PROCEEDINGS OF SCIENCE

Search for non-Standard-Model Higgs at the LHC with ATLAS

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The discovery prospects of non-Standard Model Higgs bosons with the ATLAS detector are presented. Due to the high branching ratio, results on decay channels that include tau leptons are presented both for the search of the neutral and the charged MSSM Higgs bosons. For the neutral Higgs bosons, results on the muon pair final state are also reported. Furthermore, decay scenarios that include SUSY particle cascades are investigated. Finally, in the absence of light Higgs bosons, processes of vector boson scattering at high mass are discussed, in the context of studying the mechanism of electroweak symmetry breaking. All the studies presented are based on the analysis of Monte Carlo signal and background data simulated in detail through the experimental apparatus.

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1. Introduction

In the Standard Model (SM), the electroweak symmetry breaking (EWSB) is provided by the Higgs mechanism and the corresponding Higgs boson. Beyond the SM, Higgs searches are mostly concentrated in the context of the Minimal Supersymmetric Standard Model (MSSM). In this model two Higgs doublets are required to describe the EWSB, leading to three neutral (CP-even h, H and CP-odd A) and two charged (H^+ and H^-) physical Higgs bosons. The search for these bosons is predominantly performed through their decays to SM particles [1], but supersymmetric decay channels are also investigated [2]. Results for the first case are presented in the context of the m_h^{max} scenario [3] of the MSSM, while different MSSM (or mSUGRA) assumptions are used in the second case. In the absence of light Higgs bosons, an alternative scenario to the SM and Supersymmetry must be invoked. In such a case, new physics may appear in the regime of high-mass vector boson scattering [1].

All studies are performed on MC events at $\sqrt{s}$=14 TeV, simulated in detail through the experimental apparatus. Strategies for the background estimation from real data are outlined. Details on the performance of the ATLAS detector can be found at [1] and [4]. In the following, all sections are based on material from reference [1], except section 4, which is based on reference [2].

2. Search for the Neutral MSSM Higgs Bosons

The neutral MSSM Higgs bosons are mainly produced via gluon fusion ($gg \rightarrow h/H/A$) and in associated production with b-quarks ($gg \rightarrow b\bar{b}h/H/A$), which is dominant at high tanβ values. In the latter case the tagging of at least one b-jet can be used to reduce the background. The large multi-jet production in the LHC environment makes the decay channel to a $b\bar{b}$ pair extremely challenging. Therefore the search is performed either in the $\tau^+\tau^-$ final state, which has the second higher branching fraction, or in the $\mu^+\mu^-$ final state, which, despite its small branching ratio, benefits from the excellent dimuon mass resolution of the ATLAS detector.

Search for $h/H/A \rightarrow \tau^+\tau^- \rightarrow 2l+4\nu$

The signature of the signal in this channel consists of two oppositely charged leptons, accompanied by missing tranverse energy E_T^{miss} due to the presence of the neutrinos. Leptons are selected with the requirement of tranverse momentum $p_T > 10$ GeV and pseudorapidity $|\eta| < 2.5$. The events are triggered with single or double high p_T lepton triggers. The main backgrounds consist of $Z \rightarrow \tau^+\tau^-$(+jets), $Z \rightarrow l^+l^-$ (+jets), $t\bar{t}$ and W +jets. The requirement of at least one tagged b-jet suppresses the Drell-Yan background, while $t\bar{t}$ is reduced by requiring less than three jets in the event. Further cuts on kinematic variables have been optimized for the ee, $\mu\mu$, and for the mixed $e\mu$ final states depending on the signal mass hypothesis. The collinear approximation [5] has been used for the estimation of the mass of the τ pair, resulting in a mass resolution between 20% and 30% depending on the mass of the Higgs boson. Corresponding mass windows have been applied to measure the excess of the signal events over background.

