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The ATLAS discovery potential for MSSM neutral Higgs bosons decaying into muon, tau, supersymmetric particle pairs

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Abstract. - The discovery potential for MSSM neutral Higgs bosons in the ATLAS experiment at centre-of-mass energy $\sqrt{s} = 14$ TeV at the Large Hadron Collider (LHC) is discussed. The discovery and exclusion sensitivity in the (m_A, tanβ) plane in different luminosity scenarios is discussed for three processes: $h/A/H$decaying into $\tau\tau$ or into $\mu\mu$ pairs or in supersymmetric particles (heavy neutralino/chargino pairs).

The Minimal Supersymmetric Standard Model (MSSM) is the most investigated extension of the Standard Model (SM). The theory requires two Higgs doublets giving origin to five scalar Higgs bosons: two CP-even neutral, h and H (h is the lighter of the two), one CP-odd neutral, A, and one pair of charged Higgs bosons, $H^{\pm}$.

The unconstrained MSSM has a huge number of parameters (105) in addition to the SM ones, making any phenomenological analysis very complicated. A simplified version at some GUT (Grand Unification Theory) scale with fewer parameters is mostly used. A choice of parameters corresponding to the highest mass value (≤ 140 GeV) of the h boson is denoted, as $\mathrm{m_h}$-max scenario. Another scenario that is widely investigated, is mSUGRA, based on minimal Supergravity unification.

After the conclusion of the LEP program in the year 2000, the experimental limit on the mass of the Standard Model Higgs boson was established at 114.4 GeV with 95% CL. Limits were also set on the mass of neutral and charged MSSM Higgs bosons for representative parameter sets.

To achieve an uncontroversial proof of the existence of models beyond SM, the discovery of the heavier bosons H or A is demanded, the light h being indistinguishable from SM Higgs. Many signatures of MSSM neutral Higgs have been studied for decays into known SM particles, e.g. τ or μ pairs and $b\bar{b}$, by ATLAS [1], [2] and CMS experiments [3]. In these studies it is assumed that sparticles are too heavy to participate to the process, thus the decay into sparticles is forbidden. The discovery sensitivity is given in the (m_A, tanβ) plane, where m_A is the mass of the CP-odd Higgs boson and tanβ the ratio of the vacuum expectation values of the two Higgs fields.

If the MSSM Higgs decay in sparticles is kinematically allowed, decay channels involving neutralinos ($\tilde{\chi}^0$), charginos ($\tilde{\chi}_1^{\pm}$) and sleptons ($\tilde{\ell}$) can be considered, enlarging the possibilities of discovery. The decay of neutral and charged Higgs into neutralinos and charginos and the subsequent decay into sleptons have been studied. In a recent study [4], the decay into a neutralino pair as well as a chargino pair are also taken into account, extending the sensitivity of the discovery in the (m_A, tanβ) plane.

In this paper we discuss the potential of the ATLAS detector at LHC for the discovery of neutral MSSM Higgs bosons by studying their decays:

- into SM particles, μ pairs and τ pairs with subsequent leptonic decays in the $\mathrm{m_h}$-max scenario.
- into sparticles e.g., into neutralino and chargino pairs, with subsequent decay into lighter neutralinos and leptons.

The MSSM Higgs boson production modes considered herein are $gg \to h/A/H$ (gluon-fusion) and $q\bar{q} \to h/A/H$ (quark-fusion) analogue to Standard Model Higgs boson production. This gg process is important in the region of low tanβ, where the Higgs bosons couple most strongly to up-type quarks. For larger tanβ, the rate of $h/A/H$ production in association with b-quarks becomes dominant, due to enhanced couplings to b-quarks. The final state $h/A/\mathrm{H} \to \mu\mu$ would exploit the excellent combined performance of the muon spectrometer and inner detector of the experiment [5]. Although the Higgs boson couplings are proportional to the fermion mass, thus enhancing decays into $\tau\tau$ with respect to decays into $\mu\mu$ by a factor $(\frac{m_\tau}{m_\mu})^2$, the experimental conditions favor the $\mu\mu$ channel[1] . These reasons have encouraged ATLAS experiment to perform this search [2][4].

The search for MSSM Higgs bosons decaying into $\mu\mu$ has been performed looking for a signature with 0 b-jets or at least one b-jet and two muons in the final state. The dominant background is the Drell-Yan Z boson production, with subsequent Z decay into muons. The other major background originates from $t\bar{t}$. The theoretical and experimental uncertainties can lead to large systematic errors in the determination of background rates. The strategies to estimate their contributions from measured data is based on the fact that we don't expect any signal from a dielectron final state [5].

