

<https://helda.helsinki.fi>

---

## Search for Heavy Neutral Leptons in Events with Three Charged Leptons in Proton-Proton Collisions at $\sqrt{s}=13$ TeV

The CMS collaboration

2018-05-29

---

The CMS Collaboration , Sirunyan , A M , Eerola , P , Kirschenmann , H , Pekkanen , J , Voutilainen , M , Havukainen , J , Heikkilä , J K , Järvinen , T , Karimäki , V , Kinnunen , R , Lampén , T , Lassila-Perini , K , Laurila , S , Lehti , S , Lindén , T , Luukka , P , Mäenpää , T , Siikonen , H , Tuominen , E , Tuominiemi , J & Tuuva , T 2018 , ' Search for Heavy Neutral Leptons in Events with Three Charged Leptons in Proton-Proton Collisions at  $\sqrt{s}=13$  TeV ' , Physical Review Letters , vol. 120 , no. 22 , 221801 . <https://doi.org/10.1103/PhysRevLett.120.221801>

---

<http://hdl.handle.net/10138/236719>

<https://doi.org/10.1103/PhysRevLett.120.221801>

---

cc\_by

publishedVersion

---

*Downloaded from Helda, University of Helsinki institutional repository.*

*This is an electronic reprint of the original article.*

*This reprint may differ from the original in pagination and typographic detail.*

*Please cite the original version.*

## Search for Heavy Neutral Leptons in Events with Three Charged Leptons in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV

A. M. Sirunyan *et al.*\*  
(CMS Collaboration)

 (Received 8 February 2018; published 29 May 2018)

A search for a heavy neutral lepton  $N$  of Majorana nature decaying into a  $W$  boson and a charged lepton is performed using the CMS detector at the LHC. The targeted signature consists of three prompt charged leptons in any flavor combination of electrons and muons. The data were collected in proton-proton collisions at a center-of-mass energy of 13 TeV, with an integrated luminosity of  $35.9 \text{ fb}^{-1}$ . The search is performed in the  $N$  mass range between 1 GeV and 1.2 TeV. The data are found to be consistent with the expected standard model background. Upper limits are set on the values of  $|V_{eN}|^2$  and  $|V_{\mu N}|^2$ , where  $V_{\ell N}$  is the matrix element describing the mixing of  $N$  with the standard model neutrino of flavor  $\ell$ . These are the first direct limits for  $N$  masses above 500 GeV and the first limits obtained at a hadron collider for  $N$  masses below 40 GeV.

DOI: [10.1103/PhysRevLett.120.221801](https://doi.org/10.1103/PhysRevLett.120.221801)

The standard model (SM) of particle physics has been successful in describing many phenomena; however, several observations remain unexplained, including the nature of dark matter (DM), the baryon asymmetry of the Universe, and the smallness of neutrino masses. The latter can be naturally accommodated by the so-called “seesaw” mechanism [1–11], in which a new heavy neutral Majorana lepton (or heavy neutrino)  $N$  is postulated.

A model that incorporates the seesaw mechanism, while also providing a DM candidate and giving a possible explanation for the baryon asymmetry, is known as the neutrino minimal standard model ( $\nu$ MSSM). In this model, three right-handed heavy sterile neutrinos are added to the SM [12–15]. The lightest neutrino,  $N_1$ , can explain the DM in the Universe, while the heavier neutrinos,  $N_2$  and  $N_3$ , can be responsible for the baryon asymmetry through leptogenesis [15–20] or neutrino oscillations [14,15].

In this Letter, a search for a heavy neutrino decaying into a charged lepton and a  $W$  boson (either an on-shell  $W$  or off-shell  $W^*$ ) is performed using the CMS detector at the CERN LHC [21]. The heavy neutrinos are produced through mixing with the SM neutrinos, governed by the parameters  $V_{eN}$ ,  $V_{\mu N}$ , and  $V_{\tau N}$ , where  $V_{\ell N}$  is the matrix element describing the mixing of  $N$  with the SM neutrino of flavor  $\ell$ . The production cross section, decay width, and

lifetime of  $N$  depend on  $|V_{\ell N}|^2$  and its mass  $m_N$ . In the  $\nu$ MSSM,  $N_1$  is expected to be too light and long-lived to produce an unambiguous signal in the CMS detector, but  $N_2$  and  $N_3$  could decay to  $W\ell$ ,  $Z\nu$ , or  $H\nu$ , and are therefore potentially detectable.

Earlier searches for heavy Majorana neutrinos at the LHC have been undertaken by the ATLAS and CMS Collaborations at  $\sqrt{s} = 7$  and 8 TeV [22–29], employing a signature of same-sign dileptons and jets, exploring the mass range  $40 < m_N < 500$  GeV. Other experiments have searched in the mass region  $m_N < 40$  GeV [30–43] and precision electroweak measurements provide limits on the mixing parameters independent of  $m_N$  [44–48]. A recent review of constraints can be found in Ref. [49].

This analysis targets  $N$  production in leptonic  $W^{(*)}$  boson decays,  $W^{(*)} \rightarrow N\ell$  ( $\ell = e, \mu$ ), with subsequent prompt decays of  $N$  to  $W^{(*)}\ell$ , where the vector boson decays to  $\ell\nu$  [50–62]. The event signature consists of three charged leptons in any combination of electrons and muons, excluding those events containing three leptons of the same charge. Because of the presence of a SM  $\nu$  escaping detection, a mass peak of  $N$  cannot be reconstructed. Therefore the search exploits kinematic properties of the three leptons to discriminate between the signal and SM backgrounds. These backgrounds consist of events containing leptons from hadron decays, leptons from conversions, and SM sources of multiple leptons such as diboson production or top quark (pair) production in association with a boson. Exploiting the trilepton topology allows the mass range  $1 \text{ GeV} < m_N < 1.2 \text{ TeV}$  to be explored using  $pp$  collision data collected by the CMS experiment at  $\sqrt{s} = 13$  TeV, corresponding to an integrated luminosity of  $35.9 \text{ fb}^{-1}$ .

\*Full author list given at the end of the article.

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/). Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. Funded by SCOAP<sup>3</sup>.

The central feature of the CMS apparatus [63] is a superconducting solenoid of 6 m diameter, providing a magnetic field of 3.8 T. A silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections, reside within the solenoid. Forward calorimeters extend the pseudorapidity ( $\eta$ ) coverage. Muons are detected in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. Events of interest are recorded with several triggers [64], requiring the presence of one, two, or three light leptons ( $e$  or  $\mu$ ), leading to very high efficiency, nearing 100% in most kinematic regions of the search.

Samples of simulated events are used to estimate the background from some of the SM processes and to determine the heavy neutrino signal acceptance. The SM background samples are produced using the Monte Carlo (MC) MADGRAPH5\_aMC@NLO 2.2.2 or 2.3.3 generator [65] at leading order (LO) or next-to-leading order (NLO) in perturbative quantum chromodynamics, with the exception of  $gg \rightarrow ZZ$ , which is simulated at LO with MCFM 7.0 [66], and all other diboson production processes, which are generated at NLO with the POWHEG v2 [67,68] generator.

The NNPDF3.0 [69] LO (NLO) parton distribution functions (PDFs) are used for the simulated samples generated at LO (NLO). Parton showering and hadronization are described using the PYTHIA 8.212 generator [70] with the CUETP8M1 underlying event tune [71,72]. Double counting of the partons generated with MADGRAPH5\_aMC@NLO and PYTHIA is removed using the MLM [73] and FxFx [74] matching schemes in the LO and NLO samples, respectively.

Signal samples are generated with MADGRAPH5\_aMC@NLO 2.4.2 at NLO precision, following the implementation of Ref. [75]. They include processes leading to  $N$  production via the charged-current Drell–Yan (DY) process, gluon fusion, and  $W\gamma$  fusion. The latter production mechanism is important for  $m_N > 600$  GeV [76]. The first two production mechanisms employ the NNPDF3.0 NLO PDF set [69], while the last uses the LUXqed\_plus\_PDF4LHC15\_nnlo\_100 PDF set [77]. Parton showering and hadronization are simulated with PYTHIA. Only the final states with three leptons (electrons or muons) and a neutrino are generated.

The effects of additional  $pp$  interactions in the same or adjacent  $pp$  bunch crossings (pileup) are accounted for in the simulations. The MC generated events include the full simulation of the CMS detector based on GEANT4 [78] and are reconstructed using the same CMS software as used for data.

Information from all subdetectors is combined offline by the CMS particle-flow algorithm [79] used to reconstruct and identify individual particles and to provide a global description of the event. The particles are classified into

charged hadrons, neutral hadrons, photons, electrons, and muons.

Jets are reconstructed using the anti- $k_T$  clustering algorithm [80] with a distance parameter of 0.4, as implemented in the FASTJET package [81,82]. Jet energies are corrected for residual nonuniformity and nonlinearity of the detector response using simulated and collision data event samples [83–85].

To identify jets originating from  $b$  quarks, the combined secondary vertex CSVv2 algorithm [86,87] is used. This has an efficiency of approximately 80% for tagging a  $b$  quark jet, and a mistagging rate of 10% for light-quark and gluon jets, and about 40% for  $c$  quark jets. Jets with  $p_T > 25$  GeV and  $|\eta| < 2.4$  are considered  $b$  quark jets (“ $b$  jets”) if they satisfy the loose working point requirements [87] of this algorithm. Events with one or more identified  $b$  jets are vetoed in the analysis to reduce the  $t\bar{t}$  background.

The missing transverse momentum  $p_T^{\text{miss}}$  is defined as the magnitude of the negative vector sum  $\vec{p}_T^{\text{miss}}$  of the transverse momenta of all reconstructed particles in the event, taking into account jet energy corrections [88].

The primary  $pp$  interaction vertex (PV) is taken to be the reconstructed vertex with the largest value of summed physics-object  $p_T^2$ . The physics objects are the jets, clustered using the jet finding algorithm [80,81] with the tracks assigned to the vertex as inputs, and the associated missing transverse momentum, taken as the negative vector sum of the  $p_T$  of those jets.

The analysis depends crucially on identifying electrons and muons, with good efficiency and low contamination. Electrons are reconstructed by combining the information from the ECAL and the tracker [89]. Electrons are required to be within the tracking system volume,  $|\eta| < 2.5$ , and have a minimum  $p_T$  of 10 GeV. Electron identification is performed using a multivariate discriminant that includes the shower shape and track quality information. To reject electrons originating from photon conversions in detector material, electrons must have measurements in all innermost layers of the tracking system and must not be matched to any secondary vertex [89].

Muons are reconstructed by combining the information from the tracker and muon spectrometer in a global fit [90]. The quality of the geometrical matching between measurements made separately in the two systems is used in the further selection of muons. Only muons within the muon system acceptance of  $|\eta| < 2.4$  and with  $p_T > 5$  GeV are considered. Electrons within a cone of  $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.05$  of a muon are discarded as those likely coming from radiation.

To ensure that electron and muon candidates are consistent with originating from the PV, the transverse (longitudinal) impact parameter of the leptons with respect to this vertex must not exceed 0.5 (1.0) mm, and the displacement divided by its uncertainty must not exceed 4.

Leptons originating from decays of heavy particles, such as electroweak bosons or  $N$ , are referred to as “prompt,” while leptons produced in hadron decays are called “non-prompt.” For convenience, we also include misidentified hadrons and jets in the nonprompt-lepton classification. A powerful discriminator between these two types of leptons is the isolation variable  $I_{\text{rel}}$ . It is defined as the pileup-corrected scalar  $p_T$  sum of particles within a cone of  $\Delta R < 0.3$  around the lepton candidate’s direction at the vertex, divided by the lepton candidate  $p_T$ . The summation comprises the reconstructed charged hadrons originating from the PV, neutral hadrons, and photons.

Electrons and muons that pass all the aforementioned requirements and satisfy  $I_{\text{rel}} < 0.6$  are referred to as “loose leptons.” Leptons that additionally satisfy  $I_{\text{rel}} < 0.1$  and, in the case of electrons, pass a more stringent requirement on the multivariate discriminant, chosen to maximize the signal over background ratio, are referred to as “tight leptons.” Events containing exactly three loose leptons, not all having the same charge, are retained in the analysis.

To distinguish between SM background and  $N$  production, the three leptons are required to pass the tight selection, and the following variables are used: the flavor, charge, and  $p_T$  of the leptons in the event; the invariant mass of the trilepton system  $M_{3\ell}$ ; the minimum invariant mass of all opposite-sign lepton pairs in the event  $M_{2\ell\text{OS}}^{\text{min}}$ ; and the transverse mass  $M_T = \sqrt{2p_T^\ell p_T^{\text{miss}}[1 - \cos(\Delta\phi)]}$ , where  $p_T^\ell$  is the transverse momentum of the lepton that is not used in the  $M_{2\ell\text{OS}}^{\text{min}}$  calculation, and  $\Delta\phi$  is the azimuthal angle between  $\vec{p}_T^\ell$  and  $\vec{p}_T^{\text{miss}}$ .

To address the kinematically distinct cases of  $N$  masses below and above that of the  $W$  boson, two search regions are defined, referred to as the low- and high-mass regions.

In the low-mass region (targeting  $m_N < m_W$ ),  $N$  is produced in the decay of an on-shell  $W$  boson, leading to the decay  $W \rightarrow \ell \ell' \ell'' \nu$  via an intermediate  $N$ . To reflect the targeted  $m_N$  range in this region, and to suppress the background from  $Z \rightarrow \ell^+ \ell^-$  production with an accompanying high- $p_T$  lepton from an asymmetric photon conversion, the requirement  $M_{3\ell} < 80$  GeV is imposed. The background from  $W\gamma^*$  events, with  $\gamma^* \rightarrow \ell^+ \ell^-$ , is reduced by rejecting events that contain an opposite-sign same-flavor (OSSF) lepton pair. The effectiveness of this requirement relies on the fact that  $N$  is a Majorana particle and can decay to a lepton of equal or opposite charge to that of its parent  $W$  boson.

Events in the low-mass region are required to have  $p_T^{\text{miss}} < 75$  GeV to suppress  $t\bar{t}$  background. The highest  $p_T$  (leading) lepton must satisfy  $p_T > 15$  GeV, while the next-to-highest  $p_T$  (subleading) lepton must have  $p_T > 10$  GeV. The third (trailing) lepton must have  $p_T > 10$  (5) GeV if it is an electron (muon). In addition the following conditions are imposed to avoid trigger threshold effects: in  $e\mu\mu$  events, if a trailing electron has  $10 < p_T < 15$  GeV, the leading muon is required to have  $p_T > 23$  GeV, and if a

trailing muon has  $5 < p_T < 8$  GeV, the leading and sub-leading electrons must satisfy  $p_T > 25$  and 15 GeV; in  $e\mu\mu$  events, if a trailing muon has  $p_T > 8$  GeV, either the leading electron must have  $p_T > 23$  GeV, or the subleading electron must have  $p_T > 15$  GeV. These requirements lead to a signal selection efficiency of 5%–7% for a trilepton final state depending on the  $N$  mass.

The events are subdivided into two ranges of leading lepton  $p_T$ :  $15 < p_T^{\text{leading}} < 30$  GeV and  $30 < p_T^{\text{leading}} < 55$  GeV. The lower range has higher signal efficiencies for  $m_N$  close to  $m_W$ , leading to three leptons with similar  $p_T$  spectra. The higher range targets very low  $m_N$  down to 1 GeV, with one energetic and two soft leptons in the event.

Finally, the variable  $M_{2\ell\text{OS}}^{\text{min}}$ , which is correlated with  $m_N$ , is used to further subdivide the events into four bins ( $< 10$ , 10–20, 20–30, and  $> 30$  GeV) giving a total of eight search regions, as shown in Fig. 1.

In the high-mass region (targeting  $m_N > m_W$ ),  $N$  is produced in the decay of a high-mass off-shell  $W$  boson, leading to three relatively energetic leptons, and more sizable  $p_T^{\text{miss}}$ . In this region, the three selected leptons must satisfy  $p_T > 55, 15, 10$  GeV. With these requirements, the background from  $W\gamma^*$  production is negligible, and events containing an OSSF lepton pair are therefore retained, but with the invariant mass of any OSSF lepton pair required to satisfy  $M_{\ell\ell} > 5$  GeV. The backgrounds from  $WZ$  and  $Z\gamma^{(*)}$  production are respectively suppressed by vetoing events having an OSSF lepton pair with  $|M_{\ell\ell}(\text{or } M_{3\ell}) - M_Z| < 15$  GeV. Signal selection efficiency for trilepton final state reaches up to 50%.

In order to improve the discrimination of signal from background, the high-mass region is divided into two event categories: events containing an OSSF lepton pair and events with no such pair. Both categories are divided into bins of  $M_{3\ell}$  and  $M_{2\ell\text{OS}}^{\text{min}}$ , each further subdivided according to  $M_T$ , which tends to be large for high  $N$  masses. This results in a total of 25 search regions, as shown in Fig. 1.

To extract values of  $|V_{eN}|^2$  and  $|V_{\mu N}|^2$  separately, the results for both the low- and high-mass regions are obtained for events with  $\geq 2$  electrons or  $\geq 2$  muons, respectively.

We now consider the most important sources of background and their associated systematic uncertainties. The  $t\bar{t}$  and DY processes, with an additional nonprompt lepton, constitute the main background for events in the low- and high-mass regions with no OSSF lepton pair. It is estimated by using the tight-to-loose ratio method described in Ref. [91]. The probability for a loose non-prompt lepton to pass the tight selection criteria is measured in a multijet sample in data enriched in non-prompt leptons. This probability is applied to events that pass the full signal selection, but contain at least one lepton that fails the tight selection, while satisfying the loose selection requirements. The method is validated using simulation and data in control regions enriched in  $t\bar{t}$  or DY + jets events. Agreement between the predicted

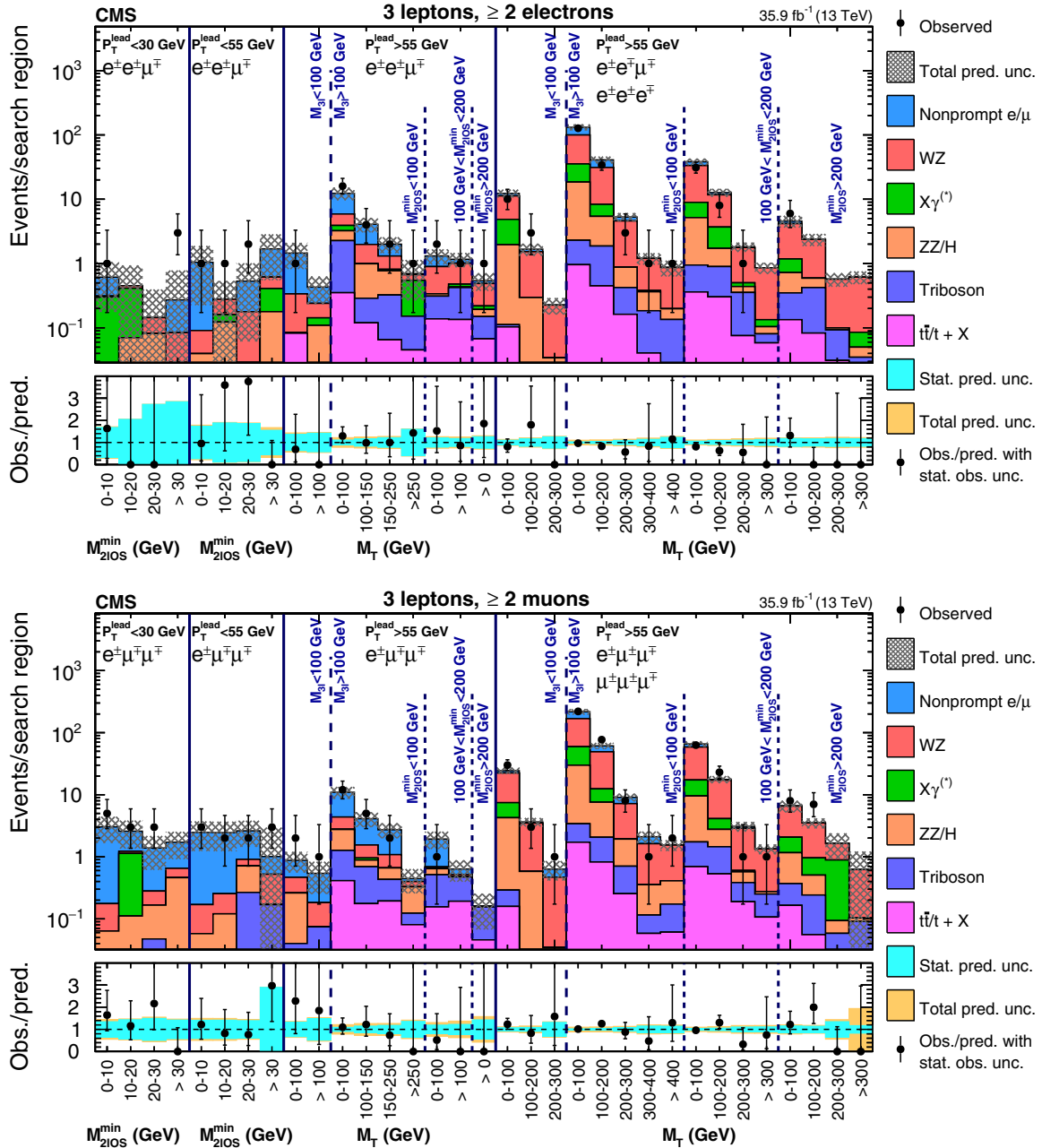


FIG. 1. Observed and expected event yields as a function of  $M_{2\ell OS}^{\min}$  and  $M_T$  for events with at least two electrons (upper), and with at least two muons (lower). The contribution of each background source is shown. The first 8 bins of each figure correspond to the low-mass region, while the rest display the high-mass region.

and observed yields in the various control regions is found to be within the overall systematic uncertainty of 30% assigned to this background estimate.

The background from  $WZ$  and  $W\gamma^*$  production is dominant in the high-mass region containing an OSSF lepton pair. It is obtained from simulation, with the simulated yield normalized to data in a control region formed by selecting three tight leptons with  $p_T > 25, 15, 10$  GeV, and requiring an OSSF lepton pair with invariant mass  $M_{\ell\ell}$  consistent with a  $Z$  boson:

$|M_{\ell\ell} - M_Z| < 15$  GeV. In addition, events are required to have  $p_T^{\text{miss}} > 50$  GeV. The ratio of the predicted to observed  $WZ$  yield in this control region is found to be  $1.08 \pm 0.09$ . This ratio is used to normalize the MC generated event samples, and its associated uncertainty is propagated to the result.

Production of  $ZZ$  events with both  $Z$  bosons decaying leptonically, and one lepton not identified, results in a tripleton signature. This contribution is estimated from simulation, and the simulated yield is normalized in a

control region containing four leptons that form two OSSF lepton pairs with invariant masses consistent with a  $Z$  boson. The ratio of data to simulation in the control region is found to be  $1.03 \pm 0.10$ . An additional uncertainty of 25% is assigned to the prediction of events with  $M_T > 75$  GeV, based on a comparison of the observed and predicted event yields in the control region.

External and internal photon conversions ( $X\gamma^{(*)}$ ) contribute to the trilepton final state when a photon is produced with a  $Z$  boson, and this photon undergoes an asymmetric conversion in which one of the leptons has very low  $p_T$  and fails the lepton selection criteria. This contribution is obtained from simulation and verified in a data control region enriched in conversions from the  $Z + \text{jets}$  process, with  $Z \rightarrow \ell\ell\gamma^{(*)}$  and  $\gamma^{(*)} \rightarrow \ell\ell$ , where one of the leptons is outside the detector acceptance. The control region is defined by  $|M_{\ell\ell} - M_Z| > 15$  GeV and  $|M_{3\ell} - M_Z| < 15$  GeV. The ratio of data to expected background in the control region is  $0.95 \pm 0.08$ , and is used to normalize the simulation. Kinematic properties of the events in data are used to set a systematic uncertainty in the photon conversion background of 15%.

Other SM processes that can yield three or more prompt leptons include triboson production ( $W, Z, H$ , or a prompt  $\gamma$ ) and single-boson production in association with a single top quark or a  $t\bar{t}$  pair ( $t\bar{t}/t + X$ ). Such processes generally have very small production rates and in some cases are further suppressed by the  $b$  jet veto. They are estimated from simulation with an uncertainty of 50%, which includes uncertainties due to experimental effects, event simulation, and theoretical calculations of the cross sections.

The background from the mismeasurement of charge arises from events with an  $e^+e^-$  pair in which the charge of one of the electrons is misreconstructed. It is predicted using simulation, which is validated to agree within 10% of an estimate obtained from data [92].

Systematic uncertainties affecting any process whose yield is estimated from simulation are considered, such as those from trigger efficiency, lepton selection efficiencies, jet energy scale,  $b$  jet veto efficiency, pileup modeling, and those related to fixed-order calculations in event simulation. The effect of each uncertainty on the event yields is computed and accounted for.

The uncertainty in the trigger efficiency is obtained by measuring the efficiencies of all trigger components using the tag-and-probe technique [89,90], and is estimated to be 2% for events with leading lepton  $p_T > 30$  GeV and 5% otherwise. Lepton identification efficiencies are also computed using the tag-and-probe technique with an uncertainty of 2% per lepton.

The impact of the jet energy scale uncertainty is determined by shifting the jet energy correction factors up and down by their estimated uncertainty for each jet, and recalculating all kinematic quantities obtained from jets. This results in an uncertainty in event yields of up to 3%,

depending on the search region. Correlation effects due to the migration of events from one search region to another are also taken into account. Similarly, the  $b$  jet veto efficiency is corrected for differences between data and simulation, leading to an uncertainty in event yields of 1%–5%. The uncertainty in yields due to modeling of pileup is computed by modifying the total inelastic scattering cross section by 5% [93], and is measured to be 1%–5%, depending on the search region. The uncertainty in the integrated luminosity is 2.5% [94].

Further uncertainties in background yields estimated from simulation arise from the unknown higher-order effects in the theoretical calculations of cross sections, and from uncertainties in the knowledge of the proton PDFs. Uncertainties in the renormalization and factorization scales affect the signal cross section and acceptance. These are evaluated by independently varying the aforementioned scales up and down by a factor of two relative to their nominal values. The uncertainties associated with the choice of PDFs are estimated by considering replica PDF sets generated using weights, giving a PDF probability distribution centered on the nominal PDF set [95].

The limited statistical precision of the available MC samples leads to an additional uncertainty of 1%–30%, depending on the process and search region.

The expected and observed yields together with the relative contributions of the different background sources in each search region are shown in Fig. 1. Tabulated results and enlarged versions of Fig. 1, with potential signals superimposed, are provided in the supplemental material [96]. We see no evidence for a significant excess in data beyond the expected SM background. We compute 95% confidence level (C.L.) upper limits on  $|V_{eN}|^2$  and  $|V_{\mu N}|^2$  separately, while assuming other matrix elements to be 0, using the  $\text{CL}_s$  criterion [97,98] under the asymptotic approximation for the test statistic [99,100]. A simultaneous fit of all search regions is performed and all systematic uncertainties are treated as log-normal nuisance parameters in the fit.

The interpretation of the results is presented in Fig. 2. The  $N$  lifetime is inversely proportional to  $m_N^5 |V_{\ell N}|^2$  [53,59]. At low masses this becomes significant, resulting in displaced decays and lower efficiency than if the decays were prompt, illustrated by comparison of the black dotted line in Fig. 2 (prompt assumption) with the final result. This is accounted for by calculating the efficiency vs  $N$  lifetime, and propagating this to the limits on mixing parameter vs mass.

In summary, a search has been performed for a heavy neutral lepton  $N$  of Majorana nature produced in the decays of a  $W$  boson, with subsequent prompt decays of  $N$  to  $W\ell$ , where the vector boson decays to  $\ell\nu$ . The event signature consists of three charged leptons in any combination of electrons and muons. No statistically significant excess of events over the expected standard model background is observed.

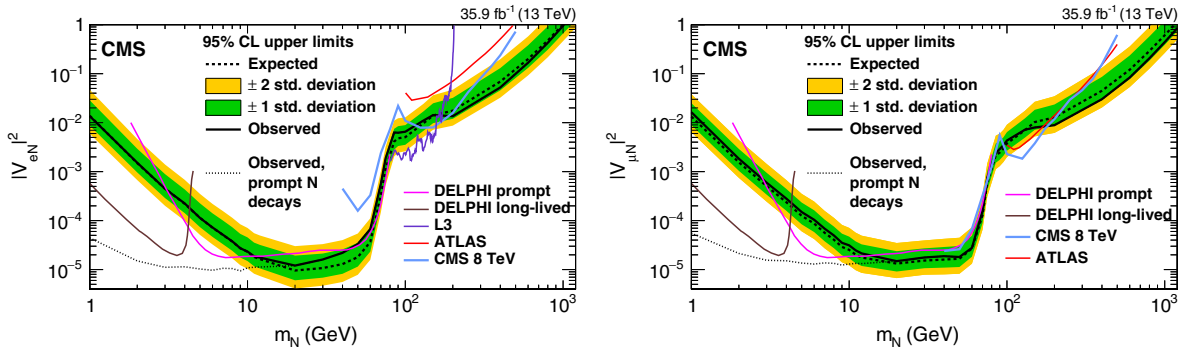


FIG. 2. Exclusion region at 95% CL in the  $|V_{eN}|^2$  vs.  $m_N$  (left) and  $|V_{\mu N}|^2$  vs.  $m_N$  (right) planes. The dashed black curve is the expected upper limit, with one and two standard-deviation bands shown in dark green and light yellow, respectively. The solid black curve is the observed upper limit, while the dotted black curve is the observed limit in the approximation of prompt  $N$  decays. Also shown are the best upper limits at 95% CL from other collider searches in L3 [41], DELPHI [38], ATLAS [28], and CMS [27].

Upper limits at 95% confidence level are set on the mixing parameters  $|V_{eN}|^2$  and  $|V_{\mu N}|^2$ , ranging between  $1.2 \times 10^{-5}$  and 1.8 for  $N$  masses in the range  $1 \text{ GeV} < m_N < 1.2 \text{ TeV}$ . These results surpass those obtained in previous searches carried out by the ATLAS [28] and CMS [27,29] Collaborations, and are the first direct limits for  $m_N > 500 \text{ GeV}$ . This search also provides the first probes for low masses ( $m_N < 40 \text{ GeV}$ ) at the LHC, improving on the limits set previously by the L3 [34] and DELPHI [38] Collaborations. For  $N$  masses below 3 GeV, the most stringent limits to date are obtained from the beam-dump experiments: CHARM [31,36], BEBC [30], FMMF [37], and NuTeV [39].

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 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 and the CMS detector provided by the following funding agencies: BMFWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RPF (Cyprus); SENESCYT (Ecuador); MoER, ERC IUT, and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, RFBR and RAEP

(Russia); MESTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU and SFFR (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

- [1] P. Minkowski,  $\mu \rightarrow e\gamma$  at a rate of one out of 1-billion muon decays?, *Phys. Lett. B* **67**, 421 (1977).
- [2] M. Gell-Mann, P. Ramond, and R. Slansky, in *Supergravity: proceedings of the Supergravity Workshop at Stony Brook*, edited by P. V. Nieuwenhuizen and D. Z. Freedman (North-Jolland, Amsterdam, Netherlands, 1979).
- [3] T. Yanagida, in *Proceedings: Workshop on the Unified Theories and the Baryon Number in the Universe*, edited by Osamu Sawada and Akio Sugamoto (National Laboratory for High Energy Physics, Tsukuba, Japan, 1979).
- [4] R. N. Mohapatra and G. Senjanović, Neutrino Mass and Spontaneous Parity Violation, *Phys. Rev. Lett.* **44**, 912 (1980).
- [5] M. Magg and Ch. Wetterich, Neutrino mass problem and gauge hierarchy, *Phys. Lett. B* **94**, 61 (1980).
- [6] J. Schechter and J. W. F. Valle, Neutrino masses in  $SU(2) \otimes U(1)$  theories, *Phys. Rev. D* **22**, 2227 (1980).
- [7] T. P. Cheng and L.-F. Li, Neutrino masses, mixings and oscillations in  $SU(2) \otimes U(1)$  models of electroweak interactions, *Phys. Rev. D* **22**, 2860 (1980).
- [8] G. Lazarides, Q. Shafi, and C. Wetterich, Proton lifetime and fermion masses in an  $SO(10)$  model, *Nucl. Phys. B* **181**, 287 (1981).
- [9] R. N. Mohapatra and G. Senjanović, Neutrino masses and mixings in gauge models with spontaneous parity violation, *Phys. Rev. D* **23**, 165 (1981).
- [10] J. Schechter and J. W. F. Valle, Neutrino decay and spontaneous violation of lepton number, *Phys. Rev. D* **25**, 774 (1982).
- [11] R. Foot, H. Lew, X.-G. He, and G. C. Joshi, See-saw neutrino masses induced by a triplet of leptons, *Z. Phys. C* **44**, 441 (1989).

- [12] T. Appelquist and R. Shrock, Neutrino masses in theories with dynamical electroweak symmetry breaking, *Phys. Lett. B* **548**, 204 (2002).
- [13] T. Appelquist and R. Shrock, Dynamical Symmetry Breaking of Extended Gauge Symmetries, *Phys. Rev. Lett.* **90**, 201801 (2003).
- [14] T. Asaka, S. Blanchet, and M. Shaposhnikov, The  $\nu$ MSM, dark matter and neutrino masses, *Phys. Lett. B* **631**, 151 (2005).
- [15] T. Asaka and M. Shaposhnikov, The  $\nu$ MSM, dark matter and baryon asymmetry of the Universe, *Phys. Lett. B* **620**, 17 (2005).
- [16] M. Fukugita and T. Yanagida, Baryogenesis without grand unification, *Phys. Lett. B* **174**, 45 (1986).
- [17] E. Akhmedov, V. A. Rubakov, and A. Yu. Smirnov, Baryogenesis via Neutrino Oscillations, *Phys. Rev. Lett.* **81**, 1359 (1998).
- [18] L. Canetti, M. Drewes, T. Frossard, and M. Shaposhnikov, Dark matter, baryogenesis and neutrino oscillations from right-handed neutrinos, *Phys. Rev. D* **87**, 093006 (2013).
- [19] L. Canetti, M. Drewes, and B. Garbrecht, Probing leptogenesis with GeV-scale sterile neutrinos at LHCb and Belle II, *Phys. Rev. D* **90**, 125005 (2014).
- [20] S. Antusch, E. Cazzato, M. Drewes, O. Fischer, B. Garbrecht, D. Gueter, and J. Klaric, Probing leptogenesis at future colliders, arXiv:1710.03744.
- [21] L. Evans and P. Bryant, LHC machine, *J. Instrum.* **3**, S08001 (2008).
- [22] ATLAS Collaboration, Inclusive search for same-sign dilepton signatures in pp collisions at  $\sqrt{s} = 7$  TeV with the ATLAS detector, *J. High Energy Phys.* **10** (2011) 107.
- [23] ATLAS Collaboration, Search for heavy neutrinos and right-handed W bosons in events with two leptons and jets in pp collisions at  $\sqrt{s} = 7$  TeV with the ATLAS detector, *Eur. Phys. J. C* **72**, 2056 (2012).
- [24] CMS Collaboration, Search for heavy Majorana neutrinos in  $\mu^{\pm}\mu^{\pm} +$  jets and  $e^{\pm}e^{\pm} +$  jets events in pp collisions at  $\sqrt{s} = 7$  TeV, *Phys. Lett. B* **717**, 109 (2012).
- [25] CMS Collaboration, Search for Heavy Neutrinos and  $W_R$  Bosons with Right-Handed Couplings in a Left-Right Symmetric Model in  $pp$  Collisions at  $\sqrt{s} = 7$  TeV, *Phys. Rev. Lett.* **109**, 261802 (2012).
- [26] CMS Collaboration, Search for heavy neutrinos and W bosons with right-handed couplings in proton-proton collisions at  $\sqrt{s} = 8$  TeV, *Eur. Phys. J. C* **74**, 3149 (2014).
- [27] CMS Collaboration, Search for heavy Majorana neutrinos in  $\mu^{\pm}\mu^{\pm} +$  jets events in proton-proton collisions at  $\sqrt{s} = 8$  TeV, *Phys. Lett. B* **748**, 144 (2015).
- [28] ATLAS Collaboration, Search for heavy Majorana neutrinos with the ATLAS detector in pp collisions at  $\sqrt{s} = 8$  TeV, *J. High Energy Phys.* **07** (2015) 162.
- [29] CMS Collaboration, Search for heavy Majorana neutrinos in  $e^{\pm}e^{\pm} +$  jets and  $e^{\pm}\mu^{\pm} +$  jets events in proton-proton collisions at  $\sqrt{s} = 8$  TeV, *J. High Energy Phys.* **04** (2016) 169.
- [30] A. M. Cooper-Sarkar *et al.* (WA66 Collaboration), Search for heavy neutrino decays in the BEBC beam dump experiment, *Phys. Lett.* **160B**, 207 (1985).
- [31] F. Bergsma *et al.* (CHARM Collaboration), A search for decays of heavy neutrinos in the mass range 0.5–2.8 GeV, *Phys. Lett.* **166B**, 473 (1986).
- [32] J. Badier *et al.* (NA3 Collaboration), Direct photon production from pions and protons at 200 GeV/c, *Z. Phys. C* **31**, 341 (1986).
- [33] G. Bernardi, G. Carugno, J. Chauveau, F. Dicarolo, M. Dris, J. Dumarchez, M. Ferro-Luzzi, J.-M. Levy, D. Lukas, J.-M. Perreau, Y. Pons, A.-M. Touchard, and F. Vannuccia, Further limits on heavy neutrino couplings, *Phys. Lett. B* **203**, 332 (1988).
- [34] O. Adriani *et al.* (L3 Collaboration), Search for isosinglet neutral heavy leptons in  $Z^0$  decays, *Phys. Lett. B* **295**, 371 (1992).
- [35] S. A. Baranov *et al.*, Search for heavy neutrinos at the IHEP-JINR Neutrino Detector, *Phys. Lett. B* **302**, 336 (1993).
- [36] P. Vilain *et al.* (CHARM II Collaboration), Search for heavy isosinglet neutrinos, *Phys. Lett. B* **343**, 453 (1995); Erratum, *Phys. Lett. B* **351**, 387 (1995).
- [37] E. Gallas *et al.* (FMMF Collaboration), Search for neutral weakly interacting massive particles in the Fermilab Tevatron wideband neutrino beam, *Phys. Rev. D* **52**, 6 (1995).
- [38] P. Abreu *et al.* (DELPHI Collaboration), Search for neutral heavy leptons produced in Z decays, *Z. Phys. C* **74**, 57 (1997); Erratum, *Z. Phys. C* **75**, 580 (1997).
- [39] A. Vaitaitis *et al.* NuTeV (E815) Collaboration, Search for Neutral Heavy Leptons in a High-Energy Neutrino Beam, *Phys. Rev. Lett.* **83**, 4943 (1999).
- [40] M. Acciarri *et al.* (L3 Collaboration), Search for heavy isosinglet neutrinos in  $e^+e^-$  annihilation at  $130 < \sqrt{s} < 189$  GeV, *Phys. Lett. B* **461**, 397 (1999).
- [41] P. Achard *et al.* (L3 Collaboration), Search for heavy isosinglet neutrino in  $e^+e^-$  annihilation at LEP, *Phys. Lett. B* **517**, 67 (2001).
- [42] D. Liventsev *et al.* (Belle Collaboration), Search for heavy neutrinos at Belle, *Phys. Rev. D* **87**, 071102 (2013); Erratum, *Phys. Rev. D* **95**, 099903 (2017).
- [43] LHCb Collaboration, Search for Majorana Neutrinos in  $B^- \rightarrow \pi^+\mu^-\mu^-$  Decays, *Phys. Rev. Lett.* **112**, 131802 (2014).
- [44] F. del Aguila, J. de Blas, and M. Perez-Victoria, Effects of new leptons in electroweak precision data, *Phys. Rev. D* **78**, 013010 (2008).
- [45] E. Akhmedov, A. Kartavtsev, M. Lindner, L. Michaels, and J. Smirnov, Improving electro-weak fits with TeV-scale sterile neutrinos, *J. High Energy Phys.* **05** (2013) 081.
- [46] J. de Blas, Electroweak limits on physics beyond the Standard Model, *Eur. Phys. J. Web Conf.* **60**, 19008 (2013).
- [47] L. Basso, O. Fischer, and J. J. van der Bij, Precision tests of unitarity in leptonic mixing, *Eur. Phys. Lett.* **105**, 11001 (2014).
- [48] S. Antusch and O. Fischer, Testing sterile neutrino extensions of the Standard Model at future lepton colliders, *J. High Energy Phys.* **05** (2015) 053.
- [49] F.F. Deppisch, P.S. Bhupal Dev, and A. Pilaftsis, Neutrinos and collider physics, *New J. Phys.* **17**, 075019 (2015).



- [50] F. del Aguila and J. A. Aguilar-Saavedra, Distinguishing seesaw models at LHC with multi-lepton signals, *Nucl. Phys.* **B813**, 22 (2009).
- [51] A. Das and N. Okada, Inverse seesaw neutrino signatures at the LHC and ILC, *Phys. Rev. D* **88**, 113001 (2013).
- [52] A. Das, P. S. Bhupal Dev, and N. Okada, Direct bounds on electroweak scale pseudo-Dirac neutrinos from  $\sqrt{s} = 8$  TeV LHC data, *Phys. Lett. B* **735**, 364 (2014).
- [53] E. Izaguirre and B. Shuve, Multilepton and lepton jet probes of sub-weak-scale right-handed neutrinos, *Phys. Rev. D* **91**, 093010 (2015).
- [54] C. O. Dib and C. S. Kim, Discovering sterile neutrinos lighter than  $M_W$  at the LHC, *Phys. Rev. D* **92**, 093009 (2015).
- [55] A. Das, P. Konar, and S. Majhi, Production of heavy neutrino in next-to-leading order QCD at the LHC and beyond, *J. High Energy Phys.* **06** (2016) 019.
- [56] C. O. Dib, C. S. Kim, K. Wang, and J. Zhang, Distinguishing Dirac/Majorana sterile neutrinos at the LHC, *Phys. Rev. D* **94**, 013005 (2016).
- [57] C. O. Dib, C. S. Kim, and K. Wang, Signatures of Dirac and Majorana sterile neutrinos in tripleton events at the LHC, *Phys. Rev. D* **95**, 115020 (2017).
- [58] C. O. Dib, C. S. Kim, and K. Wang, Search for heavy sterile neutrinos in tripletons at the LHC, *Chin. Phys. C* **41**, 103103 (2017).
- [59] S. Dube, D. Gadkari, and A. M. Thalapillil, Lepton jets and low-mass sterile neutrinos at hadron colliders, *Phys. Rev. D* **96**, 055031 (2017).
- [60] A. Das, P. Konar, and A. Thalapillil, Jet substructure shedding light on heavy Majorana neutrinos at the LHC, *J. High Energy Phys.* **02** (2018) 083.
- [61] C. Arbeláez, C. Dib, I. Schmidt, and J. C. Vasquez, Probing the Dirac or Majorana nature of the heavy neutrinos in pure leptonic decays at the LHC, *Phys. Rev. D* **97**, 055011 (2018).
- [62] A. Bhardwaj, A. Das, P. Konar, and A. Thalapillil, Challenging sterile neutrino searches at the LHC complemented by jet substructure techniques, [arXiv:1801.00797](https://arxiv.org/abs/1801.00797).
- [63] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [64] CMS Collaboration, The CMS trigger system, *J. Instrum.* **12**, P01020 (2017).
- [65] 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.
- [66] J. M. Campbell and R. K. Ellis, MCFM for the Tevatron and the LHC, *Nucl. Phys. B, Proc. Suppl.* **205**, 10 (2010).
- [67] T. Melia, P. Nason, R. Rontsch, and G. Zanderighi,  $W^+W^-$ ,  $WZ$  and  $ZZ$  production in the POWHEG BOX, *J. High Energy Phys.* **11** (2011) 078.
- [68] P. Nason and G. Zanderighi,  $W^+W^-$ ,  $WZ$  and  $ZZ$  production in the POWHEG-BOX-V2, *Eur. Phys. J. C* **74**, 2702 (2014).
- [69] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions for the LHC Run II, *J. High Energy Phys.* **04** (2015) 040.
- [70] T. Sjöstrand, S. Mrenna, and P. Z. Skands, A brief introduction to PYTHIA 8.1, *Comput. Phys. Commun.* **178**, 852 (2008).
- [71] P. Skands, S. Carrazza, and J. Rojo, Tuning PYTHIA 8.1: The Monash 2013 tune, *Eur. Phys. J. C* **74**, 3024 (2014).
- [72] CMS Collaboration, Event generator tunes obtained from underlying event and multiparton scattering measurements, *Eur. Phys. J. C* **76**, 155 (2016).
- [73] J. Alwall, S. Höche, F. Krauss, N. Lavesson, L. Lönnblad, F. Maltoni, M. L. Mangano, M. Moretti, C. G. Papadopoulos, F. Piccinini, S. Schumann, M. Treccani, J. Winter, and M. Worek, Comparative study of various algorithms for the merging of parton showers and matrix elements in hadronic collisions, *Eur. Phys. J. C* **53**, 473 (2008).
- [74] R. Frederix and S. Frixione, Merging meets matching in MC@NLO, *J. High Energy Phys.* **12** (2012) 061.
- [75] C. Degrande, O. Mattelaer, R. Ruiz, and J. Turner, Fully automated precision predictions for heavy neutrino production mechanisms at hadron colliders, *Phys. Rev. D* **94**, 053002 (2016).
- [76] D. Alva, T. Han, and R. Ruiz, Heavy Majorana neutrinos from  $W\gamma$  fusion at hadron colliders, *J. High Energy Phys.* **02** (2015) 072.
- [77] A. Manohar, P. Nason, G. P. Salam, and G. Zanderighi, How Bright is the Proton? A Precise Determination of the Photon Parton Distribution Function, *Phys. Rev. Lett.* **117**, 242002 (2016).
- [78] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—A simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [79] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, *J. Instrum.* **12**, P10003 (2017).
- [80] M. Cacciari, G. P. Salam, and G. Soyez, The anti- $k_r$  jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.
- [81] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, *Eur. Phys. J. C* **72**, 1896 (2012).
- [82] M. Cacciari and G. P. Salam, Dispelling the  $N^3$  myth for the  $k_r$  jet-finder, *Phys. Lett. B* **641**, 57 (2006).
- [83] CMS Collaboration, Determination of jet energy calibration and transverse momentum resolution in CMS, *J. Instrum.* **6**, P11002 (2011).
- [84] CMS Collaboration, Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV, *J. Instrum.* **12**, P02014 (2017).
- [85] CMS Collaboration, CMS Physics Analysis Summary CMS-PAS-JME-16-003, 2010, <https://cds.cern.ch/record/2256875>.
- [86] CMS Collaboration, Identification of b-quark jets with the CMS experiment, *J. Instrum.* **8**, P04013 (2013).
- [87] CMS Collaboration, Identification of heavy-flavour jets with the CMS detector in pp collisions at 13 TeV, [arXiv:1712.07158](https://arxiv.org/abs/1712.07158).
- [88] CMS Collaboration, Jet algorithms performance in 13 TeV data, CMS Physics Analysis Summary CMS-PAS-JME-16-004, 2016, <https://cds.cern.ch/record/2205284>.
- [89] 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).

- [90] CMS Collaboration, Performance of CMS muon reconstruction in pp collision events at  $\sqrt{s} = 7\text{TeV}$ , *J. Instrum.* **7**, P10002 (2012).
- [91] CMS Collaboration, Search for new physics in same-sign dilepton events in proton-proton collisions at  $\sqrt{s} = 13\text{ TeV}$ , *Eur. Phys. J. C* **76**, 439 (2016).
- [92] CMS Collaboration, Search for physics beyond the standard model in events with two leptons of same sign, missing transverse momentum, and jets in proton-proton collisions at  $\sqrt{s} = 13\text{ TeV}$ , *Eur. Phys. J. C* **77**, 578 (2017).
- [93] CMS Collaboration, Measurement of the underlying event activity in inclusive Z boson production in proton-proton collisions at  $\sqrt{s} = 13\text{ TeV}$ , [arXiv:1711.04299](https://arxiv.org/abs/1711.04299).
- [94] CMS Collaboration, CMS luminosity measurement for the 2016 data taking period, CMS Physics Analysis Summary CMS-PAS-LUM-15-001, 2017, <https://cds.cern.ch/record/2138682>.
- [95] J. Butterworth *et al.*, PDF4LHC recommendations for LHC Run II, *J. Phys. G* **43**, 023001 (2016).
- [96] See Supplemental Material at <http://link.aps.org/supplemental/10.1103/PhysRevLett.120.221801> containing tables with the observed and expected yields and additional figures.
- [97] T. Junk, Confidence level computation for combining searches with small statistics, *Nucl. Instrum. Methods Phys. Res., Sect. A* **434**, 435 (1999).
- [98] A. L. Read, Presentation of search results: The CL<sub>s</sub> technique, *J. Phys. G* **28**, 2693 (2002).
- [99] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, *Eur. Phys. J. C* **71**, 1554 (2011); Erratum, *Eur. Phys. J. C* **73**, 2501 (2013).
- [100] ATLAS and CMS Collaborations, Procedure for the LHC Higgs boson search combination in summer 2011, Technical Report CMS-NOTE-2011-005, ATL-PHYS-PUB-2011-011, ATL-PHYS-PUB-2011-11, 2011.

A. M. Sirunyan,<sup>1</sup> A. Tumasyan,<sup>1</sup> W. Adam,<sup>2</sup> F. Ambrogio,<sup>2</sup> E. Asilar,<sup>2</sup> T. Bergauer,<sup>2</sup> J. Brandstetter,<sup>2</sup> E. Brondolin,<sup>2</sup> M. Dragicevic,<sup>2</sup> J. Erö,<sup>2</sup> A. Escalante Del Valle,<sup>2</sup> M. Flechl,<sup>2</sup> M. Friedl,<sup>2</sup> R. Frühwirth,<sup>2,b</sup> V. M. Ghete,<sup>2</sup> J. Grossmann,<sup>2</sup> J. Hrubec,<sup>2</sup> M. Jeitler,<sup>2,b</sup> A. König,<sup>2</sup> N. Krammer,<sup>2</sup> I. Krätschmer,<sup>2</sup> D. Liko,<sup>2</sup> T. Madlener,<sup>2</sup> I. Mikulec,<sup>2</sup> E. Pree,<sup>2</sup> N. Rad,<sup>2</sup> H. Rohringer,<sup>2</sup> J. Schieck,<sup>2,b</sup> R. Schöfbeck,<sup>2</sup> M. Spanring,<sup>2</sup> D. Spitzbart,<sup>2</sup> A. Taurok,<sup>2</sup> W. Waltenberger,<sup>2</sup> J. Wittmann,<sup>2</sup> C.-E. Wulz,<sup>2,b</sup> M. Zarucki,<sup>2</sup> V. Chekhovskiy,<sup>3</sup> V. Mossolov,<sup>3</sup> J. Suarez Gonzalez,<sup>3</sup> E. A. De Wolf,<sup>4</sup> D. Di Croce,<sup>4</sup> X. Janssen,<sup>4</sup> J. Lauwers,<sup>4</sup> M. Pieters,<sup>4</sup> M. Van De Klundert,<sup>4</sup> H. Van Haevermaet,<sup>4</sup> P. Van Mechelen,<sup>4</sup> N. Van Remortel,<sup>4</sup> S. Abu Zeid,<sup>5</sup> F. Blekman,<sup>5</sup> J. D'Hondt,<sup>5</sup> I. De Bruyn,<sup>5</sup> J. De Clercq,<sup>5</sup> K. Deroover,<sup>5</sup> G. Flouris,<sup>5</sup> D. Lontkovskiy,<sup>5</sup> S. Lowette,<sup>5</sup> I. Marchesini,<sup>5</sup> S. Moortgat,<sup>5</sup> L. Moreels,<sup>5</sup> Q. Python,<sup>5</sup> K. Skovpen,<sup>5</sup> S. Tavernier,<sup>5</sup> W. Van Doninck,<sup>5</sup> P. Van Mulders,<sup>5</sup> I. Van Parijs,<sup>5</sup> D. Beghin,<sup>6</sup> B. Bilin,<sup>6</sup> H. Brun,<sup>6</sup> B. Clerbaux,<sup>6</sup> G. De Lentdecker,<sup>6</sup> H. Delannoy,<sup>6</sup> B. Dorney,<sup>6</sup> G. Fasanella,<sup>6</sup> L. Favart,<sup>6</sup> R. Goldouzian,<sup>6</sup> A. Grebenyuk,<sup>6</sup> A. K. Kalsi,<sup>6</sup> T. Lenzi,<sup>6</sup> J. Luetic,<sup>6</sup> T. Maerschalk,<sup>6</sup> T. Seva,<sup>6</sup> E. Starling,<sup>6</sup> C. Vander Velde,<sup>6</sup> P. Vanlaer,<sup>6</sup> D. Vannerom,<sup>6</sup> R. Yonamine,<sup>6</sup> F. Zenoni,<sup>6</sup> T. Cornelis,<sup>7</sup> D. Dobur,<sup>7</sup> A. Fagot,<sup>7</sup> M. Gul,<sup>7</sup> I. Khvastunov,<sup>7,c</sup> D. Poyraz,<sup>7</sup> C. Roskas,<sup>7</sup> D. Trocino,<sup>7</sup> M. Tytgat,<sup>7</sup> W. Verbeke,<sup>7</sup> M. Vit,<sup>7</sup> N. Zaganidis,<sup>7</sup> H. Bakhshiansohi,<sup>8</sup> O. Bondu,<sup>8</sup> S. Brochet,<sup>8</sup> G. Bruno,<sup>8</sup> C. Caputo,<sup>8</sup> A. Caudron,<sup>8</sup> P. David,<sup>8</sup> S. De Visscher,<sup>8</sup> C. Delaere,<sup>8</sup> M. Delcourt,<sup>8</sup> B. Francois,<sup>8</sup> A. Giammanco,<sup>8</sup> G. Krintiras,<sup>8</sup> V. Lemaître,<sup>8</sup> A. Magitteri,<sup>8</sup> A. Mertens,<sup>8</sup> M. Musich,<sup>8</sup> K. Piotrkowski,<sup>8</sup> L. Quertenmont,<sup>8</sup> A. Saggio,<sup>8</sup> M. Vidal Marono,<sup>8</sup> S. Wertz,<sup>8</sup> J. Zobec,<sup>8</sup> W. L. Aldá Júnior,<sup>9</sup> F. L. Alves,<sup>9</sup> G. A. Alves,<sup>9</sup> L. Brito,<sup>9</sup> G. Correia Silva,<sup>9</sup> C. Hensel,<sup>9</sup> A. Moraes,<sup>9</sup> M. E. Pol,<sup>9</sup> P. Rebello Teles,<sup>9</sup> E. Belchior Batista Das Chagas,<sup>10</sup> W. Carvalho,<sup>10</sup> J. Chinellato,<sup>10,d</sup> E. Coelho,<sup>10</sup> E. M. Da Costa,<sup>10</sup> G. G. Da Silveira,<sup>10,e</sup> D. De Jesus Damiao,<sup>10</sup> S. Fonseca De Souza,<sup>10</sup> L. M. Huertas Guativa,<sup>10</sup> H. Malbouisson,<sup>10</sup> M. Melo De Almeida,<sup>10</sup> C. Mora Herrera,<sup>10</sup> L. Mundim,<sup>10</sup> H. Nogima,<sup>10</sup> L. J. Sanchez Rosas,<sup>10</sup> A. Santoro,<sup>10</sup> A. Sznajder,<sup>10</sup> M. Thiel,<sup>10</sup> E. J. Tonelli Manganote,<sup>10,d</sup> F. Torres Da Silva De Araujo,<sup>10</sup> A. Vilela Pereira,<sup>10</sup> S. Ahuja,<sup>11a</sup> C. A. Bernardes,<sup>11a</sup> T. R. Fernandez Perez Tomei,<sup>11a</sup> E. M. Gregores,<sup>11b</sup> P. G. Mercadante,<sup>11b</sup> S. F. Novaes,<sup>11a</sup> Sandra S. Padula,<sup>11a</sup> D. Romero Abad,<sup>11b</sup> J. C. Ruiz Vargas,<sup>11a</sup> A. Aleksandrov,<sup>12</sup> R. Hadjiiska,<sup>12</sup> P. Iaydjiev,<sup>12</sup> A. Marinov,<sup>12</sup> M. Misheva,<sup>12</sup> M. Rodozov,<sup>12</sup> M. Shopova,<sup>12</sup> G. Sultanov,<sup>12</sup> A. Dimitrov,<sup>13</sup> L. Litov,<sup>13</sup> B. Pavlov,<sup>13</sup> P. Petkov,<sup>13</sup> W. Fang,<sup>14,f</sup> X. Gao,<sup>14,f</sup> L. Yuan,<sup>14</sup> M. Ahmad,<sup>15</sup> J. G. Bian,<sup>15</sup> G. M. Chen,<sup>15</sup> H. S. Chen,<sup>15</sup> M. Chen,<sup>15</sup> Y. Chen,<sup>15</sup> C. H. Jiang,<sup>15</sup> D. Leggat,<sup>15</sup> H. Liao,<sup>15</sup> Z. Liu,<sup>15</sup> F. Romeo,<sup>15</sup> S. M. Shaheen,<sup>15</sup> A. Spiezia,<sup>15</sup> J. Tao,<sup>15</sup> C. Wang,<sup>15</sup> Z. Wang,<sup>15</sup> E. Yazgan,<sup>15</sup> H. Zhang,<sup>15</sup> J. Zhao,<sup>15</sup> Y. Ban,<sup>16</sup> G. Chen,<sup>16</sup> J. Li,<sup>16</sup> Q. Li,<sup>16</sup> S. Liu,<sup>16</sup> Y. Mao,<sup>16</sup> S. J. Qian,<sup>16</sup> D. Wang,<sup>16</sup> Z. Xu,<sup>16</sup> Y. Wang,<sup>17</sup> C. Avila,<sup>18</sup> A. Cabrera,<sup>18</sup> C. A. Carrillo Montoya,<sup>18</sup> L. F. Chaparro Sierra,<sup>18</sup> C. Florez,<sup>18</sup> C. F. González Hernández,<sup>18</sup> J. D. Ruiz Alvarez,<sup>18</sup> M. A. Segura Delgado,<sup>18</sup> B. Courbon,<sup>19</sup> N. Godinovic,<sup>19</sup> D. Lelas,<sup>19</sup> I. Puljak,<sup>19</sup> P. M. Ribeiro Cipriano,<sup>19</sup> T. Sculac,<sup>19</sup> Z. Antunovic,<sup>20</sup> M. Kovac,<sup>20</sup> V. Brigljevic,<sup>21</sup> D. Ferencek,<sup>21</sup> K. Kadija,<sup>21</sup> B. Mesic,<sup>21</sup> A. Starodumov,<sup>21,g</sup> T. Susa,<sup>21</sup> M. W. Ather,<sup>22</sup> A. Attikis,<sup>22</sup> G. Mavromanolakis,<sup>22</sup> J. Mousa,<sup>22</sup> C. Nicolaou,<sup>22</sup> F. Ptochos,<sup>22</sup> P. A. Razis,<sup>22</sup>