The signal production cross-section is estimated assuming a theoretical uncertainty of 10-20%, originating from the b parton density function and the renormalization and factorization scales. Jet energy scale, jet resolution and b-tagging efficiency are the major sources of experimental systematic uncertainties, leading to an additional signal selection uncertainty of 5-10% and 5% on the $t\bar{t}$

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background. Theoretical and experimental background uncertainty can be reduced using dedicated signal-free control data samples. The $Z \to \tau^+\tau^-$ background, dominant for lower Higgs masses, is estimated with an accuracy of 3% by replacing the leptons in $Z \to e^+e^-, \mu^+\mu^-$ events with simulated τ decays. An uncertainty of 10% is assigned on the cross section of the $t\bar{t}$ background, which becomes more important for higher masses. The discovery potential, as well as the 95% CL exclusion limit contours in the plane m_A-tanβ at an integrated luminosity of 30 fb^{-1} are shown in Figure 1.

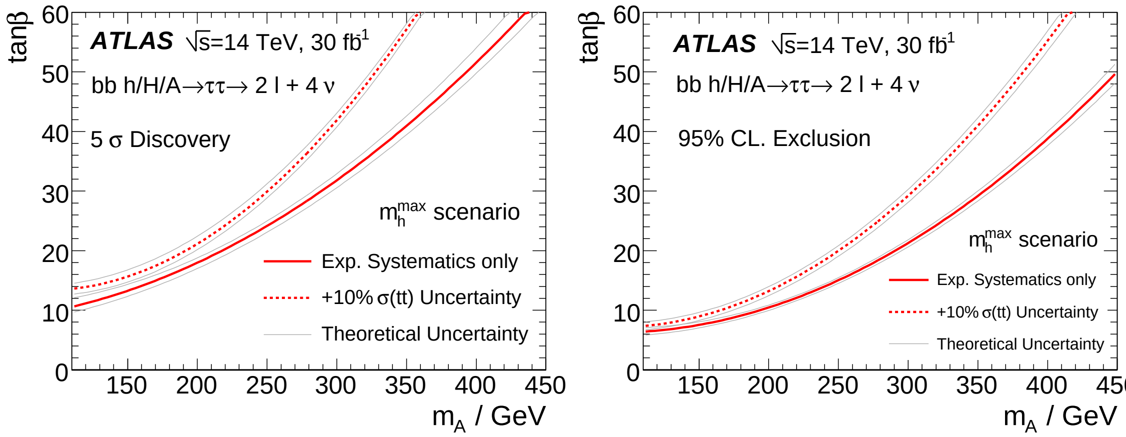

Figure 1: $h/H/A \to \tau^+\tau^- \to 2l + 4\nu$: 5σ discovery (left) and 95% CL exclusion (right)

Search for $h/H/A \to \mu^+\mu^-$

The signature of the signal consists of two high p_T, opposite charged, isolated muons. Their selection requires $p_T > 20$ GeV and $|\eta| < 2.7$). No E_T^{miss} should be present in this case, therefore events are selected if $E_T^{miss} < 40$ GeV. A single high p_T muon trigger is very efficient to trigger these events. The reconstructed dimuon mass has an excellent resolution of 3%. The main backgrounds for this process are $Z \to \mu^+\mu^-$ (+jets) and $t\bar{t}$. The Z background can be suppressed by requiring one or more b-jets, while the $t\bar{t}$ background is suppressed by requiring a b-veto. The analysis has therefore been split to follow both strategies. The major backgrounds in the b-tagged case is the irreducible Z +b-jets, as well as the mistagged Z+light jets and $t\bar{t}$, the latter being dominant at high masses. Therefore, further cuts on the dimuon azimuthal angle and on the scalar sum of the p_T of all jets are imposed to reduce it. The irreducible Z background is dominant in the b-vetoed analysis. Finally, a mass window cut $\Delta m = m_A \pm 2\sigma$ has been applied on both analyses.

