CMS Physics Analysis Summary

Search strategy for the Higgs boson in the $ZZ^{(*)}$ decay channel with the CMS experiment

The CMS Collaboration

Abstract

A study of the sensitivity for the inclusive production of Standard Model Higgs bosons $H$ decaying in $ZZ^{(*)}$ pairs is presented with the CMS experiment at the CERN LHC $pp$ collider at 14 TeV centre of mass energy, for the integrated luminosity of 1 fb$^{-1}$. The analysis is performed for the leptonic decay channels $H \to ZZ^{(*)} \to 4\ell$ with $\ell = e, \mu$ and for a mass $m_H$ in the range from 120 to 250 GeV/c$^2$. Signal and background datasets obtained with a detailed Monte Carlo simulation of the detector response, including the limited inter-calibration and alignment precision expected at startup luminosities, are treated using a complete reconstruction chain. A simple $m_H$ independent sequence of cuts is established which provides a clean sample of 4\ell events while preserving the highest signal detection efficiency. A signal with a significance above 2 standard deviations is found unlikely for a Higgs boson with a mass $m_H$ lying anywhere in the mass range considered. In absence of significant deviations from background expectations, upper limits on the production cross-section of a Standard Model-like Higgs boson can be established. The limits extend beyond existing constraints.
1 Introduction

The Standard Model (SM) of electroweak and strong interactions predicts the existence of a unique physical Higgs boson, the quantum of the scalar field responsible for electroweak symmetry breaking. The mass $m_{H}$ of this scalar boson is a free parameter of the theory.

Direct searches for the SM Higgs particle at the LEP $e^{+}e^{-}$ collider have lead to a lower mass bound of $m_{H} > 114.4$ GeV/$c^2$ (95% C.L.) [1]. Ongoing direct searches at the TeVatron $p\bar{p}$ collider by the D0 and CDF experiments set constraints on the production cross-section for a SM-like Higgs boson in a mass range extending up to about 200 GeV/$c^2$ [2]. A consistency fit including all the measured electroweak observables which are sensitive to the existence of a Higgs boson through virtual processes, favors a low mass with $m_{H} \lesssim 182$ GeV/$c^2$ (95% C.L.) [3].

The inclusive production of SM Higgs bosons followed by the decay $H \rightarrow ZZ^{(*)} \rightarrow \ell^{\pm} \ell'^{\pm} \ell^{\mp} \ell'^{\mp}$, henceforward denoted $4\ell$, is expected with $\ell, \ell' = e$ or $\mu$ to be a main discovery channel at the CERN LHC $pp$ collider over a wide range of possible $m_{H}$ values. Detailed prospective studies of the discovery potential with the CMS experiment for nominal collider luminosities of $10^{33}$ cm$^{-2}$s$^{-1}$ have been performed previously [4–8]. In this paper, an analysis is presented in the context of the startup luminosity of $2 \cdot 10^{32}$ cm$^{-2}$s$^{-1}$ at $pp$ centre of mass energy of 14 TeV and for an integrated luminosity of 1 fb$^{-1}$. The emphasis is put on a simple and robust baseline strategy en route to a discovery, with data reduction and event selection steps as well as analysis methods allowing a data-driven control of experimental and background systematic uncertainties. The expected sensitivity of the CMS experiment for the observation of a SM-like Higgs boson is studied using a sequential set of cuts, and for a $m_{H}$ hypothesis in the mass range from 120 GeV/$c^2$ to 250 GeV/$c^2$.

2 Datasets

The analysis relies on signal and background datasets produced with a detailed Monte Carlo simulation of the detector response, taking into account the limited inter-calibration and alignment precision expected for an integrated luminosity of 100 pb$^{-1}$, and subject to full reconstruction.

