

HUPD-9514

June, 1995

# The Oblique corrections from The Diagonal ETC Interaction

Tadashi YOSHIKAWA\*

*Department of Physics, Hiroshima University  
1-3-1 Kagamiyama, Higashi-Hiroshima, 724  
Japan*

## Abstract

We study the effect of the diagonal extended technicolor(ETC) gauge boson on the oblique correction parameters. It is shown that in the  $T$  parameter is unacceptably large when the  $Zbb$  vertex correction and  $S$  parameter are consistent with the experiments in the ETC model.

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HEP-PH-9506411

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\*e-mail: yosikawa@theo.phys.sci.hiroshima-u.ac.jp

In the recent works [1], it is shown that the diagonal extended technicolor(ETC) interaction may solve the  $Zbb$  problem, i.e., the discrepancy between the experiment and the prediction of the Standard Model (SM) in  $Zbb$  vertex. If the contribution of the diagonal interaction to  $Zbb$  vertex is large enough to cancel the other corrections for the  $Zbb$  vertex, the discrepancy could be explained. However, such large effect must contribute to the oblique corrections because the effect comes from the breaking of the custodial symmetry in the right handed ETC interaction. It is necessary to break the custodial symmetry to generate the mass difference between top and bottom quarks. Hence, the  $T$  parameter must receive large contribution from the ETC interactions. The diagram such as Fig.2<sup>1</sup> must contribute to the oblique correction S,T and U [2]. In this letter, we study the effect of the diagonal ETC interaction for the oblique corrections in the case that the non-oblique correction of the  $Zbb$  vertex is consistent with the experimental data in a realistic one-family model with the small  $S$  parameter[3](the model without exact custodial symmetry[4]).

We study the model that the horizontal symmetry  $SU(N_{TC} + 1)$  is broken into  $SU(N_{TC})$ . In the multiplet of  $SU(N_{TC} + 1)$ , the third generation of ordinary fermions and the techni-fermions are contained. The lagrangian for the diagonal ETC interaction in the one-family technicolor model is

$$\begin{aligned} \mathcal{L}_{ETC(3-TC)}^D = g_{ETC} X_{ETC}^\mu \frac{1}{\sqrt{2N_{TC}(N_{TC} + 1)}} & [ \xi_L^t (\bar{Q}_L^i \gamma_\mu Q_L^i - N_{TC} \bar{q}_L^i \gamma_\mu q_L^i) \\ & + \xi_R^t (\bar{U}_R^i \gamma_\mu U_R^i - N_{TC} \bar{t}_R^i \gamma_\mu t_R^i) \\ & + \xi_R^b (\bar{D}_R^i \gamma_\mu D_R^i - N_{TC} \bar{b}_R^i \gamma_\mu b_R^i) \\ & + \xi_L^\tau (\bar{L}_L \gamma_\mu L_L - N_{TC} \bar{l}_L \gamma_\mu l_L) \\ & + \xi_R^\nu (\bar{N}_R \gamma_\mu N_R - N_{TC} \bar{\nu}_R \gamma_\mu \nu_R) \end{aligned}$$

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<sup>1</sup>In Ref.[1], the contribution from Fig.2(A) has been calculated but the contribution from Fig.2(B) is not considered.

$$+ \xi_R^\tau (\bar{E}_R \gamma_\mu E_R - N_{TC} \bar{\tau}_R \gamma_\mu \tau_R)] \quad (1)$$

where  $Q_L^i = (U^i, D^i)_L$ ,  $U_R^i$  and  $D_R^i$  represent techniquarks,  $q_L^i = (t^i, b^i)_L$ ,  $t_R^i$  and  $b_R^i$  represent the third family of quarks and “i” is the color index of QCD.  $L_L = (N, E)_L$ ,  $E_R$  represent the technilepton,  $l_L = (\nu, \tau)_L$  and  $\tau_R$  represent the third family of leptons.  $g_{ETC}$  is a coupling of ETC interaction.  $X_{ETC}$  is diagonal ETC gauge boson which mediates between the third family of ordinary fermions and techni fermions.  $N_{TC}$  is the number of the technicolor.  $\frac{1}{\sqrt{2N_{TC}(N_{TC}+1)}}$  is the normalization factor of the generator of horizontal symmetry  $SU(N_{TC} + 1)$ .  $\xi_L^{t(\tau)}$  is a coefficient of left handed coupling and  $\xi_R^{t(b,\tau)}$  is one of right handed coupling. Since the left handed fermion belongs to  $SU(2)$  doublet, the couplings of up-type quark and down-type quark in the doublet are the same as each other.

