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Dimension-six anomalous $tq\gamma$ couplings in $\gamma\gamma$ collision at the LHC

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Abstract

We have investigated the flavor changing top quark physics on the dimension-six anomalous $tq\gamma$ ($q = u, c$) couplings through the process $pp \to p\gamma\gamma p \to pt\bar{q}p$ at the LHC by considering different forward detector acceptances. In this paper, we have also examined the effects of top quark decay. The sensitivity bounds on the anomalous couplings and $t \to q\gamma$ branching ratio have been obtained at the 95% confidence level for the effective Lagrangian approach. Besides, we have investigated the effect of the anomalous couplings on single top quark spin asymmetry.

1. Introduction

Top quark mass is at the electroweak symmetry-breaking scale. It is the heaviest and one of the least known elementary particle in the Standard Model (SM) [1–3]. Therefore, the top quark properties and its interactions provide a possibility for examining new physics beyond the SM. Moreover, the effects of new physics theories on the top quark interactions are considered to be larger than on any other particles [4]. New physics interactions would alter top quark production and decay at the colliders. The most widely studied cases are top quark anomalous interactions via Flavour-Changing Neutral Currents (FCNC). Tree level FCNC decay $t \to q\gamma$ ($q = u, c$) is not possible in the SM. This decay can only make loop contributions and it is highly suppressed

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due to Glashow–Iliopoulos–Maiani (GIM) mechanism. For this reason, $t \to q\gamma$ branching ratio is very small ($\approx 10^{-14}$) [5–8]. In this instance, conflicts with the SM expectations of this decay would be evidence of new physics. These kind of decays have been studied in various new physics models beyond the SM: quark-singlet model [8–10], the two-Higgs doublet model [11–16], the minimal supersymmetric model [17–23], supersymmetry [24], the top-color-assisted technicolor model [25] or extra dimensional models [26,27].

Present experimental constraints on the FCNC $tq\gamma$ couplings are the following: The CDF Collaboration limit on the branching ratio at 95% C.L. for the process $t \to q\gamma$ is $BR(t \to u\gamma) + BR(t \to c\gamma) < \%3.2$ [28]. The ZEUS Collaboration provide at 95% C.L. on the anomalous $tq\gamma$ coupling $\kappa_{tq\gamma} < 0.12$ [29] with the assumption of $m_t = 175$ GeV. The Large Hadron Collider (LHC) can produce top quarks in the order of millions per year. Therefore, top quark couplings can be probed with very high sensitivity. In particular, both the ATLAS and CMS Collaborations have presented their sensitivity bounds on these rare top quark decays induced by the anomalous FCNC interactions [30–32]. The most stringent experimental bounds recently have been obtained at 95% C.L. by the CMS Collaboration as $BR(t \to u\gamma) = \%0.0161$ and $BR(t \to c\gamma) = \%0.182$ [33]. The CMS group can be distinguished by the $tu\gamma$ and $tc\gamma$ couplings with applying charge ratio method [34]. Due to the fact that the u-quark parton distribution function is larger than the c-quark, they have found less sensitivity to $tc\gamma$ coupling.

The effects of new physics to FCNC top quark couplings can be obtained in a model independent way by means of the effective operator formalism. The theoretical basis of that kind of a method rely on the assumption that the SM of particle physics is the low-energy limit of a more fundamental theory. Such a procedure is quite general and independent of the new interactions at the new physics energy scale. According to Buchmüller and Wyler [35], these effective operators obey the $SU(2)_L \times U(1)_Y$ gauge symmetries of the SM and can be written in following form,

$$L = L_{SM} + \frac{1}{\Lambda} L^{(5)} + \frac{1}{\Lambda^2} L^{(6)} + O\left(\frac{1}{\Lambda^3}\right) \tag{1}$$

where, Λ is the energy scale of new physics, L_{SM} is the SM Lagrangian, $L^{(5)}$ and $L^{(6)}$ are all of the dimension-five and dimension-six operators. As mentioned before, they are invariant under the gauge symmetries of the SM. The five dimensional terms break the conversation of lepton and baryon numbers. Hence, we do not examine these operators in this paper. The list of $L^{(6)}$ terms is quite vast. In Refs. [36–40], the authors have investigated all dimension-six flavor changing effective operators of the tqg (g: gluon) and tqV ($V : \gamma, Z$) FCNC top physics. In this paper, we examine the dimension-six operators that give rise to flavor changing interactions of the top quark in the electromagnetic interactions. These operators can be written as shown in [39,40],

$$\begin{aligned}
O_{tB} &= i\frac{\alpha^B_{it}}{\Lambda^2}(\bar{u}^i_R \gamma^\mu D^\nu t_R)B_{\mu\nu}, \\
O_{tB\phi} &= \frac{\beta^B_{it}}{\Lambda^2}(\bar{q}^i_L \sigma^{\mu\nu} t_R)\tilde{\phi} B_{\mu\nu}, \\
O_{tW\phi} &= \frac{\beta^W_{it}}{\Lambda^2}(\bar{q}^i_L \tau_I \sigma^{\mu\nu} t_R)\tilde{\phi} W^I_{\mu\nu},
\end{aligned} \tag{2}$$

where α^B_{it}, β^B_{it} and β^W_{it} dimensionless complex coupling constants, u_R and q_L show the right-handed u-quark singlet and left-handed doublet. $B_{\mu\nu}$ and $W^I_{\mu\nu}$ are the $U(1)_Y$ and $SU(2)_L$ field tensors, respectively. ϕ is the SM Higss doublet, τ^I are the Pauli matrices and $\tilde{\phi}$ charge conjugate of the Higgs doublet ($\tilde{\phi} = i\tau^2\phi^*$). Obviously, these operators contribute to t quark anomalous