Mass Insertion Parameters from SU(5)xS_4xU(1) model of flavour

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Tuesday group seminar 17/03/15
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Outline

Introduction

❖ The SM & SUSY Flavour Problem.
❖ Solving it by imposing a Family symmetry.

The SU(5)xS$_4$xU(1) Model

❖ The fermionic sector.

❖ Construction of SUSY breaking sector:
- SCKM basis
- **Mass Insertion (MI) parameters:**

❖ Predictions for low energy MIs Vs experimental constraints.

Summary

The Flavour Problem

- Why are there 3 families of quarks & leptons?
- Why are their masses so hierarchical?
- Why is lepton mixing so large compared to quark mixing?
- Why are neutrino masses so small?

More than 1 generations → **Yukawa coupling terms become matrices**

Understanding pattern of fermion masses & mixings =
= Understanding structure of Yukawa matrices.

Here is an idea…

Family Symmetry

Extend symmetry group with a Family symmetry G_F.

- admits triplet reps

(*3 families in a triplet*)

Introduce heavy scalar fields: **Flavons**: Φ

- couple to usual matter fields

Write down operators allowed by all symmetries

- typically non-renormalisable

$$O_Y = f^i \frac{\Phi_i \Phi_j}{M^2} f^{cj} H$$

M: heavy mass scale; UV cut-off

Spontaneously **break** G_F, as Φs develop **≠0 vevs**

- effective Yukawa couplings generated:

$$Y_{ij} = \frac{\langle \Phi_i \rangle \langle \Phi_j \rangle}{M^2} \quad = \quad f\left(\lambda = \frac{\langle \Phi \rangle}{M}\right)$$

expansion parameter

build up desired hierarchical Yukawa textures

Explain form of Yukawa matrices ⟷ Find appropriate symmetry G_F, field content & vacuum alignment for flavons

Extend to **SUSY GUTs**

- Fields become superfields.
- Yukawa operators arise from the superpotential W:

$$W = f w \left(\frac{\Phi^n}{M^n} \right) f^c H$$

flavon vevs aligned via minimization of potential

- Kinetic terms & scalar masses arise from the Kähler potential K.
- **Spartner masses & mixings must also be explained.**
- **Control FC processes induced by loop diags involving sfermion masses** which are non-diagonal in the basis where Yukawa matrices are diagonal (SCKM basis).
- GUT models more constraining due to boundary conditions between hadronic & leptonic sectors.

$\theta^\nu_{13} \ll \theta^\nu_{12}, \theta^\nu_{23}$

- An interesting Family symmetry G_F would predict **TB-mixing** in the neutrino sector.

$$U_{TB} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \sqrt{\frac{1}{3}} & 0 \\ -\sqrt{\frac{1}{6}} & \sqrt{\frac{1}{3}} & -\sqrt{\frac{1}{2}} \\ -\sqrt{\frac{1}{6}} & \sqrt{\frac{1}{3}} & \sqrt{\frac{1}{2}} \end{pmatrix}$$

- Neutrino mass matrix:

✓ diagonalised by U_{TB}.

✓invariant under Klein symmetry: $Z_2^S \otimes Z_2^U$

$$S = \frac{1}{3}\begin{pmatrix} -1 & 2 & 2 \\ 2 & -1 & 2 \\ 2 & 2 & -1 \end{pmatrix} \quad U = -\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

$\theta^\nu_{13} \approx 9^o$

- Need deviations from TB.

Neutrino flavour symmetry arising from G_F

- G_F would contain the S & U generators
- preserved in the neutrino sector (m^ν_{eff} *invariant under S & U*).

A specific model :

$SU(5) \times S_4 \times U(1)$

permutations of 4 objects

Minimal GUT with smallest discrete group that contains S&U generators.

The SU(5) x S_4 x U(1) Model

$T = \mathbf{10} = (Q, u^c, e^c)$ $F = \bar{\mathbf{5}} = (L, d^c)$

Field	T_3	T	F	N	H_5	$H_{\bar{5}}$	$H_{\overline{45}}$	Φ_2^u	$\widetilde{\Phi}_2^u$	Φ_3^d	$\widetilde{\Phi}_3^d$	Φ_2^d	$\Phi_{3'}^\nu$	Φ_2^ν	Φ_1^ν
$SU(5)$	$\mathbf{10}$	$\mathbf{10}$	$\bar{\mathbf{5}}$	$\mathbf{1}$	$\mathbf{5}$	$\bar{\mathbf{5}}$	$\overline{\mathbf{45}}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
S_4	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{2}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{2}$	$\mathbf{3'}$	$\mathbf{2}$	$\mathbf{1}$
$U(1)$	0	x	y	$-y$	0	0	z	$-2x$	0	$-y$	$-x-y-2z$	z	$2y$	$2y$	$2y$

❖ **U(1) symmetry:** different flavons couple to distinct sectors at LO (according to their f label);

❖"Leading" operators: U(1) charges add up to zero $\forall$ x ,y, z ϵ Z.

❖Subleading operators allowed when values of x,y,z are fixed. Forbid the unwanted ones by choosing the most appropriate values:

(x,y,z)=(5,4,1)

Flavon vacuum alignment

- Introduce a set of **driving fields** that couple to the flavons.

- Require their F-terms to vanish: ($F^i = \partial W / \partial \phi^i = 0$)

e.g. couple the driving field $\mathbf{X_1^d}$ (S_4 singlet) Φ_2^d (S_4 doublet):

$$X_1^d(\Phi_2^d)^2 = 2X_1^d\Phi_{2,1}^d\Phi_{2,2}^d$$

require: $$\frac{\partial}{\partial X_1^d} 2X_1^d\Phi_{2,1}^d\Phi_{2,2}^d = 0 \quad \Rightarrow \quad \langle\Phi_2^d\rangle \sim \begin{pmatrix}1\\0\end{pmatrix} \quad \text{or} \quad \langle\Phi_2^d\rangle \sim \begin{pmatrix}0\\1\end{pmatrix}$$

Without loss of generality, pick $\Phi_{2,1}^d \neq 0$.

- In a similar way, all flavons are aligned through vanishing F-terms of driving fields. For the neutrino sector in particular, this process not only fixes $<\Phi_i^\nu>$ but also requires that: $\varphi_1^\nu \sim \varphi_1^\nu \sim \varphi_{3'}^\nu$

Flavon vacuum alignment

orders of magnitude

❖ The Cabibbo angle requires : **$<\Phi_2^d> \sim\lambda$ M**, where M is a generic UV cut-off & $\lambda \sim\theta_C \sim 0.22$ is the Wolfstein parameter.

❖ The correct size for the strange quark and the muon mass is achieved for **$<\Phi_3^d> \sim\lambda^3$ M**.

❖ Introducing the appropriate set of driving fields provides correlations that fix the rest:

$$\frac{\langle\Phi_2^d\rangle}{M} \sim \begin{pmatrix}1\\0\end{pmatrix}\lambda\,,\quad \frac{\langle\Phi_3^d\rangle}{M} \sim \begin{pmatrix}0\\1\\0\end{pmatrix}\lambda^2\,,\quad \frac{\langle\tilde{\Phi}_3^d\rangle}{M} \sim \begin{pmatrix}0\\-1\\1\end{pmatrix}\lambda^3$$

$$\frac{\langle\tilde{\Phi}_2^u\rangle}{M} \sim \begin{pmatrix}0\\1\end{pmatrix}\lambda^4\,,\quad \frac{\langle\Phi_2^u\rangle}{M} \sim \begin{pmatrix}0\\1\end{pmatrix}\lambda^4$$

$$\frac{\langle\Phi_2^\nu\rangle}{M} \sim \begin{pmatrix}1\\1\end{pmatrix}\lambda^4\,,\quad \frac{\langle\Phi_{3'}^\nu\rangle}{M} \sim \begin{pmatrix}1\\1\\1\end{pmatrix}\lambda^4\,,\quad \frac{\langle\Phi_1^\nu\rangle}{M} \sim \frac{\langle\eta\rangle}{M} \sim \lambda^4$$

Field	X_1^d	$\tilde{X}_1^d$	$X_{1'}^{\nu d}$	X_1^u	Y_2^{du}	Y_2^d	Y_2^ν	$Z_{3'}^\nu$	V_0	V_1	V_η	X_1^{new}	$\tilde{X}_{1'}^{new}$
$SU(5)$	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
S_4	**1**	**1**	**1**$'$	**1**	**2**	**2**	**2**	**3**$'$	**1**	**1**	**1**$^{(\prime)}$	**1**	**1**$'$
$U(1)$	-2	14	3	10	9	6	-16	-16	0	-8	-7	18	15

only have 2 free directions

Flavon vacuum alignment

CP violation & h.o. corrections

- Higher order operators shift the LO vevs.

