PROCEEDINGS OF SCIENCE

First Results on Higgs to WW at $\sqrt{s}$=13 TeV with CMS detector

Lorenzo Russo[*†]
Università di Siena and INFN Firenze
E-mail: russo@fi.infn.it

The first measurement of the Higgs boson cross section at 13 TeV in $H \to WW \to 2\ell 2\nu$ decay channel, will be show. The event sample corresponds to an integrated luminosity of 2.3 $\pm$ 0.1 fb $^{-1}$, collected by the CMS detector in 2015 at the LHC. This study has a central role to further constrain the Higgs boson measurements: any deviation from the Standard Model predictions would be a direct sign of new physics. The excellent resolution of the CMS experiment allows to identify the particles emerging from W^+W^- decay with hight degree of precision.

Corfu Summer Institute 2016 "School and Workshops on Elementary Particle Physics and Gravity"
31 August - 23 September, 2016
Corfu, Greece

[*] Speaker.
[†] A footnote may follow.

PoS(CORFU2016)060

1. Introduction

In the Standard Model (SM) of particle physics, the origin of the masses of the Z and W bosons is based on the electroweak symmetry breaking. This symmetry breaking is achieved through the introduction of a complex doublet scalar field [1, 4], leading to the prediction of the existence of one physical neutral scalar particle, commonly known as the Higgs boson. The discovery of a new particle at a mass of approximately 125 GeV with Higgs boson-like properties was reported by the ATLAS [5] and CMS [6] experiments during the first running period of the Large Hadron Collider (LHC) in proton-proton collisions at a centre of mass energy of 7 and 8 TeV.

In 2015, the LHC restarted at a center of mass energy of 13 TeV. The Run-II of the LHC will last until 2018, and it is set to deliver very high luminosities. The LHC experiments need the new data to further constrain the Higgs boson measurements. Any deviation from the SM predictions would be a direct sign of new physics. The Higgs decay to a pair of W bosons was studied by the CMS experiment using the full Run-I data set in leptonic final states exploring several production mechanisms [7]. The reported probability to observe an excess equal or larger than the one seen in this channel, had a significance of 4.3 standard deviations for a Higgs mass of 125.6 GeV. A later combination [8], that includes Higgs production in association with a top quark pair, reports an observed significance of 4.7σ for this decay.

This note presents the first analysis [9] of the H$\rightarrow$WW decay at 13 TeV, using a total integrated luminosity of 2.3 fb^{-1}. At 13 TeV, for a Higgs boson of a mass of 125 GeV, gluon fusion is the dominant production mode, and it is the main production mode targeted in this analysis. Final states in which the two W bosons decay leptonically are studied. Therefore, events with a pair of oppositely-charged leptons, exactly one electron and one muon, a substantial amount of missing transverse energy due to the presence of neutrinos in the final state, and either zero or one jet, are selected. This signature is common to other processes, which enter the analysis as backgrounds. The main contribution comes from WW production, as irreducible background that shares the same final states and can only be separated by the use of certain kinematic prop- erties. Background coming from top events (tt and single top tW) is also important, followed by other processes such as Drell-Yan, W+jets and other electroweak productions. The analysis strategy follows closely the one used during Run-I in the same channel.

2. The CMS detector

A detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [10]. The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), which provide coverage in pseudorapidity $|\eta| < 1.479$ in a cylindrical barrel and $1.479 < |\eta| < 3.0$ in two endcap regions. Forward calorimeters extend the coverage provided by the barrel and endcap detectors to $|\eta| < 5.0$. Muons are measured in gas-ionization detectors embedded in the steel

PoS(CORFU2016)060

flux-return yoke outside the solenoid in the range $|\eta| < 2.4$, with detection planes made using three technologies: drift tubes, cathode strip chambers, and resistive plate chambers.

3. Data and Monte Carlo samples

The data samples used in this analysis were recorded in proton proton collisions at 13 TeV during 2015 and correspond to a total integrated luminosity of 2.3 fb^{-1} . The integrated luminosity is measured with an uncertainty of 2.7%. The events are triggered by requiring the presence of one or two high transverse momentum (p_T) electrons or muons. The trigger efficiency for signal events selected in the analysis is measured to be 99%.

