Weak dipole moments of the top quark and flavor violation

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Summary

We calculate the weak electromagnetic static properties for any charged fermion of the Standard Model (SM) in the context of a general effective extended vector neutral current model with flavor changing $\bar{f}_i f_j Z'$. In this work we give phenomenological results for the weak electromagnetic properties of the quark top. We use known theoretical constraints coming from various Z' models to bound the effective coupling parameters, and we compare our results with the theoretical prediction of the Z from the SM. The experimental detection of non zero anomalous weak electro magnetic dipole moments of heavy fermions, at the current sensitivity, would be a clear evidence of new physics beyond the SM.

1 Motivations

- The study of the flavor violation has regain interest due to the discovery of the neutrino oscillations [1, 2], which suggests that the flavor conservation is violated in the Nature, this justifies to study processes that violates flavor as possible precursors of new theories that might explain more deeply the character of the elementary particles.
- The known experimental SM precision measurements of anomalous magnetic moments for elementary charged particles are known only for the electron and the muon [3, 4], while there still not exist experimental measures for the tau and the quarks, this moments dipole has long received considerable attention, which has been boosted in recent years due to the significant progress in the experimental area as the study of the static electromagnetic properties of fermions provides a unique opportunity to search efects of new physics, and beyond of the electromagnetic properties of a fermion, there is also great interest in its static weak properties, which are associated with the Z boson interaction, which we carry out in this work. This keeps open the investigation field on the fermions static weak electromagnetic dipole moments and its relation with possible new physics effects regarding to the flavor changing violation.
- The anomalous weak-magnetic moment of fermions carries important information about their interactions with other particles. It may be seen as the coefficient of a chirality-flipping term in the effective Lagrangian of the Z coupled to fermions. Therefore, at $q^2 \neq 0$, it is expected to be proportional to the mass of the fermion, and only heavy fermions (leptons or quarks) are good candidates to have a measurable anomalous weak magnetic moment [5].

2 The Extended Model

- The most simple extended model that predicts the existence of an extra weak neutral gauge boson, identified as Z', is that based on the extended electroweak gauge group $SU_L(2) \times U_Y(1) \times U'(1)$, which once implemented in the spontaneous symmetry breaking (SSB) give rises to mixings between the SM gauge boson Z and the Z'. [6].
- We use the most general renormalizable effective Lagrangian, which includes the fermion flavor violation mediated by a new neutral massive gauge boson Z', coming from any extended or grand unification model [6]:

$$\mathcal{L}_{NC} = \sum_{i,j}^{3} \left[\bar{f}_i \gamma^\alpha (\Omega_{Lfifj} P_L + \Omega_{Rfifj} P_R) f_j + \bar{f}_j \gamma^\alpha (\Omega^*_{Lfjfi} P_L + \Omega^*_{Rfjfi} P_R) f_i \right] Z'_\alpha, \tag{1}$$

where f_i is any fermion of the SM, $P_{L,R} \equiv \frac{1 \mp \gamma_5}{2}$ are the chiral projectors, and Z'_α is the new neutral massive gauge boson predicted by several extensions of the SM. The Ω_{L,Rf_if_j} parameters represent the strength of the $f_i f_j Z'$ coupling. We will assume that $\Omega_{Lf_if_j} = \Omega_{Lf_jf_i}$ and $\Omega_{Rf_if_j} = \Omega_{Rf_jf_i}$. The Lagrangian includes both flavor-conservation and flavor-violating couplings. The flavor-conserving couplings, $Q^{f_i}_{L,R}$ [6], are related to the Ω couplings as $\Omega_{Lf_if_i} = -g_2 Q^{f_i}_L$ and $\Omega_{Rf_if_i} = -g_2 Q^{f_i}_R$, where $g_2 = \frac{g}{\cos\theta_W}$ is the gauge coupling of the Z' boson [6] .

3 Static Weak Electromagnetic Dipole Moments

- The general vertex Lorentz structure is [7]

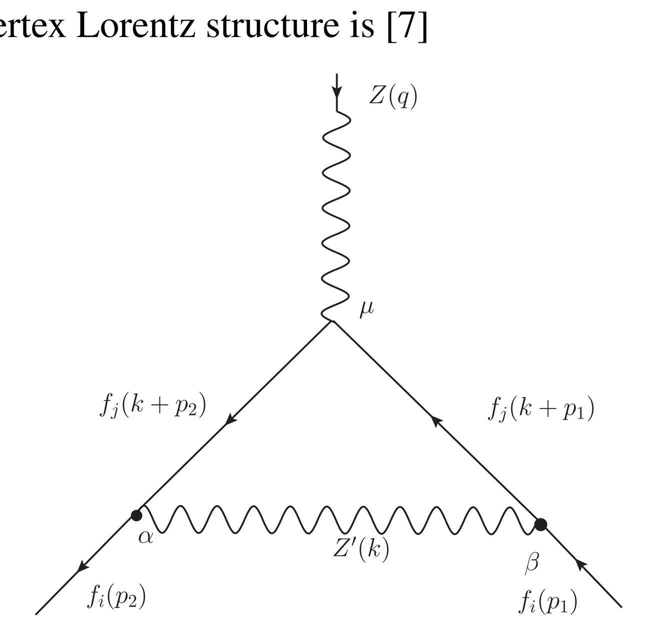

Figure 1: 1-loop contribution to the static weak electromagnetic dipole moments induced by a Z' with flavor changing.

$$ie\bar{u}(p')\Gamma^\mu u(p) = ie\bar{u}(p', m_{f_i}) \left\{ i\sigma^{\mu\nu} q_\nu \left[F_M(q^2) - iF_E(q^2)\gamma^5 \right] \right\} u(p, m_{f_i}) \ .$$

The static properties arise for the on-shell boson Z, $q^\mu \epsilon_\mu = 0$ and $q^2 = m_Z^2$:

$$F_M(m_Z^2) = -\frac{a^w_{f_i}}{2m_{f_i}} = \text{Anomalous weak magnetic dipole moment} \ ,$$

$$F_E(m_Z^2) = -\frac{d^w_{f_i}}{e} = \text{Weak electric dipole moment} \ . \tag{2}$$

- The contribution of the $f_i f_j Z'$ couplings to the static weak electromagnetic dipole moments at 1-loop level is depicted in Fig. 1., whose amplitude is

$$\mathcal{M}^\mu_{f_i} = -i^6 \frac{g}{2cW} \int \frac{d^4k}{(2\pi)^4} \bar{u}(p', m_{f_i}) [\gamma^{\alpha_1} (g^{f_if_j}_{VZ'} - g^{f_if_j}_{AZ'} \gamma^5)] (\not{k} + \not{p}' + m_{f_j}) \gamma^\mu (g^{f_j}_{VZ} - g^{f_j}_{AZ} \gamma^5)$$
$$\times \frac{(\not{k} + \not{p} + m_{f_j}) [\gamma^{\alpha_2} (g^{f_if_j}_{VZ'} * - g^{f_if_j}_{AZ'} * \gamma^5)]}{(k^2 - m^2_{Z'})[(k+p')^2 - m^2_{f_j}][(k+p)^2 - m^2_{f_j}]} u(p, m_{f_i}) \left(-g_{\alpha_1\alpha_2} + \frac{k_{\alpha_1} k_{\alpha_2}}{m^2_{Z'}} \right) . \tag{3}$$

- The tensor integral must be solved applying tensor decomposition, dimensional regularitazion, and Feynman parameterization and the functions of Passarino-Veltman.
- The static weak dipole moments have two scenarios for the CP property: i) CP conserving which only gives rise to $a^w_{f_i}$, while forbids $d^w_{f_i}$; ii) CP violation that gives rise to both $a^w_{f_i}$ and $d^w_{f_i}$.
- The weak anomalous magnetic moment:

$$a^w_{f_i} = g^Z_{Vfj} \{ |g^{Z'}_{Vfi}|^2 F^a_V(mfi, mfj, m_{Z'}) + |g^{Z'}_{Afi}|^2 F^a_A(mfi, mfj, m_{Z'}) \}$$
$$+ g^Z_{Afj} \{ g^{Z'}_{Afi} g^{Z'*}_{Vfi} + g^{Z'*}_{Afi} g^{Z'}_{Vfi} \} F^a_{VA}(mfi, mfj, m_{Z'}), \tag{4}$$

$$|g^{Z'}_{Vfi}|^2 = \frac{1}{4} \left[(\text{Re}\Omega_{Lf_if_j} + \text{Re}\Omega_{Rf_if_j})^2 + (\text{Im}\Omega_{Lf_if_j} + \text{Im}\Omega_{Rf_if_j})^2 \right] \ ,$$

$$|g^{Z'}_{Afi}|^2 = \frac{1}{4} \left[(\text{Re}\Omega_{Lf_if_j} - \text{Re}\Omega_{Rf_if_j})^2 + (\text{Im}\Omega_{Lf_if_j} - \text{Im}\Omega_{Rf_if_j})^2 \right] \ .$$

- The weak electric dipole moment:

$$d^w_{f_i} = g^Z_{Vfj} \{ g^{Z'}_{Afi} g^{Z'*}_{Vfi} - g^{Z'}_{Vfi} g^{Z'*}_{Afi} \} F^d_{VA}(mfi, mfj, mZ') \tag{5}$$

$$g^{Z'}_{Afi} g^{Z'*}_{Vfi} - g^{Z'}_{Vfi} g^{Z'*}_{Afi} = i(\text{Re}\Omega_{Lf_if_j} \text{Im}\Omega_{Rf_if_j} - \text{Re}\Omega_{Rf_if_j} \text{Im}\Omega_{Lf_if_j}) \ .$$

4 Results: the top weak electromagnetic moments

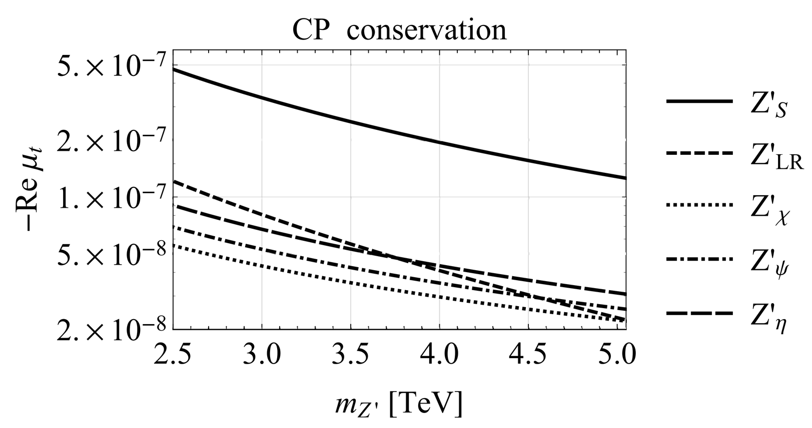

Figure 2: Anomalous weak magnetic dipole moment of the top with CP conserving.

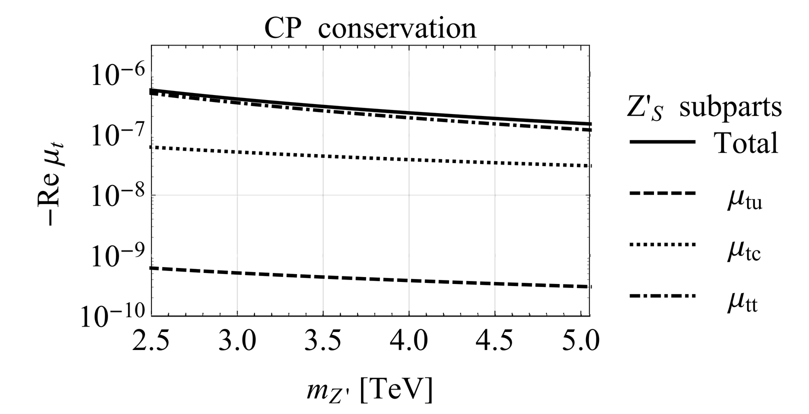

Figure 3: Main contribution due the Z'_S and its subparts.

- We take existing bounds for the Ω_{R,Lf_if_j} couplings coming from theoretical model which predicts Z' [6].
- The Fig. 2 shows the real part of the anomalous weak magnetic dipole moment of the top in the CP conserving scenario, where the Z_S provides the higher signal, and the Fig. 3 show the main contribution.
- The Fig. 4 shows the real part of the anomalous weak magnetic dipole moment of the top in the CP violation scenario, where again the Z_S provides the higher signal, and the Fig. 5 show the main contribution.
- The Fig. 6 shows the real part of the weak electric dipole moment of the top in the CP violation scenario, where the models are between the order of magnitude of $\sim 10^{-26} ecm$ and $\sim 10^{-27} ecm$, and the Fig. 7 show the main contribution.

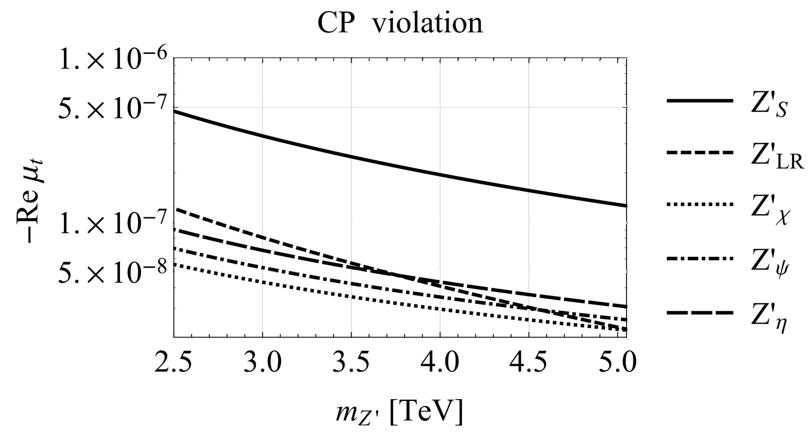

Figure 4: Anomalous weak magnetic dipole moment of the top with CP violating.

