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Searches for FCNC and lepton flavour violating interactions of the top quark with the ATLAS detector

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The LHC is a top quark factory and provides a unique opportunity to look for flavour changing neutral current or charged-lepton flavour violating interactions of the top quark. These processes are highly suppressed in the Standard model and are beyond the experimental sensitivity, but can receive enhanced contributions in many extensions of the Standard model. An overview of the ATLAS results of this search programme is presented, with emphasis on recent searches for flavour changing neutral current tqH, tqZ, and $tq\gamma$ vertices. A search for $e\mu tq$ vertices is also presented. All searches find good agreement with the background expectation and derived exclusion bounds are improved very significantly.

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1 Introduction

Until 2012, the Higgs boson was the last undiscovered particle of the Standard model (SM). The observation of the Higgs boson [1, 2] at the Large Hadron Collider (LHC) by the ATLAS and CMS collaborations completed the SM. Nonetheless, the physics programme of the LHC experiments is still rich. The precision of the measurements of the Higgs boson and top quark properties are being improved, and searches for rare new-physics processes beyond the SM (BSM) are tightening the limits. A part of the programme are also a searches for flavour changing neutral currents (FCNC) and charged-lepton flavour violation (cLFV) interactions involving Higgs boson and/or top quark. In this paper, we present the latest results of these searches provided by the ATLAS [3] experiment using full Run 2 data of 13 TeV proton-proton collisions.

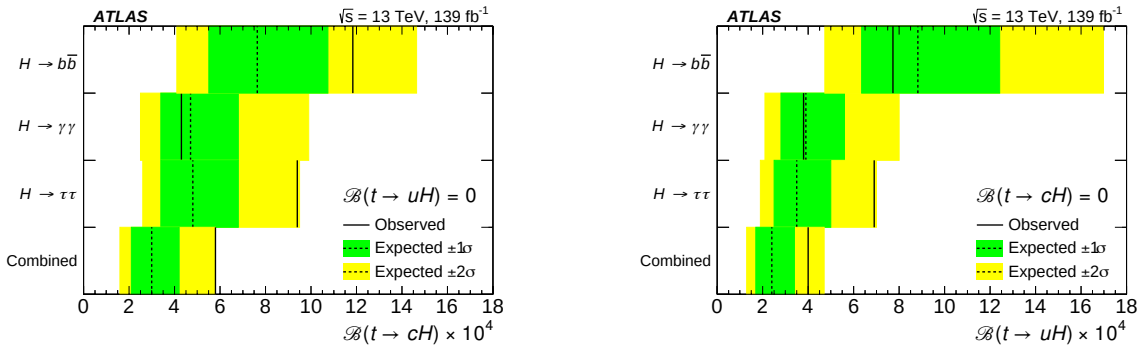
2 Flavour changing neutral currents

In the SM, the FCNC interactions are forbidden at the tree level and very suppressed at the higher orders. For decay $t \to qX$, where q stands for up-type quark (up or charm) and X represents H boson, Z boson, gluon or photon, the predicted branching ratios are at the level of 10^{-16} – 10^{-12} [4]. However, if BSM scenarios are taken into account, these branching ratios are several orders of magnitude larger [5] and could be observed at the LHC.

In the recent search for the FCNC [6], the interaction of top quark, Higgs boson and up-type quark are studied in events with the Higgs boson decaying to two photons. The integrated luminosity of the data sample used in this analysis is increased by factor of about 4 with respect to previous ATLAS measurement [7]. The following processes are investigated: associated production of single top quark and Higgs boson via FCNC vertex; and top-quark pair production with one of the top quark decaying according the SM to W boson and b quark and another top quark decaying via the FCNC vertex to Higgs boson and up-type quark (up or charm). According the decay of W boson, events with two photons and one b-tagged jet are divided into leptonic and hadronic channels. Further categorization is based on e.g. number of jets, reconstructed invariant mass(es) of top quark(s) in order to distinguish between $pp \to tH$ and $pp \to t\bar{t}$ production. In the latter case, charm tagging is used to identify tcH and tuH processes. In addition, three different boosted decision trees are employed in different event categories to suppress the background and improve sensitivity of the analysis. The branching ratio of decay $t \to c(u)H$ is determined in fit to data using a likelihood function. Two different likelihood constructions are used. In 9 of the overall 10 event categories, standard unbinned extended likelihood is used, while the background shape is estimated from the distribution of the invariant mass of the two photons, $m_{\gamma\gamma}$, using MC simulations. In one category, due to lack of statistics

in region of $m_{\gamma\gamma} \in [100, 122] \cup [129, 160]$ GeV, simple event counting is used. Data and SM predictions agree within uncertainties, i.e. no statistically significant excess due to FCNC coupling is observed. Using the CL_s method [8], the observed (expected) 95% confidence level (CL) upper limits on branching ratio are 4.3×10^{-4} (4.7×10^{-4}) for the $t \to cH$, and 3.8×10^{-4} (3.9×10^{-4}) for the $t \to uH$. The sensitivity of the analysis is limited by the statistical precision. The most relevant systematic uncertainties coming from non-resonant background estimation, photon energy resolution, the $t\bar{t}$ cross-section, the $H \to \gamma\gamma$ branching ratio, and the parton shower description. Thanks to improved event reconstruction and event categorization, the enhance of the sensitivity of the analysis is about factor of 1.5 better than expected from the increase of the integrated luminosity.

