Higgs boson decays and production in the left-right twin Higgs model

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Abstract

The left-right twin Higgs model predicts one neutral Higgs boson $\phi_0$ and it acquires mass $m_{\phi_0} \sim \mu_r$ with the $\mu$ term, which can be lighter than half the SM-like Higgs boson mass in a portion of parameter space. Thus, the SM-like Higgs boson $h$ can dominantly decay into a pair of light neutral Higgs bosons especially when $m_h$ is below the $WW$ threshold. First, we examine the branching ratios of the SM-like Higgs boson decays and find that the new decay mode $h \rightarrow \phi_0 \phi_0$ is dominant for the case of $m_h > 2m_{\phi_0}$. Then we study the production via gluon fusion followed by the decay into two photons or two weak gauge bosons and found that the production rate can be significantly suppressed for some part of parameter space. Finally, we comparatively study the process $\gamma\gamma \rightarrow h \rightarrow b\bar{b}$ at ILC in the cases of $m_h > 2m_{\phi_0}$ and $m_h < 2m_{\phi_0}$, respectively. We find that these predictions can significantly deviated from the SM predictions, e.g., the gluon-gluon fusion channel, in the cases of $m_h > 2m_{\phi_0}$ and $m_h < 2m_{\phi_0}$, can be suppressed by about 80\% and 45\%, respectively. Therefore, it is possible to probe the left-right twin Higgs model via these Higgs boson production processes at the LHC experiment or in the future ILC experiment.

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I. Introduction

The Higgs boson is the last ingredient of the standard model (SM) to be probed at experiments. The precision electroweak measurement data and direct searches suggest that the Higgs boson must be relatively light and its mass should be roughly in the range of $114.4 \text{ GeV} \sim 186 \text{ GeV}$ at 95% C.L. [1], but the SM suffers of the so-called hierarchy problem [2], which is due to the presence of quadratic divergences in the loop processes for the scalar Higgs boson self-energy. Therefore, the standard model with a light Higgs boson can be viewed as the low-energy effective approximation of a fundamental theory. A wide variety of models have been introduced to address electroweak symmetry breaking (EWSB) and the hierarchy problem: supersymmetry[3], large extra-dimensions[4], topcolor models[5], and little Higgs models[6] et al.

Recently, the twin Higgs mechanism is proposed as a solution to the little hierarchy problem [7, 8, 9]. Instead of protecting the Higgs mass from receiving large radiative corrections by using several approximate global symmetries, twin Higgs theories use a discrete symmetry in combination with an approximate global symmetry to eliminate the quadratic divergences that arise at loop level. Together with the gauge symmetries of the model, the discrete symmetry mimics the effect of a global symmetry, thus stabilizing the Higgs mass. The twin Higgs mechanism can be implemented in left-right models with the discrete symmetry being identified with left-right symmetry [8]. In the left-right twin Higgs(LRTH) model, the leading quadratically divergent contributions of the SM gauge bosons to the Higgs boson mass are canceled by the loop involving the new gauge bosons, while those for the top quark can be canceled by the contributions from a heavy top quark. Besides, the other Higgs particles acquire large masses not only at quantum level but also at tree level. The phenomenology of the LRTH model are widely discussed in literature [10, 11, 12, 13], and constraints on LRTH model parameters are studied in [14]. The LRTH model is also expected to give new significant signatures in future high energy colliders and studied in references [15].

Besides the SM-like Higgs boson $h$, there are two additional neutral Higgs bosons in the LRTH model, which are $\hat{h}_2^0$ and $\phi_0$. The neutral Higgs boson $\hat{h}_2^0$ could be a good dark matter candidate[12]. The light neutral Higgs boson $\phi_0$ is a pseudoscalar and charged under the spontaneously broken $SU(2)_R$. Its mass is determined by $\mu_r$ that can be anything below the scale
Here we consider another possibility, in which the mass $m_{\phi_0} < m_h/2$. Therefore, in addition to the SM decay channels, the Higgs boson can then decay into two $\phi_0$ bosons. This new decay channel can change other decay branching ratios and thus affect the strategy of searching for the Higgs boson at high energy colliders, which is the main aim of this paper.

