

Higgs Boson Mass in Low Energy SUSY Models with Vector-like Matters

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We show that the gauge mediation models with vector-like matters can explain the Higgs boson mass of 126 GeV without large soft scalar masses nor a large left-right mixing of the stops. The scenario has interesting features: the existence of the light non-colored SUSY particles accessible at the LHC and ILC, the explanation of the muon $g - 2$ and the possibility of the enhanced di-photon decay rate of the Higgs boson.

I. INTRODUCTION

The discovery of the Higgs boson like particle with the mass of ~ 126 GeV has great influence on the supersymmetric models. In the minimal supersymmetric standard model (MSSM), the Higgs boson mass at the tree level is at most ~ 91 GeV, and hence, the Higgs boson mass of ~ 126 GeV requires large radiative corrections; the quartic coupling in the Higgs potential should be twice as large as the tree level value. The required corrections can be obtained by heavy stops of $\mathcal{O}(10 - 1000)$ TeV or a large left-right mixing for $\mathcal{O}(1)$ TeV stops [1]. In the former case, the SUSY CP/ flavor problem as well as the cosmological moduli problem is significantly relaxed, while not in the latter case [24]. Therefore, the heavy SUSY scenarios are somewhat favored, combined with the non-observation of the SUSY signals at the LHC [3, 4].

However, there is an indication that the SUSY particles, at least, non-colored SUSY particles are light as $\mathcal{O}(100)$ GeV: the anomalous magnetic moment of the muon (muon $g - 2$). The experimental value of the muon $g - 2$ [5] is deviated from the standard model (SM) prediction [6, 7] at more than 3σ level. Using the SM prediction in Ref. [7], the deviation is given by

$$\delta a_\mu \equiv a_\mu^{\text{EXP}} - a_\mu^{\text{SM}} = (26.1 \pm 8.1) \times 10^{-10}. \quad (1)$$

It was pointed out that, in MSSM, δa_μ can be explained by the contributions from the light smuons and chargino/neutralino with the mass of $\mathcal{O}(100)$ GeV for $\tan\beta = \mathcal{O}(10)$ [8]. If the deviation is true, there exists a tension; the Higgs boson mass favors heavy SUSY particles while the muon $g - 2$ requires light SUSY particles with $\mathcal{O}(10) \tan\beta$. Because of this, there are not many SUSY scenarios which can accommodate both of them. For instance, SUSY models with a singlet extension of the Higgs sector can not explain the muon $g - 2$, since the enhancement of the Higgs boson mass occurs only in the region with low $\tan\beta$.

In this letter, we consider the gauge mediation models with the vector-like matters [9] as one of the few scenarios consistent with the muon $g - 2$ experiment and the Higgs boson mass of around 126 GeV [25]. The vector-like matters with ~ 1 TeV mass which couple to the Higgs boson chiral multiplet can enhance the Higgs boson mass by the radiative corrections in a similar manner of the top/stop loops [14–16], even for large $\tan\beta$. Because of this effect, the Higgs boson mass is explained with relatively light colored SUSY particles of 1–2 TeV, allowing the existence of the light non-colored SUSY particles of $\mathcal{O}(100)$ GeV; the scenario gives rich phenomenologies, such as the muon $g - 2$ explanation and the possibility of the enhanced di-photon decay rate of the Higgs boson.

II. GAUGE MEDIATION MODELS WITH VECTOR-LIKE MATTERS

We consider the gauge mediation models with extra vector-like matters added to the MSSM matter contents. The vector-like matters are introduced as $\mathbf{10}$ and $\overline{\mathbf{10}}$ representation in $SU(5)$ grand unified theory (GUT) gauge group so that the gauge coupling unification is maintained. Then, the superpotential of the matter sector is given by

$$W = W_{\text{MSSM-Yukawa}} + Y' Q' H_u \overline{T'} + \mu H_u H_d + M_Q Q' \overline{Q'} + M_T T' \overline{T'} + M_E E' \overline{E'}, \quad (2)$$

where $\mathbf{10} = (Q', \overline{T'}, \overline{E'})$ (and $\overline{\mathbf{10}} = (Q', T', E')$) are additional vector-like matters. The SUSY invariant mass terms, μ, M_Q, M_T and M_E , are possibly related to the Peccei-Quinn (PQ) symmetry breaking scale [17]. Here, we neglect $\overline{Q'} H_d U'$, which can be suppressed by the PQ symmetry. There are new radiative corrections through the term $Y' Q' H_u \overline{T'}$, which are similar to the top/stop loops. With a large Yukawa coupling $Y' \simeq 1$ and $M_Q \sim M_T \sim 1$ TeV, the Higgs boson mass can be efficiently enhanced and can reach to ~ 126 GeV without the

large left-right mixing nor heavy scalar masses. The leading part of the radiative correction to the Higgs boson mass from the extra-matters is

$$\Delta m_h^2 \sim \frac{3Y'^4 v^2}{4\pi^2} \sin^4 \beta \left[\ln \frac{m_{\text{squark}}^2}{M_F^2} \right], \quad (3)$$

where m_{squark} is the soft mass of the extra squark and $M_F \sim M_Q \sim M_U$. The vacuum expectation value of the Higgs boson is denoted by v ($\simeq 174$ GeV). For the hierarchical SUSY mass and SUSY breaking mass generate sufficiently large Δm_h^2 . Note that $Y' \simeq 1$ at around the weak scale is quite natural since it has a quasi infrared fix point with the value of unity [16].

