# Guildelines for the flavour structure of G2-MSSM models

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# Relevant features for flavour

- $m_{3/2} \sim O(10\ \mathrm{TeV})$
- $m_{\tilde{f}} \sim O(\mathrm{few\ TeV})$
- $m_{\tilde{g}} \sim O(1\mathrm{TeV})$

Most part of the contributions are o.k. but bounds on $Y_{ij}$, $a_{ij}$ and $m_{ij}$ can be obtained

# Flavour in SUGRA

- Knowing the form W, K, $f_{xy}$ then we can calculate

m-sugra

$$m'^2_{\bar\alpha\beta} = m^2_{3/2}\langle\tilde K_{\bar\alpha\beta}\rangle - \left\langle \mathcal{F}^{*\bar m}\left(\partial^*_{\bar m}\partial_n\tilde K_{\bar\alpha\beta} - (\partial^*_{\bar m}\tilde K_{\bar\alpha\gamma})\,\tilde K^{\gamma\bar\delta}\,\partial_n\tilde K_{\bar\delta\beta}\right)\mathcal{F}^n\right\rangle,$$

$$a'_{\alpha\beta\gamma} = \langle\mathcal{F}^m\rangle\left[\left\langle\frac{\partial_m K_{\rm H}}{M^2_{\rm P}}\right\rangle Y'_{\alpha\beta\gamma} + \frac{\mathcal{N}\partial Y_{\alpha\beta\gamma}}{\partial\langle h_m\rangle}\right] - \langle\mathcal{F}^m\rangle\left[\left\langle\tilde K^{\delta\bar\rho}\left(\partial_m\tilde K_{\bar\rho\alpha}\right)\right\rangle Y'_{\delta\beta\gamma} + (\alpha\leftrightarrow\beta) + (\alpha\leftrightarrow\gamma)\right],$$

$$K = \tilde K_{F_i^\dagger F_j}\,F_i^\dagger F_j + \tilde K_{f_i^c f_j^{c\dagger}}\,f_i^c f_j^{c\dagger} + \tilde K_{H_f^\dagger H_f}\,H_f^\dagger H_f + K_{\rm H}$$

$$W'_{\rm O} = W_{\rm O}\left\langle\frac{W^*_{\rm H}}{|W_{\rm H}|}\,e^{\frac{1}{2M^2_{\rm P}}\sum_m|h_m|^2}\right\rangle \equiv \mathcal{N}\,W_{\rm O}$$

- In m-sugra

$$F \to \hat{F} \equiv V_F^{-1} F \quad , \quad f^c \to \hat{f}^c \equiv f^c\, V_{f^c}^{-1\,\dagger} \quad , \quad H_f \to \hat{H}_f \equiv \tilde{K}^{\frac{1}{2}}_{H_f^\dagger H_f}\, H_f \ ,$$

$$V_F^\dagger \tilde{K}_{F^\dagger F} V_F = \mathbb{1} \ , \quad V_{f^c}^\dagger \tilde{K}_{f^c f^{c\dagger}} V_{f^c} = \mathbb{1}$$

$$m'^2_{\tilde{F}^\dagger \tilde{F}} = m_0^2 \ \mathbb{1}$$

$$m'^2_{\tilde{f}^c \tilde{f}^{c\dagger}} = m_0^2 \ \mathbb{1}$$

$$(a^f)_{ij} = A^f \ Y^f_{ij}$$

- In general !

- In some nice cases:

$$m'^2_{\tilde{F}_i^\dagger \tilde{F}_j} = \alpha_{ij}^{M^f} m_0^2 \left[ Y_f^\dagger Y_f \right]_{ij}$$

$$m'^2_{\tilde{f}^c_i \tilde{f}^{c\dagger}_j} = \alpha_{ij}^{M^f} m_0^2 \left[ Y_f Y_f^\dagger \right]_{ij}$$

$$(a^f)_{ij} = c^f_{ij} A_{\tilde{f}} Y^f_{ij}$$

- In G2-MSSM?

