B-meson Observables in the CP-violating MSSM with Minimal Flavour Violation

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Contents

♠ *Motivations* $(1/3)$

- The SUSY models such as the MSSM contain many possible sources of flavour and CP violation in the soft SUSY-breaking sector:

$$30 \oplus 33 \oplus 46 = \mathbf{109} \ !!!$$

  - Gaugino mass terms: $3 \oplus 3 = 6$

$$-\mathcal{L}_{\mathrm{soft}} \supset \frac{1}{2}\left(M_3\,\widetilde{g}\widetilde{g} + M_2\,\widetilde{W}\widetilde{W} + M_1\,\widetilde{B}\widetilde{B} + \mathrm{h.c.}\right)$$

  - Trilinear $\mathbf{a}$ terms $\mathbf{a}_{\mathbf{f}ij} \equiv \mathbf{h}_{\mathbf{f}ij} \cdot \mathbf{A}_{\mathbf{f}ij}$: $3 \times (3 \oplus 6 \oplus 9) = 54$

$$-\mathcal{L}_{\mathrm{soft}} \supset \left(\widetilde{u}_R^*\,\mathbf{a_u}\,\widetilde{Q}H_2 - \widetilde{d}_R^*\,\mathbf{a_d}\,\widetilde{Q}H_1 - \widetilde{e}_R^*\,\mathbf{a_e}\,\widetilde{L}H_1 + \mathrm{h.c.}\right)$$

  - Sfermion mass terms: $5 \times (3 \oplus 3 \oplus 3) = 45$

$$-\mathcal{L}_{\mathrm{soft}} \supset \widetilde{Q}^\dagger\,\mathbf{M}^2_{\widetilde{\mathbf{Q}}}\,\widetilde{Q} + \widetilde{L}^\dagger\,\mathbf{M}^2_{\widetilde{\mathbf{L}}}\,\widetilde{L} + \widetilde{u}_R^*\,\mathbf{M}^2_{\widetilde{\mathbf{u}}}\,\widetilde{u}_R + \widetilde{d}_R^*\,\mathbf{M}^2_{\widetilde{\mathbf{d}}}\,\widetilde{d}_R + \widetilde{e}_R^*\,\mathbf{M}^2_{\widetilde{\mathbf{e}}}\,\widetilde{e}_R$$

  - Higgs mass terms: $3 \oplus 1 = 4$

$$-\mathcal{L}_{\mathrm{soft}} \supset M^2_{H_u} H_2^\dagger H_2 + M^2_{H_d} H_1^\dagger H_1 - \left(m^2_{12} H_1 H_2 + \mathrm{h.c.}\right)$$

♠ *Motivations* $(2/3)$

- How to suppress FCNC and CP violation? $\Longrightarrow$ Minimal Flavour Violation (MFV) in which
  - Squarks and sleptons are aligned with quarks and leptons
  - All FCNC and CP violation vanish in the limit $\mathbf{V}_{\mathrm{CKM}} \rightarrow \mathbf{1}$

- Now we have large set of experimental results of FCNC B-meson observables which put stringent constraints especially when $\tan\beta$ is large

- For large $\tan\beta$, the one-loop threshold corrections to the flavour-changing Higgs couplings to down-type quarks can be greatly enhanced

- This $\tan\beta$-enhanced Higgs-mediated FCNC can be calculated in flavour-covariant way by adapting the effective Lagrangian approach

♠ *Motivations* (3/3)

- Our aim is to study the

Higgs-mediated FCNC B-meson observables

  - in the "maximal" MFV Framework
  - based on the "flavour-covariant" Effective Lagrangian Formalism

when $\tan\beta$ is large

♠ *MCPMFV* $(1/5)$

There can be several variants of MFV

- The scale of MFV ... anywhere between $M_{\rm EW}$ and $M_{\rm GUT}$?

- The "minimal" MFV

$$m_0(M_{\rm MFV})\,,\quad m_{1/2}(M_{\rm MFV})\,,\quad A(M_{\rm MFV})\,;\quad \tan\beta(m_t)\,,\quad M_Z\quad {\rm upto\ sign}(\mu)$$

with real and positive m_0, $m_{1/2}$, and A

- Next to the "minimal" MFV

$$m_0(M_{\rm MFV})\,,\quad m_{1/2}(M_{\rm MFV})\,,\quad A(M_{\rm MFV})\,;\quad \tan\beta(m_t)\,,\quad M_Z$$

with complex $m_{1/2}$ and A

♠ *MCPMFV* (2/5)

Then, what is the "maximal" MFV ?

- Consider the unitary flavour rotations U_X:

$$\begin{aligned} \widehat{Q}' &= \mathbf{U}_Q\,\widehat{Q}\,, \qquad \widehat{L}' = \mathbf{U}_L\,\widehat{L}\,, \\ \widehat{U}'^C &= \mathbf{U}_U^*\,\widehat{U}^C\,, \quad \widehat{D}'^C = \mathbf{U}_D^*\,\widehat{D}^C\,, \quad \widehat{E}'^C = \mathbf{U}_E^*\,\widehat{E}^C\,, \end{aligned}$$

- Then, for example,

$$\widehat{U}^C\,\mathbf{h_u}\,\widehat{Q}\,\widehat{H}_2 \quad \overset{\text{F.R.}}{\Longrightarrow} \quad \widehat{U}'^C\,\mathbf{h_u}\,\widehat{Q}'\,\widehat{H}_2 = \widehat{U}^C\,\mathbf{U}_U^\dagger\,\mathbf{h_u}\,\mathbf{U}_Q\,\widehat{Q}\,\widehat{H}_2$$

The interaction Lagrangian remains invariant under the flavour rotations with the redefinition of the up-quark Yukawa couplings: $\mathbf{h}_u \to \mathbf{U}_U^\dagger\,\mathbf{h}_u\,\mathbf{U}_Q$

♠ *MCPMFV* $(3/5)$

- Actually, in the MSSM, one can find that the flavour rotation is equivalent to the redefinition of parameters with the same interaction Lagrangian:

$$\begin{aligned} \mathbf{h}_{u,d} &\to \mathbf{U}^\dagger_{U,D}\,\mathbf{h}_{u,d}\,\mathbf{U}_Q\,, \qquad \mathbf{h}_e \to \mathbf{U}^\dagger_E\,\mathbf{h}_e\,\mathbf{U}_L\,, \\ \widetilde{\mathbf{M}}^2_{Q,L,U,D,E} &\to \mathbf{U}^\dagger_{Q,L,U,D,E}\,\widetilde{\mathbf{M}}^2_{Q,L,U,D,E}\,\mathbf{U}_{Q,L,U,D,E}\,, \\ \mathbf{a}_{u,d} &\to \mathbf{U}^\dagger_{U,D}\,\mathbf{a}_{u,d}\,\mathbf{U}_Q\,, \qquad \mathbf{a}_e \to \mathbf{U}^\dagger_E\,\mathbf{a}_e\,\mathbf{U}_L\,. \end{aligned}$$

- We define $\boxed{\text{MCPMFV}}$ framework with the maximal set of flavour-singlet mass scales:

$$M_{1,2,3}\,, \quad M^2_{H_{u,d}}\,, \quad \widetilde{\mathbf{M}}^2_{Q,L,U,D,E} = \widetilde{M}^2_{Q,L,U,D,E}\,\mathbf{1}_3\,, \quad \mathbf{A}_{u,d,e} = A_{u,d,e}\,\mathbf{1}_3$$

$$3 \oplus 3 \qquad 2 \qquad 5 \qquad 3 \oplus 3$$

$\boxed{13 \oplus 6 = 19 \text{ Parameters !}}$

♠ *MCPMFV* (4/5)

- The flavour non-singlet mass scales: For example,

$$\widetilde{\mathbf{M}}^2_Q(M_X) \;=\; \widetilde{M}^2_Q\,\mathbf{1}_3 + \widetilde{m}^2_1\,(\mathbf{h}_d^\dagger\mathbf{h}_d) + \widetilde{m}^2_2\,(\mathbf{h}_u^\dagger\mathbf{h}_u) + \widetilde{m}^2_3\,(\mathbf{h}_d^\dagger\mathbf{h}_d\,\mathbf{h}_u^\dagger\mathbf{h}_u) + \ldots$$

at arbitrary scale M_X

- These additional flavour non-singlet mass parameters $\widetilde{m}^2_n$ can be as many as 9 including $\widetilde{M}^2_Q$
- The non-singlet mass parameter $\widetilde{m}^2_n \neq 0$ can either be introduced by hand and/or induced by RG running
- With $\widetilde{m}^2_n \ll \widetilde{M}^2_Q$, the MFV solution to the flavour problem is still valid, though approximately

♠ *MCPMFV* (5/5)

- The flavour covariance of RGEs:

$$\begin{aligned}
\mathbf{U}_Q^\dagger \frac{d\widetilde{\mathbf{M}}_Q^2}{dt}\mathbf{U}_Q \;=\;& \frac{1}{16\pi^2}\,\mathbf{U}_Q^\dagger\Big[-\Big(\frac{1}{15}\,g_1^2|M_1|^2 + 3g_2^2|M_2|^2 + \frac{16}{3}\,g_3^2|M_3|^2\Big)\mathbf{1}_3 + \frac{1}{2}\,\mathbf{h}_u^\dagger\mathbf{h}_u\widetilde{\mathbf{M}}_Q^2 \\
&+ \frac{1}{2}\,\widetilde{\mathbf{M}}_Q^2\mathbf{h}_u^\dagger\mathbf{h}_u + \mathbf{h}_u^\dagger\widetilde{\mathbf{M}}_U^2\mathbf{h}_u + M_{H_u}^2\mathbf{h}_u^\dagger\mathbf{h}_u + \mathbf{a}_u^\dagger\mathbf{a}_u + \frac{1}{2}\,\mathbf{h}_d^\dagger\mathbf{h}_d\widetilde{\mathbf{M}}_Q^2 + \frac{1}{2}\,\widetilde{\mathbf{M}}_Q^2\mathbf{h}_d^\dagger\mathbf{h}_d \\
&+ \mathbf{h}_d^\dagger\widetilde{\mathbf{M}}_D^2\mathbf{h}_d + M_{H_d}^2\mathbf{h}_d^\dagger\mathbf{h}_d + \mathbf{a}_d^\dagger\mathbf{a}_d + \frac{1}{10}\,g_1^2\,\mathrm{Tr}\,(Y\mathbf{M}^2)\,\mathbf{1}_3\Big]\;\mathbf{U}_Q
\end{aligned}$$

$$\begin{aligned}
\mathbf{U}_U^\dagger \frac{d\widetilde{\mathbf{M}}_U^2}{dt}\mathbf{U}_U \;=\;& \frac{1}{16\pi^2}\,\mathbf{U}_U^\dagger\Big[-\Big(\frac{16}{15}\,g_1^2|M_1|^2 + \frac{16}{3}\,g_3^2|M_3|^2\Big)\mathbf{1}_3 + \mathbf{h}_u\mathbf{h}_u^\dagger\widetilde{\mathbf{M}}_U^2 + \widetilde{\mathbf{M}}_U^2\mathbf{h}_u\mathbf{h}_u^\dagger \\
&+ 2\,\mathbf{h}_u\widetilde{\mathbf{M}}_Q^2\mathbf{h}_u^\dagger + 2\,M_{H_u}^2\mathbf{h}_u\mathbf{h}_u^\dagger + 2\,\mathbf{a}_u\mathbf{a}_u^\dagger - \frac{2}{5}\,g_1^2\,\mathrm{Tr}\,(Y\mathbf{M}^2)\,\mathbf{1}_3\Big]\;\mathbf{U}_U
\end{aligned}$$

$$\begin{aligned}
\mathbf{U}_D^\dagger \frac{d\widetilde{\mathbf{M}}_D^2}{dt}\mathbf{U}_D \;=\;& \frac{1}{16\pi^2}\,\mathbf{U}_D^\dagger\Big[-\Big(\frac{4}{15}\,g_1^2|M_1|^2 + \frac{16}{3}\,g_3^2|M_3|^2\Big)\mathbf{1}_3 + \mathbf{h}_d\mathbf{h}_d^\dagger\widetilde{\mathbf{M}}_D^2 + \widetilde{\mathbf{M}}_D^2\mathbf{h}_d\mathbf{h}_d^\dagger \\
&+ 2\,\mathbf{h}_d\widetilde{\mathbf{M}}_Q^2\mathbf{h}_d^\dagger + 2\,M_{H_d}^2\mathbf{h}_d\mathbf{h}_d^\dagger + 2\,\mathbf{a}_d\mathbf{a}_d^\dagger + \frac{1}{5}\,g_1^2\,\mathrm{Tr}\,(Y\mathbf{M}^2)\,\mathbf{1}_3\Big]\;\mathbf{U}_D
\end{aligned}$$

where $t = \ln(Q^2/M_{\rm GUT}^2)$

♠ *Flavour-covariant Effective Lagrangian Formalism* $(1/5)$

- The effective Lagrangian of the down-type quarks can be written in gauge-symmetric and flavour-covariant form as follows ($H_u = \Phi_2$ and $H_d = i\tau_2\Phi_1^*$):

$$-\mathcal{L}^d_{\rm eff}[\Phi_1, \Phi_2] \;=\; \overline{d^0_{R\,\alpha}}\,(\,\mathbf{h}_d\,\Phi_1^\dagger \;+\; \Delta\mathbf{h}_d[\Phi_1, \Phi_2]\,)_{\alpha\beta}\,Q^0_{L\,\beta} \;+\; \text{h.c.},$$

where the superscript '0' indicates weak eigenstate fields and

- $\Delta\mathbf{h}_d[\Phi_1, \Phi_2]$ is a Coleman-Weinberg-type field-dependent effective functional of the background Higgs doublets $\Phi_{1,2}$
- It has the same flavour and gauge transformation properties as $\mathbf{h}_d\,\Phi_1^\dagger$

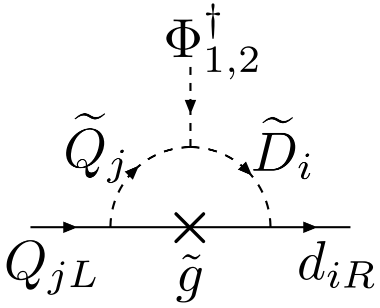
Convention:

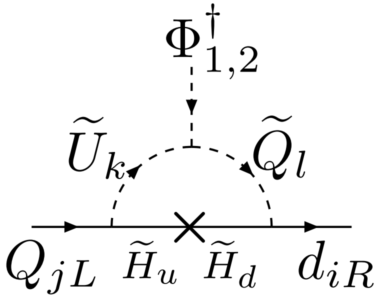
$$\Phi_i = \begin{pmatrix} \phi_i^+ \\ \phi_i^0 \end{pmatrix} = \begin{pmatrix} \phi_i^+ \\ \frac{1}{\sqrt{2}}(v_i + \phi_i + i a_i) \end{pmatrix} \;\;\text{with}\;\; \langle\Phi_{1,2}\rangle = \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}\,v_{1,2} \end{pmatrix}$$

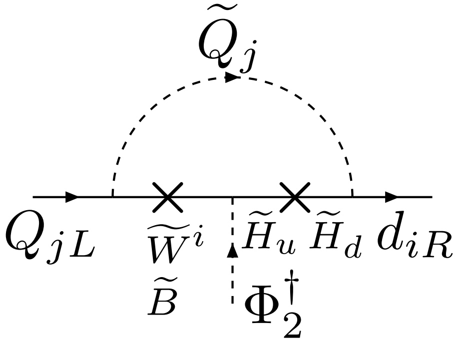
♠ *Flavour-covariant Effective Lagrangian Formalism* (2/5)

- The analytic form of $\Delta \mathbf{h}_d[\Phi_1, \Phi_2]$ may be calculated via (gauge couplings are suppressed)

$$\begin{aligned}(\Delta \mathbf{h}_d)_{ij} \;=\; & \int \frac{d^n k}{(2\pi)^n\, i} \Big[P_L \frac{M_3^*}{k^2 - |M_3^2|} \Big(\frac{1}{k^2 \mathbf{1}_{12} - \widetilde{\mathbf{M}}^2} \Big)_{\widetilde{D}_i^\dagger \widetilde{Q}_j} \\ & + P_L \Big(\frac{1}{\not{k}\mathbf{1}_8 - \mathbf{M}_C P_L - \mathbf{M}_C^\dagger P_R} \Big)_{\widetilde{H}_u \widetilde{H}_d} P_L\, (\mathbf{h}_d)_{il} \Big(\frac{1}{k^2 \mathbf{1}_{12} - \widetilde{\mathbf{M}}^2} \Big)_{\widetilde{Q}_l^\dagger \widetilde{U}_k} (\mathbf{h}_u)_{kj} \\ & + P_L \Big(\frac{1}{\not{k}\mathbf{1}_8 - \mathbf{M}_C P_L - \mathbf{M}_C^\dagger P_R} \Big)_{\widetilde{H}_d \widetilde{W}^i ,\, \widetilde{H}_d \widetilde{B}} P_L\, (\mathbf{h}_d)_{ij} \Big(\frac{1}{k^2 \mathbf{1}_{12} - \widetilde{\mathbf{M}}^2} \Big)_{\widetilde{Q}_j^\dagger \widetilde{Q}_j} \Big]\end{aligned}$$







