

Search for Charged Higgs Bosons Produced via Vector Boson Fusion and Decaying into a Pair of W and Z Bosons Using pp Collisions at $\sqrt{s} = 13$ TeV

A. M. Sirunyan *et al.**

(CMS Collaboration)

(Received 8 May 2017; published 4 October 2017)

A search for charged Higgs bosons produced via vector boson fusion and decaying into W and Z bosons using proton-proton collisions at $\sqrt{s} = 13$ TeV is presented. The data sample corresponds to an integrated luminosity of 15.2 fb^{-1} collected with the CMS detector in 2015 and 2016. The event selection requires three leptons (electrons or muons), two jets with large pseudorapidity separation and high dijet mass, and missing transverse momentum. The observation agrees with the standard model prediction. Limits on the vector boson fusion production cross section times branching fraction for new charged physical states are reported as a function of mass from 200 to 2000 GeV and interpreted in the context of Higgs triplet models.

DOI: 10.1103/PhysRevLett.119.141802

The discovery [1,2] of a Higgs boson [3–8] at the CERN LHC marks an important milestone in the exploration of the electroweak (EW) sector of the standard model (SM) [9–11]. Many aspects of EW interactions at the energy scale of 1 TeV, however, remain to be explored. At the LHC, the study of vector boson scattering (VBS) may reveal hints to extensions of the SM. In particular, extended Higgs sectors with additional SU(2) doublets [12–15] or triplets [16–23] introduce couplings of vector bosons to heavy neutral or charged Higgs bosons.

Searches for charged Higgs bosons (H^\pm) at the LHC currently focus on the production and the decay via couplings to fermions [24–32], well motivated by the minimal supersymmetric standard model [33]. In this model, the $H^\pm tb$ coupling is the dominant one irrespective of the mass of the charged Higgs boson [$m(H^\pm)$] and $\tan\beta$, the ratio of the vacuum expectation values of the two Higgs doublets. Couplings to vector bosons are, however, largely suppressed in these models.

Higgs sectors extended by SU(2) triplets, however, give rise to charged Higgs bosons with couplings to W and Z bosons at the tree level. Higgs triplets appear in left-right symmetric [34–36], little Higgs [37–39], and supersymmetric models [40,41] and can generate neutrino masses via the seesaw mechanism [17–19,42,43]. A particularly prominent model is the Georgi-Machacek (GM) model [44], where two SU(2) triplets (one real and one complex) are added to the SM Higgs sector and preserve custodial symmetry for large vacuum expectation values of the SU(2)

triplets. In such models, the charged Higgs bosons are produced via vector boson fusion (VBF), and the couplings depend on $m(H^\pm)$ and the parameter $\sin\theta_H$, or s_H , where s_H^2 denotes the fraction of the W boson mass squared generated by the vacuum expectation value of the triplets. A representative Feynman diagram for the production by and decay into a W and Z boson pair is shown in Fig. 1.

In this Letter, we discuss the search for charged Higgs bosons that are produced via VBF and decay via couplings to W and Z bosons. The analysis is performed on a sample of proton-proton collisions collected at $\sqrt{s} = 13$ TeV center-of-mass energy by the CMS experiment at the LHC. The data sample corresponds to integrated luminosities of 2.3 and 12.9 fb^{-1} recorded during the years 2015 and 2016, respectively. The search is performed using W and Z bosons decaying into electrons and muons. The event selection requires two jets with large pseudorapidity separation and a high dijet mass to select a VBF topology. The data are compared to the predictions of the GM model for a charged Higgs boson mass range of $200 < m(H^\pm) < 1000$ GeV. In addition, an exclusion limit on the VBF production cross section times branching

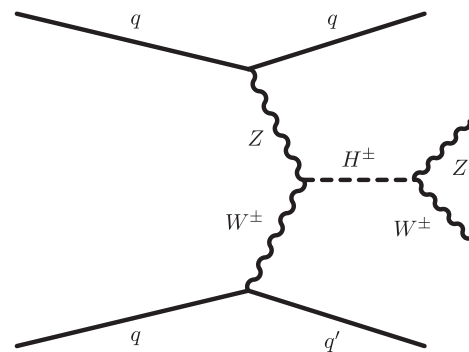


FIG. 1. Example of a Feynman diagram showing the production of charged Higgs bosons via VBF.

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

Published by the American Physical Society under the terms of the Creative Commons Attribution 4.0 International license. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

fraction (\mathcal{B}) for $200 < m(H^\pm) < 2000$ GeV is derived. A similar search was performed by the ATLAS Collaboration in proton-proton collisions at $\sqrt{s} = 8$ TeV in the semi-leptonic ($WZ \rightarrow qq'\ell\ell$) final state [45]. Other experimental constraints on the GM model can be obtained from studies of b -meson decays [46] and $W^\pm W^\pm$ VBS processes [47,48].

The signal samples are produced with MADGRAPH5_aMC@NLO [49]. WZ production in association with two jets involving exclusively electroweak interactions at the tree level is generated at leading order (LO) using MADGRAPH5_aMC@NLO and is referred to as an EW WZ background. Two-jet-associated WZ production with both the strong and electroweak interaction vertices at the tree level is simulated at next-to-leading order (NLO) using POWHEG 2.0 [50–53] and is denoted as a QCD WZ background. The $Z + \text{jets}$, $Z\gamma$, tZq , $t\bar{t}V$, and VVV backgrounds, where V refers to a W or Z boson, are produced at NLO using MADGRAPH5_aMC@NLO. Simulated tZq and $t\bar{t}V$ events are included in the background referred to as VVV . The $gg \rightarrow ZZ$ sample is generated at LO with MCFM [54] and normalized to NLO with a K factor of 1.7 [55]. The ZZ production via $q\bar{q}$ annihilation is simulated at NLO with POWHEG and normalized to the next-to-next-to-leading order (NNLO) cross-section prediction with a K factor of 1.1 [56]. The PYTHIA 8 [57] package is used for parton showering, hadronization, and the underlying event simulation with parameters affecting the underlying event simulation set to the CUETP8M1 tune [58,59]. The NNPDF 3.0 [60] set is used as the default set of parton distribution functions (PDFs). For all processes, the detector response is simulated using a detailed description of the CMS detector, based on the GEANT4 package [61], and event reconstruction is performed with the same algorithms as used for the data. The simulated samples include additional interactions per bunch crossing (pileup) matching the observed multiplicity in the data of about 11 and 20 interactions per bunch crossing in 2015 and 2016, respectively.

Details of the CMS detector, its performance, and the definition of the coordinate system can be found in Ref. [62]. The detector features a superconducting solenoid with a diameter of 6 m, providing a magnetic field of 3.8 T, and surrounding a silicon pixel and strip tracking detector, a lead tungstate electromagnetic calorimeter, and a brass scintillator hadronic calorimeter. Gas ionization detectors embedded into the steel-flux return yokes, the muon system, are installed around the solenoid. The subdetectors are composed into a barrel and two end cap sections. The hadron forward calorimeter provides calorimetry to pseudorapidities from $|\eta| > 3$ to $|\eta| < 5$. A particle-flow technique [63,64] is employed to identify and reconstruct the individual particles emerging from each collision.

Electrons are reconstructed within $|\eta| < 2.5$. The reconstruction combines the information from clusters of

energy deposits in the electromagnetic calorimeter and the trajectory in the tracker [65]. The selection criteria depend on transverse momentum p_T and $|\eta|$ and on a categorization based on observables sensitive to the amount of bremsstrahlung emitted. Muons are reconstructed within $|\eta| < 2.4$ [66]. The reconstruction combines the information from both the tracker and the muon spectrometer. Leptons are required to be isolated from other charged and neutral particles in the event. The lepton relative isolation is defined as the ratio of the p_T sum of charged hadrons and neutral particles within a cone of radius $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.4$ (where ϕ is the azimuthal angle in radians) around the lepton and the lepton p_T . The relative isolation, corrected for pileup contributions, is required to be less than 6.5% (15%) for electrons (muons). Overall efficiencies of the reconstruction, identification, and isolation requirements for the prompt leptons are measured in the data in several bins of p_T and $|\eta|$ using a “tag-and-probe” technique [67] applied to a sample of leptonically decaying Z boson events.

Jets are reconstructed using the anti- k_T clustering algorithm [68] with a distance parameter $R = 0.4$, as implemented in the FASTJET package [69,70], and jet energy corrections are applied [71,72]. To suppress the top-quark background contribution in its decay to b quarks, the combined secondary vertex b -tagging algorithm [73,74] requirement is used, corresponding to an efficiency of about 45% with a light flavor quark misidentification probability of 0.1%.

The missing transverse momentum vector \vec{p}_T^{miss} is defined as the negative vectorial sum of the momenta of all reconstructed particles in an event projected onto the plane perpendicular to the beams, corrected for the pileup contribution [75]. Its magnitude is referred to as p_T^{miss} .

Events are selected by the trigger system requiring the presence of one or two high p_T electrons or muons. The trigger efficiency is greater than 99% for events that pass all other selection criteria explained in the following. The selection of events aims to single out three-lepton events with the VBF topology. The event selection requires three lepton (electron or muon) candidates that meet the isolation and identification requirements. Two leptons are required to have $p_T > 20$ GeV, and the third lepton is required to have $p_T > 10$ GeV. Events with an additional fourth lepton with $p_T > 10$ GeV are rejected. Events are required to have at least two jets with $p_T > 30$ GeV, and $|\eta| < 4.7$. The VBF topology is exploited by requiring that the two jets of highest p_T have a large dijet mass, $m_{jj} > 500$ GeV, and a large pseudorapidity separation, $|\Delta\eta_{jj}| > 2.5$. To reconstruct a Z boson candidate, a pair of same-flavor and opposite-charge leptons is required to have a dilepton invariant mass within 15 GeV of the nominal Z boson mass [76]. When there are two or more candidate pairs, the one with the mass closest to the nominal Z boson mass is chosen. The remaining lepton is associated with the W

boson decay, and it is required to have $p_T > 20$ GeV. The p_T^{miss} in the event is required to be larger than 30 GeV to select W boson decays. To reject the top-quark background, the event must not have jets passing the b -tagging selection. After these requirements, the signal efficiency is about 10%–15%, depending on $m(H^\pm)$. For extraction of the signal, the shape of the distribution of the transverse mass variable (m_T) obtained from the WZ system is used:

$$m_T(WZ) = \sqrt{[E_T(W) + E_T(Z)]^2 - [\vec{p}_T(W) + \vec{p}_T(Z)]^2}, \quad (1)$$

where $\vec{p}_T(W)$ is reconstructed from the vectorial sum of \vec{p}_T^{miss} and the lepton \vec{p}_T and $E_T(W)$ is calculated from the scalar sum of the lepton transverse energy and p_T^{miss} . Variables such as the invariant mass of the leptonically decaying WZ system using constraints on the neutrino momentum from the W boson mass [77] may be explored in future analyses.

A combination of methods using control samples in the data and detailed simulation studies is used to estimate background contributions. The following background categories are considered: WZ , $ZZ \rightarrow 4\ell$, VVV , $Z\gamma$, and processes with nonprompt leptons.

The QCD and EW WZ background constitutes about 80% of the total expected SM background yield. The normalization of the QCD WZ background is obtained from a background-dominated sideband, outside of the search region and defined by the dijet variables, where the expected signal yield is negligible: $100 \text{ GeV} < m_{jj} < 500 \text{ GeV}$ and $|\Delta\eta_{jj}| < 2.5$. In this phase-space region, expected background contributions from EW WZ , $ZZ \rightarrow 4\ell$, VVV , $Z\gamma$ production, and nonprompt leptons are estimated to contribute about 40% to the yield and are subtracted from the overall 266 events observed in data. The simulated sample of QCD WZ processes is then normalized to match the observed number of events in this control region. The estimated normalization of events is consistent with the SM prediction obtained using the POWHEG NLO cross-section calculation. The EW WZ background contributes about 30% to the overall WZ background processes in the signal region.

The $ZZ \rightarrow 4\ell$, VVV , and $Z\gamma$ contributions are estimated from simulated samples, with corrections to the lepton reconstruction, trigger and selection efficiencies, and momentum scale and resolution, estimated from data control samples. The overall expected contribution from these processes to the total background yield is about 10%, and the uncertainties in the estimates are dominated by the statistical component introduced by the number of simulated events passing the event selection requirements. The $ZZ \rightarrow 4\ell$ background is largely reduced by the p_T^{miss} requirement and the veto on events containing an additional lepton.

The main contributions to nonprompt leptons are from Z + jets and top-quark ($t\bar{t}$ and tW) events, where at least one of the jets or a jet constituent is misidentified as an isolated lepton. The dominant background at the final-selection level is Z + jets. According to the simulation, fewer than 10% of the background events with at least one nonprompt lepton come from top-quark processes. Data control samples are used to estimate this background. Lepton candidates selected with loose identification requirements are defined in a sample of events dominated by dijet production. The efficiency for candidates to pass the full lepton selection criteria is measured and is parametrized as a function of p_T and η . The calculated efficiencies are used as weights to extrapolate the yield of the sample of loose leptons to the sample of fully selected leptons. The background estimation method is validated on a nonprompt lepton W + jets and $t\bar{t}$ enriched sample, selected by inverting the Z boson mass or b -tagging criteria, where good agreement between the data and prediction is observed.

Uncertainties in the data-to-simulation scale factors applied to leptons in simulated samples result in an overall 4% normalization uncertainty for backgrounds estimated from the simulation. The experimental uncertainties in the lepton momentum scale and resolution, p_T^{miss} modeling, and jet energy scale are applied in simulated events by smearing and scaling the relevant observables and propagating the effects to the kinematic variables used in the analysis, in particular, m_T . Uncertainties in the lepton momentum scale and resolution are smaller than 1% per lepton depending on the p_T and η of the lepton, and the effect on the yields at the analysis selection level is less than 1%. The uncertainties in the jet energy scale and resolution result in a 5% uncertainty in the signal yields. The uncertainty in the resolution of the p_T^{miss} measurement is 10%. Randomly smearing the measured p_T^{miss} by one standard deviation of the resolution gives rise to a 5% variation in the estimation of signal yields after the full selection. Uncertainties of 2.3% and 2.5% are assigned to the integrated luminosity measurements in the years 2015 and 2016, respectively [78,79]. The effect of higher-order corrections to the signal cross section in the GM model is taken from Ref. [80]. The theoretical uncertainty is dominated by missing higher-order EW corrections estimated to be 7%. Uncertainties in the signal acceptance due to PDF choice and renormalization and factorization scales are 2%–3% and less than 1%, respectively, estimated using the LO signal samples. Added in quadrature, the contributions result in an 8% uncertainty in the normalization of the signal samples.

The uncertainty in the estimation of the expected number of QCD WZ events is 12%, which is estimated from the measured yields in the two-jet control region. An uncorrelated uncertainty of 30% is assigned on the normalization of WZ events produced via EW processes, estimated from

TABLE I. Relative systematic uncertainties in the estimated signal and background yields, in units of percent.

Source	Signal	WZ	VVV	$Z\gamma$	ZZ	Nonprompt
Integrated luminosity 2015 (2016)	2.3 (2.5)	...	2.3 (2.5)	2.3 (2.5)	2.3 (2.5)	...
Lepton efficiency	4.0	...	4.0	4.0	4.0	...
Lepton momentum scale	1.0	1.0	1.0	1.0	1.0	...
Jet momentum scale	5.0	10.0	6.0	30.0	13.0	...
p_T^{miss} resolution	5.0	1.7	1.0	...	7.0	...
b tagging	2.0	...	2.0	2.0	2.0	...
QCD (EW) WZ bkg. normalization	...	12 (30)	...	...	...	...
Nonprompt bkg. normalization	...	...	...	...	...	30–80
GM uncertainties	8	...	...	...	...	...

the largest bin-by-bin differences after varying the renormalization and factorization scales. The total uncertainty in the prediction of the nonprompt background varies bin by bin in the m_T distribution between 30% and 80%, dominated by the low number of nonprompt leptons passing the sideband selection. A summary of the relative systematic uncertainties in the estimated signal and background yields is shown in Table I.

After applying the full selection, nine and 62 events are selected in the data collected in 2015 and 2016, respectively. The data yield together with the SM expectation for the different processes is given in Table II. The distribution of the m_T with bin boundaries given by $m_T = [0, 100, 200, 400, 600, 800, 1000, 1200, 1500, \infty)$ GeV (the last bin is an overflow bin) is shown in Fig. 2. No event with $m_T(WZ) > 800$ GeV is observed in the data, and overall agreement between the data and SM background prediction is observed.

A combined fit of the predicted signal and background yields in bins of m_T to the data is performed to derive expected and observed exclusion limits on $\sigma_{\text{VBF}}(H^\pm)\mathcal{B}(H^\pm \rightarrow WZ)$ at 95% confidence level using the CL_s method [81–83]. The exclusion limits as a function of $m(H^\pm)$, assuming a small intrinsic width for H^\pm , are shown in Fig. 3 (left). Values for $\sigma_{\text{VBF}}(H^\pm)\mathcal{B}(H^\pm \rightarrow WZ)$ ranging from 573 fb at $m(H^\pm) = 200$ GeV to 36 fb at $m(H^\pm) = 2000$ GeV are excluded by the data.

TABLE II. Yields of selected events in 2015 and 2016 data, together with the expected yields from various background processes. The statistical and systematic uncertainties are shown. The signal yields are shown for values of $s_H = 0.7$.

Data set	2015	2016
Data	9	62
WZ	7.5 ± 1.2	44.4 ± 5.7
ZZ	0.2 ± 0.1	1.6 ± 0.2
VVV	0.8 ± 0.2	5.5 ± 0.9
$Z\gamma$	0.2 ± 0.1	1.0 ± 0.6
Nonprompt	1.3 ± 1.0	7.4 ± 5.4
Total bkg.	10.0 ± 1.6	59.9 ± 8.0
Signal [$m(H^\pm) = 700$ GeV]	0.9 ± 0.1	4.7 ± 0.5

The model-independent exclusion limits are compared to the predicted cross sections at NNLO in the GM model [80] in the $s_H - m(H^\pm)$ plane. For the probed parameter space and m_T distribution used for signal extraction, the varying width as a function of s_H is assumed to have negligible impact on the result. The value of the branching fraction

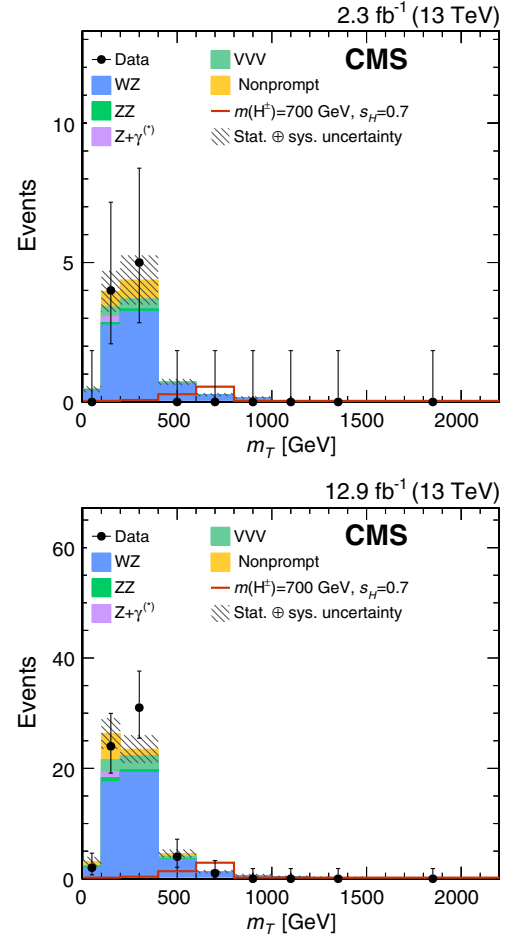


FIG. 2. Transverse mass distributions after full selection, for data collected in 2015 (left) and 2016 (right). The background yield predictions correspond to the background-only hypothesis fit result. The signal distribution is shown for $m(H^\pm) = 700$ GeV and the cross-section prediction in the GM model at $s_H = 0.7$.

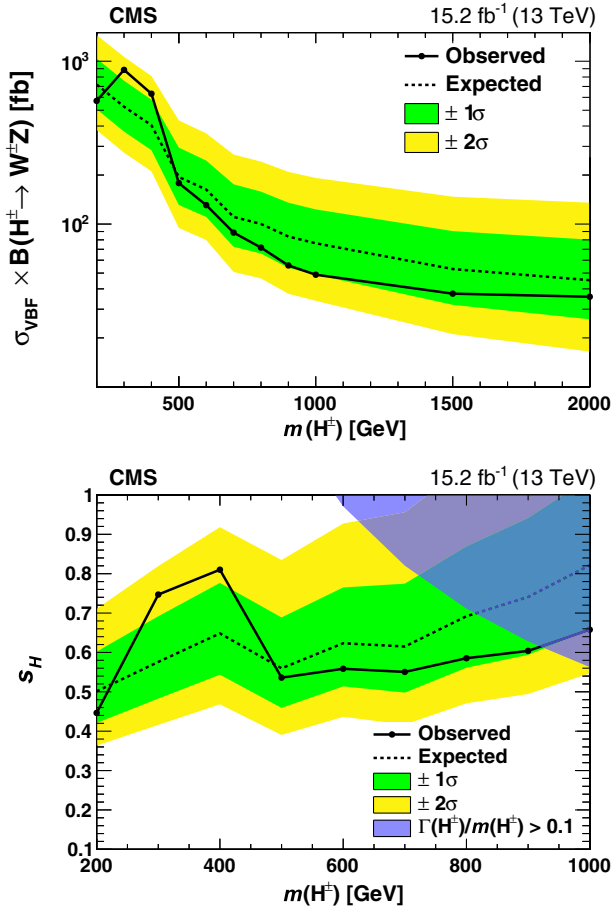


FIG. 3. Expected and observed exclusion limits at 95% confidence level as a function of $m(H^\pm)$ for $\sigma_{\text{VBF}}(H^\pm)\mathcal{B}(H^\pm \rightarrow WZ)$ (left) and on the ratio of vacuum expectation values in the GM model (right) for 15.2 fb^{-1} of proton-proton collisions at 13 TeV collected in 2015 and 2016. The blue shaded area covers the theoretically not allowed parameter space [80].

$\mathcal{B}(H^\pm \rightarrow WZ)$ is assumed to be one. In Fig. 3 (right), the excluded s_H values as a function of $m(H^\pm)$ are shown. The blue shaded region shows the parameter space for which the H^\pm total width exceeds 10% of $m(H^\pm)$, where the model is not applicable due to perturbativity and vacuum stability requirements [80]. The observed limit excludes s_H values greater than 0.45, 0.81, and 0.66 at $m(H^\pm) = 200, 400,$ and 1000 GeV , respectively.

In summary, we present a search for charged Higgs bosons produced via vector boson fusion and decaying into W and Z bosons in proton-proton collisions at $\sqrt{s} = 13 \text{ TeV}$ based on a sample corresponding to an integrated luminosity of 15.2 fb^{-1} . Events are required to have three leptons (electrons or muons), two jets with large pseudorapidity separation and high dijet mass, and missing transverse momentum. The number of events observed in the signal region agrees with the standard model prediction. The first limits on $\sigma_{\text{VBF}}(H^\pm)\mathcal{B}(H^\pm \rightarrow WZ)$ at $\sqrt{s} = 13 \text{ TeV}$ are obtained. The results are interpreted in the

Georgi-Machacek model for which the most stringent limits to date are derived.

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RPF (Cyprus); SENESCYT (Ecuador); MoER, ERC IUT, and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, and RFBR (Russia); MESTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU and SFFR (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

- [1] ATLAS Collaboration, Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, *Phys. Lett. B* **716**, 1 (2012).
- [2] CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, *Phys. Lett. B* **716**, 30 (2012).
- [3] F. Englert and R. Brout, Broken Symmetry and the Mass of Gauge Vector Mesons, *Phys. Rev. Lett.* **13**, 321 (1964).
- [4] P. W. Higgs, Broken Symmetries, Massless Particles and Gauge Fields, *Phys. Rev. Lett.* **12**, 132 (1964).
- [5] P. W. Higgs, Broken Symmetries and the Masses of Gauge Bosons, *Phys. Rev. Lett.* **13**, 508 (1964).
- [6] G. S. Guralnik, C. R. Hagen, and T. W. B. Kibble, Global Conservation Laws and Massless Particles, *Phys. Rev. Lett.* **13**, 585 (1964).
- [7] P. W. Higgs, Spontaneous Symmetry Breakdown without Massless Bosons, *Phys. Rev.* **145**, 1156 (1966).
- [8] T. W. B. Kibble, Symmetry breaking in Non-Abelian gauge theories, *Phys. Rev.* **155**, 1554 (1967).

- [9] S. L. Glashow, Partial-symmetries of weak interactions, *Nucl. Phys.* **22**, 579 (1961).
- [10] S. Weinberg, A Model of Leptons, *Phys. Rev. Lett.* **19**, 1264 (1967).
- [11] A. Salam, in *Elementary Particle Physics: Relativistic Groups and Analyticity*, edited by N. Svartholm (Almqvist & Wiskell, Stockholm, 1968), p. 367.
- [12] T. D. Lee, A theory of spontaneous T violation, *Phys. Rev. D* **8**, 1226 (1973).
- [13] P. Fayet, A gauge theory of weak and electromagnetic interactions with spontaneous parity breaking, *Nucl. Phys.* **B78**, 14 (1974).
- [14] N. Craig and S. Thomas, Exclusive signals of an extended Higgs sector, *J. High Energy Phys.* **11** (2012) 083.
- [15] G. C. Branco, P. M. Ferreira, L. Lavoura, M. N. Rebelo, M. Sher, and J. P. Silva, Theory and phenomenology of two-Higgs-doublet models, *Phys. Rep.* **516**, 1 (2012).
- [16] W. Konetschny and W. Kummer, Nonconservation of total lepton number with scalar bosons, *Phys. Lett. B* **70**, 433 (1977).
- [17] M. Magg and C. Wetterich, Neutrino mass problem and gauge hierarchy, *Phys. Lett. B* **94**, 61 (1980).
- [18] T. P. Cheng and L.-F. Li, Neutrino masses, mixings, and oscillations in $SU(2) \times U(1)$ models of electroweak interactions, *Phys. Rev. D* **22**, 2860 (1980).
- [19] J. Schechter and J. W. F. Valle, Neutrino masses in $SU(2) \otimes U(1)$ theories, *Phys. Rev. D* **22**, 2227 (1980).
- [20] C. Englert, E. Re, and M. Spannowsky, Triplet Higgs boson collider phenomenology after the LHC, *Phys. Rev. D* **87**, 095014 (2013).
- [21] C. Englert, E. Re, and M. Spannowsky, Pinning down Higgs triplets at the LHC, *Phys. Rev. D* **88**, 035024 (2013).
- [22] C.-W. Chiang and K. Yagyu, Testing the custodial symmetry in the Higgs sector of the Georgi-Machacek model, *J. High Energy Phys.* **01** (2013) 026.
- [23] C.-W. Chiang, A.-L. Kuo, and K. Yagyu, Enhancements of weak gauge boson scattering processes at the CERN LHC, *J. High Energy Phys.* **10** (2013) 072.
- [24] ATLAS Collaboration, Search for charged Higgs bosons decaying via $H^+ \rightarrow \tau\nu$ in top quark pair events using pp collision data at $\sqrt{s} = 7$ TeV with the ATLAS detector, *J. High Energy Phys.* **06** (2012) 039.
- [25] ATLAS Collaboration, Search for charged Higgs bosons through the violation of lepton universality in $t\bar{t}$ events using pp collision data at $\sqrt{s} = 7$ TeV with the ATLAS experiment, *J. High Energy Phys.* **03** (2013) 076.
- [26] ATLAS Collaboration, Search for charged Higgs bosons decaying via $H^\pm \rightarrow \tau^\pm\nu$ in fully hadronic final states using pp collision data at $\sqrt{s} = 8$ TeV with the ATLAS detector, *J. High Energy Phys.* **03** (2015) 088.
- [27] CMS Collaboration, Search for a light charged Higgs boson in top quark decays in pp collisions at $\sqrt{s} = 7$ TeV, *J. High Energy Phys.* **07** (2012) 143.
- [28] ATLAS Collaboration, Search for charged Higgs bosons in the $H^\pm \rightarrow tb$ decay channel in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector, *J. High Energy Phys.* **03** (2016) 127.
- [29] CMS Collaboration, Search for a charged Higgs boson in pp collisions at $\sqrt{s} = 8$ TeV, *J. High Energy Phys.* **11** (2015) 018.
- [30] ATLAS Collaboration, Search for a light charged Higgs boson in the decay channel $H^+ \rightarrow c\bar{s}$ in $t\bar{t}$ events using pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, *Eur. Phys. J. Spec. Top.* **73**, 2465 (2013).
- [31] CMS Collaboration, Search for a light charged Higgs boson decaying to $c\bar{s}$ in pp collisions at $\sqrt{s} = 8$ TeV, *J. High Energy Phys.* **12** (2015) 178.
- [32] ATLAS Collaboration, Search for charged Higgs bosons produced in association with a top quark and decaying via $H^\pm \rightarrow \tau\nu$ using pp collision data recorded at $\sqrt{s} = 13$ TeV by the ATLAS detector, *Phys. Lett. B* **759**, 555 (2016).
- [33] S. Dimopoulos and H. Georgi, Softly broken supersymmetry and $SU(5)$, *Nucl. Phys.* **B193**, 150 (1981).
- [34] Lepton number as the fourth “color”.
- [35] R. N. Mohapatra and J. C. Pati, A natural left-right symmetry, *Phys. Rev. D* **11**, 2558 (1975).
- [36] G. Senjanovic and R. N. Mohapatra, Exact left-right symmetry and spontaneous violation of parity, *Phys. Rev. D* **12**, 1502 (1975).
- [37] N. Arkani-Hamed, A. G. Cohen, E. Katz, and A. E. Nelson, The lightest Higgs, *J. High Energy Phys.* **07** (2002) 034.
- [38] S. Chang, A “lightest Higgs” model with custodial $SU(2)$ symmetry, *J. High Energy Phys.* **12** (2003) 057.
- [39] S. Chang and J. G. Wacker, Little Higgs and custodial $SU(2)$, *Phys. Rev. D* **69**, 035002 (2004).
- [40] M. Garcia-Pepin, S. Gori, M. Quiros, R. Vega, R. Vega-Morales, and T.-T. Yu, Supersymmetric custodial Higgs triplets and the breaking of universality, *Phys. Rev. D* **91**, 015016 (2015).
- [41] L. Cort, M. Garcia, and M. Quiros, Supersymmetric custodial triplets, *Phys. Rev. D* **88**, 075010 (2013).
- [42] G. Lazarides, Q. Shafi, and C. Wetterich, Proton lifetime and fermion masses in an $SO(10)$ model, *Nucl. Phys.* **B181**, 287 (1981).
- [43] R. N. Mohapatra and G. Senjanović, Neutrino masses and mixings in gauge models with spontaneous parity violation, *Phys. Rev. D* **23**, 165 (1981).
- [44] H. Georgi and M. Machacek, Doubly charged Higgs bosons, *Nucl. Phys.* **B262**, 463 (1985).
- [45] ATLAS Collaboration, Search for a Charged Higgs Boson Produced in the Vector-Boson Fusion Mode with Decay $H^\pm \rightarrow W^\pm Z$ Using pp Collisions at $\sqrt{s} = 8$ TeV with the ATLAS Experiment, *Phys. Rev. Lett.* **114**, 231801 (2015).
- [46] K. Hartling, K. Kumar, and H. E. Logan, Indirect constraints on the Georgi-Machacek model and implications for Higgs boson couplings, *Phys. Rev. D* **91**, 015013 (2015).
- [47] ATLAS Collaboration, Evidence for Electroweak Production of $W^\pm W^\pm jj$ in pp Collisions at $\sqrt{s} = 8$ TeV with the ATLAS Detector, *Phys. Rev. Lett.* **113**, 141803 (2014).
- [48] CMS Collaboration, Study of Vector Boson Scattering and Search for New Physics in Events with Two Same-Sign Leptons and Two Jets, *Phys. Rev. Lett.* **114**, 051801 (2015).
- [49] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H.-S. Shao, T. Stelzer, P. Torielli, 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.
- [50] S. Alioli, P. Nason, C. Oleari, and E. Re, NLO vector-boson production matched with shower in POWHEG, *J. High Energy Phys.* **07** (2008) 060.

- [51] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, *J. High Energy Phys.* **11** (2004) 040.
- [52] 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.
- [53] 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.
- [54] J. M. Campbell and R. K. Ellis, MCFM for the Tevatron and the LHC, *Nucl. Phys. B, Proc. Suppl.* **205–206**, 10 (2010).
- [55] F. Caola, K. Melnikov, R. Rötsch, and L. Tancredi, QCD corrections to ZZ production in gluon fusion at the LHC, *Phys. Rev. D* **92**, 094028 (2015).
- [56] F. Cascioli, T. Gehrmann, M. Grazzini, S. Kallweit, P. Maierhöfer, A. von Manteuffel, S. Pozzorini, D. Rathlev, L. Tancredi, and E. Weihs, ZZ production at hadron colliders in NNLO QCD, *Phys. Lett. B* **735**, 311 (2014).
- [57] 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 PYTHIA 8.2, *Comput. Phys. Commun.* **191**, 159 (2015).
- [58] P. Skands, S. Carrazza, and J. Rojo, Tuning PYTHIA 8.1: The Monash 2013 tune, *Eur. Phys. J. C* **74**, 3024 (2014).
- [59] CMS Collaboration, Event generator tunes obtained from underlying event and multiparton scattering measurements, *Eur. Phys. J. C* **76**, 155 (2016).
- [60] R. D. Ball, V. Bertone, S. Carrazza, C. S. Deans, L. Del Debbio, S. Forte, A. Guffanti, N. P. Hartland, J. I. Latorre, J. Rojo, and M. Ubiali (NNPDF Collaboration), Parton distributions for the LHC run II, *J. High Energy Phys.* **04** (2015) 040.
- [61] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—A simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [62] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [63] CMS Collaboration, CMS Physics Analysis Summary No. CMS-PAS-PFT-09-001, 2009, <http://cdsweb.cern.ch/record/1194487>.
- [64] CMS Collaboration, CMS Physics Analysis Summary No. CMS-PAS-PFT-10-001, 2010, <https://cds.cern.ch/record/1247373>.
- [65] 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).
- [66] CMS Collaboration, Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV, *J. Instrum.* **7**, P10002 (2012).
- [67] CMS Collaboration, Measurements of inclusive W and Z cross sections in pp collisions at $\sqrt{s} = 7$ TeV, *J. High Energy Phys.* **01** (2011) 080.
- [68] M. Cacciari, G. P. Salam, and G. Soyez, The anti- k_r jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.
- [69] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, *Eur. Phys. J. C* **72**, 1896 (2012).
- [70] M. Cacciari and G. P. Salam, Dispelling the N^3 myth for the k_r jet-finder, *Phys. Lett. B* **641**, 57 (2006).
- [71] CMS Collaboration, Determination of jet energy calibration and transverse momentum resolution in CMS, *J. Instrum.* **6**, P11002 (2011).
- [72] CMS Collaboration, Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV, *J. Instrum.* **12**, P02014 (2017).
- [73] CMS Collaboration, Identification of b-quark jets with the CMS experiment, *J. Instrum.* **8**, P04013 (2013).
- [74] CMS Collaboration, CMS Physics Analysis Summary No. CMS-PAS-BTV-15-001, 2016, <https://cds.cern.ch/record/2138504>.
- [75] M. Cacciari and G. P. Salam, Pileup subtraction using jet areas, *Phys. Lett. B* **659**, 119 (2008).
- [76] C. Patrignani *et al.* (Particle Data Group), Review of particle physics, *Chin. Phys. C* **40**, 100001 (2016).
- [77] A. J. Barr, T. J. Khoo, P. Konar, K. Kong, C. G. Lester, K. T. Matchev, and M. Park, Guide to transverse projections and mass-constraining variables, *Phys. Rev. D* **84**, 095031 (2011).
- [78] CMS Collaboration, CMS Physics Analysis Summary No. CMS-PAS-LUM-15-001, 2017, <https://cds.cern.ch/record/2138682>.
- [79] CMS Collaboration, CMS Physics Analysis Summary No. CMS-PAS-LUM-17-001, 2017, <https://cds.cern.ch/record/2257069>.
- [80] M. Zaro and H. Logan, CERN Report No. LHCHXSWG-2015-001, 2015, <https://cds.cern.ch/record/2002500>.
- [81] T. Junk, Confidence level computation for combining searches with small statistics, *Nucl. Instrum. Methods Phys. Res., Sect. A* **434**, 435 (1999).
- [82] A. L. Read, Presentation of search results: The CL_s technique, *J. Phys. G* **28**, 2693 (2002).
- [83] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, *Eur. Phys. J. C* **71**, 1554 (2011); Erratum, *Eur. Phys. J. C* **73**, 2501(E) (2013).

A. M. Sirunyan,¹ A. Tumasyan,¹ W. Adam,² E. Asilar,² T. Bergauer,² J. Brandstetter,² E. Brondolin,² M. Dragicevic,² J. Erö,² M. Flechl,² M. Friedl,² R. Frühwirth,^{2,b} V. M. Ghete,² C. Hartl,² N. Hörmann,² J. Hrubec,² M. Jeitler,^{2,b} A. König,² I. Krätschmer,² D. Liko,² T. Matsushita,² I. Mikulec,² D. Rabady,² N. Rad,² B. Rahbaran,² H. Rohringer,² J. Schieck,^{2,b} J. Strauss,² W. Waltenberger,² C.-E. Wulz,^{2,b} O. Dvornikov,³ V. Makarenko,³ V. Mossolov,³ J. Suarez Gonzalez,³ V. Zykunov,³ N. Shumeiko,⁴ S. Alderweireldt,⁵ E. A. De Wolf,⁵ X. Janssen,⁵ J. Lauwers,⁵ M. Van De Klundert,⁵ H. Van Haevermaet,⁵ P. Van Mechelen,⁵ N. Van Remortel,⁵ A. Van Spilbeek,⁵ S. Abu Zeid,⁶ F. Blekman,⁶ J. D’Hondt,⁶ N. Daci,⁶ I. De Bruyn,⁶ K. Deroover,⁶ S. Lowette,⁶ S. Moortgat,⁶ L. Moreels,⁶ A. Olbrechts,⁶ Q. Python,⁶ K. Skovpen,⁶

S. Tavernier,⁶ W. Van Doninck,⁶ P. Van Mulders,⁶ I. Van Parijs,⁶ H. Brun,⁷ B. Clerbaux,⁷ G. De Lentdecker,⁷ H. Delannoy,⁷ G. Fasanella,⁷ L. Favart,⁷ R. Goldouzian,⁷ A. Grebenyuk,⁷ G. Karapostoli,⁷ T. Lenzi,⁷ A. Léonard,⁷ J. Luetic,⁷ T. Maerschalk,⁷ A. Marinov,⁷ A. Randle-conde,⁷ T. Seva,⁷ C. Vander Velde,⁷ P. Vanlaer,⁷ D. Vannerom,⁷ R. Yonamine,⁷ F. Zenoni,⁷ F. Zhang,^{7,c} T. Cornelis,⁸ D. Dobur,⁸ A. Fagot,⁸ M. Gul,⁸ I. Khvastunov,⁸ D. Poyraz,⁸ S. Salva,⁸ R. Schöfbeck,⁸ M. Tytgat,⁸ W. Van Driessche,⁸ W. Verbeke,⁸ N. Zaganidis,⁸ H. Bakhshiansohi,⁹ O. Bondu,⁹ S. Brochet,⁹ G. Bruno,⁹ A. Caudron,⁹ S. De Visscher,⁹ C. Delaere,⁹ M. Delcourt,⁹ B. Francois,⁹ A. Giammanco,⁹ A. Jafari,⁹ M. Komm,⁹ G. Krintiras,⁹ V. Lemaître,⁹ A. Magitteri,⁹ A. Mertens,⁹ M. Musich,⁹ K. Piotrkowski,⁹ L. Quertenmont,⁹ M. Vidal Marono,⁹ S. Wertz,⁹ N. Belyi,¹⁰ W. L. Aldá Júnior,¹¹ F. L. Alves,¹¹ G. A. Alves,¹¹ L. Brito,¹¹ C. Hensel,¹¹ A. Moraes,¹¹ M. E. Pol,¹¹ P. Rebello Teles,¹¹ E. Belchior Batista Das Chagas,¹² W. Carvalho,¹² J. Chinellato,^{12,d} A. Custódio,¹² E. M. Da Costa,¹² G. G. Da Silveira,^{12,e} D. De Jesus Damiao,¹² C. De Oliveira Martins,¹² S. Fonseca De Souza,¹² L. M. Huertas Guativa,¹² H. Malbousson,¹² D. Matos Figueiredo,¹² C. Mora Herrera,¹² L. Mundim,¹² H. Nogima,¹² W. L. Prado Da Silva,¹² A. Santoro,¹² A. Sznajder,¹² E. J. Tonelli Manganote,^{12,d} F. Torres Da Silva De Araujo,¹² A. Vilela Pereira,¹² S. Ahuja,^{13a} C. A. Bernardes,^{13a} S. Dogra,^{13a} T. R. Fernandez Perez Tomei,^{13a} E. M. Gregores,^{13b} P. G. Mercadante,^{13b} C. S. Moon,^{13a} S. F. Novaes,^{13a} Sandra S. Padula,^{13a} D. Romero Abad,^{13b} J. C. Ruiz Vargas,^{13a} A. Aleksandrov,¹⁴ R. Hadjiiska,¹⁴ P. Iaydjiev,¹⁴ M. Rodozov,¹⁴ S. Stoykova,¹⁴ G. Sultanov,¹⁴ M. Vutova,¹⁴ A. Dimitrov,¹⁵ I. Glushkov,¹⁵ L. Litov,¹⁵ B. Pavlov,¹⁵ P. Petkov,¹⁵ W. Fang,^{16,f} X. Gao,^{16,f} M. Ahmad,¹⁷ J. G. Bian,¹⁷ G. M. Chen,¹⁷ H. S. Chen,¹⁷ M. Chen,¹⁷ Y. Chen,¹⁷ T. Cheng,¹⁷ C. H. Jiang,¹⁷ D. Leggat,¹⁷ Z. Liu,¹⁷ F. Romeo,¹⁷ M. Ruan,¹⁷ S. M. Shaheen,¹⁷ A. Spiezia,¹⁷ J. Tao,¹⁷ C. Wang,¹⁷ Z. Wang,¹⁷ E. Yazgan,¹⁷ H. Zhang,¹⁷ J. Zhao,¹⁷ Y. Ban,¹⁸ G. Chen,¹⁸ Q. Li,¹⁸ S. Liu,¹⁸ Y. Mao,¹⁸ S. J. Qian,¹⁸ D. Wang,¹⁸ Z. Xu,¹⁸ C. Avila,¹⁹ A. Cabrera,¹⁹ L. F. Chaparro Sierra,¹⁹ C. Florez,¹⁹ J. P. Gomez,¹⁹ C. F. González Hernández,¹⁹ J. D. Ruiz Alvarez,^{19,g} J. C. Sanabria,¹⁹ N. Godinovic,²⁰ D. Lelas,²⁰ I. Puljak,²⁰ P. M. Ribeiro Cipriano,²⁰ T. Sculac,²⁰ Z. Antunovic,²¹ M. Kovac,²¹ V. Brigljevic,²² D. Ferencek,²² K. Kadija,²² B. Mesic,²² T. Susa,²² M. W. Ather,²³ A. Attikis,²³ G. Mavromanolakis,²³ J. Mousa,²³ C. Nicolaou,²³ F. Ptochos,²³ P. A. Razis,²³ H. Rykaczewski,²³ M. Finger,^{24,h} M. Finger Jr.,^{24,h} E. Carrera Jarrin,²⁵ A. A. Abdelalim,^{26,i,j} Y. Mohammed,^{26,k} E. Salama,^{26,l,m} M. Kadastik,²⁷ L. Perrini,²⁷ M. Raidal,²⁷ A. Tiko,²⁷ C. Veelken,²⁷ P. Eerola,²⁸ J. Pekkanen,²⁸ M. Voutilainen,²⁸ J. Härkönen,²⁹ T. Järvinen,²⁹ V. Karimäki,²⁹ R. Kinnunen,²⁹ T. Lampén,²⁹ K. Lassila-Perini,²⁹ S. Lehti,²⁹ T. Lindén,²⁹ P. Luukka,²⁹ J. Tuominiemi,²⁹ E. Tuovinen,²⁹ L. Wendland,²⁹ J. Talvitie,³⁰ T. Tuuva,³⁰ M. Besancon,³¹ F. Couderc,³¹ M. Dejardin,³¹ D. Denegri,³¹ B. Fabbro,³¹ J. L. Faure,³¹ C. Favaro,³¹ F. Ferri,³¹ S. Ganjour,³¹ S. Ghosh,³¹ A. Givernaud,³¹ P. Gras,³¹ G. Hamel de Monchenault,³¹ P. Jarry,³¹ I. Kucher,³¹ E. Locci,³¹ M. Mached,³¹ J. Malcles,³¹ J. Rander,³¹ A. Rosowsky,³¹ M. Titov,³¹ A. Abdulsalam,³² I. Antropov,³² S. Baffioni,³² F. Beaudette,³² P. Busson,³² L. Cadamuro,³² E. Chapon,³² C. Charlot,³² O. Davignon,³² R. Granier de Cassagnac,³² M. Jo,³² S. Lisniak,³² A. Lobanov,³² P. Miné,³² M. Nguyen,³² C. Ochando,³² G. Ortona,³² P. Paganini,³² P. Pigard,³² S. Regnard,³² R. Salerno,³² Y. Sirois,³² A. G. Stahl Leiton,³² T. Strebler,³² Y. Yilmaz,³² A. Zabi,³² A. Zghiche,³² J.-L. Agram,^{33,n} J. Andrea,³³ D. Bloch,³³ J.-M. Brom,³³ M. Buttignol,³³ E. C. Chabert,³³ N. Chanon,³³ C. Collard,³³ E. Conte,^{33,n} X. Coubez,³³ J.-C. Fontaine,^{33,n} D. Gelé,³³ U. Goerlach,³³ A.-C. Le Bihan,³³ P. Van Hove,³³ S. Gadrat,³⁴ S. Beauceron,³⁵ C. Bernet,³⁵ G. Boudoul,³⁵ C. A. Carrillo Montoya,³⁵ R. Chierici,³⁵ D. Contardo,³⁵ B. Courbon,³⁵ P. Depasse,³⁵ H. El Mamouni,³⁵ J. Fay,³⁵ L. Finco,³⁵ S. Gascon,³⁵ M. Gouzevitch,³⁵ G. Grenier,³⁵ B. Ille,³⁵ F. Lagarde,³⁵ I. B. Laktineh,³⁵ M. Lethuillier,³⁵ L. Mirabito,³⁵ A. L. Pequegnot,³⁵ S. Perries,³⁵ A. Popov,^{35,o} V. Sordini,³⁵ M. Vander Donckt,³⁵ P. Verdier,³⁵ S. Viret,³⁵ A. Khvedelidze,^{36,h} Z. Tsamalaidze,^{37,h} C. Autermann,³⁸ S. Beranek,³⁸ L. Feld,³⁸ M. K. Kiesel,³⁸ K. Klein,³⁸ M. Lipinski,³⁸ M. Preuten,³⁸ C. Schomakers,³⁸ J. Schulz,³⁸ T. Verlage,³⁸ A. Albert,³⁹ M. Brodski,³⁹ E. Dietz-Laursonn,³⁹ D. Duchardt,³⁹ M. Endres,³⁹ M. Erdmann,³⁹ S. Erdweg,³⁹ T. Esch,³⁹ R. Fischer,³⁹ A. Güth,³⁹ M. Hamer,³⁹ T. Hebbeker,³⁹ C. Heidemann,³⁹ K. Hoepfner,³⁹ S. Knutzen,³⁹ M. Merschmeyer,³⁹ A. Meyer,³⁹ P. Millet,³⁹ S. Mukherjee,³⁹ M. Olschewski,³⁹ K. Padeken,³⁹ T. Pook,³⁹ M. Radziej,³⁹ H. Reithler,³⁹ M. Rieger,³⁹ F. Scheuch,³⁹ L. Sonnenschein,³⁹ D. Teyssier,³⁹ S. Thüer,³⁹ V. Cherepanov,⁴⁰ G. Flügge,⁴⁰ B. Kargoll,⁴⁰ T. Kress,⁴⁰ A. Künsken,⁴⁰ J. Lingemann,⁴⁰ T. Müller,⁴⁰ A. Nehr Korn,⁴⁰ A. Nowack,⁴⁰ C. Pistone,⁴⁰ O. Pooth,⁴⁰ A. Stahl,^{40,p} M. Aldaya Martin,⁴¹ T. Arndt,⁴¹ C. Asawatangtrakuldee,⁴¹ K. Beernaert,⁴¹ O. Behnke,⁴¹ U. Behrens,⁴¹ A. A. Bin Anuar,⁴¹ K. Borrás,^{41,q} A. Campbell,⁴¹ P. Connor,⁴¹ C. Contreras-Campana,⁴¹ F. Costanza,⁴¹ C. Diez Pardos,⁴¹ G. Dolinska,⁴¹ G. Eckerlin,⁴¹ D. Eckstein,⁴¹ T. Eichhorn,⁴¹ E. Eren,⁴¹ E. Gallo,^{41,r} J. Garay Garcia,⁴¹ A. Geiser,⁴¹ A. Gizhko,⁴¹ J. M. Grados Luyando,⁴¹ A. Grohsjean,⁴¹ P. Gunnellini,⁴¹ A. Harb,⁴¹ J. Hauk,⁴¹ M. Hempel,^{41,s} H. Jung,⁴¹ A. Kalogeropoulos,⁴¹ O. Karacheban,^{41,s} M. Kasemann,⁴¹ J. Keaveney,⁴¹ C. Kleinwort,⁴¹ I. Korol,⁴¹ D. Krücker,⁴¹ W. Lange,⁴¹ A. Lelek,⁴¹ T. Lenz,⁴¹ J. Leonard,⁴¹ K. Lipka,⁴¹ W. Lohmann,^{41,s} R. Mankel,⁴¹

I.-A. Melzer-Pellmann,⁴¹ A. B. Meyer,⁴¹ G. Mittag,⁴¹ J. Mnich,⁴¹ A. Mussgiller,⁴¹ E. Ntomari,⁴¹ D. Pitzl,⁴¹ R. Placakyte,⁴¹ A. Raspereza,⁴¹ B. Roland,⁴¹ M. Ö. Sahin,⁴¹ P. Saxena,⁴¹ T. Schoerner-Sadenius,⁴¹ S. Spannagel,⁴¹ N. Stefaniuk,⁴¹ G. P. Van Onsem,⁴¹ R. Walsh,⁴¹ C. Wissing,⁴¹ V. Blobel,⁴² M. Centis Vignali,⁴² A. R. Draeger,⁴² T. Dreyer,⁴² E. Garutti,⁴² D. Gonzalez,⁴² J. Haller,⁴² M. Hoffmann,⁴² A. Junkes,⁴² R. Klanner,⁴² R. Kogler,⁴² N. Kovalchuk,⁴² S. Kurz,⁴² T. Lapsien,⁴² I. Marchesini,⁴² D. Marconi,⁴² M. Meyer,⁴² M. Niedziela,⁴² D. Nowatschin,⁴² F. Pantaleo,^{42,p} T. Peiffer,⁴² A. Perieanu,⁴² C. Scharf,⁴² P. Schleper,⁴² A. Schmidt,⁴² S. Schumann,⁴² J. Schwandt,⁴² J. Sonneveld,⁴² H. Stadie,⁴² G. Steinbrück,⁴² F. M. Stober,⁴² M. Stöver,⁴² H. Tholen,⁴² D. Troendle,⁴² E. Usai,⁴² L. Vanelderden,⁴² A. Vanhoefer,⁴² B. Vormwald,⁴² M. Akbiyik,⁴³ C. Barth,⁴³ S. Baur,⁴³ C. Baus,⁴³ J. Berger,⁴³ E. Butz,⁴³ R. Caspart,⁴³ T. Chwalek,⁴³ F. Colombo,⁴³ W. De Boer,⁴³ A. Dierlamm,⁴³ S. Fink,⁴³ B. Freund,⁴³ R. Friese,⁴³ M. Giffels,⁴³ A. Gilbert,⁴³ P. Goldenzweig,⁴³ D. Haitz,⁴³ F. Hartmann,^{43,p} S. M. Heindl,⁴³ U. Husemann,⁴³ F. Kassel,^{43,p} I. Katkov,^{43,o} S. Kudella,⁴³ H. Mildner,⁴³ M. U. Mozer,⁴³ Th. Müller,⁴³ M. Plagge,⁴³ G. Quast,⁴³ K. Rabbertz,⁴³ S. Röcker,⁴³ F. Roscher,⁴³ M. Schröder,⁴³ I. Shvetsov,⁴³ G. Sieber,⁴³ H. J. Simonis,⁴³ R. Ulrich,⁴³ S. Wayand,⁴³ M. Weber,⁴³ T. Weiler,⁴³ S. Williamson,⁴³ C. Wöhrmann,⁴³ R. Wolf,⁴³ G. Anagnostou,⁴⁴ G. Daskalakis,⁴⁴ T. Geralis,⁴⁴ V. A. Giakoumopoulou,⁴⁴ A. Kyriakis,⁴⁴ D. Loukas,⁴⁴ I. Topsis-Giotis,⁴⁴ S. Kesisoglou,⁴⁵ A. Panagiotou,⁴⁵ N. Saoulidou,⁴⁵ E. Tziaferi,⁴⁵ K. Kousouris,⁴⁶ I. Evangelou,⁴⁷ G. Flouris,⁴⁷ C. Foudas,⁴⁷ P. Kokkas,⁴⁷ N. Loukas,⁴⁷ N. Manthos,⁴⁷ I. Papadopoulos,⁴⁷ E. Paradas,⁴⁷ F. A. Triantis,⁴⁷ N. Filipovic,⁴⁸ G. Pasztor,⁴⁸ G. Bencze,⁴⁹ C. Hajdu,⁴⁹ D. Horvath,^{49,t} F. Sikler,⁴⁹ V. Veszpremi,⁴⁹ G. Vesztergombi,^{49,u} A. J. Zsigmond,⁴⁹ N. Beni,⁵⁰ S. Czellar,⁵⁰ J. Karancsi,^{50,v} A. Makovec,⁵⁰ J. Molnar,⁵⁰ Z. Szillasi,⁵⁰ M. Bartók,^{51,u} P. Raics,⁵¹ Z. L. Trocsanyi,⁵¹ B. Ujvari,⁵¹ S. Choudhury,⁵² J. R. Komaragiri,⁵² S. Bahinipati,^{53,w} S. Bhowmik,^{53,x} P. Mal,⁵³ K. Mandal,⁵³ A. Nayak,^{53,y} D. K. Sahoo,^{53,w} N. Sahoo,⁵³ S. K. Swain,⁵³ S. Bansal,⁵⁴ S. B. Beri,⁵⁴ V. Bhatnagar,⁵⁴ R. Chawla,⁵⁴ U. Bhawandeep,⁵⁴ A. K. Kalsi,⁵⁴ A. Kaur,⁵⁴ M. Kaur,⁵⁴ R. Kumar,⁵⁴ P. Kumari,⁵⁴ A. Mehta,⁵⁴ M. Mittal,⁵⁴ J. B. Singh,⁵⁴ G. Walia,⁵⁴ Ashok Kumar,⁵⁵ A. Bhardwaj,⁵⁵ B. C. Choudhary,⁵⁵ R. B. Garg,⁵⁵ S. Keshri,⁵⁵ A. Kumar,⁵⁵ S. Malhotra,⁵⁵ M. Naimuddin,⁵⁵ K. Ranjan,⁵⁵ R. Sharma,⁵⁵ V. Sharma,⁵⁵ R. Bhattacharya,⁵⁶ S. Bhattacharya,⁵⁶ K. Chatterjee,⁵⁶ S. Dey,⁵⁶ S. Dutt,⁵⁶ S. Dutta,⁵⁶ S. Ghosh,⁵⁶ N. Majumdar,⁵⁶ A. Modak,⁵⁶ K. Mondal,⁵⁶ S. Mukhopadhyay,⁵⁶ S. Nandan,⁵⁶ A. Purohit,⁵⁶ A. Roy,⁵⁶ D. Roy,⁵⁶ S. Roy Chowdhury,⁵⁶ S. Sarkar,⁵⁶ M. Sharan,⁵⁶ S. Thakur,⁵⁶ P. K. Behera,⁵⁷ R. Chudasama,⁵⁸ D. Dutta,⁵⁸ V. Jha,⁵⁸ V. Kumar,⁵⁸ A. K. Mohanty,^{58,p} P. K. Netrakanti,⁵⁸ L. M. Pant,⁵⁸ P. Shukla,⁵⁸ A. Topkar,⁵⁸ T. Aziz,⁵⁹ S. Dugad,⁵⁹ G. Kole,⁵⁹ B. Mahakud,⁵⁹ S. Mitra,⁵⁹ G. B. Mohanty,⁵⁹ B. Parida,⁵⁹ N. Sur,⁵⁹ B. Sutar,⁵⁹ S. Banerjee,⁶⁰ R. K. Dewanjee,⁶⁰ S. Ganguly,⁶⁰ M. Guchait,⁶⁰ Sa. Jain,⁶⁰ S. Kumar,⁶⁰ M. Maity,^{60,x} G. Majumder,⁶⁰ K. Mazumdar,⁶⁰ T. Sarkar,^{60,x} N. Wickramage,^{60,z} S. Chauhan,⁶¹ S. Dube,⁶¹ V. Hegde,⁶¹ A. Kapoor,⁶¹ K. Kotheekar,⁶¹ S. Pandey,⁶¹ A. Rane,⁶¹ S. Sharma,⁶¹ S. Chenarani,^{62,aa} E. Eskandari Tadavani,⁶² S. M. Etesami,^{62,aa} M. Khakzad,⁶² M. Mohammadi Najafabadi,⁶² M. Naseri,⁶² S. Paktinat Mehdiabadi,^{62,bb} F. Rezaei Hosseinabadi,⁶² B. Safarzadeh,^{62,cc} M. Zeinali,⁶² M. Felcini,⁶³ M. Grunewald,⁶³ M. Abbrescia,^{64a,64b} C. Calabria,^{64a,64b} C. Caputo,^{64a,64b} A. Colaleo,^{64a} D. Creanza,^{64a,64c} L. Cristella,^{64a,64b} N. De Filippis,^{64a,64c} M. De Palma,^{64a,64b} L. Fiore,^{64a} G. Iaselli,^{64a,64c} G. Maggi,^{64a,64c} M. Maggi,^{64a} G. Miniello,^{64a,64b} S. My,^{64a,64b} S. Nuzzo,^{64a,64b} A. Pompili,^{64a,64b} G. Pugliese,^{64a,64c} R. Radogna,^{64a,64b} A. Ranieri,^{64a} G. Selvaggi,^{64a,64b} A. Sharma,^{64a} L. Silvestris,^{64a,p} R. Venditti,^{64a,64b} P. Verwilligen,^{64a} G. Abbiendi,^{65a} C. Battilana,^{65a} D. Bonacorsi,^{65a,65b} S. Braibant-Giacomelli,^{65a,65b} L. Brigliadori,^{65a,65b} R. Campanini,^{65a,65b} P. Capiluppi,^{65a,65b} A. Castro,^{65a,65b} F. R. Cavallo,^{65a} S. S. Chhibra,^{65a,65b} G. Codispoti,^{65a,65b} M. Cuffiani,^{65a,65b} G. M. Dallavalle,^{65a} F. Fabbri,^{65a} A. Fanfani,^{65a,65b} D. Fasanella,^{65a,65b} P. Giacomelli,^{65a} C. Grandi,^{65a} L. Guiducci,^{65a,65b} S. Marcellini,^{65a} G. Masetti,^{65a} A. Montanari,^{65a} F. L. Navarria,^{65a,65b} A. Perrotta,^{65a} A. M. Rossi,^{65a,65b} T. Rovelli,^{65a,65b} G. P. Siroli,^{65a,65b} N. Tosi,^{65a,65b,p} S. Albergo,^{66a,66b} S. Costa,^{66a,66b} A. Di Mattia,^{66a} F. Giordano,^{66a,66b} R. Potenza,^{66a,66b} A. Tricomi,^{66a,66b} C. Tuve,^{66a,66b} G. Barbagli,^{67a} V. Ciulli,^{67a,67b} C. Civinini,^{67a} R. D'Alessandro,^{67a,67b} E. Focardi,^{67a,67b} P. Lenzi,^{67a,67b} M. Meschini,^{67a} S. Paoletti,^{67a} L. Russo,^{67a,dd} G. Sguazzoni,^{67a} D. Strom,^{67a} L. Viliani,^{67a,67b,p} L. Benussi,⁶⁸ S. Bianco,⁶⁸ F. Fabbri,⁶⁸ D. Piccolo,⁶⁸ F. Primavera,^{68,p} V. Calvelli,^{69a,69b} F. Ferro,^{69a} M. R. Monge,^{69a,69b} E. Robutti,^{69a} S. Tosi,^{69a,69b} L. Brianza,^{70a,70b,p} F. Brivio,^{70a,70b} V. Ciriolo,^{70a} M. E. Dinardo,^{70a,70b} S. Fiorendi,^{70a,70b,p} S. Gennai,^{70a} A. Ghezzi,^{70a,70b} P. Govoni,^{70a,70b} M. Malberti,^{70a,70b} S. Malvezzi,^{70a} R. A. Manzoni,^{70a,70b} D. Menasce,^{70a} L. Moroni,^{70a} M. Paganoni,^{70a,70b} D. Pedrini,^{70a} S. Pigazzini,^{70a,70b} S. Ragazzi,^{70a,70b} T. Tabarelli de Fatis,^{70a,70b} S. Buontempo,^{71a} N. Cavallo,^{71a,71c} G. De Nardo,^{71a,71b} S. Di Guida,^{71a,71d,p} F. Fabozzi,^{71a,71c} F. Fienga,^{71a,71b} A. O. M. Iorio,^{71a,71b} L. Lista,^{71a} S. Meola,^{71a,71d,p} P. Paolucci,^{71a,p} C. Sciacca,^{71a,71b} F. Thyssen,^{71a} P. Azzi,^{72a,p} N. Bacchetta,^{72a} L. Benato,^{72a,72b} D. Bisello,^{72a,72b} A. Boletti,^{72a,72b} R. Carlin,^{72a,72b} A. Carvalho Antunes De Oliveira,^{72a,72b} P. Checchia,^{72a} M. Dall'Osso,^{72a,72b} P. De Castro Manzano,^{72a} T. Dorigo,^{72a} F. Gasparini,^{72a,72b} U. Gasparini,^{72a,72b} A. Gozzelino,^{72a} S. Lacaprara,^{72a} M. Margoni,^{72a,72b}

A. T. Meneguzzo,^{72a,72b} J. Pazzini,^{72a,72b} N. Pozzobon,^{72a,72b} P. Ronchese,^{72a,72b} R. Rossin,^{72a,72b} F. Simonetto,^{72a,72b}
E. Torassa,^{72a} M. Zanetti,^{72a,72b} P. Zotto,^{72a,72b} G. Zumerle,^{72a,72b} A. Braghieri,^{73a} F. Fallavollita,^{73a,73b} A. Magnani,^{73a,73b}
P. Montagna,^{73a,73b} S. P. Ratti,^{73a,73b} V. Re,^{73a} M. Ressegotti,^{73a} C. Riccardi,^{73a,73b} P. Salvini,^{73a} I. Vai,^{73a,73b} P. Vitulo,^{73a,73b}
L. Alunni Solestizi,^{74a,74b} G. M. Bilei,^{74a} D. Ciangottini,^{74a,74b} L. Fanò,^{74a,74b} P. Lariccia,^{74a,74b} R. Leonardi,^{74a,74b}
G. Mantovani,^{74a,74b} V. Mariani,^{74a,74b} M. Menichelli,^{74a} A. Saha,^{74a} A. Santocchia,^{74a,74b} K. Androsov,^{75a} P. Azzurri,^{75a,p}
G. Bagliesi,^{75a} J. Bernardini,^{75a} T. Boccali,^{75a} R. Castaldi,^{75a} M. A. Ciocci,^{75a,75b} R. Dell’Orso,^{75a} G. Fedi,^{75a} A. Giassi,^{75a}
M. T. Grippo,^{75a,dd} F. Ligabue,^{75a,75c} T. Lomtadze,^{75a} L. Martini,^{75a,75b} A. Messineo,^{75a,75b} F. Palla,^{75a} A. Rizzi,^{75a,75b}
A. Savoy-Navarro,^{75a,ee} P. Spagnolo,^{75a} R. Tenchini,^{75a} G. Tonelli,^{75a,75b} A. Venturi,^{75a} P. G. Verdini,^{75a} L. Barone,^{76a,76b}
F. Cavallari,^{76a} M. Cipriani,^{76a,76b} D. Del Re,^{76a,76b,p} M. Diemoz,^{76a} S. Gelli,^{76a,76b} E. Longo,^{76a,76b} F. Margaroli,^{76a,76b}
B. Marzocchi,^{76a,76b} P. Meridiani,^{76a} G. Organtini,^{76a,76b} R. Paramatti,^{76a,76b} F. Preiato,^{76a,76b} S. Rahatlou,^{76a,76b} C. Rovelli,^{76a}
F. Santanastasio,^{76a,76b} N. Amapane,^{77a,77b} R. Arcidiacono,^{77a,77c,p} S. Argiro,^{77a,77b} M. Arneodo,^{77a,77c} N. Bartosik,^{77a}
R. Bellan,^{77a,77b} C. Biino,^{77a} N. Cartiglia,^{77a} F. Cenna,^{77a,77b} M. Costa,^{77a,77b} R. Covarelli,^{77a,77b} A. Degano,^{77a,77b}
N. Demaria,^{77a} B. Kiani,^{77a,77b} C. Mariotti,^{77a} S. Maselli,^{77a} E. Migliore,^{77a,77b} V. Monaco,^{77a,77b} E. Monteil,^{77a,77b}
M. Monteno,^{77a} M. M. Obertino,^{77a,77b} L. Pacher,^{77a,77b} N. Pastrone,^{77a} M. Pelliccioni,^{77a} G. L. Pinna Angioni,^{77a,77b}
F. Ravera,^{77a,77b} A. Romero,^{77a,77b} M. Ruspá,^{77a,77c} R. Sacchi,^{77a,77b} K. Shchelina,^{77a,77b} V. Sola,^{77a} A. Solano,^{77a,77b}
A. Staiano,^{77a} P. Traczyk,^{77a,77b} S. Belforte,^{78a} M. Casarsa,^{78a} F. Cossutti,^{78a} G. Della Ricca,^{78a,78b} A. Zanetti,^{78a} D. H. Kim,⁷⁹
G. N. Kim,⁷⁹ M. S. Kim,⁷⁹ J. Lee,⁷⁹ S. Lee,⁷⁹ S. W. Lee,⁷⁹ Y. D. Oh,⁷⁹ S. Sekmen,⁷⁹ D. C. Son,⁷⁹ Y. C. Yang,⁷⁹ A. Lee,⁸⁰
H. Kim,⁸¹ J. A. Brochero Cifuentes,⁸² J. Goh,⁸² T. J. Kim,⁸² S. Cho,⁸³ S. Choi,⁸³ Y. Go,⁸³ D. Gyun,⁸³ S. Ha,⁸³ B. Hong,⁸³
Y. Jo,⁸³ Y. Kim,⁸³ K. Lee,⁸³ K. S. Lee,⁸³ S. Lee,⁸³ J. Lim,⁸³ S. K. Park,⁸³ Y. Roh,⁸³ J. Almond,⁸⁴ J. Kim,⁸⁴ H. Lee,⁸⁴
S. B. Oh,⁸⁴ B. C. Radburn-Smith,⁸⁴ S. h. Seo,⁸⁴ U. K. Yang,⁸⁴ H. D. Yoo,⁸⁴ G. B. Yu,⁸⁴ M. Choi,⁸⁵ H. Kim,⁸⁵ J. H. Kim,⁸⁵
J. S. H. Lee,⁸⁵ I. C. Park,⁸⁵ G. Ryu,⁸⁵ M. S. Ryu,⁸⁵ Y. Choi,⁸⁶ C. Hwang,⁸⁶ J. Lee,⁸⁶ I. Yu,⁸⁶ V. Dudená,⁸⁷ A. Juodagalvis,⁸⁷
J. Vaitkus,⁸⁷ I. Ahmed,⁸⁸ Z. A. Ibrahim,⁸⁸ M. A. B. Md Ali,^{88,ff} F. Mohamad Idris,^{88,gg} W. A. T. Wan Abdullah,⁸⁸
M. N. Yusli,⁸⁸ Z. Zolkapli,⁸⁸ H. Castilla-Valdez,⁸⁹ E. De La Cruz-Burelo,⁸⁹ I. Heredia-De La Cruz,^{89,hh}
R. Lopez-Fernandez,⁸⁹ R. Magaña Villalba,⁸⁹ J. Mejia Guisao,⁸⁹ A. Sanchez-Hernandez,⁸⁹ S. Carrillo Moreno,⁹⁰
C. Oropeza Barrera,⁹⁰ F. Vazquez Valencia,⁹⁰ S. Carpinteyro,⁹¹ I. Pedraza,⁹¹ H. A. Salazar Ibarguen,⁹¹ C. Uribe Estrada,⁹¹
A. Morelos Pineda,⁹² D. Krofcheck,⁹³ P. H. Butler,⁹⁴ A. Ahmad,⁹⁵ M. Ahmad,⁹⁵ Q. Hassan,⁹⁵ H. R. Hoorani,⁹⁵
W. A. Khan,⁹⁵ A. Saddique,⁹⁵ M. A. Shah,⁹⁵ M. Shoaib,⁹⁵ M. Waqas,⁹⁵ H. Bialkowska,⁹⁶ M. Bluj,⁹⁶ B. Boimska,⁹⁶
T. Frueboes,⁹⁶ M. Górski,⁹⁶ M. Kazana,⁹⁶ K. Nawrocki,⁹⁶ K. Romanowska-Rybinska,⁹⁶ M. Szleper,⁹⁶ P. Zalewski,⁹⁶
K. Bunkowski,⁹⁷ A. Byszuk,^{97,ii} K. Doroba,⁹⁷ A. Kalinowski,⁹⁷ M. Konecki,⁹⁷ J. Krolikowski,⁹⁷ M. Misiura,⁹⁷
M. Olszewski,⁹⁷ A. Pyskir,⁹⁷ M. Walczak,⁹⁷ P. Bargassa,⁹⁸ C. Beirão Da Cruz E Silva,⁹⁸ B. Calpas,⁹⁸ A. Di Francesco,⁹⁸
P. Faccioli,⁹⁸ M. Gallinaro,⁹⁸ J. Hollar,⁹⁸ N. Leonardo,⁹⁸ L. Lloret Iglesias,⁹⁸ M. V. Nemallapudi,⁹⁸ J. Seixas,⁹⁸ O. Toldaiev,⁹⁸
D. Vadrucchio,⁹⁸ J. Varela,⁹⁸ S. Afanasiev,⁹⁹ P. Bunin,⁹⁹ M. Gavrilenko,⁹⁹ I. Golutvin,⁹⁹ I. Gorbunov,⁹⁹ A. Kamenev,⁹⁹
V. Karjavin,⁹⁹ A. Lanev,⁹⁹ A. Malakhov,⁹⁹ V. Matveev,^{99,jj,kk} V. Palichik,⁹⁹ V. Perelygin,⁹⁹ S. Shmatov,⁹⁹ S. Shulha,⁹⁹
N. Skatchkov,⁹⁹ V. Smirnov,⁹⁹ N. Voytishin,⁹⁹ A. Zarubin,⁹⁹ L. Chtchipounov,¹⁰⁰ V. Golovtsov,¹⁰⁰ Y. Ivanov,¹⁰⁰ V. Kim,^{100,ll}
E. Kuznetsova,^{100,mmm} V. Murzin,¹⁰⁰ V. Oreshkin,¹⁰⁰ V. Sulimov,¹⁰⁰ A. Vorobyev,¹⁰⁰ Yu. Andreev,¹⁰¹ A. Dermenev,¹⁰¹
S. Gninenko,¹⁰¹ N. Golubev,¹⁰¹ A. Karneyev,¹⁰¹ M. Kirsanov,¹⁰¹ N. Krasnikov,¹⁰¹ A. Pashenkov,¹⁰¹ D. Tlisov,¹⁰¹
A. Toropin,¹⁰¹ V. Epshteyn,¹⁰² V. Gavrilov,¹⁰² N. Lychkovskaya,¹⁰² V. Popov,¹⁰² I. Pozdnyakov,¹⁰² G. Safronov,¹⁰²
A. Spiridonov,¹⁰² M. Toms,¹⁰² E. Vlasov,¹⁰² A. Zhokin,¹⁰² T. Aushev,¹⁰³ A. Bylinkin,^{103,kk} R. Chistov,^{104,nn} M. Danilov,^{104,nn}
S. Polikarpov,¹⁰⁴ V. Andreev,¹⁰⁵ M. Azarkin,^{105,kk} I. Dremin,^{105,kk} M. Kirakosyan,¹⁰⁵ A. Leonidov,^{105,kk} A. Terkulov,¹⁰⁵
A. Baskakov,¹⁰⁶ A. Belyaev,¹⁰⁶ E. Boos,¹⁰⁶ V. Bunichev,¹⁰⁶ M. Dubinin,^{106,oo} L. Dudko,¹⁰⁶ A. Gribushin,¹⁰⁶ V. Klyukhin,¹⁰⁶
O. Kodolova,¹⁰⁶ I. Lokhtin,¹⁰⁶ I. Miagkov,¹⁰⁶ S. Obraztsov,¹⁰⁶ M. Perfilov,¹⁰⁶ S. Petrushanko,¹⁰⁶ V. Savrin,¹⁰⁶ V. Blinov,^{107,pp}
Y. Skovpen,^{107,pp} D. Shtol,^{107,pp} I. Azhgirey,¹⁰⁸ I. Bayshev,¹⁰⁸ S. Bitiukov,¹⁰⁸ D. Elumakhov,¹⁰⁸ V. Kachanov,¹⁰⁸
A. Kalinin,¹⁰⁸ D. Konstantinov,¹⁰⁸ V. Krychkin,¹⁰⁸ V. Petrov,¹⁰⁸ R. Ryutin,¹⁰⁸ A. Sobol,¹⁰⁸ S. Troshin,¹⁰⁸ N. Tyurin,¹⁰⁸
A. Uzunian,¹⁰⁸ A. Volkov,¹⁰⁸ P. Adzic,^{109,qq} P. Cirkovic,¹⁰⁹ D. Devetak,¹⁰⁹ M. Dordevic,¹⁰⁹ J. Milosevic,¹⁰⁹ V. Rekovic,¹⁰⁹
J. Alcaraz Maestre,¹¹⁰ M. Barrio Luna,¹¹⁰ E. Calvo,¹¹⁰ M. Cerrada,¹¹⁰ M. Chamizo Llatas,¹¹⁰ N. Colino,¹¹⁰ B. De La Cruz,¹¹⁰
A. Delgado Peris,¹¹⁰ A. Escalante Del Valle,¹¹⁰ C. Fernandez Bedoya,¹¹⁰ J. P. Fernández Ramos,¹¹⁰ J. Flix,¹¹⁰ M. C. Fouz,¹¹⁰
P. Garcia-Abia,¹¹⁰ O. Gonzalez Lopez,¹¹⁰ S. Goy Lopez,¹¹⁰ J. M. Hernandez,¹¹⁰ M. I. Josa,¹¹⁰ E. Navarro De Martino,¹¹⁰
A. Pérez-Calero Yzquierdo,¹¹⁰ J. Puerta Pelayo,¹¹⁰ A. Quintario Olmeda,¹¹⁰ I. Redondo,¹¹⁰ L. Romero,¹¹⁰ M. S. Soares,¹¹⁰
J. F. de Trocóniz,¹¹¹ M. Missiroli,¹¹¹ D. Moran,¹¹¹ J. Cuevas,¹¹² C. Erice,¹¹² J. Fernandez Menendez,¹¹²

I. Gonzalez Caballero,¹¹² J. R. González Fernández,¹¹² E. Palencia Cortezon,¹¹² S. Sanchez Cruz,¹¹² I. Suárez Andrés,¹¹² P. Vischia,¹¹² J. M. Vizan Garcia,¹¹² I. J. Cabrillo,¹¹³ A. Calderon,¹¹³ E. Curras,¹¹³ M. Fernandez,¹¹³ J. Garcia-Ferrero,¹¹³ G. Gomez,¹¹³ A. Lopez Virto,¹¹³ J. Marco,¹¹³ C. Martinez Rivero,¹¹³ F. Matorras,¹¹³ J. Piedra Gomez,¹¹³ T. Rodrigo,¹¹³ A. Ruiz-Jimeno,¹¹³ L. Scodellaro,¹¹³ N. Trevisani,¹¹³ I. Vila,¹¹³ R. Vilar Cortabitarte,¹¹³ D. Abbaneo,¹¹⁴ E. Auffray,¹¹⁴ G. Auzinger,¹¹⁴ P. Baillon,¹¹⁴ A. H. Ball,¹¹⁴ D. Barney,¹¹⁴ P. Bloch,¹¹⁴ A. Bocci,¹¹⁴ C. Botta,¹¹⁴ T. Camporesi,¹¹⁴ R. Castello,¹¹⁴ M. Cepeda,¹¹⁴ G. Cerminara,¹¹⁴ Y. Chen,¹¹⁴ A. Cimmino,¹¹⁴ D. d'Enterria,¹¹⁴ A. Dabrowski,¹¹⁴ V. Daponte,¹¹⁴ A. David,¹¹⁴ M. De Gruttola,¹¹⁴ A. De Roeck,¹¹⁴ E. Di Marco,^{114,rr} M. Dobson,¹¹⁴ B. Dorney,¹¹⁴ T. du Pree,¹¹⁴ M. Dünser,¹¹⁴ N. Dupont,¹¹⁴ A. Elliott-Peisert,¹¹⁴ P. Everaerts,¹¹⁴ S. Fartoukh,¹¹⁴ G. Franzoni,¹¹⁴ J. Fulcher,¹¹⁴ W. Funk,¹¹⁴ D. Gigi,¹¹⁴ K. Gill,¹¹⁴ M. Girone,¹¹⁴ F. Glege,¹¹⁴ D. Gulhan,¹¹⁴ S. Gundacker,¹¹⁴ M. Guthoff,¹¹⁴ P. Harris,¹¹⁴ J. Hegeman,¹¹⁴ V. Innocente,¹¹⁴ P. Janot,¹¹⁴ J. Kieseler,¹¹⁴ H. Kirschenmann,¹¹⁴ V. Knünz,¹¹⁴ A. Kornmayer,^{114,p} M. J. Kortelainen,¹¹⁴ M. Krammer,^{114,b} C. Lange,¹¹⁴ P. Lecoq,¹¹⁴ C. Lourenço,¹¹⁴ M. T. Lucchini,¹¹⁴ L. Malgeri,¹¹⁴ M. Mannelli,¹¹⁴ A. Martelli,¹¹⁴ F. Meijers,¹¹⁴ J. A. Merlin,¹¹⁴ S. Mersi,¹¹⁴ E. Meschi,¹¹⁴ P. Milenovic,^{114,ss} F. Moortgat,¹¹⁴ S. Morovic,¹¹⁴ M. Mulders,¹¹⁴ H. Neugebauer,¹¹⁴ S. Orfanelli,¹¹⁴ L. Orsini,¹¹⁴ L. Pape,¹¹⁴ E. Perez,¹¹⁴ M. Peruzzi,¹¹⁴ A. Petrilli,¹¹⁴ G. Petrucciani,¹¹⁴ A. Pfeiffer,¹¹⁴ M. Pierini,¹¹⁴ A. Racz,¹¹⁴ T. Reis,¹¹⁴ G. Rolandi,^{114,tt} M. Rovere,¹¹⁴ H. Sakulin,¹¹⁴ J. B. Sauvan,¹¹⁴ C. Schäfer,¹¹⁴ C. Schwick,¹¹⁴ M. Seidel,¹¹⁴ M. Selvaggi,¹¹⁴ A. Sharma,¹¹⁴ P. Silva,¹¹⁴ P. Sphicas,^{114,uu} J. Steggemann,¹¹⁴ M. Stoye,¹¹⁴ Y. Takahashi,¹¹⁴ M. Tosi,¹¹⁴ D. Treille,¹¹⁴ A. Triossi,¹¹⁴ A. Tsirou,¹¹⁴ V. Veckalns,^{114,vv} G. I. Veres,^{114,u} M. Verweij,¹¹⁴ N. Wardle,¹¹⁴ H. K. Wöhri,¹¹⁴ A. Zagozdinska,^{114,ii} W. D. Zeuner,¹¹⁴ W. Bertl,¹¹⁵ K. Deiters,¹¹⁵ W. Erdmann,¹¹⁵ R. Horisberger,¹¹⁵ Q. Ingram,¹¹⁵ H. C. Kaestli,¹¹⁵ D. Kotlinski,¹¹⁵ U. Langenegger,¹¹⁵ T. Rohe,¹¹⁵ S. A. Wiederkehr,¹¹⁵ F. Bachmair,¹¹⁶ L. Bäni,¹¹⁶ L. Bianchini,¹¹⁶ B. Casal,¹¹⁶ G. Dissertori,¹¹⁶ M. Dittmar,¹¹⁶ M. Donegà,¹¹⁶ C. Grab,¹¹⁶ C. Heidegger,¹¹⁶ D. Hits,¹¹⁶ J. Hoss,¹¹⁶ G. Kasieczka,¹¹⁶ W. Lustermaan,¹¹⁶ B. Mangano,¹¹⁶ M. Marionneau,¹¹⁶ P. Martinez Ruiz del Arbol,¹¹⁶ M. Masciovecchio,¹¹⁶ M. T. Meinhard,¹¹⁶ D. Meister,¹¹⁶ F. Micheli,¹¹⁶ P. Musella,¹¹⁶ F. Nessi-Tedaldi,¹¹⁶ F. Pandolfi,¹¹⁶ J. Pata,¹¹⁶ F. Pauss,¹¹⁶ G. Perrin,¹¹⁶ L. Perrozzi,¹¹⁶ M. Quittnat,¹¹⁶ M. Rossini,¹¹⁶ M. Schönenberger,¹¹⁶ A. Starodumov,^{116,ww} V. R. Tavolaro,¹¹⁶ K. Theofilatos,¹¹⁶ R. Wallny,¹¹⁶ T. K. Aarrestad,¹¹⁷ C. Amsler,^{117,xx} L. Caminada,¹¹⁷ M. F. Canelli,¹¹⁷ A. De Cosa,¹¹⁷ S. Donato,¹¹⁷ C. Galloni,¹¹⁷ A. Hinzmann,¹¹⁷ T. Hreus,¹¹⁷ B. Kilminster,¹¹⁷ J. Ngadiuba,¹¹⁷ D. Pinna,¹¹⁷ G. Rauco,¹¹⁷ P. Robmann,¹¹⁷ D. Salerno,¹¹⁷ C. Seitz,¹¹⁷ Y. Yang,¹¹⁷ A. Zuchetta,¹¹⁷ V. Candelise,¹¹⁸ T. H. Doan,¹¹⁸ Sh. Jain,¹¹⁸ R. Khurana,¹¹⁸ M. Konyushikhin,¹¹⁸ C. M. Kuo,¹¹⁸ W. Lin,¹¹⁸ A. Pozdnyakov,¹¹⁸ S. S. Yu,¹¹⁸ Arun Kumar,¹¹⁹ P. Chang,¹¹⁹ Y. H. Chang,¹¹⁹ Y. Chao,¹¹⁹ K. F. Chen,¹¹⁹ P. H. Chen,¹¹⁹ F. Fiori,¹¹⁹ W.-S. Hou,¹¹⁹ Y. Hsiung,¹¹⁹ Y. F. Liu,¹¹⁹ R.-S. Lu,¹¹⁹ M. Miñano Moya,¹¹⁹ E. Paganis,¹¹⁹ A. Psallidas,¹¹⁹ J. f. Tsai,¹¹⁹ B. Asavapibhop,¹²⁰ G. Singh,¹²⁰ N. Srimanobhas,¹²⁰ N. Suwonjandee,¹²⁰ A. Adiguzel,¹²¹ F. Boran,¹²¹ S. Cerci,^{121,yy} S. Damarseckin,¹²¹ Z. S. Demiroglu,¹²¹ C. Dozen,¹²¹ I. Dumanoglu,¹²¹ S. Girgis,¹²¹ G. Gokbulut,¹²¹ Y. Guler,¹²¹ I. Hos,^{121,zz} E. E. Kangal,^{121,aaa} O. Kara,¹²¹ A. Kayis Topaksu,¹²¹ U. Kiminsu,¹²¹ M. Oglakci,¹²¹ G. Onengut,^{121,bbb} K. Ozdemir,^{121,ccc} D. Sunar Cerci,^{121,yy} H. Topakli,^{121,ddd} S. Turkcapar,¹²¹ I. S. Zorbakir,¹²¹ C. Zorbilmez,¹²¹ B. Bilin,¹²² B. Isildak,^{122,eee} G. Karapinar,^{122,fff} M. Yalvac,¹²² M. Zeyrek,¹²² E. Gülmez,¹²³ M. Kaya,^{123,ggg} O. Kaya,^{123,hhh} E. A. Yetkin,^{123,iii} T. Yetkin,^{123,jjj} A. Cakir,¹²⁴ K. Cankocak,¹²⁴ S. Sen,^{124,kkk} B. Grynyov,¹²⁵ L. Levchuk,¹²⁶ P. Sorokin,¹²⁶ R. Aggleton,¹²⁷ F. Ball,¹²⁷ L. Beck,¹²⁷ J. J. Brooke,¹²⁷ D. Burns,¹²⁷ E. Clement,¹²⁷ D. Cussans,¹²⁷ H. Flacher,¹²⁷ J. Goldstein,¹²⁷ M. Grimes,¹²⁷ G. P. Heath,¹²⁷ H. F. Heath,¹²⁷ J. Jacob,¹²⁷ L. Kreczko,¹²⁷ C. Lucas,¹²⁷ D. M. Newbold,^{127,lll} S. Paramesvaran,¹²⁷ A. Poll,¹²⁷ T. Sakuma,¹²⁷ S. Seif El Nasr-storey,¹²⁷ D. Smith,¹²⁷ V. J. Smith,¹²⁷ K. W. Bell,¹²⁸ A. Belyaev,^{128,mmm} C. Brew,¹²⁸ R. M. Brown,¹²⁸ L. Calligaris,¹²⁸ D. Cieri,¹²⁸ D. J. A. Cockerill,¹²⁸ J. A. Coughlan,¹²⁸ K. Harder,¹²⁸ S. Harper,¹²⁸ E. Olaiya,¹²⁸ D. Petyt,¹²⁸ C. H. Shepherd-Themistocleous,¹²⁸ A. Thea,¹²⁸ I. R. Tomalin,¹²⁸ T. Williams,¹²⁸ M. Baber,¹²⁹ R. Bainbridge,¹²⁹ O. Buchmuller,¹²⁹ A. Bundoock,¹²⁹ S. Casasso,¹²⁹ M. Citron,¹²⁹ D. Colling,¹²⁹ L. Corpe,¹²⁹ P. Dauncey,¹²⁹ G. Davies,¹²⁹ A. De Wit,¹²⁹ M. Della Negra,¹²⁹ R. Di Maria,¹²⁹ P. Dunne,¹²⁹ A. Elwood,¹²⁹ D. Futyan,¹²⁹ Y. Haddad,¹²⁹ G. Hall,¹²⁹ G. Iles,¹²⁹ T. James,¹²⁹ R. Lane,¹²⁹ C. Laner,¹²⁹ L. Lyons,¹²⁹ A.-M. Magnan,¹²⁹ S. Malik,¹²⁹ L. Mastrolorenzo,¹²⁹ J. Nash,¹²⁹ A. Nikitenko,^{129,ww} J. Pela,¹²⁹ B. Penning,¹²⁹ M. Pesaresi,¹²⁹ D. M. Raymond,¹²⁹ A. Richards,¹²⁹ A. Rose,¹²⁹ E. Scott,¹²⁹ C. Seez,¹²⁹ S. Summers,¹²⁹ A. Tapper,¹²⁹ K. Uchida,¹²⁹ M. Vazquez Acosta,^{129,nnn} T. Virdee,^{129,p} J. Wright,¹²⁹ S. C. Zenz,¹²⁹ J. E. Cole,¹³⁰ P. R. Hobson,¹³⁰ A. Khan,¹³⁰ P. Kyberd,¹³⁰ I. D. Reid,¹³⁰ P. Symonds,¹³⁰ L. Teodorescu,¹³⁰ M. Turner,¹³⁰ A. Borzou,¹³¹ K. Call,¹³¹ J. Dittmann,¹³¹ K. Hatakeyama,¹³¹ H. Liu,¹³¹ N. Pastika,¹³¹ R. Bartek,¹³² A. Dominguez,¹³² A. Buccilli,¹³³ S. I. Cooper,¹³³ C. Henderson,¹³³ P. Rumerio,¹³³ C. West,¹³³ D. Arcaro,¹³⁴ A. Avetisyan,¹³⁴ T. Bose,¹³⁴ D. Gastler,¹³⁴ D. Rankin,¹³⁴ C. Richardson,¹³⁴ J. Rohlf,¹³⁴ L. Sulak,¹³⁴ D. Zou,¹³⁴ G. Benelli,¹³⁵ D. Cutts,¹³⁵ A. Garabedian,¹³⁵ J. Hakala,¹³⁵ U. Heintz,¹³⁵

J. M. Hogan,¹³⁵ O. Jesus,¹³⁵ K. H. M. Kwok,¹³⁵ E. Laird,¹³⁵ G. Landsberg,¹³⁵ Z. Mao,¹³⁵ M. Narain,¹³⁵ S. Piperov,¹³⁵ S. Sagir,¹³⁵ E. Spencer,¹³⁵ R. Syarif,¹³⁵ R. Breedon,¹³⁶ D. Burns,¹³⁶ M. Calderon De La Barca Sanchez,¹³⁶ S. Chauhan,¹³⁶ M. Chertok,¹³⁶ J. Conway,¹³⁶ R. Conway,¹³⁶ P. T. Cox,¹³⁶ R. Erbacher,¹³⁶ C. Flores,¹³⁶ G. Funk,¹³⁶ M. Gardner,¹³⁶ W. Ko,¹³⁶ R. Lander,¹³⁶ C. Mclean,¹³⁶ M. Mulhearn,¹³⁶ D. Pellett,¹³⁶ J. Pilot,¹³⁶ S. Shalhout,¹³⁶ M. Shi,¹³⁶ J. Smith,¹³⁶ M. Squires,¹³⁶ D. Stolp,¹³⁶ K. Tos,¹³⁶ M. Tripathi,¹³⁶ M. Bachtis,¹³⁷ C. Bravo,¹³⁷ R. Cousins,¹³⁷ A. Dasgupta,¹³⁷ A. Florent,¹³⁷ J. Hauser,¹³⁷ M. Ignatenko,¹³⁷ N. Mccoll,¹³⁷ D. Saltzberg,¹³⁷ C. Schnaible,¹³⁷ V. Valuev,¹³⁷ M. Weber,¹³⁷ E. Bouvier,¹³⁸ K. Burt,¹³⁸ R. Clare,¹³⁸ J. Ellison,¹³⁸ J. W. Gary,¹³⁸ S. M. A. Ghiasi Shirazi,¹³⁸ G. Hanson,¹³⁸ J. Heilman,¹³⁸ P. Jandir,¹³⁸ E. Kennedy,¹³⁸ F. Lacroix,¹³⁸ O. R. Long,¹³⁸ M. Olmedo Negrete,¹³⁸ M. I. Paneva,¹³⁸ A. Shrinivas,¹³⁸ W. Si,¹³⁸ H. Wei,¹³⁸ S. Wimpenny,¹³⁸ B. R. Yates,¹³⁸ J. G. Branson,¹³⁹ G. B. Cerati,¹³⁹ S. Cittolin,¹³⁹ M. Derdzinski,¹³⁹ R. Gerosa,¹³⁹ A. Holzner,¹³⁹ D. Klein,¹³⁹ V. Krutelyov,¹³⁹ J. Letts,¹³⁹ I. Macneill,¹³⁹ D. Olivito,¹³⁹ S. Padhi,¹³⁹ M. Pieri,¹³⁹ M. Sani,¹³⁹ V. Sharma,¹³⁹ S. Simon,¹³⁹ M. Tadel,¹³⁹ A. Vartak,¹³⁹ S. Wasserbaech,^{139,000} C. Welke,¹³⁹ J. Wood,¹³⁹ F. Würthwein,¹³⁹ A. Yagil,¹³⁹ G. Zevi Della Porta,¹³⁹ N. Amin,¹⁴⁰ R. Bhandari,¹⁴⁰ J. Bradmiller-Feld,¹⁴⁰ C. Campagnari,¹⁴⁰ A. Dishaw,¹⁴⁰ V. Dutta,¹⁴⁰ M. Franco Sevilla,¹⁴⁰ C. George,¹⁴⁰ F. Golf,¹⁴⁰ L. Gouskos,¹⁴⁰ J. Gran,¹⁴⁰ R. Heller,¹⁴⁰ J. Incandela,¹⁴⁰ S. D. Mullin,¹⁴⁰ A. Ovcharova,¹⁴⁰ H. Qu,¹⁴⁰ J. Richman,¹⁴⁰ D. Stuart,¹⁴⁰ I. Suarez,¹⁴⁰ J. Yoo,¹⁴⁰ D. Anderson,¹⁴¹ J. Bendavid,¹⁴¹ A. Bornheim,¹⁴¹ J. Bunn,¹⁴¹ J. M. Lawhorn,¹⁴¹ A. Mott,¹⁴¹ H. B. Newman,¹⁴¹ C. Pena,¹⁴¹ M. Spiropulu,¹⁴¹ J. R. Vlimant,¹⁴¹ S. Xie,¹⁴¹ R. Y. Zhu,¹⁴¹ M. B. Andrews,¹⁴² T. Ferguson,¹⁴² M. Paulini,¹⁴² J. Russ,¹⁴² M. Sun,¹⁴² H. Vogel,¹⁴² I. Vorobiev,¹⁴² M. Weinberg,¹⁴² J. P. Cumalat,¹⁴³ W. T. Ford,¹⁴³ F. Jensen,¹⁴³ A. Johnson,¹⁴³ M. Krohn,¹⁴³ S. Leontsinis,¹⁴³ T. Mulholland,¹⁴³ K. Stenson,¹⁴³ S. R. Wagner,¹⁴³ J. Alexander,¹⁴⁴ J. Chaves,¹⁴⁴ J. Chu,¹⁴⁴ S. Dittmer,¹⁴⁴ K. McDermott,¹⁴⁴ N. Mirman,¹⁴⁴ J. R. Patterson,¹⁴⁴ A. Rinkevicius,¹⁴⁴ A. Ryd,¹⁴⁴ L. Skinnari,¹⁴⁴ L. Soffi,¹⁴⁴ S. M. Tan,¹⁴⁴ Z. Tao,¹⁴⁴ J. Thom,¹⁴⁴ J. Tucker,¹⁴⁴ P. Wittich,¹⁴⁴ M. Zientek,¹⁴⁴ D. Winn,¹⁴⁵ S. Abdullin,¹⁴⁶ M. Albrow,¹⁴⁶ G. Apollinari,¹⁴⁶ A. Apresyan,¹⁴⁶ S. Banerjee,¹⁴⁶ L. A. T. Bauerdick,¹⁴⁶ A. Beretvas,¹⁴⁶ J. Berryhill,¹⁴⁶ P. C. Bhat,¹⁴⁶ G. Bolla,¹⁴⁶ K. Burkett,¹⁴⁶ J. N. Butler,¹⁴⁶ H. W. K. Cheung,¹⁴⁶ F. Chlebana,¹⁴⁶ S. Cihangir,^{146,a} M. Cremonesi,¹⁴⁶ J. Duarte,¹⁴⁶ V. D. Elvira,¹⁴⁶ I. Fisk,¹⁴⁶ J. Freeman,¹⁴⁶ E. Gottschalk,¹⁴⁶ L. Gray,¹⁴⁶ D. Green,¹⁴⁶ S. Grünendahl,¹⁴⁶ O. Gutsche,¹⁴⁶ R. M. Harris,¹⁴⁶ S. Hasegawa,¹⁴⁶ J. Hirschauer,¹⁴⁶ Z. Hu,¹⁴⁶ B. Jayatilaka,¹⁴⁶ S. Jindariani,¹⁴⁶ M. Johnson,¹⁴⁶ U. Joshi,¹⁴⁶ B. Klima,¹⁴⁶ B. Kreis,¹⁴⁶ S. Lammel,¹⁴⁶ J. Linacre,¹⁴⁶ D. Lincoln,¹⁴⁶ R. Lipton,¹⁴⁶ M. Liu,¹⁴⁶ T. Liu,¹⁴⁶ R. Lopes De Sá,¹⁴⁶ J. Lykken,¹⁴⁶ K. Maeshima,¹⁴⁶ N. Magini,¹⁴⁶ J. M. Marraffino,¹⁴⁶ S. Maruyama,¹⁴⁶ D. Mason,¹⁴⁶ P. McBride,¹⁴⁶ P. Merkel,¹⁴⁶ S. Mrenna,¹⁴⁶ S. Nahn,¹⁴⁶ V. O'Dell,¹⁴⁶ K. Pedro,¹⁴⁶ O. Prokofyev,¹⁴⁶ G. Rakness,¹⁴⁶ L. Ristori,¹⁴⁶ E. Sexton-Kennedy,¹⁴⁶ A. Soha,¹⁴⁶ W. J. Spalding,¹⁴⁶ L. Spiegel,¹⁴⁶ S. Stoynev,¹⁴⁶ J. Strait,¹⁴⁶ N. Strobbe,¹⁴⁶ L. Taylor,¹⁴⁶ S. Tkaczyk,¹⁴⁶ N. V. Tran,¹⁴⁶ L. Uplegger,¹⁴⁶ E. W. Vaandering,¹⁴⁶ C. Vernieri,¹⁴⁶ M. Verzocchi,¹⁴⁶ R. Vidal,¹⁴⁶ M. Wang,¹⁴⁶ H. A. Weber,¹⁴⁶ A. Whitbeck,¹⁴⁶ Y. Wu,¹⁴⁶ D. Acosta,¹⁴⁷ P. Avery,¹⁴⁷ P. Bortignon,¹⁴⁷ D. Bourilkov,¹⁴⁷ A. Brinkerhoff,¹⁴⁷ A. Carnes,¹⁴⁷ M. Carver,¹⁴⁷ D. Curry,¹⁴⁷ S. Das,¹⁴⁷ R. D. Field,¹⁴⁷ I. K. Furic,¹⁴⁷ J. Konigsberg,¹⁴⁷ A. Korytov,¹⁴⁷ J. F. Low,¹⁴⁷ P. Ma,¹⁴⁷ K. Matchev,¹⁴⁷ H. Mei,¹⁴⁷ G. Mitselmakher,¹⁴⁷ D. Rank,¹⁴⁷ L. Shchutka,¹⁴⁷ D. Sperka,¹⁴⁷ L. Thomas,¹⁴⁷ J. Wang,¹⁴⁷ S. Wang,¹⁴⁷ J. Yelton,¹⁴⁷ S. Linn,¹⁴⁸ P. Markowitz,¹⁴⁸ G. Martinez,¹⁴⁸ J. L. Rodriguez,¹⁴⁸ A. Ackert,¹⁴⁹ T. Adams,¹⁴⁹ A. Askew,¹⁴⁹ S. Bein,¹⁴⁹ S. Hagopian,¹⁴⁹ V. Hagopian,¹⁴⁹ K. F. Johnson,¹⁴⁹ T. Kolberg,¹⁴⁹ T. Perry,¹⁴⁹ H. Prosper,¹⁴⁹ A. Santra,¹⁴⁹ R. Yohay,¹⁴⁹ M. M. Baarmand,¹⁵⁰ V. Bhopatkar,¹⁵⁰ S. Colafranceschi,¹⁵⁰ M. Hohlmann,¹⁵⁰ D. Noonan,¹⁵⁰ T. Roy,¹⁵⁰ F. Yumiceva,¹⁵⁰ M. R. Adams,¹⁵¹ L. Apanasevich,¹⁵¹ D. Berry,¹⁵¹ R. R. Betts,¹⁵¹ R. Cavanaugh,¹⁵¹ X. Chen,¹⁵¹ O. Evdokimov,¹⁵¹ C. E. Gerber,¹⁵¹ D. A. Hangal,¹⁵¹ D. J. Hofman,¹⁵¹ K. Jung,¹⁵¹ J. Kamin,¹⁵¹ I. D. Sandoval Gonzalez,¹⁵¹ H. Trauger,¹⁵¹ N. Varelas,¹⁵¹ H. Wang,¹⁵¹ Z. Wu,¹⁵¹ J. Zhang,¹⁵¹ B. Bilki,^{152,ppp} W. Clarida,¹⁵² K. Dilsiz,¹⁵² S. Durgut,¹⁵² R. P. Gandrajula,¹⁵² M. Haytmyradov,¹⁵² V. Khristenko,¹⁵² J.-P. Merlo,¹⁵² H. Mermerkaya,^{152,qqq} A. Mestvirishvili,¹⁵² A. Moeller,¹⁵² J. Nachtman,¹⁵² H. Ogul,¹⁵² Y. Onel,¹⁵² F. Ozok,^{152,rrr} A. Penzo,¹⁵² C. Snyder,¹⁵² E. Tiras,¹⁵² J. Wetzel,¹⁵² K. Yi,¹⁵² B. Blumenfeld,¹⁵³ A. Cocoros,¹⁵³ N. Eminizer,¹⁵³ D. Fehling,¹⁵³ L. Feng,¹⁵³ A. V. Gritsan,¹⁵³ P. Maksimovic,¹⁵³ J. Roskes,¹⁵³ U. Sarica,¹⁵³ M. Swartz,¹⁵³ M. Xiao,¹⁵³ C. You,¹⁵³ A. Al-bataineh,¹⁵⁴ P. Baringer,¹⁵⁴ A. Bean,¹⁵⁴ S. Boren,¹⁵⁴ J. Bowen,¹⁵⁴ J. Castle,¹⁵⁴ L. Forthomme,¹⁵⁴ S. Khalil,¹⁵⁴ A. Kropivnitskaya,¹⁵⁴ D. Majumder,¹⁵⁴ W. Mcbrayer,¹⁵⁴ M. Murray,¹⁵⁴ S. Sanders,¹⁵⁴ R. Stringer,¹⁵⁴ J. D. Tapia Takaki,¹⁵⁴ Q. Wang,¹⁵⁴ A. Ivanov,¹⁵⁵ K. Kaadze,¹⁵⁵ Y. Maravin,¹⁵⁵ A. Mohammadi,¹⁵⁵ L. K. Saini,¹⁵⁵ N. Skhirtladze,¹⁵⁵ S. Toda,¹⁵⁵ F. Rebassoo,¹⁵⁶ D. Wright,¹⁵⁶ C. Anelli,¹⁵⁷ A. Baden,¹⁵⁷ O. Baron,¹⁵⁷ A. Belloni,¹⁵⁷ B. Calvert,¹⁵⁷ S. C. Eno,¹⁵⁷ C. Ferraioli,¹⁵⁷ N. J. Hadley,¹⁵⁷ S. Jabeen,¹⁵⁷ G. Y. Jeng,¹⁵⁷ R. G. Kellogg,¹⁵⁷ J. Kunkle,¹⁵⁷ A. C. Mignerey,¹⁵⁷ F. Ricci-Tam,¹⁵⁷ Y. H. Shin,¹⁵⁷ A. Skuja,¹⁵⁷ M. B. Tonjes,¹⁵⁷ S. C. Tonwar,¹⁵⁷ D. Abercrombie,¹⁵⁸ B. Allen,¹⁵⁸ A. Apyan,¹⁵⁸ V. Azzolini,¹⁵⁸ R. Barbieri,¹⁵⁸ A. Baty,¹⁵⁸ R. Bi,¹⁵⁸ K. Bierwagen,¹⁵⁸ S. Brandt,¹⁵⁸ W. Busza,¹⁵⁸ I. A. Cali,¹⁵⁸ M. D'Alfonso,¹⁵⁸ Z. Demiragli,¹⁵⁸

G. Gomez Ceballos,¹⁵⁸ M. Goncharov,¹⁵⁸ D. Hsu,¹⁵⁸ Y. Iiyama,¹⁵⁸ G. M. Innocenti,¹⁵⁸ M. Klute,¹⁵⁸ D. Kovalskyi,¹⁵⁸ K. Krajczar,¹⁵⁸ Y. S. Lai,¹⁵⁸ Y.-J. Lee,¹⁵⁸ A. Levin,¹⁵⁸ P. D. Luckey,¹⁵⁸ B. Maier,¹⁵⁸ A. C. Marini,¹⁵⁸ C. McGinn,¹⁵⁸ C. Mironov,¹⁵⁸ S. Narayanan,¹⁵⁸ X. Niu,¹⁵⁸ C. Paus,¹⁵⁸ C. Roland,¹⁵⁸ G. Roland,¹⁵⁸ J. Salfeld-Nebgen,¹⁵⁸ G. S. F. Stephans,¹⁵⁸ K. Tatar,¹⁵⁸ D. Velicanu,¹⁵⁸ J. Wang,¹⁵⁸ T. W. Wang,¹⁵⁸ B. Wyslouch,¹⁵⁸ A. C. Benvenuti,¹⁵⁹ R. M. Chatterjee,¹⁵⁹ A. Evans,¹⁵⁹ P. Hansen,¹⁵⁹ S. Kalafut,¹⁵⁹ S. C. Kao,¹⁵⁹ Y. Kubota,¹⁵⁹ Z. Lesko,¹⁵⁹ J. Mans,¹⁵⁹ S. Nourbakhsh,¹⁵⁹ N. Ruckstuhl,¹⁵⁹ R. Rusack,¹⁵⁹ N. Tambe,¹⁵⁹ J. Turkewitz,¹⁵⁹ J. G. Acosta,¹⁶⁰ S. Oliveros,¹⁶⁰ E. Avdeeva,¹⁶¹ K. Bloom,¹⁶¹ D. R. Claes,¹⁶¹ C. Fangmeier,¹⁶¹ R. Gonzalez Suarez,¹⁶¹ R. Kamalieddin,¹⁶¹ I. Kravchenko,¹⁶¹ A. Malta Rodrigues,¹⁶¹ J. Monroy,¹⁶¹ J. E. Siado,¹⁶¹ G. R. Snow,¹⁶¹ B. Stieger,¹⁶¹ M. Alyari,¹⁶² J. Dolen,¹⁶² A. Godshalk,¹⁶² C. Harrington,¹⁶² I. Iashvili,¹⁶² D. Nguyen,¹⁶² A. Parker,¹⁶² S. Rappoccio,¹⁶² B. Roobahani,¹⁶² G. Alverson,¹⁶³ E. Barberis,¹⁶³ A. Hortiangtham,¹⁶³ A. Massironi,¹⁶³ D. M. Morse,¹⁶³ D. Nash,¹⁶³ T. Orimoto,¹⁶³ R. Teixeira De Lima,¹⁶³ D. Trocino,¹⁶³ R.-J. Wang,¹⁶³ D. Wood,¹⁶³ S. Bhattacharya,¹⁶⁴ O. Charaf,¹⁶⁴ K. A. Hahn,¹⁶⁴ N. Mucia,¹⁶⁴ N. Odell,¹⁶⁴ B. Pollack,¹⁶⁴ M. H. Schmitt,¹⁶⁴ K. Sung,¹⁶⁴ M. Trovato,¹⁶⁴ M. Velasco,¹⁶⁴ N. Dev,¹⁶⁵ M. Hildreth,¹⁶⁵ K. Hurtado Anampa,¹⁶⁵ C. Jessop,¹⁶⁵ D. J. Karmgard,¹⁶⁵ N. Kellams,¹⁶⁵ K. Lannon,¹⁶⁵ N. Marinelli,¹⁶⁵ F. Meng,¹⁶⁵ C. Mueller,¹⁶⁵ Y. Musienko,^{165,ij} M. Planer,¹⁶⁵ A. Reinsvold,¹⁶⁵ R. Ruchti,¹⁶⁵ N. Rupprecht,¹⁶⁵ G. Smith,¹⁶⁵ S. Taroni,¹⁶⁵ M. Wayne,¹⁶⁵ M. Wolf,¹⁶⁵ A. Woodard,¹⁶⁵ J. Alimena,¹⁶⁶ L. Antonelli,¹⁶⁶ B. Bylsma,¹⁶⁶ L. S. Durkin,¹⁶⁶ S. Flowers,¹⁶⁶ B. Francis,¹⁶⁶ A. Hart,¹⁶⁶ C. Hill,¹⁶⁶ W. Ji,¹⁶⁶ B. Liu,¹⁶⁶ W. Luo,¹⁶⁶ D. Puigh,¹⁶⁶ B. L. Winer,¹⁶⁶ H. W. Wulsin,¹⁶⁶ S. Cooperstein,¹⁶⁷ O. Driga,¹⁶⁷ P. Elmer,¹⁶⁷ J. Hardenbrook,¹⁶⁷ P. Hebda,¹⁶⁷ D. Lange,¹⁶⁷ J. Luo,¹⁶⁷ D. Marlow,¹⁶⁷ T. Medvedeva,¹⁶⁷ K. Mei,¹⁶⁷ I. Ojalvo,¹⁶⁷ J. Olsen,¹⁶⁷ C. Palmer,¹⁶⁷ P. Piroué,¹⁶⁷ D. Stickland,¹⁶⁷ A. Svyatkovskiy,¹⁶⁷ C. Tully,¹⁶⁷ S. Malik,¹⁶⁸ A. Barker,¹⁶⁹ V. E. Barnes,¹⁶⁹ S. Folgueras,¹⁶⁹ L. Gutay,¹⁶⁹ M. K. Jha,¹⁶⁹ M. Jones,¹⁶⁹ A. W. Jung,¹⁶⁹ A. Khatiwada,¹⁶⁹ D. H. Miller,¹⁶⁹ N. Neumeister,¹⁶⁹ J. F. Schulte,¹⁶⁹ J. Sun,¹⁶⁹ F. Wang,¹⁶⁹ W. Xie,¹⁶⁹ N. Parashar,¹⁷⁰ J. Stupak,¹⁷⁰ A. Adair,¹⁷¹ B. Akgun,¹⁷¹ Z. Chen,¹⁷¹ K. M. Ecklund,¹⁷¹ F. J. M. Geurts,¹⁷¹ M. Guillaud,¹⁷¹ W. Li,¹⁷¹ B. Michlin,¹⁷¹ M. Northup,¹⁷¹ B. P. Padley,¹⁷¹ J. Roberts,¹⁷¹ J. Rorie,¹⁷¹ Z. Tu,¹⁷¹ J. Zabel,¹⁷¹ B. Betchart,¹⁷² A. Bodek,¹⁷² P. de Barbaro,¹⁷² R. Demina,¹⁷² Y. t. Duh,¹⁷² T. Ferbel,¹⁷² M. Galanti,¹⁷² A. Garcia-Bellido,¹⁷² J. Han,¹⁷² O. Hindrichs,¹⁷² A. Khukhunaishvili,¹⁷² K. H. Lo,¹⁷² P. Tan,¹⁷² M. Verzetti,¹⁷² A. Agapitos,¹⁷³ J. P. Chou,¹⁷³ Y. Gershtein,¹⁷³ T. A. Gómez Espinosa,¹⁷³ E. Halkiadakis,¹⁷³ M. Heindl,¹⁷³ E. Hughes,¹⁷³ S. Kaplan,¹⁷³ R. Kunnawalkam Elayavalli,¹⁷³ S. Kyriacou,¹⁷³ A. Lath,¹⁷³ R. Montalvo,¹⁷³ K. Nash,¹⁷³ M. Osherson,¹⁷³ H. Saka,¹⁷³ S. Salur,¹⁷³ S. Schnetzer,¹⁷³ D. Sheffield,¹⁷³ S. Somalwar,¹⁷³ R. Stone,¹⁷³ S. Thomas,¹⁷³ P. Thomassen,¹⁷³ M. Walker,¹⁷³ A. G. Delannoy,¹⁷⁴ M. Foerster,¹⁷⁴ J. Heideman,¹⁷⁴ G. Riley,¹⁷⁴ K. Rose,¹⁷⁴ S. Spanier,¹⁷⁴ K. Thapa,¹⁷⁴ O. Bouhali,^{175,sss} A. Celik,¹⁷⁵ M. Dalchenko,¹⁷⁵ M. De Mattia,¹⁷⁵ A. Delgado,¹⁷⁵ S. Dildick,¹⁷⁵ R. Eusebi,¹⁷⁵ J. Gilmore,¹⁷⁵ T. Huang,¹⁷⁵ E. Juska,¹⁷⁵ T. Kamon,^{175,ttt} R. Mueller,¹⁷⁵ Y. Pakhotin,¹⁷⁵ R. Patel,¹⁷⁵ A. Perloff,¹⁷⁵ L. Perniè,¹⁷⁵ D. Rathjens,¹⁷⁵ A. Safonov,¹⁷⁵ A. Tatarinov,¹⁷⁵ K. A. Ulmer,¹⁷⁵ N. Akchurin,¹⁷⁶ J. Damgov,¹⁷⁶ F. De Guio,¹⁷⁶ C. Dragoiu,¹⁷⁶ P. R. Dudero,¹⁷⁶ J. Faulkner,¹⁷⁶ E. Gorpinar,¹⁷⁶ S. Kunori,¹⁷⁶ K. Lamichhane,¹⁷⁶ S. W. Lee,¹⁷⁶ T. Libeiro,¹⁷⁶ T. Peltola,¹⁷⁶ S. Undleeb,¹⁷⁶ I. Volobouev,¹⁷⁶ Z. Wang,¹⁷⁶ S. Greene,¹⁷⁷ A. Gurrola,¹⁷⁷ R. Janjam,¹⁷⁷ W. Johns,¹⁷⁷ C. Maguire,¹⁷⁷ A. Melo,¹⁷⁷ H. Ni,¹⁷⁷ P. Sheldon,¹⁷⁷ S. Tuo,¹⁷⁷ J. Velkovska,¹⁷⁷ Q. Xu,¹⁷⁷ M. W. Arenton,¹⁷⁸ P. Barria,¹⁷⁸ B. Cox,¹⁷⁸ R. Hirosky,¹⁷⁸ A. Ledovskoy,¹⁷⁸ H. Li,¹⁷⁸ C. Neu,¹⁷⁸ T. Sinthuprasith,¹⁷⁸ X. Sun,¹⁷⁸ Y. Wang,¹⁷⁸ E. Wolfe,¹⁷⁸ F. Xia,¹⁷⁸ C. Clarke,¹⁷⁹ R. Harr,¹⁷⁹ P. E. Karchin,¹⁷⁹ J. Sturdy,¹⁷⁹ S. Zaleski,¹⁷⁹ D. A. Belknap,¹⁸⁰ J. Buchanan,¹⁸⁰ C. Caillol,¹⁸⁰ S. Dasu,¹⁸⁰ L. Dodd,¹⁸⁰ S. Duric,¹⁸⁰ B. Gomber,¹⁸⁰ M. Grothe,¹⁸⁰ M. Herndon,¹⁸⁰ A. Hervé,¹⁸⁰ U. Hussain,¹⁸⁰ P. Klabbers,¹⁸⁰ A. Lanaro,¹⁸⁰ A. Levine,¹⁸⁰ K. Long,¹⁸⁰ R. Loveless,¹⁸⁰ G. A. Pierro,¹⁸⁰ G. Polese,¹⁸⁰ T. Ruggles,¹⁸⁰ A. Savin,¹⁸⁰ N. Smith,¹⁸⁰ W. H. Smith,¹⁸⁰ D. Taylor,¹⁸⁰ and N. Woods¹⁸⁰

(CMS Collaboration)

¹Yerevan Physics Institute, Yerevan, Armenia²Institut für Hochenergiephysik, Wien, Austria³Institute for Nuclear Problems, Minsk, Belarus⁴National Centre for Particle and High Energy Physics, Minsk, Belarus⁵Universiteit Antwerpen, Antwerpen, Belgium⁶Vrije Universiteit Brussel, Brussel, Belgium⁷Université Libre de Bruxelles, Bruxelles, Belgium⁸Ghent University, Ghent, Belgium

- ⁹*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
¹⁰*Université de Mons, Mons, Belgium*
¹¹*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*
¹²*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
^{13a}*Universidade Estadual Paulista, São Paulo, Brazil*
^{13b}*Universidade Federal do ABC, São Paulo, Brazil*
¹⁴*Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria*
¹⁵*University of Sofia, Sofia, Bulgaria*
¹⁶*Beihang University, Beijing, China*
¹⁷*Institute of High Energy Physics, Beijing, China*
¹⁸*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*
¹⁹*Universidad de Los Andes, Bogota, Colombia*
²⁰*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*
²¹*University of Split, Faculty of Science, Split, Croatia*
²²*Institute Rudjer Boskovic, Zagreb, Croatia*
²³*University of Cyprus, Nicosia, Cyprus*
²⁴*Charles University, Prague, Czech Republic*
²⁵*Universidad San Francisco de Quito, Quito, Ecuador*
²⁶*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*
²⁷*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*
²⁸*Department of Physics, University of Helsinki, Helsinki, Finland*
²⁹*Helsinki Institute of Physics, Helsinki, Finland*
³⁰*Lappeenranta University of Technology, Lappeenranta, Finland*
³¹*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
³²*Laboratoire Leprince-Ringuet, Ecole polytechnique, CNRS/IN2P3, Université Paris-Saclay, Palaiseau, France*
³³*Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France*
³⁴*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France*
³⁵*Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France*
³⁶*Georgian Technical University, Tbilisi, Georgia*
³⁷*Tbilisi State University, Tbilisi, Georgia*
³⁸*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
³⁹*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
⁴⁰*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
⁴¹*Deutsches Elektronen-Synchrotron, Hamburg, Germany*
⁴²*University of Hamburg, Hamburg, Germany*
⁴³*Institut für Experimentelle Kernphysik, Karlsruhe, Germany*
⁴⁴*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
⁴⁵*National and Kapodistrian University of Athens, Athens, Greece*
⁴⁶*National Technical University of Athens, Athens, Greece*
⁴⁷*University of Ioánnina, Ioánnina, Greece*
⁴⁸*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*
⁴⁹*Wigner Research Centre for Physics, Budapest, Hungary*
⁵⁰*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
⁵¹*Institute of Physics, University of Debrecen, Debrecen, Hungary*
⁵²*Indian Institute of Science (IISc), Bangalore, India*
⁵³*National Institute of Science Education and Research, Bhubaneswar, India*
⁵⁴*Panjab University, Chandigarh, India*
⁵⁵*University of Delhi, Delhi, India*
⁵⁶*Saha Institute of Nuclear Physics, Kolkata, India*
⁵⁷*Indian Institute of Technology Madras, Madras, India*
⁵⁸*Bhabha Atomic Research Centre, Mumbai, India*
⁵⁹*Tata Institute of Fundamental Research-A, Mumbai, India*
⁶⁰*Tata Institute of Fundamental Research-B, Mumbai, India*
⁶¹*Indian Institute of Science Education and Research (IISER), Pune, India*
⁶²*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
⁶³*University College Dublin, Dublin, Ireland*
^{64a}*INFN Sezione di Bari, Bari, Italy*
^{64b}*Università di Bari, Bari, Italy*
^{64c}*Politecnico di Bari, Bari, Italy*

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

- ¹⁰⁷*Novosibirsk State University (NSU), Novosibirsk, Russia*
- ¹⁰⁸*State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia*
- ¹⁰⁹*University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia*
- ¹¹⁰*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
- ¹¹¹*Universidad Autónoma de Madrid, Madrid, Spain*
- ¹¹²*Universidad de Oviedo, Oviedo, Spain*
- ¹¹³*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
- ¹¹⁴*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
- ¹¹⁵*Paul Scherrer Institut, Villigen, Switzerland*
- ¹¹⁶*Institute for Particle Physics, ETH Zurich, Zurich, Switzerland*
- ¹¹⁷*Universität Zürich, Zurich, Switzerland*
- ¹¹⁸*National Central University, Chung-Li, Taiwan*
- ¹¹⁹*National Taiwan University (NTU), Taipei, Taiwan*
- ¹²⁰*Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand*
- ¹²¹*Cukurova University, Physics Department, Science and Art Faculty, Adana, Turkey*
- ¹²²*Middle East Technical University, Physics Department, Ankara, Turkey*
- ¹²³*Bogazici University, Istanbul, Turkey*
- ¹²⁴*Istanbul Technical University, Istanbul, Turkey*
- ¹²⁵*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine*
- ¹²⁶*National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine*
- ¹²⁷*University of Bristol, Bristol, United Kingdom*
- ¹²⁸*Rutherford Appleton Laboratory, Didcot, United Kingdom*
- ¹²⁹*Imperial College, London, United Kingdom*
- ¹³⁰*Brunel University, Uxbridge, United Kingdom*
- ¹³¹*Baylor University, Waco, Texas, USA*
- ¹³²*Catholic University of America, Washington DC, USA*
- ¹³³*The University of Alabama, Tuscaloosa, Alabama, USA*
- ¹³⁴*Boston University, Boston, Massachusetts, USA*
- ¹³⁵*Brown University, Providence, Rhode Island, USA*
- ¹³⁶*University of California, Davis, Davis, California, USA*
- ¹³⁷*University of California, Los Angeles, California, USA*
- ¹³⁸*University of California, Riverside, Riverside, Riverside, USA*
- ¹³⁹*University of California, San Diego, La Jolla, USA*
- ¹⁴⁰*University of California, Santa Barbara - Department of Physics, Santa Barbara, California, USA*
- ¹⁴¹*California Institute of Technology, Pasadena, California, USA*
- ¹⁴²*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
- ¹⁴³*University of Colorado Boulder, Boulder, Colorado, USA*
- ¹⁴⁴*Cornell University, Ithaca, New York, USA*
- ¹⁴⁵*Fairfield University, Fairfield, Connecticut, USA*
- ¹⁴⁶*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
- ¹⁴⁷*University of Florida, Gainesville, Florida, USA*
- ¹⁴⁸*Florida International University, Miami, Florida, USA*
- ¹⁴⁹*Florida State University, Tallahassee, Florida, USA*
- ¹⁵⁰*Florida Institute of Technology, Melbourne, Florida, USA*
- ¹⁵¹*University of Illinois at Chicago (UIC), Chicago, Illinois, USA*
- ¹⁵²*The University of Iowa, Iowa City, Iowa, USA*
- ¹⁵³*Johns Hopkins University, Baltimore, Maryland, USA*
- ¹⁵⁴*The University of Kansas, Lawrence, Kansas, USA*
- ¹⁵⁵*Kansas State University, Manhattan, Kansas, USA*
- ¹⁵⁶*Lawrence Livermore National Laboratory, Livermore, California, USA*
- ¹⁵⁷*University of Maryland, College Park, Maryland, USA*
- ¹⁵⁸*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
- ¹⁵⁹*University of Minnesota, Minneapolis, Minnesota, USA*
- ¹⁶⁰*University of Mississippi, Oxford, Mississippi, USA*
- ¹⁶¹*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
- ¹⁶²*State University of New York at Buffalo, Buffalo, New York, USA*
- ¹⁶³*Northeastern University, Boston, Massachusetts, USA*
- ¹⁶⁴*Northwestern University, Evanston, Illinois, USA*
- ¹⁶⁵*University of Notre Dame, Notre Dame, Indiana, USA*
- ¹⁶⁶*The Ohio State University, Columbus, Ohio, USA*

- ¹⁶⁷Princeton University, Princeton, New Jersey, USA
¹⁶⁸University of Puerto Rico, Mayaguez, Puerto Rico, USA
¹⁶⁹Purdue University, West Lafayette, Indiana, USA
¹⁷⁰Purdue University Northwest, Hammond, Indiana, USA
¹⁷¹Rice University, Houston, Texas, USA
¹⁷²University of Rochester, Rochester, New York, USA
¹⁷³Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA
¹⁷⁴University of Tennessee, Knoxville, Tennessee, USA
¹⁷⁵Texas A&M University, College Station, Texas, USA
¹⁷⁶Texas Tech University, Lubbock, Texas, USA
¹⁷⁷Vanderbilt University, Nashville, Tennessee, USA
¹⁷⁸University of Virginia, Charlottesville, Virginia, USA
¹⁷⁹Wayne State University, Detroit, Michigan, USA
¹⁸⁰University of Wisconsin - Madison, Madison, Wisconsin, USA

^aDeceased.

^bAlso at Vienna University of Technology, Vienna, Austria.

^cAlso at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China.

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

^eAlso at Universidade Federal de Pelotas, Pelotas, Brazil.

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

^gAlso at Universidad de Antioquia, Medellín, Colombia.

^hAlso at Joint Institute for Nuclear Research, Dubna, Russia.

ⁱAlso at Helwan University, Cairo, Egypt.

^jAlso at Zewail City of Science and Technology, Zewail, Egypt.

^kAlso at Fayoum University, El-Fayoum, Egypt.

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

^mAlso at Ain Shams University, Cairo, Egypt.

ⁿAlso at Université de Haute Alsace, Mulhouse, France.

^oAlso at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.

^pAlso at CERN, European Organization for Nuclear Research, Geneva, Switzerland.

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

^rAlso at University of Hamburg, Hamburg, Germany.

^sAlso at Brandenburg University of Technology, Cottbus, Germany.

^tAlso at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.

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

^vAlso at Institute of Physics, University of Debrecen, Debrecen, Hungary.

^wAlso at IIT Bhubaneswar, Bhubaneswar, India.

^xAlso at University of Visva-Bharati, Santiniketan, India.

^yAlso at Institute of Physics, Bhubaneswar, India.

^zAlso at University of Ruhuna, Matara, Sri Lanka.

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

^{bb}Also at Yazd University, Yazd, Iran.

^{cc}Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.

^{dd}Also at Università degli Studi di Siena, Siena, Italy.

^{ee}Also at Purdue University, West Lafayette, USA.

^{ff}Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia.

^{gg}Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia.

^{hh}Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico.

ⁱⁱAlso at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.

^{jj}Also at Institute for Nuclear Research, Moscow, Russia.

^{kk}Also at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia.

^{ll}Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.

^{mm}Also at University of Florida, Gainesville, USA.

ⁿⁿAlso at P.N. Lebedev Physical Institute, Moscow, Russia.

^{oo}Also at California Institute of Technology, Pasadena, USA.

^{pp}Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia.

^{qq}Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.

^{rr}Also at INFN Sezione di Roma, Sapienza Università di Roma, Rome, Italy.

^{ss}Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.

- ^{tt} Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
- ^{uu} Also at National and Kapodistrian University of Athens, Athens, Greece.
- ^{vv} Also at Riga Technical University, Riga, Latvia.
- ^{ww} Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
- ^{xx} Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.
- ^{yy} Also at Adiyaman University, Adiyaman, Turkey.
- ^{zz} Also at Istanbul Aydin University, Istanbul, Turkey.
- ^{aaa} Also at Mersin University, Mersin, Turkey.
- ^{bbb} Also at Cag University, Mersin, Turkey.
- ^{ccc} Also at Piri Reis University, Istanbul, Turkey.
- ^{ddd} Also at Gaziosmanpasa University, Tokat, Turkey.
- ^{eee} Also at Ozyegin University, Istanbul, Turkey.
- ^{fff} Also at Izmir Institute of Technology, Izmir, Turkey.
- ^{ggg} Also at Marmara University, Istanbul, Turkey.
- ^{hhh} Also at Kafkas University, Kars, Turkey.
- ⁱⁱⁱ Also at Istanbul Bilgi University, Istanbul, Turkey.
- ^{jjj} Also at Yildiz Technical University, Istanbul, Turkey.
- ^{kkk} Also at Hacettepe University, Ankara, Turkey.
- ^{lll} Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
- ^{mmm} Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- ⁿⁿⁿ Also at Instituto de Astrofísica de Canarias, La Laguna, Spain.
- ^{ooo} Also at Utah Valley University, Orem, USA.
- ^{ppp} Also at Beykent University.
- ^{qqq} Also at Erzincan University, Erzincan, Turkey.
- ^{rrr} Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
- ^{sss} Also at Texas A&M University at Qatar, Doha, Qatar.
- ^{ttt} Also at Kyungpook National University, Daegu, Korea.