Andreas Crivellin
TTP Karlsruhe

A-terms and a right-handed W coupling in the MSSM

Effects of right-handed charged currents on the determinations of |Vub| and |Vcb|.
Andreas Crivellin **arXiv:0907.2461** [hep-ph]

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]

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

Outline:

- The SUSY flavour-problem and the squark mass matrix
- Non-decouling chirality-changing SQCD self-energies
- Flavour from SUSY?
- Flavour-changing self-energies and FCNC processes
  (D, B_s, B_d, K mixing and $b \to s\gamma$)
- Right-handed W-coupling and the determination of V_{ub} and V_{cb}.

SUSY flavour problem

- Squark mass matrices are not necessarily diagonal in the same basis as the quark mass matrices

→ Quark-squark-gluino vertex is in general flavour-changing

Dangerously large flavour-mixing in FCNC processes because of the strong coupling constant.

Squark mass matrix

$$M_{\tilde{u}}^{w\,2} = \begin{pmatrix} \mathbf{m}_{\tilde{q}}^2 + M_z^2\left(1+\frac{2}{3}\sin^2\theta_w\right)\cos 2\beta + \mathbf{m}_u^{(0)}\mathbf{m}_u^{(0)\dagger} & v_u\mathbf{A}^u - \mathbf{m}_u^{(0)}\mu\cot(\beta) \\ v_u\mathbf{A}^{u\dagger} - \mathbf{m}_u^{(0)\dagger}\mu^*\cot(\beta) & \mathbf{m}_{\tilde{u}}^2 + \frac{2}{3}M_z^2\sin^2\theta_w\cos 2\beta + \mathbf{m}_u^{(0)}\mathbf{m}_u^{(0)\dagger} \end{pmatrix}$$

$$M_{\tilde{d}}^{w\,2} = \begin{pmatrix} \mathbf{m}_{\tilde{q}}^2 - M_z^2\left(1+\frac{1}{3}\sin^2\theta_w\right)\cos 2\beta + \mathbf{m}_d^{(0)}\mathbf{m}_d^{(0)\dagger} & v_d\mathbf{A}^d - \mathbf{m}_d^{(0)}\mu\tan(\beta) \\ v_d\mathbf{A}^{d\dagger} - \mathbf{m}_d^{(0)\dagger}\mu^*\tan(\beta) & \mathbf{m}_{\tilde{d}}^2 - \frac{1}{3}M_z^2\sin^2\theta_w\cos 2\beta + \mathbf{m}_d^{(0)}\mathbf{m}_d^{(0)\dagger} \end{pmatrix}$$

Chirality conserving, flavour non-diagonal

Chirality flipping and flavour non-diagonal

Chirality flipping, flavour diagonal, but $O(1)$ for large tan(β)

$\tan(\beta)=v_u/v_d$

Squark mass matrix is hermitian → $W^{\tilde{q}\dagger} M^2_{\tilde{q}} W^{\tilde{q}} = M^{2(D)}_{\tilde{q}}$

Parameterization:

In the convention of: F. Gabbiani, E. Gabrielli, A. Masiero and L. Silvestrini, Nucl. Phys. B 477 (1996) 321 [arXiv:hep-ph/9604387].

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

with

$$M^{\tilde{q}\,2}_{AA} = \begin{pmatrix} M^{\tilde{q}\,2}_{1A} & \Delta^{\tilde{q}\,AA}_{12} & \Delta^{\tilde{q}\,AA}_{12} \\ \Delta^{\tilde{q}\,AA*}_{12} & M^{\tilde{q}\,2}_{2A} & \Delta^{\tilde{q}\,AA}_{12} \\ \Delta^{\tilde{q}\,AA*}_{13} & \Delta^{\tilde{q}\,AA*}_{23} & M^{\tilde{q}\,2}_{3A} \end{pmatrix}, \quad M^{\tilde{q}\,2}_{LR} = \begin{pmatrix} \Delta^{\tilde{q}\,LR}_{11} & \Delta^{\tilde{q}\,LR}_{12} & \Delta^{\tilde{q}\,LR}_{12} \\ \Delta^{\tilde{q}\,LR}_{21} & \Delta^{\tilde{q}\,LR}_{22} & \Delta^{\tilde{q}\,LR}_{12} \\ \Delta^{\tilde{q}\,LR}_{31} & \Delta^{\tilde{q}\,LR}_{32} & \Delta^{\tilde{q}\,LR}_{33} \end{pmatrix}$$

Mass insertion approximation

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

- Diagonalize the quark mass matrices:

$$U_L^{(0)q\dagger} m_q^{(0)} U_R^{(0)q} = m_q^{(D)}$$

- Carry out the same rotation on the squark fields

⇒ super-CKM basis

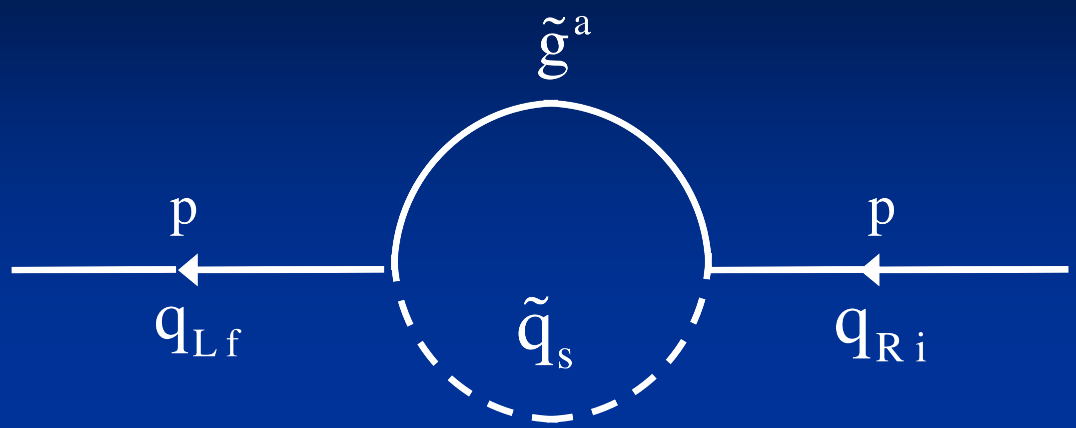
- Render the vertices flavour-diagonal and treat the off-diagonal elements as perturbations.

$$-i\Delta_{fi}^{\tilde{q}AB}$$

- Define dimensionless quantity: $$\delta_{fi}^{\tilde{q}AB} \equiv \frac{\Delta_{fi}^{\tilde{q}AB}}{\sum_{s=1}^{6}\left(\frac{M_{\tilde{q}}^2}{6}\right)_{ss}}$$

Chirality-changing self energy:

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



Chirally enhanced part in the mass insertion approximation:

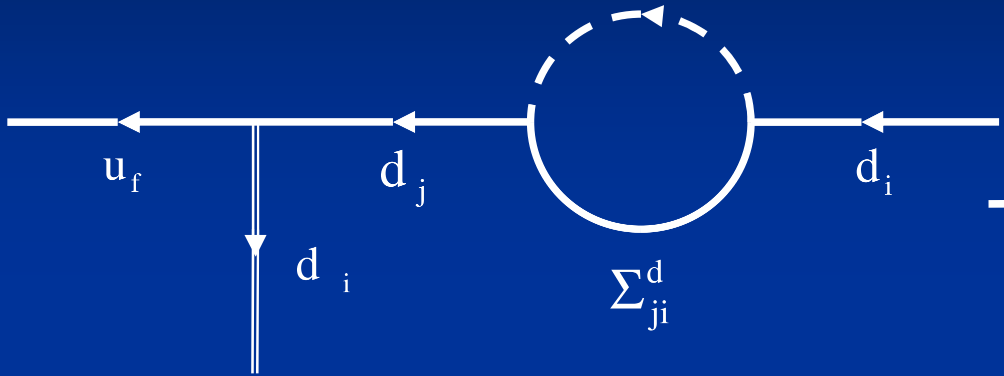
$$\Sigma^{q\,LR}_{fi} = g_s^2 \frac{m_{\tilde{g}}}{6\pi^2} \Delta^{\tilde{q}\,LR}_{fi} P_R C_0\left(m_{\tilde{g}}^2, M^{\tilde{q}}_{f\,L}, M^{\tilde{q}}_{i\,R}\right)$$

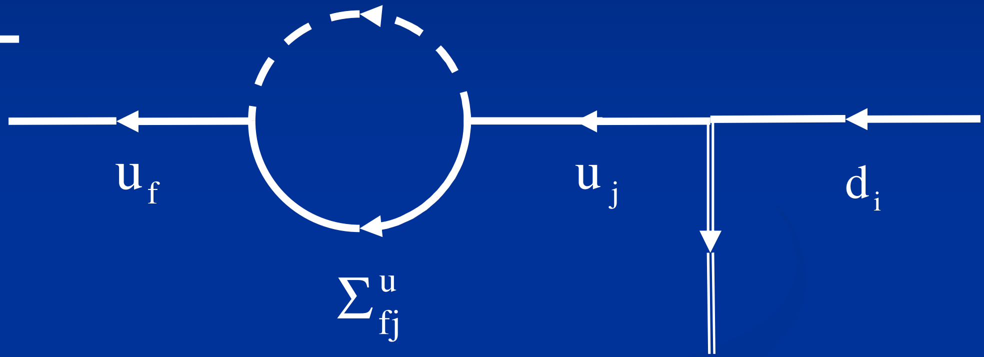
Mass renormalization:

$$m_{q_i} = v_q Y^{q_i} + \Sigma^{q\,LR}_{fi} + \delta m_{q_i}$$

Renormalization of the CKM matrix

In the SM: A. Denner and T. Sack, RENORMALIZATION OF THE QUARK MIXING MATRIX, Nucl. Phys. B **347** (1990) 203.





$$V^{(0)}_{CKM} = U^{u(0)\dagger}_L U^{d(0)}_L \to V_{CKM} = \left(1 + \Delta U^{u\dagger}_L\right) V^{(0)}_{CKM} \left(1 + \Delta U^d_L\right)$$

$$\Delta U^q_L = \begin{pmatrix} 0 & \frac{1}{m_2}\Sigma^{q\,LR}_{12} & \frac{1}{m_3}\Sigma^{q\,LR}_{13} \\ \frac{-1}{m_2}\Sigma^{q\,RL}_{21} & 0 & \frac{1}{m_3}\Sigma^{q\,LR}_{23} \\ \frac{-1}{m_3}\Sigma^{q\,RL}_{31} & \frac{-1}{m_3}\Sigma^{q\,RL}_{32} & 0 \end{pmatrix}$$

⇨ Antihermitian correction

Flavour from SUSY

Borzumati, Farrar, Polonsky, Thomas 1998/1999, Ferrandis, Haba 2004

- CKM matrix is the unit Matrix at tree-level

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

- Only the third generation Yukawa coupling is not zero

$$Y^q = \frac{1}{v_q} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_{q_3} \end{pmatrix}$$

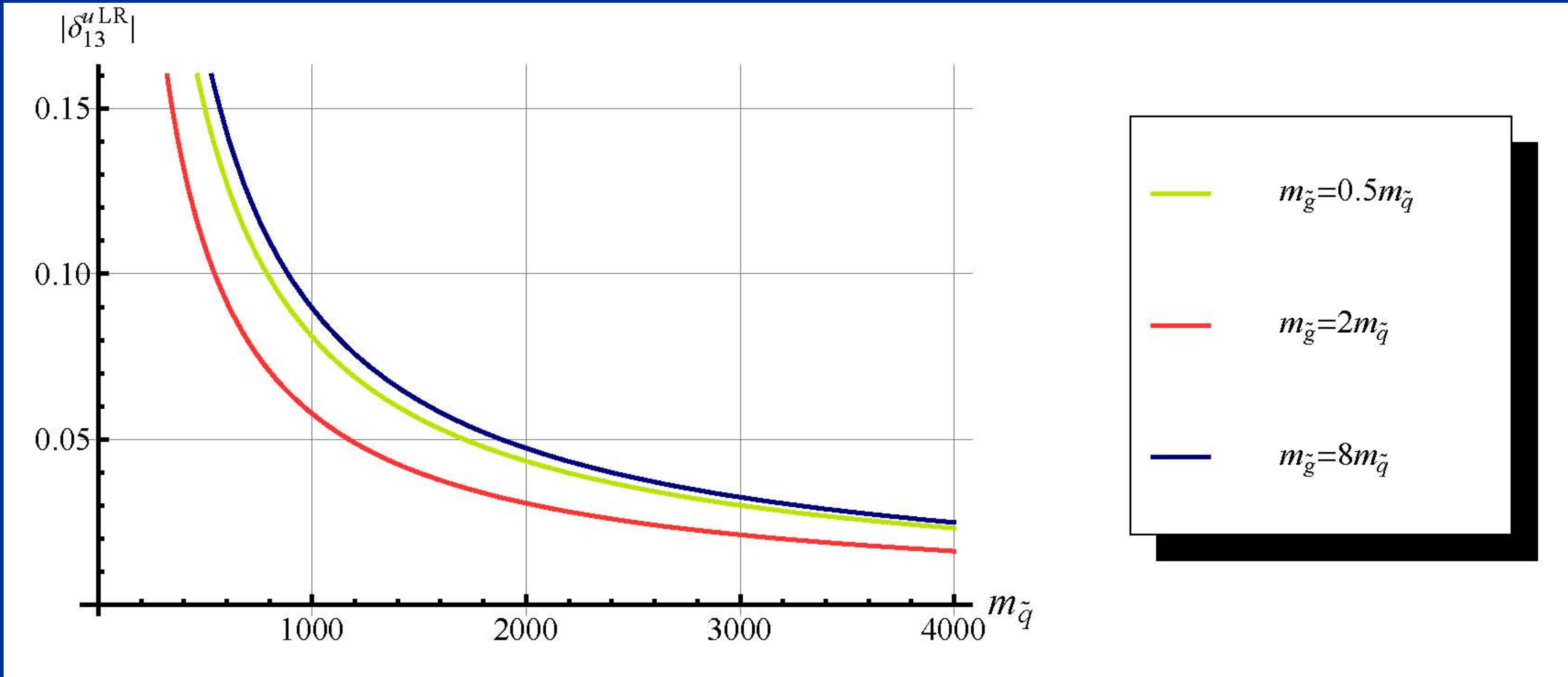
All other elements are generated radiatively!

Features of the model

- Explains small masses and mixing angles via a loop-suppression.
- Minimal flavour-violating with respect to the first two generations.
- RG invariant.
- Deviations from MFV if the third generation is involved.
- Solves the SUSY flavour and the SUSY CP problem.

⇨ **Verifiable predictions for SuperB**

Example: V_{ub} from SUSY



Results and comparison

quantity	needed size	bound from FCNC
$\delta_{13}^{d\,LR}$	0.001	0.15, B_d mixing
$\delta_{23}^{d\,LR}$	0.01	0.06, $b \to s\gamma$
$\delta_{13}^{u\,LR}$	0.027	--
$\delta_{23}^{u\,LR}$	0.27	--

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

Improvement of FCNC analysis nessecary:

Self energies can be of $O(1)$ in the flavour 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 flavour violating case, when the mixing angle is divided out.

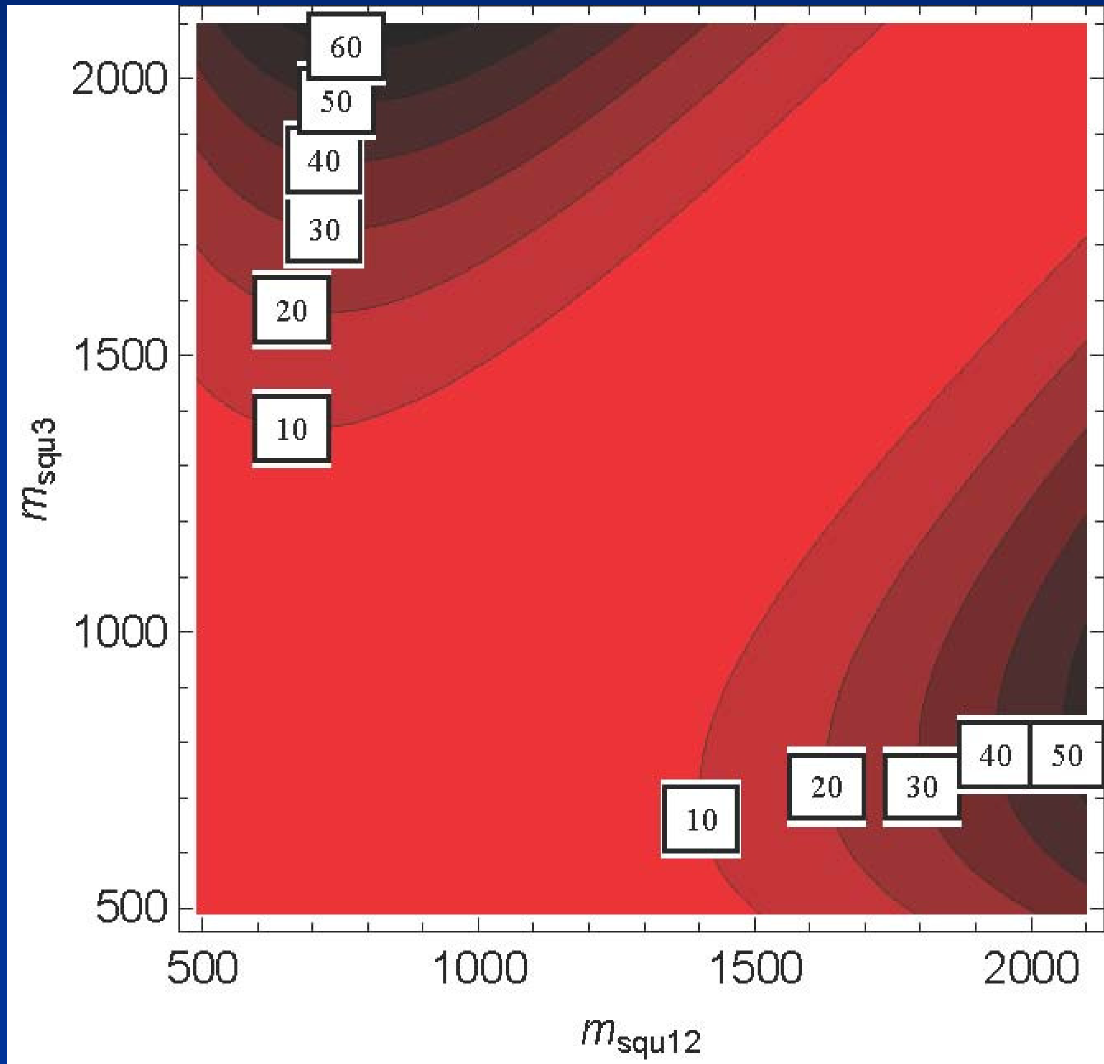
→ Two- or even three-loop processes can be of the same order as the LO process!

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

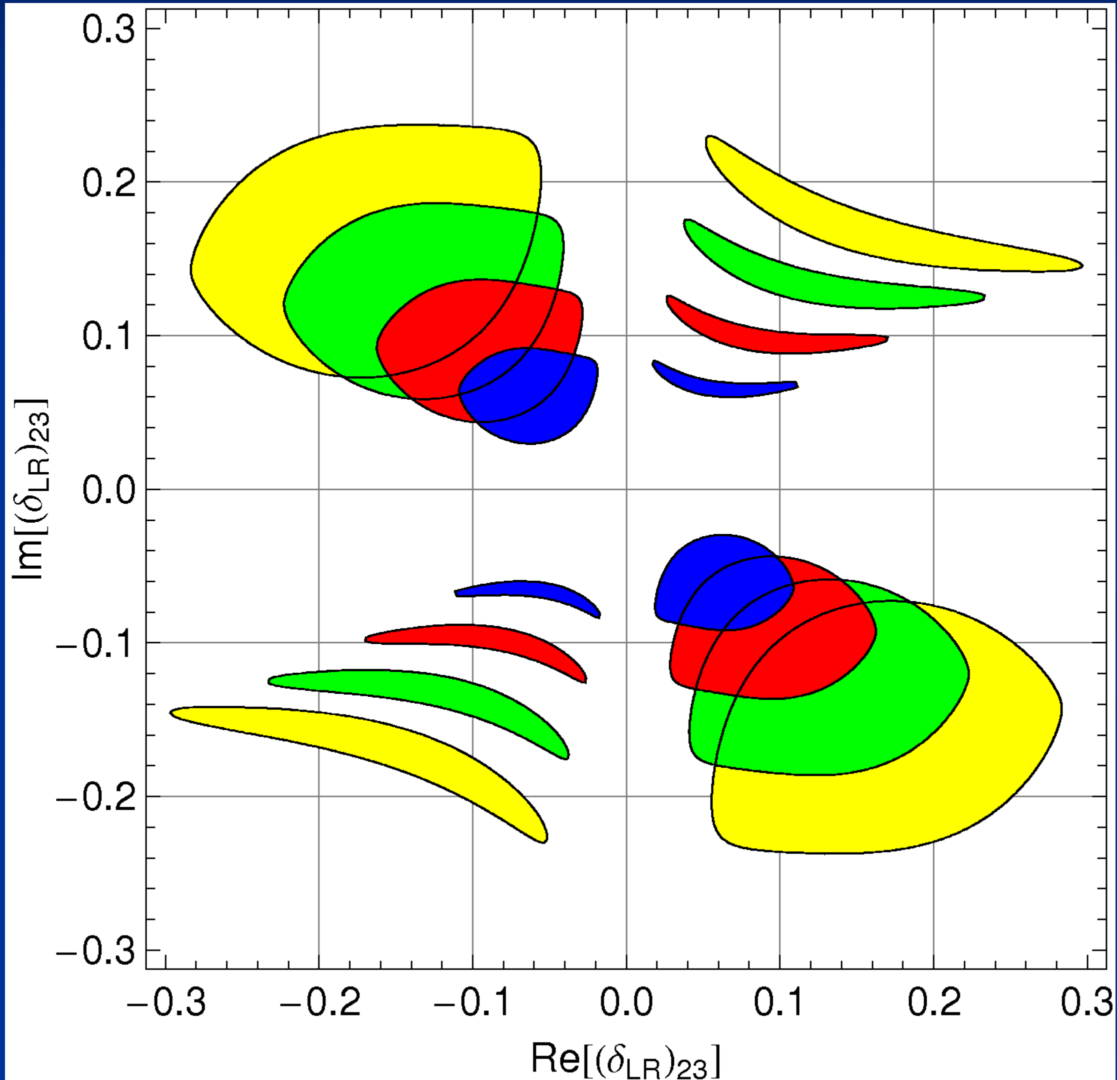
$$\frac{\Delta M_{B\,ren}}{\Delta M_B}$$

for

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



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



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

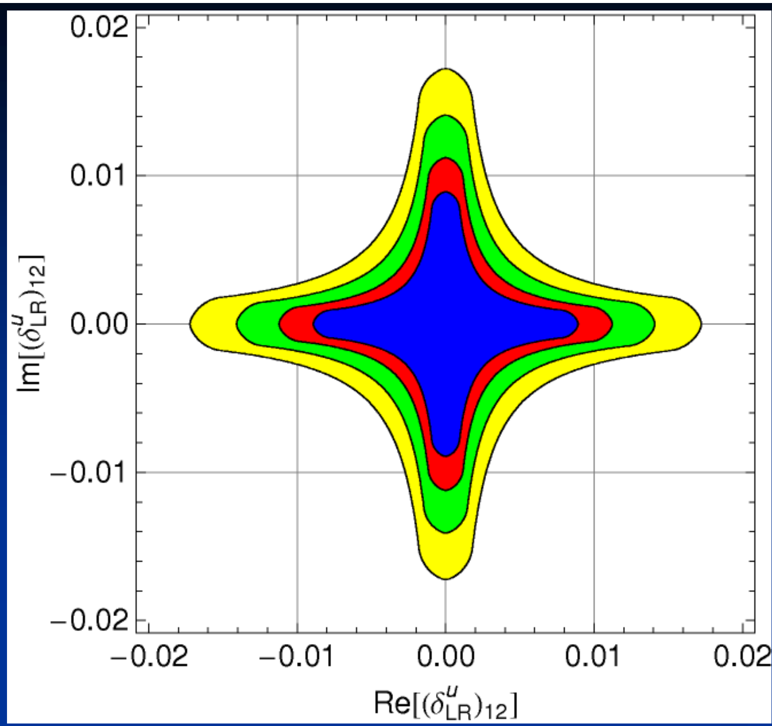
$m_{\tilde{g}} = 2000\text{GeV}$

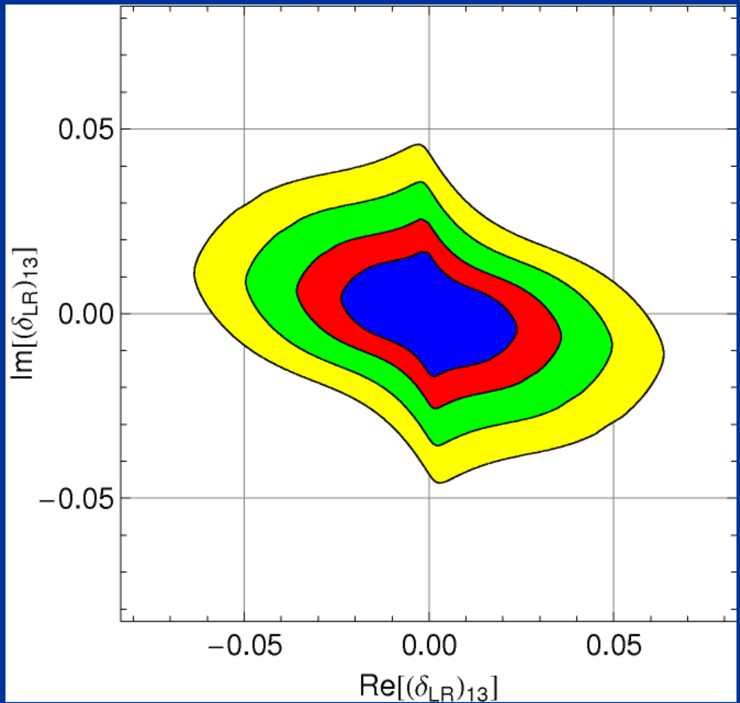
$m_{\tilde{g}} = 1500\text{GeV}$

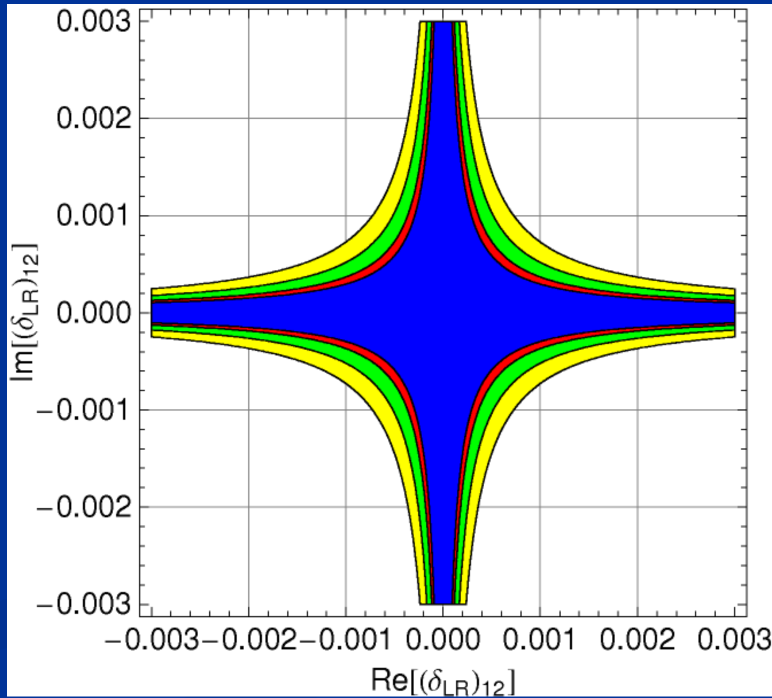
$m_{\tilde{g}} = 1000\text{GeV}$

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

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



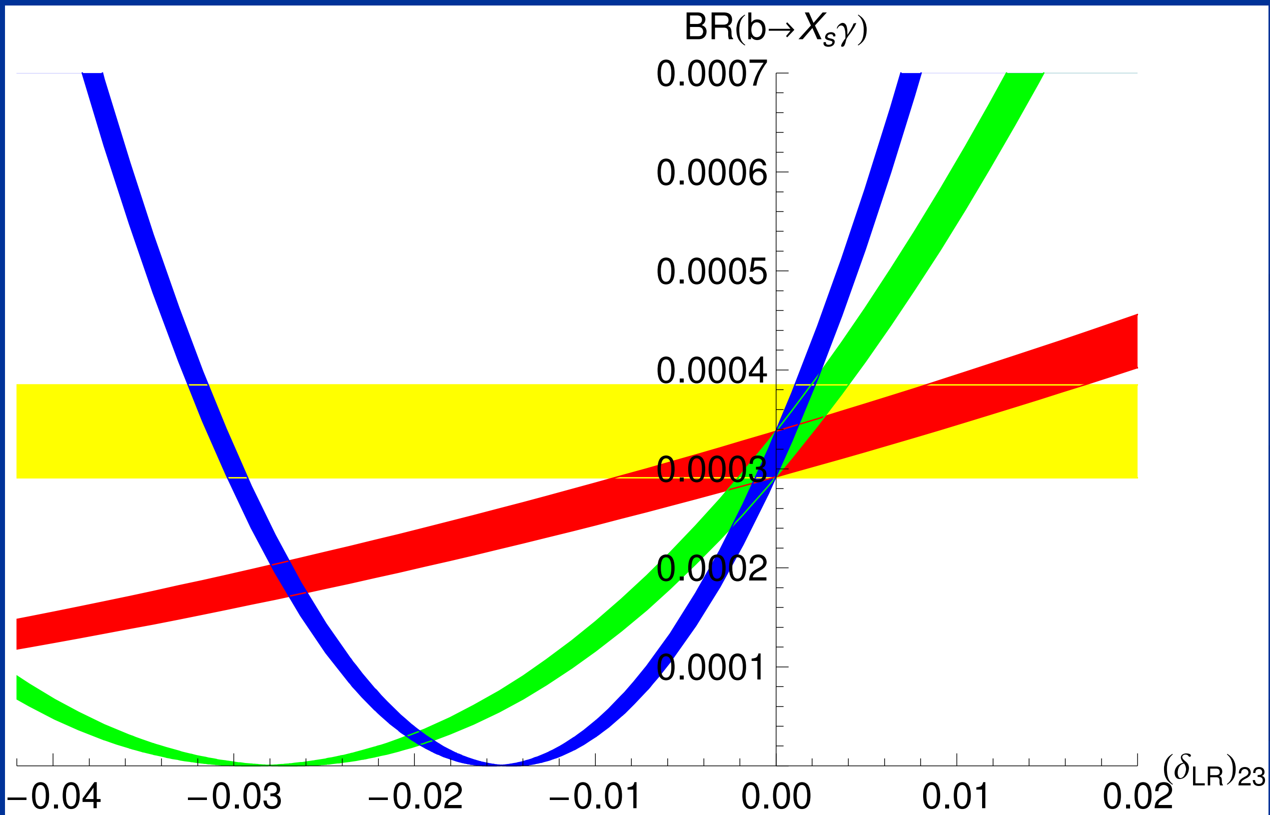




b→sγ

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

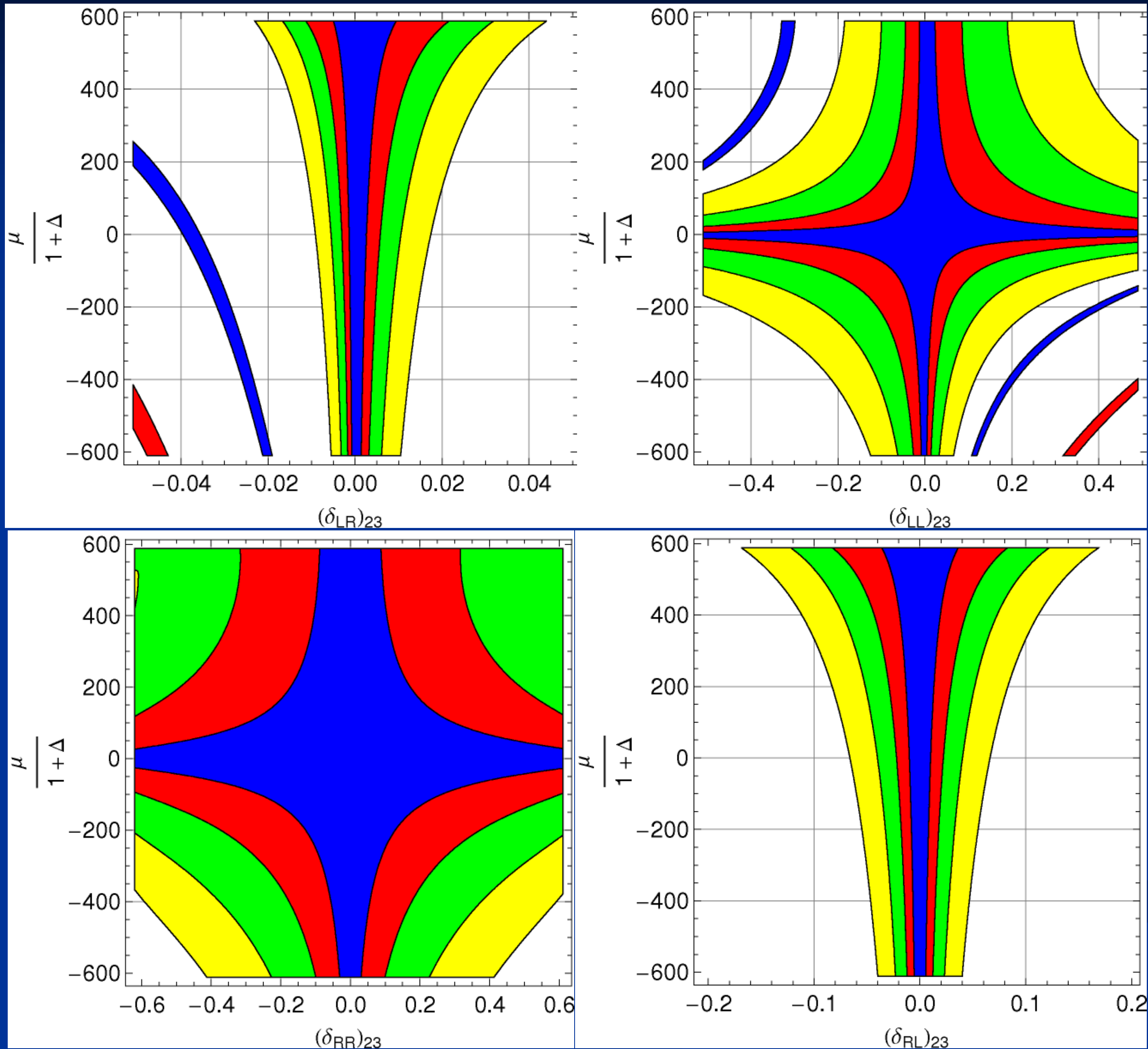
Behavior of the branching ratio for $\delta^{d\,LR}_{23}$



- 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 $b \to s\gamma$

$\tan(\beta) = 50$



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

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

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

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

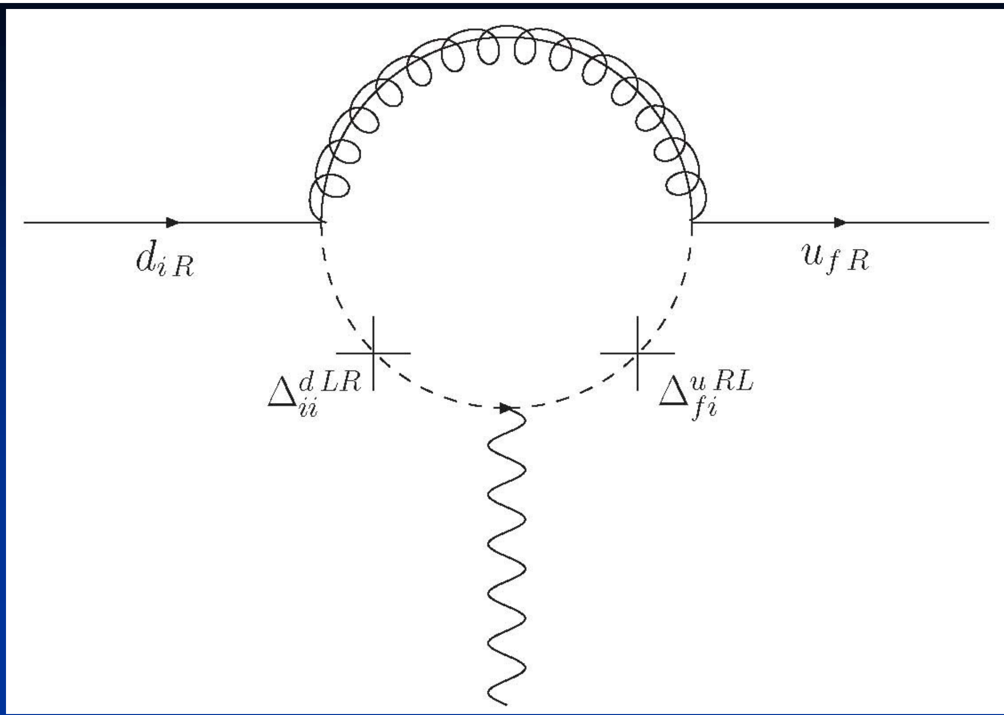
Motivation for a right-handed W coupling

