PROCEEDINGS OF SCIENCE

Prospect for Higgs search in $\mathrm{H} \rightarrow \mathrm{ZZ}$ decay channels with the CMS detector

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The prospects for the search of the Standard Model Higgs boson in the decay channel $\mathrm{H} \rightarrow \mathrm{ZZ}^{(*)} \rightarrow$ 4leptons (4e, 4μ or 2e2μ) with the CMS experiment at the LHC is presented. The analysis relies on a full simulation of the detector response and emphasis is put on the analysis steps and the strategies for the measurement of experimental and background systematics from data. The sensistivity reach at 14 TeV with an integrated luminosity of 1 fb^{-1} is derived as a function of the Higgs mass.

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1. Introduction

The Standard Model (SM) of particle interactions predicts the existence of a scalar field responsible for the electroweak symmetry breaking, the Higgs boson; the coupling of the Higgs boson to fermions and gauge bosons allows those particles to acquire mass while the Higgs mass itself is not predicted by the theory.

Direct searches for the SM Higgs particle at the LEP e^+e^- collider have led to a lower mass bound of $m_H > 114.4\,\mathrm{GeV/c^2}$ (95% C.L.) [1]. On-going direct searches at the Tevatron $p\bar{p}$ collider by the D0 and CDF experiments set exclusion limits for a SM-like Higgs boson in a mass range between 163 and $166\,\mathrm{GeV/c^2}$ at 95% C.L. [2]

The gluon-gluon fusion is the main production mechanism for SM Higgs at LHC with a cross section at NLO in between 0.1 and 50 pb depending on the Higgs mass; other production mechanisms like the associated production with W/Z bosons, the weak vector boson fusion processes and the associated Higgs production with heavy top or bottom quarks are much less favourite [3].
In the high mass range the most important decay channels of the Higgs particle are $H \rightarrow WW^{(*)}$ and $H \rightarrow ZZ^{(*)}$ which give a clear signature of multi leptons in the final state.

2. $H \rightarrow ZZ^{(*)}$ analysis

$H \rightarrow ZZ^{(*)}$ searches with four leptons (electrons and muons) in the final state at center-of-mass energy of 14 TeV are reported in this paper. The best performance on the electron and muon objects combined with a complete data-driven analysis strategy relying on a flexible and reliable analysis framework are the keys for the Higgs discovery in $H \rightarrow ZZ^{(*)}$ channels. A detailed description of the $H \rightarrow ZZ^{(*)}$ analysis could be found in Reference [4].

The full range of Higgs masses between 115 and 250 $\mathrm{GeV/c^2}$ is investigated. The most important sources of background come from $ZZ^{(*)}$, $Zb\bar{b}$ and $t\bar{t}$ to 4 leptons events while QCD di-jets, W+jets and Z+jets contributions are gradually reduced through the analysis chain.

A high level trigger selection based on single and double lepton trigger bits is used as the first step of a skimming procedure aimed to reduce the data volume and data content, keeping the signal efficiency at the 100% value while reducing the background; a cut on transverse momentum of at least three leptons in the event is applied afterwards as the last part of the skim selection.

A subsequent step of preselection is applied with the purpose of cutting completely the QCD background which contributes with fake leptons to the final state and discarding events with final state topologies different from those expected for the signal. Electron identification criteria optimized for $H \rightarrow ZZ^{(*)}$ searches are used to kill the rate of jets faking leptons. Cuts on the transverse momentum of leptons in the acceptance are used together with a lower cut on the di-lepton invariant mass to discard the contribution of low mass resonances, and a cut on 4-leptons invariant mass. A loose isolation criterium is applied on leptons, as the last step of the preselection to kill QCD di-jets events; that also reduces $t\bar{t}$ and $Zb\bar{b}$ events at a rate of same order of magnitude, as shown in Figure 1 (left) for the case of 4e final state channel.

In the subsequent steps of the analysis a tighter lepton isolation and a cut on lepton impact parameter are used to further reduce $t\bar{t}$ and $Zb\bar{b}$ events with not well isolated leptons from b-jets and with a vertex typically displaced with respect to the nominal collision point.

