

## Anomalous $tqg$ and $tqH$ couplings effects in a Top-Higgs Final State

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### Abstract

We study the anomalous production of a single top quark in association with a Higgs boson at the LHC originating from flavor-changing neutral current interactions in  $tqg$  and  $tqH$  vertices. We derive the discovery potentials and 68% C.L. upper limits considering leptonic decay of the top quark and the Higgs boson decay into a  $b\bar{b}$  pair with  $10 \text{ fb}^{-1}$  integrated luminosity of data at 14 TeV. We propose a charge ratio for the lepton in top quark decay in terms of lepton  $p_T$  and  $\eta$  as a strong tool to observe the signal.

**Keywords:** Top Quark, Higgs Boson, Flavor-Changing Neutral Current

### 1. Introduction

Because of large top quark Yukawa coupling, for studying top quark properties, it is worth looking at channels where top quark and Higgs boson are present together. Flavor-Changing Neutral Current (FCNC) couplings for top quark are forcefully suppressed within the Standard Model (SM) by Glashow-Iliopoulos-Maiani (GIM) mechanism. However, there are many extended theories which predict sizeable top quark FCNC couplings. The anomalous FCNC interactions  $tqg$  and  $tqH$  could be described by model independent effective Lagrangian as the following [1]:

$$\begin{aligned} \mathcal{L} = & \sqrt{2}g_s \sum_{q=u,c} \frac{\kappa_{tqg}}{\Lambda} \bar{t} \sigma^{\mu\nu} T_a (f_q^L P_L + f_q^R P_R) q G_{\mu\nu}^a \\ & + \frac{g}{2\sqrt{2}} \sum_{q=u,c} g_{tqH} \bar{q} (g_{tqH}^V + g_{tqH}^A \gamma_5) t H, \end{aligned} \quad (1)$$

Where  $\Lambda$  is the energy scale of new physics. In the above effective Lagrangian  $\kappa_{tqg}$  and  $g_{tqH}$  (with  $q = u, c$ ) are real dimensionless parameters,  $f_q^{L(R)}$  and  $g_{tqH}^{v(a)}$  are the parameters which define the chirality.

In this report, we consider the production of a single top quark in association with a Higgs boson for probing  $tqg$  and  $tqH$  anomalous couplings. We assume leptonic decay of the top quark and Higgs decays into  $b$  and  $\bar{b}$ . Therefore, there is one charged lepton (electron or muon), missing energy and three  $b$  jets in the final state. The analysis is performed for the LHC with  $10$  and  $100 \text{ fb}^{-1}$  of integrated luminosity of data at center-of-mass energy of 14 TeV. The representative Feynman diagram of the signal process including the decay chain is shown in Fig.1. More details of the analysis with a complete list of related references can be found in [2].

### 2. Event Simulation and Selection

Considering the final state of the signal, main backgrounds are  $Wb\bar{b}j$ ,  $Wjjj$ ,  $WZj$ , and  $t\bar{t}$ . For the sake of simulating the signal events, the effective Lagrangian has been implemented within the FEYNRULES package then inserted into

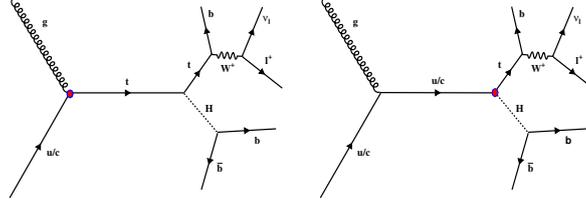


Figure 1: Feynman diagram for production of a top quark in association with a Higgs boson.

