Eur. Phys. J. C 55, 615–622 (2008)
DOI 10.1140/epjc/s10052-008-0618-2

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article – Theoretical Physics

The new charged gauge boson W' and the subprocess $eq \to \nu q'$ at e^+e^- and ep colliders

Chong-Xing Yue[a], Li Ding, Wei Ma

Department of Physics, Liaoning Normal University, Dalian 116029, P.R. China

Received: 20 January 2008 / Revised version: 4 March 2008 /
Published online: 17 May 2008 –

Abstract. In the framework of little Higgs models and the three-site Higgsless model, we discuss the contributions of the new charged gauge boson W' to the process $eq \to \nu q'$ and the possibility of detecting W' via this process in future high energy linear e^+e^- collider (ILC) and ep collider (THERA) experiments. Our numerical results show that the process $eq \to \nu q'$ is rather sensitive to the coupling $W'ff'$, and one can use this process to distinguish different new physics models in future ILC and THERA experiments.

PACS. 12.60.Cn; 14.70.Pw; 14.65.Bt

1 Introduction

Although no new charged gauge boson, generally called W', has been found yet experimentally, its existence is now a relatively common prediction, which results from many new physics scenarios. For example, little Higgs models [1], Higgsless models [2–5], non-commuting extended technicolor [6], and the Randall–Sundrum model with bulk gauge fields [7–13] are examples in which extension of the gauge group leads to the appearance of W'. If one of these new particles is discovered, it would represent irrefutable proof of new physics, most likely that the gauge group of the standard model (SM) must be extended. Thus, the search for the extra gauge boson W' provides a common tool in the quest for new physics at next generation collider experiments [14].

Although the extra gauge boson W' has not been discovered yet there are experimental limits on its mass. The indirect limits can be placed on the existence of W' through indirect searches based on the deviations from the SM, which can be obtained in precision electroweak measurements [15, 16]. Indirect searches for W' being extracted from leptonic and semileptonic decays and also from cosmological and astrophysical data give a very wide range for the upper limits on the W' mass varying from 549 GeV up to 23 TeV [17]. The direct limits the on W' mass are based on the hypothesis of a purely right- or left-handed interacting W' with SM-like coupling constants [18]. At hadron colliders, the limits can be obtained by considering its direct production via the Drell–Yan process and its subsequent decay to lepton pairs or hadronic jets. Present bounds from measurements at the Tevatron collider exclude a low W' mass, $M_{W'} > 720$ GeV [19]. The CERN large hadron collider (LHC) is expected to be able to discover W' up to a mass of ≈ 5.9 TeV [20].

So far, there are some studies of indirect searches for the W' boson at high energy colliders. For example, [15] has examined the sensitivity of the process $e^+e^- \to \nu\bar{\nu}\gamma$ to the mass of the W' boson and found that this process is sensitive to the mass of the W' up to several TeV [16]. Further studies of the sensitivity of the process $e\gamma \to \nu q + X$ to W' boson and comparing with the process $e^+e^- \to \nu\bar{\nu}\gamma$ find that, in many cases, this process is more sensitive to the W' boson than that of the process $e^+e^- \to \nu\bar{\nu}\gamma$. Recently, [21] has explored the capability of the LHC to determine the W' coupling helicity at low integrated luminosities in the $l + E_T^{\text{miss}}$ discovery channel and [22] has further studied the process $e^+e^- \to \nu\bar{\nu}\gamma$ in the context of the little Higgs model. References [23, 24] studied the possibility of detecting the W' boson predicted by the three-site Higgsless model via the processes $pp \to W' \to WZ$ and $pp \to W'jj \to WZjj$ at the upcoming LHC. In this paper, we will calculate the corrections of the gauge boson W' to the process $eq \to \nu q'$ in different extensions of the SM and see whether this process can be used to distinguish different new physics models in future high energy collider experiments.

Little Higgs theory is proposed as an alternative solution to the hierarchy problem of the SM, which provides a possible kind of electroweak symmetry breaking (EWSB) mechanism accomplished by a naturally light Higgs boson [1]. In general, this kind of models predicts the existence of the pure left-handed charged gauge boson W', which has SM-like couplings to ordinary particles. In this paper, we will first consider the process $eq \to \nu q'$ in this kind of models. The second kind of models are the Higgsless models, which have been proven to be viable alternatives to the SM and supersymmetric models in describing

[a] e-mail: yuecx0707@163.com

the breaking of the electroweak symmetry [25–29]. The three-site Higgsless model [30–32] is one of the simplest and phenomenologically viable models and has all essential features of the Higgsless models. Thus we will consider the contributions of the charged KK gauge boson W' predicted by the three-site Higgsless model to the process $eq \to \nu q'$.

Section 2 of this paper contains the elemental formulae, which are related to our calculation. Based on the structure of the extended electroweak gauge group, the little Higgs models can be divided into two classes [33, 34]: the product group models and the simple group models. The littlest Higgs model (LH) [35] and the SU(3) simple group model [34, 36] are the simple examples of these two kinds of little Higgs models, respectively. The contributions of these two models to the process $eq \to \nu q'$ are considered and the relevant phenomenology analysis in future the high energy linear e^+e^- collider (ILC) [37–40] and ep collider (THERA) [41, 42] are given in Sect. 3. Section 4 gives our numerical results obtained in the framework of three-site Higgsless model. In the last section the summary and a discussion are given.

