Using Z Boson Events to Study Parton-Medium Interactions in Pb-Pb Collisions

A. M. Sirunyan *et al.*[*]
(CMS Collaboration)

(Received 7 March 2021; revised 16 January 2022; accepted 25 February 2022; published 23 March 2022)

The spectra measurements of charged hadrons produced in the shower of a parton originating in the same hard scattering with a leptonically decaying Z boson are reported in lead-lead nuclei (Pb-Pb) and proton-proton (pp) collisions at a nucleon-nucleon center-of-mass energy of 5.02 TeV. Both Pb-Pb and pp data sets are recorded by the CMS experiment at the LHC and correspond to an integrated luminosity of 1.7 nb^{-1} and 320 pb^{-1}, respectively. Hadronic collision data with one reconstructed Z boson candidate with the transverse momentum $p_T > 30$ GeV/c are analyzed. The Z boson constrains the initial energy and direction of the associated parton. In heavy ion events, azimuthal angular distributions of charged hadrons with respect to the direction of a Z boson are sensitive to modifications of the in-medium parton shower and medium response. compared to reference data from pp interactions, the results for central Pb-Pb collisions indicate a modification of the angular correlations. The measurements of the fragmentation functions and p_T spectra of charged particles in Z boson events, which are sensitive to medium modifications of the parton shower longitudinal structure, are also reported. Significant modifications in central Pb-Pb events compared to the pp reference data are also found for these observables.

DOI: 10.1103/PhysRevLett.128.122301

In relativistic heavy ion collisions, quantum chromodynamics (QCD) predicts that a state of deconfined quarks and gluons, known as quark-gluon plasma (QGP), can be formed [1,2]. Parton scatterings with large momentum transfer, which occur very early in the collision compared to the timescale of QGP formation, can act as tomographic probes of the plasma [3]. The outgoing partons interact strongly with the QGP and lose energy [4,5], resulting in showers with more particles of lower energy. This phenomenon, known as "jet quenching," has been observed through measurements of hadrons with high transverse momentum with respect to the beam direction (p_T) [6–11] and of jets [12–20], both created by the fragmentation of energetic partons.

This Letter presents the measurement of charged hadrons from the shower of a parton (quark or gluon) produced in association with a Z boson in lead-lead nuclei (Pb-Pb) and proton-proton (pp) collisions. Both Pb-Pb and pp data sets are collected at a nucleon-nucleon center-of-mass energy $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and correspond to integrated luminosities of 1.7 nb^{-1} and 320 pb^{-1}, respectively. The advantage [21–23] of measuring jets produced in the same hard scattering with an electroweak boson (e.g., photon, Z or W bosons) arises because these do not interact strongly with the QGP [24–27]. The initial direction and energy of the associated parton that fragments into the jet, before any medium-induced energy loss happens, is determined, in the transverse plane, by the momentum of the electroweak boson (the "tag"), on average (i.e., the kinematic balance of the outgoing particles can be slightly distorted by processes that happen even in the absence of a QGP). There are several advantages to using a Z boson as a tag instead of a photon: minimal contributions from other background channels [23,28–30], absence of irreducible background sources [25,31], and smaller uncertainties arising from the experimental selection and identification of Z boson candidates.

The goals of this measurement are the following: (i) to study the medium modification of the hadron momentum spectra coming from hard-scattered partons tagged by Z bosons [23,32,33], (ii) to reveal possible angular decorrelations between the unmodified Z boson direction and the charged hadrons because of p_T broadening originating from interactions of the parent parton with the medium [34,35], and (iii) to study the possible effects of medium recoil in the angular correlation functions between the charged hadrons from the shower of a parton produced in association with a Z boson [32,33,36]. This analysis correlates Z bosons (reconstructed when decaying to pairs of electrons or muons) and charged-particle tracks in the relative azimuthal angle (ϕ). The $N_{\mathrm{trk},Z}/N_Z$, the number of tracks normalized by the number of Z bosons, is measured as a function of the difference between the ϕ angle of the Z boson (ϕ^Z) and the angles (ϕ^{trk}) of the other tracks

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

reconstructed in the event, $\Delta\phi_{\mathrm{trk},Z} = |\phi^{\mathrm{trk}} - \phi^{Z}|$. This Letter also presents measurements of the longitudinal momentum distribution of Z-tagged jet constituents, i.e., the jet fragmentation variable $\xi_{\mathrm{T}}^{\mathrm{trk},Z} = \ln[-|\vec{p}_T^{Z}|^2/(\vec{p}_T^{\mathrm{trk}} \cdot \vec{p}_T^{Z})]$, where $\vec{p}_T^{Z}$ and $\vec{p}_T^{\mathrm{trk}}$ are the p_T vectors with respect to the beam direction of the Z boson and charged-particle track, respectively [29]. These results are distinct from previous ξ measurements [37] in which the $\vec{p}_T^{Z}$ in the denominator is replaced by the p_T of a jet after it suffered medium-induced energy loss. They are complementary to photon-tagged measurements [38,39] (where effects were probed for partons with higher initial p_T) and to other Z-tagged measurements [40] (where different p_T^{Z} selections were used to test the sensitivity of energy loss processes to various initial p_T of the partons).

The central feature of the CMS detector [41] is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter. Hadron forward (HF) calorimeters extend the pseudorapidity coverage up to $|\eta| = 5.2$. For Pb-Pb events, the HF signals are used to determine the degree of overlap ("centrality") of the two colliding nuclei [18]. Muons are measured in gas-ionization detectors located outside the solenoid.

The event samples are selected in real time with dedicated lepton filters ("triggers") [42], and offline by removing noncollision events [11]. The $Z \to e^+e^-$ events are triggered if one ECAL cluster has transverse energy greater than 20 GeV and $|\eta| < 2.1$, while the $Z \to \mu^+\mu^-$ triggers require one muon of $p_T > 12$ GeV/c and $|\eta| < 2.4$ [42]. The average pileup (the mean of the number of additional collisions within the same bunch crossing) is 2 in pp, and is negligible in Pb-Pb collisions. For Pb-Pb collisions, the results are presented in four centrality intervals, 70%–90%, 50%–70%, 30%–50%, and 0%–30%. The centrality measurement is based on percentiles of the distributions of the total energy deposited in the HF calorimeters, which corresponds to the fraction of the total inelastic hadronic cross section, starting at 0% for the most central collisions [18].

The PYTHIA8.212 [43] Monte Carlo (MC) event generator with the underlying event (UE) tune CP5 [44], and MADGRAPH5_aMC@NLO8.212 [45] next-to-leading order (NLO) program (interfaced with PYTHIA) are used to simulate $Z+$jet signal events. In the Pb-Pb case, "embedded " samples are created by overlapping PYTHIA and MADGRAPH 5_aMC@NLO signal events with minimum bias (MB) heavy ion events generated with the HYDJET1.9 MC event generator [46]. The generated embedded events are propagated through the CMS apparatus using the GEANT4 toolkit [47]. These MC samples are used to evaluate reconstruction and selection efficiencies, calibrations, and to study the background. All evaluations and studies are carried separately for the pp and Pb-Pb data.

Electrons are identified as ECAL superclusters [48] matched in position and energy to tracks reconstructed in the tracker, using the particle-flow algorithm [49]. They must have $p_T > 20$ GeV/c, and their supercluster must be within the acceptance of the trigger, $|\eta| < 2.1$. Muons are selected by requiring reconstructed track segments in at least two muon detector planes and a good-quality fit when connecting them to tracker segments [50]. For both pp and Pb-Pb data, the muons are required to have $p_T > 20$ GeV/c, and they must fall within the acceptance of the muon detectors, $|\eta| < 2.4$.

The track reconstruction used in pp and Pb-Pb collisions is described in Ref. [51]. Corrections for the tracking efficiency, detector acceptance, and misreconstruction rate are obtained following the procedure in Ref. [11]. Additional corrections are applied to account for a difference in tracking efficiency ($\sim$1%), from a different particle density, seen between HYDJET and embedded MADGRAPH 5_aMC@NLO samples. The selection criteria are the same as in Ref. [11] for both the pp and Pb-Pb data.

The Z candidates are identified using an electron or muon pair, with a reconstructed invariant mass in the interval 60–120 GeV/c^2 and $p_T^{Z} > 30$ GeV/c. After all selections, there are $\sim$5 K (23K) Z boson events in the Pb-Pb (pp) data. Electron and muon pairs are corrected for losses in acceptance and efficiency during reconstruction and identification and trigger selections [48,50]. Each Z candidate is paired with all tracks in the same event that pass the $p_T^{\mathrm{trk}} > 1$ GeV/c and $|\eta^{\mathrm{trk}}| < 2.4$ selections. To avoid including the tracks of the Z candidate decay products, each track used in the correlations is required to fall outside a cone radius [defined as $\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$] of 0.02 (the smallest value for which no significant contamination is observed) around the direction of a lepton from the Z decay. Intermediate results, corrected for lepton efficiencies only, are obtained separately for Z candidates reconstructed from oppositely charged electron or muon pairs. The residual (<3%) contamination from QCD jet physics processes is estimated using same-charge lepton pairs, whose distributions are subtracted from those of opposite-charge leptons for each of the two decay channels.

Combinatorial background originating from tracks from the UE in Pb-Pb collisions is subtracted to obtain the correlation between the Z boson candidate and all tracks coming from the shower of a parton produced in the same nucleon-nucleon interaction. This background is estimated from data with an event mixing procedure [38,52], where the Z candidate is paired with tracks found in events chosen randomly from an MB Pb-Pb dataset with similar event characteristics (i.e., similar energy deposited in the HF, and interaction vertex z position). Events are split into bins of total HF calorimeter energy, E^{HF}. To ensure that the Z boson and MB events have the same size UE, an event with a Z boson candidate and with $E^{\mathrm{HF},Z}$ is mixed with MB events in the E^{HF} bin containing events with HF energy equal to $E^{\mathrm{HF},Z} - \langle E^{\mathrm{HF},Z,pp} \rangle$. The quantity $\langle E^{\mathrm{HF},Z,pp} \rangle$ is the average of E^{HF} over events in the pp data selected such that they contain a Z boson but no additional pp pileup. The bin size is chosen such that it is narrow enough to have "closure" during MC tests (i.e., an agreement between generated charged particle yields from Z + jet events, and reconstructed track yields from background-subtracted events). For the events within a given E^{HF} bin, the variation in the number of UE tracks before subtraction can be much larger than the number of tracks after subtraction. In order to reflect this statistical effect of the UE, the statistical uncertainties of the Pb-Pb distributions are calculated using the bootstrap method [53]. Dedicated tests based on control samples in data show that the UE produced by a Z boson process in a Pb-Pb collision is the same as in a pp collision, within the statistical uncertainties of the present samples. It was checked that the results obtained using information only from the $\eta < 0$ or only from the $\eta > 0$ regions of the HF calorimeters are consistent with the main result. The UE subtraction procedure was validated by performing the whole analysis on MC embedded samples. The results obtained using the generated particles versus using the reconstructed (after UE subtraction) particles were compared, and any discrepancy was included in the systematic uncertainties.

Several variations in the analysis are considered in order to account for the uncertainties related to the tracking efficiency and corrections, lepton efficiency and energy scale, as well as pp pileup and Pb-Pb background subtraction. No significant differences are observed in the results obtained with electron and muon pairs separately; therefore, uncertainties are quoted after combining the two. With the exception of the lepton energy scale and efficiencies, there are no assumed correlations between the pp and Pb-Pb uncertainties. Unless noted otherwise, the systematic uncertainties are evaluated as the differences between the final results and results obtained with varied settings. In the following, we list the variations considered, and provide in the Supplemental Material [54] the numerical values for the average uncertainties corresponding to the most extreme cases, i.e., the pp and most central 0%–30% Pb-Pb collisions.

The uncertainty related to the tracking efficiency is estimated as the difference in the track reconstruction efficiency between data and simulation [11]. The uncertainty related to the correction for the observed efficiency difference between HYDJET and embedded MADGRAPH 5_aMC@NLO samples is obtained by comparing the corrections obtained from MADGRAPH 5_aMC@NLO and PYTHIA embedded samples. Lepton efficiencies are varied by the uncertainty in their data-to-MC differences obtained using the "tag-and-probe" method [55]. To assess the uncertainty related to the lepton energy scale corrections, the p_T of leptons is shifted by their energy correction uncertainties. No corrections are applied to remove the residual pileup effects in pp data. Nominal distributions (no requirement on pileup) are compared to those from events without pileup, i.e., events with only one interaction vertex. The uncertainty in the event-mixing procedure is obtained by repeating the procedure after shifting the $\langle E^{\mathrm{HF},Z,pp} \rangle$ by 5%, the maximum difference in the HF response between the Pb-Pb and pp data-taking periods. Because the difference in the HF response between the beginning and end of the Pb-Pb run was found to be negligible (<1%), no additional uncertainty was assigned.

Three theoretical calculations are compared to the results; they use the same kinematic selection as data and incorporate the phenomenon of jet quenching, and differ just in their treatment of the medium response to the passing parton: SCET$_G$ [33,56,57], which does not consider any medium response to jet propagation; Hybrid [35,36], which considers the effects of a "wake," induced by the jet as it passes through and interacts with the QCD medium; and CoLBT [32,58] in which the quenched jet energy feeds into the hydrodynamic evolution.

Figure 1 shows $1/N_Z dN_{\mathrm{trk},Z}/d\Delta\phi_{\mathrm{trk},Z}$, i.e., the distributions of the ϕ angle difference between charged particles and Z bosons, normalized by the number of Z bosons in each dataset (and for the Pb-Pb case, in each centrality interval). This type of angular correlation function could reveal medium-induced modification of the away-side ($\Delta\phi_{\mathrm{trk},Z} \sim \pi$) jet constituents, and effects of the medium response (i.e., modification of the medium induced by the jet traversing through), over all $\Delta\phi_{\mathrm{trk},Z}$. Different pairs of datasets were compared using χ^2 tests. With a p value cutoff of 0.05, the tests show that the 0–30% Pb-Pb distribution is compatible (i.e., statistically indistinguishable) with all datasets except the most peripheral one. In turn, the pp distribution is found to be compatible only with the 70%–90% PbPb dataset. The distributions in both pp and Pb-Pb collisions are peaked at $\Delta\phi_{\mathrm{trk},Z} \sim \pi$, which is the signature of an away-side jet emitted back-to-back with the Z boson. None of the Pb-Pb or pp distributions reach zero even in the $\Delta\phi_{\mathrm{trk},Z} \sim 0$ region, around the tag Z boson, in its direction of propagation. This happens even if (i) the random combinations from UE (between the Z candidates and tracks produced in nucleon-nucleon interactions that are independent of the Z + jet process) have been removed using the event-mixing procedure, (ii) the Z boson does not interact strongly with the medium in Pb-Pb collisions while traversing it, and (iii) it is not produced during the fragmentation of a parton in Pb-Pb or pp collisions (processes that could create more particles in the direction of propagation of the Z boson).

