

## Little Higgs theory confronted with the LHC Higgs data (Postprint)

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### Abstract

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### Full Text

## Little Higgs Theory Confronted with the LHC Higgs Data

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### Abstract

We confront the little Higgs theory with the LHC Higgs search data (up to 17 fb<sup>-1</sup> of the combined 7 and 8 TeV run). Considering some typical models, namely the littlest Higgs model (LH), the littlest Higgs model with T-parity (LHT-A and LHT-B) and the simplest little Higgs model (SLH), we scan over the parameter space in the region allowed by current experiments. We find that in these models the inclusive and exclusive (via gluon-gluon fusion) diphoton and ZZ\* signal rates of the Higgs boson are always suppressed and approach the SM predictions for a large scale f. Thus, the ZZ\* signal rate is within the 1 range of the experimental data while the inclusive diphoton signal rate is always outside the 2 range. Especially, in the LHT-A the diphoton signal rate is outside the 3 range of the experimental data for f < 800 GeV. We also perform a global <sup>2</sup> fit to the available LHC and Tevatron Higgs data, and find that these

models provide no better global fit to the whole data set (only for some special channels can a better fit be obtained, especially in the LHT-B).

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## Introduction

To solve the fine-tuning problem of the Standard Model (SM), the little Higgs theory [1] is proposed as an electroweak symmetry breaking mechanism accomplished by a naturally light Higgs sector. So far various realizations of the little Higgs have been proposed [2-4], which can be categorized generally into two classes [5]. One class utilizes a product group structure, represented by the littlest Higgs model (LH) [3] in which the SM  $SU(2)$  gauge group arises from the diagonal breaking of two (or more) gauge groups. To relax the constraints from electroweak precision data [6], a discrete symmetry called T-parity is introduced to the LH [7, 8]. The LH with T-parity (LHT) can provide a candidate for cosmic dark matter. The other class uses a simple group structure, represented by the simplest little Higgs model (SLH) [4] in which a single large gauge group is broken down to the SM  $SU(2)$ . Since these little Higgs models predict different Higgs properties from the SM, they can be tested in Higgs search experiments.

Recently, the CMS and ATLAS collaborations announced the observation of a new boson around 125 GeV [9, 10]. This observation is corroborated by Tevatron search results which showed a 2.5 excess in the range 115-135 GeV [11]. The LHC search results have been updated using 17 fb<sup>-1</sup> of 7 TeV and 8 TeV data [12-16]. We note that for the inclusive data, the signal rates of  $ZZ^*$  and  $WW^*$  are consistent with SM values while the diphoton rate is sizably higher than the SM expectation. For the  $Vb\bar{b}$  and  $\tau\tau$  channels, the uncertainties are still large.

Although the inclusive Higgs search data is roughly consistent with SM predictions so far, the diphoton enhancement has been explained in various new physics models, such as SUSY models [17], two-Higgs-doublet models [18], the Higgs triplet model [19], models with extra dimensions [20], and other extensions of Higgs models [21]. For the little Higgs theory, the Higgs properties (especially the diphoton decay) were thoroughly studied [22] even before the LHC Higgs data. In this work we use the latest LHC Higgs data to check the status of the little Higgs theory. We examine some typical models, namely the littlest Higgs model (LH), the littlest Higgs model with T-parity (LHT-A and LHT-B) and the simplest little Higgs model (SLH). The model predictions for Higgs signal rates will be compared with experimental data. We also perform a global  $\chi^2$  fit to the available LHC and Tevatron Higgs data [23] to determine whether the little Higgs theory can provide a better fit than the SM. Additionally, we show the Higgs couplings and some exclusive signal rates in comparison with the Higgs data as well as the SM predictions.

Our work is organized as follows. In Sec. II we recapitulate the little Higgs models. In Sec. III we confront the model predictions for Higgs signal rates with experimental data. Finally, we give our conclusion in Sec. IV.

