Top quark Chromo-electric and Chromo-magnetic Dipole Moments in a 2HDM with CP violation.

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- I. MOTIVATION
- II. TWO HIGGS DOUBLET MODEL WITH CP VIOLATION
- III. CMDM AND CEDM IN THE GENERAL THDM
- IV. RESULTS
- V. SUMMARY

MOTIVATION

- We live exciting times! LHC era
- Top quark, an excellent new physics probe
- Extended scalar sector
  - IDM, arXiv:1410.5462, R. Gaitán, E.G., J. Montes de Oca.
  - Scalar-pseudoscalar interactions in nu-e, Int.J.Mod.Phys. A28 (2013) 1350124, R. Gaitán, E.G., O. Miranda,
  - Rare top decay t->c gamma with FCNSI in a 2HDM, arXiv: 1503.04391. R. Gaitán, E.G., R. Martínez, J. Montes de Oca.
- See talks (i. e.: J. Barranco, J. Orduz, H. Montes de O., A. Bolaños, Eysermans J., Diana Rojas, etc.)

- study of new sources of CP violation beyond the SM.
- anomalous top quark couplings affect top production, they have been widely studied at hadron colliders.
- Anomalous moments have been calculated in different new physics scenarios

CMDM and CEDM are defined through the effective Lagrangian

$$\mathcal{L} = \bar{u}(t)\frac{-g_s}{2m_t}\sigma_{\mu\nu}G^{\mu\nu a}T^a\left(\Delta\tilde{\kappa} + i\gamma_5\Delta\tilde{d}\right)u(t),$$

$\Delta\kappa$ and Δd represent the CMDM and CEDM, respectively; $G_{\mu\nu a}$ is the gluon field strength; and T_a are the QCD fundamental generators of SU(3) .

SM prediction to the CMDM is $\Delta\kappa \sim 5.6 \times 10^{-2}$

R. Martinez, M. A. Perez and N. Poveda, Eur. Phys. J. C 53 (2008) 221 [hep-ph/0701098].

In a recent study by the CMS Collaboration , $-0.045 < \text{CMDM} < 0.119$, No. CMS-PAS-TOP-14-005, 2014.

Tevatron + Atlas current limit on CEDM < 0.16 at 95% C.L. (J. F. Kamenik, et. al. Phys. Rev. D 85, 071501 (2012); 88, 039903(E) (2013).)

It is estimated to reach the future sensitivity, LHC13: ~0.05, D. B. Franzosi and C. Zhang, Phys. Rev. D 91, 114010 (2015).

II. TWO HIGGS DOUBLET MODEL WITH CP VIOLATION

If we consider a general THDM, the scalar potential can be written as:

$$
\begin{aligned}
V \; = \; & -\mu_1^2\Phi_1^\dagger\Phi_1 - \mu_2^2\Phi_2^\dagger\Phi_2 - \left[\mu_{12}^2\Phi_1^\dagger\Phi_2 + h.c.\right] \\
& + \frac{1}{2}\lambda_1\left(\Phi_1^\dagger\Phi_1\right)^2 + \frac{1}{2}\lambda_2\left(\Phi_2^\dagger\Phi_2\right)^2 + \lambda_3\left(\Phi_1^\dagger\Phi_1\right)\left(\Phi_2^\dagger\Phi_2\right) + \lambda_4\left(\Phi_1^\dagger\Phi_2\right)\left(\Phi_2^\dagger\Phi_1\right) \\
& + \left[\frac{1}{2}\lambda_5\left(\Phi_1^\dagger\Phi_2\right)^2 + \lambda_6\left(\Phi_1^\dagger\Phi_1\right)\left(\Phi_1^\dagger\Phi_2\right) + \lambda_7\left(\Phi_2^\dagger\Phi_2\right)\left(\Phi_1^\dagger\Phi_2\right) + h.c.\right],
\end{aligned}
$$

$$
\langle\Phi_1\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v_1 \end{pmatrix},
$$

$$
\langle\Phi_2\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v_2 \end{pmatrix}.
$$

The neutral components in the fields are defined as

$$
\frac{1}{\sqrt{2}}(v_a + \eta_a + i\chi_a),
$$

Due to the explicit CP symmetry breaking, there will be mixing among the CP-odd and CP-even scalar sectors.

$$
h_i = \sum_{j=1}^{3} R_{ij}\eta_j,
$$

$$
R = \begin{pmatrix} c_1c_2 & s_1c_2 & s_2 \\ -(c_1s_2s_3 + s_1c_3) & c_1c_3 - s_1s_2s_3 & c_2s_3 \\ -c_1s_2c_3 + s_1s_3 & -(c_1s_3 + s_1s_2c_3) & c_2c_3 \end{pmatrix},
$$

$$
c_i = \cos\alpha_i
$$

$$
s_i = \sin\alpha_i,
$$

I. F. Ginzburg and M. Krawczyk, Phys. Rev. D 72, 115013 (2005).

G. C. Branco, et. al , Phys. Rep. 516, 1 (2012).

The Yukawa Lagrangian for the quark sector has the general form

$$-\mathcal{L}_{\text{Yukawa}} = \sum_{i,j=1}^{3}\sum_{a=1}^{2}(\bar{q}^0_{Li}Y^{0u}_{\text{aij}}\tilde{\Phi}_a u^0_{Rj} + \bar{q}^0_{Li}Y^{0d}_{\text{aij}}\Phi_a d^0_{Rj} + \text{H.c.}).$$

After spontaneous symmetry breaking, the mass matrix can be written as

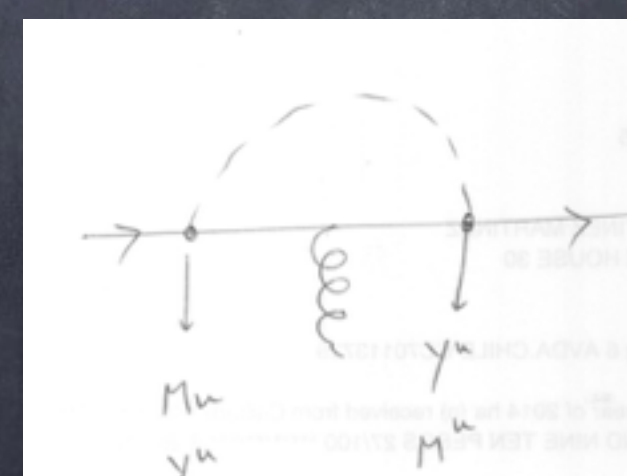
$$M^{u,d} = \sum_{a=1}^{2}\frac{v_a}{\sqrt{2}}Y^{u,d}_a,$$

$$Y^f_a = V^f_L Y^{0f}_a (V^f_R)^\dagger,$$

For the up sector, the Yukawa Lagrangian can be written as

$$\begin{aligned}-\mathcal{L}_Y &= \frac{1}{v\sin\beta}\sum_{ijk}\bar{u}_i M^u_{ij}\left(A^u_k P_L + A^{*u}_k P_R\right)u_j h_k \\ &+ \frac{1}{\sin\beta}\sum_{ijk}\bar{u}_i Y^u_{ij}\left(B^u_k P_L + B^{*u}_k P_R\right)u_j h_k,\end{aligned}$$

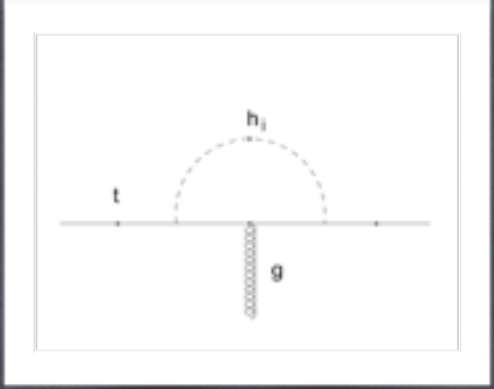
$$\begin{aligned}A^u_k &= R_{k2} - iR_{k3}\cos\beta, \\ B^u_k &= R_{k1}\sin\beta - R_{k2}\cos\beta + iR_{k3}.\end{aligned}$$



$$\Delta\tilde{\kappa}_t = \Delta\tilde{\kappa} + \Delta\tilde{\kappa}_{tt} + \Delta\tilde{\kappa}_{\text{int}}$$

$$\Delta\tilde{d}_t = \Delta\tilde{d} + \Delta\tilde{d}_{tt} + \Delta\tilde{d}_{\text{int}}.$$

$$\Delta\tilde{\kappa} = \frac{G_F m_t^2}{2\sqrt{2}\pi^2 \sin^2\beta} \sum_{i=1}^{3} \int_0^1 dx \int_0^{1-x} dy \frac{1}{(x+y)^2 - (x+y-1)\hat{m}_{h_i}^2} \times \left[(x+y)(x+y-1)(R_{i2}^2 - \cos^2\beta R_{i3}^2) - (x+y)(R_{i2}^2 + \cos^2\beta R_{i3}^2)\right],$$



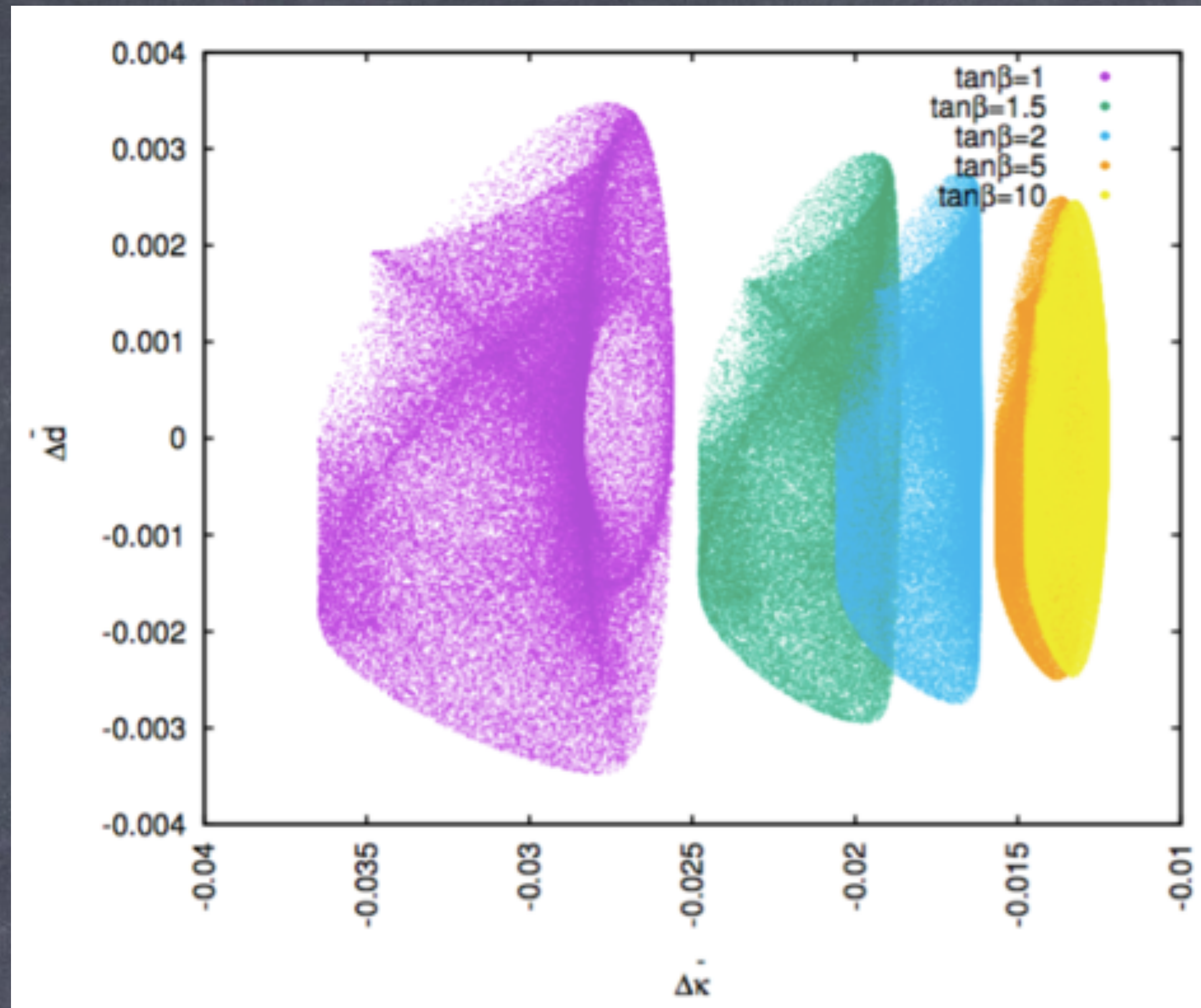
$$\Delta\tilde{d} = -\frac{G_F m_t^2}{\sqrt{2}\pi^2 \sin^2\beta} \sum_{i=1}^{3} \int_0^1 dx \int_0^{1-x} dy \frac{(x+y)(x+y-1)}{(x+y)^2 - (x+y-1)\hat{m}_{h_i}^2} \times \left[\cos\beta R_{i3} R_{i2}\right],$$