The difference in the number of associated particles, between the Pb-Pb and pp results, is also shown in Fig. 1. A χ^2 test was done to assess the hypothesis that the excess observed is $\Delta\phi_{\mathrm{trk},Z}$-dependent: with the current precision of the measurement this hypothesis is rejected at the 95% confidence level (i.e., the data are consistent with an

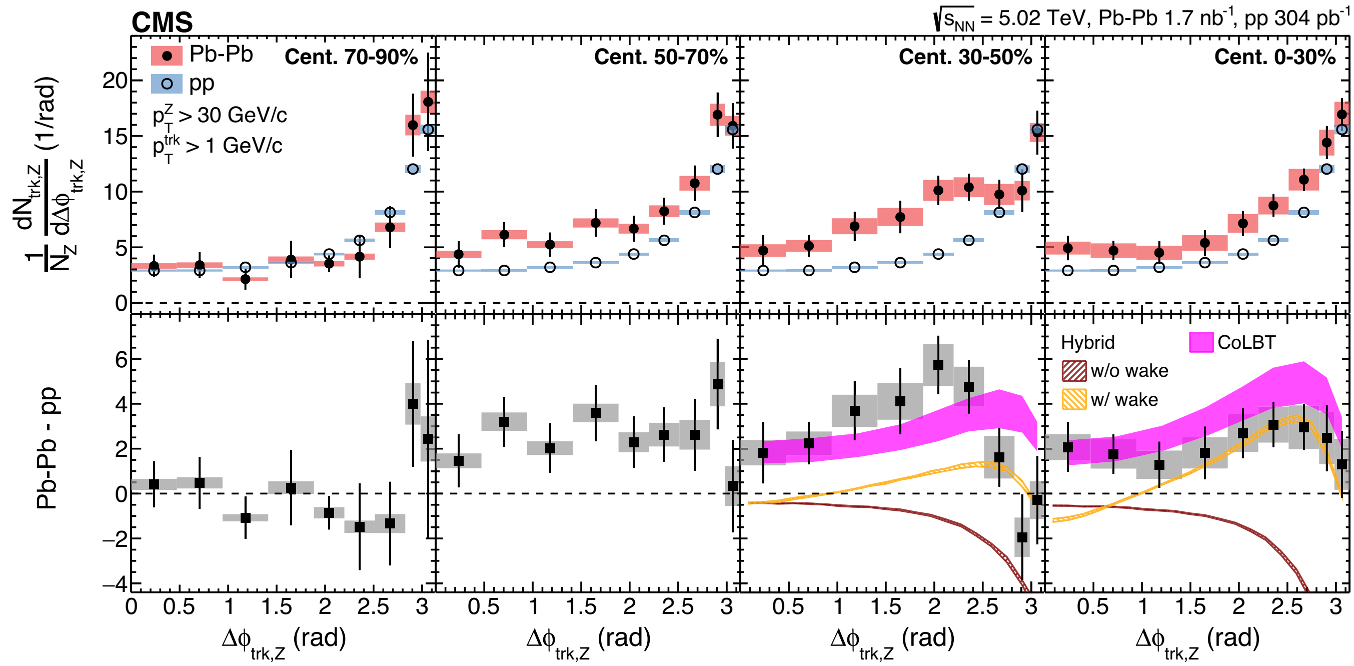

FIG. 1. Upper: distributions of $\Delta\phi_{\mathrm{trk},Z}$ in pp collisions compared to Pb-Pb collisions (left to right) in the 70%–90% (left), 50%–70%, 30%–50%, and 0%–30% (right) centrality intervals. Lower: difference between the Pb-Pb and pp distributions. The vertical bars and shaded boxes represent the statistical and systematic uncertainties, respectively. Several model calculations are added for comparison: Hybrid [36] and CoLBT [32,58].

increase of the yield that is independent of $\Delta\phi_{\mathrm{trk},Z}$). The excess observed in all bins except the most peripheral (i.e., the most pp-like) could be caused by medium response, where the traversing jet excites the medium around it. Another possible contribution to the excess could be medium modifications of partons originating from the same nucleon-nucleon collision as the $Z+\mathrm{jet}$ process, but from a different parton-parton interaction, and which would add a flat contribution over the entire $\Delta\phi_{\mathrm{trk},Z}$ range [58]. The comparison with the CoLBT and the Hybrid (with and without wake) models supports these scenarios, although the Hybrid model fails to reproduce the magnitude of the difference between pp and Pb-Pb collisions, in particular in the $\Delta\phi_{\mathrm{trk},Z}\sim 0$ region.

The fragmentation function of the parton emitted back-to-back with the Z boson is studied via the $1/N_Z dN_{\mathrm{trk},Z}/d\xi_T^{\mathrm{trk},Z}$ distributions, shown in Fig. 2. For these results (as well as for those shown in Fig. 1 in the Supplemental Material, tracks are required to satisfy $\Delta\phi_{\mathrm{trk},Z} > 7\pi/8$. Because the interest is in the shape dissimilarities, the ratios of the pp and Pb-Pb distributions are presented. All distributions are normalized by the number of Z candidates found in each dataset.

In Fig. 2, the low and high $\xi_T^{\mathrm{trk},Z}$ regions (i.e., below and above ~3) correspond to high- and low-p_T particles (or lower- and higher-p_T^Z), respectively. For instance, for $p_T^Z \sim 30(60)$ GeV/c, the high-$\xi_T^{\mathrm{trk},Z}$ region corresponds to ~1.5(3) GeV/c. No significant modification is observed in the 70%–90% Pb-Pb collisions compared to the pp data. In central collisions, charged particles are suppressed in the <3 (high-energy particles) interval, and enhanced in the >3 interval. These features are consistent with a scenario in which the initial parton loses energy (i.e., jet quenching) and the medium induces modification of the parton shower. The enhancement is also consistent with a picture in which additional low-energy particles are produced from the recoil of the medium caused by the traversing parton.

To confirm the onset of medium-induced effects and further help pinpoint the transition point in momentum space for different parton-medium interactions, a comparison of the per-Z-boson associated yields in Pb-Pb and pp collisions ($1/N_z dN_{\mathrm{trk},Z}/d$) is needed. Figure 1 in the Supplemental Material shows such a comparison, together with the ratio of the Pb-Pb and pp distributions. In the most peripheral event class, there is no significant modification of the charged-particle p_T spectrum in Pb-Pb collisions. In central events and at high ($>$2–5 GeV/c), the particle production is suppressed in Pb-Pb compared to the pp reference data. At the same time, at low (1–2 GeV/c), an enhancement is observed consistent with the one seen in the $\Delta\phi_{\mathrm{trk},Z}$ results. Modifications of the $\xi_T^{\mathrm{trk},Z}$ and $p_T^{\mathrm{trk},Z}$ distributions are the largest in the 0%–30% centrality interval, indicating the strongest medium effects. Qualitatively similar observations were reported in photon- [38,39] and Z-tagged [40] measurements.

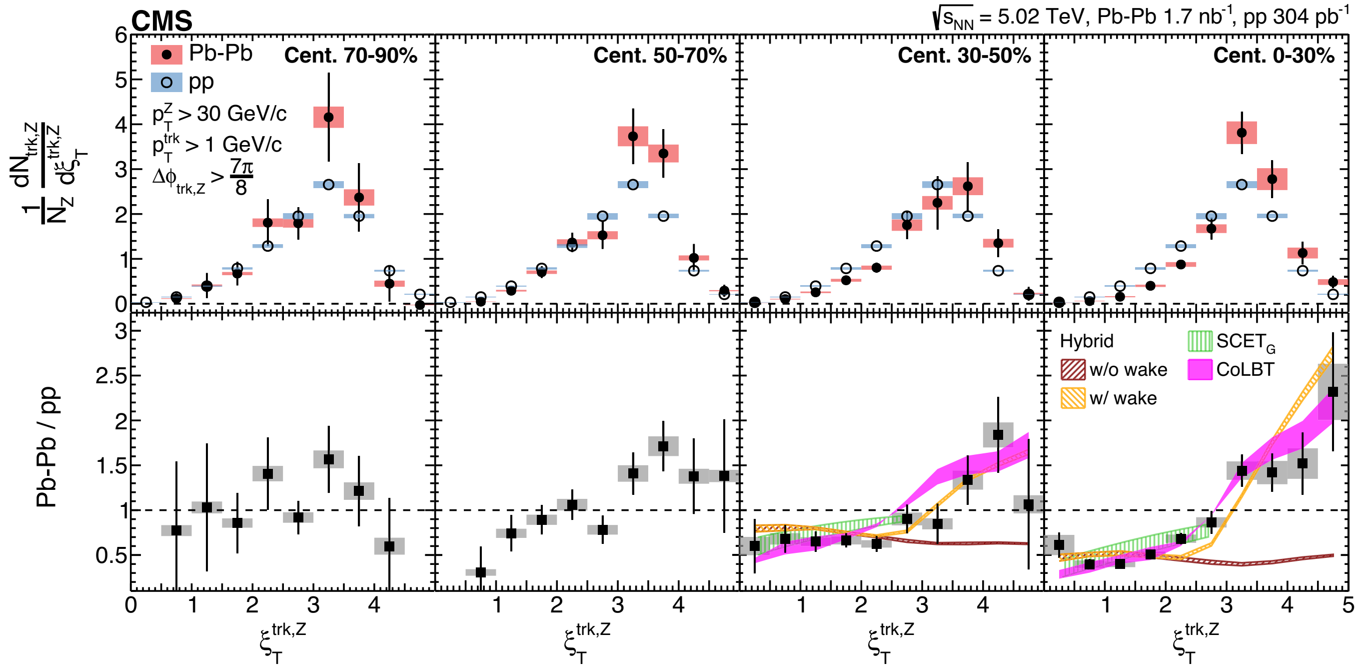

FIG. 2. Upper: distributions of in pp collisions compared to Pb-Pb collisions (left to right) in the 70%–90% (left), 50%–70%, 30%–50%, and 0%–30% (right) centrality intervals. Lower: ratios of the Pb-Pb to pp distributions. The vertical bars and shaded boxes represent the statistical and systematic uncertainties, respectively. Several model calculations are added for comparison: Hybrid [36], CoLBT [32,58], and SCET$_G$ [56].

The medium response is not expected to play an important role for the high-$p_T^{\mathrm{trk},Z}$ and low-$\xi_T^{\mathrm{trk},Z}$ regions, as is illustrated in the Hybrid model, where calculations with and without wake are indistinguishable. In this region, there is good agreement between the data and the SCET$_G$ and the Hybrid calculations. At low- and high-, the increase in the charged particle yield can only be reproduced if a feedback from the medium is considered. In these regions, both the Hybrid with wake and CoLBT models capture the general features seen in data, including the expected weakening of medium effects at higher p_T values from 0%–30% to 30%–50% Pb-Pb event centralities.

In summary, the measurements of charged hadrons produced in the shower of a parton originating in the same hard scattering with a Z boson, are reported in lead-lead nuclei (Pb-Pb) and proton-proton (pp) collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. Collision data with a Z boson candidate with transverse momentum $p_T > 30$ GeV/c are analyzed. The Z-tagged fragmentation functions and spectra, which probe the longitudinal structure of the parton shower inside the medium, are measured, and significant modifications are observed. Particle yields, which are sensitive to modification of the in-medium parton shower and medium recoils, are measured for all charged particles as a function of the azimuthal angle (ϕ) with respect to the Z boson momentum vector. Comparison of the Pb-Pb and pp results indicates a modification of the angular correlation functions extending to ϕ angles close to the Z boson in central Pb-Pb events. The data favor theoretical models that include the response of the medium to the traversing parton in addition to energy loss. These results represent the first studies of parton-medium interactions over all ϕ angles, in which the initial state of the scattered parton is known before it enters the medium.

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: BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (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); BMBF, DFG, and HGF (Germany); GSRT (Greece); NKFIA (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); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, RFBR, and NRC KI (Russia); MESTD (Serbia); SEIDI, CPAN, PCTI, and FEDER (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

[1] J. C. Collins and M. J. Perry, Superdense Matter: Neutrons or Asymptotically Free Quarks?, Phys. Rev. Lett. **34**, 1353 (1975).

[2] F. Karsch, The phase transition to the quark gluon plasma: Recent results from lattice calculations, Nucl. Phys. **A590**, 367 (1995).

[3] D. A. Appell, Jets as a probe of quark-gluon plasmas, Phys. Rev. D **33**, 717 (1986).

[4] J. P. Blaizot and L. D. McLerran, Jets in expanding quark-gluon plasmas, Phys. Rev. D **34**, 2739 (1986).

[5] M. Gyulassy and M. Plümer, Jet quenching in dense matter, Phys. Lett. B **243**, 432 (1990).

[6] J. Adams *et al.* (STAR Collaboration), Transverse-Momentum and Collision-Energy Dependence of High-p_T Hadron Suppression in AuAu Collisions at Ultrarelativistic Energies, Phys. Rev. Lett. **91**, 172302 (2003).

[7] B. B. Back *et al.* (PHOBOS Collaboration), Centrality Dependence of Charged Hadron Transverse Momentum Spectra in Au + Au Collisions from $\sqrt{s_{NN}} = 62.4$ to 200 GeV, Phys. Rev. Lett. **94**, 082304 (2005).

