# Flavour Models at 7 TeV SUSY

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SUSY 2010 - Bonn

# December 2011

- LHC: 1 $fb^{-1}$ of data, at 7 TeV.
- "We find for $m_{\tilde{g}} \sim m_q$ an LHC reach of $m_{\tilde{g}} \sim$ 800, 950, 1100 and 1200 GeV for 0.1, 0.3, 1 and 2 $fb^{-1}$, respectively."
  Baer, Barger, Lessa, Tata (1004.3594 [hep-ph])
- "From a fit to the $M_{eff}$ distribution, the SUSY mass scale can be measured in a model independent fashion with an ultimate error < 10%"
  Costanzo (EPS-HEP2007)
- "A linear fit is applied to the right part of the distribution to determine the edge position at 590 ± 9(stat)+13−6 (sys) GeV for SU3 (...). This can be compared to the expected positions of $m_{qR}$ = 611 GeV (...)."
  ATLAS Collaboration (0901.0512 [hep-ex])

# Questions

- What does this say to flavour physics?
  - Mass insertions?
  - Flavour Models?
- Can flavour physics say something back to collider physics?
  - Constraints on CMSSM?
  - Hints towards a spectrum?

# Conclusions

- Flavour and Electroweak Data can have an active role in post-2011 Collider Physics.
- Evidence of SUSY + Meson + LFV bounds give valuable information to flavour model building.
- It is feasible to use correlations between flavour + CP observables to differentiate between several models.

# Flavour Models at 7 TeV SUSY

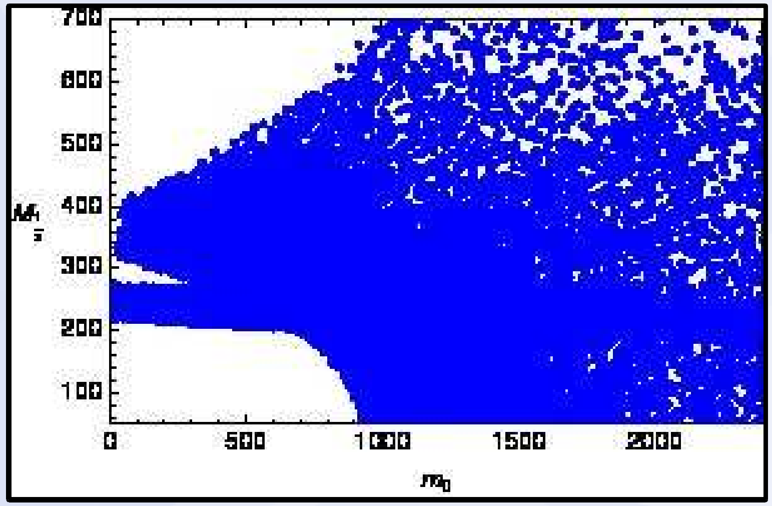
Flavour and Electroweak Feedback
in the CMSSM

# CMSSM in 2011

- CMSSM is not expected to be ***the*** theory, but it is useful for understanding the full MSSM.
- If we see some new coloured sparticle by 2011, can we say it is due to something that looks like the CMSSM?
- Suppose we get evidence for a squark or gluino with mass ~ 600 ± 60 GeV....

