Search for a charged Higgs boson decaying to a top and a bottom quarks in ATLAS

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A search for charged Higgs bosons decaying to a top quark and a bottom quark is presented. The analysis uses 13.2 fb^{-1} of pp collision data at a centre-of-mass energy of 13 TeV collected with the ATLAS detector at the Large Hadron Collider. No significant excess above the background-only hypothesis is observed and upper limits on the production cross section times the decay branching fraction are set.

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The Standard Model of particle physics (SM) does not comprise any charged scalar bosons, but many theories beyond the Standard Model (BSM) include an extended Higgs sector with at least one pair of charged Higgs bosons. [1] The discovery of a charged scalar boson would thus be a clear indication of BSM physical phenomena. The production mechanisms and decay modes of charged Higgs bosons depend on their mass, and for a charged Higgs boson heavier than the top-quark mass the dominant production mode is in association with a top quark. The decay depends on the parameters of the model, and for two-Higgs-doublet models in the limit of $\cos(\beta - \alpha) \approx 0$ [2] the dominant decay mode is $H^+ \to tb$.

In these proceedings, a search for H^+ production in pp collisions at a centre-of-mass energy of 13 TeV collected with the ATLAS detector [1] at the Large Hadron Collider (LHC) is presented. The analysis uses 13.2 fb^{-1} of pp collision data recorded during 2015 and part of 2016, and targets H^+ decays to a top quark and a bottom quark [2]. The events were recorded using single-lepton triggers and only events with exactly one lepton (electron or muon) in the final state are considered. The lepton must be associated with the lepton trigger and have p_T above 25 GeV. In addition, events must contain at least four jets with a p_T larger than 25 GeV, of which at least two must be b-tagged. The b-tagging algorithm has an efficiency of 70% for b-jets in $t\bar{t}$ events, and c-jet and light-jet rejection factors of 8 and 440, respectively. After event selection, $t\bar{t}$ events are the main background, which is simulated using the Powheg-Box v2 next-to-leading order (NLO) in QCD generator with the CT10 parton density function (PDF) set. The tbH^+ process is modelled by Madgraph5_aMC@NLO, which is a NLO in QCD generator, using the four-flavour scheme, with the NNPDF2.3 PDF set. Details about the generators can be found in reference [2].

To take advantage of the larger jet and b-jet multiplicities of events with a $H^+ \to tb$ decay with respect to the SM background, events passing the event selection are categorised into separate regions according to their jet and b-jet multiplicities. Signal regions (SR) are those where $H^+ \to tb$ events are enhanced with respect to the backgrounds, whereas the remaining regions are taken as control regions (CR) and are designed to measure backgrounds and to constrain systematic uncertainties. Four CR (4j2b, 4j≥3b, 5j2b and ≥6j2b) and four SR (5j3b, 5j≥4b, ≥6j3b and ≥6j≥4b), where XjYb means that X jets are found in the event and among them Y are b-tagged, are used in the analysis.

Different discriminant variables to separate signal from background are used depending on the event category. The variable chosen in the CR is the scalar sum of the p_T of the selected jets, H_T^{had}, whereas the output of boosted decision trees (BDTs) is used in the SR. The BDTs are trained separately at each value of the H^+ mass. Twelve kinematical variables [2] enter the BDTs, among them the leading jet transverse momentum, the scalar sum of transverse energies of all jets, or the average angular separation of all bb pairs, but no reconstruction of the charged Higgs boson kinematics has been attempted. This set of variables provides the best signal-background separation across all H^+ mass hypotheses. Figure 1 shows the expected BDT output distributions for signal and background for two values of the H^+ mass hypothesis.

A binned maximum-likelihood fit to the data is performed simultaneously in all categories.

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[1] For simplicity, in the following, charged Higgs bosons are denoted H^+, with the charge-conjugate H^- always implied.