The general multi-purpose Monte Carlo event generator PYTHIA [9] is used to generate the Higgs boson signal samples via leading order (LO) gluon and weak-boson fusion processes. An enhancement due to the interference of amplitudes with permutations of identical leptons originating from different Z-bosons and calculated with CompHEP [10] is taken into account. The events are re-weighted to correspond to the total next-to-leading order (NLO) cross-section $\sigma_{NLO}(pp \rightarrow H) \cdot BR(H \rightarrow ZZ) \cdot BR(Z \rightarrow 2\ell)^2$, with $BR(Z \rightarrow 2\ell) = 0.101$ [11], and where $\sigma(pp \rightarrow H)$ and $BR(H \rightarrow ZZ)$ are taken from Ref. [12]. PYTHIA incorporates Multi Parton Interaction (MPI) models to overlay underlying events due to additional soft interactions between the partons of the proton remnants. The so-called “DWT” tune is used for the MPI with parameters adapted to the CTEQ5L parton density functions [13].

The main background processes considered are $t\bar{t}$, $Z\ell\ell$, $Z\bar{b}b \rightarrow 2\ell\bar{b}$ and $ZZ \rightarrow 4\ell$, where $Z$ stands for $Z$, $Z'$, and $\gamma^*$, and $\gamma$ is linear in the number of jets ($n = 0, 1, 2, 3, 4$) is generated with ALPGEN [14]. Events are re-weighted to correspond to the total NLO cross-section $\sigma(pp \rightarrow t\bar{t}) = 840$ pb [15]. The $Z\ell\ell \rightarrow 2\ell\bar{b}$ sample is generated with CompHEP matrix element generator. The LO cross-section is 345 pb. This is corrected to NLO with a K-factor of $K_{NLO} = 1.66$ calculated using MCFM [16]. The $q\bar{q} \rightarrow ZZ \rightarrow 4\ell$ sample is generated with the CompHEP matrix element generator. The LO cross-section is 846 fb. To account for the contributions of all
NLO diagrams, as well as for the NNLO gluon fusion process \((gg \rightarrow ZZ)\) known to contribute
\(\approx 20\%\) [17], events are re-weighted with a \(m_{4l}\)-dependent K-factor \(K(m_{4l}) = K_{\text{NLO}}(m_{4l}) + 0.2\.
The average factor is about 1.55.

The three main background samples used in this analysis correspond to integrated luminosities
of about 2 fb\(^{-1}\) for \(t\bar{t}\), 119 fb\(^{-1}\) for \(Z\bar{b}b\) and 192 fb\(^{-1}\) for ZZ. Other relevant electroweak and QCD-induced SM processes were contained in a dataset which was conceived to mimic (to a certain degree) a “real” data stream from CMS in situ for an integrated luminosity of the order of 1 fb\(^{-1}\). For the Higgs boson signal, samples corresponding to integrated luminosities of
more than 200 fb\(^{-1}\) were used. The mean signal and background expectations are obtained by scaling down to integrated statistics equivalent to an integrated luminosity of 1 fb\(^{-1}\).

### 3 Event Selection

The Higgs boson signal is characterized by the presence of two pairs of isolated primary electrons or muons, with one pair generally resulting from the decay of a Z boson on its mass shell. Such a signal is found with high efficiency by the CMS High Level Trigger (HLT), requiring mainly either a loosely isolated single electron candidate \((p_T^e > 15 \text{ GeV}/c)\) or single muon candidate \((p_T^\mu > 11 \text{ GeV}/c)\), or a pair of electrons \((p_T^e > 10 \text{ GeV}/c)\), or a pair of muon candidates above a minimal threshold \((p_T^{\mu} > 3 \text{ GeV}/c)\). After HLT, the event rates in the lepton paths are still dominated by fake leptons coming predominantly from QCD processes. Further reduction of the event rate is obtained via a “skimming” step requiring at least two leptons \((e\text{ or }\mu)\) with \(p_T^\ell > 10 \text{ GeV}/c\) and one additional lepton with \(p_T^{\ell'} > 5 \text{ GeV}/c\) within the detector acceptance. The signal selection efficiency for the HLT and skimming is above 98% (95%)(90%) for masses \(m_H > 130 \text{ GeV}/c^2\) in the 4\(\ell\) \((2e2\mu)\) \((4e)\) channel with leptons within the detector acceptance, \(|\eta^{\ell}\| < 2.5\).