[1]The production advantage of the $\tau\tau$ channel is counterbalanced by the difficulty of identifying the hadronic decay of a τ-jet in hadronic events, by a smaller acceptance of the detector and by a worse mass resolution due to the presence of neutrinos in the final state.

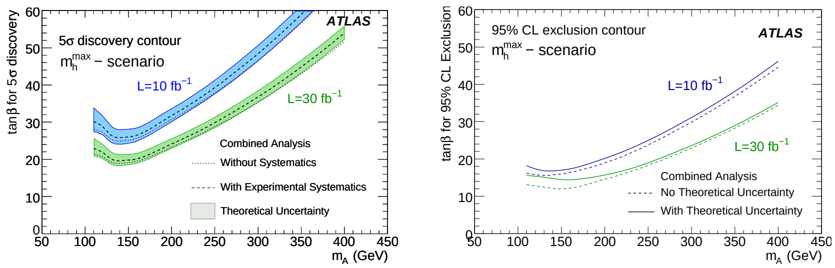

Figure 1: $b\bar{b}h/A/\ H \rightarrow \mu\mu$ at $\int \mathcal{L}\,\mathrm{d}t = 10$ and 30 fb^{-1} as a function of m_A: (left) 5-σ discovery contour, (right) 95% CL exclusion contour, Ref. [2]. The contours result from the combined analysis considering events with zero and at least one b-jets.

The 5-σ discovery curves obtained with 0 and ≥ 1 b-jets are shown for the $\mathrm{m_h}$-max scenario in Fig. 1.

The $h/H/A \rightarrow \tau\tau \rightarrow \ell\ell 4\nu$ channel is studied in b-quark associate production. The final state consists of two leptons, e or μ (trigger), at least one identified b quark and $E_{\mathrm{T}}^{\mathrm{miss}}$. Dominant backgrounds come from $Z \rightarrow \tau\tau$ and $t\bar{t}$ processes for the low and high mass range, respectively. Shape and normalization of the $Z \rightarrow \tau\tau$ background are estimated from $Z \rightarrow ee/\mu\mu$ sidebands. Dominant experimental systematic uncertainties come from the jet-energy scale and resolution uncertainties and from b-tagging. Discovery potential and 95% CL exclusion limits in the $\mathrm{m_h}$-max scenario are shown in Fig. 2.

If the MSSM Higgs boson decay in sparticles is kinematically allowed the processes involving light neutralinos, $A/H \rightarrow \widetilde{\chi}_2^0\widetilde{\chi}_2^0$, heavier neutralinos, $A/H\rightarrow\ \widetilde{\chi}_2^0\widetilde{\chi}_3^0$, $\widetilde{\chi}_2^0\widetilde{\chi}_4^0$, $\widetilde{\chi}_3^0\widetilde{\chi}_3^0$, $\widetilde{\chi}_3^0\widetilde{\chi}_4^0$, $\widetilde{\chi}_4^0\widetilde{\chi}_4^0$, and chargino states, $A/\mathrm{H}\rightarrow\ \widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^{\mp}$, $\widetilde{\chi}_2^{+}\widetilde{\chi}_2^{-}$, with the subsequent $\widetilde{\chi}_2^0\rightarrow\ \widetilde{\chi}_1^0\tilde{\ell}^{+}\tilde{\ell}^{-}$ decay, become accessible. All these processes are leading to a final state with four leptons and missing energy. The choice of MSSM parameters has been dictated by the maximization of these signals e.g. by the leptonic branching ratio enhancement [7].

Based on these considerations two sets of parameter values have been selected for the MSSM parameter space:

- **Set1** M_2 = 180 GeV, μ = -500 GeV, $\tilde{\ell}$ and $\tilde{\tau}$ mass = 250 GeV,
  $\tilde{g}$ and $\tilde{q}$ mass = 1000 GeV.

- **Set2** M_2 = 200 GeV, μ = -200 GeV , $\tilde{\ell}$ =150 GeV and $\tilde{\tau}$ mass = 250 GeV,
  $\tilde{g}$ mass = 800 GeV and $\tilde{q}$ mass = 1000 GeV.

where M_2 is the gaugino mass and μ, the strength of the supersymmetric Higgs boson mixing. The value of t and b quark mass is 175 GeV and 4.25 GeV, respectively.

Including additional assumptions on the unification of SUSY at very high mass scale (GUT) two other sets of parameter can be defined in the mSUGRA framework.

