La Thuile 06, March 5-11, 2006

New Physics and Old Flavor Problem in the LHC Era

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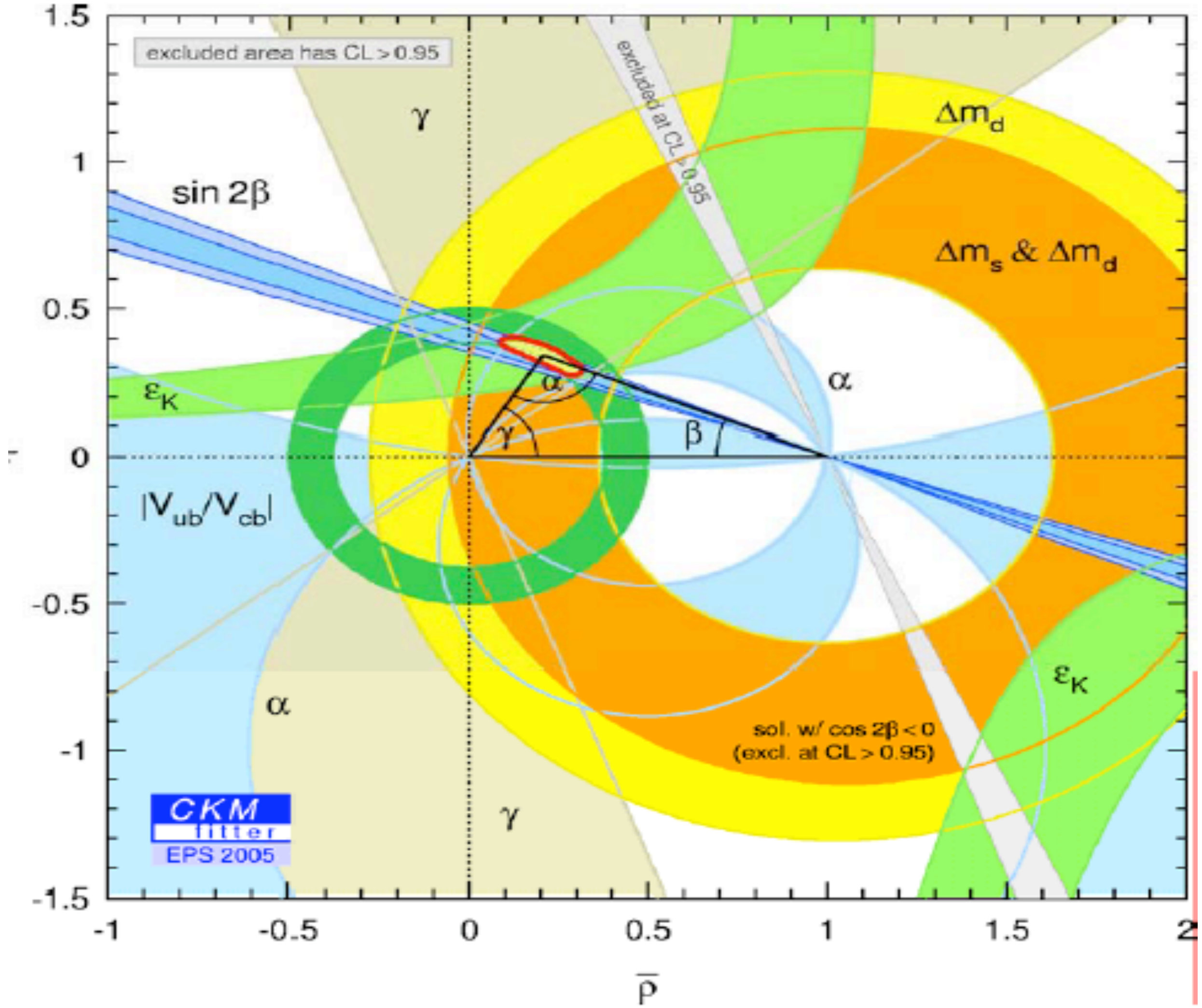
- How Standard is the CKM flavor description?
- Has New Physics at the Elw. Scale to be flavor blind?
- On the role of flavor physics in the LHC era: from discovery to understanding of New Physics

Flavor Physics at the ELW. Scale: Triumph of the SM CKM Structure

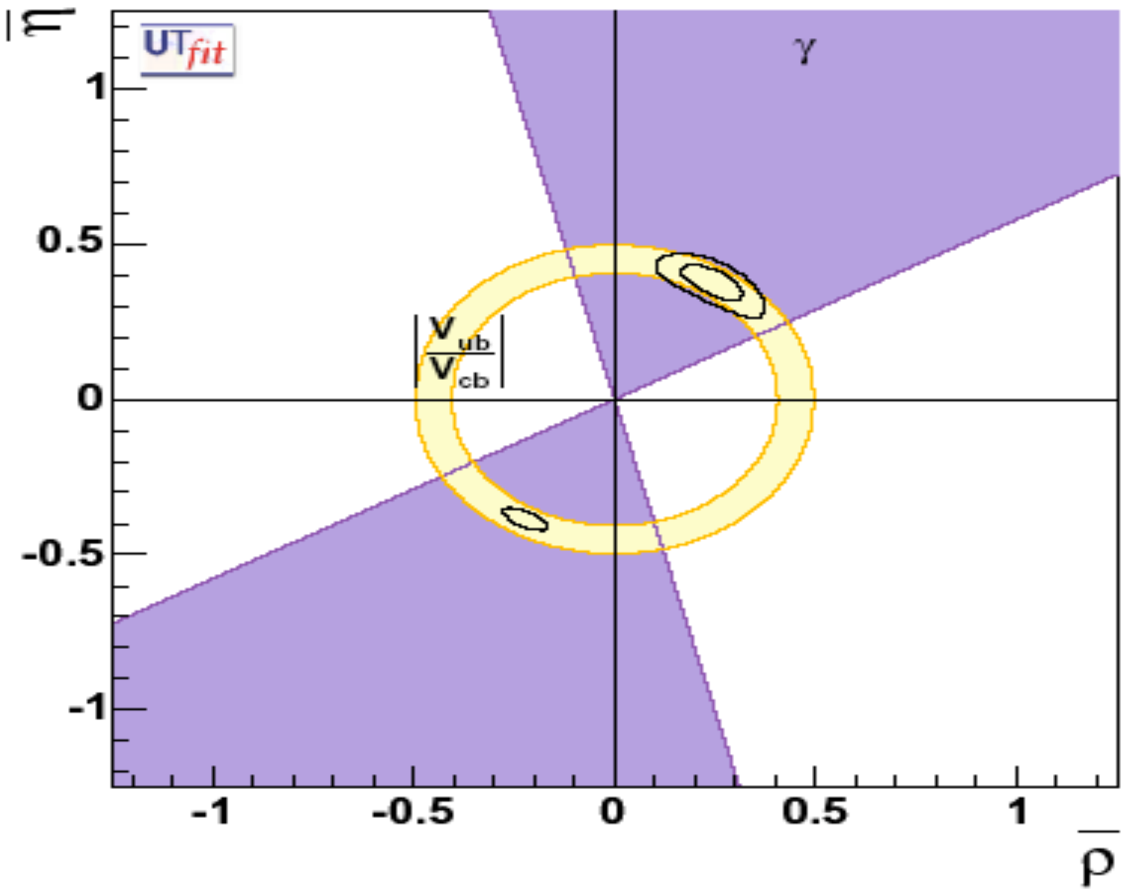
2005 ⟶ α,γ measurements (from B factories) : agreement with the area of the UT coming from SIDES measurements

⟶ TEST OF THE CONSISTENCY OF THE CKM MECHANISM in describing non-leptonic B decays + CP asymmetries

UNITARITY TRIANGLE (UT) REDUNDANT DETERMINATION



If New Physics enters observables at the LOOP LEVEL → determination of the $\bar{\rho}$ - $\bar{\eta}$



Using TREE LEVEL B DECAYS: V_{ub} and V_{cb} (semilept. Incl. and excl. B decays), γ (phase of Vub in interference of b → c and b → u in B → DK)

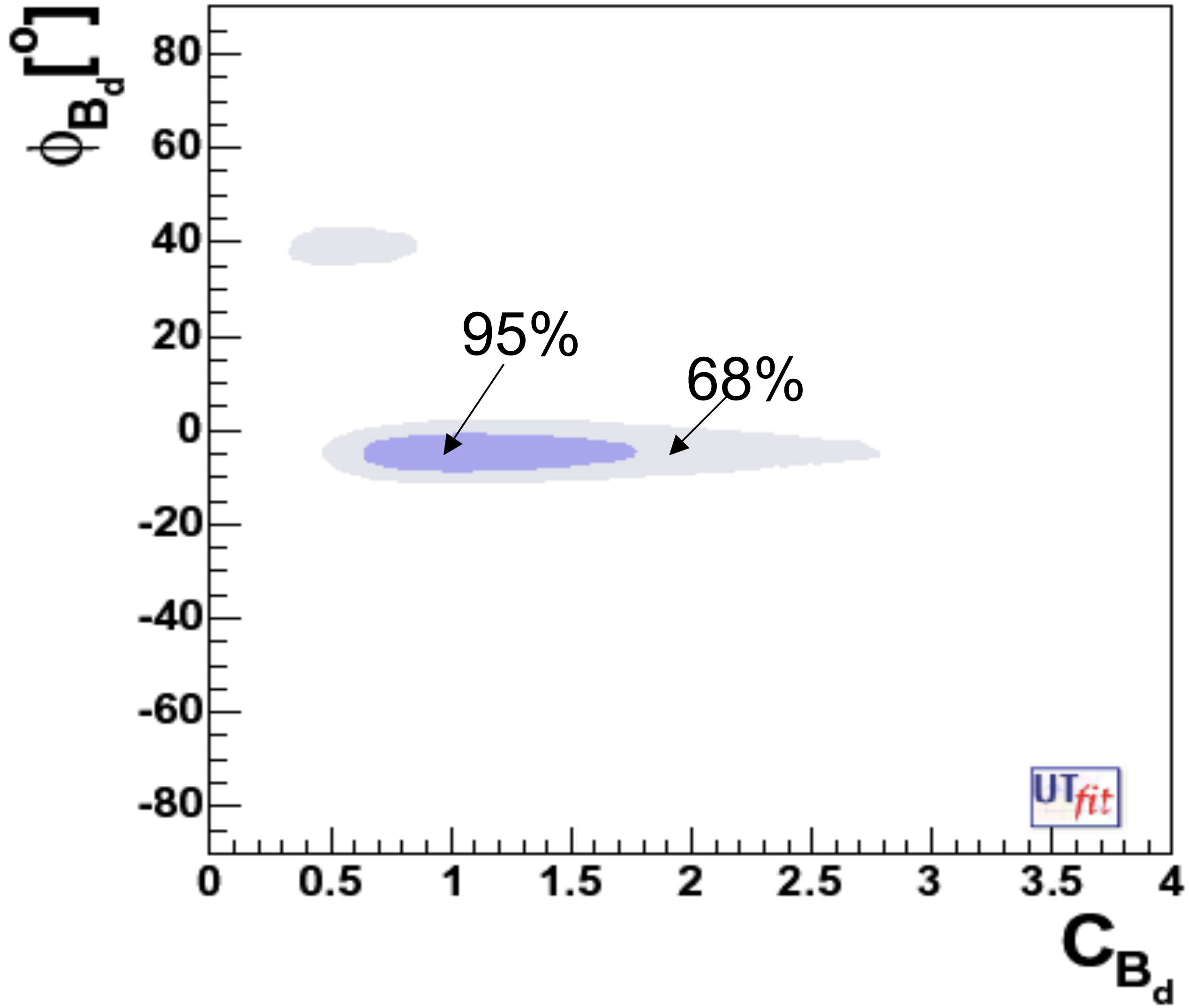
Inclusion of New Physics in the UT generalized fit

The redundancy of the UT determination allows for UT generalized fit including beyond SM New Physics

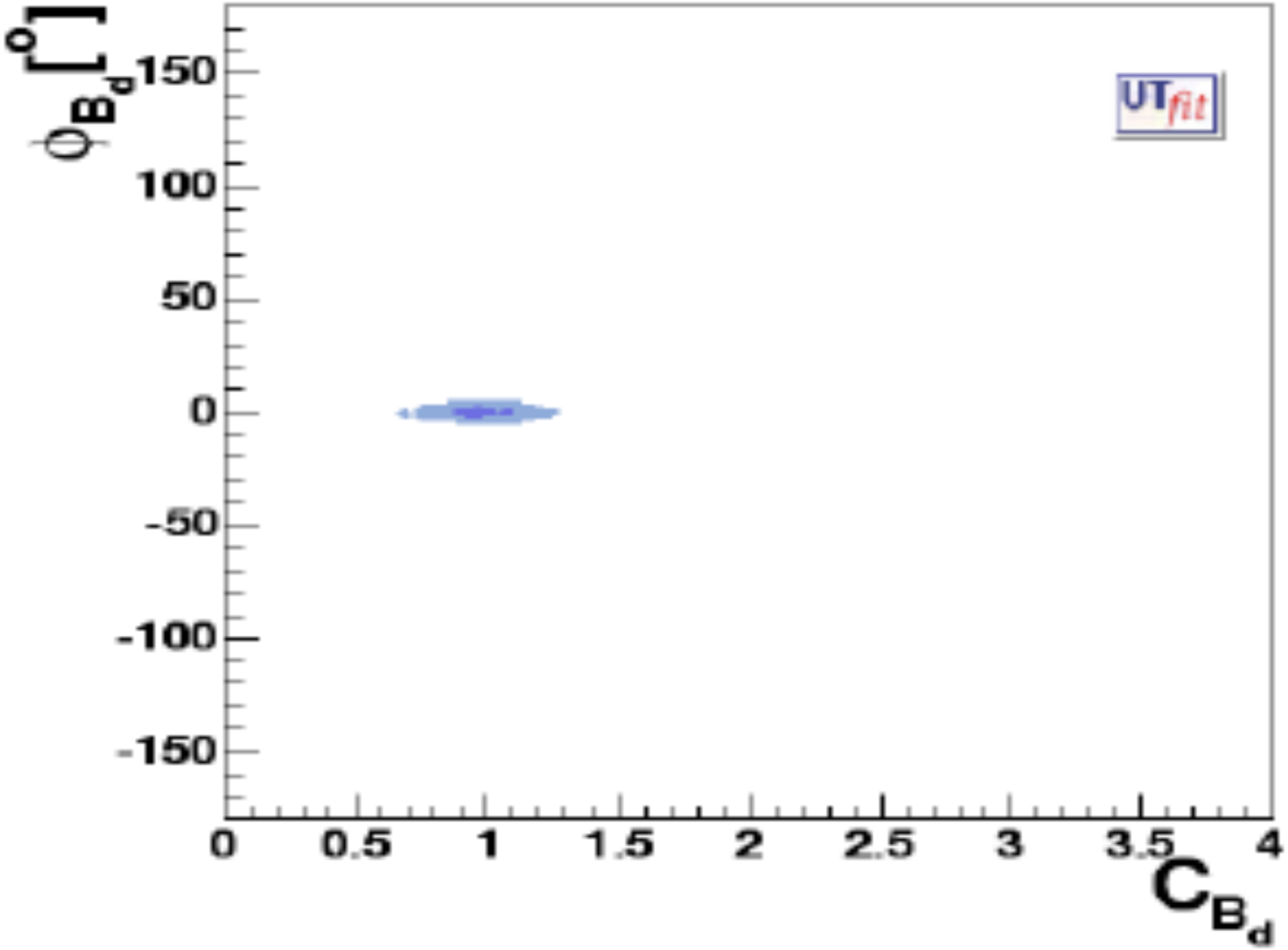
Example: B°_q - $\overline{B^\circ}_q$ mixing

$$\frac{\langle B^\circ_q \,|\, H_{TOT} \,|\, \overline{B^\circ}_q \rangle}{\langle B^\circ_q \,|\, H_{SM} \,|\, \overline{B^\circ}_q \rangle} = C_{B_q} \times \exp(2i\phi_B)$$

p.d.f. for C_{Bd} vs. ϕ_{Bd}



Extrapolation of what may happen by the end of this decade



SM prevails even in the generalized UT fit

→ good constraints on ρ and η

→ strong suppression of large New Physics enhancement

7% probability for NP solution with

$\eta < 0$ and

93% probability for SM-like solution

Is CP violation entirely due to the KM mechanism? Y.Nir

For CPV in FLAVOR CHANGING* PROCESSES it is VERY LIKELY** that the KM mechanism represents the MAIN SOURCE***

- *FC CPV : as for flavor conserving CPV there could be new phases different from the CKM phase (importance of testing EDMs!)
- **VERY LIKELY: the alternative is to invoke some rather puzzling coincidence (e.g., it could be that sin2β is not that predicted by the SM , but H_{SM} + H_{NP} in the B_d-B_d mixing has the same phase as that predicted by the SM alone or it could be that the phase of the NP contribution is just the same as the SM phase)
- *** MAIN SOURCE : Since $S_{\psi K}$ is measured with an accuracy ~ 0.04, while the SM accuracy in predicting sin2β is ~0.2 → still possible to have

$H_{NP} \leq 20\%\ H_{SM}$ in B_d-$\overline{B}_d$ mixing

What to make of this triumph of the CKM pattern in flavor tests?

