Update on Study for Anomalous Top FCNC Couplings at FCC-eh

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FCC Week 2019, 24 - 28 June, Crown Plaza Brussels, Belgium

Abstract

The top quark FCNC interactions would be a good test of new physics at present and future colliders. We present an update on study for top-quark-photon and top-quark-Z boson effective FCNC interaction vertices through the production process ep—>eWq+X at future circular collider-electron hadron (FCC-eh). The cross sections for the signal and interfering background have been calculated for different values of coupling parameters λ_q for tqγ vertices and κ_q for tqZ vertices. We find the sensitivities to the branching ratios BR(t->qγ)=1.5x10^{-6}, 8.5x10^{-7} and 5.5x10^{-7}, and BR(t->qZ)=9.5x10^{-6}, 6.0x10^{-6} and 4.5x10^{-6} for the integrated luminosity projections of 1, 2 and 3 ab^{-1}, respectively.

Introduction

Within the framework of the Standard Model (SM) of particle physics, the top quark (with mass $m_t \sim 173$ GeV) being the heaviest of fundamental fermions decays to a bottom quark and a W boson (most frequently) while it's decays to light down type quarks are suppressed due to the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1,2]. The dominant SM decay mode of top quark is t⟶W+b, the ratios of the SM decay widths are given as Γ(t⟶W+s)/Γ(t⟶W+b) $\simeq$ $|V_{ts}|^2/|V_{tb}|^2 \simeq 1.495 \times 10^{-3}$ and Γ(t⟶W+d)/Γ(t⟶W+b) $\simeq$ $|V_{td}|^2/|V_{tb}|^2 \simeq 6.318 \times 10^{-5}$ [3]. It is also known that flavor changing neutral current (FCNC) transitions in the up-sector or down-sector are absent at tree level. However, these transitions at the loop level are highly suppressed due to the Glashow-Iliopoulos-Maiani (GIM) mechanism [4]. The branchings for top to up-sector quark transitions are well beyond the current sensitivity of the Large Hadron Collider (LHC) experiments (reviewed in Ref. [3]). These decay modes could be enhanced in some extensions of the SM (see Fig. 1), for instance due to the presence of new virtual particles in the loops. Therefore, from both theoretical and experimental perspective, studying the top quark FCNC interactions is an important component of the top quark physics program.