2 The formulae relevant for our calculation

To consider the W' contributions to the process $eq \to \nu q'$ in different new physics scenarios, we write down the lowest dimension effective Lagrangian of W' interactions to ordinary fermions in most general form (possible higher dimension effective operators are not taken into account in our numerical calculation):

$$\pounds = \frac{e}{\sqrt{2}S_{\mathrm{W}}} V_{ij} \bar{f}_i \gamma^{\mu} (g_{\mathrm{L}} P_{\mathrm{L}} + g_{\mathrm{R}} P_{\mathrm{R}}) f_j W'_{\mu} + \text{h.c.}\,, \tag{1}$$

where $S_{\mathrm{W}} = \sin\theta_{\mathrm{W}}$ (θ_{W} is the Weinberg angle), V_{ij} is the CKM matrix element, and $P_{\mathrm{L(R)}} = (1 \mp \gamma_5)/2$ is the left- (right-) handed projection operator. In the SM case, the coupling constant g_{L} is equal to 1 and g_{R} is equal to 0.

The production cross section $\hat{\sigma}(\hat{s})$ of the process $e(P_1) + q(P_2) \to \nu(P_3) + q'(P_4)$ contributed by the SM gauge boson W and the new charged gauge boson W' can be written

$$\hat{\sigma}(\hat{s}) = \int \mathrm{d}\hat{t} \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}}\,, \tag{2}$$

with

$$\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}} = \frac{\pi\alpha^2}{4S_{\mathrm{W}}^4} \left[\frac{1}{\left(\hat{t} - M_W^2\right)^2} + \frac{2g_{\mathrm{L}}^{W'qq'} g_{\mathrm{L}}^{W'e\nu}}{\left(\hat{t} - M_W^2\right)\left(\hat{t} - M_{W'}^2\right)} + \frac{\left(g_{\mathrm{L}}^{W'qq'} g_{\mathrm{L}}^{W'e\nu}\right)^2}{\left(\hat{t} - M_{W'}^2\right)^2} \right], \tag{3}$$

and $\hat{t} = (P_1 - P_4)^2$. In the above equations, we have assumed that W' is the pure left-handed charged gauge boson.

The process $eq \to \nu q'$ can be seen as the subprocess of the charged current (CC) process $ep \to \nu q' + X$. Measurement and QCD analysis of the production cross section for the SM CC process $ep \to \nu q' + X$ at the HERA collider have been extensively studied [43–45]. Including the contributions of the SM gauge boson W and new gauge boson W', the production cross section $\sigma_{\mathrm{T}}(S)$ of the CC process $ep \to \nu q' + X$ at the ep colliders can be written as

$$\sigma_{\mathrm{T}}(S) = \sum_q \int_{x_{\min}}^1 f_q(x, \mu) \hat{\sigma}(\hat{s})\, \mathrm{d}x\,, \tag{4}$$

with $x_{\min} = m_{q'}^2/S$ and $\hat{s} = xS$, in which the center-of-mass (c.m.) energy $\sqrt{S}$ is taken as 320 GeV for the HERA collider and as 1 TeV for the THERA collider. q represents the quarks u, c, d, or s. In our numerical estimation, we will use the CTEQ6L parton distribution function (PDF) [46] for the quark distribution function $f_q(x, \mu)$ and assume that the factorization scale μ is of order $\sqrt{\hat{s}}$. To take into account the detector acceptance, the angle of the observed jet, $\theta_{q'}$, will be restricted to the range $10° \le \theta_{q'} \le 170°$ [43–45].

It has been shown [16] that in a suitable kinematic region the process $e\gamma \to \nu q' \bar{q}$ can be approximated quite well by the process $eq \to \nu q'$, where the quark q described by the quark parton content of the photon approach [47, 48]. The hard photon beam of $e\gamma$ collision can be obtained from laser backscattering at the high energy e^+e^- collider experiments. The expression for the effective cross section of the subprocess $eq \to \nu q'$ at the ILC is given by

$$\sigma_I = \sum_q \int \mathrm{d}x_1\, \mathrm{d}x_2 f_{\gamma/e}(x_1) f_{q/\gamma}(x_2) \hat{\sigma}(\hat{s})\,, \tag{5}$$

where $f_{\gamma/e}(x_1)$ is the photon distribution [49, 50], $f_{q/\gamma}$ is the distribution function for the quark content in the photon. To obtain our numerical results we will use the Aurenche, Fontannaz and Guillet (AFG) distribution [51] for $f_{q/\gamma}$. Other distributions are available in [52].

In the following sections, we will discuss the possibility of detecting the new charged gauge boson W' in future THERA and ILC experiments via considering its contributions to the subprocess $eq \to \nu q'$ in different new physics scenarios.

3 The subprocess $eq \to \nu q'$ in the little Higgs models

According to the structure of the extended electroweak gauge group, little Higgs models can generally be divided into two classes [33, 34]: product group models, in which the SM $\mathrm{SU}(2)_{\mathrm{L}}$ is embedded in a product gauge group, and simple group models, in which it is embedded in a large simple group. The LH model [35] and the SU(3) simple group model [34, 36] are the simplest examples of the product group models and the simple group models, respectively. To predigest our calculation, we will discuss the subprocess $eq \to \nu q'$ in the context of these two simplest models.

In the LH model, the coupling constants of the SM gauge boson W and the new gauge boson W_H to the first and second generation fermions, which are related to our calculation, can be written as [53]

$$g_{\mathrm{L}}^{Wqq'} = \frac{\mathrm{ie}}{\sqrt{2}S_{\mathrm{W}}}\left[1 - \frac{\nu^2}{2f^2}c^2\left(c^2 - s^2\right)\right], \quad g_{\mathrm{R}}^{Wqq'} = 0\,, \tag{6}$$

$$g_{\mathrm{L}}^{W_H qq'} = \frac{\mathrm{ie}}{\sqrt{2}S_{\mathrm{W}}}\frac{c}{s}, \quad g_{\mathrm{R}}^{W_H qq'} = 0\,. \tag{7}$$

Here $\nu \approx 246\,\mathrm{GeV}$ is the electroweak scale, c ($s = \sqrt{1-c^2}$) is the mixing parameter between the $\mathrm{SU}(2)_1$ and $\mathrm{SU}(2)_2$ gauge bosons, and f is the scale parameter of the gauge symmetry breaking.

