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 in CMS 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 fb^{-1} and 20 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 over the data. The upper limit of $\mathcal{B}(t \to u\gamma) < 0.0161\%$, $\mathcal{B}(t \to ug) < 0.0355\%$, $\mathcal{B}(t \to Zq) < 0.05\%$ and $\mathcal{B}(t \to cH) < 0.56\%$ 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. Therefore, new physics phenomena beyond our current theory can be realized in the top quark sector. 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 (γ) or a gluon (g) changing its flavor, $t \to Zq$, $t \to Hq$, $t \to q\gamma$ or $t \to gq$, where q is either of 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 B($t \to Xq$) 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 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 fb^{-1} in 2011 and 20 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 fb^{-1} and 20 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

$tq\gamma$ **coupling** The anomalous $tq\gamma$ coupling has been searched with the events in association with a photon using the full data collected at 8 TeV in 2012 corresponding to 19.1 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 requirements are applied 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 estimation of the W + jets and $W\gamma$ + jets process are the main uncertainty source 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 $t \to u\gamma < 0.0161$ % and $t \to c\gamma < 0.182$ % 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.

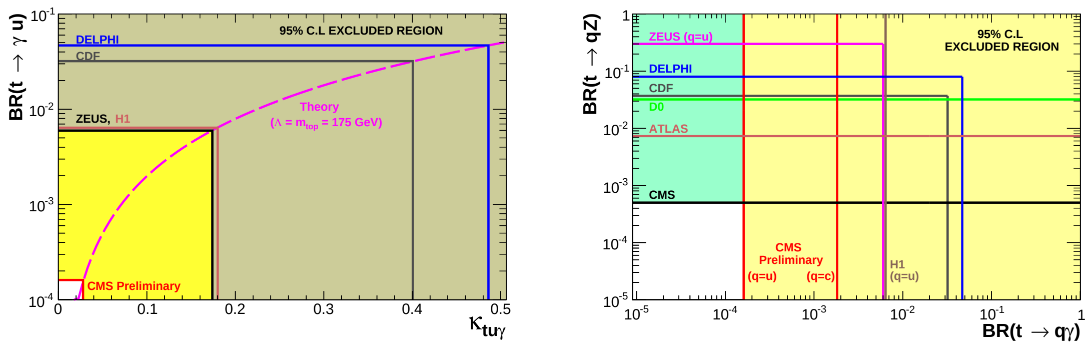

Figure 1. Relation between κ coupling and branching ratio (left). Limits on the branching ratio (right).

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 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 estimation of the W+jets process is one of the main uncertainty source. Taking into account the systematic uncertainties, the limit on the couplings of $\kappa_{tu\gamma}/\Lambda$ and $\kappa_{tc\gamma}/\Lambda$ 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 limit on $\mathcal{B}(t \to u + g) < 0.0355\%$ and $\mathcal{B}(t \to c + g) < 0.344\%$ are obtained.

$tqg(Z)$ **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 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 $\mathcal{B}(t \to gu) < 0.56\%$ and $\mathcal{B}(t \to Zu) < 0.56\%$ are obtained. These results are not competitive with the one from the single top production. 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.

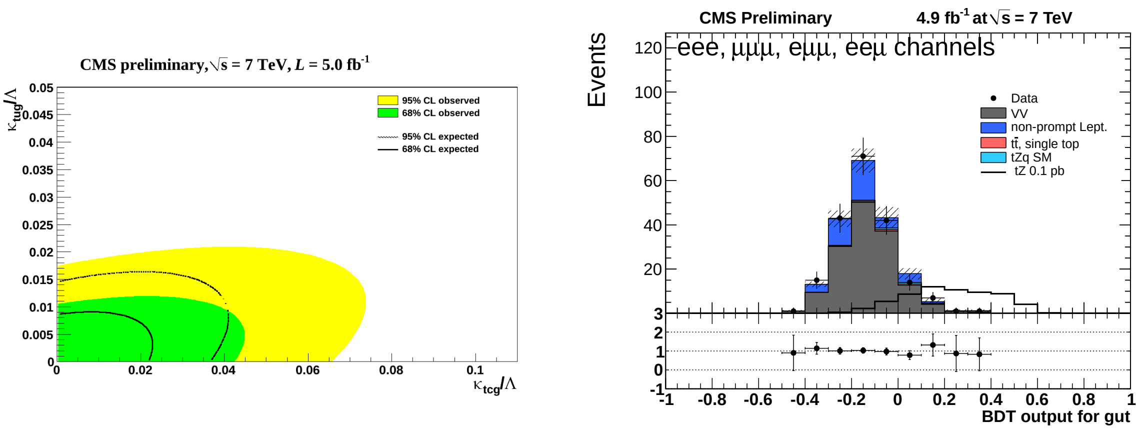

Figure 2. Limits on the couplings in two-dimensions at 68% and 96% confidence level (left). BDT distributions for Zut (right).

3. FCNC in a top decay

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 leptonic decay mode in the SM. 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 $p_{\mathrm{T}} > 20$ 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 window of top-quark mass, 172.5 GeV in the simulation. (see Fig 3) Secondly, the top-quark decaying into Zq is reconstructed considering all possible pairings and is selected with the largest separation in azimuthal angle to the first top quark. 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. Taking into account systematic uncertainties: 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 $\mathcal{B}(t \to Zq)$ 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 $\mathcal{B}(t \to Zq)$ is 0.05%.

Projections in 3000 fb^{-1} The study on $t \to c$-quark and Z boson was repeated with the upgraded detector at 14 TeV using data corresponding to 300 fb^{-1} and 3000 fb^{-1} [6]. Assuming that the systematic uncertainty is reduced by the $\sqrt{\mathcal{L}}$ where $\mathcal{L}$ is an integrated luminosity, the expected limits are obtained to be smaller than 0.027 % with 300 fb^{-1} and 0.010 % with 3000 fb^{-1} scenarios which is 10 times better limit than expected limit at Run 1 period (2011-2012).

4. Limit on $t \to cH$

The results of two CMS searches-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 fb^{-1} are reinterpreted for the rare flavor-changing decay of the top quark to a Higgs

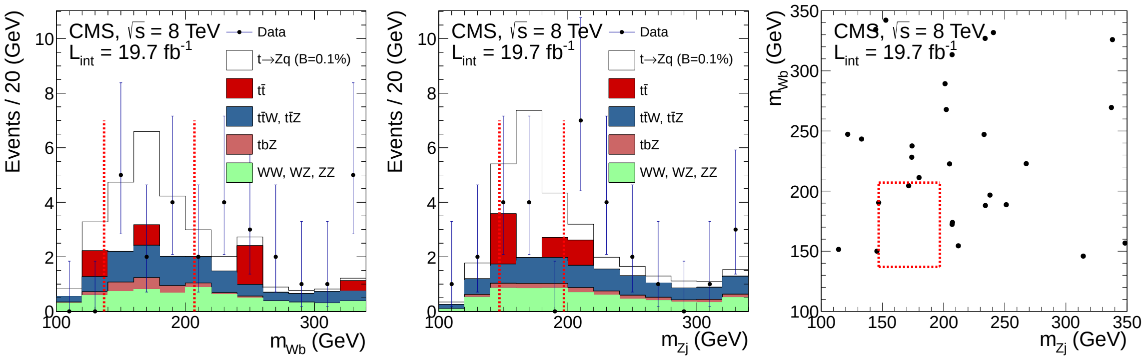

Figure 3. Reconstructed top-mass distributions in the SM decay (left). Reconstructed top-mass distributions in the FCNC decay (middle). The scatter distribution of reconstructed top-mass in 2D for both decay modes (right). The red dotted vertical line (left and middle) and box (right) indicate the top-quark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

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 $\mathrm{CL_S}$, the observed limit of $\mathcal{B}(t \to cH) < 0.56\%$ 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 $\sqrt{|\Lambda^H_{tc}|^2 + |\Lambda^H_{ct}|^2} < 0.14$. The result from the final state of multilepton search analysis alone is $\mathcal{B}(t \to cH) < 1.28\%$ and 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. $\mathcal{B}(t \to u\gamma) < 0.0161\%$, $\mathcal{B}(t \to ug) < 0.0355\%$, $\mathcal{B}(t \to Zq) < 0.05\%$ and $\mathcal{B}(t \to cH) < 0.56\%$ 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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