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Non-minimal flavor violation in the MSSM

Outline:

- The SUSY flavor and CP problem
- Self-energies in the MSSM
- Resummation of chirally enhanced corrections
- Effective Higgs vertices
- Chirally enhanced corrections to FCNC processes
- Flavor from SUSY
- Right-handed W-coupling and the determination of V_{ub} and V_{cb}.
- Constraints on the squark mass splitting from Kaon and D mixing

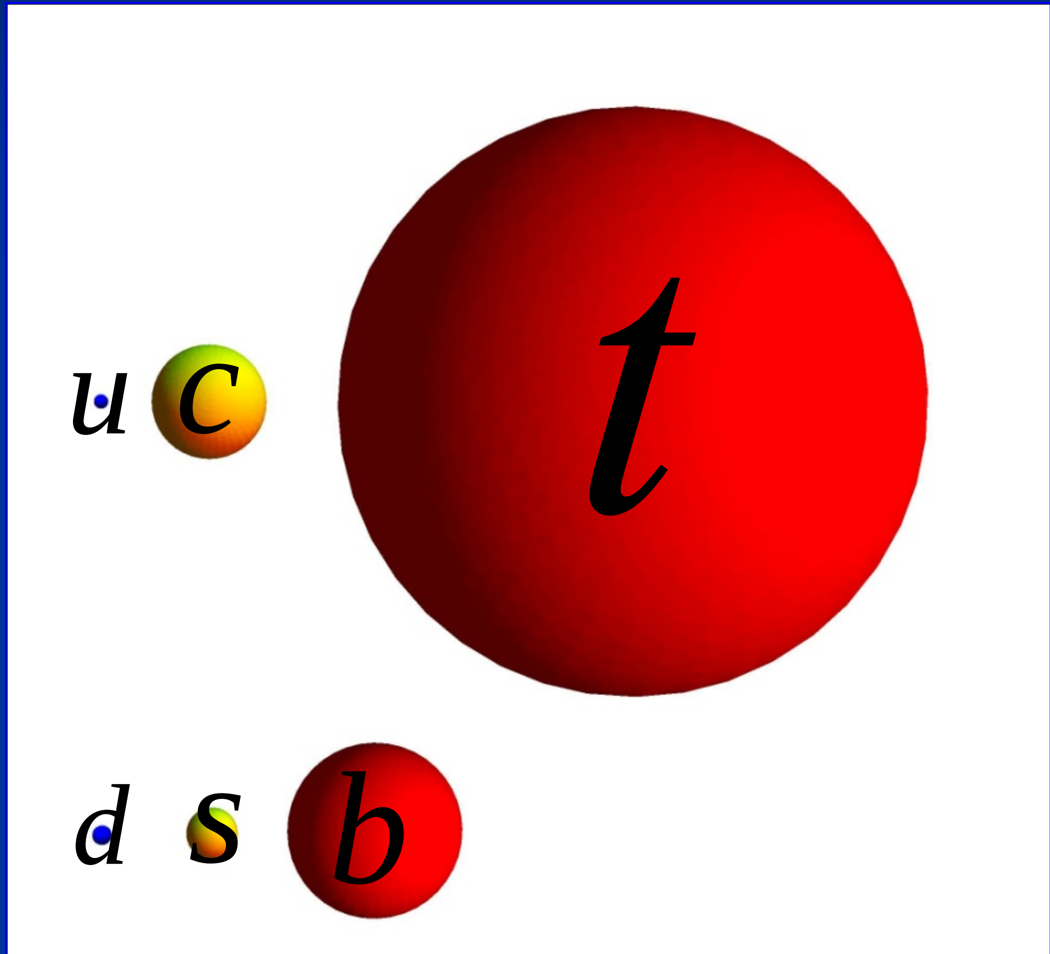
Introduction

Sources of flavor violation in the MSSM

Quark masses

- Top quark is very heavy: $m_t \approx v$
- Bottom quark rather light, but Y^b can be big at large tan(β)
- All other quark masses are very small

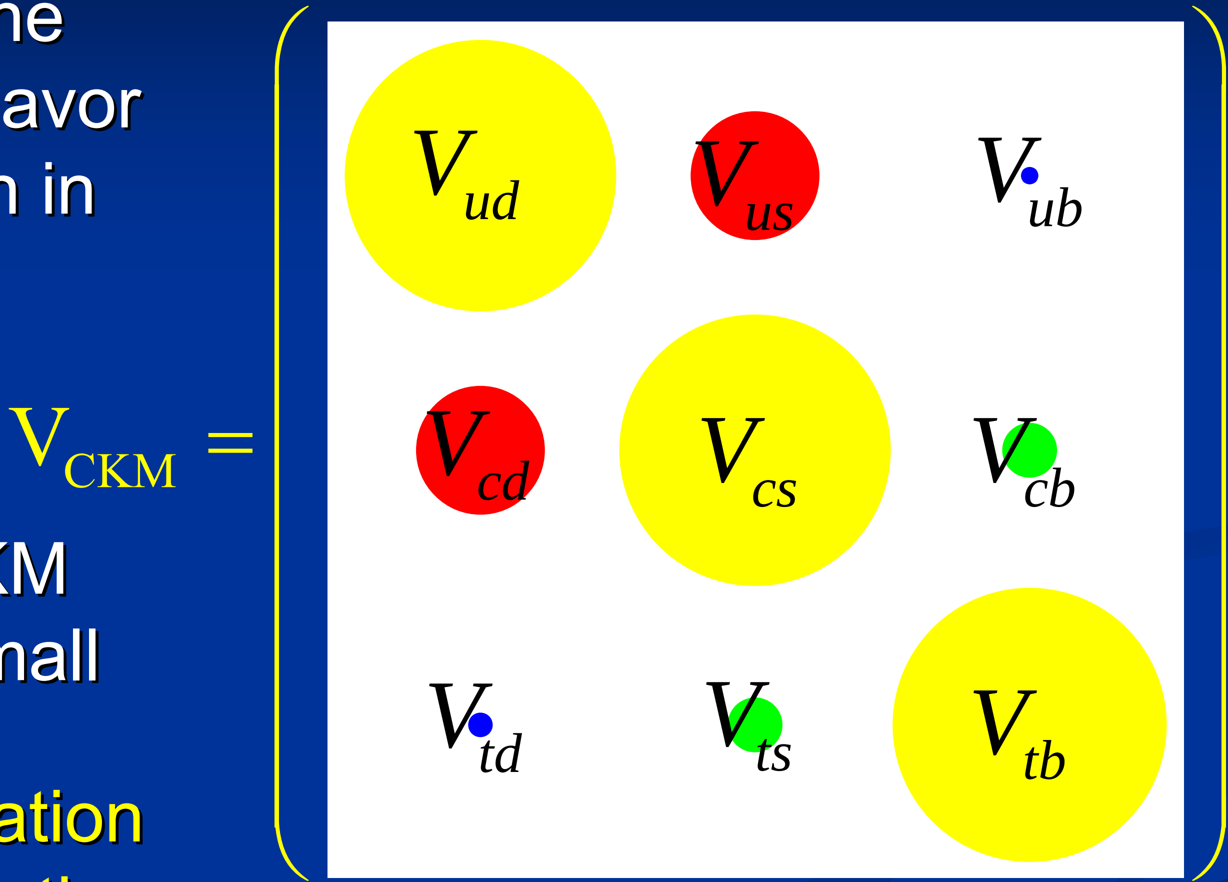
⇒ sensitive to radiative corrections



CKM matrix

- CKM matrix is the only source of flavor and CP violation in the SM.
- No tree-level FCNCs
- Off-diagonal CKM elements are small

⇒ Flavor-violation is suppressed in the Standard Model.



SUSY flavor (CP) problem

- The squark mass matrices are not necessarily diagonal (and real) in the same basis as the quark mass matrices.
- Especially the trilinear A-terms can induce dangerously large flavor-mixing (and complex phases) since they don't necessarily respect hierarchy of the SM.
- The MSSM possesses two Higgs-doublets: Flavor-changing charged and (loop-induced) neutral Higgs interactions.

➡ Why is the observed flavor violation so small?

- Possible solutions:

  - MFV D'Ambrosio, Giudice, Isidori, Strumia hep-ph/0207036

  - Flavor-symmetries

  - effective SUSY Barbieri et at hep-ph/10110730

  - Radiative flavor violation

Squark mass matrix

$$M^2_{\tilde{q}} = \begin{pmatrix} M^{\tilde{q}\,2}_{LL} & \Delta^{\tilde{q}\,LR} \\ \Delta^{\tilde{q}\,LR\,\dagger} & M^{\tilde{q}\,2}_{RR} \end{pmatrix}$$

hermitian: ➡ $W^{\tilde{q}\dagger} M^2_{\tilde{q}} W^{\tilde{q}} = M^{2(D)}_{\tilde{q}}$

$M^{\tilde{q}\,2}_{LL,RR}$ involves only bilinear terms (in the decoupling limit)

The chirality-changing elements are proportional to a vev

$$\Delta^{d\,LR}_{ij} = -v_d \left(\mu \tan(\beta) Y^{d(0)}_i \delta_{ij} + A^d_{ij} \right)$$

$$\Delta^{u\,LR}_{ij} = -v_u \left(\mu \cot(\beta) Y^{u(0)}_i \delta_{ij} + A^u_{ij} \right)$$

$$\tan(\beta) = \frac{v_u}{v_d}$$

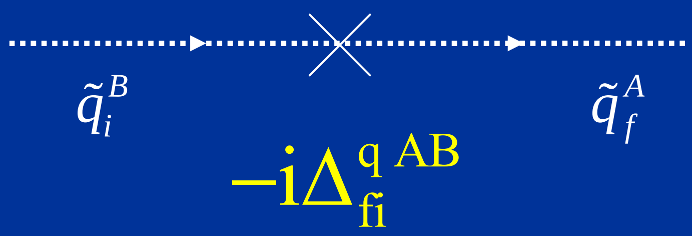
Mass insertion approximation

(L.J. Hall, V.A. Kostelecky and S. Raby, Nucl. Phys. B 267 (1986) 415.)

- Useful to visualize flavor-changes in the squark sector

  $\Delta_{ij}^{q\ AB}$ off-diagonal element of the squark mass matrix

- $q = u, d$
- i, j flavor indices 1,2,3
- A, B chiralitys L,R

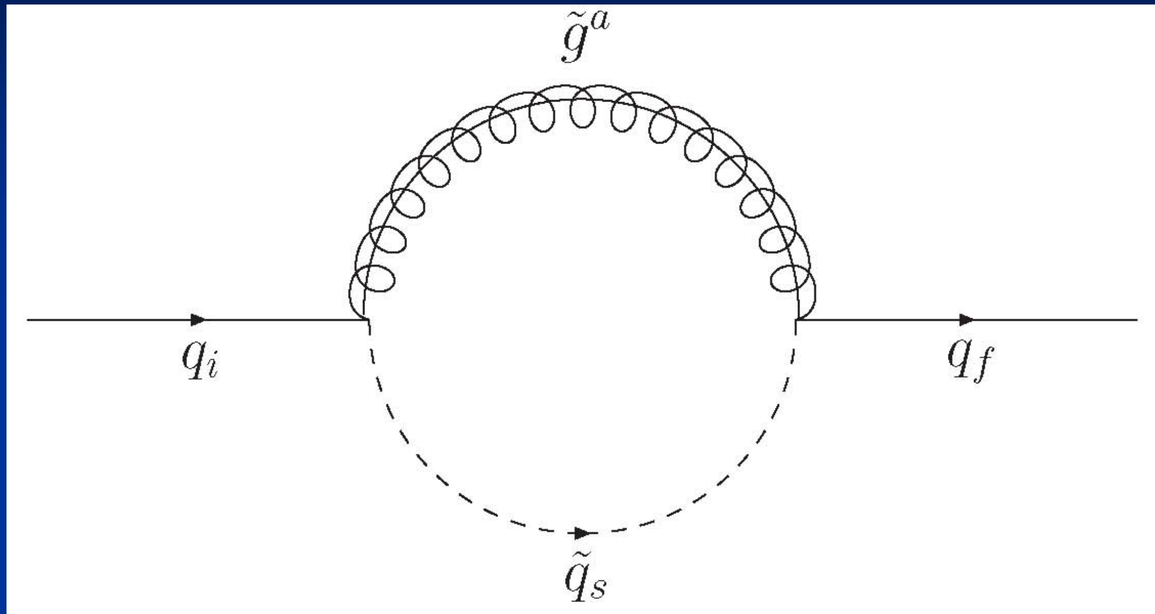


Self-energies

in the MSSM

SQCD self-energy:

$$-i\Sigma(0)^{q\,LR}_{fi} =$$



$$\Sigma^{q\,LR}_{fi} = \alpha_s \frac{2}{3\pi} m_{\tilde{g}} W_{fs} W^*_{i+3,s} B_0\left(m_{\tilde{g}}{}^2, m^2_{\tilde{q}_s}\right)$$

Finite and proportional to at least one power of $\Delta^{q\,LR}_{fi}$

$$\Sigma^{q\,LR}_{fi} = \alpha_s \frac{2}{3\pi} m_{\tilde{g}} W^q_{fs} W^{q*}_{js} \Delta^{q\,LR}_{jl} W^q_{l+3.t} W^{q*}_{i+3,t} C_0\left(m_{\tilde{g}}{}^2, m^2_{\tilde{q}_s}, m^2_{\tilde{q}_t}\right)$$

decoupling limit

Decomposition of the self-energy

Decompose the self-energy

$$\Sigma_{ii}^{d\,LR} = \Sigma_{ii\,A}^{d\,LR} + \Sigma_{ii\,Y}^{d\,LR}$$

into a holomorphic part proportional to an A-term

$$\Sigma_{fi\,A}^{d\,LR} = -v_d \alpha_s \frac{2}{3\pi} m_{\tilde{g}} W_{fs}^{d} W_{js}^{d*} A_{jl}^{q} W_{lt}^{d} W_{it}^{d*} C_0\left(m_{\tilde{g}}^{2}, m_{\tilde{q}_s}^{2}, m_{\tilde{q}_t}^{2}\right)$$

non-holomorphic part proportional to a Yukawa

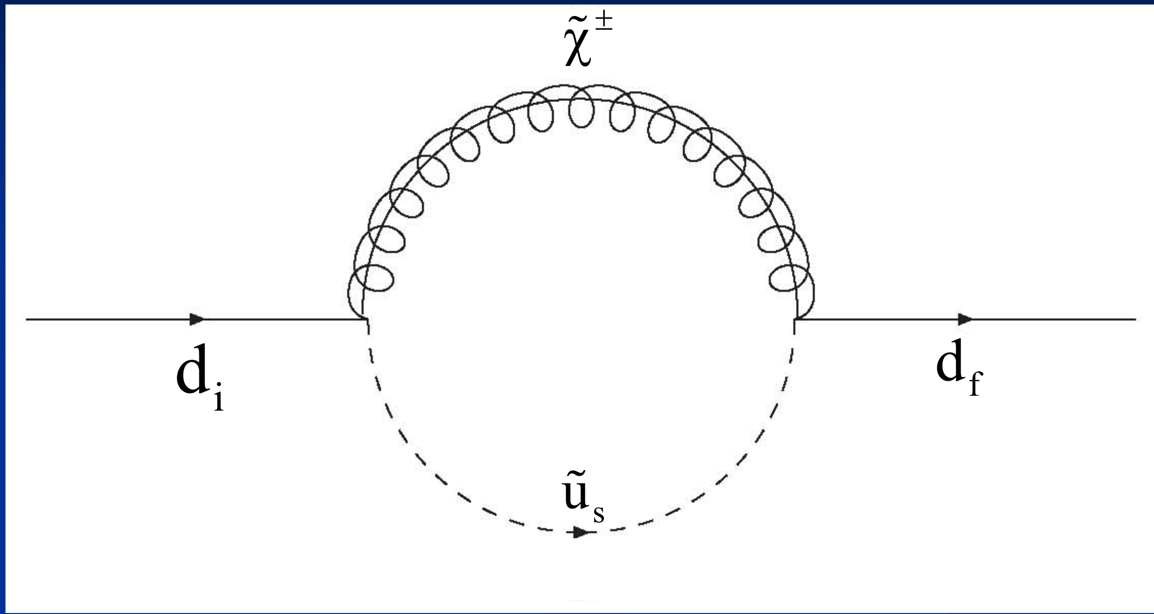
$$\Sigma_{fi\,Y}^{d\,LR} = -v_u \mu \alpha_s \frac{2}{3\pi} m_{\tilde{g}} W_{fs}^{d} W_{js}^{d*} Y^{d_j} W_{jt}^{d} W_{it}^{d*} C_0\left(m_{\tilde{g}}^{2}, m_{\tilde{q}_s}^{2}, m_{\tilde{q}_t}^{2}\right)$$

Define dimensionless quantity $\varepsilon_i^{d} = \Sigma_{ii\,Y}^{d\,LR} \big/ v_u Y^{d_i}$

which is independent of a Yukawa coupling

Chargino self-energy:

$$-i\Sigma(0)^{d\,LR}_{fi\,\tilde{\chi}^{\pm}} =$$



$$\Sigma^{\tilde{\chi}^{\pm}\,LR}_{d_f d_3} = \frac{-1}{16\pi^2}\mu Y^{d_3}\left[V^{CKM(0)*}_{3f} Y^{u_3 *} \Delta^{u\,RL}_{33} \sum_{s,t=1}^{6} V^{u\,RR}_{s\,33} V^{d\,LL}_{t\,33} C_0\left(|\mu|^2, m^2_{\tilde{u}_s}, m^2_{\tilde{u}_t}\right) \right.$$

$$\left. -\sqrt{2} g_2 \sin(\beta) M_W M_2 \sum_{s=1}^{6} V^{d\,LL}_{s\,f\,3} C_0\left(m^2_{\tilde{q}_s}, |\mu|^2, |M_2|^2\right) \right]$$

Finite Renormalization

and resummation of chirally enhanced corrections

AC, Ulrich Nierste, arXiv:0810.1613
AC, Ulrich Nierste, arXiv:0908.4404
AC, arXiv:1012.4840
AC, Lars Hofer, Janusz Rosiek arXiv:1103.4272

Renormalization I

- All corrections are finite; counter-term not necessary.
- Minimal renormalization scheme is simplest.

