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Towards the natural gauge mediation

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Abstract: The sweet spot supersymmetry (SUSY) solves the μ/B_μ problem in the Minimal Supersymmetric Standard Model (MSSM) with gauge mediated SUSY breaking (GMSB) via the generalized Giudice-Masiero (GM) mechanism where only the μ-term and soft Higgs masses are generated at the unification scale of the Grand Unified Theory (GUT) due to the approximate PQ symmetry. Because all the other SUSY breaking soft terms are generated via the GMSB below the GUT scale, there exists SUSY electroweak (EW) fine-tuning problem to explain the 125 GeV Higgs boson mass due to small trilinear soft term. Thus, to explain the Higgs boson mass, we propose the GMSB with both the generalized GM mechanism and Higgs-messenger interactions. The renormalization group equations are runnings from the GUT scale down to EW scale. So the EW symmetry breaking can be realized easier. We can keep the gauge coupling unification and solution to the flavor problem in the GMSB, as well as solve the μ/B_μ-problem. Moreover, there are only five free parameters in our model. So we can determine the characteristic low energy spectra and explore its distinct phenomenology. The fine-tuning measure can be as low as 100. For some benchmark points, the stop mass can be as low as 1.7 TeV while the glunio mass is around 2.5 TeV. The gravitino dark matter can come from a thermal production with the correct relic density and be consistent with the thermal leptogenesis. Because gluino and stop can be relatively light in our model, how to search for such GMSB at the upcoming run II of the LHC experiment could be very interesting.

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Contents

1 Introduction

A Higgs boson with mass around 125 GeV has been discovered at the LHC by both ATLAS and CMS Collaborations [1, 2]. After the run I of the LHC, it had been proven to behave, interact and decay in many of the ways similar to the Standard Model (SM) Higgs boson. More precision measurements are needed to determine if the discovered particle is exactly the SM Higgs boson, or whether multiple Higgs bosons and exotic decays exist as predicted by some other models. A SM-like Higgs boson with mass around 125 GeV renews the hierarchy problem as the quadratic divergences of the quantum corrections to its mass are a major concern from the theoretical perspective. The electroweak-scale supersymmetry (SUSY) remains an elegant solution to this problem and is still a promising extension of the SM. A SM-like Higgs boson with mass 125 GeV can be identified as the light CP-even Higgs boson h in the Minimal Supersymmetric Standard Model (MSSM) (See, for example, [3, 4].). If all the other Higgs bosons are heavy, the Higgs sector will fall into the decoupling MSSM limit, where the properties of h are similar to the SM Higgs boson. The loop contributions to the Higgs mass m_h have to be significant as the tree-level m_h is smaller than the Z boson mass M_Z [5, 6]. Although the two-loop [7] and even three-loop contributions [8] are important to achieve the mass m_h around 125 GeV, general features can be determined by the dominating one-loop contributions from top-stop sector as follows

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2}\left[\log\frac{M_{\rm SUSY}^2}{m_t^2} + \frac{\tilde{A}_t^2}{M_{\rm SUSY}^2}\left(1 - \frac{\tilde{A}_t^2}{12M_{\rm SUSY}^2}\right)\right], \tag{1.1}$$

where m_t is the top quark mass, $v = 174\,\text{GeV}$ is vacuum expectation value (VEV) for electroweak symmetry breaking (EWSB), $M_{\text{SUSY}} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$ is the geometric mean of stop masses, and $\tilde{A}_t$ is defined by

$$\tilde{A}_t = A_t - \mu \cot\beta. \tag{1.2}$$

Here A_t is the trilinear soft term for Higgs-stop coupling, μ is the bilinear Higg boson mass in the MSSM superpotential, and $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$ is the ratio of two Higgs VEVs. One can choose $M^2_{\text{SUSY}}/m_t^2 \gg 1$ in Eq. (1.1) to enhance the loop contribution. The stop masses have to be larger than 10 TeV if there is no stop mixing. This set of parameters will result in a relatively heavy SUSY spectrum, which violates the naturalness condition and cannot have any meaningful stop signals at the LHC. Therefore, in this paper, we focus on another milder way to have a large loop contribution by choosing $M^2_{\text{SUSY}}/m_t^2 > 1$ and $\tilde{A}_t^2/M^2_{\text{SUSY}} > 1$ in Eq. (1.1). Namely, the geometric mean of stop masses is larger than 1 TeV as well as a large mixing parameter $\tilde{A}_t$. The maximal mixing happens when $\tilde{A}_t \sim \sqrt{6} M_{\text{SUSY}}$ [9]. However, such a maximal mixing scenario may lead to a color-breaking minimum where the stops have non-vanishing VEVs [10–16].

Besides the discovery of the Higgs boson, no signals of SUSY particles have been observed at the run I of the LHC. Although the compressed SUSY are always hard to be tested/excluded due to the cancellation of missing energy [17, 18], squarks and gluino are in general forced to be heavy after the LHC8. Together with a 125 GeV Higgs boson, it raises uncomfortable issues with naturalness widely discussed in literatures. As we know, there are usually three kinds of ways to estimate the SUSY breaking effects from the hidden sector into visible MSSM sector: gravity, gauge, and anomaly mediations. In gravity mediation, the SUSY breaking soft terms are generally obtained by the high-dimension operators suppressed by the reduced Planck scale M_{PL}. A large A_t can be obtained from a ultraviolet (UV) boundary condition or from the evolution of the renormalization group equations (RGEs) from M_{PL} to the electroweak (EW) scale M_{EW}, which will significantly enhance the Higgs mass m_h. Because the gravity effects are universal to three generations, their soft masses and A-terms are not generation-blind. So gravity mediation always suffers from the flavor problem. In contract, gauge mediation is flavor-safe as the corresponding operators of sfermions are all aligned. But the challenges appear in the Higgs sector. In the gauge mediation SUSY breaking (GMSB), A-terms are vanishing at one-loop level when the messengers are integrated out. In order to get a sufficiently large A_t-term at the EW scale, we must either have a heavy gluino in the model, or run the RGEs for a long scale range by assuming high-scale SUSY breaking. Besides the necessary Higgs mass corrections from a large A_t-term, it is also unclear how to generate an appropriate size of μ-term in the GMSB while keeping B_μ around the same scale (for a review of the μ/B_μ problem, see [19].). The μ-term is a bilinear Higgs mass in the superpotential

$$W \supset \mu H_u H_d. \tag{1.3}$$

A successful EW symmetry breaking (EWSB) requires the μ-term to be the same order of the SUSY breaking soft mass, namely $\mu \sim m_{\text{soft}} \ll M_{\text{PL}}$. In the gravity mediation, an appropriate size of μ-term can be obtained by the Giudice-Masiero mechanism [20]. However, the minimal GMSB does not generate the μ-term when the messenger fields are integrated out. In fact, the μ-term can be forbidden if there exists a Peccei-Quinn (PQ) symmetry. An appropriate size of μ-term can be obtained if the PQ symmetry is broken or just an approximate one. In the GMSB, a simple way to break the PQ symmetry is adding Yukawa couplings between the Higgs sector and messengers in the superpotential. Hence the μ-term can be naturally generated via one-loop Feynman diagrams at the messenger scale [21]. However, the correspoding soft term B_μ is generated at one-loop level as well

$$\mathcal{L}_{\rm soft} \supset B_\mu H_u H_d. \tag{1.4}$$

Thus, the B_μ-term is too large compared to μ-term squared by a loop factor, i.e., $B_\mu \sim 16\pi^2\mu^2$. Since a successful EWSB requires $B_\mu \sim \mu^2$, this is the μ/B_μ problem in the GMSB. One simple solution is extending the MSSM to the next to MSSM (NMSSM) [22], where a new SM singlet is coupled to Higgs fields as well as messengers. The μ/B_μ problem also exists in the anomaly mediation, where the couplings between the visible and hidden sectors are much more suppressed than by the reduced Planck scale due to the one-loop suppressions. In addition, the simple anomaly mediation further suffers the tachyonic problem as the slepton mass squared are predicted to be negative.

Since we are waiting for the run II of the LHC, it is important to think about the feasible SUSY models to describe physics at the TeV scale. Although the naturalness assumption is challenged by the existing results of the LHC, no other serious paradigm has appeared to replace it. So we still take the naturalness assumption as a guiding principle in constructing SUSY models. All mentioned problems should be addressed without moving forward into the relatively heavy SUSY spectra [23, 24]. As we know, in the framework of the so-called sweet spot SUSY [25–28], the SUSY breaking sector and Higgs fields are directly coupled at the unification scale $\Lambda_{\rm GUT} \sim 10^{16}$ GeV in the Grand Unified Theories (GUTs). Because the whole sector respects the approximate PQ symmetry, μ-term is generated at $\Lambda_{\rm GUT}$ scale by the generalized Giudice-Masiero (GM) mechanism [20] with a vanishing B_μ-term. Below $\Lambda_{\rm GUT}$ it is effectively the GMSB, and then the soft masses of SUSY particles are mainly obtained after the messenger fields are integrated out. There is generally no flavor problem since the gravitino mass $m_{3/2}$ is typically smaller than $\mathcal{O}(1)$ GeV. On the other hand, to generate a non-vanishing A_t-term at the messenger scale and lift the Higgs boson mass, we can introduce the Higgs-messengers interaction [29–36]. Therefore, in this paper, we shall propose the GMSB with the generalized GM mechanism and Higgs-messenger interaction. Our model can have a SM-like Higgs boson with mass 125 GeV without moving forward into the relatively heavy SUSY spectra. We also show that the current LHC SUSY search bounds can be evaded. The fine-tuning measure can be as low as 100 in our model. For some benchmark points, the stop mass can be as low as 1.7 TeV while the glunio mass is around 2.5 TeV, which is within the search range of the coming LHC run II Moreover, the gravitino is the lightest supersymmetric particle (LSP) and can be a good dark matter candidate which is consistent with the relic density observation via thermal production. This natural SUSY scenario could be an interesting scenario at the coming run II of the LHC experiment as it is theoretically supported and simply predicted by only five parameters.

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This paper is organized as follows. In section 2, we will consider the model in details. Section 3 is devoted to studying the viable parameter spaces, which are consistent with all the current LHC observations and contain a good dark matter candidate. Finally, our conclusion is given in section 4.

2 The natural GMSB

In this section, we present the GMSB with the generalized GM mechanism and Higgs-messenger interaction. The discovery of a SM-like Higgs boson at 125 GeV as well as the natural SUSY assumption indicates a large A_t-term in the MSSM. In order to generate a non-vanishing A_t-term at the messenger scale, an extended Higgs-messenger coupling $\lambda_u H_u \Phi_1 \bar{\Phi}_2$ has always been introduced in GMSB [29–39]. In those SUSY models, the Yukawa coupling λ_d between H_d and messenger fields always turns off, otherwise the μ/B_μ-problem will show up. In order to obtain an appropriate μ-term in our model, we assume that the SUSY breaking sector and the Higgs fields are directly coupled at the GUT scale $\Lambda_{\rm GUT}$, as in the sweet spot SUSY [25–28]. Because of the approximate PQ symmetry, only the μ-term and soft masses m_{H_u}/m_{H_d} are generated at $\Lambda_{\rm GUT}$. The sfermion soft masses, gaugino soft masses, A-terms, and B_μ-term are all vanished at $\Lambda_{\rm GUT}$. Below $\Lambda_{\rm GUT}$ it is effectively the GMSB with extended Higgs-messenger coupling. The RGEs are runnings from the GUT scale to the EW scale. At the messenger scale, the messenger fields should be integrated out, and the non-vanishing soft masses of the gauginos/sfermions and A-terms are generated as threshold corrections in the RGEs. Such effects from the gravity mediation are tiny as the gravitino mass $m_{3/2}$ is assumed to be typically smaller than $\mathcal{O}(1)$ GeV. In this model, the gauge coupling unification is guaranteed. The flavor problem and μ/B_μ-problem are solved.

2.1 Supersymmetry breaking

A consequence of SUSY spontaneously breaking is the existence of a massless Goldstone fermion, the Goldstino. For a F-term SUSY breaking theory, one always assumes a chiral singlet superfield X, which is formed by the Goldstino, its superpartner sGoldstino, and its non-vanishing F-term. A broad class of SUSY breaking models can be described by the Polonyi model as a low-energy effective theory. The Polonyi model is given by the corresponding Kähler potential and superpotential as

$$\mathcal{L} = \int d^4\theta \left[X^\dagger X - \frac{\left(X^\dagger X\right)^2}{\Lambda_X^2} \right] + \left[\int d^2\theta f X + \text{h.c.} \right]. \tag{2.1}$$

Here Λ_X is the typical mass scale where the heavy particles have been integrated out. This effective description is valid as long as $f < \Lambda_X^2$ and can be realized in many UV completed models, for example, the O'Raifeartaigh model [40] and SUSY QCD models with a meta-stable vacuum [41]. The chiral superfield X can even be a composite filed if the UV completed models are some strongly coupled gauge theories [42, 43]. Based on eq. (2.1), $F_X = -f \neq 0$ is obtained by the equation of motion. The positive energy of the vacuum breaks SUSY spontaneously and $X = 0$ is the position of vacuum of the potential.

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In the gauge mediation, the vector-like messenger superfields Φ and $\bar{\Phi}$ will couple to the SUSY breaking sector generally via a superpotential $W = \kappa X \Phi \bar{\Phi}$. However, the F-component of X in this case is $F_X = -f - \kappa \Phi \bar{\Phi}$, which will lead to a SUSY-conserving minimum with $X = 0$ and $\Phi \bar{\Phi} = -f/\kappa$. In other words, SUSY will be restored after the naive introduction of the messenger fields coupling to the SUSY breaking sector. Several baroque mechanisms have been discussed in order to guarantee a SUSY-breaking meta-stable vacuum in the gauge mediation [44–49]. For example, a SUSY-breaking vaccum away from the origin $X = 0$ can be realized after taking the supergravity effect into account [49]. The minimum is at $X \sim \Lambda_X^2/M_{\rm PL}$ with $F_X \neq 0$. So a spurion structure $X = \langle X \rangle + F_X \theta^2$ can be assumed to parameterize the typical effects of SUSY breaking. It is important to have a SUSY-breaking vacuum away from the origin as the messenger mass $\kappa \langle X \rangle$ originally comes from the superpotential $W = \kappa X \Phi \bar{\Phi}$.