Ref. [16] studied the Higgs phenomenology in LRTH model by paying special attention to the decay $h \to \hat{S}\hat{S}$ which is strongly corrected with the dark matter scattering on nucleon. They found that such an invisible decay can severely suppress the conventional decay modes like $h \to VV (V = W, Z)$ and $h \to b\bar{b}$. Note that similar exotic decays for the SM-like Higgs boson may also be predicted by some other new physics models like the little Higgs models and SUSY or two Higgs-doublet models et al [17, 18]. A common feature of their phenomenology is the suppression of the conventional visible channels of the Higgs boson. To distinguish between different models, all the channels of Higgs production should be jointly analyzed. In this work we first study the decay branching ratios of the Higgs boson in the LRTH model for small value of $m_{\phi_0}$. Then we study the production via gluon fusion followed by the decay into two photons or two charged gauge bosons in the cases of $m_h > 2m_{\phi_0}$ and $m_h < 2m_{\phi_0}$, respectively. We also study the process $\gamma\gamma \to h \to b\bar{b}$ at ILC for these two cases.

This article is organized as follows. In the next section, we briefly review the left-right twin Higgs model. In Sec. III, we calculate the decay branching ratios of the Higgs boson. In Sec. IV, we calculate the main production of the Higgs boson at the LHC via gluon fusion followed by the decay into two photons or two weak gauge bosons. In Sec. V we calculated the rate of $\gamma\gamma \to h \to b\bar{b}$ at ILC. Finally, we give our conclusion in Sec.VI.

II. Review of the left-right twin Higgs model

Before our calculations we recapitulate the left-right twin Higgs (LRTH) model. The details of the LRTH model as well as the particle spectrum, Feynman rules, and some phenomenology analysis have been studied in Ref. [10]. Here we will briefly review the essential features of the LRTH model and focusing on the new particles and the couplings relevant to our computation.

The LRTH model is based on the global $U(4)_1 \times U(4)_2$ symmetry with a locally gauged subgroup $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$. The twin symmetry is identified with the left-right symmetry which interchanges L and R, implying that the gauge couplings of $SU(2)_L$ and $SU(2)_R$ are identical ($g_{2L} = g_{2R} = g_2$). Two Higgs fields, $H$ and $\tilde{H}$, are introduced and each transforms
as (4, 1) and (1, 4) respectively under the global symmetry. They can be written as

\[ H = \begin{pmatrix} H_L \\ H_R \end{pmatrix}, \quad \hat{H} = \begin{pmatrix} \hat{H}_L \\ \hat{H}_R \end{pmatrix}, \quad (1) \]

where \( H_{L,R} \) and \( \hat{H}_{L,R} \) are two component objects which are charged under the \( SU(2)_L \times SU(2)_R \times U(1)_{B-L} \) as

\[ H_L \text{ and } \hat{H}_L : (2, 1, 1), \quad H_R \text{ and } \hat{H}_R : (1, 2, 1). \quad (2) \]

The global \( U(4)_1(U(4)_2) \) symmetry is spontaneously broken down to its subgroup \( U(3)_1(U(3)_2) \) with non-zero vacuum expectation values(VEV) as \( \langle H \rangle = (0, 0, 0, f) \) and \( \langle \hat{H} \rangle = (0, 0, 0, \hat{f}) \).

Each spontaneously symmetry breaking results in seven Nambu-Goldstone bosons. Three of six Goldstone bosons that are charged under \( SU(2)_R \) are eaten by the new gauge bosons \( W_H^\pm \) and \( Z_H \), while leaves three physical Higgs: \( \phi^0 \) and \( \phi^\pm \). After the SM electroweak symmetry breaking, the three additional Goldstone bosons are eaten by the SM gauge bosons \( W^\pm \) and \( Z \).

The remaining Higgses are the SM Higgs doublet \( H_L \) and an extra Higgs doublet \( \hat{H}_L = (\hat{H}_1^+, \hat{H}_2^0) \) that only couples to the gauge boson sector. A residue matter parity in the model renders the neutral Higgs \( \hat{H}_2^0 \) stable, and it could be a good dark matter candidate.

In the LRTH model, the masses of charged gauge bosons and fermions are given by

\[ m_{W_L}^2 = \frac{1}{2} g_2^2 f^2 \sin^2 x, \quad (3) \]

\[ m_{W_H}^2 = \frac{1}{2} g_2^2 (\hat{f}^2 + f^2 \cos^2 x), \quad (4) \]

\[ m_t^2 = \frac{1}{2} (M^2 + y^2 f^2 - N_t), \quad (5) \]

\[ m_T^2 = \frac{1}{2} (M^2 + y^2 f^2 + N_t), \quad (6) \]

where \( N_t = \sqrt{(M^2 + y^2 f^2)^2 - y^4 f^4 \sin^2 2x} \) with \( x = v/\sqrt{2} f \), in which \( v = 246GeV \) is the electroweak scale. \( g_2 = e/\sin \theta_W \) and \( \theta_W \) is the Weinberg angle. The values of \( f \) and \( \hat{f} \) will be bounded by electroweak precision measurements. Once \( f \) is fixed, the values of \( \hat{f} \) can be determined from the minimization of the Coleman-Weinberg potential of the SM Higgs. The mass parameter \( M \) is essential to the mixing between the SM-like top quark and the heavy T-quark.

At the leading order, the couplings expression forms of the Higgs boson with charged gauge
bosons and fermions, which are related to our calculation can be written as [10]

\[ hWW : \frac{1}{2} g_2^2 v (1 - \frac{v^2}{3f^2}), \quad hW_H W_H : \frac{1}{2} g_2^2 v (1 - \frac{v^2}{3f^2}), \]  
(7)

\[ h\bar{t}t : -\frac{m_t}{v} C_L C_R, \quad h\bar{T}T : -\frac{y}{\sqrt{2}} (S_R S_L - C_L C_R x), \]  
(8)

where

\[ S_L = \frac{1}{\sqrt{2}} \sqrt{1 - (y^2 f^2 \cos 2x + M^2)/N_t}, \quad C_L = \sqrt{1 - S_L}, \]  
(9)

\[ S_R = \frac{1}{\sqrt{2}} \sqrt{1 - (y^2 f^2 \cos 2x - M^2)/N_t}, \quad C_R = \sqrt{1 - S_R}. \]  
(10)

The Coleman-Weinberg potential, obtained by integrating out the gauge bosons and top quarks, yields the SM Higgs potential, which determine the SM Higgs VEV and its mass, as well as the masses for the other Higgs. On the other hand, the \( \mu \)-term,

\[ V_\mu = -\mu_r^2 (H_R^\dagger \hat{H}_R + h.c.) + \hat{\mu}^2 H_L^\dagger \hat{H}_L, \]  
(11)

contributes to the Higgs masses at tree level. The mass of \( \phi_0 \) and new scalar self-interactions are given by [10]

\[ m_{\phi_0}^2 = \frac{\mu_r^2 f \tilde{f}}{f^2 + f^2 \cos^2 x} \left[ \tilde{f}^2 (\cos x + \frac{\sin x}{x} (3 + x^2)) + 2 \cos x + \frac{f^2 \cos^2 x (1 + \cos x)}{2 \tilde{f}^2} \right], \]  
(12)

\[ h\phi_0\phi_0 : x (30 \cdot p_2 \cdot p_3 + 11 \cdot p_1 \cdot p_1)/(27 \sqrt{5} f), \]  
(13)

here \( p_1, p_2, \) and \( p_3 \) refer to the incoming momentum of the first, second, and third particle, respectively. From above we can see that the mass of the neutral Higgs boson \( \phi_0 \) is a free parameter and is determined by \( \mu_r \) and \( f \). Here we consider another possibility, in which the mass is in the low mass region where the new decay \( h \to \phi_0\phi_0 \) can be open.