New Physics at the Elw. Scale is Flavor Blind
CKM exhausts the flavor changing pattern at the elw. Scale.

Ex.: in SUSY → MINIMAL FLAVOR VIOLATION (MFV)

New Physics introduces

NEW FLAVOR SOURCES in addition to the CKM pattern.
They give rise to contributions which are <20% in the “flavor observables” which have already been observed!

SUSY with MFV

Consider a SUSY breaking mechanism which is FLAVOR BLIND → FLAVOR UNIVERSALITY OF THE SOFT BREAKING SCALAR SECTOR :

Universal m_0 scalar sfermion masses;

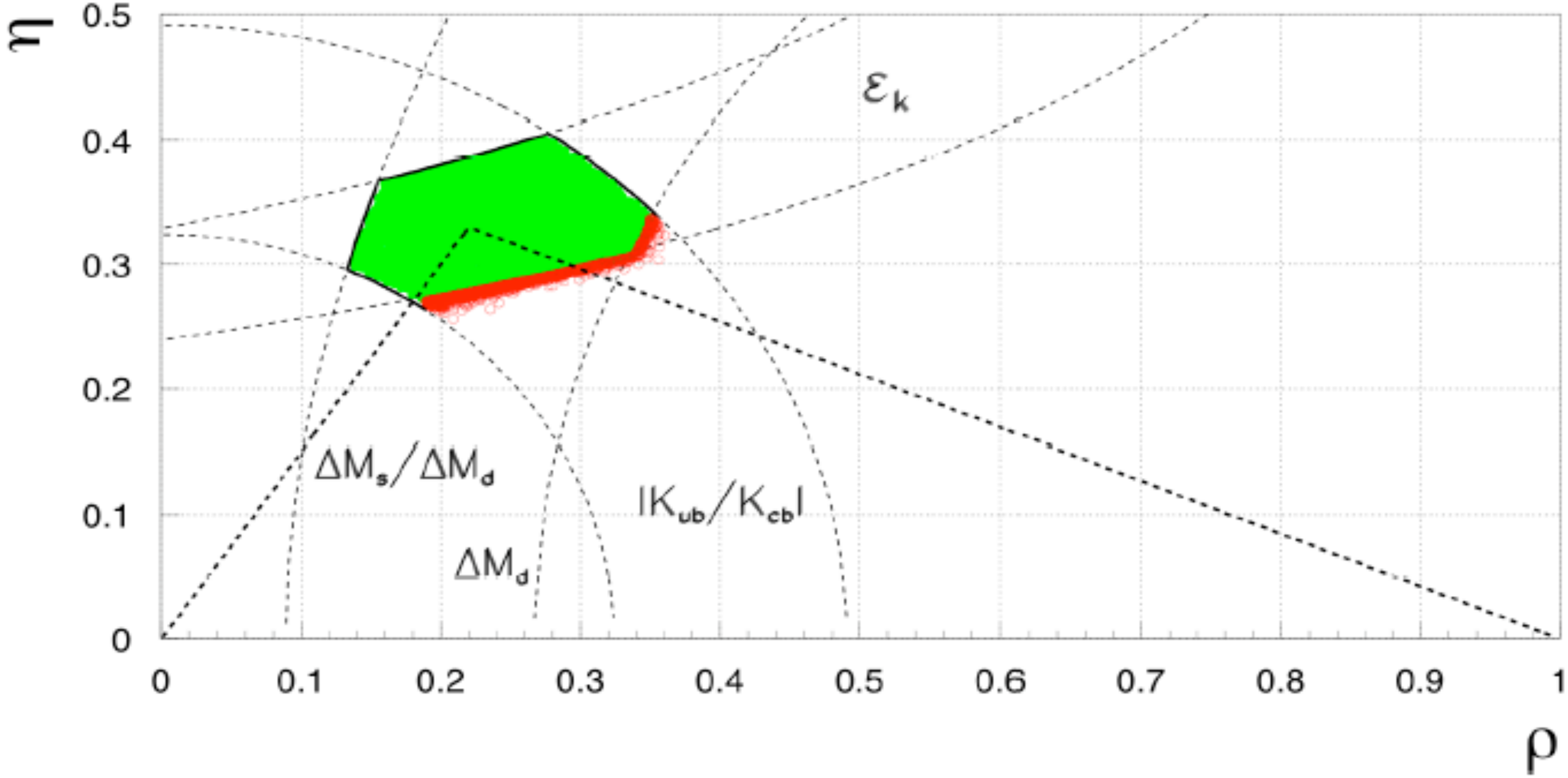
Universal A trilinear coeff.

