SEESAW 25
10-11 JUNE 2004
Institut Henri Poincaré,
Paris

SEESAW MECHANISM and SUPERSYMMETRY

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Univ. and INFN, Padova

- SUSY "MEMORY": FCNC at M_W from physics affecting sfermion masses at superlarge scales ⇒ the seesaw case
- LFV from SUSY SEESAW: SUSY SO(10) and minimal supergravity examples
- SUSY SEESAW and the QUARK-LEPTON FCNC CONNECTION

CONVERGENCE TO CKM SM PHYSICS

? ↓ ?

FLAVOR BLINDNESS OF LOW ENERGY NEW PHYSICS

i.e. CONTRIBUTIONS OF NEW PHYSICS TO FC PROCESSES CONFINED TO ADDITIONAL LOOPS WITH EXCHANGES OF NEW PARTICLES BUT GOVERNED BY THE CKM MIXINGS

$\Rightarrow$ NO NEW "FLAVOR STRUCTURES" AT LOW ENERGY

THIS IS A POSSIBILITY, BUT DATA SO FAR DO NOT NECESSARILY IMPLY SUCH STRICT LOW ENERGY FLAVOR BLINDNESS

MECHANISMS

SUSY BREAKING — **ORIGIN of FLAVOR**

a) KNOW EACH OTHER

$\Rightarrow$ SOFT SUSY BREAKING TERMS CARRY NEW (NON-CKM) FLAVOR STRUCTURES

b) SUSY BREAKING IGNORES FLAVOR

$\Rightarrow$ SUSY FLAVOR BLINDNESS

STRONG FLAVOR BLINDNESS

ONLY CKM at M_W

$\rightarrow$ hard to have SUSY novelties in FCNC

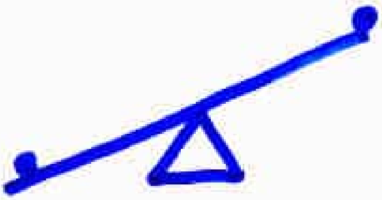
possibilities: EDMs, $(g-2)_\mu$, $B_s \to \mu^+\mu^-$, $a_{CP}(b \to s\gamma)$

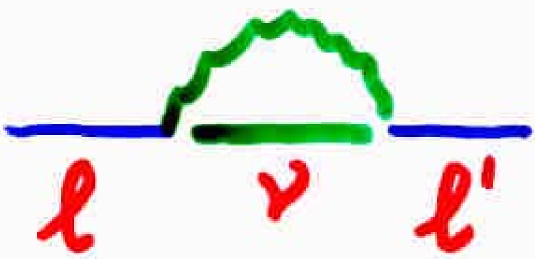
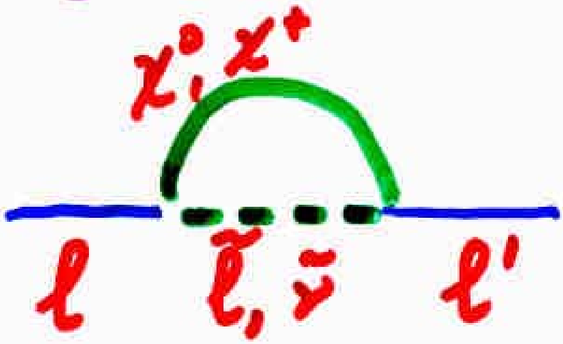
WEAK FLAVOR BLINDNESS

SOFT BREAKING UNIVERSAL AT

LARGE SCALE where soft terms appear

$\Rightarrow$ RG running SPOILS FLAVOR BLINDNESS

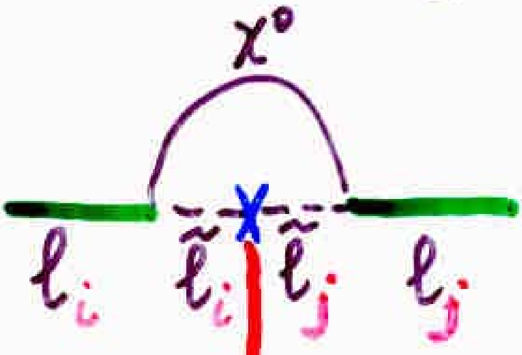
LFV and 

SM	SUSY
	

GIM $\Rightarrow$ $\dfrac{m_\nu^2}{M_W^2} < 10^{-24}$

superGIM $\Rightarrow$ $\dfrac{\Delta m_{\tilde{\ell}}^2}{\tilde{m}^2}$ can be $\gg m_\nu^2/M_W^2$

SUSY ex. :

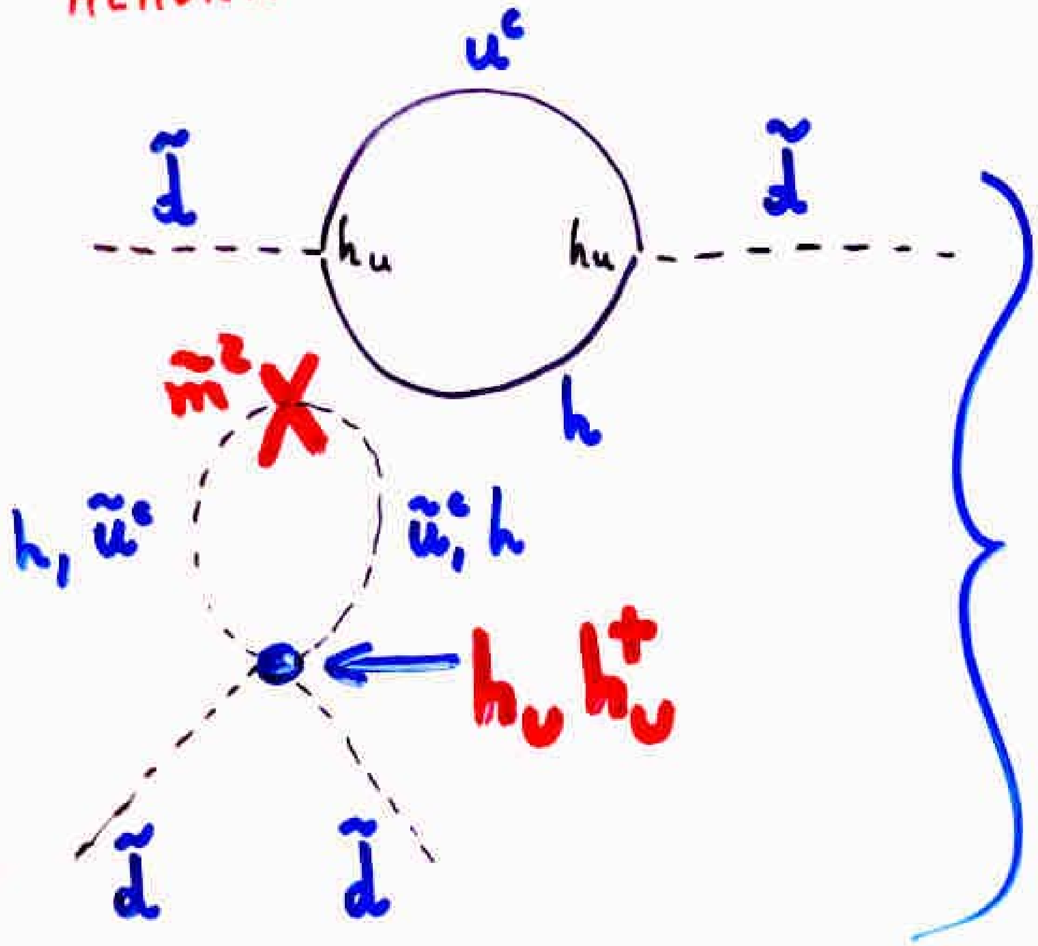


$$\Delta^{\ell}_{ij} \longrightarrow \begin{array}{c|cc} & \tilde{\ell}_i & \tilde{\ell}_j \\ \hline \tilde{\ell}_i & & \\ \tilde{\ell}_j & & \end{array}\!\!\!\!\begin{pmatrix} m_0^2 & \Delta_{ij} \\ \Delta_{ji} & m_0^2 \end{pmatrix}$$

$\dfrac{\Delta_{ij}}{\tilde{m}^2}$ $\leftarrow$ measure of the amount of FCNC

in the basis where m_ℓ is diagonal

SUSY LOW-ENERGY FLAVOR STRUCTURE:
"MEMORY" OF FLAVOR STRUCTURES IN $M_X \rightarrow M_W$ RUNNING



if $\tilde{m}^2$ is absent
$\Downarrow$
SUSY cancellation

if $\tilde{m}^2 \neq 0$
$\Downarrow$
broken SUSY softly

logarithmic divergence

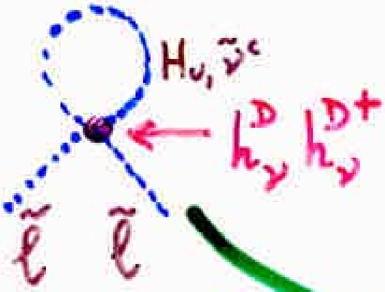
$\Rightarrow$ term $\propto h_u h_u^+$ enters the running of $m^2_{\tilde{d}\tilde{d}}$

"**MEMORY**" at low energy via the running of all interactions encountered by s-fermions from M_{Pl} to M_W

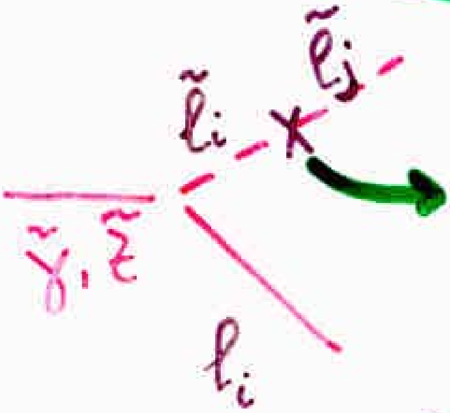
SUSY SEE SAW

→ possible example of SUSY WEAK FLAVOR BLINDNESS ←

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



$$\Rightarrow M^2_{\tilde\ell_L \tilde\ell_L^*} = \tilde m_0^2 \mathbb{1} + m_\ell m_\ell^+ + c\, m_\nu^D m_\nu^{D+}$$



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

F. BORZUMATI, A. MASIERO 1986

(after discussions with W. Marciano and A. Sanda)

at that time: for $m_\nu^D \sim 10-20$ GeV and

$U \sim V_{CKM}$ ⇒ $BR(\mu \to e\gamma) \sim 10^{-12} - 10^{-13}$

and also $\mu - e$ conversion in nuclei close to the exp. bound ($\tau \to \mu\gamma$ later by Blazek, King)

1986 → 2004: much progress in "ν knowledge"

$U, m_\nu^D \overset{?}{\Longleftrightarrow}$ PHYSICAL ν MASSES and MIXINGS

INFO FROM ν masses and mixings is NOT sufficient to fully determine the U, m_ν^D seesaw parameters CASAS, IBARRA '01

TOP-DOWN APPROACH (specific SUSY GUT models and/or flavor symmetries)

HISANO, NOMURA, YANAGIDA ; KING, OLIVEIRA ;
ELLIS, GOMEZ, LEONTARIS, LOLA, NANOPOULOS ;
BAEK, GOTO, OKADA, OKUMURA ; HISANO, TOBE ;
CARVALHO, ELLIS, GOMEZ, LOLA ; GONZALEZ FELIPE, JOAQUIM ;
ROMANINO, STRUMIA ; KAGEYAMA, KANEKO, SHIMOYAMA, TANIMOTO ;
DEPPISCH, PAES, REDELBACH, RUCKL, SHIMIZU ; FALCONE ;
BABU, DUTTA, MOHAPATRA ; HAMAGUCHI, KAKIZAKI, YAMAGUCHI ;
HISANO, SHIMIZU ; HUANG, LI, LIAO ; FUKUYAMA, KIKUCHI, OKADA ;
DUTTA, MOHAPATRA ; FENG, HUANG, LI, ZHANG, ZHAO ; KING, PEDDIE ;
ILLANA, MASIP ; BABU, ENKHBAT, GOGOLADZE ; TOBE, WELLS, YANAGIDA
IBARRA, ROSS ;
SATO, TOBE, YANAGIDA ; SATO, TOBE ; BI ;
ELLIS, RAIDAL, YANAGIDA ; BARR ; A.M., VEMPATI, VIVES

BOTTOM-UP APPROACH (specif parametrizations of low-energy unknowns)

DAVIDSON, IBARRA ; LAVIGNAC, MASINA, SAVOY ; ELLIS, HISANO, RAIDAL, SHIMIZU
PASCOLI, PETCOV, RODEJOHANN ; PETCOV, PROFUMO, TAKANISHI, YAGUNA ;
PETCOV, PASCOLI, YAGUNA

LFV $\left\{\begin{array}{l} \text{- how large } h_\nu^{DIRAC} \\ \\ \text{- how large } U \rightarrow \text{mismatch in the diagonalization of } m_\ell m_\ell^+ \text{ and } m_\nu^D m_\nu^{D+} \end{array}\right.$

CASAS, IBARRA
LAVIGNAC, MASINA, SAVOY;
CARVALHO, ELLIS, GOMEZ, LOLA

from $h_\nu L \nu^c H_u$ and $M \nu^c \nu^c$

$$M_\nu = h_\nu^T M^{-1} h_\nu v_u^2 \equiv m_\nu^{DT} M^{-1} m_\nu^D$$

$$U^T_{MNSP} M_\nu U_{MNSP} = \mathrm{diag}\left(m_{\nu_1} \; m_{\nu_2} \; m_{\nu_3}\right)^*$$

$$U_{MNSP} \sim \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1/\sqrt{2} & 1/\sqrt{2} \\ 0 & -1/\sqrt{2} & 1/\sqrt{2} \end{pmatrix}$$

single maximal mixing (ν_{atm} sector)

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

bimaximal mixing ($\nu_{atm} + \nu_{solar}$ LMA)

* hierarchical m_ν : $\left\{\begin{array}{l} m_{\nu_1} \sim 0 \\ m_{\nu_2} \sim \sqrt{\Delta m^2_{sol}} \\ m_{\nu_3} \sim \sqrt{\Delta m^2_{atm}} \end{array}\right.$

SO(10) $\Rightarrow$ LARGE h_t implies that

AT LEAST ONE h^D_ν IS LARGE

(if only $\underline{10}$'s $\Rightarrow$ quark-lepton Pati-Salam symm. $\Rightarrow$ $h_u = h^D_\nu$
$\rightarrow h_t = h^D_{\nu_3}$
but it holds true even if $\underline{126}$, $\underline{120}$ are present)

LINK U (matrix diagonalizing $m^D_\nu m^{D+}_\nu$)

U_{MNSP} (matrix diagonalizing M_ν)

depends on $M \rightarrow M_{\nu^c\nu^c}$

two "extreme" cases :

$U = U_{MNSP}$ (ex. $M \propto \mathbb{1}$)

$U = V_{CKM}$ (then M has a non-trivial structure to allow for the large mixings in U_{MNSP}

SO(10) $\rightarrow$ Buchmüller, Wyler

SUSY SO(10)

A.M., VEMPATI, VIVES

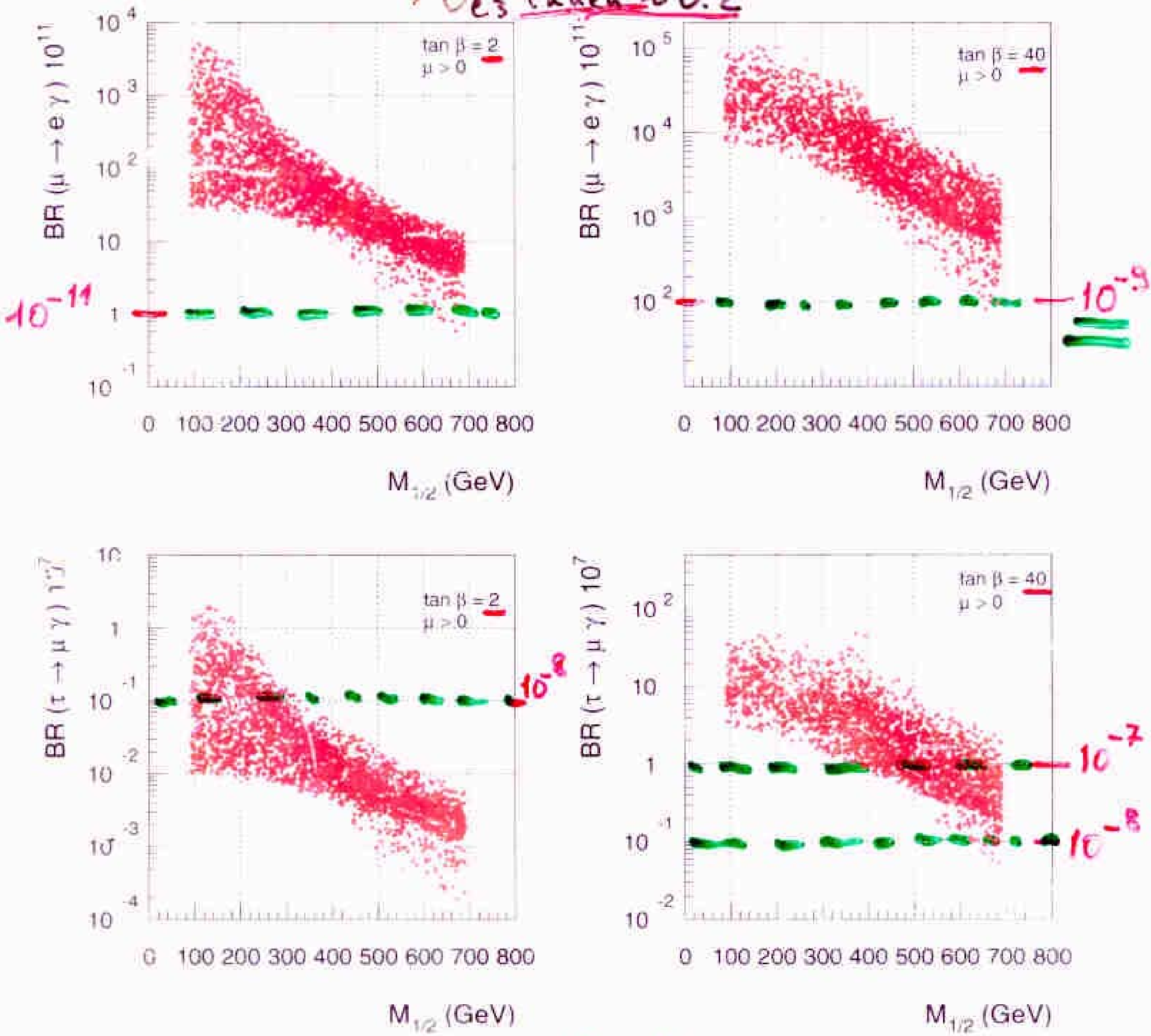
$$\begin{cases} \mu \to e\gamma \\ \tau \to \mu\gamma \end{cases}$$

"FAVOURABLE CASE": M_ν^{DIRAC} DIAGONALIZED BY MNS MATRIX $\rightarrow$ MAXIMAL MIXING

$$\tau \to \mu\gamma \propto (MNS^\dagger)_{23} \times (MNS^\dagger)_{33} \times h^2(t)$$

$$\mu \to e\gamma \propto (MNS^\dagger)_{13} \times (MNS^\dagger)_{23} \times h^2(t)$$

↳ U_{e3} taken ~0.2



SEE ALSO: SLEPTONARIUM by MASINA-SAVOY

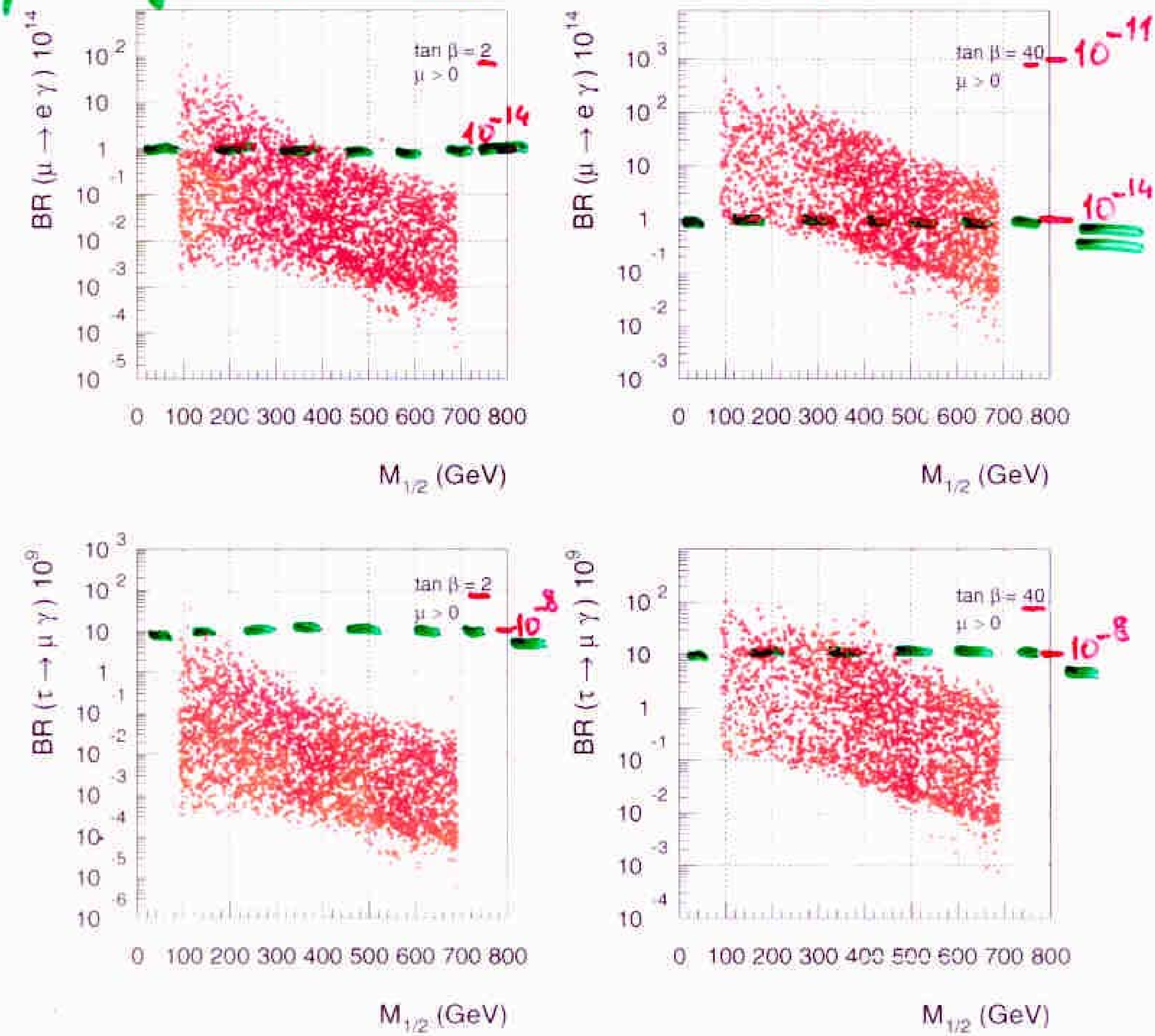
SUSY SO(10) $\left\{ \begin{array}{l} \mu \to e\gamma \\ \tau \to \mu\gamma \end{array} \right.$

A.M., VEMPATI, VIVES

"UNFAVOURABLE CASE" : M_ν^{DIRA} DIAGONALIZED BY CKM

$$\tau \to \mu\gamma \propto (CKM)_{23} \times (CKM)_{33} \times h_t^2$$

$$\mu \to e\gamma \propto \underbrace{(CKM)_{13}}_{\hookrightarrow 0.04} \times (CKM)_{23} \times h_t^2$$



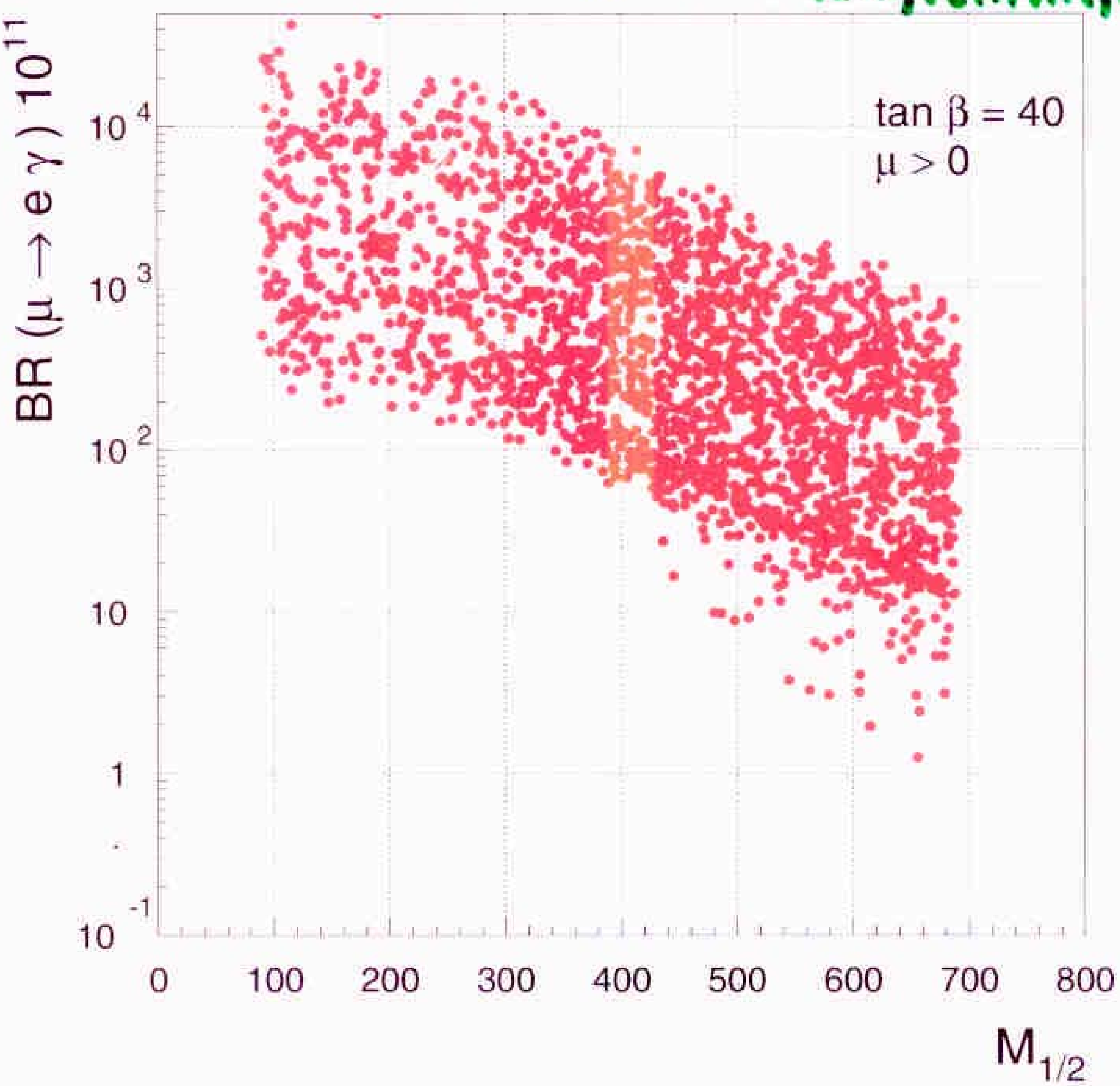
SUSY SO(10)

"FAVOURABLE CASE": M_ν^{Dirac} diagonalized by the **PMNS matrix** ⇒ **MAXIMAL MIXING**