Several different event generators are used in order to optimize the analysis and estimate the expected yields of signal and backgrounds as well as their associated systematic uncertainties.

4. Analysis strategy

A particle-flow (PF) algorithm [11] is used to reconstruct the observable particles in the event. The main production mode for a Higgs boson at m_H =125 GeV is the gluon fusion mechanism for which extra jets in the final state arise only from parton initial state radiation. The analysis is hence limited to events with no jet or at maximum one jet. In the WW decay mode of the Higgs, the fully leptonic final state is the cleanest to study, hence the analysis is limited to $e^{\pm}\mu^{\mp}$ plus neutrinos final states. The indirect contribution from τ leptons decaying leptonically is however included. The neutrinos in the final state escape direct detection and lead to large missing transverse momentum in the events. Several background processes can lead to the same event properties and tight selection criteria are needed to enhance the sensitivity to the SM Higgs boson as detailed below.

Beyond requiring the events pass the single or double lepton triggers, exactly one electron and one muon are required to be reconstructed in the event with opposite charges and a minimum p_T of 10 (13) GeV for the muon (electron), the higher p_T threshold for the electron resulting from the trigger definition. One of the two leptons should also have a p_T greater than 20 GeV and both leptons are required to be well identified and isolated to reject fake leptons and leptons coming from QCD sources. To suppress background processes with three or more leptons in the final state, such as ZZ, WZ, Zγ, Wγ, or tri-boson production, no additional identified and isolated lepton with p T > 10 GeV should be reconstructed. The low dilepton invariant mass ($m_{\ell\ell}$) region dominated by QCD production of leptons is not considered in the analysis and $m_{\ell\ell}$ is requested to be higher than 12 GeV. To suppress the background arising from DY events decaying to a τ lepton pair which subsequently decay to an $e\mu$ final state and suppress processes without genuine E_T^{miss}, a minimal E_T^{miss} of 20 GeV is required. The DY background is further reduced by requesting the dilepton transverse momentum ($p_T^{\ell\ell}$) to be higher than 30 GeV as on average $e\mu$ lepton pair from DY$\rightarrow \tau\tau$ decay have lower momentum than the ones from H$\rightarrow$WW decays. These selection criteria also reduce contributions from H$\rightarrow$WW$\rightarrow \tau\nu\tau\nu$ and H $\rightarrow \tau\tau$ in the present analysis. Finally the contribution from leptonic decays of single top and top pair production is reduced by requesting that no jets with p_T > 20 GeV are identified as originating from a b quark in the event.

The criteria described above define the WW selection. The remaining data sample is dominated by non-resonant WW events with a non negligible contribution from single top and top pair production, especially for events with additional jets. To further increase the sensitivity to the SM Higgs boson signal, events are categorized according to the jet multiplicity counting jets with p_T above 30 GeV. The zero jet category (0-jet) is dominated by the non-resonant WW background while in the one jet category (1-jet) the contributions from non-resonant WW and top backgrounds are of similar importance. Higher jet multiplicity categories that would be more sensitive to Higgs production mechanisms other than gluon fusion are not considered in the present analysis. To disentangle another important background, W+jets, where one jet mimics the signature of an isolated lepton, the 0 and 1 jet categories are further split accord- ing to the lepton flavour: $e\mu$ and μe, where the first lepton is the one with higher transverse momentum.

To extract the Higgs boson signal in these four categories, the same strategy, as in the Run-I analysis [7], is followed. Although the Higgs boson invariant mass can not be reconstructed due to the escaping neutrinos, the expected kinematic properties of the Higgs boson production and decay can be exploited. An analysis based on bi-dimensional templates of $m_{\ell\ell}$ versus $m_T^H = \sqrt{2p_T^{\ell\ell}E_T^{miss}(1-\cos\Delta\phi(\ell\ell,\vec{E}_T^{miss}))}$, where $\Delta\phi(\ell\ell,\vec{E}_T^{miss})$is the azimuthal angle between the dilepton momentum and the E_T^{miss}, is performed to extract the Higgs signal in all four categories. The distributions of the $m_{\ell\ell}$ and m_T^H variables after the WW selection are presented in Figure 1 separately in the 0-jet and 1-jet categories.

