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

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

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

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

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

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

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

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

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

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

Since the $m_{\mathcal{A}}$ range we study spans a wide range of $\mathcal{A}$ boosts, the opening angles of the $\mathcal{A} \to \gamma\gamma$ decays vary as well [23]. We thus apply a looser requirement on the output of the multivariate photon tagger [24], which then accepts more photons than for the CMS $H \to \gamma\gamma$ search. This increases the contribution from QCD background processes containing hadronic jets, which may be reconstructed as photonlike objects if they radiate an energetic photon or contain one or more neutral-meson decays ($\pi^0/\eta \to \gamma\gamma$). To compensate, we set a more restrictive requirement on the transverse momenta of charged particles in a cone around the selected photon, $\mathcal{I}_{\mathrm{ch}}$ [24]. Since neutral mesons are mainly produced inside hadronic jets, they are more likely to be accompanied by charged particle tracks. Thresholds for the above requirements are chosen to maximize the significance of a possible $H \to \mathcal{A}\mathcal{A} \to 4\gamma$ signal over the $m_{\mathcal{A}}$ range of interest. After all selection criteria are applied, signal events are selected with an estimated efficiency of 8%–24%, decreasing with $m_{\mathcal{A}}$, while background events are reduced by $>99\%$, as determined from simulation.

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

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

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

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

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

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

An overall background 2D-m_Γ template for all other nonresonant processes is estimated from data. We divide the selected events in data into regions based on $m_{\Gamma\Gamma}$ and 2D-m_Γ. Since the two $\mathcal{A}$ particles come from the decay of a Higgs boson with a mass of 125 GeV, we define an $m_{\Gamma\Gamma}$ signal region (SR) around the Higgs boson mass (labeled m_H-SR) using $110 < m_{\Gamma\Gamma} < 140$ GeV and sideband (SB) regions below (labeled m_H-SB$_{\text{low}}$) and above (labeled m_H-SB$_{\text{high}}$) the Higgs boson mass, by requiring $100 < m_{\Gamma\Gamma} < 110$ GeV and $140 < m_{\Gamma\Gamma} < 180$ GeV, respectively. Since we assume that the two $\mathcal{A}$ particles from the $H \to \mathcal{AA}$ decay have equal mass, we also divide the 2D-m_Γ distribution into a SR along the diagonal (labeled $m_\mathcal{A}$-SR), by requiring $|m_{\Gamma_1} - m_{\Gamma_2}| < 0.3$ GeV, and a SB region (labeled $m_\mathcal{A}$-SB) using $|m_{\Gamma_1} - m_{\Gamma_2}| > 0.3$ GeV. The final SR in which the MLE test is performed corresponds to the intersection of the above two SRs, $m_\mathcal{A}$-SR $\cap$ m_H-SR. A binned likelihood fit of $\mu S + B$ versus the observed 2D-m_Γ distribution with bin sizes of 0.05×0.05 GeV^2 is used. The boundaries between the SR and SB regions are tuned using the simulation to maximize the signal enrichment in the SR, while maintaining a sufficient number of events in the SB regions to give a good background estimation. Figure 1 (center) shows the observed 2D-m_Γ distribution of the selected events in data from m_H-SR and the respective 1D projections of m_{Γ_1} (left) and m_{Γ_2} (right) in the $m_\mathcal{A}$-SR. Illustrative contours in 2D-m_Γ of the signal template (center) and its 1D projections (left and right) are also provided.

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

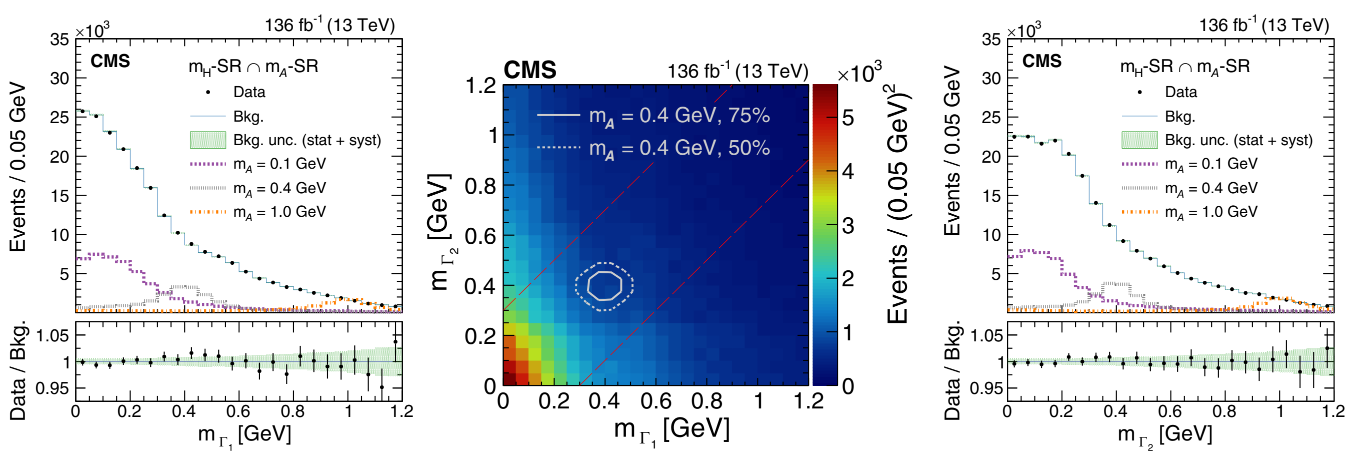

FIG. 1. Mass distributions from selected events in data. Center: the 2D-m_Γ distribution for data events in the m_H-SR. The red dashed lines indicate the $m_\mathcal{A}$-SR boundaries. The contours of simulated $H \to \mathcal{AA} \to 4\gamma$ events for $m_\mathcal{A} = 0.4$ GeV are plotted for 75%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

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

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

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

Uncertainties in the predicted signal and background templates are treated as nuisance parameters in the MLE procedure used to determine the best fit signal strength $\hat{\mu}$. The dominant uncertainties impacting the extracted $\hat{\mu}$ are those from statistical uncertainties in the background template's shape. Their largest impact on the relative uncertainty in $\hat{\mu}$ varies between 15% and 20%, depending on $m_{\mathcal{A}}$. For $m_{\mathcal{A}} = 0.1$ GeV, where the m_Γ resolution is poorest and the background contribution is largest, systematic uncertainties affecting the background template normalization are also important. These include systematic uncertainties associated with the best fit parameters of $\mathrm{pol}(m_{\Gamma_1}, m_{\Gamma_2})$ and the relative contribution of $m_H\text{-SB}_{\mathrm{low}}$ versus $m_H\text{-SB}_{\mathrm{high}}$ events in the nonresonant background 2D-m_Γ template. These systematic uncertainties impact the relative uncertainty in $\hat{\mu}$ by about 25% (10%) for $m_{\mathcal{A}} = 0.1(1.2)$ GeV.

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

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

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

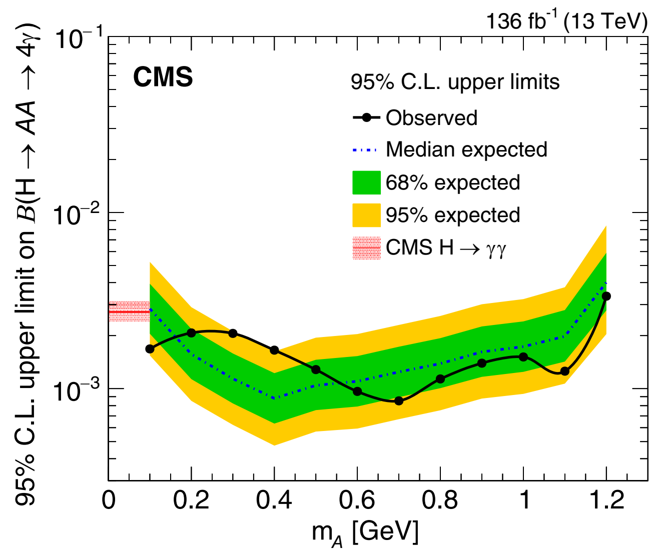

FIG. 2. Observed (black solid curve with points) and median expected (blue dashed curve) 95% C.L. upper limit on $\mathcal{B}(H \to \mathcal{A}\mathcal{A} \to 4\gamma)$ as a function of $m_{\mathcal{A}}$ for prompt $\mathcal{A}$ decays. The 68% (green band) and 95% (yellow band) CIs are plotted around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

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

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

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

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

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