
AI translation · View original & related papers at
chinaxiv.org/items/chinaxiv-201612.00369

Production of $h t$ anti- t and $h t$ anti- T in littlest Higgs model with T-parity postprint

Authors: Wang, L, Wang,W, Yang,JM, Zhang,H

Date: 2016-12-28T00:00:00+00:00

Abstract

In the littlest Higgs model with T-parity, which predicts a pair of T-even and T-odd partners for the top quark, the top quark interactions are altered with respect to the Standard Model predictions and deviation will manifest in various top quark process

Full Text

Preamble

hep-ph/0609200 Production of $ht\bar{t}$ and $ht\bar{T}$ in littlest Higgs model with T-parity
Lei Wang¹, Wenyu Wang¹, Jin Min Yang^{2,1}, Huanjun Zhang^{3,1}

Abstract

In the littlest Higgs model with T-parity, which predicts a pair of T-even and T-odd partners for the top quark, the top quark interactions are altered with respect to the Standard Model predictions and deviations will manifest in various top quark processes. In this work we examine the effects in $ht\bar{t}$ productions at the ILC and LHC. We find that in the allowed parameter space, the cross sections can be significantly deviated from the Standard Model predictions and thus provide a good test for the littlest Higgs model with T-parity. We also examine the new production channel, the $ht\bar{T}$ or $hT\bar{t}$ production, at the LHC, which gives the same final states as $ht\bar{t}$ production due to the dominant decay $T \rightarrow Wb$. We find that, compared with $ht\bar{t}$ production, this new production channel can have a sizable production rate for a T-quark below the TeV scale. Such production will be counted into $ht\bar{t}$ events or possibly extracted from $ht\bar{t}$ events, depending on whether we can distinguish the T-quark from the top quark through mass reconstruction.

PACS numbers: 14.65.Ha, 14.80.Ly

Introduction

To solve the fine-tuning problem of the Standard Model (SM), the little Higgs theory [?] was proposed as a kind of electroweak symmetry breaking mechanism accomplished by a naturally light Higgs sector. The Higgs boson remains light, being protected by the approximate global symmetry and free from one-loop quadratic sensitivity to the cutoff scale. The littlest Higgs model [?] provides an economical approach which implements the idea of the little Higgs theory. Most of the constraints from the electroweak precision tests on little Higgs models [?] come from the tree-level mixing of heavy and light mass eigenstates, which would require raising the mass of the new particles to be much higher than the TeV scale and thus reintroduce the fine-tuning in the Higgs potential [?]. However, these tree-level contributions can be avoided by introducing a discrete symmetry called T-parity [?]. In such a scenario, the top quark has a T-even partner (denoted as T) and a T-odd partner (denoted as T_-). As a result, the top quark interactions are altered with respect to the SM predictions, which will manifest in various top quark processes. In this work, we will examine such effects in the associated $ht\bar{t}$ productions at the LHC and ILC, and also study the $ht\bar{T}$ and $hT\bar{t}$ productions at the LHC (due to the heaviness of the T-quark, $ht\bar{T}$ is beyond the threshold of the ILC).

The reason for studying $ht\bar{t}$ production as a test of the littlest Higgs model with T-parity is obvious. Firstly, the large top quark Yukawa coupling is speculated to be sensitive to new physics and the $ht\bar{t}$ productions may be a sensitive probe of the littlest Higgs model with T-parity. In this model the top quark Yukawa coupling has a deviation from the SM prediction, which will affect the $ht\bar{t}$ productions. Also the T-quark can contribute to the $ht\bar{t}$ productions through its virtual effects. Secondly, $ht\bar{t}$ production will be first searched at the LHC and can be precisely measured at the ILC [?, ?]. At the ILC the top-quark Yukawa coupling can be measured with an accuracy of about 5% through the production of $ht\bar{t}$ [?] and the polarized beams can further improve the measurement precision [?]. The precision measurements of $ht\bar{t}$ production make it possible to unravel the new physics effects in this process.

