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The generic MSSM and chirally enhanced effects

Squark mass matrix

In the super-CKM basis in which the Yukawa couplings are diagonalized by biunitary transformations and the same rotations are applied to the squark fields the squark mass matrix still contains flavour-changing entries (in general). The squark mass matrices are given by:

$$M^2_{\tilde{u}} = \begin{pmatrix} m^2_{\tilde{q}} & v_u A^u - v_u Y^u \mu \cot(\beta) \\ v_u A^{u\dagger} - v_u Y^{u*}\mu^* \cot(\beta) & m^2_{\tilde{u}} \end{pmatrix}$$

$$M^2_{\tilde{d}} = \begin{pmatrix} m^2_{\tilde{q}} & v_d A^d - v_d Y^d \mu \tan(\beta) \\ v_d A^{d\dagger} - v_d Y^{d*}\mu^* \tan(\beta) & m^2_{\tilde{d}} \end{pmatrix}$$

With the following flavour and (or) chirality violating entries

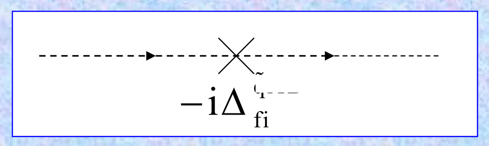
$m^2_{\tilde{q}}, m^2_{\tilde{d}}, m^2_{\tilde{u}}$: chirality - conserving squark mass terms, in general flavour changing

$v_d A^d, v_d A^d$: soft - trilinear terms; chirality and flavour changing

$m^{(0)}_d \mu \tan(\beta)$: chirality flipping quantity; can be O(1)

We denote the off-diagonal elements of the squark mass matrix with $\Delta^{q\,AB}_{ij}$ where A and B stand for the chiralities L and R. It is customary to define the dimensionless quantity $\delta^{\tilde{q}}_{fi} \equiv \Delta^{\tilde{q}}_{fi} / m_{\tilde{q}}$ where $\hat{m}_{\tilde{q}}$ denotes the average squark mass.

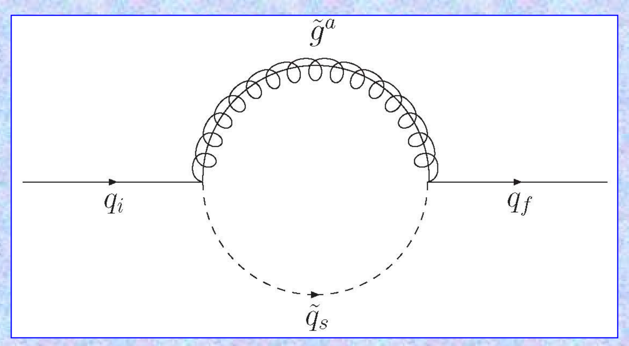
This definition is inspired by the mass insertion approximation in which a cross on a squark line stands for the insertion of a off-diagonal element of the squark mass matrix. Thus, via the duplication of the propagator a factor of $1/(M^2_{\tilde{q}})_{ss}$ arises.



Flavour changing SQCD self-energies

In the presence on non-minimal sources of flavour violation the leading additional effects to the SM stem from diagrams involving squarks and gluinos because in this case the strong coupling-constant is involved. The simplest diagram which can be constructed with this virtual particles is a (flavour changing) self-energy.

$-i\Sigma^q_{fi} =$



- Chirality flipping in vanishing order of the external momentum
- Non-decoupling; approaches a constant as $M_{SUSY} \to \infty$
- Chirally enhanced by a factor A^q/m_q or $\tan(\beta)$

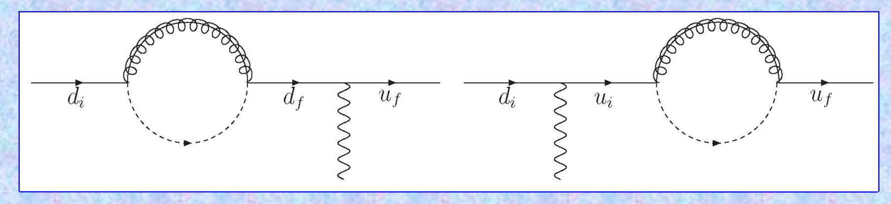
Because of the chiral enhancement these self-energies can of order one in the flavour-conserving case. This is still true in the flavour-violating case if the mixing angle is divided out. Thus these self-energies lead to a rotation of the chiral quark fields in generations space:

$$\Delta U^q_L = \begin{pmatrix} 0 & -\Sigma^{LR}_{12}/m_2 & -\Sigma^{q\,LR}_{13}/m_3 \\ -\Sigma^{q\,RL}_{21}/m_2 & 0 & \Sigma^{q\,LR}_{23}/m_3 \\ -\Sigma^{q\,RL}_{31}/m_3 & -\Sigma^{q\,RL}_{32}/m_3 & 0 \end{pmatrix}$$

- Antihermitian; unitary to first order
- Independent of the external momentum
- Of order one compared to the CKM matrix

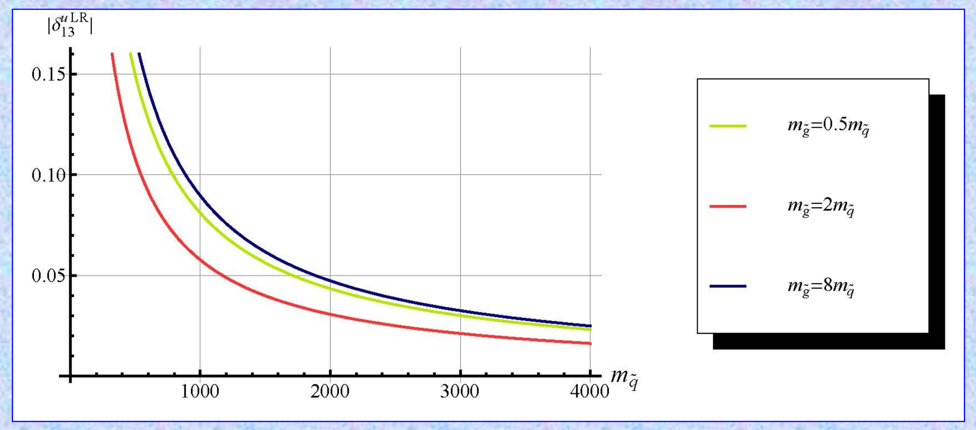
These order one corrections have to be included into the calculation of flavour-observables. This can be achieved most easily by using effective vertices.

Renormalization of the CKM matrix



The flavour-valued wave function renormalization of the last paragraph leads to a unitary correction to the W vertex.

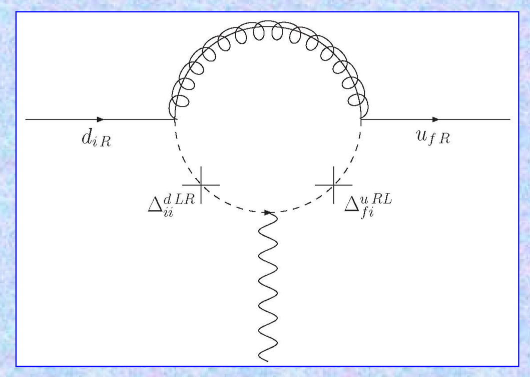
't Hooft's naturalness criterion states that large accidental cancellations which are not enforced by a symmetry are unnatural and therefore from the theoretical point of undesirable. Thus we demand that the corrections to the CKM matrix should not exceed the experimentally measured values.



Constraints on δ^u

Constraints on the off-diagonal elements of the squarks mass matrix from 't Hooft's naturalness criterion on $\delta^{u\,LR}_{13}$

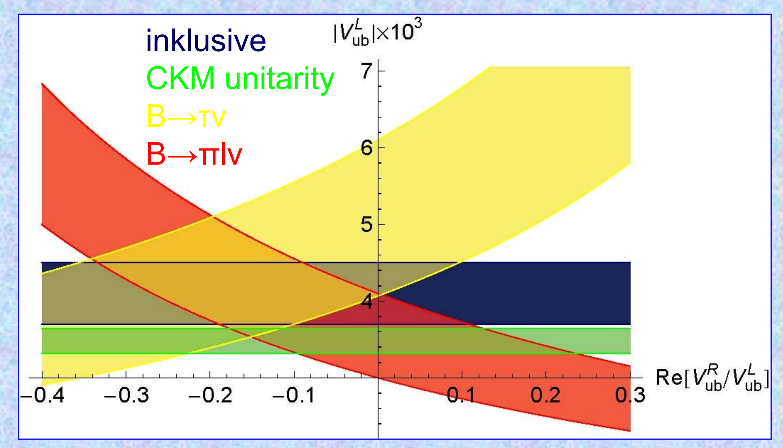
Right-handed W coupling



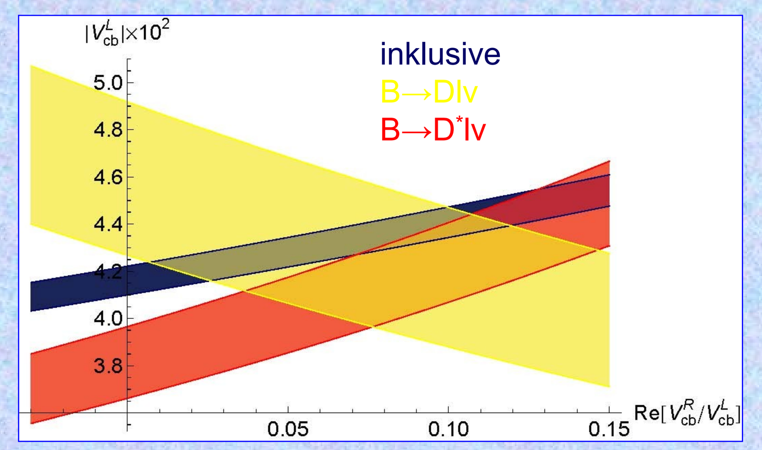
In addition to the unitary rotations induced by the self-energies, which can be absorbed into the CKM matrix, there are also "physical" corrections to the W vertex. The leading decoupling effect is an effective right-handed W coupling since no gauge cancellations with the field rotations (of the left-handed quarks) are possible.

A right-handed W coupling can explain the apparent discrepancy between the inclusive and exclusive determinations of V_{ub} and V_{cb}. Furthermore, as the considerations in the effective field theory show (both in the case of V_{ub} and V_{cb}), all three determinations (two exclusive modes and the inclusive determination) can be brought into agreement with a single parameter.

Determination of V_{ub}



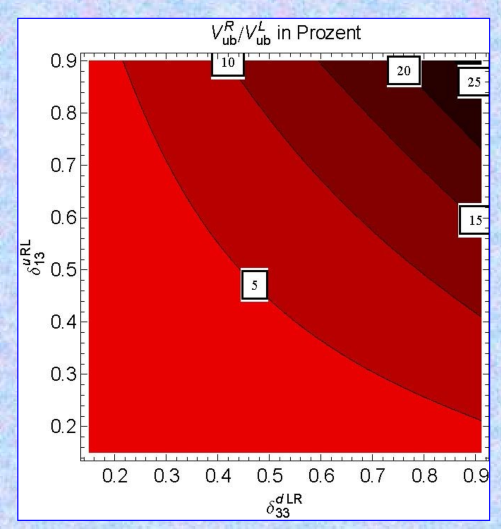
Determination of V_{cb}



Effect of a right-handed W coupling on the determination of V_{cb} and V_{ub}. The conventions for the right-handed W vertex with the matrix in generation space V^R are identical to the ones concerning V^L, only the chiral projectors are interchanged.

Possible size of the induced right-handed W coupling V^R for u→b transitions. Note the element $\delta^{u\,RL}_{13}$ is not constrained from FCNC processes. For b→c transitions the effect is only 10% of compared to V_{ub}.

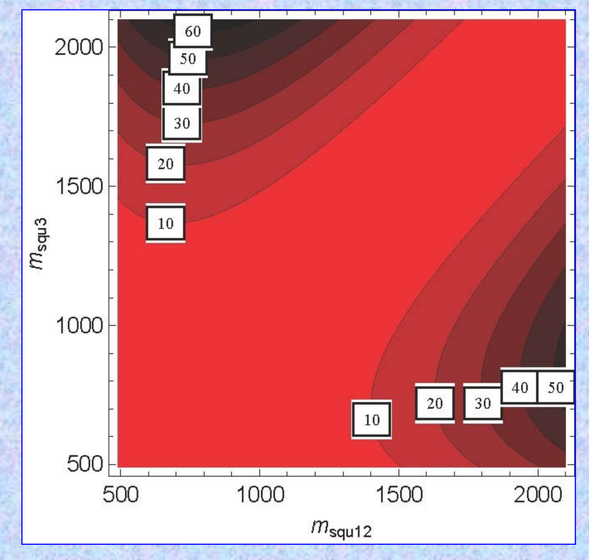
V^R_{ub}



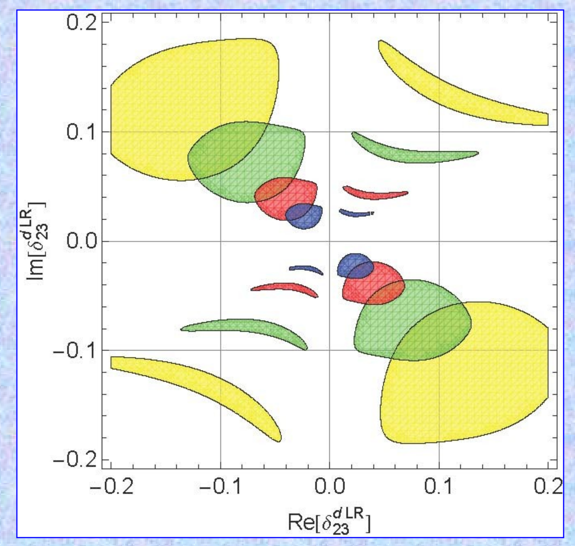
Chirally enhanced corrections to FCNC processes

Since the flavour changing self-energies can be of order one they also contribute significantly to FCNC processes. Using the effective vertices all chirally enhanced diagrams are included.

