In this talk, I briefly review a selection of SUSY effects in $B$ physics. First, I consider models with Minimal Flavour Violation. Then I discuss SUSY models with new sources of flavour violation in squark mass matrices, analyzing present constraints and possible developments with forthcoming data on $b \to s$ and $b \to d$ transitions.

1. INTRODUCTION

Flavour changing neutral currents (FCNC) and CP-violating processes are very sensitive probes of new physics. The GIM suppression of FCNC amplitudes is generally absent beyond the Standard Model (SM), giving possibly large enhancements of FCNC processes over the SM predictions. Furthermore, CP violation in weak decays in the SM is entirely governed by a single phase in the CKM matrix, resulting in a strong correlation between all CP-violating processes. In general, this correlation is lost beyond the SM. Until now, all experimental data are fully compatible with the SM, as can be clearly seen from the standard analysis of the Unitarity Triangle (UT) \cite{1}. One is then left with two basic questions: i) How can the SM be extended without spoiling the impressive consistency of the SM UT fit? ii) Can we still hope to see some hint of new physics in low-energy FCNC and CP-violating phenomena? While these two questions can be considered in full generality, I will focus in the rest of this talk on Supersymmetry (SUSY), which is at present the most successful extension of the SM with respect to the consistency with precision electroweak data. SUSY can modify the SM predictions on FCNC and CP-violating processes in three different ways: 1) With additional loop contributions still proportional to elements of the CKM matrix. A typical example of this kind of contributions is given by stop and chargino loops. This effect is present in any SUSY extension of the SM. 2) With additional loop contributions governed by new sources of flavour and CP violation \cite{2}. When these new sources of FCNC are present, typically the largest contributions arise from gluino exchange. This effect is absent in SUSY models with Minimal Flavour Violation (MFV) (see Sec. 2). 3) With additional tree-level contributions. These can only arise in models with R-parity violation, and typically affect FCNC processes in a dramatic way.

Clearly, models in which only the first kind of contributions are present tend to agree much better with experimental data than more general models. On the other hand, the presence of contributions of the second or third kind usually generates larger deviations from SM predictions on yet unobserved FCNC and CP violating processes. In this respect, $B$ physics is the next frontier of testing SUSY in weak decays: $B$ factories and the Tevatron will provide us with data on a large variety of FCNC and CP-violating decays, and $B$ physics is playing an ever-increasing role in the UT fit. In the following, I will discuss in some detail SUSY effects in $B$ physics in models with R-parity conservation.\footnote{For a recent example of the large effects in $B$ physics generated by R-violating couplings, see \cite{3}.}

2. $B$ PHYSICS IN MODELS WITH MFV

Let me start by considering models with MFV, defined by the following requirements. First, I assume that all sfermion masses are flavour diagonal and real at the electroweak scale, and all gaugino and Higgs mass parameters are real. This ensures...
that the CKM matrix is the only source of flavour and CP violation, so that only the first kind of contributions discussed above can arise. Second, I assume that $\tan \beta$ is not too large ($\tan \beta \leq 10$), so that no new operator is generated in the effective Hamiltonian for $B$ decays. This implies that the SM analysis of perturbative and non-perturbative strong interaction effects can also be applied in this model. Finally, I assume that all squarks are degenerate except for the stop. This ensures that SUSY only modifies the contribution of the top quark in the SM. In particular, this means that SUSY contributions cancel from all quantities that in the SM do not depend on the top quark mass. A typical example is given by the ratio of the mass difference of $B_d$ and $B_s$ mesons. Indeed, a Universal Unitarity Triangle (UUT) can be constructed in these models, independent of SUSY contributions [1], once a sufficient number of top-mass independent quantities becomes available. At present, this is not the case and one needs to perform the full UT analysis to determine the CKM parameters for any given value of SUSY masses. The relevant SUSY parameters for the analysis are stop masses and mixing angle, the mass of the lightest chargino, the $\mu$ parameter, $\tan \beta$ and the charged Higgs mass. Potentially large contributions to $b \rightarrow s\gamma$ arise; once the constraints from $b \rightarrow s\gamma$ and the lower bounds on Higgs and SUSY masses from direct searches are taken into account, the UT fit in these models is indistinguishable from the SM one [3]. Deviations at the level of $20 - 30\%$ are possible in rare $B$ decays [4]. This is a property shared also by non-SUSY MFV models [5]. In the near future, $b \rightarrow s\gamma$ and $b \rightarrow sl^+l^-$ will be the most sensitive probes of SUSY models with MFV [6].

If one allows $\tan \beta$ to be very large, huge effects are possible in $B_s \rightarrow \mu^+\mu^-$ [6], increasing the BR from $BR(B_s \rightarrow \mu^+\mu^-)_{SM} \sim 4 \cdot 10^{-9}$ to $10^{-6}$, behind the corner of $BR(B_s \rightarrow \mu^+\mu^-)_{EXP} < 2 \cdot 10^{-6}$ [1]. This large enhancement of $B_s \rightarrow \mu^+\mu^-$ is in general correlated to a decrease of the $B_s - \bar{B}_s$ mass difference $\Delta M_s$, cutting out a large part of parameter space [11]. Once a measurement of $\Delta M_s$ becomes available, this correlation will be very useful in determining the prediction for $B_s \rightarrow \mu^+\mu^-$ in this model. It is also interesting to notice that, in minimal supergravity models, a correlation can be established between contributions to $B_s \rightarrow \mu^+\mu^-$ and $(g - 2)_\mu$. In the region of parameter space favoured by the anomalous magnetic moment of the muon, one can obtain enhancements of one or two orders of magnitude of $BR(B_s \rightarrow \mu^+\mu^-)$ over the SM prediction [12].

3. $B$ PHYSICS IN GENERAL SUSY

We now turn from MFV to SUSY models with arbitrary sfermion mass matrices. In general, FCNC and CP-violating processes impose stringent constraints on off-diagonal sfermion mass terms [13]. To study these models in full generality, it is convenient to parameterize FCNC amplitudes in terms of $(\delta^d_{ij})_{AB}$, the ratio of the off-diagonal squark mass term $(\Delta^d_{ij})_{AB}$ connecting squarks of flavour $i$ and $j$ and helicities $A$ and $B$ over the average squark mass $\bar{m}^2_q$. Let us first consider $(\delta^d_{13})_{AB}$, the mass insertion that induces $b \leftrightarrow d$ transitions. Constraints on this parameter from the $B_d - \bar{B}_d$ mass difference $\Delta M_d$ and from the time-dependent CP asymmetry in $B_d \rightarrow J/\Psi K$ decays $\delta_{\Psi K}$ have been recently studied in [14]. This analysis includes NLO QCD corrections [15] and lattice matrix elements [16]. As an example of the constraints one obtains from this kind of analysis, I report in Fig. 3 the allowed regions in the $\text{Abs}((\delta^d_{13})_{AB} - \text{Arg}((\delta^d_{13})_{AB}$ plane ($AB = LL, LR$), for $\bar{m}^2_q = 500$ GeV. Other results and details of the analysis can be found in [14]. A similar analysis including also chargino contributions has been very recently carried out in [17]. Effects of $(\delta^d_{13})_{LR}$ can also be tested using $B \rightarrow \rho\gamma$ decays [18].

A similar analysis can be carried out for $(\delta^d_{23})_{AB}$, the mass insertions that generate $b \leftrightarrow s$ transitions [19]. In this case, however, at present we only have a lower bound on $\Delta M_s$ and the precise measurement of $BR(B \rightarrow X_s\gamma)$. The latter quantity is very effective in constraining $(\delta^d_{23})_{LR}$, while its impact on $(\delta^d_{23})_{LL}$ is quite limited. In Fig. 4 I report preliminary results on the allowed regions in the $\text{Re}((\delta^d_{23})_{AB} - \text{Im}((\delta^d_{23})_{AB}$ plane, for $AB = LL, LR$, for the present lower bound $\Delta M_s > 14$ ps$^{-1}$. To illustrate the possible
Figure 1. Top: Allowed values of $\text{Abs}(\delta_{13}^{d})_{AB}$ as a function of $\text{Arg}(\delta_{13}^{d})_{AB}$ for $AB = LL, LR$ and $m_{\tilde{q}} = 500$ GeV (from [14]). Different colours denote values of $\gamma$ belonging to different quadrants. Middle: Allowed regions in the $\text{Re}(\delta_{23}^{d})_{AB} - \text{Im}(\delta_{23}^{d})_{AB}$ plane for $AB = LL, LR$ and $m_{\tilde{q}} = 250$ GeV (from [19]). Results are preliminary. Bottom: $S_{\phi K}$ in the presence of $(\delta_{23}^{d})_{LL}$ for $m_{\tilde{q}} = 250$ GeV (from [19]). Results are preliminary.
impact of a future measurement of $\Delta M_s$ in Fig. I also report the allowed regions for 15 ps$^{-1} < \Delta M_s < 19$ ps$^{-1}$ and 16 ps$^{-1} < \Delta M_s < 18$ ps$^{-1}$. While the constraints on $(\delta^d_{23})_{LR}$ are completely dominated by $BR(B \to X_s \gamma)$, one can see clearly that a measurement of $\Delta M_s$ will drastically reduce the allowed values of $(\delta^d_{23})_{LL}$. However, given the errors on hadronic matrix elements, the allowed range for $(\delta^d_{23})_{LL}$ cannot shrink too much when the experimental error on $\Delta M_s$ is reduced.

Clearly, $(\delta^d_{23})_{AB}$ enter many other interesting $b \to s$ decays. Let us first consider $B \to \phi K_s$. The first measurements of $a_{\phi K_s}$ by the BaBar and Belle collaborations display a 2.7σ deviation from the observed value of $a_{\phi K_s}$ [20], while in the SM both quantities should measure $\sin 2\beta$ with negligible hadronic uncertainties [21] (here $\beta$ is one of the angles of the UT). In Fig. I I report $S_\phi K_s$, (the coefficient of the sin $\Delta M_t^d$ term in $a_{\phi K_s}$,) as a function of $(\delta^d_{23})_{LL}$ for different values of $\Delta M_s$ [14]. At present, SUSY effects can account for the observed central value, but this may change with future data on $\Delta M_s$. It is interesting to notice that direct CP violation can also occur in this channel [22]. Another interesting process in which effects of $(\delta^d_{23})_{AB}$ can be seen is $b \to s \ell^+ \ell^-$. Here large deviations from the SM in the asymmetries can be generated even for values of the BR close to the SM expectations [23].

4. CONCLUSIONS

For reasons of space, in this talk I was able to discuss only a few of the many interesting implications of SUSY in $B$ physics. However, already from these selected topics it is clear that the richer the flavour structure of superpartners is, the more probable it is to discover indirect signs of SUSY in $B$ physics. In any case, forthcoming data in this field will certainly help us learn more on SUSY extensions of the SM.

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