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Flavour violation in gauge-mediated supersymmetry breaking models: Experimental constraints and phenomenology at the LHC

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Abstract

We present an extensive analysis of gauge-mediated supersymmetry breaking models with minimal and non-minimal flavour violation. We first demonstrate that low-energy, precision electroweak, and cosmological constraints exclude large "collider-friendly" regions of the minimal parameter space. We then discuss various possibilities how flavour violation, although naturally suppressed, may still occur in gauge-mediation models. The introduction of non-minimal flavour violation at the electroweak scale is shown to relax the stringent experimental constraints, so that benchmark points, that are also cosmologically viable, can be defined and their phenomenology, i.e. squark and gaugino production cross sections with flavour violation, at the LHC can be studied.

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1. Introduction

Weak scale supersymmetry (SUSY) remains a both theoretically and phenomenologically attractive extension of the Standard Model (SM) of particle physics [1,2]. Apart from linking bosons with fermions and unifying internal and external (space–time) symmetries, SUSY allows

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for a stabilization of the gap between the Planck and the electroweak scale and for gauge coupling unification at high energies. It appears naturally in string theories, includes gravity, and contains a stable lightest SUSY particle (LSP) as a dark matter candidate. Spin partners of the SM particles have not yet been observed, and in order to remain a viable solution to the hierarchy problem, SUSY must be broken at low energy via soft mass terms in the Lagrangian. As a consequence, the SUSY particles must be massive in comparison to their SM counterparts, and the Tevatron and the LHC will perform a conclusive search covering a wide range of masses up to the TeV scale. After the discovery of SUSY particles, the revelation of the underlying SUSY-breaking mechanism will be one of the key challenges in the experimental high-energy physics program.

In gauge-mediated supersymmetry-breaking (GMSB) models, SUSY is broken in a secluded sector at a scale $\langle F\rangle$ related to the gravitino mass by $m_{\tilde{G}} = \langle F\rangle/(\sqrt{3}M_{\rm P})$, where $M_{\rm P}$ is the reduced Planck mass. The breaking is mediated to the visible sector of squarks, sleptons, gauginos and gluinos through a gauge-singlet chiral superfield S and n_q quark-like and n_l lepton-like messenger fields [3–6]. The superfield S is characterized by its scalar and auxiliary components, which overlap with the gravitino and acquire vacuum expectation values $\langle S\rangle$ and $\langle F_S\rangle$, respectively. Yukawa couplings of the messengers to the superfield S then induce masses of order $M_{\rm mes} \simeq \langle S\rangle$ for the messengers. Gauginos and sfermions acquire masses through ordinary gauge interactions with messengers through one- and two-loop self-energy diagrams, respectively. In these scenarios, the lightest SUSY particle is always the gravitino, which is thus a natural candidate for the dark matter in our Universe. Besides $M_{\rm mes}$, n_q, and n_l, minimal GMSB scenarios are determined by the ratio of the two Higgs vacuum expectation values, $\tan\beta$, the sign of the off-diagonal Higgs mass-parameter μ, and by the auxiliary vacuum expectation value $\langle F_S\rangle$. The latter is related to the mass splitting of the messenger fields and is considerably smaller than both the squared mass scale of the messenger fields, $\langle S\rangle^2$, and the fundamental SUSY-breaking scale, $\langle F\rangle$. It is usually re-expressed in terms of an effective SUSY-breaking scale, $\Lambda = \langle F_S\rangle/\langle S\rangle$. An additional free parameter is the gravitino mass, $m_{\tilde{G}}$, which is, however, constrained by the fact that the gravitino relic density $\Omega_{\tilde{G}}h^2$ has to agree with the current WMAP limits and that the abundances of the light elements should be correctly described, i.e. the next-to-lightest SUSY particle (NLSP) must not decay too quickly.

GMSB is an attractive scenario regarding the so-called SUSY flavour problem. SUSY is usually broken within a few orders of magnitude of the weak scale, whereas the unrelated flavour-breaking scale can be chosen much higher. This avoids important flavour-violating terms in the SUSY-breaking Lagrangian and leads to approximately flavour-conserving mass matrices at the low-energy scale and good agreement with measurements of flavour-changing neutral current observables. However, several possibilities reintroducing flavour-violating terms in the Minimal Supersymmetric Standard Model (MSSM) with GMSB have been pointed out [6–8]. For example, mixing between messenger and matter fields may lead to important flavour violations in the squark and slepton sectors.

In SUSY models with non-minimal flavour violation (NMFV), the flavour-violating off-diagonal terms Δ_{ij} of the squared sfermion mass matrices, where $i, j = {\rm L, R}$ refer to the helicities of the (SM partners of the) sfermions, are conveniently considered as arbitrary parameters. Stringent experimental constraints are then imposed by precise measurements of K^0–$\bar{K}^0$ and B^0–$\bar{B}^0$ mixing, the first evidence of D^0–$\bar{D}^0$ mixing, and rare decays [9–11]. The minimal GMSB model obviously relies on constrained minimal flavour violation (cMFV), where all the flavour-violating elements Δ_{ij} are neglected. Recently, possible effects of non-minimal flavour violation on the experimentally allowed minimal supergravity (mSUGRA) parameter space have been investigated, and all squark and gaugino production cross sections and decay widths have been recalculated