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Projected exclusion limits on the SM Higgs boson cross sections obtained by combining the H to WW^* and ZZ^* decay channels

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We present an evaluation of the CMS expected 95% C.L. exclusion limits in early Standard Model (SM) Higgs boson searches. The results are based on a statistical combinations of multiple recent Monte-Carlo analyses: $H \to WW^* \to 2l2\nu$ and $H \to ZZ^* \to 4l$ decay channels, where l stands for e or μ. We show that these two channels alone should allow for excluding the Standard Model Higgs boson in the mass range of 140-230 GeV by the time when CMS collects 1 fb^{-1} of data at a center-of-mass energy of 14 TeV. We also give an estimate of how the change of the LHC center-of-mass collision energy from 14 to 10 TeV would impact the Higgs boson exclusion limits.

XXth Hadron Collider Physics Symposium
November 16 – 20, 2009
Evian, France

*on behalf of the CMS Collaboration.

PoS(HCP2009)094

1. High Mass SM Higgs Searches

Within the Standard Model (SM) framework, Higgs Mechanism is supposed to be responsible for generation of mass of all elementary particles. This mechanism requires one spin-0 boson (Higgs boson) whose existence is the most important prediction of the SM which has not yet been verified by experiments. Although the mass of this scalar boson (m_H) is almost a free parameter of the theory, various constraints are imposed using direct and indirect experimental searches. Direct searches at the LEP e^+e^- collider set a lower bound at 114.4 GeV at 95% C.L.[1] and Tevatron excluded the mass range between 160 and 170 GeV at 95% C.L. [2]. The SM Higgs boson is excluded by electroweak measurements above 186 GeV at 95% C.L.

The LHC, which started its operation at lower energies in november 2009, is designed to collide protons at the center of mass energy ($\sqrt{s}$) of 14 TeV with high luminosity ($10^{34} cm^{-2}s^{-1}$). One of the main goals of the general purpose Compact Muon Solenoid (CMS) detector[3] at LHC is to search for the elusive Higgs boson in the TeV energy regime, accessible at LHC. The dominant Higgs production mode at the LHC is the gluon-gluon fusion. The vector boson fusion accounts for $\sim$ 20% and its contribution increases with increase in $\sqrt{s}$. The Higgs production cross-section is of the order of 0.1 - 50pb, depending on Higgs mass. For m_H > 140 GeV, the Higgs boson decays mainly in weak bosons. The $H \to WW^*$ mode has the highest branching ratio (BR), which is $\sim$ 3 times higher than $H \to ZZ^*$. When the decay into two real W bosons becomes possible, i.e. $m_H \sim$ 160 GeV, the BR to WW^* increases up to $\sim$1 due to the threshold effect. In the region 140 < m_H < 600 GeV, the most important decay channels are $H \to WW^* \to 2l2\nu$ and $H \to ZZ^* \to 4l$ because of the clean signatures produced by leptons.

2. $H \to WW^* \to 2l2\nu$ analysis

The search of SM Higgs boson decaying in WW^* pair has been studied for the CMS experiment in the context of the start-up luminosity at the CERN LHC pp collider [4]. The dominant SM backgrounds are the continuum W^+W^- and $t\bar{t}$ production. The signal and background datasets were obtained with a detailed Monte Carlo simulation of the detector response. The various electron and muon trigger-paths and a loose data reduction skimming step are combined at early stages of the analysis to preserve the signal event selection efficiency. The lepton identification and isolation tools for electron and muon as well as a jet veto and missing E_T observables are used to suppress the backgrounds. The multivariate analysis approach obtain better results than the cut based approach, specially in the region around m_H = 160 GeV. Nevertheless there is still some sensivity with the cut based analyses, which may be useful for the beginning of the data taking, where sophisticated analysis techniques are more complicated to fully evaluate. Fig.1 shows the signal significance of this channel for the multivariate analysis.

3. $H \to ZZ^* \to 4l$ analysis

The search of SM Higgs boson decaying in ZZ^* pair has been studied for the CMS experiment in the context of the startup luminosity at the LHC [5]. The sensitivity for observing a Higgs boson via the decay $Z \to l^+l^-$ with $l = e, \mu$ has been determined, assuming an integrated luminosity of

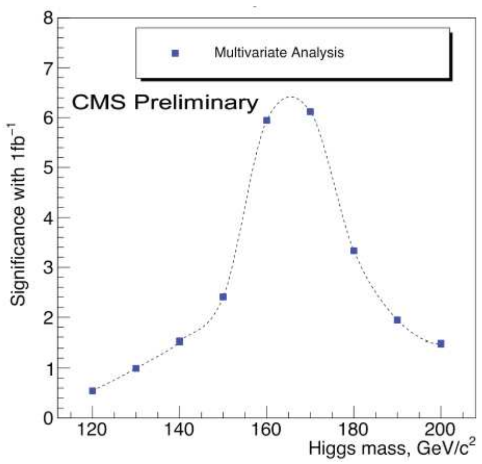

Figure 1: Signal significance for $H \to WW^*$ multivariate analysis at $\sqrt{s}$ = 10TeV with 1 fb^{-1} integrated luminosity.

