Constraints on Supersymmetric Models from $b \to s\gamma$

Farvah Mahmoudi

Laboratoire de Physique Corpusculaire de Clermont-Ferrand (LPC), Université Blaise Pascal, CNRS/IN2P3, 63177 Aubière Cedex, France

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Flavor physics constraints on supersymmetric models and in particular those from $b \to s\gamma$ transitions are discussed. These rare transitions provide valuable information in the quest for new physics and are complementary to the direct searches. The contributions of supersymmetric particles in the inclusive branching ratio in $B \to X_s\gamma$ as well as the isospin symmetry violation in $B \to K^*\gamma$ decay mode are investigated. The model parameters are adopted from the minimal supersymmetric extension of the Standard Model (MSSM) with minimal flavor violation.

1 Introduction

Rare B decays are very sensitive to new physics effects and can play an important role in disentangling different scenarios. The transition which is most often discussed in this context is the flavor changing neutral current process $b \to s\gamma$. Since this transition occurs first at one-loop level in the SM, the new physics contributions can be of comparable magnitude.

The penguin loops here involve W boson in the Standard Model, and in addition loops from charged Higgs boson, chargino, neutralino and gluino for the MSSM as presented in Figs. 1 and 2. The contribution of neutralino and gluino loops is negligible in minimal flavor violating scenarios. Charged Higgs loop always adds constructively to the SM penguin. Thus, this observable is an effective tool to probe the 2HDM scenario. Chargino loops however can add constructively or destructively. If the interference is positive, it results in a great enhancement in the BR($b \to s\gamma$), which becomes therefore a powerful observable.

In the following, we present an overview of two observables in $b \to s\gamma$ transitions, namely the inclusive branching ratio of $B \to X_s\gamma$ and isospin asymmetry in the exclusive decay of $B \to K^*\gamma$.

The calculation of $b \to s\gamma$ observables begins with introducing an effective Hamiltonian

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{8} C_i(\mu) O_i(\mu) \tag{1}$$

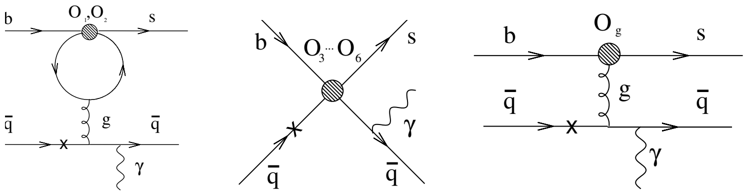

Figure 1: Example of diagrams contributing to $B \to X_s\gamma$.

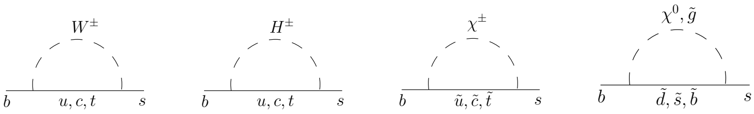

Figure 2: Loops involved in $b \to s\gamma$ transitions.

where G_F is the Fermi coupling constant, V_{ij} are elements of the CKM matrix, $O_i(\mu)$ are the relevant operators and $C_i(\mu)$ are the corresponding Wilson coefficients evaluated at the scale μ. The operators O_i can be listed as follows

$$\begin{aligned}
O_1 &= (\bar{s}\gamma_\mu T^a P_L c)(\bar{c}\gamma^\mu T^a P_L b) \;, \\
O_2 &= (\bar{s}\gamma_\mu P_L c)(\bar{c}\gamma^\mu P_L b) \;, \\
O_3 &= (\bar{s}\gamma_\mu P_L b)\sum_q (\bar{q}\gamma^\mu q) \;, \\
O_4 &= (\bar{s}\gamma_\mu T^a P_L b)\sum_q (\bar{q}\gamma^\mu T^a q) \;, \\
O_5 &= (\bar{s}\gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} P_L b)\sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} q) \;, \\
O_6 &= (\bar{s}\gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} T^a P_L b)\sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} T^a q) \;, \\
O_7 &= \frac{e}{16\pi^2}\,[\bar{s}\sigma^{\mu\nu}(m_s P_L + m_b P_R)b]\,F_{\mu\nu} \;, \\
O_8 &= \frac{g}{16\pi^2}\,[\bar{s}\sigma^{\mu\nu}(m_s P_L + m_b P_R)T^a b]\,G^a_{\mu\nu} \;,
\end{aligned} \tag{2}$$

The presence of SUSY particles does not introduce new operators in the list, however, the Wilson coefficients C_i receive additional contributions from virtual sparticles.