### III. Higgs decay branching ratios in LRTH model

In the LRTH model, the major decay modes of the Higgs boson are the SM-like ones: \( h \to f \tilde{f} (f = b, c, \tau) \), \( WW \) and \( ZZ \). The LRTH model gives corrections to these decay modes via the corresponding modified Higgs couplings

\[ \Gamma(h \to XX) = \Gamma(h \to XX)_{SM}(g_{hXX}/g_{hXX}^{SM})^2, \]  
(14)

where \( X \) denotes a SM particle, \( \Gamma(h \to XX)_{SM} \) is the decay width in the SM, and the \( g_{hXX} \) and \( g_{hXX}^{SM} \) are the couplings of \( hXX \) in the LRTH model and SM, respectively. The loop-induced
decays $H \rightarrow gg$ and $H \rightarrow \gamma\gamma$ will be also important for a low Higgs mass. In the LRTH model, in addition to the corrections via the modified couplings $ht\bar{t}$ and $hWW$, the new heavy T-quark and charged gauge bosons can also contribute to their decay widths \cite{19}. For the decay $h \rightarrow Z\gamma$, the $W$ boson loop contribution is dominant \cite{20} and thus we only consider the alteration of the Higgs coupling with the $W$ boson. Because the QCD radiative corrections are rather small \cite{21}, our results is precise enough.

As discussed in \cite{14}, the mass of neutral Higgs boson $\phi_0$ may be as low as 50 GeV. Therefore, in addition to the SM decay channels, the new decay $h \rightarrow \phi_0\phi_0$ will open for $m_h \geq 2m_{\phi_0}$, and the partial width is given by

$$\Gamma(h \rightarrow \phi_0\phi_0) = \frac{g_{h\phi_0\phi_0}^2}{8\pi m_h} \sqrt{1 - \frac{4m_{\phi_0}^2}{m_h^2}}, \quad (15)$$

here $g_{h\phi_0\phi_0}$ is the couplings of $h\phi_0\phi_0$.

In the LRTH model, the SM-like Higgs mass can be obtained via the minimization of the Higgs potential, which depends slightly on $M$ and $\Lambda$ but is insensitive to $f$. Varying $M$ between 0 and 150 GeV, $\Lambda$ between $2\pi f$ and $4\pi f$, its mass is found to be in the range of 145 – 180 GeV \cite{10}. However, if we take a little smaller value of $\Lambda$, the lower bound on the SM-like Higgs mass will be relaxed. In our calculations, the free parameters involved are $f$, $M$, $m_{\phi_0}$ and the Higgs boson mass $m_h$. For the Higgs boson mass, we will take it in the range of 110 GeV – 200 GeV. Following Ref. \cite{10}, we will assume that the values of the free parameters $f$ and $M$ are in the ranges of 500 GeV – 1500 GeV and $0 \leq M \leq f$, respectively.

A search strategy of the Higgs boson depends sensitively on its branching ratios (BR): In the SM, the major decay mode for $m_h < 2m_W$ is into $b\bar{b}$ while that for $m_h > 2m_W$ is into $W^+W^-$. In the LRTH model, there may be one new decay mode $h \rightarrow \phi_0\phi_0$ for Higgs boson. Fig. 1 show the Higgs decay branching ratios as a function of the Higgs mass $m_h$ in the LRTH model for $f = 500$ GeV and $m_{\phi_0} = 50$ GeV, 70 GeV, respectively. We see that the dominant decay channel is $h \rightarrow WW$ for $160$ GeV $< m_h < 200$ GeV, similar to the SM prediction. But for the $m_{\phi_0} = 50$ GeV case, the decay $h \rightarrow \phi_0\phi_0$ is dominant and over 70% for $120$ GeV $< m_h < 160$ GeV, then it decreases as $m_h$ gets large and become comparable with $h \rightarrow WW$ at about 160 GeV. For $2m_{\phi_0} < m_h < 160$ GeV, the decay width of $h \rightarrow \phi_0\phi_0$ is much larger than the decay $h \rightarrow bb$. The reason is that the Higgs couplings is of the electroweak strength and much larger than the Yukawa coupling of $b$ quark. Here we fixed $f = 500$ GeV and did not show the
dependence of $f$, the decay $h \rightarrow \phi_0\phi_0$ becomes less important as $f$ gets larger.

In table 1, we list the Higgs decay branching ratios normalized to the SM predictions for three main channels in the LRTH model. Table 1 shows that the deviation from the SM prediction for each decay mode becomes small as $f$ gets large. The deviation from the SM prediction is also sensitive to the Higgs boson mass. For $m_h = 120GeV$, and $500GeV \leq f \leq 1000GeV$, the deviations for the decay $h \rightarrow bb$ and $h \rightarrow gg$ are in the ranges of $11\% - 68\%$, $18\% - 78\%$, respectively. For the decay modes $h \rightarrow gg$ and $h \rightarrow \gamma\gamma$, the deviations from the SM predictions are also sensitive to $M$, which are not shown here. We will show the dependence of these decay modes on $M$ later.

Table 1: The value $R_{BR} = BR^{LRTH}(h \rightarrow XX)/BR^{SM}(h \rightarrow XX)$ is defined as a ratio of the Higgs decay branching ratios in LRTH model to one in the SM for $m_h = (120, 150, 180)GeV$, where $X = bb, gg$ and $\gamma\gamma$ with $M = 150GeV$ and $m_{\phi_0} = 50GeV$.

| $f$ (GeV) | $R_{BR}(bb)$ | $R_{BR}(gg)$ | $R_{BR}(\gamma\gamma)$ |
|-----------|-------------|-------------|------------------|
| 500       | 0.32        | 0.17        | 0.94             |
| 700       | 0.65        | 0.44        | 0.98             |
| 1000      | 0.89        | 0.77        | 0.99             |

IV. The rates $\sigma(gg \rightarrow h) \times BR(h \rightarrow \gamma\gamma(W^+W^-))$ at LHC in the LRTH model
In the SM the Higgs production at the LHC is dominated by gluon fusion process. The $h \to \gamma\gamma$ channel shows very good sensitivity in the range of $114\text{GeV} < m_h < 140\text{GeV}$. Especially, the rate $\sigma(gg \to h) \times BR(h \to \gamma\gamma)$ can be measured to $10\% (30\%)$ with an integrated luminosity $100\text{fb}^{-1} (10\text{fb}^{-1})$ from both ATLAS and CMS\cite{22}. Once we find a light Higgs boson at the LHC, this channel can provide a test for different models. In the LRTH model, $\sigma(gg \to h)$ is strongly correlated with the decay width $\Gamma(gg \to h)$. In our results we use $\sigma(gg \to h)$ to denote the hadronic cross section of the Higgs production proceeding through $gg \to h$ at parton level. We use CTEQ6L\cite{23} for parton distributions, with the renormalization scale $\mu_R$ factorization scale $\mu_F$ chosen to be $\mu_R = \mu_F = m_h$.

In Fig. 2 show the rates of $\sigma(gg \to h) \times BR(h \to \gamma\gamma)$ normalized to the SM prediction in the LRTH model as a function of $m_h$ for $M = 150\text{GeV}$, $m_{\phi_0} = 50\text{GeV}$ and various values of $f$. One can see from Fig. 2 that compared with the SM predictions, the LRTH model can suppress the rates sizably for a small value of $f$. The reason for such a severe suppression is that the decay mode $h \to \phi_0\phi_0$ can be dominant in some part of the parameter space and thus the total decay width of Higgs boson becomes much larger than the SM value. For example, for $f = 500\text{GeV}$ and $m_H = 120(150)\text{GeV}$, the rates are suppressed to about 0.2(0.1) relative to the SM predictions in LRTH model.
Figure 3: Same as Fig.2 but for the case of $m_h < 2m_{\phi_0}$.