$$A(\mu \to e\gamma) \propto (PMNS)_{13}^{*} \, (PMNS)_{33}^{*} \, h_t^2$$

take maximal allowed value $\sin^2\theta_{13} =$

A.M., VEMPATI, VIVES

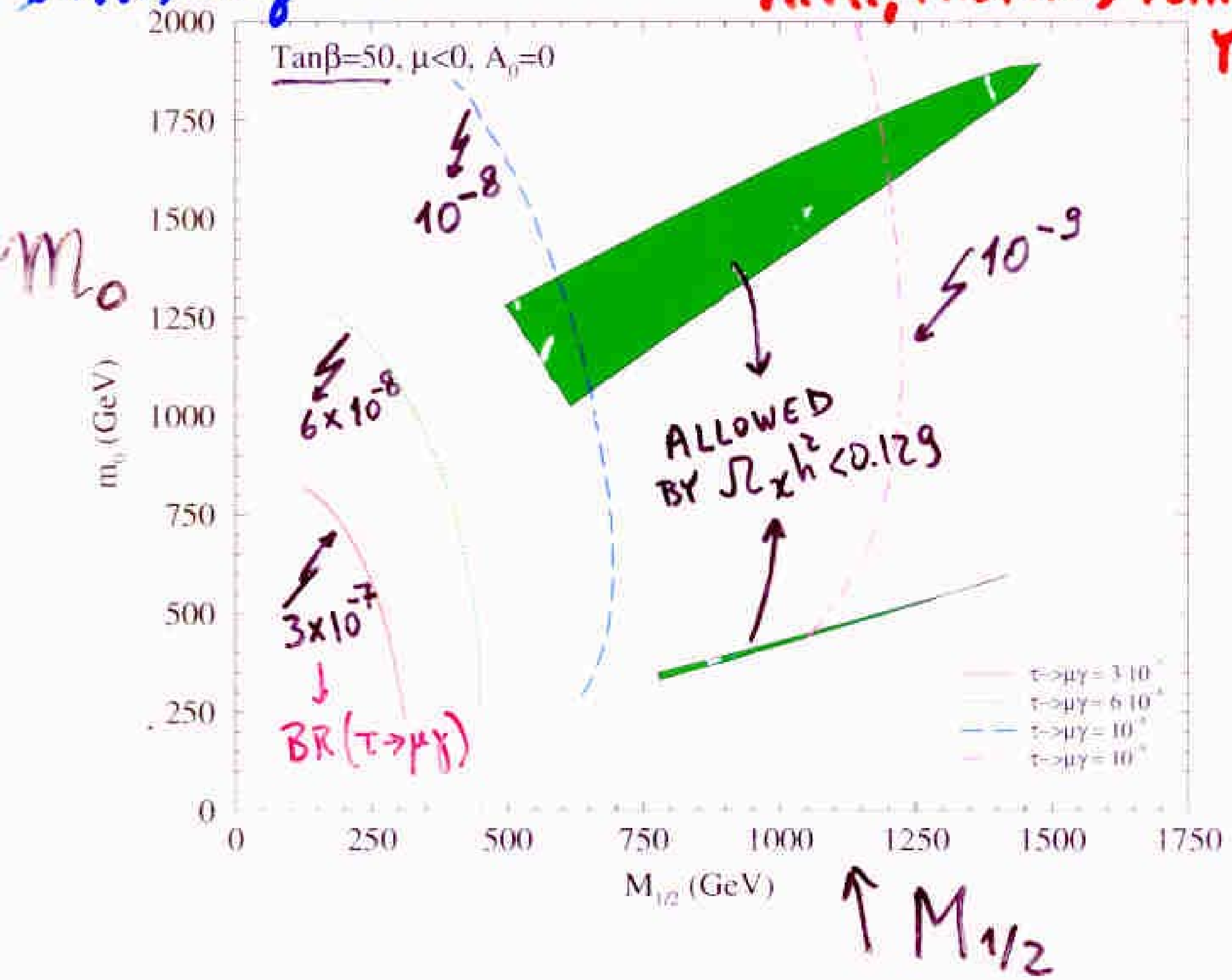


PROBING THE $M_{1/2} - m_0$ SPACE OF CMSSM WITH SEESAW MECHANISM

→ CONSTRAINTS FROM DIRECT SEARCHES, $\Omega_{CDM} h^2 < 0.129$ (WMAP) AND $\tau \to \mu + \gamma$ reach

Campbell, Maybury, Murakami; Blazek, King

A.M., PROFUMO, VEMPATI, YAGUNA

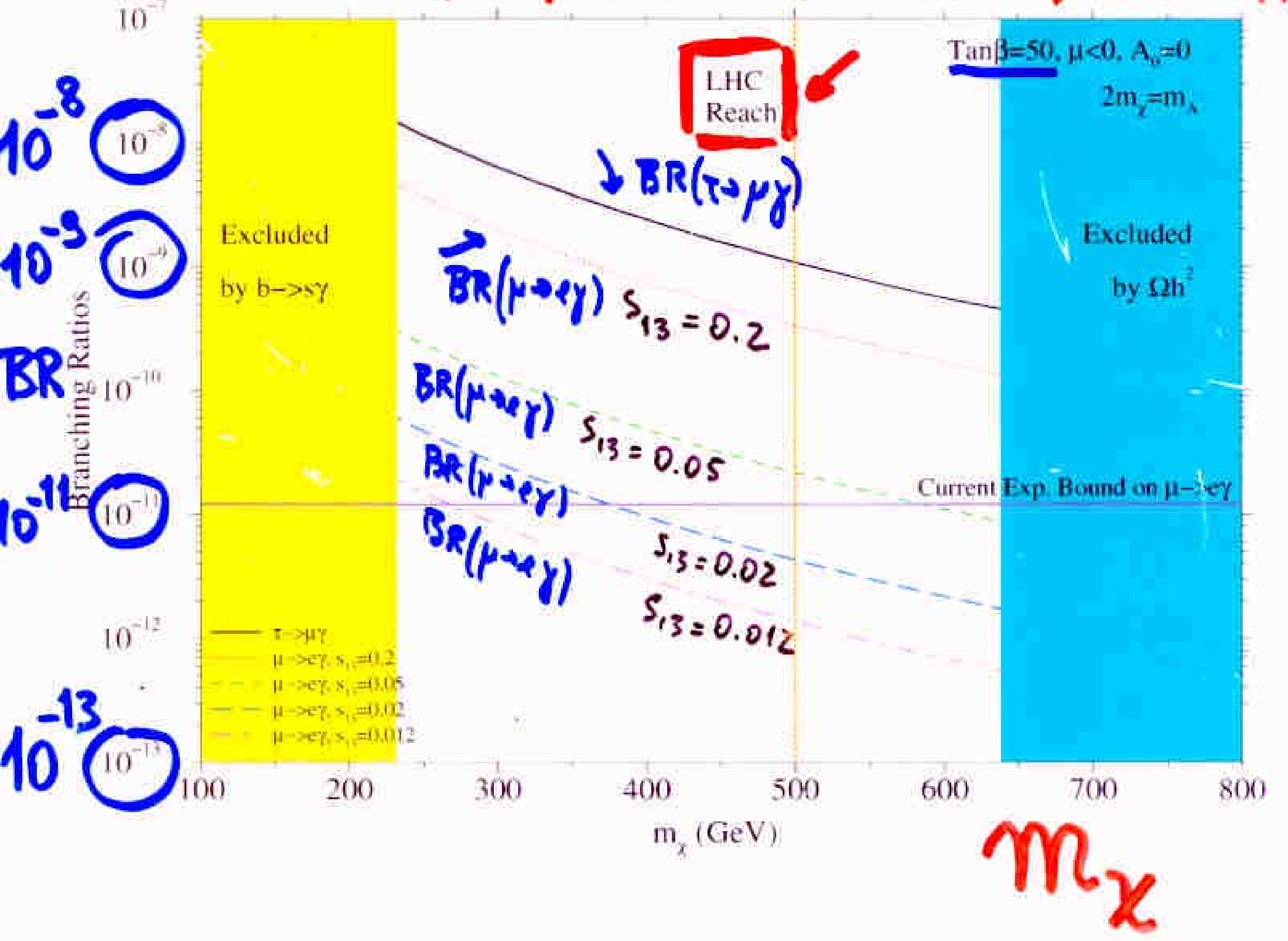


$BR(\tau \to \mu\gamma)$ and $BR(\mu \to e\gamma)$

in the central part of the funnel region in the CMSSM to respect $\Omega_\chi h^2 < 0.129$ (WMAP)

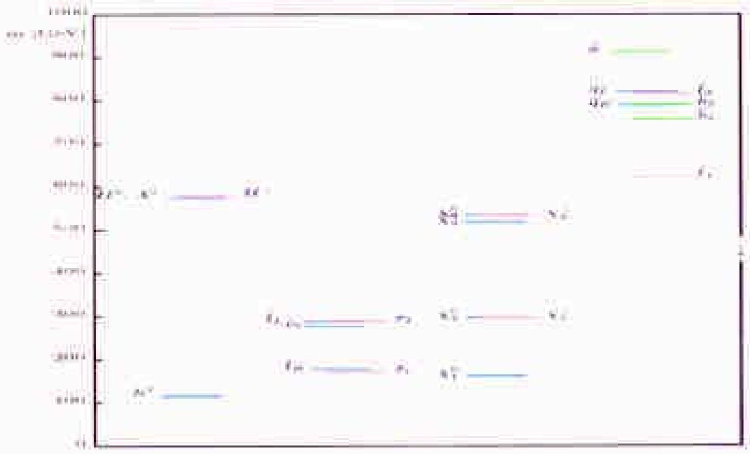
(compared to LHC reach at $\sim 100\ fb^{-1}$ in this region of CMSSM param. space)