A set of pre-selection cuts is then applied to suppress the contribution of fake leptons. One main objective is to bring the QCD multijets and Z/W+jet(s) contributions involving gluon- or light quark-initiated jets to a level comparable to or below the contribution of the three main backgrounds, \(t\bar{t}\), \(Z\bar{b}b\) and ZZ. Another virtue of the pre-selection is to diminish the problem of the combinatorial ambiguities in signal events, a consequence of the reduction of the number of extra (fake) leptons (coming e.g. from jets recoiling against the Higgs boson).

The pre-selection requires at least two \(\ell^+\ell^-\) pairs of identified leptons with opposite charge and matching flavors and with invariant mass \(m_{\ell^+\ell^-} > 12 \text{ GeV}/c^2\). Single primary muons are reconstructed and identified with a mean efficiency above 97% for \(p_T^{\mu} \gtrsim 5 \text{ GeV}/c\) by combining the silicon tracker and the muon spectrometer information from the CMS experiment. Single primary electrons are reconstructed and identified by combining the information from the silicon tracker and the electromagnetic calorimeter, with a mean efficiency rising from about 50% at \(p_T^e \simeq 5 \text{ GeV}/c\) to 80% at \(p_T^e \simeq 10 \text{ GeV}/c\), and reaching a plateau of \(\gtrsim 86\%\) for \(\gtrsim 20 \text{ GeV}/c\) (\(\sim 90\%\) for \(|\eta^{\ell}| \lesssim 1.1\)). The \(m_{\ell^+\ell^-}\) cut suppresses events with fake primary leptons originating from the decay of low mass hadronic resonances. The events are kept only if at least one combination of two matching pairs is found with an invariant mass greater than 100 GeV/c\(^2\), thus restricting the search for the SM Higgs boson to the non-excluded \(m_H\) range. To further suppress backgrounds where fake leptons come from jets, a loose track-based isolation is applied within \(\eta - \phi\) cones around the candidate leptons. This preserves 98.5% of the signal events at \(m_H = 150 \text{ GeV}/c^2\) passing the previous pre-selection steps. The event rate reduction obtained from the pre-selection of signal-like events is shown for all three channels in Fig. 1. The background events, largely dominated at the first steps by QCD and Z/W+jet(s), with large
Figure 1: Reduction of the event rate for QCD, Z/W + jet(s), tt +jets, Zb¯b and ZZ backgrounds, and H → ZZ(*) → 4ℓ signal at m_H=150 GeV/c^2, after the trigger, skimming and each pre-selection step in the (a) 4e, (b) 2e2µ and (c) 4µ channel.

Fake lepton rates coming from gluon or light quark jets, are considerably suppressed. The QCD background is eliminated after the loose lepton isolation requirements. The resulting spectra for the invariant mass of the 4 lepton system is shown in Fig. 2. After pre-selection, less than 2.5% (1.0%) of the signal events have more than 4 candidate leptons in the H → 4e (H → 4µ) channel. The remaining ambiguity is resolved at this stage and four leptons belonging to the Higgs boson decay are chosen in the following way. First, the two leptons belonging to the Z boson decay are taken as the same flavor opposite charge pair with a mass m_ℓ−ℓ+ closest to m_Z. Then the same flavor opposite charge pair with the highest p_T amongst the remaining leptons is attributed to the Z* boson.

The major reducible backgrounds remaining after pre-selection are Z+jet(s), tt and Zb¯b with fake leptons reconstructed in the jets or coming from semi-leptonic decays of bottom mesons. These leptons are likely to be accompanied by hadronic products from the fragmentation and...
Figure 2: Four-lepton invariant mass after pre-selection with cumulative backgrounds and H → ZZ(\ast) → 4\ell signal events together for different m_{tH} hypothesis in the (a) 4e, (b) 2e2\mu and (c) 4\mu channel.

decay processes initiated in the light-quark or b-quark jets. Moreover, the leptons from the b-jets in t\bar{t} and Zbb background events are likely to have a large impact parameter with respect to the primary vertex because of the long lifetime of the b-hadron. Thus, a selection incorporating tighter lepton isolation complemented by impact parameter measurements has the potential for powerful rejection. Lepton isolation observables (elso and \mu lso) are defined using tracks with p_T > 1 GeV/c as well as the energy measurements in electromagnetic and hadronic calorimeter cells. A cone with radius \Delta R = 0.3 (\Delta R = \sqrt{\Delta \eta^2 + \Delta \phi^2}) is used, centered on (and excluding) the candidate lepton. The p_T of the tracks and the transverse energies in the calorimeter cells are summed within the cone. Both calorimeters are used for computing muon isolation while the usage of the hadronic calorimeter is found sufficient for electron isolation in this analysis. The isolation observable for electrons is normalized relative to p_T. For the dominant Z+jet(s), t\bar{t} and Zbb backgrounds the third and the fourth leptons (ordered in decreasing p_T) are not isolated and, as a consequence, a sum of values by the isolation observables obtained for the
two least isolated leptons provides the best discriminating power ($\text{elso}_{\text{2least}}$ and $\mu\text{Iso}_{\text{2least}}$). The discriminating performance of the isolation is illustrated in Figs. 3 for the 4e and 4µ channel.

To form three-dimensional impact parameter observables, the tracking information is used in both the transverse and longitudinal directions (with respect to the beam axis) and divided.
with measurement uncertainties. The discriminating power of impact parameter significance (S_{IP}) is illustrated Fig. 4 in the case of the 4e and 4\mu channel. A good discrimination between signal and background is obtained.

While simple isolation characteristics prove sufficient to easily eliminate the lepton candidates from heavily boosted b-quark jets in t\bar{t} events, the b-quark jets in Zbb events are in general less collimated and lead to leptons with a softer p_T spectrum. In order to best preserve the signal detection efficiency while acting on low p_T lepton candidates to suppress the Zbb background, the isolation criteria for the leptons from the pair at lowest m_{\ell+\ell-} is made p_T dependent. The b-quark jets of the main reducible backgrounds are simultaneously non-isolated and associated to low p_T fake primary leptons. This characteristic is exploited as shown in Fig. 5. Tighter isolation cuts are found necessary against leptons in soft b-quark jets. A powerful discrimination between the signal and the background is obtained by tightening the lepton isolation (of the least isolated pair of leptons) with decreasing p_T of the third or fourth lepton in the event.

![Figure 5: The p_T for the muon with the third largest p_T in the event versus the isolation for the two least isolated muons in the 4\mu channel; the squares are the Zbb background and the dots are the signal for a Higgs boson of 150 GeV /c^2.](image)

Additional cuts on the mass of the lepton pairs can further reduce the background. The Higgs boson ZZ^{(*)} decays dominantly involve a Z boson on the mass shell such that at least one pair of leptons will form an invariant mass close to the Z mass. This remains true even for m_H values below 2 \times m_Z. The other boson Z^{(*)} saturates the phase space such that in general for the signal one expects that for each event m_{4\ell} \simeq m_Z + m_{Z^*}. The m_Z and m_{Z^*} offer discrimination power as illustrated in Fig. 6 in the case of the 2e2\mu events.

Higgs boson mass dependent cut-based analyses have been discussed in previous studies [6–8] in the context of measurements at integrated luminosities of 30 fb^{-1} at the LHC. For the start-up integrated luminosity of 1 fb^{-1} considered in this analysis, it is found sufficient to consider baseline cut-based selection independent of a Higgs boson mass. This allows a simple search procedure covering the mass range from \gtrsim 120 to \lesssim 250 GeV /c^2. The baseline selection established for the 4e, 2e2\mu and 4\mu channels follows a common sequence of cuts exploiting the observables discussed above: the lepton isolation for the two worst isolated leptons, the significance of lepton impact parameter with respect to the event interaction vertex, the minimal p_T of the leptons (5 GeV /c for muons and 7 GeV /c for electrons), and the m_{2\ell} masses. Very loose
cuts are applied around the observed $m_{2l}$ masses to preserve the simplicity of the $m_H$ independent baseline selection. The selection requires a reconstructed "Z" with $50 < m_Z < 100 \text{ GeV}/c^2$ and a "Z*" with $20 < m_{Z*} < 100 \text{ GeV}/c^2$. The set of baseline selection cuts for all three channels is given in Table 1.