$$\frac{\langle \Phi_2^u \rangle}{M} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \phi_2^u \lambda^4 + \begin{pmatrix} \delta_{21}^u \; \lambda^8 \\ \delta_{22}^u \; \lambda^5 \end{pmatrix} + \ldots, \qquad \frac{\langle \tilde{\Phi}_2^u \rangle}{M} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \tilde{\phi}_2^u \lambda^4 + \begin{pmatrix} \tilde{\delta}_{21}^u \; \lambda^6 \\ \tilde{\delta}_{22}^u \; \lambda^5 \end{pmatrix} + \ldots,$$

$$\frac{\langle \Phi_2^d \rangle}{M} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \boxed{\phi_2^d} \lambda + \begin{pmatrix} 0 \\ \delta_{22}^d \; \lambda^7 \end{pmatrix} + \ldots, \qquad \frac{\langle \Phi_3^d \rangle}{M} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \boxed{\phi_3^d} \lambda^2 + \begin{pmatrix} \delta_{31}^d \; \lambda^6 \\ 0 \\ \delta_{32}^d \; \lambda^6 \end{pmatrix} + \ldots,$$

$$\frac{\langle \tilde{\Phi}_3^d \rangle}{M} = \begin{pmatrix} 0 \\ -1 \\ 1 \end{pmatrix} \tilde{\phi}_3^d \lambda^3 + \begin{pmatrix} \tilde{\delta}_{31}^d \lambda^7 \\ \tilde{\delta}_{32}^d \; \lambda^4 - \tilde{\delta}_{32}^d \lambda^5 \\ \tilde{\delta}_{32}^d \; \lambda^4 + \tilde{\delta}_{33}^d \lambda^5 \end{pmatrix} + \ldots,$$

- CP also broken only in the flavon sector. Correlations leave us with only 2 free phases: θ^d_2, θ^d_3 .

$$\frac{\langle \Phi_2^\nu \rangle}{M} = \begin{pmatrix} 1 \\ 1 \end{pmatrix} \phi_2^\nu \lambda^4 + \begin{pmatrix} \delta_{21}^\nu \; \lambda^5 \\ \delta_{22}^\nu \; \lambda^5 \end{pmatrix} + \ldots, \qquad \frac{\langle \Phi_{3'}^\nu \rangle}{M} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} \left(\phi_{3'}^\nu \lambda^4 + \delta_{3'}^\nu \; \lambda^5 \right)$$

$$\frac{\langle \Phi_1^\nu \rangle}{M} = \phi_1^\nu \lambda^4 + \delta_1^\nu \; \lambda^5 + \ldots, \qquad \frac{\langle \eta \rangle}{M} = \eta \lambda^4 + \delta^\eta \; \lambda^5 + \ldots,$$

Constructing Y^u

$T = \mathbf{10} = (Q, u^c, e^c)$

Write down all **operators** that form a **singlet** under all symmetries

combine up to 8 flavons with TTH_5 for the first two families &
$T_3T_3H_5$ for the 3rd family.

$$\frac{1}{M^2} y_1^u TT\Phi_2^u\tilde{\Phi}_2^u H_5 + \frac{1}{M} y_2^u TT\Phi_2^u H_5 + y_t T_3T_3H_5 +$$

$$\frac{1}{M^5} Z_1 TT(\Phi_2^d)^2(\Phi_3^d)^3 H_5 + \frac{1}{M^5} Z_2 TT_3(\Phi_2^d)^3(\Phi_3^d)^2 H_5 + \frac{1}{M^3} Z_{3,4} T_3T_3(\Phi_3^d)^2\Phi_{2,3'}^\nu H_5$$

Break family symmetry with non-zero flavon vevs.

$$Y^u_{|GUT} = \begin{pmatrix} y_u e^{i\theta_u^y}\lambda^8 & 0 & 0 \\ 0 & y_c e^{i\theta_u^y}\lambda^4 & z_2^u e^{i\theta_2^{zu}}\lambda^7 \\ 0 & z_2^u e^{i\theta_2^{zu}}\lambda^7 & y_t \end{pmatrix} + \ldots$$

$$y_u e^{i\theta_u^y} = y_2^u \phi_2^u \tilde{\phi}_2^u + y_1^u \delta_{21}^u, \quad y_c\, i\theta_u^y = y_1^u \phi_2^u, \quad z_2^u e^{i\theta_2^{zu}} = y_6^u (\phi_2^d)^3(\phi_3^d)^2$$

$$\theta_u^y = \theta_c^y = 2\theta_2^d + 3\theta_3^d, \quad \theta_2^{zu} = 3\theta_2^d + 2\theta_3^d$$

❖ Similarly, write down operators consisting of T , F & Φ^d_ρ

$$Y^d_{|GUT} = Y^d_\alpha + Y^d_\beta \qquad Y^e_{|GUT} = (Y^d_\alpha - 3Y^d_\beta)^T$$

$$T = \mathbf{10} = (Q, u^c, e^c) \qquad F = \bar{\mathbf{5}} = (L, d^c)$$

$$Y^d_\alpha = \begin{pmatrix} 0 & x_2 e^{i\theta_2^x}\lambda^5 & -x_2 e^{i\theta_2^x}\lambda^5 \\ -x_2 e^{i\theta_2^x}\lambda^5 & 0 & x_2 e^{i\theta_2^x}\lambda^5 \\ z_3^d e^{i\theta_3^{zd}}\lambda^6 & z_2^d e^{i\theta_2^{zd}}\lambda^6 & y_b e^{i\theta_b^y}\lambda^2 \end{pmatrix} + \ldots$$

$$Y^d_\beta = \begin{pmatrix} z_1^d e^{i\theta_1^{zd}}\lambda^8 & 0 & z_{11}^d e^{i\theta_{11}^{zd}}\lambda^8 \\ z_{10}^d e^{i\theta_{10}^{zd}}\lambda^8 & y_s e^{i\theta_s^y}\lambda^4 & -y_s e^{i\theta_s^y}\lambda^4 \\ 0 & z_9^d e^{i\theta_9^{zd}}\lambda^7 & 0 \end{pmatrix} + \ldots$$

$$m_d : m_s : m_b \approx \lambda^4 : \lambda^2 : 1$$
$$m_e : m_\mu : m_\tau \approx (1/3)\lambda^4 : 3\lambda^2 : 1$$

$$\theta^d_{12} \approx \lambda, \quad \theta^d_{13} \approx \lambda^3, \quad \theta^d_{23}, \approx \lambda^2$$
$$\theta^e_{12} \approx (1/3)\lambda, \quad \theta^e_{13} \approx 0, \quad \theta^e_{23}, \approx 0$$

❖ Y^u almost diagonal, quark mixing coming from Y^d.

❖ Georgi-Jarlskog (GJ) relations: $m_b \approx m_\tau$, $m_\mu \approx 3m_s$, $m_d \approx 3m_e$ and GST relation: $\theta_{12} \approx \sqrt{(m_d/m_s)}$ incorporated at LO.

Neutrino sector

LO operators:

$NFH_5 \rightarrow M_D$, $NN\Phi^{\nu}_{\rho} \rightarrow M_R$

Type I see-saw formula:

$\mathbf{m^{\nu}_{eff}} = M_D\ \mathbf{M_R}^{-1} M_D^{\ T}\ \boldsymbol{\upsilon_u}^{2}$

$<\Phi_{\rho}^{\nu}>$: eigenvectors of **S&U**

$Z_2^S x Z_2^U$ Klein subgroup of S_4 preserved

TB-mixing in the neutrino sector at LO

$\mathbf{U_{PMNS} = U^{e\dagger}_{L}\ U^{\nu}_{L} = U^{e\dagger}_{L} U_{TB}}$

$\boldsymbol{\theta^l_{12}}$, $\boldsymbol{\theta^l_{23}}$ of the correct order & $\boldsymbol{\theta^l_{13} \sim 3^o}$

Deviation from TB due to charged-lepton sector not enough as $\boldsymbol{\theta^l_{13}{}^{exp} \approx 9^o}$

Further deviation from **TB:** from flavon **η** (S_4 singlet).

$\frac{1}{M}\eta\Phi_2^d NN$ **breaks Z_2^U as $<\Phi_2^d>$** **Not eigenvector of U**

θ^{ν}_{13} , θ^{ν}_{23} receive corrections $O(\lambda)$ → agreement with exp.

Canonical normalisation effects in

the fermionic sector

The soft SUSY breaking sector

A-trilinear terms:

$$\mathcal{L}_{soft} = \epsilon_{\alpha\beta}\left(-H_u^\alpha \tilde{Q}^{\beta i} A^u_{ij} \tilde{u}^{cj} - H_d^\alpha \tilde{Q}^{\beta i} A^d_{ij} \tilde{d}^{cj} - H_u^\alpha \tilde{L}^{\beta i} A^\nu_{ij} \tilde{\nu}^{cj} - H_d^\alpha \tilde{L}^{\beta j} A^e_{ij} \tilde{e}^{cj} + h.c\right)$$

$$+ \tilde{Q}^*_{i\alpha}(m^2_Q)^i_j \tilde{Q}^{\alpha j} + \tilde{u}^{c*}_i (m^2_{u^c})^i_j \tilde{u}^{cj} + \tilde{d}^{c*}_i (m^2_{d^c})^i_j \tilde{d}^{cj} + \tilde{L}^*_{i\alpha}(m^2_L)^i_j \tilde{L}^{\alpha j}$$

$$+ \tilde{e}^{c*}_i (m^2_{e^c})^i_j \tilde{e}^{cj} + \tilde{\nu}^{c*}(m^2_{\nu^c})^i_j \tilde{\nu}^{cj}$$

Scalar mass terms

Superpotential W

Gives rise to Yukawa & A-trilinear terms through $\langle \int d^2\theta \, W \rangle$

$$\frac{X}{M_X} H f \sum_{\Phi\Phi'} a^{f f^c}_{\Phi\Phi'} \frac{\Phi \otimes \Phi'}{M^2} f^c$$

picks up **F-terms** from hidden sector fields X & from flavons.

$$\langle F_{\Phi_A} \rangle_i = m_0 \, x_A \langle \Phi_A \rangle_i$$

trilinears have same structure as Yukawas but different O(1) coefs.

trilinears & Yukawas can not be simultaneously diagonalised.

$$H f \sum_{\Phi\Phi'} y^{f f^c}_{\Phi\Phi'} \frac{\Phi \otimes \Phi'}{M^2} f^c$$

Origin of **off-diagonalities** in the SCKM basis

Kähler potentials K_F, K_T, K_N

<∫d⁴θ K> give rise to kinetic terms & soft scalar masses

$$\mathcal{L}_K \supset \tilde{K}_{ij}\left(\partial_\mu \varphi_i^* \partial^\mu \varphi_j + i\eta_i^* \partial_\mu \bar{\sigma}^\mu \eta_j\right)$$

$$\frac{\langle |F_X|^2\rangle}{M_X^2} = m_0^2$$

Kähler metric: $\tilde{K}_{ij} = \left.\frac{\partial^2 K}{\partial f_i^\dagger f_j}\right|_{f=\varphi}$ *generic sfields*

Flavon expansion :

$$K_F = F^\dagger \left[\left(c_0^{K_F} + c_0^{M_F} \frac{X^\dagger X}{M_X^2} \right) \mathbb{1}_3 + \sum_{\Phi\Phi'} \left(c_{\Phi\Phi'}^{K_F} + c_{\Phi\Phi'}^{M_F} \frac{X^\dagger X}{M_X^2} \right) \frac{\Phi \otimes \Phi'}{M^2} \right] F$$

❖Kähler metrics & soft masses: same structure, different O(1) coefs.