♠ *Flavour-covariant Effective Lagrangian Formalism* $(3/5)$

- The Higgs-field dependent 12×12 squark mass matrix $\widetilde{\mathbf{M}}^2[\Phi_1, \Phi_2]$ is given by:

$$\widetilde{\mathbf{M}}^2[\Phi_1, \Phi_2] \;=\; \begin{pmatrix} (\widetilde{\mathbf{M}}^2)_{\widetilde{Q}^\dagger \widetilde{Q}} & (\widetilde{\mathbf{M}}^2)_{\widetilde{Q}^\dagger \widetilde{U}} & (\widetilde{\mathbf{M}}^2)_{\widetilde{Q}^\dagger \widetilde{D}} \\ (\widetilde{\mathbf{M}}^2)_{\widetilde{U}^\dagger \widetilde{Q}} & (\widetilde{\mathbf{M}}^2)_{\widetilde{U}^\dagger \widetilde{U}} & (\widetilde{\mathbf{M}}^2)_{\widetilde{U}^\dagger \widetilde{D}} \\ (\widetilde{\mathbf{M}}^2)_{\widetilde{D}^\dagger \widetilde{Q}} & (\widetilde{\mathbf{M}}^2)_{\widetilde{D}^\dagger \widetilde{U}} & (\widetilde{\mathbf{M}}^2)_{\widetilde{D}^\dagger \widetilde{D}} \end{pmatrix}_{ij}$$

$$\begin{aligned}
(\widetilde{\mathbf{M}}^2)_{\widetilde{Q}_i^\dagger \widetilde{Q}_j} \;&=\; (\widetilde{\mathbf{M}}_Q^2)_{ij}\, \mathbf{1}_2 \;+\; (\mathbf{h}_d^\dagger \mathbf{h}_d)_{ij}\, \Phi_1 \Phi_1^\dagger \;+\; (\mathbf{h}_u^\dagger \mathbf{h}_u)_{ij}\, (\Phi_2^\dagger \Phi_2\, \mathbf{1}_2 \;-\; \Phi_2 \Phi_2^\dagger) \\
&\quad -\, \frac{1}{2}\, g^2\, \delta_{ij}\, (\Phi_1 \Phi_1^\dagger \;-\; \Phi_2 \Phi_2^\dagger)\, \mathbf{1}_2 \;+\; \delta_{ij} \left(\frac{1}{4}\, g^2 \;-\; \frac{1}{12}\, g'^2 \right) (\Phi_1^\dagger \Phi_1 \;-\; \Phi_2^\dagger \Phi_2)\, \mathbf{1}_2\,, \\
(\widetilde{\mathbf{M}}^2)_{\widetilde{U}_i^\dagger \widetilde{Q}_j} \;&=\; (\widetilde{\mathbf{M}}^2)^\dagger_{\widetilde{Q}_j^\dagger \widetilde{U}_i} \;=\; -\, (\mathbf{a}_u)_{ij}\, \Phi_2^T i\tau_2 \;+\; (\mathbf{h}_u)_{ij}\, \mu^*\, \Phi_1^T i\tau_2\,, \\
(\widetilde{\mathbf{M}}^2)_{\widetilde{D}_i^\dagger \widetilde{Q}_j} \;&=\; (\widetilde{\mathbf{M}}^2)^\dagger_{\widetilde{Q}_j^\dagger \widetilde{D}_i} \;=\; (\mathbf{a}_d)_{ij}\, \Phi_1^\dagger \;-\; (\mathbf{h}_d)_{ij}\, \mu^*\, \Phi_2^\dagger\,, \\
(\widetilde{\mathbf{M}}^2)_{\widetilde{U}_i^\dagger \widetilde{U}_j} \;&=\; (\widetilde{\mathbf{M}}_U^2)_{ij} \;+\; (\mathbf{h}_u \mathbf{h}_u^\dagger)_{ij}\, \Phi_2^\dagger \Phi_2 \;+\; \frac{1}{3}\, \delta_{ij}\, g'^2\, (\Phi_1^\dagger \Phi_1 \;-\; \Phi_2^\dagger \Phi_2)\,, \\
(\widetilde{\mathbf{M}}^2)_{\widetilde{D}_i^\dagger \widetilde{D}_j} \;&=\; (\widetilde{\mathbf{M}}_D^2)_{ij} \;+\; (\mathbf{h}_d \mathbf{h}_d^\dagger)_{ij}\, \Phi_1^\dagger \Phi_1 \;-\; \frac{1}{6}\, \delta_{ij}\, g'^2\, (\Phi_1^\dagger \Phi_1 \;-\; \Phi_2^\dagger \Phi_2)\,, \\
(\widetilde{\mathbf{M}}^2)_{\widetilde{U}_i^\dagger \widetilde{D}_j} \;&=\; (\widetilde{\mathbf{M}}^2)^\dagger_{\widetilde{D}_j^\dagger \widetilde{U}_i} \;=\; (\mathbf{h}_u \mathbf{h}_d^\dagger)_{ij}\, \Phi_1^T i\tau_2 \Phi_2
\end{aligned}$$

♠ *Flavour-covariant Effective Lagrangian Formalism* $(4/5)$

- The Higgs-field dependent 8×8 chargino-neutralino mass matrix $\mathbf{M}_C[\Phi_1, \Phi_2]$ reads:

$$\mathbf{M}_C[\Phi_1, \Phi_2] \;=\; \begin{pmatrix} M_1 & 0 & -\frac{1}{\sqrt{2}}\, g' \Phi_2^\dagger & \frac{1}{\sqrt{2}}\, g' \Phi_1^T\, (i\tau_2) \\ 0 & M_2\, \mathbf{1}_3 & \frac{1}{\sqrt{2}}\, g \Phi_2^\dagger\, \tau_i & -\frac{1}{\sqrt{2}}\, g \Phi_1^T\, (i\tau_2)\, \tau_i \\ -\frac{1}{\sqrt{2}}\, g' \Phi_2^* & \frac{1}{\sqrt{2}}\, g \tau_i^T\, \Phi_2^* & \mathbf{0}_2 & \mu\, (i\tau_2) \\ -\frac{1}{\sqrt{2}}\, (i\tau_2)\, g' \Phi_1 & \frac{1}{\sqrt{2}}\, g \tau_i^T\, (i\tau_2) \Phi_1 & -\mu\, (i\tau_2) & \mathbf{0}_2 \end{pmatrix}$$

in the Weyl basis, $(\widetilde{B},\ \widetilde{W}^{1,2,3},\ \widetilde{H}_u,\ \widetilde{H}_d)$, with $\widetilde{H}_u = (\tilde{h}_u^+, \tilde{h}_u^0)^T$ and $\widetilde{H}_d = (\tilde{h}_d^0, \tilde{h}_d^-)^T$

♠ *Flavour-covariant Effective Lagrangian Formalism* $(5/5)$

- <u>The functional $\Delta\mathbf{h}_d$ is flavour covariant !:</u>

$$
\begin{aligned}
(\Delta\mathbf{h}_d)_{ij} \quad = \quad & \int \frac{d^n k}{(2\pi)^n\, i}\, \Big[\, P_L\, \frac{M_3^*}{k^2 - |M_3^2|}\, \Big(\frac{1}{k^2\mathbf{1}_{12} - \widetilde{\mathbf{M}}^2}\Big)_{\widetilde{D}_i^\dagger \widetilde{Q}_j} \\
& + P_L\, \Big(\frac{1}{\not{k}\mathbf{1}_8 - \mathbf{M}_C P_L - \mathbf{M}_C^\dagger P_R}\Big)_{\widetilde{H}_u \widetilde{H}_d} P_L\, (\mathbf{h}_d)_{il}\, \Big(\frac{1}{k^2\mathbf{1}_{12} - \widetilde{\mathbf{M}}^2}\Big)_{\widetilde{Q}_l^\dagger \widetilde{U}_k} (\mathbf{h}_u)_{kj} \\
& + P_L\, \Big(\frac{1}{\not{k}\mathbf{1}_8 - \mathbf{M}_C P_L - \mathbf{M}_C^\dagger P_R}\Big)_{\widetilde{H}_d \widetilde{W}^i ,\widetilde{H}_d \widetilde{B}} P_L\, (\mathbf{h}_d)_{ij}\, \Big(\frac{1}{k^2\mathbf{1}_{12} - \widetilde{\mathbf{M}}^2}\Big)_{\widetilde{Q}_j^\dagger \widetilde{Q}_j}\, \Big]
\end{aligned}
$$

For example,

$$
\mathbf{h}_d\, \Big(\frac{1}{k^2\mathbf{1}_{12} - \widetilde{\mathbf{M}}^2}\Big)_{\widetilde{Q}^\dagger \widetilde{U}} \mathbf{h}_u \quad \to \quad \big[\mathbf{U}_D^\dagger\, \mathbf{h}_d\, \mathbf{U}_Q\big]\big[\mathbf{U}_Q^\dagger \Big(\frac{1}{k^2\mathbf{1}_{12} - \widetilde{\mathbf{M}}^2}\Big)_{\widetilde{Q}^\dagger \widetilde{U}} \mathbf{U}_U\big]\big[\mathbf{U}_U^\dagger \mathbf{h}_u\, \mathbf{U}_Q\big]
$$

Flavour covariance: $\Delta\mathbf{h}_d \to \mathbf{U}_D^\dagger\, \Delta\mathbf{h}_d\, \mathbf{U}_Q$ under flavour rotations

♠ *Higgs-mediated Flavour-changing Effective Lagrangian* (1/8)

- Introduce rotation matrices which rotate the (weak) chiral states into their mass eigenstates:

$$\begin{aligned} u^0_{L\,\alpha} &= \left(\mathcal{U}^Q_L\right)_{\alpha\,i} u_{L\,i} \;\; ; \;\; d^0_{L\,\alpha} = \left(\mathcal{U}^Q_L\, V_{\rm CKM}\right)_{\alpha\,i} d_{L\,i} \\ u^0_{R\,\alpha} &= (\mathcal{U}^u_R)_{\alpha\,i}\, u_{R\,i} \;\; ; \;\; d^0_{R\,\alpha} = (\mathcal{U}^d_R)_{\alpha\,i}\, d_{R\,i} \end{aligned}$$

