Littlest Higgs model and top-charm production at high-energy linear colliders

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Abstract

Due to the presence of extra top quark $T$ in the little Higgs models, the $CKM$ matrix is not unitary and the flavor changing neutral currents may exist at the tree level. In the context of the Littlest Higgs (LH) model, we discuss the top-charm production at the high-energy linear $e^+e^-$ collider ($LC$) via the processes $e^+e^- \rightarrow t\bar{c} + t\bar{c}$, $e^+e^- \rightarrow (t\bar{c} + t\bar{c})\nu_e\bar{\nu}_e$, and $e^-\gamma \rightarrow e^-t\bar{c}$. We find that the resonance production cross section for the process $e^+e^- \rightarrow t\bar{c} + t\bar{c}$ is significantly larger, which can be detected in future $LC$ experiments.

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1. Introduction

It is well known that, in the standard model (SM), there is no flavor changing neutral currents (FCNC's) at tree-level and at one-loop level they are GIM suppressed. Searching for FCNC's is one of the most interesting means to test the SM and probe popular new physics models. The top quark, with a mass of the order of the electroweak scale $m_t = 178.0 \pm 4.36 \text{GeV}$[1], is the heaviest particle yet discovered. In some new physics models, the FCNC couplings involving the top quark may be significantly enhanced[2]. Thus, searching for FCNC's involving the top quark would be a good probe for new physics beyond the SM.

The top quark FCNC processes can be studied either in the rare top quark decays or in the top quark production through FCNC couplings at high-energy experiments. In the SM, such kind of processes are unobservably small. Any signal of these processes will be a clear evidence of new physics beyond the SM. Many new physics models predict the existence of the FCNC coupling vertices $tcv(v = Z, \gamma, or g)$, which can enhance the branching ratios $Br(t \rightarrow cv)$ and the cross sections of the top-charm production processes by several orders to make them potentially accessible at future high energy collider experiments[2]. The top-charm production processes have been extensively studied in the context of some specific popular models[3,4,5] and in a model independent approach[6]. They have shown that some of new physics models might be tested or be constrained through studying their effects on the top-charm production processes.

To solve the so-called hierarchy or fine-tuning problem of the SM, the little Higgs theory[7] was proposed as kind of electroweak symmetry breaking (EWSB) mechanism accomplished by a naturally light Higgs sector. This kind of models provide a natural mechanism of EWSB associated with the large value of the top quark Yukawa couplings. This mechanism typically involves a new heavy $SU(2)_L$ single top quark $T$. The existence of the vector-like top quark $T$ introduces new effects in the weak currents. The CKM matrix is extended to $4 \times 3$ and FCNC's occur at tree-level[8,9]. It has been shown[9] that the flavor change $Z$ couplings are allowed in the up quark sector but not in the down quark sector, which might be tested via rare top decays and same sign top pair production.
at the \textit{LHC} experiments. In this Letter, we will study the top-charm production induced by the littlest Higgs (\textit{LH}) model\cite{10} at the future high-energy linear $e^+e^-$ collider (\textit{LC'}) experiments and see whether the \textit{FC} signals of the \textit{LH} model can be detected via the top-charm production.

The \textit{FC} couplings $Ztc$ and $Z_Htc$ induced by the vector-like top quark $T$ in the \textit{LH} model are given in section 1. The contributions of these \textit{FC} couplings to the process $e^+e^-\rightarrow \bar{t}c + tc$ are also calculated in this section. The contributions of these couplings to the t-channel vector boson fusion processes $e^+e^-\rightarrow W^*W^*\nu_e\nu_e \rightarrow (\bar{t}c + tc)\nu_e\nu_e$ and $e^-\gamma\rightarrow e^-\bar{t}c$ are further calculated in section 3 and 4, respectively. Our conclusions are given in section 5.

2. The process $e^+e^-\rightarrow \bar{t}c + tc$ in the \textit{LH} model

It is well known that the most dangerous radiative corrections to the Higgs mass in the \textit{SM} come from one-loop diagrams with top quark, $SU(2)$ gauge bosons, and the Higgs self-coupling. In the little theory\cite{7}, the Higgs mass is protected from one-loop quadratic divergences by approximate global symmetries. New particles, such as heavy scalars, heavy fermions and gauge bosons, must be introduced to ensure that the global symmetries are not broken too severely and to cancel the one-loop quadratic divergence of the Higgs mass-squared. Furthermore, the numerically most large quadratic divergence comes from top quark loops. The cancellation of the quadratic divergence associated with the top Yukawa coupling is the most important. Thus, all of the little Higgs models should predict the existence of at least one vector-like top quark at the $TeV$ scale.

In general, the presence of a new extra quark modifies the electroweak currents. In the \textit{LH} model, the new vector-like top quark $T$ makes that the number of up-type quarks is four and the $3 \times 3$ CKM matrix in the \textit{SM}, which is related the quark mass eigen states with the weak eigen states, became to a $4 \times 3$ matrix. Since the top quark $t$ and the vector-like quark $T$ have different $SU(2) \otimes U(1)$ quantum numbers, their mixing can lead to the \textit{FCNC}'s mediated by the \textit{SM} gauge boson $Z$. In the \textit{LH} model, the \textit{FC}
couplings involving the top quark can be written as\cite{8,9}:

\[ \mathcal{L} = \frac{e}{2 S_W C_W} (K_{tu} \bar{f}_L \gamma_\mu u_L + K_{tc} \bar{f}_L \gamma_\mu c_L) Z^\mu \\
+ \frac{e}{2 S_W C_W} s (K_{tu} \bar{f}_L \gamma_\mu u_L + K_{tc} \bar{f}_L \gamma_\mu c_L) Z^\mu_H + h.c., \]

(1)

where \( S_W = \sin \theta_W \), \( \theta_W \) is the Weinberg angle, \( c(s = \sqrt{1 - c^2}) \) is the mixing parameter between \( SU(2)_1 \) and \( SU(2)_2 \) gauge bosons. \( Z_H \) is the new \( SU(2) \) gauge boson predicted by the LH model. The factors \( K_{tc} \) and \( K_{tu} \) are the off-diagonal matrix elements of the 4 \( \times \) 4 neutral currents mixing matrix in the up-type quark sector, which comes from the up-type quark transformation matrix. Reference\cite{9} has estimated the values of these factors via considering a perturbative diagonalization of the up-type quark mass matrix and found that their values are approximately equal to \( 2.43 \times 10^{-3} \) and \( 2.12 \times 10^{-4} \), respectively.

In the LH model, the FC process \( e^+ e^- \rightarrow \bar{t}c + \bar{t}c \) can be generated by the tree-level FC couplings \( Z \bar{t}c \) and \( Z_H \bar{t}c \). The total cross section of this process can be written as:

\[ \sigma(S) = \sigma_Z + \sigma_{Z_H} + \sigma_{ZZ} \]

\[ = \frac{\pi e^2 K_{tc}^2}{4 S_W^2 C_W^4} \left\{ (1 - 4 S_W^4 + 8 S_W^4) \beta^4 (3 - \beta^2) S \chi^2 + \frac{C_W^2 c^2}{s^2} \beta^4 (3 - \beta^2) S \chi_{ZH}^2 \right. \\
\left. + \frac{8 C_W c}{s} (1 - 2 S_W^2) \beta^4 (3 - \beta^2) R e [\chi_Z \cdot \chi_{ZH}] \right\} \]

(2)

with

\[ \chi_i = \frac{1}{S - M_i^2 + i M_i \Gamma_i}, \]

(3)

where \( \Gamma_i (i = Z, \text{or } Z_H) \) represents the total decay width of the gauge bosons \( Z \) or \( Z_H \). \( S \) is the center-of-mass(CM) energy squared.

From above equations, we can see that the cross section \( \sigma(S) \) of the top-charm production via the process \( e^+ e^- \rightarrow \bar{t}c + \bar{t}c \) mainly depends on the free parameters \( c \) and \( M_{Z_H} \) for the fixed value of the flavor factor \( K_{tc} \). Taking into account the precision electroweak constrains on the parameter space of the LH model, the free parameters \( c \) and the \( Z_H \) mass \( M_{Z_H} \) are allowed in the ranges of \( 0 \sim 0.5 \) and \( 1 \sim 2 TeV \)[11]. If we take the CM energy \( \sqrt{S} = 500 GeV \), then there is \( S \ll M^2_{Z_H} \). In this case, the contributions of the LH model to the top-charm production via the process \( e^+ e^- \rightarrow \bar{t}c + \bar{t}c \) at a LC with
\[ \sqrt{S} = 500\text{GeV} \] mainly come from the FC coupling \( Ztc \). The value of the cross section \( \sigma(S) \) is not sensitive to the free parameters \( c \) and \( M_{Z_H} \), and is about \( 1.22 \times 10^{-2} \text{fb} \) in most of all parameter space preferred by the electroweak precision data. Comparing with the SM prediction, the cross section \( \sigma(S) \) is enhanced by several orders of magnitude. However, there will be only several \( \bar{t}c \) events to be generated in the future LC experiment with \( \sqrt{S} = 500\text{GeV} \) and a yearly integrated luminosity of \( \mathcal{L} = 340\text{fb}^{-1}[12] \), which is very difficult to be detected.