The theoretical uncertainty on the signal production is the same as in the case of the $\tau^+\tau^-$ decay channel. The dominant experimental systematic uncertainties originating from the measurement of the jet energy scale and the b-tagging efficiency have a 5% impact on the signal and 10-15% on the background selection. The background uncertainty is significantly reduced once the side-bands of the dimuon mass distribution and additional data control samples are taken into account, such as e^+e^- and $e\mu$ final states. A background estimation uncertainty of about 2% can be achieved at an integrated luminosity of 30 fb^{-1}. Figure 2 shows the obtained combined discovery potential and the 95% CL exclusion limit contours.

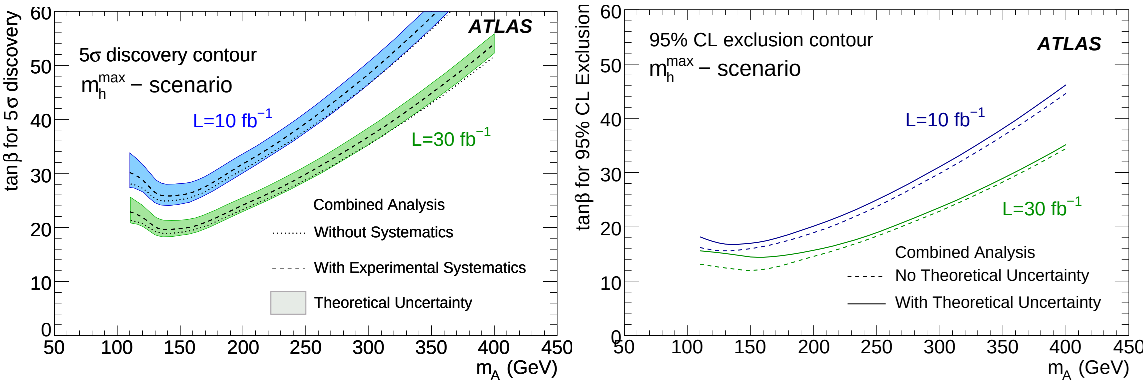

Figure 2: $h/H/A \to \mu^+\mu^-$: 5σ discovery (left) and 95% CL exclusion (right).

3. Search for the Charged MSSM Higgs Bosons

At tree level, the relative importance of the different production and decay modes of the charged MSSM Higgs bosons are defined by the Higgs boson mass $m_{H^\pm}$ and the tanβ value. A light $H^\pm$ boson ($m_{H^\pm} < m_{top}$) is predominantly produced through the top quark decays $t \to bH^+$ in $t\bar{t}$ events, with an almost exclusive subsequent Higgs decay $H^\pm \to \tau^\pm\nu_\tau$. For a heavy $H^\pm$ boson ($m_{H^\pm} > m_{top}$) the dominant production processes are $gg \to \bar{t}bH^+$ and $gb \to \bar{t}H^+$. The dominant decay channel is $H^+ \to t\bar{b}$, but in particular for large tanβ values, the decay $H^\pm \to \tau^\pm\nu_\tau$ is also sizeable and is shown to provide higher sensitivity. The charged Higgs searches are, therefore, divided into different event topologies depending on the decay modes of the involved τ leptons and the W bosons. The dominant background in all topologies are the $t\bar{t}$ events. Additional contributions from the single-top, W +jets and QCD multi-jet events have been taken into account.

For the **light charged Higgs** boson search, three signatures are considered:

$bH^\pm bW \to$ **(I)** $b\nu_\tau\tau(had)bqq$, **(II)** $b\nu_\tau\tau(lep)bqq$ and **(III)** $b\nu_\tau\tau(had)bl\nu$

Lepton or τ triggers combined with E_T^{miss} trigger, or a high E_T^{miss} trigger are used for triggering the corresponding topologies. The exact final state objects are required for each case and kinematic criteria are imposed. Case (I) has the highest production rate, even though it is experimentally challenging due to the absence of leptons. Mass criteria are imposed on the reconstructed W boson and top quark. A likelihood discriminant built out of several kinematic variables is used to separate the signal from the $t\bar{t}$ background. A similar selection strategy is applied in case (II). Triggering on these events is easier due to the presence of the lepton, but the lower decay rate results in a lower sensitivity w.r.t. case (I). The presence of neutrinos in both decays chains in case (III) makes the complete event reconstruction impossible. The signal, in this case, is observed as an excess of τ leptons in the $t\bar{t}$ process, due to the different $H^\pm \to \tau^\pm\nu_\tau$ and $W^\pm \to \tau^\pm\nu_\tau$ branching ratios.

