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Electric Dipole Moment and Chromoelectric Electric Dipole Moment of the Top quark in $SU(3)_C \times SU(3)_L \times U(1)_X$ Model

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Abstract

We show that in $SU(3)_C \times SU(3)_L \times U(1)_X$ model, leading contribution to the electric and chromolelectric dipole moment of the top quark is due to the one-loop diagrams which come from exchanging the charged and neutral Higgs bosons. The dipole moments are typically of the order of 10^{-19} e-cm and 10^{-19} g-cm respectively, for the values of relative phases of the vev's such that CP violation is maximal. From an experimentpoint of view, the q^2 dependence of dipole moment form factor is given.

1 Introduction

Recently, the CDF collaboration at Fermilab has published evidence for top quark production in the $p\bar{p}$ collisions. It is obvious that in the near future, the research of the properties of the top quark will receive a high priority from both the experimental and the theoretical perspective. The fact that the top is so heavy that it can rapidly undergo an electroweak decay to b+w before hadronization sets in is especially significant. This should enable us to probe its fundamental properties directly with a minimal amount of the masking effects of QCD. That is in sharp contrast to the other quarks wherein intricate bound-state effects get involved and, more often than not, are difficult to treat. In this regard, we recall that there are a lot of difficulty that arise in interpreting the electric dipole moment (EDM) of the neutron in terms of the underlying short-distance theory responsible for CP violation.

In this paper, we estimate the size of the electric dipole moment (edm) and chromolelectric dipole moment (cedm) of the top quark in $SU(3)_C \times SU(3)_L \times U(1)_X$ model, which has been proposed[1,2] as a possible explanation of the family replication question and its some phenomenological implications have been investigated[3,4,5,6]. We find that the EDM and CEDM of the top quark are likely to be very large, i.e., about 10^{-19} e-cm and 10^{-19} g-cm, respectively with the maximal CP violation. Not only are these numbers larger than in the SM by perhaps as much as 10 orders of magnitude[7], but more importantly, they may be measurably large for experiments with the CERN Large Hadron Collider (LHC) or with future electron-positron colliders such as the proposed SLAC Next Linear Collider (NLC). An evaluation of the dominant contribution to the dipole moments of the top quark has been given in the models that extend SM with multi-Higgs doublets and singlets and results are typically of the order 10^{-20} e-cm and 10^{-20} g-cm respectively[8].

This paper is organized as follows. Section 2 outlines the model and in particular, its relative Higgs sector. Section 3 calculates the EDM and CEDM of the top quark. The numerical results and discussions are presented in the section 4.

2 Description of the Model

We outline the model presented by Frampton[1]. The fermions transform under $SU(3)_C \times SU(3)_L \times U(1)_X$ according to

$$l_{1,2,3} = \begin{pmatrix} e^- \\ \nu_e \\ e^+ \end{pmatrix}, \begin{pmatrix} \mu^- \\ \nu_\mu \\ \mu^+ \end{pmatrix}, \begin{pmatrix} \tau^- \\ \nu_\tau \\ \tau^+ \end{pmatrix} : (1, 3^*, 0) \quad (1)$$

$$q_{1,2} = \begin{pmatrix} u \\ d \\ D \end{pmatrix}, \begin{pmatrix} c \\ s \\ S \end{pmatrix} : (3, 3, -1/3) \quad (2)$$

$$q_3 = \begin{pmatrix} b \\ t \\ T \end{pmatrix} : (3, 3^*, 2/3) \quad (3)$$

$$u^c, c^c, t^c : (3^*, 1, -2/3) \quad (4)$$

$$d^c, s^c, b^c : (3^*, 1, 1/3) \quad (5)$$

$$D^c, S^c : (3^*, 1, 4/3) \quad (6)$$

$$T^c : (3^*, 1, -5/3), \quad (7)$$

where new quarks D, S, and T carry electric charge Q=-4/3, -4/3, and 5/3 respectively.The Higgs multiplets required for the symmetry breaking and fermion masses are given by

$$\Phi = \begin{pmatrix} \phi^{++} \\ \phi^{+} \\ \phi^{0} \end{pmatrix} : (1, 3, 1) \quad (8)$$

$$\Delta = \begin{pmatrix} \Delta_1^{+} \\ \Delta^{0} \\ \Delta_2^{-} \end{pmatrix} : (1, 3, 0) \quad (9)$$

$$\Delta' = \begin{pmatrix} \Delta'^{0} \\ \Delta'^{-} \\ \Delta'^{--} \end{pmatrix} : (1, 3, -1) \quad (10)$$

and

$$\eta = \begin{pmatrix} \eta_1^{++} & \eta_1^{+}/\sqrt{2} & \eta^{0}/\sqrt{2} \\ \eta_1^{+}/\sqrt{2} & \eta'^{0} & \eta_2^{-}/\sqrt{2} \\ \eta^{0}/\sqrt{2} & \eta_2^{-}/\sqrt{2} & \eta_2^{--} \end{pmatrix} : (1, 6, 0). \quad (11)$$

The non-zero vacuum expectation value (VEV) of ϕ^0 breaks $SU(3)_L \times U(1)_X$ into $SU(2)_L \times U(1)_Y$ and electroweak breaking is achieved by VEVs of Δ^0 and Δ'^0. The sextet η is needed to obtain a realistic lepton mass spectum.

We need to know the masses of the neutral and charged Higgs bosons and their quark couplings in the model in order to calculate the EDM and CEDM of the top quark. Therefore, we recall the relevant masses and mass eigenstates of the neutral and charged Higgs bosons obtained by us [6] (we have set w=0 for the sake of simplicity in reference [6]). The mininum of the potential is achieved for

$$<\Phi>=\begin{pmatrix}0\\0\\u\exp(i\alpha)/\sqrt{2}\end{pmatrix} \tag{12}$$

$$<\Delta>=\begin{pmatrix}0\\v\exp(i\alpha+\beta)/\sqrt{2}\\0\end{pmatrix} \tag{13}$$

$$<\Delta'>=\begin{pmatrix}v'/\sqrt{2}\\0\\0\end{pmatrix} \tag{14}$$

where the phases α and β are measure of CP violation.

The relevant mass eigenstates of the charged physical Higgs bosons are

$$H_1^{\pm}=\exp(\pm i(2\alpha+\beta))sin\theta_2\Delta_2^{\pm}+cos\theta_2\phi^{\pm} \tag{15}$$

with a common mass given by $m^2_{H_1^{\pm}}=fv'(u^2+v^2)/(\sqrt{2}uv)$, where $tg\theta_2=u/v$. Furthermore, the masses of the neutral physical Higgs bosons are

$$m^2_{h_1}=\sqrt{u^4A_1^2-2u^2v^2A_1A_2+u^2v^2A_5^2+v^4A_2^2}+u^2A_1+v^2A_2, \tag{16}$$

and

$$m^2_{h_2}=-\sqrt{u^4A_1^2-2u^2v^2A_1A_2+u^2v^2A_5^2+v^4A_2^2}+u^2A_1+v^2A_2, \tag{17}$$

and the corresponding eigenstates are:(we have defined $\phi^0=(\phi_1^0+i\phi_2^0)/\sqrt{2}, \Delta^0=(\Delta_1^0+i\Delta_2^0)/\sqrt{2}$ in Ref.[6])

$$H_{h_1}=(r_1\phi_1^0+cos\beta\Delta_1^0+sin\beta\Delta_2^0)/\sqrt{r_1^2+1}, \tag{18}$$

and

$$H_{h_2}=(r_2\phi_1^0+cos\beta\Delta_1^0+sin\beta\Delta_2^0)/\sqrt{r_2^2+1}, \tag{19}$$

where

$$\begin{aligned} r_1 &= uA_5(\sqrt{u^4A_1^2-2u^2v^2A_1A_2+u^2v^2A_5^2+v^4A_2^2}+u^2A_1+v^2A_2)\\ &/(v(2\sqrt{u^4A_1^2-2u^2v^2A_1A_2+u^2v^2A_5^2+v^4A_2^2}A_2-2u^2A_1A_2+u^2A_5^2+2v^2A_2^2)), \end{aligned} \tag{20}$$

$$\begin{aligned} r_2 &= uA_5(\sqrt{u^4A_1^2-2u^2v^2A_1A_2+u^2v^2A_5^2+v^4A_2^2}-u^2A_1-v^2A_2)\\ &/(v(2\sqrt{u^4A_1^2-2u^2v^2A_1A_2+u^2v^2A_5^2+v^4A_2^2}A_2+2u^2A_1A_2-u^2A_5^2-2v^2A_2^2)). \end{aligned} \tag{21}$$

In the above equations A_i(i=1,2,5) are the coupling constants in the Higgs potential (see eq.(12) in the Ref.[6]).

3 The EDM and CEDM of the Top Quark

The EDM of a particle is defined by one of its electromagnetic form factors. In particular, for a spin-$\frac{1}{2}$ particle f, the form factor decomposition of the matrix element of the electromagnetic current J_μ is:

$$< f(p')|J_\mu(0)|f(p) >=\bar{u}(p')\Gamma_\mu(q)u(p), \tag{22}$$

where

$$\Gamma_\mu(q)=F_1(q^2)\gamma_\mu+F_2(q^2)i\sigma_{\mu\nu}q^\nu/(2m)+F_A(q^2)(\gamma_\mu\gamma_5q^2-2m\gamma_5q_\mu)+F_3(q^2)\sigma_{\mu\nu}\gamma_5q^\nu/(2m), \tag{23}$$

where $q=p'-p$ and m denotes the mass of f.

The EDM of f is then given by:

$$d_f=-F_3(0)/2m \tag{24}$$

Thus in the $SU(3)_C \times SU(3)_L \times U(1)_X$ model, the lowest order non-zero d_t and cd_t can arise through the one-loop graphs Figs.(a-c). The relevant leading terms of quark-quark-Higgs boson couplings in Lagrangian after the spontaneously symmetry breaking are:

$$\mathcal{L} = \sum_k \sum_{i=1}^3 (a_i^{h_k} \bar{q}_i q_i + i b_i^{h_k} \bar{q}_i \gamma_5 q_i) h_k + \{\bar{T}(a + b\gamma_5) t H_1^+ + H.C.\}. \tag{25}$$

where h_k, H_1^+ are neutral Higgs bosons and charged Higgs boson respectively. Obviously, the dominant contributions are the one-loop diagrams where h_k is exchanged between top quarks for neutral Higgs boson-quark coupling and H_1^+ is exchanged between T and t quarks for charged Higgs boson-quark couplings. There are some two-loop graphs contributing to the electric dipole moment of the top quark. As pointed in the Ref.[8], however, they are about 2 orders of magnitude smaller than the results from the one-loop graphs. Therefore, here, we consider only these dominant contributions(see Figs. (a), (b) and (c)).

First,caculating the diagrams in Figs. (a) and (b), we obtain the static (i.e. at $q^2 = 0$) electric dipole moment:

$$d_t^c(0) = \frac{2m_T}{16\pi^2 m_t^2} Im(ab^*)\{-eQ_{H_1^-} I_c^{(1)}(m_{H_1^-}, m_T, m_t)(0) + eQ_T I_c^{(2)}(m_{H_1^-}, m_T, m_t)\}(0), \tag{26}$$

where $Q_T = 5/3$ and $Q_{H_1^-} = -1$,

$$I_c^{(1)}(m_{H_1^-}, m_T, m_t)(0) = \int_0^1 dx \frac{x(1-x)}{\rho_{H_1^-}^2 (1-x) + \rho_T^2 x - x(1-x)} \tag{27}$$

and

$$I_c^{(2)}(m_{H_1^-}, m_T, m_t)\}(0) = \int_0^1 dx \frac{x^2}{\rho_{H_1^-}^2 (1-x) + \rho_T^2 x - x(1-x)} \tag{28}$$

Properties of the top quark are mostly likely to be explored at high energy and momenta, thus static quantities like $d_t(0)$ are not the most accessible, from an experimental point of view.

The EDM form factor at high q^2 may instead be more relevant. We, therefore, investigate the q^2 dependence of $d_t^c(q^2)$. Thus

$$d_t^c(q^2) = \frac{2m_T}{16\pi^2 m_t^2} Im(ab^*)\{-eQ_{H_1^-} I_c^{(1)}(m_{H_1^-}, m_T, m_t)(q^2) + eQ_T I_c^{(2)}(m_{H_1^-}, m_T, m_t)\}(q^2), \tag{29}$$

$$I_c^{(1)}(m_{H_1^-}, m_T, m_t)(q^2) = \int_0^1 dx \int_0^x dy \frac{1-x}{\rho_{H_1^-}^2 x + \rho_T^2 (1-x) - x(1-x) - \rho_{q^2}^2 y(x-y) - i\epsilon} \tag{30}$$

and

$$I_c^{(2)}(m_{H_1^-}, m_T, m_t)\}(0) = \int_0^1 dx \int_0^1 \frac{x}{\rho_{H_1^-}^2 (1-x) + \rho_T^2 x - x(1-x) - \rho_{q^2}^2 y(x-y) - i\epsilon} \tag{31}$$

where $\rho_i^2 = m_i^2/m_t^2$, i=T, t, H_1^-, h_k and $\rho_q^2 = q^2/m_t^2$.

In the Eq.(26) and Eq.(29),

$$a = \frac{1}{2}[h_t^3 \sin\theta_2 \cos(2\alpha + \beta) + h_T^3 \cos\theta_2 - i h_t^3 \sin\theta_2 \sin(2\alpha + \beta)], \tag{32}$$

$$b = \frac{1}{2}[h_t^3 \sin\theta_2 \cos(2\alpha + \beta) - h_T^3 \cos\theta_2 - i h_t^3 \sin\theta_2 \sin(2\alpha + \beta)], \tag{33}$$

where h_t^3 and h_T^3 are the coefficients of the Yukawa interactions which are related to the masses of top quark and T quark *respectively*[3]. From Eq.(32), Eq.(33), one has

$$\begin{aligned} I_m(ab^*) &= \tfrac{1}{2} h_t^3 h_T^3 \sin\theta_2 \cos\theta_2 \sin(2\alpha + \beta) \\ &= \tfrac{1}{4} g^2 \frac{m_t m_T}{m_{Y^+}^2} \sin(2\alpha + \beta) \end{aligned} \tag{34}$$

where m_{Y^+} is the mass of the new charged gauge bosons $Y^\pm$.

Similarly, calculating the diagram in Fig.(d), we obtain:

$$\begin{aligned} d_t^n(0) &= \frac{2Q_t e}{16\pi^2 m_t} \sum_k a_t^{h_k} b_t^{h_k} I_n(m_t, m_{h_k})(0) \\ &= \frac{2Q_t e}{16\pi^2 m_t} \sum_k a_t^{h_k} b_t^{h_k} F(\rho_{h_k}^2) \end{aligned} \tag{35}$$

where

$$I_n(m_t, m_{h_k})(0) = I_c^{(2)}(m_{h_k}, m_t, m_t)(0) = F(\rho_{h_k}^2) \tag{36}$$

and

$$F(r) = \begin{cases} 1 - \frac{r}{2}lnr + \frac{r^2-2r}{\sqrt{r(4-r)}}[arctan[\frac{2-r}{\sqrt{r(4-r)}}] + arctan[\frac{r}{\sqrt{r(4-r)}}]] & \text{if } r < 4 \\ 3 - 4ln2 & \text{if } r = 4 \\ 1 - \frac{r}{2}lnr - \frac{r^2-2r}{\sqrt{r(r-4)}}ln[\frac{\sqrt{r}-\sqrt{r-4}}{2}] & \text{if } r > 4 \end{cases} \tag{37}$$

The definition of F(r) is the same as that in Ref.[8]. and

$$d_t^n(q^2) = \frac{2Q_t e}{16\pi^2 m_t}\sum_k a_t^{h_k} b_t^{h_k} I_n(m_t, m_{h_k})(q^2) \tag{38}$$

$$I_n(m_t, m_{h_k})(q^2) = I_c^{(2)}(m_{h_k}, m_t, m_t)\}(q^2) \tag{39}$$

where the top quark-neutral Higgs coupling constants[8] $a_t^{h_k}, b_t^{h_k}$ in Eq.(35), Eq.(38) are:

$$a_t^{h_1} = \frac{m_t}{v}\cos\beta R_1, b_t^{h_1} = \frac{m_t}{v}\sin\beta R_1 \tag{40}$$

$$a_t^{h_2} = -\frac{m_t}{v}\cos\beta R_2, b_t^{h_2} = -\frac{m_t}{v}\sin\beta R_2 \tag{41}$$

where

$$R_1 = \frac{r_2\sqrt{r_1^2+1}}{r_2 - r_1}, \tag{42}$$

$$R_2 = \frac{r_1\sqrt{r_2^2+1}}{r_2 - r_1}. \tag{43}$$

In order to numerically compute d_w^n , we need to make a further assumption because there are too many free parameters in the model. In the following, we discuss two representative cases[8]:

(I) We assume: $u^2A_1 = v^2A_2$, therefore

$$m_{h_1}^2 = uvA_5 + 2u^2A_1 \tag{44}$$

$$m_{h_2}^2 = -uvA_5 + 2u^2A_1 \tag{45}$$

$$a_t^{h_1} = m_t cos\beta/(\sqrt{2}v) \tag{46}$$

$$b_t^{h_1} = m_t sin\beta/(\sqrt{2}v) \tag{47}$$

$$a_t^{h_2} = m_t cos\beta/(\sqrt{2}v) \tag{48}$$

$$b_t^{h_2} = m_t sin\beta/(\sqrt{2}v). \tag{49}$$

(II) We assume $A_1A_2 >> A_5^2, A_1 \sim A_2 or A_1 > A_2$, we obtain:

$$m_{h_1}^2 = 2u^2A_1 \tag{50}$$

$$m_{h_2}^2 = 2v^2A_2 \tag{51}$$

and $a_t^{h_1} \sim 0, b_t^{h_1} \sim 0$

$$a_t^{h_2} = m_t cos\beta/v \tag{52}$$

$$b_t^{h_2} = m_t sin\beta/v. \tag{53}$$

Finally adding all contributions from Figs. (a)-(c), one has:

$$d_t(0) = d_t^c(0) + d_t^n(0) \tag{54}$$

and

$$d_t(q^2) = d_t^c(q^2) + d_t^n(q^2) \tag{55}$$

If the photon in the Fig.(a) and Fig.(c) is replaced by a glun, then Fig.(a) and Fig.(c) would produce a chromoelectric diploe moment instead of EDM. Clearly, the CEDM cd_t^c(the contribution of exchanging neutral Higgs bosons) is immediately obtained by replaceing $\frac{2}{3}$ e with g (the QCD coupling constant) in Eq.(35), Eq.(38). The CEDM cd_t^c(the contribution of exchanging charged Higgs bosons) is obtained as follows:

$$cd_t^c(0) = \frac{2m_T}{16\pi^2 m_t^2} Im(ab^*)eQ_T CI_c^{(2)}(m_{H_1^-}, m_T, m_t)\}(0), \tag{56}$$

$$CI_c^{(2)}(m_{H_1^-}, m_T, m_t)\}(0) = I_c^{(2)}(m_{H_1^-}, m_T, m_t)\}(0) \tag{57}$$

$$cd_t^c(q^2) = \frac{2m_T}{16\pi^2 m_t^2} Im(ab^*)eQ_T CI_c^{(2)}(m_{H_1^-}, m_T, m_t)(q^2), \tag{58}$$

$$CI_c^{(2)}(m_{H_1^-}, m_T, m_t)\}(q^2) = I_c^{(2)}(m_{H_1^-}, m_T, m_t)\}(q^2) \tag{59}$$

Therefore, the chromoelectric diploe moment of the top quark is:

$$cd_t(0) = cd_t^c(0) + cd_t^n(0) \tag{60}$$

and

$$cd_t(q^2) = cd_t^c(q^2) + cd_t^n(q^2) \tag{61}$$

4 Results

First, let us define $d_t^c(0) = d_t^{c\ max}(0)sin(2\alpha+\beta)$, $d_t^c(q^2) = d_t^{c\ max}(q^2)sin(2\alpha+\beta)$, $d_t^n(0) = d_t^{n\ max}(0)sin(2\beta)$, $d_t^n(q^2) = d_t^{n\ max}(q^2)sin(2\beta)$ $cd_t^c(0) = cd_t^{c\ max}(0)sin(2\alpha+\beta)$ and $cd_t^c(q^2) = cd_t^{c\ max}(q^2)sin(2\alpha+\beta)$. In addition, we would like to mention that $d_t^c(q^2), d_t^n(q^2), cd_t^c(q^2)$ will develop an imaginary part when $q^2 \geq 4m_t^2$. For simplicity, we limit ourself to the case of $q^2 < 4m_t^2$ in this paper.

$d_t^c(0), d_t^c(q^2), d_t^n(0), d_t^n(q^2), cd_t^c(0)$ and $cd_t^c(q^2)$ are numerically computed in terms of the masses of the charged Higgs boson H_1^+, the neutral Higgs bosons h_1 and h_2, the T quark and the new charged gauge boson Y^+. By matching the coupling constants at the symmetry

breaking scale and using $\sin^2\theta_W(m_Z) = 0.2333$, it is found that the breaking scale is less than 1.7 Tev[3,12] . Therefore, the mass of the new quark T is expected to be less than 10 Tev and the mass upper bound for the new charged gauge bosons (Y^{++} and Y^+) is 330Gev[3].From the collider experiments[10] and muon decay[11], $m_{Y^{++}}$ and m_{Y^+} are greater than 210 Gev (95% C.L.) and 270 Gev (90% C.L.) respectively. Furthermore, from the analyses on oblique corrections , one obtains an upper bound for the charged Higgs masses, namely $m_{H^{\pm\pm}}$, $m_{H_2^\pm} \leq O(1Tev)$[4], which leads to $m_{H_1^+} \leq 300Gev$. In our computation, the following ranges are assumed: $m_t = 175Gev, 0.8Tev \leq m_T \leq 10Tev, 50Gev \leq m_{H_1^\pm} \leq 300Gev, 50Gev \leq m_{h_2} \leq 500Gev$. (Although m_{h_2} can be as large as O(1Tev), here, we consider only the above range because the larger m_{h_2} is, the smaller $d_t^n(0)$ and $d_t^n(q^2)$ is.) In the calculation of d_ω^n, the range $1000Gev < u < 1400Gev$ and v=250 Gev are obtained through $m_\omega^2 = g^2v^2/4, m_{Z_2}^2 = g^2cos^2\theta_\omega u^2/(3(1-4sin^2\theta_\omega))$[1],[3]. Because $cd_t^n(0) \simeq 1.5d_t^n(0)$ and $cd_t^n(q^2) \simeq 1.5d_t^n(q^2)$, we did not give them in figure.

From the Figs., we find that $d_t^{c\ max}(0)$, $d_t^{c\ max}(q^2)$, $cd_t^{c\ max}(0)$ and $cd_t^{c\ max}(q^2)$ are almost constant with the variation of $m_{H_1^-}$ and increase very slowly when m_T is increase, and obviously, decrease quadratically with m_{Y^+}. $d_t^{c\ max}(q^2)$ and $cd_t^{c\ max}(q^2)$ increase slowly when $\left(\frac{q^2}{m_t^2}\right)$ increase. Furthermore, we find that $d_t^{n\ max}(0)$ and $d_t^{n\ max}(q^2)$ (consequently $cd_t^{n\ max}(0)$ and $cd_t^{n\ max}(q^2)$) decrease almost quadratically with m_{h_2} and when $\left(\frac{q^2}{m_t^2}\right) \leq 4$, $d_t^{n\ max}(q^2)$ and $cd_t^{n\ max}(q^2)$ increase with $\left(\frac{q^2}{m_t^2}\right)$ but they decrease quickly for $\left(\frac{q^2}{m_t^2}\right) \geq 4$, similar to the result of Ref.[8]. Note that, there is not a peak existing in the $d_t^{c\ max}(q^2)$ and $cd_t^{c\ max}(q^2)$ when $\left(\frac{q^2}{m_t^2}\right) = 4$.

It is easy to see from the Figs. that when m_{h_2} is small, $d_t^{n\ max}(0) > d_t^{c\ max}(0)$, $d_t^{n\ max}(q^2) >$

$d_t^{c\ max}(q^2)$ and when m_{h_2} is large($\geq$150 Gev), $d_t^{n\ max}(0) < d_t^{c\ max}(0)$, $d_t^{n\ max}(q^2) < d_t^{c\ max}(q^2)$. From this , we can distinguish this model from other models with an arbitary number of Higgs doublets and singlets satisfying natural flavour conversation (NFC) constraints[8,14].

In conclusion, we have estimated the EDM and CEDM of the top quark in the $SU(3)_C \times SU(3)_L \times U(1)_X$ model. The dominant contributions to d_t and cd_t come from exchanging the charged Higgs bosons due to the existence of a new quark T with charge 5/3 and a not too heavy mass (O(Tev)) in this model if the mass m_{h_2} of the neutral Higgs boson h_2 is large enough, which is in contrast with the other models[8] in that the dominant contributions come only from exchanging neutral Higgs bosons. Numerically, we obtain that the electric and chromolelectric dipole moment of the top quark are typically of the order of 10^{-19} e-cm and 10^{-19} g-cm respectively, for the values of relative phases of the vev's such that CP violation is maximal.

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Figure Captions

Figs.(a) and (b), the dominant one-loop contributions to the d_t^c. Figs.(a), the dominant one-loop contribution to the cd_t^c when the photon is replaced by a glun. Figs. (c), the dominant one-loop contribution to the d_t^n (cd_t^n).

Fig.1 $d_t^{c\ max}$ (in the unit of 10^{-19} e-cm) versus $m_{H_1^-}$, we have taken $m_{Y^+} = 300$ Gev and $m_T = 5$ Tev, for q^2=0 (which is $d_t^{c\ max}(0)$) (a), for $q^2 = 2m_t^2$ (which is $d_t^{c\ max}(q^2)$) (b)

Fig.2 $d_t^{c\ max}$ (in the unit of 10^{-19} e-cm) versus m_T, we have taken $m_{Y^+} = 300$ Gev and

$m_{H_1^-}$=200 Gev, for q^2=0 (which is $d_t^{c\ max}(0)$) (a), for $q^2 = 2m_t^2$ (which is $d_t^{c\ max}(q^2)$) (b)

Fig.3 $d_t^{c\ max}$ (in the unit of 10^{-19} e-cm) versus q^2/m_t^2, we have taken $m_T = 5$ Tev, $m_{Y^+} =$ 300 Gev and $m_{H_1^-}$=200 Gev.

Fig.4 $d_t^{n\ max}(0)$ (in the unit of 10^{-19} e-cm) versus m_{h_2}, for (a): in the case (I),where m_{h_1} ranges from 937 Gev to 1214.7 Gev when m_{h_2} ranges from 50 Gev to 500 Gev with u=1200 Gev and v = 250 Gev, for (b): in the case (II), with v=250 Gev.

Fig.5 $d_t^{n\ max}(q^2)$ (in the unit of 10^{-19} e-cm) versus versus q^2/m_t^2, for (a): in the case (I),where m_{h_1} = 1092 Gev, m_{h_2} =350 Gev, with u=1200 Gev and v = 250 Gev, for (b): in the case (II), where m_{h_2} =350 Gev, with v=250 Gev.

Fig.6 $cd_t^{c\ max}$ (in the unit of 10^{-19} e-cm) versus m_T, we have taken m_{Y^+} = 300 Gev and $m_{H_1^-}$=200 Gev, for q^2=0 (which is $cd_t^{c\ max}(0)$) (a), for $q^2 = 2m_t^2$ (which is $cd_t^{c\ max}(q^2)$) (b)

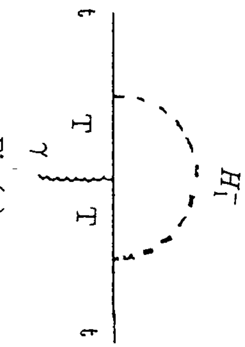


Fig.(a)

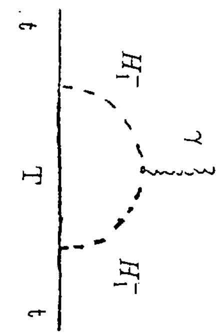


Fig.(b)

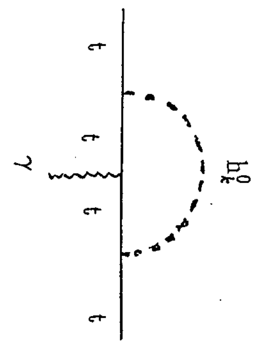


Fig.(c)

Fig.1

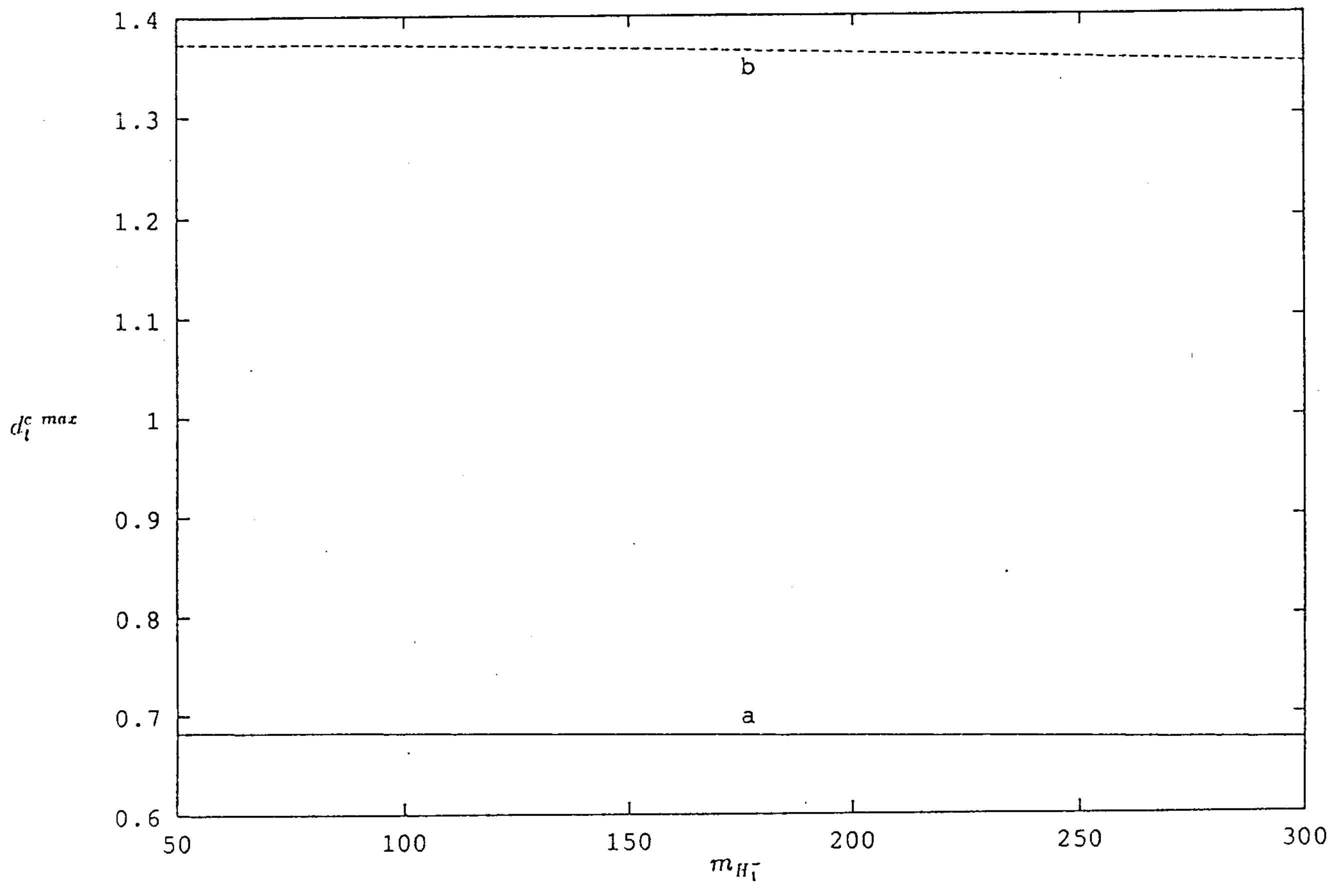

1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
$d_t^{c\ max}$
b
a
50
100
150
200
250
300
$m_{H_1^-}$

