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Searches for BSM (neutral) Higgs bosons in fermionic decays in CMS

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Abstract: An overview of neutral BSM direct Higgs searches in fermionic decays performed at CMS was presented. The first part focuses on BSM Higgs resonant searches interpreted within the Higgs-Two-Doublet Model (H2DM) framework and in particular the Minimal Supersymmetric Standard Model (MSSM). The second part illustrates the searches for NMSSM light pseudoscalars stemming from SM-like Higgs bosons with four fermions in the final state.

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1. Introduction

The Standard Model (SM) of particle physics is one of the most successful theories in the history of physics. However, it suffers from several limitations, notably the inability to provide a solution to the hierarchy problem and a theoretical framework describing the presence of dark matter. The LHC discovery of a Standard-Model-like Higgs H(125) particle in 2012 [1] could be a portal to an extended Higgs sector predicted by several models, such as the Minimal-Supersymmetric Standard Model (MSSM) [2] and the more general Two-Higgs-Doublet Model (2HDM) [3]. The phenomenology of such models can be further enriched by addition of a single scalar gauge in singlet, as in the Next-to-Minimal SuperSymmetric model (NMSSM) [4]. The combination of data collected at 13 TeV with the CMS detector [5] in searches for Higgs decays into invisible constrains the branching fraction BR($H \rightarrow inv$) to less than 0.26 at 95% CL [6]. Therefore, there is still room for additional Higgs bosons, which are the object of direct BSM Higgs searches. These searches complement the results from indirect constraints on 2HDM from H(125) coupling measurements [7] and rare B-meson decays [8]. In this paper, we shall focus on the most recent neutral BSM Higgs searches in fermionic decays performed at CMS in pp collisions at 13 TeV. These resonant Higgs searches are usually categorized according to the mass range probed and the subsequent theoretical model of interest, which are outlined in the next section. In Section 3, heavy Higgs resonant searches in fermionic decays are interpreted in the light of the 2HDM models. In section 4, the SM-like Higgs decays into light pseudoscalars predicted in the NMSSM with four fermions in the final state are discussed.

2. Theoretical models

The most natural extension of the Standard Model scalar sector is the addition of an extra $SU(2)_L$ doublet. The 2HDM is an effective theory consisting of two complex Higgs doublets (hence with a total of 8 degrees of freedom), which provide masses to both the up-type and the down-type fermions. After electroweak symmetry breaking (EWSB) , there are five physical scalar fields, consisting of neutral bosons φ = h,H,A of which the first two bosons are CP-even, opposed to the A-boson which is CP-odd and of two charged Higgs states $H^{\pm}$. The model is parameterized by the five Higgs masses, $\tan\beta = v_2/v_1$, the ratio of the vacuum expectation values of the two Higgs doublets, and the mixing angle α between the CP-even Higgs states.

In this paper, we focus on searches involving the neutral Higgs bosons only. There exist four types of 2HDM which simultaneously forbid the presence of flavour-changing-neutral currents (FCNC) and preserve CP symmetry:

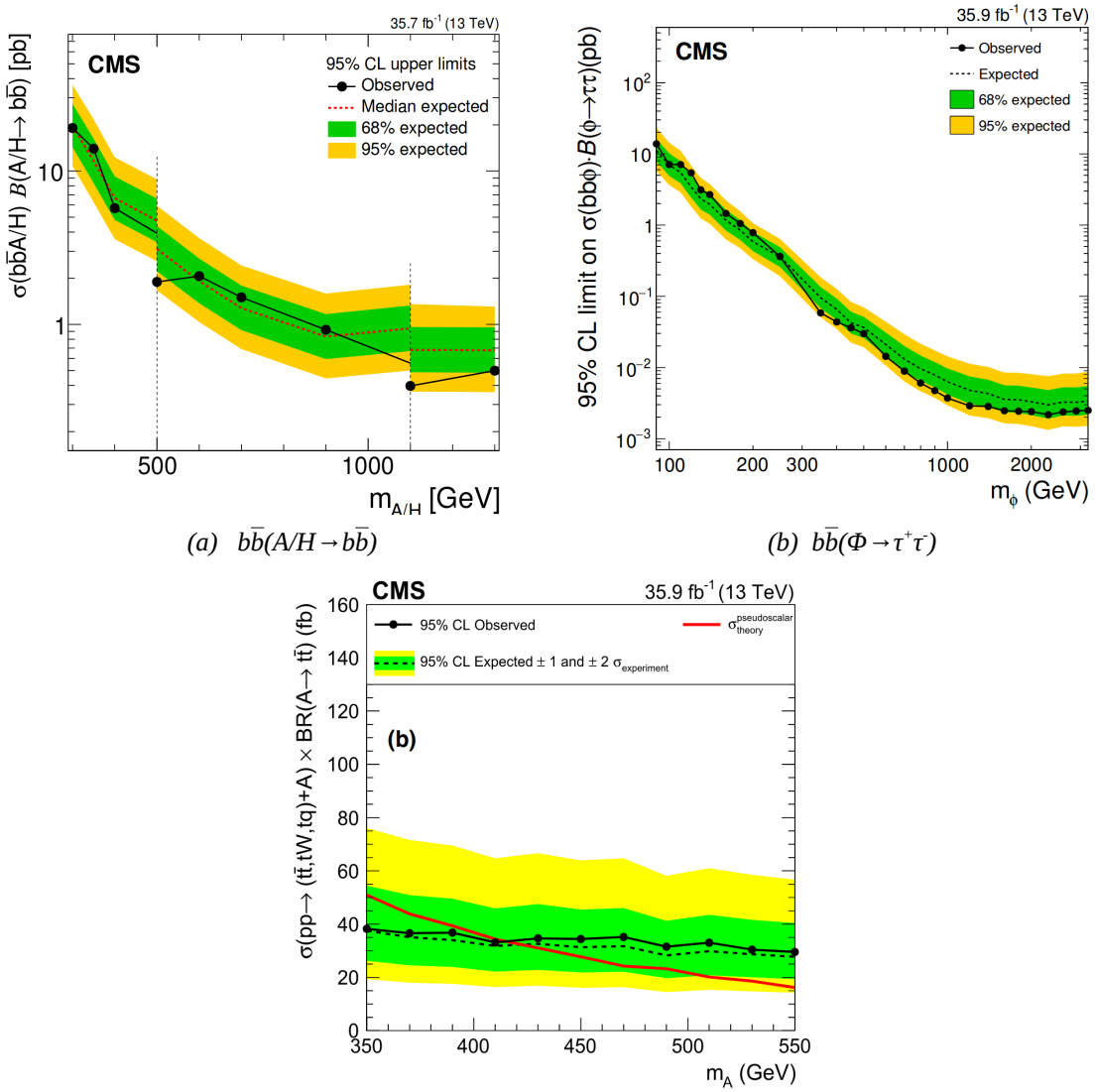
- In Type I all fermions couple to the second doublet Φ_2. It follows that BR are independent of $\tan\beta$.
- In Type II or MSSM-like scenario, lepton and down-type quarks couple to the first doublet Φ_1, whilst up-type quarks couple to Φ_2 .

- In Type III or lepton specific scenario, quarks couple to Φ_2 while leptons couple to the other doublet.
- In Type IV or flipped model, the coupling of the leptons is reversed with respect to the Type-II model.

The MSSM Higgs sector possesses the same underlying structure as 2HDM Type II but it is described solely by two parameters at tree-level: tanβ and m_{A}. Several benchmark scenarios with different phase space properties have been designed. The results presented in the next section make use of the MSSM m_h^{mod+} scenario, where the mass of the lightest CP-even Higgs state is compatible with H(125) in a large region of the tanβ-m_A plane, and the phenomenological hMSSM scenarios incorporating the observed Higgs boson mass with a fixed mass value of 125 GeV. The NMSSM is a particular case of the 2HDM+S type II representing a viable solution to the μ-problem [4]. The addition of an electroweak singlet S allows to generate dynamically the μ-term in the superpotential $\mu H_u H_d$. After EWSB, due to the additional gauge singlet there are two extra Higgs states, one pseudoscalar a_1 which can be very light and an additional SM-like CP-even state h_1.

3. Heavy Higgs searches : $A/H \to f\bar{f}$

In this section, we present the most recent Run II results of additional heavy Higgs searches in fermionic decays, with a particular emphasis on 3rd generation fermions particular $h/A/H \to \tau^+\tau^-$ [9], $b\bar{b}(A/H \to b\bar{b})$ [10], and also $t\bar{t}(A/H \to t\bar{t})$ [11]. In the 2HDM type-II model, the cross-section of $\sigma(A/H \to ff)$ is enhanced for tanβ<1 for the $t\bar{t}$ final state, and for large tanβ in the $b\bar{b}$ and $\tau^+\tau^-$ final states. All three searches have an event categorization based on the number of b-tagged jets and on the Higgs production mechanism. In the $b\bar{b}(A/H \to b\bar{b})$ search, the production mechanism probed is the b-associate production and at least three b-tagged jets are required in the final state. In the ττ search, since b-associate production dominates at high tanβ while gluon-gluon fusion dominates at low tanβ, there are two separate categories per final state, b-tagged for ggF and non b-tagged jets for bbH. In the $A/H \to t\bar{t}$ analysis, the Higgs bosons produced in association with the top quarks namely, ttH, tHq and tWH, and decaying to a top quark are included. The key signature is the presence of same-sign dileptons which is a very rare process in the SM. No significant excess over standard model background is observed in any of the model-independent exclusion limits of the above searches, see Figure 1. The most stringent exclusion limits coming from $A/H \to \tau^+\tau^-$ are translated into exclusion contours in the parameter space of MSSM m_h^{mod+} scenario (Fig. 2). An analogous MSSM-like parameterization is adopted to obtain the exclusion contours for the MSSM $A/H \to b\bar{b}$ search.



(a) $b\bar{b}(A/H \to b\bar{b})$ *(b)* $b\bar{b}(\Phi \to \tau^{+}\tau^{-})$

(c) $(t\bar{t},tW,tq)(A \to t\bar{t})$

Figure 1: Upper limits at 95% CL on σ(bb̄A/H) x BR(A/H→bb̄) [10] (top left), on σ(bb̄Φ) x BR(Φ→τ⁺τ⁻) [9] (top right) and on σ(tt,tW,tq) x BR(A→tt̄) [11] (bottom).

4. Light Higgs Searches: h→aa→4f

In the NMSSM, the pseudoscalar a_1 boson is identified as the lightest Higgs state. Consequently, SM-like Higgs bosons are allowed to decay into two NMSSM pseudoscalars, which later decay into fermions. Because of the narrow width of the Standard Model Higgs, even a tiny Yukawa coupling Y_{haa} would lead to a measurable BR(h→aa) of the order of few percent. In this section, we present the most recent results for $h \to a_1a_1 \to 2\mu 2\tau$ [12] and $h \to a_1a_1 \to 2b2\tau$ [13] search channels with 4 (3) final states respectively. The non-boosted τ pair topology restricts the search region of the a-boson mass range $15 < m_a < 62.5$ GeV. The main observable used for the combined maximum likelihood fit for all final states are the di-muon $m_{\mu\mu}$ and di-tau invariant mass $m_{\tau\tau}$ respectively.

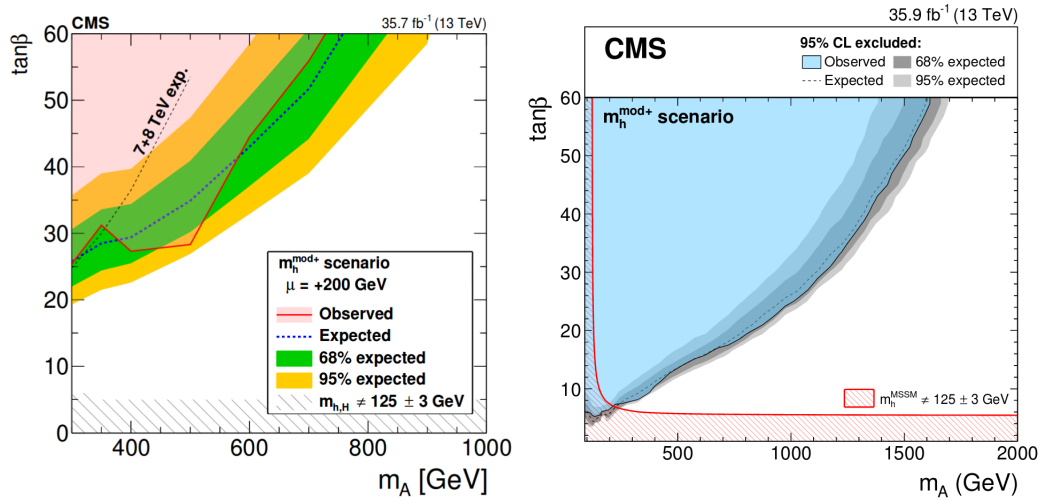


Figure 2: Exclusion contours for the A/H→ $b\bar{b}$ search [10] (left) and in the $\Phi \rightarrow \tau^{+}\tau^{-}$ search [9] (right) in the tanβ-m_A plane for the MSSM m_h^{mod+} benchmark scenario.

The upper limits on the σ_h/σ_{SM} BR(h→aa→4f) illustrated in Fig.3 are translated in exclusion contours of 2HDM+S type II an III. There is a significant improvement in exclusion limits in all 2HDM+S types with respect to Run I results. In the NMSSM BR(h→aa) > 23 % excluded at 95% CL for m_a = 35 GeV (see Fig 4.a). This limit was obtained in the 2τ2b final state probed for the first time at 13 TeV and represents, to date, the most sensitive result at the LHC. In the 2HDM Type III, the upper limits on BR(h→aa→2μ2τ) shown in Fig4 are as low as 1% for m_a =60 GeV.

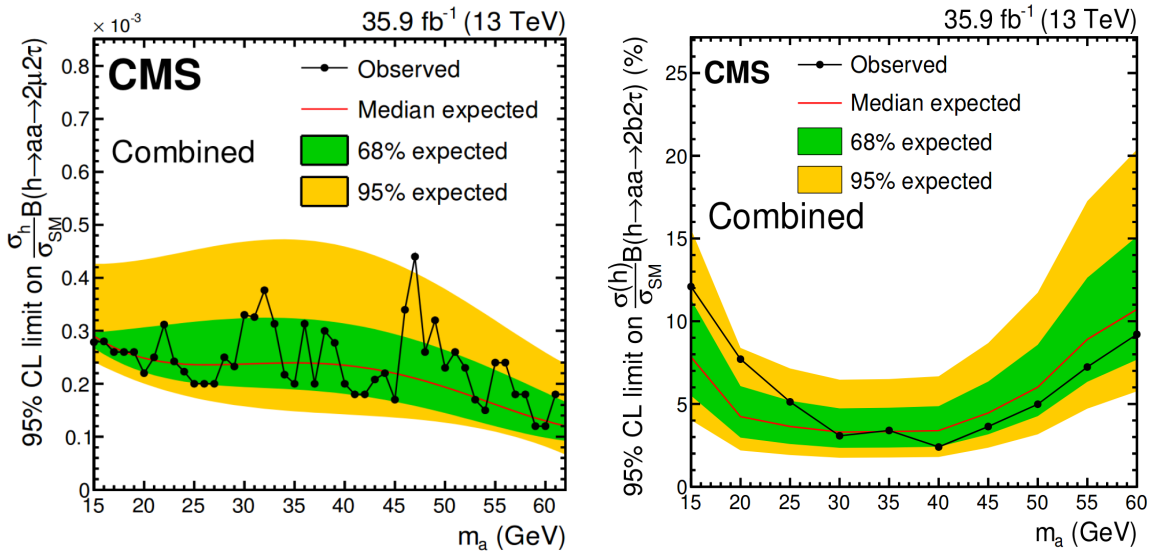


Figure 3: Upper limits at 95% CL on (σ_h/σ_{SM}) x B(h→aa→2μ2τ) [12] (left) and σ_h/σ_{SM} B(h→aa→2b2τ) [13] (right).

5. Conclusions

The observed Higgs boson at a mass of 125 GeV could be a portal to an extended Higgs sector. Searches for additional neutral Higgs bosons in fermionic decays were presented probing a mass range of $100 < m_{\Phi} < 1300$ GeV. The results of the searches for $h \rightarrow aa$ decays with four fermions in the final state for low masses $15 < m_a < 62.5$ GeV were also summarized. Since no significant excess was observed over the Standard-Model background, the model-independent limits were translated in exclusion contours in the parameter space of several 2HDM(+S) models.

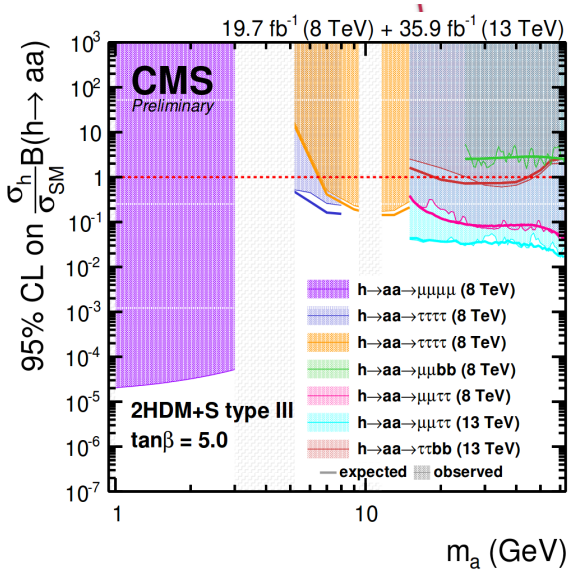


Figure 4: Exclusion limits on $\sigma_h/\sigma_{SM}\, B(h \rightarrow aa)$ in the 2HDM Type III for $\tan\beta = 5$. The upper limits on $B(h \rightarrow aa \rightarrow 2\tau 2b)$ as low as 1% for $m_a = 60$ GeV [14].

References

[1] CMS Collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC,* Phys.Lett. B716 (2012) 30-61

[2] I. J. Aitchison, Supersymmetry and the MSSM: An Elementary Introduction, arXiv:hep-ph/0505105

[3] G. C. Branco et al., *Theory and phenomenology of two-Higgs-doublet models*, arXiv:1106.0034 [hep-ph]

[4] U. Ellwanger, *The Next-to-Minimal supersymmetric Standard Model*, Phys.Rept. 496 (2010) 1-77

[5] CMS Collaboration, *The CMS experiment at the CERN LHC,* JINST 3 S08004 (2008)

[6] CMS Collaboration, *Search for invisible decays of a Higgs boson produced through vector boson fusion in proton-proton collisions at √s = 13 TeV, arXiv:1809.05937*

[7] CMS Collaboration, *Precise determination of the mass of the Higgs boson and tests of compatibility of its couplings with the standard model predictions using proton collisions at 7 and 8 TeV*, Eur.Phys.J. C75 (2015) no.5, 212

[8] M. Hussain et al., *Constraints on Two Higgs Doublet Model Parameters in the light of rare B-Decays, arXiv:1703.10845v2* [hep-ph]

[9] CMS Collaboration, *Search for additional neutral MSSM Higgs bosons in the ττ final state in proton-proton collisions at √s = 13 TeV,* JHEP 1809 (2018) 007

[10] CMS Collaboration, *Search for beyond the standard model Higgs bosons decaying into a bb pair in pp collisions at √s = 13 TeV,* JHEP 1808 (2018) 113

[11] CMS Collaboration, *Search for physics beyond the standard model in events with two leptons of same sign, missing transverse momentum, and jets in proton–proton collisions at √s = 13 TeV,* Eur.Phys.J. C77 (2017) no.9, 578

[12] CMS Collaboration, *Search for an exotic decay of the Higgs boson to a pair of light pseudoscalars in the final state of two muons and two τ leptons in proton-proton collisions at √s = 13 TeV, arXiv:1805.04865*

[13] CMS Collaboration, *Search for an exotic decay of the Higgs boson to a pair of light pseudoscalars in the final state with two b quarks and two τ leptons in proton-proton collisionst at √s = 13 TeV,* Phys.Lett. B785 (2018) 462

[14] CMS Collaboration, *Search for an exotic decay of the Higgs boson to a pair of light pseudoscalars in the final state with two b quarks and two τ leptons in proton-proton collisionst at √s = 13 TeV,* CMS PAS HIG-17-029