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Rare decays and MSSM phenomenology

Outline:

- The SUSY flavor and CP problem
- Constraints from flavour observables
- Where are large effects still possible?
- SUSY_FLAVOUR v2.0

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

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

➡ Flavor-violation is very suppressed in the SM.

SUSY flavor (CP) problem

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

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

  - Flavor-symmetries

  - effective SUSY Barbieri et at hep-ph/10110730

  - Radiative flavour violation (RFV) A.C., Hofer, Nierste, Scherer, hep-ph/11052818

Squark mass matrix

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

- Bilinear Terms

$$M_{LL}^{\tilde{q}2} = \begin{pmatrix} \left(M_{LL}^{\tilde{q}2}\right)_{11} & \Delta_{12}^{\tilde{q}LL} & \Delta_{13}^{\tilde{q}LL} \\ \Delta_{12}^{\tilde{q}LL*} & \left(M_{LL}^{\tilde{q}2}\right)_{22} & \Delta_{23}^{\tilde{q}LL} \\ \Delta_{13}^{\tilde{q}LL*} & \Delta_{23}^{\tilde{q}LL*} & \left(M_{LL}^{\tilde{q}2}\right)_{33} \end{pmatrix} \quad M_{RR}^{\tilde{q}2} = \begin{pmatrix} \left(M_{RR}^{\tilde{q}2}\right)_{11} & \Delta_{12}^{\tilde{q}RR} & \Delta_{13}^{\tilde{q}RR} \\ \Delta_{12}^{\tilde{q}RR*} & \left(M_{RR}^{\tilde{q}2}\right)_{22} & \Delta_{23}^{\tilde{q}RR} \\ \Delta_{13}^{\tilde{q}RR*} & \Delta_{23}^{\tilde{q}RR*} & \left(M_{RR}^{\tilde{q}2}\right)_{33} \end{pmatrix}$$

- Left-Right Terms

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

$$\Delta_{ij}^{d\,LR} = -v_d\left(\mu \tan(\beta)\, Y_i^{d(0)}\delta_{ij} + A_{ij}^{d}\right)$$

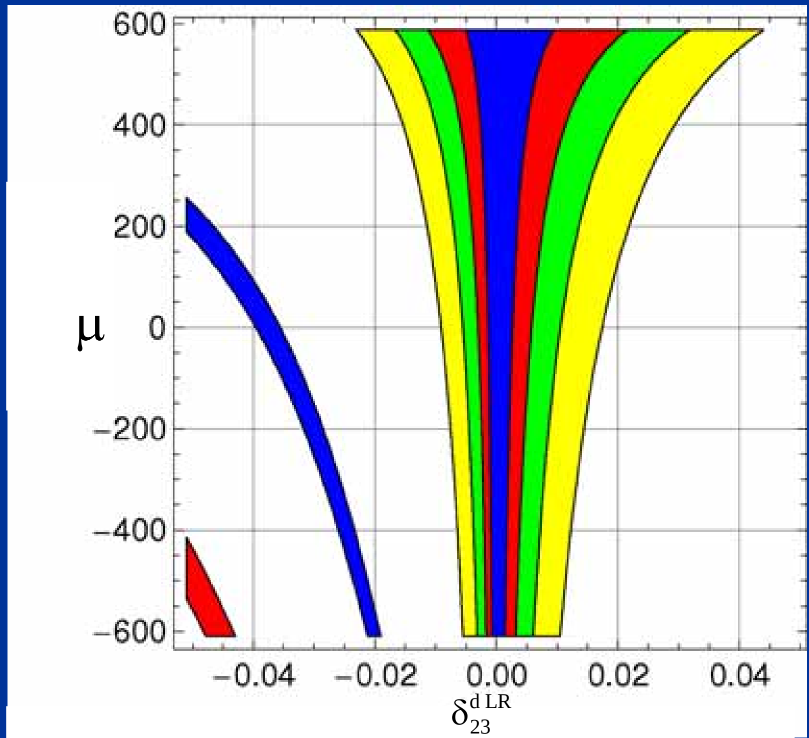
$$\Delta_{ij}^{u\,LR} = -v_u\left(\mu \cot(\beta)\, Y_i^{u(0)}\delta_{ij} + A_{ij}^{u}\right)$$

$$\delta_{ij}^{q} = \frac{\Delta_{ij}^{q}}{m_{\tilde{q}}^{2}}$$

Constraints on the sfermion mass matrices from flavour-observables

$B \to X_{s(d)}\gamma$

- Very strong constraints on $\delta^{d\,LR}_{23,13}, \delta^{d\,LR}_{32,31}$
- Strong constraints on $\delta^{d\,LL,RR}_{23,13}$ if $\tan(\beta)$ is large
- $M_{H^+} > 300\text{GeV}$ if no cancellations occur. Misiak et al. arXiv:0609232



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

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

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

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

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

$B_{s,d} \rightarrow \mu^+\mu^-$

- Neutral Higgs contribution dominant for large $\tan(\beta)$ (non-decoupling)
- Even for MFV sizable contributions

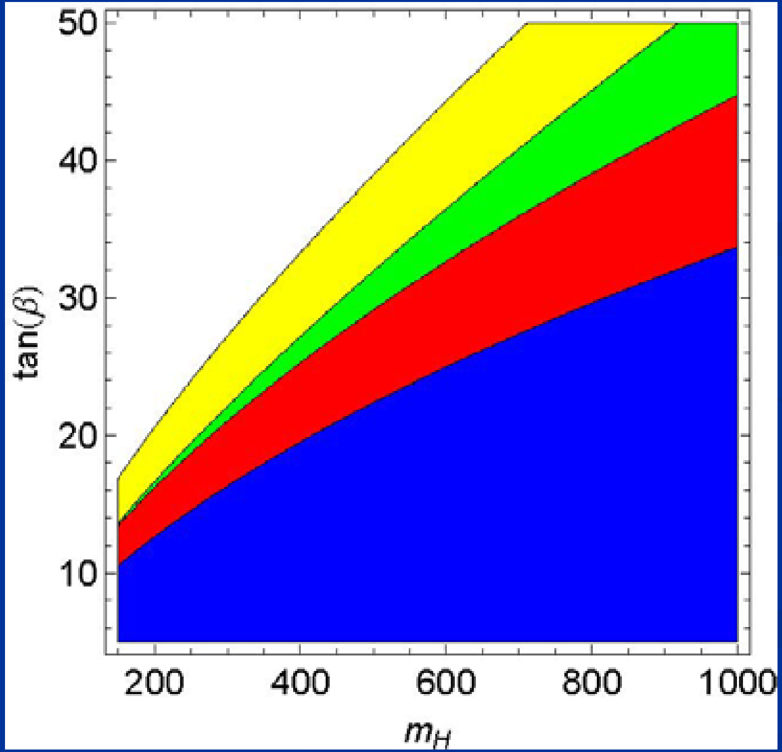
Allowed regions for RFV

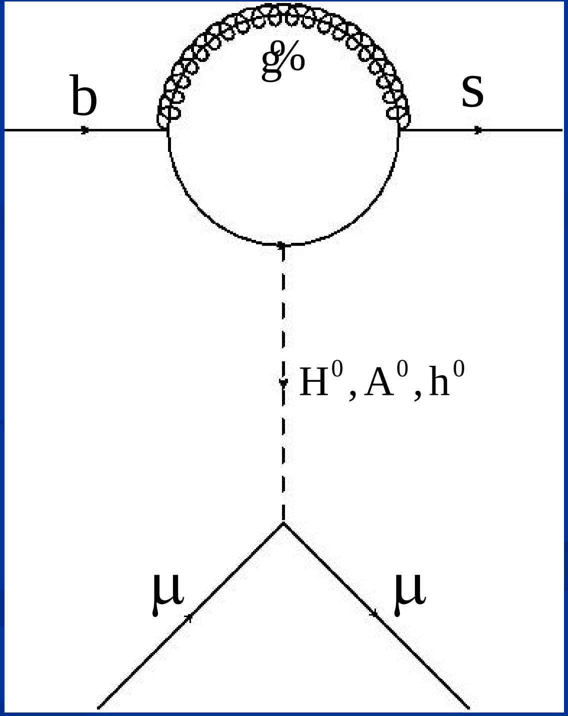
$\varepsilon_b = 0.005$

$\varepsilon_b = 0.01$

$\varepsilon_b = -0.005$

$\varepsilon_b = -0.01$





$B_{s,d}$ mixing

- At low $\tan(\beta)$ constraints on $\delta^{d\,RR}_{13,23}, \delta^{d\,LL}_{13,23}$
- Double-Higgs penguin contributions at large $\tan(\beta)$