❖Generation of **off-diagonalities** is inevitable.

❖ Work in a basis where: $\tilde{\mathbf{K}}^{\mathbf{ij}}=\mathbf{1}$. ⟶ **Canonical Normalisation**

Canonical Normalisation: change of basis such that: $(\mathbf{P}^{\dagger})^{-1}\,\tilde{\mathbf{K}}\,\mathbf{P}^{-1} = \mathbf{1}$

- Bring all quantities into that basis.
- Y^u_c: zero entries are populated; (23) & (32) entries reduced by two orders of λ.
- Y^ν_c : (12), (21) & (33) entries also reduced by two orders of λ.
- Rest of the effects just consist of changing the O(1) coefs.

Successful fermionic masses & mixings survive.

Now the off-diagonalities in the soft sector have to be controlled in order to lead to predictions that agree with the FCNC bounds.

The SUSY Flavour Problem

The SUSY Flavour Problem

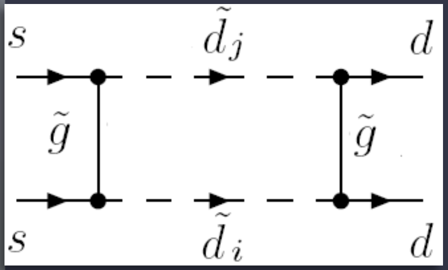
FC

generation mixing…

NC

$$\bar{d}^i_L\,(U^{d\dagger}_L)^{ik}\gamma^\mu(U^d_L)^{kj}\,d^j_L \underset{U^{d\dagger}_L U^d_L=\mathbb{1}}{\Longrightarrow} \bar{d}^i_L\,\gamma^\mu d^i_L$$

SM *No generation mixing at tree level*

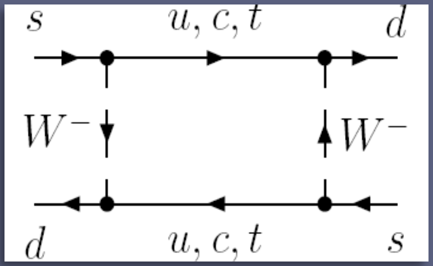


$$\bar{d}^i_L\,(U^{d\dagger}_L)^{ik}\lambda_G\,(\Gamma^d_L)^{kj}\,\tilde{d}^j_L \Longrightarrow \bar{d}^i_L\,\lambda_G K^{ij}\tilde{d}^j_L$$

$$U^{d\dagger}_L\Gamma^d_L=K\neq\mathbb{1}$$

SUSY *tree level FCNC mediated by gluino*

CC



$$\bar{u}^i_L\,(U^{u\dagger}_L)^{ik}\gamma^\mu(U^d_L)^{kj}\,d^j_L \Longrightarrow \bar{u}^i_L\,\gamma^\mu V^{ij}_{CKM}d^j_L$$

$$U^{u\dagger}_L U^d_L=V_{CKM}\neq\mathbb{1}$$

SM *Only through loops with charged particles*

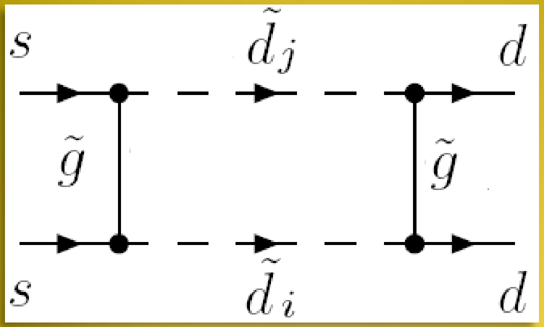
The SUSY Flavour Problem

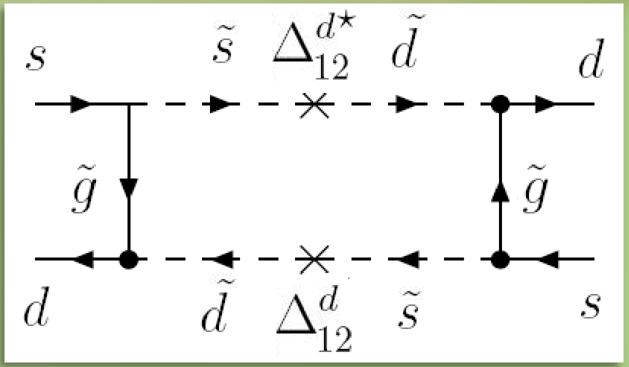
MI *Mass Insertion approximation*

- Work in Super-CKM basis (diagonal m_d)
- gluino vertex diagonal in flavour but non-diagonal $\tilde{m}^2_d$.
- Approximate squark propagator.

$$\left(\tilde{m}^d\right)^2_{ij} = \left(\tilde{m}^d\right)^2 \mathbb{1} + \Delta^d_{ij}$$

$$\frac{i}{\left(\left(k^2 - (\tilde{m}^d)^2\right) \mathbb{1} - \Delta^d \right)_{ij}} \approx i \frac{\delta_{ij}}{k^2 - (\tilde{m}^d)^2} + i \frac{\Delta^d_{ij}}{\left(k^2 - (\tilde{m}^d)^2\right)^2} + \dots$$





The SUSY Flavour Problem

MI

Mass Insertion approximation

$$(\delta^d_{AB})_{ij} = \frac{(\Delta^d_{AB})_{ij}}{(\tilde{m}^d)^2}, \quad \{A,B\} = \{L,R\}$$

$$\mathcal{H}_{\rm eff}^{\Delta F=2} = \sum_{i=1}^{5} C_i Q_i + \sum_{i=1}^{3} \tilde{C}_i \tilde{Q}_i + \text{h.c.},$$

$$C_1^{\tilde{g}} \simeq -\frac{\alpha_s^2}{\tilde{m}^2}[(\delta_d^{LL})_{21}]^2 g_1^{(1)}(x_g),$$

$$\tilde{C}_1^{\tilde{g}} \simeq -\frac{\alpha_s^2}{\tilde{m}^2}[(\delta_d^{RR})_{21}]^2 g_1^{(1)}(x_g),$$

$$C_4^{\tilde{g}} \simeq -\frac{\alpha_s^2}{\tilde{m}^2}[(\delta_d^{LL})_{21}(\delta_d^{RR})_{21}] g_4^{(1)}(x_g),$$

$$C_5^{\tilde{g}} \simeq -\frac{\alpha_s^2}{\tilde{m}^2}[(\delta_d^{LL})_{21}(\delta_d^{RR})_{21}] g_5^{(1)}(x_g),$$

$$x_g = M_{\tilde{g}}^2/\tilde{m}^2$$

- Since the observed FCNCs are strongly suppressed, experiment sets strong bounds on these parameters.

- In our particular example, the relevant observable is:

$$M_{12}^{(K^0)} \equiv \langle K^0 | \mathcal{H}_{\rm eff}^{\Delta F=2} | \bar{K}^0 \rangle$$

- Need to check whether our model predicts MIs that agree with the current bounds!

Mass Insertion (MI) Parameters

❖ Change to the basis where Yukawas are diagonal: SCKM basis

e.g.

$$\tilde{Y}^d_{|GUT} = (U^d_L)^\dagger Y^{d_C}_{|GUT} U^d_R = \begin{pmatrix} \frac{\tilde{x}_2^2}{y_s}\lambda^6 & 0 & 0 \\ 0 & y_s\lambda^4 & 0 \\ 0 & 0 & y_b\lambda^2 \end{pmatrix} + \dots$$

$$\frac{\tilde{A}^d_{|GUT}}{A_0} = (U^d_L)^\dagger \frac{A^d_{C|GUT}}{A_0} U^d_R = \begin{pmatrix} \tilde{a}^d_{11}\lambda^6 & \tilde{a}^d_{12}\lambda^5 & \tilde{a}^d_{13}\lambda^5 \\ \tilde{a}^d_{21}\lambda^5 & \tilde{a}^d_{22}\lambda^4 & \tilde{a}^d_{23}\lambda^4 \\ \tilde{a}^d_{31}\lambda^6 & \tilde{a}^d_{32}\lambda^6 & \tilde{a}^d_{33}\lambda^2 \end{pmatrix} + \dots$$

$$\tilde{a}^d_{11} = \frac{\tilde{x}_2^2}{y_s}\left(2\frac{\tilde{x}_2^a}{\tilde{x}_2}e^{i(\theta_2^{\tilde{x}a}-\theta_2^{\tilde{x}})} - \frac{a_s}{y_s}e^{i(\theta_s^a-\theta_s^y)}\right), \quad \tilde{a}^d_{22} = a_s e^{i(\theta_s^a-\theta_s^y)}, \quad \tilde{a}^d_{33} = a_b e^{i(\theta_b^a-\theta_b^y)},$$

$$\tilde{a}^d_{12} = \tilde{x}_2 e^{i(\theta_2^{\tilde{x}}-\theta_s^y)}\left(\frac{\tilde{x}_2^a}{\tilde{x}_2}e^{i(\theta_2^{\tilde{x}a}-\theta_2^{\tilde{x}})} - \frac{a_s}{y_s}e^{i(\theta_s^a-\theta_s^y)}\right), \dots$$

❖ If the trilinears were aligned with the Yukawas, their off-diag terms would drop out, while the diag ones would converge to the associated Yukawa eigenvalues, up to a global factor.

