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Flavour constraints and SuperIso

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We describe here SuperIso which is a public program for evaluation of flavor physics observables as well as the muon anomalous magnetic moment and the dark matter relic density in the Standard Model (SM), general two-Higgs-doublet model (2HDM), minimal supersymmetric Standard Model (MSSM) and next to minimal supersymmetric Standard Model (NMSSM). A few examples of the analysis and the results obtained by SuperIso are also presented.

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1. Introduction

In addition to direct searches for new physics and new effects, indirect searches play an important and complementary role in the quest for physics beyond the Standard Model (SM). The most commonly used indirect constraints originate from flavour physics observables, cosmological data and relic density, electroweak precision tests and anomalous magnetic moment of the muon. Precise experimental measurements and theoretical predictions have been achieved for the B meson systems in the past decade [1] and stringent constraints due to sizeable new physics contributions to many observables [2, 3, 4] can be obtained.

The aim of the SuperIso program is to evaluate the most relevant indirect observables, namely the flavour observables, the muon anomalous magnetic moment and the dark matter relic density using the most accurate calculations available in the literature. SuperIso is a public program and can be downloaded from `http://superiso.in2p3.fr`.

2. Flavour observables

Flavour observables can be classified in different categories, such as radiative penguin decays, electroweak penguin decays, neutrino modes and meson mixings.

The inclusive branching ratio of $B \to X_s\gamma$ and the isospin asymmetry of $B \to K^*\gamma$ are the most important observables in the first category. Since $b \to s\gamma$ transition occurs first at one-loop level in the SM, new physics contributions can be of comparable magnitude. Here penguin loops involve the W boson in the Standard Model, and in addition charged Higgs boson, chargino, neutralino and gluino in the MSSM. The charged Higgs loop always adds constructively to the SM penguin. Thus, BR($B \to X_s\gamma$) is an effective tool to probe the THDM scenario. Chargino loops however can add constructively or destructively. If the interference is positive, it results in a great enhancement in the BR($B \to X_s\gamma$), which becomes therefore a powerful observable. On the other hand, if the interference is negative, the other interesting observable which opens up is the degree of isospin asymmetry in the exclusive decay of $B \to K^*\gamma$.

The most relevant observables in electroweak penguin decays are the branching ratio of $B_s \to \mu^+\mu^-$, branching ratios and forward-backward asymmetries in $B \to X_s\ell^+\ell^-$ and $B \to K^{(*)}\mu^+\mu^-$ decays. In SUSY in the large $\tan\beta$ regime, these rare decays are dominated by the exchange of neutral Higgs bosons and substantial enhancements in the branching ratios can be expected.

Finally in the neutrino mode category, branching ratios of $B_u \to \tau\nu_\tau$, $B \to D\tau\nu_\tau$, $D_s \to \tau\nu_\tau$, $D_s \to \mu\nu_\mu$, $K \to \mu\nu_\mu$, as well as double ratios of leptonic decays are the most important observables. These decays can be mediated by a charged Higgs boson already at tree level in annihilation processes and therefore are very sensitive to the charged Higgs sector.

3. SuperIso program

SuperIso [5] is a public C program dedicated mostly to the calculation of flavour physics observables. The calculations are done in various models, such as SM, THDM, MSSM and NMSSM with minimal flavour violation. A broad set of flavour physics observables is implemented in SuperIso. This includes the branching ratio of $B \to X_s\gamma$, isospin asymmetry of $B \to K^*\gamma$, branching

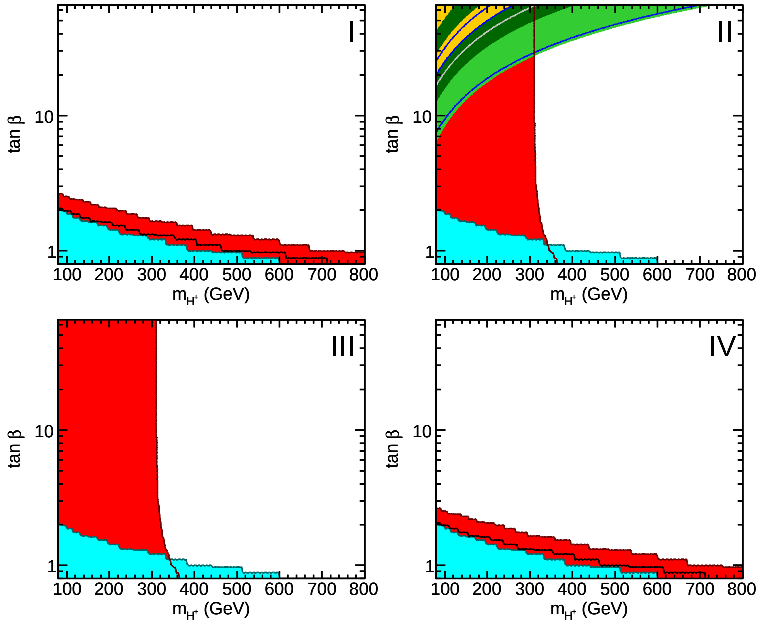

Figure 1: Excluded regions of the $(m_{H^+}, \tan\beta)$ parameter space for Z_2-symmetric THDM types. The colour coding is as follows: $B \to X_s\gamma$ (red), Δ_{0-} (black contour), ΔM_{B_d} (cyan), $B_u \to \tau\nu_\tau$ (blue), $B \to D\tau\nu_\tau$ (yellow), $K \to \mu\nu_\mu$ (grey contour), $D_s \to \tau\nu_\tau$ (light green), and $D_s \to \mu\nu_\mu$ (dark green).

ratio of $B_s \to \mu^+\mu^-$, branching ratios of $B_s \to X_s\mu^+\mu^-$, $B_s \to K^*\mu^+\mu^-$, $B_s \to K\mu^+\mu^-$ and the forward backward asymmetries in these decays, branching ratio of $B_u \to \tau\nu_\tau$, branching ratio of $B \to D\tau\nu_\tau$, branching ratio of $K \to \mu\nu_\mu$, branching ratio of $D \to \mu\nu_\mu$, and the branching ratios of $D_s \to \tau\nu_\tau$ and $D_s \to \mu\nu_\mu$. The calculation of the anomalous magnetic moment of the muon is also implemented in the program. SuperIso uses a SUSY Les Houches Accord (SLHA) file [6] as input, which can be either generated automatically by the program via a call to a spectrum generator or provided by the user. Automatic interfaces with several spectrum generators such as 2HDMC [7], SOFTSUSY [8], ISAJET [9], SPheno [10], SuSpect [11] and NMSSMTools [12] for different models and different SUSY breaking scenarios are included in the package. An extension of SuperIso including the relic density calculation, SuperIso Relic, is also available publicly [13].

Finally, in SuperIso we make use of the Flavour Les Houches Accord (FLHA) [14], the newly developed standard for flavour related quantities, and the program provides an FLHA output file as well.

4. Constraints

Figure 1 presents the combined constraints on the four Z_2-symmetric THDM types [4]. We first note the exclusion of low $\tan\beta < 1$ in all four models for $m_{H^+} < 500$ GeV as a result of three observables: $\mathrm{BR}(B \to X_s\gamma)$, isospin asymmetry, and ΔM_{B_d}. The constraints at low $\tan\beta$ are similar between the models, since the couplings to the up-type quarks are universal. In THDM types II and III, which share the same coupling pattern for the quarks, there exists a $\tan\beta$-independent lower limit of $m_{H^+} \geq 300$ GeV imposed by $\mathrm{BR}(B \to X_s\gamma)$. No generic lower limit on m_{H^+} is found in

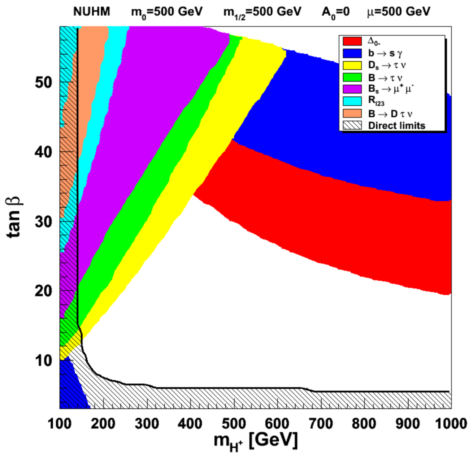

Figure 2: Combined exclusion in NUHM models by different constraints. The constraints are applied in the order they appear in the legend, and the colour coding corresponds to the first constraint by which a point is excluded. All points have $\mu > 0$ and a neutral LSP.

type I and type IV models. Constraints for high $\tan\beta$ are only obtained in the type II model since the leptonic and semi-leptonic observables require $\tan\beta$-enhanced couplings for the contributions to be interesting.

