PROCEEDINGS OF SCIENCE

Search for extended Higgs boson sectors at CMS

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Searches for beyond the standard model Higgs bosons are presented, particularly in the context of an extended Higgs boson sector containing more than the single Higgs doublet field of the standard model such as two-Higgs-doublet models, including a search for neutral Higgs boson decays into a $b\bar{b}$ pair and a search for a heavy pseudoscalar boson decaying to a Z boson and a Higgs boson. The data collected with the CMS detector at the LHC at centre-of-mass energy of 13 TeV is used, corresponding to an integrated luminosity of 35.9 fb^{-1}. No signal above the standard model background expectation is observed. Upper limits are placed on the product of the cross section and branching fraction for each search, and interpreted in different models of an extended Higgs sector.

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1. Introduction

The discovery of a Higgs boson with mass around 125 GeV and the studies of its properties by the ATLAS and CMS [1] collaborations at the CERN LHC have shown a compatibility with the standard model (SM) Higgs boson and, hence, led to a new era in physics. However, the SM is known not to be complete, and a number of beyond the standard model (BSM) theories include an extended Higgs sector.

There exist many possible extensions of the SM, and one of the simplest is the minimal supersymmetric standard model (MSSM), which incorporates supersymmetry. In the MSSM, two scalar Higgs doublets are introduced and the symmetry is spontaneously broken twice giving three neutral, ϕ = h, H, A and two charged, H^+ and H^-, Higgs bosons. Of the neutral Higgs states, the h and H are CP-even, while the A is CP-odd.

An extension of the SM Higgs boson sector is also provided in two-Higgs-doublet models (2HDM) which introduce a second scalar doublet in addition to the one from the SM.

2. Search for beyond the standard model Higgs bosons decaying into a $b\bar{b}$ pair

A search for a heavy Higgs boson decaying into a bottom quark-antiquark pair and accompanied by at least one additional bottom quark has been performed [2]. The data analyzed correspond to an integrated luminosity of 35.7 fb^{-1}, recorded in proton-proton collisions at a centre-of-mass energy of 13 TeV at the LHC. For this purpose, dedicated triggers using all-hadronic jet signatures combined with online b tagging were developed. The signal is characterized by events with at least three b-tagged jets. The search has been performed in the invariant mass spectrum of the two leading jets that are also required to be b-tagged as shown in Fig. 1.

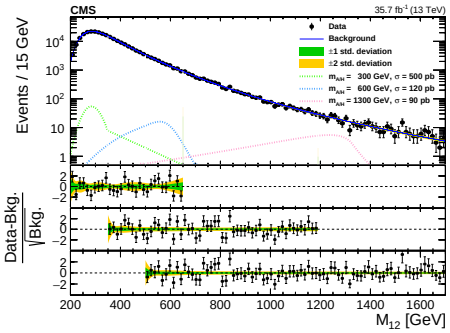

Figure 1: Distribution of the dijet invariant mass M_{12} in the data triple b tag sample showing the three subranges together with the corresponding background-only fits. The shaded area shows the post-fit uncertainty. For illustration, the expected signal contribution for three representative mass points is shown, scaled to cross sections suitable for visualization (Fig. 5 in [2]).

No evidence for a signal is found. Upper limits on the product of the Higgs boson cross section and branching fraction are obtained in the mass region 300-1300 GeV at 95% confidence level (CL). They range from about 20 pb at the lower end of the mass range, to about 0.4 pb at 1100 GeV, and extend to considerably higher masses than those accessible to previous analyses in this channel as shown in Fig. 2 (left).

The results are interpreted within various benchmark scenarios of the MSSM. They yield upper limits on the model parameter tan β as a function of the mass parameter m_A. The observed limit at 95% CL for tan β is as low as about 25 at the lowest m_A value of 300 GeV in the m_h^{mod+} scenario with a higgsino mass parameter of $\mu = +200$ GeV as shown in Fig. 2 (right). The results are also

interpreted in the 2HDM Type-II and Flipped scenarios. In the Flipped scenario, upper limits on $\tan\beta$ are set over the full $\cos(\beta-\alpha)$ range and for Higgs boson masses from 300 to 850 GeV. The limits obtained for the Flipped scenario provide competitive upper limits in the region around zero of $\cos(\beta-\alpha)$ and provide strong unique constraints on $\tan\beta$ as shown in Fig. 3.

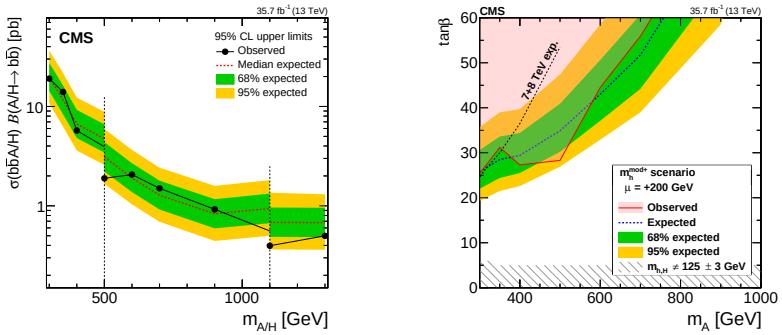

Figure 2: Left: Expected and observed upper limits on $\sigma(\mathrm{pp}\to \mathrm{bA/H+X})\mathbf{B}(\mathrm{A/H}\to \mathrm{b\bar{b}})$ at 95% CL as a function of the Higgs boson mass $m_{\mathrm{A/H}}$. Right: Expected and observed upper limits at 95% CL for m_{A} vs the MSSM parameter $\tan\beta$ in the $m_{\mathrm{h}}^{\mathrm{mod+}}$ benchmark scenario with $\mu = +200$ GeV (Fig. 6-7 in [2]).

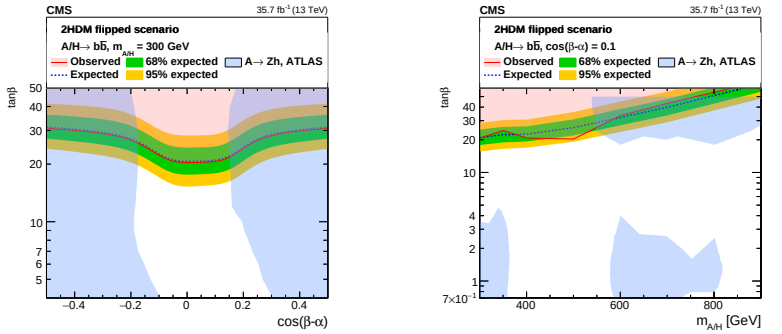

Figure 3: Upper limits for the parameter $\tan\beta$ at 95% CL for the Flipped model, as a function of $\cos(\beta-\alpha)$ in the range of $[-0.5, 0.5]$ for the mass $m_{\mathrm{H}} = m_{\mathrm{A}} = 300$ GeV (left) and as a function of $m_{\mathrm{A/H}}$ when $\cos(\beta-\alpha)$ = 0.1 (right). The observed limits from the ATLAS A $\to$ Zh analysis [3] at 95% CL, which are provided up to $\tan\beta$ = 50, are also shown as blue shaded area for comparison (Fig. 8 in [2]).

3. Search for a heavy pseudoscalar boson decaying to a Z boson and a Higgs boson

A search is presented in the context of an extended Higgs boson sector for a heavy pseudoscalar boson A that decays into a Z boson and a SM-like Higgs boson (h), with the Z boson decaying into electrons, muons, or neutrinos, and the h boson into $\mathrm{b\bar{b}}$. The standard model backgrounds are suppressed by using the characteristics of the considered signal, namely the production and decay angles of the A, Z, and h bosons, and by improving the A mass resolution.

No excess is observed and upper limits at 95% CL are set on the A boson cross section in either the gluon-gluon fusion or b quark associated production and the branching fractions, which

exclude 1 to 0.01 pb at the lower and upper ends of the 250-1000 GeV mass range as shown in Fig. 4.

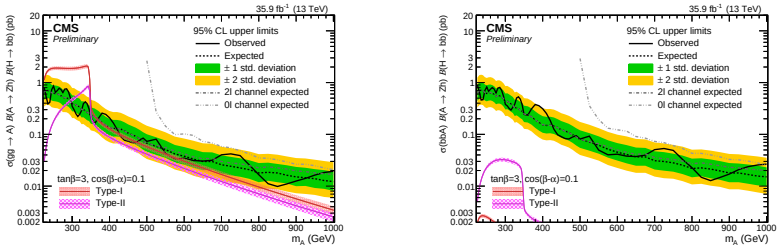

Figure 4: Observed and expected 95% CL upper limits on $\sigma_{\mathrm{A}}\mathbf{B}(\mathrm{A} \to \mathrm{Zh})\mathbf{B}(\mathrm{h} \to \mathrm{b\bar{b}})$ for an A boson produced through gluon-gluon fusion (left) and b quark association (right) as a function of m_{A} in the narrow-width approximation, including all statistical and systematic uncertainties (Fig. 5 in [4]).

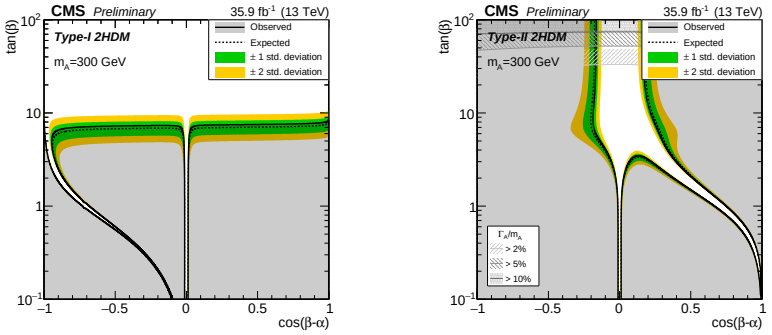

Figure 5: Observed and expected (with ± 1, 2s uncertainty bands) exclusion limit for Type-I (left) and Type-II (right) models, as a function of $\tan\beta$ and $\cos(\beta - \alpha)$ (Fig. 6 in [4]).

Interpretations are given in the context of Type-I, Type-II, Flipped, and Lepton-specific [1] 2HDM formulations, thereby reducing the parameter space for extensions of the standard model as shown in Fig. 5.

References

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

[2] CMS Collaboration, *Search for beyond the standard model Higgs bosons decaying into a* $\mathrm{b\bar{b}}$ *pair in pp collisions at* $\sqrt{s}$ *= 13 TeV*, *JHEP* **08** (2018) 113.

[3] ATLAS Collaboration, *Search for heavy resonances decaying into a W or Z boson and a Higgs boson in final states with leptons and b jets in 36 fb*$^{-1}$ *of* $\sqrt{s}$ *= 13 TeV pp collisions with the ATLAS detector*, *JHEP* **03** (2018) 174.

[4] CMS Collaboration, *Search for a heavy pseudoscalar boson decaying to a Z boson and a Higgs boson at* $\sqrt{s}$ *= 13 TeV*, CMS-PAS-HIG-18-005, `http://cds.cern.ch/record/2628545`.

[1] Interpretations in Flipped and Lepton-specific models can be found in [4]