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Search for additional neutral Higgs bosons in the MSSM

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Two searches for neutral heavy Higgs: $H/A \to \tau\tau$ and $A \to Zh, h \to b\bar{b}$ are presented with 36.1 fb^{-1} of data at $\sqrt{s} = 13$ TeV recorded by the ATLAS detector at the LHC. There is no statistically significant excess. Upper limits on cross-section times branching fraction and the interpretation of results in the m_A-tanβ plane are shown within the MSSM. Large areas of high tanβ are excluded by $H/A \to \tau\tau$: tan$\beta > 15$ for $m_A = 1$ TeV in the hMSSM scenario at the 95% confidence level.

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1. Introduction

We have learned several things so far from LHC results: There is one Higgs boson with $m_h = 125$ GeV, spin 0 and *CP*-even [1]. Its couplings to bosons and fermions are consistent with the Standard Model (SM) prediction. There is no SUSY up to ∼2 TeV for gluino/sqaurk, ∼1 TeV for scalar top [1] [2]. There is no other exotic particles up to a few TeV depending on models [3]. The SM is successful but we have strong motivations to search for physics beyond the SM (BSM): Hierarchy problem, dark matter, GUT etc. Since many new physics models require two Higgs doublets (2HDM), a search for additional neutral Higgs is one of general ways for BSM searches. For high $\tan\beta$ (β is a ratio of two vacuum expectation values), down-type fermion channels (produced from the decay of the heavy neutral Higgs) are promising and for low $\tan\beta$, up-type fermion, VV and hh channels are promising in the MSSM. In this proceedings, we show two searches at ATLAS [4] with 36.1 fb^{-1} collected at $\sqrt{s} = 13$ TeV: $H/A \to \tau\tau$ and $A \to Zh$, $h \to b\bar{b}$.

2. $H/A \to \tau\tau$

b-associated production (bbH/A) cross-section becomes larger as $\tan\beta$ higher in the MSSM and also the branching fraction of $H/A \to \tau\tau$ gets larger as $\tan\beta$ gets higher. $\tau\tau$ final state with bbH/A is one of the most important channels in the MSSM Higgs search. Both lepton-hadron ($\tau_{\text{lep}}\tau_{\text{had}}$) and hadron-hadron ($\tau_{\text{had}}\tau_{\text{had}}$) channels based on the tau-lepton decay have good sensitivity in this search.

Main background events come from mis-identification of tau-lepton: multi-jets, W-jets etc. The contribution from $Z \to \tau\tau$ is small in the high mass region. Categories of b-veto and b-tag are introduced to enhance gluon fusion and bbH/A production, respectively. The total transverse mass $m_{\text{T}}^{\text{tot}}$, which is defined as $m_{\text{T}}^{\text{tot}} = \sqrt{\left(p_{\text{T}}^{\tau_1} + p_{\text{T}}^{\tau_2} + E_{\text{T}}^{\text{miss}}\right)^2 - \left(\boldsymbol{p}_{\text{T}}^{\tau_1} + \boldsymbol{p}_{\text{T}}^{\tau_2} + \boldsymbol{E}_{\text{T}}^{\text{miss}}\right)^2}$, is shown in Figs. 1 for $\tau_{\text{lep}}\tau_{\text{had}}$ with b-veto and $\tau_{\text{had}}\tau_{\text{had}}$ with b-tag. No significant excess is observed. The cross-section times branching fraction for gluon-fusion and bbH/A productions is obtained and the latter is shown in Fig. 1 (right). Results from both $\tau_{\text{lep}}\tau_{\text{had}}$ and $\tau_{\text{had}}\tau_{\text{had}}$ channels are statistically combined. Upper limits are set to be up to $\sim (3-10)$ fb at $m_A > 1$ TeV (95% CL). The lepton-hadron channel is sensitive below ∼600 GeV but hadron-hadron becomes more sensitive above ∼600 GeV.

3. $A \to Zh$, $h \to b\bar{b}$

A search for $A \to Zh$ is sensitive in low $\tan\beta$ regions. In addition, when b-association in the production (bbA) is considered, this channel can be enhanced in high $\tan\beta$ regions.