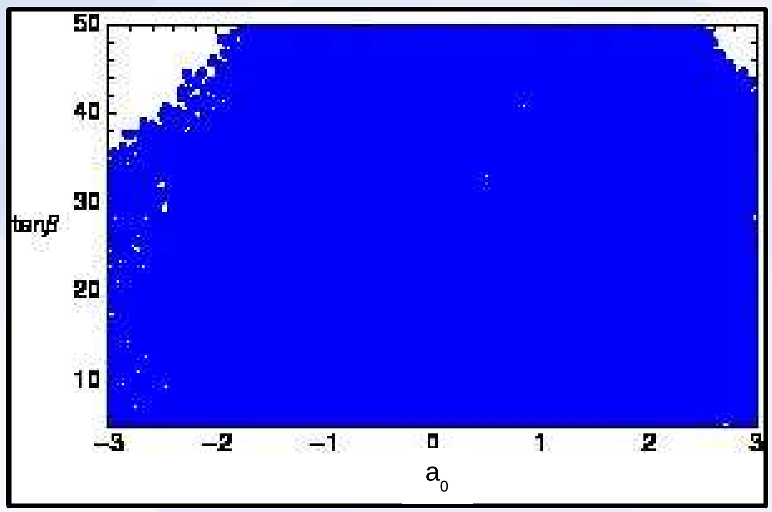
# Parameter Space

$M_{1/2}$



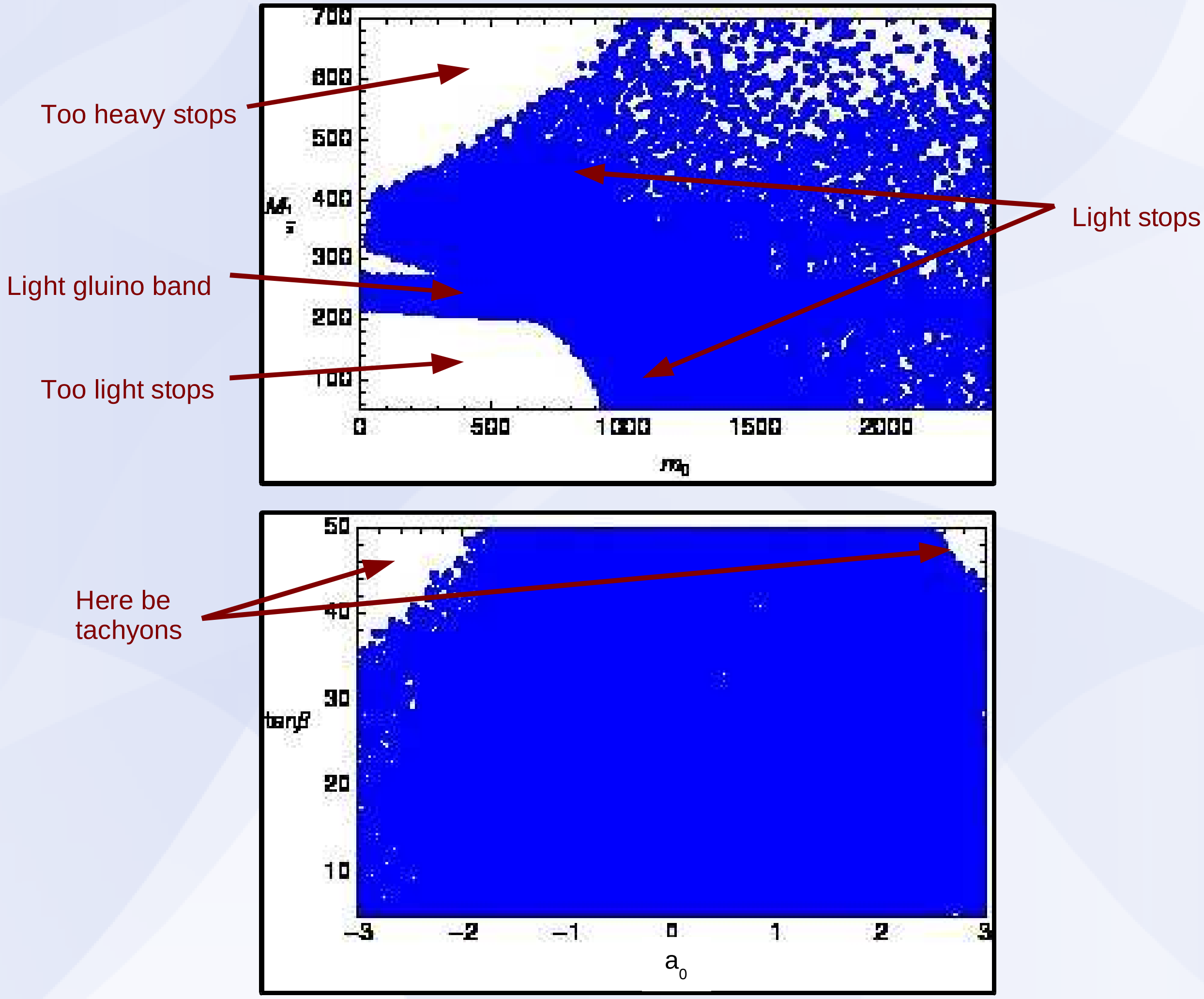

$m_0$

$\tan\beta$




$a_0=A_0/m_0$

# Parameter Space



# Direct Search Bounds

$$m_{\tilde{\chi}^{\pm}} > 103\,GeV$$

$$m_{\tilde{g}} > 390\,GeV$$

$$m_{\tilde{t}} > 115\,GeV$$

$$m_{\tilde{b}} > 95\,GeV$$

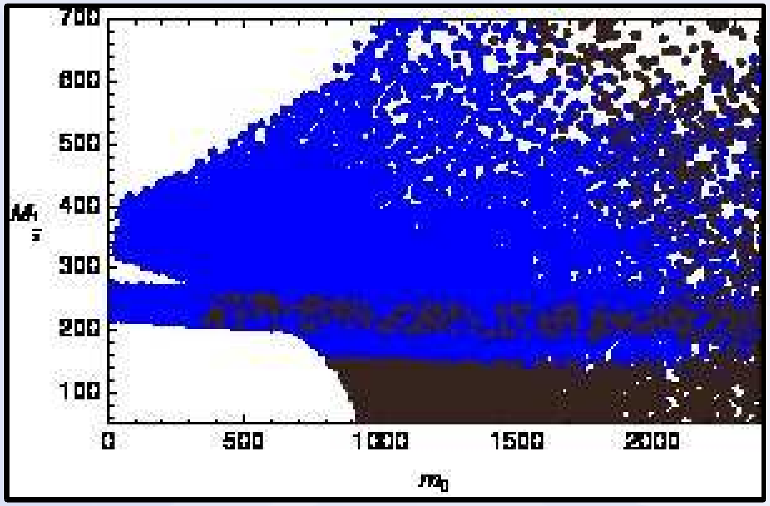
$$m_{\tilde{\chi}^{0}} > 59\,GeV$$

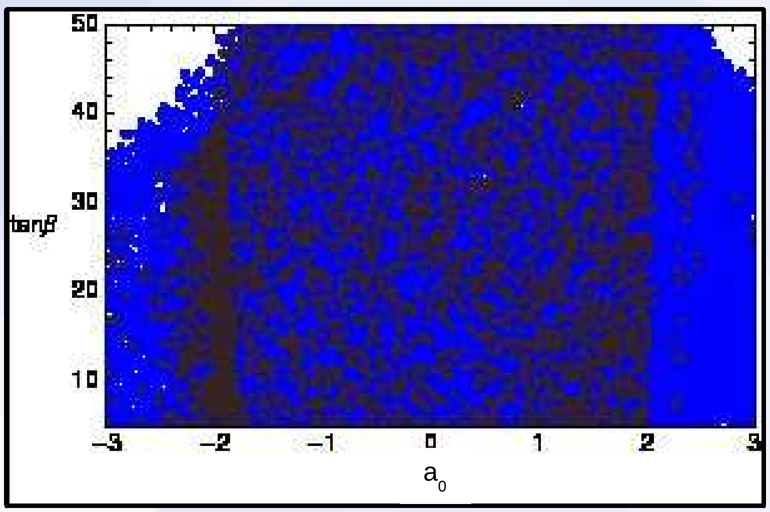
$$m_{A^{0}} > 93\,GeV$$

$$m_{H^{\pm}} > 79\,GeV$$

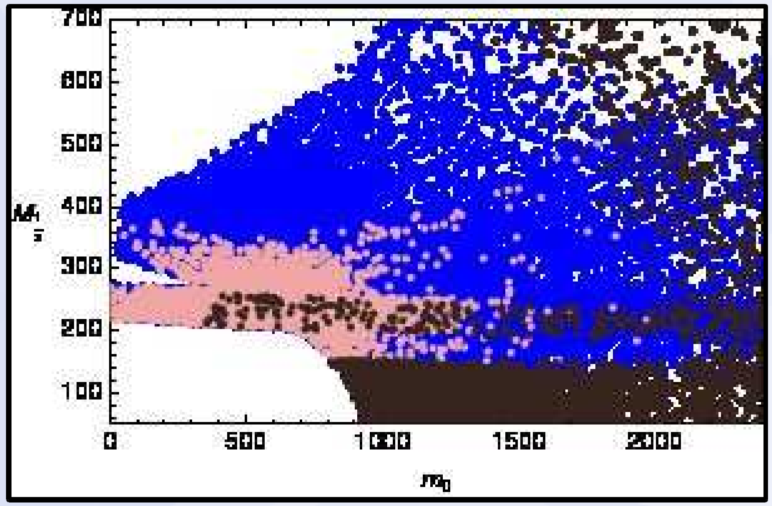
$$m_{\tilde{e}} > 95\,GeV$$

$$m_{\tilde{\nu}} > 45\,GeV$$

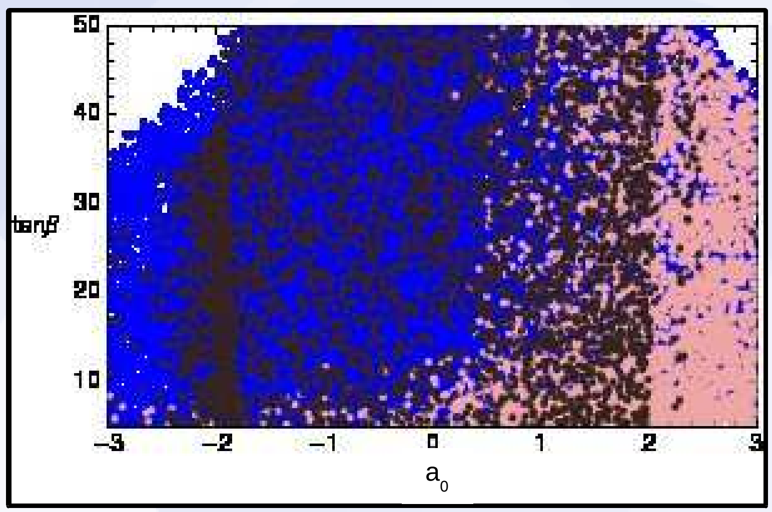


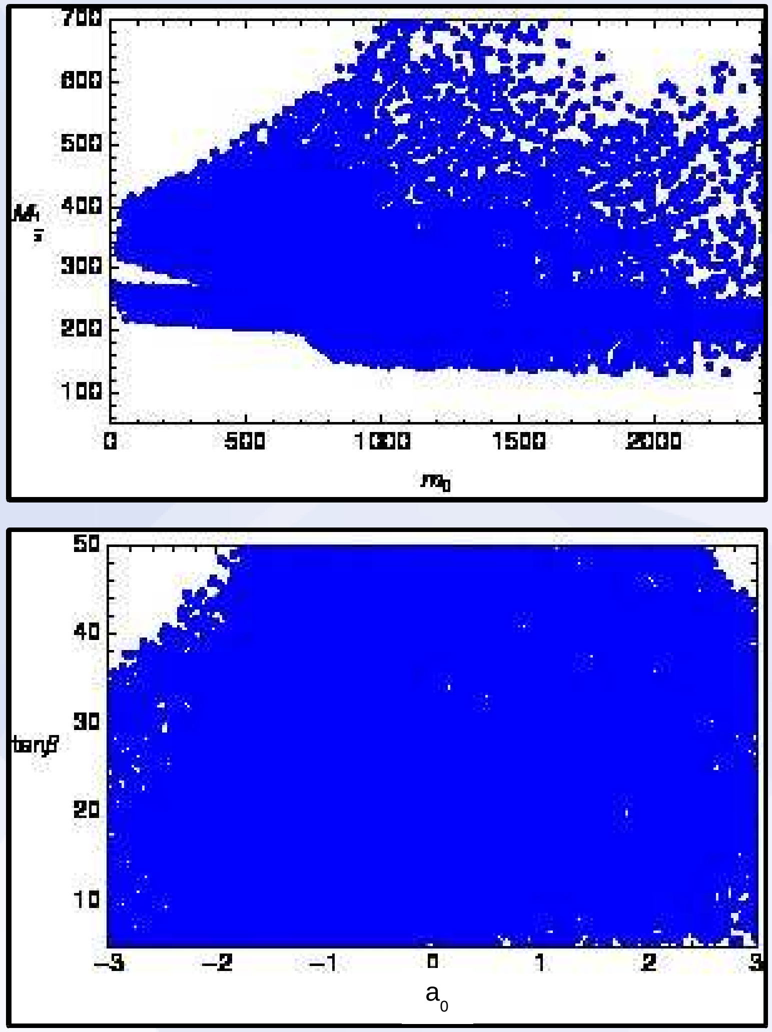
# Higgs Bounds




$$m_{h^0} > 93 \sim 113 GeV$$



# Still got lots of points...



# What can flavour say?

- CMSSM contributes to flavour phenomenology.
- MFV contribution due to loop diagrams.

$$
\begin{array}{cc}
b \to s \gamma & (3.56 \pm 0.25) \times 10^{-4} \\
b \to s \mu \mu & (4.3 \pm 1.2) \times 10^{-6} \\
B_s \to \mu \mu & < 4.7 \times 10^{-8} \\
B_u \to \tau \nu & (1.4 \pm 0.4) \times 10^{-4} \\
K \to \pi \nu \nu & < 6.7 \times 10^{-8}
\end{array}
$$

PDG, HFAG

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| | |
|---|---|
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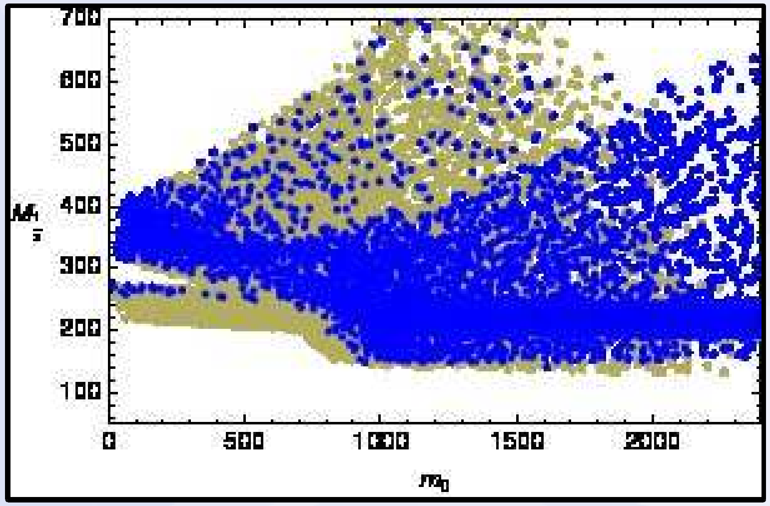
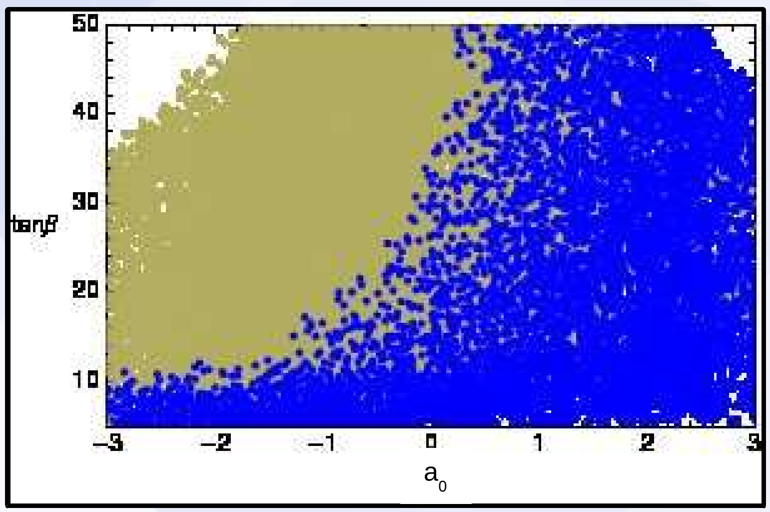
| $B_u \to \tau\nu$ | $(1.4 \pm 0.4) \times 10^{-4}$ |
| $K \to \pi\nu\nu$ | $< 6.7 \times 10^{-8}$ |