Similar with the LH model, the SU(3) simple group model [34, 36] also predicts the existence of the new charged gauge boson, which is represented by X. In the SU(3) simple group model, the coupling constants of the SM gauge boson W and the new gauge boson X to the first and second generation fermions can be written as

$$g_{\mathrm{L}}^{Wqq'} = \frac{\mathrm{ie}}{\sqrt{2}S_{\mathrm{W}}}\left(1 - \frac{1}{2}\delta_\nu^2\right), \quad g_{\mathrm{R}}^{Wqq'} = 0\,, \tag{8}$$

$$g_{\mathrm{L}}^{Xqq'} = \frac{\mathrm{ie}}{\sqrt{2}S_{\mathrm{W}}}\delta_\nu\,, \quad g_{\mathrm{R}}^{Xqq'} = 0\,, \tag{9}$$

with $\delta_\nu = -\nu/2ft_\beta$. Here $f = \sqrt{f_1^2 + f_2^2}$ and $t_\beta = \tan\beta = f_2/f_1$, in which f_1 and f_2 are the vacuum condensate values of the two sigma model fields Φ_1 and Φ_2, respectively.

After taking into account electroweak symmetry breaking (EWSB), at the leading order, the masses of the new charged gauge bosons W_H and X can be written as

$$M_{W_H} = \frac{gf}{2sc}, \qquad M_X = \frac{gf}{\sqrt{2}}\,. \tag{10}$$

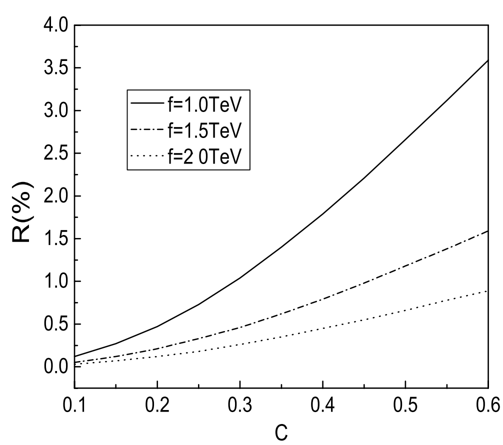
Except for the SM input parameters $\alpha = 1/128.8$, $S_{\mathrm{W}}^2 = 0.2315$, and $M_W = 80.14\,\mathrm{GeV}$ [17], the contributions of the LH model and the SU(3) simple group model to the production cross section of the subprocess $eq \to \nu q'$ dependent on the free parameters (f, c) and (f, t_β), respectively. Considering the constraints of the electroweak precision data on these free parameters, we will assume $1\,\mathrm{TeV} \le f \le 3\,\mathrm{TeV}$ and $0 < c \le 0.6$ for the LH model [54–62], and $1\,\mathrm{TeV} \le f \le 3\,\mathrm{TeV}$ and $t_\beta > 1$ for the SU(3) simple group model [33, 34, 36] in our numerical estimation.

To illustrate the contributions of the new physics model to the subprocess $eq \to \nu q'$, we define the relative correction parameter $R = \frac{\sigma(i) - \sigma(\mathrm{SM})}{\sigma(\mathrm{SM})}$, in which $\sigma(i)$ and $\sigma(\mathrm{SM})$ represent the effective cross sections predicted by the new physics model and the SM, respectively. The relative correction parameters for the LH model and the SU(3) simple group model at the THERA and ILC experiments are plotted in Figs. 1 and 2, respectively. In these figures, we have assumed the CKM matrix elements $V_{ud} \approx V_{cs} \approx 1$, and we have taken the c.m. energy $\sqrt{S} = 1000\,\mathrm{GeV}$ and $500\,\mathrm{GeV}$ for the THERA and ILC experiments, respectively. One can see from these figures that the LH model can give positive contributions to the effective cross sections at the THERA and ILC experiments, while the SU(3) simple group model can give negative contributions. The absolute value of the relative correction parameter R for the SU(3) simple group model is slight smaller than that for the LH model. For the SU(3) simple group model, the values of R at the THERA are approximately equal to those at the ILC. However, in most of the parameter spaces for the LH model and the SU(3) simple group model, all of the absolute values of the relative correction parameter R are smaller than 4.3%.

In order to see if the correction effects of the LH model and the SU(3) simple group model on the processes $ep \to \nu q' + X$ and $e^+e^- \to \nu q' + X$ can be observed in future THERA and ILC experiments, we define the statistical significance (SS) of the signal by

$$\mathrm{SS}^i = \frac{|\,\sigma(i) - \sigma(\mathrm{SM})\,|}{\sqrt{\sigma(\mathrm{SM})}}\sqrt{\pounds}\,. \tag{11}$$

Here i represents the LH model or the SU(3) simple group model. In our numerical calculation, we will assume the values of the yearly integrated luminosity $\pounds$ as $4\,\mathrm{fb}^{-1}$ and $100\,\mathrm{fb}^{-1}$ for the THERA experiment with $\sqrt{S} = 1000\,\mathrm{GeV}$ and ILC experiment with $\sqrt{S} = 500\,\mathrm{GeV}$, respectively. Our numerical results are summarized in Figs. 3 and 4. One



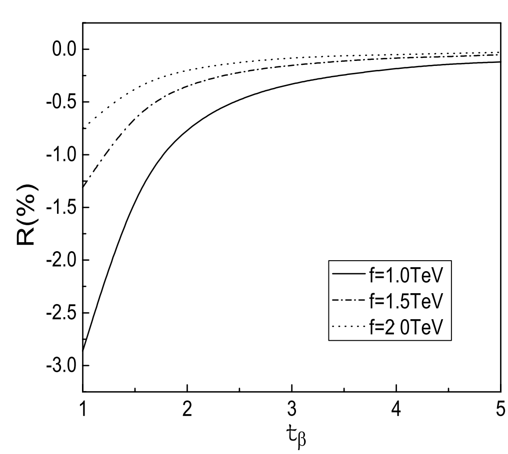


Fig. 1. At the THERA, the relative correction parameter R as function of the mixing parameter c for the LH model (**a**) and of the parameter t_β for the SU(3) simple group model (**b**) for three values of the scale parameter f

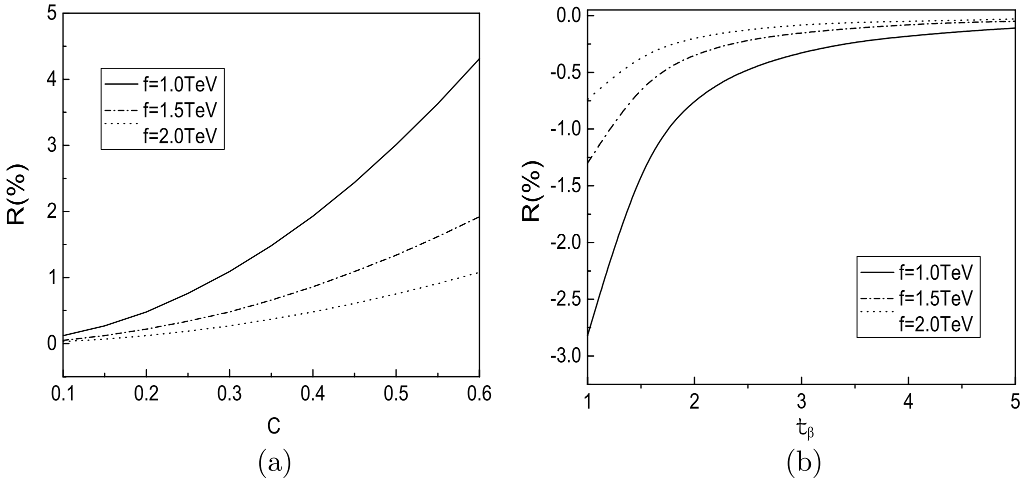


Fig. 2. Same as Fig. 1 but for ILC

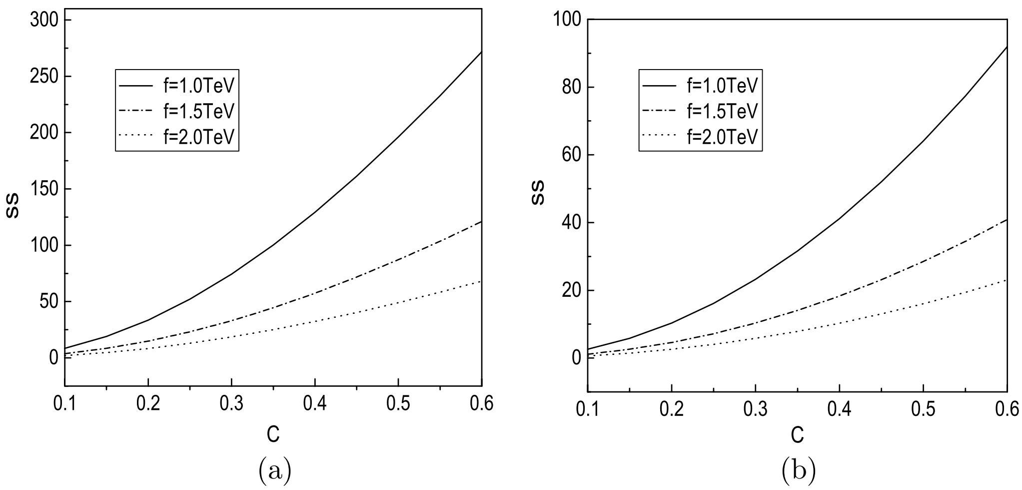


Fig. 3. For the LH model, SS as a function of the mixing parameter c for three values of f at the THERA (**a**) and the ILC (**b**)

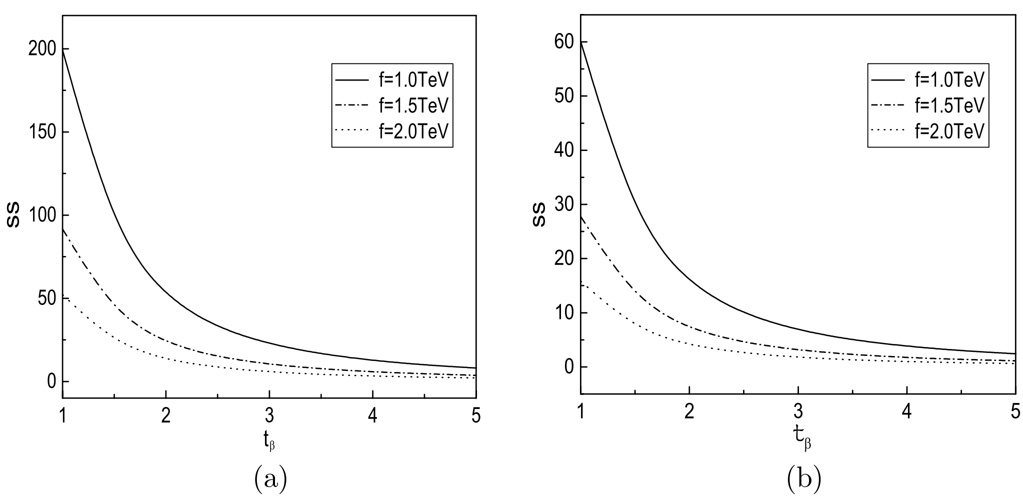


Fig. 4. For the SU(3) simple group model, SS as a function of the parameter t_β for three values of f at the THERA (**a**) and the ILC (**b**)

can see from these figures that, for these two little Higgs models, the value of SS at the THERA is larger than that at the ILC. For the assumed integrated luminosity, the effects of the little Higgs models on the subprocess $eq \to \nu q'$ can generally be easier detected at the THERA than at the ILC. For the same high energy collider experiment (ILC or THERA), the SS value contributed by the LH model is larger than that by the SU(3) simple group model. For the ILC experiment with $\sqrt{S} = 500\,\text{GeV}$ and $\pounds = 100\,\text{fb}^{-1}$, if we take $f = 2\,\text{TeV}$, $0.2 \le c \le 0.6$ and $1 \le t_\beta \le 2.5$, the values of SS are in the ranges of $2.6 \sim 23.1$ and $15.8 \sim 2.5$ for the LH model and the SU(3) simple group model, respectively. Thus, with reasonable values of the free parameters, the possible signatures of the new charged gauge boson W' predicted by the LH model or by the SU(3) simple group model might be detected via the subprocess $eq \to \nu q'$ in the future ILC and THERA experiments.

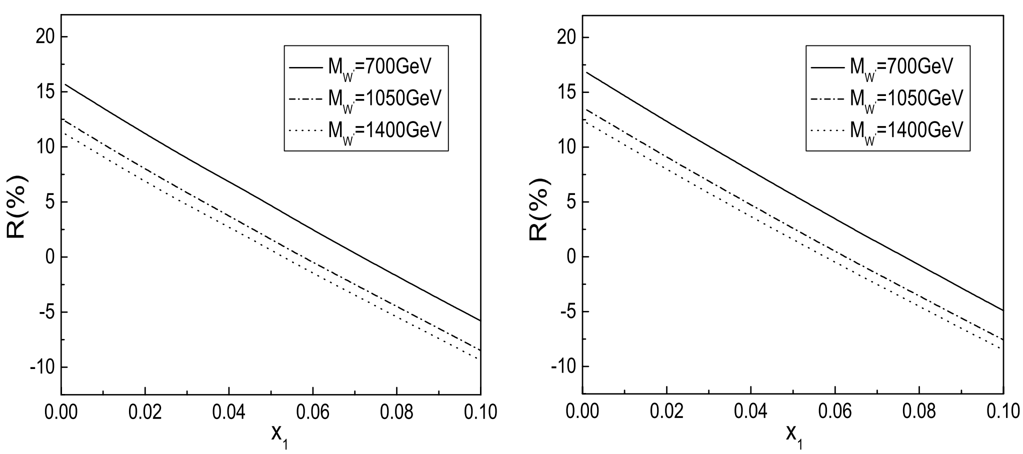
4 The subprocess $eq \to \nu q'$ in the three-site Higgsless model

So far, various kinds of models for EWSB have been proposed, among which Higgsless model [2–5] is one of the attractive new physics models. In this kind of models, EWSB can be achieved via employing gauge symmetry breaking by a boundary condition in higher dimensional theory space [63–68], and the unitarity of longitudinally polarized W boson and Z boson scattering is preserved by exchange of new vector gauge bosons [69–71]. Reconstructed Higgsless models [25–32] have been used as tools to compute the general properties of Higgsless models and to illustrate the phenomenological properties of this kind of new physics models beyond the SM.

The simplest deconstructed Higgsless model incorporates only three sites on the deconstructed lattice, which is called the three-site Higgsless model [30–32]. In this model, the ordinary fermions are ideally delocalized, which preserves the characteristic of vanishing precision electroweak corrections up to subleading order [72, 73]. Furthermore, the three-site Higgsless model is capable of approximating much of the interesting phenomenology associated with extra dimensional models and more complicated deconstructed Higgsless models [74–78].

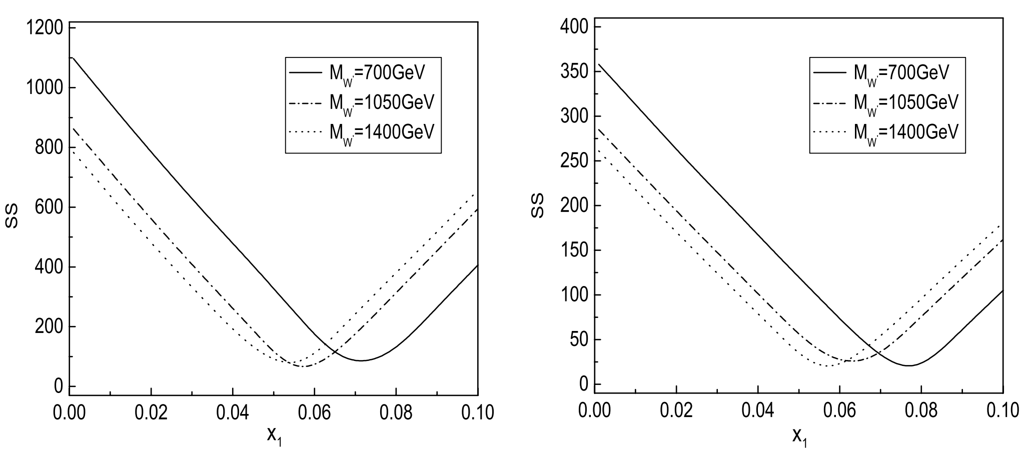
The three-site Higgsless model [30–32] has a standard color group and an extended $\mathrm{SU}(2)_1 \times \mathrm{SU}(2)_2 \times \mathrm{U}(1)$ electroweak gauge group, which is similar to that of the BESS model [79, 80]. Once EWSB occurs in this model, the gauge sector consists of a massless photon, two relatively light massive gauge bosons, which are identified with the SM W and Z gauge bosons, as well as two heavy gauge bosons, which are denoted Z' and W'. In the three-site Higgsless model, the coupling constants of the charged gauge bosons W and W' to ordinary fermions can be written

$$g_{\mathrm{L}}^{Wff'} = \frac{\mathrm{i}S_{\mathrm{W}}}{e}\left[g(1-x_1)a_{22} + \tilde{g}x_1 a_{12}\right], \quad g_{\mathrm{R}}^{Wff'} = 0, \tag{12}$$



(a) (b)

Fig. 5. The relative correction parameter R varies as the parameter x_1 for three values of the W' mass $M_{W'}$ at the THERA (**a**) and the ILC (**b**)



(a) (b)

Fig. 6. SS as a function of the parameter x_1 for three values of the W' mass $M_{W'}$ at the THERA (**a**) and the ILC (**b**)

$$g_{\mathrm{L}}^{W'ff'} = \frac{\mathrm{i}S_{\mathrm{W}}}{e}[g(1-x_1)a_{21} + \tilde{g}x_1a_{11}], \quad g_{\mathrm{R}}^{W'ff'} = 0. \tag{13}$$

Here the parameter x_1 is a measure of the amount of fermion delocalization ($0 < x_1 \ll 1$) [30–32, 72, 73]. In principle, the value of x_1 for a given fermion species depends indirectly on the mass of the fermion. However, since we are only interested in light fermions, we can assume that the parameter x_1 has the same value for the first- and second-generation fermions. The forms of the expressions of the parameters g, $\tilde{g}$, a_{22}, a_{12}, a_{21}, and a_{11} have been given by [81] in terms of the W and W' masses M_W and $M_{W'}$. In our numerical estimation, we will assume $M_{Z'}^2 = M_{W'}^2 + (M_Z^2 - M_W^2)$, and take x_1 and $M_{W'}$ as free parameters.

Our numerical results obtained in the content of the three-site Higgsless model are given in Figs. 5 and 6, in which we have assumed $M_{W'} = 700$, 1050, and 1400 GeV. One can see from these figures that the contributions of the three-site Higgsless model to the subprocess $eq \to \nu q'$ depend rather significantly on the free parameter x_1. The value of the relative correction parameter R is positive or negative, which depends on the value of the free parameter x_1. The value of R for the ILC experiment with $\sqrt{S} = 500$ GeV is approximately equal to that for the THERA experiment with $\sqrt{S} = 1$ TeV. However, the statistical significance SS of the signal for the THERA experiment is larger than that for the ILC experiment. In a wide range of the parameter space, the value of SS is significantly large. Thus, we expect that the correction effects of the three-site Higgsless model to the subprocess $eq \to \nu q'$ can be observed in future THERA and ILC experiments.

5 Conclusions and discussions

Most of all the new physics models beyond the SM predict the existence of the new charged gauge boson W', which might generate observed signatures in future high energy collider experiments. The W' arising from different new physics models can induce different physical signatures. Thus, it is very interesting to study the correction effects of the new gauge boson W' on some observables. It will be helpful to test the SM and further to distinguish various new physics models.

The process $eq \to \nu q'$ mediated by the charged gauge boson W' can be seen as the subprocess of the processes $ep \to \nu q' + X$ and $e^+e^- \to \nu q' + X$. One can use the subprocess $eq \to \nu q'$ to detect the possible signals of the new charged gauge boson W' in future THERA and ILC experiments. References [87, 88] have studied the contributions of the four-fermion contact terms to this subprocess. In this paper, we study the contributions of the W' predicted by the little Higgs models and the three-site Higgslesss model to this subprocess and discuss the possibility of detecting W' in future THERA and ILC experiments. Our numerical results are summarized in Table 1.

The contributions of the three-site Higgsless model to the subprocess $eq \to \nu q'$ are generally larger than those for the LH model or the SU(3) simple group model. The effects of the three-site Higgsless model on this subprocess can generally be easier detected than those for the little Higgs models. However, it can enhance or reduce the effective cross sections of the subprocess $eq \to \nu q'$ at the THERA and ILC experiments, which depends on the value of the free parameter x_1. Thus, we can use the subprocess $eq \to \nu q'$ to detect the possible signatures of the new charged gauge boson W' and further distinguish the three-site Higgsless model and little Higgs models in future THERA or ILC experiments.

In this paper, we have assumed that the hard photon beam is obtained from laser backscattering. Certainly, we can also take the hard photon beam to arise from Weizsäcker–Williams bremsstrahlung [82, 83]. Furthermore, in our numerical estimation, we have taken AFG PDFs for the quark distribution functions in the photon. Other PDFs can also be used to give our numerical results. These will change the above numerical results. However, they cannot change our physical conclusions.

In order to satisfy the electroweak precision constraints by avoiding tree-level contributions of the new particles and restoring the custodial SU(2) symmetry, a discrete symmetry (called T-parity) is introduced to the LH model, which forms the so-called LHT model [84–86]. Under T-parity, particle fields predicted by this model are divided into T-even and T-odd sectors. The T-even sector consists of the SM particles and a heavy top T_+, while the T-odd sector contains heavy gauge bosons ($B_H, Z_H, W_H^{\pm}$), a scalar triplet (Φ), and the so-called mirror fermions (L_H, Q_H). The mirror quark can be produced via the process $eq \to \nu_H Q_H$ mediated by the T-odd charged gauge boson W_H, which can give a signal similar to that from the process $eq \to \nu q'$. We will study the process $eq \to \nu_H Q_H$ in work in the near future.

Table 1. The contributions of the LH model, SU(3) simple group model, and the three-site Higgslesss model to the subprocess $eq \to \nu q'$ at the THERA and ILC experiments

Models	LH		SU(3)		HL	
	$f = 2$ TeV $0.2 \le c \le 0.6$		$f = 2$ TeV $1 \le t_\beta \le 2.5$		$M_{W'} = 1050$ GeV $0.002 \le x_1 \le 0.08$	
xR(%)	THERA	ILC	THERA	ILC	THERA	ILC
	$0.12 \sim 0.89$	$0.12 \sim 1.08$	$-0.75 \sim -0.12$	$-0.74 \sim -0.12$	$12.1 \sim -4.5$	$13.2 \sim -3.6$
SS	$8.4 \sim 68.1$	$2.6 \sim 23.1$	$52.2 \sim 8.4$	$15.8 \sim 2.5$	$845.5 \sim 314.2$	$280.8 \sim 76.1$

Acknowledgements. This work was supported in part by the National Natural Science Foundation of China under Grants No. 10675057 and Foundation of Liaoning Educational Committee (2007T086).

References

1. For recent review see: M. Schmaltz, D. Tucker-Smith, Ann. Rev. Nucl. Part. Sci. **55**, 299 (2005)
2. Y. Nomura, JHEP **0311**, 050 (2003)
3. C. Csaki, C. Grojean, H. Murayama, L. Pilo, J. Terning, Phys. Rev. D **69**, 055 006 (2004)
4. C. Csaki, C. Grojean, L. Pilo, J. Terning, Phys. Rev. Lett. **92**, 101 802 (2004)
5. G. Cacciapaglia, C. Csaki, C. Grojean, J. Terning, Phys. Rev. D **71**, 035 015 (2005)
6. R.S. Chivukula, E.H. Simmons, J. Terning, Phys. Rev. D **53**, 5258 (1996)
7. L. Randall, R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999)
8. H. Davoudiasl, J.L. Hewett, T.G. Rizzo, Phys. Lett. B **473**, 43 (2000)
9. A. Pomarol, Phys. Lett. B **486**, 153 (2000)
10. Y. Grossman, M. Neubert, Phys. Lett. B **474**, 361 (2000)
11. S. Chang, J. Hisano, H. Nakano, N. Okada, M. Yamaguchi, Phys. Rev. D **62**, 084 025 (2000)
12. S.J. Huber, Q. Shafi, Phys. Lett. B **498**, 256 (2001)
13. J.L. Hewett, F.J. Petriello, T.G. Rizzo, JHEP **0209**, 030 (2002)
14. LHC/LC Study Group, G. Weiglein et al., Phys. Rep. **426**, 47 (2006)
15. S. Godfrey, P. Kalyniak, B. Kamal, A. Leike, Phys. Rev. D **61**, 113 009 (2000)
16. S. Godfrey, P. Kalyniak, B. Kamal, M.A. Doncheski, A. Leike, Phys. Rev. D **63**, 053 005 (2001)
17. Particle Data Group, W.-M. Yao et al., J. Phys. G **33**, 1 (2006) and partial update for the 2008 edition
18. E. Boos, V. Bunichev, L. Dudko, M. Perfilov, Phys. Lett. B **655**, 245 (2007)
19. CDF Collaboration, T. Affolder et al., Phys. Rev. Lett. **87**, 231 803 (2001)
20. T.G. Rizzo, hep-ph/9612440
21. T.G. Rizzo, JHEP **0705**, 037 (2007)
22. T. Aliev, O. Cakir, Eur. Phys. J. C **54**, 149 (2008)
23. H.J. He et al., arXiv:0708.2588 [hep-ph]
24. A. Belyaev, arXiv:0711.1919 [hep-ph]
25. J. Hirn, J. Stern, Eur. Phys. J. C **34**, 447 (2004)
26. R. Casalbuoni, S. De Curtis, D. Dominici, Phys. Rev. D **70**, 055 010 (2004)
27. R.S. Chivukula, E.H. Simmons, H.-J. He, M. Kurachi, M. Tanabashi, Phys. Rev. D **70**, 075 008 (2004)
28. H. Georgi, Phys. Rev. D **71**, 015 016 (2005)
29. R.S. Chivukula, E.H. Simmons, H.-J. He, M. Kurachi, M. Tanabashi, Phys. Rev. D **71**, 035 007 (2005)
30. M. Perelstein, JHEP **0410**, 010 (2004)
31. R. Foadi, S. Gopalakrishna, C. Schmidt, JHEP **0403**, 042 (2004)
32. R.S. Chivukula et al., Phys. Rev. D **74**, 075 011 (2006)
33. T. Han, H.E. Logan, L.T. Wang, JHEP **0601**, 099 (2006)
34. D.E. Kaplan, M. Schmaltz, JHEP **0310**, 039 (2003)
35. N. Arkani-Hamed, A.G. Cohen, E. Katz, A.E. Nelson, JHEP **0207**, 034 (2002)
36. M. Schmaltz, JHEP **0408**, 056 (2004)
37. American Linear Collider Group, T. Abe et al., hep-ex/0106057
38. ECFA/DESY LC Physics Working Group, J.A. Aguilar-Saavedra et al., hep-ph/0106315
39. ACFA Linear Collider Working Group, K. Abe et al., hep-ph/0109166
40. W. Kiliam, P.M. Zerwas, hep-ph/0601217
41. S. Sultansoy, Eur. Phys. J. C **33**, S1064 (2004)
42. L. Gladilin, H. Karadeniz, E. Recepoglu, S. Sultansoy, Acta Phys. Pol. B **38**, 2105 (2007)
43. H1 Collaboration, C. Adloff et al., Eur. Phys. J. C **30**, 1 (2003)
44. ZEUS Collaboration, S. Chekanov et al., Eur. Phys. J. C **32**, 1 (2003)
45. H1 Collaboration, A. Aktas et al., Phys. Lett. B **634**, 173 (2006)
46. CTEQ Collaboration, J. Pumplin et al., JHEP **02**, 032 (2006)
47. For review see: R. Nisius, Phys. Rep. **332**, 165 (2000)
48. M. Krawczyk, A. Zembrzuski, M. Staszel, Phys. Rep. **345**, 265 (2001)
49. I.F. Ginzbury et al., Nucl. Instrum. Methods Phys. Res. A **219**, 5 (1984)
50. V.I. Telnov, Nucl. Instrum. Methods Phys. Res. A **294**, 72 (1990)
51. P. Aurenche, M. Fontannaz, J.P. Guillet, Eur. Phys. J. C **44**, 395 (2005)
52. F. Cornet, Acta Phys. Pol. B **37**, 663 (2006)
53. T. Han, H.E. Logan, B. McElrath, L.T. Wang, Phys. Rev. D **67**, 095 004 (2003)
54. J.L. Hewett, F.J. Petriello, T.G. Rizzo, JHEP **0310**, 062 (2003)
55. C. Csaki, J. Hubisz, G.D. Kribs, P. Meade, J. Terning, Phys. Rev. D **67**, 115 002 (2003)
56. C. Csaki et al., Phys. Rev. D **68**, 035 009 (2003)
57. R. Casalbuoni, A. Deandrea, M. Oertel, JHEP **0402**, 032 (2004)
58. M.-C. Chen, S. Dawson, Phys. Rev. D **70**, 015 003 (2004)
59. W. Kilian, J. Reuter, Phys. Rev. D **70**, 015 004 (2004)
60. T. Gregoire, D.R. Smith, J.G. Wacker, Phys. Rev. D **69**, 115 008 (2004)
61. C.-X. Yue, W. Wang, Nucl. Phys. B **683**, 48 (2004)
62. M.-C. Chen, Mod. Phys. Lett. A **21**, 621 (2006)
63. Y. Kawamura, Prog. Theor. Phys. **103**, 613 (2000)
64. Y. Kawamura, Prog. Theor. Phys. **105**, 691 (2001)
65. A. Hebecker, J. March-Russell, Nucl. Phys. B **613**, 3 (2001)
66. A. Hebecker, J. March-Russell, Nucl. Phys. B **625**, 128 (2002)
67. L.J. Hall, Y. Nomura, T. Okui, D.R. Smith, Phys. Rev. D **65**, 035 008 (2002)
68. L.J. Hall, Y. Nomura, Phys. Rev. D **65**, 125 012 (2002)
69. R.S. Chivukula, D.A. Dicus, H.-J. He, Phys. Lett. B **525**, 175 (2002)
70. R.S. Chivukula, H.-J. He, Phys. Lett. B **532**, 121 (2002)
71. R.S. Chivukula, D.A. Dicus, H.-J. He, S. Nandi, Phys. Lett. B **562**, 109 (2003)
72. S. Mastsuzaki, R.S. Chivukula, E.H. Simmons, M. Tanabashi, Phys. Rev. D **75**, 073 002 (2007)
73. R.S. Chivukula, E.H. Simmons, S. Matsuzaki, M. Tanabashi, Phys. Rev. D **75**, 075 012 (2007)
74. R.S. Chivukula, E.H. Simmons, H.-J. He, M. Kurachi, M. Tancbashi, Phys. Rev. D **71**, 115 001 (2005)

75. R.S. Chivukula, E.H. Simmons, H.-J. He, M. Kurachi, M. Tancbashi, Phys. Rev. D **72**, 015 008 (2005)
76. R. Casalbuoni, S. De Curtis, D. Dolce, D. Dominici, Phys. Rev. D **71**, 075 015 (2005)
77. R.S. Chivukula, E.H. Simmons, H.-J. He, M. Kurachi, M. Tanabashi, Phys. Rev. D **72**, 015 008 (2005)
78. R. Foadi, C. Schmidt, Phys. Rev. D **73**, 075 011 (2006)
79. R. Casalbuoni, S. De Curtis, D. Dominici, R. Gatto, Phys. Lett. B **155**, 95 (1985)
80. R. Casalbuoni, Nucl. Phys. B **282**, 235 (1987)
81. S. Dawson, C.B. Jackson, Phys. Rev. D **76**, 015 014 (2007)
82. C. Weizsäcker, Z. Phys. **99**, 612 (1934)
83. E.J. Williams, Phys. Rev. **45**, 729 (1934)
84. H.C. Cheng, I. Low, JHEP **0309**, 051 (2003)
85. H.C. Cheng, I. Low, JHEP **0408**, 061 (2004)
86. I. Low, JHEP **0410**, 067 (2004)
87. F. Cornet, J. Rico, Phys. Lett. B **412**, 343 (1997)
88. F. Cornet, M. Relano, J. Rico, Phys. Rev. D **61**, 037 701 (2000)