Fig. 3 show the rates of $\sigma(gg \to h) \times BR(h \to \gamma\gamma)$ normalized to the SM prediction in the LRTH model as a function of $m_h$ for the case of $m_h < 2m_{\phi_0}$. One can see that, as $f$ gets large, the suppression is weakened sharply. The deviation from the SM prediction is also sensitive to the mixing parameter $M$. This is because $M$ is introduced to generate the mass mixing term $M q_L q_R$, and the LRTH model can give corrections via the coupling of $h t\bar{t}$ and the heavy T-quark loop. For $m_h = 120 GeV$ and $f = 500 GeV$, the suppression of SM predictions can reach 28\% and 33\% for $M = 0 GeV$ and $M = 150 GeV$, respectively. The rate for $gg \to H \to \gamma\gamma$ can be measured with a precision of $10 - 15\%$ for $m_h < 150 GeV$. Therefore, it is possible to probe the LRTH model via such a process at the LHC.

When Higgs mass is relatively heavy ($2m_W < m_h < 2m_Z$), the decay $h \to WW \to l\nu l\nu$ is an excellent channel for searching for Higgs boson $[24]$. In Fig. 4 we plot the rates of $\sigma(gg \to h) \times BR(h \to W^+W^-)$ normalized to the SM prediction in the LRTH model versus the value of $f$ for $m_h = 180 GeV$ and $m_{\phi_0} = 50 GeV$. We see that, compared with the SM prediction, the LRTH model can suppress the rates significantly for a small of $f$. For $M = 150 GeV$ and $500 GeV \leq f \leq 800 GeV$, the suppression of SM prediction is in the range of $37\% - 14\%$, which can exceed the experimental uncertainty ($10\% - 20\%$) $[25]$.

It has been shown $[26]$ that, the Higgs boson can dominantly decay into a pair of pseudoscalar boson. Together with smaller $g_{ZZh}$ and $B(h \to b\bar{b})$ than in the SM, the LEP Higgs
boson mass bound based on the limit \((g_{ZZh}/g_{ZZh}^{SM})^2 B(h \rightarrow b\bar{b})\) can be reduced. In Ref.\[27\], the authors shown that \(h \rightarrow \eta\eta \rightarrow b\bar{b}b\bar{b}\) is complementary and can be used to detect the intermediate Higgs boson at the LHC, via \(Wh\) and \(Zh\) production. In the LRTH model, \(\phi_0\) mainly decays into \(b\bar{b}, c\bar{c}\), or \(\tau^+\tau^-\). The decay branching ratio of \(\phi_0 \rightarrow b\bar{b}, c\bar{c}\), and \(\tau^+\tau^-\) are close to the corresponding SM Higgs decay branching ratios \[10\]. Thus the ultimate dominant decay mode of the Higgs can be \(h \rightarrow \phi_0\phi_0 \rightarrow b\bar{b}b\bar{b}\). Detailed study needs to be done to optimize the cuts and identify the signal from the background. Such study is beyond the scope of the current paper and we leave it for future work.

V. The process \(\gamma\gamma \rightarrow h \rightarrow b\bar{b}\) in the LRTH model

While the LHC is widely regarded as discovery machine for Higgs boson, a precision measurement of Higgs property can be only achieved at the proposed International Linear Collider (ILC)\[28\]. A unique feature of the ILC is that it can be transformed to \(\gamma\gamma\) modes by the laser-scattering method. Such an option of photon-photon collision can possibly measure the rates of the Higgs production with a precision of a few percent. Especially, for \(\gamma\gamma \rightarrow h \rightarrow b\bar{b}\) process, the production rate could be measured at about 2\% for a light Higgs boson \[29\]. Such a process \(\gamma\gamma \rightarrow h \rightarrow b\bar{b}\) is a sensitive probe for new physics because the loop-induced \(h\gamma\gamma\) coupling and the \(hb\bar{b}\) coupling are sensitive to new physics \[30\].

Figure 4: The value of \(\sigma(gg \rightarrow h) \times BR(h \rightarrow W^+W^-)\) normalized to the SM prediction in the LRTH model versus the value of \(f\) with three values of \(M\) as indicated.
Figures 5 and 6 show the numerical results for the rate $\sigma(\gamma\gamma \rightarrow h) \times BR(h \rightarrow b\bar{b})$ normalized to the SM prediction in the LRTH model as a function of $m_h$ for $M = 150 GeV$, $m_{\phi_0} = 50 GeV$, and various values of $f$ as indicated.

Figure 5: The value of $\sigma(\gamma\gamma \rightarrow h) \times BR(h \rightarrow b\bar{b})$ normalized to the SM prediction in the LRTH model as a function of $m_h$ for $M = 150 GeV$, $m_{\phi_0} = 50 GeV$, and various values of $f$ as indicated.

Figure 6: Same as Fig. 5 but for the case of $m_h < 2m_{\phi_0}$.

From Fig. 5, we can see that the rate have a sizable deviation from the SM prediction, and the magnitude of deviation is sensitive to the scale $f$. For $M = 150 GeV$, $m_h = 120 GeV$, and
$500GeV \leq f \leq 1000GeV$, the suppression is in the range of $70\% - 12\%$. The reason for such a serve suppression is similar to what have been discussed above, i.e., the opening of new decay mode. In the case of $m_h < 2m_{\phi_0}$, the new decay mode $h \rightarrow \phi_0\phi_0$ is kinematically forbidden. Fig.6 show that the LRTH model also suppresses the rate $\sigma(\gamma\gamma \rightarrow h) \times BR(h \rightarrow b\bar{b})$, but the suppression can only reach about 4%. This is because the contribution from the LRTH model mainly come from the loops of new top partner and heavy charged gauge boson, in addition to the modified couplings $h\tilde{t}\tilde{t}$ and $hWW$ at order $v^2/f^2$ [19]. For a large value of $f$, the suppression is only a few percent.

VI. Conclusion

The twin Higgs mechanism provides an alternative method to solve the little hierarchy problem. The Left-right twin Higgs model is a concrete realization of the twin Higgs mechanism, which predicts one neutral scalar particle $\phi_0$. With the $\mu$ term introduced by hand, the $\phi_0$ boson acquires mass $m_{\phi_0} \sim \mu_v$, which can be lighter than half the Higgs boson mass in a portion of parameter space. In this paper we focus on the case of $m_h \geq 2m_{\phi_0}$ so that the new decay $h \rightarrow \phi_0\phi_0$ can be open. From our numerical results we obtain the following observations: (i) For the Higgs decay, we found that, with $f = 500GeV$ and $2m_{\phi_0} < m_h < 160GeV$, the new decay $h \rightarrow \phi_0\phi_0$ can be the dominant mode and it can give very different branching ratios from the SM prediction. The branching ratios of the conventional decay modes of the Higgs boson, $h \rightarrow gg$ and $h \rightarrow b\bar{b}$, can be suppressed over 60%, 50%, respectively; (ii) For the rates $\sigma(gg \rightarrow h) \times BR(h \rightarrow \gamma\gamma(W^+W^-))$ at the LHC, the LRTH model can give severe suppression relative to the SM predictions, whenever the neutral scalar mass is less than the mass of the Higgs boson; (iii) For the process $\gamma\gamma \rightarrow h \rightarrow b\bar{b}$, the LRTH model can always suppress the rate for the cases of $m_h > 2m_{\phi_0}$ and $m_h < 2m_{\phi_0}$, respectively. However, the production rate can be severely suppressed in some of the parameter space where the new decay mode is open and dominant for the case of $m_h > 2m_{\phi_0}$; (iv) The Higgs production cross section times the branching ratios of the conventional decays can be all suppressed significantly for a small value of the scale $f$. Therefore, it is possible to probe the LRTH model via these Higgs boson production processes at the LHC experiment or in the future ILC experiment.

Acknowledgments

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