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THE SUSY LINK OF LFV and CP VIOLATION IN B DECAYS *

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NOVELTIES IN FLAVOR PHYSICS

in the last few years

- ν OSCILLATIONS
  (in particular, large ν mixing in atm. ν's)
- $\varepsilon' \neq 0$ ("large" ε'/ε)
- $\sin 2\beta \neq 0$ (CP$\not{}$ in B physics)

IMPLICATIONS FOR NEW PHYSICS

ν OSC. $\Longrightarrow$ new physics originates ν masses and the large ν mixing in the 2-3 sector

"large" ε' $\Longrightarrow$ new physics can possibly account for the "large" ε' (but it is and, probably, it will be unclear whether the SM is not able to reproduce the exp. value of ε')

$\sin 2\beta$ $\Longrightarrow$ agreement of $\sin 2\beta$ as determined from $a_{J/\psi K_S}$ with the SM, but it is possible that new physics modifies other CP$\not{}$ B decays (involved with β, γ)

NEW FLAVOUR STRUCTURES IN THE S-FERMIONIC SECTOR

(i.e. mixings $\neq$ from the CKM pattern of the fermionic sector) can originate from: A) FLAVOUR SENSITIVITY OF THE SUSY BREAKING MECHANISM and/or

B) "MEMORY" IN THE RUNNING OF THE SFERMION MASSES OF "FLAVOUR UNIVERSALITY" VIOLATING CONTRIBUTIONS Hall, Kostelecky, Raby '86

i.e. it is possible that SUSY breaking is just flavour blind, but the "running" (even for a short interval) produces new flavour structures in the sfermion sector (this is generally expected in SUSY GUT's in the supergravity context)

LEPTON FLAVOR $\neq$

Yanagida ; Gell-Mann, Ramond, Slanski ; Mohapatra, Senjanovic

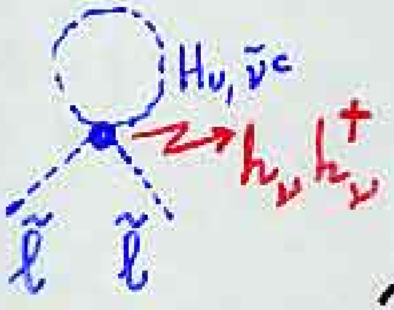
Ex: SUSY SEE-SAW MECHANISM

Borzumati, A.M. ; Leontaris, Tamvakis, Vergados ;

in SUSY SU(5) Barbieri, Hall ; Barbieri, Hall, Strumia ;

Hisano, Nomura, Yanagida ; Hisano, Moroi ; Tobe, Yamaguchi ;
Moroi ; Carvalho, Ellis, Gomez, Lola

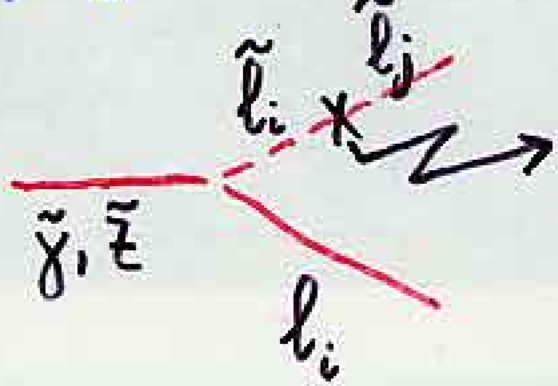
$$W = h_L L H_d e^c + h_\nu L H_u \nu^c + M \nu^c \nu^c$$



$\rightarrow h_\nu h_\nu^+ \Longrightarrow$

$$M_{\tilde{\ell}_L \tilde{\ell}_L^+} = \tilde{m}^2 \mathbb{1} + m_\ell m_\ell^+ + c\, m_\nu^D m_\nu^{D+}$$

$$m_\nu^D = h_\nu \langle H_u \rangle$$



$$\Delta^\ell_{ij} = c \left(\underbrace{U}_{\text{diagonalizes } m_\ell m_\ell^+} m_\nu^D m_\nu^{D+} U^+ \right)_{ij}$$

for $m_\nu^D \sim 10-20$ GeV and $U \sim K_{CKM}$

$$BR(\mu \to e\gamma) \sim 10^{-12} \div 10^{-13}$$

and also $\mu - e$ conversion in nuclei close to the exp. bound

link between neutrino mass textures $\rightarrow \mu \to e\gamma$ in SUSY

CASAS et al.
Lavignac et al.

