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 e+p→W+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 $\lambda_{tq}$ and $\lambda_{qZ}$ for $tqZ$ vertices. We find the sensitivities to the branching ratios $BR(t\rightarrow\gamma t)=1.5\times10^{-4}$, $8.5\times10^{-5}$ and $5.5\times10^{-5}$ and $BR(t\rightarrow q\gamma)=9.5\times10^{-6}$, $6.0\times10^{-6}$ and $4.5\times10^{-6}$ 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 $m_t \approx 173$ GeV) being the heaviest of fundamental fermions decays to a bottom quark and a W boson (most frequently) while its decay 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 $t\rightarrow W+b$, the ratios of the SM decay widths are given as $\Gamma(t\rightarrow W+b)/\Gamma(t\rightarrow W+X)=(V_{tb}V_{tb})/(1-V_{tb}V_{tb})=1.495 \times 10^{-3}$ and $\Gamma(t\rightarrow W+b)/\Gamma(t\rightarrow W+X)=(V_{tb}V_{tb})/(1-V_{tb}V_{tb})=6.318 \times 10^{-3}$ [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 branching for top to up-sector quark transitions are well beyond the current sensitivity of the Large Hadron Collider (LHC) experiments (reviewed in Ref. [5]). 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.

Future ep Colliders

The future ep colliders, namely LHeC [6] and FCC-eh [7] 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-eh) 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.

Event Selection and Analysis

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

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

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<tr>
<th>Cuts for Signal Events</th>
<th>Cuts for Background Events</th>
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<tr>
<td>$p_T(\gamma) &gt; 40$ GeV</td>
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<td>$p_T(e) &gt; 20$ GeV</td>
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After reconstruction of top quark mass from $W(\gamma)^{-}$ system (see Fig. 3), the statistical significances (SS) from the signal and background events are calculated as shown in Fig. 4.

Top FCNC Production

We study the process $e+p\rightarrow e+\gamma W$ (see Fig. 2) including $tqZ$ and $tq\gamma$ effective FCNC interaction vertices at future electron hadron collider, FCC-eh. The effective Lagrangian introduced in Ref. [8] 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 $\lambda_{tq}$ and $\lambda_{qZ}$. We produce signal and background events by using MadGraph 5_aMC@NLO [9], with an effective Lagrangian implementation through FeynRules [10] for the signal. Afterwards the parton showering and detector fast simulations are carried out with Pythia8 [11] and Delphes 3.4 [12], respectively. For Delphes card (validatd) we have used FCC-hh card for FCC-eh detector simulation. The jets were clustered using FastJet [12] with the anti-kT algorithm [13].

Results

The limits on couplings ($\lambda_{tq}$ and $\lambda_{qZ}$) 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 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 $BR(t\rightarrow \gamma q)$ and $BR(t\rightarrow q\gamma)$ as a function of the integrated luminosity (in the range from 100 fb$^{-1}$ to 3 ab$^{-1}$) at FCC-eh in Fig. 5.

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 $BR(t\rightarrow \gamma q)=1.5\times10^{-4}$, $8.5\times10^{-5}$ and $5.5\times10^{-5}$, and $BR(t\rightarrow q\gamma)=9.5\times10^{-6}$, $6.0\times10^{-6}$ and $4.5\times10^{-6}$, 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.

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References