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Correlations between high-p_T and flavour physics

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Squark and gluino decays are governed by the same mixing matrices as the contributions to flavour violating loop transitions of B-mesons. This allows for possible direct correlations between flavour non-diagonal observables in B and high-p_T physics. The present bounds on squark mixing, induced by the low-energy data on $b \to s$ transitions, still allow for large contributions to flavour violating squark decays at tree level. Due to the restrictions in flavour tagging at the LHC, additional information from future flavour experiments will be necessary to interpret those LHC data properly. Also the measurement of correlations between various squark decay modes at a future ILC would provide information about the flavour violating parameters.

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1. Introduction

Rare B and kaon decays (for a review see [1, 2]) representing loop-induced processes are highly sensitive probes for new degrees of freedom beyond the SM establishing an alternative way to search for new physics. The day the existence of new degrees of freedom is established by the Large Hadron Collider (LHC), the present stringent flavour bounds will translate in first-rate information on the new-physics model at hand.

Thus, within the next decade an important interplay of flavour and high-p_T physics most probably will take place. For example, within supersymmetric extensions of the SM, the measurement of the flavour structure is directly linked to the crucial question of the supersymmetry-breaking mechanism as the soft SUSY breaking terms are the source of flavour structures beyond the SM. LHC has the potential to discover strongly interacting supersymmetric particles up to a scale of 2 TeV and to measure several of their properties [3, 4, 5, 6]. This information can be used for a refined analysis of flavour physics observables indicating possible flavour structures and, thus, give important information for distinguishing between models of supersymmetry breaking.

Data from K and B_d physics show that new sources of flavour violation in $s \to d$ and $b \to d$ are strongly constrained, while the possibility of sizable new contributions to $b \to s$ remains open. In [7, 8] we analysed flavour violating squark and gluino decays and showed that they can still be typically of order 10% despite the stringent constraints from low energy data. For a related study see also [9].

2. Phenomenological analysis

Within the Minimal Supersymmetric Standard Model (MSSM) there are two new sources of flavour changing neutral currents (FCNC), namely new contributions which are induced through the quark mixing as in the SM and generic supersymmetric contributions through the squark mixing. In the latter case, flavour violation is induced by off-diagonal elements of the squark mass matrices. We normalize them by the average of the diagonal elements (trace of the mass matrix divided by six) in the up and down sector, denoted by $m^2_{\tilde{q}}$, to be independent of the SUSY point under study. The observables can then be studied as a function of the normalized off-diagonal elements $(i \neq j)$:

$$\delta_{LL,ij} = \frac{(M^2_{f,LL})_{ij}}{m^2_{\tilde{q}}}\,, \delta_{f,RR,ij} = \frac{(M^2_{f,RR})_{ij}}{m^2_{\tilde{f}}}\,, \delta_{f,LR,ij} = \frac{(M^2_{f,LR})_{ij}}{m^2_{\tilde{f}}}\,, \delta_{f,RL,ij} = \frac{(M^2_{f,RL})^\dagger_{ij}}{m^2_{\tilde{f}}}\,. \qquad (2.1)$$

where f is either u or d for u-squarks and d-squarks, respectively. A consistent analysis of the bounds should also include interference effects between the various contributions, namely the interplay between the various sources of flavour violation and the interference effects of SM and various new-physics contributions [10].

We first fix the flavour-diagonal set of parameters and then we vary the flavour-nondiagonal parameters and explore the bounds on those parameters by theoretical and experimental constraints. For flavour-diagonal parameter we use the popular SUSY benchmark point SPS1a' [11], for a comparison with other study points see [8]. SPS1a' contains the lightest spectrum with squarks around 500 GeV and $m_{\tilde{g}}$ around 600 GeV and $\tan\beta = 10$, being consistent with WMAP data [12] and measurements of the anomalous magnetic moment of the muon.

Table 1: Branching ratios larger than 1% for two study points. The flavour diagonal entries are according to SPS1a'. $\tilde{u}_i$ decays are like in SPS1a' [11] and in both scenarios BR$(\tilde{d}_3 \to \tilde{\chi}_1^0 d) = 99.1\%$.

decaying particle	final states and corresponding branching ratios in % for. I. $\delta_{LL,23} = 0.01, \delta_{D,RR23} = 0.1$			II. $\delta_{LL,23} = 0.04, \delta_{D,RR23} = 0.45$		
$\tilde{d}_1 \to$	$\tilde{\chi}_1^0 b$, 4.4	$\tilde{\chi}_2^0 b$, 29.8	$\tilde{\chi}_1^- t$, 37.0	$\tilde{\chi}_1^0 s$, 36.8	$\tilde{\chi}_1^0 b$, 42.2	$\tilde{\chi}_2^0 b$, 10.9
	$\tilde{u}_1 W^-$, 27.7			$\tilde{\chi}_1^- t$, 9.6		
$\tilde{d}_2 \to$	$\tilde{\chi}_1^0 s$, 8.0	$\tilde{\chi}_1^0 b$, 6.4	$\tilde{\chi}_2^0 b$, 19.0	$\tilde{\chi}_1^0 b$, 2.1	$\tilde{\chi}_2^0 b$, 27.3	$\tilde{\chi}_1^- t$, 34.6
	$\tilde{\chi}_3^0 b$, 1.1	$\tilde{\chi}_4^0 b$, 1.8	$\tilde{\chi}_1^- t$, 24.6	$\tilde{u}_1 W^-$, 33.2		
	$\tilde{u}_1 W^-$, 38.9					
$\tilde{d}_4 \to$	$\tilde{\chi}_1^0 s$, 9.1	$\tilde{\chi}_1^0 b$, 6.3	$\tilde{\chi}_2^0 s$, 25.3	$\tilde{\chi}_1^0 d$, 2.3	$\tilde{\chi}_2^0 d$, 31.7	$\tilde{\chi}_1^- u$, 59.7
	$\tilde{\chi}_1^- u$, 2.1	$\tilde{\chi}_1^- c$, 47.3	$\tilde{u}_1 W^-$, 4.8	$\tilde{\chi}_1^- c$, 3.0	$\tilde{\chi}_2^- u$, 2.3	
$\tilde{d}_5 \to$	$\tilde{\chi}_1^0 d$, 2.3	$\tilde{\chi}_2^0 d$, 31.7	$\tilde{\chi}_1^- u$, 59.9	$\tilde{\chi}_1^0 s$, 2.2	$\tilde{\chi}_2^0 s$, 30.7	$\tilde{\chi}_1^- u$, 2.9
	$\tilde{\chi}_1^- c$, 2.8	$\tilde{\chi}_2^- u$, 2.3		$\tilde{\chi}_1^- c$, 58.5	$\tilde{\chi}_2^- c$, 2.3	
$\tilde{d}_6 \to$	$\tilde{\chi}_1^0 s$, 3.1	$\tilde{\chi}_2^0 s$, 30.6	$\tilde{\chi}_1^- u$, 2.7	$\tilde{\chi}_1^0 s$, 19.7	$\tilde{\chi}_1^0 b$, 18.8	$\tilde{\chi}_3^0 b$, 2.9
	$\tilde{\chi}_1^- c$, 58.1	$\tilde{\chi}_2^- c$, 2.4		$\tilde{\chi}_4^0 b$, 2.9	$\tilde{\chi}_2^- t$, 5.8	$\tilde{g} s$, 2.2
				$\tilde{g} b$, 39.8	$\tilde{u}_1 W^-$, 5.5	
$\tilde{g} \to$	$\tilde{u}_1 t$, 19.2	$\tilde{u}_2 c$, 8.2	$\tilde{u}_3 u$, 8.3	$\tilde{u}_1 t$, 13.5	$\tilde{u}_2 c$, 5.8	$\tilde{u}_3 u$, 5.8
	$\tilde{u}_4 u$, 4.2	$\tilde{u}_5 c$, 4.2		$\tilde{u}_4 c$, 2.6	$\tilde{u}_5 u$, 2.6	
	$\tilde{d}_1 s$, 1.4	$\tilde{d}_1 b$, 20.6		$\tilde{d}_1 s$, 21.1	$\tilde{d}_1 b$, 22.7	
	$\tilde{d}_2 s$, 6.3	$\tilde{d}_2 b$, 9.0	$\tilde{d}_3 d$, 8.3	$\tilde{d}_2 b$, 14.0		$\tilde{d}_3 d$, 5.9
	$\tilde{d}_4 s$, 2.3	$\tilde{d}_4 b$, 1.3	$\tilde{d}_6 s$, 2.8	$\tilde{d}_4 d$, 2.3	$\tilde{d}_5 d$, 3.3	

On the flavour-nondiagonal parameter set we pose the theoretical vacuum stability bounds, all constraints from electroweak precision data, the squark Tevatron bounds. Finally we also use the explicit experimental constraints from the most important flavour observables, namely $Br(\bar{B} \to X_s\gamma)$, $BR(\bar{B} \to X_s l^+ l^-)$, $BR(B_s \to \mu^+\mu^-)$, and ΔM_{B_S} [13, 14, 15, 16, 17, 18]: Those bounds include experimental *and* theoretical errors which are linearly added. Explicitly our bounds are the experimental 95% bounds where twice the SM uncertainty is added in order to take into account uncertainties of the new physics contributions in a conservative way. We have also checked that the recent experimental data on $B \to \tau\nu$ do not give additional constraints. For the numerical evaluation we use an updated version of SPheno [19] which has been extended to accept flavour mixing entries in the sfermion mass matrices.

Now we consider scenarios with large flavour violating entries in the squark mass matrices focusing on the mixing between second and third generation squarks. The crucial point is that those entries govern both, flavour violating low energy observables on the one hand and squark and gluino decays on the other hand. To illustrate the effect of the flavour mixing parameters on the decay properties of squarks and gluinos, we use two study points with squark mixing consistent with present flavour data and other constraints listed above. The two study points chosen are characterized by $\delta_{LL,23} = 0.01$ and $\delta_{D,RR23} = 0.1$ (point I) and $\delta_{LL,23} = 0.04$ and $\delta_{D,RR23} = 0.45$ (point II) respectively. Study point II is characterized by large cancellations of the SUSY contributions to B-physics observables. In Table 1 we give a summary of the various branching ratios:

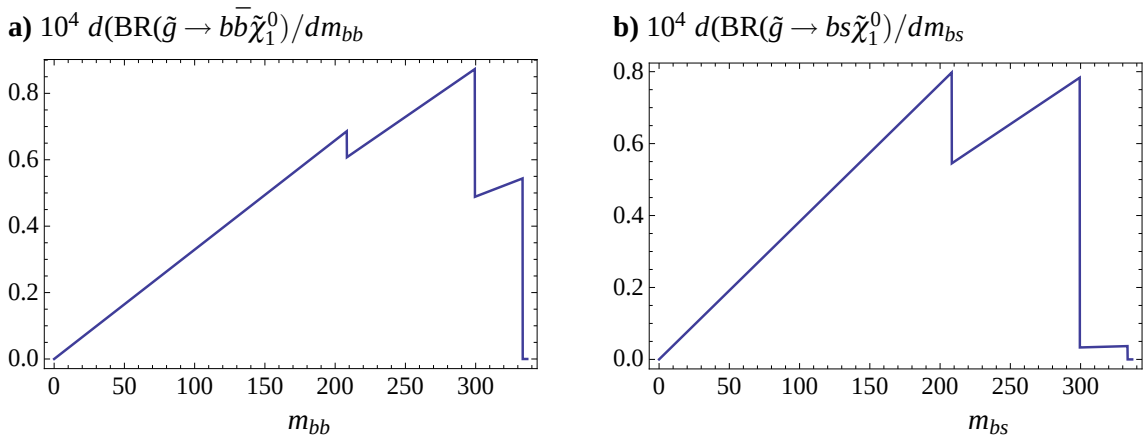

Figure 1: Differential distributions $d(\mathrm{BR}(\tilde{g} \to b\bar{b}\tilde{\chi}_1^0))/dm_{bb}$ and $d(\mathrm{BR}(\tilde{g} \to b\bar{b}\tilde{\chi}_1^0))/dm_{bb}$ as a function of $m_{bb} = \sqrt{(p_b + p_{\bar{b}})^2}$ (m_{bs}) for point 1 defined in table 1. In b) the sum over the charges is shown: $\mathrm{BR}(\tilde{g} \to bs\bar{\tilde{\chi}}_1^0) + \mathrm{BR}(\tilde{g} \to bs\tilde{\chi}_1^0)$.

The relative size of the branching ratios in Table 1 can be understood by the nature of the various squarks mass eigenstates. In point I one finds $\tilde{d}_1 \simeq \tilde{b}_L$ with a small admixture of $\tilde{b}_R$, $\tilde{d}_2 \simeq \tilde{b}_R$ with small admixtures of $\tilde{s}_R$ and $\tilde{b}_L$, $\tilde{d}_3 \simeq \tilde{d}_R$, $\tilde{d}_4 \simeq \tilde{s}_R$ with admixtures of $\tilde{s}_L$ and $\tilde{b}_R$, $\tilde{d}_5 \simeq \tilde{d}_L$ and $\tilde{d}_6 \simeq \tilde{s}_L$ with a small admixture of $\tilde{s}_R$. Thus, larger flavour effects are visible in the decays of $\tilde{d}_2$ and $\tilde{d}_4$ where the flavour violating decay branchings ratios $\tilde{d}_2 \to \tilde{\chi}_1^0 s$ and $\tilde{d}_4 \to \tilde{\chi}_1^0 b$ are of the order of 10%. This structure is also the reason for the relative importance of the flavour violating decays of the gluino. As a side remark we note that the flavour violating decays of the first generation squarks and of the 2nd/3rd generation squarks into the first generation quarks are due to CKM quark mixing.

In point II the situation is more complicated due to the larger flavour mixing parameters. With respect to the nature of the d-type squarks we find that $\tilde{d}_1$ and $\tilde{d}_6$ are strongly mixed states consisting mainly of $\tilde{s}_R$ and $\tilde{b}_R$ with a small admixture of $\tilde{b}_L$ whereas the other states are mainly electroweak eigenstates: $\tilde{d}_2 \simeq \tilde{b}_L$, $\tilde{d}_3 \simeq \tilde{d}_R$, $\tilde{d}_4 \simeq \tilde{d}_L$ and $\tilde{d}_5 \simeq \tilde{s}_L$. In this scenario the flavour violating final states can even reach about 40% in case of $\tilde{d}_2 \to \tilde{\chi}_1^0 s$ and about 20% for $\tilde{d}_6 \to \tilde{\chi}_1^0 b$. The differences for the gluino decays between these two points is not only due to the different mixing in the d-squark sector but also due to the different kinematics.

3. Impact on LHC

Large flavour changing decay modes of squarks and gluinos clearly have an impact on the discovery strategy of such particles as well as on the measurement of the underlying parameters at the LHC. For example, in mSUGRA points without flavour mixing one finds usually that the left-squarks of the first two generations as well as the right squarks have similar masses. Large flavour mixing implies that there is a considerable mass splitting. Therefore, the assumption of almost degenerate masses should be reconsidered if sizable flavour changing decays are discovered in squark and gluino decays.

An important part of the decay chains considered for SPS1a' and nearby points are $\tilde{g} \to b\tilde{b}_j \to b\bar{b}\tilde{\chi}_k^0$ which are used to determine the gluino mass as well as the sbottom masses or at least their average value if these masses are close [20]. In the latter analysis the existence of two b-jets has

been assumed stemming from this decay chain. In this case the two contributing sbottoms would lead to two edges in the partial distribution $d(\mathrm{BR}(\tilde{g} \to b\bar{b}\tilde{\chi}_1^0)/dm_{bb}$ where m_{bb} is the invariant mass of the two bottom quarks. As can be seen from Figure 1 there are scenarios where more squarks can contribute and consequently one finds a richer structure, e.g. three edges in the example shown corresponding to study point I. Such a structure is either a clear sign of flavour violation or the fact that the particle content of the MSSM needs to be extended. Moreover, also the differential distribution of the final state $bs\tilde{\chi}_1^0$ shows a similar structure where the edges occur at the same places as in the $b\bar{b}$ spectrum but with different relative heights. This gives a non-trivial cross-check on the hypothesis of sizeable flavour mixing. Clearly a detailed Monte Carlo study will be necessary to see with which precision one can extract information on these edges. Obvious difficulties will be combinatorics because in general two gluinos or a gluino together with a squark will be produced and, thus, there will be several jets stemming from light quarks. However, one could take final states where one gluino decays into d-type squarks and the second into stops or c-squarks. In the second case effective charm tagging would be crucial.

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References

[1] T. Hurth, Int. J. Mod. Phys. A **22** (2007) 1781 [arXiv:hep-ph/0703226].

[2] T. Hurth, Rev. Mod. Phys. **75** (2003) 1159 [hep-ph/0212304].

[3] G. L. Bayatian *et al.* [CMS Collaboration], J. Phys. G **34** (2007) 995.

[4] F. del Aguila *et al.*, Eur. Phys. J. C **57**, 183 (2008) [arXiv:0801.1800 [hep-ph]].

[5] M. Artuso *et al.*, Eur. Phys. J. C **57**, 309 (2008) [arXiv:0801.1833 [hep-ph]].

[6] G. Aad *et al.* [The ATLAS Collaboration], arXiv:0901.0512 [Unknown].

[7] T. Hurth and W. Porod, Eur. Phys. J. C **33**, S764 (2004) [arXiv:hep-ph/0311075].

[8] T. Hurth and W. Porod, JHEP **0908** (2009) 087 [arXiv:0904.4574 [hep-ph]].

[9] A. Bartl et al., Phys. Lett. B **679** (2009) 260 [arXiv:0905.0132 [hep-ph]].

[10] T. Besmer, C. Greub and T. Hurth, Nucl. Phys. B **609** (2001) 359 [arXiv:hep-ph/0105292].

[11] J. A. Aguilar-Saavedra *et al.*, *Eur. Phys. J.* **C46** (2006) 43–60, hep-ph/0511344.

[12] D. N. Spergel *et al.* [WMAP Collaboration], Astrophys. J. Suppl. **170** (2007) 377 [arXiv:astro-ph/0603449].

[13] M. Misiak *et al.*, Phys. Rev. Lett. **98** (2007) 022002 [arXiv:hep-ph/0609232].

[14] E. Lunghi, W. Porod, and O. Vives, *Phys. Rev.* **D74** (2006) 075003, hep-ph/0605177.

[15] P. L. Cho, M. Misiak, and D. Wyler, *Phys. Rev.* **D54** (1996) 3329–3344, hep-ph/9601360.

[16] T. Hurth, E. Lunghi, and W. Porod, *Nucl. Phys.* **B704** (2005) 56–74, hep-ph/0312260.

[17] A. J. Buras, P. H. Chankowski, J. Rosiek, and L. Slawianowska, *Nucl. Phys.* **B659** (2003) 3, hep-ph/0210145.

[18] T. Huber, T. Hurth and E. Lunghi, Nucl. Phys. B **802** (2008) 40 [arXiv:0712.3009 [hep-ph]].

[19] W. Porod, *Comput. Phys. Commun.* **153** (2003) 275–315, hep-ph/0301101.

[20] J. G. Branson, D. Denegri, I. Hinchliffe, F. Gianotti, F. E. Paige and P. Sphicas [ATLAS and CMS Collaborations], Eur. Phys. J. direct C **4** (2002) N1 [arXiv:hep-ph/0110021].