In addition, the new production channel at the LHC, the $ht\bar{T}$ or $hT\bar{t}$ productions, should also be considered since they give the same final states as $ht\bar{t}$ production due to the dominant decay $T \rightarrow Wb$. As will be shown from our study, compared with $ht\bar{t}$ production, this new production channel can have a sizable production rate for a T-quark below the TeV scale. Such production will be counted into $ht\bar{t}$ events or possibly extracted from $ht\bar{t}$ events, depending on whether we can distinguish the T-quark from the top quark through mass reconstruction.

This work is organized as follows. In Sec. II we recapitulate the littlest Higgs model with T-parity. In Sec. III and Sec. IV we study the $ht\bar{t}$ productions at the ILC and LHC, respectively. In Sec. V we study the new $ht\bar{T}$ or $hT\bar{t}$ production channel at the LHC. Finally, we give our conclusion in Sec. VI.

II. About Littlest Higgs Model with T-Parity

Before our calculations we recapitulate the littlest Higgs model with T-parity [?, ?]. The gauge sector of this model can be simply obtained from the usual littlest Higgs model [?]. T-parity acts as an automorphism which exchanges the $[SU(2) \times U(1)]_1$ and $[SU(2) \times U(1)]_2$ gauge factors. Before electroweak symmetry breaking, the gauge boson mass eigenstates have the simple form $W_{\pm}^{\alpha} = (W_1^{\alpha} \pm W_2^{\alpha})/\sqrt{2}$, $B_{\pm} = (B_1 \pm B_2)/\sqrt{2}$, where W_j^{α} and B_j are $SU(2)_j$ and $U(1)_j$ ($j = 1, 2$) gauge fields. W_{\pm}^{α} and B_{\pm} are the SM gauge bosons and have even T-parity, whereas W_{\pm}^{α} and B_{\pm} are additional heavy gauge bosons and have odd T-parity. After electroweak symmetry breaking, the new mass eigenstates in the neutral heavy sector will be a linear combination of W_{\pm}^{α} and B_{\pm} gauge bosons, producing B_H and Z_H . The B_H is typically the lightest T-odd state and may be a candidate for dark matter. Due to T-parity, the new gauge bosons do not mix with the SM gauge bosons and thus generate no corrections to precision electroweak observables at tree level.

The top quark sector contains a T-even and T-odd partner, with the T-even one mixing with the top quark and canceling the quadratic divergence contribution of the top quark to the Higgs boson mass. The masses of the T-even partner (denoted as T) and the T-odd partner (denoted as T_{-}) are given by

$$m_T \approx \frac{\sqrt{2}m_t f}{v} \sqrt{1+r^2}, \quad m_{T_{-}} \approx m_T s_{\lambda},$$

where v is the electroweak breaking scale ($v = 246$ GeV), $r = \lambda_1/\lambda_2$ with λ_1 and λ_2 being the coupling constants in the Lagrangian of the top quark sector [?, ?, ?], and $s_{\lambda} = 1/\sqrt{1+r^2}$.

The mixing of the T-quark with the top quark will alter the SM top quark couplings and induce couplings between t and T [?, ?], which are given by

$$V_{ht\bar{T}} = -\frac{m_t}{v} \left[\frac{2s_W c_W}{f^2} - \frac{3+2r^2+3r^4}{4(1+r^2)^2} \right] \gamma^{\mu} P_L,$$

$$Z_{t\bar{T}} = Z_{t\bar{t}} = \frac{e}{s_W c_W} \left(\frac{v^2}{f^2} \right) \gamma^{\mu} P_L,$$

$$V_{ht\bar{t}} = -\frac{m_t}{v} \left[1 - \frac{v^2}{f^2} \left(\frac{3+2r^2+3r^4}{4(1+r^2)^2} \right) \right],$$

where $P_{R,L} = (1 \pm \gamma_5)/2$ and $c_{\lambda} = r/\sqrt{1+r^2}$. The hZZ coupling involved in our calculations will also be different from the SM coupling, which is given by

$$hZZ = \frac{2m_Z^2}{v} \left(1 - \frac{v^2}{f^2} \right).$$

In the littlest Higgs model with T-parity, the T-quark can decay into Wb , ht , Zt and $B_H T_{-}$, among which the decay $T \rightarrow Wb$ is the most important channel