H. Rykaczewski,<sup>22</sup> M. Finger,<sup>23,h</sup> M. Finger Jr.,<sup>23,h</sup> E. Carrera Jarrin,<sup>24</sup> Y. Assran,<sup>25,ij</sup> S. Elgammal,<sup>25,j</sup> S. Khalil,<sup>25,k</sup> S. Bhowmik,<sup>26</sup> R. K. Dewanjee,<sup>26</sup> M. Kadastik,<sup>26</sup> L. Perrini,<sup>26</sup> M. Raidal,<sup>26</sup> C. Veelken,<sup>26</sup> P. Eerola,<sup>27</sup> H. Kirschenmann,<sup>27</sup> J. Pekkanen,<sup>27</sup> M. Voutilainen,<sup>27</sup> J. Havukainen,<sup>28</sup> J. K. Heikkilä,<sup>28</sup> T. Järvinen,<sup>28</sup> V. Karimäki,<sup>28</sup> R. Kinnunen,<sup>28</sup> T. Lampén,<sup>28</sup> K. Lassila-Perini,<sup>28</sup> S. Laurila,<sup>28</sup> S. Lehti,<sup>28</sup> T. Lindén,<sup>28</sup> P. Luukka,<sup>28</sup> T. Mäenpää,<sup>28</sup> H. Siikonen,<sup>28</sup> E. Tuominen,<sup>28</sup> J. Tuominiemi,<sup>28</sup> T. Tuuva,<sup>29</sup> M. Besancon,<sup>30</sup> F. Couderc,<sup>30</sup> M. DeJardin,<sup>30</sup> D. Denegri,<sup>30</sup> J. L. Faure,<sup>30</sup> F. Ferri,<sup>30</sup> S. Ganjour,<sup>30</sup> S. Ghosh,<sup>30</sup> A. Givernaud,<sup>30</sup> P. Gras,<sup>30</sup> G. Hamel de Monchenault,<sup>30</sup> P. Jarry,<sup>30</sup> C. Leloup,<sup>30</sup> E. Locci,<sup>30</sup> M. Machet,<sup>30</sup> J. Malcles,<sup>30</sup> G. Negro,<sup>30</sup> J. Rander,<sup>30</sup> A. Rosowsky,<sup>30</sup> M. Ö. Sahin,<sup>30</sup> M. Titov,<sup>30</sup> A. Abdulsalam,<sup>31,l</sup> C. Amendola,<sup>31</sup> I. Antropov,<sup>31</sup> S. Baffioni,<sup>31</sup> F. Beaudette,<sup>31</sup> P. Busson,<sup>31</sup> L. Cadamuro,<sup>31</sup> C. Charlot,<sup>31</sup> R. Granier de Cassagnac,<sup>31</sup> M. Jo,<sup>31</sup> I. Kucher,<sup>31</sup> S. Lisniak,<sup>31</sup> A. Lobanov,<sup>31</sup> J. Martin Blanco,<sup>31</sup> M. Nguyen,<sup>31</sup> C. Ochando,<sup>31</sup> G. Ortona,<sup>31</sup> P. Paganini,<sup>31</sup> P. Pigard,<sup>31</sup> R. Salerno,<sup>31</sup> J. B. Sauvan,<sup>31</sup> Y. Sirois,<sup>31</sup> A. G. Stahl Leiton,<sup>31</sup> Y. Yilmaz,<sup>31</sup> A. Zabi,<sup>31</sup> A. Zghiche,<sup>31</sup> J.-L. Agram,<sup>32,m</sup> J. Andrea,<sup>32</sup> D. Bloch,<sup>32</sup> J.-M. Brom,<sup>32</sup> M. Buttignol,<sup>32</sup> E. C. Chabert,<sup>32</sup> C. Collard,<sup>32</sup> E. Conte,<sup>32,m</sup> X. Coubez,<sup>32</sup> F. Drouhin,<sup>32,m</sup> J.-C. Fontaine,<sup>32,m</sup> D. Gelé,<sup>32</sup> U. Goerlach,<sup>32</sup> M. Jansová,<sup>32</sup> P. Juillot,<sup>32</sup> A.-C. Le Bihan,<sup>32</sup> N. Tonon,<sup>32</sup> P. Van Hove,<sup>32</sup> S. Gadrat,<sup>33</sup> S. Beauceron,<sup>34</sup> C. Bernet,<sup>34</sup> G. Boudoul,<sup>34</sup> N. Chanon,<sup>34</sup> R. Chierici,<sup>34</sup> D. Contardo,<sup>34</sup> P. Depasse,<sup>34</sup> H. El Mamouni,<sup>34</sup> J. Fay,<sup>34</sup> L. Finco,<sup>34</sup> S. Gascon,<sup>34</sup> M. Gouzevitch,<sup>34</sup> G. Grenier,<sup>34</sup> B. Ille,<sup>34</sup> F. Lagarde,<sup>34</sup> I. B. Laktineh,<sup>34</sup> H. Lattaud,<sup>34</sup> M. Lethuillier,<sup>34</sup> L. Mirabito,<sup>34</sup> A. L. Pequegnot,<sup>34</sup> S. Perries,<sup>34</sup> A. Popov,<sup>34,n</sup> V. Sordini,<sup>34</sup> M. Vander Donckt,<sup>34</sup> S. Viret,<sup>34</sup> S. Zhang,<sup>34</sup> T. Toriashvili,<sup>35,o</sup> Z. Tsamalaidze,<sup>36,h</sup> C. Autermann,<sup>37</sup> L. Feld,<sup>37</sup> M. K. Kiesel,<sup>37</sup> K. Klein,<sup>37</sup> M. Lipinski,<sup>37</sup> M. Preuten,<sup>37</sup> C. Schomakers,<sup>37</sup> J. Schulz,<sup>37</sup> M. Teroerde,<sup>37</sup> B. Wittmer,<sup>37</sup> V. Zhukov,<sup>37,n</sup> A. Albert,<sup>38</sup> D. Duchardt,<sup>38</sup> M. Endres,<sup>38</sup> M. Erdmann,<sup>38</sup> S. Erdweg,<sup>38</sup> T. Esch,<sup>38</sup> R. Fischer,<sup>38</sup> A. Güth,<sup>38</sup> T. Hebbeker,<sup>38</sup> C. Heidemann,<sup>38</sup> K. Hoepfner,<sup>38</sup> S. Knutzen,<sup>38</sup> M. Merschmeyer,<sup>38</sup> A. Meyer,<sup>38</sup> P. Millet,<sup>38</sup> S. Mukherjee,<sup>38</sup> T. Pook,<sup>38</sup> M. Radziej,<sup>38</sup> H. Reithler,<sup>38</sup> M. Rieger,<sup>38</sup> F. Scheuch,<sup>38</sup> D. Teyssier,<sup>38</sup> S. Thüer,<sup>38</sup> G. Flügge,<sup>39</sup> B. Kargoll,<sup>39</sup> T. Kress,<sup>39</sup> A. Künsken,<sup>39</sup> T. Müller,<sup>39</sup> A. Nehr Korn,<sup>39</sup> A. Nowack,<sup>39</sup> C. Pistone,<sup>39</sup> O. Pooth,<sup>39</sup> A. Stahl,<sup>39,p</sup> M. Aldaya Martin,<sup>40</sup> T. Arndt,<sup>40</sup> C. Asawatangtrakuldee,<sup>40</sup> K. Bernaert,<sup>40</sup> O. Behnke,<sup>40</sup> U. Behrens,<sup>40</sup> A. Bermúdez Martínez,<sup>40</sup> A. A. Bin Anuar,<sup>40</sup> K. Borras,<sup>40,q</sup> V. Botta,<sup>40</sup> A. Campbell,<sup>40</sup> P. Connor,<sup>40</sup> C. Contreras-Campana,<sup>40</sup> F. Costanza,<sup>40</sup> A. De Wit,<sup>40</sup> C. Diez Pardos,<sup>40</sup> G. Eckerlin,<sup>40</sup> D. Eckstein,<sup>40</sup> T. Eichhorn,<sup>40</sup> E. Eren,<sup>40</sup> E. Gallo,<sup>40,r</sup> J. Garay Garcia,<sup>40</sup> A. Geiser,<sup>40</sup> J. M. Grados Luyando,<sup>40</sup> A. Grohsjean,<sup>40</sup> P. Gunnellini,<sup>40</sup> M. Guthoff,<sup>40</sup> A. Harb,<sup>40</sup> J. Hauk,<sup>40</sup> M. Hempel,<sup>40,s</sup> H. Jung,<sup>40</sup> M. Kasemann,<sup>40</sup> J. Keaveney,<sup>40</sup> C. Kleinwort,<sup>40</sup> I. Korol,<sup>40</sup> D. Krücker,<sup>40</sup> W. Lange,<sup>40</sup> A. Lelek,<sup>40</sup> T. Lenz,<sup>40</sup> K. Lipka,<sup>40</sup> W. Lohmann,<sup>40,s</sup> R. Mankel,<sup>40</sup> I.-A. Melzer-Pellmann,<sup>40</sup> A. B. Meyer,<sup>40</sup> M. Meyer,<sup>40</sup> M. Missiroli,<sup>40</sup> G. Mittag,<sup>40</sup> J. Mnich,<sup>40</sup> A. Mussgiller,<sup>40</sup> D. Pitzl,<sup>40</sup> A. Raspereza,<sup>40</sup> M. Savitskiy,<sup>40</sup> P. Saxena,<sup>40</sup> R. Shevchenko,<sup>40</sup> N. Stefaniuk,<sup>40</sup> H. Tholen,<sup>40</sup> G. P. Van Onsem,<sup>40</sup> R. Walsh,<sup>40</sup> Y. Wen,<sup>40</sup> K. Wichmann,<sup>40</sup> C. Wissing,<sup>40</sup> O. Zenaiev,<sup>40</sup> R. Aggleton,<sup>41</sup> S. Bein,<sup>41</sup> V. Blobel,<sup>41</sup> M. Centis Vignali,<sup>41</sup> T. Dreyer,<sup>41</sup> E. Garutti,<sup>41</sup> D. Gonzalez,<sup>41</sup> J. Haller,<sup>41</sup> A. Hinzmann,<sup>41</sup> M. Hoffmann,<sup>41</sup> A. Karavdina,<sup>41</sup> G. Kasieczka,<sup>41</sup> R. Klanner,<sup>41</sup> R. Kogler,<sup>41</sup> N. Kovalchuk,<sup>41</sup> S. Kurz,<sup>41</sup> D. Marconi,<sup>41</sup> J. Multhaus,<sup>41</sup> M. Niedziela,<sup>41</sup> D. Nowatschin,<sup>41</sup> T. Peiffer,<sup>41</sup> A. Perieanu,<sup>41</sup> A. Reimers,<sup>41</sup> C. Scharf,<sup>41</sup> P. Schleper,<sup>41</sup> A. Schmidt,<sup>41</sup> S. Schumann,<sup>41</sup> J. Schwandt,<sup>41</sup> J. Sonneveld,<sup>41</sup> H. Stadie,<sup>41</sup> G. Steinbrück,<sup>41</sup> F. M. Stober,<sup>41</sup> M. Stöver,<sup>41</sup> D. Troendle,<sup>41</sup> E. Usai,<sup>41</sup> A. Vanhoefer,<sup>41</sup> B. Vormwald,<sup>41</sup> M. Akbiyik,<sup>42</sup> C. Barth,<sup>42</sup> M. Baselga,<sup>42</sup> S. Baur,<sup>42</sup> E. Butz,<sup>42</sup> R. Caspart,<sup>42</sup> T. Chwalek,<sup>42</sup> F. Colombo,<sup>42</sup> W. De Boer,<sup>42</sup> A. Dierlamm,<sup>42</sup> N. Faltermann,<sup>42</sup> B. Freund,<sup>42</sup> R. Friese,<sup>42</sup> M. Giffels,<sup>42</sup> M. A. Harrendorf,<sup>42</sup> F. Hartmann,<sup>42,p</sup> S. M. Heindl,<sup>42</sup> U. Husemann,<sup>42</sup> F. Kassel,<sup>42,p</sup> S. Kudella,<sup>42</sup> H. Mildner,<sup>42</sup> M. U. Mozer,<sup>42</sup> Th. Müller,<sup>42</sup> M. Plagge,<sup>42</sup> G. Quast,<sup>42</sup> K. Rabbertz,<sup>42</sup> M. Schröder,<sup>42</sup> I. Shvetsov,<sup>42</sup> G. Sieber,<sup>42</sup> H. J. Simonis,<sup>42</sup> R. Ulrich,<sup>42</sup> S. Wayand,<sup>42</sup> M. Weber,<sup>42</sup> T. Weiler,<sup>42</sup> S. Williamson,<sup>42</sup> C. Wöhrmann,<sup>42</sup> R. Wolf,<sup>42</sup> G. Anagnostou,<sup>43</sup> G. Daskalakis,<sup>43</sup> T. Gerasis,<sup>43</sup> A. Kyriakis,<sup>43</sup> D. Loukas,<sup>43</sup> I. Topsis-Giotis,<sup>43</sup> G. Karathanasis,<sup>44</sup> S. Kesisoglou,<sup>44</sup> A. Panagiotou,<sup>44</sup> N. Saoulidou,<sup>44</sup> E. Tziaferi,<sup>44</sup> K. Kousouris,<sup>45</sup> I. Papakrivopoulos,<sup>45</sup> I. Evangelou,<sup>46</sup> C. Foudas,<sup>46</sup> P. Giannelis,<sup>46</sup> P. Katsoulis,<sup>46</sup> P. Kokkas,<sup>46</sup> S. Mallios,<sup>46</sup> N. Manthos,<sup>46</sup> I. Papadopoulos,<sup>46</sup> E. Paradas,<sup>46</sup> J. Strologas,<sup>46</sup> F. A. Triantis,<sup>46</sup> D. Tsitsonis,<sup>46</sup> M. Csanad,<sup>47</sup> N. Filipovic,<sup>47</sup> G. Pasztor,<sup>47</sup> O. Surányi,<sup>47</sup> G. I. Veres,<sup>47,t</sup> G. Bencze,<sup>48</sup> C. Hajdu,<sup>48</sup> D. Horvath,<sup>48,u</sup> Á. Hunyadi,<sup>48</sup> F. Sikler,<sup>48</sup> V. Veszpremi,<sup>48</sup> G. Vesztergombi,<sup>48,t</sup> T. Á. Vámi,<sup>48</sup> N. Beni,<sup>49</sup> S. Czellar,<sup>49</sup> J. Karancsi,<sup>49,v</sup> A. Makovec,<sup>49</sup> J. Molnar,<sup>49</sup> Z. Szillasi,<sup>49</sup> M. Bartók,<sup>50,t</sup> P. Raics,<sup>50</sup> Z. L. Trocsanyi,<sup>50</sup> B. Ujvari,<sup>50</sup> S. Choudhury,<sup>51</sup> J. R. Komaragiri,<sup>51</sup> S. Bahinipati,<sup>52,w</sup> P. Mal,<sup>52</sup> K. Mandal,<sup>52</sup> A. Nayak,<sup>52,x</sup> D. K. Sahoo,<sup>52,w</sup> N. Sahoo,<sup>52</sup> S. K. Swain,<sup>52</sup> S. Bansal,<sup>53</sup> S. B. Beri,<sup>53</sup> V. Bhatnagar,<sup>53</sup> R. Chawla,<sup>53</sup> N. Dhingra,<sup>53</sup> R. Gupta,<sup>53</sup> A. Kaur,<sup>53</sup> M. Kaur,<sup>53</sup> S. Kaur,<sup>53</sup> R. Kumar,<sup>53</sup> P. Kumari,<sup>53</sup> A. Mehta,<sup>53</sup> S. Sharma,<sup>53</sup> J. B. Singh,<sup>53</sup> G. Walia,<sup>53</sup> Ashok Kumar,<sup>54</sup> Aashaq Shah,<sup>54</sup> A. Bhardwaj,<sup>54</sup> S. Chauhan,<sup>54</sup> B. C. Choudhary,<sup>54</sup> R. B. Garg,<sup>54</sup> S. Keshri,<sup>54</sup> A. Kumar,<sup>54</sup> S. Malhotra,<sup>54</sup> M. Naimuddin,<sup>54</sup> K. Ranjan,<sup>54</sup> R. Sharma,<sup>54</sup> R. Bhardwaj,<sup>55,y</sup> R. Bhattacharya,<sup>55</sup>

