Flavour physics and Supersymmetry in the LHC era

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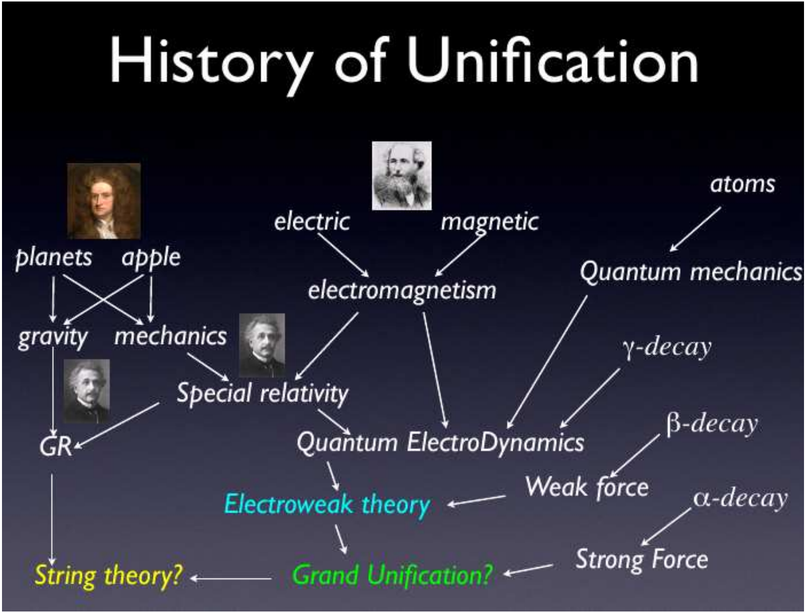
Plan of Talk

1. Status of the SM
2. Open questions
3. The SM flavor puzzle
4. Messages from the B-factories and Tevatron
5. The NP flavor puzzle
6. “Flavor-test” of NP models: the case of SUSY
7. Flavor at the LHC


History of Unification
planets
apple
gravity
mechanics
electric
magnetic
electromagnetism
atoms
Quantum mechanics
Special relativity
γ-decay
GR
Quantum ElectroDynamics
β-decay
Weak force
Electroweak theory
α-decay
Strong Force
String theory?
Grand Unification?

[Murayama]

$$
\begin{aligned}
\mathbf{L_{SM}} &= -\frac{1}{4} F^a_{\mu\nu} F^{a\mu\nu} \\
&+ i\overline{\psi} \not{D}\, \psi + h.c. \\
&+ \overline{\psi_i}\, y_{ij} \psi_j \phi + h.c. \\
&+ |D_\mu \phi|^2 - V(\phi)
\end{aligned}
$$

J.Ellis: “This is short enough to write on a T-shirt!”

The SM free parameters

Standard Model of Strong and Electroweak Interactions

Low Energy Effective Quantum Field Theory based on

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \xrightarrow[\text{broken}]{\text{spontaneously}} SU(3)_C \otimes U(1)_{QED}$$

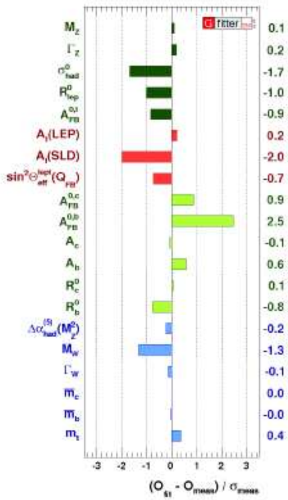
which describes low energy phenomena in terms of 28 Parameters that have to be determined from experiment.

2	+	4	+	6	+	6	+	4	+	6	=	28
QCD (α_{QCD}, θ_{QCD})		Electroweak Gauge Boson and Higgs Sector		Quark Masses		Lepton Masses		V_{CKM}		V_{PMNS}		

22 in the Flavour Sector

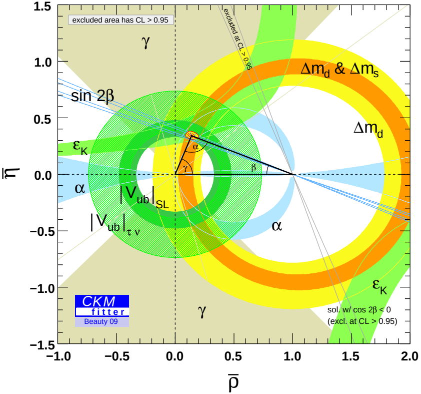
[Buras @ CERN '07]

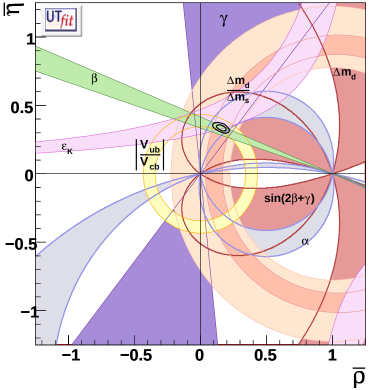
The Electroweak Fit I: SM Fit Results



- input: usage of latest experimental results of electroweak precision observables
  - incl. direct Higgs searches (LEP, Tevatron)
  - incl. latest average of $m_t = 173.3 \pm 1.1$ GeV (arXiv:1007.3178)
- floating fit parameters: M_Z, M_H, m_t, $\Delta\alpha^{(5)}_{had}(M_Z^2)$, $\alpha_S(M_Z^2)$, $\bar{m}_c$, $\bar{m}_b$
- goodness-of-fit:
  - excl. direct Higgs searches: $\chi^2_{min} = 16.4$ $\Rightarrow \text{Prob}(\chi^2_{min}, 13) = 0.23$
  - incl. direct Higgs searches: $\chi^2_{min} = 17.8$ $\Rightarrow \text{Prob}(\chi^2_{min}, 14) = 0.22$
- pull values (incl. direct Higgs searches)
  - no individual pull exceeds 3σ
  - $A^{0,b}_{FB}$ largest contributor to χ^2_{min}
  - small contributions from M_Z, $\Delta\alpha_{had}(M_Z)$, m_c, m_b: their input accuracies exceed fit requirements

[Gfitter coll. @ SUSY '10]





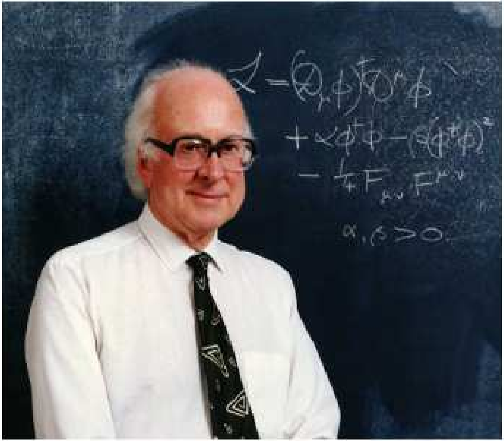
“Very likely, flavour and CP violation in FC processes are dominated by the CKM mechanism” (Nir)

Open questions

1. **Which is the underlying mechanism regulating the EWSB?**
2. **Which is the connection between EWSB and flavor physics?**
3. **Are there new flavor symmetries beyind the puzzling fermion mass spectrum?**
4. **Are there new flavor violating interactions not governed by the SM Yukawas? That is, to which extent the MFV hypothesis is valid?**
5. **Do the new sources of CPV accounting for the BAU have an impact on flavor physics and/or EDMs?**
6. **Which is the role of flavor physics in the LHC era?**
7. **Do we expect to understand the (SM and NP) flavor puzzles through the interplay of flavor physics and the LHC?**
8. **......**

The missing piece of the SM

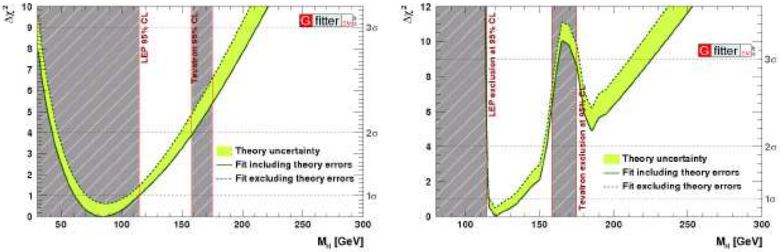
The only Higgs found : Peter Higgs



[Buras @ CERN '07]

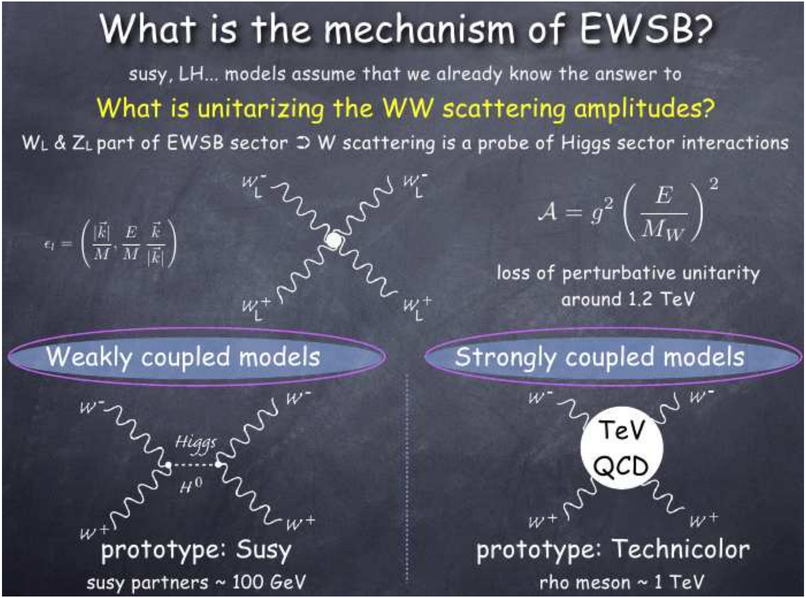
The Electroweak Fit II: Constraints on Higgs mass