2 Inclusive Branching ratio

The branching ratio of $B \to X_s\gamma$ can be written as [1]

$$\mathcal{B}[\bar{B} \to X_s\gamma]_{E_\gamma > E_0} = \mathcal{B}[\bar{B} \to X_c e\bar{\nu}]_{\exp} \left|\frac{V_{ts}^* V_{tb}}{V_{cb}}\right|^2 \frac{6\alpha_{\rm em}}{\pi C}\,[P(E_0) + N(E_0)] \tag{3}$$

with

$$C = \left|\frac{V_{ub}}{V_{cb}}\right|^2 \frac{\Gamma[\bar{B} \to X_c e\bar{\nu}]}{\Gamma[\bar{B} \to X_u e\bar{\nu}]} \;. \tag{4}$$

$P(E_0)$ and $N(E_0)$ denote respectively the perturbative and non perturbative contributions, where E_0 is a cut on the photon energy. The numerical values of C, $\mathrm{BR}(\bar{B} \to X_c e\bar{\nu})_{\rm exp}$ and E_0 can be found in [1].

Following [1], we can expand $P(E_0)$ as

$$P(E_0) = P^{(0)}(\mu_b) + \alpha_s(\mu_b)\left[P_1^{(1)}(\mu_b) + P_2^{(1)}(E_0,\mu_b)\right] \quad (5)$$

$$+ \alpha_s^2(\mu_b)\left[P_1^{(2)}(\mu_b) + P_2^{(2)}(E_0,\mu_b) + P_3^{(2)}(E_0,\mu_b)\right] + \mathcal{O}\left(\alpha_s^3(\mu_b)\right) \quad (6)$$

where P_i's are related to the Wilson coefficients. The latest combined experimental value for this branching ratio is reported by the Heavy Flavor Averaging Group (HFAG) [2]:

$$\mathcal{B}[\bar{B} \to X_s\gamma] = (3.52 \pm 0.25) \times 10^{-4} \;, \quad (7)$$

to be compared to the SM predicted value [9]:

$$\mathcal{B}[\bar{B} \to X_s\gamma] = (3.11 \pm 0.22) \times 10^{-4} \;. \quad (8)$$

The accuracy of the experimental and theoretical values, as well as the slight shift between the central values, make this observable particularly interesting to constrain new physics parameters, and especially in the MSSM where the new contributions can lead to very different predictions.

3 Isospin asymmetry

The isospin asymmetry in $B \to K^*\gamma$ decays is defined as:

$$\Delta_{0-} = \frac{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) + \Gamma(B^- \to K^{*-}\gamma)} \quad . \quad (9)$$

and similarly Δ_{0+} is defined as the charge conjugate of this equation. The isospin asymmetry has been measured experimentally by Babar [3] and Belle [4]:

$$\Delta_{0-} = +0.029 \pm 0.019(\mathrm{stat.}) \pm 0.016(\mathrm{syst.}) \pm 0.018(R^{+/0}) \quad (\mathrm{Babar}) \;, \quad (10)$$

$$\Delta_{0+} = +0.012 \pm 0.044(\mathrm{stat.}) \pm 0.026(\mathrm{syst.}) \quad (\mathrm{Belle}) \;. \quad (11)$$

Calculating the isospin asymmetry, while considering the supersymmetric contributions, and comparing the results with the above experimental data allows us to establish very tight constraints on the SUSY parameters [5, 6].

Using the QCD factorization and following the method of [7], one can show that the isospin symmetry breaking, Δ_{0-}, can be written as:

$$\Delta_{0-} = \mathrm{Re}(b_d - b_u) \;\;, \quad (12)$$

where the coefficients b_q reads:

$$b_q = \frac{12\pi^2 f_B\, Q_q}{\bar{m}_b\, T_1^{B\to K^*} a_7^c}\left(\frac{f_{K^*}^\perp}{\bar{m}_b}\, K_1 + \frac{f_{K^*} m_{K^*}}{6\lambda_B m_B}\, K_{2q}\right) \quad . \quad (13)$$

In this formula, the coefficients a_7^c, K_1 and K_{2q} can be written in function of the Wilson coefficients C_i at scale μ_b. The other parameters are described in [5].

Calculating the expected isospin asymmetry from Eqs. (1.2) and (1.3), and confronting the results to the combined experimental limits of (1.4) and (1.5) allow us to establish limits on the supersymmetry parameters.

4 Constraints

We explore the constraints from isospin asymmetry and branching ratio, while scanning over parts of the parameter spaces of different supersymmetric models such as the minimal supergravity (mSUGRA) model and the non universal Higgs mass (NUHM) framework, as well as the Anomaly Mediated Supersymmetry Breaking (AMSB) and the Gauge Mediated Supersymmetry Breaking (GMSB) models.
The results presented here, for both the inclusive branching ratio and the isospin asymmetry have been calculated using SuperIso v2.5 [8, 9]. The SUSY mass spectrum, as well as the couplings and the mixing matrices, are generated using SOFTSUSY 2.0.18 [10]. The constraints are presented in Fig. 3, where severe restrictions on the allowed parameter space regions for the aforementioned models are obtained.

In Fig. 4 we present a comparison between the constraints obtained by different flavor observables (both tree-level and one-loop induced) for fixed values of $m_0 = m_{1/2} = \mu = 500$ GeV and $A_0 = 0$. We show the results in the plane $[\tan\beta, m_A]$, for $m_A > 200$ GeV. The regions excluded by $b \to s\gamma$ observables are displayed in red for the isospin asymmetry and in blue for the branching ratio [5, 6]. The region excluded by $\mathrm{BR}(\mathrm{D_s^\pm} \to \tau^\pm\nu)$ is depicted in yellow. The green area represents the region excluded by $\mathrm{BR}(\mathrm{B}^\pm \to \tau^\pm\nu)$, the violet region by $\mathrm{BR}(\mathrm{B_s^0} \to \mu^+\mu^-)$, the light blue region by $K^\pm \to \mu^\pm\nu$, and the orange area by $\mathrm{BR}(\mathrm{B} \to \mathrm{D}\tau\nu)$ [11]. To obtain the constraints presented in this figure the input values of [9] are used. It is important to remember that the constraints can be subject to uncertainties, in particular from decay constants and CKM matrix elements. To obtain the constraint from $\mathrm{BR}(\mathrm{D_s^\pm} \to \tau^\pm\nu)$ the central value $m_s/m_c = 0.08$ is used [12]. Finally, the black region in the figure represents the region excluded by the direct searches at colliders [13].

5 Conclusions

We have shown that the flavor changing neutral current process $b \to s\gamma$ provides valuable observables for constraining the MSSM parameter space. Many other flavor physics observables can also be of great interest for the search of new physics, and they will prove to be powerful tools when combined with the future LHC data. The SuperIso package provides the possibility to explore the supersymmetry parameter space using many flavor observables and for different scenarios.

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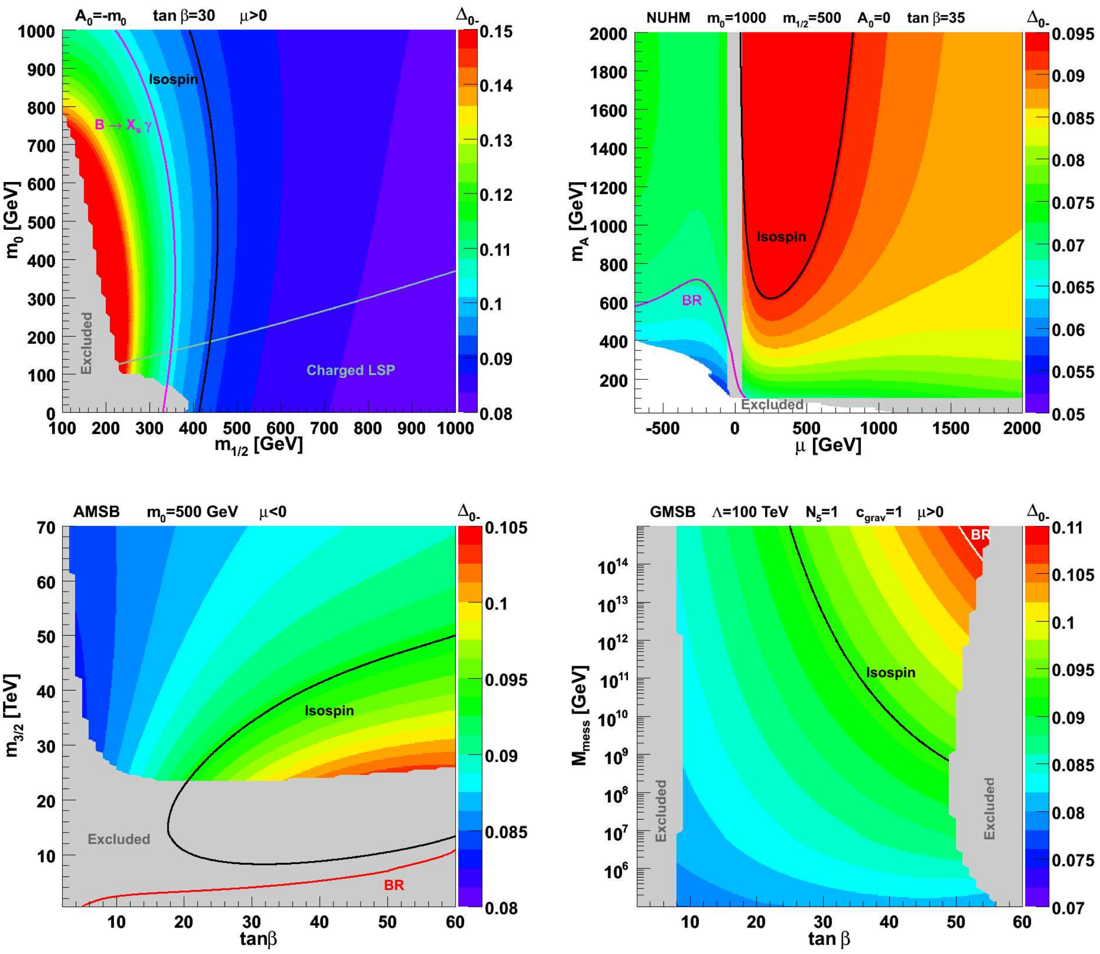

Figure 3: Constraints on the SUSY parameter space from $b \to s\gamma$ branching ratio and isospin asymmetry. The colors correspond to the intensity of isospin asymmetry. The upper left plot shows the constraints in mSUGRA parameter plane $(m_{1/2}, m_0)$ with $\mu > 0$ for $\tan\beta = 30$ and for $A_0 = 0$; the upper right plot shows the constraints in NUHM parameter plane (μ, m_A) for $m_0 = 1000$ GeV, $m_{1/2} = 500$ GeV, $\tan\beta = 35$ and $A_0 = 0$; the lower left plot illustrate the constraints in AMSB parameter plane $(m_{3/2}, \tan\beta)$ for $m_0 = 500$ GeV and $\mu < 0$; and the lower right shows the constraints in GMSB parameter plane $(M_{mess}, \tan\beta)$ for $\Lambda = 100$ TeV, $N_5 = 1$, $c_{grav} = 1$ and $\mu > 0$.

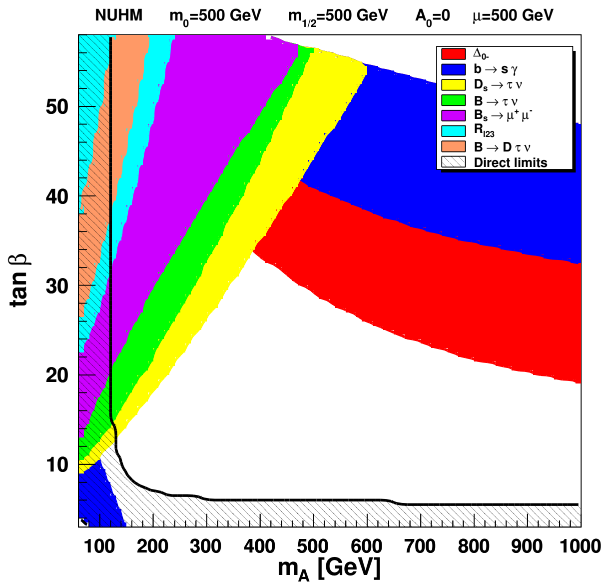

Figure 4: Constraints in NUHM $(m_A, \tan\beta)$ parameter plane. The contours are superimposed in the order given in the legend and are excluded at 95% C.L.

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