- 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→τν

Tree-level processes. Commonly believed to be free of NP.(Charged Higgs contribution to B→τν is destruktiv.)

➡ Notoriously difficult to explain the deviations from the SM

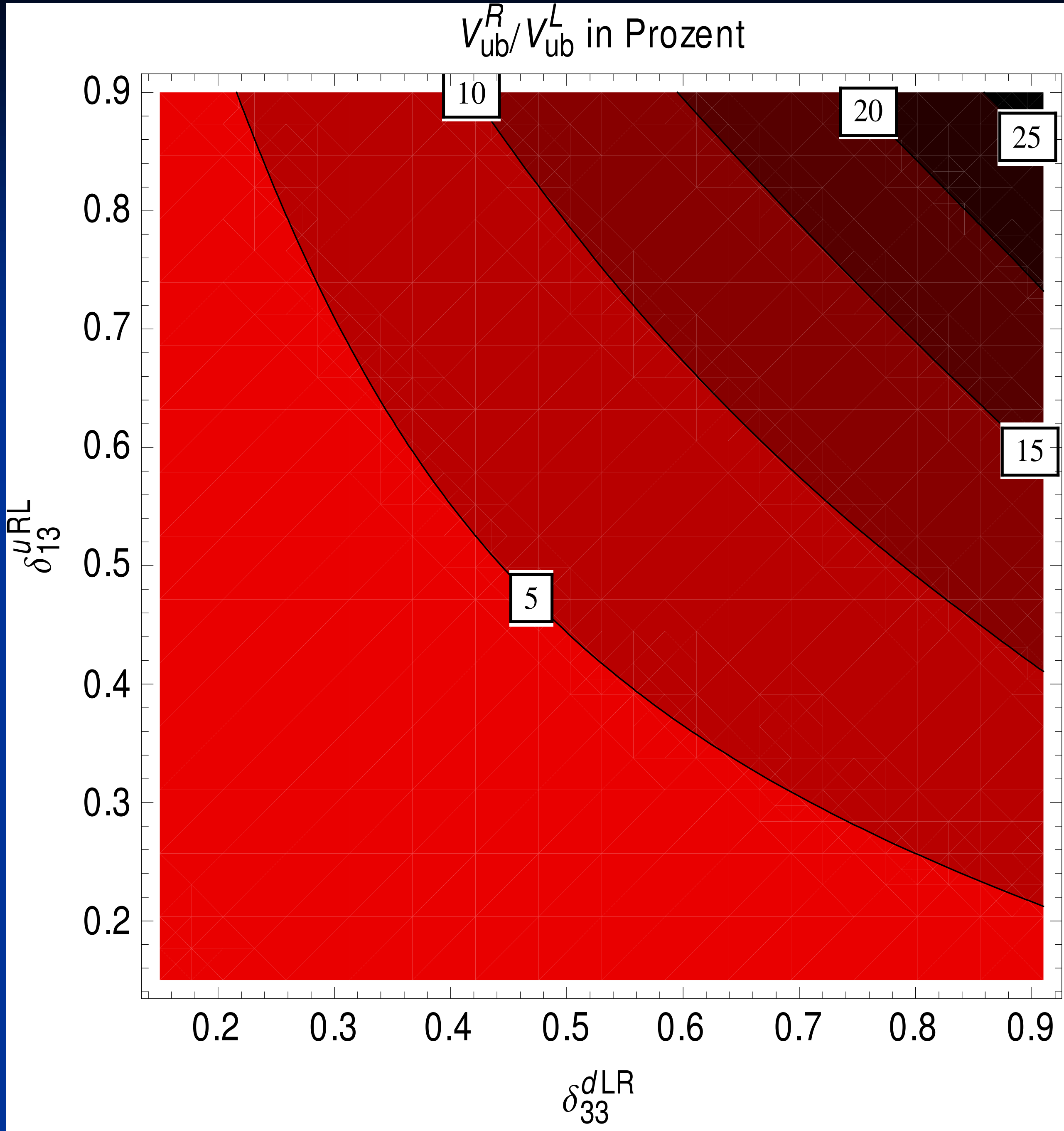
Genuine vertex-correction



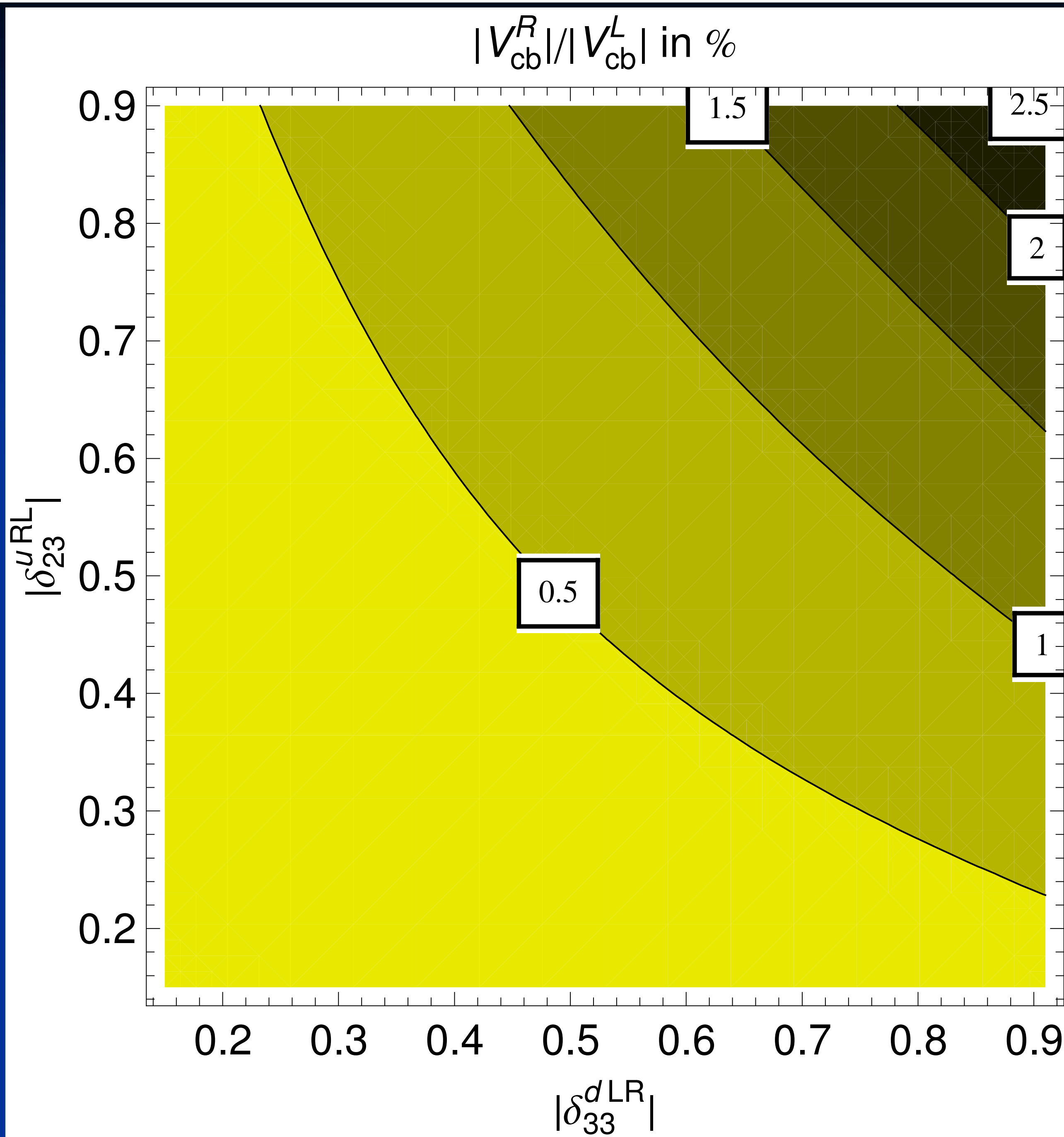
$$-i\Lambda^{W\tilde{g}}_{u_f d_i} = \frac{g_2}{\sqrt{2}} \frac{i\alpha_s}{3\pi} \gamma^\mu \sum_{s,t=1}^{6} \sum_{j,k=1}^{3} \Big(W^{\tilde{u}}_{fs} W^{\tilde{u}*}_{ks} V^{CKM}_{kj} W^{\tilde{d}}_{jt} W^{\tilde{d}*}_{it} P_L + W^{\tilde{u}}_{f+3,s} W^{\tilde{u}*}_{ks} V^{CKM}_{kj} W^{\tilde{d}}_{jt}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