- M_H from fit including all data except results from direct Higgs searches at LEP, Tevatron
  - value at minimum $\pm 1\sigma$: $M_H = 84^{+30}_{-23}$ GeV
  - 2σ interval: [42, 159] GeV
- M_H from fit also including results from direct Higgs searches at LEP, Tevatron
  - value at minimum $\pm 1\sigma$: $M_H = 120.6^{+17.0}_{-5.2}$ GeV
  - 2σ interval: [114, 155] GeV



⇒ **in SM: light Higgs preferred**

[Gfitter coll. @ SUSY '10]



[Grojean @ EPS '09]

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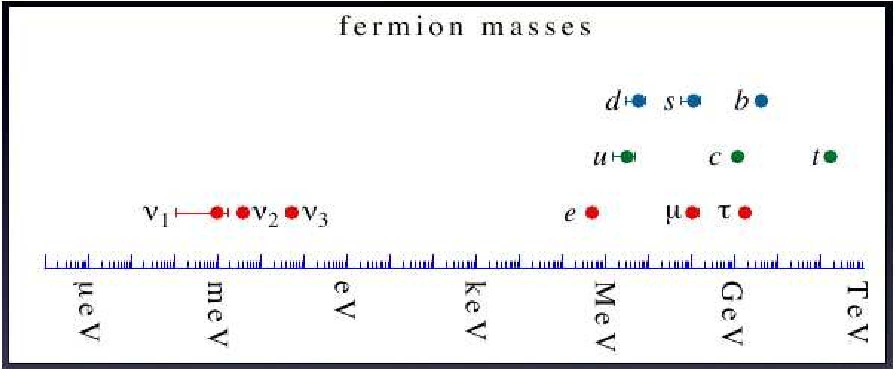


$$|V_{CKM}| \sim \begin{pmatrix} 1 & \lambda_c & \lambda_c^3 \\ \lambda_c & 1 & \lambda_c^2 \\ \lambda_c^3 & \lambda_c^2 & 1 \end{pmatrix}, \quad |V_{PMNS}| \simeq \begin{pmatrix} 0.79-0.86 & 0.50-0.61 & 0.0-0.2 \\ 0.25-0.53 & 0.47-0.73 & 0.56-0.79 \\ 0.21-0.51 & 0.42-0.69 & 0.61-0.83 \end{pmatrix}_{3\sigma}$$

Hierarchical **Anarchic / Tribimaximal**

The fermion mass puzzle

- **Quark/charged-lepton mass hierarchy**

$$\begin{aligned} Y_t &\sim 1, \quad Y_c \sim 10^{-2}, \quad Y_u \sim 10^{-5} \\ Y_b &\sim 10^{-2}, \quad Y_s \sim 10^{-3}, \quad Y_d \sim 10^{-4} \\ Y_\tau &\sim 10^{-2}, \quad Y_\mu \sim 10^{-3}, \quad Y_e \sim 10^{-6} \end{aligned}$$

- **Quark mixing angles hierarchy**

$$|V_{us}| \sim 0.2, \quad |V_{cb}| \sim 0.04, \quad |V_{ub}| \sim 0.004 \quad (\delta_{KM} \sim 1)$$

- **Neutrinos**

$$\begin{aligned} \Delta m^2_{sol} &= (7.9 \pm 0.3) \times 10^{-5}\mathrm{eV}^2, \quad |\Delta m^2_{atm}| = (2.6 \pm 0.2) \times 10^{-3}\mathrm{eV}^2, \\ \sin^2\theta_{sol} &= 0.31 \pm 0.02, \quad \sin^2\theta_{atm} = 0.47 \pm 0.07, \quad \sin^2\theta_{e3} = 0^{+0.08}_{-0.0}, \end{aligned}$$

- **Quark-Lepton complementarity: GUT + Flavor Symmetry?** [Raidal '04]

$$\theta_{sol} + \theta_c \approx \frac{\pi}{4}, \qquad \theta_{atm} + \theta_{23} \approx \frac{\pi}{4}$$

- **SM gauge couplings**

$$g_s \sim 1, \quad g \sim 0.6, \quad g' \sim 0.3, \quad \lambda_{\mathrm{Higgs}} \sim 1$$

Flavor Physics within the SM

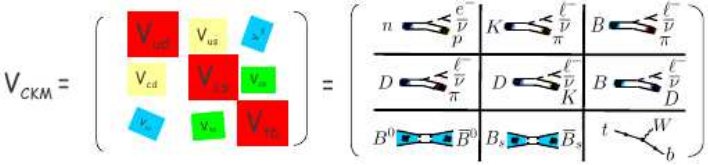
- $\mathcal{L}^{\rm SM}_{Kinetic+Gauge} + \mathcal{L}^{\rm SM}_{Higgs}$ has a large $U(3)^5$ global **flavour symmetry**

$$\mathbf{G} = \mathbf{U(3)^5} = \mathbf{U(3)_u} \otimes \mathbf{U(3)_d} \otimes \mathbf{U(3)_Q} \otimes \mathbf{U(3)_e} \otimes \mathbf{U(3)_L}$$

- $\mathcal{L}_{\rm Yukawa} = \bar{Q}_L \mathbf{Y_D} D_R \phi + \bar{Q}_L \mathbf{Y_U} U_R \tilde{\phi} + \bar{L}_L \mathbf{Y_L} E_R \phi + h.c$ break

$$\mathbf{G} \to \mathbf{U(1)_B} \times \mathbf{U(1)_e} \times \mathbf{U(1)_\mu} \times \mathbf{U(1)_\tau}$$

- **CKM matrix**: $Y_U = V_{CKM} \times \mathrm{diag}(y_u, y_c, y_t)$ for $\mathbf{Y_D} = \mathrm{diag}(y_d, y_s, y_b)$



Master Formula for Weak Decays

AJB (2001)
hep-ph/0101336
hep-ph/0109197

Non-Perturbative Factors in the SM | QCD RG Factors | Short Distance Loop Functions (Penguins, Boxes) | New Flavour-Changing Parameters

Represent different Dirac and Colour Stuctures

$$A(\text{Decay}) = B_i\ \eta^i_{QCD}\ V^i_{CKM}\ \left[F^i_{SM} + F^i_{New}\right] + B^{New}_i\ \left[\eta^i_{QCD}\right]^{New}\ V^i_{New}\ \left[G^i_{New}\right]$$

(Summation over i)

New ≡ NP

Non-Perturbative Factors beyond SM | Short Distance Loop Functions Penguins, Boxes

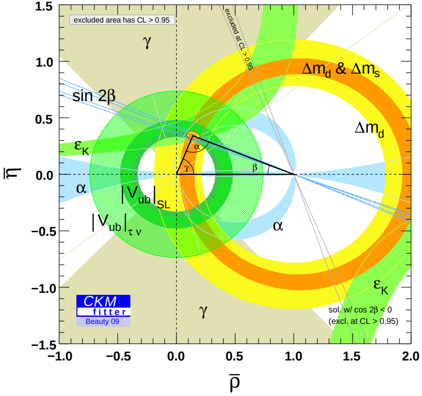
F^i_{SM}, F^i_{New}, G^i_{New} : **Fully calculable in Perturbation Theory**

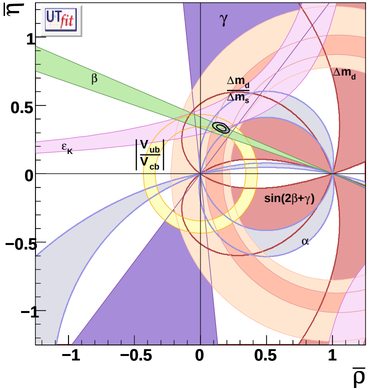
η^i_{QCD}, $\left[\eta^i_{QCD}\right]^{New}$: **Fully calculable in RG improved Perturbation Theory**

B_i, B^{New}_i : **Require Non-Perturbative Methods or can be extracted from leading decays**

(represent $\langle Q \rangle$)

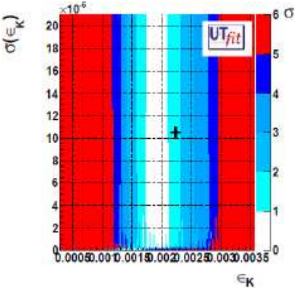
Fully calculable in the SM





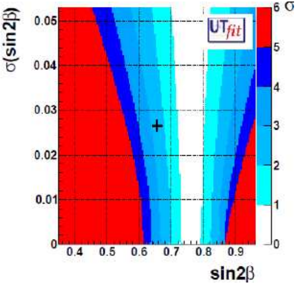
“Very likely, flavour and CP violation in FC processes are dominated by the CKM mechanism” (Nir)

UT tensions

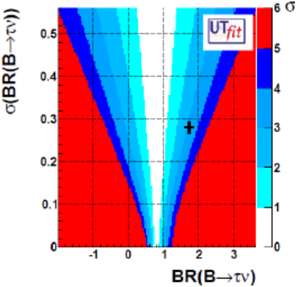


1. $\sim$ 6% reduction of $\epsilon_K^{\rm SM}$ [Buras & Guadagnoli; BG & Isidori]
2. smaller $\hat{B}_K$ from unquenced analyses [Antonio et al. '08; Aubin et al. '10]
3. fit vs. exp. $\approx -1.7\sigma$

NEW: $\epsilon_K^{\rm SM}$ @ NNLO QCD: $\sim +3\%$ [Brod & Gorbahn, '10]

