CMS search for Standard Model Higgs: $H \rightarrow W^+ W^-$ and $H \rightarrow ZZ$

Giuseppe Codispoti¹ a on behalf of the CMS Collaboration
Universidad Autónoma de Madrid, 28049 Madrid, Spain.

Abstract. A search for the Standard Model Higgs decaying to $W^+ W^-$ and $ZZ$ in pp collisions from LHC at \(\sqrt{s} = 7\) TeV using up to 1.7 fb\(^{-1}\) of data recorded by the CMS detector is presented. This search covers a mass range from 110 GeV/c\(^2\) to 600 GeV/c\(^2\). No significant excess above Standard Model background expectations is observed. Upper limits on the production cross section are derived.

1 Introduction

The Standard Model (SM) is a very successful theory in describing almost all phenomena in particle physics observed in past experiments. One of the key remaining questions is the origin of the masses of elementary particles attributed to the spontaneous breaking of electroweak symmetry. The existence of the associated field quantum, the Higgs boson (H), has still to be experimentally established. The discovery or exclusion of the SM Higgs boson is one of the central goals of the CERN Large Hadron Collider (LHC) physics program.

We report on the search for the SM Higgs decaying to $W^+ W^-$ and $ZZ$ in pp collisions from LHC at \(\sqrt{s} = 7\) TeV using up to 1.7 fb\(^{-1}\) of data recorded by Compact Muon Solenoid (CMS). A full description of the detector as well as of the physics objects and technical challenges to trigger interesting events and extract physics signal from the high luminosity scenario can be found in [1]. The analysis covers a wide mass range hypothesis for the Higgs mass, from 110 GeV/c\(^2\) to 600 GeV/c\(^2\). The main challenge of the search analysis is to distinguish the candidate signal from a wide set of backgrounds showing the very same final states but much higher cross sections. Beside to reducible backgrounds such as $Z/W$+jets, $t\bar{t}$, single top, QCD hard scattering where jets are misidentified as leptons, we have to deal also with irreducible backgrounds from $WW$ and $ZZ$ production.

2 Higgs decaying in $W^+ W^-$

The CMS search for $H \rightarrow W^+ W^-$ [2] selects di-bosons candidates where both bosons decay leptonically, yielding an experimental signature of two isolated, high transverse momentum ($p_T$) oppositely-charged leptons (electrons or muons) and large missing transverse energy ($E_T^{miss}$) due to undetected neutrinos. Given the large $E_T^{miss}$, a mass peak cannot be reconstructed and therefore the analysis has a reduced Higgs mass resolution. The zero spin of the Higgs boson gives angular constraints to the final state: the two leptons are expected with moderately small opening angle while the $E_T^{miss}$ with large angle with respect to the

\[ H \rightarrow WW \rightarrow 2\ell 2\nu \text{ search in the } H+0 \text{ jet bin for an integrated luminosity of } 1.55 \text{ fb}^{-1} \]

\[ H \rightarrow WW \rightarrow 2\ell 2\nu + 0/1/2 \text{ jets (CLS)} \]

\[ 95\% \text{ CL exclusion: median} \]

\[ 95\% \text{ CL exclusion: 68\% band} \]

\[ 95\% \text{ CL exclusion: 95\% band} \]

\[ \text{observed} \]

\[ \text{95\% CL exclusion: median} \]

\[ \text{95\% CL exclusion: 68\% band} \]

\[ \text{95\% CL exclusion: 95\% band} \]

\[ \text{observed} \]

This is an Open Access article distributed under the terms of the Creative Commons Attribution License 2.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Article available at [http://www.epj-conferences.org](http://www.epj-conferences.org) or [http://dx.doi.org/10.1051/epjconf/20122807004](http://dx.doi.org/10.1051/epjconf/20122807004)
di-lepton system. Due to different signal sensitivities, the events are separated into three exclusive categories according to the jet multiplicity: H+0 jets, dominated by WW and W+jets backgrounds; H+1 jet, dominated by WW an t\bar{t} background; and H+2 jets where the main background is t\bar{t} and the main production mechanism is Vector Boson Fusion. The W*W* non-resonant contribution is reduced requiring a small opening angle between the leptons. The remaining background is estimated using sidebands extrapolation for the di-lepton mass distribution (fig. 1) for Higgs masses lower than 200 GeV and Monte Carlo (MC) simulation for the high masses, where less statistics is available. The W+jets and QCD hard scattering background is controlled using a control sample of loosely identified leptons extrapolated to the signal region. Backgrounds induced by Z bosons are reduced requiring the dilepton mass to be outside the Z mass window. The remaining contribution is estimated using the events inside the Z mass window, rescaled using the ratio in/out estimated using simulation. The t\bar{t} background is reduced rejecting events where a jet, considering jets with p_T > 10 GeV/c, can be identified as b-quarks. The tagged sample, dominated by t\bar{t} and tW, is used to extrapolate the residual contribution. Results for 1.55 fb^{-1} are shown in figure 2: a SM Higgs is excluded in the mass range from 147 GeV/c^2 to 194 GeV/c^2, a wide sensitivity on the full mass range is exploited in the exclusion plot, even at low masses.

3 Higgs decaying in ZZ

The H \rightarrow ZZ search involves the study of several final states. The general strategy identifies a first Z that decays into a pair t\ell^+\ell^- and distinguish the case when the other decays into t\ell^+\ell^- (4\ell), in two neutrinos (2\ell2\nu) or hadronically (2\ell2q). All the final states provide a strong contribution at the high masses searches. Some of them may contribute also to the low mass search, where one of the two bosons can be off-shell. In particular the 4\ell channel, despite the low yield, provides very clean final states which can be then carefully inspected for the Higgs signal search. In general a loss of sensitivity is present around m_H \approx 180 GeV/c^2 due to the rapidly decreasing branching ratio of H \rightarrow ZZ in the SM.

3.1 The four leptons final state

A clean signature of four well identified leptons belongs to the decay channel H \rightarrow ZZ^{(*)} \rightarrow t\ell^+\ell^- t\ell'^+\ell'^- with t, t' = e, \mu [3]. The search relies solely on the measurement of leptons, and the analysis achieves high lepton reconstruction, identification and isolation efficiencies for a ZZ^{(*)} \rightarrow 4\ell system composed of two pairs of same flavour and opposi-}

te charge isolated leptons, e^+e^- or \mu^+\mu^- . On the other hand the small branching ratio associated to this decay channel leads to a low events yield and requires a very careful study of the background. The first step of the analysis requires the identification of the best Z candidate (Z_1) through the two opposite charge matching flavour leptons with closest invariant mass to the nominal Z mass and con-}

strained to 60 GeV/c^2 < m_{Z_2} < 120 GeV/c^2. Then at least two other leptons are required for the second Z (Z_2). Isolation and impact parameter requests, imposing the leptons to be originated from the same primary vertex further re-}

duce the background. A baseline selection, for the analysis in the full mass range imposes 20 GeV/c^2 < m_{Z_2} < 120 GeV/c^2. An high-mass selection, which is used for m_H > 2\times m_{Z_2} and the ZZ cross section measurement, requires 60 GeV/c^2 < m_{Z_2} < 120 GeV/c^2. The ZZ background estimation is performed using the MC prediction at Next to Leading Order (NLO) that gives a good description of the mass distribution shape. The MC prediction is then normalized using Z \rightarrow \ell^+\ell^- events in data and the ex-

pected ratio of ZZ/\sigma_{Z} and acceptance obtained from MC. The fake leptons from Z+jets instrumental background are estimated using a control sample containing the Z_1 plus loosely identified leptons. The Zbb and Zll background are estimated removing flavour, charge and isolation request for Z_2 and reversing the impact parameter cut. The invariant mass distribution of the events surviving the selection

![Figure 3](image-url)

**Fig. 3.** Distribution of the four-lepton reconstructed mass for the baseline selection in the sum of the 4\ell channels. Points represent the data, shaded histograms represent the signal and background expectations. The samples correspond to an integrated luminosity of 1.66 fb^{-1}.

![Figure 4](image-url)

**Fig. 4.** The expected and observed upper limits at 95% C.L. on \sigma(pp \rightarrow H + X) \times B(H \rightarrow ZZ \rightarrow 4\ell) relative to the SM value for an integrated luminosity of 1.66 fb^{-1} using the CLs approach. The results are obtained using a shape analysis method.
Fig. 5. The expected and observed upper limits at 95% C.L. on $\sigma(pp \rightarrow H + X) \times B(H \rightarrow ZZ \rightarrow 2 \ell 2\nu)$ relative to the SM value for an integrated luminosity of 1.1 fb$^{-1}$ using the CLs approach.

is shown in figure 3. Results of the analysis are summarized in the exclusion plot in figure 4.

3.1.1 The two leptons two taus final state

A specific analysis completes the four leptons scenario with the specific case where the second Z decays in two $\tau$ leptons [4]. The analysis is performed on a data sample where 4$\ell$ events are already discarded. Additional requirements are added in order to be able to reconstruct the 2 $\tau$. Results are shown in figure 5.

3.2 The two leptons two neutrinos final state

High branching ratio and good sensitivity to the high mass range (250-600 GeV/c$^2$) characterize the decay channel $H \rightarrow ZZ^{(*)} \rightarrow \ell^+ \ell^- \nu\bar{\nu}$ [5] where the second Z decays in two neutrinos. Two well isolated, close angle, charged leptons come from the decay of the first boosted Z. The second Z decaying in two neutrinos brings to large $E_T^{miss}$, which characterizes the event and provides a good background suppression power as shown in figure 6. The $t\bar{t}$ background is suppressed rejecting b-tagged events. The WZ and ZZ backgrounds are estimated from MC simulation. Residual backgrounds are estimated from data: Z+jets is modeled using photon+jets events and $t\bar{t}$ and WW are estimated events with different flavour leptons ($e\mu$ events). Cuts optimization is performed on the basis of the Higgs mass hypothesis. The dilepton pair is constrained to the Z mass, the $E_T^{miss}$ is requested to be not aligned with jets in order to cope with jet energy mis-measurements. Transverse mass is also used to characterize the sample. Results of this analysis are shown in figure 7.

3.3 The two leptons two jets final state

The advantage of the channel where one Z decays hadronically is the fully reconstructable final state with two lep-

tons and two jets [6]. Moreover, the branching fraction of the decay channel $H \rightarrow ZZ^{(*)} \rightarrow \ell^+ \ell^- q\bar{q}$ is about 20 times higher than the $4\ell$ channel. This may lead to better sensitivity to SM Higgs boson production at high masses, where kinematic requirements can effectively suppress background. For the analysis we select events containing at least two leptons and two jets compatible with the Z mass hypothesis. Since the final states are fully reconstructed we can perform angular analysis: the initial zero spin of the Higgs bosons constraint the relative angles between the decays product. A dedicated likelihood is used to discriminate signal compatible events. Since Z+jets events involve gluon-jets characteristics to reject them. In order to do this we build a likelihood discriminant based on number of neutral and charged tracks and their transverse momentum distribution. The effectiveness of the gluon-quark likelihood discriminator is tested on photon+jets sample where jets mainly come from quarks. The $t\bar{t}$ background is suppressed requesting small $E_T^{miss}$ and controlled using...
3. CMS Collaboration, Search for a Standard Model Higgs boson produced in the decay channel 4l, CMS-PAS-HIG-11-015 (2011)
5. CMS Collaboration, H to ZZ to 2l2nu, CMS-PAS-HIG-11-016 (2011)
6. CMS Collaboration, Search for the standard model Higgs Boson in the decay channel H to ZZ to llqq at CMS, CMS-PAS-HIG-11-017 (2011)
7. CMS Collaboration, Combination of Higgs Searches, CMS-PAS-HIG-11-022 (2011)