PROCEEDINGS OF SCIENCE

Non-resonant HH production and Higgs self-coupling at CMS

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Searches for non-resonant HH production and measurements of the Higgs self-coupling (λ) in the channels $HH \to bbWW^*$, $HH \to WW^*\gamma\gamma$ and $VHH \to 4b$ have been presented. The analysis is based on data recorded at a center of mass energy of 13 TeV by the CMS detector during LHC Run2. The results are compatible with the Standard Model expectation. Exclusion limits on the HH production cross section and on λ have been presented.

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1. Introduction

Since the discovery of the Higgs (H) boson [1][2][3] many of it's properties have been measured. So far, all measurements are consistent with Standard Model (SM) predictions. The H boson self-coupling, λ, has not yet been measured. The coupling λ can be measured either indirectly using the measurement of processes involving a single H boson or directly by H boson pair production (HH) [4]. The main production mode of the HH process is the gluon-gluon fusion (GGF) process, followed by the vector boson fusion (VBF) process. In addition to these, the associated production of the H boson pair with one vector boson (W/Z) also contributes by a small amount. The Feynman diagrams for these processes are shown in Fig. 1. The cross section (σ) of these processes are 31.05fb, 1.73fb and 0.856fb respectively at $\sqrt{s}$=13TeV [7]. While the cross section for HH production in the SM is very small due to destructive interference between two GGF processes, it can be enhanced [7] in physics Beyond the Standard Model (BSM) through anomalous couplings. The ratio of λ with respect to the SM prediction ($\lambda_{SM}= \frac{m_h^2}{2\times v^2} \approx 0.13$) is defined as coupling strength modifier $k_\lambda = \frac{\lambda}{\lambda_{SM}}$. Any deviation of the measured value k_λ from one will indicate the presence of BSM physics. Results of three recent published channels $HH \rightarrow bbWW^*$, $HH \rightarrow WW^*\gamma\gamma$, $VHH \rightarrow 4b$ by the CMS experiment[8], are presented.

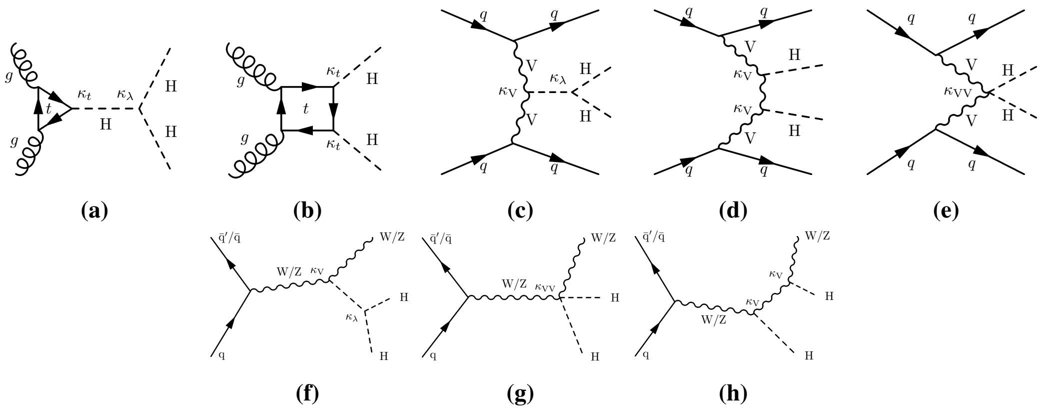

Figure 1: Non-resonant HH production in GGF (a,b), VBF (c,d,e) and associated production with one vector boson (f,g,h) process[5] [6].

2. $HH \rightarrow bbWW^*$

The analysis in the decay channel $HH \rightarrow bbWW^*$[5] targets both the GGF and VBF production modes and is studied in two final states: dilepton(DL) (both Ws: $W \rightarrow l\nu$) and single-lepton(SL) ($W \rightarrow l\nu, W \rightarrow q\bar{q}$). In both final states, events are selected in two categories. The resolved category targets events in which the $H \rightarrow b\bar{b}$ decay is reconstructed by two small radius jets while the boosted category targets events in which all particles from the $H \rightarrow b\bar{b}$ decay are merged into one large radius jet. The b-jets are identified by the DeepJet [9] algorithm and the event is required to contain at least one b-jet passing the medium working point. In the SL final state, at least one small radius jet is required from the hadronically decaying W boson in addition to one lepton, while in the DL final state, the presence of two leptons is required. Background from misidentified leptons is estimated from data, using the fake factor method[10]. A Deep Neural Network (DNN) is used to separate the GGF and VBF signal from the background. The output of the DNN distribution is used for the signal extraction. The observed (expected) upper limit on the HH production cross section, $\sigma(HH)$, amounts to 14(18) times the SM expectation (Fig. 2, left) at the 95% confidence level (CL). The corresponding limit on k_λ amounts to $-7.2(-8.7) < k_\lambda < 13.8(15.2)$(Fig. 2, right).

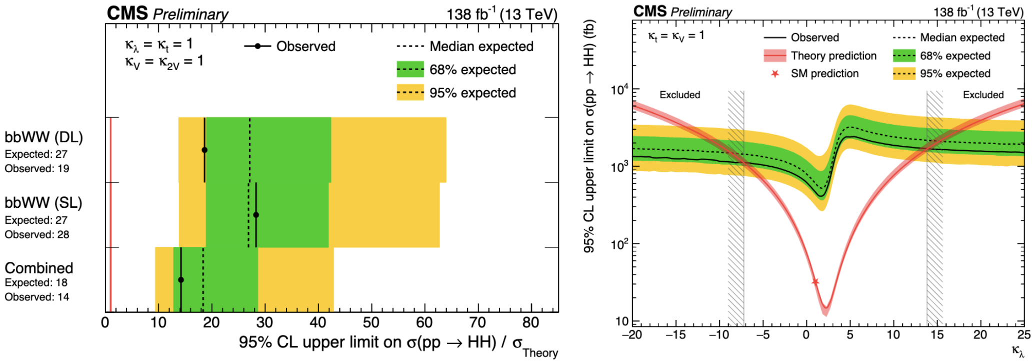

Figure 2: Observed and expected 95% CL upper limits on the HH production cross section (left) and on k_λ (right), obtained in the $HH \to bbWW^*$ channel [5].

3. $HH \to WW^*\gamma\gamma$

The analysis in the $HH \to WW^*\gamma\gamma$ [13] decay channel targets specifically the GGF production mode. The analysis is performed in three final states: DL (both Ws: $W \to l\nu$), SL ($W \to l\nu$, $W \to q\bar{q}$), fully hadronic(FH) (both Ws: $W \to q\bar{q}$). In all final states, the events are selected by requiring the presence of a photon pair with $100GeV < m_{\gamma\gamma} < 180GeV$. In the SL(FH) final state the presence of 2(4) small radius jet is required. The requirement on the multiplicity of leptons amounts to 2 in DL final state and to 1 in the SL final state. Backgrounds from multijet and $\gamma + jet$ production are estimated from side-band regions in data, while other backgrounds are estimated from Monte Carlo simulation. The $HH \to WW^*\gamma\gamma$ signal as well as the single $H \to \gamma\gamma$ background are modelled by an analytic fit to the $m_{\gamma\gamma}$ distribution in the range $115GeV < m_{\gamma\gamma} < 135GeV$ while continuum background is modelled from data in the $m_{\gamma\gamma}$ side-band region. Background contributions are removed by a cut based analysis in the DL final state, while a DNN is used in the SL and FH final states. To avoid overlap with the $HH \to bb\gamma\gamma$ analysis[11] in the FH channel, a binary classifier is used to separate $bb\gamma\gamma$ from $WW^*\gamma\gamma$ events. The observed (expected) upper limit, set at 95% CL on $\sigma(HH)$ amounts to 97(52) times the SM expectation (Fig. 3, left) . The analysis also sets a limit on k_λ, amounting to $-25.8(-14.4) < k_\lambda < 24.1(18.3)$ (Fig. 3, right).

4. $VHH \to 4b$

This analysis targets HH production in association with one vector boson (W or Z boson), where both H bosons decay to $b\bar{b}$[6]. The analysis is performed in four final states: DL($Z \to ll$), SL($W \to l\nu$), FH($W/Z \to q\bar{q}$), MET($Z \to \nu\nu$). A resolved category, where the jets coming from the hadronization of b quarks are reconstructed as small radius jets and identified by the DeepJet algorithm, is considered in all four final states. A boosted category, where the jets coming from $H \to b\bar{b}$ decay are merged into one large radius jet and identified by ParticleNet[12] algorithm, is studied only in the FH and MET final states. A Boosted Decision tree (BDT) is used to separate regions in phase space sensitive to the couplings k_λ and k_{2V}. In each region, a separate BDT or neural network is trained to separate the VHH signal from background events. The 95% CL upper

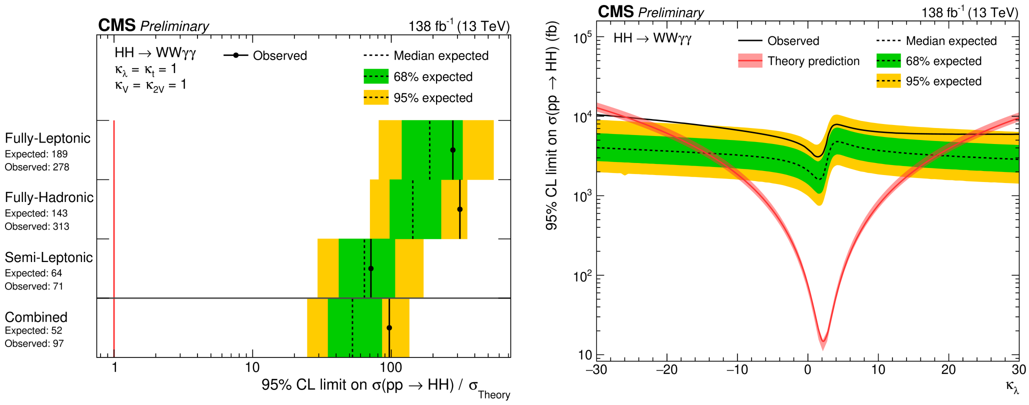

Figure 3: Observed and expected 95% CL upper limits on the inclusive HH production cross section with respect to the σ_{SM} (left) and as a function of k_λ (right) in $HH \to WW^*\gamma\gamma$ analysis [13].

limit on the VHH production cross section is 294 times the SM expectation. The constraints on k_λ amounts to $-37.7(-30.1) < k_\lambda < 37.2(28.9)$.

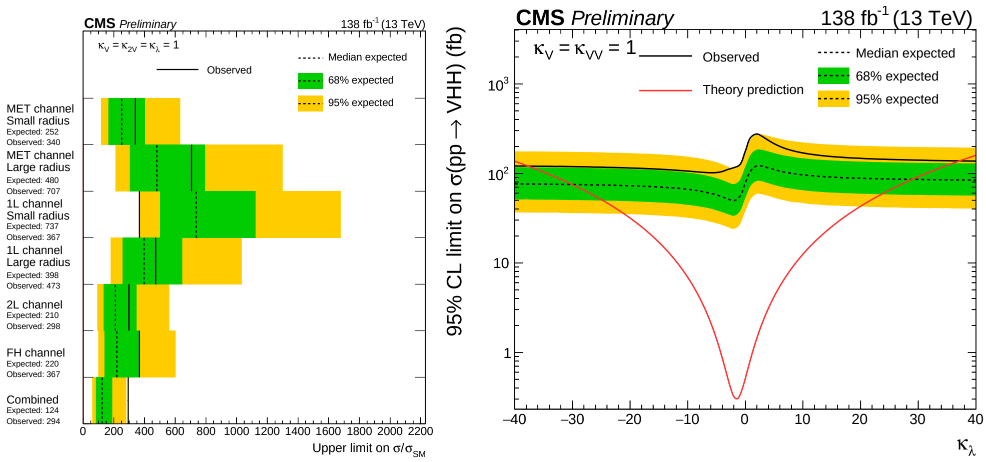

Figure 4: Observed and expected 95% CL upper limits on the cross section for VHH production (left) and on k_λ (right), obtained by the $VHH \to 4b$ analysis [6].

5. Conclusion

Studies of non-resonant HH production and of the H boson self-coupling, λ, have been presented in the decay channels $HH \to bbWW^*$, $HH \to WW^*\gamma\gamma$ and $VHH \to 4b$ using the full LHC Run-2 data set recorded at $\sqrt{s}$=13TeV. Results of the $HH \to WW^*\gamma\gamma$ and $VHH \to 4b$ have been presented by CMS for the first time. The sensitivity of the $HH \to bbWW^*$ analysis has been improved significantly with respect to the previous publication [14] based on $35.9 fb^{-1}$ of data recorded in 2016 by leveraging improved b-jet identification, using multi class DNN for separating the HH signal from backgrounds, by adding the SL channel and more data. By adding further decay channels, using improved machine learning techniques, more efficient triggers and further improvements, we expect the CMS analysis sensitivity to improve significantly by the end of LHC Run 3.

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