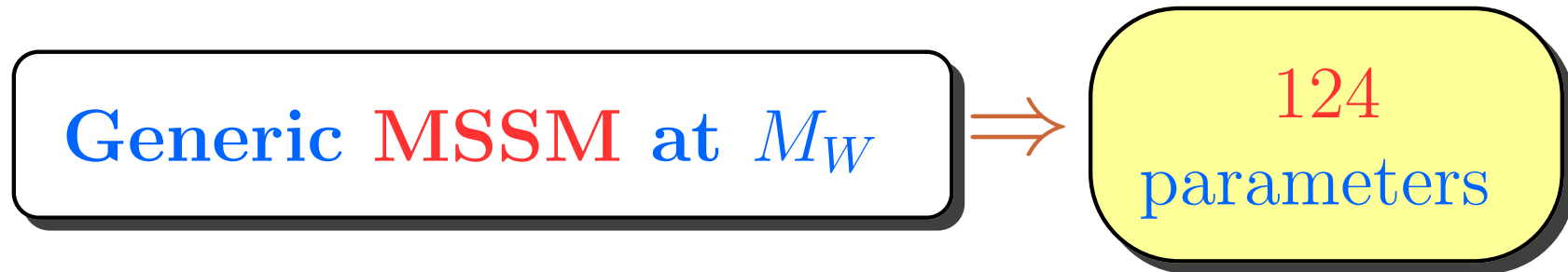


GUT Supersymmetry at SuperBabar

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Unknown SUSY breaking sector

Mass Insertion (MI)

- **SCKM** basis: Whole superfield rotated to the basis of diagonal Yukawas.
- (Small) Off-diagonality expected in sfermion masses,
- Sfermion propagators expanded in $\delta_{ij} = \Delta_{ij}^2 / \tilde{m}^2$, with Δ_{ij}^2 and \tilde{m}^2 the off-diagonal and average diagonal terms respectively.

Simple estimates

I.- Kaon physics

$$\begin{aligned}
 2.3 \times 10^{-3} \geq \varepsilon_K^{\text{SUSY}} &= \frac{\text{Im } M_{12}|_{\text{SUSY}}}{\sqrt{2} \Delta M_K|_{\text{SM}}} \simeq \frac{\alpha_s^2}{\alpha_W^2} \frac{M_W^4}{M_{\text{SUSY}}^2 m_c^2} \frac{\text{Im} \{ (\delta_L^d)_{12}^2 \}}{(V_{cd} V_{cs}^*)^2} \\
 &\simeq 12.5 \times 84 \times \frac{\text{Im} \{ (\delta_L^d)_{12}^2 \}}{0.05} \Rightarrow \sqrt{\text{Im} \{ (\delta_L^d)_{12}^2 \}} \leq 3.3 \times 10^{-4}
 \end{aligned}$$

II.- B physics

$$\begin{aligned}
 0.74 \geq a_{J/\psi}|_{\text{SUSY}} &= \frac{\text{Im } M_{12}|_{\text{SUSY}}}{|M_{12}|_{\text{SM}}} \simeq \frac{\alpha_s^2}{\alpha_W^2} \frac{M_W^4}{M_{\text{SUSY}}^2 m_t^2} \frac{\text{Im} \{ (\delta_L^d)_{13}^2 \}}{(V_{tb} V_{td}^*)^2} \\
 &\simeq 12.5 \times 0.005 \times \frac{\text{Im} \{ (\delta_L^d)_{13}^2 \}}{(0.008)^2} \Rightarrow \sqrt{\text{Im} \{ (\delta_L^d)_{13}^2 \}} \leq 0.03
 \end{aligned}$$