Mass Insertion (MI) Parameters

❖ Two types of scalar masses: $(U_L^d)^\dagger m_Q^2 \, U_L^d$ $\quad (U_R^d)^\dagger m_{d^c}^2 \, U_R^d$

$$\frac{(\tilde{m}_d^2)_{LL|_{GUT}}}{m_0^2} = (U_L^d)^\dagger \frac{(M^2_{T_{C|GUT}})^*}{m_0^2} U_L^d = \begin{pmatrix} b_{01} & \tilde{B}_{12}\lambda^3 & \tilde{B}_{13}\lambda^4 \\ \cdot & b_{01} & \tilde{B}_{23}\lambda^2 \\ \cdot & \cdot & b_{02} \end{pmatrix} + \ldots,$$

$$\frac{(\tilde{m}_d^2)_{RR|_{GUT}}}{m_0^2} = (U_R^d)^\dagger \frac{M^2_{F_{C|GUT}}}{m_0^2} U_R^d = \begin{pmatrix} 1 & \tilde{R}_{12}\lambda^4 & \tilde{R}_{13}\lambda^4 \\ \cdot & 1 & \tilde{R}_{23}\lambda^4 \\ \cdot & \cdot & 1 \end{pmatrix} + \ldots,$$

$$\tilde{B}_{23} = \frac{y_s}{y_b} e^{i(\theta_s^y - \theta_b^y)} (b_{02} - b_{01}), \qquad \tilde{R}_{23} = e^{i(\theta_s^y - \theta_b^y)} \left(B_3 e^{i\theta_3^B} - K_3 \right),$$

❖ Similarly, if the coefs of M_F^2 were universally proportional to the associated K_F ones, then canonical normalisation would render the mass matrix diagonal. This would not happen to M_T^2 however due to the splitting of the first two and the third generations ($b_{01} \neq b_{02}$).

Mass Insertion (MI) Parameters

❖ such a tuning can not be justified focus on producing small off-diagonalities, to stay in agreement with FCNC bounds.

❖ Define 3x3 full sfermion matrices as:

$$m^2_{\tilde{f}_{LL}} = (\tilde{m}^2_f)_{LL} + \tilde{Y}_f \tilde{Y}_f^\dagger v^2_{u,d} \quad , \quad m^2_{\tilde{f}_{RR}} = (\tilde{m}^2_f)_{RR} + \tilde{Y}_f^\dagger \tilde{Y}_f v^2_{u,d}$$

$$m^2_{\tilde{f}_{LR}} = \tilde{A}_f v_{u,d} - \mu \tilde{Y}_f v_{d,u} \quad , \quad m^2_{\tilde{f}_{RL}} = \tilde{A}_f^\dagger v_{u,d} - \mu \tilde{Y}_f^\dagger v_{d,u}$$

❖ Theoretical predictions in terms of the dim/less parameters:

$$(\delta^f_{LL})_{ij} = \frac{(m^2_{\tilde{f}_{LL}})_{ij}}{\langle m_{\tilde{f}} \rangle^2_{LL}}, \quad (\delta^f_{RR})_{ij} = \frac{(m^2_{\tilde{f}_{RR}})_{ij}}{\langle m_{\tilde{f}} \rangle^2_{RR}},$$

$$(\delta^f_{LR})_{ij} = \frac{(m^2_{\tilde{f}_{LR}})_{ij}}{\langle m_{\tilde{f}} \rangle^2_{LR}}, \quad (\delta^f_{RL})_{ij} = \frac{(m^2_{\tilde{f}_{RL}})_{ij}}{\langle m_{\tilde{f}} \rangle^2_{RL}}$$

$$\langle m_{\tilde{f}} \rangle^2_{AB} = \sqrt{(m^2_{\tilde{f}_{AA}})_{ii} (m^2_{\tilde{f}_{BB}})_{jj}}$$

Mass Insertion (MI) Parameters

GUT scale orders of magnitude…

dropping O(1) coefs…

$$(\delta^u)_{LL} = \begin{pmatrix} 1 & \lambda^4 & \lambda^6 \\ \cdot & 1 & \lambda^5 \\ \cdot & \cdot & 1 \end{pmatrix}, \quad (\delta^u)_{RR} = \begin{pmatrix} 1 & \lambda^4 & \lambda^6 \\ \cdot & 1 & \lambda^5 \\ \cdot & \cdot & 1 \end{pmatrix}, \quad (\delta^u)_{LR} = \begin{pmatrix} \lambda^8 & 0 & 0 \\ 0 & \lambda^4 & \lambda^7 \\ 0 & \lambda^7 & 1 \end{pmatrix}$$

$$(\delta^d)_{LL} = \begin{pmatrix} 1 & \lambda^3 & \lambda^4 \\ \cdot & 1 & \lambda^2 \\ \cdot & \cdot & 1 \end{pmatrix}, \quad (\delta^d)_{RR} = \begin{pmatrix} 1 & \lambda^4 & \lambda^4 \\ \cdot & 1 & \lambda^4 \\ \cdot & \cdot & 1 \end{pmatrix}, \quad (\delta^d)_{LR} = \begin{pmatrix} \lambda^6 & \lambda^5 & \lambda^5 \\ \lambda^5 & \lambda^4 & \lambda^4 \\ \lambda^6 & \lambda^6 & \lambda^2 \end{pmatrix}$$

$$(\delta^e)_{LL} = \begin{pmatrix} 1 & \lambda^4 & \lambda^4 \\ \cdot & 1 & \lambda^4 \\ \cdot & \cdot & 1 \end{pmatrix}, \quad (\delta^e)_{RR} = \begin{pmatrix} 1 & \lambda^3 & \lambda^4 \\ \cdot & 1 & \lambda^2 \\ \cdot & \cdot & 1 \end{pmatrix}, \quad (\delta^e)_{LR} = \begin{pmatrix} \lambda^6 & \lambda^5 & \lambda^6 \\ \lambda^5 & \lambda^4 & \lambda^6 \\ \lambda^5 & \lambda^4 & \lambda^2 \end{pmatrix}.$$

- ❖ Small off-diagonalities, close to MFV but…small enough?
- ❖ RG run down to the low energy scale where experiments are performed and compare with given bounds.

Effects of RG running

LLog approx: $M_{GUT} \approx 2\times 10^{16}\,\text{GeV},\ \ M_R \approx 10^{14}\ \text{GeV},\ \ M_{Low} \approx 10^{3}\ \text{GeV}$

$$\eta = \frac{1}{16\pi^2}\ln\left(\frac{M_{GUT}}{M_{Low}}\right) \approx 0.2$$

$$\eta_N = \frac{1}{16\pi^2}\ln\left(\frac{M_{GUT}}{M_R}\right) \approx 0.03$$

$$\tilde{Y}^d_{|_{Low}} \approx \begin{pmatrix} 1+R^y_d & 0 & 0 \\ 0 & 1+R^y_d & 0 \\ 0 & 0 & 1+R^y_b \end{pmatrix} \tilde{Y}^d_{|_{GUT}} + \begin{pmatrix} 0 & 0 & \tilde{y}^d_{13}\lambda^6 \\ 0 & 0 & \tilde{y}^d_{23}\lambda^4 \\ 0 & \tilde{y}^d_{32}\lambda^6 & 0 \end{pmatrix}$$

$$\tilde{y}^d_{13} = -\eta\, y_t^2 y_b U^{d*}_{L31} \quad , \quad \tilde{y}^d_{23} = \eta\, y_t^2 y_b U^d_{L23} \quad , \quad \tilde{y}^d_{32} = \eta\, y_t^2 y_s U^{d*}_{L23}$$

$$R^y_d = \eta \frac{44}{5} g_U^2, \quad R^y_b = R^y_d - \eta\, y_t^2$$

SCKM transformation before running ⇒ generation of off-diag elements in Yukawas, proportional to quark masses & V_{CKM} elements. Still small, can be treated as perturbation.

Effects of RG running

$$\frac{\tilde{A}^d_{|Low}}{A_0} \approx \begin{pmatrix} 1+R^y_d & 0 & 0 \\ 0 & 1+R^y_d & 0 \\ 0 & 0 & 1+R^y_b \end{pmatrix} \frac{\tilde{A}^d_{|GUT}}{A_0} - 2R^y_d \frac{M_{1/2}}{A_0} \tilde{Y}^d_{|GUT}$$

$$+ \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & \tilde{y}^d_{23}\, \tilde{\alpha}^d_{23} \lambda^4 \\ 0 & \tilde{y}_{32}\, \lambda^6 & -\frac{\eta}{2} a_t\, y_t\, y_b\, \lambda^2 \end{pmatrix}$$

- Common with Yukawa sector ⇨ often ignored.
- Generates ≠ 0 diagonal trilinears, even if A_0=0.
- Same order in λ as GUT scale elements, still suppressed by η.

