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Phenomenology of minimal supergravity with vanishing A and B soft supersymmetry-breaking parameters

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Abstract

The ansatz of vanishing A and B parameters eliminates CP-violating complex phases in soft supersymmetry-breaking parameters of the minimal supersymmetric standard model, and thus provides a simple solution to the supersymmetry CP problem. Phenomenological implications of this ansatz are investigated in the framework of minimal supergravity. We show that electroweak symmetry breakdown occurs, predicting relatively large $\tan\beta$. The ansatz survives the Higgs mass bound as well as the $b \to s\gamma$ constraint if the universal gaugino mass is larger than 300 GeV. We also find that the supersymmetric contribution to the anomalous magnetic moment of muon lies in an experimentally interesting region of order 10^{-9} in a large portion of the parameter space.

It is well known that soft supersymmetry (SUSY) breaking mass parameters in the minimal supersymmetric standard model (MSSM) generally have many CP-violating phases, which are strongly constrained by non-observation of the electric dipole moments (EDMs) of electron [1], neutron [2] and mercury atom [3]. The hypothesis of the universal gaugino mass and the universal scalar mass significantly reduces the number of the CP phases, but there still remain two phases.

In fact, the minimal supergravity model which we will consider here has four SUSY-breaking mass parameters and one SUSY-invariant mass: (1) the universal gaugino mass $M_{1/2}$, (2) the universal scalar mass m_0, (3) the SUSY-invariant higgsino mass μ, (4) the universal trilinear scalar coupling A, and (5) the Higgs mixing mass parameter $B\mu$. The two physical CP phases can be chosen to be phases of $AM^*_{1/2}$ and $BM^*_{1/2}$, on which stringent constraints are put by the present upperbounds of the EDMs [4]. (See also, e.g., Ref. [5] and references therein for a recent analysis.)

One can evade these strong constraints if the A and B parameters vanish at some high energy scale:

$$A = B = 0. \tag{1}$$

Renormalization group evolution generates non-zero values for them, which have the same phase as the gaugino mass. In fact, the solution to the SUSY CP problem with the boundary condition (1) was considered in gauge mediation of supersymmetry breaking [6–8]. This solution would be also very

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plausible in gravity mediation, where the phase of the gaugino mass is in general uncorrelated to that of the gravitino mass. Dynamical realization of this ansatz in high-scale supersymmetry breaking scenario has recently been presented in [9].

The purpose of this Letter is to show that the ansatz (1) is phenomenologically viable. To be specific, we take the framework of the minimal supergravity. We will show that the electroweak symmetry breaking can take place correctly, yielding relatively large $\tan\beta$, the ratio of the two Higgs vacuum expectation values (VEVs). To see viability of the ansatz, we will consider the constraints from the lightest Higgs boson mass, $b \to s\gamma$, and the requirement that the lightest superparticle (LSP) be neutral. It is found that a wide region of the parameter space survives these constraints. A special attention is paid to the case where the scalar mass m_0 also vanishes. It turns out that the Higgs mass constraint will eliminate the parameter region where the LSP is neutral. We will summarize several ways proposed to avoid this difficulty. Finally the SUSY contribution to the anomalous magnetic moment of the muon will be briefly discussed.

The model we are considering has, thus, three parameters[1]

$$M_{1/2}, \quad m_0, \quad \mu, \tag{2}$$

which are given at some high energy scale. Here we identify it with the grand-unification scale of 2×10^{16} GeV. The superparticle masses at low energy are computed by solving renormalization group equations. In particular, the values of A and B are given as functions of the gaugino mass $M_{1/2}$. The condition that electroweak symmetry breaking takes place at the correct energy scale gives one relation among the three parameters. Here we take $M_{1/2}$ and m_0 free parameters, and determine the value of μ. Notice that the value of $\tan\beta$ is not an input parameter, but is rather an output when m_0 and $M_{1/2}$ are given.

A survey of the parameter space was performed for the range $0 \leqslant m_0 \leqslant 1$ TeV and 100 GeV $\leqslant M_{1/2} \leqslant 1$ TeV. It turns out that the electroweak symmetry breaking occurs in almost all region of the parameter space unless m_0 is much larger than $M_{1/2}$.

[1] In the following we take a convention that $M_{1/2}$ and μ are real parameters.

In the following analysis, we solved the one-loop renormalization group equations and used the effective potential at one loop order to determine the values of $\tan\beta$ and μ. In Fig. 1 constant contours of the value of $\tan\beta$ are plotted in the m_0–$M_{1/2}$ plane. Here the top quark mass m_t has been fixed to be 174 GeV, i.e., the central value of the top mass measurements. We find that the value of $\tan\beta$ is relatively large. In particular, for $M_{1/2} \gtrsim 300$ GeV, $\tan\beta \sim 20$–35. Furthermore, we find a positive correlation between $\tan\beta$ and m_0. It is easily understood if we recall the relation

$$\sin 2\beta = -\frac{2B\mu}{2\mu^2 + \tilde{m}_1^2 + \tilde{m}_2^2}, \tag{3}$$

which is derived by minimizing tree-level scalar potential. Here $\tilde{m}_1^2$ and $\tilde{m}_2^2$ are SUSY-breaking mass-squared parameters for the two Higgs multiplets H_1 and H_2. As m_0 increases, the denominator of (3) increases and hence $\tan\beta$ also increases.

Here it is interesting to note that the value of the μ parameter is determined to be positive in the convention that $\tan\beta$ and $M_{1/2}$ are taken positive. In fact, the large top Yukawa coupling drives the B parameter negative during the renormalization group flow, which is essential to determine the sign of μ. As we will see shortly, the sign of this parameter plays an important role when discussing the constraint from $b \to s\gamma$.

Next we compute the mass of the lightest CP even Higgs boson. A contour plot of the Higgs boson mass is given in Fig. 2. The present experimental bound of 114.1 GeV [10] is also indicated in the same figure. To compute the Higgs mass, we used the `FeynHiggsFast` [11]. One finds that the value of the Higgs mass is sensitive to the gaugino mass, and the region $M_{1/2} \gtrsim 300$ GeV survives the present Higgs mass bound.

We also consider the constraint from $\mathrm{Br}(b \to s\gamma)$. Since μ is always positive in the case at hand, the SUSY contribution to $b \to s\gamma$ partially cancels the charged Higgs contribution, and thus the deviation from the Standard Model prediction is small unless the superparticles are very light. We followed Ref. [12] to estimate the Standard Model contribution. As for the charged Higgs contribution, we used the next-to-leading order calculation [13]. The superparticle loops were basically computed at one loop order. To evaluate these contributions, we additionally took into account

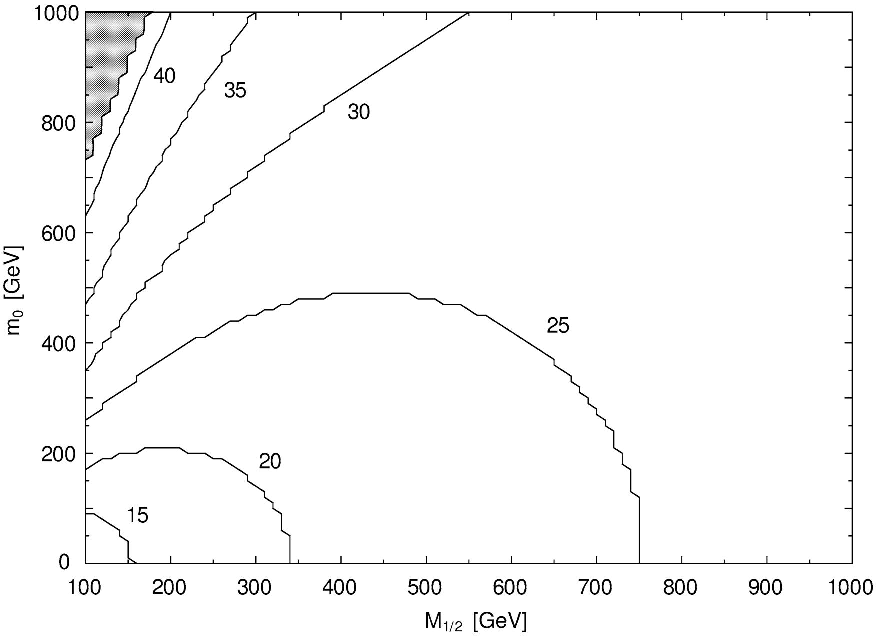

Fig. 1. Constant contours of the value of $\tan\beta$ on m_0–$M_{1/2}$ plane in the minimal supergravity model with $A = B = 0$. The electroweak symmetry breaking does not take place in the shaded region.

