PROCEEDINGS OF SCIENCE

Search for a heavy Higgs boson decaying to a pair of W bosons in proton-proton collisions at 13 TeV with CMS

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A search for a heavy Higgs boson decaying to a pair of W bosons in the mass range from 200 GeV to 3 TeV is presented. The analysis is based on proton-proton collisions recorded by the CMS experiment at the CERN LHC in 2016, corresponding to an integrated luminosity of 35.9 fb^{-1} at $\sqrt{s} = 13\,\mathrm{TeV}$. The decay of the W boson pair is reconstructed in fully leptonic and semi-leptonic final states. Combined upper limits at the 95 % confidence level on the product of the cross section and branching fraction for heavy Higgs boson with Standard Model-like couplings and decays in the mass range are evaluated. Exclusion limits are also set in the context of two Higgs doublet models.

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1. Motivation

The existence of an additional Higgs boson would prove the presence of beyond-the-SM physics. This analysis [1] is performed using proton-proton collisions recorded at a center-of-mass energy of 13 TeV by the CMS experiment [2] in 2016, corresponding to an integrated luminosity of 35.9 fb^{-1}. The analysis combines the results of searches in the di-leptonic WW $\rightarrow$ lνlν and the semi-leptonic WW $\rightarrow$ lνqq channels, where l = e,μ. The search is performed in a wide mass range from 200 GeV up to 3 TeV.

2. Analysis strategy

The search for a resonance X is being conducted in this analysis through ggF and VBF production. A parameter f_{VBF} is introduced, which is the fraction of the VBF production cross section with respect to the total cross section. It is important to consider this parameter because at higher masses the VBF/ggF ratio increases. In the analysis four different hypotheses for f_{VBF} are investigated and limits are set on each of them.
The signal region is defined by a number of cuts, which include a b-jet veto requirement, to reduce the dominant Top background. Another example is $m_{T,H} > 60$ GeV, where $m_{T,H}$ is the transverse mass of the di-lepton and MET system. This cut helps to reject Z $\rightarrow \tau\tau$ events.
The normalization of the Top (fig. 1) and DY backgrounds in the di-leptonic analysis, as well as the Top and W+Jets (fig. 2) backgrounds in the semi-leptonic analysis, are determined from data by defining control regions. The data is fitted directly to the templates derived from simulation. The resonance X is interpreted as a heavy Higgs boson with SM-like couplings and decays. Up

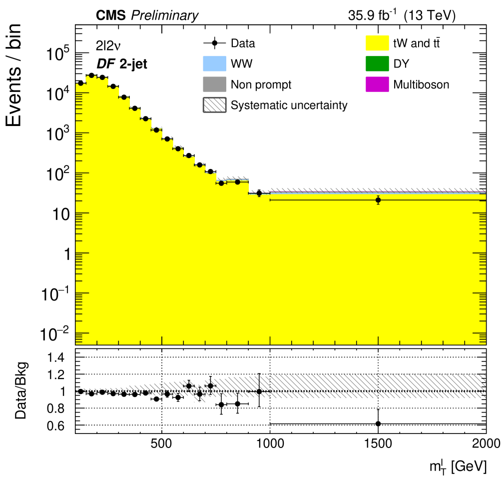

Figure 1: Top control region in the lνlν analysis [1]

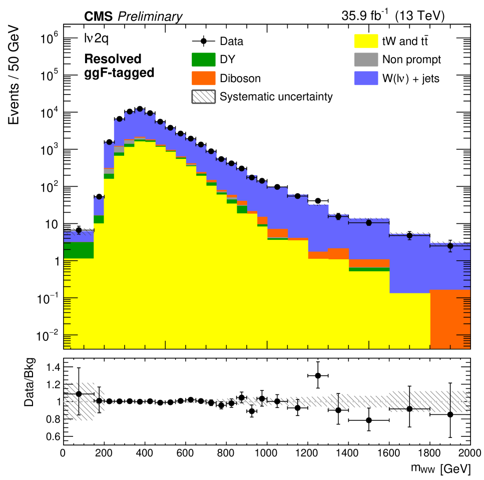

Figure 2: W+Jets control region in the lνqq analysis [1]

to 1000 GeV, the width of the resonance also corresponds to that of a heavy SM-like Higgs boson. Above 1000 GeV the width is half of the resonance mass. Due to this large width, the interference effect of the signal with the WW background continuum and the SM Higgs off-shell tail is non-negligible. The effect can be seen in figure 3 for a 700 GeV signal. The two interference sources partially cancel out, but the total interference becomes larger for higher mass signals. The interference itself is calculated using the matrix element likelihood analysis (MELA) package [6, 7].

