PROCEEDINGS OF SCIENCE

Search for FCNC with top quarks

K. Skovpen on behalf of ATLAS and CMS collaborations*
Institut Pluridisciplinaire Hubert Curien, CNRS/IN2P3, Strasbourg, France
E-mail: Kirill.Skovpen@cern.ch

Processes with Flavour Changing Neutral Currents (FCNC) are highly suppressed in the Standard Model (SM). Any anomalous enhancements of observed rates of these processes could point to the existence of new physics. At the LHC, top quark provides an unique environment to look for these anomalies in events with the production of single top quark and top quark pairs. An overview of the latest results from the ATLAS and the CMS experiments is given. No significant deviation from SM expectation is observed.

8th International Workshop on Top Quark Physics, TOP2015
14-18 September, 2015
Ischia, Italy

*Speaker.

PoS(TOP2015)048

1. Introduction

Flavour Changing Neutral Current (FCNC) processes are forbidden at tree level in the Standard Model (SM) by the Glashow-Iliopoulus-Maiani (GIM) mechanism [1] and are highly suppressed in the higher orders via penguin and box diagrams. However, FCNC processes could be significantly enhanced assuming a contribution from the new particles predicted in various beyond the Standard Model (BSM) scenarios directly at tree level. A study of FCNC interactions allows one to probe the new physics by looking for deviations in data from the extremely small predicted yields for such processes.

Search for FCNC processes in association with a top quark is particularly interesting due to its distinctive properties. Top quark is the heaviest elementary particle ever discovered and it is usually considered to have better sensitivity to BSM physics searches due to its large mass. A short decay time that allows a top quark to decay before any hadronisation takes place, results in a relatively clean experimental signature in a detector. One could look for FCNC interactions in the top quark pair production with a top quark decaying via the FCNC vertex, while the other possibility is to search for FCNC single top production. The latter is important to probe the FCNC couplings with an up-type quark, the production of which is enhanced by the parton distribution function in a proton.

FCNC processes with the top quark assumes an interaction of a top quark with either up or charm-type quark and Z, γ, Higgs boson or gluon. The Lagrangian of such interactions, expressed in terms of FCNC couplings, can be written as:

$$\begin{aligned}\mathscr{L} = \sum_{q=u,c} \Big[& \sqrt{2} g_s \frac{\kappa_{gqt}}{\Lambda} \bar{t} \sigma^{\mu\nu} T_a \left(f^L_{Gq} P_L + f^R_{Gq} P_R \right) q G^a_{\mu\nu} \\ & + \frac{g}{\sqrt{2} c_W} \frac{\kappa_{zqt}}{\Lambda} \bar{t} \sigma^{\mu\nu} \left(f^L_{Zq} P_L + f^R_{Zq} P_R \right) q Z_{\mu\nu} \\ & - e \frac{\kappa_{\gamma qt}}{\Lambda} \bar{t} \sigma^{\mu\nu} \left(f^L_{\gamma q} P_L + f^R_{\gamma q} P_R \right) q A_{\mu\nu} \\ & + \frac{g}{\sqrt{2}} \bar{t} \kappa_{Hqt} \left(f^L_{Hq} P_L + f^R_{Hq} P_R \right) q H \Big] + \text{h.c.},\end{aligned}$$

where κ_{gqt}, κ_{zqt}, $\kappa_{\gamma qt}$ and κ_{Hqt} are FCNC couplings with gluon, Z, γ and Higgs boson, respectively.

FCNC processes were searched for at LEP2 [2, 3, 4, 5], HERA [6, 7] and Tevatron [8, 9] Results which are presented in this report are obtained from the ATLAS and the CMS experiments with the data collected at the LHC at the center-of-mass energy of 7 and 8 TeV.

2. Search for *gqt*

The search for single top production via FCNC *gqt* coupling ($gq \to t$) is performed at ATLAS at 8 TeV with 20 fb^{-1} of data in the final state of one isolated lepton and one b-tagged jet [10]. Event selection criteria are based on a multivariate analysis approach to discriminate signal and background events. The dominant background is W+jets production which is predicted from Monte Carlo. The observed upper limits on the coupling strengths at 95% CL are measured to be $\kappa_{gut}/\Lambda <$

$0.58 \cdot 10^{-2}$ TeV^{-1} and $\kappa_{gct}/\Lambda < 1.3 \cdot 10^{-2}$ TeV^{-1}. The observed (expected) limits on the branching ratios are $\mathscr{B}(t \to gu) < 0.0040(0.0035)\%$ and $\mathscr{B}(t \to gc) < 0.017(0.015)\%$.

The gqt coupling is also probed at CMS in single top production with an additional jet in the final state ($q\bar{q} \to t\bar{c}$, $gg \to tc$, $c\bar{q} \to t\bar{q}$, $cg \to tg$, and similar processes with charm quark replaced with up quark) [11]. This search uses 5 fb^{-1} of 7 TeV data and is based on a Bayesian Neural Network technique to suppress background contributions. The distribution is fit to data and the result is used to set an exclusion limit on the coupling of $\kappa_{gut}/\Lambda < 1.8 \cdot 10^{-2}$ TeV^{-1} and $\kappa_{gct}/\Lambda < 5.6 \cdot 10^{-2}$ TeV^{-1}. The largest contribution from background processes comes from $t\bar{t}$ events and is validated in data. The observed (expected) limits on the branching ratios are $\mathscr{B}(t \to gu) < 0.036(0.016)\%$ and $\mathscr{B}(t \to gc) < 0.34(0.11)\%$.

3. Search for Zqt

FCNC processes via Zqt coupling ($pp \to t\bar{t} \to bWqZ$, $q = u, c$) are searched for at ATLAS in $t\bar{t}$ events with 20 fb^{-1} of data collected at 8 TeV [12]. Analysis is done with the selection of events containing three isolated leptons and one or two b-tagged jets. The dominant WZ and $t\bar{t}$+V (V=W,Z) backgrounds are validated in control regions and QCD multijet background is estimated from data. The observed (expected) upper limit on the branching ratio for Zqt (q=u,c) is $\mathscr{B}(t \to Zq) < 0.07(0.08)\%$.

Similar analysis with the search for Zqt interactions in the final state of three leptons and one b-tagged jet in $t\bar{t}$ events is performed by CMS with the data of 20 fb^{-1} at 8 TeV [13]. The dominant backgrounds, including WZ, WW, ZZ and $t\bar{t}$+V (V=W,Z) processes, are estimated from data. The observed (expected) upper limit on the branching ratio is $\mathscr{B}(t \to Zq) < 0.05(0.09)\%$.

FCNC single top production via Zqt coupling ($gq \to tZ$) is searched for at CMS in the same final state as in Refs. [12, 13] with using 5 fb^{-1} of 7 TeV data [14]. A Boosted Decision Tree discriminator is used to separate the background contributions from the expected signal. The dominant backgrounds are measured in data. The observed upper limits on the coupling strengths are $\kappa_{Zut}/\Lambda < 0.45$ TeV^{-1} and $\kappa_{Zct}/\Lambda < 2.27$ TeV^{-1}, with the observed (expected) limits on the branching ratios obtained of $\mathscr{B}(t \to Zu) < 0.51(0.61)\%$ and $\mathscr{B}(t \to Zc) < 0.11(0.16)\%$, respectively.

4. Search for γqt

A search for γqt FCNC events ($gq \to t\gamma$) is done at CMS with 19 fb^{-1} of 8 TeV data in single top events with one isolated lepton, one photon and one b-tagged jet in the final state [15]. The main background with $W\gamma$+jets and W+jets events is estimated from data. The observed upper limits on the coupling strengths are $\kappa_{tu\gamma}/\Lambda < 0.028$ TeV^{-1} and $\kappa_{tc\gamma}/\Lambda < 0.094$ TeV^{-1}. The observed (expected) branching ratios limits are $\mathscr{B}(t \to u\gamma) < 0.02(0.03)\%$ and $\mathscr{B}(t \to c\gamma) < 0.18(0.26)\%$.

5. Search for Hqt

FCNC interactions via Hqt couplings could be searched for in several final states depending on the considered decay of the Higgs boson. At ATLAS and CMS Hqt couplings are studied in $t\bar{t}$ events where one of the top quarks decays via FCNC interaction ($pp \to t\bar{t} \to bWqH$, $q = u, c$).

The analysis that considers a Higgs decay to a pair of photons is performed with 5 and 20 fb^{-1} collected at 7 and 8 TeV data, respectively, by ATLAS. Besides the two photons, the final state sought for consists of one b-tagged jet and three jets or one isolated lepton and one additional jet [16]. The main background contribution comes from the di-photon production and is estimated from data. The observed upper limit on the coupling strength is obtained of $\kappa_{tqH} < 0.17$ (q=u,c). The observed (expected) branching ratio limit is $\mathscr{B}(t \to qH) < 0.79(0.51)\%$. The analysis at CMS which looks at the same final state to search for Hqt interactions in di-photon channel uses 20 fb^{-1} of 8 TeV data [17]. The dominant di-photon non-resonant background is estimated from data. The observed (expected) branching ratios limits are $\mathscr{B}(t \to uH) < 0.42(0.65)\%$ and $\mathscr{B}(t \to cH) < 0.47(0.71)\%$.

The search for Hqt events with Higgs decay to a pair of b-quarks is done at ATLAS with 20 fb^{-1} of data collected at 8 TeV [18]. The final state consists of three b-tagged jets and one isolated lepton. The dominant $t\bar{t}$ background is estimated from data. The combined (with Refs. [16, 19]) observed (expected) branching ratios limits are $\mathscr{B}(t \to uH) < 0.45(0.29)\%$ and $\mathscr{B}(t \to cH) < 0.46(0.25)\%$.

