

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

Estela Garcés (IF-UNAM)

R. Gaitán, Montes de Oca Y. (CIT-FESC-UNAM)

R. Martínez (U.Nacional, Col.)

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- I. MOTIVATION
- II. TWO HIGGS DOUBLET MODEL WITH CP VIOLATION
- III. CDM AND CEDM IN THE GENERAL THDM
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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 ν -e, Int.J.Mod.Phys. A28 (2013) 1350124, R. Gaitán, E.G., O. Miranda,
 - Rare top decay $t \rightarrow c$ 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:

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

The neutral components in the fields are defined as

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

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

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

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

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

$$R = \begin{pmatrix} c_1 c_2 & s_1 c_2 & s_2 \\ -(c_1 s_2 s_3 + s_1 c_3) & c_1 c_3 - s_1 s_2 s_3 & c_2 s_3 \\ -c_1 s_2 c_3 + s_1 s_3 & -(c_1 s_3 + s_1 s_2 c_3) & c_2 c_3 \end{pmatrix},$$

$$c_i = \cos \alpha_i$$

$$s_i = \sin \alpha_i,$$

The Yukawa Lagrangian for the quark sector has the general form

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

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

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

$$Y_a^f = V_L^f Y_a^{0f} (V_R^f)^\dagger,$$

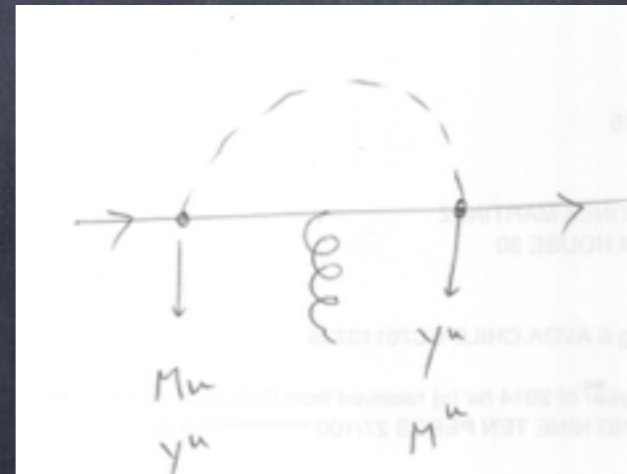
For the up sector, the Yukawa Lagrangian can be written as

$$-\mathcal{L}_Y = \frac{1}{v \sin \beta} \sum_{ijk} \bar{u}_i M_{ij}^u (A_k^u P_L + A_k^{*u} P_R) u_j h_k + \frac{1}{\sin \beta} \sum_{ijk} \bar{u}_i Y_{ij}^u (B_k^u P_L + B_k^{*u} P_R) u_j h_k,$$

$$A_k^u = R_{k2} - i R_{k3} \cos \beta, \\ B_k^u = R_{k1} \sin \beta - R_{k2} \cos \beta + i R_{k3}.$$

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

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



$$\Delta\tilde{\kappa} = \frac{G_F m_t^2}{2\sqrt{2}\pi^2 \sin^2 \beta} \sum_{i=1}^3 \int_0^1 dx \int_0^{1-x} dy \frac{1}{(x+y)^2 - (x+y-1)\hat{m}_{h_i}^2} \times$$

$$[(x+y)(x+y-1)(R_{i2}^2 - \cos^2 \beta R_{i3}^2) - (x+y)(R_{i2}^2 + \cos^2 \beta R_{i3}^2)]$$

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

$$[\cos \beta R_{i3} R_{i2}],$$

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

$$\left[(x+y)(x+y-1) \left((R_{i1} \sin \beta - R_{i2} \cos \beta)^2 - R_{i3}^2 \right) - (x+y) \left[(R_{i1} \sin \beta - R_{i2} \cos \beta)^2 + R_{i3}^2 \right] \right],$$

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

$$(R_{i1} \sin \beta - R_{i2} \cos \beta) R_{i3}.$$

$$\Delta\tilde{\kappa}_{int} = \frac{G_F m_t^2}{2\sqrt{2}\pi^2 \sin^2 \beta} \sum_{i=1}^3 \int_0^1 dx \int_0^{1-x} dy \frac{1}{(x+y)^2 - (x+y-1)\hat{m}_{h_i}^2} \times$$

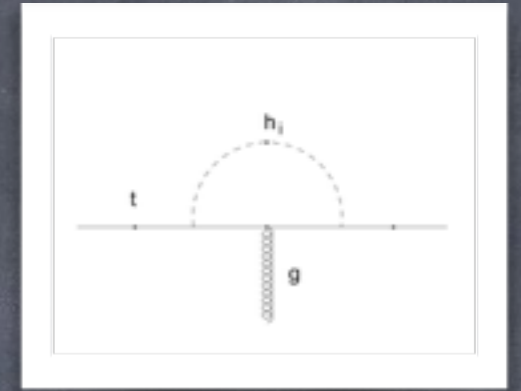
$$\left[(x+y)(x+y-1) \left((R_{i1} \sin \beta - R_{i2} \cos \beta) R_{i2} + R_{i3}^2 \cos \beta \right) \right.$$

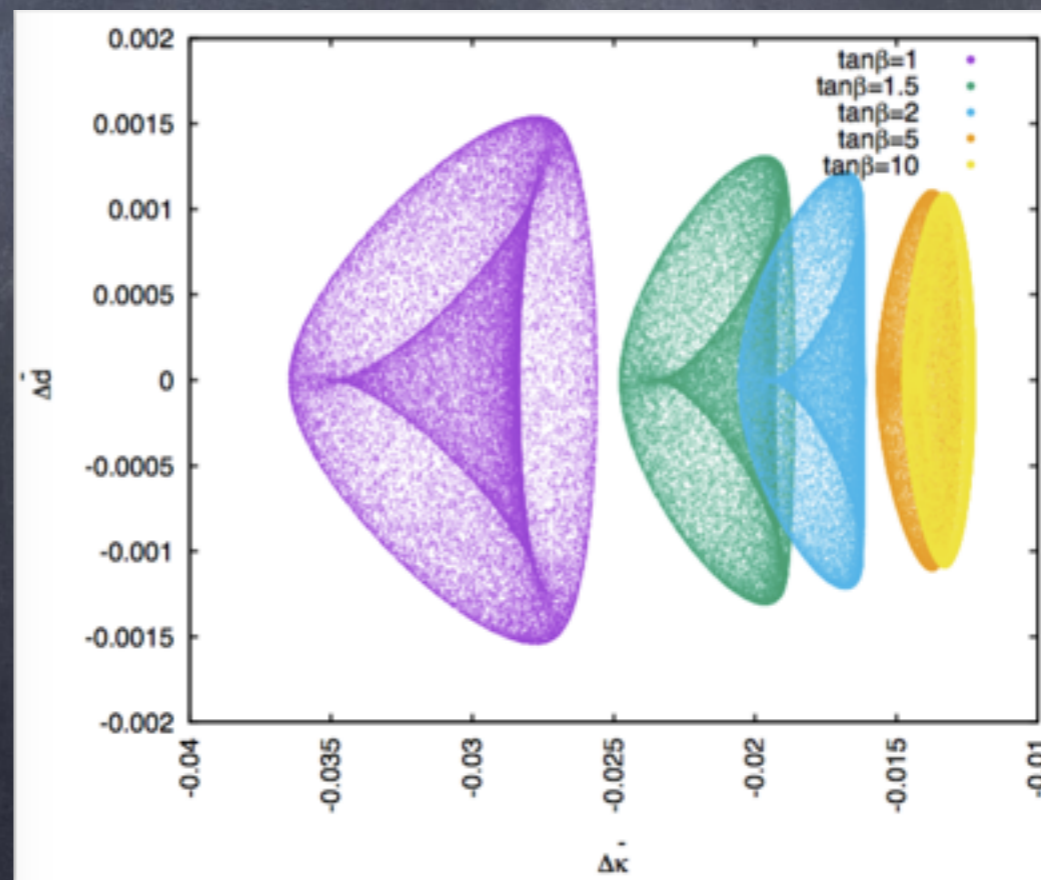
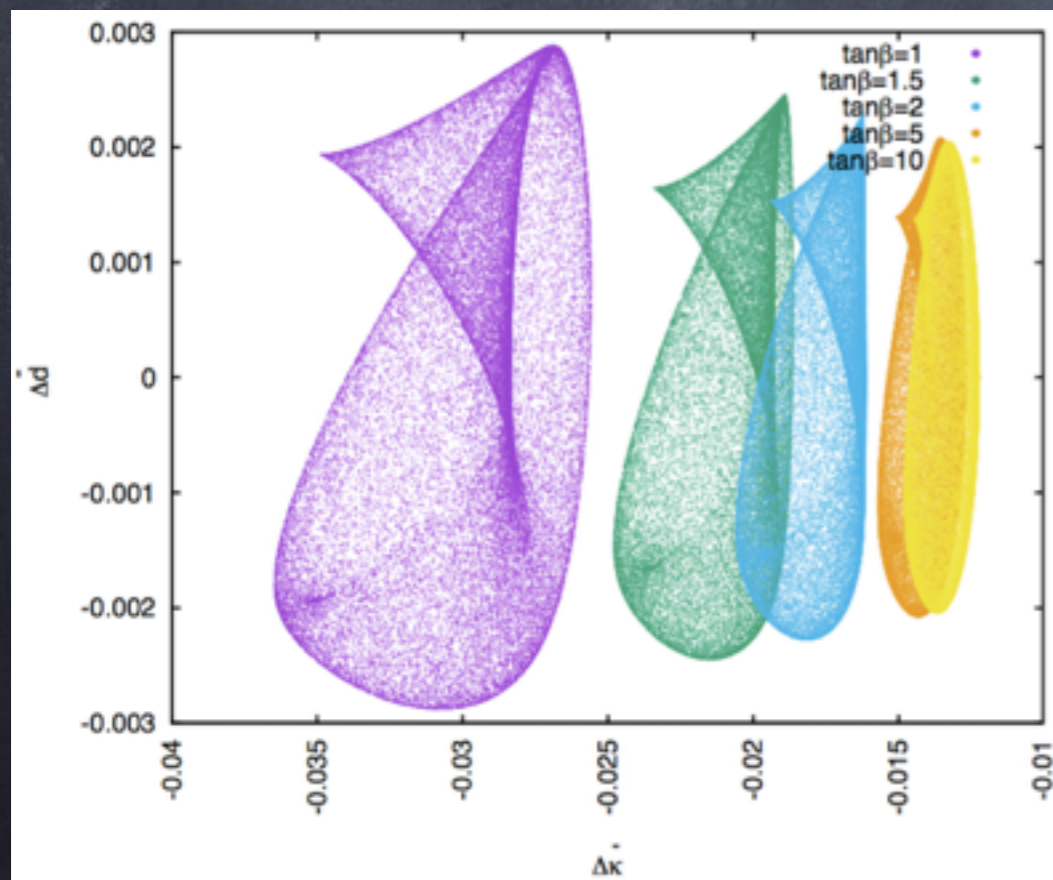
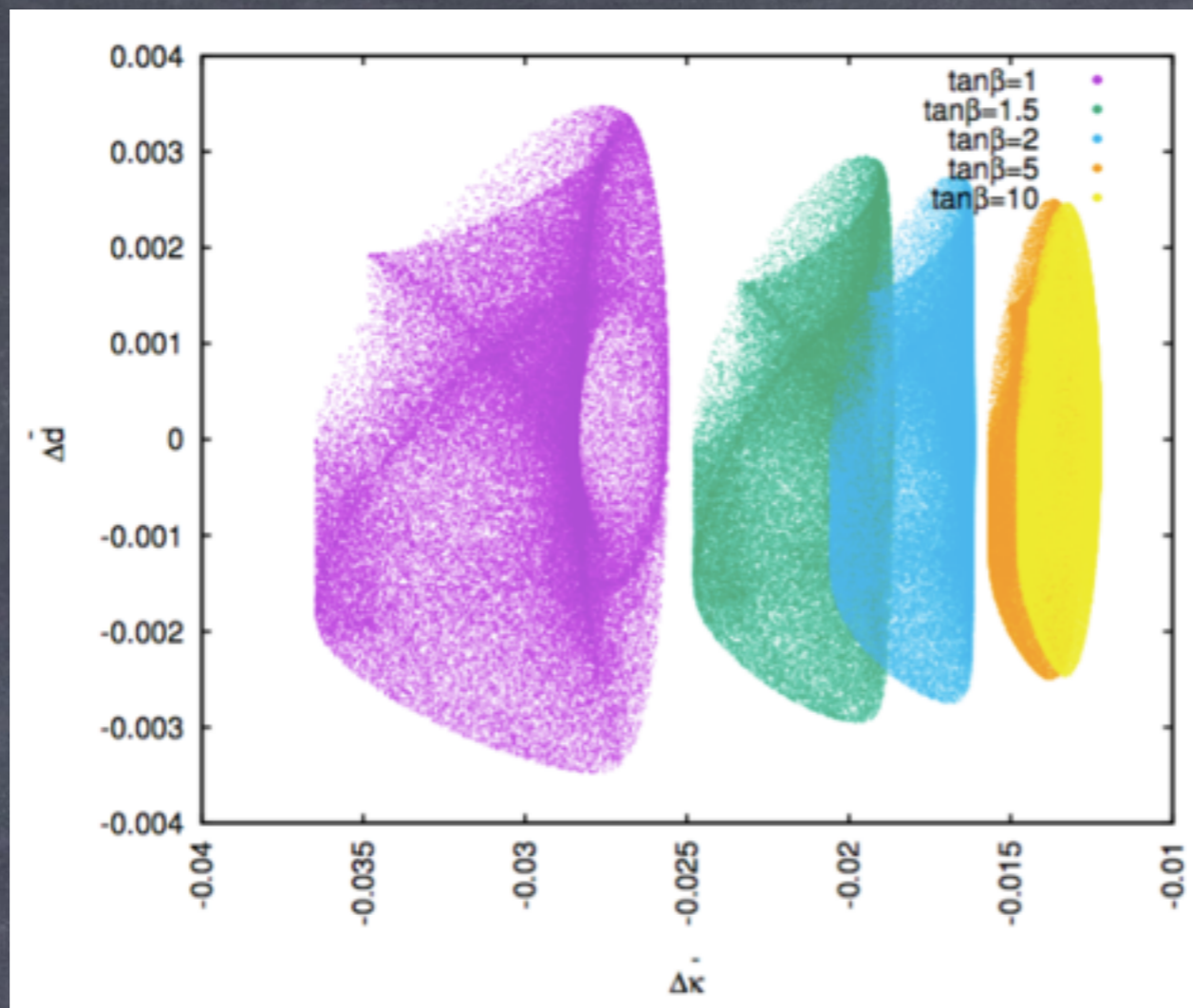
$$\left. - (x+y) \left((R_{i1} \sin \beta - R_{i2} \cos \beta) R_{i2} - R_{i3}^2 \cos \beta \right) \right],$$

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

$$\left[(x+y)(x+y-1) (R_{i2} R_{i3} - (R_{i1} \sin \beta - R_{i2} \cos \beta) R_{i3} \cos \beta) \right.$$

$$\left. - (x+y) (R_{i2} R_{i3} + (R_{i1} \sin \beta - R_{i2} \cos \beta) R_{i3} \cos \beta) \right].$$





Restricted parameter space,

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

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

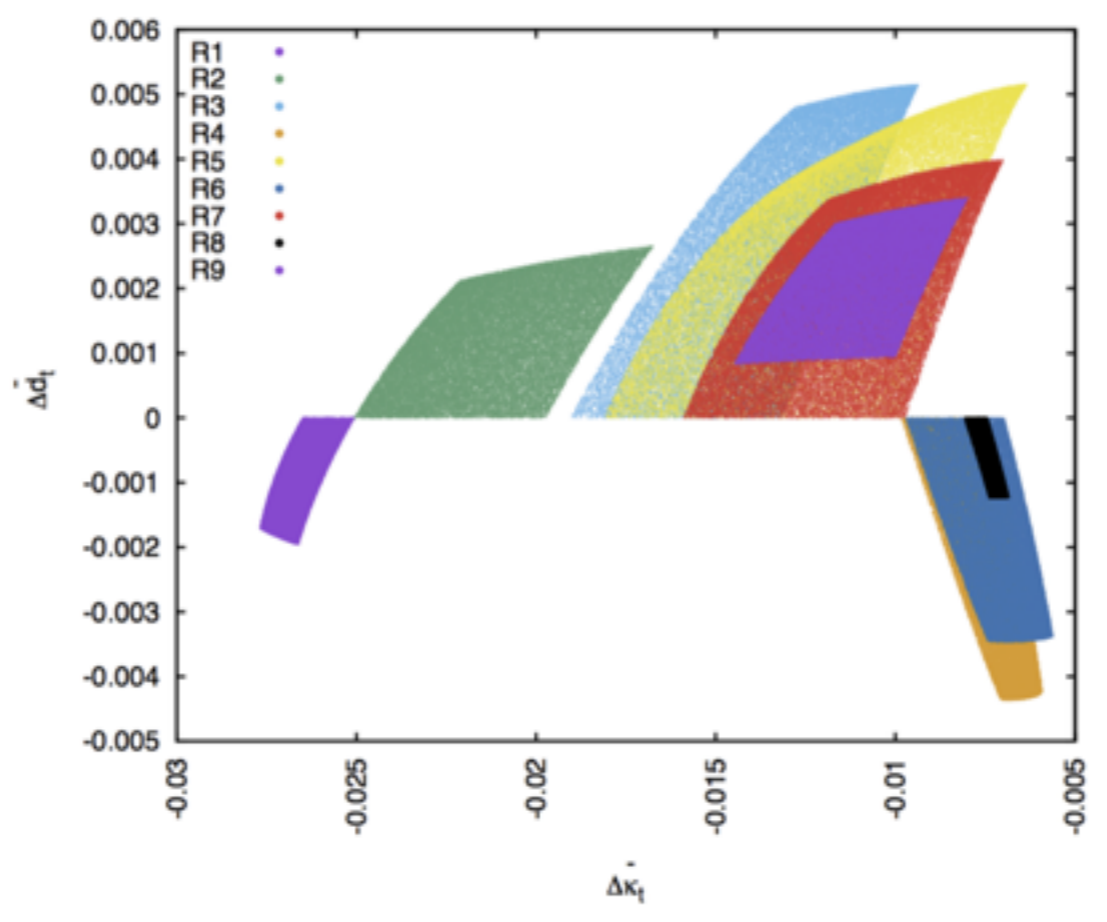
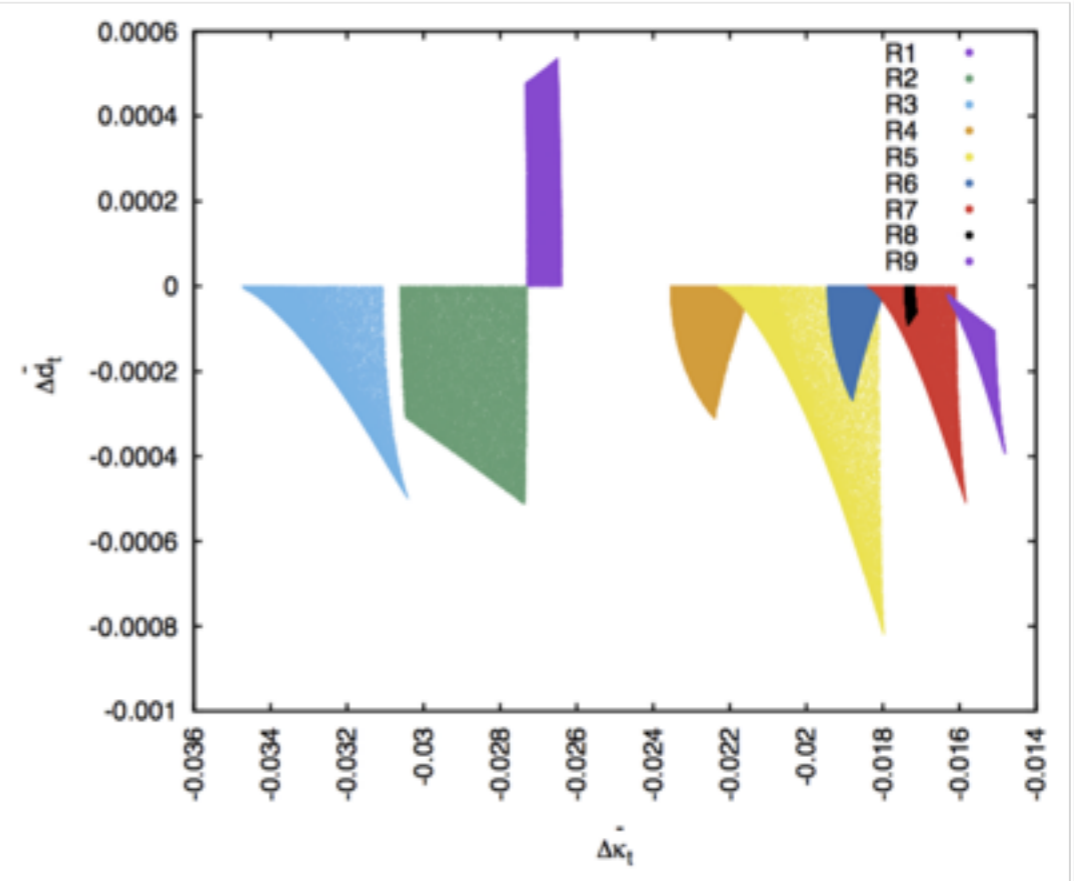
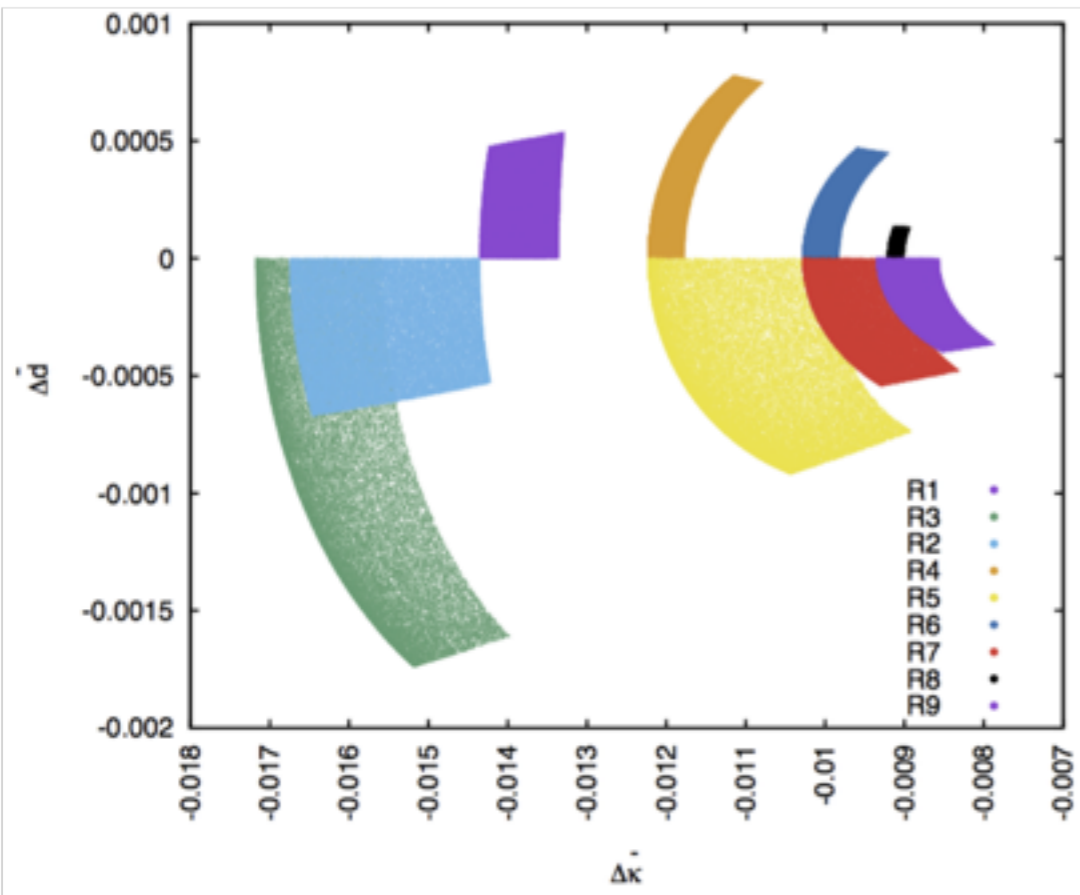
	α_1	α_2	M_{H^+} (GeV)	$\tan\beta$
R_1	$0.67 \leq \alpha_1 \leq 0.8$	$0 \leq \alpha_2 \leq 0.23$	300	1
R_2	$0.8 \leq \alpha_1 \leq 1.14$	$-0.25 \leq \alpha_2 \leq 0.$	300	1
R_3	$1.18 \leq \alpha_1 \leq 1.55$	$-0.51 \leq \alpha_2 \leq 0$	500	1
R_4	$-1.57 \leq \alpha_1 \leq -1.3$	$-0.46 \leq \alpha_2 \leq 0.$	350	1.5
R_5	$0.93 \leq \alpha_1 \leq 1.57$	$-0.61 \leq \alpha_2 \leq 0.$	350	1.5
R_6	$-1.57 \leq \alpha_1 \leq -1.28$	$-0.38 \leq \alpha_2 \leq 0.$	350	2
R_7	$1.08 \leq \alpha_1 \leq 1.57$	$-0.46 \leq \alpha_2 \leq 0.$	350	2
R_8	$-1.39 \leq \alpha_1 \leq -1.3$	$-0.13 \leq \alpha_2 \leq 0.$	350	2.5
R_9	$1.16 \leq \alpha_1 \leq 1.5$	$-0.43 \leq \alpha_2 \leq -0.1$	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 $B \rightarrow Xs\gamma$, $B \rightarrow Xs\gamma$ and $B \rightarrow Xsl+l$ $B \rightarrow Xsl+l$ at the B factories [BaBar](#) and [Belle](#) Collaborations, are used to constrain M_{H^\pm} and $\tan\beta$



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 C_{MDM} and C_{EDM} in the context of a general THDM with CP violation.

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

A precise measurement of the top quark C_{MDM} and C_{EDM} , 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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