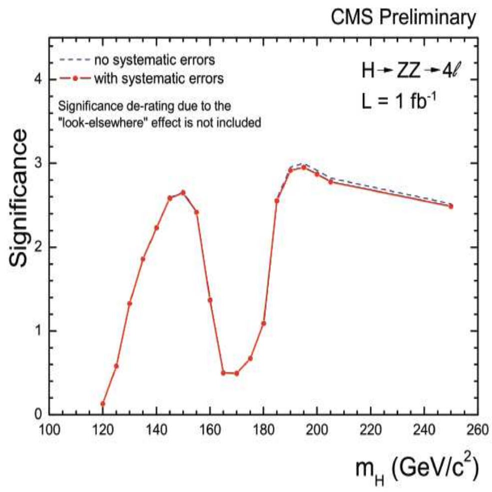

Figure 2: Signal significance for $H \to ZZ^*$ multivariate analysis at $\sqrt{s}$ = 10TeV with 1 fb^{-1} integrated luminosity.

1 fb^{-1} and the detector calibration and alignment knowledge. The Monte Carlo signal and backgrounds are simulated with full detector effects. A combination of trigger-paths and a loose data reduction skimming step are used at early stages to reduce QCD background with fake 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 further suppress 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 to 250 GeV. In absence of a significant signal observed from the combination of the $4e, 4\mu, 2e2\mu$ analyses, 95% confidence level exclusions limits are obtained for SM Higgs boson [6]. Fig.2 shows the signal significance for the $H \to ZZ^*$ analysis.

4. Combined channel results

The combination is done using two exclusion methods (with difference in assumption on the level of correlation between systematic errors) - Bayesian and Modified Frequentist (CLs). The combination is based on two analyses $H \to WW^* \to 2l2\nu$ and $H \to ZZ^* \to 4l$ and on the basis of signal-to-background ratios and correlation in dominant systematic errors. Fig.3 shows the exclusion limits on the ratio for a range of Higgs mass points, where ratio is between the cross-section excluded with the 95% C.L. to that of the SM Higgs cross-section. It is found that both exclusion methods give consistent results. The statistical combination of the results of the CMS analyses at $\sqrt{s}$ =14TeV with 1 fb^{-1} integrated luminosity shows that a SM Higgs can be excluded in the mass range 140-230 GeV. However, this range is restricted to 150-190 GeV if the LHC center-of-mass energy is reduced from $\sqrt{s}$ = 14 TeV to 10 TeV (foreseen for the first year run).

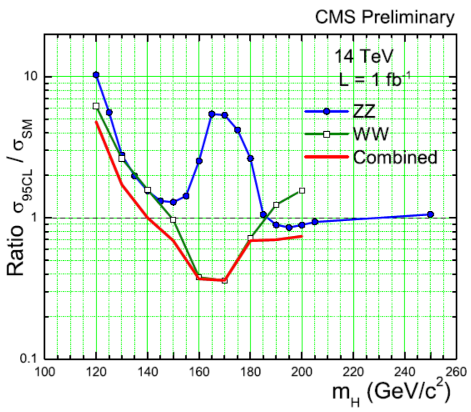

Figure 3: Ratio between the cross section excluded with 95% C.L. to SM Higgs boson cross section for $H \to ZZ^*$, $H \to WW^*$ and combination at $\sqrt{s} = 14$TeV with 1 fb^{-1} luminosity.

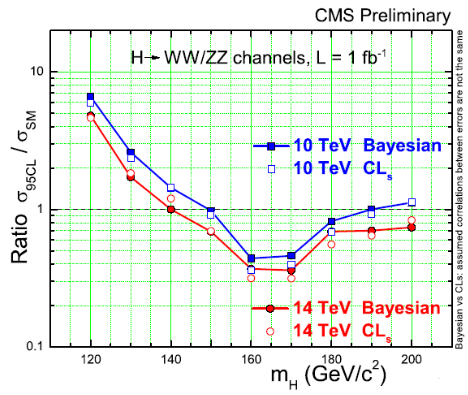

Figure 4: Ratio between the cross section excluded with 95% C.L. to SM Higgs boson cross section for $H \to ZZ^*$ and $H \to WW^*$ combination at $\sqrt{s} = 14$TeV and 10TeV with 1 fb^{-1} luminosity.

Fig.4 shows that twice the luminosity is needed for same exclusion if $\sqrt{s}$ is reduced from 14TeV to 10TeV. It is also observed that another factor of two in luminosity will be needed to get the same exclusion if $\sqrt{s}$ decrease further to 7TeV.

References

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