Flavor signature of anomalous tcZ coupling

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Plan of this talk

1. Motivation for top quark physics
2. The FCNC top quark decays
3. Anomalous tcZ coupling
4. Contribution of anomalous tcZ coupling to different loop level processes
5. Result
6. Conclusions

Motivation for top quark physics

- The top quark is the heaviest particle among all elementary particle.
- Its mass is close to the Electroweak symmetry breaking(EWSB), it may play important role in the understanding of EWSB.
- The large mass of top quark implies a large coupling to Higgs boson so it establish link to Higgs sector.
- Due to its short life time it provide unique opportunity to study the properties of a bare quark.

So study of top quark decays provide us a unique environment for test of SM and searches for physics BSM.

The FCNC top quark decays

For the FCNC top quark decay $t \to qZ$-

- $Br(t \to uZ) \sim 10^{-17}$, $Br(t \to cZ) \sim 10^{-14}$,[J. A. A. Saavedra,Acta Phys. Polon. B 35, 2695 (2004)]
- The detection level of LHC for $t \to qZ$ is $10^{-4} - 10^{-5}$[J. Carvalho *et al.* [ATLAS Collaboration], EPJC, 52 (2007)].

Anomalous tcZ couplings

In this work we study effects of anomalous tcZ couplings. Our aim is -

- To see whether the anomalous tcZ coupling can enhance the branching ratio of $t \to cZ$ decay.
- To see the effect of such couplings on the loop level processes involving the top quark. This coupling has the potential to affect rare B- and K-meson decays via the Z-penguin diagrams.

LHC is a top factory producing abundant top quark events. Hence one expects the observation of possible anomalous couplings in the top sector at the LHC.

The effective Lagrangian for anomalous tcZ coupling can be written as [H. Gong et al., JHEP(2013)]

$$\mathcal{L}_{tcZ} = \frac{g}{2cos_{\theta_w}}\left[\bar{c}\gamma^{\mu}(X^L_{ct}P_L + X^R_{ct}P_R) + \bar{c}\frac{i\sigma^{\mu\nu}p_\nu}{M_Z}(\kappa^L_{ct}P_L + \kappa^R_{ct}P_R)\right]tZ_\mu + h.c. \quad (1)$$

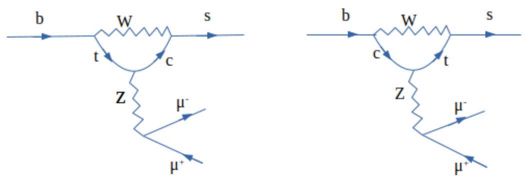
The couplings $X^{L,R}_{ct}$ and $\kappa^{L,R}_{ct}$ are in general complex.

Contribution of anomalous tcZ coupling to $b \to s\mu^+\mu^-$ transition

The SM Hamiltonian for $b \to s\mu^+\mu^-$ process is given by

$$\mathcal{H}^{SM}_{eff} = \frac{G_F}{\sqrt{2}}V_{tb}V^*_{ts}\left[C_7O_7 + C_9O_9 + C_{10}O_{10}\right] \quad (2)$$

The anomalous tcZ coupling can contribute to the $b \to s\mu^+\mu^-$ transition through the Feynman diagrams shown in following figure.



$V_{tb} = 1, \; V_{cs} = 1 - \lambda^2/2$

$V_{cb} = A\lambda^2, \; V_{ts} = -A\lambda^2$

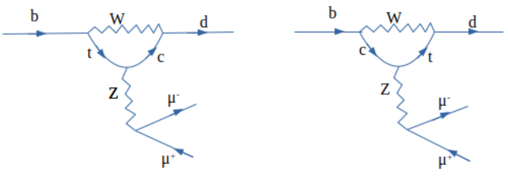
The dominant contribution comes from the diagram on the left panel. The contribution of anomalous tcZ coupling to $b \to s\mu^+\mu^-$ transition modifies the Wilson coefficients C_9 and C_{10} in the following way-