- Left-handed coupling suppressed because of gauge cancellation.
- Right-handed coupling not suppressed!

Biggest SUSY effect in V_{ub}



Effect in V_{ub}



Right-handed charged currents

Exclusive decays

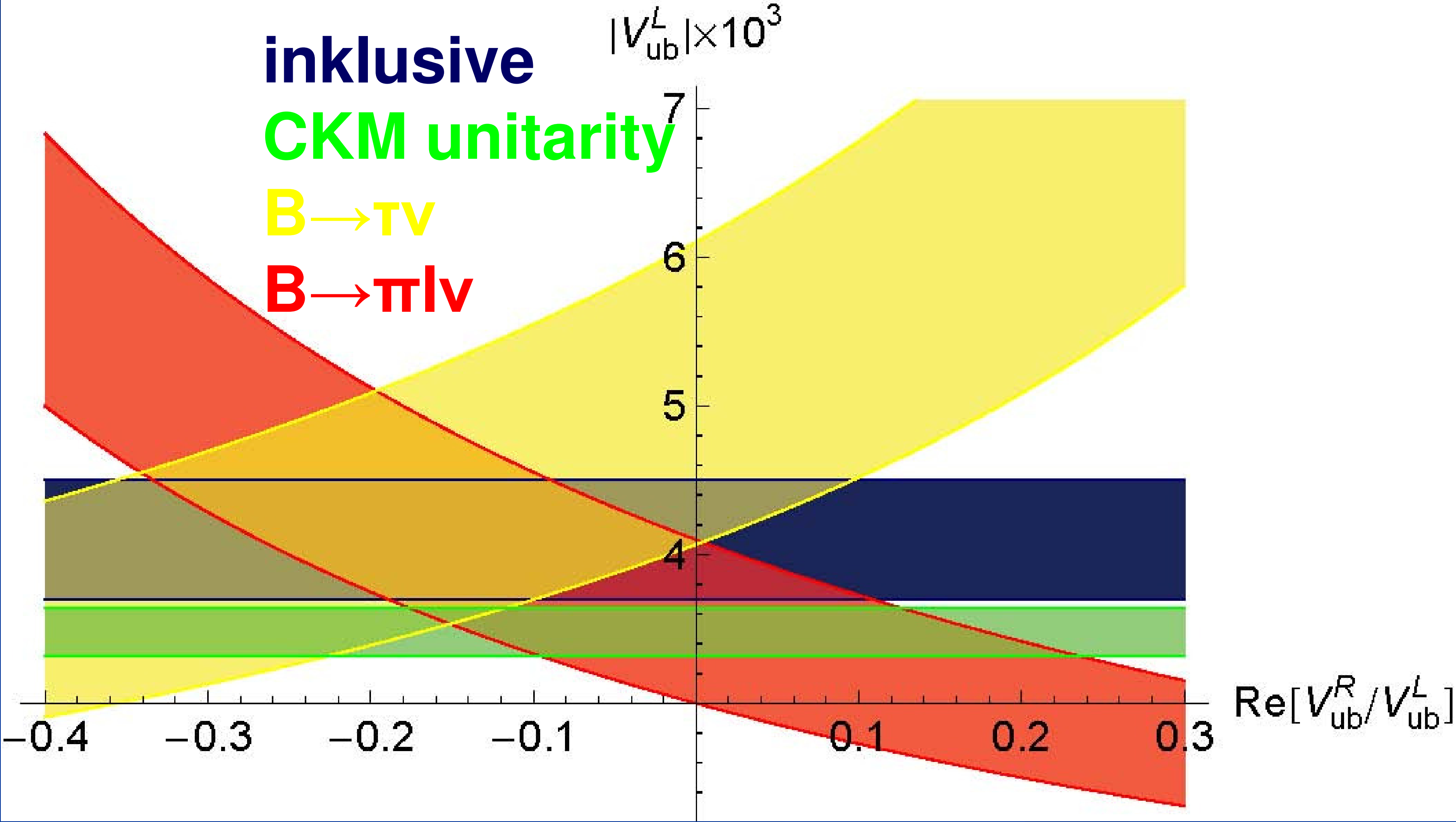
- Process proportional to the vector-current: $V^L = V - V^R$
- Process proportional to the axial vector-current: $V^L = V + V^R$