MI limits ($m_{\tilde{q}}^2 = 500 \text{ GeV}$)

x	$\sqrt{ \text{Im} (\delta_L^d)_{12}^2 }$	$\sqrt{ \text{Im} (\delta_{LR}^d)_{12}^2 }$	$\sqrt{ \text{Im} (\delta_L^d)_{12} (\delta_R^d)_{12} }$
0.3	2.9×10^{-3}	1.1×10^{-5}	1.1×10^{-4}
1.0	6.1×10^{-3}	2.0×10^{-5}	1.3×10^{-4}
4.0	1.4×10^{-2}	6.3×10^{-5}	1.8×10^{-4}

x	$\sqrt{ \text{Re} (\delta_{13}^d)_{LL}^2 }$	$\sqrt{ \text{Re} (\delta_{13}^d)_{LR}^2 }$	$\sqrt{ \text{Re} (\delta_{13}^d)_{LL} (\delta_{13}^d)_{RR} }$
0.3	4.6×10^{-2}	5.6×10^{-2}	1.6×10^{-2}
1.0	9.8×10^{-2}	3.3×10^{-2}	1.8×10^{-2}
4.0	2.3×10^{-1}	3.6×10^{-2}	2.5×10^{-2}

b \rightarrow s transitions

Only “weak” constraints from,

- $BR(B \rightarrow X_s \gamma) = (3.29 \pm 0.34) \times 10^{-4}$
- $\Delta M_s \geq 14.4 \text{ ps}^{-1}$

x	$\sqrt{ \text{Re}(\delta_{23}^d)_{LL}^2 }$	$ (\delta_{23}^d)_{LR} $	$\sqrt{ \text{Re}(\delta_{23}^d)_{LL}(\delta_{23}^d)_{RR} }$
0.3	0.21	1.3×10^{-2}	7.4×10^{-2}
1.0	0.45	1.6×10^{-2}	8.3×10^{-2}
4.0	1	3.0×10^{-2}	1.2×10^{-1}

Are large SUSY effects possible ???

GUT inspired SUSY

- Solution to **hierarchy** problem $M_W - M_{GUT}$
- Correct **gauge coupling unification** in MSSM
- Natural **radiative symmetry breaking** ...

+

Sugra mediated SUSY breaking

- **Soft breaking terms** present above M_{GUT}
- Common soft terms in a **GUT representation**
- Grand unification of quark and lepton **MI**.

Supersymmetric $SU(5)$

SM multiplets unify, $\bar{\mathbf{5}} = (\bar{\mathbf{3}}, 1) + (1, 2)$, $\mathbf{10} = (\mathbf{3}, 2) + (\bar{\mathbf{3}}, 1) + (1, 1)$,
 Above GUT scale we have,

$$\begin{aligned}
 W_{SU(5)} &= h_{ij}^u T_i T_j H + h_{ij}^d T_i \bar{F}_j \bar{H} + \mu H \bar{H}, \\
 -\mathcal{L}_{soft} &= m_{T_{ij}}^2 \tilde{T}_i^\dagger \tilde{T}_j + m_{\bar{F}}^2 \tilde{F}_i^\dagger \tilde{F}_j + m_H^2 H^\dagger \bar{H} + m_{\bar{H}}^2 \bar{H}^\dagger \bar{H} \\
 &+ A_{ij}^u T_i T_j H + A_{ij}^d T_i \bar{F}_j \bar{H} + B\mu H \bar{H},
 \end{aligned}$$

$$\Rightarrow \left(\begin{aligned}
 m_Q^2 &= m_{\tilde{e}^c}^2 = m_{\tilde{u}^c}^2 = m_T^2 \\
 m_{\tilde{d}^c}^2 &= m_L^2 = m_{\bar{F}}^2 \\
 A_{ij}^e &= A_{ji}^d
 \end{aligned} \right) \text{ at } M_{GUT}$$

$$\begin{aligned}
 (\Delta_{ij}^u)_{LL} &= (\Delta_{ij}^u)_{RR} = (\Delta_{ij}^d)_{LL} = (\Delta_{ij}^l)_{RR} \\
 (\Delta_{ij}^d)_{RR} &= (\Delta_{ij}^l)_{LL} \quad (\Delta_{ij}^d)_{LR} = (\Delta_{ji}^l)_{LR} = (\Delta_{ij}^l)_{RL}^*
 \end{aligned}$$