[2] $\tan \beta$ is the ratio of the vacuum expectation values of the two Higgs doublets, and α is the mixing angle between the CP-even Higgs bosons.
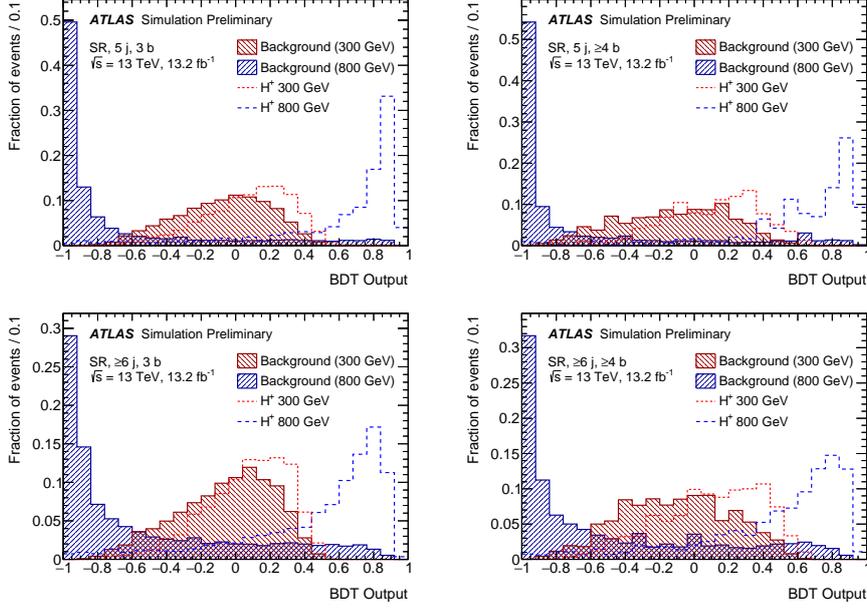
Figure 1: Expected BDT output distribution for SM backgrounds and for two H^+ signal mass hypotheses (300 and 800 GeV), in the four SR: 5j3b (top left), 5j$\geq$4b (top right), $\geq$6j3b (bottom left) and $\geq$6j$\geq$4b (bottom right). All distributions are normalised to unity [2].

The inputs to the fit are the distributions of H_T^{had} in the CR and the BDT outputs in the SR. Each mass hypothesis is tested separately. Figure 2 shows the selected data compared with the SM background expectation before and after the fit.

The procedures used to quantify the agreement with the background-only hypothesis and to determine exclusions limits are based on the profile likelihood ratio test. The parameter of interest is the product of the production cross section $\sigma(pp \rightarrow tbH^+)$ and the branching fraction $\text{BR}(H^+ \rightarrow tb)$, referred to as the signal strength μ. The normalisations of the $t\bar{t}+ \geq 1b$ and $t\bar{t}+ \geq 1c$ background components are also taken as free-floating parameters in the fit. All systematic uncertainties are implemented as nuisance parameters with log-normal constraint terms. There are about 150 nuisance parameters considered in the fit. A summary of the systematic uncertainties is given in table 1.

The modified frequentist method (CLs) [3] and asymptotic formulae [4] are used to calculate upper limits on $\sigma(pp \rightarrow H^+) \times \text{BR}(H^+ \rightarrow tb)$. The 95% confidence level (CL) upper limits are presented in Figure 3. The mass hypotheses are tested in 50 GeV steps between 300 and 400 GeV and 100 GeV steps between 400 and 1000 GeV. The observed (expected) 95% CL upper limits on $\sigma(pp \rightarrow H^+) \times \text{BR}(H^+ \rightarrow tb)$ range from $\sigma \times \text{BR} = 1.09\,(1.45)$ pb at $m_{H^+} = 300$ GeV to $\sigma \times \text{BR} = 0.18\,(0.17)$ pb at $m_{H^+} = 1000$ GeV. The compatibility of the data with the SM hypothesis is quantified with the p_0 value. The smallest p_0 value is 0.017, found at 600 GeV, corresponding to 2.1 standard deviations.

Figure 3 also shows the limits set on $\tan\beta$ for the $m_h^{\text{mod}-}$ scenario of the MSSM [5, 6, 7]. For H^+ masses of 300-855 GeV some values of $\tan\beta$ in the range 0.5-1.7 are excluded; the expected
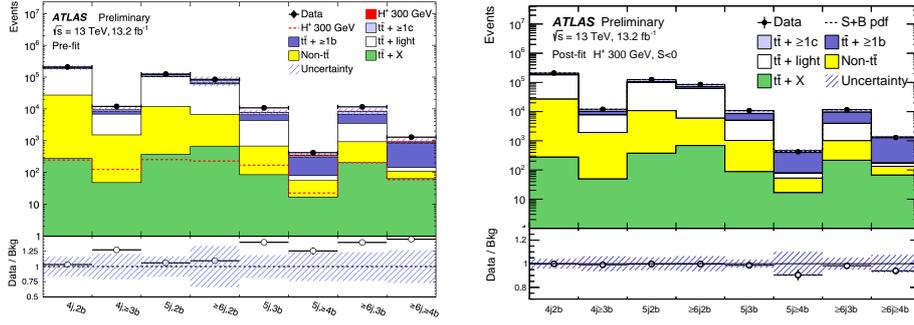
Figure 2: Comparison of predicted and observed event yields before (left) and after (right) the fit to the data under the background-plus-signal hypothesis with an H^+ signal mass of 300 GeV, as an example. $t\bar{t}+X$ includes contributions from $t\bar{t}+W$, $t\bar{t}+Z$ and $t\bar{t}+H$. The fitted signal is slightly negative (S<0) and therefore, while included, is not explicitly displayed. The lower panels display the ratio of the data to the total predicted background [2].

Uncertainty Source	$\Delta\mu(H^+_{300})$		$\Delta\mu(H^+_{800})$	
$t\bar{t}+ \geq 1b$ modelling	+0.53	−0.53	+0.07	−0.07
Jet flavour tagging	+0.30	−0.29	+0.07	−0.07
$t\bar{t}+ \geq 1c$ modelling	+0.23	−0.22	+0.03	−0.03
Background model statistics	+0.19	−0.19	+0.05	−0.05
Jet energy scale and resolution	+0.18	−0.17	+0.03	−0.03
$t\bar{t}$+light modelling	+0.16	−0.16	+0.03	−0.03
Other background modelling	+0.15	−0.14	+0.03	−0.03
Jet-vertex association, pileup modelling	+0.12	−0.11	+0.01	−0.01
$t\bar{t}+ \geq 1c$ modelling	+0.23	−0.22	+0.03	−0.03
Background model statistics	+0.19	−0.19	+0.05	−0.05
Jet energy scale and resolution	+0.18	−0.17	+0.03	−0.03
$t\bar{t}$+light modelling	+0.16	−0.16	+0.03	−0.03
Other background modelling	+0.15	−0.14	+0.03	−0.03
Jet-vertex association, pileup modelling	+0.12	−0.11	+0.01	−0.01
Luminosity	+0.12	−0.12	+0.01	−0.01
Light lepton (e,μ) ID, isolation, trigger	+0.01	−0.01	< +0.01	< −0.01
Total systematic uncertainty	+0.72	−0.79	+0.13	−0.11
$t\bar{t}+ \geq 1b$ normalisation	+0.36	−0.36	+0.03	−0.03
$t\bar{t}+ \geq 1c$ normalisation	+0.15	−0.14	+0.02	−0.02
Total statistical uncertainty	+0.44	−0.43	+0.08	−0.08
Total	+0.84	−0.90	+0.15	−0.13

Table 1: Summary of the effects of the systematic uncertainties on μ for an H^+ signal with a mass of 300 GeV (left) and 800 GeV (right). Due to correlations between the different sources of uncertainties, the total systematic uncertainty can be different from the sum in quadrature of the individual sources. The normalisation factors for both $t\bar{t}+ \geq 1b$ and $t\bar{t}+ \geq 1c$ are included in the statistical component [2].

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exclusion line reaches $\tan\beta = 0.5$ at an H^+ mass value of 948 GeV. For H^+ masses around 300 GeV the most stringent limits on $\tan\beta$ are set, and high values of $\tan\beta$ are excluded in the observed (expected) H^+ mass range 300-366 (300-378) GeV, the observed exclusion ranging from $\tan\beta > 44$ at 300 GeV to $\tan\beta > 60$ at 366 GeV.
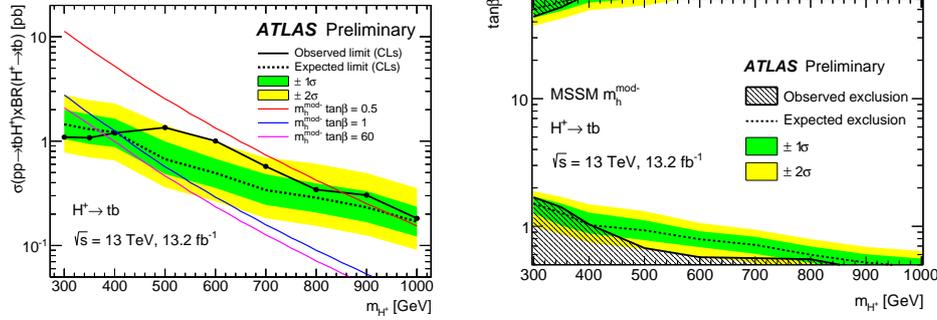
Figure 3: (left) Expected and observed limits for the production of $H^+ \rightarrow tb$ in association with a top quark and a bottom quark, as well as bands for the 68% and 95% confidence intervals; (right) Expected and observed limits on $\tan\beta$ as a function of the charged Higgs boson mass, as well as 68% and 95% confidence intervals in the $m_h^{\text{mod}-}$ scenario of the MSSM [2].

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