PROCEEDINGS OF SCIENCE

Higgs to WW measurements with CMS

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The measurement of the Higgs boson decay to a W boson pair with an integrated luminosity of 35.9 fb^{-1} collected by the CMS experiment at the LHC at 13 TeV center of mass energy is presented. The results led to the observation of the Higgs boson decay to WW with more than 5 standard deviations for the first time at CMS, providing a significant contribution to the current fit of the Higgs boson couplings to fermions and vector bosons.

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1. Introduction

The measurements of the Higgs boson decay to a pair of W bosons at $\sqrt{s} = 13$ TeV by CMS [1] is presented in this note. This decay mode has a very large branching fraction, clean experimental signature and good sensitivity to most Higgs production process, in particular gluon-gluon fusion (ggH) and vector boson fusion (VBF). The measured cross-section of the ggH production probes the Higgs boson couplings to gluons and heavy quarks, while the VBF probes the couplings to W and Z bosons.

A detailed description of CMS detector can be found in Ref. [2].

2. Analysis strategy

The events are triggered using single-lepton triggers and dilepton triggers. The analysis requires at least two opposite charge leptons with $|\eta| < 2.5$, leading lepton with $p_{\mathrm{T}} > 25$ GeV and the trailing muon (electron) with $p_{\mathrm{T}} > 10$ (13) GeV. In addiction, the events requires tight lepton identification criteria to reduce the misidentified leptons and the absence of b-tagged jets to lower the top quark backgrounds. On top of that, it is required moderate missing transverse momentum $p_{\mathrm{T}}^{\mathrm{miss}}$ due the presence of neutrinos and to reduce the Drell-Yan (DY) background contribution.

The analysis consists of 30 event categories to improve the sensitivity to the signal. The events that contain two leptons may be different or same-flavor. The different-flavor $e\mu$ decay channel dominates the sensitivity since it is the least contaminated by backgrounds. The same-flavor ee and $\mu\mu$ final states are also considered; however, their sensitivity is limited by the contamination from the DY background.

The events are also split in 0-jet, 1-jet, and 2-jets categories, counting jets with $p_{\mathrm{T}} > 30$ GeV and $|\eta| < 4.9$, to handle the large background contribution from tt production events. In addition, events are further categorized according to the trailing lepton p_{T}, since the background from misidentified leptons is larger in the low-pT region. Moreover, three dedicated 2-jets categories are included to enhance the sensitivity of ggH, VBF and VH production mechanisms.

The analysis also includes categories with three leptons which is sensitive to WH production and with four leptons which is sensitive to the ZH production mode.

3. Background estimation

The main backgrounds of $\mathrm{H} \rightarrow \mathrm{WW}$ channel are:

- WW. It has same final state as the signal. Since this is a irreducible background, the yields are estimated from the final fit procedure.
- Top. It has similar final state as the signal, but with the presence of 2 b-tagged jets. A dedicated control regions with inverted b-tagged jet veto are used to constraint this background.
- DY. It is the dominant source of background for same-flavor categories, hence a BDT is trained to discriminate signal and DY. This background is estimated from data. For the different-flavor, the events of DY decay to a pair of τ leptons is estimated with a dedicated control region.

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- Non prompt. A single W associated with a jet may populate the signal region when this jet is misidentified as a lepton. This background is estimated from data-driven with fake rate method.

The background control regions help in constraining the normalization for some of the backgrounds: Top, DY (in different-flavor categories) and WW (in same-flavor categories). These control regions consist in cut-based phase space as close as possible to the signal phase space. For subdominant backgrounds or whenever not possible to define a control region, the MC expectations and their theoretical uncertainties are used.

4. Results

The signal extraction method depends on the event category. On the one hand, the different-flavor ggH-tagged categories uses two variables to discriminate signal and background: the dilepton invariant mass (m_{ll}) and the transverse mass of the final state objects (m_T), an example is shown in Fig. 1. On the other hand, the VBF categories adopt only the dilepton invariant mass m_{ll} and the WH categories uses the minimum ΔR between opposite charge leptons. While all the other categories are event count analysis with dedicated optimised event selections.

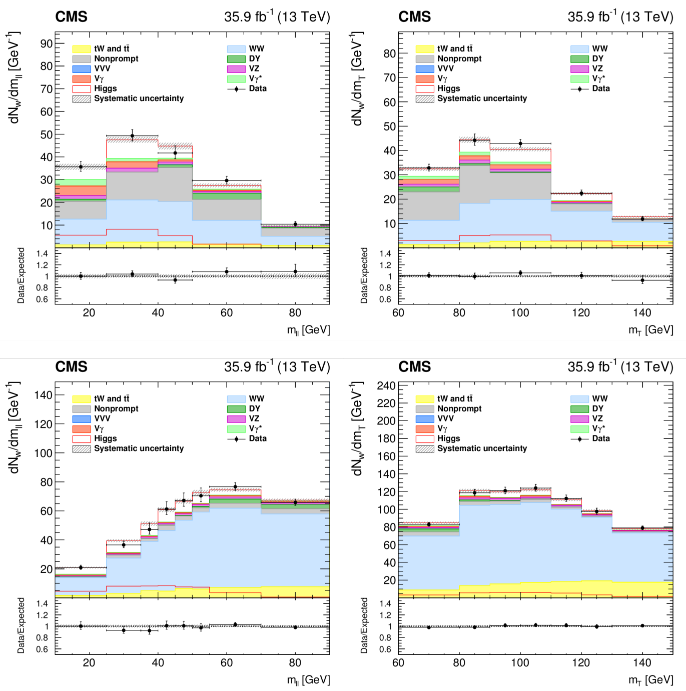


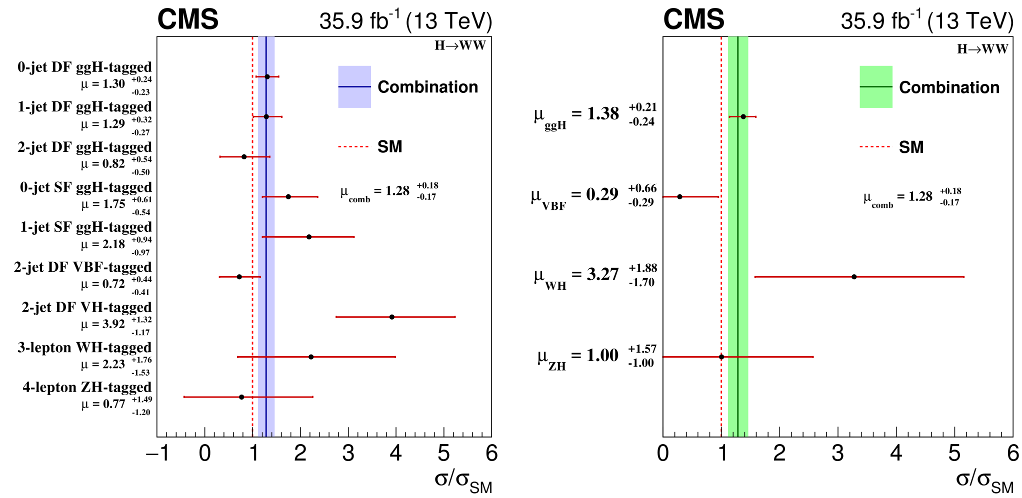
Figure 1: Weighted events as a function of m_{ll} (left) and m_T (right) for different-flavor events with 0 jets and $p_T < 20$ GeV (upper row) or $p_T > 20$ GeV (lower row). The dashed gray band accounts for all systematic uncertainties relative to signal and background yields after the fit [1] .

The final binned fit is performed using template histograms for all the signal and background process after all selection criteria. Combining all the categories, the observed (expected) significance for a SM Higgs boson with $m_H = 125.09$ GeV is 9.1 (7.1) standard deviations. This is the first observation of H→WW at CMS.

The corresponding best fit signal strength, which is extracted from a simultaneous likelihood fit of all signal and control region, is

$$\hat{\mu} = 1.28 \pm 0.10(\mathrm{stat})^{+0.11}_{-0.11}(\mathrm{syst})^{+0.10}_{-0.07}(\mathrm{theo})\,. \tag{4.1}$$

Moreover, the individual best fit of signal strength per category of the analysis and for the main production modes are shown in Fig. 2. The observed cross sections normalized to the SM predictions for the main Higgs boson production modes are shown in Fig 3. The cross-sections are measured in a simplified phase space with $|y_{\mathrm{H}}| < 2.5$, as it is specified in the stage-0 STXS framework. The dominant experimental uncertainties arise from the determination of the top, WW and DY backgrounds from data, and the uncertainties related to the lepton reconstruction and identification efficiencies.



(a) (b)

Figure 2: (a) Observed signal strength modifiers for each category. (b) Observed signal strength modifiers for each Higgs boson production mechanism. The vertical continuous line corresponds the best value of the combined signal strength and the filled area shows its 68% confidence intervals [1].

Furthermore, two-dimensional likelihood scans in a physics model where fermions induced production mechanisms (ggH, ttH and bbH) and vector induced mechanisms (VBF and VH) have different signal strength modifiers and different coupling modifiers were performed and they are shown in Fig. 4.

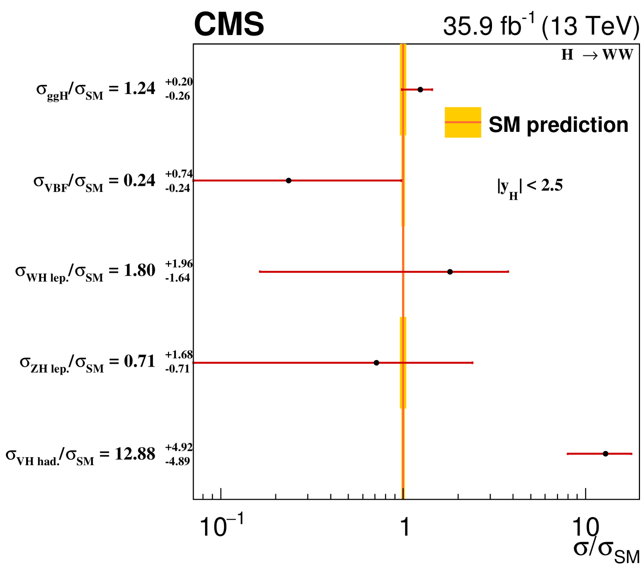
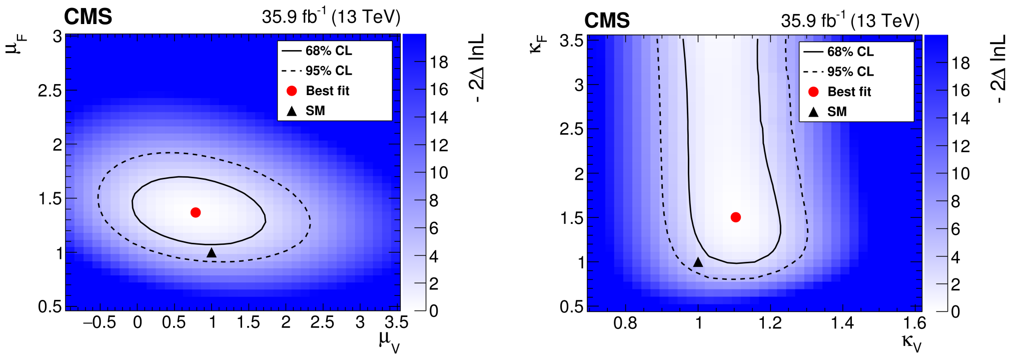


Figure 3: Observed cross sections for the main Higgs boson production modes. The vertical line and its band represent the SM prediction and associated theoretical uncertainties [1].



(a) (b)

Figure 4: Two-dimensional likelihood profile as a function of (left) the signal strength modifiers associated with fermion (μ_F) or vector boson (μ_V) couplings, and (right) the coupling modifiers associated with either fermion (k_F) or vector boson (k_V) vertices of the k-framework. The red circle corresponds the best fit value and the black triangle represents the SM prediction [1].

References

[1] CMS Collaboration, *Measurements of properties of the Higgs boson decaying to a W boson pair in pp collisions at $\sqrt{s}$ = 13TeV*, *Physics Letters B* **791** (2019) 96 [hep-ex/1806.05246].

[2] CMS Collaboration, *The CMS experiment at the CERN LHC*, *JINST* **3** (2008) S08004.