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Search for flavour-changing neutral current top quark decays $t \to Hq$ in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

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A search for flavour-changing neutral current decays of a top quark to an up-type quark ($q = u$, c) and the Standard Model Higgs boson, where the Higgs boson decays to $b\bar{b}$, is presented. The analysis searches for top quark pair events in which one top quark decays to Wb, with the W boson decaying leptonically, and the other top quark decays to Hq. The search is based on pp collisions at $\sqrt{s} = 8$ TeV recorded in 2012 with the ATLAS detector at the CERN Large Hadron Collider and uses an integrated luminosity of 20.3 fb^{-1}. No significant excess of events above the background expectation is found, and observed (expected) 95% CL upper limits of 0.56% (0.42%) and 0.61% (0.64%) are derived for the $t \to Hc$ and $t \to Hu$ branching ratios respectively. The combination of this search with other ATLAS searches in the $H \to \gamma\gamma$ and $H \to WW^*$, $\tau\tau$ decay modes significantly improves the sensitivity, yielding observed (expected) 95% CL upper limits on the $t \to Hc$ and $t \to Hu$ branching ratios of 0.46% (0.25%) and 0.45% (0.29%) respectively. The corresponding combined observed (expected) upper limits on the $|\lambda_{tcH}|$ and $|\lambda_{tuH}|$ couplings are 0.13 (0.10) and 0.13 (0.10) respectively. These are the most restrictive direct bounds on tqH interactions measured so far.

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1. Introduction

Following the observation of a Higgs boson by the ATLAS and CMS collaborations, a comprehensive programme of measurements of its properties is underway looking for deviations from the Standard Model (SM) predictions. An interesting possibility is the presence of flavour-changing neutral current (FCNC) decays of the top quark to the Higgs boson and a u- or c-quark: $t \to Hq$ (q = u, c). In the SM, such decays are extremely suppressed relative to the dominant $t \to Wb$ decay mode, since FCNC interactions are forbidden at the tree level and even suppressed at higher-orders in the perturbative expansion due to the Glashow-Iliopoulos-Maiani (GIM) mechanism. As a result, the SM predictions for the $t \to Hq$ branching ratios are exceedingly small: BR$(t \to Hc) \sim 10^{-15}$ and BR$(t \to Hu) \sim 10^{-17}$. However, large enhancements are possible in some beyond-SM scenarios with typical branching ratios as high as BR$(t \to Hq) \sim 10^{-5}$ [1]. An even larger branching ratio of BR$(t \to Hc) \sim 10^{-3}$ [2] can be reached in two-Higgs-doublet models (2HDM) without explicit flavour conservation, since a tree-level FCNC coupling is not forbidden by any symmetry.

Searches for $t \to Hq$ decays have been performed by the ATLAS collaboration, taking advantage of the large samples of $t\bar{t}$ events collected during Run 1 of the LHC. In these searches, one of the top quarks is required to decay into Wb, while the other top quark decays into Hq, yielding $t\bar{t} \to WbHq$. In the following sections, a search for FCNC decays of a top quark to an up-type quark (q = u, c) and the SM Higgs boson, where the Higgs boson decays to $b\bar{b}$, is presented. A combination of the three ATLAS searches for $t\bar{t} \to WbHq$, probing the $H \to b\bar{b}$ [3], $H \to WW^*$, $\tau\tau$ [4], and $H \to \gamma\gamma$ [5] decay modes, is also performed.

2. Data Sample and Event Selection

This search is focused on the $t\bar{t} \to WbHq$ ($q = u,c$) process, with $W \to l\nu(e,\mu)$ and $H \to b\bar{b}$, resulting in a lepton-plus-jets final state with high b-jet multiplicity, which can be effectively exploited to suppress the otherwise overwhelming $t\bar{t}$ background. The analyses use the pp collision data at $\sqrt{s} = 8$ TeV collected by the ATLAS experiment between April and December 2012. Only events recorded with a single-electron or single-muon trigger under stable beam conditions are considered. The corresponding integrated luminosity is 20.3 ± 0.6 fb^{-1}.