Figure 2 shows a combination of constraints applied to the NUHM parameter space. The scan over the six dimensional NUHM parameter space is projected into the plane $(m_{H^+}, \tan\beta)$, where different colours correspond to the zones excluded by different observables as given in the legend. Here we see that charged Higgs masses down to $m_{H^+} \simeq 145$ GeV can be accommodated, with the lowest masses allowed for intermediate $\tan\beta \sim 7$–15. For higher $\tan\beta$, the combined constraints follow the exclusion by the leptonic decays such as $D_s \to \tau\nu_\tau$ and $B_u \to \tau\nu_\tau$.

Most of the leptonic observables are subject to uncertainties from decay constants. In order to remove such uncertainties it is possible to define double ratios of leptonic decays in a way to cancel the dependency on the decay constants [15, 16]. In figure 3 we present the constraints obtained by the following double ratio [16]:

$$\left(\frac{\mathrm{BR}(B_s \to \mu^+\mu^-)}{\mathrm{BR}(B_u \to \tau\nu_\tau)}\right) \Big/ \left(\frac{\mathrm{BR}(D_s \to \tau\nu_\tau)}{\mathrm{BR}(D \to \mu\nu_\mu)}\right). \tag{4.1}$$

The results are shown for NUHM in two separate plots in the plane $(m_{H^+}, \tan\beta)$, where different colours correspond to different intervals for R. The points in black are excluded by R. In the right plot, the excluded points are displayed in the background, while they are shown in the foreground in the left plot. The excluded region in the right plot is therefore independent of the other SUSY parameters. In a large part of the parameter space, the double ratio is SM-like. In these regions, one can obtain $|V_{ub}|$ once the four decays involved in Eq. (4.1) are measured with almost no additional deviation due to SUSY. On the other hand one can use $|V_{ub}|$ as an input parameter and in this case as can be seen from the figure, the area with $m_A/\tan\beta \lesssim 8$ GeV is excluded with no dependence on the lattice inputs.

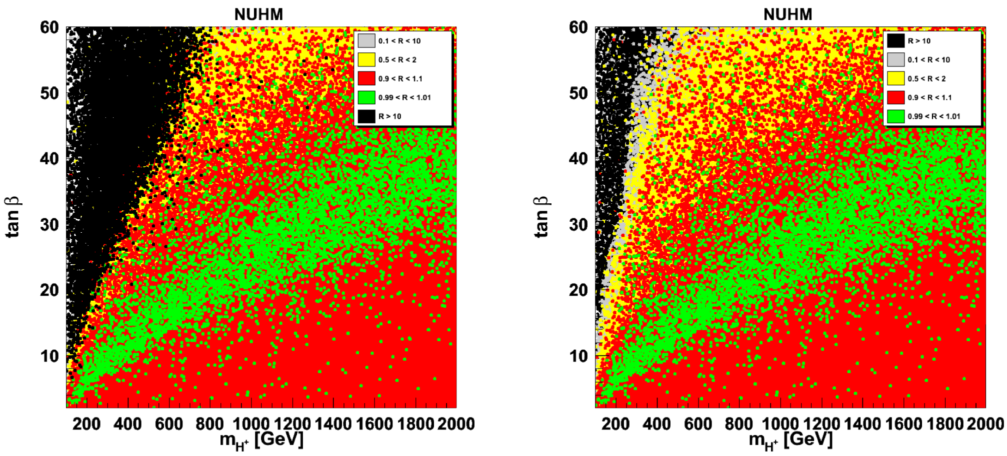

Figure 3: Variation of the double ratio R in the NUHM plane $(m_{H^+}, \tan\beta)$. The zones in green and red delimit 1% and 10% deviation from the SM value respectively. In the yellow zone R can be a factor of 2 away from the SM and in grey zone by a factor 10. The black points are excluded at 95% C.L.

5. Conclusion

Indirect constraints and in particular those from flavour physics are essential to restrict new physics parameters as we have seen here. The information obtained from these low energy observables combined with LHC data will open the door to a very rich phenomenology and would help us step forward toward a deeper understanding of the underlying physics. SuperIso program performs the calculation of the most important flavour observables as well as the muon anomalous magnetic moment and the dark matter relic density following the most precise calculations available publicly in the literature. Here we showed a few examples of possible analyses but the same methods can of course be generalized to more new physics scenarios.

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