Chirally enhanced corrections in the MSSM[1]

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In the general MSSM, chirally-enhanced corrections (to Yukawa couplings) are induced by gluino-squark, chargino-sfermion and neutralino-sfermion loops and can numerically compete with, or even dominate over, tree-level contributions, due to their enhancement by either $\tan\beta$ or $A^f_{ij}/(Y^f_{ij}M_{\mathrm{SUSY}})$. Building up on earlier work [1] we identified all potential chirally-enhanced corrections (flavor-conserving and flavor-changing) in the generic MSSM in Ref. [2] and discussed their effects on the finite renormalization of Yukawa couplings, fermion wave-functions and the CKM matrix. To leading order in v/M_{SUSY} (the so-called decoupling limit), which numerically is a very good approximation for realistic choices of MSSM parameters, we obtained analytic resummation formulae for these quantities.

For relating fermion masses m_{f_i} to their Yukawa couplings $Y^{f_i(0)}$ the procedure is rather straightforward. After calculating all chirally enhanced pieces of the fermion self-energies one has to identify which parts of the self-energies depend on Yukawa couplings and which are independent of them. In the decoupling limit the self-energies can at most involve one power of $Y^{f(0)}$. For definiteness we consider down-quarks here and decompose the self-energy as follows:

$$\Sigma^{d\,LR}_{ii} \;=\; \Sigma^{d\,LR}_{ii \not{Y}_i} + \epsilon^d_i\, v_u\, Y^{d_i(0)}\,. \tag{1}$$

Now the bare Yukawa coupling can be calculated in terms of the physical one by solving $v_d Y^{d_i(0)} + \Sigma^{d\,LR}_{ii} = m_{d_i}$ which gives

$$Y^{d_i(0)} = \frac{m_{d_i} - \Sigma^{d\,LR}_{ii\not{Y}_i}}{v_d\left(1+\tan\beta\varepsilon^d_i\right)}. \tag{2}$$

For the CKM resummation the procedure is more complicated. Here a rotation in flavor space of the quark fields is induced by the self-energy corrections

$$U^{q\,L}_{fi} = \begin{pmatrix} 1 & \dfrac{\Sigma^{q\,LR}_{12}}{m_{q_2}} & \dfrac{\Sigma^{q\,LR}_{13}}{m_{q_3}} \\ \dfrac{-\Sigma^{q\,RL}_{21}}{m_{q_2}} & 1 & \dfrac{\Sigma^{q\,LR}_{23}}{m_{q_3}} \\ \dfrac{-\Sigma^{q\,RL}_{31}}{m_{q_3}} + \dfrac{\Sigma^{q\,RL}_{32}\Sigma^{q\,RL}_{21}}{m_{q_3}m_{q_2}} & \dfrac{-\Sigma^{q\,RL}_{32}}{m_{q_3}} & 1 \end{pmatrix}_{fi}. \tag{3}$$

[1] Work done in collaboration with Lars Hofer and Janusz Rosiek

For explicitly solving the equation

$$V^{CKM(0)} = U^{u\,L\dagger} V^{CKM} U^{d\,L} \tag{4}$$

for the bare CKM matrix it is necessary to divide the self-energies into parts proportional to CKM elements and parts independent of them and to exploit in addition the CKM hierarchy. Because the bare CKM matrix (to order λ^3) has three phases, one has to extend the classical Wolfenstein parametrization allowing for complex λ and A parameters (given in the appendix of Ref. [2]).

Knowing the bare CKM matrix and the bare Yukawa couplings the chirally enhanced corrections can be absorbed into effective vertices. In principle, the procedure for fermion-sfermion-gaugino(higgsino) vertices is simple: One has to insert the bare quantities into the expressions for the Feynman rules and in addition apply the rotations in flavor space $U^{f\,L,R}$ to all SM fermion lines involved in the vertex. If these effective Feynman rules are used for the calculation of an Feynman amplitude at leading order in perturbation theory, all kinds of chirally-enhanced effects are automatically included and resummed to all orders in the final result.

For the calculation of effective Higgs-fermion-fermion vertices also a decomposition of the self-energies into holomorphic and non-holomorphic parts is necessary:

$$\Sigma^{f\,LR}_{ji} = \Sigma^{f\,LR}_{ji\,A} + \Sigma^{\prime f\,LR}_{ji}\,. \tag{5}$$

Here the holomorphic part $\Sigma^{f\,LR}_{ji\,A}$ is proportional to an A-term while the chirality flip in the non-holomorphic part $\Sigma^{\prime f\,LR}_{ji}$ is provided by a Yukawa coupling (or an A' term). The Higgs vertices are most easily calculated in the effective 2HDM obtained after integrating out the SUSY particles. For example the coupling of down-quarks to the CP-odd Higgs is then (in the large $\tan\beta$ limit) given by:

$$\Gamma^{H_k^0\,LR\,\mathrm{eff}}_{d_f d_i} = \frac{i}{\sqrt{2}v}\tan\beta\left(m_{d_i}\delta_{fi} - \widetilde{\Sigma}^{\prime d}_{fi}\right) \quad \text{with} \quad \widetilde{\Sigma}^{\prime d\,LR}_{fi} = U^{d\,L*}_{jf}\Sigma^{\prime d\,LR}_{jk}U^{d\,R}_{ki} \tag{6}$$

Note that in this way also the A-terms can lead to flavor-changing neutral Higgs couplings at large $\tan\beta$. These effective Higgs-vertices can be used in the limit $m_{H^0}, m_{A^0}, m_{H^\pm} \ll M_{\mathrm{SUSY}}$ as Feynman rules in an effective theory with the SUSY particles being integrated out. However, they remain valid in the case $m_{H^0}, m_{A^0}, m_{H^\pm} \sim M_{\mathrm{SUSY}}$ as long as the momenta flowing through the Higgs vertices are much smaller than M_{SUSY}. Thus our effective Higgs-fermion-fermion Feynman rules can e.g. be applied to calculate Higgs penguins contributing to $B_{d,s} \to \mu^+\mu^-$, $B^+ \to \tau^+\nu$ or the double Higgs penguin contributing to $\Delta F = 2$ processes.

References

[1] A. Crivellin, Phys. Rev. D **83** (2011) 056001 [arXiv:1012.4840 [hep-ph]]. A. Crivellin and U. Nierste, Phys. Rev. D **79** (2009) 035018 [arXiv:0810.1613 [hep-ph]].

A. Crivellin and U. Nierste, Phys. Rev. D **81** (2010) 095007 [arXiv:0908.4404 [hep-ph]]. A. Crivellin and J. Girrbach, Phys. Rev. D **81** (2010) 076001 [arXiv:1002.0227 [hep-ph]]. L. Hofer, U. Nierste and D. Scherer, JHEP **0910** (2009) 081 [arXiv:0907.5408 [hep-ph]]. J. Girrbach, S. Mertens, U. Nierste and S. Wiesenfeldt, JHEP **1005** (2010) 026 [arXiv:0910.2663 [hep-ph]].

[2] A. Crivellin, L. Hofer and J. Rosiek, arXiv:1103.4272 [hep-ph].