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Search for additional Higgs bosons at high mass decaying to WW with the CMS experiment

Giulio Bardelli[a,b,*] **on behalf of CMS Collaboration**

[a] *Dipartimento di Fisica, Università degli studi di Firenze, Via Sansone 1, Sesto Fiorentino (FI), Italy*

[b] *INFN, Via B. Rossi 1, Sesto Fiorentino (FI), Italy*

E-mail: giulio.bardelli@cern.ch

An integrated luminosity of 138 fb^{-1}, collected by CMS during Run 2, allows to perform search for new particles with unprecedented sensitivity. The search for a scalar particle with higher masses than the 125 GeV Higgs boson is performed investigating resonances that decays into two W bosons. Results are interpreted in a model independent way as well as in various extensions of the standard model, such as the Two Higgs Doublet Model (2HDM) and a specific subset of the Minimal Supersymmetric Standard Model (MSSM). In this document the latest updates in the H→WW channel will be presented.

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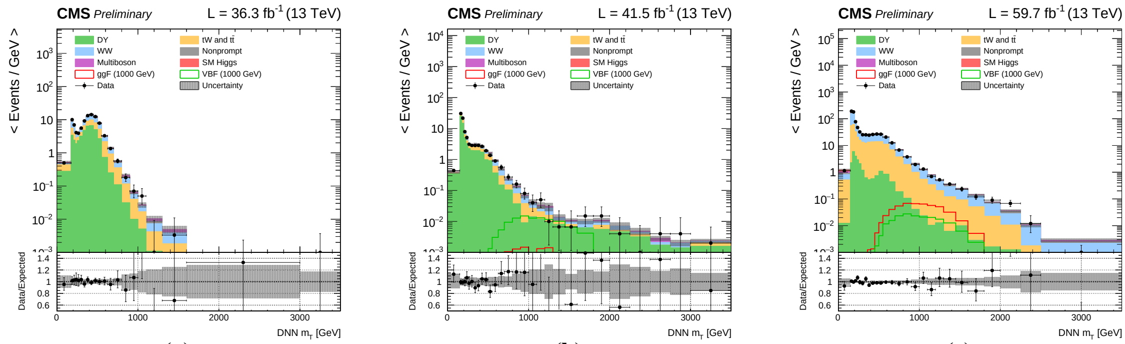
The search for an additional Higgs-like scalar particle that decays into W bosons with a di-leptonic final state aims to expand our understanding of the Standard Model. When considering the production cross-sections of a scalar particle, two mechanisms are particularly significant for high masses and are thus explored: gluon-gluon fusion (ggH) and Vector Boson Fusion (VBF), the latter characterized by the presence of two additional jets as an experimental signature. Both processes are analyzed either with their relative contributions as predicted by the Standard Model or with varying compositions, modeled through the VBF fraction, f_{VBF}, which scales the VBF signal yield by f_{VBF} and the ggH yield by (1 - f_{VBF}). The mass range investigated spans from 115 GeV to 5000 GeV. Different width assumptions are considered, with the width taken as a fraction of the generated mass. The results are interpreted either as model-independent upper limits on cross-sections under various VBF-ggH scenarios or as exclusion limits for benchmark scenarios based on the Two Higgs Doublet Model (THDM)[1] or the Minimal Supersymmetric Model (MSSM)[2].

The signature consists of two leptons, ℓ ($\ell = e, \mu$), which can be either of the same flavour (SF) or opposite flavour (OF), along with missing transverse energy (MET) attributed to the two neutrinos, ν_ℓ. Several background sources can mimic the signal, including $t\bar{t}$ with di-leptonic decay, Drell-Yan (DY), non-resonant WW background, VZ, VVV, and Vγ, all of which are estimated using MC simulations. The contribution from non-prompt leptons is evaluated using a data-driven method. Interference between the Standard Model Higgs and non-resonant WW with the high-mass signal is accounted for by applying weights to the interfering signals.

The strategy employs a preselection that targets two leptons and sufficiently high MET to be attributed to two neutrinos (ν). This is achieved through selection cuts applied to the transverse mass of the dilepton and MET system, which also helps reduce the contribution from non-prompt leptons. For each flavour category, in addition to the signal region, two control regions are defined to estimate DY and top-quark backgrounds. From these control regions, a normalization factor is derived and subsequently applied in the final fit. To estimate the top-quark background, b-jet requirements are imposed, while the DY background is estimated by exploiting the Z boson mass peak. An additional selection targeting higher mass ranges is implemented, requiring leptons to be emitted in a back-to-back configuration, with displacement observed only in ϕ due to the high momentum of the W bosons. This selection is applied for WW masses exceeding 1000 GeV. To improve the signal-to-background ratio, three regions are defined within the signal region: a VBF-enriched region, a ggH region, and an untagged region, each determined using outputs from a DNN. The DNN score are optimized as a compromise between purity and efficiency. A novel discriminating variable, m_T, is introduced as the output of a DNN trained using the kinematic variables of the two W bosons. The m_T is compared to m_{reco}, defined as $m_{reco} = \sqrt{(E_{\ell\ell} + p_T^{miss})^2 - (\vec{p_\mu} + \vec{p_T^{miss}})^2}$, which is closer to the generated mass compared to m_{reco}. The post-fit m_T distributions are displayed in Fig. 1.