S. Bhattacharya,<sup>55</sup> U. Bhawandeep,<sup>55,y</sup> D. Bhowmik,<sup>55</sup> S. Dey,<sup>55</sup> S. Dutt,<sup>55,y</sup> S. Dutta,<sup>55</sup> S. Ghosh,<sup>55</sup> N. Majumdar,<sup>55</sup> A. Modak,<sup>55</sup> K. Mondal,<sup>55</sup> S. Mukhopadhyay,<sup>55</sup> S. Nandan,<sup>55</sup> A. Purohit,<sup>55</sup> P. K. Rout,<sup>55</sup> A. Roy,<sup>55</sup> S. Roy Chowdhury,<sup>55</sup> S. Sarkar,<sup>55</sup> M. Sharan,<sup>55</sup> B. Singh,<sup>55</sup> S. Thakur,<sup>55,y</sup> P. K. Behera,<sup>56</sup> R. Chudasama,<sup>57</sup> D. Dutta,<sup>57</sup> V. Jha,<sup>57</sup> V. Kumar,<sup>57</sup> A. K. Mohanty,<sup>57,p</sup> P. K. Netrakanti,<sup>57</sup> L. M. Pant,<sup>57</sup> P. Shukla,<sup>57</sup> A. Topkar,<sup>57</sup> T. Aziz,<sup>58</sup> S. Dugad,<sup>58</sup> B. Mahakud,<sup>58</sup> S. Mitra,<sup>58</sup> G. B. Mohanty,<sup>58</sup> N. Sur,<sup>58</sup> B. Sutar,<sup>58</sup> S. Banerjee,<sup>59</sup> S. Bhattacharya,<sup>59</sup> S. Chatterjee,<sup>59</sup> P. Das,<sup>59</sup> M. Guhait,<sup>59</sup> Sa. Jain,<sup>59</sup> S. Kumar,<sup>59</sup> M. Maity,<sup>59,z</sup> G. Majumder,<sup>59</sup> K. Mazumdar,<sup>59</sup> T. Sarkar,<sup>59,z</sup> N. Wickramage,<sup>59,aa</sup> S. Chauhan,<sup>60</sup> S. Dube,<sup>60</sup> V. Hegde,<sup>60</sup> A. Kapoor,<sup>60</sup> K. Kothekar,<sup>60</sup> S. Pandey,<sup>60</sup> A. Rane,<sup>60</sup> S. Sharma,<sup>60</sup> S. Chenarani,<sup>61,bb</sup> E. Eskandari Tadavani,<sup>61</sup> S. M. Etesami,<sup>61,bb</sup> M. Khakzad,<sup>61</sup> M. Mohammadi Najafabadi,<sup>61</sup> M. Naseri,<sup>61</sup> S. Paktinat Mehdiabadi,<sup>61,cc</sup> F. Rezaei Hosseinabadi,<sup>61</sup> B. Safarzadeh,<sup>61,dd</sup> M. Zeinali,<sup>61</sup> M. Felcini,<sup>62</sup> M. Grunewald,<sup>62</sup> M. Abbrescia,<sup>63a,63b</sup> C. Calabria,<sup>63a,63b</sup> A. Colaleo,<sup>63a</sup> D. Creanza,<sup>63a,63c</sup> L. Cristella,<sup>63a,63b</sup> N. De Filippis,<sup>63a,63c</sup> M. De Palma,<sup>63a,63b</sup> A. Di Florio,<sup>63a,63b</sup> F. Errico,<sup>63a,63b</sup> L. Fiore,<sup>63a</sup> G. Iaselli,<sup>63a,63c</sup> S. Lezki,<sup>63a,63b</sup> G. Maggi,<sup>63a,63c</sup> M. Maggi,<sup>63a</sup> B. Marangelli,<sup>63a,63b</sup> G. Miniello,<sup>63a,63b</sup> S. My,<sup>63a,63b</sup> S. Nuzzo,<sup>63a,63b</sup> A. Pompili,<sup>63a,63b</sup> G. Pugliese,<sup>63a,63c</sup> R. Radogna,<sup>63a</sup> A. Ranieri,<sup>63a</sup> G. Selvaggi,<sup>63a,63b</sup> A. Sharma,<sup>63a</sup> L. Silvestris,<sup>63a,p</sup> R. Venditti,<sup>63a</sup> P. Verwilligen,<sup>63a</sup> G. Zito,<sup>63a</sup> G. Abbiendi,<sup>64a</sup> C. Battilana,<sup>64a,64b</sup> D. Bonacorsi,<sup>64a,64b</sup> L. Borgonovi,<sup>64a,64b</sup> S. Braibant-Giacomelli,<sup>64a,64b</sup> R. Campanini,<sup>64a,64b</sup> P. Capiluppi,<sup>64a,64b</sup> A. Castro,<sup>64a,64b</sup> F. R. Cavallo,<sup>64a</sup> S. S. Chhibra,<sup>64a,64b</sup> G. Codispoti,<sup>64a,64b</sup> M. Cuffiani,<sup>64a,64b</sup> G. M. Dallavalle,<sup>64a</sup> F. Fabbri,<sup>64a</sup> A. Fanfani,<sup>64a,64b</sup> D. Fasanella,<sup>64a,64b</sup> P. Giacomelli,<sup>64a</sup> C. Grandi,<sup>64a</sup> L. Guiducci,<sup>64a,64b</sup> F. Iemmi,<sup>64a</sup> S. Marcellini,<sup>64a</sup> G. Masetti,<sup>64a</sup> A. Montanari,<sup>64a</sup> F. L. Navarria,<sup>64a,64b</sup> A. Perrotta,<sup>64a</sup> A. M. Rossi,<sup>64a,64b</sup> T. Rovelli,<sup>64a,64b</sup> G. P. Siroli,<sup>64a,64b</sup> N. Tosi,<sup>64a</sup> S. Albergo,<sup>65a,65b</sup> S. Costa,<sup>65a,65b</sup> A. Di Mattia,<sup>65a</sup> F. Giordano,<sup>65a,65b</sup> R. Potenza,<sup>65a,65b</sup> A. Tricomi,<sup>65a,65b</sup> C. Tuve,<sup>65a,65b</sup> G. Barbagli,<sup>66a</sup> K. Chatterjee,<sup>66a,66b</sup> V. Ciulli,<sup>66a,66b</sup> C. Civinini,<sup>66a</sup> R. D'Alessandro,<sup>66a,66b</sup> E. Focardi,<sup>66a,66b</sup> G. Latino,<sup>66a</sup> P. Lenzi,<sup>66a,66b</sup> M. Meschini,<sup>66a</sup> S. Paoletti,<sup>66a</sup> L. Russo,<sup>66a,ee</sup> G. Sguazzoni,<sup>66a</sup> D. Strom,<sup>66a</sup> L. Viliani,<sup>66a</sup> L. Benussi,<sup>67</sup> S. Bianco,<sup>67</sup> F. Fabbri,<sup>67</sup> D. Piccolo,<sup>67</sup> F. Primavera,<sup>67,p</sup> V. Calvelli,<sup>68a,68b</sup> F. Ferro,<sup>68a</sup> F. Ravera,<sup>68a,68b</sup> E. Robutti,<sup>68a</sup> S. Tosi,<sup>68a,68b</sup> A. Benaglia,<sup>69a</sup> A. Beschi,<sup>69b</sup> L. Brianza,<sup>69a,69b</sup> F. Brivio,<sup>69a,69b</sup> V. Ciriolo,<sup>69a,69b,p</sup> M. E. Dinardo,<sup>69a,69b</sup> S. Fiorendi,<sup>69a,69b</sup> S. Gennai,<sup>69a</sup> A. Ghezzi,<sup>69a,69b</sup> P. Govoni,<sup>69a,69b</sup> M. Malberti,<sup>69a,69b</sup> S. Malvezzi,<sup>69a</sup> R. A. Manzoni,<sup>69a,69b</sup> D. Menasce,<sup>69a</sup> L. Moroni,<sup>69a</sup> M. Paganoni,<sup>69a,69b</sup> K. Pauwels,<sup>69a,69b</sup> D. Pedrini,<sup>69a</sup> S. Pigazzini,<sup>69a,69b,ff</sup> S. Ragazzi,<sup>69a,69b</sup> T. Tabarelli de Fatis,<sup>69a,69b</sup> S. Buontempo,<sup>70a</sup> N. Cavallo,<sup>70a,70c</sup> S. Di Guida,<sup>70a,70d,p</sup> F. Fabozzi,<sup>70a,70c</sup> F. Fienga,<sup>70a,70b</sup> A. O. M. Iorio,<sup>70a,70b</sup> W. A. Khan,<sup>70a</sup> L. Lista,<sup>70a</sup> S. Meola,<sup>70a,70d,p</sup> P. Paolucci,<sup>70a,p</sup> C. Sciacca,<sup>70a,70b</sup> F. Thyssen,<sup>70a</sup> P. Azzi,<sup>71a</sup> N. Bacchetta,<sup>71a</sup> L. Benato,<sup>71a,71b</sup> D. Bisello,<sup>71a,71b</sup> A. Boletti,<sup>71a,71b</sup> R. Carlin,<sup>71a,71b</sup> P. Checchia,<sup>71a</sup> M. Dall'Osso,<sup>71a,71b</sup> P. De Castro Manzano,<sup>71a</sup> T. Dorigo,<sup>71a</sup> U. Dosselli,<sup>71a</sup> F. Gasparini,<sup>71a,71b</sup> U. Gasparini,<sup>71a,71b</sup> A. Gozzelino,<sup>71a</sup> S. Lacaprara,<sup>71a</sup> P. Lujan,<sup>71a</sup> M. Margoni,<sup>71a,71b</sup> A. T. Meneguzzo,<sup>71a,71b</sup> N. Pozzobon,<sup>71a,71b</sup> P. Ronchese,<sup>71a,71b</sup> R. Rossin,<sup>71a,71b</sup> F. Simonetto,<sup>71a,71b</sup> A. Tiko,<sup>71a</sup> E. Torassa,<sup>71a</sup> M. Zanetti,<sup>71a,71b</sup> P. Zotto,<sup>71a,71b</sup> G. Zumerle,<sup>71a,71b</sup> A. Braghieri,<sup>72a</sup> A. Magnani,<sup>72a</sup> P. Montagna,<sup>72a,72b</sup> S. P. Ratti,<sup>72a,72b</sup> V. Re,<sup>72a</sup> M. Ressegotti,<sup>72a,72b</sup> C. Riccardi,<sup>72a,72b</sup> P. Salvini,<sup>72a</sup> I. Vai,<sup>72a,72b</sup> P. Vitulo,<sup>72a,72b</sup> L. Alunni Solestizi,<sup>73a,73b</sup> M. Biasini,<sup>73a,73b</sup> G. M. Bilei,<sup>73a</sup> C. Cecchi,<sup>73a,73b</sup> D. Ciangottini,<sup>73a,73b</sup> L. Fanò,<sup>73a,73b</sup> P. Lariccia,<sup>73a,73b</sup> R. Leonardi,<sup>73a,73b</sup> E. Manoni,<sup>73a</sup> G. Mantovani,<sup>73a,73b</sup> V. Mariani,<sup>73a,73b</sup> M. Menichelli,<sup>73a</sup> A. Rossi,<sup>73a,73b</sup> A. Santocchia,<sup>73a,73b</sup> D. Spiga,<sup>73a</sup> K. Androsov,<sup>74a</sup> P. Azzurri,<sup>74a,p</sup> G. Bagliesi,<sup>74a</sup> L. Bianchini,<sup>74a</sup> T. Boccali,<sup>74a</sup> L. Borrello,<sup>74a</sup> R. Castaldi,<sup>74a</sup> M. A. Ciocci,<sup>74a,74b</sup> R. Dell'Orso,<sup>74a</sup> G. Fedi,<sup>74a</sup> L. Giannini,<sup>74a,74c</sup> A. Giassi,<sup>74a</sup> M. T. Grippo,<sup>74a,ee</sup> F. Ligabue,<sup>74a,74c</sup> T. Lomtadze,<sup>74a</sup> E. Manca,<sup>74a,74c</sup> G. Mandorli,<sup>74a,74c</sup> A. Messineo,<sup>74a,74b</sup> F. Palla,<sup>74a</sup> A. Rizzi,<sup>74a,74b</sup> P. Spagnolo,<sup>74a</sup> R. Tenchini,<sup>74a</sup> G. Tonelli,<sup>74a,74b</sup> A. Venturi,<sup>74a</sup> P. G. Verdini,<sup>74a</sup> L. Barone,<sup>75a,75b</sup> F. Cavallari,<sup>75a</sup> M. Cipriani,<sup>75a,75b</sup> N. Daci,<sup>75a</sup> D. Del Re,<sup>75a,75b</sup> E. Di Marco,<sup>75a,75b</sup> M. Diemoz,<sup>75a</sup> S. Gelli,<sup>75a,75b</sup> E. Longo,<sup>75a,75b</sup> F. Margaroli,<sup>75a,75b</sup> B. Marzocchi,<sup>75a,75b</sup> P. Meridiani,<sup>75a</sup> G. Organtini,<sup>75a,75b</sup> R. Paramatti,<sup>75a,75b</sup> F. Preiato,<sup>75a,75b</sup> S. Rahatlou,<sup>75a,75b</sup> C. Rovelli,<sup>75a</sup> F. Santanastasio,<sup>75a,75b</sup> N. Amapane,<sup>76a,76b</sup> R. Arcidiacono,<sup>76a,76c</sup> S. Argiro,<sup>76a,76b</sup> M. Arneodo,<sup>76a,76c</sup> N. Bartosik,<sup>76a</sup> R. Bellan,<sup>76a,76b</sup> C. Biino,<sup>76a</sup> N. Cartiglia,<sup>76a</sup> R. Castello,<sup>76a,76b</sup> F. Cenna,<sup>76a,76b</sup> M. Costa,<sup>76a,76b</sup> R. Covarelli,<sup>76a,76b</sup> A. Degano,<sup>76a,76b</sup> N. Demaria,<sup>76a</sup> B. Kiani,<sup>76a,76b</sup> C. Mariotti,<sup>76a</sup> S. Maselli,<sup>76a</sup> E. Migliore,<sup>76a,76b</sup> V. Monaco,<sup>76a,76b</sup> E. Monteil,<sup>76a,76b</sup> M. Monteno,<sup>76a</sup> M. M. Obertino,<sup>76a,76b</sup> L. Pacher,<sup>76a,76b</sup> N. Pastrone,<sup>76a</sup> M. Pelliccioni,<sup>76a</sup> G. L. Pinna Angioni,<sup>76a,76b</sup> A. Romero,<sup>76a,76b</sup> M. Ruspa,<sup>76a,76c</sup> R. Sacchi,<sup>76a,76b</sup> K. Shchelina,<sup>76a,76b</sup> V. Sola,<sup>76a</sup> A. Solano,<sup>76a,76b</sup> A. Staiano,<sup>76a</sup> P. Traczyk,<sup>76a,76b</sup> S. Belforte,<sup>77a</sup> M. Casarsa,<sup>77a</sup> F. Cossutti,<sup>77a</sup> G. Della Ricca,<sup>77a,77b</sup> A. Zanetti,<sup>77a</sup> D. H. Kim,<sup>78</sup> G. N. Kim,<sup>78</sup> M. S. Kim,<sup>78</sup> J. Lee,<sup>78</sup> S. Lee,<sup>78</sup> S. W. Lee,<sup>78</sup> C. S. Moon,<sup>78</sup> Y. D. Oh,<sup>78</sup> S. Sekmen,<sup>78</sup> D. C. Son,<sup>78</sup> Y. C. Yang,<sup>78</sup> H. Kim,<sup>79</sup> D. H. Moon,<sup>79</sup> G. Oh,<sup>79</sup> J. A. Brochero Cifuentes,<sup>80</sup> J. Goh,<sup>80</sup> T. J. Kim,<sup>80</sup> S. Cho,<sup>81</sup> S. Choi,<sup>81</sup> Y. Go,<sup>81</sup> D. Gyun,<sup>81</sup> S. Ha,<sup>81</sup> B. Hong,<sup>81</sup> Y. Jo,<sup>81</sup> Y. Kim,<sup>81</sup> K. Lee,<sup>81</sup> K. S. Lee,<sup>81</sup> S. Lee,<sup>81</sup> J. Lim,<sup>81</sup> S. K. Park,<sup>81</sup>

Y. Roh,<sup>81</sup> J. Almond,<sup>82</sup> J. Kim,<sup>82</sup> J. S. Kim,<sup>82</sup> H. Lee,<sup>82</sup> K. Lee,<sup>82</sup> K. Nam,<sup>82</sup> S. B. Oh,<sup>82</sup> B. C. Radburn-Smith,<sup>82</sup> S. h. Seo,<sup>82</sup> U. K. Yang,<sup>82</sup> H. D. Yoo,<sup>82</sup> G. B. Yu,<sup>82</sup> H. Kim,<sup>83</sup> J. H. Kim,<sup>83</sup> J. S. H. Lee,<sup>83</sup> I. C. Park,<sup>83</sup> Y. Choi,<sup>84</sup> C. Hwang,<sup>84</sup> J. Lee,<sup>84</sup> I. Yu,<sup>84</sup> V. Dudenias,<sup>85</sup> A. Juodagalvis,<sup>85</sup> J. Vaitkus,<sup>85</sup> I. Ahmed,<sup>86</sup> Z. A. Ibrahim,<sup>86</sup> M. A. B. Md Ali,<sup>86,gg</sup> F. Mohamad Idris,<sup>86,hh</sup> W. A. T. Wan Abdullah,<sup>86</sup> M. N. Yusli,<sup>86</sup> Z. Zolkapli,<sup>86</sup> R. Reyes-Almanza,<sup>87</sup> G. Ramirez-Sanchez,<sup>87</sup> M. C. Duran-Osuna,<sup>87</sup> H. Castilla-Valdez,<sup>87</sup> E. De La Cruz-Burelo,<sup>87</sup> I. Heredia-De La Cruz,<sup>87,ii</sup> R. I. Rabadan-Trejo,<sup>87</sup> R. Lopez-Fernandez,<sup>87</sup> J. Mejia Guisao,<sup>87</sup> A. Sanchez-Hernandez,<sup>87</sup> S. Carrillo Moreno,<sup>88</sup> C. Oropeza Barrera,<sup>88</sup> F. Vazquez Valencia,<sup>88</sup> J. Eysermans,<sup>89</sup> I. Pedraza,<sup>89</sup> H. A. Salazar Ibarguen,<sup>89</sup> C. Uribe Estrada,<sup>89</sup> A. Morelos Pineda,<sup>90</sup> D. Krofcheck,<sup>91</sup> P. H. Butler,<sup>92</sup> A. Ahmad,<sup>93</sup> M. Ahmad,<sup>93</sup> Q. Hassan,<sup>93</sup> H. R. Hoorani,<sup>93</sup> A. Saddique,<sup>93</sup> M. A. Shah,<sup>93</sup> M. Shoaib,<sup>93</sup> M. Waqas,<sup>93</sup> H. Bialkowska,<sup>94</sup> M. Bluj,<sup>94</sup> B. Boimska,<sup>94</sup> T. Frueboes,<sup>94</sup> M. Górski,<sup>94</sup> M. Kazana,<sup>94</sup> K. Nawrocki,<sup>94</sup> M. Szleper,<sup>94</sup> P. Zalewski,<sup>94</sup> K. Bunkowski,<sup>95</sup> A. Byszuk,<sup>95,ij</sup> K. Doroba,<sup>95</sup> A. Kalinowski,<sup>95</sup> M. Konecki,<sup>95</sup> J. Krolikowski,<sup>95</sup> M. Misiura,<sup>95</sup> M. Olszewski,<sup>95</sup> A. Pyskir,<sup>95</sup> M. Walczak,<sup>95</sup> P. Bargassa,<sup>96</sup> C. Beirão Da Cruz E Silva,<sup>96</sup> A. Di Francesco,<sup>96</sup> P. Faccioli,<sup>96</sup> B. Galinhas,<sup>96</sup> M. Gallinaro,<sup>96</sup> J. Hollar,<sup>96</sup> N. Leonardo,<sup>96</sup> L. Lloret Iglesias,<sup>96</sup> M. V. Nemallapudi,<sup>96</sup> J. Seixas,<sup>96</sup> G. Strong,<sup>96</sup> O. Toldaiev,<sup>96</sup> D. Vadrucchio,<sup>96</sup> J. Varela,<sup>96</sup> S. Afanasiev,<sup>97</sup> P. Bunin,<sup>97</sup> M. Gavrilenko,<sup>97</sup> I. Golutvin,<sup>97</sup> I. Gorbunov,<sup>97</sup> A. Kamenev,<sup>97</sup> V. Karjavin,<sup>97</sup> A. Lanev,<sup>97</sup> A. Malakhov,<sup>97</sup> V. Matveev,<sup>97,kl,ll</sup> P. Moisezenz,<sup>97</sup> V. Palichik,<sup>97</sup> V. Perelygin,<sup>97</sup> S. Shmatov,<sup>97</sup> S. Shulha,<sup>97</sup> N. Skatchkov,<sup>97</sup> V. Smirnov,<sup>97</sup> N. Voytishin,<sup>97</sup> A. Zarubin,<sup>97</sup> Y. Ivanov,<sup>98</sup> V. Kim,<sup>98,mm</sup> E. Kuznetsova,<sup>98,nn</sup> P. Levchenko,<sup>98</sup> V. Murzin,<sup>98</sup> V. Oreshkin,<sup>98</sup> I. Smirnov,<sup>98</sup> D. Sosnov,<sup>98</sup> V. Sulimov,<sup>98</sup> L. Uvarov,<sup>98</sup> S. Vavilov,<sup>98</sup> A. Vorobyev,<sup>98</sup> Yu. Andreev,<sup>99</sup> A. Dermenev,<sup>99</sup> S. Gninenko,<sup>99</sup> N. Golubev,<sup>99</sup> A. Karneyeu,<sup>99</sup> M. Kirsanov,<sup>99</sup> N. Krasnikov,<sup>99</sup> A. Pashenkov,<sup>99</sup> D. Tlisov,<sup>99</sup> A. Toropin,<sup>99</sup> V. Epshteyn,<sup>100</sup> V. Gavrilov,<sup>100</sup> N. Lychkovskaya,<sup>100</sup> V. Popov,<sup>100</sup> I. Pozdnyakov,<sup>100</sup> G. Safronov,<sup>100</sup> A. Spiridonov,<sup>100</sup> A. Stepenov,<sup>100</sup> V. Stolin,<sup>100</sup> M. Toms,<sup>100</sup> E. Vlasov,<sup>100</sup> A. Zhokin,<sup>100</sup> T. Aushev,<sup>101</sup> A. Bylinkin,<sup>101,ll</sup> R. Chistov,<sup>102,oo</sup> M. Danilov,<sup>102,oo</sup> P. Parygin,<sup>102</sup> D. Philippov,<sup>102</sup> S. Polikarpov,<sup>102</sup> E. Tarkovskii,<sup>102</sup> V. Andreev,<sup>103</sup> M. Azarkin,<sup>103,ll</sup> I. Dremin,<sup>103,ll</sup> M. Kirakosyan,<sup>103,ll</sup> S. V. Rusakov,<sup>103</sup> A. Terkulov,<sup>103</sup> A. Baskakov,<sup>104</sup> A. Belyaev,<sup>104</sup> E. Boos,<sup>104</sup> V. Bunichev,<sup>104</sup> M. Dubinin,<sup>104,pp</sup> L. Dudko,<sup>104</sup> A. Ershov,<sup>104</sup> V. Klyukhin,<sup>104</sup> O. Kodolova,<sup>104</sup> I. Lokhtin,<sup>104</sup> I. Miagkov,<sup>104</sup> S. Obraztsov,<sup>104</sup> S. Petrushanko,<sup>104</sup> V. Savrin,<sup>104</sup> A. Snigirev,<sup>104</sup> V. Blinov,<sup>105,qq</sup> D. Shtol,<sup>105,qq</sup> Y. Skovpen,<sup>105,qq</sup> I. Azhgirey,<sup>106</sup> I. Bayshev,<sup>106</sup> S. Bitioukov,<sup>106</sup> D. Elumakhov,<sup>106</sup> A. Godizov,<sup>106</sup> V. Kachanov,<sup>106</sup> A. Kalinin,<sup>106</sup> D. Konstantinov,<sup>106</sup> P. Mandrik,<sup>106</sup> V. Petrov,<sup>106</sup> R. Ryutin,<sup>106</sup> A. Sobol,<sup>106</sup> S. Troshin,<sup>106</sup> N. Tyurin,<sup>106</sup> A. Uzunian,<sup>106</sup> A. Volkov,<sup>106</sup> A. Babaev,<sup>107</sup> P. Adzic,<sup>108,rr</sup> P. Cirkovic,<sup>108</sup> D. Devetak,<sup>108</sup> M. Dordevic,<sup>108</sup> J. Milosevic,<sup>108</sup> J. Alcaraz Maestre,<sup>109</sup> I. Bachiller,<sup>109</sup> M. Barrio Luna,<sup>109</sup> M. Cerrada,<sup>109</sup> N. Colino,<sup>109</sup> B. De La Cruz,<sup>109</sup> A. Delgado Peris,<sup>109</sup> C. Fernandez Bedoya,<sup>109</sup> J. P. Fernández Ramos,<sup>109</sup> J. Flix,<sup>109</sup> M. C. Fouz,<sup>109</sup> O. Gonzalez Lopez,<sup>109</sup> S. Goy Lopez,<sup>109</sup> J. M. Hernandez,<sup>109</sup> M. I. Josa,<sup>109</sup> D. Moran,<sup>109</sup> A. Pérez-Calero Yzquierdo,<sup>109</sup> J. Puerta Pelayo,<sup>109</sup> I. Redondo,<sup>109</sup> L. Romero,<sup>109</sup> M. S. Soares,<sup>109</sup> A. Triossi,<sup>109</sup> A. Álvarez Fernández,<sup>109</sup> C. Albajar,<sup>110</sup> J. F. de Trocóniz,<sup>110</sup> J. Cuevas,<sup>111</sup> C. Erice,<sup>111</sup> J. Fernandez Menendez,<sup>111</sup> S. Folgueras,<sup>111</sup> I. Gonzalez Caballero,<sup>111</sup> J. R. González Fernández,<sup>111</sup> E. Palencia Cortezon,<sup>111</sup> S. Sanchez Cruz,<sup>111</sup> P. Vischia,<sup>111</sup> J. M. Vizán García,<sup>111</sup> I. J. Cabrillo,<sup>112</sup> A. Calderon,<sup>112</sup> B. Chazin Quero,<sup>112</sup> J. Duarte Campderros,<sup>112</sup> M. Fernandez,<sup>112</sup> P. J. Fernández Manteca,<sup>112</sup> J. Garcia-Ferrero,<sup>112</sup> A. García Alonso,<sup>112</sup> G. Gomez,<sup>112</sup> A. Lopez Virto,<sup>112</sup> J. Marco,<sup>112</sup> C. Martinez Rivero,<sup>112</sup> P. Martinez Ruiz del Arbol,<sup>112</sup> F. Matorras,<sup>112</sup> J. Piedra Gomez,<sup>112</sup> C. Prieels,<sup>112</sup> T. Rodrigo,<sup>112</sup> A. Ruiz-Jimeno,<sup>112</sup> L. Scodellaro,<sup>112</sup> N. Trevisani,<sup>112</sup> I. Vila,<sup>112</sup> R. Vilar Cortabitarte,<sup>112</sup> D. Abbaneo,<sup>113</sup> B. Akgun,<sup>113</sup> E. Auffray,<sup>113</sup> P. Baillon,<sup>113</sup> A. H. Ball,<sup>113</sup> D. Barney,<sup>113</sup> J. Bendavid,<sup>113</sup> M. Bianco,<sup>113</sup> A. Bocci,<sup>113</sup> C. Botta,<sup>113</sup> T. Camporesi,<sup>113</sup> M. Cepeda,<sup>113</sup> G. Cerminara,<sup>113</sup> E. Chapon,<sup>113</sup> Y. Chen,<sup>113</sup> D. d'Enterria,<sup>113</sup> A. Dabrowski,<sup>113</sup> V. Daponte,<sup>113</sup> A. David,<sup>113</sup> M. De Gruttola,<sup>113</sup> A. De Roeck,<sup>113</sup> N. Deelen,<sup>113</sup> M. Dobson,<sup>113</sup> T. du Pree,<sup>113</sup> M. Dünser,<sup>113</sup> N. Dupont,<sup>113</sup> A. Elliott-Peisert,<sup>113</sup> P. Everaerts,<sup>113</sup> F. Fallavollita,<sup>113,ss</sup> G. Franzoni,<sup>113</sup> J. Fulcher,<sup>113</sup> W. Funk,<sup>113</sup> D. Gigi,<sup>113</sup> A. Gilbert,<sup>113</sup> K. Gill,<sup>113</sup> F. Glege,<sup>113</sup> D. Gulhan,<sup>113</sup> J. Hegeman,<sup>113</sup> V. Innocente,<sup>113</sup> A. Jafari,<sup>113</sup> P. Janot,<sup>113</sup> O. Karacheban,<sup>113,s</sup> J. Kieseler,<sup>113</sup> V. Knünz,<sup>113</sup> A. Kornmayer,<sup>113</sup> M. J. Kortelainen,<sup>113</sup> M. Krammer,<sup>113,b</sup> C. Lange,<sup>113</sup> P. Lecoq,<sup>113</sup> C. Lourenço,<sup>113</sup> M. T. Lucchini,<sup>113</sup> L. Malgeri,<sup>113</sup> M. Mannelli,<sup>113</sup> A. Martelli,<sup>113</sup> F. Meijers,<sup>113</sup> J. A. Merlin,<sup>113</sup> S. Mersi,<sup>113</sup> E. Meschi,<sup>113</sup> P. Milenovic,<sup>113,tt</sup> F. Moortgat,<sup>113</sup> M. Mulders,<sup>113</sup> H. Neugebauer,<sup>113</sup> J. Ngadiuba,<sup>113</sup> S. Orfanelli,<sup>113</sup> L. Orsini,<sup>113</sup> F. Pantaleo,<sup>113,p</sup> L. Pape,<sup>113</sup> E. Perez,<sup>113</sup> M. Peruzzi,<sup>113</sup> A. Petrilli,<sup>113</sup> G. Petrucciani,<sup>113</sup> A. Pfeiffer,<sup>113</sup> M. Pierini,<sup>113</sup> F. M. Pitters,<sup>113</sup> D. Rabady,<sup>113</sup> A. Racz,<sup>113</sup> T. Reis,<sup>113</sup> G. Rolandi,<sup>113,uu</sup> M. Rovere,<sup>113</sup> H. Sakulin,<sup>113</sup> C. Schäfer,<sup>113</sup> C. Schwick,<sup>113</sup> M. Seidel,<sup>113</sup> M. Selvaggi,<sup>113</sup> A. Sharma,<sup>113</sup> P. Silva,<sup>113</sup> P. Sphicas,<sup>113,vv</sup> A. Stakia,<sup>113</sup> J. Steggemann,<sup>113</sup> M. Stoye,<sup>113</sup> M. Tosi,<sup>113</sup> D. Treille,<sup>113</sup> A. Tsiros,<sup>113</sup> V. Veckalns,<sup>113,ww</sup> M. Verweij,<sup>113</sup> W. D. Zeuner,<sup>113</sup> W. Bertl,<sup>114,a</sup> L. Caminada,<sup>114,xx</sup> K. Deiters,<sup>114</sup> W. Erdmann,<sup>114</sup> R. Horisberger,<sup>114</sup> Q. Ingram,<sup>114</sup>

