 2.4$ and $p_{\mathrm{T}} > 0.3$ GeV in the laboratory reference frame. Additional, they must have a p_{T} uncertainty of $< 10\%$, and a distance of closest approach significance with respect to the primary vertex of at most 3 standard deviations (σ) [52]. The PUPPI algorithm [66,67] is used to mitigate the effect of pileup at the reconstructed particle level, using local shape information, event pileup properties, and tracking information. Jets are classified into different classes based on the number of charged particles of the jet passing these selections and PUPPI subtraction before correcting for detector effects.

Jet energy corrections are derived from MC simulation studies so that the average measured energy of jets equals that of generator-level jets. Additional selection criteria are applied to each jet to remove jets potentially dominated by instrumental effects or reconstruction failures. The jet energy resolution is typically 10% at 100 GeV, and 5% at 1 TeV [55].

The two-particle correlation analysis is similar to that employed in Ref. [22], except that the momentum vectors of all charged particles of a jet are defined in the "jet basis," as illustrated in Fig. 1. A unique jet reference coordinate basis is defined for every jet such that the z axis is aligned with the direction of the jet momentum [45]. Momentum vectors of charged particles are redefined in this new basis, $\overrightarrow{p^*} = (j_{\mathrm{T}}, \eta^*, \phi^*)$. Here, j_{T} is the particle p_{T} with respect to the jet axis. The symbols η^* and ϕ^* are the pseudorapidity and azimuthal angle coordinates with respect to the jet axis. Therefore, $\eta^* = 0$ and ∞ correspond to vectors that are perpendicular and parallel to the jet axis, as illustrated in Fig. 1. In this system, $\eta^* = 0.86$ is the approximate boundary of the anti-k_{T} jet. The origin of the ϕ^* coordinate is defined as $\hat{p}_{\mathrm{jet}} \times (\hat{p}_{\mathrm{jet}} \times \hat{z})$, where $\hat{p}_{\mathrm{jet}}$ is a unit vector along the jet momentum and $\hat{z}$ is the direction of the $+z$ axis. The choice of $\phi^* = 0$ is irrelevant to the relative ϕ^* between two particles. The azimuthal coordinates of tracks that are approximately parallel to the direction of the jet axis ($\eta^* > 5$) are sensitive to small changes in the jet axis direction caused by resolution effects. These tracks are excluded in the subsequent analysis. Reconstructed particles in the event that are not clustered into the jet of interest are not considered in the analysis. For each jet with $p_{\mathrm{T}}^{\mathrm{jet}} > 550$ GeV, the two-dimensional (2D) angular correlation function is calculated using charged particles from the jet as follows:

$$\frac{1}{N_{\mathrm{ch}}^{\mathrm{trg}}} \frac{d^2 N^{\mathrm{pair}}}{d\Delta\eta^* \mathrm{d}\Delta\phi^*} = B(0,0) \frac{S(\Delta\eta^*, \Delta\phi^*)}{B(\Delta\eta^*, \Delta\phi^*)}, \tag{1}$$

where $\Delta\eta^*$ and $\Delta\phi^*$ are the relative separation in pseudorapidity and azimuthal angle in the jet basis between a pair of charged particles selected from a given j_{T} range. The functions $S(\Delta\eta^*, \Delta\phi^*)$ and $B(\Delta\eta^*, \Delta\phi^*)$ represent the signal and combinatorial distributions, respectively,

$$S(\Delta\eta^*, \Delta\phi^*) = \frac{1}{N_{\mathrm{ch}}^{\mathrm{trg}}} \frac{d^2 N_{\mathrm{ch}}^{\mathrm{sig}}}{d\Delta\eta^* \mathrm{d}\Delta\phi^*}, \tag{2}$$

and

$$B(\Delta\eta^*, \Delta\phi^*) = \frac{1}{N_{\mathrm{ch}}^{\mathrm{trg}}} \frac{d^2 N_{\mathrm{ch}}^{\mathrm{combin}}}{d\Delta\eta^* \mathrm{d}\Delta\phi^*}, \tag{3}$$

where $N_{\mathrm{ch}}^{\mathrm{sig}}$ and $N_{\mathrm{ch}}^{\mathrm{combin}}$ are the numbers of signal and combinatorial pairs, respectively, and $N_{\mathrm{ch}}^{\mathrm{trg}}$ is the number of particles within a specific j_{T} range used to calculate the correlation functions. The measurement is performed for each class of $N_{\mathrm{ch}}^{\mathrm{j}}$, which is corrected for detector effects (a tracking efficiency of about 90%). The $S(\Delta\eta^*, \Delta\phi^*)$ distribution is calculated with pairs of charged particles from each unique jet individually, and then averaged over all jets. The combinatorial distribution serves as both a reference and a correction to the pair acceptance due to the limited η^* range. To construct the $B(\Delta\eta^*, \Delta\phi^*)$ distribution, a two-dimensional (2D) single-particle η^*–ϕ^* distribution for charged particles of all jets within the $N_{\mathrm{ch}}^{\mathrm{j}}$ range chosen for the signal distribution is first obtained. Pairs of (η^*, ϕ^*) points are then randomly selected from this distribution to construct $B(\Delta\eta^*, \Delta\phi^*)$ such that no intrinsic correlations other than the pair acceptance effect are present in $B(\Delta\eta^*, \Delta\phi^*)$. Correlations present in the signal distribution that are related to single-particle distributions or detector effects are canceled by the $B(0,0)/B(\Delta\eta^*, \Delta\phi^*)$ term in Eq. (1). The quantities $\Delta\eta^*$ and $\Delta\phi^*$ are always taken to be positive and used to fill one quadrant of the $(\Delta\eta^*, \Delta\phi^*)$ histograms with the other three quadrants filled by reflection.

The resulting 2D distribution can be further studied by integrating over $|\Delta\eta^*| > 2$ and decomposing into a one-dimensional (1D) Fourier series, as done in previous analyses [17,19,20,22,27–29],

$$\frac{1}{N_{\mathrm{ch}}^{\mathrm{trg}}} \frac{dN^{\mathrm{pair}}}{d\Delta\phi^*} \propto 1 + 2 \sum_{n=1}^{\infty} V_{\mathrm{n}\Delta}^* \cos(\mathrm{n}\Delta\phi^*). \tag{4}$$

By applying $|\Delta\eta^*| > 2$, short-range few-body correlations, such as resonance and cluster decays [17], are excluded. Of particular interest is the second Fourier component, which is associated with elliptic anisotropies. The elliptic anisotropy coefficient, v_2^*, is the main observable of interest and is related to the two-particle Fourier coefficient by assumed factorization as $v_2^* = \sqrt{V_{2\Delta}^*}$ [20,27].

The primary sources of systematic uncertainty come from the jet axis pointing resolution, the $p_{\mathrm{T}}^{\mathrm{jet}}$ resolution, residual pileup effects, and the tracking efficiency. These four sources are added together in quadrature to calculate the total systematic uncertainty for each $N_{\mathrm{ch}}^{\mathrm{j}}$ class. To minimize statistical fluctuations, the four highest jet multiplicity classes examined are combined together when evaluating systematic effects. The effect of the jet pointing resolution is studied by smearing each jet axis in the 2D η-ϕ plane according to the resolution calculated in MC samples. The coordinate transformation of particles' j_{T}, η^*, and ϕ^* into the jet basis is recalculated with the new smeared jet axis, and the analysis procedure is repeated. The difference of $V_{\mathrm{n}\Delta}^*$ values before and after smearing is taken as the systematic uncertainty. The impact of this effect on $V_{\mathrm{n}\Delta}^*$ is between 0.01 and 0.04 (depending on the j_{T} range examined) at lower $N_{\mathrm{ch}}^{\mathrm{j}}$, where particles inside a jet tend to have a narrower angular distribution and therefore larger changes to their jet basis kinematic values for a given jet axis variation. On the other hand, this uncertainty is < 0.001 at higher $N_{\mathrm{ch}}^{\mathrm{j}}$ because the particles of these jets tend to have a wider angular separation from the jet axis on average. A similar smearing procedure found the uncertainty in $V_{\mathrm{n}\Delta}^*$ coming from the $p_{\mathrm{T}}^{\mathrm{jet}}$ resolution to range from negligible to 0.002. The systematic uncertainty from residual pileup effects is estimated by first splitting the data into two roughly equal subsets based on the number of reconstructed vertices in each event. The resulting high and low vertex number subsets were then treated independently and the full analysis procedure was carried out on both. The root mean square of the deviations in measured observables of these two subsets from the nominal result is taken as the uncertainty. For $V_{2\Delta}^*$, this uncertainty ranges from 0.001–0.003. Additional pileup studies varying PUPPI selection requirements were found to have a negligible impact. Potential contamination of collective effects from the underlying event was investigated by injecting a sizable

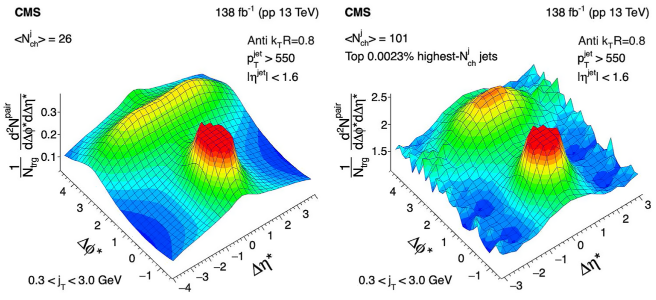

FIG. 2. Results for 2D two-particle angular correlation functions for particle $0.3 < j_T < 3.0$ GeV from inclusive (left) and the highest (right) N^{j}_{ch} jets, for anti-k_T R = 0.8 algorithm with $p_T^{jet} > 550$ GeV and $|\eta^{jet}| < 1.6$.

lab frame v_2 signal, and is found to have no impact on the jet frame v_2^*. The systematic uncertainty resulting from the tracking efficiency correction is evaluated by applying tighter and looser restrictions on the relative p_T uncertainty and track vertex association criteria, repeating the analysis procedure, and calculating the root mean square of the deviations of these variations from the nominal case. The uncertainty in $V^*_{2\Delta}$ from this source is less than 0.003.

Figure 2 shows an example of 2D two-particle angular correlation functions in the jet basis for inclusive and high-N^{j}_{ch} jets for charged particles in the range $0.3 < j_T < 3.0$ GeV. The average N^{j}_{ch} value for the two classes of jets shown, $\langle N^{j}_{ch}\rangle$, is 26 and 101. The high-N^{j}_{ch} jet class corresponds to a fraction of only 2×10^{-5} of all jets with $p_T^{jet} > 550$ GeV. The central peak at $(\Delta\eta^*, \Delta\phi^*) = (0, 0)$, truncated for better visualization, is the result of short-range correlations from the parton shower and hadronization. The far-side ridge at $\Delta\phi^* \approx \pi$ is mostly related to back-to-back particle production and conservation of momentum. These prominent features have also been found in laboratory-frame analyses of pp collisions [17], where they can also be reproduced using MC simulations for both low- and high-N^{j}_{ch} jets. This indicates that the dynamics of bulk hadron production in the jet fragmentation process may share similarities to those of a hadron-hadron collision process. Moreover, a feature commonly observed in AA collisions is the near-side enhancement at $\Delta\phi^* \approx 0$ over a long range in $\Delta\eta^*$, commonly known as the near-side "ridge." The N^{j}_{ch} reached in the single jet system of this work is comparable to the event multiplicity of pp collisions where a near-side ridge was first observed using a laboratory-frame analysis [17]. There appears to be some indication of a near-side ridge in the high-N^{j}_{ch} plot in Fig. 2, however, this feature is less prominent than the ridges observed in pp and pA collisions. There is no corresponding near-side enhancement visible in the high-N^{j}_{ch} 2D distributions from either PYTHIA8 or SHERPA.

The 1D $\Delta\phi^*$ correlation functions extracted using Eq. (4) and averaged over $|\Delta\eta^*| > 2$ are shown for data and MC in Figs. 3(a) and 3(b), respectively, for particles with $0.3 < j_T < 3.0$ GeV from jets in two N^{j}_{ch} classes. For high- and inclusive N^{j}_{ch} classes in data, PYTHIA8 and SHERPA, strong away-side correlations observed are consistent with dominant contributions of back-to-back momentum conservation effects. For inclusive N^{j}_{ch} jets, the near-side at $\Delta\phi^* \approx 0$ clearly shows a minimum. However, for the class of highest-N^{j}_{ch} jets studied in data, with $\langle N^{j}_{ch}\rangle \approx 100$,

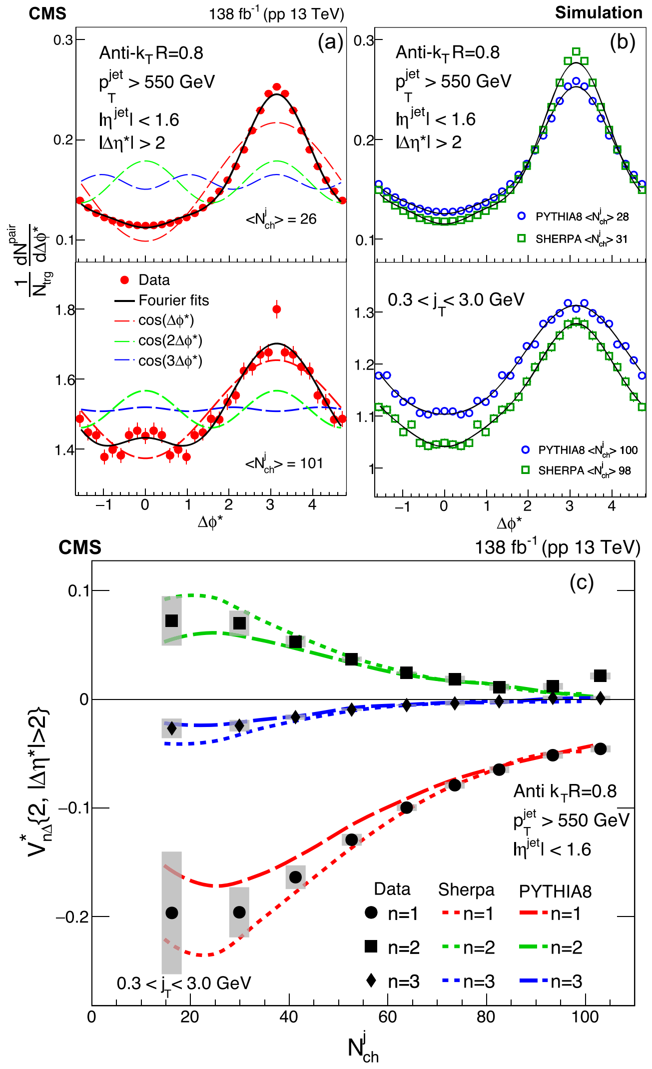

FIG. 3. Examples of two-particle angular correlations projected onto 1D $\Delta\phi^*$ for $|\Delta\eta^*| > 2$. The panels show (a) data and (b) PYTHIA8 and SHERPA for inclusive N^{j}_{ch} (upper) and high-N^{j}_{ch} (lower) jet selections. Data and both MC models are compared in (c) with a continuous evolution of extracted two-particle Fourier coefficients $V^*_{n\Delta}$ as a function of N^{j}_{ch}. Vertical bars on data points indicate statistical uncertainty while shaded boxes represent systematic uncertainties. Projections are symmetrized about $\Delta\phi^* = 0$ and π.

