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Littlest Higgs model and *W* pair production at international linear collider

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Abstract. Among the viable alternatives to the standard Higgs mechanism is the recently proposed Little Higgs model. The advantage here is that the model has an elementary light neutral scalar particle, which arises dynamically as against its *ad hoc* introduction in the standard model. The model also avoids hierarchy problem. We have investigated the W pair production at ILC to study the littlest Higgs model using different observables. Specifically, polarization fraction of W boson is expected to be measured very accurately at ILC. We use this to put limit on the scale parameter, f, in the model.

Keywords. Electroweak symmetry breaking; littlest Higgs, W polarization fraction.

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1. Introduction

Study of electroweak symmetry breaking mechanism is one of the central problems of particle physics today. The SM Higgs mechanism is simple, but *ad hoc*-ly introduces an elementary scalar particle in the theory. Mass of the Higgs particle is expected, from theoretical and experimental considerations, to be in the range of 10^2 GeV. But at one-loop level Higgs mass square acquire quadratically diverging corrections; a difficulty known as hierarchy problem. Models including supersymmetric extensions of the standard model, composite Higgs models, strongly interacting EW scenario, Higgs-less models, little Higgs models, etc. suggest different ways to take care of the hierarchy problem. Of these, we will be concerned here with the little Higgs models [1]. Unlike supersymmetric theories, little Higgs theories work on the gauge sector of the theory. An appealing aspect of the scenario is that the scalars are not introduced ad hoc-ly, and the symmetry breaking is generated dynamically.

Although LHC is expected to investigate the electroweak symmetry breaking (EWSB) mechanism, it will require the clean environment of the proposed international linear collider (ILC) to study the details and, for example, distinguish between different scenarios.

In this write-up we will discuss W pair production at ILC within the framework of one version of the little Higgs models, known as the littlest Higgs models [2]. In the next section we will introduce the littlest Higgs model. In §3 we will discuss the process $e^+e^- \to W^+W^-$ and the observables that are sensitive to the littlest Higgs model.

2. The little Higgs models

The scenario is analogous to the description of low-energy hadronic interactions by a non-linear realization of the chiral symmetry $SU(2)_{\rm L} \times SU(2)_{\rm R}$ broken down to $SU(2)_{\rm I}$ at energy scale f. Pions (π) are taken to be the Nambu–Goldstone bosons (NGB) of the symmetry breaking, and their dynamics can be defined by a non-linear sigma model.

In little Higgs models [1], similarly, we consider the non-linear realization of some global symmetry G broken down to H. The Nambu–Goldstone bosons (NGB) of the symmetry breaking are candidate Higgs field. In a specific model, called littlest Higgs (LH) model [2] $G \equiv SU(5)$ is broken down to $H \equiv SO(5)$. This leaves us $24 - 10 = 14$ NGBs. Interaction of NGBs are described by non-linear sigma model, which is an effective theory valid below the cut-off $\Lambda \sim 4\pi f$. To identify some of these NGBs as Higgs particles we gauge a subgroup of $SU(5)$. In the original version of the littlest Higgs model $[SU_1(2) \times U_1(1)] \times [SU_2(2) \times U_2(1)] \subset SU(5)$ is gauged, which is broken down to the standard model (SM) gauge group $SU(2)_{\rm L} \times U(1)_{\rm Y}$. Under the SM gauge group, the 14 NGBs transform as $(\mathbf{1},0)+(\mathbf{3},0)+(\mathbf{2},\frac{1}{2})+(\mathbf{3},1)$. SM gauge bosons, $\vec{W}^\mu_L$ and B^μ_L remain massless at this stage, while the gauge bosons belonging to the broken sector, $\vec{W}^\mu_H$ and B^μ_H, become massive after absorbing the singlet and the real triplet (with hypercharge, $Y = 0$). The doublet NGB field has all the correct quantum numbers to be identified as the standard Higgs doublet. At tree level, they have only derivative couplings. Quantum corrections at one-loop level will generate Coleman–Weinberg potential with quadratic and quartic terms. Gauge symmetry is constructed such that, in the absence of any one (original) gauge interaction, Higgs is massless at all orders. This also ensures that quadratically divergent contributions to the mass square term at one-loop level are canceled between the two gauge bosons from the two sectors. Logarithmically divergent terms contribute to the potential. In order to avoid quadratic divergence due to top quark loop, a pair of (weak-singlet) Weyl quark $U_{\rm L}, U_{\rm R}$ is introduced, which mix with the ordinary left- and right-quarks to give the mass eigenstates. Here again, it is arranged such that the quadratic divergence coming from the standard top quark is canceled by its heavy counterpart, and the logarithmically diverging part adds to the Coleman–Weinberg potential. The triplet left over NGBs also add logarithmically diverging quadratic terms to the potential. Presence of triplet in the loop also generates quartic terms in the potential. The Higgs potential thus generated breaks the $SU(2)_{\rm L} \times U(1)_{\rm Y}$ symmetry spontaneously. At the same time, Higgs mass is protected from acquiring quadratically divergent mass corrections at one loop.

