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The flavor-changing top-charm quark production in the littlest Higgs model with T-parity at the ILC

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Abstract

With high luminosity and energy at the ILC and clean SM backgrounds, the top-charm production at the ILC should have powerful potential to probe New Physics. The littlest Higgs model with discrete symmetry named "T-parity" (LHT) is one of the most promising New Physics models. In this paper, we study the FC top-charm quark production processes $e^+e^-(\gamma\gamma) \to t\bar{c}$ at the ILC in the LHT model. Our study shows that the LHT model can make a significant contribution to these processes. When the masses of mirror quarks become large, these two processes are accessible at the ILC. So the top-charm production at the ILC provides a unique way to study the properties of the FC couplings in the LHT model. On the other hand, we make a comparison among various New Physics models and find that the cross sections of $e^+e^-(\gamma\gamma) \to t\bar{c}$ in the LHT model are significantly larger than those in other New Physics models. So the processes $e^+e^-(\gamma\gamma) \to t\bar{c}$ may also provide a way to distinguish the LHT model from the others.

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1. Introduction

A simple doublet scalar field yields a perfectly appropriate gauge symmetry breaking pattern in the Standard Model (SM). On the other hand, its theoretical shortcomings, such as quadratic divergences (hierarchy problem) or the triviality of a ϕ^4 theory suggest that it is embedded in a larger scheme. Recently, an alternative known as the little Higgs mechanism [1], has been proposed. Such mechanism that makes the Higgs "little" in the current reincarnation of the PGB

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idea is collective symmetry breaking. Collective symmetry breaking protects the Higgs by several symmetries under each of which the Higgs is an exact Goldstone. Only if the symmetries are broken collectively, i.e. by more than one coupling in the theory, can the Higgs pick up a contribution to its mass and hence all one-loop quadratic divergences to the Higgs mass are avoided. The most compact implementation of the little Higgs mechanism is known as the littlest Higgs model [2]. In this model, the SM is enlarged to incorporate an approximate $SU(5)$ global symmetry. This symmetry is broken down to $SO(5)$ spontaneously, though the mechanism of this breaking is left unspecified. The Higgs is an approximate Goldstone boson of this breaking. In this model there are new vector bosons, a heavy top quark and a triplet of heavy scalars in addition to the SM particles. These new particles can make significant tree-level contributions to the experimental observables. So the original LH model suffers strong constraints from electroweak precision data [3]. The most serious constraints result from the tree-level corrections to precision electroweak observables due to the exchanges of the additional heavy gauge bosons, as well as from the small but non-vanishing vacuum expectation value (VEV) of the additional weak-triplet scalar field. To solve this problem, a Z_2 discrete symmetry named "T-parity" is introduced [4]. The littlest Higgs model with T-parity (LHT), requires the introduction of "mirror fermions" for each SM fermion doublet. The mirror fermions are odd under T-parity and can be given large masses and the SM fields are T-even. T-parity explicitly forbids any tree-level contribution from the heavy gauge bosons to the observables involving only Standard-Model particles as external states. It also forbids the interactions that induce the triplet VEV. As a result, in the LHT model, corrections to precision electroweak observables are generated at loop-level. This implies that the constraints are generically weaker than in the tree-level case, and fine tuning can be avoided [5]. In the LHT model, one of the important ingredients of the mirror sector is the existence of CKM-like unitary mixing matrices. These mirror mixing matrices parameterize flavor-changing (FC) interactions between the SM fermions and the mirror fermions. Such new FC interactions have a very different pattern from ones present in the SM and can have significant contributions to some FC processes. As we know, the SM does not contain the tree-level FC neutral currents, though it can occur at higher order through radiative corrections. Because of the loop suppression, these SM FC effects are hardly to be observed. On the other hand, a next-generation linear collider (LC) will be an ideal machine for probing New Physics. So this stimulates a lot of efforts in probing New Physics via rare top quark decay [6] or FC production processes at LC [7–18]. Because the LHT model opens up a new flavor structure, the impact of the FC interactions in the LHT model on some processes has also been studied. In the paper [19], Hubisz et al. have done a first exploratory study of this flavor structure, and found constraints on the mirror fermion mass spectrum from a one-loop analysis of neutral meson mixing in the K, B and D systems. Then an extensive study of FC transitions in the LHT model has been done by the group of Blanke et al. [20,21]. The paper [20] has confirmed the analytic expressions for the effective Hamiltonian for $\Delta F = 2$ transitions presented in [19] and generalized the analysis to other quantities that allow a deeper insight into the flavor structure of the LHT model. The group of Blanke et al. have also extended their analysis of paper [20] to included all prominent rare K and B decays and a collection of Feynman rules including v^2/f^2 contributions is given for the first time [21]. Motivated by the first experimental evidence of meson oscillations in the D system, the paper [22] has investigated the impact of D^0–$\bar{D}^0$ mixing in the LHT model on the previous LHT flavor analyses [20,21]. Following their work, Blanke et al. have also calculated the CP-violating ratio ε'/ε in the LHT model [23]. Furthermore, the paper [24] has extended the analysis of the flavor structure in the LHT model to the lepton flavor violating decays. The FC couplings between the SM fermions and the mirror fermions can also induce the loop-level $tcV(V = \gamma, Z, g)$