The effective lagrangian for fig.1 is

$$\begin{aligned} \mathcal{L}_{int} = \frac{1}{2} \frac{g_{ETC}^2}{q^2 - M_X^2} \frac{1}{2N_{TC}(N_{TC} + 1)} & [ \xi_L^t \bar{Q}_L^i \gamma^\mu Q_L^i + \xi_R^t \bar{U}_R^i \gamma^\mu U_R^i + \xi_R^b \bar{D}_R^i \gamma^\mu D_R^i \\ & - N_{TC} \xi_L^t \bar{q}_L^i \gamma_\mu q_L^i - N_{TC} \xi_R^t \bar{t}_R^i \gamma_\mu t_R^i - N_{TC} \xi_R^b \bar{b}_R^i \gamma_\mu b_R^i \\ & + \xi_L^\tau \bar{L}_L \gamma^\mu L_L + \xi_R^\nu \bar{N}_R \gamma^\mu N_R + \xi_R^\tau \bar{E}_R \gamma^\mu E_R \\ & - N_{TC} \xi_L^\tau \bar{l}_L \gamma_\mu l_L - N_{TC} \xi_R^\nu \bar{\nu}_R \gamma_\mu \nu_R - N_{TC} \xi_R^\tau \bar{\tau}_R \gamma_\mu \tau_R ]^2, \end{aligned} \quad (2)$$

where  $M_X$  is the mass of ETC gauge boson. Below the TC chiral symmetry breaking scale, the current of techniquarks are replaced by the Noether current[5, 6, 7, 8, 9] in the effective chiral lagrangian with  $SU(2N_c)_L \otimes SU(2N_c)_R \otimes U(1)_V$  in techniquark sector [4, 9]. Here, we separate the right-handed current into  $\tau^3$  and singlet components of  $SU(2)$ ,

$$\xi_R^t \bar{U}_R \gamma^\mu U_R + \xi_R^b \bar{D}_R \gamma^\mu D_R = \frac{\xi_R^t + \xi_R^b}{2} \bar{Q}_R \gamma^\mu Q_R + \frac{\xi_R^t - \xi_R^b}{2} \bar{Q}_R \tau^3 \gamma^\mu Q_R \quad (3)$$

Explicitly, the right-handed currents of techniquark are replaced by the following Noether current of the effective lagrangian.

$$\sum_{i=1}^3 \bar{Q}_R^i \gamma^\mu Q_R^i \sim -3 \frac{M_{\delta\omega}}{G_{\delta\omega}} [\omega_\delta^\mu - \frac{\sqrt{3}}{2G_{\delta\omega}} 2Y_{Lq} g' B^\mu] \frac{Y_{Lq}}{\sqrt{3}}, \quad (4)$$

$$\begin{aligned}
\sum_{i=1}^3 \bar{Q}_R^i \tau^3 \gamma^\mu Q_R^i &\sim 3F_6^2 \frac{1}{2} (gW^\mu - g'B^\mu) \\
&- 3 \frac{M_{V_6}}{G_6} [\rho_6^\mu - \frac{\sqrt{3}}{2G_6} (gW^\mu + g'B^\mu)] \frac{1}{\sqrt{3}} \\
&- 3 \frac{M_{A_6}}{\lambda_6} [a_6^\mu + \frac{\sqrt{3}}{2\lambda_6} (gW^\mu - g'B^\mu)] \frac{1}{\sqrt{3}}, \tag{5}
\end{aligned}$$

where,  $\omega_\mu$  and  $\rho_\mu$  are techni-omega meson and techni-rho meson that is composed by techniquarks and  $M_{\omega_6}$  and  $M_{V_6}$  are their masses.  $a_\mu$  is a techni-axialvectormeson and  $M_{A_6}$  is its mass.  $G$  and  $\lambda$  are the couplings which are related to the techni-vectormesons. The  $F_6$  is the decay constant of technipion in techniquark sector. We can neglect the technilepton contribution to the oblique corrections because the coefficients of ETC coupling or decay constant  $F_2$  in technilepton sector is much smaller than that of techniquark in order to generate the mass difference between techniquark and technilepton. Besides this reason, in the model with small  $S$  parameter[3][4], the decay constant  $F_2$  must be much smaller than that in the techniquark sector to satisfy the experimental bound of  $T$  parameter,.

The main part of the contributions to oblique correction from the diagonal ETC interaction (Fig.2(A)) is

$$\frac{9}{64} \frac{g_{ETC}^2}{p^2 - M_X^2} \frac{1}{N_{TC}(N_{TC} + 1)} (\xi_R^t - \xi_R^b)^2 F_\pi^4 (gW_3 - g'B)^2. \tag{6}$$

The contribution from the techni(axial)vectormesons is also given by,

$$\begin{aligned}
&\frac{9}{32} \frac{g_{ETC}^2}{p^2 - M_X^2} \frac{1}{N_{TC}(N_{TC} + 1)} (\xi_R^t - \xi_R^b)^2 \quad F_\pi^2 (gW_3 - g'B) \tag{7} \\
&\quad \times \left\{ \left[ \frac{M_V^2}{G^2} + \frac{M_V^2}{G} \frac{1}{p^2 - M_V^2} \frac{M_V^2}{G} \right] (gW_3 + g'B) \right. \\
&\quad \left. - \left[ \frac{M_A^2}{\lambda^2} + \frac{M_A^2}{\lambda} \frac{1}{p^2 - M_A^2} \frac{M_A^2}{\lambda} \right] (gW_3 - g'B) \right\} \\
&+ \frac{9}{64} \frac{g_{ETC}^2}{p^2 - M_X^2} \frac{1}{N_{TC}(N_{TC} + 1)} (\xi_R^t - \xi_R^b)^2 \left\{ \left[ \frac{M_V^2}{G^2} + \frac{M_V^2}{G} \frac{1}{p^2 - M_V^2} \frac{M_V^2}{G} \right] (gW_3 + g'B) \right. \\
&\quad \left. - \left[ \frac{M_A^2}{\lambda^2} + \frac{M_A^2}{\lambda} \frac{1}{p^2 - M_A^2} \frac{M_A^2}{\lambda} \right] (gW_3 - g'B) \right\}^2.
\end{aligned}$$

Using eq.(6) and eq.(7), we obtain the contributions to the oblique parameters[2]

from Fig.2(A)

$$S^{dETC} = -\frac{9}{2}\pi \frac{(\xi_R^t - \xi_R^b)^2}{N_{TC}(N_{TC} + 1)} \left[ \frac{g_{ETC}^2}{M_X^4} F_\pi^4 + 2 \frac{g_{ETC}^2}{M_X^2} \frac{1}{\lambda^2} F_\pi^2 \right], \quad (8)$$

$$\alpha T_A^{ETC} = \frac{9}{32} \frac{(\xi_R^t - \xi_R^b)^2}{N_{TC}(N_{TC} + 1)} \frac{g_{ETC}^2}{M_X^2} F_\pi^4 \frac{g^2 + g'^2}{M_Z^2}. \quad (9)$$

From this analysis, the contribution to the  $S$  parameter for the diagonal ETC gauge interaction is negative<sup>2</sup>.

There is also another two loop contribution to the oblique correction  $T$  from the diagonal ETC interaction (Fig. 2(B)). Below the ETC scale, the contribution is obtained from the following four-fermi lagrangian:

$$-\frac{1}{4} \frac{g_{ETC}^2}{M_X^2} \frac{1}{N_{TC} + 1} \left[ \xi_L^t{}^2 (\bar{Q}_L^i \gamma_\mu Q_L^i)^2 + \frac{(\xi_R^t + \xi_R^b)^2}{4} (\bar{Q}_R \gamma^\mu Q_R)^2 + \frac{(\xi_R^t - \xi_R^b)^2}{4} (\bar{Q}_R \tau^3 \gamma^\mu Q_R)^2 \right]. \quad (10)$$

After Fierz transformation, the lagrangian becomes to

$$-\frac{1}{4} \frac{g_{ETC}^2}{M_X^2} \frac{1}{N_{TC} + 1} \left[ \frac{\xi_L^t{}^2}{2} \sum_{A=0}^3 (\bar{Q}_L^i \gamma_\mu \tau^A Q_L^i)^2 + \frac{(\xi_R^t + \xi_R^b)^2}{8} \sum_{A=0}^3 (\bar{Q}_R \gamma^\mu \tau^A Q_R)^2 + \frac{(\xi_R^t - \xi_R^b)^2}{8} \{ (\bar{Q}_R \gamma^\mu Q_R)^2 + (\bar{Q}_R \gamma^\mu \tau^3 Q_R)^2 - \sum_{a=1}^2 (\bar{Q}_R \gamma_\mu \tau^a Q_L^i)^2 \} \right], \quad (11)$$

where,  $\tau^a (a = 1, 2, 3)$  is the Pauli matrix and  $\tau^0$  is a unit matrix. Note that the sign in the third term different with the other terms. We replace the currents of technifermion by the Noether current. Then, the contribution to  $T$  from Fig.2(B) is given by

$$-\frac{3}{32} \frac{g_{ETC}^2}{M_X^2} \frac{F_\pi^4}{N_{TC} + 1} \left[ \xi_L^2 + \frac{(\xi_R^t + \xi_R^b)^2}{4} + \frac{(\xi_R^t - \xi_R^b)^2}{4} \right] (gW_3 - g'B)^2 - \frac{3}{32} \frac{g_{ETC}^2}{M_X^2} \frac{F_\pi^4}{N_{TC} + 1} \left[ \xi_L^2 + \frac{(\xi_R^t + \xi_R^b)^2}{4} - \frac{(\xi_R^t - \xi_R^b)^2}{4} \right] \sum_{a=1}^2 (gW^a)^2 \quad (12)$$

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<sup>2</sup>In this letter, we only consider the contribution from techniquarks. The  $S^{ETC}$  of eq.(8) has negative sign but the contribution is small compared with that to the  $T$  parameter (See Fig. 5.). However there may be the large contribution to  $S$  from the other fermions.

Hence, only the terms of a factor of  $(\xi_R^t - \xi_R^b)^2$  only contribute to  $T$  from Fig.2(B). The contribution to  $T$  parameter is

$$\alpha T_B^{ETC} = \frac{3}{32} \frac{(\xi_R^t - \xi_R^b)^2}{N_{TC}(N_{TC} + 1)} \frac{g_{ETC}^2}{M_X^2} F_\pi^4 \frac{g^2 + g'^2}{M_Z^2}. \quad (13)$$

The total contribution to  $T$  from the diagonal ETC interaction is

$$T^{ETC} = T_A^{ETC} + T_B^{ETC}. \quad (14)$$

While, the non-oblique corrections for  $Zbb$  vertex [1] are given by

$$\delta g_L^{ETC} = \delta g_{LS}^{ETC} + \delta g_{LD}^{ETC}, \quad (15)$$

where, the contribution from the side-way ETC gauge interaction of Fig.3 is

$$\delta g_{LS}^{ETC} = \frac{1}{8} \xi_L^t \frac{g_{ETC}^2}{M_{ETC}^2} F_\pi^2 \sqrt{g^2 + g'^2}, \quad (16)$$

and the contribution from the diagonal ETC interaction of Fig.4 is

$$\delta g_{LD}^{ETC} = -\frac{3}{8} \xi_L^t (\xi_R^t - \xi_R^b) \frac{g_{ETC}^2}{M_{ETC}^2} \frac{1}{N_{TC} + 1} F_\pi^2 \sqrt{g^2 + g'^2}. \quad (17)$$

If the effect of the ETC gauge interaction, i.e., eq.(15) explain the difference between the experimental data of  $R_b$  and the prediction of SM, the parameter  $\xi_R^t - \xi_R^b$  must be larger than  $\xi_L(N_{TC} + 1)/3$  and small  $M_X/g_{ETC}$  is favored. Since  $S$  parameter is proportional to  $N_{TC}$ , the small  $N_{TC}$  is favored to be consistent with the experimental constraint for  $S$ . Therefore we choose  $N_{TC} = 2$ . The parameter  $\xi_L^t$  is taken to be unity for simplicity. Comparing the mass of between top quark and bottom quark,  $\xi_R^t$  is much larger than  $\xi_R^b$ . Hence, we treat  $\xi_R^t$  as the parameter which show the breaking of custodial symmetry. In the model with small  $S$  parameter[3] ( the model without exact custodial symmetry[4] ),  $F_\pi \sim \sqrt{250^2/3} \sim 144 GeV$ . In eq.(8), we put  $\lambda^2 = 106$  (See ref.[4]). Here, we define a ratio of the ETC correction to  $R_b$

$$\frac{\delta R_b^{ETC}}{R_b} \sim (1 - R_b) \frac{2g_L \delta g_L^{ETC}}{g_L^2 + g_R^2}.$$

In Fig.5, the ratio presented as the functions of  $M_X/g_{ETC}$  for several values of  $\xi_R^t$ . Because the  $\xi_R^t$  must be larger than  $\xi_L(N_{TC} + 1)/3 = 1$ , we choose the following values for  $\xi_R^t - \xi_R^b \sim \xi_R^t$ . (a)1.2, (b)1.5, (c)2 and (d)2.5. If the contribution to  $R_b$  from the ETC model explains the experimental data in  $1 \sigma$  level, the  $\delta R_b^{ETC}/R_b$  must larger than about 0.012. Then, in Fig.5, it is shown that the mass of ETC gauge boson  $M_X/g_{ETC}$  must be smaller than about 700 GeV in case (b), 900 GeV in (c), 1100 GeV in (d).

In Fig.6 and Fig.7, we plot the behavior of the contribution to oblique correction from diagonal ETC interaction (eq.(8) and eq.(14)), by choosing the same values for  $\xi_R^t$  as those in Fig.5. For the values of  $M_x/g_{ETC}$  which satisfy the experimental constraint of  $R_b$ , the contribution to  $S$  from ETC negligible compared with that from TC (The typical TC contribution to  $S$  is  $0.1N_{TC}$  from a one doublet technifermion.).  $T$  receive large value. In Fig.7, it is shown that the value of  $T$  must be larger than about 0.9 in the cases (b),(c) and (d) for  $1 \sigma$  level of experiment of  $R_b$ . This value contradict with the experimental bound of  $T$  ( $T_{exp} < 0.5$ ). In the model with small  $S$ [3], the situation is worse because  $T$  parameter already receives the contribution from the custodial symmetry breaking in technilepton sector. Hence, it is not favored that the  $T$  receives the additional contribution from ETC interaction. It is difficult that the discrepancy between the SM and the experiment for the  $R_b$  is explained by the contribution of the diagonal ETC gauge interaction, because the contribution to  $T$  parameter contradicts with the experimental bound.

The contribution to the vertex correction of  $Zbb$  from the diagonal ETC gauge interaction become large with positive sign when the  $\xi_R^t - \xi_R^b$  is larger than  $\xi_L(N_{TC} + 1)/3$ . However, because the such large  $\xi_R^t - \xi_R^b$  breaks the custodial symmetry significantly,  $T$  must receive the contribution from the diagonal ETC interaction. It is difficult that the  $\xi_R^t g_{ETC}/M_X$  becomes large enough to explain the discrepancy for  $R_b$ , unless the other mechanism suppress the  $T$  parameter in this model.

## Acknowledgement

We would like to thank Dr.T.Morozumi for discussion and reading the manuscript.

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## Figure Captions

- **Fig. 1** : The Feynman diagram for the diagonal ETC gauge interaction.
- **Fig. 2 (A),(B)**: The Feynman diagrams for the contribution to the oblique correction according to diagonal ETC gauge interaction.
- **Fig. 3** : The Feynman diagram for the contribution to the vertex correction according to diagonal ETC gauge interaction.
- **Fig. 4** : The Feynman diagram for the contribution to the oblique correction according to sideways ETC gauge interaction.
- **Fig. 5,6,7**:  $\frac{\delta R_b^{ETC}}{R_b}$ ,  $S^{ETC}$  and  $T^{ETC}$  as a function of  $M_X/g_{ETC}$  for following values for  $\xi_R^t - \xi_R^b$ . (a) 1.2 with a dashed thinline, (b) 1.5 with a thinline, (c) 2 with a thickline and (d) 2.5 with a dashed thickline.

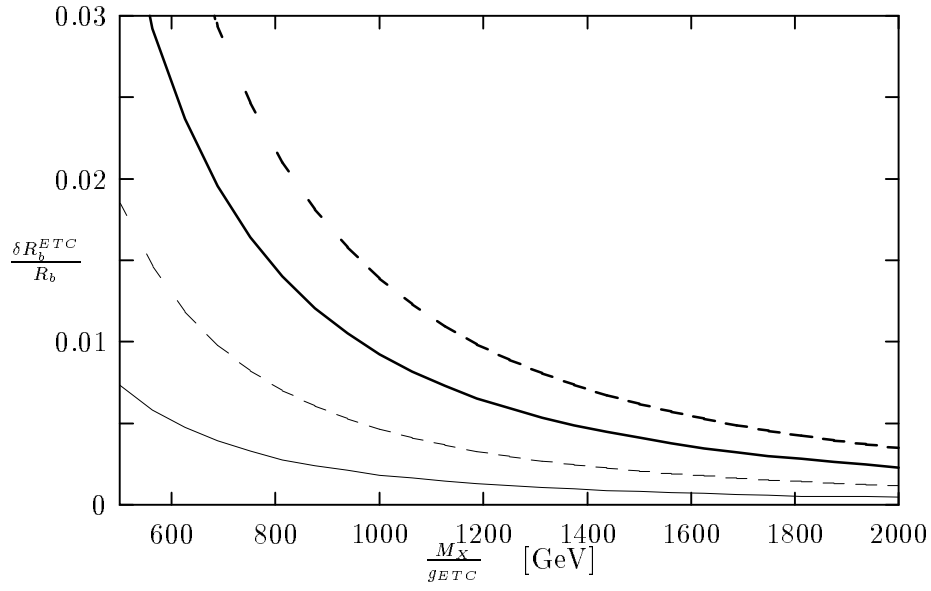


Fig.5

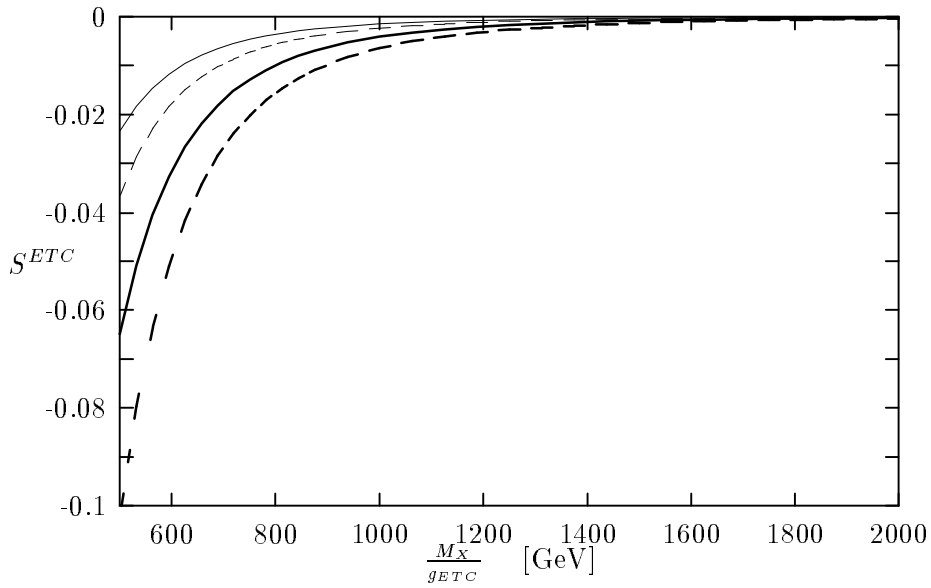
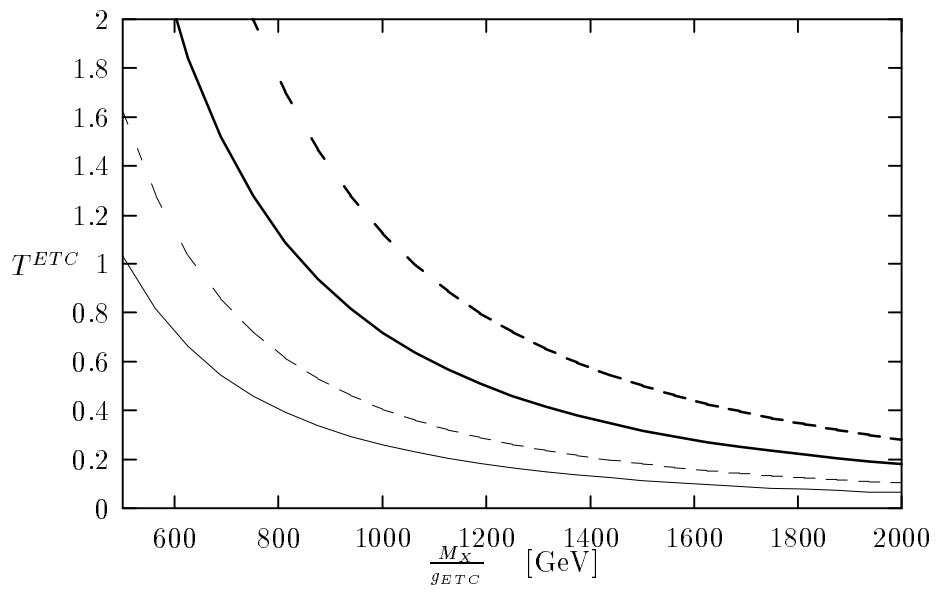


Fig.6



**Fig.7**