Inclusive decays

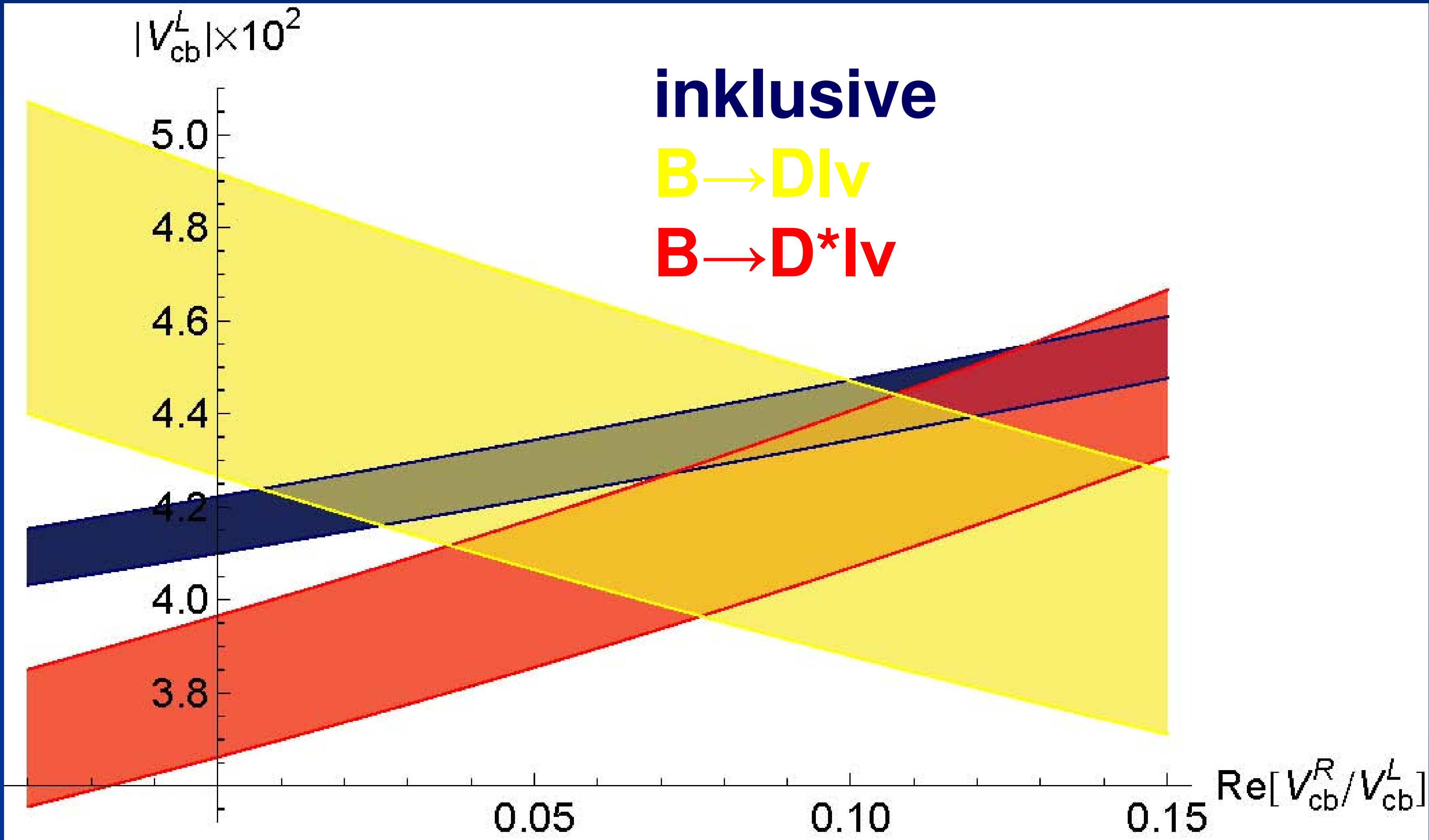
- V_{ub}: $V^L = V$
- V_{cb}: $V^L = V + 0.56 V^R$

Dassinger, Feger, Mannel:
Complete Michel Parameter Analysis of inclusive semileptonic $b \to c$ transition

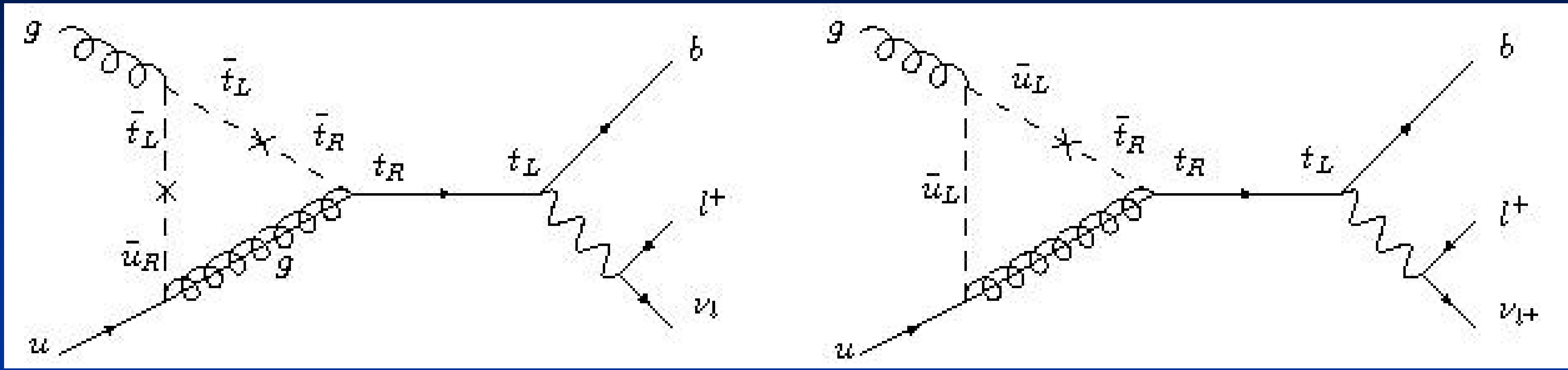
Effects of a right-handed W-coupling on V_{ub}



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

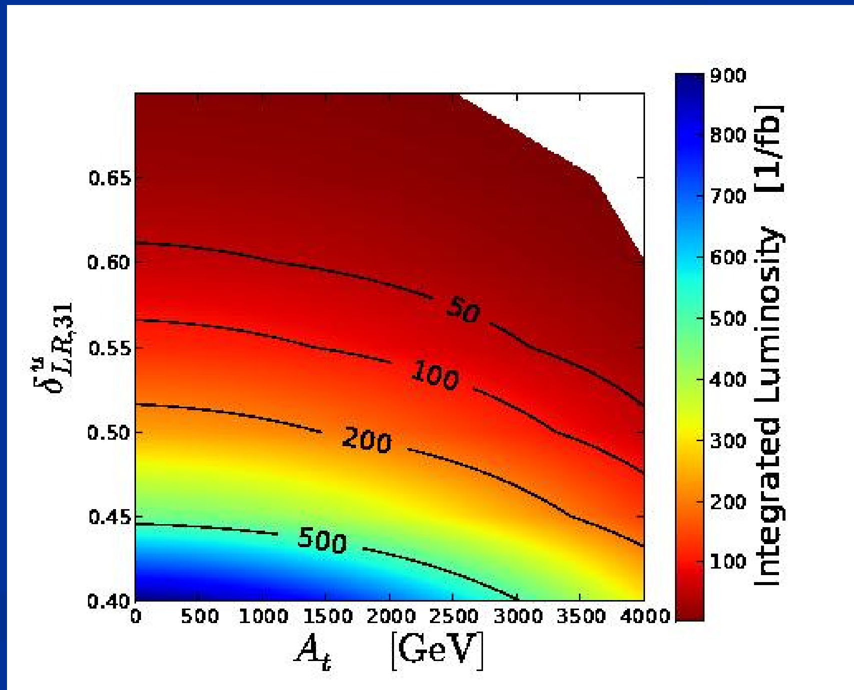


Connection to Single Top Production



Feynman diagrams contributing to Single Top production

Integrated Luminosity necessary to discover Single Tops



Plehn, Rauch, Spannowsk: 0906.1803

Conclusions

- Radiative generations of light fermion masses and mixing angles solves the SUSY flavour and the SUSY CP Problem.

  ⇒ **Verifiable predictions for SuperB.**

- Chirally enhanced corrections must be taken into account in FCNC processes.
- The MSSM can generate a right-handed W-coupling.

  ⇒ **SuperB could find NP in V_{ub} and V_{cb}.**