→ RGE's can only induce sfermion mediated FC ruled by the usual CKM mixings

→ leading contribution with stop-wino replacing top-W exchange in the loops

Deviation from the SM UT tip in the presence of new contributions in the Constrained MSSM

Bartl, Gajdisik, Lunghi, A.M., Porod, Stockinger, Stremnitzer, Vives



VISIBILITY OF MINIMAL FLAVOR VIOLATION?

- Large departures from SM within MFV are NOT possible

ex.:	SM	MFV
Br (Bs $\longrightarrow \mu\bar{\mu}$)	$<6\times10^{-9}$	$<7.4\times10^{-9}$
Br (Bd $\longrightarrow \mu\bar{\mu}$)	$<1.8\times10^{-10}$	$< 2.2\times10^{-10}$
Br (B $\longrightarrow X_s\nu\bar{\nu}$)	$<4.1\times10^{-5}$	$<5.2\times10^{-5}$
Br ($K^+ \longrightarrow \pi^+\nu\bar{\nu}$)	$<10.9\times10^{-11}$	$<11.9\times10^{-11}$

Bobeth, Bona, Buras, Everth, Pierini, Silvestrini, Pierini
hep-ph/0505110

Unless VERY SPECIAL conditions are met …

MFV with LARGE tanβ

Br ($B_{s,d} \rightarrow \mu\mu$) ~ $(\tan\beta)^6$

for large tanβ it is possible to obtain

Br ($B_s \rightarrow \mu\mu$) as large as 10^{-6} - 10^{-7}

while in the SM we expect 10^{-9}

Babu, Kolda; Chankowski, Slawianovska; Bobeth, Ewerth, Krueger, Urban; Huang, Liao,Yan,Zhu;Isidori,Retico; Dedes, Dreiner, Nierste; Dedes, Pilaftis; Chankowski, Rosiek; Foster , Okumura, Roszkowski

With relevant observational correlations

For instance, if Br ($B_s \rightarrow \mu\mu$) $>10^{-8}$ or Br ($B_d \rightarrow \mu\mu$)$>10^{-9}$,

then → $\Delta M_s^{exp} < \Delta M_s^{SM}$

then → New sources of FV are present, i. e. we are outside MFV

New physics at the Elw. Scale is NOT Flavor Blind → CKM does NOT exhaust the flavor description at low energy

- Ex. : SUSY in a NON-MFV framework

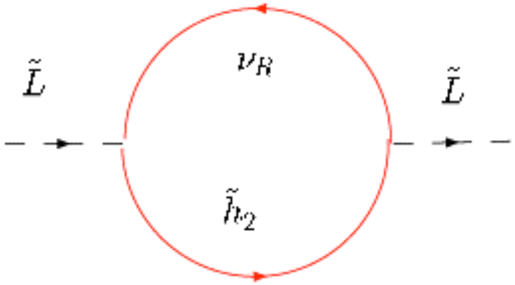
SUSY breaking mechanism is NOT flavor blind, i.e. the soft breaking scalar terms (masses and trilinear terms) are NOT flavor universal	SUSY breaking mechanism IS flavor blind, but the RGE's of the sfermion masses induce a low-energy flavor non-universality

SUSY SEESAW: Flavor universal SUSY breaking and yet large lepton flavor violation!

