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Pair production of charged scalars and lepton flavor violating signals in the littlest Higgs model at e^+e^- colliders

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Abstract

In this work pair productions of charged and doubly charged scalars in the framework of littlest Higgs model at e^+e^- colliders are studied. In the allowed parameter space of the littlest Higgs model, the production rates of the scalar pairs are calculated. It is obtained that pair productions of charged and doubly charged scalars are reachable at e^+e^- colliders with energy $\sqrt{S} \geqslant 1.7$ TeV. Using the lepton flavor violating decays of charged scalars calculated in literature, final state analysis is done for pair production processes. This analysis show that depending on the model parameters, lepton number and lepton flavor violations can be observed free from any backgrounds.

1. Introduction

Despite the impressive success of the Standard Model (SM) in describing all experimental data, it contains many unsolved problems, such as, origin of mass and CP violation, hierarchy problem, number of generations, baryon anti-baryon asymmetry, etc. For solution of these problems it is necessary to go beyond SM. To obtain a "natural" solution to hierarchy problem little Higgs models [1–4] are introduced. In little Higgs models new physics is introduced at TeV scale; these models predict existence of new particles and new interactions of these particles with SM particles as well as interactions among themselves. The phenomenologies of the little

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Higgs models are reviewed widely [5–7], and the constraints on little Higgs models are studied [8–14].

Among little Higgs models, there are several variations which differ in the assumed higher symmetry group and in the representation of the scalar multiplets, one of which is the littlest Higgs model [1]. The existence of new particles in littlest Higgs model includes new heavy gauge bosons and a new scalar sector consisting of a neutral heavy scalar (ϕ^0), a neutral pseudo-scalar (ϕ^P), a singly charged scalar (ϕ^+) and a doubly charged scalar (ϕ^{++}) receives special attention. The charged scalars ϕ^+ and ϕ^{++} of the littlest Higgs model are under special interest since they have distinct signatures in future colliders. Productions of charged scalars and their signatures at ILC, LHC and THERA are studied via $e^-\gamma \to e^+\phi^{--}$, $e^- p \to l^+ X\phi^{--}$ and $\bar{q}q' \to \phi^+\phi^{--}$ processes [15]. Also Z_L associated productions and final collider signatures of charged scalars are studied via $e^+e^- \to Z_L\phi^+\phi^-$ and $e^+e^- \to Z_L\phi^{++}\phi^{--}$ processes at a linear collider [16].

In this work, the productions of single and doubly charged scalar pairs via $e^+e^- \to \phi^+\phi^-$ and $e^+e^- \to \phi^{++}\phi^{--}$ processes at future e^-e^+ colliders, namely, International Linear Collider (ILC) [17] and Compact Linear Collider (CLIC) [18] are examined. The dependence of cross sections to the littlest Higgs model parameters at the range allowed by electroweak precision observables are calculated. It is found that the production rates of the single charged scalar pairs are less than the production rates of doubly charged scalar pairs, but both channels will be achieved at future e^-e^+ colliders at $\sqrt{s} \geqslant 1.7$ GeV. In addition to production rates, the final signatures of the productions are also analyzed considering the lepton flavor violating decays of the charged and the double charged scalars, whose branching ratios have been studied by T. Han et al. [19]. It is found that pair productions of charged and double charged scalars lead to distinct signatures in e^+e^- colliders including lepton number and lepton flavor violating ones.

The paper is organized as follows: In Section 2, the cross sections of pair productions of charged scalars at e^-e^+ colliders are calculated. Section 3 contains our numerical results and discussions.

2. Theoretical framework

Before examining the pair productions of the charged scalars, we remind the main ingredients of the littlest Higgs model and lepton flavor violation in littlest Higgs model. The littlest Higgs model assumes a higher symmetry group $SU(5)$ with a weakly gauged subgroup of $(SU(2) \otimes U(1))^2$. Among consecutive symmetry breakings first $SU(5)$ is broken to $SO(5)$ at TeV scale, and simultaneously subgauged group $(SU(2) \otimes U(1))^2$ is broken to $SU(2) \otimes U(1)$. Then at $v \sim 246$ GeV ordinary electroweak symmetry breaking (EWSB) occurs. As a result of higher symmetry breaking new scalar sector enters the model, which is the scalar triplet at the end whose members are ϕ^0, ϕ^P, ϕ^+ and ϕ^{++}. Also from symmetry breaking of gauged group $(SU(2) \otimes U(1))^2$ new bosons A_H, Z_H and W_H gain mass.

In summary, littlest Higgs model contain four physical scalars; Higgs scalar: H, new heavy scalars: ϕ^0, ϕ^+ and ϕ^{++}, and a new heavy pseudo-scalar: ϕ^P. All scalars excluding H are degenerate in mass:

$$M_\phi = \frac{\sqrt{2}f}{v\sqrt{1-(\frac{4v'f}{v^2})^2}} M_H, \tag{1}$$

where M_H is the mass of the Higgs boson, f is the higher symmetry breaking scale of the littlest Higgs model, v and v' are the vacuum expectation values (VEVs) of the Higgs field and the