[Fig. 3(a) lower] an indication of a near-side enhancement is seen, which is less obvious or possibly absent from PYTHIA8 or SHERPA events having comparable $N_{\mathrm{ch}}^{\mathrm{j}}$ [Fig. 3(b) lower]. The Fourier fits used to extract $V_{n\Delta}^{*}$ are also shown and are dominated by a negative $V_{1\Delta}^{*}$ component. The addition of more Fourier terms has little impact on the first three Fourier coefficients. The significant deviation from the fit at $\Delta\phi^{*} \approx 0$ in Fig. 3(a) lower is attributed to a local statistical fluctuation, as similar deviations are not observed in any other $N_{\mathrm{ch}}^{\mathrm{j}}$ class.

The extracted two-particle Fourier coefficients for the first three harmonics $V_{n\Delta}^{*}$, as a function of $N_{\mathrm{ch}}^{\mathrm{j}}$, are shown in Fig. 3(c). Data points are placed at the average $N_{\mathrm{ch}}^{\mathrm{j}}$ value of each jet class for the horizontal axis. Over the full $N_{\mathrm{ch}}^{\mathrm{j}}$ range, the odd-order harmonics, $V_{1\Delta}^{*}$ and $V_{3\Delta}^{*}$, are negative, while $V_{2\Delta}^{*}$ is positive. The magnitudes of all harmonics tend to decrease as $N_{\mathrm{ch}}^{\mathrm{j}}$ increases. The contribution of few-body correlations to the two-particle Fourier coefficient is expected to diminish as $N_{\mathrm{ch}}^{\mathrm{j}}$ increases [68]. These features are consistent with back-to-back correlations, as observed in laboratory-frame analyses, that are not related to collective effects. Both MC generators are generally successful in describing the experimental data for all three Fourier harmonics over a wide $N_{\mathrm{ch}}^{\mathrm{j}}$ range. There appears to be a slight deviation in $V_{2\Delta}^{*}$ between data and simulation. Figure 4 shows the elliptic anisotropies $v_2^{*} = \sqrt{V_{2\Delta}^{*}}$, in the jet basis, as a function of $N_{\mathrm{ch}}^{\mathrm{j}}$ inside the jet. To investigate possible j_{T} dependence of observed signals, particles from 0.3–3.0 GeV (Fig. 4 upper) as well as 0.5–3.0 GeV (Fig. 4 lower) are examined. Again, the MC simulation is generally successful at describing the data over a wide $N_{\mathrm{ch}}^{\mathrm{j}}$ range in both j_{T} ranges. For jets at $N_{\mathrm{ch}}^{\mathrm{j}} > 80$, however, the value v_2^{*} no longer diminishes monotonically with increasing $N_{\mathrm{ch}}^{\mathrm{j}}$. Instead, the data start to show a steady increase with $N_{\mathrm{ch}}^{\mathrm{j}}$. The nonmonotonic dependence of v_2^{*} versus $N_{\mathrm{ch}}^{\mathrm{j}}$ is not expected if few-body processes are the dominant sources of the observed correlations, as in either PYTHIA8 or SHERPA, and may indicate an onset of novel QCD phenomena related to nonperturbative dynamics of a parton fragmenting in the vacuum. These phenomena could include the emergence of collective effects possibly driven by final-state rescatterings, as suggested in Ref. [45]. Further experimental and theoretical inputs, including more j_{T}-differential studies with larger data samples, are needed to investigate the physical origin of the observed enhancement.

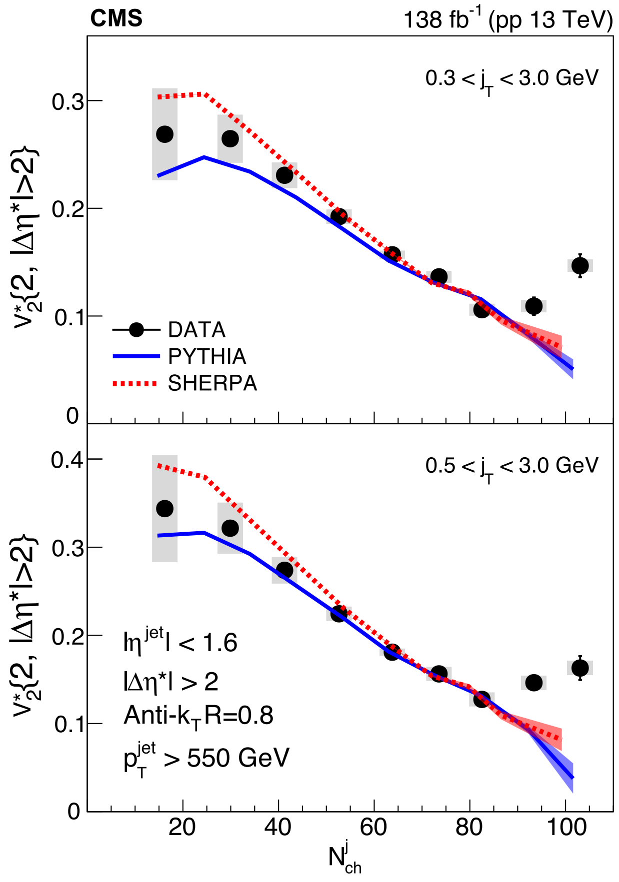

FIG. 4. The elliptic anisotropies v_2^{*}, obtained from two-particle correlations as a function of $N_{\mathrm{ch}}^{\mathrm{j}}$, for anti-$k_{\mathrm{T}}$ $\mathrm{R} = 0.8$ jets with $p_{\mathrm{T}}^{\mathrm{jet}} > 550$ GeV and $|\eta^{\mathrm{jet}}| < 1.6$ in pp collisions at 13 TeV from data, PYTHIA8, and SHERPA. Vertical bars on data points indicate statistical uncertainty, while shaded boxes represent systematic uncertainties. The shaded envelope around the MC curves shows statistical uncertainty.

In summary, the first search for long-range near-side correlations and quantum chromodynamics (QCD) collective effects in jets produced in $\sqrt{s} = 13$ TeV proton-proton collisions is presented. The measurement is performed using charged particles from individual jets, after their kinematic variables have been calculated in a coordinate basis having the z axis coinciding with the jet direction. Two-particle correlations are studied as a function of the number of charged particles in the jet, $N_{\mathrm{ch}}^{\mathrm{j}}$. The first three Fourier harmonics of long-range azimuthal correlations are extracted and compared with those calculated using the PYTHIA8 and SHERPA Monte Carlo (MC) event generators that model the jet fragmentation process. While the data and MC predictions are in good agreement for particle correlations inside jets with $N_{\mathrm{ch}}^{\mathrm{j}} < 80$, the extracted long-range elliptic azimuthal anisotropy v_2^{*} shows a distinct increase in data for $N_{\mathrm{ch}}^{\mathrm{j}} \gtrsim 80$, hinting at a possible onset of collective behavior, which is not reproduced by the MC simulations.

Acknowledgments—We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid and other centers for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC, the CMS detector, and the supporting computing infrastructure provided by the following funding agencies: SC (Armenia); BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES and BNSF (Bulgaria); CERN; CAS, MoST, and NSFC (China); MINCIENCIAS (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); MoER, ERC PUT, and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); SRNSF (Georgia); BMBF, DFG, and HGF (Germany); GSRI (Greece); NKFIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MES and NSC (Poland); FCT (Portugal); MESTD (Serbia); MCIN/AEI and PCTI (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); MHESI and NSTDA (Thailand); TUBITAK and TENMAK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

---

[1] G. F. Sterman and S. Weinberg, Jets from quantum chromodynamics, Phys. Rev. Lett. **39**, 1436 (1977).

[2] R. Brock *et al.* (CTEQ Collaboration), Handbook of perturbative QCD: Version 1.0, Rev. Mod. Phys. **67**, 157 (1995).

[3] J. Adams *et al.* (STAR Collaboration), Distributions of charged hadrons associated with high transverse momentum particles in pp and AuAu collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, Phys. Rev. Lett. **95**, 152301 (2005).

[4] B. Alver *et al.* (PHOBOS Collaboration), System size dependence of cluster properties from two-particle angular correlations in CuCu and AuAu collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, Phys. Rev. C **81**, 024904 (2010).

[5] B. Abelev *et al.* (STAR Collaboration), Long range rapidity correlations and jet production in high energy nuclear collisions, Phys. Rev. C **80**, 064912 (2009).

[6] B. Alver *et al.* (PHOBOS Collaboration), High transverse momentum triggered correlations over a large pseudorapidity acceptance in AuAu collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, Phys. Rev. Lett. **104**, 062301 (2010).

[7] B. Muller, J. Schukraft, and B. Wyslouch, First results from Pb + Pb collisions at the LHC, Annu. Rev. Nucl. Part. Sci. **62**, 361 (2012).

[8] W. Busza, K. Rajagopal, and W. van der Schee, Heavy ion collisions: The big picture, and the big questions, Annu. Rev. Nucl. Part. Sci. **68**, 339 (2018).

[9] CMS Collaboration, Extracting the speed of sound in the strongly interacting matter created in ultrarelativistic lead-lead collisions at the LHC, arXiv:2401.06896.

[10] CMS Collaboration, Long-range and short-range dihadron angular correlations in central PbPb collisions at a nucleon-nucleon center of mass energy of 2.76 TeV, J. High Energy Phys. 07 (2011) 076.

[11] CMS Collaboration, Centrality dependence of dihadron correlations and azimuthal anisotropy harmonics in PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, Eur. Phys. J. C **72**, 2012 (2012).

[12] ALICE Collaboration, Elliptic flow of charged particles in PbPb collisions at 2.76 TeV, Phys. Rev. Lett. **105**, 252302 (2010).

[13] ATLAS Collaboration, Measurement of the azimuthal anisotropy for charged particle production in $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV lead-lead collisions with the ATLAS detector, Phys. Rev. C **86**, 014907 (2012).

[14] CMS Collaboration, Studies of azimuthal dihadron correlations in ultra-central PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, J. High Energy Phys. 02 (2014) 088.

[15] D. d'Enterria, G. K. Eyyubova, V. L. Korotkikh, I. P. Lokhtin, S. V. Petrushanko, L. I. Sarycheva, and A. M. Snigirev, Estimates of hadron azimuthal anisotropy from multiparton interactions in proton-proton collisions at $\sqrt{s} = 14$ TeV, Eur. Phys. J. C **66**, 173 (2010).

[16] L. Cunqueiro, J. Dias de Deus, and C. Pajares, Nuclear like effects in proton-proton collisions at high energy, Eur. Phys. J. C **65**, 423 (2010).

[17] CMS Collaboration, Observation of long-range near-side angular correlations in proton-proton collisions at the LHC, J. High Energy Phys. 09 (2010) 091.

[18] ATLAS Collaboration, Observation of long-range elliptic azimuthal anisotropies in $\sqrt{s_{\mathrm{NN}}} = 13$ and 2.76 TeV pp collisions with the ATLAS detector, Phys. Rev. Lett. **116**, 172301 (2016).

[19] CMS Collaboration, Measurement of long-range near-side two-particle angular correlations in pp collisions at $\sqrt{s_{\mathrm{NN}}} = 13$ TeV, Phys. Rev. Lett. **116**, 172302 (2016).

[20] CMS Collaboration, Evidence for collectivity in pp collisions at the LHC, Phys. Lett. B **765**, 193 (2017).

[21] K. Dusling, W. Li, and B. Schenke, Novel collective phenomena in high-energy proton-proton and proton-nucleus collisions, Int. J. Mod. Phys. E **25**, 1630002 (2016).

[22] CMS Collaboration, Observation of long-range near-side angular correlations in proton-lead collisions at the LHC, Phys. Lett. B **718**, 795 (2013).

[23] ALICE Collaboration, Long-range angular correlations on the near and away side in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Phys. Lett. B **719**, 29 (2013).

[24] ATLAS Collaboration, Observation of associated near-side and away-side long-range correlations in $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV proton-lead collisions with the ATLAS detector, Phys. Rev. Lett. **110**, 182302 (2013).

[25] LHCb Collaboration, Measurements of long-range near-side angular correlations in $\sqrt{s_{\mathrm{NN}}} = 5$ TeV proton-lead collisions in the forward region, Phys. Lett. B **762**, 473 (2016).

[26] ALICE Collaboration, Long-range angular correlations of π, K and p in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Phys. Lett. B **726**, 164 (2013).

[27] CMS Collaboration, Multiplicity and transverse momentum dependence of two- and four-particle correlations in pPb and PbPb collisions, Phys. Lett. B **724**, 213 (2013).

[28] CMS Collaboration, Long-range two-particle correlations of strange hadrons with charged particles in pPb and PbPb collisions at LHC energies, Phys. Lett. B **742**, 200 (2015).

[29] CMS Collaboration, Evidence for collective multi-particle correlations in pPb collisions, Phys. Rev. Lett. **115**, 012301 (2015).

[30] ATLAS Collaboration, Measurement of multi-particle azimuthal correlations in pp, pPb and low-multiplicity PbPb collisions with the ATLAS detector, Eur. Phys. J. C **77**, 428 (2017).

[31] ATLAS Collaboration, Measurement of long-range multiparticle azimuthal correlations with the subevent cumulant method in pp and pPb collisions with the ATLAS detector at the CERN Large Hadron Collider, Phys. Rev. C **97**, 024904 (2018).

[32] C. Aidala *et al.* (PHENIX Collaboration), Creation of quark-gluon plasma droplets with three distinct geometries, Nat. Phys. **15**, 214 (2019).

[33] L. Adamczyk *et al.* (STAR Collaboration), Long-range pseudorapidity dihadron correlations in dAu collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, Phys. Lett. B **747**, 265 (2015).

[34] A. Adare *et al.* (PHENIX Collaboration), Measurements of elliptic and triangular flow in high-multiplicity ^{3}HeAu collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, Phys. Rev. Lett. **115**, 142301 (2015).

[35] C. Aidala *et al.* (PHENIX Collaboration), Measurements of multiparticle correlations in dAu collisions at 200, 62.4, 39, and 19.6 GeV and pAu collisions at 200 GeV and implications for collective behavior, Phys. Rev. Lett. **120**, 062302 (2018).

[36] A. Badea, A. Baty, P. Chang, G. M. Innocenti, M. Maggi, C. McGinn, M. Peters, T.-A. Sheng, J. Thaler, and Y.-J. Lee, Measurements of two-particle correlations in e^+e^- collisions at 91 GeV with ALEPH archived data, Phys. Rev. Lett. **123**, 212002 (2019).

[37] Y. C. Chen *et al.* (Belle Collaboration), Measurement of two-particle correlations of hadrons in e^+e^- collisions at Belle, Phys. Rev. Lett. **128**, 142005 (2022).

[38] Y.-C. Chen, Y. Chen, A. Badea, A. Baty, P. Chang, G. M. Innocenti, M. Maggi, C. McGinn, M. Peters, T.-A. Sheng, J. Thaler, and Y.-J. Lee, Long-range near-side correlation in e^+e^- collisions at 183–209 GeV with ALEPH archived data, Phys. Lett. B **856**, 138957 (2024).

[39] I. Abt *et al.* (ZEUS Collaboration), Two-particle azimuthal correlations as a probe of collective behaviour in deep inelastic ep scattering at HERA, J. High Energy Phys. 04 (2020) 070.

[40] I. Abt *et al.* (ZEUS Collaboration), Azimuthal correlations in photoproduction and deep inelastic ep scattering at HERA, J. High Energy Phys. 12 (2021) 102.

[41] CMS Collaboration, Two-particle azimuthal correlations in γp interactions using pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV, Phys. Lett. B **844**, 137905 (2023).

[42] ATLAS Collaboration, Two-particle azimuthal correlations in photonuclear ultraperipheral PbPb collisions at 5.02 TeV with ATLAS, Phys. Rev. C **104**, 014903 (2021).

[43] R. Perez-Ramos and D. d'Enterria, Energy evolution of the moments of the hadron distribution in QCD jets including NNLL resummation and NLO running-coupling corrections, J. High Energy Phys. 08 (2014) 068.

[44] G. P. Salam, Towards jetography, Eur. Phys. J. C **67**, 637 (2010).

[45] A. Baty, P. Gardner, and W. Li, Novel observables for exploring QCD collective evolution and quantum entanglement within individual jets, Phys. Rev. C **107**, 064908 (2023).

[46] The CMS Collaboration, HEPData record for this analysis (2024), 10.17182/hepdata.146015.

[47] CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum. **3**, S08004 (2008).

[48] CMS Collaboration, Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s} = 13$ TeV, J. Instrum. **15**, P10017 (2020).

[49] CMS Collaboration, The CMS trigger system, J. Instrum. **12**, P01020 (2017).

[50] CMS Collaboration, Electron and photon reconstruction and identification with the CMS experiment at the CERN LHC, J. Instrum. **16**, P05014 (2021).

[51] CMS Collaboration, Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s} = 13$ TeV, J. Instrum. **13**, P06015 (2018).

[52] CMS Collaboration, Description and performance of track and primary-vertex reconstruction with the CMS tracker, J. Instrum. **9**, P10009 (2014).

[53] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, J. Instrum. **12**, P10003 (2017).

[54] CMS Collaboration, Performance of reconstruction and identification of τ leptons decaying to hadrons and ν_τ in pp collisions at $\sqrt{s} = 13$ TeV, J. Instrum. **13**, P10005 (2018).

[55] CMS Collaboration, Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV, J. Instrum. **12**, P02014 (2017).

[56] CMS Collaboration, Performance of missing transverse momentum reconstruction in proton-proton collisions at $\sqrt{s} = 13$ TeV using the CMS detector, J. Instrum. **14**, P07004 (2019).

[57] CMS Collaboration, Charged-particle nuclear modification factors in PbPb and pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, J. High Energy Phys. 04 (2017) 039.

[58] M. Cacciari, G. P. Salam, and G. Soyez, The anti-k_{T} jet clustering algorithm, J. High Energy Phys. 04 (2008) 063.

[59] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, Eur. Phys. J. C **72**, 1896 (2012).

[60] T. Sjostrand, S. Mrenna, and P. Z. Skands, A brief introduction to PYTHIA8.1, Comput. Phys. Commun. **178**, 852 (2008).

[61] CMS Collaboration, Extraction and validation of a new set of CMS PYTHIA8 tunes from underlying-event measurements, Eur. Phys. J. C **80**, 4 (2020).

[62] E. Bothmann *et al.* (Sherpa Collaboration), Event generation with SHERPA2.2, SciPost Phys. **7**, 034 (2019).

[63] B. Andersson, G. Gustafson, G. Ingelman, and T. Sjostrand, Parton fragmentation and string dynamics, Phys. Rep. **97**, 31 (1983).

[64] J.-C. Winter, F. Krauss, and G. Soff, A modified cluster hadronization model, Eur. Phys. J. C **36**, 381 (2004).

[65] S. Agostinelli *et al.* (Geant4 Collaboration), GEANT4—a simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).

[66] CMS Collaboration, Pileup mitigation at CMS in 13 TeV data, J. Instrum. **15**, P09018 (2020).

[67] D. Bertolini, P. Harris, M. Low, and N. Tran, Pileup per particle identification, J. High Energy Phys. 10 (2014) 059.

[68] N. Borghini, P. M. Dinh, and J.-Y. Ollitrault, Flow analysis from multiparticle azimuthal correlations, Phys. Rev. C **64**, 054901 (2001).

A. Hayrapetyan,[1] A. Tumasyan,[1,b] W. Adam,[2] J. W. Andrejkovic,[2] T. Bergauer,[2] S. Chatterjee,[2] K. Damanakis,[2] M. Dragicevic,[2] P. S. Hussain,[2] M. Jeitler,[2,c] N. Krammer,[2] A. Li,[2] D. Liko,[2] I. Mikulec,[2] J. Schieck,[2,c] R. Schöfbeck,[2] D. Schwarz,[2] M. Sonawane,[2] S. Templ,[2] W. Waltenberger,[2] C.-E. Wulz,[2,c] M. R. Darwish,[3,d] T. Janssen,[3] P. Van Mechelen,[3] E. S. Bols,[4] J. D'Hondt,[4] S. Dansana,[4] A. De Moor,[4] M. Delcourt,[4] H. El Faham,[4] S. Lowette,[4] I. Makarenko,[4] D. Müller,[4] A. R. Sahasransu,[4] S. Tavernier,[4] M. Tytgat,[4,e] G. P. Van Onsem,[4] S. Van Putte,[4] D. Vannerom,[4] B. Clerbaux,[5] A. K. Das,[5] G. De Lentdecker,[5] L. Favart,[5] P. Gianneios,[5] D. Hohov,[5] J. Jaramillo,[5] A. Khalilzadeh,[5] K. Lee,[5] M. Mahdavikhorrami,[5] A. Malara,[5] S. Paredes,[5] L. Pétré,[5] N. Postiau,[5] L. Thomas,[5] M. Vanden Bemden,[5] C. Vander Velde,[5] P. Vanlaer,[5] M. De Coen,[6] D. Dobur,[6] Y. Hong,[6] J. Knolle,[6] L. Lambrecht,[6] G. Mestdach,[6] K. Mota Amarilo,[6] C. Rendón,[6] A. Samalan,[6] K. Skovpen,[6] N. Van Den Bossche,[6] J. van der Linden,[6] L. Wezenbeek,[6] A. Benecke,[7] A. Bethani,[7] G. Bruno,[7] C. Caputo,[7] C. Delaere,[7] I. S. Donertas,[7] A. Giammanco,[7] K. Jaffel,[7] Sa. Jain,[7] V. Lemaitre,[7] J. Lidrych,[7] P. Mastrapasqua,[7] K. Mondal,[7] T. T. Tran,[7] S. Wertz,[7] G. A. Alves,[8] E. Coelho,[8] C. Hensel,[8] T. Menezes De Oliveira,[8] A. Moraes,[8] P. Rebello Teles,[8] M. Soeiro,[8] W. L. Aldá Júnior,[9] M. Alves Gallo Pereira,[9] M. Barroso Ferreira Filho,[9] H. Brandao Malbouisson,[9] W. Carvalho,[9] J. Chinellato,[9,f] E. M. Da Costa,[9] G. G. Da Silveira,[9,g] D. De Jesus Damiao,[9] S. Fonseca De Souza,[9] R. Gomes De Souza,[9] J. Martins,[9,h] C. Mora Herrera,[9] L. Mundim,[9] H. Nogima,[9] J. P. Pinheiro,[9] A. Santoro,[9] A. Sznajder,[9] M. Thiel,[9] A. Vilela Pereira,[9] C. A. Bernardes,[10,g] L. Calligaris,[10] T. R. Fernandez Perez Tomei,[10] E. M. Gregores,[10] P. G. Mercadante,[10] S. F. Novaes,[10] B. Orzari,[10] Sandra S. Padula,[10] A. Aleksandrov,[11] G. Antchev,[11] R. Hadjiiska,[11] P. Iaydjiev,[11] M. Misheva,[11] M. Shopova,[11] G. Sultanov,[11] A. Dimitrov,[12] L. Litov,[12] B. Pavlov,[12] P. Petkov,[12] A. Petrov,[12] E. Shumka,[12] S. Keshri,[13] S. Thakur,[13] T. Cheng,[14] T. Javaid,[14] L. Yuan,[14] Z. Hu,[15] J. Liu,[15] K. Yi,[15,i,j] G. M. Chen,[16,k] H. S. Chen,[16,k] M. Chen,[16,k] F. Iemmi,[16] C. H. Jiang,[16] A. Kapoor,[16,l] H. Liao,[16] Z.-A. Liu,[16,m] R. Sharma,[16,n] J. N. Song,[16,m] J. Tao,[16] C. Wang,[16,k] J. Wang,[16] Z. Wang,[16,k] H. Zhang,[16] A. Agapitos,[17] Y. Ban,[17] A. Levin,[17] C. Li,[17] Q. Li,[17] Y. Mao,[17] S. J. Qian,[17] X. Sun,[17] D. Wang,[17] H. Yang,[17] L. Zhang,[17] C. Zhou,[17] Z. You,[18] N. Lu,[19] G. Bauer,[20,o] X. Gao,[21,p] D. Leggat,[21] H. Okawa,[21] Z. Lin,[22] C. Lu,[22] M. Xiao,[22] C. Avila,[23] D. A. Barbosa Trujillo,[23] A. Cabrera,[23] C. Florez,[23] J. Fraga,[23] J. A. Reyes Vega,[23] J. Mejia Guisao,[24] F. Ramirez,[24] M. Rodriguez,[24] J. D. Ruiz Alvarez,[24] D. Giljanovic,[25] N. Godinovic,[25] D. Lelas,[25] A. Sculac,[25] M. Kovac,[26] T. Sculac,[26] P. Bargassa,[27] V. Brigljevic,[27] B. K. Chitroda,[27] D. Ferencek,[27] S. Mishra,[27] A. Starodumov,[27,q] T. Susa,[27] A. Attikis,[28] K. Christoforou,[28] S. Konstantinou,[28] J. Mousa,[28] C. Nicolaou,[28] F. Ptochos,[28] P. A. Razis,[28] H. Rykaczewski,[28] H. Saka,[28] A. Stepennov,[28] M. Finger,[29] M. Finger Jr.,[29] A. Kveton,[29] E. Ayala,[30] E. Carrera Jarrin,[31] A. A. Abdelalim,[32,r,s] E. Salama,[32,t,u] A. Lotfy,[33] M. A. Mahmoud,[33] K. Ehataht,[34] M. Kadastik,[34] T. Lange,[34] S. Nandan,[34] C. Nielsen,[34] J. Pata,[34] M. Raidal,[34] L. Tani,[34] C. Veelken,[34] H. Kirschenmann,[35] K. Osterberg,[35] M. Voutilainen,[35] S. Bharthuar,[36] E. Brücken,[36] F. Garcia,[36] K. T. S. Kallonen,[36] R. Kinnunen,[36] T. Lampén,[36] K. Lassila-Perini,[36] S. Lehti,[36] T. Lindén,[36] L. Martikainen,[36] M. Myllymäki,[36] M. m. Rantanen,[36] H. Siikonen,[36] E. Tuominen,[36] J. Tuominiemi,[36] P. Luukka,[37] H. Petrow,[37] M. Besancon,[38] F. Couderc,[38] M. Dejardin,[38] D. Denegri,[38] J. L. Faure,[38] F. Ferri,[38] S. Ganjour,[38] P. Gras,[38] G. Hamel de Monchenault,[38] V. Lohezic,[38] J. Malcles,[38] J. Rander,[38] A. Rosowsky,[38] M. Ö. Sahin,[38] A. Savoy-Navarro,[38,v] P. Simkina,[38] M. Titov,[38] M. Tornago,[38] C. Baldenegro Barrera,[39] F. Beaudette,[39] A. Buchot Perraguin,[39] P. Busson,[39] A. Cappati,[39] C. Charlot,[39] M. Chiusi,[39] F. Damas,[39] O. Davignon,[39] A. De Wit,[39] B. A. Fontana Santos Alves,[39] S. Ghosh,[39]

A. Gilbert,[39] R. Granier de Cassagnac,[39] A. Hakimi,[39] B. Harikrishnan,[39] L. Kalipoliti,[39] G. Liu,[39] J. Motta,[39]
M. Nguyen,[39] C. Ochando,[39] L. Portales,[39] R. Salerno,[39] J. B. Sauvan,[39] Y. Sirois,[39] A. Tarabini,[39]
E. Vernazza,[39] A. Zabi,[39] A. Zghiche,[39] J.-L. Agram,[40,w] J. Andrea,[40] D. Apparu,[40] D. Bloch,[40] J.-M. Brom,[40]
E. C. Chabert,[40] C. Collard,[40] S. Falke,[40] U. Goerlach,[40] C. Grimault,[40] R. Haeberle,[40] A.-C. Le Bihan,[40]
M. Meena,[40] G. Saha,[40] M. A. Sessini,[40] P. Van Hove,[40] S. Beauceron,[41] B. Blancon,[41] G. Boudoul,[41]
N. Chanon,[41] J. Choi,[41] D. Contardo,[41] P. Depasse,[41] C. Dozen,[41,x] H. El Mamouni,[41] J. Fay,[41] S. Gascon,[41]
M. Gouzevitch,[41] C. Greenberg,[41] G. Grenier,[41] B. Ille,[41] I. B. Laktineh,[41] M. Lethuillier,[41] L. Mirabito,[41]
S. Perries,[41] A. Purohit,[41] M. Vander Donckt,[41] P. Verdier,[41] J. Xiao,[41] D. Chokheli,[42] I. Lomidze,[42]
Z. Tsamalaidze,[42,q] V. Botta,[43] L. Feld,[43] K. Klein,[43] M. Lipinski,[43] D. Meuser,[43] A. Pauls,[43] N. Röwert,[43]
M. Teroerde,[43] S. Diekmann,[44] A. Dodonova,[44] N. Eich,[44] D. Eliseev,[44] F. Engelke,[44] J. Erdmann,[44]
M. Erdmann,[44] P. Fackeldey,[44] B. Fischer,[44] T. Hebbeker,[44] K. Hoepfner,[44] F. Ivone,[44] A. Jung,[44] M. y. Lee,[44]
L. Mastrolorenzo,[44] F. Mausolf,[44] M. Merschmeyer,[44] A. Meyer,[44] S. Mukherjee,[44] D. Noll,[44] F. Nowotny,[44]
A. Pozdnyakov,[44] Y. Rath,[44] W. Redjeb,[44] F. Rehm,[44] H. Reithler,[44] U. Sarkar,[44] V. Sarkisovi,[44] A. Schmidt,[44]
A. Sharma,[44] J. L. Spah,[44] A. Stein,[44] F. Torres Da Silva De Araujo,[44,y] L. Vigilante,[44] S. Wiedenbeck,[44]
S. Zaleski,[44] C. Dziwok,[45] G. Flügge,[45] W. Haj Ahmad,[45,z] T. Kress,[45] A. Nowack,[45] O. Pooth,[45] A. Stahl,[45]
T. Ziemons,[45] A. Zotz,[45] H. Aarup Petersen,[46] M. Aldaya Martin,[46] J. Alimena,[46] S. Amoroso,[46] Y. An,[46]
S. Baxter,[46] M. Bayatmakou,[46] H. Becerril Gonzalez,[46] O. Behnke,[46] A. Belvedere,[46] S. Bhattacharya,[46]
F. Blekman,[46,aa] K. Borras,[46,bb] A. Campbell,[46] A. Cardini,[46] C. Cheng,[46] F. Colombina,[46]
S. Consuegra Rodríguez,[46] G. Correia Silva,[46] M. De Silva,[46] G. Eckerlin,[46] D. Eckstein,[46] L. I. Estevez Banos,[46]
O. Filatov,[46] E. Gallo,[46,aa] A. Geiser,[46] A. Giraldi,[46] G. Greau,[46] V. Guglielmi,[46] M. Guthoff,[46] A. Hinzmann,[46]
A. Jafari,[46,cc] L. Jeppe,[46] N. Z. Jomhari,[46] B. Kaech,[46] M. Kasemann,[46] C. Kleinwort,[46] R. Kogler,[46]
M. Komm,[46] D. Krücker,[46] W. Lange,[46] D. Leyva Pernia,[46] K. Lipka,[46,dd] W. Lohmann,[46,ee] R. Mankel,[46]
I.-A. Melzer-Pellmann,[46] M. Mendizabal Morentin,[46] A. B. Meyer,[46] G. Milella,[46] A. Mussgiller,[46] L. P. Nair,[46]
A. Nürnberg,[46] Y. Otarid,[46] J. Park,[46] D. Pérez Adán,[46] E. Ranken,[46] A. Raspereza,[46] B. Ribeiro Lopes,[46]
J. Rübenach,[46] A. Saggio,[46] M. Scham,[46,ff,bb] S. Schnake,[46,bb] P. Schütze,[46] C. Schwanenberger,[46,aa]
D. Selivanova,[46] K. Sharko,[46] M. Shchedrolosiev,[46] R. E. Sosa Ricardo,[46] D. Stafford,[46] F. Vazzoler,[46]
A. Ventura Barroso,[46] R. Walsh,[46] Q. Wang,[46] Y. Wen,[46] K. Wichmann,[46] L. Wiens,[46,bb] C. Wissing,[46]
Y. Yang,[46] A. Zimermmane Castro Santos,[46] A. Albrecht,[47] S. Albrecht,[47] M. Antonello,[47] S. Bein,[47]
L. Benato,[47] S. Bollweg,[47] M. Bonanomi,[47] P. Connor,[47] M. Eich,[47] K. El Morabit,[47] Y. Fischer,[47] A. Fröhlich,[47]
C. Garbers,[47] E. Garutti,[47] A. Grohsjean,[47] M. Hajheidari,[47] J. Haller,[47] H. R. Jabusch,[47] G. Kasieczka,[47]
P. Keicher,[47] R. Klanner,[47] W. Korcari,[47] T. Kramer,[47] V. Kutzner,[47] F. Labe,[47] J. Lange,[47] A. Lobanov,[47]
C. Matthies,[47] A. Mehta,[47] L. Moureaux,[47] M. Mrowietz,[47] A. Nigamova,[47] Y. Nissan,[47] A. Paasch,[47]
K. J. Pena Rodriguez,[47] T. Quadfasel,[47] B. Raciti,[47] M. Rieger,[47] D. Savoiu,[47] J. Schindler,[47] P. Schleper,[47]
M. Schröder,[47] J. Schwandt,[47] M. Sommerhalder,[47] H. Stadie,[47] G. Steinbrück,[47] A. Tews,[47] M. Wolf,[47]
S. Brommer,[48] M. Burkart,[48] E. Butz,[48] T. Chwalek,[48] A. Dierlamm,[48] A. Droll,[48] N. Faltermann,[48] M. Giffels,[48]
A. Gottmann,[48] F. Hartmann,[48,gg] R. Hofsaess,[48] M. Horzela,[48] U. Husemann,[48] J. Kieseler,[48] M. Klute,[48]
R. Koppenhöfer,[48] J. M. Lawhorn,[48] M. Link,[48] A. Lintuluoto,[48] S. Maier,[48] S. Mitra,[48] M. Mormile,[48]
Th. Müller,[48] M. Neukum,[48] M. Oh,[48] M. Presilla,[48] G. Quast,[48] K. Rabbertz,[48] B. Regnery,[48] N. Shadskiy,[48]
I. Shvetsov,[48] H. J. Simonis,[48] M. Toms,[48] N. Trevisani,[48] R. Ulrich,[48] R. F. Von Cube,[48] M. Wassmer,[48]
S. Wieland,[48] F. Wittig,[48] R. Wolf,[48] X. Zuo,[48] G. Anagnostou,[49] G. Daskalakis,[49] A. Kyriakis,[49]
A. Papadopoulos,[49,gg] A. Stakia,[49] P. Kontaxakis,[50] G. Melachroinos,[50] A. Panagiotou,[50] I. Papavergou,[50]
I. Paraskevas,[50] N. Saoulidou,[50] K. Theofilatos,[50] E. Tziaferi,[50] K. Vellidis,[50] I. Zisopoulos,[50] G. Bakas,[51]
T. Chatzistavrou,[51] G. Karapostoli,[51] K. Kousouris,[51] I. Papakrivopoulos,[51] E. Siamarkou,[51] G. Tsipolitis,[51]
A. Zacharopoulou,[51] K. Adamidis,[52] I. Bestintzanos,[52] I. Evangelou,[52] C. Foudas,[52] C. Kamtsikis,[52] P. Katsoulis,[52]
P. Kokkas,[52] P. G. Kosmoglou Kioseoglou,[52] N. Manthos,[52] I. Papadopoulos,[52] J. Strologas,[52] M. Bartók,[53,hh]
C. Hajdu,[53] D. Horvath,[53,ii,jj] K. Márton,[53] F. Sikler,[53] V. Veszpremi,[53] M. Csanád,[54] K. Farkas,[54]
M. M. A. Gadallah,[54,kk] Á. Kadlecsik,[54] P. Major,[54] K. Mandal,[54] G. Pásztor,[54] A. J. Rádl,[54,ll] G. I. Veres,[54]
P. Raics,[55] B. Ujvari,[55] G. Zilizi,[55] G. Bencze,[56] S. Czellar,[56] J. Molnar,[56] Z. Szillasi,[56] T. Csorgo,[57,ll] F. Nemes,[57,ll]
T. Novak,[57] J. Babbar,[58] S. Bansal,[58] S. B. Beri,[58] V. Bhatnagar,[58] G. Chaudhary,[58] S. Chauhan,[58]

N. Dhingra,[58,mm] A. Kaur,[58] A. Kaur,[58] H. Kaur,[58] M. Kaur,[58] S. Kumar,[58] K. Sandeep,[58] T. Sheokand,[58] J. B. Singh,[58] A. Singla,[58] A. Ahmed,[59] A. Bhardwaj,[59] A. Chhetri,[59] B. C. Choudhary,[59] A. Kumar,[59] A. Kumar,[59] M. Naimuddin,[59] K. Ranjan,[59] S. Saumya,[59] S. Baradia,[60] S. Barman,[60,nn] S. Bhattacharya,[60] S. Dutta,[60] S. Dutta,[60] S. Sarkar,[60] M. M. Ameen,[61] P. K. Behera,[61] S. C. Behera,[61] S. Chatterjee,[61] P. Jana,[61] P. Kalbhor,[61] J. R. Komaragiri,[61,oo] D. Kumar,[61,oo] L. Panwar,[61,oo] P. R. Pujahari,[61] N. R. Saha,[61] A. Sharma,[61] A. K. Sikdar,[61] S. Verma,[61] S. Dugad,[62] M. Kumar,[62] G. B. Mohanty,[62] P. Suryadevara,[62] A. Bala,[63] S. Banerjee,[63] R. M. Chatterjee,[63] R. K. Dewanjee,[63,pp] M. Guchait,[63] Sh. Jain,[63] A. Jaiswal,[63] S. Karmakar,[63] S. Kumar,[63] G. Majumder,[63] K. Mazumdar,[63] S. Parolia,[63] A. Thachayath,[63] S. Bahinipati,[64,qq] C. Kar,[64] D. Maity,[64,rr] P. Mal,[64] T. Mishra,[64] V. K. Muraleedharan Nair Bindhu,[64,rr] K. Naskar,[64,rr] A. Nayak,[64,rr] P. Sadangi,[64] P. Saha,[64] S. K. Swain,[64] S. Varghese,[64,rr] D. Vats,[64,rr] S. Acharya,[65,ss] A. Alpana,[65] S. Dube,[65] B. Gomber,[65,ss] B. Kansal,[65] A. Laha,[65] B. Sahu,[65,ss] S. Sharma,[65] K. Y. Vaish,[65] H. Bakhshiansohi,[66,tt] E. Khazaie,[66,uu] M. Zeinali,[66,vv] S. Chenarani,[67,ww] S. M. Etesami,[67] M. Khakzad,[67] M. Mohammadi Najafabadi,[67] M. Grunewald,[68] M. Abbrescia,[69a,69b] R. Aly,[69a,69c,r] A. Colaleo,[69a,69b] D. Creanza,[69a,69c] B. D'Anzi,[69a,69b] N. De Filippis,[69a,69c] M. De Palma,[69a,69b] A. Di Florio,[69a,69c] W. Elmetenawee,[69a,69b,r] L. Fiore,[69a] G. Iaselli,[69a,69c] M. Louka,[69a,69b] G. Maggi,[69a,69c] M. Maggi,[69a] I. Margjeka,[69a,69b] V. Mastrapasqua,[69a,69b] S. My,[69a,69b] S. Nuzzo,[69a,69b] A. Pellecchia,[69a,69b] A. Pompili,[69a,69b] G. Pugliese,[69a,69c] R. Radogna,[69a] G. Ramirez-Sanchez,[69a,69c] D. Ramos,[69a] A. Ranieri,[69a] L. Silvestris,[69a] F. M. Simone,[69a,69b] Ü. Sözbilir,[69a] A. Stamerra,[69a] R. Venditti,[69a] P. Verwilligen,[69a] A. Zaza,[69a,69b] G. Abbiendi,[70a] C. Battilana,[70a,70b] D. Bonacorsi,[70a,70b] L. Borgonovi,[70a] R. Campanini,[70a,70b] P. Capiluppi,[70a,70b] A. Castro,[70a,70b] F. R. Cavallo,[70a] M. Cuffiani,[70a,70b] G. M. Dallavalle,[70a] T. Diotalevi,[70a,70b] F. Fabbri,[70a] A. Fanfani,[70a,70b] D. Fasanella,[70a,70b] P. Giacomelli,[70a] L. Giommi,[70a,70b] C. Grandi,[70a] S. Lo Meo,[70a,xx] L. Lunerti,[70a,70b] S. Marcellini,[70a] G. Masetti,[70a] F. L. Navarria,[70a,70b] A. Perrotta,[70a] F. Primavera,[70a,70b] A. M. Rossi,[70a,70b] T. Rovelli,[70a,70b] G. P. Siroli,[70a,70b] S. Costa,[71a,71b,yy] A. Di Mattia,[71a] R. Potenza,[71a,71b] A. Tricomi,[71a,71b,yy] C. Tuve,[71a,71b] P. Assiouras,[72a] G. Barbagli,[72a] G. Bardelli,[72a,72b] B. Camaiani,[72a,72b] A. Cassese,[72a] R. Ceccarelli,[72a] V. Ciulli,[72a,72b] C. Civinini,[72a] R. D'Alessandro,[72a,72b] E. Focardi,[72a,72b] T. Kello,[72a] G. Latino,[72a,72b] P. Lenzi,[72a,72b] M. Lizzo,[72a] M. Meschini,[72a] S. Paoletti,[72a] A. Papanastassiou,[72a,72b] G. Sguazzoni,[72a] L. Viliani,[72a] L. Benussi,[73] S. Bianco,[73] S. Meola,[73,zz] D. Piccolo,[73] P. Chatagnon,[74a] F. Ferro,[74a] E. Robutti,[74a] S. Tosi,[74a,74b] A. Benaglia,[75a] G. Boldrini,[75a,75b] F. Brivio,[75a] F. Cetorelli,[75a] F. De Guio,[75a,75b] M. E. Dinardo,[75a,75b] P. Dini,[75a] S. Gennai,[75a] R. Gerosa,[75a,75b] A. Ghezzi,[75a,75b] P. Govoni,[75a,75b] L. Guzzi,[75a] M. T. Lucchini,[75a,75b] M. Malberti,[75a] S. Malvezzi,[75a] A. Massironi,[75a] D. Menasce,[75a] L. Moroni,[75a] M. Paganoni,[75a,75b] D. Pedrini,[75a] B. S. Pinolini,[75a] S. Ragazzi,[75a,75b] T. Tabarelli de Fatis,[75a,75b] D. Zuolo,[75a] S. Buontempo,[76a] A. Cagnotta,[76a,76b] F. Carnevali,[76a,76b] N. Cavallo,[76a,76c] F. Fabozzi,[76a,76c] A. O. M. Iorio,[76a,76b] L. Lista,[76a,76b,aaa] P. Paolucci,[76a,gg] B. Rossi,[76a] C. Sciacca,[76a,76b] R. Ardino,[77a] P. Azzi,[77a] N. Bacchetta,[77a,bbb] D. Bisello,[77a,77b] P. Bortignon,[77a] A. Bragagnolo,[77a,77b] R. Carlin,[77a,77b] P. Checchia,[77a] T. Dorigo,[77a] F. Gasparini,[77a,77b] U. Gasparini,[77a,77b] A. Gozzelino,[77a] M. Gulmini,[77a,ccc] E. Lusiani,[77a] M. Margoni,[77a,77b] F. Marini,[77a] A. T. Meneguzzo,[77a,77b] M. Migliorini,[77a,77b] J. Pazzini,[77a,77b] P. Ronchese,[77a,77b] R. Rossin,[77a,77b] F. Simonetto,[77a,77b] G. Strong,[77a] M. Tosi,[77a,77b] A. Triossi,[77a,77b] H. Yarar,[77a,77b] M. Zanetti,[77a,77b] P. Zotto,[77a,77b] A. Zucchetta,[77a,77b] S. Abu Zeid,[78a,u] C. Aimè,[78a,78b] A. Braghieri,[78a] S. Calzaferri,[78a] D. Fiorina,[78a] P. Montagna,[78a,78b] V. Re,[78a] C. Riccardi,[78a,78b] P. Salvini,[78a] I. Vai,[78a,78b] P. Vitulo,[78a,78b] S. Ajmal,[79a,79b] G. M. Bilei,[79a] D. Ciangottini,[79a,79b] L. Fanò,[79a,79b] M. Magherini,[79a,79b] G. Mantovani,[79a,79b] V. Mariani,[79a,79b] M. Menichelli,[79a] F. Moscatelli,[79a,ddd] A. Rossi,[79a,79b] A. Santocchia,[79a,79b] D. Spiga,[79a] T. Tedeschi,[79a,79b] P. Asenov,[80a,80b] P. Azzurri,[80a] G. Bagliesi,[80a] R. Bhattacharya,[80a] L. Bianchini,[80a,80b] T. Boccali,[80a] E. Bossini,[80a] D. Bruschini,[80a,80c] R. Castaldi,[80a] M. A. Ciocci,[80a,80b] M. Cipriani,[80a,80b] V. D'Amante,[80a,80d] R. Dell'Orso,[80a] S. Donato,[80a] A. Giassi,[80a] F. Ligabue,[80a,80c] D. Matos Figueiredo,[80a] A. Messineo,[80a,80b] M. Musich,[80a,80b] F. Palla,[80a] A. Rizzi,[80a,80b] G. Rolandi,[80a,80c] S. Roy Chowdhury,[80a] T. Sarkar,[80a] A. Scribano,[80a] P. Spagnolo,[80a] R. Tenchini,[80a] G. Tonelli,[80a,80b] N. Turini,[80a,80d] A. Venturi,[80a] P. G. Verdini,[80a] P. Barria,[81a] M. Campana,[81a,81b] F. Cavallari,[81a] L. Cunqueiro Mendez,[81a,81b] D. Del Re,[81a,81b] E. Di Marco,[81a] M. Diemoz,[81a] F. Errico,[81a,81b] E. Longo,[81a,81b] P. Meridiani,[81a] J. Mijuskovic,[81a,81b] G. Organtini,[81a,81b] F. Pandolfi,[81a] R. Paramatti,[81a,81b] C. Quaranta,[81a,81b]

