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

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Abstract

The littlest Higgs model with discrete symmetry named "T-parity" (LHT) is an interesting new physics model which does not suffer strong constraints from electroweak precision data. One of the important features of the LHT model is the existence of new source of FC interactions between the SM fermions and the mirror fermions. These FC interactions can make significant loop-level contributions to the couplings tcV, and furthermore enhance the cross sections of the FC single-top quark production processes. In this paper, we study some FC single-top quark production processes, $pp \to t\bar{c}$ and $pp \to tV$, at the LHC in the LHT model. We find that the cross sections of these processes strongly depend on the mirror quark masses. The processes $pp \to t\bar{c}$ and $pp \to tg$ have large cross sections with heavy mirror quarks. The observation of these FC processes at the LHC is certainly the clue of new physics, and further precise measurements of the cross sections can provide useful information about the free parameters in the LHT model, specially about the mirror quark masses.

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1. Introduction

On the experimental aspect, the forthcoming generation of high energy colliders, headed by the Large Hadron Collider (LHC) at CERN depicts an exciting scenario for probing the existence of physics beyond the Standard Model (SM) of strong and electroweak (EW) interaction [1]. For the probe of new physics at the high energy colliders like the LHC, there are two ways: one

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is through detecting the direct production of new particles and the other is through unravelling the quantum effects of new physics in some sensitive and well-measured processes. These two aspects can be complementary and offer a consistent check for new physics. If the collider energy is not high enough to produce the heavy new particles, probing the quantum effects of new particles will be the only way of peeking at the hints of new physics.

On the other hand, as the heaviest fermion in the SM, the top quark is speculated to be a sensitive probe of new physics. Due to the small statistics of the experiments at the Fermilab Tevatron collider, so far the top quark properties have not been precisely measured and there remained a plenty of room for new physics effects in top quark processes. Since the LHC will be a top factory and allow to scrutinize the top quark nature, unravelling new physics effects in various top quark processes will be an intriguing channel for testing new physics models. Furthermore, there exists a typical property for the top quark in the SM, i.e., its flavor-changing (FC) interactions are extremely small [2] due to the Glashow–Iliopoulos–Maiani (GIM) mechanism. This will make the observation of any FC top quark process a smoking gun for new physics. Therefore, the combination of the top quark and FC processes will be an interesting research field for LHC experiments.

On the theoretical aspect, the SM is in excellent agreement with the results of particle physics experiments, in particular with the EW precision measurements, thus suggesting that the SM cutoff scale is at least as large as 10 TeV. Having such a relatively high cutoff, however, the SM requires an unsatisfactory fine-tuning to yield a correct ($\approx 10^2$ GeV) scale for the squared Higgs mass, whose corrections are quadratic and therefore highly sensitive to the cutoff. This little hierarchy problem has been one of the main motivations to elaborate new physics. Recently, an alternative known as the little Higgs mechanism [3], has been proposed. Such mechanism that makes the Higgs "little" in the current reincarnation of the PGB 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 (LH) model [4]. 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 [5]. 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 [6]. 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, the corrections to the precision electroweak observables are generated at loop-level. This implies that the constraints are generically weaker than those in the tree-level case, and fine tuning can be avoided [7].