For the **heavy charged Higgs** boson search, two channels have been studied, defined by the decay modes of the charged Higgs boson:

$t[b]H^\pm \to$ **(IV)** $bW[b]\tau\nu_\tau \to bqq[b]\tau(had)\nu_\tau$ and **(V)** $bW[b]tb \to bl\nu_l[b]bqqb$

In case (IV), the event selection is similar to the light charged Higgs search. Case (V) is experimentally challenging due to the complex multi-jet environment, which introduces a large combinatorial background. This channel is very sensitive to systematic uncertainties.

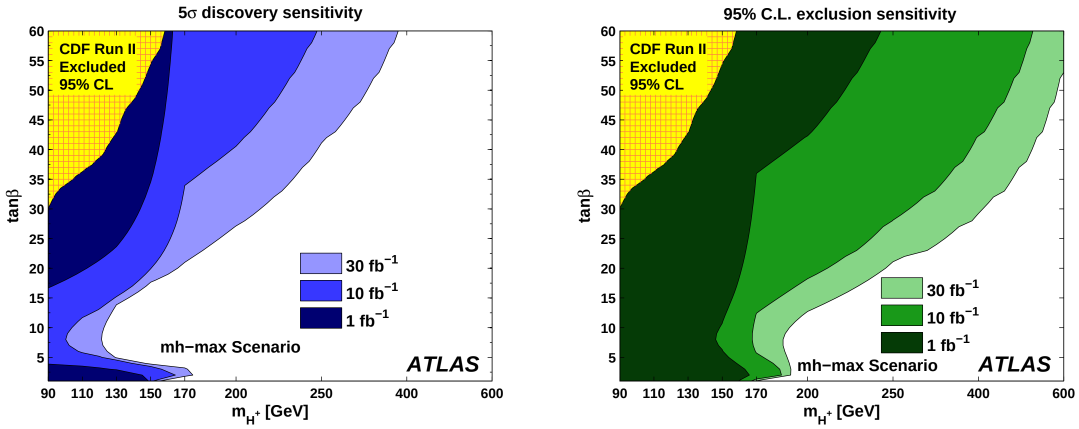

Figure 3: $H^{\pm}$: 5σ discovery (left) and 95% CL exclusion (right).

The theoretical signal uncertainty due to the renormalization and factorization scale dependence is evaluated to be 10% (<20%) for the light (heavy) $H^{\pm}$ boson. The experimental $t\bar{t}$ background uncertainty of 10-40% (depending on the event topology) is dominated by the uncertainty on the jet energy scale and the b-tagging performance. It can be reduced down to less than 10% by means of control samples with $t\bar{t} \to \mu\nu b\mu\nu b$ and $t\bar{t} \to \mu\nu bqqb$ events, in which the muons are replaced by simulated τ-lepton decays. The obtained discovery potential and the 95% CL exclusion limit contours are shown in Figure 3.

4. Search for MSSM Higgs Bosons Decaying to SUSY Cascades

In order to expand the discovery potential of the supersymmetric Higgs bosons, their decays to supersymmetic particles have been studied. In particular the final state with four leptons and E_T^{miss} has been explored. This final state originates by decays of the Higgs bosons to neutralinos or charginos and their subsequent decays to sleptons and leptons, with the sleptons decaying to the LSP and a lepton. (For example, $H/A \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to \tilde{l}^-l^+\tilde{l}^-l^+ \to \tilde{\chi}_1^0 l^-l^+\tilde{\chi}_1^0 l^-l^+$). This final state was studied in the context mSUGRA and more general MSSM scenarios. Its discovery potential depends strongly on the SUSY parameters definition, which affect the slepton masses.