Precision electroweak measurements constrain this model to have $f > 4$ TeV, leaving the cut-off $\Lambda > 12$ TeV, thwarting the original motivation of solving hierarchy problem. There are variations that avoid this difficulty; two among them are (i) introduce T-Parity [3], (ii) change the gauge sector [4]. In the second approach, which we will be concerned here with the gauge group considered is

$SU_1(2) \times SU_2(2) \times U_{\rm Y}(1)$, which is broken down to the standard $SU_{\rm L}(2) \times U_{\rm Y}(1)$. Situation is similar to the earlier case, but without B_H. In this model we have three heavy gauge bosons; $W_H^{\pm}$ and Z_H, in addition to the standard $W^{\pm}$, Z and A. Masses of the new gauge bosons are given by

$$M_{W_H} = M_{Z_H} = \frac{g}{\sin 2\theta}\, f, \tag{1}$$

where $g = g_1 g_2/\sqrt{g_1^2 + g_2^2}$ is the standard $SU(2)_{\rm L}$ coupling and θ is the mixing angle between $SU_1(2)$ and $SU_2(2)$. Electroweak precision measurements allow $f > 1$ TeV with $\cos\theta \sim 1/3$. Some of the phenomenological studies of little Higgs models in the context of LHC and ILC are listed in ref. [5].

3. The process: $e^+e^- \to W^+W^-$

We will now consider the effect of this scenario in W pair production at a high energy linear e^+e^- collider. Apart from the standard channels, this process gets contribution from a Z_H mediated s-channel. Along with this, there could also be differences between the SM predictions and the littlest Higgs model predictions through changed couplings. The SM gauge couplings $(g_{WW\gamma}, g_{WWZ})$ and the W couplings to the fermions are unchanged, but the fermionic couplings of the standard model Z boson pick up an additional contribution of the order of v^2/f^2. The vector and axial vector couplings of Z to the electrons are given respectively by

$$c^v_{eeZ} = \frac{g}{2c_W}\left[\left(-\frac{1}{2} + 2x_W\right) + \frac{v^2}{f^2}\,\frac{\sin 4\theta}{8}\right] \tag{2}$$

$$c^a_{eeZ} = \frac{g}{2c_W}\left[\frac{1}{2} - \frac{v^2}{f^2}\,\frac{\sin 4\theta}{16}\cot\theta\right]. \tag{3}$$

Couplings of the heavy Z_H with W and electrons are given by

$$g_{WWZ_H} = \frac{gv^2}{8f^2}\,\sin 4\theta, \tag{4}$$

$$c^v_{eeZ_H} = \frac{-g}{4}\,\cot\theta, \quad c^a_{eeZ_H} = \frac{g}{4}\,\cot\theta. \tag{5}$$

We will now present our results. In the first place, we study the deviation of total cross-section from the SM value. In figure 1 (left) we plot the total cross-section against the centre-of-mass energy. In order to get an estimate of how far we can probe the scale f at ILC, we consider two c.m. energy values, 500 GeV and 800 GeV, and assume a luminosity of 1 ab^{-1}. At 1σ level we can probe f up to 6 TeV at both energies. LEP has measured the fractional cross-section of the polarized Ws very precisely [6]. AT ILC this precision is expected to be even better. Defining the polarization fractions as

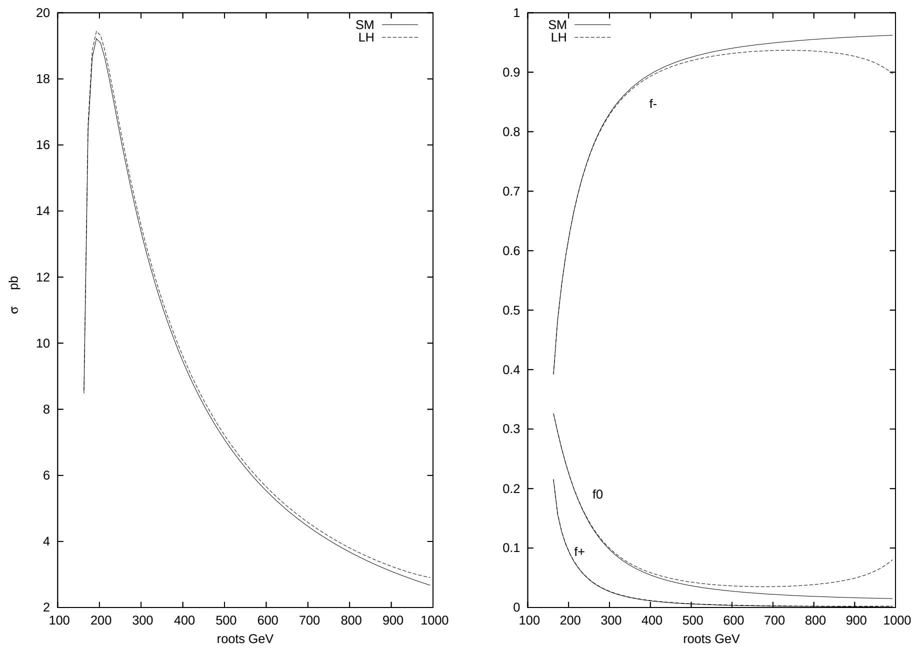

Figure 1. Unpolarized cross-section (left) and polarization fractions (right) against centre-of-mass energy. Solid line corresponds to SM, while the dashed line corresponds to the littlest Higgs model.

$$f^0 = \frac{\sigma(e^+e^- \to W^+W^-_{\rm L})}{\sigma_{\rm unpol}}, f^T = \frac{\sigma(e^+e^- \to W^+W^-_{\rm T})}{\sigma_{\rm unpol}}, \tag{6}$$

where L refers to the longitudinal polarization and T = ± refers to the transverse polarizations, we plot them in figure 1 (right). We find that the longitudinal fraction is changed from 3.8% to 4.4%, and from 1.9% to 4.0% at centre-of-mass energies 500 GeV and 800 GeV respectively.

It is clear that beam polarization can be used to switch off the dominant t-channel production to which LH model does not add any new contribution. This will enhance the sensitivity considerably. One could also consider different observables, including forward–backward asymmetry to probe the fermionic couplings of the gauge bosons. Work on this is in progress.

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