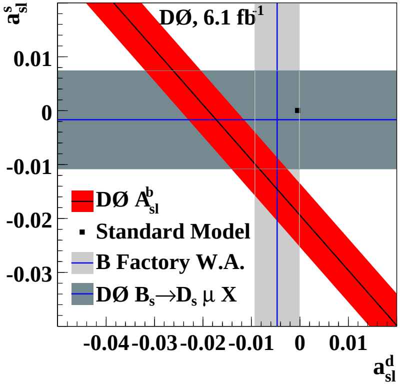


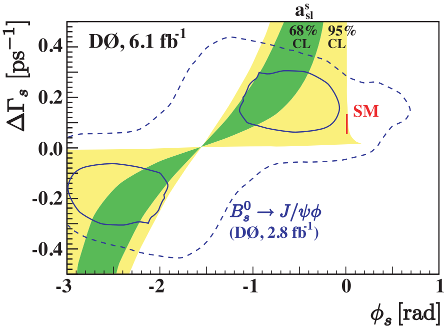
1. fit vs. exp. $\approx +2.6\sigma$



1. $B(B \to \ell\nu) \sim f_B^2 |V_{ub}|^2$
2. $B(B \to \ell\nu)/\Delta M_d \sim (\sin\beta/\sin\gamma)^2/\hat{B}_{B_d}$
3. fit vs. exp. $\approx -3.2\sigma$

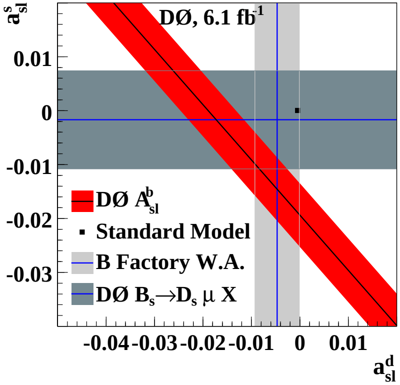
Similar conclusions also by Lenz & Nierste + CKMfitter collaboration ('10)

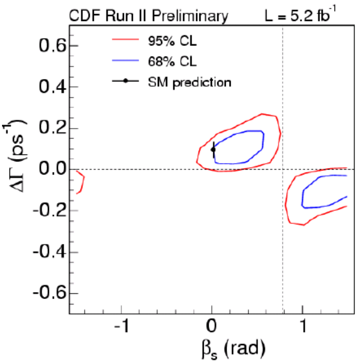




$$A_{SL}^q \equiv \frac{\Gamma(\bar{B}_q \to l^+ X) - \Gamma(B_q \to l^- X)}{\Gamma(\bar{B}_q \to l^+ X) + \Gamma(B_q \to l^- X)}\,, \qquad S_{\psi\phi} = \sin(2|\beta_s| - 2\phi_{B_s})$$

New Physics in the B_s mixing phase?





$$A^q_{SL} \equiv \frac{\Gamma(\bar{B}_q \to l^+ X) - \Gamma(B_q \to l^- X)}{\Gamma(\bar{B}_q \to l^+ X) + \Gamma(B_q \to l^- X)}\,,$$

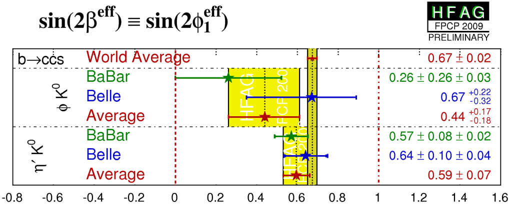
$$S_{\psi\phi} = \sin(2|\beta_s| - 2\phi_{B_s})$$

New Physics in the B_s mixing phase?

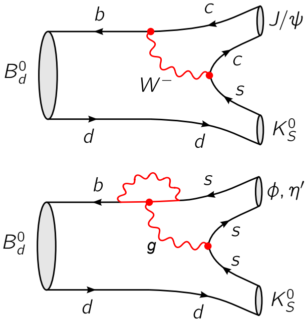
$\sin 2\beta_{\rm eff}$ tensions

- In the SM, $(\sin 2\beta)_{\psi K_S} \approx (\sin 2\beta)_{\phi K_S} \approx (\sin 2\beta)_{\eta' K_S}$
- $B_d \to \psi K_S$ dominated by tree level, ϕK_S and $\eta' K_S$ are loop-induced

Data indicate $S_{\phi K_S} < S_{\eta' K_S} < S_{\psi K_S}$



[adapted from HFAG]



New physics in the decay amplitudes?

The SuperB will tell us...

The NP "scale"

- **Gravity** $\Longrightarrow$ $\Lambda_{\text{Planck}} \sim 10^{18-19}$ GeV
- **Neutrino masses** $\Longrightarrow$ $\Lambda_{\text{see-saw}} \lesssim 10^{15}$ GeV
- **Hierarchy problem**: $m_h^{\rm SM}(\Lambda^2_{\rm NP}) \sim M_W \Longrightarrow \Lambda_{\rm NP} \lesssim$ TeV
- **Dark Matter** $\Longrightarrow$ $\Lambda_{\rm NP} \lesssim$ TeV
- **BAU**: evidence of CPV beyond SM
  - Electroweak Baryogenesis $\Longrightarrow$ $\Lambda_{\rm NP} \lesssim$ TeV
  - Leptogenesis $\Longrightarrow$ $\Lambda_{\text{see-saw}} \lesssim 10^{15}$ GeV
  - ....

$$\Downarrow$$

SM = effective theory at the EW scale

- Going BSM model-independently:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \sum_{d\geq 5} \frac{c_{ij}^{(d)}}{\Lambda_{NP}^{d-4}}\, O_{ij}^{(d)}$$

  - $\mathcal{L}_{\rm eff}^{d=5} = \frac{y_\nu^{ij}}{\Lambda_{\rm see-saw}} L_i L_j \phi\phi$
  - $\mathcal{L}_{\rm eff}^{d=6}$ generates many FCNC operators

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \sum_{d=6} \frac{c_{ij}^{(6)}}{\Lambda_{NP}^2} \, O_{ij}^{(6)}$$

[Isidori, Nir, Perez '10]

Operator	Bounds on Λ (TeV)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ε_K
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ε_K
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	Δm_{B_d}; $S_{B_d \to \psi K}$
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	Δm_{B_d}; $S_{B_d \to \psi K}$
$(\bar{b}_L \gamma^\mu s_L)^2$	1.1×10^2	1.1×10^2	7.6×10^{-5}	7.6×10^{-5}	Δm_{B_s}
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	3.7×10^2	3.7×10^2	1.3×10^{-5}	1.3×10^{-5}	Δm_{B_s}

$$\Downarrow$$

"Generic" FV sources at the TeV scale are excluded

MFV & the NP flavor puzzle

- SM without Yukawa interactions: $U(3)^5$ global **flavour symmetry**

$$\mathbf{U(3)_u \otimes U(3)_d \otimes U(3)_Q \otimes U(3)_e \otimes U(3)_L}$$

- Yukawa interactions break this symmetry
- Proposal for any New Physics model:

Yukawa structures as the only sources of flavour violation

$$\Downarrow$$

Minimal Flavour Violation [D'Ambrosio et al. '02]

Notice that MFV allows new "flavour blind"CPV phases!

[Kagan et al. '09] (model-independent)
[Ellis et al. '07] (SUSY)
[Colangelo et al., '08], [Smith et al. '09] (SUSY)
[Altmannshofer et al., '08,'09], [P.P & Straub, '09] (SUSY)
[Buras et al., '10,'10] (2HDM)

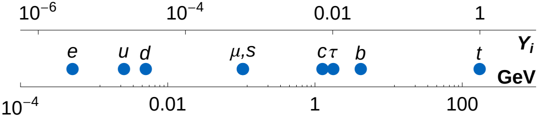
$$(c^{\Delta F=1}_{\rm MFV})_{ij} \sim V^\star_{ti} V_{tj}\,, \qquad (c^{\Delta F=2}_{\rm MFV})_{ij} \sim (V^\star_{ti} V_{tj})^2$$

$\Delta F = 1, 2$ MFV operators	Λ(TeV)	Observables
$H^\dagger \left(\overline{D}_R Y^{d\dagger} Y^u Y^{u\dagger} \sigma_{\mu\nu} Q_L\right) (eF_{\mu\nu})$	6.1 TeV	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
$\frac{1}{2}(\overline{Q}_L Y^u Y^{u\dagger} \gamma_\mu Q_L)^2$	5.9 TeV	ϵ_K, Δm_{B_d}, Δm_{B_s}
$H_D^\dagger \left(\overline{D}_R Y^{d\dagger} Y^u Y^{u\dagger} \sigma_{\mu\nu} T^a Q_L\right) (g_s G^a_{\mu\nu})$	3.4 TeV	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
$\left(\overline{Q}_L Y^u Y^{u\dagger} \gamma_\mu Q_L\right) (\overline{E}_R \gamma_\mu E_R)$	2.7 TeV	$B \to X_s\ell^+\ell^-$, $B_s \to \mu^+\mu^-$
$\left(\overline{Q}_L Y^u Y^{u\dagger} \gamma_\mu Q_L\right) (eD_\mu F_{\mu\nu})$	1.5 TeV	$B \to X_s\ell^+\ell^-$

Observable	Experiment	MFV prediction	SM prediction
$\mathcal{A}_{\rm CP}(B_s \to \psi\phi)$	[0.10, 1.44] @ 95% CL	0.04(5)	0.04(2)
$\mathcal{A}_{\rm CP}(B \to X_s\gamma)$	$< 6\%$ @ 95% CL	< 0.02	< 0.01
$\mathcal{B}(B_d \to \mu^+\mu^-)$	$< 1.8 \times 10^{-8}$	$< 1.2 \times 10^{-9}$	$1.3(3) \times 10^{-10}$
$\mathcal{B}(B \to X_s\tau^+\tau^-)$	–	$< 5 \times 10^{-7}$	$1.6(5) \times 10^{-7}$
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})$	$< 2.6 \times 10^{-8}$ @ 90% CL	$< 2.9 \times 10^{-10}$	$2.9(5) \times 10^{-11}$

[D'Ambrosio et al. '02; Hurth et al. '08, Isidori, Nir & Perez '10]

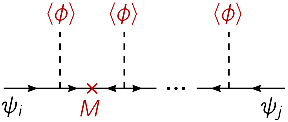
SM vs. NP flavor puzzle



$V_{CKM} \sim$ 

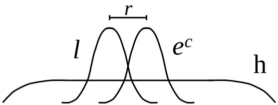
Froggat-Nielsen '79: Hierarchies from SSB of a Flavour Symmetry

$$\epsilon = \frac{\langle \phi \rangle}{M} \ll 1 \Rightarrow Y_{ij} \propto \epsilon^{(a_i + b_j)}$$



Arkani-Hamed & Schmaltz '99: Hierarchies from Extra Dimensions

$x = \mu r$	1	2	3	4	5
$e^{-\frac{x^2}{2}}$	1	10^{-1}	10^{-2}	10^{-4}	10^{-6}
	λ_t		$\cdots$		λ_e



The Gaussian wave functions of l and e^c overlap in an exponentially small region

$\Downarrow$

Small Yukawa couplings without Symmetries

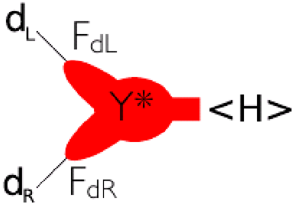
SM vs. NP flavor puzzle

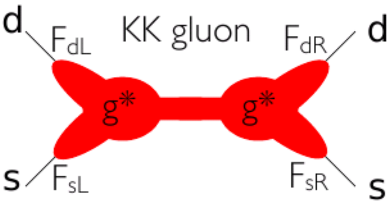
- **Flavor Models flavor protection**

[Lalak, Pokorski & Ross '10]

Operator	$U(1)$	$U(1)^2$	$SU(3)$	MFV
$(\overline{Q}_L X^Q_{LL} Q_L)_{12}$	λ	λ^5	λ^3	λ^5
$(\overline{D}_R X^D_{RR} D_R)_{12}$	λ	λ^{11}	λ^3	$(y_d y_s) \times \lambda^5$
$(\overline{Q}_L X^D_{LR} D_R)_{12}$	λ^4	λ^9	λ^3	$y_s \times \lambda^5$

- **RS flavor protection** [Gerghetta & Pomarol, '99; Huber, '03; Agashe, Perez & Soni, '04]





$$m_d \sim v\, F_{d_L} Y^\star F_{d_R}$$

$$(V_{CKM})_{ij} \sim F_{d_{L_i}} / F_{d_{L_j}}$$

$$(\epsilon_K)_{\mathbf{RS-GIM}} \sim \frac{(g^\star)^2}{M^2_{\rm KK}} \frac{\mathbf{m_d\, m_s}}{(v\ Y^\star)^2}$$

[Csaki, Falkowski & Weiler, '08]

[Blanke, Buras, Duling, Gori, Weiler, '08]

Where to look for New Physics at the low energy?

- **Processes very suppressed or even forbidden in the SM**
  - FCNC processes ($\mu \to e\gamma$, $\tau \to \mu\gamma$, $B^0_{s,d} \to \mu^+\mu^-$, $K \to \pi\nu\bar{\nu}$)
  - CPV effects in the electron/neutron EDMs, $d_{e,n}$...
  - FCNC & CPV in $B_{s,d}$ decay/mixing & D mixing amplitudes

- **Processes predicted with high precision in the SM**
  - EWPO as $\Delta\rho$, $(g-2)_\mu$....
  - LU in $R_M^{e/\mu} = \Gamma(K(\pi) \to e\nu)/\Gamma(K(\pi) \to \mu\nu)$

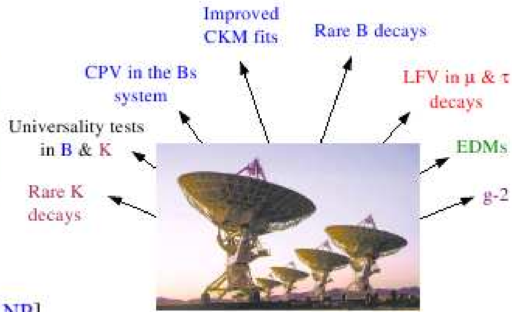
Flavour Physics in the LHC era

LHC [high p_T]

A *unique* effort toward the high-energy frontier

[to determine the energy scale of NP]

Flavour physics



A *collective* effort toward the high-intensity frontier
[to determine the flavour structure of NP]

[Isidori @ LP07]

Flavor in the LHC era

[Isidori, Nir & Perez '10]

Observable	SM prediction	Theory error	Present result	Future error	Future Facility
$\lvert V_{us}\rvert$ $[K \to \pi \ell \nu]$	input	$0.5\% \to 0.1\%_{\rm Latt}$	0.2246 ± 0.0012	0.1%	K factory
$\lvert V_{cb}\rvert$ $[B \to X_c \ell \nu]$	input	1%	$(41.54 \pm 0.73) \times 10^{-3}$	1%	Super-B
$\lvert V_{ub}\rvert$ $[B \to \pi \ell \nu]$	input	$10\% \to 5\%_{\rm Latt}$	$(3.38 \pm 0.36) \times 10^{-3}$	4%	Super-B
γ $[B \to DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	3°	LHCb
$S_{B_d \to \psi K}$	$\sin(2\beta)$	$\lesssim 0.01$	0.671 ± 0.023	0.01	LHCb
$S_{B_s \to \psi\phi}$	0.036	$\lesssim 0.01$	$0.81^{+0.12}_{-0.32}$	0.01	LHCb
$S_{B_d \to \phi K}$	$\sin(2\beta)$	$\lesssim 0.05$	0.44 ± 0.18	0.1	LHCb
$S_{B_s \to \phi\phi}$	0.036	$\lesssim 0.05$	—	0.05	LHCb
$S_{B_d \to K^*\gamma}$	few $\times$ 0.01	0.01	-0.16 ± 0.22	0.03	Super-B
$S_{B_s \to \phi\gamma}$	few $\times$ 0.01	0.01	—	0.05	LHCb
$A^d_{\rm SL}$	-5×10^{-4}	10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	LHCb
$A^s_{\rm SL}$	2×10^{-5}	$< 10^{-5}$	$(1.6 \pm 8.5) \times 10^{-3}$	10^{-3}	LHCb
$A_{CP}(b \to s\gamma)$	< 0.01	< 0.01	-0.012 ± 0.028	0.005	Super-B
$\mathcal{B}(B \to \tau\nu)$	1×10^{-4}	$20\% \to 5\%_{\rm Latt}$	$(1.73 \pm 0.35) \times 10^{-4}$	5%	Super-B
$\mathcal{B}(B \to \mu\nu)$	4×10^{-7}	$20\% \to 5\%_{\rm Latt}$	$< 1.3 \times 10^{-6}$	6%	Super-B
$\mathcal{B}(B_s \to \mu^+\mu^-)$	3×10^{-9}	$20\% \to 5\%_{\rm Latt}$	$< 5 \times 10^{-8}$	10%	LHCb
$\mathcal{B}(B_d \to \mu^+\mu^-)$	1×10^{-10}	$20\% \to 5\%_{\rm Latt}$	$< 1.5 \times 10^{-8}$	[?]	LHCb
$A_{\rm FB}(B \to K^*\mu^+\mu^-)_{q_0^2}$	0	0.05	(0.2 ± 0.2)	0.05	LHCb
$B \to K\nu\bar{\nu}$	4×10^{-6}	$20\% \to 10\%_{\rm Latt}$	$< 1.4 \times 10^{-5}$	20%	Super-B
$\lvert q/p\rvert_{D-{\rm mixing}}$	1	$< 10^{-3}$	$(0.86^{+0.18}_{-0.15})$	0.03	Super-B
ϕ_D	0	$< 10^{-3}$	$(9.6^{+8.3}_{-9.5})^\circ$	2°	Super-B
$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})$	8.5×10^{-11}	8%	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	10%	K factory
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})$	2.6×10^{-11}	10%	$< 2.6 \times 10^{-8}$	[?]	K factory
$R^{(e/\mu)}(K \to \pi\ell\nu)$	2.477×10^{-5}	0.04%	$(2.498 \pm 0.014) \times 10^{-5}$	0.1%	K factory
$\mathcal{B}(t \to c\,Z, \gamma)$	$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-13})$	$< 0.6 \times 10^{-2}$	$\mathcal{O}(10^{-5})$	LHC ($100\,{\rm fb}^{-1}$)

The SUSY flavour and CP problems

The soft-sector contains a huge number of FV and/or CPV parameters: natural $O(1)$ values for these parameters are excluded by the exp. data

Flavor problem: solutions

1. **Decoupling**: $m_{SUSY} \gg$ TeV, the hierarchy problem is (partly) reintroduced
2. **Degeneracy**: sfermion masses nearly degenerate, e.g. gauge mediation, flavour models, MFV...
3. **Alignment**: quark and squark mass matrices aligned [Nir & Seiberg '93]

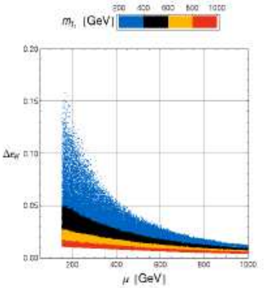
CP problem: solutions

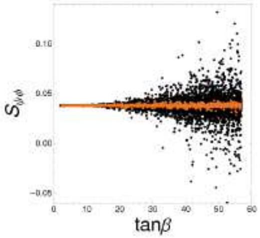
1. Degeneracy & Alignment do not solve the CP problem as flavor blind phases are allowed
2. **CPV** from **flavor effects** $\Rightarrow$ EDMs suppressed by small mixing angles
3. Hp in flavor models: CP spontaneously broken in the flavor sector by flavon VEVs [Nir & Rattazzi '96]
4. Applying the same idea to MFV: CPV only from MFV-compatible terms breaking the flavour blindness [P.P & Straub, '09]

MSSM with MFV and “flavour blind” phases

① Kaon mixing

- The mixing amplitude M_{12}^{K} has no sensitivity to the new flavor blind phases
- Still, $\epsilon_K \propto \mathrm{Im}(M_{12}^{K})$ can get a positive NP contribution up to 15%
- But only for a very light SUSY spectrum: $\mu, m_{\tilde{t}_1} \simeq 200\mathrm{GeV}$



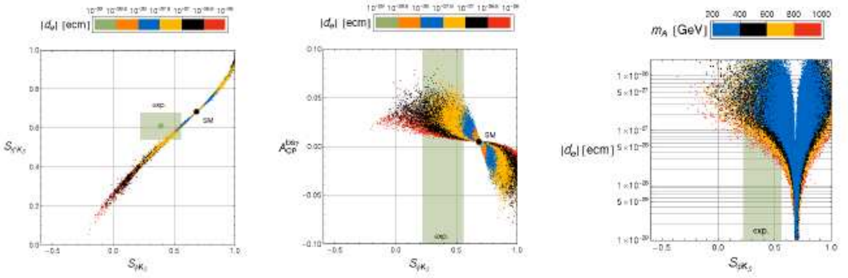


② B_d and B_s mixing

- Leading NP contributions to $M_{12}^{d,s}$ are insensitive to the new phases of a FBMSSM. (at least for moderate $\tan\beta$ . . .)
- For large $\tan\beta$, the constraint from $b \to s\gamma$ does not allow for sizeable effects
- $S_{\psi K_S}$ and $S_{\psi\phi}$ are SM like ($S_{\psi\phi} \simeq 0.03 - 0.05$)

[Altmannshofer,Buras & P.P., ’08]

MSSM with MFV and “flavour blind” phases



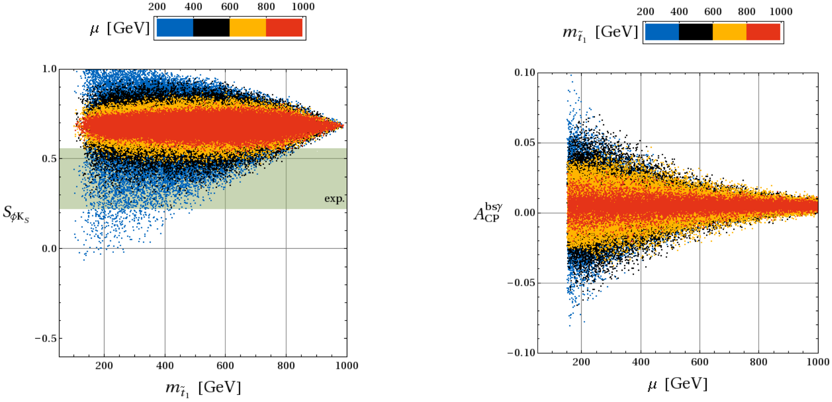
- CP violating $\Delta F = 0$ and $\Delta F = 1$ dipole amplitudes can be strongly modified
- $S_{\phi K_S}$ and $S_{\eta' K_S}$ can simultaneously be brought in agreement with the data
- sizeable and correlated effects in $A_{CP}^{bs\gamma} \simeq 1\% - 6\%$
- lower bounds on the electron and neutron EDMs at the level of $d_{e,n} \gtrsim 10^{-28}$ecm
- large and correlated effects in the CP asymmetries in $B \to K^* \mu^+ \mu^-$ (WA, Ball, Bharucha, Buras, Straub, Wick)

- the leading NP contributions to $\Delta F = 2$ amplitudes are not sensitive to the new phases of the FBMSSM
- CP violation in meson mixing is SM like
- i.e. small effects in $S_{\psi\phi}$, $S_{\psi K_S}$ and ϵ_K
- in particular: $0.03 < S_{\psi\phi} < 0.05$

A combined study of all these observables and their correlations constitutes a very powerful test of the FBMSSM

[Altmannshofer,Buras & P.P., ’08]

Implications for direct searches of SUSY particles



- $S_{\phi K_S} \simeq 0.4$ implies $\mu \lesssim 600$GeV and $m_{\tilde{t}_1} \lesssim 700$GeV
- $A_{CP}^{bs\gamma} \gtrsim 2\%$ implies $\mu \lesssim 600$GeV and $m_{\tilde{t}_1} \lesssim 800$GeV

[Altmannshofer,Buras & P.P., '08]

Abelian vs. Non-abelian flavor models

- Non-abelian models predict $\approx$ degenerate 1st & 2nd sfermion masses
  - Suppressed contributions to $1 \leftrightarrow 2$ transitions
  - Potentially large contributions to $2 \leftrightarrow 3$ transitions

- In abelian models, sfermions of different generations need not be degenerate
  - A single $U(1)$ & $O(1)$ 1-2 mass splitting lead to $(\delta^{LL}_{d,u})_{12} \sim \mathcal{O}(\lambda)$
  - $U(1) \times U(1)$ allows *alignement* in the down sector $(\delta^{LL}_{d})_{12} \approx 0 \Rightarrow (\delta^{LL}_{u})_{12} \sim \mathcal{O}(\lambda)$
  - Large effects in D^0-$\bar{D}^0$ mixing

Chirality structure of flavour violating terms

- Different flavour symmetries lead to different patterns of flavour violation
- Mass insertions: $M^2_{\tilde{d}} = \mathrm{diag}(\tilde{m}^2) + \tilde{m}^2 \begin{pmatrix} \delta^{LL}_d & \delta^{LR}_d \\ \delta^{RL}_d & \delta^{RR}_d \end{pmatrix}$
- δ^{LL}, δ^{RR}, δ^{LR} fixed by the flavour symmetry up to $O(1)$ factors

Representative (non-) abelian flavour models (not just 4 examples...!)

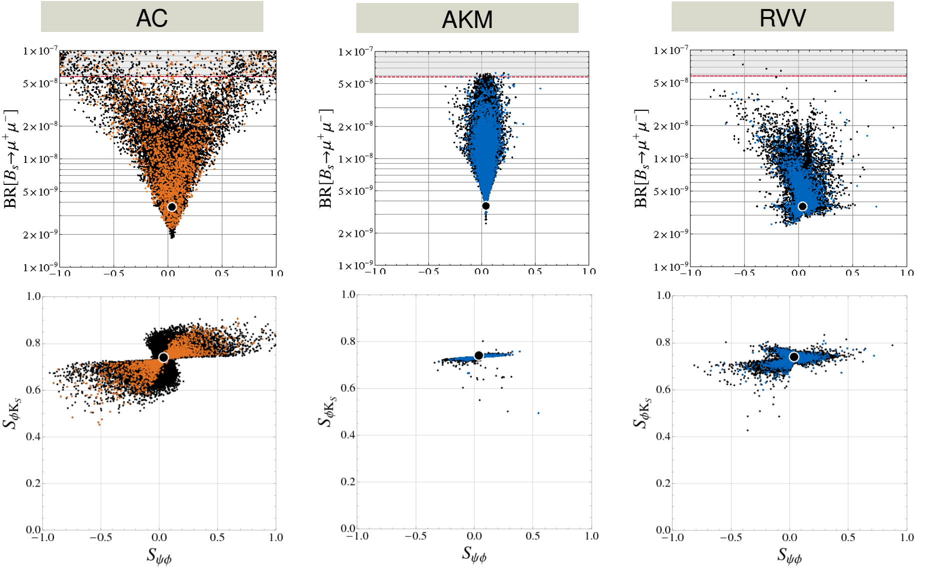
AC model $U(1)$ [Agashe, Carone]	AKM model $SU(3)$ [Antusch, King, Malinsky]	RVV model $SU(3)$ [Ross, Velasco-S., Vives]	δLL model $(S_3)^3$ [e.g. Hall, Murayama]
Large, $O(1)$ RR mass insertions	Only CKM-like RR mass insertions	CKM-like LL & RR mass insertions	Only CKM-like LL mass insertions

$$\delta_d^{LL} \sim \begin{pmatrix} \cdot & 0 & 0 \\ 0 & \cdot & \lambda^2 \\ 0 & \lambda^2 & \cdot \end{pmatrix} \quad \delta_d^{LL} \sim \begin{pmatrix} \cdot & 0 & 0 \\ 0 & \cdot & 0 \\ 0 & 0 & \cdot \end{pmatrix} \quad \delta_d^{LL} \sim \begin{pmatrix} \cdot & \lambda^3 & \lambda^2 \\ \lambda^3 & \cdot & \lambda \\ \lambda^2 & \lambda & \cdot \end{pmatrix} \quad \delta_d^{LL} \sim \begin{pmatrix} \cdot & \lambda^5 & \lambda^3 \\ \lambda^5 & \cdot & \lambda^2 \\ \lambda^3 & \lambda^2 & \cdot \end{pmatrix}$$

$$\delta_d^{RR} \sim \begin{pmatrix} \cdot & 0 & 0 \\ 0 & \cdot & 1 \\ 0 & 1 & \cdot \end{pmatrix} \quad \delta_d^{RR} \sim \begin{pmatrix} \cdot & \lambda^3 & \lambda^3 \\ \lambda^3 & \cdot & \lambda^2 \\ \lambda^3 & \lambda^2 & \cdot \end{pmatrix} \quad \delta_d^{RR} \sim \begin{pmatrix} \cdot & \lambda^3 & \lambda^2 \\ \lambda^3 & \cdot & \lambda \\ \lambda^2 & \lambda & \cdot \end{pmatrix} \quad \delta_d^{RR} \sim \begin{pmatrix} \cdot & 0 & 0 \\ 0 & \cdot & 0 \\ 0 & 0 & \cdot \end{pmatrix}$$

Hp: CP is spontaneously broken in the flavor sector [Nir & Rattazzi '96]

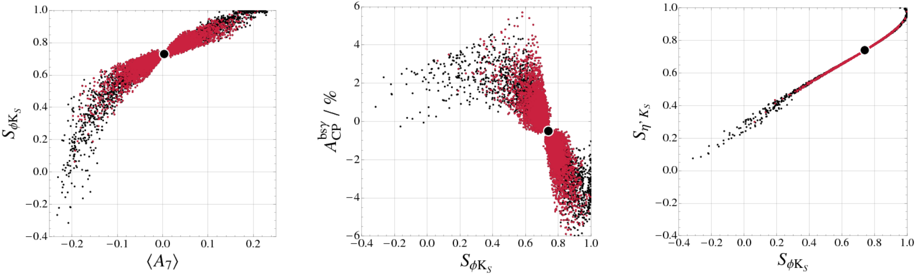
$b \to s$ transitions & SUSY flavor models [Altmannshofer et al., '09]