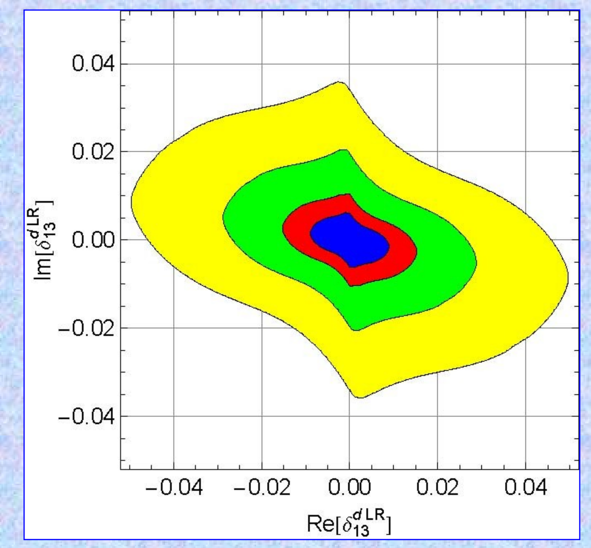
ΔF=2



B_s mixing



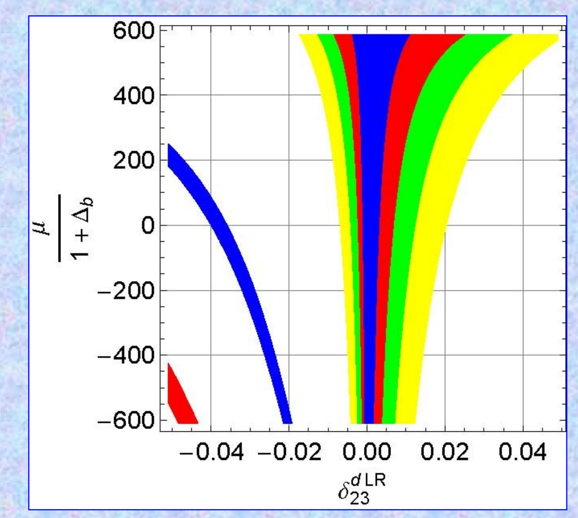
B_d mixing

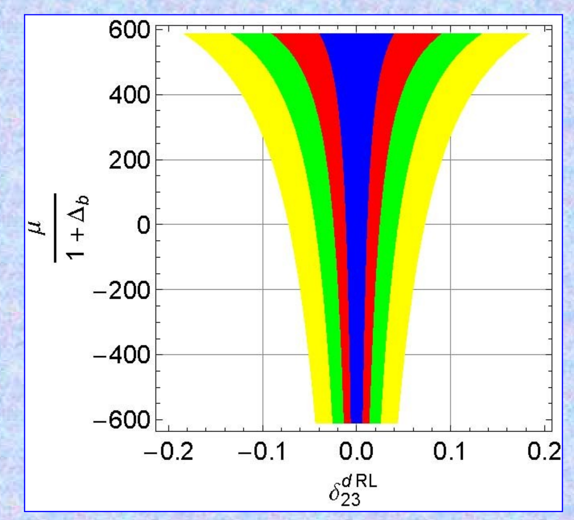


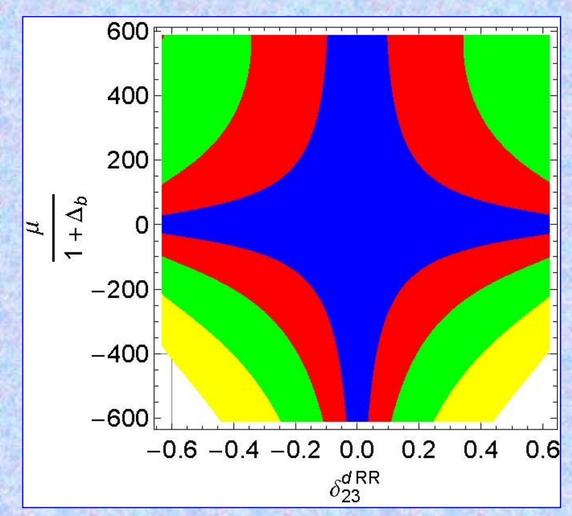
Ratio of the ΔB=2 matrix element with renormalized quark-squark-gluino vertex to the matrix element without renormalized vertices for $m_{\tilde{g}} = 1\,TeV$.

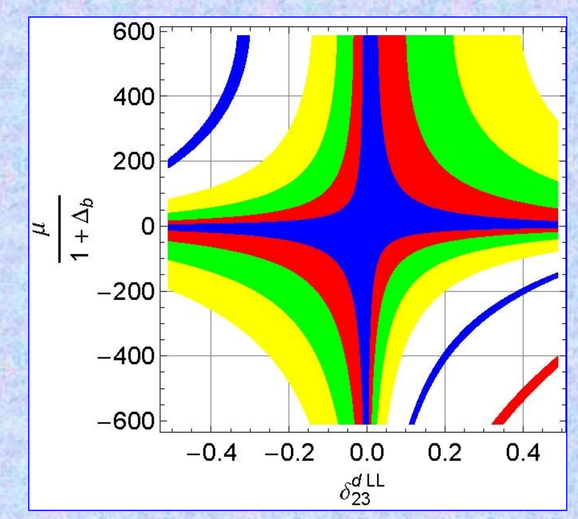
Allowed regions from B_s-mixing (left plot) and B_d-mixing (right plot) with $m_{squark1,2} = 2m_{squark3} = 1$ TeV. The yellow, green, red and blue areas correspond to the 95% CL regions for $m_g = 1.2$ TeV, $m_g = 1$TeV, $m_g = 0.8$ TeV and $m_g = 0.6$ TeV.

For b→sγ the effect of the chirally enhanced self-energies enters only if also tan(β) (or A^b) is large. This is due to the structure of the operator Q_7 which enforces a chirality flip in the magnetic loop as well.









b→sγ

Allowed regions from $B \to X_s\gamma$ for $m_{\tilde{q}_{1,2}} = 2m_{\tilde{q}_3} = 1\,TeV$ TeV and tan(β) = 50. Yellow: $m_{\tilde{g}}$ = 2TeV green: $m_{\tilde{g}}$ = 1.5 TeV, red: $m_{\tilde{g}}$ = 1 TeV and blue: $m_{\tilde{g}}$ = 0.5 TeV. The inclusion of the flavour changing self-energies can both increases or decrease the branching ratio, depending on the sign of μ.

Publications

Supersymmetric renormalisation of the CKM matrix and new constraints on the squark mass matrices.
Andreas Crivellin and Ulrich Nierste. **Phys.Rev.D79:035018,2009**. **arXiv:0810.1613** [hep-ph]

Complete resummation of chirally-enhanced loop-effects in the MSSM with non-minimal sources of flavor-violation.
Andreas Crivellin, Lars Hofer, Janusz Rosiek, Phys.Rev.D81, 2010, **arXiv:1103.4272** [hep-ph]

Effects of right-handed charged currents on the determinations of $|V_{ub}|$ and $|V_{cb}|$.
Andreas Crivellin, Phys.Rev.D81,2010, **arXiv:0907.2461** [hep-ph]

Chirally enhanced corrections to FCNC processes in the generic MSSM
Andreas Crivellin and Ulrich Nierste. **arXiv:0908.4404** [hep-ph]