[?]. As shown in Fig. 12 [Figure 12: see original paper] of [?], $BR(T \rightarrow Wb)$ is over 46% for $r = 1.0$ and $m_T = 500$ GeV, and can be over 50% when f is 2 TeV. For comparison, the subdominant decay $T \rightarrow ht$ can have a branching ratio of about 20% at most in the parameter space for $r = 1.0$ and $m_T = 2$ TeV.

III. Production of $ht\bar{t}$ at ILC

Now we examine the process $e^+e^- \rightarrow t\bar{t}h$ in the littlest Higgs model with T-parity. The Feynman diagrams are shown in Fig. 1 [Figure 1: see original paper]. In the SM it proceeds mainly through the s-channel γ and Z exchange diagrams with the Higgs boson radiated from the top quark, as shown in Fig. 1(a,b). Although a contribution can also come from the diagram Fig. 1(e) with the Higgs boson radiated from the gauge boson Z , such a contribution is relatively small. In the littlest Higgs model with T-parity we have additional diagrams Fig. 1(c,d) mediated by the T-quark. Due to T-parity, other new particles such as the heavy gauge bosons Z_H and B_H do not participate in this process.

We calculate the cross section numerically by Monte Carlo simulation. The cross section in the littlest Higgs model with T-parity depends on two free parameters: the symmetry breaking scale f and the ratio $r = \lambda_1/\lambda_2$. Considering the electroweak precision constraints [?], we vary them in the range $0.5 \text{ TeV} < f < 2 \text{ TeV}$. The SM parameters involved are taken as $m_t = 172.7$ GeV [?], $m_h = 120$ GeV, $\alpha_{EW} = 1/128.8$, $\sin^2 \theta_W = 0.2315$, and $m_Z = 91.187$ GeV [?].

The center-of-mass energy is assumed to be 800 GeV. Considering the polarization of the initial electron and positron beams, the cross section of $e^+e^- \rightarrow t\bar{t}h$ is given by [?]

$$\sigma = \frac{1}{4}[(1+p_e)(1+\bar{p}_e)\sigma_{RR} + (1+p_e)(1-\bar{p}_e)\sigma_{RL} + (1-p_e)(1+\bar{p}_e)\sigma_{LR} + (1-p_e)(1-\bar{p}_e)\sigma_{LL}],$$

where σ_{RL} is the cross section for right-handed e^- beam ($p_e = +1$) and left-handed e^+ beam ($\bar{p}_e = -1$), and the other cross sections σ_{RR} , σ_{LL} and σ_{LR} are defined analogously. As in [?], we assume $p_e = 0.8$ and $\bar{p}_e = 0.6$ in our calculations.

In Fig. 2 [Figure 2: see original paper] we plot contours for the deviation from the SM cross section in the plane of r versus the symmetry breaking scale f . For comparison we also show the corresponding results for unpolarized beams. We see that the polarized beams lead to more sizable deviations and thus make the collider more powerful in probing such new physics effects. Fig. 2 shows that the contributions of this model decrease the SM cross section in the allowed parameter space, and the magnitude of such correction depends on the parameters r and f . The corrections are more sizable for lower values of the scale f , and in a large part of the parameter space the contributions can alter the SM cross section by over 5%. When f is lower than 1 TeV, the corrections can be over 10% in magnitude.

So far the electroweak precision data have constrained the parameter space of r and f . But, as studied in [?], such constraints depend on additional parameters, i.e., the masses of extra T-odd fermions and the parameter δ_c whose value is dependent on the details of the UV physics. Therefore, we did not show these electroweak precision constraints in Fig. 2.

Another remarkable feature of our results is that the corrections are very sensitive to the scale f , but not so sensitive to the parameter r when r is larger than about 2, as shown in Fig. 2. This means that we can use this process to determine or constrain the scale f if r is large.

In Fig. 2 we also plotted the 2σ statistical significance, obtained by assuming a luminosity of 1000 fb^{-1} and an efficiency of 10% for event counting (due to kinematical cuts and b-tagging, etc.). We see that a large part of parameter space is within the 2σ statistical sensitivity. Of course, we should note that some inevitable systematic error will worsen the probing limits. Detector-dependent Monte Carlo simulations are necessary in order to determine the more practical probing limits.

Note that in the littlest Higgs model without T-parity, the new neutral gauge bosons Z_H and B_H can also contribute to the process $e^+e^- \rightarrow t\bar{t}h$ at tree-level via s-channel resonances [?]. In this case, the large values of f required by the precision electroweak data suppress the contributions of these new particles and, as a result, the T-quark effects are very small. However, in the littlest Higgs model with T-parity considered in this work, T-parity forbids the tree-level contributions of the new gauge bosons Z_H and B_H to the process since they are T-odd. Thus in this scenario only the T-quark with even T-parity can contribute to the process at tree-level and, due to the relaxed constraint on f (as low as 500 GeV is still allowed), such T-quark effects may be sizable. (However, we note that there is an alternative implementation of T-parity [?], in which all new particles which cancel the quadratic divergence of the Higgs mass are T-odd, including the top-quark sector. Thus, there is no T-quark with even T-parity, and the T-quarks cannot contribute to the process $h\bar{t}t$ at tree-level.)

IV. Production of $h\bar{t}t$ at LHC

The production of $h\bar{t}t$ at the LHC can proceed through gg fusion or $q\bar{q}$ annihilation, as shown in Fig. 3 [Figure 3: see original paper]. In the littlest Higgs model with T-parity the $h\bar{t}t$ coupling is different from the SM prediction, as shown in Eq. (6). This will cause a correction to the production cross section

$$\sigma_{h\bar{t}t} = \sigma_{h\bar{t}t}^{\text{SM}} \left| \frac{V_{h\bar{t}t}}{V_{h\bar{t}t}^{\text{SM}}} \right|^2,$$

where $V_{h\bar{t}t}^{\text{SM}}$ and $V_{h\bar{t}t}$ are the top-quark Yukawa couplings in the SM and the littlest Higgs model with T-parity [?, ?], respectively.

Fig. 4 [Figure 4: see original paper] shows contours for the deviation from the SM cross section in the plane of r versus the symmetry breaking scale f . From this figure we see that the corrections decrease the SM cross section in the allowed parameter space. The corrections are more sizable for lower values of the scale f . In a large part of the parameter space with $f < 650$ GeV, the corrections can be over 20% in magnitude.

V. Productions of $ht\bar{T}$ and $hT\bar{t}$ at LHC

Like $ht\bar{t}$ production, the production of $ht\bar{T}$ or $hT\bar{t}$ can proceed through gg fusion or $q\bar{q}$ annihilation at the LHC, as shown in Fig. 5 [Figure 5: see original paper].

In the littlest Higgs model with T-parity, the T-quark can decay into Wb , ht , Zt and $B_H T_-$, among which the decay $T \rightarrow Wb$ is the most important channel [?]. Therefore, the final states of the production $ht\bar{T}$ or $hT\bar{t}$ are the same as $ht\bar{t}$ production. If we do not try to identify the T-quark from the top quark by mass reconstruction, the productions $ht\bar{T}$ and $hT\bar{t}$ will be counted into $ht\bar{t}$ events.

In Fig. 6 [Figure 6: see original paper] we plot the ratio $\sigma(ht\bar{T} + hT\bar{t})/\sigma_{\text{SM}}(ht\bar{t})$ as a function of T-quark mass. In our calculations we used the CTEQ5M parton distribution functions [?] with $Q = 2m_t + m_h$ and two-loop running coupling constant $\alpha_s(Q)$ with $\alpha_s(m_Z) = 0.118$. From Fig. 6 we see that the ratio can be over 10% for m_T below the TeV scale. When m_T is 700 GeV, the ratio can reach 40%. With increasing m_T , the production cross section becomes small because of phase space suppression.

Note that due to the large mass difference between m_T and m_t , we may try to extract the signal of $ht\bar{T}$ production from $ht\bar{t}$ events by mass reconstruction. This is not easy since it requires mass reconstruction for both t and \bar{t} .

Given the analyses in both this section and the preceding section, we would like to remark on the overall impact of the modified cross sections for Higgs discovery at the LHC. As shown in [?], the $ht\bar{t}$ production channel will be hard to observe at the LHC. As shown in Sec. IV, the contribution of the littlest Higgs model with T-parity can decrease the SM $ht\bar{t}$ cross section by 20%, which thus makes observation of this production channel even harder. But, at the same time, the new channels of $hT\bar{t}$ and $ht\bar{T}$ production may open up. As shown in Fig. 6, for $700 \text{ GeV} < m_T < 800 \text{ GeV}$ the production of $hT\bar{t}$ and $ht\bar{T}$ can have a cross section of 20-40% with respect to the SM $ht\bar{t}$ cross section. Considering the heaviness of the T-quark, the production of $ht\bar{T} + hT\bar{t}$ may have less background than $ht\bar{t}$ production, and thus this new channel may likely be observable at the LHC.

VI. Conclusion

We studied top quark pair production associated with a light Higgs boson as a test of the littlest Higgs model with T-parity at the ILC and LHC. For the

production of $ht\bar{t}$ at the ILC, we found that in a large part of the allowed parameter space the cross section can deviate from the SM prediction by over 10% and thus may be observable. We also found that polarized beams lead to more sizable deviations and thus make the ILC more powerful in probing such effects. For the production of $ht\bar{t}$ at the LHC, we found that in a large part of the parameter space the deviation from the SM cross section can be over 20%. For the new production channel of $ht\bar{T}$ or $hT\bar{t}$, we found that their cross section can be over 10% of the SM $ht\bar{t}$ production for m_T below the TeV scale.

Acknowledgments: L. W. thanks C.-X. Yue and J. J. Cao for discussions. This work was supported by National Natural Science Foundation of China (NNSFC) under No. 10475107.

References

- [?] N. Arkani-Hamed, A. G. Cohen and H. Georgi, Phys. Lett. B 513, 232 (2001); N. Arkani-Hamed, A. G. Cohen, T. Gregoire and J. G. Wacker, JHEP 0208, 020 (2002); N. Arkani-Hamed, A. G. Cohen, E. Katz, A. E. Nelson, T. Gregoire, J. G. Wacker, JHEP 0208, 021 (2002); I. Low, W. Skiba and D. Smith, Phys. Rev. D 66, 072001 (2002); D. E. Kaplan and M. Schmaltz, JHEP 0310, 039 (2003).
- [?] N. Arkani-Hamed, A. G. Cohen, E. Katz, A. E. Nelson, JHEP 0207, 034 (2002); S. Chang, JHEP 0312, 057 (2003); T. Han, H. E. Logan, B. McElrath and L. T. Wang, Phys. Rev. D 67, 095004 (2003); M. Schmaltz, D. Tucker-smith, Ann. Rev. Nucl. Part. Sci. 55, 229 (2005).
- [?] C. Csaki, J. Hubisz, G. D. Kribs, P. Meade, J. Terning, Phys. Rev. D 67, 115002 (2003); J. L. Hewett, F. J. Petriello, T. G. Rizzo, JHEP 0310, 062 (2003); C. Csaki, J. Hubisz, G. D. Kribs, P. Meade, J. Terning, Phys. Rev. D 68, 035009 (2003); M. C. Chen, S. Dawson, Phys. Rev. D 70, 015003 (2004); M. C. Chen et al., Mod. Phys. Lett. A 21, 621 (2006); W. Kilian, J. Reuter, Phys. Rev. D 70, 015004 (2004).
- [?] G. Marandella, C. Schappacher and A. Strumia, Phys. Rev. D 72, 035041 (2005).
- [?] H. C. Cheng and I. Low, JHEP 0309, 051 (2003); JHEP 0408, 061 (2004); I. Low, JHEP 0410, 067 (2004).
- [?] D. Zeppenfeld, R. Kinnunen, A. Nikitenko, E. Richter-Was, Phys. Rev. D 62, 013009 (2000); D. Zeppenfeld, hep-ph/0203123; A. Belyaev, L. Reina, JHEP 08, 041 (2002); F. Maltoni, D. Rainwater and S. Willenbrock, Phys. Rev. D 66, 034002 (2002); M. Dürssen, ATL/PHYS-2003-30; S. Dawson et al., Nucl. Phys. Proc. Suppl. 133, 111-116 (2004); hep-ph/0305282.
- [?] J. Goldstein et al., Phys. Rev. Lett. 86, 1694 (2001); L. Reina, S. Dawson, Phys. Rev. Lett. 87, 201804 (2001); W. Beenakker et al., Phys. Rev. Lett. 87, 201805 (2001); L. Reina, S. Dawson, D. Wackerroth, Phys. Rev. D 65, 053017

(2002); A. K. Leibovich, D. Rainwater, Phys. Rev. D 65, 055012 (2002); S. Dawson et al., Phys. Rev. D 67, 071503 (2003); W. Beenakker et al., Nucl. Phys. B 653, 151 (2003); C. S. Li, et al., Phys. Rev. D 54, 4662 (1996).

[?] A. Juste, G. Merino hep-ph/9910301; T. Abe et al., hep-ex/0106057; hep-ph/0109166; J. A. Aguilar-Saavedra et al., hep-ph/0106315.

[?] A. Juste, hep-ph/0512246.

[?] J. Hubisz, P. Meade, Phys. Rev. D 71, 035016 (2005); C. R. Chen, K. Tobe, C.-P. Yuan, Phys. Lett. B 640, 263 (2006).

[?] A. Belyaev, C. R. Chen, K. Tobe, C.-P. Yuan, hep-ph/0609179.

[?] W. Kilian, D. Rainwater and J. Reuter, Phys. Rev. D 71, 015008 (2005); Phys. Rev. D 74, 095003 (2006).

[?] J. Hubisz, P. Meade, A. Noble, M. Perelstein, JHEP 0601, 135 (2006).

[?] CDF Collaboration, hep-ex/0507091.

[?] S. Eidelman et al. [Particle Data Group], Phys. Lett. B 592, 1 (2004); M. W. Grunewald, hep-ex/0304023; LEP collaborations, hep-ex/0412015.

[?] G. Moortgat-Pick et al., hep-ph/0507011.

[?] C.-X. Yue et al., Commun. Theor. Phys. 45, 511 (2006).

[?] H. C. Cheng, I. Low, L.-T. Wang, Phys. Rev. D 74, 055001 (2006).

[?] H. L. Lai, et al. (CTEQ collaboration), Eur. Phys. Jour. C 12, 375 (2000).

[?] J. Cammin, Ph.D. Thesis [ATLAS], BONN-IR-2004-06; K. Cranmer, B. Quayle, et al., ATL-PHYS-2004-034; For a review, see, D. Rainwater, hep-ph/0702124.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv – Machine translation. Verify with original.