Eur. Phys. J. C 14, 313–318 (2000)
Digital Object Identifier (DOI) 10.1007/s100520000337

THE EUROPEAN PHYSICAL JOURNAL C

TC2 dynamics and top quark production at NLC*

Chongxing Yue[1,2], Gongru Lu[1,2], Weibin Li[2], Junfeng Sun[2]

[1] CCAST (World Laboratory) P.O. Box 8730, B.J. 100080, P.R. China
[2] College of Physics and Information Engineering, Henan Normal University[a], Xingxiang 453002, P.R. China

Received: 4 September 1999 / Revised version: 19 November 1999 /
Published online: 17 March 2000 – © Springer-Verlag 2000

Abstract. We calculate the correction of the TC2 dynamics to the production cross section of the process $e^+e^- \to t\bar{t}$ in the top color-assisted multiscale technicolor model. Our results show that the corrections mainly come from the effects of the top color gauge boson Z' in the s-channel. The total corrections to cross sections σ_L and σ_R are very large; this can be detected at NLC. The total corrections to the polarized parameters $P^t_{\rm L}$ and $P^t_{\rm R}$ may be observed at NLC in most of the parameter space.

1 Introduction

The top quark is the heaviest particle yet found experimentally. Its mass, $m_t = 173.8 \pm 5.0\,\text{GeV}$ [1], is of the order of the electroweak symmetry breaking (EWSB) scale $\nu = 246\,\text{GeV}$. This means that top quark couples rather strongly to the EWSB sector so that the effects from new physics would be more apparent in processes with the top quark than with any other light quarks. Experimentally, it is possible to separately measure various production and decay form factors of the top quark at the level of a few percent [2]. Thus, theoretical calculations of various corrections to the production and decay of the top quark are of much interest for testing for new physics.

A top quark pair can be produced at various high-energy colliders. At the Next Linear Collider (NLC), a top quark pair can be produced in sufficient abundance. The luminosity, which is expected to be on the order of 50–100 fb^{-1}/yr, is sufficient to provide a yearly sample of a few times 10^4 top quark pairs [3]. The event environment in e^+e^- collisions is clean, so that precision measurements are possible. Therefore, NLC is an ideal tool for studying the properties of the top quark. The high degree of electron polarization attainable at NLC will be very useful in probing the top quark couplings to the photon and Z boson which come from new physics.

Technicolor [4] is an interesting idea for naturally breaking electroweak gauge symmetry to give rise to the electroweak gauge bosons masses. To generate ordinary fermions masses, extended technicolor (ETC) models have been proposed [5]. However, ETC models cannot explain the large mass of the top quark without conflict with precision electroweak measurements or unacceptable fine tuning of parameters. On the other hand, models with EWSB induced by strong top color interactions that are consistent with precision electroweak measurements require top color energy scales much higher than the electroweak scale and, therefore, very severe fine tuning. These problems can be solved in top color-assisted technicolor (TC2) theory [6]. Thus TC2 theory is one of the important promising candidates of the EWSB mechanism.

In TC2 theory, the majority of the $W^\pm$ and Z masses come from the technifermion condensate; the ETC interactions give contributions to all ordinary quark and lepton masses, while the mass of top quark is mainly generated by the top color interactions. The part of the mass of the top quark generated by ETC interactions is $m'_t = \varepsilon m_t$ with $0.03 \le \varepsilon \le 0.1$ [6]. Thus, TC2 theory predicts two kinds of gauge bosons, which are ETC gauge bosons (sideways, diagonal) and top color gauge bosons (coloron B^A, Z'). The coloron B^A is a color octet and Z' is a color singlet. The coloron B^A only couples to ordinary quarks. In order to cancel anomalies, the gauge boson Z' can also couple to leptons. Thus, Z' can give a new contribution to the top quark production at NLC via the process $e^+e^- \to Z'^* \to t\bar{t}$. It is possible that these gauge bosons can generate significant corrections to the $Zt\bar{t}$ couplings $g^t_{\rm L}$ and $g^t_{\rm R}$ [7,8]. These imply that the TC2 dynamics would generate significant corrections to the physical observables such as the cross sections $\sigma_{\rm L}, \sigma_{\rm R}, \sigma_{\rm L}(-+)$ and $\sigma_{\rm R}(-+)$ of the process $e^+e^- \longrightarrow t\bar{t}$. Here $\sigma_{\rm L}(\sigma_{\rm R})$ is the total cross section of the process $e^+_{\rm R}e^-_{\rm L}(e^+_{\rm L}e^-_{\rm R}) \longrightarrow t_{\rm L}\overline{t_{\rm R}} + t_{\rm R}\overline{t_{\rm L}}$. $\sigma_{\rm L(R)}(-+)$ and $\sigma_{\rm L(R)}(+-)$ are the total cross sections of the process $e^+_{\rm R}e^-_{\rm L}(e^+_{\rm L}e^-_{\rm R}) \longrightarrow t_{\rm L}\overline{t_{\rm R}}$ and $e^+_{\rm R}e^-_{\rm L}(e^+_{\rm L}e^-_{\rm R}) \longrightarrow t_{\rm R}\overline{t_{\rm L}}$. In this paper, we will first calculate the corrections of Z' to the cross sections $\sigma_{\rm L}, \sigma_{\rm R}$ in the s-channel. Second, we will calculate the corrections of ETC and the top color gauge bosons to $\sigma_{\rm L}, \sigma_{\rm R}$ which arise from their radiative corrections to the

* This work is supported by the National Natural Science Foundation of China and the Excellent Youth Foundation of Henan Scientific Committee.