S. Rahatlou,[81a,81b] C. Rovelli,[81a] F. Santanastasio,[81a,81b] L. Soffi,[81a] N. Amapane,[82a,82b] R. Arcidiacono,[82a,82c]
S. Argiro,[82a,82b] M. Arneodo,[82a,82c] N. Bartosik,[82a] R. Bellan,[82a,82b] A. Bellora,[82a,82b] C. Biino,[82a] C. Borca,[82a,82b]
N. Cartiglia,[82a] M. Costa,[82a,82b] R. Covarelli,[82a,82b] N. Demaria,[82a] L. Finco,[82a] M. Grippo,[82a,82b] B. Kiani,[82a,82b]
F. Legger,[82a] F. Luongo,[82a,82b] C. Mariotti,[82a] L. Markovic,[82a,82b] S. Maselli,[82a] A. Mecca,[82a,82b]
E. Migliore,[82a,82b] M. Monteno,[82a] R. Mulargia,[82a] M. M. Obertino,[82a,82b] G. Ortona,[82a] L. Pacher,[82a,82b]
N. Pastrone,[82a] M. Pelliccioni,[82a] M. Ruspa,[82a,82c] F. Siviero,[82a,82b] V. Sola,[82a,82b] A. Solano,[82a,82b] A. Staiano,[82a]
C. Tarricone,[82a,82b] D. Trocino,[82a] G. Umoret,[82a,82b] E. Vlasov,[82a,82b] S. Belforte,[83a] V. Candelise,[83a,83b]
M. Casarsa,[83a] F. Cossutti,[83a] K. De Leo,[83a,83b] G. Della Ricca,[83a,83b] S. Dogra,[84] J. Hong,[84] C. Huh,[84]
B. Kim,[84] D. H. Kim,[84] J. Kim,[84] H. Lee,[84] S. W. Lee,[84] C. S. Moon,[84] Y. D. Oh,[84] M. S. Ryu,[84]
S. Sekmen,[84] Y. C. Yang,[84] M. S. Kim,[85] G. Bak,[86] P. Gwak,[86] H. Kim,[86] D. H. Moon,[86] E. Asilar,[87]
D. Kim,[87] T. J. Kim,[87] J. A. Merlin,[87] S. Choi,[88] S. Han,[88] B. Hong,[88] K. Lee,[88] K. S. Lee,[88] S. Lee,[88] J. Park,[88]
S. K. Park,[88] J. Yoo,[88] J. Goh,[89] S. Yang,[89] H. S. Kim,[90] Y. Kim,[90] S. Lee,[90] J. Almond,[91] J. H. Bhyun,[91] J. Choi,[91]
W. Jun,[91] J. Kim,[91] S. Ko,[91] H. Kwon,[91] H. Lee,[91] J. Lee,[91] J. Lee,[91] B. H. Oh,[91] S. B. Oh,[91] H. Seo,[91]
U. K. Yang,[91] I. Yoon,[91] W. Jang,[92] D. Y. Kang,[92] Y. Kang,[92] S. Kim,[92] B. Ko,[92] J. S. H. Lee,[92] Y. Lee,[92]
I. C. Park,[92] Y. Roh,[92] I. J. Watson,[92] S. Ha,[93] H. D. Yoo,[93] M. Choi,[94] M. R. Kim,[94] H. Lee,[94] Y. Lee,[94] I. Yu,[94]
T. Beyrouthy,[95] Y. Maghrbi,[95] K. Dreimanis,[96] A. Gaile,[96] G. Pikurs,[96] A. Potrebko,[96] M. Seidel,[96]
V. Veckalns,[96,eee] N. R. Strautnieks,[97] M. Ambrozas,[98] A. Juodagalvis,[98] A. Rinkevicius,[98] G. Tamulaitis,[98]
N. Bin Norjoharuddeen,[99] I. Yusuff,[99,fff] Z. Zolkapli,[99] J. F. Benitez,[100] A. Castaneda Hernandez,[100]
H. A. Encinas Acosta,[100] L. G. Gallegos Maríñez,[100] M. León Coello,[100] J. A. Murillo Quijada,[100] A. Sehrawat,[100]
L. Valencia Palomo,[100] G. Ayala,[101] H. Castilla-Valdez,[101] H. Crotte Ledesma,[101] E. De La Cruz-Burelo,[101]
I. Heredia-De La Cruz,[101,ggg] R. Lopez-Fernandez,[101] C. A. Mondragon Herrera,[101] A. Sánchez Hernández,[101]
C. Oropeza Barrera,[102] M. Ramírez García,[102] I. Bautista,[103] I. Pedraza,[103] H. A. Salazar Ibarguen,[103]
C. Uribe Estrada,[103] I. Bubanja,[104] N. Raicevic,[104] P. H. Butler,[105] A. Ahmad,[106] M. I. Asghar,[106] A. Awais,[106]
M. I. M. Awan,[106] H. R. Hoorani,[106] W. A. Khan,[106] V. Avati,[107] L. Grzanka,[107] M. Malawski,[107] H. Bialkowska,[108]
M. Bluj,[108] B. Boimska,[108] M. Górski,[108] M. Kazana,[108] M. Szleper,[108] P. Zalewski,[108] K. Bunkowski,[109]
K. Doroba,[109] A. Kalinowski,[109] M. Konecki,[109] J. Krolikowski,[109] A. Muhammad,[109] K. Pozniak,[110]
W. Zabolotny,[110] M. Araujo,[111] D. Bastos,[111] C. Beirão Da Cruz E Silva,[111] A. Boletti,[111] M. Bozzo,[111]
T. Camporesi,[111] G. Da Molin,[111] P. Faccioli,[111] M. Gallinaro,[111] J. Hollar,[111] N. Leonardo,[111] T. Niknejad,[111]
A. Petrilli,[111] M. Pisano,[111] J. Seixas,[111] J. Varela,[111] J. W. Wulff,[111] P. Adzic,[112] P. Milenovic,[112]
M. Dordevic,[113] J. Milosevic,[113] V. Rekovic,[113] M. Aguilar-Benitez,[114] J. Alcaraz Maestre,[114] Cristina F. Bedoya,[114]
M. Cepeda,[114] M. Cerrada,[114] N. Colino,[114] B. De La Cruz,[114] A. Delgado Peris,[114] A. Escalante Del Valle,[114]
D. Fernández Del Val,[114] J. P. Fernández Ramos,[114] J. Flix,[114] M. C. Fouz,[114] O. Gonzalez Lopez,[114]
S. Goy Lopez,[114] J. M. Hernandez,[114] M. I. Josa,[114] D. Moran,[114] C. M. Morcillo Perez,[114] Á. Navarro Tobar,[114]
C. Perez Dengra,[114] A. Pérez-Calero Yzquierdo,[114] J. Puerta Pelayo,[114] I. Redondo,[114] D. D. Redondo Ferrero,[114]
L. Romero,[114] S. Sánchez Navas,[114] L. Urda Gómez,[114] J. Vazquez Escobar,[114] C. Willmott,[114] J. F. de Trocóniz,[115]
B. Alvarez Gonzalez,[116] J. Cuevas,[116] J. Fernandez Menendez,[116] S. Folgueras,[116] I. Gonzalez Caballero,[116]
J. R. González Fernández,[116] E. Palencia Cortezon,[116] C. Ramón Álvarez,[116] V. Rodríguez Bouza,[116]
A. Soto Rodríguez,[116] A. Trapote,[116] C. Vico Villalba,[116] P. Vischia,[116] S. Bhowmik,[117] S. Blanco Fernández,[117]
J. A. Brochero Cifuentes,[117] I. J. Cabrillo,[117] A. Calderon,[117] J. Duarte Campderros,[117] M. Fernandez,[117]
G. Gomez,[117] C. Lasaosa García,[117] C. Martinez Rivero,[117] P. Martinez Ruiz del Arbol,[117] F. Matorras,[117]
P. Matorras Cuevas,[117] E. Navarrete Ramos,[117] J. Piedra Gomez,[117] L. Scodellaro,[117] I. Vila,[117]
J. M. Vizan Garcia,[117] M. K. Jayananda,[118] B. Kailasapathy,[118,hhh] D. U. J. Sonnadara,[118]
D. D. C. Wickramarathna,[118] W. G. D. Dharmaratna,[119,iii] K. Liyanage,[119] N. Perera,[119] N. Wickramage,[119]
D. Abbaneo,[120] C. Amendola,[120] E. Auffray,[120] G. Auzinger,[120] J. Baechler,[120] D. Barney,[120]
A. Bermúdez Martínez,[120] M. Bianco,[120] B. Bilin,[120] A. A. Bin Anuar,[120] A. Bocci,[120] C. Botta,[120]
E. Brondolin,[120] C. Caillol,[120] G. Cerminara,[120] N. Chernyavskaya,[120] D. d'Enterria,[120] A. Dabrowski,[120]
A. David,[120] A. De Roeck,[120] M. M. Defranchis,[120] M. Deile,[120] M. Dobson,[120] L. Forthomme,[120]
G. Franzoni,[120] W. Funk,[120] S. Giani,[120] D. Gigi,[120] K. Gill,[120] F. Glege,[120] L. Gouskos,[120] M. Haranko,[120]
J. Hegeman,[120] B. Huber,[120] V. Innocente,[120] T. James,[120] P. Janot,[120] S. Laurila,[120] P. Lecoq,[120] E. Leutgeb,[120]