In terms of the mass eigenstates, the effective Lagrangian becomes

$$\begin{aligned} -\mathcal{L}^d_{\rm eff}[\Phi_1,\Phi_2] \;=\; \overline{d_{R\,i}} \left(\mathcal{U}^{d\,\dagger}_R\, \mathbf{h}_d\right)_{i\alpha} \Big\{ \left(\phi^-_1, \phi^{0*}_1\right)\, \delta_{\alpha\beta} + \left(\mathbf{h}^{-1}_d \Delta\mathbf{h}_d[\Phi_1,\Phi_2]\right)_{\alpha\beta} \Big\} \\ \times \left(\begin{array}{c} \left(\mathcal{U}^Q_L\right)_{\beta\,j} u_{L\,j} \\ \left(\mathcal{U}^Q_L\, V_{\rm CKM}\right)_{\beta\,j} d_{L\,j} \end{array} \right) + \text{h.c.} \end{aligned}$$

♠ *Higgs-mediated Flavour-changing Effective Lagrangian* (2/8)

- The functional $\mathbf{h}_d^{-1}\Delta\mathbf{h}_d[\Phi_1, \Phi_2]$ might be expanded as:

$$\mathbf{h}_d^{-1}\Delta\mathbf{h}_d[\Phi_1, \Phi_2] = (0\,, \Delta_d) + \sum_{i=1,2} \left(\Delta_d^{\phi_i^-}\, \phi_i^- \,,\; \frac{\Delta_d^{\phi_i}}{\sqrt{2}}\, \phi_i + \frac{\Delta_d^{a_i}}{i\,\sqrt{2}}\, a_i \right) + \cdots$$

where 7 coefficients are

$$\Delta_d = \langle \mathbf{h}_d^{-1}\Delta\mathbf{h}_d[\Phi_1, \Phi_2] \rangle \quad ; \quad \Delta_d^{\phi_i^-} = \left\langle \frac{\delta\, \mathbf{h}_d^{-1}\Delta\mathbf{h}_d[\Phi_1, \Phi_2]}{\delta \phi_i^-} \right\rangle$$

$$\frac{\Delta_d^{\phi_i}}{\sqrt{2}} = \left\langle \frac{\delta\, \mathbf{h}_d^{-1}\Delta\mathbf{h}_d[\Phi_1, \Phi_2]}{\delta \phi_i} \right\rangle \quad ; \quad \frac{\Delta_d^{a_i}}{i\,\sqrt{2}} = \left\langle \frac{\delta\, \mathbf{h}_d^{-1}\Delta\mathbf{h}_d[\Phi_1, \Phi_2]}{\delta a_i} \right\rangle$$

suppressing the vanishing iso-doublet components on the RHSs

♠ *Higgs-mediated Flavour-changing Effective Lagrangian* (3/8)

- Mass terms:

$$\left(-\,\mathcal{L}^{d}_{\rm eff}[\Phi_1,\Phi_2]\right)^{\rm Mass} = \overline{d_{R\,i}}\ \left[\mathcal{U}_R^{d\,\dagger}\,\mathbf{h}_d\left(\frac{1}{\sqrt{2}}v_1+\Delta_d\right)\ \mathcal{U}_L^{Q}\,V_{\rm CKM}\right]_{ij} d_{L\,j} = \overline{d_R}\,\widehat{M}_d\,d_L$$

Therefore, we have

$$\widehat{M}_d = {\rm diag}(m_d, m_s, m_b) = \mathcal{U}_R^{d\,\dagger}\,\mathbf{h}_d\left(\frac{1}{\sqrt{2}}v_1+\Delta_d\right)\ \mathcal{U}_L^{Q}\,V_{\rm CKM}$$

In other words, the Yukawa-coupling matrix is given by

$$\boxed{\mathcal{U}_R^{d\,\dagger}\,\mathbf{h}_d\,\mathcal{U}_L^{Q} = \frac{\sqrt{2}}{v_1}\widehat{M}_d\ V^{\dagger}_{\rm CKM}\ R_d^{-1}\quad\text{with}\quad R_d \equiv \mathcal{U}_L^{Q\,\dagger}\left(\mathbf{1}+\frac{\sqrt{2}}{v_1}\,\Delta_d\right)\mathcal{U}_L^{Q}}$$

Note that the (loop-corrected) Yukawa coupling $\mathbf{h}_d$ is in the weak basis, $\mathbf{h}_d = (\mathbf{h}_d)_{\alpha\beta}$

♠ *Higgs-mediated Flavour-changing Effective Lagrangian* (4/8)

- The interaction of the charged Higgs bosons:

$$\left(-\mathcal{L}^{d}_{\rm eff}\right)^{H^{\pm}} = \frac{g}{\sqrt{2}M_W}\,\overline{d}\,\widehat{M}_d\,\mathbf{g}^{L}_{H^-\bar{d}u}\,P_L\,u\,H^- + \text{h.c.}$$

where

$$\mathbf{g}^{L}_{H^-\bar{d}u} \equiv V^{\dagger}_{\rm CKM}\,R_d^{-1}\,\mathcal{U}^{Q\,\dagger}_{L}\left[-t_\beta(\mathbf{1}+\Delta_d^{\phi_1^-})+\Delta_d^{\phi_2^-}\right]\mathcal{U}^{Q}_{L}$$

Here we have used:

$$\phi_1 = O_{1i}\,H_i,\quad a_1 = c_\beta\,G^0 - s_\beta\,O_{3i}\,H_i,\quad \phi_1^- = c_\beta\,G^- - s_\beta\,H^-,$$

$$\phi_2 = O_{2i}\,H_i,\quad a_2 = s_\beta\,G^0 + c_\beta\,O_{3i}\,H_i,\quad \phi_2^- = s_\beta\,G^- + c_\beta\,H^-.$$

♠ *Higgs-mediated Flavour-changing Effective Lagrangian* (5/8)

- The interaction of the neutral Higgs bosons:

$$\left(-\mathcal{L}^{d}_{\mathrm{eff}}\right)^{H} = \frac{g}{2M_W}\,\overline{d}\,\widehat{M}_d\,\mathbf{g}^{L}_{H_i\bar{d}d}\,P_L\,d\,H_i + \mathrm{h.c.}$$

where

$$\begin{aligned}
\mathbf{g}^{L}_{H_i\bar{d}d} \;\equiv\;& \frac{O_{1i}}{c_\beta}\,V^{\dagger}_{\mathrm{CKM}}\,R_d^{-1}\,\mathcal{U}^{Q\,\dagger}_{L}\left(\mathbf{1}+\Delta_d^{\phi_1}\right)\mathcal{U}^{Q}_{L}\,V_{\mathrm{CKM}}\\
+\;& \frac{O_{2i}}{c_\beta}\,V^{\dagger}_{\mathrm{CKM}}\,R_d^{-1}\,\mathcal{U}^{Q\,\dagger}_{L}\,\Delta_d^{\phi_2}\,\mathcal{U}^{Q}_{L}\,V_{\mathrm{CKM}}\\
+\;& i\,O_{3i}\,t_\beta\,V^{\dagger}_{\mathrm{CKM}}\,R_d^{-1}\,\mathcal{U}^{Q\,\dagger}_{L}\,(\mathbf{1}+\Delta_d^{a_1}-\Delta_d^{a_2}/t_\beta)\,\mathcal{U}^{Q}_{L}\,V_{\mathrm{CKM}}
\end{aligned}$$

where $R_d = \mathcal{U}^{Q\,\dagger}_{L}\left(\mathbf{1}+\frac{\sqrt{2}}{v_1}\,\Delta_d\right)\mathcal{U}^{Q}_{L}$

♠ *Higgs-mediated Flavour-changing Effective Lagrangian* (6/8)

- The functional $\mathbf{h}_d^{-1}\Delta\mathbf{h}_d[\Phi_1,\Phi_2]$ should have the form:

$$\mathbf{h}_d^{-1}\Delta\mathbf{h}_d[\Phi_1,\Phi_2] \;=\; \Phi_1^\dagger\,\mathbf{f_1}(\Phi_i^\dagger\Phi_j) \;+\; \Phi_2^\dagger\,\mathbf{f_2}(\Phi_i^\dagger\Phi_j)$$

In the Single Higgs Insertion (SHI) approximation, the 3×3-dimensional functionals $\mathbf{f_1}$ and $\mathbf{f_2}$ are only functions of vevs, $\mathbf{f_1} = \langle\mathbf{f_1}\rangle$ and $\mathbf{f_2} = \langle\mathbf{f_2}\rangle$, and one can obtain

$$\Delta_d = \frac{1}{\sqrt{2}}\left(\langle\mathbf{f_1}\rangle\,v_1 + \langle\mathbf{f_2}\rangle\,v_2\right)$$

$$\Delta_d^{\phi_1^-} = \Delta_d^{a_1} = \Delta_d^{\phi_1} = \langle\mathbf{f_1}\rangle \quad ; \quad \Delta_d^{\phi_2^-} = \Delta_d^{a_2} = \Delta_d^{\phi_2} = \langle\mathbf{f_2}\rangle$$

In the limit $v_1 \to 0$ and neglecting $\mathbf{f_1}$, $\langle\mathbf{f_1}\rangle = \mathbf{0}$, we have

$$\Delta_d^{\phi_1^-} = \Delta_d^{a_1} = \Delta_d^{\phi_1} = 0 \quad ; \quad \Delta_d^{\phi_2^-} = \Delta_d^{a_2} = \Delta_d^{\phi_2} = \frac{\sqrt{2}}{v_2}\,\Delta_d = \frac{\mathcal{U}_L^Q\,(R_d - \mathbf{1})\,\mathcal{U}_L^{Q\,\dagger}}{t_\beta}$$

♠ *Higgs-mediated Flavour-changing Effective Lagrangian* (7/8)

- In the $\mathcal{U}_R^d = \mathcal{U}_L^Q = \mathbf{1}_3$ basis,
  - $\mathbf{h}_d = \frac{\sqrt{2}}{v_1}\widehat{M}_d \, V_{\rm CKM}^\dagger \, R_d^{-1}$
  - $R_d = \mathbf{1} + \frac{\sqrt{2}}{v_1}\,\Delta_d = \mathbf{1} + \tan\beta\left(\frac{\sqrt{2}}{v_2}\,\Delta_d\right)$
  - $\left(\mathbf{g}^L_{H^-\bar{d}u}\right)_{\rm SHI} = V_{\rm CKM}^\dagger \frac{1}{t_\beta}\left(\mathbf{1} - \frac{R_d^{-1}}{c_\beta^2}\right)$
  - $$\left(\mathbf{g}^L_{H_i\bar{d}d}\right)_{\rm SHI} = \frac{O_{1i}}{c_\beta} V_{\rm CKM}^\dagger \, R_d^{-1} \, V_{\rm CKM} + \frac{O_{2i}}{s_\beta}(\mathbf{1} - V_{\rm CKM}^\dagger \, R_d^{-1} \, V_{\rm CKM}) - i\,\frac{O_{3i}}{t_\beta}\left(\mathbf{1} - \frac{1}{c_\beta^2} V_{\rm CKM}^\dagger \, R_d^{-1} \, V_{\rm CKM}\right)$$

This is the same as those obtained in A. Dedes and A. Pilaftsis, PRD**67** (2003) 015012 [arXiv:hep-ph/0209306]

All we need to know is Δ_d !

N.B. In the SHI approximation, $\left(V_{\rm CKM}^\dagger \, R_d^{-1} \, V_{\rm CKM}\right)_{\bar{d}d'} \propto (V_{\rm CKM})^*_{td}(V_{\rm CKM})_{td'} \, \tan\beta$

♠ *Higgs-mediated Flavour-changing Effective Lagrangian* (8/8)

- Finally,

$$\boxed{\Delta_d \equiv \Delta_d^{\widetilde{g}} + \Delta_d^{\widetilde{H}} + \cdots}$$

$$\begin{aligned}
\frac{\sqrt{2}}{v_2}(\Delta_d^{\widetilde{g}})_{ij} &= \frac{2\alpha_3}{3\pi}\,\mu^* M_3^*\,(\mathbf{h_d}^{-1})_{ik}\,(\mathbf{h_d})_{kj}\,I(M^2_{\widetilde{D}_k}, M^2_{\widetilde{Q}_j}, |M_3|^2)\,, \\
\frac{\sqrt{2}}{v_2}(\Delta_d^{\widetilde{H}})_{ij} &= \frac{1}{16\pi^2}\,\mu^*\,(\mathbf{a_u}^{\dagger})_{ik}\,(\mathbf{h_u})_{kj}\,I(M^2_{\widetilde{U}_k}, M^2_{\widetilde{Q}_i}, |\mu|^2)\,,
\end{aligned}$$

where the flavour off-diagonal elements of $M^2_{\widetilde{Q},\widetilde{U},\widetilde{D}}$ are neglected

If, furthermore, the squark mass matrices are universal,

$$\begin{aligned}
\frac{\sqrt{2}}{v_2}\left(\Delta_d^{\widetilde{g}}\right)_{ij} &= \frac{2\alpha_3}{3\pi}\,\mu^* M_3^*\,\delta_{ij}\,I\left(M^2_{\widetilde{D}}, M^2_{\widetilde{Q}}, |M_3|^2\right)\,, \\
\frac{\sqrt{2}}{v_2}\left(\Delta_d^{\widetilde{H}}\right)_{ij} &= \frac{1}{16\pi^2}\,\mu^*\left(\mathbf{a_u}^{\dagger}\,\mathbf{h_u}\right)_{ij} I\left(M^2_{\widetilde{U}}, M^2_{\widetilde{Q}}, |\mu|^2\right)
\end{aligned}$$

For universal A terms, $\mathbf{a_u} = A_u\,\mathbf{h_u}$

♠ *Numerical Results* $(1/9)$

- For numerical analysis,
  - A dedicated RG program for the MCPMFV framework has been developed
  - The GUT scale has been taken as the MFV scale
  - The code CPsuperH is used for the Higgs mass spectrum and mixing matrix
  - The SHI approximation is used in the limit of $v_1 \to 0$
  - Δ_d is neglected during RG running
  - Only the leading contributions are kept in the calculation of Δ_d at the SUSY scale: (i) the flavour off-diagonal elements of the squark mass matrices are neglected (ii) only the diagonal elements of Δ_d are considered (iii) EW corrections are neglected

  - Calculated are: (i) $B(B_s \to \mu^+\mu^-)$ (ii) ΔM_{B_s} (iii) ΔM_{B_d}
  - Still in progress: (i) $B(b \to s\gamma)$ (ii) EDMs (iii) $\cdots$

♠ *Numerical Results* $(2/9)$

- Input parameters
  - At M_Z: Three gauge couplings $\alpha_1(M_Z)$, $\alpha_2(M_Z)$, and $\alpha_3(M_Z)$
  - At $m_t^{\rm pole}$: Quark and Lepton masses $m_{q,l}(m_t^{\rm pole})$ and $V_{\rm CKM}(m_t^{\rm pole})$
  - At $M_{\rm SUSY}$: $\tan\beta(M_{\rm SUSY})$
  - At $M_{\rm MFV} = M_{\rm GUT}$: 19 MCPMFV Parameters

$$|M_{1,2,3}|\,{\rm e}^{i\,\Phi_{1,2,3}}\,, \qquad |A_{u,d,e}|\,{\rm e}^{i\,\Phi_{A_{u,d,e}}}\,, \qquad \widetilde{M}^2_{Q,U,D,L,E}\,, \qquad M^2_{H_{u,d}}$$

Specifically, we have taken the parameter set:

$$|M_{1,2,3}| = 250 \;\; {\rm GeV}$$

$$M^2_{H_u}=M^2_{H_d}=\widetilde{M}^2_Q=\widetilde{M}^2_U=\widetilde{M}^2_D=\widetilde{M}^2_L=\widetilde{M}^2_E = (100 \;\; {\rm GeV})^2$$

$$|A_u| = |A_d| = |A_e| = 100 \;\; {\rm GeV}$$

This parameter set is equivalent to SPS1a when $\Phi_{A_{u,d,e}} = 180^\circ$ and $\Phi_{1,2,3} = 0^\circ$ if $M_{\rm SUSY} = m_t^{\rm pole}$ and $\tan\beta = 10$

♠ *Numerical Results* $(3/9)$

- For CP phases, we vary three types of CP phases:

$$\boxed{\Phi_{12}\,, \qquad \Phi_3\,, \qquad \Phi_A^{\rm GUT}}$$

  - We adopt the convention $\Phi_\mu = 0^\circ$

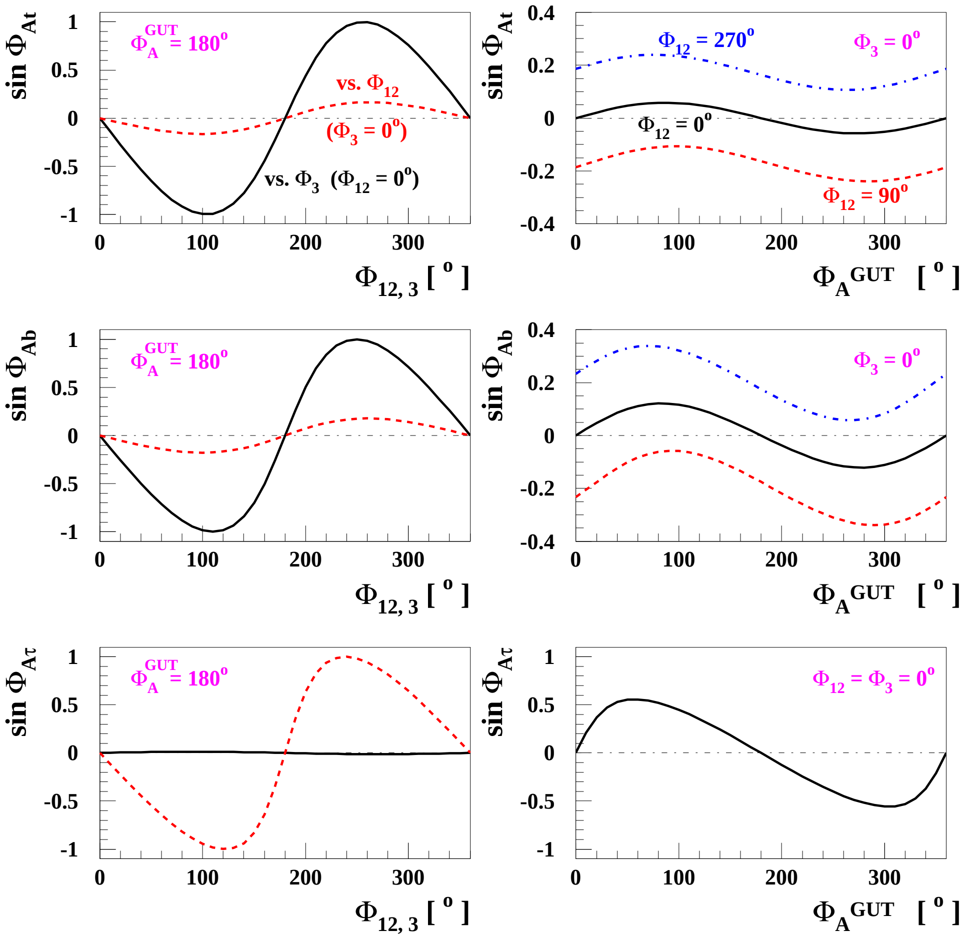
    Note that the phase of μ does not change during RG running: $\Phi_\mu(M_{\rm SUSY}) = \Phi_\mu(M_{\rm GUT})$
  - For simplicity, we take a common phase $\Phi_{12} \equiv \Phi_1 = \Phi_2$

