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Search for charged lepton flavor violation in top quark interaction with an up-type quark, a muon, and a τ lepton with the CMS experiment

Jiwon Park for the CMS Collaboration

Abstract

A search for charged-lepton flavor violation (CLFV) in top quark (t) interactions is presented. Proton-proton collision data collected with the CMS experiment corresponding to an integrated luminosity of 138 fb^{-1} are used. The analysis selects events containing a single muon, a hadronically decaying τ lepton, and three jets where one has been identified to originate from the fragmentation of a bottom quark. Machine learning multiclass classification techniques are used to distinguish signal from standard model background events. The results of this search are consistent with the standard model expectations. The upper limits at 95% confidence level on the branching fraction $\mathcal{B}$ for CLFV top quark decays to a muon, a τ lepton, and an up or a charm quark are $\mathcal{B}(\mathrm{t} \rightarrow \mu\tau\mathrm{u}) < (0.04, 0.078,$ and $0.118) \times 10^{-6}$, and $\mathcal{B}(\mathrm{t} \rightarrow \mu\tau\mathrm{c}) < (0.81, 1.71,$ and $2.05) \times 10^{-6}$ for scalar, vector, and tensor-like operators, respectively.

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PROCEEDINGS OF SCIENCE

Search for charged lepton flavor violation in top quark interaction with an up-type quark, a muon, and a τ lepton with the CMS experiment

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1. Introduction

Recent combinations of B meson decay rates report a tension of up to 3.3 standard deviations between Standard Model (SM) predictions and measured values for ratios of B decays into D and D^* mesons [1]. This has sparked interest in models that aim to explain these deviations while introducing new sources of charged lepton flavour violation (CLFV) interactions including top quark. In this proceeding, a search for CLFV involving interactions with a top quark, a muon, and a τ lepton with the CMS detector [2] is presented.

2. Samples and selections

Data events were collected with the CMS detector [3] in pp collisions in the years 2016 to 2018 at $\sqrt{s}$ = 13 TeV, corresponding to an integrated luminosity of 138 fb^{-1}. Signal CLFV events are generated at leading order (LO) accuracy with MADGRAPH5 aMC@NLO 2.6.5 [4] using EFT models described in Refs. [5, 6]. The signal samples are separately produced for each Lorentz structure of operator (scalar, vector, and tensor-like operators), quark flavor (tu$\mu\tau$ and tc$\mu\tau$), and channel (single top and $t\bar{t}$, denoted as ST and TT respectively). Background processes are divided into three groups: $t\bar{t}$ pair production, single top quark production, and the other minor backgrounds, which consists of $t\bar{t}$ associated production with a vector boson or a Higgs boson, Drell–Yan and W boson production, and doubly produced vector bosons.

Events with exactly one isolated muon (p_T > 50 GeV, $|\eta|$ < 2.4) and one hadronically decaying τ lepton (τ_h, p_T > 40 GeV, $|\eta|$ < 2.3) are selected. The muon and τ_h are required to have opposite electric charges. Events are further required to have at least 3 jets (p_T > 40 GeV, $|\eta|$ < 2.4), where exactly one of the selected jets is b-tagged. A non-negligible background contribution remaining from events with misidentified τ_h candidates is estimated the ABCD method by inverting τ_h identification criteria and the charge requirement on muon and τ_h.

3. Discrimination of signal and background

In both ST CLFV and TT CLFV signal events, a hadronically decaying top quark is produced. This provides an unique signatures of CLFV signals after lepton selections, where the majority of background comes from $t\bar{t}$ dileptoic decays. The hadronic top quark is reconstructed by finding a combination of jets minimizing a χ^2 equation constructed by a sum of mass differences of W boson (di-jet) and top quark (tri-jet) candidates.

The ST CLFV and TT CLFV signals, and background processes are discriminated using a multiclass deep neural network (DNN) algorithm. A total of 28 variables are selected for the DNN classification, which include kinematic features of individual physics objects and their combinations and variables from the χ^2 reconstruction. The DNN classifier is trained for combined data-taking period and signal samples, and evaluated for each Lorentz structure and quark flavor. The three probabilities are combined into a single DNN score = $(0.1p(\text{TT CLFV})+0.9p(\text{ST CLFV}))/p(\text{background})$, which is then used for the statistical evaluation of the results.

