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Searches for the Higgs Boson in CMS

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Abstract

The CMS potential for the Higgs boson discovery is discussed in the framework of the Standard Model (SM) and its Minimal Supersymmetric extension (MSSM).

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1 Introduction

The Large Hadron Collider (LHC) is designed to collide two counter rotating beams of protons or heavy ions. Proton-proton collisions are foreseen at an energy of 7 TeV per beam with a planned start-up in 2007. The Compact Muon Solenoid (CMS) is one of the two general purpose detectors that will be installed on the collider. One of its main challenges is the discovery of the Higgs boson. In this report, the CMS potential for the Higgs boson discovery is discussed in the framework of the Standard Model (SM) and its Minimal Supersymmetric extension (MSSM). More details can be found in [1].

2 Discovery Potential for the Standard Model Higgs Boson

The main production mechanism for the Higgs boson at 14 TeV is the gluon-gluon fusion and the WW/ZZ fusion. For low Higgs boson masses (below 130 GeV/c^2), the most promising channel for discovery is the H$\rightarrow \gamma\gamma$. Its signature is quite clean, mainly based on a well calibrated electromagnetic calorimeter. The H$\rightarrow \mathrm{b\bar{b}}$ channel is the dominant decay but due to the huge QCD background is not useful if the Higgs boson is produced via the gluon-gluon fusion. This decay mode is interesting when the Higgs boson is produced in association with $\mathrm{t\bar{t}}$ ($\mathrm{t\bar{t}H, H \rightarrow b\bar{b}}$). In that case, the background can be effectively reduced via b-jet tagging. Another interesting discovery channel, at the same mass range (around 130 GeV/c^2), is the $\mathrm{qq \rightarrow qqH, H \rightarrow \tau^+\tau^-}$. It can be searched for in the lepton plus τ-jet final state. The critical factor here is the reconstructed mass resolution due to the dominant QCD and electroweak Zjj background with $\mathrm{Z} \rightarrow \tau^+\tau^-$ and the central jet veto.

If the Higgs boson has a mass between 130 GeV/c^2 and 2M$_Z$, the preferred search channels are the $\mathrm{H \rightarrow ZZ^*}$ and $\mathrm{H \rightarrow WW^*}$, which are abundantly produced and give quite clean signatures especially when the final state involves muons and/or electrons. For heavier Higgs bosons (M$_H > 2M_Z$) the golden discovery channels are the $\mathrm{H \rightarrow ZZ \rightarrow 4e, 4\mu, 2e2\mu}$ which will allow a very fast discovery. For very high Higgs boson masses (above 500 GeV/c^2) the cross section for the qq$\rightarrow$qqH production process is large and the decay channels $\mathrm{H \rightarrow ZZ} \rightarrow ll\nu\nu, lljj$ were found to yield the highest sensitivity even though the large backgrounds and the large Higgs boson width make the discovery much more difficult compared to the lower Higgs boson masses.

The statistical significance expected for 30 fb^{-1} of integrated luminosity can be seen in Figure 1 when all channels are combined.

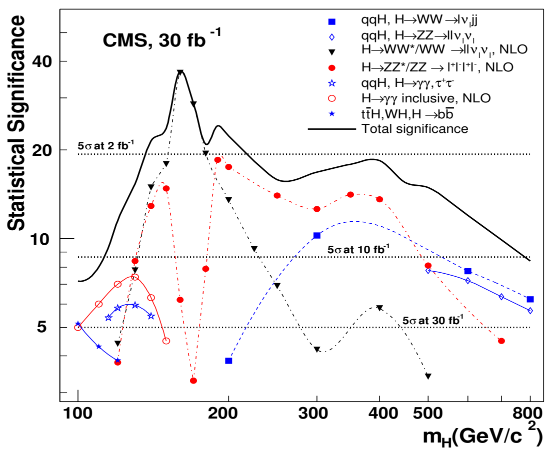

Figure 1: Expected sensitivity for the Standard Model Higgs boson observation as a function of its mass with 30 fb^{-1} integrated luminosity.

3 Discovery Potential for the MSSM Higgs Bosons

In the MSSM there are five Higgs bosons: two CP-even Higgs boson mass eigenstates h,H, a charged Higgs boson pair H$^\pm$ and a CP-odd neutral pseudoscalar A. At tree-level the Higgs boson sector is determined by two parameters. A common choice is the ratio of vacuum expectation values of the two doublets tanβ=u$_2$/u$_1$ and the mass of the pseudoscalar Higgs boson M$_A$. Radiative corrections modify the predictions of the model significantly: the mass of the lightest higgs boson at tree level is predicted to be below M$_Z$ which is already excluded by LEP [2] but after corrections its mass may rise up to 135 GeV/c^2. Several MSSM Higgs boson scenarios have been proposed depending on different choices of the soft SUSY breaking parameters. For the results presented in this report the SUSY parameters are fixed to the values used in the LEP studies [3].

In the large M_A limit ($M_A \gg M_Z$), the so-called decoupling region, the heavy Higgs bosons (H, A, $H^{\pm}$) are almost degenerate in mass. The lighter Higgs boson h is SM-like, so its production cross sections and decay partial widths are very close to those of the SM Higgs boson. The discovery potential for the lighter scalar Higgs boson h can be seen in Figure 2 for 30 fb^{-1} of integrated luminosity.

