

Search for stealth supersymmetry in final states with two photons, jets, and low missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV

A. Hayrapetyan *et al.*^{*}
(CMS Collaboration)



(Received 4 October 2023; accepted 12 February 2024; published 6 June 2024)

The results of a search for stealth supersymmetry in final states with two photons and jets, targeting a phase space region with low missing transverse momentum (p_T^{miss}), are reported. The study is based on a sample of proton-proton collisions at $\sqrt{s} = 13$ TeV collected by the CMS experiment, corresponding to an integrated luminosity of 138 fb^{-1} . As LHC results continue to constrain the parameter space of the minimal supersymmetric standard model, the low p_T^{miss} regime is increasingly valuable to explore. To estimate the backgrounds due to standard model processes in such events, we apply corrections derived from simulation to an estimate based on a control selection in data. The results are interpreted in the context of simplified stealth supersymmetry models with gluino and squark pair production. The observed data are consistent with the standard model predictions, and gluino (squark) masses of up to 2150 (1850) GeV are excluded at the 95% confidence level.

DOI: [10.1103/PhysRevD.109.112009](https://doi.org/10.1103/PhysRevD.109.112009)

I. INTRODUCTION

The search for signatures of models featuring supersymmetry (SUSY) with a stable lightest SUSY particle (LSP) [1] is an important part of the physics program at the CERN LHC. Such models can solve the hierarchy problem, can allow for the unification of the gauge couplings, and can provide a candidate for dark matter. Typically, such signatures involve a significant imbalance in the momenta of detected particles in a collision, because LSPs do not interact with the material of the detector. Therefore, many searches for SUSY focus on events that feature a significant imbalance in the sum of the momenta in the transverse plane, called the missing transverse momentum $\vec{p}_T^{\text{miss}}$, whose magnitude is defined as p_T^{miss} [2–9].

On the other hand, there are many SUSY models that do not exhibit this signature, such as those with compressed spectra [10,11], R -parity violation [1,12,13], hidden valleys [14–16], and others [17–21]. Given recent results imposing progressively higher bounds on gluino and squark masses ($m_{\tilde{g}}$ and $m_{\tilde{q}}$) in models of SUSY with high- p_T^{miss} signatures [22–27], a thorough study of such alternatives becomes important. One such alternative is the

stealth scenario [28–30], in which the minimal supersymmetric standard model (MSSM) is augmented with a light hidden sector. This sector only couples weakly to the SUSY-breaking sector. Consequently, the particles in this sector are nearly mass degenerate with their SUSY partners. The simplest hidden sector consists of a single scalar boson, called a singlet S , and its corresponding SUSY fermion, called a singlino $\tilde{S}$. As the mass degeneracy between them is broken only through suppressed or second-order diagrams, their mass difference $\Delta m(S, \tilde{S})$ is naturally expected to be small. Previously, searches have been performed for stealth SUSY in events with top quarks and several light-flavor partons [31]. A previous study was also performed for stealth SUSY with jets, photons or leptons, and low p_T^{miss} at $\sqrt{s} = 8$ TeV [32]. In that analysis, the background model for the diphoton final state used an assumption called S_T scaling, which is described in Sec. V. The present study relaxes the assumption of S_T scaling and uses simulated background samples to estimate the corrections needed to a background model derived from this assumption for a diphoton final state.

In the stealth SUSY models considered in this study, the gravitino $\tilde{G}$ is the LSP, and is produced through the decay of the stealth sector singlino, $\tilde{S} \rightarrow \tilde{G}S$. Because the mass splitting $\Delta m(S, \tilde{S})$ is small compared to the masses of S and $\tilde{S}$, the momentum of the LSP is suppressed by the small kinematic phase space available. As p_T^{miss} arises predominantly from the unobserved LSPs in the final state, stealth SUSY decays will lead to lower average values of p_T^{miss} than their regular SUSY counterparts. This is true even

^{*}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.

when the singlino is Lorentz boosted by initial state radiation (ISR): in a two-body decay with small mass splitting between the parent and the heavier of its daughters, the light daughter (here the LSP) acquires a small fraction of the parent's energy. This is in contrast with a typical compressed-spectrum SUSY model in which the heavy daughter is the LSP.

Supersymmetric particles can decay through the hidden sector without violating R -parity, with an MSSM electroweakino—an MSSM partner of a standard model (SM) gauge boson—decaying to the $\tilde{S}$ via the emission of an SM gauge boson. In this paper, we present a search for stealth SUSY signatures in final states with two photons from the decays of electroweakinos. The data used in the search correspond to an integrated luminosity of 138 fb^{-1} of proton-proton (pp) collisions collected at $\sqrt{s} = 13 \text{ TeV}$ by the CMS experiment in 2016–2018.

We consider models with strongly produced SUSY particles, with pairs either of squarks $\tilde{q}$ or of gluinos $\tilde{g}$ produced in the primary interaction, as shown in Fig. 1. These colored SUSY particles decay to quarks and neutralinos $\tilde{\chi}_1^0$. Neutralinos further decay to the stealth sector via the emission of photons. Each singlet S decays to two SM gluons.

The masses of $\tilde{S}$ and S are parameters of these models, and are fixed to 100 and 90 GeV, respectively, in this study. These values imply a small mass splitting of 10 GeV, as

required by the stealth mechanism, and are consistent with stealth benchmark points proposed in Ref. [28]. The gravitino $\tilde{G}$ is taken to be massless. We consider a two-dimensional scan of models by allowing $m_{\tilde{g}}$ ($m_{\tilde{q}}$) to vary in the range $1250 < M < 2350 \text{ GeV}$ ($1100 < M < 2000 \text{ GeV}$) in increments of 50 GeV. The neutralino mass $m_{\tilde{\chi}_1^0}$ is varied in changing increments in the range $150 \text{ GeV} < M < m_{\tilde{g}}(m_{\tilde{q}}) - 100 \text{ GeV}$, with more points simulated near the boundaries, where the acceptance of the analysis is often sensitive to small changes.

The final state consists of two photons, many jets, and low p_T^{miss} carried by the light and soft gravitinos. To obtain an estimate of the SM background, a hybrid approach is used, in which control samples in the data yield a first estimate, which is then adjusted using simulated samples of the major SM processes contributing to the diphoton background.

This paper is organized as follows. In Sec. II, we describe the features of the CMS detector and simulated samples used in this analysis. The trigger criteria and object definitions are given in Sec. III. The details of the event selection, including the definitions of the search and control regions, are given in Sec. IV. Section V discusses the method used to estimate the SM backgrounds in the search, and Sec. VI describes the sources of systematic uncertainty. The results of the search, including exclusion limits, are presented in Sec. VII. Section VIII summarizes our findings. Tabulated results are provided in the HEPData record for this analysis [33].

II. THE CMS DETECTOR AND SIMULATED SAMPLES

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections. Forward calorimeters extend the pseudorapidity (η) coverage provided by the barrel and endcap detectors. Muons are detected in gas-ionization chambers embedded in the steel flux-return yoke outside the solenoid. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [34].

Monte Carlo (MC) simulation is used to obtain the potential stealth SUSY signal yield. Each of the simplified models introduced in Sec. I is generated with MadGraph 5_aMC@NLO 2.4.3 [35,36] at leading order (LO), with PYTHIA 8.230 [37] used for showering and hadronization. For the simulation of the underlying event, the CP2 tune [38] is used. This tune uses the NNPDF3.1LO parton distribution functions (PDFs) [39]. The cross sections are calculated

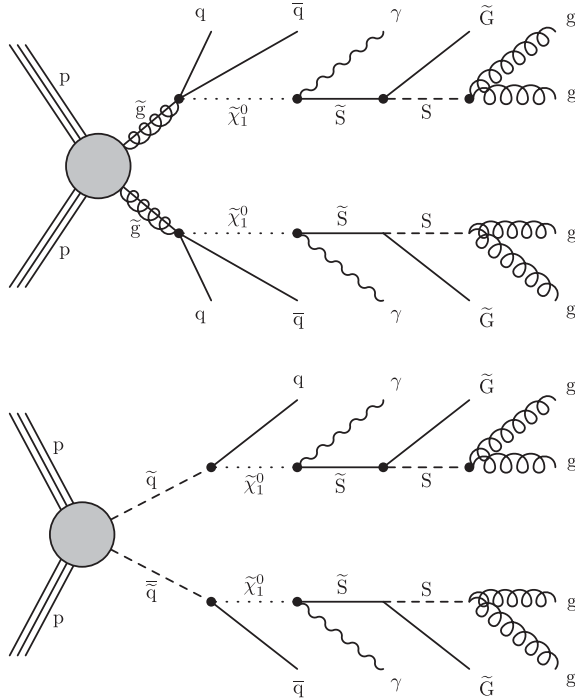


FIG. 1. Diagrams of the simplified models considered in this paper. The decay chain starts from the production of either gluino pairs (top) or squark pairs (bottom) and results in a final state consisting of two photons, multiple jets, and low p_T^{miss} .

with a next-to-next-to-LO (NNLO) approximation up to next-to-next-to-leading logarithmic (NNLL) accuracy [40–44]. The CMS detector response is determined via fast simulation [45].

The MC simulation is also used to refine the background estimate based on control samples in data by looking at the sum of three primary contributions to the SM background: diphoton (with both photons reconstructed from the initial hard scattering), γ + jet (with one photon reconstructed from the initial hard scattering and one from jet fragmentation or from a misidentified jet), and quantum chromodynamics (QCD) multijets (with both photons reconstructed from jet fragmentation or from misidentified jets). All samples are generated separately for 2016, 2017, and 2018 data-taking conditions. In each of the three samples, PYTHIA 8.230 is used for showering and hadronization. The γ + jet and QCD multijet samples are generated with MadGraph 5_aMC@NLO 2.4.3 at LO and MadGraph 5_aMC@NLO 2.6.0 at LO for 2016–2017 and 2018 running conditions, respectively. The 2016 subsamples of both the QCD multijet and γ + jet samples are generated with the CUETP8M1 tune [46], which uses the NNPDF3.0LO PDFs [47], while the 2017–2018 subsamples of both the QCD multijet and γ + jet samples are generated with the CP5 tune [38], which uses the NNPDF3.1LO PDFs. The diphoton samples are generated at LO with SHERPA 2.1.0 [48], SHERPA 2.2.4, and SHERPA 2.2.10 for 2016, 2017, and 2018 running conditions, respectively, and use the CT10 PDFs [49] from the LHAPDF sets [50] for all three years. The CMS detector response is modeled with Geant4 [51] for all background samples. Additional pp interactions within the same or nearby bunch crossings (pileup) are included in the simulation.

The particle-flow (PF) algorithm [52] aims to reconstruct and identify each particle in an event, with an optimized combination of information from the various elements of the CMS detector. The energies of photons are obtained from the ECAL measurement. The energies of electrons are determined from a combination of the electron momentum at the primary interaction vertex as determined by the tracker, the energy of the corresponding ECAL cluster, and the energy sum of all bremsstrahlung photons spatially compatible with originating from the electron track. The energies of muons are obtained from the curvature of the corresponding track. The energies of charged hadrons are determined from a combination of their momentum measured in the tracker and the matching ECAL and HCAL energy deposits, corrected for the response function of the calorimeters to hadronic showers. Finally, the energies of neutral hadrons are obtained from the corresponding corrected ECAL and HCAL energy deposits.

III. TRIGGER AND OBJECT SELECTION

Events of interest are selected using a two-tiered trigger system. The first level of the trigger system, composed of custom hardware processors, uses information from the

calorimeters and muon detectors to select events at a rate of around 100 kHz within a fixed latency of about 4 μ s [53]. The second level, known as the high-level trigger, consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing, and reduces the event rate to around 1 kHz before data storage [54].

As described in Section IV, the analysis uses a diphoton signal selection, a diphoton control selection, and a single-photon control selection. We employ two very similar diphoton triggers, of which one was active in the 2016 data-taking period, and the other in the 2017–2018 data-taking periods. These triggers require leading and subleading photons with thresholds on the transverse momentum p_T at 30 and 18 GeV, respectively. Both triggers impose a threshold requirement of 55 GeV on the invariant mass of the two photons ($m_{\gamma\gamma}$). The 2016 trigger vetoes events if both photon candidates are associated with charged tracks, to limit contamination from electrons. The 2017–2018 trigger vetoes events if either photon candidate is associated with charged tracks. These diphoton triggers are used to populate the signal selection and the diphoton control selection. In addition, we employ a single-photon trigger, which requires at least one photon with a p_T threshold of 200 GeV in addition to a loose isolation requirement. The single-photon trigger is used to populate the single-photon control selection.

Jet candidates are reconstructed using PF objects via the anti- k_T clustering algorithm [55] with a distance parameter of 0.4 [56]. Jet momentum is determined as the vectorial sum of all PF object momenta in the jet, and is found from simulation to be, on average, within 5–10% of the true momentum over the entire p_T spectrum and detector acceptance. Pileup can contribute additional tracks and calorimetric energy depositions, increasing the apparent jet momentum. To mitigate this effect, tracks identified to be originating from pileup vertices are discarded and an offset correction is applied to correct for remaining contributions. Jet energy corrections are derived from simulation studies so that the average measured energy of jets becomes identical to that of particle level jets. In-situ measurements of the momentum balance in dijet, γ + jet, Z + jet, and multijet events are used to determine any residual differences between the jet energy scale in data and simulation, and appropriate corrections are made [57]. Additional selection criteria are applied to each jet to remove jets potentially dominated by instrumental effects or reconstruction failures. After correction, jet candidates are required to have $p_T > 30$ GeV and to be within the range $|\eta| < 2.4$.

Photon candidates are reconstructed from energy clusters in the ECAL. Candidates are required to be reconstructed in the ECAL barrel, with $|\eta| < 1.442$. In order to reduce background from misidentification of electrons as photons, candidates are rejected if they have measurements in the pixel detector compatible with the ECAL cluster. This veto

eliminates candidates with two or more measurements in the pixel detectors pointing toward the ECAL cluster corresponding to the candidate. For each photon candidate, we compute PF-based isolation variables by summing the p_T magnitudes of all reconstructed charged and neutral hadrons, and additional photons within an angular cone of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3$, ϕ being the azimuthal angle in radians. These isolation variables are used to reduce the misidentification of hadrons as photons. Further details on photon identification criteria can be found in Ref. [58]. Candidates that meet all kinematic criteria, and tight shower shape and isolation requirements, are classified as nominal photons in this analysis.

The vector $\vec{p}_T^{\text{miss}}$ is defined as the negative vector p_T sum of all reconstructed PF objects in the event, adjusted for jet energy corrections. The p_T^{miss} is then the magnitude of this vector. Dedicated filters are applied to remove artificial contributions to p_T^{miss} from various sources, including the beam halo, noise from detector electronics, poorly reconstructed muons, and poorly calibrated ECAL endcap crystals [59].

IV. EVENT SELECTION

We define S_T as the scalar sum of p_T^{miss} and the p_T values of all jets and photons in the event, as selected with the criteria given in Sec. III. Events with $S_T > 1200$ GeV, and with two or more reconstructed jets, are considered for the analysis. Based on the number and quality of the selected photon candidates, events are categorized into three selections:

- (i) The signal selection is constructed from events passing the diphoton trigger preselection requirements. Events are required to have a leading photon candidate with $p_T > 35$ GeV and at least one sub-leading photon candidate with $p_T > 25$ GeV, and the two candidates are required to have $m_{\gamma\gamma} > 90$ GeV. The diphoton invariant mass requirement reduces the background, while retaining at least 98% signal efficiency for the stealth SUSY models. Both candidates are required to pass the nominal photon criteria described in Sec. III.
- (ii) The diphoton control selection is constructed from events passing the diphoton trigger preselection. Events are required to have two photon candidates passing the same requirements on the p_T values and $m_{\gamma\gamma}$ as those of the signal selection. For the diphoton control selection, one or both photon candidates are required to fail the tight shower shape or isolation requirements of nominal photons.
- (iii) The single-photon control selection is constructed from events passing the single-photon trigger preselection. The candidate photon is required to have $p_T > 200$ GeV and to pass tight shower shape and isolation requirements.

In all events, the jet multiplicity N_{jets} is defined as the number of selected jet candidates that are more than $\Delta R = 0.4$ away from a selected photon. All three selections are further divided into subregions based on S_T and N_{jets} . Events with exactly two jets compose the shape sideband, which is used to derive the shape of the S_T distribution to be used at higher values of N_{jets} , as described in Sec. V. The region $1200 < S_T < 1300$ GeV is defined as the normalization sideband and is used to obtain the normalization, in each N_{jets} bin, for the S_T shape determined from the shape sideband. In each selection, the search region consists of events with four or more jets and $S_T > 1300$ GeV, and is divided into three N_{jets} bins (4, 5, and ≥ 6) and six ranges of S_T (1300–1400, 1400–1500, 1500–1700, 1700–2000, 2000–2500, and >2500 GeV) for a total of 18 search regions.

V. BACKGROUND ESTIMATION

The SM backgrounds to this search arise mainly from multijet events with two photons produced in the initial scattering. In general, multijet SM backgrounds at high N_{jets} can be derived using the S_T shape invariance method [60–63]. The key idea is that in SM processes, the fragmentation products of a boosted jet are nearly collinear and therefore have an S_T close to that of similar events with fewer reconstructed jets. In other words, the S_T distribution of events with low values of N_{jets} , where the signal contamination is very low for the models studied, can be used to predict the background S_T distribution at high values of N_{jets} . In this analysis, because the selection requires events with two reconstructed photons, deviations from S_T scaling could arise from selection efficiency biases. Therefore, we use simulated background samples to estimate first-order corrections to the baseline expectation of S_T invariance. The background model used in this analysis can be expressed as follows:

$$b(N_{\text{jets}}, S_T \text{ bin } i) = N^{\text{evts}}(N_{\text{jets}}, 1200 < S_T < 1300 \text{ GeV}) \times f^{\text{AGK}}(S_T \text{ bin } i) r(N_{\text{jets}}, S_T \text{ bin } i), \quad (1)$$

where $b(N_{\text{jets}}, S_T \text{ bin } i)$ is the expected background in a given (N_{jets}, S_T) bin. Here, $N^{\text{evts}}(N_{\text{jets}}, 1200 < S_T < 1300 \text{ GeV})$ is the number of events in a low- S_T normalization bin in the selection at a given N_{jets} , $f^{\text{AGK}}(S_T \text{ bin } i)$ is a shape template obtained from the data selection at $N_{\text{jets}} = 2$, and $r(N_{\text{jets}}, S_T \text{ bin } i)$ is a correction to the shape template estimated from simulated background samples. These shape and correction factors are described in further detail below.

The factors $f^{\text{AGK}}(S_T \text{ bin } i)$ are obtained using the shape in the signal selection of the observed S_T distribution for the SM background for $N_{\text{jets}} = 2$. This shape is determined as an adaptive Gaussian kernel (AGK) [64], which provides

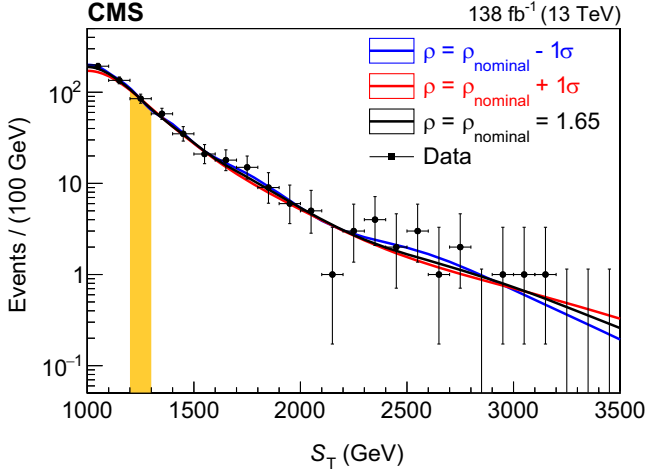


FIG. 2. The AGK template of the S_T distribution, obtained with various values of ρ , from the signal selection in data for $N_{\text{jets}} = 2$. The region shaded in yellow is the normalization sideband.

an unbinned estimate of the density of the S_T distribution. The AGK template depends only on a single parameter ρ , which is used to tune the balance between resilience to statistical fluctuations and ability to pick up small-scale features. In order to estimate the optimal value of ρ to use for the S_T template, we divide the dataset with $N_{\text{jets}} = 2$ into three equal sets, and evaluate the negative log likelihood (NLL) for each third of the dataset with respect to the kernel obtained from the remaining two sets. In this approach, called 3-fold cross-validation, the value of ρ that minimizes the sum of the NLLs over each third of the dataset is taken as the value of ρ to use in the S_T template. The factors $f^{\text{AGK}}(S_T \text{ bin } i)$ in each S_T bin are then obtained as the integral of the AGK template $K(S_T)$ in the given bin, normalized to the integral of the AGK template in the normalization bin. Figure 2 shows the data and the AGK template at the nominal value of ρ as well as templates with ρ shifted by one standard deviation ($\pm 1\sigma$), as described in Sec. VI. We note that lower values of ρ allow the kernel to pick up features in the data at smaller scales.

The correction terms $r(N_{\text{jets}}, S_T \text{ bin } i)$ are found from a sum of three simulated backgrounds, those corresponding to diphoton, $\gamma + \text{jet}$, and QCD multijet processes. We first obtain the nominal shape template from the combined background at $N_{\text{jets}} = 2$. At $N_{\text{jets}} \geq 4$, a modified version of the nominal shape template is fit to the S_T distribution in the combined background. More specifically, the template at $N_{\text{jets}} \geq 4$ is taken to be the nominal shape template multiplied by a simple linear adjustment of the form $[A + m(\frac{S_T}{S_T^{\text{norm}}} - 1)]$ (where $S_T^{\text{norm}} = 1250$ GeV is the center of the normalization bin). The A and m values for each N_{jets} bin are the parameters of the fit, and their best fit values can be found in Table I. Finally, the factors $r(N_{\text{jets}}, S_T \text{ bin } i)$ are evaluated as the ratio of the corrected to the uncorrected

TABLE I. Best fit values of A and m with statistical $\pm 1\sigma$ errors, obtained from the simulated background.

Best fit values	A	m
$N_{\text{jets}} = 4$	1.04 ± 0.03	0.75 ± 0.09
$N_{\text{jets}} = 5$	0.99 ± 0.04	1.30 ± 0.15
$N_{\text{jets}} \geq 6$	1.11 ± 0.06	2.42 ± 0.23

prediction in a given S_T bin. We note that the factors $r(N_{\text{jets}}, S_T \text{ bin } i)$ encode the deviation from S_T scaling in the combined simulated background.

In each (N_{jets}, S_T) bin, the signal prediction is obtained directly from a signal MC sample. Because the method used to obtain the background is based on control samples in the data, the background estimate is susceptible to potential signal contamination. To correct for this, we evaluate the background contamination and subtract it from the signal prediction in each (N_{jets}, S_T) bin. In addition, we limit inference of upper limits, as detailed in Sec. VII, to those regions of the $(m_{\tilde{g}}(m_{\tilde{q}}), m_{\tilde{\chi}_1^0})$ parameter space in which the potential signal contamination in the sidebands is below 10%, by eliminating the region with $m_{\tilde{g}}(m_{\tilde{q}}) - m_{\tilde{\chi}_1^0} < 100$ GeV. Furthermore, the signal efficiency is quite small in the region of the phase space with very low $m_{\tilde{\chi}_1^0}$ (at high values of N_{jets} , the signal efficiency goes from $\approx 7\%$ at low $m_{\tilde{\chi}_1^0}$ to $\approx 30\%$ at higher $m_{\tilde{\chi}_1^0}$), because in such events the neutralino is highly Lorentz-boosted, and its decay results in collimated jets and photons. Therefore, for inference, we do not consider the phase space below $m_{\tilde{\chi}_1^0} = 125(200)$ GeV for gluino (squark) samples.

VI. SYSTEMATIC UNCERTAINTIES

The background prediction is obtained from Eq. (1), each factor of which has potential uncertainties that affect the background yield. The signal prediction, being estimated from simulation, also has several potential uncertainties that affect the signal yield. In the following paragraphs, we describe the methods used to evaluate the effect of each source of uncertainty on the overall yield.

First, we describe the uncertainties affecting background yield. In Eq. (1), there exists a systematic uncertainty in the prediction arising from the statistical uncertainty in $N^{\text{evts}}(N_{\text{jets}}, 1200 < S_T < 1300 \text{ GeV})$. We use a 68% Poisson confidence interval around the observed value of $N^{\text{evts}}(N_{\text{jets}}, 1200 < S_T < 1300 \text{ GeV})$ to estimate the effect of this uncertainty, which we find to be in the range 15–22%, depending on the N_{jets} bin.

There are two sources of uncertainty in the shape factors $f^{\text{AGK}}(S_T \text{ bin } i)$ in Eq. (1). First, because of a limited number of events in the data at $N_{\text{jets}} = 2$, the template shape estimated as an AGK from the data is subject to statistical fluctuations. To evaluate this effect, we use the

nominal template as a probability distribution function to generate simulated pseudodatasets, where the number of events in each search region is chosen independently. The resulting distribution of $f^{\text{AGK}}(S_T \text{ bin } i)$ in each S_T bin is then used to determine the relative uncertainty in the nominal prediction. This uncertainty is in the range 10%–25%, depending on the S_T bin. Second, there is an uncertainty introduced by the choice of the parameter ρ of the template. This uncertainty is estimated by varying the nominal value of ρ by its $\pm 1\sigma$ fluctuations obtained from the NLL curve of the 3-fold cross-validation, and finding the relative change in $f^{\text{AGK}}(S_T \text{ bin } i)$. This uncertainty is less than 3% for all bins.

There are three sources of uncertainty in the corrections $r(N_{\text{jets}}, S_T \text{ bin } i)$ in Eq. (1). First, the best fit corrections that enter Eq. (1) are subject to statistical fluctuations because they are estimated from a statistically limited simulated background sample. This uncertainty is evaluated by diagonalizing the covariance matrix of the fits to the S_T distribution in each N_{jets} bin. The fluctuations of $r(N_{\text{jets}}, S_T \text{ bin } i)$ for each N_{jets} bin, estimated as variations of the best fit parameters consistent with the covariance matrix, are used as a measure of this uncertainty. This procedure yields uncertainty estimates of less than 7% in all bins. Next, because these corrections are estimated from a simulated sample, we account for the potential mismodeling in the simulation both as a function of S_T and as a function of N_{jets} , each of which is treated as a separate source of uncertainty. In order to estimate the uncertainty in $r(N_{\text{jets}}, S_T \text{ bin } i)$ due to mismodeling as a function of N_{jets} , we vary the cross section of each of the three backgrounds to the combination up and down by a factor of 2, thereby varying the relative composition of the simulated background, and the variation in $r(N_{\text{jets}}, S_T \text{ bin } i)$ is then used to determine the uncertainty. This uncertainty in $r(N_{\text{jets}}, S_T \text{ bin } i)$ leads to an uncertainty in the background prediction of less than 8% in all bins. Next, in order to estimate the uncertainty in $r(N_{\text{jets}}, S_T \text{ bin } i)$ due to mismodeling as a function of S_T , we consider two event selections orthogonal to the diphoton selections used in this analysis: a selection of events with exactly one selected photon, and a selection of events that pass the trigger but do not pass the event selection. In both selections, we obtain the ratio of S_T distributions at high values of N_{jets} to the S_T distribution at $N_{\text{jets}} = 2$ both for the data and for the simulated background. A ratio of the 2-to- n correction in data, $r(N_{\text{jets}}, S_T \text{ bin } i)$, to this correction in the simulated background, is a measure of the nonclosure of this procedure in both orthogonal selections, and is used to estimate the uncertainty in the background prediction due to mismodeling as a function of S_T . This leads to a flat 10% uncertainty in all signal bins.

The uncertainties in the signal prediction are typically much smaller than the uncertainties in the background.

There is a systematic uncertainty related to the finite size of the simulated signal samples (1%–5%, depending on the signal point). Next, there are systematic uncertainties due to the uncertainty in the knowledge of the jet energy scale (about 10%), due to a potential mismeasurement of the integrated luminosity (1.6%) [65–67], and due to uncertainties in the trigger efficiency (2%–10%). Other uncertainties, such as in the photon reconstruction efficiency and in the value of p_T^{miss} due to the jet energy resolution and unclustered energy in the event, are negligible.

VII. RESULTS

The yield in a given (N_{jets}, S_T) bin is modeled as $b + \mu s$, where b is the background estimate, s is the signal expectation, and μ is the signal strength. Both b and s are functions of nuisance parameters that model the various uncertainties described in Sec. VI. A comparison of the measured S_T distribution and the post-fit background prediction (i.e., the background prediction obtained by setting all nuisance parameters to those specific values that maximize the likelihood function at zero signal strength), with post-fit uncertainties, is shown in Fig. 3 for each N_{jets} bin. The data reveal no indication of any deviation from the background prediction.

The results are interpreted as 95% confidence level (CL) upper limits on the gluino and squark pair production cross sections of the simplified stealth SUSY models described in Sec. I. For the statistical inference of these upper limits, we use the CL_s criterion [68,69], which is based on a log-likelihood ratio test statistic, modified for upper limits [70], that compares the SM-only hypothesis to the hypothesis that there is an additional contribution from the signal. An asymptotic approximation [71] for the test statistic is used to extract the observed limits. Systematic uncertainties are incorporated into the test statistic as nuisance parameters. The background prediction, signal expectation, and observed number of events in each search region are combined into a single statistical interpretation, and evaluated as a multichannel counting experiment.

The upper limit on the gluino (squark) pair production cross section is shown in Fig. 4 as a function of $m_{\tilde{g}} (m_{\tilde{q}})$ and $m_{\tilde{\chi}_1^0}$, for the simplified stealth models used in this analysis. The production cross sections of the model points are determined exclusively by the value of $m_{\tilde{g}} (m_{\tilde{q}})$. For most $\tilde{\chi}_1^0$ masses, we exclude $m_{\tilde{g}}$ up to 2150 or $m_{\tilde{q}}$ up to 1850 GeV at 95% CL. Despite a relaxation of assumptions in the background modeling as compared to previously published results, we achieve a $\approx 70\%$ improvement in the reach of the exclusion contour in the $(m_{\tilde{q}}, m_{\tilde{\chi}_1^0})$ parameter space, where $m_{\tilde{\chi}_1^0}$ is the neutralino mass.

In the $(N_{\text{jets}} = 6, S_T > 2500 \text{ GeV})$ bin, we observe fewer events than predicted by the background model, making the observed limits stronger than the expected limits for most values of $m_{\tilde{g}} (m_{\tilde{q}})$ and $m_{\tilde{\chi}_1^0}$. In regions of the

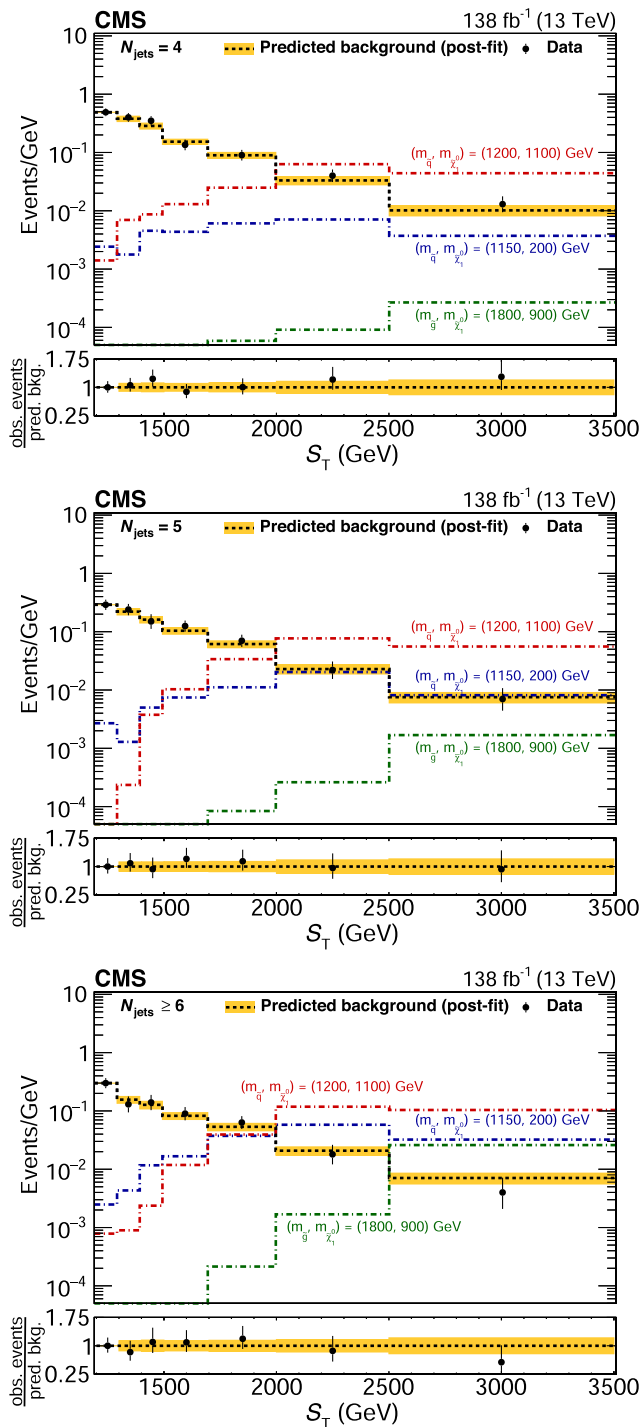


FIG. 3. Comparison of the measured S_T distribution with the post-fit background prediction in each of the search regions of the analysis for $N_{\text{jets}} = 4$ (upper), 5 (middle), and ≥ 6 (lower). The post-fit uncertainties on the background prediction are represented by the yellow band around the central prediction. Signal yields at a signal strength of 1 are also overlaid for some representative points in the $(m_{\tilde{g}}(m_{\tilde{q}}), m_{\tilde{\chi}^0_1})$ parameter space.

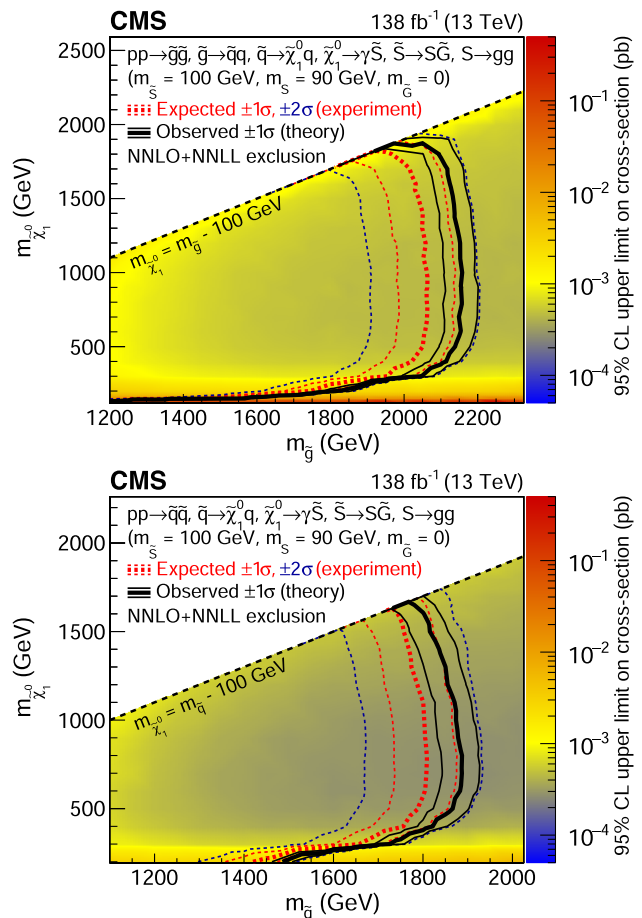


FIG. 4. The 95% C.L. upper limits on the gluino pair production cross section (top) and squark pair production cross section (upper) as functions of $m_{\tilde{g}}$ ($m_{\tilde{q}}$) and $m_{\tilde{\chi}_1^0}$. The contours show the observed (solid line) and expected (dashed line) 95% C.L. exclusions with their one standard deviation uncertainties. Two standard deviation uncertainty contours are also shown for the expected 95% C.L. exclusions.

parameter space at low $m_{\tilde{\chi}_1^0}$, the neutralino becomes boosted, and the resulting decay products become collimated. This has the effect of causing the photon to fail the isolation criteria, and results in a weakening of the exclusion limits. In regions of the parameter space where $m_{\tilde{\chi}_1^0}$ is very close to $m_{\tilde{g}}$ ($m_{\tilde{q}}$), the jets produced from the gluino decay become soft. This results in a reduction in the overall number of reconstructed jets in the event, and also causes a reduction in the excluded $m_{\tilde{q}}$.

VIII. SUMMARY

A search for stealth supersymmetry in events with two photons and at least four jets is presented. No threshold

requirement on the missing transverse momentum is imposed. The measurement is based on a data sample corresponding to an integrated luminosity of 138 fb^{-1} of proton-proton collisions at $\sqrt{s} = 13 \text{ TeV}$ recorded by the CMS experiment in 2016–2018. The analysis is performed in bins of S_T , which is the sum of transverse momenta for all reconstructed particles in the event, as well as jet multiplicity N_{jets} . A background model based on control samples in data is employed to estimate the standard model (SM) background in the data. The data are found to be consistent with the SM background prediction with no evidence of significant signal contribution. The results of the search are interpreted as 95% confidence level upper limits on the gluino and squark production cross sections in the context of simplified models of stealth supersymmetry. In simplified stealth models with gluino (squark) pair production, we exclude gluino masses $m_{\tilde{g}}$ (squark masses $m_{\tilde{q}}$) up to 2150 (1850) GeV. These are the most stringent limits to date on these models.

ACKNOWLEDGMENTS

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid and other centers for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC, the CMS detector, and the supporting computing infrastructure provided by the following funding agencies: SC (Armenia), BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES and BNSF (Bulgaria); CERN; CAS, MoST, and NSFC (China); Minciencias (Colombia); Please spell out MSES, MoER, HIP, SFI, MOS, MES, NSC, PCTI, MST; 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); SRNSF (Georgia); BMBF, DFG, and HGF (Germany); GSRI (Greece); NKFIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); 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 (USA). Individuals have received support from the Marie-Curie program and the European Research Council and Horizon 2020 Grant, contracts No. 675440, No. 724704, No. 752730, No. 758316, No. 765710, No. 824093, and COST Action No. CA16108 (European Union); the Leventis Foundation; the Alfred P. Sloan Foundation; the Alexander von Humboldt Foundation; the Science Committee, project no. 22rl-037 (Armenia); the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the F.R.S.-FNRS and FWO (Belgium) under the “Excellence of Science—EOS”—be.h project n. 30820817; the Beijing Municipal Science & Technology Commission, No. Z191100007219010 and Fundamental Research Funds for the Central Universities (China); the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Shota Rustaveli National Science Foundation, Grant No. FR-22-985 (Georgia); the Deutsche Forschungsgemeinschaft (DFG), under Germany’s Excellence Strategy—EXC 2121 “Quantum Universe”—390833306, and under project number 400140256—GRK2497; the Hellenic Foundation for Research and Innovation (HFRI), Project Number 2288 (Greece); the Hungarian Academy of Sciences, the New National Excellence Program—ÚNKP, the NKFIH research Grants No. K 124845, No. K 124850, No. K 128713, No. K 128786, No. K 129058, No. K 131991, No. K 133046, No. K 138136, No. K 143460, No. K 143477, No. 2020-2.2.1-ED-2021-00181, and No. TKP2021-NKTA-64 (Hungary); the Council of Science and Industrial Research, India; ICSC—National Research Center for High Performance Computing, Big Data and Quantum Computing, funded by the EU NexGeneration program (Italy); the Latvian Council of Science; the Ministry of Education and Science, project No. 2022/WK/14, and the National Science Center, contracts No. Opus 2021/41/B/ST2/01369 and No. 2021/43/B/ST2/01552 (Poland); the Fundação para a Ciência e a Tecnologia, Grant CEECIND/01334/2018 (Portugal); the National Priorities Research Program by Qatar National Research Fund; MCIN/AEI/10.13039/501100011033, ERDF “a way of making Europe”, and the Programa Estatal de Fomento de la Investigación Científica y Técnica de Excelencia María de Maeztu, Grant No. MDM-2017-0765 and Programa Severo Ochoa del Principado de Asturias (Spain); the Chulalongkorn Academic into Its 2nd Century Project Advancement Project, and the National Science, Research and Innovation Fund via the Program Management Unit for Human Resources & Institutional Development, Research and Innovation, Grant B05F650021 (Thailand); the Kavli Foundation; the Nvidia Corporation; the SuperMicro Corporation; the Welch Foundation, Contract C-1845; and the Weston Havens Foundation (USA).

- [1] G. R. Farrar and P. Fayet, Phenomenology of the production, decay, and detection of new hadronic states associated with supersymmetry, *Phys. Lett. B* **76**, 575 (1978).
- [2] S. Dimopoulos, G. F. Giudice, and A. Pomarol, Dark matter in theories of gauge mediated supersymmetry breaking, *Phys. Lett. B* **389**, 37 (1996).
- [3] S. P. Martin, Generalized messengers of supersymmetry breaking and the sparticle mass spectrum, *Phys. Rev. D* **55**, 3177 (1997).
- [4] E. Poppitz and S. P. Trivedi, Some remarks on gauge mediated supersymmetry breaking, *Phys. Lett. B* **401**, 38 (1997).
- [5] P. Meade, N. Seiberg, and D. Shih, General gauge mediation, *Prog. Theor. Phys. Suppl.* **177**, 143 (2009).
- [6] M. Buican, P. Meade, N. Seiberg, and D. Shih, Exploring general gauge mediation, *J. High Energy Phys.* **03** (2009) 016.
- [7] S. Abel, M. J. Dolan, J. Jaeckel, and V. V. Khoze, Phenomenology of pure general gauge mediation, *J. High Energy Phys.* **12** (2009) 001.
- [8] L. M. Carpenter, M. Dine, G. Festuccia, and J. D. Mason, Implementing general gauge mediation, *Phys. Rev. D* **79**, 035002 (2009).
- [9] T. T. Dumitrescu, Z. Komargodski, N. Seiberg, and D. Shih, General messenger gauge mediation, *J. High Energy Phys.* **05** (2010) 096.
- [10] T. J. LeCompte and S. P. Martin, Large Hadron Collider reach for supersymmetric models with compressed mass spectra, *Phys. Rev. D* **84**, 015004 (2011).
- [11] T. J. LeCompte and S. P. Martin, Compressed supersymmetry after 1/fb at the Large Hadron Collider, *Phys. Rev. D* **85**, 035023 (2012).
- [12] R. Barbier, C. Bérat, M. Besançon, M. Chemtob, A. Deandrea, E. Dudas, P. Fayet, S. Lavignac, G. Moreau, E. Perez, and Y. Sirois, R -parity violating supersymmetry, *Phys. Rep.* **420**, 1 (2005).
- [13] P. W. Graham, S. Rajendran, and P. Saraswat, Supersymmetric crevices: Missing signatures of R -parity violation at the LHC, *Phys. Rev. D* **90**, 075005 (2014).
- [14] M. J. Strassler and K. M. Zurek, Echoes of a hidden valley at hadron colliders, *Phys. Lett. B* **651**, 374 (2007).
- [15] T. Han, Z. Si, K. M. Zurek, and M. J. Strassler, Phenomenology of hidden valleys at hadron colliders, *J. High Energy Phys.* **07** (2008) 008.
- [16] Y. Nakai, M. Reece, and R. Sato, SUSY Higgs mass and collider signals with a hidden valley, *J. High Energy Phys.* **03** (2016) 143.
- [17] G. Burdman, Z. Chacko, H.-S. Goh, and R. Harnik, Folded supersymmetry and the LEP paradox, *J. High Energy Phys.* **02** (2007) 009.
- [18] P. W. Graham, D. E. Kaplan, S. Rajendran, and P. Saraswat, Displaced supersymmetry, *J. High Energy Phys.* **07** (2012) 149.
- [19] D. S. M. Alves, J. Liu, and N. Weiner, Hiding missing energy in missing energy, *J. High Energy Phys.* **04** (2015) 088.
- [20] U. Ellwanger and A. M. Teixeira, NMSSM with a singlino LSP: Possible challenges for searches for supersymmetry at the LHC, *J. High Energy Phys.* **10** (2014) 113.
- [21] B. Heidenreich and Y. Nakai, Natural supersymmetry in warped space, *J. High Energy Phys.* **10** (2014) 182.
- [22] CMS Collaboration, Search for supersymmetry in final states with two oppositely charged same-flavor leptons and missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **04** (2021) 123.
- [23] CMS Collaboration, Search for supersymmetry in proton-proton collisions at $\sqrt{s} = 13$ TeV in events with high-momentum Z bosons and missing transverse momentum, *J. High Energy Phys.* **09** (2020) 149.
- [24] CMS Collaboration, Search for physics beyond the standard model in events with jets and two same-sign or at least three charged leptons in proton-proton collisions at $\sqrt{s} = 13$ TeV, *Eur. Phys. J. C* **80**, 752 (2020).
- [25] CMS Collaboration, Search for supersymmetry in pp collisions at $\sqrt{s} = 13$ TeV with 137 fb^{-1} in final states with a single lepton using the sum of masses of large-radius jets, *Phys. Rev. D* **101**, 052010 (2020).
- [26] CMS Collaboration, Search for supersymmetry in proton-proton collisions at 13 TeV in final states with jets and missing transverse momentum, *J. High Energy Phys.* **10** (2019) 244.
- [27] CMS Collaboration, Searches for physics beyond the standard model with the M_{T2} variable in hadronic final states with and without disappearing tracks in proton-proton collisions at $\sqrt{s} = 13$ TeV, *Eur. Phys. J. C* **80**, 3 (2020).
- [28] J. Fan, M. Reece, and J. T. Ruderman, Stealth supersymmetry, *J. High Energy Phys.* **11** (2011) 012.
- [29] J. Fan, M. Reece, and J. T. Ruderman, A stealth supersymmetry sampler, *J. High Energy Phys.* **07** (2012) 196.
- [30] J. Fan, R. Krall, D. Pinner, M. Reece, and J. T. Ruderman, Stealth supersymmetry simplified, *J. High Energy Phys.* **07** (2016) 016.
- [31] CMS Collaboration, Search for top squarks in final states with two top quarks and several light-flavor jets in proton-proton collisions at $\sqrt{s} = 13$ TeV, *Phys. Rev. D* **104**, 032006 (2021).
- [32] CMS Collaboration, Search for stealth supersymmetry in events with jets, either photons or leptons, and low missing transverse momentum in pp collisions at 8 TeV, *Phys. Lett. B* **743**, 503 (2015).
- [33] HEPData record for this analysis, [10.17182/hepdata.141646](https://hepdata.net/record/10.17182/hepdata.141646) (2023).
- [34] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [35] 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.
- [36] R. Frederix, S. Frixione, V. Hirschi, D. Pagani, H. S. Shao, and M. Zaro, The automation of next-to-leading order electroweak calculations, *J. High Energy Phys.* **07** (2018) 185; **11** (2021) 85.
- [37] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA 8.2, *Comput. Phys. Commun.* **191**, 159 (2015).
- [38] CMS Collaboration, Extraction and validation of a new set of CMS PYTHIA8 tunes from underlying-event measurements, *Eur. Phys. J. C* **80**, 4 (2020).

- [39] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions from high-precision collider data, *Eur. Phys. J. C* **77**, 663 (2017).
- [40] B. Fuks, M. Klasen, D. R. Lamprea, and M. Rothering, Gaugino production in proton-proton collisions at a center-of-mass energy of 8 TeV, *J. High Energy Phys.* **10** (2012) 081.
- [41] B. Fuks, M. Klasen, D. R. Lamprea, and M. Rothering, Precision predictions for electroweak superpartner production at hadron colliders with Resummino, *Eur. Phys. J. C* **73**, 2480 (2013).
- [42] C. Borschensky, M. Krämer, A. Kulesza, M. Mangano, S. Padhi, T. Plehn, and X. Portell, Squark and gluino production cross sections in pp collisions at $\sqrt{s} = 13, 14, 33$ and 100 TeV, *Eur. Phys. J. C* **74**, 3174 (2014).
- [43] W. Beenakker, C. Borschensky, M. Krämer, A. Kulesza, E. Laenen, V. Theeuwes, and S. Thewes, NNLL resummation for squark and gluino production at the LHC, *J. High Energy Phys.* **12** (2014) 023.
- [44] W. Beenakker, C. Borschensky, M. Krämer, A. Kulesza, and E. Laenen, NNLL-fast: Predictions for coloured supersymmetric particle production at the LHC with threshold and Coulomb resummation, *J. High Energy Phys.* **12** (2016) 133.
- [45] CMS Collaboration, The fast simulation of the CMS detector at LHC, *J. Phys. Conf. Ser.* **331**, 032049 (2011).
- [46] CMS Collaboration, Event generator tunes obtained from underlying event and multiparton scattering measurements, *Eur. Phys. J. C* **76**, 155 (2016).
- [47] R. D. Ball, V. Bertone, S. Carrazza, L. Del Debbio, S. Forte, A. Guffanti, N. P. Hartland, and J. Rojo (NNPDF Collaboration), Parton distributions with QED corrections, *Nucl. Phys. B* **877**, 290 (2013).
- [48] E. Bothmann *et al.* (Sherpa Collaboration), Event generation with Sherpa 2.2, *SciPost Phys.* **7**, 034 (2019).
- [49] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, and C. P. Yuan, New parton distributions for collider physics, *Phys. Rev. D* **82**, 074024 (2010).
- [50] A. Buckley, J. Ferrando, S. Lloyd, K. Nordström, B. Page, M. Rüfenacht, M. Schönherr, and G. Watt, LHAPDF6: Parton density access in the LHC precision era, *Eur. Phys. J. C* **75**, 132 (2015).
- [51] S. Agostinelli *et al.* (GEANT4 Collaboration), Geant4—a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [52] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, *J. Instrum.* **12**, P10003 (2017).
- [53] CMS Collaboration, Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s} = 13$ TeV, *J. Instrum.* **15**, P10017 (2020).
- [54] CMS Collaboration, The CMS trigger system, *J. Instrum.* **12**, P01020 (2017).
- [55] M. Cacciari, G. P. Salam, and G. Soyez, The anti- k_T jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.
- [56] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, *Eur. Phys. J. C* **72**, 1896 (2012).
- [57] CMS Collaboration, Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV, *J. Instrum.* **12**, P02014 (2017).
- [58] CMS Collaboration, Electron and photon reconstruction and identification with the CMS experiment at the CERN LHC, *J. Instrum.* **16**, P05014 (2021).
- [59] 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).
- [60] CMS Collaboration, Search for microscopic black hole signatures at the Large Hadron Collider, *Phys. Lett. B* **697**, 434 (2011).
- [61] CMS Collaboration, Search for microscopic black holes in pp collisions at $\sqrt{s} = 7$ TeV, *J. High Energy Phys.* **04** (2012) 061.
- [62] CMS Collaboration, Search for microscopic black holes in pp collisions at $\sqrt{s} = 8$ TeV, *J. High Energy Phys.* **07** (2013) 178.
- [63] CMS Collaboration, Search for black holes in high-multiplicity final states in proton-proton collisions at $\sqrt{s} = 13$ TeV, *Phys. Lett. B* **774**, 279 (2017).
- [64] K. S. Cranmer, Kernel estimation in high-energy physics, *Comput. Phys. Commun.* **136**, 198 (2001).
- [65] CMS Collaboration, Precision luminosity measurement in proton-proton collisions at $\sqrt{s} = 13$ TeV in 2015 and 2016 at CMS, *Eur. Phys. J. C* **81**, 800 (2021).
- [66] CMS Collaboration, CMS luminosity measurement for the 2017 data-taking period at $\sqrt{s} = 13$ TeV, CMS Physics Analysis Summary Report No. CMS-PAS-LUM-17-004, 2018, <http://cds.cern.ch/record/2621960>.
- [67] CMS Collaboration, CMS luminosity measurement for the 2018 data-taking period at $\sqrt{s} = 13$ TeV, CMS Physics Analysis Summary Report No. CMS-PAS-LUM-18-002, 2019, <http://cds.cern.ch/record/2676164>.
- [68] T. Junk, Confidence level computation for combining searches with small statistics, *Nucl. Instrum. Methods Phys. Res., Sect. A* **434**, 435 (1999).
- [69] A. L. Read, Presentation of search results: The CL_s technique, *J. Phys. G* **28**, 2693 (2002).
- [70] ATLAS and CMS Collaborations, and the LHC Higgs Combination Group, Procedure for the LHC Higgs boson search combination in summer 2011, Technical Report No. ATL-PHYS-PUB-2011-11 and CMS-NOTE-2011-005, 2011, <https://cds.cern.ch/record/1379837>.
- [71] 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).

A. Hayrapetyan,¹ A. Tumasyan^{1,b}, W. Adam², J. W. Andrejkovic,² T. Bergauer², S. Chatterjee², K. Damanakis², M. Dragicevic², A. Escalante Del Valle², P. S. Hussain², M. Jeitler^{2,c}, N. Krammer², D. Liko², I. Mikulec², J. Schieck^{2,c}, R. Schofbeck², D. Schwarz², M. Sonawane², S. Templ², W. Waltenberger², C.-E. Wulz^{2,c}, M. R. Darwish^{3,d}, T. Janssen³, P. Van Mechelen³, E. S. Bols⁴, J. D'Hondt⁴, S. Dansana⁴, A. De Moor⁴

M. Delcourt⁴, H. El Faham⁴, S. Lowette⁴, I. Makarenko⁴, A. Morton⁴, D. Muller⁴, A. R. Sahasransu⁴, S. Tavernier⁴, M. Tytgat^{4,e}, S. Van Putte⁴, D. Vannerom⁴, B. Clerbaux⁵, G. De Lentdecker⁵, L. Favart⁵, D. Hohov⁵, J. Jaramillo⁵, A. Khalilzadeh⁵, K. Lee⁵, M. Mahdavihorrani⁵, A. Malara⁵, S. Paredes⁵, L. Petre⁵, N. Postiau⁵, L. Thomas⁵, M. Vanden Bemden⁵, C. Vander Velde⁵, P. Vanlaer⁵, M. De Coen⁶, D. Dobur⁶, J. Knolle⁶, L. Lambrecht⁶, G. Mestdach⁶, C. Rendon⁶, A. Samalan⁶, K. Skovpen⁶, N. Van Den Bossche⁶, B. Vermassen⁶, L. Wezenbeek⁶, A. Benecke⁷, G. Bruno⁷, C. Caputo⁷, C. Delaere⁷, I. S. Donertas⁷, A. Giammanco⁷, K. Jaffel⁷, Sa. Jain⁷, V. Lemaître⁷, J. Lidrych⁷, P. Mastrapasqua⁷, K. Mondal⁷, T. T. Tran⁷, S. Wertz⁷, G. A. Alves⁸, E. Coelho⁸, C. Hensel⁸, T. Menezes De Oliveira⁸, A. Moraes⁸, P. Rebello Teles⁸, M. Soeiro⁸, W. L. Alda Junior⁹, 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, S. Fronseca 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, A. Vilela Pereira⁹, C. A. Bernardes^{10,g}, L. Calligaris¹⁰, T. R. Fernandez Perez Tomei¹⁰, E. M. Gregores¹⁰, P. G. Mercadante¹⁰, S. F. Novaes¹⁰, B. Orzari¹⁰, Sandra S. Padula¹⁰, A. Aleksandrov¹¹, G. Antchev¹¹, R. Hadjiiska¹¹, P. Iaydjiev¹¹, M. Misheva¹¹, M. Shopova¹¹, G. Sultanov¹¹, A. Dimitrov¹², T. Ivanov¹², L. Litov¹², B. Pavlov¹², P. Petkov¹², A. Petrov¹², E. Shumka¹², S. Keshri¹³, S. Thakur¹³, T. Cheng¹⁴, Q. Guo¹⁴, T. Javai¹⁴, M. Mittal¹⁴, L. Yuan¹⁴, G. Bauer^{15,i}, Z. Hu¹⁵, K. Yi^{15,j}, G. M. Chen^{16,k}, H. S. Chen^{16,k}, M. Chen^{16,k}, F. Iemmi¹⁶, C. H. Jiang¹⁶, A. Kapoor¹⁶, H. Liao¹⁶, Z.-A. Liu^{16,l}, F. Monti¹⁶, R. Sharma¹⁶, J. N. Song^{16,l}, J. Tao¹⁶, J. Wang¹⁶, H. Zhang¹⁶, A. Agapitos¹⁷, Y. Ban¹⁷, A. Levin¹⁷, C. Li¹⁷, Q. Li¹⁷, X. Lyu¹⁷, Y. Mao¹⁷, S. J. Qian¹⁷, X. Sun¹⁷, D. Wang¹⁷, H. Yang¹⁷, C. Zhou¹⁷, Z. You¹⁸, N. Lu¹⁹, X. Gao^{20,m}, D. Leggat²⁰, H. Okawa²⁰, Y. Zhang²⁰, Z. Lin²¹, C. Lu²¹, M. Xiao²¹, C. Avila²², D. A. Barbosa Trujillo²², A. Cabrera²², C. Florez²², J. Fraga²², J. A. Reyes Vega²², J. Mejia Guisao²³, F. Ramirez²³, M. Rodriguez²³, J. D. Ruiz Alvarez²³, D. Giljanovic²⁴, N. Godinovic²⁴, D. Lelas²⁴, A. Sculac²⁴, M. Kovac²⁵, T. Sculac²⁵, P. Bargassa²⁶, V. Brigljevic²⁶, B. K. Chitroda²⁶, D. Ferencek²⁶, S. Mishra²⁶, A. Starodumov^{26,n}, T. Susa²⁶, A. Attikis²⁷, K. Christoforou²⁷, S. Konstantinou²⁷, J. Mousa²⁷, C. Nicolaou²⁷, F. Ptochos²⁷, P. A. Razis²⁷, H. Rykaczewski²⁷, H. Saka²⁷, A. Stepennov²⁷, M. Finger²⁸, M. Finger Jr.²⁸, A. Kveton²⁸, E. Ayala²⁹, E. Carrera Jarrin³⁰, Y. Assran^{31,o,p}, S. Elgammal^{31,p}, A. Lotfy³², M. A. Mahmoud³², R. K. Dewanjee^{33,q}, K. Ehataht³³, M. Kadastik³³, T. Lange³³, S. Nandan³³, C. Nielsen³³, J. Pata³³, M. Raidal³³, L. Tani³³, C. Veelken³³, H. Kirschenmann³⁴, K. Osterberg³⁴, M. Voutilainen³⁴, S. Bharthuar³⁵, E. Brucken³⁵, F. Garcia³⁵, J. Havukainen³⁵, K. T. S. Kallonen³⁵, M. S. Kim³⁵, R. Kinnunen³⁵, T. Lampen³⁵, K. Lassila-Perini³⁵, S. Lehti³⁵, T. Linden³⁵, M. Lotti³⁵, L. Martikainen³⁵, M. Myllymaki³⁵, M. m. Rantanen³⁵, H. Siikonen³⁵, E. Tuominen³⁵, J. Tuominiemi³⁵, P. Luukka³⁶, H. Petrow³⁶, T. Tuuva^{36,a}, M. Besancon³⁷, F. Couderc³⁷, M. Dejardin³⁷, D. Denegri³⁷, J. L. Faure³⁷, F. Ferri³⁷, S. Ganjour³⁷, P. Gras³⁷, G. Hamel de Monchenault³⁷, V. Lohezic³⁷, J. Malcles³⁷, J. Rander³⁷, A. Rosowsky³⁷, M. O. Sahin³⁷, A. Savoy-Navarro^{37,r}, P. Simkina³⁷, M. Titov³⁷, C. Baldenegro Barrera³⁸, F. Beaudette³⁸, A. Buchot Perraguin³⁸, P. Busson³⁸, A. Cappati³⁸, C. Charlot³⁸, F. Damas³⁸, O. Davignon³⁸, G. Falmagne³⁸, B. A. Fontana Santos Alves³⁸, S. Ghosh³⁸, A. Gilbert³⁸, R. Granier de Cassagnac³⁸, A. Hakimi³⁸, B. Harikrishnan³⁸, L. Kalipoliti³⁸, G. Liu³⁸, J. Motta³⁸, M. Nguyen³⁸, C. Ochando³⁸, L. Portales³⁸, R. Salerno³⁸, U. Sarkar³⁸, J. B. Sauvan³⁸, Y. Sirois³⁸, A. Tarabini³⁸, E. Vernazza³⁸, A. Zabi³⁸, A. Zghiche³⁸, J.-L. Agram^{39,s}, J. Andrea³⁹, D. Apparu³⁹, D. Bloch³⁹, J.-M. Brom³⁹, E. C. Chabert³⁹, C. Collard³⁹, S. Falke³⁹, U. Goerlach³⁹, C. Grimault³⁹, R. Haeberle³⁹, A.-C. Le Bihan³⁹, M. A. Sessini³⁹, P. Van Hove³⁹, S. Beauceron⁴⁰, B. Blancon⁴⁰, G. Boudoul⁴⁰, N. Chanon⁴⁰, J. Choi⁴⁰, D. Contardo⁴⁰, P. Depasse⁴⁰, C. Dozen^{40,t}, H. El Mamouni⁴⁰, J. Fay⁴⁰, S. Gascon⁴⁰, M. Gouzevitch⁴⁰, C. Greenberg⁴⁰, G. Grenier⁴⁰, B. Ille⁴⁰, I. B. Laktineh⁴⁰, M. Lethuillier⁴⁰, L. Mirabito⁴⁰, S. Perries⁴⁰, M. Vander Donckt⁴⁰, P. Verdier⁴⁰, J. Xiao⁴⁰, I. Lomidze⁴¹, T. Toriashvili^{41,u}, Z. Tsamalaidze^{41,n}, V. Botta⁴², L. Feld⁴², K. Klein⁴², M. Lipinski⁴², D. Meuser⁴², A. Pauls⁴², N. Rowert⁴², M. Teroerde⁴², S. Diekmann⁴³, A. Dodonova⁴³, N. Eich⁴³, D. Eliseev⁴³, F. Engelke⁴³, M. Erdmann⁴³, P. Fackeldey⁴³, B. Fischer⁴³, T. Hebbeker⁴³, K. Hoepfner⁴³, F. Ivone⁴³, A. Jung⁴³, M. y. Lee⁴³, L. Mastrolorenzo⁴³, M. Merschmeyer⁴³, A. Meyer⁴³, S. Mukherjee⁴³, D. Noll⁴³, A. Novak⁴³, F. Nowotny⁴³, A. Pozdnyakov⁴³, Y. Rath⁴³, W. Redjeb⁴³, F. Rehm⁴³, H. Reithler⁴³, V. Sarkisovi⁴³, A. Schmidt⁴³, S. C. Schuler⁴³, A. Sharma⁴³, A. Stein⁴³, F. Torres Da Silva De Araujo^{43,v}, L. Vigilante⁴³, S. Wiedenbeck⁴³, S. Zaleski⁴³

- C. Dziwok⁴⁴, G. Flugge⁴⁴, W. Haj Ahmad^{44,w}, T. Kress⁴⁴, A. Nowack⁴⁴, O. Pooth⁴⁴, A. Stahl⁴⁴, T. Ziemons⁴⁴,
A. Zotz⁴⁴, H. Aarup Petersen⁴⁵, M. Aldaya Martin⁴⁵, J. Alimena⁴⁵, S. Amoroso⁴⁵, Y. An⁴⁵, S. Baxter⁴⁵,
M. Bayatmakou⁴⁵, H. Becerril Gonzalez⁴⁵, O. Behnke⁴⁵, A. Belvedere⁴⁵, S. Bhattacharya⁴⁵, F. Blekman^{45,x},
K. Borras^{45,y}, D. Brunner⁴⁵, A. Campbell⁴⁵, A. Cardini⁴⁵, C. Cheng⁴⁵, F. Colombina⁴⁵,
S. Consuegra Rodriguez⁴⁵, G. Correia Silva⁴⁵, M. De Silva⁴⁵, G. Eckerlin⁴⁵, D. Eckstein⁴⁵, L. I. Estevez Banos⁴⁵,
O. Filatov⁴⁵, E. Gallo^{45,x}, A. Geiser⁴⁵, A. Giraldi⁴⁵, G. Greau⁴⁵, V. Guglielmi⁴⁵, M. Guthoff⁴⁵, A. Hinzmann⁴⁵,
A. Jafari^{45,z}, L. Jeppe⁴⁵, N. Z. Jomhari⁴⁵, H. Jung⁴⁵, B. Kaech⁴⁵, M. Kasemann⁴⁵, H. Kaveh⁴⁵, C. Kleinwort⁴⁵,
R. Kogler⁴⁵, M. Komm⁴⁵, D. Krucker⁴⁵, W. Lange⁴⁵, D. Leyva Pernia⁴⁵, K. Lipka^{45,aa}, W. Lohmann^{45,bb},
R. Mankel⁴⁵, I.-A. Melzer-Pellmann⁴⁵, M. Mendizabal Morentin⁴⁵, J. Metwally⁴⁵, A. B. Meyer⁴⁵, G. Milella⁴⁵,
M. Mormile⁴⁵, A. Mussgiller⁴⁵, A. Nurnberg⁴⁵, Y. Otari⁴⁵, D. Perez Adan⁴⁵, E. Ranken⁴⁵, A. Raspereza⁴⁵,
B. Ribeiro Lopes⁴⁵, J. Rubenach⁴⁵, A. Saggio⁴⁵, M. Scham^{45,cc,y}, V. Scheurer⁴⁵, S. Schnake^{45,y}, P. Schutze⁴⁵,
C. Schwanenberger^{45,x}, M. Shchedrolosiev⁴⁵, R. E. Sosa Ricardo⁴⁵, L. P. Sreelatha Pramod⁴⁵, D. Stafford⁴⁵,
F. Vazzoler⁴⁵, A. Ventura Barroso⁴⁵, R. Walsh⁴⁵, Q. Wang⁴⁵, Y. Wen⁴⁵, K. Wichmann⁴⁵, L. Wiens^{45,y},
C. Wissing⁴⁵, S. Wuchterl⁴⁵, Y. Yang⁴⁵, A. Zimmermann Castro Santos⁴⁵, A. Albrecht⁴⁶, S. Albrecht⁴⁶,
M. Antonello⁴⁶, S. Bein⁴⁶, L. Benato⁴⁶, M. Bonanomi⁴⁶, P. Connor⁴⁶, M. Eich⁴⁶, K. El Morabit⁴⁶, Y. Fischer⁴⁶,
A. Frohlich⁴⁶, C. Garbers⁴⁶, E. Garutti⁴⁶, A. Grohsjean⁴⁶, M. Hajheidari⁴⁶, J. Haller⁴⁶, H. R. Jabusch⁴⁶,
G. Kasieczka⁴⁶, P. Keicher⁴⁶, R. Klanner⁴⁶, W. Korcar⁴⁶, T. Kramer⁴⁶, V. Kutzner⁴⁶, F. Labe⁴⁶, J. Lange⁴⁶,
A. Lobanov⁴⁶, C. Matthies⁴⁶, A. Mehta⁴⁶, L. Moureaux⁴⁶, M. Mrowietz⁴⁶, A. Nigamova⁴⁶, Y. Nissan⁴⁶,
A. Paasch⁴⁶, K. J. Pena Rodriguez⁴⁶, T. Quadfasel⁴⁶, B. Raciti⁴⁶, M. Rieger⁴⁶, D. Savoie⁴⁶, J. Schindler⁴⁶,
P. Schleper⁴⁶, M. Schroder⁴⁶, J. Schwandt⁴⁶, M. Sommerhalder⁴⁶, H. Stadie⁴⁶, G. Steinbrück⁴⁶, A. Tews⁴⁶,
M. Wolf⁴⁶, S. Brommer⁴⁷, M. Burkart⁴⁷, E. Butz⁴⁷, T. Chwalek⁴⁷, A. Dierlamm⁴⁷, A. Droll⁴⁷, N. Faltermann⁴⁷,
M. Giffels⁴⁷, A. Gottmann⁴⁷, F. Hartmann^{47,dd}, M. Horzela⁴⁷, U. Husemann⁴⁷, M. Klute⁴⁷, R. Koppenhofer⁴⁷,
M. Link⁴⁷, A. Lintuluoto⁴⁷, S. Maier⁴⁷, S. Mitra⁴⁷, Th. Muller⁴⁷, M. Neukum⁴⁷, M. Oh⁴⁷, G. Quast⁴⁷,
K. Rabbertz⁴⁷, I. Shvetsov⁴⁷, H. J. Simonis⁴⁷, N. Trevisani⁴⁷, R. Ulrich⁴⁷, J. van der Linden⁴⁷, R. F. Von Cube⁴⁷,
M. Wassmer⁴⁷, S. Wieland⁴⁷, F. Wittig⁴⁷, R. Wolf⁴⁷, S. Wunsch⁴⁷, X. Zuo⁴⁷, G. Anagnostou⁴⁸, P. Assiouras⁴⁸,
G. Daskalakis⁴⁸, A. Kyriakis⁴⁸, A. Papadopoulos^{48,dd}, A. Stakia⁴⁸, D. Karasavvas⁴⁹, P. Kontaxakis⁴⁹,
G. Melachroinos⁴⁹, A. Panagiotou⁴⁹, I. Papavergou⁴⁹, I. Paraskevas⁴⁹, N. Saoulidou⁴⁹, K. Theofilatos⁴⁹,
E. Tziaferi⁴⁹, K. Vellidis⁴⁹, I. Zisopoulos⁴⁹, G. Bakas⁵⁰, T. Chatzistavrou⁵⁰, G. Karapostoli⁵⁰, K. Kousouris⁵⁰,
I. Papakrivopoulos⁵⁰, E. Siamarkou⁵⁰, G. Tsiopolitis⁵⁰, A. Zacharopoulou⁵⁰, K. Adamidis⁵¹, I. Bestintzanos⁵¹,
I. Evangelou⁵¹, C. Foudas⁵¹, P. Gianneios⁵¹, C. Kamtsikis⁵¹, P. Katsoulis⁵¹, P. Kokkas⁵¹,
P. G. Kosmoglou Kioseoglou⁵¹, N. Manthos⁵¹, I. Papadopoulos⁵¹, J. Strolgas⁵¹, M. Bartok^{52,ee}, C. Hajdu⁵²,
D. Horvath^{52,ff,gg}, F. Sikler⁵², V. Veszpremi⁵², M. Csanad⁵³, K. Farkas⁵³, M. M. A. Gadallah^{53,hh},
A. Kadlecik⁵³, P. Major⁵³, K. Mandal⁵³, G. Pasztor⁵³, A. J. Radl^{53,ii}, O. Suranyi⁵³, G. I. Veres⁵³, G. Bencze⁵⁴,
S. Czele⁵⁴, J. Karancsi^{54,ee}, J. Molnar⁵⁴, Z. Szillasi⁵⁴, P. Raics⁵⁵, B. Ujvari^{55,jj}, G. Zilizi⁵⁵, T. Csorgo^{56,ii},
F. Nemes^{56,ii}, T. Novak⁵⁶, J. Babbar⁵⁷, S. Bansal⁵⁷, S. B. Beri⁵⁷, V. Bhatnagar⁵⁷, G. Chaudhary⁵⁷, S. Chauhan⁵⁷,
N. Dhirra^{57,kk}, R. Gupta⁵⁷, A. Kaur⁵⁷, A. Kaur⁵⁷, H. Kaur⁵⁷, M. Kaur⁵⁷, S. Kumar⁵⁷, P. Kumari⁵⁷,
M. Meena⁵⁷, K. Sandeep⁵⁷, T. Sheokand⁵⁷, J. B. Singh^{57,ll}, A. Singla⁵⁷, A. Ahmed⁵⁸, A. Bhardwaj⁵⁸,
A. Chhetri⁵⁸, B. C. Choudhary⁵⁸, A. Kumar⁵⁸, M. Naimuddin⁵⁸, K. Ranjan⁵⁸, S. Saumya⁵⁸, S. Baradia⁵⁹,
S. Barman^{59,mm}, S. Bhattacharya⁵⁹, D. Bhowmik⁵⁹, S. Dutta⁵⁹, S. Dutta⁵⁹, B. Gomber^{59,nn}, P. Palit⁵⁹, G. Saha⁵⁹,
B. Sahu^{59,nn}, S. Sarkar⁵⁹, P. K. Behera⁶⁰, S. C. Behera⁶⁰, S. Chatterjee⁶⁰, P. Jana⁶⁰, P. Kalbhor⁶⁰,
J. R. Komaragiri^{60,oo}, D. Kumar^{60,oo}, M. Mohammad Mobassir Ameen⁶⁰, L. Panwar^{60,oo}, R. Pradhan⁶⁰,
P. R. Pujahari⁶⁰, N. R. Saha⁶⁰, A. Sharma⁶⁰, A. K. Sikdar⁶⁰, S. Verma⁶⁰, T. Aziz⁶¹, I. Das⁶¹, S. Dugad⁶¹,
M. Kumar⁶¹, G. B. Mohanty⁶¹, P. Suryadevara⁶¹, A. Bala⁶², S. Banerjee⁶², R. M. Chatterjee⁶², M. Guchait⁶²,
S. Karmakar⁶², S. Kumar⁶², G. Majumder⁶², K. Mazumdar⁶², S. Mukherjee⁶², A. Thachayath⁶²,
S. Bahinipati^{63,pp}, A. K. Das⁶³, C. Kar⁶³, D. Maity^{63,qq}, P. Mal⁶³, T. Mishra⁶³,
Bindhu V. K. Muraleedharan Nair^{63,qq}, K. Naskar^{63,qq}, A. Nayak^{63,qq}, P. Sadangi⁶³, P. Saha⁶³, S. K. Swain⁶³,
S. Varghese^{63,qq}, D. Vats^{63,qq}, A. Alpana⁶⁴, S. Dube⁶⁴, B. Kansal⁶⁴, A. Laha⁶⁴, S. Pandey⁶⁴, A. Rastogi⁶⁴,
S. Sharma⁶⁴, H. Bakhshiansohi^{65,rr,ss}, E. Khazaie^{65,ss}, M. Zeinali^{65,tt}, S. Chenarani^{66,uu}, S. M. Etesami⁶⁶,
M. Khakzad⁶⁶, M. Mohammadi Najafabadi⁶⁶, M. Grunewald⁶⁷, M. Abbrescia^{68a,68b}, R. Aly^{68a,68b,vv}

A. Colaleo^{68a} D. Creanza^{68a,68c} B. D'Anzi^{68a,68b} N. De Filippis^{68a,68c} M. De Palma^{68a,68b} A. Di Florio^{68a,68c}
W. Elmetenawee^{68a,68b} L. Fiore^{68a} G. Iaselli^{68a,68c} G. Maggi^{68a,68c} M. Maggi^{68a} I. Margjeka^{68a,68b}
V. Mastrapasqua^{68a,68b} S. My^{68a,68b} S. Nuzzo^{68a,68b} A. Pellicchia^{68a,68b} A. Pompili^{68a,68b} G. Pugliese^{68a,68c}
R. Radogna^{68a} G. Ramirez-Sanchez^{68a,68c} D. Ramos^{68a} A. Ranieri^{68a} L. Silvestris^{68a} F. M. Simone^{68a,68b}
U. Sozibilir^{68a} A. Stamerra^{68a} R. Venditti^{68a} P. Verwilligen^{68a} A. Zaza^{68a,68b} G. Abbiendi^{69a}
C. Battilana^{69a,69b} D. Bonacorsi^{69a,69b} L. Borroni^{69a} R. Campanini^{69a,69b} P. Capiluppi^{69a,69b} A. Castro^{69a,69b}
F. R. Cavallo^{69a} M. Cuffiani^{69a,69b} T. Diotallevi^{69a,69b} F. Fabbri^{69a} A. Fanfani^{69a,69b} D. Fasanella^{69a,69b}
P. Giacomelli^{69a} L. Giommi^{69a,69b} C. Grandi^{69a} L. Guiducci^{69a,69b} S. Lo Meo^{69a,ww} L. Lunerti^{69a,69b}
S. Marcellini^{69a} G. Masetti^{69a} F. L. Navarria^{69a,69b} A. Perrotta^{69a} F. Primavera^{69a,69b} A. M. Rossi^{69a,69b}
T. Rovelli^{69a,69b} G. P. Siroli^{69a,69b} S. Costa^{70a,70b,xx} A. Di Mattia^{70a} R. Potenza^{70a,70b} A. Tricomi^{70a,70b,xx}
C. Tuve^{70a,70b} G. Barbagli^{71a} G. Bardelli^{71a,71b} B. Camaiani^{71a,71b} A. Cassese^{71a} R. Ceccarelli^{71a}
V. Ciulli^{71a,71b} C. Civinini^{71a} R. D'Alessandro^{71a,71b} E. Focardi^{71a,71b} G. Latino^{71a,71b} P. Lenzi^{71a,71b}
M. Lizzo^{71a,71b} M. Meschini^{71a} S. Paoletti^{71a} A. Papanastassiou^{71a,71b} G. Sguazzoni^{71a} L. Viliani^{71a}
L. Benussi⁷² S. Bianco⁷² S. Meola^{72,yy} D. Piccolo⁷² P. Chatagnon^{73a} F. Ferro^{73a} E. Robutti^{73a}
S. Tosi^{73a,73b} A. Benaglia^{74a} G. Boldrini^{74a} F. Brivio^{74a,74b} F. Cetorelli^{74a,74b} F. De Guio^{74a,74b}
M. E. Dinardo^{74a,74b} P. Dini^{74a} S. Gennai^{74a} A. Ghezzi^{74a,74b} P. Govoni^{74a,74b} L. Guzzi^{74a,74b}
M. T. Lucchini^{74a,74b} M. Malberti^{74a} S. Malvezzi^{74a} A. Massironi^{74a} D. Menasce^{74a} L. Moroni^{74a}
M. Paganoni^{74a,74b} D. Pedrini^{74a} B. S. Pinolini^{74a} S. Ragazzi^{74a,74b} N. Redaelli^{74a} T. Tabarelli de Fatis^{74a,74b}
D. Zuolo^{74a,74b} S. Buontempo^{75a} A. Cagnotta^{75a,75b} F. Carnevali^{75a,75b} N. Cavallo^{75a,75c} A. De Iorio^{75a,75b}
F. Fabozzi^{75a,75c} A. O. M. Iorio^{75a,75b} L. Lista^{75a,75b,zz} P. Paolucci^{75a,dd} B. Rossi^{75a} C. Sciacca^{75a,75b}
R. Ardino^{76a} P. Azzi^{76a} N. Bacchetta^{76a,aaa} A. Bergnoli^{76a} D. Bisello^{76a,76b} P. Bortignon^{76a}
A. Bragagnolo^{76a,76b} R. Carlin^{76a,76b} P. Checchia^{76a} T. Dorigo^{76a} F. Gasparini^{76a,76b} G. Grosso^{76a} L. Layer^{76a,bbb}
E. Lusiani^{76a} M. Margoni^{76a,76b} A. T. Meneguzzo^{76a,76b} M. Migliorini^{76a,76b} J. Pazzini^{76a,76b} P. Ronchese^{76a,76b}
R. Rossin^{76a,76b} F. Simonetto^{76a,76b} G. Strong^{76a} M. Tosi^{76a,76b} A. Triossi^{76a,76b} S. Ventura^{76a} H. Yarar^{76a,76b}
M. Zanetti^{76a,76b} P. Zotto^{76a,76b} A. Zucchetta^{76a,76b} G. Zumerle^{76a,76b} S. Abu Zeid^{77a,ccc} C. Aime^{77a,77b}
A. Braghieri^{77a} S. Calzaferri^{77a,77b} D. Fiorina^{77a,77b} P. Montagna^{77a,77b} V. Re^{77a} C. Riccardi^{77a,77b}
P. Salvini^{77a} I. Vai^{77a,77b} P. Vitulo^{77a,77b} S. Ajmal^{78a,78b} P. Asenov^{78a,ddd} G. M. Bilei^{78a} D. Ciangottini^{78a,78b}
L. Fano^{78a,78b} M. Magherini^{78a,78b} G. Mantovani^{78a,78b} V. Mariani^{78a,78b} M. Menichelli^{78a} F. Moscatelli^{78a,ddd}
A. Piccinelli^{78a,78b} M. Presilla^{78a,78b} A. Rossi^{78a,78b} A. Santocchia^{78a,78b} D. Spiga^{78a} T. Tedeschi^{78a,78b}
P. Azzurri^{79a} G. Bagliesi^{79a} R. Bhattacharya^{79a} L. Bianchini^{79a,79b} T. Boccali^{79a} E. Bossini^{79a}
D. Bruschini^{79a,79c} R. Castaldi^{79a} M. A. Ciocci^{79a,79b} M. Cipriani^{79a,79b} V. D'Amante^{79a,79d} R. Dell'Orso^{79a}
S. Donato^{79a} A. Giassi^{79a} F. Ligabue^{79a,79c} D. Matos Figueiredo^{79a} A. Messineo^{79a,79b} M. Musich^{79a,79b}
F. Palla^{79a} S. Parolia^{79a} A. Rizzi^{79a,79b} G. Rolandi^{79a,79c} S. Roy Chowdhury^{79a} T. Sarkar^{79a} A. Scribano^{79a}
P. Spagnolo^{79a} R. Tenchini^{79a,79b} G. Tonelli^{79a,79b} N. Turini^{79a,79d} A. Venturi^{79a} P. G. Verdini^{79a} P. Barria^{80a}
M. Campana^{80a,80b} F. Cavallari^{80a} L. Cunqueiro Mendez^{80a,80b} D. Del Re^{80a,80b} E. Di Marco^{80a} M. Diemoz^{80a}
F. Errico^{80a,80b} E. Longo^{80a,80b} P. Meridiani^{80a} J. Mijuskovic^{80a,80b} G. Organtini^{80a,80b} F. Pandolfi^{80a}
R. Paramatti^{80a,80b} C. Quaranta^{80a,80b} S. Rahatlou^{80a,80b} C. Rovelli^{80a} F. Santanastasio^{80a,80b} L. Soffi^{80a}
R. Tramontano^{80a,80b} N. Amapane^{81a,81b} R. Arcidiacono^{81a,81c} S. Argiro^{81a,81b} M. Arneodo^{81a,81c} N. Bartosik^{81a}
R. Bellan^{81a,81b} A. Bellora^{81a,81b} C. Biino^{81a} N. Cartiglia^{81a} M. Costa^{81a,81b} R. Covarelli^{81a,81b} N. Demaria^{81a}
L. Finco^{81a} M. Grippo^{81a,81b} B. Kiani^{81a,81b} F. Legger^{81a} F. Luongo^{81a,81b} C. Mariotti^{81a} S. Maselli^{81a}
A. Mecca^{81a,81b} E. Migliore^{81a,81b} M. Monteno^{81a} R. Mulargia^{81a} M. M. Obertino^{81a,81b} G. Ortona^{81a}
L. Pacher^{81a,81b} N. Pastrone^{81a} M. Pelliccioni^{81a} M. Ruspa^{81a,81c} F. Siviero^{81a,81b} V. Sola^{81a,81b}
A. Solano^{81a,81b} D. Soldi^{81a,81b} A. Staiano^{81a} C. Tarricone^{81a,81b} M. Tornago^{81a,81b} D. Trocino^{81a}
G. Umoret^{81a,81b} A. Vagnerini^{81a,81b} E. Vlasov^{81a,81b} S. Belforte^{82a} V. Candelise^{82a,82b} M. Casarsa^{82a}
F. Cossutti^{82a} K. De Leo^{82a,82b} G. Della Ricca^{82a,82b} G. Sorrentino^{82a,82b} S. Dogra⁸³ C. Huh⁸³ B. Kim⁸³
D. H. Kim⁸³ J. Kim⁸³ J. Lee⁸³ S. W. Lee⁸³ C. S. Moon⁸³ Y. D. Oh⁸³ S. I. Pak⁸³ M. S. Ryu⁸³
S. Sekmen⁸³ Y. C. Yang⁸³ G. Bak⁸⁴ P. Gwak⁸⁴ H. Kim⁸⁴ D. H. Moon⁸⁴ E. Asilar⁸⁵ D. Kim⁸⁵
T. J. Kim⁸⁵ J. A. Merlin⁸⁵ J. Park⁸⁵ S. Choi⁸⁶ S. Han⁸⁶ B. Hong⁸⁶ K. Lee⁸⁶ K. S. Lee⁸⁶ J. Park⁸⁶ S. K. Park⁸⁶
J. Yoo⁸⁶ J. Goh⁸⁷ H. S. Kim⁸⁸ Y. Kim⁸⁸ S. Lee⁸⁸ J. Almond⁸⁹ J. H. Bhyun⁸⁹ J. Choi⁸⁹ S. Jeon⁸⁹ W. Jun⁸⁹

J. Kim,⁸⁹ J. S. Kim,⁸⁹ S. Ko,⁸⁹ H. Kwon,⁸⁹ H. Lee,⁸⁹ J. Lee,⁸⁹ S. Lee,⁸⁹ B. H. Oh,⁸⁹ S. B. Oh,⁸⁹ H. Seo,⁸⁹ U. K. Yang,⁸⁹ I. Yoon,⁸⁹ W. Jang,⁹⁰ D. Y. Kang,⁹⁰ Y. Kang,⁹⁰ S. Kim,⁹⁰ B. Ko,⁹⁰ J. S. H. Lee,⁹⁰ Y. Lee,⁹⁰ I. C. Park,⁹⁰ Y. Roh,⁹⁰ I. J. Watson,⁹⁰ S. Yang,⁹⁰ S. Ha,⁹¹ H. D. Yoo,⁹¹ M. Choi,⁹² M. R. Kim,⁹² H. Lee,⁹² Y. Lee,⁹² I. Yu,⁹² T. Beyrouthy,⁹³ Y. Maghrbi,⁹³ K. Dreimanis,⁹⁴ A. Gaile,⁹⁴ G. Pikurs,⁹⁴ A. Potrebko,⁹⁴ M. Seidel,⁹⁴ V. Veckalns,^{94,eee} N. R. Strautnieks,⁹⁵ M. Ambrozys,⁹⁶ A. Juodagalvis,⁹⁶ A. Rinkevicius,⁹⁶ G. Tamulaitis,⁹⁶ N. Bin Norjoharuddeen,⁹⁷ I. Yusuff,^{97,fff} Z. Zolkapli,⁹⁷ J. F. Benitez,⁹⁸ A. Castaneda Hernandez,⁹⁸ H. A. Encinas Acosta,⁹⁸ L. G. Gallegos Martinez,⁹⁸ M. Leon Coello,⁹⁸ J. A. Murillo Quijada,⁹⁸ A. Sehwat,⁹⁸ L. Valencia Palomo,⁹⁸ G. Ayala,⁹⁹ H. Castilla-Valdez,⁹⁹ E. De La Cruz-Burelo,⁹⁹ I. Heredia-De La Cruz,^{99,ggg} R. Lopez-Fernandez,⁹⁹ C. A. Mondragon Herrera,⁹⁹ D. A. Perez Navarro,⁹⁹ A. Sanchez Hernandez,⁹⁹ C. Oropeza Barrera,¹⁰⁰ M. Ramirez Garcia,¹⁰⁰ I. Bautista,¹⁰¹ I. Pedraza,¹⁰¹ H. A. Salazar Ibarguen,¹⁰¹ C. Uribe Estrada,¹⁰¹ I. Bujanja,¹⁰² N. Raicevic,¹⁰² P. H. Butler,¹⁰³ A. Ahmad,¹⁰⁴ M. I. Asghar,¹⁰⁴ A. Awais,¹⁰⁴ M. I. M. Awan,¹⁰⁴ H. R. Hoorani,¹⁰⁴ W. A. Khan,¹⁰⁴ V. Avati,¹⁰⁵ L. Grzanka,¹⁰⁵ M. Malawski,¹⁰⁵ H. Bialkowska,¹⁰⁶ M. Bluj,¹⁰⁶ B. Boimska,¹⁰⁶ M. Gorski,¹⁰⁶ M. Kazana,¹⁰⁶ M. Szeleper,¹⁰⁶ P. Zalewski,¹⁰⁶ K. Bunkowski,¹⁰⁷ K. Doroba,¹⁰⁷ A. Kalinowski,¹⁰⁷ M. Konecki,¹⁰⁷ J. Krolikowski,¹⁰⁷ K. Pozniak,¹⁰⁸ W. Zabolotny,¹⁰⁸ M. Araujo,¹⁰⁹ D. Bastos,¹⁰⁹ C. Beirao Da Cruz E Silva,¹⁰⁹ A. Boletti,¹⁰⁹ M. Bozzo,¹⁰⁹ P. Faccioli,¹⁰⁹ M. Gallinaro,¹⁰⁹ J. Hollar,¹⁰⁹ N. Leonardo,¹⁰⁹ T. Niknejad,¹⁰⁹ M. Pisano,¹⁰⁹ J. Seixas,¹⁰⁹ J. Varela,¹⁰⁹ P. Adzic,¹¹⁰ P. Milenovic,¹¹⁰ M. Dordevic,¹¹¹ J. Milosevic,¹¹¹ V. Rekovic,¹¹¹ M. Aguilar-Benitez,¹¹² J. Alcaraz Maestre,¹¹² M. Barrio Luna,¹¹² Cristina F. Bedoya,¹¹² M. Cepeda,¹¹² M. Cerrada,¹¹² N. Colino,¹¹² B. De La Cruz,¹¹² A. Delgado Peris,¹¹² D. Fernandez Del Val,¹¹² J. P. Fernandez Ramos,¹¹² J. Flix,¹¹² M. C. Fouz,¹¹² O. Gonzalez Lopez,¹¹² S. Goy Lopez,¹¹² J. M. Hernandez,¹¹² M. I. Josa,¹¹² J. Leon Holgado,¹¹² D. Moran,¹¹² C. M. Morcillo Perez,¹¹² A. Navarro Tobar,¹¹² C. Perez Dengra,¹¹² A. Perez-Calero Yzquierdo,¹¹² J. Puerta Pelayo,¹¹² I. Redondo,¹¹² D. D. Redondo Ferrero,¹¹² L. Romero,¹¹² S. Sanchez Navas,¹¹² L. Urda Gomez,¹¹² J. Vazquez Escobar,¹¹² C. Willmott,¹¹² J. F. de Troconiz,¹¹³ B. Alvarez Gonzalez,¹¹⁴ J. Cuevas,¹¹⁴ J. Fernandez Menendez,¹¹⁴ S. Folgueras,¹¹⁴ I. Gonzalez Caballero,¹¹⁴ J. R. Gonzalez Fernandez,¹¹⁴ E. Palencia Cortezon,¹¹⁴ C. Ramon Alvarez,¹¹⁴ V. Rodriguez Bouza,¹¹⁴ A. Soto Rodriguez,¹¹⁴ A. Trapote,¹¹⁴ C. Vico Villalba,¹¹⁴ P. Vischia,¹¹⁴ S. Bhowmik,¹¹⁵ S. Blanco Fernandez,¹¹⁵ J. A. Brochero Cifuentes,¹¹⁵ I. J. Cabrillo,¹¹⁵ A. Calderon,¹¹⁵ J. Duarte Campderros,¹¹⁵ M. Fernandez,¹¹⁵ C. Fernandez Madrazo,¹¹⁵ G. Gomez,¹¹⁵ C. Lasasoa Garcia,¹¹⁵ C. Martinez Rivero,¹¹⁵ P. Martinez Ruiz del Arbol,¹¹⁵ F. Matorras,¹¹⁵ P. Matorras Cuevas,¹¹⁵ E. Navarrete Ramos,¹¹⁵ J. Piedra Gomez,¹¹⁵ C. Prieels,¹¹⁵ L. Scodellaro,¹¹⁵ I. Vila,¹¹⁵ J. M. Vizan Garcia,¹¹⁵ M. K. Jayananda,¹¹⁶ B. Kailasapathy,^{116,hhh} D. U. J. Sonnadara,¹¹⁶ D. D. C. Wickramaratna,¹¹⁶ W. G. D. Dharmaratna,¹¹⁷ K. Liyanage,¹¹⁷ N. Perera,¹¹⁷ N. Wickramage,¹¹⁷ D. Abbaneo,¹¹⁸ C. Amendola,¹¹⁸ E. Auffray,¹¹⁸ G. Auzinger,¹¹⁸ J. Baechler,¹¹⁸ D. Barney,¹¹⁸ A. Bermudez Martinez,¹¹⁸ M. Bianco,¹¹⁸ B. Bilin,¹¹⁸ A. A. Bin Anuar,¹¹⁸ A. Bocci,¹¹⁸ E. Brondolin,¹¹⁸ C. Caillol,¹¹⁸ T. Camporesi,¹¹⁸ G. Cerminara,¹¹⁸ N. Chernyavskaya,¹¹⁸ D. d'Enterria,¹¹⁸ A. Dabrowski,¹¹⁸ A. David,¹¹⁸ A. De Roeck,¹¹⁸ M. M. Defranchis,¹¹⁸ M. Deile,¹¹⁸ M. Dobson,¹¹⁸ F. Fallavollita,^{118,iii} L. Forthomme,¹¹⁸ G. Franzoni,¹¹⁸ W. Funk,¹¹⁸ S. Giani,¹¹⁸ D. Gigi,¹¹⁸ K. Gill,¹¹⁸ F. Glege,¹¹⁸ L. Gouskos,¹¹⁸ M. Haranko,¹¹⁸ J. Hegeman,¹¹⁸ V. Innocente,¹¹⁸ T. James,¹¹⁸ P. Janot,¹¹⁸ J. Kieseler,¹¹⁸ N. Kratochwil,¹¹⁸ S. Laurila,¹¹⁸ P. Lecoq,¹¹⁸ E. Leutgeb,¹¹⁸ C. Lourenco,¹¹⁸ B. Maier,¹¹⁸ L. Malgeri,¹¹⁸ M. Mannelli,¹¹⁸ A. C. Marini,¹¹⁸ F. Meijers,¹¹⁸ S. Mersi,¹¹⁸ E. Meschi,¹¹⁸ V. Milosevic,¹¹⁸ F. Moortgat,¹¹⁸ M. Mulders,¹¹⁸ S. Orfanelli,¹¹⁸ F. Pantaleo,¹¹⁸ M. Peruzzi,¹¹⁸ A. Petrilli,¹¹⁸ G. Petrucciani,¹¹⁸ A. Pfeiffer,¹¹⁸ M. Pierini,¹¹⁸ D. Piparo,¹¹⁸ H. Qu,¹¹⁸ D. Rabady,¹¹⁸ G. Reales Gutierrez,¹¹⁸ M. Rovere,¹¹⁸ H. Sakulin,¹¹⁸ S. Scarfi,¹¹⁸ C. Schwick,¹¹⁸ M. Selvaggi,¹¹⁸ A. Sharma,¹¹⁸ K. Shchelina,¹¹⁸ P. Silva,¹¹⁸ P. Sphicas,^{118,iii} A. G. Stahl Leiton,¹¹⁸ A. Steen,¹¹⁸ S. Summers,¹¹⁸ D. Treille,¹¹⁸ P. Tropea,¹¹⁸ A. Tsiros,¹¹⁸ D. Walter,¹¹⁸ J. Wanczyk,^{118,kkk} K. A. Wozniak,¹¹⁸ P. Zehetner,¹¹⁸ P. Zejdl,¹¹⁸ W. D. Zeuner,¹¹⁸ T. Bevilacqua,^{119,iii} L. Caminada,^{119,iii} A. Ebrahimi,¹¹⁹ W. Erdmann,¹¹⁹ R. Horisberger,¹¹⁹ Q. Ingram,¹¹⁹ H. C. Kaestli,¹¹⁹ D. Kotlinski,¹¹⁹ C. Lange,¹¹⁹ M. Missiroli,^{119,iii} L. Nohte,^{119,iii} T. Rohe,¹¹⁹ T. K. Aarrestad,¹²⁰ K. Androsov,^{120,kkk} M. Backhaus,¹²⁰ A. Calandri,¹²⁰ C. Cazzaniga,¹²⁰ K. Datta,¹²⁰ A. De Cosa,¹²⁰ G. Dissertori,¹²⁰ M. Dittmar,¹²⁰ M. Donega,¹²⁰ F. Eble,¹²⁰ M. Galli,¹²⁰ K. Gedia,¹²⁰ F. Glessgen,¹²⁰ C. Grab,¹²⁰ D. Hits,¹²⁰ W. Lustermann,¹²⁰ A.-M. Lyon,¹²⁰ R. A. Manzoni,¹²⁰ M. Marchegiani,¹²⁰ L. Marchese,¹²⁰ C. Martin Perez,¹²⁰ A. Mascellani,^{120,kkk}

F. Nessi-Tedaldi¹²⁰, F. Pauss¹²⁰, V. Perovic¹²⁰, S. Pigazzini¹²⁰, M. G. Ratti¹²⁰, M. Reichmann¹²⁰, C. Reissel¹²⁰, T. Reitenspiess¹²⁰, B. Ristic¹²⁰, F. Riti¹²⁰, D. Ruini¹²⁰, D. A. Sanz Becerra¹²⁰, R. Seidita¹²⁰, J. Steggemann^{120,kkk}, D. Valsecchi¹²⁰, R. Wallny¹²⁰, C. Amsler^{121,mmm}, P. Bartschi¹²¹, C. Botta¹²¹, D. Brzhechko¹²¹, M. F. Canelli¹²¹, K. Cormier¹²¹, A. De Wit¹²¹, R. Del Burgo¹²¹, J. K. Heikkilä¹²¹, M. Huwiler¹²¹, W. Jin¹²¹, A. Jofrehei¹²¹, B. Kilminster¹²¹, S. Leontsinis¹²¹, S. P. Liechti¹²¹, A. Macchiolo¹²¹, P. Meiring¹²¹, V. M. Mikuni¹²¹, U. Molinatti¹²¹, I. Neutelings¹²¹, A. Reimers¹²¹, P. Robmann¹²¹, S. Sanchez Cruz¹²¹, K. Schweiger¹²¹, M. Senger¹²¹, Y. Takahashi¹²¹, C. Adloff^{122,nnn}, C. M. Kuo¹²², W. Lin¹²², P. K. Rout¹²², P. C. Tiwari^{122,oo}, S. S. Yu¹²², L. Ceard¹²³, Y. Chao¹²³, K. F. Chen¹²³, P. s. Chen¹²³, Z. g. Chen¹²³, W.-S. Hou¹²³, T. h. Hsu¹²³, Y. w. Kao¹²³, R. Khurana¹²³, G. Kole¹²³, Y. y. Li¹²³, R.-S. Lu¹²³, E. Paganis¹²³, A. Psallidas¹²³, X. f. Su¹²³, J. Thomas-Wilsker¹²³, H. y. Wu¹²³, E. Yazgan¹²³, C. Asawatangkuldee¹²⁴, N. Srimanobhas¹²⁴, V. Wachirapusanand¹²⁴, D. Agyel¹²⁵, F. Boran¹²⁵, Z. S. Demiroglu¹²⁵, F. Dolek¹²⁵, I. Dumanoglu^{125,ooo}, E. Eskut¹²⁵, Y. Guler^{125,ppp}, E. Gurpinar Guler^{125,ppp}, C. Isik¹²⁵, O. Kara¹²⁵, A. Kayis Topaksu¹²⁵, U. Kiminsu¹²⁵, G. Onengut¹²⁵, K. Ozdemir^{125,qqq}, A. Polatoz¹²⁵, B. Tali^{125,rrr}, U. G. Tok¹²⁵, S. Turkcpar¹²⁵, E. Uslan¹²⁵, I. S. Zorbakir¹²⁵, K. Ocalan^{126,sss}, M. Yalvac^{126,ttt}, B. Akgun¹²⁷, I. O. Atakisi¹²⁷, E. Gulmez¹²⁷, M. Kaya^{127,uuu}, O. Kaya^{127,vvv}, S. Tekten^{127,www}, A. Cakir¹²⁸, K. Cankocak^{128,ooo}, Y. Komurcu¹²⁸, S. Sen^{128,xxx}, O. Aydilek¹²⁹, S. Cerci^{129,rrr}, V. Epshteyn¹²⁹, B. Haciasahinoglu¹²⁹, I. Hos^{129,yyy}, B. Isildak^{129,zzz}, B. Kaynak¹²⁹, S. Ozkorucuklu¹²⁹, H. Sert¹²⁹, C. Simsek¹²⁹, D. Sunar Cerci^{129,rrr}, C. Zorbilmez¹²⁹, A. Boyaryntsev¹³⁰, B. Grynyov¹³⁰, L. Levchuk¹³¹, D. Anthony¹³², J. J. Brooke¹³², A. Bundock¹³², F. Bury¹³², E. Clement¹³², D. Cussans¹³², H. Flacher¹³², M. Glowacki¹³², J. Goldstein¹³², H. F. Heath¹³², L. Kreczko¹³², B. Krikler¹³², S. Paramesvaran¹³², S. Seif El Nasr-Storey¹³², V. J. Smith¹³², N. Stylianou^{132,aaaa}, K. Walkingshaw Pass¹³², R. White¹³², A. H. Ball¹³³, K. W. Bell¹³³, A. Belyaev^{133,bbbb}, C. Brew¹³³, R. M. Brown¹³³, D. J. A. Cockerill¹³³, C. Cooke¹³³, K. V. Ellis¹³³, K. Harder¹³³, S. Harper¹³³, M.-L. Holmberg^{133,ccccc}, Sh. Jain¹³³, J. Linacre¹³³, K. Manolopoulos¹³³, D. M. Newbold¹³³, E. Olaiya¹³³, D. Petyt¹³³, T. Reis¹³³, G. Salvi¹³³, T. Schuh¹³³, C. H. Shepherd-Themistocleous¹³³, I. R. Tomalin¹³³, T. Williams¹³³, R. Bainbridge¹³⁴, P. Bloch¹³⁴, C. E. Brown¹³⁴, O. Buchmuller¹³⁴, V. Cacchio¹³⁴, C. A. Carrillo Montoya¹³⁴, G. S. Chahal^{134,dddd}, D. Colling¹³⁴, J. S. Dancu¹³⁴, P. Dauncey¹³⁴, G. Davies¹³⁴, J. Davies¹³⁴, M. Della Negra¹³⁴, S. Fayer¹³⁴, G. Fedi¹³⁴, G. Hall¹³⁴, M. H. Hassanshahi¹³⁴, A. Howard¹³⁴, G. Iles¹³⁴, M. Knight¹³⁴, J. Langford¹³⁴, L. Lyons¹³⁴, A.-M. Magnan¹³⁴, S. Malik¹³⁴, A. Martelli¹³⁴, M. Mieskolainen¹³⁴, J. Nash^{134,eeee}, M. Pesaresi¹³⁴, B. C. Radburn-Smith¹³⁴, A. Richards¹³⁴, A. Rose¹³⁴, C. Seez¹³⁴, R. Shukla¹³⁴, A. Tapper¹³⁴, K. Uchida¹³⁴, G. P. Uttley¹³⁴, L. H. Vage¹³⁴, T. Virdee^{134,dd}, M. Vojinovic¹³⁴, N. Wardle¹³⁴, D. Winterbottom¹³⁴, K. Coldham¹³⁵, J. E. Cole¹³⁵, A. Khan¹³⁵, P. Kyberd¹³⁵, I. D. Reid¹³⁵, S. Abdullin¹³⁶, A. Brinkerhoff¹³⁶, B. Caraway¹³⁶, J. Dittmann¹³⁶, K. Hatakeyama¹³⁶, J. Hiltbrand¹³⁶, A. R. Kanuganti¹³⁶, B. McMaster¹³⁶, M. Saunders¹³⁶, S. Sawant¹³⁶, C. Sutantawibul¹³⁶, M. Toms¹³⁶, J. Wilson¹³⁶, R. Bartek¹³⁷, A. Dominguez¹³⁷, C. Huerta Escamilla¹³⁷, A. E. Simsek¹³⁷, R. Uniyal¹³⁷, A. M. Vargas Hernandez¹³⁷, R. Chudasama¹³⁸, S. I. Cooper¹³⁸, S. V. Gleyzer¹³⁸, C. U. Perez¹³⁸, P. Rumerio^{138,ffff}, E. Usai¹³⁸, C. West¹³⁸, A. Akpinar¹³⁹, A. Albert¹³⁹, D. Arcaro¹³⁹, C. Cosby¹³⁹, Z. Demiragli¹³⁹, C. Erice¹³⁹, E. Fontanesi¹³⁹, D. Gastler¹³⁹, J. Rohlf¹³⁹, K. Salyer¹³⁹, D. Sperka¹³⁹, D. Spitzbart¹³⁹, I. Suarez¹³⁹, A. Tsatsos¹³⁹, S. Yuan¹³⁹, G. Benelli¹⁴⁰, X. Coubez^{140,y}, D. Cutts¹⁴⁰, M. Hadley¹⁴⁰, U. Heintz¹⁴⁰, J. M. Hogan^{140,gggg}, T. Kwon¹⁴⁰, G. Landsberg¹⁴⁰, K. T. Lau¹⁴⁰, D. Li¹⁴⁰, J. Luo¹⁴⁰, S. Mondal¹⁴⁰, M. Narain^{140,a}, N. Pervan¹⁴⁰, S. Sagir^{140,hhhh}, F. Simpson¹⁴⁰, W. Y. Wong¹⁴⁰, X. Yan¹⁴⁰, D. Yu¹⁴⁰, W. Zhang¹⁴⁰, S. Abbott¹⁴¹, J. Bonilla¹⁴¹, C. Brainerd¹⁴¹, R. Breedon¹⁴¹, M. Calderon De La Barca Sanchez¹⁴¹, M. Chertok¹⁴¹, M. Citron¹⁴¹, J. Conway¹⁴¹, P. T. Cox¹⁴¹, R. Erbacher¹⁴¹, G. Haza¹⁴¹, F. Jensen¹⁴¹, O. Kukral¹⁴¹, G. Mocellin¹⁴¹, M. Mulhearn¹⁴¹, D. Pellett¹⁴¹, B. Regnery¹⁴¹, W. Wei¹⁴¹, Y. Yao¹⁴¹, F. Zhang¹⁴¹, M. Bachtis¹⁴², R. Cousins¹⁴², A. Datta¹⁴², J. Hauser¹⁴², M. Ignatenko¹⁴², M. A. Iqbal¹⁴², T. Lam¹⁴², E. Manca¹⁴², W. A. Nash¹⁴², D. Saltzberg¹⁴², B. Stone¹⁴², V. Valuev¹⁴², R. Clare¹⁴³, M. Gordon¹⁴³, G. Hanson¹⁴³, W. Si¹⁴³, S. Wimpenny^{143,a}, J. G. Branson¹⁴⁴, S. Cittolin¹⁴⁴, S. Cooperstein¹⁴⁴, D. Diaz¹⁴⁴, J. Duarte¹⁴⁴, R. Gerosa¹⁴⁴, L. Giannini¹⁴⁴, J. Guiang¹⁴⁴, R. Kansal¹⁴⁴, V. Krutelyov¹⁴⁴, R. Lee¹⁴⁴, J. Letts¹⁴⁴, M. Masciovecchio¹⁴⁴, F. Mokhtar¹⁴⁴, M. Pieri¹⁴⁴, M. Quinnan¹⁴⁴, B. V. Sathia Narayanan¹⁴⁴, V. Sharma¹⁴⁴, M. Tadel¹⁴⁴, E. Vourliotis¹⁴⁴, F. Wurthwein¹⁴⁴, Y. Xiang¹⁴⁴, A. Yagil¹⁴⁴, L. Brennan¹⁴⁵, C. Campagnari¹⁴⁵, G. Collura¹⁴⁵, A. Dorsett¹⁴⁵, J. Incandela¹⁴⁵, M. Kilpatrick¹⁴⁵, J. Kim¹⁴⁵, A. J. Li¹⁴⁵, P. Masterson¹⁴⁵

H. Mei¹⁴⁵, M. Oshiro¹⁴⁵, J. Richman¹⁴⁵, U. Sarica¹⁴⁵, R. Schmitz¹⁴⁵, F. Setti¹⁴⁵, J. Sheplock¹⁴⁵, D. Stuart¹⁴⁵, S. Wang¹⁴⁵, A. Bornheim¹⁴⁶, O. Cerri¹⁴⁶, A. Latorre¹⁴⁶, J. M. Lawhorn¹⁴⁶, J. Mao¹⁴⁶, H. B. Newman¹⁴⁶, T. Q. Nguyen¹⁴⁶, M. Spiropulu¹⁴⁶, J. R. Vlimant¹⁴⁶, C. Wang¹⁴⁶, S. Xie¹⁴⁶, R. Y. Zhu¹⁴⁶, J. Alison¹⁴⁷, S. An¹⁴⁷, M. B. Andrews¹⁴⁷, P. Bryant¹⁴⁷, V. Dutta¹⁴⁷, T. Ferguson¹⁴⁷, A. Harilal¹⁴⁷, C. Liu¹⁴⁷, T. Mudholkar¹⁴⁷, S. Murthy¹⁴⁷, M. Paulini¹⁴⁷, A. Roberts¹⁴⁷, A. Sanchez¹⁴⁷, W. Terrill¹⁴⁷, J. P. Cumalat¹⁴⁸, W. T. Ford¹⁴⁸, A. Hassani¹⁴⁸, G. Karathanasis¹⁴⁸, E. MacDonald¹⁴⁸, N. Manganelli¹⁴⁸, F. Marini¹⁴⁸, A. Perloff¹⁴⁸, C. Savard¹⁴⁸, N. Schonbeck¹⁴⁸, K. Stenson¹⁴⁸, K. A. Ulmer¹⁴⁸, S. R. Wagner¹⁴⁸, N. Zipper¹⁴⁸, J. Alexander¹⁴⁹, S. Bright-Thonney¹⁴⁹, X. Chen¹⁴⁹, D. J. Cranshaw¹⁴⁹, J. Fan¹⁴⁹, X. Fan¹⁴⁹, D. Gadkari¹⁴⁹, S. Hogan¹⁴⁹, J. Monroy¹⁴⁹, J. R. Patterson¹⁴⁹, J. Reichert¹⁴⁹, M. Reid¹⁴⁹, A. Ryd¹⁴⁹, J. Thom¹⁴⁹, P. Wittich¹⁴⁹, R. Zou¹⁴⁹, M. Albrow¹⁵⁰, M. Alyari¹⁵⁰, O. Amram¹⁵⁰, G. Apollinari¹⁵⁰, A. Apresyan¹⁵⁰, L. A. T. Bauerdick¹⁵⁰, D. Berry¹⁵⁰, J. Berryhill¹⁵⁰, P. C. Bhat¹⁵⁰, K. Burkett¹⁵⁰, J. N. Butler¹⁵⁰, A. Canepa¹⁵⁰, G. B. Cerati¹⁵⁰, H. W. K. Cheung¹⁵⁰, F. Chlebana¹⁵⁰, G. Cummings¹⁵⁰, J. Dickinson¹⁵⁰, I. Dutta¹⁵⁰, V. D. Elvira¹⁵⁰, Y. Feng¹⁵⁰, J. Freeman¹⁵⁰, A. Gandrakota¹⁵⁰, Z. Gece¹⁵⁰, L. Gray¹⁵⁰, D. Green¹⁵⁰, S. Grunendahl¹⁵⁰, D. Guerrero¹⁵⁰, O. Gutsche¹⁵⁰, R. M. Harris¹⁵⁰, R. Heller¹⁵⁰, T. C. Herwig¹⁵⁰, J. Hirschauer¹⁵⁰, L. Horyn¹⁵⁰, B. Jayatilaka¹⁵⁰, S. Jindariani¹⁵⁰, M. Johnson¹⁵⁰, U. Joshi¹⁵⁰, T. Klijnsma¹⁵⁰, B. Klima¹⁵⁰, K. H. M. Kwok¹⁵⁰, S. Lammel¹⁵⁰, D. Lincoln¹⁵⁰, R. Lipton¹⁵⁰, T. Liu¹⁵⁰, C. Madrid¹⁵⁰, K. Maeshima¹⁵⁰, C. Mantilla¹⁵⁰, D. Mason¹⁵⁰, P. McBride¹⁵⁰, P. Merkel¹⁵⁰, S. Mrenna¹⁵⁰, S. Nahn¹⁵⁰, J. Ngadiuba¹⁵⁰, D. Noonan¹⁵⁰, V. Papadimitriou¹⁵⁰, N. Pastika¹⁵⁰, K. Pedro¹⁵⁰, C. Pena^{150,iii}, F. Ravera¹⁵⁰, A. Reinsvold Hall^{150,iii}, L. Ristori¹⁵⁰, E. Sexton-Kennedy¹⁵⁰, N. Smith¹⁵⁰, A. Soha¹⁵⁰, L. Spiegel¹⁵⁰, S. Stoynev¹⁵⁰, J. Strait¹⁵⁰, L. Taylor¹⁵⁰, S. Tkaczyk¹⁵⁰, N. V. Tran¹⁵⁰, L. Uplegger¹⁵⁰, E. W. Vaandering¹⁵⁰, I. Zoi¹⁵⁰, C. Aruta¹⁵¹, P. Avery¹⁵¹, D. Bourilkov¹⁵¹, L. Cadamuro¹⁵¹, P. Chang¹⁵¹, V. Cherepanov¹⁵¹, R. D. Field¹⁵¹, E. Koenig¹⁵¹, M. Kolosova¹⁵¹, J. Konigsberg¹⁵¹, A. Korytov¹⁵¹, K. H. Lo¹⁵¹, K. Matchev¹⁵¹, N. Menendez¹⁵¹, G. Mitselmakher¹⁵¹, A. Muthirakalayil Madhu¹⁵¹, N. Rawal¹⁵¹, D. Rosenzweig¹⁵¹, S. Rosenzweig¹⁵¹, K. Shi¹⁵¹, J. Wang¹⁵¹, T. Adams¹⁵², A. Al Kadhimi¹⁵², A. Askew¹⁵², N. Bower¹⁵², R. Habibullah¹⁵², V. Hagopian¹⁵², R. Hashmi¹⁵², R. S. Kim¹⁵², S. Kim¹⁵², T. Kolberg¹⁵², G. Martinez¹⁵², H. Prosper¹⁵², P. R. Prova¹⁵², O. Viazlo¹⁵², M. Wulansatiti¹⁵², R. Yohay¹⁵², J. Zhang¹⁵², B. Alsufyani¹⁵³, M. M. Baarmand¹⁵³, S. Butalla¹⁵³, T. Elkafrawy^{153,ccc}, M. Hohmann¹⁵³, R. Kumar Verma¹⁵³, M. Rahmani¹⁵³, F. Yumiceva¹⁵³, M. R. Adams¹⁵⁴, C. Bennett¹⁵⁴, R. Cavanaugh¹⁵⁴, S. Dittmer¹⁵⁴, R. Escobar Franco¹⁵⁴, O. Evdokimov¹⁵⁴, C. E. Gerber¹⁵⁴, D. J. Hofman¹⁵⁴, J. h. Lee¹⁵⁴, D. S. Lemos¹⁵⁴, A. H. Merrit¹⁵⁴, C. Mills¹⁵⁴, S. Nanda¹⁵⁴, G. Oh¹⁵⁴, B. Ozek¹⁵⁴, D. Pilipovic¹⁵⁴, T. Roy¹⁵⁴, S. Rudrabhatla¹⁵⁴, M. B. Tonjes¹⁵⁴, N. Varelas¹⁵⁴, X. Wang¹⁵⁴, Z. Ye¹⁵⁴, J. Yoo¹⁵⁴, M. Alhusseini¹⁵⁵, D. Blend¹⁵⁵, K. Dilsiz^{155,kkk}, L. Emediato¹⁵⁵, G. Karaman¹⁵⁵, O. K. Koseyan¹⁵⁵, J.-P. Merlo¹⁵⁵, A. Mestvirishvili^{155,liii}, J. Nachtman¹⁵⁵, O. Neogi¹⁵⁵, H. Ogul^{155,mmmm}, Y. Onel¹⁵⁵, A. Penzo¹⁵⁵, C. Snyder¹⁵⁵, E. Tiras^{155,nnnn}, B. Blumenfeld¹⁵⁶, L. Corcodilos¹⁵⁶, J. Davis¹⁵⁶, A. V. Gritsan¹⁵⁶, L. Kang¹⁵⁶, S. Kyriacou¹⁵⁶, P. Maksimovic¹⁵⁶, M. Roguljic¹⁵⁶, J. Roskes¹⁵⁶, S. Sekhar¹⁵⁶, M. Swartz¹⁵⁶, T. A. Vami¹⁵⁶, A. Abreu¹⁵⁷, L. F. Alcerro Alcerro¹⁵⁷, J. Anguiano¹⁵⁷, P. Baringer¹⁵⁷, A. Bean¹⁵⁷, Z. Flowers¹⁵⁷, D. Grove¹⁵⁷, J. King¹⁵⁷, G. Krintiras¹⁵⁷, M. Lazarovits¹⁵⁷, C. Le Mahieu¹⁵⁷, C. Lindsey¹⁵⁷, J. Marquez¹⁵⁷, N. Minafra¹⁵⁷, M. Murray¹⁵⁷, M. Nickel¹⁵⁷, M. Pitt¹⁵⁷, S. Popescu^{157,oooo}, C. Rogan¹⁵⁷, C. Royon¹⁵⁷, R. Salvatico¹⁵⁷, S. Sanders¹⁵⁷, C. Smith¹⁵⁷, Q. Wang¹⁵⁷, G. Wilson¹⁵⁷, B. Allmond¹⁵⁸, A. Ivanov¹⁵⁸, K. Kaadze¹⁵⁸, A. Kalogeropoulos¹⁵⁸, D. Kim¹⁵⁸, Y. Maravin¹⁵⁸, K. Nam¹⁵⁸, J. Natoli¹⁵⁸, D. Roy¹⁵⁸, F. Rebassoo¹⁵⁹, D. Wright¹⁵⁹, E. Adams¹⁶⁰, A. Baden¹⁶⁰, O. Baron¹⁶⁰, A. Belloni¹⁶⁰, A. Bethani¹⁶⁰, Y. m. Chen¹⁶⁰, S. C. Eno¹⁶⁰, N. J. Hadley¹⁶⁰, S. Jabeen¹⁶⁰, R. G. Kellogg¹⁶⁰, T. Koeth¹⁶⁰, Y. Lai¹⁶⁰, S. Lascio¹⁶⁰, A. C. Mignerey¹⁶⁰, S. Nabili¹⁶⁰, C. Palmer¹⁶⁰, C. Papageorgakis¹⁶⁰, M. M. Paranjpe¹⁶⁰, L. Wang¹⁶⁰, K. Wong¹⁶⁰, J. Bendavid¹⁶¹, W. Busza¹⁶¹, I. A. Cali¹⁶¹, Y. Chen¹⁶¹, M. D'Alfonso¹⁶¹, J. Eysermans¹⁶¹, C. Freer¹⁶¹, G. Gomez-Ceballos¹⁶¹, M. Goncharov¹⁶¹, P. Harris¹⁶¹, D. Hoang¹⁶¹, D. Kovalskiy¹⁶¹, J. Krupa¹⁶¹, L. Lavezzo¹⁶¹, Y.-J. Lee¹⁶¹, K. Long¹⁶¹, C. Mironov¹⁶¹, C. Paus¹⁶¹, D. Rankin¹⁶¹, C. Roland¹⁶¹, G. Roland¹⁶¹, S. Rothman¹⁶¹, Z. Shi¹⁶¹, G. S. F. Stephans¹⁶¹, J. Wang¹⁶¹, Z. Wang¹⁶¹, B. Wyslouch¹⁶¹, T. J. Yang¹⁶¹, B. Crossman¹⁶², B. M. Joshi¹⁶², C. Kapsiak¹⁶², M. Krohn¹⁶², D. Mahon¹⁶², J. Mans¹⁶², M. Revering¹⁶², R. Rusack¹⁶², R. Saradhy¹⁶², N. Schroeder¹⁶², N. Strobbe¹⁶², M. A. Wadud¹⁶², L. M. Cremaldi¹⁶³, K. Bloom¹⁶⁴, M. Bryson¹⁶⁴, D. R. Claes¹⁶⁴, C. Fangmeier¹⁶⁴, F. Golf¹⁶⁴, C. Joo¹⁶⁴, I. Kravchenko¹⁶⁴, I. Reed¹⁶⁴, J. E. Siado¹⁶⁴, G. R. Snow^{164,a}, W. Tabb¹⁶⁴, A. Wightman¹⁶⁴, F. Yan¹⁶⁴

A. G. Zecchinelli¹⁶⁴ G. Agarwal¹⁶⁵ H. Bandyopadhyay¹⁶⁵ L. Hay¹⁶⁵ I. Iashvili¹⁶⁵ A. Kharchilava¹⁶⁵
C. McLean¹⁶⁵ M. Morris¹⁶⁵ D. Nguyen¹⁶⁵ J. Pekkanen¹⁶⁵ S. Rappoccio¹⁶⁵ H. Rejeb Sfar¹⁶⁵ A. Williams¹⁶⁵
G. Alverson¹⁶⁶ E. Barberis¹⁶⁶ Y. Haddad¹⁶⁶ Y. Han¹⁶⁶ A. Krishna¹⁶⁶ J. Li¹⁶⁶ M. Lu¹⁶⁶ G. Madigan¹⁶⁶
B. Marzocchi¹⁶⁶ D. M. Morse¹⁶⁶ V. Nguyen¹⁶⁶ T. Orimoto¹⁶⁶ A. Parker¹⁶⁶ L. Skinnari¹⁶⁶
A. Tishelman-Charny¹⁶⁶ B. Wang¹⁶⁶ D. Wood¹⁶⁶ S. Bhattacharya¹⁶⁷ J. Bueghly¹⁶⁷ Z. Chen¹⁶⁷ K. A. Hahn¹⁶⁷
Y. Liu¹⁶⁷ Y. Miao¹⁶⁷ D. G. Monk¹⁶⁷ M. H. Schmitt¹⁶⁷ A. Talierecio¹⁶⁷ M. Velasco¹⁶⁷ R. Band¹⁶⁸ R. Bucci¹⁶⁸
S. Castells¹⁶⁸ M. Cremonesi¹⁶⁸ A. Das¹⁶⁸ R. Goldouzian¹⁶⁸ M. Hildreth¹⁶⁸ K. W. Ho¹⁶⁸
K. Hurtado Anampa¹⁶⁸ C. Jessop¹⁶⁸ K. Lannon¹⁶⁸ J. Lawrence¹⁶⁸ N. Loukas¹⁶⁸ L. Lutton¹⁶⁸ J. Mariano¹⁶⁸
N. Marinelli¹⁶⁸ I. Mcalister¹⁶⁸ T. McCauley¹⁶⁸ C. Mcgrady¹⁶⁸ K. Mohrman¹⁶⁸ C. Moore¹⁶⁸ Y. Musienko^{168,n}
H. Nelson¹⁶⁸ M. Osherson¹⁶⁸ R. Ruchti¹⁶⁸ A. Townsend¹⁶⁸ M. Wayne¹⁶⁸ H. Yockey¹⁶⁸ M. Zarucki¹⁶⁸
L. Zygala¹⁶⁸ A. Basnet¹⁶⁹ B. Bylsma¹⁶⁹ M. Carrigan¹⁶⁹ L. S. Durkin¹⁶⁹ C. Hill¹⁶⁹ M. Joyce¹⁶⁹
A. Lesauvage¹⁶⁹ M. Nunez Ornelas¹⁶⁹ K. Wei¹⁶⁹ B. L. Winer¹⁶⁹ B. R. Yates¹⁶⁹ F. M. Addesa¹⁷⁰
H. Bouchamaoui¹⁷⁰ P. Das¹⁷⁰ G. Dezoort¹⁷⁰ P. Elmer¹⁷⁰ A. Frankenthal¹⁷⁰ B. Greenberg¹⁷⁰ N. Haubrich¹⁷⁰
S. Higginbotham¹⁷⁰ G. Kopp¹⁷⁰ S. Kwan¹⁷⁰ D. Lange¹⁷⁰ A. Loeliger¹⁷⁰ D. Marlow¹⁷⁰ I. Ojalvo¹⁷⁰
J. Olsen¹⁷⁰ D. Stickland¹⁷⁰ C. Tully¹⁷⁰ S. Malik¹⁷¹ A. S. Bakshi¹⁷² V. E. Barnes¹⁷² S. Chandra¹⁷²
R. Chawla¹⁷² S. Das¹⁷² A. Gu¹⁷² L. Gutay¹⁷² M. Jones¹⁷² A. W. Jung¹⁷² D. Kondratyev¹⁷² A. M. Koshy¹⁷²
M. Liu¹⁷² G. Negro¹⁷² N. Neumeister¹⁷² G. Paspalaki¹⁷² S. Piperov¹⁷² A. Purohit¹⁷² J. F. Schulte¹⁷²
M. Stojanovic^{172,r} J. Thieman¹⁷² A. K. Viridi¹⁷² F. Wang¹⁷² W. Xie¹⁷² J. Dolen¹⁷³ N. Parashar¹⁷³
A. Pathak¹⁷³ D. Acosta¹⁷⁴ A. Baty¹⁷⁴ T. Carnahan¹⁷⁴ S. Dildick¹⁷⁴ K. M. Ecklund¹⁷⁴
P. J. Fernandez Manteca¹⁷⁴ S. Freed¹⁷⁴ P. Gardner¹⁷⁴ F. J. M. Geurts¹⁷⁴ A. Kumar¹⁷⁴ W. Li¹⁷⁴
O. Miguel Colin¹⁷⁴ B. P. Padley¹⁷⁴ R. Redjimi¹⁷⁴ J. Rotter¹⁷⁴ E. Yigitbasi¹⁷⁴ Y. Zhang¹⁷⁴ A. Bodek¹⁷⁵
P. de Barbaro¹⁷⁵ R. Demina¹⁷⁵ J. L. Dulemba¹⁷⁵ C. Fallon¹⁷⁵ A. Garcia-Bellido¹⁷⁵ O. Hindrichs¹⁷⁵
A. Khukhunaishvili¹⁷⁵ P. Parygin¹⁷⁵ E. Popova¹⁷⁵ R. Taus¹⁷⁵ G. P. Van Onsem¹⁷⁵ K. Goulianos¹⁷⁶
B. Chiarito¹⁷⁷ J. P. Chou¹⁷⁷ Y. Gershtein¹⁷⁷ E. Halkiadakis¹⁷⁷ A. Hart¹⁷⁷ M. Heindl¹⁷⁷ D. Jaroslawski¹⁷⁷
O. Karacheban^{177,bb} I. Laflotte¹⁷⁷ A. Lath¹⁷⁷ R. Montalvo¹⁷⁷ K. Nash¹⁷⁷ H. Routray¹⁷⁷ S. Salur¹⁷⁷
S. Schnetzer¹⁷⁷ S. Somalwar¹⁷⁷ R. Stone¹⁷⁷ S. A. Thayil¹⁷⁷ S. Thomas¹⁷⁷ J. Vora¹⁷⁷ H. Wang¹⁷⁷ H. Acharya¹⁷⁸
D. Ally¹⁷⁸ A. G. Delannoy¹⁷⁸ S. Fiorendi¹⁷⁸ T. Holmes¹⁷⁸ N. Karunarathna¹⁷⁸ L. Lee¹⁷⁸ E. Nibigira¹⁷⁸
S. Spanier¹⁷⁸ D. Aebi¹⁷⁹ M. Ahmad¹⁷⁹ O. Bouhali^{179,pppp} M. Dalchenko¹⁷⁹ R. Eusebi¹⁷⁹ J. Gilmore¹⁷⁹
T. Huang¹⁷⁹ T. Kamon^{179,qqqq} H. Kim¹⁷⁹ S. Luo¹⁷⁹ S. Malhotra¹⁷⁹ R. Mueller¹⁷⁹ D. Overton¹⁷⁹
D. Rathjens¹⁷⁹ A. Safonov¹⁷⁹ N. Akchurin¹⁸⁰ J. Damgov¹⁸⁰ V. Hegde¹⁸⁰ A. Hussain¹⁸⁰ Y. Kazhykarim¹⁸⁰
K. Lamichhane¹⁸⁰ S. W. Lee¹⁸⁰ A. Mankel¹⁸⁰ T. Mengke¹⁸⁰ S. Muthumuni¹⁸⁰ T. Peltola¹⁸⁰ I. Volobouev¹⁸⁰
A. Whitbeck¹⁸⁰ E. Appelt¹⁸¹ S. Greene¹⁸¹ A. Gurrola¹⁸¹ W. Johns¹⁸¹ R. Kunnawalkam Elayavalli¹⁸¹
A. Melo¹⁸¹ F. Romeo¹⁸¹ P. Sheldon¹⁸¹ S. Tuo¹⁸¹ J. Velkovska¹⁸¹ J. Viinikainen¹⁸¹ B. Cardwell¹⁸²
B. Cox¹⁸² J. Hakala¹⁸² R. Hirosky¹⁸² A. Ledovskoy¹⁸² A. Li¹⁸² C. Neu¹⁸² C. E. Perez Lara¹⁸²
P. E. Karchin¹⁸³ A. Aravind¹⁸⁴ S. Banerjee¹⁸⁴ K. Black¹⁸⁴ T. Bose¹⁸⁴ S. Dasu¹⁸⁴ I. De Bruyn¹⁸⁴
P. Everaerts¹⁸⁴ C. Galloni¹⁸⁴ H. He¹⁸⁴ M. Herndon¹⁸⁴ A. Herve¹⁸⁴ C. K. Koraka¹⁸⁴ A. Lanaro¹⁸⁴
R. Loveless¹⁸⁴ J. Madhusudan Sreekala¹⁸⁴ A. Mallampalli¹⁸⁴ A. Mohammadi¹⁸⁴ S. Mondal¹⁸⁴ G. Parida¹⁸⁴
D. Pinna¹⁸⁴ A. Savin¹⁸⁴ V. Shang¹⁸⁴ V. Sharma¹⁸⁴ W. H. Smith¹⁸⁴ D. Teague¹⁸⁴ H. F. Tsoi¹⁸⁴ W. Vetens¹⁸⁴
A. Warden¹⁸⁴ S. Afanasiev¹ V. Andreev¹ Yu. Andreev¹ T. Aushev¹ M. Azarkin¹ A. Babaev¹ A. Belyaev¹
V. Blinov^{1,n} E. Boos¹ V. Borshch¹ D. Budkouski¹ V. Bunichev¹ M. Chadeeva^{1,n} V. Chekhovsky¹
M. Danilov^{1,n} A. Dermenev¹ T. Dimova^{1,n} D. Druzhkin^{1,mm} M. Dubinin^{1,iiii} L. Dudko¹ A. Ershov¹
G. Gavrillov¹ V. Gavrillov¹ S. Gninenko¹ V. Golovtsov¹ N. Golubev¹ I. Golutvin¹ I. Gorbunov¹
A. Gribushin¹ Y. Ivanov¹ V. Kachanov¹ L. Kardapoltsev^{1,n} V. Karjavine¹ A. Karneyeu¹ V. Kim^{1,n}
M. Kirakosyan¹ D. Kirpichnikov¹ M. Kirsanov¹ V. Klyukhin¹ O. Kodolova^{1,ssss} D. Konstantinov¹
V. Korenkov¹ A. Kozyrev^{1,n} N. Krasnikov¹ A. Lanev¹ P. Levchenko^{1,tttt} N. Lychkovskaya¹ V. Makarenko¹
A. Malakhov¹ V. Matveev^{1,n,n} V. Murzin¹ A. Nikitenko^{1,uuuu,ssss} S. Obraztsov¹ V. Oreshkin¹ A. Oskin¹
V. Palichik¹ V. Perelygin¹ M. Perfilov¹ V. Popov¹ O. Radchenko^{1,n} V. Rusinov¹ M. Savina¹ V. Savrin¹
D. Selivanova¹ V. Shalaev¹ S. Shmatov¹ S. Shulha¹ Y. Skovpen^{1,n} S. Slabospitskii¹ V. Smirnov¹
D. Sosnov¹ V. Sulimov¹ E. Tcherniaev¹ A. Terkulov¹ O. Teryaev¹ I. Tlisova¹ A. Toropin¹ L. Uvarov¹

A. Uzunian¹, A. Vorobyev,^{1,a} N. Voytishin¹, B. S. Yuldashev,^{1,vvv} A. Zarubin¹, I. Zhizhin¹, and A. Zhokin¹

(CMS Collaboration)

- ¹*Yerevan Physics Institute, Yerevan, Armenia*
- ²*Institut für Hochenergiephysik, Vienna, Austria*
- ³*Universiteit Antwerpen, Antwerpen, Belgium*
- ⁴*Vrije Universiteit Brussel, Brussel, Belgium*
- ⁵*Université Libre de Bruxelles, Bruxelles, Belgium*
- ⁶*Ghent University, Ghent, Belgium*
- ⁷*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
- ⁸*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*
- ⁹*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
- ¹⁰*Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil*
- ¹¹*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*
- ¹²*University of Sofia, Sofia, Bulgaria*
- ¹³*Instituto De Alta Investigación, Universidad de Tarapacá, Casilla 7 D, Arica, Chile*
- ¹⁴*Beihang University, Beijing, China*
- ¹⁵*Department of Physics, Tsinghua University, Beijing, China*
- ¹⁶*Institute of High Energy Physics, Beijing, China*
- ¹⁷*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*
- ¹⁸*Sun Yat-Sen University, Guangzhou, China*
- ¹⁹*University of Science and Technology of China, Hefei, China*
- ²⁰*Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE)—Fudan University, Shanghai, China*
- ²¹*Zhejiang University, Hangzhou, Zhejiang, China*
- ²²*Universidad de Los Andes, Bogota, Colombia*
- ²³*Universidad de Antioquia, Medellin, Colombia*
- ²⁴*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*
- ²⁵*University of Split, Faculty of Science, Split, Croatia*
- ²⁶*Institute Rudjer Boskovic, Zagreb, Croatia*
- ²⁷*University of Cyprus, Nicosia, Cyprus*
- ²⁸*Charles University, Prague, Czech Republic*
- ²⁹*Escuela Politécnica Nacional, Quito, Ecuador*
- ³⁰*Universidad San Francisco de Quito, Quito, Ecuador*
- ³¹*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*
- ³²*Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt*
- ³³*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*
- ³⁴*Department of Physics, University of Helsinki, Helsinki, Finland*
- ³⁵*Helsinki Institute of Physics, Helsinki, Finland*
- ³⁶*Lappeenranta-Lahti University of Technology, Lappeenranta, Finland*
- ³⁷*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
- ³⁸*Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*
- ³⁹*Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France*
- ⁴⁰*Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France*
- ⁴¹*Georgian Technical University, Tbilisi, Georgia*
- ⁴²*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
- ⁴³*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
- ⁴⁴*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
- ⁴⁵*Deutsches Elektronen-Synchrotron, Hamburg, Germany*
- ⁴⁶*University of Hamburg, Hamburg, Germany*
- ⁴⁷*Karlsruher Institut fuer Technologie, Karlsruhe, Germany*
- ⁴⁸*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
- ⁴⁹*National and Kapodistrian University of Athens, Athens, Greece*
- ⁵⁰*National Technical University of Athens, Athens, Greece*
- ⁵¹*University of Ioánnina, Ioánnina, Greece*

- ⁵²*HUN-REN Wigner Research Centre for Physics, Budapest, Hungary*
- ⁵³*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*
- ⁵⁴*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
- ⁵⁵*Institute of Physics, University of Debrecen, Debrecen, Hungary*
- ⁵⁶*Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary*
- ⁵⁷*Panjab University, Chandigarh, India*
- ⁵⁸*University of Delhi, Delhi, India*
- ⁵⁹*Saha Institute of Nuclear Physics, HBNI, Kolkata, India*
- ⁶⁰*Indian Institute of Technology Madras, Madras, India*
- ⁶¹*Tata Institute of Fundamental Research-A, Mumbai, India*
- ⁶²*Tata Institute of Fundamental Research-B, Mumbai, India*
- ⁶³*National Institute of Science Education and Research, An OCC of Homi Bhabha National Institute, Bhubaneswar, Odisha, India*
- ⁶⁴*Indian Institute of Science Education and Research (IISER), Pune, India*
- ⁶⁵*Isfahan University of Technology, Isfahan, Iran*
- ⁶⁶*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
- ⁶⁷*University College Dublin, Dublin, Ireland*
- ^{68a}*INFN Sezione di Bari, Bari, Italy*
- ^{68b}*Università di Bari, Bari, Italy*
- ^{68c}*Politecnico di Bari, Bari, Italy*
- ^{69a}*INFN Sezione di Bologna, Bologna, Italy*
- ^{69b}*Università di Bologna, Bologna, Italy*
- ^{70a}*INFN Sezione di Catania, Catania, Italy*
- ^{70b}*Università di Catania, Catania, Italy*
- ^{71a}*INFN Sezione di Firenze, Firenze, Italy*
- ^{71b}*Università di Firenze, Firenze, Italy*
- ⁷²*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
- ^{73a}*INFN Sezione di Genova, Genova, Italy*
- ^{73b}*Università di Genova, Genova, Italy*
- ^{74a}*INFN Sezione di Milano-Bicocca, Milano, Italy*
- ^{74b}*Università di Milano-Bicocca, Milano, Italy*
- ^{75a}*INFN Sezione di Napoli, Napoli, Italy*
- ^{75b}*Università di Napoli 'Federico II', Napoli, Italy*
- ^{75c}*Università della Basilicata, Potenza, Italy*
- ^{75d}*Università G. Marconi, Roma, Italy*
- ^{76a}*INFN Sezione di Padova, Padova, Italy*
- ^{76b}*Università di Padova, Padova, Italy*
- ^{76c}*Università di Trento, Trento, Italy*
- ^{77a}*INFN Sezione di Pavia, Pavia, Italy*
- ^{77b}*Università di Pavia, Pavia, Italy*
- ^{78a}*INFN Sezione di Perugia, Perugia, Italy*
- ^{78b}*Università di Perugia, Perugia, Italy*
- ^{79a}*INFN Sezione di Pisa, Pisa, Italy*
- ^{79b}*Università di Pisa, Pisa, Italy*
- ^{79c}*Scuola Normale Superiore di Pisa, Pisa, Italy*
- ^{79d}*Università di Siena, Siena, Italy*
- ^{80a}*INFN Sezione di Roma, Roma, Italy*
- ^{80b}*Sapienza Università di Roma, Roma, Italy*
- ^{81a}*INFN Sezione di Torino, Torino, Italy*
- ^{81b}*Università di Torino, Torino, Italy*
- ^{81c}*Università del Piemonte Orientale, Novara, Italy*
- ^{82a}*INFN Sezione di Trieste, Trieste, Italy*
- ^{82b}*Università di Trieste, Trieste, Italy*
- ⁸³*Kyungpook National University, Daegu, Korea*
- ⁸⁴*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
- ⁸⁵*Hanyang University, Seoul, Korea*
- ⁸⁶*Korea University, Seoul, Korea*
- ⁸⁷*Kyung Hee University, Department of Physics, Seoul, Korea*
- ⁸⁸*Sejong University, Seoul, Korea*

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

¹⁴⁵*University of California, Santa Barbara—Department of Physics, Santa Barbara, California, USA*

¹⁴⁶*California Institute of Technology, Pasadena, California, USA*

¹⁴⁷*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*

¹⁴⁸*University of Colorado Boulder, Boulder, Colorado, USA*

¹⁴⁹*Cornell University, Ithaca, New York, USA*

¹⁵⁰*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*

¹⁵¹*University of Florida, Gainesville, Florida, USA*

¹⁵²*Florida State University, Tallahassee, Florida, USA*

¹⁵³*Florida Institute of Technology, Melbourne, Florida, USA*

¹⁵⁴*University of Illinois Chicago, Chicago, USA, Chicago, USA*

¹⁵⁵*The University of Iowa, Iowa City, Iowa, USA*

¹⁵⁶*Johns Hopkins University, Baltimore, Maryland, USA*

¹⁵⁷*The University of Kansas, Lawrence, Kansas, USA*

¹⁵⁸*Kansas State University, Manhattan, Kansas, USA*

¹⁵⁹*Lawrence Livermore National Laboratory, Livermore, California, USA*

¹⁶⁰*University of Maryland, College Park, Maryland, USA*

¹⁶¹*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*

¹⁶²*University of Minnesota, Minneapolis, Minnesota, USA*

¹⁶³*University of Mississippi, Oxford, Mississippi, USA*

¹⁶⁴*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*

¹⁶⁵*State University of New York at Buffalo, Buffalo, New York, USA*

¹⁶⁶*Northeastern University, Boston, Massachusetts, USA*

¹⁶⁷*Northwestern University, Evanston, Illinois, USA*

¹⁶⁸*University of Notre Dame, Notre Dame, Indiana, USA*

¹⁶⁹*The Ohio State University, Columbus, Ohio, USA*

¹⁷⁰*Princeton University, Princeton, New Jersey, USA*

¹⁷¹*University of Puerto Rico, Mayaguez, Puerto Rico, USA*

¹⁷²*Purdue University, West Lafayette, Indiana, USA*

¹⁷³*Purdue University Northwest, Hammond, Indiana, USA*

¹⁷⁴*Rice University, Houston, Texas, USA*

¹⁷⁵*University of Rochester, Rochester, New York, USA*

¹⁷⁶*The Rockefeller University, New York, New York, USA*

¹⁷⁷*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*

¹⁷⁸*University of Tennessee, Knoxville, Tennessee, USA*

¹⁷⁹*Texas A&M University, College Station, Texas, USA*

¹⁸⁰*Texas Tech University, Lubbock, Texas, USA*

¹⁸¹*Vanderbilt University, Nashville, Tennessee, USA*

¹⁸²*University of Virginia, Charlottesville, Virginia, USA*

¹⁸³*Wayne State University, Detroit, Michigan, USA*

¹⁸⁴*University of Wisconsin—Madison, Madison, Wisconsin, USA*

¹⁸⁵*An institute or international laboratory covered by a cooperation agreement with CERN*

^aDeceased.

^bAlso at Yerevan State University, Yerevan, Armenia.

^cAlso at TU Wien, Vienna, Austria.

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

^eAlso at Ghent University, Ghent, Belgium.

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

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

^hAlso at UFMS, Nova Andradina, Brazil.

ⁱAlso at Nanjing Normal University, Nanjing, China.

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

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

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

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

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

^oAlso at Suez University, Suez, Egypt.

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

^qAlso at Birla Institute of Technology, Mesra, Mesra, India.

- ^rAlso at Purdue University, West Lafayette, Indiana, USA.
- ^sAlso at Université de Haute Alsace, Mulhouse, France.
- ^tAlso at Department of Physics, Tsinghua University, Beijing, China.
- ^uAlso at Tbilisi State University, Tbilisi, Georgia.
- ^vAlso at The University of the State of Amazonas, Manaus, Brazil.
- ^wAlso at Erzincan Binali Yildirim University, Erzincan, Turkey.
- ^xAlso at University of Hamburg, Hamburg, Germany.
- ^yAlso at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
- ^zAlso at Isfahan University of Technology, Isfahan, Iran.
- ^{aa}Also at Bergische University Wuppertal (BUW), Wuppertal, Germany.
- ^{bb}Also at Brandenburg University of Technology, Cottbus, Germany.
- ^{cc}Also at Forschungszentrum Jülich, Juelich, Germany.
- ^{dd}Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
- ^{ee}Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.
- ^{ff}Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
- ^{gg}Also at Universitatea Babes-Bolyai—Facultatea de Fizica, Cluj-Napoca, Romania.
- ^{hh}Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt.
- ⁱⁱAlso at HUN-REN Wigner Research Centre for Physics, Budapest, Hungary.
- ^{jj}Also at Faculty of Informatics, University of Debrecen, Debrecen, Hungary.
- ^{kk}Also at Punjab Agricultural University, Ludhiana, India.
- ^{ll}Also at UPES—University of Petroleum and Energy Studies, Dehradun, India.
- ^{mm}Also at University of Visva-Bharati, Santiniketan, India.
- ⁿⁿAlso at University of Hyderabad, Hyderabad, India.
- ^{oo}Also at Indian Institute of Science (IISc), Bangalore, 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 Helwan University, Cairo, Egypt.
- ^{ww}Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy.
- ^{xx}Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy.
- ^{yy}Also at Università degli Studi Guglielmo Marconi, Roma, Italy.
- ^{zz}Also at Scuola Superiore Meridionale, Università di Napoli 'Federico II', Napoli, Italy.
- ^{aaa}Also at Fermi National Accelerator Laboratory, Batavia, Illinois, USA.
- ^{bbb}Also at Università di Napoli 'Federico II', Napoli, Italy.
- ^{ccc}Also at Ain Shams University, Cairo, Egypt.
- ^{ddd}Also at Consiglio Nazionale delle Ricerche—Istituto Officina dei Materiali, Perugia, Italy.
- ^{eee}Also at Riga Technical University, Riga, Latvia.
- ^{fff}Also at Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Malaysia.
- ^{ggg}Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
- ^{hhh}Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka.
- ⁱⁱⁱAlso at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy.
- ^{jjj}Also at National and Kapodistrian University of Athens, Athens, Greece.
- ^{kkk}Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland.
- ^{lll}Also at Universität Zürich, Zurich, Switzerland.
- ^{mmm}Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
- ⁿⁿⁿAlso at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
- ^{ooo}Also at Near East University, Research Center of Experimental Health Science, Mersin, Turkey.
- ^{ppp}Also at Konya Technical University, Konya, Turkey.
- ^{qqq}Also at Izmir Bakircay University, Izmir, Turkey.
- ^{rrr}Also at Adiyaman University, Adiyaman, Turkey.
- ^{sss}Also at Necmettin Erbakan University, Konya, Turkey.
- ^{ttt}Also at Bozok Universitetesi Rektörlüğü, Yozgat, Turkey.
- ^{uuu}Also at Marmara University, Istanbul, Turkey.
- ^{vvv}Also at Milli Savunma University, Istanbul, Turkey.
- ^{www}Also at Kafkas University, Kars, Turkey.
- ^{xxx}Also at Hacettepe University, Ankara, Turkey.
- ^{yyy}Also at Istanbul University—Cerrahpasa, Faculty of Engineering, Istanbul, Turkey.

- ^{zzz} Also at Ozyegin University, Istanbul, Turkey.
- ^{aaaa} Also at Vrije Universiteit Brussel, Brussel, Belgium.
- ^{bbbb} Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- ^{cccc} Also at University of Bristol, Bristol, United Kingdom.
- ^{dddd} Also at IPPP Durham University, Durham, United Kingdom.
- ^{eeee} Also at Monash University, Faculty of Science, Clayton, Australia.
- ^{ffff} Also at Università di Torino, Torino, Italy.
- ^{gggg} Also at Bethel University, St. Paul, Minnesota, USA.
- ^{hhhh} Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
- ⁱⁱⁱⁱ Also at California Institute of Technology, Pasadena, California, USA.
- ^{jjjj} Also at United States Naval Academy, Annapolis, Maryland, USA.
- ^{kkkk} Also at Bingol University, Bingol, Turkey.
- ^{llll} Also at Georgian Technical University, Tbilisi, Georgia.
- ^{mmmm} Also at Sinop University, Sinop, Turkey.
- ⁿⁿⁿⁿ Also at Erciyes University, Kayseri, Turkey.
- ^{oooo} Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania.
- ^{pppp} Also at Texas A&M University at Qatar, Doha, Qatar.
- ^{qqqq} Also at Kyungpook National University, Daegu, Korea.
- ^{rrrr} Also at Universiteit Antwerpen, Antwerpen, Belgium.
- ^{ssss} Also at Yerevan Physics Institute, Yerevan, Armenia.
- ^{tttt} Also at Northeastern University, Boston, Massachusetts, USA.
- ^{uuuu} Also at Imperial College, London, United Kingdom.
- ^{vvvv} Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan.