Beyond the Standard Model Higgs Searches at ATLAS

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Abstract. The discovery of a neutral Higgs boson with large decay branching fraction to tau and muon pairs final states, as well as the discovery of a charged Higgs boson would represent a strong evidence of New Physics beyond the Standard Model. The potential discovery of these processes with the ATLAS detector at the Large Hadron Collider is presented. The studies are based on the analysis of Monte Carlo signal and background data simulated in detail through the experimental apparatus.

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INTRODUCTION

Among the many competing beyond-the-standard-model theories, one of the most popular is supersymmetry. The so-called Minimal Supersymmetric Standard Model (MSSM) is the simplest manifestation of supersymmetry, and will be the focus of the initial beyond-the-standard-model Higgs boson searches at ATLAS. This paper will provide a brief review of the search techniques being developed for use at ATLAS to look for such a particle, as well as a summary of the expected sensitivity.

The MSSM provides rich phenomenology for Higgs searches. It predicts two Higgs doublets, resulting in five physical Higgs particles: three neutral (h, H, and A), and two charged (H^+ and H^-). The exact properties of the Higgs bosons depend on the true MSSM parameters. The sensitivity studies described herein are performed within the so-called m_h-max scenario, summarized in Table 1. The MSSM Higgs sector has two degrees of freedom, usually chosen to be $\tan\beta$ (the ratio of the vacuum expectation values of the two Higgs doublets) and the mass of one of the Higgs bosons (m_A or $m_{H^\pm}$).

TABLE 1. The parameters of the m_h-max scenario.

Parameter	Value
m_t	170 GeV
M_{SUSY}	1000 GeV
μ	200 GeV
M_2	200 GeV
M_3	800 GeV
X_t	2000 GeV
A_t	$X_t + \frac{\mu}{tan\beta}$

This paper is primarily concerned with studies performed at a centre-of-mass energy of 14 TeV outlined in [1]. There are several other analysis techniques that were not fully investigated before the SUSY09 conference, which should improve upon the results shown here.

NEUTRAL HIGGS BOSON

There are three neutral Higgs bosons, two CP-even (h and H), and one CP-odd (A). The h boson is the lightest, with the upper theoretical mass limit of $M_h^{max} \approx 130$ GeV. For $m_A \geq M_h^{max}$, the h boson has similar properties of the standard model Higgs boson, while the heavier H and A bosons have nearly degenerate masses. We sum the cross sections of the H and A bosons when determining our sensitivity to them.

There are two neutral Higgs boson decay channels that were investigated as of the SUSY09 conference. $\Phi \rightarrow \tau^+\tau^- \rightarrow \ell^+\ell^- 4\nu$ with associated b-jets, and inclusive $\Phi \rightarrow \mu^+\mu^-$, where Φ is one of the neutral Higgs bosons.

The $\Phi \rightarrow \tau^+\tau^- \rightarrow \ell^+\ell^- 4\nu$ with associated b-jets channel is the more sensitive of the two channels presented. The primary backgrounds to this decay include $Z \rightarrow \tau\tau$, $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ processes. Additionally, for $m_A \geq 200$ GeV, $t\bar{t}$ also is an important background, which can be reduced somewhat by requiring $N_{jets} \leq 2$. While the $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ events are well suppressed due to low missing transverse energy, the $Z \rightarrow \tau\tau$ is an irreducible background which becomes dominant for m_A <200 GeV. To estimate its shape in a data driven way, $Z \rightarrow \ell^+\ell^-$ events in a sideband region are selected, then their momentum is scaled to correspond to the leptons from the $Z \rightarrow \tau\tau$ decays.

Our sensitivity to the $\Phi \rightarrow \tau^+\tau^- \rightarrow \ell^+\ell^- 4\nu$ channel is shown in Figure 1. The 5-σ discovery and 95% CL exclusion regions are shown as a function of tanβ and m_A at 30 fb^{-1}. Both curves on the plot take into account the statistical and detector-related systematic uncertainties. The lower curve assumes additional 10% uncertainty on the data-driven measurement of the $t\bar{t}$ contribution. A good sensitivity is reached for high tanβ and low m_A values.

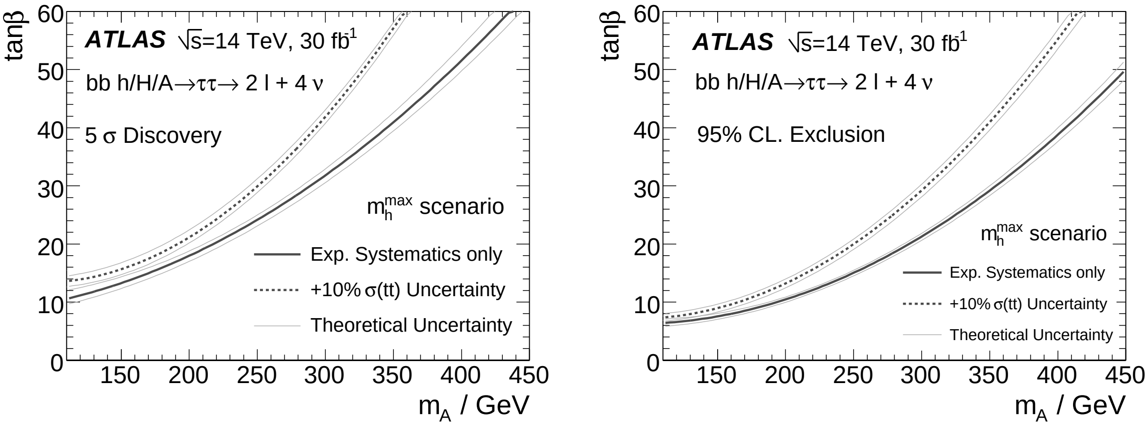

FIGURE 1. $\Phi \rightarrow \tau^+\tau^- \rightarrow \ell^+\ell^- 4\nu$ discovery potential and 95% confidence level exclusion after 30 fb^{-1}.

The $\Phi \rightarrow \mu^+\mu^-$ channel has an approximately 300 times smaller branching ratio than the $\tau\tau$ channel. However, it is a cleaner signal, and it provides better mass resolution of 3% compared with 20% for the $\tau\tau$ channel. The channel's primary backgrounds are $t\bar{t}$ and $Z \rightarrow \mu\mu$. Two separate analyses are performed. One requires no b-jets in the final state, which suppresses the $t\bar{t}$ background, but leaves a rather large Z background contribution. The other requires at least 1 b-jet, where further cuts are applied to reduce the $t\bar{t}$ background.

The sensitivity determined for the $\mu\mu$ channel is shown in Figure 2, plotted for both $10 fb^{-1}$ and $30 fb^{-1}$. The channel has a smaller coverage of the tanβ / m_A plane than the $\tau\tau$ channel. At $30 fb^{-1}$, the lowest tanβ value covered by the 5-σ discovery region is 20 as opposed to 10. The experimental systematic uncertainties due to the jet energy scale and b-tagging efficiency are reduced down to 1-3% by means of the signal-free e^+e^- control samples and further background control with side-band fits.

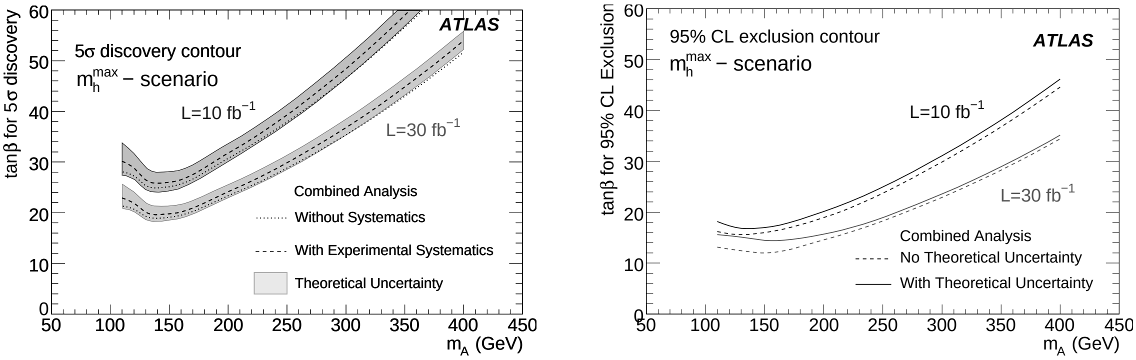

FIGURE 2. $\Phi \rightarrow \mu^+\mu^-$ discovery potential and 95% confidence level exclusion after 30 fb^{-1}.

CHARGED HIGGS BOSON

The search strategies appropriate for the charged Higgs boson depend greatly on the value of m_{H^+} relative to the mass of the top quark. For a light $H^\pm$, with a mass below m_{top}, the primary production mode is through top quark decays in the $t\bar{t}$ process, and the primary decay mode through $H^\pm \rightarrow \tau\nu$. For a heavy $H^\pm$ with a mass above the top quark mass, production takes place primarily through gluon-bottom fusion ($gb \rightarrow tH^\pm$), and the dominant decay mode is $H^\pm \rightarrow tb$.

There are several backgrounds common to all of the $H^\pm$ channels, including single top, QCD dijet, W + jets, and $t\bar{t}$, $t\bar{t}$ being the primary background for all explored channels. To estimate it, a data driven technique using control samples of $t\bar{t} \rightarrow WbWb \rightarrow \mu\nu b\mu\nu b$ / $\mu\nu bqqb$ has been devised. In the control samples the μ's are replaced with τ's, scaling the 4-momenta to correct for the mass difference between the two particles. The decay of these τ's is then simulated to give the background estimate.

There have been studies for three primary production channels for a light $H^\pm$: (1) $t\bar{t} \rightarrow bH^\pm bW \rightarrow b\nu\tau(had)bqq$, (2) $t\bar{t} \rightarrow bH^\pm bW \rightarrow b\nu\tau(lep)bqq$, and (3) $t\bar{t} \rightarrow bH^\pm bW \rightarrow b\nu\tau(had)bl\nu$. The first mode is challenging because it contains no leptons in the final state for triggering, and the high hadronic activity complicates the signal with many jets.

Still, due to its comparatively high cross section, it contributes more to the $H^{\pm}$ combined sensitivity than the other two channels.

For a heavy charged Higgs boson, there are two production methods: $gg \rightarrow H^{\pm}tb$ and the dominant $gb \rightarrow H^{\pm}t$. We have investigated two decay channels: (1) $H^{\pm}t \rightarrow \nu\tau(had)bqq$ and (2) $H^{\pm}t \rightarrow tbt \rightarrow bWbbW \rightarrow bqqbbl\nu$. The second channel proves to be relatively difficult, largely due to the complicated jet combinatorics required. A multivariate likelihood analysis is used to help alleviate this. Nevertheless the first channel provides a cleaner signal and provides the most sensitivity of the two.

Figure 3 shows the combined $H^{\pm}$ sensitivity from all the listed channels for 1, 10, and 30 fb^{-1}. As for the neutral Higgs boson, sensitivity is good for high tanβ and low $m_{H^{+}}$. However, sensitivity is limited for intermediate tanβ values, an issue worsened in Fig. 3 by low Monte Carlo statistics. There is ongoing effort to improve sensitivity in this region, $H^{\pm} \rightarrow \tilde{\chi}^{\pm}\tilde{\chi}^{0} \rightarrow 3$ lep + $E_{\mathrm{T}}^{\mathrm{miss}}$ being a promising example [3].

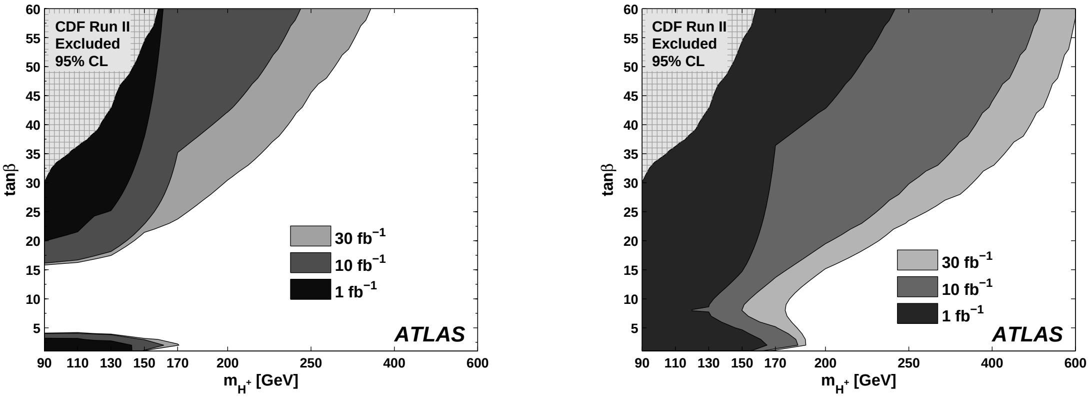

FIGURE 3. Charged Higgs combined discovery potential and 95% confidence level exclusion after 30 fb^{-1} for the m_h-max scenario.

CONCLUSION

The ATLAS detector [2] has demonstrated its sensitivity to both neutral and charged varieties of MSSM Higgs bosons. For high tanβ and low Higgs boson masses, it has good discovering power. There are several analyses still being developed which should increase ATLAS's sensitivity further, hopefully illuminating the uncovered regions of parameter space.

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