The recent tqH analysis with $H \to \gamma\gamma$ [6] is combined with the previous results from tqH with $H \to b\bar{b}$ [9] and $H \to \tau\tau$ [10]. The summary of the upper limits on the branching ratios from the individual measurements and the combination is shown in Fig. 1. As the individual measurements have different dominant systematic uncertainties and searches with $H \to \gamma\gamma$ and $H \to \tau\tau$ decays are limited by statistical uncertainty, the combined results have low sensitivity to assumed correlations. The observed limits on the branching ratios from the combination are translated to the upper limits on the corresponding Wilson coefficients in the SM effective field theory: $C_{c\phi} = 1.07$, $C_{u\phi} = 0.88$ [6].



(a) (b)

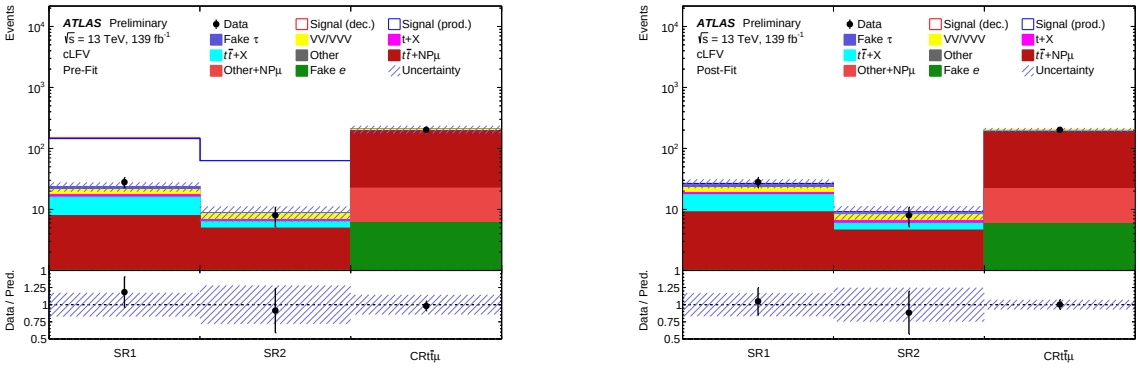
Figure 1: 95% CL upper limits on (a) $\mathcal{B}(t \to cH)$ assuming $\mathcal{B}(t \to uH) = 0$ and (b) $\mathcal{B}(t \to uH)$ assuming $\mathcal{B}(t \to cH) = 0$ for the individual searches and their combination.

The 95% confidence level observed limits on the branching ratios of the top quark decays via FCNC to up-type quark and a neutral boson provided by ATLAS are summarized Ref. [11].

3 Charged-lepton flavour violation

Until the observation of neutrino oscillations, the flavour of the charged and neutral leptons was expected to be conserved in the SM. Production rate of cLFV processes are far beyond current experimental sensitivity [12]. In extensions of the SM, non-zero neutrino mass and mixing is provided together with local conservation of charged-lepton flavor. Observation of cLFV process would be a sign of new physics.

In the recent analysis [13], $pp \to t\bar{t}$ (with $t \to \ell^{\pm}\ell'^{\mp}q_k$ decay) and $gq_k \to t\ell^{\pm}\ell'^{\mp}$ production processes are investigated, where q_k stands for up-type quark (up or charm) and opposite signed leptons $\ell^{\pm}\ell'^{\mp}$ represent pair $\tau\mu$ or $\mu\tau$. In the event selection, presence of the hadronically decaying τ, at least one jet and exactly one b-jet is required. In addition, there have to be two same-sign muons in the event - one from the semileptonic decay of top quark, another from cLFV vertex. Selected events are divided into two signal regions, one for each production process. A control region is defined for the dominant background process, which is dilepton decay channel of $t\bar{t}$ production with additional non-prompt μ from heavy-flavour decay inside a jet. The event yields in the two signal regions and background control region are shown in Fig. 2. The normalisation factors for these three regions are obtained by simultaneous profile-likelihood fit. The measured data and SM predictions agree within the uncertainties and no significant cLFV contributions are observed. The results are interpreted as constraints on the Wilson coefficients related to top quark 2-quark-2-lepton operators involving μ and τ in the effective field theory, which were highly unconstrained prior this measurement. The obtained upper limit on $\mathcal{B}(t \to \mu\tau q)$ is 11×10^{-7} at 95% CL.



(a) (b)

Figure 2: Observed event yields compared to (a) pre-fit and (b) post-fit expectations from Monte Carlo simulations. SR1 (SR2) represents processes with $t \to \ell^{\pm}\ell'^{\mp}q_k$ decay ($gq_k \to t\ell^{\pm}\ell'^{\mp}$ production), while CR$t\bar{t}\mu$ corresponds to the control region for dominant background.

Conclusions

The recent search for FCNC in the tqH processes with H decaying to two photons provide improved limits on the $\mathcal{B}(t \to u(c)H)$. After combining this results with results from searches using tqH events with $H \to b\bar{b}$ and $H \to \tau\tau$ decays, more stringent limits on Wilson coefficients are obtained. The recent search for cLFV processes presents constraints on Wilson coefficients improved by factor of $8 - 51$ (depending on coefficient). The observed upper limit on $\mathcal{B}(t \to \mu\tau q)$ complements CMS searches for cLFV in $e\mu qt$ interactions.

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