- Orange (Blue) points: UT tension solved through contribution to $\Delta M_d/\Delta M_s$ (ϵ_K)
- Scan ranges: $m_0 < 2$ TeV, $M_{1/2} < 1$ TeV, $|A_0| < 3m_0$, $5 < \tan\beta < 55$

Pattern of NP effects in the δLL model:

- No large effects in $S_{\psi\phi}$
- Large, correlated effects in $S_{\phi K_S}$, $S_{\eta' K_S}$, $A_{CP}(b \to s\gamma)$, $\langle A_{7,8} \rangle$ and EDMs
- $\langle A_{7,8} \rangle$: T-odd CP asymmetries in $B \to K^* \ell^+ \ell^-$

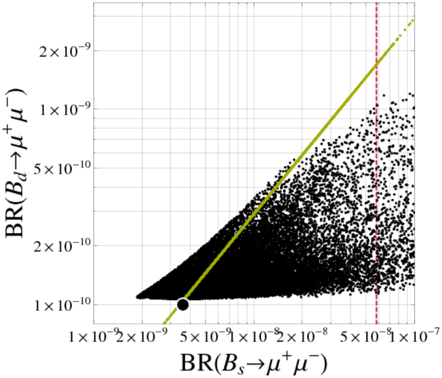


- Scan ranges: $m_0 < 2$ TeV, $M_{1/2} < 1$ TeV, $|A_0| < 3m_0$, $5 < \tan\beta < 55$,

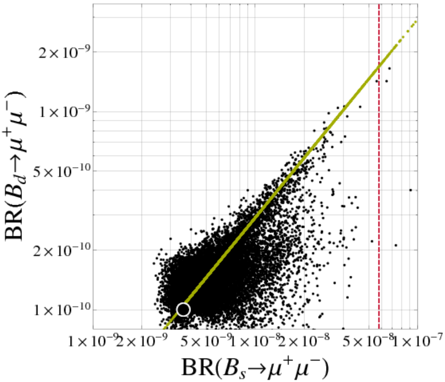
[Altmannshofer et al., '09]

$Br(B_s \to \mu^+\mu^-)$ vs. $Br(B_d \to \mu^+\mu^-)$

Abelian (AC)



Non abelian (RVV)



[Altmannshofer et al., '09]

$Br(B_s \to \mu^+\mu^-)/Br(B_d \to \mu^+\mu^-) = |V_{ts}/V_{td}|^2$ **in MFV models**

[Hurth, Isidori, Kamenik & Mescia, '08]

CPV in $\mathbf{D^0 - \overline{D}^0} \sim ((V_{cb}V_{ub})/(V_{cs}V_{us})) \sim \mathbf{10^{-3}}$ in the **SM**

- $\langle D^0|\mathcal{H}_{\rm eff}|\bar{D}^0\rangle = M_{12} - \frac{i}{2}\Gamma_{12}, \qquad |D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$
- $\frac{q}{p} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}, \qquad \phi = \mathrm{Arg}(q/p)$
- $x = \frac{\Delta M_D}{\Gamma} = 2\tau \mathrm{Re}\left[\frac{q}{p}\left(M_{12} - \frac{i}{2}\Gamma_{12}\right)\right]$
- $y = \frac{\Delta\Gamma}{2\Gamma} = -2\tau \mathrm{Im}\left[\frac{q}{p}\left(M_{12} - \frac{i}{2}\Gamma_{12}\right)\right]$

$$\mathbf{S_f} = 2\Delta Y_f = \frac{1}{\Gamma_D}\left(\hat{\Gamma}_{\bar{D}^0\to f} - \hat{\Gamma}_{D^0\to f}\right)$$

$$\eta_f^{\rm CP} S_f = x\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right)\sin\phi - y\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right)\cos\phi$$

$$\mathbf{a}_{\rm SL} = \frac{\Gamma(D^0 \to K^+\ell^-\nu) - \Gamma(\bar{D}^0 \to K^-\ell^+\nu)}{\Gamma(D^0 \to K^+\ell^-\nu) + \Gamma(\bar{D}^0 \to K^-\ell^+\nu)} = \frac{|q|^4 - |p|^4}{|q|^4 + |p|^4}$$

[Nir et al.,Kagan et al., Petrov et al., Bigi et al., Buras et al., ...]

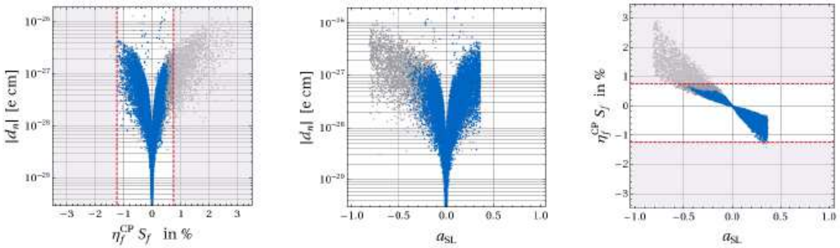


FIG. 3: Correlations between d_n and S_f (left), d_n and a_{SL} (middle) and a_{SL} and S_f (right) in SUSY alignment models. Gray points satisfy the constraints (8)-(10) while blue points further satisfy the constraint (11) from ϕ. Dashed lines stand for the allowed range (18) for S_f.

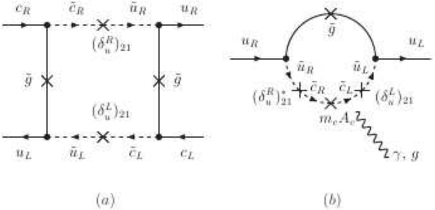
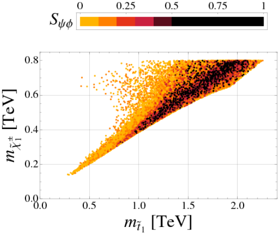


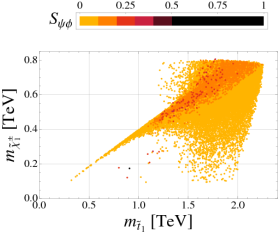
FIG. 2: Examples of relevant Feynman diagrams contributing (a) to $D^0 - \bar{D}^0$ mixing and (b) to the up quark (C)EDM in SUSY alignment models.

LHC vs. flavour

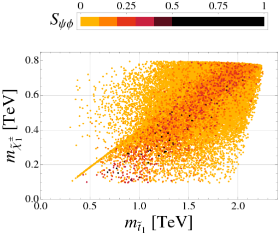
AC



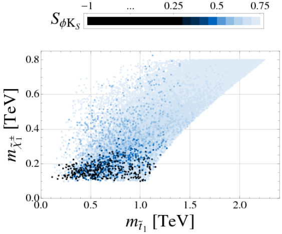
AKM



RVV

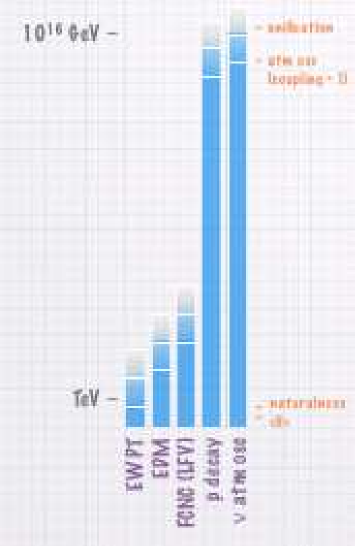


δLL



- Large effects in $S_{\psi\phi}$ even possible for spectra beyond the LHC reach in the models with RH currents
- Large effects in $S_{\phi K_S}$ not possible for spectra beyond the LHC reach in the δLL model

$$\mathbf{BR}(\ell_i \to \ell_j \gamma) \sim \frac{1}{\Lambda_{NP}^4}$$



- **Gravity** $\Longrightarrow$ $\Lambda_{\text{Planck}} \sim 10^{18-19}$ GeV
- **Neutrino masses** $\Longrightarrow$ $\Lambda_{\text{see-saw}} \lesssim 10^{15}$ GeV
- **Hierarchy problem**: $\Lambda_{\text{NP}} \lesssim$ TeV
- **Dark Matter** $\Longrightarrow$ $\Lambda_{\text{NP}} \lesssim$ TeV
- **BAU**: evidence of CPV beyond SM
  - Electroweak Baryogenesis $\Longrightarrow$ $\Lambda_{\text{NP}} \lesssim$ TeV
  - Leptogenesis $\Longrightarrow$ $\Lambda_{\text{see-saw}} \lesssim 10^{15}$ GeV
  - ....

Brief status of Lepton Flavor Violation searches

- tau LFV
  - past: CLEO explored up to BRs $\sim 10^{-6}$
  - **present: B-factories are completing exploration up to BRs $\sim 10^{-8}$**
  - future: Super Flavor Factories can explore up to BRs $\sim 10^{-10}$
  - **$\tau \to \mu\gamma$ is the most sensitive channel for most mainstream NP models**
- muon LFV
  - past: LAMPF, MEGA, BF($\mu \to e\gamma$) $< 1.2 \cdot 10^{-11}$ at 90% CL
  - past: SINDRUM II, BF($\mu \to e$ in nucleon field) $< 7 \cdot 10^{-13}$ at 90% CL
  - **present: MEG, BF($\mu \to e\gamma$) $< 1.5 \cdot 10^{-11}$ at 90% CL, (sensitivity $6 \cdot 10^{-12}$)**
  - future: MEG will soon reach sensitivity $\sim 10^{-13}$
  - future: Mu2E and COMET/PRISM can much increase reach on BF($\mu \to e$ in nucleon field)

Process	Expected 90% CL upper limit	3σ evidence reach
BF($\tau \to \mu\gamma$)	$2.4 \cdot 10^{-9}$	$5.4 \cdot 10^{-9}$
BF($\tau \to e\gamma$)	$3.0 \cdot 10^{-9}$	$6.8 \cdot 10^{-9}$
BF($\tau \to \ell\ell\ell$)	$2.3\text{–}8.2 \cdot 10^{-10}$	$1.2\text{–}4.0 \cdot 10^{-9}$

[Lusiani @ HQL10]

LFV frameworks

- **Neutrino Oscillation** $\Rightarrow m_{\nu_i} \neq m_{\nu_j} \Rightarrow$ **LFV**
- **see-saw**: $m_\nu = \frac{(m_\nu^D)^2}{M_R} \sim eV,\ M_R \sim 10^{14-16} \Rightarrow m_\nu^D \sim m_{top}$
- LFV transitions like $\mu \to e\gamma$ @ 1 loop with exchange of
  - W and ν in the SM framework (GIM)

$$Br(\mu \to e\gamma) \sim \frac{m_\nu^4}{M_W^4} \leq 10^{-50} \qquad m_\nu \sim \mathrm{eV}$$

  - $\tilde{W}$ and $\tilde{\nu}$ in the MSSM framework (SUPER-GIM)

$$Br(\mu \to e\gamma) \sim \frac{m_\nu^{D\,4}}{\tilde{m}^4} \leq 10^{-11} \qquad m_\nu^D \sim m_{top}$$

$$\Downarrow$$

- LFV signals are undetectable (detectable) in the SM (MSSM)

Flavour universal SUSY breaking and yet large LFV from SUSY see-saw

- SUSY see-saw superpotential (MSSM + RN)

$$W = h^e L e^c H_1 + h^\nu L \nu^c H_2 + M_R \nu^c \nu^c + \mu H_1 H_2,$$

$$\mathcal{M}_\nu = -h^\nu M_R^{-1} h^{\nu\ T} v_2^2,$$

$$M_{\tilde{\ell}}^2 = \begin{pmatrix} m_L^2(1+\delta_{LL}^{ij}) & (A-\mu t_\beta) m_\ell + m_L m_R \delta_{LR}^{ij} \\ (A-\mu t_\beta) m_\ell + m_L m_R {\delta_{LR}^{ij}}^\dagger & m_R^2(1+\delta_{RR}^{ij}) \end{pmatrix}$$

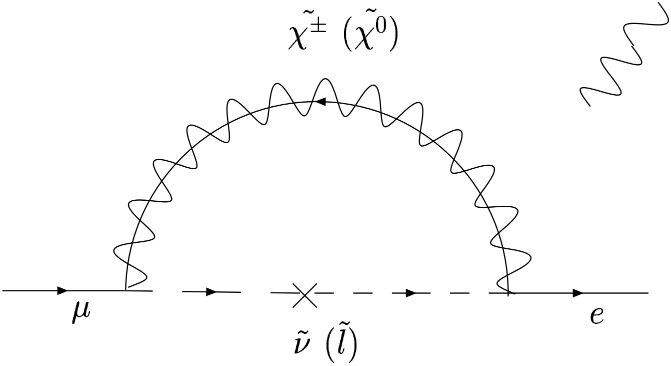
- If $h^e = h^e_{ij}\delta_{ij}$ and $M_R = (M_R)_{ij}\delta_{ij} \Rightarrow h^\nu \neq h^\nu_{ij}\delta_{ij}$ in general.

$$\delta_{LL}^{ij} \approx -\frac{3}{8\pi^2}(h^\nu h^{\nu\dagger})_{ij} \ln \frac{M_X}{M_R},$$

[Borzumati & Masiero, '86]

LFV interactions – leptons/sleptons/gauginos

$$\mathcal{L} = \bar{\ell}_i \left(C^R_{ijA} P_R + C^L_{ijA} P_L \right) \tilde{\chi}^-_A \tilde{\nu}_j + \bar{\ell}_i \left(N^R_{ijA} P_R + N^L_{ijA} P_L \right) \tilde{\chi}^0_A \tilde{\ell}_j$$



$$\frac{BR(\ell_i \to \ell_j \gamma)}{BR(\ell_i \to \ell_j \nu_i \bar{\nu}_j)} \sim \left(\frac{m_W^4}{m_{SUSY}^4} \right) \left(\delta^{21}_{LL} \right)^2 t^2_\beta \qquad \delta_{LL} \sim h^\nu h^{\nu\dagger}$$

h^ν **is unknown** $\Rightarrow$ **No model independent predictions for LFV**

$$h^\nu = U^\star_{\rm MNS}\, \mathcal{D}_{\sqrt{\mathcal{M}_\nu}}\, R^T\, \mathcal{D}_{\sqrt{M_R}}\, \frac{1}{v_2},$$

$R^\dagger R = 1 \Rightarrow$ **three angles** and **three phases**

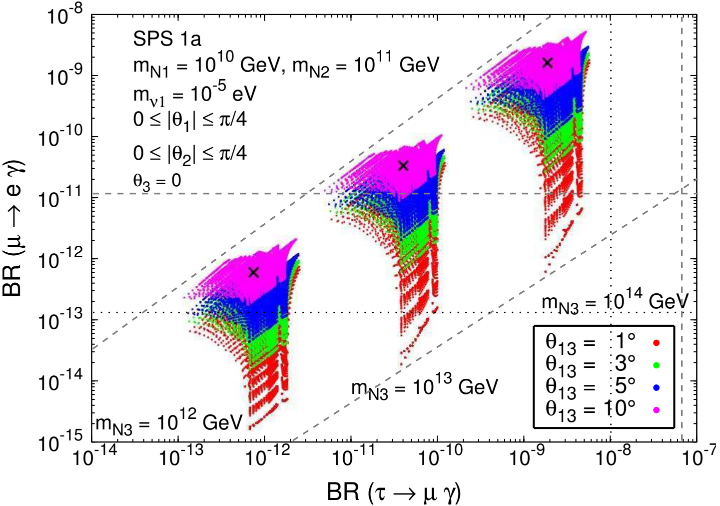
- ν_L **&** ν_R **hierarchical (and R real)**

$$\frac{B(\mu \to e\gamma)}{B(\tau \to \mu\gamma)} \sim \frac{|U_{e3}|^2}{B(\tau \to \mu\nu_\tau\bar{\nu}_\mu)}$$

- ν_L **hierarchical and** ν_R **degenerate (and R real)**

$$\frac{B(\mu \to e\gamma)}{B(\tau \to \mu\gamma)} \sim \frac{|s_{12}c_{12}\,(m_{sol}/m_{atm}) + U_{e3}|^2}{B(\tau \to \mu\nu_\tau\bar{\nu}_\mu)}$$

$\mu \to e\gamma$ and $\tau \to \mu\gamma$ in SUSY see-saw



[Herrero et al., '06]

RG induced LFV interactions in SUSY GUTs

- **SUSY SU(5)** [Barbieri & Hall, '95]

$$(\delta^{\tilde{q}}_{LL})_{ij} \sim {h^u h^{u\dagger}}_{ij} \sim h_t^2 V^{ik}_{CKM} V^{kj*}_{CKM} \rightarrow (\delta^{\tilde{\ell}}_{RR})_{ij} \simeq (\delta^{\tilde{q}}_{LL})_{ij}$$

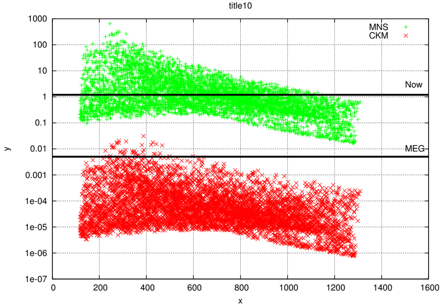
- **SUSY SU(5)+RN** [Yanagida et al., '95]

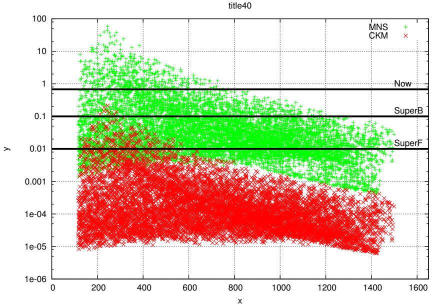
$$(\delta^{\tilde{\ell}}_{LL})_{ij} \sim (h^\nu h^{\nu\dagger})_{ij} \qquad \& \qquad (\delta^{\tilde{\ell}}_{RR})_{ij} \sim (h^u h^{u\dagger})_{ij}$$

- **SUSY SU(5)+RN** [Moroi, '00] **&** **SO(10)** [Chang, Masiero & Murayama, '02]

$$\sin\theta_{\mu\tau} \sim \frac{\sqrt{2}}{2} \Rightarrow (\delta^{\tilde{\ell}}_{LL})_{23} \sim 1 \Rightarrow (\delta^{\tilde{q}}_{RR})_{23} \sim 1$$

Br($\mu \to e\gamma$) **Br($\tau \to \mu\gamma$)**



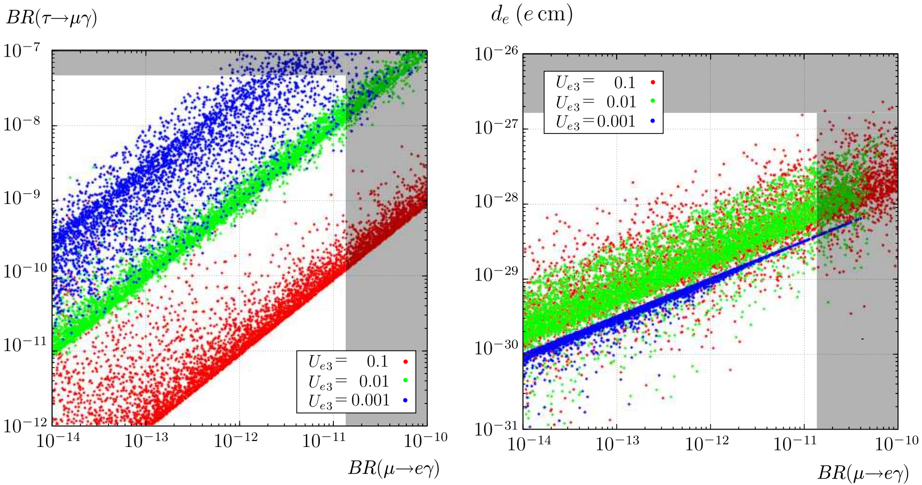


$M_{1/2}$ $M_{1/2}$

$m_0 \leq 1\,\mathrm{TeV}$, $\tan\beta = 40$

[Calibbi, Faccia, Masiero and Vempati, '06]

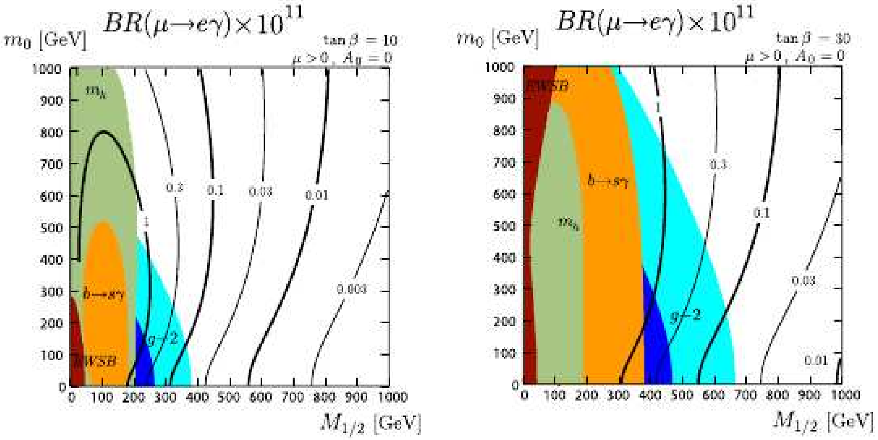
$\mu \to e\gamma$ and $\tau \to \mu\gamma$ in SUSY SU(5)+RN



hierarchical ν_L and N_R, $U_{e3} = 0.1$, $M_{N_3} = 10^{-13}$ GeV

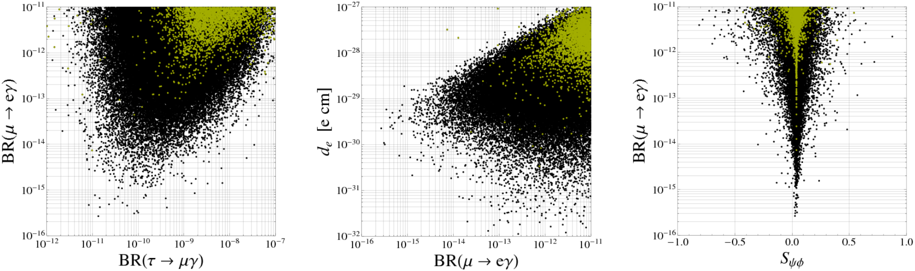
[Hisano, Nagai, Paradisi & Shimizu, '09]

$\mathrm{BR}(\mu \to e\gamma)$ in $SU(5)_{RN}$ and the LHC reach



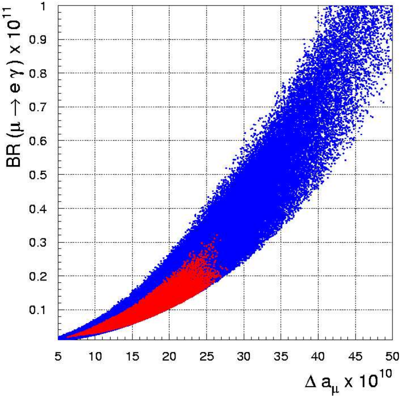
hierarchical ν_L and N_R, $U_{e3} = 0.1$, $M_{N_3} = 10^{-13}\,\mathrm{GeV}$

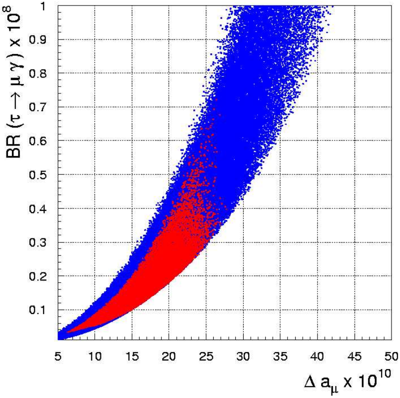
[Hisano, Nagai, Paradisi & Shimizu, '09]



- Yellow points satisfy $\Delta a_\mu > 10^{-9}$
- Scan ranges: $m_0 < 2$ TeV, $M_{1/2} < 1$ TeV, $|A_0| < 3m_0$, $5 < \tan\beta < 55$

[Altmannshofer, Buras, Gori, Paradisi and Straub, '09]





$|\delta_{LL}^{12}| = 10^{-4}$ and $|\delta_{LL}^{23}| = 10^{-2}$,

[Isidori, Mescia, Paradisi & Temes, 07]

$$BR(\ell_i \to \ell_j\gamma) \approx \left[\frac{\Delta a_\mu}{20\times 10^{-10}}\right]^2 \times \left\{ \begin{array}{ll} 1\times 10^{-4}\,\left|\delta_{LL}^{12}\right|^2 & [\mu\to e] \\ 2\times 10^{-5}\,\left|\delta_{LL}^{23}\right|^2 & [\tau\to\mu] \end{array} \right\}$$

Pattern of LFV in NP models

- **Ratios of BR for different flavor transitions**
- **Ratios of BR for different processes**

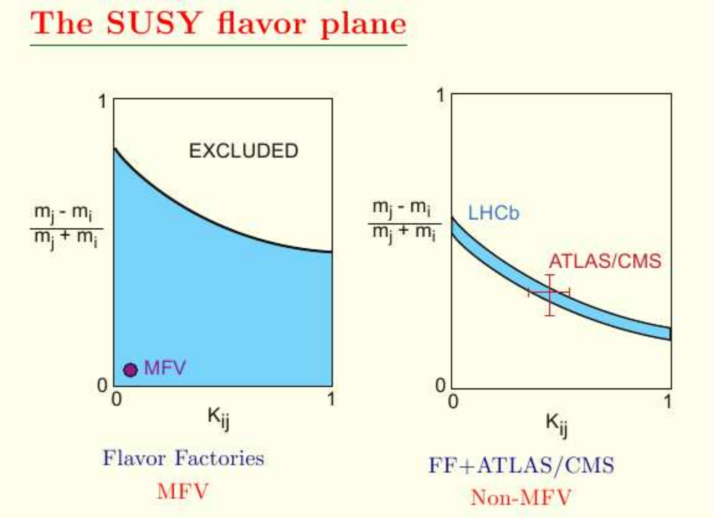
ratio	LHT	MSSM	SM4
$\frac{Br(\mu\to eee)}{Br(\mu\to e\gamma)}$	$0.02\ldots 1$	$\sim 2\cdot 10^{-3}$	$0.06\ldots 2.2$
$\frac{Br(\tau\to eee)}{Br(\tau\to e\gamma)}$	$0.04\ldots 0.4$	$\sim 1\cdot 10^{-2}$	$0.07\ldots 2.2$
$\frac{Br(\tau\to \mu\mu\mu)}{Br(\tau\to \mu\gamma)}$	$0.04\ldots 0.4$	$\sim 2\cdot 10^{-3}$	$0.06\ldots 2.2$
$\frac{Br(\tau\to e\mu\mu)}{Br(\tau\to e\gamma)}$	$0.04\ldots 0.3$	$\sim 2\cdot 10^{-3}$	$0.03\ldots 1.3$
$\frac{Br(\tau\to \mu ee)}{Br(\tau\to \mu\gamma)}$	$0.04\ldots 0.3$	$\sim 1\cdot 10^{-2}$	$0.04\ldots 1.4$
$\frac{Br(\tau\to eee)}{Br(\tau\to e\mu\mu)}$	$0.8\ldots 2$	~ 5	$1.5\ldots 2.3$
$\frac{Br(\tau\to \mu\mu\mu)}{Br(\tau\to \mu ee)}$	$0.7\ldots 1.6$	~ 0.2	$1.4\ldots 1.7$
$\frac{\mathrm{R}(\mu\mathrm{Ti}\to e\mathrm{Ti})}{Br(\mu\to e\gamma)}$	$10^{-3}\ldots 10^{2}$	$\sim 5\cdot 10^{-3}$	$10^{-12}\ldots 26$

[Buras et al., '07, '10]

“DNA-Flavour Test”

	GMSSM	AC	RVV2	AKM	δLL	FBMSSM	
$S_{\phi K_S}$	★★★	★★★	●●	■	★★★	★★★	
$A_{CP}(B \to X_s\gamma)$	★★★	■	■	■	★★★	★★★	
$B \to K^{(*)}\nu\bar{\nu}$	●●	■	■	■	■	■	
$\tau \to \mu\gamma$	★★★	★★★	★★★	■	★★★	★★★	
$D^0 - \bar{D}^0$	★★★	★★★	■	■	■	■	
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★★★	■	■	■	★★★	★★★	vs.
$A_9(B \to K^*\mu^+\mu^-)$	★★★	■	■	■	■	■	
$S_{\psi\phi}$	★★★	★★★	★★★	★★★	■	■	
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★★★	
ϵ_K	★★★	■	★★★	★★★	■	■	
$K^+ \to \pi^+\nu\bar{\nu}$	★★★	■	■	■	■	■	
$K_L \to \pi^0\nu\bar{\nu}$	★★★	■	■	■	■	■	
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	
d_n	★★★	★★★	★★★	★★★	●●	★★★	
d_e	★★★	★★★	★★★	●●	■	★★★	
$(g-2)_\mu$	★★★	★★★	★★★	●●	★★★	★★★	

[Altmannshofer et al., ’09]



[Nir @ Planck ’09]