In order to optimise the sensitivity of the search, the selected events are categorised into nine channels depending on the number of jets (4, 5 and $\geq$6) and on the number of b-tagged jets (2, 3 and $\geq$4). The channels most sensitive to the $t\bar{t} \to WbHu$ and $t\bar{t} \to WbHc$ signals are (4 j, 3 b) and (4 j, 4 b) respectively. The rest of the channels have significantly lower signal-to-background ratios, but they are useful for calibrating the $t\bar{t}$+jets background prediction and constraining the related systematic uncertainties through a likelihood fit, a strategy first used in the ATLAS search for $t\bar{t} \to H$ associated production, with $H \to b\bar{b}$ [6].

3. Discriminating Variable

After event categorisation, the signal-to-background ratio is very low even in the most sensitive analysis channels, and a suitable discriminating variable between signal and background needs to be constructed in order to improve the sensitivity of the search. A powerful discriminant between signal and background can be defined as:

$$D(\mathbf{x}) = \frac{P^{\mathrm{sig}}(\mathbf{x})}{P^{\mathrm{sig}}(\mathbf{x}) + P^{\mathrm{bkg}}(\mathbf{x})}, \tag{3.1}$$

where $P^{\mathrm{sig}}(\mathbf{x})$ and $P^{\mathrm{bkg}}(\mathbf{x})$ represent the probability density functions (pdf) of a given event under the signal hypothesis ($t\bar{t} \to WbHq$) and under the background hypothesis ($t\bar{t} \to WbWb$) respectively. The calculation of $P^{\mathrm{sig}}(\mathbf{x})$ and $P^{\mathrm{bkg}}(\mathbf{x})$ is discussed in detail in [3].

4. Results

The best-fit branching ratio obtained for $t\bar{t} \to WbHq$, $H \to b\bar{b}$ is $\mathrm{BR}(t \to Hc) = [0.17 \pm 0.12\,(\mathrm{stat.}) \pm 0.17\,(\mathrm{syst.})]\%$, under the assumption that $\mathrm{BR}(t \to Hu) = 0$, and $\mathrm{BR}(t \to Hu) = [-0.07 \pm 0.17\,(\mathrm{stat.}) \pm 0.28\,(\mathrm{syst.})]\%$, under the assumption that $\mathrm{BR}(t \to Hc) = 0$. Figure 1 shows a comparison of the data and prediction in the final discriminant in the most sensitive (4j, 4b) channel, both pre- and post-fit to data, in the case of the $t \to Hc$ search.

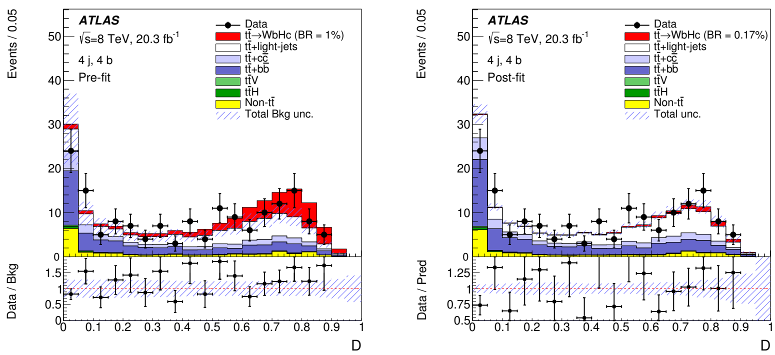

Figure 1: $t\bar{t} \to WbHc$ search: comparison between the data and prediction for the distribution of the discriminant used in the (4 j, 4 b) channels before and after the fit. The fit is performed to data under the signal-plus-background hypothesis. In the pre-fit distributions the $t \to Hc$ signal (solid red) is normalised to $\mathrm{BR}(t \to Hc) = 1\%$ and the $t\bar{t} \to WbWb$ background is normalised to the SM prediction, while in the post-fit distributions both signal and $t\bar{t} \to WbWb$ background are normalised using the best-fit $\mathrm{BR}(t \to Hc)$. The bottom panels display the ratios between data and either the SM background prediction before the fit or the total signal-plus-background prediction after the fit. The dashed area represents the uncertainty on the background [3].

In absence of a significant excess in data above the background expectation, 95% CL limits are set on $\mathrm{BR}(t \to Hc)$ and $\mathrm{BR}(t \to Hu)$. The observed (expected) 95% CL upper limits on the branching ratios are $\mathrm{BR}(t \to Hc) < 0.56\%\,(0.42\%)$ and $\mathrm{BR}(t \to Hu) < 0.61\%\,(0.64\%)$. These upper limits can be translated into corresponding observed (expected) limits on the couplings of $|\lambda_{tcH}| < 0.14\,(0.12)$ and $|\lambda_{tuH}| < 0.15\,(0.15)$.

A combination of the three ATLAS searches for $t\bar{t} \to Hq$, probing the $H \to b\bar{b}$, $H \to WW^*$, $\tau\tau$, and $H \to \gamma\gamma$ decay modes, is also performed. The observed (expected) 95% CL combined upper limits on the branching ratios are $\mathrm{BR}(t \to Hc) < 0.46\%\,(0.25\%)$ and $\mathrm{BR}(t \to Hu) < 0.45\%\,(0.29\%)$. The corresponding observed (expected) upper limits on the couplings are $|\lambda_{tcH}| < 0.13\,(0.10)$ and

$|\lambda_{tuH}| < 0.13\,(0.10)$. A summary of the upper limits on the branching ratios obtained by the individual searches, as well as their combination, can be found in Figure 2.

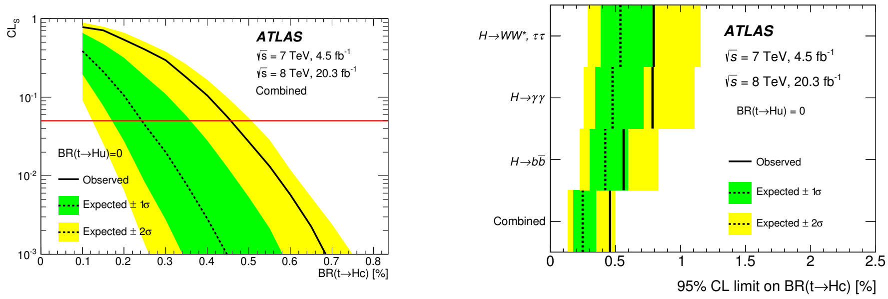

Figure 2: (left) $\mathrm{CL_s}$ versus $\mathrm{BR}(t \to Hc)$ for the combination of searches, under the assumption that $\mathrm{BR}(t \to Hu)$ is zero. (right) 95% CL upper limits on $\mathrm{BR}(t \to Hc)$ for the individual searches as well as their combination, under the assumption that the $\mathrm{BR}(t \to Hu)$ is zero. The observed $\mathrm{CL_s}$ values (solid black lines) are compared to the expected (median) $\mathrm{CL_s}$ values under the background-only hypothesis (dotted black lines). The surrounding shaded bands correspond to the 68% and 95% CL intervals around the expected limits, denoted as $\pm 1\sigma$ and $\pm 2\sigma$, respectively [3].

5. Conclusions

The first search for $t\bar{t} \to WbHq$ with $H \to b\bar{b}$, exploiting the lepton-plus-jets final state at high b-tag multiplicity, has been presented. A novel discriminant is built to separate signal from background, whose uncertainties are constrained via a profile likelihood fit to 9 analysis channels. This analysis constitutes the single most sensitive search for $t \to Hc$ decays to date. The combination of the three ATLAS searches yields the most sensitive direct bounds on tqH interactions to date.

References

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