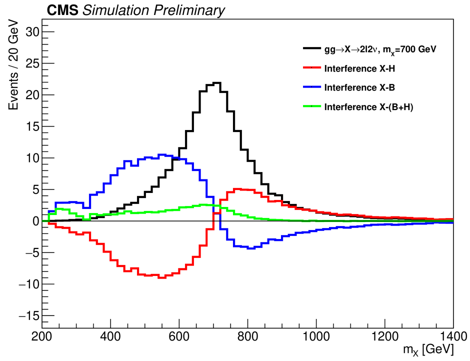

Figure 3: Interference effect for a 700 GeV signal [1]

3. WW $\to l\nu l\nu$ Analysis

The di-leptonic analysis is split into two channels: An opposite flavor (WW $\to$ eμ) and a same flavor (WW $\to$ ee/$\mu\mu$) channel. The events are categorized by the number of jets in an event. A category exists for events with either 0 jets, 1 jet or at least 2 jets. There is also a VBF category, which is orthogonal to the 2 jet category, and also requires to satisfy $m_{jj} > 500\,\text{GeV}$ and $\Delta\eta > 3.5$. The DY (Z $\to$ ee/$\mu\mu$) background dominates the same flavor region. For this reason, only the VBF

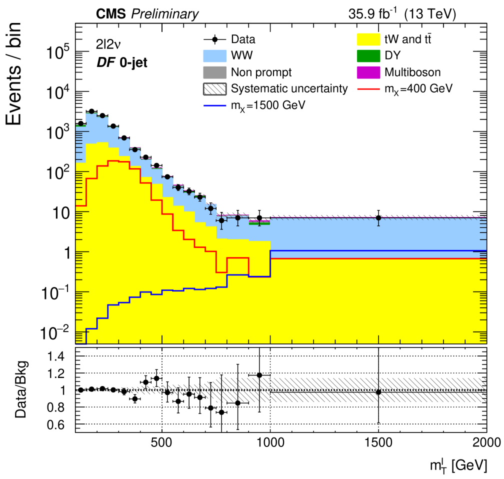

Figure 4: eμ channel, 0 jet category [1]

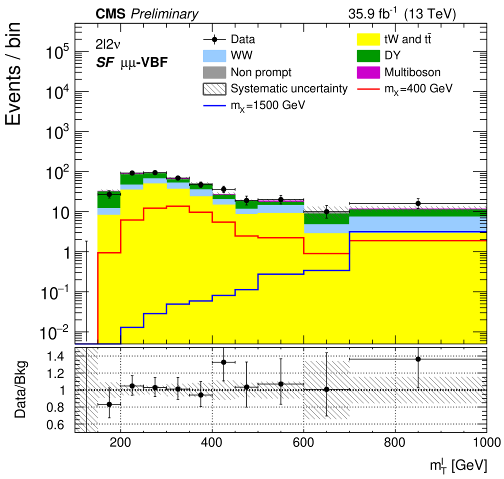

Figure 5: $\mu\mu$ channel, VBF category [1]

category is considered in the same flavor channel. In order to further reduce this background, a larger cut on MET $> 50\,\text{GeV}$ is imposed. Additionally, the invariant di-lepton mass must fulfill $70\,\text{GeV} < m_{ll} < 120\,\text{GeV}$ in the DY control region and $m_{ll} > 120\,\text{GeV}$ in the signal region.
Two of the signal regions are displayed in figure 4 and 5.

4. WW $\rightarrow$ lνqq Analysis

In the semileptonic analysis, AK8 jets are considered to reconstruct the hadronically decaying W, because the W bosons from high mass resonances are highly boosted and thus the two jets coming each from one of the quarks are likely to be merged into one jet. The reconstructed AK8 jets are reweighted by the pileup per particle identification (PUPPI) algorithm [3], then groomed using the soft-drop algorithm [4], from which the soft-drop jetmass is calculated. Signal AK8 jets are discriminated from other jets coming from background by using N-subjettiness [5] variable τ_N. The variable $\tau_{21} = \tau_2/\tau_1$ gives a measure on how well a jet can be divided into 2 subjets. If the identification of an AK8 jet as a candidate for the W boson fails in an event, it is attempted to reconstruct the W $\rightarrow$ qq candidate as a pair of resolved low p_T AK4 jets.
Events in the semi-leptonic analysis categorized by reconstruction of the hadronically decaying W boson, as well as the production mode: VBF, ggF or untagged. The VBF category is defined the same as in the lνlν analysis. If an event is not categorized as an VBF event, the angular distributions of the Higgs decay products are used as inputs for MELA, which calculates whether the event can be tagged as coming from ggF. If this fails, the event is categorized as untagged.
One of the signal regions of the semi-leptonic analysis is seen in figure 6.

