

# Flavor Changing Neutral Currents in top production and decay at CMS

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**Abstract.** Searches for flavor changing neutral currents (FCNC) in top production and decay using data collected by the Compact Muon Solenoid (CMS) experiment at  $\sqrt{s} = 7$  and 8 TeV corresponding to an integrated luminosity of around  $5 \text{ fb}^{-1}$  and  $20 \text{ fb}^{-1}$  are presented. FCNC searches are conducted to probe  $tqZ$ ,  $tq\gamma$ ,  $tqH$ , and  $tgq$  interactions in various channels. There is no excess of signal observed in the data. The upper limit of  $\mathcal{B}(t \rightarrow u\gamma) < 0.0161\%$ ,  $\mathcal{B}(t \rightarrow ug) < 0.0355\%$ ,  $\mathcal{B}(t \rightarrow Zq) < 0.05\%$  and  $\mathcal{B}(t \rightarrow cH) < 0.56\%$  at 95% confidence level are obtained. Future prospects of FCNC searches with the upgraded detector at 14 TeV are also presented.

## 1. Introduction

In 2012, a new boson with a mass around 125 GeV has been discovered. The discovery of this scalar type of particle opens a new window in our research. Within the standard model (SM) the new boson is expected to have a strong relation with the top quark, the heaviest known fundamental particle in nature. The top quark decays mostly to a bottom quark and a  $W$  boson. However, some extensions of the SM predict that a top quark can also decay through a neutral  $Z$  boson, a Higgs boson ( $H$ ), a gamma ( $\gamma$ ) or a gluon ( $g$ ) changing its flavor,  $t \rightarrow Zq$ ,  $t \rightarrow Hq$ ,  $t \rightarrow q\gamma$  or  $t \rightarrow gq$ , where  $q$  is either a  $u$  or  $c$  quark. The flavor changing neutral current (FCNC) interaction is suppressed in the SM by the Glashow-Iliopoulos-Maiani (GIM) mechanism and only occurs at the level of quantum loop corrections. The branching ratio  $\mathcal{B}(t \rightarrow Xq)$  where  $X = Z, H, \gamma$  or gluon is predicted to be around  $10^{-17} \sim 10^{-12}$  in the SM far below the experimental reach of the Large Hadron Collider (LHC). However, in several models beyond the SM such as R-parity-violation-supersymmetry models and topcolor-assisted technicolor models and, in particular, two scalar Higgs doublets (2HDMs), the branching ratio can reach up to  $10^{-3}$ . Therefore, detection of this signal would be an indication of a large enhancement in the branching ratio and clear evidence for violations of the SM prediction.

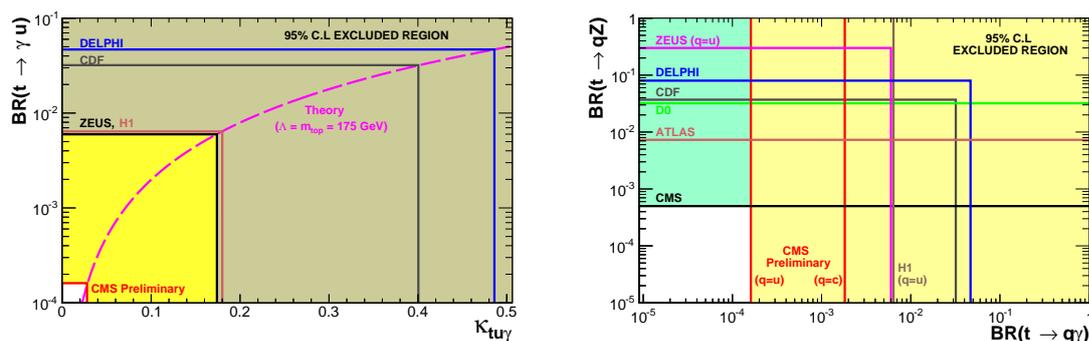
The Compact Muon Solenoid (CMS) experiment [1] at the LHC has accumulated data corresponding to an integrated luminosity of  $5 \text{ fb}^{-1}$  in 2011 and  $20 \text{ fb}^{-1}$  in 2012. Searches for FCNC in top production and decay using data collected by the CMS experiment at  $\sqrt{s} = 7$  and 8 TeV corresponding to an integrated luminosity of around  $5 \text{ fb}^{-1}$  and  $20 \text{ fb}^{-1}$  are presented. FCNC searches are conducted to probe  $tqZ$ ,  $tq\gamma$ ,  $tqH$ , and  $tgq$  interactions in various channels. Future prospects of FCNC searches with the upgraded detector at 14 TeV are also presented.



## 2. FCNC in a single top production

### 2.1. $tq\gamma$ coupling

The anomalous  $tq\gamma$  coupling has been searched with events in association with a photon using the full data collected at 8 TeV in 2012 corresponding to  $19.1 \text{ fb}^{-1}$  [2]. In order to reduce the QCD multijet background, the top quark in the lepton decay mode is considered. Therefore, one isolated muon, one isolated photon and one  $b$ -tagged jet are required to select the final signature. Boosted Decision Tree (BDT) is used to separate the signal signature from the background contributions. There is no excess observed and the limits on the anomalous  $\kappa_{tu\gamma}$  and  $\kappa_{tc\gamma}$  coupling are calculated at 95% confidence level using the BDT distribution. Photon energy scale and the estimate of  $W\gamma + \text{jets}$  process are the main uncertainty sources in this analysis. The limit on the coupling and on the corresponding branching ratio is shown in Fig 1 (left) and the limits on the branching ratios of  $tq\gamma$  and  $tc\gamma$  are shown in Fig 1 (right) for the case of coupling with  $c$ -quark and  $u$ -quark indicated by red vertical line. The observed limits on the anomalous coupling of  $\kappa_{tu\gamma}$  and  $\kappa_{tc\gamma}$  are 0.0279 and 0.0094, respectively. The corresponding branching ratios of  $t \rightarrow u\gamma < 0.0161 \%$  and  $t \rightarrow c\gamma < 0.182 \%$  are obtained. This result is the first measurement of the limit on these couplings at the LHC and the most stringent bounds on the anomalous FCNC  $tc(u)\gamma$  coupling to date.