PDG, HFAG

# b -> s γ Constraints (3σ)

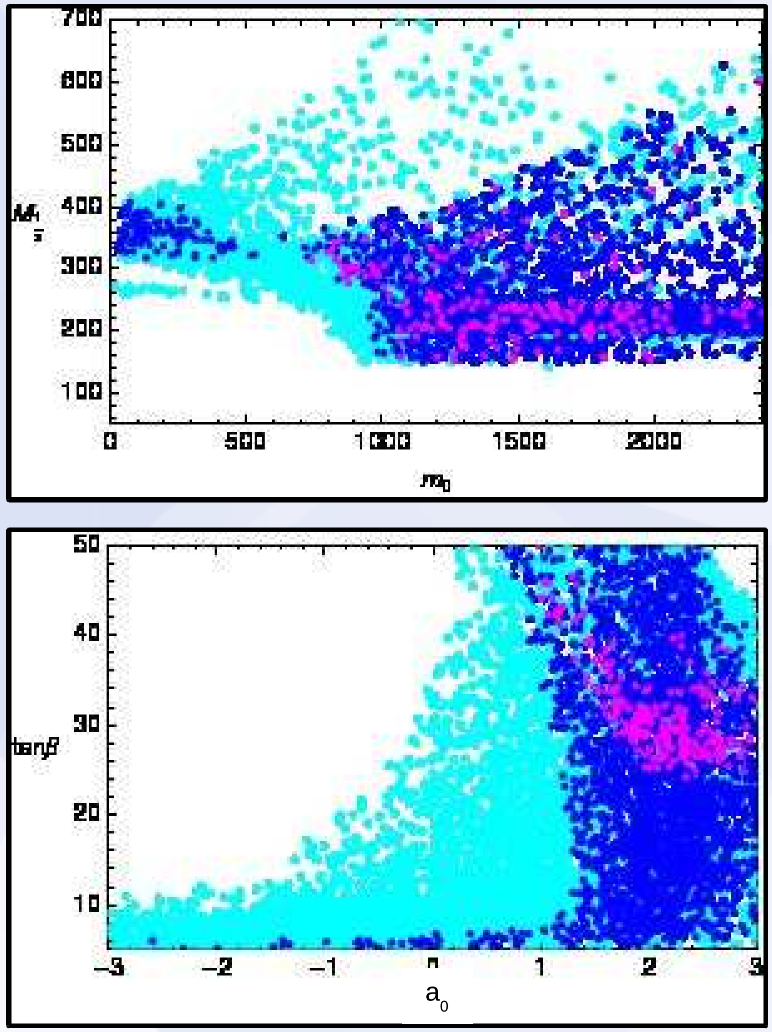
$$BR(b \to s\gamma) = (3.56 \pm 0.25) \times 10^{-4}$$



# b -> s γ Constraints

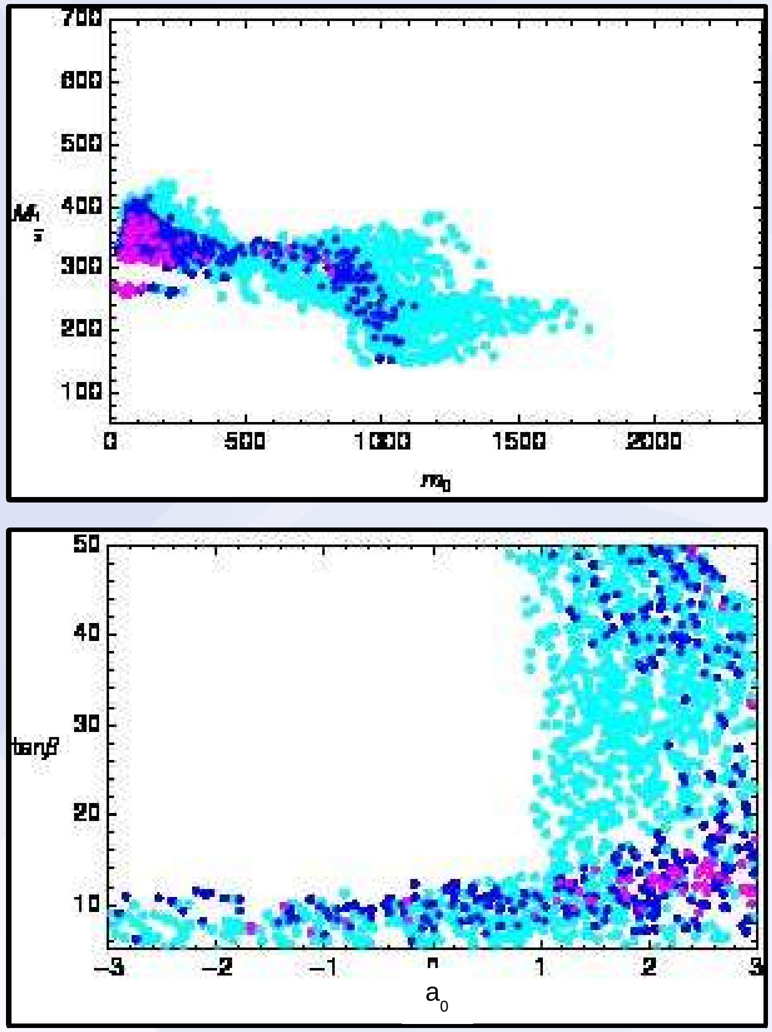
$$BR(b \rightarrow s\gamma) = (3.56 \pm 0.25) \times 10^{-4}$$




Magenta: 1 σ
Blue: 2 σ
Cyan: 3 σ

# $(g\text{-}2)_\mu$ Constraints

$$a_\mu = \frac{(g-2)_\mu}{2}$$




Magenta: 1 σ
Blue: 2 σ
Cyan: 3 σ

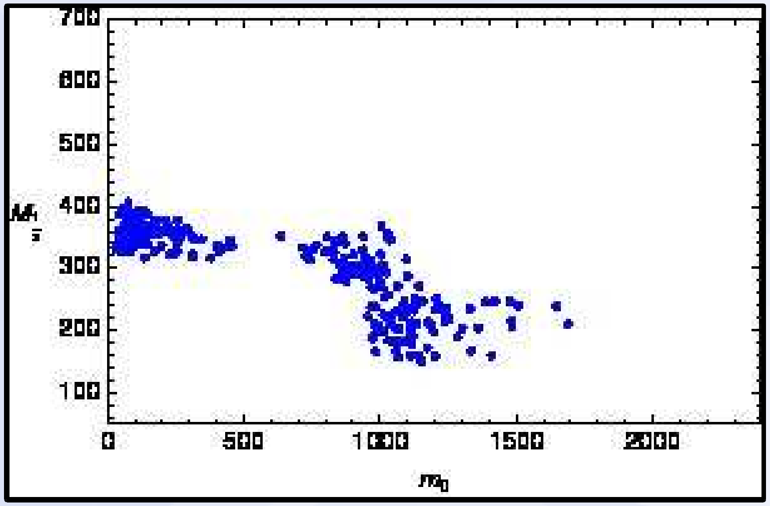
$$\Delta a_\mu = (31.6 \pm 7.9) \times 10^{-10}$$

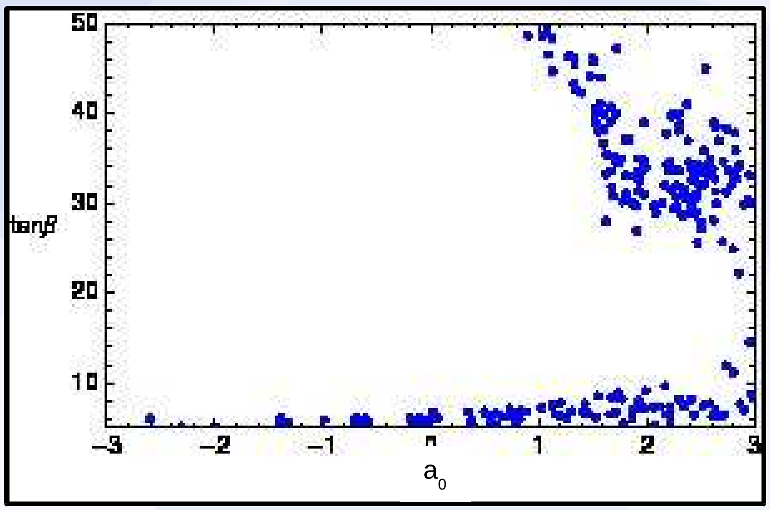
Passera, Marciano, Sirlin
1001.4528 [hep-ph]

# b -> s $\gamma$ + $(g\text{-}2)_\mu$ Constraints

$\Delta a_\mu @ 3\sigma$

$BR(b \to s\gamma) @ 2\sigma$



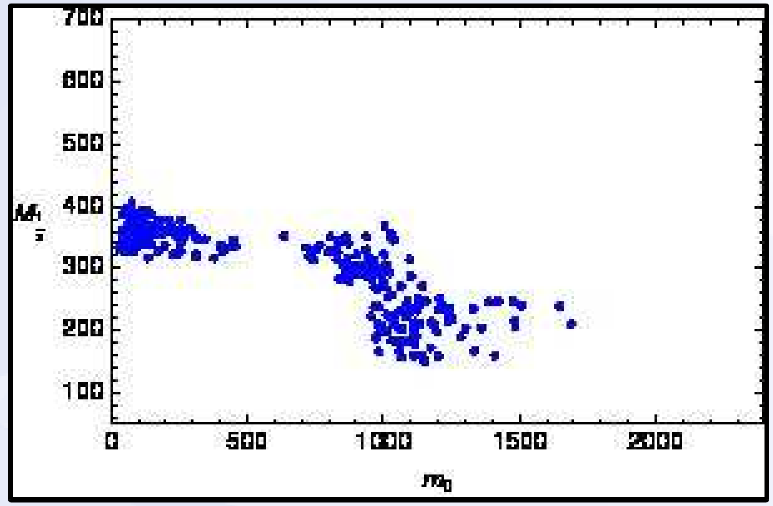



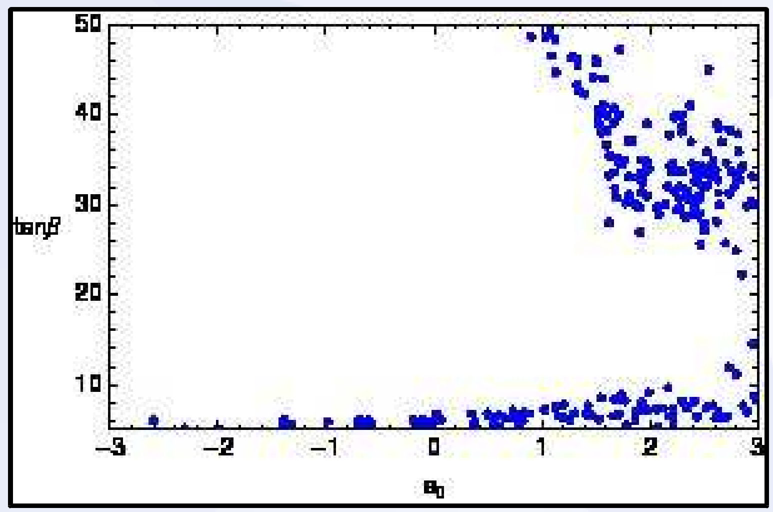
# b -> s $\gamma$ + $(g-2)_\mu$ Constraints

We obtain a reduced parameter space.

Regions define particle spectrum, which can give further hints at colliders (i.e. preference of one decay over another)

We thus get a “Flavour and Electroweak Feedback”



# Flavour Models at 7 TeV SUSY

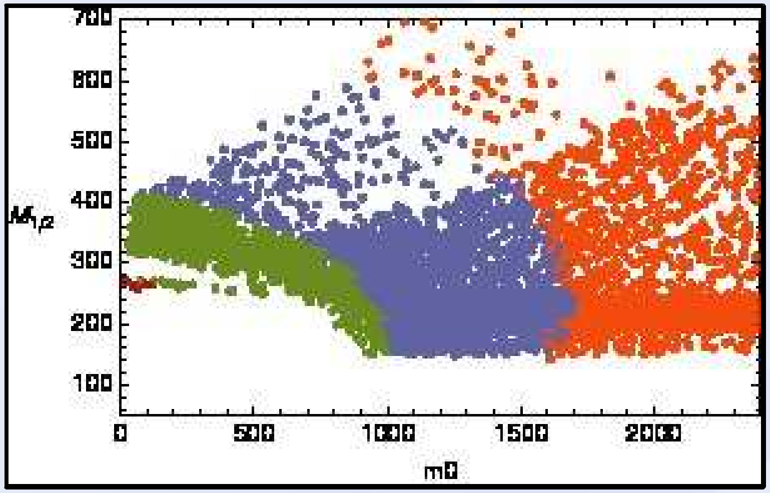
Mass Insertion Bounds

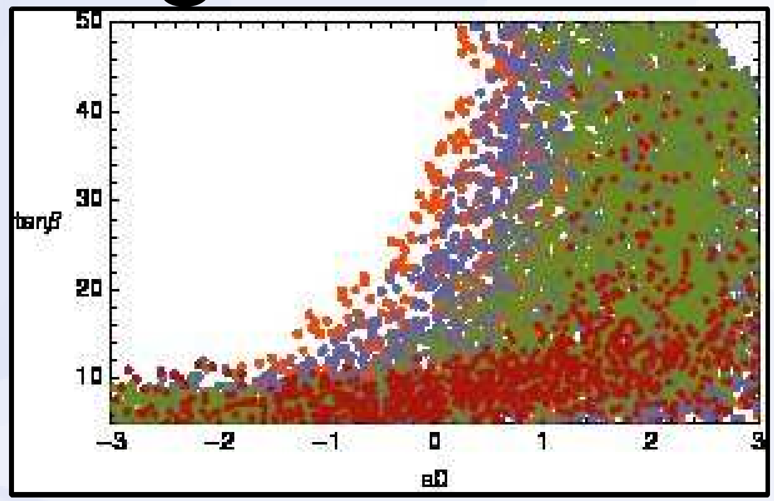
# What can we tell Flavour Physics?

Mass Insertion Bounds!

$$m^2_{\tilde{Q}_L} = \begin{pmatrix} x & (\delta^d_{12})_{LL} & (\delta^d_{13})_{LL} \\ (\delta^d_{12})^*_{LL} & x & (\delta^d_{23})_{LL} \\ (\delta^d_{13})^*_{LL} & (\delta^d_{23})^*_{LL} & x \end{pmatrix} m^2_0$$

# Kaon Mixing



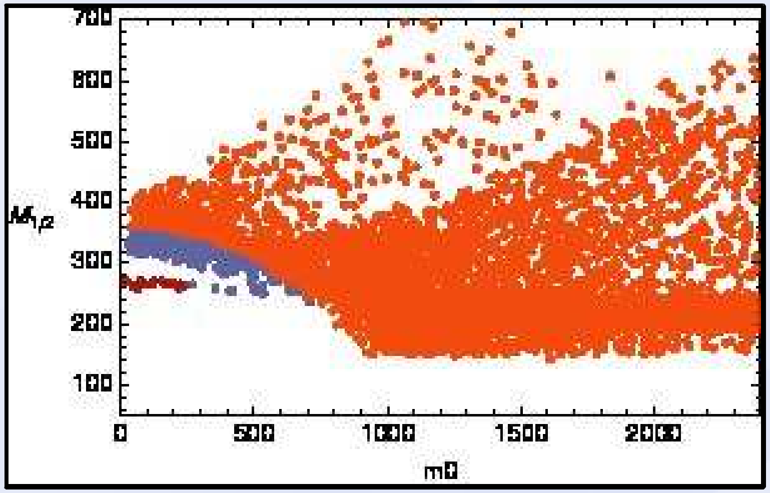



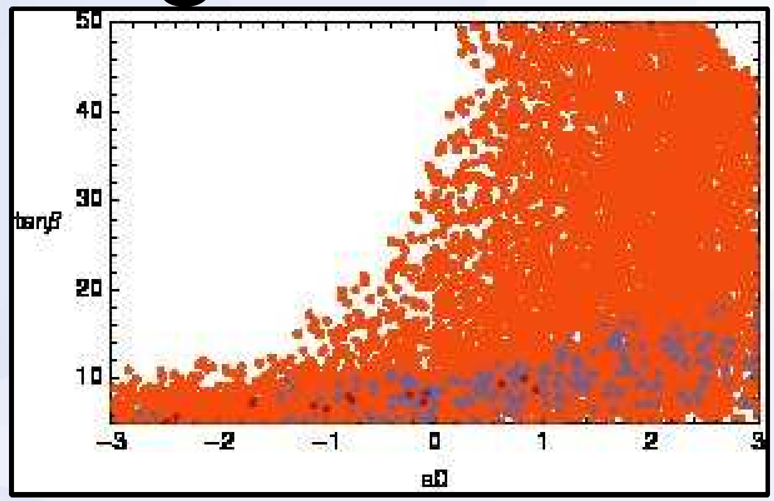

$$\sqrt{\Re(\delta^d_{12})_{LL}(\delta^d_{12})_{RR}}\,(\times 10^3)$$

$$\Delta m_K$$

| | | | | |
|---|---|---|---|---|
| 8.0 | > | Orange | > | 4.8 |
| 4.8 | > | Blue | > | 2.8 |
| 2.8 | > | Green | > | 1.7 |
| 1.7 | > | Red | > | 0.1 |

# Kaon Mixing



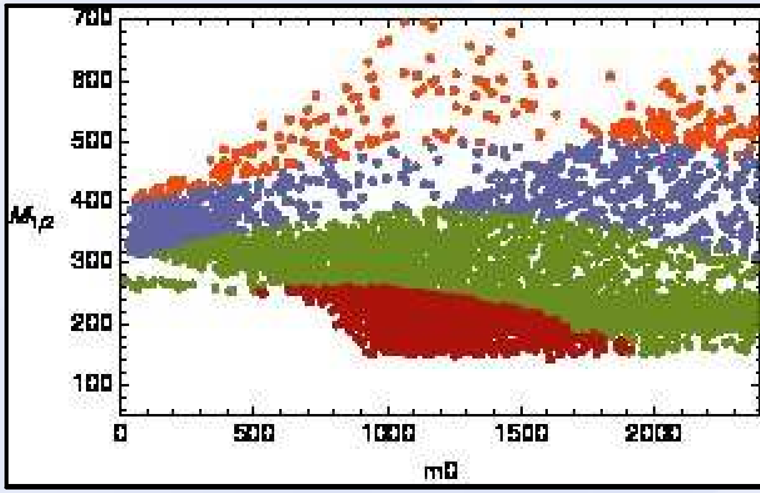




$$\sqrt{\Im(\delta^d_{12})_{LL}(\delta^d_{12})_{RR}}\,(\times 10^3)$$

$\epsilon_K$

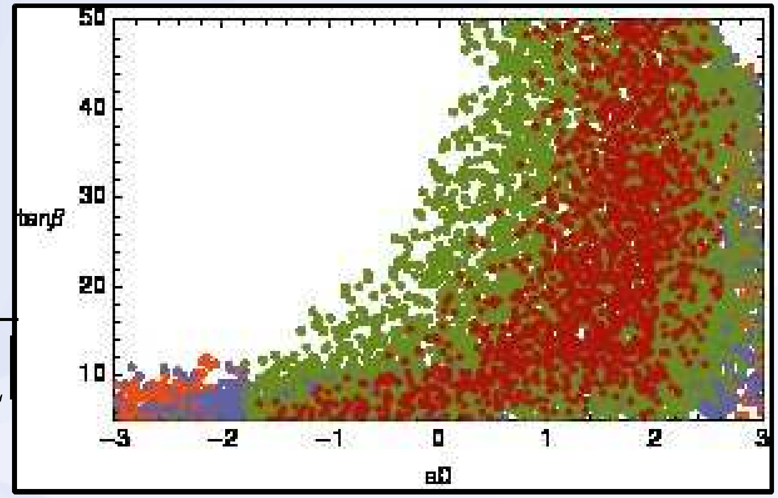
| | | | | |
|---|---|---|---|---|
| 10.0 | > | Orange | > | 9.5 |
| 9.5 | > | Blue | > | 8.5 |
| 8.5 | > | Red | > | 8.0 |