Mass renormalization

$$m_{d_i} = v_d Y^{d_i(0)} + \Sigma_{ii}^{d\,LR}$$
$$= v_d Y^{d_i(0)} + \Sigma_{ii\,A}^{q\,LR} + v_d \tan(\beta) Y^{d_i(0)} \varepsilon_{d_i}$$

$$\Rightarrow \quad Y^{d_i(0)} = \frac{m_{d_i} - \Sigma_{ii\,A}^{q\,LR}}{v_d\left(1+\tan(\beta)\varepsilon_i^d\right)}$$

- tan(β) is automatically resummed to all orders

Renormalization II

- Flavour-changing corrections

important two-loop corrections
A.C. Jennifer Girrbach 2010

$$U^{q\,L} = \begin{pmatrix} 1-\frac{\left|\Sigma^{q\,LR}_{12}\right|^2}{2m^2_{q_2}} & \frac{1}{m_{q_2}}\Sigma^{q\,LR}_{12} & \frac{1}{m_{q_3}}\Sigma^{q\,LR}_{13} \\ \frac{-1}{m_{q_2}}\Sigma^{q\,RL}_{21} & 1-\frac{\left|\Sigma^{q\,LR}_{12}\right|^2}{2m^2_{q_2}} & \frac{1}{m_{q_3}}\Sigma^{q\,LR}_{23} \\ \frac{-1}{m_{q_3}}\Sigma^{q\,RL}_{31}+\frac{\Sigma^{q\,RL}_{32}\Sigma^{q\,RL}_{21}}{m_{q_2}m_{q_3}} & \frac{-1}{m_{q_3}}\Sigma^{q\,RL}_{32} & 1 \end{pmatrix}$$

Renormalization III

- Renormalization of the CKM matrix:

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

- Decomposition of the rotation matrices

$$U^{q\,L} = U^{q\,L}_{\not{CKM}} U^{q\,L}_{CKM}$$

- Corrections independent of the CKM matrix

$$\tilde{V} = U^{u\,L\dagger}_{\not{CKM}} V^{(0)} U^{d\,L}_{\not{CKM}}$$

- CKM dependent corrections

$$U^{u\,L\dagger}_{CKM} \tilde{V} U^{d\,L}_{CKM}$$

$$\Rightarrow \quad V^{(0)}_{13,23} = \frac{\tilde{V}_{13,23}}{1+\varepsilon_{FC}}$$

Effective gaugino and higgsino vertices

- No enhanced genuine vertex corrections.

→

- Calculate $\varepsilon_{d_i}, \varepsilon^{d}_{FC}, \Sigma^{q\,LR}_{ii\,\not{Y}_i}, \Sigma^{q\,LR}_{ii\,\not{CKM}}$
- Determine the bare Yukawas and bare CKM matrix
- Insert the bare quantities for the vertices.
- Apply rotations $U^{q\,L,R}_{fi}$ to the external quark fields.
- Similar procedure for leptons (up-quarks)

Chiral enhancement

$$\Sigma_{fi}^{d\,LR} \approx \frac{1}{50}\frac{\Delta_{fi}^{q\,LR}}{M_{SUSY}} = \frac{-v_d}{50}\left(\tan(\beta)\, Y_i^{d(0)} \delta_{ij} + \frac{A_{ij}^{d}}{M_{SUSY}} \right)$$

- For the bottom quark only the term proportional to tan(β) is important.
  ➡ tan(β) enhancement
  Blazek, Raby, Pokorski, hep-ph/9504364

$$\Sigma_{33\,Y}^{d\,LR} = \frac{-1}{100} v_d \tan(\beta)\, Y^{b(0)} \sim m_b$$

$$O\left(\frac{\tan(\beta)}{100} \right)$$

- For the light quarks also the part proportional to the A-term is relevant.

$$\Sigma_{22\,A}^{d\,LR} = O(1) \triangleq A_{22}^{d} \approx M_{SUSY}$$

$$\Sigma_{11\,A}^{d\,LR} = O(1) \triangleq A_{11}^{d} \approx \frac{1}{50} M_{SUSY}$$

Flavor-changing corrections

$$\frac{\Sigma_{fi}^{q\,LR}}{m_{q_{max(f,i)}}} \sim V_{fi}^{CKM}$$

$$V_{cb}^{CKM} : \quad A_{23}^{q} \approx M_{SUSY}$$

$$V_{ub}^{CKM} : \quad A_{13}^{q} \approx M_{SUSY} \times 10^{-1}$$

$$V_{us}^{CKM} : \quad A_{12}^{q} \approx M_{SUSY} \times 10^{-1}$$

- Flavor-changing A-term can easily lead to order one correction.

Chirally enhanced Corrections to FCNC processes

AC, Ulrich Nierste, arXiv:0908.4404

Improvement of FCNC analysis necessary if A-terms are big:

Self energies can be of $O(1)$ in the flavor conserving case, and have to be resummed.

M.S.Carena, D.Garcia, U.Nierste and C.E.M.Wagner, [arXiv:hep-ph/9912516].

They are still of $O(1)$ in the flavor violating case, when the mixing angle is divided out.

➡ Two- or even three-loop processes can be of the same order as the LO process!

Inclusion of the self-energies

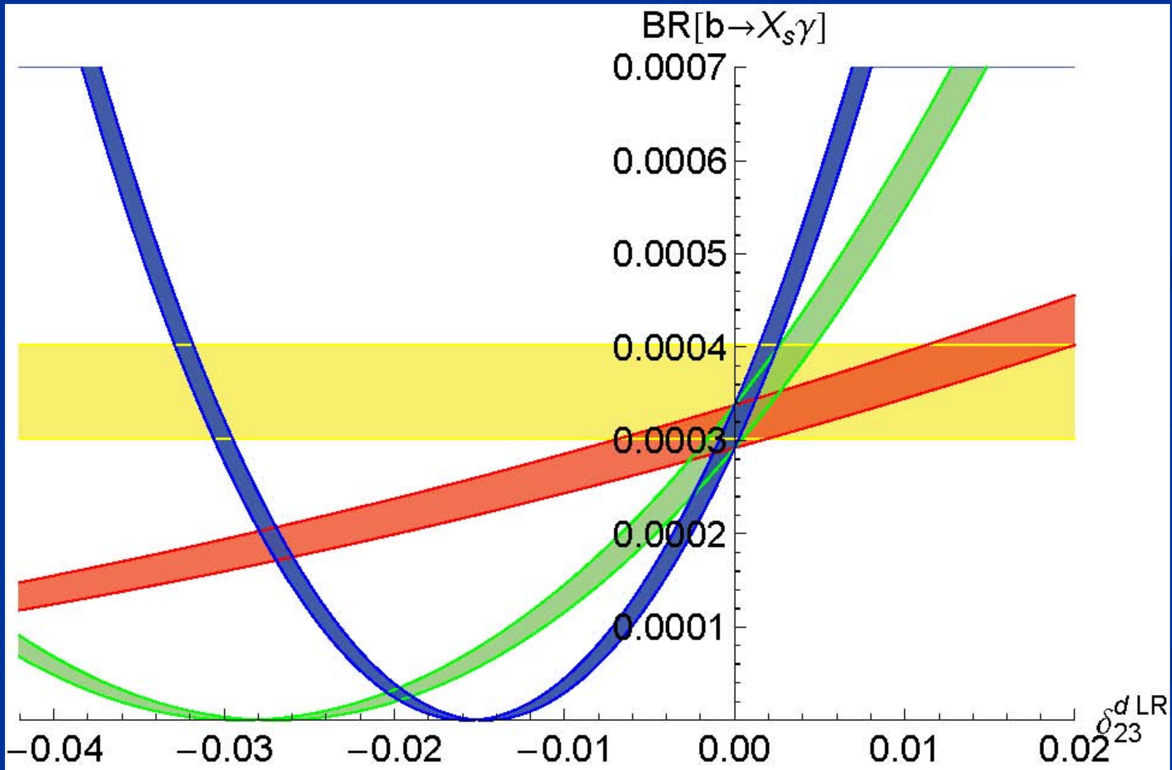
- We treat all diagrams in which no flavor appears twice on an external leg as one particle irreducible.
- Use of the MS-bar scheme allows for a direct relation between the parameters in the squark mass matrices and observables.
- Computations are easiest if one includes the chirally enhanced self-energies into a renormalized quark-squark-gluino vertex:

$$W^{\tilde{q}*}_{s,i} \to W^{\tilde{q}*}_{s,j}\left(1+\Delta U^{q}_{L}\right)_{ji}, \quad W^{\tilde{q}*}_{s,i+3} \to W^{\tilde{q}*}_{s,j}\left(1+\Delta U^{q}_{R}\right)_{ji}$$

b→sγ

Two-loop effects enter only if also $m_b\mu\tan(\beta)$ is large.

Behavior of the branching ratio for $\delta_{23}^{d\,LR}$



experimentally allowed range

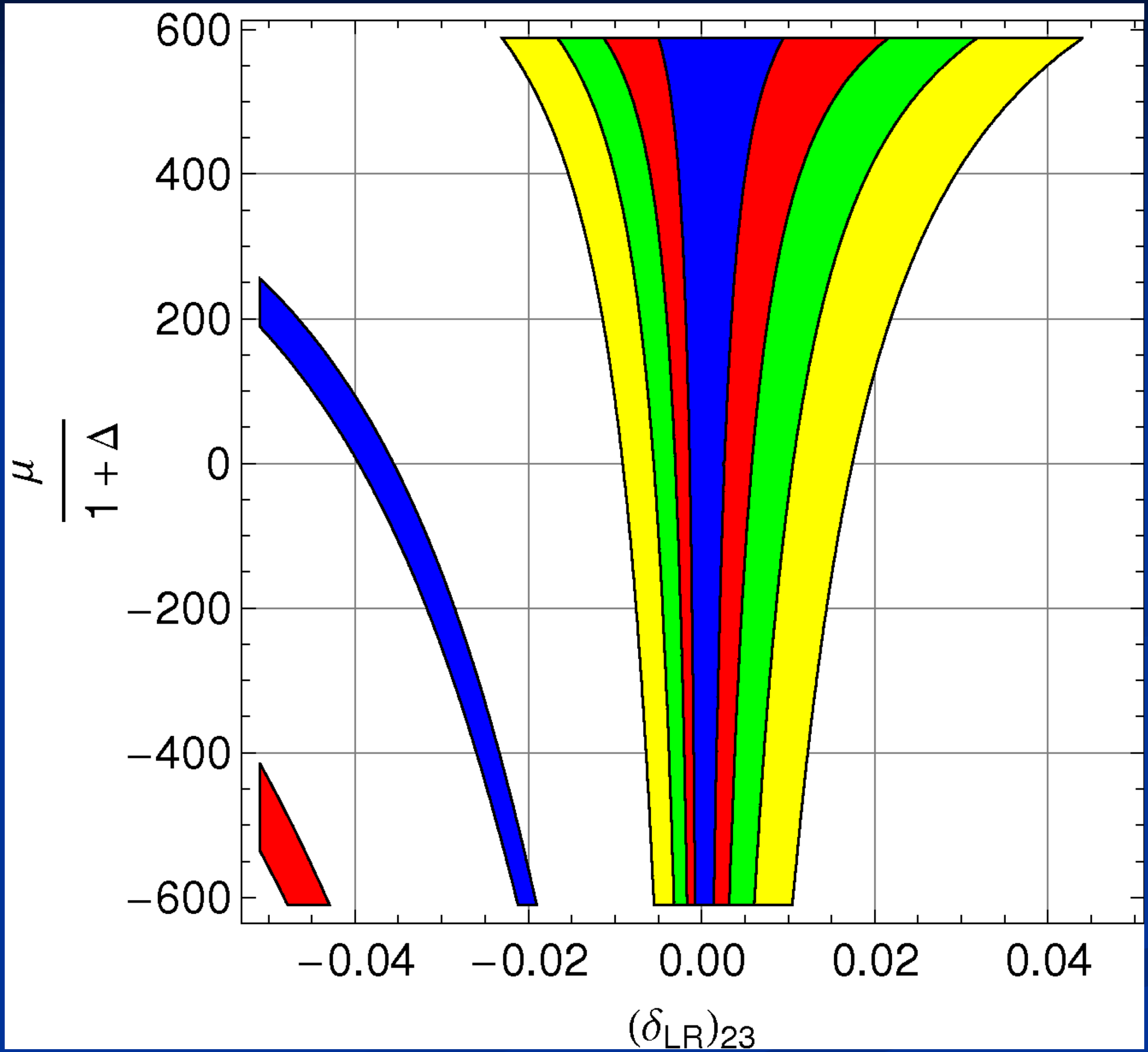
$m_b\mu\tan(\beta) = 0\text{TeV}$

$m_b\mu\tan(\beta) = 30\text{TeV}$

$m_b\mu\tan(\beta) = -30\text{TeV}$

Constraints on δ_{23} from $b\to s\gamma$

$\tan(\beta) = 50$

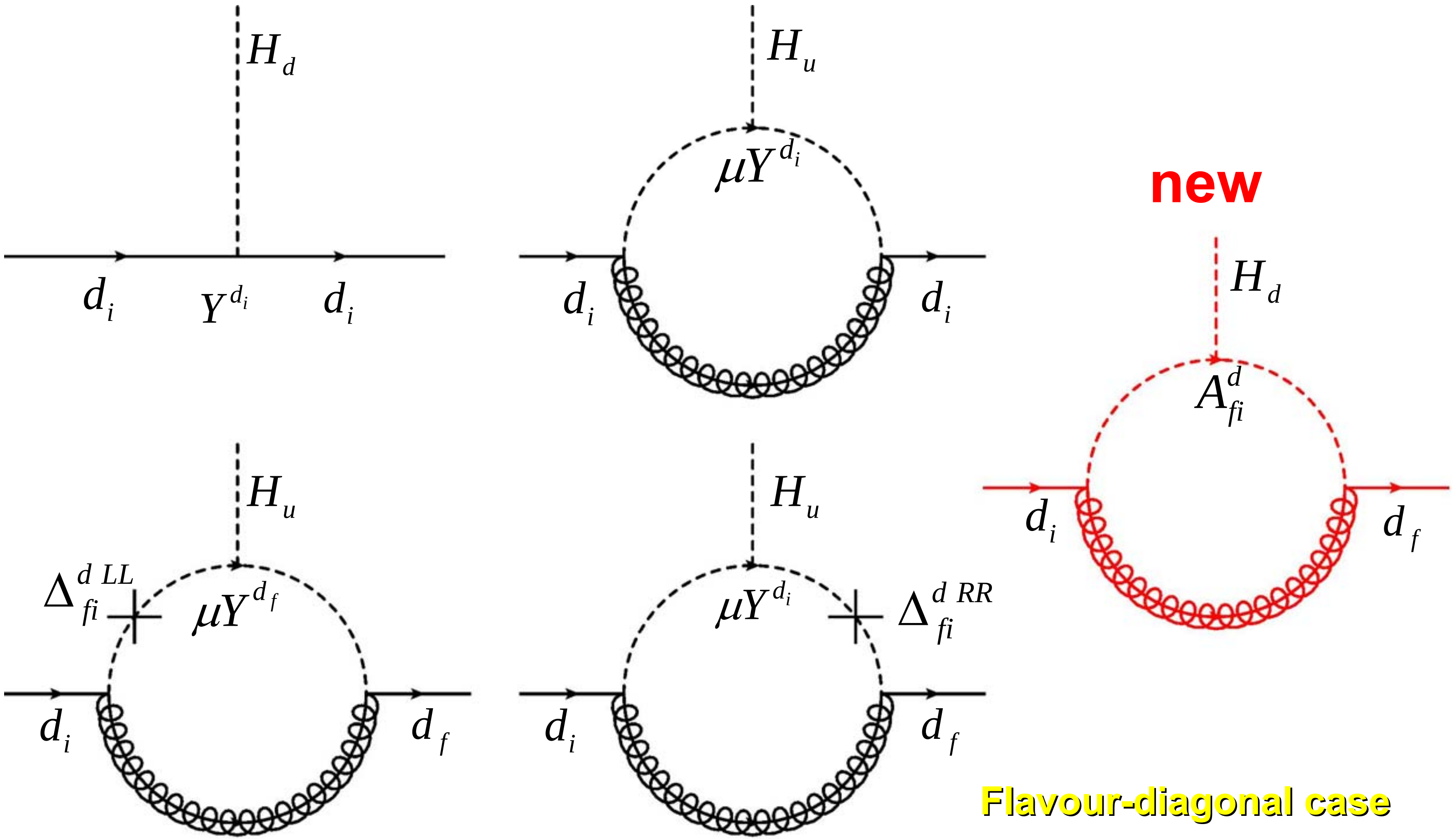


- Yellow: $m_{\tilde{g}} = 2000\text{GeV}$
- Green: $m_{\tilde{g}} = 1500\text{GeV}$
- Red: $m_{\tilde{g}} = 1000\text{GeV}$
- White: $m_{\tilde{g}} = 500\text{GeV}$

Effective Higgs vertices

AC, arXiv:1012.4840

Higgs vertices in the EFT I



Flavour-diagonal case

M. Spira et al arXiv:0305101

Higgs vertices in the EFT II

$$L_Y^{eff} = \bar{Q}^a_{f\,L}\left(\left(Y_i^d \delta_{fi} + E_{fi}^d\right)\varepsilon_{ba} H_d^b + E'^d_{fi} H_u^{a*}\right) d_{i\,R}$$

- Non-holomorphic corrections $E'^d_{fi} = \Sigma^{d\,LR}_{fi\,Y} / v_u$
- Holomorphic corrections $E^d_{fi} = \Sigma^{d\,LR}_{fi\,A} / v_d$
- The quark mass matrix $m^d_{fi} = v_d \left(Y^{d_i} \delta_{fi} + E^d_{fi}\right) + v_u E'^d_{fi}$ is no longer diagonal in the same basis as the Yukawa coupling

➡ Flavor-changing neutral Higgs couplings

Effective Yukawa couplings

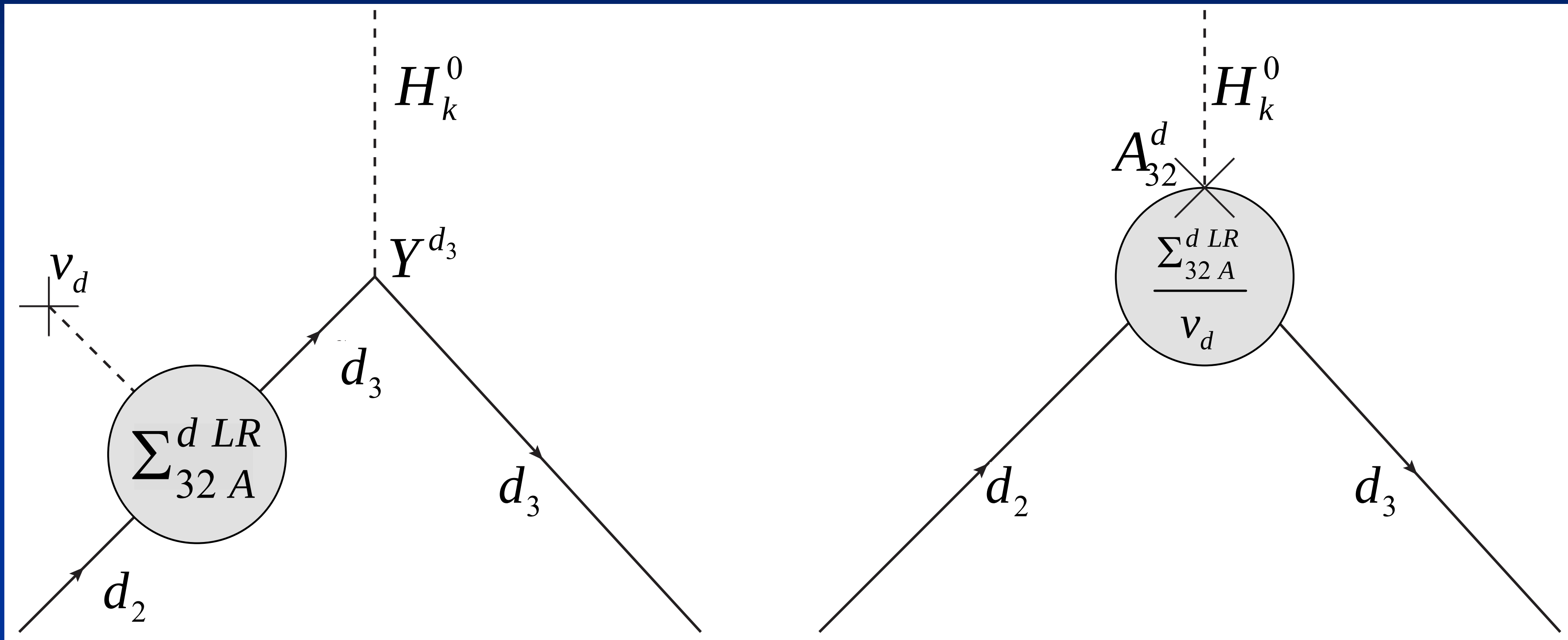
- Final result: $Y_{ij}^{d\,\mathrm{eff}} = \frac{1}{v_d}\left(m_{d_i}\delta_{ij} - \tilde{\Sigma}_{ij\,Y}^{d\,LR}\right)$ with

$$\tilde{\Sigma}_{jk\,Y}^{d\,LR} = U_{jf}^{d\,L*}\Sigma_{jk\,Y}^{d\,LR}U_{ki}^{d\,R}$$

$$\approx \Sigma_{fi\,Y}^{d\,LR} - \begin{pmatrix} 0 & \frac{\Sigma_{22\,Y}^{d\,LR}}{m_{d_2}}\Sigma_{12}^{d\,LR} & \frac{\Sigma_{33\,Y}^{d\,LR}}{m_{d_3}}\Sigma_{13}^{d\,LR} \\ \frac{\Sigma_{22\,Y}^{d\,LR}}{m_{d_2}}\Sigma_{21}^{d\,LR} & 0 & \frac{\Sigma_{33\,Y}^{d\,LR}}{m_{q_3}}\Sigma_{23}^{d\,LR} \\ \frac{\Sigma_{33\,Y}^{d\,LR}}{m_{d_3}}\Sigma_{31}^{d\,LR} & \frac{\Sigma_{33\,Y}^{d\,LR}}{m_{q_3}}\Sigma_{32}^{d\,LR} & 0 \end{pmatrix}$$

Diagrammatic explanation in the full theory:

Higgs vertices in the full theory



- Cancellation incomplete since $v_d Y^{d_3} \neq m_{d_3}$
  Part proportional to $\Sigma^{d\,LR}_{33\,Y}$ is left over.

➡ A-terms generate flavor-changing Higgs couplings

Radiative generation of light quark masses and mixing angels

AC, Ulrich Nierste, arXiv:0908.4404
AC, Jennifer Girrbach, Ulrich Nierste, arXiv:1010.4485
AC, Ulrich Nierste, Lars Hofer, Dominik Scherer arXiv:1105.2818

Radiative flavor-violation

SU(2)³ flavor-symmetry in the MSSM superpotential:

- CKM matrix is the unit matrix.
- Only the third generation Yukawa coupling is different from zero.

$$V_{CKM}^{(0)} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$Y^{q} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & Y^{q_3} \end{pmatrix}$$

All other elements are generated radiatively using the trilinear A-terms!

Features of the model

- Additional flavor symmetries in the superpotential.
- Explains small masses and mixing angles via a loop-suppression.
- Deviations from MFV if the third generation is involved.
- Solves the SUSY CP problem via a mandatory phase alignment. (Phase of μ enters only at two loops)
  Borzumati, Farrar, Polonsky, Thomas 1999.
- The SUSY flavor problem reduces to the elements $\delta_{32}^{q\,LR}, \delta_{31}^{q\,LR}$
- Can explain the B_s mixing phase

CKM generation in the down-sector:

$$\Sigma_{13}^{d\,LR} \stackrel{!}{=} m_b V_{ub}$$

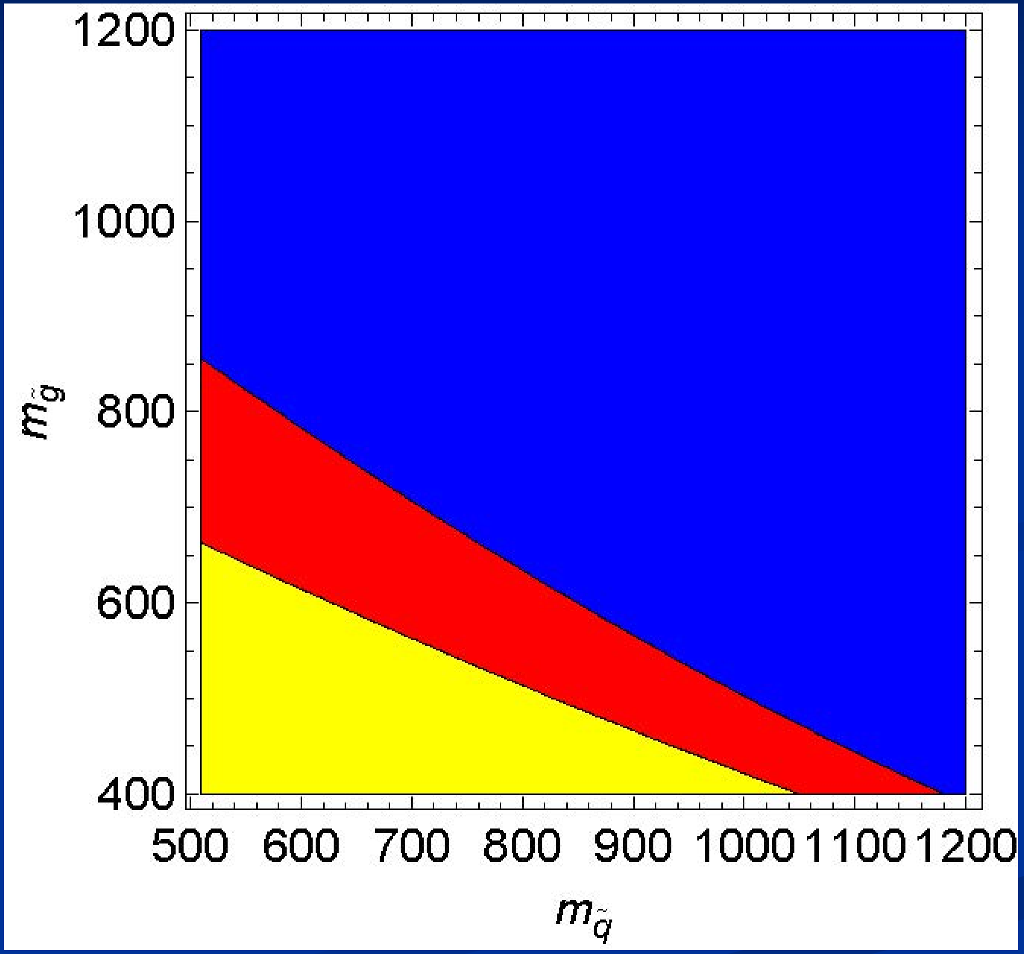
$$\Sigma_{23}^{d\,LR} \stackrel{!}{=} m_b V_{cb}$$

- Allowed regions from $b \to s\gamma$.
  Chirally enhanced corrections must be taken into account.
  A.C., Ulrich Nierste 2009

$m_b \mu \tan(\beta) = 0.12\ \text{TeV}^2$ (blue)

$m_b \mu \tan(\beta) = 0\ \text{TeV}^2$ (red)

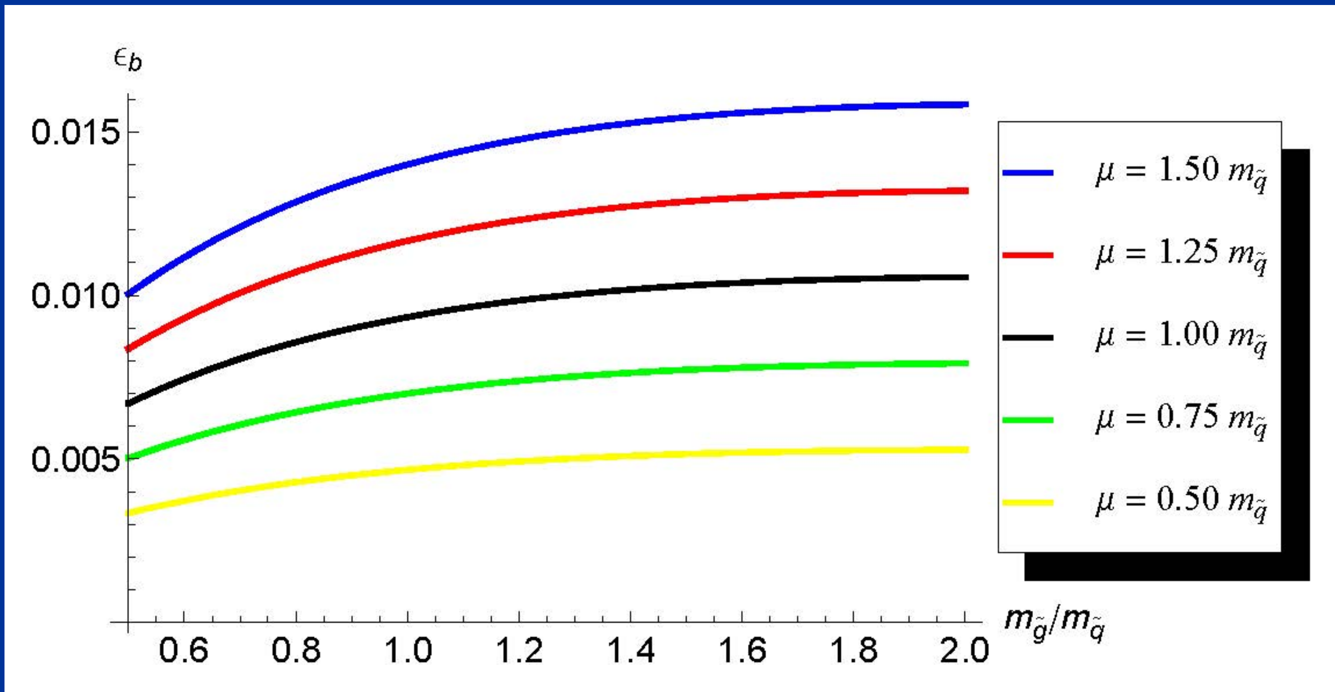
$m_b \mu \tan(\beta) = 0.12\ \text{TeV}^2$ (yellow)



Non-decoupling effects

- Non-holomorphic self-energies induce flavour-changing neutral Higgs couplings.
- Effect proportional to ε_b

$$\varepsilon_b = \frac{\Sigma_{33\,Y}^{d\,LR}}{v_u Y^b} \approx \frac{\alpha_s}{3\pi} \frac{m_{\tilde{g}}\mu}{\max\left(m_{\tilde{q}}^2, m_{\tilde{g}}^2\right)}$$



Higgs effects: $B_s \to \mu^+\mu^-$

- Constructive contribution due to

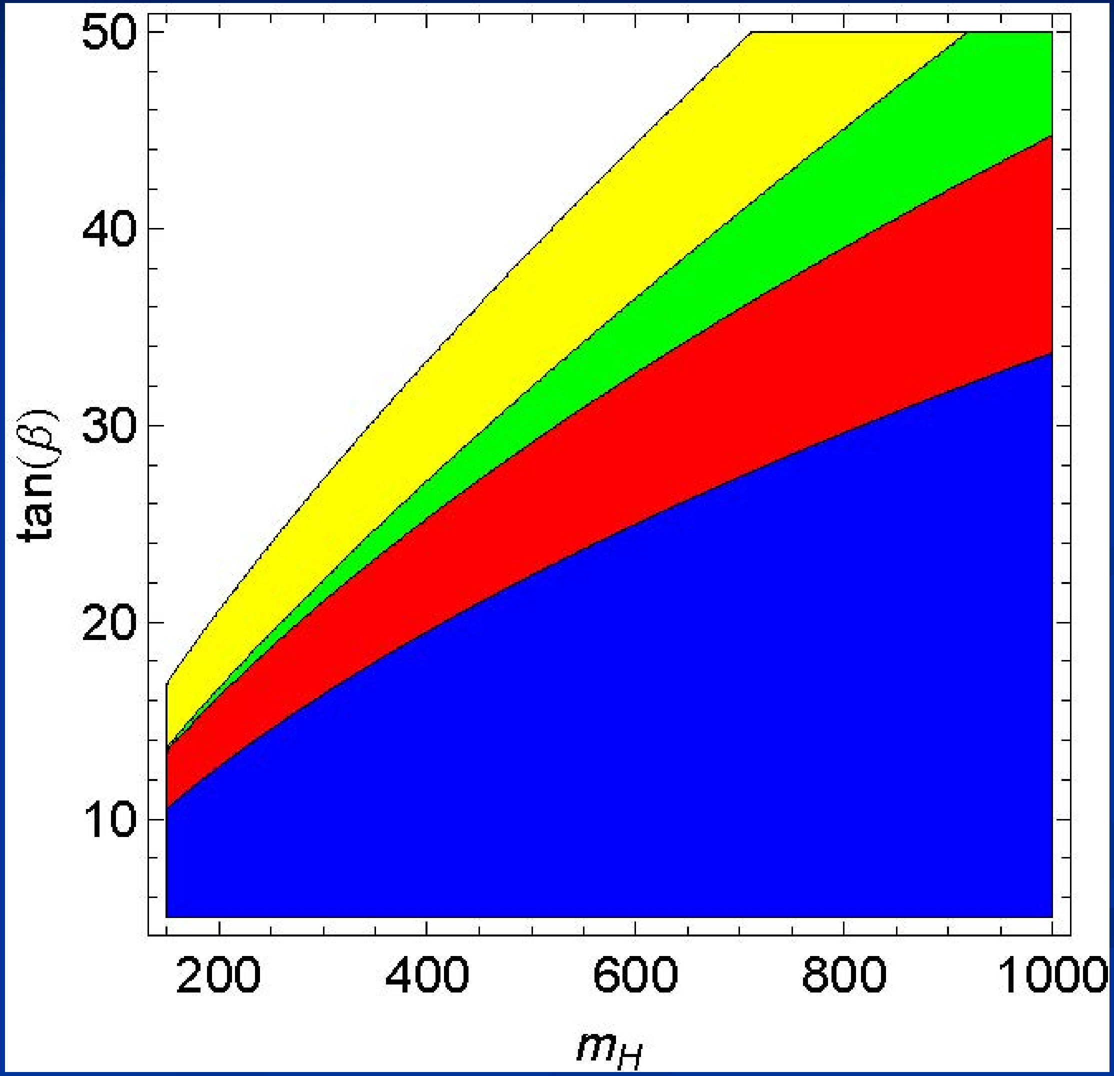
$$\Sigma_{23}^{d\,LR} = m_b V_{cb}$$

$\varepsilon_b = 0.005$

$\varepsilon_b = 0.01$

$\varepsilon_b = -0.005$

$\varepsilon_b = -0.01$

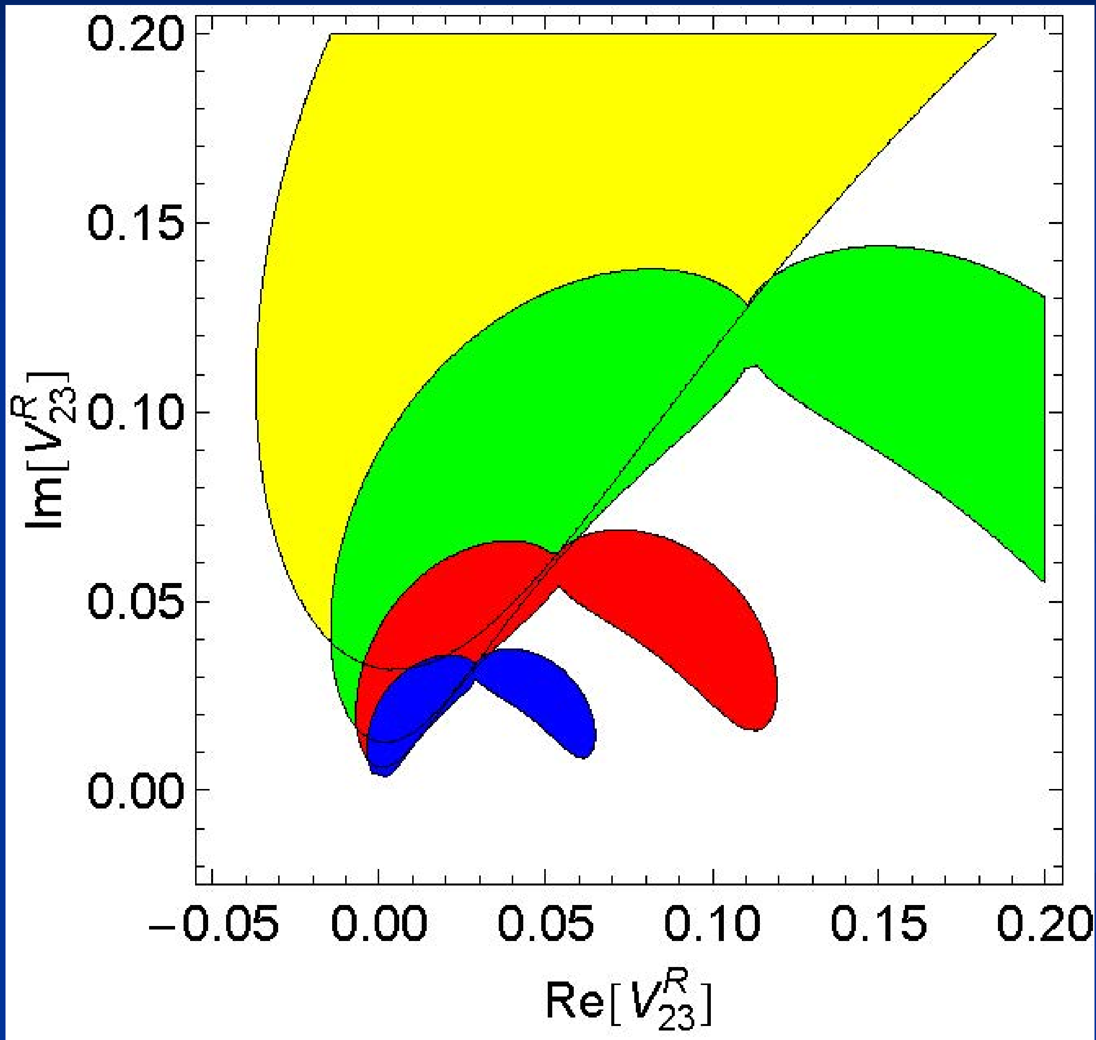


Higgs effects: B_s mixing

- Contribution only if

$$V_{23}^{R} = \frac{\Sigma_{23}^{d\,RL}}{m_b} \neq 0$$

due to Peccei-Quinn symmetry



$\tan(\beta) = 11$

$\tan(\beta) = 14$

$\tan(\beta) = 17$

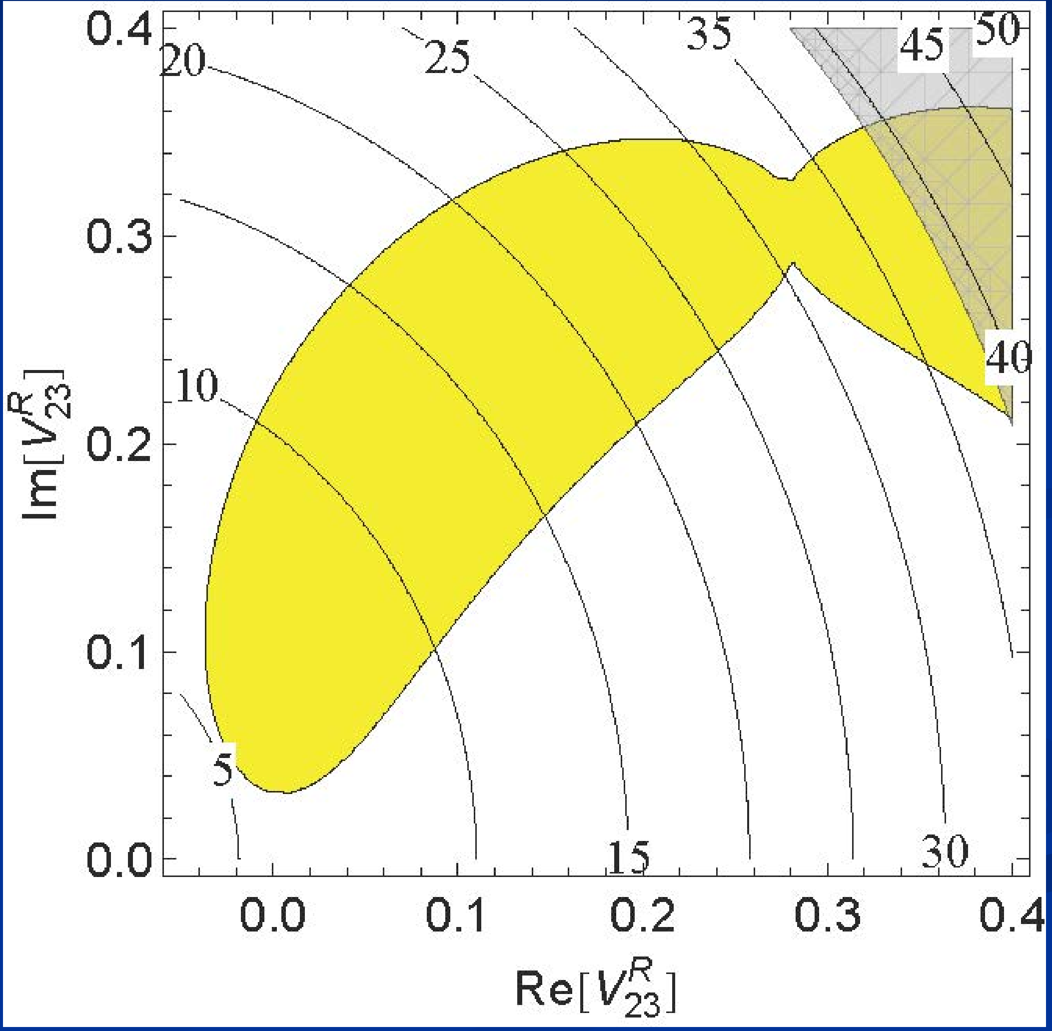
$\tan(\beta) = 20$

Correlations between B_s mixing and $B_s \to \mu^+\mu^-$

- $Br[B_s \to \mu^+\mu^-] \times 10^{-9}$

excluded by $B_s \to \mu^+\mu^-$

Allowed from B_s mixing for $\tan(\beta) = 11$

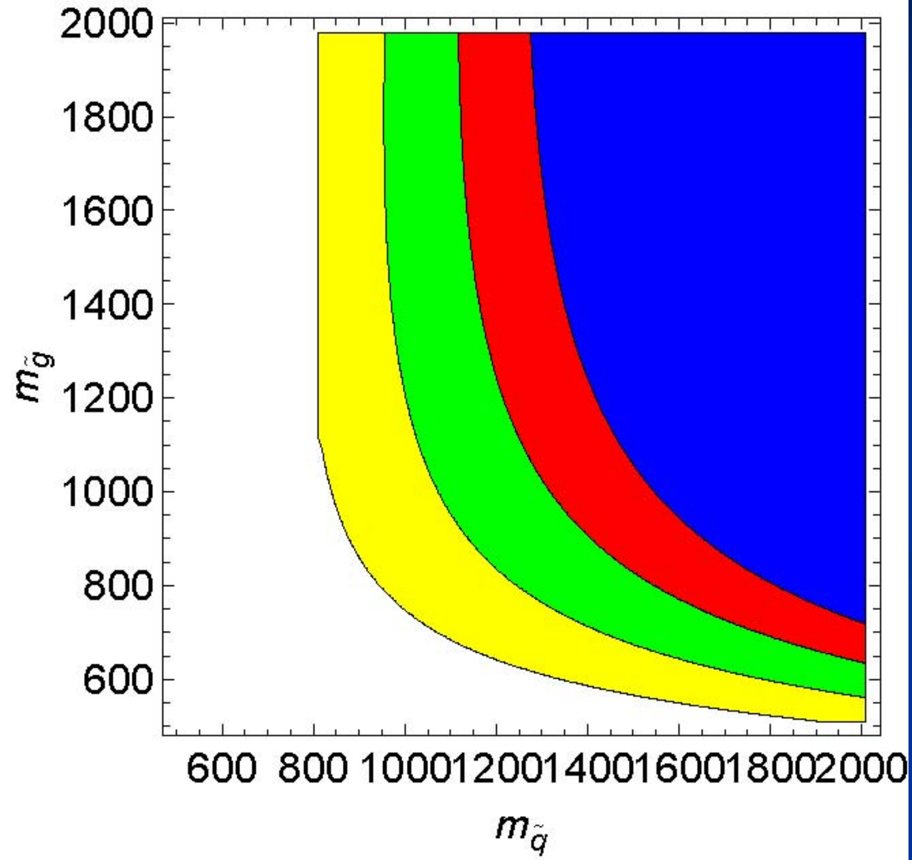


CKM generation in the up-sector:

$$\Sigma^{u\,LR}_{13} \overset{!}{=} m_t V^*_{td}$$

$$\Sigma^{u\,LR}_{23} \overset{!}{=} m_t V^*_{cb}$$

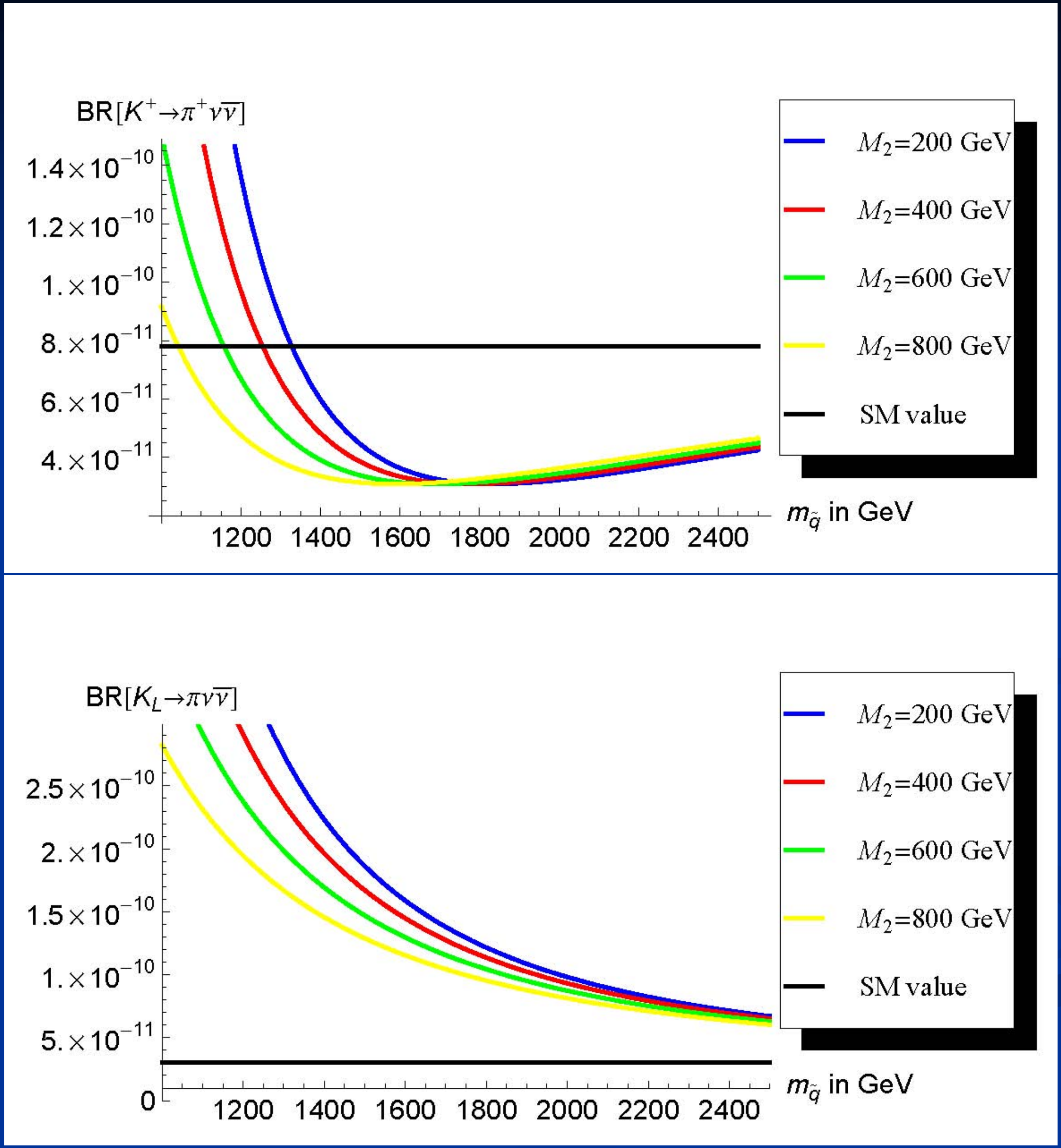
- Constraints from Kaon mixing.
- $\delta^{u\,LR}_{31}, \delta^{u\,LR}_{32}$ unconstrained from FCNC processes.
- $\delta^{u\,LR}_{31}$ can induce a sizable right-handed W coupling.



$M_2 = 200\text{GeV}$ $M_2 = 400\text{GeV}$

$M_2 = 400\text{GeV}$ $M_2 = 800\text{GeV}$

- Effects in K→πνν
- Verifiable predictions for NA62



A right-handed W coupling

in the MSSM

Effects on the determination of V_{ub} and V_{cb}

AC, arXiv:0907.2461

Motivation for a right-handed W coupling

- 2.2 σ discrepancy between the inclusive and exclusive determination of V_{cb}
- 2.5-2.7 σ deviation from the SM expectation in $B \to \tau\nu$
- Tree-level processes. Commonly believed to be free of NP. (Charged Higgs contribution to $B \to \tau\nu$ is destructive.)

➡ Notoriously difficult to explain the deviations from the SM

Effective field theory

$$L = L_{SM} + \frac{1}{\Lambda}\sum_i C_i Q_i^{(5)} + \frac{1}{\Lambda^2}\sum_i C_i Q_i^{(6)} + O\left(\frac{1}{\Lambda^3}\right)$$

Buchmüller, Wyler Nucl. Phys. B268 (1986)

- $O^{(5)}$ gives rise to neutrino masses
- Focus on the dimension 6 operator

$$Q_{RR} = \bar{u}_f \gamma^\mu P_R d_i \left(\tilde{\phi}^\dagger i D_\mu \phi\right)$$

which generates the anomalous W couplings

$$-i\frac{g_W}{\sqrt{2}}\gamma^\mu \left(P_L V_{fi}^L + P_R V_{fi}^R\right)$$

Possible size of V^R

- V_{tb}^R strongly constrained from $b \to s\gamma$

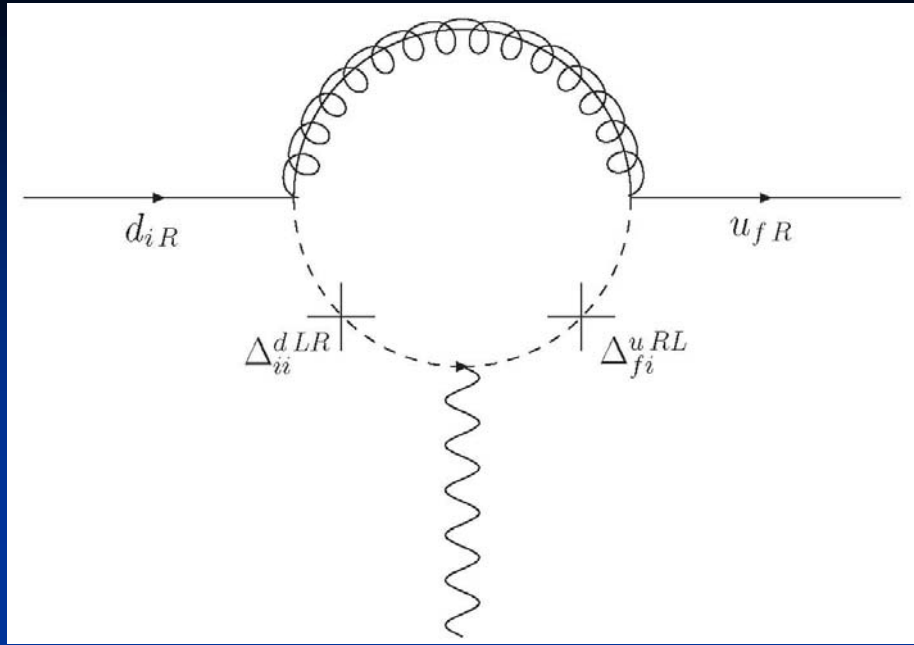
  Misiak et. al. 0802.1413

- $V_{ts}^R \left(V_{td}^R\right)$ also constrained from $b \to s\gamma$ ($b \to d\gamma$)

  A.C. Lorenzo Mercolli arXiv:1106.5499

- No large effect for the first two generations possible because the CKM elements are big and the chirality violation is small.
- Sizable effects possible in V_{ub}^R and V_{cb}^R

Genuine vertex-correction



$$-i\Lambda^{W\tilde{g}}_{u_f d_i} = \frac{g_2}{\sqrt{2}}\frac{i\alpha_s}{3\pi}\gamma^\mu \sum_{s,t=1}^{6}\sum_{j,k=1}^{3}\Big(W^{\tilde{u}}_{fs} W^{\tilde{u}*}_{ks} V^{CKM}_{kj} W^{\tilde{d}}_{jt} W^{\tilde{d}*}_{it} P_L + W^{\tilde{u}}_{f+3,s} W^{\tilde{u}*}_{ks} V^{CKM}_{kj} W^{\tilde{d}}_{jt} W^{\tilde{d}}_{i+3,t}{}^{*} P_R \Big) C_2\left(m_{\tilde{u}_s}, m_{\tilde{d}_t}, m_{\tilde{g}}\right)$$

- Corrections to the left-handed coupling suppressed because the hermitian part of the WFR cancels with the genuine vertex correction.
- Right-handed coupling not suppressed!

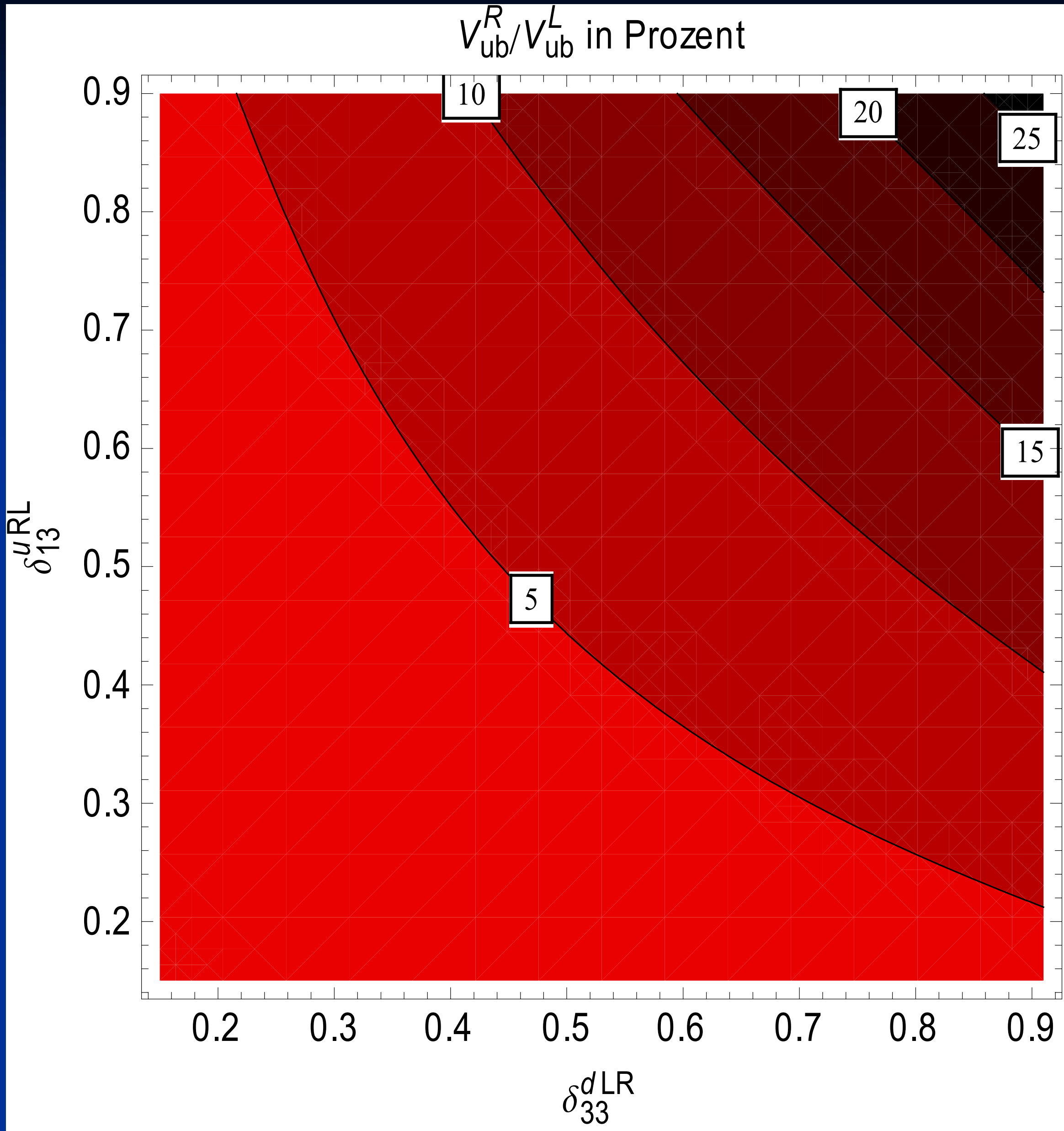
Where are SUSY effects possible?

- $\delta^{d\,LR/RL}_{fi}$ strongly constrained from FCNC processes.
- $\delta^{u\,LR}_{13,23}$ less constrained from FCNC but constrained from the CKM renormalization.

  $\delta^{u\,LR,LL,RR}_{12,21}$ constrained from D mixing
- $\delta^{u\,RL}_{13,23}$ nearly unconstrained from FCNCs and not involved in the CKM renormalization.
- Large $\delta^{d\,LR}_{33}$ possible if A^b or tan(β) is large.
- V_{ud}, V_{us}, V_{cd}, V_{cs} are to large for observable effects

⟹ Only V_{ub}, V_{cb} can be affected by SUSY effects.

Biggest SUSY effect in $V_{ub.}$



Effect in V_{cb} ≈10%

Right-handed W coupling in exclusive and inclusive B decays

V = measured CKM element

- Exclusive leptonic B decays: $\sim|\gamma^\mu\gamma^5|^2$

  ⇒ $V^L=V+V^R$

- Exclusive semi-leptonic B decays to pseudo-scalar mesons $\sim|\gamma^\mu|^2$

  ⇒ $V^L=V-V^R$

- Exclusive semi-leptonic B decays to vector mesons $\sim|\gamma^\mu\gamma^5|^2$ at $\omega=1$
- Inclusive B→u decay $\sim|1+\gamma^\mu\gamma^5|^2+|1-\gamma^\mu\gamma^5|^2$

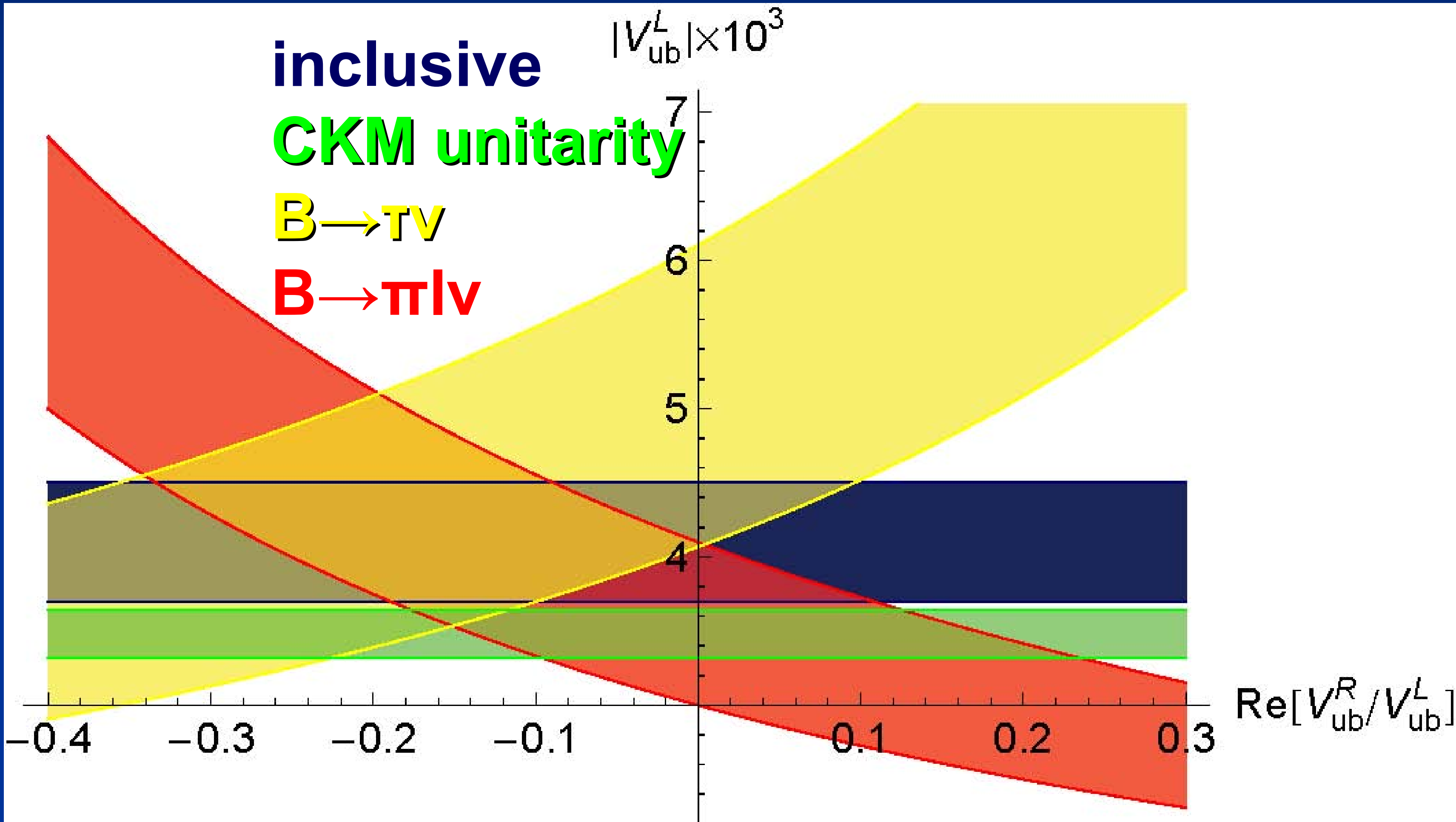
  ⇒ $V^L\approx V$

- Inclusive B→c decay receive correction proportional to m_c/m_b

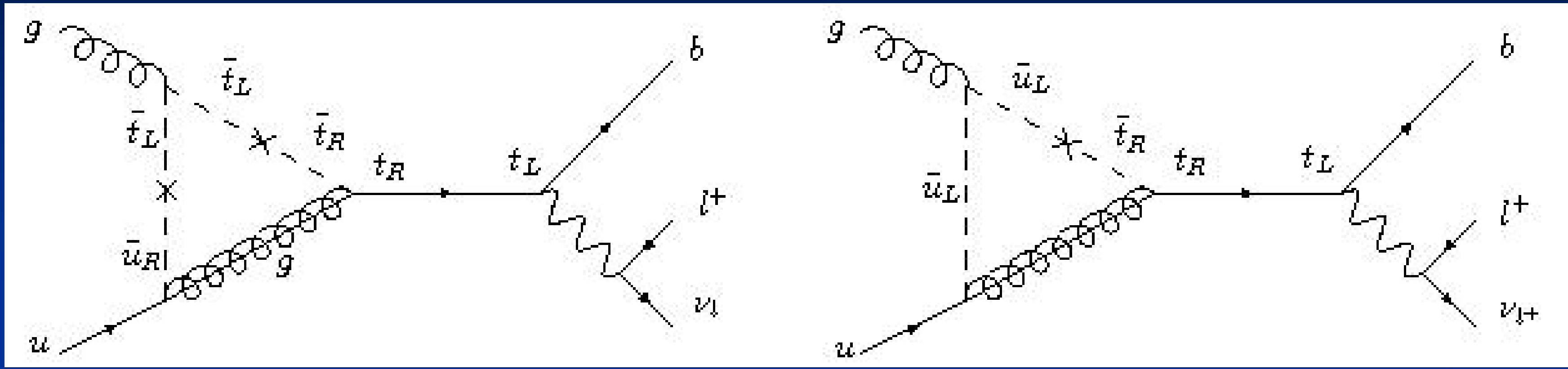
Dassinger, Feger, Mannel: Complete Michel Parameter Analysis of inclusive semileptonic b→c transition

⇒ $V^L=V+0.56V^R$

Effects of a right-handed W-coupling on V_{ub}

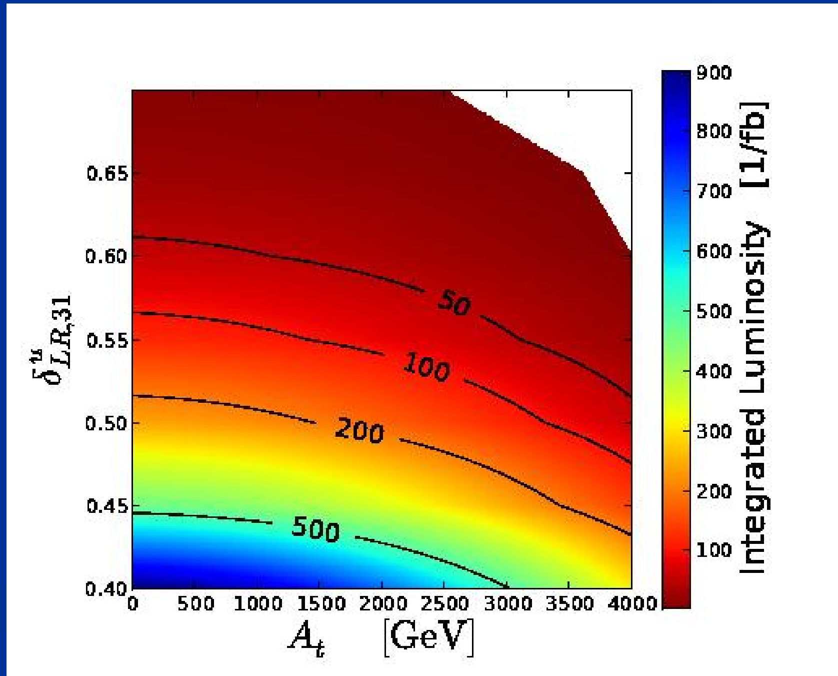


Connection to Single Top Production



Feynman diagrams contributing to Single Top production

Integrated luminosity necessary to discover Single Tops



Plehn, Rauch, Spannowski: 0906.1803

Constraints on the mass splitting between left-handed squarks from D and K mixing

AC, Momchil Davidkov, arXiv:1002.2653

K and D mixing

- Mass difference is small:

$$\Delta m_K / m_K = (7.01 \pm 0.01) \times 10^{-15}$$

$$\Delta m_D / m_D = (8.6 \pm 2.1) \times 10^{-15}$$

- CP violation is tiny

$$\varepsilon_K = (2.23 \pm 0.01) \times 10^{-3}$$

$$A_T = (1.2 \pm 2.5) \times 10^{-3}$$

➡ Constrains FCNCs between the first two generations in a stringent way.

