Collider signatures related to quark flavour violation in the MSSM

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In the Standard Model (SM), the only source of flavour violation are the Yukawa interactions and the resulting rotation from the gauge to the mass eigenstates of the fermions. In consequence, all quark-flavour violating (QFV) interactions can be parametrized in terms of the CKM-matrix. Among the numerous extensions of the SM, Supersymmetry (SUSY) and in particular the Minimal Supersymmetric Standard Model (MSSM) is among the most popular and best-studied ones. Postulating a superpartner with opposite statistics for each of the SM particles, it cures the hierarchy problem by stabilizing the Higgs mass, leads to gauge coupling unification, and includes interesting candidates for the cold dark matter observed in our Universe. Although it is clear that SUSY must be broken at the electroweak scale, there is no theoretical consensus about the exact breaking mechanism. One therefore introduces so-called soft-breaking terms in the SUSY Lagrangian.

One of the open questions related to the breaking mechanism concerns the flavour structure of the theory. The hypothesis of minimal flavour violation (MFV) assumes that flavour violation is the same as in the SM. Then, all QFV interactions (e.g. the squark-quark-chargino vertex) are again parameterized through the CKM-matrix. However, new sources of flavour violation can appear in SUSY models, especially if they are embedded in larger frameworks such as grand unified theories. This non-minimal flavour violation (NMFV) allows then for non-diagonal – i.e. flavour-violating – entries in the mass matrices of the sfermions that are not related to the CKM-matrix any more. These entries are conveniently considered as additional free parameters at the electroweak scale and can imply a different phenomenology as compared to the case of MFV. For a review on flavour violation in the MSSM see, e.g., Ref. [1]. Details on the parametrization of NMFV in the MSSM can also be found in Refs. [2, 3, 4, 5].

The studies discussed in the following focus on NMFV in the sector of squarks. Analogous arguments hold for sleptons, where the CKM-matrix is replaced by the PMNS-matrix. Moreover, the present analyses are based on flavour-mixing between the second and third generation and within the right-right sector of the squark mass matrices, which are least constrained by experimental measurements. The benchmark scenario SPS1a' [6], which serves as input for many experimental studies, is taken as reference point within the framework of minimal supergravity. The observed features are, however, present in wide ranges of the MSSM parameter space and also for variations of other QFV entries in the mass matrices.

Experimental limits from a large variety of rare decays, meson oscillations, or other precision measurements put strong constraints on the QFV elements of the squark mass matrices. Most

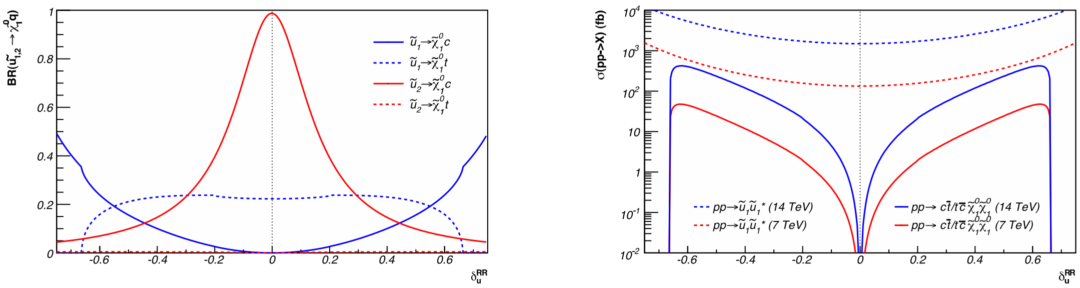

Figure 1: Branching ratios (left) of the two lightest up-type squarks and production cross-sections (right) of the discussed NMFV-signature for squark generation mixing between the second and third generations.

important in the context of QFV are the decays $b \to s\gamma$ and $b \to s\mu\mu$ as well as the observable ΔM_{B_s} related to B-meson oscillations. In the present study, all relevant constraints have explicitly been taken into account at the 95% confidence level and combined with the theoretical error estimate where available. Detailed discussions of the resulting allowed regions are given in Refs. [2, 3, 4, 5, 7, 8].

The physical mass spectrum of the squarks strongly depends on the introduced flavour-violating elements of the mass matrices [2, 4, 5, 7, 8]. In particular, the mass splitting between the involved mass eigenstates is increased with increasing flavour mixing. At the same time, the flavour content of the different squarks is modified. For example, the lightest up-type squark is a pure stop-mixture in the case of MFV, but receives sizeable charm-admixtures for larger values of the corresponding non-diagonal entries in the mass matrix. Vice versa, the charm content of the second-lightest squark is then exchanged for a stop-admixture.

The modified mass spectrum and flavour contents alter the decay modes of the squarks. In particular, new channels can be opened when introducing NMFV-elements in the mass matrices [4, 5]. The left panel of Fig. 1 shows the example of the fermionic decays of the two lightest up-type squarks into neutralinos. Here and in the following, the variables δ_u^{RR} and δ_d^{RR} parametrize the mixing (in the right-right sector) between the second and third generation up- and down-type squarks, respectively. The non-diagonal elements of the squark mass matrix are normalized to the diagonal ones according to Refs. [4, 5]. For a wide range of the NMFV-parameter, at least three of the branching ratios are simultaneously large, which may lead to important QFV effects in collider experiments [4].

In particular, they can give rise to sizeable event rates for the signal

$$pp \to \tilde{u}_{1,2}\tilde{u}^*_{1,2} \to c\bar{t}\ (t\bar{c})\ \tilde{\chi}_1^0\tilde{\chi}_1^0,$$

where the neutralinos give rise to missing transverse energy ($E_T^{\rm miss}$). While this process is practically not realized in the MSSM with MFV or in the Standard Model, allowing for NMFV can lead to rather sizeable cross-sections already for a moderate amount of additional flavour-mixing, as can be seen in the right panel of Fig. 1. The expected number of signal events at the LHC would be up to about 20.000 (10) for an integrated luminosity of 100 fb^{-1} (1 fb^{-1}) at $\sqrt{s} = 14$ TeV (7 TeV) [4].

Concerning the detectibility, top-quark identification is necessary to distinguish the proposed signal from top-antitop production including missing energy. The most crucial point for flavour-

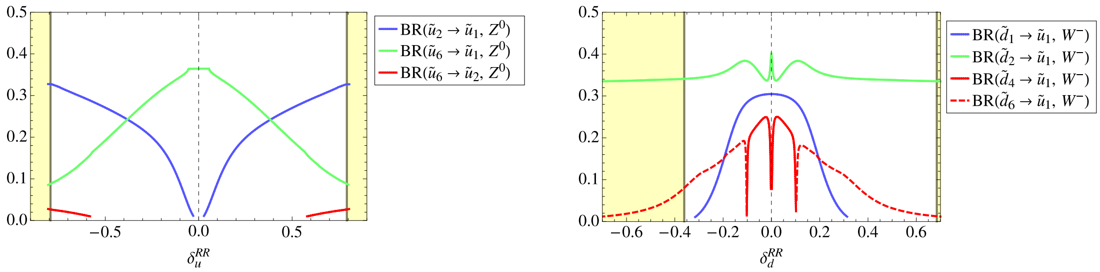

Figure 2: Typical NMFV-signatures related to squarks decaying into Z- or W-bosons for generation mixing between the second and third generations.

mixing between the second and third generation would be efficient charm-tagging. Otherwise, one should rather search for the signature $jet + (anti)top + E_T^{\rm miss}$ [4].

Another type of NMFV-signature at colliders is connected to the bosonic decay modes of the squarks [5]. As for the fermionic case discussed above, new channels can be opened when allowing for new flavour-mixing entries in the mass matrices. Fig. 2 shows the example for decays of selected squarks into Z- or W-bosons and an up-type squark. Assuming MFV, only one squark can decay into the final state $\tilde{u}_1 Z^0$ in the given example. For increasing non-minimal flavour-mixing, as discussed above, a second mass eigenstate obtains a sizeable stop-content. At the same time, the mass of the lightest squark $\tilde{u}_1$ is decreasing so that the new decay channel $\tilde{u}_6 \to \tilde{u}_1 Z^0$ is opened [5].

Similar arguments hold for the decay of squarks into W-bosons. Here, two modes are present for MFV, while additional channels become possible already for moderate flavour-violating entries. If it will be possible to observe squarks at the LHC and to reconstruct their decays modes, the observation of such a signature would exclude the hypothesis of MFV [5].

In summary, despite the strong constraints from experimental data, NMFV can lead to new signatures in collider experiments that can challenge the hypothesis of MFV. Here, this has been shown for the benchmark scenario SPS1a'. The given conclusions hold, however, for wide ranges of the MSSM parameter space [4, 5]. The presented results are a clear call for detailed Monte-Carlo studies including background reactions and detector simulation. Such studies will in particular be necessary to identify the regions of parameter space where the proposed signatures are observable.

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