2.2 μ-term in sweet spot SUSY

A successful EWSB puts two constraints at the EW scale on the Higgs sector of the MSSM including the μ-term, which are shown as follows

$$\sin 2\beta = \frac{2B_\mu}{2\mu^2 + m_{H_u}^2 + m_{H_d}^2}, \tag{2.2}$$

$$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1} - \mu^2, \tag{2.3}$$

where $m_{H_u}^2$ and $m_{H_d}^2$ are the soft masses of H_u and H_d, respectively. From eq. (2.2) we know that $B_\mu \sim \mu^2$ at the EW scale. Moreover, for a moderately large $\tan\beta$ eq. (2.3) can be simplified as below

$$m_Z^2 \approx -2\left(\mu^2 + m_{H_u}^2\right) \ . \tag{2.4}$$

Here $m_{H_u}^2$ should be negative at the electroweak scale, which is required by the EWSB. A natural EWSB requires that the cancellation between μ^2 and $m_{H_u}^2$ be relatively small. Namely, it is unnatural that μ-term is much larger than m_Z at the electroweak scale although it is supersymmetric. The scale of μ coincides with the soft mass. This is the so-called μ-problem: how to generate such an appropriate μ-term in SUSY models. Because of $\mu \ll M_{\rm PL}$, one can always assume that the μ-term is prohibited by some symmetry and induced by a small breaking of such a symmetry. The requirement $B_\mu \sim \mu^2$ at the electroweak scale always results in the so-called B_μ-problem in the GMSB, if it cannot be satisfied.

No matter how the SUSY breaking effects translate into the MSSM Higgs sector, an effective Kähler potential between the SUSY breaking sector X and Higgs sector can be obtained as follows

$$\mathcal{K}_{\rm eff} = Z_{H_u}(X, X^\dagger) H_u^\dagger H_u + Z_{H_d}(X, X^\dagger) H_d^\dagger H_d + \left[Z_{H_u H_d}(X, X^\dagger) H_u H_d + \text{h.c.} \right] + \dots \ . \tag{2.5}$$

Here all the wavefunctions depend on some dimensional scale and can be determined from a specific UV completed theory. We expand all the wavefunctions

$$\begin{cases} Z_{H_u}(X,\, X^\dagger) &= 1 + (a_1 X + a_1^* X^\dagger) + a_2 X^\dagger X + \dots, \\ Z_{H_d}(X,\, X^\dagger) &= 1 + (b_1 X + b_1^* X^\dagger) + b_2 X^\dagger X + \dots, \\ Z_{H_u H_d}(X,\, X^\dagger) &= c_0 + (c_1 X + c_1^* X^\dagger) + c_2 X^\dagger X + \dots, \end{cases} \tag{2.6}$$

where both Z_{H_u} and Z_{H_d} are canonically normalized. These terms are responsible for generating A_u, $m^2_{H_u}$, A_d, $m^2_{H_d}$, μ and B_μ. To the leading order,

$$\begin{cases} A_\mu &= F_X \dfrac{\partial Z_{H_u}}{\partial X}, \\ m^2_{H_u} &= F_X^\dagger F_X \dfrac{\partial^2 Z_{H_u}}{\partial X^\dagger \partial X}, \\ A_d &= F_X \dfrac{\partial Z_{H_d}}{\partial X}, \\ m^2_{H_d} &= F_X^\dagger F_X \dfrac{\partial^2 Z_{H_d}}{\partial X^\dagger \partial X}, \\ \mu &= F_X^\dagger \dfrac{\partial Z_{H_u H_d}}{\partial X}, \\ B_\mu &= F_X^\dagger F_X \dfrac{\partial^2 Z_{H_u H_d}}{\partial X^\dagger \partial X}. \end{cases} \tag{2.7}$$

In supergravity, all the coefficients a_i, b_j, and c_k in eq. (2.6) are suppressed by $M_{\rm PL}$. In the unit of $M_{\rm PL} = 1$, all the coefficients are actually $\mathcal{O}(1)$. This is the Giudice-Masiero mechanism [20], which will lead to the desired relation $\mu^2 \sim B_\mu \sim m^2_{\rm soft} \ll M^2_{\rm Pl}$. Unfortunately, gravity mediation always suffers from the flavor problem as the gravity effects are universal to three generations. In the GMSB, the μ-term can be generated by adding couplings between the Higgs sector and messengers in the superpotential. Hence $\mu^2 \sim m^2_{\rm soft}$ can be naturally achieved since all are generated at one-loop level. However, the B_μ-term is also generated at one loop. This implies that B_μ-term is too large by a loop factor compared to μ-term squared as $B_\mu \sim 16\pi^2\mu^2$. This is the μ/B_μ-problem in the gauge mediation. An analogous problem, the A/m^2_H problem in the gauge mediation, draws a lot of attention after the discovery of the 125 GeV Higgs boson [30]. In the gauge mediation, both A-term and the soft mass m^2_H can be generated at the same loop order. Since a large A_t-term is preferred by the Higgs discovery as well as the natural SUSY assumption, the corresponding large m^2_H will seriously affect the EWSB, i.e., the EWSB may not be realized.

In this paper, we base on the framework of the so-called sweet spot SUSY [25–28] to solve the μ/B_μ-problem. Sweet spot SUSY is a phenomenological effective Lagrangian with certain natural assumptions, which is designed to avoid problems in low energy phenomenology. In this framework, the SUSY breaking sector and the Higgs fields are assumed to be directly coupled at the some energy scale. The PQ charge to H_u, H_d and X are assigned as follows

$$\text{PQ}(H_u) = 1,\ \text{PQ}(H_d) = 1,\ \text{PQ}(X) = 2. \tag{2.8}$$

Then the wavefunctions in eq. (2.6) will be constrained due to such a PQ symmetry. At the leading order, we have

$$\begin{cases} Z_{H_u}(X,\,X^\dagger) &= 1 + c_{H_u}\dfrac{X^\dagger X}{\Lambda_H^2}, \\ Z_{H_d}(X,\,X^\dagger) &= 1 + c_{H_d}\dfrac{X^\dagger X}{\Lambda_H^2}, \\ Z_{H_uH_d}(X,\,X^\dagger) &= c_\mu \dfrac{X^\dagger}{\Lambda_H}. \end{cases} \tag{2.9}$$

Here Λ_H is the energy scale where the Higgs fields are directly coupled to the hidden sector. Because of the PQ symmetry, only the μ-term and the soft masses m_{H_u}, m_{H_d} are generated at Λ_H. The B_μ-term is vanishing at the scale Λ_H as the UV boundary condition and can be non-vanishing at the EW scale due to the RGE running. So the μ-term is generated without B_μ-problem. The PQ symmetry is approximate because it is explicitly breaking in the SUSY-breaking sector by the superpotential $W = fX$ in eq. (2.1). The MSSM Higgs sector will receive the explicit and small breaking of this approximate PQ symmetry when it is directly coupled to the hidden sector below the energy scale Λ_H.