<table>
<thead>
<tr>
<th>Channel</th>
<th>$4\mu$</th>
<th>$2e2\mu$</th>
<th>$4e$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isolation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{eIso} &lt; 0.35$</td>
<td>$\mu\text{Iso} &lt; 30$</td>
<td>$\text{eIso} &lt; 0.35$ or $\mu\text{Iso} &lt; 30$</td>
<td></td>
</tr>
<tr>
<td>$\text{eIso} &lt; 0.060 \cdot p_T^2 - 0.9$</td>
<td>$\mu\text{Iso} &lt; 1.5 \cdot p_T^2 - 15$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{eIso} &lt; 0.035 \cdot p_T^2 - 0.2$</td>
<td>$\mu\text{Iso} &lt; 2.0 \cdot p_T^2 - 10$</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IP</strong></td>
<td>$S_{IP}^{(4^2)} &lt; 5$ &amp; $S_{IP}^{(3^2)} &lt; 4$</td>
<td>$S_{IP}^{(4^2)} &lt; 12$ &amp; $S_{IP}^{(3^2)} &lt; 4$</td>
<td></td>
</tr>
<tr>
<td><strong>Lepton $p_T$</strong></td>
<td>$p_{T_{Min}}^{l} &gt; 5 \text{ GeV}/c^{2}$</td>
<td>$p_{T_{Min}}^{l} &gt; 5 \text{ GeV}/c^{2}$</td>
<td></td>
</tr>
<tr>
<td>$M_Z$</td>
<td>$[50 \text{ GeV}/c^2, 100 \text{ GeV}/c^2]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_{Z*}$</td>
<td>$[20 \text{ GeV}/c^2, 100 \text{ GeV}/c^2]$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Set of baseline selection cuts for all three channels.

4 Results

After the baseline selection, the four lepton invariant mass distributions, shown for all three channels in Fig. 7, are obtained.

The Z+jet(s) and $t\bar{t}$ backgrounds are completely eliminated. The $Zb\bar{b}$ background is considerably reduced and now only survives towards low masses, with an event rate far below that of the ZZ continuum. The ZZ continuum production with both Z’s decaying leptonically has the same characteristics as the signal, and thus can only be reduced on a statistical basis. The
presence of a peak in the mass spectrum for the signal is the most discriminating observable against the ZZ continuum. The signal from a SM Higgs boson is visible in Fig. 7 as a narrow peak with a mean expected number of events emerging above the continuum.

The experimental sources of systematic uncertainties are the trigger and lepton reconstruction and identification efficiency (6%), lepton isolation (2%), mis-calibration and mis-alignment (2%). The mean expected number of ZZ background events in the signal mass range is estimated by normalizing to the measured single Z event rate [6–8]. Besides the propagation of experimental uncertainties, other contributions in the extrapolation from the single Z to the ZZ in the Higgs boson signal phase space come from the theory (or modeling) with an uncertainty of about 3% in the generated production from parton density functions QCD scale [18]. The uncertainty on the mean expected number of $Zb\bar{b}$ events is larger, with a contribution from the
Table 2: Mean expected number of signal plus background and expected background only events for different Higgs boson masses at $L = 1 \text{ fb}^{-1}$. Events are counted in $m_{4l} \pm 2\sigma_{m_{4l}}$ windows around the given Higgs boson masses.

