Testing Technicolor Models via Top Quark Pair Production in High Energy Photon Collisions

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Pseudo-Goldstone boson contributions 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 and hadron colliders are reviewed. For reasonable ranges of the parameters, the contributions are large enough to be experimentally observable. Models with topcolor, without topcolor and the MSSM with $\tan\beta \geq 1$ can be experimentally distinguished.

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 multi-scale 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. Testing their virtual effects are complimentary to the direct searches for them.

The top quark couples strongly to the PGB’s due to its large mass, 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.

The PGB’s one-loop virtual effects of some typical TC models in the top quark pair production via $\gamma\gamma \to t\bar{t}$ have been studied in Ref. \cite{1} in which the Appelquist-Terning one-family model (AT) \cite{2} was taken as a typical example of the TC models without assisted by topcolor; the original TOPCTC model by Hill \cite{3} and the top-color assisted multiscale TC model (TOPCMTC) \cite{4} were taken as typical models assisted by topcolor. For the TOPCMTC, the resonance contributions of the neutral PGB’s to $t\bar{t}$ production at hadron colliders have been studied in Ref. \cite{5}.

Here we give a brief review of these studies.

II. PGB corrections to $t\bar{t}$ production at photon colliders in the one family model

We consider the Appelquist-Terning one-family model (AT) \cite{2}. 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 $\Pi_0^a$ [$SU(2)_W$ singlet] and $\Pi_3^a$ [$SU(2)_W$ triplet] composed of the techniquarks $Q$ (the colorsinglet 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 \cite{2}. The mass of $\Pi_3^a$ is taken to be in the range 250 GeV $< m_{\Pi_3^a} < 500$ GeV. We also take the mass of $\Pi_0^a$ in the same range in our calculation.

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.
\[ \sigma(s) = \int_{2m_t/\sqrt{s}}^{x_{\text{max}}} \frac{dL_{\gamma\gamma}}{dz} \sigma(\hat{s}) , \]

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

\[ \frac{dL_{\gamma\gamma}}{dz} = 2z \int_{z/\hat{s}_{\text{max}}}^{x_{\text{max}}} \frac{dx}{x} F_{\gamma/e}(x) F_{\gamma/e}(z^2/x) . \]

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

\[ |y| < 2.5, \quad p_T > 20 \text{ GeV} . \]

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

\[ \sigma_0 = 57.77 \text{ fb for } \sqrt{s} = 0.5 \text{ TeV} ; \]
\[ \sigma_0 = 535.4 \text{ fb for } \sqrt{s} = 1.5 \text{ TeV} . \]

To see the main feature of the TC PGB contributions to the cross section, we simply take \( m_{\Pi^0} = m_{\Pi^0_t} = m_{\Pi^0_b} \equiv m_{\Pi^0} \) to calculate the correction \( \Delta \sigma \). We find that for \( \sqrt{s} = 0.5 \text{ TeV} \), the relative correction \( \Delta \sigma/\sigma_0 \) is of the order of 10\% which is about one order of magnitude larger than that in the MSSM with \( \tan \beta \geq 1 \) (which is about one percent \( \beta \)). For \( \sqrt{s} = 1.5 \text{ TeV} \), 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

\[ \int \mathcal{L} dt = 50 \text{ fb}^{-1}, \quad \text{for } \sqrt{s} = 0.5 \text{ TeV} , \]
\[ \int \mathcal{L} dt = 100 \text{ fb}^{-1}, \quad \text{for } \sqrt{s} = 1.5 \text{ TeV} , \]

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

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

1. The Original TOPCTC Model \[ \]

For TOPCTC models, we first consider the original TOPCTC model proposed by Hill \[ \]. In this model, there are 60 TC PGB’s in the TC sector with the decay constant \( f_{\Pi} = 120 \text{ GeV} \) and three topions \( \Pi^0, \Pi^\pm \) in the topcolor sector with the decay constant \( f_{\Pi_t} = 50 \text{ GeV} \[ \]. 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 \text{ GeV} \[ \). The mass of the top-pion depends on a parameter in the model \[ \]. For reasonable values of the parameter, \( m_{\Pi_t} \) is around 200 GeV \[ \]. 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 \( m_{\Pi_t} \leq 300 \text{ GeV} \[ \), to see its effect, and we shall take the masses of the color- singlet TC PGB’s to vary in the range \( 100 – 325 \text{ GeV} \). We find that the cross section correction in photon colliders 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 \( \sqrt{s} = 0.5 \text{ TeV} \) and around 40000 events for \( \sqrt{s} = 1.5 \text{ TeV} \). The corresponding statistical uncertainties at the 95\% C.L. are then 6\% and 1\%, respectively. We get the conclusion that \( \text{this model is experimentally distinguishable from the Appelquist-Terning model and the MSSM with } \tan \beta \geq 1 \text{ in } \gamma\gamma \rightarrow t\bar{t} \).\]

2. The TOPCMTC Model \[ \]
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.

For $\sqrt{s} = 0.5$ TeV, the results of this model at photon colliders 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 $m_{\prime}$. From the results we conclude that even the difference between the original TOPCTC model and the TOPCMTC model can be clearly observed in the $\gamma\gamma \rightarrow t\bar{t}$ experiment at the $\sqrt{s} = 1.5$ TeV photon collider.

The PGB corrections to $t\bar{t}$ production at the Fermilab Tevatron and the CERN LHC in this model are also studied [5] (for other models, see Ref. [7]). We find that the Tevatron experimental results can give constrains on the parameters. At the LHC, the resonance peaks in the production are significant. Even though we can obtain much more better statistical errors at the LHC, the systematic error of the cross section is about 5%. Whether it is possible to distinguish the different TC models at the LHC is under investigation.

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Reference

1. Hong-Yi Zhou, Yu-Ping Kuang, Chong-Xing Yue, Hua Wang, Gong-Ru Lu, Phys. Rev. D 57 (1998) 4205.
2. T. Appelquist and J. Terning, Phys. Lett. B315 (1993) 139.
3. C. T. Hill, Phys. Lett. B345 (1995) 483; K. Lane and E. Eichten, Phys. Lett. B352 (1995) 382; G. Buchalla, G. Burdman, C. T. Hill and D. Kominis, Phys. Rev. D53 (1996) 5185, FERMILAB-PUB-95/322-T.
4. K. Lane, Phys. Lett. B357, (1995) 624.
5. Chong-Xing Yue, Hong-Yi Zhou, Yu-Ping Kuang, Gong-Ru Lu, Phys. Rev. D 55 (1997) 5541.
6. C.-S. Li, J.-M. Yang, Y.-L. Zhu, and H.-Y. Zhou, Phys. Rev. D54 (1996) 4662; H. Wang, C.-S. Li, H.-Y. Zhou, and Y.-P. Kuang, Phys. Rev. D54 (1996) 4374.
7. E. Eichten and K. Lane, Phys. Lett. B327 (1994) 129; G.L. Lu, Y. Hua, J.M. Yang, and X.L. Wang, Phys. Rev. D 54 (1996) 1083.