Alternative approach to $b \to s\gamma$ in the u-MSSM

(u = unconstrained)

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★ L. Everett, G. Kane, S. R., L. Wang and T.Wang, *"Alternative approach to $b \to s\gamma$ in the uMSSM"*, JHEP **0201**, 022 (2002) [arXiv:hep-ph/0112126].

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■ CONTENTS ■

(I) Brief Summary of $b \to s\gamma$

(b) General Theoretical Framework for $b \to s\gamma$

The starting point: low-energy effective Hamiltonian at the bottom mass scale μ_b:

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu_b) Q_i(\mu_b)$$

The operators relevant to the $b \to s\gamma$ process are (L $\leftrightarrow$ R conjugate):

$$Q_2 = \bar{s}_L \gamma_\mu c_L \bar{c}_L \gamma^\mu b_L \quad , \quad Q_2' = \bar{s}_R \gamma_\mu c_R \bar{c}_R \gamma^\mu b_R$$

$$Q_7 = \frac{e}{16\pi^2} m_b \bar{s}_L \sigma^{\mu\nu} b_R F_{\mu\nu} \quad , \quad Q_7' = \frac{e}{16\pi^2} m_b \bar{s}_R \sigma^{\mu\nu} b_L F_{\mu\nu}$$

$$Q_8 = \frac{g_s}{16\pi^2} m_b \bar{s}_L \sigma^{\mu\nu} G^a_{\mu\nu} T_a b_R \quad , \quad Q_8' = \frac{g_s}{16\pi^2} m_b \bar{s}_R \sigma^{\mu\nu} G^a_{\mu\nu} T_a b_L$$

The Wilson Coefficients (WC) are calculated at the EW scale μ_W. $C_2(\mu_W) = 1$ and $C_2'(\mu_W) = 0$ are affected "only" by SM physics (NP appears at higher order). The WC C_7, C_7' and C_8, C_8' have to be calculated case by case and here NP could be dominant.

The WCs scale from the EW scale down to the b-scale μ_b ($\eta = \alpha_s(\mu_W)/\alpha_s(\mu_b)$) accordingly to:

$$
\begin{aligned}
C_2(\mu_b) &= \frac{1}{2}\left(\eta^{-\frac{12}{23}} + \eta^{\frac{6}{23}}\right) \\
C_7(\mu_b) &= \eta^{\frac{16}{23}} C_7(\mu_W) + \frac{8}{3}\left(\eta^{\frac{14}{23}} - \eta^{\frac{16}{23}}\right) C_8(\mu_W) + \sum_{i=1}^{8} h_i \eta^{a_i} \\
C_8(\mu_b) &= \eta^{\frac{14}{23}} C_8(\mu_W) + \sum_{i=1}^{8} \bar{h}_i \eta^{a_i}
\end{aligned}
$$

The C_i' coefficients obey the same running (provided the constant green terms are set to 0). The inclusive $b \to s\gamma$ Branching Ratio is calculated using the following NLO formula ($z^2 = m_c/m_b$):

$$
BR(B \to X_s \gamma)|_{E_\gamma > (1-\delta)E_\gamma^{max}} = BR(B \to X_c e \bar{\nu}) \frac{6\alpha}{\pi f(z)} \left| \frac{V_{tb} V_{ts}^*}{V_{cb}} \right|^2 K(\delta, z)
$$

$$
\begin{aligned}
K_{NLO}(\delta, z) = & \sum_{i \leq j = 2,7,8} k_{ij}^{(0)}(\delta, z) \left\{ \mathrm{Re}[C_i^{(0)}(\mu_b) C_j^{(0)*}(\mu_b)] + (C_{i,j} \to C'_{i,j}) \right\} + \\
& k_{77}^{(1)}(\delta, z) \left\{ \mathrm{Re}[C_7^{(1)}(\mu_b) C_7^{(0)*}(\mu_b)] + (C_7 \to C_7') \right\}
\end{aligned}
$$

$$
K_{LO} = |C_7(\mu_b)|^2 + |C_7'(\mu_b)|^2 \qquad \text{(for } K_{NLO} \text{ see [Kagan and Neubert])}
$$

(b) Experiment vs SM Calculation

1. Experimental result for $b \to s\gamma$ (weighted average including ALEPH, BELLE and CLEO)

$$BR(B \to X_s\gamma)_{exp} = (3.23 \pm 0.41) \times 10^{-4}$$

2. The original SM-NLO calculation of the $BR(B \to X_s\gamma)$ gives, for $(m_c/m_b)_{\rm pole} = 0.29$:

$$BR(B \to X_s\gamma)_{SM} = (3.28 \pm 0.33) \times 10^{-4}$$ [Chetyrkin *et al.*]

3. The main source of uncertainty being the NNLO QCD ambiguities. For $(m_c/m_b)_{\rm run} = 0.22$:

$$BR(B \to X_s\gamma)_{SM} = (3.73 \pm 0.30) \times 10^{-4}$$ [Gambino and Misiak]

- Experimental and theoretical errors are comparable and of $\mathcal{O}(10\%)$. Theoretical errors must be improved to follow experimental improvements:

★ VERY DIFFICULT QCD TASK

- Experiment and SM calculation are in agreement at 1-1.5 σ. No CLAIMS of discrepancy are possible at this stage:

★ CONSTRAINTS on NEW PHYSICS

- An analysis of $b \to s\gamma$ can give important pieces of informations on the "critical" flavour sector of the MSSM together with $K - \bar{K}$, ϵ/ϵ' (s-d) and $B_{d,s} - \bar{B}_{d,s}$ (b-(s-d)):

★ MSSM FLAVOUR PROBLEM and FCNC

(c) State of the Art in $b \to s\gamma$ Calculations

1. NLO calculation in the SM $\to$ AGREEMENT with EXP DATA $\to$ NNLO ambiguities ?

2. NLO calculation in 2HDM + 2-loop large $\tan\beta$ effects [Ciafaloni et al., Degrassi et al.]

3. LO calculation in c-MSSM scenarios (MFV, mSUGRA) + NLO order terms (only in MFV with light chargino) + 2-loops large $\tan\beta$ effects [Degrassi et al., Carena et al.]

★ In c-MSSM ONLY $C_{7(8)}$ WC is relevant for the $b \to s\gamma$ BR

4. LO calculation in u-MSSM scenarios (usually using SINGLE MIA) [Gabbiani et al.]

★ u-MSSM LARGELY UNEXPLORED even at LO (lots of parameters)

★ Both $C_{7(8)}$ and $C'_{7(8)}$ can be RELEVANT in u-MSSM (gluino sector)

(II) "Alternative" Scenario in the u-MSSM

(a) Example of "ALTERNATIVE" Scenarios in u-MSSM

In the c-MSSM scenarios the contribution to $b \to s\gamma$ comes ONLY from the WC $C_{7(8)}$ (as in the SM or 2HDM). For example in MFV (being the CKM the only source of FV) one has:

$$\star \; C_7(TOT) \approx C_7(W^\pm) + C_7(H^\pm) + C_7(\tilde{\chi}^\pm)$$

$$\star \; C_7'(TOT) \approx 0$$

- In MFV scenarios (and more in general in c-MSSM) C_7' is suppressed by the ratio m_s/m_b (i.e. the chirality is flipped through a "mass insertion" m_s in the external fermion line)
- Neutralino and gluino contributions to C_7 and C_7' are negligible (there is no contribution in the limit of diagonal down-squark mass matrix)
- As SM prediction is compatible with experiment $\rightarrow$ $C_7(H^\pm) + C_7(\tilde{\chi}^\pm) \approx 0$

In the u-MSSM the situation is more complicate:

$$\star\ C_7(TOT) = C_7(W^\pm) + C_7(H^\pm) + C_7(\tilde{\chi}^\pm) + C_7(\tilde{\chi}^0) + C_7(\tilde{g})$$

$$\star\ C_7'(TOT) = C_7'(\tilde{g}) + \mathcal{O}(m_s/m_b)$$

■ Many independent sources of FV are contemporaneously present (CKM, up-squark and down-squark mass matrices) and give non negligible contributions to both $C_{7(8)}$ and $C'_{7(8)}$

"Alternative" Approach to $b \to s\gamma$

$\downarrow$

$$C_7(TOT) \approx 0 \quad \leftrightarrow \quad C_7(W^\pm) + C_7(H^\pm) + C_7(\tilde{\chi}^\pm) + C_7(\tilde{\chi}^0) + C_7(\tilde{g}) \approx 0$$

■ All the contribution to the $b \to s\gamma$ Branching Ratio comes form $C'_{7(8)}$

★ **SAME FINE TUNING as in the c-MSSM (if $C_7(\tilde{\chi}^\pm) \approx C_7(\tilde{g})$)** ★