<table>
<thead>
<tr>
<th>$m_H$ (GeV/$c^2$)</th>
<th>$N_{4e}$</th>
<th>$N_{4\mu}$</th>
<th>$N_{2e2\mu}$</th>
<th>total $4l$</th>
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<tr>
<td>120</td>
<td>0.11</td>
<td>0.05</td>
<td>0.17</td>
<td>0.24</td>
</tr>
<tr>
<td>130</td>
<td>0.30</td>
<td>0.07</td>
<td>0.50</td>
<td>0.77</td>
</tr>
<tr>
<td>140</td>
<td>0.60</td>
<td>0.11</td>
<td>0.87</td>
<td>1.38</td>
</tr>
<tr>
<td>150</td>
<td>0.72</td>
<td>0.12</td>
<td>1.10</td>
<td>1.69</td>
</tr>
<tr>
<td>160</td>
<td>0.44</td>
<td>0.12</td>
<td>0.57</td>
<td>0.97</td>
</tr>
<tr>
<td>170</td>
<td>0.32</td>
<td>0.16</td>
<td>0.36</td>
<td>0.67</td>
</tr>
<tr>
<td>180</td>
<td>0.74</td>
<td>0.35</td>
<td>0.91</td>
<td>1.52</td>
</tr>
<tr>
<td>190</td>
<td>2.00</td>
<td>0.66</td>
<td>2.68</td>
<td>4.57</td>
</tr>
<tr>
<td>200</td>
<td>2.25</td>
<td>0.81</td>
<td>3.00</td>
<td>5.33</td>
</tr>
<tr>
<td>250</td>
<td>1.62</td>
<td>0.59</td>
<td>2.38</td>
<td>4.02</td>
</tr>
</tbody>
</table>

With a total systematic error of about 21% (8%) on the total background mean expectation at low (high) Higgs boson masses and at most a handful of background events expected in the signal region, the uncertainty on the observations in the $4l$ channels is dominated by statistical fluctuations. For the interpretation of the results in terms of exclusion limits on the SM Higgs boson production cross-section systematic error on signal is also included (with the same amount as for the ZZ background) as well as the uncertainty on the $pp$ luminosity. In order to quantify the sensitivity of the experiment to the presence of a Higgs boson signal, a simple counting experiment approach is used. For each possible $m_{H}$ hypothesis, the mean number of expected signal plus background ($N_{s+b}$) and mean number of expected background events ($N_{b}$) is evaluated at $L = 1 \text{ fb}^{-1}$ in a mass window $m_{4l} \pm 2\sigma_{m_{4l}}$, where the central value $m_{4l}$ and the $\sigma_{m_{4l}}$ for any given $m_{H}$ is obtained from a Gaussian fit using the Monte Carlo simulation for the signal. The results are given in Table 2 around a few selected mass points. The table shows the event counts for individual channels, $4e$, $4\mu$, and $2e2\mu$, as well as the total for the three channels grouped together.

For a counting experiment, the log-likelihood ratio $-2\ln Q$ is given by the following equation:

$$-2\ln Q = -2 \left( N_{s+b} \right) \ln \left( 1 + N_s / N_b \right) + 2 N_s. \quad (1)$$

Fig. 8 shows the mean expected values for the log-likelihood ratio $-2\ln Q$ in the signal plus background and for the background-only hypothesis. In such a representation for real data, large negative values could be interpreted as a signal for the presence of a Higgs boson. The green and yellow bands indicate ranges of possible statistical fluctuations for the $-2\ln Q$ value (the green band gives a 68% probability band; the yellow band a 95% probability band). The red curve indicates where one may expect to find data points, should the Higgs boson exist at one of these masses. Systematic errors are not included.

The actual quantitative measure for an event excess is a significance $S_{CP}$ [19]. To evaluate it, a probability for the background to fluctuate to number of events equal or greater than the
expected signal plus background number of events \( N_{s+b} \) is calculated. The calculation of such a probability includes Poisson fluctuations and uncertainties on the level of background. Then, this probability is converted in an equivalent number of sigmas of the Gaussian distribution.