$$m'^2_{\tilde{F}^\dagger \tilde{F}} = m_0^2 \; \mathbb{1}$$
$$m'^2_{\tilde{f}^c \tilde{f}^{c\dagger}} = m_0^2 \; \mathbb{1}$$

$$(a^f)_{ij} = c^f_{ij} A_{\tilde{f}} Y^f_{ij}$$

$M_{GUT}$ → EW, decay scales

$$\mathcal{L}^{\text{eff}}_{m_{\tilde{q}}} = -(\tilde{q}'_L, \tilde{q}'_R)_i (\mathcal{M}^2_{\tilde{q}'})_{ij} \begin{pmatrix} \tilde{q}'^*_L \\ \tilde{q}'^*_R \end{pmatrix}_j$$

$$(\mathcal{M}^2_{\tilde{f}})_{ij} = \begin{bmatrix} M^2_{LL} & M^{2\dagger}_{LR} \\ M^2_{LR} & M^2_{RR} \end{bmatrix}_{ij}$$
$$= \begin{bmatrix} (M^2_{\tilde{Q}})_{ij} + (M^2_f)_{ij} + D^f_L & -(a_{f_{ij}} v_f + \mu^* \tan^p \beta (M_f)_{ij}) \\ -(a^*_{f_{ij}} v_f + \mu \tan^p \beta (M^*_f)_{ij}) & (M^2_{\tilde{f}_R})_{ij} + (M^2_f)_{ij} + D^f_R \end{bmatrix}$$

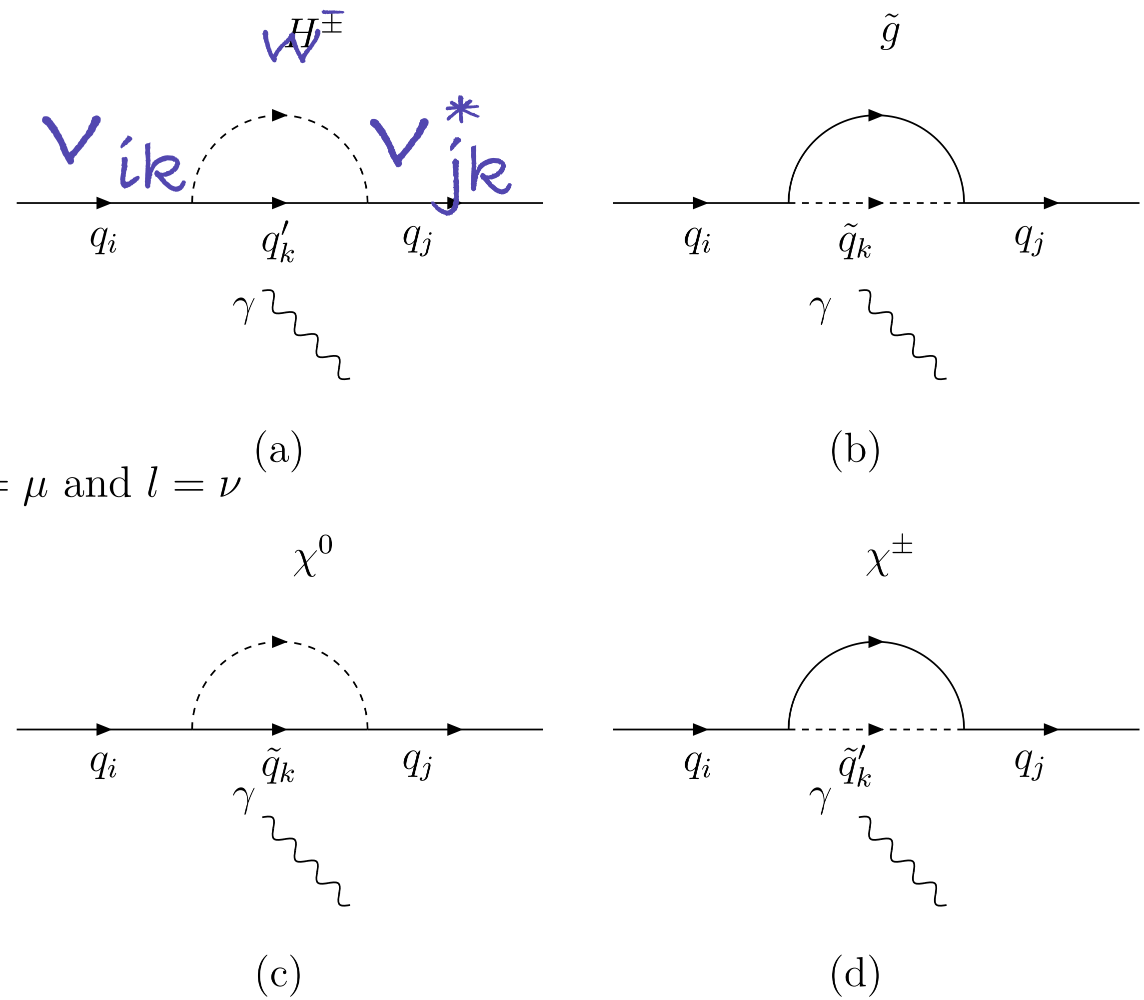
$$D^f_{L,R} = \cos 2\beta M^2_Z (T^3_f - \mathcal{Q}_{f_{L,R}} \sin^2 \theta_W), \quad p = \begin{cases} 1, & f = d \\ -1, & f = u. \end{cases}$$

