

## Observation of $t\bar{t}H$ Production

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

 (Received 8 April 2018; revised manuscript received 1 May 2018; published 4 June 2018)

The observation of Higgs boson production in association with a top quark-antiquark pair is reported, based on a combined analysis of proton-proton collision data at center-of-mass energies of  $\sqrt{s} = 7, 8,$  and  $13$  TeV, corresponding to integrated luminosities of up to  $5.1, 19.7,$  and  $35.9$  fb $^{-1}$ , respectively. The data were collected with the CMS detector at the CERN LHC. The results of statistically independent searches for Higgs bosons produced in conjunction with a top quark-antiquark pair and decaying to pairs of  $W$  bosons,  $Z$  bosons, photons,  $\tau$  leptons, or bottom quark jets are combined to maximize sensitivity. An excess of events is observed, with a significance of 5.2 standard deviations, over the expectation from the background-only hypothesis. The corresponding expected significance from the standard model for a Higgs boson mass of 125.09 GeV is 4.2 standard deviations. The combined best fit signal strength normalized to the standard model prediction is  $1.26^{+0.31}_{-0.26}$ .

DOI: [10.1103/PhysRevLett.120.231801](https://doi.org/10.1103/PhysRevLett.120.231801)

Proton-proton ( $pp$ ) collisions at the CERN LHC, at the center-of-mass (c.m.) energies of  $\sqrt{s} = 7, 8,$  and  $13$  TeV, have allowed direct measurements of the properties of the Higgs boson [1–3]. In particular, the 13 TeV data collected so far by the ATLAS [4] and CMS [5] experiments have led to improved constraints on the couplings of the Higgs boson compared to those performed at the lower energies [6], permitting more precise consistency checks with the predictions of the standard model (SM) of particle physics [7–9]. Nonetheless, not all properties of the Higgs boson have been established, in part because of insufficiently large data sets. The lack of statistical precision can be partially overcome by combining the results of searches in different decay channels of the Higgs boson and at different c.m. energies. Among the properties that are not yet well established is the tree-level coupling of Higgs bosons to top quarks.

In this Letter, we present a combination of searches for the Higgs boson ( $H$ ) produced in association with a top quark-antiquark pair ( $t\bar{t}$ ), based on data collected with the CMS detector. Results from data collected at  $\sqrt{s} = 13$  TeV [10–14] are combined with analogous results from  $\sqrt{s} = 7$  and  $8$  TeV [15]. As a result of this combination, we establish the observation of  $t\bar{t}H$  production. This constitutes the first confirmation of the tree-level coupling of the Higgs boson to top quarks.

A top quark decays almost exclusively to a bottom quark and a  $W$  boson, with the  $W$  boson subsequently decaying either to a quark and an antiquark or to a charged lepton and its associated neutrino. The Higgs boson exhibits a rich spectrum of decay modes that includes the decay to a bottom quark-antiquark pair, a  $\tau^+\tau^-$  lepton pair, a photon pair, and combinations of quarks and leptons from the decay of intermediate on- or off-shell  $W$  and  $Z$  bosons. Thus,  $t\bar{t}H$  production gives rise to a wide variety of final-state event topologies, which we consider in our analyses and in the combination of results presented below.

In the SM, the masses of elementary fermions are accounted for by introducing a minimal set of Yukawa interactions, compatible with gauge invariance, between the Higgs and fermion fields. Following the spontaneous breaking of electroweak symmetry [16–21], charged fermions of flavor  $f$  couple to  $H$  with a strength  $y_f$  proportional to the mass  $m_f$  of those fermions, namely  $y_f = m_f/v$ , where  $v \approx 246$  GeV is the vacuum expectation value of the Higgs field. Measurements of the Higgs boson decay rates to down-type fermions ( $\tau$  leptons and bottom quarks) agree with the SM predictions within their uncertainties [22,23]. However, the top quark Yukawa coupling ( $y_t$ ) cannot be similarly tested from the measurement of a decay rate since on-shell top quarks are too heavy to be produced in Higgs boson decay. Instead, constraints on  $y_t$  can be obtained through the measurement of the  $pp \rightarrow t\bar{t}H$  production process. Example tree-level Feynman diagrams for this process are shown in Fig. 1. To date,  $t\bar{t}H$  production has eluded definite observation, although first evidence has been recently reported by the ATLAS [24] and CMS [10] Collaborations.

The overall agreement observed between the SM predictions and data for the rate of Higgs boson production

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

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>.

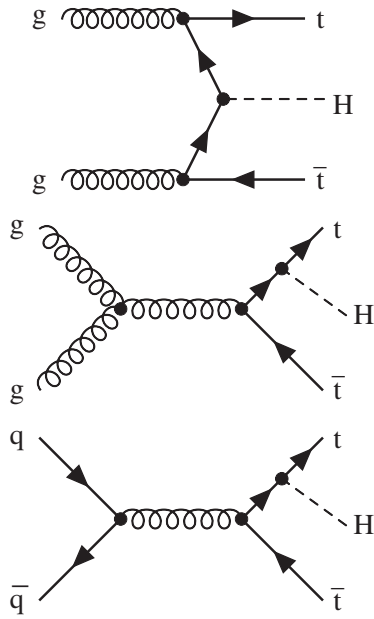


FIG. 1. Example tree-level Feynman diagrams for the  $pp \rightarrow t\bar{t}H$  production process, with  $g$  a gluon,  $q$  a quark,  $t$  a top quark, and  $H$  a Higgs boson. For the present study, we consider Higgs boson decays to a pair of  $W$  bosons,  $Z$  bosons, photons,  $\tau$  leptons, or bottom quark jets.

through gluon-gluon fusion and for the  $H \rightarrow \gamma\gamma$  decay mode [6] suggests that the Higgs boson coupling to top quarks is SM-like, since the quantum loops in these processes include top quarks. However, non-SM particles in the loops could introduce terms that compensate for, and thus mask, other deviations from the SM. A measurement of the production rate of the tree-level  $t\bar{t}H$  process can provide evidence for, or against, such new-physics contributions.

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two end cap sections. Forward calorimeters extend the pseudorapidity coverage provided by the barrel and end cap detectors. Muons are detected in gas-ionization chambers embedded in the steel flux-return yoke outside the solenoid. A detailed description of the CMS detector can be found in Ref. [5].

Events of interest are selected using a two-tiered trigger system [25] based on custom hardware processors and a farm of commercial processors running a version of the full reconstruction software optimized for speed. Offline, a particle-flow algorithm [26] is used to reconstruct and identify each particle in an event based on a combination of information from the various CMS subdetectors. Additional identification criteria are employed to improve

purities and define the final samples of candidate electrons, muons, hadronically decaying  $\tau$  leptons ( $\tau_h$ ) [27,28], and photons. Jets are reconstructed from particle-flow candidates using the anti- $k_T$  clustering algorithm [29] implemented in the FASTJET package [30]. Multivariate algorithms [31,32] are used to identify (tag) jets arising from the hadronization of bottom quarks ( $b$  jets) and discriminate against gluon and light flavor quark jets. The algorithms utilize observables related to the long lifetimes of hadrons containing  $b$  quarks and the relatively larger particle multiplicity and mass of  $b$  jets compared to light flavor quark jets. The  $\tau_h$  identification is based on the reconstruction of the hadronic  $\tau$  decay modes  $\tau^- \rightarrow h^- \nu_\tau$ ,  $h^- \pi^0 \nu_\tau$ ,  $h^- \pi^0 \pi^0 \nu_\tau$ , and  $h^- h^+ h^- \nu_\tau$  (plus the charge conjugate reactions), where  $h^\pm$  denotes either a charged pion or kaon. More details about the reconstruction procedures are given in Refs. [10–15].

The 13 TeV data employed for the current study were collected in 2016 and correspond to an integrated luminosity of up to  $35.9 \text{ fb}^{-1}$  [33]. The 7 and 8 TeV data, collected in 2011 and 2012, correspond to integrated luminosities of up to  $5.1$  and  $19.7 \text{ fb}^{-1}$  [34], respectively. The 13 TeV analyses are improved relative to the 7 and 8 TeV studies in that they employ triggers with higher efficiencies, contain improvements in the reconstruction and background-rejection methods, and use more precise theory calculations to describe the signal and the background processes. For the 7, 8, and 13 TeV data, the theoretical calculations of Ref. [35] for Higgs boson production cross sections and branching fractions are used to normalize the expected signal yields.

The event samples are divided into exclusive categories depending on the multiplicity and kinematic properties of reconstructed electrons, muons,  $\tau_h$  candidates, photons, jets, and tagged  $b$  jets in an event. Samples of simulated events based on Monte Carlo event generators, with simulation of the detector response based on the GEANT4 [36] suite of programs, are used to evaluate the detector acceptance and optimize the event selection for each category. In the analysis of data, the background is, in general, evaluated from data control regions. When this is not feasible, either because the background process has a very small cross section or a control region depleted of signal events cannot be identified, the background is evaluated from simulation with a systematic uncertainty assigned to account for the known model dependence. Multivariate algorithms [37–41] based on deep neural networks, boosted decision trees, and matrix element calculations are used to reduce backgrounds.

At 13 TeV, we search for  $t\bar{t}H$  production in the  $H \rightarrow b\bar{b}$  decay mode by selecting events with at least three tagged  $b$  jets and with zero leptons [11], one lepton [12], or an opposite-sign lepton pair [12], where “lepton” refers to an electron or muon candidate. A search for  $t\bar{t}H$  production in the  $H \rightarrow \gamma\gamma$  decay mode is performed in events with two

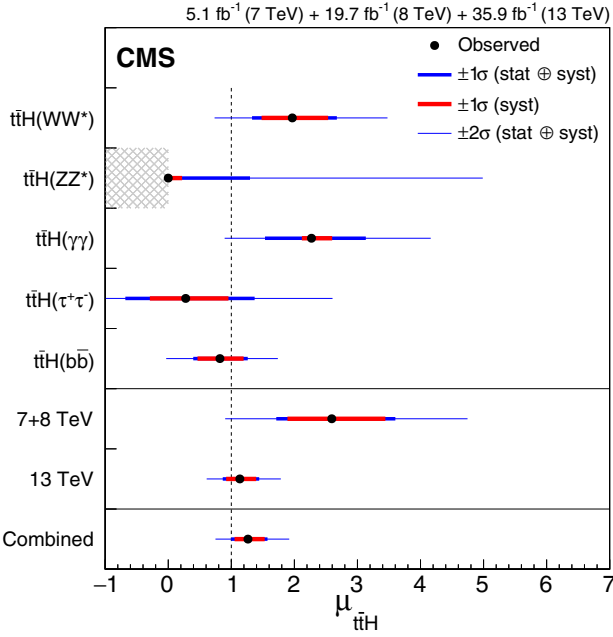


FIG. 2. Best fit value of the  $t\bar{t}H$  signal strength modifier  $\mu_{t\bar{t}H}$ , with its 1 and 2 standard deviation confidence intervals ( $\sigma$ ), for (upper section) the five individual decay channels considered, (middle section) the combined result for 7 + 8 TeV alone and for 13 TeV alone, and (lower section) the overall combined result. The Higgs boson mass is taken to be 125.09 GeV. For the  $H \rightarrow ZZ^*$  decay mode,  $\mu_{t\bar{t}H}$  is constrained to be positive to prevent the corresponding event yield from becoming negative. The SM expectation is shown as a dashed vertical line.

reconstructed photons in combination with reconstructed electrons or muons, jets, and tagged  $b$  jets [13]. The signal yield is extracted from a fit to the diphoton invariant mass spectrum. Events with combinations of jets and tagged  $b$  jets and with two same-sign leptons, three leptons, or four leptons are used to search for  $t\bar{t}H$  production in the  $H \rightarrow \tau^+\tau^-$ ,  $WW^*$ , or  $ZZ^*$  decay modes [10,14], where in this case “lepton” refers to an electron, muon, or  $\tau_h$  candidate (the asterisk denotes an off-shell particle). The searches in the different decay channels are statistically independent from each other. Analogous searches have been performed with the 7 and 8 TeV data [15].

The presence of a  $t\bar{t}H$  signal is assessed by performing a simultaneous fit to the data from the different decay modes and also from the different c.m. energies as described below. A detailed description of the statistical methods can be found in Ref. [42]. The test statistic  $q$  is defined as the negative of twice the logarithm of the profile likelihood ratio [42]. Systematic uncertainties are incorporated through the use of nuisance parameters treated according to the frequentist paradigm. The ratio between the normalization of the  $t\bar{t}H$  production process and its SM expectation [35], defined as the signal strength modifier  $\mu_{t\bar{t}H}$ , is a freely floating parameter in the fit. The SM expectation is evaluated assuming the combined ATLAS

and CMS value for the mass of the Higgs boson, which is 125.09 GeV [43]. We consider the five Higgs boson decay modes with the largest expected event yields, namely,  $H \rightarrow WW^*$ ,  $ZZ^*$ ,  $\gamma\gamma$ ,  $\tau^+\tau^-$ , and  $b\bar{b}$ . Other Higgs boson decay modes and production processes, including  $pp \rightarrow tH + X$  (or  $\bar{t}H + X$ ), with  $X$  a light flavor quark or  $W$  boson, are treated as backgrounds and normalized using the predicted SM cross sections, subject to the corresponding uncertainties.

The measured values of the five independent signal strength modifiers, corresponding to the five decay channels considered, are shown in the upper section of Fig. 2 along with their 1 and 2 standard deviation confidence intervals obtained in the asymptotic approximation [44]. Numerical values are given in Table I. The individual measurements are seen to be consistent with each other within the uncertainties.

We also perform a combined fit, using a single signal strength modifier  $\mu_{t\bar{t}H}$ , that simultaneously scales the  $t\bar{t}H$  production cross sections of the five decay channels considered, with all Higgs boson branching fractions fixed to their SM values [35]. Besides the five decay modes

TABLE I. Best fit value, with its uncertainty, of the  $t\bar{t}H$  signal strength modifier  $\mu_{t\bar{t}H}$ , for the five individual decay channels considered, the combined result for 7 + 8 TeV alone and for 13 TeV alone, and the overall combined result. The total uncertainties are decomposed into their statistical, experimental systematic, background theory systematic, and signal theory components. The numbers in parentheses are those expected for  $\mu_{t\bar{t}H} = 1$ .

Parameter	Best fit	Uncertainty			
		Statistical	Experi- mental	Background theory	Signal theory
$\mu_{t\bar{t}H}^{WW^*}$	$1.97^{+0.71}_{-0.64}$ (+0.57) (-0.54)	+0.42 -0.41 (+0.39) (-0.38)	+0.46 -0.42 (+0.36) (-0.34)	+0.21 -0.21 (+0.17) (-0.17)	+0.25 -0.12 (+0.12) (-0.03)
$\mu_{t\bar{t}H}^{ZZ^*}$	$0.00^{+1.30}_{-0.00}$ (+2.89) (-0.99)	+1.28 -0.00 (+2.82) (-0.99)	+0.20 -0.00 (+0.51) (-0.00)	+0.04 -0.00 (+0.15) (-0.00)	+0.09 -0.00 (+0.27) (-0.00)
$\mu_{t\bar{t}H}^{\gamma\gamma}$	$2.27^{+0.86}_{-0.74}$ (+0.73) (-0.64)	+0.80 -0.72 (+0.71) (-0.64)	+0.15 -0.09 (+0.09) (-0.04)	+0.02 -0.01 (+0.01) (-0.00)	+0.29 -0.13 (+0.13) (-0.05)
$\mu_{t\bar{t}H}^{\tau^+\tau^-}$	$0.28^{+1.09}_{-0.96}$ (+1.00) (-0.89)	+0.86 -0.77 (+0.83) (-0.76)	+0.64 -0.53 (+0.54) (-0.47)	+0.10 -0.09 (+0.09) (-0.08)	+0.20 -0.19 (+0.14) (-0.01)
$\mu_{t\bar{t}H}^{b\bar{b}}$	$0.82^{+0.44}_{-0.42}$ (+0.44) (-0.42)	+0.23 -0.23 (+0.23) (-0.22)	+0.24 -0.23 (+0.24) (-0.23)	+0.27 -0.27 (+0.26) (-0.27)	+0.11 -0.03 (+0.11) (-0.04)
$\mu_{t\bar{t}H}^{7+8 \text{ TeV}}$	$2.59^{+1.01}_{-0.88}$ (+0.87) (-0.79)	+0.54 -0.53 (+0.51) (-0.49)	+0.53 -0.49 (+0.48) (-0.44)	+0.55 -0.49 (+0.50) (-0.44)	+0.37 -0.13 (+0.14) (-0.02)
$\mu_{t\bar{t}H}^{13 \text{ TeV}}$	$1.14^{+0.31}_{-0.27}$ (+0.29) (-0.26)	+0.17 -0.16 (+0.16) (-0.16)	+0.17 -0.17 (+0.17) (-0.16)	+0.13 -0.12 (+0.13) (-0.12)	+0.14 -0.06 (+0.11) (-0.05)
$\mu_{t\bar{t}H}$	$1.26^{+0.31}_{-0.26}$ (+0.28) (-0.25)	+0.16 -0.16 (+0.15) (-0.15)	+0.17 -0.15 (+0.16) (-0.15)	+0.14 -0.13 (+0.13) (-0.12)	+0.15 -0.07 (+0.11) (-0.05)

considered, the signal normalizations for the Higgs boson decay modes to gluons, charm quarks, and  $Z\gamma$ , which are subleading and cannot be constrained with existing data, are scaled by  $\mu_{\bar{t}tH}$ . The results combining the decay modes at 7 + 8 TeV, and separately at 13 TeV, are shown in the middle section of Fig. 2. The overall result, combining all decay modes and all c.m. energies, is shown in the lower section, with numerical values given in Table I. Table I includes a breakdown of the total uncertainties into their statistical and systematic components. The overall result is  $\mu_{\bar{t}tH} = 1.26^{+0.31}_{-0.26}$ , which agrees with the SM expectation  $\mu_{\bar{t}tH} = 1$  within 1 standard deviation.

The principal sources of experimental systematic uncertainty in the overall result for  $\mu_{\bar{t}tH}$  stem from the uncertainty in the lepton and  $b$  jet identification efficiencies and in the  $\tau_h$  and jet energy scales. The background theory systematic uncertainty is dominated by modeling uncertainties in  $\bar{t}t$  production in association with a  $W$  boson, a  $Z$  boson, or a pair of  $b$  or  $c$  quark jets. The dominant contribution to the signal theory systematic uncertainty arises from the finite accuracy in the SM prediction for the  $\bar{t}tH$  cross section because of missing higher order terms and uncertainties in the proton parton density functions [35].

To highlight the excess of data over the expectation from the background-only hypothesis, we classify each event

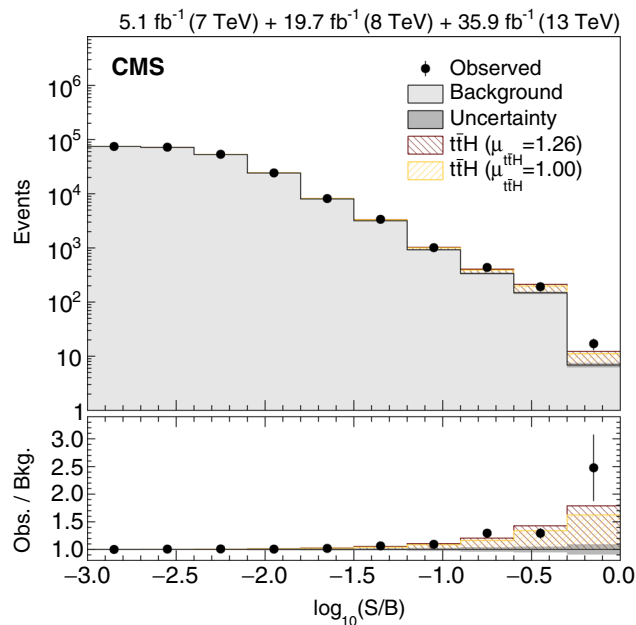


FIG. 3. Distribution of events as a function of the decimal logarithm of  $S/B$ , where  $S$  and  $B$  are the expected postfit signal (with  $\mu_{\bar{t}tH} = 1$ ) and background yields, respectively, in each bin of the distributions considered in this combination. The shaded histogram shows the expected background distribution. The two hatched histograms, each stacked on top of the background histogram, show the signal expectation for the SM ( $\mu_{\bar{t}tH} = 1$ ) and the observed ( $\mu_{\bar{t}tH} = 1.26$ ) signal strengths. The lower panel shows the ratios of the expected signal and observed results relative to the expected background.

that enters the combined fit by the ratio  $S/B$ , where  $S$  and  $B$  are the expected postfit signal (with  $\mu_{\bar{t}tH} = 1$ ) and background yields, respectively, in each bin of the distributions considered in the combination. The distribution of  $\log_{10}(S/B)$  is shown in Fig. 3. The main sensitivity at high values of  $S/B$  is given by events selected in the  $H \rightarrow \gamma\gamma$  analysis with a diphoton mass around 125 GeV and by events selected in the  $H \rightarrow \tau^+\tau^-$ ,  $H \rightarrow WW^*$ , and  $H \rightarrow b\bar{b}$  analyses with high values of the multivariate discriminating variables used for the signal extraction. A broad excess of events in the rightmost bins of this distribution is observed, consistent with the expectation for  $\bar{t}tH$  production with a SM-like cross section.

The value of the test statistic  $q$  as a function of  $\mu_{\bar{t}tH}$  is shown in Fig. 4, with  $\mu_{\bar{t}tH}$  based on the combination of decay modes described above for the combined fit. The results are shown for the combination of all decay modes at 7 + 8 TeV and at 13 TeV, separately, and for all decay modes at all c.m. energies. To quantify the significance of the measured  $\bar{t}tH$  yield, we compute the probability of the background-only hypothesis ( $p$  value) as the tail integral of the test statistic using the overall combination evaluated at  $\mu_{\bar{t}tH} = 0$  under the asymptotic approximation [45]. This corresponds to a significance of 5.2 standard deviations for a one-tailed Gaussian distribution. The expected significance for a SM Higgs boson with a mass of 125.09 GeV, evaluated through use of an Asimov data set [45], is 4.2 standard deviations.

In summary, we have reported the observation of  $\bar{t}tH$  production with a significance of 5.2 standard deviations

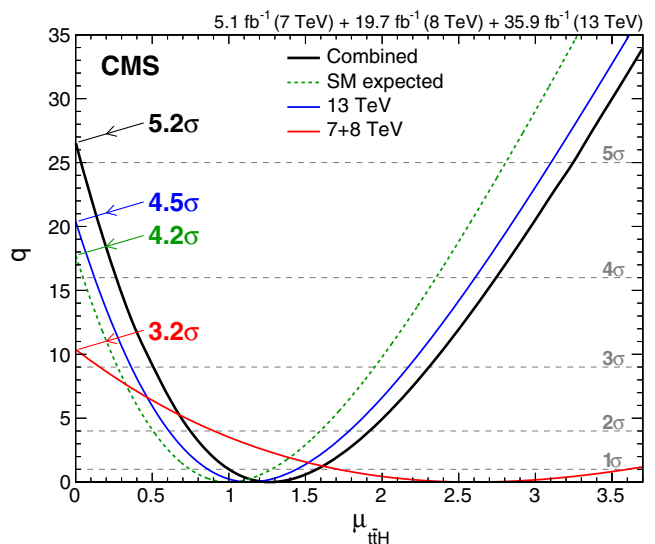


FIG. 4. Test statistic  $q$ , described in the text, as a function of  $\mu_{\bar{t}tH}$  for all decay modes at 7 + 8 TeV and at 13 TeV, separately, and for all decay modes at all c.m. energies. The expected SM result for the overall combination is also shown. The horizontal dashed lines indicate the  $p$  values for the background-only hypothesis obtained from the asymptotic distribution of  $q$ , expressed in units of the number of standard deviations.

above the background-only hypothesis, at a Higgs boson mass of 125.09 GeV. The measured production rate is consistent with the standard model prediction within one standard deviation. In addition to comprising the first observation of a new Higgs boson production mechanism, this measurement establishes the tree-level coupling of the Higgs boson to the top quark, and hence to an up-type quark.

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: BMWF 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, CPAN, PCTI and FEDER (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] ATLAS Collaboration, Observation of a new particle in the search for the standard model Higgs boson with the ATLAS detector at the LHC, *Phys. Lett. B* **716**, 1 (2012).  
 [2] CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, *Phys. Lett. B* **716**, 30 (2012).  
 [3] CMS Collaboration, Observation of a new boson with mass near 125 GeV in pp collisions at  $\sqrt{s} = 7$  and 8 TeV, *J. High Energy Phys.* **06** (2013) 081.  
 [4] ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider, *J. Instrum.* **3**, S08003 (2008).  
 [5] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).

[6] ATLAS and CMS Collaborations, Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC  $pp$  collision data at  $\sqrt{s} = 7$  and 8 TeV, *J. High Energy Phys.* **08** (2016) 045.  
 [7] S. L. Glashow, Partial-symmetries of weak interactions, *Nucl. Phys.* **22**, 579 (1961).  
 [8] S. Weinberg, A Model of Leptons, *Phys. Rev. Lett.* **19**, 1264 (1967).  
 [9] Abdus Salam, Weak and electromagnetic interactions, in *Elementary Particle Physics: Relativistic Groups and Analyticity*, edited by N. Svartholm (Almqvist & Wiksells, Stockholm, 1968), p. 367.  
 [10] CMS Collaboration, Evidence for associated production of a Higgs boson with a top quark pair in final states with electrons, muons, and hadronically decaying  $\tau$  leptons at  $\sqrt{s} = 13$  TeV, [arXiv:1803.05485](https://arxiv.org/abs/1803.05485) [*J. High Energy Phys.* (to be published)].  
 [11] CMS Collaboration, Search for  $t\bar{t}H$  in all-jet final states in proton-proton collisions at  $\sqrt{s} = 13$  TeV, [arXiv:1803.06986](https://arxiv.org/abs/1803.06986) [*J. High Energy Phys.* (to be published)].  
 [12] CMS Collaboration, Search for  $t\bar{t}H$  production in the  $H \rightarrow b\bar{b}$  decay channel with leptonic  $t\bar{t}$  decays in proton-proton collisions at  $\sqrt{s} = 13$  TeV, [arXiv:1804.03682](https://arxiv.org/abs/1804.03682) [*J. High Energy Phys.* (to be published)].  
 [13] CMS Collaboration, Measurements of Higgs boson properties in the diphoton decay channel in proton-proton collisions at  $\sqrt{s} = 13$  TeV, [arXiv:1804.02716](https://arxiv.org/abs/1804.02716) [*J. High Energy Phys.* (to be published)].  
 [14] CMS Collaboration, Measurements of properties of the Higgs boson decaying into the four-lepton final state in pp collisions at  $\sqrt{s} = 13$  TeV, *J. High Energy Phys.* **11** (2017) 047.  
 [15] CMS Collaboration, Search for the associated production of the Higgs boson with a top-quark pair, *J. High Energy Phys.* **09** (2014) 087.  
 [16] P. W. Higgs, Broken symmetries, massless particles and gauge fields, *Phys. Lett.* **12**, 132 (1964).  
 [17] F. Englert and R. Brout, Broken Symmetry and the Mass of Gauge Vector Mesons, *Phys. Rev. Lett.* **13**, 321 (1964).  
 [18] P. W. Higgs, Broken Symmetries and the Masses of Gauge Bosons, *Phys. Rev. Lett.* **13**, 508 (1964).  
 [19] G. S. Guralnik, C. R. Hagen, and T. W. B. Kibble, Global Conservation Laws and Massless Particles, *Phys. Rev. Lett.* **13**, 585 (1964).  
 [20] P. W. Higgs, Spontaneous symmetry breakdown without massless bosons, *Phys. Rev.* **145**, 1156 (1966).  
 [21] T. W. B. Kibble, Symmetry breaking in non-Abelian gauge theories, *Phys. Rev.* **155**, 1554 (1967).  
 [22] CMS Collaboration, Observation of the Higgs boson decay to a pair of  $\tau$  leptons, *Phys. Lett. B* **779**, 283 (2018).  
 [23] CMS Collaboration, Evidence for the Higgs boson decay to a bottom quark-antiquark pair, *Phys. Lett. B* **780**, 501 (2018).  
 [24] ATLAS Collaboration, Evidence for the associated production of the Higgs boson and a top quark pair with the ATLAS detector, *Phys. Rev. D* **97**, 072003 (2018).  
 [25] CMS Collaboration, The CMS trigger system, *J. Instrum.* **12**, P01020 (2017).

- [26] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, *J. Instrum.* **12**, P10003 (2017).
- [27] CMS Collaboration, Reconstruction and identification of  $\tau$  lepton decays to hadrons and  $\nu_\tau$  at CMS, *J. Instrum.* **11**, P01019 (2016).
- [28] CMS Collaboration, Performance of Reconstruction and Identification of Tau Leptons in their Decays to Hadrons and Tau Neutrino in LHC Run-2, CMS Physics Analysis Summary CMS-PAS-TAU-16-002 CERN, 2016, <https://cds.cern.ch/record/2196972>.
- [29] M. Cacciari, G. P. Salam, and G. Soyez, The anti- $k_T$  jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.
- [30] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, *Eur. Phys. J. C* **72**, 1896 (2012).
- [31] CMS Collaboration, Identification of b-quark jets with the CMS experiment, *J. Instrum.* **8**, P04013 (2013).
- [32] 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) [*J. Instrum.* (to be published)].
- [33] CMS Collaboration, CMS Luminosity Measurements for the 2016 Data Taking Period, CMS Physics Analysis Summary CMS-PAS-LUM-17-001 CERN, 2017, <https://cds.cern.ch/record/2257069>.
- [34] CMS Collaboration, CMS Luminosity Based on Pixel Cluster Counting—Summer 2013 Update, CMS Physics Analysis Summary CMS-PAS-LUM-13-001 CERN, 2013, <https://cds.cern.ch/record/1598864>.
- [35] LHC Higgs Cross Section Working Group, Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector, CYRM-2017-002 CERN, 2016.
- [36] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [37] I. Goodfellow, Y. Bengio, and A. Courville, *Deep Learning* (MIT Press, Cambridge, MA, 2016).
- [38] J. Therhaag, A. Hoecker, P. Speckmeyer, E. von Toerne, and H. Voss, TMVA—toolkit for multivariate data analysis, in *Proceedings, Int'l Conf. on Computational Methods in Science and Engineering, 2009, ICCMSE2009*, Vol. 1504 (ICCMSE, 2012), p. 1013.
- [39] V. M. Abazov *et al.* (D0 Collaboration), A precision measurement of the mass of the top quark, *Nature (London)* **429**, 638 (2004).
- [40] V. M. Abazov *et al.* (D0 Collaboration), Helicity of the W boson in lepton + jets  $t\bar{t}$  events, *Phys. Lett. B* **617**, 1 (2005).
- [41] CMS Collaboration, Search for a standard model Higgs boson produced in association with a top-quark pair and decaying to bottom quarks using a matrix element method, *Eur. Phys. J. C* **75**, 251 (2015).
- [42] ATLAS Collaboration, CMS Collaboration, LHC Higgs Combination Group, Procedure for the LHC Higgs Boson Search Combination in Summer 2011, Technical Report CMS-NOTE-2011-005, ATL-PHYS-PUB-2011-11 2011, <https://cds.cern.ch/record/1379837>.
- [43] ATLAS and CMS Collaborations, Combined Measurement of the Higgs Boson Mass in pp Collisions at  $\sqrt{s} = 7$  and 8 TeV with the ATLAS and CMS Experiments, *Phys. Rev. Lett.* **114**, 191803 (2015).
- [44] CMS Collaboration, Precise determination of the mass of the Higgs boson and tests of compatibility of its couplings with the standard model predictions using proton collisions at 7 and 8 TeV, *Eur. Phys. J. C* **75**, 212 (2015).
- [45] 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).

A. M. Sirunyan,<sup>1</sup> A. Tumasyan,<sup>1</sup> W. Adam,<sup>2</sup> F. Ambroggi,<sup>2</sup> E. Asilar,<sup>2</sup> T. Bergauer,<sup>2</sup> J. Brandstetter,<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> R. Frühwirth,<sup>2,b</sup> V. M. Ghete,<sup>2</sup> J. Hrubec,<sup>2</sup> M. Jeitler,<sup>2,b</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> N. Rad,<sup>2</sup> H. Rohringer,<sup>2</sup> J. Schieck,<sup>2,b</sup> R. Schöffbeck,<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. Chekhovsky,<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. Lontkovskyi,<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> N. Postiau,<sup>6</sup> E. Starling,<sup>6</sup> L. Thomas,<sup>6</sup> C. Vander Velde,<sup>6</sup> P. Vanlaer,<sup>6</sup> D. Vannerom,<sup>6</sup> Q. Wang,<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> B. Vermassen,<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> P. David,<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> A. Saggio,<sup>8</sup> M. Vidal Marono,<sup>8</sup> S. Wertz,<sup>8</sup> J. Zobec,<sup>8</sup> F. L. Alves,<sup>9</sup> G. A. Alves,<sup>9</sup> L. Brito,<sup>9</sup> M. Correa Martins Junior,<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> C. De Oliveira Martins,<sup>10</sup> S. Fonseca De Souza,<sup>10</sup> H. Malbouisson,<sup>10</sup> D. Matos Figueiredo,<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> W. L. Prado Da Silva,<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> L. Calligaris,<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> 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,g</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> A. Levin,<sup>16</sup> J. Li,<sup>16</sup> L. Li,<sup>16</sup> Q. Li,<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> 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> 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,h</sup> T. Susa,<sup>21</sup> M. W. Ather,<sup>22</sup> A. Attikis,<sup>22</sup> M. Kolosova,<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,i</sup> M. Finger Jr.,<sup>23,i</sup> E. Ayala,<sup>24</sup> E. Carrera Jarrin,<sup>25</sup> H. Abdalla,<sup>26,j</sup> A. A. Abdelalim,<sup>26,k,l</sup> A. Mohamed,<sup>26,l</sup> S. Bhowmik,<sup>27</sup> A. Carvalho Antunes De Oliveira,<sup>27</sup> R. K. Dewanjee,<sup>27</sup> K. Ehataht,<sup>27</sup> M. Kadastik,<sup>27</sup> M. Raidal,<sup>27</sup> C. Veelken,<sup>27</sup> P. Eerola,<sup>28</sup> H. Kirschenmann,<sup>28</sup> J. Pekkanen,<sup>28</sup> M. Voutilainen,<sup>28</sup> J. Havukainen,<sup>29</sup> J. K. Heikkilä,<sup>29</sup> T. Järvinen,<sup>29</sup> V. Karimäki,<sup>29</sup> R. Kinnunen,<sup>29</sup> T. Lampén,<sup>29</sup> K. Lassila-Perini,<sup>29</sup> S. Laurila,<sup>29</sup> S. Lehti,<sup>29</sup> T. Lindén,<sup>29</sup> P. Luukka,<sup>29</sup> T. Mäenpää,<sup>29</sup> H. Siikonen,<sup>29</sup> E. Tuominen,<sup>29</sup> J. Tuominiemi,<sup>29</sup> T. Tuuva,<sup>30</sup> M. Besancon,<sup>31</sup> F. Couderc,<sup>31</sup> M. Dejardin,<sup>31</sup> D. Denegri,<sup>31</sup> J. L. Faure,<sup>31</sup> F. Ferri,<sup>31</sup> S. Ganjour,<sup>31</sup> A. Givernaud,<sup>31</sup> P. Gras,<sup>31</sup> G. Hamel de Monchenault,<sup>31</sup> P. Jarry,<sup>31</sup> C. Leloup,<sup>31</sup> E. Locci,<sup>31</sup> J. Malcles,<sup>31</sup> G. Negro,<sup>31</sup> J. Rander,<sup>31</sup> A. Rosowsky,<sup>31</sup> M. Ö. Sahin,<sup>31</sup> M. Titov,<sup>31</sup> A. Abdulsalam,<sup>32,m</sup> C. Amendola,<sup>32</sup> I. Antropov,<sup>32</sup> F. Beaudette,<sup>32</sup> P. Busson,<sup>32</sup> C. Charlot,<sup>32</sup> R. Granier de Cassagnac,<sup>32</sup> I. Kucher,<sup>32</sup> A. Lobanov,<sup>32</sup> J. Martin Blanco,<sup>32</sup> M. Nguyen,<sup>32</sup> C. Ochando,<sup>32</sup> G. Ortona,<sup>32</sup> P. Pigard,<sup>32</sup> R. Salerno,<sup>32</sup> J. B. Sauvan,<sup>32</sup> Y. Sirois,<sup>32</sup> A. G. Stahl Leitner,<sup>32</sup> A. Zabi,<sup>32</sup> A. Zghiche,<sup>32</sup> J.-L. Agram,<sup>33,n</sup> J. Andrea,<sup>33</sup> D. Bloch,<sup>33</sup> J.-M. Brom,<sup>33</sup> E. C. Chabert,<sup>33</sup> V. Cherepanov,<sup>33</sup> C. Collard,<sup>33</sup> E. Conte,<sup>33,n</sup> J.-C. Fontaine,<sup>33,n</sup> D. Gelé,<sup>33</sup> U. Goerlach,<sup>33</sup> M. Jansová,<sup>33</sup> A.-C. Le Bihan,<sup>33</sup> N. Tonon,<sup>33</sup> P. Van Hove,<sup>33</sup> S. Gadrat,<sup>34</sup> S. Beauceron,<sup>35</sup> C. Bernet,<sup>35</sup> G. Boudoul,<sup>35</sup> N. Chanon,<sup>35</sup> R. Chierici,<sup>35</sup> D. Contardo,<sup>35</sup> P. Depasse,<sup>35</sup> H. El Mamouni,<sup>35</sup> J. Fay,<sup>35</sup> L. Finco,<sup>35</sup> S. Gascon,<sup>35</sup> M. Gouzevitch,<sup>35</sup> G. Grenier,<sup>35</sup> B. Ille,<sup>35</sup> F. Lagarde,<sup>35</sup> I. B. Laktineh,<sup>35</sup> H. Lattaud,<sup>35</sup> M. Lethuillier,<sup>35</sup> L. Mirabito,<sup>35</sup> A. L. Pequegot,<sup>35</sup> S. Perries,<sup>35</sup> A. Popov,<sup>35,o</sup> V. Sordini,<sup>35</sup> M. Vander Donckt,<sup>35</sup> S. Viret,<sup>35</sup> S. Zhang,<sup>35</sup> A. Khvedelidze,<sup>36,i</sup> Z. Tsamalaidze,<sup>37,i</sup> C. Autermann,<sup>38</sup> L. Feld,<sup>38</sup> M. K. Kiesel,<sup>38</sup> K. Klein,<sup>38</sup> M. Lipinski,<sup>38</sup> M. Preuten,<sup>38</sup> M. P. Rauch,<sup>38</sup> C. Schomakers,<sup>38</sup> J. Schulz,<sup>38</sup> M. Teroerde,<sup>38</sup> B. Wittmer,<sup>38</sup> V. Zhukov,<sup>38,o</sup> A. Albert,<sup>39</sup> D. Duchardt,<sup>39</sup> M. Endres,<sup>39</sup> M. Erdmann,<sup>39</sup> T. Esch,<sup>39</sup> R. Fischer,<sup>39</sup> S. Ghosh,<sup>39</sup> A. Güth,<sup>39</sup> T. Hebbeker,<sup>39</sup> C. Heidemann,<sup>39</sup> K. Hoepfner,<sup>39</sup> H. Keller,<sup>39</sup> S. Knutzen,<sup>39</sup> L. Mastrolorenzo,<sup>39</sup> M. Merschmeyer,<sup>39</sup> A. Meyer,<sup>39</sup> P. Millet,<sup>39</sup> S. Mukherjee,<sup>39</sup> T. Pook,<sup>39</sup> M. Radziej,<sup>39</sup> Y. Rath,<sup>39</sup> H. Reithler,<sup>39</sup> M. Rieger,<sup>39</sup> F. Scheuch,<sup>39</sup> A. Schmidt,<sup>39</sup> D. Teyssier,<sup>39</sup> G. Flügge,<sup>40</sup> O. Hlushchenko,<sup>40</sup> T. Kress,<sup>40</sup> A. Künsken,<sup>40</sup> T. Müller,<sup>40</sup> A. Nehr Korn,<sup>40</sup> A. Nowack,<sup>40</sup> C. Pistone,<sup>40</sup> O. Pooth,<sup>40</sup> D. Roy,<sup>40</sup> H. Sert,<sup>40</sup> A. Stahl,<sup>40,p</sup> M. Aldaya Martin,<sup>41</sup> T. Arndt,<sup>41</sup> C. Asawatangtrakuldee,<sup>41</sup> I. Babounikau,<sup>41</sup> K. Beernaert,<sup>41</sup> O. Behnke,<sup>41</sup> U. Behrens,<sup>41</sup> A. Bermúdez Martínez,<sup>41</sup> D. Bertsche,<sup>41</sup> A. A. Bin Anuar,<sup>41</sup> K. Borras,<sup>41,q</sup> V. Botta,<sup>41</sup> A. Campbell,<sup>41</sup> P. Connor,<sup>41</sup> C. Contreras-Campana,<sup>41</sup> F. Costanza,<sup>41</sup> V. Danilov,<sup>41</sup> A. De Wit,<sup>41</sup> M. M. Defranichis,<sup>41</sup> C. Diez Pardos,<sup>41</sup> D. Domínguez Damiani,<sup>41</sup> G. Eckerlin,<sup>41</sup> T. Eichhorn,<sup>41</sup> A. Elwood,<sup>41</sup> E. Eren,<sup>41</sup> E. Gallo,<sup>41,r</sup> A. Geiser,<sup>41</sup> J. M. Grados Luyando,<sup>41</sup> A. Grohsjean,<sup>41</sup> P. Gunnellini,<sup>41</sup> M. Guthoff,<sup>41</sup> M. Haranko,<sup>41</sup> A. Harb,<sup>41</sup> J. Hauk,<sup>41</sup> H. Jung,<sup>41</sup> M. Kasemann,<sup>41</sup> J. Keaveney,<sup>41</sup> C. Kleinwort,<sup>41</sup> J. Knolle,<sup>41</sup> D. Krücker,<sup>41</sup> W. Lange,<sup>41</sup> A. Lelek,<sup>41</sup> T. Lenz,<sup>41</sup> K. Lipka,<sup>41</sup> W. Lohmann,<sup>41,s</sup> R. Mankel,<sup>41</sup> I.-A. Melzer-Pellmann,<sup>41</sup> A. B. Meyer,<sup>41</sup> M. Meyer,<sup>41</sup> M. Missiroli,<sup>41</sup> G. Mittag,<sup>41</sup> J. Mnich,<sup>41</sup> V. Myronenko,<sup>41</sup> S. K. Pflitsch,<sup>41</sup> D. Pitzl,<sup>41</sup> A. Raspereza,<sup>41</sup> A. Saibel,<sup>41</sup> M. Savitskyi,<sup>41</sup> P. Saxena,<sup>41</sup> P. Schütze,<sup>41</sup> C. Schwanenberger,<sup>41</sup> R. Shevchenko,<sup>41</sup> A. Singh,<sup>41</sup> H. Tholen,<sup>41</sup> O. Turkot,<sup>41</sup> A. Vagnerini,<sup>41</sup> G. P. Van Onsem,<sup>41</sup> R. Walsh,<sup>41</sup> Y. Wen,<sup>41</sup> K. Wichmann,<sup>41</sup> C. Wissing,<sup>41</sup> O. Zenaiev,<sup>41</sup> R. Aggleton,<sup>42</sup> S. Bein,<sup>42</sup> L. Benato,<sup>42</sup> A. Benecke,<sup>42</sup> V. Blobel,<sup>42</sup> M. Centis Vignali,<sup>42</sup> T. Dreyer,<sup>42</sup> E. Garutti,<sup>42</sup> D. Gonzalez,<sup>42</sup> J. Haller,<sup>42</sup> A. Hinzmann,<sup>42</sup> A. Karavdina,<sup>42</sup> G. Kasieczka,<sup>42</sup> R. Klanner,<sup>42</sup> R. Kogler,<sup>42</sup> N. Kovalchuk,<sup>42</sup> S. Kurz,<sup>42</sup> V. Kutzner,<sup>42</sup> J. Lange,<sup>42</sup> D. Marconi,<sup>42</sup> J. Multhaup,<sup>42</sup> M. Niedziela,<sup>42</sup> D. Nowatschin,<sup>42</sup> A. Perieanu,<sup>42</sup> A. Reimers,<sup>42</sup> O. Rieger,<sup>42</sup> C. Scharf,<sup>42</sup> P. Schleper,<sup>42</sup> S. Schumann,<sup>42</sup> J. Schwandt,<sup>42</sup> J. Sonneveld,<sup>42</sup> H. Stadie,<sup>42</sup> G. Steinbrück,<sup>42</sup> F. M. Stober,<sup>42</sup> M. Stöver,<sup>42</sup> D. Troendle,<sup>42</sup> A. Vanhoefer,<sup>42</sup> B. Vormwald,<sup>42</sup> M. Akbiyik,<sup>43</sup> C. Barth,<sup>43</sup> M. Baselga,<sup>43</sup> S. Baur,<sup>43</sup> E. Butz,<sup>43</sup> R. Caspart,<sup>43</sup> T. Chwalek,<sup>43</sup> F. Colombo,<sup>43</sup>

W. De Boer,<sup>43</sup> A. Dierlamm,<sup>43</sup> K. El Morabit,<sup>43</sup> N. Faltermann,<sup>43</sup> B. Freund,<sup>43</sup> M. Giffels,<sup>43</sup> M. A. Harrendorf,<sup>43</sup> F. Hartmann,<sup>43,p</sup> S. M. Heindl,<sup>43</sup> U. Husemann,<sup>43</sup> F. Kassel,<sup>43,p</sup> I. Katkov,<sup>43,o</sup> P. Keicher,<sup>43</sup> S. Kudella,<sup>43</sup> H. Mildner,<sup>43</sup> S. Mitra,<sup>43</sup> M. U. Mozer,<sup>43</sup> Th. Müller,<sup>43</sup> M. Plagge,<sup>43</sup> G. Quast,<sup>43</sup> K. Rabbertz,<sup>43</sup> M. Schröder,<sup>43</sup> I. Shvetsov,<sup>43</sup> G. Sieber,<sup>43</sup> H. J. Simonis,<sup>43</sup> R. Ulrich,<sup>43</sup> S. Wayand,<sup>43</sup> M. Waßmer,<sup>43</sup> M. Weber,<sup>43</sup> T. Weiler,<sup>43</sup> S. Williamson,<sup>43</sup> C. Wöhrmann,<sup>43</sup> R. Wolf,<sup>43</sup> G. Anagnostou,<sup>44</sup> G. Daskalakis,<sup>44</sup> T. Gerialis,<sup>44</sup> A. Kyriakis,<sup>44</sup> D. Loukas,<sup>44</sup> G. Paspalaki,<sup>44</sup> I. Topsis-Giotis,<sup>44</sup> G. Karathanasis,<sup>45</sup> S. Kesisoglou,<sup>45</sup> P. Kontaxakis,<sup>45</sup> A. Panagiotou,<sup>45</sup> I. Papavergou,<sup>45</sup> N. Saoulidou,<sup>45</sup> E. Tziaferi,<sup>45</sup> K. Vellidis,<sup>45</sup> K. Kousouris,<sup>46</sup> I. Papakrivopoulos,<sup>46</sup> G. Tsiopolitis,<sup>46</sup> I. Evangelou,<sup>47</sup> C. Foudas,<sup>47</sup> P. Gianneios,<sup>47</sup> P. Katsoulis,<sup>47</sup> P. Kokkas,<sup>47</sup> S. Mallios,<sup>47</sup> N. Manthos,<sup>47</sup> I. Papadopoulos,<sup>47</sup> E. Paradis,<sup>47</sup> J. Strologas,<sup>47</sup> F. A. Triantis,<sup>47</sup> D. Tsitsonis,<sup>47</sup> M. Bartók,<sup>48,t</sup> M. Csanad,<sup>48</sup> N. Filipovic,<sup>48</sup> P. Major,<sup>48</sup> M. I. Nagy,<sup>48</sup> G. Pasztor,<sup>48</sup> O. Surányi,<sup>48</sup> G. I. Veres,<sup>48</sup> G. Bencze,<sup>49</sup> C. Hajdu,<sup>49</sup> D. Horvath,<sup>49,u</sup> Á. Hunyadi,<sup>49</sup> F. Sikler,<sup>49</sup> V. Veszpremi,<sup>49</sup> G. Vesztergombi,<sup>49,a</sup> T. Á. Vámi,<sup>49</sup> N. Beni,<sup>50</sup> S. Czellar,<sup>50</sup> J. Karancsi,<sup>50,v</sup> A. Makovec,<sup>50</sup> J. Molnar,<sup>50</sup> Z. Szillasi,<sup>50</sup> P. Raics,<sup>51</sup> Z. L. Trocsanyi,<sup>51</sup> B. Ujvari,<sup>51</sup> S. Choudhury,<sup>52</sup> J. R. Komaragiri,<sup>52</sup> P. C. Tiwari,<sup>52</sup> S. Bahinipati,<sup>53,w</sup> C. Kar,<sup>53</sup> P. Mal,<sup>53</sup> K. Mandal,<sup>53</sup> A. Nayak,<sup>53,x</sup> D. K. Sahoo,<sup>53,w</sup> S. K. Swain,<sup>53</sup> S. Bansal,<sup>54</sup> S. B. Beri,<sup>54</sup> V. Bhatnagar,<sup>54</sup> S. Chauhan,<sup>54</sup> R. Chawla,<sup>54</sup> N. Dhingra,<sup>54</sup> R. Gupta,<sup>54</sup> A. Kaur,<sup>54</sup> A. Kaur,<sup>54</sup> M. Kaur,<sup>54</sup> S. Kaur,<sup>54</sup> R. Kumar,<sup>54</sup> P. Kumari,<sup>54</sup> M. Lohan,<sup>54</sup> A. Mehta,<sup>54</sup> K. Sandeep,<sup>54</sup> S. Sharma,<sup>54</sup> J. B. Singh,<sup>54</sup> G. Walia,<sup>54</sup> Ashok Kumar,<sup>55</sup> Aashaq Shah,<sup>55</sup> A. Bhardwaj,<sup>55</sup> B. C. Choudhary,<sup>55</sup> R. B. Garg,<sup>55</sup> M. Gola,<sup>55</sup> S. Keshri,<sup>55</sup> S. Malhotra,<sup>55</sup> M. Naimuddin,<sup>55</sup> P. Priyanka,<sup>55</sup> K. Ranjan,<sup>55</sup> R. Sharma,<sup>55</sup> R. Bhardwaj,<sup>56,y</sup> M. Bharti,<sup>56</sup> R. Bhattacharya,<sup>56</sup> S. Bhattacharya,<sup>56</sup> U. Bhawandeep,<sup>56,y</sup> D. Bhowmik,<sup>56</sup> S. Dey,<sup>56</sup> S. Dutt,<sup>56,y</sup> S. Dutta,<sup>56</sup> S. Ghosh,<sup>56</sup> K. Mondal,<sup>56</sup> S. Nandan,<sup>56</sup> A. Purohit,<sup>56</sup> P. K. Rout,<sup>56</sup> A. Roy,<sup>56</sup> S. Roy Chowdhury,<sup>56</sup> G. Saha,<sup>56</sup> S. Sarkar,<sup>56</sup> M. Sharan,<sup>56</sup> B. Singh,<sup>56</sup> S. Thakur,<sup>56,y</sup> P. K. Behera,<sup>57</sup> R. Chudasama,<sup>58</sup> D. Dutta,<sup>58</sup> V. Jha,<sup>58</sup> V. Kumar,<sup>58</sup> P. K. Netrakanti,<sup>58</sup> L. M. Pant,<sup>58</sup> P. Shukla,<sup>58</sup> Ravindra Kumar Verma,<sup>59</sup> T. Aziz,<sup>59</sup> M. A. Bhat,<sup>59</sup> S. Dugad,<sup>59</sup> G. B. Mohanty,<sup>59</sup> N. Sur,<sup>59</sup> B. Sutar,<sup>59</sup> S. Banerjee,<sup>60</sup> S. Bhattacharya,<sup>60</sup> S. Chatterjee,<sup>60</sup> P. Das,<sup>60</sup> M. Guchait,<sup>60</sup> Sa. Jain,<sup>60</sup> S. Karmakar,<sup>60</sup> S. Kumar,<sup>60</sup> M. Maity,<sup>60,z</sup> G. Majumder,<sup>60</sup> K. Mazumdar,<sup>60</sup> N. Sahoo,<sup>60</sup> T. Sarkar,<sup>60,z</sup> S. Chauhan,<sup>61</sup> S. Dube,<sup>61</sup> V. Hegde,<sup>61</sup> A. Kapoor,<sup>61</sup> K. Kothekar,<sup>61</sup> S. Pandey,<sup>61</sup> A. Rane,<sup>61</sup> S. Sharma,<sup>61</sup> S. Chenarani,<sup>62,aa</sup> E. Eskandari Tadavani,<sup>62</sup> S. M. Etesami,<sup>62,aa</sup> M. Khakzad,<sup>62</sup> M. Mohammadi Najafabadi,<sup>62</sup> M. Naseri,<sup>62</sup> F. Rezaei Hosseinabadi,<sup>62</sup> B. Safarzadeh,<sup>62,bb</sup> M. Zeinali,<sup>62</sup> M. Felcini,<sup>63</sup> M. Grunewald,<sup>63</sup> M. Abbrescia,<sup>64a,64b</sup> C. Calabria,<sup>64a,64b</sup> A. Colaleo,<sup>64a</sup> D. Creanza,<sup>64a,64c</sup> L. Cristella,<sup>64a,64b</sup> N. De Filippis,<sup>64a,64c</sup> M. De Palma,<sup>64a,64b</sup> A. Di Florio,<sup>64a,64b</sup> F. Errico,<sup>64a,64b</sup> L. Fiore,<sup>64a</sup> A. Gelmi,<sup>64a,64b</sup> G. Iaselli,<sup>64a,64c</sup> M. Ince,<sup>64a,64b</sup> S. Lezki,<sup>64a,64b</sup> G. Maggi,<sup>64a,64c</sup> M. Maggi,<sup>64a</sup> G. Miniello,<sup>64a,64b</sup> S. My,<sup>64a,64b</sup> S. Nuzzo,<sup>64a,64b</sup> A. Pompili,<sup>64a,64b</sup> G. Pugliese,<sup>64a,64c</sup> R. Radogna,<sup>64a</sup> A. Ranieri,<sup>64a</sup> G. Selvaggi,<sup>64a,64b</sup> A. Sharma,<sup>64a</sup> L. Silvestris,<sup>64a</sup> R. Venditti,<sup>64a</sup> P. Verwilligen,<sup>64a</sup> G. Zito,<sup>64a</sup> G. Abbiendi,<sup>65a</sup> C. Battilana,<sup>65a,65b</sup> D. Bonacorsi,<sup>65a,65b</sup> L. Borgonovi,<sup>65a,65b</sup> S. Braibant-Giacomelli,<sup>65a,65b</sup> R. Campanini,<sup>65a,65b</sup> P. Capiluppi,<sup>65a,65b</sup> A. Castro,<sup>65a,65b</sup> F. R. Cavallo,<sup>65a</sup> S. S. Chhibra,<sup>65a,65b</sup> C. Ciocca,<sup>65a</sup> G. Codispoti,<sup>65a,65b</sup> M. Cuffiani,<sup>65a,65b</sup> G. M. Dallavalle,<sup>65a</sup> F. Fabbri,<sup>65a</sup> A. Fanfani,<sup>65a,65b</sup> P. Giacomelli,<sup>65a</sup> C. Grandi,<sup>65a</sup> L. Guiducci,<sup>65a,65b</sup> F. Iemmi,<sup>65a,65b</sup> S. Marcellini,<sup>65a</sup> G. Masetti,<sup>65a</sup> A. Montanari,<sup>65a</sup> F. L. Navarra,<sup>65a,65b</sup> A. Perrotta,<sup>65a</sup> F. Primavera,<sup>65a,65b,p</sup> A. M. Rossi,<sup>65a,65b</sup> T. Rovelli,<sup>65a,65b</sup> G. P. Siroli,<sup>65a,65b</sup> N. Tosi,<sup>65a</sup> S. Albergo,<sup>66a,66b</sup> A. Di Mattia,<sup>66a</sup> R. Potenza,<sup>66a,66b</sup> A. Tricoli,<sup>66a,66b</sup> C. Tuve,<sup>66a,66b</sup> G. Barbagli,<sup>67a</sup> K. Chatterjee,<sup>67a,67b</sup> V. Ciulli,<sup>67a,67b</sup> C. Civinini,<sup>67a</sup> R. D'Alessandro,<sup>67a,67b</sup> E. Focardi,<sup>67a,67b</sup> G. Latino,<sup>67a</sup> P. Lenzi,<sup>67a,67b</sup> M. Meschini,<sup>67a</sup> S. Paoletti,<sup>67a</sup> L. Russo,<sup>67a,cc</sup> G. Sguazzoni,<sup>67a</sup> D. Strom,<sup>67a</sup> L. Viliani,<sup>67a</sup> L. Benussi,<sup>68</sup> S. Bianco,<sup>68</sup> F. Fabbri,<sup>68</sup> D. Piccolo,<sup>68</sup> F. Ferro,<sup>69a</sup> F. Ravera,<sup>69a,69b</sup> E. Robutti,<sup>69a</sup> S. Tosi,<sup>69a,69b</sup> A. Benaglia,<sup>70a</sup> A. Beschi,<sup>70b</sup> L. Brianza,<sup>70a,70b</sup> F. Brivio,<sup>70a,70b</sup> V. Ciriolo,<sup>70a,70b,p</sup> S. Di Guida,<sup>70a,p</sup> M. E. Dinardo,<sup>70a,70b</sup> S. Fiorendi,<sup>70a,70b</sup> S. Gennai,<sup>70a</sup> A. Ghezzi,<sup>70a,70b</sup> P. Govoni,<sup>70a,70b</sup> M. Malberti,<sup>70a,70b</sup> S. Malvezzi,<sup>70a</sup> A. Massironi,<sup>70a,70b</sup> D. Menasce,<sup>70a</sup> L. Moroni,<sup>70a</sup> M. Paganoni,<sup>70a,70b</sup> D. Pedrini,<sup>70a</sup> S. Ragazzi,<sup>70a,70b</sup> T. Tabarelli de Fatis,<sup>70a,70b</sup> D. Zuolo,<sup>70a</sup> S. Buontempo,<sup>71a</sup> N. Cavallo,<sup>71a,71c</sup> A. Di Crescenzo,<sup>71a,71b</sup> F. Fabozzi,<sup>71a,71c</sup> F. Fienga,<sup>71a</sup> G. Galati,<sup>71a</sup> A. O. M. Iorio,<sup>71a,71b</sup> W. A. Khan,<sup>71a</sup> L. Lista,<sup>71a</sup> S. Meola,<sup>71a,71d,p</sup> P. Paolucci,<sup>71a,p</sup> C. Sciacca,<sup>71a,71b</sup> E. Voevodina,<sup>71a,71b</sup> P. Azzi,<sup>72a</sup> N. Bacchetta,<sup>72a</sup> D. Bisello,<sup>72a,72b</sup> A. Boletti,<sup>72a,72b</sup> A. Bragagnolo,<sup>72a</sup> R. Carlin,<sup>72a,72b</sup> P. Checchia,<sup>72a</sup> M. Dall'Osso,<sup>72a,72b</sup> P. De Castro Manzano,<sup>72a</sup> T. Dorigo,<sup>72a</sup> F. Fanzago,<sup>72a</sup> U. Gasparini,<sup>72a,72b</sup> A. Gozzelino,<sup>72a</sup> S. Y. Hoh,<sup>72a</sup> S. Lacaprara,<sup>72a</sup> P. Lujan,<sup>72a</sup> M. Margoni,<sup>72a,72b</sup> A. T. Meneguzzo,<sup>72a,72b</sup> J. Pazzini,<sup>72a,72b</sup> N. Pozzobon,<sup>72a,72b</sup> P. Ronchese,<sup>72a,72b</sup> R. Rossin,<sup>72a,72b</sup> F. Simonetto,<sup>72a,72b</sup> A. Tiko,<sup>72a</sup> E. Torassa,<sup>72a</sup> M. Zanetti,<sup>72a,72b</sup> P. Zotto,<sup>72a,72b</sup> G. Zumerle,<sup>72a,72b</sup> A. Braghieri,<sup>73a</sup> A. Magnani,<sup>73a</sup> P. Montagna,<sup>73a,73b</sup> S. P. Ratti,<sup>73a,73b</sup> V. Re,<sup>73a</sup> M. Ressegotti,<sup>73a,73b</sup> C. Riccardi,<sup>73a,73b</sup> P. Salvini,<sup>73a</sup> I. Vai,<sup>73a,73b</sup> P. Vitulo,<sup>73a,73b</sup> L. Alunni Solestizi,<sup>74a,74b</sup> M. Biasini,<sup>74a,74b</sup> G. M. Bilei,<sup>74a</sup> C. Cecchi,<sup>74a,74b</sup> D. Ciangottini,<sup>74a,74b</sup> L. Fanò,<sup>74a,74b</sup> P. Lariccia,<sup>74a,74b</sup> R. Leonardi,<sup>74a,74b</sup> E. Manoni,<sup>74a</sup> G. Mantovani,<sup>74a,74b</sup> V. Mariani,<sup>74a,74b</sup> M. Menichelli,<sup>74a</sup> A. Rossi,<sup>74a,74b</sup> A. Santocchia,<sup>74a,74b</sup> D. Spiga,<sup>74a</sup> K. Androsov,<sup>75a</sup>



P. Azzurri,<sup>75a</sup> G. Bagliesi,<sup>75a</sup> L. Bianchini,<sup>75a</sup> T. Boccali,<sup>75a</sup> L. Borrello,<sup>75a</sup> R. Castaldi,<sup>75a</sup> M. A. Ciocci,<sup>75a,75b</sup> R. Dell'Orso,<sup>75a</sup>  
 G. Fedi,<sup>75a</sup> F. Fiori,<sup>75a,75c</sup> L. Giannini,<sup>75a,75c</sup> A. Giassi,<sup>75a</sup> M. T. Grippo,<sup>75a</sup> F. Ligabue,<sup>75a,75c</sup> E. Manca,<sup>75a,75c</sup>  
 G. Mandorli,<sup>75a,75c</sup> A. Messineo,<sup>75a,75b</sup> F. Palla,<sup>75a</sup> A. Rizzi,<sup>75a,75b</sup> P. Spagnolo,<sup>75a</sup> R. Tenchini,<sup>75a</sup> G. Tonelli,<sup>75a,75b</sup>  
 A. Venturi,<sup>75a</sup> P. G. Verdini,<sup>75a</sup> L. Barone,<sup>76a,76b</sup> F. Cavallari,<sup>76a</sup> M. Cipriani,<sup>76a,76b</sup> N. Daci,<sup>76a</sup> D. Del Re,<sup>76a,76b</sup>  
 E. Di Marco,<sup>76a,76b</sup> M. Diemoz,<sup>76a</sup> S. Gelli,<sup>76a,76b</sup> E. Longo,<sup>76a,76b</sup> B. Marzocchi,<sup>76a,76b</sup> P. Meridiani,<sup>76a</sup> G. Organtini,<sup>76a,76b</sup>  
 F. Pandolfi,<sup>76a</sup> R. Paramatti,<sup>76a,76b</sup> F. Preiato,<sup>76a,76b</sup> S. Rahatlou,<sup>76a,76b</sup> C. Rovelli,<sup>76a</sup> F. Santanastasio,<sup>76a,76b</sup> N. Amapane,<sup>77a,77b</sup>  
 R. Arcidiacono,<sup>77a,77c</sup> S. Argiro,<sup>77a,77b</sup> M. Arneodo,<sup>77a,77c</sup> N. Bartosik,<sup>77a</sup> R. Bellan,<sup>77a,77b</sup> C. Biino,<sup>77a</sup> N. Cartiglia,<sup>77a</sup>  
 F. Cenna,<sup>77a,77b</sup> S. Cometti,<sup>77a</sup> M. Costa,<sup>77a,77b</sup> R. Covarelli,<sup>77a,77b</sup> N. Demaria,<sup>77a</sup> B. Kiani,<sup>77a,77b</sup> C. Mariotti,<sup>77a</sup> S. Maselli,<sup>77a</sup>  
 E. Migliore,<sup>77a,77b</sup> V. Monaco,<sup>77a,77b</sup> E. Monteil,<sup>77a,77b</sup> M. Monteno,<sup>77a</sup> M. M. Obertino,<sup>77a,77b</sup> L. Pacher,<sup>77a,77b</sup> N. Pastrone,<sup>77a</sup>  
 M. Pelliccioni,<sup>77a</sup> G. L. Pinna Angioni,<sup>77a,77b</sup> A. Romero,<sup>77a,77b</sup> M. Ruspa,<sup>77a,77c</sup> R. Sacchi,<sup>77a,77b</sup> K. Shchelina,<sup>77a,77b</sup>  
 V. Sola,<sup>77a</sup> A. Solano,<sup>77a,77b</sup> D. Soldi,<sup>77a</sup> A. Staiano,<sup>77a</sup> S. Belforte,<sup>78a</sup> V. Candelise,<sup>78a,78b</sup> M. Casarsa,<sup>78a</sup> F. Cossutti,<sup>78a</sup>  
 G. Della Ricca,<sup>78a,78b</sup> F. Vazzoler,<sup>78a,78b</sup> A. Zanetti,<sup>78a</sup> D. H. Kim,<sup>79</sup> G. N. Kim,<sup>79</sup> M. S. Kim,<sup>79</sup> J. Lee,<sup>79</sup> S. Lee,<sup>79</sup> S. W. Lee,<sup>79</sup>  
 C. S. Moon,<sup>79</sup> Y. D. Oh,<sup>79</sup> S. Sekmen,<sup>79</sup> D. C. Son,<sup>79</sup> Y. C. Yang,<sup>79</sup> H. Kim,<sup>80</sup> D. H. Moon,<sup>80</sup> G. Oh,<sup>80</sup> J. Goh,<sup>81,dd</sup> T. J. Kim,<sup>81</sup>  
 S. Cho,<sup>82</sup> S. Choi,<sup>82</sup> Y. Go,<sup>82</sup> D. Gyun,<sup>82</sup> S. Ha,<sup>82</sup> B. Hong,<sup>82</sup> Y. Jo,<sup>82</sup> K. Lee,<sup>82</sup> K. S. Lee,<sup>82</sup> S. Lee,<sup>82</sup> J. Lim,<sup>82</sup> S. K. Park,<sup>82</sup>  
 Y. Roh,<sup>82</sup> H. S. Kim,<sup>83</sup> J. Almond,<sup>84</sup> J. Kim,<sup>84</sup> J. S. Kim,<sup>84</sup> H. Lee,<sup>84</sup> K. Lee,<sup>84</sup> K. Nam,<sup>84</sup> S. B. Oh,<sup>84</sup> B. C. Radburn-Smith,<sup>84</sup>  
 S. h. Seo,<sup>84</sup> U. K. Yang,<sup>84</sup> H. D. Yoo,<sup>84</sup> G. B. Yu,<sup>84</sup> D. Jeon,<sup>85</sup> H. Kim,<sup>85</sup> J. H. Kim,<sup>85</sup> J. S. H. Lee,<sup>85</sup> I. C. Park,<sup>85</sup> Y. Choi,<sup>86</sup>  
 C. Hwang,<sup>86</sup> J. Lee,<sup>86</sup> I. Yu,<sup>86</sup> V. Dudenias,<sup>87</sup> A. Juodagalvis,<sup>87</sup> J. Vaitkus,<sup>87</sup> I. Ahmed,<sup>88</sup> Z. A. Ibrahim,<sup>88</sup>  
 M. A. B. Md Ali,<sup>88,ee</sup> F. Mohamad Idris,<sup>88,ff</sup> W. A. T. Wan Abdullah,<sup>88</sup> M. N. Yusli,<sup>88</sup> Z. Zolkapli,<sup>88</sup>  
 A. Castaneda Hernandez,<sup>89</sup> J. A. Murillo Quijada,<sup>89</sup> R. Reyes-Almanza,<sup>90</sup> G. Ramirez-Sanchez,<sup>90</sup> M. C. Duran-Osuna,<sup>90</sup>  
 H. Castilla-Valdez,<sup>90</sup> E. De La Cruz-Burelo,<sup>90</sup> I. Heredia-De La Cruz,<sup>90,gg</sup> R. I. Rabadan-Trejo,<sup>90</sup> R. Lopez-Fernandez,<sup>90</sup>  
 J. Mejia Guisao,<sup>90</sup> M. Ramirez-Garcia,<sup>90</sup> A. Sanchez-Hernandez,<sup>90</sup> S. Carrillo Moreno,<sup>91</sup> C. Oropeza Barrera,<sup>91</sup>  
 F. Vazquez Valencia,<sup>91</sup> J. Eysermans,<sup>92</sup> I. Pedraza,<sup>92</sup> H. A. Salazar Ibarquen,<sup>92</sup> C. Uribe Estrada,<sup>92</sup> A. Morelos Pineda,<sup>93</sup>  
 D. Krofcheck,<sup>94</sup> S. Bheesette,<sup>95</sup> P. H. Butler,<sup>95</sup> A. Ahmad,<sup>96</sup> M. Ahmad,<sup>96</sup> M. I. Asghar,<sup>96</sup> Q. Hassan,<sup>96</sup> H. R. Hoorani,<sup>96</sup>  
 A. Saddique,<sup>96</sup> M. A. Shah,<sup>96</sup> M. Shoaib,<sup>96</sup> M. Waqas,<sup>96</sup> H. Bialkowska,<sup>97</sup> M. Bluj,<sup>97</sup> B. Boimska,<sup>97</sup> T. Frueboes,<sup>97</sup>  
 M. Górski,<sup>97</sup> M. Kazana,<sup>97</sup> K. Nawrocki,<sup>97</sup> M. Szleper,<sup>97</sup> P. Traczyk,<sup>97</sup> P. Zalewski,<sup>97</sup> K. Bunkowski,<sup>98</sup> A. Byszuk,<sup>98,hh</sup>  
 K. Doroba,<sup>98</sup> A. Kalinowski,<sup>98</sup> M. Konecki,<sup>98</sup> J. Krolikowski,<sup>98</sup> M. Misiura,<sup>98</sup> M. Olszewski,<sup>98</sup> A. Pyskir,<sup>98</sup> M. Walczak,<sup>98</sup>  
 M. Araujo,<sup>99</sup> P. Bargassa,<sup>99</sup> C. Beirão Da Cruz E Silva,<sup>99</sup> A. Di Francesco,<sup>99</sup> P. Faccioli,<sup>99</sup> B. Galinhas,<sup>99</sup> M. Gallinaro,<sup>99</sup>  
 J. Hollar,<sup>99</sup> N. Leonardo,<sup>99</sup> M. V. Nemallapudi,<sup>99</sup> J. Seixas,<sup>99</sup> G. Strong,<sup>99</sup> O. Toldaiev,<sup>99</sup> D. Vadrucchio,<sup>99</sup> J. Varela,<sup>99</sup>  
 S. Afanasiev,<sup>100</sup> V. Alexakhin,<sup>100</sup> P. Bunin,<sup>100</sup> M. Gavrilenko,<sup>100</sup> A. Golunov,<sup>100</sup> I. Golutvin,<sup>100</sup> N. Gorbounov,<sup>100</sup>  
 V. Karjavin,<sup>100</sup> A. Lanev,<sup>100</sup> A. Malakhov,<sup>100</sup> V. Matveev,<sup>100,ii,jj</sup> P. Moisenz,<sup>100</sup> V. Palichik,<sup>100</sup> V. Perelygin,<sup>100</sup> M. Savina,<sup>100</sup>  
 S. Shmatov,<sup>100</sup> V. Smirnov,<sup>100</sup> N. Voytishin,<sup>100</sup> A. Zarubin,<sup>100</sup> V. Golovtsov,<sup>101</sup> Y. Ivanov,<sup>101</sup> V. Kim,<sup>101,kk</sup> E. Kuznetsova,<sup>101,ll</sup>  
 P. Levchenko,<sup>101</sup> V. Murzin,<sup>101</sup> V. Oreshkin,<sup>101</sup> I. Smirnov,<sup>101</sup> D. Sosnov,<sup>101</sup> V. Sulimov,<sup>101</sup> L. Uvarov,<sup>101</sup> S. Vavilov,<sup>101</sup>  
 A. Vorobyev,<sup>101</sup> Yu. Andreev,<sup>102</sup> A. Dermenev,<sup>102</sup> S. Gninenko,<sup>102</sup> N. Golubev,<sup>102</sup> A. Karneyeu,<sup>102</sup> M. Kirsanov,<sup>102</sup>  
 N. Krasnikov,<sup>102</sup> A. Pashenkov,<sup>102</sup> D. Tlisov,<sup>102</sup> A. Toropin,<sup>102</sup> V. Epshteyn,<sup>103</sup> V. Gavrilov,<sup>103</sup> N. Lychkovskaya,<sup>103</sup>  
 V. Popov,<sup>103</sup> I. Pozdnyakov,<sup>103</sup> G. Safronov,<sup>103</sup> A. Spiridonov,<sup>103</sup> A. Stepenov,<sup>103</sup> V. Stolin,<sup>103</sup> M. Toms,<sup>103</sup> E. Vlasov,<sup>103</sup>  
 A. Zhokin,<sup>103</sup> T. Aushev,<sup>104</sup> R. Chistov,<sup>105,mm</sup> M. Danilov,<sup>105,mm</sup> P. Parygin,<sup>105</sup> D. Philippov,<sup>105</sup> S. Polikarpov,<sup>105,mm</sup>  
 E. Tarkovskii,<sup>105</sup> V. Andreev,<sup>106</sup> M. Azarkin,<sup>106,jj</sup> I. Dremin,<sup>106,jj</sup> M. Kirakosyan,<sup>106,jj</sup> S. V. Rusakov,<sup>106</sup> A. Terkulov,<sup>106</sup>  
 A. Baskakov,<sup>107</sup> A. Belyaev,<sup>107</sup> E. Boos,<sup>107</sup> V. Bunichev,<sup>107</sup> M. Dubinin,<sup>107,nn</sup> L. Dudko,<sup>107</sup> V. Klyukhin,<sup>107</sup> O. Kodolova,<sup>107</sup>  
 N. Korneeva,<sup>107</sup> I. Lokhtin,<sup>107</sup> I. Miagkov,<sup>107</sup> S. Obraztsov,<sup>107</sup> M. Perfilov,<sup>107</sup> V. Savrin,<sup>107</sup> P. Volkov,<sup>107</sup> V. Blinov,<sup>108,oo</sup>  
 T. Dimova,<sup>108,oo</sup> L. Kardapoltsev,<sup>108,oo</sup> D. Shtol,<sup>108,oo</sup> Y. Skovpen,<sup>108,oo</sup> I. Azhgirey,<sup>109</sup> I. Bayshev,<sup>109</sup> S. Bitioukov,<sup>109</sup>  
 D. Elumakhov,<sup>109</sup> A. Godizov,<sup>109</sup> V. Kachanov,<sup>109</sup> A. Kalinin,<sup>109</sup> D. Konstantinov,<sup>109</sup> P. Mandrik,<sup>109</sup> V. Petrov,<sup>109</sup>  
 R. Ryutin,<sup>109</sup> S. Slabospitskii,<sup>109</sup> A. Sobol,<sup>109</sup> S. Troshin,<sup>109</sup> N. Tyurin,<sup>109</sup> A. Uzunian,<sup>109</sup> A. Volkov,<sup>109</sup> A. Babaev,<sup>110</sup>  
 S. Baidali,<sup>110</sup> V. Okhotnikov,<sup>110</sup> P. Adzic,<sup>111,pp</sup> P. Cirkovic,<sup>111</sup> D. Devetak,<sup>111</sup> M. Dordevic,<sup>111</sup> J. Milosevic,<sup>111</sup>  
 J. Alcaraz Maestre,<sup>112</sup> I. Bachiller,<sup>112</sup> M. Barrio Luna,<sup>112</sup> J. A. Brochero Cifuentes,<sup>112</sup> M. Cerrada,<sup>112</sup> N. Colino,<sup>112</sup>  
 B. De La Cruz,<sup>112</sup> A. Delgado Peris,<sup>112</sup> C. Fernandez Bedoya,<sup>112</sup> J. P. Fernández Ramos,<sup>112</sup> J. Flix,<sup>112</sup> M. C. Fouz,<sup>112</sup>  
 O. Gonzalez Lopez,<sup>112</sup> S. Goy Lopez,<sup>112</sup> J. M. Hernandez,<sup>112</sup> M. I. Josa,<sup>112</sup> D. Moran,<sup>112</sup> A. Pérez-Calero Yzquierdo,<sup>112</sup>  
 J. Puerta Pelayo,<sup>112</sup> I. Redondo,<sup>112</sup> L. Romero,<sup>112</sup> M. S. Soares,<sup>112</sup> A. Triossi,<sup>112</sup> A. Álvarez Fernández,<sup>112</sup> C. Albajar,<sup>113</sup>  
 J. F. de Trocóniz,<sup>113</sup> J. Cuevas,<sup>114</sup> C. Erice,<sup>114</sup> J. Fernandez Menendez,<sup>114</sup> S. Folgueras,<sup>114</sup> I. Gonzalez Caballero,<sup>114</sup>  
 J. R. González Fernández,<sup>114</sup> E. Palencia Cortezon,<sup>114</sup> V. Rodríguez Bouza,<sup>114</sup> S. Sanchez Cruz,<sup>114</sup> P. Vischia,<sup>114</sup>

J. M. Vizan Garcia,<sup>114</sup> I. J. Cabrillo,<sup>115</sup> A. Calderon,<sup>115</sup> B. Chazin Quero,<sup>115</sup> J. Duarte Campderros,<sup>115</sup> M. Fernandez,<sup>115</sup> P. J. Fernández Manteca,<sup>115</sup> J. Garcia-Ferrero,<sup>115</sup> A. García Alonso,<sup>115</sup> G. Gomez,<sup>115</sup> A. Lopez Virto,<sup>115</sup> J. Marco,<sup>115</sup> C. Martinez Rivero,<sup>115</sup> P. Martinez Ruiz del Arbol,<sup>115</sup> F. Matorras,<sup>115</sup> J. Piedra Gomez,<sup>115</sup> C. Prieels,<sup>115</sup> T. Rodrigo,<sup>115</sup> A. Ruiz-Jimeno,<sup>115</sup> L. Scodellaro,<sup>115</sup> N. Trevisani,<sup>115</sup> I. Vila,<sup>115</sup> R. Vilar Cortabitarte,<sup>115</sup> D. Abbaneo,<sup>116</sup> B. Akgun,<sup>116</sup> E. Auffray,<sup>116</sup> P. Baillon,<sup>116</sup> A. H. Ball,<sup>116</sup> D. Barney,<sup>116</sup> J. Bendavid,<sup>116</sup> M. Bianco,<sup>116</sup> A. Bocci,<sup>116</sup> C. Botta,<sup>116</sup> E. Brondolin,<sup>116</sup> T. Camporesi,<sup>116</sup> M. Cepeda,<sup>116</sup> G. Cerminara,<sup>116</sup> E. Chapon,<sup>116</sup> Y. Chen,<sup>116</sup> G. Cucciati,<sup>116</sup> D. d'Enterria,<sup>116</sup> A. Dabrowski,<sup>116</sup> V. Daponte,<sup>116</sup> A. David,<sup>116</sup> A. De Roeck,<sup>116</sup> N. Deelen,<sup>116</sup> M. Dobson,<sup>116</sup> M. Dünser,<sup>116</sup> N. Dupont,<sup>116</sup> A. Elliott-Peisert,<sup>116</sup> P. Everaerts,<sup>116</sup> F. Fallavollita,<sup>116,qq</sup> D. Fasanella,<sup>116</sup> G. Franzoni,<sup>116</sup> J. Fulcher,<sup>116</sup> W. Funk,<sup>116</sup> D. Gigi,<sup>116</sup> A. Gilbert,<sup>116</sup> K. Gill,<sup>116</sup> F. Glege,<sup>116</sup> M. Guilbaud,<sup>116</sup> D. Gulhan,<sup>116</sup> J. Hegeman,<sup>116</sup> V. Innocente,<sup>116</sup> A. Jafari,<sup>116</sup> P. Janot,<sup>116</sup> O. Karacheban,<sup>116,s</sup> J. Kieseler,<sup>116</sup> A. Kornmayer,<sup>116</sup> M. Kramer,<sup>116,b</sup> C. Lange,<sup>116</sup> P. Lecoq,<sup>116</sup> C. Lourenço,<sup>116</sup> L. Malgeri,<sup>116</sup> M. Mannelli,<sup>116</sup> F. Meijers,<sup>116</sup> J. A. Merlin,<sup>116</sup> S. Mersi,<sup>116</sup> E. Meschi,<sup>116</sup> P. Milenovic,<sup>116,rr</sup> F. Moortgat,<sup>116</sup> M. Mulders,<sup>116</sup> J. Ngadiuba,<sup>116</sup> S. Orfanelli,<sup>116</sup> L. Orsini,<sup>116</sup> F. Pantaleo,<sup>116,p</sup> L. Pape,<sup>116</sup> E. Perez,<sup>116</sup> M. Peruzzi,<sup>116</sup> A. Petrilli,<sup>116</sup> G. Petrucciani,<sup>116</sup> A. Pfeiffer,<sup>116</sup> M. Pierini,<sup>116</sup> F. M. Pitters,<sup>116</sup> D. Rabady,<sup>116</sup> A. Racz,<sup>116</sup> T. Reis,<sup>116</sup> G. Rolandi,<sup>116,ss</sup> M. Rovere,<sup>116</sup> H. Sakulin,<sup>116</sup> C. Schäfer,<sup>116</sup> C. Schwick,<sup>116</sup> M. Seidel,<sup>116</sup> M. Selvaggi,<sup>116</sup> A. Sharma,<sup>116</sup> P. Silva,<sup>116</sup> P. Sphicas,<sup>116,t</sup> A. Stakia,<sup>116</sup> J. Steggemann,<sup>116</sup> M. Tosi,<sup>116</sup> D. Treille,<sup>116</sup> A. Tsirova,<sup>116</sup> V. Veckalns,<sup>116,uu</sup> W. D. Zeuner,<sup>116</sup> L. Caminada,<sup>117,vv</sup> K. Deiters,<sup>117</sup> W. Erdmann,<sup>117</sup> R. Horisberger,<sup>117</sup> Q. Ingram,<sup>117</sup> H. C. Kaestli,<sup>117</sup> D. Kotlinski,<sup>117</sup> U. Langenegger,<sup>117</sup> T. Rohe,<sup>117</sup> S. A. Wiederkehr,<sup>117</sup> M. Backhaus,<sup>118</sup> L. Bäni,<sup>118</sup> P. Berger,<sup>118</sup> N. Chernyavskaya,<sup>118</sup> G. Dissertori,<sup>118</sup> M. Dittmar,<sup>118</sup> M. Donegà,<sup>118</sup> C. Dorfer,<sup>118</sup> C. Grab,<sup>118</sup> C. Heidegger,<sup>118</sup> D. Hits,<sup>118</sup> J. Hoss,<sup>118</sup> T. Klijnsma,<sup>118</sup> W. Lustermann,<sup>118</sup> R. A. Manzoni,<sup>118</sup> M. Marionneau,<sup>118</sup> M. T. Meinhard,<sup>118</sup> F. Micheli,<sup>118</sup> P. Musella,<sup>118</sup> F. Nessi-Tedaldi,<sup>118</sup> J. Pata,<sup>118</sup> F. Pauss,<sup>118</sup> G. Perrin,<sup>118</sup> L. Perrozzi,<sup>118</sup> S. Pigazzini,<sup>118</sup> M. Quittnat,<sup>118</sup> D. Ruini,<sup>118</sup> D. A. Sanz Becerra,<sup>118</sup> M. Schönenberger,<sup>118</sup> L. Shchutska,<sup>118</sup> V. R. Tavolaro,<sup>118</sup> K. Theofilatos,<sup>118</sup> M. L. Vesterbacka Olsson,<sup>118</sup> R. Wallny,<sup>118</sup> D. H. Zhu,<sup>118</sup> T. K. Aarrestad,<sup>119</sup> C. AMSler,<sup>119,ww</sup> D. Brzhechko,<sup>119</sup> M. F. Canelli,<sup>119</sup> A. De Cosa,<sup>119</sup> R. Del Burgo,<sup>119</sup> S. Donato,<sup>119</sup> C. Galloni,<sup>119</sup> T. Hreus,<sup>119</sup> B. Kilminster,<sup>119</sup> I. Neutelings,<sup>119</sup> D. Pinna,<sup>119</sup> G. Raucó,<sup>119</sup> P. Robmann,<sup>119</sup> D. Salerno,<sup>119</sup> K. Schweiger,<sup>119</sup> C. Seitz,<sup>119</sup> Y. Takahashi,<sup>119</sup> A. Zucchetta,<sup>119</sup> Y. H. Chang,<sup>120</sup> K. y. Cheng,<sup>120</sup> T. H. Doan,<sup>120</sup> Sh. Jain,<sup>120</sup> R. Khurana,<sup>120</sup> C. M. Kuo,<sup>120</sup> W. Lin,<sup>120</sup> A. Pozdnyakov,<sup>120</sup> S. S. Yu,<sup>120</sup> Arun Kumar,<sup>121</sup> P. Chang,<sup>121</sup> Y. Chao,<sup>121</sup> K. F. Chen,<sup>121</sup> P. H. Chen,<sup>121</sup> W.-S. Hou,<sup>121</sup> Y. y. Li,<sup>121</sup> Y. F. Liu,<sup>121</sup> R.-S. Lu,<sup>121</sup> E. Paganis,<sup>121</sup> A. Psallidas,<sup>121</sup> A. Steen,<sup>121</sup> B. Asavapibhop,<sup>122</sup> N. Srimanobhas,<sup>122</sup> N. Suwonjandee,<sup>122</sup> A. Bat,<sup>123</sup> F. Boran,<sup>123</sup> S. Cerci,<sup>123,xx</sup> S. Damarseckin,<sup>123</sup> Z. S. Demiroglu,<sup>123</sup> F. Dolek,<sup>123</sup> C. Dozen,<sup>123</sup> I. Dumanoglu,<sup>123</sup> S. Girgis,<sup>123</sup> G. Gokbulut,<sup>123</sup> Y. Guler,<sup>123</sup> E. Gurpinar,<sup>123</sup> I. Hos,<sup>123,yy</sup> C. Isik,<sup>123</sup> E. E. Kangal,<sup>123,zz</sup> O. Kara,<sup>123</sup> A. Kayis Topaksu,<sup>123</sup> U. Kiminsu,<sup>123</sup> M. Oglakci,<sup>123</sup> G. Onengut,<sup>123</sup> K. Ozdemir,<sup>123,aaa</sup> S. Ozturk,<sup>123,bbb</sup> D. Sunar Cerci,<sup>123,xx</sup> B. Tali,<sup>123,xx</sup> U. G. Tok,<sup>123</sup> S. Turkcapar,<sup>123</sup> I. S. Zorbakir,<sup>123</sup> C. Zorbilmez,<sup>123</sup> B. Isildak,<sup>124,ccc</sup> G. Karapinar,<sup>124,ddd</sup> M. Yalvac,<sup>124</sup> M. Zeyrek,<sup>124</sup> I. O. Atakisi,<sup>125</sup> E. Gülmez,<sup>125</sup> M. Kaya,<sup>125,eee</sup> O. Kaya,<sup>125,fff</sup> S. Tekten,<sup>125</sup> E. A. Yetkin,<sup>125,ggg</sup> M. N. Agaras,<sup>126</sup> S. Atay,<sup>126</sup> A. Cakir,<sup>126</sup> K. Cankocak,<sup>126</sup> Y. Komurcu,<sup>126</sup> S. Sen,<sup>126,hhh</sup> B. Grynyov,<sup>127</sup> L. Levchuk,<sup>128</sup> F. Ball,<sup>129</sup> L. Beck,<sup>129</sup> J. J. Brooke,<sup>129</sup> D. Burns,<sup>129</sup> E. Clement,<sup>129</sup> D. Cussans,<sup>129</sup> O. Davignon,<sup>129</sup> H. Flacher,<sup>129</sup> J. Goldstein,<sup>129</sup> G. P. Heath,<sup>129</sup> H. F. Heath,<sup>129</sup> L. Kreczko,<sup>129</sup> D. M. Newbold,<sup>129,iii</sup> S. Paramesvaran,<sup>129</sup> B. Penning,<sup>129</sup> T. Sakuma,<sup>129</sup> D. Smith,<sup>129</sup> V. J. Smith,<sup>129</sup> J. Taylor,<sup>129</sup> A. Titterton,<sup>129</sup> K. W. Bell,<sup>130</sup> A. Belyaev,<sup>130,iii</sup> C. Brew,<sup>130</sup> R. M. Brown,<sup>130</sup> D. Cieri,<sup>130</sup> D. J. A. Cockerill,<sup>130</sup> J. A. Coughlan,<sup>130</sup> K. Harder,<sup>130</sup> S. Harper,<sup>130</sup> J. Linacre,<sup>130</sup> E. Olaiya,<sup>130</sup> D. Petyt,<sup>130</sup> C. H. Shepherd-Themistocleous,<sup>130</sup> A. Thea,<sup>130</sup> I. R. Tomalin,<sup>130</sup> T. Williams,<sup>130</sup> W. J. Womersley,<sup>130</sup> G. Auzinger,<sup>131</sup> R. Bainbridge,<sup>131</sup> P. Bloch,<sup>131</sup> J. Borg,<sup>131</sup> S. Breeze,<sup>131</sup> O. Buchmuller,<sup>131</sup> A. Bundock,<sup>131</sup> S. Casasso,<sup>131</sup> D. Colling,<sup>131</sup> L. Corpe,<sup>131</sup> P. Dauncey,<sup>131</sup> G. Davies,<sup>131</sup> M. Della Negra,<sup>131</sup> R. Di Maria,<sup>131</sup> Y. Haddad,<sup>131</sup> G. Hall,<sup>131</sup> G. Iles,<sup>131</sup> T. James,<sup>131</sup> M. Komm,<sup>131</sup> C. Laner,<sup>131</sup> L. Lyons,<sup>131</sup> A.-M. Magnan,<sup>131</sup> S. Malik,<sup>131</sup> A. Martelli,<sup>131</sup> J. Nash,<sup>131,kkk</sup> A. Nikitenko,<sup>131,h</sup> V. Palladino,<sup>131</sup> M. Pesaresi,<sup>131</sup> A. Richards,<sup>131</sup> A. Rose,<sup>131</sup> E. Scott,<sup>131</sup> C. Seez,<sup>131</sup> A. Shtipliyski,<sup>131</sup> T. Strebler,<sup>131</sup> S. Summers,<sup>131</sup> A. Tapper,<sup>131</sup> K. Uchida,<sup>131</sup> T. Virdee,<sup>131,p</sup> N. Wardle,<sup>131</sup> D. Winterbottom,<sup>131</sup> J. Wright,<sup>131</sup> S. C. Zenz,<sup>131</sup> J. E. Cole,<sup>132</sup> P. R. Hobson,<sup>132</sup> A. Khan,<sup>132</sup> P. Kyberd,<sup>132</sup> C. K. Mackay,<sup>132</sup> A. Morton,<sup>132</sup> I. D. Reid,<sup>132</sup> L. Teodorescu,<sup>132</sup> S. Zahid,<sup>132</sup> K. Call,<sup>133</sup> J. Dittmann,<sup>133</sup> K. Hatakeyama,<sup>133</sup> H. Liu,<sup>133</sup> C. Madrid,<sup>133</sup> B. McMaster,<sup>133</sup> N. Pastika,<sup>133</sup> C. Smith,<sup>133</sup> R. Bartek,<sup>134</sup> A. Dominguez,<sup>134</sup> A. Buccilli,<sup>135</sup> S. I. Cooper,<sup>135</sup> C. Henderson,<sup>135</sup> P. Rumerio,<sup>135</sup> C. West,<sup>135</sup> D. Arcaro,<sup>136</sup> T. Bose,<sup>136</sup> D. Gastler,<sup>136</sup> D. Rankin,<sup>136</sup> C. Richardson,<sup>136</sup> J. Rohlf,<sup>136</sup> L. Sulak,<sup>136</sup> D. Zou,<sup>136</sup> G. Benelli,<sup>137</sup> X. Coubez,<sup>137</sup> D. Cutts,<sup>137</sup> M. Hadley,<sup>137</sup> J. Hakala,<sup>137</sup> U. Heintz,<sup>137</sup> J. M. Hogan,<sup>137,iii</sup> K. H. M. Kwok,<sup>137</sup> E. Laird,<sup>137</sup> G. Landsberg,<sup>137</sup> J. Lee,<sup>137</sup> Z. Mao,<sup>137</sup> M. Narain,<sup>137</sup> S. Piperov,<sup>137</sup> S. Sagir,<sup>137,mmmm</sup> R. Syarif,<sup>137</sup> E. Usai,<sup>137</sup>

D. Yu,<sup>137</sup> R. Band,<sup>138</sup> C. Brainerd,<sup>138</sup> R. Breedon,<sup>138</sup> D. Burns,<sup>138</sup> M. Calderon De La Barca Sanchez,<sup>138</sup> M. Chertok,<sup>138</sup>  
 J. Conway,<sup>138</sup> R. Conway,<sup>138</sup> P. T. Cox,<sup>138</sup> R. Erbacher,<sup>138</sup> C. Flores,<sup>138</sup> G. Funk,<sup>138</sup> W. Ko,<sup>138</sup> O. Kukral,<sup>138</sup> R. Lander,<sup>138</sup>  
 M. Mulhearn,<sup>138</sup> D. Pellett,<sup>138</sup> J. Pilot,<sup>138</sup> S. Shalhout,<sup>138</sup> M. Shi,<sup>138</sup> D. Stolp,<sup>138</sup> D. Taylor,<sup>138</sup> K. Tos,<sup>138</sup> M. Tripathi,<sup>138</sup>  
 Z. Wang,<sup>138</sup> F. Zhang,<sup>138</sup> M. Bachtis,<sup>139</sup> C. Bravo,<sup>139</sup> R. Cousins,<sup>139</sup> A. Dasgupta,<sup>139</sup> A. Florent,<sup>139</sup> J. Hauser,<sup>139</sup>  
 M. Ignatenko,<sup>139</sup> N. Mccoll,<sup>139</sup> S. Regnard,<sup>139</sup> D. Saltzberg,<sup>139</sup> C. Schnaible,<sup>139</sup> V. Valuev,<sup>139</sup> E. Bouvier,<sup>140</sup> K. Burt,<sup>140</sup>  
 R. Clare,<sup>140</sup> J. W. Gary,<sup>140</sup> S. M. A. Ghiasi Shirazi,<sup>140</sup> G. Hanson,<sup>140</sup> G. Karapostoli,<sup>140</sup> E. Kennedy,<sup>140</sup> F. Lacroix,<sup>140</sup>  
 O. R. Long,<sup>140</sup> M. Olmedo Negrete,<sup>140</sup> M. I. Paneva,<sup>140</sup> W. Si,<sup>140</sup> L. Wang,<sup>140</sup> H. Wei,<sup>140</sup> S. Wimpenny,<sup>140</sup> B. R. Yates,<sup>140</sup>  
 J. G. Branson,<sup>141</sup> S. Cittolin,<sup>141</sup> M. Derdzinski,<sup>141</sup> R. Gerosa,<sup>141</sup> D. Gilbert,<sup>141</sup> B. Hashemi,<sup>141</sup> A. Holzner,<sup>141</sup> D. Klein,<sup>141</sup>  
 G. Kole,<sup>141</sup> V. Krutelyov,<sup>141</sup> J. Letts,<sup>141</sup> M. Masciovecchio,<sup>141</sup> D. Olivito,<sup>141</sup> S. Padhi,<sup>141</sup> M. Pieri,<sup>141</sup> M. Sani,<sup>141</sup>  
 V. Sharma,<sup>141</sup> S. Simon,<sup>141</sup> M. Tadel,<sup>141</sup> A. Vartak,<sup>141</sup> S. Wasserbaech,<sup>141,nnn</sup> J. Wood,<sup>141</sup> F. Würthwein,<sup>141</sup> A. Yagil,<sup>141</sup>  
 G. Zevi Della Porta,<sup>141</sup> N. Amin,<sup>142</sup> R. Bhandari,<sup>142</sup> J. Bradmiller-Feld,<sup>142</sup> C. Campagnari,<sup>142</sup> M. Citron,<sup>142</sup> A. Dishaw,<sup>142</sup>  
 V. Dutta,<sup>142</sup> M. Franco Sevilla,<sup>142</sup> L. Gouskos,<sup>142</sup> R. Heller,<sup>142</sup> J. Incandela,<sup>142</sup> A. Ovcharova,<sup>142</sup> H. Qu,<sup>142</sup> J. Richman,<sup>142</sup>  
 D. Stuart,<sup>142</sup> I. Suarez,<sup>142</sup> S. Wang,<sup>142</sup> J. Yoo,<sup>142</sup> D. Anderson,<sup>143</sup> A. Bornheim,<sup>143</sup> J. M. Lawhorn,<sup>143</sup> H. B. Newman,<sup>143</sup>  
 T. Q. Nguyen,<sup>143</sup> M. Spiropulu,<sup>143</sup> J. R. Vlimant,<sup>143</sup> R. Wilkinson,<sup>143</sup> S. Xie,<sup>143</sup> Z. Zhang,<sup>143</sup> R. Y. Zhu,<sup>143</sup> M. B. Andrews,<sup>144</sup>  
 T. Ferguson,<sup>144</sup> T. Mudholkar,<sup>144</sup> M. Paulini,<sup>144</sup> M. Sun,<sup>144</sup> I. Vorobiev,<sup>144</sup> M. Weinberg,<sup>144</sup> J. P. Cumalat,<sup>145</sup> W. T. Ford,<sup>145</sup>  
 F. Jensen,<sup>145</sup> A. Johnson,<sup>145</sup> M. Krohn,<sup>145</sup> S. Leontsinis,<sup>145</sup> E. MacDonald,<sup>145</sup> T. Mulholland,<sup>145</sup> K. Stenson,<sup>145</sup>  
 K. A. Ulmer,<sup>145</sup> S. R. Wagner,<sup>145</sup> J. Alexander,<sup>146</sup> J. Chaves,<sup>146</sup> Y. Cheng,<sup>146</sup> J. Chu,<sup>146</sup> A. Datta,<sup>146</sup> K. McDermott,<sup>146</sup>  
 N. Mirman,<sup>146</sup> J. R. Patterson,<sup>146</sup> D. Quach,<sup>146</sup> A. Rinkevicius,<sup>146</sup> A. Ryd,<sup>146</sup> L. Skinnari,<sup>146</sup> L. Soffi,<sup>146</sup> S. M. Tan,<sup>146</sup>  
 Z. Tao,<sup>146</sup> J. Thom,<sup>146</sup> J. Tucker,<sup>146</sup> P. Wittich,<sup>146</sup> M. Zientek,<sup>146</sup> S. Abdullin,<sup>147</sup> M. Albrow,<sup>147</sup> M. Alyari,<sup>147</sup> G. Apollinari,<sup>147</sup>  
 A. Apresyan,<sup>147</sup> A. Apyan,<sup>147</sup> S. Banerjee,<sup>147</sup> L. A. T. Bauerdick,<sup>147</sup> A. Beretvas,<sup>147</sup> J. Berryhill,<sup>147</sup> P. C. Bhat,<sup>147</sup>  
 G. Bolla,<sup>147,a</sup> K. Burkett,<sup>147</sup> J. N. Butler,<sup>147</sup> A. Canepa,<sup>147</sup> G. B. Cerati,<sup>147</sup> H. W. K. Cheung,<sup>147</sup> F. Chlebana,<sup>147</sup>  
 M. Cremonesi,<sup>147</sup> J. Duarte,<sup>147</sup> V. D. Elvira,<sup>147</sup> J. Freeman,<sup>147</sup> Z. Gecse,<sup>147</sup> E. Gottschalk,<sup>147</sup> L. Gray,<sup>147</sup> D. Green,<sup>147</sup>  
 S. Grünendahl,<sup>147</sup> O. Gutsche,<sup>147</sup> J. Hanlon,<sup>147</sup> R. M. Harris,<sup>147</sup> S. Hasegawa,<sup>147</sup> J. Hirschauer,<sup>147</sup> Z. Hu,<sup>147</sup> B. Jayatilaka,<sup>147</sup>  
 S. Jindariani,<sup>147</sup> M. Johnson,<sup>147</sup> U. Joshi,<sup>147</sup> B. Klima,<sup>147</sup> M. J. Kortelainen,<sup>147</sup> B. Kreis,<sup>147</sup> S. Lammel,<sup>147</sup> D. Lincoln,<sup>147</sup>  
 R. Lipton,<sup>147</sup> M. Liu,<sup>147</sup> T. Liu,<sup>147</sup> J. Lykken,<sup>147</sup> K. Maeshima,<sup>147</sup> J. M. Marraffino,<sup>147</sup> D. Mason,<sup>147</sup> P. McBride,<sup>147</sup>  
 P. Merkel,<sup>147</sup> S. Mrenna,<sup>147</sup> S. Nahn,<sup>147</sup> V. O'Dell,<sup>147</sup> K. Pedro,<sup>147</sup> O. Prokofyev,<sup>147</sup> G. Rakness,<sup>147</sup> L. Ristori,<sup>147</sup>  
 A. Savoy-Navarro,<sup>147,ooo</sup> B. Schneider,<sup>147</sup> E. Sexton-Kennedy,<sup>147</sup> A. Soha,<sup>147</sup> W. J. Spalding,<sup>147</sup> L. Spiegel,<sup>147</sup> S. Stoynev,<sup>147</sup>  
 J. Strait,<sup>147</sup> N. Strobbe,<sup>147</sup> L. Taylor,<sup>147</sup> S. Tkaczyk,<sup>147</sup> N. V. Tran,<sup>147</sup> L. Uplegger,<sup>147</sup> E. W. Vaandering,<sup>147</sup> C. Vernieri,<sup>147</sup>  
 M. Verzocchi,<sup>147</sup> R. Vidal,<sup>147</sup> M. Wang,<sup>147</sup> H. A. Weber,<sup>147</sup> A. Whitbeck,<sup>147</sup> D. Acosta,<sup>148</sup> P. Avery,<sup>148</sup> P. Bortignon,<sup>148</sup>  
 D. Bourilkov,<sup>148</sup> A. Brinkerhoff,<sup>148</sup> L. Cadamuro,<sup>148</sup> A. Carnes,<sup>148</sup> M. Carver,<sup>148</sup> D. Curry,<sup>148</sup> R. D. Field,<sup>148</sup> S. V. Gleyzer,<sup>148</sup>  
 B. M. Joshi,<sup>148</sup> J. Konigsberg,<sup>148</sup> A. Korytov,<sup>148</sup> P. Ma,<sup>148</sup> K. Matchev,<sup>148</sup> H. Mei,<sup>148</sup> G. Mitselmakher,<sup>148</sup> K. Shi,<sup>148</sup>  
 D. Sperka,<sup>148</sup> J. Wang,<sup>148</sup> S. Wang,<sup>148</sup> Y. R. Joshi,<sup>149</sup> S. Linn,<sup>149</sup> A. Ackert,<sup>150</sup> T. Adams,<sup>150</sup> A. Askew,<sup>150</sup> S. Hagopian,<sup>150</sup>  
 V. Hagopian,<sup>150</sup> K. F. Johnson,<sup>150</sup> T. Kolberg,<sup>150</sup> G. Martinez,<sup>150</sup> T. Perry,<sup>150</sup> H. Prosper,<sup>150</sup> A. Saha,<sup>150</sup> C. Schiber,<sup>150</sup>  
 V. Sharma,<sup>150</sup> R. Yohay,<sup>150</sup> M. M. Baarmand,<sup>151</sup> V. Bhopatkar,<sup>151</sup> S. Colafranceschi,<sup>151</sup> M. Hohlmann,<sup>151</sup> D. Noonan,<sup>151</sup>  
 M. Rahmani,<sup>151</sup> T. Roy,<sup>151</sup> F. Yumiceva,<sup>151</sup> M. R. Adams,<sup>152</sup> L. Apanasevich,<sup>152</sup> D. Berry,<sup>152</sup> R. R. Betts,<sup>152</sup>  
 R. Cavanaugh,<sup>152</sup> X. Chen,<sup>152</sup> S. Dittmer,<sup>152</sup> O. Evdokimov,<sup>152</sup> C. E. Gerber,<sup>152</sup> D. A. Hangal,<sup>152</sup> D. J. Hofman,<sup>152</sup>  
 K. Jung,<sup>152</sup> J. Kamin,<sup>152</sup> C. Mills,<sup>152</sup> I. D. Sandoval Gonzalez,<sup>152</sup> M. B. Tonjes,<sup>152</sup> N. Varelas,<sup>152</sup> H. Wang,<sup>152</sup> X. Wang,<sup>152</sup>  
 Z. Wu,<sup>152</sup> J. Zhang,<sup>152</sup> M. Alhusseini,<sup>153</sup> B. Bilki,<sup>153,ppp</sup> W. Clarida,<sup>153</sup> K. Dilsiz,<sup>153,qqq</sup> S. Durgut,<sup>153</sup> R. P. Gandrajula,<sup>153</sup>  
 M. Haytmyradov,<sup>153</sup> V. Khristenko,<sup>153</sup> J.-P. Merlo,<sup>153</sup> A. Mestvirishvili,<sup>153</sup> A. Moeller,<sup>153</sup> J. Nachtman,<sup>153</sup> H. Ogul,<sup>153,rrr</sup>  
 Y. Onel,<sup>153</sup> F. Ozok,<sup>153,sss</sup> A. Penzo,<sup>153</sup> C. Snyder,<sup>153</sup> E. Tiras,<sup>153</sup> J. Wetzel,<sup>153</sup> B. Blumenfeld,<sup>154</sup> A. Cocoros,<sup>154</sup>  
 N. Eminizer,<sup>154</sup> D. Fehling,<sup>154</sup> L. Feng,<sup>154</sup> A. V. Gritsan,<sup>154</sup> W. T. Hung,<sup>154</sup> P. Maksimovic,<sup>154</sup> J. Roskes,<sup>154</sup> U. Sarica,<sup>154</sup>  
 M. Swartz,<sup>154</sup> M. Xiao,<sup>154</sup> C. You,<sup>154</sup> A. Al-bataineh,<sup>155</sup> P. Baringer,<sup>155</sup> A. Bean,<sup>155</sup> S. Boren,<sup>155</sup> J. Bowen,<sup>155</sup> A. Bylinkin,<sup>155</sup>  
 J. Castle,<sup>155</sup> S. Khalil,<sup>155</sup> A. Kropivnitskaya,<sup>155</sup> D. Majumder,<sup>155</sup> W. Mcbrayer,<sup>155</sup> M. Murray,<sup>155</sup> C. Rogan,<sup>155</sup> S. Sanders,<sup>155</sup>  
 E. Schmitz,<sup>155</sup> J. D. Tapia Takaki,<sup>155</sup> Q. Wang,<sup>155</sup> S. Duric,<sup>156</sup> A. Ivanov,<sup>156</sup> K. Kaadze,<sup>156</sup> D. Kim,<sup>156</sup> Y. Maravin,<sup>156</sup>  
 D. R. Mendis,<sup>156</sup> T. Mitchell,<sup>156</sup> A. Modak,<sup>156</sup> A. Mohammadi,<sup>156</sup> L. K. Saini,<sup>156</sup> N. Skhirtladze,<sup>156</sup> F. Rebassoo,<sup>157</sup>  
 D. Wright,<sup>157</sup> A. Baden,<sup>158</sup> O. Baron,<sup>158</sup> A. Belloni,<sup>158</sup> S. C. Eno,<sup>158</sup> Y. Feng,<sup>158</sup> C. Ferraioli,<sup>158</sup> N. J. Hadley,<sup>158</sup> S. Jabeen,<sup>158</sup>  
 G. Y. Jeng,<sup>158</sup> R. G. Kellogg,<sup>158</sup> J. Kunkle,<sup>158</sup> A. C. Mignerey,<sup>158</sup> F. Ricci-Tam,<sup>158</sup> Y. H. Shin,<sup>158</sup> A. Skuja,<sup>158</sup> S. C. Tonwar,<sup>158</sup>  
 K. Wong,<sup>158</sup> D. Abercrombie,<sup>159</sup> B. Allen,<sup>159</sup> V. Azzolini,<sup>159</sup> A. Baty,<sup>159</sup> G. Bauer,<sup>159</sup> R. Bi,<sup>159</sup> S. Brandt,<sup>159</sup> W. Busza,<sup>159</sup>  
 I. A. Cali,<sup>159</sup> M. D'Alfonso,<sup>159</sup> Z. Demiragli,<sup>159</sup> G. Gomez Ceballos,<sup>159</sup> M. Goncharov,<sup>159</sup> P. Harris,<sup>159</sup> D. Hsu,<sup>159</sup> M. Hu,<sup>159</sup>

Y. Iiyama,<sup>159</sup> G. M. Innocenti,<sup>159</sup> M. Klute,<sup>159</sup> D. Kovalskyi,<sup>159</sup> Y.-J. Lee,<sup>159</sup> P. D. Luckey,<sup>159</sup> B. Maier,<sup>159</sup> A. C. Marini,<sup>159</sup> C. Mcginn,<sup>159</sup> C. Mironov,<sup>159</sup> S. Narayanan,<sup>159</sup> X. Niu,<sup>159</sup> C. Paus,<sup>159</sup> C. Roland,<sup>159</sup> G. Roland,<sup>159</sup> G. S. F. Stephans,<sup>159</sup> K. Sumorok,<sup>159</sup> K. Tatar,<sup>159</sup> D. Velicanu,<sup>159</sup> J. Wang,<sup>159</sup> T. W. Wang,<sup>159</sup> B. Wyslouch,<sup>159</sup> S. Zhaozhong,<sup>159</sup> A. C. Benvenuti,<sup>160</sup> R. M. Chatterjee,<sup>160</sup> A. Evans,<sup>160</sup> P. Hansen,<sup>160</sup> S. Kalafut,<sup>160</sup> Y. Kubota,<sup>160</sup> Z. Lesko,<sup>160</sup> J. Mans,<sup>160</sup> S. Nourbakhsh,<sup>160</sup> N. Ruckstuhl,<sup>160</sup> R. Rusack,<sup>160</sup> J. Turkewitz,<sup>160</sup> M. A. Wadud,<sup>160</sup> J. G. Acosta,<sup>161</sup> S. Oliveros,<sup>161</sup> E. Avdeeva,<sup>162</sup> K. Bloom,<sup>162</sup> D. R. Claes,<sup>162</sup> C. Fangmeier,<sup>162</sup> F. Golf,<sup>162</sup> R. Gonzalez Suarez,<sup>162</sup> R. Kamalieddin,<sup>162</sup> I. Kravchenko,<sup>162</sup> J. Monroy,<sup>162</sup> J. E. Siado,<sup>162</sup> G. R. Snow,<sup>162</sup> B. Stieger,<sup>162</sup> A. Godshalk,<sup>163</sup> C. Harrington,<sup>163</sup> I. Iashvili,<sup>163</sup> A. Kharchilava,<sup>163</sup> C. Mclean,<sup>163</sup> D. Nguyen,<sup>163</sup> A. Parker,<sup>163</sup> S. Rappoccio,<sup>163</sup> B. Roozbahani,<sup>163</sup> E. Barberis,<sup>164</sup> C. Freer,<sup>164</sup> A. Hortiangtham,<sup>164</sup> D. M. Morse,<sup>164</sup> T. Orimoto,<sup>164</sup> R. Teixeira De Lima,<sup>164</sup> T. Wamorkar,<sup>164</sup> B. Wang,<sup>164</sup> A. Wisecarver,<sup>164</sup> D. Wood,<sup>164</sup> S. Bhattacharya,<sup>165</sup> O. Charaf,<sup>165</sup> K. A. Hahn,<sup>165</sup> N. Mucia,<sup>165</sup> N. Odell,<sup>165</sup> M. H. Schmitt,<sup>165</sup> K. Sung,<sup>165</sup> M. Trovato,<sup>165</sup> M. Velasco,<sup>165</sup> R. Bucci,<sup>166</sup> N. Dev,<sup>166</sup> M. Hildreth,<sup>166</sup> K. Hurtado Anampa,<sup>166</sup> C. Jessop,<sup>166</sup> D. J. Karmgard,<sup>166</sup> N. Kellams,<sup>166</sup> K. Lannon,<sup>166</sup> W. Li,<sup>166</sup> N. Loukas,<sup>166</sup> N. Marinelli,<sup>166</sup> F. Meng,<sup>166</sup> C. Mueller,<sup>166</sup> Y. Musienko,<sup>166,ii</sup> M. Planer,<sup>166</sup> A. Reinsvold,<sup>166</sup> R. Ruchti,<sup>166</sup> P. Siddireddy,<sup>166</sup> G. Smith,<sup>166</sup> S. Taroni,<sup>166</sup> M. Wayne,<sup>166</sup> A. Wightman,<sup>166</sup> M. Wolf,<sup>166</sup> A. Woodard,<sup>166</sup> J. Alimena,<sup>167</sup> L. Antonelli,<sup>167</sup> B. Bylsma,<sup>167</sup> L. S. Durkin,<sup>167</sup> S. Flowers,<sup>167</sup> B. Francis,<sup>167</sup> A. Hart,<sup>167</sup> C. Hill,<sup>167</sup> W. Ji,<sup>167</sup> A. Lefeld,<sup>167</sup> T. Y. Ling,<sup>167</sup> W. Luo,<sup>167</sup> B. L. Winer,<sup>167</sup> H. W. Wulsin,<sup>167</sup> S. Cooperstein,<sup>168</sup> P. Elmer,<sup>168</sup> J. Hardenbrook,<sup>168</sup> S. Higginbotham,<sup>168</sup> A. Kalogeropoulos,<sup>168</sup> D. Lange,<sup>168</sup> M. T. Lucchini,<sup>168</sup> J. Luo,<sup>168</sup> D. Marlow,<sup>168</sup> K. Mei,<sup>168</sup> I. Ojalvo,<sup>168</sup> J. Olsen,<sup>168</sup> C. Palmer,<sup>168</sup> P. Piroué,<sup>168</sup> J. Salfeld-Nebgen,<sup>168</sup> D. Stickland,<sup>168</sup> C. Tully,<sup>168</sup> S. Malik,<sup>169</sup> S. Norberg,<sup>169</sup> A. Barker,<sup>170</sup> V. E. Barnes,<sup>170</sup> L. Gutay,<sup>170</sup> M. Jones,<sup>170</sup> A. W. Jung,<sup>170</sup> A. Khatiwada,<sup>170</sup> B. Mahakud,<sup>170</sup> D. H. Miller,<sup>170</sup> N. Neumeister,<sup>170</sup> C. C. Peng,<sup>170</sup> H. Qiu,<sup>170</sup> J. F. Schulte,<sup>170</sup> J. Sun,<sup>170</sup> F. Wang,<sup>170</sup> R. Xiao,<sup>170</sup> W. Xie,<sup>170</sup> T. Cheng,<sup>171</sup> J. Dolen,<sup>171</sup> N. Parashar,<sup>171</sup> Z. Chen,<sup>172</sup> K. M. Ecklund,<sup>172</sup> S. Freed,<sup>172</sup> F. J. M. Geurts,<sup>172</sup> M. Kilpatrick,<sup>172</sup> W. Li,<sup>172</sup> B. Michlin,<sup>172</sup> B. P. Padley,<sup>172</sup> J. Roberts,<sup>172</sup> J. Rorie,<sup>172</sup> W. Shi,<sup>172</sup> Z. Tu,<sup>172</sup> J. Zabel,<sup>172</sup> A. Zhang,<sup>172</sup> A. Bodek,<sup>173</sup> P. de Barbaro,<sup>173</sup> R. Demina,<sup>173</sup> Y. t. Duh,<sup>173</sup> J. L. Dulemba,<sup>173</sup> C. Fallon,<sup>173</sup> T. Ferbel,<sup>173</sup> M. Galanti,<sup>173</sup> A. Garcia-Bellido,<sup>173</sup> J. Han,<sup>173</sup> O. Hindrichs,<sup>173</sup> A. Khukhunaishvili,<sup>173</sup> K. H. Lo,<sup>173</sup> P. Tan,<sup>173</sup> R. Taus,<sup>173</sup> M. Verzetti,<sup>173</sup> A. Agapitos,<sup>174</sup> J. P. Chou,<sup>174</sup> Y. Gershtein,<sup>174</sup> T. A. Gómez Espinosa,<sup>174</sup> E. Halkiadakis,<sup>174</sup> M. Heindl,<sup>174</sup> E. Hughes,<sup>174</sup> S. Kaplan,<sup>174</sup> R. Kunnawalkam Elayavalli,<sup>174</sup> S. Kyriacou,<sup>174</sup> A. Lath,<sup>174</sup> R. Montalvo,<sup>174</sup> K. Nash,<sup>174</sup> M. Osherson,<sup>174</sup> H. Saka,<sup>174</sup> S. Salur,<sup>174</sup> S. Schnetzer,<sup>174</sup> D. Sheffield,<sup>174</sup> S. Somalwar,<sup>174</sup> R. Stone,<sup>174</sup> S. Thomas,<sup>174</sup> P. Thomassen,<sup>174</sup> M. Walker,<sup>174</sup> A. G. Delannoy,<sup>175</sup> J. Heideman,<sup>175</sup> G. Riley,<sup>175</sup> S. Spanier,<sup>175</sup> K. Thapa,<sup>175</sup> O. Bouhali,<sup>176,uu</sup> A. Celik,<sup>176</sup> M. Dalchenko,<sup>176</sup> M. De Mattia,<sup>176</sup> A. Delgado,<sup>176</sup> S. Dildick,<sup>176</sup> R. Eusebi,<sup>176</sup> J. Gilmore,<sup>176</sup> T. Huang,<sup>176</sup> T. Kamon,<sup>176,uuu</sup> S. Luo,<sup>176</sup> R. Mueller,<sup>176</sup> R. Patel,<sup>176</sup> A. Perloff,<sup>176</sup> L. Perniè,<sup>176</sup> D. Rathjens,<sup>176</sup> A. Safonov,<sup>176</sup> N. Akchurin,<sup>177</sup> J. Damgov,<sup>177</sup> F. De Guio,<sup>177</sup> P. R. Duerdo,<sup>177</sup> S. Kunori,<sup>177</sup> K. Lamichhane,<sup>177</sup> S. W. Lee,<sup>177</sup> T. Mengke,<sup>177</sup> S. Muthumuni,<sup>177</sup> T. Peltola,<sup>177</sup> S. Undleeb,<sup>177</sup> I. Volobouev,<sup>177</sup> Z. Wang,<sup>177</sup> S. Greene,<sup>178</sup> A. Gurrola,<sup>178</sup> R. Janjam,<sup>178</sup> W. Johns,<sup>178</sup> C. Maguire,<sup>178</sup> A. Melo,<sup>178</sup> H. Ni,<sup>178</sup> K. Padeken,<sup>178</sup> J. D. Ruiz Alvarez,<sup>178</sup> P. Sheldon,<sup>178</sup> S. Tuo,<sup>178</sup> J. Velkovska,<sup>178</sup> M. Verweij,<sup>178</sup> Q. Xu,<sup>178</sup> M. W. Arenton,<sup>179</sup> P. Barria,<sup>179</sup> B. Cox,<sup>179</sup> R. Hirosky,<sup>179</sup> M. Joyce,<sup>179</sup> A. Ledovskoy,<sup>179</sup> H. Li,<sup>179</sup> C. Neu,<sup>179</sup> T. Sinthuprasith,<sup>179</sup> Y. Wang,<sup>179</sup> E. Wolfe,<sup>179</sup> F. Xia,<sup>179</sup> R. Harr,<sup>180</sup> P. E. Karchin,<sup>180</sup> N. Poudyal,<sup>180</sup> J. Sturdy,<sup>180</sup> P. Thapa,<sup>180</sup> S. Zaleski,<sup>180</sup> M. Brodski,<sup>181</sup> J. Buchanan,<sup>181</sup> C. Caillol,<sup>181</sup> D. Carlsmith,<sup>181</sup> S. Dasu,<sup>181</sup> L. Dodd,<sup>181</sup> B. Gomber,<sup>181</sup> M. Grothe,<sup>181</sup> M. Herndon,<sup>181</sup> A. Hervé,<sup>181</sup> U. Hussain,<sup>181</sup> P. Klabbers,<sup>181</sup> A. Lanaro,<sup>181</sup> K. Long,<sup>181</sup> R. Loveless,<sup>181</sup> T. Ruggles,<sup>181</sup> A. Savin,<sup>181</sup> N. Smith,<sup>181</sup> W. H. Smith,<sup>181</sup> and N. Woods<sup>181</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>*Escuela Politecnica Nacional, Quito, Ecuador*  
<sup>25</sup>*Universidad San Francisco de Quito, Quito, Ecuador*  
<sup>26</sup>*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*  
<sup>27</sup>*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*  
<sup>28</sup>*Department of Physics, University of Helsinki, Helsinki, Finland*  
<sup>29</sup>*Helsinki Institute of Physics, Helsinki, Finland*  
<sup>30</sup>*Lappeenranta University of Technology, Lappeenranta, Finland*  
<sup>31</sup>*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*  
<sup>32</sup>*Laboratoire Leprince-Ringuet, Ecole polytechnique, CNRS/IN2P3, Université Paris-Saclay, Palaiseau, France*  
<sup>33</sup>*Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France*  
<sup>34</sup>*Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France*  
<sup>35</sup>*Université de Lyon, Université Claude Bernard Lyon I, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France*  
<sup>36</sup>*Georgian Technical University, Tbilisi, Georgia*  
<sup>37</sup>*Tbilisi State University, Tbilisi, Georgia*  
<sup>38</sup>*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*  
<sup>39</sup>*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*  
<sup>40</sup>*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*  
<sup>41</sup>*Deutsches Elektronen-Synchrotron, Hamburg, Germany*  
<sup>42</sup>*University of Hamburg, Hamburg, Germany*  
<sup>43</sup>*Institut für Experimentelle Teilchenphysik, Karlsruhe, Germany*  
<sup>44</sup>*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*  
<sup>45</sup>*National and Kapodistrian University of Athens, Athens, Greece*  
<sup>46</sup>*National Technical University of Athens, Athens, Greece*  
<sup>47</sup>*University of Ioánnina, Ioánnina, Greece*  
<sup>48</sup>*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*  
<sup>49</sup>*Wigner Research Centre for Physics, Budapest, Hungary*  
<sup>50</sup>*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*  
<sup>51</sup>*Institute of Physics, University of Debrecen, Debrecen, Hungary*  
<sup>52</sup>*Indian Institute of Science (IISc), Bangalore, India*  
<sup>53</sup>*National Institute of Science Education and Research, Bhubaneswar, India*  
<sup>54</sup>*Panjab University, Chandigarh, India*  
<sup>55</sup>*University of Delhi, Delhi, India*  
<sup>56</sup>*Saha Institute of Nuclear Physics, HBNI, Kolkata, India*  
<sup>57</sup>*Indian Institute of Technology Madras, Madras, India*  
<sup>58</sup>*Bhabha Atomic Research Centre, Mumbai, India*  
<sup>59</sup>*Tata Institute of Fundamental Research-A, Mumbai, India*  
<sup>60</sup>*Tata Institute of Fundamental Research-B, Mumbai, India*  
<sup>61</sup>*Indian Institute of Science Education and Research (IISER), Pune, India*  
<sup>62</sup>*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*  
<sup>63</sup>*University College Dublin, Dublin, Ireland*  
<sup>64a</sup>*INFN Sezione di Bari, Bari, Italy*  
<sup>64b</sup>*Università di Bari, Bari, Italy*  
<sup>64c</sup>*Politecnico di Bari, Bari, Italy*  
<sup>65a</sup>*INFN Sezione di Bologna, Bologna, Italy*

- <sup>65b</sup> *Università di Bologna, Bologna, Italy*  
<sup>66a</sup> *INFN Sezione di Catania, Catania, Italy*  
<sup>66b</sup> *Università di Catania, Catania, Italy*  
<sup>67a</sup> *INFN Sezione di Firenze, Firenze, Italy*  
<sup>67b</sup> *Università di Firenze, Firenze, Italy*  
<sup>68</sup> *INFN Laboratori Nazionali di Frascati, Frascati, Italy*  
<sup>69a</sup> *INFN Sezione di Genova, Genova, Italy*  
<sup>69b</sup> *Università di Genova, Genova, Italy*  
<sup>70a</sup> *INFN Sezione di Milano-Bicocca, Milano, Italy*  
<sup>70b</sup> *Università di Milano-Bicocca, Milano, Italy*  
<sup>71a</sup> *INFN Sezione di Napoli, Napoli, Italy*  
<sup>71b</sup> *Università di Napoli 'Federico II', Napoli, Italy*  
<sup>71c</sup> *Università della Basilicata, Potenza, Italy*  
<sup>71d</sup> *Università G. Marconi, Roma, Italy*  
<sup>72a</sup> *INFN Sezione di Padova, Padova, Italy*  
<sup>72b</sup> *Università di Padova, Padova, Italy*  
<sup>72c</sup> *Università di Trento, Trento, Italy*  
<sup>73a</sup> *INFN Sezione di Pavia, Pavia, Italy*  
<sup>73b</sup> *Università di Pavia, Pavia, Italy*  
<sup>74a</sup> *INFN Sezione di Perugia, Perugia, Italy*  
<sup>74b</sup> *Università di Perugia, Perugia, Italy*  
<sup>75a</sup> *INFN Sezione di Pisa, Pisa, Italy*  
<sup>75b</sup> *Università di Pisa, Pisa, Italy*  
<sup>75c</sup> *Scuola Normale Superiore di Pisa, Pisa, Italy*  
<sup>76a</sup> *INFN Sezione di Roma, Rome, Italy*  
<sup>76b</sup> *Sapienza Università di Roma, Rome, Italy*  
<sup>77a</sup> *INFN Sezione di Torino, Torino, Italy*  
<sup>77b</sup> *Università di Torino, Torino, Italy*  
<sup>77c</sup> *Università del Piemonte Orientale, Novara, Italy*  
<sup>78a</sup> *INFN Sezione di Trieste, Trieste, Italy*  
<sup>78b</sup> *Università di Trieste, Trieste, Italy*  
<sup>79</sup> *Kyungpook National University, Daegu, Korea*  
<sup>80</sup> *Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*  
<sup>81</sup> *Hanyang University, Seoul, Korea*  
<sup>82</sup> *Korea University, Seoul, Korea*  
<sup>83</sup> *Sejong University, Seoul, Korea*  
<sup>84</sup> *Seoul National University, Seoul, Korea*  
<sup>85</sup> *University of Seoul, Seoul, Korea*  
<sup>86</sup> *Sungkyunkwan University, Suwon, Korea*  
<sup>87</sup> *Vilnius University, Vilnius, Lithuania*  
<sup>88</sup> *National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia*  
<sup>89</sup> *Universidad de Sonora (UNISON), Hermosillo, Mexico*  
<sup>90</sup> *Centro de Investigación y de Estudios Avanzados del IPN, Mexico City, Mexico*  
<sup>91</sup> *Universidad Iberoamericana, Mexico City, Mexico*  
<sup>92</sup> *Benemerita Universidad Autónoma de Puebla, Puebla, Mexico*  
<sup>93</sup> *Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico*  
<sup>94</sup> *University of Auckland, Auckland, New Zealand*  
<sup>95</sup> *University of Canterbury, Christchurch, New Zealand*  
<sup>96</sup> *National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*  
<sup>97</sup> *National Centre for Nuclear Research, Swierk, Poland*  
<sup>98</sup> *Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*  
<sup>99</sup> *Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal*  
<sup>100</sup> *Joint Institute for Nuclear Research, Dubna, Russia*  
<sup>101</sup> *Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia*  
<sup>102</sup> *Institute for Nuclear Research, Moscow, Russia*  
<sup>103</sup> *Institute for Theoretical and Experimental Physics, Moscow, Russia*  
<sup>104</sup> *Moscow Institute of Physics and Technology, Moscow, Russia*  
<sup>105</sup> *National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia*  
<sup>106</sup> *P.N. Lebedev Physical Institute, Moscow, Russia*  
<sup>107</sup> *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*

- <sup>108</sup>*Novosibirsk State University (NSU), Novosibirsk, Russia*
- <sup>109</sup>*State Research Center of Russian Federation, Institute for High Energy Physics of NRC “Kurchatov Institute”, Protvino, Russia*
- <sup>110</sup>*National Research Tomsk Polytechnic University, Tomsk, Russia*
- <sup>111</sup>*University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia*
- <sup>112</sup>*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
- <sup>113</sup>*Universidad Autónoma de Madrid, Madrid, Spain*
- <sup>114</sup>*Universidad de Oviedo, Oviedo, Spain*
- <sup>115</sup>*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
- <sup>116</sup>*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
- <sup>117</sup>*Paul Scherrer Institut, Villigen, Switzerland*
- <sup>118</sup>*ETH Zurich-Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland*
- <sup>119</sup>*Universität Zürich, Zurich, Switzerland*
- <sup>120</sup>*National Central University, Chung-Li, Taiwan*
- <sup>121</sup>*National Taiwan University (NTU), Taipei, Taiwan*
- <sup>122</sup>*Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand*
- <sup>123</sup>*Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey*
- <sup>124</sup>*Middle East Technical University, Physics Department, Ankara, Turkey*
- <sup>125</sup>*Bogazici University, Istanbul, Turkey*
- <sup>126</sup>*Istanbul Technical University, Istanbul, Turkey*
- <sup>127</sup>*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine*
- <sup>128</sup>*National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine*
- <sup>129</sup>*University of Bristol, Bristol, United Kingdom*
- <sup>130</sup>*Rutherford Appleton Laboratory, Didcot, United Kingdom*
- <sup>131</sup>*Imperial College, London, United Kingdom*
- <sup>132</sup>*Brunel University, Uxbridge, United Kingdom*
- <sup>133</sup>*Baylor University, Waco, Texas, USA*
- <sup>134</sup>*Catholic University of America, Washington DC, USA*
- <sup>135</sup>*The University of Alabama, Tuscaloosa, Alabama, USA*
- <sup>136</sup>*Boston University, Boston, Massachusetts, USA*
- <sup>137</sup>*Brown University, Providence, Rhode Island, USA*
- <sup>138</sup>*University of California, Davis, Davis, California, USA*
- <sup>139</sup>*University of California, Los Angeles, California, USA*
- <sup>140</sup>*University of California, Riverside, Riverside, California, USA*
- <sup>141</sup>*University of California, San Diego, La Jolla, California, USA*
- <sup>142</sup>*University of California, Santa Barbara—Department of Physics, Santa Barbara, California, USA*
- <sup>143</sup>*California Institute of Technology, Pasadena, California, USA*
- <sup>144</sup>*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
- <sup>145</sup>*University of Colorado Boulder, Boulder, Colorado, USA*
- <sup>146</sup>*Cornell University, Ithaca, New York, USA*
- <sup>147</sup>*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
- <sup>148</sup>*University of Florida, Gainesville, Florida, USA*
- <sup>149</sup>*Florida International University, Miami, Florida, USA*
- <sup>150</sup>*Florida State University, Tallahassee, Florida, USA*
- <sup>151</sup>*Florida Institute of Technology, Melbourne, Florida, USA*
- <sup>152</sup>*University of Illinois at Chicago (UIC), Chicago, Illinois, USA*
- <sup>153</sup>*The University of Iowa, Iowa City, Iowa, USA*
- <sup>154</sup>*Johns Hopkins University, Baltimore, Maryland, USA*
- <sup>155</sup>*The University of Kansas, Lawrence, Kansas, USA*
- <sup>156</sup>*Kansas State University, Manhattan, Kansas, USA*
- <sup>157</sup>*Lawrence Livermore National Laboratory, Livermore, California, USA*
- <sup>158</sup>*University of Maryland, College Park, Maryland, USA*
- <sup>159</sup>*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
- <sup>160</sup>*University of Minnesota, Minneapolis, Minnesota, USA*
- <sup>161</sup>*University of Mississippi, Oxford, Mississippi, USA*
- <sup>162</sup>*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
- <sup>163</sup>*State University of New York at Buffalo, Buffalo, New York, USA*
- <sup>164</sup>*Northeastern University, Boston, Massachusetts, USA*
- <sup>165</sup>*Northwestern University, Evanston, Illinois, USA*
- <sup>166</sup>*University of Notre Dame, Notre Dame, Indiana, USA*
- <sup>167</sup>*The Ohio State University, Columbus, Ohio, USA*

- <sup>168</sup>*Princeton University, Princeton, New Jersey, USA*  
<sup>169</sup>*University of Puerto Rico, Mayaguez, Puerto Rico, USA*  
<sup>170</sup>*Purdue University, West Lafayette, Indiana, USA*  
<sup>171</sup>*Purdue University Northwest, Hammond, Indiana, USA*  
<sup>172</sup>*Rice University, Houston, Texas, USA*  
<sup>173</sup>*University of Rochester, Rochester, New York, USA*  
<sup>174</sup>*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*  
<sup>175</sup>*University of Tennessee, Knoxville, Tennessee, USA*  
<sup>176</sup>*Texas A&M University, College Station, Texas, USA*  
<sup>177</sup>*Texas Tech University, Lubbock, Texas, USA*  
<sup>178</sup>*Vanderbilt University, Nashville, Tennessee, USA*  
<sup>179</sup>*University of Virginia, Charlottesville, Virginia, USA*  
<sup>180</sup>*Wayne State University, Detroit, Michigan, USA*  
<sup>181</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 University of Chinese Academy of Sciences.

<sup>h</sup>Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.

<sup>i</sup>Also at Joint Institute for Nuclear Research, Dubna, Russia.

<sup>j</sup>Also at Cairo University, Cairo, Egypt.

<sup>k</sup>Also at Helwan University, Cairo, Egypt.

<sup>l</sup>Also at Zewail City of Science and Technology, Zewail, Egypt.

<sup>m</sup>Also at Department of Physics, King Abdulaziz University, Jeddah, Saudi Arabia.

<sup>n</sup>Also at Université de Haute Alsace, Mulhouse, France.

<sup>o</sup>Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.

<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 Isfahan University of Technology, Isfahan, Iran.

<sup>bb</sup>Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.

<sup>cc</sup>Also at Università degli Studi di Siena, Siena, Italy.

<sup>dd</sup>Also at Kyunghee University, Seoul, Korea.

<sup>ee</sup>Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia.

<sup>ff</sup>Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia.

<sup>gg</sup>Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico.

<sup>hh</sup>Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.

<sup>ii</sup>Also at Institute for Nuclear Research, Moscow, Russia.

<sup>jj</sup>Also at National Research Nuclear University “Moscow Engineering Physics Institute” (MEPhI), Moscow, Russia.

<sup>kk</sup>Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.

<sup>ll</sup>Also at University of Florida, Gainesville, FL, USA.

<sup>mmm</sup>Also at P.N. Lebedev Physical Institute, Moscow, Russia.

<sup>nn</sup>Also at California Institute of Technology, Pasadena, CA, USA.

<sup>oo</sup>Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia.

<sup>pp</sup>Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.

<sup>qq</sup>Also at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy.

<sup>rr</sup>Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.

<sup>ss</sup>Also at Scuola Normale e Sezione dell’INFN, Pisa, Italy.



- <sup>tt</sup> Also at National and Kapodistrian University of Athens, Athens, Greece.
- <sup>uu</sup> Also at Riga Technical University, Riga, Latvia.
- <sup>vv</sup> Also at Universität Zürich, Zurich, Switzerland.
- <sup>ww</sup> Also at Stefan Meyer Institute for Subatomic Physics.
- <sup>xx</sup> Also at Adiyaman University, Adiyaman, Turkey.
- <sup>yy</sup> Also at Istanbul Aydin University, Istanbul, Turkey.
- <sup>zz</sup> Also at Mersin University, Mersin, Turkey.
- <sup>aaa</sup> Also at Piri Reis University, Istanbul, Turkey.
- <sup>bbb</sup> Also at Gaziosmanpasa University, Tokat, Turkey.
- <sup>ccc</sup> Also at Ozyegin University, Istanbul, Turkey.
- <sup>ddd</sup> Also at Izmir Institute of Technology, Izmir, Turkey.
- <sup>eee</sup> Also at Marmara University, Istanbul, Turkey.
- <sup>fff</sup> Also at Kafkas University, Kars, Turkey.
- <sup>ggg</sup> Also at Istanbul Bilgi University, Istanbul, Turkey.
- <sup>hhh</sup> Also at Hacettepe University, Ankara, Turkey.
- <sup>iii</sup> Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
- <sup>jjj</sup> Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- <sup>kkk</sup> Also at Monash University, Faculty of Science, Clayton, Australia.
- <sup>lll</sup> Also at Bethel University, Arden Hills, MN, USA.
- <sup>mmm</sup> Also at Karamanoğlu Mehmetbey University.
- <sup>nnn</sup> Also at Utah Valley University, Orem, UT, USA.
- <sup>ooo</sup> Also at Purdue University, West Lafayette, IN, USA.
- <sup>ppp</sup> Also at Beykent University, Istanbul, Turkey.
- <sup>qqq</sup> Also at Bingol University, Bingol, Turkey.
- <sup>rrr</sup> Also at Sinop University, Sinop, Turkey.
- <sup>sss</sup> Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
- <sup>ttt</sup> Also at Texas A&M University at Qatar, Doha, Qatar.
- <sup>uuu</sup> Also at Kyungpook National University, Daegu, Korea.