ATLAS Search for the MSSM Charged Higgs Boson

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Abstract. The discovery of a charged Higgs boson would be definitive evidence of new physics beyond the Standard Model. The discovery potential of a MSSM charged Higgs boson with the ATLAS detector at the Large Hadron Collider is presented. The study is based on the analysis of signal and background simulated in detail through the experimental apparatus.

Keywords: ATLAS, MSSM, Charged Higgs Boson
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INTRODUCTION

The ATLAS detector was built to analyze collisions produced by the Large Hadron Collider (LHC), a proton-proton collider with a nominal center-of-mass energy √s = 14 TeV. ATLAS and the LHC provide an unprecedented opportunity to search for new physics.

In the Standard Model (SM) of particle physics, the Higgs mechanism is considered to be the agent of electroweak symmetry breaking. The SM contains a single Higgs doublet, which produces a single neutral scalar Higgs particle. In more complicated models more doublets produce a richer phenomenology which includes charged scalar Higgs particles H± as well as neutral ones. The Minimal Supersymmetric Model (MSSM) is one such model.

In the MSSM, the H± can be produced by several mechanisms with production cross sections depending on the H± mass mH± and tanβ, the ratio of Higgs doublet vacuum expectation values. For the light H± (mH± < mtop), the dominant production mechanism is through top quark decay t → bH± in t¯t events. For the heavy H± (mH± > mtop) the dominant production mechanisms are gg → tH± and g¯b → tH±. The MSSM production cross sections for these processes (Fig. 1) have been calculated in the so-called mH±-max scenario [1] and are shown in Fig. 2. For the light H± with only one top quark decaying via t → bH±, the cross section is

$$\sigma = 2\sigma_t \times BR(t \to bH^+) \times (1 - BR(t \to bH^+)),$$

where $\sigma_t$ is the t¯t production cross section. The branching ratio $BR(t \to bH^+)$ is calculated in the mH±-max scenario using FeynHiggs 2.6.2 [2]. For the heavy H±, the cross section has been calculated with private computer code obtained from the authors of Ref. [3]. We use these cross sections and branching ratios to predict the signal counts at ATLAS.

The ATLAS acceptance and signal selection efficiencies were determined with signal simulation samples generated by Pythia [4] with Tauola [5] for τ decay and Photos [6] for final-state radiation. For the heavy H±, Matchig [7] was used as an external process to Pythia to remove double-counted events originating in the breakdown of the parton shower description at high transverse momentum of the final state b quark. The samples were then passed through a detailed simulation of the ATLAS detector. Ten masses were simulated: mH± = 90, 110, 120, 130, 150, 170, 200, 250, 400 and 600 GeV. The background processes studied include QCD dijets, W+jets, t¯t and single top production. Details of the following analyses are given in Ref. [8].

LIGHT CHARGED HIGGS BOSON

For the light H±, the decay $H^\pm \to \tau^\pm \nu$ dominates all others in the MSSM for most regions of parameter space. The final states of events $t\bar{t} \to 2bW^- H^+ (\to \tau^\pm \nu)$ contain up to two leptons $\ell = e, \mu$ depending on the $W^-$ and $\tau^\pm$ decays. We denote by $W_{\ell \nu}$ the decays to leptons $\ell = e, \mu$ and by $W_{\text{had}}$ the decays to hadrons. We investigated the following final states: $2bW_{\text{had}} W_{\text{had}}$.

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1 Charge conjugate states are implicitly included throughout this paper.
FIGURE 2. LHC production cross sections versus $\tan \beta$ for the light and heavy $H^+$ for a variety of $m_{H^+}$. The $m_0$-max scenario of the MSSM is assumed.

$2bW_{\text{had}}\tau_{\text{lep}}$ and $2bW_{\text{lep}}\tau_{\text{had}}$.

The $2bW_{\text{had}}\tau_{\text{had}}$ analysis expects to trigger on $E_T^{miss} > 50$ GeV and a $\tau$-jet with $E_T > 30$ GeV. It requires exactly one $\tau$-jet with $E_T > 25$ GeV, exactly two $b$-tagged jets with $E_T > 15$ GeV, at least two jets with $E_T > 15$ GeV which have not been $b$-tagged, zero isolated leptons $\ell = e, \mu$ with $E_T > 5$ GeV, $E_T^{miss} > 30$ GeV, the reconstructed $W$ boson satisfies $|m_W^{rec} - m_W| < 30$ GeV, $|m_{\text{top}}^{rec} - m_{\text{top}}| < 40$ GeV, $\Delta \phi (t_{\text{hard}}^{rec}, t_{\text{soft}}^{rec}) > 2.5$, and $E_T (t_{\text{hard}}^{rec})/E_T (t_{\text{soft}}^{rec}) < 2$ ($t_{\text{hard}}^{rec}$ indicates the reconstructed top quark with highest $E_T$ and $t_{\text{soft}}^{rec}$ indicates the reconstructed top quark with lowest $E_T$). Finally, a likelihood is constructed which exploits differences between signal and background in the reconstructed $H^+$ mass and $\tau$ polarization. Lower bounds are placed on the likelihood and the transverse mass of the reconstructed $H^+$.

The $2bW_{\text{lep}}\tau_{\text{had}}$ analysis triggers on $E_T^{miss} > 30$ GeV and one $\ell = e, \mu$ with $E_T > 22$ GeV ($e$) or $E_T > 20$ GeV ($\mu$). It requires exactly one isolated lepton $\ell = e, \mu$ with $E_T > 5$ GeV, $E_T^{miss} > 120$ GeV, at least four jets with $E_T > 40$ GeV and pseudorapidity $|\eta| < 2.5$, and that exactly two of the four leading jets are $b$-tagged. The $W$ boson is reconstructed from two jets which have not been $b$-tagged and the $b$-jets are assigned to either the hadronic reconstructed $W$ or the lepton $\ell$ based on a likelihood with input variables: $m_W^{rec}$, reconstructed $b$-jet charge and angles between $b$-jets, the lepton $\ell$ and the reconstructed $W$. A top quark is reconstructed with the reconstructed $W$ boson and the $b$-jet with the appropriate charge and is required to satisfy $100 < m_{\text{top}}^{rec} < 300$ GeV. After $b$-jet assignment, the requirement $\cos \psi < -0.8$ is imposed, where $\psi$ is the angle between the lepton and its parent top quark in the $W$ boson rest frame.

The $2bW_{\text{lep}}\tau_{\text{had}}$ analysis triggers on $E_T^{miss} > 30$ GeV and one $\ell = e, \mu$ with $E_T > 22$ GeV ($e$) or $E_T > 20$ GeV ($\mu$), or $E_T^{miss} > 50$ GeV and a $\tau$-jet with $E_T > 30$ GeV. It requires at least one isolated lepton $\ell = e, \mu$ with $E_T > 25$ GeV ($e$ trigger or $e$ and $\mu$ trigger) or $E_T > 20$ GeV ($\mu$ trigger only) and pseudorapidity $|\eta| < 2.5$ ($e$) or $|\eta| < 2.7$ ($\mu$), at least three jets with $E_T > 20$ GeV, at least one $\tau$-jet with $E_T > 40$ GeV, at least one $b$-tagged jet with $E_T > 20$ GeV, the $\tau$-jet and the lepton $\ell = e, \mu$ have opposite charge, and $E_T^{miss} > 175$ GeV.

HEAVY CHARGED HIGGS BOSON

For most regions of the MSSM parameter space, the dominant heavy $H^+$ decays are $H^+ \rightarrow t\bar{b}$ and $H^+ \rightarrow \tau^+\nu$. In gg fusion, the former proceeds via $gg \rightarrow 4bW^+W^-$ while the latter proceeds via $gg \rightarrow 2bW^+\tau^+$. We investigated the following final states: $2bW_{\text{had}}\tau_{\text{had}}$ and $4bW_{\text{lep}}W_{\text{had}}$. The latter final state includes the case in which the $W$ boson originating from the $H^+$ top quark daughter decays leptonically and the case in which it decays hadronically.