$$Y^f = U^{f\dagger}_R \hat{Y}^f U^f_L$$
$$V_{CKM} = U^u_L U^{d\dagger}_L$$

$$(\mathcal{M}^{\text{SCKM}}_{\tilde{f}})^2_{ij} = \begin{bmatrix} M^{\text{SCKM}^2}_{LL} & M^{\text{SCKM}\dagger^2}_{LR} \\ M^{\text{SCKM}^2}_{LR} & M^{\text{SCKM}^2}_{RR} \end{bmatrix}_{ij} \equiv (\widehat{\mathcal{M}}^2_{\tilde{f}})_{ij}$$
$$= \begin{bmatrix} (U^f_L M^2_{\tilde{Q}} U^{f\dagger}_L)_{ij} + \hat{M}^2_{f_i} \delta_{ij} + D^f_L & -((U^f_R a_f U^{f\dagger}_L)_{ij} v_f + \mu^* \tan^p \beta \hat{M}_{f_i} \delta_{ij}) \\ -((U^f_L a^\dagger_f U^{f\dagger}_R)_{ij} v_f + \mu \tan^p \beta \hat{M}_{f_i} \delta_{ij}) & (U^f_R M^2_{\tilde{f}_R} U^{f\dagger}_R)_{ij} + \hat{M}^2_{f_i} \delta_{ij} + D^f_R \end{bmatrix}$$

# Non-diagonal $a_{ij}$ and $m^2_{ij}$ FCNC

1. $\Delta F = 1$ processes
   (a) $l_i \to l_j \gamma$
   (b) $b \to s\gamma$
   (c) $b \to s l^+ l^-$, in particular $l = \mu$ and $l = \nu$
   (d) $s \to d\gamma$
   (e) top decays




loop functions depend on the scale of the particles and the ratio

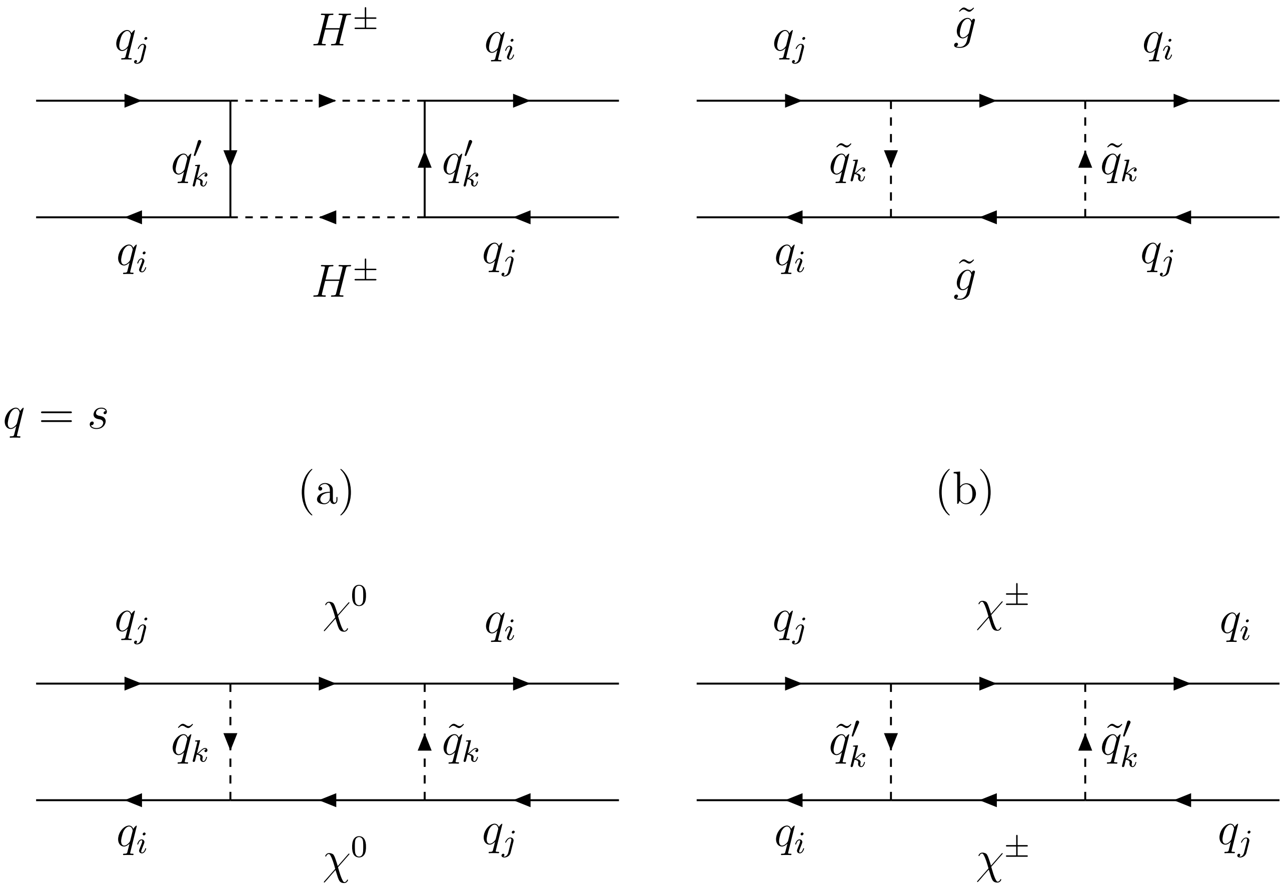
$$x_{p_1 p_2} \equiv \frac{M_{p_1}^2}{M_{p_2}^2}$$

$\Delta F = 2$ processes

(a) $B_q - \bar{B}_q$, in particular $q = s$

(b) $K_0 - \bar{K}_0$ mixing ($\epsilon_k$)

(c) $D_0 - \bar{D}_0$ mixing



# Most sensitive observables

- Eve n when the scale is large, leptonic decays can be dangerous $l_i \to l_j \gamma$
- $\mathrm{BR}(\mu \to e\gamma) < 1.2 \times 10^{-11}$

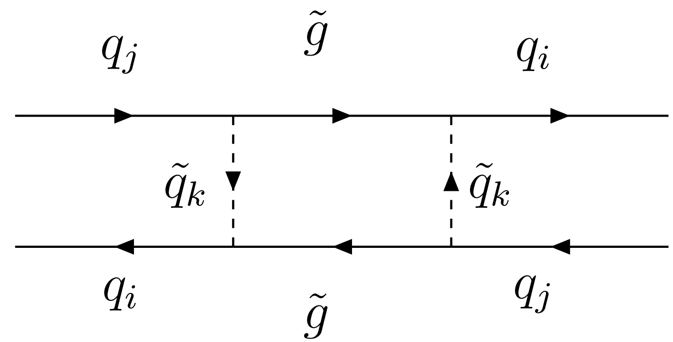
  $\epsilon_K$

$$\begin{aligned} \epsilon_K^{SM} &= (0.00198 \pm 0.00026) \\ \epsilon_K^{exp} &= (0.00229 \pm 0.00010) \end{aligned}$$

$$\epsilon_K^{SUSY} \propto \mathrm{Im}\left\{ < \bar{K} | H^{\tilde{g}} | K > \right\}$$

# Example $\epsilon_K$

$K = s\bar{d}$




Easy to understand why this may be not that supressed:

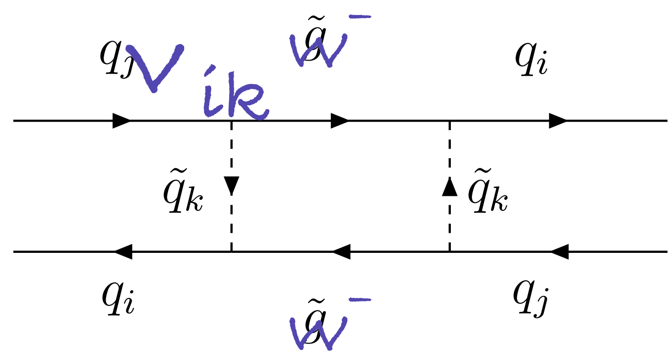
$$\mathcal{L}_{q-\tilde{q}-\tilde{g}} = i\sqrt{2} g_3 T^a_{\alpha\beta} \left[ \bar{q}'^{\alpha}_i \mathcal{P}_L \tilde{g}_a \tilde{q}'^{\beta}_{Ri} + \bar{q}^{\alpha}_i \mathcal{P}_R \tilde{g}_a \tilde{q}^{\beta}_{Li} + \text{h.c.} \right]$$

how many mixings do we have? 2

what would be the supression scales? $\frac{1}{m_{\tilde{g}}^2}$ & $\frac{m_{\tilde{g}}^2}{m_{\tilde{d}}^2}$

# In the SM:

$$|\epsilon_K|^{\rm SM} = \kappa_\epsilon C_\epsilon \hat{B}_K |V_{cb}|^2 |V_{us}|^2 \left( \frac{1}{2} |V_{cb}|^2 R_t^2 \sin 2\beta \eta_{tt} S_0(x_t) + R_t \sin\beta (\eta_{ct} S_0(x_c, x_t) - \eta_{cc} x_c) \right)$$




forgetting about the couplings

$$\frac{1}{M_W^2}\{S_0[x_t], S_0[x_c, x_t], x_c\}\,, \quad x_f = \frac{m_f^2}{M_W^2}$$

$$\{0.00038, 3.0819 \times 10^{-7}, 3.8969 \times 10^{-8}\}$$

MFV: $\Lambda_S > \sim 10^4$ TeV

# Whereas for a G2-MSSM point

$$\{m_{\tilde{d}}, m_{\tilde{g}}\} = \{1610, 1518\}\, GeV$$

$$\frac{1}{m_{\tilde{g}}^2}\left(\frac{11}{18} G[x_{\tilde{d},\tilde{g}}] + \frac{2}{9} G[x_{\tilde{d},\tilde{g}}]\right)$$

$$= 6.6 \times 10^{-8}$$

$\Lambda_S > \sim 10^6$ TeV

If the couplings where O(1) the SM couplings->

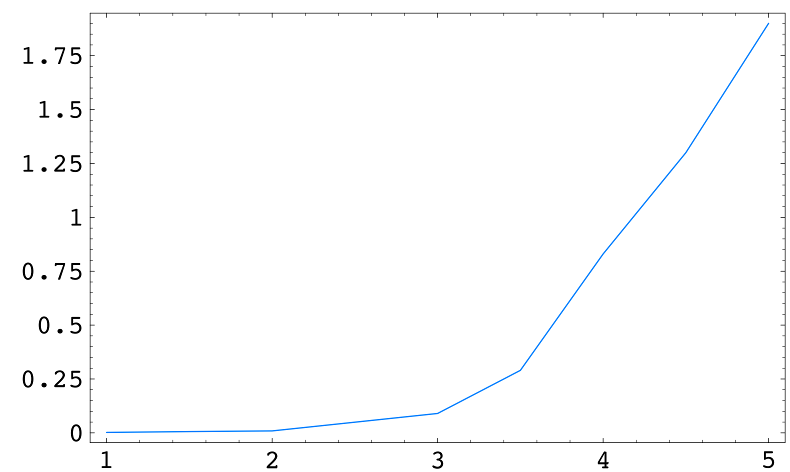
This cannot happen in a true Minimal Flavour violating case (MFV) (i.e. only $V_{CKM} = U_L^u U_L^{d\dagger}$ is the source of mixings)

But as long as we have deviations, we can easily get a bound on

$$(\delta^f_{\rm RR})_{ij} := \frac{(\widetilde{m}^2_{\tilde{f},\rm RR})_{ij}}{(\widetilde{m}^2_{\tilde{f},\rm RR})_{ii}},$$

$$\left(\delta^f_{LR,RL}\right)_{ij} := \frac{(\tilde{m}^2_{\tilde{f},\rm LR,RL})_{ij}}{\sqrt{(\tilde{m}^2_{\tilde{f},\rm LL})_{ii}(\tilde{m}^2_{\tilde{f},\rm RR})_{jj}}}.$$

$\mathrm{Im}(\delta^d_{\rm LR,RL})_{12}$




$c^f_{12}$

In this notation the allowed range for $\mathrm{Im}(\delta^d_{\rm LR,RL})_{12}$

$\sim 10^{-2}$

$$(a^f)_{ij} = c^f_{ij} A_{\tilde{f}} Y^f_{ij}$$

# Idea of this analysis

- While we know flavour effects should be small, we need to quantify them
- Sensitive observables (e.g. $\epsilon_K$) can put bounds on the off-diagonal elements of $Y_{ij}$, $a_{ij}$ and $m_{ij}$

Thank you!