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Search for the neutral MSSM Higgs bosons in the $H \to \tau^+\tau^-$ and $H \to \mu^+\mu^-$ decay modes with the ATLAS detector at the LHC

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The Minimal Supersymmetric extension of the Standard Model (MSSM) predicts the existence of three neutral and two charged Higgs bosons. The search for the neutral MSSM Higgs bosons in the $H \to \tau^+\tau^-$ and $H \to \mu^+\mu^-$ decay modes has been performed using proton-proton collision data recently collected with the ATLAS detector at the Large Hadron Collider. No significant excess of data above the expected Standard Model background has been observed. The exclusion limits at the 95% confidence level are discussed as a function of the m_A and $\tan\beta$ parameters.

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1. Introduction

The Minimal Supersymmetric Standard Model (MSSM) [1, 2] is a supersymmetric extension to the Standard Model with minimal particle content. In contrast to the Standard Model, the MSSM requires the existence of two Higgs doublets to separately generate masses for up- and down-type fermions. The corresponding mass eigenstates are the neutral and CP-even bosons h and H, of which h is lighter by convention, one neutral and CP-odd boson A and two charged bosons $H^{\pm}$.

At tree level their properties can be expressed in terms of the ratio of the vacuum expectation values of the two Higgs doublets, $\tan\beta$, and the mass of the CP-odd Higgs boson, m_A. In large parts of the m_A–$\tan\beta$ plane the couplings of the neutral Higgs bosons to down-type fermions are strongly enhanced. Therefore, the dominant Higgs boson production modes in these parts are the gluon-fusion process, that predominantly proceeds through a b quark loop for large $\tan\beta$, and the production in association with b quarks.

A search for these neutral MSSM Higgs bosons has been performed with the ATLAS detector [3], assuming masses, decay widths and production cross sections as given in the $m_h^{\max}$ benchmark scenario with $\mu > 0$ [4]. The proton-proton collision data used for this search have been collected in 2011 at a centre-of-mass energy of 7 TeV and correspond to an integrated luminosity of $4.7-4.8\ fb^{-1}$. The decay modes taken into account were $h/A/H \to \mu^+\mu^-$ and $h/A/H \to \tau^+\tau^-$, of which the latter is categorized according to the decay products of the τ leptons. Further categorization of all final states depends on the presence or absence of a b jet. This enhances the ratio of signal produced in association with b quark to the background.

2. Search for the $h/A/H \to \mu^+\mu^-$ decay mode

The direct decay of the neutral Higgs bosons into two muons has a very low branching ratio of around 0.04%. However, this decay mode provides a clean signature and a very good mass resolution. The signal signature is a pair of isolated muons with large transverse momenta, opposite charge and a large invariant mass of the di-muon system. In addition, low missing transverse momentum is expected.

The final observable in this search is the invariant mass of the di-muon system. The signal would manifest as a small resonance on a large background that is dominated by the Z/γ^* production process. To cope with this challenge the total background contribution to the signal region is estimated completely from data. A signal model parameterizes the sum of all three resonances h, H and A at each point of a m_A–$\tan\beta$ grid. At each of these points the model is used to define a signal window, outside of which the signal is expected to contribute at a negligible level. A background model is defined as a Breit-Wigner function describing the complete background distribution convolved with a Gaussian to account for the finite mass resolution. This parameterization is found to be a good approximation of the shape of the total di-muon background in both categories, with and without the presence of a b jet. Sideband fits of this background model to data are performed outside each signal window. This results in an estimate for the complete background contribution inside the signal windows at each point of the m_A–$\tan\beta$ grid.
In the signal window for the parameter combination m_A=150 GeV and $\tan\beta$=40 the sideband fits predict a total number of 980 ± 50 and 35900 ± 600 background events for the event samples with

and without identified b jets, respectively. These numbers agree well with the numbers of observed data events of 985 and 36044 in the same signal window. A hypothetical signal would contribute with 30.6 ± 3.2 and 412 ± 34 events to the event samples with and without identified b jets, respectively. The uncertainties quoted above include both statistical and systematic uncertainties.