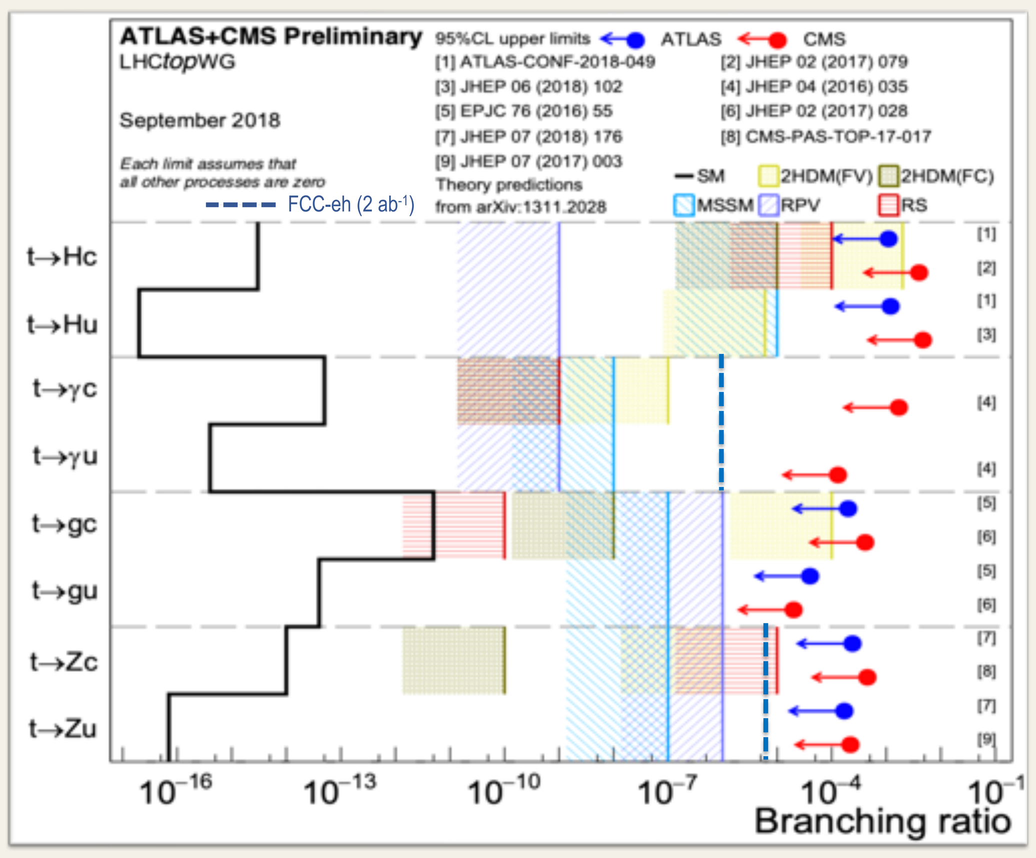

Fig. 1: Experimental limits (red and blue dots) on branching ratios for top FCNC in different decay modes and theoretical expectations beyond the standard model.

Future ep Colliders

The future ep colliders, namely LHeC [5] and FCC-eh [6] have been considered to have unique physics programme with deep inelastic scattering and electroweak physics. They would collect a factor of thousand more luminosity than the HERA (where the ep physics was explored by the years) while exhibiting the novel concept of synchronous operation alongside the pp collider. The FCC-eh collider will serve as an excellent platform for the top FCNC searches, and they have advantages with respect to the LHC (or FCC-hh) due to the clean environment (with suppressed background from strong interaction initiated processes), high precision measurements of dynamical properties of the proton allowing test of EW and QCD effects simultaneously, and a kinematic reach for asymmetric lepton-nucleon scattering at high c.m. energy.

Top FCNC Production

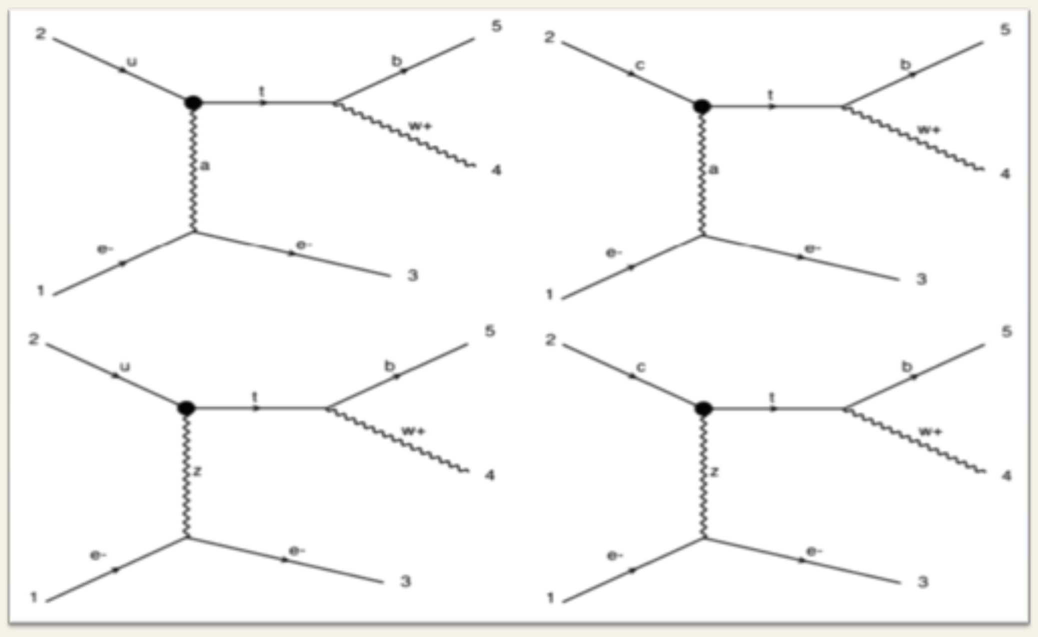

Fig. 2: Leading order diagrams including anomalous tqγ and tqZ vertices (black dot).