LEPTON FLAVOUR VIOLATION IN MINIMAL SUSY SU(5)

Barbieri, Hall; Barbieri, Hall, Strumia; Hisano, Moroi, Tobe, Yamaguchi; Hisano, Nomura, Yanagida; Ciafaloni, Romanino, Strumia; Baek, Goto, Okada, Okumura

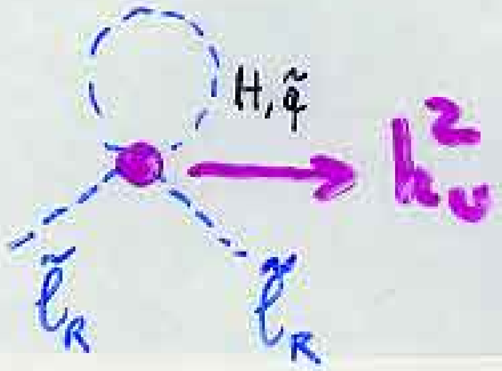
- assume universal soft breaking terms at M_{Planck}

- in the running $M_{Planck} \to M_{GUT}$

  $m^2_{\tilde{\ell}_R}$ receives contributions from loops $\propto$ top Yukawa couplings

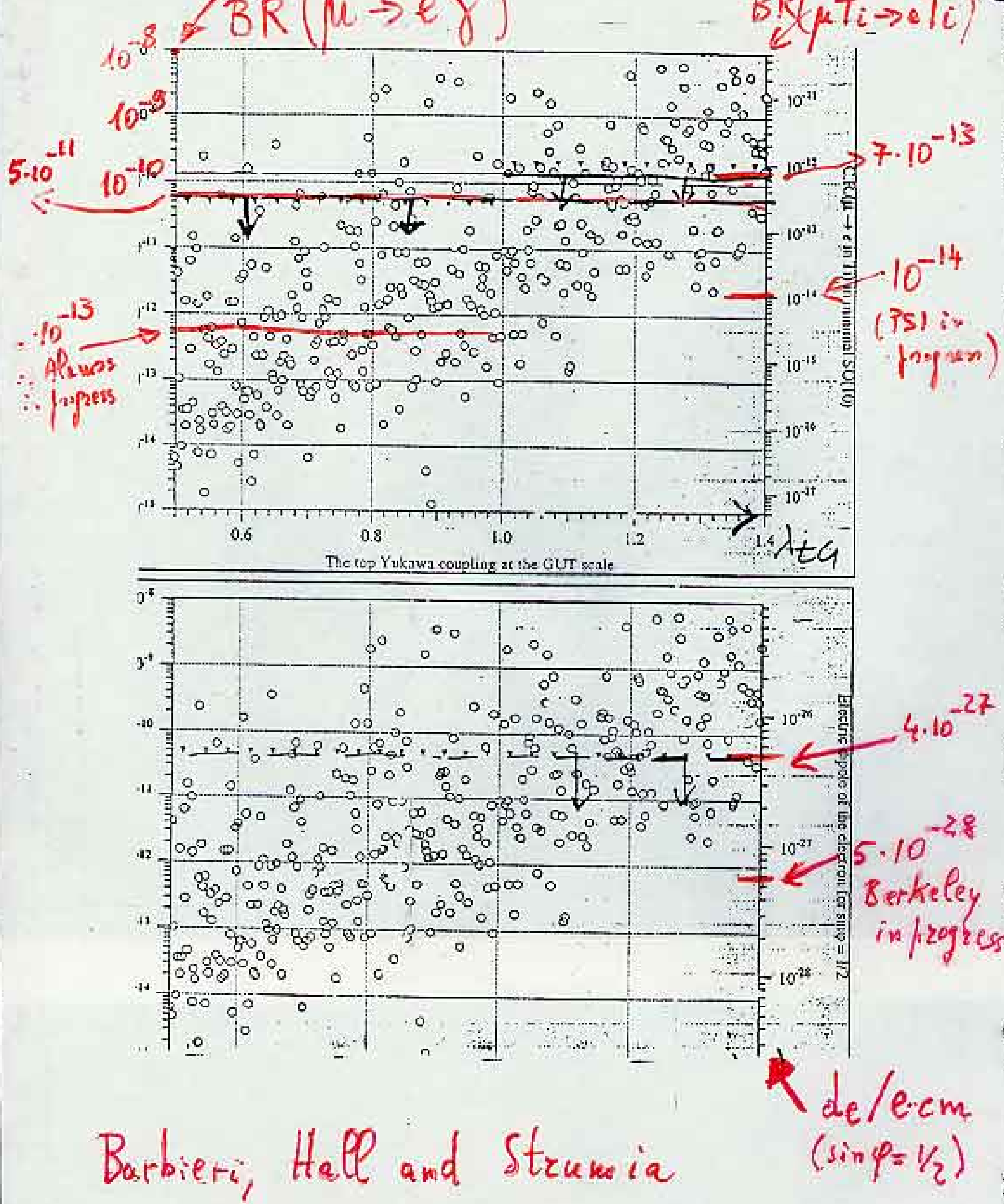
$h_u \, 10 \cdot 10 \cdot 5_H$

$\tilde{\ell}_R \in 10$



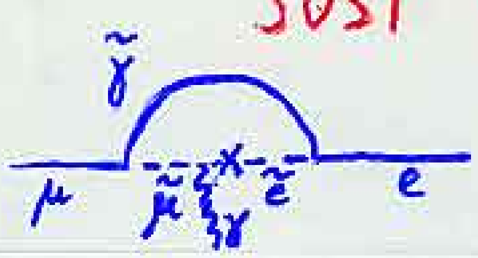
$\to$ large (negat.) contribution to $m^2_{\tilde{\ell}_R}$

$\Rightarrow m^2_{\tilde{\ell}_R}, m^2_{e}$ no longer simult. diag. at M_{GUT}



Barbieri, Hall and Strumia

SUSY SO(10) MODEL



$$W = W_0 + \nu_R^{cT} Y_\nu L H^u - \frac{1}{2} \nu_R^{cT} \mathcal{M} \nu_R$$

$\mathcal{M} \simeq M \mathbb{1}$ (but in SO(10) $\mathcal{M}$ hierarch.)

$$W_{eff} = W_0 + \frac{1}{2} (Y_\nu L H^u) \mathcal{M}^{-1} (Y_\nu L H^u)$$

$$\delta \mathcal{L}_{\nu mass} = -\frac{1}{2} \nu^T \mathcal{M}_\nu \nu + h.c.$$

$$\mathcal{M}_\nu = Y_\nu^T \mathcal{M}^{-1} Y_\nu \langle H_0^u \rangle^2 \equiv m_D^T \mathcal{M}^{-1} m_D$$

$\langle H_0^u \rangle^2 \simeq v^2 \sin^2\beta \quad v = 174$ GeV

$$U^T \mathcal{M}_\nu U = \mathrm{diag}\left(m_{\nu_1} \; m_{\nu_2} \; m_{\nu_3} \right)$$

take hierarchical m_ν :

$m_{\nu_1} \sim 0$

$m_{\nu_2} \sim \sqrt{\Delta m^2_{solar}}$

$m_{\nu_3} \sim \sqrt{\Delta m^2_{atm}}$

neglecting phases

$$U \sim \begin{pmatrix} 1 & 0 & 0 \\ 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 0 & -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

single maximal mixing (in the ν_{atm} sector)

$$U \sim \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \\ -\frac{1}{2} & \frac{1}{2} & 1/\sqrt{2} \\ \frac{1}{2} & -\frac{1}{2} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

bimaximal mixing (if also large mixing in ν_{solar} → now LMA in MSW is slightly favoured by the data)

CASAS, IBARRA
LAVIGNAC, MASINA, SAVOY; in SO(10) BUCHMULLER, WYLER
CARVALHO, ELLIS, GOMEZ, LOLÁ

$$\left(Y_\nu^+ Y_\nu\right)_{ij} \simeq M\left[\frac{m_{\nu_2}}{v_u^2} U_{i2} U_{j2}^* + \frac{m_{\nu_3}}{v_u^2} U_{i3} U_{j3}^*\right]$$

$$\left|\left(Y_\nu^+ Y_\nu\right)_{23}\right| \sim \left|M \frac{m_{\nu_3}}{v_u^2} U_{23} U_{33}^*\right| \sim \frac{1}{2}\left|Y_0\right|^2$$

$|Y_0|^2 \rightarrow$ largest eigenvalue of $Y_\nu^+ Y_\nu$

$\left|Y_0(M_x)\right| = \left|Y_t(M_x)\right|$ unif. condition

$t-\nu_\tau$ unif. (in addition to $b-\tau$ unif.)

if t-ν_τ unif. :

$$(Y_\nu^+ Y_\nu)_{23} \sim \frac{1}{2} Y_t^2$$

$$(\Delta^\ell_{23})_{LL} \sim -\frac{1}{8\pi^2}\left(3m_0^2 + A_0^2\right)(Y_\nu^+ Y_\nu)_{23} \log \frac{M_{Pl}}{M_X}$$

$$\Rightarrow (\delta^\ell_{23})_{LL} \sim \frac{(\Delta^\ell_{23})_{LL}}{\tilde{m}^2} \sim 0.2-0.3$$

(upper bound on $(Y_\nu^+ Y_\nu)_{\mu\tau} \log \frac{M_{Pl}}{M_X}$ for $Br(\tau \to \mu\gamma) < 1.1 \times 10^{-6}$ Lavignac, Masina, Savoy allowed to take $(Y_\nu^+ Y_\nu)_{\mu\tau} \sim h_t^2/2$)

$$(Y_\nu^+ Y_\nu)_{12} \sim M\left(\frac{m_{\nu_2}}{v_u^2} U_{12} U_{22} + \frac{m_{\nu_3}}{v_u^2} U_{13} U_{23}\right)$$

$$\sim M \frac{m_{\nu_2}}{v_u^2} U_{12} U_{22} \underset{\uparrow}{\sim} \frac{1}{2\sqrt{2}}\left(\frac{m_{\nu_2}}{m_{\nu_3}}\right)|Y_0|^2$$

if bimaximal (~ 0 if single maximal)

$\rightarrow$ respects $BR(\mu \to e\gamma) < 1.2 \times 10^{-11}$

So far:

$$\left.\begin{array}{l}\text{LARGE } \nu \text{ MIXING} \\ + \\ \text{LARGE } Y_\nu\end{array}\right\} \Rightarrow \begin{array}{l}\text{LARGE} \\ \Delta^{\ell}_{LL}\end{array}$$

significant effects in LFV physics

Now: add LEPTON-QUARK UNIFICATION

example: $SU(5)$ $d^c \leftrightarrow \nu$ MORO1 p0104263

$SO(10)$ $u \leftrightarrow \nu$ CHANG, A.M., MURAYAMA (in progress)

$\Rightarrow$ LARGE Δ^{ℓ} TRANSLATE INTO

LARGE Δ^{d}

$\rightarrow$ large $(\delta^{\ell}_{LL})_{23}$ $\rightarrow$ large $(\delta^{d}_{RR})_{23}$

$\Rightarrow$ effects for B physics

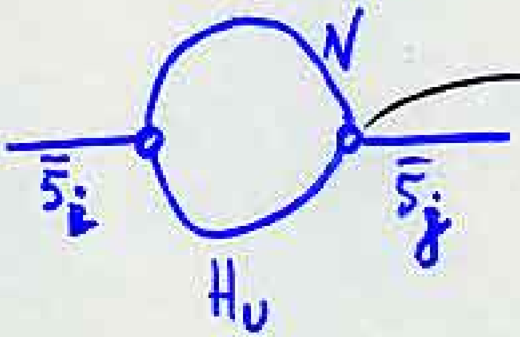
SU(5)

$$\psi_i (Y_U)_{ij}\, \psi_j\, H_U \qquad \psi_i (Y_D)_{ij}\, \phi_j\, H_D$$

$$N_i (Y_\nu)_{ij}\, \phi_j\, H_U \qquad N_i (M_N)_{ij}\, N_j$$

$\psi \to 10 \quad \phi \to \bar{5} \quad N \to 1 \quad H_U \to 5 \quad H_D \to \bar{5}$

MOROI $$(m^2_{\tilde{D}_R})_{ij} \simeq -\frac{1}{8\pi^2}\left(Y_\nu^+ Y_\nu\right)_{ij}\left(3m_0^2 + A_0^2\right)\ln\frac{M_*}{M_{GUT}}$$



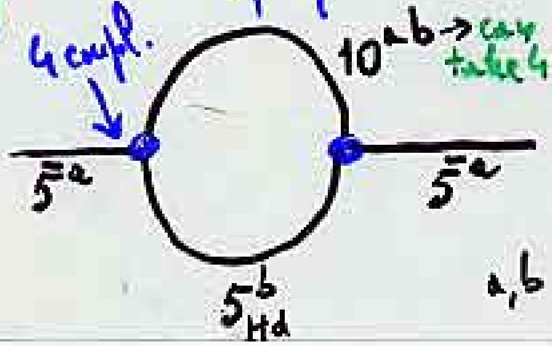
1 coupling

in SO(10) $\quad h\ 16\ 16\ 10_U \qquad h'\ 16'\ 16'\ 10_D$

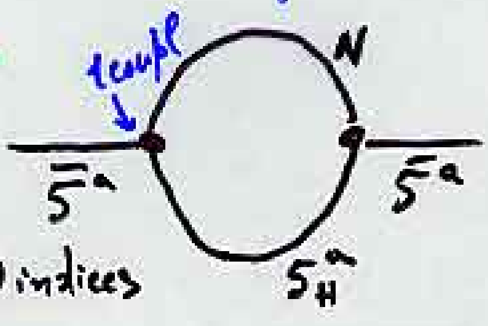
mass to the up-quarks $\qquad$ mass to the down-quarks

D. CHANG
A. M
H. MURAYAMA
(in progress)

$(m^2_{\tilde{D}_R})_{ij} \Longrightarrow$



a, b SU(5) indices



$\Rightarrow$ from $SU(5)$ to $SO(10)$ factor 5

multiplying $-\frac{1}{8\pi^2}(3m_0^2 + A_0^2)(Y_\nu^\dagger Y)_{ij} \ln \frac{M_{PP}}{M_{GUT}}$

even larger $(\delta^d_{23})_{RR}$ in $SO(10)$!

$(\delta^d_{23})^{SO(10)}_{RR} \sim 5\, (\delta^d_{23})^{SU(5)}_{RR}$

in SUSY GUT's with $d_R \leftrightarrow \nu$

$\Downarrow$

expect large $(\delta^d_{23})_{RR}$ as a result of:

- LARGE MIXING IN ν_{ATM}
- LARGE TOP YUKAWA COUPL
- quark-lepton unif.

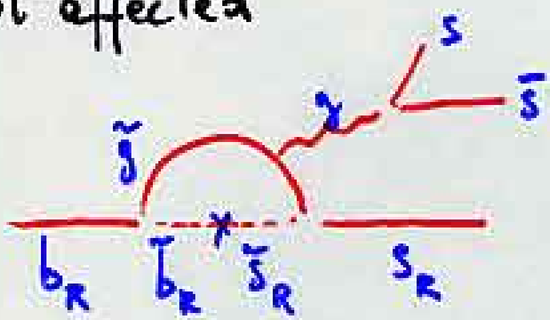
IMPLICATIONS OF A LARGE $(\delta^d_{23})_{RR}$ (with possibly a large phase)

Chang, A.M., Murayama

- ΔM_s : ΔM_s^{SUSY} becomes comparable to ΔM_s^{SM}
- $b \to s\gamma$: no sizeable effect
- effects on $\sin 2\beta$:

$B_d \to J/\psi K_S$ not affected

$B_d \to \phi K_S$



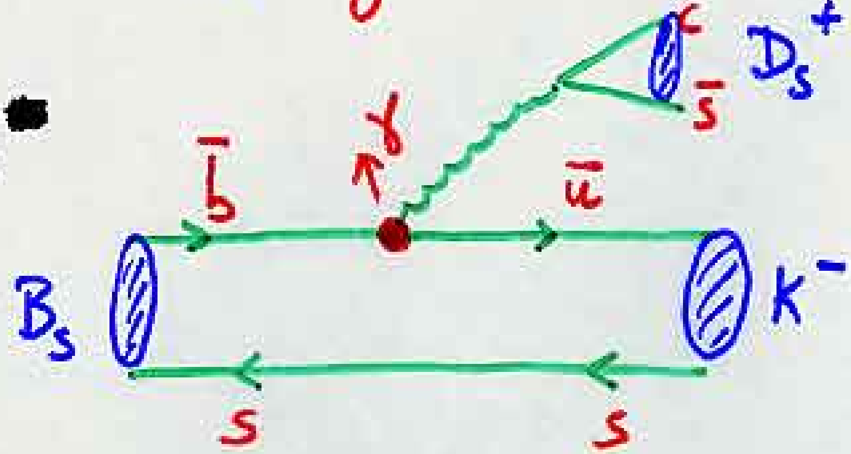
from Ciuchini et al. for $(\delta^d_{23})_{RR} \simeq 1$

$$\frac{A^{SUSY}_{B\to\phi K_S}}{A^{SM}_{B\to\phi K_S}} \begin{cases} 0.7 \text{ for } \tilde{m} \sim 500 \text{ GeV} \\ 0.2 \text{ for } \tilde{m} \sim 950 \text{ GeV} \end{cases}$$

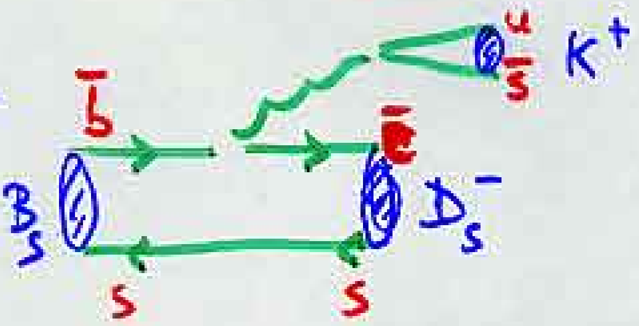
$\Rightarrow$ if $(\delta^d_{23})_{RR}$ has also a large phase: $\sin 2\beta$ measured from $B \to J/\psi K_S$ and $B \to \phi K_S$ could differ as much as 50% due to the new SUSY contributions

EFFECTS OF A LARGE $(\delta^d_{23})_{RR}$ on the DETERMINATION OF γ

1) $B_s \to D_s^+ K^-$



$B_s \to D_s^- K^+$



B_s can reach $D_s^+ K^-$ either through the $b\bar{u}$ vertex or first oscillating to $\bar{B}_s$ with $\bar{B}_s$ then decaying into $D_s^+ K^-$ via a normal $b\bar{c}$ vertex

SM:

$$\frac{\overset{\gamma}{A(B_s \to D_s^+ K^-)}}{\underset{\text{no phase}}{A(B_s - \bar{B}_s)}\ \underset{\text{no phase}}{A(\bar{B}_s \to D_s^+ K^-)}} \Longrightarrow \gamma$$

SUSY + SM :

$$\frac{A\left(B_s \xrightarrow{\gamma} D_s^+ K^-\right)}{A\left(B_s - \bar{B}_s\right) A\left(\bar{B}_s \to D_s^+ K^-\right)}$$

$2\varphi_d$

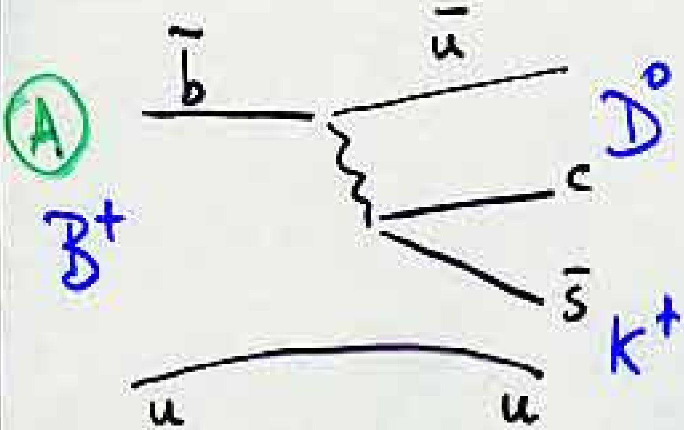
if $(\delta_{23}^d)_{RR} = |(\delta_{23}^d)_{RR}| e^{i\varphi_d}$

$$A(B_s - \bar{B}_s) = A^{SM}(B_s - \bar{B}_s)\left(1 + \frac{b_{box}^{SUSY}}{b_{box}^{SM}} e^{2i\varphi_d}\right)$$

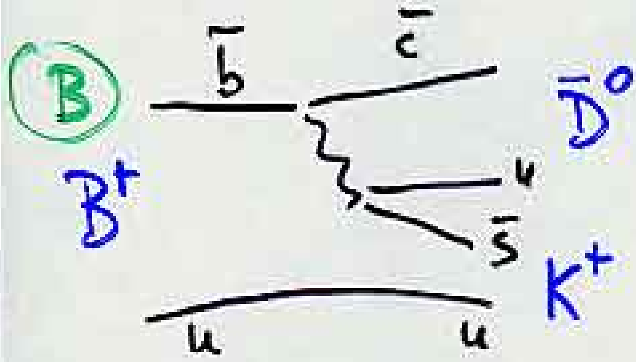
if $(\delta_{23}^d)_{RR}$ large $b_{box}^{SUSY} \sim b_{box}^{SM}$

$\Rightarrow$ for large $|(\delta_{23}^d)_{RR}|$ and large φ_d the determination of "γ" from $B_s \to D_s^+ K^-$ can be strongly affected by $\mathrm{Im}\,(\delta_{23}^d)_{RR}$

2) $B^\pm \to D^0 K^\pm$



expected BR $\sim 2\cdot 10^{-6}$



$B^+ \to \bar{D}^0 K^+$

expected BR $\sim 2\times 10^{-4}$

in $B^+ \to D_{CP} K^+$ interference of A and B

$\Rightarrow \gamma$

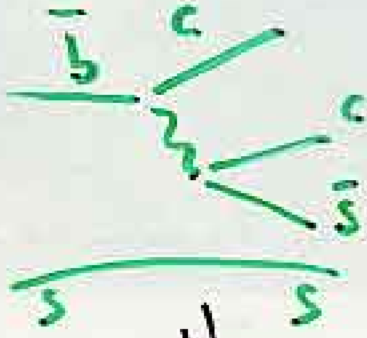
Here No SUSY contribution

"γ" as determined from $B^+ \to D^0 K^+$ and from $B_s \to D_s^+ K^-$ would be quite different for large $(\delta^d_{23})_{RR}$

STRIKING EFFECT OF A LARGE COMPLEX $(\delta^d_{23})_{RR}$

CP$\not=$ in some B decays which are expected to be essentially CP conserving in the SM

ex : $B_s \to J/\psi\, \phi$ (expected BR ~ 10^{-3})



no phase

interference with
$B_s \to \bar{B}_s \to J/\psi\, \phi$

also here
no phase in SM
but φ_d in SUSY

$\Rightarrow$ possible large CP asymmetry for large $(\delta^d_{23})_{RR}$ and large φ_d

Just a conclusive thought

The only strong, direct evidence for new physics beyond the SM so far:

ν mixings and masses

ν mass $\Rightarrow$ "best" mechanism (at least in 4-dim): see-saw

see-saw

$\not{L}$, if $\not{CP}$ in ν_R decays
LEPTOGENESIS $\Rightarrow$ BARYOGENESIS

if also SUSY (in a GUT scheme)
$\Rightarrow$ sizeable departures from SM expectations in $\not{CP}$ B decays

* this is true even if SUSY breaking is completely flavor blind *

ν masses could lead to some new physics surprise also in the hadronic sector ...