C. Lourenço,[120] B. Maier,[120] L. Malgeri,[120] M. Mannelli,[120] A. C. Marini,[120] M. Matthewman,[120] F. Meijers,[120]
S. Mersi,[120] E. Meschi,[120] V. Milosevic,[120] F. Monti,[120] F. Moortgat,[120] M. Mulders,[120] I. Neutelings,[120]
S. Orfanelli,[120] F. Pantaleo,[120] G. Petrucciani,[120] A. Pfeiffer,[120] M. Pierini,[120] D. Piparo,[120] H. Qu,[120]
D. Rabady,[120] G. Reales Gutiérrez,[120] M. Rovere,[120] H. Sakulin,[120] S. Scarfi,[120] C. Schwick,[120] M. Selvaggi,[120]
A. Sharma,[120] K. Shchelina,[120] P. Silva,[120] P. Sphicas,[120,jjj] A. G. Stahl Leiton,[120] A. Steen,[120] S. Summers,[120]
D. Treille,[120] P. Tropea,[120] A. Tsirou,[120] D. Walter,[120] J. Wanczyk,[120,kkk] J. Wang,[120] S. Wuchterl,[120]
P. Zehetner,[120] P. Zejdl,[120] W. D. Zeuner,[120] T. Bevilacqua,[121,lll] L. Caminada,[121,lll] A. Ebrahimi,[121]
W. Erdmann,[121] R. Horisberger,[121] Q. Ingram,[121] H. C. Kaestli,[121] D. Kotlinski,[121] C. Lange,[121]
M. Missiroli,[121,lll] L. Noehte,[121,lll] T. Rohe,[121] T. K. Aarrestad,[122] K. Androsov,[122,kkk] M. Backhaus,[122]
A. Calandri,[122] C. Cazzaniga,[122] K. Datta,[122] A. De Cosa,[122] G. Dissertori,[122] M. Dittmar,[122] M. Donegà,[122]
F. Eble,[122] M. Galli,[122] K. Gedia,[122] F. Glessgen,[122] C. Grab,[122] D. Hits,[122] W. Lustermann,[122] A.-M. Lyon,[122]
R. A. Manzoni,[122] M. Marchegiani,[122] L. Marchese,[122] C. Martin Perez,[122] A. Mascellani,[122,kkk]
F. Nessi-Tedaldi,[122] F. Pauss,[122] V. Perovic,[122] S. Pigazzini,[122] C. Reissel,[122] T. Reitenspiess,[122] B. Ristic,[122]
F. Riti,[122] D. Ruini,[122] R. Seidita,[122] J. Steggemann,[122,kkk] D. Valsecchi,[122] R. Wallny,[122] C. Amsler,[123,mmm]
P. Bärtschi,[123] D. Brzhechko,[123] M. F. Canelli,[123] K. Cormier,[123] J. K. Heikkilä,[123] M. Huwiler,[123] W. Jin,[123]
A. Jofrehei,[123] B. Kilminster,[123] S. Leontsinis,[123] S. P. Liechti,[123] A. Macchiolo,[123] P. Meiring,[123]
U. Molinatti,[123] A. Reimers,[123] P. Robmann,[123] S. Sanchez Cruz,[123] M. Senger,[123] Y. Takahashi,[123]
R. Tramontano,[123] C. Adloff,[124,nnn] D. Bhowmik,[124] C. M. Kuo,[124] W. Lin,[124] P. K. Rout,[124] P. C. Tiwari,[124,oo]
S. S. Yu,[124] L. Ceard,[125] Y. Chao,[125] K. F. Chen,[125] P. s. Chen,[125] Z. g. Chen,[125] A. De Iorio,[125] W.-S. Hou,[125]
T. h. Hsu,[125] Y. w. Kao,[125] R. Khurana,[125] G. Kole,[125] Y. y. Li,[125] R.-S. Lu,[125] E. Paganis,[125] X. f. Su,[125]
J. Thomas-Wilsker,[125] L. s. Tsai,[125] H. y. Wu,[125] E. Yazgan,[125] C. Asawatangtrakuldee,[126] N. Srimanobhas,[126]
V. Wachirapusitanand,[126] D. Agyel,[127] F. Boran,[127] Z. S. Demiroglu,[127] F. Dolek,[127] I. Dumanoglu,[127,ooo]
E. Eskut,[127] Y. Guler,[127,ppp] E. Gurpinar Guler,[127,ppp] C. Isik,[127] O. Kara,[127] A. Kayis Topaksu,[127] U. Kiminsu,[127]
G. Onengut,[127] K. Ozdemir,[127,qqq] A. Polatoz,[127] B. Tali,[127,rrr] U. G. Tok,[127] S. Turkcapar,[127] E. Uslan,[127]
I. S. Zorbakir,[127] M. Yalvac,[128,sss] B. Akgun,[129] I. O. Atakisi,[129] E. Gülmez,[129] M. Kaya,[129,ttt] O. Kaya,[129,uuu]
S. Tekten,[129,vvv] A. Cakir,[130] K. Cankocak,[130,ooo,www] Y. Komurcu,[130] S. Sen,[130,xxx] O. Aydilek,[131] S. Cerci,[131,rrr]
V. Epshteyn,[131] B. Hacisahinoglu,[131] I. Hos,[131,yyy] B. Kaynak,[131] S. Ozkorucuklu,[131] O. Potok,[131] H. Sert,[131]
C. Simsek,[131] C. Zorbilmez,[131] B. Isildak,[132,zzz] D. Sunar Cerci,[132,rrr] A. Boyaryntsev,[133] B. Grynyov,[133]
L. Levchuk,[134] D. Anthony,[135] J. J. Brooke,[135] A. Bundock,[135] F. Bury,[135] E. Clement,[135] D. Cussans,[135]
H. Flacher,[135] M. Glowacki,[135] J. Goldstein,[135] H. F. Heath,[135] L. Kreczko,[135] S. Paramesvaran,[135]
S. Seif El Nasr-Storey,[135] V. J. Smith,[135] N. Stylianou,[135,aaaa] K. Walkingshaw Pass,[135] R. White,[135] A. H. Ball,[136]
K. W. Bell,[136] A. Belyaev,[136,bbbb] C. Brew,[136] R. M. Brown,[136] D. J. A. Cockerill,[136] C. Cooke,[136] K. V. Ellis,[136]
K. Harder,[136] S. Harper,[136] M.-L. Holmberg,[136,cccc] J. Linacre,[136] K. Manolopoulos,[136] D. M. Newbold,[136]
E. Olaiya,[136] D. Petyt,[136] T. Reis,[136] G. Salvi,[136] T. Schuh,[136] C. H. Shepherd-Themistocleous,[136] I. R. Tomalin,[136]
T. Williams,[136] R. Bainbridge,[137] P. Bloch,[137] C. E. Brown,[137] O. Buchmuller,[137] V. Cacchio,[137]
C. A. Carrillo Montoya,[137] G. S. Chahal,[137,dddd] D. Colling,[137] J. S. Dancu,[137] I. Das,[137] P. Dauncey,[137]
G. Davies,[137] J. Davies,[137] M. Della Negra,[137] S. Fayer,[137] G. Fedi,[137] G. Hall,[137] M. H. Hassanshahi,[137]
A. Howard,[137] G. Iles,[137] M. Knight,[137] J. Langford,[137] J. León Holgado,[137] L. Lyons,[137] A.-M. Magnan,[137]
S. Malik,[137] M. Mieskolainen,[137] J. Nash,[137,eeee] M. Pesaresi,[137] B. C. Radburn-Smith,[137] A. Richards,[137]
A. Rose,[137] K. Savva,[137] C. Seez,[137] R. Shukla,[137] A. Tapper,[137] K. Uchida,[137] G. P. Uttley,[137] L. H. Vage,[137]
T. Virdee,[137,gg] M. Vojinovic,[137] N. Wardle,[137] D. Winterbottom,[137] K. Coldham,[138] J. E. Cole,[138] A. Khan,[138]
P. Kyberd,[138] I. D. Reid,[138] S. Abdullin,[139] A. Brinkerhoff,[139] B. Caraway,[139] J. Dittmann,[139] K. Hatakeyama,[139]
J. Hiltbrand,[139] B. McMaster,[139] M. Saunders,[139] S. Sawant,[139] C. Sutantawibul,[139] J. Wilson,[139] R. Bartek,[140]
A. Dominguez,[140] C. Huerta Escamilla,[140] A. E. Simsek,[140] R. Uniyal,[140] A. M. Vargas Hernandez,[140] B. Bam,[141]
R. Chudasama,[141] S. I. Cooper,[141] S. V. Gleyzer,[141] C. U. Perez,[141] P. Rumerio,[141,ffff] E. Usai,[141] R. Yi,[141]
A. Akpinar,[142] D. Arcaro,[142] C. Cosby,[142] Z. Demiragli,[142] C. Erice,[142] C. Fangmeier,[142]
C. Fernandez Madrazo,[142] E. Fontanesi,[142] D. Gastler,[142] F. Golf,[142] S. Jeon,[142] I. Reed,[142] J. Rohlf,[142]
K. Salyer,[142] D. Sperka,[142] D. Spitzbart,[142] I. Suarez,[142] A. Tsatsos,[142] S. Yuan,[142] A. G. Zecchinelli,[142]
G. Benelli,[143] X. Coubez,[143,bb] D. Cutts,[143] M. Hadley,[143] U. Heintz,[143] J. M. Hogan,[143,gggg] T. Kwon,[143]

G. Landsberg,[143] K. T. Lau,[143] D. Li,[143] J. Luo,[143] S. Mondal,[143] M. Narain,[143,a] N. Pervan,[143] S. Sagir,[143,hhhh]
F. Simpson,[143] M. Stamenkovic,[143] W. Y. Wong,[143] X. Yan,[143] W. Zhang,[143] S. Abbott,[144] J. Bonilla,[144]
C. Brainerd,[144] R. Breedon,[144] M. Calderon De La Barca Sanchez,[144] M. Chertok,[144] M. Citron,[144] J. Conway,[144]
P. T. Cox,[144] R. Erbacher,[144] F. Jensen,[144] O. Kukral,[144] G. Mocellin,[144] M. Mulhearn,[144] D. Pellett,[144]
W. Wei,[144] Y. Yao,[144] F. Zhang,[144] M. Bachtis,[145] R. Cousins,[145] A. Datta,[145] G. Flores Avila,[145] J. Hauser,[145]
M. Ignatenko,[145] M. A. Iqbal,[145] T. Lam,[145] E. Manca,[145] A. Nunez Del Prado,[145] D. Saltzberg,[145] V. Valuev,[145]
R. Clare,[146] J. W. Gary,[146] M. Gordon,[146] G. Hanson,[146] W. Si,[146] S. Wimpenny,[146,a] J. G. Branson,[147]
S. Cittolin,[147] S. Cooperstein,[147] D. Diaz,[147] J. Duarte,[147] L. Giannini,[147] J. Guiang,[147] R. Kansal,[147]
V. Krutelyov,[147] R. Lee,[147] J. Letts,[147] M. Masciovecchio,[147] F. Mokhtar,[147] S. Mukherjee,[147] M. Pieri,[147]
M. Quinnan,[147] B. V. Sathia Narayanan,[147] V. Sharma,[147] M. Tadel,[147] E. Vourliotis,[147] F. Würthwein,[147]
Y. Xiang,[147] A. Yagil,[147] A. Barzdukas,[148] L. Brennan,[148] C. Campagnari,[148] A. Dorsett,[148] J. Incandela,[148]
J. Kim,[148] A. J. Li,[148] P. Masterson,[148] H. Mei,[148] J. Richman,[148] U. Sarica,[148] R. Schmitz,[148] F. Setti,[148]
J. Sheplock,[148] D. Stuart,[148] T. Á. Vámi,[148] S. Wang,[148] A. Bornheim,[149] O. Cerri,[149] A. Latorre,[149] J. Mao,[149]
H. B. Newman,[149] M. Spiropulu,[149] J. R. Vlimant,[149] C. Wang,[149] S. Xie,[149] R. Y. Zhu,[149] J. Alison,[150] S. An,[150]
M. B. Andrews,[150] P. Bryant,[150] M. Cremonesi,[150] V. Dutta,[150] T. Ferguson,[150] A. Harilal,[150] C. Liu,[150]
T. Mudholkar,[150] S. Murthy,[150] P. Palit,[150] M. Paulini,[150] A. Roberts,[150] A. Sanchez,[150] W. Terrill,[150]
J. P. Cumalat,[151] W. T. Ford,[151] A. Hart,[151] A. Hassani,[151] G. Karathanasis,[151] E. MacDonald,[151]
N. Manganelli,[151] A. Perloff,[151] C. Savard,[151] N. Schonbeck,[151] K. Stenson,[151] K. A. Ulmer,[151] S. R. Wagner,[151]
N. Zipper,[151] J. Alexander,[152] S. Bright-Thonney,[152] X. Chen,[152] D. J. Cranshaw,[152] J. Fan,[152] X. Fan,[152]
D. Gadkari,[152] S. Hogan,[152] P. Kotamnives,[152] J. Monroy,[152] M. Oshiro,[152] J. R. Patterson,[152] J. Reichert,[152]
M. Reid,[152] A. Ryd,[152] J. Thom,[152] P. Wittich,[152] R. Zou,[152] M. Albrow,[153] M. Alyari,[153] O. Amram,[153]
G. Apollinari,[153] A. Apresyan,[153] L. A. T. Bauerdick,[153] D. Berry,[153] J. Berryhill,[153] P. C. Bhat,[153] K. Burkett,[153]
J. N. Butler,[153] A. Canepa,[153] G. B. Cerati,[153] H. W. K. Cheung,[153] F. Chlebana,[153] G. Cummings,[153]
J. Dickinson,[153] I. Dutta,[153] V. D. Elvira,[153] Y. Feng,[153] J. Freeman,[153] A. Gandrakota,[153] Z. Gecse,[153]
L. Gray,[153] D. Green,[153] A. Grummer,[153] S. Grünendahl,[153] D. Guerrero,[153] O. Gutsche,[153] R. M. Harris,[153]
R. Heller,[153] T. C. Herwig,[153] J. Hirschauer,[153] L. Horyn,[153] B. Jayatilaka,[153] S. Jindariani,[153] M. Johnson,[153]
U. Joshi,[153] T. Klijnsma,[153] B. Klima,[153] K. H. M. Kwok,[153] S. Lammel,[153] D. Lincoln,[153] R. Lipton,[153]
T. Liu,[153] C. Madrid,[153] K. Maeshima,[153] C. Mantilla,[153] D. Mason,[153] P. McBride,[153] P. Merkel,[153]
S. Mrenna,[153] S. Nahn,[153] J. Ngadiuba,[153] D. Noonan,[153] V. Papadimitriou,[153] N. Pastika,[153] K. Pedro,[153]
C. Pena,[153,iiii] F. Ravera,[153] A. Reinsvold Hall,[153,jjjj] L. Ristori,[153] E. Sexton-Kennedy,[153] N. Smith,[153]
A. Soha,[153] L. Spiegel,[153] S. Stoynev,[153] J. Strait,[153] L. Taylor,[153] S. Tkaczyk,[153] N. V. Tran,[153] L. Uplegger,[153]
E. W. Vaandering,[153] I. Zoi,[153] C. Aruta,[154] P. Avery,[154] D. Bourilkov,[154] L. Cadamuro,[154] P. Chang,[154]
V. Cherepanov,[154] R. D. Field,[154] E. Koenig,[154] M. Kolosova,[154] J. Konigsberg,[154] A. Korytov,[154] K. H. Lo,[154]
K. Matchev,[154] N. Menendez,[154] G. Mitselmakher,[154] K. Mohrman,[154] A. Muthirakalayil Madhu,[154] N. Rawal,[154]
D. Rosenzweig,[154] S. Rosenzweig,[154] K. Shi,[154] J. Wang,[154] T. Adams,[155] A. Al Kadhim,[155] A. Askew,[155]
S. Bower,[155] R. Habibullah,[155] V. Hagopian,[155] R. Hashmi,[155] R. S. Kim,[155] S. Kim,[155] T. Kolberg,[155]
G. Martinez,[155] H. Prosper,[155] P. R. Prova,[155] M. Wulansatiti,[155] R. Yohay,[155] J. Zhang,[155] B. Alsufyani,[156]
M. M. Baarmand,[156] S. Butalla,[156] T. Elkafrawy,[156,u] M. Hohlmann,[156] R. Kumar Verma,[156] M. Rahmani,[156]
E. Yanes,[156] M. R. Adams,[157] A. Baty,[157] C. Bennett,[157] R. Cavanaugh,[157] R. Escobar Franco,[157] O. Evdokimov,[157]
C. E. Gerber,[157] D. J. Hofman,[157] J. h. Lee,[157] D. S. Lemos,[157] A. H. Merrit,[157] C. Mills,[157] S. Nanda,[157]
G. Oh,[157] B. Ozek,[157] D. Pilipovic,[157] R. Pradhan,[157] T. Roy,[157] S. Rudrabhatla,[157] M. B. Tonjes,[157]
N. Varelas,[157] Z. Ye,[157] J. Yoo,[157] M. Alhusseini,[158] D. Blend,[158] K. Dilsiz,[158,kkkk] L. Emediato,[158]
G. Karaman,[158] O. K. Köseyan,[158] J.-P. Merlo,[158] A. Mestvirishvili,[158,llll] J. Nachtman,[158] O. Neogi,[158]
H. Ogul,[158,mmmm] Y. Onel,[158] A. Penzo,[158] C. Snyder,[158] E. Tiras,[158,nnnn] B. Blumenfeld,[159] L. Corcodilos,[159]
J. Davis,[159] A. V. Gritsan,[159] L. Kang,[159] S. Kyriacou,[159] P. Maksimovic,[159] M. Roguljic,[159] J. Roskes,[159]
S. Sekhar,[159] M. Swartz,[159] A. Abreu,[160] L. F. Alcerro Alcerro,[160] J. Anguiano,[160] P. Baringer,[160] A. Bean,[160]
Z. Flowers,[160] D. Grove,[160] J. King,[160] G. Krintiras,[160] M. Lazarovits,[160] C. Le Mahieu,[160] C. Lindsey,[160]
J. Marquez,[160] N. Minafra,[160] M. Murray,[160] M. Nickel,[160] M. Pitt,[160] S. Popescu,[160,oooo] C. Rogan,[160]
C. Royon,[160] R. Salvatico,[160] S. Sanders,[160] C. Smith,[160] Q. Wang,[160] G. Wilson,[160] B. Allmond,[161]

