

Search for charged lepton-flavour violation in top-quark decays
at the LHC with the ATLAS detectorCARLO A. GOTTARDO¹, ON BEHALF OF THE ATLAS COLLABORATION*Physikalisches Institut
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A direct search for charged lepton-flavour violation in top-quark decays is presented. The data analysed correspond to 79.8 fb^{-1} of proton–proton collisions at a centre-of-mass energy of $\sqrt{s} = 13 \text{ TeV}$ recorded by the ATLAS experiment at the LHC. The process studied is the production of top-quark pairs, where one top quark decays into a pair of opposite-sign different-flavour charged leptons and an up-type quark, while the other decays semileptonically according to the Standard Model. The signature of the signal is thus characterised by the presence of three charged leptons, a light jet and a b -jet. A multivariate discriminant is deployed and its distribution used as input to extract the signal strength. In the absence of a signal, an upper limit on the branching ratio of $\mathcal{B}(t \rightarrow \ell\ell'q) < 1.86 \times 10^{-5}$ is set at the 95% confidence level.

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1 Introduction

The observation of charged lepton-flavour violation (cLFV) would provide a strong evidence for New Physics, beyond the simple inclusion of right-handed neutrinos in the Standard Model (SM) [1]. Several extensions to the SM entail cLFV [1], but a model-independent approach, based on effective field theory (EFT), is adopted here. The set of operators reported in Equation 1, describing two-lepton, two-quarks contact interactions, induces cLFV in processes involving the top quark. The notation $e_i = \{e, \mu, \tau\}$ and $u_q = \{u, c\}$ is used, and $H, H', \bar{H} = L, R$ indicate the chirality of the projectors P , with $H \neq \bar{H}$.

$$\begin{aligned}
 \mathcal{O}_{HH'}^{AV} &= (\bar{e}_i \gamma^\alpha P_H e_j)(\bar{u}_q \gamma_\alpha P_{H'} t), \\
 \mathcal{O}_H^{S+P} &= (\bar{e}_i P_H e_j)(\bar{u}_q P_H t), \\
 \mathcal{O}_H^{S-P} &= (\bar{e}_i P_H e_j)(\bar{u}_q P_{\bar{H}} t), \\
 \mathcal{O}_H^{LQ} &= (\bar{u}_q P_H e_j)(\bar{e}_i P_H t).
 \end{aligned}
 \tag{1}$$

The couplings of the operators are rather unconstrained, allowing for a branching fraction of the decay $t \rightarrow e\mu q$, with $q = u, c$, of order 10^{-3} , well within the sensitivity of the Large Hadron Collider (LHC) and not previously probed directly [2]. Taking advantage of the copious production of top-quark pairs at the LHC, the present analysis investigates the decay $t(\bar{t}) \rightarrow \ell^\pm \ell'^\mp q(\ell^\pm \ell'^\mp \bar{q})$ with $\ell = \{e, \mu, \tau\}$ and $q = \{u, c\}$, in $t\bar{t}$ events, where the other top quark of the pair decays semileptonically, according to the SM. Signal events are generated at leading order precision in QCD with MADGRAPH5_aMC@NLO interfaced with PYTHIA. The response of the detector is simulated with GEANT4. The search is performed using the pp collision data collected by ATLAS [3] in 2015, 2016 and 2017, corresponding to an integrated luminosity of 79.8 fb^{-1} . More details about the analysis can be found in Reference [4].

2 Analysis strategy

Only events with three reconstructed charged light leptons (electrons or muons, called leptons in the following) and at least two jets are selected. Events having two opposite-sign same-flavour leptons whose invariant mass is within 81.2 and 101.2 GeV, or less than 15 GeV are vetoed. At most one b -tagged jet is allowed. The signal region is defined by requiring the presence of at least one electron and at least one muon. The signal kinematic is reconstructed, and a multivariate discriminant, namely a boosted decision tree (BDT), is trained in the signal region in order to separate the signal from all backgrounds. Thirteen input variables are selected and provided to the BDT, which is trained on simulated events. Several sources of background populate the signal region: $t\bar{t}$, Z + jets, diboson production, $t\bar{t}Z$, $t\bar{t}W$, $t\bar{t}H$, associated

