Discovery Reach of Charged MSSM Higgs Bosons at CMS

S. Heinemeyer†, A. Nikitenko‡ and G. Weiglein‡

1 Instituto de Fisica de Cantabria (CSIC-UC), Santander, Spain
2 Imperial College, London, UK; on leave from ITEP, Moscow, Russia
3 IPPP, University of Durham, Durham DH1 3LE, UK

Abstract

We review the $5\sigma$ discovery contours for the charged MSSM Higgs boson at the CMS experiment with 30 fb$^{-1}$ for the two cases $M_{H^\pm} < m_t$ and $M_{H^\pm} > m_t$. In order to analyze the search reach we combine the latest results for the CMS experimental sensitivities based on full simulation studies with state-of-the-art theoretical predictions of MSSM Higgs-boson production and decay properties. Special emphasis is put on the SUSY parameter dependence of the $5\sigma$ contours. The variation of $\mu$ can shift the prospective discovery reach in $\tan\beta$ by up to $\Delta\tan\beta = 40$. 

* talk given at the SUSY 08, June 2008, Seoul, Korea
† email: Sven.Heinemeyer@cern.ch
‡ email: Alexandre.Nikitenko@cern.ch
§ email: Georg.Weiglein@durham.ac.uk
Discovery Reach of Charged MSSM Higgs Bosons at CMS

S. Heinemeyer*, A. Nikitenko† and G. Weiglein**

*Instituto de Fisica de Cantabria (CSIC-UC), Santander, Spain
†Imperial College, London, UK; on leave from ITEP, Moscow, Russia
**IPPP, University of Durham, Durham DH1 3LE, UK

Abstract. We review the 5σ discovery contours for the charged MSSM Higgs boson at the CMS experiment with 30 fb⁻¹ for the two cases \( M_{H^\pm} < m_t \) and \( M_{H^\pm} > m_t \). In order to analyze the search reach we combine the latest results for the CMS experimental sensitivities based on full simulation studies with state-of-the-art theoretical predictions of MSSM Higgs-boson production and decay properties. Special emphasis is put on the SUSY parameter dependence of the 5σ contours. The variation of \( \mu \) can shift the prospective discovery reach in \( \tan \beta \) by up to \( \Delta \tan \beta = 40 \).

INTRODUCTION

One of the main goals of the LHC is the identification of the mechanism of electroweak symmetry breaking. The most frequently investigated models are the Higgs mechanism within the Standard Model (SM) and within the Minimal Supersymmetric Standard Model (MSSM). Contrary to the case of the SM, in the MSSM two Higgs doublets are required. This results in five physical Higgs bosons: the light and heavy \( CP \)-even Higgs bosons, \( h \) and \( H \), the \( CP \)-odd Higgs boson, \( A \), and the charged Higgs bosons, \( H^\pm \). The Higgs sector of the MSSM can be specified at lowest order in terms of the gauge couplings, the ratio of the two Higgs vacuum expectation values, \( \tan \beta \equiv v_2/v_1 \), and the mass of the \( CP \)-even neutral and the charged Higgs bosons as well as their production and decay characteristics are dependent quantities that can be predicted in terms of the Higgs-sector parameters, e.g. \( M_{H^\pm} = M_A^2 + M_W^2 \), where \( M_W \) denotes the mass of the W boson. This tree-level results in the MSSM are strongly affected by higher-order corrections, in particular from the sector of the third generation quarks and squarks, so that the dependencies on various other MSSM parameters can be important, see e.g. Ref. [1] for reviews.

Here we review [2] the 5σ charged MSSM Higgs discovery contours at the LHC for the two cases \( M_{H^\pm} < m_t \) and \( M_{H^\pm} > m_t \) within the \( CP \)-conserving \( m^\text{max} \) scenario [3,4]. The results are displayed in the \( M_{H^\pm} - \tan \beta \) plane. The respective LHC analyses are given in Ref. [5] for ATLAS and in Refs. [6,7] for CMS. However, within these analyses the variation with relevant SUSY parameters as well as possibly relevant loop corrections in the Higgs production and decay [4] have been neglected. Earlier analyses can be found in Ref. [8].

ANALYSIS

The analysis of the variation with respect to the relevant SUSY parameters of the 5σ discovery contours of the charged Higgs boson has been performed in Ref. [2]. The results have been obtained by using the latest CMS analyses [6,7] (based on 30 fb⁻¹) derived in a model-independent approach, i.e. making no assumption on the Higgs boson production mechanism or decays. However, only SM backgrounds have been considered. These experimental results are combined with up-to-date theoretical predictions for charged Higgs production and decay in the MSSM, taking into account also the decay to SUSY particles that can in principle suppress the branching ratio of the charged Higgs boson decay to \( \tau \nu_\tau \).