The $bW_{\text{had}}\tau_{\text{had}}$ analysis employs a trigger signature which requires $E_T^{miss} > 50$ GeV and an isolated $\tau$-jet with $E_T > 45$ GeV. It requires exactly one $\tau$-jet with $E_T > 50$ GeV, $E_T^{miss} > 40$ GeV, at least three additional jets with $E_T > 15$ GeV one of which is $b$-tagged, zero isolated leptons $\ell = e, \mu$ with $E_T > 7$ GeV and a reconstructed top quark and $W$ boson with

$$\chi^2 = \frac{(m_W^{rec} - m_W)^2}{\sigma_m^2} + \frac{(m_{\text{top}}^{rec} - m_{\text{top}})^2}{\sigma_m^2} < 3 \quad (2)$$

where $\sigma_m = 10$ GeV and $\sigma_{m_{\text{top}}} = 15$ GeV. A likelihood is constructed with the $\tau$-jet $E_T$, $E_T^{miss}$, the azimuthal angle between the $\tau$-jet and $E_T^{miss}$, the scalar sum of all jet $E_T$, and the ratio of the $\tau$-jet $E_T$ to the leading $E_T$ of the jets not used in the top quark reconstruction. A lower bound is then placed on the likelihood output and the transverse mass of the reconstructed $H^+$.

The $4bW_{\text{lep}}W_{\text{had}}$ analysis triggers on $E_T^{miss} > 30$ GeV and one $\ell = e, \mu$ with $E_T > 22$ GeV ($e$) or $E_T > 20$ GeV ($\mu$). The analysis requires exactly one isolated lepton $\ell = e, \mu$ with $E_T > 25$ GeV ($e$) or $E_T > 20$ GeV ($\mu$),

| Process              | $H^+$ Signal [fb] | Background [fb] |
|----------------------|-------------------|-----------------|
| $tf \rightarrow 2bW_{\text{had}}\tau_{\text{had}}$ | 35                | 31              |
| $tf \rightarrow 2bW_{\text{had}}\tau_{\text{lep}}$ | 37                | 144             |
| $tf \rightarrow 2bW_{\text{lep}}\tau_{\text{had}}$ | 30                | 78              |
| $gg \rightarrow 2bW_{\text{had}}\tau_{\text{had}}$ | 1.4               | 2.0             |
| $gg \rightarrow 4bW_{\text{lep}}W_{\text{had}}$   | 0.9               | 19.2            |
at least five jets with $E_T > 20$ GeV and pseudorapidity $|\eta| < 5$ and at least four of the jets $b$-tagged with $|\eta| < 2.5$. The $W$ boson which decays via $W \to \ell \nu$ is reconstructed using the lepton $\ell$, $E_T^{miss}$ and the $W$ boson mass constraint. The four $b$-tagged jets are assigned to their parent particles using a likelihood which uses the invariant masses and $\Delta R \equiv \sqrt{\Delta \eta^2 + \Delta \phi^2}$ of the reconstructed objects, as well as the $E_T$ of the $b$-tagged jet associated to the $H^\pm$. For each possible assignment of the $b$-tagged jets, the assignment with the highest likelihood is chosen and the event is vetoed if the likelihood falls below a lower bound. A second likelihood is constructed for suppressing background which uses the following variables: pseudorapidity $\eta$ of the $b$-tagged jet associated to the $H^\pm$ decay, the sum of the weights of the $b$-tagged jets associated to the top quark and $H^\pm$ decay, the mean of the combinatorial likelihood outputs, the $\Delta R$ between the $b$-tagged jet associated to the $H^\pm$ decay and the system of the two top quarks associated to the top quark decays and the ratio of the $E_T$ of the $b$-tagged jets not associated to top quark decay. A lower bound is placed on this likelihood.

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**REFERENCES**

1. M. Carena, S. Heinemeyer, C.E.M. Wagner, G. Weiglein, Eur. Phys. J. C45 (2006) 797-814.
2. J. Ellis, S. Heinemeyer, K.A. Olive, A.M. Weber, G. Weiglein, J. High Energy Phys. 02 (2007) 047.
3. E. Boos and T. Plehn, Phys. Rev. D 69 (2004) 094005.
4. T. Sjostrand, S. Mrenna, P. Skands, JHEP 05 (2006) 026.
5. S. Jadach, J.H. Kuhn, Z. Was, Comput. Phys. Commun.79 (1990) 275.
6. E. Barberio, Z. Was, Phys. Commun. 79 (1994) 291.
7. J. Alwall, hep-ph/0503124 (2005).
8. ATLAS Collaboration, CERN-OPEN-2008-020 (to appear)