$$\Delta\tilde{\kappa}_{tt} = \frac{G_F m_t^2}{2\sqrt{2}\pi^2 \sin^2\beta} \sum_{i=1}^{3} \int_0^1 dx \int_0^{1-x} dy \frac{1}{(x+y)^2 - (x+y-1)\hat{m}_{h_i}^2} \times \left[(x+y)(x+y-1)\left((R_{i1}\sin\beta - R_{i2}\cos\beta)^2 - R_{i3}^2\right) - (x+y)\left[(R_{i1}\sin\beta - R_{i2}\cos\beta)^2 + R_{i3}^2\right]\right],$$

$$\Delta\tilde{d}_{tt} = -\frac{G_F m_t^2}{\sqrt{2}\pi^2 \sin^2\beta} \sum_{i=1}^{3} \int_0^1 dx \int_0^{1-x} dy \frac{(x+y)(x+y-1)}{(x+y)^2 - (x+y-1)\hat{m}_{h_i}^2} \times (R_{i1}\sin\beta - R_{i2}\cos\beta)R_{i3}.$$

$$\Delta\tilde{\kappa}_{int} = \frac{G_F m_t^2}{2\sqrt{2}\pi^2 \sin^2\beta} \sum_{i=1}^{3} \int_0^1 dx \int_0^{1-x} dy \frac{1}{(x+y)^2 - (x+y-1)\hat{m}_{h_i}^2} \times \left[(x+y)(x+y-1)\left((R_{i1}\sin\beta - R_{i2}\cos\beta)R_{i2} + R_{i3}^2\cos\beta\right) - (x+y)\left((R_{i1}\sin\beta - R_{i2}\cos\beta)R_{i2} - R_{i3}^2\cos\beta\right)\right],$$

$$\Delta\tilde{d}_{int} = -\frac{G_F m_t^2}{\sqrt{2}\pi^2 \sin^2\beta} \sum_{i=1}^{3} \int_0^1 dx \int_0^{1-x} dy \frac{(x+y)(x+y-1)}{(x+y)^2 - (x+y-1)\hat{m}_{h_i}^2} \times \left[(x+y)(x+y-1)\left(R_{i2}R_{i3} - (R_{i1}\sin\beta - R_{i2}\cos\beta)R_{i3}\cos\beta\right) - (x+y)\left(R_{i2}R_{i3} + (R_{i1}\sin\beta - R_{i2}\cos\beta)R_{i3}\cos\beta\right)\right].$$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tanβ=2
tanβ=5
tanβ=10
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0.002
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0
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-0.002
-0.003
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Δd
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-0.03
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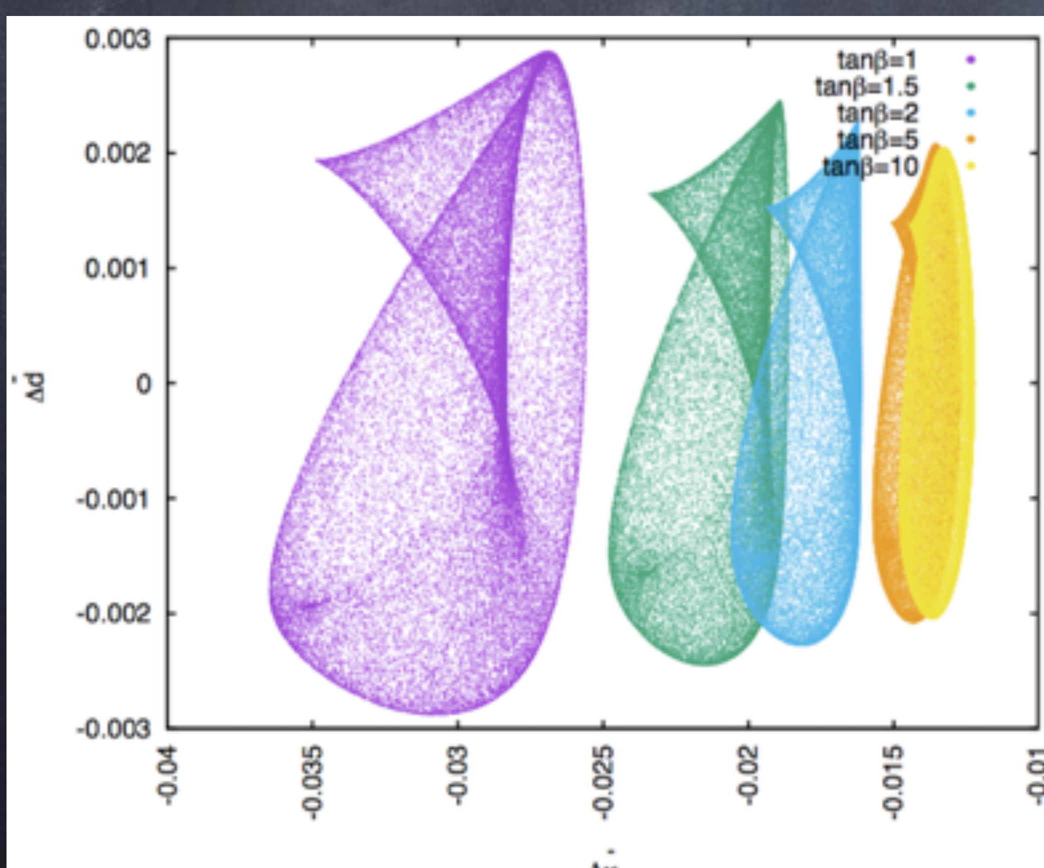
-0.015
-0.01
Δκ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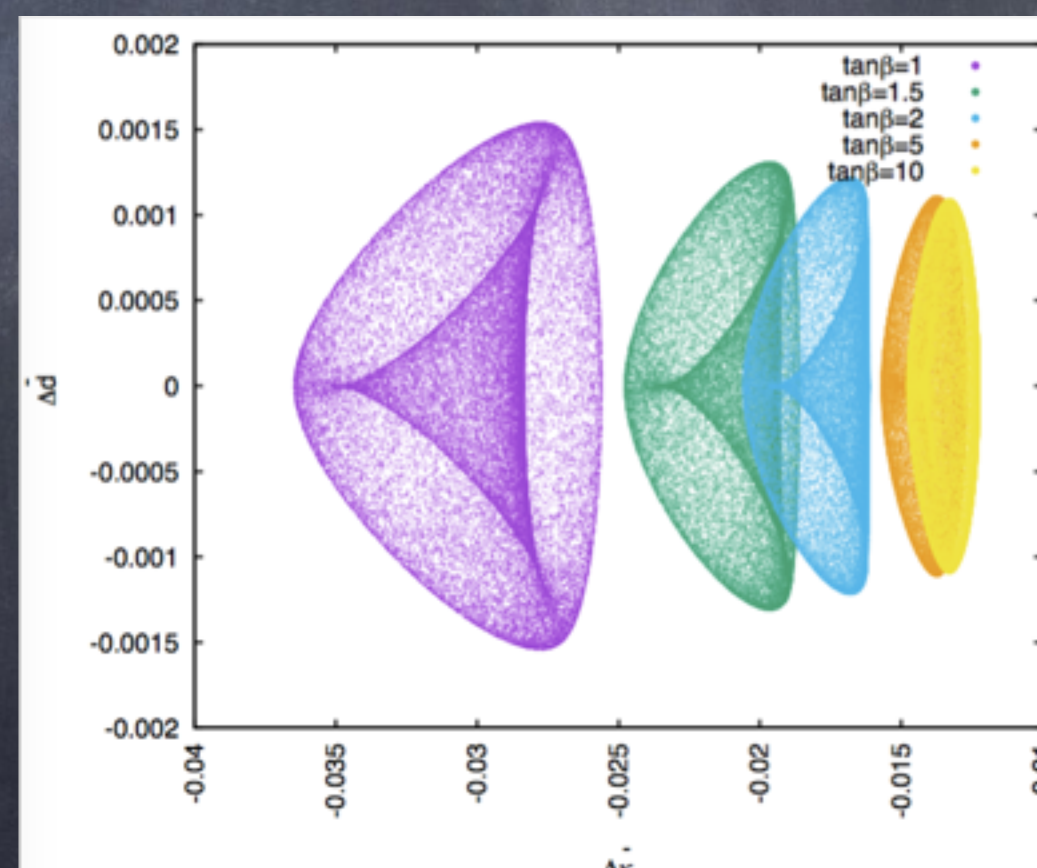
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-0.0015
-0.002
Δd
-0.04
-0.035
-0.03
-0.025
-0.02
-0.015
-0.01
Δκ

Restricted parameter space,

$$R_{\gamma\gamma} = \frac{\sigma(gg \to h_1)Br(h_1 \to \gamma\gamma)}{\sigma(gg \to h_{SM})Br(h_{SM} \to \gamma\gamma)}.$$

TABLE I. M_{H^+} and $\tan\beta$ in each region.