single-top production as tZ , tWZ and tH , and other minor processes. Despite the fact that three isolated leptons are required, $t\bar{t}$ and $Z + \text{jets}$ constitute the largest fraction of background (60% in the signal region), due to the occurrence of additional non-prompt leptons originating from secondary processes, such as the decay of a b - or c -hadrons, photon conversion or object mis-reconstruction. This so-called non-prompt lepton background is related to the details in the particles' interactions with the detector material, therefore it has been modelled with a data-driven approach. The technique used provides, through data events reweighting, both normalisation and shape predictions for the non-prompt lepton background. The total expected background is obtained by combining the data-driven non-prompt lepton background prediction with simulated events containing three prompt leptons in the region's acceptance.

Systematic uncertainties, including both normalisation and shape components, are derived and assigned to the data-driven non-prompt lepton background. Modelling and instrumental uncertainties are assigned to the simulated event samples. The most impacting uncertainties are those associated to the non-prompt lepton background, which correspond to a 10% variation in the total background yield and to a 9% variation in the observed limit.

3 Results

The expected and observed event yields in the signal region are summarized in Table 1. The full BDT distribution, presented in Figure 1, is used as input for a binned profile-likelihood fit, meant to test for the presence of signal events. The data are found to be compatible with the absence of the signal and an upper limit is set at the 95% confidence level, using the CL_s method. The observed and expected limits on the cLFV decay branching ratio are:

$$\mathcal{B}(t \rightarrow \ell\ell'q) < 1.36_{-0.37}^{+0.61} \times 10^{-5} \quad (\text{expected}),$$

$$\mathcal{B}(t \rightarrow \ell\ell'q) < 1.86 \times 10^{-5} \quad (\text{observed}).$$

The upper limit is recomputed removing all generated signal events where a τ lepton is present in the cLFV decay vertex, resulting in:

$$\mathcal{B}(t \rightarrow e\mu q) < 4.8_{-1.4}^{+2.1} \times 10^{-6} \quad (\text{no } \tau \text{ in cLFV vertex, expected}),$$

$$\mathcal{B}(t \rightarrow e\mu q) < 6.6 \times 10^{-6} \quad (\text{no } \tau \text{ in cLFV vertex, observed}).$$

Table 1: Background and data events expected in the signal region [4].

Non-prompt leptons	WZ	ZZ	$t\bar{t}V$	Other prompt SM	Expected events	Data
1190(180)	350(140)	140(52)	108(10)	76(10)	1860(230)	1857

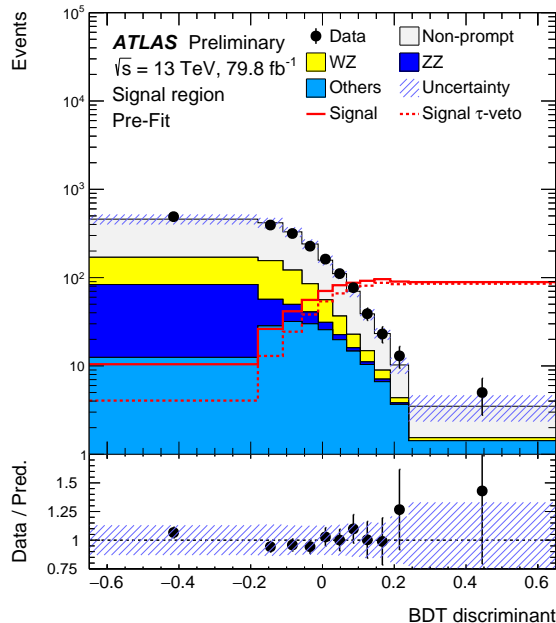


Figure 1: BDT discriminant distribution, with the signal including and excluding τ leptons (Signal τ -veto) in the cLFV vertex overlaid. The signals are normalised to the branching fraction $\mathcal{B}(t \rightarrow \ell^\pm \ell'^\mp q) = 3 \times 10^{-4}$ and $\mathcal{B}(t \rightarrow e\mu q) = 1 \times 10^{-4}$, respectively. All sources of systematic uncertainty are included. Data (black points) are compared to the sum of backgrounds in the upper panel, while the ratio is shown in the lower panel [4].

References

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