the MADGRAPH package [3]. For generating events for signal and backgrounds at parton level, MADGRAPH 5 package has been employed with the CTEQ6 as the proton PDF then for parton showering PYTHIA 8 has been used. FASTJET package accomplishes jet reconstruction with the cone size of  $R = 0.4$ . A b-tagging efficiency is considered 60% for b-jets and a mis-tagging rate is assumed 10% for other quarks. We apply basic cuts on the final state objects. Charged lepton and jets  $p_T$  cut is required to be greater than 25 GeV within the pseudorapidity range of  $|\eta| < 2.5$ . The missing transverse energy should be greater than 25 GeV. The angular distance between each two objects should be larger than 0.4. For top quark reconstruction, we need to have the full momentum of the neutrino which is found by using  $W$ -boson mass constraint. Two solutions are obtained which gives us two neutrinos. The combination of the charged lepton, two neutrinos and three b-jets leads six different top quarks. Among all of these combinations we choose the one which has closest mass to the nominal top quark mass. After that with two remaining b-jets, we reconstruct Higgs boson. For suppressing the backgrounds, we look at some kinematic distributions. To reduce the background contributions, we reject events with  $|m_{H,rec} - 125| > 15$  GeV and  $p_{T,Higgs} < 100$  GeV. Also to enhance the signal contribution, we require the events with  $|y_l - y_H| < 1.2$  and  $|y_H| > 0.8$ .

### 3. Results

As mentioned before, the  $t + Higgs$  final state can arise from both  $tqg$  and  $tqH$  anomalous couplings. In the presence of both couplings cross section could be parameterised as:

$$\sigma\left(\frac{\kappa_{tqg}}{\Lambda}, g_{tqH}\right)[pb] = c_{tqg} \times \left(\frac{\kappa_{tqg}}{\Lambda}\right)^2 + c_{tqH} \times g_{tqH}^2 + c_{int.} \times \frac{\kappa_{tqg}}{\Lambda} \times g_{tqH}. \quad (2)$$

After the basic cuts, the coefficients are  $c_{tu(c)g} = 5.6(1.05)$ ,  $c_{tu(c)H} = 0.09(0.01)$ , and  $c_{int.} = 0.46(0.2)$ . The contribution of  $tqg$  couplings is larger than  $tqH$  in the cross section of signal. After applying all cuts we calculate the  $3\sigma$  and  $5\sigma$  discovery. Figure 2 shows the  $3\sigma$  exclusion regions using  $10 \text{ fb}^{-1}$  of the integrated luminosity at 14 TeV. In case of finding no evidence for signal, we can set upper limits on the anomalous couplings. We choose distribution of  $|y_l - y_H|$  for a shape analysis, because the shape of signal and background are different in this distribution [2]. The  $\chi^2$  criterion is defined as:

$$\chi^2\left(\frac{\kappa_{u,c}}{\Lambda}\right) = \sum_{i=bins} \frac{(s_i - b_i)^2}{\Delta_i^2}, \quad (3)$$

where  $s_i$  and  $b_i$  denotes the number of signal and background events in the  $i$ -th bin, respectively.  $\Delta_i$  is defined as  $b_i \sqrt{\delta_{stat}^2 + \delta_{syst}^2}$ . Where  $\delta_{stat}$  and  $\delta_{syst}$  are the statistical and systematic uncertainties, respectively. We take into account 10% for systematic uncertainty. The number of signal events depend on the anomalous couplings of  $\kappa_{u,c}/\Lambda$ . So, the 68% C.L. upper limits on the anomalous FCNC couplings are found to be:

$$\frac{\kappa_{tug}}{\Lambda} \leq 0.014 \text{ TeV}^{-1}, \quad \frac{\kappa_{tcg}}{\Lambda} \leq 0.045 \text{ TeV}^{-1}. \quad (4)$$

One of the interesting features of the signal ( $g + u(\bar{u}) \rightarrow t(\bar{t}) + H$ ), is the asymmetry between top and anti-top rates. This fact is related to the difference between the  $u$ -quark and  $\bar{u}$ -quark parton distribution functions of proton. When top quark decays leptonically, this asymmetry is translated into a corresponding lepton charge asymmetry. We define

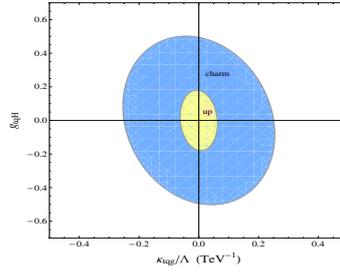


Figure 2: The  $3\sigma$  exclusion upper limits on the anomalous couplings  $\frac{\kappa_{tqg}}{\Lambda}$  and  $g_{tqH}$  for  $10 \text{ fb}^{-1}$  of integrated luminosity at the LHC with 14 TeV.

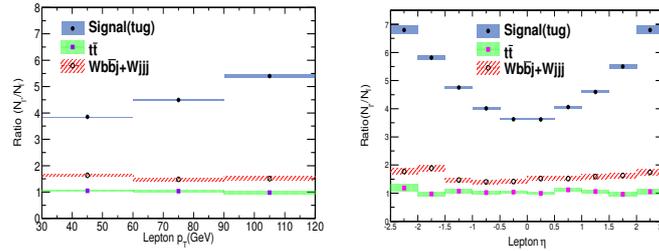


Figure 3: The ratio of positive to negative leptons as a function of lepton  $p_T$  and lepton  $\eta$ .

a ratio  $R$  as the number of events with positive charged lepton to the number of events with negative charge. The inclusive values of  $R$  for signal and backgrounds are:  $R_{\text{signal}} = 4.35 \pm 0.02$ ,  $R_{W+\text{jets}} = 1.57 \pm 0.03$ ,  $R_{t\bar{t}} = 1.04 \pm 0.03$ , where the uncertainties are only statistical uncertainties. Also, we investigate the dependence of the charge ratio  $R$  for the signal and main backgrounds on the transverse momentum and pseudorapidity of the charged lepton. Figure 3 shows the charge ratio  $R$  as a function of lepton  $p_T$  and lepton  $\eta$ .

As it can be seen in Figure 3,  $R$  grows with increasing the lepton  $p_T$  for signal while it is almost flat for backgrounds. This behavior can be understood by considering the fact that the high  $p_T$  lepton in the final state needs larger fraction of the parton momentum from the proton PDF. It is well-known that the up quark PDF are much larger than the anti-up quark PDF at large values of  $x$  ( $x$  is the fraction of the proton momentum which a parton carries). Thus, at large lepton  $p_T$ , larger ratio is expected. Also for top pair events the ratio is almost flat and fluctuating around one while for  $W+\text{jets}$  is very slowly increasing with  $|\eta|$ . For the signal,  $R$  starts from 3.5 at  $\eta \sim 0$  and grows significantly up to 6.8 at  $2.0 < |\eta| < 2.5$ . There is a correlation between  $p_T$  and  $\eta$  of the charged lepton for the signal events. According to the Figure 3, it is apparent that the ratio  $R(p_T)$  and  $R(\eta)$  has a strong discriminating power between signal and the main backgrounds.

#### 4. Conclusions

In this work we propose to use the  $pp \rightarrow t(\bar{t}) + H$  process to probe the anomalous  $tug$  and  $tcg$  couplings as a complementary channel besides the other channels. We show that the LHC can probe the anomalous  $tug(tcg)$  couplings down to 0.01 (0.04)  $\text{TeV}^{-1}$  with  $10 \text{ fb}^{-1}$  of integrated luminosity. Also, we propose charge ratio versus the transverse momentum and the pseudorapidity of the charge lepton as a strong tool to discriminate between signal and backgrounds.

#### References

- [1] E. Malkawi and T. M. P. Tait, Phys. Rev. D **54**, 5758 (1996) [hep-ph/9511337], J. A. Aguilar-Saavedra, Acta Phys. Polon. B **35**, 2695 (2004) [hep-ph/0409342].
- [2] S. Khatibi and M. M. Najafabadi, Phys. Rev. D **89**, 054011 (2014) [arXiv:1402.3073 [hep-ph]].
- [3] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer and T. Stelzer, JHEP **1106**, 128 (2011) [arXiv:1106.0522 [hep-ph]].