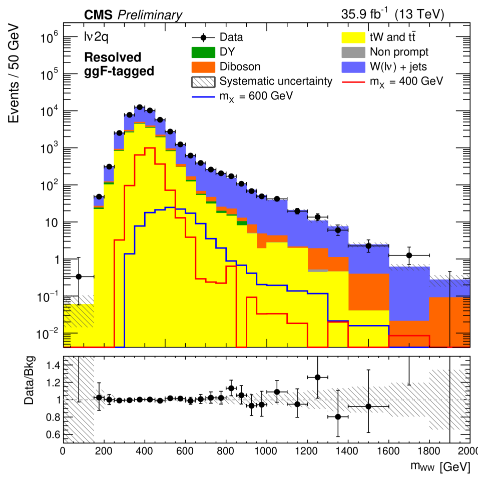

Figure 6: Resolved, ggF-tagged category [1]

5. Results

No evidence for an excess of events with respect to the SM predictions is observed in this analysis. Therefore exclusion limits are provided at 95 % confidence level (CL) on the cross section times branching fraction for different hypotheses of f_{VBF}. These include allowing f_{VBF} to float (fig. 7) or setting $f_{VBF} = 0$ (fig. 8). Additionally exclusion limits are given for a neutral heavy Higgs boson in the context of MSSM scenarios, as well as for a more general Type-I and Type-II 2HDM (fig. 9). The 2HDM scenarios assume for the Higgs boson masses $m_h = 125\,\text{GeV}$ and $m_H = m_A = m_{H^\pm}$. It is also assumed that $\cos(\beta - \alpha) = 0.1$. For the MSSM limits provided for the m_h^{mod+}, the hMSSM (fig. 10) [8], as well as the new M_h^{125} scenarios [9].

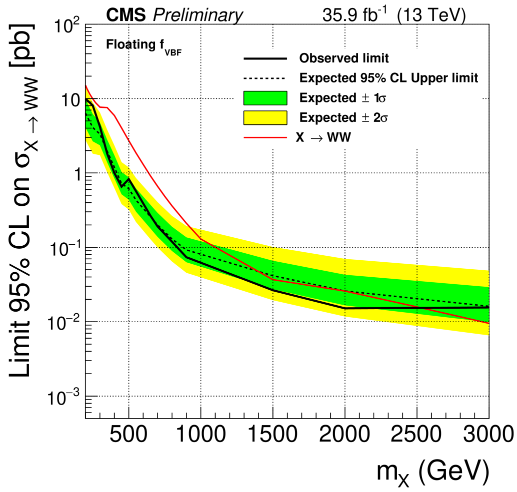

Figure 7: Expected and observed exclusion limits at 95 % CL on the cross section times branching fraction to WW for floating f_{VBF}. [1]

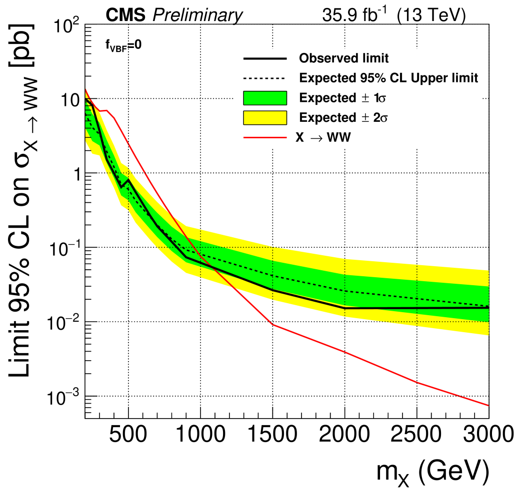

Figure 8: Expected and observed exclusion limits at 95 % CL on the cross section times branching fraction to WW for $f_{\mathrm{VBF}} = 0$. [1]

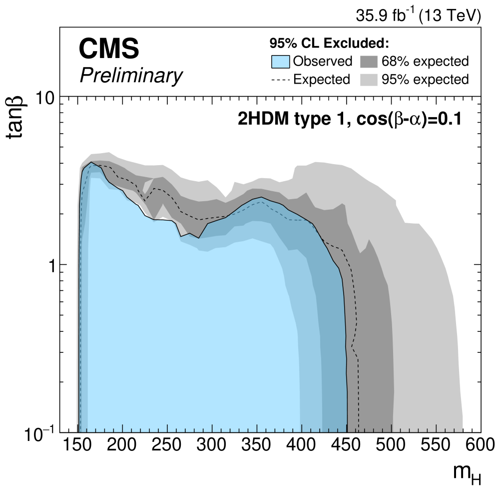

Figure 9: Expected and observed 95 % CL upper limits on $\tan\beta$ as a function of m_H for a type-2 2HDM. [1]

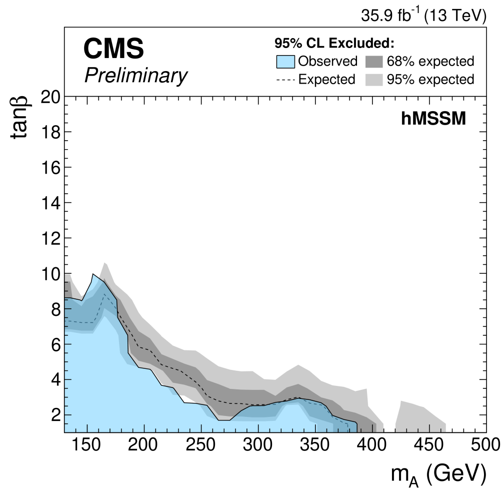

Figure 10: Expected and observed 95 % CL upper limits on $\tan\beta$ as a function of m_A for the hMSSM scenario. [1]

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