The mean expected sensitivity for a combination of the three channels is given in Table 3 and shown in Fig. 9 (red line). To better show the role of systematic errors in this analysis, the significance calculated without systematic errors (dashed line) is also shown. One can see that systematic errors have only a barely visible effect. The expected mean significance for the signal observation at \( L = 1 \text{ fb}^{-1} \) reaches values above two standard deviations (2\( \sigma \)) in a mass range from 140 – 155 GeV/c\(^2\) and above 185 GeV/c\(^2\). It comes close to 3\( \sigma \) for Higgs boson masses in the vicinity of 200 GeV/c\(^2\). Note that, should one see an excess of events at some particular mass, the significance of such an observation would need to be further de-rated by about 1\( \sigma \) unit to take into account the probability of a random fluctuation anywhere in the mass spectrum (the so-called look-elsewhere effect). Thus, it is unlikely that an integrated luminosity of 1 fb\(^{-1}\) will yield an observation of a mass peak with an overall significance above 2\( \sigma \).

In the absence of a significant deviation from the SM expectations, an upper limit on the cross-section for the production of a SM-like Higgs boson can be derived using a Bayesian approach [11]. The results are given in Table 3 for various \( m_H \) hypotheses and expressed in terms of the ratio of excluded to Standard Model cross sections \( R_{95\% \text{ C.L.}} = \sigma_{95\% \text{ C.L.}} / \sigma_{SM} \). These results are represented in Fig. 10. The shown results take into account the systematic errors on the signal and background assuming 100% correlation, which is a very good approximation for this analysis. One can see that there is a fair chance of excluding the SM-like Higgs boson at 95% C.L. for the mass above 185 GeV/c\(^2\). This would extend beyond existing constraints.

### 5 Conclusions

A prospective analysis for the search of a SM-like Higgs boson decaying in ZZ\(^*\) pairs has been presented for the CMS experiment in the context of the startup luminosity at the CERN LHC.
Table 3: Expected significance and expected values of $R_{95\% \text{ C.L.}}$ for selected Higgs boson masses.

<table>
<thead>
<tr>
<th>$m_H$ (GeV/c$^2$)</th>
<th>Events at 1 fb$^{-1}$</th>
<th>Significance</th>
<th>$R_{95% \text{ C.L.}}$</th>
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<tr>
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<td>0.52</td>
<td>0.13</td>
<td>10.3</td>
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<tr>
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<td>170</td>
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<td>0.50</td>
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<td>10.6</td>
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<tr>
<td>250</td>
<td>8.02</td>
<td>2.49</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Figure 9: The expected significance of an event excess in assumption of a SM Higgs boson presence. The solid curve includes systematic errors, while the dashed curve is calculated without systematic errors.

The sensitivity for observing a Higgs boson via the decay $Z \rightarrow \ell^+\ell^-$ with $\ell = e, \mu$ has been determined, assuming an integrated luminosity of 1 fb$^{-1}$ and the detector calibration and alignment knowledge of the first 100 pb$^{-1}$.

A complete search strategy is established. A combination of electron and muon trigger-paths and a loose data reduction skimming step are used at early stages to reduce QCD background with fake primary leptons while preserving efficiency for the selection of signal events. Further suppression of QCD and $Z+$jet(s) backgrounds is obtained with lepton identification and loose isolation leaving a background dominated by $Z+$jet(s), $t\bar{t}$, $Zb\bar{b}$ and ZZ. Lepton isolation criteria and impact parameter constraints are used to eliminate the $Z+$jet(s), $t\bar{t}$ and $Zb\bar{b}$ contamination. The $Zb\bar{b}$ contamination is further reduced by exploiting a correlation between the least isolated leptons and the two lowest $p_T$ leptons. The ZZ continuum remains the dominant background everywhere in the mass range considered for the Higgs boson from 120 GeV/c$^2$ to 250 GeV/c$^2$.

The Higgs boson search is performed with a window in the hypothetical mass $m_H$, and using $pp$ collider.
a simple sequential cut-based approach. A baseline selection common to all mass hypotheses was used. A sensitivity at the 2σ level is obtained for favorable values of $m_H$ combining the $4e$, $4\mu$ and $2e2\mu$ channels. In the absence of a significant deviation from background expectations, 95% C.L. exclusion limits are obtained for a Standard Model-like Higgs boson.
References


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