# Probing New Physics from Top Quark FCNC Processes at LHC: A Mini Review (Postprint)

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**Date:** 2016-12-28T00:00:00+00:00

## Abstract

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## Full Text

## Preamble

arXiv:0801.0210 Probing New Physics from Top Quark FCNC Processes at LHC: A Mini Review

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## Abstract

Since the top quark FCNC processes are extremely suppressed in the Standard Model (SM) but could be greatly enhanced in some new physics models, they could serve as a smoking gun for new physics hunting at the LHC. In this brief review we summarize the new physics predictions for various top quark FCNC processes at the LHC by focusing on two typical models: the minimal supersymmetric model (MSSM) and the topcolor-assisted technicolor (TC2) model. The conclusion is: (1) Both new physics models can greatly enhance the SM predictions by several orders; (2) The TC2 model allows for largest enhancement, and for each channel the maximal prediction is much larger than in the MSSM; (3) Compared with the 3 sensitivity at the LHC, only a couple of channels are accessible for the MSSM while most channels are accessible for the TC2 model.

**Keywords:** top quark; supersymmetry; technicolor, LHC
**PACS numbers:** 14.65.Ha, 14.80.Ly, 11.30.Hv
to appear in Int. J. Mod. Phys. A

# INTRODUCTION

With the upcoming experiments at the Large Hadron Collider (LHC), elementary particle physics stands at a critical crossroads: the discovery of new physics at the TeV scale would herald an exciting new era, while its absence would deal a severe blow to the field. Among the various proposals for TeV-scale new physics, two prominent directions stand out: supersymmetry, a weakly-coupled theory with fundamental scalars that elegantly extends the energy scale to achieve grand unification, and dynamical symmetry breaking theories (such as technicolor) that involve no fundamental scalars. Undoubtedly, these elegant theories will soon be put to the test at the LHC.

The search for new physics at high-energy colliders like the LHC proceeds along two complementary paths: direct detection of new particle production, and uncovering the quantum effects of new physics in sensitive, precisely measured processes. These two approaches are complementary and provide consistency checks for any new physics framework. When collider energies significantly exceed the mass thresholds of new particles, direct production studies dominate. However, when energies are insufficient to surpass these thresholds, deciphering quantum effects becomes the sole means of glimpsing hints of new physics. Consequently, a lower-energy collider with high precision can serve as a telescope for probing new physics at much higher energy scales.

Given the importance of quantum effects in probing new physics and the uncertainty of the new physics scale, it is crucial to examine LHC processes that are particularly sensitive to new physics. As the heaviest fermion in the Standard Model, the top quark is expected to be a sensitive probe of new physics [1]. Due to limited statistics at the Fermilab Tevatron collider, top quark properties have not yet been precisely measured, leaving considerable room for new physics effects in top quark processes. With the LHC operating as a top quark factory enabling detailed scrutiny of top quark properties, uncovering new physics effects in various top quark processes will provide a compelling channel for testing new physics models.

A distinctive feature of the top quark in the Standard Model is its extremely small flavor-changing neutral-current (FCNC) interactions [2], suppressed by the Glashow-Iliopoulos-Maiani (GIM) mechanism. Consequently, the observation of any FCNC top quark process would constitute a smoking gun for physics beyond the Standard Model. Numerous studies [3] have demonstrated that FCNC top quark interactions can be significantly enhanced in various new physics models. Since different models predict different magnitudes of enhancement, measurements of these processes at the LHC will not only illuminate the nature of new physics but may also provide evidence for or against specific models. This review summarizes predictions for the Minimal Supersymmetric Standard Model (MSSM) [4-6] and the topcolor-assisted technicolor (TC2) model [7-9]. As these two models represent opposing paradigms for new physics, they are mutually exclusive in principle, and as this review demonstrates, they predict substantially different enhancements for FCNC top quark processes.

## II. FCNC TOP QUARK PROCESSES IN MSSM AND TC2

### Standard Model Predictions

In the Standard Model, the GIM mechanism forbids top quark FCNC interactions at tree level and strongly suppresses them at loop level. Such loop-induced FCNC interactions arise from W-boson charged-current transitions with down-type quarks in the loops, which are much lighter than the top quark. The magnitude of W-loop contributions depends on the mass splittings among these down-type quarks. If their masses are neglected or assumed to be degenerate, the one-loop FCNC interactions vanish due to the unitarity of the CKM matrix and the universality of W-boson couplings to fermions.

### MSSM Predictions

While top quark FCNC interactions are also loop-induced in the MSSM, they can be substantially enhanced compared to Standard Model predictions. Beyond W-boson loops, four additional loop contributions exist. First, charged Higgs loops can dominate over W-boson loops because their Yukawa couplings are proportional to fermion masses and non-universal among the down-type quarks in the loops. Second, chargino loops can also exceed W-boson contributions due to potentially large mass splittings between squarks in the loops and the non-universal Higgsino-component Yukawa couplings. Third, gluino loops arise from flavor mixing between stop squarks and other up-type squarks (primarily scharm squarks). Since such stop-scharm mixing can be significant, these strong-coupling-mediated loops may be substantial or even dominant. Fourth, neutralino loops, also originating from stop-up-squark mixing, are typically smaller than gluino or chargino contributions.

### TC2 Model Predictions

Technicolor represents a classic approach to dynamical electroweak symmetry breaking. However, the original minimal technicolor theory faces severe challenges in generating fermion masses (particularly the heavy top quark mass) and struggles to satisfy precision electroweak constraints. The topcolor-assisted technicolor (TC2) model [10] addresses these issues by combining technicolor, responsible for electroweak symmetry breaking, with topcolor, which generates the large top quark mass. This model remains viable under current experimental constraints and will be rigorously tested at the LHC. Top quark FCNC interactions can be dramatically enhanced in the TC2 model for the following reasons:

(1) Topcolor is non-universal, inducing condensation only in the top quark sector and contributing the dominant portion $(1-\epsilon_t)$ of the top quark

mass. Consequently, the neutral top-pion has large Yukawa couplings exclusively to the top quark.

(2) Extended technicolor (ETC) generates masses for all quarks, but contributes only a small fraction $\epsilon_t$ to the top quark mass. ETC-pions consequently have small Yukawa couplings to all quarks, with the top quark coupling being much weaker than that of the top-pion.

Since the top quark mass—and thus the up-type quark mass matrix—receives contributions from both ETC and topcolor, diagonalizing the mass matrix does not guarantee simultaneous diagonalization of the top-pion Yukawa couplings in the topcolor sector and the ETC-pion Yukawa couplings in the ETC sector. Consequently, after diagonalizing the up-type quark mass matrix, the top-pion in the topcolor sector possesses tree-level FCNC Yukawa couplings involving the top quark. This contrasts sharply with the Standard Model Higgs boson, which has no tree-level FCNC couplings because all fermion masses originate from a single Higgs doublet, and diagonalizing the fermion mass matrix (given by the Yukawa coupling matrix times the vacuum expectation value $v$) automatically diagonalizes the Yukawa coupling matrix.

Table 1 summarizes the maximal predictions for five FCNC top quark decay modes in the MSSM and TC2 models. Standard Model predictions fall far below LHC sensitivity and are omitted. The MSSM maximal predictions [4] were derived from a comprehensive parameter space scan incorporating all current experimental constraints, including bounds on squark and Higgs boson masses, precision measurements of the W-boson mass and effective weak mixing angle, and data from $B_s$-$\bar{B}_s$ mixing and $b \to s\gamma$ decays.

**Table 1:** Maximal predictions for the branching ratios of FCNC top quark decays and production cross sections (hadronic) at the LHC.

| Process | LHC 3 sensitivity | MSSM | TC2 | Other studies |
|---|---|---|---|---|
| $t \to cZ$ | $1.8 \times 10^{-6}$ [4] | $\mathcal{O}(10^{-4})$ [7] | $3.6 \times 10^{-5}$ [11] | |
| $t \to c\gamma$ | $5.2 \times 10^{-7}$ [4] | $\mathcal{O}(10^{-6})$ [7] | $1.2 \times 10^{-5}$ [11] | |
| $t \to ch$ | $6.0 \times 10^{-5}$ [4] | $\mathcal{O}(10^{-1})$ [7] | $5.8 \times 10^{-5}$ [11] | |
| $t \to cg$ | $3.2 \times 10^{-5}$ [4] | $\mathcal{O}(10^{-3})$ [7] | | |
| $t \to cgg$ | $3.5 \times 10^{-5}$ [4] | $\mathcal{O}(10^{-3})$ [7] | | |
| $gg \to t\bar{c}$ | 700 fb [4] | 30 pb [8] | 1500 fb [11] | |
| $cg \to t$ | 950 fb [4] | 1.5 pb [8] | 800 fb [11] | |

| Process | LHC 3  sensitivity | MSSM | TC2 | Other studies |
|---|---|---|---|---|
| $cg \to tg$ | 520 fb [4] | 3 pb [8] | 1500 fb [11] | |
| $cg \to t\gamma$ | 1.8 fb [4] | 20 fb [8] | 5 fb [11] | |
| $cg \to tZ$ | 5.7 fb [4] | 100 fb [8] | 35 fb [11] | |
| $cg \to th$ | 24 fb [4] | 1 pb [8] | 200 fb [11] | |

## III. CONCLUSION

Table 1 leads to the following conclusions: (1) Both new physics models can enhance Standard Model predictions by several orders of magnitude; (2) The TC2 model permits the largest enhancements, with maximal predictions for each channel far exceeding those in the MSSM; (3) Compared to the 3  sensitivity reach of the LHC, only a few channels are accessible in the MSSM, whereas most channels become accessible in the TC2 model.

## Acknowledgments

This work is supported in part by the National Natural Science Foundation of China under Grant No. 10475107 and 10505007.

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