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The natural explanation of the muon anomalous magnetic moment via the electroweak supersymmetry from the GmSUGRA in the MSSM

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ABSTRACT

The Fermi-Lab Collaboration has announced the results for the measurement of muon anomalous magnetic moment. Combining with the previous results by the BNL experiment, we have 4.2σ deviation from the Standard Model (SM), which strongly implies the new physics around 1 TeV. To explain the muon anomalous magnetic moment naturally, we analyze the corresponding five Feynman diagrams in the supersymmetry SMs (SSMs), and show that the Electroweak Supersymmetry (EWSUSY) is definitely needed. We realize the EWSUSY in the Minimal SSM (MSSM) with Generalized Minimal Supergravity (GmSUGRA). With the Feynman diagram inspired focus scan and general scan, we find large viable parameter space, which is consistent with all the current experimental constraints. In particular, the Lightest Supersymmetric Particle (LSP) neutralino can be at least as heavy as 550 GeV. Most of the viable parameter space can be probed at the future HL-LHC, while we do need the future HE-LHC to probe some viable parameter space. However, it might still be challenge if R-parity is violated.

1. Introduction

After Higgs particle was discovered at the LHC, the Standard Model (SM) has been confirmed. However, there exists some problems, and thus we need to study the new physics beyond the SM. It is well-known that Supersymmetry (SUSY) is the most natural solution to the gauge hierarchy problem. In the supersymmetric SMs (SSMs) with R-parity, we can achieve gauge coupling unification [1], have the Lightest Supersymmetric Particle (LSP) like the lightest neutralino as dark matter (DM) candidate [2], and break the electroweak (EW) gauge symmetry radiatively because of the large top quark Yukawa coupling, etc. Moreover, gauge coupling unification strongly implies the Grand Unified Theories (GUTs) [3–7], and the SSMs and SUSY GUTs can be constructed from superstring theory. Therefore, supersymmetry provides a bridge between the low energy phenomenology and high-energy fundamental physics, and thus is the most promising new physics beyond the SM.

However, after the second run at the Large Hadron Collider (LHC), we still did not have any SUSY signals, and then the LHC SUSY searches have already given strong constraints on the SSMs. For instance, the masses of the gluino, first-two generation squarks, stop, and sbottom must be larger than about 2.3 TeV, 1.9 TeV, 1.25 TeV, and 1.5 TeV, respectively [8–12]. Thus, at least the colored supersymmetric particles (sparticles) must be heavy around a few TeV.

Interestingly, a well-known long-standing deviation is a 3.7 σ discrepancy for the muon anomalous magnetic moment $a_\mu = (g_\mu - 2)/2$ between the experimental results [13,14] and theoretical predictions [15–18]

$$\Delta a_\mu = a_\mu^{exp} - a_\mu^{th} = (27.4 \pm 7.3) \times 10^{-10} \,. \quad (1)$$

Computing the hadronic light-by-light contribution with all errors under control by using lattice QCD, several groups have tried to improve the precision of the SM predictions [19–21]. And the Δa_μ discrepancy has been confirmed by the recent lattice calculation for the hadronic light-by-light scattering contribution [22], and then a new physics explanation is needed. Also, the ongoing ex-

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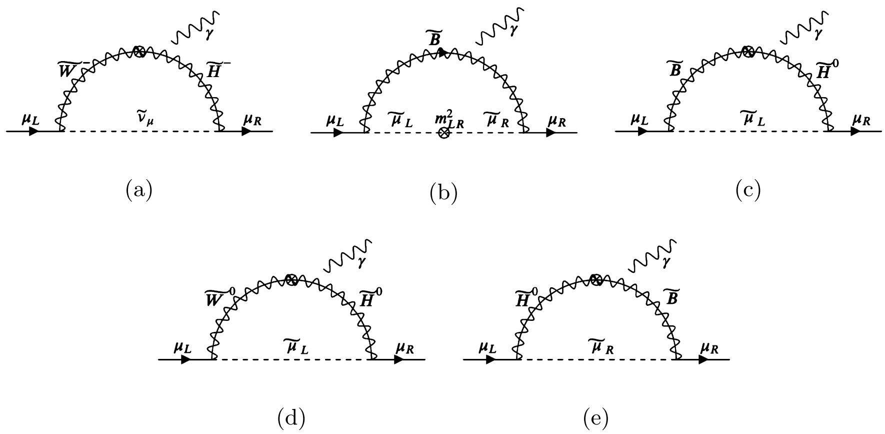