Figure 1: The top-charm production cross section \( \sigma(S) \) as a function of the CM energy \( \sqrt{S} \) for three values of \( M_{Z_H} \).

To see the effects of the CM energy \( \sqrt{S} \) on the top-charm production, we plot the \( \sigma(S) \) versus \( \sqrt{S} \) in Fig.1 for \( c = 0.4 \) and three values of \( M_{Z_H} \). From Fig.1, we can see that the cross section \( \sigma(S) \) resonance emerges when the \( Z_H \) mass \( M_{Z_H} \) approaches the CM energy \( \sqrt{S} \). In this case, the contributions of the LH model to the top-charm production mainly come from the FC coupling \( Z_{H}\bar{t}c \). The resonance values of the \( \sigma(S) \) decrease as \( \sqrt{S} \) increasing. For \( c = 0.4 \) and \( \sqrt{S} = M_{Z_H} = 1\text{TeV}, 1.5\text{TeV}, \) and \( 2\text{TeV} \), the cross
section $\sigma(S)$ can reach 16.8 fb, 7.7 fb, and 4.4 fb, respectively. Then there will be several hundreds and up to thousands $\bar{t}c$ events to be generated at the future LC experiments with $\mathcal{L} = 500 fb^{-1}$ and $\sqrt{S} \geq 1 TeV$, which should be observable. Thus, the possible FC signals of the LH model can be detected in future LC experiments.

3. The process $e^+e^- \rightarrow WW\nu_e\bar{\nu}_e \rightarrow (\bar{t}c + t\bar{c})\nu_e\bar{\nu}_e$ in the LH model

The $WW$-fusion process $e^+e^- \rightarrow WW\nu_e\bar{\nu}_e \rightarrow (\bar{t}c + t\bar{c})\nu_e\bar{\nu}_e$ is very sensitive to the FC couplings\cite{5,6}. Thus, the FC couplings $Z\bar{t}c$ and $Z_H\bar{t}c$ might be probed via this process in future LC experiments. Furthermore, the cross section of this process grows with the CM energy $\sqrt{S}$ of the LC experiment, while the production cross section of the $s$-channel process $e^+e^- \rightarrow \bar{t}c + t\bar{c}$ generally drops as $\sqrt{S}$ increasing. Thus, there is a strong motivation to study the $WW$ process $e^+e^- \rightarrow WW\nu_e\bar{\nu}_e \rightarrow (\bar{t}c + t\bar{c})\nu_e\bar{\nu}_e$ at somewhat higher CM energies. In this section, we consider the contributions of the FC couplings $Z\bar{t}c$ and $Z_H\bar{t}c$ to this process in the context of the LH model, the relevant Feynman diagrams are shown in Fig.2.

![Feynman diagrams](image.png)

Figure 2: Feynman diagrams contribute to the $WW$-fusion process $e^+e^- \rightarrow WW\nu_e\bar{\nu}_e \rightarrow \bar{t}c\nu_e\bar{\nu}_e$.

The process $e^+e^- \rightarrow (\bar{t}c + t\bar{c})\nu_e\bar{\nu}_e$ can be well approximated by the $WW$-fusion process $W_{\lambda_+}^+ W_{\lambda_-}^- \rightarrow \bar{t}c + t\bar{c}$. It has been shown the effective $W$-boson approximation (EWA) provides a viable simplification for $WW$-fusion processes at the high CM energies\cite{13}. Thus, we use the effective EWA to estimate the production cross section of the process.
\[ e^+e^- \rightarrow W^+W^-\nu_e\bar{\nu}_e \rightarrow (\bar{t}c + t\bar{c})\nu_e\bar{\nu}_e \] in the future LC experiments with \( \sqrt{S} \geq 1 \text{TeV} \).