Fig.2

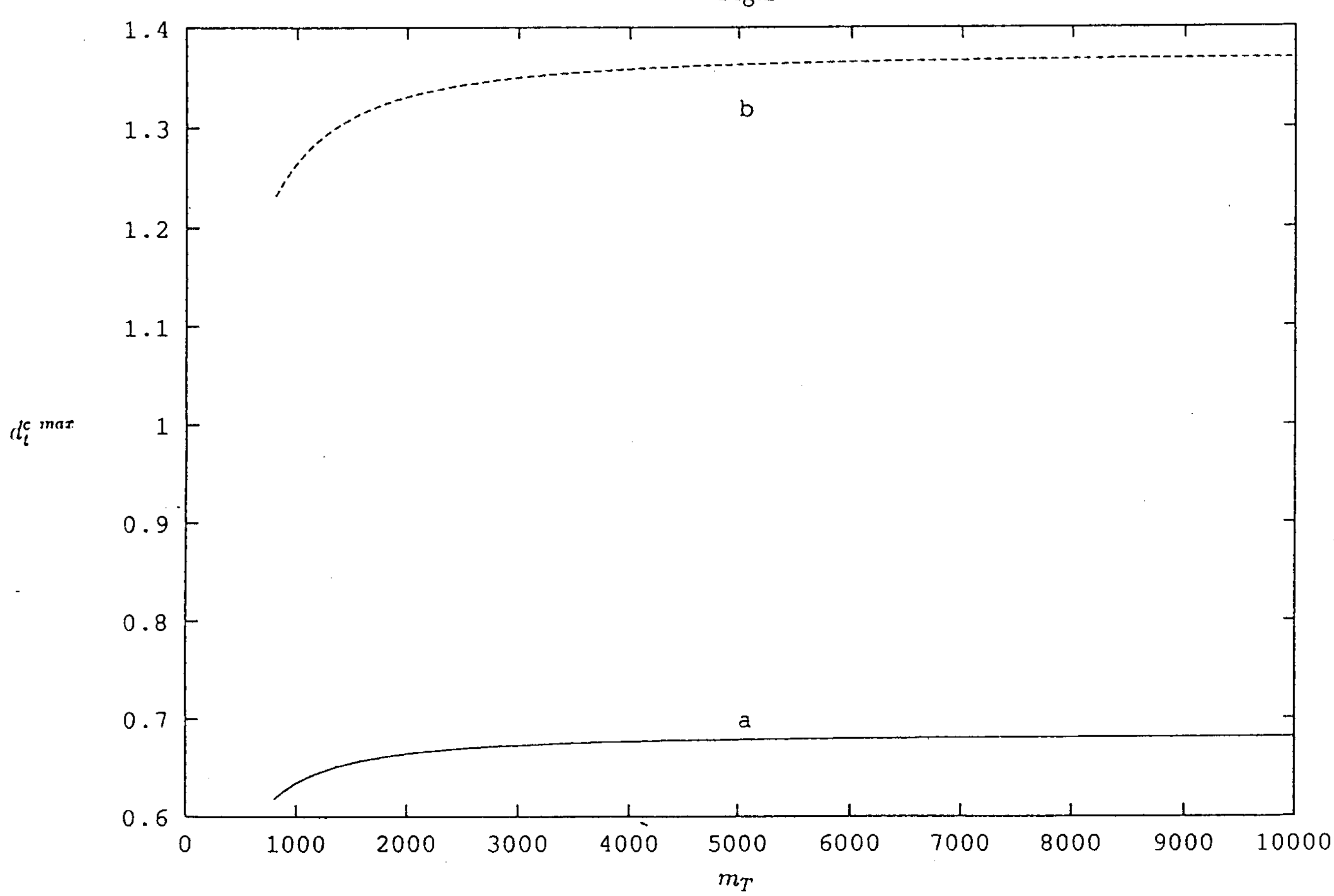

1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
$d_t^{c\ max}$
b
a
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
m_T

Fig.4

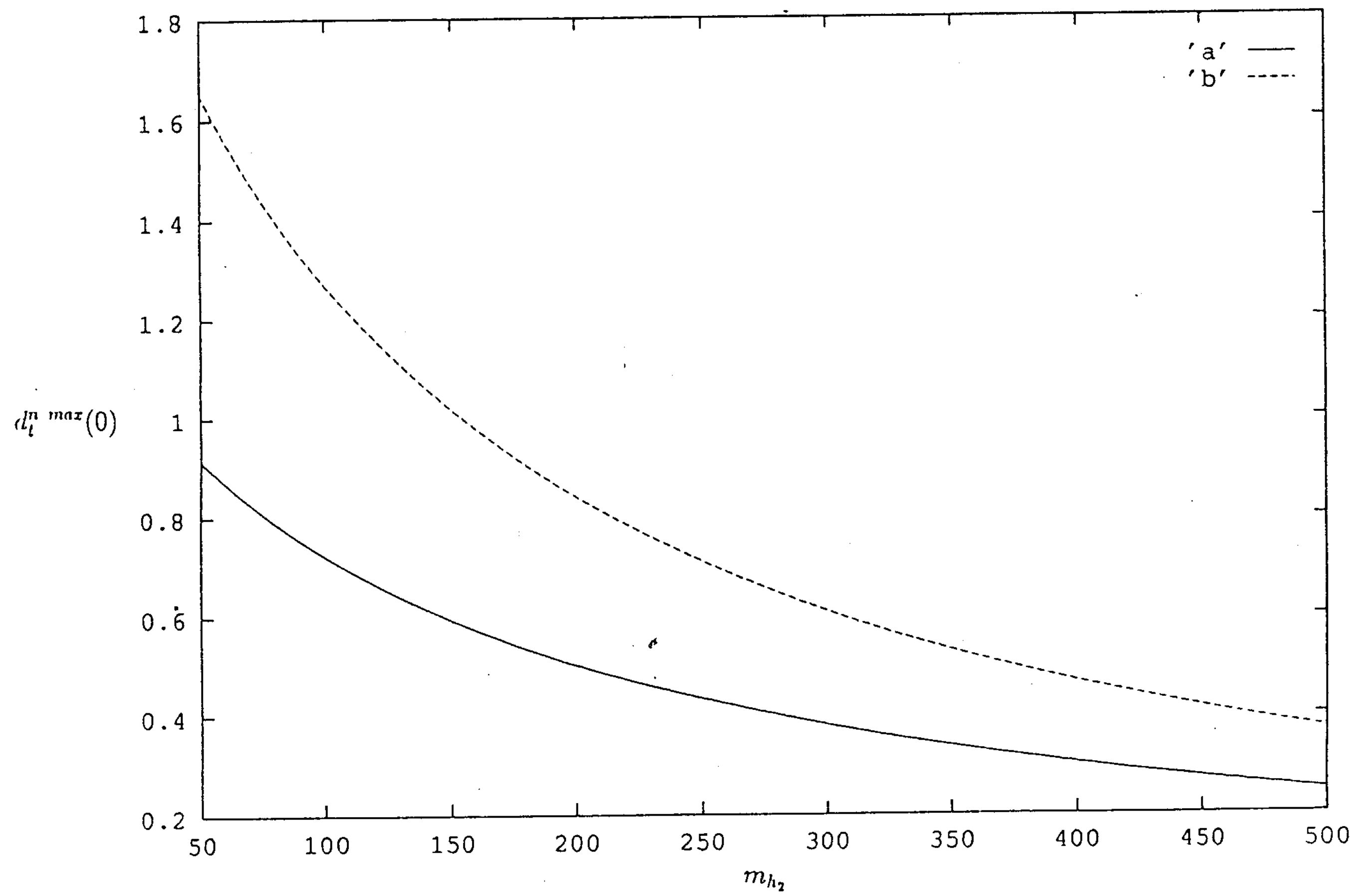


Fig.3

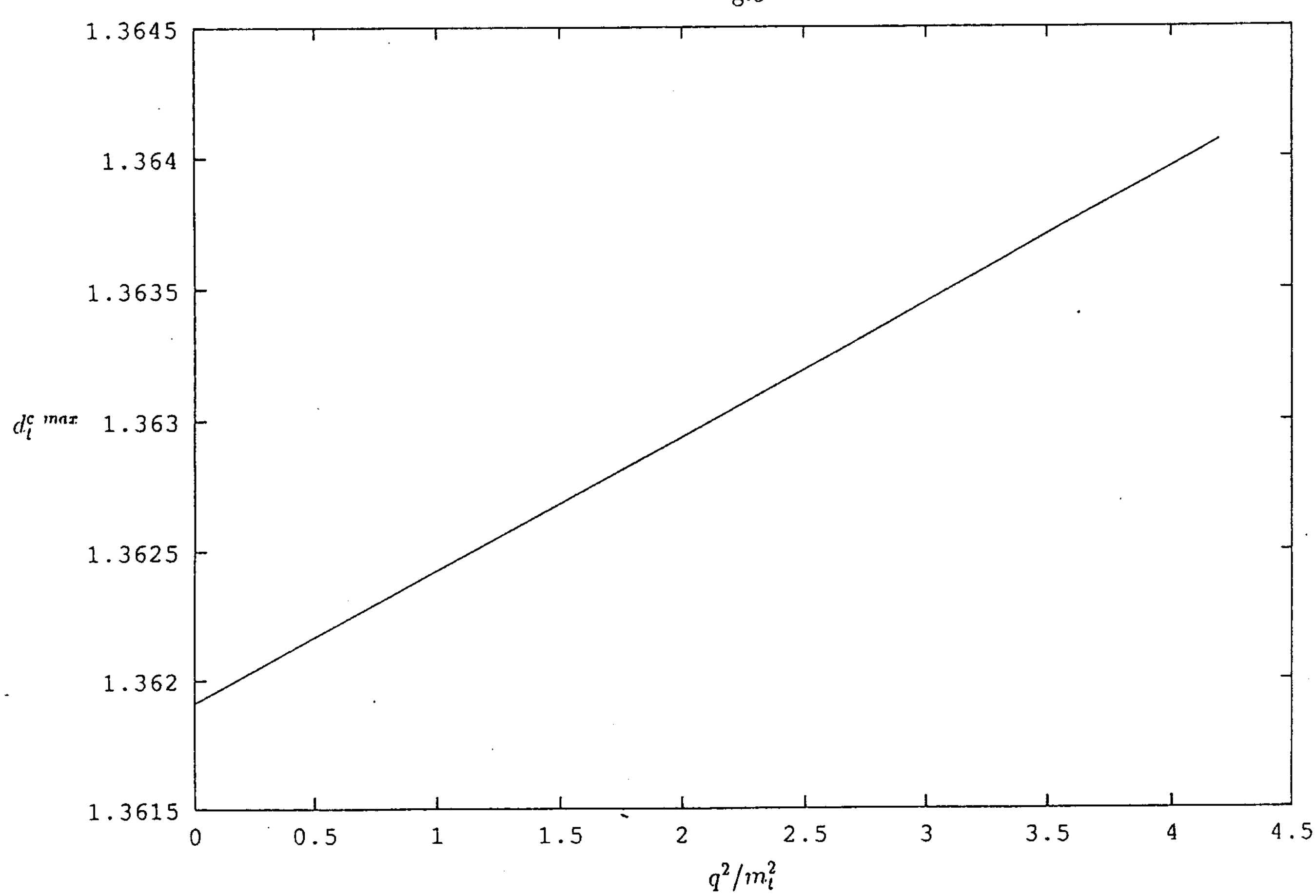


Fig.6

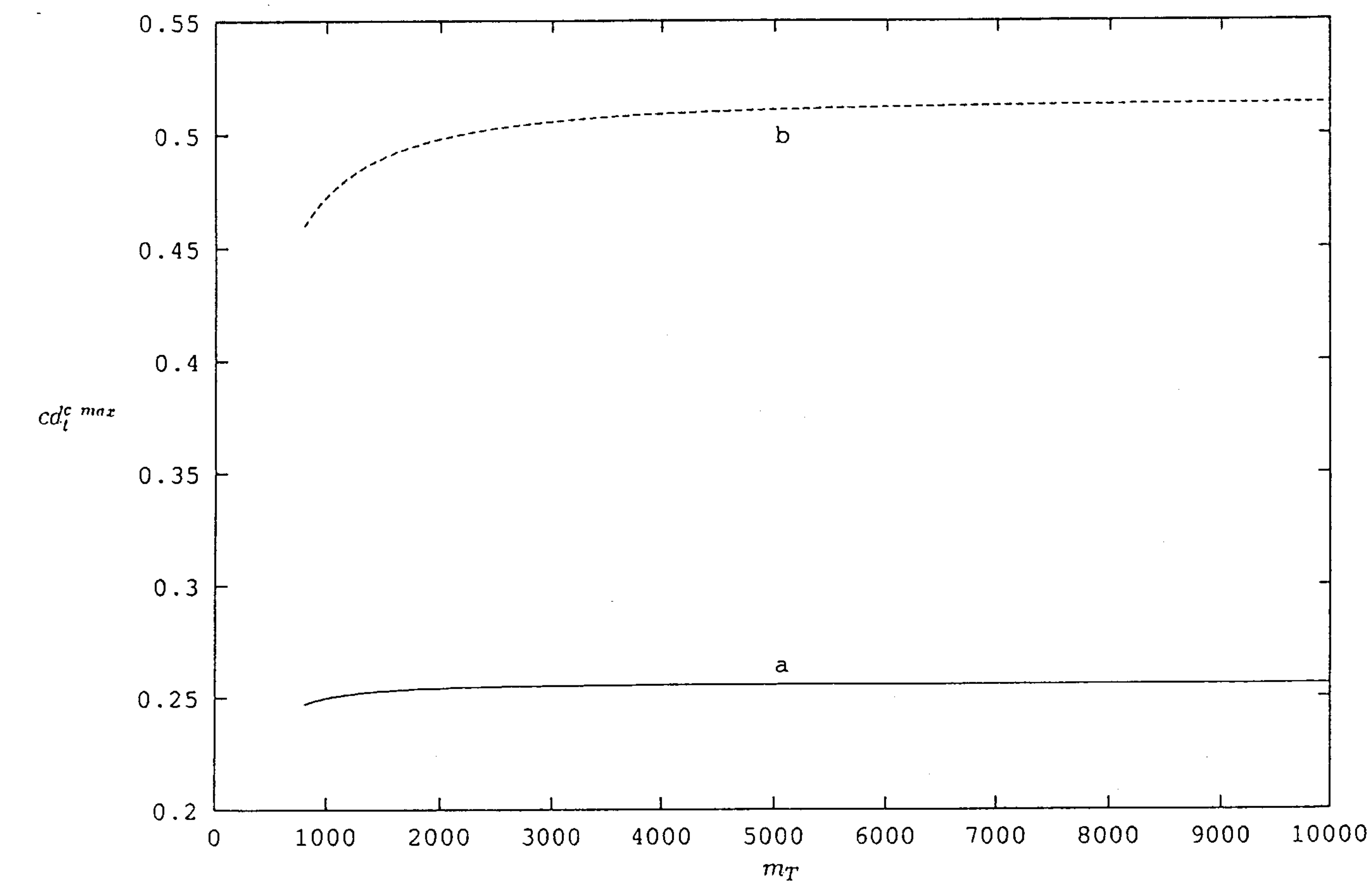
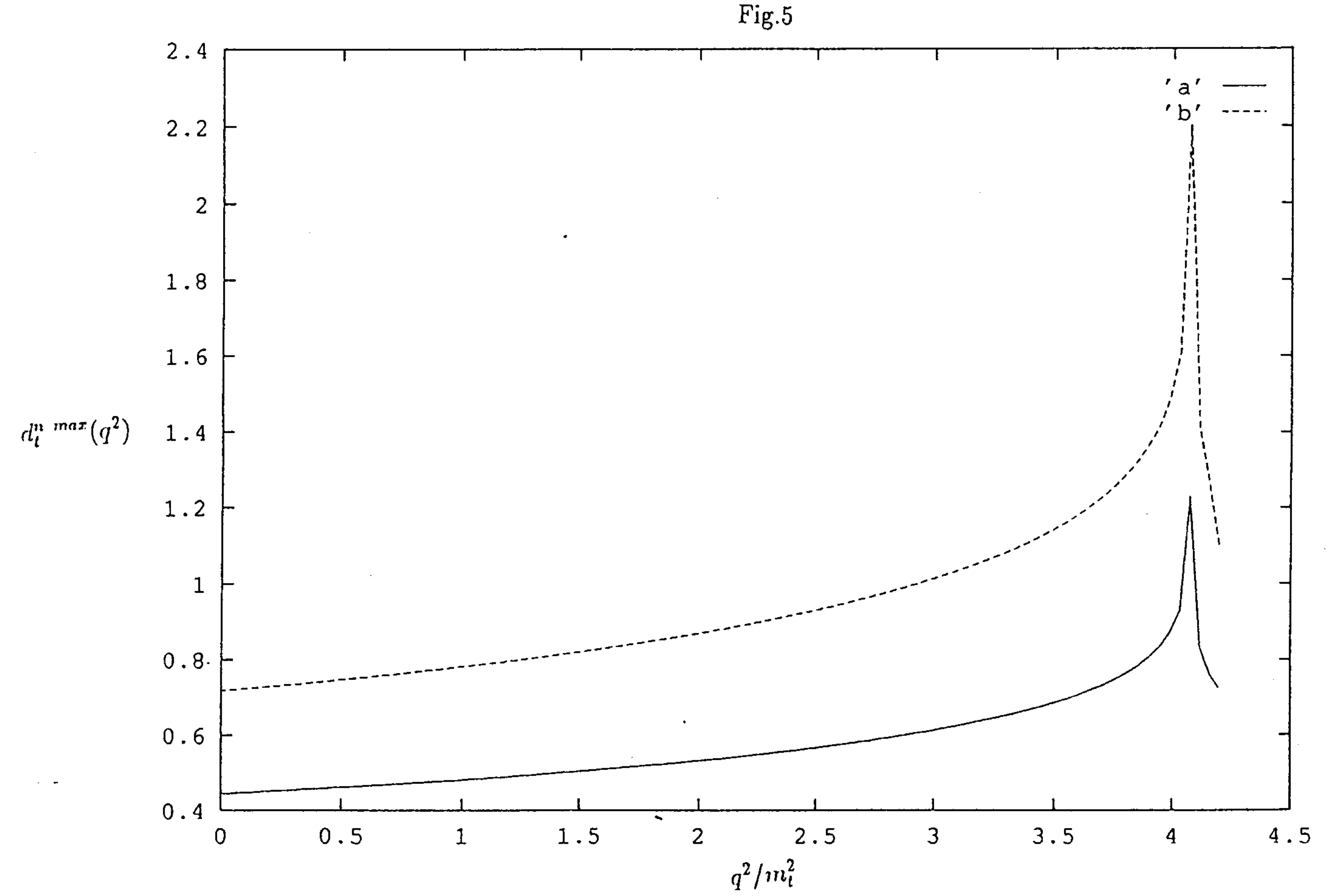

0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
$cd_t^{c\ max}$
b
a
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
m_T

Fig.5


2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
$d_t^{n\ max}(q^2)$
'a'
'b'
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
q^2/m_t^2