SUYS Contributions

- SU(2)$_L$ relation: $m_{LL}^{\tilde{u}\,2} = V^{\dagger} m_{LL}^{\tilde{d}\,2} V$

SUSY contributions to D and Kaon mixing can only be simultaneously avoided if $m_{LL}^{\tilde{u}\,2}$ is proportional to the unit matrix.

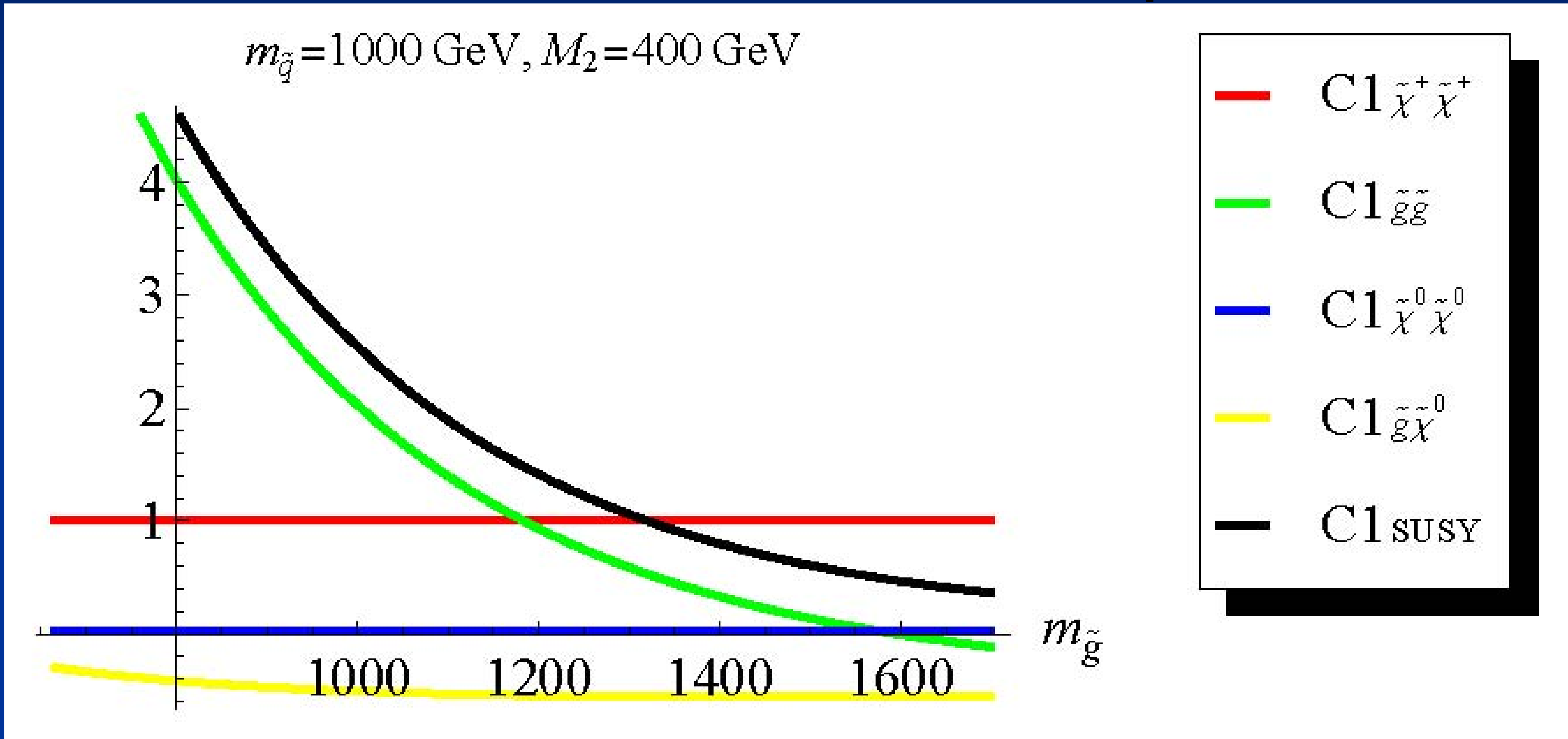
➡ $\delta_{12}^{q\,LL}$ elements are induced if the left-handed squarks of the first two generations are not degenerate.

Electroweak contributions are important for

In non-minimal flavor violation the main focus is on the gluino contributions, however:

- The gluino contributions suffer from cancellations between the crossed and uncrossed boxes for $m_{\tilde{q}} = 1.5 m_{\tilde{g}}$
- Chargino diagrams do not suffer from such a cancellation.
- Winos couple directly to left-handed squarks with g_2. $\delta_{ij}^{q\,LL}$ can contribute without small LR or gaugino mixing.
- The wino mass is often assumed to be much lighter than the gluino mass. In most GUT scenarios: $M_2 \approx m_{\tilde{g}}\,\alpha_2/\alpha_s$

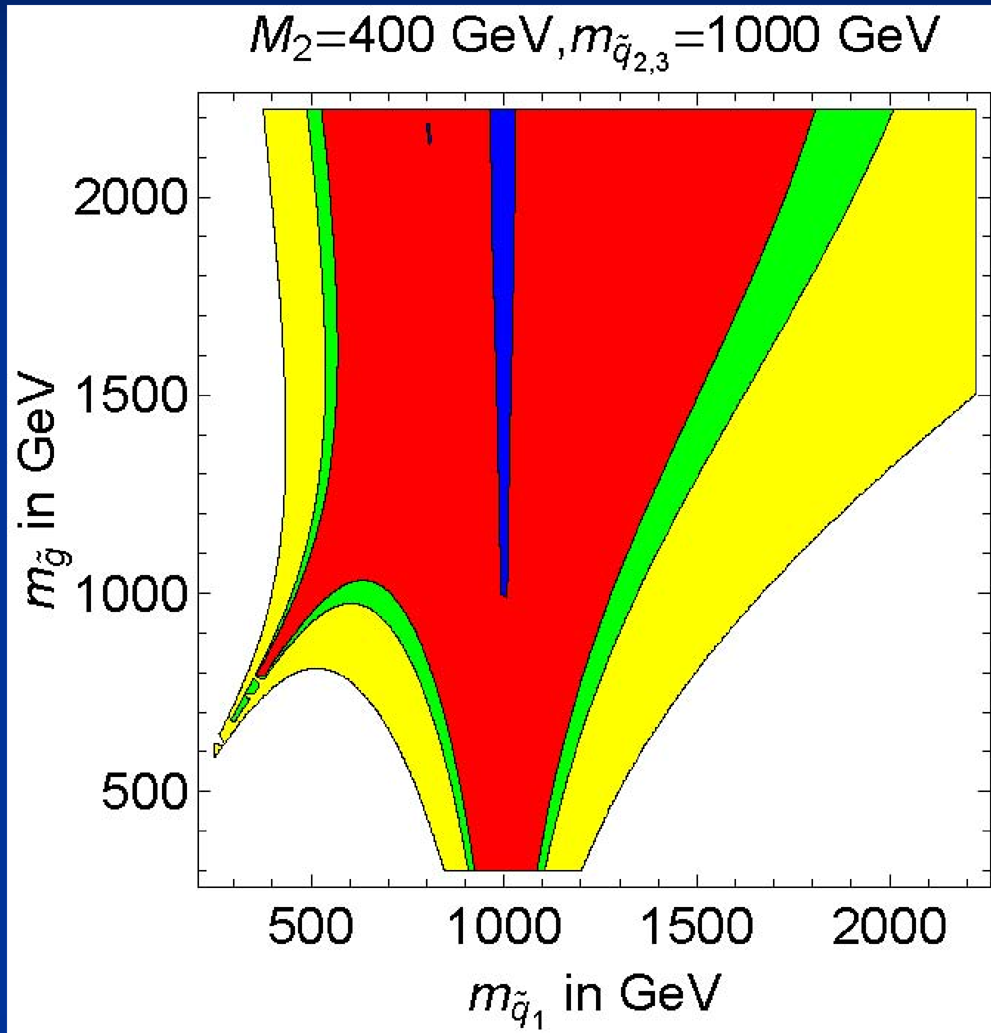
Relative importance of the contributions to C_1



normalized to the chargino contribution:

Allowed mass splitting

- Non-degenerate squark masses are allowed.
- More space for models with abelian flavor symmetries.
- Interesting for LHC benchmark scenarios.



Maximally allowed mass-splitting

Alignment to Y^d

Alignment to Y^u

Minimally allowed mass-splitting

Conclusions

- Self-energies in the MSSM can be of order one.
- Chirally enhanced corrections must be taken into account in FCNC processes.
- A-terms generate flavor-changing neutral Higgs couplings.
- Radiative generations of light fermion masses and mixing angles solves the SUSY flavor and the SUSY CP problem. It can explain B_s mixing and enhance $B_s \to \mu^+\mu^-$.
- The first two generations of left-handed squarks can be non-degenerate.
- The MSSM can generate a sizeable right-handed W-coupling.

⇒ **Tree-level processes are not necessarily free of NP!**

Finite renormalization

(general formalism)

Decomposition of the self-energies:

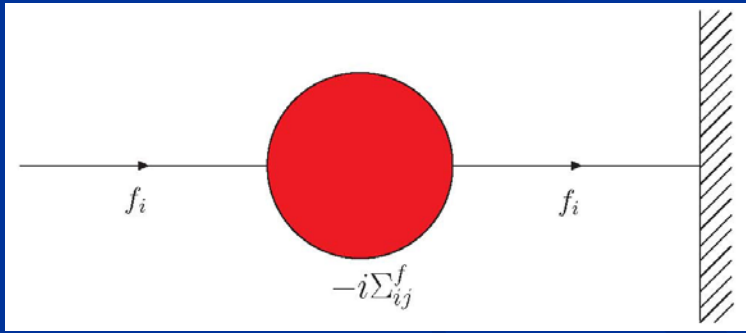
$$\Sigma_{fi}^{q}(p) = \Sigma_{fi}^{q\,LR}(p^2)P_R + \Sigma_{fi}^{q\,RL}(p^2)P_L + \not{p}\left(\Sigma_{fi}^{q\,RR}(p^2)P_R + \Sigma_{fi}^{q\,LL}(p^2)P_L\right)$$

Corrections to the Mass:

$$m_{q_i}^{(0)} \to m_{q_i}^{(0)} + \Sigma_{ii}^{q\,LR}(m_{q_i}^2) + \frac{1}{2}m_{q_i}\left(\Sigma_{ii}^{q\,LL}(m_{q_i}^2) + \Sigma_{ii}^{q\,RR}(m_{q_i}^2)\right) + \delta_{q_i}^{m} = m_{q_i}^{phys}$$

Flavor valued wave-function corrections:

$$U_{fi}^{L(0)} \to U_{fi}^{L(0)} + \sum_{j=1}^{3} U_{fj}^{L(0)} \Delta U_{ji}^{q\,L}$$



with

$$\Delta U_{fi}^{q\,L} = \frac{1}{m_{q_i}{}^2 - m_{q_f}{}^2}\left(m_{q_i}{}^2\Sigma_{fi}^{d\,LL}(m_{q_f}^2) + m_{q_i}m_{q_f}\Sigma_{fi}^{d\,RR}(m_{q_f}^2) + m_{q_i}\Sigma_{fi}^{d\,LR}(m_{q_f}^2) + m_{q_f}\Sigma_{fi}^{d\,RL}(m_{q_f}^2)\right), \quad f \neq i$$

$$\Delta U_{ii}^{q\,L} = \frac{1}{2}\mathrm{Re}\left[\Sigma_{ii}^{q\,LL}(m_{q_i}^2) + 2m_{q_i}\Sigma_{ii}^{q\,LR\prime}(m_{q_i}^2) + m_{q_i}^2\left(\Sigma_{ii}^{q\,LL\prime}(m_{q_i}^2) + \Sigma_{ii}^{q\,RR\prime}(m_{q_i}^2)\right)\right]$$

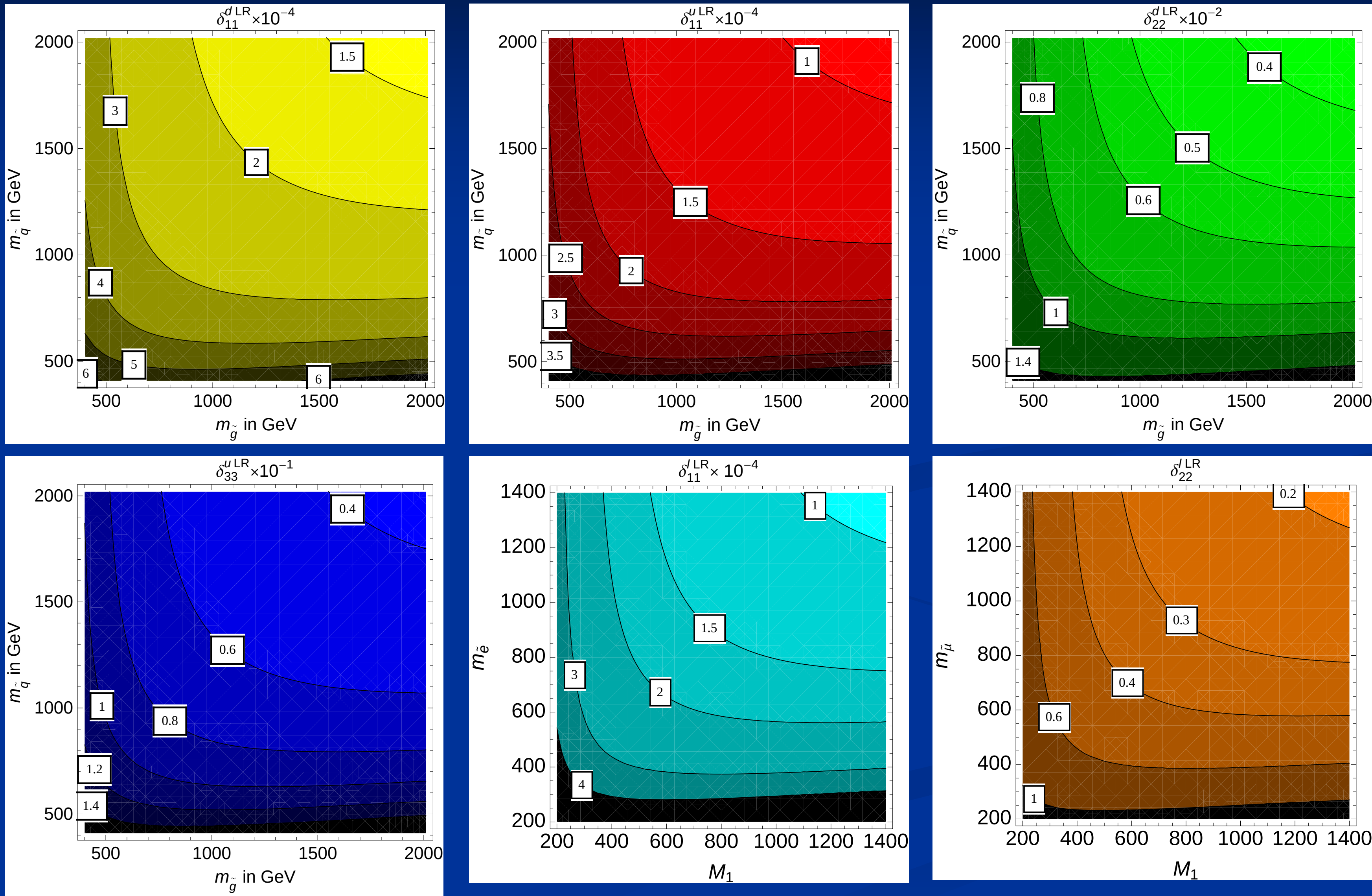
Fine-tuning constraints

't Hooft's naturalness argument:

- A small parameter is natural if a symmetry is gained if parameter is put to zero
- Large accidental cancellations, not enforced by a symmetry are unnatural

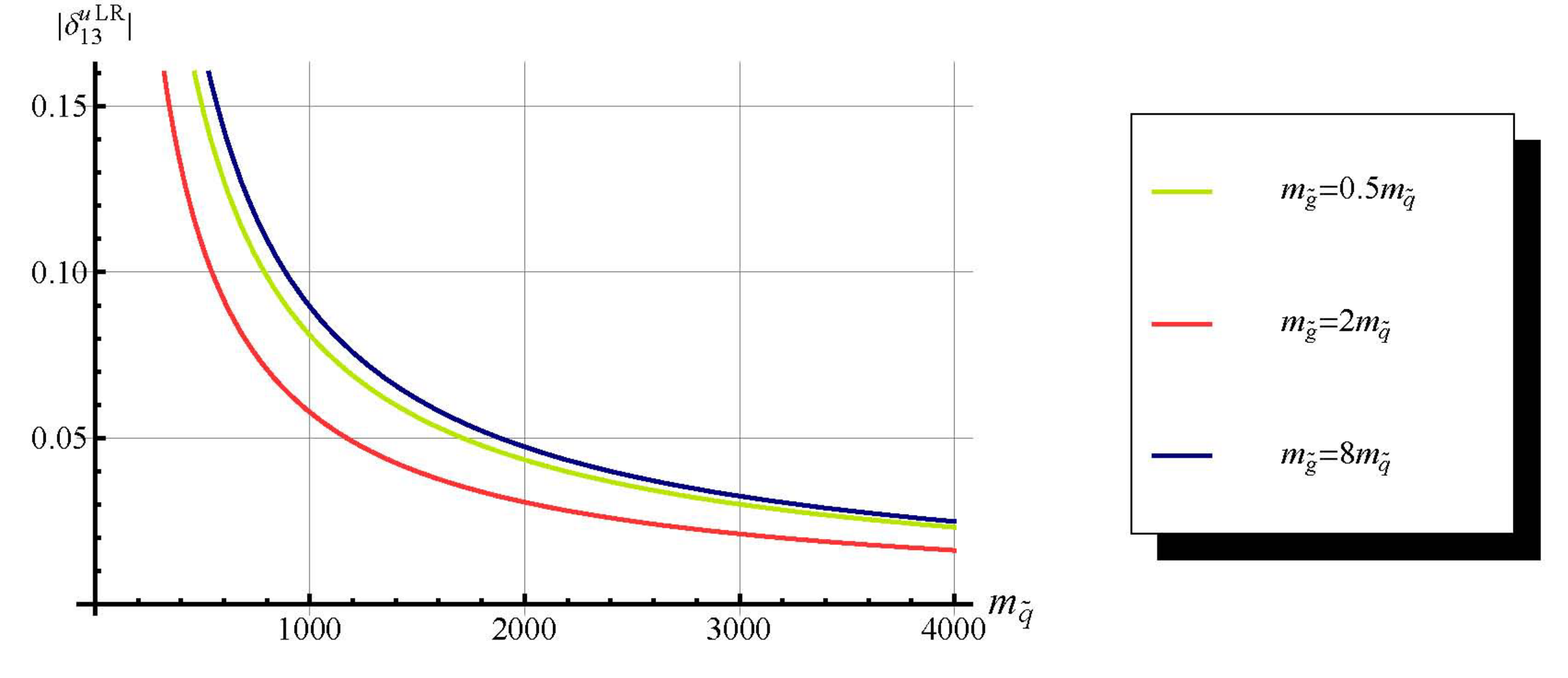
⇒ The SUSY corrections to the masses and mixing angels should not exceed the measured values.

Constrains from fermion masses I:



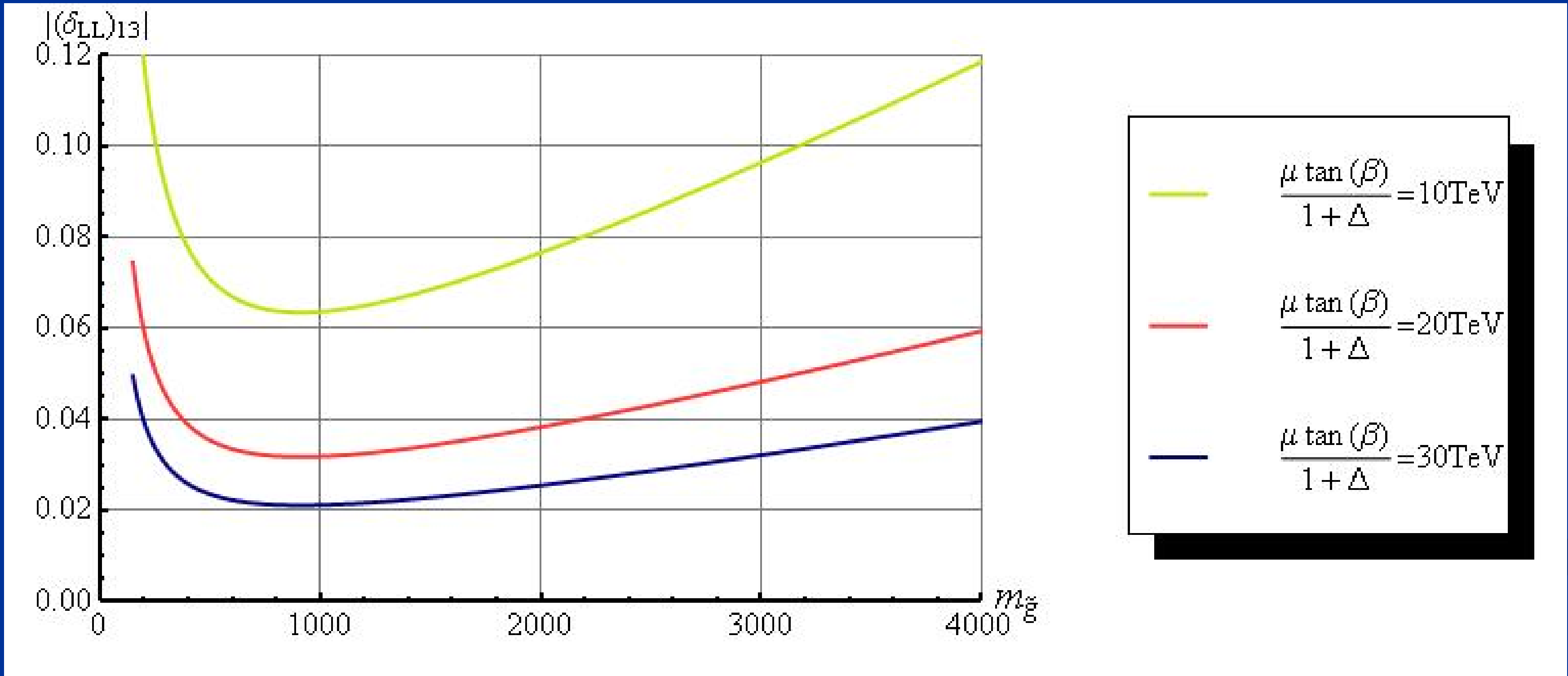
Constrains from the CKM matrix:

Example: V_{ub}



Constraints on $\delta_{13}^{d\,LL}$ from V_{ub}

For large helicity flipping elements, for example $m_b \mu \tan(\beta)$, also $\delta_{ij}^{q\,LL}$ can be constrained. Strongest for $\delta_{13}^{q\,LL}$:



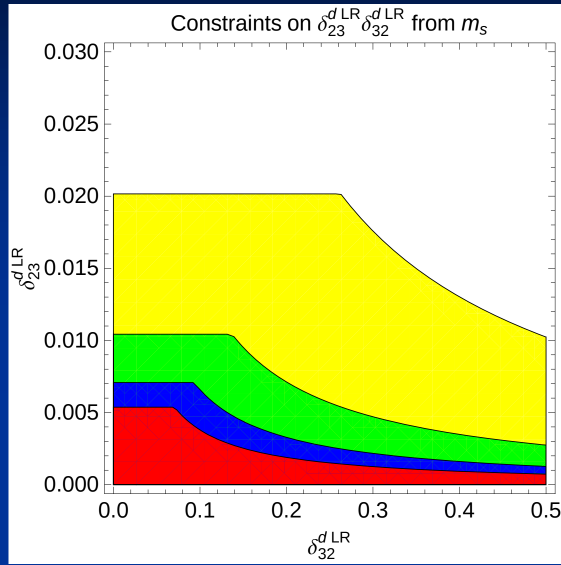
Constrains from fermion masses II:

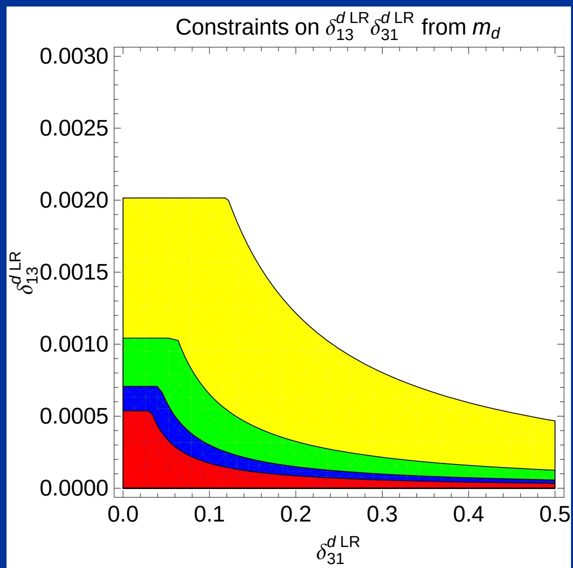
$m_{SUSY} = 500\text{GeV}$ (yellow)

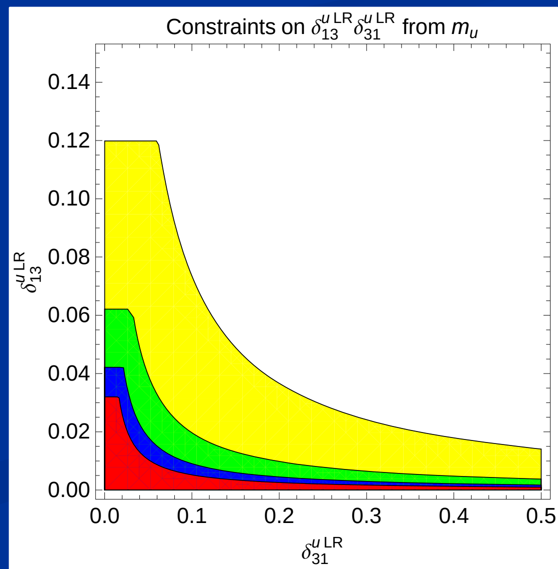
$m_{SUSY} = 1000\text{GeV}$ (green)

$m_{SUSY} = 1500\text{GeV}$ (blue)

$m_{SUSY} = 2000\text{GeV}$ (red)







Existing results:

FCNC bounds (decoupling):

•M. Ciuchini et al. [arXiv:hep-ph/9808328]
•F. Borzumati, C.Greub, T.Hurth and D.Wyler [arXiv:hep-ph/9911245]
•D. Becirevic et al. [arXiv:hep-ph/0112303]
•M. Ciuchini et al. [arXiv:hep-ph/0703204]
•…

Vacuum stability bounds (non-decoupling):

J.A.Casas and S.Dimopoulos,
Stability bounds on flavor-violating trilinear soft terms in the MSSM,
Phys. Lett. B**387** (1996) 107 [arXiv:hep-ph/9606237]

Results and comparison

quantity	our bound	bound from FCNC	bound from vacuum stability
$\delta^{d\,LR}_{12}$	0.0011	0.006, K mixing	0.00015
$\delta^{d\,LR}_{13}$	0.001	0.15, B_d mixing	0.005
$\delta^{d\,LR}_{23}$	0.01	0.06, $b \to s\gamma$	0.05
$\delta^{d\,LL}_{13}$	0.032	0.5, B_d mixing	--
$\delta^{u\,LR}_{12}$	0.0047	0.016, D mixing	0.0012
$\delta^{u\,LR}_{13}$	0.027	--	0.22
$\delta^{u\,LR}_{23}$	0.27	--	0.22

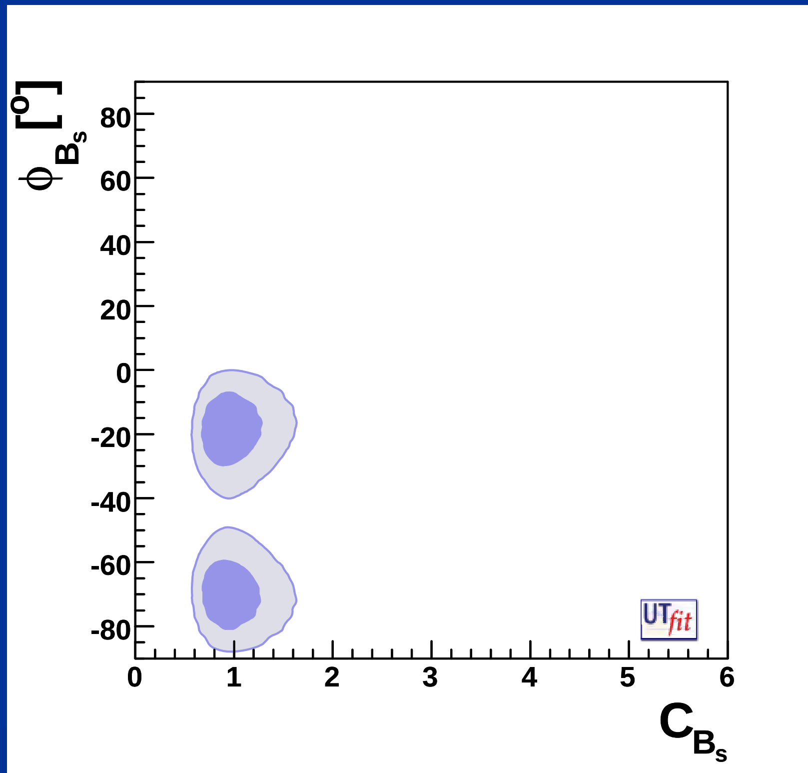
Bounds calculated with $m_{squark}=m_{gluino}=1000GeV$

Allowed range for NP in ΔF=2 processes

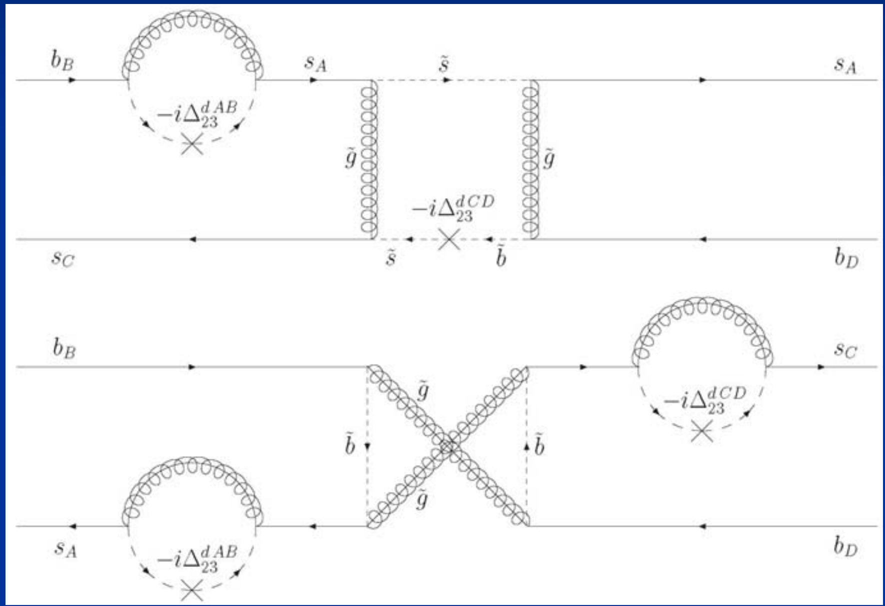
Results taken for: **UTfit** Collaboration: www.utfit.org

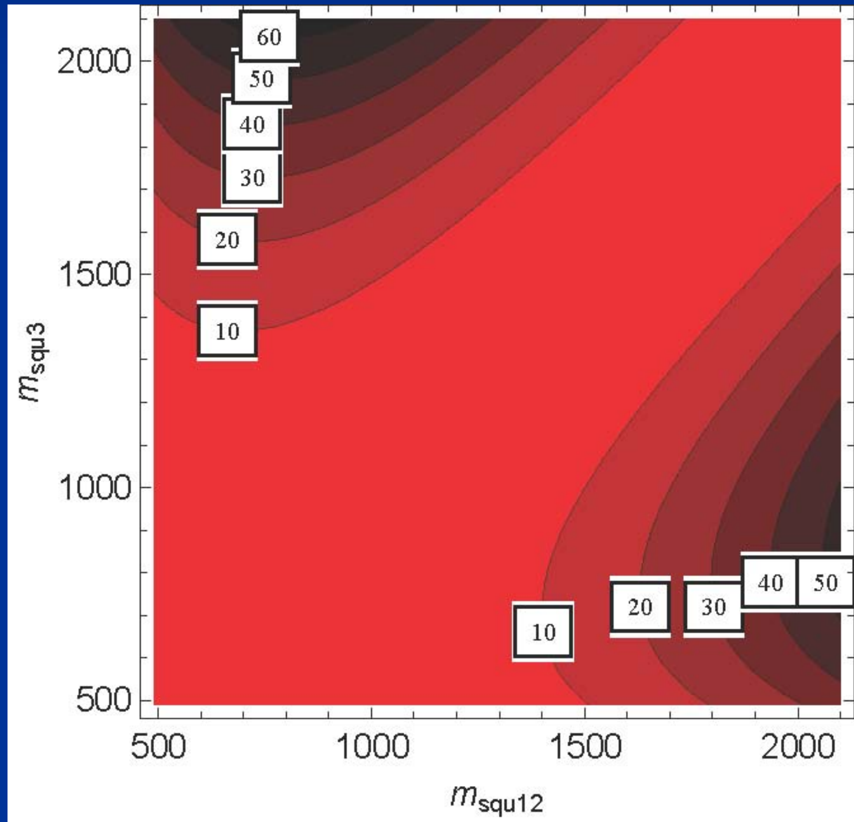
Example: B_s mixing

$$C_{B_s} e^{2i\phi_{B_s}} = \frac{\langle B_s | H_{eff}^{full} | \bar{B}_s \rangle}{\langle B_s | H_{eff}^{SM} | \bar{B}_s \rangle}$$



