

## MIT Open Access Articles

*Observation of the Associated Production of a Single Top Quark and a W Boson in pp Collisions at  $\sqrt{s} = 8$  TeV*

The MIT Faculty has made this article openly available. **Please share** how this access benefits you. Your story matters.

**Citation:** Chatrchyan, S., V. Khachatryan, A. M. Sirunyan, A. Tumasyan, W. Adam, T. Bergauer, M. Dragicevic, et al. "Observation of the Associated Production of a Single Top Quark and a W Boson in pp Collisions at  $\sqrt{s} = 8$  TeV." Physical Review Letters 112, no. 23 (June 2014). © 2014 CERN, for the CMS Collaboration

**As Published:** <http://dx.doi.org/10.1103/PhysRevLett.112.231802>

**Publisher:** American Physical Society

**Persistent URL:** <http://hdl.handle.net/1721.1/90892>

**Version:** Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

**Terms of Use:** Article is made available in accordance with the publisher's policy and may be subject to US copyright law. Please refer to the publisher's site for terms of use.





## Observation of the Associated Production of a Single Top Quark and a $W$ Boson in $pp$ Collisions at $\sqrt{s} = 8$ TeV

S. Chatrchyan *et al.*\*  
(CMS Collaboration)

(Received 13 January 2014; published 9 June 2014)

The first observation of the associated production of a single top quark and a  $W$  boson is presented. The analysis is based on a data set corresponding to an integrated luminosity of  $12.2 \text{ fb}^{-1}$  of proton-proton collisions at  $\sqrt{s} = 8$  TeV recorded by the CMS experiment at the LHC. Events with two leptons and a jet originating from a  $b$  quark are selected. A multivariate analysis based on kinematic and topological properties is used to separate the signal from the dominant  $t\bar{t}$  background. An excess consistent with the signal hypothesis is observed, with a significance which corresponds to 6.1 standard deviations above a background-only hypothesis. The measured production cross section is  $23.4 \pm 5.4 \text{ pb}$ , in agreement with the standard model prediction.

DOI: [10.1103/PhysRevLett.112.231802](https://doi.org/10.1103/PhysRevLett.112.231802)

PACS numbers: 13.85.Ni, 12.15.Hh, 13.85.Qk, 14.65.Ha

Since its discovery in 1995 by the CDF [1] and D0 [2] experiments at the Tevatron, studies of the top quark have raised great interest within high energy physics. As the heaviest of all standard model (SM) particles, the top quark potentially plays an important role in electroweak symmetry breaking as well as in physics beyond the SM. The measurement of the different mechanisms by which top quarks can be produced is instrumental in advancing the understanding of physics at the TeV scale.

Top quarks are produced predominantly in pairs via the strong interaction in proton-proton ( $pp$ ) collisions but they can also be produced singly via electroweak interactions, involving a  $Wtb$  vertex. In the SM, single-top-quark production occurs mainly through three processes:  $t$ -channel ( $tqb$ ),  $s$ -channel ( $tb$ ), and associated production of a top quark and a  $W$  boson ( $tW$ ). Single-top-quark production was first observed by the D0 [3] and CDF [4] experiments. The  $t$ -channel production mode has been measured by D0 [5,6] and CDF [7] as well as at the Large Hadron Collider (LHC) by the Compact Muon Solenoid (CMS) [8] and ATLAS [9] experiments, while the observation of  $s$ -channel production was recently presented through a combination of the results of the CDF and D0 experiments [10]. The  $tW$  production cross section is negligible at the Tevatron, but large enough at the LHC to make it accessible. Evidence for this process was presented by both the ATLAS [11] and CMS [12] experiments using the 7 TeV collision data, with significances of  $3.6$  and  $4.0\sigma$ , respectively. This Letter presents the first observation of  $tW$  production at a significance of at least

$5\sigma$ , using data collected with the CMS experiment in  $pp$  collisions at  $\sqrt{s} = 8$  TeV and corresponding to an integrated luminosity of  $12.2 \text{ fb}^{-1}$ .

In addition to testing the SM predictions at the electroweak scale, associated  $tW$  production is of interest because of its sensitivity to non-SM couplings of the  $Wtb$  vertex [13–17], while being relatively insensitive to scenarios that affect the other single-top-quark production channels.

The theoretical prediction for the cross section of  $tW$  production in  $pp$  collisions at  $\sqrt{s} = 8$  TeV at approximate next-to-next-to-leading order (NNLO) is  $22.2 \pm 0.6(\text{scale}) \pm 1.4(\text{PDF}) \text{ pb}$  [18], with the first uncertainty coming from factorization and renormalization scale variations and the second from variations in the parton distribution functions of the proton. At next-to-leading order (NLO), the definition of  $tW$  production in perturbative quantum chromodynamics mixes with top-quark pair production ( $t\bar{t}$ ) [19–21]. Two schemes for defining the  $tW$  signal to distinguish it from  $t\bar{t}$  production have been proposed: the “diagram removal” (DR) [19], in which all doubly resonant NLO  $tW$  diagrams are removed, and the “diagram subtraction” [19,22], where a gauge-invariant subtraction term modifies the NLO  $tW$  cross section to locally cancel the contribution from  $t\bar{t}$ . In this Letter, the DR scheme is used for simulating the signal, but it was verified that the results are consistent between the two methods and any differences are accounted for in the systematic uncertainties.

The analysis is performed using the dilepton decay channels, in which the  $W$  boson produced in association with the top quark and the  $W$  boson from the decay of the top quark both decay leptonically into a muon or an electron, and a neutrino. This leads to a final state composed of two oppositely charged isolated leptons, a jet resulting from the fragmentation of a  $b$  quark, and two neutrinos. The neutrinos escape detection and are only discernible by the presence of missing transverse energy

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

Published by the American Physical Society under the terms of the [Creative Commons Attribution 3.0 License](https://creativecommons.org/licenses/by/3.0/). Further distribution of this work must maintain attribution to the author(s) and the published articles title, journal citation, and DOI.

( $E_T^{\text{miss}}$ ), defined as the magnitude of the vector sum of the transverse momentum of all reconstructed particles. The primary background to  $tW$  production in this final state comes from  $t\bar{t}$  production, with  $Z/\gamma^*$  events being the next most significant.

The analysis uses a multivariate technique, exploiting kinematic and topological differences to distinguish the  $tW$  signal from the dominant  $t\bar{t}$  background. To assess the robustness of the result, two additional analyses were conducted. One involves a fit to a single kinematic variable, the other is based on event counts.

The central feature of the CMS apparatus [23] is a superconducting solenoid with an internal diameter of 6 m, providing a magnetic field of 3.8 T. Within the bore of the solenoid are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter. Muons are measured in gas-ionization detectors embedded in the steel flux return yoke outside the magnet. In addition, CMS has extensive forward calorimetry. The detector covers a region of  $|\eta| < 5.0$ , where the pseudorapidity  $\eta$  is defined as  $\eta = -\ln[\tan(\theta/2)]$ , where  $\theta$  is the polar angle.

Data samples are selected based on triggers requiring two leptons (either an electron or muon), one with transverse momentum,  $p_T$ , of at least 17 GeV and a second with  $p_T$  of at least 8 GeV. All events are required to have a well-reconstructed primary vertex [24]. The primary vertex with the largest sum of  $p_T^2$  of associated tracks is chosen.

Electrons are reconstructed from energy deposits in the electromagnetic calorimeter (including energy deposits from radiated photons) matched to tracks in the silicon tracker. Muons,  $E_T^{\text{miss}}$ , and jets are reconstructed using the CMS particle flow (PF) algorithm [25,26], which performs a global event reconstruction. Electrons and muons are required to have  $p_T > 20$  GeV and fall within the pseudorapidity range of  $|\eta| < 2.5$  for electrons and  $|\eta| < 2.4$  for muons. Exactly two oppositely charged, isolated leptons are required in the event, and events are rejected if they contain additional leptons passing a looser criteria, for which the  $p_T$  threshold is lowered to 10 GeV. In order to limit the contribution from low-mass dilepton resonances, the invariant mass of the dilepton system,  $m_{\ell\ell}$  ( $\ell = e$  or  $\mu$ ), is required to be greater than 20 GeV. Events in the  $ee$  and  $\mu\mu$  final states are rejected if  $m_{\ell\ell}$  is between 81 and 101 GeV, to suppress the  $Z \rightarrow \ell\ell$  process in the same-flavor final states. Additionally, a requirement of  $E_T^{\text{miss}} > 50$  GeV is applied for these final states.

Jets are reconstructed by clustering PF candidates using the anti- $k_T$  algorithm [27] with a distance parameter of 0.5. Selected jets must be within  $|\eta| < 2.4$  and have  $p_T > 30$  GeV. Corrections are made to the jet energies for detector response as a function of  $\eta$  and  $p_T$  [28]. Additional corrections are made to subtract energy in the jet from multiple  $pp$  collisions (pileup) [29]. Jets originating from the decay of a  $b$  quark are tagged based on the

presence of a secondary vertex, identified using a multivariate algorithm combining tracking information in a discriminant [30]. A working point is chosen, corresponding to a  $b$ -tagging efficiency of approximately 70% and with a misidentification rate of 1%–2%. Loose jets, whose discrimination power against  $t\bar{t}$  background is discussed later, are defined as jets failing the requirements on  $p_T$  and  $\eta$ , but passing the less restrictive selection requirement of  $p_T > 20$  GeV and  $|\eta| < 4.9$ , while still passing all other selection criteria. In particular, loose jets that fall within  $|\eta| < 2.4$  are classified as central loose jets.

For events passing the dilepton and  $E_T^{\text{miss}}$  criteria described above, a region in which the  $tW$  signal is enhanced (signal region) and two regions dominated by background (control regions) are defined. The signal region contains events with exactly one jet passing the selection requirements, which is  $b$  tagged (1j1t region). Two control regions enriched in  $t\bar{t}$  background are defined as having exactly two jets with either one or both being  $b$  tagged (2j1t and 2j2t regions, respectively).

Events from Monte Carlo simulation are used to estimate the contributions and kinematics of signal and background processes. Single-top-quark events are simulated at NLO with the POWHEG 1.0 event generator [31–34]; MADGRAPH 5.1.3 is used for simulating  $t\bar{t}$  and single-boson events ( $V + \text{jets}$ , where  $V = W, Z$ ) [35]. Samples are produced using a top-quark mass  $m_t = 172.5$  GeV, consistent with its current best measurement [36]. Diboson backgrounds are simulated using PYTHIA 6.426 [37]. In all samples, fragmentation and hadronization are modeled with PYTHIA, and TAUOLA v27.121.5 is used to simulate  $\tau$  decays [38]. The CTEQ6L1 and CTEQ6.6M PDF sets [39] are used for samples simulated at leading-order and NLO, respectively. A full simulation of the response of the CMS detector is performed for all generated events using a GEANT4-based model [40]. The simulation includes modeling of pileup, with the distribution of the number of interactions in simulation matching that in data. Simulated samples are normalized to the NNLO cross sections for  $t\bar{t}$  [ $\sigma_{t\bar{t}} = 245.8_{-8.4}^{+6.2}(\text{scale})_{-6.4}^{+6.2}(\text{PDF})$  pb] [41],  $Z/\gamma^*$ , and  $W + \text{jets}$  processes, with approximate NNLO cross sections used for single top quark [18] and NLO for diboson processes. The  $Z/\gamma^*$  simulation is reweighted to reproduce the  $E_T^{\text{miss}}$  distribution observed in data, using events with  $m_{\ell\ell}$  in the vicinity of the  $Z$ -boson mass (81 to 101 GeV) to derive scale factors.

After the selection, the simulated samples in the 1j1t signal region contain predominantly  $tW$  and  $t\bar{t}$  events (comprising 16% and 76% of the events, respectively), with a smaller contribution from  $Z/\gamma^*$  events (6%). The two control regions are dominated by  $t\bar{t}$  production. Event yields in simulation and data in the signal and control regions are shown in Table I.

In order to separate the  $tW$  signal from the  $t\bar{t}$  background, a multivariate analysis based on boosted decision

TABLE I. Event yields in the signal and control regions. Yields from simulation are shown with statistical (first) and systematic (second) uncertainties.

|                      | $1j1t$                 | $2j1t$                  | $2j2t$                 |
|----------------------|------------------------|-------------------------|------------------------|
| $tW$                 | $1500 \pm 20 \pm 130$  | $790 \pm 20 \pm 80$     | $220 \pm 10 \pm 30$    |
| $t\bar{t}$           | $7090 \pm 60 \pm 900$  | $12910 \pm 80 \pm 1320$ | $7650 \pm 60 \pm 1020$ |
| $Z/\gamma^*$ , other | $670 \pm 30 \pm 90$    | $370 \pm 30 \pm 60$     | $36 \pm 7 \pm 12$      |
| Total simulation     | $9260 \pm 70 \pm 1040$ | $14070 \pm 90 \pm 1410$ | $7910 \pm 70 \pm 1020$ |
| Data                 | 9353                   | 13479                   | 7615                   |

trees (BDT) [42] is used, implemented with the toolkit for multivariate data analysis [43]. The BDT analyzer is trained using 13 variables, chosen for their separation power in distinguishing  $tW$  and  $t\bar{t}$ , as well as being well modeled in simulation when checked in control regions. The most powerful variables are those involving loose jets in the event: the number of loose jets, number of central loose jets, and the number of loose jets that are  $b$  tagged. Other variables with significant separation power are related to the kinematics of the system comprised of the leptons, jets and  $E_T^{\text{miss}}$ : the scalar sum of their transverse momenta ( $H_T$ ), the magnitude of the vector sum of their transverse momenta ( $p_T^{\text{sys}}$ ), and invariant mass of the system. A complete list of the variables used can be found in the Supplemental Material [44]). The distributions of the number of loose jets and the  $p_T$  of the system in the  $1j1t$  signal region are shown in Fig. 1 for all three final states ( $ee$ ,  $e\mu$ , and  $\mu\mu$ ) combined.

The BDT analyzer provides a single discriminant value for each event. The distributions of the BDT discriminant in data and simulation are shown in Fig. 2 for the  $1j1t$ ,  $2j1t$ , and  $2j2t$  regions, combining all three final states together.

The uncertainty from all systematic sources is determined by estimating their effect on the normalization and shape of the BDT discriminant for all regions and final states. The dominant systematic uncertainties come from the choice of thresholds for the matrix element and parton showering (ME/PS) matching in simulation of  $t\bar{t}$  production and the renormalization and factorization scale. The effect of these uncertainties was estimated by producing simulated samples with the value of the ME/PS matching thresholds and renormalization and factorization scale doubled and halved from their respective initial values of 20 GeV and  $m_t^2 + \sum p_T^2$  (where the sum is over all additional final state partons), contributing a 14% and 12% uncertainty, respectively, to the measured cross section. The uncertainty due to the value of the top-quark mass used in simulation is estimated by simulating  $tW$  and  $t\bar{t}$  processes with a varied value for  $m_t$ , resulting in a 9% effect on the cross section. The complete list of systematic uncertainties and corresponding effects on the cross section can be found in the Supplemental Material [44].

A simultaneous binned likelihood fit to the rate and shape of the BDT distributions of the three final states in the

three regions is performed. The two control regions are included in the fit to allow for better determination of the  $t\bar{t}$  contribution. The distributions for signal and background are taken from simulation. In the likelihood function, for each source of systematic uncertainty  $u$ , a nuisance parameter  $\theta_u$  is introduced. The rates of signal and background are allowed to vary in the fit, constrained in the likelihood function by the systematic uncertainties. The excess of events is quantified based on the score statistic  $q$ , chosen to enhance numerical stability, defined as

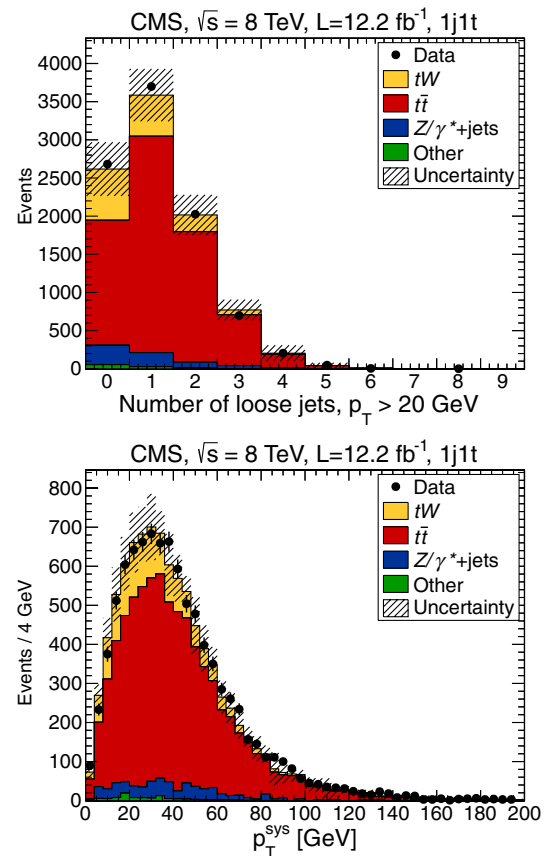


FIG. 1 (color online). The number of loose jets in the event and the  $p_T$  of the system ( $p_T^{\text{sys}}$ ) composed of the jet, leptons, and  $E_T^{\text{miss}}$ , in the signal region ( $1j1t$ ) for all final states combined. Shown are data (points) and simulation (histogram). The hatched band represents the combined effect of all sources of systematic uncertainty.

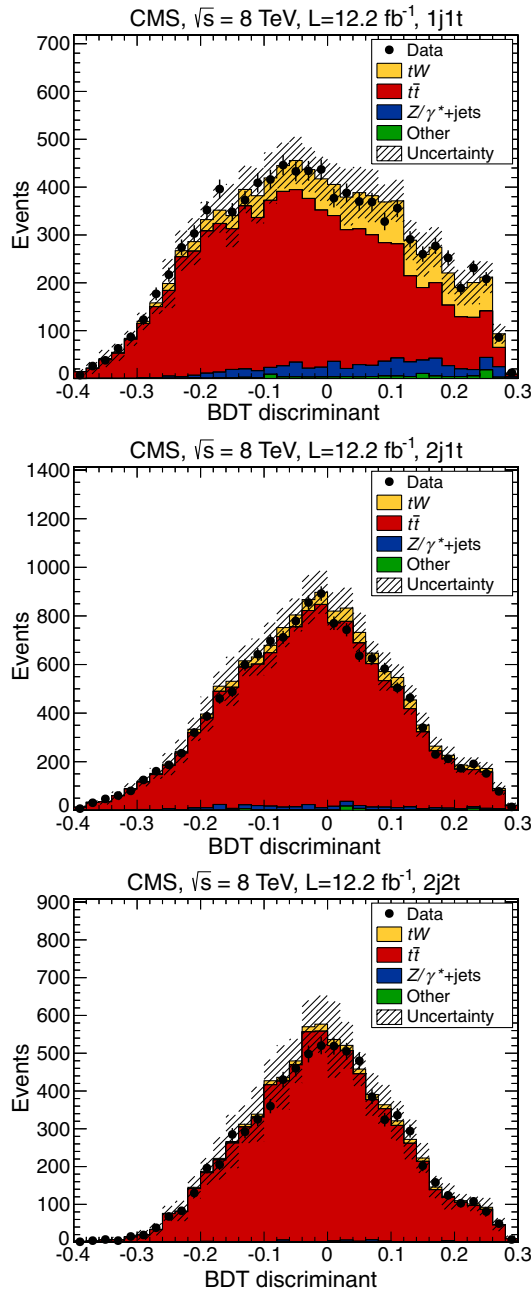


FIG. 2 (color online). The BDT discriminant, in the signal region ( $1j1t$ ) and control regions ( $2j1t$  and  $2j2t$ ) for all final states combined. Shown are data (points) and simulation (histogram). The hatched band represents the combined effect of all sources of systematic uncertainty.

$$q = \frac{\partial}{\partial \mu} \ln \mathcal{L}(\mu = 0, \hat{\theta}_0 | \text{data}),$$

where  $\mu$  is the signal strength parameter (defined as the signal cross section in units of the SM prediction) and  $\hat{\theta}_0$  is the set of nuisance parameters that maximizes the likelihood  $\mathcal{L}$  for a background-only hypothesis ( $\mu = 0$ ). The score statistic is evaluated for sets of four billion

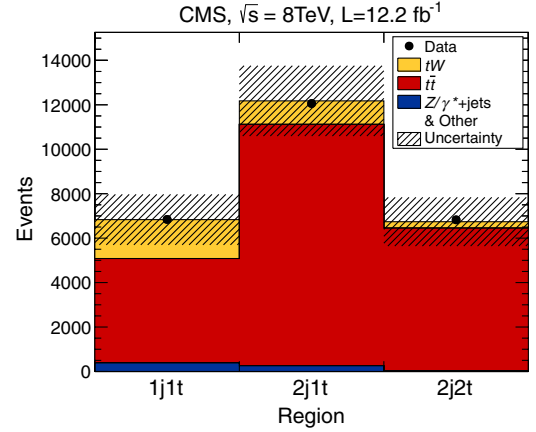


FIG. 3 (color online). Event yields in data and simulation for events passing additional requirements from the cross-check analyses. Yields are shown in the  $1j1t$  signal regions and  $2j1t$  and  $2j2t$  control regions for a combination of all three final states, with the simulation scaled to the outcome of the statistical fit from the event-count analysis. The hatched band represents the combined effect of all systematic uncertainties on the event yields.

pseudoexperiments using a background-only hypothesis. The significance is determined based on the probability of producing a score statistic value in the background-only hypothesis as high or higher than that observed in data. The expected significance is evaluated using the median and central 68% interval of the score statistic values obtained in pseudo-experiments generated under a signal-plus-background hypothesis. A profile likelihood method is used to determine the signal cross section and 68% confidence level (C.L) interval.

We observe an excess of events above the expected background with a  $p$  value of  $5 \times 10^{-10}$  corresponding to a significance of  $6.1\sigma$ , compared to an expected significance from simulation of  $5.4 \pm 1.4\sigma$ . The measured cross section is found to be  $23.4 \pm 5.4$  pb, where the uncertainty is mainly systematic, in agreement with the predicted SM value of  $22.2 \pm 0.6(\text{scale}) \pm 1.4(\text{PDF})$  pb.

The cross section measurement is used to determine the absolute value of the Cabibbo-Kobayashi-Maskawa matrix element  $|V_{tb}|$ , assuming  $|V_{tb}| \gg |V_{td}|$  and  $|V_{ts}|$

$$|V_{tb}| = \sqrt{\sigma_{tW}/\sigma_{tW}^{\text{th}}} = 1.03 \pm 0.12(\text{exp}) \pm 0.04(\text{th.}),$$

where  $\sigma_{tW}^{\text{th}}$  is the theoretical prediction of the  $tW$  cross section assuming  $|V_{tb}| = 1$ , and the uncertainties are separated into experimental and theoretical values. Using the SM assumption  $0 \leq |V_{tb}|^2 \leq 1$ , a lower bound  $|V_{tb}| > 0.78$  at 95% C.L. is found using the approach of Feldman and Cousins [45].

Using the same selection as in the BDT analysis, two cross-check analyses are performed. Events containing any

$b$ -tagged loose jets are rejected. Additionally, a requirement of  $H_T > 160$  GeV is added in the  $e\mu$  final state, where no  $E_T^{\text{miss}}$  requirement is applied. The effects of systematic uncertainties are taken into account in the same way as for the BDT analysis, and the same method for extraction of the significance and cross section is used. The first cross-check analysis is based on the distribution of  $p_T^{\text{sys}}$  rather than the BDT discriminant, and results in an observed significance of  $4.0\sigma$  above a background-only hypothesis, with an expected significance of  $3.2_{-0.9}^{+0.4}\sigma$ , and a measured cross section of  $24.3 \pm 8.6$  pb. The second cross-check analysis is based only on event counts after selection, and an excess of events is observed above the background with a significance of  $3.6\sigma$ , with an expected significance based on simulation of  $2.8 \pm 0.9\sigma$ , and a measured cross section of  $33.9 \pm 8.6$  pb. Event yields in data and simulation for this analysis are shown in Fig. 3, with the simulation scaled to the result of the statistical fit. The results of both analyses are consistent with those found in the BDT analysis, but with larger, mostly systematic, uncertainties.

In summary, the production of a single top quark in association with a  $W$  boson is observed for the first time. The analysis uses data collected by the CMS experiment in  $pp$  collisions at  $\sqrt{s} = 8$  TeV, corresponding to an integrated luminosity of  $12.2 \text{ fb}^{-1}$ . An excess of events above background is found with a significance of  $6.1\sigma$ , and a  $tW$  production cross section of  $23.4 \pm 5.4$  pb is measured, in agreement with the standard model prediction.

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); MoER, Contract No. SF0690030s09, 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); NRF and WCU (Republic of Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, and RFBR (Russia); MESTD (Serbia); SEIDI and CPAN

(Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

- 
- [1] CDF Collaboration, *Phys. Rev. Lett.* **74**, 2626 (1995).
  - [2] D0 Collaboration, *Phys. Rev. Lett.* **74**, 2632 (1995).
  - [3] D0 Collaboration, *Phys. Rev. Lett.* **103**, 092001 (2009).
  - [4] CDF Collaboration, *Phys. Rev. Lett.* **103**, 092002 (2009).
  - [5] D0 Collaboration, *Phys. Lett. B* **682**, 363 (2010).
  - [6] D0 Collaboration, *Phys. Lett. B* **705**, 313 (2011).
  - [7] CDF Collaboration, *Phys. Rev. D* **82**, 112005 (2010).
  - [8] CMS Collaboration, *Phys. Rev. Lett.* **107**, 091802 (2011).
  - [9] ATLAS Collaboration, *Phys. Lett. B* **717**, 330 (2012).
  - [10] CDF and D0 Collaborations, *Phys. Rev. Lett.* **112**, 231803 (2014).
  - [11] ATLAS Collaboration, *Phys. Lett. B* **716**, 142 (2012).
  - [12] CMS Collaboration, *Phys. Rev. Lett.* **110**, 022003 (2013).
  - [13] T. M. P. Tait and C.-P. Yuan, *Phys. Rev. D* **63**, 014018 (2000).
  - [14] Q.-H. Cao, J. Wudka, and C.-P. Yuan, *Phys. Lett. B* **658**, 50 (2007).
  - [15] V. Barger, M. McCaskey, and G. Shaughnessy, *Phys. Rev. D* **81**, 034020 (2010).
  - [16] R. M. Godbole, L. Hartgring, I. Niessen, and C. D. White, *J. High Energy Phys.* **01** (2012), 011.
  - [17] S. Y. Ayazi, H. Hesari, and M. M. Najafabadi, *Phys. Lett. B* **727**, 199 (2013).
  - [18] N. Kidonakis, [arXiv:1210.7813](https://arxiv.org/abs/1210.7813).
  - [19] S. Frixione, E. Laenen, P. Motylinski, C. White, and B. R. Webber, *J. High Energy Phys.* **07** (2008) 029.
  - [20] A. S. Belyaev, E. E. Boos, and L. V. Dudko, *Phys. Rev. D* **59**, 075001 (1999).
  - [21] C. D. White, S. Frixione, E. Laenen, and F. Maltoni, *J. High Energy Phys.* **11** (2009) 074.
  - [22] T. M. P. Tait, *Phys. Rev. D* **61**, 034001 (1999).
  - [23] CMS Collaboration, *JINST* **3**, S08004 (2008).
  - [24] CMS Collaboration, Tracking and Primary Vertex Results in First 7 TeV Collisions, CMS Physics Analysis Summary Report No. CMS-PAS-TRK-10-005, 2010 (unpublished); <http://cdsweb.cern.ch/record/1279383>.
  - [25] CMS Collaboration, Particle Flow Event Reconstruction in CMS and Performance for Jets, Taus, and MET, CMS Physics Analysis Summary Report No. CMS-PAS-PFT-09-001, 2009 (unpublished); <http://cdsweb.cern.ch/record/1194487>.
  - [26] CMS Collaboration, Commissioning of the Particle-Flow Reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV, CMS Physics Analysis Summary Report No. CMS-PAS-PFT-10-002, 2010 (unpublished); <http://cdsweb.cern.ch/record/1279341>.
  - [27] M. Cacciari, G. P. Salam, and G. Soyez, *J. High Energy Phys.* **04** (2008) 063.

- [28] CMS Collaboration, *JINST* **6**, P11002 (2011).  
 [29] G. Soyez, G. P. Salam, J.-H. Kim, S. Dutta, and M. Cacciari, *Phys. Rev. Lett.* **110**, 162001 (2013).  
 [30] CMS Collaboration, *JINST* **8**, P04013 (2013).  
 [31] P. Nason, *J. High Energy Phys.* **11** (2004) 040.  
 [32] S. Frixione, P. Nason, and C. Oleari, *J. High Energy Phys.* **11** (2007) 070.  
 [33] S. Alioli, P. Nason, C. Oleari, and E. Re, *J. High Energy Phys.* **06** (2010) 043.  
 [34] E. Re, *Eur. Phys. J. C* **71**, 1547 (2011).  
 [35] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, and T. Stelzer, *J. High Energy Phys.* **06** (2011) 128.  
 [36] CDF and D0 Collaborations, *Phys. Rev. D* **86**, 092003 (2012), an update can be found in [arXiv:1305.3929](https://arxiv.org/abs/1305.3929).  
 [37] T. Sjöstrand, S. Mrenna, and P. Skands, *J. High Energy Phys.* **05** (2006) 026.  
 [38] N. Davidson, G. Nanava, T. Przedzinski, E. Richter-Was, and Z. Was, *Comput. Phys. Commun.* **183**, 821 (2012).  
 [39] P. M. Nadolsky, H.-L. Lai, Q.-H. Cao, J. Huston, J. Pumplin, D. Stump, W.-K. Tung, and C.-P. Yuan, *Phys. Rev. D* **78**, 013004 (2008).  
 [40] GEANT4, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).  
 [41] M. Czakon, P. Fiedler, and A. Mitov, *Phys. Rev. Lett.* **110**, 252004 (2013).  
 [42] L. Breiman, J. Friedman, C. J. Stone, and R. A. Olshen, *Classification and Regression Trees* (Chapman and Hall, London, 1984).  
 [43] H. Voss, A. Höcker, J. Stelzer, and F. Tegenfeldt, *Proc. Sci.*, ACAT2007 (2007) 040 [[arXiv:physics/0703039](https://arxiv.org/abs/physics/0703039)].  
 [44] See Supplemental Material at <http://link.aps.org/supplemental/10.1103/PhysRevLett.112.231802> for a list and distributions of the variables used in the BDT, BDT distributions in additional control regions, the event yields split by channel, and a list of the systematic uncertainties.  
 [45] G. J. Feldman and R. D. Cousins, *Phys. Rev. D* **57**, 3873 (1998).

---

S. Chatrchyan,<sup>1</sup> V. Khachatryan,<sup>1</sup> A. M. Sirunyan,<sup>1</sup> A. Tumasyan,<sup>1</sup> W. Adam,<sup>2</sup> T. Bergauer,<sup>2</sup> M. Dragicevic,<sup>2</sup> J. Erö,<sup>2</sup> C. Fabjan,<sup>2,b</sup> M. Friedl,<sup>2</sup> R. Frühwirth,<sup>2,b</sup> V. M. Ghete,<sup>2</sup> C. Hartl,<sup>2</sup> N. Hörmann,<sup>2</sup> J. Hrubec,<sup>2</sup> M. Jeitler,<sup>2,b</sup> W. Kiesenhofer,<sup>2</sup> V. Knünz,<sup>2</sup> M. Krammer,<sup>2,b</sup> I. Krätschmer,<sup>2</sup> D. Liko,<sup>2</sup> I. Mikulec,<sup>2</sup> D. Rabady,<sup>2,c</sup> B. Rahbaran,<sup>2</sup> H. Rohringer,<sup>2</sup> R. Schöfbeck,<sup>2</sup> J. Strauss,<sup>2</sup> A. Taurok,<sup>2</sup> W. Treberer-Treberspurg,<sup>2</sup> W. Waltenberger,<sup>2</sup> C.-E. Wulz,<sup>2,b</sup> V. Mossolov,<sup>3</sup> N. Shumeiko,<sup>3</sup> J. Suarez Gonzalez,<sup>3</sup> S. Alderweireldt,<sup>4</sup> M. Bansal,<sup>4</sup> S. Bansal,<sup>4</sup> T. Cornelis,<sup>4</sup> E. A. De Wolf,<sup>4</sup> X. Janssen,<sup>4</sup> A. Knutsson,<sup>4</sup> S. Luyckx,<sup>4</sup> L. Mucibello,<sup>4</sup> S. Ochesanu,<sup>4</sup> B. Roland,<sup>4</sup> R. Rougny,<sup>4</sup> H. Van Haevermaet,<sup>4</sup> P. Van Mechelen,<sup>4</sup> N. Van Remortel,<sup>4</sup> A. Van Spilbeeck,<sup>4</sup> F. Blekman,<sup>5</sup> S. Blyweert,<sup>5</sup> J. D'Hondt,<sup>5</sup> N. Heracleous,<sup>5</sup> A. Kalogeropoulos,<sup>5</sup> J. Keaveney,<sup>5</sup> T. J. Kim,<sup>5</sup> S. Lowette,<sup>5</sup> M. Maes,<sup>5</sup> A. Olbrechts,<sup>5</sup> D. Strom,<sup>5</sup> S. Tavernier,<sup>5</sup> W. Van Doninck,<sup>5</sup> P. Van Mulders,<sup>5</sup> G. P. Van Onsem,<sup>5</sup> I. Van Parijs,<sup>5</sup> I. Villella,<sup>5</sup> C. Caillol,<sup>6</sup> B. Clerbaux,<sup>6</sup> G. De Lentdecker,<sup>6</sup> L. Favart,<sup>6</sup> A. P. R. Gay,<sup>6</sup> A. Léonard,<sup>6</sup> P. E. Marage,<sup>6</sup> A. Mohammadi,<sup>6</sup> L. Perniè,<sup>6</sup> T. Reis,<sup>6</sup> T. Seva,<sup>6</sup> L. Thomas,<sup>6</sup> C. Vander Velde,<sup>6</sup> P. Vanlaer,<sup>6</sup> J. Wang,<sup>6</sup> V. Adler,<sup>7</sup> K. Beernaert,<sup>7</sup> L. Benucci,<sup>7</sup> A. Cimmino,<sup>7</sup> S. Costantini,<sup>7</sup> S. Dildick,<sup>7</sup> G. Garcia,<sup>7</sup> B. Klein,<sup>7</sup> J. Lellouch,<sup>7</sup> J. McCartin,<sup>7</sup> A. A. Ocampo Rios,<sup>7</sup> D. Ryckbosch,<sup>7</sup> S. Salva Diblen,<sup>7</sup> M. Sigamani,<sup>7</sup> N. Strobbe,<sup>7</sup> F. Thyssen,<sup>7</sup> M. Tytgat,<sup>7</sup> S. Walsh,<sup>7</sup> E. Yazgan,<sup>7</sup> N. Zaganidis,<sup>7</sup> S. Basegmez,<sup>8</sup> C. Beluffi,<sup>8,d</sup> G. Bruno,<sup>8</sup> R. Castello,<sup>8</sup> A. Caudron,<sup>8</sup> L. Ceard,<sup>8</sup> G. G. Da Silveira,<sup>8</sup> C. Delaere,<sup>8</sup> T. du Pree,<sup>8</sup> D. Favart,<sup>8</sup> L. Forthomme,<sup>8</sup> A. Giammanco,<sup>8,e</sup> J. Hollar,<sup>8</sup> P. Jez,<sup>8</sup> M. Komm,<sup>8</sup> V. Lemaître,<sup>8</sup> J. Liao,<sup>8</sup> O. Militaru,<sup>8</sup> C. Nuttens,<sup>8</sup> D. Pagano,<sup>8</sup> A. Pin,<sup>8</sup> K. Piotrkowski,<sup>8</sup> A. Popov,<sup>8,f</sup> L. Quertenmont,<sup>8</sup> M. Selvaggi,<sup>8</sup> M. Vidal Marono,<sup>8</sup> J. M. Vizan Garcia,<sup>8</sup> N. Belyi,<sup>9</sup> T. Caebergs,<sup>9</sup> E. Daubie,<sup>9</sup> G. H. Hammad,<sup>9</sup> G. A. Alves,<sup>10</sup> M. Correa Martins Junior,<sup>10</sup> T. Martins,<sup>10</sup> M. E. Pol,<sup>10</sup> M. H. G. Souza,<sup>10</sup> W. L. Aldá Júnior,<sup>11</sup> W. Carvalho,<sup>11</sup> J. Chinellato,<sup>11,g</sup> A. Custódio,<sup>11</sup> E. M. Da Costa,<sup>11</sup> D. De Jesus Damiao,<sup>11</sup> C. De Oliveira Martins,<sup>11</sup> S. Fonseca De Souza,<sup>11</sup> H. Malbouisson,<sup>11</sup> M. Malek,<sup>11</sup> D. Matos Figueiredo,<sup>11</sup> L. Mundim,<sup>11</sup> H. Nogima,<sup>11</sup> W. L. Prado Da Silva,<sup>11</sup> J. Santaolalla,<sup>11</sup> A. Santoro,<sup>11</sup> A. Sznajder,<sup>11</sup> E. J. Tonelli Manganote,<sup>11,g</sup> A. Vilela Pereira,<sup>11</sup> C. A. Bernardes,<sup>12b</sup> F. A. Dias,<sup>12a,h</sup> T. R. Fernandez Perez Tomei,<sup>12a</sup> E. M. Gregores,<sup>12b</sup> C. Lagana,<sup>12a</sup> P. G. Mercadante,<sup>12b</sup> S. F. Novaes,<sup>12a</sup> Sandra S. Padula,<sup>12a</sup> V. Genchev,<sup>13,c</sup> P. Iaydjiev,<sup>13,c</sup> A. Marinov,<sup>13</sup> S. Piperov,<sup>13</sup> M. Rodozov,<sup>13</sup> G. Sultanov,<sup>13</sup> M. Vutova,<sup>13</sup> A. Dimitrov,<sup>14</sup> I. Glushkov,<sup>14</sup> R. Hadjiiska,<sup>14</sup> V. Kozhuharov,<sup>14</sup> L. Litov,<sup>14</sup> B. Pavlov,<sup>14</sup> P. Petkov,<sup>14</sup> J. G. Bian,<sup>15</sup> G. M. Chen,<sup>15</sup> H. S. Chen,<sup>15</sup> M. Chen,<sup>15</sup> R. Du,<sup>15</sup> C. H. Jiang,<sup>15</sup> D. Liang,<sup>15</sup> S. Liang,<sup>15</sup> X. Meng,<sup>15</sup> R. Plestina,<sup>15,i</sup> J. Tao,<sup>15</sup> X. Wang,<sup>15</sup> Z. Wang,<sup>15</sup> C. Asawatangtrakuldee,<sup>16</sup> Y. Ban,<sup>16</sup> Y. Guo,<sup>16</sup> Q. Li,<sup>16</sup> W. Li,<sup>16</sup> S. Liu,<sup>16</sup> Y. Mao,<sup>16</sup> S. J. Qian,<sup>16</sup> D. Wang,<sup>16</sup> L. Zhang,<sup>16</sup> W. Zou,<sup>16</sup> C. Avila,<sup>17</sup> C. A. Carrillo Montoya,<sup>17</sup> L. F. Chaparro Sierra,<sup>17</sup> C. Florez,<sup>17</sup> J. P. Gomez,<sup>17</sup> B. Gomez Moreno,<sup>17</sup> J. C. Sanabria,<sup>17</sup> N. Godinovic,<sup>18</sup> D. Lelas,<sup>18</sup> D. Polic,<sup>18</sup> I. Puljak,<sup>18</sup> Z. Antunovic,<sup>19</sup> M. Kovac,<sup>19</sup> V. Brigljevic,<sup>20</sup> K. Kadija,<sup>20</sup> J. Luetic,<sup>20</sup> D. Mekterovic,<sup>20</sup> S. Morovic,<sup>20</sup> L. Tikvica,<sup>20</sup> A. Attikis,<sup>21</sup> G. Mavromanolakis,<sup>21</sup> J. Mousa,<sup>21</sup> C. Nicolaou,<sup>21</sup> F. Ptochos,<sup>21</sup> P. A. Razis,<sup>21</sup> M. Finger,<sup>22</sup> M. Finger Jr.,<sup>22</sup> A. A. Abdelalim,<sup>23,j</sup> Y. Assran,<sup>23,k</sup> S. Elgammal,<sup>23,j</sup> A. Ellithi Kamel,<sup>23,l</sup> M. A. Mahmoud,<sup>23,m</sup> A. Radi,<sup>23,n,o</sup>

M. Kadastik,<sup>24</sup> M. Müntel,<sup>24</sup> M. Murumaa,<sup>24</sup> M. Raidal,<sup>24</sup> L. Rebane,<sup>24</sup> A. Tiko,<sup>24</sup> P. Eerola,<sup>25</sup> G. Fedi,<sup>25</sup> M. Voutilainen,<sup>25</sup> J. Härkönen,<sup>26</sup> V. Karimäki,<sup>26</sup> R. Kinnunen,<sup>26</sup> M. J. Kortelainen,<sup>26</sup> T. Lampén,<sup>26</sup> K. Lassila-Perini,<sup>26</sup> S. Lehti,<sup>26</sup> T. Lindén,<sup>26</sup> P. Luukka,<sup>26</sup> T. Mäenpää,<sup>26</sup> T. Peltola,<sup>26</sup> E. Tuominen,<sup>26</sup> J. Tuominiemi,<sup>26</sup> E. Tuovinen,<sup>26</sup> L. Wendland,<sup>26</sup> T. Tuuva,<sup>27</sup> M. Besancon,<sup>28</sup> F. Couderc,<sup>28</sup> M. Dejardin,<sup>28</sup> D. Denegri,<sup>28</sup> B. Fabbro,<sup>28</sup> J. L. Faure,<sup>28</sup> F. Ferri,<sup>28</sup> S. Ganjour,<sup>28</sup> A. Givernaud,<sup>28</sup> P. Gras,<sup>28</sup> G. Hamel de Monchenault,<sup>28</sup> P. Jarry,<sup>28</sup> E. Locci,<sup>28</sup> J. Malcles,<sup>28</sup> A. Nayak,<sup>28</sup> J. Rander,<sup>28</sup> A. Rosowsky,<sup>28</sup> M. Titov,<sup>28</sup> S. Baffioni,<sup>29</sup> F. Beaudette,<sup>29</sup> P. Busson,<sup>29</sup> C. Charlot,<sup>29</sup> N. Daci,<sup>29</sup> T. Dahms,<sup>29</sup> M. Dalchenko,<sup>29</sup> L. Dobrzynski,<sup>29</sup> A. Florent,<sup>29</sup> R. Granier de Cassagnac,<sup>29</sup> P. Miné,<sup>29</sup> C. Mironov,<sup>29</sup> I. N. Naranjo,<sup>29</sup> M. Nguyen,<sup>29</sup> C. Ochando,<sup>29</sup> P. Paganini,<sup>29</sup> D. Sabes,<sup>29</sup> R. Salerno,<sup>29</sup> Y. Sirois,<sup>29</sup> C. Veelken,<sup>29</sup> Y. Yilmaz,<sup>29</sup> A. Zabi,<sup>29</sup> J.-L. Agram,<sup>30,p</sup> J. Andrea,<sup>30</sup> D. Bloch,<sup>30</sup> J.-M. Brom,<sup>30</sup> E. C. Chabert,<sup>30</sup> C. Collard,<sup>30</sup> E. Conte,<sup>30,p</sup> F. Drouhin,<sup>30,p</sup> J.-C. Fontaine,<sup>30,p</sup> D. Gelé,<sup>30</sup> U. Goerlach,<sup>30</sup> C. Goetzmann,<sup>30</sup> P. Juillot,<sup>30</sup> A.-C. Le Bihan,<sup>30</sup> P. Van Hove,<sup>30</sup> S. Gadrat,<sup>31</sup> S. Beauceron,<sup>32</sup> N. Beaupere,<sup>32</sup> G. Boudoul,<sup>32</sup> S. Brochet,<sup>32</sup> J. Chasserat,<sup>32</sup> R. Chierici,<sup>32</sup> D. Contardo,<sup>32</sup> P. Depasse,<sup>32</sup> H. El Mamouni,<sup>32</sup> J. Fan,<sup>32</sup> J. Fay,<sup>32</sup> S. Gascon,<sup>32</sup> M. Gouzevitch,<sup>32</sup> B. Ille,<sup>32</sup> T. Kurca,<sup>32</sup> M. Lethuillier,<sup>32</sup> L. Mirabito,<sup>32</sup> S. Perries,<sup>32</sup> J. D. Ruiz Alvarez,<sup>32</sup> L. Sgandurra,<sup>32</sup> V. Sordini,<sup>32</sup> M. Vander Donckt,<sup>32</sup> P. Verdier,<sup>32</sup> S. Viret,<sup>32</sup> H. Xiao,<sup>32</sup> Z. Tsamalaidze,<sup>33,q</sup> C. Autermann,<sup>34</sup> S. Beranek,<sup>34</sup> M. Bontenackels,<sup>34</sup> B. Calpas,<sup>34</sup> M. Edelhoff,<sup>34</sup> L. Feld,<sup>34</sup> O. Hindrichs,<sup>34</sup> K. Klein,<sup>34</sup> A. Ostapchuk,<sup>34</sup> A. Perieanu,<sup>34</sup> F. Raupach,<sup>34</sup> J. Sammet,<sup>34</sup> S. Schael,<sup>34</sup> D. Sprenger,<sup>34</sup> H. Weber,<sup>34</sup> B. Wittmer,<sup>34</sup> V. Zhukov,<sup>34,f</sup> M. Ata,<sup>35</sup> J. Caudron,<sup>35</sup> E. Dietz-Laursonn,<sup>35</sup> D. Duchardt,<sup>35</sup> M. Erdmann,<sup>35</sup> R. Fischer,<sup>35</sup> A. Güth,<sup>35</sup> T. Hebbeker,<sup>35</sup> C. Heidemann,<sup>35</sup> K. Hoepfner,<sup>35</sup> D. Klingebiel,<sup>35</sup> S. Knutzen,<sup>35</sup> P. Kreuzer,<sup>35</sup> M. Merschmeyer,<sup>35</sup> A. Meyer,<sup>35</sup> M. Olschewski,<sup>35</sup> K. Padeken,<sup>35</sup> P. Papacz,<sup>35</sup> H. Reithler,<sup>35</sup> S. A. Schmitz,<sup>35</sup> L. Sonnenschein,<sup>35</sup> D. Teyssier,<sup>35</sup> S. Thüer,<sup>35</sup> M. Weber,<sup>35</sup> V. Cherepanov,<sup>36</sup> Y. Erdogan,<sup>36</sup> G. Flügge,<sup>36</sup> H. Geenen,<sup>36</sup> M. Geisler,<sup>36</sup> W. Haj Ahmad,<sup>36</sup> F. Hoehle,<sup>36</sup> B. Kargoll,<sup>36</sup> T. Kress,<sup>36</sup> Y. Kuessel,<sup>36</sup> J. Lingemann,<sup>36,c</sup> A. Nowack,<sup>36</sup> I. M. Nugent,<sup>36</sup> L. Perchalla,<sup>36</sup> O. Pooth,<sup>36</sup> A. Stahl,<sup>36</sup> I. Asin,<sup>37</sup> N. Bartosik,<sup>37</sup> J. Behr,<sup>37</sup> W. Behrenhoff,<sup>37</sup> U. Behrens,<sup>37</sup> A. J. Bell,<sup>37</sup> M. Bergholz,<sup>37,r</sup> A. Bethani,<sup>37</sup> K. Borras,<sup>37</sup> A. Burgmeier,<sup>37</sup> A. Cakir,<sup>37</sup> L. Calligaris,<sup>37</sup> A. Campbell,<sup>37</sup> S. Choudhury,<sup>37</sup> F. Costanza,<sup>37</sup> C. Diez Pardos,<sup>37</sup> S. Dooling,<sup>37</sup> T. Dorland,<sup>37</sup> G. Eckerlin,<sup>37</sup> D. Eckstein,<sup>37</sup> T. Eichhorn,<sup>37</sup> G. Flucke,<sup>37</sup> A. Geiser,<sup>37</sup> A. Grebenyuk,<sup>37</sup> P. Gunnellini,<sup>37</sup> S. Habib,<sup>37</sup> J. Hauk,<sup>37</sup> G. Hellwig,<sup>37</sup> M. Hempel,<sup>37</sup> D. Horton,<sup>37</sup> H. Jung,<sup>37</sup> M. Kasemann,<sup>37</sup> P. Katsas,<sup>37</sup> J. Kieseler,<sup>37</sup> C. Kleinwort,<sup>37</sup> M. Krämer,<sup>37</sup> D. Krücker,<sup>37</sup> W. Lange,<sup>37</sup> J. Leonard,<sup>37</sup> K. Lipka,<sup>37</sup> W. Lohmann,<sup>37,r</sup> B. Lutz,<sup>37</sup> R. Mankel,<sup>37</sup> I. Marfin,<sup>37</sup> I.-A. Melzer-Pellmann,<sup>37</sup> A. B. Meyer,<sup>37</sup> J. Mnich,<sup>37</sup> A. Mussgiller,<sup>37</sup> S. Naumann-Emme,<sup>37</sup> O. Novgorodova,<sup>37</sup> F. Nowak,<sup>37</sup> H. Perrey,<sup>37</sup> A. Petrukhin,<sup>37</sup> D. Pitzl,<sup>37</sup> R. Placakyte,<sup>37</sup> A. Raspereza,<sup>37</sup> P. M. Ribeiro Cipriano,<sup>37</sup> C. Riedl,<sup>37</sup> E. Ron,<sup>37</sup> M. Ö. Sahin,<sup>37</sup> J. Salfeld-Nebgen,<sup>37</sup> P. Saxena,<sup>37</sup> R. Schmidt,<sup>37,r</sup> T. Schoerner-Sadenius,<sup>37</sup> M. Schröder,<sup>37</sup> M. Stein,<sup>37</sup> A. D. R. Vargas Trevino,<sup>37</sup> R. Walsh,<sup>37</sup> C. Wissing,<sup>37</sup> M. Aldaya Martin,<sup>38</sup> V. Blobel,<sup>38</sup> H. Enderle,<sup>38</sup> J. Erfle,<sup>38</sup> E. Garutti,<sup>38</sup> K. Goebel,<sup>38</sup> M. Görner,<sup>38</sup> M. Gosselink,<sup>38</sup> J. Haller,<sup>38</sup> R. S. Höing,<sup>38</sup> H. Kirschenmann,<sup>38</sup> R. Klanner,<sup>38</sup> R. Kogler,<sup>38</sup> J. Lange,<sup>38</sup> I. Marchesini,<sup>38</sup> J. Ott,<sup>38</sup> T. Peiffer,<sup>38</sup> N. Pietsch,<sup>38</sup> D. Rathjens,<sup>38</sup> C. Sander,<sup>38</sup> H. Schettler,<sup>38</sup> P. Schleper,<sup>38</sup> E. Schlieckau,<sup>38</sup> A. Schmidt,<sup>38</sup> M. Seidel,<sup>38</sup> J. Sibille,<sup>38,s</sup> V. Sola,<sup>38</sup> H. Stadie,<sup>38</sup> G. Steinbrück,<sup>38</sup> D. Troendle,<sup>38</sup> E. Usai,<sup>38</sup> L. Vanelderen,<sup>38</sup> C. Barth,<sup>39</sup> C. Baus,<sup>39</sup> J. Berger,<sup>39</sup> C. Böser,<sup>39</sup> E. Butz,<sup>39</sup> T. Chwalek,<sup>39</sup> W. De Boer,<sup>39</sup> A. Descroix,<sup>39</sup> A. Dierlamm,<sup>39</sup> M. Feindt,<sup>39</sup> M. Guthoff,<sup>39,c</sup> F. Hartmann,<sup>39,c</sup> T. Hauth,<sup>39,c</sup> H. Held,<sup>39</sup> K. H. Hoffmann,<sup>39</sup> U. Husemann,<sup>39</sup> I. Katkov,<sup>39,f</sup> A. Kornmayer,<sup>39,c</sup> E. Kuznetsova,<sup>39</sup> P. Lobelle Pardo,<sup>39</sup> D. Martschei,<sup>39</sup> M. U. Mozer,<sup>39</sup> Th. Müller,<sup>39</sup> M. Niegel,<sup>39</sup> A. Nürnberg,<sup>39</sup> O. Oberst,<sup>39</sup> G. Quast,<sup>39</sup> K. Rabbertz,<sup>39</sup> F. Ratnikov,<sup>39</sup> S. Röcker,<sup>39</sup> F.-P. Schilling,<sup>39</sup> G. Schott,<sup>39</sup> H. J. Simonis,<sup>39</sup> F. M. Stober,<sup>39</sup> R. Ulrich,<sup>39</sup> J. Wagner-Kuhr,<sup>39</sup> S. Wayand,<sup>39</sup> T. Weiler,<sup>39</sup> R. Wolf,<sup>39</sup> M. Zeise,<sup>39</sup> G. Anagnostou,<sup>40</sup> G. Daskalakis,<sup>40</sup> T. Geralis,<sup>40</sup> S. Kesisoglou,<sup>40</sup> A. Kyriakis,<sup>40</sup> D. Loukas,<sup>40</sup> A. Markou,<sup>40</sup> C. Markou,<sup>40</sup> E. Ntomari,<sup>40</sup> A. Psallidas,<sup>40</sup> I. Topsis-giotis,<sup>40</sup> L. Gouskos,<sup>41</sup> A. Panagiotou,<sup>41</sup> N. Saoulidou,<sup>41</sup> E. Stiliaris,<sup>41</sup> X. Aslanoglou,<sup>42</sup> I. Evangelou,<sup>42</sup> G. Flouris,<sup>42</sup> C. Foudas,<sup>42</sup> P. Kokkas,<sup>42</sup> N. Manthos,<sup>42</sup> I. Papadopoulos,<sup>42</sup> E. Paradas,<sup>42</sup> G. Bencze,<sup>43</sup> C. Hajdu,<sup>43</sup> P. Hidas,<sup>43</sup> D. Horvath,<sup>43,t</sup> F. Sikler,<sup>43</sup> V. Veszpremi,<sup>43</sup> G. Vesztergombi,<sup>43,u</sup> A. J. Zsigmond,<sup>43</sup> N. Beni,<sup>44</sup> S. Czellar,<sup>44</sup> J. Molnar,<sup>44</sup> J. Palinkas,<sup>44</sup> Z. Szillasi,<sup>44</sup> J. Karancsi,<sup>45</sup> P. Raics,<sup>45</sup> Z. L. Trocsanyi,<sup>45</sup> B. Ujvari,<sup>45</sup> S. K. Swain,<sup>46</sup> S. B. Beri,<sup>47</sup> V. Bhatnagar,<sup>47</sup> N. Dhingra,<sup>47</sup> R. Gupta,<sup>47</sup> M. Kaur,<sup>47</sup> M. Z. Mehta,<sup>47</sup> M. Mittal,<sup>47</sup> N. Nishu,<sup>47</sup> A. Sharma,<sup>47</sup> J. B. Singh,<sup>47</sup> Ashok Kumar,<sup>48</sup> Arun Kumar,<sup>48</sup> S. Ahuja,<sup>48</sup> A. Bhardwaj,<sup>48</sup> B. C. Choudhary,<sup>48</sup> A. Kumar,<sup>48</sup> S. Malhotra,<sup>48</sup> M. Naimuddin,<sup>48</sup> K. Ranjan,<sup>48</sup> V. Sharma,<sup>48</sup> R. K. Shivpuri,<sup>48</sup> S. Banerjee,<sup>49</sup> S. Bhattacharya,<sup>49</sup> K. Chatterjee,<sup>49</sup> S. Dutta,<sup>49</sup> B. Gomber,<sup>49</sup> Sa. Jain,<sup>49</sup> Sh. Jain,<sup>49</sup> R. Khurana,<sup>49</sup> A. Modak,<sup>49</sup> S. Mukherjee,<sup>49</sup> D. Roy,<sup>49</sup> S. Sarkar,<sup>49</sup> M. Sharan,<sup>49</sup> A. P. Singh,<sup>49</sup> A. Abdulsalam,<sup>50</sup> D. Dutta,<sup>50</sup> S. Kailas,<sup>50</sup> V. Kumar,<sup>50</sup> A. K. Mohanty,<sup>50,c</sup> L. M. Pant,<sup>50</sup> P. Shukla,<sup>50</sup> A. Topkar,<sup>50</sup> T. Aziz,<sup>51</sup> R. M. Chatterjee,<sup>51</sup> S. Ganguly,<sup>51</sup> S. Ghosh,<sup>51</sup> M. Guchait,<sup>51,v</sup> A. Gurtu,<sup>51,w</sup> G. Kole,<sup>51</sup> S. Kumar,<sup>51</sup> M. Maity,<sup>51,x</sup> G. Majumder,<sup>51</sup> K. Mazumdar,<sup>51</sup> G. B. Mohanty,<sup>51</sup> B. Parida,<sup>51</sup> K. Sudhakar,<sup>51</sup>



N. Wickramage,<sup>51,y</sup> S. Banerjee,<sup>52</sup> S. Dugad,<sup>52</sup> H. Arfaei,<sup>53</sup> H. Bakhshiansohi,<sup>53</sup> H. Behnamian,<sup>53</sup> S. M. Etesami,<sup>53,z</sup>  
A. Fahim,<sup>53,aa</sup> A. Jafari,<sup>53</sup> M. Khakzad,<sup>53</sup> M. Mohammadi Najafabadi,<sup>53</sup> M. Naseri,<sup>53</sup> S. Paktinat Mehdiabadi,<sup>53</sup>  
B. Safarzadeh,<sup>53,bb</sup> M. Zeinali,<sup>53</sup> M. Grunewald,<sup>54</sup> M. Abbrescia,<sup>55a,55b</sup> L. Barbone,<sup>55a,55b</sup> C. Calabria,<sup>55a,55b</sup>  
S. S. Chhibra,<sup>55a,55b</sup> A. Colaleo,<sup>55a</sup> D. Creanza,<sup>55a,55c</sup> N. De Filippis,<sup>55a,55c</sup> M. De Palma,<sup>55a,55b</sup> L. Fiore,<sup>55a</sup> G. Iaselli,<sup>55a,55c</sup>  
G. Maggi,<sup>55a,55c</sup> M. Maggi,<sup>55a</sup> B. Marangelli,<sup>55a,55b</sup> S. My,<sup>55a,55c</sup> S. Nuzzo,<sup>55a,55b</sup> N. Pacifico,<sup>55a</sup> A. Pompili,<sup>55a,55b</sup>  
G. Pugliese,<sup>55a,55c</sup> R. Radogna,<sup>55a,55b</sup> G. Selvaggi,<sup>55a,55b</sup> L. Silvestris,<sup>55a</sup> G. Singh,<sup>55a,55b</sup> R. Venditti,<sup>55a,55b</sup> P. Verwilligen,<sup>55a</sup>  
G. Zito,<sup>55a</sup> G. Abbiendi,<sup>56a</sup> A. C. Benvenuti,<sup>56a</sup> D. Bonacorsi,<sup>56a,56b</sup> S. Braibant-Giacomelli,<sup>56a,56b</sup> L. Brigliadori,<sup>56a,56b</sup>  
R. Campanini,<sup>56a,56b</sup> P. Capiluppi,<sup>56a,56b</sup> A. Castro,<sup>56a,56b</sup> F. R. Cavallo,<sup>56a</sup> G. Codispoti,<sup>56a,56b</sup> M. Cuffiani,<sup>56a,56b</sup>  
G. M. Dallavalle,<sup>56a</sup> F. Fabbri,<sup>56a</sup> A. Fanfani,<sup>56a,56b</sup> D. Fasanella,<sup>56a,56b</sup> P. Giacomelli,<sup>56a</sup> C. Grandi,<sup>56a</sup> L. Guiducci,<sup>56a,56b</sup>  
S. Marcellini,<sup>56a</sup> G. Masetti,<sup>56a</sup> M. Meneghelli,<sup>56a,56b</sup> A. Montanari,<sup>56a</sup> F. L. Navarria,<sup>56a,56b</sup> F. Odorici,<sup>56a</sup> A. Perrotta,<sup>56a</sup>  
F. Primavera,<sup>56a,56b</sup> A. M. Rossi,<sup>56a,56b</sup> T. Rovelli,<sup>56a,56b</sup> G. P. Siroli,<sup>56a,56b</sup> N. Tosi,<sup>56a,56b</sup> R. Travaglini,<sup>56a,56b</sup> S. Albergo,<sup>57a,57b</sup>  
G. Cappello,<sup>57a</sup> M. Chiorboli,<sup>57a,57b</sup> S. Costa,<sup>57a,57b</sup> F. Giordano,<sup>57a,57c</sup> R. Potenza,<sup>57a,57b</sup> A. Tricomi,<sup>57a,57b</sup> C. Tuve,<sup>57a,57b</sup>  
G. Barbagli,<sup>58a</sup> V. Ciulli,<sup>58a,58b</sup> C. Civinini,<sup>58a</sup> R. D'Alessandro,<sup>58a,58b</sup> E. Focardi,<sup>58a,58b</sup> E. Gallo,<sup>58a</sup> S. Gonzi,<sup>58a,58b</sup>  
V. Gori,<sup>58a,58b</sup> P. Lenzi,<sup>58a,58b</sup> M. Meschini,<sup>58a</sup> S. Paoletti,<sup>58a</sup> G. Sguazzoni,<sup>58a</sup> A. Tropiano,<sup>58a,58b</sup> L. Benussi,<sup>59</sup> S. Bianco,<sup>59</sup>  
F. Fabbri,<sup>59</sup> D. Piccolo,<sup>59</sup> P. Fabbriatore,<sup>60a</sup> R. Ferretti,<sup>60a,60b</sup> F. Ferro,<sup>60a</sup> M. Lo Vetere,<sup>60a,60b</sup> R. Musenich,<sup>60a</sup> E. Robutti,<sup>60a</sup>  
S. Tosi,<sup>60a,60b</sup> A. Benaglia,<sup>61a</sup> M. E. Dinardo,<sup>61a,61b</sup> S. Fiorendi,<sup>61a,61b,c</sup> S. Gennai,<sup>61a</sup> A. Ghezzi,<sup>61a,61b</sup> P. Govoni,<sup>61a,61b</sup>  
M. T. Lucchini,<sup>61a,61b,c</sup> S. Malvezzi,<sup>61a</sup> R. A. Manzoni,<sup>61a,61b,c</sup> A. Martelli,<sup>61a,61b,c</sup> D. Menasce,<sup>61a</sup> L. Moroni,<sup>61a</sup>  
M. Paganoni,<sup>61a,61b</sup> D. Pedrini,<sup>61a</sup> S. Ragazzi,<sup>61a,61b</sup> N. Redaelli,<sup>61a</sup> T. Tabarelli de Fatis,<sup>61a,61b</sup> S. Buontempo,<sup>62a</sup>  
N. Cavallo,<sup>62a,62c</sup> F. Fabozzi,<sup>62a,62c</sup> A. O. M. Iorio,<sup>62a,62b</sup> L. Lista,<sup>62a</sup> S. Meola,<sup>62a,62d,c</sup> M. Merola,<sup>62a</sup> P. Paolucci,<sup>62a,c</sup> P. Azzi,<sup>63a</sup>  
N. Bacchetta,<sup>63a</sup> D. Bisello,<sup>63a,63b</sup> A. Branca,<sup>63a,63b</sup> R. Carlin,<sup>63a,63b</sup> P. Checchia,<sup>63a</sup> T. Dorigo,<sup>63a</sup> M. Galanti,<sup>63a,63b,c</sup>  
F. Gasparini,<sup>63a,63b</sup> U. Gasparini,<sup>63a,63b</sup> P. Giubileo,<sup>63a,63b</sup> A. Gozzelino,<sup>63a</sup> K. Kanishchev,<sup>63a,63c</sup> S. Lacaprara,<sup>63a</sup>  
I. Lazzizzera,<sup>63a,63c</sup> M. Margoni,<sup>63a,63b</sup> A. T. Meneguzzo,<sup>63a,63b</sup> J. Pazzini,<sup>63a,63b</sup> N. Pozzobon,<sup>63a,63b</sup> P. Ronchese,<sup>63a,63b</sup>  
F. Simonetto,<sup>63a,63b</sup> E. Torassa,<sup>63a</sup> M. Tosi,<sup>63a,63b</sup> A. Triossi,<sup>63a</sup> S. Vanini,<sup>63a,63b</sup> S. Ventura,<sup>63a</sup> P. Zotto,<sup>63a,63b</sup>  
A. Zucchetta,<sup>63a,63b</sup> G. Zumerle,<sup>63a,63b</sup> M. Gabusi,<sup>64a,64b</sup> S. P. Ratti,<sup>64a,64b</sup> C. Riccardi,<sup>64a,64b</sup> P. Vitulo,<sup>64a,64b</sup> M. Biasini,<sup>65a,65b</sup>  
G. M. Bilei,<sup>65a</sup> L. Fanò,<sup>65a,65b</sup> P. Lariccia,<sup>65a,65b</sup> G. Mantovani,<sup>65a,65b</sup> M. Menichelli,<sup>65a</sup> F. Romeo,<sup>65a,65b</sup> A. Saha,<sup>65a</sup>  
A. Santocchia,<sup>65a,65b</sup> A. Spiezia,<sup>65a,65b</sup> K. Androsov,<sup>66a,cc</sup> P. Azzurri,<sup>66a</sup> G. Bagliesi,<sup>66a</sup> J. Bernardini,<sup>66a</sup> T. Boccali,<sup>66a</sup>  
G. Broccolo,<sup>66a,66c</sup> R. Castaldi,<sup>66a</sup> M. A. Ciocci,<sup>66a,cc</sup> R. Dell'Orso,<sup>66a</sup> F. Fiori,<sup>66a,66c</sup> L. Foà,<sup>66a,66c</sup> A. Giassi,<sup>66a</sup>  
M. T. Grippo,<sup>66a,cc</sup> A. Kraan,<sup>66a</sup> F. Ligabue,<sup>66a,66c</sup> T. Lomtadze,<sup>66a</sup> L. Martini,<sup>66a,66b</sup> A. Messineo,<sup>66a,66b</sup> C. S. Moon,<sup>66a,dd</sup>  
F. Palla,<sup>66a</sup> A. Rizzi,<sup>66a,66b</sup> A. Savoy-Navarro,<sup>66a,ee</sup> A. T. Serban,<sup>66a</sup> P. Spagnolo,<sup>66a</sup> P. Squillacioti,<sup>66a,cc</sup> R. Tenchini,<sup>66a</sup>  
G. Tonelli,<sup>66a,66b</sup> A. Venturi,<sup>66a</sup> P. G. Verdini,<sup>66a</sup> C. Vernieri,<sup>66a,66c</sup> L. Barone,<sup>67a,67b</sup> F. Cavallari,<sup>67a</sup> D. Del Re,<sup>67a,67b</sup>  
M. Diemoz,<sup>67a</sup> M. Grassi,<sup>67a,67b</sup> C. Jorda,<sup>67a</sup> E. Longo,<sup>67a,67b</sup> F. Margaroli,<sup>67a,67b</sup> P. Meridiani,<sup>67a</sup> F. Micheli,<sup>67a,67b</sup>  
S. Nourbakhsh,<sup>67a,67b</sup> G. Organtini,<sup>67a,67b</sup> R. Paramatti,<sup>67a</sup> S. Rahatlou,<sup>67a,67b</sup> C. Rovelli,<sup>67a</sup> L. Soffi,<sup>67a,67b</sup> P. Traczyk,<sup>67a,67b</sup>  
N. Amapane,<sup>68a,68b</sup> R. Arcidiacono,<sup>68a,68c</sup> S. Argiro,<sup>68a,68b</sup> M. Arneodo,<sup>68a,68c</sup> R. Bellan,<sup>68a,68b</sup> C. Biino,<sup>68a</sup> N. Cartiglia,<sup>68a</sup>  
S. Casasso,<sup>68a,68b</sup> M. Costa,<sup>68a,68b</sup> A. Degano,<sup>68a,68b</sup> N. Demaria,<sup>68a</sup> C. Mariotti,<sup>68a</sup> S. Maselli,<sup>68a</sup> E. Migliore,<sup>68a,68b</sup>  
V. Monaco,<sup>68a,68b</sup> M. Musich,<sup>68a</sup> M. M. Obertino,<sup>68a,68c</sup> G. Ortona,<sup>68a,68b</sup> L. Pacher,<sup>68a,68b</sup> N. Pastrone,<sup>68a</sup> M. Pelliccioni,<sup>68a,c</sup>  
A. Potenza,<sup>68a,68b</sup> A. Romero,<sup>68a,68b</sup> M. Ruspa,<sup>68a,68c</sup> R. Sacchi,<sup>68a,68b</sup> A. Solano,<sup>68a,68b</sup> A. Staiano,<sup>68a</sup> U. Tamponi,<sup>68a</sup>  
S. Belforte,<sup>69a</sup> V. Candelise,<sup>69a,69b</sup> M. Casarsa,<sup>69a</sup> F. Cossutti,<sup>69a</sup> G. Della Ricca,<sup>69a,69b</sup> B. Gobbo,<sup>69a</sup> C. La Licata,<sup>69a,69b</sup>  
M. Marone,<sup>69a,69b</sup> D. Montanino,<sup>69a,69b</sup> A. Penzo,<sup>69a</sup> A. Schizzi,<sup>69a,69b</sup> T. Umer,<sup>69a,69b</sup> A. Zanetti,<sup>69a</sup> S. Chang,<sup>70</sup> T. Y. Kim,<sup>70</sup>  
S. K. Nam,<sup>70</sup> D. H. Kim,<sup>71</sup> G. N. Kim,<sup>71</sup> J. E. Kim,<sup>71</sup> D. J. Kong,<sup>71</sup> S. Lee,<sup>71</sup> Y. D. Oh,<sup>71</sup> H. Park,<sup>71</sup> D. C. Son,<sup>71</sup> J. Y. Kim,<sup>72</sup>  
Zero J. Kim,<sup>72</sup> S. Song,<sup>72</sup> S. Choi,<sup>73</sup> D. Gyun,<sup>73</sup> B. Hong,<sup>73</sup> M. Jo,<sup>73</sup> H. Kim,<sup>73</sup> Y. Kim,<sup>73</sup> K. S. Lee,<sup>73</sup> S. K. Park,<sup>73</sup> Y. Roh,<sup>73</sup>  
M. Choi,<sup>74</sup> J. H. Kim,<sup>74</sup> C. Park,<sup>74</sup> I. C. Park,<sup>74</sup> S. Park,<sup>74</sup> G. Ryu,<sup>74</sup> Y. Choi,<sup>75</sup> Y. K. Choi,<sup>75</sup> J. Goh,<sup>75</sup> M. S. Kim,<sup>75</sup>  
E. Kwon,<sup>75</sup> B. Lee,<sup>75</sup> J. Lee,<sup>75</sup> S. Lee,<sup>75</sup> H. Seo,<sup>75</sup> I. Yu,<sup>75</sup> A. Juodagalvis,<sup>76</sup> J. R. Komaragiri,<sup>77</sup> H. Castilla-Valdez,<sup>78</sup>  
E. De La Cruz-Burelo,<sup>78</sup> I. Heredia-de La Cruz,<sup>78,ff</sup> R. Lopez-Fernandez,<sup>78</sup> J. Martínez-Ortega,<sup>78</sup> A. Sanchez-Hernandez,<sup>78</sup>  
L. M. Villasenor-Cendejas,<sup>78</sup> S. Carrillo Moreno,<sup>79</sup> F. Vazquez Valencia,<sup>79</sup> H. A. Salazar Ibarguen,<sup>80</sup> E. Casimiro Linares,<sup>81</sup>  
A. Morelos Pineda,<sup>81</sup> D. Krofcheck,<sup>82</sup> P. H. Butler,<sup>83</sup> R. Doesburg,<sup>83</sup> S. Reucroft,<sup>83</sup> H. Silverwood,<sup>83</sup> M. Ahmad,<sup>84</sup>  
M. I. Asghar,<sup>84</sup> J. Butt,<sup>84</sup> H. R. Hoorani,<sup>84</sup> W. A. Khan,<sup>84</sup> T. Khurshid,<sup>84</sup> S. Qazi,<sup>84</sup> M. A. Shah,<sup>84</sup> M. Shoaib,<sup>84</sup>  
H. Bialkowska,<sup>85</sup> M. Bluj,<sup>85,gg</sup> B. Boimska,<sup>85</sup> T. Frueboes,<sup>85</sup> M. Górski,<sup>85</sup> M. Kazana,<sup>85</sup> K. Nawrocki,<sup>85</sup>  
K. Romanowska-Rybinska,<sup>85</sup> M. Szleper,<sup>85</sup> G. Wrochna,<sup>85</sup> P. Zalewski,<sup>85</sup> G. Brona,<sup>86</sup> K. Bunkowski,<sup>86</sup> M. Cwiok,<sup>86</sup>  
W. Dominik,<sup>86</sup> K. Doroba,<sup>86</sup> A. Kalinowski,<sup>86</sup> M. Konecki,<sup>86</sup> J. Krolikowski,<sup>86</sup> M. Misiura,<sup>86</sup> W. Wolszczak,<sup>86</sup> P. Bargassa,<sup>87</sup>

C. Beirão Da Cruz E Silva,<sup>87</sup> P. Faccioli,<sup>87</sup> P. G. Ferreira Parracho,<sup>87</sup> M. Gallinaro,<sup>87</sup> F. Nguyen,<sup>87</sup> J. Rodrigues Antunes,<sup>87</sup> J. Seixas,<sup>87,c</sup> J. Varela,<sup>87</sup> P. Vischia,<sup>87</sup> S. Afanasiev,<sup>88</sup> P. Bunin,<sup>88</sup> I. Golutvin,<sup>88</sup> I. Gorbunov,<sup>88</sup> A. Kamenev,<sup>88</sup> V. Karjavin,<sup>88</sup> V. Konoplyanikov,<sup>88</sup> G. Kozlov,<sup>88</sup> A. Lanev,<sup>88</sup> A. Malakhov,<sup>88</sup> V. Matveev,<sup>88,hh</sup> P. Moisev,<sup>88</sup> V. Palichik,<sup>88</sup> V. Perelygin,<sup>88</sup> S. Shmatov,<sup>88</sup> N. Skatchkov,<sup>88</sup> V. Smirnov,<sup>88</sup> A. Zarubin,<sup>88</sup> V. Golovtsov,<sup>89</sup> Y. Ivanov,<sup>89</sup> V. Kim,<sup>89</sup> P. Levchenko,<sup>89</sup> V. Murzin,<sup>89</sup> V. Oreshkin,<sup>89</sup> I. Smirnov,<sup>89</sup> V. Sulimov,<sup>89</sup> L. Uvarov,<sup>89</sup> S. Vavilov,<sup>89</sup> A. Vorobyev,<sup>89</sup> An. Vorobyev,<sup>89</sup> Yu. Andreev,<sup>90</sup> A. Dermenev,<sup>90</sup> S. Gninenko,<sup>90</sup> N. Golubev,<sup>90</sup> M. Kirsanov,<sup>90</sup> N. Krasnikov,<sup>90</sup> A. Pashenkov,<sup>90</sup> D. Tlisov,<sup>90</sup> A. Toropin,<sup>90</sup> V. Epshteyn,<sup>91</sup> V. Gavrilov,<sup>91</sup> N. Lychkovskaya,<sup>91</sup> V. Popov,<sup>91</sup> G. Safronov,<sup>91</sup> S. Semenov,<sup>91</sup> A. Spiridonov,<sup>91</sup> V. Stolin,<sup>91</sup> E. Vlasov,<sup>91</sup> A. Zhokin,<sup>91</sup> V. Andreev,<sup>92</sup> M. Azarkin,<sup>92</sup> I. Dremin,<sup>92</sup> M. Kirakosyan,<sup>92</sup> A. Leonidov,<sup>92</sup> G. Mesyats,<sup>92</sup> S. V. Rusakov,<sup>92</sup> A. Vinogradov,<sup>92</sup> A. Belyaev,<sup>93</sup> E. Boos,<sup>93</sup> V. Bunichev,<sup>93</sup> M. Dubinin,<sup>93,h</sup> L. Dudko,<sup>93</sup> A. Gribushin,<sup>93</sup> V. Klyukhin,<sup>93</sup> I. Lokhtin,<sup>93</sup> S. Obraztsov,<sup>93</sup> M. Perfilov,<sup>93</sup> V. Savrin,<sup>93</sup> A. Snigirev,<sup>93</sup> N. Tsirova,<sup>93</sup> I. Azhgirey,<sup>94</sup> I. Bayshev,<sup>94</sup> S. Bitioukov,<sup>94</sup> V. Kachanov,<sup>94</sup> A. Kalinin,<sup>94</sup> D. Konstantinov,<sup>94</sup> V. Krychkin,<sup>94</sup> V. Petrov,<sup>94</sup> R. Ryutin,<sup>94</sup> A. Sobol,<sup>94</sup> L. Tourtchanovitch,<sup>94</sup> S. Troshin,<sup>94</sup> N. Tyurin,<sup>94</sup> A. Uzunian,<sup>94</sup> A. Volkov,<sup>94</sup> P. Adzic,<sup>95,ii</sup> M. Djordjevic,<sup>95</sup> M. Ekmedzic,<sup>95</sup> J. Milosevic,<sup>95</sup> M. Aguilar-Benitez,<sup>96</sup> J. Alcaraz Maestre,<sup>96</sup> C. Battilana,<sup>96</sup> E. Calvo,<sup>96</sup> M. Cerrada,<sup>96</sup> M. Chamizo Llatas,<sup>96,c</sup> N. Colino,<sup>96</sup> B. De La Cruz,<sup>96</sup> A. Delgado Peris,<sup>96</sup> D. Domínguez Vázquez,<sup>96</sup> C. Fernandez Bedoya,<sup>96</sup> J. P. Fernández Ramos,<sup>96</sup> A. Ferrando,<sup>96</sup> J. Flix,<sup>96</sup> M. C. Fouz,<sup>96</sup> P. Garcia-Abia,<sup>96</sup> O. Gonzalez Lopez,<sup>96</sup> S. Goy Lopez,<sup>96</sup> J. M. Hernandez,<sup>96</sup> M. I. Josa,<sup>96</sup> G. Merino,<sup>96</sup> E. Navarro De Martino,<sup>96</sup> J. Puerta Pelayo,<sup>96</sup> A. Quintario Olmeda,<sup>96</sup> I. Redondo,<sup>96</sup> L. Romero,<sup>96</sup> M. S. Soares,<sup>96</sup> C. Willmott,<sup>96</sup> C. Albajar,<sup>97</sup> J. F. de Trocóniz,<sup>97</sup> M. Missiroli,<sup>97</sup> H. Brun,<sup>98</sup> J. Cuevas,<sup>98</sup> J. Fernandez Menendez,<sup>98</sup> S. Folgueras,<sup>98</sup> I. Gonzalez Caballero,<sup>98</sup> L. Lloret Iglesias,<sup>98</sup> J. A. Brochero Cifuentes,<sup>99</sup> I. J. Cabrillo,<sup>99</sup> A. Calderon,<sup>99</sup> S. H. Chuang,<sup>99</sup> J. Duarte Campderros,<sup>99</sup> M. Fernandez,<sup>99</sup> G. Gomez,<sup>99</sup> J. Gonzalez Sanchez,<sup>99</sup> A. Graziano,<sup>99</sup> A. Lopez Virto,<sup>99</sup> J. Marco,<sup>99</sup> R. Marco,<sup>99</sup> C. Martinez Rivero,<sup>99</sup> F. Matorras,<sup>99</sup> F. J. Munoz Sanchez,<sup>99</sup> J. Piedra Gomez,<sup>99</sup> T. Rodrigo,<sup>99</sup> A. Y. Rodríguez-Marrero,<sup>99</sup> A. Ruiz-Jimeno,<sup>99</sup> L. Scodellaro,<sup>99</sup> I. Vila,<sup>99</sup> R. Vilar Cortabitarte,<sup>99</sup> D. Abbaneo,<sup>100</sup> E. Auffray,<sup>100</sup> G. Auzinger,<sup>100</sup> M. Bachtis,<sup>100</sup> P. Baillon,<sup>100</sup> A. H. Ball,<sup>100</sup> D. Barney,<sup>100</sup> J. Bendavid,<sup>100</sup> L. Benhabib,<sup>100</sup> J. F. Benitez,<sup>100</sup> C. Bernet,<sup>100,i</sup> G. Bianchi,<sup>100</sup> P. Bloch,<sup>100</sup> A. Bocci,<sup>100</sup> A. Bonato,<sup>100</sup> O. Bondu,<sup>100</sup> C. Botta,<sup>100</sup> H. Breuer,<sup>100</sup> T. Camporesi,<sup>100</sup> G. Cerminara,<sup>100</sup> T. Christiansen,<sup>100</sup> J. A. Coarasa Perez,<sup>100</sup> S. Colafranceschi,<sup>100,ji</sup> M. D'Alfonso,<sup>100</sup> D. d'Enterria,<sup>100</sup> A. Dabrowski,<sup>100</sup> A. David,<sup>100</sup> F. De Guio,<sup>100</sup> A. De Roeck,<sup>100</sup> S. De Visscher,<sup>100</sup> S. Di Guida,<sup>100</sup> M. Dobson,<sup>100</sup> N. Dupont-Sagorin,<sup>100</sup> A. Elliott-Peisert,<sup>100</sup> J. Eugster,<sup>100</sup> G. Franzoni,<sup>100</sup> W. Funk,<sup>100</sup> M. Giffels,<sup>100</sup> D. Gigi,<sup>100</sup> K. Gill,<sup>100</sup> M. Girone,<sup>100</sup> M. Giunta,<sup>100</sup> F. Glege,<sup>100</sup> R. Gomez-Reino Garrido,<sup>100</sup> S. Gowdy,<sup>100</sup> R. Guida,<sup>100</sup> J. Hammer,<sup>100</sup> M. Hansen,<sup>100</sup> P. Harris,<sup>100</sup> V. Innocente,<sup>100</sup> P. Janot,<sup>100</sup> E. Karavakis,<sup>100</sup> K. Kousouris,<sup>100</sup> K. Krajczar,<sup>100</sup> P. Lecoq,<sup>100</sup> C. Lourenço,<sup>100</sup> N. Magini,<sup>100</sup> L. Malgeri,<sup>100</sup> M. Mannelli,<sup>100</sup> L. Masetti,<sup>100</sup> F. Meijers,<sup>100</sup> S. Mersi,<sup>100</sup> E. Meschi,<sup>100</sup> F. Moortgat,<sup>100</sup> M. Mulders,<sup>100</sup> P. Musella,<sup>100</sup> L. Orsini,<sup>100</sup> E. Palencia Cortezon,<sup>100</sup> E. Perez,<sup>100</sup> L. Perrozzi,<sup>100</sup> A. Petrilli,<sup>100</sup> G. Petrucciani,<sup>100</sup> A. Pfeiffer,<sup>100</sup> M. Pierini,<sup>100</sup> M. Pimiä,<sup>100</sup> D. Piparo,<sup>100</sup> M. Plagge,<sup>100</sup> A. Racz,<sup>100</sup> W. Reece,<sup>100</sup> G. Rolandi,<sup>100,kk</sup> M. Rovere,<sup>100</sup> H. Sakulin,<sup>100</sup> F. Santanastasio,<sup>100</sup> C. Schäfer,<sup>100</sup> C. Schwick,<sup>100</sup> S. Sekmen,<sup>100</sup> A. Sharma,<sup>100</sup> P. Siegrist,<sup>100</sup> P. Silva,<sup>100</sup> M. Simon,<sup>100</sup> P. Sphicas,<sup>100,ll</sup> J. Steggemann,<sup>100</sup> B. Stieger,<sup>100</sup> M. Stoye,<sup>100</sup> A. Tsirova,<sup>100</sup> G. I. Veres,<sup>100,u</sup> J. R. Vlimant,<sup>100</sup> H. K. Wöhri,<sup>100</sup> W. D. Zeuner,<sup>100</sup> W. Bertl,<sup>101</sup> K. Deiters,<sup>101</sup> W. Erdmann,<sup>101</sup> R. Horisberger,<sup>101</sup> Q. Ingram,<sup>101</sup> H. C. Kaestli,<sup>101</sup> S. König,<sup>101</sup> D. Kotlinski,<sup>101</sup> U. Langenegger,<sup>101</sup> D. Renker,<sup>101</sup> T. Rohe,<sup>101</sup> F. Bachmair,<sup>102</sup> L. Bäni,<sup>102</sup> L. Bianchini,<sup>102</sup> P. Bortignon,<sup>102</sup> M. A. Buchmann,<sup>102</sup> B. Casal,<sup>102</sup> N. Chanon,<sup>102</sup> A. Deisher,<sup>102</sup> G. Dissertori,<sup>102</sup> M. Dittmar,<sup>102</sup> M. Donegà,<sup>102</sup> M. Dünser,<sup>102</sup> P. Eller,<sup>102</sup> C. Grab,<sup>102</sup> D. Hits,<sup>102</sup> W. Lustermann,<sup>102</sup> B. Mangano,<sup>102</sup> A. C. Marini,<sup>102</sup> P. Martinez Ruiz del Arbol,<sup>102</sup> D. Meister,<sup>102</sup> N. Mohr,<sup>102</sup> C. Nägeli,<sup>102,mmm</sup> P. Nef,<sup>102</sup> F. Nessi-Tedaldi,<sup>102</sup> F. Pandolfi,<sup>102</sup> L. Pape,<sup>102</sup> F. Pauss,<sup>102</sup> M. Peruzzi,<sup>102</sup> M. Quittnat,<sup>102</sup> F. J. Ronga,<sup>102</sup> M. Rossini,<sup>102</sup> A. Starodumov,<sup>102,nn</sup> M. Takahashi,<sup>102</sup> L. Tauscher,<sup>102,a</sup> K. Theofilatos,<sup>102</sup> D. Treille,<sup>102</sup> R. Wallny,<sup>102</sup> H. A. Weber,<sup>102</sup> C. Amsler,<sup>103,oo</sup> V. Chiochia,<sup>103</sup> A. De Cosa,<sup>103</sup> C. Favaro,<sup>103</sup> A. Hinzmann,<sup>103</sup> T. Hreus,<sup>103</sup> M. Ivova Rikova,<sup>103</sup> B. Kilminster,<sup>103</sup> B. Millan Mejias,<sup>103</sup> J. Ngadiuba,<sup>103</sup> P. Robmann,<sup>103</sup> H. Snoek,<sup>103</sup> S. Taroni,<sup>103</sup> M. Verzetti,<sup>103</sup> Y. Yang,<sup>103</sup> M. Cardaci,<sup>104</sup> K. H. Chen,<sup>104</sup> C. Ferro,<sup>104</sup> C. M. Kuo,<sup>104</sup> S. W. Li,<sup>104</sup> W. Lin,<sup>104</sup> Y. J. Lu,<sup>104</sup> R. Volpe,<sup>104</sup> S. S. Yu,<sup>104</sup> P. Bartalini,<sup>105</sup> P. Chang,<sup>105</sup> Y. H. Chang,<sup>105</sup> Y. W. Chang,<sup>105</sup> Y. Chao,<sup>105</sup> K. F. Chen,<sup>105</sup> P. H. Chen,<sup>105</sup> C. Dietz,<sup>105</sup> U. Grundler,<sup>105</sup> W.-S. Hou,<sup>105</sup> Y. Hsiung,<sup>105</sup> K. Y. Kao,<sup>105</sup> Y. J. Lei,<sup>105</sup> Y. F. Liu,<sup>105</sup> R.-S. Lu,<sup>105</sup> D. Majumder,<sup>105</sup> E. Petrakou,<sup>105</sup> X. Shi,<sup>105</sup> J. G. Shiu,<sup>105</sup> Y. M. Tzeng,<sup>105</sup> M. Wang,<sup>105</sup> R. Wilken,<sup>105</sup> B. Asavapibhop,<sup>106</sup> N. Suwonjandee,<sup>106</sup> A. Adiguzel,<sup>107</sup> M. N. Bakirci,<sup>107,pp</sup> S. Cerci,<sup>107,qq</sup> C. Dozen,<sup>107</sup> I. Dumanoglu,<sup>107</sup> E. Eskut,<sup>107</sup> S. Girgis,<sup>107</sup> G. Gokbulut,<sup>107</sup> E. Gurpinar,<sup>107</sup> I. Hos,<sup>107</sup> E. E. Kangal,<sup>107</sup> A. Kayis Topaksu,<sup>107</sup> G. Onengut,<sup>107,rr</sup> K. Ozdemir,<sup>107</sup> S. Ozturk,<sup>107,pp</sup>

A. Polatoz,<sup>107</sup> K. Sogut,<sup>107,ss</sup> D. Sunar Cerci,<sup>107,qq</sup> B. Tali,<sup>107,qq</sup> H. Topakli,<sup>107,pp</sup> M. Vergili,<sup>107</sup> I. V. Akin,<sup>108</sup> T. Aliev,<sup>108</sup> B. Bilin,<sup>108</sup> S. Bilmis,<sup>108</sup> M. Deniz,<sup>108</sup> H. Gamsizkan,<sup>108</sup> A. M. Guler,<sup>108</sup> G. Karapinar,<sup>108,tt</sup> K. Ocalan,<sup>108</sup> A. Ozpineci,<sup>108</sup> M. Serin,<sup>108</sup> R. Sever,<sup>108</sup> U. E. Surat,<sup>108</sup> M. Yalvac,<sup>108</sup> M. Zeyrek,<sup>108</sup> E. Gülmez,<sup>109</sup> B. Isildak,<sup>109,uu</sup> M. Kaya,<sup>109,vv</sup> O. Kaya,<sup>109,vv</sup> S. Ozkorucuklu,<sup>109,ww</sup> H. Bahtiyar,<sup>110,xx</sup> E. Barlas,<sup>110</sup> K. Cankocak,<sup>110</sup> Y. O. Günaydin,<sup>110,yy</sup> F. I. Vardarli,<sup>110</sup> M. Yücel,<sup>110</sup> L. Levchuk,<sup>111</sup> P. Sorokin,<sup>111</sup> J. J. Brooke,<sup>112</sup> E. Clement,<sup>112</sup> D. Cussans,<sup>112</sup> H. Flacher,<sup>112</sup> R. Frazier,<sup>112</sup> J. Goldstein,<sup>112</sup> M. Grimes,<sup>112</sup> G. P. Heath,<sup>112</sup> H. F. Heath,<sup>112</sup> J. Jacob,<sup>112</sup> L. Kreczko,<sup>112</sup> C. Lucas,<sup>112</sup> Z. Meng,<sup>112</sup> D. M. Newbold,<sup>112,zz</sup> S. Paramesvaran,<sup>112</sup> A. Poll,<sup>112</sup> S. Senkin,<sup>112</sup> V. J. Smith,<sup>112</sup> T. Williams,<sup>112</sup> K. W. Bell,<sup>113</sup> A. Belyaev,<sup>113,aaa</sup> C. Brew,<sup>113</sup> R. M. Brown,<sup>113</sup> D. J. A. Cockerill,<sup>113</sup> J. A. Coughlan,<sup>113</sup> K. Harder,<sup>113</sup> S. Harper,<sup>113</sup> J. Ilic,<sup>113</sup> E. Olaiya,<sup>113</sup> D. Petyt,<sup>113</sup> C. H. Shepherd-Themistocleous,<sup>113</sup> A. Thea,<sup>113</sup> I. R. Tomalin,<sup>113</sup> W. J. Womersley,<sup>113</sup> S. D. Worm,<sup>113</sup> M. Baber,<sup>114</sup> R. Bainbridge,<sup>114</sup> O. Buchmuller,<sup>114</sup> D. Burton,<sup>114</sup> D. Colling,<sup>114</sup> N. Cripps,<sup>114</sup> M. Cutajar,<sup>114</sup> P. Dauncey,<sup>114</sup> G. Davies,<sup>114</sup> M. Della Negra,<sup>114</sup> W. Ferguson,<sup>114</sup> J. Fulcher,<sup>114</sup> D. Futyan,<sup>114</sup> A. Gilbert,<sup>114</sup> A. Guneratne Bryer,<sup>114</sup> G. Hall,<sup>114</sup> Z. Hatherell,<sup>114</sup> J. Hays,<sup>114</sup> G. Iles,<sup>114</sup> M. Jarvis,<sup>114</sup> G. Karapostoli,<sup>114</sup> M. Kenzie,<sup>114</sup> R. Lane,<sup>114</sup> R. Lucas,<sup>114,zz</sup> L. Lyons,<sup>114</sup> A.-M. Magnan,<sup>114</sup> J. Marrouche,<sup>114</sup> B. Mathias,<sup>114</sup> R. Nandi,<sup>114</sup> J. Nash,<sup>114</sup> A. Nikitenko,<sup>114,nn</sup> J. Pela,<sup>114</sup> M. Pesaresi,<sup>114</sup> K. Petridis,<sup>114</sup> M. Pioppi,<sup>114,bbb</sup> D. M. Raymond,<sup>114</sup> S. Rogerson,<sup>114</sup> A. Rose,<sup>114</sup> C. Seez,<sup>114</sup> P. Sharp,<sup>114,a</sup> A. Sparrow,<sup>114</sup> A. Tapper,<sup>114</sup> M. Vazquez Acosta,<sup>114</sup> T. Virdee,<sup>114</sup> S. Wakefield,<sup>114</sup> N. Wardle,<sup>114</sup> J. E. Cole,<sup>115</sup> P. R. Hobson,<sup>115</sup> A. Khan,<sup>115</sup> P. Kyberd,<sup>115</sup> D. Leggat,<sup>115</sup> D. Leslie,<sup>115</sup> W. Martin,<sup>115</sup> I. D. Reid,<sup>115</sup> P. Symonds,<sup>115</sup> L. Teodorescu,<sup>115</sup> M. Turner,<sup>115</sup> J. Dittmann,<sup>116</sup> K. Hatakeyama,<sup>116</sup> A. Kasmi,<sup>116</sup> H. Liu,<sup>116</sup> T. Scarborough,<sup>116</sup> O. Charaf,<sup>117</sup> S. I. Cooper,<sup>117</sup> C. Henderson,<sup>117</sup> P. Rumerio,<sup>117</sup> A. Avetisyan,<sup>118</sup> T. Bose,<sup>118</sup> C. Fantasia,<sup>118</sup> A. Heister,<sup>118</sup> P. Lawson,<sup>118</sup> D. Lazic,<sup>118</sup> J. Rohlf,<sup>118</sup> D. Sperka,<sup>118</sup> J. St. John,<sup>118</sup> L. Sulak,<sup>118</sup> J. Alimena,<sup>119</sup> S. Bhattacharya,<sup>119</sup> G. Christopher,<sup>119</sup> D. Cutts,<sup>119</sup> Z. Demiragli,<sup>119</sup> A. Ferapontov,<sup>119</sup> A. Garabedian,<sup>119</sup> U. Heintz,<sup>119</sup> S. Jabeen,<sup>119</sup> G. Kukartsev,<sup>119</sup> E. Laird,<sup>119</sup> G. Landsberg,<sup>119</sup> M. Luk,<sup>119</sup> M. Narain,<sup>119</sup> M. Segala,<sup>119</sup> T. Sinthuprasith,<sup>119</sup> T. Speer,<sup>119</sup> J. Swanson,<sup>119</sup> R. Breedon,<sup>120</sup> G. Breto,<sup>120</sup> M. Calderon De La Barca Sanchez,<sup>120</sup> S. Chauhan,<sup>120</sup> M. Chertok,<sup>120</sup> J. Conway,<sup>120</sup> R. Conway,<sup>120</sup> P. T. Cox,<sup>120</sup> R. Erbacher,<sup>120</sup> M. Gardner,<sup>120</sup> W. Ko,<sup>120</sup> A. Kopecky,<sup>120</sup> R. Lander,<sup>120</sup> T. Miceli,<sup>120</sup> D. Pellett,<sup>120</sup> J. Pilot,<sup>120</sup> F. Ricci-Tam,<sup>120</sup> B. Rutherford,<sup>120</sup> M. Searle,<sup>120</sup> S. Shalhout,<sup>120</sup> J. Smith,<sup>120</sup> M. Squires,<sup>120</sup> M. Tripathi,<sup>120</sup> S. Wilbur,<sup>120</sup> R. Yohay,<sup>120</sup> V. Andreev,<sup>121</sup> D. Cline,<sup>121</sup> R. Cousins,<sup>121</sup> S. Erhan,<sup>121</sup> P. Everaerts,<sup>121</sup> C. Farrell,<sup>121</sup> M. Felcini,<sup>121</sup> J. Hauser,<sup>121</sup> M. Ignatenko,<sup>121</sup> C. Jarvis,<sup>121</sup> G. Rakness,<sup>121</sup> P. Schlein,<sup>121,a</sup> E. Takasugi,<sup>121</sup> V. Valuev,<sup>121</sup> M. Weber,<sup>121</sup> J. Babb,<sup>122</sup> R. Clare,<sup>122</sup> J. Ellison,<sup>122</sup> J. W. Gary,<sup>122</sup> G. Hanson,<sup>122</sup> J. Heilman,<sup>122</sup> P. Jandir,<sup>122</sup> F. Lacroix,<sup>122</sup> H. Liu,<sup>122</sup> O. R. Long,<sup>122</sup> A. Luthra,<sup>122</sup> M. Malberti,<sup>122</sup> H. Nguyen,<sup>122</sup> A. Shrinivas,<sup>122</sup> J. Sturdy,<sup>122</sup> S. Sumowidagdo,<sup>122</sup> S. Wimpenny,<sup>122</sup> W. Andrews,<sup>123</sup> J. G. Branson,<sup>123</sup> G. B. Cerati,<sup>123</sup> S. Cittolin,<sup>123</sup> R. T. D'Agnolo,<sup>123</sup> D. Evans,<sup>123</sup> A. Holzner,<sup>123</sup> R. Kelley,<sup>123</sup> D. Kovalskyi,<sup>123</sup> M. Lebourgeois,<sup>123</sup> J. Letts,<sup>123</sup> I. Macneill,<sup>123</sup> S. Padhi,<sup>123</sup> C. Palmer,<sup>123</sup> M. Pieri,<sup>123</sup> M. Sani,<sup>123</sup> V. Sharma,<sup>123</sup> S. Simon,<sup>123</sup> E. Sudano,<sup>123</sup> M. Tadel,<sup>123</sup> Y. Tu,<sup>123</sup> A. Vartak,<sup>123</sup> S. Wasserbaech,<sup>123,ccc</sup> F. Würthwein,<sup>123</sup> A. Yagil,<sup>123</sup> J. Yoo,<sup>123</sup> D. Barge,<sup>124</sup> C. Campagnari,<sup>124</sup> T. Danielson,<sup>124</sup> K. Flowers,<sup>124</sup> P. Geffert,<sup>124</sup> C. George,<sup>124</sup> F. Golf,<sup>124</sup> J. Incandela,<sup>124</sup> C. Justus,<sup>124</sup> R. Magaña Villalba,<sup>124</sup> N. Mccoll,<sup>124</sup> V. Pavlunin,<sup>124</sup> J. Richman,<sup>124</sup> R. Rossin,<sup>124</sup> D. Stuart,<sup>124</sup> W. To,<sup>124</sup> C. West,<sup>124</sup> A. Apresyan,<sup>125</sup> A. Bornheim,<sup>125</sup> J. Bunn,<sup>125</sup> Y. Chen,<sup>125</sup> E. Di Marco,<sup>125</sup> J. Duarte,<sup>125</sup> D. Kcira,<sup>125</sup> A. Mott,<sup>125</sup> H. B. Newman,<sup>125</sup> C. Pena,<sup>125</sup> C. Rogan,<sup>125</sup> M. Spiropulu,<sup>125</sup> V. Timciuc,<sup>125</sup> R. Wilkinson,<sup>125</sup> S. Xie,<sup>125</sup> R. Y. Zhu,<sup>125</sup> V. Azzolini,<sup>126</sup> A. Calamba,<sup>126</sup> R. Carroll,<sup>126</sup> T. Ferguson,<sup>126</sup> Y. Iiyama,<sup>126</sup> D. W. Jang,<sup>126</sup> M. Paulini,<sup>126</sup> J. Russ,<sup>126</sup> H. Vogel,<sup>126</sup> I. Vorobiev,<sup>126</sup> J. P. Cumalat,<sup>127</sup> B. R. Drell,<sup>127</sup> W. T. Ford,<sup>127</sup> A. Gaz,<sup>127</sup> E. Luiggi Lopez,<sup>127</sup> U. Nauenberg,<sup>127</sup> J. G. Smith,<sup>127</sup> K. Stenson,<sup>127</sup> K. A. Ulmer,<sup>127</sup> S. R. Wagner,<sup>127</sup> J. Alexander,<sup>128</sup> A. Chatterjee,<sup>128</sup> N. Eggert,<sup>128</sup> L. K. Gibbons,<sup>128</sup> W. Hopkins,<sup>128</sup> A. Khukhunaishvili,<sup>128</sup> B. Kreis,<sup>128</sup> N. Mirman,<sup>128</sup> G. Nicolas Kaufman,<sup>128</sup> J. R. Patterson,<sup>128</sup> A. Ryd,<sup>128</sup> E. Salvati,<sup>128</sup> W. Sun,<sup>128</sup> W. D. Teo,<sup>128</sup> J. Thom,<sup>128</sup> J. Thompson,<sup>128</sup> J. Tucker,<sup>128</sup> Y. Weng,<sup>128</sup> L. Winstrom,<sup>128</sup> P. Wittich,<sup>128</sup> D. Winn,<sup>129</sup> S. Abdullin,<sup>130</sup> M. Albrow,<sup>130</sup> J. Anderson,<sup>130</sup> G. Apollinari,<sup>130</sup> L. A. T. Bauerdick,<sup>130</sup> A. Beretvas,<sup>130</sup> J. Berryhill,<sup>130</sup> P. C. Bhat,<sup>130</sup> K. Burkett,<sup>130</sup> J. N. Butler,<sup>130</sup> V. Chetluru,<sup>130</sup> H. W. K. Cheung,<sup>130</sup> F. Chlebana,<sup>130</sup> S. Cihangir,<sup>130</sup> V. D. Elvira,<sup>130</sup> I. Fisk,<sup>130</sup> J. Freeman,<sup>130</sup> Y. Gao,<sup>130</sup> E. Gottschalk,<sup>130</sup> L. Gray,<sup>130</sup> D. Green,<sup>130</sup> S. Grünendahl,<sup>130</sup> O. Gutsche,<sup>130</sup> D. Hare,<sup>130</sup> R. M. Harris,<sup>130</sup> J. Hirschauer,<sup>130</sup> B. Hooberman,<sup>130</sup> S. Jindariani,<sup>130</sup> M. Johnson,<sup>130</sup> U. Joshi,<sup>130</sup> K. Kaadze,<sup>130</sup> B. Klima,<sup>130</sup> S. Kwan,<sup>130</sup> J. Linacre,<sup>130</sup> D. Lincoln,<sup>130</sup> R. Lipton,<sup>130</sup> J. Lykken,<sup>130</sup> K. Maeshima,<sup>130</sup> J. M. Marraffino,<sup>130</sup> V. I. Martinez Outschoorn,<sup>130</sup> S. Maruyama,<sup>130</sup> D. Mason,<sup>130</sup> P. McBride,<sup>130</sup> K. Mishra,<sup>130</sup> S. Mrenna,<sup>130</sup> Y. Musienko,<sup>130,hh</sup> S. Nahn,<sup>130</sup> C. Newman-Holmes,<sup>130</sup> V. O'Dell,<sup>130</sup> O. Prokofyev,<sup>130</sup> N. Ratnikova,<sup>130</sup> E. Sexton-Kennedy,<sup>130</sup> S. Sharma,<sup>130</sup> W. J. Spalding,<sup>130</sup> L. Spiegel,<sup>130</sup> L. Taylor,<sup>130</sup> S. Tkaczyk,<sup>130</sup> N. V. Tran,<sup>130</sup> L. Uplegger,<sup>130</sup> E. W. Vaandering,<sup>130</sup> R. Vidal,<sup>130</sup>

A. Whitbeck,<sup>130</sup> J. Whitmore,<sup>130</sup> W. Wu,<sup>130</sup> F. Yang,<sup>130</sup> J. C. Yun,<sup>130</sup> D. Acosta,<sup>131</sup> P. Avery,<sup>131</sup> D. Bourilkov,<sup>131</sup> T. Cheng,<sup>131</sup> S. Das,<sup>131</sup> M. De Gruttola,<sup>131</sup> G. P. Di Giovanni,<sup>131</sup> D. Dobur,<sup>131</sup> R. D. Field,<sup>131</sup> M. Fisher,<sup>131</sup> Y. Fu,<sup>131</sup> I. K. Furic,<sup>131</sup> J. Hugon,<sup>131</sup> B. Kim,<sup>131</sup> J. Konigsberg,<sup>131</sup> A. Korytov,<sup>131</sup> A. Kropivnitskaya,<sup>131</sup> T. Kypreos,<sup>131</sup> J. F. Low,<sup>131</sup> K. Matchev,<sup>131</sup> P. Milenovic,<sup>131,ddd</sup> G. Mitselmakher,<sup>131</sup> L. Muniz,<sup>131</sup> A. Rinkevicius,<sup>131</sup> L. Shchutska,<sup>131</sup> N. Skhirtladze,<sup>131</sup> M. Snowball,<sup>131</sup> J. Yelton,<sup>131</sup> M. Zakaria,<sup>131</sup> V. Gaultney,<sup>132</sup> S. Hewamanage,<sup>132</sup> S. Linn,<sup>132</sup> P. Markowitz,<sup>132</sup> G. Martinez,<sup>132</sup> J. L. Rodriguez,<sup>132</sup> T. Adams,<sup>133</sup> A. Askew,<sup>133</sup> J. Bochenek,<sup>133</sup> J. Chen,<sup>133</sup> B. Diamond,<sup>133</sup> J. Haas,<sup>133</sup> S. Hagopian,<sup>133</sup> V. Hagopian,<sup>133</sup> K. F. Johnson,<sup>133</sup> H. Prosper,<sup>133</sup> V. Veeraraghavan,<sup>133</sup> M. Weinberg,<sup>133</sup> M. M. Baarmand,<sup>134</sup> B. Dorney,<sup>134</sup> M. Hohlmann,<sup>134</sup> H. Kalakhety,<sup>134</sup> F. Yumiceva,<sup>134</sup> M. R. Adams,<sup>135</sup> L. Apanasevich,<sup>135</sup> V. E. Bazterra,<sup>135</sup> R. R. Betts,<sup>135</sup> I. Bucinskaite,<sup>135</sup> R. Cavanaugh,<sup>135</sup> O. Evdokimov,<sup>135</sup> L. Gauthier,<sup>135</sup> C. E. Gerber,<sup>135</sup> D. J. Hofman,<sup>135</sup> S. Khalatyan,<sup>135</sup> P. Kurt,<sup>135</sup> D. H. Moon,<sup>135</sup> C. O'Brien,<sup>135</sup> C. Silkworth,<sup>135</sup> P. Turner,<sup>135</sup> N. Varelas,<sup>135</sup> U. Akgun,<sup>136</sup> E. A. Albayrak,<sup>136,xx</sup> B. Bilki,<sup>136,eee</sup> W. Clarida,<sup>136</sup> K. Dilsiz,<sup>136</sup> F. Duru,<sup>136</sup> M. Haytmyradov,<sup>136</sup> J.-P. Merlo,<sup>136</sup> H. Mermerkaya,<sup>136,fff</sup> A. Mestvirishvili,<sup>136</sup> A. Moeller,<sup>136</sup> J. Nachtman,<sup>136</sup> H. Ogul,<sup>136</sup> Y. Onel,<sup>136</sup> F. Ozok,<sup>136,xx</sup> S. Sen,<sup>136</sup> P. Tan,<sup>136</sup> E. Tiras,<sup>136</sup> J. Wetzel,<sup>136</sup> T. Yetkin,<sup>136,ggg</sup> K. Yi,<sup>136</sup> B. A. Barnett,<sup>137</sup> B. Blumenfeld,<sup>137</sup> S. Bolognesi,<sup>137</sup> D. Fehling,<sup>137</sup> A. V. Gritsan,<sup>137</sup> P. Maksimovic,<sup>137</sup> C. Martin,<sup>137</sup> M. Swartz,<sup>137</sup> P. Baringer,<sup>138</sup> A. Bean,<sup>138</sup> G. Benelli,<sup>138</sup> R. P. Kenny III,<sup>138</sup> M. Murray,<sup>138</sup> D. Noonan,<sup>138</sup> S. Sanders,<sup>138</sup> J. Sekaric,<sup>138</sup> R. Stringer,<sup>138</sup> Q. Wang,<sup>138</sup> J. S. Wood,<sup>138</sup> A. F. Barfuss,<sup>139</sup> I. Chakaberia,<sup>139</sup> A. Ivanov,<sup>139</sup> S. Khalil,<sup>139</sup> M. Makouski,<sup>139</sup> Y. Maravin,<sup>139</sup> L. K. Saini,<sup>139</sup> S. Shrestha,<sup>139</sup> I. Svintradze,<sup>139</sup> J. Gronberg,<sup>140</sup> D. Lange,<sup>140</sup> F. Rebassoo,<sup>140</sup> D. Wright,<sup>140</sup> A. Baden,<sup>141</sup> B. Calvert,<sup>141</sup> S. C. Eno,<sup>141</sup> J. A. Gomez,<sup>141</sup> N. J. Hadley,<sup>141</sup> R. G. Kellogg,<sup>141</sup> T. Kolberg,<sup>141</sup> Y. Lu,<sup>141</sup> M. Marionneau,<sup>141</sup> A. C. Mignerey,<sup>141</sup> K. Pedro,<sup>141</sup> A. Skuja,<sup>141</sup> J. Temple,<sup>141</sup> M. B. Tonjes,<sup>141</sup> S. C. Tonwar,<sup>141</sup> A. Apyan,<sup>142</sup> R. Barbieri,<sup>142</sup> G. Bauer,<sup>142</sup> W. Busza,<sup>142</sup> I. A. Cali,<sup>142</sup> M. Chan,<sup>142</sup> L. Di Matteo,<sup>142</sup> V. Dutta,<sup>142</sup> G. Gomez Ceballos,<sup>142</sup> M. Goncharov,<sup>142</sup> D. Gulhan,<sup>142</sup> M. Klute,<sup>142</sup> Y. S. Lai,<sup>142</sup> Y.-J. Lee,<sup>142</sup> A. Levin,<sup>142</sup> P. D. Luckey,<sup>142</sup> T. Ma,<sup>142</sup> C. Paus,<sup>142</sup> D. Ralph,<sup>142</sup> C. Roland,<sup>142</sup> G. Roland,<sup>142</sup> G. S. F. Stephans,<sup>142</sup> F. Stöckli,<sup>142</sup> K. Sumorok,<sup>142</sup> D. Velicanu,<sup>142</sup> J. Veverka,<sup>142</sup> B. Wyslouch,<sup>142</sup> M. Yang,<sup>142</sup> A. S. Yoon,<sup>142</sup> M. Zanetti,<sup>142</sup> V. Zhukova,<sup>142</sup> B. Dahmes,<sup>143</sup> A. De Benedetti,<sup>143</sup> A. Gude,<sup>143</sup> S. C. Kao,<sup>143</sup> K. Klapoetke,<sup>143</sup> Y. Kubota,<sup>143</sup> J. Mans,<sup>143</sup> N. Pastika,<sup>143</sup> R. Rusack,<sup>143</sup> A. Singovsky,<sup>143</sup> N. Tambe,<sup>143</sup> J. Turkewitz,<sup>143</sup> J. G. Acosta,<sup>144</sup> L. M. Cremaldi,<sup>144</sup> R. Kroeger,<sup>144</sup> S. Oliveros,<sup>144</sup> L. Perera,<sup>144</sup> R. Rahmat,<sup>144</sup> D. A. Sanders,<sup>144</sup> D. Summers,<sup>144</sup> E. Avdeeva,<sup>145</sup> K. Bloom,<sup>145</sup> S. Bose,<sup>145</sup> D. R. Claes,<sup>145</sup> A. Dominguez,<sup>145</sup> R. Gonzalez Suarez,<sup>145</sup> J. Keller,<sup>145</sup> D. Knowlton,<sup>145</sup> I. Kravchenko,<sup>145</sup> J. Lazo-Flores,<sup>145</sup> S. Malik,<sup>145</sup> F. Meier,<sup>145</sup> G. R. Snow,<sup>145</sup> J. Dolen,<sup>146</sup> A. Godshalk,<sup>146</sup> I. Iashvili,<sup>146</sup> S. Jain,<sup>146</sup> A. Kharchilava,<sup>146</sup> A. Kumar,<sup>146</sup> S. Rappoccio,<sup>146</sup> Z. Wan,<sup>146</sup> G. Alverson,<sup>147</sup> E. Barberis,<sup>147</sup> D. Baumgartel,<sup>147</sup> M. Chasco,<sup>147</sup> J. Haley,<sup>147</sup> A. Massironi,<sup>147</sup> D. Nash,<sup>147</sup> T. Orimoto,<sup>147</sup> D. Trocino,<sup>147</sup> D. Wood,<sup>147</sup> J. Zhang,<sup>147</sup> A. Anastassov,<sup>148</sup> K. A. Hahn,<sup>148</sup> A. Kubik,<sup>148</sup> L. Lusito,<sup>148</sup> N. Mucia,<sup>148</sup> N. Odell,<sup>148</sup> B. Pollack,<sup>148</sup> A. Pozdnyakov,<sup>148</sup> M. Schmitt,<sup>148</sup> S. Stoynev,<sup>148</sup> K. Sung,<sup>148</sup> M. Velasco,<sup>148</sup> S. Won,<sup>148</sup> D. Berry,<sup>149</sup> A. Brinkerhoff,<sup>149</sup> K. M. Chan,<sup>149</sup> A. Drozdetskiy,<sup>149</sup> M. Hildreth,<sup>149</sup> C. Jessop,<sup>149</sup> D. J. Karmgard,<sup>149</sup> N. Kellams,<sup>149</sup> J. Kolb,<sup>149</sup> K. Lannon,<sup>149</sup> W. Luo,<sup>149</sup> S. Lynch,<sup>149</sup> N. Marinelli,<sup>149</sup> D. M. Morse,<sup>149</sup> T. Pearson,<sup>149</sup> M. Planer,<sup>149</sup> R. Ruchti,<sup>149</sup> J. Slaunwhite,<sup>149</sup> N. Valls,<sup>149</sup> M. Wayne,<sup>149</sup> M. Wolf,<sup>149</sup> A. Woodard,<sup>149</sup> L. Antonelli,<sup>150</sup> B. Bylsma,<sup>150</sup> L. S. Durkin,<sup>150</sup> S. Flowers,<sup>150</sup> C. Hill,<sup>150</sup> R. Hughes,<sup>150</sup> K. Kotov,<sup>150</sup> T. Y. Ling,<sup>150</sup> D. Puigh,<sup>150</sup> M. Rodenburg,<sup>150</sup> G. Smith,<sup>150</sup> C. Vuosalo,<sup>150</sup> B. L. Winer,<sup>150</sup> H. Wolfe,<sup>150</sup> H. W. Wulsin,<sup>150</sup> E. Berry,<sup>151</sup> P. Elmer,<sup>151</sup> V. Halyo,<sup>151</sup> P. Hebda,<sup>151</sup> J. Hegeman,<sup>151</sup> A. Hunt,<sup>151</sup> P. Jindal,<sup>151</sup> S. A. Koay,<sup>151</sup> P. Lujan,<sup>151</sup> D. Marlow,<sup>151</sup> T. Medvedeva,<sup>151</sup> M. Mooney,<sup>151</sup> J. Olsen,<sup>151</sup> P. Piroué,<sup>151</sup> X. Quan,<sup>151</sup> A. Raval,<sup>151</sup> H. Saka,<sup>151</sup> D. Stickland,<sup>151</sup> C. Tully,<sup>151</sup> J. S. Werner,<sup>151</sup> S. C. Zenz,<sup>151</sup> A. Zuranski,<sup>151</sup> E. Brownson,<sup>152</sup> A. Lopez,<sup>152</sup> H. Mendez,<sup>152</sup> J. E. Ramirez Vargas,<sup>152</sup> E. Alagoz,<sup>153</sup> D. Benedetti,<sup>153</sup> G. Bolla,<sup>153</sup> D. Bortoletto,<sup>153</sup> M. De Mattia,<sup>153</sup> A. Everett,<sup>153</sup> Z. Hu,<sup>153</sup> M. Jones,<sup>153</sup> K. Jung,<sup>153</sup> M. Kress,<sup>153</sup> N. Leonardo,<sup>153</sup> D. Lopes Pegna,<sup>153</sup> V. Maroussov,<sup>153</sup> P. Merkel,<sup>153</sup> D. H. Miller,<sup>153</sup> N. Neumeister,<sup>153</sup> B. C. Radburn-Smith,<sup>153</sup> I. Shipsey,<sup>153</sup> D. Silvers,<sup>153</sup> A. Svyatkovskiy,<sup>153</sup> F. Wang,<sup>153</sup> W. Xie,<sup>153</sup> L. Xu,<sup>153</sup> H. D. Yoo,<sup>153</sup> J. Zablocki,<sup>153</sup> Y. Zheng,<sup>153</sup> N. Parashar,<sup>154</sup> A. Adair,<sup>155</sup> B. Akgun,<sup>155</sup> K. M. Ecklund,<sup>155</sup> F. J. M. Geurts,<sup>155</sup> W. Li,<sup>155</sup> B. Michlin,<sup>155</sup> B. P. Padley,<sup>155</sup> R. Redjimi,<sup>155</sup> J. Roberts,<sup>155</sup> J. Zabel,<sup>155</sup> B. Betchart,<sup>156</sup> A. Bodek,<sup>156</sup> R. Covarelli,<sup>156</sup> P. de Barbaro,<sup>156</sup> R. Demina,<sup>156</sup> Y. Eshaq,<sup>156</sup> T. Ferbel,<sup>156</sup> A. Garcia-Bellido,<sup>156</sup> P. Goldenzweig,<sup>156</sup> J. Han,<sup>156</sup> A. Harel,<sup>156</sup> D. C. Miner,<sup>156</sup> G. Petrillo,<sup>156</sup> D. Vishnevskiy,<sup>156</sup> M. Zielinski,<sup>156</sup> A. Bhatti,<sup>157</sup> R. Ciesielski,<sup>157</sup> L. Demortier,<sup>157</sup> K. Goulianos,<sup>157</sup> G. Lungu,<sup>157</sup> S. Malik,<sup>157</sup> C. Mesropian,<sup>157</sup> S. Arora,<sup>158</sup> A. Barker,<sup>158</sup> J. P. Chou,<sup>158</sup> C. Contreras-Campana,<sup>158</sup> E. Contreras-Campana,<sup>158</sup> D. Duggan,<sup>158</sup> D. Ferencek,<sup>158</sup> Y. Gershtein,<sup>158</sup> R. Gray,<sup>158</sup> E. Halkiadakis,<sup>158</sup> D. Hidas,<sup>158</sup> A. Lath,<sup>158</sup> S. Panwalkar,<sup>158</sup> M. Park,<sup>158</sup> R. Patel,<sup>158</sup> V. Rekovic,<sup>158</sup> J. Robles,<sup>158</sup> S. Salur,<sup>158</sup> S. Schnetzer,<sup>158</sup> C. Seitz,<sup>158</sup> S. Somalwar,<sup>158</sup> R. Stone,<sup>158</sup> S. Thomas,<sup>158</sup> P. Thomassen,<sup>158</sup> M. Walker,<sup>158</sup>

K. Rose,<sup>159</sup> S. Spanier,<sup>159</sup> Z. C. Yang,<sup>159</sup> A. York,<sup>159</sup> O. Bouhali,<sup>160,hhh</sup> R. Eusebi,<sup>160</sup> W. Flanagan,<sup>160</sup> J. Gilmore,<sup>160</sup> T. Kamon,<sup>160,iii</sup> V. Khotilovich,<sup>160</sup> V. Krutelyov,<sup>160</sup> R. Montalvo,<sup>160</sup> I. Osipenkov,<sup>160</sup> Y. Pakhotin,<sup>160</sup> A. Perloff,<sup>160</sup> J. Roe,<sup>160</sup> A. Safonov,<sup>160</sup> T. Sakuma,<sup>160</sup> I. Suarez,<sup>160</sup> A. Tatarinov,<sup>160</sup> D. Toback,<sup>160</sup> N. Akchurin,<sup>161</sup> C. Cowden,<sup>161</sup> J. Damgov,<sup>161</sup> C. Dragoiu,<sup>161</sup> P. R. Duderø,<sup>161</sup> K. Kovitanggoon,<sup>161</sup> S. Kunori,<sup>161</sup> S. W. Lee,<sup>161</sup> T. Libeiro,<sup>161</sup> I. Volobouev,<sup>161</sup> E. Appelt,<sup>162</sup> A. G. Delannoy,<sup>162</sup> S. Greene,<sup>162</sup> A. Gurrola,<sup>162</sup> W. Johns,<sup>162</sup> C. Maguire,<sup>162</sup> Y. Mao,<sup>162</sup> A. Melo,<sup>162</sup> M. Sharma,<sup>162</sup> P. Sheldon,<sup>162</sup> B. Snook,<sup>162</sup> S. Tuo,<sup>162</sup> J. Velkovska,<sup>162</sup> M. W. Arenton,<sup>163</sup> S. Boutle,<sup>163</sup> B. Cox,<sup>163</sup> B. Francis,<sup>163</sup> J. Goodell,<sup>163</sup> R. Hirosky,<sup>163</sup> A. Ledovskoy,<sup>163</sup> C. Lin,<sup>163</sup> C. Neu,<sup>163</sup> J. Wood,<sup>163</sup> S. Gollapinni,<sup>164</sup> R. Harr,<sup>164</sup> P. E. Karchin,<sup>164</sup> C. Kottachchi Kankanamge Don,<sup>164</sup> P. Lamichhane,<sup>164</sup> D. A. Belknap,<sup>165</sup> L. Borrello,<sup>165</sup> D. Carlsmith,<sup>165</sup> M. Cepeda,<sup>165</sup> S. Dasu,<sup>165</sup> S. Duric,<sup>165</sup> E. Friis,<sup>165</sup> M. Grothe,<sup>165</sup> R. Hall-Wilton,<sup>165</sup> M. Herndon,<sup>165</sup> A. Hervé,<sup>165</sup> P. Klabbers,<sup>165</sup> J. Klukas,<sup>165</sup> A. Lanaro,<sup>165</sup> A. Levine,<sup>165</sup> R. Loveless,<sup>165</sup> A. Mohapatra,<sup>165</sup> I. Ojalvo,<sup>165</sup> T. Perry,<sup>165</sup> G. A. Pierro,<sup>165</sup> G. Polese,<sup>165</sup> I. Ross,<sup>165</sup> A. Sakharov,<sup>165</sup> T. Sarangi,<sup>165</sup> A. Savin<sup>165</sup> and W. H. Smith<sup>165</sup>

(CMS Collaboration)

<sup>1</sup>*Yerevan Physics Institute, Yerevan, Armenia*

<sup>2</sup>*Institut für Hochenergiephysik der OeAW, Wien, Austria*

<sup>3</sup>*National Centre for Particle and High Energy Physics, 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>*Université de Mons, Mons, Belgium*

<sup>10</sup>*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*

<sup>11</sup>*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*

<sup>12</sup>*Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil*

<sup>12a</sup>*Universidade Estadual Paulista*

<sup>12b</sup>*Universidade Federal do ABC*

<sup>13</sup>*Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria*

<sup>14</sup>*University of Sofia, Sofia, Bulgaria*

<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>*Universidad de Los Andes, Bogota, Colombia*

<sup>18</sup>*Technical University of Split, Split, Croatia*

<sup>19</sup>*University of Split, Split, Croatia*

<sup>20</sup>*Institute Rudjer Boskovic, Zagreb, Croatia*

<sup>21</sup>*University of Cyprus, Nicosia, Cyprus*

<sup>22</sup>*Charles University, Prague, Czech Republic*

<sup>23</sup>*Academy of Scientific Research and Technology of the Arab Republic of Egypt,*

*Egyptian Network of High Energy Physics, Cairo, Egypt*

<sup>24</sup>*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*

<sup>25</sup>*Department of Physics, University of Helsinki, Helsinki, Finland*

<sup>26</sup>*Helsinki Institute of Physics, Helsinki, Finland*

<sup>27</sup>*Lappeenranta University of Technology, Lappeenranta, Finland*

<sup>28</sup>*DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France*

<sup>29</sup>*Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France*

<sup>30</sup>*Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse,*

*CNRS/IN2P3, Strasbourg, France*

<sup>31</sup>*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France*

<sup>32</sup>*Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France*

<sup>33</sup>*Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia*

<sup>34</sup>*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*

<sup>35</sup>*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*

<sup>36</sup>*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*

<sup>37</sup>*Deutsches Elektronen-Synchrotron, Hamburg, Germany*

<sup>38</sup>*University of Hamburg, Hamburg, Germany*

<sup>39</sup>*Institut für Experimentelle Kernphysik, Karlsruhe, Germany*

- <sup>40</sup>*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
- <sup>41</sup>*University of Athens, Athens, Greece*
- <sup>42</sup>*University of Ioánnina, Ioánnina, Greece*
- <sup>43</sup>*Wigner Research Centre for Physics, Budapest, Hungary*
- <sup>44</sup>*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
- <sup>45</sup>*University of Debrecen, Debrecen, Hungary*
- <sup>46</sup>*National Institute of Science Education and Research, Bhubaneswar, India*
- <sup>47</sup>*Panjab University, Chandigarh, India*
- <sup>48</sup>*University of Delhi, Delhi, India*
- <sup>49</sup>*Saha Institute of Nuclear Physics, Kolkata, India*
- <sup>50</sup>*Bhabha Atomic Research Centre, Mumbai, India*
- <sup>51</sup>*Tata Institute of Fundamental Research - EHEP, Mumbai, India*
- <sup>52</sup>*Tata Institute of Fundamental Research - HECR, Mumbai, India*
- <sup>53</sup>*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
- <sup>54</sup>*University College Dublin, Dublin, Ireland*
- <sup>55</sup>*INFN Sezione di Bari, Università di Bari, Politecnico di Bari, Bari, Italy*
- <sup>55a</sup>*INFN Sezione di Bari*
- <sup>55b</sup>*Università di Bari*
- <sup>55c</sup>*Politecnico di Bari*
- <sup>56</sup>*INFN Sezione di Bologna, Università di Bologna, Bologna, Italy*
- <sup>56a</sup>*INFN Sezione di Bologna*
- <sup>56b</sup>*Università di Bologna*
- <sup>57</sup>*INFN Sezione di Catania, Università di Catania, CSFNSM, Catania, Italy*
- <sup>57a</sup>*INFN Sezione di Catania*
- <sup>57b</sup>*Università di Catania*
- <sup>57c</sup>*CSFNSM*
- <sup>58</sup>*INFN Sezione di Firenze, Università di Firenze, Firenze, Italy*
- <sup>58a</sup>*INFN Sezione di Firenze*
- <sup>58b</sup>*Università di Firenze*
- <sup>59</sup>*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
- <sup>60</sup>*INFN Sezione di Genova, Università di Genova, Genova, Italy*
- <sup>60a</sup>*INFN Sezione di Genova*
- <sup>60b</sup>*Università di Genova*
- <sup>61</sup>*INFN Sezione di Milano-Bicocca, Università di Milano-Bicocca, Milano, Italy*
- <sup>61a</sup>*INFN Sezione di Milano-Bicocca*
- <sup>61b</sup>*Università di Milano-Bicocca*
- <sup>62</sup>*INFN Sezione di Napoli, Università di Napoli 'Federico II', Università della Basilicata (Potenza),  
Università G. Marconi (Roma), Napoli, Italy*
- <sup>62a</sup>*INFN Sezione di Napoli*
- <sup>62b</sup>*Università di Napoli 'Federico II'*
- <sup>62c</sup>*Università della Basilicata (Potenza)*
- <sup>62d</sup>*Università G. Marconi (Roma)*
- <sup>63</sup>*INFN Sezione di Padova, Università di Padova, Università di Trento (Trento), Padova, Italy*
- <sup>63a</sup>*INFN Sezione di Padova*
- <sup>63b</sup>*Università di Padova*
- <sup>63c</sup>*Università di Trento (Trento)*
- <sup>64</sup>*INFN Sezione di Pavia, Università di Pavia, Pavia, Italy*
- <sup>64a</sup>*INFN Sezione di Pavia*
- <sup>64b</sup>*Università di Pavia*
- <sup>65a</sup>*INFN Sezione di Perugia*
- <sup>65b</sup>*Università di Perugia*
- <sup>66</sup>*INFN Sezione di Pisa, Università di Pisa, Scuola Normale Superiore di Pisa, Pisa, Italy*
- <sup>66a</sup>*INFN Sezione di Pisa*
- <sup>66b</sup>*Università di Pisa*
- <sup>66c</sup>*Scuola Normale Superiore di Pisa*
- <sup>67</sup>*INFN Sezione di Roma, Università di Roma, Roma, Italy*
- <sup>67a</sup>*INFN Sezione di Roma*
- <sup>67b</sup>*Università di Roma*
- <sup>68</sup>*INFN Sezione di Torino, Università di Torino, Università del Piemonte Orientale (Novara), Torino, Italy*
- <sup>68a</sup>*INFN Sezione di Torino*

- <sup>68b</sup>*Università di Torino*  
<sup>68c</sup>*Università del Piemonte Orientale (Novara)*  
<sup>69</sup>*INFN Sezione di Trieste, Università di Trieste, Trieste, Italy*  
<sup>69a</sup>*INFN Sezione di Trieste*  
<sup>69b</sup>*Università di Trieste*  
<sup>70</sup>*Kangwon National University, Chunchon, Korea*  
<sup>71</sup>*Kyungpook National University, Daegu, Korea*  
<sup>72</sup>*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*  
<sup>73</sup>*Korea University, Seoul, Korea*  
<sup>74</sup>*University of Seoul, Seoul, Korea*  
<sup>75</sup>*Sungkyunkwan University, Suwon, Korea*  
<sup>76</sup>*Vilnius University, Vilnius, Lithuania*  
<sup>77</sup>*University of Malaya Jabatan Fizik, Kuala Lumpur, Malaysia*  
<sup>78</sup>*Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico*  
<sup>79</sup>*Universidad Iberoamericana, Mexico City, Mexico*  
<sup>80</sup>*Benemerita Universidad Autonoma de Puebla, Puebla, Mexico*  
<sup>81</sup>*Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico*  
<sup>82</sup>*University of Auckland, Auckland, New Zealand*  
<sup>83</sup>*University of Canterbury, Christchurch, New Zealand*  
<sup>84</sup>*National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*  
<sup>85</sup>*National Centre for Nuclear Research, Swierk, Poland*  
<sup>86</sup>*Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*  
<sup>87</sup>*Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal*  
<sup>88</sup>*Joint Institute for Nuclear Research, Dubna, Russia*  
<sup>89</sup>*Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia*  
<sup>90</sup>*Institute for Nuclear Research, Moscow, Russia*  
<sup>91</sup>*Institute for Theoretical and Experimental Physics, Moscow, Russia*  
<sup>92</sup>*P.N. Lebedev Physical Institute, Moscow, Russia*  
<sup>93</sup>*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*  
<sup>94</sup>*State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia*  
<sup>95</sup>*University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia*  
<sup>96</sup>*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*  
<sup>97</sup>*Universidad Autónoma de Madrid, Madrid, Spain*  
<sup>98</sup>*Universidad de Oviedo, Oviedo, Spain*  
<sup>99</sup>*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*  
<sup>100</sup>*CERN, European Organization for Nuclear Research, Geneva, Switzerland*  
<sup>101</sup>*Paul Scherrer Institut, Villigen, Switzerland*  
<sup>102</sup>*Institute for Particle Physics, ETH Zurich, Zurich, Switzerland*  
<sup>103</sup>*Universität Zürich, Zurich, Switzerland*  
<sup>104</sup>*National Central University, Chung-Li, Taiwan*  
<sup>105</sup>*National Taiwan University (NTU), Taipei, Taiwan*  
<sup>106</sup>*Chulalongkorn University, Bangkok, Thailand*  
<sup>107</sup>*Cukurova University, Adana, Turkey*  
<sup>108</sup>*Middle East Technical University, Physics Department, Ankara, Turkey*  
<sup>109</sup>*Bogazici University, Istanbul, Turkey*  
<sup>110</sup>*Istanbul Technical University, Istanbul, Turkey*  
<sup>111</sup>*National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine*  
<sup>112</sup>*University of Bristol, Bristol, United Kingdom*  
<sup>113</sup>*Rutherford Appleton Laboratory, Didcot, United Kingdom*  
<sup>114</sup>*Imperial College, London, United Kingdom*  
<sup>115</sup>*Brunel University, Uxbridge, United Kingdom*  
<sup>116</sup>*Baylor University, Waco, USA*  
<sup>117</sup>*The University of Alabama, Tuscaloosa, USA*  
<sup>118</sup>*Boston University, Boston, USA*  
<sup>119</sup>*Brown University, Providence, USA*  
<sup>120</sup>*University of California, Davis, Davis, USA*  
<sup>121</sup>*University of California, Los Angeles, USA*  
<sup>122</sup>*University of California, Riverside, Riverside, USA*  
<sup>123</sup>*University of California, San Diego, La Jolla, USA*  
<sup>124</sup>*University of California, Santa Barbara, Santa Barbara, USA*

- <sup>125</sup>*California Institute of Technology, Pasadena, USA*  
<sup>126</sup>*Carnegie Mellon University, Pittsburgh, USA*  
<sup>127</sup>*University of Colorado at Boulder, Boulder, USA*  
<sup>128</sup>*Cornell University, Ithaca, USA*  
<sup>129</sup>*Fairfield University, Fairfield, USA*  
<sup>130</sup>*Fermi National Accelerator Laboratory, Batavia, USA*  
<sup>131</sup>*University of Florida, Gainesville, USA*  
<sup>132</sup>*Florida International University, Miami, USA*  
<sup>133</sup>*Florida State University, Tallahassee, USA*  
<sup>134</sup>*Florida Institute of Technology, Melbourne, USA*  
<sup>135</sup>*University of Illinois at Chicago (UIC), Chicago, USA*  
<sup>136</sup>*The University of Iowa, Iowa City, USA*  
<sup>137</sup>*Johns Hopkins University, Baltimore, USA*  
<sup>138</sup>*The University of Kansas, Lawrence, USA*  
<sup>139</sup>*Kansas State University, Manhattan, USA*  
<sup>140</sup>*Lawrence Livermore National Laboratory, Livermore, USA*  
<sup>141</sup>*University of Maryland, College Park, USA*  
<sup>142</sup>*Massachusetts Institute of Technology, Cambridge, USA*  
<sup>143</sup>*University of Minnesota, Minneapolis, USA*  
<sup>144</sup>*University of Mississippi, Oxford, USA*  
<sup>145</sup>*University of Nebraska-Lincoln, Lincoln, USA*  
<sup>146</sup>*State University of New York at Buffalo, Buffalo, USA*  
<sup>147</sup>*Northeastern University, Boston, USA*  
<sup>148</sup>*Northwestern University, Evanston, USA*  
<sup>149</sup>*University of Notre Dame, Notre Dame, USA*  
<sup>150</sup>*The Ohio State University, Columbus, USA*  
<sup>151</sup>*Princeton University, Princeton, USA*  
<sup>152</sup>*University of Puerto Rico, Mayaguez, USA*  
<sup>153</sup>*Purdue University, West Lafayette, USA*  
<sup>154</sup>*Purdue University Calumet, Hammond, USA*  
<sup>155</sup>*Rice University, Houston, USA*  
<sup>156</sup>*University of Rochester, Rochester, USA*  
<sup>157</sup>*The Rockefeller University, New York, USA*  
<sup>158</sup>*Rutgers, The State University of New Jersey, Piscataway, USA*  
<sup>159</sup>*University of Tennessee, Knoxville, USA*  
<sup>160</sup>*Texas A&M University, College Station, USA*  
<sup>161</sup>*Texas Tech University, Lubbock, USA*  
<sup>162</sup>*Vanderbilt University, Nashville, USA*  
<sup>163</sup>*University of Virginia, Charlottesville, USA*  
<sup>164</sup>*Wayne State University, Detroit, USA*  
<sup>165</sup>*University of Wisconsin, Madison, USA*

<sup>a</sup>Deceased.

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

<sup>c</sup>Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.

<sup>d</sup>Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France.

<sup>e</sup>Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia.

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

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

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

<sup>i</sup>Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.

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

<sup>k</sup>Also at Suez Canal University, Suez, Egypt.

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

<sup>m</sup>Also at Fayoum University, El-Fayoum, Egypt.

<sup>n</sup>Also at British University in Egypt, Cairo, Egypt.

<sup>o</sup>Present address: Ain Shams University, Cairo, Egypt.

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

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



- <sup>r</sup> Also at Brandenburg University of Technology, Cottbus, Germany.
- <sup>s</sup> Also at The University of Kansas, Lawrence, USA.
- <sup>t</sup> Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
- <sup>u</sup> Also at Eötvös Loránd University, Budapest, Hungary.
- <sup>v</sup> Also at Tata Institute of Fundamental Research—HECR, Mumbai, India.
- <sup>w</sup> Present address: King Abdulaziz University, Jeddah, Saudi Arabia.
- <sup>x</sup> Also at University of Visva-Bharati, Santiniketan, India.
- <sup>y</sup> Also at University of Ruhuna, Matara, Sri Lanka.
- <sup>z</sup> Also at Isfahan University of Technology, Isfahan, Iran.
- <sup>aa</sup> Also at Sharif University of Technology, Tehran, 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 Centre National de la Recherche Scientifique (CNRS)—IN2P3, Paris, France.
- <sup>ee</sup> Also at Purdue University, West Lafayette, USA.
- <sup>ff</sup> Also at Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico.
- <sup>gg</sup> Also at National Centre for Nuclear Research, Swierk, Poland.
- <sup>hh</sup> Also at Institute for Nuclear Research, Moscow, Russia.
- <sup>ii</sup> Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
- <sup>jj</sup> Also at Facoltà Ingegneria, Università di Roma, Roma, Italy.
- <sup>kk</sup> Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
- <sup>ll</sup> Also at University of Athens, Athens, Greece.
- <sup>mmm</sup> Also at Paul Scherrer Institut, Villigen, Switzerland.
- <sup>nn</sup> Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
- <sup>oo</sup> Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.
- <sup>pp</sup> Also at Gaziosmanpasa University, Tokat, Turkey.
- <sup>qq</sup> Also at Adiyaman University, Adiyaman, Turkey.
- <sup>rr</sup> Also at Cag University, Mersin, Turkey.
- <sup>ss</sup> Also at Mersin University, Mersin, Turkey.
- <sup>tt</sup> Also at Izmir Institute of Technology, Izmir, Turkey.
- <sup>uu</sup> Also at Ozyegin University, Istanbul, Turkey.
- <sup>vv</sup> Also at Kafkas University, Kars, Turkey.
- <sup>ww</sup> Also at Istanbul University, Faculty of Science, Istanbul, Turkey.
- <sup>xx</sup> Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
- <sup>yy</sup> Also at Kahramanmaraş Sütcü Imam University, Kahramanmaraş, Turkey.
- <sup>zz</sup> Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
- <sup>aaa</sup> Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- <sup>bbb</sup> Also at INFN Sezione di Perugia, Università di Perugia, Perugia, Italy.
- <sup>ccc</sup> Also at Utah Valley University, Orem, USA.
- <sup>ddd</sup> Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
- <sup>eee</sup> Also at Argonne National Laboratory, Argonne, USA.
- <sup>fff</sup> Also at Erzincan University, Erzincan, Turkey.
- <sup>ggg</sup> Also at Yildiz Technical University, Istanbul, Turkey.
- <sup>hhh</sup> Also at Texas A&M University at Qatar, Doha, Qatar.
- <sup>iii</sup> Also at Kyungpook National University, Daegu, Korea.