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SUSY Higgs searches at the LHC

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Abstract

Searches for the Higgs bosons of the Minimal Supersymmetric Standard Model are discussed at the LHC in the CMS and ATLAS experiments. Results are presented for the scenario which maximizes the mass of the lighter scalar Higgs boson. Low integrated luminosity is assumed.

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1 Introduction

With the completion of the CERN LHC collider in the near future direct searches for Higgs bosons can start in the full expected mass range. The experimental results from LEP and Tevatron have lead to a prediction of a light Higgs boson. In the framework of the Standard Model (SM) fits to all electro-weak data yield a 95% CL upper limit of 260 GeV/c^2 for the mass of this Higgs boson [1]. An accurate one-loop calculation of the W boson mass in the Minimal Supersymmetric Standard Model (MSSM), including complex phase dependences and all available two-loop corrections has been shown to lead to a result clearly favoring the MSSM with heavy SUSY scale over the SM [2].

The MSSM contains five Higgs bosons: the lighter scalar h, the heavier scalar H, the pseudoscalar A and the two charged bosons $H^{\pm}$. At the tree-level the mass spectrum can be presented in terms of two parameters, the pseudoscalar mass m_A and the ratio tanβ of the vacuum expectation values of the two Higgs doublets. The predictions depend on other eight parameters: the top mass, the SU(1) and SU(2) gaugino mass terms (M_2) unified at the GUT scale, the sfermion mass terms (M_{SUSY}) unified at the electro-weak scale (M_{EW}), gluino mass ($M_{\tilde{g}}$), Higgs mixing parameter (μ) and the squark trilinear couplings A unified at M_{EW}. The mixing parameter in the stop sector X_t is defined by X_t = A_t - $\mu\cot\beta$. The SUSY corrections to Higgs boson masses and couplings come from the $t/\tilde{t}$ sector and at large tanβ from the $b/\tilde{b}$ sector. The size of the correction is particularly sensitive to the Higgsino mass parameter μ. Most the LHC studies for the MSSM Higgs bosons have been performed in the m_h^{max} scenario, where the parameters X_t and μ are chosen to maximize the mass of the lighter scalar Higgs boson h. In this scenario the mixing parameter X_t is large leading also to maximal mixing in the stop sector. The No-mixing scenario, with X_t set to zero, yields smaller m_h values than the m_h^{max} scenario.

In the MSSM the loop effects, mediated predominantly by third-generation squarks, can lead to sizeable violations of the tree-level CP-invariance of the Higgs potential, creating scalar-pseudoscalar transitions in the Higgs sector [3]. As a consequence, the three neutral Higgs mass eigenstates have no definite CP parities, but become mixtures of CP-even and CP-odd states. These eigenstates are labeled as $H_{1,2,3}$ in order of increasing mass with $m_{H_1} \leq m_{H_2} \leq m_{H_3}$. The mass of the charged Higgs bosons remains still physical and is used as a parameter of the model.

The LEP measurements yield the 95% CL limits of 92.8, 93.8 and 78.6 GeV/c^2 for the masses of the h, A and $H^{\pm}$ bosons [4, 5], respectively, in the m_h^{max} scenario. The excluded tanβ regions are for 0.7$<$ tanβ $<$ 2.0 and 0.4$<$ tanβ $<$ 10.2 in the m_h^{max} and No-mixing scenarios, respectively [4]. These tanβ exclusion limits are sensitive to the value of m_{top}. With m_{top} = 169.3 GeV/c^2, for instance, the No-mixing scenario would be fully excluded.

In this report, the LHC potential for the Higgs boson discovery is discussed in the framework of the MSSM. The experimental studies have been performed mainly in the CP-conserving real SUSY scenario. Discovery potential for the MSSM Higgs bosons in various discovery channels is presented in Ref. [6] for the CMS detector and in Ref. [7] for the ATLAS detector. Preliminary studies for the Higgs boson searches in the CP-violating SUSY can be found in Ref. [3] for the ATLAS detector. In the scenario maximizing the CPV effect (CPX) almost full coverage of the parameter space may be obtained at the LHC [3]. Detailed descriptions of the CMS and ATLAS detectors can be found in Refs. [8,9]. In the following, the searches for the neutral and charged MSSM Higgs bosons are discussed in Sections 3 and 4, respectively and the conclusions are given in Section 5.

2 Searches for the neutral MSSM Higgs bosons

Figure 1 shows 5σ-discovery potential of CMS for the lighter scalar MSSM Higgs boson h with the most important discovery channels $h \rightarrow \gamma\gamma$ and $h \rightarrow \tau^+\tau^- \rightarrow \ell + \mathrm{jet}$ with 30 and 60 fb^{-1} of integrated luminosity [6]. Full detector simulation is used and systematic uncertainties are included for the background determinations. The results are shown in the the m_h^{max} scenario. In the parameter space outside the LEP reach the lighter scalar Higgs boson is largely SM-like and the discovery channels are closely the same as for the light SM Higgs boson. For the inclusive $h \rightarrow \gamma\gamma$ channel the gluon-gluon fusion is the dominant production process. The analysis is presented in detail is Ref. [6]. For the $h \rightarrow \tau^+\tau^-$ decay mode the prominent final state is the one with one hadronic τ decay (τ jet) and one lepton from the other τ. Production through the weak gauge boson fusion, $qq \rightarrow qqH$, has been assumed searching for energetic forward jets, which allow an efficient background suppression. To further suppress the $t\bar{t}$ background the central hadronic jets in rapidity between the two tagging jets are vetoed. In the decoupling region the m_A, tanβ-plane is covered with the $h \rightarrow \tau^+\tau^-$ channel while the region of small m_A is covered with the SM-like heavy scalar with the $H \rightarrow \tau^+\tau^-$ decay, also shown in Fig. 1. For 60 fb^{-1} only a small area around m_A = 140 GeV/c^2 is left uncovered by these two channels.

Figure 2 shows the 5σ-discovery potential for the heavy neutral MSSM Higgs bosons for 30 and 60 fb^{-1} [6].

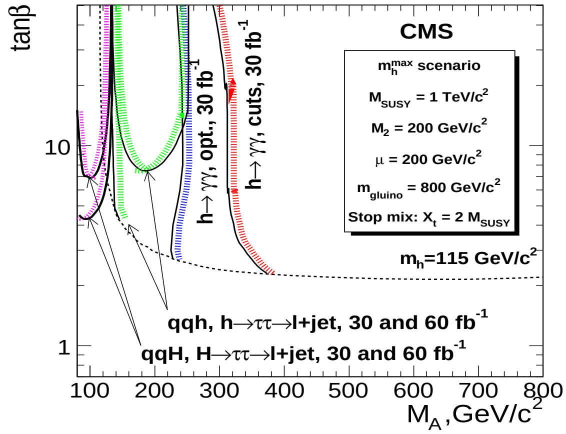

Figure 1: Discovery potential of CMS for the lighter scalar MSSM Higgs boson h with the $\mathrm{h} \to \gamma\gamma$ and $\mathrm{h} \to \tau^+\tau^- \to \ell + \mathrm{jet}$ channels for 30 and 60 fb^{-1}.

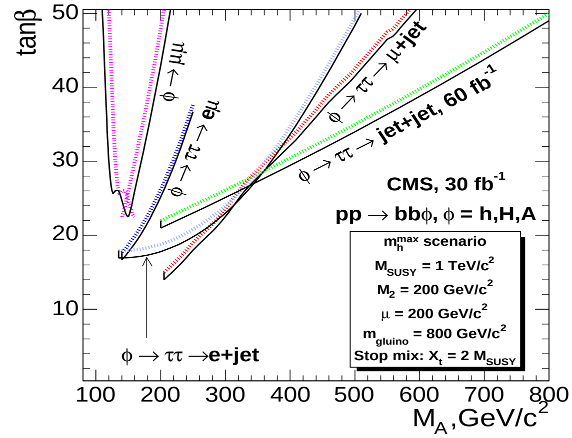

Figure 2: Discovery potential of CMS for the heavy neutral MSSM Higgs bosons H and A with the H/A $\to \mu^+\mu^-$ and H/A $\to \tau^+\tau^-$ decay channels for 30 and 60 fb^{-1}.