Fig. 1. Feynman diagrams that give the dominant SUSY contributions to the a_μ.

periment at Fermilab [23,24] and one planned at J-PARC [25] will try to reduce the uncertainty.

To escape the LHC SUSY search constraints, explain the muon anomalous magnetic moment, and be consistent with various experimental results, some of us proposed the Electroweak Supersymmetry (EWSUSY) [26–28], where the squarks and/or gluinos are around a few TeV while the sleptons, sneutrinos, Bino and Winos are within about 1 TeV. The Higgsinos (or say the Higgs bilinear μ term) can be either heavy or light. Especially, the EWSUSY can be realized in the Generalized Minimal Supergravity (GmSUGRA) [29,30].

Recently, the Fermi-Lab Collaboration has announced the results for the measurement of the anomalous magnetic moment of the muon. Combining with the previous results by the Brookhaven National Lab (BNL) experiment, we have 4.2σ deviation from the SM [31][1]

$$\Delta a_\mu = a_\mu^{exp} - a_\mu^{th} = (25.1 \pm 5.9) \times 10^{-10} \,. \tag{2}$$

This finding suggests the new physics around 1 TeV and has generated flurry of activity [63–99]. We shall explain the muon anomalous magnetic moment in the SSMs in this paper. Here, we will not consider the SSMs where the supersymmetry breaking soft terms are introduced at the low scale since such kind of scenarios has more freedoms and might not be consistent with the GUTs and string models. To explain the muon anomalous magnetic moment naturally, we analyze five corresponding Feynman diagrams, and show that the EWSUSY is definitely needed. We realize the EWSUSY in the Minimal SSM (MSSM) with the GmSUGRA. With the Feynman diagram inspired focus scan and general scan, we find large viable parameter space, which is consistent with all the current experimental constraints. In particular, the LSP neutralino can be at least as heavy as 550 GeV. Most of the viable parameter space can be probed by the future High Luminosity-LHC (HL-LHC), while we do need the future High Energy-LHC (HE-LHC) with center-of-mass energy 27 TeV to probe some viable parameter space. However, it may be a big challenge if R-parity is violated.

2. Muon anomalous magnetic moment and EWSUSY

There are five Feynman diagrams in the SSMs which will contribute to Δa_μ [100], as given in Fig. 1. First, for $M_2\mu > 0$ and $M_1\mu > 0$, diagrams (a), (b), and (c) give positive contributions, while diagrams (d) and (e) give negative contributions. Second, if Higgsino is very heavy, only the diagram (b) will give dominant contribution. Third, if the mass splitting between the muon sneutrino and left-handed smuon is small as in our study, the sum of the diagrams (a) and (d) is positive, *i.e.*, the contributions from diagram (a) are generically larger. Fourth, the contribution from diagram (c) is always relatively smaller compared to these from diagrams (a) and (b) in our study. Of course, the contribution from diagram (c) can be dominant if we choose light Bino, Higgsino, and left-handed smuon, as well as heavy M_2 and right-handed smuon by hand at low energy, and we have confirmed it numerically. However, this is not consistent with GUTs and string models since larger M_2 will increase the left-handed smuon mass due to the renormalization group equation (RGE) running. Fifth, we find that the contribution to Δa_μ from diagram (e) is smaller than 6×10^{-10} in our study, and is generically smaller than 10×10^{-10}, *i.e.*, out of 2σ region. In short, within 2σ region, we can only explain the muon anomalous magnetic moment via diagrams (a) and (b). And then we obtain that the sleptons, sneutrinos, Bino and Winos must be light and cannot be much heavier than 1 TeV. Also, if diagram (b) gives dominant contribution, the Higgsinos can be very heavy, while Wino cannot be very heavy since it will contribute to the left-handed smuon mass due to the RGE running. Therefore, we have shown that EWSUSY is definitely needed to explain the muon anomalous magnetic moment.

3. The EWSUSY from the GmSUGRA in the MSSM

The EWSUSY can be realized in the GmSUGRA [29,30], where the sleptons and electroweakinos (charginos, Bino, Wino, and/or Higgsinos) are within about 1 TeV while squarks and/or gluinos can be in several TeV mass ranges [26–28]. The gauge coupling relation and gaugino mass relation at the GUT scale are [29,101]

$$\frac{1}{\alpha_2} - \frac{1}{\alpha_3} = k \left(\frac{1}{\alpha_1} - \frac{1}{\alpha_3} \right) \,, \tag{3}$$

$$\frac{M_2}{\alpha_2} - \frac{M_3}{\alpha_3} = k \left(\frac{M_1}{\alpha_1} - \frac{M_3}{\alpha_3} \right) \,, \tag{4}$$

where k is the index and equal to 5/3 in the simple GmSUGRA. We obtain a simple gaugino mass relation

$$M_2 - M_3 = \frac{5}{3} \left(M_1 - M_3 \right) \,, \tag{5}$$

by assuming gauge coupling unification at the GUT scale ($\alpha_1 = \alpha_2 = \alpha_3$). It is obvious that the universal gaugino mass relation $M_1 = M_2 = M_3$ in the mSUGRA, is just a special case of this general one. Choosing M_1 and M_2 to be free input parameters, which

[1] for recent SM calculations see [32–62].

vary around several hundred GeV for the EWSUSY, we get M_3 from Eq. (5):

$$M_3 = \frac{5}{2} M_1 - \frac{3}{2} M_2 \,, \quad (6)$$

which could be as large as several TeV or as small as several hundred GeV, depending on specific values of M_1 and M_2.

The general SSB scalar masses at the GUT scale are given in Ref. [30]. Taking the slepton masses as free parameters, we obtain the following squark masses in the $SU(5)$ model with an adjoint Higgs field

$$m^2_{\tilde{Q}_i} = \frac{5}{6}(m_0^U)^2 + \frac{1}{6} m^2_{\tilde{E}_i^c} \,, \quad (7)$$

$$m^2_{\tilde{U}_i^c} = \frac{5}{3}(m_0^U)^2 - \frac{2}{3} m^2_{\tilde{E}_i^c} \,, \quad (8)$$

$$m^2_{\tilde{D}_i^c} = \frac{5}{3}(m_0^U)^2 - \frac{2}{3} m^2_{\tilde{L}_i} \,, \quad (9)$$

where $m_{\tilde{Q}}$, $m_{\tilde{U}^c}$, $m_{\tilde{D}^c}$, $m_{\tilde{L}}$, and $m_{\tilde{E}^c}$ represent the scalar masses of the left-handed squark doublets, right-handed up-type squarks, right-handed down-type squarks, left-handed sleptons, and right-handed sleptons, respectively, while m_0^U is the universal scalar mass, as in the mSUGRA. In the EWSUSY, $m_{\tilde{L}}$ and $m_{\tilde{E}^c}$ are both within 1 TeV, resulting in light sleptons. Especially, in the limit $m_0^U \gg m_{\tilde{L}/\tilde{E}^c}$, we have the approximated relations for squark masses: $2m^2_{\tilde{Q}} \sim m^2_{\tilde{U}^c} \sim m^2_{\tilde{D}^c}$. In addition, the Higgs soft masses $m_{\tilde{H}_u}$ and $m_{\tilde{H}_d}$, and the trilinear soft terms A_U, A_D and A_E can all be free parameters from the GmSUGRA [26,30].

4. Scanning process

We employ the ISAJET 7.85 package [102] to perform random scans over the parameter space given below. In this package, the weak-scale values of the gauge and third generation Yukawa couplings are evolved to M_{GUT} via the MSSM RGEs in the $\overline{DR}$ regularization scheme. We do not strictly enforce the unification condition $g_3 = g_1 = g_2$ at the GUT scale M_{GUT}, since a few percent deviation from unification can be assigned to the unknown GUT-scale threshold corrections [103]. With the boundary conditions given at M_{GUT}, all the SBS parameters, along with the gauge and Yukawa couplings, are evolved back to the weak scale M_Z (for more detail see [102]). We have performed the random scans for the following parameter ranges

$$\begin{aligned}
100\,\text{GeV} \le & m_0^U \le 10000\,\text{GeV}\,, \\
100\,\text{GeV} \le & |M_1| \le 1600\,\text{GeV}\,, \\
100\,\text{GeV} \le & |M_2| \le 10000\,\text{GeV}\,, \\
100\,\text{GeV} \le & m_{\tilde{L}} \le 10000\,\text{GeV}\,, \\
100\,\text{GeV} \le & m_{\tilde{E}^c} \le 1000\,\text{GeV}\,, \\
-10000\,\text{GeV} \le & m_{\tilde{H}_{u,d}} \le 10000\,\text{GeV}\,, \\
-10000\,\text{GeV} \le & A_U = A_D \le 10000\,\text{GeV}\,, \\
-10000\,\text{GeV} \le & A_E \le 10000\,\text{GeV}\,, \\
2 \le & \tan\beta \le 60\,.
\end{aligned} \quad (10)$$

Also, we consider $\mu > 0$, and use $m_t = 173.3\,\text{GeV}$ and $m_b^{\overline{DR}}(M_Z) = 2.83$ GeV [104]. Note that our results are not too sensitive to one or two sigma variations in the value of m_t [105]. Also, we will use the notations A_t, A_b, A_τ for A_U, A_D and A_E, respectively. In scanning the parameter space, we employ the Metropolis-Hastings algorithm as described in [106]. *In particular, we also perform some focus scans inspired from the diagrams (a) and (b), which do give us better viable parameter spaces to explain the* Δa_μ. The collected data points all satisfy the requirement of the Radiative Electroweak Symmetry Breaking (REWSB), with the lightest neutralino being the LSP.

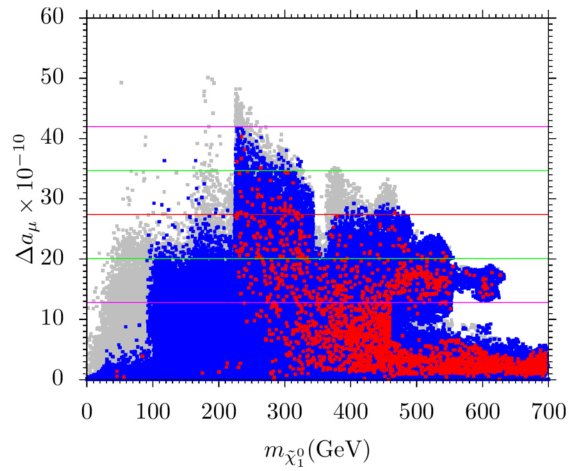

Fig. 2. Gray points are consistent with the REWSB and LSP neutralino. Blue points satisfy the mass bounds including $m_h = 125 \pm 2\,\text{GeV}$ and the constraints from rare $B-$ meson decays. Red points form a subset of blue points and satisfy the 5σ Planck bounds on dark matter relic density. Red line shows the central value of Δa_μ, and greens and purple lines represent 1σ and 2σ deviations from the central value.