The signature of the signal is two opposite sign, same flavour pairs of leptons and E_T^{miss} originating from the two LSPs. The main background consists of $t\bar{t}$, ZZ, Zbb events, as well as other SUSY processes. The event selection is similar to the one applied in the search for the SM Higgs to four leptons [1], with two important differences. The first being the presence of E_T^{miss}, and the second that the dilepton masses should not be consistent with the Z mass. After the event selection, the dominant remaining SM background is $t\bar{t}$ events and could be estimated from the data using relevant control samples. The second more significant background originates from SUSY processes, which are expected to be discovered before the Higgs bosons in this search. The experimental systematics in this search are shown to be negligible, compared to the theoretical uncertainties induced by the not known sleptons masses involved in the cascade decays. In certain scenarios (see set 2 in [2]), however, the discovery potential is enhanced for m_A between 400 and 700 GeV and the signal could be observed with an integrated luminosity below 100 fb^{-1}.

5. Vector Boson Scattering at High Mass

The characteristic signature of vector boson scattering is the presence of two high rapidity and high energy jets arising from the quarks which radiate the incoming vector bosons. The process can thus be efficiently distinguished from events with vector bosons radiated off outgoing quarks. In the latter case, the accompanying jets are softer and more central. A further component of the signature is the suppression of QCD radiation in the rapidity interval between the tag jets due to the fact that no colour is exchanged between the protons in these processes. This characteristic feature allows for efficient use of central jet veto.

The decay of a high-mass resonance will produce two highly boosted vector bosons in the central rapidity region of the detector. For high transverse momenta, the hadronically decaying vector bosons will be seen as one single wide and heavy jet, so methods of distinguishing such jets from single-parton jets have been investigated. The large QCD background at the LHC naturally leads to focus on events where at least one of the W or Z bosons decays leptonically. This way, the signal events can be efficiently triggered and the backgrounds can be reduced to a manageable level by the requirement of leptons and/or E_T^{miss}.

Apart from the non-resonant SM diboson production, the main backgrounds in this process are $Z(W) + \geq 3$ jets and $t\bar{t}$ events. The invariant or the tranverse mass of the diboson system is used for the final determination of the excess of signal events. The experimental systematic uncertainties are at the level of 5%. The theoretical uncertainty, due to the renormalization and factorization scales, results, presently, a factor of two on the background cross section. Assuming that data driven methods will be developed to control the background, a few tens of fb^{-1} could be enough to discover the signal.

6. Summary

The discovery potential of ATLAS for the MSSM Higgs bosons has been presented. Due to their high brancing ratios, final states with τ leptons offer the highest sensitivity. For neutral MSSM higgs bosons, the $\mu\mu$ channel complements the discovery potential of the $\tau\tau$ final state, offering also the possibility of an accurate Higgs mass measurement. Their possible decay to cascades of supersymmetric particles with a final state of four leptons and missing tranverse energy, has also been studied. In case no light Higgs boson exists, the discovery of resonances of vector boson scattering at high mass, could shed light on the mechanism of electroweak symmetry breaking.

References

[1] The ATLAS Collaboration, Expected Performance of the ATLAS Experiment - Detector, Trigger and Physics, CERN-OPEN-2008-020, arXiv:0901.0512 (2009).

[2] Gentile, S., MSSM Higgs search in SUSY cascade, ATL-PHYS-PROC-2008-077.

[3] Carena, M. S., Heinemeyer, S., Wagner, C. E.M. and Weiglein, G., Eur. Phys. J. C26 (2003) 601-607.

[4] The ATLAS Collaboration, The ATLAS Experiment at the Large Hadron Collider, JINST 3 (2008) S08003.

[5] Ellis, R. K. and Hinchliffe, I. and Soldate, M. and van der Bij, J. J., Nucl. Phys. B297 (1988) 221.

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