Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B 772 (2007) 49–66
NUCLEAR PHYSICS B

Testable flipped $SU(5) \times U(1)_X$ models

Jing Jiang [a], Tianjun Li [b,c,d,*], Dimitri V. Nanopoulos [b,e,f]

[a] Institute of Theoretical Science, University of Oregon, Eugene, OR 97403, USA
[b] George P. and Cynthia W. Mitchell Institute for Fundamental Physics, Texas A&M University, College Station, TX 77843, USA
[c] Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100080, PR China
[d] Department of Physics and Astronomy, Rutgers University, Piscataway, NJ 08854, USA
[e] Astroparticle Physics Group, Houston Advanced Research Center (HARC), Mitchell Campus, Woodlands, TX 77381, USA
[f] Academy of Athens, Division of Natural Sciences, 28 Panepistimiou Avenue, Athens 10679, Greece

Received 6 October 2006; received in revised form 16 February 2007; accepted 19 February 2007

Available online 12 March 2007

Abstract

The little hierarchy between the GUT scale and the string scale may give us some hints that can be tested at the LHC. To achieve string-scale gauge coupling unification, we introduce additional vector-like particles. We require that these vector-like particles be standard, form complete GUT multiplets, and have masses around the TeV scale or close to the string scale. Interestingly, only the flipped $SU(5) \times U(1)_X$ models can work elegantly. We consider all possible sets of vector-like particles with masses around the TeV scale. And we introduce vector-like particles with masses close to the string scale which can mimic the string-scale threshold corrections. We emphasize that all of these vector-like particles can be obtained in the interesting flipped $SU(5) \times U(1)_X$ string models from the four-dimensional free fermionic string construction. Assuming the low-energy supersymmetry, high-scale supersymmetry, and split supersymmetry, we show that the string-scale gauge coupling unification can indeed be achieved in the flipped $SU(5) \times U(1)_X$ models. These models can be tested at the LHC by observing simple sets of vector-like particles at the TeV scale. Moreover, we discuss a simple flipped $SU(5) \times U(1)_X$ model with string-scale gauge coupling unification and high-scale supersymmetry by introducing only one pair of the vector-like particles at the TeV scale, and we predict the corresponding Higgs boson masses. Also, we briefly comment on the string-scale gauge coupling unification in the model with low-energy supersymmetry by introducing only one pair of the vector-like particles at the intermediate scale. And we briefly comment on the mixings among the SM fermions and the corresponding extra vector-like particles.

* Corresponding author.
E-mail address: tjli@physics.rutgers.edu (T. Li).

0550-3213/$ – see front matter
doi:10.1016/j.nuclphysb.2007.02.025

PACS: 11.25.Mj; 12.10.Kt; 12.10.-g

1. Introduction

Supersymmetry provides an elegant solution to the gauge hierarchy problem, and Grand Unified Theories (GUTs) gives us a simple understanding of the quantum numbers of the Standard Model (SM) fermions. In particular, the success of gauge coupling unification in the Minimal Supersymmetric Standard Model (MSSM) strongly supports the possibility of the supersymmetric GUTs [1]. Moreover, the electroweak gauge symmetry can be broken by the radiative corrections due to the large top quark Yukawa coupling [2], and the tiny neutrino masses can be generated naturally via the see-saw mechanism. Therefore, supersymmetric GUTs may describe all the known fundamental interactions in nature except gravity.

The interesting question is whether we can test supersymmetric GUTs at future colliders and experiments. The major prediction of supersymmetric GUTs is the dimension-5 proton decay from the colored Higgsino exchange [3]. This kind of proton decay is suppressed due to the Yukawa couplings. However, we can introduce the non-renormalizable operators to mimic such proton decay, i.e., generic dimensional-5 proton decay operators with Planck scale suppression and without Yukawa coupling suppression [4]. So, even if we observe such proton decay at future experiments, we cannot confirm the possibility of supersymmetric GUTs.

If string theory is correct, it seems to us that one new clue is the little hierarchy between the GUT scale M_{GUT} and the string scale M_{string}. It is well known that the gauge coupling unification scale in the MSSM, which is called the GUT scale in the literature, is around 2×10^{16} GeV [1]. The gauge coupling unification in the MSSM is based on two implicit assumptions: (1) the $U(1)_Y$ normalization is canonical; (2) there are no intermediate-scale threshold corrections. On the other hand, the string scale M_{string} in the weakly coupled heterotic string theory is [5]

$$M_{\text{string}} = g_{\text{string}} \times 5.27 \times 10^{17}\ \text{GeV}, \tag{1}$$

where g_{string} is the string coupling constant. Note that since $g_{\text{string}} \sim \mathcal{O}(1)$, we have

$$M_{\text{string}} \approx 5 \times 10^{17}\ \text{GeV}. \tag{2}$$

Thus, there exists a factor of approximately 20–25 between the MSSM unification scale and the string scale. (In the strong coupled heterotic string theory or M-theory on S^1/Z_2 [6], the eleven-dimensional Planck scale can be the MSSM unification scale due to the large eleventh dimension [7]. But in this paper we concentrate on the weakly coupled heterotic string theory.) The discrepancy between the scales M_{GUT} and M_{string} implies that the weakly coupled heterotic string theory naively predicts wrong values for the electroweak mixing angle ($\sin^2\theta_W$) and strong coupling (α_3) at the weak scale. Because the weakly coupled heterotic string theory is one of the leading candidates for a unified theory of the fundamental particles and interactions in the nature, how to achieve the string-scale gauge coupling unification is an important question in string phenomenology [8–20].

In general, we can always achieve the string-scale gauge coupling unification by introducing additional vector-like particles with arbitrary masses or arbitrary SM quantum numbers. Therefore, in order to have interesting and natural models, we make the following three requirements for the additional vector-like particles: