

Chasing the light-gluino scenario through $b \rightarrow s\gamma$

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ABSTRACT

We investigate the impact of a light gluino, which might have escaped detection at colliders, on inclusive radiative B -decays mediated through penguin-like diagrams. We find that the viability of the scenario depends largely on the magnitude of the flavour-violating c -parameter. Some previously allowed regions of parameter space are now ruled out.

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There has been a continued speculation that a light gluino ($\sim 2 - 5$ GeV) has escaped detection at the colliders [1]. This assertion had also been fueled by the observation that a light, coloured, neutral fermion improves the agreement between low- and high-energy α_S measurements; the light gluino is a strong candidate to satisfy such a requirement. This possibility has been looked into by a number of experiments [2], but it is still very much open, crying out for verification. It is noteworthy the direct search limits on squark masses from the CDF collaboration at Fermilab [3] are evaded in the presence of a light gluino; the squarks need, in principle, to be heavier than only $M_Z/2$, from non-observation at the CERN e^+e^- collider, LEP. However, it has been pointed out [4] that the precision LEP measurements disfavour squarks below 60 GeV associated with such a light gluino. Of late, a particularly interesting gateway to examine various varieties of new physics, including this speculative light-gluino scenario, has been provided by the inclusive B -decay measurement, setting a limit $Br(b \rightarrow s\gamma) < 5.4 \times 10^{-4}$ [5]. It has already been pointed out [6,7] that this rare decay has a strong influence on restricting the parameter space of supersymmetry (SUSY). This motivates us to examine in this paper the present status of the light gluino through this ‘microscope’. SUSY contributions to the rare decay $b \rightarrow s\gamma$ have been examined in the literature [8] earlier. On top of these investigations, we adopt a timely specialization to the recently reheated issue of a light gluino, following the improved experimental measurement.

The branching ratio of $b \rightarrow s\gamma$ is given in units of the semileptonic b -decay branching ratio, as

$$\frac{Br(b \rightarrow s\gamma)}{Br(b \rightarrow ce\bar{\nu})} = \frac{6\alpha}{\pi\rho\lambda} \left| \frac{K_{tb}K_{ts}^*}{K_{bc}} \right|^2 \left[\eta^{16/23} A_\gamma + \frac{8}{3}(\eta^{14/23} - \eta^{16/23}) A_g + C \right]^2, \quad (1)$$

where $\eta = \alpha_S(M_Z)/\alpha_S(m_b) = 0.548$, $\rho = (1 - 8r^2 + 8r^6 - r^8 - 24r^4 \ln r)$ with $r = m_c/m_b$, $\lambda = 1 - 1.61 \alpha_S(m_b)/\pi$, and $C (= -0.1766)$ is a coefficient from a complete calculation of the leading-logarithmic QCD corrections [9]; K is the standard Cabibbo-Kobayashi-Maskawa matrix. It may be noted that the m_b^5 dependence in the partial decay widths of the b quark cancels out in eq. (1). An $\mathcal{O}(m_s^2/m_b^2)$ part in the branching ratio is neglected. We take $Br(b \rightarrow ce\bar{\nu}) = 0.107$. A_γ and A_g are the coefficients of the effective operators for bs -photon and bs -gluon interactions [10] following from

$$\mathcal{L}_{eff} = \sqrt{\frac{G_F^2}{8\pi^3}} K_{tb}K_{ts}^* \bar{s} \sigma^{\mu\nu} \left[\sqrt{\alpha} A_\gamma F_{\mu\nu} + \sqrt{\alpha_S} A_g T_a G_{\mu\nu}^a \right] (m_b P_R + m_s P_L) b. \quad (2)$$

The contributions to A_γ and A_g from W bosons, charged Higgs bosons and gauginos are listed in [7].

The core of the interaction under our investigation is contained in a particular subset of SUSY induced by the quark-squark-gluino Lagrangian. For the sake of making this note self-contained, we extract, in what follows, the essence of the formalism of

our earlier work [4, 11]. The quark-squark-gluino Lagrangian is given by

$$\mathcal{L}_{q\tilde{q}\tilde{g}} = i\sqrt{2}g_s\tilde{q}_i^{\dagger a}\tilde{g}_\alpha(\lambda_\alpha/2)_{ab}\left[\Gamma_L^{ip}\frac{1-\gamma_5}{2} + \Gamma_R^{ip}\frac{1+\gamma_5}{2}\right]q_p^b, \quad (3)$$

where, for three generations of quarks $p = 1 - 3$, $i = 1 - 6$ (for each quark flavour there are two squark states), the colour indices $a, b = 1 - 3$ and $\alpha = 1 - 8$. The (6×3) matrices Γ_L and Γ_R are determined by the quark and squark mass matrices shown below.

Flavour violation stems from the fact that the quark and squark mass matrices are not diagonal in the same basis. The (6×6) \tilde{d} mass squared matrix (in a basis in which the d -quark mass matrix is diagonal) is

$$M_{\tilde{d}}^2 = \begin{pmatrix} m_{0L}^2 I + \hat{M}_d^2 + cK\hat{M}_u^2 K^\dagger & Am_{3/2}\hat{M}_d \\ Am_{3/2}\hat{M}_d & m_{0R}^2 I + \hat{M}_d^2 \end{pmatrix}, \quad (4)$$

where m_{0L} and m_{0R} are flavour-blind supersymmetry-breaking parameters for the left- and right-type squarks, respectively. (For the sake of simplification, we have taken $m_{0L} = m_{0R} = m_0$ for numerical purposes, which does not materially affect the conclusion of the paper.) Here, \hat{M}_u and \hat{M}_d are diagonal up- and down-quark mass matrices respectively. The c -term corresponds to a quantum mass correction for a d -type left squark driven by higgsino exchange. It may be noted that c is the most crucial parameter, originating from an electroweak one-loop effect, which triggers flavour-violating interactions like $b \rightarrow s\gamma$. In specific models c can be estimated by the renormalization group (RG) equations of the quark and squark mass parameters. In our analysis c is a phenomenological input. The off-diagonal block in eq. (4) corresponds to left-right squark mixings and is proportional to the d -type quark mass matrix. Γ_L and Γ_R in eq. (3) are

$$\Gamma_L = \tilde{U} \begin{pmatrix} I \\ 0 \end{pmatrix}, \quad \Gamma_R = \tilde{U} \begin{pmatrix} 0 \\ I \end{pmatrix}; \quad (5)$$

\tilde{U} is the matrix that diagonalises $M_{\tilde{d}}^2$; $m_{3/2}$ stands for the gravitino mass, and I is the (3×3) identity matrix. It should be mentioned that although the above mass matrix is of the texture that follows from $N = 1$ supergravity, a mild extension of the minimal supersymmetric standard model (MSSM) keeps the general structure unaltered.

When the c -induced SUSY interaction is turned on, A_γ and A_g in eq. (2) pick up terms in addition to those given in [7]. Their modified expressions, denoted by A'_γ and A'_g , respectively, are given by:

$$\begin{aligned} A'_\gamma &= A_\gamma + \frac{4\alpha_S(M_Z)}{9\alpha} \sin^2 \theta_W M_W^2 S_\gamma, \\ A'_g &= A_g + \frac{\alpha_S(M_Z)}{6\alpha} \sin^2 \theta_W M_W^2 S_g. \end{aligned} \quad (6)$$

Although we compute with the complete set of parameters, we present in the following the expressions of S_γ and S_g in the simplified case when $A = 0$:

$$S_\gamma = C_{11} + C_{21} \quad (7)$$

and

$$S_g = (C_{11} + C_{21}) + 9(\tilde{C}_{11} + \tilde{C}_{21}) \quad (8)$$

where the C - and \tilde{C} -functions are the three-point integrals [12], the arguments of which are the three external and the three internal masses of the relevant penguins. Generically, the C -functions correspond to the case when a photon (or a gluon) couples to the internal squark lines in the penguin diagrams, while the \tilde{C} -functions refer to the situation when a gluon is emitted from an internal gluino line. The C - and \tilde{C} -functions in eqs. (7) and (8) represent their final forms after the super-GIM subtraction (generically, $C \equiv C(m_b^2) - C(m_d^2)$ and $\tilde{C} \equiv \tilde{C}(m_b^2) - \tilde{C}(m_d^2)$). Both C and \tilde{C} are proportional to cm_t^2 , the mass splitting between \tilde{b}_L and any of the remaining d -type squarks, controlling the rate of flavour violation. (In the actual calculation, the GIM-subtraction is done numerically.) To evaluate the three-point functions we use the code developed in [13] and employed subsequently in [4, 11]. We also cross-check our calculation by performing a systematic expansion in powers of the ratios of the masses of the light and heavy particles. The approximate expressions of S_γ and S_g used in eq. (6), which agree within 1% with those in eqs. (7) and (8), are shown below ($x = m_\gamma^2/m_0^2$, where m_γ is the mass of the gluino):

$$S_\gamma = \frac{cm_t^2}{6m_0^4} \left[(x-1)^{-4}(1-8x-17x^2) + 6(x-1)^{-5}x^2(x+3)\ln x \right] \quad (9)$$

and

$$S_g = \frac{cm_t^2}{6m_0^4} \left[(x-1)^{-4}(x^2+172x+19) + 6x(x-1)^{-5}(x^2-15x-18)\ln x \right]. \quad (10)$$

The results of our analysis are presented in fig. 1. To appreciate the effect of the light gluino in the context of the full theory of SUSY, we have included the contributions of the charged Higgs and the gauginos. For this, we have assumed the same simplified limit $\mu = 0$ and $\tan\beta = 1$ as in [7], which is in agreement with the light-gluino scenario. Results are presented for three different values of the parameter c . The broken line corresponds to choosing $c = 0$, i.e. no contribution from the gluino sector at all. The SM contribution for $m_t = 180$ GeV is also shown as the dotted line (the m_t -dependence of the branching ratio is rather mild). m_γ is set to 3 GeV in our analysis.

Since $c < 0$ is preferred in the MSSM, the lightest of the \tilde{d} -type squarks, dominantly \tilde{b}_L , has a mass $\simeq \sqrt{m_0^2 + cm_t^2}$ (for $A = 0$). Thus for a given choice of m_0 and for a fixed

m_t , the maximum magnitude of c is restricted by the LEP bound $\sqrt{m_0^2 + cm_t^2} \geq 45$ GeV. For $m_t = 180$ GeV and $m_0 = 60$ GeV, this requires $|c| \leq 0.05$. Now, choosing $c = -0.05$ and a charged Higgs mass (M_{H^+}) equal to 100 GeV, it becomes evident from fig. 1 that the squark-gluino contribution dominates over the rest for $m_0 < 100$ GeV. The figure corresponds to the situation when there is no left-right squark mixing, i.e. $A = 0$. Under these circumstances, if one uses the CLEO bound $Br(b \rightarrow s\gamma) < 5.4 \times 10^{-4}$, the light gluino is completely disfavoured, no matter what the squark mass is. It ought to be stressed that such a choice of c is in good consonance with the predictions from the RG evolution of the squark masses [14]. If one chooses $c = -0.01$, then for the same m_t and M_{H^+} , the gluino-induced effect suffers a significant reduction, ensuring the viability of a light gluino. Moreover, a larger value of M_{H^+} , say 500 GeV, reduces the H^+ contribution to a large extent, leaving ample room for a light gluino to be accommodated for $m_0 > 65$ GeV, even with a choice of $c = -0.05$ and $m_t = 180$ GeV. Other parameters remaining the same, choosing $A = 3$ decreases the effect very slightly, at most by $\sim 2\%$. If one deviates from the MSSM and assumes a positive value for c , the gluino-induced effect becomes less prominent as a result of its destructive interference with the other sectors, and no significant bound could be set at all. It may be noted that varying $m_{\tilde{g}}$ in the range (1 – 5) GeV has no numerical impact within the scale of the figure.

We conclude that the inclusive $b \rightarrow s\gamma$ measurement imposes a stringent constraint on the light-gluino scenario for a reasonable choice of the model parameters. For example, for $c = -0.05$, $m_t = 180$ GeV and $M_{H^+} = 100$ GeV, the light-gluino window is virtually closed for arbitrary choices of the squark masses. Needless to say, the sign and the magnitude of c , for which there is a significant freedom, has a crucial role to play in drawing such a conclusion. On the other hand, the consequence of a light gluino in the MSSM, in the context of unification of gauge and Yukawa couplings, has been shown [15] to pose a very tight restriction on the allowed values of $\alpha_S(M_Z)$, keeping it consistent, nevertheless, with the prediction at LEP. Additionally, if one demands the breakdown of electroweak symmetry radiatively in the MSSM (irrespective of the criterion of unification), a light gluino is difficult to be accommodated [16]. This analysis, which probes a rather direct contribution of a light gluino, concludes that the window is still open, albeit with a smaller region of allowed parameter space. Further investigation and more accurate experimental measurements are therefore called for before any final verdict can be drawn on this issue.

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Figure caption

1. The branching ratio for the process $b \rightarrow s\gamma$ as a function of the average squark mass (m_0) for different values of the flavour-violation parameter c (solid lines). Also shown are the branching ratio with no contribution from the gluino sector (broken line) and from the standard model alone (dotted line).

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