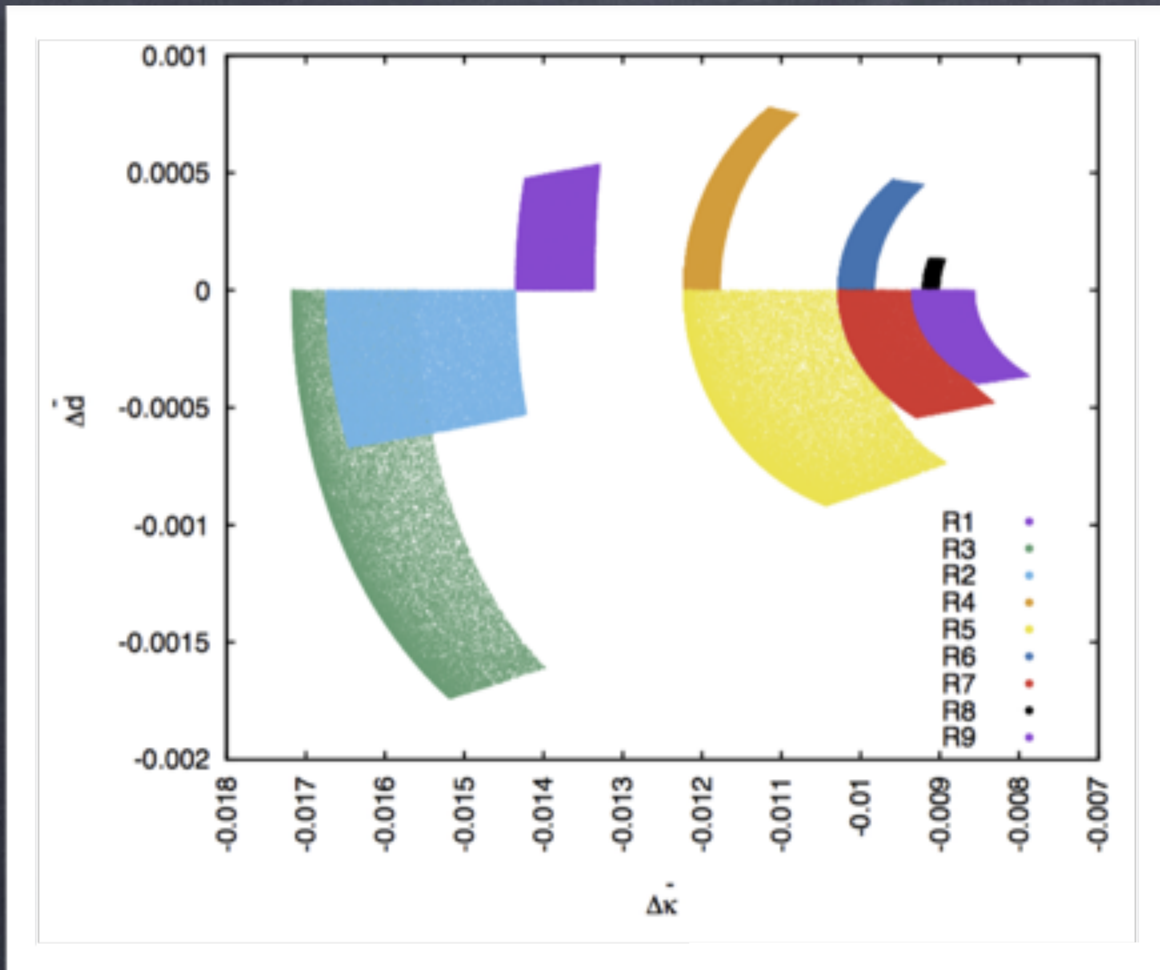
	α_1	α_2	M_{H^+} (GeV)	$\tan\beta$
R_1	$0.67 \le \alpha_1 \le 0.8$	$0 \le \alpha_2 \le 0.23$	300	1
R_2	$0.8 \le \alpha_1 \le 1.14$	$-0.25 \le \alpha_2 \le 0.$	300	1
R_3	$1.18 \le \alpha_1 \le 1.55$	$-0.51 \le \alpha_2 \le 0$	500	1
R_4	$-1.57 \le \alpha_1 \le -1.3$	$-0.46 \le \alpha_2 \le 0.$	350	1.5
R_5	$0.93 \le \alpha_1 \le 1.57$	$-0.61 \le \alpha_2 \le 0.$	350	1.5
R_6	$-1.57 \le \alpha_1 \le -1.28$	$-0.38 \le \alpha_2 \le 0.$	350	2
R_7	$1.08 \le \alpha_1 \le 1.57$	$-0.46 \le \alpha_2 \le 0.$	350	2
R_8	$-1.39 \le \alpha_1 \le -1.3$	$-0.13 \le \alpha_2 \le 0.$	350	2.5
R_9	$1.16 \le \alpha_1 \le 1.5$	$-0.43 \le \alpha_2 \le -0.1$	350	2.5

A. W. El Kaffas, et. al, Nucl. Phys. B 775, 45 (2007) [hep-ph/0605142].

L. Basso et al, JHEP 1211 (2012) 011 [arXiv:1205.6569 [hep-ph]].

Gaitan et al, Eur. Phys. J. C 74, 2788 (2014) [arXiv:1312.0044 [hep-ph]].