Effects of RG running

$$\frac{(\tilde{m}_d^2)_{LL}|_{Low}}{m_0^2} \approx \frac{(\tilde{m}_d^2)_{LL}|_{GUT}}{m_0^2} + \left(6.5\,\frac{M_{1/2}^2}{m_0^2} + T_L^d\right)\mathbb{1} - 2\eta R_q \begin{pmatrix} 0 & 0 & U_{L31}^{d*}\,\lambda^4 \\ \cdot & 0 & -\,U_{L23}^{d}\,\lambda^2 \\ \cdot & \cdot & 2 \end{pmatrix}$$

$$\frac{(\tilde{m}_d^2)_{RR}|_{Low}}{m_0^2} \approx \frac{(\tilde{m}_d^2)_{RR}|_{GUT}}{m_0^2} + \left(6.1\,\frac{M_{1/2}^2}{m_0^2} + T_R^d\right)\mathbb{1}$$

❖ same order as at high scale, further suppressed by η.

$$R_q = (2b_{02} + c_{H_u})\,y_t^2 + \frac{A_0^2}{m_0^2}\;a_t^2\,,$$

$$T_L^d = \frac{1}{20}T + \left(-\frac{1}{2} + \frac{1}{3}\sin^2(\theta_W)\right)\cos(2\beta)M_Z^2,$$

$$T_R^d = \frac{1}{5}T - \frac{1}{3}\sin^2(\theta_W)\cos(2\beta)M_Z^2\,, \quad T = \frac{1}{4\pi^2}\int_{\ln(M_{GUT})}^{\ln(M_{Low})} g_U^2\,(c_{H_u} - c_{H_d})m_0^2$$

❖ high scale off-diagonalities not significantly affected but diagonal elements increased

Effects of RG running

- Low energy Mis suppressed as sfermion masses get larger with running.
- *again work in the basis with diagonal Yukawas*

$$(\delta^d_{ij})_{RR} = \frac{1}{(p^d_R)^2}(\delta^d_{ij})_{RR|_{GUT}}, \qquad (\delta^d_{12})_{LL} = \frac{b_{01}}{(p^d_{L1G})^2}(\delta^d_{12})_{LL|_{GUT}},$$

$$(\delta^d_{13(23)})_{LL} = \frac{\sqrt{b_{01}\, b_{02}}}{p^d_{L1G}\, p^d_{L3G}}\left(1+\eta\left(y_t^2 - \frac{2R_q}{b_{02}-b_{01}}\right)\right)(\delta^d_{13(23)})_{LL|_{GUT}}$$

$$p^d_R = \sqrt{1+6.1\frac{M^2_{1/2}}{m_0^2}}, \quad p^d_{L1G} = \sqrt{b_{01}+6.5\frac{M^2_{1/2}}{m_0^2}},$$

$$p^d_{L3G} = \sqrt{b_{02}+6.5\frac{M^2_{1/2}}{m_0^2} - 2\eta R_q}$$

In the charged lepton sector , effects from the seesaw mechanism enter the running for $\mathbf{(m^2_e)_{LL}}$ through the term:

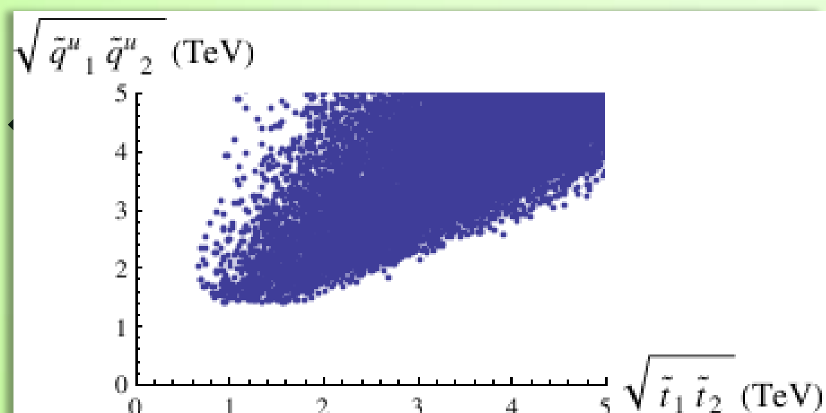
$$\tilde{F}^\nu_L = \frac{1}{2}\left(\frac{1}{2}\tilde{Y}_\nu\tilde{Y}^\dagger_\nu(\tilde{m}^2_e)_{LL} + \frac{1}{2}(\tilde{m}^2_e)_{LL}\tilde{Y}_\nu\tilde{Y}^\dagger_\nu + \tilde{Y}_\nu(\tilde{m}^2_N)_{RR}\tilde{Y}^\dagger_\nu + (m^2_{H_u})\tilde{Y}_\nu\tilde{Y}^\dagger_\nu + \tilde{A}_\nu\tilde{A}^\dagger_\nu\right)$$

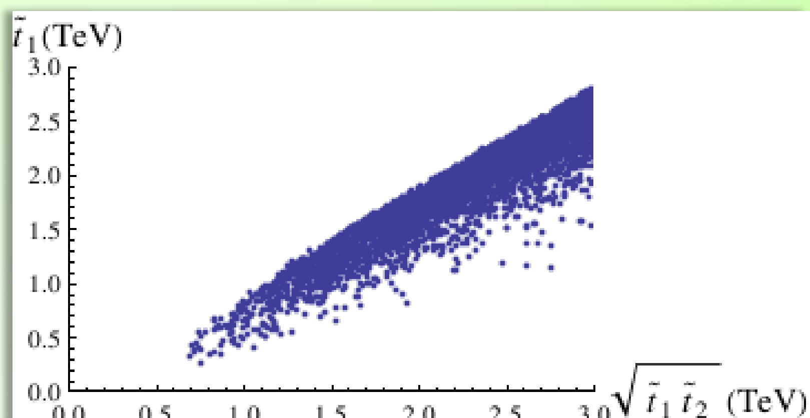
Numerical estimates

- SM fit for fermionic sector and scan over $t_\beta \epsilon [5, 25]$, $M_{1/2} \epsilon [300, 3000]$, $m_0 \epsilon [50, 10000]$, $A_0 \epsilon [-3,3]\, m_0$ & unknown SUSY coefficients in $\pm[0.5, 2]$.
- μ parameter fixed through:

$$\frac{M_Z^2}{2} = \frac{m_{H_d}^2 + \Sigma_d^d(\tilde{t}_{1,2}) - (m_{H_u}^2 + \Sigma_u^u(\tilde{t}_{1,2}))\, t_\beta^2}{t_\beta^2 - 1} - \mu^2$$

radiative corrections





Numerical estimates

Parameter	Prediction	Bound
$\lvert(\delta^e_{LL})_{12}\rvert$	$O(10^{-6},10^{-2})$	$O(10^{-5},10^{-4})$
$\lvert(\delta^e_{LR})_{12}\rvert$	$O(10^{-9},10^{-4})$	$O(10^{-6},10^{-5})$
$\lvert(\delta^e_{LL})_{13,23}\rvert$	$O(10^{-6},10^{-2})$	$O(10^{-3},10^{-2})$
$\lvert(\delta^e_{LR})_{13,31,23}\rvert$	$O(10^{-9},10^{-4})$	$O(10^{-2},10^{-1})$
$\lvert(\delta^e_{LR})_{32}\rvert$	$O(10^{-8},10^{-3})$	$O(10^{-2},10^{-1})$
$\lvert(\delta^e_{RR})_{12}\rvert$	$O(10^{-5},10^{-2})$	$O(10^{-3}, 10^{-2})$
$\lvert(\delta^e_{RR})_{13}\rvert$	$O(10^{-5},5*10^{-4})$	$O(10^{-1}, 1)$
$\lvert(\delta^e_{RR})_{23}\rvert$	$O(10^{-3},10^{-1})$	$O(10^{-1}, 1)$

Numerical estimates

Parameter	Prediction	Bound
$\lvert(\delta^d_{LL})_{23}\rvert$	$O(10^{-8}, 5*10^{-2})$	$O(10^{-2},10^{-1})$
$\lvert(\delta^d_{LL})_{12}\rvert$	$O(10^{-5}, 5*10^{-2})$	$O(10^{-3},10^{-2})$
$\lvert Im(\delta^d_{LR})_{12}\rvert$	$O(10^{-7},10^{-6})$	$O(10^{-4},10^{-3})$
$\lvert(\delta^d_{RR})_{23}\rvert$	$O(10^{-4},10^{-3})$	$O(10^{-1}, 1)$
$\lvert(\delta^d_{RL})_{23}\rvert$	$O(10^{-7},10^{-6})$	$O(10^{-2})$
$\lvert(\delta^d_{LR})_{23}\rvert$	$O(10^{-6},10^{-5})$	$O(10^{-3},10^{-2})$
$\lvert(\delta^u_{LR})_{23}\rvert$	$O(10^{-6})$	0.3 (MS~1TeV) 0.1 (MS~3TeV)

Phenomenological Implications

- Bounds on MIs available in the literature.

- They are placed by demanding that the contribution of each MI to an observable does not exceed the relevant experimental limit.