5. Background estimation

Events in which a **single W boson** is produced in association with jets give rise to background when a jet is misidentified as a lepton. These events contain a real lepton and real E_T^{miss} from the W decay as well a second fake lepton from a misidentified jet. These backgrounds are particularly important at low p_T of the leptons and low $m_{\ell\ell}$ and hence in the Higgs signal region of the analysis. A control sample is defined with events in which one lepton passes the standard lepton identification and isolation criteria and another lepton candidate fails the criteria but passes a looser selection. The probability for a jet satisfying this looser selection to pass the standard one is estimated directly from data in an independent sample dominated by events with non-prompt leptons from multijet processes.

Background contamination from **single top** processes, in particular tW associated production, and **tt pair** production, arise due to the limited efficiencies of b jet identification and the relatively large top cross sections at 13 TeV. The estimation of the top background in the analysis is performed computing a scale factor to take account for the different efficiencies in data and simulation, such as the discrepancies related to different b-tagging efficiencies and mistag rates. This correction is applied by reweighting all the simulated samples with an weight per event. The top quark enriched control region for the 0-jet category is defined with the same selection but requiring at least one jet with 20< p_T <30 GeV to be identified as a b jet and no jet with p_T >30 GeV. For the 1-jet top enriched region, exactly one jet with $p_T >$ 30 GeV identified as a b jet is requested. To reduce other backgrounds in these two regions, the dilepton mass has to be higher than 50 GeV.

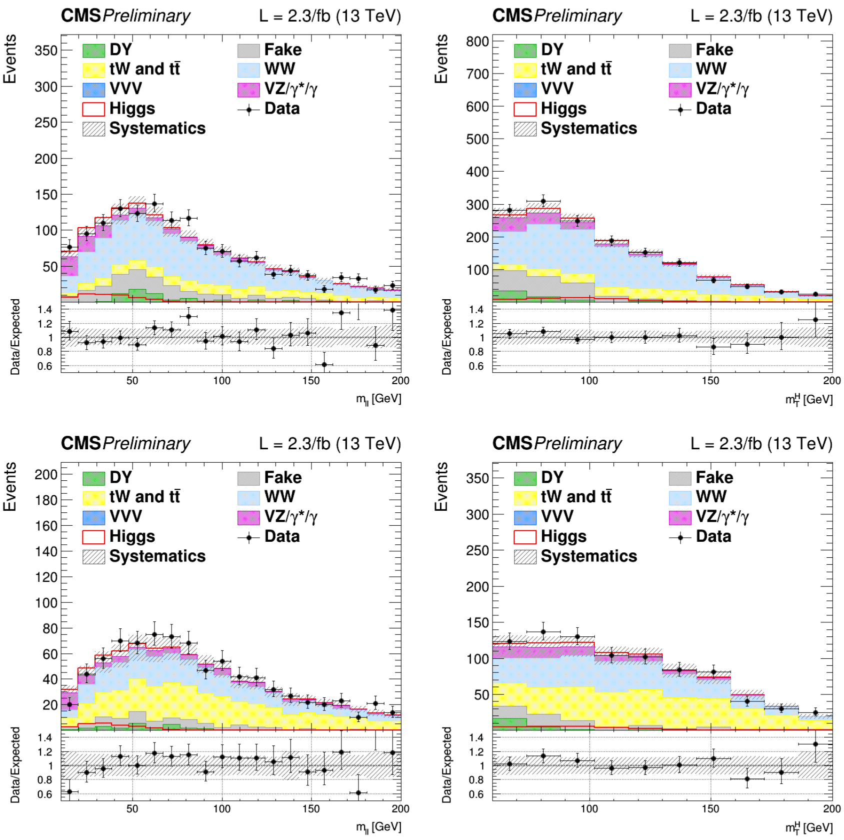

Figure 1: Distributions of $m_{\ell\ell}$ (left) and m_T^H (right) for events with 0 jet (upper row) and 1 jet (lower row), for the main backgrounds (stacked histograms), and for the expected SM Higgs boson signal with m_H=125 GeV (superimposed and stacked red histogram) after all selection criteria. The last bin of the histograms includes overflows. Scale factors estimated from data are applied to the jet induced, the Drell-Yan, and top backgrounds.

