Higgs Searches at CMS

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1 Introduction

A search for the Higgs boson in the Standard Model (SM) and the Beyond Standard Model scenarios conducted by the Compact Muon Solenoid (CMS) experiment with the 2010 data at the Large Hadron Collider (LHC) running at the center of mass energy ($\sqrt{s}$) of 7 TeV is presented. No signal was found but limits on cross section times branching fraction in the different channels were derived and found to reach beyond the existing constraints. The projected CMS sensitivity for the SM Higgs Boson searches at the center of mass energy of 7 TeV under various integrated luminosities is also discussed.

2 Standard Model Higgs

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. The direct searches at the Large Electron - Positron (LEP) collider set a lower bound of 114.4 GeV at 95% confidence level (C.L.)[1] and Tevatron excluded the mass range between 158 to 173 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 is designed to collide protons at the center of mass energy of 14 TeV with high luminosity ($10^{34}\text{cm}^{-2}\text{s}^{-1}$), is presently under operation at the center of mass energy of 7 TeV. One of the main goals of the general purpose 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 the center of mass energy. Despite its small branching ratio of about 0.2%, the $H \to \gamma\gamma$ decay channel provides a clean final-state topology with an effective mass peak around $m_H \simeq 120$ GeV. 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. The $H \to WW^*$ mode has the highest branching fraction (BR), which is ~ 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.

2.1 $H \to \gamma\gamma$

The $H \to \gamma\gamma$ search is expected to have the best sensitivity to the SM Higgs boson in the low mass range. For the purposes of this projection, CMS used a conservative option of not distinguishing between reconstructed photon categories and simply counting events in an optimal $\gamma\gamma$ mass window. The projection presented here is for a generic search for a narrow $\gamma\gamma$ resonance, since nothing specific to the SM Higgs boson was utilized. The SM Higgs boson cannot be excluded anywhere in the entire mass range but a fermio-phobic Higgs boson with a mass $m_H < 110$ GeV could be excluded using integrated luminosity of 1 fb^{-1}.

2.2 $H \to WW^* \to 2l2\nu$

The search of $H \to WW^* \to 2l2\nu$ is performed using integrated luminosity of 36 pb^{-1}. The dominant SM backgrounds are the continuum W^+W^- and $t\bar{t}$ production. 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. No excess above the SM expectations was found. The limits on the Higgs boson production cross section have been derived [4]. In the presence of a sequential fourth family of fermions with very high masses, a Higgs boson with standard model couplings and a mass between 144 and 207 GeV has been excluded at 95% C. L..

2.3 $H \to ZZ^* \to 4l$

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. The sensitivity for observing a Higgs boson via the decay $Z \to l^+l^-$ (where $l = e, \mu$) has been determined, assuming an integrated luminosity of 1 fb^{-1} and the detector calibration and alignment knowledge [5]. 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. The lepton isolation criteria and impact parameter constraints are used to further suppress $Z + jet(s)$, $t\bar{t}$ 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 the absence of a significant signal observed from the combination of the $4e, 4\mu, 2e2\mu$ analyses, 95% C.L. exclusions limits are obtained for the SM Higgs boson.

3 Beyond Standard Model Higgs

In the Beyond Standard Model scenario, with 36 pb^{-1} of data collected at the center of mass energy of 7 TeV, CMS experiment has searched for neutral, charged and doubly charged Higgs.

3.1 Neutral Higgs searches

The search for neutral Minimal Supersymmetric Standard Model (MSSM) Higgs boson production in the pp collisions at the LHC at center of mass energy of 7 TeV is also performed using a data sample corresponding to an integrated luminosity of 36 pb^{-1}. The Higgs boson decay to tau pairs provide the most sensitive search channel. No excess is observed in the fully reconstructed tau pair invariant mass spectrum. The resulting upper bounds on the Higgs production cross section times branching fraction to tau pairs as a function of the Higgs boson mass yield stringent new bounds in the MSSM parameter space m_A versus $tan\ \beta$ [6], as shown in the Figure 1 .