    Again the three phases of the gaugino mass parameters $\Phi_{1,2,3}$ remain same: $\Phi_{1,2,3}(M_{\rm SUSY}) = \Phi_{1,2,3}(M_{\rm GUT})$
  - Again, for simplicity, we take a common phase for A terms:

$$\Phi_A^{\rm GUT} \equiv \Phi_{A_u} = \Phi_{A_d} = \Phi_{A_e}$$

♠ *Numerical Results* $(4/9)$

- $A_f(M_{\rm SUSY}) \equiv (\mathbf{a}_f)_{33}/(\mathbf{h}_f)_{33}$ at $M_{\rm SUSY}$ with $f = t, b, \tau$ $\tan\beta(M_{\rm SUSY}) = 10$ with $M_{\rm SUSY} \sim 535$ GeV



We have found $A_f(M_{\rm SUSY})$ can be written as:

$$\boxed{A_f(M_{\rm SUSY}) \approx C_f^{A_f}\, A_f^{\rm GUT} - C_f^{M_j}\, M_j^{\rm GUT}}$$

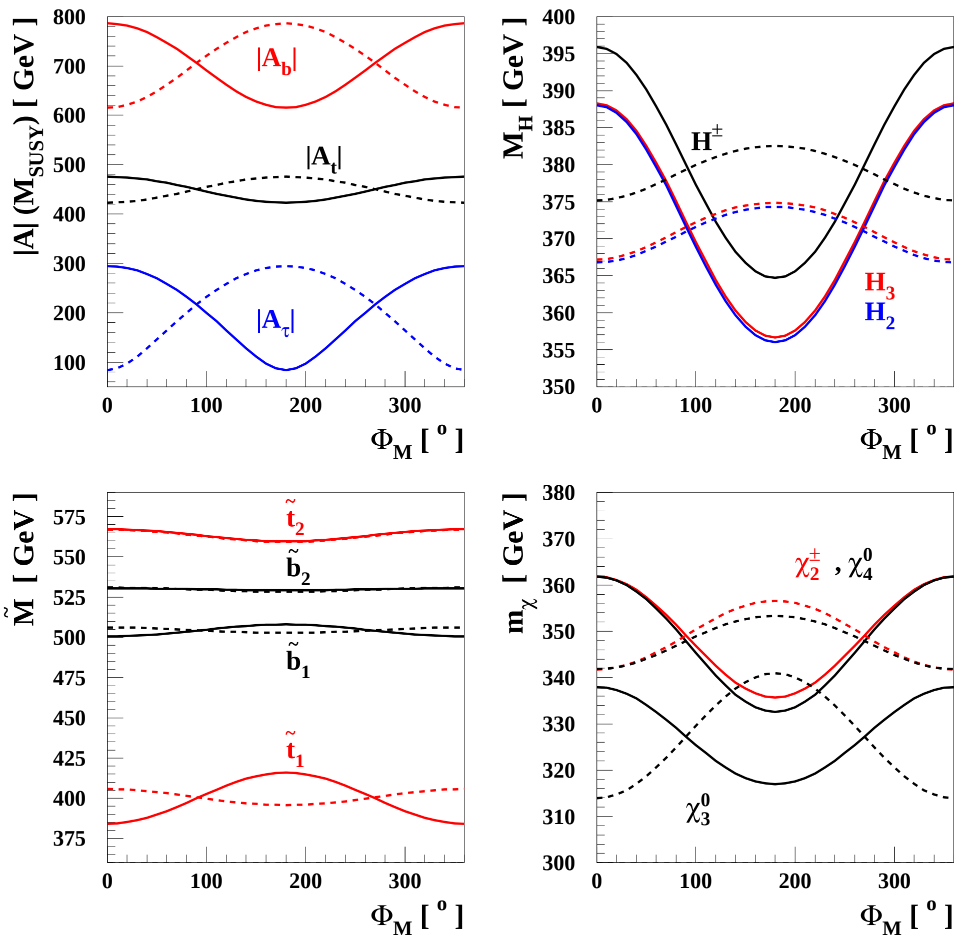
T. Goto, Y. Y. Keum, T. Nihei, Y. Okada and Y. Shimizu, PLB**460** (1999) 333, [arXiv:hep-ph/9812369]

Some comments:

- $C_{t,b}^{A_{t,b}} < C_{t,b}^{M_{1,2}} \ll C_{t,b}^{M_3}$
- $C_t^{A_t} < C_b^{A_b}$
- $C_\tau^{A_\tau} < C_\tau^{M_{1,2}}$
- $C_\tau^{M_3} \sim 0$
- For large $\tan\beta$, $|C_\tau^{M_3}|$ becomes significant and $C_b^{A_b}$ becomes smaller

♠ *Numerical Results* (5/9)

- Masses as functions of $\Phi_M \equiv \Phi_1 = \Phi_2 = \Phi_3$ $\tan\beta(M_{\mathrm{SUSY}}) = 10$



$$|A_f(M_{\mathrm{SUSY}})|^2 \approx \alpha_f - \beta_f \cos(\Phi_A^{\mathrm{GUT}} - \Phi_M)$$

$\alpha_f\,,\beta_f\ > 0$

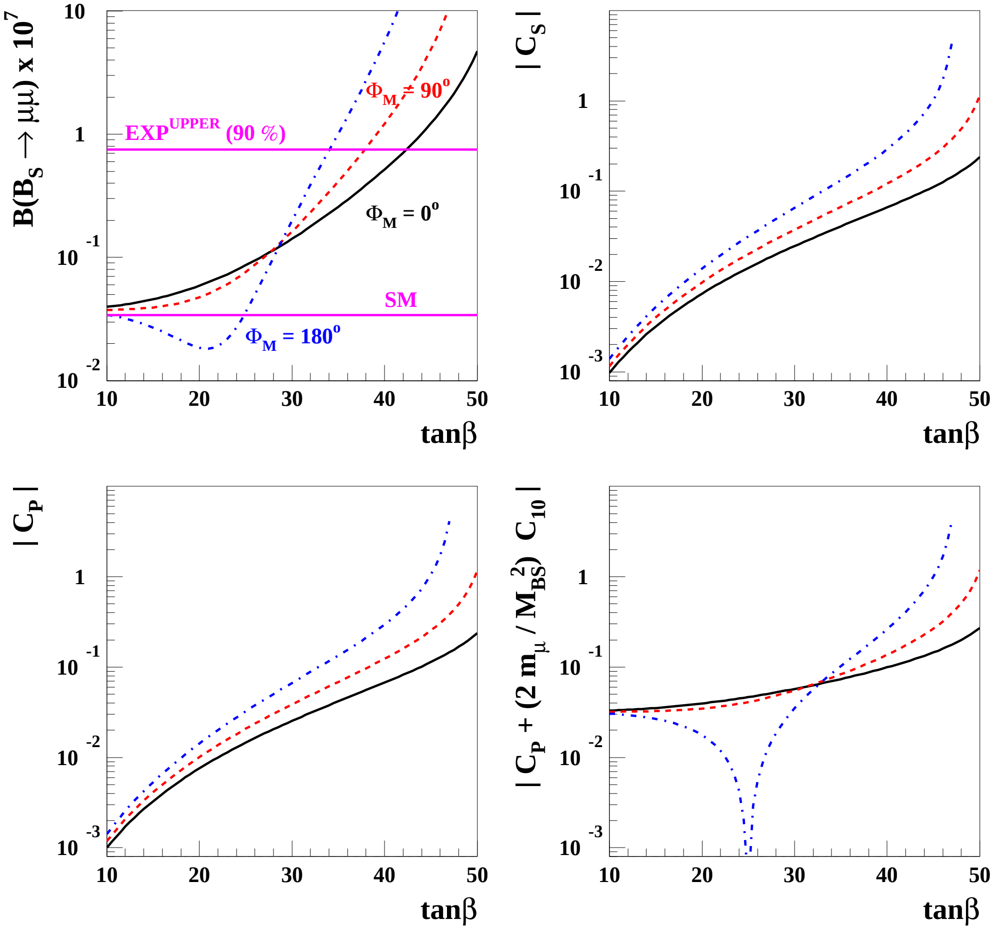
Some comments:

- ▼ Solid : $\Phi_A^{\mathrm{GUT}} = 180^\circ$; Dashed : $\Phi_A^{\mathrm{GUT}} = 0^\circ$
- ▼ Strong correlation between $|A_f(M_{\mathrm{SUSY}})|$ and the particle masses mainly due to the CP-phase dependent term $\mathrm{Tr}(\mathbf{a}_u^\dagger \mathbf{a}_u)$ in RGEs:

  - ▽ $\mathrm{Tr}(\mathbf{a}_u^\dagger \mathbf{a}_u) \Uparrow \longrightarrow |M^2_{H_u}| \Uparrow \longrightarrow M_{H^\pm} \Uparrow$
  - ▽ $\mathrm{Tr}(\mathbf{a}_u^\dagger \mathbf{a}_u) \Uparrow \longrightarrow \widetilde{M}^2_{U,Q} \Downarrow$
  - ▽ $\mathrm{Tr}(\mathbf{a}_u^\dagger \mathbf{a}_u) \Uparrow \longrightarrow |M^2_{H_u}| \Uparrow \longrightarrow |\mu| \Uparrow$

Numerical Results (6/9)

- $B(\bar{B}_s^0 \to \mu^+\mu^-)$ as functions of $\tan\beta(M_{\rm SUSY})$ for three values of $\Phi_M \equiv \Phi_1 = \Phi_2 = \Phi_3$ $\widetilde{M}_{L,E} = 200$ GeV and $\Phi_A^{\rm GUT} = 0^\circ$



$$\boxed{B(\bar{B}_s^0 \to \mu^+\mu^-)} =$$

$$\frac{G_F^2\alpha_{\rm em}^2}{16\pi^3} M_{B_s}\tau_{B_s}|V_{tb}V_{ts}^*|^2 \sqrt{1-\frac{4m_\mu^2}{M_{B_s}^2}}$$

$$\times \left[\left(1-\frac{4m_\mu^2}{M_{B_s}^2}\right)|F_S|^2 + |F_P + 2m_\mu F_A|^2\right]$$

$$F_{S,P} = -\frac{i}{2} M_{B_s}^2 F_{B_s} \frac{m_b}{m_b+m_s} C_{S,P}$$

$$F_A = -\frac{i}{2} F_{B_s} C_{10}^{\rm SM}$$

where $C_{10}^{\rm SM} = -4.221$ and, with $\mathbf{g}_{H_i\bar{d}d}^R = \left(\mathbf{g}_{H_i\bar{d}d}^L\right)^\dagger$,

$$C_{S(P)} = (i)\frac{2\pi m_\mu}{\alpha_{\rm em}} \frac{1}{V_{tb}V_{ts}^*} \sum_{i=1}^{3} \frac{\mathbf{g}_{H_i\bar{s}b}^R\, g_{H_i\bar{\mu}\mu}^{S(P)}}{M_{H_i}^2},$$

$$g_{H_i\bar{\mu}\mu}^S = \frac{O_{1i}}{\cos\beta}, \qquad g_{H_i\bar{\mu}\mu}^P = -\tan\beta\, O_{3i}$$

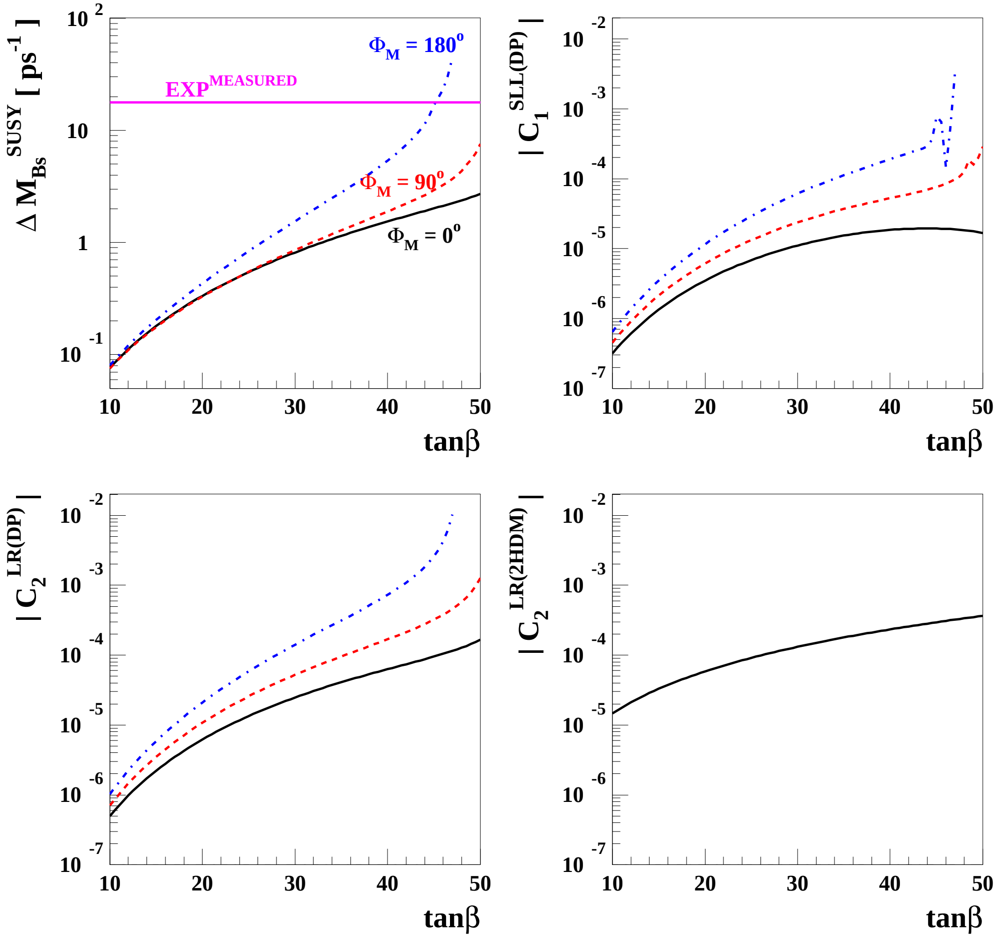
Note $|C_P| \sim |C_S|$ since $H_1 \sim \phi_2$ and $M_{H_2} \sim M_{H_3}$

♠ *Numerical Results* (7/9)

- $\Delta M_{B_s}^{\rm SUSY}$ as functions of $\tan\beta(M_{\rm SUSY})$ for three values of $\Phi_M \equiv \Phi_1 = \Phi_2 = \Phi_3$

$\widetilde{M}_{L,E} = 200$ GeV and $\Phi_A^{\rm GUT} = 0^\circ$

$$\boxed{\Delta M_{B_s}^{\rm SUSY} \; = \; 2\,|\langle \bar{B}_s^0|\, H_{\rm eff}^{\Delta B=2}\, |B_s^0\rangle_{\rm SUSY}|}$$



$$\Delta M_{B_s}^{\rm EXP} \;=\; 17.77 \pm 0.10(stat) \pm 0.07(syst)\,{\rm ps}^{-1}$$

H. G. Evans, arXiv:0705.4598v1 [hep-ex]

$$\langle \bar{B}_s^0|\, H_{\rm eff}^{\Delta B=2}\, |B_s^0\rangle_{\rm SUSY} = \frac{2310}{\rm ps}\left(\frac{\hat{B}_{B_s}^{1/2}\, F_{B_s}}{265\ {\rm MeV}}\right)^2 \left(\frac{\eta_B}{0.55}\right)$$

$$\times \left[0.88\left(C_{2\,\rm LR}^{\rm (DP)} + C_{2\,\rm LR}^{\rm 2HDM}\right) - 0.52\left(C_{1\,\rm SLL}^{\rm (DP)} + C_{1\,\rm SRR}^{\rm (DP)}\right)\right]$$

$$C_{1\,\rm SLL}^{\rm (DP)} \;=\; -\frac{16\pi^2 m_b^2}{\sqrt{2}\,G_F M_W^2} \sum_{i=1}^{3} \frac{{\rm g}^L_{H_i\bar{b}s}\,{\rm g}^L_{H_i\bar{b}s}}{M_{H_i}^2}$$

$$C_{1\,\rm SRR}^{\rm (DP)} \;=\; -\frac{16\pi^2 m_s^2}{\sqrt{2}\,G_F M_W^2} \sum_{i=1}^{3} \frac{{\rm g}^R_{H_i\bar{b}s}\,{\rm g}^R_{H_i\bar{b}s}}{M_{H_i}^2}$$

$$C_{2\,\rm LR}^{\rm (DP)} \;=\; -\frac{32\pi^2 m_b m_s}{\sqrt{2}\,G_F M_W^2} \sum_{i=1}^{3} \frac{{\rm g}^L_{H_i\bar{b}s}\,{\rm g}^R_{H_i\bar{b}s}}{M_{H_i}^2}$$

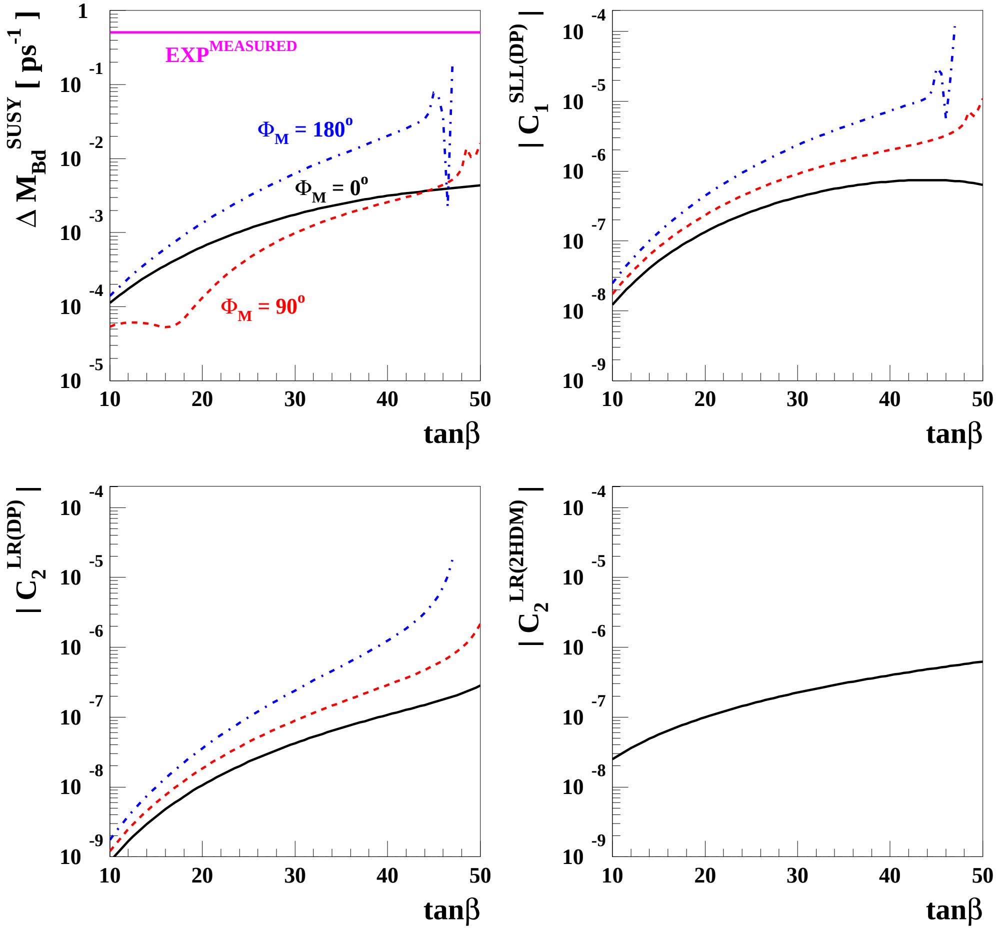
$$C_{2\,\rm LR}^{\rm (2HDM)} \;\approx\; -\frac{2m_b m_s}{M_W^2}\,(V_{tb}^* V_{ts})^2\,\tan^2\beta$$

♠ *Numerical Results* (8/9)

- $\Delta M_{B_d}^{\rm SUSY}$ as functions of $\tan\beta(M_{\rm SUSY})$ for three values of $\Phi_M \equiv \Phi_1 = \Phi_2 = \Phi_3$

$\widetilde{M}_{L,E} = 200$ GeV and $\Phi_A^{\rm GUT} = 0^\circ$

$$\boxed{\Delta M_{B_d}^{\rm SUSY} \;=\; 2\,|\langle \bar{B}_d^0|\, H_{\rm eff}^{\Delta B=2}\, |B_d^0\rangle_{\rm SUSY}|}$$



$$\Delta M_{B_d}^{\rm EXP} \;=\; 0.507 \pm 0.005\ {\rm ps}^{-1} \qquad \text{PDG2006}$$

$$\langle \bar{B}_d^0|\, H_{\rm eff}^{\Delta B=2}\, |B_d^0\rangle_{\rm SUSY} = \frac{1711}{\rm ps}\left(\frac{\hat{B}_{B_d}^{1/2}\, F_{B_d}}{230\ {\rm MeV}}\right)^2 \left(\frac{\eta_B}{0.55}\right)$$

$$\times \left[0.88\left(C_{2\,{\rm LR}}^{\rm (DP)} + C_{2\,{\rm LR}}^{\rm 2HDM}\right) - 0.52\left(C_{1\,{\rm SLL}}^{\rm (DP)} + C_{1\,{\rm SRR}}^{\rm (DP)}\right)\right]$$

$$C_{1\,{\rm SLL}}^{\rm (DP)} \;=\; -\frac{16\pi^2 m_b^2}{\sqrt{2}\,G_F M_W^2} \sum_{i=1}^{3} \frac{{\rm g}^L_{H_i\bar{b}d}\,{\rm g}^L_{H_i\bar{b}d}}{M_{H_i}^2}$$

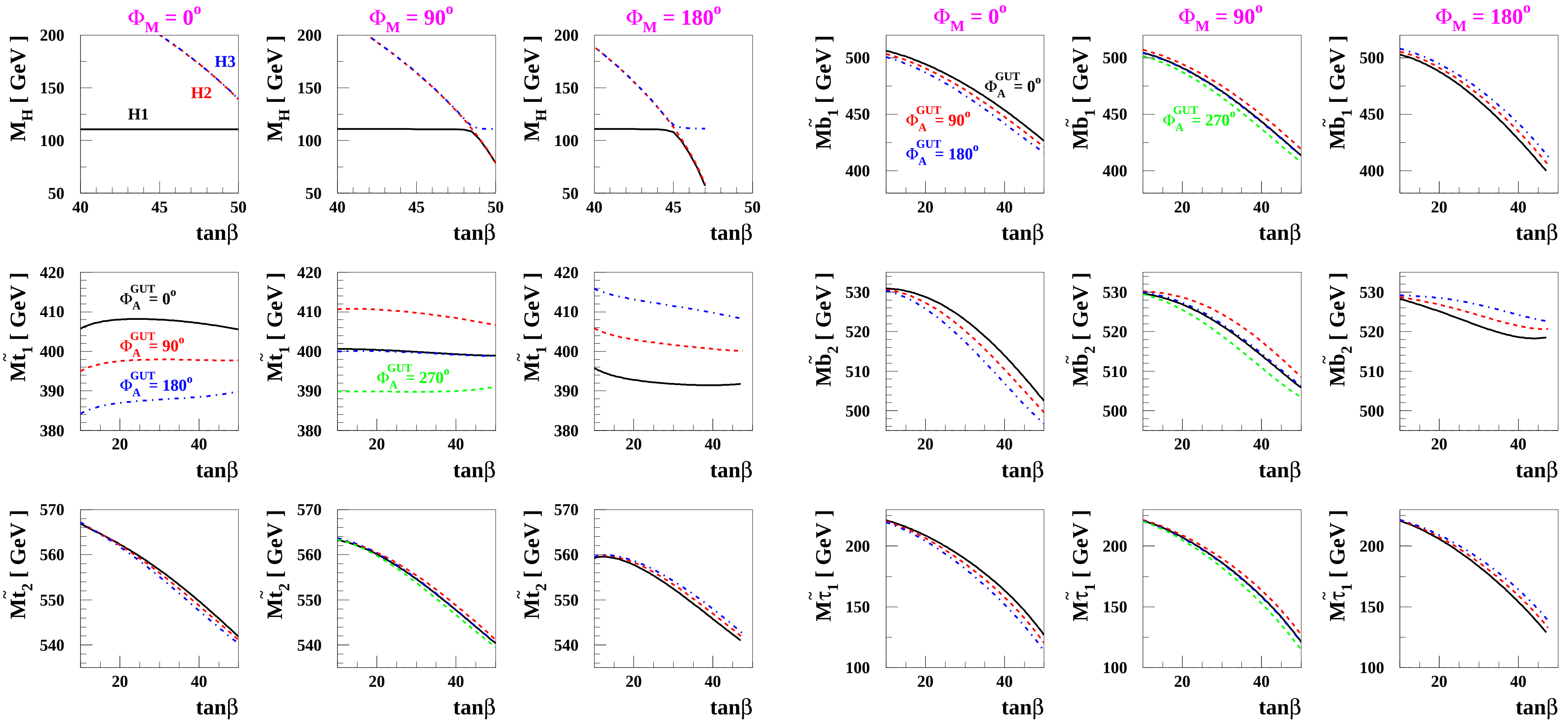
$$C_{1\,{\rm SRR}}^{\rm (DP)} \;=\; -\frac{16\pi^2 m_d^2}{\sqrt{2}\,G_F M_W^2} \sum_{i=1}^{3} \frac{{\rm g}^R_{H_i\bar{b}d}\,{\rm g}^R_{H_i\bar{b}d}}{M_{H_i}^2}$$

$$C_{2\,{\rm LR}}^{\rm (DP)} \;=\; -\frac{32\pi^2 m_b m_d}{\sqrt{2}\,G_F M_W^2} \sum_{i=1}^{3} \frac{{\rm g}^L_{H_i\bar{b}d}\,{\rm g}^R_{H_i\bar{b}d}}{M_{H_i}^2}$$

$$C_{2\,{\rm LR}}^{\rm (2HDM)} \;\approx\; -\frac{2 m_b m_d}{M_W^2}\,(V_{tb}^* V_{td})^2\, \tan^2\beta$$

♠ *Numerical Results* (9/9)

- (BACKUP) Masses as functions of $\tan\beta(M_{\rm SUSY})$ for three values of $\Phi_M \equiv \Phi_1 = \Phi_2 = \Phi_3$ $\widetilde{M}_{L,E} = 200$ GeV and $\Phi_A^{\rm GUT} = 0^\circ$



♠ *Conclusions* $(1/1)$

- We have introduced the so-called *Maximally CP-violating and Minimally Flavour-Violating MSSM framework, MCPMFV*
- We have presented the flavour-covariant effective Lagrangian formalism and, based on it, we have derived the Higgs-mediated flavour-changing effective Lagrangian
- For high $\tan\beta$, FCNC B-meson observables put stringent constraints on parameters