Λ_H is not necessary to be the exact hidden sector scale Λ_X in eq. (2.1). However, there is a sweet spot in SUSY models with $\Lambda_H = \Lambda_X = \Lambda_{\rm GUT} \sim 10^{16}\,\text{GeV}$ [25–28], in which the gauge coupling unification is realized. Though sweet spot SUSY is a phenomenological effective Lagrangian, the UV completed models can be realized in several different ways [25, 26]. We leave the discussion of the UV realizations in a future publication. In this paper, our model is only based on the simple effective theory, without any UV completion. The μ-term and soft masses m_{H_u}/m_{H_d} are generated at $\Lambda_{\rm GUT}$ while the sfermion soft masses, gaugino masses, A-terms, and B_μ-term are all vanishing. This is the UV boundary conditions at $\Lambda_{\rm GUT}$ in our model as

$$\mu(M_{\rm GUT}) = c_\mu \frac{F_X^\dagger}{\Lambda_H}, \tag{2.10}$$

$$m_{H_u}^2(M_{\rm GUT}) = c_{H_u}\frac{F_X^\dagger F_X}{\Lambda_H^2}, \tag{2.11}$$

$$m_{H_d}^2(M_{\rm GUT}) = c_{H_d}\frac{F_X^\dagger F_X}{\Lambda_H^2}, \tag{2.12}$$

$$B_\mu(M_{\rm GUT}) = 0, \tag{2.13}$$

$$M_{1,2,3}(M_{\rm GUT}) = 0, \tag{2.14}$$

$$m_{\tilde\phi}^2(M_{\rm GUT}) = 0, \tag{2.15}$$

$$A_{Y_{u,d,e}}(M_{\rm GUT}) = 0. \tag{2.16}$$

In the exact sweet spot SUSY models [25–28], it is effectively the GMSB below $\Lambda_{\rm GUT}$ as

$$W_{\rm GMSB} = \kappa X \Phi_i \bar\Phi_i, \tag{2.17}$$

where the fields Φ_i and $\bar{\Phi}_i$ form the $5 \oplus \bar{5}$ or $10 \oplus \overline{10}$ representation of SU(5) as the gauge coupling unification is preserved. The RGE runnings from $\Lambda_{\rm GUT}$ down to the messenger scale $M_{\rm mess}$ will lead to the non-vanishing sfermion soft masses and a small correction to μ-term. At the messenger scale, the messenger fields are integrated out, which generate the non-vanishing soft masses of the gauginos and sfermions as threshold corrections. This procedure called "matching" is another part of the boundary conditions of the exact sweet spot SUSY models. The MSSM spectra will be generated after further running RGEs from the messenger scale to EW scale. However, as already mentioned in ref. [28], the exact sweet spot SUSY would result in a heavy spectrum in order to obtain a 125 GeV Higgs boson. In particular, the gluino mass must be around 5 TeV as well as $M_{\rm SUSY} \sim 5\,\text{TeV}$, which definitely raises the SUSY EW fine-tuning problem. Although the LHC is a QCD machine, the colored particles in this scenario are too heavy to be produced and detected. An solution to the heavy spectrum problem can be found in refs. [29–39] by adding extra Higgs-messenger Yukawa couplings. In this paper, we would like to add such couplings in the sweet spot SUSY, where the μ-problem and the flavor problem are still evaded. As the SUSY particles will become relatively light in the modified sweet spot SUSY, it is hopeful to test this scenario in the coming run II of the LHC.

2.3 The GMSB with Higgs-messenger coupling

The GMSB models can be extended by introducing new Yukawa couplings between the Higgs sector and messengers [29–39]. In this paper, we modestly modify the exact sweet spot SUSY models by including the a direct interaction between Higgs field H_u and messengers Φ_1, Φ_2 as

$$\delta W_{\text{Extended GMSB}} = \lambda_u H_u \Phi_1 \bar{\Phi}_2. \tag{2.18}$$

Due to the new coupling λ_u, the trilinear soft terms get the non-vanishing contributions $A_u \propto -\frac{\lambda_u^2 \Lambda}{16\pi^2}$ at the messenger scale with $\Lambda = F_X/M_{\rm mess}$. The RGE runnings will result in large A-terms at the EW scale, which are preferred by the Higgs discovery as well as the natural SUSY condition. No extra flavor problem will be caused by introducing the extended Higgs-messenger coupling. There must exist another symmetry between H_u and H_d, otherwise we should have another Yukawa coupling λ_d between H_d and messenger fields. If both λ_u and λ_d are non-vanishing, the extra contributions to $\delta\mu$ and δB_μ are naturally generated at one loop at the messenger scale. The dangerous μ/B_μ problem could emerge again. In this paper, we turn off the coupling λ_d, which can be forbidden by introducing another symmetry between H_u and H_d.

Now we can embed the MSSM into the modified sweet spot SUSY and assume that the effective model below $M_{\rm GUT}$ reduces to the GMSB with an extended Higgs-messenger coupling λ_u. After the messenger fields are integrated out, the non-vanishing soft masses of the gauginos/sfermions and A-terms are generated at the messenger scale. In order to get the Higgs boson m_h around 125 GeV, λ_u is usually required to be quite large at the messenger scale like $\lambda_u \sim 1$. If the messenger fields form the $5 \oplus \bar{5}$ representation of SU(5), the one-loop RGE running of λ_u is dominated by λ_u and y_t. The RGE running may make λ_u reach a Landau pole before the GUT scale $M_{\rm GUT}$, which is particularly troublesome [30]. In contrast, λ_u will not meet a Landau pole if the messengers form the $10 \oplus \overline{10}$ representation of SU(5). In $10 \oplus \overline{10}$ models, the RG evolution of λ_u is given as

$$\beta_{\lambda_u} = \frac{\lambda_u}{16\pi^2}\left[(3n_{10}+3)\lambda_u^2 + 3y_t^2 - \frac{16}{3}g_3^2 + \ldots\right]. \tag{2.19}$$

