PROCEEDINGS OF SCIENCE

Light Stop, Heavy Higgs, and Heavy Gluino in Supersymmetric Standard Models with Extra Matters

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We have explored the possibilities of scenarios with heavy gluinos and light stops in the supersymmetric (SUSY) standard models with extra vector-like multiplets. If we assume the hierarchical structure for soft masses of the minimal supersymmetric standard model (MSSM) scalar fields and extra scalars, the light stop and the observed Higgs boson can be realized. In the context of the gaugino mediation, naturally these hierarchy for soft mass are created and the FCNC processes are suppressed. While the stau is the lightest SUSY particle (LSP) in broad parameter space, we have found the neutralino LSP is realized in the case that the non-zero soft parameters for the MSSM Higgs doublets or the non-universal gaugino masses are assumed.

The 3rd International Symposium on " Quest for the Origin of Particles and the Universe"
5-7 January 2017
Nagoya University, Japan

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PoS(KMI2017)039

1. Introduction

The ATLAS and CMS collaborations found the Higgs boson whose mass is around 125 GeV [1] and the standard model (SM) was established. While the SM describes physics near the electro-weak (EW) scale quite accurately, there are several problems which the SM cannot solve: the hierarchy problem, absence of the dark matter candidate, reason for charge quantization, origin of the EW symmetry breaking (EWSB), and so on. Supersymmetry (SUSY) is one of the most attractive candidate of the physics beyond the SM that can address all of problems listed above. The EW symmetry is broken radiatively, but the EWSB vacuum requires that the sum of the supersymmetric and SUSY-breaking mass parameters for the up-type Higgs results in the EW scale. Since the latter is sensitive to the stop mass, large stop mass requires fine-tuning of these parameters. To avoid this, around 1 TeV stop mass is desired.

The minimum supersymmetric standard model (MSSM) predicts the Higgs boson mass less than the Z boson mass. Thus, it is important to consider the radiative correction to the Higgs mass to realize the observed Higgs boson mass, 125 GeV. The logarithmic correction to the Higgs boson mass can explain the observed value when the stop is sufficiently heavy, but this is unfavorable in the naturalness point of view. The finite correction can potentially explain the observed Higgs mass when light stops and large A-term is realized.

Up to the present, signals of SUSY has not been observed yet. The null results of the LHC implies that masses of new colored particles are quite heavy. For instance, gluinos should be heavier than 1.9 TeV when the lightest neutralino is lighter than about 800 GeV. From the renormalization group equation (RGE) analysis, heavy gauginos pushes up the sfermion masses at low-energy scale. Therefore, heavy gluinos naïvely predicts heavy stops and tend to spoil the naturalness.

In this work, we introduce extra vector-like multiplets to the MSSM. The two-loop RGE effects of the D-term contribution from extra matters decrease the sfermion soft masses at low-energy. Therefore, light stops can be realized in spite of heavy gluinos. Furthermore, since heavy gluinos give large absolute value of the A-term from the one-loop RGE and extra matters are irrelevant to this, it is expected that the observed Higgs mass can be explained owing to the large A-term relative to the stop mass. In this way, we have explored the possibilities of scenarios with heavy gluinos and light stops consistent with the observed Higgs mass.

This contribution is based on our work, Ref. [2].

2. Model

As mentioned in the introduction, we consider the model with vector-like extra multiplets. We introduce the vector-like matters which are irreducible representation of $SU(5)$ in order to maintain the gauge coupling unification [3]. we assume there are a pair of $\mathbf{5}+\overline{\mathbf{5}}$ representation of $SU(5)$ who do not mix with the MSSM fields. The differences of the superpotential and soft SUSY-breaking terms are

$$\Delta W = M_{D'}\overline{D'}D' + M_{L'}\overline{L'}L', \tag{2.1}$$

$$-\Delta\mathscr{L}_{\rm soft} = m_{D'}^2(|\widetilde{d'}|^2 + |\widetilde{\overline{d'}}|^2) + m_{L'}^2(|\widetilde{l'}|^2 + |\widetilde{\overline{l'}}|^2), \tag{2.2}$$

where $D', \overline{D'}, L'$, and $\overline{L'}$ are extra chiral superfields embedded as like $\mathbf{5} = (D', \overline{L'})$ and $\overline{\mathbf{5}} = (\overline{D'}, L')$ while $\widetilde{d'}, \widetilde{\overline{d'}}, \widetilde{l'}$, and $\widetilde{\overline{l'}}$ are scalar component field of them.

