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Testing Technicolor Models in Top Quark Pair Production at High Energy Photon Colliders

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Abstract

We study pseudo-Goldstone boson corrections to $\gamma\gamma \to t\bar{t}$ production rates in technicolor models with and without topcolor at the $\sqrt{s} = 0.5$ and 1.5 TeV photon colliders. We find that, for reasonable ranges of the parameters, the corrections are large enough to be observable, and the corrections in models with topcolor are considerably larger than those in models without topcolor, and they are all significantly larger than the corresponding corrections in the minimal supersymmetric standard model (MSSM) with $\tan\beta \geq 1$. So that the two kinds of technicolor models and the MSSM with $\tan\beta \geq 1$ can be experimentally distinguished.

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I. Introduction

Technicolor (TC) theory is an attractive idea of dynamical Electroweak Symmetry Breaking(EWSB) which avoids the shortcomings arising from elementary scalar fields. There are

· extended technicolor (ETC) theory to give quark and lepton masses;

· walking technicolor (WTC) or multiscale walking technicolor theory (MTC) to give small FCNC;

· topcolor-assisted technicolor (TOPCTC) theory to account for large top quark mass.

These theories all contain certain pseudo Goldstone bosons (PGB's) in the few hundred GeV region. Their virtual effects are complimentary to the direct searches for them.

The large top quark mass means that the top quark couples rather strongly to the PGB's so that the virtual effects would be more apparent in processes with the top quark than with any other light quarks. Top quark pair can be produced at various high energy colliders. Of special interest is the suggested future TeV energy photon colliders which can be realized by laser back scattering technique from e^+e^- colliders.

In this contribution, we study the PGB's one-loop virtual effects of some typical TC models in the top quark pair production via $\gamma\gamma \to t\bar{t}$. We shall take the Appelquist-Terning one-family model(AT) [1] as a typical example of the TC models without assisted by topcolor and the original TOPCTC model by Hill [2] and the top-color assisted multiscale TC model (TOPCMTC) [3].

II. $t\bar{t}$ production cross section in the one family model

We consider the Appelquist-Terning one-family model(AT) [1]. In this model, The TC group is taken to be $SU(2)_{TC}$ which minimizes the S parameter. There are 36 TC PGB's composed of weak $SU(2)_W$ doublets of techniquarks Q and technileptons L. The relevant PGB's in this study are the color-octet Π_a^0 [$SU(2)_W$- singlet] and Π_a^α [$SU(2)_W$-triplet] composed of the techniquarks Q (the color-singlet PGB's in this model are mainly composed of technileptons L, so that they are irrelevant to the $t\bar{t}$ production). The decay constants of these PGB's is $F_Q = 140$ GeV . The masses of these PGB's are model dependent [1]. The mass of Π_a^α is taken to be in the range $250\ \mathrm{GeV} < m_a^\alpha < 500\ \mathrm{GeV}$. We shall also take the mass of Π_a^0 in the same range in our calculation.

The PGB-top (bottom) interactions are take to be

$$\frac{\sqrt{2}m_t}{f_Q}(i\bar{t}\gamma_5\frac{\lambda^a}{2}t\Pi_a^0 + i\bar{t}\gamma_5\frac{\lambda^a}{2}t\Pi_a^3 + \frac{1}{\sqrt{2}}\bar{t}(1-\gamma_5)\frac{\lambda^a}{2}b\Pi_a^+ + \frac{1}{\sqrt{2}}\bar{b}(1+\gamma_5)\frac{\lambda^a}{2}t\Pi_a^-). \qquad (1)$$

All the virtual correction amplitude can be expressed as

$$\Delta M_{ij} = ie^2\epsilon^\mu(p_4)\epsilon^\nu(p_3)\bar{u}(p_2)[f_1 g_{\mu\nu} + f_2\gamma\mu\gamma_\nu + f_3 p_{1\nu}\gamma_\mu + f_4 p_{1\mu}\gamma_\nu + f_5 p_{2\nu}\gamma_\mu + f_6 p_{2\mu}\gamma_\nu + f_7 p_{1\mu}p_{1\nu} + f_8 p_{1\mu}p_{2\nu} + f_9 p_{2\mu}p_{1\nu} + f_{10}p_{2\mu}p_{2\nu} + f_{11}\not{p}_4 g_{\mu\nu} + f_{12}\not{p}_4\gamma_\mu\gamma_\nu + f_{13}\not{p}_4 p_{1\nu}\gamma_\mu + f_{14}\not{p}_4 p_{1\mu}\gamma_\nu + f_{15}\not{p}_4 p_{2\nu}\gamma_\mu + f_{16}\not{p}_4 p_{2\mu}\gamma_\nu + f_{17}\not{p}_4 p_{1\mu}p_{1\nu} + f_{18}\not{p}_4 p_{1\mu}p_{2\nu} + f_{19}\not{p}_4 p_{2\mu}p_{1\nu} + f_{20}\not{p}_4 p_{2\mu}p_{2\nu}]v(p_1)\delta_{ij}\,, \quad (2)$$

where f_n are form factors which can be expressed with loop integral functions. For detail calculations, we refer to Ref. [4].

The total cross section $\sigma(s)$ of the production of $t\bar{t}$ in $\gamma\gamma$ collisions is obtained by folding the elementary cross section $\sigma(\hat{s})$ for the subprocess $\gamma\gamma \to t\bar{t}$ with the photon luminosity at the e^+e^- collider, i.e.

$$\sigma(s) = \int_{2m_t/\sqrt{s}}^{x_{max}} dz \frac{dL_{\gamma\gamma}}{dz}\sigma(\hat{s}) \quad (\gamma\gamma \to t\bar{t} \text{ at } \hat{s} = z^2 s)\,, \quad (3)$$

where $\sqrt{s}(\sqrt{\hat{s}})$ is the $e^+e^-(\gamma\gamma)$ center-of -mass energy and $dL_{\gamma\gamma}/dz$ is the photon luminosity defined as

$$\frac{dL_{\gamma\gamma}}{dz} = 2z\int_{z^2/x_{max}}^{x_{max}} \frac{dx}{x} F_{\gamma/e}(x)F_{\gamma/e}(z^2/x)\,. \quad (4)$$

The following cuts on the rapidity y and the transverse momentum p_T are taken in all the calculations:

$$|y| < 2.5, \qquad p_T > 20 \text{ GeV}\,. \quad (5)$$

We take $m_t = 176$ GeV, $m_b = 4.9$ GeV, and we take $\alpha_{em}(m_Z^2) = 1/128.8$ with the one-loop running formula to determine the electromagnetic fine structure constant α_{em} at the desired scale. The result of the tree-level cross sections are

$\sigma_0 = 57.77$ fb for $\sqrt{s} = 0.5$ TeV;

$\sigma_0 = 535.4$ fb for $\sqrt{s} = 1.5$ TeV.

To see the main feature of the TC PGB corrections to the cross section, we simply take $m_{\Pi_a^0} = m_{\Pi_a^3} = m_{\Pi_a^\pm} \equiv m_{\Pi_a}$ to calculate the correction $\Delta\sigma$. We find that for $\sqrt{s} = 0.5$ TeV, the relative correction $\Delta\sigma/\sigma_0$ is of the order of ten percent(cf. Table I.) which is about one order of magnitude larger than that in the MSSM with $\tan\beta \geq 1$ (which is about one percent [5]). For $\sqrt{s} = 1.5$ TeV, the relative corrections are around $(4-10)\%$ which is also larger than that in the MSSM with $\tan\beta \geq 1$.

For estimating the event rates, we take an integrated luminosity of

$$\int \mathcal{L}dt = 50 \text{ fb}^{-1}, \quad \text{for } \sqrt{s} = 0.5 \text{ TeV}\,,$$
$$\int \mathcal{L}dt = 100 \text{ fb}^{-1}, \quad \text{for } \sqrt{s} = 1.5 \text{ TeV}\,, \quad (6)$$

which corresponds to a one year run at the NLC. There will be about 2500 events for $\sqrt{s} = 0.5$ TeV and 25000 events for $\sqrt{s} = 1.5$ TeV. The statistical uncertainty at 95% C.L. is then around 4% for $\sqrt{s} = 0.5$ TeV and 1.2% for $\sqrt{s} = 1.5$ TeV. Therefore *this model can be experimentally distinguished from the MSSM model with* $\tan\beta \geq 1$ *in* $\gamma\gamma \to t\bar{t}$ *at the future photon collider.*

III. $t\bar{t}$ Production cross sections in TOPCTC Models

1. The Original TOPCTC Model [2]

For TOPCTC models, we first consider the original TOPCTC model proposed by Hill [2]. In this model, there are 60 TC PGB's in the TC sector with the decay constant $f_\Pi = 120$ GeV and three top-pions Π_t^0 , $\Pi_t^\pm$ in the topcolor sector with the decay constant $f_{\Pi_t} = 50$ GeV [2]. The top quark mass m_t is mainly provided by the topcolor sector, while the TC sector only provide a small portion of it, say $m_t' \sim 5 - 24$ GeV [2]. The mass of the top-pion depends on a parameter in the model [2]. For reasonable values of the parameter, m_{Π_t} is around 200 GeV [2]. The prediction of the light top-pion is the characteristic feature of the TOPCTC models and this is the main difference between this kind of models and TC models without topcolor. In the following calculation, we would rather take a slightly larger range, 180 GeV $\leq m_{\Pi_t} \leq$ 300 GeV, to see its effect, and we shall take the masses of the color-singlet TC PGB's to vary in the range $100 - 325$ GeV.

The color-octet TC PGB-top (bottom) interactions are similar to Eq.(1) but with m_t replaced by m_t' and f_Q replaced by f_Π, i.e.

$$\frac{\sqrt{2}m_t'}{f_\Pi}(i\bar{t}\gamma_5\frac{\lambda^a}{2}t\Pi_a^0 + i\bar{t}\gamma_5\frac{\lambda^a}{2}t\Pi_a^3 + \frac{1}{\sqrt{2}}\bar{t}(1-\gamma_5)\frac{\lambda^a}{2}b\Pi_a^+ + \frac{1}{\sqrt{2}}\bar{b}(1+\gamma_5)\frac{\lambda^a}{2}t\Pi_a^-)\,. \tag{7}$$

The color-singlet TC PGB-top (bottom) interactions are

$$\frac{c_t m_t'}{\sqrt{2}f_\Pi}(i\bar{t}\gamma_5 t\Pi^0 + i\bar{t}\gamma_5 t\Pi^3 + \frac{1}{\sqrt{2}}\bar{t}(1-\gamma_5)b\Pi^+ + \frac{1}{\sqrt{2}}\bar{b}(1+\gamma_5)t\Pi^-)\,, \tag{8}$$

where $c_t = \frac{1}{\sqrt{6}}$. The interactions between the top-pions and the top (bottom) quark are

$$\frac{m_t - m_t'}{\sqrt{2}f_{\Pi_t}}(i\bar{t}\gamma_5 t\Pi_t^0 + \frac{1}{\sqrt{2}}\bar{t}(1-\gamma_5)b\Pi_t^+ + \frac{1}{\sqrt{2}}\bar{b}(1+\gamma_5)t\Pi_t^-)\,. \tag{9}$$

The color-singlet TC PGB's and the top-pions can also couple to the two photons via triangle fermion loops. The general form of the effective $\Pi - B_1$-B_2 interaction (Π denotes the PGB's Π^0, Π^3, B_1 and B_2 are gauge fields) is

$$\frac{1}{(1+\delta_{B_1B_2})}\left(\frac{S_{\Pi B_1 B_2}}{4\sqrt{2}\pi^2 F_\Pi}\right)\Pi\epsilon_{\mu\nu\lambda\rho}(\partial^\mu B_1^\nu)(\partial^\lambda B_2^\rho)\,. \tag{10}$$

where for the technifermion loops

$$S_{\Pi^0\gamma\gamma} = \frac{-4e^2}{3\sqrt{6}}N_{TC}\,, \tag{11}$$

$$S_{\Pi^3\gamma\gamma} = \frac{4e^2}{\sqrt{6}}N_{TC}\,. \tag{12}$$

This interaction gives resonant effects if $m_\Pi > 2m_t$.

The results of this model are shown Table II. We find that the cross section correction are considerably larger than those in the AT model. This is because of the large top pion contributions. Taking the integrated luminosity in the above, we have around 1000 events for $\sqrt{s} = 0.5$ TeV and around 40000 events for $\sqrt{s} = 1.5$ TeV. The corresponding statistical uncertainties at the 95% C.L. are then 6% and 1%, respectively. We get the conclusion that *this model is experimentally distinguishable from the Appelquist-Terning model and the MSSM with* $\tan\beta \geq 1$ *in* $\gamma\gamma \to t\bar{t}$.

2. The TOPCMTC Model [3]

In this model, the technicolor sector is multiscale. It is different from the original TOPCTC model mainly by the change of the TC sector in which $f_\Pi = 40$ GeV instead of the original $f_\Pi = 120$ GeV, and [3]

$$c_t = \frac{2}{\sqrt{6}}, \tag{13}$$

$$S_{\Pi^0\gamma\gamma} = \frac{10e^2}{3\sqrt{6}} N_{TC}, \tag{14}$$

$$S_{\Pi^3\gamma\gamma} = \frac{2e^2}{\sqrt{6}} N_{TC}. \tag{15}$$

The corresponding results is presented in Table III. For $\sqrt{s} = 0.5$ TeV, the results of this model are close to those in the original TOPCTC model. For $\sqrt{s} = 1.5$ TeV, the corrections are much larger than those in the original TOPCTC model, especially with large m_t'. From the results we conclude that *even the difference between the original TOPCTC model and the TOPCMTC model can be clearly observed in the* $\gamma\gamma \to t\bar{t}$ *experiment at the* $\sqrt{s} = 1.5$ *TeV photon collider.*

Table I. TC PGB corrections to the $\gamma\gamma \to t\bar{t}$ cross section $\Delta\sigma$, the relative correction $\Delta\sigma/\sigma_0$, and the total cross section $\sigma = \sigma_0 + \Delta\sigma$ for various values of m_{Π_a} in the Appelquist-Terning model ($\sigma_0 = 57.77$ fb for $\sqrt{s} = 0.5$ TeV, $\sigma_0 = 535.4$ fb for $\sqrt{s} = 1.5$ TeV).

	$\sqrt{s} = 0.5$ TeV			$\sqrt{s} = 1.5$ TeV		
m_{Π^a} (GeV)	$\Delta\sigma$ (fb)	$\Delta\sigma/\sigma_0(\%)$	σ (fb)	$\Delta\sigma$ (fb)	$\Delta\sigma/\sigma_0(\%)$	σ (fb)
250	-9.11	-15.8	48.66	-50.77	-9.5	484.6
275	-8.22	-14.2	49.55	-43.81	-8.2	491.6
300	-7.47	-12.9	50.30	-37.76	-7.1	497.6
325	-6.83	-11.8	50.94	-33.82	-6.3	501.6
350	-6.28	-10.9	51.49	-30.56	-5.7	504.8
375	-5.80	-10.0	51.97	-28.62	-5.3	506.8
400	-5.38	-9.3	52.39	-26.71	-5.0	508.7
425	-5.02	-8.7	52.75	-25.16	-4.7	510.2
450	-4.69	-8.1	53.08	-23.76	-4.4	511.6
475	-4.40	-7.6	53.37	-22.50	-4.2	512.9
500	-4.13	-7.1	53.64	-21.62	-4.0	513.8

Table II. Total TC PGB and top-pion contributions from Fig.1(a)-(p) to the $\gamma\gamma \to t\bar{t}$ production cross section $\Delta\sigma$ and the total production cross section $\sigma = \sigma_0 + \Delta\sigma$ in the original TOPCTC model ($N_{TC} = 4$, $\sigma_0 = 57.77$ fb for $\sqrt{s} = 0.5$ TeV, $\sigma_0 = 535.4$ fb for $\sqrt{s} = 1.5$ TeV,).

	$\sqrt{s} = 0.5$ TeV				$\sqrt{s} = 1.5$ TeV			
m_{Π_t} (GeV)	$m_t' = 5$ GeV		$m_t' = 20$ GeV		$m_t' = 5$ GeV		$m_t' = 20$ GeV	
	$\Delta\sigma$ (fb)	σ (fb)	$\Delta\sigma$ (fb)	σ (fb)	$\Delta\sigma$ (fb)	σ (fb)	$\Delta\sigma$ (fb)	σ (fb)
180	-41.96	15.81	-38.53	19.24	-179.5	355.9	-154.7	380.7
200	-37.70	20.07	-35.13	22.64	-145.3	390.1	-125.3	410.1
225	-40.53	17.24	-38.04	19.73	-123.9	411.5	-108.2	427.2
250	-41.27	16.50	-39.68	18.09	-113.8	421.6	-99.3	436.1
275	-40.34	17.43	-40.87	16.90	-107.0	428.4	-96.1	439.3
300	-33.37	22.40	-38.97	18.80	-101.9	433.5	-94.2	441.2

Table III. Total TC PGB and top-pion contributions from Fig.1(a)-(p) to the $\gamma\gamma \to t\bar{t}$ production cross section $\Delta\sigma$ and the total production cross section $\sigma = \sigma_0 + \Delta\sigma$ in the TOPCMTC model ($N_{TC} = 4$, $\sigma_0 = 57.77$ fb for $\sqrt{s} = 0.5$ TeV, $\sigma_0 = 535.4$ fb for $\sqrt{s} = 1.5$ TeV).

$\sqrt{s} = 0.5$ TeV								
m_{Π^0,Π^3}	$m_t' = 5$ GeV				$m_t' = 20$ GeV			
	$m_{\Pi_t} = 180$ GeV		$m_{\Pi_t} = 250$ GeV		$m_{\Pi_t} = 180$ GeV		$m_{\Pi_t} = 250$ GeV	
	$\Delta\sigma$ (fb)	σ (fb)	$\Delta\sigma$ (fb)	σ (fb)	$\Delta\sigma$ (fb)	σ (fb)	$\Delta\sigma$ (fb)	σ (fb)
100	-42.88	14.89	-41.35	16.42	-42.92	14.85	-41.30	16.47
150	-42.95	14.82	-41.33	16.44	-43.03	14.74	-41.12	16.65
200	-43.06	14.71	-41.29	16.48	-43.06	14.71	-40.63	17.14
250	-43.23	14.54	-41.17	16.60	-42.54	15.23	-39.07	18.70
300	-43.43	14.34	-40.51	17.26	-38.11	19.66	-32.19	25.58
325	-43.24	14.53	-39.30	18.47	-26.16	31.61	-17.22	40.55
$\sqrt{s} = 1.5$ TeV								
m_{Π^0,Π^3}	$m_t' = 5$ GeV				$m_t' = 20$ GeV			
	$m_{\Pi_t} = 180$ GeV		$m_{\Pi_t} = 250$ GeV		$m_{\Pi_t} = 180$ GeV		$m_{\Pi_t} = 250$ GeV	
	$\Delta\sigma$ (fb)	σ (fb)	$\Delta\sigma$ (fb)	σ (fb)	$\Delta\sigma$ (fb)	σ (fb)	$\Delta\sigma$ (fb)	σ (fb)
100	-201.2	334.2	-136.9	398.5	-218.3	317.1	-166.7	368.7
150	-201.8	333.6	-137.7	397.7	-218.3	317.1	-166.1	369.3
200	-203.4	332.0	-138.2	397.2	-219.3	316.1	-166.9	368.5
250	-204.3	331.1	-139.0	396.4	-220.0	315.4	-167.2	368.2
300	-206.7	328.7	-140.8	394.6	-219.9	315.5	-166.0	369.4
325	-207.1	328.3	-141.3	394.1	-212.7	322.7	-157.8	377.6

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