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Production of the quintuplet leptons in future high energy linear e^+e^- colliders

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Abstract

The quintuplet heavy leptons are the typical particles predicted by the TeV scale seesaw model which is proposed as a viable and testable solution to the neutrino masses problem. The observation of these particles might be regarded as a direct evidence of the new model. In this paper, we investigate production and detection prospects of the quintuplet heavy leptons in the processes $e^+e^- \to \Sigma^{++}\overline{\Sigma^{++}}(\Sigma^+\overline{\Sigma^+})$ and $e^+e^- \to Z\Sigma^{++}\overline{\Sigma^{++}}(Z\Sigma^+\overline{\Sigma^+})$ at the ILC. We present the production cross sections and the main kinematic distributions of the various observables. Our numerical results show that the values of cross sections can reach a few hundreds of fb. We also study the possible final state signals of quintuplet heavy leptons and relevant SM backgrounds. Due to high produced rate and small SM backgrounds, the possible signals of quintuplet heavy leptons might be detected via some processes in the future ILC experiments.

1. Introduction

The standard model (SM) of particle physics has been proven to be extremely successful in describing collider experimented data so far. In July 2012, both the ATLAS and the CMS Collaborations announced the discovery of a new scalar particle with a mass of 126 GeV, which is consistent with the predictions of the SM Higgs boson [1,2]. However, this newly discovered scalar particle has been interpreted in various new physics models [3–7], since the SM cannot

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present an explanation for some fundamental problems, such as the hierarchy problem, neutrino masses and dark matter.

The observation of neutrino oscillations has unequivocally established that at least two of the three active neutrinos have nonvanishing mass and that individual lepton flavor is violated [8]. Which can be seen as the typical experimental clue to new physics beyond the SM. Therefore, a precise understanding of the neutrino mass mechanism is an important step in unraveling the nature of new physics.

There have been numerous attempts to build new physics models aiming to explain these puzzles. The seesaw mechanism is one of the most attractive approaches, which can explain the smallness of neutrino mass via introducing the new particles with sufficiently large masses. At the tree level, type-I [9], type-II [10] and type-III [11] seesaw mechanisms proceed via introducing heavy lepton singlet, scalar triplet and lepton triplet, respectively, which also predict the existence of the new scalars particles or gauge bosons.

We here focus on a new TeV scale seesaw model [12], which is proposed as a viable and testable solution to the neutrino masses problem. This new model is proposed for generating small neutrino masses which predicts the relation $m_\nu \sim v^6/M^5$ at tree-level, rather than the conventional three types seesaw formula $m_\nu \sim v^2/M$, where v is the electroweak scale and M is the scale of new physics. This new model introduces a scalar quadruplet Φ and fermion quintuplets Σ_R. The fermion quintuplet contains the doubly charged heavy leptons (Σ^{++} and $\overline{\Sigma^{++}}$), singly charged heavy leptons (Σ^{+} and $\overline{\Sigma^{+}}$) and neutral heavy leptons (Σ^{0}). The neutral component of the fermion quintuplet is identified as a minimal dark matter candidate.

The fermion quintuplet is provided with outstanding features, which can give the unravel signals of possible scenarios beyond the SM. Thus, the discovery of these exotic fermions at the future high-energy colliders might shed some light on the new physics.

Many works have been done to study of the exotic leptons in various of new physics models [13–16]. Both single production and pair production of exotic leptons have been studied in Refs. [17–20]. Doubly charged leptons also appear in left–right symmetric models [24], in extra dimensional models [21], in string inspired models [22], and in generic lepton triplets minimally coupling to the SM fields [23]. The phenomenology of the exotic leptons has also been analyzed in Refs. [25–27].

The heavy leptons have been searched at the LHC [28,29], which has already posed significant bounds on the masses of the heavy leptons. Furthermore, the LHC Run-2 with higher energy and higher luminosity will certainly extend the horizon to seek for the heavy leptons. Some phenomenological researches of this new seesaw model at the LHC have been fruitfully analyzed in Refs. [12,30]. It is well known that the TeV scale linear colliders with high luminosity, such as the international linear collider (ILC) [31], are the best options to complement and extend the LHC physics program.

In this paper, we will study the direct searches for quintuplet leptons predicted via processes: $e^+e^- \to \Sigma^{++}\overline{\Sigma^{++}}(\Sigma^{+}\overline{\Sigma^{+}})$ and $e^+e^- \to Z\Sigma^{++}\overline{\Sigma^{++}}(Z\Sigma^{+}\overline{\Sigma^{+}})$, and give detailed analysis of the signals and the corresponding SM backgrounds at the ILC in the context of this new model.

2. The TeV scale seesaw model and relevant couplings

The new model we concern here is based on the SM gauge symmetry $SU(3)_C \times SU(2)_L \times U(1)_Y$. Besides usual SM fermions, three generations of hypercharge zero quintuplets $\Sigma_R = (\Sigma_R^{++}, \Sigma_R^{+}, \Sigma_R^{0}, \Sigma_R^{-}, \Sigma_R^{--})$ are introduced transforming as $(1, 5, 0)$ under the gauge group. Be-