The **DY**$\rightarrow \tau\tau$ background is predominant at low m_T^H although it also populates the phase space of the Higgs signal. This background kinematic is predicted by the DY Monte Carlo simulation, after reweighting the Z boson transverse spectrum to match the observed distribution measured in data, whose effect is actually negligible in the analysis phase space.

6. Systematic uncertainties

All experimental sources, except luminosity, are treated both as normalization and shape uncertainties. The following experimental uncertainties are considered:

- The uncertainty determined by the CMS online luminosity monitoring, 2.7%.
- The trigger acceptance uncertainty.
- The lepton reconstruction and identification efficiencies uncertainties.
- The muon momentum and electron energy scale and resolution uncertainties.

- The jet energy scale uncertainties.
- The E_T^{miss} resolution uncertainty.
- The scale factors correcting the b tagging efficiency and mistagging rate.

The uncertainties in the signal and background production rates due to theoretical uncertainties include several components, which are assumed to be independent: the PDFs and α_S , the underlying event and parton shower model, and the effect of missing higher-order corrections via variations of the renormalization and factorization scales.

7. Results

The final binned fit is performed using template histograms for all signal and background processes obtained after all selection criteria. The signal and background templates, as well as the distribution observed in the data for the 0-jet and 1-jet and μe and $e\mu$ categories. Combining the four categories the observed (expected) significance is 0.7σ (2.0σ) for a SM Higgs boson with a mass of 125 GeV. The corresponding best fit signal strength, σ/σ_{SM}, which is the ratio of the measured H→WW→ $e\nu\mu\nu$ signal yield to the expectation for the SM Higgs boson is 0.3 ± 0.5.

8. Summary

A measurement of the SM Higgs boson decaying to WW in pp collisions at $\sqrt{s}$ =13 TeV is performed by the CMS experiment using a data sample corresponding to an integrated luminosity of 2.3 fb^{-1} . The W^+W^- candidates are selected in events with an oppositely charged $e\mu$ pair and large missing transverse momentum in association with up to one additional jet. The observed (expected) significance for a SM Higgs boson with a mass of 125 GeV is 0.7σ (2.0σ), corresponding to an observed cross section times branching ratio of 0.3 ± 0.5 times the standard model prediction.

PoS(CORFU2016)060

References

[1] F. Englert and R. Brout, “Broken Symmetry and the Mass of Gauge Vector Mesons”, Phys. Rev. Lett. 13 (1964) 321, doi:10.1103/PhysRevLett.13.321.

[2] P. W. Higgs, “Broken symmetries, massless particles and gauge fields”, Phys. Lett. 12 (1964) 132, doi:10.1016/0031-9163(64)91136-9.

[3] P. W. Higgs, “Broken Symmetries and the Masses of Gauge Bosons”, Phys. Rev. Lett. 13 (1964) 508, doi:10.1103/PhysRevLett.13.508.

[4] G. S. Guralnik, C. R. Hagen, and T. W. B. Kibble, “Global conservation laws and massless particles”, Phys. Rev. Lett. 13 (1964) 585, doi:10.1103/PhysRevLett.13.585.

[5] 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. B 716 (2012) 1, doi:10.1016/j.physletb.2012.08.020, arXiv:1207.7214.

[6] 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, arXiv:1207.7235.

[7] CMS Collaboration, “Measurement of Higgs boson production and properties in the WW decay channel with leptonic final states”, JHEP 01 (2014) 096, doi:10.1007/JHEP01(2014)096, arXiv:1312.1129.

[8] CMS Collaboration, “Precise determination of the mass of the Higgs boson and tests of compatibility of its couplings with the standard model predictions using proton collisions at 7 and 8 TeV”, Eur. Phys. J. C75 (2015), no. 5, 212, doi:10.1140/epjc/s10052-015-3351-7, arXiv:1412.8662.

[9] First results on Higgs to WW at $\sqrt{s} = 13$ TeV,"CERN", "CMS Collaboration", "Geneva", "CMS-PAS-HIG-15-003", "2016", "CMS-PAS-HIG-15-003", "https://cds.cern.ch/record/2161793".

[10] CMS Collaboration, “The CMS experiment at the CERN LHC”, JINST 3 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

[11] CMS Collaboration, “Commissioning of the Particle-Flow reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV”, CMS Physics Analysis Summary CMS-PAS-PFT-10-002 (2010).