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Measurements of Higgs boson production and properties in the WW decay channel using the CMS detector

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The most recent results from 7 and 8 TeV data taking period at LHC with the CMS detector, looking at the Higgs boson decaying to a W-boson pair, are reported. The search at $\sqrt{s} = 13$ TeV with an integrated luminosity of 2.3 ± 0.1 fb^{-1}, collected by the CMS detector in 2015, is described as well. The W^+W^- candidates are selected in events with an oppositely charged eμ pair in association with up to one jet. The observed (expected) significance with the 13 TeV analysis for the 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.

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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, leading to the prediction of the existence of one physical neutral scalar particle, 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 and CMS 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. Subsequent publications from both experiments based on the full LHC Run-I datasets established that all measurements of the properties of the new particle, including its spin, parity, and coupling strengths to ordinary particles, are consistent with those expected for the SM Higgs boson within uncertainties. Two of the most recent results based on 7 and 8 TeV data are the Higgs width indirect constraint by means of a simultaneous estimation of the on-shell and off-shell production of the Higgs boson looking at WW and ZZ final states [1], leading to the most stringent observed (expected) limit on the Higgs width so far, $\Gamma_H < 13$ (26) MeV, and the differential Higgs transverse momentum in WW measurement [2].
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, obtaining an excess significance of 4.3 standard deviations for a Higgs mass of 125.6 GeV [3].
In 2015, the LHC restarted at a center of mass energy of 13 TeV. In this presentation the first analysis of the H$\to$WW decay at 13 TeV, using a total integrated luminosity of 2.3 fb^{-1}, for a Higgs boson of a mass of 125 GeV [4] has been shown. Gluon fusion is the dominant production mode and it is then 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 (MET) 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 properties. Background coming from top events ($t\bar{t}$ and single top tW) is also important, followed by other processes such as Drell-Yan, W+jets and other electroweak productions.

