

2011

Measurement of the t-Channel Single Top Quark Production Cross Section in $p\bar{p}$ Collisions at $\sqrt{s}=7$ TeV

S. Chatrchyan

Yerevan Physics Institute, Yerevan, Armenia

Kenneth A. Bloom

University of Nebraska - Lincoln, kbloom2@unl.edu

S. Bose

University of Nebraska - Lincoln, sbose2@unl.edu

Jamila Butt

University of Nebraska-Lincoln

Daniel R. Claes

University of Nebraska - Lincoln, dclaes@unl.edu

See next page for additional authors

Follow this and additional works at: <http://digitalcommons.unl.edu/physicsbloom>



Part of the [Physics Commons](#)

Chatrchyan, S.; Bloom, Kenneth A.; Bose, S.; Butt, Jamila; Claes, Daniel R.; Dominguez, Aaron; Eads, Michael; Keller, J; Kelly, T; Kravchenko, Ilya; Lazo-Flores, J.; Malbouisson, Helena; Malik, Sudhir; and Snow, Gregory, "Measurement of the t-Channel Single Top Quark Production Cross Section in $p\bar{p}$ Collisions at $\sqrt{s}=7$ TeV" (2011). *Kenneth Bloom Publications*. 331.
<http://digitalcommons.unl.edu/physicsbloom/331>

This Article is brought to you for free and open access by the Research Papers in Physics and Astronomy at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Kenneth Bloom Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Authors

S. Chatrchyan, Kenneth A. Bloom, S. Bose, Jamila Butt, Daniel R. Claes, Aaron Dominguez, Michael Eads, J Keller, T Kelly, Ilya Kravchenko, J. Lazo-Flores, Helena Malbouisson, Sudhir Malik, and Gregory Snow

Measurement of the t -Channel Single Top Quark Production Cross Section in pp Collisions at $\sqrt{s} = 7$ TeV

S. Chatrchyan *et al.**

(CMS Collaboration)

(Received 16 June 2011; published 25 August 2011)

Electroweak production of the top quark is measured for the first time in pp collisions at $\sqrt{s} = 7$ TeV, using a data set collected with the CMS detector at the LHC and corresponding to an integrated luminosity of 36 pb^{-1} . With an event selection optimized for t -channel production, two complementary analyses are performed. The first one exploits the special angular properties of the signal, together with background estimates from the data. The second approach uses a multivariate analysis technique to probe the compatibility with signal topology expected from electroweak top-quark production. The combined measurement of the cross section is $83.6 \pm 29.8(\text{stat} + \text{syst}) \pm 3.3(\text{lumi}) \text{ pb}$, consistent with the standard model expectation.

DOI: 10.1103/PhysRevLett.107.091802

PACS numbers: 13.85.Ni, 12.15.Ji, 14.65.Ha

Electroweak theory predicts three mechanisms for single-top quark production in hadron-hadron collisions: t -channel, s -channel, and tW (or W -associated) production. Single-top events have been observed by the D0 and CDF experiments at the Tevatron $p\bar{p}$ collider [1–3], and first measurements of individual channels have recently been reported [4–6]. In proton-proton collisions at 7 TeV, t -channel single-top quark production, Fig. 1, has the largest cross section and the cleanest final-state topology, because of the presence of a light jet recoiling against the single-top quark. In the standard model (SM), next-to-leading order (NLO) computations with resummation of collinear and soft-gluon corrections at next-to-next-to-leading logarithmic accuracy predict $\sigma_t = 64.3^{+2.1+1.5}_{-0.7-1.7} \text{ pb}$ [7], for a top mass of $m_t = 173 \text{ GeV}/c^2$ and with parton distribution functions (PDFs) as given in Ref. [8]. The first uncertainty comes from doubling and halving the renormalization and factorization scales and the second from PDF uncertainty at the 90% confidence level. The single-top cross section measurement can be used as a test of the Cabibbo-Kobayashi-Maskawa matrix unitarity [9], of the PDFs and of the higher-order corrections from quantum chromodynamics. Departures from the SM prediction are expected in several new physics scenarios, for example, in models with flavor-changing neutral currents (FCNCs) or anomalous top-quark couplings [10].

This Letter presents the first measurement of the t -channel single-top quark production cross section in pp collisions at $\sqrt{s} = 7$ TeV in the decay channels $t \rightarrow e\nu b$, $t \rightarrow \mu\nu b$, and $t \rightarrow \tau\nu b$ with leptonic τ decays. Two

complementary measurements are performed. The first analysis exploits two angular observables sensitive to t -channel single-top quark production: the noncentral pseudorapidity distribution of the light jet, and the cosine of the angle between this jet and the final-state lepton, in the reconstructed top-quark rest frame. A multivariate analysis technique with boosted decision trees (BDTs) [11,12] is used in the second method, which probes the overall compatibility of the signal event candidates with the event topology of electroweak top-quark production. Hereafter, these analyses will be referred to as 2D analysis and BDT analysis, respectively. The 2D analysis is the first single-top quark measurement that does not depend on multivariate techniques.

Both analyses use a data sample corresponding to an integrated luminosity of $35.9 \pm 1.4 \text{ pb}^{-1}$ [13], collected by the Compact Muon Solenoid (CMS) detector [14] operating at the Large Hadron Collider (LHC). The central feature of the CMS detector is a superconducting solenoid providing a field of 3.8 T. Located within the solenoid are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter, and the brass or scintillator hadron calorimeter. Muons are measured in gas-ionization detectors embedded in the steel return yoke. In addition to the barrel and end cap detectors, a quartz-fiber Cherenkov

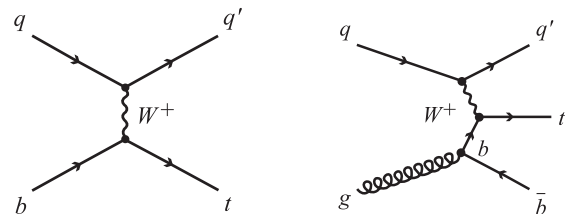


FIG. 1. Feynman diagrams for single-top quark production in t channel: $2 \rightarrow 2$ (left) and $2 \rightarrow 3$ (right) processes.

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

detector extends the jet acceptance to $|\eta| = 5$, where the pseudorapidity η is defined as $\eta = -\ln \tan \frac{\theta}{2}$, where θ is the polar angle of the particle or jet trajectory with respect to the counterclockwise beam direction.

Events are selected by requiring the presence of at least one muon or electron having high transverse momentum (p_T). The particle flow (PF) algorithm described in [15] performs a global event reconstruction and provides the full list of particles identified as electrons, muons, photons, charged and neutral hadrons. A fully reconstructed isolated muon (electron) candidate originating from the leading primary vertex is required [16] with $p_T > 20(30)$ GeV/ c , $|\eta| < 2.1$ (2.5), and a veto is applied on additional leptons passing lower thresholds.

Jets are reconstructed using the anti- k_T algorithm [17] with a distance parameter of 0.5, clustering particles identified by the PF algorithm. Jets within the full calorimeter acceptance are considered, with $p_T > 30$ GeV/ c after corrections for the jet energy scale, as determined from simulations and collision data [18]. The BDT analysis first identifies isolated leptons, which are then excluded for the jet clustering step. In the 2D analysis, possible jet-lepton ambiguities are resolved on the basis of the distance $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ between the reconstructed jet and the nearest lepton [16]. The event is accepted for further analysis only if exactly two jets are reconstructed.

In order to reduce the large background from W + light partons, we apply a b -tagging algorithm [19] that calculates the signed 3D impact-parameter (IP) significance ($\text{IP}/\sigma_{\text{IP}}$) of all the tracks, passing tight quality criteria, associated with the jet.

The tracks are ordered decreasingly, following their value of $\text{IP}/\sigma_{\text{IP}}$, and a tight selection threshold is applied on the impact-parameter significance of the third track in the list. This threshold corresponds to a b -jet identification efficiency of $\sim 40\%$ and a misidentification rate of $\sim 0.1\%$. The efficiency and misidentification probability are determined in the data as a function of p_T and η [19]. The 2D analysis exploits the expectation that most of the signal events, even in the $2 \rightarrow 3$ process, have only one b quark inside the tracking acceptance ($|\eta| < 2.4$). Events are rejected if the jet failing the tight threshold passes a loose threshold on the IP significance of the second track. The loose threshold corresponds to an efficiency and misidentification rate of about 80% and 10%, respectively. The BDT analysis applies no veto on the second b -tagged jet, and rejects events where the jets are back-to-back, which are found to be poorly reproduced by the W + jets simulation. To further suppress contributions from processes where the muon (electron) does not come from the decay of a W boson, we require a transverse mass of the W boson $M_T > 40(50)$ GeV/ c^2 , where the transverse missing energy (E_T^{miss}) from the PF algorithm is used as a measurement of the p_T of the undetected neutrino. No cut on E_T^{miss} is applied.

The 2D analysis selects 112 (72) events in the muon (electron) decay channel, while the BDT analysis selects 139 (82). In both analyses a signal purity of around 18% (16%) is expected in the muon (electron) decay channel. The main backgrounds are $t\bar{t}$, $Wb\bar{b}$, W + light-partons, Wc , tW , and processes where the lepton does not originate from a W/Z , hereafter called QCD events.

The t -channel events from Monte Carlo simulation used in this study have been generated with the MADGRAPH 4.4 event generator [20]. To give a fair approximation of the full next-to-leading order properties of the signal, we combine the dominant NLO contribution ($2 \rightarrow 3$ diagram $qg \rightarrow q't\bar{b}$ and its charge conjugate) with the leading order diagram ($2 \rightarrow 2$, $qb \rightarrow q't$) by a matching procedure based on Ref. [21]. MADGRAPH is used also for $t\bar{t}$, single-top s and tW channels, and W/Z + jets. Di-boson production (WW , WZ , ZZ) is simulated using PYTHIA 6.4.22 [22]. The CTEQ 6.6 PDF sets [23] are used for all simulated samples. All generated events undergo a full simulation of the detector response based on GEANT4 [24].

The NLO theoretical prediction is used to normalize the single-top production in s and tW channels [25,26] and diboson processes [27]. The $t\bar{t}$ cross section is normalized to 150 pb, constrained using the uncertainty from the result of a dedicated analysis. The same analysis constrains the $VQ\bar{Q}$ ($V = W, Z$ and $Q = b, c$) and Wc components, obtaining, in particular, a factor of 2 ± 1 for $Wb\bar{b}$ over the LO prediction.

The QCD yield is estimated from the same data set by a maximum likelihood fit to the M_T distribution after all other selection criteria have been applied. The M_T distribution for QCD events is taken from a control sample obtained by inverting the lepton isolation requirement. The latter requirement rejects most of the signal-like events (single top, W/Z + jets, $t\bar{t}$) leaving a QCD-dominated sample. The distribution for the sum of all non-QCD processes is taken from simulation. The uncertainty on this estimate is conservatively estimated such as to cover the differences observed when varying the fit range and the QCD shape.

The BDT analysis normalizes the result of the W + jets simulation to the inclusive W cross section at next-to-next-to-leading order (NNLO) [27], while the collision data are used in the 2D analysis to extract the normalization of the W + light-partons background. Two control samples are used, orthogonal to the standard selection. Control sample “region A,” dominated by the W + light partons background, is defined by the requirement of one isolated lepton and exactly two jets, one of which is required to be within the tracker acceptance and with at least two tracks satisfying the quality selection of the b -tagging algorithm. Both jets should fail the tight b -tagging selection. A second control sample, “region B,” is defined as a subset of the former where at least one jet passes the loose b -tagging selection although it fails the tight one. In both samples a fit

of the M_T distribution is performed, allowing the QCD and W + light-partons background to float, while all other processes, including heavy-flavor contributions and the t -channel signal, are constrained to their expected values. A scale factor of 1.27 in the muon and 1.05 in the electron decay channel is observed between the number of W + light-partons events obtained from the fit in sample region B and the predictions from simulation. These scale factors are used to obtain the central value of the predicted background. A $\pm 30\%$ ($\pm 20\%$) uncertainty is assigned on the muon (electron) scale factor, covering both the statistical uncertainty from the fit, the difference between the background predictions obtained from the two control samples, region- A and region- B , and between data and simulation results for both samples. The normalization of Z + jets background is rescaled by the same factor as that for the W + light-parton background.

A top-quark candidate is reconstructed in each event by pairing the b -tagged jet with a W -boson candidate. The latter is reconstructed by imposing the W -boson mass as a kinematic constraint, leading to a quadratic equation in the longitudinal neutrino momentum, $p_{z,\nu}$. When two real solutions are found the smallest $|p_{z,\nu}|$ is taken, and for complex solutions the imaginary component is eliminated by modifying $E_{T,x}^{\text{miss}}$ and $E_{T,y}^{\text{miss}}$ independently, such as to give $M_T = M_W$ [28].

In the 2D analysis a two-dimensional maximum likelihood fit is performed. One of the two fit variables is the cosine of the angle θ^* between the direction of the outgoing lepton and the spin axis, approximated by the direction of the untagged jet, in the top-quark rest frame [29,30]. This observable has a distinct slope in signal events, coming from the almost 100% polarization of the top-quark due to the V - A structure of the electroweak interaction [31]. This property holds true also in many theories beyond the SM [32]. The other fit variable is the pseudorapidity distribution of the untagged jet, $\eta_{\text{light jet}}$, interpreted as the light quark jet recoiling against the single top, whose characteristic η distribution allows a discrimination against the typically central jets from the main background processes. The distributions in $\cos\theta^*$ and $\eta_{\text{light jet}}$ are shown in Fig. 2 for events passing the 2D selection.

The inputs to the fit are the distributions for the signal and backgrounds in the $\cos\theta^*$ - $\eta_{\text{light jet}}$ plane, separately in the muon and electron decay channels. The overall background is allowed to float unconstrained in the fit, while its relative components are fixed according to the background estimates. The QCD and W + light-partons shapes are taken from the anti-isolated and region- A control samples described above, respectively, while all others are taken from the simulation.

The BDT method combines a given set of observables into one single classifier variable bdt . A total of 37 observables have been chosen. Their selection has been inspired by the D0 analysis [33] and optimized for the LHC

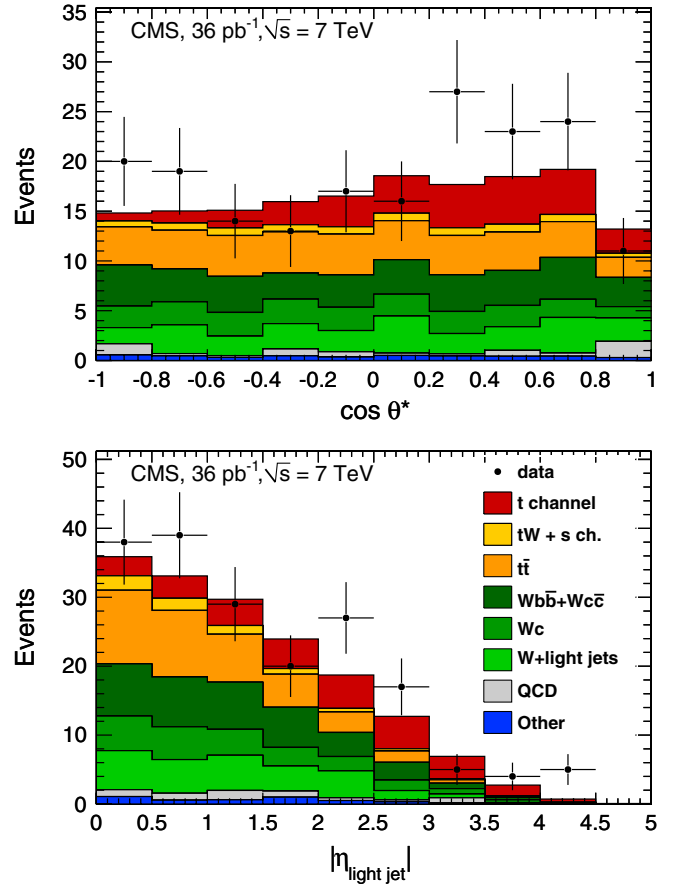


FIG. 2 (color online). Cosine of the angle between the charged lepton and the untagged jet ($\cos\theta^*$, top panel) and pseudorapidity of the untagged jet ($\eta_{\text{light jet}}$, bottom panel) after the 2D selection, for both electron and muon decay channels. QCD and W + light-partons events are normalized to the data, $t\bar{t}$, $VQ\bar{Q}$ ($V = W, Z$ and $Q = b, c$), and Wc are normalized to the result of a dedicated measurement, all other processes are normalized to theoretical expectations.

kinematics. The most discriminant ones are the lepton momentum, the mass of the system formed by the reconstructed W boson and the two jets, the p_T of the system formed by the two jets, the p_T of the jet passing tight b -tagging requirements, and the reconstructed top-quark mass. The validity of the description of all the input variables in the simulation has been checked using a Kolmogorov-Smirnov test in a W -enriched control sample with no b -tagged jet, shown in Fig. 3 (top). The bdt classifier has been validated both in simulation and in the data: negligible differences are found by comparing its distribution for signal events with MADGRAPH, SINGLETOP [21], and MC@NLO 3.4 [34], and for $t\bar{t}$ events with MADGRAPH, PYTHIA and MC@NLO. In the W -enriched control sample the distribution of bdt from the simulation is statistically compatible with the data.

The cross section is extracted from binned bdt distributions using a Bayesian approach with a uniformly

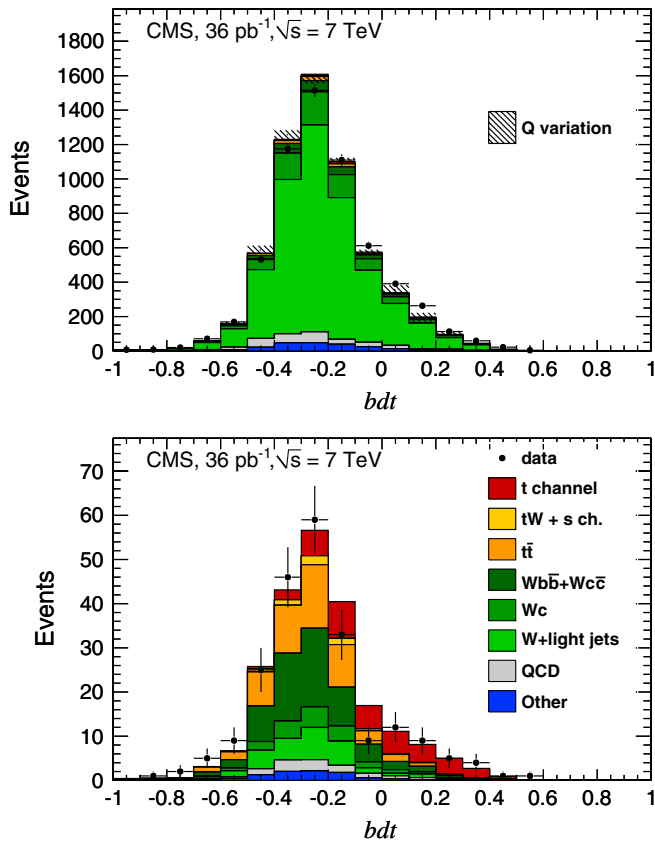


FIG. 3 (color online). Boosted decision tree discriminant (bdt) for both electron and muon decay channels in the W -enriched control sample (top panel), with simulation normalized to the data, also shown for W + jets samples with doubled and halved renormalization and factorization scales (Q). Same observable after the complete BDT selection (bottom panel), with the signal scaled to the measured cross section and all systematic uncertainties and backgrounds scaled to the medians of their posterior distributions.

distributed positive prior. The normalizations of the backgrounds and the other systematic uncertainties are treated as nuisance parameters. The measured distribution of the classifier bdt is shown in Fig. 3 (bottom).

The following sources of systematic uncertainties are common to both analyses: background normalization; jet energy scale [18], propagated coherently to the E_T^{miss} measurement; calibration of the unclustered energy deposits contributing to E_T^{miss} , varied by $\pm 10\%$; b -tagging and mistagging efficiencies [19]; modeling of the signal and of the main backgrounds; and a 4% uncertainty on the integrated luminosity [13].

The uncertainty on the signal model is estimated by comparing MADGRAPH and SINGLETOP events with different fragmentation models. The uncertainty on the $t\bar{t}$ and W/Z + jets models is determined by comparing simulated samples with varied renormalization and factorization scales (within half and double the nominal values, independently for $t\bar{t}$ and for W/Z + jets), initial- and final-state

radiation parameters, and two different fragmentation models.

The impact of pileup is estimated by comparing the default simulated samples with no pileup and dedicated samples where minimum bias interactions are superimposed with a probability distribution roughly corresponding to the one observed in the overall 2010 data set. The shapes of the bdt classifier and of both variables used in the 2D analysis are negligibly affected.

In the 2D analysis a conservative systematic uncertainty is assigned to the degree of correlation between $\eta_{\text{light jet}}$ and $\cos\theta^*$ (estimated as 6% from simulation) by comparing to the result obtained using the product of uncorrelated one-dimensional distributions for the signal. The W + light-partons background shapes in $\eta_{\text{light jet}}$ and $\cos\theta^*$ are extracted from the data in the 2D analysis, and studies with simulated events show that the shapes extracted from the control sample are statistically consistent with those in the signal region for the same process. Nevertheless, a small difference is observed in the $\eta_{\text{light jet}}$ shapes in the two selections for the Wc process, and we conservatively consider this difference as a systematic uncertainty on all W + jets processes.

The efficiencies of the muon and electron triggers, identification, and isolation for the 2D selection have been evaluated from the data using dilepton events at the Z peak [16]. The uncertainties on these efficiencies have a negligible effect on this analysis.

The impact of each individual source of uncertainty on both analyses has been estimated with an ensemble of pseudoexperiments. The dominant systematic uncertainty on the cross section determination comes from the b -tagging efficiency, known within $\pm 15\%$, because of its large effect on the signal acceptance. Nevertheless, this source has a negligible effect on the shapes of the final discriminant variables in both analyses. Other important systematic uncertainties come from the signal model, the factorization or renormalization scale for W/Z + jets, the jet energy scale, and the Wc background.

Table I shows the cross section measured by both analyses in each decay channel, corrected for acceptance and branching ratios. In the muon + electron combination all systematic uncertainties are considered fully correlated, with the exception of the uncertainty on multijet QCD obtained from the data. All measurements are consistent among each other and with the SM expectation.

Under the assumption that all uncertainties are Gaussian and symmetric, which is fulfilled by the dominant uncertainties, the 2D and BDT cross section measurements are combined with the BLUE technique [35], taking into account a statistical correlation of 51% estimated with pseudoexperiments, and treating all the systematic uncertainties as fully correlated with the exceptions of those coming from estimates based on the data. The combined result is $\sigma^{\text{exp}} = 83.6 \pm 29.8(\text{stat} + \text{syst}) \pm 3.3(\text{lumi})$ pb

TABLE I. Cross section measurements by channel and by analysis. The first uncertainty is statistical, the second systematic. An additional 4% uncertainty on the luminosity [13] for each measurement is not included.

Channel	2D analysis	BDT analysis
μ	$104.1 \pm 42.3_{-28.0}^{+24.8}$ pb	$90.4 \pm 35.1_{-19.7}^{+16.5}$ pb
e	$154.2 \pm 56.0_{-46.6}^{+40.6}$ pb	$59.2 \pm 35.1_{-13.7}^{+13.1}$ pb
$\mu + e$	$124.2 \pm 33.8_{-33.9}^{+30.0}$ pb	$78.7 \pm 25.4_{-14.6}^{+13.2}$ pb
	combined: 83.6 ± 29.8 pb	

where the BDT analysis contributes with the largest weight (89%).

The expected and observed significances, including systematic uncertainties, are estimated with an ensemble of pseudoexperiments. The probability of the predicted background distributions to fluctuate to the observed data corresponds to 3.7 (3.5) Gaussian standard deviations in the 2D (BDT) analysis, combining the electron and muon decay channels, while $2.1_{-1.1}^{+1.0}$ ($2.9_{-0.9}^{+1.0}$) are expected when assuming SM t -channel production cross section. The combined significance is well approximated by the BDT significance of 3.5 Gaussian standard deviations.

We infer an effective value of $|V_{tb}|$ under the assumption that $|V_{td}|$ and $|V_{ts}|$ are much smaller than $|V_{tb}|$, and therefore that $|V_{tb}| = \sqrt{\frac{\sigma^{\text{exp}}}{\sigma^{\text{th}}}} = 1.14 \pm 0.22(\text{exp}) \pm 0.02(\text{th})$ where σ^{th} is the SM prediction under the $|V_{tb}| = 1$ assumption. Using the SM assumption that $0 \leq |V_{tb}|^2 \leq 1$, at the 95% confidence level we infer the lower bound $|V_{tb}| > 0.62$ (0.68) from the 2D (BDT) analysis, respectively.

In summary, we confirm the Tevatron observation of single-top quark production and present the first measurement of the t -channel single-top quark production cross section in pp collisions at $\sqrt{s} = 7$ TeV, finding a good agreement with the SM prediction [7].

We wish to congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the technical and administrative staff at CERN and other CMS institutes, and acknowledge support from: FMSR (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); Academy of Sciences and NICPB (Estonia); Academy of Finland, ME, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); PAEC (Pakistan); SCSR (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MST and MAE (Russia); MSTD (Serbia);

MICINN and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); TUBITAK and TAEK (Turkey); STFC (United Kingdom); DOE and NSF (USA).

- [1] V.M. Abazov *et al.* (D0), *Phys. Rev. Lett.* **103**, 092001 (2009).
- [2] T. Aaltonen *et al.* (CDF Collaboration), *Phys. Rev. Lett.* **103**, 092002 (2009).
- [3] Tevatron Electroweak Working Group (CDF) and (D0), [arXiv:0908.2171](https://arxiv.org/abs/0908.2171).
- [4] V.M. Abazov *et al.* (D0), *Phys. Lett. B* **682**, 363 (2010).
- [5] V.M. Abazov *et al.* (D0 Collaboration), [arXiv:1105.2788](https://arxiv.org/abs/1105.2788).
- [6] T. Aaltonen *et al.* (CDF Collaboration), *Phys. Rev. D* **82**, 112005 (2010).
- [7] N. Kidonakis, *Phys. Rev. D* **83**, 091503(R)(2011).
- [8] A.D. Martin *et al.*, *Eur. Phys. J. C* **63**, 189 (2009).
- [9] J. Alwall *et al.*, *Eur. Phys. J. C* **49**, 791 (2007).
- [10] T.M.P. Tait and C.-P. Yuan, *Phys. Rev. D* **63**, 014018 (2000).
- [11] L. Breiman *et al.*, *Classification and Regression Trees* (Wadsworth and Brooks, Monterey, CA, 1984).
- [12] Y. Freund and E. Schapire, *Proceedings of the Thirteenth International Conference on Machine Learning* (Morgan Kaufmann Publishers, San Francisco, CA, 1996), p. 148.
- [13] CMS Collaboration (CMS), Report No. CMS-DP-11-002, 2011.
- [14] S. Chatrchyan *et al.* (CMS), *JINST* **3**, S08004 (2008).
- [15] CMS Collaboration (CMS), Report No. CMS-PAS-PFT-09-001, 2009.
- [16] CMS Collaboration (CMS), [arXiv:1106.0902](https://arxiv.org/abs/1106.0902) [*Eur. Phys. J. C* (to be published)].
- [17] M. Cacciari, G.P. Salam, and G. Soyez, *J. High Energy Phys.* **04** (2008) 063.
- [18] CMS Collaboration (CMS), Report No. CMS-PAS-JME-10-010, 2010.
- [19] CMS Collaboration (CMS), Report No. CMS-PAS-BTV-10-001, 2010.
- [20] F. Maltoni and T. Stelzer, *J. High Energy Phys.* **02** (2003) 027.
- [21] E. Boos *et al.*, *Phys. At. Nucl.* **69**, 1317 (2006).
- [22] T. Sjostrand *et al.*, *J. High Energy Phys.* **05** (2006) 026.
- [23] J. Pumplin *et al.*, *J. High Energy Phys.* **07** (2002) 012.
- [24] J. Allison *et al.*, *IEEE Trans. Nucl. Sci.* **53**, 270 (2006).
- [25] N. Kidonakis, *Phys. Rev. D* **81**, 054028 (2010).
- [26] J. Campbell and F. Tramontano, *Nucl. Phys. B* **726**, 109 (2005).
- [27] R. Gavin *et al.*, [arXiv:1011.3540](https://arxiv.org/abs/1011.3540).
- [28] J. Bauer, Ph.D. thesis, Karlsruhe Institut für Technologie, 2010.
- [29] G. Mahlon and S. Parke, *Phys. Rev. D* **55**, 7249 (1997).
- [30] P. Motylinski, *Phys. Rev. D* **80**, 074015 (2009).
- [31] G. Mahlon and S.J. Parke, *Phys. Lett. B* **476**, 323 (2000).
- [32] S. Batebi, S.M. Etesami, and M. Mohammadi-Najafabadi, *Phys. Rev. D* **83**, 057502 (2011).
- [33] V.M. Abazov *et al.* (D0), *Phys. Rev. D* **78**, 012005 (2008).
- [34] S. Frixione and B.R. Webber, *J. High Energy Phys.* **06** (2002) 029.
- [35] L. Lyons, D. Gibaut, and P. Cliord, *Nucl. Instrum. Methods Phys. Res., Sect. A* **270**, 110 (1988).

S. Chatrchyan,¹ V. Khachatryan,¹ A. M. Sirunyan,¹ A. Tumasyan,¹ W. Adam,² T. Bergauer,² M. Dragicevic,² J. Erö,² C. Fabjan,² M. Friedl,² R. Frühwirth,² V. M. Ghetta,² J. Hammer,^{2,b} S. Häseler,² M. Hoch,² N. Hörmann,² J. Hrubec,² M. Jeitler,² W. Kiesenhofer,² M. Krammer,² D. Liko,² I. Mikulec,² M. Pernicka,² H. Rohringer,² R. Schöfbeck,² J. Strauss,² A. Taurok,² F. Teischinger,² P. Wagner,² W. Waltenberger,² G. Walzel,² E. Widl,² C.-E. Wulz,² V. Mossolov,³ N. Shumeiko,³ J. Suarez Gonzalez,³ S. Bansal,⁴ L. Benucci,⁴ E. A. De Wolf,⁴ X. Janssen,⁴ J. Maes,⁴ T. Maes,⁴ L. Mucibello,⁴ S. Ochesanu,⁴ B. Roland,⁴ R. Rougny,⁴ M. Selvaggi,⁴ H. Van Haevermaet,⁴ P. Van Mechelen,⁴ N. Van Remortel,⁴ F. Blekman,⁵ S. Blyweert,⁵ J. D'Hondt,⁵ O. Devroede,⁵ R. Gonzalez Suarez,⁵ A. Kalogeropoulos,⁵ M. Maes,⁵ W. Van Doninck,⁵ P. Van Mulders,⁵ G. P. Van Onsem,⁵ I. Vilella,⁵ O. Charaf,⁶ B. Clerbaux,⁶ G. De Lentdecker,⁶ V. Dero,⁶ A. P. R. Gay,⁶ G. H. Hammad,⁶ T. Hreus,⁶ P. E. Marage,⁶ L. Thomas,⁶ C. Vander Velde,⁶ P. Vanlaer,⁶ V. Adler,⁷ A. Cimmino,⁷ S. Costantini,⁷ M. Grunewald,⁷ B. Klein,⁷ J. Lellouch,⁷ A. Marinov,⁷ J. McCartin,⁷ D. Ryckbosch,⁷ F. Thyssen,⁷ M. Tytgat,⁷ L. Vanelderen,⁷ P. Verwilligen,⁷ S. Walsh,⁷ N. Zaganidis,⁷ S. Basesmez,⁸ G. Bruno,⁸ J. Caudron,⁸ L. Ceard,⁸ E. Cortina Gil,⁸ J. De Favereau De Jeneret,⁸ C. Delaere,^{8,b} D. Favart,⁸ A. Giammanco,⁸ G. Grégoire,⁸ J. Hollar,⁸ V. Lemaître,⁸ J. Liao,⁸ O. Militaru,⁸ C. Nuttens,⁸ S. Olyn,⁸ D. Pagano,⁸ A. Pin,⁸ K. Piotrkowski,⁸ N. Schul,⁸ N. Belyi,⁹ T. Caebergs,⁹ E. Daubie,⁹ G. A. Alves,¹⁰ L. Brito,¹⁰ D. De Jesus Damiao,¹⁰ M. E. Pol,¹⁰ M. H. G. Souza,¹⁰ W. L. Aldá Júnior,¹¹ W. Carvalho,¹¹ E. M. Da Costa,¹¹ C. De Oliveira Martins,¹¹ S. Fonseca De Souza,¹¹ L. Mundim,¹¹ H. Nogima,¹¹ V. Oguri,¹¹ W. L. Prado Da Silva,¹¹ A. Santoro,¹¹ S. M. Silva Do Amaral,¹¹ A. Sznajder,¹¹ C. A. Bernardes,^{12,c} F. A. Dias,¹² T. R. Fernandez Perez Tomei,¹² E. M. Gregores,^{12,c} C. Lagana,¹² F. Marinho,¹² P. G. Mercadante,^{12,c} S. F. Novaes,¹² Sandra S. Padula,¹² N. Darmenov,^{13,b} V. Genchev,^{13,b} P. Iaydjiev,^{13,b} S. Piperov,¹³ M. Rodozov,¹³ S. Stoykova,¹³ G. Sultanov,¹³ V. Tchoulakov,¹³ R. Trayanov,¹³ A. Dimitrov,¹⁴ R. Hadjiiska,¹⁴ A. Karadzhanova,¹⁴ V. Kozhuharov,¹⁴ L. Litov,¹⁴ M. Mateev,¹⁴ B. Pavlov,¹⁴ P. Petkov,¹⁴ J. G. Bian,¹⁵ G. M. Chen,¹⁵ H. S. Chen,¹⁵ C. H. Jiang,¹⁵ D. Liang,¹⁵ S. Liang,¹⁵ X. Meng,¹⁵ J. Tao,¹⁵ J. Wang,¹⁵ J. Wang,¹⁵ X. Wang,¹⁵ Z. Wang,¹⁵ H. Xiao,¹⁵ M. Xu,¹⁵ J. Zang,¹⁵ Z. Zhang,¹⁵ Y. Ban,¹⁶ S. Guo,¹⁶ Y. Guo,¹⁶ W. Li,¹⁶ Y. Mao,¹⁶ S. J. Qian,¹⁶ H. Teng,¹⁶ B. Zhu,¹⁶ W. Zou,¹⁶ A. Cabrera,¹⁷ B. Gomez Moreno,¹⁷ A. A. Ocampo Rios,¹⁷ A. F. Osorio Oliveros,¹⁷ J. C. Sanabria,¹⁷ N. Godinovic,¹⁸ D. Lelas,¹⁸ K. Lelas,¹⁸ R. Plestina,^{18,d} D. Polic,¹⁸ I. Puljak,¹⁸ Z. Antunovic,¹⁹ M. Dzelalija,¹⁹ V. Brigljevic,²⁰ S. Duric,²⁰ K. Kadija,²⁰ S. Morovic,²⁰ A. Attikis,²¹ M. Galanti,²¹ J. Mousa,²¹ C. Nicolaou,²¹ F. Ptochos,²¹ P. A. Razis,²¹ M. Finger,²² M. Finger, Jr.,²² Y. Assran,^{23,e} S. Khalil,^{23,f} M. A. Mahmoud,^{23,g} A. Hektor,²⁴ M. Kadastik,²⁴ M. Müntel,²⁴ M. Raidal,²⁴ L. Rebane,²⁴ A. Tiko,²⁴ V. Azzolini,²⁵ P. Eerola,²⁵ G. Fedi,²⁵ S. Czellar,²⁶ J. Härkönen,²⁶ A. Heikkinen,²⁶ V. Karimäki,²⁶ R. Kinnunen,²⁶ M. J. Kortelainen,²⁶ T. Lampén,²⁶ K. Lassila-Perini,²⁶ S. Lehti,²⁶ T. Lindén,²⁶ P. Luukka,²⁶ T. Mäenpää,²⁶ E. Tuominen,²⁶ J. Tuominiemi,²⁶ E. Tuovinen,²⁶ D. Ungaro,²⁶ L. Wendland,²⁶ K. Banzuzi,²⁷ A. Karjalainen,²⁷ A. Korpela,²⁷ T. Tuuva,²⁷ D. Sillou,²⁸ M. Besancon,²⁹ S. Choudhury,²⁹ M. Dejardin,²⁹ D. Denegri,²⁹ B. Fabbro,²⁹ J. L. Faure,²⁹ F. Ferri,²⁹ S. Ganjour,²⁹ F. X. Gentit,²⁹ A. Givernaud,²⁹ P. Gras,²⁹ G. Hamel de Monchenault,²⁹ P. Jarry,²⁹ E. Locci,²⁹ J. Malcles,²⁹ M. Marionneau,²⁹ L. Millischer,²⁹ J. Rander,²⁹ A. Rosowsky,²⁹ I. Shreyber,²⁹ M. Titov,²⁹ P. Verrecchia,²⁹ S. Baffioni,³⁰ F. Beaudette,³⁰ L. Benhabib,³⁰ L. Bianchini,³⁰ M. Bluj,^{30,h} C. Brouin,³⁰ P. Busson,³⁰ C. Charlot,³⁰ T. Dahms,³⁰ L. Dobrzynski,³⁰ S. Elgammal,³⁰ R. Granier de Cassagnac,³⁰ M. Hagnauer,³⁰ P. Miné,³⁰ C. Mironov,³⁰ C. Ochando,³⁰ P. Paganini,³⁰ D. Sabes,³⁰ R. Salerno,³⁰ Y. Sirois,³⁰ C. Thiebaux,³⁰ B. Wyslouch,^{30,i} A. Zabi,³⁰ J.-L. Agram,^{31,j} J. Andrea,³¹ D. Bloch,³¹ D. Bodin,³¹ J.-M. Brom,³¹ M. Cardaci,³¹ E. C. Chabert,³¹ C. Collard,³¹ E. Conte,^{31,j} F. Drouhin,^{31,j} C. Ferro,³¹ J.-C. Fontaine,^{31,j} D. Gelé,³¹ U. Goerlach,³¹ S. Greder,³¹ P. Juillot,³¹ M. Karim,^{31,j} A.-C. Le Bihan,³¹ Y. Mikami,³¹ P. Van Hove,³¹ F. Fassi,³² D. Mercier,³² C. Baty,³³ S. Beauceron,³³ N. Beaupere,³³ M. Bedjidian,³³ O. Bondu,³³ G. Boudoul,³³ D. Boumediene,³³ H. Brun,³³ J. Chasserat,³³ R. Chierici,³³ D. Contardo,³³ P. Depasse,³³ H. El Mamouni,³³ J. Fay,³³ S. Gascon,³³ B. Ille,³³ T. Kurca,³³ T. Le Grand,³³ M. Lethuillier,³³ L. Mirabito,³³ S. Perries,³³ V. Sordini,³³ S. Tosi,³³ Y. Tschudi,³³ P. Verdier,³³ D. Lomidze,³⁴ G. Anagnostou,³⁵ S. Beranek,³⁵ M. Edelhoff,³⁵ L. Feld,³⁵ N. Heracleous,³⁵ O. Hindrichs,³⁵ R. Jussen,³⁵ K. Klein,³⁵ J. Merz,³⁵ N. Mohr,³⁵ A. Ostapchuk,³⁵ A. Perieanu,³⁵ F. Raupach,³⁵ J. Sammet,³⁵ S. Schael,³⁵ D. Sprenger,³⁵ H. Weber,³⁵ M. Weber,³⁵ B. Wittmer,³⁵ M. Ata,³⁶ E. Dietz-Laursonn,³⁶ M. Erdmann,³⁶ R. Fischer,³⁶ T. Hebbeker,³⁶ A. Hinzmann,³⁶ K. Hoepfner,³⁶ R. S. Höing,³⁶ T. Klimkovich,³⁶ D. Klingebiel,³⁶ P. Kreuzer,³⁶ D. Lanske,^{36,a} J. Lingemann,³⁶ C. Magass,³⁶ M. Merschmeyer,³⁶ A. Meyer,³⁶ P. Papacz,³⁶ H. Pieta,³⁶ H. Reithler,³⁶ S. A. Schmitz,³⁶ L. Sonnenschein,³⁶ J. Steggemann,³⁶ D. Teyssier,³⁶ M. Bontenackels,³⁷ M. Davids,³⁷ M. Duda,³⁷ G. Flügge,³⁷

H. Geenen,³⁷ M. Giffels,³⁷ W. Haj Ahmad,³⁷ D. Heydhausen,³⁷ F. Hoehle,³⁷ B. Kargoll,³⁷ T. Kress,³⁷ Y. Kuessel,³⁷ A. Linn,³⁷ A. Nowack,³⁷ L. Perchalla,³⁷ O. Pooth,³⁷ J. Rennefeld,³⁷ P. Sauerland,³⁷ A. Stahl,³⁷ M. Thomas,³⁷ D. Tornier,³⁷ M. H. Zoeller,³⁷ M. Aldaya Martin,³⁸ W. Behrenhoff,³⁸ U. Behrens,³⁸ M. Bergholz,^{38,k} A. Bethani,³⁸ K. Borras,³⁸ A. Cakir,³⁸ A. Campbell,³⁸ E. Castro,³⁸ D. Dammann,³⁸ G. Eckerlin,³⁸ D. Eckstein,³⁸ A. Flossdorf,³⁸ G. Flucke,³⁸ A. Geiser,³⁸ J. Hauk,³⁸ H. Jung,^{38,b} M. Kasemann,³⁸ I. Katkov,^{38,1} P. Katsas,³⁸ C. Kleinwort,³⁸ H. Kluge,³⁸ A. Knutsson,³⁸ M. Krämer,³⁸ D. Krücker,³⁸ E. Kuznetsova,³⁸ W. Lange,³⁸ W. Lohmann,^{38,k} R. Mankel,³⁸ M. Marienfeld,³⁸ I.-A. Melzer-Pellmann,³⁸ A. B. Meyer,³⁸ J. Mnich,³⁸ A. Mussgiller,³⁸ J. Olzem,³⁸ A. Petrukhin,³⁸ D. Pitzl,³⁸ A. Raspereza,³⁸ A. Raval,³⁸ M. Rosin,³⁸ R. Schmidt,^{38,k} T. Schoerner-Sadenius,³⁸ N. Sen,³⁸ A. Spiridonov,³⁸ M. Stein,³⁸ J. Tomaszewska,³⁸ R. Walsh,³⁸ C. Wissing,³⁸ C. Autermann,³⁹ V. Blobel,³⁹ S. Bobrovskiy,³⁹ J. Draeger,³⁹ H. Enderle,³⁹ U. Gebbert,³⁹ M. Görner,³⁹ K. Kaschube,³⁹ G. Kaussen,³⁹ H. Kirschenmann,³⁹ R. Klanner,³⁹ J. Lange,³⁹ B. Mura,³⁹ S. Naumann-Emme,³⁹ F. Nowak,³⁹ N. Pietsch,³⁹ C. Sander,³⁹ H. Schettler,³⁹ P. Schleper,³⁹ E. Schlieckau,³⁹ M. Schröder,³⁹ T. Schum,³⁹ J. Schwandt,³⁹ H. Stadie,³⁹ G. Steinbrück,³⁹ J. Thomsen,³⁹ C. Barth,⁴⁰ J. Bauer,⁴⁰ J. Berger,⁴⁰ V. Buege,⁴⁰ T. Chwalek,⁴⁰ W. De Boer,⁴⁰ A. Dierlamm,⁴⁰ G. Dirkes,⁴⁰ M. Feindt,⁴⁰ J. Gruschke,⁴⁰ C. Hackstein,⁴⁰ F. Hartmann,⁴⁰ M. Heinrich,⁴⁰ H. Held,⁴⁰ K. H. Hoffmann,⁴⁰ S. Honc,⁴⁰ J. R. Komaragiri,⁴⁰ T. Kuhr,⁴⁰ D. Martschei,⁴⁰ S. Mueller,⁴⁰ Th. Müller,⁴⁰ M. Niegel,⁴⁰ O. Oberst,⁴⁰ A. Oehler,⁴⁰ J. Ott,⁴⁰ T. Peiffer,⁴⁰ G. Quast,⁴⁰ K. Rabbertz,⁴⁰ F. Ratnikov,⁴⁰ N. Ratnikova,⁴⁰ M. Renz,⁴⁰ S. Röcker,⁴⁰ C. Saout,⁴⁰ A. Scheurer,⁴⁰ P. Schieferdecker,⁴⁰ F.-P. Schilling,⁴⁰ G. Schott,⁴⁰ H. J. Simonis,⁴⁰ F. M. Stober,⁴⁰ D. Troendle,⁴⁰ J. Wagner-Kuhr,⁴⁰ T. Weiler,⁴⁰ M. Zeise,⁴⁰ V. Zhukov,^{40,1} E. B. Ziebarth,⁴⁰ G. Daskalakis,⁴¹ T. Gerasis,⁴¹ S. Kesisoglou,⁴¹ A. Kyriakis,⁴¹ D. Loukas,⁴¹ I. Manolagos,⁴¹ A. Markou,⁴¹ C. Markou,⁴¹ C. Mavrommatis,⁴¹ E. Ntomari,⁴¹ E. Petrakou,⁴¹ L. Gouskos,⁴² T. J. Mertzimekis,⁴² A. Panagiotou,⁴² E. Stiliaris,⁴² I. Evangelou,⁴³ C. Foudas,⁴³ P. Kokkas,⁴³ N. Manthos,⁴³ I. Papadopoulos,⁴³ V. Patras,⁴³ F. A. Triantis,⁴³ A. Aranyi,⁴⁴ G. Bencze,⁴⁴ L. Boldizsar,⁴⁴ C. Hajdu,^{44,b} P. Hidas,⁴⁴ D. Horvath,^{44,m} A. Kapusi,⁴⁴ K. Krajczar,^{44,n} F. Sikler,^{44,b} G. I. Veres,^{44,n} G. Vesztergombi,^{44,n} N. Beni,⁴⁵ J. Molnar,⁴⁵ J. Palinkas,⁴⁵ Z. Szillasi,⁴⁵ V. Veszpremi,⁴⁵ P. Raics,⁴⁶ Z. L. Trocsanyi,⁴⁶ B. Ujvari,⁴⁶ S. B. Beri,⁴⁷ V. Bhatnagar,⁴⁷ N. Dhirra,⁴⁷ R. Gupta,⁴⁷ M. Jindal,⁴⁷ M. Kaur,⁴⁷ J. M. Kohli,⁴⁷ M. Z. Mehta,⁴⁷ N. Nishu,⁴⁷ L. K. Saini,⁴⁷ A. Sharma,⁴⁷ A. P. Singh,⁴⁷ J. Singh,⁴⁷ S. P. Singh,⁴⁷ S. Ahuja,⁴⁸ B. C. Choudhary,⁴⁸ P. Gupta,⁴⁸ S. Jain,⁴⁸ A. Kumar,⁴⁸ A. Kumar,⁴⁸ M. Naimuddin,⁴⁸ K. Ranjan,⁴⁸ R. K. Shivpuri,⁴⁸ S. Banerjee,⁴⁹ S. Bhattacharya,⁴⁹ S. Dutta,⁴⁹ B. Gumber,⁴⁹ S. Jain,⁴⁹ R. Khurana,⁴⁹ S. Sarkar,⁴⁹ R. K. Choudhury,⁵⁰ D. Dutta,⁵⁰ S. Kailas,⁵⁰ V. Kumar,⁵⁰ P. Mehta,⁵⁰ A. K. Mohanty,^{50,b} L. M. Pant,⁵⁰ P. Shukla,⁵⁰ T. Aziz,⁵¹ M. Guchait,^{51,o} A. Gurtu,⁵¹ M. Maity,^{51,p} D. Majumder,⁵¹ G. Majumder,⁵¹ K. Mazumdar,⁵¹ G. B. Mohanty,⁵¹ A. Saha,⁵¹ K. Sudhakar,⁵¹ N. Wickramage,⁵¹ S. Banerjee,⁵² S. Dugad,⁵² N. K. Mondal,⁵² H. Arfaei,⁵³ H. Bakhshiansohi,^{53,q} S. M. Etesami,⁵³ A. Fahim,^{53,q} M. Hashemi,⁵³ A. Jafari,^{53,q} M. Khakzad,⁵³ A. Mohammadi,^{53,r} M. Mohammadi Najafabadi,⁵³ S. Paktinat Mehdiabadi,⁵³ B. Safarzadeh,⁵³ M. Zeinali,^{53,s} M. Abbrescia,^{54a,54b} L. Barbone,^{54a,54b} C. Calabria,^{54a,54b} A. Colaleo,^{54a} D. Creanza,^{54a,54c} N. De Filippis,^{54a,54c,b} M. De Palma,^{54a,54b} L. Fiore,^{54a} G. Iaselli,^{54a,54c} L. Lusito,^{54a,54b} G. Maggi,^{54a,54c} M. Maggi,^{54a} N. Manna,^{54a,54b} B. Marangelli,^{54a,54b} S. My,^{54a,54c} S. Nuzzo,^{54a,54b} N. Pacifico,^{54a,54b} G. A. Pierro,^{54a} A. Pompili,^{54a,54b} G. Pugliese,^{54a,54c} F. Romano,^{54a,54c} G. Roselli,^{54a,54b} G. Selvaggi,^{54a,54b} L. Silvestris,^{54a} R. Trentadue,^{54a} S. Tupputi,^{54a,54b} G. Zito,^{54a} G. Abbiendi,^{55a} A. C. Benvenuti,^{55a} D. Bonacorsi,^{55a} S. Braibant-Giacomelli,^{55a,55b} L. Brigliadori,^{55a} P. Capiluppi,^{55a,55b} A. Castro,^{55a,55b} F. R. Cavallo,^{55a} M. Cuffiani,^{55a,55b} G. M. Dallavalle,^{55a} F. Fabbri,^{55a} A. Fanfani,^{55a,55b} D. Fasanella,^{55a} P. Giacomelli,^{55a} M. Giunta,^{55a} C. Grandi,^{55a} S. Marcellini,^{55a} G. Masetti,^{55b} M. Meneghelli,^{55a,55b} A. Montanari,^{55a} F. L. Navarria,^{55a,55b} F. Odorici,^{55a} A. Perrotta,^{55a} F. Primavera,^{55a} A. M. Rossi,^{55a,55b} T. Rovelli,^{55a,55b} G. Siroli,^{55a,55b} R. Travaglini,^{55a,55b} S. Albergo,^{56a,56b} G. Cappello,^{56a,56b} M. Chiorboli,^{56a,56b} S. Costa,^{56a,56b} A. Tricoli,^{56a,56b} C. Tuve,^{56a,56b} G. Barbagli,^{57a} V. Ciulli,^{57a,57b} C. Civinini,^{57a} R. D' Alessandro,^{57a,57b} E. Focardi,^{57a,57b} S. Frosali,^{57a,57b} E. Gallo,^{57a} S. Gonzi,^{57a,57b} P. Lenzi,^{57a,57b} M. Meschini,^{57a} S. Paoletti,^{57a} G. Sguazzoni,^{57a} A. Tropiano,^{57a,b} L. Benussi,⁵⁸ S. Bianco,⁵⁸ S. Colafranceschi,^{58,t} F. Fabbri,⁵⁸ D. Piccolo,⁵⁸ P. Fabricatore,⁵⁹ R. Musenich,⁵⁹ A. Benaglia,^{60a,60b} F. De Guio,^{60a,60b} L. Di Matteo,^{60a,60b} S. Gennai,^{60a,b} A. Ghezzi,^{60a,60b} S. Malvezzi,^{60a} A. Martelli,^{60a,60b} A. Massironi,^{60a,60b} D. Menasce,^{60a} L. Moroni,^{60a} M. Paganoni,^{60a,60b} D. Pedrini,^{60a} S. Ragazzi,^{60a,60b} N. Redaelli,^{60a} S. Sala,^{60a} T. Tabarelli de Fatis,^{60a,60b} S. Buontempo,^{61a} C. A. Carrillo Montoya,^{61a,b} N. Cavallo,^{61a,u} A. De Cosa,^{61a,61b} F. Fabozzi,^{61a,u} A. O. M. Iorio,^{61a,b} L. Lista,^{61a} M. Merola,^{61a,61b} P. Paolucci,^{61a} P. Azzi,^{62a} N. Bacchetta,^{62a} P. Bellan,^{62a,62b} D. Bisello,^{62a,62b} A. Branca,^{62a} R. Carlin,^{62a,62b} P. Checchia,^{62a} T. Dorigo,^{62a} U. Dosselli,^{62a} F. Fanzago,^{62a} F. Gasparini,^{62a,62b} U. Gasparini,^{62a,62b} A. Gozzelino,^{62a} S. Lacaprarà,^{62a}

I. Lazzizzera,^{62a,62c} M. Margoni,^{62a,62b} M. Mazzucato,^{62a} A. T. Meneguzzo,^{62a,62b} M. Nespolo,^{62a,b} L. Perrozzi,^{62a,b}
 N. Pozzobon,^{62a,62b} P. Ronchese,^{62a,62b} F. Simonetto,^{62a,62b} E. Torassa,^{62a} M. Tosi,^{62a,62b} S. Vanini,^{62a,62b}
 P. Zotto,^{62a,62b} G. Zumerle,^{62a,62b} P. Baesso,^{63a,63b} U. Berzano,^{63a} S. P. Ratti,^{63a,63b} C. Riccardi,^{63a,63b} P. Torre,^{63a,63b}
 P. Vitulo,^{63a,63b} C. Viviani,^{63a,63b} M. Biasini,^{64a,64b} G. M. Bilei,^{64a} B. Caponeri,^{64a,64b} L. Fanò,^{64a,64b}
 P. Lariccia,^{64a,64b} A. Lucaroni,^{64a,64b,b} G. Mantovani,^{64a,64b} M. Menichelli,^{64a} A. Nappi,^{64a,64b} F. Romeo,^{64a,64b}
 A. Santocchia,^{64a,64b} S. Taroni,^{64a,64b,b} M. Valdata,^{64a,64b} P. Azzurri,^{65a,65c} G. Bagliesi,^{65a} J. Bernardini,^{65a,65b}
 T. Boccali,^{65a,b} G. Broccolo,^{65a,65c} R. Castaldi,^{65a} R. T. D'Agno, ^{65a,65c} R. Dell'Orso,^{65a} F. Fiori,^{65a,65b} L. Foà,^{65a,65c}
 A. Giassi,^{65a} A. Kraan,^{65a} F. Ligabue,^{65a,65c} T. Lomtadze,^{65a} L. Martini,^{65a,v} A. Messineo,^{65a,65b} F. Palla,^{65a}
 G. Segneri,^{65a} A. T. Serban,^{65a} P. Spagnolo,^{65a} R. Tenchini,^{65a} G. Tonelli,^{65a,65b,b} A. Venturi,^{65a,b} P. G. Verdini,^{65a}
 L. Barone,^{66a,66b} F. Cavallari,^{66a} D. Del Re,^{66a,66b} E. Di Marco,^{66a,66b} M. Diemoz,^{66a} D. Franci,^{66a,66b} M. Grassi,^{66a,b}
 E. Longo,^{66a,66b} P. Meridiani,^{66a} S. Nourbakhsh,^{66a} G. Organtini,^{66a,66b} F. Pandolfi,^{66a,66b,b} R. Paramatti,^{66a}
 S. Rahatlou,^{66a,66b} C. Rovelli,^{66a,b} N. Amapane,^{67a,67b} R. Arcidiacono,^{67a,67c} S. Argiro,^{67a,67b} M. Arneodo,^{67a,67c}
 C. Biino,^{67a} C. Botta,^{67a,67b,b} N. Cartiglia,^{67a} R. Castello,^{67a,67b} M. Costa,^{67a,67b} N. Demaria,^{67a} A. Graziano,^{67a,67b,b}
 C. Mariotti,^{67a} M. Marone,^{67a,67b} S. Maselli,^{67a} E. Migliore,^{67a,67b} G. Mila,^{67a,67b} V. Monaco,^{67a,67b} M. Musich,^{67a,67b}
 M. M. Obertino,^{67a,67c} N. Pastrone,^{67a} M. Pelliccioni,^{67a,67b} A. Potenza,^{67a,67b} A. Romero,^{67a,67b} M. Ruspa,^{67a,67c}
 R. Sacchi,^{67a,67b} V. Sola,^{67a,67b} A. Solano,^{67a,67b} A. Staiano,^{67a} A. Vilela Pereira,^{67a} S. Belforte,^{68a} F. Cossutti,^{68a}
 G. Della Ricca,^{68a,68b} B. Gobbo,^{68a} D. Montanino,^{68a,68b} A. Penzo,^{68a} S. G. Heo,⁶⁹ S. K. Nam,⁶⁹ S. Chang,⁷⁰
 J. Chung,⁷⁰ D. H. Kim,⁷⁰ G. N. Kim,⁷⁰ J. E. Kim,⁷⁰ D. J. Kong,⁷⁰ H. Park,⁷⁰ S. R. Ro,⁷⁰ D. Son,⁷⁰ D. C. Son,⁷⁰
 T. Son,⁷⁰ Zero Kim,⁷¹ J. Y. Kim,⁷¹ S. Song,⁷¹ S. Choi,⁷² B. Hong,⁷² M. Jo,⁷² H. Kim,⁷² J. H. Kim,⁷² T. J. Kim,⁷²
 K. S. Lee,⁷² D. H. Moon,⁷² S. K. Park,⁷² K. S. Sim,⁷² M. Choi,⁷³ S. Kang,⁷³ H. Kim,⁷³ C. Park,⁷³ I. C. Park,⁷³
 S. Park,⁷³ G. Ryu,⁷³ Y. Choi,⁷⁴ Y. K. Choi,⁷⁴ J. Goh,⁷⁴ M. S. Kim,⁷⁴ J. Lee,⁷⁴ S. Lee,⁷⁴ H. Seo,⁷⁴ I. Yu,⁷⁴
 M. J. Bilinskas,⁷⁵ I. Grigelionis,⁷⁵ M. Janulis,⁷⁵ D. Martisiute,⁷⁵ P. Petrov,⁷⁵ T. Sabonis,⁷⁵ H. Castilla-Valdez,⁷⁶
 E. De La Cruz-Burelo,⁷⁶ I. Heredia-de La Cruz,⁷⁶ R. Lopez-Fernandez,⁷⁶ R. Magaña Villalba,⁷⁶
 A. Sánchez-Hernández,⁷⁶ L. M. Villasenor-Cendejas,⁷⁶ S. Carrillo Moreno,⁷⁷ F. Vazquez Valencia,⁷⁷
 H. A. Salazar Ibarquen,⁷⁸ E. Casimiro Linares,⁷⁹ A. Morelos Pineda,⁷⁹ M. A. Reyes-Santos,⁷⁹ D. Krofcheck,⁸⁰
 J. Tam,⁸⁰ P. H. Butler,⁸¹ R. Doesburg,⁸¹ H. Silverwood,⁸¹ M. Ahmad,⁸² I. Ahmed,⁸² M. I. Asghar,⁸² H. R. Hoorani,⁸²
 W. A. Khan,⁸² T. Khurshid,⁸² S. Qazi,⁸² G. Brona,⁸³ M. Cwiok,⁸³ W. Dominik,⁸³ K. Doroba,⁸³ A. Kalinowski,⁸³
 M. Konecki,⁸³ J. Krolkowski,⁸³ T. Frueboes,⁸⁴ R. Gokiel,⁸⁴ M. Górski,⁸⁴ M. Kazana,⁸⁴ K. Nawrocki,⁸⁴
 K. Romanowska-Rybinska,⁸⁴ M. Szleper,⁸⁴ G. Wrochna,⁸⁴ P. Zalewski,⁸⁴ N. Almeida,⁸⁵ P. Bargassa,⁸⁵ A. David,⁸⁵
 P. Faccioli,⁸⁵ P. G. Ferreira Parracho,⁸⁵ M. Gallinaro,⁸⁵ P. Musella,⁸⁵ A. Nayak,⁸⁵ J. Pela,^{85,b} P. Q. Ribeiro,⁸⁵
 J. Seixas,⁸⁵ J. Varela,⁸⁵ S. Afanasiev,⁸⁶ I. Belotelov,⁸⁶ P. Bunin,⁸⁶ I. Golutvin,⁸⁶ A. Kamenev,⁸⁶ V. Karjavin,⁸⁶
 G. Kozlov,⁸⁶ A. Lanev,⁸⁶ P. Moisezenz,⁸⁶ V. Palichik,⁸⁶ V. Perelygin,⁸⁶ S. Shmatov,⁸⁶ V. Smirnov,⁸⁶ A. Volodko,⁸⁶
 A. Zarubin,⁸⁶ V. Golovtsov,⁸⁷ Y. Ivanov,⁸⁷ V. Kim,⁸⁷ P. Levchenko,⁸⁷ V. Murzin,⁸⁷ V. Oreshkin,⁸⁷ I. Smirnov,⁸⁷
 V. Sulimov,⁸⁷ L. Uvarov,⁸⁷ S. Vavilov,⁸⁷ A. Vorobyev,⁸⁷ An. Vorobyev,⁸⁷ Yu. Andreev,⁸⁸ A. Dermenev,⁸⁸
 S. Gninenko,⁸⁸ N. Golubev,⁸⁸ M. Kirsanov,⁸⁸ N. Krasnikov,⁸⁸ V. Matveev,⁸⁸ A. Pashenkov,⁸⁸ A. Toropin,⁸⁸
 S. Troitsky,⁸⁸ V. Epshteyn,⁸⁹ V. Gavrilo, ⁸⁹ V. Kaftanov,^{89,a} M. Kossov,^{89,b} A. Krokhotin,⁸⁹ N. Lychkovskaya,⁸⁹
 V. Popov,⁸⁹ G. Safronov,⁸⁹ S. Semenov,⁸⁹ V. Stolin,⁸⁹ E. Vlasov,⁸⁹ A. Zhokin,⁸⁹ E. Boos,⁹⁰ M. Dubinin,^{90,w}
 L. Dudko,⁹⁰ A. Ershov,⁹⁰ A. Gribushin,⁹⁰ O. Kodolova,⁹⁰ I. Lokhtin,⁹⁰ A. Markina,⁹⁰ S. Obraztsov,⁹⁰ M. Perfilov,⁹⁰
 S. Petrushanko,⁹⁰ L. Sarycheva,⁹⁰ V. Savrin,⁹⁰ A. Snigirev,⁹⁰ V. Andreev,⁹¹ M. Azarkin,⁹¹ I. Dremin,⁹¹
 M. Kirakosyan,⁹¹ A. Leonidov,⁹¹ S. V. Rusakov,⁹¹ A. Vinogradov,⁹¹ I. Azhgirey,⁹² I. Bayshev,⁹² S. Bitioukov,⁹²
 V. Grishin,^{92,b} V. Kachanov,⁹² D. Konstantinov,⁹² A. Korablev,⁹² V. Krychkin,⁹² V. Petrov,⁹² R. Ryutin,⁹²
 A. Sobol,⁹² L. Tourtchanovitch,⁹² S. Troshin,⁹² N. Tyurin,⁹² A. Uzunian,⁹² A. Volkov,⁹² P. Adzic,^{93,x}
 M. Djordjevic,⁹³ D. Krpic,^{93,x} J. Milosevic,⁹³ M. Aguilar-Benitez,⁹⁴ J. Alcaraz Maestre,⁹⁴ P. Arce,⁹⁴ C. Battilana,⁹⁴
 E. Calvo,⁹⁴ M. Cepeda,⁹⁴ M. Cerrada,⁹⁴ M. Chamizo Llatas,⁹⁴ N. Colino,⁹⁴ B. De La Cruz,⁹⁴ A. Delgado Peris,⁹⁴
 C. Diez Pardos,⁹⁴ D. Domínguez Vázquez,⁹⁴ C. Fernandez Bedoya,⁹⁴ J. P. Fernández Ramos,⁹⁴ A. Ferrando,⁹⁴
 J. Flix,⁹⁴ M. C. Fouz,⁹⁴ P. Garcia-Abia,⁹⁴ O. Gonzalez Lopez,⁹⁴ S. Goy Lopez,⁹⁴ J. M. Hernandez,⁹⁴ M. I. Josa,⁹⁴
 G. Merino,⁹⁴ J. Puerta Pelayo,⁹⁴ I. Redondo,⁹⁴ L. Romero,⁹⁴ J. Santaolalla,⁹⁴ M. S. Soares,⁹⁴ C. Willmott,⁹⁴
 C. Albajar,⁹⁵ G. Codispoti,⁹⁵ J. F. de Trocóniz,⁹⁵ J. Cuevas,⁹⁶ J. Fernandez Menendez,⁹⁶ S. Folgueras,⁹⁶
 I. Gonzalez Caballero,⁹⁶ L. Lloret Iglesias,⁹⁶ J. M. Vizan Garcia,⁹⁶ J. A. Brochero Cifuentes,⁹⁷ I. J. Cabrillo,⁹⁷
 A. Calderon,⁹⁷ S. H. Chuang,⁹⁷ J. Duarte Campderros,⁹⁷ M. Felcini,^{97,y} M. Fernandez,⁹⁷ G. Gomez,⁹⁷
 J. Gonzalez Sanchez,⁹⁷ C. Jorda,⁹⁷ P. Lobelle Pardo,⁹⁷ A. Lopez Virto,⁹⁷ J. Marco,⁹⁷ R. Marco,⁹⁷

C. Martinez Rivero,⁹⁷ F. Matorras,⁹⁷ F. J. Munoz Sanchez,⁹⁷ J. Piedra Gomez,^{97,z} T. Rodrigo,⁹⁷
A. Y. Rodríguez-Marrero,⁹⁷ A. Ruiz-Jimeno,⁹⁷ L. Scodellaro,⁹⁷ M. Sobron Sanudo,⁹⁷ I. Vila,⁹⁷
R. Vilar Cortabitarte,⁹⁷ D. Abbaneo,⁹⁸ E. Auffray,⁹⁸ G. Auzinger,⁹⁸ P. Baillon,⁹⁸ A. H. Ball,⁹⁸ D. Barney,⁹⁸
A. J. Bell,^{98,aa} D. Benedetti,⁹⁸ C. Bernet,^{98,d} W. Bialas,⁹⁸ P. Bloch,⁹⁸ A. Bocci,⁹⁸ S. Bolognesi,⁹⁸ M. Bona,⁹⁸
H. Breuer,⁹⁸ K. Bunkowski,⁹⁸ T. Camporesi,⁹⁸ G. Cerminara,⁹⁸ T. Christiansen,⁹⁸ J. A. Coarasa Perez,⁹⁸ B. Curé,⁹⁸
D. D'Enterria,⁹⁸ A. De Roeck,⁹⁸ S. Di Guida,⁹⁸ N. Dupont-Sagorin,⁹⁸ A. Elliott-Peisert,⁹⁸ B. Frisch,⁹⁸ W. Funk,⁹⁸
A. Gaddi,⁹⁸ G. Georgiou,⁹⁸ H. Gerwig,⁹⁸ D. Gigi,⁹⁸ K. Gill,⁹⁸ D. Giordano,⁹⁸ F. Glege,⁹⁸ R. Gomez-Reino Garrido,⁹⁸
M. Gouzevitch,⁹⁸ P. Govoni,⁹⁸ S. Gowdy,⁹⁸ L. Guiducci,⁹⁸ M. Hansen,⁹⁸ C. Hartl,⁹⁸ J. Harvey,⁹⁸ J. Hegeman,⁹⁸
B. Hegner,⁹⁸ H. F. Hoffmann,⁹⁸ A. Honma,⁹⁸ V. Innocente,⁹⁸ P. Janot,⁹⁸ K. Kaadze,⁹⁸ E. Karavakis,⁹⁸ P. Lecoq,⁹⁸
C. Lourenço,⁹⁸ T. Mäki,⁹⁸ M. Malberti,⁹⁸ L. Malgeri,⁹⁸ M. Mannelli,⁹⁸ L. Masetti,⁹⁸ A. Maurisset,⁹⁸ F. Meijers,⁹⁸
S. Mersi,⁹⁸ E. Meschi,⁹⁸ R. Moser,⁹⁸ M. U. Mozer,⁹⁸ M. Mulders,⁹⁸ E. Nesvold,^{98,b} M. Nguyen,⁹⁸ T. Orimoto,⁹⁸
L. Orsini,⁹⁸ E. Perez,⁹⁸ A. Petrilli,⁹⁸ A. Pfeiffer,⁹⁸ M. Pierini,⁹⁸ M. Pimiä,⁹⁸ D. Piparo,⁹⁸ G. Polese,⁹⁸ A. Racz,⁹⁸
W. Reece,⁹⁸ J. Rodrigues Antunes,⁹⁸ G. Rolandi,^{98,bb} T. Rommerskirchen,⁹⁸ M. Rovere,⁹⁸ H. Sakulin,⁹⁸ C. Schäfer,⁹⁸
C. Schwick,⁹⁸ I. Segoni,⁹⁸ A. Sharma,⁹⁸ P. Siegrist,⁹⁸ M. Simon,⁹⁸ P. Sphicas,^{98,cc} M. Spiropulu,^{98,w} M. Stoye,⁹⁸
P. Tropea,⁹⁸ A. Tsiros,⁹⁸ P. Vichoudis,⁹⁸ M. Voutilainen,⁹⁸ W. D. Zeuner,⁹⁸ W. Bertl,⁹⁹ K. Deiters,⁹⁹ W. Erdmann,⁹⁹
K. Gabathuler,⁹⁹ R. Horisberger,⁹⁹ Q. Ingram,⁹⁹ H. C. Kaestli,⁹⁹ S. König,⁹⁹ D. Kotlinski,⁹⁹ U. Langenegger,⁹⁹
F. Meier,⁹⁹ D. Renker,⁹⁹ T. Rohe,⁹⁹ J. Sibille,^{99,dd} A. Starodumov,^{99,ee} L. Bäni,¹⁰⁰ P. Bortignon,¹⁰⁰ L. Caminada,^{100,ff}
N. Chanon,¹⁰⁰ Z. Chen,¹⁰⁰ S. Cittolin,¹⁰⁰ G. Dissertori,¹⁰⁰ M. Dittmar,¹⁰⁰ J. Eugster,¹⁰⁰ K. Freudenreich,¹⁰⁰
C. Grab,¹⁰⁰ W. Hintz,¹⁰⁰ P. Lecomte,¹⁰⁰ W. Lustermann,¹⁰⁰ C. Marchica,^{100,ff} P. Martinez Ruiz del Arbol,¹⁰⁰
P. Milenovic,^{100,gg} F. Moortgat,¹⁰⁰ C. Nägeli,^{100,ff} P. Nef,¹⁰⁰ F. Nessi-Tedaldi,¹⁰⁰ L. Pape,¹⁰⁰ F. Pauss,¹⁰⁰ T. Punz,¹⁰⁰
A. Rizzi,¹⁰⁰ F. J. Ronga,¹⁰⁰ M. Rossini,¹⁰⁰ L. Sala,¹⁰⁰ A. K. Sanchez,¹⁰⁰ M.-C. Sawley,¹⁰⁰ B. Stieger,¹⁰⁰
L. Tauscher,^{100,a} A. Thea,¹⁰⁰ K. Theofilatos,¹⁰⁰ D. Treille,¹⁰⁰ C. Urscheler,¹⁰⁰ R. Wallny,¹⁰⁰ M. Weber,¹⁰⁰
L. Wehrli,¹⁰⁰ J. Weng,¹⁰⁰ E. Aguilo,¹⁰¹ C. Amsler,¹⁰¹ V. Chiochia,¹⁰¹ S. De Visscher,¹⁰¹ C. Favaro,¹⁰¹
M. Ivova Rikova,¹⁰¹ B. Millan Mejias,¹⁰¹ P. Otiougova,¹⁰¹ C. Regenfus,¹⁰¹ P. Robmann,¹⁰¹ A. Schmidt,¹⁰¹
H. Snoek,¹⁰¹ Y. H. Chang,¹⁰² K. H. Chen,¹⁰² C. M. Kuo,¹⁰² S. W. Li,¹⁰² W. Lin,¹⁰² Z. K. Liu,¹⁰² Y. J. Lu,¹⁰²
D. Mekterovic,¹⁰² R. Volpe,¹⁰² J. H. Wu,¹⁰² S. S. Yu,¹⁰² P. Bartalini,¹⁰³ P. Chang,¹⁰³ Y. H. Chang,¹⁰³ Y. W. Chang,¹⁰³
Y. Chao,¹⁰³ K. F. Chen,¹⁰³ W.-S. Hou,¹⁰³ Y. Hsiung,¹⁰³ K. Y. Kao,¹⁰³ Y. J. Lei,¹⁰³ R.-S. Lu,¹⁰³ J. G. Shiu,¹⁰³
Y. M. Tzeng,¹⁰³ M. Wang,¹⁰³ A. Adiguzel,¹⁰⁴ M. N. Bakirci,^{104,hh} S. Cerci,^{104,ii} C. Dozen,¹⁰⁴ I. Dumanoglu,¹⁰⁴
E. Eskut,¹⁰⁴ S. Girgis,¹⁰⁴ G. Gokbulut,¹⁰⁴ I. Hos,¹⁰⁴ E. E. Kangal,¹⁰⁴ A. Kayis Topaksu,¹⁰⁴ G. Onengut,¹⁰⁴
K. Ozdemir,¹⁰⁴ S. Ozturk,^{104,jj} A. Polatoz,¹⁰⁴ K. Sogut,^{104,kk} D. Sunar Cerci,^{104,ii} B. Tali,^{104,ii} H. Topakli,^{104,hh}
D. Uzun,¹⁰⁴ L. N. Vergili,¹⁰⁴ M. Vergili,¹⁰⁴ I. V. Akin,¹⁰⁵ T. Aliev,¹⁰⁵ B. Bilin,¹⁰⁵ S. Bilmis,¹⁰⁵ M. Deniz,¹⁰⁵
H. Gamsizkan,¹⁰⁵ A. M. Guler,¹⁰⁵ K. Ocalan,¹⁰⁵ A. Ozpineci,¹⁰⁵ M. Serin,¹⁰⁵ R. Sever,¹⁰⁵ U. E. Surat,¹⁰⁵
E. Yildirim,¹⁰⁵ M. Zeyrek,¹⁰⁵ M. Deliomeroglu,¹⁰⁶ D. Demir,^{106,ll} E. Gülmez,¹⁰⁶ B. Isildak,¹⁰⁶ M. Kaya,^{106,mm}
O. Kaya,^{106,mm} M. Özbek,¹⁰⁶ S. Ozkorucuklu,^{106,nn} N. Sonmez,^{106,oo} L. Levchuk,¹⁰⁷ F. Bostock,¹⁰⁸ J. J. Brooke,¹⁰⁸
T. L. Cheng,¹⁰⁸ E. Clement,¹⁰⁸ D. Cussans,¹⁰⁸ R. Frazier,¹⁰⁸ J. Goldstein,¹⁰⁸ M. Grimes,¹⁰⁸ D. Hartley,¹⁰⁸
G. P. Heath,¹⁰⁸ H. F. Heath,¹⁰⁸ L. Kreczko,¹⁰⁸ S. Metson,¹⁰⁸ D. M. Newbold,^{108,pp} K. Nirunpong,¹⁰⁸ A. Poll,¹⁰⁸
S. Senkin,¹⁰⁸ V. J. Smith,¹⁰⁸ L. Basso,^{109,qq} K. W. Bell,¹⁰⁹ A. Belyaev,^{109,qq} C. Brew,¹⁰⁹ R. M. Brown,¹⁰⁹
B. Camanzi,¹⁰⁹ D. J. A. Cockerill,¹⁰⁹ J. A. Coughlan,¹⁰⁹ K. Harder,¹⁰⁹ S. Harper,¹⁰⁹ J. Jackson,¹⁰⁹ B. W. Kennedy,¹⁰⁹
E. Olaiya,¹⁰⁹ D. Petyt,¹⁰⁹ B. C. Radburn-Smith,¹⁰⁹ C. H. Shepherd-Themistocleous,¹⁰⁹ I. R. Tomalin,¹⁰⁹
W. J. Womersley,¹⁰⁹ S. D. Worm,¹⁰⁹ R. Bainbridge,¹¹⁰ G. Ball,¹¹⁰ J. Ballin,¹¹⁰ R. Beuselinck,¹¹⁰ O. Buchmuller,¹¹⁰
D. Colling,¹¹⁰ N. Cripps,¹¹⁰ M. Cutajar,¹¹⁰ G. Davies,¹¹⁰ M. Della Negra,¹¹⁰ W. Ferguson,¹¹⁰ J. Fulcher,¹¹⁰
D. Futyan,¹¹⁰ A. Gilbert,¹¹⁰ A. Guneratne Bryer,¹¹⁰ G. Hall,¹¹⁰ Z. Hatherell,¹¹⁰ J. Hays,¹¹⁰ G. Iles,¹¹⁰ M. Jarvis,¹¹⁰
G. Karapostoli,¹¹⁰ L. Lyons,¹¹⁰ B. C. MacEvoy,¹¹⁰ A.-M. Magnan,¹¹⁰ J. Marrouche,¹¹⁰ B. Mathias,¹¹⁰ R. Nandi,¹¹⁰
J. Nash,¹¹⁰ A. Nikitenko,^{110,ee} A. Papageorgiou,¹¹⁰ M. Pesaresi,¹¹⁰ K. Petridis,¹¹⁰ M. Pioppi,^{110,rr} D. M. Raymond,¹¹⁰
S. Rogerson,¹¹⁰ N. Rompotis,¹¹⁰ A. Rose,¹¹⁰ M. J. Ryan,¹¹⁰ C. Seez,¹¹⁰ P. Sharp,¹¹⁰ A. Sparrow,¹¹⁰ A. Tapper,¹¹⁰
S. Tourneur,¹¹⁰ M. Vazquez Acosta,¹¹⁰ T. Virdee,¹¹⁰ S. Wakefield,¹¹⁰ N. Wardle,¹¹⁰ D. Wardrope,¹¹⁰ T. Whyntie,¹¹⁰
M. Barrett,¹¹¹ M. Chadwick,¹¹¹ J. E. Cole,¹¹¹ P. R. Hobson,¹¹¹ A. Khan,¹¹¹ P. Kyberd,¹¹¹ D. Leslie,¹¹¹ W. Martin,¹¹¹
I. D. Reid,¹¹¹ L. Teodorescu,¹¹¹ K. Hatakeyama,¹¹² H. Liu,¹¹² C. Henderson,¹¹³ T. Bose,¹¹⁴ E. Carrera Jarrin,¹¹⁴
C. Fantasia,¹¹⁴ A. Heister,¹¹⁴ J. St. John,¹¹⁴ P. Lawson,¹¹⁴ D. Lazic,¹¹⁴ J. Rohlf,¹¹⁴ D. Sperka,¹¹⁴ L. Sulak,¹¹⁴
A. Avetisyan,¹¹⁵ S. Bhattacharya,¹¹⁵ J. P. Chou,¹¹⁵ D. Cutts,¹¹⁵ A. Ferapontov,¹¹⁵ U. Heintz,¹¹⁵ S. Jabeen,¹¹⁵
G. Kukartsev,¹¹⁵ G. Landsberg,¹¹⁵ M. Luk,¹¹⁵ M. Narain,¹¹⁵ D. Nguyen,¹¹⁵ M. Segala,¹¹⁵ T. Sinthuprasith,¹¹⁵

T. Speer,¹¹⁵ K. V. Tsang,¹¹⁵ R. Breedon,¹¹⁶ G. Breto,¹¹⁶ M. Calderon De La Barca Sanchez,¹¹⁶ S. Chauhan,¹¹⁶ M. Chertok,¹¹⁶ J. Conway,¹¹⁶ P. T. Cox,¹¹⁶ J. Dolen,¹¹⁶ R. Erbacher,¹¹⁶ E. Friis,¹¹⁶ W. Ko,¹¹⁶ A. Kopecky,¹¹⁶ R. Lander,¹¹⁶ H. Liu,¹¹⁶ S. Maruyama,¹¹⁶ T. Miceli,¹¹⁶ M. Nikolic,¹¹⁶ D. Pellett,¹¹⁶ J. Robles,¹¹⁶ S. Salur,¹¹⁶ T. Schwarz,¹¹⁶ M. Searle,¹¹⁶ J. Smith,¹¹⁶ M. Squires,¹¹⁶ M. Tripathi,¹¹⁶ R. Vasquez Sierra,¹¹⁶ C. Veelken,¹¹⁶ V. Andreev,¹¹⁷ K. Arisaka,¹¹⁷ D. Cline,¹¹⁷ R. Cousins,¹¹⁷ A. Deisher,¹¹⁷ J. Duris,¹¹⁷ S. Erhan,¹¹⁷ C. Farrell,¹¹⁷ J. Hauser,¹¹⁷ M. Ignatenko,¹¹⁷ C. Jarvis,¹¹⁷ C. Plager,¹¹⁷ G. Rakness,¹¹⁷ P. Schlein,^{117,a} J. Tucker,¹¹⁷ V. Valuev,¹¹⁷ J. Babb,¹¹⁸ A. Chandra,¹¹⁸ R. Clare,¹¹⁸ J. Ellison,¹¹⁸ J. W. Gary,¹¹⁸ F. Giordano,¹¹⁸ G. Hanson,¹¹⁸ G. Y. Jeng,¹¹⁸ S. C. Kao,¹¹⁸ F. Liu,¹¹⁸ H. Liu,¹¹⁸ O. R. Long,¹¹⁸ A. Luthra,¹¹⁸ H. Nguyen,¹¹⁸ B. C. Shen,^{118,a} R. Stringer,¹¹⁸ J. Sturdy,¹¹⁸ S. Sumowidagdo,¹¹⁸ R. Wilken,¹¹⁸ S. Wimpenny,¹¹⁸ W. Andrews,¹¹⁹ J. G. Branson,¹¹⁹ G. B. Cerati,¹¹⁹ D. Evans,¹¹⁹ F. Golf,¹¹⁹ A. Holzner,¹¹⁹ R. Kelley,¹¹⁹ M. Lebourgeois,¹¹⁹ J. Letts,¹¹⁹ B. Mangano,¹¹⁹ S. Padhi,¹¹⁹ C. Palmer,¹¹⁹ G. Petrucciani,¹¹⁹ H. Pi,¹¹⁹ M. Pieri,¹¹⁹ R. Ranieri,¹¹⁹ M. Sani,¹¹⁹ V. Sharma,¹¹⁹ S. Simon,¹¹⁹ E. Sudano,¹¹⁹ M. Tadel,¹¹⁹ Y. Tu,¹¹⁹ A. Vartak,¹¹⁹ S. Wasserbaech,^{119,ss} F. Würthwein,¹¹⁹ A. Yagil,¹¹⁹ J. Yoo,¹¹⁹ D. Barge,¹²⁰ R. Bellan,¹²⁰ C. Campagnari,¹²⁰ M. D'Alfonso,¹²⁰ T. Danielson,¹²⁰ K. Flowers,¹²⁰ P. Geffert,¹²⁰ J. Incandela,¹²⁰ C. Justus,¹²⁰ P. Kalavase,¹²⁰ S. A. Koay,¹²⁰ D. Kovalskyi,¹²⁰ V. Krutelyov,¹²⁰ S. Lowette,¹²⁰ N. Mccoll,¹²⁰ V. Pavlunin,¹²⁰ F. Rebassoo,¹²⁰ J. Ribnik,¹²⁰ J. Richman,¹²⁰ R. Rossin,¹²⁰ D. Stuart,¹²⁰ W. To,¹²⁰ J. R. Vlimant,¹²⁰ A. Apresyan,¹²¹ A. Bornheim,¹²¹ J. Bunn,¹²¹ Y. Chen,¹²¹ M. Gataullin,¹²¹ Y. Ma,¹²¹ A. Mott,¹²¹ H. B. Newman,¹²¹ C. Rogan,¹²¹ K. Shin,¹²¹ V. Timciuc,¹²¹ P. Traczyk,¹²¹ J. Veverka,¹²¹ R. Wilkinson,¹²¹ Y. Yang,¹²¹ R. Y. Zhu,¹²¹ B. Akgun,¹²² R. Carroll,¹²² T. Ferguson,¹²² Y. Iiyama,¹²² D. W. Jang,¹²² S. Y. Jun,¹²² Y. F. Liu,¹²² M. Paulini,¹²² J. Russ,¹²² H. Vogel,¹²² I. Vorobiev,¹²² J. P. Cumalat,¹²³ M. E. Dinardo,¹²³ B. R. Drell,¹²³ C. J. Edelmaier,¹²³ W. T. Ford,¹²³ A. Gaz,¹²³ B. Heyburn,¹²³ E. Luigi Lopez,¹²³ U. Nauenberg,¹²³ J. G. Smith,¹²³ K. Stenson,¹²³ K. A. Ulmer,¹²³ S. R. Wagner,¹²³ S. L. Zang,¹²³ L. Agostino,¹²⁴ J. Alexander,¹²⁴ D. Cassel,¹²⁴ A. Chatterjee,¹²⁴ N. Eggert,¹²⁴ L. K. Gibbons,¹²⁴ B. Heltsley,¹²⁴ W. Hopkins,¹²⁴ A. Khukhunaishvili,¹²⁴ B. Kreis,¹²⁴ G. Nicolas Kaufman,¹²⁴ J. R. Patterson,¹²⁴ D. Puigh,¹²⁴ A. Ryd,¹²⁴ M. Saelim,¹²⁴ E. Salvati,¹²⁴ X. Shi,¹²⁴ W. Sun,¹²⁴ W. D. Teo,¹²⁴ J. Thom,¹²⁴ J. Thompson,¹²⁴ J. Vaughan,¹²⁴ Y. Weng,¹²⁴ L. Winstrom,¹²⁴ P. Wittich,¹²⁴ A. Biselli,¹²⁵ G. Cirino,¹²⁵ D. Winn,¹²⁵ S. Abdullin,¹²⁶ M. Albrow,¹²⁶ J. Anderson,¹²⁶ G. Apollinari,¹²⁶ M. Atac,¹²⁶ J. A. Bakken,¹²⁶ L. A. T. Bauerdick,¹²⁶ A. Beretvas,¹²⁶ J. Berryhill,¹²⁶ P. C. Bhat,¹²⁶ I. Bloch,¹²⁶ F. Borcharding,¹²⁶ K. Burkett,¹²⁶ J. N. Butler,¹²⁶ V. Chetluru,¹²⁶ H. W. K. Cheung,¹²⁶ F. Chlebana,¹²⁶ S. Cihangir,¹²⁶ W. Cooper,¹²⁶ D. P. Eartly,¹²⁶ V. D. Elvira,¹²⁶ S. Esen,¹²⁶ I. Fisk,¹²⁶ J. Freeman,¹²⁶ Y. Gao,¹²⁶ E. Gottschalk,¹²⁶ D. Green,¹²⁶ K. Gunthoti,¹²⁶ O. Gutsche,¹²⁶ J. Hanlon,¹²⁶ R. M. Harris,¹²⁶ J. Hirschauer,¹²⁶ B. Hooberman,¹²⁶ H. Jensen,¹²⁶ M. Johnson,¹²⁶ U. Joshi,¹²⁶ R. Khatiwada,¹²⁶ B. Klima,¹²⁶ K. Kousouris,¹²⁶ S. Kunori,¹²⁶ S. Kwan,¹²⁶ C. Leonidopoulos,¹²⁶ P. Limon,¹²⁶ D. Lincoln,¹²⁶ R. Lipton,¹²⁶ J. Lykken,¹²⁶ K. Maeshima,¹²⁶ J. M. Marraffino,¹²⁶ D. Mason,¹²⁶ P. McBride,¹²⁶ T. Miao,¹²⁶ K. Mishra,¹²⁶ S. Mrenna,¹²⁶ Y. Musienko,^{126,t} C. Newman-Holmes,¹²⁶ V. O'Dell,¹²⁶ R. Pordes,¹²⁶ O. Prokofyev,¹²⁶ N. Saoulidou,¹²⁶ E. Sexton-Kennedy,¹²⁶ S. Sharma,¹²⁶ W. J. Spalding,¹²⁶ L. Spiegel,¹²⁶ P. Tan,¹²⁶ L. Taylor,¹²⁶ S. Tkaczyk,¹²⁶ L. Uplegger,¹²⁶ E. W. Vaandering,¹²⁶ R. Vidal,¹²⁶ J. Whitmore,¹²⁶ W. Wu,¹²⁶ F. Yang,¹²⁶ F. Yumiceva,¹²⁶ J. C. Yun,¹²⁶ D. Acosta,¹²⁷ P. Avery,¹²⁷ D. Bourilkov,¹²⁷ M. Chen,¹²⁷ S. Das,¹²⁷ M. De Gruttola,¹²⁷ G. P. Di Giovanni,¹²⁷ D. Dobur,¹²⁷ A. Drozdetskiy,¹²⁷ R. D. Field,¹²⁷ M. Fisher,¹²⁷ Y. Fu,¹²⁷ I. K. Furic,¹²⁷ J. Gartner,¹²⁷ B. Kim,¹²⁷ J. Konigsberg,¹²⁷ A. Korytov,¹²⁷ A. Kropivnitskaya,¹²⁷ T. Kypreos,¹²⁷ K. Matchev,¹²⁷ G. Mitselmakher,¹²⁷ L. Muniz,¹²⁷ C. Prescott,¹²⁷ R. Remington,¹²⁷ A. Rinkevicius,¹²⁷ M. Schmitt,¹²⁷ B. Scurlock,¹²⁷ P. Sellers,¹²⁷ N. Skhirtladze,¹²⁷ M. Snowball,¹²⁷ D. Wang,¹²⁷ J. Yelton,¹²⁷ M. Zakaria,¹²⁷ V. Gaultney,¹²⁸ L. Kramer,¹²⁸ L. M. Lebolo,¹²⁸ S. Linn,¹²⁸ P. Markowitz,¹²⁸ G. Martinez,¹²⁸ J. L. Rodriguez,¹²⁸ T. Adams,¹²⁹ A. Askew,¹²⁹ J. Bochenek,¹²⁹ J. Chen,¹²⁹ B. Diamond,¹²⁹ S. V. Gleyzer,¹²⁹ J. Haas,¹²⁹ S. Hagopian,¹²⁹ V. Hagopian,¹²⁹ M. Jenkins,¹²⁹ K. F. Johnson,¹²⁹ H. Prosper,¹²⁹ L. Quertenmont,¹²⁹ S. Sekmen,¹²⁹ V. Veeraraghavan,¹²⁹ M. M. Baarmand,¹³⁰ B. Dorney,¹³⁰ S. Guragain,¹³⁰ M. Hohmann,¹³⁰ H. Kalakhety,¹³⁰ R. Ralich,¹³⁰ I. Vodopiyarov,¹³⁰ M. R. Adams,¹³¹ I. M. Anghel,¹³¹ L. Apanasevich,¹³¹ Y. Bai,¹³¹ V. E. Bazterra,¹³¹ R. R. Betts,¹³¹ J. Callner,¹³¹ R. Cavanaugh,¹³¹ C. Dragoiu,¹³¹ L. Gauthier,¹³¹ C. E. Gerber,¹³¹ D. J. Hofman,¹³¹ S. Khalatyan,¹³¹ G. J. Kunde,¹³¹ F. Lacroix,¹³¹ M. Malek,¹³¹ C. O'Brien,¹³¹ C. Silkworth,¹³¹ C. Silvestre,¹³¹ A. Smoron,¹³¹ D. Strom,¹³¹ N. Varelas,¹³¹ U. Akgun,¹³² E. A. Albayrak,¹³² B. Bilki,¹³² W. Clarida,¹³² F. Duru,¹³² C. K. Lae,¹³² E. McCliment,¹³² J.-P. Merlo,¹³² H. Mermerkaya,^{132,uu} A. Mestvirishvili,¹³² A. Moeller,¹³² J. Nachtman,¹³² C. R. Newsom,¹³² E. Norbeck,¹³² J. Olson,¹³² Y. Onel,¹³² F. Ozok,¹³² S. Sen,¹³² J. Wetzel,¹³² T. Yetkin,¹³² K. Yi,¹³² B. A. Barnett,¹³³ B. Blumenfeld,¹³³ A. Bonato,¹³³ C. Eskew,¹³³ D. Fehling,¹³³ G. Giurgiu,¹³³ A. V. Gritsan,¹³³ Z. J. Guo,¹³³ G. Hu,¹³³ P. Maksimovic,¹³³

S. Rappoccio,¹³³ M. Swartz,¹³³ N. V. Tran,¹³³ A. Whitbeck,¹³³ P. Baringer,¹³⁴ A. Bean,¹³⁴ G. Benelli,¹³⁴ O. Grachov,¹³⁴ R. P. Kenny Iii,¹³⁴ M. Murray,¹³⁴ D. Noonan,¹³⁴ S. Sanders,¹³⁴ J. S. Wood,¹³⁴ V. Zhukova,¹³⁴ A. F. Barfuss,¹³⁵ T. Bolton,¹³⁵ I. Chakaberia,¹³⁵ A. Ivanov,¹³⁵ S. Khalil,¹³⁵ M. Makouski,¹³⁵ Y. Maravin,¹³⁵ S. Shrestha,¹³⁵ I. Svintradze,¹³⁵ Z. Wan,¹³⁵ J. Gronberg,¹³⁶ D. Lange,¹³⁶ D. Wright,¹³⁶ A. Baden,¹³⁷ M. Boutemour,¹³⁷ S. C. Eno,¹³⁷ D. Ferencek,¹³⁷ J. A. Gomez,¹³⁷ N. J. Hadley,¹³⁷ R. G. Kellogg,¹³⁷ M. Kirn,¹³⁷ Y. Lu,¹³⁷ A. C. Mignerey,¹³⁷ K. Rossato,¹³⁷ P. Rumerio,¹³⁷ F. Santanastasio,¹³⁷ A. Skuja,¹³⁷ J. Temple,¹³⁷ M. B. Tonjes,¹³⁷ S. C. Tonwar,¹³⁷ E. Twedt,¹³⁷ B. Alver,¹³⁸ G. Bauer,¹³⁸ J. Bendavid,¹³⁸ W. Busza,¹³⁸ E. Butz,¹³⁸ I. A. Cali,¹³⁸ M. Chan,¹³⁸ V. Dutta,¹³⁸ P. Everaerts,¹³⁸ G. Gomez Ceballos,¹³⁸ M. Goncharov,¹³⁸ K. A. Hahn,¹³⁸ P. Harris,¹³⁸ Y. Kim,¹³⁸ M. Klute,¹³⁸ Y.-J. Lee,¹³⁸ W. Li,¹³⁸ C. Loizides,¹³⁸ P. D. Luckey,¹³⁸ T. Ma,¹³⁸ S. Nahn,¹³⁸ C. Paus,¹³⁸ D. Ralph,¹³⁸ C. Roland,¹³⁸ G. Roland,¹³⁸ M. Rudolph,¹³⁸ G. S. F. Stephans,¹³⁸ F. Stöckli,¹³⁸ K. Sumorok,¹³⁸ K. Sung,¹³⁸ E. A. Wenger,¹³⁸ R. Wolf,¹³⁸ S. Xie,¹³⁸ M. Yang,¹³⁸ Y. Yilmaz,¹³⁸ A. S. Yoon,¹³⁸ M. Zanetti,¹³⁸ S. I. Cooper,¹³⁹ P. Cushman,¹³⁹ B. Dahmes,¹³⁹ A. De Benedetti,¹³⁹ P. R. Duderø,¹³⁹ G. Franzoni,¹³⁹ J. Haupt,¹³⁹ K. Klapoetke,¹³⁹ Y. Kubota,¹³⁹ J. Mans,¹³⁹ N. Pastika,¹³⁹ V. Rekovic,¹³⁹ R. Rusack,¹³⁹ M. Sasseville,¹³⁹ A. Singovsky,¹³⁹ N. Tambe,¹³⁹ L. M. Cremaldi,¹⁴⁰ R. Godang,¹⁴⁰ R. Kroeger,¹⁴⁰ L. Perera,¹⁴⁰ R. Rahmat,¹⁴⁰ D. A. Sanders,¹⁴⁰ D. Summers,¹⁴⁰ K. Bloom,¹⁴¹ S. Bose,¹⁴¹ J. Butt,¹⁴¹ D. R. Claes,¹⁴¹ A. Dominguez,¹⁴¹ M. Eads,¹⁴¹ J. Keller,¹⁴¹ T. Kelly,¹⁴¹ I. Kravchenko,¹⁴¹ J. Lazo-Flores,¹⁴¹ H. Malbouissou,¹⁴¹ S. Malik,¹⁴¹ G. R. Snow,¹⁴¹ U. Baur,¹⁴² A. Godshalk,¹⁴² I. Iashvili,¹⁴² S. Jain,¹⁴² A. Kharchilava,¹⁴² A. Kumar,¹⁴² S. P. Shipkowski,¹⁴² K. Smith,¹⁴² J. Zennaro,¹⁴² G. Alverson,¹⁴³ E. Barberis,¹⁴³ D. Baumgartel,¹⁴³ O. Boeriu,¹⁴³ M. Chasco,¹⁴³ S. Reucroft,¹⁴³ J. Swain,¹⁴³ D. Trocino,¹⁴³ D. Wood,¹⁴³ J. Zhang,¹⁴³ A. Anastassov,¹⁴⁴ A. Kubik,¹⁴⁴ N. Odell,¹⁴⁴ R. A. Ofierzynski,¹⁴⁴ B. Pollack,¹⁴⁴ A. Pozdnyakov,¹⁴⁴ M. Schmitt,¹⁴⁴ S. Stoynev,¹⁴⁴ M. Velasco,¹⁴⁴ S. Won,¹⁴⁴ L. Antonelli,¹⁴⁵ D. Berry,¹⁴⁵ A. Brinkerhoff,¹⁴⁵ M. Hildreth,¹⁴⁵ C. Jessop,¹⁴⁵ D. J. Karmgard,¹⁴⁵ J. Kolb,¹⁴⁵ T. Kolberg,¹⁴⁵ K. Lannon,¹⁴⁵ W. Luo,¹⁴⁵ S. Lynch,¹⁴⁵ N. Marinelli,¹⁴⁵ D. M. Morse,¹⁴⁵ T. Pearson,¹⁴⁵ R. Ruchti,¹⁴⁵ J. Slaunwhite,¹⁴⁵ N. Valls,¹⁴⁵ M. Wayne,¹⁴⁵ J. Ziegler,¹⁴⁵ B. Bylsma,¹⁴⁶ L. S. Durkin,¹⁴⁶ J. Gu,¹⁴⁶ C. Hill,¹⁴⁶ P. Killewald,¹⁴⁶ K. Kotov,¹⁴⁶ T. Y. Ling,¹⁴⁶ M. Rodenburg,¹⁴⁶ G. Williams,¹⁴⁶ N. Adam,¹⁴⁷ E. Berry,¹⁴⁷ P. Elmer,¹⁴⁷ D. Gerbaudo,¹⁴⁷ V. Halyo,¹⁴⁷ P. Hebda,¹⁴⁷ A. Hunt,¹⁴⁷ J. Jones,¹⁴⁷ E. Laird,¹⁴⁷ D. Lopes Pegna,¹⁴⁷ D. Marlow,¹⁴⁷ T. Medvedeva,¹⁴⁷ M. Mooney,¹⁴⁷ J. Olsen,¹⁴⁷ P. Piroué,¹⁴⁷ X. Quan,¹⁴⁷ B. Safdi,¹⁴⁷ H. Saka,¹⁴⁷ D. Stickland,¹⁴⁷ C. Tully,¹⁴⁷ J. S. Werner,¹⁴⁷ A. Zuranski,¹⁴⁷ J. G. Acosta,¹⁴⁸ X. T. Huang,¹⁴⁸ A. Lopez,¹⁴⁸ H. Mendez,¹⁴⁸ S. Oliveros,¹⁴⁸ J. E. Ramirez Vargas,¹⁴⁸ A. Zatserklyaniy,¹⁴⁸ E. Alagoz,¹⁴⁹ V. E. Barnes,¹⁴⁹ G. Bolla,¹⁴⁹ L. Borrello,¹⁴⁹ D. Bortoletto,¹⁴⁹ M. De Mattia,¹⁴⁹ A. Everett,¹⁴⁹ A. F. Garfinkel,¹⁴⁹ L. Gutay,¹⁴⁹ Z. Hu,¹⁴⁹ M. Jones,¹⁴⁹ O. Koybasi,¹⁴⁹ M. Kress,¹⁴⁹ A. T. Laasanen,¹⁴⁹ N. Leonardo,¹⁴⁹ C. Liu,¹⁴⁹ V. Maroussov,¹⁴⁹ P. Merkel,¹⁴⁹ D. H. Miller,¹⁴⁹ N. Neumeister,¹⁴⁹ I. Shipsey,¹⁴⁹ D. Silvers,¹⁴⁹ A. Svyatkovskiy,¹⁴⁹ H. D. Yoo,¹⁴⁹ J. Zablocki,¹⁴⁹ Y. Zheng,¹⁴⁹ P. Jindal,¹⁵⁰ N. Parashar,¹⁵⁰ C. Boulahouache,¹⁵¹ K. M. Ecklund,¹⁵¹ F. J. M. Geurts,¹⁵¹ B. P. Padley,¹⁵¹ R. Redjimi,¹⁵¹ J. Roberts,¹⁵¹ J. Zabel,¹⁵¹ B. Betchart,¹⁵² A. Bodek,¹⁵² Y. S. Chung,¹⁵² R. Covarelli,¹⁵² P. de Barbaro,¹⁵² R. Demina,¹⁵² Y. Eshaq,¹⁵² H. Flacher,¹⁵² A. Garcia-Bellido,¹⁵² P. Goldenzweig,¹⁵² Y. Gotra,¹⁵² J. Han,¹⁵² A. Harel,¹⁵² D. C. Miner,¹⁵² D. Orbaker,¹⁵² G. Petrillo,¹⁵² W. Sakumoto,¹⁵² D. Vishnevskiy,¹⁵² M. Zielinski,¹⁵² A. Bhatti,¹⁵³ R. Ciesielski,¹⁵³ L. Demortier,¹⁵³ K. Goulianos,¹⁵³ G. Lungu,¹⁵³ S. Malik,¹⁵³ C. Mesropian,¹⁵³ O. Atramentov,¹⁵⁴ A. Barker,¹⁵⁴ D. Duggan,¹⁵⁴ Y. Gershtein,¹⁵⁴ R. Gray,¹⁵⁴ E. Halkiadakis,¹⁵⁴ D. Hidas,¹⁵⁴ D. Hits,¹⁵⁴ A. Lath,¹⁵⁴ S. Panwalkar,¹⁵⁴ R. Patel,¹⁵⁴ K. Rose,¹⁵⁴ S. Schnetzer,¹⁵⁴ S. Somalwar,¹⁵⁴ R. Stone,¹⁵⁴ S. Thomas,¹⁵⁴ G. Cerizza,¹⁵⁵ M. Hollingsworth,¹⁵⁵ S. Spanier,¹⁵⁵ Z. C. Yang,¹⁵⁵ A. York,¹⁵⁵ R. Eusebi,¹⁵⁶ W. Flanagan,¹⁵⁶ J. Gilmore,¹⁵⁶ A. Gurrola,¹⁵⁶ T. Kamon,¹⁵⁶ V. Khotilovich,¹⁵⁶ R. Montalvo,¹⁵⁶ I. Osipenkov,¹⁵⁶ Y. Pakhotin,¹⁵⁶ J. Pivarski,¹⁵⁶ A. Safonov,¹⁵⁶ S. Sengupta,¹⁵⁶ A. Tatarinov,¹⁵⁶ D. Toback,¹⁵⁶ M. Weinberger,¹⁵⁶ N. Akchurin,¹⁵⁷ C. Bardak,¹⁵⁷ J. Damgov,¹⁵⁷ C. Jeong,¹⁵⁷ K. Kovitanggoon,¹⁵⁷ S. W. Lee,¹⁵⁷ T. Libeiro,¹⁵⁷ P. Mane,¹⁵⁷ Y. Roh,¹⁵⁷ A. Sill,¹⁵⁷ I. Volobouev,¹⁵⁷ R. Wigmans,¹⁵⁷ E. Yazgan,¹⁵⁷ E. Appelt,¹⁵⁸ E. Brownson,¹⁵⁸ D. Engh,¹⁵⁸ C. Florez,¹⁵⁸ W. Gabella,¹⁵⁸ M. Issah,¹⁵⁸ W. Johns,¹⁵⁸ P. Kurt,¹⁵⁸ C. Maguire,¹⁵⁸ A. Melo,¹⁵⁸ P. Sheldon,¹⁵⁸ B. Snook,¹⁵⁸ S. Tuo,¹⁵⁸ J. Velkovska,¹⁵⁸ M. W. Arenton,¹⁵⁹ M. Balazs,¹⁵⁹ S. Boutle,¹⁵⁹ B. Cox,¹⁵⁹ B. Francis,¹⁵⁹ R. Hirosky,¹⁵⁹ A. Ledovskoy,¹⁵⁹ C. Lin,¹⁵⁹ C. Neu,¹⁵⁹ R. Yohay,¹⁵⁹ S. Gollapinni,¹⁶⁰ R. Harr,¹⁶⁰ P. E. Karchin,¹⁶⁰ P. Lamichhane,¹⁶⁰ M. Mattson,¹⁶⁰ C. Milstène,¹⁶⁰ A. Sakharov,¹⁶⁰ M. Anderson,¹⁶¹ M. Bachtis,¹⁶¹ J. N. Bellinger,¹⁶¹ D. Carlsmith,¹⁶¹ S. Dasu,¹⁶¹ J. Efron,¹⁶¹ L. Gray,¹⁶¹ K. S. Grogg,¹⁶¹ M. Grothe,¹⁶¹ R. Hall-Wilton,¹⁶¹ M. Herndon,¹⁶¹ A. Hervé,¹⁶¹ P. Klabbers,¹⁶¹ J. Klukas,¹⁶¹ A. Lanaro,¹⁶¹ C. Lazaridis,¹⁶¹ J. Leonard,¹⁶¹ R. Loveless,¹⁶¹ A. Mohapatra,¹⁶¹ F. Palmonari,¹⁶¹ D. Reeder,¹⁶¹ I. Ross,¹⁶¹ A. Savin,¹⁶¹ W. H. Smith,¹⁶¹ J. Swanson,¹⁶¹ and M. Weinberg¹⁶¹

(CMS Collaboration)

- ¹Yerevan Physics Institute, Yerevan, Armenia
²Institut für Hochenergiephysik der OeAW, Wien, Austria
³National Centre for Particle and High Energy Physics, Minsk, Belarus
⁴Universiteit Antwerpen, Antwerpen, Belgium
⁵Vrije Universiteit Brussel, Brussel, Belgium
⁶Université Libre de Bruxelles, Bruxelles, Belgium
⁷Ghent University, Ghent, Belgium
⁸Université Catholique de Louvain, Louvain-la-Neuve, Belgium
⁹Université de Mons, Mons, Belgium
¹⁰Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
¹¹Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
¹²Instituto de Física Teórica, Universidade Estadual Paulista, Sao Paulo, Brazil
¹³Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
¹⁴University of Sofia, Sofia, Bulgaria
¹⁵Institute of High Energy Physics, Beijing, China
¹⁶State Key Lab. of Nucl. Phys. and Tech., Peking University, Beijing, China
¹⁷Universidad de Los Andes, Bogota, Colombia
¹⁸Technical University of Split, Split, Croatia
¹⁹University of Split, Split, Croatia
²⁰Institute Rudjer Boskovic, Zagreb, Croatia
²¹University of Cyprus, Nicosia, Cyprus
²²Charles University, Prague, Czech Republic
²³Academy of Scientific Research and Technology of the Arab Republic of Egypt,
Egyptian Network of High Energy Physics, Cairo, Egypt
²⁴National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
²⁵Department of Physics, University of Helsinki, Helsinki, Finland
²⁶Helsinki Institute of Physics, Helsinki, Finland
²⁷Lappeenranta University of Technology, Lappeenranta, Finland
²⁸Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France
²⁹DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France
³⁰Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
³¹Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse,
CNRS/IN2P3, Strasbourg, France
³²Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France
³³Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France
³⁴Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia
³⁵RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
³⁶RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
³⁷RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
³⁸Deutsches Elektronen-Synchrotron, Hamburg, Germany
³⁹University of Hamburg, Hamburg, Germany
⁴⁰Institut für Experimentelle Kernphysik, Karlsruhe, Germany
⁴¹Institute of Nuclear Physics "Demokritos", Aghia Paraskevi, Greece
⁴²University of Athens, Athens, Greece
⁴³University of Ioánnina, Ioánnina, Greece
⁴⁴KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
⁴⁵Institute of Nuclear Research ATOMKI, Debrecen, Hungary
⁴⁶University of Debrecen, Debrecen, Hungary
⁴⁷Panjab University, Chandigarh, India
⁴⁸University of Delhi, Delhi, India
⁴⁹Saha Institute of Nuclear Physics, Kolkata, India
⁵⁰Bhabha Atomic Research Centre, Mumbai, India
⁵¹Tata Institute of Fundamental Research—EHEP, Mumbai, India
⁵²Tata Institute of Fundamental Research—HECR, Mumbai, India
⁵³Institute for Research and Fundamental Sciences (IPM), Tehran, Iran
^{54a}INFN Sezione di Bari, Bari, Italy
^{54b}Università di Bari, Bari, Italy

- ^{54c}Politecnico di Bari, Bari, Italy
- ^{55a}INFN Sezione di Bologna, Bologna, Italy
- ^{55b}Università di Bologna, Bologna, Italy
- ^{56a}INFN Sezione di Catania, Catania, Italy
- ^{56b}Università di Catania, Catania, Italy
- ^{57a}INFN Sezione di Firenze, Firenze, Italy
- ^{57b}Università di Firenze, Firenze, Italy
- ⁵⁸INFN Laboratori Nazionali di Frascati, Frascati, Italy
- ⁵⁹INFN Sezione di Genova, Genova, Italy
- ^{60a}INFN Sezione di Milano-Bicocca, Milano, Italy
- ^{60b}Università di Milano-Bicocca, Milano, Italy
- ^{61a}INFN Sezione di Napoli, Napoli, Italy
- ^{61b}Università di Napoli “Federico II”, Napoli, Italy
- ^{62a}INFN Sezione di Padova, Padova, Italy
- ^{62b}Università di Padova, Padova, Italy
- ^{62c}Università di Trento (Trento), Padova, Italy
- ^{63a}INFN Sezione di Pavia, Pavia, Italy
- ^{63b}Università di Pavia, Pavia, Italy
- ^{64a}INFN Sezione di Perugia, Perugia, Italy
- ^{64b}Università di Perugia, Perugia, Italy
- ^{65a}INFN Sezione di Pisa, Pisa, Italy
- ^{65b}Università di Pisa, Pisa, Italy
- ^{65c}Scuola Normale Superiore di Pisa, Pisa, Italy
- ^{66a}INFN Sezione di Roma, Roma, Italy
- ^{66b}Università di Roma “La Sapienza”, Roma, Italy
- ^{67a}INFN Sezione di Torino, Torino, Italy
- ^{67b}Università di Torino, Torino, Italy
- ^{67c}Università del Piemonte Orientale (Novara), Torino, Italy
- ^{68a}INFN Sezione di Trieste, Trieste, Italy
- ^{68b}Università di Trieste, Trieste, Italy
- ⁶⁹Kangwon National University, Chunchon, Korea
- ⁷⁰Kyungpook National University, Daegu, Korea
- ⁷¹Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
- ⁷²Korea University, Seoul, Korea
- ⁷³University of Seoul, Seoul, Korea
- ⁷⁴Sungkyunkwan University, Suwon, Korea
- ⁷⁵Vilnius University, Vilnius, Lithuania
- ⁷⁶Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
- ⁷⁷Universidad Iberoamericana, Mexico City, Mexico
- ⁷⁸Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
- ⁷⁹Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
- ⁸⁰University of Auckland, Auckland, New Zealand
- ⁸¹University of Canterbury, Christchurch, New Zealand
- ⁸²National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
- ⁸³Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
- ⁸⁴Soltan Institute for Nuclear Studies, Warsaw, Poland
- ⁸⁵Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
- ⁸⁶Joint Institute for Nuclear Research, Dubna, Russia
- ⁸⁷Petersburg Nuclear Physics Institute, Gatchina (St Petersburg), Russia
- ⁸⁸Institute for Nuclear Research, Moscow, Russia
- ⁸⁹Institute for Theoretical and Experimental Physics, Moscow, Russia
- ⁹⁰Moscow State University, Moscow, Russia
- ⁹¹P.N. Lebedev Physical Institute, Moscow, Russia
- ⁹²State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
- ⁹³University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- ⁹⁴Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
- ⁹⁵Universidad Autónoma de Madrid, Madrid, Spain
- ⁹⁶Universidad de Oviedo, Oviedo, Spain
- ⁹⁷Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
- ⁹⁸CERN, European Organization for Nuclear Research, Geneva, Switzerland

- ⁹⁹Paul Scherrer Institut, Villigen, Switzerland
¹⁰⁰Institute for Particle Physics, ETH Zurich, Zurich, Switzerland
¹⁰¹Universität Zürich, Zurich, Switzerland
¹⁰²National Central University, Chung-Li, Taiwan
¹⁰³National Taiwan University (NTU), Taipei, Taiwan
¹⁰⁴Cukurova University, Adana, Turkey
¹⁰⁵Middle East Technical University, Physics Department, Ankara, Turkey
¹⁰⁶Bogazici University, Istanbul, Turkey
¹⁰⁷National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine
¹⁰⁸University of Bristol, Bristol, United Kingdom
¹⁰⁹Rutherford Appleton Laboratory, Didcot, United Kingdom
¹¹⁰Imperial College, London, United Kingdom
¹¹¹Brunel University, Uxbridge, United Kingdom
¹¹²Baylor University, Waco, Texas 76706, USA
¹¹³The University of Alabama, Tuscaloosa, Alabama 35487, USA
¹¹⁴Boston University, Boston, Massachusetts 02215, USA
¹¹⁵Brown University, Providence, Rhode Island 02912, USA
¹¹⁶University of California, Davis, Davis, California 95616, USA
¹¹⁷University of California, Los Angeles, Los Angeles, California 90095, USA
¹¹⁸University of California, Riverside, Riverside, California 92521, USA
¹¹⁹University of California, San Diego, La Jolla, California 92093, USA
¹²⁰University of California, Santa Barbara, Santa Barbara, California 93106, USA
¹²¹California Institute of Technology, Pasadena, California 91125, USA
¹²²Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA
¹²³University of Colorado at Boulder, Boulder, Colorado 80309, USA
¹²⁴Cornell University, Ithaca, New York 14853, USA
¹²⁵Fairfield University, Fairfield, Connecticut 06824, USA
¹²⁶Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA
¹²⁷University of Florida, Gainesville, Florida 32611, USA
¹²⁸Florida International University, Miami, Florida 33199, USA
¹²⁹Florida State University, Tallahassee, Florida 32306, USA
¹³⁰Florida Institute of Technology, Melbourne, Florida 32901, USA
¹³¹University of Illinois at Chicago (UIC), Chicago, Illinois 60607, USA
¹³²The University of Iowa, Iowa City, Iowa 52242, USA
¹³³Johns Hopkins University, Baltimore, Maryland 21218, USA
¹³⁴The University of Kansas, Lawrence, Kansas 66045, USA
¹³⁵Kansas State University, Manhattan, Kansas 66506, USA
¹³⁶Lawrence Livermore National Laboratory, Livermore, California 94720, USA
¹³⁷University of Maryland, College Park, Maryland 20742, USA
¹³⁸Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
¹³⁹University of Minnesota, Minneapolis, Minnesota 55455, USA
¹⁴⁰University of Mississippi, University, Mississippi 38677, USA
¹⁴¹University of Nebraska-Lincoln, Lincoln, Nebraska 68588, USA
¹⁴²State University of New York at Buffalo, Buffalo, New York 14260, USA
¹⁴³Northeastern University, Boston, Massachusetts 02115, USA
¹⁴⁴Northwestern University, Evanston, Illinois 60208, USA
¹⁴⁵University of Notre Dame, Notre Dame, Indiana 46556, USA
¹⁴⁶The Ohio State University, Columbus, Ohio 43210, USA
¹⁴⁷Princeton University, Princeton, New Jersey 08544, USA
¹⁴⁸University of Puerto Rico, Mayaguez, Puerto Rico 00680,
¹⁴⁹Purdue University, West Lafayette, Indiana 47907, USA
¹⁵⁰Purdue University Calumet, Hammond, Indiana 46323, USA
¹⁵¹Rice University, Houston, Texas 77251, USA
¹⁵²University of Rochester, Rochester, New York 14627, USA
¹⁵³The Rockefeller University, New York, New York 10021, USA
¹⁵⁴Rutgers, the State University of New Jersey, Piscataway, New Jersey 08854, USA
¹⁵⁵University of Tennessee, Knoxville, Tennessee 37996, USA
¹⁵⁶Texas A&M University, College Station, Texas 77843, USA
¹⁵⁷Texas Tech University, Lubbock, Texas 79409, USA
¹⁵⁸Vanderbilt University, Nashville, Tennessee 37235, USA
¹⁵⁹University of Virginia, Charlottesville, Virginia 22901, USA

¹⁶⁰Wayne State University, Detroit, Michigan 48202, USA¹⁶¹University of Wisconsin, Madison, Wisconsin 53706, USA^aDeceased.^bAlso at CERN, European Organization for Nuclear Research, Geneva, Switzerland.^cAlso at Universidade Federal do ABC, Santo Andre, Brazil.^dAlso at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.^eAlso at Suez Canal University, Suez, Egypt.^fAlso at British University, Cairo, Egypt.^gAlso at Fayoum University, El-Fayoum, Egypt.^hAlso at Soltan Institute for Nuclear Studies, Warsaw, Poland.ⁱAlso at Massachusetts Institute of Technology, Cambridge, MA, USA.^jAlso at Université de Haute-Alsace, Mulhouse, France.^kAlso at Brandenburg University of Technology, Cottbus, Germany.^lAlso at Moscow State University, Moscow, Russia.^mAlso at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.ⁿAlso at Eötvös Loránd University, Budapest, Hungary.^oAlso at Tata Institute of Fundamental Research-HECR, Mumbai, India.^pAlso at University of Visva-Bharati, Santiniketan, India.^qAlso at Sharif University of Technology, Tehran, Iran.^rAlso at Shiraz University, Shiraz, Iran.^sAlso at Isfahan University of Technology, Isfahan, Iran.^tAlso at Facoltà Ingegneria Università di Roma “La Sapienza”, Roma, Italy.^uAlso at Università della Basilicata, Potenza, Italy.^vAlso at Università degli studi di Siena, Siena, Italy.^wAlso at California Institute of Technology, Pasadena, CA, USA.^xAlso at Faculty of Physics of University of Belgrade, Belgrade, Serbia.^yAlso at University of California, Los Angeles, Los Angeles, CA, USA.^zAlso at University of Florida, Gainesville, FL, USA.^{aa}Also at Université de Genève, Geneva, Switzerland.^{bb}Also at Scuola Normale e Sezione dell’ INFN, Pisa, Italy.^{cc}Also at University of Athens, Athens, Greece.^{dd}Also at The University of Kansas, Lawrence, KS, USA.^{ee}Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.^{ff}Also at Paul Scherrer Institut, Villigen, Switzerland.^{gg}Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.^{hh}Also at Gaziosmanpasa University, Tokat, Turkey.ⁱⁱAlso at Adiyaman University, Adiyaman, Turkey.^{jj}Also at The University of Iowa, Iowa City, IA, USA.^{kk}Also at Mersin University, Mersin, Turkey.^{ll}Also at Izmir Institute of Technology, Izmir, Turkey.^{mmm}Also at Kafkas University, Kars, Turkey.ⁿⁿAlso at Suleyman Demirel University, Isparta, Turkey.^{oo}Also at Ege University, Izmir, Turkey.^{pp}Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.^{qq}Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.^{rr}Also at INFN Sezione di Perugia, Università di Perugia, Perugia, Italy.^{ss}Also at Utah Valley University, Orem, UT, USA.^{tt}Also at Institute for Nuclear Research, Moscow, Russia.^{uu}Also at Erzincan University, Erzincan, Turkey.