PROCEEDINGS OF SCIENCE

Higgs boson measurements in the $\mathrm{W^+W^-}$ decay channel with the CMS detector

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Recent measurements of the production of the Higgs boson with subsequent decay to a W boson pair are discussed. Leptonic decays of the W bosons are sought, selecting events with a pair of leptons with opposite charge and missing transverse momentum. Jet activity associated with the Higgs boson production, together with event topology, are used to classify events in categories sensitive to different Higgs boson production mechanisms. The data sample corresponds to an integrated luminosity of $35.9\,\mathrm{fb}^{-1}$, collected by the CMS detector at the LHC in pp collisions at $\sqrt{s} = 13\,\mathrm{TeV}$. The combination of all categories lead to an observed signal strength of $1.28^{+0.18}_{-0.17}$, compared to the standard model prediction for a Higgs boson with a mass of $125.09\,\mathrm{GeV}$. With an observed signal significance of 9.1σ, this is the first observation of the Higgs boson decay to a W boson pair with CMS.

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1. Introduction

After the discovery, the precise measurement of the Higgs boson properties has become one of the main targets of the ATLAS and CMS Collaborations, which established that the new particle spin, parity, and couplings with the SM particles are consistent with the SM predictions within uncertainties [1, 2, 3]. The precise measurement of the Higgs boson couplings to fermions and vector bosons, as well as the differential measurement of its production cross section as a function of kinematic variables, has become a fundamental way to test the SM predictions, and a useful tool to search for beyond the standard model (BSM) effects. Given its large branching fraction, the decay channel of the Higgs boson to a pair of W bosons ($\mathrm{H} \to \mathrm{WW}$) is one of the most sensitive for a precision measurement of the Higgs boson cross section and couplings. The final state in which both W bosons decay to leptons ($\mathrm{H} \to \mathrm{WW} \to 2\ell 2\nu$) is the cleanest decay channel and is affected by a moderate amount of background. The characteristic signature is the presence of two oppositely charged leptons, either $\mathrm{e}^{\pm}\mu^{\mp}$, $\mathrm{e}^{\pm}\mathrm{e}^{\mp}$, or $\mu^{\pm}\mu^{\mp}$, and a substantial amount of transverse momentum imbalance ($\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$) due to the neutrinos from the W boson decays, which is reconstructed in the detector as the negative vector sum of the p_{T} of all particle-flow objects in the event [4]. The main background processes arise from nonresonant production of W boson pairs (WW), production of top quarks (mainly $\mathrm{t\bar{t}}$ but also tW), W+jets (dubbed as nonprompt lepton production) in which one jet can be misidentified in the detector as a prompt lepton, and Drell-Yan (DY) production. The latter is particularly important for final states with a charged lepton pair with same flavor. This channel is suitable for a precision measurement of the Higgs boson production cross section through the gluon fusion mechanism (ggH), which is the dominant production mode at LHC, and also allows measurements of the subleading production channels, such as production via vector boson fusion (VBF) and associated production with a vector boson (VH). All this channels are studied in this report and contribute to the precision in the measurement of the Higgs boson couplings. Results reported here are based on a data sample collected in pp collision at $\sqrt{s} = 13\,\mathrm{TeV}$ by the CMS detector at the LHC [5], corresponding to an integrated luminosity of $35.9\,\mathrm{fb}^{-1}$.

2. Analysis strategy

All details about physics objects definition and reconstruction are described in Ref. [6]. Events are selected requiring at least two isolated lepton candidates with opposite charge originating from the same primary vertex, and a minimum $p_{\mathrm{T}}^{\mathrm{miss}}$ of $20\,\mathrm{GeV}$. The leading lepton is required to have $p_{\mathrm{T}} > 25\,\mathrm{GeV}$, while a minimum value of $13(10)\,\mathrm{GeV}$ is required for the subleading electron (muon). Given the large background contribution from top quark production, events are categorized based on the number of jets, where jet counting is performed on jets with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$. The 0-jet and 1-jet categories are sensitive to the ggH production mode and are labeled as 0-jet and 1-jet ggH-tagged, respectively. To increase the signal significance, these events are further split in several orthogonal sub-categories with different signal and background contributions. Events containing at least two jets are categorized in order to be sensitive to different production mechanisms: events with an invariant mass of the pair of jets (m_{jj}) less than $65\,\mathrm{GeV}$, or $105 < m_{\mathrm{jj}} < 400\,\mathrm{GeV}$, are used to probe the ggH production mode with two additional jets (2-jet ggH-tagged); events with $65 < m_{\mathrm{jj}} < 105\,\mathrm{GeV}$ and with a pseudorapidity separation between the two jets of $|\Delta\eta_{jj}| < 3.5$ are sensitive to the VH production mechanism, where the associated vector boson decays to a pair of jets (2-jet VH-tagged); finally, events with $m_{jj} > 400\,\mathrm{GeV}$ and $|\Delta\eta_{jj}| > 3.5$ are used to measure the VBF production mode (2-jet VBF-tagged). Two additional categories of events containing 3 and 4 charged leptons are defined to probe the WH production, where the associated W boson decays to one charged lepton and one neutrino, and ZH, where the Z boson decays to two leptons with opposite charge and same flavor. The kinematic properties of the Higgs boson production and decay are exploited to distinguish signal and background processes. The most sensitive variables are the dilepton invariant mass ($m_{\ell\ell}$), and the transverse mass, defined as $m_T = \sqrt{2p_T^{\ell\ell} p_T^{\text{miss}}[1-\cos\Delta\phi(\ell\ell,\vec{p}_T^{\text{miss}})]}$. The normalization of the top quark and DY backgrounds is estimated using data in dedicated control regions, while the WW background normalization is estimated from data directly in the signal region. This is possible because of the different $m_{\ell\ell}$ and m_T shapes for signal and WW processes. The shapes of these and other minor background processes are taken from simulated events usually based on theoretical calculations at next-to-leading order (NLO) QCD accuracy. The nonprompt background contribution is fully estimated using data, as well as the DY contribution in the same-flavor categories. Detailed information about background estimation and relative systematic uncertainties is given in Ref. [6]. The signal extraction procedure relies on a binned maximum likelihood template fit using $m_{\ell\ell}$ and m_T as discriminating variables in most categories.