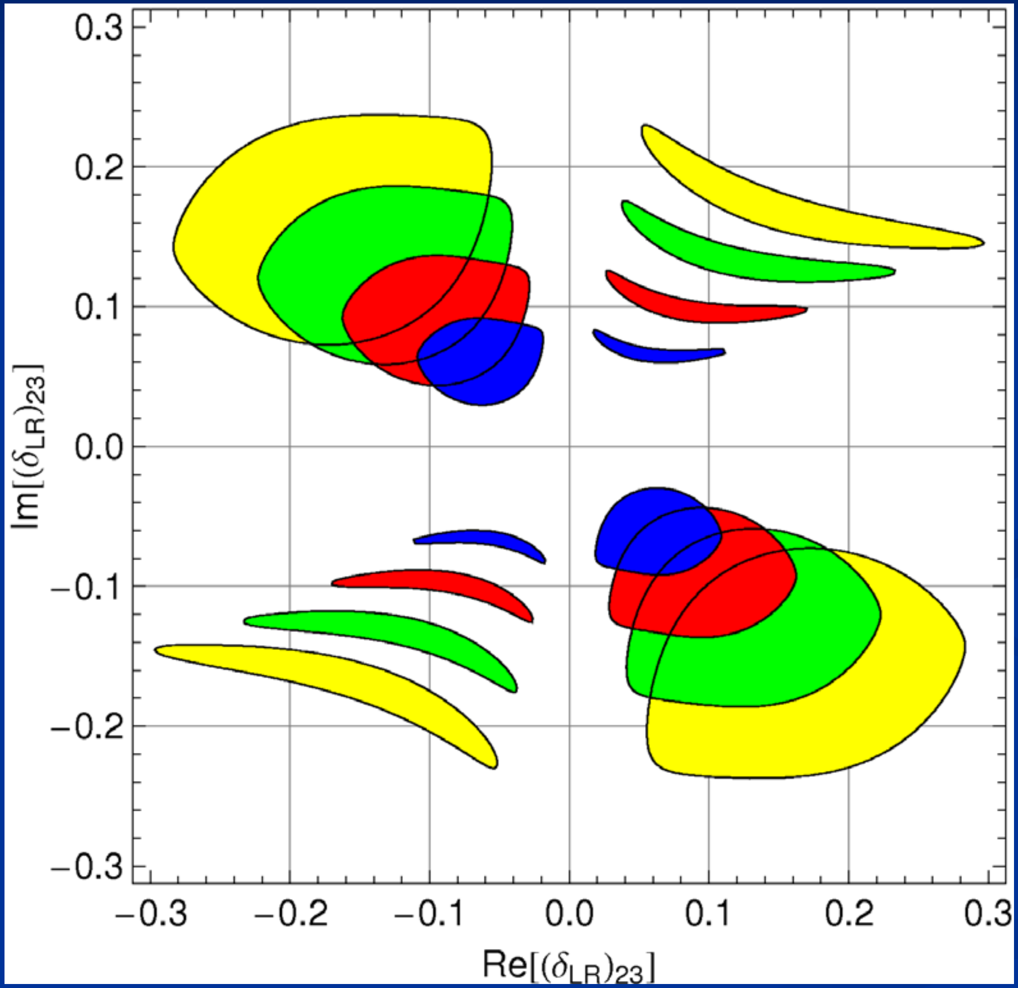
Effect of including the self-energies in ΔF=2 processes





$$\frac{\Delta M_{Bren}}{\Delta M_B} \quad \text{for} \quad m_{\tilde{g}} = 1000\text{GeV}$$

Constraints on $(\delta_{LR})_{23}$ from B_s mixing



$$M^{\tilde{q}}_{1,2L/R} = 2M^{\tilde{q}}_{3L/R} = 1\mathrm{TeV}$$

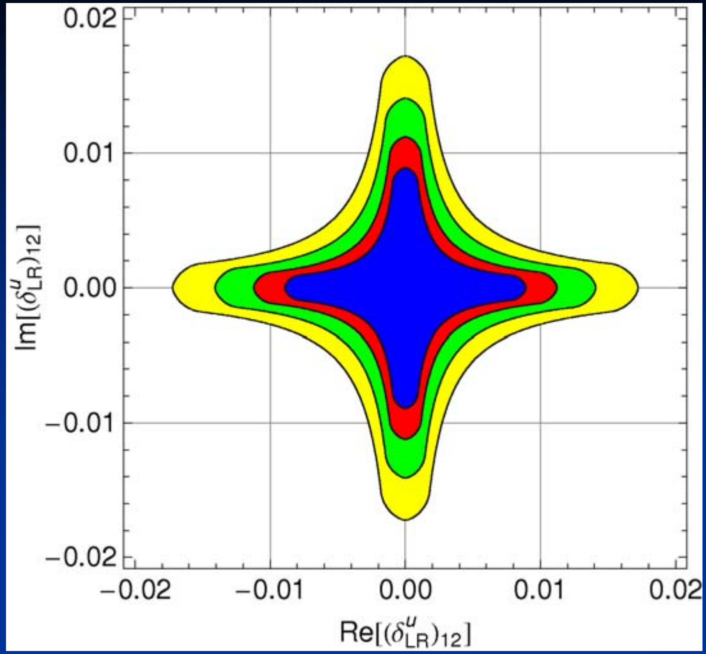
$m_{\tilde{g}} = 2000\mathrm{GeV}$

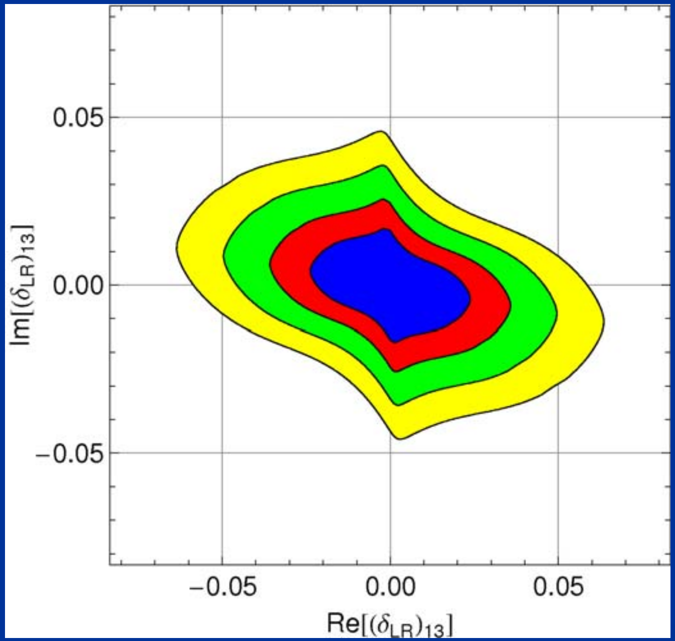
$m_{\tilde{g}} = 1500\mathrm{GeV}$

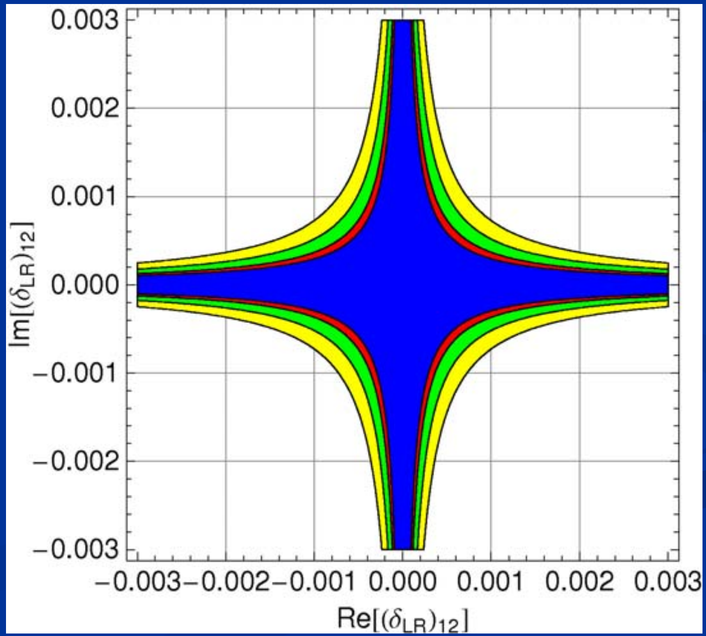
$m_{\tilde{g}} = 1000\mathrm{GeV}$

$m_{\tilde{g}} = 500\mathrm{GeV}$

Constraints on δ_{LR} from D, B, and K mixing







Constraints on δ_{23} from $b \to s\gamma$

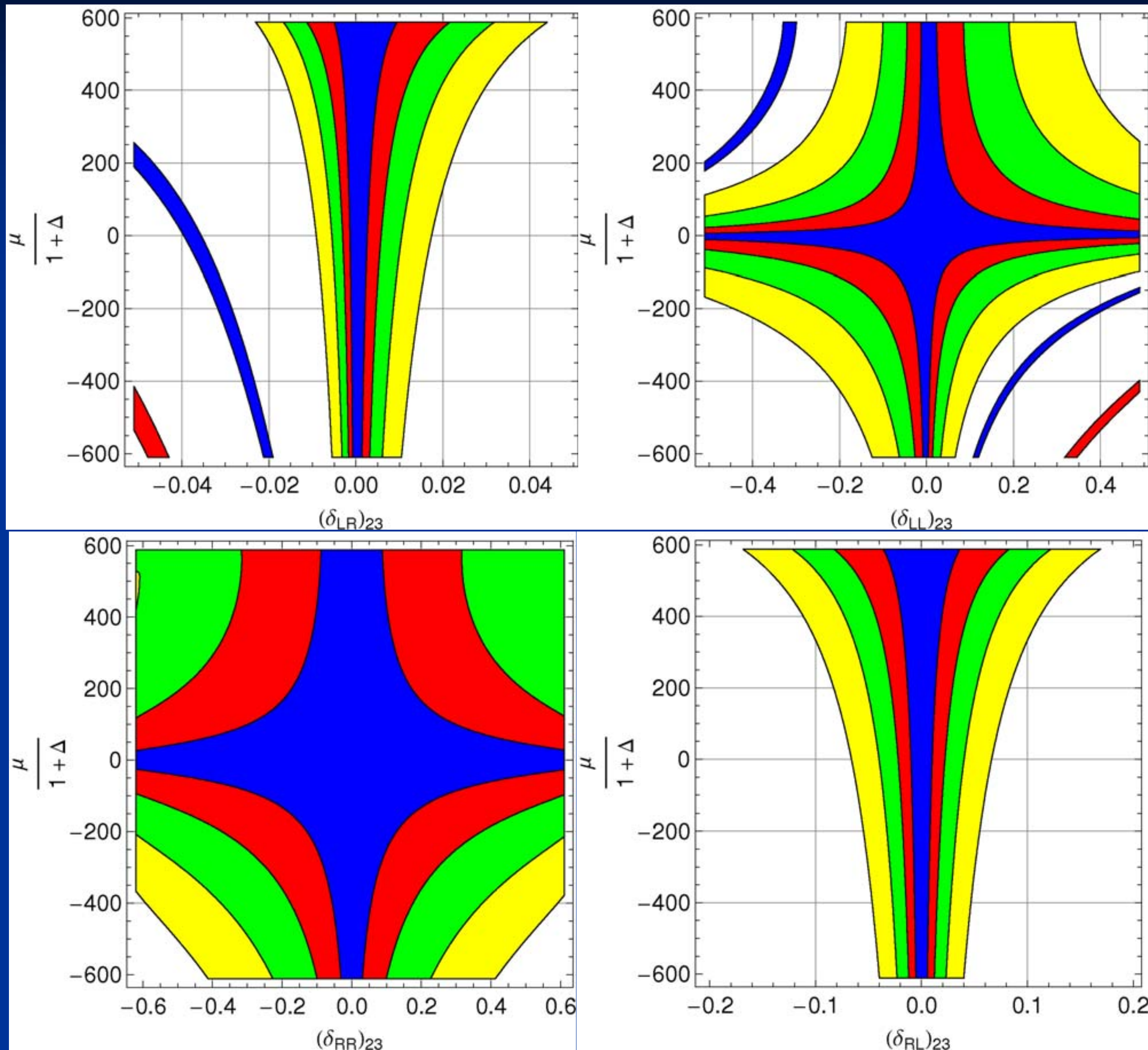
$\tan(\beta) = 50$

$m_{\tilde{g}} = 2000\text{GeV}$

$m_{\tilde{g}} = 1500\text{GeV}$

$m_{\tilde{g}} = 1000\text{GeV}$

$m_{\tilde{g}} = 500\text{GeV}$

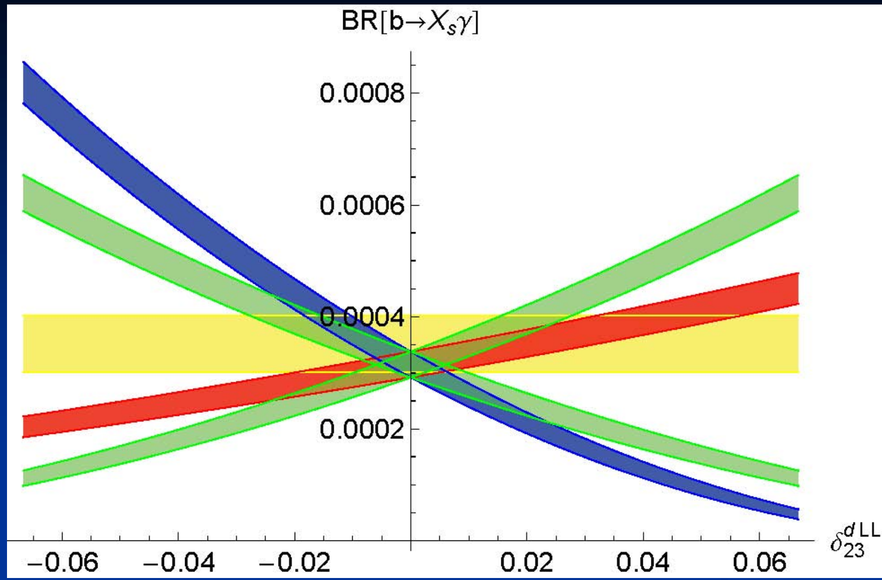


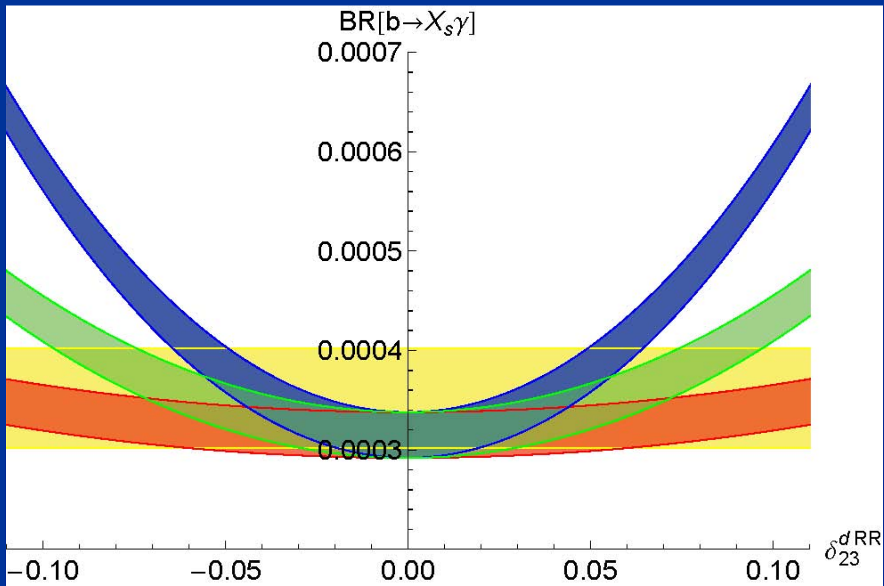
experimentally allowed range

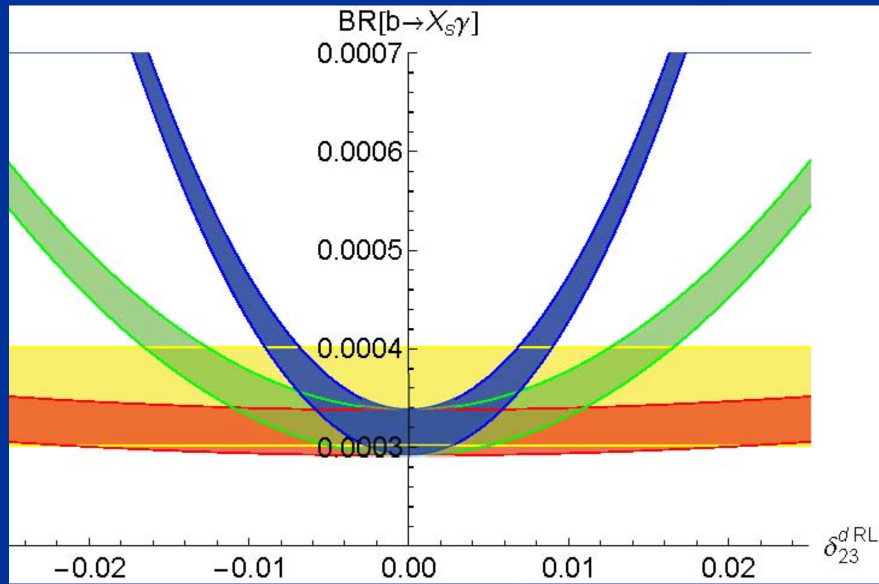
$m_b \mu \tan(\beta) = 0\text{TeV}$

$m_b \mu \tan(\beta) = -30\text{TeV}$

$m_b \mu \tan(\beta) = 30\text{TeV}$







Effects of a right-handed W-coupling on V_{cb}