Snowmass2021 - Letter of Interest

Probing top quark FCNC couplings $tq\gamma, tqZ$ at future e^+e^- collider

Thematic Areas: (check all that apply □/■)

□ (EF01) EW Physics: Higgs Boson properties and couplings
□ (EF02) EW Physics: Higgs Boson as a portal to new physics
■ (EF03) EW Physics: Heavy flavor and top quark physics
□ (EF04) EW Precision Physics and constraining new physics
□ (EF05) QCD and strong interactions: Precision QCD
□ (EF06) QCD and strong interactions: Hadronic structure and forward QCD
□ (EF07) QCD and strong interactions: Heavy Ions
□ (EF08) BSM: Model specific explorations
□ (EF09) BSM: More general explorations
□ (EF10) BSM: Dark Matter at colliders
□ (Other) *[Please specify frontier/topical group]*

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Abstract: Many new physics models Beyond the Standard Model (BSM) can generate sizable top quark Flavor Changing Neutral Current (FCNC) couplings possibly detectable at future colliders. Lepton colliders such as FCC-ee, CEPC and CLIC have clean environment related to Quantum Chromodynamics (QCD) and well controlled beam collision energy. Through processes such as $e^+e^- \to \gamma^*/Z^* \to t\bar{q}, \bar{t}q$ with $q = u, c$ and leptonically/hadronically decaying top quark, CEPC has a great potential to probe the top quark FCNC couplings predicted by a wide range of BSM models.

Despite the fact that the quark couplings through Flavor Changing Neutral Current (FCNC) are forbidden at tree-level in the Standard Model (SM) due to the GIM mechanism[?], many new physics models Beyond SM (BSM) can generate sizable contributions to couplings of FCNC type. Another subject closely related to BSM physics is top quark, which is the heaviest particle in the SM and may reveal the keen information of electroweak symmetry breaking related to physical principles existing at high energy scales. The top quark FCNC effective interactions up to dimension 5 can be written in the following form[?]:

$$
\begin{aligned}
-\mathcal{L}^{\text{eff}} \;=\;& \frac{g}{2c_W} X_{qt}\, \bar{q}\gamma_\mu (x_{qt}^L P_L + x_{qt}^R P_R) t Z^\mu + \frac{g}{2c_W}\kappa_{qt}\, \bar{q}(\kappa_{qt}^v + \kappa_{qt}^a \gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t} t Z^\mu \\
&+ e\lambda_{qt}\, \bar{q}(\lambda_{qt}^v + \lambda_{qt}^a\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t} t A^\mu + g_s\zeta_{qt}\, \bar{q}(\zeta_{tq}^v + \zeta_{qt}^a\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t} T^a q G^{a\mu} \\
&+ \frac{g}{2\sqrt{2}} g_{qt}\, \bar{q}(g_{qt}^v + g_{qt}^a\gamma_5) t H + \text{H.c.}\,, \qquad (1)
\end{aligned}
$$

in which $q = u, c$ and $q^\nu = (p_t - p_q)^\nu$ denotes the boson momentum. $\bar{q}$, t are the shorthands for the quark fields $\bar{u}(p_q)$ and $u(p_t)$, respectively. The couplings are the first terms in the expansion with respect to momenta, with normalization of $|x_{qt}^L|^2 + |x_{qt}^R|^2 = 1$, $|\kappa_{qt}^v|^2 + |\kappa_{qt}^a|^2 = 1$, etc., with X_{qt}, κ_{qt}, λ_{qt}, ζ_{qt} and g_{qt} being real and positive quantities.

Both the ATLAS and CMS collaborations at the Large Hadron Collider (LHC) have performed measurements of top quark FCNC couplings. Fig.**??** summarizes various experimental bounds on top quark FCNC decay Branch Ratios (BRs) in comparison to some theoretical predictions of BSM models.

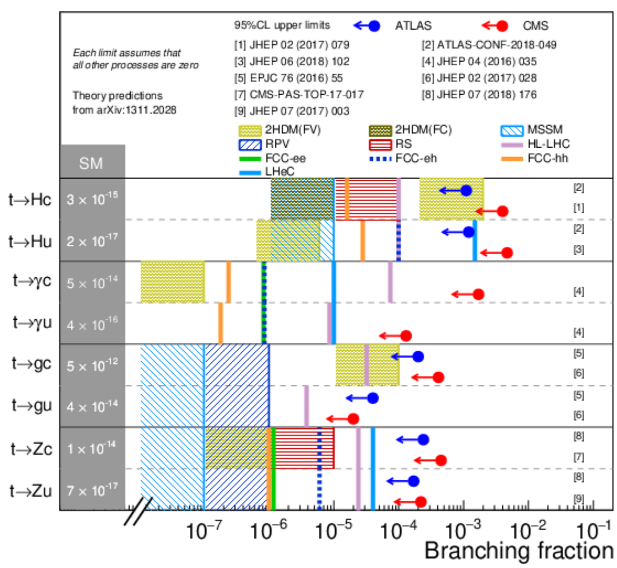

Figure 1: Experimental bounds on top quark FCNC decay BRs compared to some theoretical predictions of BSM models[?].

Future e^+e^- colliders such as FCC-ee, CEPC and CLIC can benefit from the cleaner environment related to Quantum Chromodynamics (QCD) compared to LHC and well controlled beam collision energy. Taking the Circular Electron Positron Collider (CEPC) as an example, it is expected to have excellent performance in flavor tagging[?][?]. The reconstruction of top quark from its decay products involves the reconstruction of secondary vertex where the performance of the vertex system is crucial. Especially, compared with the b-jet tagging, c-jet tagging is particularly challenging which suffers more from backgrounds from light-quark and gluon jets. Benefiting from the high precision vertex system, the CEPC detector provides reasonable separation of c-jets from other flavor jets. Through processes such as $e^+e^- \to \gamma^*/Z^* \to t\bar{q}, \bar{t}q$ with $q = u, c$ and leptonically/hadronically decaying top quark, the prospected improvement in top quark tagging efficiency at CEPC can provide a great potential to probe the top quark FCNC couplings predicted by a wide range of BSM models.

References

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