Inclusive $B \to X_s\gamma$, $B \to X_s\gamma$ and $B \to X_s\ell^+\ell^-$ $B \to X_s\ell^+\ell^-$ at the B factories BaBar and Belle Collaborations, are used to constrain M_{H-} and tanB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0
-0.0005
-0.001
-0.0015
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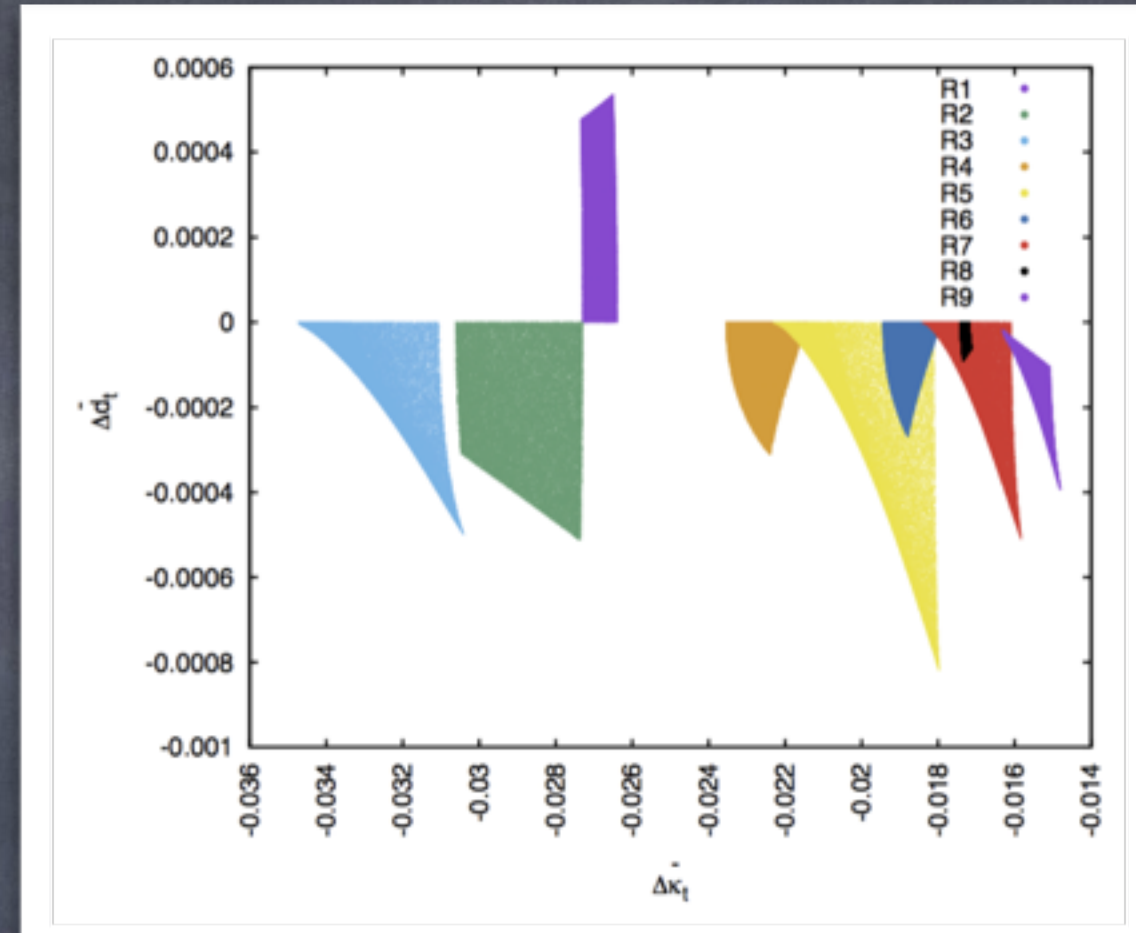
-0.017
-0.016
-0.015
-0.014
-0.013
-0.012
-0.011
-0.01
-0.009
-0.008
-0.007
R1
R3
R2
R4
R5
R6
R7
R8
R9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-0.001
-0.036
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-0.032
-0.03
-0.028
-0.026
-0.024
-0.022
-0.02
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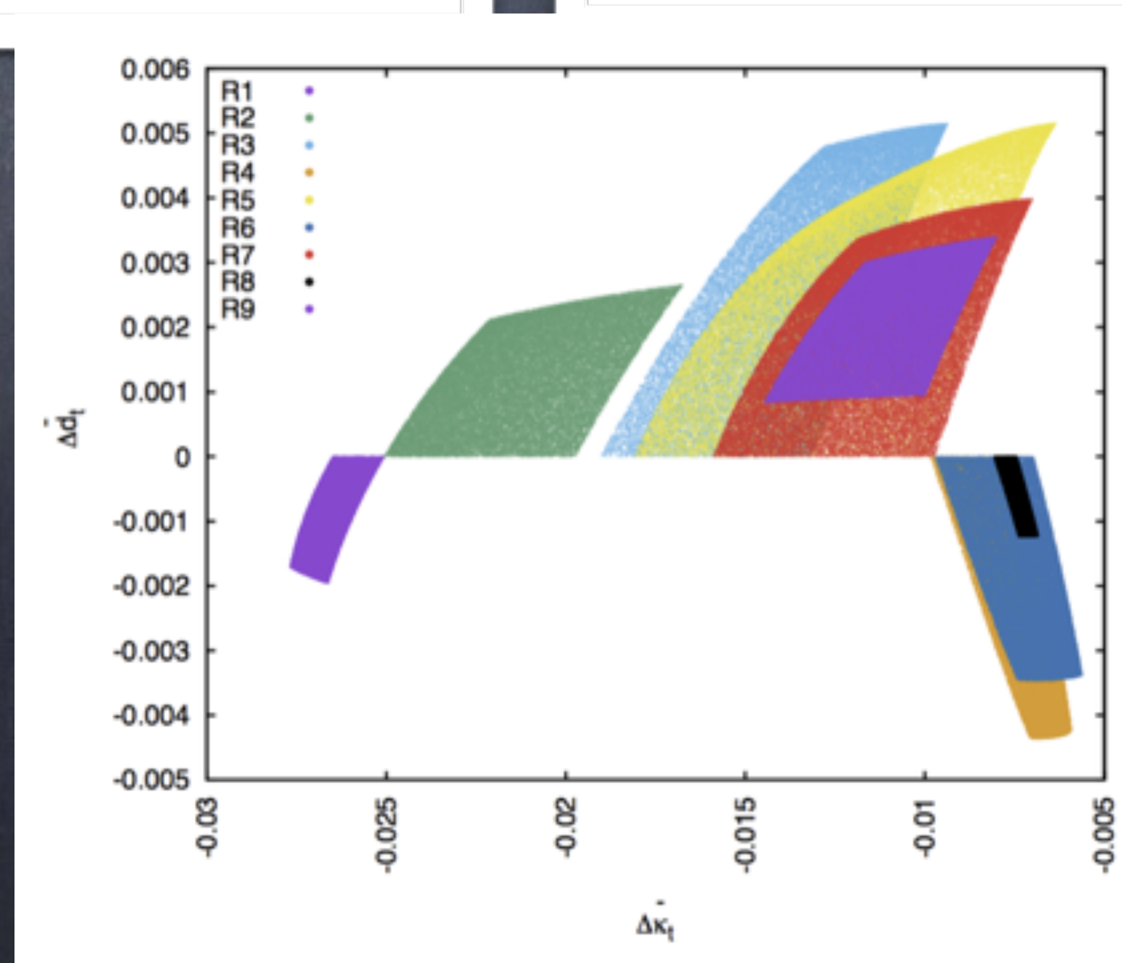
R1
R2
R3
R4
R5
R6
R7
R8
R9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-0.025
-0.02
-0.015
-0.01
-0.005
R1
R2
R3
R4
R5
R6
R7
R8
R9

Conclusions

In this work we have studied regions of interest in the α_1-α_2 parameter space, in order to calculate the contribution to the top anomalous couplings CMDM and CEDM in the context of a general THDM with CP violation.

We find for the nine regions of interest that the value for CMDM can be at most $\sim 10^{-2}$ and CEDM$\sim 10^{-4}$.

A precise measurement of the top quark CMDM and CEDM, expected soon after future LHC results, will be a useful source of information in order to discriminate among different SM extensions.

Thanks!


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