We study the process e−p ⟶ e−Wb (see Fig. 2) including tqγ and tqZ effective FCNC interaction vertices at future electron hadron collider, FCC-eh. The effective Lagrangian introduced in Ref. [7] is used to calculate the top quark FCNC decay widths and branching ratios, as well as the cross sections for the signal for different values of the parameters λ_q and κ_q. We produce signal and background events by using MadGraph 5_aMC@NLO [8], with an effective Lagrangian implementation through FeynRules [9] for the signal. Afterwards the parton showering and detector fast simulations are carried out with Pythia 6 [10] and Delphes 3.4 [11], respectively. For Delphes card (validated) we have used FCC-hh card for FCC-eh detector simulation. The jets were clustered using FastJet [12] with the anti-k_T algorithm [13].

Event Selection and Analysis

Table 1: Preselection and set of cuts for the analysis of signal and background events

Cuts	Definition
Cut-0	Preselection: $N_{jets} >= 3$ and $N_e >= 1$
Cut-1	$b-$tag: one $b-$tagged jet (j_b)
Cut-2	Transverse momentum: $p_T(j_2, j_3) > 30$ GeV and $p_T(j_b) > 40$ GeV and $p_T(e) > 20$ GeV
Cut-3	Pseudo-rapidity: $-4 < \eta(j_b, j_2, j_3) < 0$ and $\|\eta(e)\| < 2.5$
Cut-4	W boson mass: $50 < M_{inv}^{rec}(j_2, j_3) < 100$ GeV
Cut-5	Top quark mass: $130 < M_{inv}^{rec}(j_b, j_2, j_3) < 200$ GeV

For the event selection, we require at least three jets and one electron in the events, one of the jets should be b-tagged with leading jet p_T (j) > 40 GeV and other jets having p_T (j) > 30 GeV and |η(j)| < 2.5, the electron with p_T (e) > 20 GeV and |η(e)| < 2.5 (cuts given in Table 1).

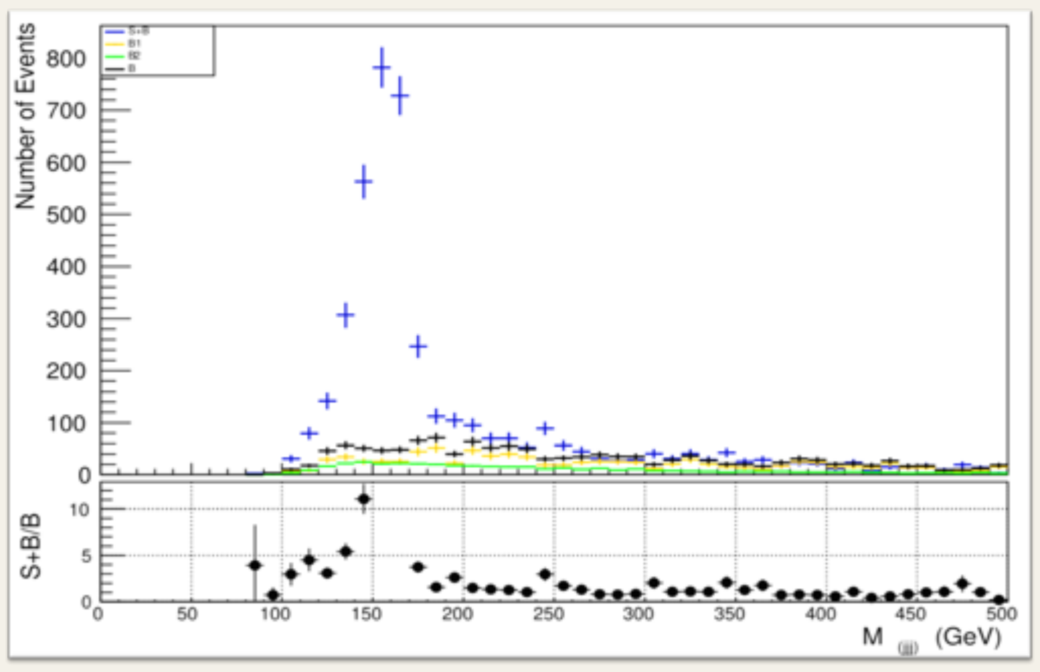

Fig. 3: Invariant mass distributions of W(->jj)b_j system.

After reconstruction of top quark mass from W(->jj)b system (see Fig. 3), the statistical significances (SS) from the signal and background events are calculated as shown in Fig. 4.

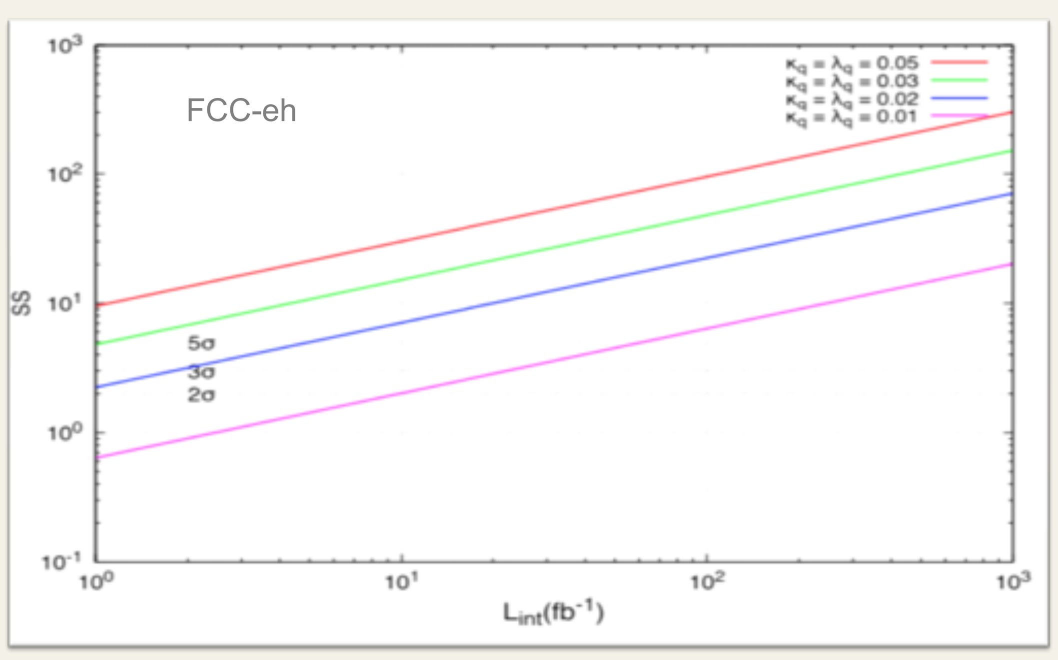

Fig. 4: The statistical significance for integrated luminosity range from 1 fb^{-1} to 1 ab^{-1}.

Results

The limits on couplings (λ_q and κ_q) can be translated into the branching ratios (BR) using top quark FCNC branching expressions [14]. In our previous studies given in Refs. [15] and [16], we have obtained the limits on the top quark FCNC tqγ couplings depending on the integrated luminosity of future ep colliders. Updating and adding study for tqZ vertex at higher luminosity projections, we present the expected sensitivities on BR(t⟶qγ) and BR(t⟶qZ) as a function of the integrated luminosity (in the range from 100 fb^{-1} to 3 ab^{-1}) at FCC-eh in Fig. 5.