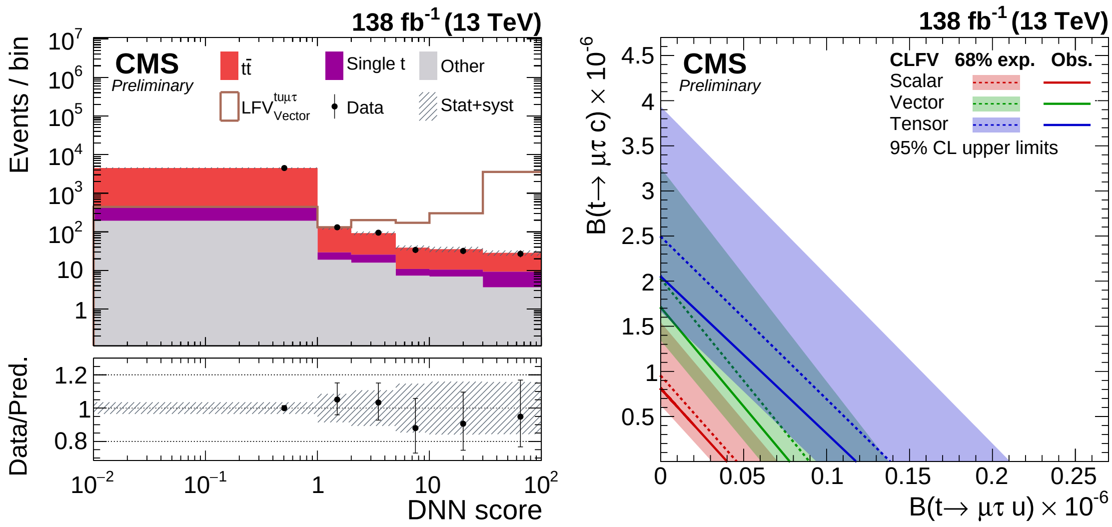

Figure 1: Left: DNN score distribution after the profile likelihood fit for all data-taking periods for the vector operators in tu$\mu\tau$ interaction. The signal distribution is normalized to the data, and the last bin of each histogram contains the overflow. The hatched bands represent the total post-fit uncertainties in the background predictions. Right: Exclusion contours for the observed and expected upper limits and central probability intervals containing 68% of the expected upper limits for the branching fractions corresponding to the tu$\mu\tau$ and tc$\mu\tau$ couplings for scalar, vector and tensor Lorentz structures.

4. Results and conclusion

A binned maximum likelihood fit is constructed using the measured distribution in the DNN score, the simulated background processes, and the predicted CLFV signals. The distribution of the DNN score is shown for tu$\mu\tau$ vector signal hypotheses in the left plot in Fig. 1 after the fit for all data-taking periods combined.

No significant excess is observed and upper limits on the cross section of CLFV operators are set at the 95% confidence level, and translated into the limits on the branching fraction. The observed limits are $\mathcal{B}(\mathrm{t} \to \mu\tau\mathrm{u}) < (0.04, 0.078, \text{and } 0.118)\times 10^{-6}$, and $\mathcal{B}(\mathrm{t} \to \mu\tau\mathrm{c}) < (0.81, 1.71, \text{and } 2.05)\times 10^{-6}$ for scalar, vector, and tensor-like operators, respectively. This search complements previous CMS analyses [7, 8] and results in more stringent upper limits by approximately a factor of two compared to the latest experimental results performed by the ATLAS Collaboration in the same CLFV interactions [9].

References

[1] HFLAV Collaboration, *Averages of b-hadron, c-hadron, and τ-lepton properties as of 2021*, *Phys. Rev. D* **107** (2023) 052008 [2206.07501]

[2] CMS Collaboration, *Search for lepton flavour violation in top quark interactions with an up-type quark, a muon, and a τ lepton*, CMS-PAS-TOP-22-011 (2024)

[3] CMS Collaboration, *The CMS experiment at the CERN LHC*, *JINST* **3** (2008) S08004

[4] J. Alwall et al., *The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations*, *JHEP* **07** (2014) 079 [1405.0301]

[5] A. Dedes et al., *SmeftFR—Feynman rules generator for the Standard Model Effective Field Theory*, *Comput. Phys. Commun.* **247** (2020) 106931 [1904.03204]

[6] I. Brivio, “SMEFTsim 3.0 — a practical guide”, *JHEP* **04** (2021) 073 [2012.11343]

[7] CMS Collaboration, *Search for charged-lepton flavor violation in top quark production and decay in pp collisions at* $\sqrt{s}$ = 13TeV, *JHEP* **06** (2022) 082 [2201.07859]

[8] CMS Collaboration, *Search for charged-lepton flavor violation in the production and decay of top quarks using trilepton final states in proton-proton collisions at* $\sqrt{s}$ = 13TeV [2312.03199] Submitted to *Phys. Rev. D.*

[9] ATLAS Collaboration, *Search for charged-lepton-flavour violating $\mu\tau qt$ interactions in top-quark production and decay in pp collisions at* $\sqrt{s}$ = 13TeV *with the ATLAS detector at the LHC*, *Phys. Rev. D* **110** (2024) 1, 012014 [2403.06742]