


Search for Exotic Higgs Boson Decays $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ with Events Containing Two Merged Diphotons in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV

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

 (Received 13 September 2022; accepted 19 January 2023; published 5 September 2023)

We present the first direct search for exotic Higgs boson decays $H \rightarrow \mathcal{A}\mathcal{A}$, $\mathcal{A} \rightarrow \gamma\gamma$ in events with two photonlike objects. The hypothetical particle \mathcal{A} is a low-mass spin-0 particle decaying promptly to a merged diphoton reconstructed as a single photonlike object. We analyze the data collected by the CMS experiment at $\sqrt{s} = 13$ TeV corresponding to an integrated luminosity of 136 fb^{-1} . No excess above the estimated background is found. We set upper limits on the branching fraction $\mathcal{B}(H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma)$ of $(0.9\text{--}3.3) \times 10^{-3}$ at 95% confidence level for masses of \mathcal{A} in the range 0.1–1.2 GeV.

DOI: [10.1103/PhysRevLett.131.101801](https://doi.org/10.1103/PhysRevLett.131.101801)

Despite current constraints on the Higgs boson coupling to standard model (SM) particles from experiments at the CERN LHC [1,2], the Higgs sector remains an important area for physics searches beyond the SM (BSM). This is possible because the Higgs sector can potentially access BSM states that do not directly participate in the SM gauge interactions, called SM neutral. The simplest extensions of the Higgs sector include exotic decays of the form $H \rightarrow \mathcal{A}\mathcal{A}$, where H is the 125 GeV boson with a non-SM decay, and \mathcal{A} is a hypothetical new spin-0 particle decaying to a pair of SM particles [3]. Such decays are found in BSM models containing an additional SM-neutral singlet [3,4] and are of interest in searches for axionlike particle (ALP) production [5–7], including analyses performed at CMS [8–12]. In ALP models, \mathcal{A} is identified as a CP -odd spin-0 particle, where CP is the charge-conjugation and parity operator. The experimental search presented in this Letter is insensitive to the CP quantum numbers of \mathcal{A} , since its polarization is not measured.

For particle \mathcal{A} masses $m_{\mathcal{A}} \lesssim 1$ GeV, decays to many of the heavier fermions become inaccessible and the diphoton decay mode $\mathcal{A} \rightarrow \gamma\gamma$ becomes particularly relevant [3,13]. Generic $\mathcal{A} \rightarrow \gamma\gamma$ searches are prevalent in astrophysics, cosmology [14–16], and particle collider experiments [17,18] because of the potential impact of \mathcal{A} on stellar formation and the evolution of the early Universe. The particle \mathcal{A} is also a potential dark matter candidate [19–22].

A measurement of the diphoton invariant mass spectrum at the LHC in this \mathcal{A} mass regime is challenging if \mathcal{A} is

produced from the decay $H \rightarrow \mathcal{A}\mathcal{A}$. In the \mathcal{A} mass range of $m_{\mathcal{A}} < 0.4$ GeV, \mathcal{A} will have a Lorentz boost $\gamma_L \gtrsim 150$, where $\gamma_L = E_{\mathcal{A}}/m_{\mathcal{A}}$ and $E_{\mathcal{A}}$ is the \mathcal{A} energy. In the CMS experiment, this boost corresponds to a distance between the photons from the $\mathcal{A} \rightarrow \gamma\gamma$ decay at the electromagnetic calorimeter (ECAL) that is equal to or less than the Molière radius (r_M) of the ECAL material. The two photons will be predominantly reconstructed as one photonlike object (labeled Γ) by the standard CMS photon reconstruction algorithm, as described in Ref. [23]. If \mathcal{A} decays promptly, the $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ decay will lead to a measured two-photon invariant mass $m_{\Gamma\Gamma}$ peak degenerate with that of the SM $H \rightarrow \gamma\gamma$ decay. The $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ signal will then be hidden by reconstructed SM $H \rightarrow \gamma\gamma$ events [1,24]. With \mathcal{A} decays to more-massive particles being inaccessible, \mathcal{A} can also be long-lived [3].

To separate a possible signal from the SM background, we present the first search that directly measures the invariant mass spectrum of merged diphoton candidates Γ reconstructed in events resembling a SM $H \rightarrow \gamma\gamma$ final state. We assume that each \mathcal{A} in the $H \rightarrow \mathcal{A}\mathcal{A}$ decay has the same mass and decays promptly to photons, though we provide estimated results where these assumptions are relaxed. The direct search is made possible by a novel particle reconstruction technique that is able to measure the invariant mass m_{Γ} of merged diphoton candidates, something not possible with standard CMS reconstruction software. The technique utilizes deep learning algorithms trained directly on ECAL energy deposits to estimate $m_{\mathcal{A}}$ in a so-called end-to-end m_{Γ} reconstruction [23]. It is applied for the first time at CMS to probe masses from 0.1 GeV (corresponding to $\gamma_L \approx 600$ with the diphotons collimated enough to enter the same ECAL crystal) to 1.2 GeV (corresponding to $\gamma_L \approx 50$ and diphotons separated by around $3r_M$ at the ECAL). Tabulated results for this analysis can be found in [25]. Signal events with larger $m_{\mathcal{A}}$ have at least one of the $\mathcal{A} \rightarrow \gamma\gamma$ decays reconstructed as

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

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two distinct photons and are not studied. We note that the technique requires access to the full CMS event content, which is not readily accessible because of storage constraints. No special event triggers are otherwise required.

The analysis is performed using proton-proton (pp) collision data at $\sqrt{s} = 13$ TeV, collected by the CMS detector at the LHC from 2016 to 2018, corresponding to an integrated luminosity of 136 fb^{-1} . The CMS apparatus [26] is a multipurpose, nearly hermetic detector, designed to trigger on [27,28] and identify electrons, muons, photons, and hadrons [29–33]. A global reconstruction algorithm [34] combines the information provided by the all-silicon inner tracker and by the lead tungstate ECAL and brass-scintillator hadron calorimeters, operating inside a 3.8 T superconducting solenoid, with data from gas-ionization muon detectors embedded in the solenoid return yoke, to build τ leptons, jets, missing transverse momentum, and other physics objects [35–37]. The integrated luminosities for the 2016–2018 data-taking years have 1.2%–2.5% individual uncertainties [38–40], while the overall uncertainty for the 2016–2018 period is 1.6%.

The $\mathcal{A} \rightarrow \gamma\gamma$ decay is primarily detected in the ECAL, which contains a barrel section covering the pseudorapidity range $|\eta| < 1.48$ and two end cap sections on either end extending the range to $|\eta| < 3$. The crystal r_M is comparable to the barrel crystal width of 2.2 cm, resulting in more than 90% of the energy of photons converting only in the ECAL barrel to be laterally contained within a 3×3 crystal matrix [31].

A sample of events containing two reconstructed photonlike objects ($\Gamma\Gamma$) is selected for analysis. We assume that each reconstructed photonlike object Γ corresponds to a single merged diphoton candidate. Events selected for study are required to pass trigger, photon reconstruction, and kinematic selection requirements similar to those used in the CMS SM $H \rightarrow \gamma\gamma$ analysis [24]. Key differences in the photon reconstruction criteria are described in the following paragraph. The SM background processes contributing to the selected sample are composed of nonresonant quantum chromodynamic (QCD) dijet and $\gamma + \text{jet}$ production, prompt-diphoton production, and $H \rightarrow \gamma\gamma$ decays.

Since the $m_{\mathcal{A}}$ range we study spans a wide range of \mathcal{A} boosts, the opening angles of the $\mathcal{A} \rightarrow \gamma\gamma$ decays vary as well [23]. We thus apply a looser requirement on the output of the multivariate photon tagger [24], which then accepts more photons than for the CMS $H \rightarrow \gamma\gamma$ search. This increases the contribution from QCD background processes containing hadronic jets, which may be reconstructed as photonlike objects if they radiate an energetic photon or contain one or more neutral-meson decays ($\pi^0/\eta \rightarrow \gamma\gamma$). To compensate, we set a more restrictive requirement on the transverse momenta of charged particles in a cone around the selected photon, \mathcal{I}_{ch} [24]. Since neutral mesons are mainly produced inside hadronic jets, they are more likely

to be accompanied by charged particle tracks. Thresholds for the above requirements are chosen to maximize the significance of a possible $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ signal over the $m_{\mathcal{A}}$ range of interest. After all selection criteria are applied, signal events are selected with an estimated efficiency of 8%–24%, decreasing with $m_{\mathcal{A}}$, while background events are reduced by $>99\%$, as determined from simulation.

To simplify the application of the new m_{Γ} reconstruction technique, only events with both $\Gamma\Gamma$ reconstructed in the barrel section of the ECAL are analyzed. These account for about two thirds of the total expected signal yield. Events with more than two selected photons passing the selection criteria are not used to maintain orthogonality with a complementary CMS search at higher $m_{\mathcal{A}}$ where the $\mathcal{A} \rightarrow \gamma\gamma$ photons are fully resolved [41].

To discriminate $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ events from background, the end-to-end m_{Γ} reconstruction technique is used to measure the two-dimensional (2D) invariant mass spectrum, m_{Γ_1} versus m_{Γ_2} (labeled 2D- m_{Γ}), where $\Gamma_{1(2)}$ is the higher-(lower-)energy reconstructed photon. Each Γ is assumed to correspond to a single $\mathcal{A} \rightarrow \gamma\gamma$ leg of the presumed $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ decay. We construct signal (S) 2D- m_{Γ} templates for each signal mass hypothesis $m_{\mathcal{A}} = 0.1\text{--}1.2$ GeV, in 0.1 GeV steps, using simulation. This defines our signal model at each $m_{\mathcal{A}}$ hypothesis. The relative m_{Γ} resolution varies from approximately 100% to 20% for $m_{\mathcal{A}} = 0.1\text{--}1.2$ GeV [23]. Background (B) 2D- m_{Γ} templates are constructed for the SM processes contributing to our selected sample, derived from data and simulation. The sum of these background templates defines our background model, representing the SM-only hypothesis. A scan over different signal $m_{\mathcal{A}}$ hypotheses is performed. At each point, maximum likelihood estimation (MLE) [42] is used to extract the best fit between the observed 2D- m_{Γ} spectrum and the signal-plus-background model, $\mu S + B$, for some signal strength parameter μ . The detection of a potential $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ contribution at a given $m_{\mathcal{A}}$ is expressed in terms of the significance of the extracted best fit signal strength.

Simulated $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ events are generated with MadGraph_MC@NLO [43] at leading order using the SM + dark vector + dark Higgs model [3,4] and a Higgs boson mass of 125 GeV. A rounded mass value of 125 GeV is chosen, as this search is insensitive to the exact value of the Higgs boson mass. The Higgs boson is produced with up to one associated jet, and the \mathcal{A} has a negligible lifetime. The events are fully simulated in the CMS detector and account for effects from the underlying event and additional pp collisions in the same or nearby bunch crossings. Signal samples are generated separately for each $m_{\mathcal{A}}$ hypothesis.

The simulated $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ events are used to construct the signal 2D- m_{Γ} templates. Theoretical estimates of the $H \rightarrow \mathcal{A}\mathcal{A}$ production cross section vary depending on the model assumptions. Our final results, however, are expressed in terms of the signal branching fraction

$\mathcal{B}(H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma)$, which is independent of the choice of cross section used to normalize the signal templates.

Background $2D$ - m_{Γ} templates are derived to account for the $H \rightarrow \gamma\gamma$ contribution and all other nonresonant processes. The SM $H \rightarrow \gamma\gamma$ $2D$ - m_{Γ} template is found from simulation. The $H \rightarrow \gamma\gamma$ events are generated with MadGraph_MC@NLO [43] at next-to-leading order, with up to two extra jets in the matrix element calculation using FxFx merging [44]. The generated events are fully simulated in the CMS detector in the same way that the signal events described earlier are simulated. The normalization of the template is determined by fixing the template yield to the integrated luminosity of the data sample times the SM theoretical prediction for the total inclusive H production cross section [45] times the $H \rightarrow \gamma\gamma$ branching fraction and efficiency to pass selection criteria.

An overall background $2D$ - m_{Γ} template for all other nonresonant processes is estimated from data. We divide the selected events in data into regions based on $m_{\Gamma\Gamma}$ and $2D$ - m_{Γ} . Since the two \mathcal{A} particles come from the decay of a Higgs boson with a mass of 125 GeV, we define an $m_{\Gamma\Gamma}$ signal region (SR) around the Higgs boson mass (labeled m_H -SR) using $110 < m_{\Gamma\Gamma} < 140$ GeV and sideband (SB) regions below (labeled m_H -SB_{low}) and above (labeled m_H -SB_{high}) the Higgs boson mass, by requiring $100 < m_{\Gamma\Gamma} < 110$ GeV and $140 < m_{\Gamma\Gamma} < 180$ GeV, respectively. Since we assume that the two \mathcal{A} particles from the $H \rightarrow \mathcal{A}\mathcal{A}$ decay have equal mass, we also divide the $2D$ - m_{Γ} distribution into a SR along the diagonal (labeled $m_{\mathcal{A}}$ -SR),

by requiring $|m_{\Gamma_1} - m_{\Gamma_2}| < 0.3$ GeV, and a SB region (labeled $m_{\mathcal{A}}$ -SB) using $|m_{\Gamma_1} - m_{\Gamma_2}| > 0.3$ GeV. The final SR in which the MLE test is performed corresponds to the intersection of the above two SRs, $m_{\mathcal{A}}$ -SR \cap m_H -SR. A binned likelihood fit of $\mu S + B$ versus the observed $2D$ - m_{Γ} distribution with bin sizes of 0.05×0.05 GeV² is used. The boundaries between the SR and SB regions are tuned using the simulation to maximize the signal enrichment in the SR, while maintaining a sufficient number of events in the SB regions to give a good background estimation. Figure 1 (center) shows the observed $2D$ - m_{Γ} distribution of the selected events in data from m_H -SR and the respective $1D$ projections of m_{Γ_1} (left) and m_{Γ_2} (right) in the $m_{\mathcal{A}}$ -SR. Illustrative contours in $2D$ - m_{Γ} of the signal template (center) and its $1D$ projections (left and right) are also provided.

An estimate of the nonresonant background shape of the $2D$ - m_{Γ} template in the m_H -SR is obtained from data SBs by taking the event-weighted average of the shapes from the two m_H -SB regions (together labeled m_H -SB). To determine the normalization of the template, we assume that the ratio of the number of events along the $m_{\mathcal{A}}$ -SR diagonal, from that observed in the m_H -SRs to that estimated from the m_H -SB, $N(m_{\mathcal{A}}$ -SR \cap m_H -SR)/ $N(m_{\mathcal{A}}$ -SR \cap m_H -SB), is the same as for the $m_{\mathcal{A}}$ -SB off diagonal, $N(m_{\mathcal{A}}$ -SB \cap m_H -SR)/ $N(m_{\mathcal{A}}$ -SB \cap m_H -SB). This is justified since the ratio of the number of events in the m_H -SR to the m_H -SB as a function of $2D$ - m_{Γ} is estimated to be constant after the reweighting procedure described below. The normalization

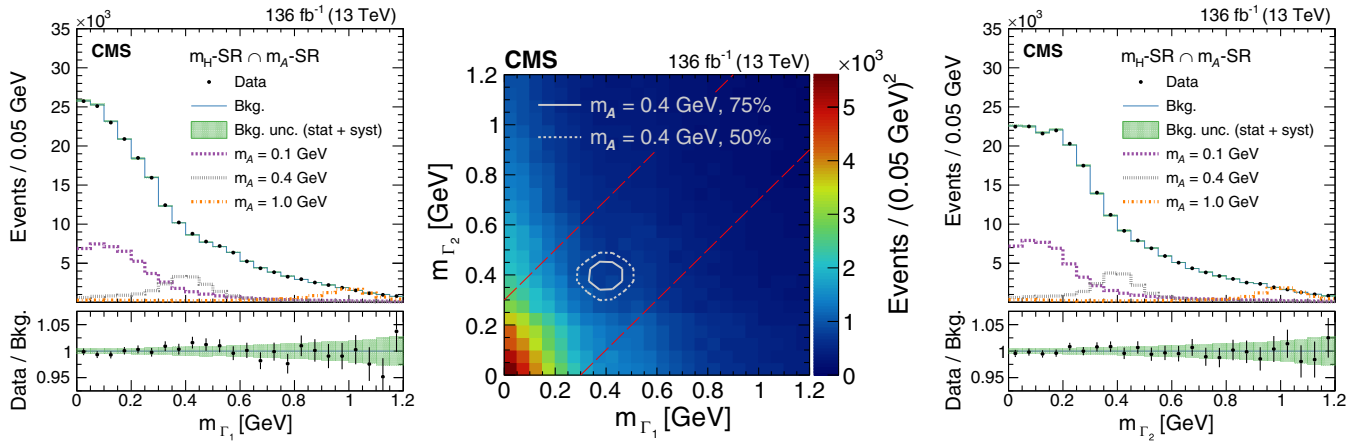


FIG. 1. Mass distributions from selected events in data. Center: the $2D$ - m_{Γ} distribution for data events in the m_H -SR. The red dashed lines indicate the $m_{\mathcal{A}}$ -SR boundaries. The contours of simulated $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ events for $m_{\mathcal{A}} = 0.4$ GeV are plotted for 75% (solid contour) and 50% (dotted contour) of the distribution maximum. The corresponding m_{Γ_1} (left) and m_{Γ_2} (right) projections for the overlap of the m_H -SR and $m_{\mathcal{A}}$ -SR are also shown. The data distributions (black points) are plotted against the total predicted background distributions (blue curves). The statistical uncertainties in the former are negligible and the total uncertainties in the latter are barely visible as green bands. The spectra of simulated $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ events for $m_{\mathcal{A}} = 0.1$ (purple dashed curve), 0.4 (gray dotted curve), and 1.0 GeV (orange dash-dotted curve) are also provided. They are each normalized to the value of $\mathcal{B}(H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma)$ that is expected to be excluded by the background model (described under the CL_s criterion in our results) times 10^3 . The black points in the lower panels of the left and right plots give the ratios of the data to the predicted background distributions. The vertical bars represent the statistical uncertainties in the former, and the green bands represent the total uncertainty in the latter.

for the template shape is then determined by solving for the expression for $N(m_{\mathcal{A}}\text{-SR} \cap m_H\text{-SR})$.

For hadronic jets passing the event selection, there is an energy dependence, and thus an m_{Γ} dependence, that violates the assumption described in the previous paragraph. With increasing jet energy, more energy becomes available to produce additional hadrons in the jet, which increases the effective mass of the jet and thus its reconstructed m_{Γ} . To correct for this effect, prior to deriving the 2D- m_{Γ} shape, events from the two $m_H\text{-SB}$ regions are first reweighted so that their transverse momentum distributions match that in the target $m_H\text{-SR}$.

The normalized $H \rightarrow \gamma\gamma$ and nonresonant background templates are then added together. Their combined yield is renormalized so that the ratio of the predicted to the observed yields in the $m_{\mathcal{A}}\text{-SB}$ region remains unity. The $H \rightarrow \gamma\gamma$ template accounts for about 0.4% of the total background template yield. To account for residual differences in the 2D- m_{Γ} shape between the background estimate and the observed distribution in the $m_{\mathcal{A}}\text{-SB}$ region, the total background template is multiplied by a 2D polynomial function $\text{pol}(m_{\Gamma_1}, m_{\Gamma_2})$ over the full 2D- m_{Γ} range. A linear polynomial is used with parameters chosen to maximize the likelihood with respect to the observed 2D- m_{Γ} shape in the $m_{\mathcal{A}}\text{-SB}$ region. No further improvement in the goodness of fit is found with higher polynomial orders. The resulting corrected 2D- m_{Γ} background template defines the background model used in the MLE fit. The left and right plots in Fig. 1 show that the SM background in the observed 2D- m_{Γ} distribution is dominated by single photonlike objects, which exhibit a smoothly falling m_{Γ} spectrum, rather than by neutral-meson decays, which would be manifested as peaks [23]. Neutral-meson decays from $\gamma + \text{jet}$ production are more likely to be reconstructed in the lower-energy Γ_2 . The background estimation is validated using an orthogonal data sample obtained by inverting the \mathcal{I}_{ch} requirement on Γ_2 , to ensure negligible signal contamination. No significant bias is observed when the signal extraction procedure is performed on this sample.

Uncertainties in the predicted signal and background templates are treated as nuisance parameters in the MLE procedure used to determine the best fit signal strength $\hat{\mu}$. The dominant uncertainties impacting the extracted $\hat{\mu}$ are those from statistical uncertainties in the background template's shape. Their largest impact on the relative uncertainty in $\hat{\mu}$ varies between 15% and 20%, depending on $m_{\mathcal{A}}$. For $m_{\mathcal{A}} = 0.1$ GeV, where the m_{Γ} resolution is poorest and the background contribution is largest, systematic uncertainties affecting the background template normalization are also important. These include systematic uncertainties associated with the best fit parameters of $\text{pol}(m_{\Gamma_1}, m_{\Gamma_2})$ and the relative contribution of $m_H\text{-SB}_{\text{low}}$ versus $m_H\text{-SB}_{\text{high}}$ events in the nonresonant background 2D- m_{Γ} template. These systematic uncertainties impact

the relative uncertainty in $\hat{\mu}$ by about 25% (10%) for $m_{\mathcal{A}} = 0.1(1.2)$ GeV.

The systematic uncertainty in the signal strength from using the 2D- m_{Γ} template determined from simulation is estimated from a sample of electrons in events with $Z \rightarrow e^+e^-$ decays, selected from both data and simulation with the “tag-and-probe” technique [46]. Electrons are preferred over decays of neutral mesons in jets because of the complicating effects of accompanying hadrons in the same jet [23]. Specifically, uncertainties associated with a relative m_{Γ} scale shift and an increase in the smearing of the mass peak are estimated and found to have a negligible impact on $\hat{\mu}$.

The best fit background estimate determined from the MLE procedure is shown by the blue solid curves in Fig. 1 (left and right), together with its associated best fit total statistical plus systematic (stat + syst) uncertainties. We find no statistically significant excess in the data over the SM background predictions for $m_{\mathcal{A}}$ masses in the range 0.1–1.2 GeV.

The CL_s criterion [47,48] is used to interpret this result in terms of excluded $\mathcal{B}(H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma)$ values. The observed upper limit on $\mathcal{B}(H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma)$ at 95% confidence level (C.L.) as a function of $m_{\mathcal{A}}$ in the range 0.1–1.2 GeV is shown in Fig. 2 and varies between $(0.9\text{--}3.3) \times 10^{-3}$ for $m_{\mathcal{A}}$ values 0.1–1.2 GeV. The expected 95% C.L. limits and their associated 68% and 95% confidence intervals (CIs) are determined by simulating SM background-only pseudo-experiments. The LHC measurements of $\mathcal{B}(H \rightarrow \gamma\gamma)$ [1,2] give an effective upper bound on a possible measurement of $\mathcal{B}(H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma)$ because of

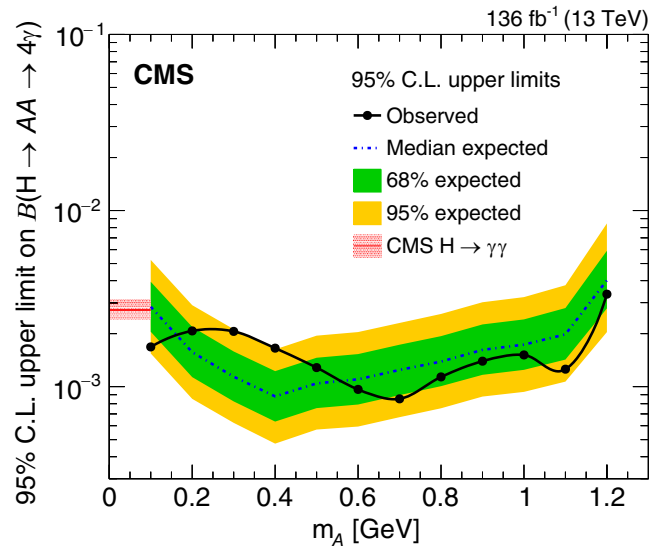


FIG. 2. Observed (black solid curve with points) and median expected (blue dashed curve) 95% C.L. upper limit on $\mathcal{B}(H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma)$ as a function of $m_{\mathcal{A}}$ for prompt \mathcal{A} decays. The 68% (green band) and 95% (yellow band) CIs are plotted around the expected limit. The 95% C.L. upper limit from the CMS measurement [1] of $\mathcal{B}(H \rightarrow \gamma\gamma)$ is also shown (red band, where the width represents the uncertainty in the measurement).

the degeneracy between the final states. The constraint from the CMS measurement [1] is shown in Fig. 2. It is relevant for values of $m_{\mathcal{A}} \approx 0.1$ GeV where the $\mathcal{A} \rightarrow \gamma\gamma$ decay resembles a single photon and increases at larger $m_{\mathcal{A}}$. Our observed upper limits thus set the best constraints for this decay mode in the $m_{\mathcal{A}}$ range that we study.

We estimate the upper limits for long-lived \mathcal{A} decays by comparing the signal yield in the $m_{\mathcal{A}}$ -SR \cap m_H -SR for different simulated \mathcal{A} decay lengths compared with that for prompt decays. For $m_{\mathcal{A}} = 0.1(0.4)$ GeV, the 95% C.L. upper limit on $\mathcal{B}(H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma)$ is 1.6 (0.9) times the prompt-decay upper limit for an \mathcal{A} decay length of $c\tau_0 = 1$ mm, and 30 (3) times larger for $c\tau_0 = 10$ mm, with a linear interpolation between the two limits in both cases. Better upper limits result when the increased merging from long-lived \mathcal{A} decays improves photon reconstruction more than it degrades m_{Γ} resolution. The prompt-decay upper limits are also relevant for models with dissimilar \mathcal{A} masses, $H \rightarrow \mathcal{A}_1\mathcal{A}_2$, with $m_{\mathcal{A}_1} \neq m_{\mathcal{A}_2}$, for mass differences less than the $m_{\mathcal{A}}$ -SR window, $|m_{\mathcal{A}_1} - m_{\mathcal{A}_2}| \lesssim 0.3$ GeV. For larger mass differences, the signal mass peak would fall outside of the $m_{\mathcal{A}}$ -SR and be absorbed into the $m_{\mathcal{A}}$ -SB, making a measurement impossible.

In summary, the results of a search for the exotic Higgs boson decay $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ for a Higgs boson mass of 125 GeV are presented. Events reconstructed with two photonlike objects are used, where each photonlike object is assumed to be a merged $\mathcal{A} \rightarrow \gamma\gamma$ candidate. A method is developed to measure the invariant mass of merged diphoton candidates to discriminate a potential signal from the standard model background. This is the first search of its kind at CMS and made possible by a novel end-to-end reconstruction technique of merged diphotons. No excess of events above the estimated background is found. An upper limit on the branching fraction $\mathcal{B}(H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma)$ of $(0.9\text{--}3.3) \times 10^{-3}$ is set at 95% C.L. for masses of \mathcal{A} in the range 0.1–1.2 GeV, assuming prompt \mathcal{A} decays. These are the current best constraints on $H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma$ in this $m_{\mathcal{A}}$ range.

Tabulated results for this analysis are provided in the HEPData record [25].

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid and other centers for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC, the CMS detector, and the supporting computing infrastructure provided by the following funding agencies: BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES

and BNSF (Bulgaria); CERN; CAS, MoST, and NSFC (China); MINCIENCIAS (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); MoER, ERC PUT, and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRI (Greece); NKFIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MES and NSC (Poland); FCT (Portugal); MESTD (Serbia); MCIN/AEI and PCTI (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); MHESI and NSTDA (Thailand); TUBITAK and TENMAK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (U.S.).

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A. Tumasyan^{1,b} W. Adam² J. W. Andrejkovic² T. Bergauer² S. Chatterjee² K. Damanakis² M. Dragicevic²
A. Escalante Del Valle² P. S. Hussain² M. Jeitler^{2,c} N. Krammer² L. Lechner² D. Liko² I. Mikulec²
P. Paulitsch² F. M. Pitters² J. Schieck^{2,c} R. Schöfbeck² D. Schwarz² S. Templ² W. Waltenberger²
C.-E. Wulz^{2,c} M. R. Darwish^{3,d} T. Janssen³ T. Kello^{3,e} H. Rejeb Sfar³ P. Van Mechelen³ E. S. Bols⁴
J. D'Hondt⁴ A. De Moor⁴ M. Delcourt⁴ H. El Faham⁴ S. Lowette⁴ S. Moortgat⁴ A. Morton⁴ D. Müller⁴
A. R. Sahasransu⁴ S. Tavernier⁴ W. Van Doninck⁴ D. Vannerom⁴ B. Clerbaux⁵ G. De Lentdecker⁵ L. Favart⁵
D. Hohov⁵ J. Jaramillo⁵ K. Lee⁵ M. Mahdavihorrani⁵ I. Makarenko⁵ A. Malara⁵ S. Paredes⁵ L. Pétré⁵
N. Postiau⁵ E. Starling⁵ L. Thomas⁵ M. Vanden Bemden⁵ C. Vander Velde⁵ P. Vanlaere⁵ D. Dobur⁶ J. Knolle⁶
L. Lambrecht⁶ G. Mestdach⁶ M. Niedziela⁶ C. Rendón⁶ C. Roskas⁶ A. Samalan⁶ K. Skovpen⁶ M. Tytgat⁶
N. Van Den Bossche⁶ B. Vermassen⁶ L. Wezenbeek⁶ A. Benecke⁷ G. Bruno⁷ F. Bury⁷ C. Caputo⁷
P. David⁷ C. Delaere⁷ I. S. Donertas⁷ A. Giammanco⁷ K. Jaffel⁷ Sa. Jain⁷ V. Lemaître⁷ K. Mondal⁷
J. Prisciandaro⁷ A. Talierecio⁷ T. T. Tran⁷ P. Vischia⁷ S. Wertz⁷ G. A. Alves⁸ E. Coelho⁸ C. Hensel⁸
A. Moraes⁸ P. Rebello Teles⁸ W. L. Aldá Júnior⁹ M. Alves Gallo Pereira⁹ M. Barroso Ferreira Filho⁹
H. Brandao Malbouisson⁹ W. Carvalho⁹ J. Chinellato^{9,f} E. M. Da Costa⁹ G. G. Da Silveira^{9,g}
D. De Jesus Damiao⁹ V. Dos Santos Sousa⁹ S. Fonseca De Souza⁹ J. Martins^{9,h} C. Mora Herrera⁹
K. Mota Amarilo⁹ L. Mundim⁹ H. Nogima⁹ A. Santoro⁹ S. M. Silva Do Amaral⁹ A. Sznajder⁹ M. Thiel⁹
F. Torres Da Silva De Araujo^{9,i} A. Vilela Pereira⁹ C. A. Bernardes^{10,g} L. Calligaris¹⁰
T. R. Fernandez Perez Tomei¹⁰ E. M. Gregores¹⁰ P. G. Mercadante¹⁰ S. F. Novaes¹⁰ Sandra S. Padula¹⁰
A. Aleksandrov¹¹ G. Antchev¹¹ R. Hadjiiska¹¹ P. Iaydjiev¹¹ M. Misheva¹¹ M. Rodozov¹¹ M. Shopova¹¹
G. Sultanov¹¹ A. Dimitrov¹² T. Ivanov¹² L. Litov¹² B. Pavlov¹² P. Petkov¹² A. Petrov¹² E. Shumka¹²
T. Cheng¹³ T. Javaid^{13,j} M. Mittal¹³ L. Yuan¹³ M. Ahmad¹⁴ G. Bauer^{14,k} Z. Hu¹⁴ S. Lezki¹⁴ K. Yi^{14,l}
G. M. Chen^{15,j} H. S. Chen^{15,j} M. Chen^{15,j} F. Iemmi¹⁵ C. H. Jiang¹⁵ A. Kapoor¹⁵ H. Liao¹⁵ Z.-A. Liu^{15,m}
V. Milosevic¹⁵ F. Monti¹⁵ R. Sharma¹⁵ J. Tao¹⁵ J. Thomas-Wilsker¹⁵ J. Wang¹⁵ H. Zhang¹⁵ J. Zhao¹⁵
A. Agapitos¹⁶ Y. An¹⁶ Y. Ban¹⁶ C. Chen¹⁶ A. Levin¹⁶ C. Li¹⁶ Q. Li¹⁶ X. Lyu¹⁶ Y. Mao¹⁶ S. J. Qian¹⁶
X. Sun¹⁶ D. Wang¹⁶ J. Xiao¹⁶ H. Yang¹⁶ M. Lu¹⁷ Z. You¹⁷ X. Gao^{18,e} D. Leggat¹⁸ H. Okawa¹⁸
Y. Zhang¹⁸ Z. Lin¹⁹ C. Lu¹⁹ M. Xiao¹⁹ C. Avila²⁰ D. A. Barbosa Trujillo²⁰ A. Cabrera²⁰ C. Florez²⁰
J. Fraga²⁰ J. Mejia Guisao²¹ F. Ramirez²¹ M. Rodriguez²¹ J. D. Ruiz Alvarez²¹ D. Giljanovic²²
N. Godinovic²² D. Lelas²² I. Puljak²² Z. Antunovic²³ M. Kovac²³ T. Sculac²³ V. Brigljevic²⁴
B. K. Chitroda²⁴ D. Ferencek²⁴ D. Majumder²⁴ M. Roguljic²⁴ A. Starodumov^{24,n} T. Susa²⁴ A. Attikis²⁵
K. Christoforou²⁵ G. Kole²⁵ M. Kolosova²⁵ S. Konstantinou²⁵ J. Mousa²⁵ C. Nicolaou²⁵ F. Ptochos²⁵
P. A. Razis²⁵ H. Rykaczewski²⁵ H. Saka²⁵ M. Finger^{26,n} M. Finger Jr.^{26,n} A. Kveton²⁶ E. Ayala²⁷
E. Carrera Jarrin²⁸ A. A. Abdelalim^{29,o,p} E. Salama^{29,q,r} M. Abdullah Al-Mashad³⁰ M. A. Mahmoud³⁰
S. Bhowmik³¹ R. K. Dewanjee³¹ K. Ehataht³¹ M. Kadastik³¹ T. Lange³¹ S. Nandan³¹ C. Nielsen³¹ J. Pata³¹
M. Raidal³¹ L. Tani³¹ C. Veelken³¹ P. Eerola³² H. Kirschenmann³² K. Osterberg³² M. Voutilainen³²
S. Bharthuar³³ E. Brücken³³ F. Garcia³³ J. Havukainen³³ M. S. Kim³³ R. Kinnunen³³ T. Lampén³³
K. Lassila-Perini³³ S. Lehti³³ T. Lindén³³ M. Lotti³³ L. Martikainen³³ M. Myllymäki³³ J. Ott³³
M. m. Rantanen³³ H. Siikonen³³ E. Tuominen³³ J. Tuominiemi³³ P. Luukka³⁴ H. Petrow³⁴ T. Tuuva³⁴
C. Amendola³⁵ M. Besancon³⁵ F. Couderc³⁵ M. Dejardin³⁵ D. Denegri³⁵ J. L. Faure³⁵ F. Ferri³⁵ S. Ganjour³⁵
P. Gras³⁵ G. Hamel de Monchenault³⁵ P. Jarry³⁵ V. Lohezic³⁵ J. Malcles³⁵ J. Rander³⁵ A. Rosowsky³⁵
M. Ö. Sahin³⁵ A. Savoy-Navarro^{35,s} P. Simkina³⁵ M. Titov³⁵ C. Baldenegro Barrera³⁶ F. Beaudette³⁶
A. Buchot Perraguin³⁶ P. Busson³⁶ A. Cappati³⁶ C. Charlot³⁶ F. Damas³⁶ O. Davignon³⁶ B. Diab³⁶
G. Falmagne³⁶ B. A. Fontana Santos Alves³⁶ S. Ghosh³⁶ R. Granier de Cassagnac³⁶ A. Hakimi³⁶
B. Harikrishnan³⁶ G. Liu³⁶ J. Motta³⁶ M. Nguyen³⁶ C. Ochando³⁶ L. Portales³⁶ R. Salerno³⁶ U. Sarkar³⁶
J. B. Sauvan³⁶ Y. Sirois³⁶ A. Tarabini³⁶ E. Vernazza³⁶ A. Zabi³⁶ A. Zghiche³⁶ J.-L. Agram^{37,t} J. Andrea³⁷
D. Apparú³⁷ D. Bloch³⁷ G. Bourgatte³⁷ J.-M. Brom³⁷ E. C. Chabert³⁷ C. Collard³⁷ D. Darej³⁷
U. Goerlach³⁷ C. Grimault³⁷ A.-C. Le Bihan³⁷ P. Van Hove³⁷ S. Beauceron³⁸ C. Bernet³⁸ B. Blancon³⁸
G. Boudoul³⁸ A. Carle³⁸ N. Chanon³⁸ J. Choi³⁸ D. Contardo³⁸ P. Depasse³⁸ C. Dozen^{38,u} H. El Mamouni³⁸
J. Fay³⁸ S. Gascon³⁸ M. Gouzevitch³⁸ G. Grenier³⁸ B. Ille³⁸ I. B. Laktineh³⁸ M. Lethuillier³⁸ L. Mirabito³⁸
S. Perries³⁸ L. Torterotot³⁸ M. Vander Donckt³⁸ P. Verdier³⁸ S. Viret³⁸ D. Chokheli³⁹ I. Lomidze³⁹

Z. Tsamalaidze^{39,n} V. Botta⁴⁰ L. Feld⁴⁰ K. Klein⁴⁰ M. Lipinski⁴⁰ D. Meuser⁴⁰ A. Pauls⁴⁰ N. Röwert⁴⁰
M. Teroerde⁴⁰ S. Diekmann⁴¹ A. Dodonova⁴¹ N. Eich⁴¹ D. Eliseev⁴¹ M. Erdmann⁴¹ P. Fackeldey⁴¹
D. Fasanella⁴¹ B. Fischer⁴¹ T. Hebbeker⁴¹ K. Hoepfner⁴¹ F. Ivone⁴¹ M. y. Lee⁴¹ L. Mastrolorenzo⁴¹
M. Merschmeyer⁴¹ A. Meyer⁴¹ S. Mondal⁴¹ S. Mukherjee⁴¹ D. Noll⁴¹ A. Novak⁴¹ F. Nowotny⁴¹
A. Pozdnyakov⁴¹ Y. Rath⁴¹ W. Redjeb⁴¹ H. Reithler⁴¹ A. Schmidt⁴¹ S. C. Schuler⁴¹ A. Sharma⁴¹ L. Vigilante⁴¹
S. Wiedenbeck⁴¹ S. Zaleski⁴¹ C. Dziwok⁴² G. Flügge⁴² W. Haj Ahmad^{42,v} O. Hlushchenko⁴² T. Kress⁴²
A. Nowack⁴² O. Pooth⁴² A. Stahl⁴² T. Ziemons⁴² A. Zotz⁴² H. Aarup Petersen⁴³ M. Aldaya Martin⁴³
P. Asmuss⁴³ S. Baxter⁴³ M. Bayatmakou⁴³ O. Behnke⁴³ A. Bermúdez Martínez⁴³ S. Bhattacharya⁴³
A. A. Bin Anuar⁴³ F. Blekman^{43,w} K. Borrás^{43,x} D. Brunner⁴³ A. Campbell⁴³ A. Cardini⁴³ C. Cheng⁴³
F. Colombina⁴³ S. Consuegra Rodríguez⁴³ G. Correia Silva⁴³ M. De Silva⁴³ L. Didukh⁴³ G. Eckerlin⁴³
D. Eckstein⁴³ L. I. Estevez Banos⁴³ O. Filatov⁴³ E. Gallo^{43,w} A. Geiser⁴³ A. Giraldi⁴³ G. Greau⁴³
A. Grohsjean⁴³ V. Guglielmi⁴³ M. Guthoff⁴³ A. Jafari^{43,y} N. Z. Jomhari⁴³ B. Kaech⁴³ A. Kasem^{43,x}
M. Kasemann⁴³ H. Kaveh⁴³ C. Kleinwort⁴³ R. Kogler⁴³ M. Komm⁴³ D. Krücker⁴³ W. Lange⁴³
D. Leyva Pernia⁴³ K. Lipka⁴³ W. Lohmann^{43,z} R. Mankel⁴³ I.-A. Melzer-Pellmann⁴³
M. Mendizabal Morentin⁴³ J. Metwally⁴³ A. B. Meyer⁴³ G. Milella⁴³ M. Mormile⁴³ A. Mussgiller⁴³
A. Nürnberg⁴³ Y. Otari⁴³ D. Pérez Adán⁴³ A. Raspereza⁴³ B. Ribeiro Lopes⁴³ J. Rübenach⁴³ A. Saggio⁴³
A. Saibel⁴³ M. Savitskiy⁴³ M. Scham^{43,x,aa} V. Scheurer⁴³ S. Schnake^{43,x} P. Schütze⁴³ C. Schwanenberger^{43,w}
M. Shchedrolosiev⁴³ R. E. Sosa Ricardo⁴³ D. Stafford⁴³ N. Tonon^{43,a} M. Van De Klundert⁴³ F. Vazzoler⁴³
A. Ventura Barroso⁴³ R. Walsh⁴³ D. Walter⁴³ Q. Wang⁴³ Y. Wen⁴³ K. Wichmann⁴³ L. Wiens^{43,x}
C. Wissing⁴³ S. Wuchterl⁴³ Y. Yang⁴³ A. Zimmermann Castro Santos⁴³ A. Albrecht⁴⁴ S. Albrecht⁴⁴
M. Antonello⁴⁴ S. Bein⁴⁴ L. Benato⁴⁴ M. Bonanomi⁴⁴ P. Connor⁴⁴ K. De Leo⁴⁴ M. Eich⁴⁴ K. El Morabit⁴⁴
F. Feindt⁴⁴ A. Fröhlich⁴⁴ C. Garbers⁴⁴ E. Garutti⁴⁴ M. Hajheidari⁴⁴ J. Haller⁴⁴ A. Hinzmann⁴⁴ H. R. Jabusch⁴⁴
G. Kasieczka⁴⁴ R. Klanner⁴⁴ W. Korcarí⁴⁴ T. Kramer⁴⁴ V. Kutzner⁴⁴ J. Lange⁴⁴ A. Lobanov⁴⁴
C. Matthies⁴⁴ A. Mehta⁴⁴ L. Moureaux⁴⁴ M. Mrowietz⁴⁴ A. Nigamova⁴⁴ Y. Nissan⁴⁴ A. Paasch⁴⁴
K. J. Pena Rodriguez⁴⁴ M. Rieger⁴⁴ O. Rieger⁴⁴ P. Schleper⁴⁴ M. Schröder⁴⁴ J. Schwandt⁴⁴ H. Stadie⁴⁴
G. Steinbrück⁴⁴ A. Tews⁴⁴ M. Wolf⁴⁴ J. Bechtel⁴⁵ S. Brommer⁴⁵ M. Burkart⁴⁵ E. Butz⁴⁵ R. Caspart⁴⁵
T. Chwalek⁴⁵ A. Dierlamm⁴⁵ A. Droll⁴⁵ N. Faltermann⁴⁵ M. Giffels⁴⁵ J. O. Gosewisch⁴⁵ A. Gottmann⁴⁵
F. Hartmann^{45,bb} M. Horzela⁴⁵ U. Husemann⁴⁵ P. Keicher⁴⁵ M. Klute⁴⁵ R. Koppenhöfer⁴⁵ S. Maier⁴⁵
S. Mitra⁴⁵ Th. Müller⁴⁵ M. Neukum⁴⁵ G. Quast⁴⁵ K. Rabbertz⁴⁵ J. Rauser⁴⁵ D. Savoie⁴⁵ M. Schnepf⁴⁵
D. Seith⁴⁵ I. Shvetsov⁴⁵ H. J. Simonis⁴⁵ N. Trevisani⁴⁵ R. Ulrich⁴⁵ J. van der Linden⁴⁵ R. F. Von Cube⁴⁵
M. Wassmer⁴⁵ S. Wieland⁴⁵ R. Wolf⁴⁵ S. Wozniowski⁴⁵ S. Wunsch⁴⁵ G. Anagnostou⁴⁶ P. Assiouras⁴⁶
G. Daskalakis⁴⁶ A. Kyriakis⁴⁶ A. Stakia⁴⁶ M. Diamantopoulou⁴⁷ D. Karasavvas⁴⁷ P. Kontaxakis⁴⁷
A. Manousakis-Katsikakis⁴⁷ A. Panagiotou⁴⁷ I. Papavergou⁴⁷ N. Saoulidou⁴⁷ K. Theofilatos⁴⁷ E. Tziaferi⁴⁷
K. Vellidis⁴⁷ E. Vourliotis⁴⁷ I. Zisopoulos⁴⁷ G. Bakas⁴⁸ T. Chatzistavrou⁴⁸ K. Kousouris⁴⁸
I. Papakrivopoulos⁴⁸ G. Tsiapolitis⁴⁸ A. Zacharopoulou⁴⁸ K. Adamidis⁴⁹ I. Bestintzanos⁴⁹ I. Evangelou⁴⁹ C. Foudas⁴⁹
P. Gianneios⁴⁹ C. Kamtsikis⁴⁹ P. Katsoulis⁴⁹ P. Kokkas⁴⁹ P. G. Kosmoglou Kioseoglou⁴⁹ N. Manthos⁴⁹
I. Papadopoulos⁴⁹ J. Strogas⁴⁹ M. Csanád⁵⁰ K. Farkas⁵⁰ M. M. A. Gadallah^{50,cc} S. Lökös^{50,dd} P. Major⁵⁰
K. Mandal⁵⁰ G. Pásztor⁵⁰ A. J. Rádl^{50,ee} O. Surányi⁵⁰ G. I. Veres⁵⁰ M. Bartók^{51,ff} G. Bencze⁵¹ C. Hajdu⁵¹
D. Horvath^{51,gg,hh} F. Sikler⁵¹ V. Veszpremi⁵¹ N. Beni⁵² S. Czellar⁵² J. Karancsi^{52,ff} J. Molnar⁵² Z. Szillasi⁵²
D. Teyssier⁵² P. Raics⁵³ B. Ujvari^{53,ii} T. Csorgo^{54,ee} F. Nemes^{54,ee} T. Novak⁵⁴ J. Babbar⁵⁵ S. Bansal⁵⁵
S. B. Beri⁵⁵ V. Bhatnagar⁵⁵ G. Chaudhary⁵⁵ S. Chauhan⁵⁵ N. Dhingra^{55,jj} R. Gupta⁵⁵ A. Kaur⁵⁵ A. Kaur⁵⁵
H. Kaur⁵⁵ M. Kaur⁵⁵ S. Kumar⁵⁵ P. Kumari⁵⁵ M. Meena⁵⁵ K. Sandeep⁵⁵ T. Sheokand⁵⁵ J. B. Singh^{55,kk}
A. Singla⁵⁵ A. K. Viridi⁵⁵ A. Ahmed⁵⁶ A. Bhardwaj⁵⁶ B. C. Choudhary⁵⁶ M. Gola⁵⁶ A. Kumar⁵⁶
M. Naimuddin⁵⁶ P. Priyanka⁵⁶ K. Ranjan⁵⁶ S. Saumya⁵⁶ A. Shah⁵⁶ S. Baradia⁵⁷ S. Barman^{57,ll}
S. Bhattacharya⁵⁷ D. Bhowmik⁵⁷ S. Dutta⁵⁷ S. Dutta⁵⁷ B. Gomber^{57,mm} M. Maity^{57,ll} P. Palit⁵⁷ P. K. Rout⁵⁷
G. Saha⁵⁷ B. Sahu⁵⁷ S. Sarkar⁵⁷ P. K. Behera⁵⁸ S. C. Behera⁵⁸ P. Kalbhor⁵⁸ J. R. Komaragiri^{58,nn}
D. Kumar^{58,nn} A. Muhammad⁵⁸ L. Panwar^{58,nn} R. Pradhan⁵⁸ P. R. Pujahari⁵⁸ A. Sharma⁵⁸ A. K. Sikdar⁵⁸
P. C. Tiwari^{58,nn} S. Verma⁵⁸ K. Naskar^{59,oo} T. Aziz⁶⁰ I. Das⁶⁰ S. Dugad⁶⁰ M. Kumar⁶⁰ G. B. Mohanty⁶⁰
P. Suryadevara⁶⁰ S. Banerjee⁶¹ R. Chudasama⁶¹ M. Guchait⁶¹ S. Karmakar⁶¹ S. Kumar⁶¹ G. Majumder⁶¹

K. Mazumdar⁶¹, S. Mukherjee⁶¹, A. Thachayath⁶¹, S. Bahinipati^{62,pp}, A. K. Das⁶², C. Kar⁶², P. Mal⁶²,
 T. Mishra⁶², V. K. Muraleedharan Nair Bindhu^{62,qq}, A. Nayak^{62,qq}, P. Saha⁶², S. K. Swain⁶², D. Vats^{62,qq},
 A. Alpina⁶³, S. Dube⁶³, B. Kansal⁶³, A. Laha⁶³, S. Pandey⁶³, A. Rastogi⁶³, S. Sharma⁶³,
 H. Bakhshiansohi^{64,rr,ss}, E. Khazaie^{64,ss}, M. Zeinali^{64,tt}, S. Chenarani^{65,uu}, S. M. Etesami⁶⁵, M. Khakzad⁶⁵,
 M. Mohammadi Najafabadi⁶⁵, M. Grunewald⁶⁶, M. Abbrescia^{67a,67b}, R. Aly^{67a,67b}, C. Aruta^{67a,67b}, A. Colaleo^{67a},
 D. Creanza^{67a,67c}, N. De Filippis^{67a,67c}, M. De Palma^{67a,67b}, A. Di Florio^{67a,67b}, W. Elmetenawee^{67a,67b},
 F. Errico^{67a,67b}, L. Fiore^{67a}, G. Iaselli^{67a,67c}, M. Ince^{67a,67b}, G. Maggi^{67a,67c}, M. Maggi^{67a}, I. Margjeka^{67a,67b},
 V. Mastrapasqua^{67a,67b}, S. My^{67a,67b}, S. Nuzzo^{67a,67b}, A. Pellecchia^{67a,67b}, A. Pompili^{67a,67b}, G. Pugliese^{67a,67c},
 R. Radogna^{67a}, D. Ramos^{67a}, A. Ranieri^{67a}, G. Selvaggi^{67a,67b}, L. Silvestris^{67a}, F. M. Simone^{67a,67b},
 Ü. Sözbilir^{67a}, A. Stamerra^{67a}, R. Venditti^{67a}, P. Verwilligen^{67a}, G. Abbiendi^{68a}, C. Battilana^{68a,68b},
 D. Bonacorsi^{68a,68b}, L. Borgonovi^{68a}, L. Brigliadori^{68a}, R. Campanini^{68a,68b}, P. Capiluppi^{68a,68b}, A. Castro^{68a},
 F. R. Cavallo^{68a}, M. Cuffiani^{68a,68b}, G. M. Dallavalle^{68a}, T. Diotallevi^{68a,68b}, F. Fabbri^{68a}, A. Fanfani^{68a,68b},
 P. Giacomelli^{68a}, L. Giommi^{68a,68b}, C. Grandi^{68a}, L. Guiducci^{68a,68b}, S. Lo Meo^{68a,vv}, L. Lunerti^{68a,68b},
 S. Marcellini^{68a}, G. Masetti^{68a}, F. L. Navarria^{68a,68b}, A. Perrotta^{68a}, F. Primavera^{68a,68b}, A. M. Rossi^{68a,68b},
 T. Rovelli^{68a,68b}, G. P. Siroli^{68a,68b}, S. Costa^{69a,69b,ww}, A. Di Mattia^{69a}, R. Potenza^{69a,69b}, A. Tricomi^{69a,69b,ww},
 C. Tuve^{69a,69b}, G. Barbagli^{70a}, B. Camaiani^{70a,70b}, A. Cassese^{70a}, R. Ceccarelli^{70a,70b}, V. Ciulli^{70a,70b},
 C. Civinini^{70a}, R. D'Alessandro^{70a,70b}, E. Focardi^{70a,70b}, G. Latino^{70a,70b}, P. Lenzi^{70a,70b}, M. Lizzo^{70a,70b},
 M. Meschini^{70a}, S. Paoletti^{70a}, R. Seidita^{70a,70b}, G. Sguazzoni^{70a}, L. Viliani^{70a}, L. Benussi⁷¹, S. Bianco⁷¹,
 S. Meola^{71,bb}, D. Piccolo⁷¹, M. Bozzo^{72a,72b}, P. Chatagnon^{72a}, F. Ferro^{72a}, R. Mulargia^{72a}, E. Robutti^{72a},
 S. Tosi^{72a,72b}, A. Benaglia^{73a}, G. Boldrini^{73a}, F. Brivio^{73a,73b}, F. Cetorelli^{73a,73b}, F. De Guio^{73a,73b},
 M. E. Dinardo^{73a,73b}, P. Dini^{73a}, S. Gennai^{73a}, A. Ghezzi^{73a,73b}, P. Govoni^{73a,73b}, L. Guzzi^{73a,73b},
 M. T. Lucchini^{73a,73b}, M. Malberti^{73a}, S. Malvezzi^{73a}, A. Massironi^{73a}, D. Menasce^{73a}, L. Moroni^{73a},
 M. Paganoni^{73a,73b}, D. Pedrini^{73a}, B. S. Pinolini^{73a}, S. Ragazzi^{73a,73b}, N. Redaelli^{73a}, T. Tabarelli de Fatis^{73a,73b},
 D. Zuolo^{73a,73b}, S. Buontempo^{74a}, F. Carnevali^{74a,74b}, N. Cavallo^{74a,74c}, A. De Iorio^{74a,74b}, F. Fabozzi^{74a,74c},
 A. O. M. Iorio^{74a,74b}, L. Lista^{74a,74b,xx}, P. Paolucci^{74a,bb}, B. Rossi^{74a}, C. Sciacca^{74a,74b}, P. Azzi^{75a},
 N. Bacchetta^{75a,yy}, M. Benettoni^{75a}, D. Bisello^{75a,75b}, P. Bortignon^{75a}, A. Bragagnolo^{75a,75b}, R. Carlin^{75a,75b},
 P. Checchia^{75a}, T. Dorigo^{75a}, F. Gasparini^{75a,75b}, U. Gasparini^{75a,75b}, G. Grosso^{75a}, L. Layer^{75a,zz}, E. Lusiani^{75a},
 M. Margoni^{75a,75b}, A. T. Meneguzzo^{75a,75b}, J. Pazzini^{75a,75b}, P. Ronchese^{75a,75b}, R. Rossin^{75a,75b}, G. Strong^{75a},
 M. Tosi^{75a,75b}, H. Yarar^{75a,75b}, M. Zanetti^{75a,75b}, P. Zotto^{75a,75b}, A. Zucchetta^{75a,75b}, G. Zumerle^{75a,75b},
 S. Abu Zeid^{76a,q}, C. Aimè^{76a,76b}, A. Braghieri^{76a}, S. Calzaferri^{76a,76b}, D. Fiorina^{76a,76b}, P. Montagna^{76a,76b},
 V. Re^{76a}, C. Riccardi^{76a,76b}, P. Salvini^{76a}, I. Vai^{76a}, P. Vitulo^{76a,76b}, P. Asenov^{77a,aaa}, G. M. Bilei^{77a},
 D. Ciangottini^{77a,77b}, L. Fanò^{77a,77b}, M. Magherini^{77a,77b}, G. Mantovani^{77a,77b}, V. Mariani^{77a,77b}, M. Menichelli^{77a},
 F. Moscatelli^{77a,aaa}, A. Piccinelli^{77a,77b}, M. Presilla^{77a,77b}, A. Rossi^{77a,77b}, A. Santocchia^{77a,77b}, D. Spiga^{77a},
 T. Tedeschi^{77a,77b}, P. Azzurri^{78a}, G. Bagliesi^{78a}, V. Bertacchi^{78a,78c}, R. Bhattacharya^{78a}, L. Bianchini^{78a,78b},
 T. Boccali^{78a}, E. Bossini^{78a,78b}, D. Bruschini^{78a,78c}, R. Castaldi^{78a}, M. A. Ciocci^{78a,78b}, V. D'Amante^{78a,78d},
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 N. Shafiei^{78a,78b}, P. Spagnolo^{78a}, R. Tenchini^{78a}, G. Tonelli^{78a,78b}, N. Turini^{78a,78d}, A. Venturi^{78a}, P. G. Verdini^{78a},
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 P. Meridiani^{79a}, G. Organtini^{79a,79b}, F. Pandolfi^{79a}, R. Paramatti^{79a,79b}, C. Quaranta^{79a,79b}, S. Rahatlou^{79a,79b},
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 S. Argiro^{80a,80b}, M. Arneodo^{80a,80c}, N. Bartosik^{80a}, R. Bellan^{80a,80b}, A. Bellora^{80a,80b}, C. Biino^{80a}, N. Cartiglia^{80a},
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 G. Umoret^{80a,80b}, A. Vagnerini^{80a,80b}, S. Belforte^{81a}, V. Candelise^{81a,81b}, M. Casarsa^{81a}, F. Cossutti^{81a},
 A. Da Rold^{81a,81b}, G. Della Ricca^{81a,81b}, G. Sorrentino^{81a,81b}, S. Dogra⁸², C. Huh⁸², B. Kim⁸², D. H. Kim⁸²,

G. N. Kim⁸², J. Kim,⁸² J. Lee⁸², S. W. Lee⁸², C. S. Moon⁸², Y. D. Oh⁸², S. I. Pak⁸², M. S. Ryu⁸², S. Sekmen⁸²,
 Y. C. Yang⁸², H. Kim⁸³, D. H. Moon⁸³, E. Asilar⁸⁴, T. J. Kim⁸⁴, J. Park⁸⁴, S. Choi⁸⁵, S. Han,⁸⁵ B. Hong⁸⁵,
 K. Lee⁸⁵, K. S. Lee⁸⁵, J. Lim,⁸⁵ J. Park⁸⁵, S. K. Park,⁸⁵ J. Yoo⁸⁵, J. Goh⁸⁶, H. S. Kim⁸⁷, Y. Kim,⁸⁷ S. Lee,⁸⁷
 J. Almond,⁸⁸ J. H. Bhyun,⁸⁸ J. Choi⁸⁸, S. Jeon⁸⁸, W. Jun⁸⁸, J. Kim⁸⁸, J. Kim⁸⁸, J. S. Kim,⁸⁸ S. Ko⁸⁸, H. Kwon⁸⁸,
 H. Lee⁸⁸, J. Lee⁸⁸, S. Lee,⁸⁸ B. H. Oh⁸⁸, M. Oh⁸⁸, S. B. Oh⁸⁸, H. Seo⁸⁸, U. K. Yang,⁸⁸ I. Yoon⁸⁸, W. Jang⁸⁹,
 D. Y. Kang,⁸⁹ Y. Kang⁸⁹, D. Kim⁸⁹, S. Kim⁸⁹, B. Ko,⁸⁹ J. S. H. Lee⁸⁹, Y. Lee⁸⁹, J. A. Merlin,⁸⁹ I. C. Park⁸⁹,
 Y. Roh,⁸⁹ D. Song,⁸⁹ I. J. Watson⁸⁹, S. Yang⁸⁹, S. Ha⁹⁰, H. D. Yoo⁹⁰, M. Choi⁹¹, M. R. Kim⁹¹, H. Lee⁹¹,
 Y. Lee⁹¹, Y. Lee⁹¹, I. Yu⁹¹, T. Beyrouthy,⁹² Y. Maghrbi⁹², K. Dreimanis⁹³, A. Gaile⁹³, A. Potrebko⁹³,
 M. Seidel⁹³, T. Torims⁹³, V. Veckalns⁹³, M. Ambrozias⁹⁴, A. Carvalho Antunes De Oliveira⁹⁴, A. Juodagalvis⁹⁴,
 A. Rinkevicius⁹⁴, G. Tamulaitis⁹⁴, N. Bin Norjoharuddeen⁹⁵, S. Y. Hoh^{95,bbb}, I. Yusuff^{95,bbb}, Z. Zolkapli,⁹⁵
 J. F. Benitez⁹⁶, A. Castaneda Hernandez⁹⁶, H. A. Encinas Acosta,⁹⁶ L. G. Gallegos Maríñez,⁹⁶ M. León Coello⁹⁶,
 J. A. Murillo Quijada⁹⁶, A. Sehrawat⁹⁶, L. Valencia Palomo⁹⁶, G. Ayala⁹⁷, H. Castilla-Valdez⁹⁷,
 I. Heredia-De La Cruz^{97,ccc}, R. Lopez-Fernandez⁹⁷, C. A. Mondragon Herrera,⁹⁷ D. A. Perez Navarro⁹⁷,
 A. Sánchez Hernández⁹⁷, C. Oropeza Barrera⁹⁸, F. Vazquez Valencia⁹⁸, I. Pedraza⁹⁹, H. A. Salazar Ibarguen⁹⁹,
 C. Uribe Estrada⁹⁹, I. Bubanja,¹⁰⁰ J. Mijuskovic^{100,ddd}, N. Raicevic¹⁰⁰, A. Ahmad¹⁰¹, M. I. Asghar,¹⁰¹ A. Awais¹⁰¹,
 M. I. M. Awan,¹⁰¹ M. Gul¹⁰¹, H. R. Hoorani,¹⁰¹ W. A. Khan¹⁰¹, M. Shoaib¹⁰¹, M. Waqas¹⁰¹, V. Avati,¹⁰²
 L. Grzanka¹⁰², M. Malawski¹⁰², H. Bialkowska¹⁰³, M. Bluj¹⁰³, B. Boimska¹⁰³, M. Górski¹⁰³, M. Kazana¹⁰³,
 M. Sziper¹⁰³, P. Zalewski¹⁰³, K. Bunkowski¹⁰⁴, K. Doroba¹⁰⁴, A. Kalinowski¹⁰⁴, M. Konecki¹⁰⁴,
 J. Krolkowski¹⁰⁴, M. Araujo¹⁰⁵, P. Bargassa¹⁰⁵, D. Bastos¹⁰⁵, A. Boletti¹⁰⁵, P. Faccioli¹⁰⁵, M. Gallinaro¹⁰⁵,
 J. Hollar¹⁰⁵, N. Leonardo¹⁰⁵, T. Niknejad¹⁰⁵, M. Pisano¹⁰⁵, J. Seixas¹⁰⁵, J. Varela¹⁰⁵, P. Adzic^{106,eee},
 M. Dordevic¹⁰⁶, P. Milenovic¹⁰⁶, J. Milosevic¹⁰⁶, M. Aguilar-Benitez,¹⁰⁷ J. Alcaraz Maestre¹⁰⁷,
 A. Álvarez Fernández¹⁰⁷, M. Barrio Luna,¹⁰⁷ Cristina F. Bedoya¹⁰⁷, C. A. Carrillo Montoya¹⁰⁷, M. Cepeda¹⁰⁷,
 M. Cerrada¹⁰⁷, N. Colino¹⁰⁷, B. De La Cruz¹⁰⁷, A. Delgado Peris¹⁰⁷, D. Fernández Del Val¹⁰⁷,
 J. P. Fernández Ramos¹⁰⁷, J. Flix¹⁰⁷, M. C. Fouz¹⁰⁷, O. Gonzalez Lopez¹⁰⁷, S. Goy Lopez¹⁰⁷, J. M. Hernandez¹⁰⁷,
 M. I. Josa¹⁰⁷, J. León Holgado¹⁰⁷, D. Moran¹⁰⁷, C. Perez Dengra¹⁰⁷, A. Pérez-Calero Yzquierdo¹⁰⁷,
 J. Puerta Pelayo¹⁰⁷, I. Redondo¹⁰⁷, D. D. Redondo Ferrero¹⁰⁷, L. Romero,¹⁰⁷ S. Sánchez Navas¹⁰⁷, J. Sastre¹⁰⁷,
 L. Urda Gómez¹⁰⁷, J. Vazquez Escobar¹⁰⁷, C. Willmott,¹⁰⁷ J. F. de Trocóniz¹⁰⁸, B. Alvarez Gonzalez¹⁰⁹,
 J. Cuevas¹⁰⁹, J. Fernandez Menendez¹⁰⁹, S. Folgueras¹⁰⁹, I. Gonzalez Caballero¹⁰⁹, J. R. González Fernández¹⁰⁹,
 E. Palencia Cortezon¹⁰⁹, C. Ramón Álvarez¹⁰⁹, V. Rodríguez Bouza¹⁰⁹, A. Soto Rodríguez¹⁰⁹, A. Trapote¹⁰⁹,
 C. Vico Villalba¹⁰⁹, J. A. Brochero Cifuentes¹¹⁰, I. J. Cabrillo¹¹⁰, A. Calderon¹¹⁰, J. Duarte Campderros¹¹⁰,
 M. Fernandez¹¹⁰, C. Fernandez Madrazo¹¹⁰, A. García Alonso,¹¹⁰ G. Gomez¹¹⁰, C. Lasiosa García¹¹⁰,
 C. Martinez Rivero¹¹⁰, P. Martinez Ruiz del Arbol¹¹⁰, F. Matorras¹¹⁰, P. Matorras Cuevas¹¹⁰, J. Piedra Gomez¹¹⁰,
 C. Prieels,¹¹⁰ A. Ruiz-Jimeno¹¹⁰, L. Scodellaro¹¹⁰, I. Vila¹¹⁰, J. M. Vizan Garcia¹¹⁰, M. K. Jayananda¹¹¹,
 B. Kailasapathy^{111,fff}, D. U. J. Sonnadara¹¹¹, D. D. C. Wickramaratna¹¹¹, W. G. D. Dharmaratna¹¹²,
 K. Liyanage¹¹², N. Perera¹¹², N. Wickramage¹¹², D. Abbaneo¹¹³, J. Alimena¹¹³, E. Auffray¹¹³, G. Auzinger¹¹³,
 J. Baechler,¹¹³ P. Baillon,^{113,a} D. Barney¹¹³, J. Bendavid¹¹³, M. Bianco¹¹³, B. Bilin¹¹³, A. Bocci¹¹³,
 E. Brondolin¹¹³, C. Caillol¹¹³, T. Camporesi¹¹³, G. Cerminara¹¹³, N. Chernyavskaya¹¹³, S. S. Chhibra¹¹³,
 S. Choudhury,¹¹³ M. Cipriani¹¹³, L. Cristella¹¹³, D. d'Enterria¹¹³, A. Dabrowski¹¹³, A. David¹¹³, A. De Roeck¹¹³,
 M. M. Defranchis¹¹³, M. Deile¹¹³, M. Dobson¹¹³, M. Dünser¹¹³, N. Dupont,¹¹³ A. Elliott-Peisert,¹¹³
 F. Fallavollita,^{113,ggg} A. Florent¹¹³, L. Forthomme¹¹³, G. Franzoni¹¹³, W. Funk¹¹³, S. Ghosh¹¹³, S. Giani,¹¹³
 D. Gigi,¹¹³ K. Gill¹¹³, F. Glege¹¹³, L. Gouskos¹¹³, E. Govorkova¹¹³, M. Haranko¹¹³, J. Hegeman¹¹³,
 V. Innocente¹¹³, T. James¹¹³, P. Janot¹¹³, J. Kaspar¹¹³, J. Kieseler¹¹³, N. Kratochwil¹¹³, S. Laurila¹¹³,
 P. Lecoq¹¹³, E. Leutgeb¹¹³, A. Lintuluoto¹¹³, C. Lourenço¹¹³, B. Maier¹¹³, L. Malgeri¹¹³, M. Mannelli¹¹³,
 A. C. Marini¹¹³, F. Meijers¹¹³, S. Mersi¹¹³, E. Meschi¹¹³, F. Moortgat¹¹³, M. Mulders¹¹³, S. Orfanelli,¹¹³
 L. Orsini,¹¹³ F. Pantaleo¹¹³, E. Perez,¹¹³ M. Peruzzi¹¹³, A. Petrilli¹¹³, G. Petrucciani¹¹³, A. Pfeiffer¹¹³,
 M. Pierini¹¹³, D. Piparo¹¹³, M. Pitt¹¹³, H. Qu¹¹³, T. Quast,¹¹³ D. Rabaday¹¹³, A. Racz,¹¹³ G. Reales Gutiérrez,¹¹³
 M. Rovere¹¹³, H. Sakulin¹¹³, J. Salfeld-Nebgen¹¹³, S. Scarfi¹¹³, M. Selvaggi¹¹³, A. Sharma¹¹³, P. Silva¹¹³,
 P. Sphicas^{113,hhh}, A. G. Stahl Leitner¹¹³, S. Summers¹¹³, K. Tatar¹¹³, V. R. Tavolaro¹¹³, D. Treille¹¹³, P. Tropea¹¹³,
 A. Tsirou,¹¹³ J. Wanczyk^{113,iii}, K. A. Wozniak¹¹³, W. D. Zeuner,¹¹³ L. Caminada^{114,jjj}, A. Ebrahimi¹¹⁴

W. Erdmann¹¹⁴ R. Horisberger¹¹⁴ Q. Ingram¹¹⁴ H. C. Kaestli¹¹⁴ D. Kotlinski¹¹⁴ C. Lange¹¹⁴
M. Missiroli^{114,iii} L. Noehte^{114,iii} T. Rohe¹¹⁴ T. K. Aarrestad¹¹⁵ K. Androsov^{115,iii} M. Backhaus¹¹⁵ P. Berger¹¹⁵
A. Calandri¹¹⁵ K. Datta¹¹⁵ A. De Cosa¹¹⁵ G. Dissertori¹¹⁵ M. Dittmar¹¹⁵ M. Donegà¹¹⁵ F. Eble¹¹⁵
M. Galli¹¹⁵ K. Gedia¹¹⁵ F. Glessgen¹¹⁵ T. A. Gómez Espinosa¹¹⁵ C. Grab¹¹⁵ D. Hits¹¹⁵ W. Luster¹¹⁵
A.-M. Lyon¹¹⁵ R. A. Manzoni¹¹⁵ L. Marchese¹¹⁵ C. Martin Perez¹¹⁵ A. Mascellani^{115,iii} M. T. Meinhard¹¹⁵
F. Nessi-Tedaldi¹¹⁵ J. Niedziela¹¹⁵ F. Pauss¹¹⁵ V. Perovic¹¹⁵ S. Pigazzini¹¹⁵ M. G. Ratti¹¹⁵ M. Reichmann¹¹⁵
C. Reissel¹¹⁵ T. Reitenspiess¹¹⁵ B. Ristic¹¹⁵ F. Riti¹¹⁵ D. Ruini¹¹⁵ D. A. Sanz Becerra¹¹⁵ J. Steggemann^{115,iii}
D. Valsecchi^{115,bb} R. Wallny¹¹⁵ C. Amsler^{116,kkk} P. Bärtzsch¹¹⁶ C. Botta¹¹⁶ D. Brzhechko¹¹⁶ M. F. Canelli¹¹⁶
K. Cormier¹¹⁶ A. De Wit¹¹⁶ R. Del Burgo¹¹⁶ J. K. Heikkilä¹¹⁶ M. Huwiler¹¹⁶ W. Jin¹¹⁶ A. Jofrehei¹¹⁶
B. Kilminster¹¹⁶ S. Leontsinis¹¹⁶ S. P. Liechti¹¹⁶ A. Macchiolo¹¹⁶ P. Meiring¹¹⁶ V. M. Mikuni¹¹⁶
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K. F. Chen¹¹⁸ P. s. Chen¹¹⁸ H. Cheng¹¹⁸ W.-S. Hou¹¹⁸ R. Khurana¹¹⁸ Y. y. Li¹¹⁸ R.-S. Lu¹¹⁸ E. Paganis¹¹⁸
A. Psallidas¹¹⁸ A. Steen¹¹⁸ H. y. Wu¹¹⁸ E. Yazgan¹¹⁸ P. r. Yu¹¹⁸ C. Asawatangtrakuldee¹¹⁹ N. Srimanobhas¹¹⁹
D. Agyel¹²⁰ F. Boran¹²⁰ Z. S. Demiroglu¹²⁰ F. Dolek¹²⁰ I. Dumanoglu^{120,mmm} E. Eskut¹²⁰ Y. Guler^{120,nnn}
E. Gurpinar Guler^{120,nnn} C. Isik¹²⁰ O. Kara¹²⁰ A. Kayis Topaksu¹²⁰ U. Kiminsu¹²⁰ G. Onengut¹²⁰
K. Ozdemir^{120,ooo} A. Polatoz¹²⁰ A. E. Simsek¹²⁰ B. Tali^{120,ppp} U. G. Tok¹²⁰ S. Turkcapar¹²⁰ E. Uslan¹²⁰
I. S. Zorbakir¹²⁰ G. Karapinar^{121,qqq} K. Ocalan^{121,rrr} M. Yalvac^{121,sss} B. Akgun¹²² I. O. Atakisi¹²²
E. Gülmez¹²² M. Kaya^{122,ttt} O. Kaya^{122,uuu} Ö. Özçelik¹²² S. Tekten^{122,vvv} A. Cakir¹²³ K. Cankocak^{123,mmm}
Y. Komurcu¹²³ S. Sen^{123,mmm} O. Aydılek¹²⁴ S. Cerci^{124,ppp} B. Hacıahinoglu¹²⁴ I. Hos^{124,www}
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L. Levchuk¹²⁶ D. Anthony¹²⁷ E. Bhal¹²⁷ J. J. Brooke¹²⁷ A. Bundock¹²⁷ E. Clement¹²⁷ D. Cussans¹²⁷
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S. Paramesvaran¹²⁷ S. Seif El Nasr-Storey¹²⁷ V. J. Smith¹²⁷ N. Stylianou^{127,yyy} K. Walkingshaw Pass¹²⁷
R. White¹²⁷ A. H. Ball¹²⁸ K. W. Bell¹²⁸ A. Belyaev^{128,zzz} C. Brew¹²⁸ R. M. Brown¹²⁸ D. J. A. Cockerill¹²⁸
C. Cooke¹²⁸ K. V. Ellis¹²⁸ K. Harder¹²⁸ S. Harper¹²⁸ M.-L. Holmberg^{128,aaaa} J. Linacre¹²⁸ K. Manolopoulos¹²⁸
D. M. Newbold¹²⁸ E. Olaiya¹²⁸ D. Petyt¹²⁸ T. Reis¹²⁸ G. Salvi¹²⁸ T. Schuh¹²⁸
C. H. Shepherd-Themistocleous¹²⁸ I. R. Tomalin¹²⁸ T. Williams¹²⁸ R. Bainbridge¹²⁹ P. Bloch¹²⁹
S. Bonomally¹²⁹ J. Borg¹²⁹ S. Breeze¹²⁹ C. E. Brown¹²⁹ O. Buchmuller¹²⁹ V. Cacchio¹²⁹ V. Cepaitis¹²⁹
G. S. Chahal^{129,bbbb} D. Colling¹²⁹ J. S. Dancu¹²⁹ P. Dauncey¹²⁹ G. Davies¹²⁹ J. Davies¹²⁹ M. Della Negra¹²⁹
S. Fayer¹²⁹ G. Fedi¹²⁹ G. Hall¹²⁹ M. H. Hassanshahi¹²⁹ A. Howard¹²⁹ G. Iles¹²⁹ J. Langford¹²⁹ L. Lyons¹²⁹
A.-M. Magnan¹²⁹ S. Malik¹²⁹ A. Martelli¹²⁹ M. Mieskolainen¹²⁹ D. G. Monk¹²⁹ J. Nash¹²⁹ M. Pesaresi¹²⁹
B. C. Radburn-Smith¹²⁹ D. M. Raymond¹²⁹ A. Richards¹²⁹ A. Rose¹²⁹ E. Scott¹²⁹ C. Seez¹²⁹ A. Shtipliyski¹²⁹
R. Shukla¹²⁹ A. Tapper¹²⁹ K. Uchida¹²⁹ G. P. Uttley¹²⁹ L. H. Vage¹²⁹ T. Virdee^{129,bb} M. Vojinovic¹²⁹
N. Wardle¹²⁹ S. N. Webb¹²⁹ D. Winterbottom¹²⁹ K. Coldham¹³⁰ J. E. Cole¹³⁰ A. Khan¹³⁰ P. Kyberd¹³⁰
I. D. Reid¹³⁰ S. Abdullin¹³¹ A. Brinkerhoff¹³¹ B. Caraway¹³¹ J. Dittmann¹³¹ K. Hatakeyama¹³¹
A. R. Kanuganti¹³¹ B. McMaster¹³¹ M. Saunders¹³¹ S. Sawant¹³¹ C. Sutantawibul¹³¹ J. Wilson¹³¹
R. Bartek¹³² A. Dominguez¹³² R. Uniyal¹³² A. M. Vargas Hernandez¹³² A. Buccilli¹³³ S. I. Cooper¹³³
D. Di Croce¹³³ S. V. Gleyzer¹³³ C. Henderson¹³³ C. U. Perez¹³³ P. Rumerio^{133,dddd} C. West¹³³ A. Akpinar¹³⁴
A. Albert¹³⁴ D. Arcaro¹³⁴ C. Cosby¹³⁴ Z. Demiragli¹³⁴ C. Erice¹³⁴ E. Fontanesi¹³⁴ D. Gastler¹³⁴
S. May¹³⁴ J. Rohlf¹³⁴ K. Salyer¹³⁴ D. Sperka¹³⁴ D. Spitzbart¹³⁴ I. Suarez¹³⁴ A. Tsatsos¹³⁴ S. Yuan¹³⁴
G. Benelli¹³⁵ B. Burkley¹³⁵ X. Coubez^{135,x} D. Cutts¹³⁵ M. Hadley¹³⁵ U. Heintz¹³⁵ J. M. Hogan^{135,eeee}
T. Kwon¹³⁵ G. Landsberg¹³⁵ K. T. Lau¹³⁵ D. Li¹³⁵ J. Luo¹³⁵ M. Narain¹³⁵ N. Pervan¹³⁵ S. Sagir^{135,fff}
F. Simpson¹³⁵ E. Usai¹³⁵ W. Y. Wong¹³⁵ X. Yan¹³⁵ D. Yu¹³⁵ W. Zhang¹³⁵ J. Bonilla¹³⁶ C. Brainerd¹³⁶
R. Breedon¹³⁶ M. Calderon De La Barca Sanchez¹³⁶ M. Chertok¹³⁶ J. Conway¹³⁶ P. T. Cox¹³⁶ R. Erbacher¹³⁶
G. Haza¹³⁶ F. Jensen¹³⁶ O. Kukral¹³⁶ G. Mocellin¹³⁶ M. Mulhearn¹³⁶ D. Pellett¹³⁶ B. Regnery¹³⁶
D. Taylor¹³⁶ Y. Yao¹³⁶ F. Zhang¹³⁶ M. Bachtis¹³⁷ R. Cousins¹³⁷ A. Datta¹³⁷ D. Hamilton¹³⁷ J. Hauser¹³⁷
M. Ignatenko¹³⁷ M. A. Iqbal¹³⁷ T. Lam¹³⁷ E. Manca¹³⁷ W. A. Nash¹³⁷ S. Regnard¹³⁷ D. Saltzberg¹³⁷
B. Stone¹³⁷ V. Valuev¹³⁷ Y. Chen¹³⁸ R. Clare¹³⁸ J. W. Gary¹³⁸ M. Gordon¹³⁸ G. Hanson¹³⁸ G. Karapostoli¹³⁸

O. R. Long¹³⁸, N. Manganello¹³⁸, W. Si¹³⁸, S. Wimpenny¹³⁸, J. G. Branson¹³⁹, P. Chang¹³⁹, S. Cittolin¹³⁹, S. Cooperstein¹³⁹, D. Diaz¹³⁹, J. Duarte¹³⁹, R. Gerosa¹³⁹, L. Giannini¹³⁹, J. Guiang¹³⁹, R. Kansal¹³⁹, V. Krutelyov¹³⁹, R. Lee¹³⁹, J. Letts¹³⁹, M. Masciovecchio¹³⁹, F. Mokhtar¹³⁹, M. Pieri¹³⁹, B. V. Sathia Narayanan¹³⁹, V. Sharma¹³⁹, M. Tadel¹³⁹, F. Würthwein¹³⁹, Y. Xiang¹³⁹, A. Yagil¹³⁹, N. Amin¹⁴⁰, C. Campagnari¹⁴⁰, M. Citron¹⁴⁰, G. Collura¹⁴⁰, A. Dorsett¹⁴⁰, V. Dutta¹⁴⁰, J. Incandela¹⁴⁰, M. Kilpatrick¹⁴⁰, J. Kim¹⁴⁰, A. J. Li¹⁴⁰, P. Masterson¹⁴⁰, H. Mei¹⁴⁰, M. Oshiro¹⁴⁰, M. Quinnan¹⁴⁰, J. Richman¹⁴⁰, U. Sarica¹⁴⁰, R. Schmitz¹⁴⁰, F. Setti¹⁴⁰, J. Sheplock¹⁴⁰, P. Siddireddy¹⁴⁰, D. Stuart¹⁴⁰, S. Wang¹⁴⁰, A. Bornheim¹⁴¹, O. Cerri¹⁴¹, I. Dutta¹⁴¹, J. M. Lawhorn¹⁴¹, N. Lu¹⁴¹, J. Mao¹⁴¹, H. B. Newman¹⁴¹, T. Q. Nguyen¹⁴¹, M. Spiropulu¹⁴¹, J. R. Vlimant¹⁴¹, C. Wang¹⁴¹, S. Xie¹⁴¹, R. Y. Zhu¹⁴¹, J. Alison¹⁴², S. An¹⁴², M. B. Andrews¹⁴², P. Bryant¹⁴², T. Ferguson¹⁴², A. Harilal¹⁴², C. Liu¹⁴², T. Mudholkar¹⁴², S. Murthy¹⁴², M. Paulini¹⁴², A. Roberts¹⁴², A. Sanchez¹⁴², W. Terrill¹⁴², J. P. Cumalat¹⁴³, W. T. Ford¹⁴³, A. Hassani¹⁴³, G. Karathanasis¹⁴³, E. MacDonald¹⁴³, F. Marini¹⁴³, R. Patel¹⁴³, A. Perloff¹⁴³, C. Savard¹⁴³, N. Schonbeck¹⁴³, K. Stenson¹⁴³, K. A. Ulmer¹⁴³, S. R. Wagner¹⁴³, N. Zipper¹⁴³, J. Alexander¹⁴⁴, S. Bright-Thonney¹⁴⁴, X. Chen¹⁴⁴, D. J. Cranshaw¹⁴⁴, J. Fan¹⁴⁴, X. Fan¹⁴⁴, D. Gadkari¹⁴⁴, S. Hogan¹⁴⁴, J. Monroy¹⁴⁴, J. R. Patterson¹⁴⁴, D. Quach¹⁴⁴, J. Reichert¹⁴⁴, M. Reid¹⁴⁴, A. Ryd¹⁴⁴, J. Thom¹⁴⁴, P. Wittich¹⁴⁴, R. Zou¹⁴⁴, M. Albrow¹⁴⁵, M. Alyari¹⁴⁵, G. Apollinari¹⁴⁵, A. Apresyan¹⁴⁵, L. A. T. Bauerdick¹⁴⁵, D. Berry¹⁴⁵, J. Berryhill¹⁴⁵, P. C. Bhat¹⁴⁵, K. Burkett¹⁴⁵, J. N. Butler¹⁴⁵, A. Canepa¹⁴⁵, G. B. Cerati¹⁴⁵, H. W. K. Cheung¹⁴⁵, F. Chlebana¹⁴⁵, K. F. Di Petrillo¹⁴⁵, J. Dickinson¹⁴⁵, V. D. Elvira¹⁴⁵, Y. Feng¹⁴⁵, J. Freeman¹⁴⁵, A. Gandrakota¹⁴⁵, Z. Gece¹⁴⁵, L. Gray¹⁴⁵, D. Green¹⁴⁵, S. Grünendahl¹⁴⁵, O. Gutsche¹⁴⁵, R. M. Harris¹⁴⁵, R. Heller¹⁴⁵, T. C. Herwig¹⁴⁵, J. Hirschauer¹⁴⁵, L. Horyn¹⁴⁵, B. Jayatilaka¹⁴⁵, S. Jindariani¹⁴⁵, M. Johnson¹⁴⁵, U. Joshi¹⁴⁵, T. Klijnsma¹⁴⁵, B. Klima¹⁴⁵, K. H. M. Kwok¹⁴⁵, S. Lammel¹⁴⁵, D. Lincoln¹⁴⁵, R. Lipton¹⁴⁵, T. Liu¹⁴⁵, C. Madrid¹⁴⁵, K. Maeshima¹⁴⁵, C. Mantilla¹⁴⁵, D. Mason¹⁴⁵, P. McBride¹⁴⁵, P. Merkel¹⁴⁵, S. Mrenna¹⁴⁵, S. Nahn¹⁴⁵, J. Ngadiuba¹⁴⁵, D. Noonan¹⁴⁵, V. Papadimitriou¹⁴⁵, N. Pastika¹⁴⁵, K. Pedro¹⁴⁵, C. Pena¹⁴⁵, F. Ravera¹⁴⁵, A. Reinsvold Hall¹⁴⁵, L. Ristori¹⁴⁵, E. Sexton-Kennedy¹⁴⁵, N. Smith¹⁴⁵, A. Soha¹⁴⁵, L. Spiegel¹⁴⁵, J. Strait¹⁴⁵, L. Taylor¹⁴⁵, S. Tkaczyk¹⁴⁵, N. V. Tran¹⁴⁵, L. Uplegger¹⁴⁵, E. W. Vaandering¹⁴⁵, H. A. Weber¹⁴⁵, I. Zoi¹⁴⁵, P. Avery¹⁴⁶, D. Bourilkov¹⁴⁶, L. Cadamuro¹⁴⁶, V. Cherepanov¹⁴⁶, R. D. Field¹⁴⁶, D. Guerrero¹⁴⁶, M. Kim¹⁴⁶, E. Koenig¹⁴⁶, J. Konigsberg¹⁴⁶, A. Korytov¹⁴⁶, K. H. Lo¹⁴⁶, K. Matchev¹⁴⁶, N. Menendez¹⁴⁶, G. Mitselmakher¹⁴⁶, A. Muthirakalayil Madhu¹⁴⁶, N. Rawal¹⁴⁶, D. Rosenzweig¹⁴⁶, S. Rosenzweig¹⁴⁶, K. Shi¹⁴⁶, J. Wang¹⁴⁶, Z. Wu¹⁴⁶, T. Adams¹⁴⁷, A. Askew¹⁴⁷, R. Habibullah¹⁴⁷, V. Hagopian¹⁴⁷, T. Kolberg¹⁴⁷, G. Martinez¹⁴⁷, H. Prosper¹⁴⁷, C. Schiber¹⁴⁷, O. Viazlo¹⁴⁷, R. Yohay¹⁴⁷, J. Zhang¹⁴⁷, M. M. Baarmand¹⁴⁸, S. Butalla¹⁴⁸, T. Elkafrawy^{148,q}, M. Hohlmann¹⁴⁸, R. Kumar Verma¹⁴⁸, M. Rahmani¹⁴⁸, F. Yumiceva¹⁴⁸, M. R. Adams¹⁴⁹, H. Becerril Gonzalez¹⁴⁹, R. Cavanaugh¹⁴⁹, S. Dittmer¹⁴⁹, O. Evdokimov¹⁴⁹, C. E. Gerber¹⁴⁹, D. J. Hofman¹⁴⁹, D. S. Lemos¹⁴⁹, A. H. Merrit¹⁴⁹, C. Mills¹⁴⁹, G. Oh¹⁴⁹, T. Roy¹⁴⁹, S. Rudrabhatla¹⁴⁹, M. B. Tonjes¹⁴⁹, N. Varelas¹⁴⁹, X. Wang¹⁴⁹, Z. Ye¹⁴⁹, J. Yoo¹⁴⁹, M. Alhousseini¹⁵⁰, K. Dilsiz^{150,iii}, L. Emediato¹⁵⁰, R. P. Gandrajula¹⁵⁰, G. Karaman¹⁵⁰, O. K. Köseyan¹⁵⁰, J.-P. Merlo¹⁵⁰, A. Mestvirishvili^{150,iiij}, J. Nachtman¹⁵⁰, O. Neogi¹⁵⁰, H. Ogul^{150,kkkk}, Y. Onel¹⁵⁰, A. Penzo¹⁵⁰, C. Snyder¹⁵⁰, E. Tiras^{150,liii}, O. Amram¹⁵¹, B. Blumenfeld¹⁵¹, L. Corcodilos¹⁵¹, J. Davis¹⁵¹, A. V. Gritsan¹⁵¹, L. Kang¹⁵¹, S. Kyriacou¹⁵¹, P. Maksimovic¹⁵¹, J. Roskes¹⁵¹, S. Sekhar¹⁵¹, M. Swartz¹⁵¹, T. Á. Vami¹⁵¹, A. Abreu¹⁵², L. F. Alcerro Alcerro¹⁵², J. Anguiano¹⁵², P. Baringer¹⁵², A. Bean¹⁵², Z. Flowers¹⁵², T. Isidori¹⁵², S. Khalil¹⁵², J. King¹⁵², G. Krintiras¹⁵², M. Lazarovits¹⁵², C. Le Mahieu¹⁵², C. Lindsey¹⁵², J. Marquez¹⁵², N. Minafra¹⁵², M. Murray¹⁵², M. Nickel¹⁵², C. Rogan¹⁵², C. Royon¹⁵², R. Salvatico¹⁵², S. Sanders¹⁵², C. Smith¹⁵², Q. Wang¹⁵², J. Williams¹⁵², G. Wilson¹⁵², B. Allmond¹⁵³, S. Duric¹⁵³, R. Gujju Gurunadha¹⁵³, A. Ivanov¹⁵³, K. Kaadze¹⁵³, D. Kim¹⁵³, Y. Maravin¹⁵³, T. Mitchell¹⁵³, A. Modak¹⁵³, K. Nam¹⁵³, J. Natoli¹⁵³, D. Roy¹⁵³, F. Rebassoo¹⁵⁴, D. Wright¹⁵⁴, E. Adams¹⁵⁵, A. Baden¹⁵⁵, O. Baron¹⁵⁵, A. Belloni¹⁵⁵, A. Bethani¹⁵⁵, S. C. Eno¹⁵⁵, N. J. Hadley¹⁵⁵, S. Jabeen¹⁵⁵, R. G. Kellogg¹⁵⁵, T. Koeth¹⁵⁵, Y. Lai¹⁵⁵, S. Lascio¹⁵⁵, A. C. Mignerey¹⁵⁵, S. Nabili¹⁵⁵, C. Palmer¹⁵⁵, C. Papageorgakis¹⁵⁵, L. Wang¹⁵⁵, K. Wong¹⁵⁵, D. Abercrombie¹⁵⁶, W. Busza¹⁵⁶, I. A. Cali¹⁵⁶, Y. Chen¹⁵⁶, M. D'Alfonso¹⁵⁶, J. Eysermans¹⁵⁶, C. Freer¹⁵⁶, G. Gomez-Ceballos¹⁵⁶, M. Goncharov¹⁵⁶, P. Harris¹⁵⁶, M. Hu¹⁵⁶, D. Kovalskiy¹⁵⁶, J. Krupa¹⁵⁶, Y.-J. Lee¹⁵⁶, K. Long¹⁵⁶, C. Mironov¹⁵⁶, C. Paus¹⁵⁶, D. Rankin¹⁵⁶, C. Roland¹⁵⁶, G. Roland¹⁵⁶, Z. Shi¹⁵⁶, G. S. F. Stephans¹⁵⁶, J. Wang¹⁵⁶, Z. Wang¹⁵⁶, B. Wyslouch¹⁵⁶, R. M. Chatterjee¹⁵⁷

B. Crossman¹⁵⁷, A. Evans¹⁵⁷, J. Hiltbrand¹⁵⁷, Sh. Jain¹⁵⁷, B. M. Joshi¹⁵⁷, C. Kapsiak¹⁵⁷, M. Krohn¹⁵⁷, Y. Kubota¹⁵⁷, J. Mans¹⁵⁷, M. Reverting¹⁵⁷, R. Rusack¹⁵⁷, R. Saradhy¹⁵⁷, N. Schroeder¹⁵⁷, N. Strobbe¹⁵⁷, M. A. Wadud¹⁵⁷, L. M. Cremaldi¹⁵⁸, K. Bloom¹⁵⁹, M. Bryson¹⁵⁹, D. R. Claes¹⁵⁹, C. Fangmeier¹⁵⁹, L. Finco¹⁵⁹, F. Golf¹⁵⁹, C. Joo¹⁵⁹, I. Kravchenko¹⁵⁹, I. Reed¹⁵⁹, J. E. Siado¹⁵⁹, G. R. Snow^{159,a}, W. Tabb¹⁵⁹, A. Wightman¹⁵⁹, F. Yan¹⁵⁹, A. G. Zecchinelli¹⁵⁹, G. Agarwal¹⁶⁰, H. Bandyopadhyay¹⁶⁰, L. Hay¹⁶⁰, I. Iashvili¹⁶⁰, A. Kharchilava¹⁶⁰, C. McLean¹⁶⁰, M. Morris¹⁶⁰, D. Nguyen¹⁶⁰, J. Pekkanen¹⁶⁰, S. Rappoccio¹⁶⁰, A. Williams¹⁶⁰, G. Alverson¹⁶¹, E. Barberis¹⁶¹, Y. Haddad¹⁶¹, Y. Han¹⁶¹, A. Krishna¹⁶¹, J. Li¹⁶¹, J. Lidrych¹⁶¹, G. Madigan¹⁶¹, B. Marzocchi¹⁶¹, D. M. Morse¹⁶¹, V. Nguyen¹⁶¹, T. Orimoto¹⁶¹, A. Parker¹⁶¹, L. Skinnari¹⁶¹, A. Tishelman-Charny¹⁶¹, T. Wamorkar¹⁶¹, B. Wang¹⁶¹, A. Wisecarver¹⁶¹, D. Wood¹⁶¹, S. Bhattacharya¹⁶², J. Bueghly¹⁶², Z. Chen¹⁶², A. Gilbert¹⁶², K. A. Hahn¹⁶², Y. Liu¹⁶², N. Odell¹⁶², M. H. Schmitt¹⁶², M. Velasco¹⁶², R. Band¹⁶³, R. Bucci¹⁶³, S. Castells¹⁶³, M. Cremonesi¹⁶³, A. Das¹⁶³, R. Goldouzian¹⁶³, M. Hildreth¹⁶³, K. Hurtado Anampa¹⁶³, C. Jessop¹⁶³, K. Lannon¹⁶³, J. Lawrence¹⁶³, N. Loukas¹⁶³, L. Lutton¹⁶³, J. Mariano¹⁶³, N. Marinelli¹⁶³, I. Mcalister¹⁶³, T. McCauley¹⁶³, C. Mcgrady¹⁶³, K. Mohrman¹⁶³, C. Moore¹⁶³, Y. Musienko^{163,n}, H. Nelson¹⁶³, R. Ruchti¹⁶³, A. Townsend¹⁶³, M. Wayne¹⁶³, H. Yockey¹⁶³, M. Zarucki¹⁶³, L. Zygala¹⁶³, B. Bylsma¹⁶⁴, M. Carrigan¹⁶⁴, L. S. Durkin¹⁶⁴, B. Francis¹⁶⁴, C. Hill¹⁶⁴, A. Lesauvage¹⁶⁴, M. Nunez Ornelas¹⁶⁴, K. Wei¹⁶⁴, B. L. Winer¹⁶⁴, B. R. Yates¹⁶⁴, F. M. Addesa¹⁶⁵, P. Das¹⁶⁵, G. Dezoort¹⁶⁵, P. Elmer¹⁶⁵, A. Frankenthal¹⁶⁵, B. Greenberg¹⁶⁵, N. Haubrich¹⁶⁵, S. Higginbotham¹⁶⁵, A. Kalogeropoulos¹⁶⁵, G. Kopp¹⁶⁵, S. Kwan¹⁶⁵, D. Lange¹⁶⁵, D. Marlow¹⁶⁵, K. Mei¹⁶⁵, I. Ojalvo¹⁶⁵, J. Olsen¹⁶⁵, D. Stickland¹⁶⁵, C. Tully¹⁶⁵, S. Malik¹⁶⁶, S. Norberg¹⁶⁶, A. S. Bakshi¹⁶⁷, V. E. Barnes¹⁶⁷, R. Chawla¹⁶⁷, S. Das¹⁶⁷, L. Gutay¹⁶⁷, M. Jones¹⁶⁷, A. W. Jung¹⁶⁷, D. Kondratyev¹⁶⁷, A. M. Koshy¹⁶⁷, M. Liu¹⁶⁷, G. Negro¹⁶⁷, N. Neumeister¹⁶⁷, G. Paspalaki¹⁶⁷, S. Piperov¹⁶⁷, A. Purohit¹⁶⁷, J. F. Schulte¹⁶⁷, M. Stojanovic¹⁶⁷, J. Thieman¹⁶⁷, F. Wang¹⁶⁷, R. Xiao¹⁶⁷, W. Xie¹⁶⁷, J. Dolen¹⁶⁸, N. Parashar¹⁶⁸, D. Acosta¹⁶⁹, A. Baty¹⁶⁹, T. Carnahan¹⁶⁹, M. Decaro¹⁶⁹, S. Dildick¹⁶⁹, K. M. Ecklund¹⁶⁹, P. J. Fernández Manteca¹⁶⁹, S. Freed¹⁶⁹, P. Gardner¹⁶⁹, F. J. M. Geurts¹⁶⁹, A. Kumar¹⁶⁹, W. Li¹⁶⁹, B. P. Padley¹⁶⁹, R. Redjimi¹⁶⁹, J. Rotter¹⁶⁹, W. Shi¹⁶⁹, S. Yang¹⁶⁹, E. Yigitbasi¹⁶⁹, L. Zhang^{169,mmmm}, Y. Zhang¹⁶⁹, X. Zuo¹⁶⁹, A. Bodek¹⁷⁰, P. de Barbaro¹⁷⁰, R. Demina¹⁷⁰, J. L. Dulemba¹⁷⁰, C. Fallon¹⁷⁰, T. Ferbel¹⁷⁰, M. Galanti¹⁷⁰, A. Garcia-Bellido¹⁷⁰, O. Hindrichs¹⁷⁰, A. Khukhunaishvili¹⁷⁰, E. Ranken¹⁷⁰, R. Taus¹⁷⁰, G. P. Van Onsem¹⁷⁰, K. Goulios¹⁷¹, B. Chiarito¹⁷², J. P. Chou¹⁷², Y. Gershtein¹⁷², E. Halkiadakis¹⁷², A. Hart¹⁷², M. Heindl¹⁷², D. Jaroslawski¹⁷², O. Karacheban^{172,z}, I. Laflotte¹⁷², A. Lath¹⁷², R. Montalvo¹⁷², K. Nash¹⁷², M. Osherson¹⁷², S. Salur¹⁷², S. Schnetzer¹⁷², S. Somalwar¹⁷², R. Stone¹⁷², S. A. Thayil¹⁷², S. Thomas¹⁷², H. Wang¹⁷², H. Acharya¹⁷³, A. G. Delannoy¹⁷³, S. Fiorendi¹⁷³, T. Holmes¹⁷³, E. Nibigira¹⁷³, S. Spanier¹⁷³, O. Bouhali^{174,nnnn}, M. Dalchenko¹⁷⁴, A. Delgado¹⁷⁴, R. Eusebi¹⁷⁴, J. Gilmore¹⁷⁴, T. Huang¹⁷⁴, T. Kamon^{174,oooo}, H. Kim¹⁷⁴, S. Luo¹⁷⁴, S. Malhotra¹⁷⁴, R. Mueller¹⁷⁴, D. Overton¹⁷⁴, D. Rathjens¹⁷⁴, A. Safonov¹⁷⁴, N. Akchurin¹⁷⁵, J. Damgov¹⁷⁵, V. Hegde¹⁷⁵, K. Lamichhane¹⁷⁵, S. W. Lee¹⁷⁵, T. Mengke¹⁷⁵, S. Muthumuni¹⁷⁵, T. Peltola¹⁷⁵, I. Volobouev¹⁷⁵, Z. Wang¹⁷⁵, A. Whitbeck¹⁷⁵, E. Appelt¹⁷⁶, S. Greene¹⁷⁶, A. Gurrola¹⁷⁶, W. Johns¹⁷⁶, A. Melo¹⁷⁶, F. Romeo¹⁷⁶, P. Sheldon¹⁷⁶, S. Tuo¹⁷⁶, J. Velkovska¹⁷⁶, J. Viinikainen¹⁷⁶, B. Cardwell¹⁷⁷, B. Cox¹⁷⁷, G. Cummings¹⁷⁷, J. Hakala¹⁷⁷, R. Hirosky¹⁷⁷, M. Joyce¹⁷⁷, A. Ledovskoy¹⁷⁷, A. Li¹⁷⁷, C. Neu¹⁷⁷, C. E. Perez Lara¹⁷⁷, B. Tannenwald¹⁷⁷, P. E. Karchin¹⁷⁸, N. Poudyal¹⁷⁸, S. Banerjee¹⁷⁹, K. Black¹⁷⁹, T. Bose¹⁷⁹, S. Dasu¹⁷⁹, I. De Bruyn¹⁷⁹, P. Everaerts¹⁷⁹, C. Galloni¹⁷⁹, H. He¹⁷⁹, M. Herndon¹⁷⁹, A. Herve¹⁷⁹, C. K. Koraka¹⁷⁹, A. Lanaro¹⁷⁹, A. Loeliger¹⁷⁹, R. Loveless¹⁷⁹, J. Madhusudanan Sreekala¹⁷⁹, A. Mallampalli¹⁷⁹, A. Mohammadi¹⁷⁹, S. Mondal¹⁷⁹, G. Parida¹⁷⁹, D. Pinna¹⁷⁹, A. Savin¹⁷⁹, V. Shang¹⁷⁹, V. Sharma¹⁷⁹, W. H. Smith¹⁷⁹, D. Teague¹⁷⁹, H. F. Tsoi¹⁷⁹, W. Vetens¹⁷⁹, S. Afanasiev¹⁸⁰, V. Andreev¹⁸⁰, Yu. Andreev¹⁸⁰, T. Aushev¹⁸⁰, M. Azarkin¹⁸⁰, A. Babaev¹⁸⁰, A. Belyaev¹⁸⁰, V. Blinov^{180,n}, E. Boos¹⁸⁰, V. Borshch¹⁸⁰, D. Budkouski¹⁸⁰, V. Bunichev¹⁸⁰, O. Bychkova¹⁸⁰, V. Chekhovsky¹⁸⁰, R. Chistov^{180,n}, M. Danilov^{180,n}, A. Dermenev¹⁸⁰, T. Dimova^{180,n}, I. Dremin¹⁸⁰, M. Dubinin^{180,gggg}, L. Dudko¹⁸⁰, V. Epshteyn¹⁸⁰, A. Ershov¹⁸⁰, G. Gavrillov¹⁸⁰, V. Gavrillov¹⁸⁰, S. Gninenko¹⁸⁰, V. Golovtsov¹⁸⁰, N. Golubev¹⁸⁰, I. Golutvin¹⁸⁰, I. Gorbunov¹⁸⁰, V. Ivanchenko¹⁸⁰, Y. Ivanov¹⁸⁰, V. Kachanov¹⁸⁰, L. Kardapoltsev^{180,n}, V. Karjavine¹⁸⁰, A. Karneyeu¹⁸⁰, V. Kim^{180,n}, M. Kirakosyan¹⁸⁰, D. Kirpichnikov¹⁸⁰, M. Kirsanov¹⁸⁰, V. Klyukhin¹⁸⁰, O. Kodolova^{180,pppp}, D. Konstantinov¹⁸⁰, V. Korenkov¹⁸⁰, A. Kozyrev^{180,n}, N. Krasnikov¹⁸⁰, E. Kuznetsova^{180,qqqq}, A. Lanev¹⁸⁰, P. Levchenko¹⁸⁰, A. Litomin¹⁸⁰, N. Lychkovskaya¹⁸⁰, V. Makarenko¹⁸⁰

A. Malakhov¹⁸⁰, V. Matveev^{180,n}, V. Murzin¹⁸⁰, A. Nikitenko^{180,rrrr}, S. Obraztsov¹⁸⁰, V. Okhotnikov¹⁸⁰,
 I. Ovtin^{180,n}, V. Palichik¹⁸⁰, P. Parygin¹⁸⁰, V. Perelygin¹⁸⁰, M. Perfilov¹⁸⁰, S. Petrushanko¹⁸⁰, G. Pivovarov¹⁸⁰,
 S. Polikarpov^{180,n}, V. Popov¹⁸⁰, O. Radchenko^{180,n}, M. Savina¹⁸⁰, V. Savrin¹⁸⁰, D. Selivanova¹⁸⁰, V. Shalaev¹⁸⁰,
 S. Shmatov¹⁸⁰, S. Shulha¹⁸⁰, Y. Skovpen^{180,n}, S. Slabospitskii¹⁸⁰, V. Smirnov¹⁸⁰, D. Sosnov¹⁸⁰, A. Stepenov¹⁸⁰,
 V. Sulimov¹⁸⁰, E. Tcherniaev¹⁸⁰, A. Terkulov¹⁸⁰, O. Teryaev¹⁸⁰, I. Tlisova¹⁸⁰, M. Toms¹⁸⁰, A. Toropin¹⁸⁰,
 L. Uvarov¹⁸⁰, A. Uzunian¹⁸⁰, E. Vlasov¹⁸⁰, A. Vorobyev¹⁸⁰, N. Voytishin¹⁸⁰, B. S. Yuldashev^{180,ssss}, A. Zarubin¹⁸⁰,
 I. Zhizhin¹⁸⁰ and A. Zhokin¹⁸⁰

(CMS Collaboration)

- ¹*Yerevan Physics Institute, Yerevan, Armenia*
²*Institut für Hochenergiephysik, Vienna, Austria*
³*Universiteit Antwerpen, Antwerpen, Belgium*
⁴*Vrije Universiteit Brussel, Brussel, Belgium*
⁵*Université Libre de Bruxelles, Bruxelles, Belgium*
⁶*Ghent University, Ghent, Belgium*
⁷*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
⁸*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*
⁹*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
¹⁰*Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil*
¹¹*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*
¹²*University of Sofia, Sofia, Bulgaria*
¹³*Beihang University, Beijing, China*
¹⁴*Department of Physics, Tsinghua University, Beijing, China*
¹⁵*Institute of High Energy Physics, Beijing, China*
¹⁶*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*
¹⁷*Sun Yat-Sen University, Guangzhou, China*
¹⁸*Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) - Fudan University, Shanghai, China*
¹⁹*Zhejiang University, Hangzhou, Zhejiang, China*
²⁰*Universidad de Los Andes, Bogota, Colombia*
²¹*Universidad de Antioquia, Medellin, Colombia*
²²*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*
²³*University of Split, Faculty of Science, Split, Croatia*
²⁴*Institute Rudjer Boskovic, Zagreb, Croatia*
²⁵*University of Cyprus, Nicosia, Cyprus*
²⁶*Charles University, Prague, Czech Republic*
²⁷*Escuela Politecnica Nacional, Quito, Ecuador*
²⁸*Universidad San Francisco de Quito, Quito, Ecuador*
²⁹*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*
³⁰*Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt*
³¹*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*
³²*Department of Physics, University of Helsinki, Helsinki, Finland*
³³*Helsinki Institute of Physics, Helsinki, Finland*
³⁴*Lappeenranta-Lahti University of Technology, Lappeenranta, Finland*
³⁵*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
³⁶*Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*
³⁷*Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France*
³⁸*Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France*
³⁹*Georgian Technical University, Tbilisi, Georgia*
⁴⁰*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
⁴¹*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
⁴²*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
⁴³*Deutsches Elektronen-Synchrotron, Hamburg, Germany*
⁴⁴*University of Hamburg, Hamburg, Germany*
⁴⁵*Karlsruher Institut fuer Technologie, Karlsruhe, Germany*

- ⁴⁶*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
- ⁴⁷*National and Kapodistrian University of Athens, Athens, Greece*
- ⁴⁸*National Technical University of Athens, Athens, Greece*
- ⁴⁹*University of Ioánnina, Ioánnina, Greece*
- ⁵⁰*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*
- ⁵¹*Wigner Research Centre for Physics, Budapest, Hungary*
- ⁵²*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
- ⁵³*Institute of Physics, University of Debrecen, Debrecen, Hungary*
- ⁵⁴*Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary*
- ⁵⁵*Panjab University, Chandigarh, India*
- ⁵⁶*University of Delhi, Delhi, India*
- ⁵⁷*Saha Institute of Nuclear Physics, HBNI, Kolkata, India*
- ⁵⁸*Indian Institute of Technology Madras, Madras, India*
- ⁵⁹*Bhabha Atomic Research Centre, Mumbai, India*
- ⁶⁰*Tata Institute of Fundamental Research-A, Mumbai, India*
- ⁶¹*Tata Institute of Fundamental Research-B, Mumbai, India*
- ⁶²*National Institute of Science Education and Research, An OCC of Homi Bhabha National Institute, Bhubaneswar, Odisha, India*
- ⁶³*Indian Institute of Science Education and Research (IISER), Pune, India*
- ⁶⁴*Isfahan University of Technology, Isfahan, Iran*
- ⁶⁵*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
- ⁶⁶*University College Dublin, Dublin, Ireland*
- ^{67a}*INFN Sezione di Bari, Bari, Italy*
- ^{67b}*Università di Bari, Bari, Italy*
- ^{67c}*Politecnico di Bari, Bari, Italy*
- ^{68a}*INFN Sezione di Bologna, Bologna, Italy*
- ^{68b}*Università di Bologna, Bologna, Italy*
- ^{69a}*INFN Sezione di Catania, Catania, Italy*
- ^{69b}*Università di Catania, Catania, Italy*
- ^{70a}*INFN Sezione di Firenze, Firenze, Italy*
- ^{70b}*Università di Firenze, Firenze, Italy*
- ⁷¹*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
- ^{72a}*INFN Sezione di Genova, Genova, Italy*
- ^{72b}*Università di Genova, Genova, Italy*
- ^{73a}*INFN Sezione di Milano-Bicocca, Milano, Italy*
- ^{73b}*Università di Milano-Bicocca, Milano, Italy*
- ^{74a}*INFN Sezione di Napoli, Napoli, Italy*
- ^{74b}*Università di Napoli 'Federico II', Napoli, Italy*
- ^{74c}*Università della Basilicata, Potenza, Italy*
- ^{74d}*Università G. Marconi, Roma, Italy*
- ^{75a}*INFN Sezione di Padova, Padova, Italy*
- ^{75b}*Università di Padova, Padova, Italy*
- ^{75c}*Università di Trento, Trento, Italy*
- ^{76a}*INFN Sezione di Pavia, Pavia, Italy*
- ^{76b}*Università di Pavia, Pavia, Italy*
- ^{77a}*INFN Sezione di Perugia, Perugia, Italy*
- ^{77b}*Università di Perugia, Perugia, Italy*
- ^{78a}*INFN Sezione di Pisa, Pisa, Italy*
- ^{78b}*Università di Pisa, Pisa, Italy*
- ^{78c}*Scuola Normale Superiore di Pisa, Pisa, Italy*
- ^{78d}*Università di Siena, Siena, Italy*
- ^{79a}*INFN Sezione di Roma, Roma, Italy*
- ^{79b}*Sapienza Università di Roma, Roma, Italy*
- ^{80a}*INFN Sezione di Torino, Torino, Italy*
- ^{80b}*Università di Torino, Torino, Italy*
- ^{80c}*Università del Piemonte Orientale, Novara, Italy*
- ^{81a}*INFN Sezione di Trieste, Trieste, Italy*
- ^{81b}*Università di Trieste, Trieste, Italy*
- ⁸²*Kyungpook National University, Daegu, Korea*
- ⁸³*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
- ⁸⁴*Hanyang University, Seoul, Korea*

- ⁸⁵Korea University, Seoul, Korea
⁸⁶Kyung Hee University, Department of Physics, Seoul, Korea
⁸⁷Sejong University, Seoul, Korea
⁸⁸Seoul National University, Seoul, Korea
⁸⁹University of Seoul, Seoul, Korea
⁹⁰Yonsei University, Department of Physics, Seoul, Korea
⁹¹Sungkyunkwan University, Suwon, Korea
⁹²College of Engineering and Technology, American University of the Middle East (AUM), Dasman, Kuwait
⁹³Riga Technical University, Riga, Latvia
⁹⁴Vilnius University, Vilnius, Lithuania
⁹⁵National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
⁹⁶Universidad de Sonora (UNISON), Hermosillo, Mexico
⁹⁷Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
⁹⁸Universidad Iberoamericana, Mexico City, Mexico
⁹⁹Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
¹⁰⁰University of Montenegro, Podgorica, Montenegro
¹⁰¹National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
¹⁰²AGH University of Science and Technology Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland
¹⁰³National Centre for Nuclear Research, Swierk, Poland
¹⁰⁴Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
¹⁰⁵Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
¹⁰⁶VINCA Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
¹⁰⁷Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
¹⁰⁸Universidad Autónoma de Madrid, Madrid, Spain
¹⁰⁹Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain
¹¹⁰Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
¹¹¹University of Colombo, Colombo, Sri Lanka
¹¹²University of Ruhuna, Department of Physics, Matara, Sri Lanka
¹¹³CERN, European Organization for Nuclear Research, Geneva, Switzerland
¹¹⁴Paul Scherrer Institut, Villigen, Switzerland
¹¹⁵ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
¹¹⁶Universität Zürich, Zurich, Switzerland
¹¹⁷National Central University, Chung-Li, Taiwan
¹¹⁸National Taiwan University (NTU), Taipei, Taiwan
¹¹⁹Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand
¹²⁰Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
¹²¹Middle East Technical University, Physics Department, Ankara, Turkey
¹²²Bogazici University, Istanbul, Turkey
¹²³Istanbul Technical University, Istanbul, Turkey
¹²⁴Istanbul University, Istanbul, Turkey
¹²⁵Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkiv, Ukraine
¹²⁶National Science Centre, Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine
¹²⁷University of Bristol, Bristol, United Kingdom
¹²⁸Rutherford Appleton Laboratory, Didcot, United Kingdom
¹²⁹Imperial College, London, United Kingdom
¹³⁰Brunel University, Uxbridge, United Kingdom
¹³¹Baylor University, Waco, Texas, USA
¹³²Catholic University of America, Washington, DC, USA
¹³³The University of Alabama, Tuscaloosa, Alabama, USA
¹³⁴Boston University, Boston, Massachusetts, USA
¹³⁵Brown University, Providence, Rhode Island, USA
¹³⁶University of California, Davis, Davis, California, USA
¹³⁷University of California, Los Angeles, California, USA
¹³⁸University of California, Riverside, Riverside, California, USA
¹³⁹University of California, San Diego, La Jolla, California, USA
¹⁴⁰University of California, Santa Barbara - Department of Physics, Santa Barbara, California, USA
¹⁴¹California Institute of Technology, Pasadena, California, USA
¹⁴²Carnegie Mellon University, Pittsburgh, Pennsylvania, USA
¹⁴³University of Colorado Boulder, Boulder, Colorado, USA
¹⁴⁴Cornell University, Ithaca, New York, USA

- ¹⁴⁵*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
¹⁴⁶*University of Florida, Gainesville, Florida, USA*
¹⁴⁷*Florida State University, Tallahassee, Florida, USA*
¹⁴⁸*Florida Institute of Technology, Melbourne, Florida, USA*
¹⁴⁹*University of Illinois at Chicago (UIC), Chicago, Illinois, USA*
¹⁵⁰*The University of Iowa, Iowa City, Iowa, USA*
¹⁵¹*Johns Hopkins University, Baltimore, Maryland, USA*
¹⁵²*The University of Kansas, Lawrence, Kansas, USA*
¹⁵³*Kansas State University, Manhattan, Kansas, USA*
¹⁵⁴*Lawrence Livermore National Laboratory, Livermore, California, USA*
¹⁵⁵*University of Maryland, College Park, Maryland, USA*
¹⁵⁶*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
¹⁵⁷*University of Minnesota, Minneapolis, Minnesota, USA*
¹⁵⁸*University of Mississippi, Oxford, Mississippi, USA*
¹⁵⁹*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
¹⁶⁰*State University of New York at Buffalo, Buffalo, New York, USA*
¹⁶¹*Northeastern University, Boston, Massachusetts, USA*
¹⁶²*Northwestern University, Evanston, Illinois, USA*
¹⁶³*University of Notre Dame, Notre Dame, Indiana, USA*
¹⁶⁴*The Ohio State University, Columbus, Ohio, USA*
¹⁶⁵*Princeton University, Princeton, New Jersey, USA*
¹⁶⁶*University of Puerto Rico, Mayaguez, Puerto Rico, USA*
¹⁶⁷*Purdue University, West Lafayette, Indiana, USA*
¹⁶⁸*Purdue University Northwest, Hammond, Indiana, USA*
¹⁶⁹*Rice University, Houston, Texas, USA*
¹⁷⁰*University of Rochester, Rochester, New York, USA*
¹⁷¹*The Rockefeller University, New York, New York, USA*
¹⁷²*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*
¹⁷³*University of Tennessee, Knoxville, Tennessee, USA*
¹⁷⁴*Texas A&M University, College Station, Texas, USA*
¹⁷⁵*Texas Tech University, Lubbock, Texas, USA*
¹⁷⁶*Vanderbilt University, Nashville, Tennessee, USA*
¹⁷⁷*University of Virginia, Charlottesville, Virginia, USA*
¹⁷⁸*Wayne State University, Detroit, Michigan, USA*
¹⁷⁹*University of Wisconsin - Madison, Madison, Wisconsin, USA*
¹⁸⁰*An institute or international laboratory covered by a cooperation agreement with CERN*

^aDeceased.

^bAlso at Yerevan State University, Yerevan, Armenia.

^cAlso at TU Wien, Vienna, Austria.

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

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

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

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

^hAlso at UFMS, Nova Andradina, Brazil.

ⁱAlso at The University of the State of Amazonas, Manaus, Brazil.

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

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

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

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

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

^oAlso at Helwan University, Cairo, Egypt.

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

^qAlso at Ain Shams University, Cairo, Egypt.

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

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

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

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

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

- ^wAlso at University of Hamburg, Hamburg, Germany.
- ^xAlso at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
- ^yAlso at Isfahan University of Technology, Isfahan, Iran.
- ^zAlso at Brandenburg University of Technology, Cottbus, Germany.
- ^{aa}Also at Forschungszentrum Jülich, Juelich, Germany.
- ^{bb}Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
- ^{cc}Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt.
- ^{dd}Also at Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary.
- ^{ee}Also at Wigner Research Centre for Physics, Budapest, Hungary.
- ^{ff}Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.
- ^{gg}Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
- ^{hh}Also at Universitatea Babeş-Bolyai—Facultatea de Fizica, Cluj-Napoca, Romania.
- ⁱⁱAlso at Faculty of Informatics, University of Debrecen, Debrecen, Hungary.
- ^{jj}Also at Punjab Agricultural University, Ludhiana, India.
- ^{kk}Also at UPES—University of Petroleum and Energy Studies, Dehradun, India.
- ^{ll}Also at University of Visva-Bharati, Santiniketan, India.
- ^{mm}Also at University of Hyderabad, Hyderabad, India.
- ⁿⁿAlso at Indian Institute of Science (IISc), Bangalore, India.
- ^{oo}Also at Indian Institute of Technology (IIT), Mumbai, India.
- ^{pp}Also at IIT Bhubaneswar, Bhubaneswar, India.
- ^{qq}Also at Institute of Physics, Bhubaneswar, India.
- ^{rr}Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany.
- ^{ss}Also at Department of Physics, Isfahan University of Technology, Isfahan, Iran.
- ^{tt}Also at Sharif University of Technology, Tehran, Iran.
- ^{uu}Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran.
- ^{vv}Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy.
- ^{ww}Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy.
- ^{xx}Also at Scuola Superiore Meridionale, Università di Napoli 'Federico II', Napoli, Italy.
- ^{yy}Also at Fermi National Accelerator Laboratory, Batavia, Illinois, USA.
- ^{zz}Also at Università di Napoli 'Federico II', Napoli, Italy.
- ^{aaa}Also at Consiglio Nazionale delle Ricerche—Istituto Officina dei Materiali, Perugia, Italy.
- ^{bbb}Also at Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Malaysia.
- ^{ccc}Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
- ^{ddd}Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France.
- ^{eee}Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
- ^{fff}Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka.
- ^{ggg}Also at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy.
- ^{hhh}Also at National and Kapodistrian University of Athens, Athens, Greece.
- ⁱⁱⁱAlso at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland.
- ^{jjj}Also at Universität Zürich, Zurich, Switzerland.
- ^{kkk}Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
- ^{lll}Also at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
- ^{mmm}Also at Near East University, Research Center of Experimental Health Science, Mersin, Turkey.
- ⁿⁿⁿAlso at Konya Technical University, Konya, Turkey.
- ^{ooo}Also at Izmir Bakircay University, Izmir, Turkey.
- ^{ppp}Also at Adiyaman University, Adiyaman, Turkey.
- ^{qqq}Also at Istanbul Gedik University, Istanbul, Turkey.
- ^{rrr}Also at Necmettin Erbakan University, Konya, Turkey.
- ^{sss}Also at Bozok Universitetesi Rektörlüğü, Yozgat, Turkey.
- ^{ttt}Also at Marmara University, Istanbul, Turkey.
- ^{uuu}Also at Milli Savunma University, Istanbul, Turkey.
- ^{vvv}Also at Kafkas University, Kars, Turkey.
- ^{www}Also at Istanbul University—Cerrahpasa, Faculty of Engineering, Istanbul, Turkey.
- ^{xxx}Also at Yildiz Technical University, Istanbul, Turkey.
- ^{yyy}Also at Vrije Universiteit Brussel, Brussel, Belgium.
- ^{zzz}Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- ^{aaaa}Also at University of Bristol, Bristol, United Kingdom.
- ^{bbbb}Also at IPPP Durham University, Durham, United Kingdom.
- ^{cccc}Also at Monash University, Faculty of Science, Clayton, Australia.
- ^{dddd}Also at Università di Torino, Torino, Italy.

- ^{cccc} Also at Bethel University, St. Paul, Minnesota, USA.
- ^{ffff} Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
- ^{gggg} Also at California Institute of Technology, Pasadena, California, USA.
- ^{hhhh} Also at United States Naval Academy, Annapolis, Maryland, USA.
- ⁱⁱⁱⁱ Also at Bingol University, Bingol, Turkey.
- ^{jjjj} Also at Georgian Technical University, Tbilisi, Georgia.
- ^{kkkk} Also at Sinop University, Sinop, Turkey.
- ^{llll} Also at Erciyes University, Kayseri, Turkey.
- ^{mmmm} Also at Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE)—Fudan University, Shanghai, China.
- ⁿⁿⁿⁿ Also at Texas A&M University at Qatar, Doha, Qatar.
- ^{oooo} Also at Kyungpook National University, Daegu, Korea.
- ^{pppp} Also at Yerevan Physics Institute, Yerevan, Armenia.
- ^{qqqq} Also at University of Florida, Gainesville, Florida, USA.
- ^{rrrr} Also at Imperial College, London, United Kingdom.
- ^{ssss} Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan.