Searches for high and low mass additional Higgs bosons at CMS

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Abstract

This contribution summarizes five of the most recent analyses by the CMS Collaboration investigating signatures of additional Higgs bosons at low and high mass using proton-proton collision data collected at $\sqrt{s} = 13$ TeV during Run 2 of the LHC. The results reviewed here correspond to the following searches: a narrow di-photon resonance, neutral Higgs bosons decaying to $b\bar{b}$, charged Higgs bosons decaying to $t\,b$, light pseudo-scalars in Higgs decays to 4τ and $2\mu 2\tau$ final states, and pair-produced new bosons decaying to muons. Together, these analyses demonstrate the breadth of the CMS program in probing new scalar and pseudo-scalar particles predicted by many extensions of the Standard Model (SM).

1 Introduction

The discovery of the Higgs boson in 2012 completed the Standard Model (SM), yet it also opened a path for exploring phenomena beyond it. Several theoretical frameworks, such as the Minimal Supersymmetric Standard Model (MSSM), two-Higgs-doublet models (2HDM), and Higgs-portal models with singlet extensions, predict the existence of additional scalar and pseudo-scalar states, including charged Higgs bosons and light neutral resonances.

The CMS Collaboration [1] has pursued a broad program of searches for such states across multiple final states, exploiting the full Run 2 dataset collected between 2016 and 2018, corresponding to integrated luminosities up to 138 fb^{-1}. This document summarizes the most recent results from five representative analyses, covering a range of signatures from low-mass di-photon to heavy charged Higgs bosons and exotic decays of the 125 GeV Higgs boson.

2 Search for a narrow resonance decaying to di-photon [2]

Low-mass resonances decaying into two photons arise in various scenarios involving singlet scalars or axion-like particles (ALPs). The clean final state and excellent photon energy resolution of CMS make it a sensitive probe for narrow resonances in the mass range between 10 GeV and 70 GeV.

The search targets resonances produced predominantly via gluon–gluon fusion. Dedicated low-threshold di-photon triggers are employed to access this mass region. The analysis reconstructs photon candidates using the CMS electromagnetic calorimeter (ECAL) with tight identification criteria based on shower shape and isolation variables.

A smooth analytic function is fitted to the di-photon invariant mass spectrum to model the background from prompt QCD $\gamma\gamma$ production and γ+jet processes. The signal would appear as a narrow peak whose width is dominated by the detector resolution. Separate categories are defined based on photon pseudo-rapidity and shower shape to optimize sensitivity.

Using the full Run 2 dataset, no significant excess is observed. Model-independent 95% confidence level (CL) upper limits on $\sigma(pp \to X) \times \mathcal{B}(X \to \gamma\gamma)$ are set. The most important excess is seen at 13.6 GeV with a 3.47σ (1.9σ) local (global) significance. These constraints represent the most stringent limits in this low-mass region from a hadron collider.

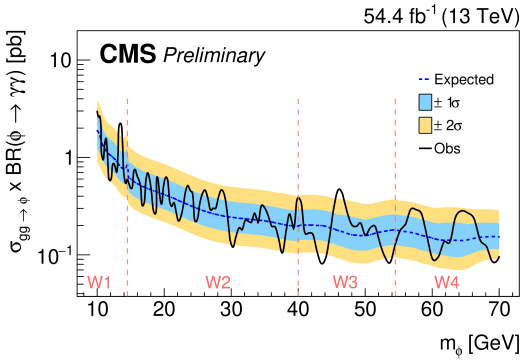

Figure 1: Expected (dashed blue) and observed (solid black) limits at 95% CL on the production cross-section of a narrow di-photon resonance, as a function of the mass in the range 10–70 GeV with minimal model-dependent assumptions, along with 1σ (blue) and 2σ (yellow) uncertainty bands from the expected limits [2].

3 Search for neutral Higgs bosons decaying to $b\bar{b}$ [3]

Extended Higgs sectors such as the MSSM predict additional heavy neutral bosons H and A. At large values of $\tan\beta$, these states couple strongly to down-type fermions and are expected to decay predominantly into $b\bar{b}$ pairs. The most promising production mechanism at the LHC is in association with one or more b quarks.

The analysis uses the full Run 2 dataset. Events are selected with at least three b-tagged jets reconstructed using the anti-k_T algorithm with $R = 0.4$. Triggers requiring large scalar transverse momentum H_T and multiple b-jets are employed. Multivariate discriminants based on jet kinematics and b-tagging information are used to enhance separation from the overwhelming QCD multi-jet background.

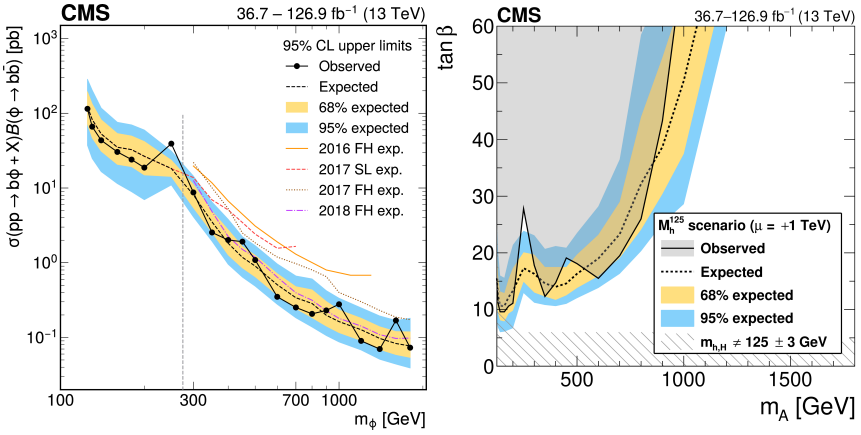

Figure 2: On the left: expected and observed upper limits for the b-quark-associated Higgs boson production cross-section times branching fraction of the decay into a b quark pair at 95% CL as functions of m_ϕ. On the right: interpretation in the m_h^{125} scenario of the MSSM: observed and expected upper limits at 95% CL on the parameter tan β as functions of the mass m_A of the CP-odd Higgs boson [3].

The invariant mass of the two leading b jets serves as the final discriminant. The background shape is extracted from control regions with fewer b-tags to reduce reliance on simulation. A simultaneous fit across several event categories is performed.

No significant deviation from the SM background expectation is observed. Upper limits are placed on $\sigma(pp\to b\Phi + b) \times \mathcal{B}(\Phi\to b\bar{b})$, where Φ denotes H or A. Interpreted in the context of the MSSM m_h^{125} benchmark scenario, these results exclude $\tan\beta > 20$ for $m_A < 600$ GeV, improving upon previous CMS results.

4 Search for charged Higgs bosons decaying to $t\,b$ [4]

Charged Higgs bosons are a distinctive prediction of models with more than one Higgs doublet. For $m_{H^\pm} > m_t$, the dominant decay mode is $H^\pm \to t\,b$. The search targets both single and pair production modes, depending on $m_{H^\pm}$.

Events are required to contain at least one isolated lepton (electron or muon), multiple jets including at least two b-tags, and large missing transverse momentum. The main backgrounds arise from SM $t\bar{t}$ and single-top production. Signal discrimination is achieved using the reconstructed invariant mass m_{tb} or the transverse mass built from reconstructed top and b-jet candidates. Boosted topologies are treated with dedicated reconstruction algorithms for high-mass hypotheses.

The search covers masses between 200 GeV and 3 TeV. No significant signal excess is found according to the observed 95% CL limits on $\sigma(pp \to H^\pm t) \times \mathcal{B}(H^\pm \to t\,b)$. In MSSM interpretations, the results constrain high-mass regions up to $m_{H^\pm} \sim 1.5$ TeV depending on $\tan\beta$.

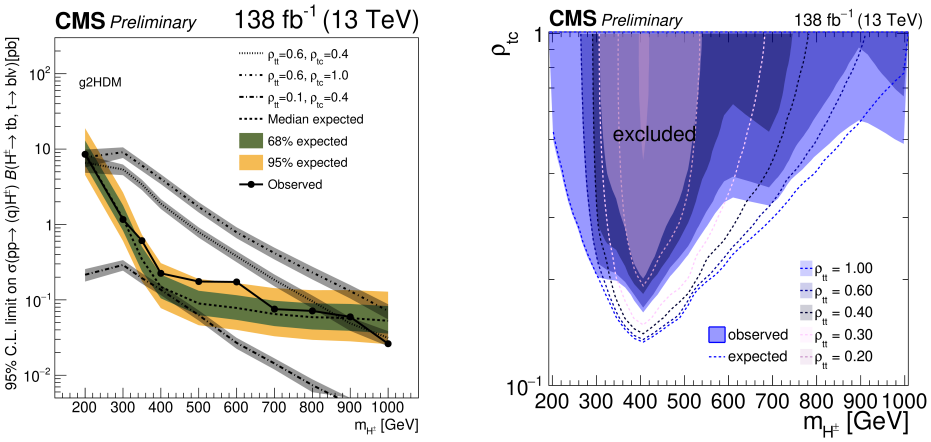

Figure 3: On the left: observed and expected 95% CL limits on the cross-section times branching ratio for different $m_{H^\pm}$ hypotheses, along with 1σ (green) and 2σ (yellow) uncertainty bands from the expected limits. Theoretical prediction with different ρ_{tc} and ρ_{tt} couplings are shown with the grey bands. On the right: observed and expected excluded phase-space regions as a function of $m_{H^\pm}$ and ρ_{tc} for various ρ_{tt} values [4].

5 Search for light pseudo-scalars in Higgs decays [5]

Many singlet-extended models, such as the NMSSM or 2HDM+S, introduce a light pseudo-scalar boson a_1. If kinematically allowed, the 125 GeV Higgs boson can decay as $H \to a_1 a_1$, providing a portal to a hidden sector. Depending on its mass, the a_1 can decays to $\tau^+\tau^-$, $\mu^+\mu^-$, or $b\bar{b}$ pairs.

The analysis focuses on two final states: $H \to a_1 a_1 \to 4\tau$ and $H \to a_1 a_1 \to 2\mu 2\tau$, using the full Run 2 dataset. Triggers requiring di-muon or lepton+τ_h objects are used. Because of the potentially low a_1 mass ($4 < m_{a_1} < 15$ GeV), the decay products are often collimated; overlapping τ leptons are reconstructed using boosted τ algorithms and dedicated isolation definitions.

Backgrounds include Z+jets, $t\bar{t}$, and multi-boson production, estimated using data-driven methods. Signal extraction is performed using a two-dimensional likelihood fit in the plane of the reconstructed di-τ masses (or $\mu\mu$ and $\tau\tau$ masses in the mixed channel).

No evidence for a signal is observed. Upper limits are derived on $\mathcal{B}(H \to a_1 a_1) \times \mathcal{B}^2(a_1 \to \tau\tau)$, typically at the level of $1-10\%$ depending on m_{a_1}. These represent the most stringent limits to date for light pseudo-scalars below 15 GeV. The results significantly constrain NMSSM parameter space and complement other exotic Higgs decay searches involving muons or b-jets.

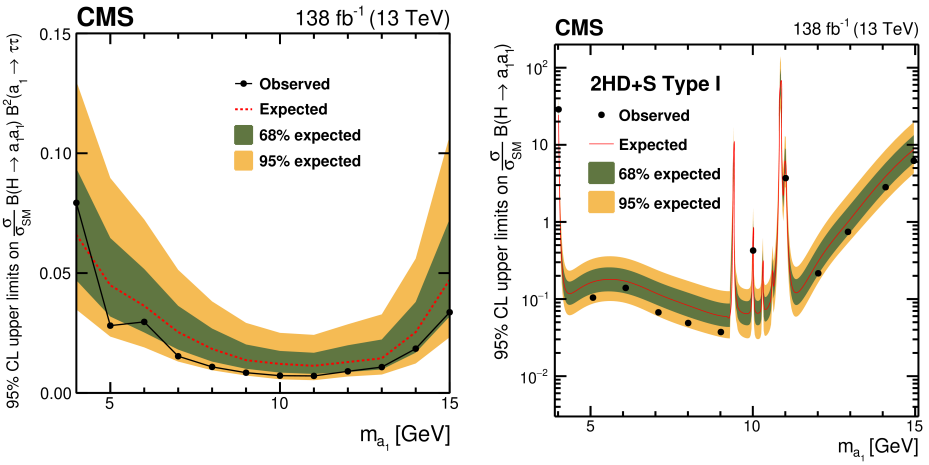

Figure 4: On the left: expected (dashed red) and observed (solid) limits at 95% CL on the production cross-section of the signal, as a function of m_{a_1}, along with 1σ (green) and 2σ (yellow) uncertainty bands from the expected limits. On the left: expected (red line) and observed (points) 95% CL upper limits on the production cross-section, as a function of m_{a_1} for different 2HD+S Type I model [5].

6 Model-independent search for pair-produced bosons decaying to muons [6]

This analysis performs a generic search for pair-produced new bosons (X) each decaying into a muon pair. Such a topology arises in many models, including dark-sector Z' or scalar mediators.

Events with at least four identified muons are selected from data collected in 2016–2018. Di-muon pairs are formed by minimizing mass differences to identify potential X candidates. The analysis is sensitive to both prompt and long-lived decays with transverse decay lengths up to 100 mm. The dominant backgrounds are from $b\bar{b}$ events producing multiple semi-leptonic decays and from SM Z or Υ resonances combined with misidentified muons.

A shape-based fit to the two di-muon masses is performed in bins of lifetime hypothesis. No assumption on production mode is made, making the result applicable to a wide class of models.

No significant deviation is observed across the explored mass range $0.21 < m_X < 60$ GeV. Model-independent upper limits are set on $\sigma(pp \to XX) \times \mathcal{B}^2(X \to \mu\mu) \times \alpha$, where α denotes the acceptance. Interpretations in benchmark models such as dark photons and Higgs-portal scalars demonstrate the strong reach of the analysis in both prompt and displaced regimes.

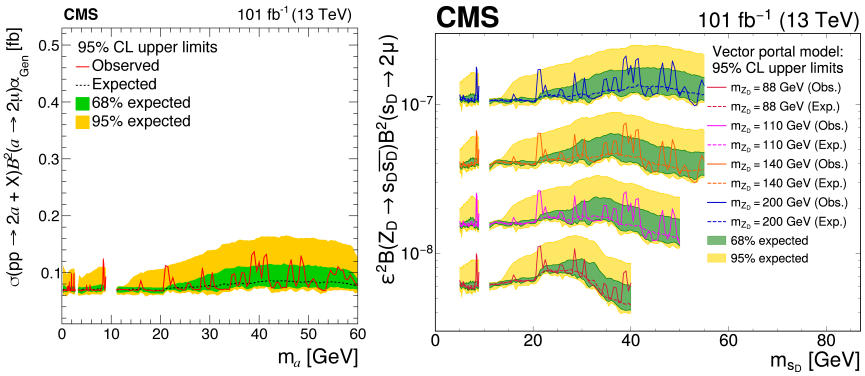

Figure 5: On the left: model-independent upper limits on $\sigma(pp \to XX) \times \mathcal{B}^2(X \to \mu\mu) \times \alpha$ as a function of m_a. On the right: the 95% CL observed upper limits on $\epsilon^2\mathcal{B}(Z_D \to s_D\bar{s_D})\mathcal{B}^2(s_D \to 2\mu)$ for the vector portal model as a function of the dark scalar mass m_{s_D} and dark vector boson mass m_{Z_D} [6].

7 Conclusion

These five analyses cover a broad spectrum of final states and theoretical motivations, illustrating the comprehensive nature of the CMS extended-Higgs and SUSY search program. While no statistically significant deviation from the SM has been found, the limits obtained provide the most stringent constraints to date across a wide mass range from a few GeV to several TeV.

The methodologies developing low-threshold triggers, boosted object reconstruction, and multivariate discriminants will be essential for Run 3 and the High-Luminosity LHC era. Future work will combine results across channels and explore global interpretations within frameworks such as the 2HDM+S and the phenomenological MSSM. The sensitivity to rare exotic Higgs decays is expected to improve by an order of magnitude with the forthcoming dataset.

References

[1] CMS Collaboration, *"The CMS Experiment at the CERN LHC"*, JINST 3 S08004 (2008).

[2] CMS Collaboration, *"Search for a narrow resonance with mass between 10 and 70 GeV decaying to a pair of photons in proton–proton collisions at* $\sqrt{s} = 13$ TeV*"*, CMS-PAS-HIG-24-014 (CERN, Geneva, 2025).

[3] CMS Collaboration, *"Search for beyond-the-standard-model neutral Higgs bosons decaying to a pair of bottom quarks produced in association with additional bottom quarks"*, CMS-SUS-24-001 (CERN, Geneva, 2025).

[4] CMS Collaboration, *"Search for charged Higgs bosons decaying into a top and a bottom quark in proton–proton collisions at* $\sqrt{s} = 13$ TeV*"*, CMS-PAS-B2G-24-008 (CERN, Geneva, 2025).

[5] CMS Collaboration, *"Search for light pseudo-scalar boson pairs produced from Higgs boson decays in the* 4τ *and* $2\mu 2\tau$ *final states"*, CMS-SUS-24-002 (CERN, Geneva, 2025).

[6] CMS Collaboration, *"Model-independent search for pair production of new bosons decaying into muons in proton–proton collisions at* $\sqrt{s} = 13$ TeV*"*, JHEP 12 (2024) 172, CMS-HIG-21-004.