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Search for a Higgs boson decaying to a pair of 125 GeV Higgs bosons hh or for a Higgs boson decaying to Zh, with τ leptons in the final state

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A search for a heavy scalar Higgs boson H decaying into a pair of lighter (Standard Model like) 125 GeV Higgs bosons h or a pseudo scalar Higgs boson A decaying into a Z boson and an h boson is presented [1]. This search is performed on data collected by CMS experiment during 2012 proton–proton collisions, corresponding to an integrated luminosity of 19.7 fb^{-1}. A final state consisting of two τ leptons and two b-jets is searched for the H $\rightarrow$ hh decay and a final state consisting of two τ leptons and two additional leptons, compatible with being the decay products of a Z boson, is searched for the decay A $\rightarrow$ Zh. This search is interpreted in the contexts of both the minimal supersymmetric extension to the standard model and two Higgs Doublet Models. No excess is found and upper limits at 95% confidence level are set on the production cross-section times branching ratio in the mass range 220 < m_A < 350 GeV and 260 < m_H < 350 GeV.

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1. Introduction

The observation of a boson at LHC [2, 3] and the recent measurements of its properties [4] confirm the compatibility of the discovered particle with the predicted Standard Model (SM) Higgs boson. On the other hand these results do not exclude the possibility of including this SM-like Higgs boson in extended models, like the MSSM scenario [5] or the 2HDM model [6]. The discovered h could then be produced also as a decay product of heavier Higgs bosons such as H and A. In the mass region below $2m_{\mathrm{t}}$ and at low values of tanβ, the decay mode of the heavy scalar H $\rightarrow$ hh and that of the pseudoscalar A $\rightarrow$ Zh can have sizeable branching fractions. This encourages a programme of searches for 260 GeV < $\mathrm{m_A}$ < $2m_{\mathrm{t}}$ in the H $\rightarrow$ hh decay mode and for 220 GeV < $\mathrm{m_A}$ < $2m_{\mathrm{t}}$ for A $\rightarrow$ Zh channel, where the lower mass bounds are approximately 2 $\mathrm{m_h}$ and $\mathrm{m_h}$ + $\mathrm{m_Z}$ respectively.

These proceedings report the results of searches for the decays H $\rightarrow$ hh $\rightarrow$ bb$\tau\tau$ and A $\rightarrow$ Zh $\rightarrow \ell\ell\tau\tau$ (where $\ell\ell$ denotes $\mu\mu$ or ee), exploiting the same techniques used for the search for the SM Higgs boson at 125 GeV in a τ leptons pair [7]. Several different $\tau\tau$ signatures are studied: for the channel H $\rightarrow$ hh $\rightarrow$ bb$\tau\tau$, the $\mu\tau_{\mathrm{h}}$, $e\tau_{\mathrm{h}}$, and $\tau_{\mathrm{h}}\tau_{\mathrm{h}}$ final states are considered, where τ_{h} denotes a hadronically decaying τ, whereas for the channel A $\rightarrow$ Zh $\rightarrow \ell\ell\tau\tau$, the $\mu\tau_{\mathrm{h}}$, $e\tau_{\mathrm{h}}$, $\tau_{\mathrm{h}}\tau_{\mathrm{h}}$, and $e\mu$ final states are selected. The data used for this search were recorded by the CMS detector [8] in proton-proton collisions at the CERN LHC and correspond to an integrated luminosity of 19.7 fb^{-1} at a centre of mass energy of $\sqrt{s}$ =8 TeV.

For simplicity neither the charge of the leptons nor the particle-antiparticle nature of quarks are indicated in the following.

2. Event selection

In each H $\rightarrow$ hh $\rightarrow$ bb$\tau\tau$ final state the presence of two well identified and isolated oppositely charged τ leptons and no additional leptons in the event is required. In the $\mu\tau_{\mathrm{h}}$ and $e\tau_{\mathrm{h}}$ final states it is also required that the transverse mass, $m_{\mathrm{T}} = \sqrt{2p_T E_{\mathrm{T}}^{\mathrm{miss}}(1-\cos\Delta\phi)}$, of the lepton and $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ is less than 30 GeV, to reject events coming from W+jets and tt backgrounds (Fig. 1 left). In addition to the $\tau\tau$ selection, each event must contain two b jet candidates that come from h $\rightarrow$ bb which are ordered by the b-tagging discriminator value, CSV [7], such that the leading and subleading jets are defined as those with the two highest CSV values and are used to reconstruct $\mathrm{m_{bb}}$. Then the events are separated into categories, according to the number of b-jets, which pass the medium CSV working point.

In the A $\rightarrow$ Zh $\rightarrow \ell\ell\tau\tau$ channel the Z boson is reconstructed from two same-flavour, isolated, oppositely charged light leptons with an invariant mass between 60 GeV and 120 GeV. After the Z candidate is chosen, the $h \rightarrow \tau\tau$ decay is selected, requiring an oppositely charged di-τ pair and no additional light leptons in the event. An optimized requirement on the $L_{\mathrm{T}}^{\mathrm{h}}$ variable, the scalar sum of the visible transverse momenta of the two τ candidates originating from the h boson, (Fig. 1 on the right) is applied to reduce the reducible background from misidentified leptons as well as the irreducible background from ZZ production.

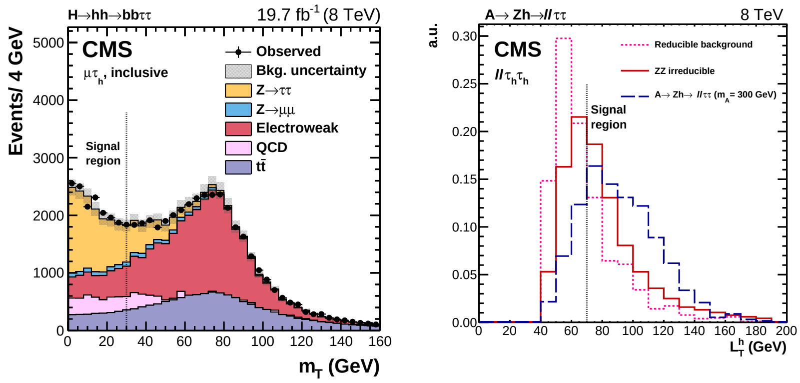

Figure 1: Distribution of m_{T} for events in the $\mu\tau_{\mathrm{h}}$ final state (left), containing at least two additional jets. The W+jets background is included in the "electroweak" category. Multijet events are indicated as QCD. Distribution of the variable $L_{\mathrm{T}}^{\mathrm{h}}$ for events in the $\ell\ell\tau_{\mathrm{h}}\tau_{\mathrm{h}}$ final state (right). The reducible background is estimated from data, instead the ZZ irreducible background is taken from simulation.

3. Background estimation

The main contributing background to the H $\rightarrow$ hh $\rightarrow$ bb$\tau\tau$ final state is composed of tt events, which have the same signature of the signal and are estimated from MC simulation. The $Z \rightarrow \tau\tau$ process also constitutes an irreducible background but it is greatly reduced thanks to the b-tagging requirements. It is estimated combining Drell-Yan MC sample and data with a dedicated data-driven technique [7]. Another significant source of background comes from QCD multijet events, where one or more jets are misidentified as τ_{h}. The estimation is obtained from a QCD-enriched region in data samples. In the semileptonic channels, W+jets events, in which there could be a jet misidentified as a τ_{h}, are another sizeable source of background. The W+jets contribution is estimated using a control region of events with large m_{T} close to the W mass. In the $\tau_{\mathrm{h}}\tau_{\mathrm{h}}$ channel this background is found to be less relevant and it is taken from MC simulation. Further details can be found in Ref. [1].

The backgrounds affecting the A $\rightarrow$ Zh $\rightarrow$ $\ell\ell\tau\tau$ channel can be divided into a reducible component and an irreducible component which contribute in equal parts. The irreducible backgrounds are estimated using MC samples: the predominant source comes from ZZ production, followed by the SM Higgs boson associated production with a Z boson, ttZ production, and triboson events (WWZ, WZZ, ZZZ). The reducible backgrounds have at least one misidentified lepton in the final state due to a misidentified object that passes the lepton identification. They are estimated from data samples with the so called *fake-rate* method, exploting the probabilities of misidentifying an object as lepton in a signal-free region, which depend on the transverse momentum of the object closest to the candidate, $f(p_T^{\mathrm{fake}})$. Finally, the number of reducible background events in the final selection is evaluated by applying the weight $f(p_T^{\mathrm{fake}})/(1 - f(p_T^{\mathrm{fake}}))$ to the events, according to the observed misidentified lepton candidates in the sideband.

4. Results and interpretation

For the H $\rightarrow$ hh $\rightarrow$ bb$\tau\tau$ process, the distribution used for signal extraction is the four-body mass, which is reconstructed using a kinematic fit [1], denoted by $m_{\mathrm{H}}^{\mathrm{kinfit}}$. The kinematic fit selects events that are consistent with a mass of 125 GeV for both the dijet (m_{bb}) and di-τ masses ($m_{\tau\tau}$ is reconstructed using a dedicated algorithm called SVFit [7]). The signal events are also selected requiring that $70 < m_{\mathrm{bb}} < 150$ GeV and $90 < m_{\tau\tau} < 150$ GeV. For the $\mathrm{A} \to \mathrm{Zh} \to \ell\ell\tau\tau$ process, the A boson mass is used for the signal extraction and is reconstructed making the invariant mass of the Z boson candidate and of the h boson candidate, from SVFit.

In none of the two searches the invariant mass spectra show an evidence of a signal. Model independent upper limits at 95% confidence level (CL) on the cross section times branching fraction are set using the CL_s method [9, 10] (Fig. 2 top left and right). Systematic uncertainties are taken into account as nuisance parameters in the fit procedure [1]. The observed limits on the cross section times branching fraction are interpreted in the MSSM and 2HDM frameworks: in the MSSM the "low tanβ" scenario is used [11] and different low tanβ values versus $\mathrm{m_A}$ parameter points are considered. The exclusion region in the $\mathrm{m_A}$ - tanβ plane for the combination of the analyses, in such a scenario, is shown in Fig. 2 bottom left. The interpretation of the observed limits in a Type II 2HDM is performed using the cross-sections and branching fractions provided by the LHC Higgs Cross Section Working Group [12]. The exclusion regions, calculated using the combination of both analyses, in the $\cos(\beta-\alpha)$ vs. tanβ plane for such a scenario with a heavy Higgs boson mass of 300 GeV are shown in Fig. 2 bottom right.

5. Conclusion

A search for a heavy scalar Higgs boson H decaying into a pair of SM-like Higgs bosons hh and a search for a heavy neutral pseudoscalar Higgs boson A decaying into a Z boson and a SM-like Higgs boson h, are performed using events recorded by the CMS experiment at the LHC in 2012. No evidence for a signal is found and exclusion limits on the production cross section times branching fraction for the processes $\mathrm{H} \to \mathrm{hh} \to \mathrm{bb}\tau\tau$ and $\mathrm{A} \to \mathrm{Zh} \to \mathrm{LL}\tau\tau$ are presented. The results are also interpreted in the context of the MSSM and 2HDM models.

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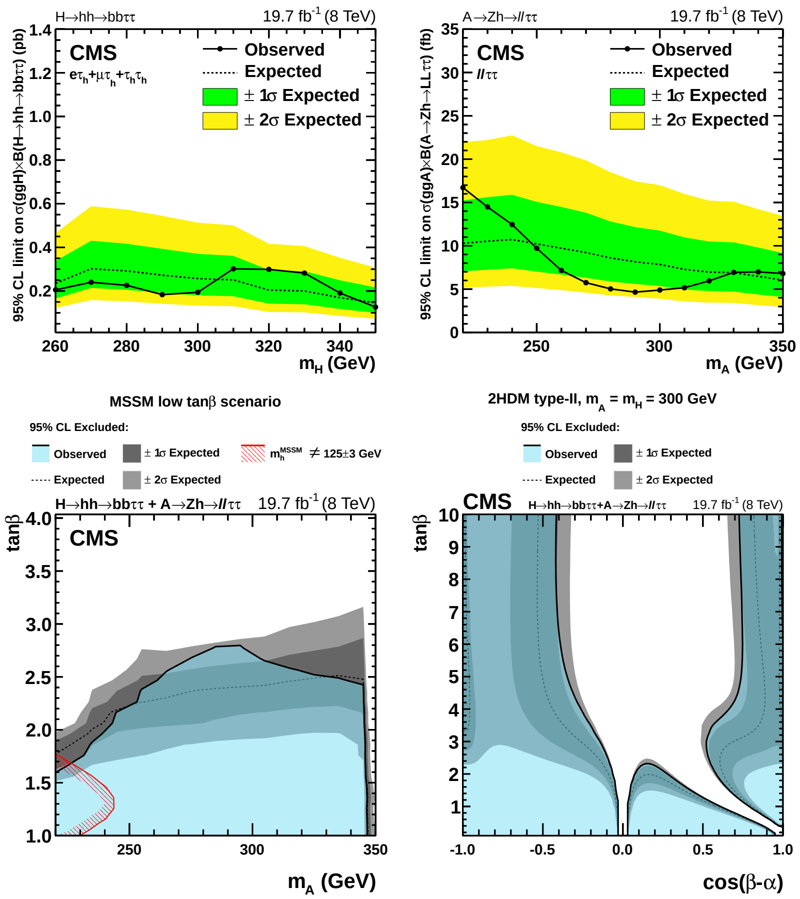

Figure 2: Upper limits at 95% CL on the H $\to$ hh $\to$ bb$\tau\tau$ cross section times branching fraction for final states combined (top left). Upper limits at 95% CL on cross section times branching fraction on A $\to$ Zh $\to$ LL$\tau\tau$ for all $\ell\ell\tau\tau$ final states combined (top right), where $L = e, \mu$ or τ in order to reflect the small Z $\to \tau\tau$ contribution to the signal acceptance. The 95% CL exclusion region in the m_{A} - tanβ plane for the low-tanβ scenario (bottom left), and the 95% CL exclusion regions in the cos$(\beta-\alpha)$ vs. tanβ plane of 2HDM Type II model for $m_{\mathrm{A}} = m_{\mathrm{H}} = 300$ GeV (bottom right), combining the results of both channels. The area highlighted in blue below the black curve marks the observed exclusion. The dashed curve and the grey bands show the expected exclusion limit with the relative uncertainty.

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