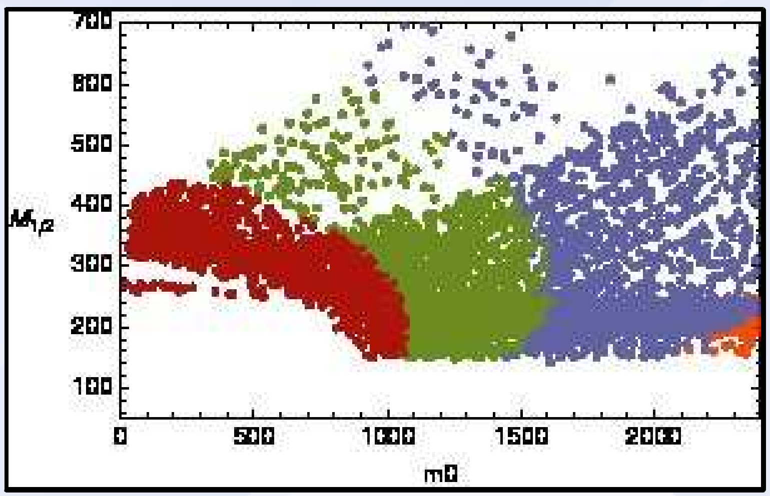
# B, $B_s$ Mixing




6.0 ~ 3.8
3.8 ~ 2.4
2.4 ~ 1.6
1.6 ~ 0.1

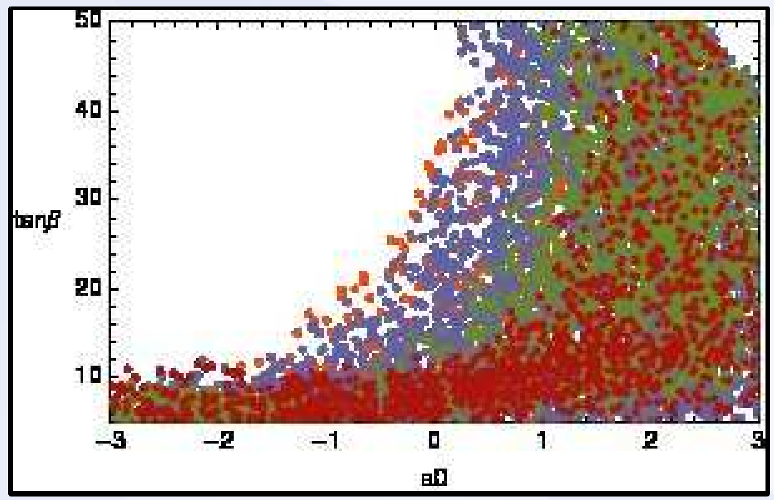
$$\sqrt{|(\delta^d_{13})^2_{LL}|}\ (\times 10)$$



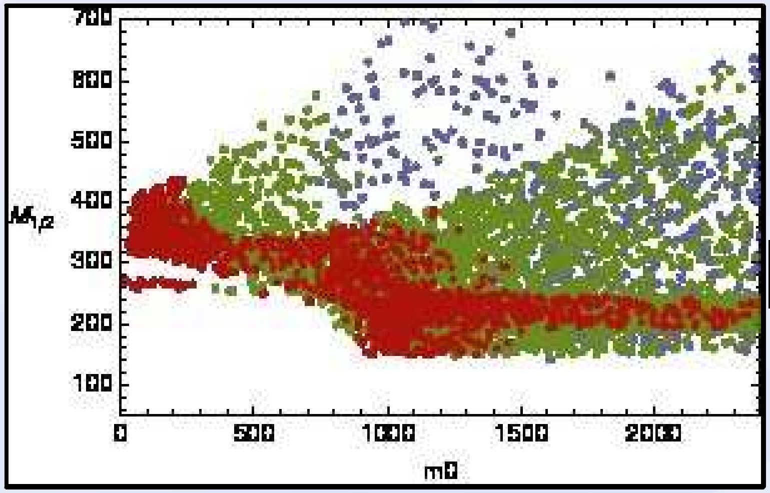




$$\sqrt{|(\delta^d_{23})^2_{LR}|}$$

No Bound
> 0.6
0.6 ~ 0.3
0.3 ~ 0.2

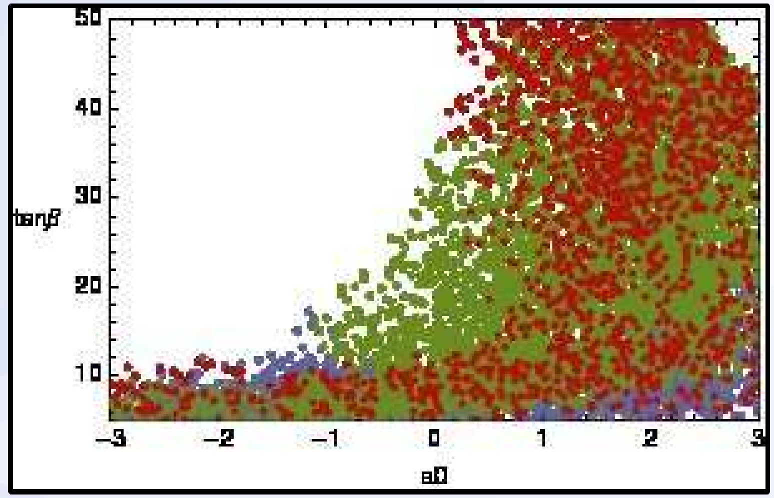


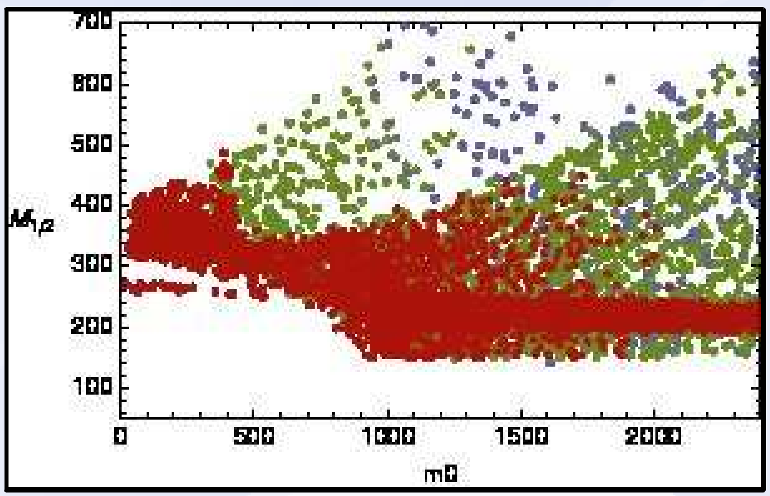
# LFV




80 ~ 15
15 ~ 2.9
2.9 ~ 0.5

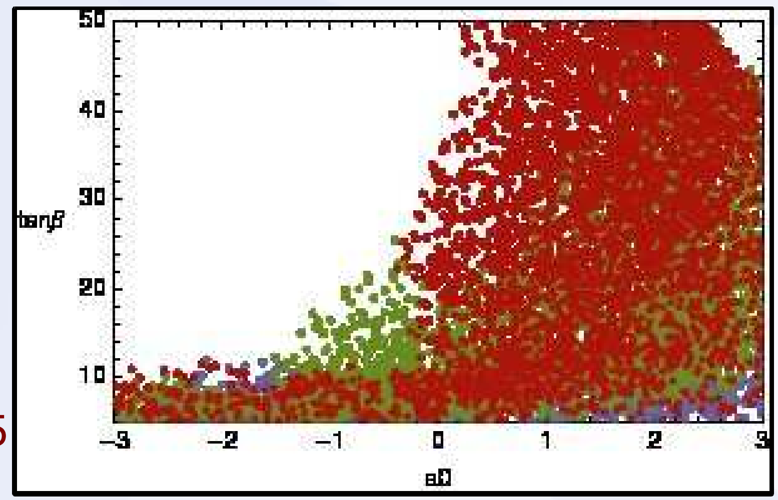
$$|(\delta^e_{12})_{LL}|$$
$$(\times 10^4)$$




$$|(\delta^e_{23})_{LL}|$$
$$(\times 10)$$

7.2 ~ 1.3
1.3 ~ 0.3
0.3 ~ 0.05



# What Now?

- We have Mass Insertion bounds
- Check if Flavour Models respect bounds.
- Within this restricted parameter space, derive predictions for other processes.

# Flavour Models at 7 TeV SUSY

Flavour Model Phenomenology

# Some Models...

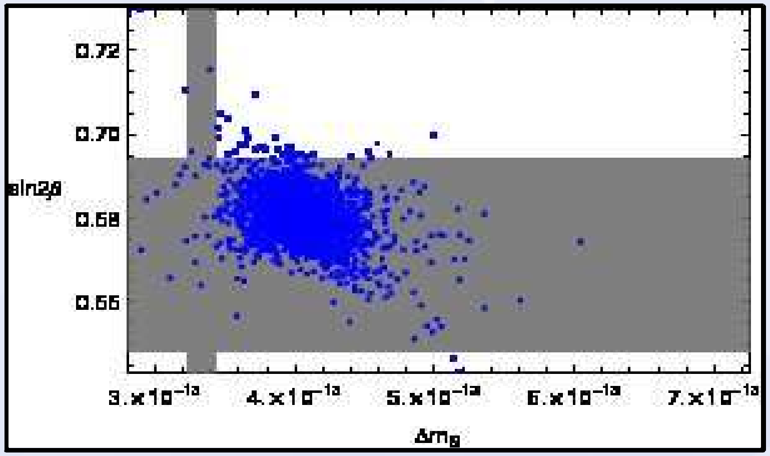
- RVV1: $SU(3) \otimes U(1) \otimes U(1) \otimes U(1)$
  Ross, Vives, Velasco-Sevilla (hep-ph/0401064)

- RVV2: $SU(3) \otimes U(1) \otimes U(1)$
  Calibbi, JP, Masiero, Park, Porod, Vives (0907.4069 [hep-ph])

- NR: $U(1) \otimes U(1)$
  Nir, Rattazzi (hep-ph/9603233)