A. Ivanov,[161] K. Kaadze,[161] A. Kalogeropoulos,[161] D. Kim,[161] Y. Maravin,[161] K. Nam,[161] J. Natoli,[161] D. Roy,[161] G. Sorrentino,[161] F. Rebassoo,[162] D. Wright,[162] A. Baden,[163] A. Belloni,[163] Y. M. Chen,[163] S. C. Eno,[163] N. J. Hadley,[163] S. Jabeen,[163] R. G. Kellogg,[163] T. Koeth,[163] Y. Lai,[163] S. Lascio,[163] A. C. Mignerey,[163] S. Nabili,[163] C. Palmer,[163] C. Papageorgakis,[163] M. M. Paranjpe,[163] L. Wang,[163] J. Bendavid,[164] I. A. Cali,[164] M. D'Alfonso,[164] J. Eysermans,[164] C. Freer,[164] G. Gomez-Ceballos,[164] M. Goncharov,[164] G. Grosso,[164] P. Harris,[164] D. Hoang,[164] D. Kovalskyi,[164] J. Krupa,[164] L. Lavezzo,[164] Y.-J. Lee,[164] K. Long,[164] C. Mironov,[164] A. Novak,[164] C. Paus,[164] D. Rankin,[164] C. Roland,[164] G. Roland,[164] S. Rothman,[164] G. S. F. Stephans,[164] Z. Wang,[164] B. Wyslouch,[164] T. J. Yang,[164] B. Crossman,[165] B. M. Joshi,[165] C. Kapsiak,[165] M. Krohn,[165] D. Mahon,[165] J. Mans,[165] B. Marzocchi,[165] S. Pandey,[165] M. Revering,[165] R. Rusack,[165] R. Saradhy,[165] N. Schroeder,[165] N. Strobbe,[165] M. A. Wadud,[165] L. M. Cremaldi,[166] K. Bloom,[167] D. R. Claes,[167] G. Haza,[167] J. Hossain,[167] C. Joo,[167] I. Kravchenko,[167] J. E. Siado,[167] W. Tabb,[167] A. Vagnerini,[167] A. Wightman,[167] F. Yan,[167] D. Yu,[167] H. Bandyopadhyay,[168] L. Hay,[168] I. Iashvili,[168] A. Kharchilava,[168] M. Morris,[168] D. Nguyen,[168] S. Rappoccio,[168] H. Rejeb Sfar,[168] A. Williams,[168] G. Alverson,[169] E. Barberis,[169] J. Dervan,[169] Y. Haddad,[169] Y. Han,[169] A. Krishna,[169] J. Li,[169] M. Lu,[169] G. Madigan,[169] R. Mccarthy,[169] D. M. Morse,[169] V. Nguyen,[169] T. Orimoto,[169] A. Parker,[169] L. Skinnari,[169] A. Tishelman-Charny,[169] B. Wang,[169] D. Wood,[169] S. Bhattacharya,[170] J. Bueghly,[170] Z. Chen,[170] S. Dittmer,[170] K. A. Hahn,[170] Y. Liu,[170] Y. Miao,[170] D. G. Monk,[170] M. H. Schmitt,[170] A. Taliercio,[170] M. Velasco,[170] G. Agarwal,[171] R. Band,[171] R. Bucci,[171] S. Castells,[171] A. Das,[171] R. Goldouzian,[171] M. Hildreth,[171] K. W. Ho,[171] K. Hurtado Anampa,[171] T. Ivanov,[171] C. Jessop,[171] K. Lannon,[171] J. Lawrence,[171] N. Loukas,[171] L. Lutton,[171] J. Mariano,[171] N. Marinelli,[171] I. Mcalister,[171] T. McCauley,[171] C. Mcgrady,[171] C. Moore,[171] Y. Musienko,[171,q] H. Nelson,[171] M. Osherson,[171] A. Piccinelli,[171] R. Ruchti,[171] A. Townsend,[171] Y. Wan,[171] M. Wayne,[171] H. Yockey,[171] M. Zarucki,[171] L. Zygala,[171] A. Basnet,[172] B. Bylsma,[172] M. Carrigan,[172] L. S. Durkin,[172] C. Hill,[172] M. Joyce,[172] M. Nunez Ornelas,[172] K. Wei,[172] B. L. Winer,[172] B. R. Yates,[172] F. M. Addesa,[173] H. Bouchamaoui,[173] P. Das,[173] G. Dezoort,[173] P. Elmer,[173] A. Frankenthal,[173] B. Greenberg,[173] N. Haubrich,[173] G. Kopp,[173] S. Kwan,[173] D. Lange,[173] A. Loeliger,[173] D. Marlow,[173] I. Ojalvo,[173] J. Olsen,[173] A. Shevelev,[173] D. Stickland,[173] C. Tully,[173] S. Malik,[174] A. S. Bakshi,[175] V. E. Barnes,[175] S. Chandra,[175] R. Chawla,[175] S. Das,[175] A. Gu,[175] L. Gutay,[175] M. Jones,[175] A. W. Jung,[175] D. Kondratyev,[175] A. M. Koshy,[175] M. Liu,[175] G. Negro,[175] N. Neumeister,[175] G. Paspalaki,[175] S. Piperov,[175] V. Scheurer,[175] J. F. Schulte,[175] M. Stojanovic,[175] J. Thieman,[175] A. K. Virdi,[175] F. Wang,[175] W. Xie,[175] J. Dolen,[176] N. Parashar,[176] A. Pathak,[176] D. Acosta,[177] T. Carnahan,[177] K. M. Ecklund,[177] P. J. Fernández Manteca,[177] S. Freed,[177] P. Gardner,[177] F. J. M. Geurts,[177] W. Li,[177] O. Miguel Colin,[177] B. P. Padley,[177] R. Redjimi,[177] J. Rotter,[177] E. Yigitbasi,[177] Y. Zhang,[177] A. Bodek,[178] P. de Barbaro,[178] R. Demina,[178] J. L. Dulemba,[178] A. Garcia-Bellido,[178] O. Hindrichs,[178] A. Khukhunaishvili,[178] N. Parmar,[178] P. Parygin,[178,q] E. Popova,[178,q] R. Taus,[178] K. Goulianos,[179] B. Chiarito,[180] J. P. Chou,[180] Y. Gershtein,[180] E. Halkiadakis,[180] M. Heindl,[180] D. Jaroslawski,[180] O. Karacheban,[180,ee] I. Laflotte,[180] A. Lath,[180] R. Montalvo,[180] K. Nash,[180] H. Routray,[180] S. Salur,[180] S. Schnetzer,[180] S. Somalwar,[180] R. Stone,[180] S. A. Thayil,[180] S. Thomas,[180] J. Vora,[180] H. Wang,[180] H. Acharya,[181] D. Ally,[181] A. G. Delannoy,[181] S. Fiorendi,[181] S. Higginbotham,[181] T. Holmes,[181] A. R. Kanuganti,[181] N. Karunarathna,[181] L. Lee,[181] E. Nibigira,[181] S. Spanier,[181] D. Aebi,[182] M. Ahmad,[182] O. Bouhali,[182,pppp] R. Eusebi,[182] J. Gilmore,[182] T. Huang,[182] T. Kamon,[182,qqqq] H. Kim,[182] S. Luo,[182] R. Mueller,[182] D. Overton,[182] D. Rathjens,[182] A. Safonov,[182] N. Akchurin,[183] J. Damgov,[183] V. Hegde,[183] A. Hussain,[183] Y. Kazhykarim,[183] K. Lamichhane,[183] S. W. Lee,[183] A. Mankel,[183] T. Peltola,[183] I. Volobouev,[183] A. Whitbeck,[183] E. Appelt,[184] Y. Chen,[184] S. Greene,[184] A. Gurrola,[184] W. Johns,[184] R. Kunnawalkam Elayavalli,[184] A. Melo,[184] F. Romeo,[184] P. Sheldon,[184] S. Tuo,[184] J. Velkovska,[184] J. Viinikainen,[184] B. Cardwell,[185] B. Cox,[185] J. Hakala,[185] R. Hirosky,[185] A. Ledovskoy,[185] C. Neu,[185] C. E. Perez Lara,[185] P. E. Karchin,[186] A. Aravind,[187] S. Banerjee,[187] K. Black,[187] T. Bose,[187] S. Dasu,[187] I. De Bruyn,[187] P. Everaerts,[187] C. Galloni,[187] H. He,[187] M. Herndon,[187] A. Herve,[187] C. K. Koraka,[187] A. Lanaro,[187] R. Loveless,[187] J. Madhusudanan Sreekala,[187] A. Mallampalli,[187] A. Mohammadi,[187] S. Mondal,[187] G. Parida,[187] D. Pinna,[187] A. Savin,[187] V. Shang,[187] V. Sharma,[187] W. H. Smith,[187] D. Teague,[187] H. F. Tsoi,[187] W. Vetens,[187] A. Warden,[187] S. Afanasiev,[188] V. Andreev,[188] Yu. Andreev,[188] T. Aushev,[188] M. Azarkin,[188] A. Babaev,[188] A. Belyaev,[188] V. Blinov,[188,q] E. Boos,[188] V. Borshch,[188] D. Budkouski,[188]

V. Chekhovsky,[188] R. Chistov,[188,q] M. Danilov,[188,q] A. Dermenev,[188] T. Dimova,[188,q] D. Druzhkin,[188,rrrr] A. Ershov,[188] G. Gavrilov,[188] V. Gavrilov,[188] S. Gninenko,[188] V. Golovtcov,[188] N. Golubev,[188] I. Golutvin,[188] I. Gorbunov,[188] A. Gribushin,[188] Y. Ivanov,[188] V. Kachanov,[188] A. Kaminskiy,[188] V. Karjavine,[188] A. Karneyeu,[188] L. Khein,[188] V. Kim,[188,q] M. Kirakosyan,[188] D. Kirpichnikov,[188] M. Kirsanov,[188] O. Kodolova,[188,ssss] V. Korenkov,[188] V. Korotkikh,[188] A. Kozyrev,[188,q] N. Krasnikov,[188] A. Lanev,[188] P. Levchenko,[188,tttt] N. Lychkovskaya,[188] V. Makarenko,[188] A. Malakhov,[188] V. Matveev,[188,q] V. Murzin,[188] A. Nikitenko,[188,uuuu,ssss] S. Obraztsov,[188] V. Oreshkin,[188] V. Palichik,[188] V. Perelygin,[188] S. Petrushanko,[188] S. Polikarpov,[188,q] V. Popov,[188] O. Radchenko,[188,q] M. Savina,[188] V. Savrin,[188] V. Shalaev,[188] S. Shmatov,[188] S. Shulha,[188] Y. Skovpen,[188,q] S. Slabospitskii,[188] V. Smirnov,[188] A. Snigirev,[188] D. Sosnov,[188] V. Sulimov,[188] E. Tcherniaev,[188] A. Terkulov,[188] O. Teryaev,[188] I. Tlisova,[188] A. Toropin,[188] L. Uvarov,[188] A. Uzunian,[188] I. Vardanyan,[188] A. Vorobyev,[188,a] N. Voytishin,[188] B. S. Yuldashev,[188,vvvv] A. Zarubin,[188] I. Zhizhin,[188] and A. Zhokin[188]

(CMS Collaboration)

[1]*Yerevan Physics Institute, Yerevan, Armenia*
[2]*Institut für Hochenergiephysik, Vienna, Austria*
[3]*Universiteit Antwerpen, Antwerpen, Belgium*
[4]*Vrije Universiteit Brussel, Brussel, Belgium*
[5]*Université Libre de Bruxelles, Bruxelles, Belgium*
[6]*Ghent University, Ghent, Belgium*
[7]*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
[8]*Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
[9]*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
[10]*Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil*
[11]*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*
[12]*University of Sofia, Sofia, Bulgaria*
[13]*Instituto De Alta Investigación, Universidad de Tarapacá, Casilla 7 D, Arica, Chile*
[14]*Beihang University, Beijing, China*
[15]*Department of Physics, Tsinghua University, Beijing, China*
[16]*Institute of High Energy Physics, Beijing, China*
[17]*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*
[18]*Sun Yat-Sen University, Guangzhou, China*
[19]*University of Science and Technology of China, Hefei, China*
[20]*Nanjing Normal University, Nanjing, China*
[21]*Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) - Fudan University, Shanghai, China*
[22]*Zhejiang University, Hangzhou, Zhejiang, China*
[23]*Universidad de Los Andes, Bogota, Colombia*
[24]*Universidad de Antioquia, Medellin, Colombia*
[25]*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*
[26]*University of Split, Faculty of Science, Split, Croatia*
[27]*Institute Rudjer Boskovic, Zagreb, Croatia*
[28]*University of Cyprus, Nicosia, Cyprus*
[29]*Charles University, Prague, Czech Republic*
[30]*Escuela Politecnica Nacional, Quito, Ecuador*
[31]*Universidad San Francisco de Quito, Quito, Ecuador*
[32]*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*
[33]*Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt*
[34]*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*
[35]*Department of Physics, University of Helsinki, Helsinki, Finland*
[36]*Helsinki Institute of Physics, Helsinki, Finland*
[37]*Lappeenranta-Lahti University of Technology, Lappeenranta, Finland*
[38]*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
[39]*Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*

