B-decays at Large $\tan\beta$ as a Probe of SUSY Breaking *

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We consider $B_s \to \mu^+\mu^-$ and the muon $(g-2)_\mu$ in various SUSY breaking mediation mechanisms. If the decay $B_s \to \mu^+\mu^-$ is observed at Tevatron Run II with a branching ratio larger than $\sim 2 \times 10^{-8}$, the noscale supergravity (including the gaugino mediation), the gauge mediation scenario with small number of messenger fields and low messenger scale, and a class of anomaly mediation scenarios will be excluded, even if they can accommodate a large muon $(g-2)_\mu$. On the other hand, the minimal supergravity scenario and similar mechanisms derived from string models can accommodate this observation.

The minimal supersymmetric standard model (MSSM) is one of the leading candidates for the physics beyond the standard model (SM). Its detailed phenomenology depends on soft SUSY breaking terms which contain 105 new parameters compared to the SM. There are some interesting suggestions that have been put forward over the last two decades: gravity mediation (SUGRA), gauge mediation (GMSB), anomaly mediation (AMSB), and gaugino mediation ($\tilde{g}$MSB), etc.. Each mechanism predicts specific forms of soft SUSY breaking parameters at some messenger scale. It is most important to determine the soft parameters from various different experiments, and compare the resulting soft SUSY breaking parameters with those predicted in the aforementioned SUSY breaking mediation mechanisms. This process will provide invaluable informations on the origin of SUSY breaking, which may be intrinsically rooted in very high energy regimes such as intermediate, GUT or Planck scales.

Direct productions of SUSY particles and measuring their properties are indispensable for this purpose. However, indirect searches such as FCNC and/or CP violating processes, can be complementary to the direct search.

We considered the low energy processes $(g-2)_\mu$, $B \to X_s\gamma$ and $B_s \to \mu^+\mu^-$ for theoretically well motivated SUSY breaking mediation mechanisms [1]: no scale scenario

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[2] including $\tilde{g}$MSB [3], GMSB [4] and the minimal AMSB [5] and some of variations [6–8]. It turns out there are qualitative differences among some correlations for different SUSY breaking mediation mechanisms [1, 9]. Especially the branching ratio for $B_s \to \mu^+\mu^-$ turns out sensitive to the SUSY breaking mediation mechanisms, irrespective of the muon anomalous magnetic moment $a_\mu^{\rm SUSY}$ as long as $10 \times 10^{-10} \lesssim a_\mu^{\rm SUSY} \lesssim 40 \times 10^{-10}$. If $B_s \to \mu^+\mu^-$ is observed at Tevatron Run II with a branching ratio larger than $\sim 2\times10^{-8}$, the GMSB with a small number of messenger fields with low messenger scale and a class of AMSB scenarios will be excluded. Only supergravity or GMSB with high messenger scale and large number of messenger fields and the deflected AMSB would survive.

The SUSY contributions to a_μ come from the chargino-sneutrino and the neutralino-smuon loop, the former of which is dominant in most parameter space. In particular, $\mu > 0$ implies $a_\mu^{\rm SUSY} > 0$ in our convention. The deviation between the new BNL data [10] and the most recently updated SM prediction[11] based on the $\sigma(e^+e^- \to {\rm hadrons})$ data is $(33.9 \pm 11.2) \times 10^{-10}$.On the other hand, the deviation becomes smaller if the hadronic tau decays are used. Therefore, we do not use a_μ as a constraint except for $a_\mu > 0$, and give predictions for it in this letter.

It has long been known that the $B \to X_s\gamma$ branching ratio puts a severe constraint on many new physics scenarios including weak scale SUSY models. The magnetic dipole coefficient $C_{7\gamma}$ for this decay gets contributions from SM, charged Higgs and SUSY particles in the loop. The charged Higgs contributions always add up to the SM contributions, thereby increasing the rate. On the other hand, the last (mainly by the stop - chargino loop) can interfere with the SM and the charged Higgs contributions either in a constructive or destructive manner depending on the sign of $\mu M_{\tilde{g}}$. Note that the positive $a_\mu^{\rm SUSY}$ picks up $\mu > 0$ (for $M_2 > 0$) in our convention. Fortunately, this results in destructive interference of the stop-chargino loop with the SM and the charged Higgs contribution in $B \to X_s\gamma$ decay, in all the models considered except the AMSB scenario. In the AMSB scenario, the constructive interference between the stop-chargino loop and the SM contributions to $B \to X_s\gamma$, increases the rate even more. Therefore the AMSB scenario is strongly constrained if $a_\mu^{\rm SUSY} > 0$.

Another important effect is the nonholomorphic SUSY QCD corrections to the $hb\bar{b}$ couplings in the large $\tan\beta$ limit: the Hall-Rattazzi-Sarid (HRS) effect [12]. Also, the stop - chargino loop could be quite important for large A_t and y_t couplings. One can summarize these effects as the following relation between the bottom quark mass and the bottom Yukawa coupling y_b:

$$m_b = y_b \frac{\sqrt{2} M_W \cos\beta}{g} \, (1 + \Delta_b) \tag{1}$$

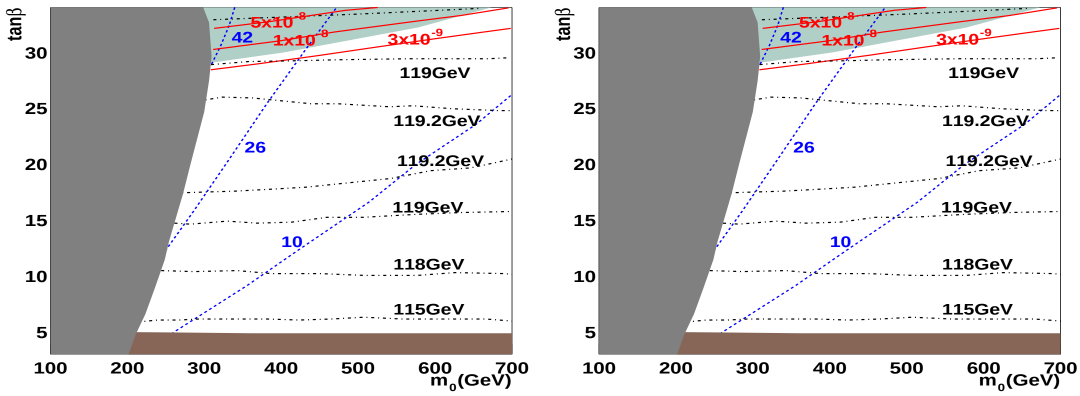
where the explicit form of Δ_b can be found in Ref. [13]. In the large $\tan\beta$ limit, the SUSY loop correction Δ_b which is proportional to $\mu M_{\tilde{g}} \tan\beta$ can be large as well with either sign, depending on the signs of the μ parameter and the gluino mass parameter $M_{\tilde{g}}$. In particular, the bottom Yukawa coupling y_b becomes too large and nonperturbative, when $\mu > 0$ in the AMSB scenario, since the sign of Δ_b would be negative. This puts additional constraint on $\tan\beta \lesssim 35$ for the positive μ in the AMSB scenario.

The decay $B_s \to \mu^+\mu^-$ has a very small branching ratio in the SM ($(3.7 \pm 1.2) \times 10^{-9}$)[14]. But it can occur with much higher branching ratio in SUSY models when $\tan\beta$ is large, because the Higgs exchange contributions can be significant for large $\tan\beta$ [15][16]. The branching ratio for $B_s \to \mu^+\mu^-$ is proportional to $\tan^6\beta$ for large $\tan\beta$. Thus this decay may be observable at the Tevatron Run II down to the level of 2×10^{-8}, and could be complementary to the direct search for SUSY particles at the Tevatron Run II in the large $\tan\beta$ region.

In the following, we consider three aforementioned SUSY breaking mediation mechanisms. Each scenario gives definite predictions for the soft terms at some messenger scale. We use renormalization group equations in order to get soft parameters at the electroweak scale, impose the radiative electroweak symmetry breaking (REWSB) condition and then obtain particle spectra and mixing angles. Then we impose the direct search limits on Higgs and SUSY particles [1]. Also we impose the $B \to X_s\gamma$ branching ratio as a constraint with a conservative bound (at 95 % C.L.) considering theoretical uncertainties related with QCD corrections: $2.0 \times 10^{-4} < B(B \to X_s\gamma) < 4.5 \times 10^{-4}$ [17].

The correlation between $a_\mu^{\rm SUSY}$ and $B_s \to \mu^+\mu^-$ were recently studied in the minimal SUGRA scenario [16][18]. The result is that the positive large $a_\mu^{\rm SUSY}$ implies that $B(B_s \to \mu^+\mu^-)$ can be enhanced by a few orders of magnitude compared to the SM prediction, and can be reached at the Tevatron Run II. The $\tilde{g}$MSB scenario, which finds a natural setting in the brane world scenarios, leads to the no-scale SUGRA type boundary condition for soft parameters, in which scalar mass and trilinear scalar terms all vanish at GUT scale, $B = m_{ij}^2 = A_{ijk} = 0$ and only gaugino masses are non-vanishing. The result is shown in Fig. 1(a). Assuming the gaugino mass unification at GUT scale, we find that overall phenomenology of $\tilde{g}$MSB scenario (and the noscale scenario) in the $a_\mu^{\rm SUSY}$ and $B_s \to \mu^+\mu^-$ is similar to the mSUGRA scenario (see Ref. [20] for details including $B \to X_s l^+ l^-$). In the allowed parameter space, the $a_\mu^{\rm SUSY}$ can easily become upto $\sim 60 \times 10^{-10}$. But the branching ratio for $B_s \to \mu^+\mu^-$ is always smaller than 2×10^{-8} and becomes unobservable at the Tevatron Run II. The reason is that the large $\tan\beta$ region, where the branching ratio for $B_s \to \mu^+\mu^-$ can be much enhanced, is significantly constrained by stau or smuon mass bounds and the lower bound of $B \to X_s\gamma$. Therefore if the $a_\mu^{\rm SUSY}$ turns out to be positive and the decay $B_s \to \mu^+\mu^-$ is observed at the Tevatron Run II, the $\tilde{g}$MSB scenario would be excluded.

The 'pure' AMSB model has the tachyonic slepton problem. For phenomenological study we take the 'minimal' AMSB model which has additional universal scalar mass m_0^2 at the GUT scale [19]. It is specified by the following four parameters :



(a) (b)

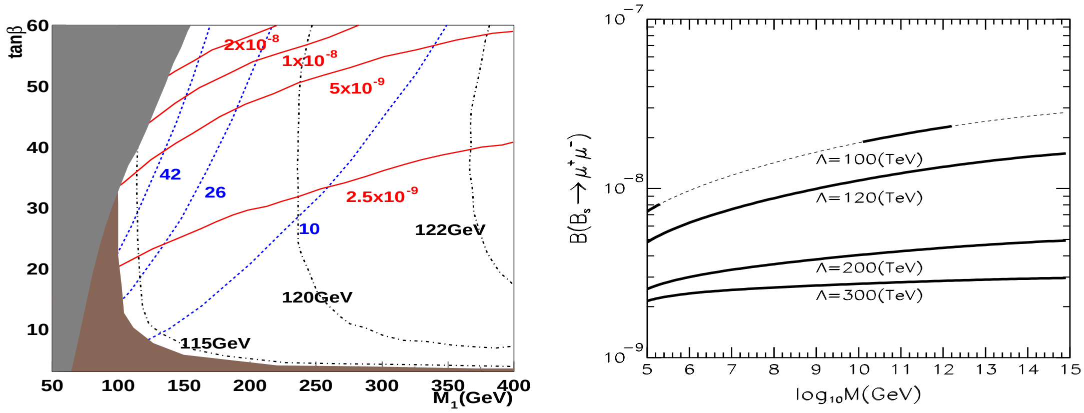
FIG. 1: The contour plots for $a_\mu^{\rm SUSY}$ in unit of 10^{-10} (in the blue short dashed curves), the lightest neutral Higgs mass (in the black dash-dotted curves) and the Br ($B_s \to \mu^+\mu^-$) (in the red solid curves) for (a) the $\tilde{g}$MSB scenario, (b) the AMSB scenario for $M_{\rm aux} = 50$ TeV. The dark regions are excluded by the bounds from direct searches.

$\tan\beta,\ {\rm sign}(\mu),\ m_0,\ M_{aux}$.

In Fig. 1(b), we show the contour plots for the $a_\mu^{\rm SUSY}$ and $B(B_s \to \mu^+\mu^-)$ in the $(m_0, \tan\beta)$ plane for $M_{\rm aux} = 50$ TeV. In the case of the AMSB scenario with $\mu > 0$, the $B \to X_s\gamma$ constraint is even stronger compared to other scenarios and almost all the parameter space with large $\tan\beta > 30$ is excluded. Therefore the branching ratio for $B_s \to \mu^+\mu^-$ is smaller than 4×10^{-9}, and this process becomes unobservable at the Tevatron Run II. If the decay $B_s \to \mu^+\mu^-$ is observed at the Tevatron Run II, the minimal AMSB scenario would be excluded.

GMSB scenarios are specified by the following set of parameters: M, N, Λ, $\tan\beta$ and sign(μ), where N is the number of messenger superfields, M is the messenger scale, and the Λ is SUSY breaking scale, $\Lambda \approx \langle F_X \rangle / \langle X \rangle$. In Fig. 2(a), we show the contour plots for the $a_\mu^{\rm SUSY}$, m_{h^0}, and $B(B_s \to \mu^+\mu^-)$ with $N = 1$ and $M = 10^6$ GeV. For low messenger scale, the charged Higgs and stops are heavy and their effects on the $B \to X_s\gamma$ and $B_s \to \mu^+\mu^-$ are small. And the A_t is small since it can generated by only RG running, so that the stop mixing angle becomes small. These effects lead to very small branching ratio for $B_s \to \mu^+\mu^-$ ($\lesssim 10^{-8}$), making this decay unobservable at the Tevatron Run II. On the other hand, the $a_\mu^{\rm SUSY}$ can be as large as 60×10^{-10}. For a given N, $B(B_s \to \mu^+\mu^-)$ increases as M due to RG effect (see Fig. 2(b)). Also for larger N, $B(B_s \to \mu^+\mu^-)$ is enhanced because the scalar masses are suppressed relative to the gaugino masses.

In conclusion, we showed that there are qualitative differences in correlations among $(g-2)_\mu$, $B \to X_s\gamma$, and $B_s \to \mu^+\mu^-$ in various models for SUSY breaking mediation mechanisms, even if all of them can accommodate the muon a_μ: $10 \times 10^{-10} \lesssim a_\mu^{\rm SUSY} \lesssim$



(a) (b)

FIG. 2: (a) The contour plots for the $a_\mu^{\rm SUSY}$, m_{h^0}, and $B(B_s \to \mu^+\mu^-)$ with $N = 1$ and $M = 10^6$ GeV. (b) The branching ratio for $B_s \to \mu^+\mu^-$ as a function of the messenger scale M in the GMSB with $N = 1$ for various Λ's with a fixed $\tan\beta = 50$. The dashed parts are excluded by the direct search limits on the Higgs and SUSY particle masses.

40×10^{-10}. Especially, if the $B_s \to \mu^+\mu^-$ decay is observed at Tevatron Run II with the branching ratio greater than 2×10^{-8}, the GMSB with low number of messenger fields N and certain class of AMSB scenarios would be excluded. On the other hand, the minimal supergravity scenario and similar mechanisms derived from string models and the deflected AMSB scenario can accommodate this observation [20] without difficulty for large $\tan\beta$. Therefore search for $B_s \to \mu^+\mu^-$ decay at the Tevatron Run II would provide us with important informations on the SUSY breaking mediation mechanisms, independent of informations from direct search for SUSY particles at high energy colliders.

Acknowledgments

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