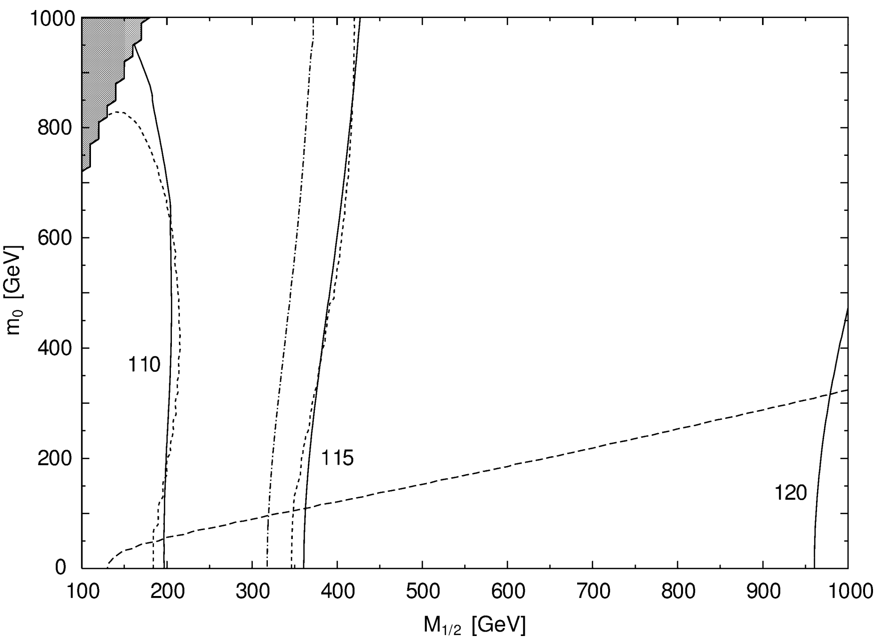

Fig. 2. The experimental bounds on m_0–$M_{1/2}$ plane in the minimal supergravity model with $A = B = 0$. The solid lines represent the contours of the constant Higgs boson mass. The dot-dashed line is the present Higgs boson mass bound of 114.1 GeV. The dotted lines are the contours of the constant $b \to s\gamma$ branching ratio ($\mathrm{Br}(b \to s\gamma) = 2 \times 10^{-4}$ and 3×10^{-4} from left). The stau and the lightest neutralino are degenerate in mass on the dashed line. The neutralino is the LSP above this line and the stau is lightest below this line. The electroweak symmetry breaking does not take place in the shaded region.

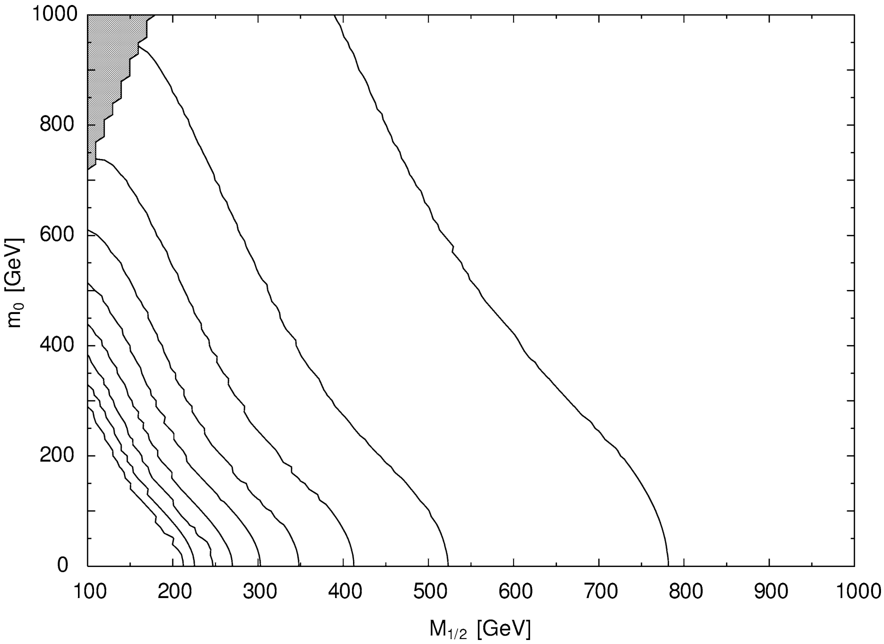

Fig. 3. Constant contours of the value of the SUSY contribution to the anomalous magnetic moment of muon on m_0–$M_{1/2}$ plane in the minimal supergravity model with $A = B = 0$. The solid lines denote the values of a_μ(SUSY) of $1, 2, \ldots, 9$ (from right) in units of 10^{-9}. The electroweak symmetry breaking does not take place in the shaded region.

corrections in powers of $\tan\beta$, which are important for large $\tan\beta$ [14]. The calculated branching ratio should be compared with the recent measurement at CLEO Collaboration $\mathrm{Br}(b \to s\gamma) = (3.21 \pm 0.43 \pm 0.27^{+0.18}_{-0.10}) \times 10^{-4}$, where the errors are of statistical, systematic and theoretical, respectively [15]. Here we take rather a conservative range

$$2 \times 10^{-4} < \mathrm{Br}(b \to s\gamma) < 4.5 \times 10^{-4}. \tag{4}$$

The allowed region consistent with the experimental data is shown in Fig. 2. One finds that it does not severely restrict the parameter space. In fact, once the Higgs mass constraint is imposed, the $b \to s\gamma$ does not further constrain the parameter space. Namely, the severest constraint comes from the Higgs boson mass. This is an interesting characteristic of the $A = B = 0$ ansatz.

Let us next discuss which particle will be the LSP. As is well known, cosmological argument[2] requires that the LSP must be neutral as far as R-parity is conserved and thus the LSP is stable. In our case, the lightest neutralino is always bino-like and the LSP (among the MSSM superparticles) is either the neutralino or a stau. In Fig. 2 we show the line where the stau and the lightest neutralino are degenerate in mass. The region above this line, the neutralino will be the LSP and thus the region is cosmologically viable. On the other hand, in the region below this line, the stau becomes the lightest among the superparticles in the MSSM.

A special attention should be paid to the case of $m_0 = 0$, which is often referred to as the no-scale boundary condition. In fact, if supersymmetry is broken in the sequestered sector where the Kähler potential is of the sequestered form, one obtains $m_0 = 0$ as well as $A = 0$ [17,18] (see also Ref. [19]). The boundary condition $m_0 = A = B = 0$ was considered in the framework of gaugino mediation [20]. When $m_0 = 0$, the stau mass and the bino-like neutralino mass are very degenerate. It is known that the neutralino is lighter only when $M_{1/2} \lesssim 300$ GeV, which corresponds to $M_1 \lesssim 120$ GeV [19]. The situation becomes even worse when $\tan\beta$ is large, which is indeed the case in our ansatz, because the stau be-

[2] See, for example, Ref. [16] for a recent argument.

comes light partly due to the renormalization group effect coming from the non-negligible tau Yukawa coupling and partly due to the left–right mixing of the stau mass-squared matrix. From Fig. 2 one sees that the neutralino is lighter than the stau only if $M_{1/2} \lesssim$ 130 GeV. As was discussed earlier, this region is already excluded by the Higgs mass bound which requires $M_{1/2} \gtrsim 300$ GeV.

One might think that one can exclude the no-scale boundary condition $m_0 = 0$ in our case. However, this is not necessarily true. There are several ways out proposed in the literature. Firstly, if the theory is embedded in a grand unified theory (GUT), the renormalization group effect above the GUT scale can sufficiently raise the stau mass, because the right-handed stau is in the 10-plet of SU(5) [20,21].[3] Secondly, D-term contribution to the stau can give a positive correction to the stau mass [22]. Thirdly, the gravitino can be lighter than the stau. In this case the stau decays to gravitino and thus is unstable.[4]

We also would like to briefly discuss SUSY contribution to the anomalous magnetic moment of muon $a_\mu(\mathrm{SUSY})$. Since $\tan\beta$ is large, the SUSY contribution is quite sizable. In Fig. 3 we draw constant contours of the values of $a_\mu(\mathrm{SUSY})$. In a large portion of the parameter space, it is of the order of 10^{-9}, which may be accessible in near future experiments.

Finally, we should note here how our results suffer from the uncertainty of the top quark mass. In fact, larger top Yukawa coupling makes the magnitude of B parameter larger, and also enhances the radiative correction to the lightest Higgs boson mass. Therefore, $\tan\beta$ becomes smaller and the constraint from the Higgs boson mass becomes looser when the top quark mass increases. We analyzed the case where $m_t = 179$ GeV which is 1-σ away from the central experimental value of the top quark mass. In this case, $\tan\beta$ becomes smaller than about 2–3 compared to the previous case of $m_t = 174$ GeV. And the Higgs boson mass becomes larger about 1–3 GeV. Thus we conclude that our results are rather insensitive to the change of the top quark mass.

Before closing, we should emphasize that the ansatz presented here has a characteristic feature for the superparticle masses and can be tested in future collider experiments. In this respect, it may be very interesting if one will be able to reconstruct the Higgs potential by using experimental data, which may reveal how the SUSY CP problem is solved in nature.

[3] The renormalization group flow above the GUT does not significantly change the other conclusions about the Higgs mass bound and the $b \to s\gamma$ constraint.

[4] A cosmological constraint may come from the requirement that the stau decay does not spoil the success of big-bang nucleosynthesis [23–25].

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