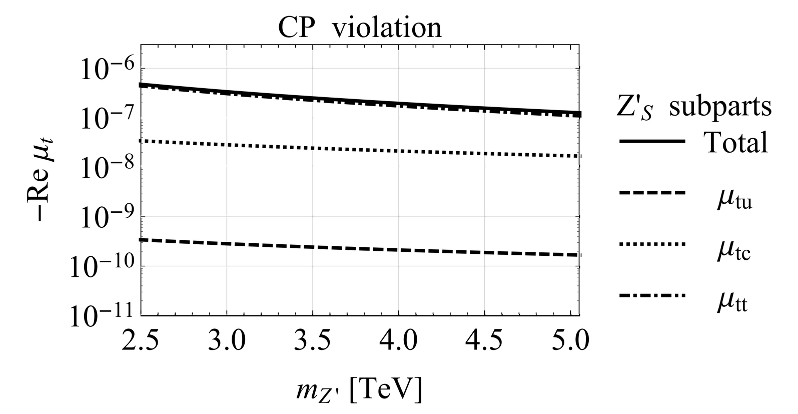

Figure 5: Main contribution due the Z'_S and its subparts.

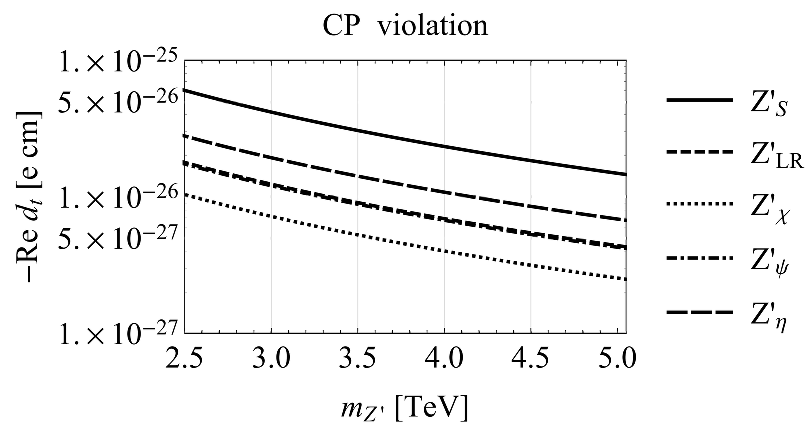

Figure 6: Anomalous weak electric dipole moment of the top.

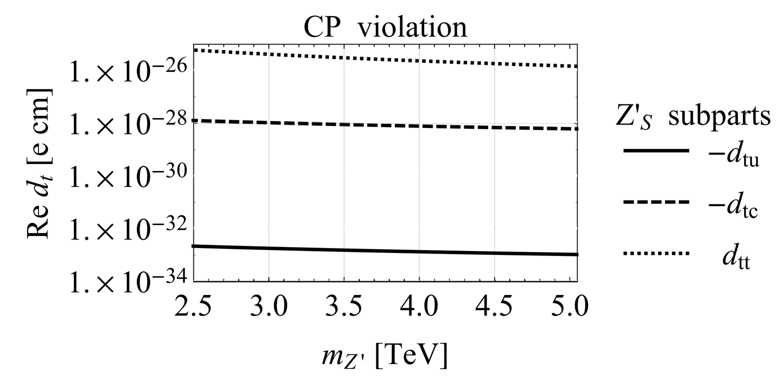

Figure 7: Main contribution due the Z'_S and its subparts.

- The theoretical SM contribution to the weak dipole magnetic moment of the top at $\sqrt{q^2} = 500\ GeV$ is $\mu_{t_{SM}} = -2.4585 \times 10^{-4} - i1.4502 \times 10^{-3}$ [9], on the other hand, we obteined the value of this contribution on-sell of $\mu_{t_{SM}} = -1.15125 \times 10^{-3} - i7.21 \times 10^{-20}$, and with respect to this value we can compare our results, shown in Figs. 2 and 4.

5 Conclusions

- We have obtained analytically the static weak electromagnetic dipole moments for any SM charged fermion in the context of extended models which predict new neutral currents with flavor changing mediated by a Z'.
- We have analyzed the quark top static weak electromagnetic dipole moments.
- For the $\mu_t(Z')$ we have found signatures in the range of $\sim 10^{-7}$ and $\sim 10^{-8}$, for both CP conserving and violation scenarios, which is barely 4 orders of magnitude lower than the SM $\mu_t(SM) \sim 10^{-3}$.
- For the $d_\tau(Z')$ we predict signatures of $\sim 10^{-26} ecm$ and $\sim 10^{-27} ecm$.
- The Z' provide promising predictions which might shed light on new physics effects.

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