$$\tilde{C_9} = C_9 + \frac{C^{NP}_{b\to s}}{sin^2\theta_w}, \qquad \tilde{C_{10}} = C_{10} - \frac{C^{NP}_{b\to s}}{sin^2\theta_w}, \tag{3}$$

$$C^{NP}_{b\to s} = -\frac{1}{8}\frac{V^*_{cs}}{V^*_{ts}}\left[(-x_t \ln(\frac{M_W^2}{\mu^2}) + \frac{3}{2} + x_t - x_t \ln x_t)X^L_{ct} + \mathcal{O}(\frac{m_c}{M_W})X^R_{ct}\right], \tag{4}$$

with $x_t = \frac{m_t^2}{M_W^2}$. The right handed coupling, X^R_{ct}, is suppressed by a factor of m_c/M_W and is neglected in our analysis.

The anomalous tcZ couplings contributes to $b \to d\mu^+\mu^-$ transition via Feynman diagrams shown in following figure-



$$V_{tb} = 1,\ V_{cd} = -\lambda,\ V_{cb} = A\lambda^2,$$
$$V_{td} = -A\lambda^3(1 - \rho - \iota\eta)$$

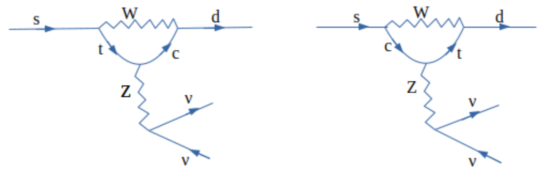
The contribution of anomalous tcZ coupling to $b \to d\mu^+\mu^-$ transition modifies the Wilson coefficients C_9 and C_{10} in the following way-

$$\tilde{C_9} = C_9 + \frac{C^{NP}_{b\to d}}{sin^2\theta_w}, \qquad \tilde{C_{10}} = C_{10} - \frac{C^{NP}_{b\to d}}{sin^2\theta_w}, \tag{5}$$

$$C^{NP}_{b\to d} = -\frac{1}{8}\frac{V^*_{cd}}{V^*_{td}}\left[(-x_t \ln(\frac{M_W^2}{\mu^2}) + \frac{3}{2} + x_t - x_t \ln x_t)X^L_{ct} + \mathcal{O}(\frac{m_c}{M_W})X^R_{ct}\right] \tag{6}$$

Contribution of anomalous tcZ coupling to $s \to d\nu\bar{\nu}$ transition

The anomalous tcZ couplings contributes to $s \to d\nu\bar{\nu}$ transition via Feynman diagrams shown in following figure-



$$V_{ts} = -A\lambda^2, \; V_{cd} = -\lambda, \; V_{cs} = 1 - \lambda^2/2, \; V_{td} = -A\lambda^3(1 - \rho - \iota\eta)$$

In this case, the CKM contribution from both the diagrams is of the same order, $\mathcal{O}(\lambda^3)$, and hence we include both of them in our analysis.

The effective Hamiltonian for $\bar{s} \to \bar{d}\nu\bar{\nu}$ transition can be written as

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \frac{\alpha}{2\pi Sin^2\theta_w} \sum_{l=e,\mu,\tau} \left[V_{cs}^* V_{cd} X_{NL}^l + V_{ts}^* V_{td} X(x_t) \right] \times (\bar{s}d)_{V-A} (\bar{\nu}_l \nu_l)_{V-A} \tag{7}$$

where X_{NL}^l and $X(x_t)$ are the structure functions corresponding to charm and top sector. The anomalous tcZ coupling to $\bar{s} \to \bar{d}\nu\bar{\nu}$ transition then modifies the structure function $X(x_t)$ in the following way