Quark and lepton suffer different **RG** effects \Rightarrow previous relations modified at M_W :

- Assume a single MI present at M_{GUT} .
- Small CKM \Rightarrow off-diagonal elements in squark masses unchanged.
- If no ν_R \Rightarrow off-diagonal elements in slepton masses unchanged.
- Trilinear couplings “**roughly**” renormalised as Yukawa .
- Diagonal elements strongly modified by gaugino masses MI.



$$\begin{aligned}
 (\delta_{ij}^d)_{RR} &\approx \frac{m_L^2}{m_{dc}^2} (\delta_{ij}^l)_{LL} & (\delta_{ij}^{u,d})_{LL} &\approx \frac{m_{ec}^2}{m_Q^2} (\delta_{ij}^l)_{RR} \\
 (\delta_{ij}^u)_{RR} &\approx \frac{m_{ec}^2}{m_{uc}^2} (\delta_{ij}^l)_{RR} & (\delta_{ij}^d)_{LR} &\approx \frac{m_{Lavg}^2}{m_{Qavg}^2} \frac{m_b}{m_\tau} (\delta_{ij}^l)_{RL}^*
 \end{aligned}$$

In the presence of ν_R , large Y_{ij}^ν generate additional LFV entries.

Even in this case, bounds on **leptonic MI** at M_W apply equally to RG induced MI and to MI already present at M_{GUT} .

$$\Rightarrow \quad |(\delta_{ij}^d)_{RR}| \leq \frac{m_L^2}{m_{dc}^2} |(\delta_{ij}^l)_{LL}|$$

other relations unchanged ...

\Rightarrow Links between leptonic and hadronic FCNC at M_W .

$$\begin{array}{llll}
 \mu \rightarrow e\gamma & \leftrightarrow & K^0 - \bar{K}^0 & \leftrightarrow & D^0 - \bar{D}^0 \\
 \tau \rightarrow e\gamma & \leftrightarrow & B_d - \bar{B}_d & \leftrightarrow & - \\
 \tau \rightarrow \mu\gamma & \leftrightarrow & B \rightarrow \phi K_S & \leftrightarrow & -
 \end{array}$$

Numerical analysis

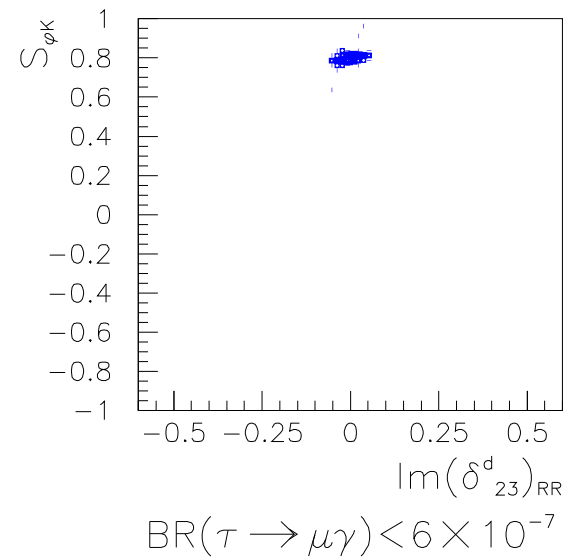
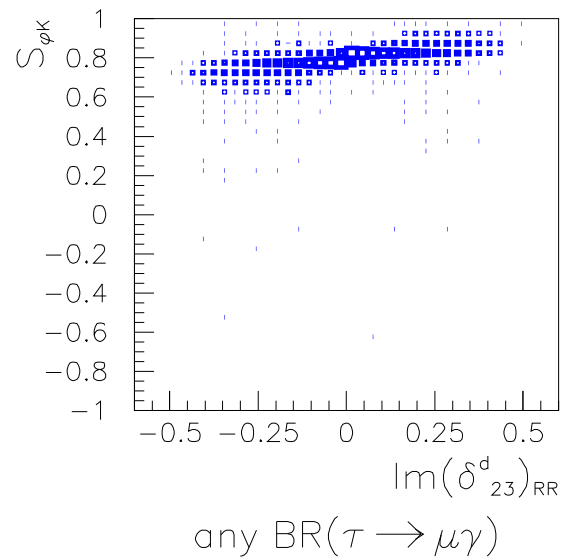
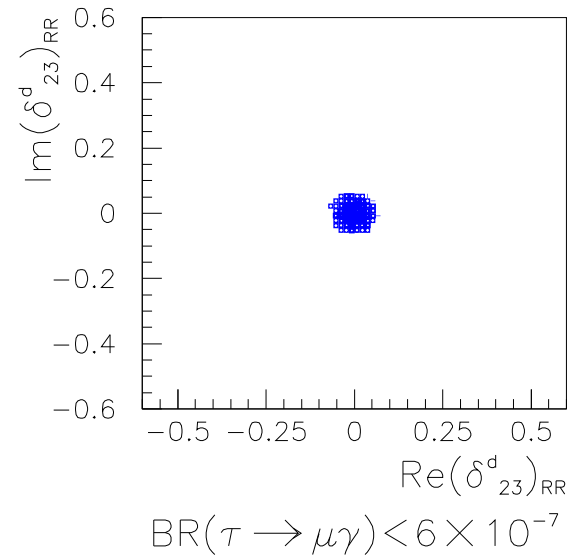
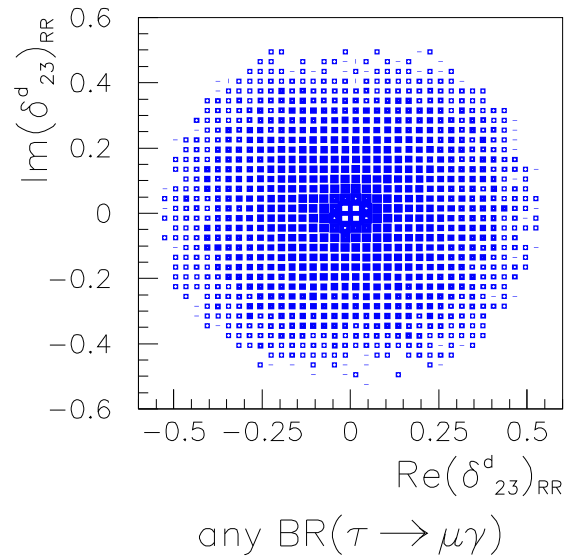
- Approx. equal flavour diagonal sfermion masses.

$$m_T^2 = m_{\tilde{F}}^2 = m_H^2 = m_{\tilde{H}}^2 = m_0^2$$

- Gaugino masses unify at M_{GUT} , $M_{1/2} \simeq \mathcal{O}(m_0)$
- Single flavour off-diagonal entry,

$$m_{\tilde{f}}^2 = m_0^2 \mathbb{1} + \Delta_{ij}^f, \quad \text{with} \quad |\Delta_{ij}^f| \leq m_0^2.$$

- μ fixed from radiative symmetry breaking
- Initial conditions ($M_{1/2}, m_0^2, A_0, \Delta_{ij}, \tan \beta$).
- Limits from direct searches + BR($b \rightarrow s\gamma$)
- Light sparticles, $m_{\tilde{q}} \simeq 350 - 550$ GeV, $m_{\tilde{l}} \simeq 150 - 400$ GeV.
- Calculate δ contributions to both leptonic and hadronic processes.





