HOW TO LOOK FOR A CHARGED HIGGS IN ATLAS DATA. THE MVA APPROACH*

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The ATLAS experiment at the Large Hadron Collider searches for very rare processes of the beyond Standard Model physics. The greatest challenge in these studies is to extract the extremely rare signals from overwhelming background that arise from the Standard Model processes. The use of the multivariate analysis techniques is crucial in achieving this goal. An example of such a signal would be the production of a charged Higgs boson, predicted, for example, by the Two-Higgs-Doublet Model. This paper presents two analyses: the search for the charged Higgs boson decaying into a τ lepton and neutrino, based on 2015–2016 data; and the search for the charged Higgs boson decaying into top and bottom quarks, based on the data from the whole Run 2. The different applications of the multivariate analysis are presented.

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1. Introduction

The Higgs boson was discovered in 2012 by the ATLAS [1] and CMS [2] experiments at the Large Hadron Collider (LHC) [3, 4]. Even though its properties are consistent with the particle predicted by the Standard Model (SM), some beyond the Standard Model (BSM) theories — like Two-Higgs-Doublet Model (2HDM) — predict the existence of the extended scalar sector, which would include more than one Higgs boson. Specifically in 2HDM five Higgs states are predicted: two CP-even neutral bosons, one of which would be the particle observed at the LHC; two charged bosons $H^{\pm}$; and one CP-odd neutral boson [5]. In type-II, 2HDM $H^{\pm}$ production and its decay modes depend on its mass. In the mass range above the mass of top quark, the dominant decay channel is $H^{\pm} \to tb$. Below the mass of top

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quark, the dominant decay channel is $H^{\pm} \to \tau\nu$, which also remains significant in the higher masses for high values of the ratio of the two doublets vacuum expectation values ($\tan(\beta)$). Therefore, both of these channels are worth investigating for the wide range of $H^{\pm}$ mass. Due to the overwhelming SM background in both cases, an effective method of signal–background separation is needed.

2. Search for a charged Higgs boson decaying via $H^{\pm} \to \tau\nu$

The $H^{\pm} \to \tau\nu$ analysis is based on 36.1 fb^{-1} pp collision data of $\sqrt{s} =$ 13 TeV collected by the ATLAS experiment in 2015 and 2016. The investigated signal mass range of $H^{\pm}$ is 90–2000 GeV. Only hadronically decaying τ are taken into account. Two different channels are considered depending on the decay mode of the W produced in association with $H^{\pm}$: either into hadrons (τ-jet) or leptons (τ-lep). Outside of the Signal Region, two Control Regions are introduced in order to check the modelling of the background estimation. The main backgrounds to this process are $t\bar{t}$ production and jets misidentified as τ. Backgrounds with true τ are estimated with Monte Carlo (MC) simulations, backgrounds with τ faked by lepton — with MC and data-driven corrections, and backgrounds with τ faked by jets — with data-driven fake-factor method. A full description of the $H^{\pm} \to \tau\nu$ analysis strategy and event selection can be found in [6].

In the presented analysis, the Boosted Decision Trees (BDTs) machine learning algorithm is used for separating the signal from the background. The training of the BDTs is performed using the FastBDT [9] library via the TMVA toolkit [10]. Ten kinematic variables are used as an input to the algorithm, and its output score is used for the separation. BDTs are trained separately for τ-jet and τ-lep channels, for 1-prong and 3-prong events, and for five $H^{\pm}$ mass ranges: 90–120 GeV, 130–160 GeV, 160–180 GeV, 200–400 GeV, and 500–2000 GeV. The BDTs scores obtained for different mass ranges and decay channels are shown in figure 1. Good separation between the signal and background can be observed, specifically for the high-$H^{\pm}$ masses. Good agreement between the data and predicted background can be observed.

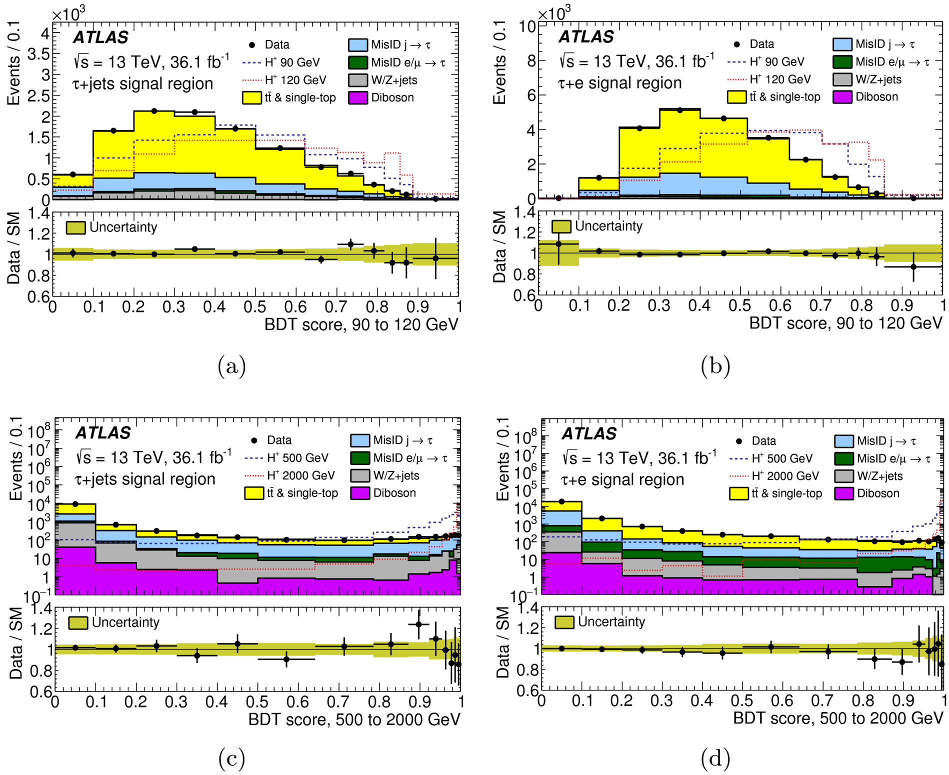

Fig. 1. BDT score distributions for τ-jet channel, 90–120 GeV mass range (a), τ-lep channel, 90–120 GeV mass range (b), τ-jet channel, 500–2000 GeV mass range (c), and τ-lep channel, 500–2000 GeV mass range (d) [6].

3. Search for a charged Higgs boson decaying via $H^{\pm} \to tb$

The $H^{\pm} \to tb$ analysis is based on 139 fb^{-1} pp collision data of $\sqrt{s}$ = 13 TeV collected by the ATLAS experiment in Run 2 (2015–2016). The investigated signal mass range is 200–2000 GeV. Four signal regions are targeted, depending on the number of jets (j) and b-tagged jets (b): 5j3b, 5j$\geq$4b, $\geq$6j3b, $\geq$6j$\geq$4b. The most significant background comes from $t\bar{t}$ production. A full description of the $H^{\pm} \to tb$ analysis strategy and event selection can be found in [7].

In the presented analysis, the Parametrised Neural Networks (PNNs) [8] machine learning algorithm is used. A single parameterized network can replace a set of individual networks trained for specific cases, as well as smoothly interpolate to cases where it has not been trained. In the presented analysis, the $H^{\pm}$ mass is used as a parameter, as opposed to the separate training of BDTs for different mass ranges in the $H^{\pm} \to \tau\nu$ analysis. PNNs are trained separately for different signal regions and high-level kinematic variables are used as the input. The PNNs scores for different signal masses in various signal regions are shown in figure 2. Good agreement between the data and predicted background can be observed.

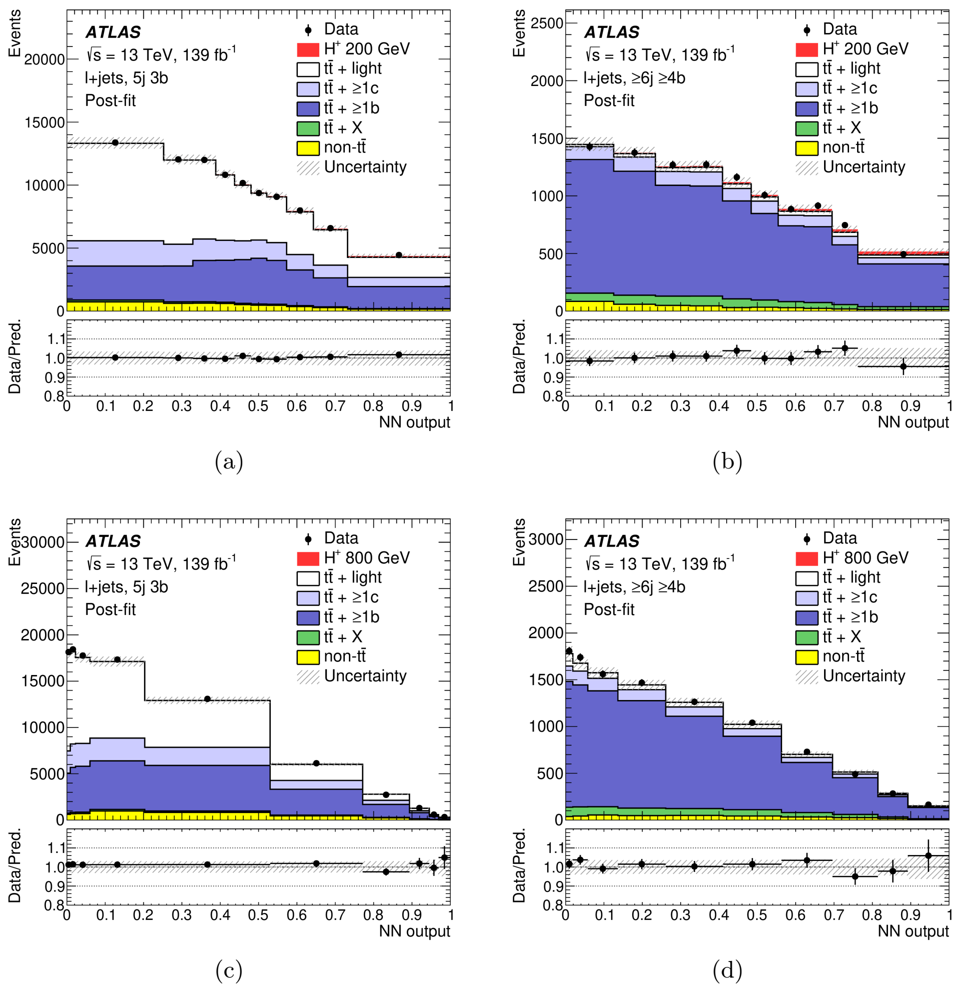

Fig. 2. PNNs score distributions for 5j3b region, $H^{\pm}$ mass 200 GeV (a), 6j4b region, $H^{\pm}$ mass 200 GeV (b), 5j3b region, $H^{\pm}$ mass 800 GeV (c) and 6j4b region, $H^{\pm}$ mass 800 GeV (d) [7].

4. Results

Both presented analyses found a good agreement between the data and the background-only hypothesis. No statistically significant deviations from the SM predictions were found. Upper limits at the 95% confidence level for the mass range of $m_{H^\pm} = 90$–2000 GeV were set on the production cross section of the $H^\pm$ times the branching fraction $\mathcal{B}(H^+ \to \tau\nu)$ in the range of 4.2–0.0025 pb. For the production cross section of the $H^\pm$ times the branching fraction $\mathcal{B}(H^+ \to tb)$, upper limits at the 95% confidence level range from 3.6 pb for $H^\pm$ mass of 200 GeV to 0.036 pb for $H^\pm$ mass of 2000 GeV. Results from both analyses allowed for tightening the limits on the parameters of Minimal Supersymmetric Standard Model extension (MSSM), see figure 3.

In both presented analyses, the multivariate analysis methods proved to be a valuable tool for separating the signal from the background. In particular, PNNs prove to be a very efficient method for data analysis.

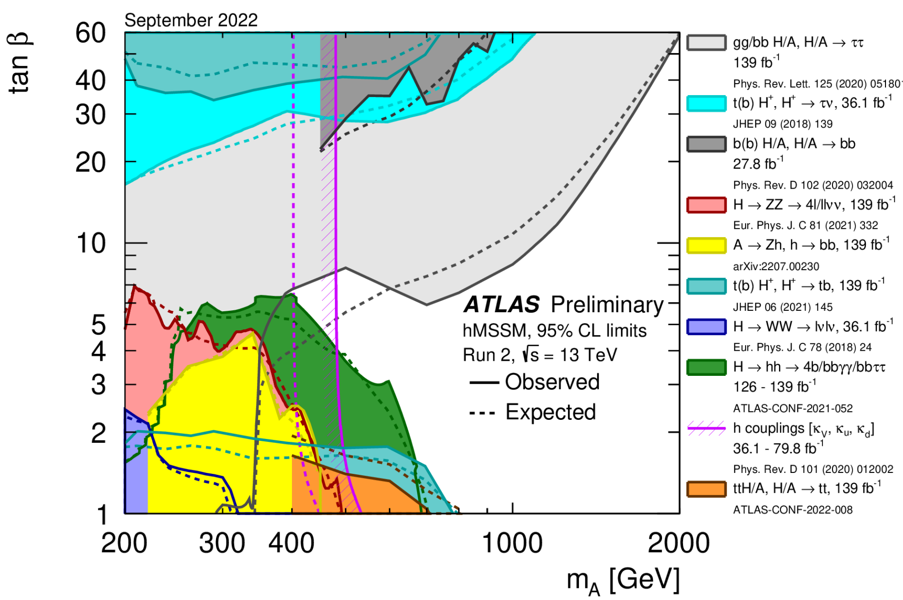

Fig. 3. Exclusion limits on $\tan(\beta)$ in the context of hMSSM. Results from both described analyses are included [11].

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