The main production channels at the LHC are

\[
pp \to t\bar{t} + X, \quad t\bar{t} \to tH^\pm \bar{b} \quad \text{or} \quad H^\pm b\bar{t},
\]

\( (1) \)

\[
gb \to H^- t \quad \text{or} \quad gb \to H^+ \bar{t}.
\]

\( (2) \)

The decay used in the analysis to detect the charged Higgs boson is

\[
H^\pm \to \tau \nu_\tau \to \text{hadrons} \nu_\tau.
\]

\( (3) \)

The “light charged Higgs boson” is characterized by \( M_{H^\pm} < m_t \). The main production channel is given in eq. (1). Close to threshold also eq. (2) contributes. The relevant (i.e. detectable) decay channel is given by eq. (3). The experimental analysis is based on 30 fb⁻¹ collected with CMS. The events were required to be selected with the single lepton trigger, thus exploiting the \( W \to \ell \nu \) decay mode of a W boson from the decay of one of the top quarks in eq. (1). More details can be found in Refs. [6,7].

The “heavy charged Higgs boson” is characterized by \( M_{H^\pm} > m_t \). Here eq. (2) gives the largest contribution to the production cross section, and very close to threshold eq. (1) can contribute somewhat. The relevant decay
channel is again given in eq. \(3\). The experimental analysis is based on 30 fb\(^{-1}\) collected with CMS. The fully hadronic final state topology was considered, thus events were selected with the single \(\tau\) trigger at Level-1 and the combined \(\tau\)-E\(_{T}\)\(^{\text{miss}}\) High Level trigger. The backgrounds considered were \(t\bar{t}, W^\pm t, W^\pm + 3\) jets as well as QCD multi-jet background \(9, 10, 11\). The production cross sections for the \(t\bar{t}\) background processes were normalized to the NLO cross sections \(12\). More details can be found in Refs. \(7, 2\).

For the calculation of cross sections and branching ratios we use a combination of up-to-date theory evaluations. The interaction of the charged Higgs boson with the \(t\bar{b}\) doublet can be expressed in terms of an effective Lagrangian \(13\),

\[
\mathcal{L} = \frac{g}{2M_W} \frac{m_b}{1 + \Delta_b} \left[ \sqrt{2} V_{tb} \tan \beta \ H^+ \tau \bar{b} \right] + \text{h.c.} \tag{4}
\]

Here \(m_b\) denotes the running bottom quark mass including SM QCD corrections, \(\Delta_b = \mu \tan \beta\) depends on the scalar top and bottom masses, the gluino mass, the Higgs mixing parameter \(\mu\) and \(\tan \beta\). The explicit expression can be found in Refs. \(14, 4\).

For the production cross section in eq. \(1\), we use the SM cross section \(\sigma(pp \rightarrow t\bar{t}) = 840\) pb \(12\) times the BR\((t \rightarrow H^+ b)\) including the \(\Delta_b\) corrections described above. The production cross section in eq. \(2\) is evaluated as given in Ref. \(15\). In addition also the \(\Delta_b\) corrections of eq. \(4\) are applied. Finally the BR\((H^+ \rightarrow \tau \nu\tau\)) is evaluated taking into account all decay channels, among which the most relevant are \(H^+ \rightarrow tb, cs, W^{(*)}h\). Also possible decays to SUSY particles are considered. For the decay to \(tb\) again the \(\Delta_b\) corrections are included. All the numerical evaluations are performed with the program FeynHiggs \(16\), see also Ref. \(17\).

**RESULTS**

The numerical analysis has been performed \(2\) in the \(m_{h}^{\text{max}}\) scenario \(3, 4\) for \(\mu = -1000, 0, 200, +200, +1000\) GeV. In Fig. \(1\) we show the results for the variation of the 5 \(\sigma\) discovery contours for the light (left plot) and the heavy (right plot) charged Higgs boson, where the charged Higgs boson discovery will be possible in the areas above the curves shown in the figure. The top quark mass is set to \(m_t = 175\) GeV. The thick (thin) lines correspond to positive (negative) \(\mu\), and the solid (dotted) lines have \(|\mu| = 1000(200)\) GeV.

Concerning the light charged Higgs case, the curves stop at \(\tan \beta = 54\), where we stopped the evaluation of production cross section and branching ratios. For negative \(\mu\) very large values of \(\tan \beta\) result in a strong enhancement of the bottom Yukawa coupling, and for \(\Delta_b \rightarrow -1\) the MSSM enters a non-perturbative regime, see eq. \(4\). The search for the light charged Higgs boson covers the area of large \(\tan \beta\) and \(M_{H^\pm} \lesssim 130 \ldots 160\) GeV. The variation with \(\mu\) induces a strong shift in the 5 \(\sigma\) discovery contours. This corresponds to a shift in \(\tan \beta\) of \(\Delta \tan \beta = 15\) for \(M_{H^\pm} \lesssim 110\) GeV, rising up to \(\Delta \tan \beta = 40\) for larger \(M_{H^\pm}\) values. The discovery region is largest (smallest) for \(\mu = -(+)\)1000 GeV, corresponding to the largest (smallest) production cross section.