The large negative contributions from g_3 would help to control the running of λ_u. This negative contribution from g_3 is missing in the $5 \oplus \bar{5}$ case. However, if the messenger scale is very close to the GUT scale in the $5 \oplus \bar{5}$ case, the RGE effects between the messenger scale and the GUT scale will be under control. Without any Landau pole issue, this $5 \oplus \bar{5}$ scenario has been realized in this paper. The Giudice-Masiero mechanism requires that c_μ should be around $\mathcal{O}$ (1). Since the μ term is proportional to $M_{\text{Mess}}/\Lambda_{\text{GUT}}\Lambda$ as

$$\mu = c_\mu \frac{M_{\text{mess}}}{\Lambda_{\text{GUT}}}\Lambda, \tag{2.20}$$

a successful EWSB asks for $\mu \sim \mathcal{O}$ (100) GeV, which will lead to M_{mess} around 10^{13} GeV. Therefore, the RGE effect of λ_u between M_{Mess} and M_{GUT} will not cause a Landau pole. The $5 \oplus \bar{5}$ scenario remains available without moving forward to the more complex $10 \oplus \overline{10}$ scenario. For the $5 \oplus \bar{5}$ model, the threshold corrections at the messenger scale M_{mess} are given as

$$\delta M_a(M_{\text{mess}}) = n_5 \Lambda \frac{g_a^2(M_{\text{mess}})}{16\pi^2} g\left(\frac{\Lambda}{M_{\text{mess}}}\right) \quad (a = 1,2,3), \tag{2.21}$$

$$\delta m_{\tilde{\phi}}^2(M_{\text{mess}}) = n_5 \Lambda^2 \sum_a C_a(k) \frac{g_a^4(M_{\text{mess}})}{(16\pi^2)^2} f\left(\frac{\Lambda}{M_{\text{mess}}}\right), \tag{2.22}$$

$$\delta A_{Y_{d,e}}(M_{\text{mess}}) = 0, \tag{2.23}$$

$$\delta A_{Y_u}(M_{\text{mess}}) = -n_5 \Lambda \frac{\lambda_u^2}{16\pi^2}, \tag{2.24}$$

$$\delta m_Q^2(M_{\text{mess}}) = -n_5 \Lambda^2 \frac{\lambda_u^2 y_t^2}{256\pi^4}, \tag{2.25}$$

$$\delta m_u^2(M_{\text{mess}}) = -n_5 \Lambda^2 \frac{\lambda_u^2 y_t^2}{128\pi^4}, \tag{2.26}$$

$$\delta m_{H_u}^2(M_{\text{mess}}) = n_5 \Lambda^2 \frac{(3+n_5)\lambda_u^4 - 2\sum_a C_a(k) g_a^2 \lambda_u^2}{256\pi^4}, \tag{2.27}$$

where we introduce $\Lambda = F_X/M_{\text{mess}}$. The first three equations (eqs. (2.21), (2.22) and (2.23)) are soft SUSY-breaking parameters in the original GMSB while the last four equations (eqs. (2.24), (2.25), (2.26), and (2.27)) are generated due to the extended Higgs-messenger coupling λ_u in eq. (2.18). If we turn off the coupling λ_u in eq. (2.18), the threshold corrections shown in the last four equations will vanish.

It is easy to find out that our model depends on the following parameters

$$\{\Lambda, M_{\text{mess}}, \tan\beta, \lambda_u, n_5\} \oplus \{\mu(M_{\text{GUT}}), m_{H_u}^2(M_{\text{GUT}}), m_{H_d}^2(M_{\text{GUT}}), \alpha_{\text{GUT}}, M_{\text{GUT}}, Y_u, Y_d, Y_e\}, \tag{2.28}$$

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where $\alpha_{\rm GUT} = g^2_{\rm GUT}/4\pi$ with $g_{\rm GUT}$ the unified gauge coupling constant. The parameter $\alpha_{\rm GUT}$ is evaluated consistently with the experimental values of the electromagnetic constant $\alpha_{\rm em}$, strong fine-structure constant α_s, and the Weinberg angle $\sin^2\theta_W$ by solving RGEs numerically. The same integration procedure can also be applied to the Yukawa coupling constants Y_u, Y_d, and Y_e. Therefore, the free parameters in eq. (2.28) can be reduced to

$$\{\Lambda, M_{\rm mess}, \tan\beta, \lambda_u, n_5\} \oplus \{\mu(M_{\rm GUT}), m^2_{H_u}(M_{\rm GUT}), m^2_{H_d}(M_{\rm GUT})\}. \tag{2.29}$$

We emphasize that the soft masses of H_u and H_d are generated not only at the GUT scale but also at the messenger scale $M_{\rm mess}$. Because the radiative EWSB is reproduced through the RGE effects on $m^2_{H_u}$, we can express $m^2_{H_u}$ and $m^2_{H_d}$ at the EW scale in terms of the other input parameters by minimizing the tree-level scalar potential

$$m^2_{H_u} = -\mu^2 + \frac{1}{2}M_Z^2\cos(2\beta) + B_\mu\cot\beta, \tag{2.30}$$

$$m^2_{H_d} = -\mu^2 - \frac{1}{2}M_Z^2\cos(2\beta) + B_\mu\tan\beta. \tag{2.31}$$

Thus, $m^2_{H_u}(M_{\rm GUT})$ and $m^2_{H_d}(M_{\rm GUT})$ are not free parameters, which are constrained by the successful EWSB. Of course, we should require $m^2_{H_u}(M_{\rm GUT}) > 0$ and $m^2_{H_d}(M_{\rm GUT}) > 0$ if the corresponding operators in the Kähler potential are generated at one loop. In short, the free parameters of our model can be further reduced to

$$\{\Lambda, M_{\rm mess}, \tan\beta, \lambda_u, n_5\} \oplus \{\mu(M_{\rm GUT})\}. \tag{2.32}$$

We define $\mu(M_{\rm GUT}) = \mu_0$, which is the only free parameter at the GUT scale. Without losing the generality, we fix $n_5 = 1$ in this paper when we scan the parameter space. So finally, this model depends on only five free parameters

$$\{\Lambda, M_{\rm mess}, \tan\beta, \lambda_u, \mu_0\}. \tag{2.33}$$

The B_μ-term at the GUT scale vanishes automatically due to the approximate PQ symmetry, which is one of our UV boundary conditions as well.

We summarize our model here. At the GUT scale $\Lambda_{\rm GUT}$, the μ-term and soft masses m_{H_u}/m_{H_d} are generated as the visible Higgs sector receives the SUSY-breaking effects in eq. (2.9). Only the parameter μ_0 is a free parameter by requring the correct EWSB, and the B_μ-term vanishes at the GUT scale due to the PQ symmetry. Of course, we should require $m^2_{H_u}(M_{\rm GUT}) > 0$ and $m^2_{H_d}(M_{\rm GUT}) > 0$. Below $\Lambda_{\rm GUT}$ it is effectively the GMSB with an extended Higgs-messenger coupling, which is governed by the free parameters Λ, $M_{\rm mess}$, and λ_u. At the messenger scale, the non-vanishing soft masses of the gauginos/sfermions and A-terms are generated as the threshold corrections, which are shown in eqs. (2.21)–(2.27). The effects from gravity mediation are negligible in our model as the gravity mass $m_{3/2}$ is assumed to be not larger than $\mathcal{O}(1)$ GeV. Therefore, we construct a complete model in which a 125 SM-like Higgs boson is predicted, the flavor changing neutral currents are suppressed due to the gauge mediation, and the μ/B_μ problem is naturally solved with the minimal set of parameters.

