PROCEEDINGS OF SCIENCE

# Searches for Light Higgs Bosons at the CMS Experiment

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The searches for light pseudoscalar Higgs bosons pair produced from the decay of the 125 GeV Higgs boson and resulting in various final states ($4\mu$, $2\mu 2\tau$, $2b2\tau$) according to the mass of the light boson and searches for low mass scalar bosons below 125 GeV in decays to photon pairs will be summarised. The analyses are performed using data collected with the CMS experiment at the LHC from pp collisions at centre-of-mass energy of 13 TeV.

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## 1. Introduction

The discovery of a Higgs boson [1, 2] by the ATLAS [3] and CMS [4] experiments at the Large Hadron Collider (LHC) has shed light on the mechanism for electroweak symmetry breaking. It still remains to be determined whether the particle is indeed the predicted Higgs boson of the standard model (SM). A route to uncover the nature of the Higgs sector is via direct searches for additional Higgs bosons beyond the standard model (BSM). A review of searches for light Higgs bosons in BSM scenarios conducted with the CMS detector at the LHC in 13 TeV pp collisions has been summarised.

## 2. Light Higgs Boson Searches

The Higgs boson at 125 GeV can be identified as the next-to-lightest scalar allowing to envisage a possible lighter particle which is possible in the 2HDM+S models. The H(125) boson can kinematically decay to a pair of light Higgs bosons which further decay in modes according to the mass of the light boson. Branching fractions of a light pseudoscalar Higgs boson to SM particles depend on the mass of the light boson, the type of 2HDM+S model and model parameters like tan$\beta$. Searches for scalar bosons below 125 GeV in diphoton decay mode is also performed.

### 2.1 H(125)$\rightarrow$aa$\rightarrow$4$\mu$

The lightest Higgs boson can be very light (less than a GeV) and due to helicity suppression, the branching fraction to the heaviest possible pair of particles depending on the mass of the light particle is significantly enhanced. The search for H(125)$\rightarrow$aa$\rightarrow$4$\mu$ [5] is conducted by counting events that contain two well reconstructed muon pairs with a good mass compatibility. The SM background is dominated by $b\bar{b}$ production in which both b-quarks decay to muon pairs via double semi-leptonic decay or resonances. There are small contributions from electroweak production of four muons and direct J/$\Psi$ pair production. A 2D background template includes all SM processes. One event is observed in signal region, with 0.74$\pm$0.34(stat.)$\pm$0.15(syst.) events expected from SM backgrounds. Upper limit at 95% CL on cross section times branching fraction times acceptance obtained for $m_a$ in range from $2m_\mu$ to $2m_\tau$ is shown in Fig. 1.

### 2.2 H(125)$\rightarrow$aa$\rightarrow$2$\mu$2$\tau$

Four final states scenarios are studied for the process H(125)$\rightarrow$aa$\rightarrow$2$\mu$2$\tau$ [6], namely $\mu\mu$ with (e$\mu$, e$\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$) targeting non-boosted tau pairs, and requiring 4 well reconstructed and isolated leptons. $\tau_h$ refers to the decay of tau lepton to hadrons. The main backgrounds (fake leptons or taus) are estimated from data which are mostly Z+jets and WZ+jets events. The background shape is obtained from data in signal and ZZ background free control region with tau candidates of same sign and relaxed isolation. The yield is estimated from data events that have one or two non-isolated tau. The final observable for extraction of limits is the dimuon invariant mass distribution. A maximum-likelihood fit to the dimuon invariant mass distribution is performed. No significant excess of events is observed above expected backgrounds in $m_{\mu\mu}$ range from 15 to 62.5 GeV. The most stringent limits are obtained in 2HDM+S type-III at large tan$\beta$ as seen in Fig. 1, where couplings to leptons are enhanced.

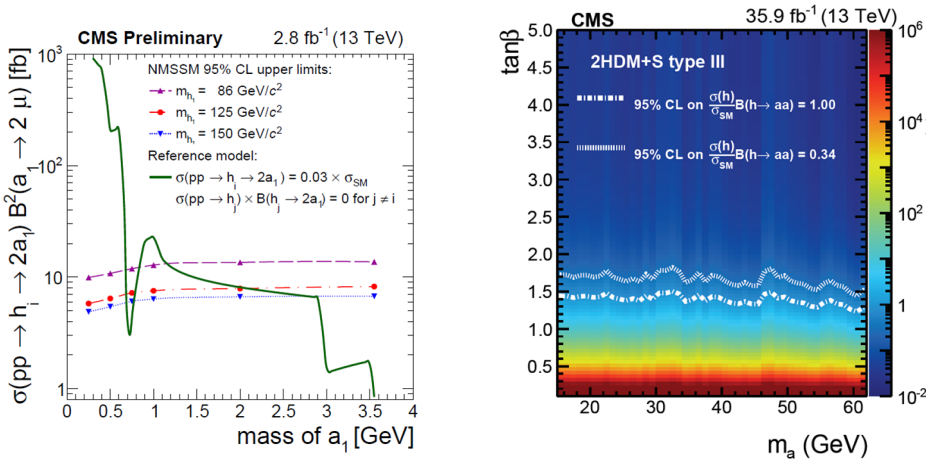


**Figure 1:** The 95% CL upper limits on $\sigma(pp \to h_{1,2} \to 2a_1)$ times square of the branching ratio of $a_1$ to $2\mu$ as functions of $m_{a1}$ for the NMSSM case [5] (left); Observed limits on ratio of observed to expected SM cross-section times the BR[H(125)→aa→2$\mu$2$\tau$] in 2HDM+S type-III model [6]. The contour lines shown for BR(H(125)→aa)= 1.0 and 0.34 correspond to the colour scale indicated on the right vertical scale (right).

### 2.3 H(125)→aa→2b2$\tau$

The three tau pair final states investigated in the H(125)→aa→2b2$\tau$ analysis [7] are e$\mu$, e$\tau_h$ and $\mu\tau_h$. $\tau_h\tau_h$ is discarded because of high trigger thresholds, while ee and $\mu\mu$ are discarded because of low branching ratio and large backgrounds. At least one b-quark tagged jet with transverse momentum $p_T$>20 GeV is required in the event, in addition to the leptons. Most signal events only have one b-tagged jet because the generated b-jets are too soft. The visible invariant mass of tau pair and b-jet is less than 125 GeV as neutrinos in tau decays and soft b-jets are not reconstructed. The events are classified in 4 categories based on $m_{bb\tau}$. Lowest $m_{bb\tau}$ category is the most sensitive category with the smallest background contribution. The highest $m_{bb\tau}$ category corresponds to maximum background and is used as control region. The thresholds on various kinematic cuts depend on the final state and category in the event. The results are extracted by fits to di-tau visible mass distributions (to peak below $m_a$). No significant excess of events observed. In the NMSSM, BR(H→aa)>23% is excluded at 95% CL for $m_a$ = 35 GeV as seen in Fig. 2. The limits improved by several factors in the mass region 25 GeV < $m_a$ < 62.5 GeV.

### 2.4 Light Scalar →$\gamma\gamma$

The decay of a light scalar boson below 125 GeV is investigated in the clean final state of 2 isolated photons [8]. The smoothly decreasing background continuum comprises the reducible di-jet and photon+jet backgrounds with jet faking photon, and the irreducible diphoton production. The low-mass analysis is concerned with the Drell-Yan (DY) background, with electrons from the Z boson misidentified as photons. The analysis makes use of a stricter electron veto based on the pixel detector and inclusion of the relic DY contribution in background model. To gain sensitivity, diphoton events are classified according to their expected signal (S) over background (B) ratio where the events are categorised based on the photon kinematics, per-event mass resolution, photon identification and good vertex probablity by a multivariate classifier. Fits of S+B model over all event classes are performed and each event is weighted by the ratio S/(S+B) for its event class. The

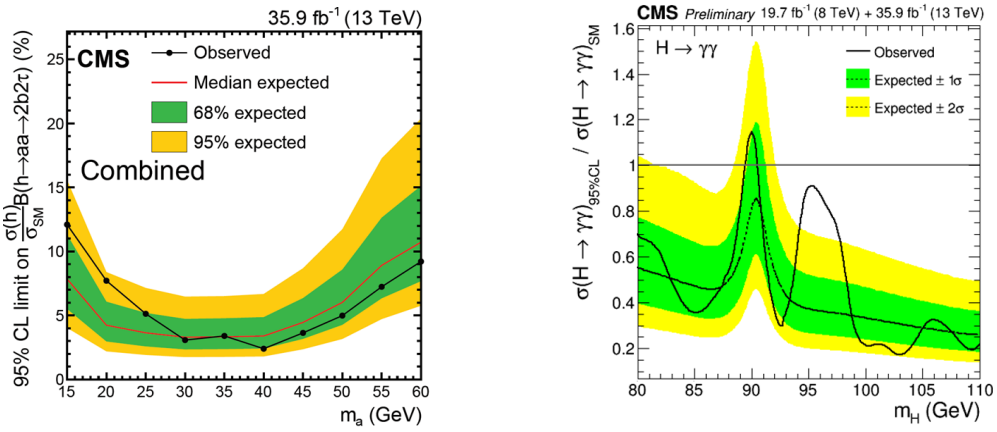


**Figure 2:** Expected and observed 95% CL limits on ratio of observed to expected SM cross-section times BR[H(125)→aa→2b2$\tau$] with combination of all decay modes and the expected limits under the background-only hypothesis [7] (left); Expected and observed exclusion limits at 95% CL on the production cross section times branching ratio into two photons for a second Higgs boson relative to the expected SM-like expectation [8], with the 8 TeV and 13 TeV datasets (right).

combined limits with 8 and 13 TeV datasets shown in Fig. 2 correspond to minimum (maximum) limit on $(\sigma\times\text{BR})/(\sigma\times\text{BR})\text{SM}$ as 0.17 (1.15) at m = 103.0 (90.0) GeV with $\sigma\times$BR limit normalised to SM expectation. The excess with combined 8 TeV and 13 TeV datasets corresponds to 2.8$\sigma$ local (1.3$\sigma$ global) significance. More data are required to ascertain the origin of this mild excess.

## 3. Conclusion

The observed Higgs boson at mass 125 GeV may be part of an extended Higgs sector. Searches for light Higgs bosons in the mass range from less than a GeV to 110 GeV have been explored and interpretation made in 2HDM+S models. The searches for light pseudoscalar Higgs bosons pair produced from the decay of the 125 GeV Higgs boson and resulting in various final states (4$\mu$, 2$\mu$2$\tau$, 2b2$\tau$) according to the mass of the light boson; and light scalar Higgs bosons (below mass of 125 GeV) in decays to photon pairs have been reviewed with no significant event excess observed.

## References

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