5. Constraints

After collecting the data, we impose the bounds that the LEP2 experiments set on charged sparticle masses ($\gtrsim 100$ GeV) [107]. The combined value of Higgs mass reported by the ATLAS and CMS Collaborations is [108] $\text{m}_\text{h} = 125.09 \pm 0.21(stat.) \pm (syst.)$GeV. Due to the theoretical uncertainty in the Higgs mass calculations in the MSSM – see *e.g.* [109,110] – we apply the constraint from the Higgs boson mass to our results as $m_h = [122, 128]$GeV. In addition, based on [8–12], we consider the constraints on gluino $m_{\tilde{g}} \gtrsim 2.2\,\text{TeV}$. The constraints from rare decay processes $B_s \to \mu^+\mu^-$ [111], $b \to s\gamma$ [112], and $B_u \to \tau\nu_\tau$ [113]. We also require the relic abundance of the LSP neutralino to below the 5σ Planck bound [114]. More explicitly, we set

$$m_h = 122 - 128 \text{ GeV}, \quad (11)$$

$$m_{\tilde{g}} \ge 2.2 \text{ TeV}, \quad (12)$$

$$0.8 \times 10^{-9} \le \text{BR}(B_s \to \mu^+\mu^-) \le 6.2 \times 10^{-9}\ (2\sigma), \quad (13)$$

$$2.99 \times 10^{-4} \le \text{BR}(b \to s\gamma) \le 3.87 \times 10^{-4}\ (2\sigma), \quad (14)$$

$$0.15 \le \frac{\text{BR}(B_u \to \tau\nu_\tau)_{\text{MSSM}}}{\text{BR}(B_u \to \tau\nu_\tau)_{\text{SM}}} \le 2.41\ (3\sigma), \quad (15)$$

$$0.114 \le \Omega_{\text{CDM}} h^2(\text{Planck}) \le 0.126\ (5\sigma). \quad (16)$$

6. Results

We shall discuss results of the scans in the following. In Fig. 2, we display plot in $m_{\tilde{\chi}_1^0} - \Delta a_\mu$ plane. Gray points are consistent with the REWSB and LSP neutralino. Blue points satisfy the mass bounds including $m_h = 125 \pm 2\,\text{GeV}$ and the constraints from rare $B-$ meson decays. Red points form a subset of blue points and satisfy the 5σ Planck bounds on dark matter relic density. Red line shows the central value of Δa_μ, and greens and purple lines represent 1σ and 2σ deviations from the central value. So in our

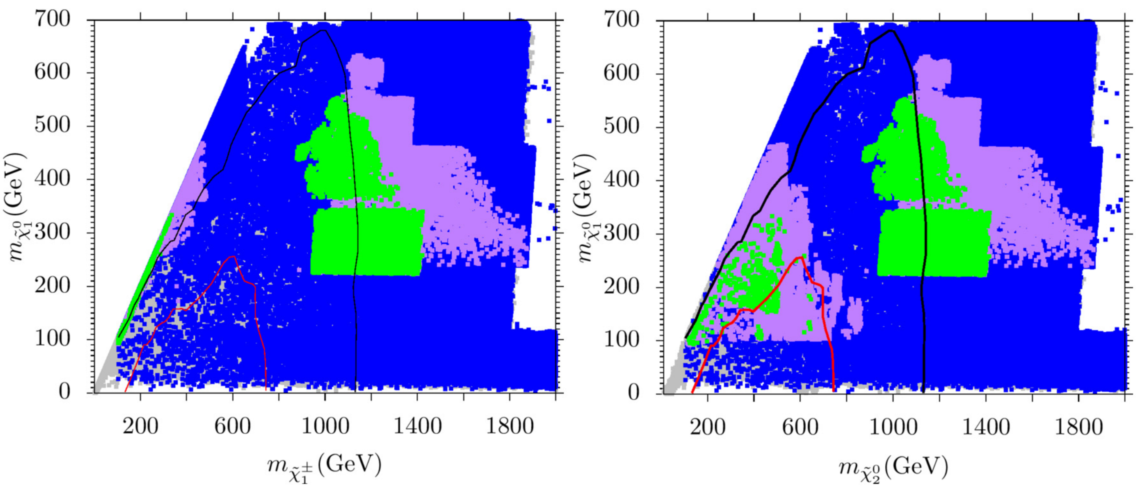

Fig. 3. Gray points are consistent with the REWSB and LSP neutralino. Blue points satisfy the mass bounds including $m_h = 125 \pm 2$ GeV and the constraints from rare $B-$ meson decays. The green and purple points form the subsets of blue points and are consistent with 1σ and $2\ \sigma$ deviations from the central value of Δa_μ, respectively. Black and red curves represent the ATLAS SUSY search bounds [117].

model, we can explain Δa_μ very easily. In particular, some viable parameter spaces including the viable parameter spaces with the correct dark matter relic density have Δa_μ around the central value 25.1×10^{-10}. Note that the peak at $m_{\tilde{\chi}_1^0} \sim 300$ GeV is not the unique feature but the artifact of focused scans.

Another important point to be noted is that the solutions with relatively heavy LSP neutralino ~ 600 GeV are still consistent within 2σ values of Δa_μ. We would also like to mention that our solutions are consistent with [115,116]. In [115], $m_{\tilde{\mu}_{1,2}}$ and $m_{\tilde{\nu}_\mu}$ were kept above 1 TeV in contras with our analysis where they can be below 400 GeV. Note that these studies used low energy MSSM parameters in their analysis. We like to emphasis that our study is based on a GUT model. In such a scenario it is not that easy to control parameters at low energy due to RGE running such that we can take care of Δa_μ and other constraints simultaneously. One should also note that the parameter space they used is the subspace of GmSUGRA. However, we want to make a comment here about the solutions with $m_{\tilde{\chi}_1^0} > 600$ GeV: we have checked some points and found that some of them might not be numerically stable.

In Fig. 3, we depict plots in $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$. Gray points are consistent with the REWSB and LSP neutralino. Blue points satisfy the mass bounds including $m_h = 125 \pm 2$ GeV and the constraints from rare $B-$ meson decays. The green and purple points form the subsets of blue points and are consistent with 1σ and 2σ deviations from the central value of Δa_μ, respectively. The solid black and red curves are the 95% CL exclusion limits on $\tilde{\chi}_1^+\tilde{\chi}_1^-$ and $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ from pair productions with $\tilde{l}$-mediated decays as a function of the $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ masses [117]. Purple and green patches as stated before are due to the focused scans. In the left panel, we see that we have two sets of solutions which satisfy Δa_μ within 1σ and 2σ that is the compressed region where $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^\pm$ are almost degenerate in mass and region where $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^\pm$ mass splitting is greater than 500 GeV. Green solutions in the compressed region mostly belong to diagram (a) of Fig. 1 and the solutions with heavy chargino masses but light $m_{\tilde{\chi}_1^0}$ belong to diagram (b) of Fig. 1. Here we want to make a comment that since Higgsino-like and Wino-like dark matter consistent with relic density bounds have to be around TeV scale [118,119] which results in too heavy electroweakino spectrum to generate sizable contributions to Δa_μ. The LSP in our study is Bino-type. Since in mSUGRA/CMSSM [120,121], we have universal gaugino mass parameter $M_{1/2}$, we can not satisfy present relic density and Δa_μ bounds simultaneously. One needs at least non-universal guaginos. We also like to mention that in Fig.3 we have not imposed relic density bounds. However we have checked that some of the points of compressed region which belong to chargino coannihilation scenario and consistent with relic density bounds. Similarly there are solutions in the two green patches which belong to stau coannihilation scenario and saturate relic density bounds. Point 4 is one the representative example of such a scenario. We also note that we have some slepton coannihilation solutions consistent with relic density bounds similar to the solutions reported in [64,122] but somehow solutions are not stable. In most of the studies where MSSM is employed to address Δa_μ problem, authors have used positive values of the input parameters M_1 and M_2. In our analysis we see that the green patches where we have large mass difference between chargino and LSP neutralino, $M_2 < 0$ and M_1 is positive and thus creating a mass difference at the GUT scale. Since we are using a High scale model, the constraints from Δa_μ are also constraining the GmSUGRA parameters at the GUT scale. To remind the reader again our study of Δa_μ issue based on a GUT model stands out among the other studies because others have used MSSM at low energy.

As stated above SUSY contributions to Δa_μ are proportional to Higgsino mass parameter μ. Sizable SUSY contributions to Δa_μ require large values of μ. This has implications such as finetuning in the GUT theory (since often small Higgsino mass is seen as preferred by naturalness in the Z-boson mass). The SUSY electroweak fine-tuning problem is a serious issue, and some promising and successful solutions can be found in the literatures [123–135]. In particular, in an interesting scenario, known as Super-Natural SUSY [131,136], it was shown that no residual electroweak fine-tuning (EWFT) is left in the MSSM if we employ the No-Scale supergravity boundary conditions [137] and Giudice-Masiero (GM) mechanism [138] despite having relatively heavy spectra. One might think that the Super-Natural SUSY have a problem related to the Higgsino mass parameter μ, which is generated by the GM mechanism and is proportional to the universal gaugino mass $M_{1/2}$. It should be noted that the ratio $M_{1/2}/\mu$ is of order one but cannot be determined as an exact number. This problem, if it is, can be addressed in the M-theory inspired the Next to MSSM (NMSSM) [139].

We show four benchmark points in Table 1. Point 1 represents a set of solutions with relatively heavy neutralino $m_{\tilde{\chi}_1^0} > 400$ GeV. Because Wino and Higgsinos are heavy in Points 1 and 2, these points belong to the diagram (b) explanation. Point 3 is an exam-

Table 1
The sparticle and Higgs masses (in GeV units) for the benchmark points.

	Point 1	Point 2	Point 3	Point 4
m_0^U	2493	1523	2547	2624
M_1	1052	672	850.7	1179
M_2	-1255	-1304	373.5	-1156
M_3	4497	3644.5	1566.5	4681.5
$m_{\tilde{E}^c}$	150.5	159.9	566.4	136.4
$m_{\tilde{L}}$	176.1	217	698.1	224.7
m_{H_u}	777.1	883	221.9	699.1
m_{H_d}	3817	2437	397.5	3789
$m_{\tilde{Q}}$	2324.1	1404.8	2336.6	2396
$m_{\tilde{U}^c}$	3283.3	1979.4	3255.5	3385.7
$m_{\tilde{D}^c}$	3285.6	1984.3	3288.2	3387.6
$A_t = A_b$	-5912	-5990	-5542	-7760
A_τ	-836.5	-1088	466.4	-698.2
$\tan\beta$	56.8	59.4	54.7	58
m_h	125	125	124	125
m_H	2845	2843	2366	3291
m_A	2827	2824	2350	3269
$m_{H^\pm}$	2847	2844	2368	3292
Δa_μ	18.86×10^{-10}	26.98×10^{-10}	20.04×10^{-10}	20.4×10^{-10}
$m_{\tilde{\chi}^0_{1,2}}$	450,1160	283, 1180	303,365	508,1077
$m_{\tilde{\chi}^0_{3,4}}$	4878,4879	4322,4383	3546,3546	5523,5524
$m_{\tilde{\chi}^\pm_{1,2}}$	1164,4879	1185,4383	304, 3526	1081,5525
$m_{\tilde{g}}$	9001	7358	3472	9349
$m_{\tilde{u}_{L,R}}$	7793,8308	6462,6583	3726,4300	8283,8625
$m_{\tilde{t}_{1,2}}$	6503,6760	5060,5423	2573, 3129	6566, 6858
$m_{\tilde{d}_{L,R}}$	7984,8320	6463,6591	3727,4411	8283,8640
$m_{\tilde{b}_{1,2}}$	6718,7532	5385,5845	2635, 3777	6817,7690
$m_{\tilde{\nu}_1}$	725	816	385	645
$m_{\tilde{\nu}_3}$	897	918	579	918
$m_{\tilde{e}_{L,R}}$	749,491	842,301	334, 1083	677,577
$m_{\tilde{\tau}_{1,2}}$	490,999	299,969	399,1201	568,1087
$\sigma_{SI}(pb)$	2.01×10^{-14}	2.26×10^{-14}	1.03×10^{-12}	4.41×10^{-15}
$\Omega_{CDM}h^2$	0.042	0.004	0.007	0.124

ple where Bino, Wino and sneutrino are light but Higgsinos are heavy, so diagrams (a) and (b) both contribute here. Point 4 has the similar description to Point 1 but with relic density consistent with Eq. (16).

7. Collider searches: bounds and prospects

The SUSY has been searched inclusively at the LHC. The light EW sector of the EWSUSY model that is used to address the Δa_μ will have been excluded by those searches, except that the spectrum is compressed or the mass scale is high. All benchmark points are featured by large mass splitting between the left-handed and right-handed sleptons. For the benchmark points 1, 2 and 4, the left-handed sleptons are relatively heavy and the right-handed sleptons have masses close to the LSP (it is opposite for benchmark point 3), such that the direct slepton search at 13 TeV 139 fb^{-1} [140,141] cannot probe them. The most sensitive search for those three points is the trilepton search [142] for Wino production $\tilde{\chi}^0_2\tilde{\chi}^\pm_1 \to (\tilde{\ell}\ell)(\tilde{\ell}\nu) \to (\tilde{\chi}^0_1\ell\ell)(\tilde{\chi}^0_1\ell\nu)$. Those three benchmark points just fall beyond the current bound for this channel and may be probed/excluded in the near future, when the same analysis is performed on higher integrated luminosity dataset. For benchmark point 3, although the $\tilde{\chi}^0_2$ has relatively large mass spitting with the LSP and decays through $\tilde{\chi}^0_2 \to \tilde{\ell}\ell \to \tilde{\chi}^0_1\ell\ell$ producing leptons in the final state, it is Bino dominate and its production rate at the LHC is suppressed. To probe the light compressed wino for this benchmark point, the HE-LHC with collision energy 27 TeV is required [143].

8. Discussion and conclusion

Combining the BNL and Fermi-Lab experimental results for the measurements of muon anomalous magnetic moment, we have 4.2σ deviation from the SM, which strongly suggests the new physics around 1 TeV. We analyzed the corresponding five Feynman diagrams in the SSMs, and showed that the EWSUSY is definitely needed. We realized the EWSUSY in the MSSM with the GmSUGRA. We found large viable parameter space, which is consistent with all the current experimental constraints. In particular, the LSP neutralino can be at least as heavy as 550 GeV. Most of the viable parameter space can be probed at the future HL-LHC, while we do need the future HE-LHC to probe some viable parameter space. The benchmark points, which have been studied in this work, are based on the assumption of R-parity conservation. If the R-parity is broken via the operators $U_i^c D_j^c D_k^c$ in the superpotential, the corresponding collider bounds may become much weaker and then the wider classes of benchmark points become viable. As a result, testing the EWSUSY which can explain the Δa_μ naturally at the future HL-LHC and HE-LHC will become a big challenge.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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