Bounds taken from:
arXiv: 1405.6960 , arXiv: 1304.2783, arXiv: 1207.3016

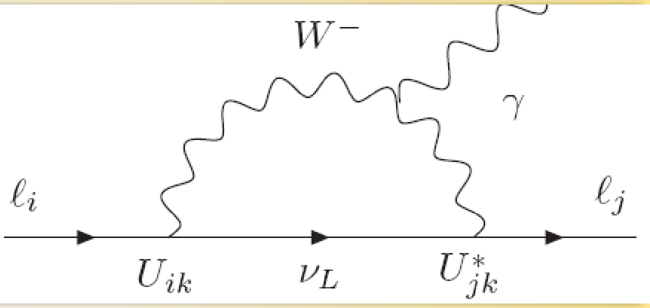
- Comparison with our predictions suggests study of phenomenology related **$\mu \to e\gamma$** , **edms** and **$b \to s$** transitions.

Phenome μ→eγ plications

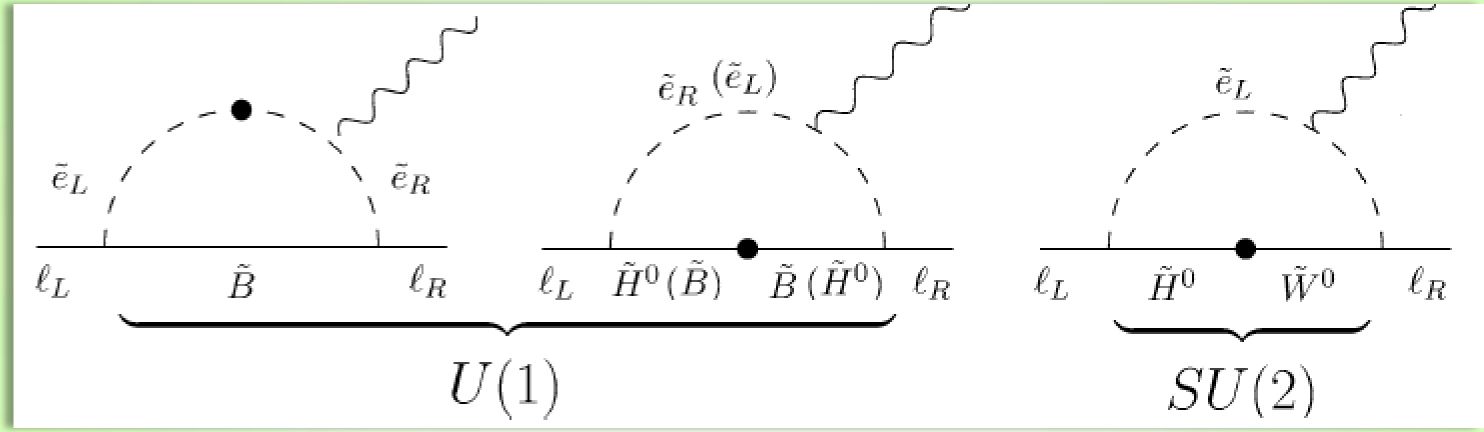
❖ Strongest constraint from **Br(μ→eγ)**

In the SM suppressed by small neutrino masses

$$Br(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_i U^*_{\mu i} U_{ei} \frac{m^2_{\nu_i}}{m^2_W}\right|^2 \lesssim 10^{-54}$$



❖ The SUSY contribution through bino, bino-higgsino & wino-higgsino loops, involves the $\boldsymbol{\delta^e_{12}}$ parameters.

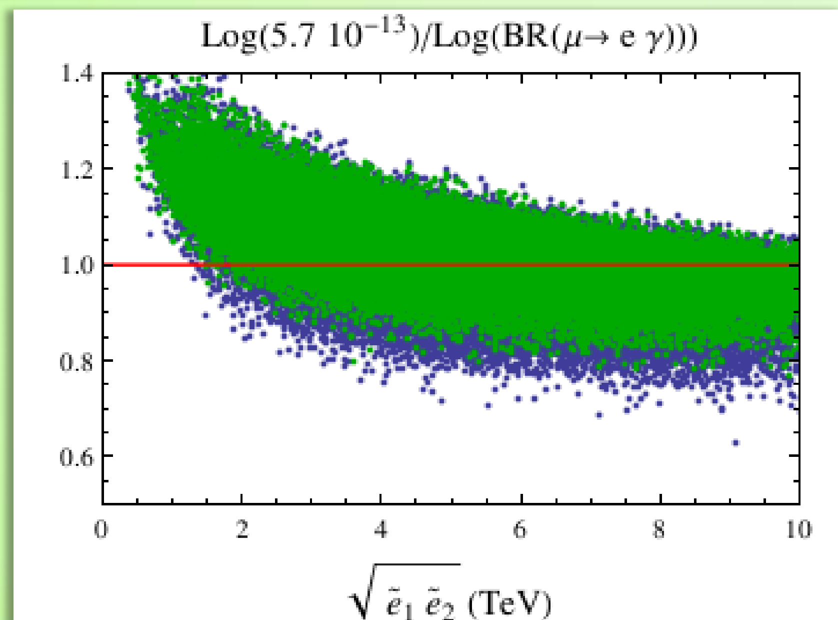


Phenome μ→eγ plications

$$BR(\mu \to e\,\gamma) = 3.4 \times 10^{-4} \times \frac{1}{4}\, x\, \frac{\mu^2\, t_\beta^2}{m_0^6}\, M_W^4 \times$$

$$\left(\left| (\delta^e_{LL})_{12} \left(-(\delta^e_{LR})_{22}\, \frac{\tilde{m}^e_{LL}\; \tilde{m}^e_{RR}}{\mu\, t_\beta\, m_\mu}\; A'_{B,L} + \frac{1}{2} A'_L + A'_2 \right) + (\delta^e_{LR})_{12}\, \frac{\tilde{m}^e_{LL}\; \tilde{m}^e_{RR}}{\mu\, t_\beta\, m_\mu}\; A_B \right|^2 \right.$$

$$\left. + \left| (\delta^e_{RR})_{12} \left(-(\delta^e_{LR})^*_{22}\, \frac{\tilde{m}^e_{LL}\; \tilde{m}^e_{RR}}{\mu\, t_\beta\, m_\mu}\; A'_{B,R} - A'_R \right) + (\delta^e_{LR})^*_{21}\, \frac{\tilde{m}^e_{LL}\; \tilde{m}^e_{RR}}{\mu\, t_\beta\, m_\mu}\; A_B \right|^2 \right)$$



$x=(M_{1/2}/m_0)^2$,

A_i: dim/less loop functions

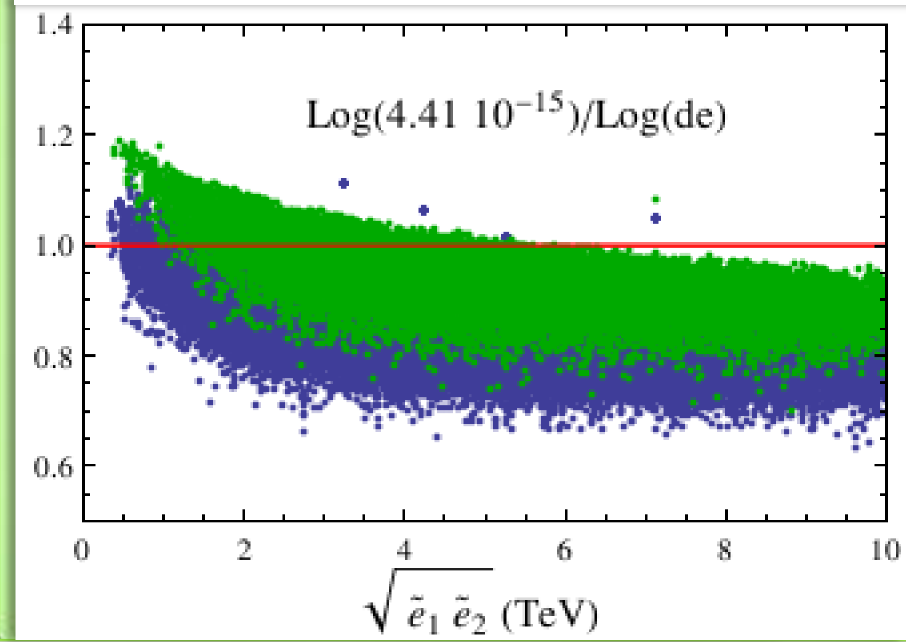
$(\delta^e_{12})_{LL}$, $(\delta^e_{12})_{LR}$:
dominant contributions

Pheno… electron edm …cations

$$\frac{d_e}{e} = \frac{\alpha M_1}{8\pi\, m_0^4 \cos^2\theta_W}\, \tilde{m}^e_{LL}\, \tilde{m}^e_{RR}$$

$$\mathrm{Im}\Big[-\boxed{(\delta^e_{LR})_{11} A_B} + (\delta^e_{LL})_{1i}(\delta^e_{LR})_{i1} A'_{B,L} + \boxed{(\delta^e_{LR})_{1i}(\delta^e_{RR})_{i1} A'_{B,R}}$$
$$- \Big((\delta^e_{LL})_{1i}(\delta^e_{LR})_{ij}(\delta^e_{RR})_{j1} + (\delta^e_{LR})_{1i}(\delta^e_{RL})_{ij}(\delta^e_{LR})_{j1}$$
$$+ (\delta^e_{LL})_{1i}(\delta^e_{LL})_{ij}(\delta^e_{LR})_{j1} + (\delta^e_{LR})_{1i}(\delta^e_{RR})_{ij}(\delta^e_{RR})_{j1} \Big) A''_B \Big]$$

❖strongest constraint for CPV.



❖ If the phases of the trilinear sector are the same as the corresponding Yukawa ones, $(\delta^e_{LR})_{11} \sim\lambda^6$ dominates (green points)

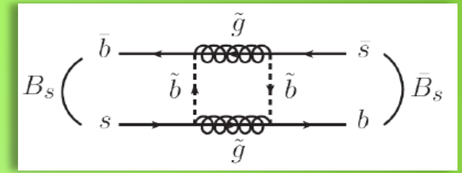
❖Alternatively, $(\delta^e_{LR})_{12}\,(\delta^e_{RR})_{21} \sim\lambda^9$ dominates (blue points).

Phenome B-mixing plications

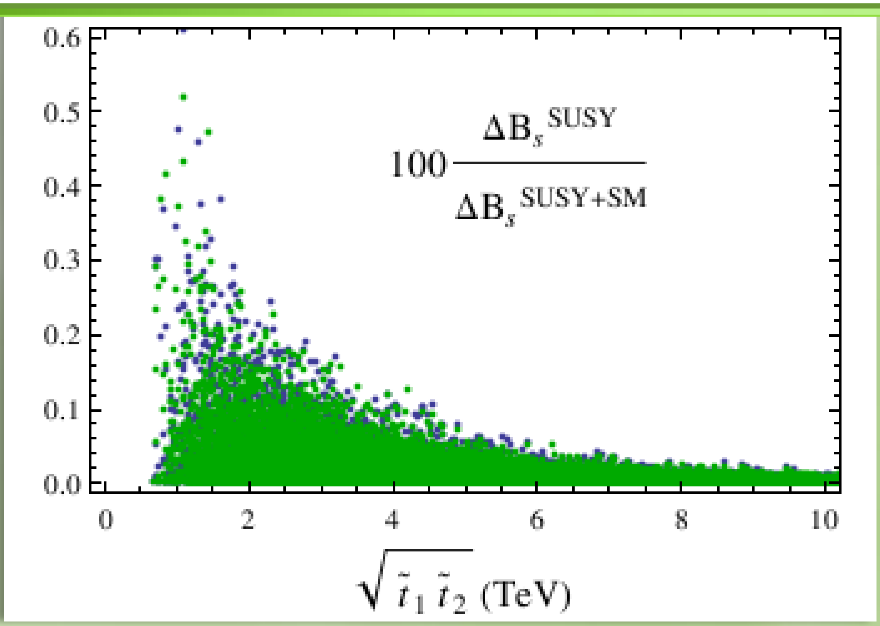
$$M_{12}^{q,SM} = \frac{G_F^2 M_{B_q}}{12\pi^2} M_W^2 (V_{tb}V_{tq}^*)^2 \hat{\eta}_B S_0(x_t) f_{B_q}^2 B_q$$

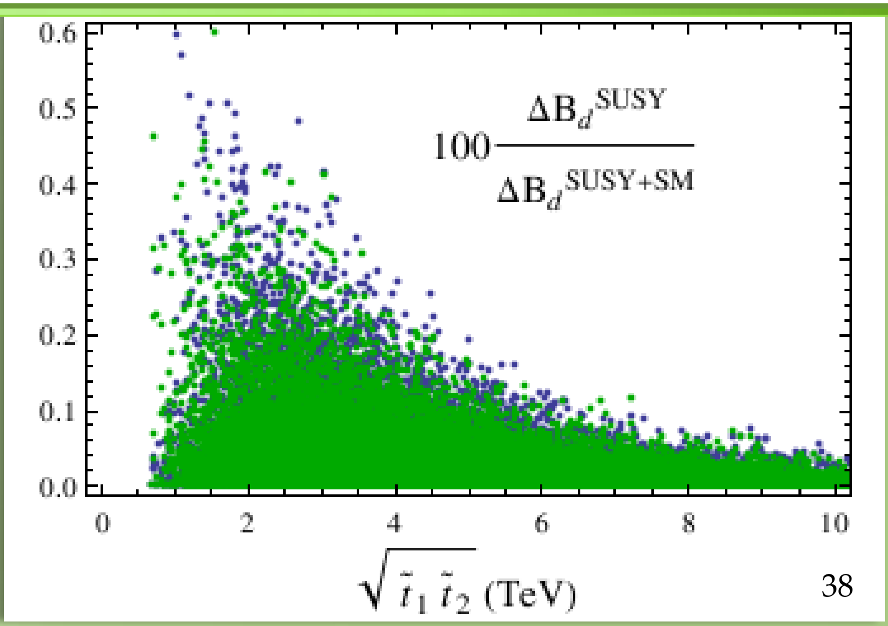
$$M_{12}^q = M_{12}^{q,SM} + M_{12}^{q,SUSY} = M_{12}^{q,SM}\left(1 + h_q e^{2i\sigma_q}\right)$$

$$h_q = \left|\frac{M_{12}^{q,SUSY}}{M_{12}^{q,SM}}\right|, \quad 2\sigma_q = \mathrm{Arg}[M_{12}^{q,SUSY}] + \phi_q^{SM}$$

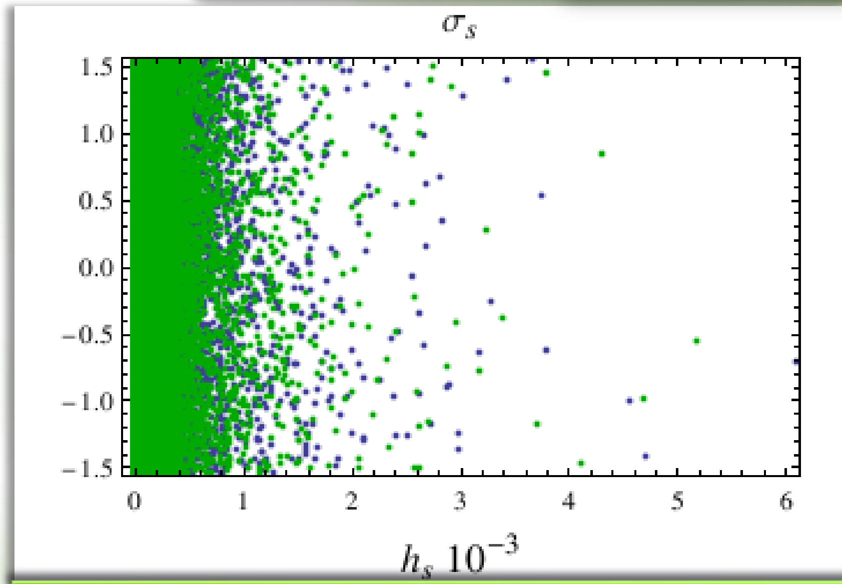


$$\frac{M_{12}^{q,SUSY}}{A_1^q} = A_2^q\left((\delta_{ij}^d)_{LL}^2 + (\delta_{ij}^d)_{RR}^2\right) + A_3^q(\delta_{ij}^d)_{LL}(\delta_{ij}^d)_{RR} + A_4^q\left((\delta_{ij}^d)_{LR}^2 + (\delta_{ij}^d)_{RL}^2\right) + A_5^q(\delta_{ij}^d)_{LR}(\delta_{ij}^d)_{RL}$$





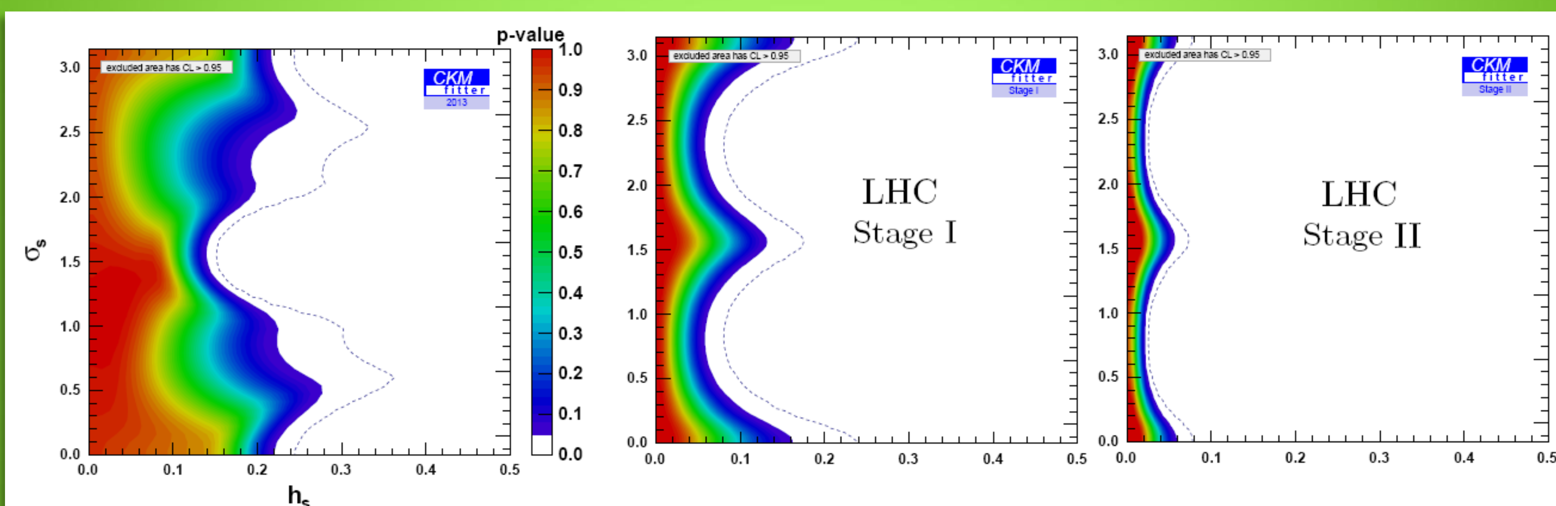
Phenome B-mixing plications



$$h_q = \left|\frac{M_{12}^{q,SUSY}}{M_{12}^{q,SM}}\right|, \quad 2\sigma_q = \mathrm{Arg}[M_{12}^{q,SUSY}] + \phi_q^{SM}$$

Within current & future experimental limits.
Similar results for σ_d-h_d.

From arXiv: 1309.2293



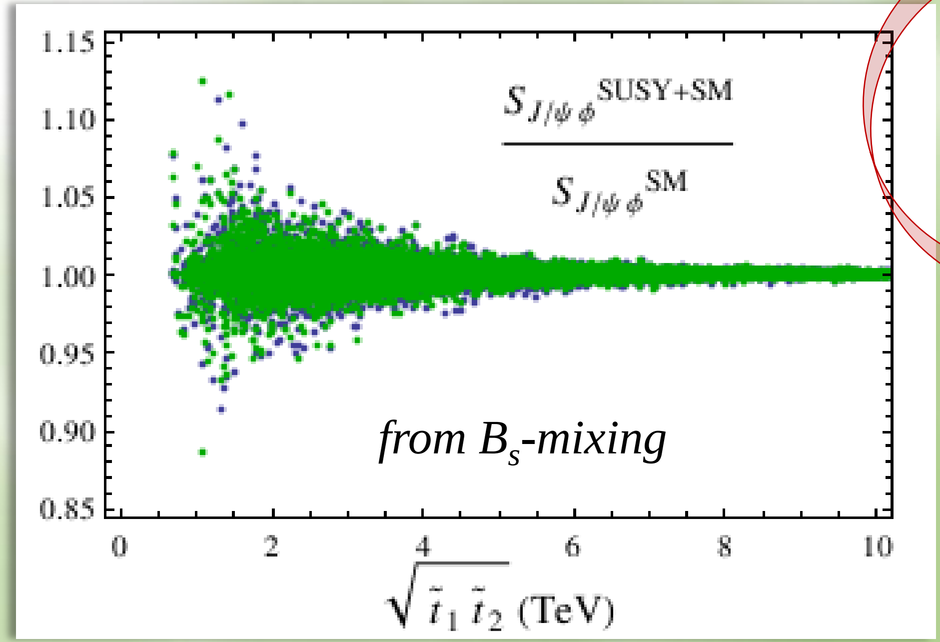
Phenomenological Implications

B-mixing

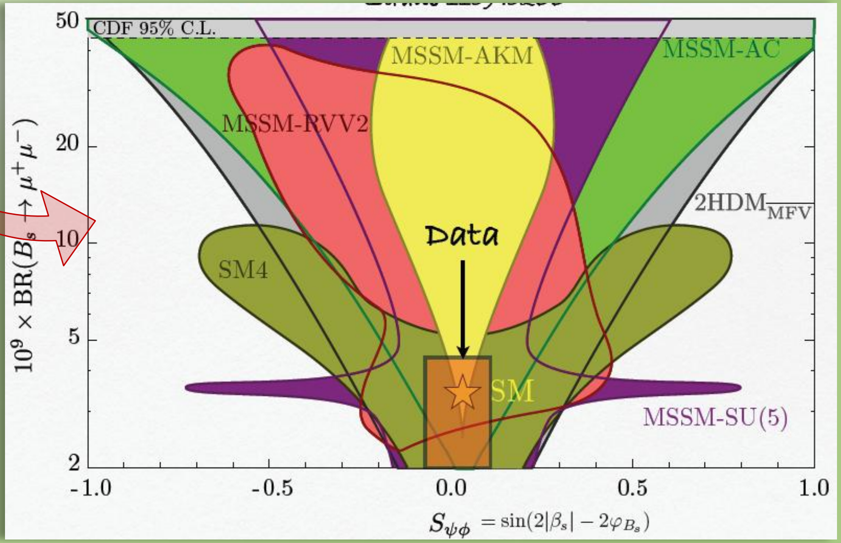
Time-dependent CP Asymmetry

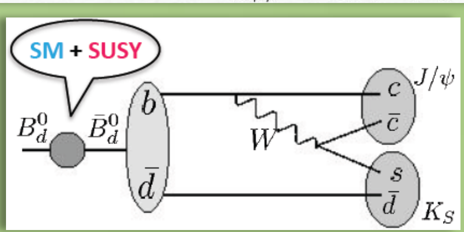
$$A^q_{CP}(f,t) \equiv \frac{\Gamma\left(\bar{B}_q(t) \to f\right) - \Gamma\left(B_q(t) \to f\right)}{\Gamma\left(\bar{B}_q(t) \to f\right) + \Gamma\left(B_q(t) \to f\right)} \approx S_f \sin(2|M^q_{12}|\, t)$$

$$S_f = \sin\left(\phi^q_{SM} + Arg[1 + h_q e^{2i\sigma_q}]\right)$$



Strongly constrains parameter space.





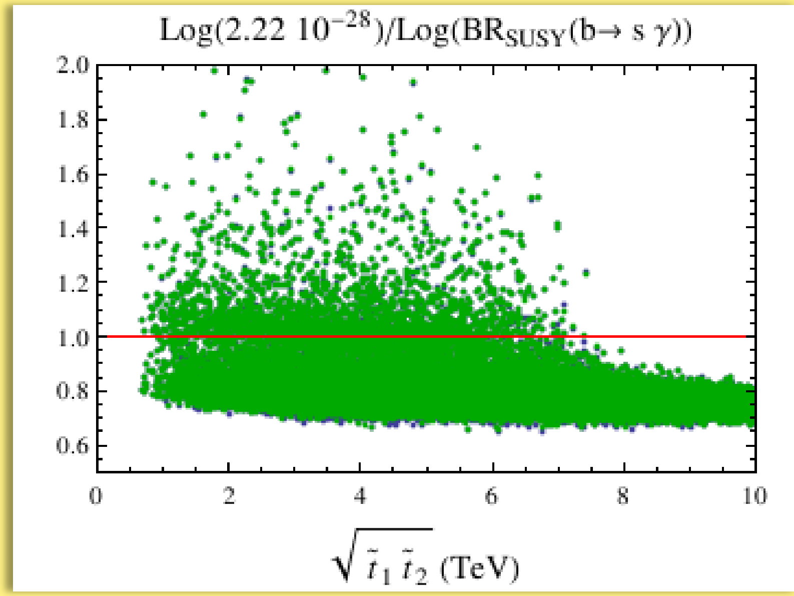
within limits both for the B_s & for the B_d sectors.

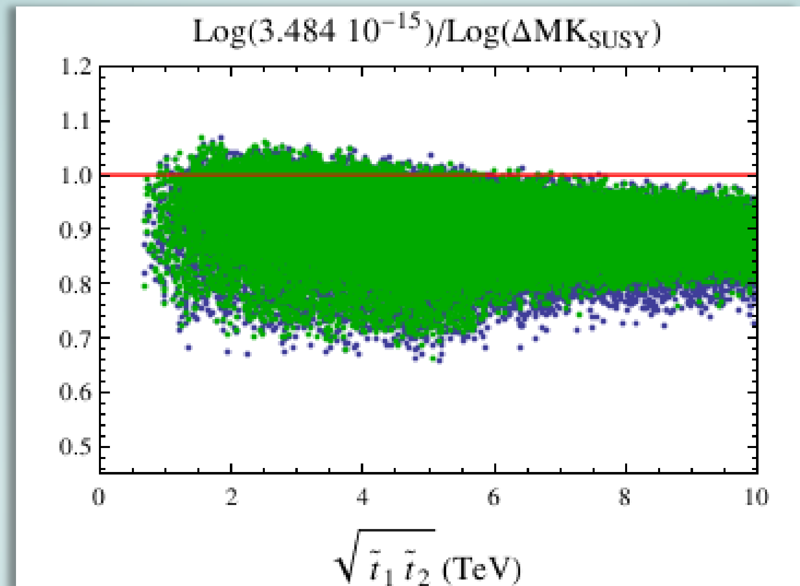
$$x = \frac{m_{\tilde{g}}^2}{m_{\tilde{q}}^2}$$

Phenome … plications

b → s γ

$$\mathrm{BR}(b \to s\gamma) = \frac{\alpha_s^2 \alpha}{81\pi^2 m_{\tilde{q}}^4} m_b^3 \tau_B \left\{ \left| m_b M_3(x) \left(\delta^d_{23}\right)_{LL} + m_{\tilde{g}} M_1(x) \left(\delta^d_{23}\right)_{LR} \right|^2 + L \leftrightarrow R \right\}$$





K-mixing

$$\frac{M_{12}^{q,SUSY}}{A_1^q} = A_2^q \left((\delta^d_{ij})^2_{LL} + (\delta^d_{ij})^2_{RR}\right) + A_3^q\, (\delta^d_{ij})_{LL}(\delta^d_{ij})_{RR} + A_4^q \left((\delta^d_{ij})^2_{LR} + (\delta^d_{ij})^2_{RL}\right) + A_5^q\, (\delta^d_{ij})_{LR}(\delta^d_{ij})_{RL}$$

Summary

- SU(5) x S_4xU(1) Flavour model successfully predicts the fermionic masses and mixing angles.

- Considering canonical normalisation effects does not spoil the original features of the fermionic sector.

- Predicted off-diagonalities of soft terms (and MIs) small at the GUT scale.

- Strongest constraint from **$\mu \to e\gamma$. $(\delta^e_{12})_{AB}$** around their upper limits.

- Comparison with the rest of the bounds points towards phenomenological study of edms, ϵ_κ and $b \to s$ transitions.

Thank you for your attention