# B Bounds

RVV1

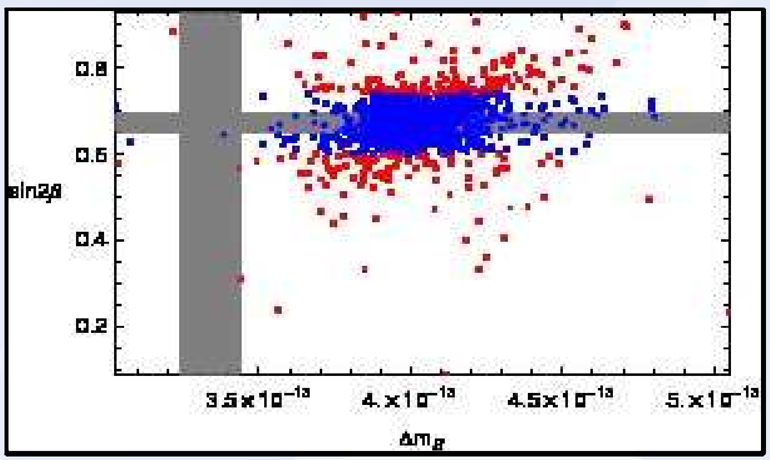



$$\sin 2\beta_{eff}$$

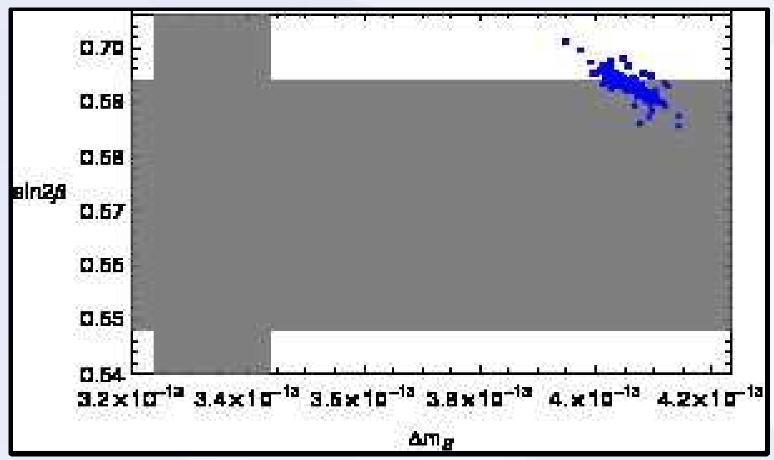
*vs.*

$$\Delta m_B$$

RVV2

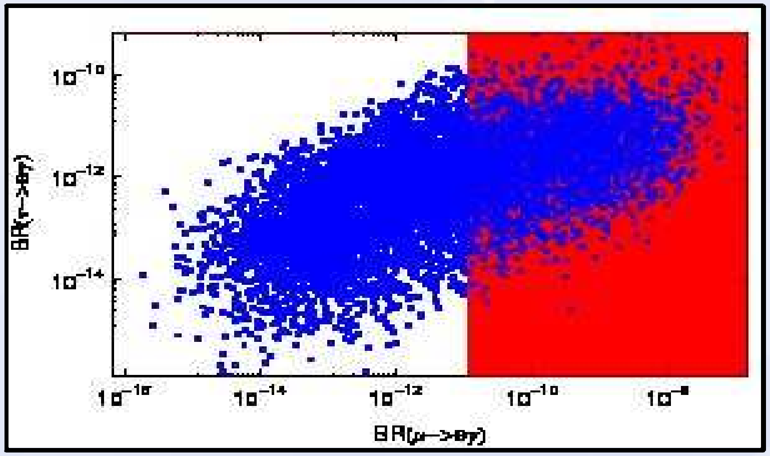



NR



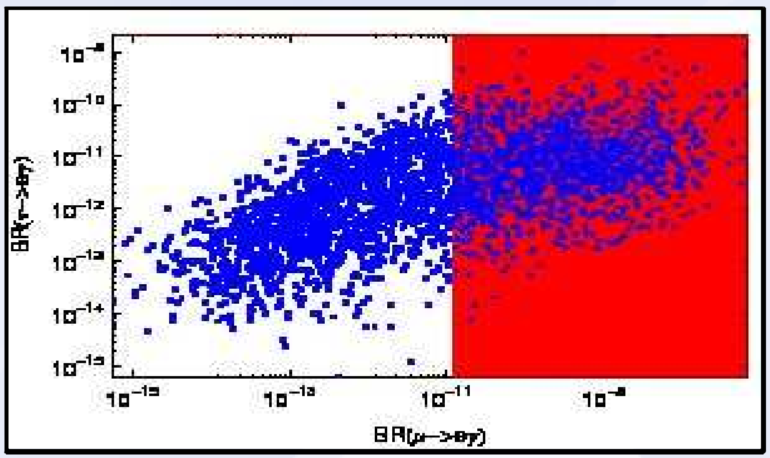
# LFV Bounds

RVV1

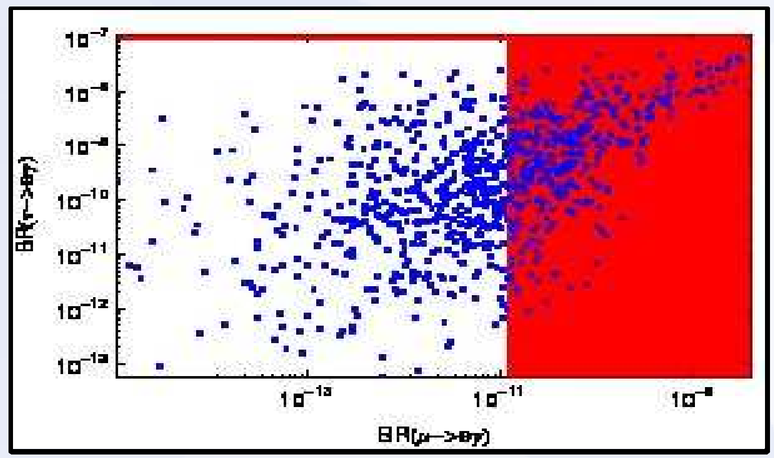



$$\tau \to e\,\gamma$$
$$vs.$$
$$\mu \to e\,\gamma$$

RVV2

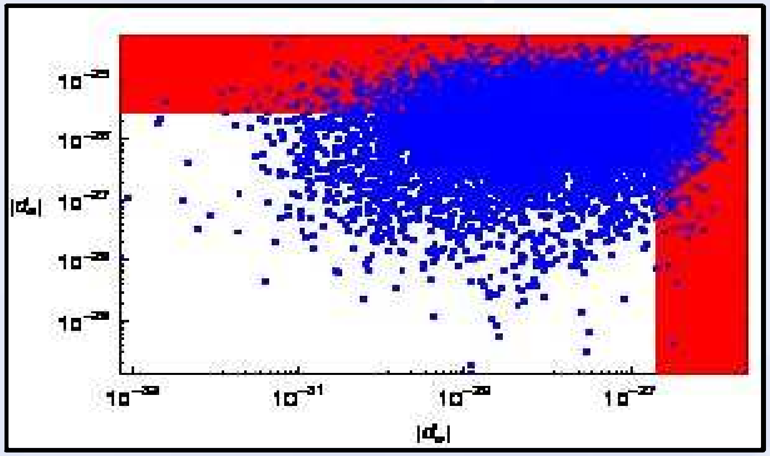



NR



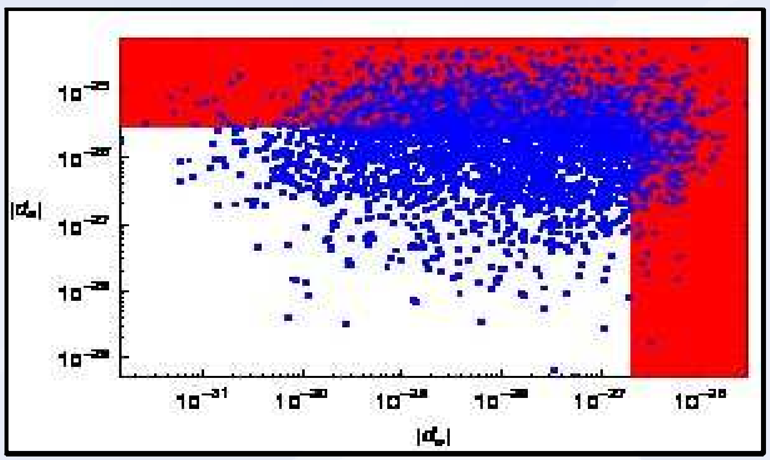
# EDM Bounds

RVV1

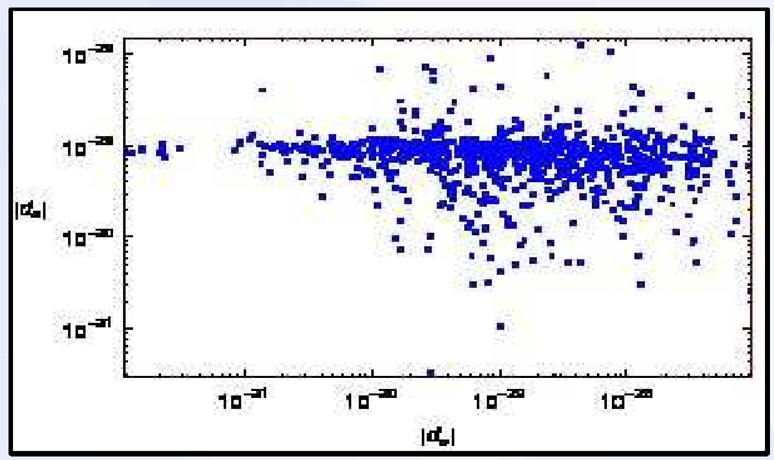


$d_n \; vs. \; d_e$

RVV2

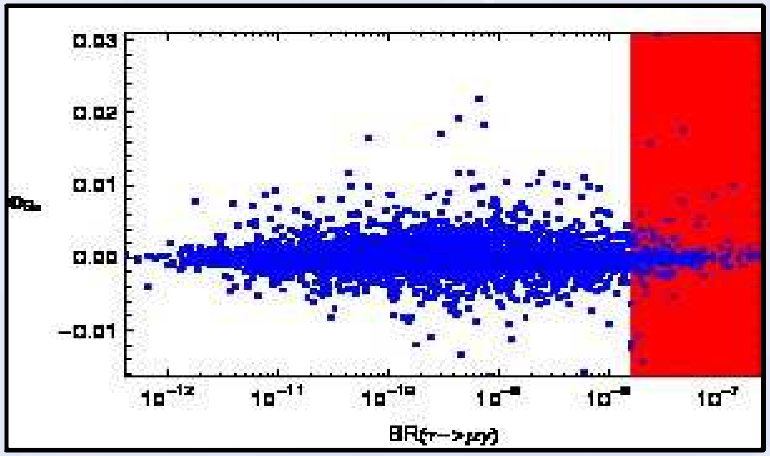


NR



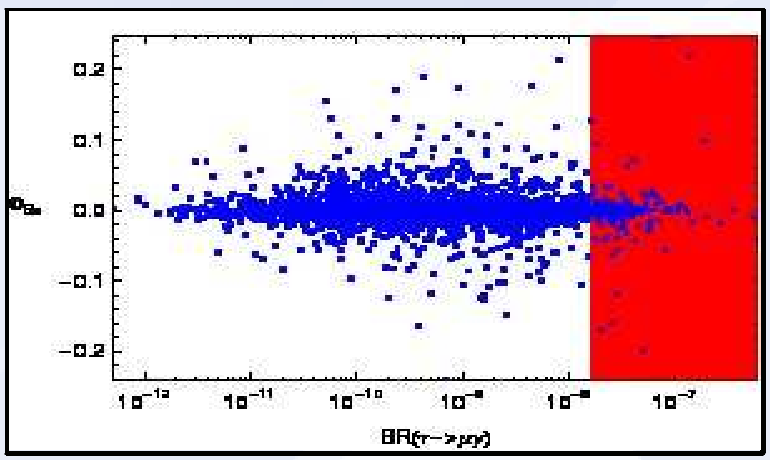
# LFV vs $\Phi_{Bs}$

RVV1

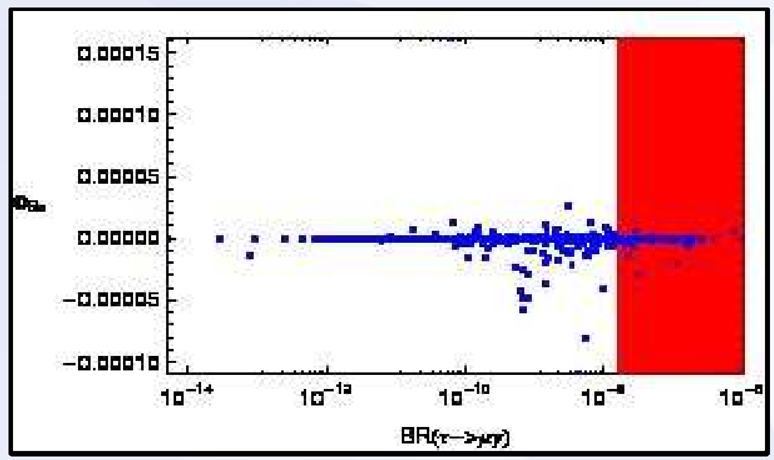



$$\Phi_{B_s}$$
$$vs.$$
$$\tau \to \mu \gamma$$

RVV2



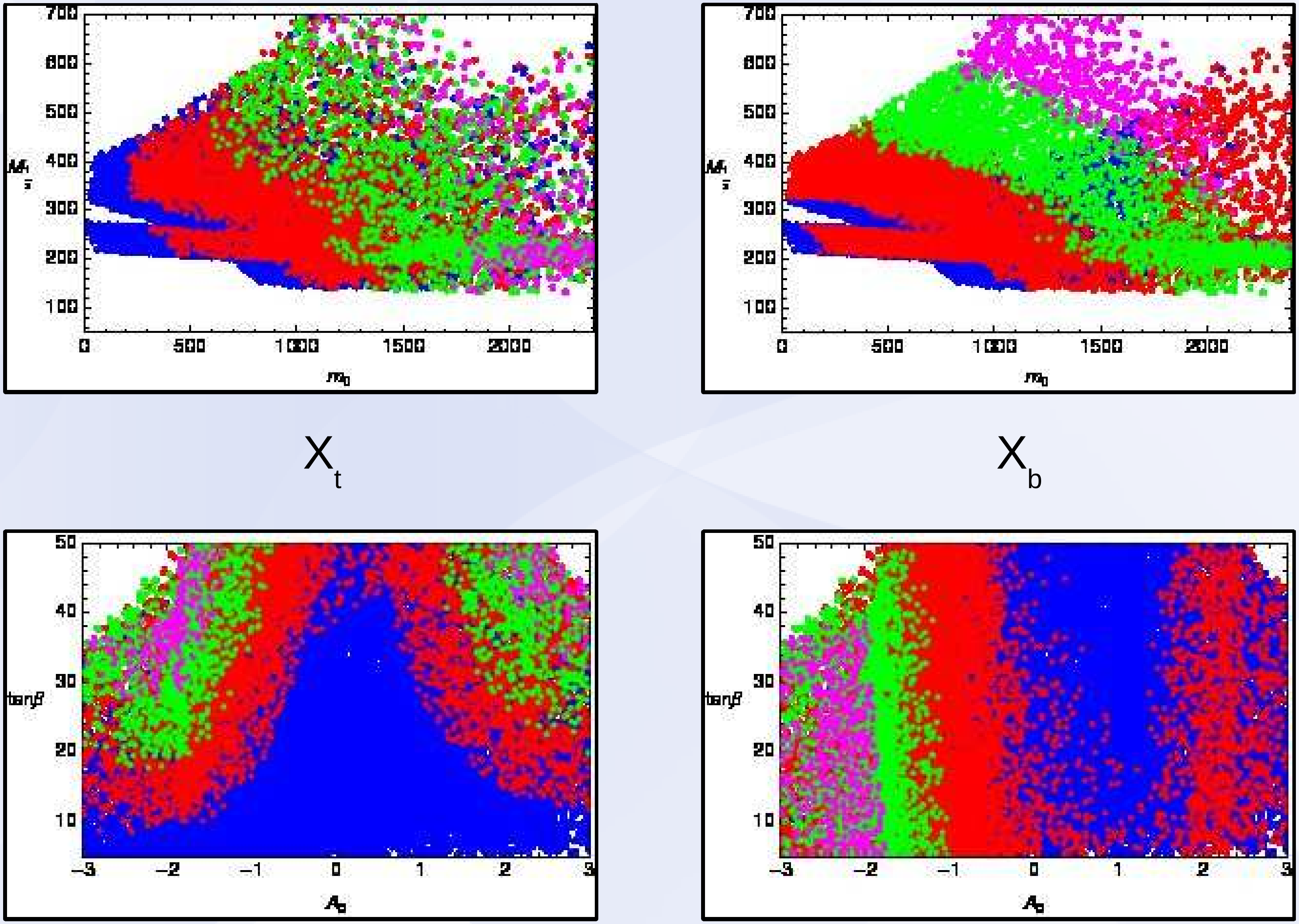

NR



# Conclusions

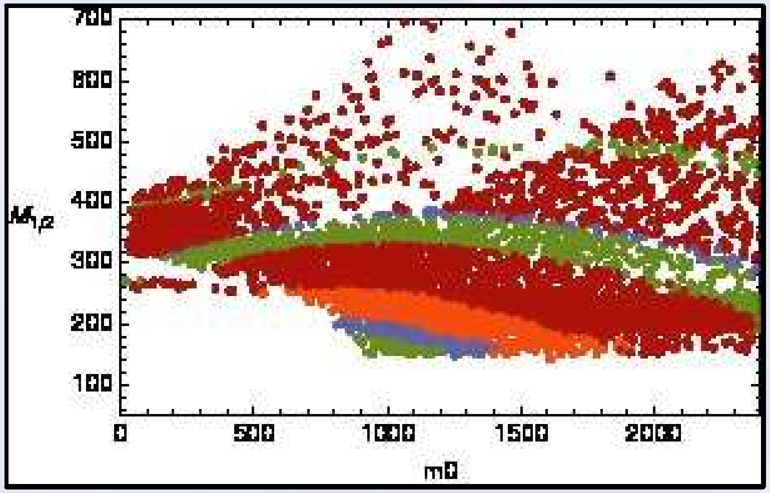
- Flavour and Electroweak Data can have an active role in post-2011 Collider Physics.
- Evidence of SUSY + Meson + LFV bounds give valuable information to flavour model building.
- It is feasible to use correlations between flavour + CP observables to differentiate between several models.

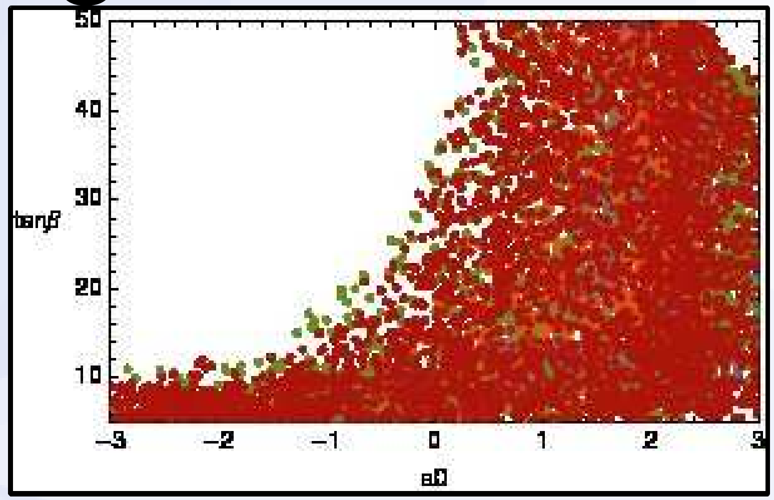
# Backups



X_t
X_b
m_0
M_1/2
tanβ
A_0

# B Mixing



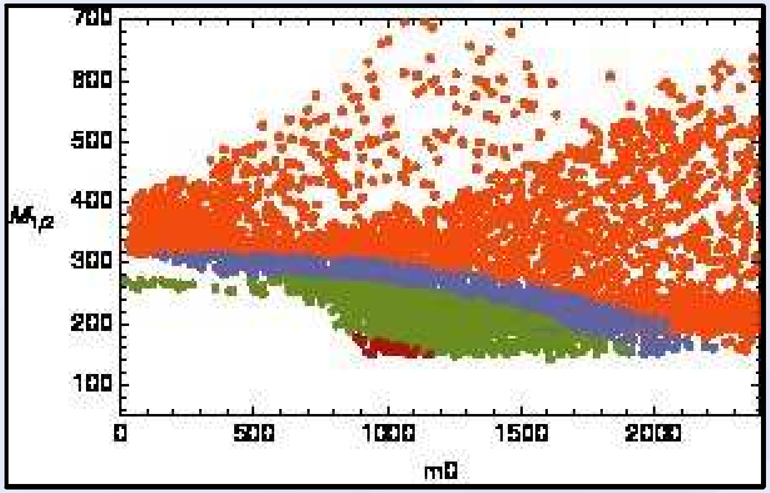



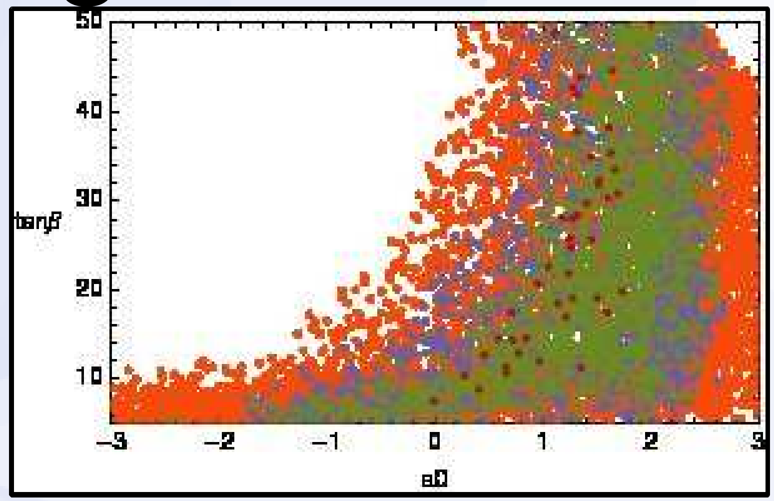

$$arg\left(\sqrt{(\delta_{13}^{d})_{LL}^{2}}\right)-\beta_{SM}$$

$$\sin 2\beta_{eff}$$

| | | | | |
|---|---|---|---|---|
| 10º | > | Orange | > | 8.5º |
| 8.5º | > | Blue | > | 7º |
| 7º | > | Green | > | 5.5º |
| 5.5º | > | Red | > | 4º |

# D Mixing



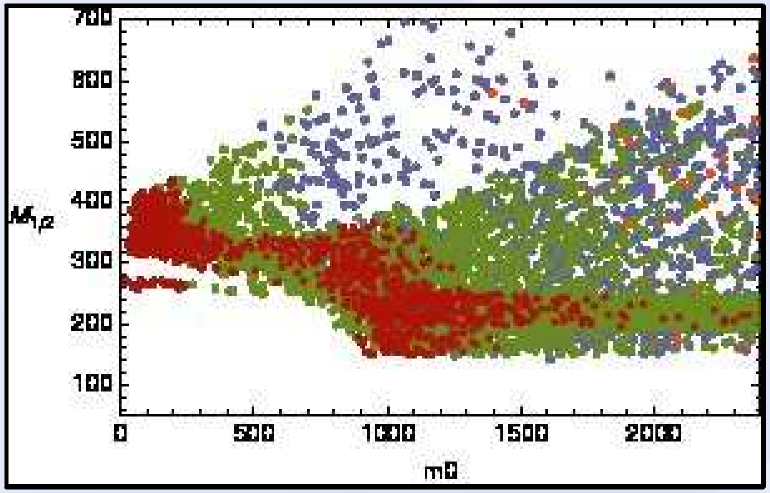

$$\sqrt{\left|(\delta^u_{12})_{LR}(\delta^u_{12})_{RL}\right|}\,(\times 10^3)$$

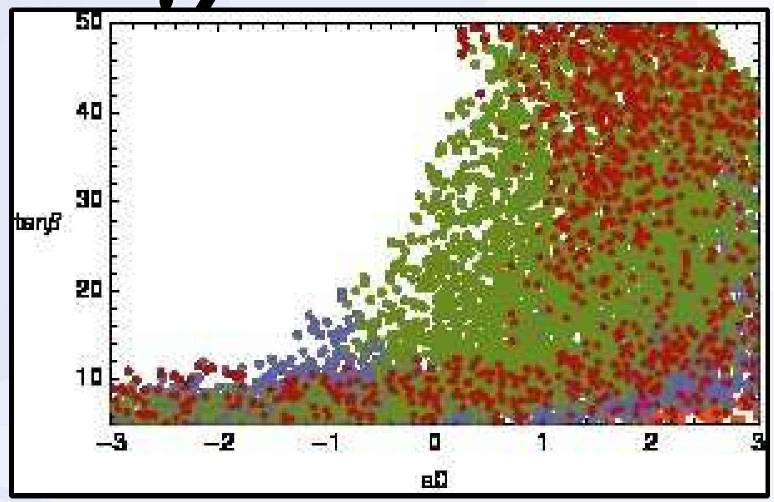
$x(\Delta m_D)$

$y(\Delta \Gamma_D)$

| | | | | |
|---|---|---|---|---|
| 10. | > | Orange | > | 8.4 |
| 8.4 | > | Blue | > | 7.1 |
| 7.1 | > | Green | > | 5.9 |
| 5.9 | > | Red | > | 5.0 |

# LFV ($\tau$ -> e $\gamma$)




$$|(\delta^e_{13})_{LL}|(\times 10)$$

Orange: No Bound

| | | | | |
|---|---|---|---|---|
| | | Blue | > | 2.2 |
| 2.2 | > | Green | > | 0.5 |
| 0.5 | > | Red | > | 0.1 |

# Why Flavour Models?

- There seems to be a suppression mechanism at work in the SM flavour sector.
- There seems to be a suppression mechanism at work in the NP contributions to FCNC.
- Flavour Models are an attempt to explain the origin of these suppressions, hopefully relating the known (Yukawas) with the unknown (soft masses, trilinears).
- Some models also describe the origin of CP-violation.

# Goals of Flavour Models

- Explain mass and mixing hierarchy in the quark sector.
- Explain mass and mixing hierarchy in the lepton sector.
- Address CP Violation

- If effective, it must be straightforward to generalize it into a full flavour model.
- Generate testable new physics.
- Have less suppression parameters than the SM.

# SU(3) Flavour Model

Effective Superpotential:

$$W = H_d Q_\alpha d^c_\beta \left[ \frac{\theta_3^\alpha \theta_3^\beta}{M_d^2} + \frac{\theta_{23}^\alpha \theta_{23}^\beta (\theta_3 \overline{\theta}_3)}{M_d^4} + \varepsilon^{\alpha\mu\nu} \frac{\overline{\theta}_{23\mu} \overline{\theta}_{3\nu} \theta_{23}^\beta (\theta_{23} \overline{\theta}_3)}{M_d^5} \right.$$

$$\left. + \varepsilon^{\alpha\beta\mu} \frac{\overline{\theta}_{23\mu} (\theta_{23} \overline{\theta}_3)^2}{M_d^5} + \varepsilon^{\alpha\beta\mu} \frac{\overline{\theta}_{3\mu} (\theta_{23} \overline{\theta}_3)(\theta_{23} \overline{\theta}_{23})}{M_d^5} + \ldots \right]$$

$$\langle \theta_3 \rangle = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \otimes \begin{pmatrix} a_3^u & 0 \\ 0 & a_3^d e^{i\chi} \end{pmatrix} \qquad \langle \theta_{23} \rangle = \begin{pmatrix} 0 \\ b_{23} \\ b_{23} e^{i\beta_3} \end{pmatrix}$$

$$\frac{a_3^u}{M_u} = y_t \quad \frac{a_3^d}{M_d} = y_b \quad \frac{b_{23}}{M_u} = \varepsilon \quad \frac{b_{23}}{M_d} = \overline{\varepsilon}$$