Flavor Physics in the LHC Era:

The (Supersymmetric) Case for a SuperB Factory

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Greetings from...

A common sentiment:

The Standard Model works unreasonably well!

Over past 20 years, (almost) all pieces verified:

- LEP checked weak gauge sector at 1-2 loops
- Tevatron has completed fermion spectrum
- Tevatron + HERA + LEP + ... have verified strong interactions/QCD
- B-factories have verified CKM picture of flavor-mixing and CP violation
- Neutrino masses found -- AS EXPECTED
- Only EW symmetry breaking mechanism remains undiscovered.

If Standard Model works so well, why do we KNOW it must be wrong?

The most serious problems arise from astro-physics. Standard Model does not produce:

- dark matter
- enough baryons
- dark energy

N.B. Not on my list: that neutrinos have mass.

"Post-Wilsonian" minimal Standard Model MUST have Majorana ν-masses UNLESS we extend its symmetries.

(Also missing: strong CP problem.)

The most serious problems:

- dark matter
- enough baryons
- dark energy

- Astrophysics requires a new weakly-interacting (at most), massive particle with $\tau > 10^{10}$ yr.
- For $\Omega_{DM} \approx 0.3$ today, want $M_{DM} \sim \sigma^{-1/2} \sim M_{weak}$!

➡ So physics of dark matter may be tied to EW scale!

The most serious problems:

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- enough baryons
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- Sakharov conditions require B-violation, CP-violation, and baryon production out of equilibrium.
- All exist at EW phase transition, but require light Higgs, $m_h < 40$ GeV.

➡ The CKM explanation of CPV can't be whole story.

The most serious problems:

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- dark energy

- SM unable to make sensible prediction for cosmological constant, or any energy density $\rho \sim (10^{-3}\ \mathrm{GeV})^4$.

- Question may or may not be tied to quantum gravity / M-theory.

- Evidence of a triple-coincidence problem, which is solved by tying dark energy to weak scale.

(Arkani-Hamed, Hall, Murayama, Kolda)

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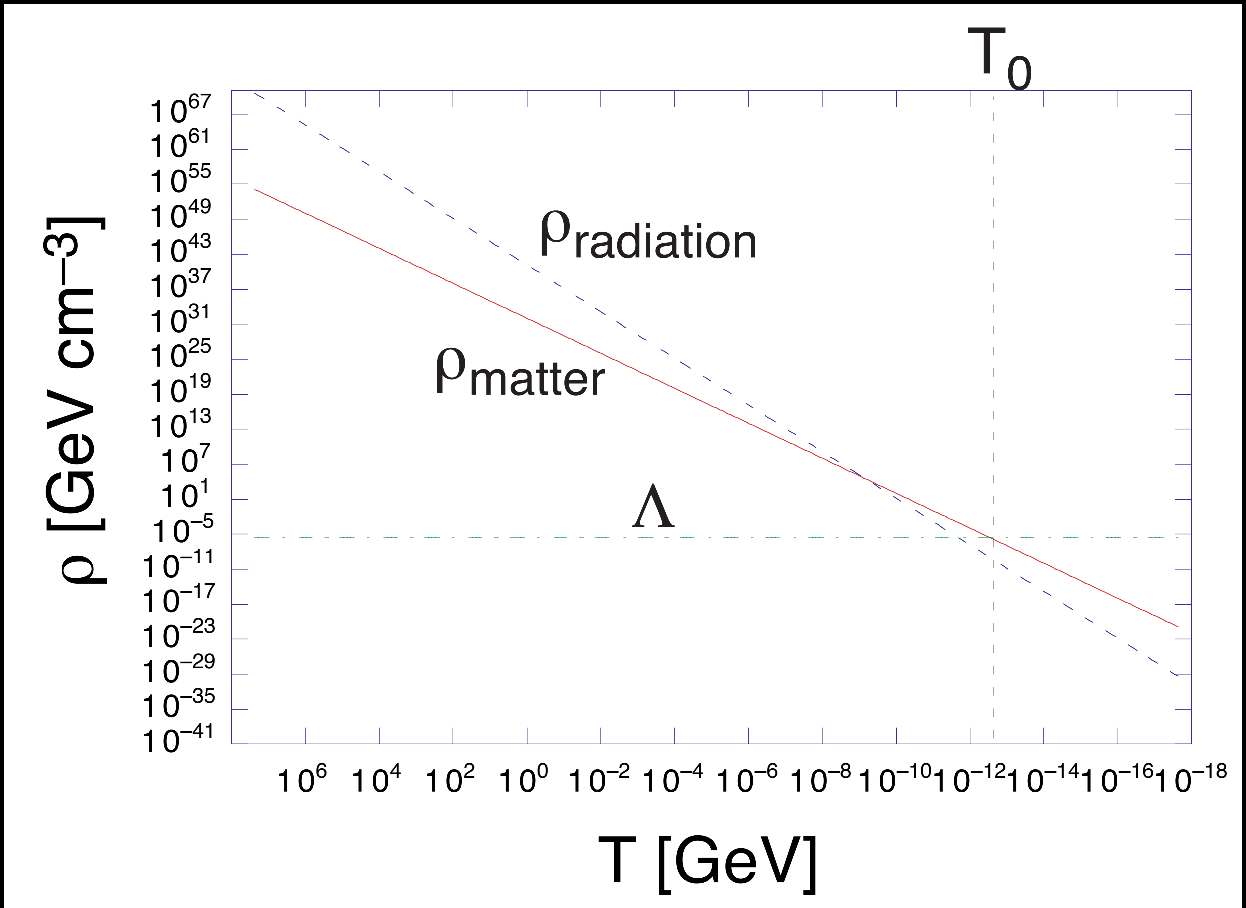

$$\rho_\Lambda \sim \frac{m_W^8}{m_{P\ell}^4}$$

“Major” theoretical problems:

- The SM doesn’t include gravity (at the quantum level).
- The SM cannot be embedded into a more fundamental, high-energy theory thanks to quadratic divergences ⇒ hierarchy problem.
- Source of weak scale (What sets scale in Higgs potential?)

Proposed solutions to first include: string theory, quantum loop gravity, not much else.

➡ Implies new physics at 10^{17-18} GeV.

Proposed solutions to other two: SUSY, extra dimensions, technicolor, etc.

➡ Implies new physics at 10^{2-3} GeV.

“Annoying” theoretical problems:

- Why 3 separate gauge groups?
- Why such strange quantum numbers?
- Why 3 generations?
- Why the large fermion mass hierarchies?
- Why is MNS matrix so unlike CKM?

Three classes of answers to all these problems:

1. Grand unification conjecture:

   Physics at very high scales answers all these in a (nearly?) unique way. Goal of physics is to find this ultimate T.O.E.

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Three classes of answers to all these problems:

1. Grand unification conjecture:
2. Intermediate flavor dynamics hope:

   Perhaps physics of flavor explained by physics at intermediate scales, 10^{6-16} GeV. If low enough, expect to see evidence in precision flavor studies.

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Three classes of answers to all these problems:

1. Grand unification conjecture:
2. Intermediate flavor dynamics hope:
3. Landscape surrender:

   ∃ billions of possible universes. Cosmology chose this one by chance. Gauge groups, q-numbers, masses, etc are pure "anarchy".

Most problems have a preferred scale for solution:

- Solve hierarchy problem/dark matter problems at 10^{2-3} GeV.
- Explain small neutrino masses at 10^{14} GeV.
- Solve unification/quantum gravity problems at 10^{16-18} GeV.

Of these, hierarchy/dark matter within our reach.

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But there is no preferred scale for new flavor physics, except that:

$M_{flavor} > 10^6$ GeV (or 10^7 GeV if CPV)

Worse, flavor dynamics anywhere near 10^6 GeV would probably corrupt hierarchy solution.

E.g. In mSUGRA, flavor dynamics below M_{GUT} can be ruled out in almost all cases.

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- Deciphering the 3 generation riddle
- Determining dynamics leading to CKM structure
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Theorists' view: We are used to "decoupling" flavor physics from new physics that solves hierarchy problem. We generally don't expect non-trivial flavor dynamics anywhere near weak scale.

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WRONG

Europe seems to have the right idea:

Most models of Beyond-the-SM physics have a

“FLAVOR PROBLEM”

In the Standard Model, large FCNCs are prevented by combo of CKM unitarity and small mixings between heavy and light quarks.

In most BTSM proposals, CKM mechanism fails by one loop. It fails because:

- Difficult to maintain CKM as only source of FCNCs if more states carry flavor (e.g. SUSY)
- If 3rd generation is “special”, it feeds back into all FCNCs (e.g. topcolor)
- If new gauge interactions differentiate flavors, then they directly meditate FCNCs.

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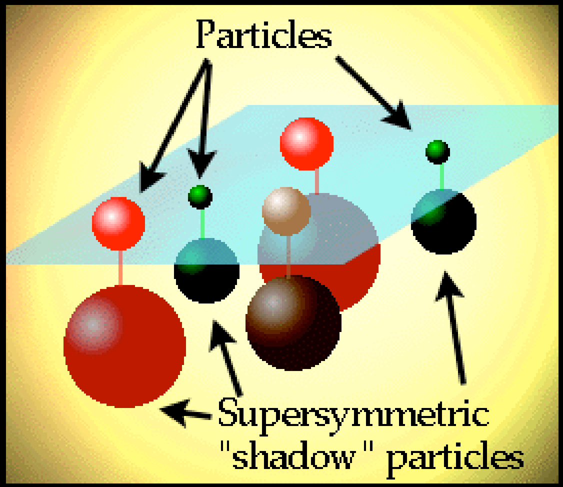
First, what is SUSY?

SUSY is a predicted symmetry of nature:

- Only possible symmetry between fermions and bosons.
- Solves gauge hierarchy problem by canceling quadratic divergences, stabilizing weak scale.
- Consistent with GUT models, including coupling unification.
- Breaks EW symmetry dynamically thanks to large y_{top}.
- Predicts a superpartner for each SM particle, with spin different by 1/2.
- Requires 2 Higgs doublets, with ratio of vevs = tanβ (≈ 1 to 60)



In SUSY:

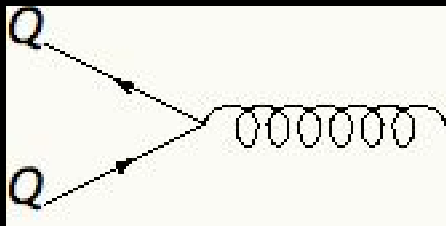
- Quark masses from Yukawa couplings/EWSB.
- Squark masses from Yukawas/EWSB and SUSY-breaking.
- Two sources uncorrelated, so squark mixing uncorrelated to quark mixing:

$$Q: \quad Q = V_{\rm CKM} Q^0 \qquad = V Q^0$$

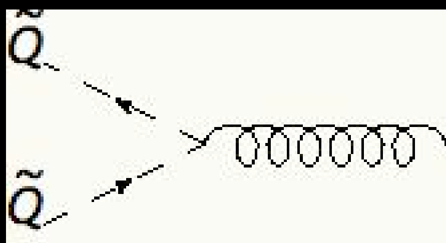
$$\tilde{Q}: \quad \tilde{Q} = V_{\rm CKM} V_{\rm SUSY} \tilde{Q}^0 \quad = \tilde{V} \tilde{Q}^0$$

For general SUSY models, squark mixing need not be anywhere near same as quark mixing.

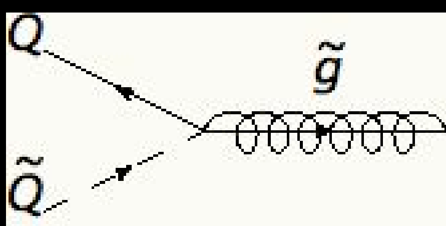
In SUSY:



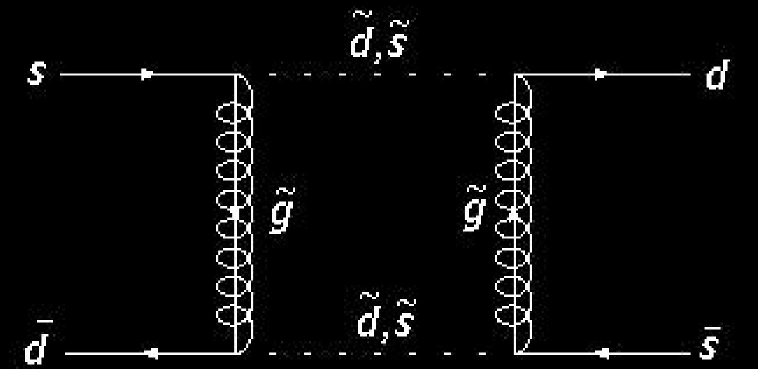
$\sim V^\dagger V = 1$

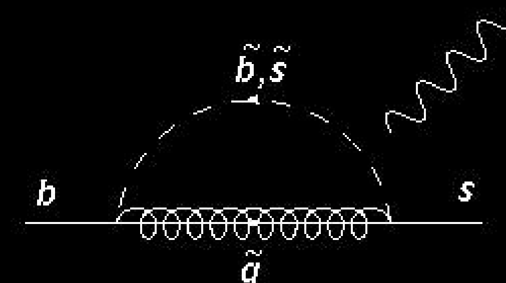


$\sim \tilde{V}^\dagger \tilde{V} = 1$



$\sim V^\dagger \tilde{V} \neq 1$



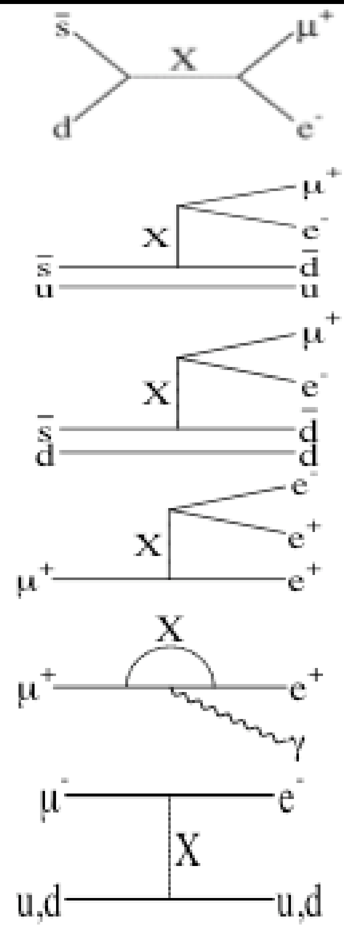


If two matrices not the same, large FCNCs result -- this is ruled out!

Note: flavor-changing always in loops.

The "flavor problem" is even more general -- scale of physics required to solve hierarchy problem already ruled out by precision flavor studies:

$\Delta F=1$ processes:

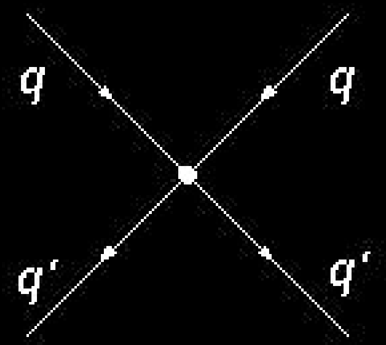


$B(K_L \to \mu e) < 4.7 \times 10^{-12}$	$M_X > 150$ TeV/c^2
$B(K^+ \to \pi^+\mu^+e^-) < 4 \times 10^{-11}$	$M_X > 31$ TeV/c^2
$B(K_L \to \pi^\circ\mu^+e^-) < 3.2 \times 10^{-10}$	$M_X > 37$ TeV/c^2
$B(\mu^+ \to eee) < 1 \times 10^{-12}$	$M_X > 86$ TeV/c^2
$B(\mu^+ \to e^+\gamma) < 1.2 \times 10^{-11}$	$M_X > 21$ TeV/c^2
Normalized Rate $< 6.1 \times 10^{-13}$	$M_X > 365$ TeV/c^2

S.Geer

Even worse, ΔF=2 processes...

Given some new operator:



$$\frac{1}{\Lambda^2}(q\Gamma q')(q\Gamma q')$$

If {q,q'} =
- {d,s}, ΔM_K gives Λ < 1500 TeV;
- {d,b}, ΔM_B gives Λ < 500 TeV;
- {s,b}, ΔM_{Bs} gives Λ < 100 TeV.

These are extremely strong constraints on the scale of new physics!! And CPV pushes them up another factor of 10!!!

Two questions raised by meson mixing data:

1. Is there any point to further high precision studies? Are meson-antimeson constraints so powerful that they rule out new physics in rare decays?

2. Is there any point in using flavor physics to probe (rather than just constrain) new physics?
(Direct searches for 1500 TeV particles a long way off...)

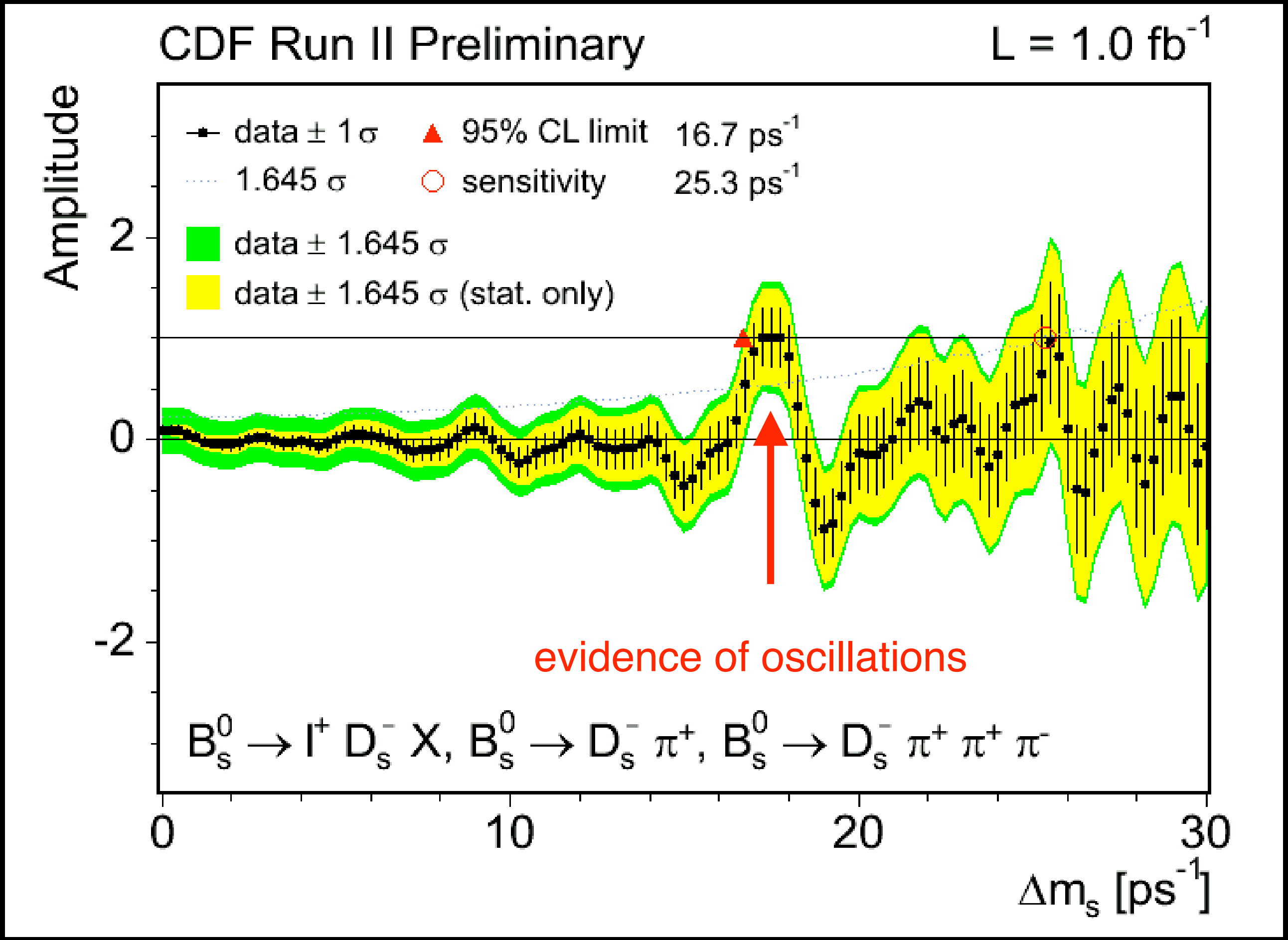
Two questions raised by meson mixing data:

1. Is there any point to further high precision studies? Are meson-antimeson constraints so powerful that they rule out new physics in rare decays?

Yes, there is a point. The case is harder to make for kaons, but easily made for B's. Scales probed by mixing and by rare decays very similar for B's: 10's to 100's of TeV.

Success of CKM picture at BaBar/Belle means new physics effects probably not huge in 1-3 sector, but what about 2-3 sector?

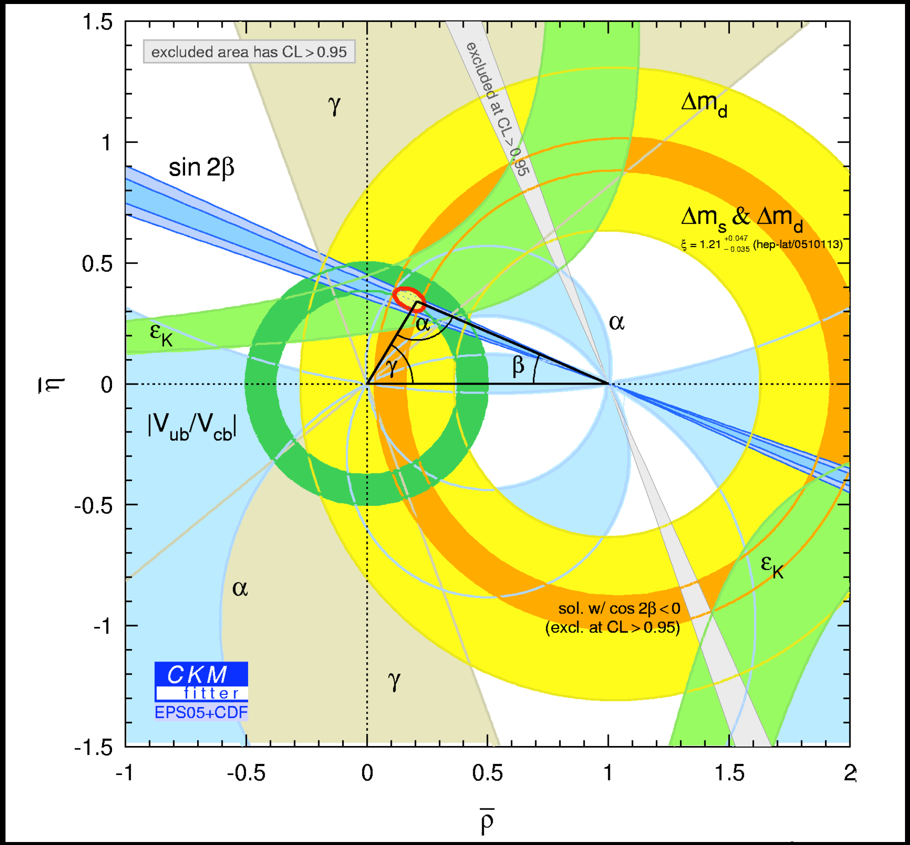
In the news...



$$\Delta m_s = 17.33^{+0.42}_{-0.21} \pm 0.07 \text{ ps}^{-1} \text{ (CDF)}$$

$$\Delta m_s = \begin{cases} 21.7^{+5.9}_{-4.2} \text{ ps}^{-1} & \text{(CKMFitter)} \\ 21.5 \pm 2.6 \text{ ps}^{-1} & \text{(UTFit)} \end{cases}$$

This is great news for the Standard Model. The CKM picture is in impressive agreement with all the data!



The (somewhat) bad news for new physics:

New physics could be hiding in 2–3 sector, but don't expect huge signals. There is no one "smoking gun" measurement to be done.

What lesson have the theorists learned from success of SM in flavor sector?

Either:

- New physics completely commutes with SM flavor structure (like universal Z′).
- Or new physics is Minimally Flavor Violating (MFV).

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Either:

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- Or new physics is Minimally Flavor Violating (MFV).

Minimal Flavor Violation is ansatz that only source of flavor violation in new physics is usual Yukawas, and that this is dominated by y_{top}.

All quark mixing encoded in CKM matrix!

N.B. This is not a model, it is a constraint placed on models. But results protected by approximate flavor symmetries of the SM, i.e., $U(3)^3$.

MFV implies that:

- No FCNC operators not already in SM will appear.*
- New contributions to FCNC operators suppressed by usual CKM factors.
- Existing operators will get O(1) corrections at best. Usually even smaller.*
- No new source of CPV, so no new CPV asymmetries.*
- Unitarity triangle expected to close approximately.

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In MFV models, ΔM_K probes

$$\Lambda_{NP} = 1500\ \text{TeV} \times V_{td}V_{ts} = 500\ \text{GeV!}$$

Meanwhile, ΔM_B probes

$$\Lambda_{NP} = 500\ \text{TeV} \times V_{td}V_{tb} = 4\ \text{TeV!}$$

(similarly for ΔM_{Bs})

If effects are 1-loop, then scales drop to 40 GeV and 350 GeV.

In MFV, ΔF=1 four-fermion operators are not so suppressed:

$$\begin{aligned} \Delta F = 2: &\quad \Lambda_{\rm MFV} = V_{ti} V_{tj} \times \Lambda_{\rm naive} \\ \Delta F = 1: &\quad \Lambda_{\rm MFV} = \sqrt{V_{ti} V_{tj}} \times \Lambda_{\rm naive} \end{aligned}$$

For the specific case of B-meson:

$$\begin{aligned} B^0 - \bar{B}^0: &\quad \Lambda_{\rm MFV} = V_{td} V_{tb} \times \Lambda_{\rm naive} \simeq \frac{1}{100} \Lambda_{\rm naive} \\ B^0 \to \ell^+ \ell^-: &\quad \Lambda_{\rm MFV} = \sqrt{V_{td} V_{tb}} \times \Lambda_{\rm naive} \simeq \frac{1}{10} \Lambda_{\rm naive} \end{aligned}$$

So the constraints from ΔF=2 operators become weaker in relation to probative power of ΔF=1 rare decays!

MFV works twice: to reduce tight FCNC constraints on all forms of new physics and to increase phase space for new effects in rare decays.

There is one caveat (*):

"Minimal" MFV assumes only y_{top} is large. Implicitly assumes single Higgs structure.

In models with 2+ Higgs, y_{bot} can be sizable ⇒ new operators can appear:

- New effects still ∝ CKM elements.
- Largest effect is Higgs-mediated rare decays, $B \to l^+ l^-$, $B \to K l^+ l^-$, etc.
- SM prediction too small for 50 ab^{-1} SuperB, but NP can be orders greater.
- In SUSY, these are the well-known $\tan^6\beta$ effects that occur even in mSUGRA models.

Babu, Kolda

MFV is commonly assumed in SUSY model building. In mSUGRA, gauge-mediation, anomaly-mediation, or any other model with squark degeneracy.*

LHC will find the states, but will it really be MFV? Even if approximate degeneracy found, can there be non-CKM sources of flavor violation?

That's a vitally important question, and can't be answered at the LHC. One of the goals of SuperB must be to test MFV!

[* SUSY models w/o degeneracy either require decoupling or alignment. The latter implies new, large contributions to D^0-mixing, another target for SuperB.]

One clean MFV prediction:

$$\frac{\mathrm{Br}(B_d \to (X_s)\ell\ell)}{\mathrm{Br}(B_s \to (X_s)\ell\ell)} = \left(\frac{V_{td}}{V_{ts}}\right)^2 \approx \frac{1}{25}$$

This is bad(?) news for a SuperB factory:

CDF finds $\mathrm{Br}(B_s \to \mu\mu) < 1\times10^{-7}$, which means $\mathrm{Br}(B \to \mu\mu) < 4\times10^{-9}$ in MFV.

With 50 ab^{-1}, SuperB can get to $\mathrm{Br}(B \to \mu\mu) \approx 7\times10^{-9}$, so not enough. (Why not 10^{-10}?)

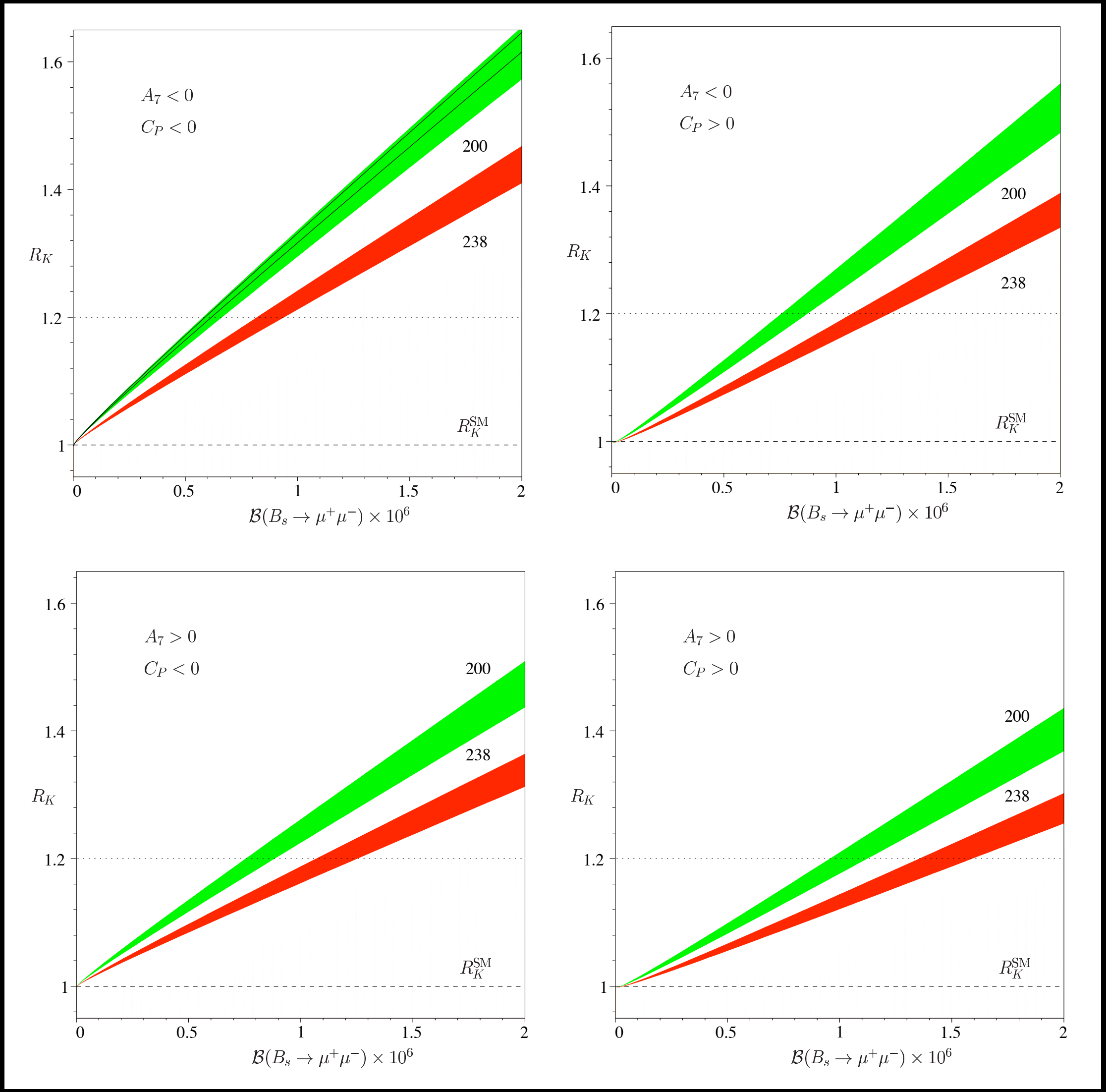
(Or need to get $\mathrm{Br}(B \to \tau\tau)$ down to 10^{-6}. Unlikely!)

But SuperB can compete in 3-body final state:

$$\frac{\mathrm{Br}(B \to X_s \mu\mu)}{\mathrm{Br}(B \to X_s ee)} \sim 1 + \frac{1}{16\pi^2} \times (\mathrm{factors}) \times \frac{m_\mu^2}{m_W^2}$$

Can be measured to 4% with 10 ab^{-1} or 2% with 50 ab^{-1}.

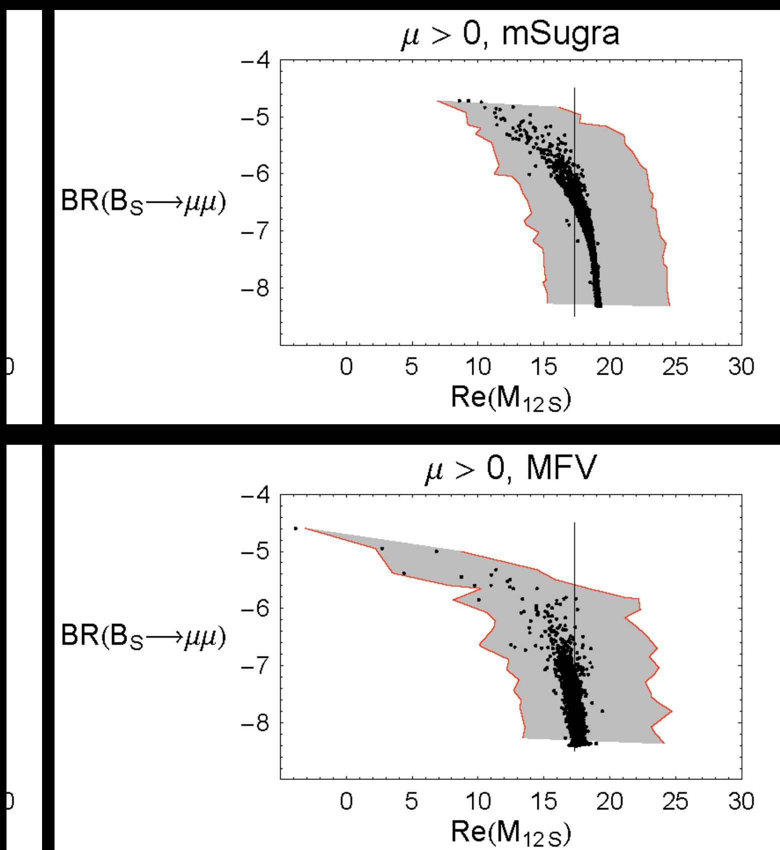
Current CDF bound on $B_s \to \mu\mu$ of 10^{-7} implies needed precision of at least 1-3%. So need that 50 ab^{-1}!



Hiller, Krüger

In MFV, a correlation exists between B→μμ and B_s-mixing: ΔMs should be < SM value, more so the larger $Br(B_s \to \mu\mu)$ is.

Recent CDF result could imply a new constraint:



Lunghi, Porod, Vives

But model dependence too big at present to constrain MFV scenario, except that $Br < 10^{-6}$ predicted (OK!)

Another (unfortunate?) prediction of MFV:

Since there are no new sources of CPV, CP asymmetries will take their SM values, up to small corrections. Any zero/tiny asymmetry in SM will remain so.

So some new physics could appear in $B \to \Phi K_S$, but it won't be large. With 50 ab^{-1}, SuperB can get to 4% in $S(B \to \Phi K_S)$ and compare to $B \to \Psi K_S$, a nice test of MFV, even if result is null.

Another way to test whether any observed sparticle degeneracy is really MFV or not:

SQUARK MASS SUM RULES

Almost all SUSY models start from a degenerate spectrum:

$$\tilde{m}^2_{u,d_L} = \tilde{m}^2_{c,s_L} = \tilde{m}^2_{t,b_L}$$
$$\tilde{m}^2_{u_R} = \tilde{m}^2_{c_R} = \tilde{m}^2_{t_R}$$
$$\tilde{m}^2_{d_R} = \tilde{m}^2_{s_R} = \tilde{m}^2_{b_R}$$

at some scale

Perfect degeneracy would mean no new FCNC's:

"super-GIM mechanism"

But loop corrections spoil degeneracy:

$$\frac{d}{d\log Q}\left(m^2_{\tilde{Q}}\right)_{ij} = \frac{1}{16\pi^2}\Big\{-\frac{2}{15}g_1^2M_1^2 - 6g_2^2M_2^2 - \frac{32}{3}g_3^2M_3^2 + 2\Big(Y_u^\dagger m^2_{\tilde{Q}}Y_u + Y_d m^2_{\tilde{Q}}Y_d^\dagger + Y_u^\dagger m^2_{\tilde{U}}Y_u + Y_d m^2_{\tilde{D}}Y_d^\dagger + Y_u^\dagger Y_u m^2_{H_u} + Y_d Y_d^\dagger m^2_{H_d} + A_u^\dagger A_u + A_d A_d^\dagger\Big)\Big\}_{ij}$$

Can't both be diagonal or no CKM mixing

This generates squark mixing (i.e. partner of down quark is not down squark, but admixture).

The resulting d-squark mass matrix is 6x6 (incl. LR mixing):

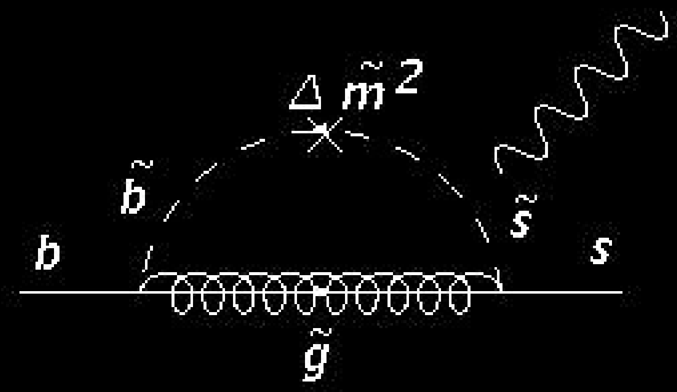
$$
\begin{array}{cccccc}
d_L & d_R & s_L & s_R & b_L & b_R
\end{array}
$$

$$
\begin{pmatrix}
m^2_{\tilde{d}_L} & m_d(A_d - \mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\
 & m^2_{\tilde{d}_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\
 & & m^2_{\tilde{s}_L} & m_s(A_s - \mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\
 & & & m^2_{\tilde{s}_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\
 & [\tilde{m}^2_D]_{ij} & & & m^2_{\tilde{b}_L} & m_b(A_b - \mu\tan\beta) \\
 & & & & & m^2_{\tilde{b}_R}
\end{pmatrix}
$$

LHC measures eigenvalues of this matrix. How do we learn the mixing angles?

By measuring rare FCNC's. And since this is MFV, look for signal in 3rd generation: SuperB!

Example: $b \to s\gamma$



Rate is $\propto \left[\Delta \tilde{m}_d^2\right]_{23}$. Measure rate, measure the squark mixing parameters.

Then compare to MFV predictions. This can be done in a model-independent way using sum rules that connect squark mass matrix eigenvalues to their mixing angles.

Dudley & Kolda

At small tanβ, sum rules are simple and require few inputs from LHC:

$$(\Delta^u_{LL})_{ij} = (\Delta^u_{RR})_{ij} = (\Delta^d_{RR})_{ij} = 0$$

$$\begin{aligned}(\Delta^d_{LL})_{ij} &= V^*_{3i}V_{3j}\left[\tilde{m}^2_{b,1} + \tilde{m}^2_{b,2} - \tilde{m}^2_{d,L} - \tilde{m}^2_{d,R}\right] \\ &= \frac{1}{3}V^*_{3i}V_{3j}\left[\tilde{m}^2_{t,1} + \tilde{m}^2_{t,2} - 2m^2_t - \tilde{m}^2_{u,L} + \tilde{m}^2_{u,R}\right]\end{aligned}$$

At moderate to high tanβ, sum rules are slightly more complicated and require more LHC input:

$$(\Delta^u_{RR})_{ij} = (\Delta^d_{RR})_{ij} = 0$$

$$\begin{aligned}(\Delta^d_{LL})_{ij} &= \frac{V^*_{3i}V_{3j}}{8}\left[3\left(\tilde{m}^2_{t,1} + \tilde{m}^2_{t,2} - \tilde{m}^2_{u_L} - \tilde{m}^2_{u_R} - 2m^2_t\right)\right. \\ &\qquad \left. - \tilde{m}^2_{b,1} - \tilde{m}^2_{b,2} + \tilde{m}^2_{d_L} + \tilde{m}^2_{d_R}\right].\end{aligned}$$

The sum rules don't just test one particular SUSY scenario, but all SUSY scenarios with MFV.

Deviations from sum rules would be strong evidence for new sources of flavor violation not encoded in the CKM matrix.

I'm skipping much...

- $b \to s\gamma$ already puts tight constraints on SUSY parameter space, especially on $H^\pm$ mass.
- $B \to \tau\nu$ places similar constraints on $H^\pm$.
- $S(B \to \Phi K_s)$ constrains many non-MFV SUSY models.

...not to mention important constraints from rare K decays, $(g-2)_\mu$, EDM measurements, μ-e conversion, etc, not relevant to SuperB but still flavor physics.

But there's more: A SuperB factory is really a Super-Flavor factory. Will produce around 10^{10} τ-pairs!

Lots of interesting New Physics in τ-sector, thanks to neutrino mixing results.

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Reminder:

- In neutrino sector, large mixings occur between ν_μ and ν_τ, and between ν_μ and ν_e.
- This νLFV translates into cLFV in SM, but with amplitudes $\propto (m_\nu/m_W)^2$. Will never be seen!

- $\Delta m^2_{23} = 2,4(1^{+0.21}_{-0.15})\times 10^{-3}\,\mathrm{eV}^2, \quad \sin^2\theta_{\mu 3} = 0.44(1^{+0.41}_{-0.22})$
- $\Delta m^2_{12} = 7.92(1\pm 0.09)\times 10^{-5}\,\mathrm{eV}^2, \quad \sin^2\theta_{e2} = 0.314(1^{+0.18}_{-0.15})$
- $\sin^2\theta_{e3} = 0.9^{+2.3}_{-0.9}\times 10^{-2}$

(Fogli et al)

Large ν-mixing but no cLFV seen!

	2000PDG	current	future
$\tau \to \mu(e)\gamma$	$< 1.1(2.7)\times 10^{-6}$	$< 6.8(11)\times 10^{-8}$	$\sim 10^{-(8-9)}$
$\tau \to \mu(e)\eta$	$< 9.6(8.2)\times 10^{-6}$	$< 1.5(2.3)\times 10^{-7}$	$10^{-(9-10)}$
$\tau \to lll$	$<\sim 10^{-6}$	$<\sim 10^{-7}$	$<\sim 10^{-(9-10)}$
$\mu \to e\gamma$	$< 1.2\times 10^{-11}$		$\sim 10^{-(13-14)}$ (MEG)
$\mu \to 3e$	$< 1.0\times 10^{-12}$		$\sim 10^{-14}$ (?)
$\mu - e$: Ti	$< 4.3\times 10^{-12}$		$\sim 10^{-18}$ (PRISM)

But there's more: A SuperB factory is really a Super-Flavor factory. Will produce around 10^{10} τ-pairs!

Lots of interesting New Physics in τ-sector, thanks to neutrino mixing results.

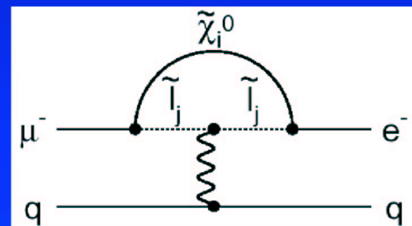
Reminder:

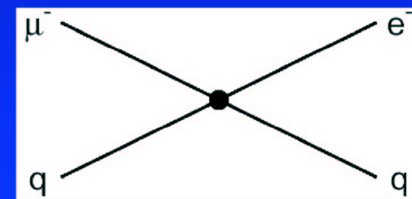
- In neutrino sector, large mixings occur between ν_μ and ν_τ, and between ν_μ and ν_e.
- This νLFV translates into cLFV in SM, but with amplitudes $\propto (m_\nu/m_W)^2$. Will never be seen!
- New Physics model often have more direct ways to turn νLFV into cLFV.

Example: μ-e conversion

Supersymmetry

Predictions at 10^{-15}





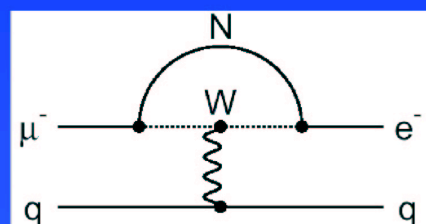
Compositeness

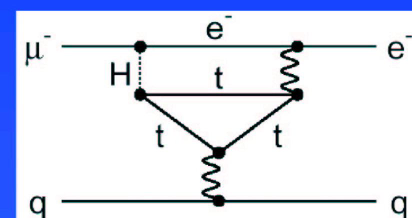
Λ_c = 3000 TeV

Heavy Neutrinos

$|U^*_{\mu N} U_{eN}|^2 =$

8×10^{-13}

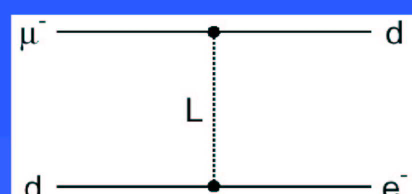


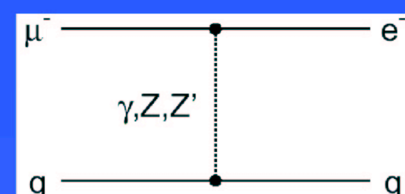


Second Higgs doublet

$g_{H\mu e} = 10^{-4} \times g_{H\mu\mu}$

Leptoquarks





Heavy Z', Anomalous Z coupling

$M_L =$

$3000\ (\lambda_{\mu d}\lambda_{ed})^{1/2}$ TeV/c^2

After W. Marciano

$M_{Z'}$ = 3000 TeV/c^2

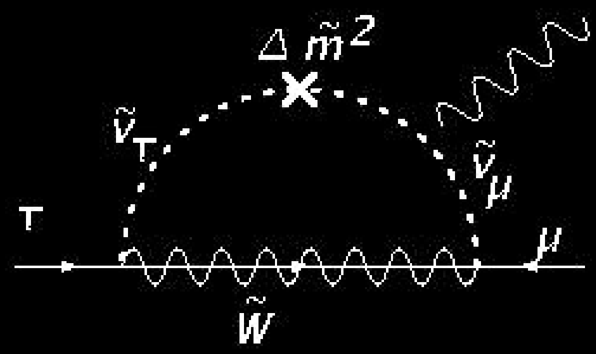
$B(Z \rightarrow \mu e) < 10^{-17}$

SUSY has a simple way to turn νLFV into cLFV:

SLEPTONS!

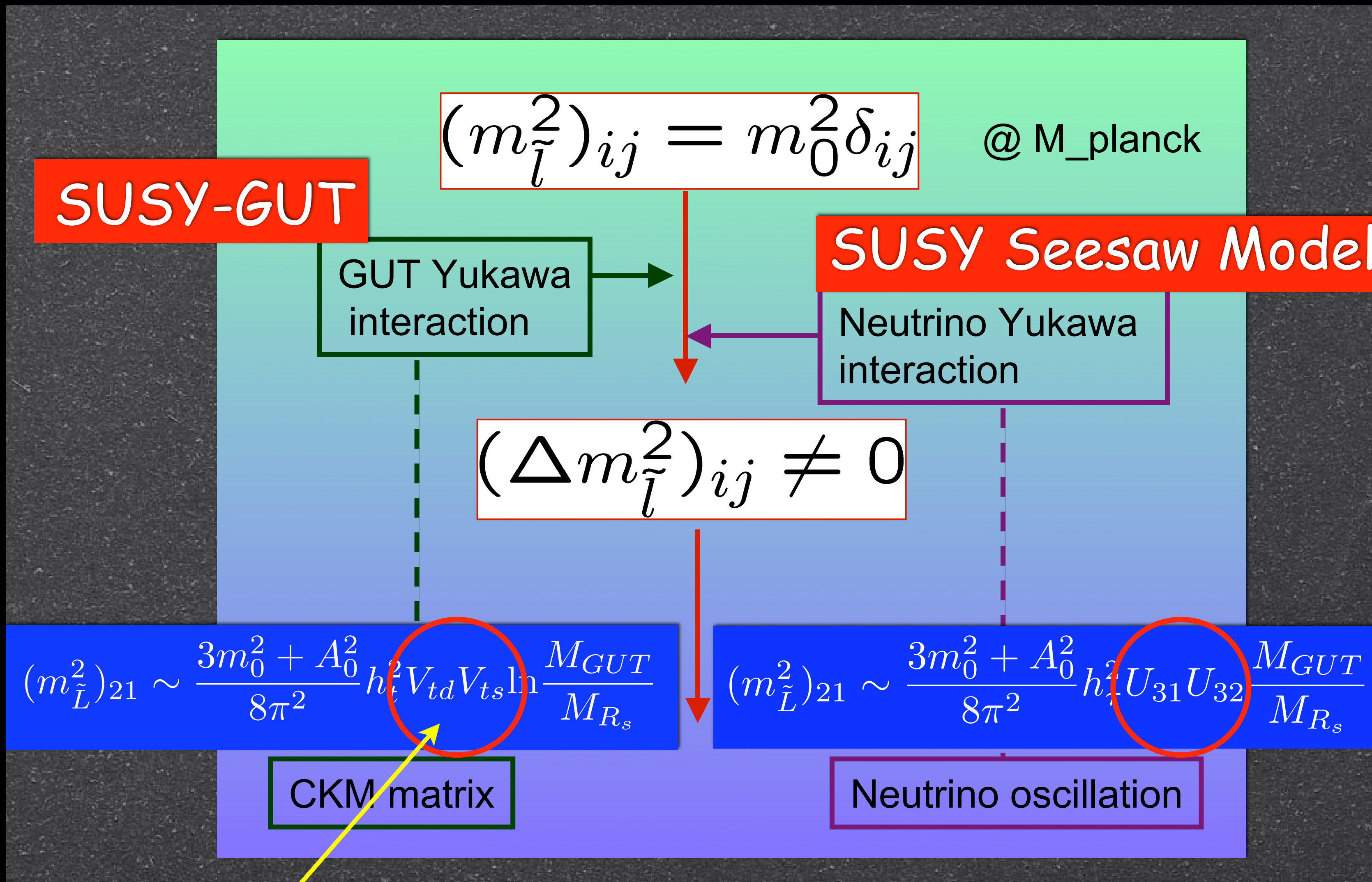
Sleptons encode the LFV in their mass matrices.

$$m_{\tilde{L}}^2 = \begin{pmatrix} \tilde{m}_e^2 & \Delta\tilde{m}_{e\mu}^2 & \Delta\tilde{m}_{e\tau}^2 \\ - & \tilde{m}_\mu^2 & \Delta\tilde{m}_{\mu\tau}^2 \\ - & - & \tilde{m}_\tau^2 \end{pmatrix}$$



The off-diagonal pieces generate cLFV at 1-loop.

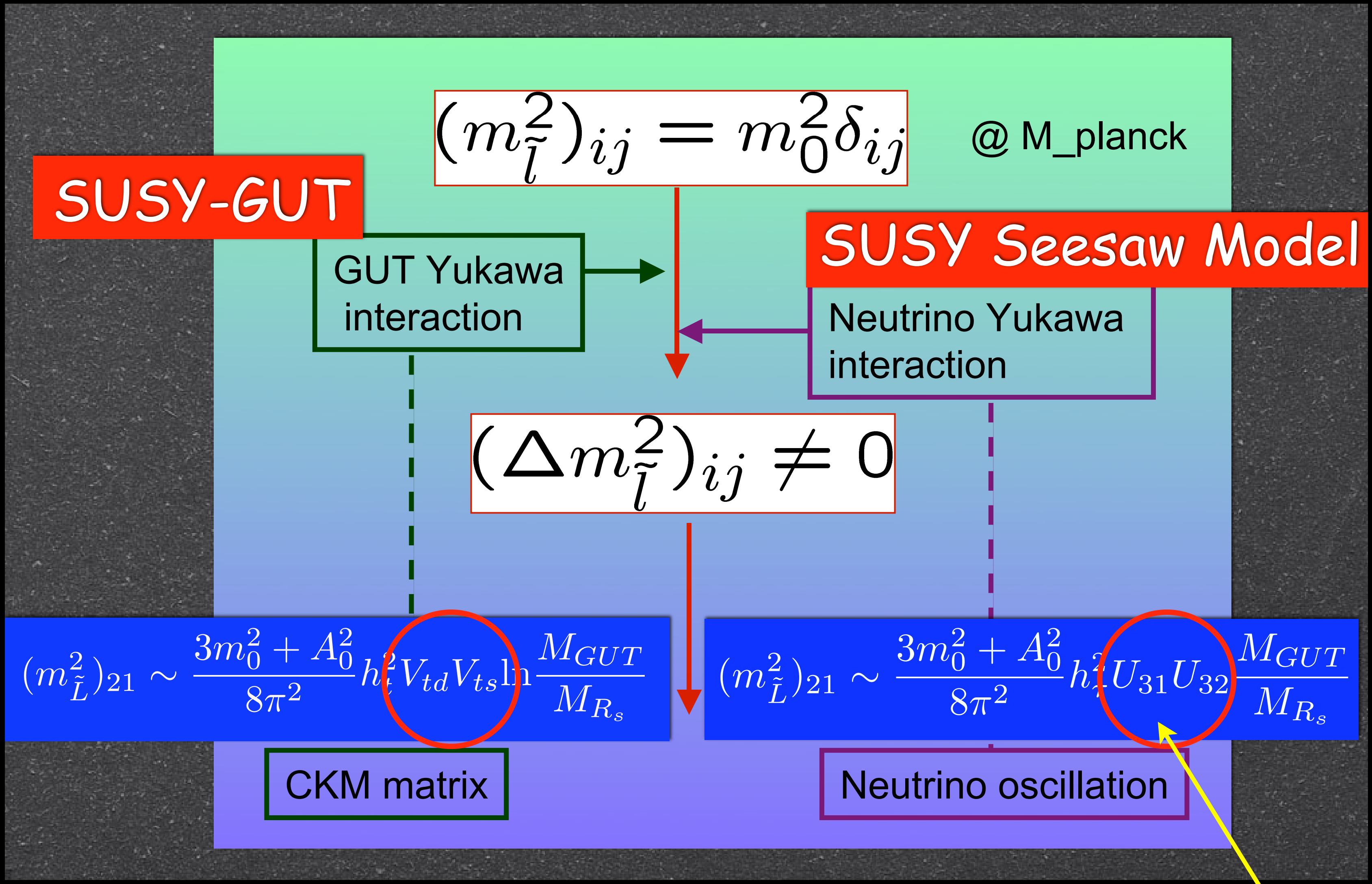
SUSY has 2 main mechanisms for generating off-diagonal slepton masses:



[Talk of Y. Kuno @ CIPANP '06]

Tied to quark mixing

SUSY has 2 main mechanisms for generating off-diagonal slepton masses:



Tied to neutrino mixing

How do ν-masses affect sleptons?

In seesaw models, there are heavy RH neutrinos and neutrino Yukawa couplings at a scale M_R, where

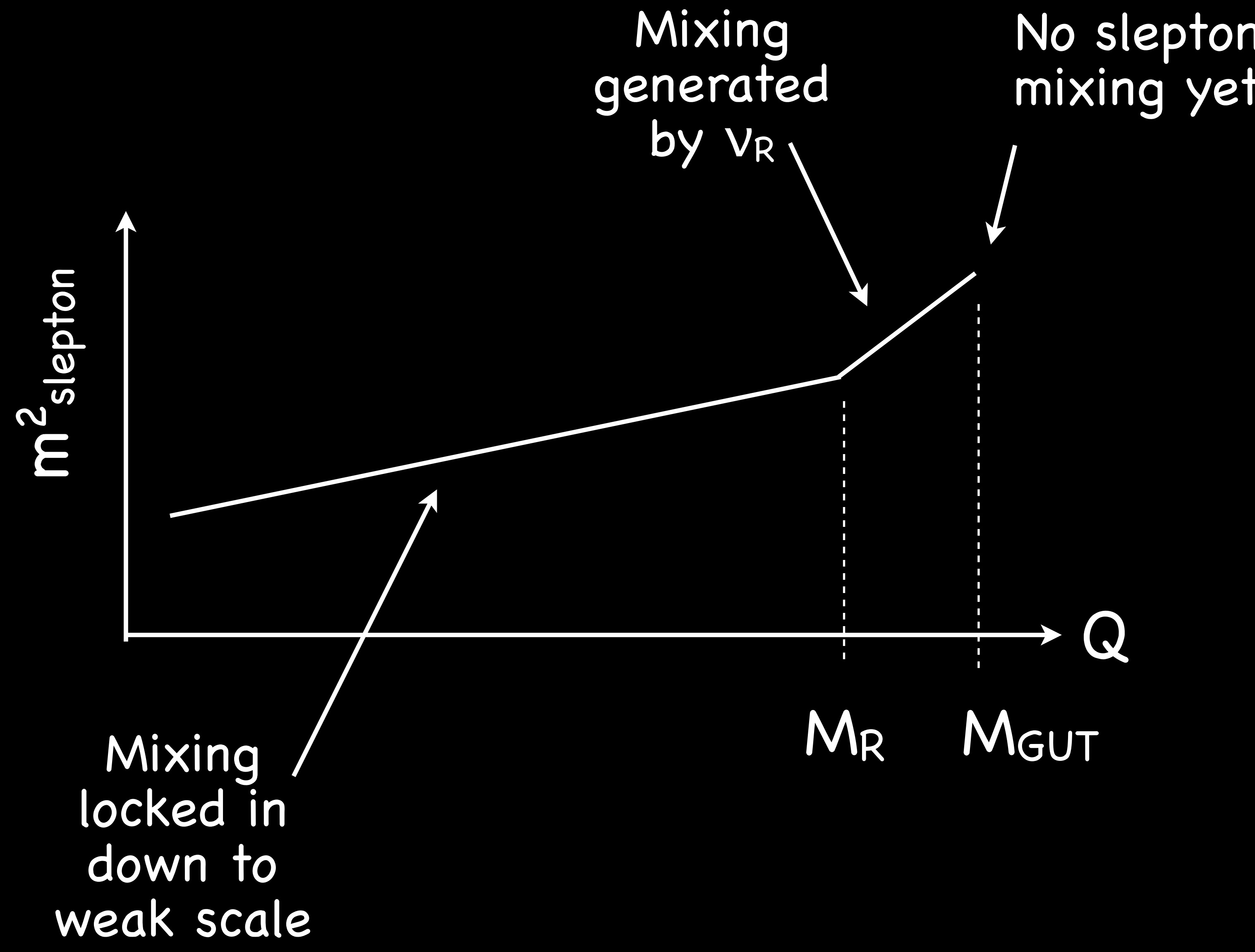
$$m_\nu = \frac{y_\nu^2 \langle H \rangle^2}{M_R}$$

At scales above M_R, the slepton mass RGE's include effects from y_ν :

$$\frac{d\tilde{m}_\ell^2}{dt} = \cdots + \frac{1}{8\pi^2} Y_\nu^\dagger Y_\nu (\tilde{m}_L^2 + \tilde{m}_E^2 + \tilde{m}_{H_u}^2 + A_\nu^2)$$

Large neutrino mixings imply Y_ν possibly highly mixed.

$$\left(\Delta m_{\tilde{\ell}}^2\right)_{ij} \simeq -\frac{\log(M_X/M_R)}{16\pi^2} \left(6 m_0^2 (Y_\nu^\dagger Y_\nu)_{ij} + 2 \left(A_\nu^\dagger A_\nu\right)_{ij}\right)$$



Mixing generated by ν_R
No slepton mixing yet
$m^2_{slepton}$
Q
M_R
M_{GUT}
Mixing locked in down to weak scale

Branching ratio $\tau \rightarrow l\gamma$ depends on slepton mass mixing:

$$\mathrm{Br}(\tau \to \mu\gamma) \simeq \frac{\alpha g^4}{64\pi^2} \frac{m_\tau^5 \tau_\tau}{M_{\mathrm{SUSY}}^4} \frac{(\delta m^2)_{23}^2}{M_{\mathrm{SUSY}}^4}$$

But there are 2 alternative ν-mass matrices:

$$m_\nu \propto \begin{pmatrix} \epsilon & \epsilon & \epsilon \\ \epsilon & s_\theta^2 & c_\theta s_\theta \\ \epsilon & c_\theta s_\theta & c_\theta^2 \end{pmatrix}$$

Normal Hierarchy

$$m_\nu \propto \begin{pmatrix} \epsilon & c_\theta & s_\theta \\ c_\theta & \epsilon & \epsilon \\ s_\theta & \epsilon & \epsilon \end{pmatrix}$$

Inverted Hierarchy

Branching ratio τ→lγ depends on slepton mass mixing:

$$\mathrm{Br}(\tau \to \mu\gamma) \simeq \frac{\alpha g^4}{64\pi^2} \frac{m_\tau^5 \tau_\tau}{M_{\mathrm{SUSY}}^4} \frac{(\delta m^2)_{23}^2}{M_{\mathrm{SUSY}}^4}$$

But there are 2 alternative ν-mass matrices:

$$m_\nu \propto \begin{pmatrix} \epsilon & \epsilon & \epsilon \\ \epsilon & s_\theta^2 & c_\theta s_\theta \\ \epsilon & c_\theta s_\theta & c_\theta^2 \end{pmatrix}$$

Normal Hierarchy

↓

τ→μγ

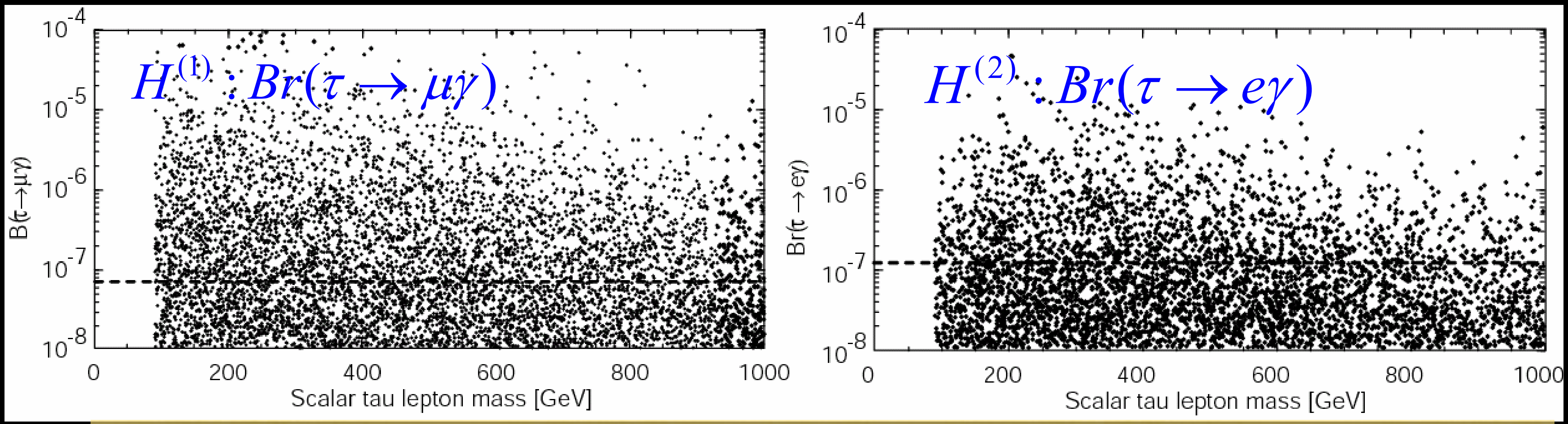
$$m_\nu \propto \begin{pmatrix} \epsilon & c_\theta & s_\theta \\ c_\theta & \epsilon & \epsilon \\ s_\theta & \epsilon & \epsilon \end{pmatrix}$$

Inverted Hierarchy

↓

τ→eγ

SuperB factory may solve an enduring problem in neutrino physics!



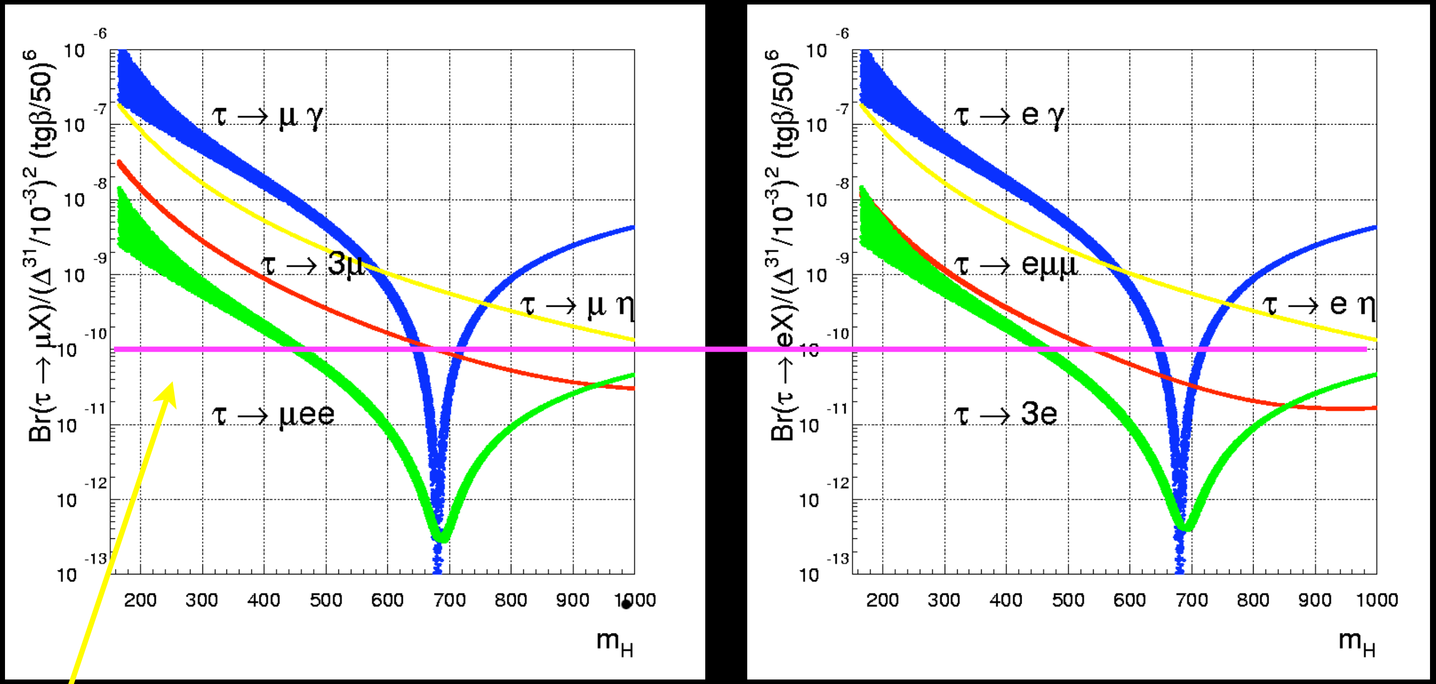
Ellis, Hisano, Raidal, Shimizu

SuperB range (10^{-9} to 10^{-10})

Most (all?) reasonable mSUGRA parameter space probed by SuperB!

Higgs bosons can also mediate cLFV in models with 2+ Higgs bosons, if tanβ large. Babu, CK

Modes are the same as standard cLFV, but ratios point to Higgs origin.



Paradisi

Approx SuperB limit

Conclusions:

- The success of the Standard Model CKM scenario under severe tests by BaBar/Belle and CDF/D0 means that there is no one golden mode around which to sell a Super-B factory.
- But we KNOW the SM is incomplete from astrophysical data and theoretical consistency. New physics is expected at TeV scale.
- A SuperB factory is needed to constrain and test the kinds of new physics seen at LHC, particularly SUSY. Is nature minimally flavor violating or not?
- A SuperB factory is needed because our arguments might simply be wrong, and we'll never know if we don't check.