The two-loop RGE for the soft masses m_s^2 is given by

$$\frac{dm_s^2}{d\ln\mu} = \sum_{A=1,2,3}\left[-\frac{1}{16\pi^2}8g_A^2C_A(s)|M_A|^2 + \frac{1}{(16\pi^2)^2}4g_A^4C_A(s)\sum_r 2S_A(r)m_r^2\right], \tag{2.3}$$

where dummy index A indicates the SM gauge group indices and g_A and M_A denote the gauge coupling and the gaugino mass of the relevant gauge group, respectively. $C_A(s)$ and $S_A(s)$ are the quadratic Casimir invariant and the Dynkin index for the chiral multiplet s. In this expression, only important terms are shown: the first term is one-loop gaugino contribution and the second term is two-loop D-term contribution. Due to the the first term heavy gluinos implies heavy stops at low-energy scale, but if soft masses for extra matters are much larger than gaugino masses the second term can compensate the first term contribution and light stops can be realized. The remaining soft parameters, soft masses and A-terms of MSSM sfermions should be vanish at the initial scale in order to suppress the dangerous flavor-changing neutral current (FCNC) process.

These hierarchical structure for soft parameters are obtained from the variant gaugino mediation scenario (*e.g.* Ref. [4]). In the ordinary gaugino mediation scenario, only gauginos couple to the SUSY breaking brane and sfermions feel SUSY-breaking via gaugino loops. Therefore, sfermion masses and A-terms in the MSSM are vanish at the initial scale while gaugino masses are non-zero. If the extra matters are treated as bulk fields and couple to the SUSY-breaking brane, they also can obtain the non-zero soft masses at the initial scale. The mass hierarchy to cancel the one- and two-loop contributions in Eq. (2.3) is controlled by the $U(1)_R$ breaking which suppress the gaugino masses. Thus, light stops are realized despite heavy gluinos. Here, the MSSM Higgs multiplets may be coupled with the SUSY-breaking brane or they may not. The soft terms for MSSM Higgs doublet are model-dependent.

The existence of the extra matters does not affect to The RGE for A-terms a^{ijk}. Dominant contribution from gauginos at one-loop level is given by

$$\frac{da^{ijk}}{d\ln\mu} = \frac{1}{16\pi^2}\sum_{A=1,2,3}4g_A^2Y^{ijk}C_A(k)M_A + (k\leftrightarrow i) + (k\leftrightarrow j), \tag{2.4}$$

where Y^{ijk} are the Yukawa couplings. Owing to heavy gluinos, the trilinear stop coupling A_t receives large absolute value. Here, light stops and large A_t are realized, and observed Higgs mass may be explained.

3. Results

In this section, we present our numerical results for the lightest Higgs and stop masses in model described in previous section. To begin with, we briefly show our procedure to evaluate the low-energy mass spectrum. We give initial conditions for soft parameters at GUT scale ($= 2\times 10^{16}$ GeV), and we evolve the soft parameters with the RGEs at two-loop level [5]. We also obtain the gauge couplings and Yukawa couplings at the GUT scale by using the two-loop RGEs for them. We set the SUSY breaking scale to 1 TeV, and then we treat the effective theories above the this scale as the SUSY SM with extra matters.

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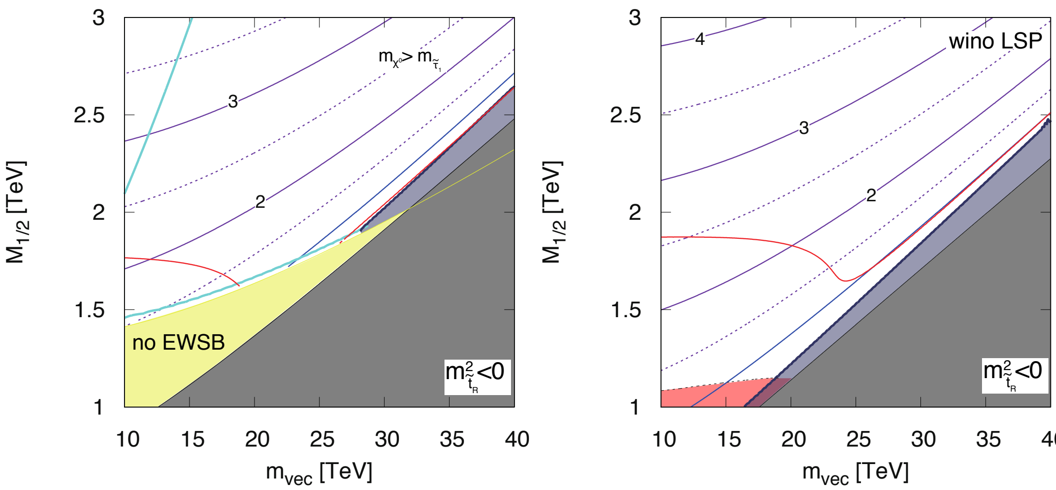

Figure 1: Positive input values for $m^2_{H_u}$ and $m^2_{H_d}$ case (Left) and non-universal gaugino mass case (Right). The lightest stop mass is shown in units of TeV. The red solid line corresponds to the 125 GeV Higgs mass. The gray and navy shaded region is excluded by tachyonic stops and the stop LSP. The yellow shaded region is excluded due to no radiative EWSB.

From the soft parameters for the MSSM Higgs doublets $m^2_{H_u}$ and $m^2_{H_d}$ at the SUSY breaking scale, we evaluate the supersymmetric higgsino mass μ_H and holomorphic Higgs soft mass, b-terms, via the conditions for potential minima. Then, we obtain the low-energy Higgs mass with the use of `SPheno` [6]. We take $\tan\beta = 10$ and $\mu_H > 0$ for simplicity.

If we impose the universal conditions

$$m^2_{D'} = m^2_{L'} \equiv m^2_{\rm vec}, \qquad M_1 = M_2 = M_3 \equiv M_{1/2} \tag{3.1}$$

at GUT scale and take $m_{\rm vec}$ and $M_{1/2}$ as free parameters, stau becomes tachyonic in broad parameter region which is excluded due to charge breaking minima.

In order to avoid the tachyonic stau, we assume that the colored extra scalars obtain non-zero soft masses, while soft masses for non-colored ones are zero or nigligible at the GUT scale as

$$m^2_{D'} = m^2_{\rm vec}, \qquad m^2_{L'} = 0. \tag{3.2}$$

The sleptons do not get much negative contribution from the extra matters by imposing this condition. Nevertheless, in the parameter region which explains the observed Higgs mass and around 1 TeV stops simultaneously, stau is still the LSP.

We consider two cases of avoiding the stau LSP scenario: (1) positive input values for $m^2_{H_u}$ and $m^2_{H_d}$, and (2) the non-universal gaugino masses. In both cases, numerical results are shown in Fig. 1. The left panel of Fig. 1 stands for the positive $m^2_{H_u}$ and $m^2_{H_d}$ case. At the GUT scale we imposed initial condition,

$$m^2_{H_u} = m^2_{H_d} = (2.0\ {\rm TeV})^2. \tag{3.3}$$

We also assume the same condition for extra matters as Eq. (3.2), so that the tachyonic stop is the strongest constraint in the large $m^2_{\rm vec}$ limit. Two cyan lines illustrate the boundary where the LSP changes into the other sparticle. The stau is the LSP in the medium region between two cyan lines. Above the upper line, the bino-like neutralino LSP is realized while the higgsio-like neutralino is the LSP below the bottom line. In the tiny region around the no EWSB boundary, the higgsino-like neutralino is the LSP and, the observed Higgs mass and around 1 TeV stops are realized.

The right panel of Fig. 1 is for the non-universal gaugino mass case. If bino is heavier than the other gauginos, we can easily shift all sfermion masses up and avoid the stau LSP. We assume the initial condition for gaugino masses as follows;

$$M_1 = 1.5M_{1/2}, \quad M_2 = 0.5M_{1/2}, \quad M_3 = M_{1/2}. \tag{3.4}$$

In this figure, the LSP dominates the neutral component of wino in the whole unshaded region. From this figure, we see that the stop mass around 1 TeV, the observed Higgs mass, and the wino LSP can be realized.

4. Conclusion

We have explored the possibilities that the theories with heavy gluino predict lighter stop mass and the observed Higgs mass, introducing a pair of $\mathbf{5}+\overline{\mathbf{5}}$ representation. By assuming gaugino mediation, hierarchical structure of soft masses is naturally created and allow the cancellation of one- and two-loop contribution to the RGE for sfermion masses, and suppress the FCNC process. The LSP in the scenario is model-dependent. The higgsino-like neutralino is the LSP for the positive m_{H_u} and m_{H_d} case near the boundary for no EWSB, and the neutral wino is LSP for the non-universal gaugino mass scenario which the bino is heavier than other gauginos.

Finally, introduction of the extra matter leads to fruitful phenomenology. Even if the b-term at the GUT scale is zero, the electric dipole moments (EDMs) may get the two-loop contributions by integrating out the vector-like extra matter [7]. The gauge coupling constants at the GUT scale are larger due to introduction of the extra matters, and it implies that the X-boson proton decay rate is enhanced [8]. Introduction of the extra matter leads to new phenomenology which should be pursued furthermore.

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