(b) Example of "String Derived" SBT Texture

In many classes of SUSY breaking models the following structure of the trilinear couplings can be derived, $\tilde{A}_{ij} = A_{ij} Y_{ij}$ with: $A^{(u)}_{ij} = A^L_{ii} + A^{R,u}_{jj}$, $A^{(d)}_{ij} = A^L_{ii} + A^{R,d}_{jj}$

- This FACTORIZATION holds in many string models, gauge- and anomaly-mediated models
- UNIVERSALITY and MFV are not generally predictions of these models
- From the factorization ANSAZT in the SCKM basis one has:

$$\tilde{A}^{(u)}_{23} \propto m_t \left[(A^L_{22} - A^L_{11})(V^{(u)}_L)_{22}(V^{(u)}_L)^*_{32} + (A^L_{33} - A^L_{11})(V^{(u)}_L)_{23}(V^{(u)}_L)^*_{33} \right]$$

$$\tilde{A}^{(d)}_{23} \propto m_b \left[(A^L_{22} - A^L_{11})(V^{(d)}_L)_{22}(V^{(d)}_L)^*_{32} + (A^L_{33} - A^L_{11})(V^{(d)}_L)_{23}(V^{(d)}_L)^*_{33} \right]$$

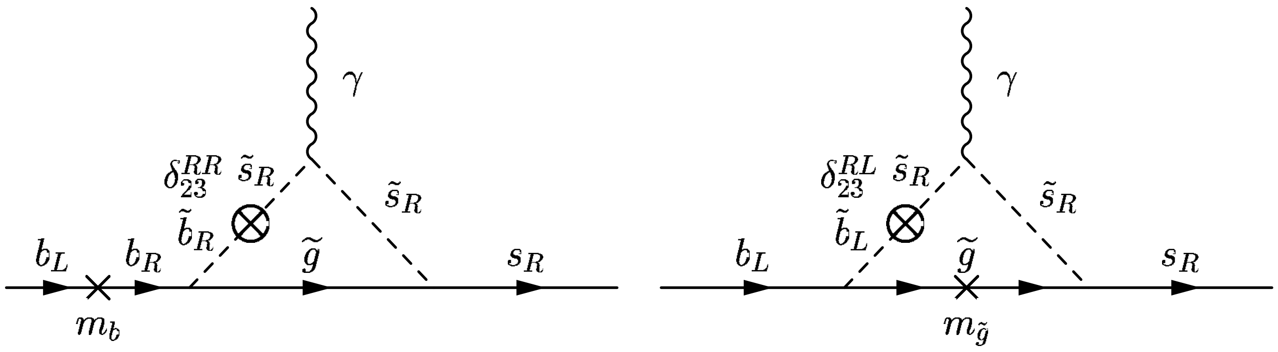
$$\rightarrow \quad (\delta^{LR}_{23})^d \approx \frac{m_b}{m_t} (\delta^{LR}_{23})^u$$

★ "Strong" and "Weak" Contributions are of the same Order ★

(c) Results in the "ALTERNATIVE" Framework

- C_7' **gluino contribution at the 1st order in the MI expansion**

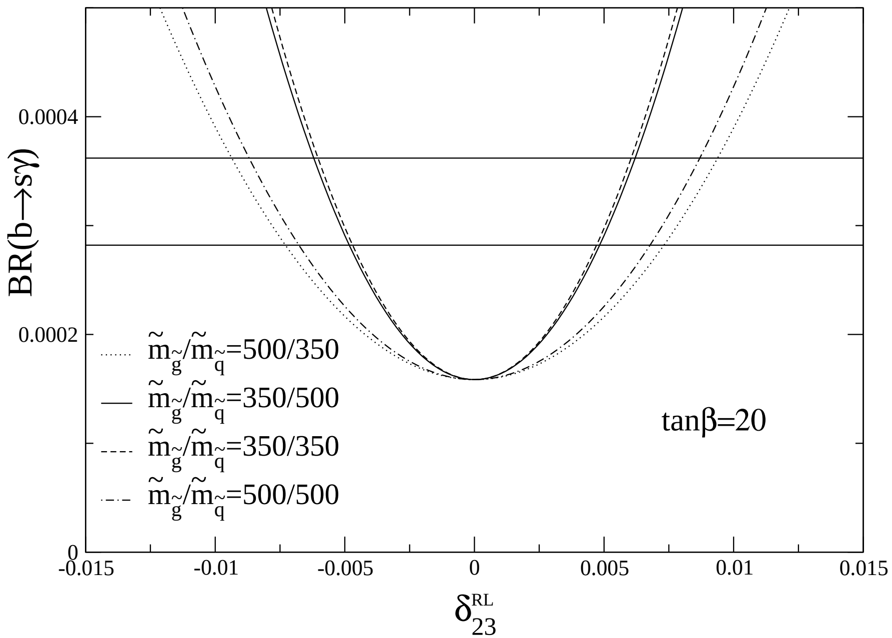
Neglecting terms $\mathcal{O}(m_s/m_b)$ two diagrams contribute to $C_7'(\tilde{g})$ in the MI formalism:

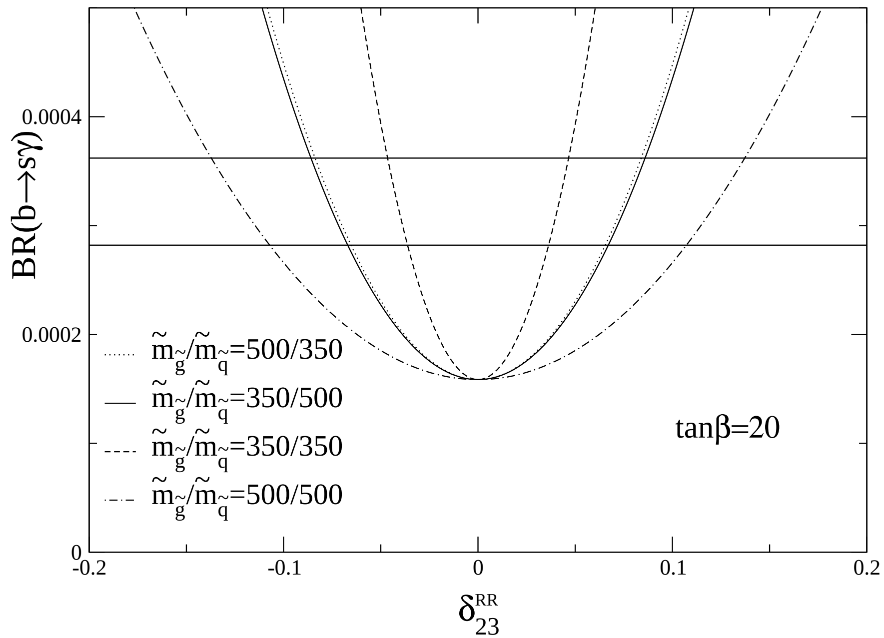


$$C_7^{\prime\tilde{g}}(1) = \frac{8g_s^2}{3g^2}\frac{Q_d}{V_{tb}V_{ts}^*}\frac{m_W^2}{\tilde{m}_D^2}\left\{\delta_{23}^{RR}F_2^{(1)}\left(\frac{\tilde{m}_{\tilde{g}}^2}{\tilde{m}_D^2}\right) - \frac{\tilde{m}_{\tilde{g}}}{m_b}\delta_{23}^{RL}F_4^{(1)}\left(\frac{\tilde{m}_{\tilde{g}}^2}{\tilde{m}_D^2}\right)\right\} + \mathcal{O}\left(\frac{m_s}{m_b}\right)$$

★ **From $BR(B \to X_s\gamma)_{exp}$ LIMITS on these MI parameters are derived** ★

- **Dependence of $BR(B \to X_s\gamma)$ on δ_{23}^{RL} and δ_{23}^{RR} (single MI dominance)**

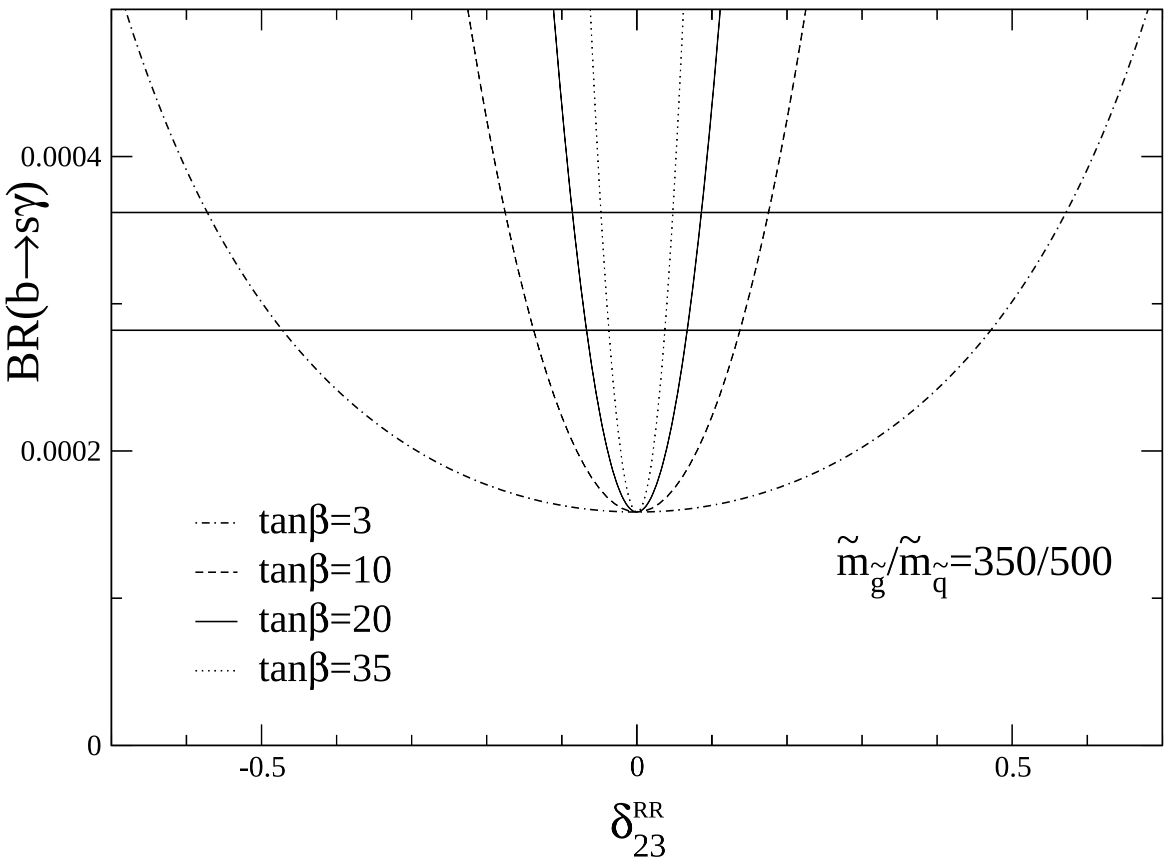




★ WHY such a STRONG BOUND on δ_{23}^{RR} ?

One would expect NO bound on δ_{23}^{RR} as "suppressed" by $\dfrac{m_b}{m_{\tilde{g}}} \approx 10^{-2}$

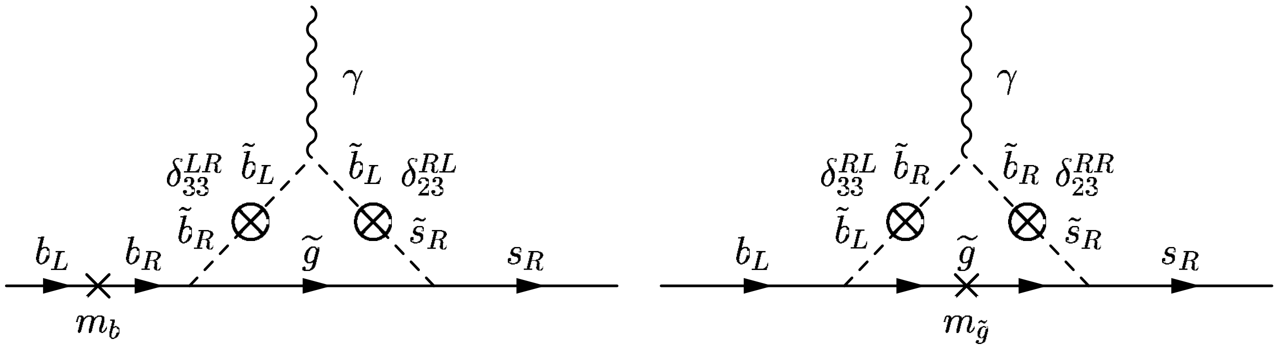
- **Dependence of $BR(B \to X_s\gamma)$ on δ_{23}^{RR} (single MI dominance)**



★ WHY such a DEPENDENCE of the δ_{23}^{RR} bound on $\tan\beta$?