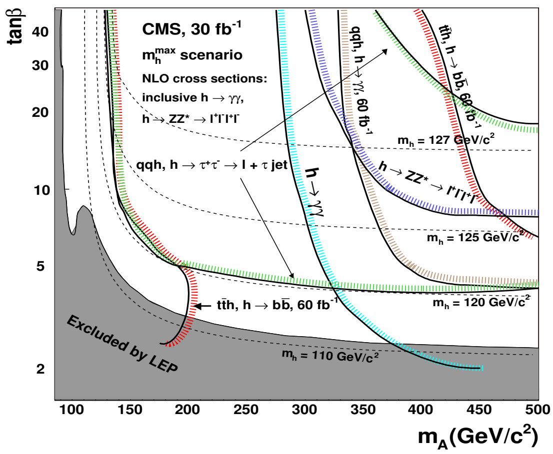

Figure 2: The 5 σ discovery contours in the (M_A , tanβ) plane for the light scalar MSSM Higgs boson with 30 fb^{-1} integrated luminosity in the M_h-max scenario.

At large tanβ the couplings of the heavy neutral Higgs bosons (H,A) to the electroweak gauge bosons are strongly suppressed while the couplings to down-type fermions are enhanced allowing a search for H,A in the H,A→ $\mu^+\mu^-$ and H,A→ $\tau^+\tau^-$ decay channels in the associated production gg→ $b\bar{b}$H/A. In this production process, the associated b-jets can be used to suppress the Z,γ^* and QCD multi-jet backgrounds with b-tagging methods. To take advantage of the hadronic τ decays in the lepton-plus-τ-jet and two-τ-jet final states from the H/A→ $\tau^+\tau^-$ decay, an efficient τ-jet (coming from τ hadronic decays) identification method is required to suppress further QCD multi-jet and W-plus-jet backgrounds. The Higgs boson mass can be reconstructed also in the H/A→ $\tau^+\tau^-$ channels from the missing E_T and the visible τ momenta exploiting the neutrino collinearity with the parent τ direction. The discovery potential for the H/A Higgs bosons can be seen in Figure 3 for 30 fb^{-1} of integrated luminosity.

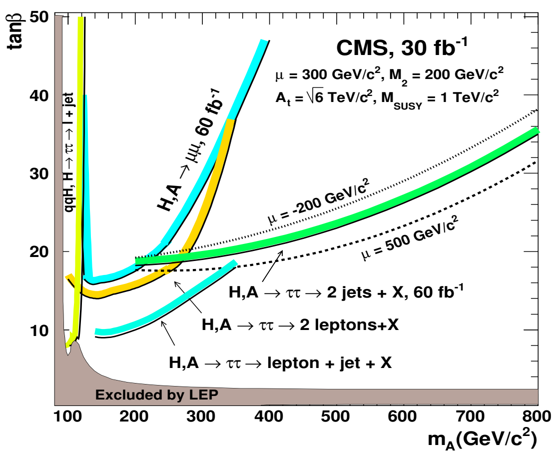

Figure 3: The 5 σ discovery contours in the (M_A , tanβ) plane for the heavy neutral MSSM Higgs bosons H and A with 30 fb^{-1} integrated luminosity in the M_h-max scenario.

The heavy charged Higgs bosons search proceeds via $H^{\pm} \to \tau\nu_{\tau}, tb, Wh$ decay channels, in the associated production process gg$\to btH^{\pm}$. The W+jet and QCD multi-jet backgrounds can be suppressed with b/τ-tagging and reconstruction of the associated top quark. The $H^{\pm} \to \tau\nu_{\tau}$ decay channel is particularly interesting, when hadronic decays are required. The light charged Higgs bosons ($M_{H^{\pm}} < M_{top}$) can be searched for in the $H^{\pm} \to \tau\nu_{\tau}$ decay channel in the $t\bar{t}$ production, by suppressing the backgrounds with an isolated lepton from the accompanying W decay. The discovery potential for the $H^{\pm}$ Higgs bosons can be seen in Figure 4 for 30 fb^{-1} of integrated luminosity.

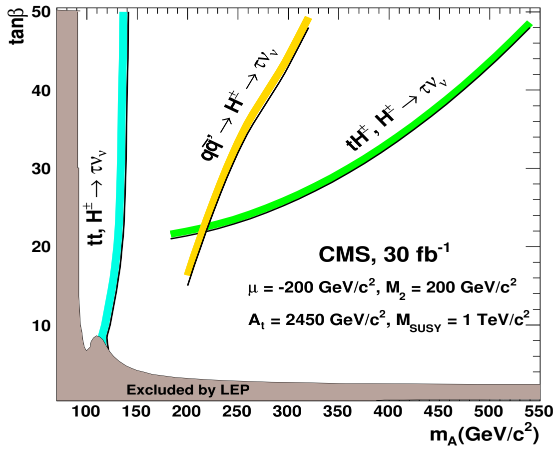

Figure 4: The 5 σ discovery contours in the (M_A , tanβ) plane for the charged Higgs bosons with 30 fb^{-1} integrated luminosity in the M_h-max scenario.

4 Conclusions

The present understanding of the CMS potential for the SM and MSSM Higgs boson discovery has been reviewed. Detailed studies are on going including systematic uncertainties and more sophisticated analysis methods.

References

[1] S. Abdullin *et al.*, *CMS Note* **2003/033**.

[2] LEP Higgs Working Group, *Phys. Lett.* **B565**, 61 (2003).

[3] LEP Higgs Working Group, *LHWG-Note***2005-01**.