The search for Hqt events in the final states of three and two same-charge leptons is performed at CMS with 20 fb^{-1} of 8 TeV data [20]. The Higgs boson's decay channels that mainly contribute to these final states are $H \to W^+W^-$, ZZ and $\tau^+\tau^-$. The dominant WZ+jets (three leptons) and fake lepton (same-charge two leptons) backgrounds are estimated from data. The observed upper limit on the coupling strength is $\kappa_{tqH} < 0.18$ (q=u,c). The observed (expected) branching ratio limit is $\mathscr{B}(t \to qH) < 0.93(0.89)\%$.

6. Conclusion

The recent searches for FCNC processes performed with the ATLAS and the CMS detectors with the data provided by the LHC at 7 and 8 TeV provided the most stringent limits to date set on this type of interactions with a top quark. The summary of the current limits on the branching ratios for the FCNC processes with a top quark are presented in Fig. 1. No evidence for the new physics is observed yet. The current limits on FCNC couplings are expected to be further improved with the new data still to be obtained from the LHC at 13 TeV.

References

[1] S. L. Glashow, J. Iliopoulos and L. Maiani, *Phys.Rev.* **D2** (1970) 1285.

[2] L3 Collaboration, *Phys.Lett.* **B549** (2002) 290-300.

[3] OPAL Collaboration, *Phys.Lett.* **B521** (2001) 181-194.

[4] ALEPH Collaboration, *Phys.Lett.* **B494** (2000) 33.

[5] DELPHI Collaboration, *Phys.Lett.* **B590** (2004) 21-34.

[6] ZEUS Collaboration, *Phys.Lett.* **B708** (2012) 27-36.

[7] H1 Collaboration, *Phys.Lett.* **B678** (2009) 450.

[8] DØ Collaboration, V. Abazov, et al., *Phys.Lett.* **B693** (2010) 81-87.

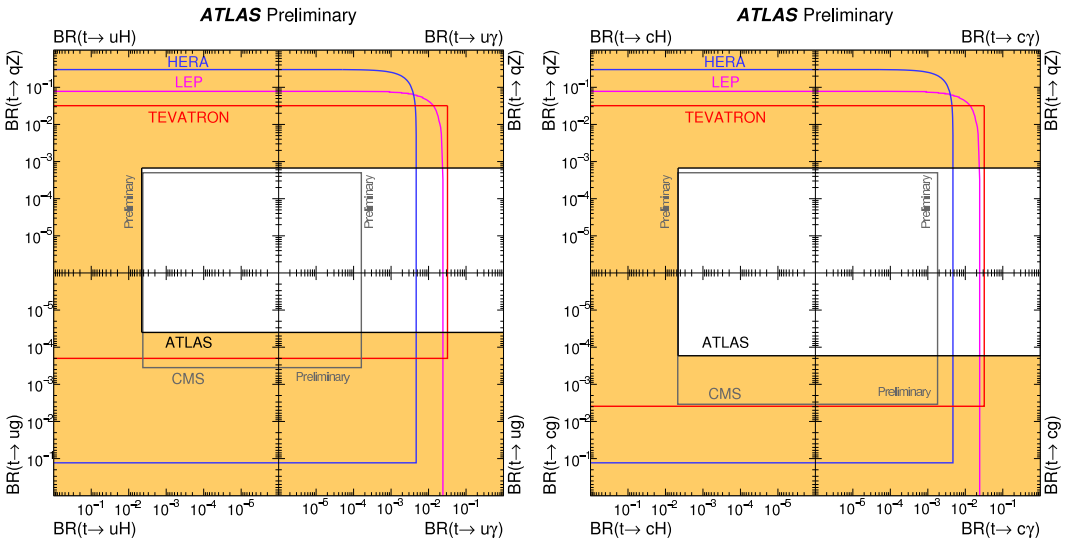

Figure 1: Summary of the current 95% CL limits on the branching ratios for the FCNC (left) $t \to uX$ and (right) $\to cX$ (X=g, Z, γ or H) processes [21]. The grey contour denotes the region excluded by CMS, while the yellow area represents the region excluded by ATLAS.

[9] CDF Collaboration, T. Aaltonen, et al., *Phys.Lett.* **101** (2008) 192002.

[10] ATLAS Collaboration, *Eur.Phys.J.* **C76** (2016) 55.

[11] CMS Collaboration, *CMS PAS TOP-14-007*.

[12] ATLAS Collaboration, *Eur.Phys.J.* **C76** (2016) 12.

[13] CMS Collaboration, *Phys.Rev.Lett.* **112** (2014) 171802.

[14] CMS Collaboration, *CMS PAS TOP-12-021*.

[15] CMS Collaboration, *CMS PAS TOP-14-003*.

[16] ATLAS Collaboration, *JHEP* **06** (2014) 008.

[17] CMS Collaboration, *CMS PAS TOP-14-019*.

[18] ATLAS Collaboration, *JHEP* **12** (2015) 061.

[19] ATLAS Collaboration, *Phys.Lett.B* **749** (2015) 519.

[20] CMS Collaboration, *CMS PAS TOP-13-017*.

[21] ATLAS Collaboration,
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/TOP/