Lepton categories: 0, 2 charged-leptons are introduced based on the Z boson decay. As a *CP*-odd Higgs boson A mass gets heavier, the 125 GeV Higgs boson h is boosted. As a result, the distance between two b-jets from h becomes closer. From this consideration, two categories are introduced: resolved and merged. In the resolved category, two b-jets are reconstructed with a nominal jet radius ($R = 0.4$) but in the merged category, two b-jets are reconstructed as a single

[1] The values of these limits depends on SUSY parameters.

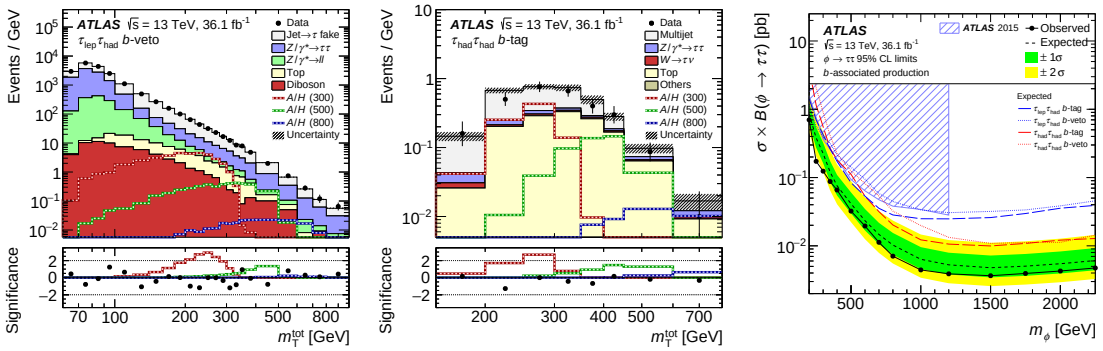

Figure 1: Distributions of $m_{\mathrm{T}}^{\mathrm{tot}}$ for (left) b-veto category of $\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ and (middle) b-tag category of $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$ channels. The combined prediction for A and H bosons with 300, 500, 800 GeV and $\tan\beta = 10$ in the hMSSM scenario are shown. (Right) the observed and expected 95% CL upper limits on the production cross-section times branching fraction for a scalar boson via b-associated production. All plots are taken from Ref. [5].

jet with a large-radius ($R = 1.0$). A mass distribution of the heavy Higgs boson candidate m_{Vh} is shown in the left of Figs. 2 for the 2-lepton channel, where a 125 GeV Higgs boson candidate is reconstructed as a large-R jet. For the bbA search, 3 or more b-tags is required and a transverse mass of the heavy Higgs boson candidate $m_{\mathrm{T},Vh}$ is shown in the middle of Figs. 2 for the 0-lepton channel. In all the categories, no significant excess is observed. Upper limits on the cross-section times branching fraction for gluon-fusion and bbA production are set to be $\sim (1-10)$ fb at $m_A > 1$ TeV (95% CL). Results are also interpreted in term of 2HDM Type-II, where the MSSM is one of them, as shown in the right of Figs. 2 for $m_A = 300$ GeV and large areas except for so-called alignment limit ($\beta - \alpha = \pi/2$) are excluded, where α is a mixing angles between up-type and down-type neutral Higgs.

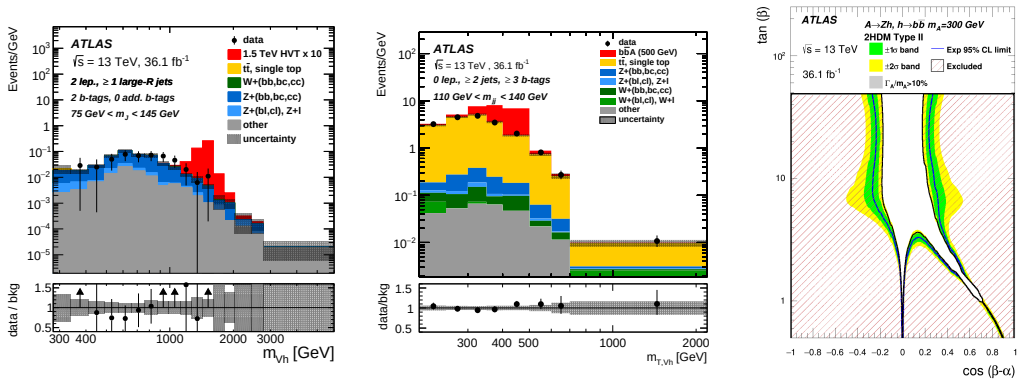

Figure 2: (Left) a m_{Vh} distribution corresponding to the mass of heavy neutral Higgs boson candidates for the 2-lepton channel in the merged category. The signal for the benchmark heavy vector triplet (HVT) *ModelA* with 1.5 TeV normalized to 10 times the theoretical cross-section is shown by red color. (Middle) a $m_{\mathrm{T},Vh}$ distribution for the 0-lepton channel with $\geq$3 b-jets for the bbA search in the resolved category. The signal for an A boson with 500 GeV is shown by red color using a cross-section of 5 pb. (Right) the interpretation of the cross-section limits in the 2HDM Type-II in the $\cos(\beta-\alpha)$-$\tan\beta$ plane for $m_A =$ 300 GeV. Both gluon fusion and bbA productions are taken into account. All plots are taken from Ref. [6].

4. Summary

Two searches for heavy neutral Higgs: $H/A \to \tau\tau$ and $A \to Zh, h \to b\bar{b}$ with 36.1 fb^{-1} of data collected at $\sqrt{s} = 13$ TeV in the ATLAS experiment are presented. No statistically significant excess is observed. Upper limits on cross-section times branching fraction are obtained for them. Lastly Figures 3 show the interpretation of limits in the m_A-tanβ plane with several analyzes for the hMSSM scenario. Large areas of high tanβ are excluded by $H/A \to \tau\tau$, which is displayed by gray of the left plot and also in the right plot: tan$\beta > 15$ for $m_A = 1$ TeV, tan$\beta > 42$ for $m_A = 1.5$ TeV at the 95% CL. The result from $A \to Zh, h \to b\bar{b}$ but with the only gluon-fusion production is shown by yellow.

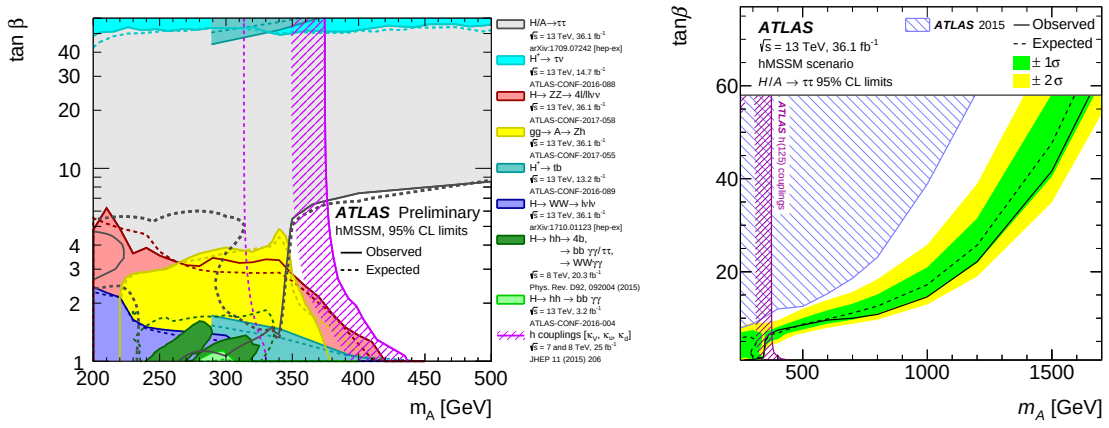

Figure 3: Regions of the m_A-tanβ plane excluded in the hMSSM model via direct searches (left) for heavy Higgs bosons and fits to the measured rates of observed Higgs boson production and decays [7] and (right) for $H/A \to \tau\tau$ [5]. Limits are quoted at 95% CL and are indicated for the data (solid lines) and the expectation for the SM Higgs sector (dashed lines). Results of ATLAS-CONF-2017-055 shown in the plot are superseded by Ref. [6] (Section 3).

References

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[7] ATLAS, Summary plots from the ATLAS Higgs physics group, https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/HIGGS/