Full detector simulation is used and systematic uncertainties are included in the background determinations. At large tanβ, the coupling enhancement to down-type fermions can be exploited to search for the H and A bosons with the H/A $\to$ $\mu^+\mu^-$ and H/A $\to$ $\tau^+\tau^-$ decay channels in the associated production $\mathrm{gg} \to \mathrm{b\bar{b}H/A}$. In this production process, the tagging of the associated b jets suppresses efficiently the $\mathrm{Z}/\gamma^* \to \tau^+\tau^-$ and QCD multi-jet backgrounds. For the higher integrated luminosities several other discovery channels are open, like A $\to$ ZH $\to \ell\ell\mathrm{bb}$, H $\to \mathrm{hh} \to \mathrm{bb}\gamma\gamma$, H,A $\to \mathrm{t\bar{t}}$, H $\to$ ZZ$^* \to 4$ leptons at small tanβ, as is shown in Ref. [7] for the ATLAS experiment.

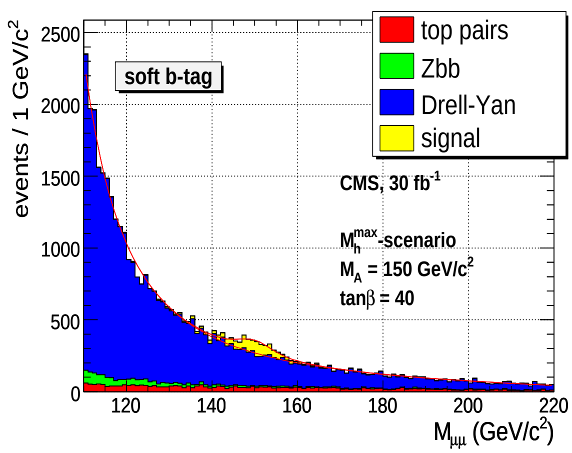

Figure 3: Invariant di-muon distribution for the H/A $\to$ $\mu^+\mu^-$ signal with $\mathrm{m_A}$ = 150 GeV/c^2 and tanβ = 40 and for the total background for 30 fb^{-1} in CMS.

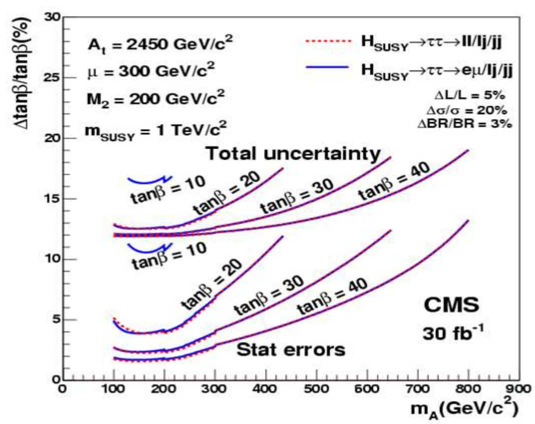

Figure 4: Expected precision of tanβ measurement from the event rates in the H/A $\to \tau^+\tau^-$ decay channels as a function of $\mathrm{m_A}$ and tanβ for 30 fb^{-1} in the CMS detector.

The branching fraction for the H/A $\to$ $\mu^+\mu^-$ decay mode is small ($\sim 10^{-4}$) but this channel leads to a clean final state and a good Higgs boson mass resolution. At large tanβ experimental mass resolution is comparable to the intrinsic Higgs boson width. Therefore the width measurement yields a constraint for the value of tanβ. For tanβ = 40, for instance, the uncertainty on the tanβ measurement is between 17 and 25% for $150 \leq \mathrm{m_A} \leq 200$ GeV/c^2, including the theoretical uncertainty in the production rate. Figure 3 shows the invariant mass distribution for the H/A $\rightarrow \mu^+\mu^-$ signal with tanβ = 40 and $\mathrm{m_A}$ = 150 GeV/c^2, and for the total background with 30 fb^{-1} integrated luminosity.

The H/A $\rightarrow \tau^+\tau^-$ decay channels can be searched for with the electron+jet, μ+jet, two-lepton and 2-jet final states. The fully hadronic H/A $\rightarrow \tau^+\tau^- \rightarrow$ 2 jet+X channel is particularly challenging experimentally due to the hadronic τ trigger and the need to suppress the very large hadronic multi-jet background [6]. The Higgs boson mass can be reconstructed in the H/A $\rightarrow \tau^+\tau^-$ decay channels with the collinear neutrino approximation exploiting the missing $\mathrm{E_T}$ measurement. Visible signals can be reached within the expected discovery range for the 2-jet, electron+jet and μ+jet final states.

Measurement of event rates in the H/A $\rightarrow \tau^+\tau^-$ decay channels can be used to determine the value of tanβ, exploiting the tan$^2\beta$ dependence of the production cross section. In the discovery region of large tanβ the branching fraction is only weakly dependent on the value of tanβ. Figure 4 shows the expected precision of tanβ measurement for 30 fb^{-1} with the H/A $\rightarrow \tau^+\tau^-$ decay modes combining the 2-jet, electron+jet, μ+jet and two-lepton final states in the CMS experiment. Uncertainties due to luminosity measurement and due to calculation of production cross sections and the H/A $\rightarrow \tau^+\tau^-$ branching fraction are included. Estimated uncertainties are below 20% in the expected discovery region (tan$\beta \gtrsim$ 10).

As Figs. 1 and 2 indicate, a significant fraction of the MSSM parameter space at small and medium tanβ values remains where only the lighter scalar Higgs boson can be discovered. The SM and MSSM may be still separated in this region up to the masses of $\mathrm{m_A} \sim$ 400 GeV/c^2 exploiting the coupling measurements. Figure 5 shows the regions of the MSSM parameter space, where the discrepancy between SM and the MSSM is larger than 3σ for three different integrated luminosities in the ATLAS detector [10]. The fits are based on the h measurements alone. The ratio of the hbb and h$\tau\tau$ couplings gives the highest sensitivity to these fits due to the slower decoupling behavior of the latter.

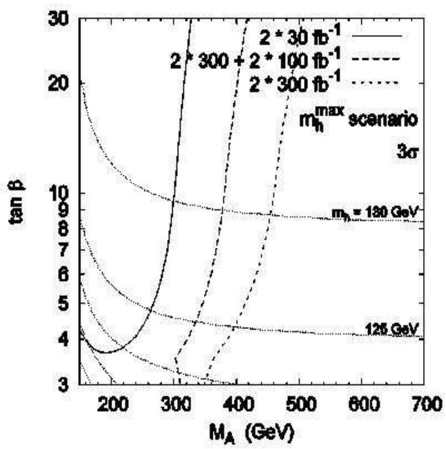

Figure 5: Regions of the MSSM parameter space, where the discrepancy between SM and the MSSM is larger than 3σ for three different integrated luminosities in the ATLAS detector.

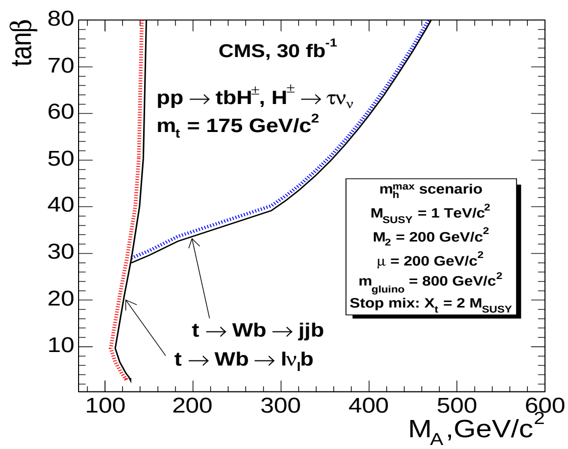

Figure 6: Discovery potential of CMS for the charged MSSM Higgs bosons $\mathrm{H^\pm}$ with the $\mathrm{H^\pm} \rightarrow \tau\nu_\tau$ decay mode for 30 fb^{-1}.

3 Searches for the charged MSSM Higgs bosons

Figure 6 shows 5σ-discovery potential of CMS [6] for the charged MSSM Higgs bosons with the $\mathrm{H^\pm} \rightarrow \tau\nu_\tau$ decay channel for 30 fb^{-1}. Full detector simulation is used and systematic uncertainties are included for the background determinations. In this decay channel with hadronic τ decays, the $\mathrm{t\bar{t}}$, Wt and W+3jet backgrounds with genuine τ's can be suppressed exploiting the opposite τ helicity correlations in the $\mathrm{H^\pm} \rightarrow \tau\nu_\tau$ and the $\mathrm{W^\pm} \rightarrow \tau\nu_\tau$ decays [11]. These correlations lead to a more energetic leading pion in the signal process from the $\tau \rightarrow \pi^\pm + \nu_\tau$ decay and from the longitudinal vector meson components of the decay channels through ρ and $\mathrm{a_1}$ mesons. The light charged Higgs bosons with $\mathrm{m_{H^\pm}} < \mathrm{m_{top}}$ are produced in the $\mathrm{t\bar{t}}$ events through the $\mathrm{t} \rightarrow \mathrm{bH^\pm}$ decay. The heavy charged Higgs bosons with $\mathrm{m_{H^\pm}} > \mathrm{m_{top}}$ are produced mainly in the associated production with top quarks in the processes $\mathrm{gb} \rightarrow \mathrm{tH}^{\pm}$ and $\mathrm{gg} \rightarrow \mathrm{tbH}^{\pm}$. In the intermediate region around $\mathrm{m_{H^\pm}} \sim \mathrm{m_{top}}$ both the production in the $\mathrm{t\bar{t}}$ events and the process $\mathrm{gg} \rightarrow \mathrm{tbH}^{\pm}$ can contribute. The light charged Higgs bosons ($\mathrm{m_{H^\pm}} < \mathrm{m_{top}}$) from the $\mathrm{t\bar{t}}$ event can be triggered with the lepton from the decays of one of the top quarks. The signal for $\mathrm{H}^{\pm} \rightarrow \tau\nu_\tau$ will be an excess of τ's in the $\mathrm{t\bar{t}}$ events relative to electrons and muons. To search for the heavy charged Higgs bosons events with hadronic top decays are selected. In these fully hadronic events the missing transverse energy originates mainly from the $\mathrm{H}^{\pm} \rightarrow \tau\nu_\tau$ decay, making possible the reconstruction of the transverse mass from the τ jet and the missing transverse energy with an endpoint at $\mathrm{m_{H^\pm}}$ for the signal and at $\mathrm{m_W}$ for the backgrounds with the $\mathrm{W}^{\pm} \rightarrow \tau\nu_\tau$ decay.

4 Conclusions

The most important discovery channels for the MSSM Higgs bosons at the LHC in the CMS and ATLAS experiments were discussed for low integrated luminosity of 30-60 fb^{-1}. For the searches of the lighter scalar Higgs boson the most prominent channels are the inclusive $\mathrm{h} \rightarrow \gamma\gamma$ production and the $\mathrm{h} \rightarrow \tau^+\tau^-$ decay channel in the weak gauge boson fusion $\mathrm{qq} \rightarrow \mathrm{qqh}$. For 60 fb^{-1} of integrated luminosity only a small area around $\mathrm{m_A} \sim 140$ GeV/c^2 is left uncovered.

The heavy neutral MSSM Higgs bosons can be found through the $\mathrm{H/A} \rightarrow \mu^+\mu^-$ and $\mathrm{H/A} \rightarrow \tau^+\tau^-$ decays channels at large tanβ ($\gtrsim$ 10). The discovery domain obtained with the two-lepton and lepton+jet final states from the $\mathrm{H/A} \rightarrow \tau^+\tau^-$ decay ($\mathrm{m_A} \lesssim$ 300 GeV/c^2) can be extended to larger mass values with the two-jet final states. The heavy scalar H can be discovered in the $\mathrm{H} \rightarrow \tau^+\tau^-$ decay channel also in the gauge boson fusion for $\mathrm{m_A} \lesssim$ 120 GeV/c^2. For the searches of the charged Higgs bosons the $\mathrm{H}^{\pm} \rightarrow \tau\nu_\tau$ decay channel with hadronic τ decays plays a crucial rule. For $\mathrm{m_{H^\pm}} < \mathrm{m_{top}}$ the reach is for $\mathrm{m_A} \lesssim$ 140 GeV/c^2 in the $\mathrm{t\bar{t}}$ events with leptonic decay of one of the top quarks. The heavy charged Higgs bosons can be found at large tanβ ($\gtrsim$ 30) with this decay channel in the associated production with top quarks in fully hadronic final states. The value of tanβ is expected to be measured with the precision of $\lesssim$ 20% from the event rates in the $\mathrm{H/A} \rightarrow \tau^+\tau^-$ decay channels. At large tanβ similar precision can be obtained for the tanβ determination from the direct width measurement in the $\mathrm{H/A} \rightarrow \mu^+\mu^-$ decay channel.

At the LHC a significant fraction of the parameter space at small and medium tanβ values remains where only the lighter scalar Higgs boson can be discovered. In part of this area ($\mathrm{m_A} \lesssim$ 400 GeV/c^2), however, the MSSM may be distinguished from the SM exploiting the coupling measurements.

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