[40]*Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France*
[41]*Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France*
[42]*Georgian Technical University, Tbilisi, Georgia*
[43]*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
[44]*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
[45]*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
[46]*Deutsches Elektronen-Synchrotron, Hamburg, Germany*
[47]*University of Hamburg, Hamburg, Germany*
[48]*Karlsruher Institut fuer Technologie, Karlsruhe, Germany*
[49]*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
[50]*National and Kapodistrian University of Athens, Athens, Greece*
[51]*National Technical University of Athens, Athens, Greece*
[52]*University of Ioánnina, Ioánnina, Greece*
[53]*HUN-REN Wigner Research Centre for Physics, Budapest, Hungary*
[54]*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*
[55]*Faculty of Informatics, University of Debrecen, Debrecen, Hungary*
[56]*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
[57]*Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary*
[58]*Panjab University, Chandigarh, India*
[59]*University of Delhi, Delhi, India*
[60]*Saha Institute of Nuclear Physics, HBNI, Kolkata, India*
[61]*Indian Institute of Technology Madras, Madras, India*
[62]*Tata Institute of Fundamental Research-A, Mumbai, India*
[63]*Tata Institute of Fundamental Research-B, Mumbai, India*
[64]*National Institute of Science Education and Research, An OCC of Homi Bhabha National Institute, Bhubaneswar, Odisha, India*
[65]*Indian Institute of Science Education and Research (IISER), Pune, India*
[66]*Isfahan University of Technology, Isfahan, Iran*
[67]*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
[68]*University College Dublin, Dublin, Ireland*
[69a]*INFN Sezione di Bari, Bari, Italy*
[69b]*Università di Bari, Bari, Italy*
[69c]*Politecnico di Bari, Bari, Italy*
[70a]*INFN Sezione di Bologna, Bologna, Italy*
[70b]*Università di Bologna, Bologna, Italy*
[71a]*INFN Sezione di Catania, Catania, Italy*
[71b]*Università di Catania, Catania, Italy*
[72a]*INFN Sezione di Firenze, Firenze, Italy*
[72b]*Università di Firenze, Firenze, Italy*
[73]*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
[74a]*INFN Sezione di Genova, Genova, Italy*
[74b]*Università di Genova, Genova, Italy*
[75a]*INFN Sezione di Milano-Bicocca, Milano, Italy*
[75b]*Università di Milano-Bicocca, Milano, Italy*
[76a]*INFN Sezione di Napoli, Napoli, Italy*
[76b]*Università di Napoli 'Federico II', Napoli, Italy*
[76c]*Università della Basilicata, Potenza, Italy*
[76d]*Scuola Superiore Meridionale (SSM), Napoli, Italy*
[77a]*INFN Sezione di Padova, Padova, Italy*
[77b]*Università di Padova, Padova, Italy*
[77c]*Università di Trento, Trento, Italy*
[78a]*INFN Sezione di Pavia, Pavia, Italy*
[78b]*Università di Pavia, Pavia, Italy*
[79a]*INFN Sezione di Perugia, Perugia, Italy*
[79b]*Università di Perugia, Perugia, Italy*
[80a]*INFN Sezione di Pisa, Pisa, Italy*
[80b]*Università di Pisa, Pisa, Italy*
[80c]*Scuola Normale Superiore di Pisa, Pisa, Italy*
[80d]*Università di Siena, Siena, Italy*
[81a]*INFN Sezione di Roma, Roma, Italy*
[81b]*Sapienza Università di Roma, Roma, Italy*

[82a]*INFN Sezione di Torino, Torino, Italy*
[82b]*Università di Torino, Torino, Italy*
[82c]*Università del Piemonte Orientale, Novara, Italy*
[83a]*INFN Sezione di Trieste, Trieste, Italy*
[83b]*Università di Trieste, Trieste, Italy*
[84]*Kyungpook National University, Daegu, Korea*
[85]*Department of Mathematics and Physics - GWNU, Gangneung, Korea*
[86]*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
[87]*Hanyang University, Seoul, Korea*
[88]*Korea University, Seoul, Korea*
[89]*Kyung Hee University, Department of Physics, Seoul, Korea*
[90]*Sejong University, Seoul, Korea*
[91]*Seoul National University, Seoul, Korea*
[92]*University of Seoul, Seoul, Korea*
[93]*Yonsei University, Department of Physics, Seoul, Korea*
[94]*Sungkyunkwan University, Suwon, Korea*
[95]*College of Engineering and Technology, American University of the Middle East (AUM), Dasman, Kuwait*
[96]*Riga Technical University, Riga, Latvia*
[97]*University of Latvia (LU), Riga, Latvia*
[98]*Vilnius University, Vilnius, Lithuania*
[99]*National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia*
[100]*Universidad de Sonora (UNISON), Hermosillo, Mexico*
[101]*Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico*
[102]*Universidad Iberoamericana, Mexico City, Mexico*
[103]*Benemerita Universidad Autonoma de Puebla, Puebla, Mexico*
[104]*University of Montenegro, Podgorica, Montenegro*
[105]*University of Canterbury, Christchurch, New Zealand*
[106]*National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*
[107]*AGH University of Krakow, Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland*
[108]*National Centre for Nuclear Research, Swierk, Poland*
[109]*Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*
[110]*Warsaw University of Technology, Warsaw, Poland*
[111]*Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal*
[112]*Faculty of Physics, University of Belgrade, Belgrade, Serbia*
[113]*VINCA Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia*
[114]*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
[115]*Universidad Autónoma de Madrid, Madrid, Spain*
[116]*Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain*
[117]*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
[118]*University of Colombo, Colombo, Sri Lanka*
[119]*University of Ruhuna, Department of Physics, Matara, Sri Lanka*
[120]*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
[121]*Paul Scherrer Institut, Villigen, Switzerland*
[122]*ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland*
[123]*Universität Zürich, Zurich, Switzerland*
[124]*National Central University, Chung-Li, Taiwan*
[125]*National Taiwan University (NTU), Taipei, Taiwan*
[126]*High Energy Physics Research Unit, Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand*
[127]*Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey*
[128]*Middle East Technical University, Physics Department, Ankara, Turkey*
[129]*Bogazici University, Istanbul, Turkey*
[130]*Istanbul Technical University, Istanbul, Turkey*
[131]*Istanbul University, Istanbul, Turkey*
[132]*Yildiz Technical University, Istanbul, Turkey*
[133]*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkiv, Ukraine*
[134]*National Science Centre, Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine*
[135]*University of Bristol, Bristol, United Kingdom*
[136]*Rutherford Appleton Laboratory, Didcot, United Kingdom*
[137]*Imperial College, London, United Kingdom*
[138]*Brunel University, Uxbridge, United Kingdom*

[139]*Baylor University, Waco, Texas, USA*
[140]*Catholic University of America, Washington, DC, USA*
[141]*The University of Alabama, Tuscaloosa, Alabama, USA*
[142]*Boston University, Boston, Massachusetts, USA*
[143]*Brown University, Providence, Rhode Island, USA*
[144]*University of California, Davis, Davis, California, USA*
[145]*University of California, Los Angeles, California, USA*
[146]*University of California, Riverside, Riverside, California, USA*
[147]*University of California, San Diego, La Jolla, California, USA*
[148]*University of California, Santa Barbara - Department of Physics, Santa Barbara, California, USA*
[149]*California Institute of Technology, Pasadena, California, USA*
[150]*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
[151]*University of Colorado Boulder, Boulder, Colorado, USA*
[152]*Cornell University, Ithaca, New York, USA*
[153]*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
[154]*University of Florida, Gainesville, Florida, USA*
[155]*Florida State University, Tallahassee, Florida, USA*
[156]*Florida Institute of Technology, Melbourne, Florida, USA*
[157]*University of Illinois Chicago, Chicago, USA, Chicago, USA*
[158]*The University of Iowa, Iowa City, Iowa, USA*
[159]*Johns Hopkins University, Baltimore, Maryland, USA*
[160]*The University of Kansas, Lawrence, Kansas, USA*
[161]*Kansas State University, Manhattan, Kansas, USA*
[162]*Lawrence Livermore National Laboratory, Livermore, California, USA*
[163]*University of Maryland, College Park, Maryland, USA*
[164]*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
[165]*University of Minnesota, Minneapolis, Minnesota, USA*
[166]*University of Mississippi, Oxford, Mississippi, USA*
[167]*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
[168]*State University of New York at Buffalo, Buffalo, New York, USA*
[169]*Northeastern University, Boston, Massachusetts, USA*
[170]*Northwestern University, Evanston, Illinois, USA*
[171]*University of Notre Dame, Notre Dame, Indiana, USA*
[172]*The Ohio State University, Columbus, Ohio, USA*
[173]*Princeton University, Princeton, New Jersey, USA*
[174]*University of Puerto Rico, Mayaguez, Puerto Rico, USA*
[175]*Purdue University, West Lafayette, Indiana, USA*
[176]*Purdue University Northwest, Hammond, Indiana, USA*
[177]*Rice University, Houston, Texas, USA*
[178]*University of Rochester, Rochester, New York, USA*
[179]*The Rockefeller University, New York, New York, USA*
[180]*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*
[181]*University of Tennessee, Knoxville, Tennessee, USA*
[182]*Texas A&M University, College Station, Texas, USA*
[183]*Texas Tech University, Lubbock, Texas, USA*
[184]*Vanderbilt University, Nashville, Tennessee, USA*
[185]*University of Virginia, Charlottesville, Virginia, USA*
[186]*Wayne State University, Detroit, Michigan, USA*
[187]*University of Wisconsin - Madison, Madison, Wisconsin, USA*
[188]*An institute or international laboratory covered by a cooperation agreement with CERN*

[a] Deceased.

[b] Also at Yerevan State University, Yerevan, Armenia.

[c] Also at TU Wien, Vienna, Austria.

[d] Also at Institute of Basic and Applied Sciences, Faculty of Engineering, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt.

[e] Also at Ghent University, Ghent, Belgium.

[f] Also at Universidade Estadual de Campinas, Campinas, Brazil.

[g] Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil.

[h] Also at UFMS, Nova Andradina, Brazil.

[i] Also at Nanjing Normal University, Nanjing, China.
[j] Also at The University of Iowa, Iowa City, Iowa, USA.
[k] Also at University of Chinese Academy of Sciences, Beijing, China.
[l] Also at China Center of Advanced Science and Technology, Beijing, China.
[m] Also at University of Chinese Academy of Sciences, Beijing, China.
[n] Also at China Spallation Neutron Source, Guangdong, China.
[o] Also at Henan Normal University, Xinxiang, China.
[p] Also at Université Libre de Bruxelles, Bruxelles, Belgium.
[q] Also at Another institute or international laboratory covered by a cooperation agreement with CERN.
[r] Also at Helwan University, Cairo, Egypt.
[s] Also at Zewail City of Science and Technology, Zewail, Egypt.
[t] Also at British University in Egypt, Cairo, Egypt.
[u] Also at Ain Shams University, Cairo, Egypt.
[v] Also at Purdue University, West Lafayette, Indiana, USA.
[w] Also at Université de Haute Alsace, Mulhouse, France.
[x] Also at Department of Physics, Tsinghua University, Beijing, China.
[y] Also at The University of the State of Amazonas, Manaus, Brazil.
[z] Also at Erzincan Binali Yildirim University, Erzincan, Turkey.
[aa] Also at University of Hamburg, Hamburg, Germany.
[bb] Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
[cc] Also at Isfahan University of Technology, Isfahan, Iran.
[dd] Also at Bergische University Wuppertal (BUW), Wuppertal, Germany.
[ee] Also at Brandenburg University of Technology, Cottbus, Germany.
[ff] Also at Forschungszentrum Jülich, Juelich, Germany.
[gg] Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
[hh] Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.
[ii] Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
[jj] Also at Universitatea Babes-Bolyai—Facultatea de Fizica, Cluj-Napoca, Romania.
[kk] Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt.
[ll] Also at HUN-REN Wigner Research Centre for Physics, Budapest, Hungary.
[mm] Also at Punjab Agricultural University, Ludhiana, India.
[nn] Also at University of Visva-Bharati, Santiniketan, India.
[oo] Also at Indian Institute of Science (IISc), Bangalore, India.
[pp] Also at Birla Institute of Technology, Mesra, Mesra, India.
[qq] Also at IIT Bhubaneswar, Bhubaneswar, India.
[rr] Also at Institute of Physics, Bhubaneswar, India.
[ss] Also at University of Hyderabad, Hyderabad, India.
[tt] Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany.
[uu] Also at Department of Physics, Isfahan University of Technology, Isfahan, Iran.
[vv] Also at Sharif University of Technology, Tehran, Iran.
[ww] Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran.
[xx] Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy.
[yy] Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy.
[zz] Also at Università degli Studi Guglielmo Marconi, Roma, Italy.
[aaa] Also at Scuola Superiore Meridionale, Università di Napoli ’Federico II’, Napoli, Italy.
[bbb] Also at Fermi National Accelerator Laboratory, Batavia, Illinois, USA.
[ccc] Also at Laboratori Nazionali di Legnaro dell’INFN, Legnaro, Italy.
[ddd] Also at Consiglio Nazionale delle Ricerche—Istituto Officina dei Materiali, Perugia, Italy.
[eee] Also at Riga Technical University, Riga, Latvia.
[fff] Also at Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Malaysia.
[ggg] Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
[hhh] Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka.
[iii] Also at Saegis Campus, Nugegoda, Sri Lanka.
[jjj] Also at National and Kapodistrian University of Athens, Athens, Greece.
[kkk] Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland.
[lll] Also at Universität Zürich, Zurich, Switzerland.
[mmm] Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
[nnn] Also at Laboratoire d’Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
[ooo] Also at Near East University, Research Center of Experimental Health Science, Mersin, Turkey.
[ppp] Also at Konya Technical University, Konya, Turkey.

[qqq] Also at Izmir Bakircay University, Izmir, Turkey.
[rrr] Also at Adiyaman University, Adiyaman, Turkey.
[sss] Also at Bozok Universitetesi Rektörlügü, Yozgat, Turkey.
[ttt] Also at Marmara University, Istanbul, Turkey.
[uuu] Also at Milli Savunma University, Istanbul, Turkey.
[vvv] Also at Kafkas University, Kars, Turkey.
[www] Also at stanbul Okan University, Istanbul, Turkey.
[xxx] Also at Hacettepe University, Ankara, Turkey.
[yyy] Also at Istanbul University—Cerrahpasa, Faculty of Engineering, Istanbul, Turkey.
[zzz] Also at Yildiz Technical University, Istanbul, Turkey.
[aaaa] Also at Vrije Universiteit Brussel, Brussel, Belgium.
[bbbb] Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[cccc] Also at University of Bristol, Bristol, United Kingdom.
[dddd] Also at IPPP Durham University, Durham, United Kingdom.
[eeee] Also at Monash University, Faculty of Science, Clayton, Australia.
[ffff] Also at Università di Torino, Torino, Italy.
[gggg] Also at Bethel University, St. Paul, Minnesota, USA.
[hhhh] Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
[iiii] Also at California Institute of Technology, Pasadena, California, USA.
[jjjj] Also at United States Naval Academy, Annapolis, Maryland, USA.
[kkkk] Also at Bingol University, Bingol, Turkey.
[llll] Also at Georgian Technical University, Tbilisi, Georgia.
[mmmm] Also at Sinop University, Sinop, Turkey.
[nnnn] Also at Erciyes University, Kayseri, Turkey.
[oooo] Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania.
[pppp] Also at Texas A&M University at Qatar, Doha, Qatar.
[qqqq] Also at Kyungpook National University, Daegu, Korea.
[rrrr] Also at Universiteit Antwerpen, Antwerpen, Belgium.
[ssss] Also at Yerevan Physics Institute, Yerevan, Armenia.
[tttt] Also at Northeastern University, Boston, Massachusetts, USA.
[uuuu] Also at Imperial College, London, United Kingdom.
[vvvv] Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan.