

Search for Higgs Boson Pair Production in the Four b Quark Final State in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV

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

 (Received 19 February 2022; accepted 7 July 2022; published 18 August 2022)

A search for pairs of Higgs bosons produced via gluon and vector boson fusion is presented, focusing on the four b quark final state. The data sample consists of proton-proton collisions at a center-of-mass energy of 13 TeV, collected with the CMS detector at the LHC, and corresponds to an integrated luminosity of 138 fb^{-1} . No deviation from the background-only hypothesis is observed. A 95% confidence level upper limit on the Higgs boson pair production cross section is observed at 3.9 times the standard model prediction for an expected value of 7.8. Constraints are also set on the modifiers of the Higgs field self-coupling, κ_λ , and of the coupling of two Higgs bosons to two vector bosons, κ_{2V} . The observed (expected) allowed intervals at the 95% confidence level are $-2.3 < \kappa_\lambda < 9.4$ ($-5.0 < \kappa_\lambda < 12.0$) and $-0.1 < \kappa_{2V} < 2.2$ ($-0.4 < \kappa_{2V} < 2.5$). These are the most stringent observed constraints to date on the HH production cross section and on the κ_{2V} coupling.

DOI: [10.1103/PhysRevLett.129.081802](https://doi.org/10.1103/PhysRevLett.129.081802)

The discovery of the Higgs boson (H) by the ATLAS and CMS Collaborations [1–3] proves the existence of a fundamental scalar sector of the standard model of particle physics (SM), but the experimental confirmation of the Brout-Englert-Higgs mechanism [4–6] requires the determination of the shape of the postulated scalar potential. This shape is governed by a parameter λ that drives the strength of the Higgs boson self-couplings and can thus be determined experimentally with a measurement of Higgs boson pair (HH) production.

At the CERN Large Hadron Collider (LHC), at the energy of $\sqrt{s} = 13$ TeV, the dominant HH production mode in the SM is through the gluon fusion mechanism (ggF), with a cross section of $31.1^{+2.1}_{-7.2} \text{ fb}$ [7–14], followed by the vector boson fusion process (VBF), with a cross section of $1.726 \pm 0.036 \text{ fb}$ [15] and characterized by the presence of two additional hadronic jets, j , giving a $b\bar{b}b\bar{b}jj$ final state. Variations of the Higgs boson self-coupling with respect to the SM prediction are parametrized by the modifier $\kappa_\lambda = \lambda/\lambda^{\text{SM}}$ and affect the ggF and VBF production modes. The VBF production mode also depends on the strength of the interaction of pairs of vector bosons V ($= W, Z$) with a single (VVH) and a pair (VVHH) of Higgs bosons, whose values with respect to the SM prediction are parametrized by the modifiers κ_V and κ_{2V} , respectively. Departures from the relation $\kappa_{2V} = \kappa_V^2$

predicted in the Brout-Englert-Higgs mechanism are possible in models of physics beyond the SM where the Higgs boson is a composite state emerging from the presence of new strong dynamics at the TeV scale [16].

The ATLAS and CMS Collaborations have searched for ggF HH production with a dataset corresponding to an integrated luminosity of about 36 fb^{-1} in a variety of final states [17–26], whose combinations [27,28] set an observed (expected) upper limit at the 95% confidence level (CL) on the SM production cross section of 7 (10) and 22 (13) times theoretical prediction, respectively. Updated searches have been performed with an integrated luminosity of about 140 fb^{-1} [29–31], and the most stringent observed limits are from the ATLAS search in the $b\bar{b}\gamma\gamma$ final state and correspond to 4.2 times the SM prediction, with a value of κ_λ between -1.5 and 6.7 at the 95% CL. The VBF HH production process has been studied in the $b\bar{b}b\bar{b}$ [32] and $b\bar{b}\gamma\gamma$ [30] final states by the ATLAS and CMS Collaborations, respectively, and the most stringent observed constraints at the 95% CL correspond to $-0.43 < \kappa_{2V} < 2.56$ from $b\bar{b}b\bar{b}$ and 225 times the SM cross section prediction from $b\bar{b}\gamma\gamma$.

This Letter reports on searches for both the ggF and VBF HH production mechanisms in the $b\bar{b}b\bar{b}$ decay channel. In the SM, this decay mode is characterized by a combined branching fraction of 0.339 ± 0.008 for $m_H = 125 \text{ GeV}$ [33]. The analysis uses a sample of proton-proton collision (pp) events at $\sqrt{s} = 13$ TeV recorded between 2016 and 2018 with the CMS detector, corresponding to an integrated luminosity of 138 fb^{-1} .

The CMS apparatus [34] is a multipurpose, nearly hermetic detector, designed to trigger on [35,36] and identify electrons, muons, photons, and hadrons [37–41].

*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](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.

A global event reconstruction “particle-flow” (PF) algorithm [42] combines the information provided by the all-silicon inner tracker and by the crystal electromagnetic and brass-scintillator hadron calorimeters, operating inside a 3.8 T superconducting solenoid, with data from gas-ionization muon detectors embedded in the solenoid iron return yoke, to build τ leptons, jets, missing transverse momentum, and other physics objects [43–45].

Hadronic jets are clustered from the PF objects using the anti- k_T algorithm [46,47] with a distance parameter of 0.4. Jet energy corrections are derived from simulation studies and corrected with *in situ* measurements to match the energy scale in data and in simulation [44]. Jets originating from b quarks are identified using as a discriminant the output of a deep neural network algorithm (DEEPIET) [48,49], trained using as input information the properties of the PF constituents of the jets and of the secondary vertices associated with them. For the jets in this search, two working points (WPs) of the DEEPIET discriminant are considered: the medium WP, which yields a b jet identification efficiency of 75% with a corresponding misidentification rate of light flavor and gluon (charm) jets of about 1 (10)%, and the tight WP, which corresponds to a b jet identification efficiency of 58% and to a misidentification rate of about 0.1(2)%.

Signal processes from ggF HH production are simulated at next-to-leading order (NLO) accuracy in quantum chromodynamics (QCD) with POWHEG2.0 [50–52], and samples for VBF HH production are generated at leading order (LO) accuracy in QCD using MADGRAPH5_aMC@NLO2.6.5 [53] for various combinations of couplings. The distributions are scaled by functions of the couplings defined according to the known dependence of the theoretical cross section [54] and added together to model arbitrary coupling combinations, and the total predictions are normalized to the corresponding next-to-NLO (NNLO) cross section [13] for ggF and by the ratio of the next-to-NNLO [15] to LO SM cross sections for VBF. Although not used to model the background, simulated samples for the QCD multijet, $t\bar{t}$, and ZZ backgrounds are used for the optimization of the analysis. For all simulations, the generators are interfaced with PYTHIA8.226 (2016) and 8.230 (2017–2018) [55], and the CMS detector response is modeled with GEANT4 [56]. The simulated events are weighted to match the distribution of additional pp interactions (pileup) within the same or nearby bunch crossings, relative to the collision of interest, to the one observed in data. See Supplemental Material [57] for further details on the simulated samples.

The trigger selection for events collected in 2016 requires the presence of four jets with transverse momentum $p_T > 45$ GeV or of two jets with $p_T > 30$ GeV and two jets with $p_T > 90$ GeV. For 2017 (2018) data, the presence of four jets above the p_T thresholds of 40, 45, 60, and 75 GeV is required together with $H_T > 300(330)$ GeV,

respectively, where H_T denotes the scalar sum of the transverse momentum of the jets reconstructed in the event. As a consequence of the change in jet trigger thresholds, data collected in 2017 and 2018 are analyzed separately from those collected in 2016.

Offline, events are required to contain at least four jets with pseudorapidity $|\eta| < 2.4(2.5)$ and $p_T > 30(40)$ GeV for the 2016 (2017–2018) data, respectively. Jets are required to satisfy the tight WP of the PF jet identification algorithm [58,59], corresponding to an efficiency larger than 99%. If their p_T is below 50 GeV, the medium WP of the pileup discriminant [58] is also required, for a signal jet efficiency of about 90%. If more than four jets satisfy these criteria, the four objects with the largest DEEPIET output are selected. The p_T of these four jets are corrected with a multivariate regression method developed for b jets that improves the determination of the momentum by up to 15% and simultaneously estimates the per jet resolution achieved [60]. After the application of this method, the resolution on the dijet invariant mass for $H \rightarrow b\bar{b}$ events reconstructed in this analysis ranges between 11% and 14%. At least three of the selected jets are required to satisfy the medium WP of the DEEPIET discriminant.

Events are rejected if they contain an electron or a muon with $p_T > 15$ and 10 GeV, respectively, and $|\eta| < 2.4$, where these objects must satisfy identification discriminants and criteria that include isolation and impact parameter with respect to the primary interaction vertex. This selection suppresses background events containing leptonic top quark decays.

The two Higgs boson candidates are formed by pairing the four jets. There are three possible pairings of jets, and in each the two Higgs boson candidates, denoted as H_1 and H_2 , are defined by the relation $p_T(H_1) > p_T(H_2)$. The (H_1, H_2) pairings are ordered according to the increasing value of a distance parameter $d = |m_{H_1} - km_{H_2}|/\sqrt{1+k^2}$. The constant k is the ratio of the expected peak positions of the reconstructed Higgs boson masses for events that are correctly paired, $k = c_1/c_2 = (125 \text{ GeV})/(120 \text{ GeV}) = 1.04$. Its value differs from 1 because of the residual jet momentum dependence of the multivariate energy regression that more strongly impacts the softer H candidate. If the difference in the distance parameter of the first and second pairing, Δd , is larger than 30 GeV, corresponding to about 2 times the resolution on the Higgs boson mass, the pairing with the smallest d is chosen. Conversely, if $\Delta d \leq 30$ GeV, the experimental resolution limits the capability to identify the correct pairing based on the invariant masses, and a choice is made between the first and second pairing as the one that maximizes the p_T of the two Higgs boson candidates in the four-jet center-of-mass reference frame. This procedure results in a correct jet pairing of about 96% of the selected events in a ggF SM HH sample, and amounts to 82%–96% (91–98)% for the different couplings studied in ggF (VBF) signal events.

The two non- b jets in the VBF production events are selected with $p_T > 25$ GeV and $|\eta| < 4.7$, and they must satisfy the tight WP of the jet identification algorithm and the medium WP of the pileup discriminant if $p_T < 50$ GeV. For the 2017 data, affected by large noise in the end caps of the electromagnetic calorimeter (ECAL), jets in the region $2.6 < |\eta| < 3.1$ are additionally required to satisfy the tight WP of the pileup discriminant to mitigate the noise effects. The two VBF jet candidates j_1 and j_2 are chosen as the highest p_T jet and the second-highest p_T jet that has an opposite η sign with respect to the former.

Events that do not contain such a VBF jet pair are assigned to the ggF category. About 26%–28% of ggF events contain additional jets that satisfy the above requirements on the VBF jet candidates, and in order to correctly classify them, a boosted decision tree (BDT) discriminant is trained to separate ggF and VBF HH signal events. The discriminant uses $p_T(H_1)$, $p_T(H_2)$, $p_T(j_1)$, $p_T(j_2)$, the invariant mass and absolute value of pseudorapidity of the jj system, the angular separation $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, where ϕ is the azimuthal angle, between the two H candidates and between each H and VBF jet, the absolute value of the polar angles with respect to the beam direction of the two VBF jets in the center-of-mass frame of the six selected jets and the product of the two Higgs boson centralities $\exp[-([\eta(H_1) - \eta_{\text{avg}}]/\Delta\eta)^2 - ([\eta(H_2) - \eta_{\text{avg}}]/\Delta\eta)^2]$, where $\Delta\eta = \eta(j_1) - \eta(j_2)$ and $\eta_{\text{avg}} = [\eta(j_1) + \eta(j_2)]/2$. The discriminant is trained to separate the SM ggF HH signal from the $\kappa_{2\nu} = 2$ VBF signal, in order to optimize both the sensitivity to the anomalous $\kappa_{2\nu}$ coupling hypotheses and the correct classification of SM ggF signal events. The value $\kappa_{2\nu} = 2$ is chosen because it is representative of the event kinematics in the presence of anomalous couplings, characterized by the large invariant mass of the jj and HH systems. These signals are associated with a large increase of the total cross section that would make them detectable with the available dataset. A threshold on the BDT output is chosen to assign events to either the ggF or VBF category. It results in the correct assignment of about 97% of all ggF HH signal events to the ggF category and of about 60% (80)% of SM ($\kappa_{2\nu} = 2$) VBF HH events that contain the additional jets to the VBF category.

Events classified as ggF or VBF signal are further divided into subcategories to optimize the sensitivity of the search for anomalous coupling hypotheses. Events in the ggF category are divided into a low- and high-mass category if the reconstructed invariant mass of the HH system, m_{HH} , is below or above 450 GeV, where the boundary is defined according to the kinematic properties of the signal. The latter category efficiently collects SM ggF HH events, while the former increases the acceptance to signals with anomalous κ_λ values. Events in the VBF category are instead divided into a “SM-like” and an “anomalous $\kappa_{2\nu}$ -like” category depending on the value

of the discriminant trained to separate ggF and VBF. The categorization thresholds were chosen to maximize the expected sensitivity to VBF HH signals, and result in the assignment of about 25%–30% of the VBF $\kappa_{2\nu} = 2$ events to the anomalous $\kappa_{2\nu}$ -like category and 95% of SM VBF events to the SM-like category.

The large multijet background that originates from QCD and $t\bar{t}$ hadronic processes is estimated from the data using background-dominated regions. Analysis signal (A_{SR}) and control (A_{CR}) regions are defined by requiring $\chi < 25$ GeV and $25 \leq \chi < 50$ GeV, respectively, where χ is the distance from the expected peak position of the two Higgs boson candidates’ invariant masses and is defined as $\chi = \sqrt{(m_{H_1} - c_1)^2 + (m_{H_2} - c_2)^2}$, where c_1 and c_2 are as defined for the pairing of the four jets. Both A_{SR} and A_{CR} are divided into a four b jet ($4b$) and three b jet ($3b$) region by requiring the b jet candidate with the lowest DEEPIET output to satisfy or fail the medium WP of the discriminant, respectively. There are between 5.5 and 11 times more events in the $3b$ region than in the $4b$ region, depending on the topological category and data taking year considered. The overall efficiency for both ggF and VBF signal events to be selected in the A_{SR}^{4b} region ranges from 0.3% to 3% depending on the couplings considered and is minimal for the SM VBF production and for the ggF production with $\kappa_\lambda \approx 5$ due to the interference effects in the HH production that result in low momenta of the Higgs bosons. The signal acceptance is mostly limited by the trigger acceptance and the jet b tagging efficiency.

Background events in the A_{SR}^{4b} region are modeled from events in the A_{SR}^{3b} region. The former represents the sensitive region of the analysis, while the latter provides a sample enriched in multijet background events with similar kinematic properties. Events in A_{SR}^{4b} were analyzed only after all the methods were defined and validated. The normalization is determined by scaling the observed number of events in A_{SR}^{3b} by a transfer factor computed as the ratio of the number of events in the A_{CR}^{4b} and A_{CR}^{3b} regions. Variations of the transfer factor depending on the position in the (m_{H_1}, m_{H_2}) plane are accounted for by measuring it as a function of m_{\parallel} , defined as the projection of the point in the plane on the line $m_{H_1} = (c_1/c_2)m_{H_2}$ that is used for the H candidate reconstruction. Higher values of m_{\parallel} are correlated with a higher average p_T of the selected jets.

Differences in the distributions of several variables between the $3b$ and the $4b$ regions are addressed with the BDT-based reweighting method described in Ref. [61], which uses a dedicated metric to identify the phase space regions with the largest differences in the distributions and compute an event weight to correct for them. This method accurately models multiple variables and their correlations, while minimizing issues related to the statistical uncertainties arising from the limited number of events in the two

regions. The BDT is trained in the A_{CR}^{4b} and A_{CR}^{3b} regions, and applied to events in A_{SR}^{3b} to model A_{SR}^{4b} .

Trainings of this BDT are performed separately for each ggF and VBF category. All trainings use as inputs the following ten variables: p_T of the four b jets, m_{HH} , the invariant masses and p_T of the H_1 and H_2 candidates, and the absolute value of their pseudorapidity difference ($|\Delta\eta(H_1, H_2)|$). In the ggF category, ten additional variables are used: the magnitude of the scalar ($\sum p_T$) and vector ($p_T(HH)$) sums of the p_T of the four b jets, the angular ΔR separations between the two jets that constitute H_1 and H_2 [$\Delta R^{H_1}(bb)$, $\Delta R^{H_2}(bb)$], the minimal ΔR (ΔR^{min}) and the maximal $|\Delta\eta|$ ($|\Delta\eta|^{\text{max}}$) between all the possible b jet pairs, the absolute value of the angle with respect to the beam line of one Higgs boson in the four-jet reference frame ($|\cos\theta^*|$) and of one jet of H_1 in the H_1 candidate reference frame ($|\cos\theta_b^{H_1}|$), the sum of the resolution estimators of the three b -tagged jets with the best DEEPIET value ($\sum R_e$), and the number of these three jets that satisfy the tight DEEPIET WP (N_b^T). In the VBF category, four additional variables are used: the absolute value of the ϕ separation between the two Higgs bosons, the VBF jets invariant mass and absolute value of the η separation, and the output of the production mode BDT discriminant. These variables are chosen as those that best represent the kinematic properties of the events in the $3b$ and the $4b$ regions and that provide separation between signal and background and are used in subsequent steps of the analysis.

The training parameters are optimized with a two-step procedure. First, a Kolmogorov-Smirnov distance test is used to ensure that the distributions of the BDT input variables in the target A_{CR}^{4b} region are compatible with the ones in the reweighted A_{CR}^{3b} region. Once that is verified, a BDT is trained to separate the A_{CR}^{4b} and reweighted A_{CR}^{3b} data, thus testing also the correlations of variables. All the training configurations that are chosen are required to have an area of 0.5 under the receiver operating curve of the discriminant, corresponding to no separation.

The procedure is validated by applying it to a signal-depleted region, defined by shifting the signal and control regions according to the definition of χ , using as values of the center position $c_1 = 179$ and $c_2 = 172$ GeV. The center of this validation region is chosen to be along the $m_{H_1} = 1.04m_{H_2}$ line used in the reconstruction of the H candidates to provide an accurate proxy of the analysis region. In analogy to the analysis regions, signal and control validation regions, V_{SR} and V_{CR} , are defined as $\chi < 25$ GeV and $25 \leq \chi < 50$ GeV, respectively. After training and applying the reweighting BDT in these regions and computing the normalization transfer factors, the data in V_{SR}^{4b} were found to be compatible within uncertainties with the predicted background, validating the modeling method. The agreement is quantified with a goodness-of-fit

test based on a saturated model [62] performed on the observables used in the analysis. For a fit under the background-only hypothesis, a p value of 53% is observed, ranging between 12% and 83% for the individual categories.

The impact on the estimated background from the presence of signal events in the A_{SR}^{3b} region due to jets failing the b tagging requirement is estimated by generating pseudodata in A_{SR}^{4b} according to the modeled background plus simulated HH signal, and fitting them under a different background hypothesis that includes the contribution from signal events in A_{SR}^{3b} weighted as done for background events. This study is repeated for signal yields up to five times larger than the expected sensitivity of this search, and in all cases a signal yield compatible with the true one is observed. We conclude that signal events in A_{SR}^{3b} do not have any significant impact on the background model and on the results.

For the background model, systematic uncertainties are considered for the limited number of events in the A_{SR}^{3b} . These uncertainties are uncorrelated across the individual bins of the background templates used for the statistical analysis, and correspond to the propagation of a bin-by-bin Poisson uncertainty from the A_{SR}^{3b} to the A_{SR}^{4b} region. The uncertainty in the estimation of the transfer factor from the $3b$ to the $4b$ region is computed from the statistical uncertainty in A_{CR}^{3b} and A_{CR}^{4b} and is 1%–2% for the ggF categories, 2%–3% for the SM-like VBF category and 18%–32% for the anomalous κ_2 v -like VBF category. An uncertainty is also considered for the limited number of events in the validation region, in some cases lower than the number of events in the analysis region. It is large (30%–33%) for the anomalous κ_2 v -like VBF category while it is about 2%–3% and below 1% for the other VBF category and the ggF categories, respectively, and represents the inherent limitation on the capability to validate the performance of the background model. For analysis categories where the agreement between the observed and predicted background yields in the validation region differs by more than 1 standard deviation, an additional uncertainty is included and ranges between 1.5% and 4.7%, depending on the category and year. Finally, the uncertainty in the performance of the reweighting method to interpolate the kinematics from A_{CR} into A_{SR} is estimated by performing alternative trainings in two regions of A_{CR} . The two regions are defined by requiring the product of m_{\perp} and m_{\parallel} to be either positive or negative, where m_{\perp} is defined as the projection of the point in the (m_{H_1}, m_{H_2}) plane onto the axis perpendicular to the one corresponding to m_{\parallel} previously defined. The two regions correspond to four quadrants in the (m_{H_1}, m_{H_2}) plane, and allow for tests of the capability of the reweighting method to model A_{SR} , starting from events with kinematic properties that are either similar ($m_{\perp}m_{\parallel} < 0$) or that are harder or softer ($m_{\perp}m_{\parallel} > 0$)

compared to A_{SR} , thus testing the capability of the model to interpolate across different learning domains. The alternative background templates obtained from trainings in these regions represent the uncertainty on the shape of the predicted background distribution. All the uncertainties are independent between the 2016 and 2017–2018 background models. The dominant uncertainties in this search are those associated to the background modeling, and in particular the bin-by-bin and the normalization uncertainties due to the limited number of events in A_{SR}^{3b} , A_{CR}^{3b} , and A_{CR}^{4b} .

The effects of the imperfect modeling of the detector response and the inaccurate simulation of signal processes are accounted for as systematic uncertainties. The most important sources of systematic uncertainty are the total integrated luminosity, the jet energy scale and resolution, the efficiency of the trigger and of the b -tagging requirements, the modeling of the pileup distribution, the $HH \rightarrow b\bar{b}b\bar{b}$ branching fraction, and the parameters used for the generators. A specific uncertainty on the parton shower is considered for the VBF production mode. Uncertainties on the theoretically determined HH cross section are considered only when quoting a limit on the HH signal strength (μ), defined as the ratio of the value of the cross section limit relative to the theoretical cross section expectation in

the SM ($\sigma_{HH}/\sigma_{HH}^{\text{SM}}$). These uncertainties are negligible in comparison to the background uncertainties. See Supplemental Material [57] for more details.

A multivariate BDT discriminant is trained with the XGBOOST software [63] in the two ggF subcategories to separate the signal from the weighted A_{SR}^{3b} background events. The discriminant uses as inputs $p_T(H_1)$, $p_T(H_2)$, m_{H_1} , m_{H_2} , $|\Delta\eta(H_1, H_2)|$, m_{HH} , $p_T(HH)$, $\Delta R^{H_1}(bb)$, $\Delta R^{H_2}(bb)$, ΔR^{min} , $|\Delta\eta|^{\text{max}}$, $\sum p_T$, N_b^T , $\sum R_e$, $|\cos\theta^*|$, and $|\cos\theta_b^*|$. For each subcategory, a separate training is performed to separate the SM ggF HH signal from the weighted A_{SR}^{3b} region data. Since the same A_{SR}^{3b} data are also used to model the background, this dataset is divided in two equal-size subsamples. Two trainings are performed on each half and applied to the other half, and the two partial background templates are added together. In this way, the full dataset can be used for the modeling, while the BDT discriminant is not evaluated on events used for its training. In the VBF SM-like category, m_{HH} is used as the discriminating variable, while in the anomalous κ_2 V-like category, a counting experiment is performed because of the small number of expected background events. The distributions of these variables are shown in Fig. 1. For the

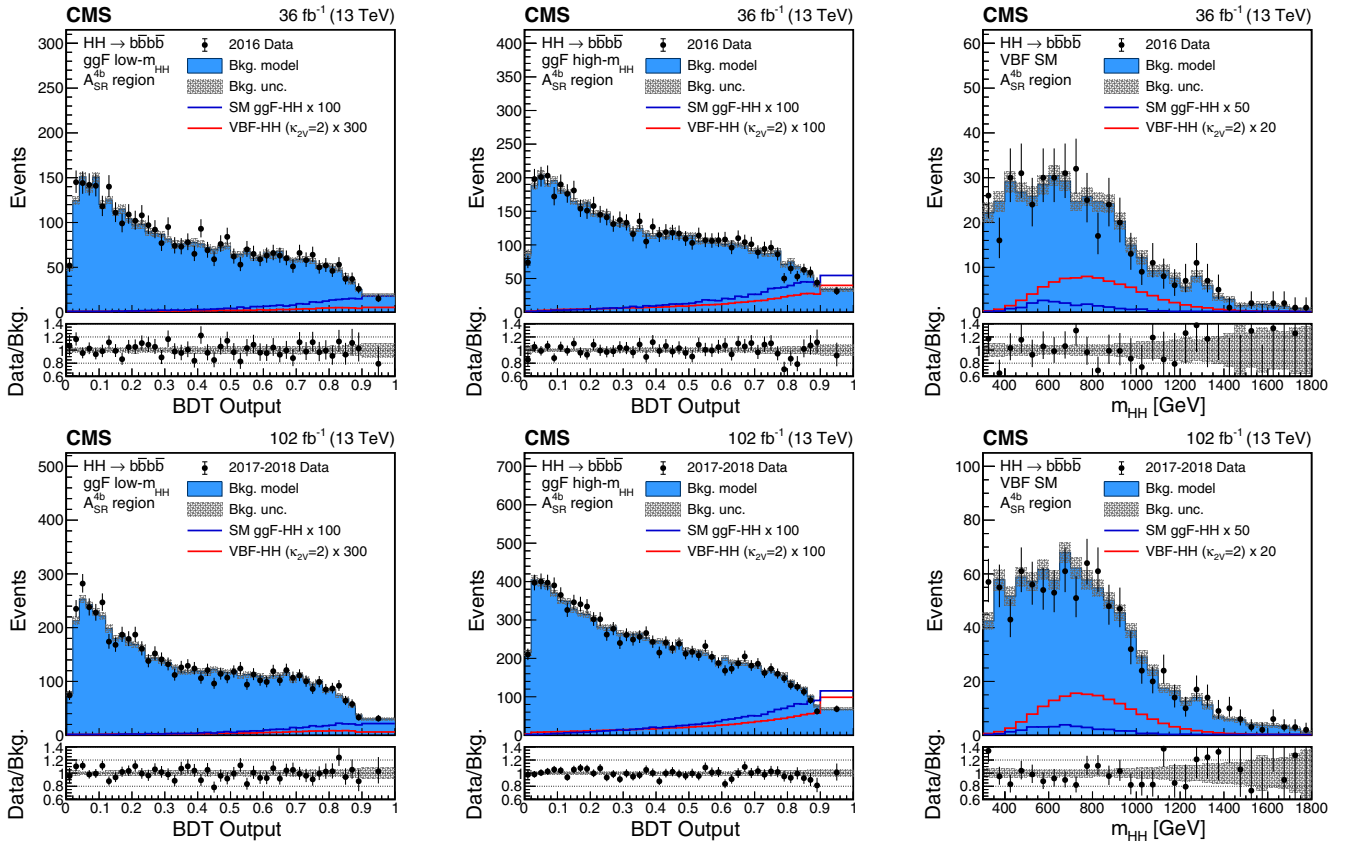


FIG. 1. Distributions of the events observed in the A_{SR}^{4b} signal region for 2016 (top) and 2017–2018 (bottom) data. The two leftmost columns show the BDT output in the low- and high-mass categories, and the rightmost column shows the m_{HH} distribution in the VBF SM-like category.

VBF anomalous κ_{2V} -like category in the 2016 (2017–2018) data set, 4 (13) events are observed for a total of 4.0 ± 1.3 (15.0 ± 3.4) background and 1.5 (3.5) VBF $\kappa_{2V} = 2$ signal events expected.

A binned maximum likelihood fit is simultaneously performed in all analysis categories, where the systematic uncertainties previously discussed are introduced as nuisance parameters. No deviation from a background-only hypothesis is observed. Results are used to set 95% CL upper limits on the HH production cross section using the modified frequentist CL_s criterion [64,65] with the profile likelihood ratio modified for upper limits [66] as the test statistics, and making use of the asymptotic approximation [67].

Figure 2 shows the 95% CL cross section upper limits as functions of the κ_λ and κ_{2V} values. The value of κ_λ is observed (expected) to be in the range $-2.3 < \kappa_\lambda < 9.4$

($-5.0 < \kappa_\lambda < 12.0$) at the 95% CL, while the value of κ_{2V} is observed (expected) to be in the range $-0.1 < \kappa_{2V} < 2.2$ ($-0.4 < \kappa_{2V} < 2.5$) at the 95% CL. The total HH production cross section, defined as the sum of the ggF and VBF production modes, is observed (expected) to be smaller than 120 (238) fb, corresponding to 3.9 (7.8) times the SM prediction, when uncertainties on the theoretical production cross section are included. The HH VBF production cross section is observed (expected) to be smaller than 226 (412) times the SM prediction. The deficit in the observed number of events localized around the BDT discriminant values of 0.85–0.9 in the ggF high-mass category in the 2017–2018 dataset, which provides the largest sensitivity to the signal, results in the observed limit to be below the expected one. Studies of the background model for the individual BDT input variables and the absence of deficit in the 2016 data in the same high-sensitivity region, and in the other categories suggest that this under fluctuation is of statistical nature.

The intervals containing 68% and 95% of the expected signal strength upper limits correspond to [5.5, 12.3] and [4.0, 18.7] ([291, 598] and [216, 846]) for the ggF (VBF) production modes, and the observed limit is thus compatible with the expectation within about 2 standard deviations. The sensitivity is mostly limited by the number of events in the signal and control regions of the analysis.

Tabulated results are available in the HEPData record of this analysis [68].

In summary, a search for the production of Higgs boson pairs via gluon and vector boson fusion in the four b quark decay channel has been presented. The data are found to be statistically compatible with the background-only hypothesis, and an observed (expected) upper limit at the 95% confidence level is set to 3.9 (7.8) times the SM prediction for the combined ggF and VBF HH cross section. The value of the Higgs boson self-coupling, normalized to the SM expectation, is observed (expected) to be in the range $-2.3 < \kappa_\lambda < 9.4$ ($-5.0 < \kappa_\lambda < 12.0$), and the value of the coupling of Higgs boson pairs to vector boson pairs, normalized to the SM expectation, to be in the range $-0.1 < \kappa_{2V} < 2.2$ ($-0.4 < \kappa_{2V} < 2.5$). These are the most stringent observed constraints to date on the HH production cross sections and on the κ_{2V} coupling.

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

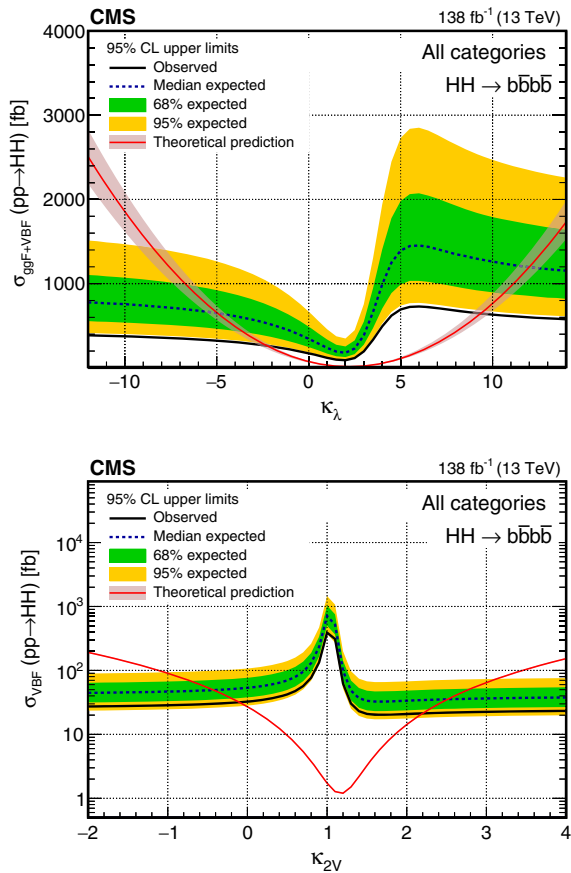


FIG. 2. Observed and expected 95% CL upper limits on the $\sigma_{ggF+VBF} HH$ cross section as a function of κ_λ (left), and on the $\sigma_{VBF} HH$ cross section as a function of κ_{2V} (right). The green (yellow) band indicates the regions containing 68% (95%) of the limit values expected under the background-only hypothesis. The red lines denote the theoretical cross section expectation assuming that other couplings are set to the SM prediction. For the cross section limit as a function of κ_{2V} , the ggF HH production is assumed to correspond to the SM prediction.

provided by the following funding agencies: BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); MINCIENCIAS (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); MoER, ERC PUT and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); NKFI (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, RFBR, and NRC KI (Russia); MESTD (Serbia); SEIDI, CPAN, PCTI, and FEDER (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

-
- [1] ATLAS Collaboration, Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, *Phys. Lett. B* **716**, 1 (2012).
- [2] CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, *Phys. Lett. B* **716**, 30 (2012).
- [3] CMS Collaboration, Observation of a new boson with mass near 125 GeV in pp collisions at $\sqrt{s} = 7$ and 8 TeV, *J. High Energy Phys.* **06** (2013) 081.
- [4] F. Englert and R. Brout, Broken Symmetry and the Mass of Gauge Vector Mesons, *Phys. Rev. Lett.* **13**, 321 (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] S. Dawson, S. Dittmaier, and M. Spira, Neutral Higgs boson pair production at hadron colliders: QCD corrections, *Phys. Rev. D* **58**, 115012 (1998).
- [8] S. Borowka, N. Greiner, G. Heinrich, S. P. Jones, M. Kerner, J. Schlenk, U. Schubert, and T. Zirke, Higgs Boson Pair Production in Gluon Fusion at Next-to-Leading Order with Full Top-Quark Mass Dependence, *Phys. Rev. Lett.* **117**, 012001 (2016); **117**, 079901(E) (2016).
- [9] J. Baglio, F. Campanario, S. Glaus, M. Mühlleitner, M. Spira, and J. Streicher, Gluon fusion into Higgs pairs at NLO QCD and the top mass scheme, *Eur. Phys. J. C* **79**, 459 (2019).
- [10] D. de Florian and J. Mazzitelli, Higgs Boson Pair Production at Next-to-Next-to-Leading Order in QCD, *Phys. Rev. Lett.* **111**, 201801 (2013).
- [11] D. Y. Shao, C. S. Li, H. T. Li, and J. Wang, Threshold resummation effects in Higgs boson pair production at the LHC, *J. High Energy Phys.* **07** (2013) 169.
- [12] D. de Florian and J. Mazzitelli, Higgs pair production at next-to-next-to-leading logarithmic accuracy at the LHC, *J. High Energy Phys.* **09** (2015) 053.
- [13] M. Grazzini, G. Heinrich, S. Jones, S. Kallweit, M. Kerner, J. M. Lindert, and J. Mazzitelli, Higgs boson pair production at NNLO with top quark mass effects, *J. High Energy Phys.* **05** (2018) 059.
- [14] J. Baglio, F. Campanario, S. Glaus, M. Mühlleitner, J. Ronca, and M. Spira, $gg \rightarrow HH$: Combined uncertainties, *Phys. Rev. D* **103**, 056002 (2021).
- [15] F. A. Dreyer and A. Karlberg, Vector-boson fusion Higgs pair production at N³LO, *Phys. Rev. D* **98**, 114016 (2018).
- [16] F. Bishara, R. Contino, and J. Rojo, Higgs pair production in vector-boson fusion at the LHC and beyond, *Eur. Phys. J. C* **77**, 481 (2017).
- [17] ATLAS Collaboration, Search for pair production of Higgs bosons in the $b\bar{b}b\bar{b}$ final state using proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *J. High Energy Phys.* **01** (2019) 030.
- [18] CMS Collaboration, Search for nonresonant Higgs boson pair production in the $b\bar{b}b\bar{b}$ final state at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **04** (2019) 112.
- [19] ATLAS Collaboration, Search for Resonant and Non-Resonant Higgs Boson Pair Production in the $b\bar{b}\tau^+\tau^-$ Decay Channel in pp Collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector, *Phys. Rev. Lett.* **121**, 191801 (2018); **122**, 089901(E) (2019).
- [20] CMS Collaboration, Search for Higgs boson pair production in events with two bottom quarks and two tau leptons in proton-proton collisions at $\sqrt{s} = 13$ TeV, *Phys. Lett. B* **778**, 101 (2018).
- [21] ATLAS Collaboration, Search for Higgs boson pair production in the $b\bar{b}WW^*$ decay mode at $\sqrt{s} = 13$ TeV with the ATLAS detector, *J. High Energy Phys.* **04** (2019) 092.
- [22] CMS Collaboration, Search for resonant and nonresonant Higgs boson pair production in the $b\bar{b}\ell\nu\ell\nu$ final state in proton-proton collisions at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **01** (2018) 054.
- [23] ATLAS Collaboration, Search for Higgs boson pair production in the $\gamma\gamma b\bar{b}$ final state with 13 TeV pp collision data collected by the ATLAS experiment, *J. High Energy Phys.* **11** (2018) 040.
- [24] CMS Collaboration, Search for Higgs boson pair production in the $\gamma\gamma b\bar{b}$ final state in pp collisions at $\sqrt{s} = 13$ TeV, *Phys. Lett. B* **788**, 7 (2019).
- [25] ATLAS Collaboration, Search for Higgs boson pair production in the $\gamma\gamma WW^*$ channel using pp collision data recorded at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Eur. Phys. J. C* **78**, 1007 (2018).
- [26] ATLAS Collaboration, Search for Higgs boson pair production in the $WW^{(*)}WW^{(*)}$ decay channel using ATLAS data recorded at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **05** (2019) 124.
- [27] ATLAS Collaboration, Combination of searches for Higgs boson pairs in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Phys. Lett. B* **800**, 135103 (2020).

- [28] CMS Collaboration, Combination of Searches for Higgs Boson Pair Production in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV, *Phys. Rev. Lett.* **122**, 121803 (2019).
- [29] ATLAS Collaboration, Search for non-resonant Higgs boson pair production in the $b\bar{b}\ell\nu\ell\nu$ final state with the ATLAS detector in pp collisions at $\sqrt{s} = 13$ TeV, *Phys. Lett. B* **801**, 135145 (2020).
- [30] CMS Collaboration, Search for nonresonant Higgs boson pair production in final states with two bottom quarks and two photons in proton-proton collisions at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **03** (2021) 257.
- [31] ATLAS Collaboration, Search for Higgs boson pair production in the two bottom quarks plus two photons final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, [arXiv:2112.11876](https://arxiv.org/abs/2112.11876) [Phys. Rev. D (to be published)].
- [32] ATLAS Collaboration, Search for the $HH \rightarrow b\bar{b}b\bar{b}$ process via vector-boson fusion production using proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *J. High Energy Phys.* **07** (2020) 108.
- [33] LHC Higgs Cross Section Working Group, Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector, Report Nos. CERN CERN-2017-002-M, CERN-2017-002, 2016, [10.23731/CYRM-2017-002](https://arxiv.org/abs/10.23731/CYRM-2017-002).
- [34] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [35] CMS Collaboration, Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s} = 13$ TeV, *J. Instrum.* **15**, P10017 (2020).
- [36] CMS Collaboration, The CMS trigger system, *J. Instrum.* **12**, P01020 (2017).
- [37] 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).
- [38] CMS Collaboration, Electron and photon reconstruction and identification with the CMS experiment at the CERN LHC, *J. Instrum.* **16**, P05014 (2021).
- [39] 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).
- [40] CMS Collaboration, Performance of photon reconstruction and identification with the CMS Detector in proton-proton collisions at $\sqrt{s} = 8$ TeV, *J. Instrum.* **10**, P08010 (2015).
- [41] CMS Collaboration, Description and performance of track and primary-vertex reconstruction with the CMS tracker, *J. Instrum.* **9**, P10009 (2014).
- [42] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, *J. Instrum.* **12**, P10003 (2017).
- [43] CMS Collaboration, Performance of reconstruction and identification of τ leptons decaying to hadrons and ν_τ in pp collisions at $\sqrt{s} = 13$ TeV, *J. Instrum.* **13**, P10005 (2018).
- [44] CMS Collaboration, Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV, *J. Instrum.* **12**, P02014 (2017).
- [45] 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).
- [46] M. Cacciari, G. P. Salam, and G. Soyez, The anti- k_T jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.
- [47] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, *Eur. Phys. J. C* **72**, 1896 (2012).
- [48] CMS Collaboration, Identification of heavy-flavour jets with the CMS detector in pp collisions at 13 TeV, *J. Instrum.* **13**, P05011 (2018).
- [49] E. Bols, J. Kieseler, M. Verzetti, M. Stoye, and A. Stakia, Jet flavour classification using DEEPJET, *J. Instrum.* **15**, P12012 (2020).
- [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] 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.
- [54] G. Heinrich, S. P. Jones, M. Kerner, G. Luisoni, and L. Scyboz, Probing the trilinear Higgs boson coupling in di-Higgs production at NLO QCD including parton shower effects, *J. High Energy Phys.* **06** (2019) 066.
- [55] 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).
- [56] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [57] See Supplemental Material at <http://link.aps.org/supplemental/10.1103/PhysRevLett.129.081802> for more details on simulation and systematic uncertainties.
- [58] CMS Collaboration, Pileup mitigation at CMS in 13 TeV data, *J. Instrum.* **15**, P09018 (2020).
- [59] CMS Collaboration, Jet algorithms performance in 13 TeV data, CMS Physics Analysis Summary, CMS-PAS-JME-16-003, 2017, <https://cds.cern.ch/record/2256875>.
- [60] CMS Collaboration, A deep neural network for simultaneous estimation of b jet energy and resolution, *Comput. Softw. Big Sci.* **4**, 10 (2020).
- [61] A. Rogozhnikov, Reweighting with boosted decision trees, *J. Phys. Conf. Ser.* **762**, 012036 (2016).
- [62] S. Baker and R. D. Cousins, Clarification of the use of chi-square and likelihood functions in fits to histograms, *Nucl. Instrum. Methods* **221**, 437 (1984).
- [63] T. Chen and C. Guestrin, XGBoost: A scalable tree boosting system, in *Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, KDD '16* (ACM, New York, NY, USA, 2016), p. 785, [10.1145/2939672.2939785](https://arxiv.org/abs/10.1145/2939672.2939785).
- [64] T. Junk, Confidence level computation for combining searches with small statistics, *Nucl. Instrum. Methods Phys. Res., Sect. A* **434**, 435 (1999).

- [65] A. L. Read, Presentation of search results: The CL_s technique, *J. Phys. G* **28**, 2693 (2002).
- [66] The ATLAS Collaboration, The CMS Collaboration, and The LHC Higgs Combination Group, Procedure for the LHC Higgs boson search combination in Summer 2011, Technical Report Nos. CMS-NOTE-2011-005, ATL-PHYS-PUB-2011-11, 2011, <https://cds.cern.ch/record/1379837>.
- [67] 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); **73**, 2501(E) (2013).
- [68] HEPData record for this analysis (2022), [10.17182/hepdata.114358](https://hepdata.cern.ch/10.17182/hepdata.114358).

A. Tumasyan,¹ W. Adam,² J. W. Andrejkovic,² T. Bergauer,² S. Chatterjee,² K. Damanakis,² M. Dragicevic,² A. Escalante Del Valle,² R. Frühwirth,^{2,b} M. Jeitler,^{2,b} N. Krammer,² L. Lechner,² D. Liko,² I. Mikulec,² P. Paulitsch,² F. M. Pitters,² J. Schieck,^{2,b} R. Schöfbeck,² D. Schwarz,² S. Templ,² W. Waltenberger,² C.-E. Wulz,^{2,b} V. Chekhovskiy,³ A. Litomin,³ V. Makarenko,³ M. R. Darwish,^{4,c} E. A. De Wolf,⁴ T. Janssen,⁴ T. Kello,^{4,d} A. Lelek,⁴ H. Rejeb Sfar,⁴ P. Van Mechelen,⁴ S. Van Putte,⁴ N. Van Remortel,⁴ F. Blekman,⁵ E. S. Bols,⁵ J. D'Hondt,⁵ M. Delcourt,⁵ H. El Faham,⁵ S. Lowette,⁵ S. Moortgat,⁵ A. Morton,⁵ D. Müller,⁵ A. R. Sahasransu,⁵ S. Tavernier,⁵ W. Van Doninck,⁵ D. Beghin,⁶ B. Bilin,⁶ B. Clerbaux,⁶ G. De Lentdecker,⁶ L. Favart,⁶ A. Grebenyuk,⁶ A. K. Kalsi,⁶ K. Lee,⁶ M. Mahdavihorrani,⁶ I. Makarenko,⁶ L. Moureaux,⁶ L. Pétré,⁶ A. Popov,⁶ N. Postiau,⁶ E. Starling,⁶ L. Thomas,⁶ M. Vanden Bemden,⁶ C. Vander Velde,⁶ P. Vanlaer,⁶ T. Cornelis,⁷ D. Dobur,⁷ J. Knolle,⁷ L. Lambrecht,⁷ G. Mestdach,⁷ M. Niedziela,⁷ C. Roskas,⁷ A. Samalan,⁷ K. Skovpen,⁷ M. Tytgat,⁷ B. Vermassen,⁷ L. Wezenbeek,⁷ A. Benecke,⁸ A. Bethani,⁸ G. Bruno,⁸ F. Bury,⁸ C. Caputo,⁸ P. David,⁸ C. Delaere,⁸ I. S. Donertas,⁸ A. Giammanco,⁸ K. Jaffel,⁸ Sa. Jain,⁸ V. Lemaître,⁸ K. Mondal,⁸ J. Prisciandaro,⁸ A. Taliencio,⁸ M. Teklishyn,⁸ T. T. Tran,⁸ P. Vischia,⁸ S. Wertz,⁸ G. A. Alves,⁹ C. Hensel,⁹ A. Moraes,⁹ P. Rebello Teles,⁹ W. L. Aldá Júnior,¹⁰ M. Alves Gallo Pereira,¹⁰ M. Barroso Ferreira Filho,¹⁰ H. Brandao Malbouisson,¹⁰ W. Carvalho,¹⁰ J. Chinellato,^{10,e} E. M. Da Costa,¹⁰ G. G. Da Silveira,^{10,f} D. De Jesus Damiao,¹⁰ S. Fonseca De Souza,¹⁰ C. Mora Herrera,¹⁰ K. Mota Amarilo,¹⁰ L. Mundim,¹⁰ H. Nogima,¹⁰ A. Santoro,¹⁰ S. M. Silva Do Amaral,¹⁰ A. Sznajder,¹⁰ M. Thiel,¹⁰ F. Torres Da Silva De Araujo,^{10,g} A. Vilela Pereira,¹⁰ C. A. Bernardes,^{11,f} L. Calligaris,¹¹ T. R. Fernandez Perez Tomei,¹¹ E. M. Gregores,¹¹ D. S. Lemos,¹¹ P. G. Mercadante,¹¹ S. F. Novaes,¹¹ Sandra S. Padula,¹¹ A. Aleksandrov,¹² G. Antchev,¹² R. Hadjiiska,¹² P. Iaydjiev,¹² M. Misheva,¹² M. Rodozov,¹² M. Shopova,¹² G. Sultanov,¹² A. Dimitrov,¹³ T. Ivanov,¹³ L. Litov,¹³ B. Pavlov,¹³ P. Petkov,¹³ A. Petrov,¹³ T. Cheng,¹⁴ T. Javaid,^{14,h} M. Mittal,¹⁴ L. Yuan,¹⁴ M. Ahmad,¹⁵ G. Bauer,¹⁵ C. Dozen,^{15,i} Z. Hu,¹⁵ J. Martins,^{15,j} Y. Wang,¹⁵ K. Yi,^{15,k,l} E. Chapon,¹⁶ G. M. Chen,^{16,h} H. S. Chen,^{16,h} M. Chen,¹⁶ F. Iemmi,¹⁶ A. Kapoor,¹⁶ D. Leggat,¹⁶ H. Liao,¹⁶ Z.-A. Liu,^{16,m} V. Milosevic,¹⁶ F. Monti,¹⁶ R. Sharma,¹⁶ J. Tao,¹⁶ J. Thomas-Wilsker,¹⁶ J. Wang,¹⁶ H. Zhang,¹⁶ J. Zhao,¹⁶ A. Agapitos,¹⁷ Y. An,¹⁷ Y. Ban,¹⁷ C. Chen,¹⁷ A. Levin,¹⁷ Q. Li,¹⁷ X. Lyu,¹⁷ Y. Mao,¹⁷ S. J. Qian,¹⁷ D. Wang,¹⁷ J. Xiao,¹⁷ M. Lu,¹⁸ Z. You,¹⁸ X. Gao,^{19,d} H. Okawa,¹⁹ Y. Zhang,¹⁹ Z. Lin,²⁰ M. Xiao,²⁰ C. Avila,²¹ A. Cabrera,²¹ C. Florez,²¹ J. Fraga,²¹ J. Mejia Guisao,²² F. Ramirez,²² J. D. Ruiz Alvarez,²² C. A. Salazar González,²² D. Giljanovic,²³ N. Godinovic,²³ D. Lelas,²³ I. Puljak,²³ Z. Antunovic,²⁴ M. Kovac,²⁴ T. Sculac,²⁴ V. Brigljevic,²⁵ D. Ferencek,²⁵ D. Majumder,²⁵ M. Roguljic,²⁵ A. Starodumov,^{25,n} T. Susa,²⁵ A. Attikis,²⁶ K. Christoforou,²⁶ E. Erodoutou,²⁶ A. Ioannou,²⁶ G. Kole,²⁶ M. Kolosova,²⁶ S. Konstantinou,²⁶ J. Mousa,²⁶ C. Nicolaou,²⁶ F. Ptochos,²⁶ P. A. Razis,²⁶ H. Rykaczewski,²⁶ H. Saka,²⁶ M. Finger,^{27,o} M. Finger Jr.,^{27,o} A. Kveton,²⁷ E. Ayala,²⁸ E. Carrera Jarrin,²⁹ S. Elgammal,^{30,p} S. Khalil,^{30,q} M. A. Mahmoud,³¹ Y. Mohammed,³¹ S. Bhowmik,³² R. K. Dewanjee,³² K. Ehataht,³² M. Kadastik,³² S. Nandan,³² C. Nielsen,³² J. Pata,³² M. Raidal,³² L. Tani,³² C. Veelken,³² P. Eerola,³³ L. Forthomme,³³ H. Kirschenmann,³³ K. Osterberg,³³ M. Voutilainen,³³ S. Bharthuar,³⁴ E. Brücken,³⁴ F. Garcia,³⁴ J. Havukainen,³⁴ M. S. Kim,³⁴ R. Kinnunen,³⁴ T. Lampén,³⁴ K. Lassila-Perini,³⁴ S. Lehti,³⁴ T. Lindén,³⁴ M. Lotti,³⁴ L. Martikainen,³⁴ M. Myllymäki,³⁴ J. Ott,³⁴ H. Siikonen,³⁴ E. Tuominen,³⁴ J. Tuominiemi,³⁴ P. Luukka,³⁵ H. Petrow,³⁵ T. Tuuva,³⁵ C. Amendola,³⁶ M. Besancon,³⁶ F. Couderc,³⁶ M. Dejardin,³⁶ D. Denegri,³⁶ J. L. Faure,³⁶ F. Ferri,³⁶ S. Ganjour,³⁶ P. Gras,³⁶ G. Hamel de Monchenault,³⁶ P. Jarry,³⁶ B. Lenzi,³⁶ E. Locci,³⁶ J. Malcles,³⁶ J. Rander,³⁶ A. Rosowsky,³⁶ M. Ö. Sahin,³⁶ A. Savoy-Navarro,^{36,r} M. Titov,³⁶ G. B. Yu,³⁶ S. Ahuja,³⁷ F. Beaudette,³⁷ M. Bonanomi,³⁷ A. Buchot Perraguin,³⁷ P. Busson,³⁷ A. Cappati,³⁷ C. Charlot,³⁷ O. Davignon,³⁷ B. Diab,³⁷ G. Falmagne,³⁷ S. Ghosh,³⁷ R. Granier de Cassagnac,³⁷ A. Hakimi,³⁷ I. Kucher,³⁷ J. Motta,³⁷ M. Nguyen,³⁷ C. Ochando,³⁷ P. Paganini,³⁷ J. Rembser,³⁷ R. Salerno,³⁷ U. Sarkar,³⁷ J. B. Sauvan,³⁷ Y. Sirois,³⁷ A. Tarabini,³⁷ A. Zabi,³⁷ A. Zghiche,³⁷ J.-L. Agram,^{38,s} J. Andrea,³⁸ D. Apparú,³⁸ D. Bloch,³⁸ G. Bourgatte,³⁸ J.-M. Brom,³⁸ E. C. Chabert,³⁸ C. Collard,³⁸ D. Darej,³⁸ J.-C. Fontaine,^{38,s}

U. Goerlach,³⁸ C. Grimault,³⁸ A.-C. Le Bihan,³⁸ E. Nibigira,³⁸ P. Van Hove,³⁸ E. Asilar,³⁹ S. Beauceron,³⁹ C. Bernet,³⁹ G. Boudoul,³⁹ C. Camen,³⁹ A. Carle,³⁹ N. Chanon,³⁹ D. Contardo,³⁹ P. Depasse,³⁹ H. El Mamouni,³⁹ J. Fay,³⁹ S. Gascon,³⁹ M. Gouzevitch,³⁹ B. Ille,³⁹ I. B. Laktineh,³⁹ H. Lattaud,³⁹ A. Lesauvage,³⁹ M. Lethuillier,³⁹ L. Mirabito,³⁹ S. Perries,³⁹ K. Shchablo,³⁹ V. Sordini,³⁹ L. Torterotot,³⁹ G. Touquet,³⁹ M. Vander Donckt,³⁹ S. Viret,³⁹ A. Khvedelidze,^{40,o} I. Lomidze,⁴⁰ Z. Tsamalaidze,^{40,o} V. Botta,⁴¹ L. Feld,⁴¹ K. Klein,⁴¹ M. Lipinski,⁴¹ D. Meuser,⁴¹ A. Pauls,⁴¹ N. Röwert,⁴¹ J. Schulz,⁴¹ M. Teroerde,⁴¹ A. Dodonova,⁴² D. Eliseev,⁴² M. Erdmann,⁴² P. Fackeldey,⁴² B. Fischer,⁴² S. Ghosh,⁴² T. Hebbeker,⁴² K. Hoepfner,⁴² F. Ivone,⁴² L. Mastrolorenzo,⁴² M. Merschmeyer,⁴² A. Meyer,⁴² G. Mocellin,⁴² S. Mondal,⁴² S. Mukherjee,⁴² D. Noll,⁴² A. Novak,⁴² T. Pook,⁴² A. Pozdnyakov,⁴² Y. Rath,⁴² H. Reithler,⁴² J. Roemer,⁴² A. Schmidt,⁴² S. C. Schuler,⁴² A. Sharma,⁴² L. Vigilante,⁴² S. Wiedenbeck,⁴² S. Zaleski,⁴² C. Dziwok,⁴³ G. Flügge,⁴³ W. Haj Ahmad,^{43,t} O. Hlushchenko,⁴³ T. Kress,⁴³ A. Nowack,⁴³ C. Pistone,⁴³ O. Pooth,⁴³ D. Roy,⁴³ A. Stahl,^{43,u} T. Ziemons,⁴³ A. Zotz,⁴³ H. Aarup Petersen,⁴⁴ M. Aldaya Martin,⁴⁴ P. Asmuss,⁴⁴ S. Baxter,⁴⁴ M. Bayatmakou,⁴⁴ O. Behnke,⁴⁴ A. Bermúdez Martínez,⁴⁴ S. Bhattacharya,⁴⁴ A. A. Bin Anuar,⁴⁴ K. Borrás,^{44,v} D. Brunner,⁴⁴ A. Campbell,⁴⁴ A. Cardini,⁴⁴ C. Cheng,⁴⁴ F. Colombina,⁴⁴ S. Consuegra Rodríguez,⁴⁴ G. Correia Silva,⁴⁴ V. Danilov,⁴⁴ M. De Silva,⁴⁴ L. Didukh,⁴⁴ G. Eckerlin,⁴⁴ D. Eckstein,⁴⁴ L. I. Estevez Banos,⁴⁴ O. Filatov,⁴⁴ E. Gallo,^{44,w} A. Geiser,⁴⁴ A. Giralaldi,⁴⁴ A. Grohsjean,⁴⁴ M. Guthoff,⁴⁴ A. Jafari,^{44,x} N. Z. Jomhari,⁴⁴ H. Jung,⁴⁴ A. Kasem,^{44,v} M. Kasemann,⁴⁴ H. Kaveh,⁴⁴ C. Kleinwort,⁴⁴ R. Kogler,⁴⁴ D. Krücker,⁴⁴ W. Lange,⁴⁴ J. Lidrych,⁴⁴ K. Lipka,⁴⁴ W. Lohmann,^{44,y} R. Mankel,⁴⁴ I.-A. Melzer-Pellmann,⁴⁴ M. Mendizabal Morentin,⁴⁴ J. Metwally,⁴⁴ A. B. Meyer,⁴⁴ M. Meyer,⁴⁴ J. Mnich,⁴⁴ A. Mussgiller,⁴⁴ Y. Otari,⁴⁴ D. Pérez Adán,⁴⁴ D. Pitzl,⁴⁴ A. Raspereza,⁴⁴ B. Ribeiro Lopes,⁴⁴ J. Rübenach,⁴⁴ A. Saggio,⁴⁴ A. Saibel,⁴⁴ M. Savitskyi,⁴⁴ M. Scham,^{44,z} V. Scheurer,⁴⁴ S. Schnake,⁴⁴ P. Schütze,⁴⁴ C. Schwanenberger,^{44,w} M. Shchedrolosiev,⁴⁴ R. E. Sosa Ricardo,⁴⁴ D. Stafford,⁴⁴ N. Tonon,⁴⁴ M. Van De Klundert,⁴⁴ R. Walsh,⁴⁴ D. Walter,⁴⁴ Q. Wang,⁴⁴ Y. Wen,⁴⁴ K. Wichmann,⁴⁴ L. Wiens,⁴⁴ C. Wissing,⁴⁴ S. Wuchterl,⁴⁴ R. Aggleton,⁴⁵ S. Albrecht,⁴⁵ S. Bein,⁴⁵ L. Benato,⁴⁵ P. Connor,⁴⁵ K. De Leo,⁴⁵ M. Eich,⁴⁵ F. Feindt,⁴⁵ A. Fröhlich,⁴⁵ C. Garbers,⁴⁵ E. Garutti,⁴⁵ P. Gunnellini,⁴⁵ M. Hajheidari,⁴⁵ J. Haller,⁴⁵ A. Hinzmann,⁴⁵ G. Kasieczka,⁴⁵ R. Klanner,⁴⁵ T. Kramer,⁴⁵ V. Kutzner,⁴⁵ J. Lange,⁴⁵ T. Lange,⁴⁵ A. Lobanov,⁴⁵ A. Malara,⁴⁵ A. Nigamova,⁴⁵ K. J. Pena Rodriguez,⁴⁵ M. Rieger,⁴⁵ O. Rieger,⁴⁵ P. Schleper,⁴⁵ M. Schröder,⁴⁵ J. Schwandt,⁴⁵ J. Sonneveld,⁴⁵ H. Stadie,⁴⁵ G. Steinbrück,⁴⁵ A. Tews,⁴⁵ I. Zoi,⁴⁵ J. Bechtel,⁴⁶ S. Brommer,⁴⁶ M. Burkart,⁴⁶ E. Butz,⁴⁶ R. Caspart,⁴⁶ T. Chwalek,⁴⁶ W. De Boer,^{46,a} A. Dierlamm,⁴⁶ A. Droll,⁴⁶ K. El Morabit,⁴⁶ N. Faltermann,⁴⁶ M. Giffels,⁴⁶ J. o. Gosewisch,⁴⁶ A. Gottmann,⁴⁶ F. Hartmann,^{46,u} C. Heidecker,⁴⁶ U. Husemann,⁴⁶ P. Keicher,⁴⁶ R. Koppenhöfer,⁴⁶ S. Maier,⁴⁶ M. Metzler,⁴⁶ S. Mitra,⁴⁶ Th. Müller,⁴⁶ M. Neukum,⁴⁶ A. Nürnberg,⁴⁶ G. Quast,⁴⁶ K. Rabbertz,⁴⁶ J. Rauser,⁴⁶ D. Savoie,⁴⁶ M. Schnepf,⁴⁶ D. Seith,⁴⁶ I. Shvetsov,⁴⁶ H. J. Simonis,⁴⁶ R. Ulrich,⁴⁶ J. Van Der Linden,⁴⁶ R. F. Von Cube,⁴⁶ M. Wassmer,⁴⁶ M. Weber,⁴⁶ S. Wieland,⁴⁶ R. Wolf,⁴⁶ S. Wozniowski,⁴⁶ S. Wunsch,⁴⁶ G. Anagnostou,⁴⁷ G. Daskalakis,⁴⁷ T. Geralis,⁴⁷ A. Kyriakis,⁴⁷ D. Loukas,⁴⁷ A. Stakia,⁴⁷ M. Diamantopoulou,⁴⁸ D. Karasavvas,⁴⁸ G. Karathanasis,⁴⁸ P. Kontaxakis,⁴⁸ C. K. Koraka,⁴⁸ A. Manousakis-Katsikakis,⁴⁸ A. Panagiotou,⁴⁸ I. Papavergou,⁴⁸ N. Saoulidou,⁴⁸ K. Theofilatos,⁴⁸ E. Tziaferi,⁴⁸ K. Vellidis,⁴⁸ E. Vourliotis,⁴⁸ G. Bakas,⁴⁹ K. Kousouris,⁴⁹ I. Papakrivopoulos,⁴⁹ G. Tsiolitis,⁴⁹ A. Zacharopoulou,⁴⁹ K. Adamidis,⁵⁰ I. Bestintzanos,⁵⁰ I. Evangelou,⁵⁰ C. Foudas,⁵⁰ P. Gianneios,⁵⁰ P. Katsoulis,⁵⁰ P. Kokkas,⁵⁰ N. Manthos,⁵⁰ I. Papadopoulos,⁵⁰ J. Strologas,⁵⁰ M. Csanad,⁵¹ K. Farkas,⁵¹ M. M. A. Gadallah,^{51,aa} S. Lökös,^{51,bb} P. Major,⁵¹ K. Mandal,⁵¹ A. Mehta,⁵¹ G. Pasztor,⁵¹ A. J. Rádl,⁵¹ O. Surányi,⁵¹ G. I. Veres,⁵¹ M. Bartók,^{52,cc} G. Bencze,⁵² C. Hajdu,⁵² D. Horvath,^{52,dd} F. Sikler,⁵² V. Veszpremi,⁵² S. Czellar,⁵³ D. Fasanella,⁵³ J. Karancsi,^{53,cc} J. Molnar,⁵³ Z. Szillasi,⁵³ D. Teyssier,⁵³ P. Raics,⁵⁴ Z. L. Trocsanyi,^{54,ee} B. Ujvari,⁵⁴ T. Csorgo,^{55,ff} F. Nemes,^{55,ff} T. Novak,⁵⁵ S. Choudhury,⁵⁶ J. R. Komaragiri,⁵⁶ D. Kumar,⁵⁶ L. Panwar,⁵⁶ P. C. Tiwari,⁵⁶ S. Bahinipati,^{57,gg} C. Kar,⁵⁷ P. Mal,⁵⁷ T. Mishra,⁵⁷ V. K. Muraleedharan Nair Bindhu,^{57,hh} A. Nayak,^{57,hh} P. Saha,⁵⁷ N. Sur,⁵⁷ S. K. Swain,⁵⁷ D. Vats,^{57,hh} S. Bansal,⁵⁸ S. B. Beri,⁵⁸ V. Bhatnagar,⁵⁸ G. Chaudhary,⁵⁸ S. Chauhan,⁵⁸ N. Dhingra,^{58,ii} R. Gupta,⁵⁸ A. Kaur,⁵⁸ M. Kaur,⁵⁸ S. Kaur,⁵⁸ P. Kumari,⁵⁸ M. Meena,⁵⁸ K. Sandeep,⁵⁸ J. B. Singh,⁵⁸ A. K. Viridi,⁵⁸ A. Ahmed,⁵⁹ A. Bhardwaj,⁵⁹ B. C. Choudhary,⁵⁹ M. Gola,⁵⁹ S. Keshri,⁵⁹ A. Kumar,⁵⁹ M. Naimuddin,⁵⁹ P. Priyanka,⁵⁹ K. Ranjan,⁵⁹ A. Shah,⁵⁹ M. Bharti,^{60,ij} R. Bhattacharya,⁶⁰ S. Bhattacharya,⁶⁰ D. Bhowmik,⁶⁰ S. Dutta,⁶⁰ S. Dutta,⁶⁰ B. Gomber,^{60,kk} M. Maity,^{60,ll} P. Palit,⁶⁰ P. K. Rout,⁶⁰ G. Saha,⁶⁰ B. Sahu,⁶⁰ S. Sarkar,⁶⁰ M. Sharan,⁶⁰ B. Singh,^{60,ij} S. Thakur,^{60,ij} P. K. Behera,⁶¹ S. C. Behera,⁶¹ P. Kalbhor,⁶¹ A. Muhammad,⁶¹ R. Pradhan,⁶¹ P. R. Pujahari,⁶¹ A. Sharma,⁶¹ A. K. Sikdar,⁶¹ D. Dutta,⁶² V. Jha,⁶² V. Kumar,⁶² D. K. Mishra,⁶² K. Naskar,^{62,mmm} P. K. Netrakanti,⁶² L. M. Pant,⁶² P. Shukla,⁶² T. Aziz,⁶³ S. Dugad,⁶³ M. Kumar,⁶³ G. B. Mohanty,⁶³ S. Banerjee,⁶⁴ R. Chudasama,⁶⁴ M. Guchait,⁶⁴ S. Karmakar,⁶⁴ S. Kumar,⁶⁴ G. Majumder,⁶⁴ K. Mazumdar,⁶⁴ S. Mukherjee,⁶⁴ K. Alpana,⁶⁵ S. Dube,⁶⁵ B. Kansal,⁶⁵ A. Laha,⁶⁵ S. Pandey,⁶⁵ A. Rane,⁶⁵ A. Rastogi,⁶⁵ S. Sharma,⁶⁵ H. Bakhshiansohi,^{66,nn} E. Khazaie,⁶⁶

M. Zeinali,^{66,oo} S. Chenarani,^{67,pp} S. M. Etesami,⁶⁷ M. Khakzad,⁶⁷ M. Mohammadi Najafabadi,⁶⁷ M. Grunewald,⁶⁸
 M. Abbrescia,^{69a,69b} R. Aly,^{69a,69b,qq} C. Aruta,^{69a,69b} A. Colaleo,^{69a} D. Creanza,^{69a,69c} N. De Filippis,^{69a,69c} M. De Palma,^{69a,69b}
 A. Di Florio,^{69a,69b} A. Di Pilato,^{69a,69b} W. Elmetenawee,^{69a,69b} L. Fiore,^{69a} A. Gelmi,^{69a,69b} M. Gul,^{69a} G. Iaselli,^{69a,69c}
 M. Ince,^{69a,69b} S. Lezki,^{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} D. Ramos,^{69a} A. Ranieri,^{69a} G. Selvaggi,^{69a,69b}
 L. Silvestris,^{69a} F. M. Simone,^{69a,69b} Ü. Sözbilir,^{69a} R. Venditti,^{69a} P. Verwilligen,^{69a} G. Abbiendi,^{70a} C. Battilana,^{70a,70b}
 D. Bonacorsi,^{70a,70b} L. Borgonovi,^{70a} L. Brigliadori,^{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} P. Giacomelli,^{70a}
 L. Giommi,^{70a,70b} C. Grandi,^{70a} L. Guiducci,^{70a,70b} S. Lo Meo,^{70a,rr} 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. Albergo,^{71a,71b,ss} S. Costa,^{71a,71b,ss} A. Di Mattia,^{71a} R. Potenza,^{71a,71b} A. Tricomi,^{71a,71b,ss} C. Tuve,^{71a,71b} G. Barbagli,^{72a}
 A. Cassese,^{72a} R. Ceccarelli,^{72a,72b} V. Ciulli,^{72a,72b} C. Civinini,^{72a} R. D'Alessandro,^{72a,72b} E. Focardi,^{72a,72b} G. Latino,^{72a,72b}
 P. Lenzi,^{72a,72b} M. Lizzo,^{72a,72b} M. Meschini,^{72a} S. Paoletti,^{72a} R. Seidita,^{72a,72b} G. Sguazzoni,^{72a} L. Viliani,^{72a} L. Benussi,⁷³
 S. Bianco,⁷³ D. Piccolo,⁷³ M. Bozzo,^{74a,74b} F. Ferro,^{74a} R. Mulargia,^{74a,74b} E. Robutti,^{74a} S. Tosi,^{74a,74b} A. Benaglia,^{75a}
 G. Boldrini,^{75a} F. Brivio,^{75a,75b} F. Cetorelli,^{75a,75b} F. De Guio,^{75a,75b} M. E. Dinardo,^{75a,75b} P. Dini,^{75a} S. Gennai,^{75a}
 A. Ghezzi,^{75a,75b} P. Govoni,^{75a,75b} L. Guzzi,^{75a,75b} 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} N. Redaelli,^{75a}
 T. Tabarelli de Fatis,^{75a,75b} D. Valsecchi,^{75a,75b,u} D. Zuolo,^{75a,75b} S. Buontempo,^{76a} F. Carnevali,^{76a,76b} N. Cavallo,^{76a,76c}
 A. De Iorio,^{76a,76b} F. Fabozzi,^{76a,76c} A. O. M. Iorio,^{76a,76b} L. Lista,^{76a,76b,tt} S. Meola,^{76a,76d,u} P. Paolucci,^{76a,u} B. Rossi,^{76a}
 C. Sciacca,^{76a,76b} P. Azzi,^{77a} N. Bacchetta,^{77a} D. Bisello,^{77a,77b} P. Bortignon,^{77a} A. Bragagnolo,^{77a,77b} R. Carlin,^{77a,77b}
 P. Checchia,^{77a} T. Dorigo,^{77a} U. Dosselli,^{77a} F. Gasparini,^{77a,77b} U. Gasparini,^{77a,77b} G. Grosso,^{77a} S. Y. Hoh,^{77a,77b}
 L. Layer,^{77a,uu} E. Lusiani,^{77a} M. Margoni,^{77a,77b} A. T. Meneguzzo,^{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} H. Yarar,^{77a,77b} M. Zanetti,^{77a,77b} P. Zotto,^{77a,77b} A. Zucchetta,^{77a,77b}
 G. Zumerle,^{77a,77b} C. Aime,^{78a,78b} A. Braghieri,^{78a} S. Calzaferri,^{78a,78b} D. Fiorina,^{78a,78b} P. Montagna,^{78a,78b} S. P. Ratti,^{78a,78b}
 V. Re,^{78a} C. Riccardi,^{78a,78b} P. Salvini,^{78a} I. Vai,^{78a} P. Vitulo,^{78a,78b} P. Asenov,^{79a,vv} 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,vv}
 A. Piccinelli,^{79a,79b} M. Presilla,^{79a,79b} A. Rossi,^{79a,79b} A. Santocchia,^{79a,79b} D. Spiga,^{79a} T. Tedeschi,^{79a,79b} P. Azzurri,^{80a}
 G. Bagliesi,^{80a} V. Bertacchi,^{80a,80c} L. Bianchini,^{80a} T. Boccali,^{80a} E. Bossini,^{80a,80b} R. Castaldi,^{80a} M. A. Ciocci,^{80a,80b}
 V. D'Amante,^{80a,80d} R. Dell'Orso,^{80a} M. R. Di Domenico,^{80a,80d} S. Donato,^{80a} A. Giassi,^{80a} F. Ligabue,^{80a,80c} E. Manca,^{80a,80c}
 G. Mandorli,^{80a,80c} D. Matos Figueiredo,^{80a} A. Messineo,^{80a,80b} F. Palla,^{80a} S. Parolia,^{80a,80b} G. Ramirez-Sanchez,^{80a,80c}
 A. Rizzi,^{80a,80b} G. Rolandi,^{80a,80c} S. Roy Chowdhury,^{80a,80c} A. Scribano,^{80a} N. Shafiei,^{80a,80b} P. Spagnolo,^{80a} R. Tenchini,^{80a}
 G. Tonelli,^{80a,80b} N. Turini,^{80a,80d} A. Venturi,^{80a} P. G. Verdini,^{80a} P. Barria,^{81a} M. Campana,^{81a,81b} F. Cavallari,^{81a}
 D. Del Re,^{81a,81b} E. Di Marco,^{81a} M. Diemoz,^{81a} E. Longo,^{81a,81b} P. Meridiani,^{81a} 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}
 R. Tramontano,^{81a,81b} 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} J. Berenguer Antequera,^{82a,82b} C. Biino,^{82a} N. Cartiglia,^{82a} S. Cometti,^{82a} M. Costa,^{82a,82b}
 R. Covarelli,^{82a,82b} N. Demaria,^{82a} B. Kiani,^{82a,82b} F. Legger,^{82a} C. Mariotti,^{82a} S. Maselli,^{82a} E. Migliore,^{82a,82b}
 E. Monteil,^{82a,82b} M. Monteno,^{82a} M. M. Obertino,^{82a,82b} G. Ortona,^{82a} L. Pacher,^{82a,82b} N. Pastrone,^{82a} M. Pelliccioni,^{82a}
 G. L. Pinna Angioni,^{82a,82b} M. Ruspa,^{82a,82c} K. Shchelina,^{82a} F. Siviero,^{82a,82b} V. Sola,^{82a} A. Solano,^{82a,82b} D. Soldi,^{82a,82b}
 A. Staiano,^{82a} M. Tornago,^{82a,82b} D. Trocino,^{82a} A. Vagnerini,^{82a,82b} S. Belforte,^{83a} V. Candelise,^{83a,83b} M. Casarsa,^{83a}
 F. Cossutti,^{83a} A. Da Rold,^{83a,83b} G. Della Ricca,^{83a,83b} G. Sorrentino,^{83a,83b} F. Vazzoler,^{83a,83b} S. Dogra,⁸⁴ C. Huh,⁸⁴ B. Kim,⁸⁴
 D. H. Kim,⁸⁴ G. N. Kim,⁸⁴ J. Kim,⁸⁴ J. Lee,⁸⁴ S. W. Lee,⁸⁴ C. S. Moon,⁸⁴ Y. D. Oh,⁸⁴ S. I. Pak,⁸⁴ B. C. Radburn-Smith,⁸⁴
 S. Sekmen,⁸⁴ Y. C. Yang,⁸⁴ H. Kim,⁸⁵ D. H. Moon,⁸⁵ B. Francois,⁸⁶ T. J. Kim,⁸⁶ J. Park,⁸⁶ S. Cho,⁸⁷ S. Choi,⁸⁷ Y. Go,⁸⁷
 B. Hong,⁸⁷ K. Lee,⁸⁷ K. S. Lee,⁸⁷ J. Lim,⁸⁷ J. Park,⁸⁷ S. K. Park,⁸⁷ J. Yoo,⁸⁷ J. Goh,⁸⁸ A. Gurtu,⁸⁸ H. S. Kim,⁸⁹ Y. Kim,⁸⁹
 J. Almond,⁹⁰ J. H. Bhyun,⁹⁰ J. Choi,⁹⁰ S. Jeon,⁹⁰ J. Kim,⁹⁰ J. S. Kim,⁹⁰ S. Ko,⁹⁰ H. Kwon,⁹⁰ H. Lee,⁹⁰ S. Lee,⁹⁰ B. H. Oh,⁹⁰
 M. Oh,⁹⁰ S. B. Oh,⁹⁰ H. Seo,⁹⁰ U. K. Yang,⁹⁰ I. Yoon,⁹⁰ W. Jang,⁹¹ D. Y. Kang,⁹¹ Y. Kang,⁹¹ S. Kim,⁹¹ B. Ko,⁹¹ J. S. H. Lee,⁹¹
 Y. Lee,⁹¹ J. A. Merlin,⁹¹ I. C. Park,⁹¹ Y. Roh,⁹¹ M. S. Ryu,⁹¹ D. Song,⁹¹ I. J. Watson,⁹¹ S. Yang,⁹¹ S. Ha,⁹² H. D. Yoo,⁹²
 M. Choi,⁹³ H. Lee,⁹³ Y. Lee,⁹³ I. Yu,⁹³ T. Beyrouthy,⁹⁴ Y. Maghrbi,⁹⁴ K. Dreimanis,⁹⁵ V. Veckalns,^{95,ww} M. Ambrozias,⁹⁶
 A. Carvalho Antunes De Oliveira,⁹⁶ A. Juodagalvis,⁹⁶ A. Rinkevicius,⁹⁶ G. Tamulaitis,⁹⁶ N. Bin Norjoharuddeen,⁹⁷

W. A. T. Wan Abdullah,⁹⁷ M. N. Yusli,⁹⁷ Z. Zolkapli,⁹⁷ J. F. Benitez,⁹⁸ A. Castaneda Hernandez,⁹⁸ M. León Coello,⁹⁸ J. A. Murillo Quijada,⁹⁸ A. Sehrawat,⁹⁸ L. Valencia Palomo,⁹⁸ G. Ayala,⁹⁹ H. Castilla-Valdez,⁹⁹ E. De La Cruz-Burelo,⁹⁹ I. Heredia-De La Cruz,^{99,xx} R. Lopez-Fernandez,⁹⁹ C. A. Mondragon Herrera,⁹⁹ D. A. Perez Navarro,⁹⁹ A. Sánchez Hernández,⁹⁹ S. Carrillo Moreno,¹⁰⁰ C. Oropeza Barrera,¹⁰⁰ F. Vazquez Valencia,¹⁰⁰ I. Pedraza,¹⁰¹ H. A. Salazar Ibarguen,¹⁰¹ C. Uribe Estrada,¹⁰¹ J. Mijuskovic,^{102,yy} N. Raicevic,¹⁰² D. Krofcheck,¹⁰³ P. H. Butler,¹⁰⁴ A. Ahmad,¹⁰⁵ M. I. Asghar,¹⁰⁵ A. Awais,¹⁰⁵ M. I. M. Awan,¹⁰⁵ H. R. Hoorani,¹⁰⁵ W. A. Khan,¹⁰⁵ M. A. Shah,¹⁰⁵ M. Shoaib,¹⁰⁵ M. Waqas,¹⁰⁵ V. Avati,¹⁰⁶ L. Grzanka,¹⁰⁶ M. Malawski,¹⁰⁶ H. Bialkowska,¹⁰⁷ M. Bluj,¹⁰⁷ B. Boimska,¹⁰⁷ M. Górski,¹⁰⁷ M. Kazana,¹⁰⁷ M. Szeleper,¹⁰⁷ P. Zalewski,¹⁰⁷ K. Bunkowski,¹⁰⁸ K. Doroba,¹⁰⁸ A. Kalinowski,¹⁰⁸ M. Konecki,¹⁰⁸ J. Krolikowski,¹⁰⁸ M. Araujo,¹⁰⁹ P. Bargassa,¹⁰⁹ D. Bastos,¹⁰⁹ A. Boletti,¹⁰⁹ P. Faccioli,¹⁰⁹ M. Gallinaro,¹⁰⁹ J. Hollar,¹⁰⁹ N. Leonardo,¹⁰⁹ T. Niknejad,¹⁰⁹ M. Pisano,¹⁰⁹ J. Seixas,¹⁰⁹ O. Toldaiev,¹⁰⁹ J. Varela,¹⁰⁹ S. Afanasiev,¹¹⁰ D. Budkouski,¹¹⁰ I. Golutvin,¹¹⁰ I. Gorbunov,¹¹⁰ V. Karjavine,¹¹⁰ V. Korenkov,¹¹⁰ A. Lanev,¹¹⁰ A. Malakhov,¹¹⁰ V. Matveev,^{110,zz,aaa} V. Palichik,¹¹⁰ V. Perelygin,¹¹⁰ M. Savina,¹¹⁰ D. Seitova,¹¹⁰ V. Shalaev,¹¹⁰ S. Shmatov,¹¹⁰ S. Shulha,¹¹⁰ V. Smirnov,¹¹⁰ O. Teryaev,¹¹⁰ N. Voytishin,¹¹⁰ B. S. Yuldashev,^{110,bbb} A. Zarubin,¹¹⁰ I. Zhizhin,¹¹⁰ G. Gavrillov,¹¹¹ V. Golovtsov,¹¹¹ Y. Ivanov,¹¹¹ V. Kim,^{111,ccc} E. Kuznetsova,^{111,ddd} V. Murzin,¹¹¹ V. Oreshkin,¹¹¹ I. Smirnov,¹¹¹ D. Sosnov,¹¹¹ V. Sulimov,¹¹¹ L. Uvarov,¹¹¹ S. Volkov,¹¹¹ A. Vorobyev,¹¹¹ Yu. Andreev,¹¹² A. Dermenev,¹¹² S. Gninenko,¹¹² N. Golubev,¹¹² A. Karneyev,¹¹² D. Kirpichnikov,¹¹² M. Kirsanov,¹¹² N. Krasnikov,¹¹² A. Pashenkov,¹¹² G. Pivovarov,¹¹² A. Toropin,¹¹² T. Aushev,¹¹³ V. Epshteyn,¹¹⁴ V. Gavrillov,¹¹⁴ N. Lychkovskaya,¹¹⁴ A. Nikitenko,^{114,eee} V. Popov,¹¹⁴ A. Stepanov,¹¹⁴ M. Toms,¹¹⁴ E. Vlasov,¹¹⁴ A. Zhokin,¹¹⁴ O. Bychkova,¹¹⁵ R. Chistov,^{115,fff} M. Danilov,^{115,ggg} A. Oskin,¹¹⁵ P. Parygin,¹¹⁵ S. Polikarpov,^{115,ggg} V. Andreev,¹¹⁶ M. Azarkin,¹¹⁶ I. Dremin,¹¹⁶ M. Kirakosyan,¹¹⁶ A. Terkulov,¹¹⁶ A. Belyaev,¹¹⁷ E. Boos,¹¹⁷ V. Bunichev,¹¹⁷ M. Dubinin,^{117,hhh} L. Dudko,¹¹⁷ A. Ershov,¹¹⁷ A. Gribushin,¹¹⁷ V. Klyukhin,¹¹⁷ O. Kodolova,¹¹⁷ I. Lokhtin,¹¹⁷ S. Obraztsov,¹¹⁷ S. Petrushanko,¹¹⁷ V. Savrin,¹¹⁷ V. Blinov,^{118,iii} T. Dimova,^{118,iii} L. Kardapoltsev,^{118,iii} A. Kozyrev,^{118,iii} I. Ovtin,^{118,iii} O. Radchenko,^{118,iii} Y. Skovpen,^{118,iii} I. Azhgirey,¹¹⁹ I. Bayshev,¹¹⁹ D. Elumakhov,¹¹⁹ V. Kachanov,¹¹⁹ D. Konstantinov,¹¹⁹ P. Mandrik,¹¹⁹ V. Petrov,¹¹⁹ R. Ryutin,¹¹⁹ S. Slabospitskii,¹¹⁹ A. Sobol,¹¹⁹ S. Troshin,¹¹⁹ N. Tyurin,¹¹⁹ A. Uzunian,¹¹⁹ A. Volkov,¹¹⁹ A. Babaev,¹²⁰ V. Okhotnikov,¹²⁰ V. Borshch,¹²¹ V. Ivanchenko,¹²¹ E. Tcherniaev,¹²¹ P. Adzic,^{122,jjj} M. Dordevic,¹²² P. Milenovic,¹²² J. Milosevic,¹²² M. Aguilar-Benitez,¹²³ J. Alcaraz Maestre,¹²³ A. Álvarez Fernández,¹²³ I. Bachiller,¹²³ M. Barrio Luna,¹²³ Cristina F. Bedoya,¹²³ C. A. Carrillo Montoya,¹²³ M. Cepeda,¹²³ M. Cerrada,¹²³ N. Colino,¹²³ B. De La Cruz,¹²³ A. Delgado Peris,¹²³ J. P. Fernández Ramos,¹²³ J. Flix,¹²³ M. C. Fouz,¹²³ O. Gonzalez Lopez,¹²³ S. Goy Lopez,¹²³ J. M. Hernandez,¹²³ M. I. Josa,¹²³ J. León Holgado,¹²³ D. Moran,¹²³ Á. Navarro Tobar,¹²³ C. Perez Dengra,¹²³ A. Pérez-Calero Yzquierdo,¹²³ J. Puerta Pelayo,¹²³ I. Redondo,¹²³ L. Romero,¹²³ S. Sánchez Navas,¹²³ L. Urda Gómez,¹²³ C. Willmott,¹²³ J. F. de Trocóniz,¹²⁴ R. Reyes-Almanza,¹²⁴ B. Alvarez Gonzalez,¹²⁵ J. Cuevas,¹²⁵ C. Erice,¹²⁵ J. Fernandez Menendez,¹²⁵ S. Folgueras,¹²⁵ I. Gonzalez Caballero,¹²⁵ J. R. González Fernández,¹²⁵ E. Palencia Cortezon,¹²⁵ C. Ramón Álvarez,¹²⁵ V. Rodríguez Bouza,¹²⁵ A. Soto Rodríguez,¹²⁵ A. Trapote,¹²⁵ N. Trevisani,¹²⁵ C. Vico Villalba,¹²⁵ J. A. Brochero Cifuentes,¹²⁶ I. J. Cabrillo,¹²⁶ A. Calderon,¹²⁶ J. Duarte Campderros,¹²⁶ M. Fernandez,¹²⁶ C. Fernandez Madrazo,¹²⁶ P. J. Fernández Manteca,¹²⁶ A. García Alonso,¹²⁶ G. Gomez,¹²⁶ C. Martinez Rivero,¹²⁶ P. Martinez Ruiz del Arbol,¹²⁶ F. Matorras,¹²⁶ P. Matorras Cuevas,¹²⁶ J. Piedra Gomez,¹²⁶ C. Prieels,¹²⁶ T. Rodrigo,¹²⁶ A. Ruiz-Jimeno,¹²⁶ L. Scodellaro,¹²⁶ I. Vila,¹²⁶ J. M. Vizan Garcia,¹²⁶ M. K. Jayananda,¹²⁷ B. Kailasapathy,^{127,kkk} D. U. J. Sonnadara,¹²⁷ D. D. C. Wickramaratna,¹²⁷ W. G. D. Dharmaratna,¹²⁸ K. Liyanage,¹²⁸ N. Perera,¹²⁸ N. Wickramage,¹²⁸ T. K. Aarrestad,¹²⁹ D. Abbaneo,¹²⁹ J. Alimena,¹²⁹ E. Auffray,¹²⁹ G. Auzinger,¹²⁹ J. Baechler,¹²⁹ P. Baillon,^{129,a} D. Barney,¹²⁹ J. Bendavid,¹²⁹ M. Bianco,¹²⁹ A. Bocci,¹²⁹ T. Camporesi,¹²⁹ M. Capeans Garrido,¹²⁹ G. Cerminara,¹²⁹ N. Chernyavskaya,¹²⁹ S. S. Chhibra,¹²⁹ M. Cipriani,¹²⁹ L. Cristella,¹²⁹ D. d'Enterria,¹²⁹ A. Dabrowski,¹²⁹ A. David,¹²⁹ A. De Roeck,¹²⁹ M. M. Defranchis,¹²⁹ M. Deile,¹²⁹ M. Dobson,¹²⁹ M. Dünser,¹²⁹ N. Dupont,¹²⁹ A. Elliott-Peisert,¹²⁹ N. Emrskova,¹²⁹ F. Fallavollita,^{129,lll} A. Florent,¹²⁹ G. Franzoni,¹²⁹ W. Funk,¹²⁹ S. Giani,¹²⁹ D. Gigi,¹²⁹ K. Gill,¹²⁹ F. Glege,¹²⁹ L. Gouskos,¹²⁹ M. Haranko,¹²⁹ J. Hegeman,¹²⁹ V. Innocente,¹²⁹ T. James,¹²⁹ P. Janot,¹²⁹ J. Kaspar,¹²⁹ J. Kieseler,¹²⁹ M. Komm,¹²⁹ N. Kratochwil,¹²⁹ C. Lange,¹²⁹ S. Laurila,¹²⁹ P. Lecoq,¹²⁹ A. Lintuluoto,¹²⁹ K. Long,¹²⁹ C. Lourenço,¹²⁹ B. Maier,¹²⁹ L. Malgeri,¹²⁹ S. Mallios,¹²⁹ M. Mannelli,¹²⁹ A. C. Marini,¹²⁹ F. Meijers,¹²⁹ S. Mersi,¹²⁹ E. Meschi,¹²⁹ F. Moortgat,¹²⁹ M. Mulders,¹²⁹ S. Orfanelli,¹²⁹ L. Orsini,¹²⁹ F. Pantaleo,¹²⁹ E. Perez,¹²⁹ M. Peruzzi,¹²⁹ A. Petrilli,¹²⁹ G. Petrucciani,¹²⁹ A. Pfeiffer,¹²⁹ M. Pierini,¹²⁹ D. Piparo,¹²⁹ M. Pitt,¹²⁹ H. Qu,¹²⁹ T. Quast,¹²⁹ D. Rabady,¹²⁹ A. Racz,¹²⁹ G. Reales Gutiérrez,¹²⁹ M. Rovere,¹²⁹ H. Sakulin,¹²⁹ J. Salfeld-Nebgen,¹²⁹ S. Scarfi,¹²⁹ C. Schäfer,¹²⁹

C. Schwick,¹²⁹ M. Selvaggi,¹²⁹ A. Sharma,¹²⁹ P. Silva,¹²⁹ W. Snoeys,¹²⁹ P. Sphicas,^{129,mmm} S. Summers,¹²⁹ K. Tatar,¹²⁹ V. R. Tavolaro,¹²⁹ D. Treille,¹²⁹ P. Tropea,¹²⁹ A. Tsiro,¹²⁹ G. P. Van Onsem,¹²⁹ J. Wanczyk,^{129,nnn} K. A. Wozniak,¹²⁹ W. D. Zeuner,¹²⁹ L. Caminada,^{130,ooo} A. Ebrahimi,¹³⁰ W. Erdmann,¹³⁰ R. Horisberger,¹³⁰ Q. Ingram,¹³⁰ H. C. Kaestli,¹³⁰ D. Kotlinski,¹³⁰ U. Langenegger,¹³⁰ M. Missiroli,^{130,ooo} L. Noehte,^{130,ooo} T. Rohe,¹³⁰ K. Androso,^{131,nnn} M. Backhaus,¹³¹ P. Berger,¹³¹ A. Calandri,¹³¹ A. De Cosa,¹³¹ G. Dissertori,¹³¹ M. Dittmar,¹³¹ M. Donegà,¹³¹ C. Dorfer,¹³¹ F. Eble,¹³¹ K. Gedia,¹³¹ F. Glessgen,¹³¹ T. A. Gómez Espinosa,¹³¹ C. Grab,¹³¹ D. Hits,¹³¹ W. Lusterma,¹³¹ A.-M. Lyon,¹³¹ R. A. Manzoni,¹³¹ L. Marchese,¹³¹ C. Martin Perez,¹³¹ M. T. Meinhard,¹³¹ F. Nessi-Tedaldi,¹³¹ J. Niedziela,¹³¹ F. Pauss,¹³¹ V. Perovic,¹³¹ S. Pigazzini,¹³¹ M. G. Ratti,¹³¹ M. Reichmann,¹³¹ C. Reissel,¹³¹ T. Reitenspiess,¹³¹ B. Ristic,¹³¹ D. Ruini,¹³¹ D. A. Sanz Becerra,¹³¹ V. Stampf,¹³¹ J. Steggemann,^{131,nnn} R. Wallny,¹³¹ D. H. Zhu,¹³¹ C. Amsler,^{132,ppp} P. Bäertschi,¹³² C. Botta,¹³² D. Brzhechko,¹³² M. F. Canelli,¹³² K. Cormier,¹³² A. De Wit,¹³² R. Del Burgo,¹³² J. K. Heikkilä,¹³² M. Huwiler,¹³² W. Jin,¹³² A. Jofrehei,¹³² B. Kilminster,¹³² S. Leontsinis,¹³² S. P. Liechti,¹³² A. Macchiolo,¹³² P. Meiring,¹³² V. M. Mikuni,¹³² U. Molinatti,¹³² I. Neutelings,¹³² A. Reimers,¹³² P. Robmann,¹³² S. Sanchez Cruz,¹³² K. Schweiger,¹³² M. Senger,¹³² Y. Takahashi,¹³² C. Adloff,^{133,qqq} C. M. Kuo,¹³³ W. Lin,¹³³ A. Roy,¹³³ T. Sarkar,^{133,ll} S. S. Yu,¹³³ L. Ceard,¹³⁴ Y. Chao,¹³⁴ K. F. Chen,¹³⁴ P. H. Chen,¹³⁴ W.-S. Hou,¹³⁴ Y. y. Li,¹³⁴ R.-S. Lu,¹³⁴ E. Paganis,¹³⁴ A. Psallidas,¹³⁴ A. Steen,¹³⁴ H. y. Wu,¹³⁴ E. Yazgan,¹³⁴ P. r. Yu,¹³⁴ B. Asavapibhop,¹³⁵ C. Asawatangtrakuldee,¹³⁵ N. Srimanobhas,¹³⁵ F. Boran,¹³⁶ S. Damarseckin,^{136,rrr} Z. S. Demiroglu,¹³⁶ F. Dolek,¹³⁶ I. Dumanoglu,^{136,sss} E. Eskut,¹³⁶ Y. Guler,^{136,ttt} E. Gurpinar Guler,^{136,ttt} C. Isik,¹³⁶ O. Kara,¹³⁶ A. Kayis Topaksu,¹³⁶ U. Kiminsu,¹³⁶ G. Onengut,¹³⁶ K. Ozdemir,^{136,uuu} A. Polatoz,¹³⁶ A. E. Simsek,¹³⁶ B. Tali,^{136,vvv} U. G. Tok,¹³⁶ S. Turkcapar,¹³⁶ I. S. Zorbakir,¹³⁶ B. Isildak,^{137,www} G. Karapinar,¹³⁷ K. Ocalan,^{137,xxx} M. Yalvac,^{137,yyy} B. Akgun,¹³⁸ I. O. Atakisi,¹³⁸ E. Gülmez,¹³⁸ M. Kaya,^{138,zzz} O. Kaya,^{138,aaaa} Ö. Özçelik,¹³⁸ S. Tekten,^{138,bbbb} E. A. Yetkin,^{138,cccc} A. Cakir,¹³⁹ K. Cankocak,^{139,sss} Y. Komurcu,¹³⁹ S. Sen,^{139,ddd} S. Cerci,^{140,vvv} I. Hos,^{140,eeee} B. Kaynak,¹⁴⁰ S. Ozkorucuklu,¹⁴⁰ H. Sert,¹⁴⁰ D. Sunar Cerci,^{140,vvv} C. Zorbilmez,¹⁴⁰ B. Grynyov,¹⁴¹ L. Levchuk,¹⁴² D. Anthony,¹⁴³ E. Bhal,¹⁴³ S. Bologna,¹⁴³ J. J. Brooke,¹⁴³ A. Bundock,¹⁴³ E. Clement,¹⁴³ D. Cussans,¹⁴³ H. Flacher,¹⁴³ J. Goldstein,¹⁴³ G. P. Heath,¹⁴³ H. F. Heath,¹⁴³ L. Kreczko,¹⁴³ B. Krikler,¹⁴³ S. Paramesvaran,¹⁴³ S. Seif El Nasr-Storey,¹⁴³ V. J. Smith,¹⁴³ N. Stylianou,^{143,ffff} K. Walkingshaw Pass,¹⁴³ R. White,¹⁴³ K. W. Bell,¹⁴⁴ A. Belyaev,^{144,gggg} C. Brew,¹⁴⁴ R. M. Brown,¹⁴⁴ D. J. A. Cockerill,¹⁴⁴ C. Cooke,¹⁴⁴ K. V. Ellis,¹⁴⁴ K. Harder,¹⁴⁴ S. Harper,¹⁴⁴ M.-L. Holmberg,^{144,hhhh} J. Linacre,¹⁴⁴ K. Manolopoulos,¹⁴⁴ D. M. Newbold,¹⁴⁴ E. Olaiya,¹⁴⁴ D. Petyt,¹⁴⁴ T. Reis,¹⁴⁴ T. Schuh,¹⁴⁴ C. H. Shepherd-Themistocleous,¹⁴⁴ I. R. Tomalin,¹⁴⁴ T. Williams,¹⁴⁴ R. Bainbridge,¹⁴⁵ P. Bloch,¹⁴⁵ S. Bonomally,¹⁴⁵ J. Borg,¹⁴⁵ S. Breeze,¹⁴⁵ O. Buchmuller,¹⁴⁵ V. Cepaitis,¹⁴⁵ G. S. Chahal,^{145,iiii} D. Colling,¹⁴⁵ P. Dauncey,¹⁴⁵ G. Davies,¹⁴⁵ M. Della Negra,¹⁴⁵ S. Fayer,¹⁴⁵ G. Fedi,¹⁴⁵ G. Hall,¹⁴⁵ M. H. Hassanshahi,¹⁴⁵ G. Iles,¹⁴⁵ J. Langford,¹⁴⁵ L. Lyons,¹⁴⁵ A.-M. Magnan,¹⁴⁵ S. Malik,¹⁴⁵ A. Martelli,¹⁴⁵ D. G. Monk,¹⁴⁵ J. Nash,^{145,jjjj} M. Pesaresi,¹⁴⁵ D. M. Raymond,¹⁴⁵ A. Richards,¹⁴⁵ A. Rose,¹⁴⁵ E. Scott,¹⁴⁵ C. Seez,¹⁴⁵ A. Shtipliyski,¹⁴⁵ A. Tapper,¹⁴⁵ K. Uchida,¹⁴⁵ T. Virdee,^{145,u} M. Vojinovic,¹⁴⁵ N. Wardle,¹⁴⁵ S. N. Webb,¹⁴⁵ D. Winterbottom,¹⁴⁵ K. Coldham,¹⁴⁶ J. E. Cole,¹⁴⁶ A. Khan,¹⁴⁶ P. Kyberd,¹⁴⁶ I. D. Reid,¹⁴⁶ L. Teodorescu,¹⁴⁶ S. Zahid,¹⁴⁶ S. Abdullin,¹⁴⁷ A. Brinkerhoff,¹⁴⁷ B. Caraway,¹⁴⁷ J. Dittmann,¹⁴⁷ K. Hatakeyama,¹⁴⁷ A. R. Kanuganti,¹⁴⁷ B. McMaster,¹⁴⁷ N. Pastika,¹⁴⁷ M. Saunders,¹⁴⁷ S. Sawant,¹⁴⁷ C. Sutantawibul,¹⁴⁷ J. Wilson,¹⁴⁷ R. Bartek,¹⁴⁸ A. Dominguez,¹⁴⁸ R. Uniyal,¹⁴⁸ A. M. Vargas Hernandez,¹⁴⁸ A. Buccilli,¹⁴⁹ S. I. Cooper,¹⁴⁹ D. Di Croce,¹⁴⁹ S. V. Gleyzer,¹⁴⁹ C. Henderson,¹⁴⁹ C. U. Perez,¹⁴⁹ P. Rumerio,^{149,kkkk} C. West,¹⁴⁹ A. Akpinar,¹⁵⁰ A. Albert,¹⁵⁰ D. Arcaro,¹⁵⁰ C. Cosby,¹⁵⁰ Z. Demiragli,¹⁵⁰ E. Fontanesi,¹⁵⁰ D. Gastler,¹⁵⁰ S. May,¹⁵⁰ J. Rohlf,¹⁵⁰ K. Salyer,¹⁵⁰ D. Sperka,¹⁵⁰ D. Spitzbart,¹⁵⁰ I. Suarez,¹⁵⁰ A. Tsatsos,¹⁵⁰ S. Yuan,¹⁵⁰ D. Zou,¹⁵⁰ G. Benelli,¹⁵¹ B. Burkley,¹⁵¹ X. Coubez,^{151,v} D. Cutts,¹⁵¹ M. Hadley,¹⁵¹ U. Heintz,¹⁵¹ J. M. Hogan,^{151,llll} T. KWON,¹⁵¹ G. Landsberg,¹⁵¹ K. T. Lau,¹⁵¹ D. Li,¹⁵¹ M. Lukasik,¹⁵¹ J. Luo,¹⁵¹ M. Narain,¹⁵¹ N. Pervan,¹⁵¹ S. Sagir,^{151,mmmm} F. Simpson,¹⁵¹ E. Usai,¹⁵¹ W. Y. Wong,¹⁵¹ X. Yan,¹⁵¹ D. Yu,¹⁵¹ W. Zhang,¹⁵¹ J. Bonilla,¹⁵² C. Brainerd,¹⁵² R. Breedon,¹⁵² M. Calderon De La Barca Sanchez,¹⁵² M. Chertok,¹⁵² J. Conway,¹⁵² P. T. Cox,¹⁵² R. Erbacher,¹⁵² G. Haza,¹⁵² F. Jensen,¹⁵² O. Kukral,¹⁵² R. Lander,¹⁵² M. Mulhearn,¹⁵² D. Pellett,¹⁵² B. Regnery,¹⁵² D. Taylor,¹⁵² Y. Yao,¹⁵² F. Zhang,¹⁵² M. Bachtis,¹⁵³ R. Cousins,¹⁵³ A. Datta,¹⁵³ D. Hamilton,¹⁵³ J. Hauser,¹⁵³ M. Ignatenko,¹⁵³ M. A. Iqbal,¹⁵³ T. Lam,¹⁵³ W. A. Nash,¹⁵³ S. Regnard,¹⁵³ D. Saltzberg,¹⁵³ B. Stone,¹⁵³ V. Valuev,¹⁵³ K. Burt,¹⁵⁴ Y. Chen,¹⁵⁴ R. Clare,¹⁵⁴ J. W. Gary,¹⁵⁴ M. Gordon,¹⁵⁴ G. Hanson,¹⁵⁴ G. Karapostoli,¹⁵⁴ O. R. Long,¹⁵⁴ N. Manganelli,¹⁵⁴ M. Olmedo Negrete,¹⁵⁴ W. Si,¹⁵⁴ S. Wimpenny,¹⁵⁴ Y. Zhang,¹⁵⁴ J. G. Branson,¹⁵⁵ P. Chang,¹⁵⁵ S. Cittolin,¹⁵⁵ S. Cooperstein,¹⁵⁵ N. Deelen,¹⁵⁵ D. Diaz,¹⁵⁵ J. Duarte,¹⁵⁵ R. Gerosa,¹⁵⁵ L. Giannini,¹⁵⁵ J. Guiang,¹⁵⁵ R. Kansal,¹⁵⁵ V. Krutelyov,¹⁵⁵ R. Lee,¹⁵⁵ J. Letts,¹⁵⁵ M. Masciovecchio,¹⁵⁵ F. Mokhtar,¹⁵⁵ M. Pieri,¹⁵⁵ B. V. Sathia Narayanan,¹⁵⁵ V. Sharma,¹⁵⁵ M. Tadel,¹⁵⁵ A. Vartak,¹⁵⁵ F. Würthwein,¹⁵⁵ Y. Xiang,¹⁵⁵ A. Yagil,¹⁵⁵ N. Amin,¹⁵⁶

C. Campagnari,¹⁵⁶ M. Citron,¹⁵⁶ A. Dorsett,¹⁵⁶ V. Dutta,¹⁵⁶ J. Incandela,¹⁵⁶ M. Kilpatrick,¹⁵⁶ J. Kim,¹⁵⁶ B. Marsh,¹⁵⁶ H. Mei,¹⁵⁶ M. Oshiro,¹⁵⁶ M. Quinnan,¹⁵⁶ J. Richman,¹⁵⁶ U. Sarica,¹⁵⁶ F. Setti,¹⁵⁶ J. Sheplock,¹⁵⁶ P. Siddireddy,¹⁵⁶ D. Stuart,¹⁵⁶ S. Wang,¹⁵⁶ A. Bornheim,¹⁵⁷ O. Cerri,¹⁵⁷ I. Dutta,¹⁵⁷ J. M. Lawhorn,¹⁵⁷ N. Lu,¹⁵⁷ J. Mao,¹⁵⁷ H. B. Newman,¹⁵⁷ T. Q. Nguyen,¹⁵⁷ M. Spiropulu,¹⁵⁷ J. R. Vlimant,¹⁵⁷ C. Wang,¹⁵⁷ S. Xie,¹⁵⁷ Z. Zhang,¹⁵⁷ R. Y. Zhu,¹⁵⁷ J. Alison,¹⁵⁸ S. An,¹⁵⁸ M. B. Andrews,¹⁵⁸ P. Bryant,¹⁵⁸ T. Ferguson,¹⁵⁸ A. Harilal,¹⁵⁸ C. Liu,¹⁵⁸ T. Mudholkar,¹⁵⁸ M. Paulini,¹⁵⁸ A. Sanchez,¹⁵⁸ W. Terrill,¹⁵⁸ J. P. Cumalat,¹⁵⁹ W. T. Ford,¹⁵⁹ A. Hassani,¹⁵⁹ E. MacDonald,¹⁵⁹ R. Patel,¹⁵⁹ A. Perloff,¹⁵⁹ C. Savard,¹⁵⁹ K. Stenson,¹⁵⁹ K. A. Ulmer,¹⁵⁹ S. R. Wagner,¹⁵⁹ J. Alexander,¹⁶⁰ S. Bright-Thonney,¹⁶⁰ X. Chen,¹⁶⁰ Y. Cheng,¹⁶⁰ D. J. Cranshaw,¹⁶⁰ S. Hogan,¹⁶⁰ J. Monroy,¹⁶⁰ J. R. Patterson,¹⁶⁰ D. Quach,¹⁶⁰ J. Reichert,¹⁶⁰ M. Reid,¹⁶⁰ A. Ryd,¹⁶⁰ W. Sun,¹⁶⁰ J. Thom,¹⁶⁰ P. Wittich,¹⁶⁰ R. Zou,¹⁶⁰ M. Albrow,¹⁶¹ M. Alyari,¹⁶¹ G. Apollinari,¹⁶¹ A. Apresyan,¹⁶¹ A. Apyan,¹⁶¹ S. Banerjee,¹⁶¹ L. A. T. Bauerdick,¹⁶¹ D. Berry,¹⁶¹ J. Berryhill,¹⁶¹ P. C. Bhat,¹⁶¹ K. Burkett,¹⁶¹ J. N. Butler,¹⁶¹ A. Canepa,¹⁶¹ G. B. Cerati,¹⁶¹ H. W. K. Cheung,¹⁶¹ F. Chlebana,¹⁶¹ K. F. Di Petrillo,¹⁶¹ V. D. Elvira,¹⁶¹ Y. Feng,¹⁶¹ J. Freeman,¹⁶¹ Z. Gece,¹⁶¹ L. Gray,¹⁶¹ D. Green,¹⁶¹ S. Grünendahl,¹⁶¹ O. Gutsche,¹⁶¹ R. M. Harris,¹⁶¹ R. Heller,¹⁶¹ T. C. Herwig,¹⁶¹ J. Hirschauer,¹⁶¹ B. Jayatilaka,¹⁶¹ S. Jindariani,¹⁶¹ M. Johnson,¹⁶¹ U. Joshi,¹⁶¹ T. Klijsma,¹⁶¹ B. Klima,¹⁶¹ K. H. M. Kwok,¹⁶¹ S. Lammel,¹⁶¹ D. Lincoln,¹⁶¹ R. Lipton,¹⁶¹ T. Liu,¹⁶¹ C. Madrid,¹⁶¹ K. Maeshima,¹⁶¹ C. Mantilla,¹⁶¹ D. Mason,¹⁶¹ P. McBride,¹⁶¹ P. Merkel,¹⁶¹ S. Mrenna,¹⁶¹ S. Nahn,¹⁶¹ J. Ngadiuba,¹⁶¹ V. O'Dell,¹⁶¹ V. Papadimitriou,¹⁶¹ K. Pedro,¹⁶¹ C. Pena,^{161,hhh} O. Prokofyev,¹⁶¹ F. Ravera,¹⁶¹ A. Reinsvold Hall,¹⁶¹ L. Ristori,¹⁶¹ E. Sexton-Kennedy,¹⁶¹ N. Smith,¹⁶¹ A. Soha,¹⁶¹ W. J. Spalding,¹⁶¹ L. Spiegel,¹⁶¹ S. Stoynev,¹⁶¹ J. Strait,¹⁶¹ L. Taylor,¹⁶¹ S. Tkaczyk,¹⁶¹ N. V. Tran,¹⁶¹ L. Uplegger,¹⁶¹ E. W. Vaandering,¹⁶¹ H. A. Weber,¹⁶¹ D. Acosta,¹⁶² P. Avery,¹⁶² D. Bourilkov,¹⁶² L. Cadamuro,¹⁶² V. Cherepanov,¹⁶² F. Errico,¹⁶² R. D. Field,¹⁶² D. Guerrero,¹⁶² B. M. Joshi,¹⁶² M. Kim,¹⁶² E. Koenig,¹⁶² J. Konigsberg,¹⁶² A. Korytov,¹⁶² K. H. Lo,¹⁶² K. Matchev,¹⁶² N. Menendez,¹⁶² G. Mitselmakher,¹⁶² A. Muthirakalayil Madhu,¹⁶² N. Rawal,¹⁶² D. Rosenzweig,¹⁶² S. Rosenzweig,¹⁶² J. Rotter,¹⁶² K. Shi,¹⁶² J. Sturdy,¹⁶² J. Wang,¹⁶² E. Yigitbasi,¹⁶² X. Zuo,¹⁶² T. Adams,¹⁶³ A. Askew,¹⁶³ R. Habibullah,¹⁶³ V. Hagopian,¹⁶³ K. F. Johnson,¹⁶³ R. Khurana,¹⁶³ T. Kolberg,¹⁶³ G. Martinez,¹⁶³ H. Prosper,¹⁶³ C. Schiber,¹⁶³ O. Viazlo,¹⁶³ R. Yohay,¹⁶³ J. Zhang,¹⁶³ M. M. Baarmand,¹⁶⁴ S. Butalla,¹⁶⁴ T. Elkafrawy,^{164,nnnn} M. Hohlmann,¹⁶⁴ R. Kumar Verma,¹⁶⁴ D. Noonan,¹⁶⁴ M. Rahmani,¹⁶⁴ F. Yumiceva,¹⁶⁴ M. R. Adams,¹⁶⁵ H. Becerril Gonzalez,¹⁶⁵ R. Cavanaugh,¹⁶⁵ S. Dittmer,¹⁶⁵ O. Evdokimov,¹⁶⁵ C. E. Gerber,¹⁶⁵ D. A. Hangal,¹⁶⁵ D. J. Hofman,¹⁶⁵ A. H. Merrit,¹⁶⁵ C. Mills,¹⁶⁵ G. Oh,¹⁶⁵ T. Roy,¹⁶⁵ S. Rudrabhatla,¹⁶⁵ M. B. Tonjes,¹⁶⁵ N. Varelas,¹⁶⁵ J. Viinikainen,¹⁶⁵ X. Wang,¹⁶⁵ Z. Wu,¹⁶⁵ Z. Ye,¹⁶⁵ M. Alhousseini,¹⁶⁶ K. Dilsiz,^{166,oooo} L. Emediato,¹⁶⁶ R. P. Gandrajula,¹⁶⁶ O. K. Köseyan,¹⁶⁶ J.-P. Merlo,¹⁶⁶ A. Mestvirishvili,^{166,pppp} J. Nachtman,¹⁶⁶ H. Ogul,^{166,qqqq} Y. Onel,¹⁶⁶ A. Penzo,¹⁶⁶ C. Snyder,¹⁶⁶ E. Tiras,^{166,rrr} O. Amram,¹⁶⁷ B. Blumenfeld,¹⁶⁷ L. Corcodilos,¹⁶⁷ J. Davis,¹⁶⁷ M. Eminizer,¹⁶⁷ A. V. Gritsan,¹⁶⁷ S. Kyriacou,¹⁶⁷ P. Maksimovic,¹⁶⁷ J. Roskes,¹⁶⁷ M. Swartz,¹⁶⁷ T. Á. Vámi,¹⁶⁷ A. Abreu,¹⁶⁸ J. Anguiano,¹⁶⁸ C. Baldenegro Barrera,¹⁶⁸ P. Baringer,¹⁶⁸ A. Bean,¹⁶⁸ A. Bylinkin,¹⁶⁸ Z. Flowers,¹⁶⁸ T. Isidori,¹⁶⁸ S. Khalil,¹⁶⁸ J. King,¹⁶⁸ G. Krintiras,¹⁶⁸ A. Kropivnitskaya,¹⁶⁸ M. Lazarovits,¹⁶⁸ C. Le Mahieu,¹⁶⁸ C. Lindsey,¹⁶⁸ J. Marquez,¹⁶⁸ N. Minafra,¹⁶⁸ M. Murray,¹⁶⁸ M. Nickel,¹⁶⁸ C. Rogan,¹⁶⁸ C. Royon,¹⁶⁸ R. Salvatico,¹⁶⁸ S. Sanders,¹⁶⁸ E. Schmitz,¹⁶⁸ C. Smith,¹⁶⁸ J. D. Tapia Takaki,¹⁶⁸ Q. Wang,¹⁶⁸ Z. Warner,¹⁶⁸ J. Williams,¹⁶⁸ G. Wilson,¹⁶⁸ S. Duric,¹⁶⁹ A. Ivanov,¹⁶⁹ K. Kaadze,¹⁶⁹ D. Kim,¹⁶⁹ Y. Maravin,¹⁶⁹ T. Mitchell,¹⁶⁹ A. Modak,¹⁶⁹ K. Nam,¹⁶⁹ F. Rebassoo,¹⁷⁰ D. Wright,¹⁷⁰ E. Adams,¹⁷¹ A. Baden,¹⁷¹ O. Baron,¹⁷¹ A. Belloni,¹⁷¹ S. C. Eno,¹⁷¹ N. J. Hadley,¹⁷¹ S. Jabeen,¹⁷¹ R. G. Kellogg,¹⁷¹ T. Koeth,¹⁷¹ S. Lascio,¹⁷¹ A. C. Mignerey,¹⁷¹ S. Nabili,¹⁷¹ C. Palmer,¹⁷¹ M. Seidel,¹⁷¹ A. Skuja,¹⁷¹ L. Wang,¹⁷¹ K. Wong,¹⁷¹ D. Abercrombie,¹⁷² G. Andreassi,¹⁷² R. Bi,¹⁷² W. Busza,¹⁷² I. A. Cali,¹⁷² Y. Chen,¹⁷² M. D'Alfonso,¹⁷² J. Eysermans,¹⁷² C. Freer,¹⁷² G. Gomez Ceballos,¹⁷² M. Goncharov,¹⁷² P. Harris,¹⁷² M. Hu,¹⁷² M. Klute,¹⁷² D. Kovalskyi,¹⁷² J. Krupa,¹⁷² Y.-J. Lee,¹⁷² C. Mironov,¹⁷² C. Paus,¹⁷² D. Rankin,¹⁷² C. Roland,¹⁷² G. Roland,¹⁷² Z. Shi,¹⁷² G. S. F. Stephans,¹⁷² J. Wang,¹⁷² Z. Wang,¹⁷² B. Wyslouch,¹⁷² R. M. Chatterjee,¹⁷³ A. Evans,¹⁷³ J. Hiltbrand,¹⁷³ Sh. Jain,¹⁷³ M. Krohn,¹⁷³ Y. Kubota,¹⁷³ J. Mans,¹⁷³ M. Revering,¹⁷³ R. Rusack,¹⁷³ R. Saradhy,¹⁷³ N. Schroeder,¹⁷³ N. Strobbe,¹⁷³ M. A. Wadud,¹⁷³ K. Bloom,¹⁷⁴ M. Bryson,¹⁷⁴ S. Chauhan,¹⁷⁴ D. R. Claes,¹⁷⁴ C. Fangmeier,¹⁷⁴ L. Finco,¹⁷⁴ F. Golf,¹⁷⁴ C. Joo,¹⁷⁴ I. Kravchenko,¹⁷⁴ M. Musich,¹⁷⁴ I. Reed,¹⁷⁴ J. E. Siado,¹⁷⁴ G. R. Snow,^{174,a} W. Tabb,¹⁷⁴ F. Yan,¹⁷⁴ A. G. Zecchinelli,¹⁷⁴ G. Agarwal,¹⁷⁵ H. Bandyopadhyay,¹⁷⁵ L. Hay,¹⁷⁵ I. Iashvili,¹⁷⁵ A. Kharchilava,¹⁷⁵ C. McLean,¹⁷⁵ D. Nguyen,¹⁷⁵ J. Pekkanen,¹⁷⁵ S. Rappoccio,¹⁷⁵ A. Williams,¹⁷⁵ G. Alverson,¹⁷⁶ E. Barberis,¹⁷⁶ Y. Haddad,¹⁷⁶ A. Hortiangtham,¹⁷⁶ J. Li,¹⁷⁶ G. Madigan,¹⁷⁶ B. Marzocchi,¹⁷⁶ D. M. Morse,¹⁷⁶ V. Nguyen,¹⁷⁶ T. Orimoto,¹⁷⁶ A. Parker,¹⁷⁶ L. Skinnari,¹⁷⁶ A. Tishelman-Charny,¹⁷⁶ T. Wamorkar,¹⁷⁶ B. Wang,¹⁷⁶ A. Wisecarver,¹⁷⁶ D. Wood,¹⁷⁶ S. Bhattacharya,¹⁷⁷ J. Bueghly,¹⁷⁷ Z. Chen,¹⁷⁷ A. Gilbert,¹⁷⁷ T. Gunter,¹⁷⁷ K. A. Hahn,¹⁷⁷ Y. Liu,¹⁷⁷ N. Odell,¹⁷⁷ M. H. Schmitt,¹⁷⁷ M. Velasco,¹⁷⁷

R. Band,¹⁷⁸ R. Bucci,¹⁷⁸ M. Cremonesi,¹⁷⁸ A. Das,¹⁷⁸ N. Dev,¹⁷⁸ R. Goldouzian,¹⁷⁸ M. Hildreth,¹⁷⁸ K. Hurtado Anampa,¹⁷⁸ C. Jessop,¹⁷⁸ K. Lannon,¹⁷⁸ J. Lawrence,¹⁷⁸ N. Loukas,¹⁷⁸ D. Lutton,¹⁷⁸ J. Mariano,¹⁷⁸ N. Marinelli,¹⁷⁸ I. Mcalister,¹⁷⁸ T. McCauley,¹⁷⁸ C. Mcgrady,¹⁷⁸ K. Mohrman,¹⁷⁸ C. Moore,¹⁷⁸ Y. Musienko,^{178,zz} R. Ruchti,¹⁷⁸ A. Townsend,¹⁷⁸ M. Wayne,¹⁷⁸ A. Wightman,¹⁷⁸ M. Zarucki,¹⁷⁸ L. Zygala,¹⁷⁸ B. Bylsma,¹⁷⁹ B. Cardwell,¹⁷⁹ L. S. Durkin,¹⁷⁹ B. Francis,¹⁷⁹ C. Hill,¹⁷⁹ M. Nunez Ornelas,¹⁷⁹ K. Wei,¹⁷⁹ B. L. Winer,¹⁷⁹ B. R. Yates,¹⁷⁹ F. M. Addesa,¹⁸⁰ B. Bonham,¹⁸⁰ P. Das,¹⁸⁰ G. Dezoort,¹⁸⁰ P. Elmer,¹⁸⁰ A. Frankenthal,¹⁸⁰ B. Greenberg,¹⁸⁰ N. Haubrich,¹⁸⁰ S. Higginbotham,¹⁸⁰ A. Kalogeropoulos,¹⁸⁰ G. Kopp,¹⁸⁰ S. Kwan,¹⁸⁰ D. Lange,¹⁸⁰ D. Marlow,¹⁸⁰ K. Mei,¹⁸⁰ I. Ojalvo,¹⁸⁰ J. Olsen,¹⁸⁰ D. Stickland,¹⁸⁰ C. Tully,¹⁸⁰ S. Malik,¹⁸¹ S. Norberg,¹⁸¹ A. S. Bakshi,¹⁸² V. E. Barnes,¹⁸² R. Chawla,¹⁸² S. Das,¹⁸² L. Gutay,¹⁸² M. Jones,¹⁸² A. W. Jung,¹⁸² S. Karmarkar,¹⁸² D. Kondratyev,¹⁸² M. Liu,¹⁸² G. Negro,¹⁸² N. Neumeister,¹⁸² G. Paspalaki,¹⁸² S. Piperov,¹⁸² A. Purohit,¹⁸² J. F. Schulte,¹⁸² M. Stojanovic,^{182,r} J. Thieman,¹⁸² F. Wang,¹⁸² R. Xiao,¹⁸² W. Xie,¹⁸² J. Dolen,¹⁸³ N. Parashar,¹⁸³ A. Baty,¹⁸⁴ T. Carnahan,¹⁸⁴ M. Decaro,¹⁸⁴ S. Dildick,¹⁸⁴ K. M. Ecklund,¹⁸⁴ S. Freed,¹⁸⁴ P. Gardner,¹⁸⁴ F. J. M. Geurts,¹⁸⁴ A. Kumar,¹⁸⁴ W. Li,¹⁸⁴ B. P. Padley,¹⁸⁴ R. Redjimi,¹⁸⁴ W. Shi,¹⁸⁴ A. G. Stahl Leiton,¹⁸⁴ S. Yang,¹⁸⁴ L. Zhang,^{184,ssss} Y. Zhang,¹⁸⁴ A. Bodek,¹⁸⁵ P. de Barbaro,¹⁸⁵ R. Demina,¹⁸⁵ J. L. Dulemba,¹⁸⁵ C. Fallon,¹⁸⁵ T. Ferbel,¹⁸⁵ M. Galanti,¹⁸⁵ A. Garcia-Bellido,¹⁸⁵ O. Hindrichs,¹⁸⁵ A. Khukhunaishvili,¹⁸⁵ E. Ranken,¹⁸⁵ R. Taus,¹⁸⁵ B. Chiarito,¹⁸⁶ J. P. Chou,¹⁸⁶ A. Gandrakota,¹⁸⁶ Y. Gershtein,¹⁸⁶ E. Halkiadakis,¹⁸⁶ A. Hart,¹⁸⁶ M. Heindl,¹⁸⁶ O. Karacheban,^{186,y} I. Laflotte,¹⁸⁶ A. Lath,¹⁸⁶ R. Montalvo,¹⁸⁶ K. Nash,¹⁸⁶ M. Osherson,¹⁸⁶ S. Salur,¹⁸⁶ S. Schnetzer,¹⁸⁶ S. Somalwar,¹⁸⁶ R. Stone,¹⁸⁶ S. A. Thayil,¹⁸⁶ S. Thomas,¹⁸⁶ H. Wang,¹⁸⁶ H. Acharya,¹⁸⁷ A. G. Delannoy,¹⁸⁷ S. Fiorendi,¹⁸⁷ S. Spanier,¹⁸⁷ O. Bouhali,^{188,tttt} M. Dalchenko,¹⁸⁸ A. Delgado,¹⁸⁸ R. Eusebi,¹⁸⁸ J. Gilmore,¹⁸⁸ T. Huang,¹⁸⁸ T. Kamon,^{188,uuuu} H. Kim,¹⁸⁸ S. Luo,¹⁸⁸ S. Malhotra,¹⁸⁸ R. Mueller,¹⁸⁸ D. Overton,¹⁸⁸ D. Rathjens,¹⁸⁸ A. Safonov,¹⁸⁸ N. Akchurin,¹⁸⁹ J. Damgov,¹⁸⁹ V. Hegde,¹⁸⁹ S. Kunori,¹⁸⁹ K. Lamichhane,¹⁸⁹ S. W. Lee,¹⁸⁹ T. Mengke,¹⁸⁹ S. Muthumuni,¹⁸⁹ T. Peltola,¹⁸⁹ I. Volobouev,¹⁸⁹ Z. Wang,¹⁸⁹ A. Whitbeck,¹⁸⁹ E. Appelt,¹⁹⁰ S. Greene,¹⁹⁰ A. Gurrola,¹⁹⁰ W. Johns,¹⁹⁰ A. Melo,¹⁹⁰ H. Ni,¹⁹⁰ K. Padeken,¹⁹⁰ F. Romeo,¹⁹⁰ P. Sheldon,¹⁹⁰ S. Tuo,¹⁹⁰ J. Velkovska,¹⁹⁰ M. W. Arenton,¹⁹¹ B. Cox,¹⁹¹ G. Cummings,¹⁹¹ J. Hakala,¹⁹¹ R. Hirosky,¹⁹¹ M. Joyce,¹⁹¹ A. Ledovskoy,¹⁹¹ A. Li,¹⁹¹ C. Neu,¹⁹¹ C. E. Perez Lara,¹⁹¹ B. Tannenwald,¹⁹¹ S. White,¹⁹¹ E. Wolfe,¹⁹¹ N. Poudyal,¹⁹² K. Black,¹⁹³ T. Bose,¹⁹³ C. Caillol,¹⁹³ S. Dasu,¹⁹³ I. De Bruyn,¹⁹³ P. Everaerts,¹⁹³ F. Fienga,¹⁹³ C. Galloni,¹⁹³ H. He,¹⁹³ M. Herndon,¹⁹³ A. Hervé,¹⁹³ U. Hussain,¹⁹³ A. Lanaro,¹⁹³ A. Loeliger,¹⁹³ R. Loveless,¹⁹³ J. Madhusudanan Sreekala,¹⁹³ A. Mallampalli,¹⁹³ A. Mohammadi,¹⁹³ D. Pinna,¹⁹³ A. Savin,¹⁹³ V. Shang,¹⁹³ V. Sharma,¹⁹³ W. H. Smith,¹⁹³ D. Teague,¹⁹³ S. Trembath-Reichert,¹⁹³ and W. Vetens¹⁹³

(CMS Collaboration)

¹*Yerevan Physics Institute, Yerevan, Armenia*

²*Institut für Hochenergiephysik, Vienna, Austria*

³*Institute for Nuclear Problems, Minsk, Belarus*

⁴*Universiteit Antwerpen, Antwerpen, Belgium*

⁵*Vrije Universiteit Brussel, Brussel, Belgium*

⁶*Université Libre de Bruxelles, Bruxelles, Belgium*

⁷*Ghent University, Ghent, Belgium*

⁸*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*

⁹*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*

¹⁰*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*

¹¹*Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil*

¹²*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*

¹³*University of Sofia, Sofia, Bulgaria*

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*Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE)—Fudan University, Shanghai, China*

²⁰*Zhejiang University, Hangzhou, China, Zhejiang, China*

²¹*Universidad de Los Andes, Bogota, Colombia*

- ²²*Universidad de Antioquia, Medellin, Colombia*
- ²³*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*
- ²⁴*University of Split, Faculty of Science, Split, Croatia*
- ²⁵*Institute Rudjer Boskovic, Zagreb, Croatia*
- ²⁶*University of Cyprus, Nicosia, Cyprus*
- ²⁷*Charles University, Prague, Czech Republic*
- ²⁸*Escuela Politecnica Nacional, Quito, Ecuador*
- ²⁹*Universidad San Francisco de Quito, Quito, Ecuador*
- ³⁰*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*
- ³¹*Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt*
- ³²*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*
- ³³*Department of Physics, University of Helsinki, Helsinki, Finland*
- ³⁴*Helsinki Institute of Physics, Helsinki, Finland*
- ³⁵*Lappeenranta University of Technology, Lappeenranta, Finland*
- ³⁶*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
- ³⁷*Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*
- ³⁸*Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France*
- ³⁹*Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France*
- ⁴⁰*Georgian Technical University, Tbilisi, Georgia*
- ⁴¹*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
- ⁴²*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
- ⁴³*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
- ⁴⁴*Deutsches Elektronen-Synchrotron, Hamburg, Germany*
- ⁴⁵*University of Hamburg, Hamburg, Germany*
- ⁴⁶*Karlsruher Institut fuer Technologie, Karlsruhe, Germany*
- ⁴⁷*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
- ⁴⁸*National and Kapodistrian University of Athens, Athens, Greece*
- ⁴⁹*National Technical University of Athens, Athens, Greece*
- ⁵⁰*University of Ioánnina, Ioánnina, Greece*
- ⁵¹*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*
- ⁵²*Wigner Research Centre for Physics, Budapest, Hungary*
- ⁵³*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
- ⁵⁴*Institute of Physics, University of Debrecen, Debrecen, Hungary*
- ⁵⁵*Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary*
- ⁵⁶*Indian Institute of Science (IISc), Bangalore, India*
- ⁵⁷*National Institute of Science Education and Research, HBNI, Bhubaneswar, India*
- ⁵⁸*Panjab University, Chandigarh, India*
- ⁵⁹*University of Delhi, Delhi, India*
- ⁶⁰*Saha Institute of Nuclear Physics, HBNI, Kolkata, India*
- ⁶¹*Indian Institute of Technology Madras, Madras, India*
- ⁶²*Bhabha Atomic Research Centre, Mumbai, India*
- ⁶³*Tata Institute of Fundamental Research-A, Mumbai, India*
- ⁶⁴*Tata Institute of Fundamental Research-B, Mumbai, India*
- ⁶⁵*Indian Institute of Science Education and Research (IISER), Pune, India*
- ⁶⁶*Isfahan University of Technology, Isfahan, Iran*
- ⁶⁷*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
- ⁶⁸*University 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*
- ⁷³*INFN 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}*Università G. Marconi, Roma, 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, Rome, Italy*
^{81b}*Sapienza Università di Roma, Rome, 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*
⁸⁴*Kyungpook National University, Daegu, Korea*
⁸⁵*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
⁸⁶*Hanyang University, Seoul, Korea*
⁸⁷*Korea University, Seoul, Korea*
⁸⁸*Kyung Hee University, Department of Physics, Seoul, Republic of Korea, Seoul, Korea*
⁸⁹*Sejong University, Seoul, Korea*
⁹⁰*Seoul National University, Seoul, Korea*
⁹¹*University of Seoul, Seoul, Korea*
⁹²*Yonsei University, Department of Physics, Seoul, Korea*
⁹³*Sungkyunkwan University, Suwon, Korea*
⁹⁴*College of Engineering and Technology, American University of the Middle East (AUM), Egaila, Kuwait, Dasman, Kuwait*
⁹⁵*Riga Technical University, Riga, Latvia*
⁹⁶*Vilnius University, Vilnius, Lithuania*
⁹⁷*National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia*
⁹⁸*Universidad de Sonora (UNISON), Hermosillo, Mexico*
⁹⁹*Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico*
¹⁰⁰*Universidad Iberoamericana, Mexico City, Mexico*
¹⁰¹*Benemerita Universidad Autonoma de Puebla, Puebla, Mexico*
¹⁰²*University of Montenegro, Podgorica, Montenegro*
¹⁰³*University of Auckland, Auckland, New Zealand*
¹⁰⁴*University of Canterbury, Christchurch, New Zealand*
¹⁰⁵*National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*
¹⁰⁶*AGH University of Science and Technology Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland*
¹⁰⁷*National Centre for Nuclear Research, Swierk, Poland*
¹⁰⁸*Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*
¹⁰⁹*Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal*
¹¹⁰*Joint Institute for Nuclear Research, Dubna, Russia*
¹¹¹*Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia*
¹¹²*Institute for Nuclear Research, Moscow, Russia*
¹¹³*Moscow Institute of Physics and Technology, Moscow, Russia*
¹¹⁴*National Research Center 'Kurchatov Institute', Moscow, Russia*
¹¹⁵*National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia*
¹¹⁶*P.N. Lebedev Physical Institute, Moscow, Russia*
¹¹⁷*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*
¹¹⁸*Novosibirsk State University (NSU), Novosibirsk, Russia*
¹¹⁹*Institute for High Energy Physics of National Research Centre 'Kurchatov Institute', Protvino, Russia*

- ¹²⁰*National Research Tomsk Polytechnic University, Tomsk, Russia*
¹²¹*Tomsk State University, Tomsk, Russia*
¹²²*University of Belgrade: Faculty of Physics and VINCA Institute of Nuclear Sciences, Belgrade, Serbia*
¹²³*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
¹²⁴*Universidad Autónoma de Madrid, Madrid, Spain*
¹²⁵*Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain*
¹²⁶*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
¹²⁷*University of Colombo, Colombo, Sri Lanka*
¹²⁸*University of Ruhuna, Department of Physics, Matara, Sri Lanka*
¹²⁹*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
¹³⁰*Paul Scherrer Institut, Villigen, Switzerland*
¹³¹*ETH Zurich—Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland*
¹³²*Universität Zürich, Zurich, Switzerland*
¹³³*National Central University, Chung-Li, Taiwan*
¹³⁴*National Taiwan University (NTU), Taipei, Taiwan*
¹³⁵*Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand*
¹³⁶*Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey*
¹³⁷*Middle East Technical University, Physics Department, Ankara, Turkey*
¹³⁸*Bogazici University, Istanbul, Turkey*
¹³⁹*Istanbul Technical University, Istanbul, Turkey*
¹⁴⁰*Istanbul University, Istanbul, Turkey*
¹⁴¹*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine*
¹⁴²*National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine*
¹⁴³*University of Bristol, Bristol, United Kingdom*
¹⁴⁴*Rutherford Appleton Laboratory, Didcot, United Kingdom*
¹⁴⁵*Imperial College, London, United Kingdom*
¹⁴⁶*Brunel University, Uxbridge, United Kingdom*
¹⁴⁷*Baylor University, Waco, Texas, USA*
¹⁴⁸*Catholic University of America, Washington, DC, USA*
¹⁴⁹*The University of Alabama, Tuscaloosa, Alabama, USA*
¹⁵⁰*Boston University, Boston, Massachusetts, USA*
¹⁵¹*Brown University, Providence, Rhode Island, USA*
¹⁵²*University of California, Davis, Davis, California, USA*
¹⁵³*University of California, Los Angeles, California, USA*
¹⁵⁴*University of California, Riverside, Riverside, California, USA*
¹⁵⁵*University of California, San Diego, La Jolla, California, USA*
¹⁵⁶*University of California, Santa Barbara—Department of Physics, Santa Barbara, California, USA*
¹⁵⁷*California Institute of Technology, Pasadena, California, USA*
¹⁵⁸*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
¹⁵⁹*University of Colorado Boulder, Boulder, Colorado, USA*
¹⁶⁰*Cornell University, Ithaca, New York, USA*
¹⁶¹*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
¹⁶²*University of Florida, Gainesville, Florida, USA*
¹⁶³*Florida State University, Tallahassee, Florida, USA*
¹⁶⁴*Florida Institute of Technology, Melbourne, Florida, USA*
¹⁶⁵*University of Illinois at Chicago (UIC), Chicago, Illinois, USA*
¹⁶⁶*The University of Iowa, Iowa City, Iowa, USA*
¹⁶⁷*Johns Hopkins University, Baltimore, Maryland, USA*
¹⁶⁸*The University of Kansas, Lawrence, Kansas, USA*
¹⁶⁹*Kansas State University, Manhattan, Kansas, USA*
¹⁷⁰*Lawrence Livermore National Laboratory, Livermore, California, USA*
¹⁷¹*University of Maryland, College Park, Maryland, USA*
¹⁷²*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
¹⁷³*University of Minnesota, Minneapolis, Minnesota, USA*
¹⁷⁴*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
¹⁷⁵*State University of New York at Buffalo, Buffalo, New York, USA*
¹⁷⁶*Northeastern University, Boston, Massachusetts, USA*
¹⁷⁷*Northwestern University, Evanston, Illinois, USA*
¹⁷⁸*University of Notre Dame, Notre Dame, Indiana, USA*
¹⁷⁹*The Ohio State University, Columbus, Ohio, USA*

- ¹⁸⁰*Princeton University, Princeton, New Jersey, USA*
¹⁸¹*University of Puerto Rico, Mayaguez, Puerto Rico, USA*
¹⁸²*Purdue University, West Lafayette, Indiana, USA*
¹⁸³*Purdue University Northwest, Hammond, Indiana, USA*
¹⁸⁴*Rice University, Houston, Texas, USA*
¹⁸⁵*University of Rochester, Rochester, New York, USA*
¹⁸⁶*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*
¹⁸⁷*University of Tennessee, Knoxville, Tennessee, USA*
¹⁸⁸*Texas A&M University, College Station, Texas, USA*
¹⁸⁹*Texas Tech University, Lubbock, Texas, USA*
¹⁹⁰*Vanderbilt University, Nashville, Tennessee, USA*
¹⁹¹*University of Virginia, Charlottesville, Virginia, USA*
¹⁹²*Wayne State University, Detroit, Michigan, USA*
¹⁹³*University of Wisconsin—Madison, Madison, WI, Wisconsin, USA*

^aDeceased.

^bAlso at TU Wien, Wien, Austria.

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

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

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

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

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

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

ⁱAlso at Department of Physics, Tsinghua University, Beijing, China.

^jAlso at UFMS, Nova Andradina, Brazil.

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

^lAlso at Nanjing Normal University Department of Physics, Nanjing, China.

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

ⁿAlso at National Research Center 'Kurchatov Institute', Moscow, Russia.

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

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

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

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

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

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

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

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

^wAlso at University of Hamburg, Hamburg, Germany.

^xAlso at Isfahan University of Technology, Isfahan, Iran.

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

^zAlso at Forschungszentrum Jülich, Juelich, Germany.

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

^{bb}Also at Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary.

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

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

^{ee}Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.

^{ff}Also at Wigner Research Centre for Physics, Budapest, Hungary.

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

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

ⁱⁱAlso at Punjab Agricultural University, Ludhiana, India.

^{jj}Also at Shoolini University, Solan, India.

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

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

^{mm}Also at Indian Institute of Technology (IIT), Mumbai, India.

ⁿⁿAlso at Deutsches Elektronen-Synchrotron, Hamburg, Germany.

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

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

^{qq}Also at INFN Sezione di Bari, Università di Bari, Politecnico di Bari, Bari, Italy.

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

- ^{ss} Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy.
- ^{tt} Also at Scuola Superiore Meridionale, Università di Napoli Federico II, Napoli, Italy.
- ^{uu} Also at Università di Napoli 'Federico II', Napoli, Italy.
- ^{vv} Also at Consiglio Nazionale delle Ricerche—Istituto Officina dei Materiali, Perugia, Italy.
- ^{ww} Also at Riga Technical University, Riga, Latvia.
- ^{xx} Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
- ^{yy} Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France.
- ^{zz} Also at Institute for Nuclear Research, Moscow, Russia.
- ^{aaa} Also at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia.
- ^{bbb} Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan.
- ^{ccc} Also at St. Petersburg Polytechnic University, St. Petersburg, Russia.
- ^{ddd} Also at University of Florida, Gainesville, Florida, USA.
- ^{eee} Also at Imperial College, London, United Kingdom.
- ^{fff} Also at Moscow Institute of Physics and Technology, Moscow, Russia.
- ^{ggg} Also at P.N. Lebedev Physical Institute, Moscow, Russia.
- ^{hhh} Also at California Institute of Technology, Pasadena, California, USA.
- ⁱⁱⁱ Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia.
- ^{jjj} Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
- ^{kkk} Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka.
- ^{lll} Also at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy.
- ^{mmm} Also at National and Kapodistrian University of Athens, Athens, Greece.
- ⁿⁿⁿ Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland.
- ^{ooo} Also at Universität Zürich, Zurich, Switzerland.
- ^{ppp} Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
- ^{qqq} Also at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
- ^{rrr} Also at Şırnak University, Şırnak, Turkey.
- ^{sss} Also at Near East University, Research Center of Experimental Health Science, Nicosia, Turkey.
- ^{ttt} Also at Konya Technical University, Konya, Turkey.
- ^{uuu} Also at Piri Reis University, Istanbul, Turkey.
- ^{vvv} Also at Adiyaman University, Adiyaman, Turkey.
- ^{www} Also at Ozyegin University, Istanbul, Turkey.
- ^{xxx} Also at Necmettin Erbakan University, Konya, Turkey.
- ^{yyy} Also at Bozok Universitetesi Rektörlüğü, Yozgat, Turkey.
- ^{zzz} Also at Marmara University, Istanbul, Turkey.
- ^{aaaa} Also at Milli Savunma University, Istanbul, Turkey.
- ^{bbbb} Also at Kafkas University, Kars, Turkey.
- ^{cccc} Also at Istanbul Bilgi University, Istanbul, Turkey.
- ^{dddd} Also at Hacettepe University, Ankara, Turkey.
- ^{eeee} Also at Istanbul University—Cerrahpasa, Faculty of Engineering, Istanbul, Turkey.
- ^{ffff} Also at Vrije Universiteit Brussel, Brussel, Belgium.
- ^{gggg} Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- ^{hhhh} Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
- ⁱⁱⁱⁱ Also at IPPP Durham University, Durham, United Kingdom.
- ^{jjjj} Also at Monash University, Faculty of Science, Clayton, Australia.
- ^{kkkk} Also at Università di Torino, Torino, Italy.
- ^{llll} Also at Bethel University, St. Paul, Minneapolis, USA.
- ^{mmmm} Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
- ⁿⁿⁿⁿ Also at Ain Shams University, Cairo, Egypt.
- ^{oooo} Also at Bingol University, Bingol, Turkey.
- ^{pppp} Also at Georgian Technical University, Tbilisi, Georgia.
- ^{qqqq} Also at Sinop University, Sinop, Turkey.
- ^{rrrr} Also at Erciyes University, Kayseri, Turkey.
- ^{ssss} Also at Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE)—Fudan University, Shanghai, China.
- ^{tttt} Also at Texas A&M University at Qatar, Doha, Qatar.
- ^{uuuu} Also at Kyungpook National University, Daegu, Korea.