$$X(x_t) \to X^{tot}(x_t) = X(x_t) + C^{NP}_{\bar{s}\to\bar{d}}$$

$$X(x_t) = \eta_x \frac{x_t}{8} \left[\frac{2+x_t}{x_t-1} + \frac{3x_t-6}{(1-x_t)^2} \ln x_t \right], \tag{8}$$

$$C^{NP}_{\bar{s}\to\bar{d}} = -\frac{1}{8} \left(\frac{V_{cd} V_{ts}^* + V_{td} V_{cs}^*}{V_{td} V_{ts}^*} \right) \left(-x_t \ln \frac{M_W^2}{\mu^2} + 1.5 + x_t - x_t \ln x_t \right) (X_{ct}^L)^* \tag{9}$$

Constraint on the anomalous tcZ coupling

In order to obtain constraints on the anomalous tcZ coupling, X^L_{ct}, we consider all flavour physics observables in B and K sector. Thus the total χ^2 is written as a function of two parameters:imaginary part of X^L_{ct} and real part of X^L_{ct}. The χ^2 function is constructed as-

$$\chi^2(C_i) = (\mathcal{O}_{th}(C_i) - \mathcal{O}_{exp})^T \mathcal{C}^{-1} (\mathcal{O}_{th}(C_i) - \mathcal{O}_{exp})$$

where $\mathcal{C}$ is covariance matrix.

We include following observables in our analyses-

- Observables from $b \to s\mu^+\mu^-$ sector-
  Instead of including all observables induced by $b \to s\mu^+\mu^-$ transition explicitly, we include constraint on NP Wilsion coefficient only [AKA *et al.* PRD 96, 015034 (2017)].

$$Re(WC) = (-0.8 \pm 0.3),\ Im(WC) = (1.2 \pm 0.7)$$

- Observables induced by $b \to d\mu^+\mu^-$ transition
  1. $\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)$
- Observables induced by $s \to d\nu\overline{\nu}$ transition
  1. $\mathcal{B}(K^+ \to \pi^+\nu\overline{\nu})$

Results

1. The preliminary fit results are-

$$Re(X^L_{ct}) = (2.2 \pm 0.9) \times 10^{-3}, \quad Im(X^L_{ct}) = (-3.8 \pm 2.8) \times 10^{-3}$$

.

2. Using above results, we obtain $\mathcal{B}(t \to cZ) \sim 10^{-5}$.

Other Signature of Anomalous tcZ coupling

$\mathcal{B}(K_L \to \pi^0 \nu \bar{\nu})$

- $\mathcal{B}(K_L \to \pi^0 \nu \bar{\nu})|_{SM} = (2.67^{+0.29}_{-0.36}) \times 10^{-11}$ [F. Mescia *et al.*, PRD 76, 034017 (2007)].
- With anomalous tcZ coupling its branching ratio is calculated as-

$$\mathcal{B}(K_L \to \pi^0 \nu \bar{\nu}) = (9.80 \pm 7.58) \times 10^{-11}$$

$\mathcal{B}(B \to X_s \nu \bar{\nu})$

- $\mathcal{B}(B \to X_s \nu \bar{\nu})|_{SM} = (3.13^{+0.14}_{-0.20}) \times 10^{-5}$. [J. P. Lees *et al.* [BaBar Collaboration], PRL 112, 211802 (2014)].
- With anomalous tcZ coupling its branching ratio is calculated as-

$$\mathcal{B}(B \to X_s \nu \bar{\nu}) = (3.17 \pm 1.19) \times 10^{-5}$$

Conclusions

- Presence of anomalous tcZ imply about nine order of magnitude enhancement in the $\mathcal{B}(t \to cZ)$.
- The $\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu})$ is enhanced in presence of anomalous tcZ coupling.
- The $\mathcal{B}(B \to X_s \nu\bar{\nu})$ shows no enhancement of in presence of anomalous tcZ coupling.

Thus the observation of the FCNF top quark decay $t \to cZ$ at the LHC would imply discovery of new physics.

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