Associated productions of the new gauge boson B_H in the Littlest Higgs model with a SM gauge boson via e^+e^- collision*

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Abstract With the high energy and luminosity, the planned ILC has the considerable capability to probe the new heavy particles predicted by the new physics models. In this paper, we study the potential to discover the lightest new gauge boson B_H of the Littlest Higgs model via the processes $e^+e^- \to \gamma(Z)B_H$ at the ILC. The results show that the production rates of these two processes are large enough to detect B_H in a wide range of the parameter spaces, specially for the process $e^+e^- \to \gamma B_H$. Furthermore, there exist some decay modes for B_H which can provide the typical signal and clean backgrounds. Therefore, the new gauge boson B_H should be observable via these production processes with the running of the ILC if it exist.

Key words Littlest Higgs model, cross section, new gauge boson B_H

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1 Introduction

A simple double scalar field yields a perfectly appropriate gauge symmetry breaking pattern in the Standard Model(SM). However, one well-known difficulty is that the mass of the Higgs boson receives quadratic loop corrections and such corrections become large at a high energy scale which is known as the hierarchy problem. In order to achieve an effective Higgs boson mass on the order of 100 GeV, as required by fits to precision electroweak parameters, new physics at the TeV scale is therefore needed to cancel the quadratic corrections in the SM. The possible new physics scenarios at the TeV scale might be supersymmetry (SUSY)[1], the extra dimension[2], and the technicolor(TC) model[3], etc. Recently, there has been a new formulation for the physics of electroweak symmetry breaking, dubbed the "Little Higgs" models[4, 5], which offer a very promising solution to the hierarchy problem in which the Higgs boson is naturally light as a result of nonlinearly realized symmetry. The key idea of the Little Higgs theory may be that the Higgs boson is a Goldstone boson which acquires mass and becomes the pseudo-Goldstone boson via symmetry breaking at the electroweak scale and remains light, being protected by the approximate global symmetry and free from 1-loop quadratic sensitivity to the cutoff scale. Such models can be regarded as the important candidates of new physics beyond the SM. The Littlest Higgs (LH) model[5], based on a $SU(5)/SO(5)$ nonlinear sigma model, is the simplest and phenomenologically viable model to realize the Little Higgs idea. It consists of a $SU(5)$ global symmetry, which is spontaneously broken down to $SO(5)$ by a vacuum condensate f. At the same time, the gauge subgroup $[SU(2)\times U(1)]^2$ is broken to its diagonal subgroup $SU(2)\times U(1)$, identified as the SM electroweak gauge group. In such breaking scenario, four new massive gauge bosons (B_H, Z_H, $W_H^{\pm}$) are introduced and their masses are in the range of a few TeV, except for B_H in the range of hundreds GeV. The existence of these new particles might provide the characteristic signatures at the present and future high energy collider experiments[6, 7] and the observation of them can be regarded as the reliable evidence of the LH model.

On the experimental aspect, although the hadron colliders Tevatron and LHC can play an important

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role in probing the new particles predicted by the new physics models, the search for new particles has strongly motivated projects at the future high energy e^+e^- linear collider, i.e., the International Linear Collider (ILC), with the center of mass (c.m.) energy $\sqrt{s}$=300 GeV—1.5 TeV and the integrated luminosity 500 fb^{-1} within the first four years[8]. With high luminosity and clean environment, the most precise measurements will be performed at the ILC.

The ILC will provide some good chances to probe the new gauge bosons in the LH model and some production processes of these new gauge bosons at the ILC have been studied[9—11]. As we know, with the mass of hundreds GeV, the gauge boson B_H is the lightest new particle in the LH model and it is light enough to be produced at the first running of the ILC. So the exploration of B_H at the ILC would play an important role in testing the LH model. We have studied some B_H production processes at the photon collider, i.e., $\gamma\gamma \to W^+W^-B_H$ and $e^-\gamma \to \gamma(Z)e^-B_H$[11]. As we know, the photon collider has advantages in probing the new particles in the new physics models. Our studies show that the sufficient typical B_H events could be detected at the photon collider. However, with the running of the ILC, B_H might be first discovered via e^+e^- collision if it exist, and the study of the B_H productions via e^+e^- collision is more imperative. In this paper, we study two interesting B_H production processes via e^+e^- collision at the ILC, i.e., $e^+e^- \to \gamma B_H$ and $e^+e^- \to ZB_H$. These processes are particularly interesting in various aspects. From an experimental point of view, these processes can produce enough B_H signals with clean backgrounds and the final states are easily detected. Furthermore, these processes can be realized at the first running of the ILC. From the theoretical point of view, these processes have a simple structure providing clean tests of the properties of the $B_He^+e^-$ coupling.

The rest parts of this paper are organized as follows. In Section II, we first present a brief review of the LH model and then give the production amplitudes of the processes. the numerical results and conclusions are given in Section III.

2 The processes $e^+e^- \to \gamma(Z)B_H$

2.1 A brief review of the LH model

The LH model is one of the simplest and phenomenologically viable models to realize the Little Higgs idea. The LH model is embedded into a non-linear σ-model with the corset space of $SU(5)/SO(5)$. At the scale $\Lambda_s \sim 4\pi f$, the vacuum condensate scale parameter f breaks the global $SU(5)$ symmetry into its subgroup $SO(5)$ resulting in 14 Goldstone bosons. The effective field theory of these Goldstone bosons is parameterized by a non-linear σ-model with a gauge symmetry $[SU(2)\times U(1)]^2$, and the $[SU(2)\times U(1)]^2$ gauge symmetry is broken to the diagonal $SU(2)_L \times U(1)_Y$ subgroup which is identified as the electroweak gauge symmetry. The effective non-linear lagrangian which is invariant under the local gauge group $[SU(2)\times U(1)]^2$ can be written as

$$L_{\rm eff} = L_G + L_F + L_\Sigma + L_Y - V_{\rm CW}(\Sigma), \tag{1}$$

where L_G consists of the pure gauge terms; L_F is the fermion kinetic terms, L_Σ consists of the σ-model terms of the LH model, L_Y is the Yukawa couplings of fermions and pseudo-Goldstone bosons, and $V_{\rm CW}(\Sigma)$ is the Coleman-Weinberg potential generated radiatively from L_Y and L_Σ. The scalar fields are parameterized by

$$\Sigma(x) = e^{2i\Pi/f}\Sigma_0\,, \tag{2}$$

with $\langle\Sigma_0\rangle \sim f$, which generates the masses and mixing between the gauge bosons. The leading order dimension-two term for the scalar sector in the non-linear σ-model can be written as

$$L_\Sigma = \frac{f^2}{8}{\rm Tr}\{(D_\mu\Sigma)(D^\mu\Sigma)^+\}, \tag{3}$$

with the covariant derivative of Σ given by

$$\begin{aligned} D_\mu\Sigma = {} & \partial_\mu\Sigma - i\sum_{j=1}^{2}\left[g_j(W_{\mu j}\Sigma + \Sigma W_{\mu j}^{\rm T}) + \right. \\ & \left. g'_j(B_{\mu j}\Sigma + \Sigma B_{\mu j}^{\rm T})\right], \end{aligned}$$

where g_j and g'_j are the couplings of the $[SU(2)\times U(1)]$ groups, respectively. $W_{\mu j} = \sum_{a=1}^{3} W_{\mu j}^a Q_j^a$ and $B_{\mu j} = B_{\mu j}Y_j$ are the $SU(2)$ and $U(1)$ gauge fields, respectively.

The spontaneous gauge symmetry breaking there by gives the gauge boson mass eigenstates

$$\begin{aligned} W_\mu &= sW_{\mu1} + cW_{\mu2}, \quad W'_\mu = -cW_{\mu1} + sW_{\mu2}\,, \\ B_\mu &= s'B_{\mu1} + c'B_{\mu2}, \quad B'_\mu = -c'B_{\mu1} + s'B_{\mu2}. \end{aligned} \tag{4}$$

The gauge bosons W and B are massless states identified as the SM gauge bosons, with couplings $g = g_1 s = g_2 c$ and $g' = g'_1 s' = g'_2 c'$. In this paper, the vacuum condensate scale parameter f, the mixing parameters c' and c between the charged and neutral vector bosons are the free parameters.