[8] A. Adare *et al.* (PHENIX Collaboration), Suppression Pattern of Neutral Pions at High Transverse Momentum in AuAu Collisions at $\sqrt{s_{NN}} = 200$ GeV and Constraints on Medium Transport Coefficients, Phys. Rev. Lett. **101**, 232301 (2008).

[9] ALICE Collaboration, Centrality dependence of charged particle production at large transverse momentum in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B **720**, 52 (2013).

[10] ATLAS Collaboration, Measurement of charged-particle spectra in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector at the LHC, J. High Energy Phys. 09 (2015) 050.

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

[12] CMS Collaboration, First measurement of large area jet transverse momentum spectra in heavy-ion collisions, J. High Energy Phys. 05 (2021) 284.

[13] CMS Collaboration, Measurement of inclusive jet cross sections in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. C **96**, 015202 (2017).

[14] ALICE Collaboration, Measurement of jet suppression in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B **746**, 1 (2015).

[15] ALICE Collaboration, Measurements of inclusive jet spectra in pp and central Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, Phys. Rev. C **101**, 034911 (2020).

[16] ALICE Collaboration, Measurement of jet quenching with semi-inclusive hadron-jet distributions in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, J. High Energy Phys. 09 (2015) 170.

[17] L. Adamczyk *et al.* (STAR Collaboration), Dijet Imbalance Measurements in AuAu and pp Collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR, Phys. Rev. Lett. **119**, 062301 (2017).

[18] CMS Collaboration, Observation and studies of jet quenching in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. C **84**, 024906 (2011).

[19] ATLAS Collaboration, Measurement of the nuclear modification factor for inclusive jets in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector, Phys. Lett. B **790**, 108 (2019).

[20] ATLAS Collaboration, Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS Detector at the LHC, Phys. Rev. Lett. **105**, 252303 (2010).

[21] V. Kartvelishvili, R. Kvatadze, and R. Shanidze, On Z and $Z +$ jet production in heavy ion collisions, Phys. Lett. B **356**, 589 (1995).

[22] X.-N. Wang, Z. Huang, and I. Sarcevic, Jet Quenching in the Direction Opposite to a Tagged Photon in High-Energy Heavy Ion Collisions, Phys. Rev. Lett. **77**, 231 (1996).

[23] Z.-B. Kang, I. Vitev, and H. Xing, Vector-boson-tagged jet production in heavy ion collisions at energies available at the CERN large hadron collider, Phys. Rev. C **96**, 014912 (2017).

[24] ATLAS Collaboration, Centrality, rapidity, and transverse momentum dependence of isolated prompt photon production in lead-lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV measured with the ATLAS detector, Phys. Rev. C **93**, 034914 (2016).

[25] CMS Collaboration, Measurement of isolated photon production in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B **710**, 256 (2012).

[26] CMS Collaboration, Study of W boson production in Pb-Pb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B **715**, 66 (2012).

[27] CMS Collaboration, Study of Z production in Pb-Pb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV in the dimuon and dielectron decay channels, J. High Energy Phys. 03 (2015) 022.

[28] R. B. Neufeld and I. Vitev, Z^0-Tagged Jet Event Asymmetry in Heavy-Ion Collisions at the CERN Large Hadron Collider, Phys. Rev. Lett. **108**, 242001 (2012).

[29] J. Casalderrey-Solana, D. C. Gulhan, J. G. Milhano, D. Pablos, and K. Rajagopal, Predictions for boson-jet observables and fragmentation function ratios from a hybrid strong/weak coupling model for jet quenching, J. High Energy Phys. 03 (2016) 053.

[30] R. Kunnawalkam Elayavalli and K. C. Zapp, Simulating V + jet processes in heavy ion collisions with JEWEL, Eur. Phys. J. C **76**, 695 (2016).

[31] S. Chatrchyan *et al.* (CMS Collaboration), Studies of jet quenching using isolated-photon + jet correlations in PbPb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B **718**, 773 (2013).

[32] W. Chen, S. Cao, T. Luo, L.-G. Pang, and X.-N. Wang, Medium modification of γ-jet fragmentation functions in Pb-Pb collisions at LHC, Phys. Lett. B **810**, 135783 (2020).
[33] G. Ovanesyan and I. Vitev, An effective theory for jet propagation in dense QCD matter: jet broadening and medium-induced bremsstrahlung, J. High Energy Phys. 06 (2011) 080.
[34] W. Chen, S. Cao, T. Luo, L.-G. Pang, and X.-N. Wang, Effects of jet-induced medium excitation in γ-hadron correlation in AA collisions, Phys. Lett. B **777**, 86 (2018).
[35] J. Casalderrey-Solana, D. C. Gulhan, J. G. Milhano, D. Pablos, and K. Rajagopal, A hybrid strong/weak coupling approach to jet quenching, J. High Energy Phys. 10 (2014) 019.
[36] J. Casalderrey-Solana, D. Gulhan, G. Milhano, D. Pablos, and K. Rajagopal, Angular structure of jet quenching within a hybrid strong/weak coupling model, J. High Energy Phys. 03 (2017) 135.
[37] CMS Collaboration, Measurement of jet fragmentation in Pb-Pb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. C **90**, 024908 (2014).
[38] CMS Collaboration, Observation of Medium-Induced Modifications of Jet Fragmentation in Pb-Pb Collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV using Isolated Photon-Tagged Jets, Phys. Rev. Lett. **121**, 242301 (2018).
[39] ATLAS Collaboration, Comparison of Fragmentation Functions for Jets Dominated by Light Quarks and Gluons from pp and Pb + Pb Collisions in ATLAS, Phys. Rev. Lett. **123**, 042001 (2019).
[40] ATLAS Collaboration, Medium-Induced Modification of Z-Tagged Charged Particle Yields in $Pb + Pb$ Collisions at 5.02 TeV with the ATLAS Detector, Phys. Rev. Lett. **126**, 072301 (2021).
[41] CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum. **3**, S08004 (2008).
[42] CMS Collaboration, The CMS trigger system, J. Instrum. **12**, P01020 (2017).
[43] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA 8.2, Comput. Phys. Commun. **191**, 159 (2015).
[44] CMS Collaboration, Extraction and validation of a new set of CMS PYTHIA8 tunes from underlying-event measurements, Eur. Phys. J. C **80**, 4 (2020).
[45] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, J. High Energy Phys. 07 (2014) 079.
[46] I. P. Lokhtin and A. M. Snigirev, A model of jet quenching in ultrarelativistic heavy ion collisions and high-p_T hadron spectra at RHIC, Eur. Phys. J. C **45**, 211 (2006).
[47] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—a simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[48] CMS Collaboration, Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV, J. Instrum. **10**, P06005 (2015).
[49] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, J. Instrum. **12**, P10003 2017.
[50] CMS Collaboration, Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV, J. Instrum. **7**, P10002 (2012).
[51] CMS Collaboration, Description and performance of track and primary-vertex reconstruction with the CMS tracker, J. Instrum. **9**, P10009 (2014).
[52] CMS Collaboration, Jet Shapes of Isolated Photon-Tagged Jets in Pb-Pb and pp Collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Phys. Rev. Lett. **122**, 152001 (2019).
[53] B. Efron, Bootstrap methods: Another look at the jackknife, Ann. Stat. **7**, 1 (1979).
[54] See Supplemental Material at http://link.aps.org/supplemental/10.1103/PhysRevLett.128.122301 for average relative systematic uncertainties for $\Delta\phi_{\mathrm{trk},Z}$, $\xi_T^{\mathrm{trk},Z}$, and p_T^{trk}.
[55] CMS Collaboration, Measurement of the inclusive W and Z production cross sections in pp collisions at $\sqrt{s} = 7$ TeV with the CMS experiment, J. High Energy Phys. 10 (2011) 132.
[56] H. T. Li and I. Vitev, Jet charge modification in finite QCD matter, Phys. Rev. D **101**, 076020 (2020).
[57] Y.-T. Chien, A. Emerman, Z.-B. Kang, G. Ovanesyan, and I. Vitev, Jet quenching from QCD evolution, Phys. Rev. D **93**, 074030 (2016).
[58] W. Chen, Z. Yang, Y. He, W. Ke, L. G. Pang, and X.-N. Wang, Search for the Elusive Jet-Induced Diffusion Wake in Z/γ-Jets with 2D Jet Tomography in High-Energy Heavy-Ion Collisions, Phys. Rev. Lett. **127**, 082301 (2021).

A. M. Sirunyan,[1,a] A. Tumasyan,[1] W. Adam,[2] F. Ambrogi,[2] T. Bergauer,[2] M. Dragicevic,[2] J. Erö,[2] A. Escalante Del Valle,[2] R. Frühwirth,[2,b] M. Jeitler,[2,b] N. Krammer,[2] L. Lechner,[2] D. Liko,[2] T. Madlener,[2] I. Mikulec,[2] F. M. Pitters,[2] N. Rad,[2] J. Schieck,[2,b] R. Schöfbeck,[2] M. Spanring,[2] S. Templ,[2] W. Waltenberger,[2] C.-E. Wulz,[2,b] M. Zarucki,[2] V. Chekhovsky,[3] A. Litomin,[3] V. Makarenko,[3] J. Suarez Gonzalez,[3] M. R. Darwish,[4,c] E. A. De Wolf,[4] D. Di Croce,[4] X. Janssen,[4] T. Kello,[4,d] A. Lelek,[4] M. Pieters,[4] H. Rejeb Sfar,[4] H. Van Haevermaet,[4] P. Van Mechelen,[4] S. Van Putte,[4] N. Van Remortel,[4] F. Blekman,[5] E. S. Bols,[5] S. S. Chhibra,[5] J. D'Hondt,[5] J. De Clercq,[5] D. Lontkovskyi,[5] S. Lowette,[5] I. Marchesini,[5] S. Moortgat,[5] A. Morton,[5] Q. Python,[5] S. Tavernier,[5] W. Van Doninck,[5] P. Van Mulders,[5] D. Beghin,[6] B. Bilin,[6] B. Clerbaux,[6] G. De Lentdecker,[6] B. Dorney,[6] L. Favart,[6] A. Grebenyuk,[6] A. K. Kalsi,[6] I. Makarenko,[6] L. Moureaux,[6] L. Pétré,[6] A. Popov,[6] N. Postiau,[6] E. Starling,[6] L. Thomas,[6] C. Vander Velde,[6] P. Vanlaer,[6] D. Vannerom,[6] L. Wezenbeek,[6]

