Discovery Potential for the SM Higgs Boson in the $H \rightarrow WW^* \rightarrow 2l2\nu$ channel at LHC

Rebeca Gonzalez Suarez (for the CMS Collaboration)
U. de Cantabria, IFCA, Santander, Spain

A prospective analysis for the search of the Standard Model (SM) Higgs boson with the CMS detector is presented in the context of the early LHC data. The aim is to establish an analysis strategy for inclusive production of the Higgs boson decaying in $WW^*$ pairs in the context of the early LHC data. Higgs mass region between 120-200 GeV, in which this signature was proposed as highly sensitive \cite{2}, has been studied. The $W$ decays into $l\nu$ are considered, where $l$ stands for $e$ or $\mu$. The final states are characterized by two, opposite-sign, high transverse momentum leptons, missing energy, carried out by the undetected neutrinos, and little jet activity. This study uses Monte Carlo (MC) events with full detector simulation, including limited calibration and alignment precision as expected at the LHC startup. Sets of sequential cuts are applied to each of the three topologies, in order to isolate a signal which exceeds the $t\bar{t}$ and continuum $WW$ backgrounds. Alternatively, an artificial neural network multi-variate analysis technique is used.

1. INTRODUCTION

1.1. Decay and production modes

$H \rightarrow WW^*$ is the dominant Higgs decay mode in a wide mass range, and for masses between $2m_W$ and $2m_Z$ the Branching ratio is close to the unity.

SM Higgs in this mass range is mainly produced via two mechanisms, Gluon fusion, in which case no hard jet activity is expected; and Vector-boson fusion, characterized by 2 forward jets, opposite in rapidity, with high mass. The leptonic final states of the $W$ bosons, electrons or muons, give clear signature of the Higgs boson.

1.2. Signal and background topology

The signal, $H \rightarrow WW^* \rightarrow 2l2\nu$, presents two leptons in the final state, with opposite charge and small opening angle; and a significant missing transverse energy ($E_T$), due to the undetected neutrinos.

As no mass peak can be reconstructed, in this analysis the background control is very important. The sources of possible background are multi-lepton final states, specially final states with $E_T$: di-boson production, especially $WW$, $t\bar{t}$, $tW$, Drell-Yan and $W + jets$. When compared with the signal, the cross-sections of the backgrounds are much larger.

2. EVENT SELECTION

2.1. Trigger and lepton identification

The amount of signal events recorded by the CMS experiment will depend on the trigger efficiency. A global OR between different HLT sequences (trigger-paths) is chosen to maximize the signal detection efficiency. The trigger-paths taken into consideration require either a single lepton (electron or muon with loose isolation requirements) or double leptons (electrons, muons or a combination without isolation requirements) and they have high efficiency at luminosities in the range $10^{31}$ to $10^{33}$ cm$^{-2}$s$^{-1}$.

Standard CMS lepton reconstruction techniques are used. The effective selection of $e$ and $\mu$ show high efficiency for true isolated leptons coming from $W$ boson decays, while at the same time effectively suppressing leptons from heavy quark decays or fake leptons produced by other objects.
We use a tight identification criteria for electrons due to the large \( W + \text{jets} \) background, based on the matching of a charged track reconstructed in the central tracker with a supercluster in the electromagnetic calorimeter \[3\] \[4\]. Muon candidates are identified by matching a track reconstructed in the muon detectors with a track reconstructed in the central tracker \[4\] \[5\].

2.2. Lepton Selection

Events are required to have exactly two leptons with opposite electric charge sign, \(|\eta| \leq 2.5\), \(p_T \geq 10, 20\) GeV, and isolated (with tracks and in the calorimeter). If more than two leptons fulfill the requirements, the event is rejected to reduce \(WZ\) and \(ZZ\) contamination.

2.3. Jet Veto and Missing \(E_T\)

No hard jet activity in the central region is expected for signal, which can be used against \(t\bar{t}\) background as shown in Figure 1.

Jets are reconstructed using iterative cone algorithm with \(\Delta R = 0.5\). If an event contains any jet with \(p_T > 15\) GeV and \(|\eta| < 2.5\), it is rejected. The application of a jet veto is also useful against: \(tW\), \(QCD\), \(Z + \text{jets}\) and \(W + \text{jets}\) backgrounds. Significant \(E_T\) is expected due to the neutrinos in the final state, and is computed from the raw calorimeter tower energies, applying a correction due to the presence of muons. The \(E_T\) cut is specially useful against Drell-Yan background after the invariant mass cut.

2.4. Kinematic Variables

To optimize the signal event selection against the main backgrounds the following variables are used:

- **angle between the leptons in the transverse plane** \(\Delta \Phi_{ll}\): for \(WW\) events this angle is expected to be large, for the scalar \(SM\) Higgs boson this angle tends to be small due to spin correlations.

- **invariant mass of the lepton pair** \(m_{ll}\): an upper cut is applied in the case of \(e^+e^-\), \(\mu^+\mu^-\) final states to reduce the contamination by leptons coming from Z-boson decays.

- **transverse momenta of the harder** \((p_T^{l_{\max}})\) **and the softer** \((p_T^{l_{\min}})\) **lepton**: upper/lower limit applied in order to reduce the background further.
Figure 2: Distribution of $m_{ll}$ (left) and $\Delta \Phi_{ll}$ (right) for signal and background in the $2\mu 2\nu$ channel.

The distribution of the invariant mass $m_{ll}$ and the opening angle $\Delta \phi_{ll}$ is shown in Figure 2 for the $m_H = 160$ GeV Higgs Boson signal and for the main background in the $2\mu 2\nu$ channel.

3. ANALYSIS

The analysis is split in three complementary topologies according to the considered final states, $ee$, $e\mu$ and $\mu\mu$. A first analysis based on sequential cuts was performed and then a multivariate approach was also made.

The first part of the analysis is common for all the final states and consist in the application of the skimming (to reduce data and select potentially interesting events) and the pre-selection (to define common objects of the analysis -such as leptons or jets- and also to select events). Then, each final state applies its own cuts to select events, due to the experimental differences in the identification of $e$ and $\mu$ and also because some background processes do not equally affect all the final states.

After the Jet Veto, the cuts on the sensible variables ($E_T$, $\Delta \Phi$, invariant mass and the $p_T$ of the leptons) are applied. At the end, the results for the three final states are combined to improve CMS discovery potential.

4. RESULTS

The conclusion of the Physics TDR [1] was that the SM Higgs boson could be discovered in the $H \rightarrow WW^* \rightarrow 2l2\nu$ channel with less than 1 fb$^{-1}$ if its mass is around 165 GeV. A new analysis taking fully into account the understanding of the detector and the control of experimental and background systematics expected for integrated luminosities up to 1 fb$^{-1}$ has been performed and progress towards a complete and realistic event strategy is obtained.

References

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