3. Search for the $h/A/H \to \tau^+\tau^-$ decay mode

The decays of the neutral Higgs bosons into τ leptons can reach branching fractions close to 10%, depending on m_A and $\tan\beta$. The search for this decay mode is further categorized according to the decay products of the τ leptons. These are hadrons and one neutrino (τ_{had}) or an electron (τ_{e}) or muon (τ_μ) and two neutrinos. The $\tau^+\tau^-$ final states considered are $\tau_{\text{e}}\tau_\mu$ (6%), $\tau_{\text{e}}\tau_{\text{had}}$ (23%), $\tau_\mu\tau_{\text{had}}$ (23%) and $\tau_{\text{had}}\tau_{\text{had}}$ (42%), with decay probabilities as given in the parentheses.

The $\tau_{\text{e}}\tau_\mu$ final state is characterised by the presence of exactly one isolated electron and one isolated muon of opposite electric charge, a large opening angle in between them and a large invariant mass of the di-lepton system. In the presence of a b jet upper thresholds are applied to the sum of the transverse energies of all jets and to the scalar sum of the lepton transverse momenta and the missing transverse momentum. Furthermore, the combination of the transverse opening angles between the lepton directions and the direction of the missing transverse momentum is restricted to large values in that case. These requirements mainly reduce the contributions from top quark and di-boson production. In this final state a total of 181 events are observed in the data. The predicted contribution from Standard Model backgrounds is $200{\pm}13^{+15}_{-13}$ and a hypothetical signal with $m_A{=}150\,\text{GeV}$ and $\tan\beta{=}20$ would contribute with $21.4{\pm}0.67^{+4.3}_{-5.3}$ events. If no b jet is present, a veto against events containing jets is applied. The search in this final state is performed in windows of the invariant mass of the $\tau_{\text{e}}\tau_\mu$ system that are defined for each point in a m_A–$\tan\beta$ grid. In the search window for the parameter combination $m_A{=}150\,\text{GeV}$ and $\tan\beta{=}20$ a number of 1245 data events are observed and a total of $1197{\pm}22^{+91}_{-80}$ background events are expected. Given these values of m_A and $\tan\beta$ a hypothetical signal would contribute with $147{\pm}8^{+14}_{-17}$ events.

The $\tau_\mu\tau_{\text{had}}$ and $\tau_{\text{e}}\tau_{\text{had}}$ final states contain exactly one isolated muon or electron, respectively, with large transverse momenta and a τ_{had} of opposite charge. The transverse mass between the lepton and the missing transverse momentum is required to be low to reduce the contributions of $W+$jets and $t\bar{t}$ background processes. In the absence of a b jet a lower threshold on the missing transverse momentum is applied. A total number of 6424 and 5034 data events are observed in final states containing selected muons and electrons, respectively. The expected contributions from Standard Model background processes to these event samples are $6610{\pm}70^{+760}_{-770}$ and $5220{\pm}80^{+640}_{-620}$. A hypothetical signal would contribute with $289{\pm}6^{+31}_{-38}$ and $237{\pm}5^{+27}_{-32}$ events for the parameter choice $m_A{=}150\,\text{GeV}$ and $\tan\beta{=}20$. If a b jet is present its transverse momentum is restricted to low values to further reduce the contribution of top quark production processes. In this final state a total number of 202 and 175 data events are observed in final states containing selected muons and electrons, respectively. Given the parameters $m_A{=}150\,\text{GeV}$ and $\tan\beta{=}20$ a hypothetical signal would contribute with $21.6{\pm}1,5^{+4.6}_{-6.1}$ and $16.2{\pm}1.3^{+3.0}_{-4.8}$ events. The expected background contributions to the final states with selected muons and electrons are $180{\pm}12^{+17}_{-16}$ and $154{\pm}14^{+25}_{-26}$, respectively.