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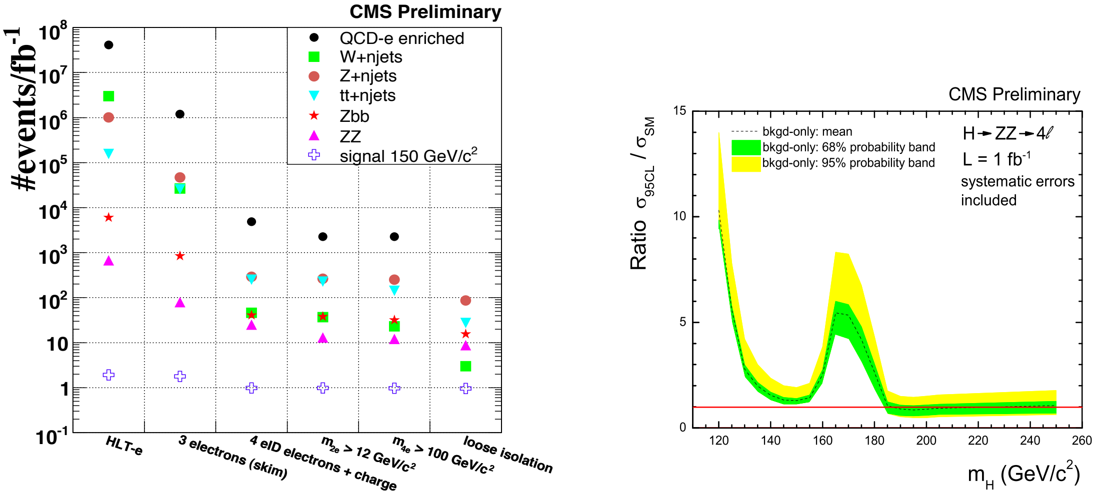

Figure 1: (left) Reduction of the event rate for QCD, Z/W + jet(s), $t\bar{t}$ +jet(s), $Zb\bar{b}$ and ZZ backgrounds, and Higgs signal at $m_H = 150\,\mathrm{GeV/c^2}$, after the skimming and each pre-selection step in the 4e final state channel. (right) Upper limit at 95% C.L. on the production cross-section of a SM Higgs boson normalized to the expected the cross section for selected Higgs boson masses.

Then cuts on di-lepton invariant mass fitting the Z on mass-shell and the $Z^{(*)}$ built with the remaining high p_T opposite charge leptons were used. Cuts on sum of the values of the isolation variables for the two less isolated leptons is imposed, sliding with the transverse momentum of the two lowest p_T leptons, respectively; those cuts are useful to further reduce $Zb\bar{b}$ events.
All the cuts were tuned at $m_H = 150\,\mathrm{GeV/c^2}$ and a m_H independent analysis was defined as a baseline selection valid in the pointed mass range.

Few $Zb\bar{b}$ events survive at the end of the selection giving a meaningful contribution to the low mass part of the 4-leptons invariant mass spectrum. The ZZ background, almost indistinguishable from the signal, is the main source of the remaining background. The number of signal and background events expected after the full analysis at center-of-mass energy of 14 TeV with an integrated luminosity of $1\,\mathrm{fb}^{-1}$ are reported in Table 1. Systematic uncertainties on signal and background estimates are evaluated and specific techniques to estimate the rate of ZZ and $Zb\bar{b}$ events from data are also developed.

$m_H\,(\mathrm{GeV/c^2})$	Events at 1 $1\,\mathrm{fb}^{-1}$		Significance	95 % C.L. for R
	N_{s+b}	N_b		
120	0.52	0.19	0.13	10.3
140	2.85	0.42	2.22	1.55
150	3.52	0.47	2.64	1.29
160	1.98	0.47	1.36	2.53
190	9.24	2.74	2.92	0.89
200	10.6	3.52	2.87	0.89

Table 1: Expected number of signal+background and background only events, expected significance and values of R at 95% confidence level for selected Higgs boson masses.

The significance of a Higgs signal observation with an integrated luminosity of 1 fb^{-1} is computed for different Higgs mass hypotheses and its values are reported in Table 1. That significance needs 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); when taking into account that effect, it is unlikely that an integrated luminosity of 1 fb^{-1} will yield an observation of a mass peak with an overall significance above 2σ.

In absence of significant deviations from background expectations, upper limits at 95% C.L. on the production cross-section of a SM Higgs boson can be derived and normalized to the expected the cross section, as reported in Table 1. Higgs masses within the 190-230 GeV/c^2 approximate range could be excluded at 95% C.L. with an integrated luminosity of 1 fb^{-1} at center-of-mass energy of 14 TeV, as shown in Figure 1 (right).

References

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[4] *Search strategy for the Higgs boson in the* ZZ^* *decay channel with the CMS experiment*, CMS Collaboration, CMS PAS HIG-08-003.