A.M., PROFUMO, VEMPATI, YAGUNA

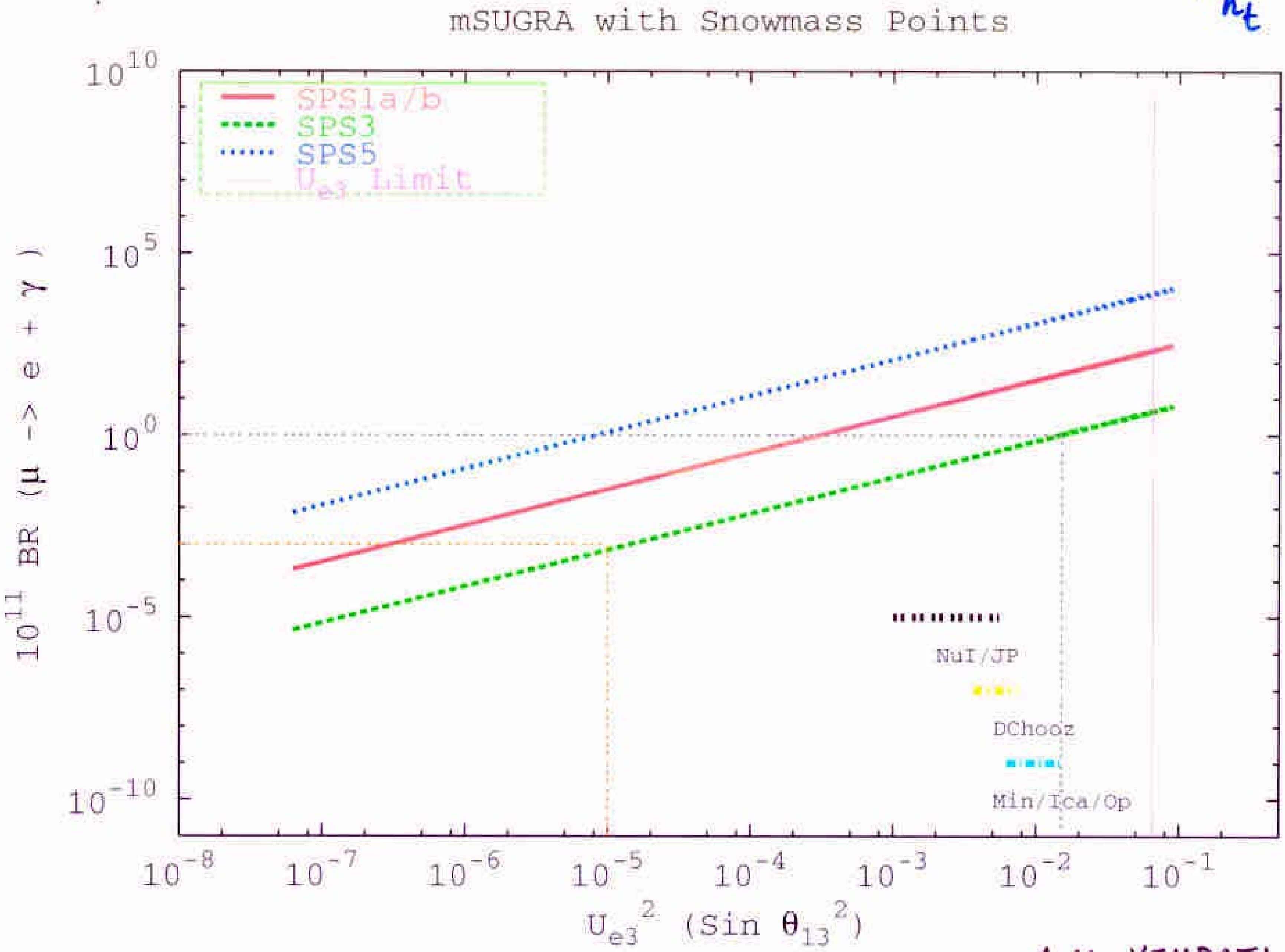


Snowmass Points in mSUGRA

	m_0	$M_{1/2}$	A_0	$\tan\beta$	sg(μ)
SPS1a	100	250	-100	10	> 0
SPS1b	200	400	0	30	> 0
SPS2	1450	300	0	10	> 0
SPS3	90	400	0	10	> 0
SPS4	400	300	0	50	> 0
SPS5	150	300	-1000	5	> 0



SUSY SEESAW in mSUGRA "FAVOURABLE CASE" : $A(\mu \to e\gamma) \propto (PMNS)_{13} \cdot (PMNS)_{32} \cdot h_t^2$



A.M., VEMPATI, VIVES

LARGE ν MIXING
+
LARGE h_ν^D
$\Rightarrow$ LARGE Δ^ℓ_{LL}
LARGE LFV

+

LEPTON-QUARK UNIFICATION $\Rightarrow$ LARGE Δ^ℓ_{LL} $\downarrow$ LARGE Δ^q

$\downarrow$

$$\begin{pmatrix} d_R \\ d_R \\ d_R \\ \ell \\ \nu \end{pmatrix} \Rightarrow$$

LARGE $(\Delta^\ell_{LL})_{23}$ translates into LARGE $(\Delta^d_{RR})_{23}$

in SU(5) MOROI (assume one large h_ν^D)

in SO(10) CHANG, A.M., MURAYAMA ($h_t \leftrightarrow h^D_{\nu_3}$ Pati-Salam symm.)

Akama, Kiyo, Komine, Moroi ; Hisano, Moroi, Tobe, Yamaguchi, Yanagida ; Hisano, Nomura Kitano, Koike, Komine, Okada

$b \to s$ TRANSITIONS

Available exp. info :

$BR(B \to X_s \gamma) = (3.29 \pm 0.34) \times 10^{-4}$

$A_{CP}(B \to X_s \gamma) = -0.02 \pm 0.04$

$BR(B \to X_s e^+e^-) = (6.1 \pm 1.4 \pm 1.3) \times 10^{-6}$

$\Delta M_{B_s} > 14.4\ ps^{-1}$

STILL POSSIBLE TO HAVE "SUSY SURPRISES"

IN SPITE OF THE ABOVE CONSTRAINTS

ex: $CP\!\!\!/$ in $b \to s$ transitions

"$\sin 2\beta$" from $B_d \to \phi K_S$ and $B_d \to J/\psi K_S$

$\sin 2\beta$ from $B_d \to J/\psi K_S$ 0.734 ± 0.054

$S_{\phi K}$ from $B_d \to \phi K_S$

BELLE	BABAR
-0.99 ± 0.50	$+0.45 \pm 0.43$

in SM $\sin 2\beta = S_{\phi K}$!

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

CHANG, A.M., MURAYAMA

- $\sin 2\beta$: $A_{CP}(B_d \to J/\psi K_S)$ unaffected, but new contributions to $\mathrm{Im}\, A(B_d \to \phi K_S)$

  $\Rightarrow$ DISCREPANCY BETWEEN $\sin 2\beta$ INFERRED from $J/\psi K_S$ and ϕK_S CHANNELS

- $B_s \to J/\psi\, \Phi$ SM: negligible $A_{CP}(B_s \to J/\psi\, \phi)$

  $\hookrightarrow$ no phase in $B_s - \bar{B}_s$
  no phase in 

  SUSY: possible large $A_{CP}(B_s \to J/\psi\, \phi)$ because of phase in $B_s - \bar{B}_s$

- $B_s \to D_s^+ K^-$ SM: γ 

  SUSY: different "γ" because of new CP$\neq$ contribution to $B_s - \bar{B}_s$

  $B^\pm \to D^0 K^\pm$ SM-SUSY same CP$\neq$ contrib.

  $\Rightarrow$ same "γ"

(48

CIUCHINI, FRANCO, A.M., SILVESTRINI

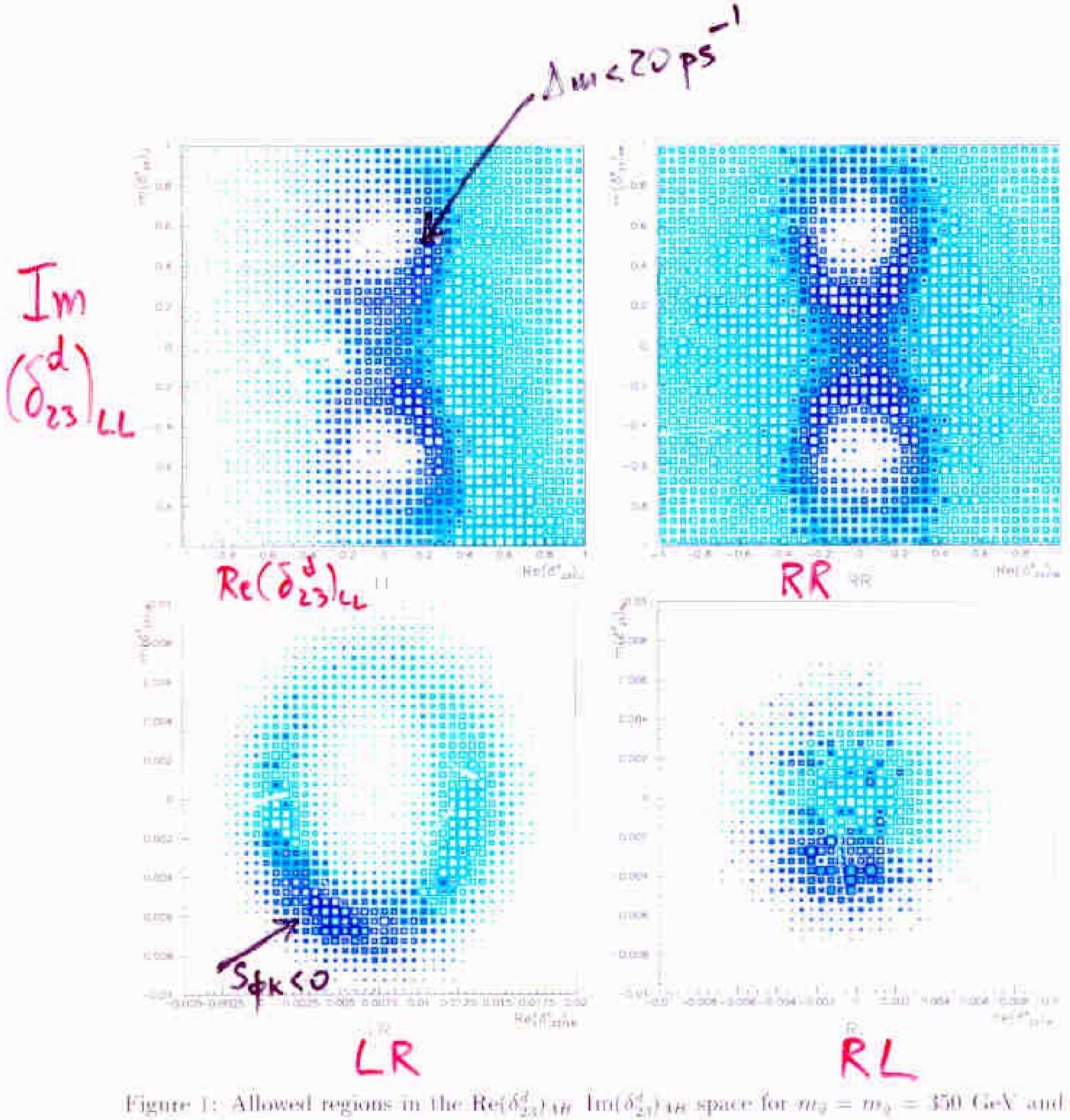


Figure 1: Allowed regions in the Re$(\delta^d_{23})_{AB}$–Im$(\delta^d_{23})_{AB}$ space for $m_{\tilde g} = m_{\tilde q} = 350$ GeV and $AB = (LL, RR, LR, RL)$. Constraints from $BR(B \to X_s\gamma)$, $A_{CP}(B \to X_s\gamma)$, $BR(B \to X_s l^+ l^-)$ and the lower bound on ΔM_s have been used. The darker regions are selected imposing the further constraint $\Delta m_s < 20$ ps^{-1} for LL and RR insertions and $S_{\phi K} < 0$ for LR and RL insertions.

$S_{\phi K} - A_{CP}(b \to s\gamma)$

CFMS

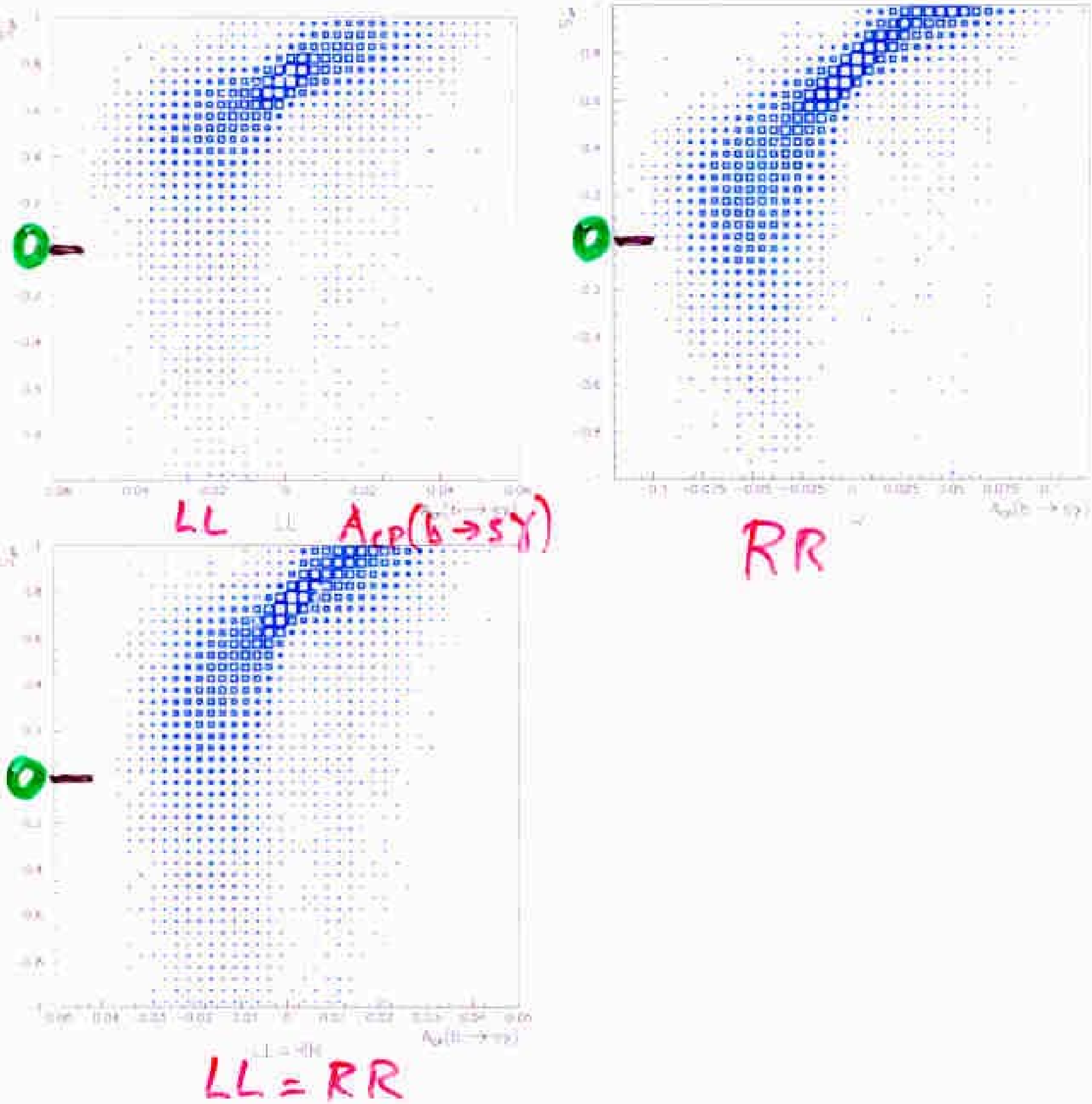


Figure 7: Correlation between $S_{\phi K}$ and $A_{CP}(b \to s\gamma)$ for various SUSY mass insertions $(\delta^d_{23})_{AB}$ with $AB = (LL, RR, LLRR)$. Constraints from $BR(B \to X_s\gamma)$, $A_{CP}(B \to X_s\gamma)$, $BR(B \to X_s l^+ l^-)$ and the lower bound on ΔM_s have been used.