We now turn to the heavy charged Higgs case. For \(M_{H^\pm} = 170\) GeV, where the experimental analysis stops, we find a strong variation in the accessible parameter space for \(\mu = -(+)\)1000 GeV of \(\Delta \tan \beta = 40\). It should be noted in this context that close to threshold, where both production mechanisms, eqs. \(1\) and \(2\), contribute, the theoretical uncertainties are somewhat larger than in the other regions. For \(M_{H^\pm} = 300\) GeV the variation in the 5 \(\sigma\) discovery contours goes from \(\tan \beta = 38\) to \(\tan \beta = 54\). For \(\mu = -1000\) GeV and larger \(\tan \beta\) values the bottom Yukawa coupling becomes so large...
that a perturbative treatment would no longer be reliable in this region, and correspondingly we do not continue the respective curve(s). Detailed explanations about the shape of the $\mu = +1000$ GeV curve for $M_{h^\pm} \approx 300$ GeV can be found in Ref. [2].

In Fig. 2 we show the combined results for the 5σ discovery contours for the $m_h^{\text{max}}$ scenario in the $M_A$--$\tan\beta$ plane for $\mu = \pm 200 \pm 1000$ GeV in comparison with the results from the CMS PTDR [18] (see text), obtained for $\mu = +200$ GeV and neglecting the $\Delta_b$ effects [2].

**FIGURE 2.** Discovery reach for the charged Higgs boson of CMS with 30 fb$^{-1}$ in the $M_A$--$\tan\beta$ plane for the $m_h^{\text{max}}$ scenario for $\mu = \pm 200 \pm 1000$ GeV in comparison with the results from the CMS PTDR [18] (see text), obtained for $\mu = +200$ GeV and neglecting the $\Delta_b$ effects [2].

**REFERENCES**

1. S. Heinemeyer, W. Hollik and G. Weiglein, *Phys. Rept.* **425** (2006) 265; S. Heinemeyer, *Int. J. Mod. Phys.* **A 21** (2006) 2659; A. Djouadi, *Phys. Rept.* **459** (2008) 1.
2. M. Hashemi et al., arXiv:0804.1228 [hep-ph];
3. M. Carena et al., *Eur. Phys. J.* **C 26** (2003) 601.
4. M. Carena et al., *Eur. Phys. J.* **C 45** (2006) 797.
5. K. Assamagan, Y. Coadou and A. Deandrea, *Eur. Phys. J. direct C* **4** (2002) 9; K. Assamagan and N. Gollub, *Eur. Phys. J.* **C 39** (2005) 25.
6. M. Baarmand, M. Hashemi and A. Nikitenko, CMS Note 2006/056.
7. R. Kinnunen, CMS Note 2006/100.
8. J. Coarasa et al., *Eur. Phys. J.* **C 2** (1998) 373; A. Belyaev et al., *Phys. Rev.* **D 65** (2002) 031701; *JHEP* **0206** (2002) 059; K. Assamagan et al., arXiv:hep-ph/0402212; Czech. *J. Phys.* **55** (2005) B787.
9. W. Long and T. Stelzer, *Comput. Phys. Commun.* **81** (1994) 357; F. Maltoni and T. Stelzer, *JHEP* **0302** (2003) 027.
10. T. Sjostrand et al., *Comput. Phys. Commun.* **135** (2001) 238.
11. S. Slabospitsky and L. Sonnenschein, *Comput. Phys. Commun.* **148** (2002) 87.
12. P. Nason, S. Dawson and R. K. Ellis, *Nucl. Phys.* **B 303** (1988) 607; W. Beenakker et al., *Phys. Rev.* **D 40** (1989) 54; M. Beneke et al., arXiv:hep-ph/0003033, and references therein.
13. M. Carena et al., *Nucl. Phys.* **B 577** (2000) 577.
14. R. Hempfling, *Phys. Rev.* **D 49** (1994) 6168; L. Hall, R. Rattazzi and U. Sarid, *Phys. Rev.* **D 50** (1994) 7048; M. Carena et al., *Nucl. Phys.* **B 426** (1994) 269.
15. T. Plehn, *Phys. Rev.* **D 67** (2003) 014018; E. Berger et al., *Phys. Rev.* **D 71** (2005) 115012.
16. S. Heinemeyer, W. Hollik and G. Weiglein, *Comput. Phys. Commun.* **124** (2000) 76; *Eur. Phys. J.* **C 9** (1999) 343; G. Degrassi et al., *Eur. Phys. J.* **C 28** (2003) 133; M. Frank et al., *JHEP* **0702** (2007) 047; see: www.feynhiggs.de.
17. S. Heinemeyer et al., *Phys. Lett.* **B 652** (2007) 300.
18. CMS Collaboration, *Physics Technical Design Report, Volume 2. CERN/LHCC 2006-021*.
19. O. Buchmueller et al., arXiv:0808.4212 [hep-ph]; S. Heinemeyer, M. Mondragón and G. Zoupanos, *JHEP* **0807** (2008) 135; arXiv:0809.2397 [hep-ph]; S. Heinemeyer, arXiv:0809.2395 [hep-ph].