(if the Peccei-Quinn symmetry is broken)

Kaon and D mixing

- Stringent constraints on $\delta^{d\,LR}_{12,21}, \delta^{u\,LR}_{12,21}, \delta^{d\,RR}_{12}, \delta^{u\,RR}_{12}, \delta^{d\,LL}_{12}, \delta^{u\,LL}_{12}$
- Constraints on the mass splitting of left-handed squarks. Because of the SU(2) relation

$$M^{\tilde{u}2}_{LL} = V^{\dagger} M^{\tilde{d}2}_{LL} V$$

effects in Kaon and D mixing cannot be simultaneously avoided for non-degenerate squarks.

Allowed mass splitting

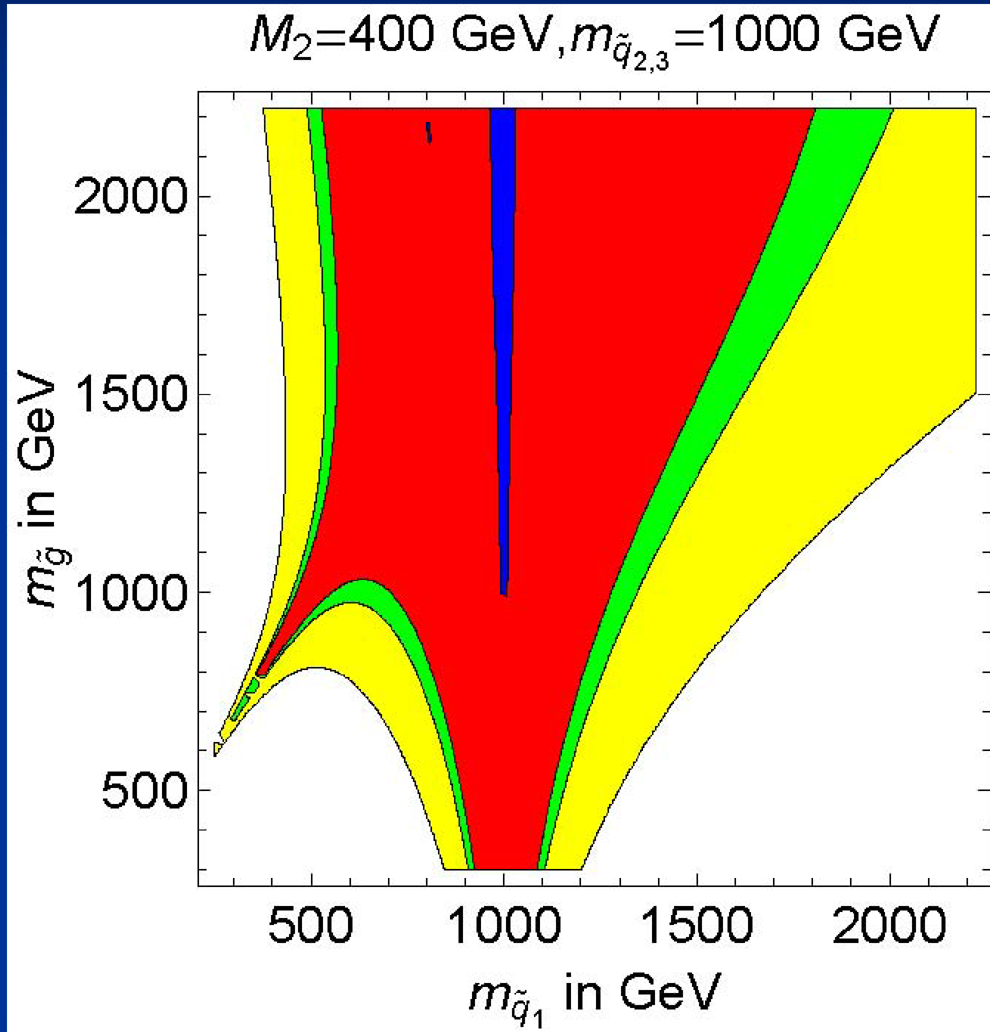
- Non-degenerate squark masses are allowed.
- More space for models with abelian flavor symmetries.
- Interesting for LHC benchmark scenarios.

Maximally allowed mass-splitting

Alignment to Y^d

Alignment to Y^u

Minimally allowed mass-splitting



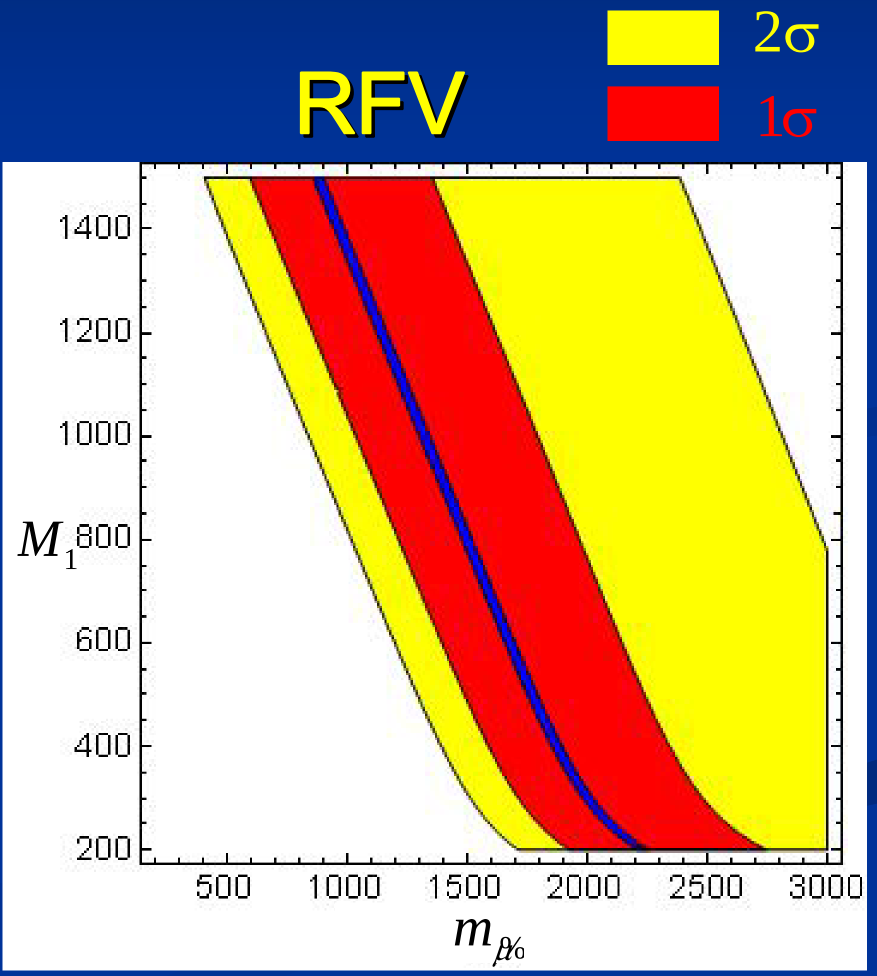
Anomalous magnetic moments and EDMs

- Constraints on

$$\mathrm{Re}\left[\delta^{l\,LR}_{11,22}\right], \mathrm{Re}\left[\delta^{d,u\,LR}_{11}\right]$$

$$\mathrm{Im}\left[\delta^{l\,LR}_{11,22}\right], \mathrm{Im}\left[\delta^{d,u\,LR}_{11}\right]$$

