Search for supersymmetry in rare B meson decays

T. M. Aliev and M. I. Dobrolyubov
Institute for Nuclear Research, Academy of Sciences of the USSR

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Manifestations of supersymmetry are sought in rare B meson decays $B_d \to K^0\phi$, $K^+\pi^-$. It is shown that there is a region of mass of supersymmetry particles where the contribution of supersymmetry particles exceeds the standard contribution. Limits are derived for the mass of supersymmetry particles.

Elementary particle physicists have awaited with impatience new results from the collaborations CLEO and ARGUS regarding the properties of B mesons and also the startup of future B meson factories. This impatience stems from the fact that thorough and multifaceted investigations of the properties of B mesons will allow a more refined understanding of many aspects of the Standard Model that are presently poorly studied. As examples, one might cite a reliable measurements of the Kobayashi-Maskawa angles V_{bu} and V_{bc}, investigation of CP violation, verification of the predictions of quantum chromodynamics, etc. At the same time, the decay of B mesons is an extremely appropriate area for looking for new physics that lies outside the framework of the standard model, in particular, supersymmetry (SUSY).

In spite of the large amount of work that has been devoted to SUSY, we still do not know if it has any relation to reality. All existing experimental data say nothing either for or against SUSY. Therefore, a clarification of the experimental status of SUSY is now at the focus of attention of experimentalists and theorists.

Two different strategies are ordinarily used. The first involves attempts to observe SUSY particles directly in colliders with high-energy beams of colliding particles. In this way lower limits were obtained for the masses of the superpartners, with the most reliable results coming from an analysis of data on e^+e^- annihilation, in particular,

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for the mass of the scalar quarks, $m_{\tilde{q}} \gtrsim 21.5$ GeV (Ref. 1). Tighter limits were obtained from pp collisions, but these limits are more model-dependent. For example, assuming $m_{\tilde{\gamma}}$ 20 GeV and $m_{\tilde{g}} > m_{\tilde{q}}$ one can find that $m_{\tilde{g}} > 53$ GeV and $m_{\tilde{q}} > 45$ GeV (Ref. 2).

The second strategy is based on a search for indirect evidence of SUSY, such as the contribution of supersymmetry particles to the anomalous magnetic moment of the electron and the muon, in $K^0 - \overline{K}^0$ and $B^0 - \overline{B}^0$ mixing, and so forth. A principal role is played by rare B meson decays, in which unusual instances may occur where the contribution of the SUSY particles to the amplitude of the processes exceeds that of the ordinary particles. As we show below, this circumstance makes it possible to look for SUSY particles with masses up to 100 GeV.

The issue revolves around the fact that the decay occurs via neutral currents, with change of flavor. In the SUSY models, a gluon may have an interaction that is nondiagonal in quark flavor, and consequently can give a contribution to these processes.[3] Therefore, in the expressions for the amplitudes of these processes the strong interaction coupling constant will enter, in addition to the weak interaction constant. Moreover, gluons and scalar quarks may easily be lighter than the W boson. All these factors enhance the contribution of SUSY relative to the standard contribution. In many cases of super GIM, however, the suppression turns out to be stronger than in ordinary GIM. In order to know, therefore, whether the SUSY contribution is competitive with the standard contribution, it is necessary to carry out a detailed calculation of the amplitudes. In Refs. 5 and 6 similar ideas were used to study SUSY effects in $K^0 - \overline{K}^0$ mixing and in $B \to K_\gamma{}^*$ decays. We should note that B meson decay is far less sensitive to the effects of large distances than is the decay of K mesons, and therefore calculations for the former are more reliable.

In this paper, within the framework of spontaneously broken minimal $N=1$ supergravity[3] we investigate the effects of SUSY particles in the rare decays $B_d \to K^0\phi$ and $B_d \to K^+\pi^-$, in which the penguin graphs dominate.[4] Our results can be used in the analysis of other analogous rare decays of B mesons: $B_d \to K^{*0}\phi, K_S^0\eta$, $B'_S \to \phi\phi, \phi\eta$, and $B_u \to K^-\phi, K^{*-}\eta$.

We restrict the discussion to just the left-hand external quarks, since it is these that give the main contribution in transitions with change of quark flavor.[7] The contribution of SUSY particles to the effective Lagrangian of these transitions is[1)]

$$\mathcal{L}_{eff}^{SUSY} = -\frac{\alpha_s^2}{3}\tilde{V}_{ts}^*\tilde{V}_{tb}\bar{s}_L\gamma_\mu\frac{\lambda^a}{2}b_L\sum_{q=u,d...}\bar{q}\gamma_\mu\frac{\lambda^a}{2}q\frac{1}{m_{\tilde{g}}^2}[f(x_b)-f(x_s)], \tag{1}$$

where $\tilde{V}_{tb,s}$ are the matrix elements of super Kobayashi-Maskawa, and

$$f(x) = \{-146x^3 + 414x^2 - 342x + 74 + (6 - 162x^2 + 108x^3)\ln x\}/36(x-1)^4,$$

where $x_i = \tilde{m}_i^2/m_{\tilde{g}}^2$, and $m_{\tilde{g}}$ is the mass of the gluon. In this model the mass of the scalar quarks is[2] $\tilde{m}_b^2 = m_{3/2}^2 + m_b^2 + cm_t^2, \tilde{m}_s^2 = m_{3/2}^2$, where $m_{3/2}$ is the mass of the gravitino. The value of the coefficient c is most models is from 0.1 to 1 (Ref. 6). In the following discussion, following Ref. 5, we shall assume that $\tilde{V}_{tq} \approx V_{tq}$ and $c = 0.5$. As pointed out in Ref. 6, we can expect that QCD corrections will have little effect on the final result.

The contribution of SUSY particles (1) should be compared with the standard contribution:[9]

$$\mathcal{L}_{eff}^{SM} = \frac{\alpha_s}{12\pi} G_F V_{ts}^* V_{tb} \bar{s}_L \gamma_\mu \frac{\lambda^a}{2} b_L \sum_{q=u,d\ldots} \bar{q} \gamma_\mu \frac{\lambda^a}{2} q \ln(m_t^2/m_c^2). \qquad (2)$$

Using (1) and (2) and the results of Ref. 8, we obtain the following expressions for the width of the decays with allowance for the contribution of the SUSY particles:

$$\Gamma(B_d \to K_s^0 \phi) = \frac{8}{9\pi} G_F^2 | V_{ts}^* V_{tb} |^2 \omega^2 (M_\phi^2 / f_\phi^2) p_\phi^3,$$

$$\Gamma(B_d \to K^+ \pi^-) = \frac{4}{9\pi} G_F^2 | V_{ts}^* V_{tb} |^2 c^2 M_B^2 f_K^2 p_K,$$

where

$$\omega = -\frac{\alpha_s}{12\pi} \ln(m_t^2/m_c^2) + \frac{\alpha_s^2}{24} \frac{\sqrt{2}}{m_{\tilde{g}}^2 G_F} [f(x_b) - f(x_s)], \qquad (3)$$

and $f_\phi^2 = 60\pi$, $f_K = 155.6$, and $p_{\phi,K}$ are the momenta of the corresponding particles.

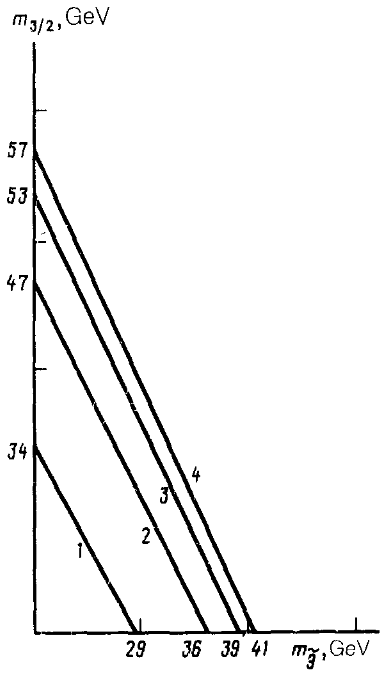

FIG. 1. Region of mass of SUSY particles where the SUSY contribution to the b-s transition exceeds the standard contribution (below the lines). The lines correspond to various masses of the t-quark: 1) $m_t = 50$ GeV; 2) $m_t = 100$ GeV; 3) $m_t = 150$ GeV; 4) $m_t = 200$ GeV.

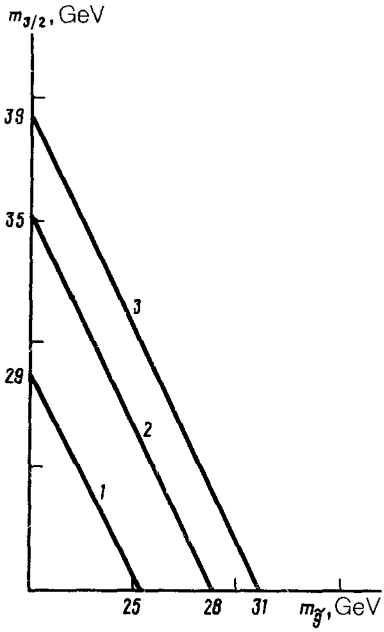

FIG. 2. Region of mass of the SUSY particles that does not contradict data on the $B_d \to K^0\phi$ decay. The lines correspond to various masses of the t-quark: 1) $m_t = 100$ GeV; 2) $m_t = 150$ GeV; 3) $m_t = 200$ GeV.

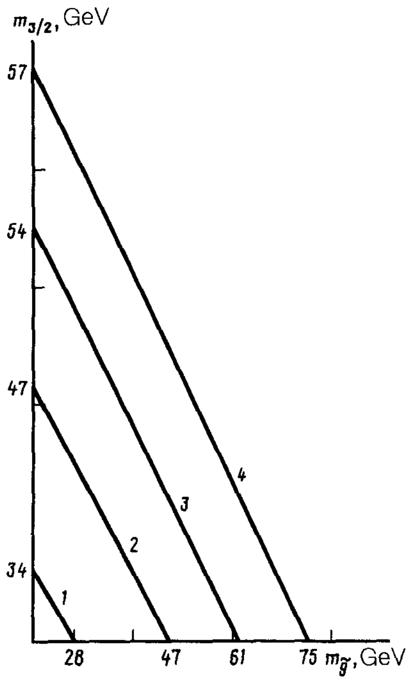

FIG. 3. Region of mass of SUSY particles that does not contradict decay data. The lines correspond to various masses of the t-quark: 1) $m_t = 50$ GeV; 2) $m_t = 100$ GeV; 3) $m_t = 150$ GeV; 4) $m_t = 200$ GeV.

It should be emphasized that since $f(x_s) > f(x_b)$ (since $\tilde{m}_s < \tilde{m}_b$), the standard contribution and the supersymmetry contribution in (3) have the same sign. Their numerical values, on the other hand, depend on the masses of the t-quark, of the gluinos and of the scalar quarks. Calculations show that there exists a region of these masses where the SUSY contribution to the amplitude of the $b-s$ transition exceeds the standard contribution (Fig. 1).

By using the experimentally determined limits on these processes:

$$BR(B_d \to K^0\phi) < 4.5 \cdot 10^{-4}, \quad 90\%\ CL$$ [10]

and

$$BR(B_d \to K^+\pi^-) < 0.9 \cdot 10^{-4}, \quad 90\%\ CL$$ [11],

one can obtain limits on the masses of the SUSY particles (assuming that m_t is fixed).

The region of nonallowed values for the masses of the SUSY particles is shown in Figs. 2 and 3, where we set $|V_{ts}^* V_{tb}|^2 = 0.002$ in the calculations. It can be seen that tighter limits are obtained from the analysis of the $B_d \to K^+\pi^-$ decay. For example, setting $m_t = 100$ GeV, the following limits are set on the masses of the SUSY particles: $m_{\tilde{g}} > 47$ GeV and $m_{\tilde{g}} > 73$ GeV. These limits compare quite favorably with those determined in colliders.

We can thus anticipate that considerable progress in the search for supersymmetry particles will be made when the B meson factories start to operate and the partial widths of the various decay channels of the B mesons will be determined with extremely high accuracy.

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