It is worth mentioning that the large trilinear A_t-term generated by the extended Higgs-messenger coupling λ_u plays a crucial role in lifting the Higgs mass while keeping the MSSM spectrum light [50]. As a result, the fine-tuning in such kind of models generally becomes smaller compared to the conventional GMSB. However, the integration over the RGEs are not straightforward running from $M_{\rm GUT}$ to $M_{\rm SUSY}$. At the messenger scale, the additional soft terms are generated as shown in eqs. (2.21)–(2.27). In this paper, we use the hign-scale fine-tuning measures defined in refs. [51, 52] to quantify the fine-tunings of our model. The parameter choice is defined as

$$\Delta_{\rm FT} = \max\{\Delta_a\}, \text{ with } \Delta_a = \frac{\partial \log m_Z^2}{\partial \log a}, \tag{2.34}$$

where a sums over a set of fundamental parameters. Here we choose $a = \{\Lambda, \lambda_u, \mu_0, B_\mu\}$. In the next section, we will present the detailed discussions about the MSSM spectra and phenomenological consequences.

3 Numerical results

In this section, we will present the numerical studies of our model, including the particle spectra and high-scale fine-tuning measures. For this purpose, we implement this model in the Mathamatica package `SARAH` [53–57] and generate the corresponding `SPheno` file [58, 59] to calculate the corresponding particle spectra. There are a lot of constraints on parameter spaces from the run I of the LHC. First, a SM-like Higgs boson at 125 GeV must be realized without resorting to heavy SUSY particles. Therefore, we impose the selection rule of the CP-even Higgs boson h in our data as

$$123 \text{ GeV} \leq m_h \leq 127 \text{ GeV}. \tag{3.1}$$

If the other Higgs bosons are heavy, the Higgs sector will fall into the decoupling limit, and the properties of h will be SM-like which is preferred by the LHC data. Second, due to the null results of the SUSY searches at the LHC, several limits must be imposed on the masses of the colored particles, such as gluino and stop. So we will briefly summarize the current LHC bounds before discussing our results.

3.1 Summary of current LHC bounds

This section is based on ref. [60]. The current ATLAS and CMS summary plots can be found in refs. [61] and [62], respectively. These plots present the sparticle mass low bounds for various SUSY search channels, which are based on the simplified models for the masses and branching ratios. For most of SUSY models, gluino is supposed to have large production cross-sections at the LHC due to the strong interaction. According to refs. [61] and [62], the strongest constraint on glunio mass comes from ref. [63], where gluino is excluded for masses below 1700 GeV. The cascade decay of gluino is assumed to be $\tilde{g} \to \tilde{q} q$ and then $\tilde{q} \to q \tilde{\chi}_0^1$. The data, which focus on final states containing high-p_T jets, missing transverse momentum, no electrons or muons, were recorded in 2012 by the ATLAS experiment in $\sqrt{s}$=8 TeV at the LHC with a total integrated luminosity of 20.3 fb^{-1} [63].

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The stop final state is also important because of the strong interaction as well as the relatively large Yukawa coupling. Before the LHC, the light stop $\tilde{t}_1$ in many natural SUSY scenarios is expected to have a mass below 1 TeV in order to avoid a large fine-tuning. Depending on the mass assumptions, the following decay channels could be dominant: $\tilde{t}_1 \to t\tilde{\chi}_1^0$, $\tilde{t}_1 \to bW\tilde{\chi}_1^0$, $\tilde{t}_1 \to bff'\tilde{\chi}_1^0$ or $\tilde{t}_1 \to c\tilde{\chi}_1^0$ [64–71]. The searches are designed such that they can cover all the possible decays of the stop into a neutralino LSP. For a massless $\tilde{\chi}_1^0$ the stop can be excluded up to 650-700 GeV (except some regions where the mass difference between the stop and the neutralino is near to the top mass), while for $m_{\tilde{\chi}_1^0} > 240$ GeV no limits can be provided. Limits on the first and second generation squark masses for simplified models are typically involved squark pair production $pp \to \tilde{q}\tilde{q}$ with only one decay chain $\tilde{q} \to q\tilde{\chi}_1^0$. Here it is simply assumed that the left and right-handed squarks have degenerate masses with the gluino mass decoupled. As shown in ref. [63], in this scenario squarks with a mass below about 800 GeV are excluded for a light neutralino.

In our model with a relatively large $\sqrt{F_X}$, the LSP is still gravitino. Although all the SUSY particles will eventually decay into final states involving gravitino, these decays are extremely slow. The next lightest supersymmetric particle (NLSP) can be regarded as a stable particle at the collider scale and the gravitino will play no role in the collider physics. In our cases, the NLSP could be neutralino or stau depending on the parameter space. All above constraints are based on the assumption that heavy SUSY particles will decay into neutralino final state at the LHC. If the NLSP is neutralino and stable at the collider scale, these constraints are still valid. If the NLSP is stau, the searches could be different as some stau final state might be recorded as charged tracks in the muon detector (for example, see [72–75]). In this paper, we naively impose the following selection rules of gluino mass and squark masses as follows

$$M_{\tilde{g}} \geq 1700 \text{ GeV}, \tag{3.2}$$
$$M_{\tilde{t}} \geq 700 \text{ GeV}, \tag{3.3}$$
$$M_{\tilde{q}} \geq 800 \text{ GeV}, \text{ (for the first and second generation squarks)}. \tag{3.4}$$

3.2 Particle spectra and fine-tuning

For simplicity, we fix the messenger scale as $M_{\text{mess}} = 10^{13}$ GeV. For the other free parameters in our model, we make a random scan over them as below

$$5 \times 10^4 \text{ GeV} \leq \Lambda \leq 3 \times 10^5 \text{ GeV}, \tag{3.5}$$
$$10 \leq \tan\beta \leq 45, \tag{3.6}$$
$$0 \leq \lambda_u \leq 1, \tag{3.7}$$
$$100 \text{ GeV} \leq \mu_0 \leq 250 \text{ GeV}. \tag{3.8}$$

μ_0 is given at the GUT scale. The RGEs are runnings from the GUT scale to the EW scale. At the messenger scale, the non-vanishing soft masses of the gauginos/sfermions and A-terms are generated as the threshold corrections in the RGEs. A successful EWSB is required, which will determine the exact values of $m_{H_u}^2(M_{\text{EW}})$ and $m_{H_d}^2(M_{\text{EW}})$. Based on

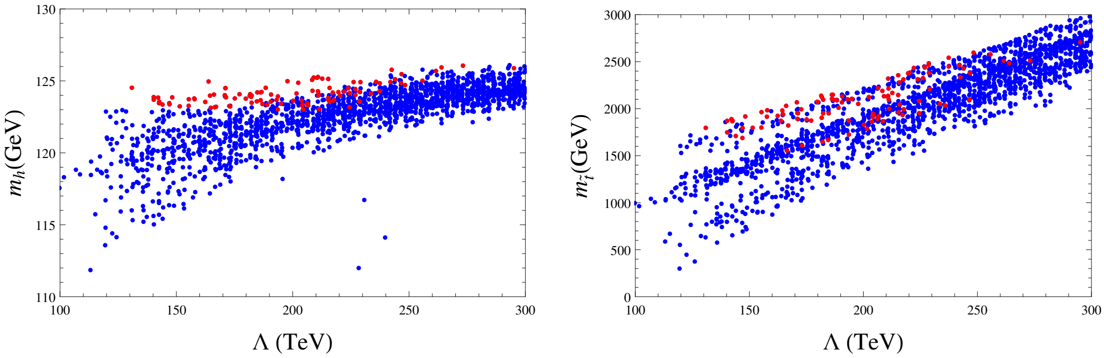

Figure 1. After our scan, the Higgs mass m_h (left) and the lightest Stop mass $m_{\tilde{t}_1}$ (right) are presented as a function of the parameter Λ. Blue points are corresponding to all scan results. Red points are corresponding to points satisfying the selection rules, i.e., 123 GeV $\leq m_h \leq$ 127 GeV, $M_{\tilde{g}} \geq$ 1700 GeV, $M_{\tilde{t}} \geq$ 700 GeV, and $M_{\tilde{q}} \geq$ 800 GeV.

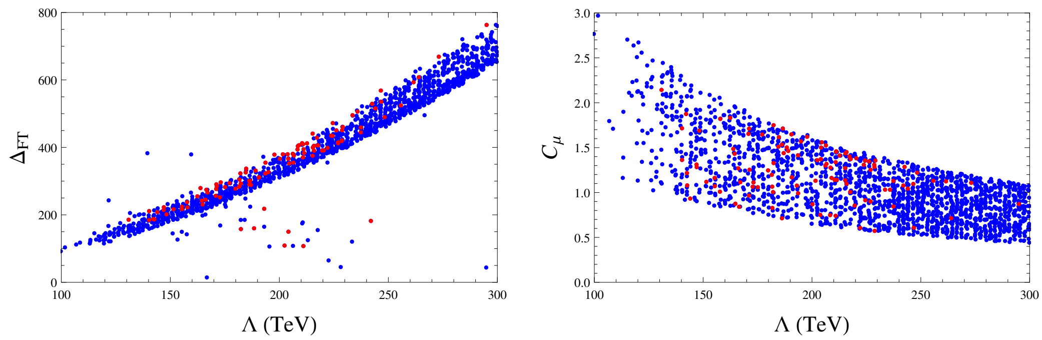

Figure 2. The fine-tuning measure $\Delta_{\rm FT}$ (left) and c_μ (right) are presented as a function of the parameter Λ.

the results at the EW scale, we will also run the RG evolutions back to the GUT scale to make sure $m^2_{H_u}(M_{\rm GUT}) > 0$, $m^2_{H_d}(M_{\rm GUT}) > 0$ and no Landau pole.

First, we would like to show the particle spectra in our model. In figure 1, the Higgs mass m_h and light Stop mass $m_{\tilde{t}_1}$ are presented as a function of the parameter Λ. Here, blue points are all the scan results, and red points satisfying 123 GeV $\leq m_h \leq$ 127 GeV, $M_{\tilde{g}} \geq$ 1700 GeV, $M_{\tilde{t}} \geq$ 700 GeV, and $M_{\tilde{q}} \geq$ 800 GeV, which are required by the LHC searches. Some crucial features are summarized as follows:

- The 125 GeV Higgs boson as well as relatively heavy gluino/stop prefers a relatively large Λ, because all the soft masses from gauge mediation are proportional to it. A relatively heavy stop sector also significantly contributes to the Higgs mass m_h, as shown in eq. (1.1).

- All the red points are within the range $\lambda_u > 0.2$, which leads to a relatively large A_t at the messenger scale. Thus those points are more effective for lifting the Higgs boson mass. Notice that a part of the parameter space with $\lambda_u > 0.6$ has been excluded due to the EWSB requirement, since a relatively large λ_u induces a relatively large positive threshold contribution of $\delta m^2_{H_u}$ at the messenger scale. When the RGEs run from the GUT scale down to the electroweak scale, $m^2_{H_u}$ fails to be negative due to

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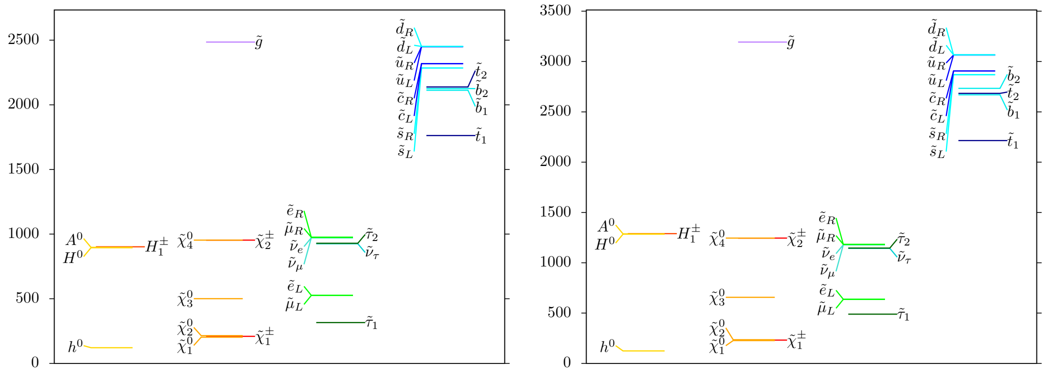

Figure 3. Two benchmark spectra respectively correspond to the minimal lightest Stop mass (left) and minimal fine-tuning measure (right).

such a large positive threshold effect $\delta m_{H_u}^2(M_{\rm mess})$. Therefore, the EWSB can not be triggered in these cases. But our boundary condition of $m_{H_u}^2$ is firstly given at the GUT scale. When the RGEs run from the GUT scale to messenger scale, the Yukawa coupling Y_t will persistently provide negative contributions to $m_{H_u}^2$ even if all the gaugino masses are still vanishing during the running. For the survived points, the EWSB is guaranteed because of the contribution from the Yukawa coupling Y_t, even a positive threshold $\delta m_{H_u}^2$ is provided at the messenger scale.

- The survived red points are almost independent of the parameter μ_0 at the GUT scale. However, the GUT input μ_0 will significantly influence the NLSP in our model. As the gravitino is the LSP, the lightest neutralino $\tilde{\chi}_1^0$ and the lightest stau $\tilde{\tau}_1$ are the NLSP candidates in our model. When μ_0 is relatively small, NLSP in most cases is Higgsino-like $\tilde{\chi}_1^0$. When μ_0 grows up, the Bino and Wino components of $\tilde{\chi}_1^0$ become important. $\tilde{\tau}_1$ becomes the NLSP candidate in most of this case.

In figure 2, we present fine-tuning measure $\Delta_{\rm FT}$ and quantity c_μ versus the input parameter Λ. Notice that there are two SUSY breaking scale in our model, i.e., the GUT scale and the messenger scale. Thus for each parameter a in the parameter set $\{\Lambda, \lambda_u, \mu, B_\mu\}$, Δ_a is calculated at the corresponding scale where parameter a is generated. In most case, $\Delta_{\rm FT}$ is dominated by Λ. So we show it in the left of figure 2. The high-scale fine-tuning measure can be as low as 100 in our model with the light stop mass below 1 TeV. In the right of figure 2, the values of c_μ always fall into the region $c_\mu \sim \mathcal{O}(1)$, which is numerically confirmed the reliability of our scenario.

In figure 3, we list the spectra of two benchmark points in our model. In the left panel, the lightest stop mass $m_{\tilde{t}_1}$ reaches its minimal value in our model. The stop mass can be as low as 1.7 TeV while the glunio mass is around 2.5 TeV, which is within the search range of the coming LHC run II. In the right panel, this benchmark point is corresponding to a minimal fine-tuning measure $\Delta_{\rm FT}$. Beside the spectra shown in figure 3, we also show other important relevant quantities in table 3.2. Both two benchmark points have relatively large Stop mixings and appropriate c_μ values.

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	m_h	$A_t/\sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$	$\Delta_{\rm FT}$	c_μ
bench1	123	-1.09	274.3	0.98
bench2	124	-0.96	107.4	1.68

Table 1. Higgs mass, Stop mixing $A_t/\sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$, fine-tuning measure $\Delta_{\rm FT}$ and c_μ for two benchmark points in our model.

3.3 Gravitino dark matter

Gravitino is the LSP in our model. The gravitino mass should not be larger than $\mathcal{O}(1)$ GeV, otherwise, the flavor problem will be generated due to gravity mediation. Interestingly, such a gravitino dark matter can come from a thermal production and be consistent with the thermal leptongenesis. The baryon number asymmetry Ω_b can be produced by thermal leptogenesis, which is given by

$$\Omega_b \leq 0.04 \left(\frac{T_R}{10^9 \, \text{GeV}} \right), \tag{3.9}$$

with T_R being the reheating temperature. In order to realize the observed value $\Omega_b = 0.0499$ [76], one has $T_R \geq 10^9$ GeV [77–80]. In the thermal leptogenesis, it is difficult to realize the observed value $\Omega_{\rm dm} = 0.265$ [76] if gravitino is the dark matter candidate. This is because the relic abundance of thermally produced gravitino is usually also proportional to T_R [81–84]. Under these conditions, the correct ratio $\Omega_{\rm dm}/\Omega_b \sim 5$ can not be realized.

However, the estimation of the relic abundance for thermally produced gravitino should be corrected. The relic density is still fixed by T_R if $T_R < M_{\rm mess}$, but it can be insensitive to the reheating temperature if $T_R > M_{\rm mess}$ [28, 85]. For $T_R > M_{\rm mess}$, the relic density is [28]

$$\Omega_{3/2}\, h^2 \simeq 370 \left(\frac{M_{\rm mess}}{10^6 \, \text{GeV}} \right) \left(\frac{\text{GeV}}{m_{3/2}} \right) \left(\frac{m_{\tilde{g}}}{5 \text{ TeV}} \right)^2 + 0.53 \left(\frac{T_R}{10^{13} \text{ GeV}} \right) \left(\frac{m_{3/2}}{\text{GeV}} \right). \tag{3.10}$$

The former contribution in the right-handed side of eq. (3.10) comes from the longitudinal mode of the gravitino, while the latter arises from the transverse component. When the reheating temperature is higher than messenger scale, the thermally produced gravitino and thermal leptogenesis can be compatible so that the observed ratio $\Omega_{3/2}/\Omega_b = 5$ can be realized. In order to get the correct values $\Omega_{\rm dm} = 0.265$ and $\Omega_b = 0.0499$, a late-time entropy release is required. The SUSY breaking field X can be the pseudo-modulus field which provides an appropriate dilution factor [28]. Compared to the exact sweet spot SUSY discussed in refs. [25–28], our modified model can predict a relatively light spectra which can be checked by the run II of the LHC. In the mean time, there still exists large viable parameter space to account for the cosmological observations. The thermal production of gravitino as well as thermal leptogenesis can still be realized, and the discussion should be similar to that in ref. [28].

4 Conclusion

The discovery of a 125 GeV SM-like Higgs boson as well as the natural SUSY assumption suggest a large A_t term in the MSSM. So in the GMSB, the extended Higgs-messenger coupling is always introduced to generate the non-vanishing A-terms at the messenger scale. However, the μ-B_μ problem is still unsolved unless one considers the NMSSM. Since the run II of the LHC will start soon, it is important to think about the feasible SUSY models which describe new physics at the TeV scale and can be detected by the coming LHC experiments. In this paper, we have proposed the MSSM with the GMSB, Higgs-messenger interaction, and generalized GM mechanism. At the GUT scale, the SUSY breaking sector and Higgs fields are assumed to be directly coupled. Because of the approximate PQ symmetry, only the μ-term and soft masses m_{H_u}/m_{H_d} are generated. While the sfermion soft masses, gaugino masses, A-terms, and B_μ-term are all vanished. Below the GUT scale, it is effectively the GMSB with extended Higgs-messenger coupling. The RGEs are run from the GUT scale down to EW scale. At the messenger scale the messenger fields are integrated out. The non-vanishing soft masses of the gauginos/sfermions and A-terms are generated as the threshold corrections in the RGE runnings. Especially, a large non-vanishing A_t-term at the messenger scale is produced by the extended Higgs-messenger coupling. So our model can have a SM-like Higgs boson at 125 GeV without moving forward into the heavy spectra SUSY or even split SUSY. In addition, it is easier in our model to obtain a negative $m^2_{H_u}$ at the EW scale because our boundary condition of $m^2_{H_u}$ is given at the GUT scale. When the RGEs run from the GUT scale to messenger scale, the Yukawa coupling Y_t will persistently provide a negative contributions to $m^2_{H_u}$. For the survived points, the EWSB is guaranteed in our model as we run the RGE of $m^2_{H_u}$ for a long energy scale range from the GUT scale. On the theoretical aspect, gauge coupling unification is guaranteed. The flavor problem and μ/B_μ problem are solved. On the phenomenological aspects, our model has only five free parameters, can predict a 125 GeV SM-like Higgs boson, and evades all the current LHC SUSY search constraints. The high-scale fine-tuning measure can be as low as 100. For some benchmark points, the stop mass can be as low as 1.7 TeV while the glunio mass is around 2.5 TeV. Since glunio and stop can be relatively light, this natural SUSY model could be tested at the upcoming run II of the LHC experiment.

Furthermore, the gravitino mass $m_{3/2}$ is typically smaller than $\mathcal{O}(1)$ GeV in order to evade the flavor constraints. Due to a relatively large $\sqrt{F_X}$, the gravitino will play no role in the collider physics. Interestingly, the gravitino can be a good dark matter candidate. Such a gravitino dark matter can come from a thermal production with the correct relic density and be consistent with the thermal leptongenesis.

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