H. C. Kaestli,<sup>114</sup> D. Kotlinski,<sup>114</sup> U. Langenegger,<sup>114</sup> T. Rohe,<sup>114</sup> S. A. Wiederkehr,<sup>114</sup> M. Backhaus,<sup>115</sup> L. Bäni,<sup>115</sup>  
 P. Berger,<sup>115</sup> B. Casal,<sup>115</sup> G. Dissertori,<sup>115</sup> M. Dittmar,<sup>115</sup> M. Donegà,<sup>115</sup> C. Dorfer,<sup>115</sup> C. Grab,<sup>115</sup> C. Heidegger,<sup>115</sup>  
 D. Hits,<sup>115</sup> J. Hoss,<sup>115</sup> T. Klijnsma,<sup>115</sup> W. Lustermaun,<sup>115</sup> M. Marionneau,<sup>115</sup> M. T. Meinhard,<sup>115</sup> D. Meister,<sup>115</sup> F. Micheli,<sup>115</sup>  
 P. Musella,<sup>115</sup> F. Nessi-Tedaldi,<sup>115</sup> F. Pandolfi,<sup>115</sup> J. Pata,<sup>115</sup> F. Pauss,<sup>115</sup> G. Perrin,<sup>115</sup> L. Perrozzi,<sup>115</sup> M. Quittnat,<sup>115</sup>  
 M. Reichmann,<sup>115</sup> D. A. Sanz Becerra,<sup>115</sup> M. Schönenberger,<sup>115</sup> L. Shchutska,<sup>115</sup> V. R. Tavolaro,<sup>115</sup> K. Theofilatos,<sup>115</sup>  
 M. L. Vesterbacka Olsson,<sup>115</sup> R. Wallny,<sup>115</sup> D. H. Zhu,<sup>115</sup> T. K. Aarrestad,<sup>116</sup> C. Amsler,<sup>116,yy</sup> D. Brzzechko,<sup>116</sup>  
 M. F. Canelli,<sup>116</sup> A. De Cosa,<sup>116</sup> R. Del Burgo,<sup>116</sup> S. Donato,<sup>116</sup> C. Galloni,<sup>116</sup> T. Hreus,<sup>116</sup> B. Kilminster,<sup>116</sup> I. Neutelings,<sup>116</sup>  
 D. Pinna,<sup>116</sup> G. Rauco,<sup>116</sup> P. Robmann,<sup>116</sup> D. Salerno,<sup>116</sup> K. Schweiger,<sup>116</sup> C. Seitz,<sup>116</sup> Y. Takahashi,<sup>116</sup> A. Zucchetta,<sup>116</sup>  
 V. Candelise,<sup>117</sup> Y. H. Chang,<sup>117</sup> K. Y. Cheng,<sup>117</sup> T. H. Doan,<sup>117</sup> Sh. Jain,<sup>117</sup> R. Khurana,<sup>117</sup> C. M. Kuo,<sup>117</sup> W. Lin,<sup>117</sup>  
 A. Pozdnyakov,<sup>117</sup> S. S. Yu,<sup>117</sup> Arun Kumar,<sup>118</sup> P. Chang,<sup>118</sup> Y. Chao,<sup>118</sup> K. F. Chen,<sup>118</sup> P. H. Chen,<sup>118</sup> F. Fiori,<sup>118</sup>  
 W.-S. Hou,<sup>118</sup> Y. Hsiung,<sup>118</sup> Y. F. Liu,<sup>118</sup> R.-S. Lu,<sup>118</sup> E. Paganis,<sup>118</sup> A. Psallidas,<sup>118</sup> A. Steen,<sup>118</sup> J. F. Tsai,<sup>118</sup>  
 B. Asavapibhop,<sup>119</sup> K. Kovitanggoon,<sup>119</sup> G. Singh,<sup>119</sup> N. Srimanobhas,<sup>119</sup> M. N. Bakirci,<sup>120,zz</sup> A. Bat,<sup>120</sup> F. Boran,<sup>120</sup>  
 S. Damarseckin,<sup>120</sup> Z. S. Demiroglu,<sup>120</sup> C. Dozen,<sup>120</sup> E. Eskut,<sup>120</sup> S. Girgis,<sup>120</sup> G. Gokbulut,<sup>120</sup> Y. Guler,<sup>120</sup> I. Hos,<sup>120,aaa</sup>  
 E. E. Kangal,<sup>120,bbb</sup> O. Kara,<sup>120</sup> U. Kiminsu,<sup>120</sup> M. Oglakci,<sup>120</sup> G. Onengut,<sup>120</sup> K. Ozdemir,<sup>120,ccc</sup> S. Ozturk,<sup>120,zz</sup>  
 A. Polatoz,<sup>120</sup> D. Sunar Cerci,<sup>120,ddd</sup> U. G. Tok,<sup>120</sup> S. Turcpar,<sup>120</sup> I. S. Zorbakir,<sup>120</sup> C. Zorbilmez,<sup>120</sup> G. Karapinar,<sup>121,eee</sup>  
 K. Ocalan,<sup>121,fff</sup> M. Yalvac,<sup>121</sup> M. Zeyrek,<sup>121</sup> E. Gülmez,<sup>122</sup> M. Kaya,<sup>122,ggg</sup> O. Kaya,<sup>122,hhh</sup> S. Tekten,<sup>122</sup> E. A. Yetkin,<sup>122,iii</sup>  
 M. N. Agaras,<sup>123</sup> S. Atay,<sup>123</sup> A. Cakir,<sup>123</sup> K. Cankocak,<sup>123</sup> Y. Komurcu,<sup>123</sup> B. Grynyov,<sup>124</sup> L. Levchuk,<sup>125</sup> F. Ball,<sup>126</sup>  
 L. Beck,<sup>126</sup> J. J. Brooke,<sup>126</sup> D. Burns,<sup>126</sup> E. Clement,<sup>126</sup> D. Cussans,<sup>126</sup> O. Davignon,<sup>126</sup> H. Flacher,<sup>126</sup> J. Goldstein,<sup>126</sup>  
 G. P. Heath,<sup>126</sup> H. F. Heath,<sup>126</sup> L. Kreczko,<sup>126</sup> D. M. Newbold,<sup>126,jjj</sup> S. Paramesvaran,<sup>126</sup> T. Sakuma,<sup>126</sup>  
 S. Seif El Nasr-storey,<sup>126</sup> D. Smith,<sup>126</sup> V. J. Smith,<sup>126</sup> K. W. Bell,<sup>127</sup> A. Belyaev,<sup>127,kkk</sup> C. Brew,<sup>127</sup> R. M. Brown,<sup>127</sup>  
 L. Calligaris,<sup>127</sup> D. Cieri,<sup>127</sup> D. J. A. Cockerill,<sup>127</sup> J. A. Coughlan,<sup>127</sup> K. Harder,<sup>127</sup> S. Harper,<sup>127</sup> J. Linacre,<sup>127</sup> E. Olaiya,<sup>127</sup>  
 D. Petyt,<sup>127</sup> C. H. Shepherd-Themistocleous,<sup>127</sup> A. Thea,<sup>127</sup> I. R. Tomalin,<sup>127</sup> T. Williams,<sup>127</sup> W. J. Womersley,<sup>127</sup>  
 G. Auzinger,<sup>128</sup> R. Bainbridge,<sup>128</sup> P. Bloch,<sup>128</sup> J. Borg,<sup>128</sup> S. Breeze,<sup>128</sup> O. Buchmuller,<sup>128</sup> A. Bundock,<sup>128</sup> S. Casasso,<sup>128</sup>  
 D. Colling,<sup>128</sup> L. Corpe,<sup>128</sup> P. Dauncey,<sup>128</sup> G. Davies,<sup>128</sup> M. Della Negra,<sup>128</sup> R. Di Maria,<sup>128</sup> Y. Haddad,<sup>128</sup> G. Hall,<sup>128</sup>  
 G. Iles,<sup>128</sup> T. James,<sup>128</sup> M. Komm,<sup>128</sup> R. Lane,<sup>128</sup> C. Laner,<sup>128</sup> L. Lyons,<sup>128</sup> A.-M. Magnan,<sup>128</sup> S. Malik,<sup>128</sup>  
 L. Mastrolorenzo,<sup>128</sup> T. Matsushita,<sup>128</sup> J. Nash,<sup>128,lll</sup> A. Nikitenko,<sup>128,g</sup> V. Palladino,<sup>128</sup> M. Pesaresi,<sup>128</sup> A. Richards,<sup>128</sup>  
 A. Rose,<sup>128</sup> E. Scott,<sup>128</sup> C. Seez,<sup>128</sup> A. Shtipliyski,<sup>128</sup> T. Strebler,<sup>128</sup> S. Summers,<sup>128</sup> A. Tapper,<sup>128</sup> K. Uchida,<sup>128</sup>  
 M. Vazquez Acosta,<sup>128,mmm</sup> T. Virdee,<sup>128,p</sup> N. Wardle,<sup>128</sup> D. Winterbottom,<sup>128</sup> J. Wright,<sup>128</sup> S. C. Zenz,<sup>128</sup> J. E. Cole,<sup>129</sup>  
 P. R. Hobson,<sup>129</sup> A. Khan,<sup>129</sup> P. Kyberd,<sup>129</sup> A. Morton,<sup>129</sup> I. D. Reid,<sup>129</sup> L. Teodorescu,<sup>129</sup> S. Zahid,<sup>129</sup> A. Borzou,<sup>130</sup>  
 K. Call,<sup>130</sup> J. Dittmann,<sup>130</sup> K. Hatakeyama,<sup>130</sup> H. Liu,<sup>130</sup> N. Pastika,<sup>130</sup> C. Smith,<sup>130</sup> R. Bartek,<sup>131</sup> A. Dominguez,<sup>131</sup>  
 A. Buccilli,<sup>132</sup> S. I. Cooper,<sup>132</sup> C. Henderson,<sup>132</sup> P. Rumerio,<sup>132</sup> C. West,<sup>132</sup> D. Arcaro,<sup>133</sup> A. Avetisyan,<sup>133</sup> T. Bose,<sup>133</sup>  
 D. Gastler,<sup>133</sup> D. Rankin,<sup>133</sup> C. Richardson,<sup>133</sup> J. Rohlf,<sup>133</sup> L. Sulak,<sup>133</sup> D. Zou,<sup>133</sup> G. Benelli,<sup>134</sup> D. Cutts,<sup>134</sup> M. Hadley,<sup>134</sup>  
 J. Hakala,<sup>134</sup> U. Heintz,<sup>134</sup> J. M. Hogan,<sup>134,nnn</sup> K. H. M. Kwok,<sup>134</sup> E. Laird,<sup>134</sup> G. Landsberg,<sup>134</sup> J. Lee,<sup>134</sup> Z. Mao,<sup>134</sup>  
 M. Narain,<sup>134</sup> J. Pazzini,<sup>134</sup> S. Piperov,<sup>134</sup> S. Sagir,<sup>134</sup> R. Syarif,<sup>134</sup> D. Yu,<sup>134</sup> R. Band,<sup>135</sup> C. Brainerd,<sup>135</sup> R. Breedon,<sup>135</sup>  
 D. Burns,<sup>135</sup> M. Calderon De La Barca Sanchez,<sup>135</sup> M. Chertok,<sup>135</sup> J. Conway,<sup>135</sup> R. Conway,<sup>135</sup> P. T. Cox,<sup>135</sup> R. Erbacher,<sup>135</sup>  
 C. Flores,<sup>135</sup> G. Funk,<sup>135</sup> W. Ko,<sup>135</sup> R. Lander,<sup>135</sup> C. Mclean,<sup>135</sup> M. Mulhearn,<sup>135</sup> D. Pellett,<sup>135</sup> J. Pilot,<sup>135</sup> S. Shalhout,<sup>135</sup>  
 M. Shi,<sup>135</sup> J. Smith,<sup>135</sup> D. Stolp,<sup>135</sup> D. Taylor,<sup>135</sup> K. Tos,<sup>135</sup> M. Tripathi,<sup>135</sup> Z. Wang,<sup>135</sup> F. Zhang,<sup>135</sup> M. Bachtis,<sup>136</sup>  
 C. Bravo,<sup>136</sup> R. Cousins,<sup>136</sup> A. Dasgupta,<sup>136</sup> A. Florent,<sup>136</sup> J. Hauser,<sup>136</sup> M. Ignatenko,<sup>136</sup> N. Mccoll,<sup>136</sup> S. Regnard,<sup>136</sup>  
 D. Saltzberg,<sup>136</sup> C. Schnaible,<sup>136</sup> V. Valuev,<sup>136</sup> E. Bouvier,<sup>137</sup> K. Burt,<sup>137</sup> R. Clare,<sup>137</sup> J. Ellison,<sup>137</sup> J. W. Gary,<sup>137</sup>  
 S. M. A. Ghiasi Shirazi,<sup>137</sup> G. Hanson,<sup>137</sup> G. Karapostoli,<sup>137</sup> E. Kennedy,<sup>137</sup> F. Lacroix,<sup>137</sup> O. R. Long,<sup>137</sup>  
 M. Olmedo Negrete,<sup>137</sup> M. I. Paneva,<sup>137</sup> W. Si,<sup>137</sup> L. Wang,<sup>137</sup> H. Wei,<sup>137</sup> S. Wimpenny,<sup>137</sup> B. R. Yates,<sup>137</sup> J. G. Branson,<sup>138</sup>  
 S. Cittolin,<sup>138</sup> M. Derdzinski,<sup>138</sup> R. Gerosa,<sup>138</sup> D. Gilbert,<sup>138</sup> B. Hashemi,<sup>138</sup> A. Holzner,<sup>138</sup> D. Klein,<sup>138</sup> G. Kole,<sup>138</sup>  
 V. Krutelyov,<sup>138</sup> J. Letts,<sup>138</sup> M. Masciovecchio,<sup>138</sup> D. Olivito,<sup>138</sup> S. Padhi,<sup>138</sup> M. Pieri,<sup>138</sup> M. Sani,<sup>138</sup> V. Sharma,<sup>138</sup>  
 S. Simon,<sup>138</sup> M. Tadel,<sup>138</sup> A. Vartak,<sup>138</sup> S. Wasserbaech,<sup>138,ooo</sup> J. Wood,<sup>138</sup> F. Würthwein,<sup>138</sup> A. Yagil,<sup>138</sup>  
 G. Zevi Della Porta,<sup>138</sup> N. Amin,<sup>139</sup> R. Bhandari,<sup>139</sup> J. Bradmiller-Feld,<sup>139</sup> C. Campagnari,<sup>139</sup> M. Citron,<sup>139</sup> A. Dishaw,<sup>139</sup>  
 V. Dutta,<sup>139</sup> M. Franco Sevilla,<sup>139</sup> L. Gouskos,<sup>139</sup> R. Heller,<sup>139</sup> J. Incandela,<sup>139</sup> A. Ovcharova,<sup>139</sup> H. Qu,<sup>139</sup> J. Richman,<sup>139</sup>  
 D. Stuart,<sup>139</sup> I. Suarez,<sup>139</sup> J. Yoo,<sup>139</sup> D. Anderson,<sup>140</sup> A. Bornheim,<sup>140</sup> J. Bunn,<sup>140</sup> J. M. Lawhorn,<sup>140</sup> H. B. Newman,<sup>140</sup>  
 T. Q. Nguyen,<sup>140</sup> C. Pena,<sup>140</sup> M. Spiropulu,<sup>140</sup> J. R. Vlimant,<sup>140</sup> R. Wilkinson,<sup>140</sup> S. Xie,<sup>140</sup> Z. Zhang,<sup>140</sup> R. Y. Zhu,<sup>140</sup>  
 M. B. Andrews,<sup>141</sup> T. Ferguson,<sup>141</sup> T. Mudholkar,<sup>141</sup> M. Paulini,<sup>141</sup> J. Russ,<sup>141</sup> M. Sun,<sup>141</sup> H. Vogel,<sup>141</sup> I. Vorobiev,<sup>141</sup>

M. Weinberg,<sup>141</sup> J. P. Cumalat,<sup>142</sup> W. T. Ford,<sup>142</sup> F. Jensen,<sup>142</sup> A. Johnson,<sup>142</sup> M. Krohn,<sup>142</sup> S. Leontsinis,<sup>142</sup> E. Macdonald,<sup>142</sup>  
 T. Mulholland,<sup>142</sup> K. Stenson,<sup>142</sup> K. A. Ulmer,<sup>142</sup> S. R. Wagner,<sup>142</sup> J. Alexander,<sup>143</sup> J. Chaves,<sup>143</sup> Y. Cheng,<sup>143</sup> J. Chu,<sup>143</sup>  
 A. Datta,<sup>143</sup> S. Dittmer,<sup>143</sup> K. McDermott,<sup>143</sup> N. Mirman,<sup>143</sup> J. R. Patterson,<sup>143</sup> D. Quach,<sup>143</sup> A. Rinkevicius,<sup>143</sup> A. Ryd,<sup>143</sup>  
 L. Skinnari,<sup>143</sup> L. Soffi,<sup>143</sup> S. M. Tan,<sup>143</sup> Z. Tao,<sup>143</sup> J. Thom,<sup>143</sup> J. Tucker,<sup>143</sup> P. Wittich,<sup>143</sup> M. Zientek,<sup>143</sup> S. Abdullin,<sup>144</sup>  
 M. Albrow,<sup>144</sup> M. Alyari,<sup>144</sup> G. Apollinari,<sup>144</sup> A. Apresyan,<sup>144</sup> A. Apyan,<sup>144</sup> S. Banerjee,<sup>144</sup> L. A. T. Bauerdick,<sup>144</sup>  
 A. Beretvas,<sup>144</sup> J. Berryhill,<sup>144</sup> P. C. Bhat,<sup>144</sup> G. Bolla,<sup>144,a</sup> K. Burkett,<sup>144</sup> J. N. Butler,<sup>144</sup> A. Canepa,<sup>144</sup> G. B. Cerati,<sup>144</sup>  
 H. W. K. Cheung,<sup>144</sup> F. Chlebana,<sup>144</sup> M. Cremonesi,<sup>144</sup> J. Duarte,<sup>144</sup> V. D. Elvira,<sup>144</sup> J. Freeman,<sup>144</sup> Z. Gecse,<sup>144</sup>  
 E. Gottschalk,<sup>144</sup> L. Gray,<sup>144</sup> D. Green,<sup>144</sup> S. Grünendahl,<sup>144</sup> O. Gutsche,<sup>144</sup> J. Hanlon,<sup>144</sup> R. M. Harris,<sup>144</sup> S. Hasegawa,<sup>144</sup>  
 J. Hirschauer,<sup>144</sup> Z. Hu,<sup>144</sup> B. Jayatilaka,<sup>144</sup> S. Jindariani,<sup>144</sup> M. Johnson,<sup>144</sup> U. Joshi,<sup>144</sup> B. Klima,<sup>144</sup> B. Kreis,<sup>144</sup>  
 S. Lammel,<sup>144</sup> D. Lincoln,<sup>144</sup> R. Lipton,<sup>144</sup> M. Liu,<sup>144</sup> T. Liu,<sup>144</sup> R. Lopes De Sá,<sup>144</sup> J. Lykken,<sup>144</sup> K. Maeshima,<sup>144</sup>  
 N. Magini,<sup>144</sup> J. M. Marraffino,<sup>144</sup> D. Mason,<sup>144</sup> P. McBride,<sup>144</sup> P. Merkel,<sup>144</sup> S. Mrenna,<sup>144</sup> S. Nahn,<sup>144</sup> V. O'Dell,<sup>144</sup>  
 K. Pedro,<sup>144</sup> O. Prokofyev,<sup>144</sup> G. Rakness,<sup>144</sup> L. Ristori,<sup>144</sup> A. Savoy-Navarro,<sup>144,ppp</sup> B. Schneider,<sup>144</sup> E. Sexton-Kennedy,<sup>144</sup>  
 A. Soha,<sup>144</sup> W. J. Spalding,<sup>144</sup> L. Spiegel,<sup>144</sup> S. Stoynev,<sup>144</sup> J. Strait,<sup>144</sup> N. Strobbe,<sup>144</sup> L. Taylor,<sup>144</sup> S. Tkaczyk,<sup>144</sup>  
 N. V. Tran,<sup>144</sup> L. Uplegger,<sup>144</sup> E. W. Vaandering,<sup>144</sup> C. Vernieri,<sup>144</sup> M. Verzocchi,<sup>144</sup> R. Vidal,<sup>144</sup> M. Wang,<sup>144</sup>  
 H. A. Weber,<sup>144</sup> A. Whitbeck,<sup>144</sup> W. Wu,<sup>144</sup> D. Acosta,<sup>145</sup> P. Avery,<sup>145</sup> P. Bortignon,<sup>145</sup> D. Bourilkov,<sup>145</sup> A. Brinkerhoff,<sup>145</sup>  
 A. Carnes,<sup>145</sup> M. Carver,<sup>145</sup> D. Curry,<sup>145</sup> R. D. Field,<sup>145</sup> I. K. Furic,<sup>145</sup> S. V. Gleyzer,<sup>145</sup> B. M. Joshi,<sup>145</sup> J. Konigsberg,<sup>145</sup>  
 A. Korytov,<sup>145</sup> K. Kotov,<sup>145</sup> P. Ma,<sup>145</sup> K. Matchev,<sup>145</sup> H. Mei,<sup>145</sup> G. Mitselmakher,<sup>145</sup> K. Shi,<sup>145</sup> D. Sperka,<sup>145</sup>  
 N. Terentyev,<sup>145</sup> L. Thomas,<sup>145</sup> J. Wang,<sup>145</sup> S. Wang,<sup>145</sup> J. Yelton,<sup>145</sup> Y. R. Joshi,<sup>146</sup> S. Linn,<sup>146</sup> P. Markowitz,<sup>146</sup>  
 J. L. Rodriguez,<sup>146</sup> A. Ackert,<sup>147</sup> T. Adams,<sup>147</sup> A. Askew,<sup>147</sup> S. Hagopian,<sup>147</sup> V. Hagopian,<sup>147</sup> K. F. Johnson,<sup>147</sup> T. Kolberg,<sup>147</sup>  
 G. Martinez,<sup>147</sup> T. Perry,<sup>147</sup> H. Prosper,<sup>147</sup> A. Saha,<sup>147</sup> A. Santra,<sup>147</sup> V. Sharma,<sup>147</sup> R. Yohay,<sup>147</sup> M. M. Baarmand,<sup>148</sup>  
 V. Bhopatkar,<sup>148</sup> S. Colafranceschi,<sup>148</sup> M. Hohlmann,<sup>148</sup> D. Noonan,<sup>148</sup> T. Roy,<sup>148</sup> F. Yumiceva,<sup>148</sup> M. R. Adams,<sup>149</sup>  
 L. Apanasevich,<sup>149</sup> D. Berry,<sup>149</sup> R. R. Betts,<sup>149</sup> R. Cavanaugh,<sup>149</sup> X. Chen,<sup>149</sup> O. Evdokimov,<sup>149</sup> C. E. Gerber,<sup>149</sup>  
 D. A. Hangal,<sup>149</sup> D. J. Hofman,<sup>149</sup> K. Jung,<sup>149</sup> J. Kamin,<sup>149</sup> I. D. Sandoval Gonzalez,<sup>149</sup> M. B. Tonjes,<sup>149</sup> N. Varelas,<sup>149</sup>  
 H. Wang,<sup>149</sup> Z. Wu,<sup>149</sup> J. Zhang,<sup>149</sup> B. Bilki,<sup>150,qqq</sup> W. Clarida,<sup>150</sup> K. Dilsiz,<sup>150,rrr</sup> S. Durgut,<sup>150</sup> R. P. Gandrajula,<sup>150</sup>  
 M. Haytmyradov,<sup>150</sup> V. Khristenko,<sup>150</sup> J.-P. Merlo,<sup>150</sup> H. Mermerkaya,<sup>150,sss</sup> A. Mestvirishvili,<sup>150</sup> A. Moeller,<sup>150</sup>  
 J. Nachtman,<sup>150</sup> H. Ogul,<sup>150,ttt</sup> Y. Onel,<sup>150</sup> F. Ozok,<sup>150,uuu</sup> A. Penzo,<sup>150</sup> C. Snyder,<sup>150</sup> E. Tiras,<sup>150</sup> J. Wetzel,<sup>150</sup> K. Yi,<sup>150</sup>  
 B. Blumenfeld,<sup>151</sup> A. Cocoros,<sup>151</sup> N. Eminizer,<sup>151</sup> D. Fehling,<sup>151</sup> L. Feng,<sup>151</sup> A. V. Gritsan,<sup>151</sup> P. Maksimovic,<sup>151</sup> J. Roskes,<sup>151</sup>  
 U. Sarica,<sup>151</sup> M. Swartz,<sup>151</sup> M. Xiao,<sup>151</sup> C. You,<sup>151</sup> A. Al-bataineh,<sup>152</sup> P. Baringer,<sup>152</sup> A. Bean,<sup>152</sup> S. Boren,<sup>152</sup> J. Bowen,<sup>152</sup>  
 J. Castle,<sup>152</sup> S. Khalil,<sup>152</sup> A. Kropivnitskaya,<sup>152</sup> D. Majumder,<sup>152</sup> W. Mcbrayer,<sup>152</sup> M. Murray,<sup>152</sup> C. Rogan,<sup>152</sup> C. Royon,<sup>152</sup>  
 S. Sanders,<sup>152</sup> E. Schmitz,<sup>152</sup> J. D. Tapia Takaki,<sup>152</sup> Q. Wang,<sup>152</sup> A. Ivanov,<sup>153</sup> K. Kaadze,<sup>153</sup> Y. Maravin,<sup>153</sup>  
 A. Mohammadi,<sup>153</sup> L. K. Saini,<sup>153</sup> N. Skhirtladze,<sup>153</sup> F. Rebassoo,<sup>154</sup> D. Wright,<sup>154</sup> A. Baden,<sup>155</sup> O. Baron,<sup>155</sup> A. Belloni,<sup>155</sup>  
 S. C. Eno,<sup>155</sup> Y. Feng,<sup>155</sup> C. Ferraioli,<sup>155</sup> N. J. Hadley,<sup>155</sup> S. Jabeen,<sup>155</sup> G. Y. Jeng,<sup>155</sup> R. G. Kellogg,<sup>155</sup> J. Kunkle,<sup>155</sup>  
 A. C. Mignerey,<sup>155</sup> F. Ricci-Tam,<sup>155</sup> Y. H. Shin,<sup>155</sup> A. Skuja,<sup>155</sup> S. C. Tonwar,<sup>155</sup> D. Abercrombie,<sup>156</sup> B. Allen,<sup>156</sup>  
 V. Azzolini,<sup>156</sup> R. Barbieri,<sup>156</sup> A. Baty,<sup>156</sup> G. Bauer,<sup>156</sup> R. Bi,<sup>156</sup> S. Brandt,<sup>156</sup> W. Busza,<sup>156</sup> I. A. Cali,<sup>156</sup> M. D'Alfonso,<sup>156</sup>  
 Z. Demiragli,<sup>156</sup> G. Gomez Ceballos,<sup>156</sup> M. Goncharov,<sup>156</sup> P. Harris,<sup>156</sup> D. Hsu,<sup>156</sup> M. Hu,<sup>156</sup> Y. Iiyama,<sup>156</sup>  
 G. M. Innocenti,<sup>156</sup> M. Klute,<sup>156</sup> D. Kovalskyi,<sup>156</sup> Y.-J. Lee,<sup>156</sup> A. Levin,<sup>156</sup> P. D. Luckey,<sup>156</sup> B. Maier,<sup>156</sup> A. C. Marini,<sup>156</sup>  
 C. McGinn,<sup>156</sup> C. Mironov,<sup>156</sup> S. Narayanan,<sup>156</sup> X. Niu,<sup>156</sup> C. Paus,<sup>156</sup> C. Roland,<sup>156</sup> G. Roland,<sup>156</sup> J. Salfeld-Nebgen,<sup>156</sup>  
 G. S. F. Stephans,<sup>156</sup> K. Sumorok,<sup>156</sup> K. Tatar,<sup>156</sup> D. Velicanu,<sup>156</sup> J. Wang,<sup>156</sup> T. W. Wang,<sup>156</sup> B. Wyslouch,<sup>156</sup>  
 S. Zhaozhong,<sup>156</sup> A. C. Benvenuti,<sup>157</sup> R. M. Chatterjee,<sup>157</sup> A. Evans,<sup>157</sup> P. Hansen,<sup>157</sup> S. Kalafut,<sup>157</sup> Y. Kubota,<sup>157</sup>  
 Z. Lesko,<sup>157</sup> J. Mans,<sup>157</sup> S. Nourbakhsh,<sup>157</sup> N. Ruckstuhl,<sup>157</sup> R. Rusack,<sup>157</sup> J. Turkewitz,<sup>157</sup> M. A. Wadud,<sup>157</sup> J. G. Acosta,<sup>158</sup>  
 S. Oliveros,<sup>158</sup> E. Avdeeva,<sup>159</sup> K. Bloom,<sup>159</sup> D. R. Claes,<sup>159</sup> C. Fangmeier,<sup>159</sup> F. Golf,<sup>159</sup> R. Gonzalez Suarez,<sup>159</sup>  
 R. Kamalieddin,<sup>159</sup> I. Kravchenko,<sup>159</sup> J. Monroy,<sup>159</sup> J. E. Siado,<sup>159</sup> G. R. Snow,<sup>159</sup> B. Stieger,<sup>159</sup> J. Dolen,<sup>160</sup> A. Godshalk,<sup>160</sup>  
 C. Harrington,<sup>160</sup> I. Iashvili,<sup>160</sup> D. Nguyen,<sup>160</sup> A. Parker,<sup>160</sup> S. Rappoccio,<sup>160</sup> B. Roobahani,<sup>160</sup> G. Alverson,<sup>161</sup>  
 E. Barberis,<sup>161</sup> C. Freer,<sup>161</sup> A. Hortiangtham,<sup>161</sup> A. Massironi,<sup>161</sup> D. M. Morse,<sup>161</sup> T. Orimoto,<sup>161</sup> R. Teixeira De Lima,<sup>161</sup>  
 T. Wamorkar,<sup>161</sup> B. Wang,<sup>161</sup> A. Wisecarver,<sup>161</sup> D. Wood,<sup>161</sup> S. Bhattacharya,<sup>162</sup> O. Charaf,<sup>162</sup> K. A. Hahn,<sup>162</sup> N. Mucia,<sup>162</sup>  
 N. Odell,<sup>162</sup> M. H. Schmitt,<sup>162</sup> K. Sung,<sup>162</sup> M. Trovato,<sup>162</sup> M. Velasco,<sup>162</sup> R. Bucci,<sup>163</sup> N. Dev,<sup>163</sup> M. Hildreth,<sup>163</sup>  
 K. Hurtado Anampa,<sup>163</sup> C. Jessop,<sup>163</sup> D. J. Karmgard,<sup>163</sup> N. Kellams,<sup>163</sup> K. Lannon,<sup>163</sup> W. Li,<sup>163</sup> N. Loukas,<sup>163</sup>  
 N. Marinelli,<sup>163</sup> F. Meng,<sup>163</sup> C. Mueller,<sup>163</sup> Y. Musienko,<sup>163,kk</sup> M. Planer,<sup>163</sup> A. Reinsvold,<sup>163</sup> R. Ruchti,<sup>163</sup> P. Siddireddy,<sup>163</sup>  
 G. Smith,<sup>163</sup> S. Taroni,<sup>163</sup> M. Wayne,<sup>163</sup> A. Wightman,<sup>163</sup> M. Wolf,<sup>163</sup> A. Woodard,<sup>163</sup> J. Alimena,<sup>164</sup> L. Antonelli,<sup>164</sup>

B. Bylsma,<sup>164</sup> L. S. Durkin,<sup>164</sup> S. Flowers,<sup>164</sup> B. Francis,<sup>164</sup> A. Hart,<sup>164</sup> C. Hill,<sup>164</sup> W. Ji,<sup>164</sup> T. Y. Ling,<sup>164</sup> W. Luo,<sup>164</sup>  
 B. L. Winer,<sup>164</sup> H. W. Wulsin,<sup>164</sup> S. Cooperstein,<sup>165</sup> O. Driga,<sup>165</sup> P. Elmer,<sup>165</sup> J. Hardenbrook,<sup>165</sup> P. Hebda,<sup>165</sup>  
 S. Higginbotham,<sup>165</sup> A. Kalogeropoulos,<sup>165</sup> D. Lange,<sup>165</sup> J. Luo,<sup>165</sup> D. Marlow,<sup>165</sup> K. Mei,<sup>165</sup> I. Ojalvo,<sup>165</sup> J. Olsen,<sup>165</sup>  
 C. Palmer,<sup>165</sup> P. Piroué,<sup>165</sup> D. Stickland,<sup>165</sup> C. Tully,<sup>165</sup> S. Malik,<sup>166</sup> S. Norberg,<sup>166</sup> A. Barker,<sup>167</sup> V. E. Barnes,<sup>167</sup> S. Das,<sup>167</sup>  
 L. Gutay,<sup>167</sup> M. Jones,<sup>167</sup> A. W. Jung,<sup>167</sup> A. Khatiwada,<sup>167</sup> D. H. Miller,<sup>167</sup> N. Neumeister,<sup>167</sup> C. C. Peng,<sup>167</sup> H. Qiu,<sup>167</sup>  
 J. F. Schulte,<sup>167</sup> J. Sun,<sup>167</sup> F. Wang,<sup>167</sup> R. Xiao,<sup>167</sup> W. Xie,<sup>167</sup> T. Cheng,<sup>168</sup> N. Parashar,<sup>168</sup> Z. Chen,<sup>169</sup> K. M. Ecklund,<sup>169</sup>  
 S. Freed,<sup>169</sup> F. J. M. Geurts,<sup>169</sup> M. Guilbaud,<sup>169</sup> M. Kilpatrick,<sup>169</sup> W. Li,<sup>169</sup> B. Michlin,<sup>169</sup> B. P. Padley,<sup>169</sup> J. Roberts,<sup>169</sup>  
 J. Rorie,<sup>169</sup> W. Shi,<sup>169</sup> Z. Tu,<sup>169</sup> J. Zabel,<sup>169</sup> A. Zhang,<sup>169</sup> A. Bodek,<sup>170</sup> P. de Barbaro,<sup>170</sup> R. Demina,<sup>170</sup> Y. T. Duh,<sup>170</sup>  
 T. Ferbel,<sup>170</sup> M. Galanti,<sup>170</sup> A. Garcia-Bellido,<sup>170</sup> J. Han,<sup>170</sup> O. Hindrichs,<sup>170</sup> A. Khukhunaishvili,<sup>170</sup> K. H. Lo,<sup>170</sup> P. Tan,<sup>170</sup>  
 M. Verzetti,<sup>170</sup> R. Ciesielski,<sup>171</sup> K. Goulianos,<sup>171</sup> C. Mesropian,<sup>171</sup> A. Agapitos,<sup>172</sup> J. P. Chou,<sup>172</sup> Y. Gershtein,<sup>172</sup>  
 T. A. Gómez Espinosa,<sup>172</sup> E. Halkiadakis,<sup>172</sup> M. Heindl,<sup>172</sup> E. Hughes,<sup>172</sup> S. Kaplan,<sup>172</sup> R. Kunnawalkam Elayavalli,<sup>172</sup>  
 S. Kyriacou,<sup>172</sup> A. Lath,<sup>172</sup> R. Montalvo,<sup>172</sup> K. Nash,<sup>172</sup> M. Osherson,<sup>172</sup> H. Saka,<sup>172</sup> S. Salur,<sup>172</sup> S. Schnetzer,<sup>172</sup>  
 D. Sheffield,<sup>172</sup> S. Somalwar,<sup>172</sup> R. Stone,<sup>172</sup> S. Thomas,<sup>172</sup> P. Thomassen,<sup>172</sup> M. Walker,<sup>172</sup> A. G. Delannoy,<sup>173</sup>  
 J. Heideman,<sup>173</sup> G. Riley,<sup>173</sup> K. Rose,<sup>173</sup> S. Spanier,<sup>173</sup> K. Thapa,<sup>173</sup> O. Bouhali,<sup>174, vvv</sup> A. Castaneda Hernandez,<sup>174, vvv</sup>  
 A. Celik,<sup>174</sup> M. Dalchenko,<sup>174</sup> M. De Mattia,<sup>174</sup> A. Delgado,<sup>174</sup> S. Dildick,<sup>174</sup> R. Eusebi,<sup>174</sup> J. Gilmore,<sup>174</sup> T. Huang,<sup>174</sup>  
 T. Kamon,<sup>174, www</sup> R. Mueller,<sup>174</sup> Y. Pakhotin,<sup>174</sup> R. Patel,<sup>174</sup> A. Perloff,<sup>174</sup> L. Perniè,<sup>174</sup> D. Rathjens,<sup>174</sup> A. Safonov,<sup>174</sup>  
 A. Tatarinov,<sup>174</sup> N. Akchurin,<sup>175</sup> J. Damgov,<sup>175</sup> F. De Guio,<sup>175</sup> P. R. Duerdo,<sup>175</sup> J. Faulkner,<sup>175</sup> E. Garpinar,<sup>175</sup> S. Kunori,<sup>175</sup>  
 K. Lamichhane,<sup>175</sup> S. W. Lee,<sup>175</sup> T. Mengke,<sup>175</sup> S. Muthumuni,<sup>175</sup> T. Peltola,<sup>175</sup> S. Undleeb,<sup>175</sup> I. Volobouev,<sup>175</sup> Z. Wang,<sup>175</sup>  
 S. Greene,<sup>176</sup> A. Gurrola,<sup>176</sup> R. Janjam,<sup>176</sup> W. Johns,<sup>176</sup> C. Maguire,<sup>176</sup> A. Melo,<sup>176</sup> H. Ni,<sup>176</sup> K. Padeken,<sup>176</sup> P. Sheldon,<sup>176</sup>  
 S. Tuo,<sup>176</sup> J. Velkovska,<sup>176</sup> Q. Xu,<sup>176</sup> M. W. Arenton,<sup>177</sup> P. Barria,<sup>177</sup> B. Cox,<sup>177</sup> R. Hirosky,<sup>177</sup> M. Joyce,<sup>177</sup> A. Ledovskoy,<sup>177</sup>  
 H. Li,<sup>177</sup> C. Neu,<sup>177</sup> T. Sinthuprasith,<sup>177</sup> Y. Wang,<sup>177</sup> E. Wolfe,<sup>177</sup> F. Xia,<sup>177</sup> R. Harr,<sup>178</sup> P. E. Karchin,<sup>178</sup> N. Poudyal,<sup>178</sup>  
 J. Sturdy,<sup>178</sup> P. Thapa,<sup>178</sup> S. Zaleski,<sup>178</sup> M. Brodski,<sup>179</sup> J. Buchanan,<sup>179</sup> C. Caillol,<sup>179</sup> D. Carlsmith,<sup>179</sup> S. Dasu,<sup>179</sup> L. Dodd,<sup>179</sup>  
 S. Duric,<sup>179</sup> B. Gomber,<sup>179</sup> M. Grothe,<sup>179</sup> M. Herndon,<sup>179</sup> A. Hervé,<sup>179</sup> U. Hussain,<sup>179</sup> P. Klabbbers,<sup>179</sup> A. Lanaro,<sup>179</sup>  
 A. Levine,<sup>179</sup> K. Long,<sup>179</sup> R. Loveless,<sup>179</sup> V. Rekovic,<sup>179</sup> T. Ruggles,<sup>179</sup> A. Savin,<sup>179</sup> N. Smith,<sup>179</sup>  
 W. H. Smith,<sup>179</sup> and N. Woods<sup>179</sup>

(CMS Collaboration)

- <sup>1</sup>*Yerevan Physics Institute, Yerevan, Armenia*  
<sup>2</sup>*Institut für Hochenergiephysik, Wien, Austria*  
<sup>3</sup>*Institute for Nuclear Problems, Minsk, Belarus*  
<sup>4</sup>*Universiteit Antwerpen, Antwerpen, Belgium*  
<sup>5</sup>*Vrije Universiteit Brussel, Brussel, Belgium*  
<sup>6</sup>*Université Libre de Bruxelles, Bruxelles, Belgium*  
<sup>7</sup>*Ghent University, Ghent, Belgium*  
<sup>8</sup>*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*  
<sup>9</sup>*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*  
<sup>10</sup>*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*  
<sup>11a</sup>*Universidade Estadual Paulista, São Paulo, Brazil*  
<sup>11b</sup>*Universidade Federal do ABC, São Paulo, Brazil*  
<sup>12</sup>*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*  
<sup>13</sup>*University of Sofia, Sofia, Bulgaria*  
<sup>14</sup>*Beihang University, Beijing, China*  
<sup>15</sup>*Institute of High Energy Physics, Beijing, China*  
<sup>16</sup>*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*  
<sup>17</sup>*Tsinghua University, Beijing, China*  
<sup>18</sup>*Universidad de Los Andes, Bogota, Colombia*  
<sup>19</sup>*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*  
<sup>20</sup>*University of Split, Faculty of Science, Split, Croatia*  
<sup>21</sup>*Institute Rudjer Boskovic, Zagreb, Croatia*  
<sup>22</sup>*University of Cyprus, Nicosia, Cyprus*  
<sup>23</sup>*Charles University, Prague, Czech Republic*  
<sup>24</sup>*Universidad San Francisco de Quito, Quito, Ecuador*



- <sup>25</sup>*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*
- <sup>26</sup>*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*
- <sup>27</sup>*Department of Physics, University of Helsinki, Helsinki, Finland*
- <sup>28</sup>*Helsinki Institute of Physics, Helsinki, Finland*
- <sup>29</sup>*Lappeenranta University of Technology, Lappeenranta, Finland*
- <sup>30</sup>*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
- <sup>31</sup>*Laboratoire Leprince-Ringuet, Ecole polytechnique, CNRS/IN2P3, Université Paris-Saclay, Palaiseau, France*
- <sup>32</sup>*Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France*
- <sup>33</sup>*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France*
- <sup>34</sup>*Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France*
- <sup>35</sup>*Georgian Technical University, Tbilisi, Georgia*
- <sup>36</sup>*Tbilisi State University, Tbilisi, Georgia*
- <sup>37</sup>*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
- <sup>38</sup>*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
- <sup>39</sup>*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
- <sup>40</sup>*Deutsches Elektronen-Synchrotron, Hamburg, Germany*
- <sup>41</sup>*University of Hamburg, Hamburg, Germany*
- <sup>42</sup>*Institut für Experimentelle Teilchenphysik, Karlsruhe, Germany*
- <sup>43</sup>*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
- <sup>44</sup>*National and Kapodistrian University of Athens, Athens, Greece*
- <sup>45</sup>*National Technical University of Athens, Athens, Greece*
- <sup>46</sup>*University of Ioánnina, Ioánnina, Greece*
- <sup>47</sup>*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*
- <sup>48</sup>*Wigner Research Centre for Physics, Budapest, Hungary*
- <sup>49</sup>*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
- <sup>50</sup>*Institute of Physics, University of Debrecen, Debrecen, Hungary*
- <sup>51</sup>*Indian Institute of Science (IISc), Bangalore, India*
- <sup>52</sup>*National Institute of Science Education and Research, Bhubaneswar, India*
- <sup>53</sup>*Panjab University, Chandigarh, India*
- <sup>54</sup>*University of Delhi, Delhi, India*
- <sup>55</sup>*Saha Institute of Nuclear Physics, HBNI, Kolkata, India*
- <sup>56</sup>*Indian Institute of Technology Madras, Madras, India*
- <sup>57</sup>*Bhabha Atomic Research Centre, Mumbai, India*
- <sup>58</sup>*Tata Institute of Fundamental Research-A, Mumbai, India*
- <sup>59</sup>*Tata Institute of Fundamental Research-B, Mumbai, India*
- <sup>60</sup>*Indian Institute of Science Education and Research (IISER), Pune, India*
- <sup>61</sup>*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
- <sup>62</sup>*University College Dublin, Dublin, Ireland*
- <sup>63a</sup>*INFN Sezione di Bari, Bari, Italy*
- <sup>63b</sup>*Università di Bari, Bari, Italy*
- <sup>63c</sup>*Politecnico di Bari, Bari, Italy*
- <sup>64a</sup>*INFN Sezione di Bologna, Bologna, Italy*
- <sup>64b</sup>*Università di Bologna, Bologna, Italy*
- <sup>65a</sup>*INFN Sezione di Catania, Catania, Italy*
- <sup>65b</sup>*Università di Catania, Catania, Italy*
- <sup>66a</sup>*INFN Sezione di Firenze, Firenze, Italy*
- <sup>66b</sup>*Università di Firenze, Firenze, Italy*
- <sup>67</sup>*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
- <sup>68a</sup>*INFN Sezione di Genova, Genova, Italy*
- <sup>68b</sup>*Università di Genova, Genova, Italy*
- <sup>69a</sup>*INFN Sezione di Milano-Bicocca, Milano, Italy*
- <sup>69b</sup>*Università di Milano-Bicocca, Milano, Italy*
- <sup>70a</sup>*INFN Sezione di Napoli, Napoli, Italy*
- <sup>70b</sup>*Università di Napoli 'Federico II', Napoli, Italy*
- <sup>70c</sup>*Università della Basilicata, Potenza, Italy*
- <sup>70d</sup>*Università G. Marconi, Roma, Italy*
- <sup>71a</sup>*INFN Sezione di Padova, Padova, Italy*
- <sup>71b</sup>*Università di Padova, Padova, Italy*
- <sup>72a</sup>*INFN Sezione di Pavia, Pavia, Italy*

- <sup>72b</sup>*Università di Pavia, Pavia, Italy*
- <sup>73a</sup>*INFN Sezione di Perugia, Perugia, Italy*
- <sup>73b</sup>*Università di Perugia, Perugia, Italy*
- <sup>74a</sup>*INFN Sezione di Pisa, Pisa, Italy*
- <sup>74b</sup>*Università di Pisa, Pisa, Italy*
- <sup>74c</sup>*Scuola Normale Superiore di Pisa, Pisa, Italy*
- <sup>75a</sup>*INFN Sezione di Roma, Rome, Italy*
- <sup>75b</sup>*Sapienza Università di Roma, Rome, Italy*
- <sup>76a</sup>*INFN Sezione di Torino, Torino, Italy*
- <sup>76b</sup>*Università di Torino, Torino, Italy*
- <sup>76c</sup>*Università del Piemonte Orientale, Novara, Italy*
- <sup>77a</sup>*INFN Sezione di Trieste, Trieste, Italy*
- <sup>77b</sup>*Università di Trieste, Trieste, Italy*
- <sup>78</sup>*Kyungpook National University, Daegu, South Korea*
- <sup>79</sup>*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
- <sup>80</sup>*Hanyang University, Seoul, Korea*
- <sup>81</sup>*Korea University, Seoul, Korea*
- <sup>82</sup>*Seoul National University, Seoul, Korea*
- <sup>83</sup>*University of Seoul, Seoul, Korea*
- <sup>84</sup>*Sungkyunkwan University, Suwon, Korea*
- <sup>85</sup>*Vilnius University, Vilnius, Lithuania*
- <sup>86</sup>*National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia*
- <sup>87</sup>*Centro de Investigación y de Estudios Avanzados del IPN, Mexico City, Mexico*
- <sup>88</sup>*Universidad Iberoamericana, Mexico City, Mexico*
- <sup>89</sup>*Benemerita Universidad Autónoma de Puebla, Puebla, Mexico*
- <sup>90</sup>*Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico*
- <sup>91</sup>*University of Auckland, Auckland, New Zealand*
- <sup>92</sup>*University of Canterbury, Christchurch, New Zealand*
- <sup>93</sup>*National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*
- <sup>94</sup>*National Centre for Nuclear Research, Swierk, Poland*
- <sup>95</sup>*Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*
- <sup>96</sup>*Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal*
- <sup>97</sup>*Joint Institute for Nuclear Research, Dubna, Russia*
- <sup>98</sup>*Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia*
- <sup>99</sup>*Institute for Nuclear Research, Moscow, Russia*
- <sup>100</sup>*Institute for Theoretical and Experimental Physics, Moscow, Russia*
- <sup>101</sup>*Moscow Institute of Physics and Technology, Moscow, Russia*
- <sup>102</sup>*National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia*
- <sup>103</sup>*P.N. Lebedev Physical Institute, Moscow, Russia*
- <sup>104</sup>*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*
- <sup>105</sup>*Novosibirsk State University (NSU), Novosibirsk, Russia*
- <sup>106</sup>*State Research Center of Russian Federation, Institute for High Energy Physics of NRC "Kurchatov Institute", Protvino, Russia*
- <sup>107</sup>*National Research Tomsk Polytechnic University, Tomsk, Russia*
- <sup>108</sup>*University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia*
- <sup>109</sup>*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
- <sup>110</sup>*Universidad Autónoma de Madrid, Madrid, Spain*
- <sup>111</sup>*Universidad de Oviedo, Oviedo, Spain*
- <sup>112</sup>*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
- <sup>113</sup>*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
- <sup>114</sup>*Paul Scherrer Institut, Villigen, Switzerland*
- <sup>115</sup>*ETH Zurich—Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland*
- <sup>116</sup>*Universität Zürich, Zurich, Switzerland*
- <sup>117</sup>*National Central University, Chung-Li, Taiwan*
- <sup>118</sup>*National Taiwan University (NTU), Taipei, Taiwan*
- <sup>119</sup>*Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand*
- <sup>120</sup>*Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey*
- <sup>121</sup>*Middle East Technical University, Physics Department, Ankara, Turkey*
- <sup>122</sup>*Bogazici University, Istanbul, Turkey*
- <sup>123</sup>*Istanbul Technical University, Istanbul, Turkey*
- <sup>124</sup>*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine*

- <sup>125</sup>*National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine*
- <sup>126</sup>*University of Bristol, Bristol, United Kingdom*
- <sup>127</sup>*Rutherford Appleton Laboratory, Didcot, United Kingdom*
- <sup>128</sup>*Imperial College, London, United Kingdom*
- <sup>129</sup>*Brunel University, Uxbridge, United Kingdom*
- <sup>130</sup>*Baylor University, Waco, Texas, USA*
- <sup>131</sup>*Catholic University of America, Washington DC, USA*
- <sup>132</sup>*The University of Alabama, Tuscaloosa, Alabama, USA*
- <sup>133</sup>*Boston University, Boston, Massachusetts, USA*
- <sup>134</sup>*Brown University, Providence, Rhode Island, USA*
- <sup>135</sup>*University of California, Davis, Davis, California, USA*
- <sup>136</sup>*University of California, Los Angeles, California, USA*
- <sup>137</sup>*University of California, Riverside, Riverside, California, USA*
- <sup>138</sup>*University of California, San Diego, La Jolla, California, USA*
- <sup>139</sup>*University of California, Santa Barbara—Department of Physics, Santa Barbara, California, USA*
- <sup>140</sup>*California Institute of Technology, Pasadena, California, USA*
- <sup>141</sup>*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
- <sup>142</sup>*University of Colorado Boulder, Boulder, Colorado, USA*
- <sup>143</sup>*Cornell University, Ithaca, New York, USA*
- <sup>144</sup>*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
- <sup>145</sup>*University of Florida, Gainesville, Florida, USA*
- <sup>146</sup>*Florida International University, Miami, Florida, USA*
- <sup>147</sup>*Florida State University, Tallahassee, Florida, USA*
- <sup>148</sup>*Florida Institute of Technology, Melbourne, Florida, USA*
- <sup>149</sup>*University of Illinois at Chicago (UIC), Chicago, Illinois, USA*
- <sup>150</sup>*The University of Iowa, Iowa City, Iowa, USA*
- <sup>151</sup>*Johns Hopkins University, Baltimore, Maryland, USA*
- <sup>152</sup>*The University of Kansas, Lawrence, Kansas, USA*
- <sup>153</sup>*Kansas State University, Manhattan, Kansas, USA*
- <sup>154</sup>*Lawrence Livermore National Laboratory, Livermore, California, USA*
- <sup>155</sup>*University of Maryland, College Park, Maryland, USA*
- <sup>156</sup>*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
- <sup>157</sup>*University of Minnesota, Minneapolis, Minnesota, USA*
- <sup>158</sup>*University of Mississippi, Oxford, Mississippi, USA*
- <sup>159</sup>*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
- <sup>160</sup>*State University of New York at Buffalo, Buffalo, New York, USA*
- <sup>161</sup>*Northeastern University, Boston, Massachusetts, USA*
- <sup>162</sup>*Northwestern University, Evanston, Illinois, USA*
- <sup>163</sup>*University of Notre Dame, Notre Dame, Indiana, USA*
- <sup>164</sup>*The Ohio State University, Columbus, Ohio, USA*
- <sup>165</sup>*Princeton University, Princeton, New Jersey, USA*
- <sup>166</sup>*University of Puerto Rico, Mayaguez, Puerto Rico, USA*
- <sup>167</sup>*Purdue University, West Lafayette, Indiana, USA*
- <sup>168</sup>*Purdue University Northwest, Hammond, Indiana, USA*
- <sup>169</sup>*Rice University, Houston, Texas, USA*
- <sup>170</sup>*University of Rochester, Rochester, New York, USA*
- <sup>171</sup>*The Rockefeller University, New York, New York, USA*
- <sup>172</sup>*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*
- <sup>173</sup>*University of Tennessee, Knoxville, Tennessee, USA*
- <sup>174</sup>*Texas A&M University, College Station, Texas, USA*
- <sup>175</sup>*Texas Tech University, Lubbock, Texas, USA*
- <sup>176</sup>*Vanderbilt University, Nashville, Tennessee, USA*
- <sup>177</sup>*University of Virginia, Charlottesville, Virginia, USA*
- <sup>178</sup>*Wayne State University, Detroit, Michigan, USA*
- <sup>179</sup>*University of Wisconsin—Madison, Madison, Wisconsin, USA*

<sup>a</sup>Deceased.

<sup>b</sup>Also at Vienna University of Technology, Vienna, Austria.

<sup>c</sup>Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France.

<sup>d</sup>Also at Universidade Estadual de Campinas, Campinas, Brazil.

- <sup>e</sup> Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil.
- <sup>f</sup> Also at Université Libre de Bruxelles, Bruxelles, Belgium.
- <sup>g</sup> Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
- <sup>h</sup> Also at Joint Institute for Nuclear Research, Dubna, Russia.
- <sup>i</sup> Also at Suez University, Suez, Egypt.
- <sup>j</sup> Also at British University in Egypt, Cairo, Egypt.
- <sup>k</sup> Also at Zewail City of Science and Technology, Zewail, Egypt.
- <sup>l</sup> Also at Department of Physics, King Abdulaziz University, Jeddah, Saudi Arabia.
- <sup>m</sup> Also at Université de Haute Alsace, Mulhouse, France.
- <sup>n</sup> Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.
- <sup>o</sup> Also at Tbilisi State University, Tbilisi, Georgia.
- <sup>p</sup> Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
- <sup>q</sup> Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
- <sup>r</sup> Also at University of Hamburg, Hamburg, Germany.
- <sup>s</sup> Also at Brandenburg University of Technology, Cottbus, Germany.
- <sup>t</sup> Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.
- <sup>u</sup> Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
- <sup>v</sup> Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.
- <sup>w</sup> Also at IIT Bhubaneswar, Bhubaneswar, India.
- <sup>x</sup> Also at Institute of Physics, Bhubaneswar, India.
- <sup>y</sup> Also at Shoolini University, Solan, India.
- <sup>z</sup> Also at University of Visva-Bharati, Santiniketan, India.
- <sup>aa</sup> Also at University of Ruhuna, Matara, Sri Lanka.
- <sup>bb</sup> Also at Isfahan University of Technology, Isfahan, Iran.
- <sup>cc</sup> Also at Yazd University, Yazd, Iran.
- <sup>dd</sup> Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.
- <sup>ee</sup> Also at Università degli Studi di Siena, Siena, Italy.
- <sup>ff</sup> Also at INFN Sezione di Milano-Bicocca, Università di Milano-Bicocca, Milano, Italy.
- <sup>gg</sup> Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia.
- <sup>hh</sup> Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia.
- <sup>ii</sup> Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico.
- <sup>jj</sup> Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.
- <sup>kk</sup> Also at Institute for Nuclear Research, Moscow, Russia.
- <sup>ll</sup> Also at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia.
- <sup>mm</sup> Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
- <sup>nn</sup> Also at University of Florida, Gainesville, USA.
- <sup>oo</sup> Also at P.N. Lebedev Physical Institute, Moscow, Russia.
- <sup>pp</sup> Also at California Institute of Technology, Pasadena, USA.
- <sup>qq</sup> Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia.
- <sup>rr</sup> Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
- <sup>ss</sup> Also at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy.
- <sup>tt</sup> Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
- <sup>uu</sup> Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
- <sup>vv</sup> Also at National and Kapodistrian University of Athens, Athens, Greece.
- <sup>ww</sup> Also at Riga Technical University, Riga, Latvia.
- <sup>xx</sup> Also at Universität Zürich, Zurich, Switzerland.
- <sup>yy</sup> Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
- <sup>zz</sup> Also at Gaziosmanpasa University, Tokat, Turkey.
- <sup>aaa</sup> Also at Istanbul Aydin University, Istanbul, Turkey.
- <sup>bbb</sup> Also at Mersin University, Mersin, Turkey.
- <sup>ccc</sup> Also at Piri Reis University, Istanbul, Turkey.
- <sup>ddd</sup> Also at Adiyaman University, Adiyaman, Turkey.
- <sup>eee</sup> Also at Izmir Institute of Technology, Izmir, Turkey.
- <sup>fff</sup> Also at Necmettin Erbakan University, Konya, Turkey.
- <sup>ggg</sup> Also at Marmara University, Istanbul, Turkey.
- <sup>hhh</sup> Also at Kafkas University, Kars, Turkey.
- <sup>iii</sup> Also at Istanbul Bilgi University, Istanbul, Turkey.
- <sup>jjj</sup> Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
- <sup>kkk</sup> Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- <sup>lll</sup> Also at Monash University, Faculty of Science, Clayton, Australia.

- <sup>mmm</sup> Also at Instituto de Astrofísica de Canarias, La Laguna, Spain.
- <sup>nnn</sup> Also at Bethel University, Arden Hills, Minnesota, USA.
- <sup>ooo</sup> Also at Utah Valley University, Orem, Utah, USA.
- <sup>ppp</sup> Also at Purdue University, West Lafayette, Indiana, USA.
- <sup>qqq</sup> Also at Beykent University, Istanbul, Turkey.
- <sup>rrr</sup> Also at Bingol University, Bingol, Turkey.
- <sup>sss</sup> Also at Erzincan University, Erzincan, Turkey.
- <sup>ttt</sup> Also at Sinop University, Sinop, Turkey.
- <sup>uuu</sup> Also at Mimar Sinan University, Istanbul, Turkey.
- <sup>vvv</sup> Also at Texas A&M University at Qatar, Doha, Qatar.
- <sup>www</sup> Also at Kyungpook National University, Daegu, South Korea.