**Figure 1.** Relation between  $\kappa$  coupling and branching ratio (left). Limits on the branching ratio (right).

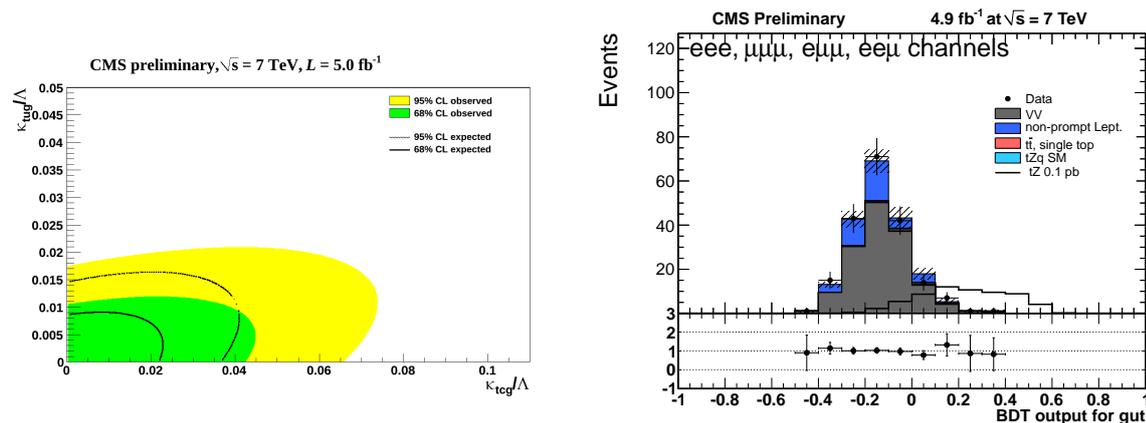
### 2.2. $tqg$ coupling

The anomalous couplings of  $tcg$  and  $tug$  were searched in the  $t$ -channel single top-quark production using data collected at 7 TeV corresponding to an integrated luminosity of  $5 \text{ fb}^{-1}$  [3]. The final signature of the anomalous FCNC coupling is the same as the SM single top quark production processes with one isolated muon, 2 or 3 jets and one  $b$ -tagged jet. However, the signal has different kinematic distributions and is separated from the backgrounds using Bayesian Neural Network (BNN) based on their kinematical properties. Data and the SM predictions agree well within the uncertainties. In this analysis, the estimate of the  $W + \text{jets}$  process is one of the main uncertainty source. Taking into account the systematic uncertainties, the limit on the couplings of  $tcg$  and  $tug$  are calculated at 95% confidence level. The limits on the couplings of  $tcg$  and  $tug$  are shown in Fig. 2 (left) and the coupling can be converted to the limit on the branching ratio. The observed upper limits on  $\mathcal{B}(t \rightarrow u + g) < 0.0355\%$  and  $\mathcal{B}(t \rightarrow c + g) < 0.344\%$  are obtained.

### 2.3. $tqg(Z)$ coupling

The single top production in association with a  $Z$  boson has been also analyzed for the searches for the coupling of  $tqZ$  and  $tqg$  with data corresponding to an integrated luminosity of  $4.9 \text{ fb}^{-1}$

collected at 7 TeV [4]. The BDT distribution for the coupling  $Zut$  is shown in Fig. 2 (right) which shows a good agreement between data and the SM background prediction. The observed limit on the branching ratios of  $\mathcal{B}(t \rightarrow gu) < 0.56\%$  and  $\mathcal{B}(t \rightarrow Zu) < 0.56\%$  are obtained. These results are not competitive with the one from the single top production 2.2. However, it is important to note that it gives interesting cross check in different physics process. For  $tqZ$  coupling, it is conceivable to combine the result with the one from the top quark decay mode in  $t\bar{t}$  pair production to improve the sensitivity.

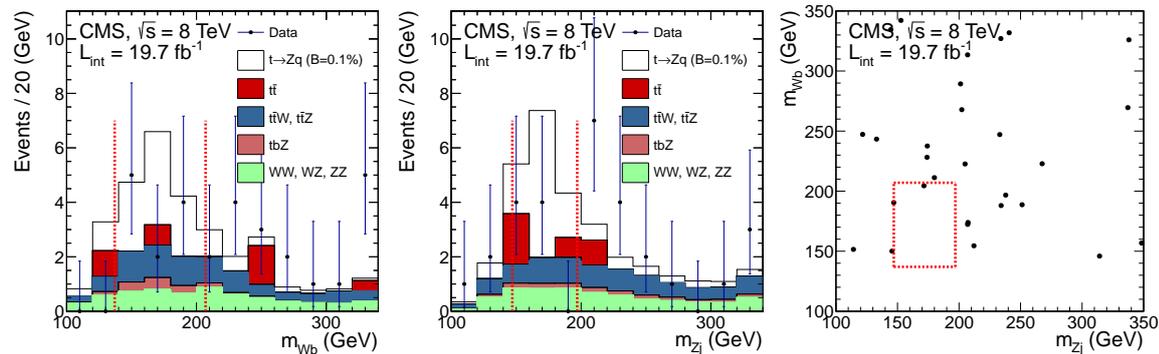


**Figure 2.** Exclusion upper limits in two-dimensions on FCNC  $tug$  and  $tcg$  couplings at 68% and 96% confidence level (left). BDT distributions for  $Zut$  (right).

### 3. FCNC in a top decay

A searching for  $t\bar{t}$  events where one of top quarks decays into  $Zq$  has been pursued with the full data collected at 7 and 8 TeV [5]. The other top is assumed to decay in the SM leptonic decay mode. Events with opposite-sign, same-flavor, isolated leptons from a  $Z$  boson candidate and exclusive one extra lepton are selected. All three leptons must satisfy  $p_T > 20$  GeV and  $|\eta| < 2.5$  for electrons and  $|\eta| < 2.4$  for muons. The large transverse momentum and the presence of at least two jets where one of these jets should be a  $b$ -tagged jet are also required to remove the background contributions from  $Z$  boson or diboson events. The top-quark mass decaying into  $Wb$  ( $m_{Wb}$ ) in the SM decay is reconstructed with  $W$  boson and  $b$ -tagged jets and is required to be within 35 GeV of the top-quark mass, equal to 172.5 GeV in the simulation. (see Fig 3) Secondly, the top-quark decaying into  $Zq$  is reconstructed considering all possible pairings and the pair with the largest separation in azimuthal angle to the first top quark is selected. The second top-quark mass  $m_{Zj}$  is required to be within 25 GeV of the assumed top-quark mass. After the final selection, only 1 event remains in data while  $3.3 \pm 1.1$  events are expected from the SM backgrounds. The dominant uncertainties are from the renormalization and factorization uncertainty, PDF and the cross section of  $\sigma_{t\bar{t}}$ . The observed upper limit on the branching ratio  $\mathcal{B}(t \rightarrow Zq)$  at 95% confidence level is 0.06% with 8 TeV data alone. Combining the result with the statistically independent result with 7 TeV data, the observed upper limit on the  $\mathcal{B}(t \rightarrow Zq)$  is 0.05%.

**Projections in 3000 fb<sup>-1</sup>** The study of  $t \rightarrow c$ -quark and  $Z$  boson was simulated at 14 TeV for the upgraded detector and will be repeated at the new energy using data corresponding to 300 fb<sup>-1</sup> and 3000 fb<sup>-1</sup> [6]. Assuming that the systematic uncertainty is reduced by the  $\sqrt{\mathcal{L}}$  where  $\mathcal{L}$  is an integrated luminosity, the expected limits are predicted to be smaller than 0.010 % with 3000 fb<sup>-1</sup>, this is 10 times better than the expected limit from the Run 1 period.



**Figure 3.** Reconstructed top-mass distributions in the SM decay (left). Reconstructed top-mass distributions in the FCNC decay (middle). The scatter distribution of reconstructed top-mass in 2D for both decay modes (right). The red dotted vertical lines (left and middle) and box (right) indicate the top-quark mass requirements.

#### 4. Limit on $t \rightarrow cH$

The results of two CMS searches from heavy Higgs models with multileptons as well as diphotons final states [7] and the inclusive multilepton search [8] using data collected at 8 TeV corresponding to  $19.5 \text{ fb}^{-1}$  are reinterpreted for the rare flavor-changing decay of the top quark to a Higgs boson and a charm quark [9]. In this analysis, the flavor-changing decay in  $t\bar{t}$  production followed by one of the top quarks decaying to  $cH$  where Higgs decays  $WW$ ,  $ZZ$ ,  $\tau\tau$  and  $\gamma\gamma$  are considered as the signal. No excess over the data is found in both analyses. Using the modified frequentist construction  $\text{CL}_S$ , the observed limit of  $\mathcal{B}(t \rightarrow cH) < 0.56\%$  is calculated at 95% confidence level. This branching ratio is related to the left- and right-handed top flavor changing Yukawa couplings so that the observed limit can be converted to the limit on the coupling of  $\sqrt{|\Lambda_{tc}^H|^2 + |\Lambda_{ct}^H|^2} < 0.14$ . The result from the final state of multilepton search analysis alone is  $\mathcal{B}(t \rightarrow cH) < 1.28\%$  and is 0.69% from two photon final state search analysis. The combination with the result from the two photon final state search analysis gives a significant improvement with respect to the one from multilepton search analysis alone.

#### 5. Conclusions

The CMS collaboration has performed the FCNC searches in a single top-quark production and decay with data collected at 7 and 8 TeV and found no signature of FCNC. Limits of  $\mathcal{B}(t \rightarrow u\gamma) < 0.0161\%$ ,  $\mathcal{B}(t \rightarrow uq) < 0.0355\%$ ,  $\mathcal{B}(t \rightarrow Zq) < 0.05\%$  and  $\mathcal{B}(t \rightarrow cH) < 0.56\%$  at 95% confidence level are obtained. More results from Run 1 are expected to come soon. Exciting time is ahead of us with data to be collected at 13 TeV in 2015 which would be suitable for the FCNC rare process searches.

#### References

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