3.2 Charged Higgs searches

The large top quark production cross section at the LHC offers the opportunity to search for the charged Higgs boson as the decay can be large in extensions of the standard model, if the mass is lighter than the top quark mass. A direct search for the charged Higgs boson in events with one lepton (electron or muon), at least two jets, missing transverse energy, and one hadronically decaying tau lepton has been performed with 36 pb^{-1} of data collected. No signal was found in this search and an upper limit on the branching fraction for masses between 80 GeV and 140 GeV [7] is derived, assuming branching fraction $H^+ \to \tau^+\nu = 1$.

The inclusive search for the doubly charged Higgs boson, a member of $SU(2)_L$ scalar triplet ϕ participating in the seesaw mechanism of type II, is performed in events with three and four isolated charged leptons of all flavours originating from the decays of pair produced triplet components $\phi^{++}\phi^{--}$ and $\phi^{++}\phi^{-}$. The present collected luminosity by the CMS experiment is sensitive to the ϕ mass range in which

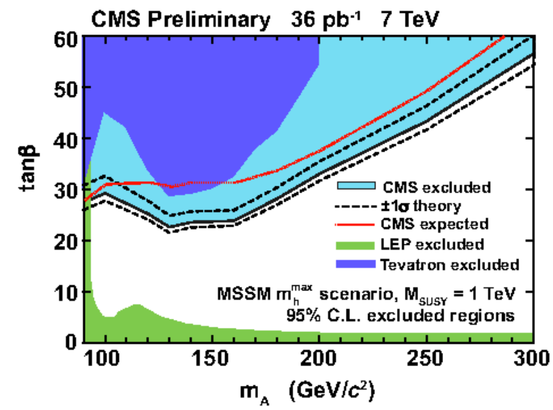

Figure 1: The region in the parameter space of m_A versus $tan\ \beta$ excluded at 95% C.L. in the context of the MSSM with excluded regions (shaded) from the LEP and Tevatron experiments.

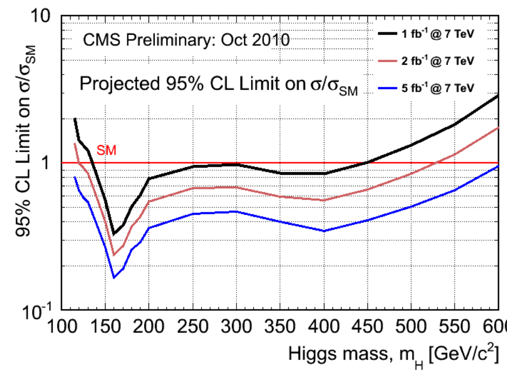

Figure 2: The projected 95% C.L. exclusion limits in terms of a ratio of an excluded cross section to the SM Higgs cross section for $\sqrt{s} = 7$ TeV at integrated luminosity of 1,2 and 5 fb^{-1}.

the possible decays $\phi^{++} \to W^+W^+$ are forbidden kinematically. No signal excess is observed and lower limits at the 95% confidence level are set on the ϕ^{++} mass of 156 GeV in the $\mu\mu$ channel, 154 GeV in $e\mu$ channel, and 144 GeV in ee channel and between 116 GeV to 131 GeV in the four defined benchmark points [8].

4 Projected Limits and Exclusions

The projected sensitivity and exclusion limits for SM Higgs boson searches at the center of mass energies of 7 TeV and 8 TeV, and using integrated luminosities between 1 fb^{-1} to 10 fb^{-1}, is obtained using an expanded list of SM Higgs signatures, namely: $H \to WW \to 2l2\nu(+0/1jets)$, Vector Boson Fusion (VBF) $H \to WW \to 2l2\nu$, $H \to ZZ \to 4l, H \to ZZ \to 2l2\nu, H \to ZZ \to 2l2b, H \to \gamma\gamma$, VBF $H \to \tau\tau$, associate production $VH \to V(bb)$ (highly boosted), associate production $ZH \to Z(WW) \to (ll)(l\nu jj)$, associate production $WH \to W(WW) \to (l\nu)(l\nu jj)$ (same sign di-leptons) [9]. The 95% C.L. exclusion limits in terms of a ratio of an excluded cross section to the SM Higgs cross section for the center of mass energy of 7 TeV are shown in Figure 2 for a range of Higgs mass points. At the center of mass energy of 7 TeV and integrated luminosity of 5 fb^{-1}, CMS is expected to reach an exclusion sensitivity in the mass range from the LEP limits (114 GeV) to 600 GeV.

References

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