→ Expansion at 1^{st} order in the MI is not enough ←

The leading correction at the 2^{nd} order in the MI expansion is given by:

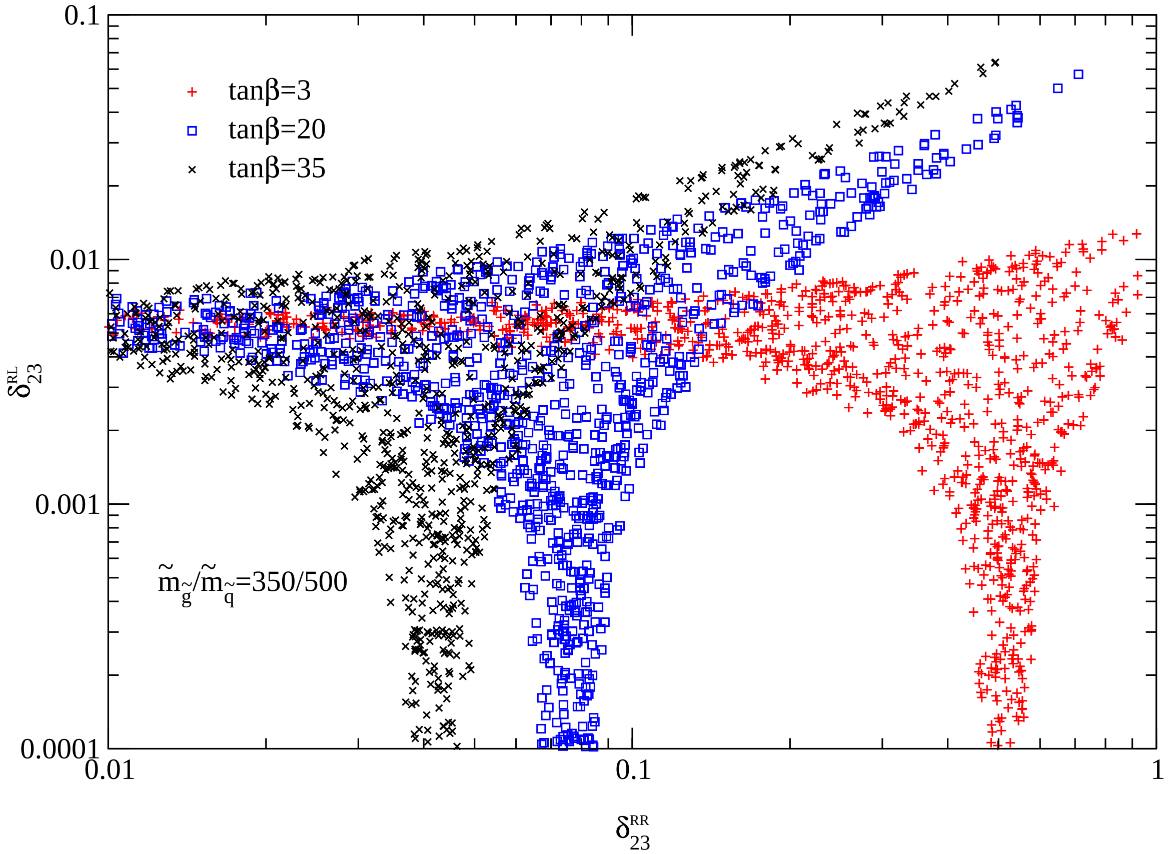


$$C_7^{\prime\tilde{g}}(2) \;=\; \frac{4g_s^2}{3g^2}\frac{Q_d}{V_{tb}V_{ts}^*}\frac{m_W^2}{\tilde{m}_D^2}\delta_{33}^{RL}\left\{\delta_{23}^{RL}F_2^{\prime(2)}\left(\frac{\tilde{m}_{\tilde{g}}^2}{\tilde{m}_D^2}\right) - \frac{\tilde{m}_{\tilde{g}}}{m_b}\delta_{23}^{RR}F_4^{\prime(2)}\left(\frac{\tilde{m}_{\tilde{g}}^2}{\tilde{m}_D^2}\right)\right\}$$

★ **When** $\delta_{33}^{RL} \equiv \dfrac{m_b(A_b - \mu\,\tan\beta\,)}{\tilde{m}_D^2} \approx \mathcal{O}(1)$, δ_{23}^{RR} **CANNOT be NEGLECTED** ★