The soft SUSY breaking mass parameters are induced by messenger loops. The superpotential of the messenger sector is written as

$$W_{\text{mess}} = (M_D + F_D \theta^2) \Psi_D \Psi_{\bar{D}} + (M_L + F_L \theta^2) \Psi_L \Psi_{\bar{L}}, \quad (4)$$

where Ψ_L and $\Psi_{\bar{D}}$ are $SU(2)_L$ doublet and $SU(3)_C$ triplet messengers, respectively. The hyper-charge of Ψ_L ($\Psi_{\bar{D}}$) is $-1/2$ ($1/3$). If relations, $M_D = M_L$ and $F_D = F_L$ are hold at the GUT scale, $F_D/M_D \simeq F_L/M_L$ is hold at any scale. However, such relations can be violated by, e.g., a higher dimensional operator picking up the GUT scale VEV. Here, we consider only a pair of the messengers. This is because introducing two or more messengers leads to the Landau pole below the GUT scale, unless the messenger scale is sufficiently high.

The leading contributions to gaugino masses and scalar masses at the messenger scale are given by

$$M_1 \simeq \frac{g_1^2}{16\pi^2} [(2/5)(F_D/M_D) + (3/5)(F_L/M_L)], \quad M_2 \simeq \frac{g_2^2}{16\pi^2} (F_L/M_L), \quad M_3 \simeq \frac{g_3^2}{16\pi^2} (F_D/M_D), \quad (5)$$

and

$$\begin{aligned} m_Q^2 &\simeq \frac{2}{(16\pi^2)^2} [g_3^4(4/3)(F_D/M_D)^2 + g_2^4(3/4)(F_L/M_L)^2 \\ &\quad + g_1^4(1/60)((2/5)(F_D/M_D)^2 + (3/5)(F_L/M_L)^2)], \\ m_U^2 &\simeq \frac{2}{(16\pi^2)^2} [g_3^4(4/3)(F_D/M_D)^2 \\ &\quad + g_1^4(4/15)((2/5)(F_D/M_D)^2 + (3/5)(F_L/M_L)^2)], \\ m_D^2 &\simeq \frac{2}{(16\pi^2)^2} [g_3^4(4/3)(F_D/M_D)^2 \\ &\quad + g_1^4(1/15)((2/5)(F_D/M_D)^2 + (3/5)(F_L/M_L)^2)], \\ m_L^2 &\simeq \frac{2}{(16\pi^2)^2} [g_2^4(3/4)(F_L/M_L)^2 \\ &\quad + g_1^4(3/20)((2/5)(F_D/M_D)^2 + (3/5)(F_L/M_L)^2)], \\ m_E^2 &\simeq \frac{2}{(16\pi^2)^2} [g_1^4(3/5)((2/5)(F_D/M_D)^2 + (3/5)(F_L/M_L)^2)], \\ m_{H_u}^2 &= m_{H_d}^2 = m_L^2, \end{aligned} \quad (6)$$

where M_1 , M_2 and M_3 are the bino, wino and gluino, respectively. The mass of the $SU(2)$ doublet squark is denoted by m_Q while those of the $SU(2)$ singlet are denoted by m_U (up-type) and m_D (down-type). The slepton masses are written as m_L and m_E for $SU(2)$ doublet and singlet, respectively. By taking the ratio $(F_L/M_L)/(F_D/M_D)$ to be smaller than unity, we can split the masses of the colored and non-colored SUSY particles, which enhances the SUSY contributions to the muon $g-2$ for the fixed masses of the colored SUSY particles.

The contours of the Higgs boson mass and the region consistent with the muon $g-2$ are shown on the gluino mass - $\tan \beta$ plane in Fig. 1. In the deep (light) green region, δa_μ is explained by the SUSY contributions at 1σ (2σ) level. The Higgs boson mass is calculated with $M_Q = M_T = 900$ GeV. Taking smaller value of M_Q (and M_T) makes the Higgs boson mass larger while larger M_Q makes the mass smaller. The region above the black dashed line is excluded by the vacuum stability condition; there exists a charge breaking global minimum induced by the large left-right mixing of the stau ($\sim m_\tau \mu \tan \beta$) and the electroweak symmetry breaking (EWSB) minimum is unstable. Requiring that the life-time of the EWSB minimum be longer than the age of the universe, $\mu \tan \beta$ can not be too large [18].

The contours of the ratio of the Higgs branching fraction to di-photon, $r_{\gamma\gamma}$, are also shown. Here, $r_{\gamma\gamma}$ is defined as $r_{\gamma\gamma} \equiv \text{Br}(h \rightarrow \gamma\gamma)/\text{Br}(h_{\text{SM}} \rightarrow \gamma\gamma)$. It was shown that the di-photon decay rate is enhanced by the stau loops with the large left-right mixing [19]. In our case, the di-photon ratio can be enhanced up to about 40% compared to the SM prediction. The enhancement is bounded from above by the vacuum stability constraint [20].

In most of the region consistent with the muon $g-2$ at 1σ level, the stau is the next-to-lightest SUSY particle (NLSP) with the mass less than about 200 GeV. The light (quasi-)stable stau is severely constrained from the LHC. The stau mass should be larger than about 340 GeV [21]. On the other hand, the stau can decay with a relatively short decay length, say, less than ~ 10 cm. For example, the stau decays into the tau plus gravitino or axino. The former case corresponds to the ultra-light gravitino with the mass of less than about 10 eV, the latter case is realized in the DFSZ axion model [22] with the small axion decay constant $f_a \sim 10^9$ GeV. Although the production of the stau through the colored SUSY particles can be suppressed, the production through the chargino/neutralino is not; the chargino mass should be larger than about 280 GeV [23]. The sample mass spectrum is shown in Table. 1.

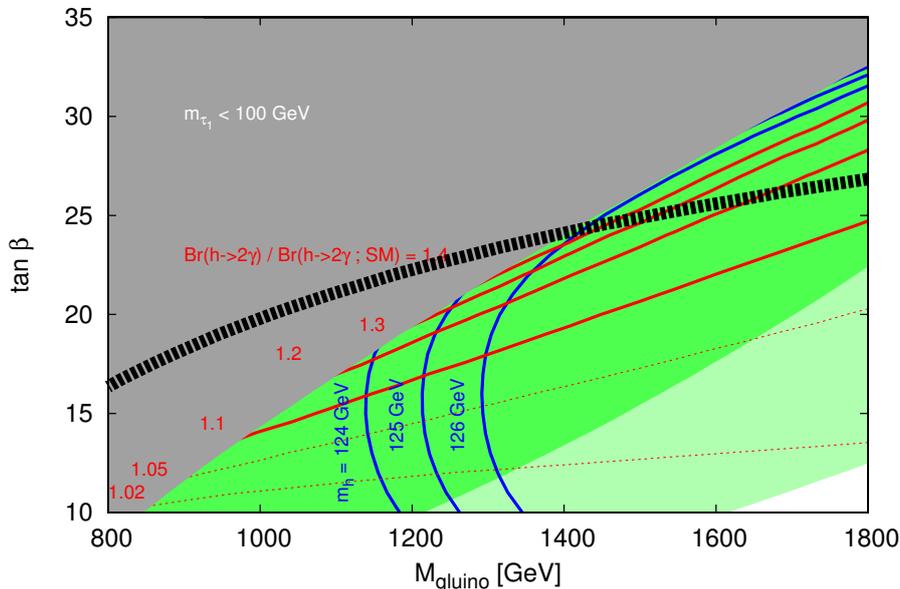


FIG. 1: Contours of the Higgs boson mass (blue solid line) and the region consistent with the muon $g-2$. The Higgs to di-photon ratio $r_{\gamma\gamma}$ is also shown (red solid line). The Higgs boson mass is calculated with $M_Q = M_T = 900$ GeV, $m_t(\text{pole}) = 173.3$ GeV and $Y'(m_{\text{SUSY}}) = 1.0$. In the deep (light) green region, the muon $g-2$ is explained at 1σ (2σ) level. The black dashed line shows the stability bound of the electroweak symmetry breaking (EWSB) minimum. The region above the line is excluded since the lifetime of the EWSB minimum becomes shorter than the age of the universe. Here, we take the messenger scale and SUSY breaking masses as $M_D = M_L = 4 \times 10^5$ GeV and $(F_L/F_D) = 0.6$, respectively.

III. CONCLUSION

In this letter, we have considered a gauge mediation model with the vector-like matters at around 1 TeV. With the help of the radiative corrections from the vector-like matters, this scenario can explain the Higgs boson mass of ~ 126 GeV without large scalar masses nor the large left-right mixing, which is suitable for the gauge mediated SUSY breaking scenarios. Because of the light non-colored SUSY particles, the muon $g-2$ deviation is successfully explained. Interestingly, in some region, the di-photon decay rate of the Higgs boson can be enhanced up to 40%. It has been shown that the constraint from the LHC SUSY search can be avoided, but still, the (right handed) sleptons are lighter than ~ 250 GeV and can be target at the International Linear Collider experiment.

TABLE I: A sample mass spectrum

M_{mess}	300 TeV
F_D	170 TeV
F_L/F_D	0.6
$\tan \beta$	20
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m_{gluino}	1.6 TeV
m_{squark}	2.4 TeV
m_L	413 GeV
m_E	243 GeV
$m_{\tilde{\tau}_1}$	165 GeV
$m_{\chi_1^0}$	190 GeV
$m_{\chi_1^\pm}$	302 GeV
δa_μ	21.4×10^{-10}

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