## II. Little Higgs Models

### A. Littlest Higgs Model (LH)

The LH model [3] consists of a nonlinear sigma model with a global  $SU(5)$  symmetry which is broken down to  $SO(5)$  by a vacuum expectation value (VEV)  $f$ . A subgroup  $[SU(2) \times U(1)]^2$  of  $SU(5)$  is gauged. The heavy gauge bosons ( $W, Z, A$ ), triplet scalar ( $\Phi, \Phi, \Phi, \Phi$ ) and top quark partner  $T$  quark are respectively introduced to cancel the one-loop quadratic divergence of the Higgs mass contributed by the gauge bosons, Higgs boson and top quark of the SM. Their masses are given as

$$m_Z = m_W = \sqrt{(1-x^2)} m_A = g' f / (5s' c' \sin \nu)$$

where  $h$  and  $\nu$  are respectively the SM-like Higgs boson and its vacuum expectation value (vev),  $c, s, c', s'$  and  $s' - c'$  are the mixing parameters in the gauge boson sector,  $x$  is a free parameter of the Higgs sector proportional to the triplet vev  $v'$  and defined as  $x = 4fv' / v^2$ ,  $c$  and  $s$  are the mixing parameters between  $t$  and  $T$ .

The relevant Higgs couplings are given as [24, 25]

$$L = 2y_W W W h + 2y_Z Z Z h - y_t \bar{t} t h - y_\Phi \Phi \Phi h - 2y_T T \bar{T} h - y_\Phi \Phi \Phi h, y_{ffh} (f = b, \tau)$$

$$y_W = 1 + (c^2 - s^2)^2 (v^2/f^2) / (16^2), y_Z = 1 + (c'^2 - s'^2)^2 (v^2/f^2) / (16^2), y_\Phi = y_\Phi = y = -c^2 (v^2/f^2) / (16^2), y_T = 1 + O(v/f)$$

In the LH model the relation between  $GF$  and  $v$  is modified from its SM form, which can induce [25]

$$v = v_{SM} [1 - (v^2/f^2)(-x^2)], \text{ where } v_{SM} = 246 \text{ GeV is the SM Higgs vev.}$$

### B. Littlest Higgs Models with T-Parity (LHT)

T-parity requires that the coupling constant of  $SU(2) \times U(1)$  equals that of  $SU(2) \times U(1)$ , which leads to the four mixing parameters in the gauge sector  $c, s, c'$  and  $s'$  all equaling  $1/\sqrt{2}$ . Under T-parity, the SM bosons are T-even and the new bosons are T-odd. Therefore, the coupling  $H^\dagger H$  is forbidden, leading to the triplet vev  $v' = 0$  and  $x = 0$ . Since the correction of  $W$  to the relation between  $GF$  and  $v$  is forbidden by T-parity, the Higgs vev  $v$  differs from that of the LH [26], which is

$$v = v_{SM} (1 + v^2/f^2).$$

Taking  $c = s = c' = s' = 1/\sqrt{2}$  and  $x = 0$ , we can obtain the Higgs couplings to the gauge bosons and scalars of the LHT from Eq.(2) and Eq.(3).

For each SM quark (lepton), a heavy copy of mirror quark (lepton) with T-odd quantum number is added to preserve T-parity. The Higgs couplings to each generation of mirror quarks are given by [26]

$$\mathcal{L} = -(1+c) m_q \bar{q}_L q_R - m_q \bar{L} R + \text{h.c.} - (1-c) m_q \bar{u}_L q_R - (1-c) m_q \bar{u}_L R$$

with  $c = \cos((v+h)/\sqrt{2}f)$  and  $s = \sin((v+h)/\sqrt{2}f)$ . After diagonalization of the mass matrix in Eq.(6), we can get the T-odd mass eigenstates  $u, q$  and  $\bar{u}$  as well as their couplings to the Higgs boson.

For the implementation of T-parity in the Yukawa sector of the top quark, the T-parity images for the original top quark interaction of the LH are introduced to make the Lagrangian T-invariant [26, 27],

$$\mathcal{L} = f [s\Sigma/\sqrt{2} \bar{t}L+tR + (1+c\Sigma)/\sqrt{2} \bar{U}L+tR] - f \bar{U}L+UR + \text{h.c.}$$

with  $c\Sigma = \cos(2(v+h)/\sqrt{2}f)$  and  $s\Sigma = \sin(2(v+h)/\sqrt{2}f)$ . The mass eigenstates  $t$  and  $T$  can be obtained by mixing the interaction eigenstates in Eq.(7). The mixing parameters are the same as  $c$  and  $s$  of the LH, which are given by

$$c = r^2/(r^2 + 1), s = 1/(1 + r^2)$$

where  $r = \sqrt{f^2 - v^2}/v$ . The Higgs couplings to  $t$  and  $T$  are the same as those of LH with  $x = 0$ .

For the SM down-type quarks (leptons), the Higgs couplings of LHT have two different cases [26]:

$$C_{dd} = 1 - (v^2/f^2) \text{ for LHT-A,}$$

$$C_{dd} = 1 + (v^2/f^2) \text{ for LHT-B.}$$

The relation of down-type quark couplings also applies to the lepton couplings.

### C. Simplest Little Higgs Model (SLH)

The SLH [4] model has an  $[SU(3) \times U(1)]^2$  global symmetry. The gauge symmetry  $SU(3) \times U(1)$  is broken down to the SM electroweak gauge group by two copies of scalar fields  $\Phi$  and  $\bar{\Phi}$ , which are triplets under  $SU(3)$  with aligned vevs  $f$  and  $\bar{f}$ .

The new heavy charged gauge boson  $W'_{\pm}$  can contribute to the effective  $h$  coupling.

The Higgs couplings to  $W', W, WW$  and  $ZZ$  are given by [28]

$$\mathcal{L} = 2yW' W' W' h + 2yW W W h + 2yZ ZZh,$$

where

$$yW' = (v^2/2f^2),$$

$$yW = yZ = (-t^2 + 1)/(-t^2 + 1) + (1 - t^2)/(-t^2 + 1) (1 - t^2W)$$

with  $f = \sqrt{f^2 + \bar{f}^2}$ ,  $t = \tan \theta = f/\bar{f}$ ,  $c = \bar{f}/f$ ,  $s = f/\bar{f}$  and  $tW = \tan W$ .

The gauged  $SU(3)$  symmetry promotes the SM fermion doublets into  $SU(3)$  triplets. The Higgs interactions with the quarks are given by

$$\begin{aligned} L &= -f [c t' L + s t' L] + \text{h.c.}, \\ L_d &= -f_d [c d' L + s d' L] + \text{h.c.}, \\ L_s &= -f_s [c s' L + s s' L] + \text{h.c.}, \end{aligned}$$

where

$$s = \sin(t(h+v)/\sqrt{2f}), \quad c = \cos((h+v)/\sqrt{2f}).$$

After diagonalization of the mass matrices in Eqs.(14), (15) and (16), we can get the mass eigenstates  $(t, T)$ ,  $(d, D)$  and  $(s, S)$  as well as their couplings to the Higgs boson.

The Higgs couplings to  $b\bar{b}$  and  $\tau\tau$  normalized to the SM values are

$$C_{b\bar{b}} = C_{\tau\tau} = (1 - t^2)/(1 + t^2).$$

The SLH model predicts a pseudo-scalar  $A$ , which obtains its mass via a tree-level term,

$$-2(\Phi^\dagger \Phi + \text{h.c.}) = -2f^2 s c \cos(\sqrt{2f} s c) + (1/2)m^2 A^2 + \dots$$

with  $H$  being the SM-like Higgs doublet field.

In the SLH, the relation between  $GF$  and  $v$  is modified from its SM form, which can induce [28]

$$v = v_{\text{SM}} [1 - (v^2/12f^2)(1 - t^2) + (v/180f)(-t + 1)/(1 + t^2)].$$

### III. Higgs Properties Confronted with the Higgs Data

#### A. Calculations

As an effective theory, the Higgs potential of little Higgs models is affected by the theory at the cutoff scale [29]. We assume that there are large direct contributions to the potential from the physics at the cutoff, so that the constraints of Higgs mass on the parameter space of the little Higgs models are greatly loosened. In our calculations, the Higgs mass is fixed as 125.5 GeV. We consider the relevant QCD and electroweak corrections using the code Hdecay [30]. For Higgs production and decays, the little Higgs models give corrections by directly modifying the Higgs couplings to the relevant SM particles.

For the loop-induced decays  $h \rightarrow gg$  and  $h \rightarrow \gamma\gamma$ , the little Higgs models give partial corrections via the reduced  $h\bar{t}t$  and  $hWW$  couplings, respectively. Besides,  $h \rightarrow gg$  can be corrected by loops of the heavy partner quark  $T$  in the LH,  $T$  and  $T$ -odd quarks in the LHT, and  $T$ ,  $D$  and  $S$  in the SLH. In addition to the loops of heavy quarks involved in  $h \rightarrow gg$ , the decay  $h \rightarrow \gamma\gamma$  can also be corrected by loops of  $W$ ,  $\Phi$ ,  $\Phi'$  in the LH and LHT and by  $W'$  in the SLH. Note that the LHT and SLH also predict some neutral heavy neutrinos, which do not contribute to the  $h \rightarrow \gamma\gamma$  coupling at the one-loop level. Although charged heavy leptons are predicted by the LHT, they do not have direct couplings with the Higgs boson.

In the LH the new free parameters are  $f$ ,  $c$ ,  $c'$ ,  $s$  and  $x$ . We scan over these parameters in the ranges:

$$1 \text{ TeV} < f < 3.5 \text{ TeV}, 0 < c < 1, 0 < c' < 1, 0.45 < c < 0.9, 0 < x < 1.$$

Since the  $h\Phi\Phi$  coupling is very small, the contributions of the doubly-charged scalar to the effective  $h$  coupling can be ignored.

In the LHT, the new T-odd quarks can give additional contributions to  $h \rightarrow gg$  and  $h \rightarrow \gamma\gamma$  via loops, which are not sensitive to the actual values of their masses as long as they are much larger than half of the Higgs boson mass. The parameters  $c = s = c' = s' = 1/\sqrt{2}$  and  $x = 0$  are fixed by T-parity. T-parity can relax the constraints from electroweak precision data sizably, leading to a scale  $f$  as low as 500 GeV [31]. In our calculation we scan  $f$  in the range of 0.5-3.5 TeV.

In the LH and LHT, the parameter  $c$  determines the Higgs couplings to  $t$ ,  $T$  and  $mT$ , and is involved in the calculations of  $h \rightarrow gg$  and  $h \rightarrow \gamma\gamma$ . The  $c$  dependence of the top quark loop and  $T$  quark loop can cancel to a large extent (see Eq.(3)). For  $0.45 < c < 0.9$ , the corresponding parameter  $r$  varies from 0.5 to 2.0, which is favored by electroweak precision data [31]. Besides, for the LH, the  $c$  and  $s$  dependence of the  $W$  loop and  $W$  loop in the  $h \rightarrow \gamma\gamma$  decay can cancel each other to some extent (see Eq.(3)). The parameter  $x$  can affect  $\Gamma(h \rightarrow \gamma\gamma)$  and  $\Gamma(h \rightarrow \gamma b\bar{b})$ , but the effects of  $x$  on  $\Gamma(h \rightarrow \gamma\gamma)/\Gamma(h \rightarrow \gamma b\bar{b})$  are weakened to a large extent (see Eq.(3)). For  $m = 125.5$  GeV, the decay  $h \rightarrow A A$  is kinematically forbidden in the LH and LHT.

In the SLH, we take  $f$ ,  $t$ ,  $mT$ ,  $mD$ ,  $mS$  and  $m$  as new free parameters. Ref. [4] shows that LEP-II data requires  $f > 2$  TeV. Here, we assume the new flavor mixing matrices in lepton and quark sectors are diagonal [5, 32] so that  $f$  and  $t$  are free from experimental constraints of lepton and quark flavor violating processes. Besides, the contributions to EWPD can be suppressed by a large  $t$  [4, 33]. For perturbation to be valid,  $t$  must be such that  $O(v/f) < 0.1$  in the expansion of  $\Gamma$ . The small masses of d-quark and s-quark require that  $d$  and  $s$  are very small. So there is almost no mixing between the SM down-type quarks and their heavy partners, and the results are not sensitive to  $mD$  and  $mS$ . In addition to SM-like decays, the new decays  $h \rightarrow \gamma\gamma$  and  $h \rightarrow Z\gamma$  are open for a sufficiently light  $\gamma$ , whose partial widths are given by

$$\begin{aligned} \Gamma(h \rightarrow \gamma\gamma) &= (\gamma^2/32 f^2) m \sqrt{(1-x)}, \\ \Gamma(h \rightarrow Z\gamma) &= (\gamma^2/32 f^2) m (1-xZ, x), \end{aligned}$$

where  $\gamma^2 = -m^2/(2f^2 s c)$ ,  $xZ = mZ^2/m^2$ ,  $x = 4m^2/m^2$  and  $(1-x, y) = (1-x-y)^2 - 4xy$ .

The constraint from the nonobservation in the decay  $\Upsilon \rightarrow \gamma\gamma$  excludes  $\gamma$  with a mass below  $2f s c$  [34]. So, we scan over the following parameter space:

$$0.5 \text{ TeV} < mD \text{ (mS)} < 3 \text{ TeV}, 1 < t < 30, 10 \text{ GeV} < m < 500 \text{ GeV}.$$

## B. Numerical Results and Discussions

The diphoton and  $ZZ^*$  channels are the cleanest channels for the Higgs boson. We show their inclusive signal rates normalized to the SM values in Fig. 1 and Fig. 2, respectively. The experimental data come from [12] for ATLAS and [13] for CMS. In combining the data from the two collaborations, we assume they are independent and Gaussian distributed. The figures show that the rates for the two signals in the little Higgs models are always suppressed, and approach the SM predictions for a large scale  $f$ .

For the diphoton channel, in these models the signal rates are always outside the  $2\sigma$  range of the experimental data. Especially, in the LHT-A the rate is outside the  $3\sigma$  range for  $f < 800$  GeV. In the SLH the diphoton rate is also sensitive to  $\tan\beta$  and the data favors a small  $\tan\beta$ . The value of  $m_h$  can be as low as 10 GeV, and the total branching ratio of  $h \rightarrow Z\gamma$  and  $h \rightarrow \gamma\gamma$  can only reach 15% to make the diphoton rate within the  $3\sigma$  range.

For the  $ZZ^*$  channel, these models can fit the LHC experimental data quite well. The signal rate can equal the central value of the experimental data for  $1 \text{ TeV} < f < 1.6 \text{ TeV}$  in the LH,  $f = 1.2 \text{ TeV}$  in the LHT-A,  $f = 0.8 \text{ TeV}$  in the LHT-B, and  $2 \text{ TeV} < f < 6 \text{ TeV}$  in the SLH. For the LH, LHT-A and LHT-B, the rate of  $ZZ^*$  is always within the  $2\sigma$  range of the experimental data in the scanned parameter ranges. For the SLH, only the parameter space where the total branching ratio of  $h \rightarrow Z\gamma$  and  $h \rightarrow \gamma\gamma$  is larger than 60% is disfavored.

Now we perform a global  $\chi^2$  fit to the available LHC and Tevatron Higgs data in these little Higgs models. We compute the  $\chi^2$  values by the method introduced in [35, 36] with the experimental data of 21 channels from [23], which are shown in Fig. 7. We assume that data from different collaborations or for different inclusive search channels are independent. However, the data for different exclusive search channels presented by one collaboration are not independent, and we use the correlation coefficient given in [23]. Note that the Higgs mass from  $h \rightarrow ZZ^* \rightarrow 4\gamma$  data from ATLAS is about 123.5 GeV, which differs from that of the diphoton data at more than  $2\sigma$  level. Therefore, we rescale the rate at  $m_h = 123.5$  GeV for a Higgs mass of 125 GeV and use data  $\sigma(ZZ) = 1.15 \cdot \sigma_{SM}$  at  $m_h = 125$  GeV [15, 23]. For the case of  $\sigma(ZZ) = \hat{\sigma}$ , we use  $\sigma = \hat{\sigma}$  for  $(XX)$  and  $\sigma = \hat{\sigma}$  for  $(XX)$ .

In Fig. 3 we project these samples on the plane of  $\chi^2$  versus  $f$ . We see that the  $\chi^2$  values of these models are larger than the SM value and approach the SM value for a sufficiently large  $f$  (larger than 2 TeV, 3 TeV, 1.6 TeV and 3 TeV for the LH, LHT-A, LHT-B and SLH, respectively). Especially, in the LHT-A the value of  $\chi^2$  is larger than 32.7 for  $f < 530$  GeV, which implies that  $f < 530$  GeV is excluded at 95% confidence level from an experimental viewpoint.

Figs. 4 and 5 show the Higgs couplings normalized to the SM values. We see that in these little Higgs models the Higgs couplings are all suppressed, and approach the SM values for a large  $f$ . The correlations between the couplings

are also interesting and may be useful for distinguishing different models. For example, the value of  $|C_{gg}/SM|/|C_{\bar{b}b}/SM|$  is around 1 for the LH and SLH, but smaller than 1 for the LHT-A and LHT-B. In the LHT-A and LHT-B, the T-odd quarks further suppress the  $hgg$  coupling, and the suppression is equal compared with that of the top quark and T quark. Note that the reduced  $\bar{b}b$  coupling can suppress the total width of the 125.5 GeV Higgs boson, which helps to enhance the branching ratios of  $h \rightarrow \gamma\gamma, WW, ZZ, \dots$ . However, the reduced  $hgg$  coupling suppresses the cross section of  $gg \rightarrow h$  more sizably, and the reduced couplings  $h\gamma\gamma, hWW, hZZ$  and  $h\bar{b}b$  suppress the widths of  $h \rightarrow \gamma\gamma, WW, ZZ, \dots$ . Besides, the total width of the Higgs boson in the SLH is enhanced by the new decay modes  $h \rightarrow Z\gamma$  and  $h \rightarrow \gamma\gamma$  for a light  $\gamma$ , and thus the signal rates are reduced further.

Figs. 4 and 5 show that the Higgs couplings of LHT-B can be very different from those of the SM, which can lead to interesting Higgs phenomena at colliders. Therefore, we pay special attention to this model in the following discussions, with LHT-A also considered comparatively.

In Fig. 6 we show the exclusive diphoton signal rates from the VBF + VH and  $ggF + \bar{t}tH$  channels. We can see that, although the Higgs couplings and inclusive diphoton rate are always reduced, the exclusive rate of VBF + VH can be enhanced in the LHT-B. The reason is that the  $\bar{b}b$  coupling in the LHT-B is suppressed much more sizably, which greatly enhances the branching ratio of  $h \rightarrow \gamma\gamma$ . Therefore, the LHT-B is favored by the enhanced exclusive diphoton data of VBF + VH from ATLAS and CMS (note that the data has a rather large uncertainty).

Now we take some benchmark points in the LHT-A and LHT-B to demonstrate the Higgs properties in Table I and Fig. 7. We see that in the LHT-A all signal rates are suppressed while in the LHT-B the exclusive signal rates (except  $h \rightarrow \bar{b}b$  and  $h \rightarrow \gamma\gamma$ ) of VBF + VH are enhanced, especially for a small  $f$ . Compared to the experimental data shown in Fig. 7, we find that the LHT-B can provide a better fit than the SM for some channels like VBF + VH,  $\gamma\gamma$  from ATLAS and CMS, incl.  $ZZ, 0/1\text{ jet}, WW, \dots$  data from CMS.

## IV. Conclusion

In this paper we compared the properties of the SM-like Higgs boson predicted by typical little Higgs models (namely the LH, LHT-A, LHT-B and SLH) with the latest LHC Higgs search data. For a SM-like Higgs boson around 125.5 GeV, we obtained the following observations: (i) In these models the inclusive diphoton signal rates cannot be enhanced and lie outside the 2 $\sigma$  range of the present data; (ii) While most signal rates are suppressed in these models, some exclusive signal rates in the VBF and VH channels can be enhanced in the LHT-B; (iii) Compared with the SM, these models provide no better global fit to the whole data set, but for some special channels a better fit can be obtained, especially in the LHT-B; (iv) In these models the Higgs couplings are suppressed

and approach the SM values for a sufficiently large scale  $f$ .

We should stress again that in little Higgs models the inclusive diphoton rate cannot be enhanced for obvious reasons. In these models the T-quark (top quark partner) and new heavy gauge bosons are responsible for canceling the one-loop quadratic divergence of the Higgs mass contributed by the top quark and SM gauge bosons, respectively. As a result, the Higgs couplings to the top quark and T-quark have opposite sign, and the contributions of the T-quark loop reduce the effective  $hgg$  coupling. Similarly, the Higgs couplings to the W boson and the heavy charged gauge boson have opposite sign, and the contributions of the heavy charged gauge boson loop reduce the effective  $h\gamma\gamma$  coupling. In addition, with the expansion of the nonlinear sigma field, the Higgs couplings to the top quark and W boson are suppressed, which further reduces the effective  $hgg$  and  $h\gamma\gamma$  couplings. However, the  $hbb$  coupling is also reduced sizably in the LH, SLH and LHT-B, and thus the signal rates in some channels are quite close to the SM values.

Future LHC Higgs data (especially the diphoton rate) with large statistics will allow for a critical test of these little Higgs models. If the enhancement of the diphoton rates persists or becomes larger, the little Higgs models will be strongly disfavored or excluded. Otherwise, if these rates drop below the SM value, these models will be favored. Also, these models have other correlated phenomenology like enhanced Higgs pair production [37] and suppressed  $h\tau\tau$  production [38] at the LHC. All these phenomena can be jointly utilized to test the little Higgs models and distinguish them from other new physics models.

**Note added:** When this manuscript was being prepared, a paper with similar analysis and similar results appeared on arXiv [39].

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