In the $\tau_{\rm had}\tau_{\rm had}$ final state two $\tau_{\rm had}$ leptons with large transverse momenta and opposite charges are expected. Events containing electrons or muons are rejected and a lower threshold on the missing transverse momentum is set. In case no b jet is found in the final state, the threshold on the transverse momentum of the leading $\tau_{\rm had}$ is raised in order to gain further background suppression, especially against multi-jet production processes. In the corresponding signal region 1223 data events are observed and a total of $1233\pm23^{+69}_{-59}$ background events are expected. A hypothetical signal (m_A=150 GeV and tanβ=20) would contribute with $120\pm3^{+24}_{-22}$ events. In the presence of a b jet an upper threshold on its transverse momentum is applied to reduce the contribution from top quark production processes. In the signal region to this final state 27 data events are observed. The expected contributions from Standard Model backgrounds are $25.4\pm4.8^{+2.2}_{-1.9}$ events. For m_A=150 GeV and tanβ=20 a hypothetical signal would contribute with $8.2\pm0.6^{+3.3}_{-3.2}$ events to the signal region of this final state.

The $Z/\gamma^* \to \tau^+\tau^-$ background forms a largely irreducible background to all $\tau^+\tau^-$ final states. Simulated $Z/\gamma^* \to \tau^+\tau^-$ events are validated against ($\tau_{\rm had}\tau_{\rm had}$ final state) or replaced ($\tau_{\rm e}\tau_{\mu}$, $\tau_{\rm e}\tau_{\rm had}$ and $\tau_{\mu}\tau_{\rm had}$ final states) by $Z/\gamma^* \to \mu^+\mu^-$ events selected in data that are modified using a τ-embedding technique. This technique replaces the muons in data events by simulated τ leptons and hence only these and the detector response to their decay products are taken from simulations.

The contributions from multi-jet background processes are estimated from data. Two uncorrelated variables are selected to define four data regions of which one is the signal region. The other three are regions dominated by multi-jet background processes. The contribution of the multi-jet background to the signal region is estimated by extrapolating the data from one of the control regions using the ratio of data events in the remaining two control regions.

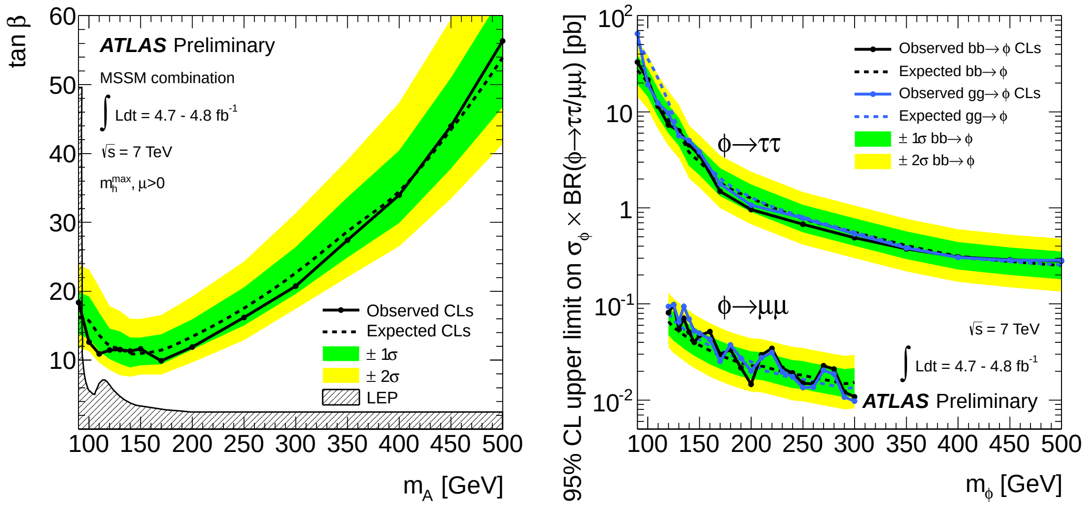
For the $\tau_{\rm e}\tau_{\mu}$, $\tau_{\rm e}\tau_{\rm had}$ and $\tau_{\mu}\tau_{\rm had}$ final states containing b jets the background contribution from $t\bar{t}$ production processes is estimated from data using background dominated control regions.

For several backgrounds a fraction of jets originating from quarks or gluons are misidentified as $\tau_{\rm had}$ candidates. Since this misidentification fraction is higher in simulated event samples than in data, the Monte Carlo estimates for these backgrounds are corrected using background dominated data control samples.