3. Results

The signal strength modifier (μ), defined as the ratio between the measured cross section and the SM expectation, is measured performing a simultaneous fit of all the categories, assuming that the relative proportions among different production mechanisms are those predicted by the SM. The observed value is $\mu = 1.28^{+0.18}_{-0.17} = 1.28 \pm 0.10(\text{stat}) \pm 0.11(\text{syst})^{+0.10}_{-0.07}(\text{theo})$, showing the contribution of statistical, systematic, and theoretical uncertainty separately. The probability to observe a signal at least as large as the one seen by combining all channels, under the background-only hypothesis, corresponds to an observed significance of 9.1 standard deviations for $m_H = 125.09\,\mathrm{GeV}$, to be compared with the expected value of 7.1 standard deviations. Additional simultaneous fits are performed scaling the signal contribution in each category with a different signal strength modifier, and using different signal strengths for each production mechanism. The results are shown in Fig. 1 and no significant deviation with respect to the SM expectation is observed. A fit is also performed to probe the Higgs boson couplings to either fermions or vector bosons, using the two-coupling parameterization defined in the κ-framework [7]. The two-dimensional likelihood profile in the (κ_V, κ_F) plane is shown in Fig. 2, and the best fit result is consistent with the SM model expected value within two standard deviations.

References

[1] CMS Collaboration, "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC", *Phys. Lett. B* **716** (2012) 30, doi:10.1016/j.physletb.2012.08.021

[2] ATLAS and CMS Collaborations, "Combined measurement of the Higgs boson mass in pp collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS and CMS experiments", *Phys. Rev. Lett.* **114** (2015) 191803, doi:10.1103/PhysRevLett.114.191803

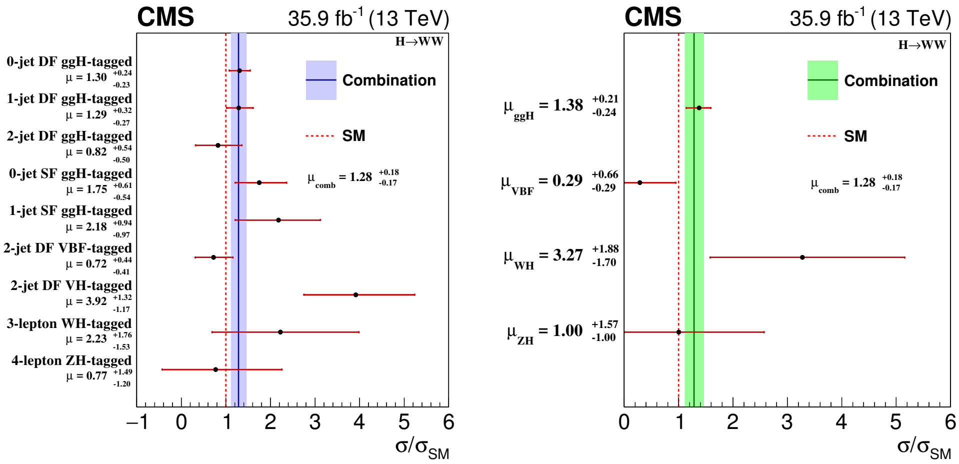

Figure 1: (Left) Observed signal strength modifiers for the categories used in the combination [6]. (Right) Observed signal strength modifiers corresponding to the main SM Higgs boson production mechanisms [6]. The vertical continuous line represents the combined signal strength best fit value, while the horizontal bars and the filled area show the 68% confidence intervals. The vertical dashed line corresponds to the SM expectation.

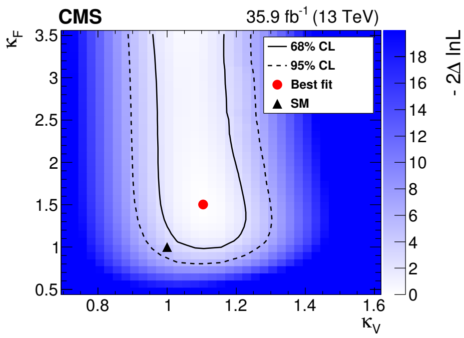

Figure 2: Two-dimensional likelihood profile as a function of the coupling modifiers associated with either fermion (κ_F) or vector boson (κ_V) vertices [6].. The 68% and 95% CL contours are shown as continuous and dashed lines, respectively. The red circle represents the best fit value, while the black triangle corresponds to the SM prediction.

[3] ATLAS and CMS Collaborations, "Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC pp collision data at $\sqrt{s} = 7$ and 8 TeV", *JHEP* **08** (2016) 045, doi:10.1007/JHEP08(2016)045

[4] CMS Collaboration, "Particle-flow reconstruction and global event description with the CMS detector", *JINST* **12** (2017) P10003, doi:10.1088/1748-0221/12/10/P10003

[5] CMS Collaboration, "The CMS Experiment at the CERN LHC", *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004

[6] CMS Collaboration, "Measurements of properties of the Higgs boson decaying to a W boson pair in pp collisions at $\sqrt{s} = 13$ TeV", *Submitted to Phys. Lett. B* (2018), arXiv:1806.05246

[7] LHC Higgs Cross Section Working Group, "Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector", (2016), arXiv:1610.07922