

Search for Baryon Number Violation in Top Quark Production and Decay Using Proton-Proton Collisions at $\sqrt{s} = 13$ TeV

A. Hayrapetyan *et al.**
(CMS Collaboration)

 (Received 28 February 2024; accepted 8 May 2024; published 13 June 2024)

A search is presented for baryon number violating interactions in top quark production and decay. The analysis uses data from proton-proton collisions at a center-of-mass energy of 13 TeV, collected with the CMS detector at the LHC with an integrated luminosity of 138 fb^{-1} . Candidate events are selected by requiring two oppositely charged leptons (electrons or muons) and exactly one jet identified as originating from a bottom quark. Multivariate discriminants are used to separate the signal from the background. No significant deviation from the standard model prediction is observed. Upper limits are placed on the strength of baryon number violating couplings. For the first time the production of single top quarks via baryon number violating interactions is studied. This allows the search to set the most stringent constraints to date on the branching fraction of the top quark decay to a lepton, an up-type quark (u or c), and a down-type quark (d , s , or b). The results improve the previous bounds by 3 to 6 orders of magnitude based on the fermion flavor combination of the baryon number violating interactions.

DOI: [10.1103/PhysRevLett.132.241802](https://doi.org/10.1103/PhysRevLett.132.241802)

In the standard model (SM), the baryon number is a conserved quantum number. Its conservation, however, is not a direct consequence of fundamental symmetries within the SM, and it can be violated by nonperturbative effects [1]. The size of such violations is too small to explain the observed matter-antimatter asymmetry in the Universe [2]. Certain scenarios of physics beyond the SM, such as grand unified theories [3] and supersymmetry [4], naturally include baryon number violation (BNV) and could provide a mechanism to explain this observation. Various low-energy direct searches for signatures of BNV have been conducted over the past decades, with constraints set on the BNV energy scale via processes such as nucleon [5], τ lepton [6], c [7], and b quark [8] decays. There are also stringent indirect constraints from proton stability involving heavy quarks [9] for specific theoretical assumptions [10]. Experiments at the CERN LHC provide the highest sensitivity for potential high-energy BNV processes involving the top quark. Previously, the CMS Collaboration has performed a search for BNV decays of the top quark in single lepton (electron or muon) channels in proton-proton (pp) collisions at $\sqrt{s} = 8$ TeV [11]. This Letter presents the first search for top quark BNV interactions via single top quark production in association with a lepton in pp

collisions at 13 TeV in dilepton final states. The data used in the analysis correspond to an integrated luminosity of 138 fb^{-1} , collected by the CMS experiment at the LHC during 2016–2018.

Assuming the mass scale of new physics responsible for BNV processes is larger than the energy scale directly accessible at the LHC, BNV interactions of top quarks can be described through an effective Lagrangian, \mathcal{L}_{eff} . Assuming the SM field content and gauge symmetries, the terms in the BNV effective Lagrangian must involve three quark fields and one lepton field [12]. Including up to dimension-six operators, the most general effective Lagrangian that describes the BNV interactions of the top quark and a charged lepton takes the form [13]

$$\mathcal{L}_{\text{eff}} = \frac{C_s}{\Lambda^2} \epsilon^{\alpha\beta\gamma} [\bar{t}_\alpha^c d_\gamma] [\bar{u}_\beta^c \ell] + \frac{C_t}{\Lambda^2} \epsilon^{\alpha\beta\gamma} [\bar{t}_\alpha^c \ell] [\bar{u}_\beta^c d_\gamma] + \text{H.c.}, \quad (1)$$

where d , u , and ℓ are down-type quark, up-type quark, and charged-lepton fields, respectively, where the superscript “c” denotes charged conjugated fields. Colors are labeled by greek indices, Λ is the generic scale of new physics, and C_s and C_t are fermion-flavor-dependent effective couplings. The s and t labels in Eq. (1) denote that the new physics scale may be linked to the mass of a heavy mediator exchanged in the s or t channels, respectively [13]. No specific chirality is assumed for the BNV interactions. The terms in \mathcal{L}_{eff} violate baryon and lepton numbers simultaneously. These effective interactions open new top quark decay and production channels at the LHC. Figure 1 displays representative Feynman diagrams for single top quark production (“ST mode”) and top quark decay

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

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/). Further distribution of this work must maintain attribution to the author(s) and the published article’s title, journal citation, and DOI. Funded by SCOAP³.

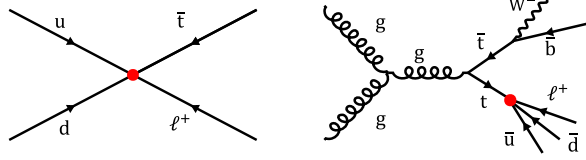


FIG. 1. Representative Feynman diagrams for single top quark production (left) and top quark decays (right) via BNV interactions. The red circles mark the BNV vertices.

(“TT mode”) via BNV interactions in top quark-antiquark pair production ($t\bar{t}$).

This analysis uses events in dileptonic final states (e^+e^- , $e^\pm\mu^\mp$, and $\mu^+\mu^-$), where one lepton is produced via the BNV interaction and a second lepton comes from the decay of the W boson produced in the dominant $t \rightarrow bW$ decay. The strength of the 12 flavor combinations of top quark four-fermion BNV interactions are probed in these final states. These take the form $t\ell q_u q_d$, where ℓ can be an electron or muon, q_u can be an up or charm quark, and q_d can be any down-type quark. The BNV interactions with a tau lepton can contribute to the dileptonic final states considered in this analysis via its leptonic decays. However, only a small fraction of these events appears in the signal selection because of the low branching fraction of the leptonic final states and the lower energies of the decay electrons or muons. Therefore, $t\tau q_u q_d$ interactions are not probed in this analysis.

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two end-cap sections. Forward calorimeters extend the pseudorapidity (η) coverage provided by the barrel and end-cap detectors. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [14].

The data are modeled by Monte Carlo (MC) simulations of the signal and background processes. Simulated events are produced with event generator programs using the next-to-next-to-leading order (NNLO) parton distribution function (PDF) sets from NNPDF 3.1 [15]. Parton showering and hadronization are done with PYTHIA v8.240 [16] using the underlying-event tune CP5 [17]. Generated events undergo a full simulation of the detector response using GEANT4 [18]. The presence of simultaneous pp collisions in the same or nearby bunch crossings, referred to as pileup (PU), is modeled by superimposing inelastic pp interactions, simulated using PYTHIA, on all MC events. Simulated events are then reweighted to reproduce the PU distribution observed in data.

Contributions to the background include SM $t\bar{t}$ production, single top quark production in association with a W boson (tW), W , or Z bosons produced in association with $t\bar{t}$ ($t\bar{t} + W/Z$), Drell-Yan in association with jets (DY + jets) processes, W + jets production, and diboson processes (including WW , WZ , and ZZ). The contribution from quantum chromodynamics (QCD) multijet production is found to be negligible. The POWHEG v2.0 next-to-leading order (NLO) MC generator is used to simulate the SM $t\bar{t}$, tW , and diboson events [19–21]. The MadGraph5_aMC@NLO v2.6.5 generator is used to simulate the $t\bar{t} + W/Z$, DY + jets, W + jets, and diboson events [22]. The $t\bar{t}$ sample is normalized to the cross section calculated at NNLO in QCD including resummation of next-to-next-to-leading logarithmic (NNLL) soft-gluon terms with the Top++2.0 program [23], $832_{-29}^{+20}(\text{scale}) \pm 35(\text{PDF} + \alpha_s)$ pb, where α_s is the strong coupling. To improve the modeling of the transverse momentum (p_T) spectrum of the top quark in POWHEG, simulated SM $t\bar{t}$ events are weighted as a function of the p_T of the top quark to match the expectations at NNLO QCD accuracy, including electroweak corrections [24]. Other simulated samples are normalized to their cross section predictions at NNLO (for DY + jets and W + jets [25]), NLO + NNLL (for tW production [26]), or NLO (for the diboson and $t\bar{t} + W/Z$ processes [27,28]).

The simulated signal samples are generated using the MadGraph5_aMC@NLO v2.6.5 generator with the TopBNV model [13] at leading order in QCD. The top quark BNV signal sample has two independent components: (i) ST mode, and (ii) TT mode, as shown in Fig. 1. Independent samples are generated for the various possible fermion flavor combinations. The top quark mass and width are set to 172.5 and 1.33 GeV, respectively. There is no interference considered between the BNV signal and SM processes and the BNV couplings affect only the signal yield. Since the BNV couplings are probed individually, signal samples are generated separately for nonzero C_t and C_s couplings, assuming $\Lambda = 1$ TeV. The BNV signal cross sections and the branching fractions for the BNV top quark decays depend quadratically on C/Λ^2 [13]. Theoretical cross sections for single top quark production and top quark decays via the BNV interactions are shown in Table I. The dominant signal process is the ST mode because of its larger cross section. Final-state particles in the ST mode also have a harder p_T spectrum compared to SM processes and the TT mode [13]. Therefore, the analysis is optimized with respect to the ST mode signatures and the TT mode contribution is added for completeness.

Signal events in the ST mode contain two opposite-sign leptons, one jet originating from a bottom quark, and missing energy due to the undetected neutrino from the top quark decay. Events were selected online during data taking by a combination of single-electron and di-electron triggers for the e^+e^- events as in Refs. [29,30]. Single-muon triggers are used for the $e^\pm\mu^\mp$ and $\mu^+\mu^-$ events, as

TABLE I. Theoretical inclusive cross sections, in units of pico barn (pb), for single top quark production (ST) and top quark-antiquark pair production with the decay (TT) via BNV interactions, assuming a top quark mass of 172.5 GeV, the top quark decay width 1.33 GeV, $\Lambda = 1$ TeV, and $C_t = 1$ or $C_s = 1$. The uncertainties arising from the choice of the renormalization and factorization scales and PDFs are given as $(\sigma \pm \text{Scale} \pm \text{PDF})$. Here, the sum of the two cross sections is given where $\ell = e$ or μ .

Process	$\sigma(C_t = 1)$ [pb]	$\sigma(C_s = 1)$ [pb]
ST ($t\ell ud$)	$31.5 \pm 2.1 \pm 1.0$	$10.7 \pm 0.7 \pm 0.4$
ST ($t\ell us$)	$8.1 \pm 0.3 \pm 0.5$	$2.8 \pm 0.1 \pm 0.2$
ST ($t\ell ub$)	$3.31 \pm 0.13 \pm 0.06$	$1.14 \pm 0.05 \pm 0.02$
ST ($t\ell cd$)	$2.77 \pm 0.22 \pm 0.01$	$0.96 \pm 0.01 \pm 0.07$
ST ($t\ell cs$)	$0.79 \pm 0.02 \pm 0.11$	$0.27 \pm 0.01 \pm 0.04$
ST ($t\ell cb$)	$0.28 \pm 0.03 \pm 0.04$	$0.10 \pm 0.01 \pm 0.01$
TT	$0.007 \pm 0.002 \pm 0.001$	$0.007 \pm 0.002 \pm 0.001$

described in Ref. [31]. The particle-flow (PF) algorithm aims at reconstructing individual particles (photons, charged and neutral hadrons, muons, and electrons) by combining information from the various components of the CMS detector [32]. The primary vertex is taken to be the vertex corresponding to the hardest scattering in the event, evaluated using tracking information alone, as described in Sec. 9.4.1 of Ref. [33]. Electron and muon candidates [34,35] are required to lie within $|\eta| < 2.4$ to keep them within the silicon tracker coverage. Electron candidates in the transition region between barrel and end-cap calorimeters ($1.44 < |\eta| < 1.57$) are removed. The same high- p_T lepton identification and isolation criteria described in Ref. [31] are used to reject nonprompt leptons. Events are required to have exactly two opposite-sign leptons. To operate well above the trigger threshold, the selected electron (muon) should have $p_T > 35(53)$ GeV. Selected events are divided based on their lepton flavors into three mutually exclusive categories: e^+e^- , $e^\pm\mu^\mp$, and $\mu^+\mu^-$. To suppress backgrounds, especially from the DY + jets processes, we reject events in which the two leptons have an invariant mass below 106 GeV.

Jets are reconstructed from the PF candidates using the anti- k_T clustering algorithm with a distance parameter of 0.4 [36,37]. We select jets with $|\eta| < 2.4$ and $p_T > 30$ GeV. Jets originating from b quarks (b jets) are identified (b -tagged) using the DeepJet algorithm [38] with an average b tagging efficiency of 68% and a light quark and gluon jet misidentification rate of 1.1%. Events are required to have exactly one b -tagged jet. The missing transverse momentum (\vec{p}_T^{miss}) is defined as the negative vector \vec{p}_T sum of all PF particles, and its magnitude is denoted as p_T^{miss} [39]. Events with $p_T^{\text{miss}} < 60$ GeV are rejected to further suppress the DY + jets events.

The selected events in the signal region have exactly one opposite-sign lepton pair with invariant mass greater than 106 GeV, $p_T^{\text{miss}} > 60$ GeV, and exactly one b -tagged jet

irrespective of the number of untagged jets. The dominant background is the $t\bar{t}$ process ($\sim 89\%$), followed by the tW ($\sim 9\%$) and DY + jets ($\sim 1\%$) processes. Signal selection efficiencies for the ST (TT) mode are about 2.8% (1.1%) with respect to an inclusive MC sample for the $t\ell ud$ flavor combination, assuming $C_s = 0$ and nonzero C_t . The fractional uncertainties on the signal efficiencies due to the effects described below range from 4% to 9%.

In the ST mode, the lepton and top quark are produced directly from the annihilation of the incoming quarks, and are Lorentz-boosted and approximately back to back. The subleading lepton in the ST mode is primarily from the top quark decay chain. To use these specific features of the signal events, the four-momentum vectors of the top quarks are reconstructed from the decay products: the subleading lepton, the neutrino, and the b jet candidate. The neutrino p_T can be inferred from the \vec{p}_T^{miss} . The longitudinal momentum of the neutrino is inferred assuming energy-momentum conservation at the W boson decay vertex and constraining the W boson mass to 80.4 GeV as discussed in Ref. [40].

A boosted decision tree (BDT) [41,42] is employed to distinguish signal from the sum of the background processes. Independent signal and background samples are used for training the BDT. A merged sample from $t\bar{t}$, tW , and DY + jets background events, weighted by their cross sections, is used as the background training and testing sample. For the signal, events from various BNV flavor combinations of the ST mode are merged with equal weights and are used in the BDT training and testing. Ten variables are inputs to the BDT: the transverse momenta of the leading lepton (ℓ_1), subleading lepton (ℓ_2), and the top quark candidate (t); the distances between the leading and subleading leptons [$\Delta R(\ell_1, \ell_2) = \sqrt{(\eta^{\ell_1} - \eta^{\ell_2})^2 + (\phi^{\ell_1} - \phi^{\ell_2})^2}$] and $\Delta R(\ell_1, t)$; the azimuthal angles between the leading and subleading leptons [$\Delta\phi(\ell_1, \ell_2) = |\phi^{\ell_1} - \phi^{\ell_2}|$] and $\Delta\phi(\ell_1, t)$; the invariant mass and p_T of the dilepton system; and $|p_T^t - p_T^{\ell_1}| / |p_T^t + p_T^{\ell_1}|$.

The templates describing the BDT distributions for the signal and background events are taken from simulation. The normalization of the DY + jets background, which is important in the e^+e^- and $\mu^+\mu^-$ channels, is determined by applying a scale factor to the simulation derived from data in a control region where the reconstructed dilepton mass is close to the Z boson mass [43].

The list of uncertainties considered and the techniques used to estimate their values are very similar to those in Ref. [44]. We consider uncertainties in the integrated luminosity [45–47], pileup effects [48], trigger, lepton identification [34,49], and b tagging [38,50] efficiencies, in the calculation of p_T^{miss} , and those related to the jet energy scale and resolution [51]. Uncertainties arising from choices in signal and $t\bar{t}$ modeling include PDFs, renormalization and factorization scales, and initial- and final-state QCD radiation. The uncertainty arising from the modeling

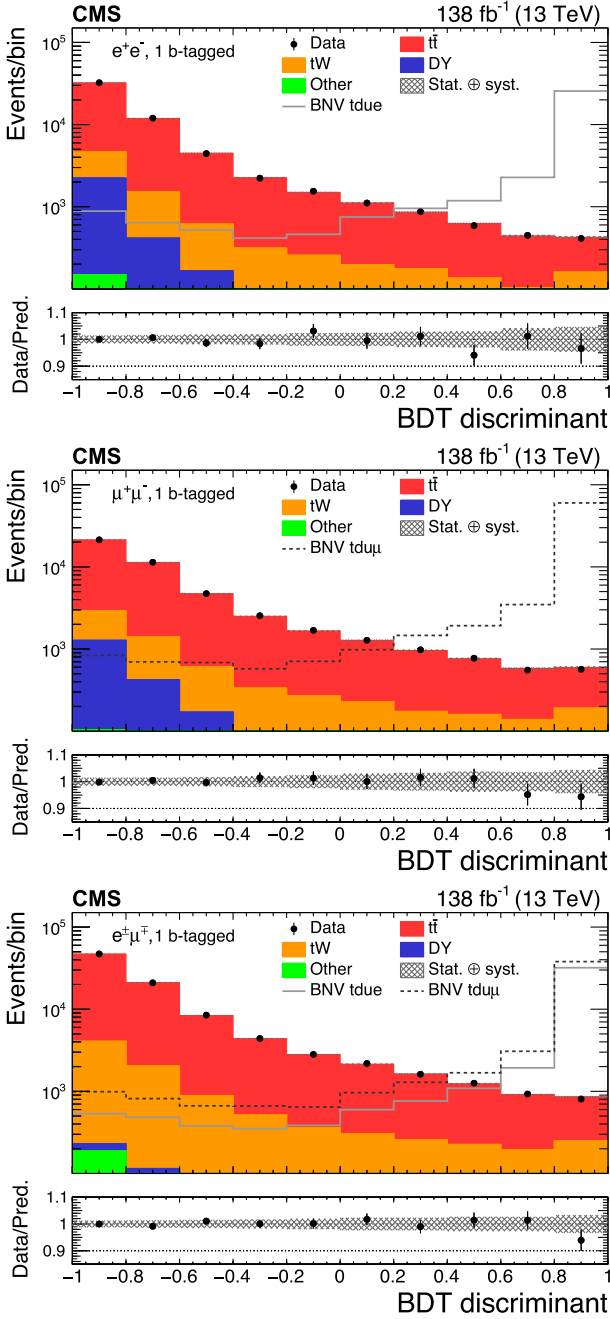


FIG. 2. The BDT output distributions for data (points) and backgrounds (histograms) for the e^+e^- (upper left), $\mu^+\mu^-$ (right), and $e^\pm\mu^\mp$ (lower) channels, including the ratio of data to the predicted total background yield. The hatched bands indicate the total uncertainty (statistical and systematic added in quadrature) for the SM background predictions. The predicted yields of the backgrounds and the uncertainty bands are shown after the simultaneous fits for the signal-plus-background hypothesis. Examples of the predicted signal contribution for the BNV interactions via $teud$ (solid gray line) and $t\mu ud$ (dashed black line) vertices are shown.

of the top quark p_T spectrum is evaluated by the renormalization and factorization scales at NNLO QCD accuracy, including NLO electroweak corrections [24]. Modeling

uncertainties from the matching of the matrix element level calculation to the parton shower simulation, the modeling of the underlying event defined in PYTHIA tunes, and the models of color reconnection are considered for the SM $t\bar{t}$ process, as described in Ref. [52]. The modeling uncertainties apply only to the signal acceptances. Normalization uncertainties of 5%, 10%, and 30% are considered for the $t\bar{t}$, tW , and other processes based on experimental measurements [52,53], respectively. An additional 20% normalization uncertainty is added for DY + jets processes to account for PU mismodeling in large p_T^{miss} events.

Figure 2 shows the BDT discriminant distributions for events in the three channels (e^+e^- , $e^\pm\mu^\mp$, and $\mu^+\mu^-$) passing the event selection for the three data-taking years (2016–2018) combined. To illustrate signal distributions, simulated “ $teud$ ” and “ $t\mu ud$ ” samples are included in the figure, assuming $\Lambda = 1$ TeV and $C_t = C_s = 1$. Signal events are well separated from background events. To extract the signal contribution, a simultaneous binned maximum-likelihood fit is performed of the BDT output distributions in the signal region for three years and three channels, with the systematic uncertainties described above treated as nuisance parameters. The best fit for the BNV effective couplings is consistent with zero and no significant excess over the background expectations is observed.

TABLE II. Expected and observed 95% CL upper limits on the BNV effective couplings and top quark BNV branching fractions.

Vertex	C_x	C_x/Λ^2	C_x/Λ^2	\mathcal{B}_x [10 ⁻⁶]	\mathcal{B}_x [10 ⁻⁶]
		[TeV ⁻²]	[TeV ⁻²]		
		Exp.	Obs.	Exp.	Obs.
$teud$	s	0.055	0.048	0.015	0.011
	t	0.031	0.027	0.005	0.003
$t\mu ud$	s	0.046	0.036	0.010	0.006
	t	0.025	0.020	0.003	0.002
$tecd$	s	0.207	0.184	0.208	0.164
	t	0.114	0.102	0.063	0.050
$t\mu cd$	s	0.178	0.141	0.153	0.095
	t	0.100	0.080	0.048	0.030
$teus$	s	0.115	0.101	0.063	0.050
	t	0.064	0.056	0.019	0.015
$t\mu us$	s	0.102	0.079	0.050	0.030
	t	0.056	0.043	0.015	0.009
$tecs$	s	0.448	0.403	0.973	0.786
	t	0.243	0.218	0.286	0.229
$t\mu cs$	s	0.394	0.311	0.752	0.468
	t	0.217	0.169	0.228	0.138
$teub$	s	0.199	0.178	0.191	0.154
	t	0.109	0.097	0.057	0.045
$t\mu ub$	s	0.168	0.134	0.136	0.087
	t	0.095	0.076	0.044	0.028
$tecb$	s	0.718	0.657	2.503	2.090
	t	0.405	0.367	0.795	0.652
$t\mu cb$	s	0.703	0.564	2.393	1.521
	t	0.386	0.307	0.722	0.455

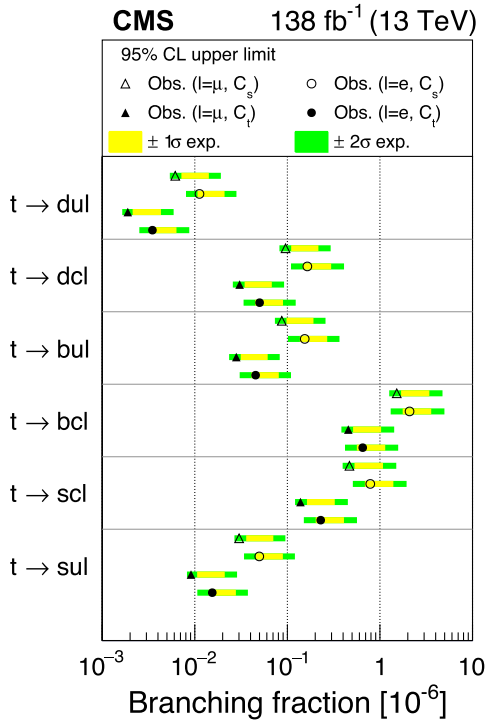


FIG. 3. The observed upper limits on the branching fractions of the top quark BNV decays are shown with circle and triangle shapes for electron and muon couplings, respectively. The observed limits corresponding to the C_l and C_s coefficients are shown with filled and open markers, respectively. The yellow light (green dark) bands indicate the range within plus or minus 1 (2) standard deviations bands around the expected limits.

The sources of systematic uncertainty with the largest impact on the estimated signal contribution depend on the fermion flavor combination of the BNV interactions. The three main sources of uncertainty that are common among the BNV interactions are uncertainties in the normalization of the SM tW process, muon energy scale, and modeling of the top quark p_T spectrum in the SM $t\bar{t}$ simulation. The exclusion limits are calculated using the asymptotic approximation of the CL_s method [54]. The adequacy of the asymptotic approximation has been validated with pseudoexperiments. The limit-setting procedure is performed for each individual BNV coupling while setting the other BNV couplings to zero. The observed and expected limits at 95% confidence level (CL) on the BNV effective coupling strengths are listed in Table II. The limits on the strengths of the BNV couplings are translated to limits on the branching fractions for the BNV top quark decays. The differences between different quark flavor combinations stem mainly from the different PDFs involved in the production mode. The results for limits on various BNV branching fractions are displayed in Fig. 3. Tabulated results are provided in the HEPData record for this analysis [55].

In summary, a search for baryon number violation (BNV) in events with top quarks is performed using the LHC proton-proton collision data at a center-of-mass

energy of 13 TeV. The analysis explores baryon number violating effects in single top quark production for the first time. Data were collected by the CMS experiment in 2016–2018 and correspond to an integrated luminosity of 138 fb^{-1} . Events with a lepton pair and exactly one b -tagged jet are selected. A boosted decision tree (BDT) is used to separate signal events from background events. A binned maximum likelihood fit to the BDT output distribution is performed to search for the BNV processes. Considering BNV vertices in the production of top quarks dramatically increases the sensitivity of this search. No significant excess of events over the background prediction is observed. Upper limits are placed on the strengths of the BNV couplings, which are multiple orders of magnitude more stringent than the previous limits [11].

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid and other centers for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC, the CMS detector, and the supporting computing infrastructure provided by the following funding agencies: SC (Armenia); BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES and BNSF (Bulgaria); CERN; CAS, MoST, and NSFC (China); Minciencias (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); ERC PRG, RVTT3 and MoER TK202 (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); SRNSF (Georgia); BMBF, DFG, and HGF (Germany); GSRI (Greece); NKFIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); LMTLT (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MES and NSC (Poland); FCT (Portugal); MESTD (Serbia); MCIN/AEI and PCTI (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); MHESI and NSTDA (Thailand); TUBITAK and TENMAK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

- [1] G. 't Hooft, Symmetry breaking through Bell-Jackiw anomalies, *Phys. Rev. Lett.* **37**, 8 (1976).
- [2] A. D. Sakharov, Violation of CP Invariance, C asymmetry, and baryon asymmetry of the universe, *Pis'ma Zh. Eksp. Teor. Fiz.* **5**, 32 (1967).

- [3] H. Georgi and S.L. Glashow, Unity of all elementary particle forces, *Phys. Rev. Lett.* **32**, 438 (1974).
- [4] S. Weinberg, Supersymmetry at ordinary energies. 1. masses and conservation laws, *Phys. Rev. D* **26**, 287 (1982).
- [5] A. Takenaka *et al.* (Super-Kamiokande Collaboration), Search for proton decay via $p \rightarrow e^+\pi^0$ and $p \rightarrow \mu^+\pi^0$ with an enlarged fiducial volume in Super-Kamiokande I-IV, *Phys. Rev. D* **102**, 112011 (2020).
- [6] LHCb Collaboration, Searches for violation of lepton flavour and baryon number in tau lepton decays at LHCb, *Phys. Lett. B* **724**, 36 (2013).
- [7] M. Ablikim *et al.* (BESIII Collaboration), Search for baryon- and lepton-number violating decays $D^0 \rightarrow \bar{p}e^+$ and $D^0 \rightarrow pe^-$, *Phys. Rev. D* **105**, 032006 (2022).
- [8] P. del Amo Sanchez *et al.* (BABAR Collaboration), Searches for the baryon- and lepton-number violating decays $B^0 \rightarrow \Lambda_c^+\ell^-$, $B^- \rightarrow \Lambda\ell^-$, and $B^- \rightarrow \bar{\Lambda}\ell^-$, *Phys. Rev. D* **83**, 091101 (2011).
- [9] W.-S. Hou, M. Nagashima, and A. Soddu, Baryon number violation involving higher generations, *Phys. Rev. D* **72**, 095001 (2005).
- [10] M.E. McCracken *et al.*, Search for baryon-number and lepton-number violating decays of Λ hyperons using the CLAS detector at Jefferson Laboratory, *Phys. Rev. D* **92**, 072002 (2015).
- [11] CMS Collaboration, Search for baryon number violation in top-quark decays, *Phys. Lett. B* **731**, 173 (2014).
- [12] S. Weinberg, Baryon and lepton nonconserving processes, *Phys. Rev. Lett.* **43**, 1566 (1979).
- [13] Z. Dong, G. Durieux, J.-M. Gerard, T. Han, and F. Maltoni, Baryon number violation at the LHC: The top option, *Phys. Rev. D* **85**, 016006 (2012).
- [14] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [15] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions from high-precision collider data, *Eur. Phys. J. C* **77**, 663 (2017).
- [16] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA8.2, *Comput. Phys. Commun.* **191**, 159 (2015).
- [17] CMS Collaboration, Extraction and validation of a new set of CMS PYTHIA8 tunes from underlying-event measurements, *Eur. Phys. J. C* **80**, 4 (2020).
- [18] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [19] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, *J. High Energy Phys.* **11** (2004) 040.
- [20] S. Alioli, P. Nason, C. Oleari, and E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: The POWHEG BOX, *J. High Energy Phys.* **06** (2010) 043.
- [21] S. Frixione, P. Nason, and C. Oleari, Matching NLO QCD computations with parton shower simulations: The POWHEG method, *J. High Energy Phys.* **11** (2007) 070.
- [22] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, *J. High Energy Phys.* **07** (2014) 079.
- [23] M. Czakon and A. Mitov, Top++: A program for the calculation of the top-pair cross-section at hadron colliders, *Comput. Phys. Commun.* **185**, 2930 (2014).
- [24] M. Czakon, D. Heymes, A. Mitov, D. Pagani, I. Tsinikos, and M. Zaro, Top-pair production at the LHC through NNLO QCD and NLOEW, *J. High Energy Phys.* **10** (2017) 186.
- [25] Y. Li and F. Petriello, Combining QCD and electroweak corrections to dilepton production in FEWZ, *Phys. Rev. D* **86**, 094034 (2012).
- [26] N. Kidonakis, Two-loop soft anomalous dimensions for single top quark associated production with W^- or H^- , *Phys. Rev. D* **82**, 054018 (2010).
- [27] J.M. Campbell, R.K. Ellis, and C. Williams, Vector boson pair production at the LHC, *J. High Energy Phys.* **07** (2011) 018.
- [28] F. Maltoni, D. Pagani, and I. Tsinikos, Associated production of a top-quark pair with vector bosons at NLO in QCD: impact on $t\bar{t}$ searches at the LHC, *J. High Energy Phys.* **02** (2016) 113.
- [29] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section, the top quark mass, and the strong coupling constant using dilepton events in pp collisions at $\sqrt{s} = 13$ TeV, *Eur. Phys. J. C* **79**, 368 (2019).
- [30] CMS Collaboration, The CMS trigger system, *J. Instrum.* **12**, P01020 (2017).
- [31] CMS Collaboration, Search for resonant and nonresonant new phenomena in high-mass dilepton final states at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **07** (2021) 208.
- [32] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, *J. Instrum.* **12**, P10003 (2017).
- [33] CMS Collaboration, Technical proposal for the Phase-II upgrade of the Compact Muon Solenoid, CMS Technical Proposal, Report No. CERN-LHCC-2015-010, CMS-TDR-15-02, 2015.
- [34] CMS Collaboration, Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV, *J. Instrum.* **10**, P06005 (2015).
- [35] CMS Collaboration, Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s} = 13$ TeV, *J. Instrum.* **13**, P06015 (2018).
- [36] M. Cacciari, G. P. Salam, and G. Soyez, The anti- k_T jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.
- [37] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, *Eur. Phys. J. C* **72**, 1896 (2012).
- [38] CMS Collaboration, Identification of heavy-flavour jets with the CMS detector in pp collisions at 13 TeV, *J. Instrum.* **13**, P05011 (2018).
- [39] CMS Collaboration, Performance of missing transverse momentum reconstruction in proton-proton collisions at $\sqrt{s} = 13$ TeV using the CMS detector, *J. Instrum.* **14**, P07004 (2019).
- [40] CMS Collaboration, Cross section measurement of t -channel single top quark production in pp collisions at $\sqrt{s} = 13$ TeV, *Phys. Lett. B* **772**, 752 (2017).

- [41] H. Voss, A. Höcker, J. Stelzer, and F. Tegenfeldt, TMVA, the toolkit for multivariate data analysis with ROOT, in *XIth International Workshop on Advanced Computing and Analysis Techniques in Physics Research (ACAT)* (Proceedings of Science, Trieste, Italy, 2007), p. 40, [10.22323/1.050.0040](https://arxiv.org/abs/10.22323/1.050.0040).
- [42] J.R. Quinlan, Simplifying decision trees, *International Journal of Man-Machine Studies* **27**, 221 (1987).
- [43] CMS Collaboration, Measurement of the top quark pair production cross section in proton-proton collisions at $\sqrt{s} = 13$ TeV, *Phys. Rev. Lett.* **116**, 052002 (2016).
- [44] CMS Collaboration, Search for charged-lepton flavor violation in top quark production and decay in pp collisions at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **06** (2022) 082.
- [45] CMS Collaboration, Precision luminosity measurement in proton-proton collisions at $\sqrt{s} = 13$ TeV in 2015 and 2016 at CMS, *Eur. Phys. J. C* **81**, 800 (2021).
- [46] CMS Collaboration, CMS luminosity measurement for the 2017 data-taking period at $\sqrt{s} = 13$ TeV, CMS Physics Analysis Summary, Report No. CMS-PAS-LUM-17-004, 2017, <http://cds.cern.ch/record/2621960>.
- [47] CMS Collaboration, CMS luminosity measurement for the 2018 data-taking period at $\sqrt{s} = 13$ TeV, CMS Physics Analysis Summary, Report No. CMS-PAS-LUM-18-002, 2018, <http://cds.cern.ch/record/2676164>.
- [48] CMS Collaboration, Measurement of the inelastic proton-proton cross section at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **07** (2018) 161.
- [49] CMS Collaboration, Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV, *J. Instrum.* **7**, P10002 (2012).
- [50] CMS Collaboration, Performance summary of AK4 jet b tagging with data from proton-proton collisions at 13 TeV with the CMS detector, CMS Detector Performance Note, Report No. CMS-DP-2023-005, 2023, <https://cds.cern.ch/record/2854609>.
- [51] CMS Collaboration, Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV, *J. Instrum.* **12**, P02014 (2017).
- [52] CMS Collaboration, Measurements of $t\bar{t}$ differential cross sections in proton-proton collisions at $\sqrt{s} = 13$ TeV using events containing two leptons, *J. High Energy Phys.* **02** (2019) 149.
- [53] CMS Collaboration, Measurement of the production cross section for single top quarks in association with W bosons in proton-proton collisions at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **10** (2018) 117.
- [54] A. L. Read, Presentation of search results: The CL_s technique, *J. Phys. G* **28**, 2693 (2002).
- [55] HEPData record for this analysis (2023), <http://dx.doi.org/10.17182/hepdata.138414>.

A. Hayrapetyan,¹ A. Tumasyan,^{1,b} W. Adam,² J. W. Andrejkovic,² T. Bergauer,² S. Chatterjee,² K. Damanakis,² M. Dragicevic,² P. S. Hussain,² M. Jeitler,^{2,c} N. Krammer,² A. Li,² D. Liko,² I. Mikulec,² J. Schieck,^{2,c} R. Schöfbeck,² D. Schwarz,² M. Sonawane,² S. Templ,² W. Waltenberger,² C.-E. Wulz,^{2,c} M. R. Darwish,^{3,d} T. Janssen,³ P. Van Mechelen,³ E. S. Bols,⁴ J. D'Hondt,⁴ S. Dansana,⁴ A. De Moor,⁴ M. Delcourt,⁴ S. Lowette,⁴ I. Makarenko,⁴ D. Müller,⁴ S. Tavernier,⁴ M. Tytgat,^{4,e} G. P. Van Onsem,⁴ S. Van Putte,⁴ D. Vannerom,⁴ B. Clerbaux,⁵ A. K. Das,⁵ G. De Lentdecker,⁵ H. Evard,⁵ L. Favart,⁵ P. Gianneios,⁵ D. Hohov,⁵ J. Jaramillo,⁵ A. Khalilzadeh,⁵ F. A. Khan,⁵ K. Lee,⁵ M. Mahdavihorrani,⁵ A. Malara,⁵ S. Paredes,⁵ L. Thomas,⁵ M. Vanden Bemden,⁵ C. Vander Velde,⁵ P. Vanlaer,⁵ M. De Coen,⁶ D. Dobur,⁶ Y. Hong,⁶ J. Knolle,⁶ L. Lambrecht,⁶ G. Mestdach,⁶ K. Mota Amarilo,⁶ C. Rendón,⁶ A. Samalan,⁶ K. Skovpen,⁶ N. Van Den Bossche,⁶ J. van der Linden,⁶ L. Wezenbeek,⁶ A. Benecke,⁷ A. Bethani,⁷ G. Bruno,⁷ C. Caputo,⁷ C. Delaere,⁷ I. S. Donertas,⁷ A. Giammanco,⁷ Sa. Jain,⁷ V. Lemaître,⁷ J. Lidrych,⁷ P. Mastrapasqua,⁷ T. T. Tran,⁷ S. Wertz,⁷ G. A. Alves,⁸ E. Coelho,⁸ C. Hensel,⁸ T. Menezes De Oliveira,⁸ A. Moraes,⁸ P. Rebello Teles,⁸ M. Soeiro,⁸ W. L. Aldá Júnior,⁹ M. Alves Gallo Pereira,⁹ M. Barroso Ferreira Filho,⁹ H. Brandao Malbouisson,⁹ W. Carvalho,⁹ J. Chinellato,^{9,f} E. M. Da Costa,⁹ G. G. Da Silveira,^{9,g} D. De Jesus Damiao,⁹ S. Fonseca De Souza,⁹ R. Gomes De Souza,⁹ J. Martins,^{9,h} C. Mora Herrera,⁹ L. Mundim,⁹ H. Nogima,⁹ J. P. Pinheiro,⁹ A. Santoro,⁹ A. Sznajder,⁹ M. Thiel,⁹ A. Vilela Pereira,⁹ C. A. Bernardes,^{10,g} L. Calligaris,¹⁰ T. R. Fernandez Perez Tomei,¹⁰ E. M. Gregores,¹⁰ P. G. Mercadante,¹⁰ S. F. Novaes,¹⁰ B. Orzari,¹⁰ Sandra S. Padula,¹⁰ A. Aleksandrov,¹¹ G. Antchev,¹¹ R. Hadjiiska,¹¹ P. Iaydjiev,¹¹ M. Misheva,¹¹ M. Shopova,¹¹ G. Sultanov,¹¹ A. Dimitrov,¹² L. Litov,¹² B. Pavlov,¹² P. Petkov,¹² A. Petrov,¹² E. Shumka,¹² S. Keshri,¹³ S. Thakur,¹³ T. Cheng,¹⁴ T. Javaid,¹⁴ L. Yuan,¹⁴ Z. Hu,¹⁵ J. Liu,¹⁵ K. Yi,^{15,i,j} G. M. Chen,^{16,k} H. S. Chen,^{16,k} M. Chen,^{16,k} F. Iemmi,¹⁶ C. H. Jiang,¹⁶ A. Kapoor,^{16,l} H. Liao,¹⁶ Z.-A. Liu,^{16,m} R. Sharma,^{16,n} J. N. Song,^{16,m} J. Tao,¹⁶ C. Wang,^{16,k} J. Wang,¹⁶ Z. Wang,^{16,k} H. Zhang,¹⁶ A. Agapitos,¹⁷ Y. Ban,¹⁷ A. Levin,¹⁷ C. Li,¹⁷ Q. Li,¹⁷ Y. Mao,¹⁷ S. J. Qian,¹⁷ X. Sun,¹⁷ D. Wang,¹⁷ H. Yang,¹⁷ L. Zhang,¹⁷ C. Zhou,¹⁷ Z. You,¹⁸ K. Jaffel,¹⁹ N. Lu,¹⁹ G. Bauer,^{20,o} X. Gao,^{21,p} Z. Lin,²² C. Lu,²² M. Xiao,²² C. Avila,²³ D. A. Barbosa Trujillo,²³ A. Cabrera,²³ C. Florez,²³ J. Fraga,²³ J. A. Reyes Vega,²³ J. Mejia Guisao,²⁴ F. Ramirez,²⁴ M. Rodriguez,²⁴ J. D. Ruiz Alvarez,²⁴

D. Giljanovic²⁵, N. Godinovic²⁵, D. Lelas²⁵, A. Sculac²⁵, M. Kovac²⁶, T. Sculac²⁶, P. Bargassa²⁷, V. Brigljevic²⁷, B. K. Chitroda²⁷, D. Ferencek²⁷, K. Jakovic²⁷, S. Mishra²⁷, A. Starodumov^{27,q}, T. Susa²⁷, A. Attikis²⁸, K. Christoforou²⁸, A. Hadjiagapiou²⁸, S. Konstantinou²⁸, J. Mousa²⁸, C. Nicolaou²⁸, F. Ptochos²⁸, P. A. Razis²⁸, H. Rykaczewski²⁸, H. Saka²⁸, A. Stepennov²⁸, M. Finger²⁹, M. Finger Jr.²⁹, A. Kveton²⁹, E. Ayala³⁰, E. Carrera Jarrin³¹, S. Elgammal^{32,r}, A. Ellithi Kamel^{32,s}, A. Lofly³³, M. A. Mahmoud³³, K. Ehataht³⁴, M. Kadastik³⁴, T. Lange³⁴, S. Nandan³⁴, C. Nielsen³⁴, J. Pata³⁴, M. Raidal³⁴, L. Tani³⁴, C. Veelken³⁴, H. Kirschenmann³⁵, K. Osterberg³⁵, M. Voutilainen³⁵, S. Bharthuar³⁶, E. Brücken³⁶, F. Garcia³⁶, K. T. S. Kallonen³⁶, R. Kinnunen³⁶, T. Lampén³⁶, K. Lassila-Perini³⁶, S. Lehti³⁶, T. Lindén³⁶, L. Martikainen³⁶, M. Myllymäki³⁶, M. m. Rantanen³⁶, H. Siikonen³⁶, E. Tuominen³⁶, J. Tuominiemi³⁶, P. Luukka³⁷, H. Petrow³⁷, M. Besancon³⁸, F. Couderc³⁸, M. Dejardin³⁸, D. Denegri³⁸, J. L. Faure³⁸, F. Ferri³⁸, S. Ganjour³⁸, P. Gras³⁸, G. Hamel de Monchenault³⁸, V. Lohezic³⁸, J. Malcles³⁸, J. Rander³⁸, A. Rosowsky³⁸, M. Ö. Sahin³⁸, A. Savoy-Navarro^{38,t}, P. Simkina³⁸, M. Titov³⁸, M. Tornago³⁸, F. Beaudette³⁹, A. Buchot Perraguin³⁹, P. Busson³⁹, A. Cappati³⁹, C. Charlot³⁹, M. Chiusi³⁹, F. Damas³⁹, O. Davignon³⁹, A. De Wit³⁹, I. T. Ehle³⁹, B. A. Fontana Santos Alves³⁹, S. Ghosh³⁹, A. Gilbert³⁹, R. Granier de Cassagnac³⁹, A. Hakimi³⁹, B. Harikrishnan³⁹, L. Kalipoliti³⁹, G. Liu³⁹, J. Motta³⁹, M. Nguyen³⁹, C. Ochando³⁹, L. Portales³⁹, R. Salerno³⁹, J. B. Sauvan³⁹, Y. Sirois³⁹, A. Tarabini³⁹, E. Vernazza³⁹, A. Zabi³⁹, A. Zghiche³⁹, J.-L. Agram^{40,u}, J. Andrea⁴⁰, D. Apparú⁴⁰, D. Bloch⁴⁰, J.-M. Brom⁴⁰, E. C. Chabert⁴⁰, C. Collard⁴⁰, S. Falke⁴⁰, U. Goerlach⁴⁰, C. Grimault⁴⁰, R. Haeblerle⁴⁰, A.-C. Le Bihan⁴⁰, M. Meena⁴⁰, G. Saha⁴⁰, M. A. Sessini⁴⁰, P. Van Hove⁴⁰, S. Beauceron⁴¹, B. Blancon⁴¹, G. Boudoul⁴¹, N. Chanon⁴¹, J. Choi⁴¹, D. Contardo⁴¹, P. Depasse⁴¹, C. Dozen^{41,v}, H. El Mamouni⁴¹, J. Fay⁴¹, S. Gascon⁴¹, M. Gouzevitch⁴¹, C. Greenberg⁴¹, G. Grenier⁴¹, B. Ille⁴¹, I. B. Laktineh⁴¹, M. Lethuillier⁴¹, L. Mirabito⁴¹, S. Perries⁴¹, A. Purohit⁴¹, M. Vander Donckt⁴¹, P. Verdier⁴¹, J. Xiao⁴¹, G. Adamov⁴², I. Lomidze⁴², Z. Tsamalaidze^{42,q}, V. Botta⁴³, L. Feld⁴³, K. Klein⁴³, M. Lipinski⁴³, D. Meuser⁴³, A. Pauls⁴³, N. Röwert⁴³, M. Teroerde⁴³, S. Diekmann⁴⁴, A. Dodonova⁴⁴, N. Eich⁴⁴, D. Eliseev⁴⁴, F. Engelke⁴⁴, J. Erdmann⁴⁴, M. Erdmann⁴⁴, P. Fackeldey⁴⁴, B. Fischer⁴⁴, T. Hebbeker⁴⁴, K. Hoepfner⁴⁴, F. Ivone⁴⁴, A. Jung⁴⁴, M. y. Lee⁴⁴, F. Mausolf⁴⁴, M. Merschmeyer⁴⁴, A. Meyer⁴⁴, S. Mukherjee⁴⁴, D. Noll⁴⁴, F. Nowotny⁴⁴, A. Pozdnyakov⁴⁴, Y. Rath⁴⁴, W. Redjeb⁴⁴, F. Rehm⁴⁴, H. Reithler⁴⁴, U. Sarkar⁴⁴, V. Sarkisovi⁴⁴, A. Schmidt⁴⁴, A. Sharma⁴⁴, J. L. Spah⁴⁴, A. Stein⁴⁴, F. Torres Da Silva De Araujo^{44,w}, S. Wiedenbeck⁴⁴, S. Zaleski⁴⁴, C. Dziwok⁴⁵, G. Flüge⁴⁵, W. Haj Ahmad^{45,x}, T. Kress⁴⁵, A. Nowack⁴⁵, O. Pooth⁴⁵, A. Stahl⁴⁵, T. Ziemons⁴⁵, A. Zotz⁴⁵, H. Aarup Petersen⁴⁶, M. Aldaya Martin⁴⁶, J. Alimena⁴⁶, S. Amoroso⁴⁶, Y. An⁴⁶, S. Baxter⁴⁶, M. Bayatmakou⁴⁶, H. Becerril Gonzalez⁴⁶, O. Behnke⁴⁶, A. Belvedere⁴⁶, S. Bhattacharya⁴⁶, F. Blekman^{46,y}, K. Borras^{46,z}, A. Campbell⁴⁶, A. Cardini⁴⁶, C. Cheng⁴⁶, F. Colombina⁴⁶, S. Consuegra Rodríguez⁴⁶, G. Correia Silva⁴⁶, M. De Silva⁴⁶, G. Eckerlin⁴⁶, D. Eckstein⁴⁶, L. I. Estevez Banos⁴⁶, O. Filatov⁴⁶, E. Gallo^{46,y}, A. Geiser⁴⁶, A. Giraldi⁴⁶, V. Guglielmi⁴⁶, M. Guthoff⁴⁶, A. Hinzmann⁴⁶, A. Jafari^{46,aa}, L. Jeppe⁴⁶, N. Z. Jomhari⁴⁶, B. Kaech⁴⁶, M. Kasemann⁴⁶, C. Kleinwort⁴⁶, R. Kogler⁴⁶, M. Komm⁴⁶, D. Krücker⁴⁶, W. Lange⁴⁶, D. Leyva Pernia⁴⁶, K. Lipka^{46,bb}, W. Lohmann^{46,cc}, R. Mankel⁴⁶, I.-A. Melzer-Pellmann⁴⁶, M. Mendizabal Morentin⁴⁶, A. B. Meyer⁴⁶, G. Milella⁴⁶, A. Mussgiller⁴⁶, L. P. Nair⁴⁶, A. Nürnberg⁴⁶, Y. Otari⁴⁶, J. Park⁴⁶, D. Pérez Adán⁴⁶, E. Ranken⁴⁶, A. Raspereza⁴⁶, B. Ribeiro Lopes⁴⁶, J. Rübenach⁴⁶, A. Saggio⁴⁶, M. Scham^{46,dd,z}, S. Schnake^{46,z}, P. Schütze⁴⁶, C. Schwanenberger^{46,y}, D. Selivanova⁴⁶, K. Sharko⁴⁶, M. Shchedrolosiev⁴⁶, R. E. Sosa Ricardo⁴⁶, D. Stafford⁴⁶, F. Vazzoler⁴⁶, A. Ventura Barroso⁴⁶, R. Walsh⁴⁶, Q. Wang⁴⁶, Y. Wen⁴⁶, K. Wichmann⁴⁶, L. Wiens^{46,z}, C. Wissing⁴⁶, Y. Yang⁴⁶, A. Zimmermann Castro Santos⁴⁶, A. Albrecht⁴⁷, S. Albrecht⁴⁷, M. Antonello⁴⁷, S. Bein⁴⁷, L. Benato⁴⁷, S. Bollweg⁴⁷, M. Bonanomi⁴⁷, P. Connor⁴⁷, K. El Morabit⁴⁷, Y. Fischer⁴⁷, E. Garutti⁴⁷, A. Grohsjean⁴⁷, J. Haller⁴⁷, H. R. Jabusch⁴⁷, G. Kasieczka⁴⁷, P. Keicher⁴⁷, R. Klanner⁴⁷, W. Korcarí⁴⁷, T. Kramer⁴⁷, V. Kutzner⁴⁷, F. Labe⁴⁷, J. Lange⁴⁷, A. Lobanov⁴⁷, C. Matthies⁴⁷, A. Mehta⁴⁷, L. Moureaux⁴⁷, M. Mrowietz⁴⁷, A. Nigamova⁴⁷, Y. Nissan⁴⁷, A. Paasch⁴⁷, K. J. Pena Rodriguez⁴⁷, T. Quadfasel⁴⁷, B. Raciti⁴⁷, M. Rieger⁴⁷, D. Savoie⁴⁷, J. Schindler⁴⁷, P. Schleper⁴⁷, M. Schröder⁴⁷, J. Schwandt⁴⁷, M. Sommerhalder⁴⁷, H. Stadie⁴⁷, G. Steinbrück⁴⁷, A. Tews⁴⁷, M. Wolf⁴⁷, S. Brommer⁴⁸, M. Burkart⁴⁸, E. Butz⁴⁸, T. Chwalek⁴⁸, A. Dierlamm⁴⁸, A. Droll⁴⁸, N. Faltermann⁴⁸, M. Giffels⁴⁸, A. Gottmann⁴⁸, F. Hartmann^{48,ee}, R. Hofsaess⁴⁸, M. Horzela⁴⁸, U. Husemann⁴⁸, J. Kieseler⁴⁸

M. Klute⁴⁸, R. Koppenhöfer⁴⁸, J. M. Lawhorn⁴⁸, M. Link⁴⁸, A. Lintuluoto⁴⁸, B. Maier⁴⁸, S. Maier⁴⁸, S. Mitra⁴⁸,
M. Mormile⁴⁸, Th. Müller⁴⁸, M. Neukum⁴⁸, M. Oh⁴⁸, E. Pfeffer⁴⁸, M. Presilla⁴⁸, G. Quast⁴⁸, K. Rabbertz⁴⁸,
B. Regnery⁴⁸, N. Shadskiy⁴⁸, I. Shvetsov⁴⁸, H. J. Simonis⁴⁸, M. Toms⁴⁸, N. Trevisani⁴⁸, R. F. Von Cube⁴⁸,
M. Wassmer⁴⁸, S. Wieland⁴⁸, F. Wittig⁴⁸, R. Wolf⁴⁸, X. Zuo⁴⁸, G. Anagnostou⁴⁹, G. Daskalakis⁴⁹, A. Kyriakis,⁴⁹
A. Papadopoulos,^{49,ee} A. Stakia⁴⁹, P. Kontaxakis⁵⁰, G. Melachroinos,⁵⁰ Z. Painesis⁵⁰, A. Panagiotou,⁵⁰
I. Papavergou,⁵⁰ I. Paraskevas⁵⁰, N. Saoulidou⁵⁰, K. Theofilatos⁵⁰, E. Tziaferi⁵⁰, K. Vellidis⁵⁰, I. Zisopoulos⁵⁰,
G. Bakas⁵¹, T. Chatzistavrou,⁵¹ G. Karapostoli⁵¹, K. Kousouris⁵¹, I. Papakrivopoulos⁵¹, E. Siamarkou,⁵¹
G. Tsipolitis,⁵¹ A. Zacharopoulou,⁵¹ K. Adamidis,⁵² I. Bestintzanos,⁵² I. Evangelou⁵², C. Foudas,⁵² C. Kamtsikis,⁵²
P. Katsoulis,⁵² P. Kokkas⁵², P. G. Kosmoglou Kioseoglou⁵², N. Manthos⁵², I. Papadopoulos⁵², J. Strologas⁵²,
M. Bartók^{53,ff}, C. Hajdu⁵³, D. Horvath^{53,gg,hh}, K. Márton,⁵³ A. J. Rádl^{53,ii}, F. Sikler⁵³, V. Veszpremi⁵³,
M. Csanád⁵⁴, K. Farkas⁵⁴, M. M. A. Gadallah^{54,jj}, Á. Kadlecik⁵⁴, P. Major⁵⁴, K. Mandal⁵⁴, G. Pásztor⁵⁴,
G. I. Veres⁵⁴, P. Raics,⁵⁵ B. Ujvari⁵⁵, G. Zilizi⁵⁵, G. Bencze,⁵⁶ S. Czellar,⁵⁶ J. Molnar,⁵⁶ Z. Szillasi,⁵⁶ T. Csorgo^{57,kk},
F. Nemes^{57,kk}, T. Novak⁵⁷, J. Babbar⁵⁸, S. Bansal⁵⁸, S. B. Beri,⁵⁸ V. Bhatnagar⁵⁸, G. Chaudhary⁵⁸, S. Chauhan⁵⁸,
N. Dhingra^{58,ll}, A. Kaur⁵⁸, A. Kaur⁵⁸, H. Kaur⁵⁸, M. Kaur⁵⁸, S. Kumar⁵⁸, K. Sandeep⁵⁸, T. Sheokand,⁵⁸
J. B. Singh⁵⁸, A. Singla⁵⁸, A. Ahmed⁵⁹, A. Bhardwaj⁵⁹, A. Chhetri⁵⁹, B. C. Choudhary⁵⁹, A. Kumar⁵⁹,
A. Kumar⁵⁹, M. Naimuddin⁵⁹, K. Ranjan⁵⁹, S. Saumya⁵⁹, S. Baradia⁶⁰, S. Barman^{60,mm}, S. Bhattacharya⁶⁰,
S. Dutta⁶⁰, S. Dutta,⁶⁰ S. Sarkar,⁶⁰ M. M. Ameen⁶¹, P. K. Behera⁶¹, S. C. Behera⁶¹, S. Chatterjee⁶¹, P. Jana⁶¹,
P. Kalbhor⁶¹, J. R. Komaragiri^{61,nn}, D. Kumar^{61,nn}, P. R. Pujhari⁶¹, N. R. Saha⁶¹, A. Sharma⁶¹, A. K. Sikdar⁶¹,
S. Verma⁶¹, S. Dugad,⁶² M. Kumar⁶², G. B. Mohanty⁶², P. Suryadevara,⁶² A. Bala⁶³, S. Banerjee⁶³,
R. M. Chatterjee,⁶³ R. K. Dewanjee^{63,oo}, M. Guchait⁶³, Sh. Jain⁶³, A. Jaiswal,⁶³ S. Karmakar⁶³, S. Kumar⁶³,
G. Majumder⁶³, K. Mazumdar⁶³, S. Parolia⁶³, A. Thachayath⁶³, S. Bahinipati^{64,pp}, C. Kar⁶⁴, D. Maity^{64,qq},
P. Mal⁶⁴, T. Mishra⁶⁴, V. K. Muraleedharan Nair Bindhu^{64,qq}, K. Naskar^{64,qq}, A. Nayak^{64,qq}, P. Sadangi,⁶⁴
S. K. Swain⁶⁴, S. Varghese^{64,qq}, D. Vats^{64,qq}, S. Acharya^{65,rr}, A. Alpana⁶⁵, S. Dube⁶⁵, B. Gomber^{65,rr},
B. Kansal⁶⁵, A. Laha⁶⁵, B. Sahu^{65,rr}, S. Sharma⁶⁵, K. Y. Vaish,⁶⁵ H. Bakhshiansohi^{66,ss}, E. Khazaie^{66,tt},
M. Zeinali^{66,uu}, S. Chenarani^{67,vv}, S. M. Etesami⁶⁷, M. Khakzad⁶⁷, M. Mohammadi Najafabadi⁶⁷,
M. Grunewald⁶⁸, M. Abbrescia^{69a,69b}, R. Aly^{69a,69c,ww}, A. Colaleo^{69a,69b}, D. Creanza^{69a,69c}, B. D'Anzi^{69a,69b},
N. De Filippis^{69a,69c}, M. De Palma^{69a,69b}, A. Di Florio^{69a,69c}, W. Elmetenawee^{69a,69b,ww}, L. Fiore^{69a}, G. Iaselli^{69a,69c},
M. Louka,^{69a,69b} G. Maggi^{69a,69c}, M. Maggi^{69a}, I. Margjeka^{69a,69b}, V. Mastrapasqua^{69a,69b}, S. My^{69a,69b},
S. Nuzzo^{69a,69b}, A. Pellecchia^{69a,69b}, A. Pompili^{69a,69b}, G. Pugliese^{69a,69c}, R. Radogna^{69a},
G. Ramirez-Sanchez^{69a,69c}, D. Ramos^{69a}, A. Ranieri^{69a}, L. Silvestris^{69a}, F. M. Simone^{69a,69b}, Ü. Sözbilir^{69a},
A. Stamerra^{69a}, R. Venditti^{69a}, P. Verwilligen^{69a}, A. Zaza^{69a,69b}, G. Abbiendi^{70a}, C. Battilana^{70a,70b},
L. Borgonovi^{70a}, R. Campanini^{70a,70b}, P. Capiluppi^{70a,70b}, A. Castro^{70a,70b}, F. R. Cavallo^{70a}, M. Cuffiani^{70a,70b},
G. M. Dallavalle^{70a}, T. Diotallevi^{70a,70b}, F. Fabbri^{70a}, A. Fanfani^{70a,70b}, D. Fasanella^{70a,70b}, P. Giacomelli^{70a},
L. Giommi^{70a,70b}, C. Grandi^{70a}, L. Guiducci^{70a,70b}, S. Lo Meo^{70a,xx}, L. Lunerti^{70a,70b}, S. Marcellini^{70a},
G. Masetti^{70a}, F. L. Navarria^{70a,70b}, A. Perrotta^{70a}, F. Primavera^{70a,70b}, A. M. Rossi^{70a,70b}, T. Rovelli^{70a,70b},
G. P. Siroli^{70a,70b}, S. Costa^{71a,71b,yy}, A. Di Mattia^{71a}, R. Potenza,^{71a,71b} A. Tricomi^{71a,71b,yy}, C. Tuve^{71a,71b},
P. Assiouras^{72a}, G. Barbagli^{72a}, G. Bardelli^{72a,72b}, B. Camaiani^{72a,72b}, A. Cassese^{72a}, R. Ceccarelli^{72a},
V. Ciulli^{72a,72b}, C. Civinini^{72a}, R. D' Alessandro^{72a,72b}, E. Focardi^{72a,72b}, T. Kello,^{72a} G. Latino^{72a,72b}, P. Lenzi^{72a,72b},
M. Lizzo^{72a}, M. Meschini^{72a}, S. Paoletti^{72a}, A. Papanastassiou,^{72a,72b} G. Sguazzoni^{72a}, L. Vilianni^{72a}, L. Benussi⁷³,
S. Bianco⁷³, S. Meola^{73,zz}, D. Piccolo⁷³, P. Chatagnon^{74a}, F. Ferro^{74a}, E. Robutti^{74a}, S. Tosi^{74a,74b},
A. Benaglia^{75a}, G. Boldrini^{75a,75b}, F. Brivio^{75a}, F. Cetorelli^{75a}, F. De Guio^{75a,75b}, M. E. Dinardo^{75a,75b}, P. Dini^{75a},
S. Gennai^{75a}, R. Gerosa^{75a,75b}, A. Ghezzi^{75a,75b}, P. Govoni^{75a,75b}, L. Guzzi^{75a}, M. T. Lucchini^{75a,75b},
M. Malberti^{75a}, S. Malvezzi^{75a}, A. Massironi^{75a}, D. Menasce^{75a}, L. Moroni^{75a}, M. Paganoni^{75a,75b}, D. Pedrini^{75a},
B. S. Pinolini,^{75a} S. Ragazzi^{75a,75b}, T. Tabarelli de Fatis^{75a,75b}, D. Zuolo^{75a}, S. Buontempo^{76a}, A. Cagnotta^{76a,76b},
F. Carnevali,^{76a,76b} N. Cavallo^{76a,76c}, F. Fabozzi^{76a,76c}, A. O. M. Iorio^{76a,76b}, L. Lista^{76a,76b,aaa}, P. Paolucci^{76a,ee},
B. Rossi^{76a}, C. Sciacca^{76a,76b}, R. Ardino^{77a}, P. Azzi^{77a}, N. Bacchetta^{77a,bbb}, D. Bisello^{77a,77b}, P. Bortignon^{77a},
G. Bortolato,^{77a,77b} A. Bragagnolo^{77a,77b}, R. Carlin^{77a,77b}, P. Checchia^{77a}, T. Dorigo^{77a}, F. Gasparini^{77a,77b},
U. Gasparini^{77a,77b}, E. Lusiani^{77a}, M. Margoni^{77a,77b}, F. Marini^{77a}, G. Maron^{77a,ccc}, M. Michelotto^{77a},
M. Migliorini^{77a,77b}, J. Pazzini^{77a,77b}, P. Ronchese^{77a,77b}, R. Rossin^{77a,77b}, F. Simonetto^{77a,77b}, G. Strong^{77a}

M. Tosi^{77a,77b} A. Triossi^{77a,77b} S. Ventura^{77a} H. Yarar^{77a,77b} M. Zanetti^{77a,77b} P. Zotto^{77a,77b} A. Zucchetta^{77a,77b}
 S. Abu Zeid^{78a,ddd} C. Aimè^{78a,78b} A. Braghieri^{78a} S. Calzaferri^{78a} D. Fiorina^{78a} P. Montagna^{78a,78b} V. Re^{78a}
 C. Riccardi^{78a,78b} P. Salvini^{78a} I. Vai^{78a,78b} P. Vitulo^{78a,78b} S. Ajmal^{79a,79b} G. M. Bilei^{79a} D. Ciangottini^{79a,79b}
 L. Fanò^{79a,79b} M. Magherini^{79a,79b} G. Mantovani^{79a,79b} V. Mariani^{79a,79b} M. Menichelli^{79a} F. Moscatelli^{79a,eee}
 A. Rossi^{79a,79b} A. Santocchia^{79a,79b} D. Spiga^{79a} T. Tedeschi^{79a,79b} P. Asenov^{80a,80b} P. Azzurri^{80a}
 G. Bagliesi^{80a} R. Bhattacharya^{80a} L. Bianchini^{80a,80b} T. Boccali^{80a} E. Bossini^{80a} D. Bruschini^{80a,80c}
 R. Castaldi^{80a} M. A. Ciocci^{80a,80b} M. Cipriani^{80a,80b} V. D'Amante^{80a,80d} R. Dell'Orso^{80a} S. Donato^{80a}
 A. Giassi^{80a} F. Ligabue^{80a,80c} D. Matos Figueiredo^{80a} A. Messineo^{80a,80b} M. Musich^{80a,80b} F. Palla^{80a}
 A. Rizzi^{80a,80b} G. Rolandi^{80a,80c} S. Roy Chowdhury^{80a} T. Sarkar^{80a} A. Scribano^{80a} P. Spagnolo^{80a}
 R. Tenchini^{80a} G. Tonelli^{80a,80b} N. Turini^{80a,80d} F. Vaselli^{80a,80c} A. Venturi^{80a} P. G. Verdini^{80a}
 C. Baldenegro Barrera^{81a,81b} P. Barria^{81a} C. Basile^{81a,81b} M. Campana^{81a,81b} F. Cavallari^{81a}
 L. Cunqueiro Mendez^{81a,81b} D. Del Re^{81a,81b} E. Di Marco^{81a} M. Diemoz^{81a} F. Errico^{81a,81b} E. Longo^{81a,81b}
 P. Meridiani^{81a} J. Mijuskovic^{81a,81b} G. Organtini^{81a,81b} F. Pandolfi^{81a} R. Paramatti^{81a,81b} C. Quaranta^{81a,81b}
 S. Rahatlou^{81a,81b} C. Rovelli^{81a} F. Santanastasio^{81a,81b} L. Soffi^{81a} N. Amapane^{82a,82b} R. Arcidiacono^{82a,82c}
 S. Argiro^{82a,82b} M. Arneodo^{82a,82c} N. Bartosik^{82a} R. Bellan^{82a,82b} A. Bellora^{82a,82b} C. Biino^{82a} C. Borca^{82a,82b}
 N. Cartiglia^{82a} M. Costa^{82a,82b} R. Covarelli^{82a,82b} N. Demaria^{82a} L. Finco^{82a} M. Grippo^{82a,82b} B. Kiani^{82a,82b}
 F. Legger^{82a} F. Luongo^{82a,82b} C. Mariotti^{82a} L. Markovic^{82a,82b} S. Maselli^{82a} A. Mecca^{82a,82b}
 E. Migliore^{82a,82b} M. Monteno^{82a} R. Mulargia^{82a} M. M. Obertino^{82a,82b} G. Ortona^{82a} L. Pacher^{82a,82b}
 N. Pastrone^{82a} M. Pelliccioni^{82a} M. Ruspa^{82a,82c} F. Siviero^{82a,82b} V. Sola^{82a,82b} A. Solano^{82a,82b} A. Staiano^{82a}
 C. Tarricone^{82a,82b} D. Trocino^{82a} G. Umoret^{82a,82b} E. Vlasov^{82a,82b} R. White^{82a} S. Belforte^{83a}
 V. Candelise^{83a,83b} M. Casarsa^{83a} F. Cossutti^{83a} K. De Leo^{83a} G. Della Ricca^{83a,83b} S. Dogra⁸⁴ J. Hong⁸⁴
 C. Huh⁸⁴ B. Kim⁸⁴ D. H. Kim⁸⁴ J. Kim⁸⁴ H. Lee⁸⁴ S. W. Lee⁸⁴ C. S. Moon⁸⁴ Y. D. Oh⁸⁴ M. S. Ryu⁸⁴
 S. Sekmen⁸⁴ Y. C. Yang⁸⁴ M. S. Kim⁸⁵ G. Bak⁸⁶ P. Gwak⁸⁶ H. Kim⁸⁶ D. H. Moon⁸⁶ E. Asilar⁸⁷
 D. Kim⁸⁷ T. J. Kim⁸⁷ J. A. Merlin⁸⁷ S. Choi⁸⁸ S. Han⁸⁸ B. Hong⁸⁸ K. Lee⁸⁸ K. S. Lee⁸⁸ S. Lee⁸⁸ J. Park⁸⁸
 S. K. Park⁸⁸ J. Yoo⁸⁸ J. Goh⁸⁹ S. Yang⁸⁹ H. S. Kim⁹⁰ Y. Kim⁹⁰ S. Lee⁹⁰ J. Almond⁹¹ J. H. Bhyun⁹¹ J. Choi⁹¹
 W. Jun⁹¹ J. Kim⁹¹ S. Ko⁹¹ H. Kwon⁹¹ H. Lee⁹¹ J. Lee⁹¹ J. Lee⁹¹ B. H. Oh⁹¹ S. B. Oh⁹¹ H. Seo⁹¹
 U. K. Yang⁹¹ I. Yoon⁹¹ W. Jang⁹² D. Y. Kang⁹² Y. Kang⁹² S. Kim⁹² B. Ko⁹² J. S. H. Lee⁹² Y. Lee⁹²
 I. C. Park⁹² Y. Roh⁹² I. J. Watson⁹² S. Ha⁹³ H. D. Yoo⁹³ M. Choi⁹⁴ M. R. Kim⁹⁴ H. Lee⁹⁴ Y. Lee⁹⁴ I. Yu⁹⁴
 T. Beyrouthy⁹⁵ K. Dreimanis⁹⁶ A. Gaile⁹⁶ G. Pikurs⁹⁶ A. Potrebko⁹⁶ M. Seidel⁹⁶ N. R. Strautnieks⁹⁷
 M. Ambrozias⁹⁸ A. Juodagalvis⁹⁸ A. Rinkevicius⁹⁸ G. Tamulaitis⁹⁸ N. Bin Norjoharuddeen⁹⁹ I. Yusuff^{99,fff}
 Z. Zolkapli⁹⁹ J. F. Benitez¹⁰⁰ A. Castaneda Hernandez¹⁰⁰ H. A. Encinas Acosta¹⁰⁰ L. G. Gallegos Maríñez¹⁰⁰
 M. León Coello¹⁰⁰ J. A. Murillo Quijada¹⁰⁰ A. Sehwat¹⁰⁰ L. Valencia Palomo¹⁰⁰ G. Ayala¹⁰¹
 H. Castilla-Valdez¹⁰¹ H. Crotte Ledesma¹⁰¹ E. De La Cruz-Burelo¹⁰¹ I. Heredia-De La Cruz^{101,ggg}
 R. Lopez-Fernandez¹⁰¹ C. A. Mondragon Herrera¹⁰¹ A. Sánchez Hernández¹⁰¹ C. Oropeza Barrera¹⁰²
 M. Ramírez García¹⁰² I. Bautista¹⁰³ I. Pedraza¹⁰³ H. A. Salazar Ibarguen¹⁰³ C. Uribe Estrada¹⁰³ I. Bujanja¹⁰⁴
 N. Raicevic¹⁰⁴ P. H. Butler¹⁰⁵ A. Ahmad¹⁰⁶ M. I. Asghar¹⁰⁶ A. Awais¹⁰⁶ M. I. M. Awan¹⁰⁶ H. R. Hoorani¹⁰⁶
 W. A. Khan¹⁰⁶ V. Avati¹⁰⁷ L. Grzanka¹⁰⁷ M. Malawski¹⁰⁷ H. Bialkowska¹⁰⁸ M. Bluj¹⁰⁸ B. Boimska¹⁰⁸
 M. Górski¹⁰⁸ M. Kazana¹⁰⁸ M. Szeleper¹⁰⁸ P. Zalewski¹⁰⁸ K. Bunkowski¹⁰⁹ K. Doroba¹⁰⁹ A. Kalinowski¹⁰⁹
 M. Konecki¹⁰⁹ J. Krolikowski¹⁰⁹ A. Muhammad¹⁰⁹ K. Pozniak¹¹⁰ W. Zabolotny¹¹⁰ M. Araujo¹¹¹
 D. Bastos¹¹¹ C. Beirão Da Cruz E Silva¹¹¹ A. Boletti¹¹¹ M. Bozzo¹¹¹ T. Camporesi¹¹¹ G. Da Molin¹¹¹
 P. Faccioli¹¹¹ M. Gallinaro¹¹¹ J. Hollar¹¹¹ N. Leonardo¹¹¹ T. Niknejad¹¹¹ A. Petrilli¹¹¹ M. Pisano¹¹¹
 J. Seixas¹¹¹ J. Varela¹¹¹ J. W. Wulff¹¹¹ P. Adzic¹¹² P. Milenovic¹¹² M. Dordevic¹¹³ J. Milosevic¹¹³
 V. Rekovic¹¹³ M. Aguilar-Benitez¹¹⁴ J. Alcaraz Maestre¹¹⁴ Cristina F. Bedoya¹¹⁴ Oliver M. Carretero¹¹⁴
 M. Cepeda¹¹⁴ M. Cerrada¹¹⁴ N. Colino¹¹⁴ B. De La Cruz¹¹⁴ A. Delgado Peris¹¹⁴ A. Escalante Del Valle¹¹⁴
 D. Fernández Del Val¹¹⁴ J. P. Fernández Ramos¹¹⁴ J. Flix¹¹⁴ M. C. Fouz¹¹⁴ O. Gonzalez Lopez¹¹⁴
 S. Goy Lopez¹¹⁴ J. M. Hernandez¹¹⁴ M. I. Josa¹¹⁴ D. Moran¹¹⁴ C. M. Morcillo Perez¹¹⁴ Á. Navarro Tobar¹¹⁴
 C. Perez Dengra¹¹⁴ A. Pérez-Calero Yzquierdo¹¹⁴ J. Puerta Pelayo¹¹⁴ I. Redondo¹¹⁴ D. D. Redondo Ferrero¹¹⁴
 L. Romero¹¹⁴ S. Sánchez Navas¹¹⁴ L. Urda Gómez¹¹⁴ J. Vazquez Escobar¹¹⁴ C. Willmott¹¹⁴ J. F. de Trocóniz¹¹⁵
 B. Alvarez Gonzalez¹¹⁶ J. Cuevas¹¹⁶ J. Fernandez Menendez¹¹⁶ S. Folgueras¹¹⁶ I. Gonzalez Caballero¹¹⁶

J. R. González Fernández¹¹⁶, P. Leguina¹¹⁶, E. Palencia Cortezon¹¹⁶, C. Ramón Álvarez¹¹⁶, V. Rodríguez Bouza,¹¹⁶
A. Soto Rodríguez¹¹⁶, A. Trapote¹¹⁶, C. Vico Villalba¹¹⁶, P. Vischia¹¹⁶, S. Bhowmik¹¹⁷, S. Blanco Fernández¹¹⁷,
J. A. Brochero Cifuentes¹¹⁷, I. J. Cabrillo¹¹⁷, A. Calderon¹¹⁷, J. Duarte Campderros¹¹⁷, M. Fernandez¹¹⁷,
G. Gomez¹¹⁷, C. Lasaos García¹¹⁷, C. Martinez Rivero¹¹⁷, P. Martinez Ruiz del Arbol¹¹⁷, F. Matorras¹¹⁷,
P. Matorras Cuevas¹¹⁷, E. Navarrete Ramos¹¹⁷, J. Piedra Gomez¹¹⁷, L. Scodellaro¹¹⁷, I. Vila¹¹⁷,
J. M. Vizan Garcia¹¹⁷, M. K. Jayananda¹¹⁸, B. Kailasapathy^{118,hhh}, D. U. J. Sonnadara¹¹⁸,
D. D. C. Wickramaratna¹¹⁸, W. G. D. Dharmaratna^{119,iii}, K. Liyanage¹¹⁹, N. Perera¹¹⁹, N. Wickramage¹¹⁹,
D. Abbaneo¹²⁰, C. Amendola¹²⁰, E. Auffray¹²⁰, G. Auzinger¹²⁰, J. Baechler¹²⁰, D. Barney¹²⁰,
A. Bermúdez Martínez¹²⁰, M. Bianco¹²⁰, B. Bilin¹²⁰, A. A. Bin Anuar¹²⁰, A. Bocci¹²⁰, C. Botta¹²⁰,
E. Brondolin¹²⁰, C. Caillol¹²⁰, G. Cerminara¹²⁰, N. Chernyavskaya¹²⁰, D. d'Enterria¹²⁰, A. Dabrowski¹²⁰,
A. David¹²⁰, A. De Roeck¹²⁰, M. M. Defranichis¹²⁰, M. Deile¹²⁰, M. Dobson¹²⁰, L. Forthomme¹²⁰,
G. Franzoni¹²⁰, W. Funk¹²⁰, S. Giani¹²⁰, D. Gigi¹²⁰, K. Gill¹²⁰, F. Glege¹²⁰, L. Gouskos¹²⁰, M. Haranko¹²⁰,
J. Hegeman¹²⁰, B. Huber¹²⁰, V. Innocente¹²⁰, T. James¹²⁰, P. Janot¹²⁰, O. Kaluzinska¹²⁰, S. Laurila¹²⁰,
P. Lecoq¹²⁰, E. Leutgeb¹²⁰, C. Lourenço¹²⁰, L. Malgeri¹²⁰, M. Mannelli¹²⁰, A. C. Marini¹²⁰, M. Matthewman¹²⁰,
F. Meijers¹²⁰, S. Mersi¹²⁰, E. Meschi¹²⁰, V. Milosevic¹²⁰, F. Monti¹²⁰, F. Moortgat¹²⁰, M. Mulders¹²⁰,
I. Neutelings¹²⁰, S. Orfanelli¹²⁰, F. Pantaleo¹²⁰, G. Petrucciani¹²⁰, A. Pfeiffer¹²⁰, M. Pierini¹²⁰, D. Piparo¹²⁰,
H. Qu¹²⁰, D. Rabady¹²⁰, M. Rovere¹²⁰, H. Sakulin¹²⁰, S. Scarfi¹²⁰, C. Schwick¹²⁰, M. Selvaggi¹²⁰, A. Sharma¹²⁰,
K. Shchelina¹²⁰, P. Silva¹²⁰, P. Sphicas^{120,iii}, A. G. Stahl Leitner¹²⁰, A. Steen¹²⁰, S. Summers¹²⁰, D. Treille¹²⁰,
P. Tropea¹²⁰, A. Tsiro, D. Walter¹²⁰, J. Wanczyk^{120,kkk}, J. Wang¹²⁰, S. Wuchterl¹²⁰, P. Zehetner¹²⁰,
P. Zejd¹²⁰, W. D. Zeuner¹²⁰, T. Bevilacqua^{121,iii}, L. Caminada^{121,iii}, A. Ebrahimi¹²¹, W. Erdmann¹²¹,
R. Horisberger¹²¹, Q. Ingram¹²¹, H. C. Kaestli¹²¹, D. Kotlinski¹²¹, C. Lange¹²¹, M. Missiroli^{121,iii},
L. Noehte^{121,iii}, T. Rohe¹²¹, T. K. Aarrestad¹²², K. Androsov^{122,kkk}, M. Backhaus¹²², A. Calandri¹²²,
C. Cazzaniga¹²², K. Datta¹²², A. De Cosa¹²², G. Dissertori¹²², M. Dittmar¹²², M. Donegà¹²², F. Eble¹²²,
M. Galli¹²², K. Gedia¹²², F. Glessgen¹²², C. Grab¹²², N. Härringer¹²², T. G. Harte¹²², D. Hits¹²²,
W. Lustermann¹²², A.-M. Lyon¹²², R. A. Manzoni¹²², M. Marchegiani¹²², L. Marchese¹²², C. Martin Perez¹²²,
A. Mascellani^{122,kkk}, F. Nessi-Tedaldi¹²², F. Pauss¹²², V. Perovic¹²², S. Pigazzini¹²², C. Reissel¹²²,
T. Reitenspiess¹²², B. Ristic¹²², F. Riti¹²², R. Seidita¹²², J. Steggemann^{122,kkk}, D. Valsecchi¹²², R. Wallny¹²²,
C. Amsler^{123,mmm}, P. Bärtzsch¹²³, M. F. Canelli¹²³, K. Cormier¹²³, J. K. Heikkilä¹²³, M. Huwiler¹²³, W. Jin¹²³,
A. Jofrehei¹²³, B. Kilminster¹²³, S. Leontsinis¹²³, S. P. Liechti¹²³, A. Macchiolo¹²³, P. Meiring¹²³,
U. Molinatti¹²³, A. Reimers¹²³, P. Robmann¹²³, S. Sanchez Cruz¹²³, M. Senger¹²³, F. Stäger¹²³, Y. Takahashi¹²³,
R. Tramontano¹²³, C. Adloff^{124,nnn}, D. Bhowmik¹²⁴, C. M. Kuo¹²⁴, W. Lin¹²⁴, P. K. Rout¹²⁴, P. C. Tiwari^{124,nn},
S. S. Yu¹²⁴, L. Ceard¹²⁵, Y. Chao¹²⁵, K. F. Chen¹²⁵, P. s. Chen¹²⁵, Z. g. Chen¹²⁵, A. De Iorio¹²⁵, W.-S. Hou¹²⁵,
T. h. Hsu¹²⁵, Y. w. Kao¹²⁵, R. Khurana¹²⁵, G. Kole¹²⁵, Y. y. Li¹²⁵, R.-S. Lu¹²⁵, E. Paganis¹²⁵, X. f. Su¹²⁵,
J. Thomas-Wilsker¹²⁵, L. s. Tsai¹²⁵, H. y. Wu¹²⁵, E. Yazgan¹²⁵, C. Asawatangtrakuldee¹²⁶, N. Srimanobhas,
V. Wachirapusanand¹²⁶, D. Agyel¹²⁷, F. Boran¹²⁷, Z. S. Demiroglu¹²⁷, F. Dolek¹²⁷, I. Dumanoglu^{127,ooo},
E. Eskut¹²⁷, Y. Guler^{127,ppp}, E. Gurpinar Guler^{127,ppp}, C. Isik¹²⁷, O. Kara¹²⁷, A. Kayis Topaksu¹²⁷, U. Kiminsu¹²⁷,
G. Onengut¹²⁷, K. Ozdemir^{127,qqq}, A. Polatoz¹²⁷, B. Tali^{127,rrr}, U. G. Tok¹²⁷, S. Turkcapar¹²⁷, E. Uslan¹²⁷,
I. S. Zorbakir¹²⁷, M. Yalvac^{128,sss}, B. Akgun¹²⁹, I. O. Atakisi¹²⁹, E. Gülmez¹²⁹, M. Kaya^{129,ttt}, O. Kaya^{129,uuu},
S. Tekten^{129,vvv}, A. Cakir¹³⁰, K. Cankocak^{130,ooo,www}, G. G. Dincer¹³⁰, Y. Komurcu¹³⁰, S. Sen^{130,xxx},
O. Aydılek^{131,x}, S. Cerci^{131,rrr}, V. Epshteyn¹³¹, B. Hacısalınoğlu¹³¹, I. Hos^{131,yyy}, B. Kaynak¹³¹,
S. Ozkorucuklu¹³¹, O. Potok¹³¹, H. Sert¹³¹, C. Simsek¹³¹, C. Zorbilmez¹³¹, B. Isildak^{132,zzz}, D. Sunar Cerci^{132,rrr},
A. Boyaryntsev¹³³, B. Grynyov¹³³, L. Levchuk¹³⁴, D. Anthony¹³⁵, J. J. Brooke¹³⁵, A. Bundock¹³⁵, F. Bury¹³⁵,
E. Clement¹³⁵, D. Cussans¹³⁵, H. Flacher¹³⁵, M. Glowacki¹³⁵, J. Goldstein¹³⁵, H. F. Heath¹³⁵, M.-L. Holmberg¹³⁵,
L. Kreczko¹³⁵, S. Paramesvaran¹³⁵, L. Robertshaw¹³⁵, S. Seif El Nasr-Storey¹³⁵, V. J. Smith¹³⁵, N. Stylianou^{135,aaa},
K. Walkingshaw Pass¹³⁵, A. H. Ball¹³⁶, K. W. Bell¹³⁶, A. Belyaev^{136,bbbb}, C. Brew¹³⁶, R. M. Brown¹³⁶,
D. J. A. Cockerill¹³⁶, C. Cooke¹³⁶, K. V. Ellis¹³⁶, K. Harder¹³⁶, S. Harper¹³⁶, J. Linacre¹³⁶, K. Manolopoulos¹³⁶,
D. M. Newbold¹³⁶, E. Olaiya¹³⁶, D. Petyt¹³⁶, T. Reis¹³⁶, A. R. Sahasransu¹³⁶, G. Salvi¹³⁶, T. Schuh¹³⁶,
C. H. Shepherd-Themistocleous¹³⁶, I. R. Tomalin¹³⁶, T. Williams¹³⁶, R. Bainbridge¹³⁷, P. Bloch¹³⁷,
C. E. Brown¹³⁷, O. Buchmuller¹³⁷, V. Cacchio¹³⁷, C. A. Carrillo Montoya¹³⁷, G. S. Chahal^{137,cccc}, D. Colling¹³⁷

J. S. Dancu,¹³⁷ I. Das,¹³⁷ P. Dauncey,¹³⁷ G. Davies,¹³⁷ J. Davies,¹³⁷ M. Della Negra,¹³⁷ S. Fayer,¹³⁷ G. Fedi,¹³⁷ G. Hall,¹³⁷ M. H. Hassanshahi,¹³⁷ A. Howard,¹³⁷ G. Iles,¹³⁷ M. Knight,¹³⁷ J. Langford,¹³⁷ J. León Holgado,¹³⁷ L. Lyons,¹³⁷ A.-M. Magnan,¹³⁷ S. Malik,¹³⁷ M. Mieskolainen,¹³⁷ J. Nash,^{137,dddd} M. Pesaresi,¹³⁷ B. C. Radburn-Smith,¹³⁷ A. Richards,¹³⁷ A. Rose,¹³⁷ K. Savva,¹³⁷ C. Seez,¹³⁷ R. Shukla,¹³⁷ A. Tapper,¹³⁷ K. Uchida,¹³⁷ G. P. Uttley,¹³⁷ L. H. Vage,¹³⁷ T. Virdee,^{137,ee} M. Vojinovic,¹³⁷ N. Wardle,¹³⁷ D. Winterbottom,¹³⁷ K. Coldham,¹³⁸ J. E. Cole,¹³⁸ A. Khan,¹³⁸ P. Kyberd,¹³⁸ I. D. Reid,¹³⁸ S. Abdullin,¹³⁹ A. Brinkerhoff,¹³⁹ B. Caraway,¹³⁹ E. Collins,¹³⁹ J. Dittmann,¹³⁹ K. Hatakeyama,¹³⁹ J. Hiltbrand,¹³⁹ B. McMaster,¹³⁹ M. Saunders,¹³⁹ S. Sawant,¹³⁹ C. Sutantawibul,¹³⁹ J. Wilson,¹³⁹ R. Bartek,¹⁴⁰ A. Dominguez,¹⁴⁰ C. Huerta Escamilla,¹⁴⁰ A. E. Simsek,¹⁴⁰ R. Uniyal,¹⁴⁰ A. M. Vargas Hernandez,¹⁴⁰ B. Bam,¹⁴¹ R. Chudasama,¹⁴¹ S. I. Cooper,¹⁴¹ S. V. Gleyzer,¹⁴¹ C. U. Perez,¹⁴¹ P. Rumerio,^{141,eeee} E. Usai,¹⁴¹ R. Yi,¹⁴¹ A. Akpinar,¹⁴² D. Arcaro,¹⁴² C. Cosby,¹⁴² Z. Demiragli,¹⁴² C. Erice,¹⁴² C. Fangmeier,¹⁴² C. Fernandez Madrazo,¹⁴² E. Fontanesi,¹⁴² D. Gastler,¹⁴² F. Golf,¹⁴² S. Jeon,¹⁴² I. Reed,¹⁴² J. Rohlf,¹⁴² K. Salyer,¹⁴² D. Sperka,¹⁴² D. Spitzbart,¹⁴² I. Suarez,¹⁴² A. Tsatsos,¹⁴² S. Yuan,¹⁴² A. G. Zecchinelli,¹⁴² G. Benelli,¹⁴³ X. Coubez,^{143,z} D. Cutts,¹⁴³ M. Hadley,¹⁴³ U. Heintz,¹⁴³ J. M. Hogan,^{143,fff} T. Kwon,¹⁴³ G. Landsberg,¹⁴³ K. T. Lau,¹⁴³ D. Li,¹⁴³ J. Luo,¹⁴³ S. Mondal,¹⁴³ M. Narain,^{143,a} N. Pervan,¹⁴³ S. Sagir,^{143,gggg} F. Simpson,¹⁴³ M. Stamenkovic,¹⁴³ X. Yan,¹⁴³ W. Zhang,¹⁴³ S. Abbott,¹⁴⁴ J. Bonilla,¹⁴⁴ C. Brainerd,¹⁴⁴ R. Breedon,¹⁴⁴ H. Cai,¹⁴⁴ M. Calderon De La Barca Sanchez,¹⁴⁴ M. Chertok,¹⁴⁴ M. Citron,¹⁴⁴ J. Conway,¹⁴⁴ P. T. Cox,¹⁴⁴ R. Erbacher,¹⁴⁴ F. Jensen,¹⁴⁴ O. Kukral,¹⁴⁴ G. Mocellin,¹⁴⁴ M. Mulhearn,¹⁴⁴ D. Pellett,¹⁴⁴ W. Wei,¹⁴⁴ Y. Yao,¹⁴⁴ F. Zhang,¹⁴⁴ M. Bachtis,¹⁴⁵ R. Cousins,¹⁴⁵ A. Datta,¹⁴⁵ G. Flores Avila,¹⁴⁵ J. Hauser,¹⁴⁵ M. Ignatenko,¹⁴⁵ M. A. Iqbal,¹⁴⁵ T. Lam,¹⁴⁵ E. Manca,¹⁴⁵ A. Nunez Del Prado,¹⁴⁵ D. Saltzberg,¹⁴⁵ V. Valuev,¹⁴⁵ R. Clare,¹⁴⁶ J. W. Gary,¹⁴⁶ M. Gordon,¹⁴⁶ G. Hanson,¹⁴⁶ W. Si,¹⁴⁶ S. Wimpenny,^{146,a} J. G. Branson,¹⁴⁷ S. Cittolin,¹⁴⁷ S. Cooperstein,¹⁴⁷ D. Diaz,¹⁴⁷ J. Duarte,¹⁴⁷ L. Giannini,¹⁴⁷ J. Guiang,¹⁴⁷ R. Kansal,¹⁴⁷ V. Krutelyov,¹⁴⁷ R. Lee,¹⁴⁷ J. Letts,¹⁴⁷ M. Masciovecchio,¹⁴⁷ F. Mokhtar,¹⁴⁷ S. Mukherjee,¹⁴⁷ M. Pieri,¹⁴⁷ M. Quinnan,¹⁴⁷ B. V. Sathia Narayanan,¹⁴⁷ V. Sharma,¹⁴⁷ M. Tadel,¹⁴⁷ E. Vourliotis,¹⁴⁷ F. Würthwein,¹⁴⁷ Y. Xiang,¹⁴⁷ A. Yagil,¹⁴⁷ A. Barzdukas,¹⁴⁸ L. Brennan,¹⁴⁸ C. Campagnari,¹⁴⁸ J. Incandela,¹⁴⁸ J. Kim,¹⁴⁸ A. J. Li,¹⁴⁸ P. Masterson,¹⁴⁸ H. Mei,¹⁴⁸ J. Richman,¹⁴⁸ U. Sarica,¹⁴⁸ R. Schmitz,¹⁴⁸ F. Setti,¹⁴⁸ J. Sheplock,¹⁴⁸ D. Stuart,¹⁴⁸ T. Á. Vámi,¹⁴⁸ S. Wang,¹⁴⁸ A. Bornheim,¹⁴⁹ O. Cerri,¹⁴⁹ A. Latorre,¹⁴⁹ J. Mao,¹⁴⁹ H. B. Newman,¹⁴⁹ G. Reales Gutiérrez,¹⁴⁹ M. Spiropulu,¹⁴⁹ J. R. Vlimant,¹⁴⁹ C. Wang,¹⁴⁹ S. Xie,¹⁴⁹ R. Y. Zhu,¹⁴⁹ J. Alison,¹⁵⁰ S. An,¹⁵⁰ M. B. Andrews,¹⁵⁰ P. Bryant,¹⁵⁰ M. Cremonesi,¹⁵⁰ V. Dutta,¹⁵⁰ T. Ferguson,¹⁵⁰ A. Harilal,¹⁵⁰ C. Liu,¹⁵⁰ T. Mudholkar,¹⁵⁰ S. Murthy,¹⁵⁰ P. Palit,¹⁵⁰ M. Paulini,¹⁵⁰ A. Roberts,¹⁵⁰ A. Sanchez,¹⁵⁰ W. Terrill,¹⁵⁰ J. P. Cumalat,¹⁵¹ W. T. Ford,¹⁵¹ A. Hart,¹⁵¹ A. Hassani,¹⁵¹ G. Karathanasis,¹⁵¹ N. Manganelli,¹⁵¹ A. Perloff,¹⁵¹ C. Savard,¹⁵¹ N. Schonbeck,¹⁵¹ K. Stenson,¹⁵¹ K. A. Ulmer,¹⁵¹ S. R. Wagner,¹⁵¹ N. Zipper,¹⁵¹ J. Alexander,¹⁵² S. Bright-Thonney,¹⁵² X. Chen,¹⁵² D. J. Cranshaw,¹⁵² J. Fan,¹⁵² X. Fan,¹⁵² S. Hogan,¹⁵² P. Kotamnives,¹⁵² J. Monroy,¹⁵² M. Oshiro,¹⁵² J. R. Patterson,¹⁵² J. Reichert,¹⁵² M. Reid,¹⁵² A. Ryd,¹⁵² J. Thom,¹⁵² P. Wittich,¹⁵² R. Zou,¹⁵² M. Albrow,¹⁵³ M. Alyari,¹⁵³ O. Amram,¹⁵³ G. Apollinari,¹⁵³ A. Apresyan,¹⁵³ L. A. T. Bauerdick,¹⁵³ D. Berry,¹⁵³ J. Berryhill,¹⁵³ P. C. Bhat,¹⁵³ K. Burkett,¹⁵³ J. N. Butler,¹⁵³ A. Canepa,¹⁵³ G. B. Cerati,¹⁵³ H. W. K. Cheung,¹⁵³ F. Chlebana,¹⁵³ G. Cummings,¹⁵³ J. Dickinson,¹⁵³ I. Dutta,¹⁵³ V. D. Elvira,¹⁵³ Y. Feng,¹⁵³ J. Freeman,¹⁵³ A. Gandrakota,¹⁵³ Z. Gecse,¹⁵³ L. Gray,¹⁵³ D. Green,¹⁵³ A. Grummer,¹⁵³ S. Grünendahl,¹⁵³ D. Guerrero,¹⁵³ O. Gutsche,¹⁵³ R. M. Harris,¹⁵³ R. Heller,¹⁵³ T. C. Herwig,¹⁵³ J. Hirschauer,¹⁵³ L. Horyn,¹⁵³ B. Jayatilaka,¹⁵³ S. Jindariani,¹⁵³ M. Johnson,¹⁵³ U. Joshi,¹⁵³ T. Klijsma,¹⁵³ B. Klima,¹⁵³ K. H. M. Kwok,¹⁵³ S. Lammel,¹⁵³ D. Lincoln,¹⁵³ R. Lipton,¹⁵³ T. Liu,¹⁵³ C. Madrid,¹⁵³ K. Maeshima,¹⁵³ C. Mantilla,¹⁵³ D. Mason,¹⁵³ P. McBride,¹⁵³ P. Merkel,¹⁵³ S. Mrenna,¹⁵³ S. Nahn,¹⁵³ J. Ngadiuba,¹⁵³ D. Noonan,¹⁵³ V. Papadimitriou,¹⁵³ N. Pastika,¹⁵³ K. Pedro,¹⁵³ C. Pena,^{153,hhhh} F. Ravera,¹⁵³ A. Reinsvold Hall,^{153,iiii} L. Ristori,¹⁵³ E. Sexton-Kennedy,¹⁵³ N. Smith,¹⁵³ A. Soha,¹⁵³ L. Spiegel,¹⁵³ S. Stoynev,¹⁵³ J. Strait,¹⁵³ L. Taylor,¹⁵³ S. Tkaczyk,¹⁵³ N. V. Tran,¹⁵³ L. Uplegger,¹⁵³ E. W. Vaandering,¹⁵³ A. Whitbeck,¹⁵³ I. Zoi,¹⁵³ C. Aruta,¹⁵⁴ P. Avery,¹⁵⁴ D. Bourilkov,¹⁵⁴ L. Cadamuro,¹⁵⁴ P. Chang,¹⁵⁴ V. Cherepanov,¹⁵⁴ R. D. Field,¹⁵⁴ E. Koenig,¹⁵⁴ M. Kolosova,¹⁵⁴ J. Konigsberg,¹⁵⁴ A. Korytov,¹⁵⁴ K. Matchev,¹⁵⁴ N. Menendez,¹⁵⁴ G. Mitselmakher,¹⁵⁴ K. Mohrman,¹⁵⁴ A. Muthirakalayil Madhu,¹⁵⁴ N. Rawal,¹⁵⁴ D. Rosenzweig,¹⁵⁴ S. Rosenzweig,¹⁵⁴ J. Wang,¹⁵⁴ T. Adams,¹⁵⁵ A. Al Kadhim,¹⁵⁵ A. Askew,¹⁵⁵ S. Bower,¹⁵⁵ R. Habibullah,¹⁵⁵

V. Hagopian¹⁵⁵ R. Hashmi¹⁵⁵ R. S. Kim¹⁵⁵ S. Kim¹⁵⁵ T. Kolberg¹⁵⁵ G. Martinez¹⁵⁵ H. Prosper¹⁵⁵
P. R. Prova¹⁵⁵ M. Wulansatiti¹⁵⁵ R. Yohay¹⁵⁵ J. Zhang¹⁵⁵ B. Alsufyani¹⁵⁶ M. M. Baarmand¹⁵⁶ S. Butalla¹⁵⁶
S. Das¹⁵⁶ T. Elkafrawy^{156,ddd} M. Hohlmann¹⁵⁶ R. Kumar Verma¹⁵⁶ M. Rahmani¹⁵⁶ E. Yanes¹⁵⁶ M. R. Adams¹⁵⁷
A. Baty¹⁵⁷ C. Bennett¹⁵⁷ R. Cavanaugh¹⁵⁷ R. Escobar Franco¹⁵⁷ O. Evdokimov¹⁵⁷ C. E. Gerber¹⁵⁷
M. Hawksworth¹⁵⁷ A. Hingrajiya¹⁵⁷ D. J. Hofman¹⁵⁷ J. h. Lee¹⁵⁷ D. S. Lemos¹⁵⁷ A. H. Merrit¹⁵⁷ C. Mills¹⁵⁷
S. Nanda¹⁵⁷ G. Oh¹⁵⁷ B. Ozek¹⁵⁷ D. Pilipovic¹⁵⁷ R. Pradhan¹⁵⁷ E. Prifti¹⁵⁷ T. Roy¹⁵⁷ S. Rudrabhatla¹⁵⁷
M. B. Tonjes¹⁵⁷ N. Varelas¹⁵⁷ Z. Ye¹⁵⁷ J. Yoo¹⁵⁷ M. Alhusseini¹⁵⁸ D. Blend¹⁵⁸ K. Dilsiz^{158,jjj}
L. Emediato¹⁵⁸ G. Karaman¹⁵⁸ O. K. Köseyan¹⁵⁸ J.-P. Merlo¹⁵⁸ A. Mestvirishvili^{158,kkkk} J. Nachtman¹⁵⁸
O. Neogi¹⁵⁸ H. Ogul^{158,llll} Y. Onel¹⁵⁸ A. Penzo¹⁵⁸ C. Snyder¹⁵⁸ E. Tiras^{158,mmmm} B. Blumenfeld¹⁵⁹
L. Corcodilos¹⁵⁹ J. Davis¹⁵⁹ A. V. Gritsan¹⁵⁹ L. Kang¹⁵⁹ S. Kyriacou¹⁵⁹ P. Maksimovic¹⁵⁹ M. Roguljic¹⁵⁹
J. Roskes¹⁵⁹ S. Sekhar¹⁵⁹ M. Swartz¹⁵⁹ A. Abreu¹⁶⁰ L. F. Alcerro Alcerro¹⁶⁰ J. Anguiano¹⁶⁰ P. Baringer¹⁶⁰
A. Bean¹⁶⁰ Z. Flowers¹⁶⁰ D. Grove¹⁶⁰ J. King¹⁶⁰ G. Krintiras¹⁶⁰ M. Lazarovits¹⁶⁰ C. Le Mahieu¹⁶⁰
J. Marquez¹⁶⁰ N. Minafra¹⁶⁰ M. Murray¹⁶⁰ M. Nickel¹⁶⁰ M. Pitt¹⁶⁰ S. Popescu^{160,nnnn} C. Rogan¹⁶⁰
C. Royon¹⁶⁰ R. Salvatico¹⁶⁰ S. Sanders¹⁶⁰ C. Smith¹⁶⁰ Q. Wang¹⁶⁰ G. Wilson¹⁶⁰ B. Allmond¹⁶¹
A. Ivanov¹⁶¹ K. Kaadze¹⁶¹ A. Kalogeropoulos¹⁶¹ D. Kim¹⁶¹ Y. Maravin¹⁶¹ J. Natoli¹⁶¹ D. Roy¹⁶¹
G. Sorrentino¹⁶¹ F. Rebassoo¹⁶² D. Wright¹⁶² A. Baden¹⁶³ A. Belloni¹⁶³ Y. M. Chen¹⁶³ S. C. Eno¹⁶³
N. J. Hadley¹⁶³ S. Jabeen¹⁶³ R. G. Kellogg¹⁶³ T. Koeth¹⁶³ Y. Lai¹⁶³ S. Lascio¹⁶³ A. C. Mignerey¹⁶³
S. Nabili¹⁶³ C. Palmer¹⁶³ C. Papageorgakis¹⁶³ M. M. Paranjpe¹⁶³ L. Wang¹⁶³ J. Bendavid¹⁶⁴ I. A. Cali¹⁶⁴
M. D'Alfonso¹⁶⁴ J. Eysermans¹⁶⁴ C. Freer¹⁶⁴ G. Gomez-Ceballos¹⁶⁴ M. Goncharov¹⁶⁴ G. Grosso¹⁶⁴ P. Harris¹⁶⁴
D. Hoang¹⁶⁴ D. Kovalskiy¹⁶⁴ J. Krupa¹⁶⁴ L. Lavezzo¹⁶⁴ Y.-J. Lee¹⁶⁴ K. Long¹⁶⁴ A. Novak¹⁶⁴ C. Paus¹⁶⁴
D. Rankin¹⁶⁴ C. Roland¹⁶⁴ G. Roland¹⁶⁴ S. Rothman¹⁶⁴ G. S. F. Stephans¹⁶⁴ Z. Wang¹⁶⁴ B. Wyslouch¹⁶⁴
T. J. Yang¹⁶⁴ B. Crossman¹⁶⁵ B. M. Joshi¹⁶⁵ C. Kapsiak¹⁶⁵ M. Krohn¹⁶⁵ D. Mahon¹⁶⁵ J. Mans¹⁶⁵
B. Marzocchi¹⁶⁵ S. Pandey¹⁶⁵ M. Revering¹⁶⁵ R. Rusack¹⁶⁵ R. Saradhy¹⁶⁵ N. Schroeder¹⁶⁵ N. Strobbe¹⁶⁵
M. A. Wadud¹⁶⁵ L. M. Cremaldi¹⁶⁶ K. Bloom¹⁶⁷ D. R. Claes¹⁶⁷ G. Haza¹⁶⁷ J. Hossain¹⁶⁷ C. Joo¹⁶⁷
I. Kravchenko¹⁶⁷ J. E. Siado¹⁶⁷ W. Tabb¹⁶⁷ A. Vagnerini¹⁶⁷ A. Wightman¹⁶⁷ F. Yan¹⁶⁷ D. Yu¹⁶⁷
H. Bandyopadhyay¹⁶⁸ L. Hay¹⁶⁸ I. Iashvili¹⁶⁸ A. Kharchilava¹⁶⁸ M. Morris¹⁶⁸ D. Nguyen¹⁶⁸
S. Rappoccio¹⁶⁸ H. Rejeb Sfar¹⁶⁸ A. Williams¹⁶⁸ G. Alverson¹⁶⁹ E. Barberis¹⁶⁹ J. Dervan¹⁶⁹ Y. Haddad¹⁶⁹
Y. Han¹⁶⁹ A. Krishna¹⁶⁹ J. Li¹⁶⁹ M. Lu¹⁶⁹ G. Madigan¹⁶⁹ R. Mccarthy¹⁶⁹ D. M. Morse¹⁶⁹ V. Nguyen¹⁶⁹
T. Orimoto¹⁶⁹ A. Parker¹⁶⁹ L. Skinnari¹⁶⁹ B. Wang¹⁶⁹ D. Wood¹⁶⁹ S. Bhattacharya¹⁷⁰ J. Bueghly¹⁷⁰
Z. Chen¹⁷⁰ S. Dittmer¹⁷⁰ K. A. Hahn¹⁷⁰ Y. Liu¹⁷⁰ Y. Miao¹⁷⁰ D. G. Monk¹⁷⁰ M. H. Schmitt¹⁷⁰
A. Taliercio¹⁷⁰ M. Velasco¹⁷⁰ G. Agarwal¹⁷¹ R. Band¹⁷¹ R. Bucci¹⁷¹ S. Castells¹⁷¹ A. Das¹⁷¹
R. Goldouzian¹⁷¹ M. Hildreth¹⁷¹ K. W. Ho¹⁷¹ K. Hurtado Anampa¹⁷¹ T. Ivanov¹⁷¹ C. Jessop¹⁷¹
K. Lannon¹⁷¹ J. Lawrence¹⁷¹ N. Loukas¹⁷¹ L. Lutton¹⁷¹ J. Mariano¹⁷¹ N. Marinelli¹⁷¹ I. Mcalister¹⁷¹
T. McCauley¹⁷¹ C. Mcgrady¹⁷¹ C. Moore¹⁷¹ Y. Musienko^{171,q} H. Nelson¹⁷¹ M. Osherson¹⁷¹ A. Piccinelli¹⁷¹
R. Ruchti¹⁷¹ A. Townsend¹⁷¹ Y. Wan¹⁷¹ M. Wayne¹⁷¹ H. Yockey¹⁷¹ M. Zarucki¹⁷¹ L. Zygala¹⁷¹ A. Basnet¹⁷²
B. Bylsma¹⁷² M. Carrigan¹⁷² L. S. Durkin¹⁷² C. Hill¹⁷² M. Joyce¹⁷² M. Nunez Ornelas¹⁷² K. Wei¹⁷²
B. L. Winer¹⁷² B. R. Yates¹⁷² F. M. Addesa¹⁷³ H. Bouchamaoui¹⁷³ P. Das¹⁷³ G. Dezoort¹⁷³ P. Elmer¹⁷³
A. Frankenthal¹⁷³ B. Greenberg¹⁷³ N. Haubrich¹⁷³ G. Kopp¹⁷³ S. Kwan¹⁷³ D. Lange¹⁷³ A. Loeliger¹⁷³
D. Marlow¹⁷³ I. Ojalvo¹⁷³ J. Olsen¹⁷³ A. Shevelev¹⁷³ D. Stickland¹⁷³ C. Tully¹⁷³ S. Malik¹⁷⁴
A. S. Bakshi¹⁷⁵ V. E. Barnes¹⁷⁵ S. Chandra¹⁷⁵ R. Chawla¹⁷⁵ A. Gu¹⁷⁵ L. Gutay¹⁷⁵ M. Jones¹⁷⁵
A. W. Jung¹⁷⁵ D. Kondratyev¹⁷⁵ A. M. Koshy¹⁷⁵ M. Liu¹⁷⁵ G. Negro¹⁷⁵ N. Neumeister¹⁷⁵ G. Paspalaki¹⁷⁵
S. Piperov¹⁷⁵ V. Scheurer¹⁷⁵ J. F. Schulte¹⁷⁵ M. Stojanovic¹⁷⁵ J. Thieman¹⁷⁵ A. K. Viridi¹⁷⁵ F. Wang¹⁷⁵
W. Xie¹⁷⁵ J. Dolen¹⁷⁶ N. Parashar¹⁷⁶ A. Pathak¹⁷⁶ D. Acosta¹⁷⁷ T. Carnahan¹⁷⁷ K. M. Ecklund¹⁷⁷
P. J. Fernández Manteca¹⁷⁷ S. Freed¹⁷⁷ P. Gardner¹⁷⁷ F. J. M. Geurts¹⁷⁷ W. Li¹⁷⁷ O. Miguel Colin¹⁷⁷
B. P. Padley¹⁷⁷ R. Redjimi¹⁷⁷ J. Rotter¹⁷⁷ E. Yigitbasi¹⁷⁷ Y. Zhang¹⁷⁷ A. Bodek¹⁷⁸ P. de Barbaro¹⁷⁸
R. Demina¹⁷⁸ J. L. Dulemba¹⁷⁸ A. Garcia-Bellido¹⁷⁸ O. Hindrichs¹⁷⁸ A. Khukhunaishvili¹⁷⁸ N. Parmar¹⁷⁸
P. Parygin^{178,q} E. Popova^{178,q} R. Taus¹⁷⁸ K. Goulianos¹⁷⁹ B. Chiarito¹⁸⁰ J. P. Chou¹⁸⁰ S. V. Clark¹⁸⁰
D. Gadkari¹⁸⁰ Y. Gershtein¹⁸⁰ E. Halkiadakis¹⁸⁰ M. Heindl¹⁸⁰ C. Houghton¹⁸⁰ D. Jaroslawski¹⁸⁰
O. Karacheban^{180,cc} I. Laflotte¹⁸⁰ A. Lath¹⁸⁰ R. Montalvo¹⁸⁰ K. Nash¹⁸⁰ H. Routray¹⁸⁰ P. Saha¹⁸⁰ S. Salur¹⁸⁰

S. Schnetzer,¹⁸⁰ S. Somalwar¹⁸⁰, R. Stone¹⁸⁰, S. A. Thayil¹⁸⁰, S. Thomas,¹⁸⁰ J. Vora¹⁸⁰, H. Wang¹⁸⁰, H. Acharya,¹⁸¹ D. Ally¹⁸¹, A. G. Delannoy¹⁸¹, S. Fiorendi¹⁸¹, S. Higginbotham¹⁸¹, T. Holmes¹⁸¹, A. R. Kanuganti¹⁸¹, N. Karunaratna¹⁸¹, L. Lee¹⁸¹, E. Nibigira¹⁸¹, S. Spanier¹⁸¹, D. Aebi¹⁸², M. Ahmad¹⁸², O. Bouhali^{182,0000}, R. Eusebi¹⁸², J. Gilmore¹⁸², T. Huang¹⁸², T. Kamon^{182,pppp}, H. Kim¹⁸², S. Luo¹⁸², R. Mueller¹⁸², D. Overton¹⁸², D. Rathjens¹⁸², A. Safonov¹⁸², N. Akchurin¹⁸³, J. Damgov¹⁸³, V. Hegde¹⁸³, A. Hussain¹⁸³, Y. Kazhykarim,¹⁸³ K. Lamichhane¹⁸³, S. W. Lee¹⁸³, A. Mankel¹⁸³, T. Peltola¹⁸³, I. Volobouev¹⁸³, E. Appelt¹⁸⁴, Y. Chen¹⁸⁴, S. Greene,¹⁸⁴ A. Gurrola¹⁸⁴, W. Johns¹⁸⁴, R. Kunnawalkam Elayavalli¹⁸⁴, A. Melo¹⁸⁴, F. Romeo¹⁸⁴, P. Sheldon¹⁸⁴, S. Tuo¹⁸⁴, J. Velkovska¹⁸⁴, J. Viinikainen¹⁸⁴, B. Cardwell¹⁸⁵, B. Cox¹⁸⁵, J. Hakala¹⁸⁵, R. Hirosky¹⁸⁵, A. Ledovskoy¹⁸⁵, C. Neu¹⁸⁵, C. E. Perez Lara¹⁸⁵, P. E. Karchin¹⁸⁶, A. Aravind,¹⁸⁷ S. Banerjee¹⁸⁷, K. Black¹⁸⁷, T. Bose¹⁸⁷, S. Dasu¹⁸⁷, I. De Bruyn¹⁸⁷, P. Everaerts¹⁸⁷, C. Galloni,¹⁸⁷ H. He¹⁸⁷, M. Herndon¹⁸⁷, A. Herve¹⁸⁷, C. K. Koraka¹⁸⁷, A. Lanaro,¹⁸⁷ R. Loveless¹⁸⁷, J. Madhusudanan Sreekala,¹⁸⁷ A. Mallampalli¹⁸⁷, A. Mohammadi¹⁸⁷, S. Mondal,¹⁸⁷ G. Parida¹⁸⁷, L. Pétre¹⁸⁷, D. Pinna,¹⁸⁷ A. Savin,¹⁸⁷ V. Shang¹⁸⁷, V. Sharma¹⁸⁷, W. H. Smith¹⁸⁷, D. Teague,¹⁸⁷ H. F. Tsoi,¹⁸⁷ W. Vetens¹⁸⁷, A. Warden¹⁸⁷, S. Afanasiev¹⁸⁸, V. Andreev¹⁸⁸, Yu. Andreev¹⁸⁸, T. Aushev¹⁸⁸, M. Azarkin¹⁸⁸, I. Azhgirey¹⁸⁸, A. Babaev¹⁸⁸, A. Belyaev¹⁸⁸, V. Blinov,^{188,q} E. Boos¹⁸⁸, V. Borshch¹⁸⁸, D. Budkouski¹⁸⁸, V. Bunichev¹⁸⁸, V. Chekhovskiy,¹⁸⁸ R. Chistov^{188,q}, M. Danilov^{188,q}, A. Dermenev¹⁸⁸, T. Dimova^{188,q}, D. Druzhkin^{188,qqqq}, M. Dubinin^{188,hhhh}, L. Dudko¹⁸⁸, G. Gavrilo¹⁸⁸, V. Gavrilo¹⁸⁸, S. Gninenko¹⁸⁸, V. Golovtsov¹⁸⁸, N. Golubev¹⁸⁸, I. Golutvin¹⁸⁸, I. Gorbunov¹⁸⁸, A. Gribushin¹⁸⁸, Y. Ivanov¹⁸⁸, V. Kachanov¹⁸⁸, V. Karjavine¹⁸⁸, A. Karneyev¹⁸⁸, V. Kim^{188,q}, M. Kirakosyan,¹⁸⁸ D. Kirpichnikov¹⁸⁸, M. Kirsanov¹⁸⁸, V. Klyukhin¹⁸⁸, D. Konstantinov¹⁸⁸, V. Korenkov¹⁸⁸, A. Kozyrev^{188,q}, N. Krasnikov¹⁸⁸, A. Lanev¹⁸⁸, P. Levchenko^{188,rrrr}, N. Lychkovskaya¹⁸⁸, V. Makarenko¹⁸⁸, A. Malakhov¹⁸⁸, V. Matveev^{188,q}, V. Murzin¹⁸⁸, A. Nikitenko^{188,ssss,tttt}, S. Obraztsov¹⁸⁸, V. Oreshkin¹⁸⁸, V. Palichik¹⁸⁸, V. Perelygin¹⁸⁸, M. Perfilov,¹⁸⁸ S. Petrushanko¹⁸⁸, S. Polikarpov^{188,q}, V. Popov¹⁸⁸, O. Radchenko^{188,q}, R. Ryutin,¹⁸⁸ M. Savina¹⁸⁸, V. Savrin¹⁸⁸, V. Shalaev¹⁸⁸, S. Shmatov¹⁸⁸, S. Shulha¹⁸⁸, Y. Skovpen^{188,q}, S. Slabospitskii¹⁸⁸, V. Smirnov¹⁸⁸, D. Sosnov¹⁸⁸, V. Sulimov¹⁸⁸, E. Tcherniaev¹⁸⁸, A. Terkulov¹⁸⁸, O. Teryaev¹⁸⁸, I. Tlisova¹⁸⁸, A. Toropin¹⁸⁸, L. Uvarov¹⁸⁸, A. Uzunian¹⁸⁸, P. Volkov¹⁸⁸, A. Vorobyev,^{188,a} G. Vorotnikov¹⁸⁸, N. Voytishin¹⁸⁸, B. S. Yuldashev,^{188,uuuu} A. Zarubin¹⁸⁸, I. Zhizhin¹⁸⁸, and A. Zhokin¹⁸⁸

(CMS Collaboration)

- ¹*Yerevan Physics Institute, Yerevan, Armenia*
²*Institut für Hochenergiephysik, Vienna, Austria*
³*Universiteit Antwerpen, Antwerpen, Belgium*
⁴*Vrije Universiteit Brussel, Brussel, Belgium*
⁵*Université Libre de Bruxelles, Bruxelles, Belgium*
⁶*Ghent University, Ghent, Belgium*
⁷*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
⁸*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*
⁹*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
¹⁰*Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil*
¹¹*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*
¹²*University of Sofia, Sofia, Bulgaria*
¹³*Instituto De Alta Investigación, Universidad de Tarapacá, Casilla 7 D, Arica, Chile*
¹⁴*Beihang University, Beijing, China*
¹⁵*Department of Physics, Tsinghua University, Beijing, China*
¹⁶*Institute of High Energy Physics, Beijing, China*
¹⁷*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*
¹⁸*Sun Yat-Sen University, Guangzhou, China*
¹⁹*University of Science and Technology of China, Hefei, China*
²⁰*Nanjing Normal University, Nanjing, China*
²¹*Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) - Fudan University, Shanghai, China*
²²*Zhejiang University, Hangzhou, Zhejiang, China*
²³*Universidad de Los Andes, Bogota, Colombia*

- ²⁴Universidad de Antioquia, Medellin, Colombia
- ²⁵University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia
- ²⁶University of Split, Faculty of Science, Split, Croatia
- ²⁷Institute Rudjer Boskovic, Zagreb, Croatia
- ²⁸University of Cyprus, Nicosia, Cyprus
- ²⁹Charles University, Prague, Czech Republic
- ³⁰Escuela Politecnica Nacional, Quito, Ecuador
- ³¹Universidad San Francisco de Quito, Quito, Ecuador
- ³²Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
- ³³Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt
- ³⁴National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
- ³⁵Department of Physics, University of Helsinki, Helsinki, Finland
- ³⁶Helsinki Institute of Physics, Helsinki, Finland
- ³⁷Lappeenranta-Lahti University of Technology, Lappeenranta, Finland
- ³⁸IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
- ³⁹Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France
- ⁴⁰Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France
- ⁴¹Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France
- ⁴²Georgian Technical University, Tbilisi, Georgia
- ⁴³RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
- ⁴⁴RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
- ⁴⁵RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
- ⁴⁶Deutsches Elektronen-Synchrotron, Hamburg, Germany
- ⁴⁷University of Hamburg, Hamburg, Germany
- ⁴⁸Karlsruher Institut fuer Technologie, Karlsruhe, Germany
- ⁴⁹Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece
- ⁵⁰National and Kapodistrian University of Athens, Athens, Greece
- ⁵¹National Technical University of Athens, Athens, Greece
- ⁵²University of Ioánnina, Ioánnina, Greece
- ⁵³HUN-REN Wigner Research Centre for Physics, Budapest, Hungary
- ⁵⁴MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
- ⁵⁵Faculty of Informatics, University of Debrecen, Debrecen, Hungary
- ⁵⁶Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- ⁵⁷Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary
- ⁵⁸Panjab University, Chandigarh, India
- ⁵⁹University of Delhi, Delhi, India
- ⁶⁰Saha Institute of Nuclear Physics, HBNI, Kolkata, India
- ⁶¹Indian Institute of Technology Madras, Madras, India
- ⁶²Tata Institute of Fundamental Research-A, Mumbai, India
- ⁶³Tata Institute of Fundamental Research-B, Mumbai, India
- ⁶⁴National Institute of Science Education and Research, An OCC of Homi Bhabha National Institute, Bhubaneswar, Odisha, India
- ⁶⁵Indian Institute of Science Education and Research (IISER), Pune, India
- ⁶⁶Isfahan University of Technology, Isfahan, Iran
- ⁶⁷Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
- ⁶⁸University College Dublin, Dublin, Ireland
- ^{69a}INFN Sezione di Bari, Bari, Italy
- ^{69b}Università di Bari, Bari, Italy
- ^{69c}Politecnico di Bari, Bari, Italy
- ^{70a}INFN Sezione di Bologna, Bologna, Italy
- ^{70b}Università di Bologna, Bologna, Italy
- ^{71a}INFN Sezione di Catania, Catania, Italy
- ^{71b}Università di Catania, Catania, Italy
- ^{72a}INFN Sezione di Firenze, Firenze, Italy
- ^{72b}Università di Firenze, Firenze, Italy
- ⁷³INFN Laboratori Nazionali di Frascati, Frascati, Italy
- ^{74a}INFN Sezione di Genova, Genova, Italy
- ^{74b}Università di Genova, Genova, Italy
- ^{75a}INFN Sezione di Milano-Bicocca, Milano, Italy
- ^{75b}Università di Milano-Bicocca, Milano, Italy

- ^{76a}INFN Sezione di Napoli, Napoli, Italy
^{76b}Università di Napoli 'Federico II', Napoli, Italy
^{76c}Università della Basilicata, Potenza, Italy
^{76d}Scuola Superiore Meridionale (SSM), Napoli, Italy
^{77a}INFN Sezione di Padova, Padova, Italy
^{77b}Università di Padova, Padova, Italy
^{77c}Università di Trento, Trento, Italy
^{78a}INFN Sezione di Pavia, Pavia, Italy
^{78b}Università di Pavia, Pavia, Italy
^{79a}INFN Sezione di Perugia, Perugia, Italy
^{79b}Università di Perugia, Perugia, Italy
^{80a}INFN Sezione di Pisa, Pisa, Italy
^{80b}Università di Pisa, Pisa, Italy
^{80c}Scuola Normale Superiore di Pisa, Pisa, Italy
^{80d}Università di Siena, Siena, Italy
^{81a}INFN Sezione di Roma, Roma, Italy
^{81b}Sapienza Università di Roma, Roma, Italy
^{82a}INFN Sezione di Torino, Torino, Italy
^{82b}Università di Torino, Torino, Italy
^{82c}Università del Piemonte Orientale, Novara, Italy
^{83a}INFN Sezione di Trieste, Trieste, Italy
^{83b}Università di Trieste, Trieste, Italy
⁸⁴Kyungpook National University, Daegu, Korea
⁸⁵Department of Mathematics and Physics - GWNU, Gangneung, Korea
⁸⁶Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
⁸⁷Hanyang University, Seoul, Korea
⁸⁸Korea University, Seoul, Korea
⁸⁹Kyung Hee University, Department of Physics, Seoul, Korea
⁹⁰Sejong University, Seoul, Korea
⁹¹Seoul National University, Seoul, Korea
⁹²University of Seoul, Seoul, Korea
⁹³Yonsei University, Department of Physics, Seoul, Korea
⁹⁴Sungkyunkwan University, Suwon, Korea
⁹⁵College of Engineering and Technology, American University of the Middle East (AUM), Dasman, Kuwait
⁹⁶Riga Technical University, Riga, Latvia
⁹⁷University of Latvia (LU), Riga, Latvia
⁹⁸Vilnius University, Vilnius, Lithuania
⁹⁹National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
¹⁰⁰Universidad de Sonora (UNISON), Hermosillo, Mexico
¹⁰¹Centro de Investigación y de Estudios Avanzados del IPN, Mexico City, Mexico
¹⁰²Universidad Iberoamericana, Mexico City, Mexico
¹⁰³Benemerita Universidad Autónoma de Puebla, Puebla, Mexico
¹⁰⁴University of Montenegro, Podgorica, Montenegro
¹⁰⁵University of Canterbury, Christchurch, New Zealand
¹⁰⁶National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
¹⁰⁷AGH University of Krakow, Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland
¹⁰⁸National Centre for Nuclear Research, Swierk, Poland
¹⁰⁹Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
¹¹⁰Warsaw University of Technology, Warsaw, Poland
¹¹¹Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
¹¹²Faculty of Physics, University of Belgrade, Belgrade, Serbia
¹¹³VINCA Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
¹¹⁴Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
¹¹⁵Universidad Autónoma de Madrid, Madrid, Spain
¹¹⁶Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain
¹¹⁷Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
¹¹⁸University of Colombo, Colombo, Sri Lanka
¹¹⁹University of Ruhuna, Department of Physics, Matara, Sri Lanka
¹²⁰CERN, European Organization for Nuclear Research, Geneva, Switzerland
¹²¹Paul Scherrer Institut, Villigen, Switzerland

- ¹²²*ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland*
¹²³*Universität Zürich, Zurich, Switzerland*
¹²⁴*National Central University, Chung-Li, Taiwan*
¹²⁵*National Taiwan University (NTU), Taipei, Taiwan*
¹²⁶*High Energy Physics Research Unit, Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand*
¹²⁷*Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey*
¹²⁸*Middle East Technical University, Physics Department, Ankara, Turkey*
¹²⁹*Bogazici University, Istanbul, Turkey*
¹³⁰*Istanbul Technical University, Istanbul, Turkey*
¹³¹*Istanbul University, Istanbul, Turkey*
¹³²*Yildiz Technical University, Istanbul, Turkey*
¹³³*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkiv, Ukraine*
¹³⁴*National Science Centre, Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine*
¹³⁵*University of Bristol, Bristol, United Kingdom*
¹³⁶*Rutherford Appleton Laboratory, Didcot, United Kingdom*
¹³⁷*Imperial College, London, United Kingdom*
¹³⁸*Brunel University, Uxbridge, United Kingdom*
¹³⁹*Baylor University, Waco, Texas, USA*
¹⁴⁰*Catholic University of America, Washington, DC, USA*
¹⁴¹*The University of Alabama, Tuscaloosa, Alabama, USA*
¹⁴²*Boston University, Boston, Massachusetts, USA*
¹⁴³*Brown University, Providence, Rhode Island, USA*
¹⁴⁴*University of California, Davis, Davis, California, USA*
¹⁴⁵*University of California, Los Angeles, California, USA*
¹⁴⁶*University of California, Riverside, Riverside, California, USA*
¹⁴⁷*University of California, San Diego, La Jolla, California, USA*
¹⁴⁸*University of California, Santa Barbara - Department of Physics, Santa Barbara, California, USA*
¹⁴⁹*California Institute of Technology, Pasadena, California, USA*
¹⁵⁰*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
¹⁵¹*University of Colorado Boulder, Boulder, Colorado, USA*
¹⁵²*Cornell University, Ithaca, New York, USA*
¹⁵³*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
¹⁵⁴*University of Florida, Gainesville, Florida, USA*
¹⁵⁵*Florida State University, Tallahassee, Florida, USA*
¹⁵⁶*Florida Institute of Technology, Melbourne, Florida, USA*
¹⁵⁷*University of Illinois Chicago, Chicago, USA, Chicago, USA*
¹⁵⁸*The University of Iowa, Iowa City, Iowa, USA*
¹⁵⁹*Johns Hopkins University, Baltimore, Maryland, USA*
¹⁶⁰*The University of Kansas, Lawrence, Kansas, USA*
¹⁶¹*Kansas State University, Manhattan, Kansas, USA*
¹⁶²*Lawrence Livermore National Laboratory, Livermore, California, USA*
¹⁶³*University of Maryland, College Park, Maryland, USA*
¹⁶⁴*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
¹⁶⁵*University of Minnesota, Minneapolis, Minnesota, USA*
¹⁶⁶*University of Mississippi, Oxford, Mississippi, USA*
¹⁶⁷*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
¹⁶⁸*State University of New York at Buffalo, Buffalo, New York, USA*
¹⁶⁹*Northeastern University, Boston, Massachusetts, USA*
¹⁷⁰*Northwestern University, Evanston, Illinois, USA*
¹⁷¹*University of Notre Dame, Notre Dame, Indiana, USA*
¹⁷²*The Ohio State University, Columbus, Ohio, USA*
¹⁷³*Princeton University, Princeton, New Jersey, USA*
¹⁷⁴*University of Puerto Rico, Mayaguez, Puerto Rico, USA*
¹⁷⁵*Purdue University, West Lafayette, Indiana, USA*
¹⁷⁶*Purdue University Northwest, Hammond, Indiana, USA*
¹⁷⁷*Rice University, Houston, Texas, USA*
¹⁷⁸*University of Rochester, Rochester, New York, USA*
¹⁷⁹*The Rockefeller University, New York, New York, USA*
¹⁸⁰*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*
¹⁸¹*University of Tennessee, Knoxville, Tennessee, USA*

¹⁸²*Texas A&M University, College Station, Texas, USA*

¹⁸³*Texas Tech University, Lubbock, Texas, USA*

¹⁸⁴*Vanderbilt University, Nashville, Tennessee, USA*

¹⁸⁵*University of Virginia, Charlottesville, Virginia, USA*

¹⁸⁶*Wayne State University, Detroit, Michigan, USA*

¹⁸⁷*University of Wisconsin - Madison, Madison, Wisconsin, USA*

¹⁸⁸*An institute or international laboratory covered by a cooperation agreement with CERN*

^aDeceased.

^bAlso at Yerevan State University, Yerevan, Armenia.

^cAlso at TU Wien, Vienna, Austria.

^dAlso at Institute of Basic and Applied Sciences, Faculty of Engineering, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt.

^eAlso at Ghent University, Ghent, Belgium.

^fAlso at Universidade Estadual de Campinas, Campinas, Brazil.

^gAlso at Federal University of Rio Grande do Sul, Porto Alegre, Brazil.

^hAlso at UFMS, Nova Andradina, Brazil.

ⁱAlso at Nanjing Normal University, Nanjing, China.

^jAlso at The University of Iowa, Iowa City, Iowa, USA.

^kAlso at University of Chinese Academy of Sciences, Beijing, China.

^lAlso at China Center of Advanced Science and Technology, Beijing, China.

^mAlso at University of Chinese Academy of Sciences, Beijing, China.

ⁿAlso at China Spallation Neutron Source, Guangdong, China.

^oAlso at Henan Normal University, Xinxiang, China.

^pAlso at Université Libre de Bruxelles, Bruxelles, Belgium.

^qAlso at Another institute or international laboratory covered by a cooperation agreement with CERN.

^rAlso at British University in Egypt, Cairo, Egypt.

^sAlso at Cairo University, Cairo, Egypt.

^tAlso at Purdue University, West Lafayette, Indiana, USA.

^uAlso at Université de Haute Alsace, Mulhouse, France.

^vAlso at Department of Physics, Tsinghua University, Beijing, China.

^wAlso at The University of the State of Amazonas, Manaus, Brazil.

^xAlso at Erzincan Binali Yildirim University, Erzincan, Turkey.

^yAlso at University of Hamburg, Hamburg, Germany.

^zAlso at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.

^{aa}Also at Isfahan University of Technology, Isfahan, Iran.

^{bb}Also at Bergische University Wuppertal (BUW), Wuppertal, Germany.

^{cc}Also at Brandenburg University of Technology, Cottbus, Germany.

^{dd}Also at Forschungszentrum Jülich, Juelich, Germany.

^{ee}Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.

^{ff}Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.

^{gg}Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.

^{hh}Also at Universitatea Babeş-Bolyai—Facultatea de Fizica, Cluj-Napoca, Romania.

ⁱⁱAlso at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.

^{jj}Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt.

^{kk}Also at HUN-REN Wigner Research Centre for Physics, Budapest, Hungary.

^{ll}Also at Punjab Agricultural University, Ludhiana, India.

^{mm}Also at University of Visva-Bharati, Santiniketan, India.

ⁿⁿAlso at Indian Institute of Science (IISc), Bangalore, India.

^{oo}Also at Birla Institute of Technology, Mesra, Mesra, India.

^{pp}Also at IIT Bhubaneswar, Bhubaneswar, India.

^{qq}Also at Institute of Physics, Bhubaneswar, India.

^{rr}Also at University of Hyderabad, Hyderabad, India.

^{ss}Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany.

^{tt}Also at Department of Physics, Isfahan University of Technology, Isfahan, Iran.

^{uu}Also at Sharif University of Technology, Tehran, Iran.

^{vv}Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran.

^{ww}Also at Helwan University, Cairo, Egypt.

^{xx}Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy.

^{yy}Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy.

- ^{zz} Also at Università degli Studi Guglielmo Marconi, Roma, Italy.
- ^{aaa} Also at Scuola Superiore Meridionale, Università di Napoli 'Federico II', Napoli, Italy.
- ^{bbb} Also at Fermi National Accelerator Laboratory, Batavia, Illinois, USA.
- ^{ccc} Also at Laboratori Nazionali di Legnaro dell'INFN, Legnaro, Italy.
- ^{ddd} Also at Ain Shams University, Cairo, Egypt.
- ^{eee} Also at Consiglio Nazionale delle Ricerche—Istituto Officina dei Materiali, Perugia, Italy.
- ^{fff} Also at Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Malaysia.
- ^{ggg} Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
- ^{hhh} Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka.
- ⁱⁱⁱ Also at Saegis Campus, Nugegoda, Sri Lanka.
- ^{jjj} Also at National and Kapodistrian University of Athens, Athens, Greece.
- ^{kkk} Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland.
- ^{lll} Also at Universität Zürich, Zurich, Switzerland.
- ^{mmm} Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
- ⁿⁿⁿ Also at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
- ^{ooo} Also at Near East University, Research Center of Experimental Health Science, Mersin, Turkey.
- ^{ppp} Also at Konya Technical University, Konya, Turkey.
- ^{qqq} Also at Izmir Bakircay University, Izmir, Turkey.
- ^{rrr} Also at Adiyaman University, Adiyaman, Turkey.
- ^{sss} Also at Bozok Universitetesi Rektörlüğü, Yozgat, Turkey.
- ^{ttt} Also at Marmara University, Istanbul, Turkey.
- ^{uuu} Also at Milli Savunma University, Istanbul, Turkey.
- ^{vvv} Also at Kafkas University, Kars, Turkey.
- ^{www} Also at Istanbul Okan University, Istanbul, Turkey.
- ^{xxx} Also at Hacettepe University, Ankara, Turkey.
- ^{yyy} Also at Istanbul University—Cerrahpasa, Faculty of Engineering, Istanbul, Turkey.
- ^{zzz} Also at Yildiz Technical University, Istanbul, Turkey.
- ^{aaaa} Also at Vrije Universiteit Brussel, Brussel, Belgium.
- ^{bbbb} Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- ^{cccc} Also at IPPP Durham University, Durham, United Kingdom.
- ^{dddd} Also at Monash University, Faculty of Science, Clayton, Australia.
- ^{eeee} Also at Università di Torino, Torino, Italy.
- ^{fff} Also at Bethel University, St. Paul, Minnesota, USA.
- ^{gggg} Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
- ^{hhhh} Also at California Institute of Technology, Pasadena, California, USA.
- ⁱⁱⁱⁱ Also at United States Naval Academy, Annapolis, Maryland, USA.
- ^{jjjj} Also at Bingol University, Bingol, Turkey.
- ^{kkkk} Also at Georgian Technical University, Tbilisi, Georgia.
- ^{llll} Also at Sinop University, Sinop, Turkey.
- ^{mmmm} Also at Erciyes University, Kayseri, Turkey.
- ⁿⁿⁿⁿ Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania.
- ^{oooo} Also at Texas A&M University at Qatar, Doha, Qatar.
- ^{pppp} Also at Kyungpook National University, Daegu, Korea.
- ^{qqqq} Also at Universiteit Antwerpen, Antwerpen, Belgium.
- ^{rrrr} Also at Northeastern University, Boston, Massachusetts, USA.
- ^{ssss} Also at Imperial College, London, United Kingdom.
- ^{tttt} Also at Yerevan Physics Institute, Yerevan, Armenia.
- ^{uuuu} Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan.