Search for associated production of a Higgs boson and a single-top quark in the $2\ell+\tau_{had}$ final state at 13 TeV in ATLAS

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The discovery of a Higgs boson by the ATLAS and CMS experiments in 2012 opened a new field for exploration in the realm of particle physics. In order to better understand the Standard Model (SM) of particle physics, it is of prominent interest to understand the Yukawa coupling of the Higgs boson to the top quark (y_t), being the latter the most massive fundamental particle and, consequently, the one with the largest coupling to the Higgs boson.

The direct measurement of y_t is only possible at the LHC via two associated Higgs productions: with a top-quark-antiquark pair ($t\bar{t}H$) and with a single-top quark (tH). While the $t\bar{t}H$ just permits the determination of the magnitude of y_t, the only way of directly measuring its sign is through the tH production (Fig. 1). This is due to the fact that the two leading order Feynman diagrams for the tH production interfere with each other depending on the y_t sign. Current experimental constrains on y_t favour the SM predictions, but an opposite sign with respect to the expectations of the SM is not completely excluded yet [2].

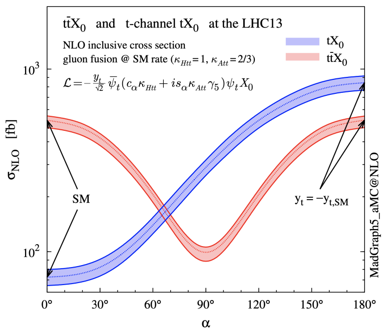

Figure 1. Production cross-section as a function of the CP mixing angle, α, at NLO for tX_0 and $t\bar{t}X_0$, where X_0 represents a Higgs boson [1].

In this work it is presented a search for the tH production in a final state with two light-flavoured-charged leptons (electrons or muons) and one hadronically-decaying tau lepton (named $2\ell+\tau_{had}$ channel). This analysis uses an integrated luminosity of 139 fb^{-1} of proton-proton collision data at centre-of-mass energy of 13 TeV collected by the ATLAS detector during LHC Run 2.

This search is exceptionally challenging due to the extremely small cross-section of the tH process (70 fb), and of the $2\ell+\tau_{had}$ final-state channel, in particular, which only accounts for a 3.5% of the total tH production. Therefore, the separation of the tH signal events from background events is done by means of machine-learning (ML) techniques using boosted-decision trees (BDT) to define both signal (Fig. 2) and control regions to constrain the most important background processes, which are those related to top-quark-antiquark-pair production without and with and additional boson ($t\bar{t}$, $t\bar{t}H$, $t\bar{t}W$ and $t\bar{t}Z$) and Z boson plus jets.

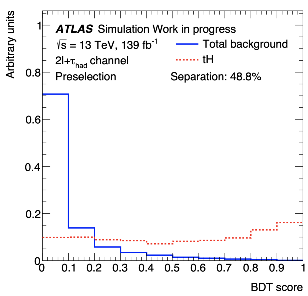

Figure 2. Score of the BDT targeting tH events over all backgrounds, used to define the signal region.

Significant suppression of the background events with jets wrongly selected as leptons or non-prompt leptons originating from heavy-flavour decays is achieved by demanding electrons and muons to pass strict identification and isolation requirements. Simultaneously, hadronic-τ leptons are demanded to pass the requirement of a recurrent-neural-network-based discriminator to reduce misidentifications from jets.

The reconstruction of the events is also enhanced by similar ML methods since in the scenario in which the light-flavour leptons have the same sign, a priori, it is not possible to determine which lepton is originated from the Higgs boson and which from the top quark.

The possible observation of an excess of signal events with respect to the SM prediction, would be an evidence of new physics in terms of CP-violating y_t coupling.

[1] F. Demartin, F. Maltoni, K. Mawatari and M. Zaro, *Eur. Phys. J. C* **75** (2015) 267.
[2] CMS Collaboration, *Eur. Phys. J. C* **81** (2021) 378