Strong bounds from leptonic processes on $b \rightarrow s$

with $\tan \beta = 10$

	BR ($\tau \rightarrow \mu \gamma$)		
	$< 6 \cdot 10^{-7}$	$< 1 \cdot 10^{-7}$	$< 1 \cdot 10^{-8}$
$(\delta_{23}^d)_{LL}$	–	–	–
$(\delta_{23}^d)_{RR}$	0.070	0.030	0.010
$(\delta_{23}^d)_{RL}$	0.080	0.035	0.010
$(\delta_{23}^d)_{LR}$	0.080	0.035	0.010

(No bound on $(\delta_{23}^{e(d)})_{RR(LL)}$, due to cancellations of higgsino – bino.)

Similar constrains from other processes and different MI Work in progress Ciuchini, Masiero, Silvestrini, Paradisi, Vempati and O.V.

$SU(3)$ Flavour Symmetry and Soft Breaking

- Spontaneously broken $SU(3)$ generates Yukawa textures.

$$SU(3) \xrightarrow{\langle \theta_3 \rangle} SU(2) \xrightarrow{\langle \theta_{23} \rangle} 0$$

- Yukawa superpotential,

$$W_Y = H\psi_i\psi_j^c \left[\theta_3^i\theta_3^j + \theta_{23}^i\theta_{23}^j\Sigma + \left(\epsilon^{ikl}\bar{\theta}_{23,k}\bar{\theta}_{3,l}\theta_{23}^j (\theta_{23}\bar{\theta}_3) + (i \leftrightarrow j) \right) \right]$$

$$Y^f \propto \begin{pmatrix} 0 & \epsilon^3 e^{i\delta} (1 + X) & \epsilon^3 e^{i(\delta+\beta_3)} (1 - X) \\ \dots & \epsilon^2 \frac{\Sigma}{|a_3|^2} & \epsilon^2 e^{i\beta_3} \frac{\Sigma}{|a_3|^2} \\ \dots & \dots & e^{2i\chi} \end{pmatrix},$$

with $\bar{\epsilon} = \langle \theta_{23} \rangle / \langle \theta_3 \rangle \simeq 0.15$

- Kahler real and universal at M_{Planck} . After spontaneous breaking,

$$K = \psi_i^\dagger \psi_j \left(\delta^{ij} + \frac{1}{M^2} [\theta_3^{i\dagger} \theta_3^j + \theta_{23}^{i\dagger} \theta_{23}^j] + \frac{1}{M^4} [(\epsilon^{ikl}\bar{\theta}_{3,k}\bar{\theta}_{23,l})^\dagger (\epsilon^{jmn}\bar{\theta}_{3,m}\bar{\theta}_{23,n}) + h.c.] + \dots \right)$$

Sfermion mass matrices,

$$M_{\tilde{D}, \tilde{E}}^2 \simeq \begin{pmatrix} 1 + \bar{\epsilon}^3 & 0 & 0 \\ 0 & 1 + \bar{\epsilon}^2 & \bar{\epsilon}^2 e^{i\beta_3} \\ 0 & \bar{\epsilon}^2 e^{-i\beta_3} & 1 + \bar{\epsilon} \end{pmatrix} m_0^2$$

G.G. Ross, L. Velasco-Sevilla and O.V., work in progress.

In leptonic sector $(\delta_L^e)_{23} \simeq 2 \times 10^{-2}$ to be compared with bound $(\delta_L^e)_{12} \simeq 3 \times 10^{-2}$ for $\tan \beta = 10$ and $m_{\tilde{l}} = 300$ GeV.



**Possible sizeable
contributions to
LFV (and B FCNC...)**

Conclusions

- GUT inspired MSSM + Supergravity mediated SUSY breaking relates quark and lepton FCNC.
- $\tau \rightarrow \mu\gamma$ decay constrains strongly $b \rightarrow s$ transitions in the quark sector.
- LFV observables may be closer than hadronic FCNC, although measure different parameters.
- Sizeable contributions possible in “realistic” flavour models.
- Precision measurements necessary to understand flavour physics (SuperBaBar ??).