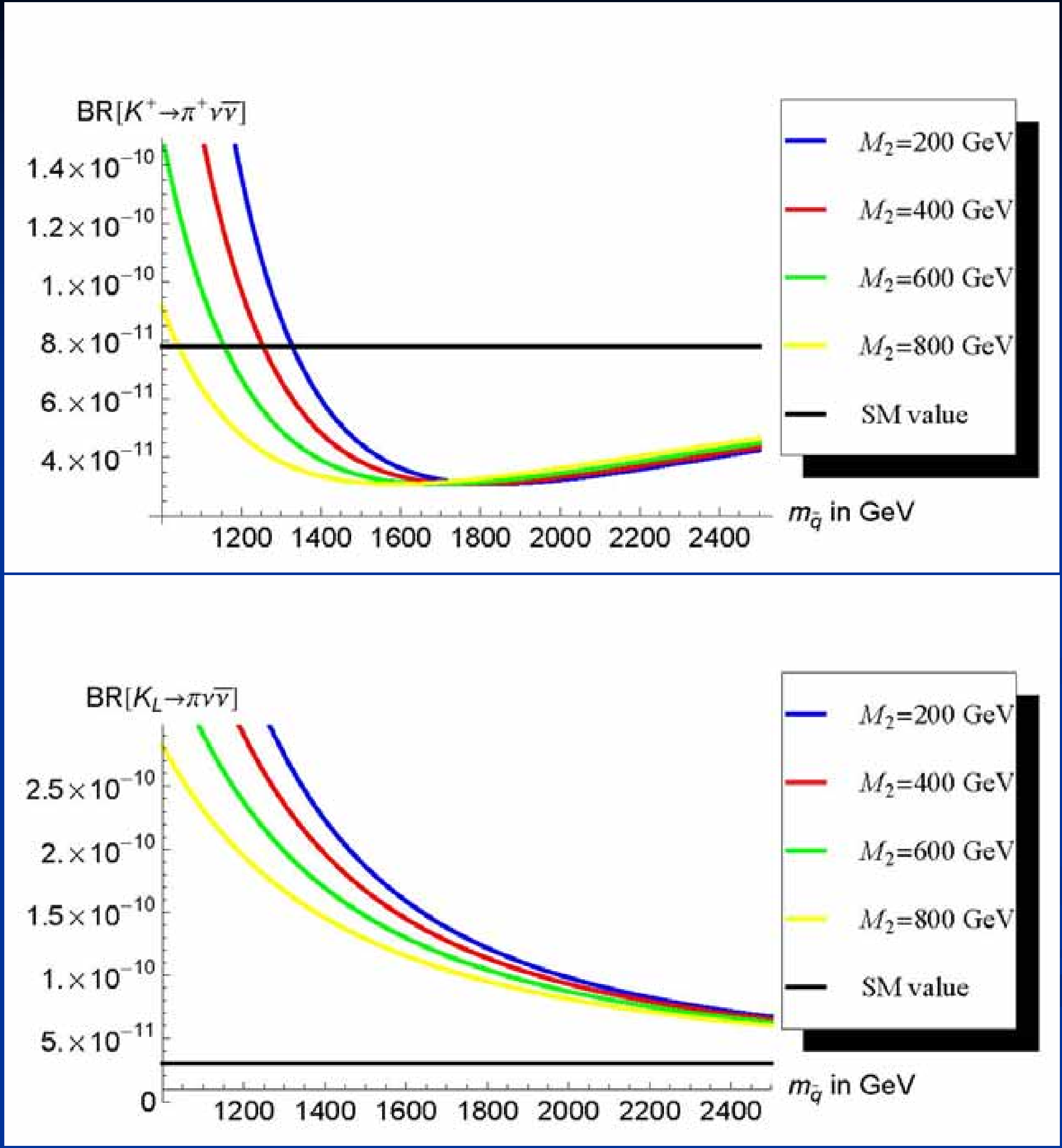
- The deviation from the SM expectation of the anomalous magnetic moment of the muon can be explained with large $\tan(\beta)$ or large A-terms.



Where are large effects still possible?

$\delta_{13}^{u\,LR} \times \delta_{23}^{u\,LR}$

- RFV-effects in K→πνν
- Verifiable predictions for NA62

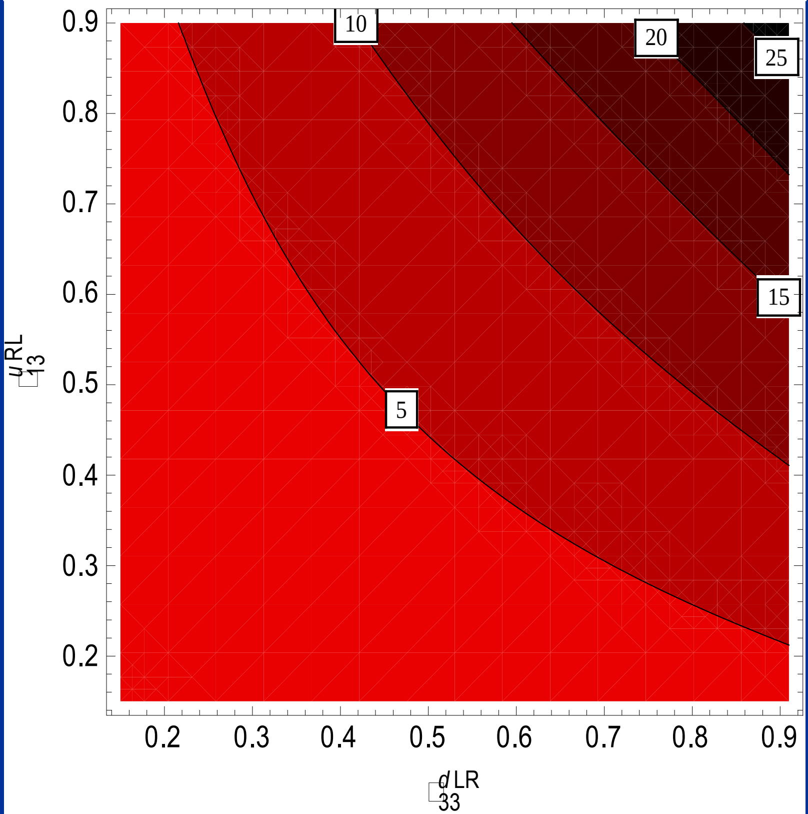


Right-handed W-coupling

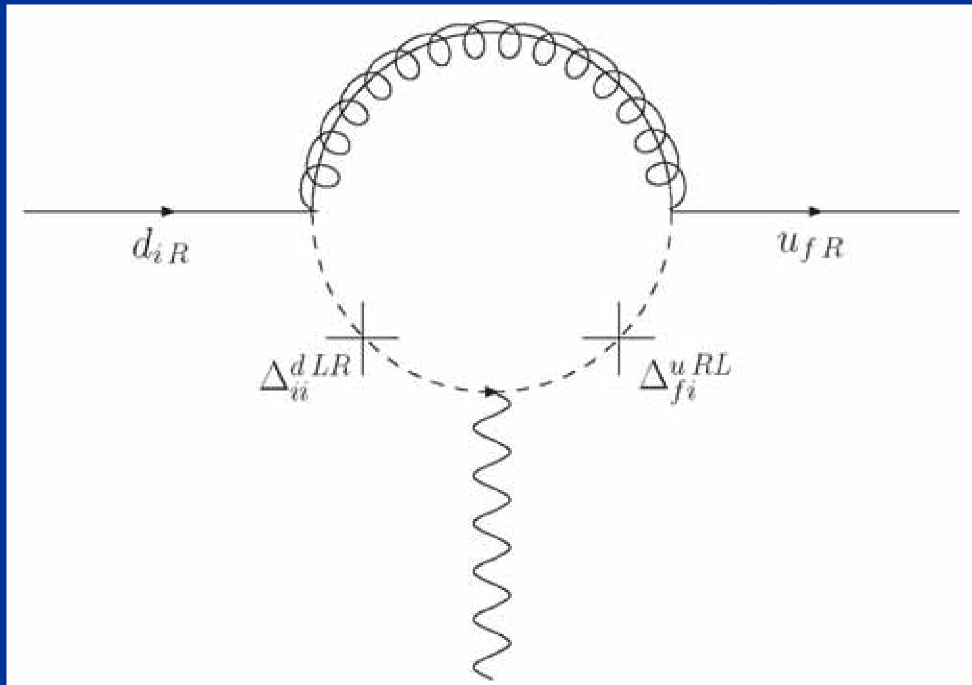
AC, arXiv:0907.2461

$\delta_{31}^{u\,LR} \times \delta_{33}^{d\,LR}$ generates V_{ub}^{R}

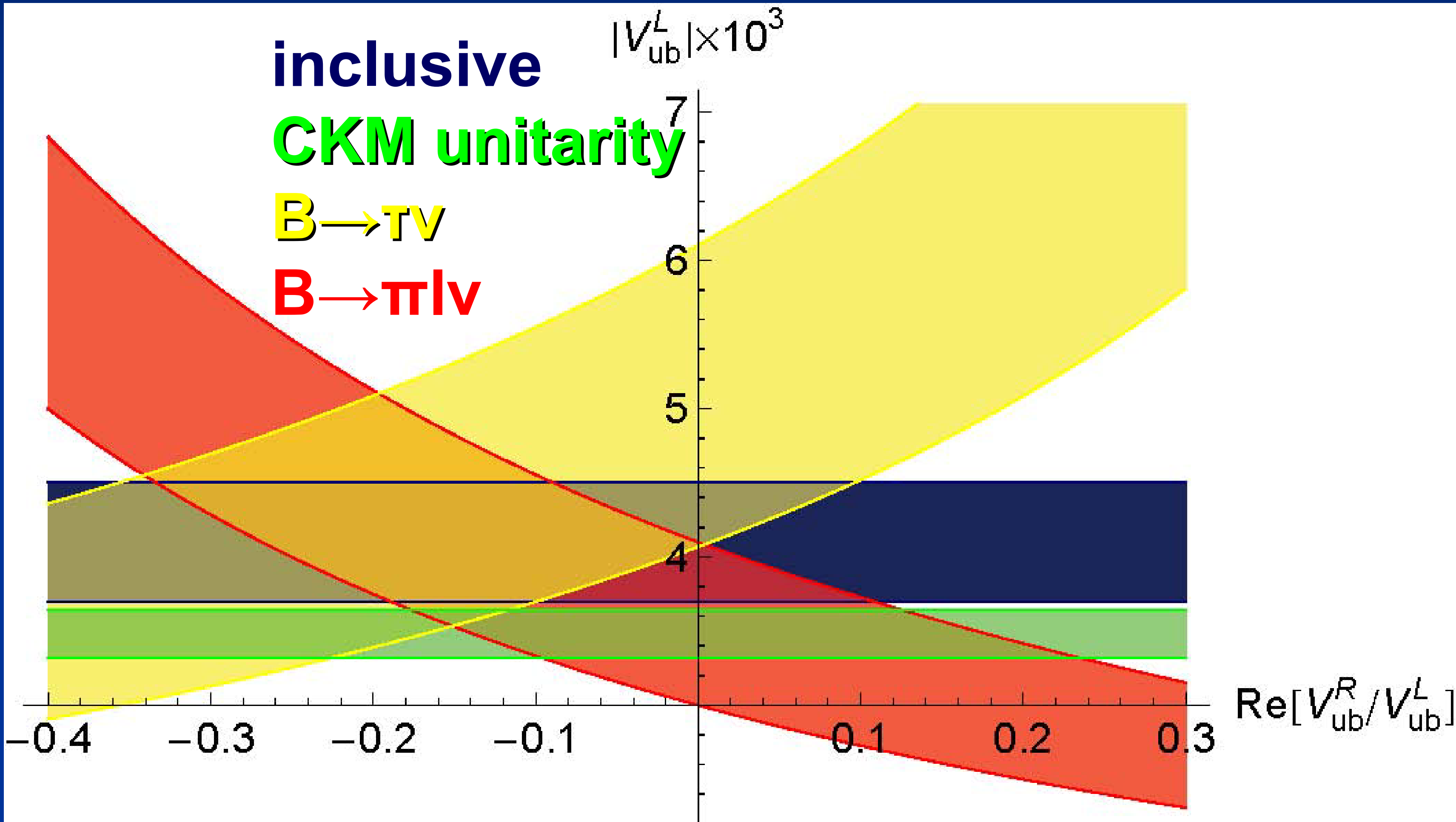
V_{ub}^{R} / V_{ub}^{L} in %



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



Determination of V_{ub}



SUSY_FLAVOUR v2.0

A.C., Janusz Rosiek, arXiv:1203.XXXX

Calculates in the generic MSSM:

- EDMs and anomalous magnetic moments
- $\bar{D}-D,\ \bar{B}_{s,d}-B_{s,d},\ \bar{K}-K$
- $b \to s\gamma,\ \mu \to e\gamma,\ \tau \to \mu\gamma,\ \tau \to e\gamma$
- $K_L \to \pi\nu\bar{\nu},\ K^+ \to \pi^+\nu\bar{\nu}$
- $B_{s,d} \to l^+l^-,\ K_L \to l^+l^-$
- $B \to \tau\nu,\ B \to D\tau\nu$

Including the important resummation of all chirally enhanced effects A.C., L. Hofer, J. Rosiek arXiv:1103.4272

Conclusions

- The flavour structure of the MSSM is constrained from many flavour-observables.
- Except $\delta^{u\,RL,RR}_{13,23}$ all flavour-changing elements of the squark mass matrices are stringently constrained
- Radiative-flavour-violation is an interesting alternative to MFV.
- $\delta^{u\,LR}_{13,23}$ might generate large effects in $K \to \pi\nu\bar{\nu}$ or an anomalous W-coupling which affects the determination of V_{ub} and enhanced single top production.
- Chirally enhanced corrections are numerically important.

⇒ SUSY_FLAVOUR v2.0 is a valuable tool for calculating FCNC processes in the MSSM