Through radiative corrections, the gauge, the Yukawa, and self-interactions of the Higgs field generate a Higgs potential which triggers the EWSB. Now the SM gauge bosons W and Z acquire masses of order v, and a small (of order v^2/f^2) mixing between the heavy gauge bosons and the SM gauge bosons W, Z occurs. The masses of W, Z and their couplings to the SM particles are modified from those in the SM at the order of v^2/f^2. In the following, we denote the mass eigenstates of SM gauge fields by $\mathrm{W_L^\pm}$, $\mathrm{Z_L}$ and $\mathrm{A_L}$ and the new heavy gauge bosons by $\mathrm{W_H^\pm}$, $\mathrm{Z_H}$ and $\mathrm{B_H}$. The masses of the neutral gauge bosons are given to $O(v^2/f^2)$ by[6, 9]

$$\begin{aligned}
M_{\mathrm{A_L}}^2 =\ & 0, \\
M_{\mathrm{B_H}}^2 =\ & (M_{\mathrm{Z}}^{\mathrm{SM}})^2 s_{\mathrm{W}}^2\left\{\frac{f^2}{5s'^2c'^2v^2}-1+\right. \\
& \left.\frac{v^2}{2f^2}\left[\frac{5(c'^2-s'^2)^2}{2s_{\mathrm{W}}^2}-\chi_{\mathrm{H}}\frac{g}{g'}\frac{c'^2s^2+c^2s'^2}{cc'ss'}\right]\right\}, \\
M_{\mathrm{Z_L}}^2 =\ & (M_{\mathrm{Z}}^{\mathrm{SM}})^2\left\{1-\frac{v^2}{f^2}\left[\frac{1}{6}+\frac{1}{4}(c^2-s^2)^2+\right.\right. \\
& \left.\left.\frac{5}{4}(c'^2-s'^2)^2\right]+8\frac{v'^2}{v^2}\right\}, \\
M_{\mathrm{Z_H}}^2 =\ & (M_{\mathrm{W}}^{\mathrm{SM}})^2\left\{\frac{f^2}{s^2c^2v^2}-1+\right. \\
& \left.\frac{v^2}{2f^2}\left[\frac{(c^2-s^2)^2}{2c_{\mathrm{W}}^2}+\chi_{\mathrm{H}}\frac{g'}{g}\frac{c'^2s^2+c^2s'^2}{cc'ss'}\right]\right\},
\end{aligned} \tag{5}$$

with $\chi_{\mathrm{H}} = \dfrac{5}{2}gg'\dfrac{scs'c'(c^2s'^2+s^2c'^2)}{5g^2s'^2c'^2-g'^2s^2c^2}$. Where $v = 246$ GeV is the elecroweak scale, v' is the vacuum expectation value of the scalar $SU(2)_{\mathrm{L}}$ triplet, $c_{\mathrm{W}} = \cos\theta_{\mathrm{W}}$ and $s_{\mathrm{W}} = \sin\theta_{\mathrm{W}}$ represent the weak mixing angle.

In the LH model, the relevant couplings of the neutral gauge bosons to the electron pair can be written in the form $\Lambda_\mu^{\mathrm{V_iee}} = \mathrm{i}\gamma_\mu(g_V^{\mathrm{V_iee}}+g_A^{\mathrm{V_iee}}\gamma^5)$ with[6, 12]

$$\begin{aligned}
g_V^{\mathrm{B_Hee}} =\ & \frac{g'}{2s'c'}\left(2y_{\mathrm{e}}-\frac{9}{5}+\frac{3}{2}c'^2\right), \\
g_A^{\mathrm{B_Hee}} =\ & \frac{g'}{2s'c'}\left(-\frac{1}{5}+\frac{1}{2}c'^2\right), \\
g_V^{\mathrm{Z_Lee}} =\ & -\frac{g}{2c_{\mathrm{W}}}\left\{\left(-\frac{1}{2}+2s_{\mathrm{W}}^2\right)-\right. \\
& \left.\frac{v^2}{f^2}\left[-c_{\mathrm{w}}\chi_{\mathrm{Z}}^{\mathrm{W'}}c/2s+\frac{s_{\mathrm{w}}\chi_{\mathrm{Z}}^{\mathrm{B'}}}{s'c'}\left(2y_{\mathrm{e}}-\frac{9}{5}+\frac{3}{2}c'^2\right)\right]\right\}, \\
g_A^{\mathrm{Z_Lee}} =\ & -\frac{g}{2c_{\mathrm{W}}}\left\{\frac{1}{2}-\frac{v^2}{f^2}\left[c_{\mathrm{W}}\chi_{\mathrm{Z}}^{\mathrm{W'}}c/2s+\right.\right. \\
& \left.\left.\frac{s_{\mathrm{W}}\chi_{\mathrm{Z}}^{\mathrm{B'}}}{s'c'}\left(-\frac{1}{5}+\frac{1}{2}c'^2\right)\right]\right\}, \\
g_V^{\gamma\mathrm{ee}} =\ & -\mathrm{e}, \\
g_A^{\gamma\mathrm{ee}} =\ & 0,
\end{aligned} \tag{6}$$

where, $\chi_{\mathrm{Z}}^{\mathrm{B'}} = \dfrac{5}{2s_{\mathrm{W}}}s'c'(c'^2-s'^2)$ and $\chi_{\mathrm{Z}}^{\mathrm{W'}} = \dfrac{1}{2c_{\mathrm{W}}}sc(c^2-s^2)$. The $U(1)$ hypercharge of electron, y_{e}, can be fixed by requiring that the $U(1)$ hypercharge assignments be anomaly free, i.e., $y_{\mathrm{e}} = \dfrac{3}{5}$. This is only one example among several alternatives for the $U(1)$ hypercharge choice[6, 13].

2.2 The production amplitudes of the processes $\mathrm{e^+e^-}\to\gamma(\mathrm{Z})\mathrm{B_H}$

As we have mentioned above, the lightest $\mathrm{B_H}$ should be the first signal of the LH model. With the coupling $\mathrm{e^+e^-B_H}$, $\mathrm{B_H}$ can be produced associated with a neutral SM gauge boson γ or Z at tree-level via $\mathrm{e^+e^-}$ collision, i.e., $\mathrm{e^+e^-}\to\gamma(\mathrm{Z})\mathrm{B_H}$. The relevant Feynman diagrams of the processes are shown in Fig. 1.

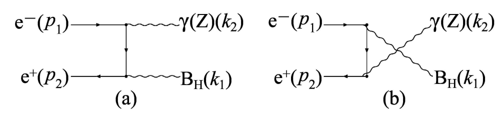

Fig. 1. The Feynman diagrams of the processes $\mathrm{e^+e^-}\to\gamma(\mathrm{Z})\mathrm{B_H}$.

The invariant scattering amplitudes of the processes can be written as

$$\begin{aligned}
M_a^{\gamma(\mathrm{Z})\mathrm{B_H}} =\ & \frac{\mathrm{i}}{(p_1-k_2)^2}\bar{v}(p_2)\Lambda_\mu^{\mathrm{B_Hee}}\varepsilon^\mu(k_1)\times \\
& (\not{p}_1-\not{k}_2)\Lambda_\nu^{\gamma(\mathrm{Z})\mathrm{ee}}\varepsilon^\nu(k_2)u(p_1), \\
M_b^{\gamma(\mathrm{Z})\mathrm{B_H}} =\ & \frac{\mathrm{i}}{(p_1-k_1)^2}\bar{v}(p_2)\Lambda_\nu^{\gamma(\mathrm{Z})\mathrm{ee}}\varepsilon^\nu(k_2)\times \\
& (\not{p}_1-\not{k}_1)\Lambda_\mu^{\mathrm{B_Hee}}\varepsilon^\mu(k_1)u(p_1).
\end{aligned} \tag{7}$$

The initial electron and positron are denoted by $u(p_1)$ and $\bar{v}(p_2)$, the final states $\mathrm{B_H}$ and $\gamma(\mathrm{Z})$ are presented as $\varepsilon_\mu(k_1)$ and $\varepsilon_\nu(k_2)$, respectively.

3 The numerical results and conclusions

From the scattering amplitudes shown in Eq. (7), we can see that there are three new free parameters of the LH model involved in the scattering amplitudes, i.e., the vev f, the mixing parameters c' and c. The custodial $SU(2)$ global symmetry is explicitly broken, which can generate large contributions to the electroweak observables. If one adjusts that the SM fermions are charged only under $U(1)_1$, there exist the global severe constraints on the parameter spaces of the LH model[14]. But if the SM fermions are charged under $U(1)_1\times U(1)_2$, the constraints become relaxed. The scale parameter f=1—2 TeV is allowed for the mixing parameters c' and c in the ranges of 0.62—0.73 and 0—0.5, respectively[13, 15]. To obtain numerical results of the cross sections, we take into account the constraints on the parameters of the LH model, and fix the SM input parameters as s_W^2=0.23, M_Z=91.187 GeV, $v=246$ GeV. The electromagnetic fine-structure constant α at a certain energy scale is calculated from the simple QED one-loop evolution with the boundary value $\alpha=\frac{1}{137.04}$[16]. On the other hand, we put the kinematic cuts on the final states in the calculation of the cross sections, i.e., $|y|<2.5$, $p_T>20$ GeV.

From Eqs. (5), (6), we can see that both the coupling $B_He^+e^-$ and the B_H mass strongly depend on the mixing parameter c', so the cross sections of $e^+e^-\rightarrow\gamma(Z)B_H$ should be sensitive to the c'. In Fig. 2, we plot the cross sections as a function of c'(c'=0.62—0.73), and take $f=2$ TeV, $c=0.5$, the c.m. energy $\sqrt{s}=800$ GeV as the examples. It is shown in Fig. 2 that the cross sections vanish at $c'=\sqrt{\frac{2}{5}}$ because the coupling $B_He^+e^-$ becomes decoupled in this case. In the range $c'>\sqrt{\frac{2}{5}}$, the cross sections sharply increase with c' increasing. On the other hand, we find that the cross section of γB_H production is much large than that of ZB_H production. In a wide range of the parameter spaces, the cross sections are at the level from tens fb to one hundred fb for γB_H production and from a few fb to tens fb for ZB_H production.

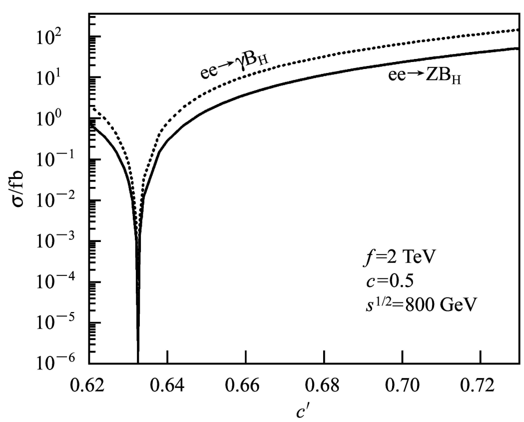

Fig. 2. The cross sections of the processes $e^+e^-\rightarrow\gamma(Z)B_H$ as a function of the mixing parameter c', with $\sqrt{s}=800$ GeV, c=0.5, and $f=2$ TeV.

The influence of f on the cross sections is also significant. Fig. 3 shows the plots of the cross sections versus f(f=1—5 TeV), with $\sqrt{s}=800$ GeV, $c'=0.68$, and $c=0.5$. With f increasing, the B_H mass increases and the cross sections sharply decrease when the B_H mass approaches the kinetic threshold value.

The mixing parameter c only has a little effect on the masses of the final states B_H and Z, so the cross sections are insensitive to the parameter c and we fix c=0.5 as an example in our calculations.

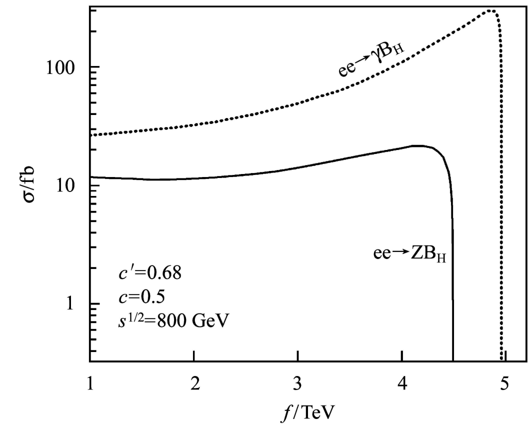

Fig. 3. The cross sections of the processes $e^+e^-\rightarrow\gamma(Z)B_H$ as a function of the scale f, with $\sqrt{s}=800$ GeV, $c'=0.68$, and c=0.5.

In order to give more information about the $\gamma(Z)B_H$ productions, we also plot the angular distributions of these processes in Fig. 4, where θ is the angle between the incoming electron beams and the scattering B_H. Fig. 4 shows that the angular distributions sharply increase when $\cos\theta$ approaches 1 or -1 due to the t-channel resonance effect. This means that the B_H signals are more concentrated near to the incoming e^+e^- axis.

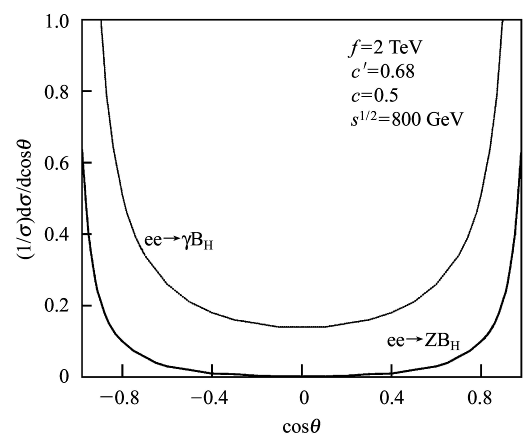

Fig. 4. The angular distributions of the processes $e^+e^-\rightarrow\gamma(Z)B_H$, with $\sqrt{s}=800$ GeV, $c'=0.68$, c=0.5, and $f=2$ TeV. Here θ is the angle between the outgoing gauge boson B_H and the incoming electron.

As we have discussed above, with the integrated luminosity 500 fb^{-1} at the ILC, a large number of B_H events can be produced via the processes $e^+e^-\rightarrow\gamma(Z)B_H$ in a wide range of parameter spaces of the LH model, specially for the process $e^+e^-\rightarrow\gamma B_H$. However, the event rate of B_H identified not only depends on the cross section, but also depends on the reconstruction efficiencies of the decay channels of B_H. The final states of the $\gamma(Z)B_H$ productions should include two jets. One is a photon jet or a jet decaying from Z (such jet should include the light quark pair or the lepton pair). Another jet is just the final states decaying from B_H. Both γ and Z can be easily identified experimentally, and such identification is necessary which can depress the SM background efficiently. To identify B_H from its final states, we also need to study the decay modes of B_H. The main decay modes of B_H are $e^+e^- + \mu^+\mu^- + \tau^+\tau^-$, $d\bar{d} + s\bar{s}$, $u\bar{u} + c\bar{c}$, ZH, W^+W^-. The decay branching ratios of these modes have been studied in Ref. [6]. Because the light lepton pairs $l^+l^-(l = e, \mu)$ are typically well isolated from all other particles with high efficiency and the number of l^+l^- background events with such a high invariant mass is very small, the peak in the invariant mass distribution of l^+l^- should be sensitive to the presence of B_H. So the decay modes l^+l^- are the most ideal modes to detect B_H in most cases. For these leptonic decay modes, the final states of γB_H production should be γl^+l^-. In this case, the main SM background arises from the process $e^+e^- \to \gamma Z$ with large production rate (at the level of a few pb for $\sqrt{s} = 800$ GeV[17]), which can lead to similar multi-jet topologies. In order to see whether the signal can be observed from its background, in Fig. 5, we plot the curve of signal over background ratio $S/\sqrt{B}$ as a function of c'. Here we only take into account the main SM background process $e^+e^- \to \gamma Z$ and take the yearly luminosity 500 fb^{-1}. We can see that the ratio $S/\sqrt{B}$ is over 3 in a wide range of the parameter spaces, and the signal can be observed in such range with high C.L. On the other hand, it should be very easy to distinguish B_H from Z by measuring the invariant mass distributions of the l^+l^- because such invariant mass distributions between B_H and Z are significantly different. The measurement of this lepton pair invariant mass distributions can drastically reduce the background further and the production mode $e^+e^- \to \gamma B_H \to \gamma l^+l^-$ can achieve a very clean SM background. For the production mode $e^+e^- \to ZB_H \to Zl^+l^-$, the main SM backgrounds arise from the processes $e^+e^- \to ZZ, ZH$. The ratio $S/\sqrt{B}$ is also shown in Fig. 5 (Here we take into account the main background processes $e^+e^- \to ZZ, ZH$ and take the mass of Higgs as 120 GeV) which is smaller than that for γB_H production but is large enough to detect B_H in a wide range of the parameter spaces. Furthermore, as we have mentioned above, B_H can be easily distinguished from Z via their decay modes l^+l^-, and the decay branching ratios of $H \to l^+l^-$ are very small. Therefore, a clean SM background can also be achieved if one detects B_H via the production mode $e^+e^- \to ZB_H \to Zl^+l^-$. When the parameter c' is near $\sqrt{\frac{2}{5}}$, the couplings $B_H l^+l^-$ become decoupled and the decay modes l^+l^- can not be used to detect B_H. In this case, the decay modes W^+W^-, ZH can provide a complementary method to probe B_H. The decay branching ratios of W^+W^-, ZH greatly increase when c' is near $\sqrt{\frac{2}{5}}$, and in this case we might assume enough W^+W^- and ZH signals to be produced with high luminosity. The decay mode $Z \to W^+W^-$ is of course kinematically forbidden in the SM but $H \to W^+W^-$ is the dominant decay mode with Higgs mass above 135 GeV (one or both of W are off-shell for Higgs mass below $2M_W$). So the dominant background for the signal ZW^+W^- arises from the Higgsstrahlung process $e^+e^- \to ZH \to ZW^+W^-$ which is at the order of tens fb[18]. Such background is significant if one can not distinguish the W^+W^- invariant mass distribution between H and B_H. However, the signal γW^+W^- does not suffer from such large background problem which would be one advantage of the process $e^+e^- \to \gamma B_H$. For $B_H \to ZH$, the main final states of B_H are $l^+l^-b\bar{b}$. Two b-jets are reconstructed to the Higgs mass and a l^+l^- pair is reconstructed to the Z mass. On the other hand, the decay mode ZH involves the off-diagonal coupling HZB_H and the experimental precise measurement of such off-diagonal

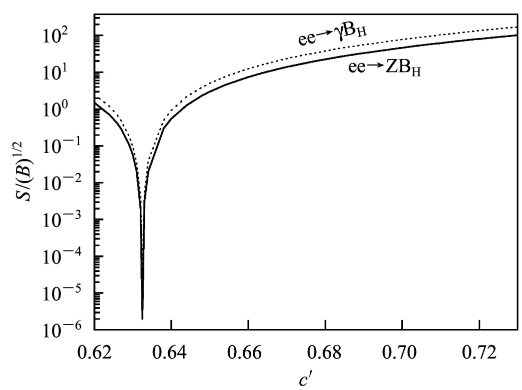

Fig. 5. The signal over background ratio $S/\sqrt{B}$ as a function of c', with $\sqrt{s} = 800$ GeV, c=0.5, and $f = 2$ TeV.

coupling is much easier than that of diagonal coupling. So, the decay mode ZH would provide an ideal way to verify the crucial feature of quadratic divergence cancellation in Higgs mass. Furthermore, such signal would provide a crucial evidence that an observed new gauge boson is of the type predicted in the Little Higgs models. For the signal γZH or ZZH, although the same final states can be produced via e^+e^- collision in the SM, the cross sections of these processes in the SM are small and the feature that there exists a peak in the ZH invariant mass distribution for the signal can further help one to depress such background.

In summary, with the mass in the range of hundreds GeV, the $U(1)$ gauge boson B_H is the lightest one among the new gauge bosons in the LH model. Such particle would be accessible in the first running of the ILC and provide an earliest signal of the LH model. In this paper, we study the B_H production processes associated with a SM gauge boson Z or γ via e^+e^- collision, i.e., $e^+e^- \rightarrow \gamma(Z)B_H$. We find that the cross sections are very sensitive to the parameters c', f and the cross section of γB_H production is much larger than that of ZB_H production. In a wide range of the parameter spaces, sufficient events can be produced to detect B_H via these processes. The signals are more concentrated near to the incoming e^+e^- axis. In general, B_H can be detected via its decay modes $e^+e^-, \mu^+\mu^-$ which can provide the typical signal and clean backgrounds. Therefore, the processes $e^+e^- \rightarrow \gamma(Z)B_H$ would open an ideal window to probe B_H with the high luminosity at the planned ILC. Furthermore, if such gauge boson is observed, the precise measurement is needed which could offer the important insight for the gauge structure of the LH model and distinguish this model from the alternative theories.

References

1 Nilles H P. Phys. Rep., 1984, **110**: 1—399; Haber H E, Kane G L. Phys. Rep., 1985, **117**: 1—376

2 Antoniadis I, Munoz C, Quiros M. Nucl. Phys., 1999, **B397**: 515—538; Arkani-Hamed N, Dimopoulos S, Dvali G R. Phys. Rev., 1999, **D59**: 086004

3 Weinberg S. Phys. Rev., 1976, **D13**: 974—996; Weinberg S. Phys. Rev., 1979, **D19**: 1277—1280; Susskind L. Phys. Rev., 1979, **D20**: 2619—2625

4 Arkani-Hamed N, Cohen A G, Georgi H. Phys. Lett., 2001, **B513**: 232—240; Arkani-Hamed N, Cohen A G, Gregoire T et al. JHEP, 2002, **0208**: 020; Arkani-Hamed N, Cohen A G, Katz E et al. JHEP, 2002, **0208**: 021; Low I, Skiba W, Smith D. Phys. Rev., 2002, **D66**: 072001; Schmaltz M. Nucl. Phys. Proc. Suppl., 2003, **117**: 40—49; Skiba W, Terning J. Phys. Rev., 2003, **D68**: 075001

5 Arkani-Hamed N, Cohen A G, Katz E et al. JHEP, 2002, **0207**: 034

6 HAN T, Logan H E, McElrath B et al. Phys. Rev., 2003, **D67**: 095004

7 Park S C, Song J. Phys. Rev., 2004, **D69**: 15010; Hubisz J, Meade P. Phys. Rev., 2005, **D71**: 035016; Schmaltz M, Tucker-Smith D. Ann. Rev. Nucl. Part. Sci., 2005, **55**: 229—270; HAN T, Logan H E, WANG L T. JHEP, 2006, **0601**: 099; Kilian W, Reuter J. Phys. Rev., 2004, **D70**: 015004; Blanke M, Buras A J, Poschenrieder A et al. JHEP, 2007, **0701**: 066

8 Thlnov V I. Acta Phys. Polon., 2006, **B37**: 1049—1072; Telnov V I. Acta Phys. Polon., 2006, **B37**: 633—656

9 Conley J A, Hewett J, Le M P. Phys. Rev., 2005, **D72**: 115014

10 YUE C X, ZHANG F, WANG L N et al. Phys. Rev., 2005, **D72**: 055008

11 WANG X L, CHEN J H, LIU Y B et al. Phys. Rev., 2006, **D74**: 015006

12 Buras A J, Poschenrieder A, Uhlig S et al. JHEP, 2006, **0611**: 062

13 Csaki C, Hubisz J, Kribs G D et al. Phys. Rev., 2003, **D68**: 035009

14 CHEN M C, Dawson S. Phys. Rev., 2004, **D70**: 015003; Casalbuoni R, Deandrea A, Oertel M. JHEP, 2004, **0402**: 032; Hewett J L, Petriello F J, Rizzo T G. JHEP, 2003, **0310**: 062; Cs'aki C, Hubisz J, Kribs G D et al. Phys. Rev., 2003, **D67**: 115002

15 Gregoire T, Smith D R, Wacker J G. Phys. Rev., 2004, **D69**: 115008

16 Donoghue J F, Golowich E, Holstein B R. Dynamics of the Standard Model. Cambridge: Cambridge Univiversity Press, 1992. 34

17 Atag S, Sahin I. Phys. Rev., 2004, **D70**: 053014

18 Accomando E et al. Phys. Rep., 1998, **299**: 1—78