LEPTONIC
FCNC RELATED IF
HADRONIC

CIUCHINI, A.M., SILVESTRINI, VEMPATI, VIVES

$M_P \quad M_X \quad M_{GUT} \qquad\qquad M_W \longrightarrow$

M_X: scale where soft breaking terms appear

at M_{GUT} $\Downarrow$ SU(5)

$$\begin{cases} \left(\Delta^u_{ij}\right)_{LL} = \left(\Delta^u_{ij}\right)_{RR} = \left(\Delta^d_{ij}\right)_{LL} = \left(\Delta^\ell_{ij}\right)_{RR} \\ \left(\Delta^d_{ij}\right)_{RR} = \left(\Delta^\ell_{ij}\right)_{LL} \\ \left(\Delta^d_{ij}\right)_{LR} = \left(\Delta^\ell_{ji}\right)_{LR} = \left(\Delta^\ell_{ij}\right)^*_{RL} \end{cases}$$

if no new part. couple $M_G \to M_W$

$\Downarrow$ RG EVOLUTION FROM M_{GUT} TO M_W

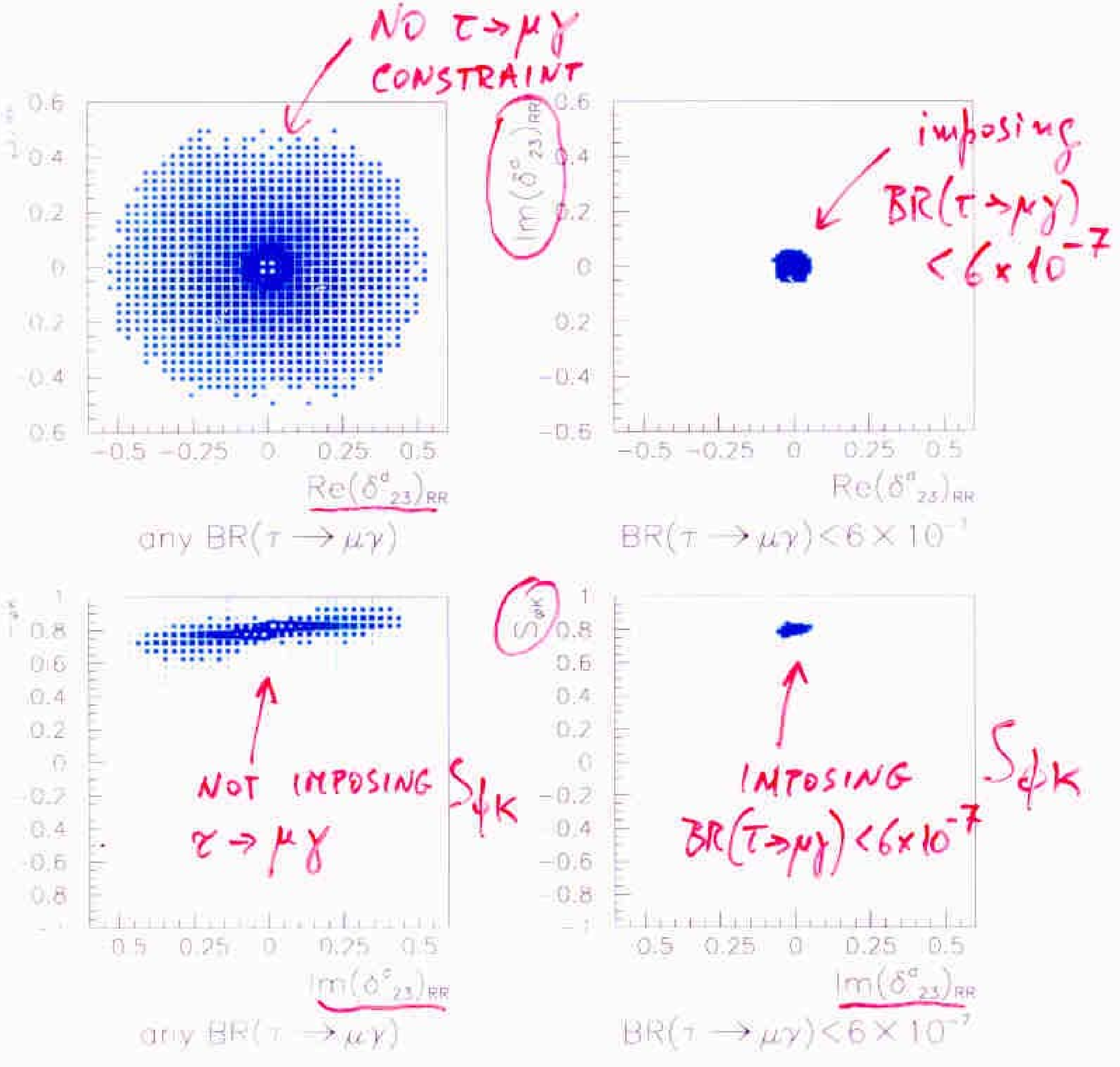
$$\begin{cases} \left(\delta^u_{ij}\right)_{RR} \simeq \dfrac{m^2_{\tilde{e}^c}}{m^2_{\tilde{u}^c}} \left(\delta^\ell_{ij}\right)_{RR} \\ \left(\delta^q_{ij}\right)_{LL} \simeq \dfrac{m^2_{\tilde{e}^c}}{m^2_{\tilde{Q}}} \left(\delta^\ell_{ij}\right)_{RR} \\ \left(\delta^d_{ij}\right)_{RR} \simeq m^2_{\tilde{L}}/m^2_{\tilde{d}^c} \left(\delta^\ell_{ij}\right)_{LL} \\ \left(\delta^d_{ij}\right)_{LR} \simeq \dfrac{m_b}{m_\tau} \left(\delta^\ell_{ij}\right)^*_{LR} \dfrac{\sqrt{m^2_{\tilde{L}} \cdot m^2_{\tilde{e}^c}}}{\sqrt{m^2_{\tilde{Q}}\, m^2_{\tilde{d}^c}}} \end{cases}$$

CONSTRAINTS ON

$$Re(\delta^d_{23})_{RR} - Im(\delta^d_{23})_{RR}$$

AND $S_{\phi K} - Im(\delta^d_{23})_{RR}$

from $\tau \to \mu + \gamma$



OUTLOOK

FROM THE PAST

SUSY 30

SUGRA 25

SEESAW 25

SUSY SEESAW

TO THE FUTURE

LFV

($\mu \to e\gamma$, $ee\bar{e}$
$\mu \to e$ conv. in nucl.;
$\tau \to \mu\gamma$, $\tau \to \mu\mu\bar{\mu}$...)

- possibly first smoking gun for SUSY (before LHC direct observation ?)
- after "direct discovery", LFV crucial for the "reconstruction" of the right SUSY extension of the SM !
- HADRON-LEPTON FCNC connection in SUSYGUTs: Susy seesaw in CP $\neq$ B Physics, ...