T. Cornelis,[7] D. Dobur,[7] M. Gruchala,[7] I. Khvastunov,[7,e] M. Niedziela,[7] C. Roskas,[7] K. Skovpen,[7] M. Tytgat,[7] W. Verbeke,[7] B. Vermassen,[7] M. Vit,[7] G. Bruno,[8] F. Bury,[8] C. Caputo,[8] P. David,[8] C. Delaere,[8] M. Delcourt,[8] I. S. Donertas,[8] A. Giammanco,[8] V. Lemaitre,[8] K. Mondal,[8] J. Prisciandaro,[8] A. Taliercio,[8] M. Teklishyn,[8] P. Vischia,[8] S. Wuyckens,[8] J. Zobec,[8] G. A. Alves,[9] G. Correia Silva,[9] C. Hensel,[9] A. Moraes,[9] W. L. Aldá Júnior,[10] E. Belchior Batista Das Chagas,[10] H. BRANDAO MALBOUISSON,[10] W. Carvalho,[10] J. Chinellato,[10,f] E. Coelho,[10] E. M. Da Costa,[10] G. G. Da Silveira,[10,g] D. De Jesus Damiao,[10] S. Fonseca De Souza,[10] J. Martins,[10,h] D. Matos Figueiredo,[10] M. Medina Jaime,[10,i] M. Melo De Almeida,[10] C. Mora Herrera,[10] L. Mundim,[10] H. Nogima,[10] P. Rebello Teles,[10] L. J. Sanchez Rosas,[10] A. Santoro,[10] S. M. Silva Do Amaral,[10] A. Sznajder,[10] M. Thiel,[10] E. J. Tonelli Manganote,[10,f] F. Torres Da Silva De Araujo,[10] A. Vilela Pereira,[10] C. A. Bernardes,[11a] L. Calligaris,[11a] T. R. Fernandez Perez Tomei,[11a] E. M. Gregores,[11a,11b] D. S. Lemos,[11a] P. G. Mercadante,[11a,11b] S. F. Novaes,[11a] Sandra S. Padula,[11a] A. Aleksandrov,[12] G. Antchev,[12] I. Atanasov,[12] R. Hadjiiska,[12] P. Iaydjiev,[12] M. Misheva,[12] M. Rodozov,[12] M. Shopova,[12] G. Sultanov,[12] M. Bonchev,[13] A. Dimitrov,[13] T. Ivanov,[13] L. Litov,[13] B. Pavlov,[13] P. Petkov,[13] A. Petrov,[13] W. Fang,[14,d] Q. Guo,[14] H. Wang,[14] L. Yuan,[14] M. Ahmad,[15] Z. Hu,[15] Y. Wang,[15] E. Chapon,[16] G. M. Chen,[16,j] H. S. Chen,[16,j] M. Chen,[16] D. Leggat,[16] H. Liao,[16] Z. Liu,[16] R. Sharma,[16] A. Spiezia,[16] J. Tao,[16] J. Thomas-wilsker,[16] J. Wang,[16] H. Zhang,[16] S. Zhang,[16,j] J. Zhao,[16] A. Agapitos,[17] Y. Ban,[17] C. Chen,[17] A. Levin,[17] Q. Li,[17] M. Lu,[17] X. Lyu,[17] Y. Mao,[17] S. J. Qian,[17] D. Wang,[17] Q. Wang,[17] J. Xiao,[17] Z. You,[18] X. Gao,[19,d] M. Xiao,[20] C. Avila,[21] A. Cabrera,[21] C. Florez,[21] J. Fraga,[21] A. Sarkar,[21] M. A. Segura Delgado,[21] J. Jaramillo,[22] J. Mejia Guisao,[22] F. Ramirez,[22] J. D. Ruiz Alvarez,[22] C. A. Salazar González,[22] N. Vanegas Arbelaez,[22] D. Giljanovic,[23] N. Godinovic,[23] D. Lelas,[23] I. Puljak,[23] T. Sculac,[23] Z. Antunovic,[24] M. Kovac,[24] V. Brigljevic,[25] D. Ferencek,[25] D. Majumder,[25] M. Roguljic,[25] A. Starodumov,[25,k] T. Susa,[25] M. W. Ather,[26] A. Attikis,[26] E. Erodotou,[26] A. Ioannou,[26] G. Kole,[26] M. Kolosova,[26] S. Konstantinou,[26] G. Mavromanolakis,[26] J. Mousa,[26] C. Nicolaou,[26] F. Ptochos,[26] P. A. Razis,[26] H. Rykaczewski,[26] H. Saka,[26] D. Tsiakkouri,[26] M. Finger,[27,l] M. Finger Jr.,[27,l] A. Kveton,[27] J. Tomsa,[27] E. Ayala,[28] E. Carrera Jarrin,[29] H. Abdalla,[30,m] S. Abu Zeid,[30,n] A. Ellithi Kamel,[30,m] M. A. Mahmoud,[31] Y. Mohammed,[31,o] S. Bhowmik,[32] A. Carvalho Antunes De Oliveira,[32] R. K. Dewanjee,[32] K. Ehataht,[32] M. Kadastik,[32] M. Raidal,[32] C. Veelken,[32] P. Eerola,[33] L. Forthomme,[33] H. Kirschenmann,[33] K. Osterberg,[33] M. Voutilainen,[33] E. Brücken,[34] F. Garcia,[34] J. Havukainen,[34] V. Karimäki,[34] M. S. Kim,[34] R. Kinnunen,[34] T. Lampén,[34] K. Lassila-Perini,[34] S. Laurila,[34] S. Lehti,[34] T. Lindén,[34] H. Siikonen,[34] E. Tuominen,[34] J. Tuominiemi,[34] P. Luukka,[35] T. Tuuva,[35] C. Amendola,[36] M. Besancon,[36] F. Couderc,[36] M. Dejardin,[36] D. Denegri,[36] J. L. Faure,[36] F. Ferri,[36] S. Ganjour,[36] A. Givernaud,[36] P. Gras,[36] G. Hamel de Monchenault,[36] P. Jarry,[36] B. Lenzi,[36] E. Locci,[36] J. Malcles,[36] J. Rander,[36] A. Rosowsky,[36] M. Ö. Sahin,[36] A. Savoy-Navarro,[36,p] M. Titov,[36] G. B. Yu,[36] S. Ahuja,[37] F. Beaudette,[37] M. Bonanomi,[37] A. Buchot Perraguin,[37] P. Busson,[37] C. Charlot,[37] O. Davignon,[37] B. Diab,[37] G. Falmagne,[37] R. Granier de Cassagnac,[37] A. Hakimi,[37] I. Kucher,[37] A. Lobanov,[37] C. Martin Perez,[37] M. Nguyen,[37] C. Ochando,[37] P. Paganini,[37] J. Rembser,[37] R. Salerno,[37] J. B. Sauvan,[37] Y. Sirois,[37] A. Zabi,[37] A. Zghiche,[37] J.-L. Agram,[38,q] J. Andrea,[38] D. Bloch,[38] G. Bourgatte,[38] J.-M. Brom,[38] E. C. Chabert,[38] C. Collard,[38] J.-C. Fontaine,[38,q] D. Gelé,[38] U. Goerlach,[38] C. Grimault,[38] A.-C. Le Bihan,[38] P. Van Hove,[38] E. Asilar,[39] S. Beauceron,[39] C. Bernet,[39] G. Boudoul,[39] C. Camen,[39] A. Carle,[39] N. Chanon,[39] D. Contardo,[39] P. Depasse,[39] H. El Mamouni,[39] J. Fay,[39] S. Gascon,[39] M. Gouzevitch,[39] B. Ille,[39] Sa. Jain,[39] I. B. Laktineh,[39] H. Lattaud,[39] A. Lesauvage,[39] M. Lethuillier,[39] L. Mirabito,[39] L. Torterotot,[39] G. Touquet,[39] M. Vander Donckt,[39] S. Viret,[39] A. Khvedelidze,[40,l] Z. Tsamalaidze,[40,l] L. Feld,[41] K. Klein,[41] M. Lipinski,[41] D. Meuser,[41] A. Pauls,[41] M. Preuten,[41] M. P. Rauch,[41] J. Schulz,[41] M. Teroerde,[41] D. Eliseev,[42] M. Erdmann,[42] P. Fackeldey,[42] B. Fischer,[42] S. Ghosh,[42] T. Hebbeker,[42] K. Hoepfner,[42] H. Keller,[42] L. Mastrolorenzo,[42] M. Merschmeyer,[42] A. Meyer,[42] P. Millet,[42] G. Mocellin,[42] S. Mondal,[42] S. Mukherjee,[42] D. Noll,[42] A. Novak,[42] T. Pook,[42] A. Pozdnyakov,[42] T. Quast,[42] M. Radziej,[42] Y. Rath,[42] H. Reithler,[42] J. Roemer,[42] A. Schmidt,[42] S. C. Schuler,[42] A. Sharma,[42] S. Wiedenbeck,[42] S. Zaleski,[42] C. Dziwok,[43] G. Flügge,[43] W. Haj Ahmad,[43,r] O. Hlushchenko,[43] T. Kress,[43] A. Nowack,[43] C. Pistone,[43] O. Pooth,[43] D. Roy,[43] H. Sert,[43] A. Stahl,[43,s] T. Ziemons,[43] H. Aarup Petersen,[44] M. Aldaya Martin,[44] P. Asmuss,[44] I. Babounikau,[44] S. Baxter,[44] O. Behnke,[44] A. Bermúdez Martínez,[44] A. A. Bin Anuar,[44] K. Borras,[44,t] V. Botta,[44] D. Brunner,[44] A. Campbell,[44] A. Cardini,[44] P. Connor,[44] S. Consuegra Rodríguez,[44] V. Danilov,[44] A. De Wit,[44] M. M. Defranchis,[44] L. Didukh,[44] D. Domínguez Damiani,[44] G. Eckerlin,[44] D. Eckstein,[44] T. Eichhorn,[44] L. I. Estevez Banos,[44] E. Gallo,[44,u] A. Geiser,[44] A. Giraldi,[44] A. Grohsjean,[44] M. Guthoff,[44] A. Harb,[44] A. Jafari,[44,v] N. Z. Jomhari,[44] H. Jung,[44] A. Kasem,[44,t] M. Kasemann,[44] H. Kaveh,[44] C. Kleinwort,[44] J. Knolle,[44] D. Krücker,[44] W. Lange,[44] T. Lenz,[44] J. Lidrych,[44] K. Lipka,[44] W. Lohmann,[44,w] R. Mankel,[44] I.-A. Melzer-Pellmann,[44] J. Metwally,[44]

A. B. Meyer,[44] M. Meyer,[44] M. Missiroli,[44] J. Mnich,[44] A. Mussgiller,[44] V. Myronenko,[44] Y. Otarid,[44] D. Pérez Adán,[44] S. K. Pflitsch,[44] D. Pitzl,[44] A. Raspereza,[44] A. Saggio,[44] A. Saibel,[44] M. Savitskyi,[44] V. Scheurer,[44] P. Schütze,[44] C. Schwanenberger,[44] A. Singh,[44] R. E. Sosa Ricardo,[44] N. Tonon,[44] O. Turkot,[44] A. Vagnerini,[44] M. Van De Klundert,[44] R. Walsh,[44] D. Walter,[44] Y. Wen,[44] K. Wichmann,[44] C. Wissing,[44] S. Wuchterl,[44] O. Zenaiev,[44] R. Zlebcik,[44] R. Aggleton,[45] S. Bein,[45] L. Benato,[45] A. Benecke,[45] K. De Leo,[45] T. Dreyer,[45] A. Ebrahimi,[45] M. Eich,[45] F. Feindt,[45] A. Fröhlich,[45] C. Garbers,[45] E. Garutti,[45] P. Gunnellini,[45] J. Haller,[45] A. Hinzmann,[45] A. Karavdina,[45] G. Kasieczka,[45] R. Klanner,[45] R. Kogler,[45] V. Kutzner,[45] J. Lange,[45] T. Lange,[45] A. Malara,[45] C. E. N. Niemeyer,[45] A. Nigamova,[45] K. J. Pena Rodriguez,[45] O. Rieger,[45] P. Schleper,[45] S. Schumann,[45] J. Schwandt,[45] D. Schwarz,[45] J. Sonneveld,[45] H. Stadie,[45] G. Steinbrück,[45] B. Vormwald,[45] I. Zoi,[45] M. Baselga,[46] S. Baur,[46] J. Bechtel,[46] T. Berger,[46] E. Butz,[46] R. Caspart,[46] T. Chwalek,[46] W. De Boer,[46] A. Dierlamm,[46] A. Droll,[46] K. El Morabit,[46] N. Faltermann,[46] K. Flöh,[46] M. Giffels,[46] A. Gottmann,[46] F. Hartmann,[46,s] C. Heidecker,[46] U. Husemann,[46] M. A. Iqbal,[46] I. Katkov,[46,x] P. Keicher,[46] R. Koppenhöfer,[46] S. Maier,[46] M. Metzler,[46] S. Mitra,[46] D. Müller,[46] Th. Müller,[46] M. Musich,[46] G. Quast,[46] K. Rabbertz,[46] J. Rauser,[46] D. Savoiu,[46] D. Schäfer,[46] M. Schnepf,[46] M. Schröder,[46] D. Seith,[46] I. Shvetsov,[46] H. J. Simonis,[46] R. Ulrich,[46] M. Wassmer,[46] M. Weber,[46] R. Wolf,[46] S. Wozniewski,[46] G. Anagnostou,[47] P. Asenov,[47] G. Daskalakis,[47] T. Geralis,[47] A. Kyriakis,[47] D. Loukas,[47] G. Paspalaki,[47] A. Stakia,[47] M. Diamantopoulou,[48] D. Karasavvas,[48] G. Karathanasis,[48] P. Kontaxakis,[48] C. K. Koraka,[48] A. Manousakis-katsikakis,[48] A. Panagiotou,[48] I. Papavergou,[48] N. Saoulidou,[48] K. Theofilatos,[48] K. Vellidis,[48] E. Vourliotis,[48] G. Bakas,[49] K. Kousouris,[49] I. Papakrivopoulos,[49] G. Tsipolitis,[49] A. Zacharopoulou,[49] I. Evangelou,[50] C. Foudas,[50] P. Gianneios,[50] P. Katsoulis,[50] P. Kokkas,[50] S. Mallios,[50] K. Manitara,[50] N. Manthos,[50] I. Papadopoulos,[50] J. Strologas,[50] M. Bartók,[51,y] R. Chudasama,[51] M. Csanad,[51] M. M. A. Gadallah,[51,z] S. Lökös,[51,aa] P. Major,[51] K. Mandal,[51] A. Mehta,[51] G. Pasztor,[51] O. Surányi,[51] G. I. Veres,[51] G. Bencze,[52] C. Hajdu,[52] D. Horvath,[52,bb] F. Sikler,[52] V. Veszpremi,[52] G. Vesztergombi,[52,a,aa] S. Czellar,[53] J. Karancsi,[53,y] J. Molnar,[53] Z. Szillasi,[53] D. Teyssier,[53] P. Raics,[54] Z. L. Trocsanyi,[54] G. Zilizi,[54] T. Csorgo,[55] F. Nemes,[55] T. Novak,[55] S. Choudhury,[56] J. R. Komaragiri,[56] D. Kumar,[56] L. Panwar,[56] P. C. Tiwari,[56] S. Bahinipati,[57,cc] D. Dash,[57] C. Kar,[57] P. Mal,[57] T. Mishra,[57] V. K. Muraleedharan Nair Bindhu,[57] A. Nayak,[57,dd] D. K. Sahoo,[57,cc] N. Sur,[57] S. K. Swain,[57] S. Bansal,[58] S. B. Beri,[58] V. Bhatnagar,[58] S. Chauhan,[58] N. Dhingra,[58,ee] R. Gupta,[58] A. Kaur,[58] S. Kaur,[58] P. Kumari,[58] M. Lohan,[58] M. Meena,[58] K. Sandeep,[58] S. Sharma,[58] J. B. Singh,[58] A. K. Virdi,[58] A. Ahmed,[59] A. Bhardwaj,[59] B. C. Choudhary,[59] R. B. Garg,[59] M. Gola,[59] S. Keshri,[59] A. Kumar,[59] M. Naimuddin,[59] P. Priyanka,[59] K. Ranjan,[59] A. Shah,[59] M. Bharti,[60,ff] R. Bhattacharya,[60] S. Bhattacharya,[60] D. Bhowmik,[60] S. Dutta,[60] S. Ghosh,[60] B. Gomber,[60,gg] M. Maity,[60,hh] S. Nandan,[60] P. Palit,[60] A. Purohit,[60] P. K. Rout,[60] G. Saha,[60] S. Sarkar,[60] M. Sharan,[60] B. Singh,[60,ff] S. Thakur,[60,ff] P. K. Behera,[61] S. C. Behera,[61] P. Kalbhor,[61] A. Muhammad,[61] R. Pradhan,[61] P. R. Pujahari,[61] A. Sharma,[61] A. K. Sikdar,[61] D. Dutta,[62] V. Kumar,[62] K. Naskar,[62,ii] P. K. Netrakanti,[62] L. M. Pant,[62] P. Shukla,[62] T. Aziz,[63] M. A. Bhat,[63] S. Dugad,[63] R. Kumar Verma,[63] U. Sarkar,[63] S. Banerjee,[64] S. Bhattacharya,[64] S. Chatterjee,[64] M. Guchait,[64] S. Karmakar,[64] S. Kumar,[64] G. Majumder,[64] K. Mazumdar,[64] S. Mukherjee,[64] D. Roy,[64] N. Sahoo,[64] S. Dube,[65] B. Kansal,[65] A. Kapoor,[65] K. Kothekar,[65] S. Pandey,[65] A. Rane,[65] A. Rastogi,[65] S. Sharma,[65] H. Bakhshiansohi,[66,jj] S. Chenarani,[67,kk] S. M. Etesami,[67] M. Khakzad,[67] M. Mohammadi Najafabadi,[67] M. Felcini,[68] M. Grunewald,[68] M. Abbrescia,[69a,69b] R. Aly,[69a,69b,ll] C. Aruta,[69a,69b] A. Colaleo,[69a] D. Creanza,[69a,69c] N. De Filippis,[69a,69c] M. De Palma,[69a,69b] A. Di Florio,[69a,69b] A. Di Pilato,[69a,69b] W. Elmetenawee,[69a,69b] L. Fiore,[69a] A. Gelmi,[69a,69b] M. Gul,[69a] G. Iaselli,[69a,69c] M. Ince,[69a,69b] S. Lezki,[69a,69b] G. Maggi,[69a,69c] M. Maggi,[69a] I. Margjeka,[69a,69b] V. Mastrapasqua,[69a,69b] J. A. Merlin,[69a] S. My,[69a,69b] S. Nuzzo,[69a,69b] A. Pompili,[69a,69b] G. Pugliese,[69a,69c] A. Ranieri,[69a] G. Selvaggi,[69a,69b] L. Silvestris,[69a] F. M. Simone,[69a,69b] R. Venditti,[69a] P. Verwilligen,[69a] G. Abbiendi,[70a] C. Battilana,[70a,70b] D. Bonacorsi,[70a,70b] L. Borgonovi,[70a,70b] S. Braibant-Giacomelli,[70a,70b] 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] E. Fontanesi,[70a,70b] P. Giacomelli,[70a] L. Giommi,[70a,70b] C. Grandi,[70a] L. Guiducci,[70a,70b] F. Iemmi,[70a,70b] S. Lo Meo,[70a,mm] 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] N. Tosi,[70a] S. Albergo,[71a,71b,nn] S. Costa,[71a,71b,nn] A. Di Mattia,[71a] R. Potenza,[71a,71b] A. Tricomi,[71a,71b,nn] C. Tuve,[71a,71b] G. Barbagli,[72a] A. Cassese,[72a] R. Ceccarelli,[72a,72b] V. Ciulli,[72a,72b] C. Civinini,[72a] R. D'Alessandro,[72a,72b] F. Fiori,[72a] E. Focardi,[72a,72b] G. Latino,[72a,72b] P. Lenzi,[72a,72b] M. Lizzo,[72a,72b] M. Meschini,[72a] S. Paoletti,[72a] R. Seidita,[72a,72b] G. Sguazzoni,[72a] L. Viliani,[72a] L. Benussi,[73] S. Bianco,[73] D. Piccolo,[73] M. Bozzo,[74a,74b] F. Ferro,[74a] R. Mulargia,[74a,74b] E. Robutti,[74a] S. Tosi,[74a,74b] A. Benaglia,[75a] A. Beschi,[75a,75b] F. Brivio,[75a,75b] F. Cetorelli,[75a,75b] V. Ciriolo,[75a,75b,s] F. De Guio,[75a,75b] M. E. Dinardo,[75a,75b] P. Dini,[75a] S. Gennai,[75a]

A. Ghezzi,[75a,75b] P. Govoni,[75a,75b] L. Guzzi,[75a,75b] M. Malberti,[75a] S. Malvezzi,[75a] D. Menasce,[75a] F. Monti,[75a,75b] L. Moroni,[75a] M. Paganoni,[75a,75b] D. Pedrini,[75a] S. Ragazzi,[75a,75b] T. Tabarelli de Fatis,[75a,75b] D. Valsecchi,[75a,75b,s] D. Zuolo,[75a,75b] S. Buontempo,[76a] N. Cavallo,[76a,76c] A. De Iorio,[76a,76b] F. Fabozzi,[76a,76c] F. Fienga,[76a] A. O. M. Iorio,[76a,76b] L. Layer,[76a,76b] L. Lista,[76a,76b] S. Meola,[76a,76d,s] P. Paolucci,[76a,s] B. Rossi,[76a] C. Sciacca,[76a,76b] E. Voevodina,[76a,76b] P. Azzi,[77a] N. Bacchetta,[77a] D. Bisello,[77a,77b] A. Boletti,[77a,77b] A. Bragagnolo,[77a,77b] R. Carlin,[77a,77b] P. Checchia,[77a] P. De Castro Manzano,[77a] T. Dorigo,[77a] F. Gasparini,[77a,77b] U. Gasparini,[77a,77b] S. Y. Hoh,[77a,77b] M. Margoni,[77a,77b] A. T. Meneguzzo,[77a,77b] M. Presilla,[77a,77b] P. Ronchese,[77a,77b] R. Rossin,[77a,77b] F. Simonetto,[77a,77b] G. Strong,[77a] A. Tiko,[77a] M. Tosi,[77a,77b] M. Zanetti,[77a,77b] P. Zotto,[77a,77b] A. Zucchetta,[77a,77b] G. Zumerle,[77a,77b] C. Aime`,[78a,78b] A. Braghieri,[78a] S. Calzaferri,[78a,78b] D. Fiorina,[78a,78b] P. Montagna,[78a,78b] S. P. Ratti,[78a,78b] V. Re,[78a] M. Ressegotti,[78a,78b] C. Riccardi,[78a,78b] P. Salvini,[78a] I. Vai,[78a] P. Vitulo,[78a,78b] M. Biasini,[79a,79b] G. M. Bilei,[79a] D. Ciangottini,[79a,79b] L. Fanò,[79a,79b] P. Lariccia,[79a,79b] G. Mantovani,[79a,79b] V. Mariani,[79a,79b] M. Menichelli,[79a] F. Moscatelli,[79a] A. Rossi,[79a,79b] A. Santocchia,[79a,79b] D. Spiga,[79a] T. Tedeschi,[79a,79b] K. Androsov,[80a] P. Azzurri,[80a] G. Bagliesi,[80a] V. Bertacchi,[80a,80c] L. Bianchini,[80a] T. Boccali,[80a] R. Castaldi,[80a] M. A. Ciocci,[80a,80b] R. Dell'Orso,[80a] M. R. Di Domenico,[80a,80d] S. Donato,[80a] L. Giannini,[80a,80c] A. Giassi,[80a] M. T. Grippo,[80a] F. Ligabue,[80a,80c] E. Manca,[80a,80c] G. Mandorli,[80a,80c] A. Messineo,[80a,80b] F. Palla,[80a] G. Ramirez-Sanchez,[80a,80c] A. Rizzi,[80a,80b] G. Rolandi,[80a,80c] S. Roy Chowdhury,[80a,80c] A. Scribano,[80a] N. Shafiei,[80a,80b] P. Spagnolo,[80a] R. Tenchini,[80a] G. Tonelli,[80a,80b] N. Turini,[80a,80d] A. Venturi,[80a] P. G. Verdini,[80a] F. Cavallari,[81a] M. Cipriani,[81a,81b] D. Del Re,[81a,81b] E. Di Marco,[81a] M. Diemoz,[81a] E. Longo,[81a,81b] P. Meridiani,[81a] 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,81b] R. Tramontano,[81a,81b] 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] A. Cappati,[82a,82b] N. Cartiglia,[82a] S. Cometti,[82a] M. Costa,[82a,82b] R. Covarelli,[82a,82b] N. Demaria,[82a] B. Kiani,[82a,82b] F. Legger,[82a] C. Mariotti,[82a] S. Maselli,[82a] E. Migliore,[82a,82b] V. Monaco,[82a,82b] E. Monteil,[82a,82b] M. Monteno,[82a] M. M. Obertino,[82a,82b] G. Ortona,[82a] L. Pacher,[82a,82b] N. Pastrone,[82a] M. Pelliccioni,[82a] G. L. Pinna Angioni,[82a,82b] M. Ruspa,[82a,82c] R. Salvatico,[82a,82b] F. Siviero,[82a,82b] V. Sola,[82a] A. Solano,[82a,82b] D. Soldi,[82a,82b] A. Staiano,[82a] D. Trocino,[82a,82b] S. Belforte,[83a] V. Candelise,[83a,83b] M. Casarsa,[83a] F. Cossutti,[83a] A. Da Rold,[83a,83b] G. Della Ricca,[83a,83b] F. Vazzoler,[83a,83b] S. Dogra,[84] C. Huh,[84] B. Kim,[84] D. H. Kim,[84] G. N. Kim,[84] J. Lee,[84] S. W. Lee,[84] C. S. Moon,[84] Y. D. Oh,[84] S. I. Pak,[84] B. C. Radburn-Smith,[84] S. Sekmen,[84] Y. C. Yang,[84] H. Kim,[85] D. H. Moon,[85] B. Francois,[86] T. J. Kim,[86] J. Park,[86] S. Cho,[87] S. Choi,[87] Y. Go,[87] S. Ha,[87] B. Hong,[87] K. Lee,[87] K. S. Lee,[87] J. Lim,[87] J. Park,[87] S. K. Park,[87] J. Yoo,[87] J. Goh,[88] A. Gurtu,[88] H. S. Kim,[89] Y. Kim,[89] J. Almond,[90] J. H. Bhyun,[90] J. Choi,[90] S. Jeon,[90] J. Kim,[90] J. S. Kim,[90] S. Ko,[90] H. Kwon,[90] H. Lee,[90] K. Lee,[90] S. Lee,[90] K. Nam,[90] B. H. Oh,[90] M. Oh,[90] S. B. Oh,[90] H. Seo,[90] U. K. Yang,[90] I. Yoon,[90] D. Jeon,[91] J. H. Kim,[91] B. Ko,[91] J. S. H. Lee,[91] I. C. Park,[91] Y. Roh,[91] D. Song,[91] I. J. Watson,[91] H. D. Yoo,[92] Y. Choi,[93] C. Hwang,[93] Y. Jeong,[93] H. Lee,[93] Y. Lee,[93] I. Yu,[93] Y. Maghrbi,[94] V. Veckalns,[95,oo] A. Juodagalvis,[96] A. Rinkevicius,[96] G. Tamulaitis,[96] W. A. T. Wan Abdullah,[97] M. N. Yusli,[97] Z. Zolkapli,[97] J. F. Benitez,[98] A. Castaneda Hernandez,[98] J. A. Murillo Quijada,[98] L. Valencia Palomo,[98] H. Castilla-Valdez,[99] E. De La Cruz-Burelo,[99] I. Heredia-De La Cruz,[99,pp] R. Lopez-Fernandez,[99] A. Sanchez-Hernandez,[99] S. Carrillo Moreno,[100] C. Oropeza Barrera,[100] M. Ramirez-Garcia,[100] F. Vazquez Valencia,[100] J. Eysermans,[101] I. Pedraza,[101] H. A. Salazar Ibarguen,[101] C. Uribe Estrada,[101] A. Morelos Pineda,[102] J. Mijuskovic,[103,e] N. Raicevic,[103] D. Krofcheck,[104] S. Bheesette,[105] P. H. Butler,[105] A. Ahmad,[106] M. I. Asghar,[106] M. I. M. Awan,[106] H. R. Hoorani,[106] W. A. Khan,[106] M. A. Shah,[106] M. Shoaib,[106] M. Waqas,[106] V. Avati,[107] L. Grzanka,[107] M. Malawski,[107] H. Bialkowska,[108] M. Bluj,[108] B. Boimska,[108] T. Frueboes,[108] M. Górski,[108] M. Kazana,[108] M. Szleper,[108] P. Traczyk,[108] P. Zalewski,[108] K. Bunkowski,[109] A. Byszuk,[109,qq] K. Doroba,[109] A. Kalinowski,[109] M. Konecki,[109] J. Krolikowski,[109] M. Olszewski,[109] M. Walczak,[109] M. Araujo,[110] P. Bargassa,[110] D. Bastos,[110] P. Faccioli,[110] M. Gallinaro,[110] J. Hollar,[110] N. Leonardo,[110] T. Niknejad,[110] J. Seixas,[110] K. Shchelina,[110] O. Toldaiev,[110] J. Varela,[110] S. Afanasiev,[111] P. Bunin,[111] M. Gavrilenko,[111] I. Golutvin,[111] I. Gorbunov,[111] A. Kamenev,[111] V. Karjavine,[111] A. Lanev,[111] A. Malakhov,[111] V. Matveev,[111,rr,ss] P. Moisenz,[111] V. Palichik,[111] V. Perelygin,[111] M. Savina,[111] V. Shalaev,[111] S. Shmatov,[111] S. Shulha,[111] V. Smirnov,[111] O. Teryaev,[111] N. Voytishin,[111] B. S. Yuldashev,[111,tt] A. Zarubin,[111] I. Zhizhin,[111] G. Gavrilov,[112] V. Golovtcov,[112] Y. Ivanov,[112] V. Kim,[112,uu] E. Kuznetsova,[112,vv] V. Murzin,[112] V. Oreshkin,[112] I. Smirnov,[112] D. Sosnov,[112] V. Sulimov,[112] L. Uvarov,[112] S. Volkov,[112] A. Vorobyev,[112] Yu. Andreev,[113] A. Dermenev,[113] S. Gninenko,[113] N. Golubev,[113] A. Karneyeu,[113] M. Kirsanov,[113] N. Krasnikov,[113] A. Pashenkov,[113] G. Pivovarov,[113] D. Tlisov,[113,a] A. Toropin,[113] V. Epshteyn,[114] V. Gavrilov,[114] N. Lychkovskaya,[114] A. Nikitenko,[114,ww] V. Popov,[114] G. Safronov,[114] A. Spiridonov,[114] A. Stepennov,[114] M. Toms,[114]

E. Vlasov,[114] A. Zhokin,[114] T. Aushev,[115] R. Chistov,[116,xx] M. Danilov,[116,yy] A. Oskin,[116] P. Parygin,[116] S. Polikarpov,[116,xx] V. Andreev,[117] M. Azarkin,[117] I. Dremin,[117] M. Kirakosyan,[117] A. Terkulov,[117] A. Belyaev,[118] E. Boos,[118] A. Ershov,[118] A. Gribushin,[118] A. Kaminskiy,[118,zz] O. Kodolova,[118] V. Korotkikh,[118] I. Lokhtin,[118] S. Obraztsov,[118] S. Petrushanko,[118] V. Savrin,[118] A. Snigirev,[118] I. Vardanyan,[118] V. Blinov,[119,aaa] T. Dimova,[119,aaa] L. Kardapoltsev,[119,aaa] I. Ovtin,[119,aaa] Y. Skovpen,[119,aaa] I. Azhgirey,[120] I. Bayshev,[120] V. Kachanov,[120] A. Kalinin,[120] D. Konstantinov,[120] V. Petrov,[120] R. Ryutin,[120] A. Sobol,[120] S. Troshin,[120] N. Tyurin,[120] A. Uzunian,[120] A. Volkov,[120] A. Babaev,[121] A. Iuzhakov,[121] V. Okhotnikov,[121] L. Sukhikh,[121] V. Borchsh,[122] V. Ivanchenko,[122] E. Tcherniaev,[122] P. Adzic,[123,bbb] P. Cirkovic,[123] M. Dordevic,[123] P. Milenovic,[123] J. Milosevic,[123] M. Aguilar-Benitez,[124] J. Alcaraz Maestre,[124] A. Álvarez Fernández,[124] I. Bachiller,[124] M. Barrio Luna,[124] Cristina F. Bedoya,[124] J. A. Brochero Cifuentes,[124] C. A. Carrillo Montoya,[124] M. Cepeda,[124] M. Cerrada,[124] N. Colino,[124] B. De La Cruz,[124] A. Delgado Peris,[124] J. P. Fernández Ramos,[124] J. Flix,[124] M. C. Fouz,[124] A. García Alonso,[124] O. Gonzalez Lopez,[124] S. Goy Lopez,[124] J. M. Hernandez,[124] M. I. Josa,[124] J. León Holgado,[124] D. Moran,[124] Á. Navarro Tobar,[124] A. Pérez-Calero Yzquierdo,[124] J. Puerta Pelayo,[124] I. Redondo,[124] L. Romero,[124] S. Sánchez Navas,[124] M. S. Soares,[124] A. Triossi,[124] L. Urda Gómez,[124] C. Willmott,[124] C. Albajar,[125] J. F. de Trocóniz,[125] R. Reyes-Almanza,[125] B. Alvarez Gonzalez,[126] J. Cuevas,[126] C. Erice,[126] J. Fernandez Menendez,[126] S. Folgueras,[126] I. Gonzalez Caballero,[126] E. Palencia Cortezon,[126] C. Ramón Álvarez,[126] J. Ripoll Sau,[126] V. Rodríguez Bouza,[126] S. Sanchez Cruz,[126] A. Trapote,[126] I. J. Cabrillo,[127] A. Calderon,[127] B. Chazin Quero,[127] J. Duarte Campderros,[127] M. Fernandez,[127] P. J. Fernández Manteca,[127] G. Gomez,[127] C. Martinez Rivero,[127] P. Martinez Ruiz del Arbol,[127] F. Matorras,[127] J. Piedra Gomez,[127] C. Prieels,[127] F. Ricci-Tam,[127] T. Rodrigo,[127] A. Ruiz-Jimeno,[127] L. Scodellaro,[127] I. Vila,[127] J. M. Vizan Garcia,[127] MK Jayananda,[128] B. Kailasapathy,[128,ccc] D. U. J. Sonnadara,[128] DDC Wickramarathna,[128] W. G. D. Dharmaratna,[129] K. Liyanage,[129] N. Perera,[129] N. Wickramage,[129] T. K. Aarrestad,[130] D. Abbaneo,[130] B. Akgun,[130] E. Auffray,[130] G. Auzinger,[130] J. Baechler,[130] P. Baillon,[130] A. H. Ball,[130] D. Barney,[130] J. Bendavid,[130] N. Beni,[130] M. Bianco,[130] A. Bocci,[130] P. Bortignon,[130] E. Bossini,[130] E. Brondolin,[130] T. Camporesi,[130] G. Cerminara,[130] L. Cristella,[130] D. d'Enterria,[130] A. Dabrowski,[130] N. Daci,[130] V. Daponte,[130] A. David,[130] A. De Roeck,[130] M. Deile,[130] R. Di Maria,[130] M. Dobson,[130] M. Dünser,[130] N. Dupont,[130] A. Elliott-Peisert,[130] N. Emriskova,[130] F. Fallavollita,[130,ddd] D. Fasanella,[130] S. Fiorendi,[130] G. Franzoni,[130] J. Fulcher,[130] S. Giani,[130] D. Gigi,[130] K. Gill,[130] F. Glege,[130] L. Gouskos,[130] M. Guilbaud,[130] D. Gulhan,[130] M. Haranko,[130] J. Hegeman,[130] Y. Iiyama,[130] V. Innocente,[130] T. James,[130] P. Janot,[130] J. Kaspar,[130] J. Kieseler,[130] M. Komm,[130] N. Kratochwil,[130] C. Lange,[130] P. Lecoq,[130] K. Long,[130] C. Lourenço,[130] L. Malgeri,[130] M. Mannelli,[130] A. Massironi,[130] F. Meijers,[130] S. Mersi,[130] E. Meschi,[130] F. Moortgat,[130] M. Mulders,[130] J. Ngadiuba,[130] J. Niedziela,[130] S. Orfanelli,[130] L. Orsini,[130] F. Pantaleo,[130,s] L. Pape,[130] E. Perez,[130] M. Peruzzi,[130] A. Petrilli,[130] G. Petrucciani,[130] A. Pfeiffer,[130] M. Pierini,[130] D. Rabady,[130] A. Racz,[130] M. Rieger,[130] M. Rovere,[130] H. Sakulin,[130] J. Salfeld-Nebgen,[130] S. Scarfi,[130] C. Schäfer,[130] C. Schwick,[130] M. Selvaggi,[130] A. Sharma,[130] P. Silva,[130] W. Snoeys,[130] P. Sphicas,[130,eee] J. Steggemann,[130] S. Summers,[130] V. R. Tavolaro,[130] D. Treille,[130] A. Tsirou,[130] G. P. Van Onsem,[130] A. Vartak,[130] M. Verzetti,[130] K. A. Wozniak,[130] W. D. Zeuner,[130] L. Caminada,[131,fff] W. Erdmann,[131] R. Horisberger,[131] Q. Ingram,[131] H. C. Kaestli,[131] D. Kotlinski,[131] U. Langenegger,[131] T. Rohe,[131] M. Backhaus,[132] P. Berger,[132] A. Calandri,[132] N. Chernyavskaya,[132] A. De Cosa,[132] G. Dissertori,[132] M. Dittmar,[132] M. Donegà,[132] C. Dorfer,[132] T. Gadek,[132] T. A. Gómez Espinosa,[132] C. Grab,[132] D. Hits,[132] W. Lustermann,[132] A.-M. Lyon,[132] R. A. Manzoni,[132] M. T. Meinhard,[132] F. Micheli,[132] F. Nessi-Tedaldi,[132] F. Pauss,[132] V. Perovic,[132] G. Perrin,[132] L. Perrozzi,[132] S. Pigazzini,[132] M. G. Ratti,[132] M. Reichmann,[132] C. Reissel,[132] T. Reitenspiess,[132] B. Ristic,[132] D. Ruini,[132] D. A. Sanz Becerra,[132] M. Schönenberger,[132] V. Stampf,[132] M. L. Vesterbacka Olsson,[132] R. Wallny,[132] D. H. Zhu,[132] C. Amsler,[133,ggg] C. Botta,[133] D. Brzhechko,[133] M. F. Canelli,[133] R. Del Burgo,[133] J. K. Heikkilä,[133] M. Huwiler,[133] A. Jofrehei,[133] B. Kilminster,[133] S. Leontsinis,[133] A. Macchiolo,[133] P. Meiring,[133] V. M. Mikuni,[133] U. Molinatti,[133] I. Neutelings,[133] G. Rauco,[133] A. Reimers,[133] P. Robmann,[133] K. Schweiger,[133] Y. Takahashi,[133] S. Wertz,[133] C. Adloff,[134,hhh] C. M. Kuo,[134] W. Lin,[134] A. Roy,[134] T. Sarkar,[134,hh] S. S. Yu,[134] L. Ceard,[135] P. Chang,[135] Y. Chao,[135] K. F. Chen,[135] P. H. Chen,[135] W.-S. Hou,[135] Y. y. Li,[135] R.-S. Lu,[135] E. Paganis,[135] A. Psallidas,[135] A. Steen,[135] E. Yazgan,[135] B. Asavapibhop,[136] C. Asawatangtrakuldee,[136] N. Srimanobhas,[136] F. Boran,[137] S. Damarseckin,[137,iii] Z. S. Demiroglu,[137] F. Dolek,[137] C. Dozen,[137,jjj] I. Dumanoglu,[137,kkk] E. Eskut,[137] G. Gokbulut,[137] Y. Guler,[137] E. Gurpinar Guler,[137,lll] I. Hos,[137,mmm] C. Isik,[137] E. E. Kangal,[137,nnn] O. Kara,[137] A. Kayis Topaksu,[137] U. Kiminsu,[137] G. Onengut,[137] K. Ozdemir,[137,ooo] A. Polatoz,[137] A. E. Simsek,[137] B. Tali,[137,ppp] U. G. Tok,[137] S. Turkcapar,[137] I. S. Zorbakir,[137] C. Zorbilmez,[137] B. Isildak,[138,qqq] G. Karapinar,[138,rrr] K. Ocalan,[138,sss] M. Yalvac,[138,ttt] I. O. Atakisi,[139] E. Gülmez,[139]

M. Kaya,[139,uuu] O. Kaya,[139,vvv] Ö. Özçelik,[139] S. Tekten,[139,www] E. A. Yetkin,[139,xxx] A. Cakir,[140] K. Cankocak,[140,kkk] Y. Komurcu,[140] S. Sen,[140,yyy] F. Aydogmus Sen,[141] S. Cerci,[141,ppp] B. Kaynak,[141] S. Ozkorucuklu,[141] D. Sunar Cerci,[141,ppp] B. Grynyov,[142] L. Levchuk,[143] E. Bhal,[144] S. Bologna,[144] J. J. Brooke,[144] E. Clement,[144] D. Cussans,[144] H. Flacher,[144] J. Goldstein,[144] G. P. Heath,[144] H. F. Heath,[144] L. Kreczko,[144] B. Krikler,[144] S. Paramesvaran,[144] T. Sakuma,[144] S. Seif El Nasr-Storey,[144] V. J. Smith,[144] J. Taylor,[144] A. Titterton,[144] K. W. Bell,[145] A. Belyaev,[145,zzz] C. Brew,[145] R. M. Brown,[145] D. J. A. Cockerill,[145] K. V. Ellis,[145] K. Harder,[145] S. Harper,[145] J. Linacre,[145] K. Manolopoulos,[145] D. M. Newbold,[145] E. Olaiya,[145] D. Petyt,[145] T. Reis,[145] T. Schuh,[145] C. H. Shepherd-Themistocleous,[145] A. Thea,[145] I. R. Tomalin,[145] T. Williams,[145] R. Bainbridge,[146] P. Bloch,[146] S. Bonomally,[146] J. Borg,[146] S. Breeze,[146] O. Buchmuller,[146] A. Bundock,[146] V. Cepaitis,[146] G. S. Chahal,[146,aaaa] D. Colling,[146] P. Dauncey,[146] G. Davies,[146] M. Della Negra,[146] G. Fedi,[146] G. Hall,[146] G. Iles,[146] J. Langford,[146] L. Lyons,[146] A.-M. Magnan,[146] S. Malik,[146] A. Martelli,[146] V. Milosevic,[146] J. Nash,[146,bbbb] V. Palladino,[146] M. Pesaresi,[146] D. M. Raymond,[146] A. Richards,[146] A. Rose,[146] E. Scott,[146] C. Seez,[146] A. Shtipliyski,[146] M. Stoye,[146] A. Tapper,[146] K. Uchida,[146] T. Virdee,[146,s] N. Wardle,[146] S. N. Webb,[146] D. Winterbottom,[146] A. G. Zecchinelli,[146] J. E. Cole,[147] P. R. Hobson,[147] A. Khan,[147] P. Kyberd,[147] C. K. Mackay,[147] I. D. Reid,[147] L. Teodorescu,[147] S. Zahid,[147] A. Brinkerhoff,[148] K. Call,[148] B. Caraway,[148] J. Dittmann,[148] K. Hatakeyama,[148] A. R. Kanuganti,[148] C. Madrid,[148] B. McMaster,[148] N. Pastika,[148] S. Sawant,[148] C. Smith,[148] R. Bartek,[149] A. Dominguez,[149] R. Uniyal,[149] A. M. Vargas Hernandez,[149] A. Buccilli,[150] O. Charaf,[150] S. I. Cooper,[150] S. V. Gleyzer,[150] C. Henderson,[150] P. Rumerio,[150] C. West,[150] A. Akpinar,[151] A. Albert,[151] D. Arcaro,[151] C. Cosby,[151] Z. Demiragli,[151] D. Gastler,[151] C. Richardson,[151] J. Rohlf,[151] K. Salyer,[151] D. Sperka,[151] D. Spitzbart,[151] I. Suarez,[151] S. Yuan,[151] D. Zou,[151] G. Benelli,[152] B. Burkle,[152] X. Coubez,[152,t] D. Cutts,[152] Y. t. Duh,[152] M. Hadley,[152] U. Heintz,[152] J. M. Hogan,[152,cccc] K. H. M. Kwok,[152] E. Laird,[152] G. Landsberg,[152] K. T. Lau,[152] J. Lee,[152] M. Narain,[152] S. Sagir,[152,dddd] R. Syarif,[152] E. Usai,[152] W. Y. Wong,[152] D. Yu,[152] W. Zhang,[152] R. Band,[153] C. Brainerd,[153] R. Breedon,[153] M. Calderon De La Barca Sanchez,[153] M. Chertok,[153] J. Conway,[153] R. Conway,[153] P. T. Cox,[153] R. Erbacher,[153] C. Flores,[153] G. Funk,[153] F. Jensen,[153] W. Ko,[153,a] O. Kukral,[153] R. Lander,[153] M. Mulhearn,[153] D. Pellett,[153] J. Pilot,[153] M. Shi,[153] D. Taylor,[153] K. Tos,[153] M. Tripathi,[153] Y. Yao,[153] F. Zhang,[153] M. Bachtis,[154] R. Cousins,[154] A. Dasgupta,[154] A. Florent,[154] D. Hamilton,[154] J. Hauser,[154] M. Ignatenko,[154] T. Lam,[154] N. Mccoll,[154] W. A. Nash,[154] S. Regnard,[154] D. Saltzberg,[154] C. Schnaible,[154] B. Stone,[154] V. Valuev,[154] K. Burt,[155] Y. Chen,[155] R. Clare,[155] J. W. Gary,[155] S. M. A. Ghiasi Shirazi,[155] G. Hanson,[155] G. Karapostoli,[155] O. R. Long,[155] N. Manganelli,[155] M. Olmedo Negrete,[155] M. I. Paneva,[155] W. Si,[155] S. Wimpenny,[155] Y. Zhang,[155] J. G. Branson,[156] P. Chang,[156] S. Cittolin,[156] S. Cooperstein,[156] N. Deelen,[156] M. Derdzinski,[156] J. Duarte,[156] R. Gerosa,[156] D. Gilbert,[156] B. Hashemi,[156] V. Krutelyov,[156] J. Letts,[156] M. Masciovecchio,[156] S. May,[156] S. Padhi,[156] M. Pieri,[156] V. Sharma,[156] M. Tadel,[156] F. Würthwein,[156] A. Yagil,[156] N. Amin,[157] C. Campagnari,[157] M. Citron,[157] A. Dorsett,[157] V. Dutta,[157] J. Incandela,[157] B. Marsh,[157] H. Mei,[157] A. Ovcharova,[157] H. Qu,[157] M. Quinnan,[157] J. Richman,[157] U. Sarica,[157] D. Stuart,[157] S. Wang,[157] D. Anderson,[158] A. Bornheim,[158] O. Cerri,[158] I. Dutta,[158] J. M. Lawhorn,[158] N. Lu,[158] J. Mao,[158] H. B. Newman,[158] T. Q. Nguyen,[158] J. Pata,[158] M. Spiropulu,[158] J. R. Vlimant,[158] S. Xie,[158] Z. Zhang,[158] R. Y. Zhu,[158] J. Alison,[159] M. B. Andrews,[159] T. Ferguson,[159] T. Mudholkar,[159] M. Paulini,[159] M. Sun,[159] I. Vorobiev,[159] J. P. Cumalat,[160] W. T. Ford,[160] E. MacDonald,[160] T. Mulholland,[160] R. Patel,[160] A. Perloff,[160] K. Stenson,[160] K. A. Ulmer,[160] S. R. Wagner,[160] J. Alexander,[161] Y. Cheng,[161] J. Chu,[161] D. J. Cranshaw,[161] A. Datta,[161] A. Frankenthal,[161] K. Mcdermott,[161] J. Monroy,[161] J. R. Patterson,[161] D. Quach,[161] A. Ryd,[161] W. Sun,[161] S. M. Tan,[161] Z. Tao,[161] J. Thom,[161] P. Wittich,[161] M. Zientek,[161] S. Abdullin,[162] M. Albrow,[162] M. Alyari,[162] G. Apollinari,[162] A. Apresyan,[162] A. Apyan,[162] S. Banerjee,[162] L. A. T. Bauerdick,[162] A. Beretvas,[162] D. Berry,[162] J. Berryhill,[162] P. C. Bhat,[162] K. Burkett,[162] J. N. Butler,[162] A. Canepa,[162] G. B. Cerati,[162] H. W. K. Cheung,[162] F. Chlebana,[162] M. Cremonesi,[162] V. D. Elvira,[162] J. Freeman,[162] Z. Gecse,[162] E. Gottschalk,[162] L. Gray,[162] D. Green,[162] S. Grünendahl,[162] O. Gutsche,[162] R. M. Harris,[162] S. Hasegawa,[162] R. Heller,[162] T. C. Herwig,[162] J. Hirschauer,[162] B. Jayatilaka,[162] S. Jindariani,[162] M. Johnson,[162] U. Joshi,[162] P. Klabbers,[162] T. Klijnsma,[162] B. Klima,[162] M. J. Kortelainen,[162] S. Lammel,[162] D. Lincoln,[162] R. Lipton,[162] M. Liu,[162] T. Liu,[162] J. Lykken,[162] K. Maeshima,[162] D. Mason,[162] P. McBride,[162] P. Merkel,[162] S. Mrenna,[162] S. Nahn,[162] V. O'Dell,[162] V. Papadimitriou,[162] K. Pedro,[162] C. Pena,[162,eeee] O. Prokofyev,[162] F. Ravera,[162] A. Reinsvold Hall,[162] L. Ristori,[162] B. Schneider,[162] E. Sexton-Kennedy,[162] N. Smith,[162] A. Soha,[162] W. J. Spalding,[162] L. Spiegel,[162] S. Stoynev,[162] J. Strait,[162] L. Taylor,[162] S. Tkaczyk,[162] N. V. Tran,[162] L. Uplegger,[162] E. W. Vaandering,[162] H. A. Weber,[162] A. Woodard,[162] D. Acosta,[163] P. Avery,[163] D. Bourilkov,[163] L. Cadamuro,[163] V. Cherepanov,[163] F. Errico,[163] R. D. Field,[163] D. Guerrero,[163] B. M. Joshi,[163] M. Kim,[163] J. Konigsberg,[163] A. Korytov,[163] K. H. Lo,[163] K. Matchev,[163] N. Menendez,[163]

G. Mitselmakher,[163] D. Rosenzweig,[163] K. Shi,[163] J. Wang,[163] S. Wang,[163] X. Zuo,[163] T. Adams,[164] A. Askew,[164] D. Diaz,[164] R. Habibullah,[164] S. Hagopian,[164] V. Hagopian,[164] K. F. Johnson,[164] R. Khurana,[164] T. Kolberg,[164] G. Martinez,[164] H. Prosper,[164] C. Schiber,[164] R. Yohay,[164] J. Zhang,[164] M. M. Baarmand,[165] S. Butalla,[165] T. Elkafrawy,[165,n] M. Hohlmann,[165] D. Noonan,[165] M. Rahmani,[165] M. Saunders,[165] F. Yumiceva,[165] M. R. Adams,[166] L. Apanasevich,[166] H. Becerril Gonzalez,[166] R. Cavanaugh,[166] X. Chen,[166] S. Dittmer,[166] O. Evdokimov,[166] C. E. Gerber,[166] D. A. Hangal,[166] D. J. Hofman,[166] C. Mills,[166] G. Oh,[166] T. Roy,[166] M. B. Tonjes,[166] N. Varelas,[166] J. Viinikainen,[166] X. Wang,[166] Z. Wu,[166] M. Alhusseini,[167] K. Dilsiz,[167,ffff] S. Durgut,[167] R. P. Gandrajula,[167] M. Haytmyradov,[167] V. Khristenko,[167] O. K. Köseyan,[167] J.-P. Merlo,[167] A. Mestvirishvili,[167,gggg] A. Moeller,[167] J. Nachtman,[167] H. Ogul,[167,hhhh] Y. Onel,[167] F. Ozok,[167,iiii] A. Penzo,[167] C. Snyder,[167] E. Tiras,[167] J. Wetzel,[167] K. Yi,[167,jjjj] O. Amram,[168] B. Blumenfeld,[168] L. Corcodilos,[168] M. Eminizer,[168] A. V. Gritsan,[168] S. Kyriacou,[168] P. Maksimovic,[168] C. Mantilla,[168] J. Roskes,[168] M. Swartz,[168] T. Á. Vámi,[168] C. Baldenegro Barrera,[169] P. Baringer,[169] A. Bean,[169] A. Bylinkin,[169] T. Isidori,[169] S. Khalil,[169] J. King,[169] G. Krintiras,[169] A. Kropivnitskaya,[169] C. Lindsey,[169] N. Minafra,[169] M. Murray,[169] C. Rogan,[169] C. Royon,[169] S. Sanders,[169] E. Schmitz,[169] J. D. Tapia Takaki,[169] Q. Wang,[169] J. Williams,[169] G. Wilson,[169] S. Duric,[170] A. Ivanov,[170] K. Kaadze,[170] D. Kim,[170] Y. Maravin,[170] T. Mitchell,[170] A. Modak,[170] A. Mohammadi,[170] F. Rebassoo,[171] D. Wright,[171] E. Adams,[172] A. Baden,[172] O. Baron,[172] A. Belloni,[172] S. C. Eno,[172] Y. Feng,[172] N. J. Hadley,[172] S. Jabeen,[172] G. Y. Jeng,[172] R. G. Kellogg,[172] T. Koeth,[172] A. C. Mignerey,[172] S. Nabili,[172] M. Seidel,[172] A. Skuja,[172] S. C. Tonwar,[172] L. Wang,[172] K. Wong,[172] D. Abercrombie,[173] B. Allen,[173] R. Bi,[173] S. Brandt,[173] W. Busza,[173] I. A. Cali,[173] Y. Chen,[173] M. D'Alfonso,[173] G. Gomez Ceballos,[173] M. Goncharov,[173] P. Harris,[173] D. Hsu,[173] M. Hu,[173] M. Klute,[173] D. Kovalskyi,[173] J. Krupa,[173] Y.-J. Lee,[173] P. D. Luckey,[173] B. Maier,[173] A. C. Marini,[173] C. Mcginn,[173] C. Mironov,[173] S. Narayanan,[173] X. Niu,[173] C. Paus,[173] D. Rankin,[173] C. Roland,[173] G. Roland,[173] Z. Shi,[173] G. S. F. Stephans,[173] K. Sumorok,[173] K. Tatar,[173] D. Velicanu,[173] J. Wang,[173] T. W. Wang,[173] Z. Wang,[173] B. Wyslouch,[173] R. M. Chatterjee,[174] A. Evans,[174] S. Guts,[174,a] P. Hansen,[174] J. Hiltbrand,[174] Sh. Jain,[174] M. Krohn,[174] Y. Kubota,[174] Z. Lesko,[174] J. Mans,[174] M. Revering,[174] R. Rusack,[174] R. Saradhy,[174] N. Schroeder,[174] N. Strobbe,[174] M. A. Wadud,[174] J. G. Acosta,[175] S. Oliveros,[175] K. Bloom,[176] S. Chauhan,[176] D. R. Claes,[176] C. Fangmeier,[176] L. Finco,[176] F. Golf,[176] J. R. González Fernández,[176] I. Kravchenko,[176] J. E. Siado,[176] G. R. Snow,[176,a] B. Stieger,[176] W. Tabb,[176] F. Yan,[176] G. Agarwal,[177] C. Harrington,[177] L. Hay,[177] I. Iashvili,[177] A. Kharchilava,[177] C. McLean,[177] D. Nguyen,[177] A. Parker,[177] J. Pekkanen,[177] S. Rappoccio,[177] B. Roozbahani,[177] G. Alverson,[178] E. Barberis,[178] C. Freer,[178] Y. Haddad,[178] A. Hortiangtham,[178] J. Li,[178] G. Madigan,[178] B. Marzocchi,[178] D. M. Morse,[178] V. Nguyen,[178] T. Orimoto,[178] L. Skinnari,[178] A. Tishelman-Charny,[178] T. Wamorkar,[178] B. Wang,[178] A. Wisecarver,[178] D. Wood,[178] S. Bhattacharya,[179] J. Bueghly,[179] Z. Chen,[179] A. Gilbert,[179] T. Gunter,[179] K. A. Hahn,[179] N. Odell,[179] M. H. Schmitt,[179] K. Sung,[179] M. Velasco,[179] R. Bucci,[180] N. Dev,[180] R. Goldouzian,[180] M. Hildreth,[180] K. Hurtado Anampa,[180] C. Jessop,[180] D. J. Karmgard,[180] K. Lannon,[180] W. Li,[180] N. Loukas,[180] N. Marinelli,[180] I. Mcalister,[180] F. Meng,[180] K. Mohrman,[180] Y. Musienko,[180,rr] R. Ruchti,[180] P. Siddireddy,[180] S. Taroni,[180] M. Wayne,[180] A. Wightman,[180] M. Wolf,[180] L. Zygala,[180] J. Alimena,[181] B. Bylsma,[181] B. Cardwell,[181] L. S. Durkin,[181] B. Francis,[181] C. Hill,[181] A. Lefeld,[181] B. L. Winer,[181] B. R. Yates,[181] P. Das,[182] G. Dezoort,[182] P. Elmer,[182] B. Greenberg,[182] N. Haubrich,[182] S. Higginbotham,[182] A. Kalogeropoulos,[182] G. Kopp,[182] S. Kwan,[182] D. Lange,[182] M. T. Lucchini,[182] J. Luo,[182] D. Marlow,[182] K. Mei,[182] I. Ojalvo,[182] J. Olsen,[182] C. Palmer,[182] P. Piroué,[182] D. Stickland,[182] C. Tully,[182] S. Malik,[183] S. Norberg,[183] V. E. Barnes,[184] R. Chawla,[184] S. Das,[184] L. Gutay,[184] M. Jones,[184] A. W. Jung,[184] B. Mahakud,[184] G. Negro,[184] N. Neumeister,[184] C. C. Peng,[184] S. Piperov,[184] H. Qiu,[184] J. F. Schulte,[184] N. Trevisani,[184] F. Wang,[184] R. Xiao,[184] W. Xie,[184] T. Cheng,[185] J. Dolen,[185] N. Parashar,[185] M. Stojanovic,[185] A. Baty,[186] S. Dildick,[186] K. M. Ecklund,[186] S. Freed,[186] F. J. M. Geurts,[186] M. Kilpatrick,[186] A. Kumar,[186] W. Li,[186] B. P. Padley,[186] R. Redjimi,[186] J. Roberts,[186,a] J. Rorie,[186] W. Shi,[186] A. G. Stahl Leiton,[186] A. Bodek,[187] P. de Barbaro,[187] R. Demina,[187] J. L. Dulemba,[187] C. Fallon,[187] T. Ferbel,[187] M. Galanti,[187] A. Garcia-Bellido,[187] O. Hindrichs,[187] A. Khukhunaishvili,[187] E. Ranken,[187] R. Taus,[187] B. Chiarito,[188] J. P. Chou,[188] A. Gandrakota,[188] Y. Gershtein,[188] E. Halkiadakis,[188] A. Hart,[188] M. Heindl,[188] E. Hughes,[188] S. Kaplan,[188] O. Karacheban,[188,w] I. Laflotte,[188] A. Lath,[188] R. Montalvo,[188] K. Nash,[188] M. Osherson,[188] S. Salur,[188] S. Schnetzer,[188] S. Somalwar,[188] R. Stone,[188] S. A. Thayil,[188] S. Thomas,[188] H. Wang,[188] H. Acharya,[189] A. G. Delannoy,[189] S. Spanier,[189] O. Bouhali,[190,kkkk] M. Dalchenko,[190] A. Delgado,[190] R. Eusebi,[190] J. Gilmore,[190] T. Huang,[190] T. Kamon,[190,llll] H. Kim,[190] S. Luo,[190] S. Malhotra,[190] R. Mueller,[190] D. Overton,[190] L. Perniè,[190] D. Rathjens,[190] A. Safonov,[190] J. Sturdy,[190] N. Akchurin,[191] J. Damgov,[191] V. Hegde,[191] S. Kunori,[191] K. Lamichhane,[191] S. W. Lee,[191] T. Mengke,[191] S. Muthumuni,[191] T. Peltola,[191] S. Undleeb,[191] I. Volobouev,[191] Z. Wang,[191] A. Whitbeck,[191] E. Appelt,[192] S. Greene,[192] A. Gurrola,[192]

R. Janjam,[192] W. Johns,[192] C. Maguire,[192] A. Melo,[192] H. Ni,[192] K. Padeken,[192] F. Romeo,[192] P. Sheldon,[192] S. Tuo,[192] J. Velkovska,[192] M. Verweij,[192] M. W. Arenton,[193] B. Cox,[193] G. Cummings,[193] J. Hakala,[193] R. Hirosky,[193] M. Joyce,[193] A. Ledovskoy,[193] A. Li,[193] C. Neu,[193] B. Tannenwald,[193] Y. Wang,[193] E. Wolfe,[193] F. Xia,[193] P. E. Karchin,[194] N. Poudyal,[194] P. Thapa,[194] K. Black,[195] T. Bose,[195] J. Buchanan,[195] C. Caillol,[195] S. Dasu,[195] I. De Bruyn,[195] P. Everaerts,[195] C. Galloni,[195] H. He,[195] M. Herndon,[195] A. Hervé,[195] U. Hussain,[195] A. Lanaro,[195] A. Loeliger,[195] R. Loveless,[195] J. Madhusudanan Sreekala,[195] A. Mallampalli,[195] D. Pinna,[195] T. Ruggles,[195] A. Savin,[195] V. Shang,[195] V. Sharma,[195] W. H. Smith,[195] D. Teague,[195] S. Trembath-reichert,[195] and W. Vetens[195]

(CMS Collaboration)

[1]*Yerevan Physics Institute, Yerevan, Armenia*
[2]*Institut für Hochenergiephysik, Wien, Austria*
[3]*Institute for Nuclear Problems, Minsk, Belarus*
[4]*Universiteit Antwerpen, Antwerpen, Belgium*
[5]*Vrije Universiteit Brussel, Brussel, Belgium*
[6]*Université Libre de Bruxelles, Bruxelles, Belgium*
[7]*Ghent University, Ghent, Belgium*
[8]*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
[9]*Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
[10]*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
[11a]*Universidade Estadual Paulista, São Paulo, Brazil*
[11b]*Universidade Federal do ABC, São Paulo, Brazil*
[12]*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*
[13]*University of Sofia, Sofia, Bulgaria*
[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]*Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) - Fudan University, Shanghai, China*
[20]*Zhejiang University, Hangzhou, China*
[21]*Universidad de Los Andes, Bogota, Colombia*
[22]*Universidad de Antioquia, Medellin, Colombia*
[23]*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*
[24]*University of Split, Faculty of Science, Split, Croatia*
[25]*Institute Rudjer Boskovic, Zagreb, Croatia*
[26]*University of Cyprus, Nicosia, Cyprus*
[27]*Charles University, Prague, Czech Republic*
[28]*Escuela Politecnica Nacional, Quito, Ecuador*
[29]*Universidad San Francisco de Quito, Quito, Ecuador*
[30]*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*
[31]*Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt*
[32]*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*
[33]*Department of Physics, University of Helsinki, Helsinki, Finland*
[34]*Helsinki Institute of Physics, Helsinki, Finland*
[35]*Lappeenranta University of Technology, Lappeenranta, Finland*
[36]*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
[37]*Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*
[38]*Université de Strasbourg, CNRS, IPHC UMR 7178 Strasbourg, France*
[39]*Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France*
[40]*Georgian Technical University, Tbilisi, Georgia*
[41]*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
[42]*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
[43]*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
[44]*Deutsches Elektronen-Synchrotron, Hamburg, Germany*

[45]University of Hamburg, Hamburg, Germany
[46]Karlsruher Institut fuer Technologie, Karlsruhe, Germany
[47]Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece
[48]National and Kapodistrian University of Athens, Athens, Greece
[49]National Technical University of Athens, Athens, Greece
[50]University of Ioánnina, Ioánnina, Greece
[51]MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
[52]Wigner Research Centre for Physics, Budapest, Hungary
[53]Institute of Nuclear Research ATOMKI, Debrecen, Hungary
[54]Institute of Physics, University of Debrecen, Debrecen, Hungary
[55]Eszterhazy Karoly University, Karoly Robert Campus, Gyongyos, Hungary
[56]Indian Institute of Science (IISc), Bangalore, India
[57]National Institute of Science Education and Research, HBNI, Bhubaneswar, India
[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]Bhabha Atomic Research Centre, Mumbai, India
[63]Tata Institute of Fundamental Research-A, Mumbai, India
[64]Tata Institute of Fundamental Research-B, Mumbai, India
[65]Indian Institute of Science Education and Research (IISER), Pune, India
[66]Department of Physics, 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]Università G. Marconi, Roma, 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, Rome, Italy
[81b]Sapienza Università di Roma, Rome, 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]Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
[86]Hanyang University, Seoul, Korea
[87]Korea University, Seoul, Korea
[88]Kyung Hee University, Department of Physics, Seoul, Republic of Korea
[89]Sejong University, Seoul, Korea
[90]Seoul National University, Seoul, Korea
[91]University of Seoul, Seoul, Korea
[92]Yonsei University, Department of Physics, Seoul, Korea
[93]Sungkyunkwan University, Suwon, Korea
[94]College of Engineering and Technology, American University of the Middle East (AUM), Egaila, Kuwait
[95]Riga Technical University, Riga, Latvia
[96]Vilnius University, Vilnius, Lithuania
[97]National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
[98]Universidad de Sonora (UNISON), Hermosillo, Mexico
[99]Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
[100]Universidad Iberoamericana, Mexico City, Mexico
[101]Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
[102]Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
[103]University of Montenegro, Podgorica, Montenegro
[104]University of Auckland, Auckland, New Zealand
[105]University of Canterbury, Christchurch, New Zealand
[106]National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
[107]AGH University of Science and Technology 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]Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
[111]Joint Institute for Nuclear Research, Dubna, Russia
[112]Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
[113]Institute for Nuclear Research, Moscow, Russia
[114]Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC ‘Kurchatov Institute’, Moscow, Russia
[115]Moscow Institute of Physics and Technology, Moscow, Russia
[116]National Research Nuclear University ’Moscow Engineering Physics Institute’ (MEPhI), Moscow, Russia
[117]P.N. Lebedev Physical Institute, Moscow, Russia
[118]Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
[119]Novosibirsk State University (NSU), Novosibirsk, Russia
[120]Institute for High Energy Physics of National Research Centre ‘Kurchatov Institute’, Protvino, Russia
[121]National Research Tomsk Polytechnic University, Tomsk, Russia
[122]Tomsk State University, Tomsk, Russia
[123]University of Belgrade: Faculty of Physics and VINCA Institute of Nuclear Sciences, Belgrade, Serbia
[124]Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
[125]Universidad Autónoma de Madrid, Madrid, Spain
[126]Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain
[127]Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
[128]University of Colombo, Colombo, Sri Lanka
[129]University of Ruhuna, Department of Physics, Matara, Sri Lanka
[130]CERN, European Organization for Nuclear Research, Geneva, Switzerland
[131]Paul Scherrer Institut, Villigen, Switzerland
[132]ETH Zurich—Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
[133]Universität Zürich, Zurich, Switzerland
[134]National Central University, Chung-Li, Taiwan
[135]National Taiwan University (NTU), Taipei, Taiwan
[136]Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand
[137]Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
[138]Middle East Technical University, Physics Department, Ankara, Turkey
[139]Bogazici University, Istanbul, Turkey
[140]Istanbul Technical University, Istanbul, Turkey
[141]Istanbul University, Istanbul, Turkey
[142]Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine

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

[a]Deceased.
[b]Also at Vienna University of Technology, Vienna, Austria.
[c]Also at Institute of Basic and Applied Sciences, Faculty of Engineering, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt.
[d]Also at Université Libre de Bruxelles, Bruxelles, Belgium.
[e]Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France.

[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 Universidade Federal do Mato Grosso do Sul (UFMS), Nova Andradina, Mato Grosso do Sul, Brazil.
[i]Also at Universidade Federal de Pelotas, Pelotas, Brazil.
[j]Also at University of Chinese Academy of Sciences, Beijing, China.
[k]Also at Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC ‘Kurchatov Institute’, Moscow, Russia.
[l]Also at Joint Institute for Nuclear Research, Dubna, Russia.
[m]Also at Cairo University, Cairo, Egypt.
[n]Also at Ain Shams University, Cairo, Egypt.
[o]Also at Fayoum University, El-Fayoum, Egypt.
[p]Also at Purdue University, West Lafayette, Indiana, USA.
[q]Also at Université de Haute Alsace, Mulhouse, France.
[r]Also at Erzincan Binali Yildirim University, Erzincan, Turkey.
[s]Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
[t]Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
[u]Also at University of Hamburg, Hamburg, Germany.
[v]Also at Department of Physics, Isfahan University of Technology, Isfahan, Iran.
[w]Also at Brandenburg University of Technology, Cottbus, Germany.
[x]Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.
[y]Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.
[z]Also at Physics Department, Faculty of Science, Assiut University.
[aa]Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.
[bb]Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
[cc]Also at IIT Bhubaneswar, Bhubaneswar, India.
[dd]Also at Institute of Physics, Bhubaneswar, India.
[ee]Also at G.H.G. Khalsa College, Punjab, India.
[ff]Also at Shoolini University, Solan, India.
[gg]Also at University of Hyderabad, Hyderabad, India.
[hh]Also at University of Visva-Bharati, Santiniketan, India.
[ii]Also at Indian Institute of Technology (IIT), Mumbai, India.
[jj]Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany.
[kk]Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran.
[ll]Also at INFN Sezione di Bari, Università di Bari, Politecnico di Bari, Bari, Italy.
[mm]Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Rome, Italy.
[nn]Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy.
[oo]Also at Riga Technical University, Riga, Latvia.
[pp]Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
[qq]Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.
[rr]Also at Institute for Nuclear Research, Moscow, Russia.
[ss]Also at National Research Nuclear University ’Moscow Engineering Physics Institute’ (MEPhI), Moscow, Russia.
[tt]Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan.
[uu]Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[vv]Also at University of Florida, Gainesville, Florida, USA.
[ww]Also at Imperial College, London, United Kingdom.
[xx]Also at P.N. Lebedev Physical Institute, Moscow, Russia.
[yy]Also at Moscow Institute of Physics and Technology, Moscow, Russia.
[zz]Also at INFN Sezione di Padova, Università di Padova, Padova, Italy, Università di Trento, Trento, Italy.
[aaa]Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia.
[bbb]Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
[ccc]Also at Trincomalee Campus, Eastern University, Konesapuri, Sri Lanka.
[ddd]Also at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy.
[eee]Also at National and Kapodistrian University of Athens, Athens, Greece.
[fff]Also at Universität Zürich, Zurich, Switzerland.
[ggg]Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
[hhh]Also at Laboratoire d’Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
[iii]Also at Şırnak University, Şırnak, Turkey.
[jjj]Also at Department of Physics, Tsinghua University, Beijing, China.
[kkk]Also at Near East University, Research Center of Experimental Health Science, Nicosia, Turkey.
[lll]Also at Beykent University, Istanbul, Turkey.

[mmm]Also at Istanbul Aydin University, Application and Research Center for Advanced Studies (App. & Res. Cent. for Advanced Studies).
[nnn]Also at Mersin University, Mersin, Istanbul, Turkey.
[ooo]Also at Piri Reis University, Istanbul, Turkey.
[ppp]Also at Adiyaman University, Adiyaman, Turkey.
[qqq]Also at Ozyegin University, Istanbul, Turkey.
[rrr]Also at Izmir Institute of Technology, Izmir, Turkey.
[sss]Also at Necmettin Erbakan University, Konya, Turkey.
[ttt]Also at Bozok Universitetesi Rektörlügü, Yozgat, Turkey.
[uuu]Also at Marmara University, Istanbul, Turkey.
[vvv]Also at Milli Savunma University, Istanbul, Turkey.
[www]Also at Kafkas University, Kars, Turkey.
[xxx]Also at Istanbul Bilgi University, Istanbul, Turkey.
[yyy]Also at Hacettepe University, Ankara, Turkey.
[zzz]Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[aaaa]Also at IPPP Durham University, Durham, United Kingdom.
[bbbb]Also at Monash University, Faculty of Science, Clayton, Australia.
[cccc]Also at Bethel University, St. Paul, Minneapolis, USA.
[dddd]Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
[eeee]Also at California Institute of Technology, Pasadena, California, USA.
[ffff]Also at Bingol University, Bingol, Turkey.
[gggg]Also at Georgian Technical University, Tbilisi, Georgia.
[hhhh]Also at Sinop University, Sinop, Turkey.
[iiii]Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
[jjjj]Also at Nanjing Normal University Department of Physics.
[kkkk]Also at Texas A&M University at Qatar, Doha, Qatar.
[llll]Also at Kyungpook National University, Daegu, Korea.