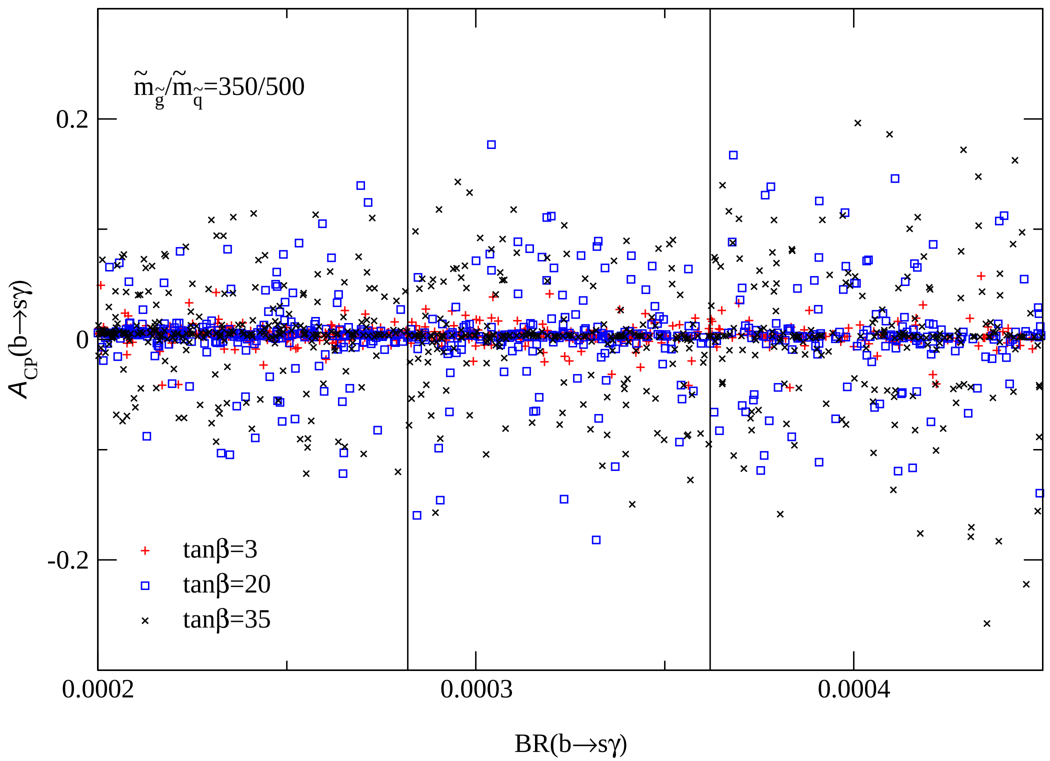
IMPORTANT phenomenological consequences

- 1σ-allowed region in the $(\delta_{23}^{RR}\,,\,\delta_{23}^{RL}\,)$ parameter space



The ALLOWED region in the $(\delta_{23}^{RR}\,,\,\delta_{23}^{RL}\,)$ plane is "unlimited"

- **CP-Asymmetry vs Branching Ratio**



$$\mathcal{A}_{CP}(b \to s\gamma) = -\frac{4}{9}\alpha_s(\mu_b)\frac{\mathrm{Im}\,[C_7' C_8'^*]}{|C_7'|^2} \approx k(x_D^g)\left(\frac{m_b\ \mu\ \tan\beta}{\tilde{m}_D^2}\right)|\delta_{23}^{RL}\ \delta_{23}^{RR}|\sin\varphi$$

If only ONE MI is considered $\mathcal{A}_{CP}(b \to s\gamma) = 0$!!

■ Conclusions

(I) $b \to s\gamma$ **provides a very important test of the flavour sector**

- Consistency at 1σ level between EXP and SM
- Constraints on new sources of FCNC (as MSSM, etc.)

(II) **In the u-MSSM both C_7 and C'_7 contribute**

- Dependence on "new" (opposite chirality) MI parameters δ_{23}^{RL} and δ_{23}^{RR} (down sector)
- Limits on these parameters have been provided (single MI dominance)

(III) **Alternative approach to $b \to s\gamma$** $(C_7(TOT) \approx 0,\ C'_7(TOT) \approx C'_7(\tilde{g}))$

- SAME fine tuning as the conventional approach $(C_7(NP) \approx 0\ \leftrightarrow\ C_7(TOT) \approx 0)$
- Large CP-asymmetry and "opposite" LR-asymmetry could provide exp signatures