PROCEEDINGS OF SCIENCE

Search for Higgs boson pair production in the $bbWW^*$ final state in proton-proton collisions with the full Run2 CMS data

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The results of a search for Higgs boson pair (HH) production in the final state $bbWW^*$ 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 Run 2. Both non-resonant and resonant productions have been studied. The results are compatible with the standard model expectations. Exclusion limits on the HH production cross section in both non-resonant and resonant production modes as well as limits in different Effective Field Theory scenarios have been presented.

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1. Introduction

Since the discovery of the Higgs (H) boson [1–3] many of its properties have been measured. So far, all measurements are consistent with standard model (SM) predictions. The H boson self-coupling, λ_{HHH}, has not yet been measured. The coupling λ_{HHH} can be measured directly via H boson pair production (HH). The main production mode of the HH process is the gluon-gluon fusion (GGF) process(Fig. 1a, 1b), followed by the vector boson fusion (VBF) process (Fig. 1c, 1e). The cross section (σ) of these processes are approximately 31.05 fb and 1.73 fb respectively at $\sqrt{s}$=13 TeV. The VBF process allows to measure the quartic coupling between two vector bosons and two H bosons. While the cross section for HH production in the SM is very small, it can be enhanced in Beyond the standard model (BSM) scenarios through anomalous couplings (Fig. 1f, 1h). The deviation of the value of λ_{HHH} and of the quartic coupling from the SM value is quantified by the coupling modifiers κ_λ and κ_{2V}, respectively. In Effective Field Theory (EFT) interpretation [4], signal events with similar distributions in m_{HH} and and $\cos\Theta^*$ (angle between one of the Higgs bosons and beam axis), are grouped into different EFT benchmark (BM) points in the 5D space of $\kappa_\lambda, \kappa_{2V}, c_{2g}, c_g c_V$. The HH production may also be enhanced by decays of new heavy resonance (X) particles of spin-0 (Radion) or spin-2 (Graviton). While the $bbWW^*$ final state provides the second highest branching ratio among all HH decay channels, resulting in a large signal yield, this final state suffers from huge $t\bar{t}$ background. Results on $HH \to bbWW^*$ final state [5] by the CMS [6] experiment are presented here.

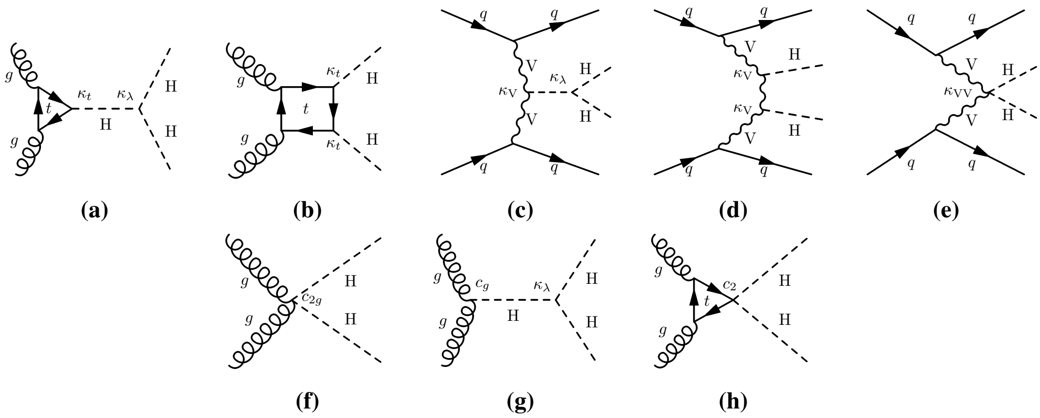


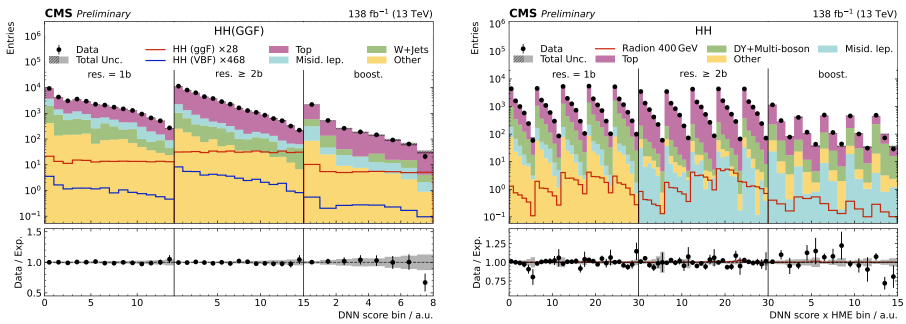
Figure 1: Non-resonant HH production via the GGF (a,b), and VBF (c,d,e) process and possible contributions of BSM physics via anomalous couplings (f,g,h) [5].

2. Analysis Strategy

The analysis is performed both in non-resonant and resonant production modes. Non-resonant HH production is studied in the GGF and VBF production modes, while resonant HH production is limited to the GGF production mode. In both production modes, events are split into two channels depending on the decay of the W bosons: dilepton (DL) (both Ws: $W \to l\nu$) and single lepton (SL) ($W \to l\nu, W \to q\bar{q}$). Events in the SL channel are triggered by triggers demanding the presence of a single lepton, while events in the DL channel are triggered by a combination of single and double lepton triggers. Events in which both jets from $H \to b\bar{b}$ decay are reconstructed as one large radius jet are considered in the boosted category, while the events in which the two b-tagged jets are reconstructed as two separate small radius jets are considered in the resolved category. In the resolved category, the b-tagged jets are identified by the DeepJet [7] algorithm and the event is required to contain at least one b-tagged jet passing the medium working point. The resolved category is further split into 2b and 1b-tagged categories based on how many jets pass the medium working point of the DeepJet algorithm. In the SL channel, at least one small radius jet originating from the hadronically decaying W boson is required.

The background from misidentified leptons is estimated from data, using a fake factor method [8]. The contribution of Drell-Yan (DY) background in the DL channel is also measured from data using the ABCD method. Transfer factors from events with 0 b-tagged jets to events with either 1 or 2 b-tagged jets are determined by selecting DY events in which the mass of the lepton pair is within a window $|m_{ll} - m_Z| \leq 10$ GeV where m_Z denotes the Z boson mass. The transfer factors are applied to events with 0 b-tagged jets and dilepton mass not within $|m_{ll} - m_Z| \leq 10$ GeV in signal region except the modified b-tagging requirement. Other backgrounds are estimated from simulation.

A Multiclassifier Deep Neural Network (DNN) is used to separate the backgrounds from signal. In the non-resonant analyses, two separate DNN output nodes for GGF and VBF production modes are used. In the resonant DL channel, the mass of the resonant particle is reconstructed using the Heavy Mass Estimator (HME) algorithm [9]. The DNN distributions from all output nodes are used to extract the signal (Fig. 2). In the resonant DL channel, 2D distribution in the HME and DNN output in signal nodes are unrolled into a 1D distributions which are used to extract the signal (Fig. 2b).

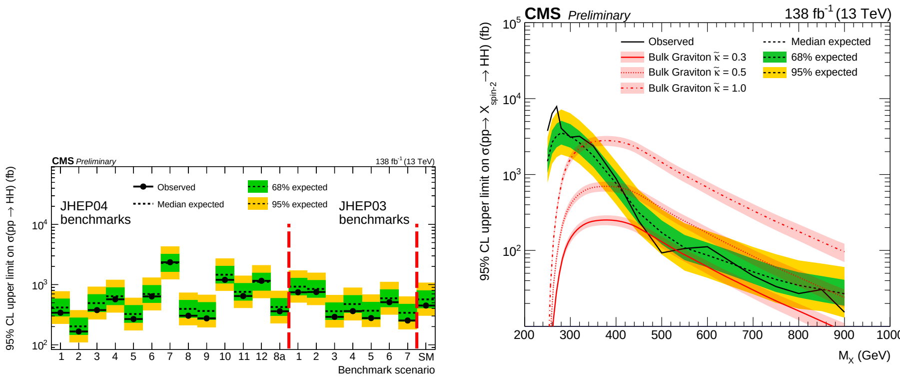


(a) **(b)**

Figure 2: DNN distribution in non-resonant GGF node in SL channel (a) and resonant DL channel (b) [5].

3. Results and Conclusion

No significant evidence for a HH signal is observed in the $bbWW^*$ final state. Upper limits on $\sigma(HH)$ are set at 95% confidence level. The observed (expected) upper limit on non-resonant HH production amounts to 14(18) times the SM expectation. A corresponding observed (expected) limit on κ_λ is set within the interval $-7.2(-8.7) < \kappa_\lambda < 13.8(15.2)$. This analysis also sets an upper limit on the VBF production mode, amounting to 277(301) times the SM expectation and a corresponding limit on κ_{2V} is set within the interval $-1.1(-1.4) < \kappa_{2V} < 3.2(3.5)$. The upper limits on $\sigma(HH)$ in different EFT BM points vary from 0.16(0.2) to 2.3(2.2) pb (Fig. 3a) depending on event kinematics in different BM points. The upper limit on the resonant HH production cross section depends on the mass of the new heavy resonance (X) particle as shown in Fig. 3b. The sensitivity of the presented analysis has been improved significantly with respect to the previous publication [10] based on 2016 data only by leveraging improved b-jet identification, using multi-class DNN, by adding the SL channel and by analyzing the full Run 2 dataset.



(a) EFT **(b)** spin2-Graviton

Figure 3: Upper limits in different EFT BM scenarios (a) and on $\sigma(pp \to X \to HH)$ for resonance of spin-2 (b), as function of the mass (M_X) of the resonance [5].

References

[1] CMS Collaboration, "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC" $Physics.Letters.B716(2012)30$

[2] ATLAS Collaboration, "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC", $Phys.Lett.B716(2012)1-29$

[3] CMS Collaboration, "Observation of a new boson with mass near 125 GeV in pp collisions at $\sqrt{s}$=7 and 8 TeV", $JHEP06, 081(2013)$

[4] Alexandra Carvalho et al., "Higgs pair production: choosing benchmarks with cluster analysis", $JHEP04(2016)126$

[5] CMS Collaboration, "Search for HH production in the bbWW decay mode", CMS-PAS-HIG-21-005

[6] CMS Collaboration, "The CMS experiment at the CERN LHC", $JINST3(2008)S08004.361p$

[7] Emil Bols et.al., "Jet flavour classification using DeepJet" arXiv:2008.10519

[8] CMS Collaboration, "Evidence for associated production of a Higgs boson with a top quark pair in final states with electrons, muons, and hadronically decaying τ leptons at $\sqrt{(s)} = 13$TeV", $JHEP66(2018)$

[9] T. Huang et al., "Resonant di-Higgs boson production in the $bbWW$ channel: Probing the electroweak phase transition at the LHC" $Phys.Rev.D96, 035007$

[10] CMS Collaboration, "Search for resonant and nonresonant Higgs boson pair production in the $bbl\nu l\nu$ final state in proton-proton collisions at $\sqrt{s} = 13$TeV", $JHEP2018, 54(2018)$