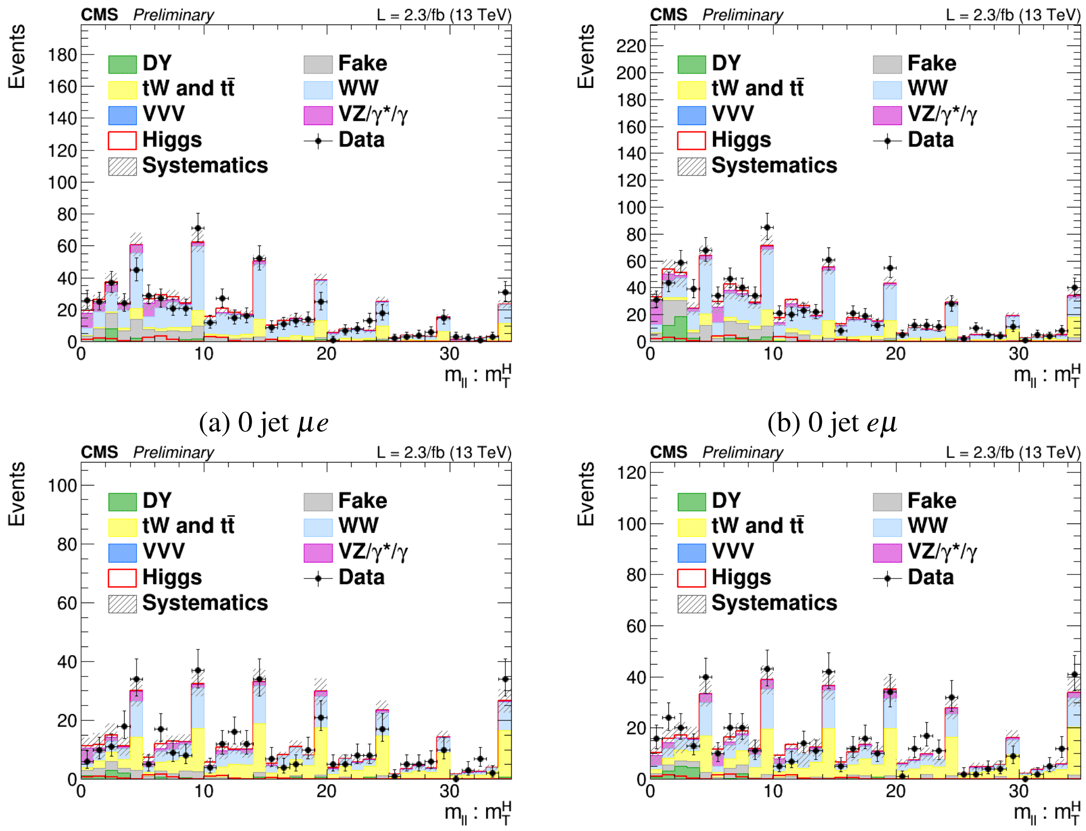
2. Analysis strategy

The events are required to pass the single or double lepton triggers. Exactly one electron and one muon with opposite charges and a minimum p_T of 10 (13) GeV for the muon (electron) are required to be reconstructed in the event. The higher p_T threshold for the electron is due to trigger requirements. 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 non-prompt leptons. To suppress background processes with three or more leptons in the final state, such as ZZ, WZ, Zγ, Wγ, or tri-boson production, additional identified and isolated leptons with $p_T > 10$ GeV are vetoed. The low di-lepton invariant mass (m_{ll}) region dominated by QCD production of leptons is not considered in the analysis: m_{ll} 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 to suppress processes without genuine MET, a minimal MET of 20 GeV is required. The DY and the non-prompt lepton backgrounds are further reduced by requesting the di-lepton transverse momentum (p_T^{ll}) to be higher than 30 GeV. These selection criteria also reduce contributions from H$\rightarrow$WW$\rightarrow$ $\tau\nu\tau\nu$ and H$\rightarrow$ $\tau\tau$. 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 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 other Higgs production mechanisms, will be considered in future 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 according to the lepton flavour: eμ and μe, where the first lepton is the one with higher transverse momentum.

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: the spin 0 nature of the SM Higgs boson results in the emission of the two charged leptons close together, the invariant mass of the two leptons in the signal is relatively small with respect to the one expected for a lepton pair arising from other processes such as non-resonant WW and top production, and the Higgs transverse mass $m_T = \sqrt{2p_T^{ll}MET(1-cos\Delta\phi_{ll,MET})}$, where $\Delta\phi_{ll,MET}$ is the azimuthal angle between the di-lepton system and the MET, can be used to disentangle signal from background. The different backgrounds populate different regions of the two dimensional plane in m_{ll} and m_T, so that an analysis based on bi-dimensional templates of m_{ll} versus m_T is performed to extract the Higgs signal in all four categories. The bi-dimensional templates are shown in Figure 1. Background data-driven estimations are performed, wherever possible, to get the shape and the normalization of the different contributions. If no data-driven estimation is possible, the most up to date cross sections and theoretical uncertainties are used. Control regions to normalize two backgrounds (DY and top) are defined exploiting particular phase spaces: low m_T region for DY, and events with at least one b-tagged jet for top. The non-prompt contribution is estimated from data by means of measuring the probability of a non-prompt lepton to fake the lepton identification criteria, and extrapolating from a control region its contribution in the signal phase space.

3. Results

The final binned fit is performed using template histograms for signal and background processes obtained after all selections are applied. The signal and background templates, as well as the distribution observed in the data, are shown in Figure 1 for the 0-jet and 1-jet, μe and eμ 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



(a) 0 jet μe (b) 0 jet $e\mu$ (c) 1 jet μe (d) 1 jet $e\mu$

Figure 1: Bi-dimensional distributions of the m_{ll} and m_T templates in the 0-jet (top) and 1-jet (bottom) and μe (left) and eμ (right) categories. The bi-dimensional templates ranges are $10 < m_{ll} < 110$ GeV and $0 < m_T < 200$ GeV with 5 bins in m_{ll} and 10 bins in m_T. The distributions are unrolled to one dimensional histograms such that that identical values of m_T are in adjacent bins. The background and signal contributions are normalized according to their pre-fit values except that scale factors estimated from data are applied to the jet induced, the Drell-Yan, and top backgrounds.

is the ratio of the measured H→WW signal yield to the expectation for the SM Higgs boson, is 0.3 ± 0.5.

4. Conclusion

The 7 and 8 TeV data taking periods for LHC led to the discovery of the Higgs boson. With more and more data collected, dedicated analyses have been performed, aiming to the complete characterization of the newly discovered Higgs boson. One of the new most recent results presented in this talk is related to Higgs width measurement, by means of a simultaneous estimation of the on-shell and off-shell production of the Higgs boson, leading to the most stringent observed (expected) limit on the Higgs width so far, $\Gamma_H < 13$ (26) MeV [1]. Another recent analysis is the measurement of the differential Higgs transverse momentum in WW final state [2], which is exploiting the high branching ratio of the Higgs in WW and the reasonable signal to noise ration in leptonic final states.

A measurement of the SM Higgs boson decaying to WW in pp collisions at $\sqrt{s} = 13$ TeV has been 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 eμ 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.

References

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