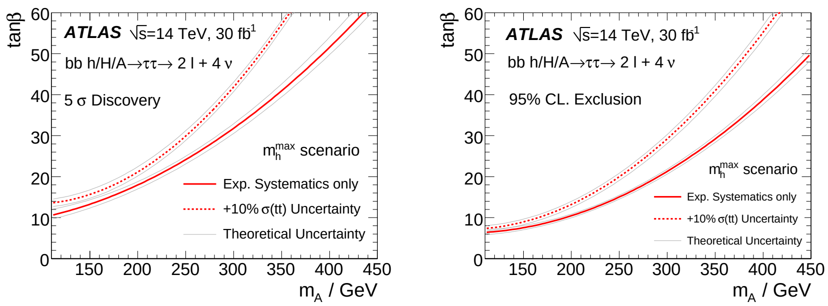

Figure 2: $b\bar{b}h/A/H\rightarrow\ \tau\tau\ \rightarrow\ \ell\ell 4\nu$ at $\int\mathcal{L}\,\mathrm{d}t\ =\ 30\ \mathrm{fb}^{-1}$ as a function of m_A: (left) 5-σ discovery contour, (right) 95% CL exclusion contour, Ref.[2]. The bands indicate the theoretical uncertainty on the cross section for signal process. The dashed lines (compared to solid) include an additional systematic uncertainty on the $t\bar{t}$ cross section of 10%.

In both MSSM and mSUGRA, a search of A/H decays into a neutralino/chargino pair has been performed in the (m_A, tanβ) plane inside the interval 3 - 50 for tanβ (in steps of 5), and 375 - 900 GeV for m_A (in steps of 250 GeV). To this purpose the signal and supersymmetric background Monte Carlo events have been studied using the HERWIG MC package through ISAWIG and HDECAY (see reference in [7]) for a center-of-mass energy $\sqrt{s}$= 14 TeV and Standard Model background events as in Ref. [2]. The efficiency of the selection criteria, the detector acceptance and the purity of the data sample are estimated from these events and the ATLAS detector response [2] .

The SM background sources are events originating from a ZZ pair or at a $t\bar{t}$ pair or a Z accompanied by a $b\bar{b}$ pair. The MSSM background processes are from direct neutralino (chargino) pair production, denoted as $\tilde{\chi}^0\tilde{\chi}^0(\tilde{\chi}^{\pm}\tilde{\chi}^{\mp})$, from squark (gluino)-neutralino ($\tilde{q}(\tilde{g})/\ \tilde{\chi}^0$) and from slepton pairs.

The search significance for the A/H neutral boson is shown as a function of m_A, in Fig. 3 for all scanned values of tanβ and two luminosities $\int\mathcal{L}\,\mathrm{d}t$ = 300 and 100 fb^{-1}, for Set2. The values for the lower luminosity are derived from the first one, which corresponds to the highest statistics.

We can conclude that the ATLAS detector, ready to collect data, offers a promising perspective with a view to discover MSSM Higgs bosons in a decay channel involving either SM particles or supersimmetric particles. In the last case among the sets of parameters investigated (at $\int\mathcal{L}\,\mathrm{d}t$ = 300 and 100 fb^{-1}) the MSSM Set2 is the most promising scenario, for the optimal choice of parameters particularly $\tilde{\tau}$ and $\tilde{\ell}$ masses.

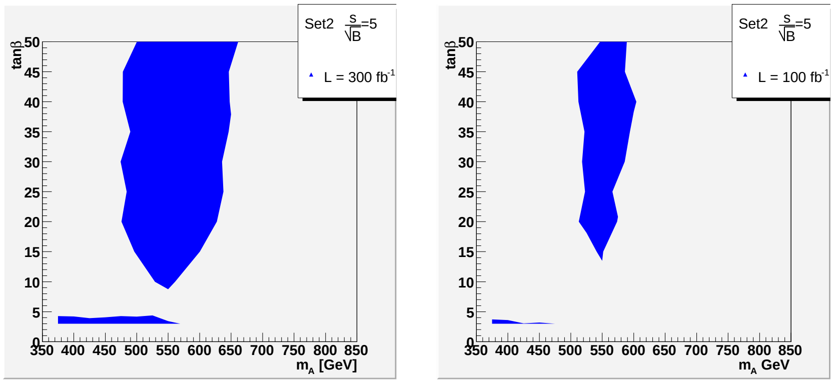

Figure 3: Discovery potential (for MSSM Set2) for Higgs boson A/H as a function of mass m_A for final states with four leptons and missing transverse energy, as a function of m_A: contours are drawn for a search significance $\frac{S}{\sqrt{B}}$ $= 5$ for an integrated luminosity of $\int \mathcal{L}\,\mathrm{d}t = 300$ (left) and 100 fb^{-1}(right).

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