For the subprocess \( W^+_{\lambda^+} W^-_{\lambda^-} \rightarrow \bar{t}c + t\bar{c} \) generated by the gauge bosons \( Z_H \) and \( Z \) with the helicities \( \lambda_{\pm} = 0, \pm 1 \), the non-vanishing helicity amplitudes are \( M_{+1+} = M_{-1-}, M_{+10} = M_{-10} \) and \( M_{00}[6] \). The production cross section \( \hat{\sigma}(s) \) of this subprocess contributed by \( Z \) exchange and \( Z_H \) exchange can be written as:

\[
\hat{\sigma}(s) = \hat{\sigma}_{11}(s) + \hat{\sigma}_{-1-}(s) + \hat{\sigma}_{10}(s) + \hat{\sigma}_{-10}(s) + \hat{\sigma}_{00}(s)
\]

\[
= (A_1 + A_2 + A_3)[1 + \frac{\hat{s}}{2M_W^2} + \frac{\hat{s}}{2M_W^2} + (1 + \frac{\hat{s}}{2M_W^2})^2]
\]

with

\[
A_1 = \frac{32\pi\alpha_{\text{em}}^2K^2_{\text{em}}}{3s_{\text{em}}^2}\beta_1^4\beta_W(1 + \frac{m_t^2}{2\hat{s}})\hat{s}\chi_Z^2,
\]

\[
A_2 = \frac{8\pi\alpha_{\text{em}}^2K^2_{\text{em}}}{3s_{\text{em}}^2C_{\text{em}}^2}\frac{\nu^4}{f^2} [c^4(c^2 - s^2)]_\nu^4\beta_1^4\beta_W(1 + \frac{m_t^2}{2\hat{s}})\hat{s}\chi_Z H,
\]

\[
A_3 = -\frac{32\pi\alpha_{\text{em}}^2K^2_{\text{em}}}{3s_{\text{em}}^2C_{\text{em}}^2}\frac{\nu^2}{f^2} [c^4(c^2 - s^2)]_\nu^2\beta_1^4\beta_W(1 + \frac{m_t^2}{2\hat{s}})\hat{s}\chi_Z e \mid \chi Z \cdot \chi Z_H |,
\]

where \( \sqrt{\hat{s}} \) is the CM energy of the subprocess \( W^+_{\lambda^+} W^-_{\lambda^-} \rightarrow \bar{t}c + t\bar{c} \), \( \beta_t = \sqrt{1 - \frac{m_t^2}{\hat{s}}} \), and \( \beta_W = \sqrt{1 - \frac{4M_W^2}{\hat{s}}} \). The factors \( A_1, A_2 \) and \( A_3 \) come from \( Z \) exchange, \( Z_H \) exchange, and interference between \( Z \) and \( Z_H \), respectively.

In general, the cross section \( \sigma(\bar{t}c) \) for the process \( e^+e^- \rightarrow W^+W^-\nu_e\bar{\nu}_e \rightarrow (\bar{t}c + t\bar{c})\nu_e\bar{\nu}_e \) can be obtained by folding the cross section \( \hat{\sigma}(s) \) for the subprocess \( W^+_{\lambda^+} W^-_{\lambda^-} \rightarrow \bar{t}c + t\bar{c} \) with \( W^+_{\lambda_{\pm}} \) distribution functions \( f_{\lambda_{\pm}}^{W^\pm} \):

\[
\sigma(\bar{t}c) = \sum_{\lambda_{\pm}} \int_{m_{t}/\sqrt{\hat{s}}}^1 2xdx \int_{x^2}^1 \frac{dx_+}{x_+} f_{\lambda_{\pm}}^{W^+}(x_+)f_{\lambda_{\pm}}^{W^-}(\frac{x^2}{x_+}\hat{s})\hat{s}(W^+_{\lambda^+} W^-_{\lambda^-} \rightarrow \bar{t}c + t\bar{c})
\]

\[
= \int_{m_{t}/\sqrt{\hat{s}}}^1 2xdx \int_{x^2}^1 \frac{dx_+}{x_+} [f_{\lambda_{\pm}}^{W^+}(x_+)f_{\lambda_{\pm}}^{W^-}(\frac{x^2}{x_+}) + f_{\lambda_{\pm}}^{W+}(x_+)f_{\lambda_{\pm}}^{W^-}(\frac{x^2}{x_+}) + f_{\lambda_{\pm}}^{W}(x_+)f_{\lambda_{\pm}}^{0}(\frac{x^2}{x_+}) - \frac{\hat{s}^2}{2m_W^2} f_{\lambda_{\pm}}^{W}(x_+)]\hat{s}(A_1 + A_2 + A_3)
\]

In our calculation, we will use the full distribution functions \( f_{\lambda_{\pm}}^{W^\pm}(x) \) given by Refs[13,14] and \( \hat{s} = x^2\sqrt{\hat{s}} \).

The production cross section \( \sigma(\bar{t}c) \) for the process \( e^+e^- \rightarrow W^+W^-\nu_e\bar{\nu}_e \rightarrow (\bar{t}c + t\bar{c})\nu_e\bar{\nu}_e \) is plotted in Fig.3 as a function of the CM energy \( \sqrt{\hat{s}} \) for the free parameters \( c = 0.4 \)
and $M_{Z_H} = 1.5 \text{ TeV}$. Our numerical results show that the production cross section $\sigma(\bar{t}c)$ mainly comes from $Z$ exchange and is not sensitive to the free parameters $c$ and $M_{Z_H}$. In most of the parameter space preferred by the electroweak precision data, the value of $\sigma(\bar{t}c)$ is about $1.5 \times 10^{-3} \text{ fb}$. Thus, the possible FC signals of the LH model are very difficult to be detected via the process $e^+e^- \rightarrow W^+W^-\nu_e\bar{\nu}_e \rightarrow (\bar{t}c+t\bar{c})\nu_e\bar{\nu}_e$ in future LC experiments.

![Graph showing production cross section $\sigma(\bar{t}c)$ as a function of the CM energy $\sqrt{S}$ for $M_{Z_H} = 1.5 \text{ TeV}$ and $c = 0.4$.](image)

Figure 3: The production cross section $\sigma(\bar{t}c)$ as a function of the $CM$ energy $\sqrt{S}$ for $M_{Z_H} = 1.5 \text{ TeV}$ and $c = 0.4$.

Certainly, the FC couplings $Z\bar{t}c$ and $Z_H\bar{t}c$ can also has contribute to the top-charm production at the LC experiments via the process $e^+e^- \rightarrow ZZ e^+e^- \rightarrow Z(\bar{t}c+tc)\nu_e\bar{\nu}_e$. The main difference between $\sigma(\bar{t}c)$ and $\sigma(\bar{t}ce^+e^-)$ arises from the dissimilarity between the distribution functions for $W$ and $Z$ bosons. Since the $W$ distribution function is larger than $Z$ distribution function, $\sigma(\bar{t}ce^+e^-)$ is smaller than $\sigma(\bar{t}c)$ by about one order of magnitude[5]. Thus, we do not need to further consider the process $e^+e^- \rightarrow Z(\bar{t}c+tc)\nu_e\bar{\nu}_e$ in the context of the LH model.
4. The process $e^{-\gamma} \rightarrow e^{-\bar{t}c}$ in the LH model

A future LC can also operate in $e^{-\gamma}$ collisions, where the $\gamma$-beam is generated by the backward Compton scattering of the incident positron- and laser-beam. Its energy and luminosity can reach the same order of magnitude of the corresponding positron beam\cite{15}. From Eq.(1), we can see that the FC couplings $Z\bar{t}c$ and $Z_H\bar{t}c$ might have significant contributions to the top-charm production via the process $e^{-\gamma} \rightarrow e^{-Z^*\gamma} \rightarrow e^{-\bar{t}c}$. The relevant Feynman diagrams are shown in Fig.4.

![Feynman diagrams](https://via.placeholder.com/150)

Figure 4: Feynman diagrams contribute to the process $e^{-\gamma} \rightarrow e^{-\bar{t}c}$

For the subprocess $Z(P_Z) + \gamma(k) \rightarrow t(P_t) + c(P_c)$, we define the kinematical invariant $t = (P_t - P_Z)^2$. The renomalization amplitude can be written as:

$$
M = M_Z + M_{Z_H} \\
= -\frac{e^2}{3S_WC_W}K_{tc}\bar{u}_c\gamma_\mu \frac{i}{P_Z - P_t - m_c + i\epsilon} \gamma_\nu P_L v_t e^{\mu}(k) e^{\nu}(Z) \\
- \frac{e^2}{3S_WC_W}K_{tc}\bar{v}_t\gamma_\mu \frac{i}{P>Z - P_c - m_t + i\epsilon} \gamma_\nu P_L u_c e^{\mu}(k) e^{\nu}(Z) \\
- \frac{e^2}{3S_WC_Ws}cK_{tc}\bar{u}_c\gamma_\mu \frac{i}{P_{Z_H} - P_t - m_c + i\epsilon} \gamma_\nu P_L v_t e^{\mu}(k) e^{\nu}(Z_H) \\
- \frac{e^2}{3S_WC_Ws}cK_{tc}\bar{v}_t\gamma_\mu \frac{i}{P_{Z_H} - P_c - m_t + i\epsilon} \gamma_\nu P_L u_c e^{\mu}(k) e^{\nu}(Z_H)
$$

(9)

with $P_L = \frac{1 - \gamma_5}{2}$. 

9
The effective cross section $\sigma(e^-\bar{t}c)$ at a $LC$ with $CM$ energy $\sqrt{S}$ can be obtained by folding the subprocess cross section $\hat{\sigma}(Z\gamma \to \bar{t}c)$ with the gauge boson $Z$ and photon distribution functions $f_{Z/e}$[13,14] and $f_{\gamma/e}$[16]:

$$
\sigma(e^-\bar{t}c) = \int_{(m_t+m_c)^2/S}^{0.83} d\tau \int_{\tau/0.83}^{1} \frac{d\tau}{x} f_{\gamma/e}(x) f_{Z/e}(\tau) \hat{\sigma}(Z\gamma \to \bar{t}c)
$$

(10)

In above equation, we have assumed $\hat{s} = \tau S$, in which $\hat{s}$ is the $CM$ energy of the subprocess $Z\gamma \to \bar{t}c$.

Figure 5: The cross section $\sigma(e^-\bar{t}c)$ as a function of the $CM$ energy $\sqrt{S}$ for $c = 0.4$ and $M_{ZH} = 2 TeV$.

Observably, the contributions of the $LH$ model to the process $e^-\gamma \to e^-\bar{t}c$ mainly come from the $FC$ coupling $Z\bar{t}c$. The cross section $\sigma(e^-\bar{t}c)$ is not sensitive to the mixing parameter $c$ and the $Z_H$ mass $M_{ZH}$. Thus, in our numerical estimation, we taken $c = 0.4$ and $M_{ZH} = 2 TeV$. Our numerical result are shown in Fig.5. One can see from Fig.5 that the cross-section $\sigma(e^-\bar{t}c)$ increases as the $CM$ energy $\sqrt{S}$ increasing. For $\sqrt{S} \leq 2 TeV$, the value of $\sigma(e^-\bar{t}c)$ is smaller than $1.2 \times 10^{-2} fb$. Thus, the possible $FC$ signals of the
**LH** model is very difficult to be detected via the process $e^-\gamma \to e^-\bar{t}c$ in future LC experiments.

5. Conclusions

Little Higgs theory has generated much interest as one kind of models of **EWSB**, which can be regarded as one of the important candidates of new physics beyond the **SM**. For all of the little Higgs models, at least one vector-like top quark $T$ is needed to cancel the numerically most large quadratic divergence coming from top Yukawa couplings. Due to the presence of extra quarks, the **CKM** matrix is not unitary and **FCNC**'s may exist at tree-level. Thus, the little Higgs models generally predict the **FC** couplings $Z\bar{t}c$ and $Z_H\bar{t}c$.

In this Letter, we study the contributions of the **FC** couplings predicted by the **LH** model to the top charm production via the the processes $e^+e^-\to \bar{t}c+\bar{t}c$, $e^+e^-\to (\bar{t}c+t\bar{c})\nu\bar{\nu}e$, and $e^-\gamma\to e^-\bar{t}c$ in future LC experiments. We find that the cross sections of the processes $e^+e^-\to (\bar{t}c+t\bar{c})\nu\bar{\nu}e$ and $e^-\gamma\to e^-\bar{t}c$ are very small in all of the parameter space, which can not give detectable signals. For the process $e^+e^-\to \bar{t}c+t\bar{c}$, the top-charm production cross section is approximately equal to $1.2 \times 10^{-2} fb$ in part of the parameter space preferred by the electroweak precision data. However, for $\sqrt{S} \approx M_{Z_H}$, the cross section $\sigma(S)$ can be significantly enhanced and the contributions of the **LH** model to the top-charm production mainly come from the **FC** couplings $Z_H\bar{t}c$. For example, for $\sqrt{S} \approx M_{Z_H} = 1 TeV, 1.5 TeV, 2 TeV$, the value of $\sigma(S)$ is $16.8 fb, 7.7 fb$, and $4.4 fb$, respectively. The resonance effects of the heavy gauge boson $Z_H$ on the top-charm production should be detected in future LC experiments.

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