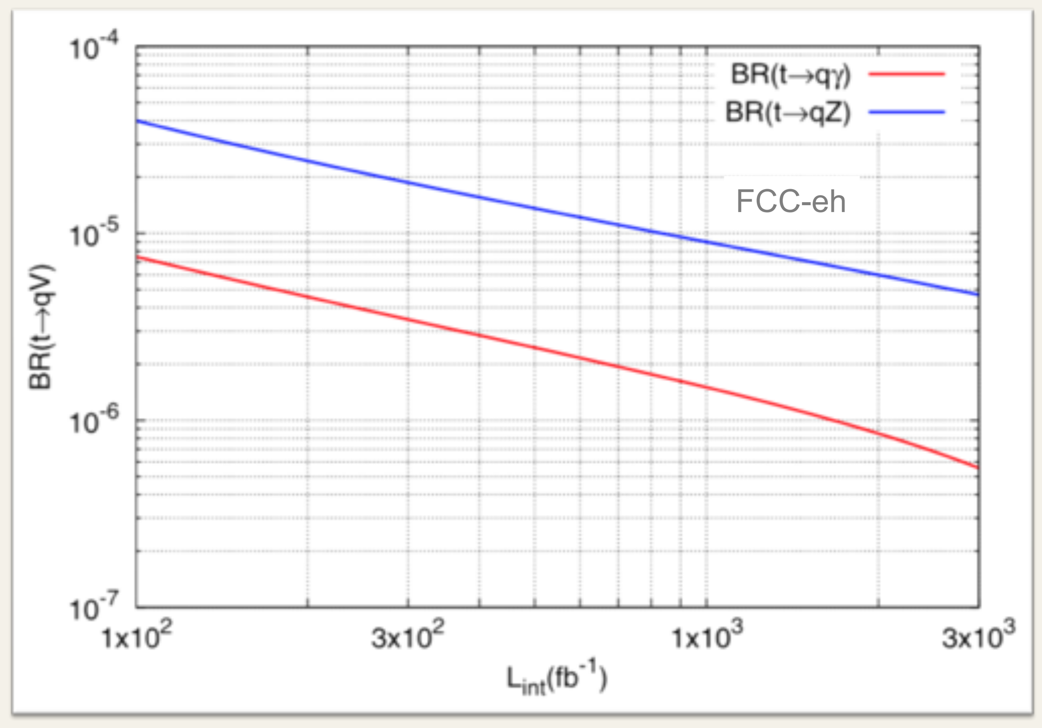

Fig. 5: Expected sensitivities on BR(t⟶qγ) (red line) and BR(t⟶qZ) (blue line) as a function of the integrated luminosity at FCC-he.

Conclusions

The top quark FCNC interactions are important probes for new physics beyond the SM. It is also worth to mention that the analysis include the signal and background interference effects. The physics potential of FCC-eh for probing new physics through top FCNC is promoted with their expected complementarity to the future lepton and hadron colliders. The higher center of mass energy of 3.5 TeV and an integrated luminosity of 1, 2 and 3 ab^{-1} will allow us to significantly improve the sensitivity to the top quark FCNC with branchings BR(t->qγ)=1.5x10^{-6}, 8.5x10^{-7} and 5.5x10^{-7}, and BR(t->qZ)=9.5x10^{-6}, 6.0x10^{-6} and 4.5x10^{-6}, respectively. At the high energy and high luminosity future ep collider environment, cleanliness of the final state compared to the hadron colliders provides top quark physics for an attractive and competitive search area, which includes high precision EW top quark measurements and sensitive searches for new physics beyond the SM.

Acknowledgements

Authors' work was partially supported by Turkish Atomic Energy Authority (TAEK) under the project grant no. 2018TAEK(CERN)A5.H6.F2-20.

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