The final observable for the $\tau^+\tau^-$ final states is the invariant mass of the $\tau^+\tau^-$ pair that is reconstructed using the Missing Mass Calculator (MMC) technique [5]. An exception is the $\tau_{\rm e}\tau_{\mu}$ final state in the absence of a b jet. In that case the invariant mass of the di-lepton system is used as the final discriminator.

4. Results

No significant excess of data above the expected Standard Model background has been observed in all final states. Therefore, a 95% confidence level upper limit on tanβ is set for each m_A point using the CL$_s$ frequentist approach [6]. A significant part of the parameter space can be excluded as can be seen in Figure 1 (a). For Higgs boson masses of m_A=170 GeV values of tan$\beta\simeq$10 and above can be excluded. In addition, a general interpretation of the search results is performed and 95% exclusion limits on the production cross section times branching fraction for a generic scalar boson produced in the gluon-fusion mode or in association with b quarks and



(a) (b)

Figure 1: Figure (a) shows the upper limits on $\tan\beta$ as a function of m_A for the statistical combination of all channels. All limits are given as upper CL_s limits at 95% confidence level. Expected limits are shown as dashed lines, the observed limits as solid line. The green and yellow bands indicate the $\pm 1\sigma$ and $\pm 2\sigma$ bands for the expected limits, respectively. Figure (b) shows the upper limits on the cross section times the branching ratio for a generic resonance ϕ produced in the gluon-fusion mode or in association with b quarks and decaying into τ and μ pairs. These figures are taken from Reference [7].

decaying to $\mu^+\mu^-$ or $\tau^+\tau^-$ are derived as a function of the bosons mass. These results are shown in Figure 1 (b). A detailed discussion of all results presented here can be found in Reference [7].

5. Conclusion

A search for the neutral Higgs bosons of the Minimal Supersymmetric Standard Model has been performed assuming an MSSM parameter set as defined in the $m_h^{\max}$ benchmark scenario with $\mu > 0$. The search used $4.7 - 4.8\, fb^{-1}$ of proton-proton collision data recorded with the ATLAS detector in 2011 at a centre-of-mass energy of 7 TeV. The final states considered were the $\mu^+\mu^-$ decay mode of the Higgs bosons and the $\tau^+\tau^-$ decay mode in the $\tau_e\tau_\mu$, $\tau_e\tau_{\mathrm{had}}$, $\tau_\mu\tau_{\mathrm{had}}$ and $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$ final states. Further categorization was applied depending on the absence or presence of a b jet. No significant excess of data above the expected Standard Model background has been observed. Hence, upper exclusion limits at 95% confidence level have been set on the MSSM parameter $\tan\beta$ as a function of the mass of the CP-odd Higgs boson m_A. A significant part of the MSSM parameter space can be excluded, ranging down to values of $\tan\beta \simeq 10$ for a Higgs boson mass of m_A=170 GeV. Furthermore, upper exclusion limits at 95% confidence level have been set on the production cross section times branching ratio for a generic resonance in the considered production and decay modes.

References

[1] N. P. Nilles, "*Supersymmetry, supergravity and particle physics*", Phys. Rep. 110 (1984)

[2] H. E. Haber and G. L. Kane, "*The search for supersymmetry: Probing physics beyond the standard model*", Phys. Rep. 117 (1985)

[3] ATLAS collaboration, "*The ATLAS Experiment at the CERN Large Hadron Collider*", JINST 3 (2008)

[4] M. Carena et al., "*Suggestions for benchmark scenarios for MSSM Higgs boson searches at hadron colliders*", Eur. Phys. J. C26 (2003) arXiv:hep-ph/0202167

[5] A. Elagin et al., "*A New Mass Reconstruction Technique for Resonances Decaying to di-tau*", Nucl. Instrum. Meth. A654 (2011) arXiv:1012.4686 [hep-ex]

[6] A. L. Read,"*Presentation of search results: the CL_s technique*", J. Phys. G 28 (2002)

[7] ATLAS collaboration, "*Search for Neutral MSSM Higgs bosons in $\sqrt{s} = 7$ TeV pp collisions at ATLAS*" (2012) ATLAS-CONF-2012-094