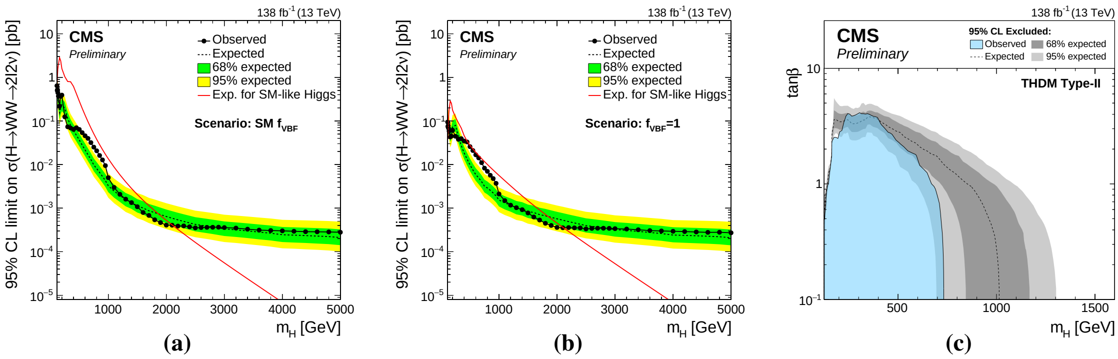
The fit is conducted using m_T as the sole discriminating variable, applied across all three signal regions for both SF and OF final states. The fit model accounts for interference between the SM Higgs, the WW continuum, and high-mass signals, using the expression: $(\mu - \sqrt{\mu})S + \sqrt{\mu}SBI + (1-\mu)B$, where S is the signal's PDF, B represents the background PDF, and SBI is a combined PDF that includes the signal, interference, and background contributions, accounting for possible negative interference. The parameter μ denotes the signal strength. As no significant excess above the background is observed, the results are interpreted as upper limits on the cross section using



(a) (b) (c)

Figure 1: The m_T in various signal regions for either SF leptons or OF leptons for different years. From left to right: SF electrons for the untagged node in 2016, 1a, SF muons in the VBF node for 2017, 1b and OF leptons for ggH node in 2018 1c. The considered mass hypothesis is 1 TeV. Ref. [3]

the asymptotic approximation. The limits for independent channels are presented in Fig.2a for the f_{VBF} SM hypothesis and in Fig. 2b for $f_{VBF} = 1$. Different width hypotheses were tested, showing consistent behavior between the observed and expected fit. The highest global significance for an excess is $2.6 \pm 0.2\ \sigma$, observed at a mass of 650 GeV for the $f_{VBF} = 1$ hypothesis. The interpretation within the THDM Type II in the m_H-$\tan\beta$ plane is depicted in Fig. 2c. In all the MSSM and THDM interpretations the observed exclusion regions behave as the expected ones, excluding masses up to 450 GeV in the MSSM case and up to 700 GeV in the THDM case. Further studies of the $H \to WW \to 2\ell 2\nu$ channel with the full Run II dataset can be found in [3].



(a) (b) (c)

Figure 2: The limit interpretation of the H→WW→ $2\ell 2\nu$. On Fig. 2a the cross section independent limit with SM f_{VBF} and $f_{VBF} = 1$ on Fig. 2b. In Fig. 2c the THDM interpretation. Ref. [3]

References

[1] Branco, G.C. et al., *Theory and phenomenology of two-Higgs-doublet models*, *Physics Reports* **516** (2012)[hep-ph/1106.0034].

[2] Bagnaschi, E. et al., *MSSM Higgs Boson Searches at the LHC: Benchmark Scenarios for Run 2 and Beyond*, *The European Physical Journal C* **79** (2019)[hep-ph/1808.07542].

[3] The CMS collaboration, *Search for high mass resonances decaying into* W^+W^- *in the dileptonic final state with* $138\,fb^{-1}$ *of proton-proton collisions at* $\sqrt{s} = 13\,TeV$, *CERN-CDS* **CMS-PAS-HIG-20-016** (2022).