[a] e-mail: dphnu@pbulic.xxptt.ha.cn

$Zt\bar{t}$ vertex, and compare these values with the values given by Z' in the s-channel. Finally, we will further calculate the total corrections of the TC2 dynamics to the polarized parameters $P^t_{\rm L} = (\sigma_{\rm L}(-+) - \sigma_{\rm L}(+-))/(\sigma_{\rm L}(-+) + \sigma_{\rm L}(+-))$ and $P^t_{\rm R} = (\sigma_{\rm R}(-+) - \sigma_{\rm R}(+-))/(\sigma_{\rm R}(-+) + \sigma_{\rm R}(+-))$ which can be measured with a high precision at the NLC experiments. We expect that our results are useful in testing TC2 theory at the future e^+e^- collider experiments.

This paper is organized as follows. In Sect. 2, we give the new couplings which relate to the process $e^+e^- \to t\bar{t}$. In Sect. 3, we calculate the corrections of ETC and the top color gauge bosons to the cross sections $\sigma_{\rm L}, \sigma_{\rm R}$. The total corrections of the TC2 dynamics to the polarized parameters $P^t_{\rm L}, P^t_{\rm R}$ are calculated in Sect. 4. Our conclusions are given in Sect. 5.

2 The new couplings related to the process $e^+e^- \to t\bar{t}$

For simplicity, we consider top color-assisted multiscale technicolor (TOPCMTC) model, in which the simple multiscale technicolor model studied in [9] is assisted with top color interactions for the third generation. The top color sector of this model is the same as in the usual TC2 theory. In the TOPCMTC model, the dynamics at the $\wedge \sim 1\,\mathrm{TeV}$ scale involves the following structure [6]:

$$SU(3)_1 SU(3)_2 U(1)_{y1} U(1)_{y2} SU(2)_{\rm L} \longrightarrow SU(3)_{\rm QCD} U(1)_{\rm EM}\,, \tag{1}$$

where $SU(3)_1 \times U(1)_{y1} (SU(3)_2 \times U(1)_{y2})$ generally couples preferentially to the third (first and second) generations. The $U(1)_{y2}$ are just strongly rescaled versions of electroweak $U(1)_Y$. This breaking scenario leaves a residual global symmetry, $SU(3)' \times U(1)'$, implying a degenerate, massive color octet of colorons B^A_μ and a singlet heavy Z'_μ. The couplings of the new heavy gauge bosons Z' and B^A to the ordinary fermions are given by

$$L_{Z'} = \sqrt{4\pi k_1} Z' \cdot J_{Z'}, \quad L_B = \sqrt{4\pi k} B^A \cdot J^A_B. \tag{2}$$

Here $k_1(k)$ are the Z' (coloron B^A) coupling coefficients. Considering the requirement of vacuum tilting and the constraint from Z-pole physics and $U(1)$ triviality, we have the region of coupling constant parameter space $k = 2, k_1 \le 1$ [10]. In our calculations, we will take $k = 2$ and $k_1 = 1$. The currents $J_{Z'}$ and J_B in general involve all three generations of fermions. For the first and third generations, the currents can be written as

$$J^\mu_{Z',1} = -\tan^2\theta' \times \left(\frac{1}{6}\bar{u}_{\rm L}\gamma^\mu u_{\rm L} + \frac{1}{6}\bar{d}_{\rm L}\gamma^\mu d_{\rm L} + \frac{2}{3}\bar{u}_{\rm R}\gamma^\mu u_{\rm R} - \frac{1}{3}\bar{d}_{\rm R}\gamma^\mu d_{\rm R} - \frac{1}{2}\bar{\nu}_{eL}\gamma^\mu \nu_{eL} - \frac{1}{2}\bar{e}_{\rm L}\gamma^\mu e_{\rm L} - \bar{e}_{\rm R}\gamma^\mu e_{\rm R}\right), \tag{3}$$

$$J^\mu_{B,1} = -\tan^2\theta \left(\bar{u}\gamma^\mu \frac{\lambda^A}{2} u + \bar{d}\gamma^\mu \frac{\lambda^A}{2} d\right), \tag{4}$$

$$J^\mu_{Z',3} = \frac{1}{6}\bar{t}_{\rm L}\gamma^\mu t_{\rm L} + \frac{1}{6}\bar{b}_{\rm L}\gamma^\mu b_{\rm L} + \frac{2}{3}\bar{t}_{\rm R}\gamma^\mu t_{\rm R} - \frac{1}{3}\bar{b}_{\rm R}\gamma^\mu b_{\rm R} + \cdots, \tag{5}$$

$$J^\mu_{B,3} = \bar{t}\gamma^\mu \frac{\lambda^A}{2} t + \bar{b}\gamma^\mu \frac{\lambda^A}{2} b, \tag{6}$$

where θ (θ') is the mixing angle and λ^A is a Gell-Mann matrix acting on the color indices. Thus, the new couplings given by the top color interactions which for the process $e^+e^- \to t\bar{t}$ can be written as

$$g^{e,Z'}_{\rm R} = 2g^{e,Z'}_{\rm L} = 2\tan^2\theta' \sqrt{\pi k_1}, \qquad g^{t,Z'}_{\rm R} = 4g^{t,Z'}_{\rm L} = \frac{4}{3}\sqrt{\pi k_1}. \tag{7}$$

At low energy, the effects of the ETC gauge bosons can be described by the effective four-fermion interactions. Using the effective Lagrangian approach, the technifermion currents in the effective four-fermion interactions can be replaced by the corresponding sigma currents [11]. Then the new $Zt\bar{t}$ couplings $g^{t,E}_{\rm L}$ and $g^{t,E}_{\rm R}$ given by the ETC dynamics can be written as [8]

$$g^{t,E}_{\rm L} = \frac{-1}{4}\frac{\varepsilon m_t}{4\pi F}\sqrt{\frac{N_{\rm TC}}{N_{\rm C}}}\left(\frac{2N_{\rm C}}{N_{\rm TC}+1} + \xi^2_{\rm L}\right), \tag{8}$$

$$g^{t,E}_{\rm R} = \frac{-1}{4}\frac{\varepsilon m_t}{4\pi F}\sqrt{\frac{N_{\rm TC}}{N_{\rm C}}}\left(\frac{2N_{\rm C}}{N_{\rm TC}+1} - 1\right)\xi^{-2}_{\rm L}, \tag{9}$$

where F is the decay constant of the technipions and $N_{\rm TC}$ is the technicolor index. In the TOPCMTC model, we have $F = 40\,\mathrm{GeV}$ and $N_{\rm TC} = 6$ [9]. From (8) and (9) we can see that the new $Zt\bar{t}$ couplings are dependent on the parameters ε and $\xi_{\rm L}$. It has been pointed out that the parameter ε is in the range of $0.03 \le \varepsilon \le 0.1$ [6]. For the free parameter $\xi_{\rm L}$ we will take the reasonable value $\xi_{\rm L} = 1$ [8].

It has been shown [12] that ETC interactions cannot give the new $\gamma t\bar{t}$ coupling. Thus we have $g^{\gamma,E} = 0$.

From (5) and (6) we can see that the coloron B^A and Z' can generate corrections to the $Zt\bar{t}$ couplings $g^t_{\rm L}, g^t_{\rm R}$. Similar to the computation of [13], we can give the radiative corrections to the $Zt\bar{t}$ vertex. Thus, the new $Zt\bar{t}$ couplings $g^{t,t}_{\rm L}, g^{t,t}_{\rm R}$ arising from the top color gauge bosons can be written as

$$g^{t,t}_{\rm L} = \frac{kC_F m^2_Z}{6\pi M^2_B}\ln\left(\frac{M^2_B}{m^2_Z}\right) g^t_{\rm L} + \frac{k_1 m^2_Z}{6\pi M^2_{Z'}}\ln\left(\frac{M^2_{Z'}}{m^2_Z}\right) g^t_{\rm L}, \tag{10}$$

$$g^{t,t}_{\rm R} = \frac{kC_F m^2_Z}{6\pi M^2_B}\ln\left(\frac{M^2_B}{m^2_Z}\right) g^t_{\rm R} + \frac{k_1 m^2_Z}{6\pi M^2_{Z'}}\ln\left(\frac{M^2_{Z'}}{m^2_Z}\right) g^t_{\rm R}, \tag{11}$$

where M_B ($M_{Z'}$) is the coloron (Z') mass and C_F is the color factor with $C_F = 4/3$. $Y^t_{\rm L}$ and $Y^t_{\rm R}$ are the hypercharges with $Y^t_{\rm L} = 1/3, Y^t_{\rm R} = 4/3$ [10].

TC2 theory predicts some technipions and three top pions. These new particles may generate significant one-loop corrections to the $Zt\bar{t}$ vertex. However, these corrections are "low-energy" contributions. In this paper, we only consider "high-energy" contributions which come from the TC2 dynamics. Thus, the total new $Zt\bar{t}$ couplings can be written as

$$g^{t,R}_{\rm L} = g^{t,E}_{\rm L} + g^{t,t}_{\rm L}, \quad g^{t,R}_{\rm R} = g^{t,E}_{\rm R} + g^{t,t}_{\rm R}. \tag{12}$$

3 The corrections of ETC and top color gauge bosons to the cross sections $\sigma_{\rm L}, \sigma_{\rm R}$

At the NLC experiments, top quark pairs can be produced in sufficient abundance. The main production mechanism proceeds at the Born level by the s-channel annihilation of an initial electron–positron pair into virtual photons or neutral electroweak gauge bosons, and their subsequent splitting into a top–antitop pair,

$$e^+e^- \longrightarrow \gamma^*, \quad Z^{0*} \longrightarrow t\bar{t}. \tag{13}$$

At lowest order the polarized cross sections $\sigma_{\rm L}, \sigma_{\rm R}$ in the SM can be written as [12]

$$\begin{aligned}\sigma^{\rm SM}_{\rm L(R)} = \frac{\beta S}{32\pi}\Bigg\{&\frac{16}{9}(3-\beta^2)\left(\frac{e^2}{S}\right)^2 + \left(\frac{e^2}{S_{\rm W}^2 C_W^2}\right)^2 \\ &\times (g^e_{\rm L(R)})^2[(3+\beta^2)[(g^t_{\rm L})^2+(g^t_{\rm R})^2]+6(1-\beta^2)g^t_{\rm L}g^t_{\rm R}] \\ &\times \frac{1}{(S-m_Z^2)^2+m_Z^2\Gamma_Z^2} \\ &- \frac{8}{3}(3-\beta^2)\frac{e^4}{S_{\rm W}^2C_W^2}g^e_{\rm L(R)}\frac{(g^t_{\rm L}+g^t_{\rm R})(S-m_Z^2)}{S[(S-m_Z^2)^2+m_Z^2\Gamma_Z^2]}\Bigg\}.\end{aligned} \tag{14}$$

In TC2 theory, the exchange of Z' can produce the top quark pairs via the process $e^+e^- \to Z'^* \to t\bar{t}$. Thus the Z' has a contribution to the cross sections $\sigma_{\rm L}, \sigma_{\rm R}$ in the s-channel. The expressions produced by the Z' exchange can be written as

$$\begin{aligned}\delta\sigma^{\rm top\ color}_{\rm L(R)} = \frac{\beta S}{32\pi}\Bigg\{&(g^{e,Z'}_{\rm L(R)})^2[(3+\beta^2) \\ &\times[(g^{t,Z'}_{\rm L})^2+(g^{t,Z'}_{\rm R})^2]+6(1-\beta^2)g^{t,Z'}_{\rm L}g^{t,Z'}_{\rm R}] \\ &\times\frac{1}{(S-M_{Z'}^2)^2+M_{Z'}^2\Gamma_{Z'}^2} \\ &-\frac{8}{3}e^2 g^{e,Z'}_{\rm L(R)}(g^{t,Z'}_{\rm L}+g^{t,Z'}_{\rm R})\frac{(3-\beta^2)(S-M_{Z'})}{S[(S-M_{Z'}^2)^2+M_{Z'}^2\Gamma_{Z'}^2]} \\ &+\frac{2e^2}{S_{\rm W}^2C_W^2}g^{e,Z'}_{\rm L(R)}g^e_{\rm L(R)}[(3+\beta^2)g^t_{\rm L}g^{t,Z'}_{\rm L}+3(1-\beta^2)g^t_{\rm R}g^{t,Z'}_{\rm R}] \\ &\times\frac{(S-m_Z^2)(S-M_{Z'}^2)+m_ZM_{Z'}\Gamma_Z\Gamma_{Z'}}{[(S-m_Z^2)^2+m_Z^2\Gamma_Z^2][(S-M_{Z'}^2)^2+M_{Z'}^2\Gamma_{Z'}^2]}\Bigg\},\end{aligned} \tag{15}$$

where $S^{1/2}$ is the center-of-mass energy, $\beta = (1-4m_t^2/S)^{1/2}$ and

$$g^e_{\rm L} = -\frac{1}{2}+S_{\rm W}^2, \quad g^e_{\rm R} = S_{\rm W}^2, \tag{16}$$

$$g^t_{\rm L} = \frac{1}{2}-\frac{2}{3}S_{\rm W}^2, \quad g^t_{\rm R} = -\frac{2}{3}S_{\rm W}^2, \tag{17}$$

with $S_{\rm W}^2 = \sin\theta_{\rm w}^2$; $\theta_{\rm w}$ is the Weinberg angle. In (15), $\delta\sigma^{\rm top\ color}_{\rm L(R)}$ also contains γ, Z' and Z, Z' interference terms. In our calculations, we will take the reasonable value $S_{\rm W}^2 = 0.2315$, $m_Z = 91.867\,{\rm GeV}$ [15] and $M_{Z'} = 1\,{\rm TeV}$ [10]. $\Gamma_Z(\Gamma_{Z'})$ is the total decay width of $Z(Z')$. From [15], we know $\Gamma_Z = 2.4939\,{\rm GeV}$. For the top color gauge boson Z', the decay width is dominated by $t\bar{t}+b\bar{b}$ for large $\cot\theta'$ [16] and we have

$$\Gamma_{Z'} \approx \frac{g_1^2\cot^2\theta'}{12\pi}M_{Z'} = \frac{k_1}{3}M_{Z'}. \tag{18}$$

In our calculations, we will take $k_1 = 1$. The choice $k_1 = 1$ corresponds to $\tan^2\theta' = 0.01$ [17]. From Sect. 2, we can see that the TC2 dynamics can give the new $Zt\bar{t}$ couplings $g^{t,R}_{\rm L}$, $g^{t,R}_{\rm R}$. This implies that the TC2 dynamics can generate corrections to $\sigma_{\rm L}$ and $\sigma_{\rm R}$ via one-loop corrections of the ETC and top color gauge bosons to the $Zt\bar{t}$ vertex. The formulas can be written as

$$\begin{aligned}\delta\sigma^R_{\rm L(R)} = \frac{\beta S}{32\pi}\Bigg\{&\left(\frac{e^2}{S_{\rm W}^2C_W^2}\right)^2(g^e_{\rm L(R)})^2 \\ &\times\Big[2(3+\beta^2)(g^t_{\rm L}g^{t,R}_{\rm L}+g^t_{\rm R}g^{t,R}_{\rm R}) \\ &+6(1-\beta^2)(g^t_{\rm L}g^{t,R}_{\rm R}+g^t_{\rm R}g^{t,R}_{\rm L})\Big] \\ &\times\frac{1}{(S-m_Z^2)^2+m_Z^2\Gamma_Z^2} \\ &-\frac{8}{3}\frac{e^4}{S_{\rm W}^2C_W^2}g^e_{\rm L(R)}(g^{t,R}_{\rm L}+g^{t,R}_{\rm R}) \\ &\times\frac{S-m_Z^2}{S[(S-m_Z^2)^2+m_Z^2\Gamma_Z^2]}\Bigg\}.\end{aligned} \tag{19}$$

In the above equation, we have neglected the high order terms.

To compare the corrections of Z' in the s-channel to $\sigma_{\rm L}, \sigma_{\rm R}$ with the radiative corrections of the TC2 dynamics to $\sigma_{\rm L}, \sigma_{\rm R}$, we plot the relative corrections $\delta\sigma^{\rm top\ color}_{\rm L}/\delta\sigma^R_{\rm L}$, $\delta\sigma^{\rm top\ color}_{\rm R}\delta\sigma^R_{\rm R}$ versus $S^{1/2}$ in Fig. 1 and Fig. 2, in which the solid, dashed and dotted lines stand for $\varepsilon = 0.05, 0.08$ and 0.1, respectively. From Fig. 1 and Fig. 2, we can see that the corrections of the TC2 dynamics to the cross sections $\sigma_{\rm L}, \sigma_{\rm R}$ mainly come from the effects of Z' in the s-channel. The contributions of the new $Zt\bar{t}$ couplings can be safely ignored in most of the range of the center-of-mass energy $S^{1/2} = 500$–$1500\,{\rm GeV}$. The relative corrections are not sensitive to the value of parameter ε. For simplicity, we will take the fixed value $\varepsilon = 0.08$ in the following calculation.

To see the correction effects of the TC2 dynamics on the cross sections $\sigma_{\rm L}, \sigma_{\rm R}$, we plot the relative corrections $\delta\sigma^{\rm total}_{\rm L}/\sigma^{\rm SM}_{\rm L}$ and $\delta\sigma^{\rm total}_{\rm R}/\sigma^{\rm SM}_{\rm R}$ as functions of $S^{1/2}$ in Fig. 3 and Fig. 4, respectively. The corrections of the TC2 dynamics to the cross section of the process $e^+e^- \to t\bar{t}$ are very large for $800\,{\rm GeV} \leq S^{1/2} \leq 1500\,{\rm GeV}$. For $S^{1/2} = 500\,{\rm GeV}$, we have $\delta\sigma^{\rm total}_{\rm L}/\sigma^{\rm SM}_{\rm L} = 18\%$ and $\delta\sigma^{\rm total}_{\rm R}/\sigma^{\rm SM}_{\rm R} = 95\%$. If it really exists, the future e^+e^- collision experiments will certainly be able to detect the effect of the TC2 dynamics on the top quark production.

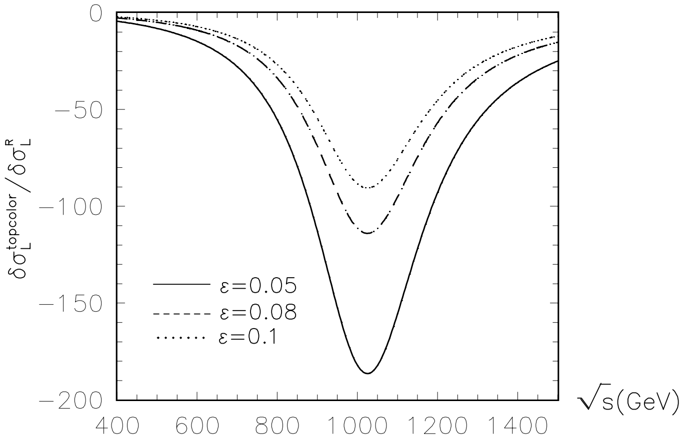

Fig. 1. The relative corrections $\delta\sigma_{\mathrm{L}}^{\mathrm{top\ color}}/\delta\sigma_{\mathrm{L}}^{R}$ versus $S^{1/2}$ for $\varepsilon = 0.05, 0.08, 0.1$

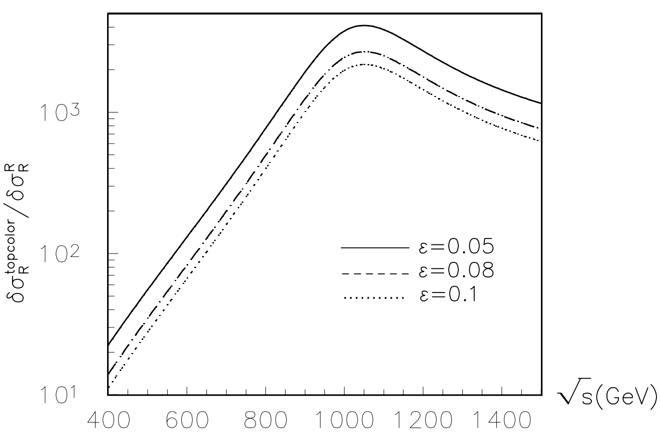

Fig. 2. The relative corrections $\delta\sigma_{\mathrm{R}}^{\mathrm{top\ color}}/\delta\sigma_{\mathrm{R}}^{R}$ versus $S^{1/2}$ for $\varepsilon = 0.05, 0.08, 0.1$

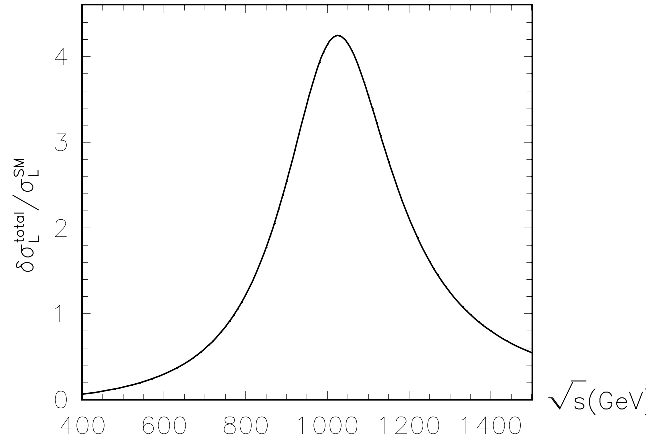

Fig. 3. The relative correction $\delta\sigma_{\mathrm{L}}^{\mathrm{total}}/\sigma_{\mathrm{L}}^{\mathrm{SM}}$ versus $S^{1/2}$ for $\varepsilon = 0.08$

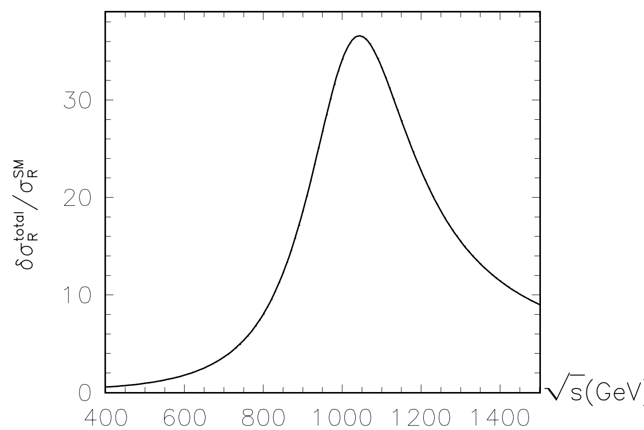

Fig. 4. The relative correction $\delta\sigma_{\mathrm{R}}^{\mathrm{total}}/\sigma_{\mathrm{R}}^{\mathrm{SM}}$ versus $S^{1/2}$ for $\varepsilon = 0.08$

4 The corrections of the TC2 dynamics to the polarized parameters $P_{\mathrm{L}}^{t}, P_{\mathrm{R}}^{t}$

At the lowest order, the cross sections $\sigma_{\mathrm{L(R)}}(+-)$, $\sigma_{\mathrm{L(R)}}(-+)$ predicted by the SM can be written as [14]

$$\begin{aligned}\sigma_{\mathrm{L(R)}}^{\mathrm{SM}}(+-) = \frac{\beta S(3+\beta^2)}{32\pi}\Bigg[\frac{4}{9}\left(\frac{e^2}{S}\right)^2 &+ \left(\frac{e^2}{S_{\mathrm{W}}^2 C_W^2}\right)^2 (g_{\mathrm{L(R)}}^{e})^2 (g_{\mathrm{R}}^{t})^2 \\ &\times \frac{1}{(S-m_Z^2)^2+m_Z^2\Gamma_Z^2} \\ &- \frac{4}{3}\frac{e^4}{S_{\mathrm{W}}^2 C_W^2} g_{\mathrm{L(R)}}^{e} g_{\mathrm{R}}^{t} \frac{S-m_Z^2}{S[(S-m_Z^2)^2+m_Z^2\Gamma_Z^2]}\Bigg],\end{aligned} \tag{20}$$

$$\begin{aligned}\sigma_{\mathrm{L(R)}}^{\mathrm{SM}}(-+) = \frac{\beta S(3+\beta^2)}{32\pi}\Bigg[\frac{4}{9}\left(\frac{e^2}{S}\right)^2 &+ \left(\frac{e^2}{S_{\mathrm{W}}^2 C_W^2}\right)^2 (g_{\mathrm{L(R)}}^{e})^2 (g_{\mathrm{L}}^{t})^2 \\ &\times \frac{1}{(S-m_Z^2)^2+m_Z^2\Gamma_Z^2} \\ &- \frac{4}{3}\frac{e^4}{S_{\mathrm{W}}^2 C_W^2} g_{\mathrm{L(R)}}^{e} g_{\mathrm{L}}^{t} \frac{S-m_Z^2}{S[(S-m_Z^2)^2+m_Z^2\Gamma_Z^2]}\Bigg].\end{aligned} \tag{21}$$

If we consider the corrections of the TC2 dynamics to $\sigma_{\mathrm{L(R)}}(+-), \sigma_{\mathrm{L(R)}}(-+)$, then the total cross sections can be written as

$$\begin{aligned}\sigma_{\mathrm{L(R)}}^{\mathrm{total}}(-+) = \frac{\beta S(3+\beta^2)}{32\pi}\Bigg[&\frac{4}{9}\left(\frac{e^2}{S}\right)^2 + \left(\frac{e^2}{S_{\mathrm{W}}^2 C_W^2}\right)^2 \\ &\times (g_{\mathrm{L(R)}}^{e})^2 (g_{\mathrm{L}}^{t} + g_{\mathrm{L}}^{t,R})^2 \frac{1}{(S-m_Z^2)^2+m_Z^2\Gamma_Z^2} \\ &+ (g_{\mathrm{L(R)}}^{e,Z'})^2 (g_{\mathrm{L}}^{t,Z'})^2 \frac{1}{(S-M_{Z'}^2)^2+M_{Z'}^2\Gamma_{Z'}^2} \\ &- g_{\mathrm{L(R)}}^{e,Z'} g_{\mathrm{L}}^{t,Z'} \frac{4e^2(S-M_{Z'}^2)}{3S[(S-M_{Z'}^2)^2+M_{Z'}^2\Gamma_{Z'}^2]} \\ &- \frac{4}{3}\frac{e^4}{S_{\mathrm{W}}^2 C_W^2} g_{\mathrm{L(R)}}^{e} (g_{\mathrm{L}}^{t} + g_{\mathrm{L}}^{t,R}) \frac{S-m_Z^2}{S[(S-m_Z^2)^2+m_Z^2\Gamma_Z^2]} \\ &+ 2 g_{\mathrm{L(R)}}^{e} g_{\mathrm{L(R)}}^{e,Z'} g_{\mathrm{L}}^{t} g_{\mathrm{L}}^{t,Z'}\end{aligned}$$

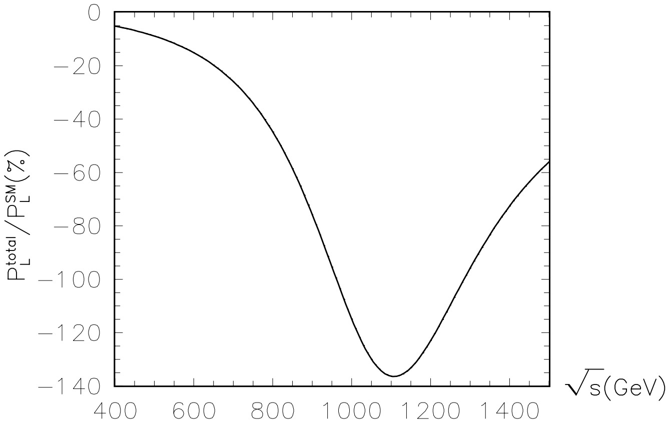

Fig. 5. The relative correction $\delta P_{\rm L}^{t,{\rm total}}/P_{\rm L}^{t,{\rm SM}}$ of the polarized parameter $P_{\rm L}^t$ versus $S^{1/2}$ for $\varepsilon = 0.08$

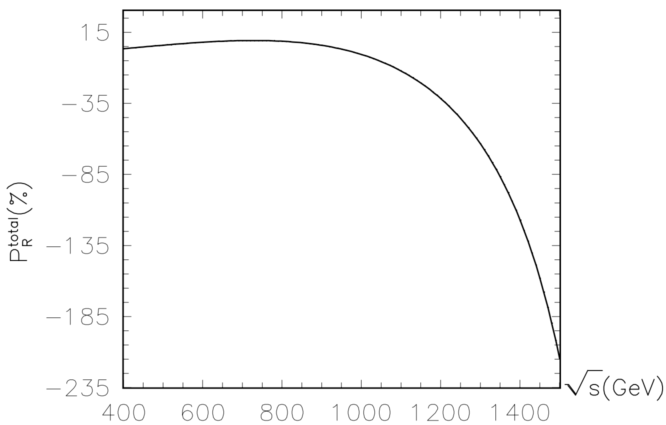

Fig. 6. The relative correction $\delta P_{\rm R}^{t,{\rm total}}/P_{\rm R}^{t,{\rm SM}}$ of the polarized parameter $P_{\rm R}^t$ versus $S^{1/2}$ for $\varepsilon = 0.08$

$$\left. \times \frac{(S-m_Z^2)(S-M_{Z'}^2)+m_Z M_{Z'}\Gamma_Z\Gamma_{Z'}}{[(S-m_Z^2)^2+m_Z^2\Gamma_Z^2][(S-m_{Z'}^2)^2+m_{Z'}^2\Gamma_{Z'}^2]}\right], \quad (22)$$

$$\begin{aligned} \sigma_{\rm L(R)}^{\rm total}(+-) = {} & \frac{\beta S(3+\beta^2)}{32\pi}\left[\frac{4}{9}\left(\frac{e^2}{S}\right)^2 \right.\\ & + \left(\frac{e^2}{S_{\rm W}^2 C_W^2}\right)^2 (g_{\rm L(R)}^e)^2 (g_{\rm R}^t + g_{\rm R}^{t,R})^2 \frac{1}{(S-m_Z^2)^2+m_Z^2\Gamma_Z^2} \\ & + (g_{\rm L(R)}^{e,Z'})^2 (g_{\rm R}^{t,Z'})^2 \frac{1}{(S-M_{Z'}^2)^2+M_{Z'}^2\Gamma_{Z'}^2} \\ & - g_{\rm L(R)}^{e,Z'} g_{\rm R}^{t,Z'} \frac{4e^2(S-M_{Z'}^2)}{3S[(S-M_{Z'}^2)^2+M_{Z'}^2\Gamma_{Z'}^2]} \\ & - \frac{4}{3}\frac{e^4}{S_{\rm W}^2 C_W^2} g_{\rm L(R)}^e (g_{\rm R}^t + g_{\rm R}^{t,R}) \frac{S-m_Z^2}{S[(S-m_Z^2)^2+m_Z^2\Gamma_Z^2]} \\ & + 2 g_{\rm L(R)}^e g_{\rm L(R)}^{e,Z'} g_{\rm R}^t g_{\rm R}^{t,Z'} \\ & \left. \times \frac{(S-m_Z^2)(S-M_{Z'}^2)+m_Z M_{Z'}\Gamma_Z\Gamma_{Z'}}{[(S-m_Z^2)^2+m_Z^2\Gamma_Z^2][(S-m_{Z'}^2)^2+m_{Z'}^2\Gamma_{Z'}^2]}\right]. \quad (23) \end{aligned}$$

Using the above equations, we can calculate the integrated polarization asymmetry parameters $P_{\rm L}^t = [\sigma_{\rm L}(-+) - \sigma_{\rm L}(+-)]/[\sigma_{\rm L}(-+) + \sigma_{\rm L}(+-)]$ and $P_{\rm R}^t = [\sigma_{\rm R}(-+) - \sigma_{\rm R}(+-)]/[\sigma_{\rm R}(-+)+\sigma_{\rm R}(+-)]$. The values of the involved parameters are taken to be the same as that of Sect. 3. To see whether the TC2 dynamics can produce significant deviations from the SM predictions of $P_{\rm L}^t$ and $P_{\rm R}^t$, we plot the diagrams for $P_{\rm L}^{t,{\rm total}}/P_{\rm L}^{t,{\rm SM}}$ and $P_{\rm R}^{t,total}/P_{\rm R}^{t,{\rm SM}}$ as functions of the center-of- mass energy $S^{1/2}$ in Fig. 5 and Fig. 6, respectively. From Fig. 5, we can see that $P_{\rm L}^{t,{\rm total}}/P_{\rm L}^{t,{\rm SM}}$ varies between -5% and -136% as $S^{1/2}$ increases from 500 GeV to 1500 GeV, which can certainly be measured at the future e^+e^- high-energy colliders. The maximum value of $|P_{\rm L}^{t,{\rm total}}/P_{\rm L}^{t,{\rm SM}}|$ occurs at $S^{1/2} \approx$ 1100 GeV which is approximately equal to 136%. For $S^{1/2} \leq 1000$ GeV, $|P_{\rm R}^{t,{\rm total}}/P_{\rm R}^{t,{\rm SM}}|$ is less than 5%, which cannot be detected at the $S^{1/2} = 500$ GeV e^+e^- collider. The correction effects of the TC2 dynamics on the polarized parameter $P_{\rm R}^t$ can be observed at the $S^{1/2} = 1500$ GeV e^+e^- collider.

5 Conclusions

TC2 theory is the only scheme known in which there is an explicit dynamical and natural mechanism for breaking electroweak symmetry and generating the fermion masses including $m_t \approx 175$ GeV. In TC2 theory, there are no elementary scalar fields and there is no unnatural or excessive fine tuning of the parameters. TC2 theory predicts two kinds of new gauge bosons; these are the ETC gauge bosons and the top color gauge bosons. These new particles can couple to the ordinary fermions. Thus, they may produce significant corrections to the physical observables. In this paper, we consider the contributions of the TC2 dynamics, which come from ETC and top color gauge bosons, to the produced cross section of the process $e^+e^- \to t\bar{t}$ in TOPCMTC model. Our calculation results show that the contributions mainly are generated by the top color gauge boson Z' in the s-channel. The total corrections of the TC2 dynamics to $\sigma_{\rm L}$ and $\sigma_{\rm R}$ are very large, which will be detected at the future NLC experiments. The total corrections to the polarized parameters $P_{\rm L}^t$ and $P_{\rm R}^t$ may be observed in most of the parameter space. We hope that these results will be of help for testing TC2 theory in the future high-energy experiments.

References

1. P.C. Bhat, H.B. Prosper, S.S. Snyder, Int. J. Mod. Phys. A **13**, 5113 (1998)
2. M.E. Peskin, in Physics and experiments with linear collider, Proceeding of the Workshop, Saarilka, Finland, 1991, edited by R. Orava, P. Eerala, M. Nordberg (World Scientific, Singapore 1992), p. 1
3. The NLC ZDR Design Group and the NLC Physics Working Group, Physics and technology of the next linear collider (Report at Snow-mass'96), BNL 52–502, Fermilab-Pub-96/112
4. S. Weiberg, Phys. Rev. D **13**, 974 (1976); D **19**, 1277 (1979); L. Susskind, ibid. D **20**, 2617 (1979)

5. S. Dimopoulos, L. Susskind, Nucl. Phys. B **155**, 237 (1979); E. Eichten, K. Lane, Phys. Lett. B **90**, 125 (1980)
6. C.T. Hill, Phys. Lett. B **345**, 483 (1995); K. Lane, E. Eichten, ibid. B **352**, 382 (1995); K. Lane, Phys. Lett. B **433**, 96 (1998)
7. Guohong Wu, Phys. Rev. Lett. **74**, 4137 (1995); Chongxing Yue, Yuping Kuang, Gongru Lu, Lingde Wan, Phys. Rev. D **52**, 5314 (1995); K. Hagiwara, N. Kitazawa, Phys. Rev. D **52**, 5374 (1995)
8. Chongxing Yue, Yuping Kuang, Gongru Lu, J. Phys G **23**, 163 (1997); U. Mahanta, Phys. Lett. B **392**, 145 (1997)
9. K. Eichten, K. Lane, Phys. Lett. B **222**, 129 (1989); K. Lane, M.V. Ramana, Phys. Rev. D **44**, 2678 (1991)
10. M.B. Popovic, E.H. Simmons, Phys. Rev. D **58**, 095007 (1998); W. Loinaz, T. Takeuchi, Phys. Rev. D **60**, 015005 (1999)
11. H. Georgi, Weak interactions and modern particle theory (Benjarmin-Cummings, Menlo Park, CH, 1984) p. 77
12. U. Mahanta, Phys. Rev. D **51**, 3557 (1995)
13. C.T. Hill, Xin-Min Zhang, Phys. Rev. D **51**, 3563 (1995)
14. F. Cuypers, S.D. Rindani, Phys. Lett. B **343**, 333 (1995); U. Mahanta, Phys. Rev. D **56**, 402 (1997)
15. J. Erler, P. Langacker, Status of the standard model, UR0816-T, hep-ph/9809352
16. C.T. Hill, S.J. Parke, Phys. Rev. D **49**, 4454 (1994)
17. G. Buchalla, G. Burdman, C.T. Hill, D. Kominis, Phys. Rev. D **53**, 5185 (1996)