Borzumati, A. M. 1986

•

$$L = f_l \, \overline{e}_R L h_1 + f_\nu \, \overline{\nu}_R L h_2 + M \, \nu_R \nu_R$$



$$\left(m^2_{\tilde{L}}\right)_{ij} \quad \frac{1}{8\pi^2}(3m_0^2 + A_0^2)\left(f_\nu^\dagger f_\nu\right)_{ij} \log\frac{M}{M_G}$$

Non-diagonality of the slepton mass matrix in the basis of diagonal lepton mass matrix depends on the unitary matrix U which diagonalizes ($f_\nu^+ f_\nu$)

How Large LFV in SUSY SEESAW?

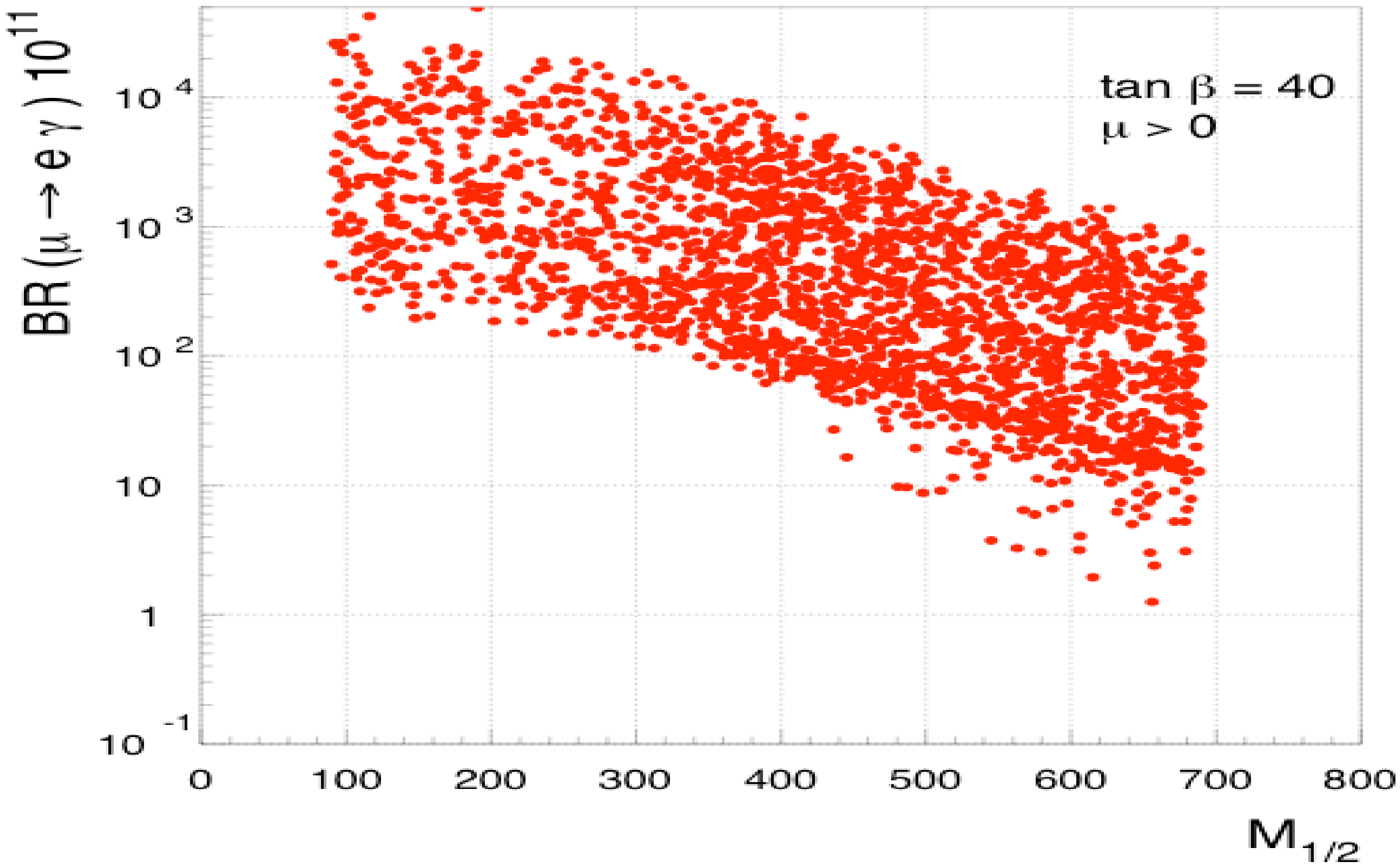
- 1) Size of the Dirac neutrino couplings f_ν
- 2) Size of the diagonalizing matrix U

1) → in MSSM seesaw or in SUSY SU(5) (Moroi):
not possible to correlate the neutrino Yukawa couplings to known Yukawas;
in SUSY SO(10) at least one neutrino Dirac Yukawa coupling has to be of the order of the top Yukawa coupling → one large of O(1) f_ν

2) U → two "extreme" cases:
a) U with "small" entries → U = CKM;
b) U with "large" entries with the exception of the 13 entry
→ U=PMNS matrix responsible for the diagonalization of the neutrino mass matrix

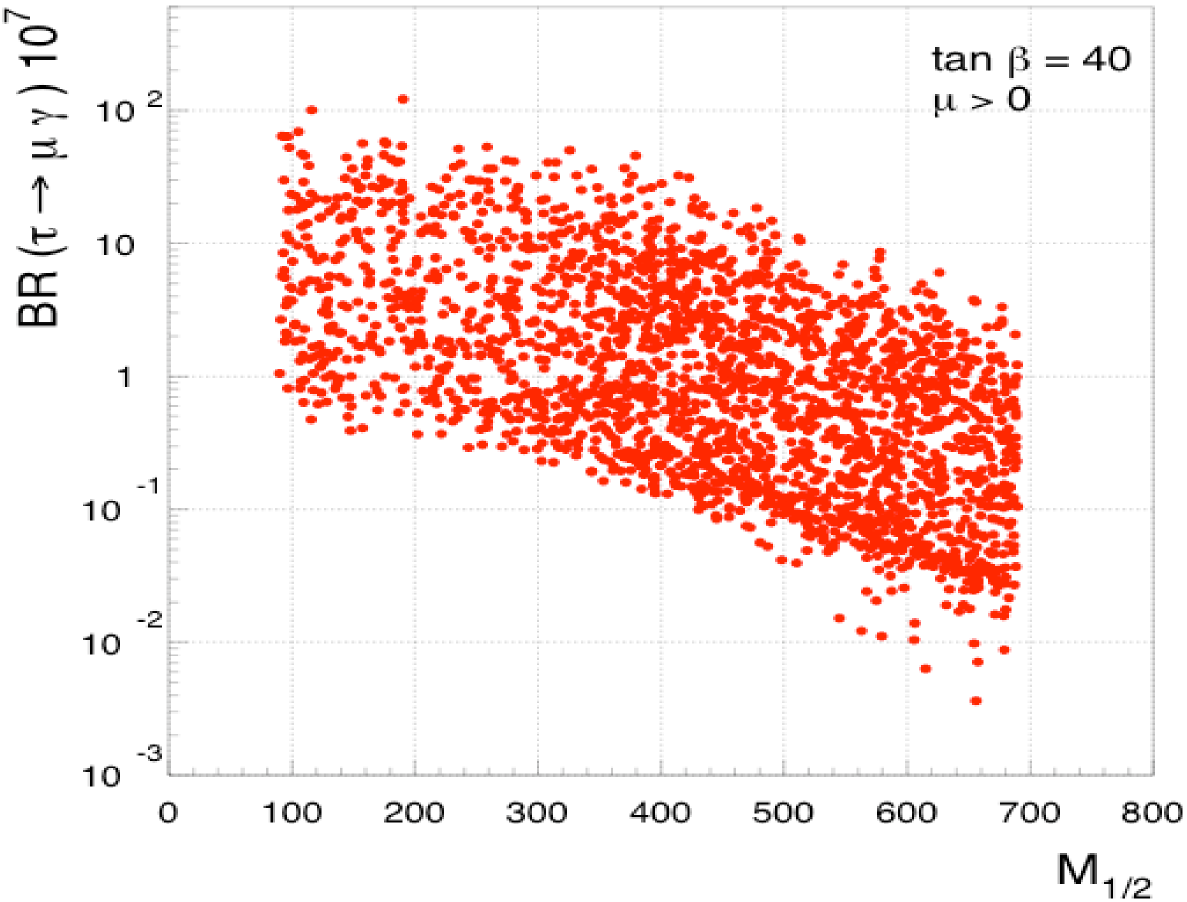
$\mu \longrightarrow e\gamma$ in SUSY SO(10) : PMNS case with U_{e3} as large as allowed by the Chooz bound

A.M., Vempati, Vives

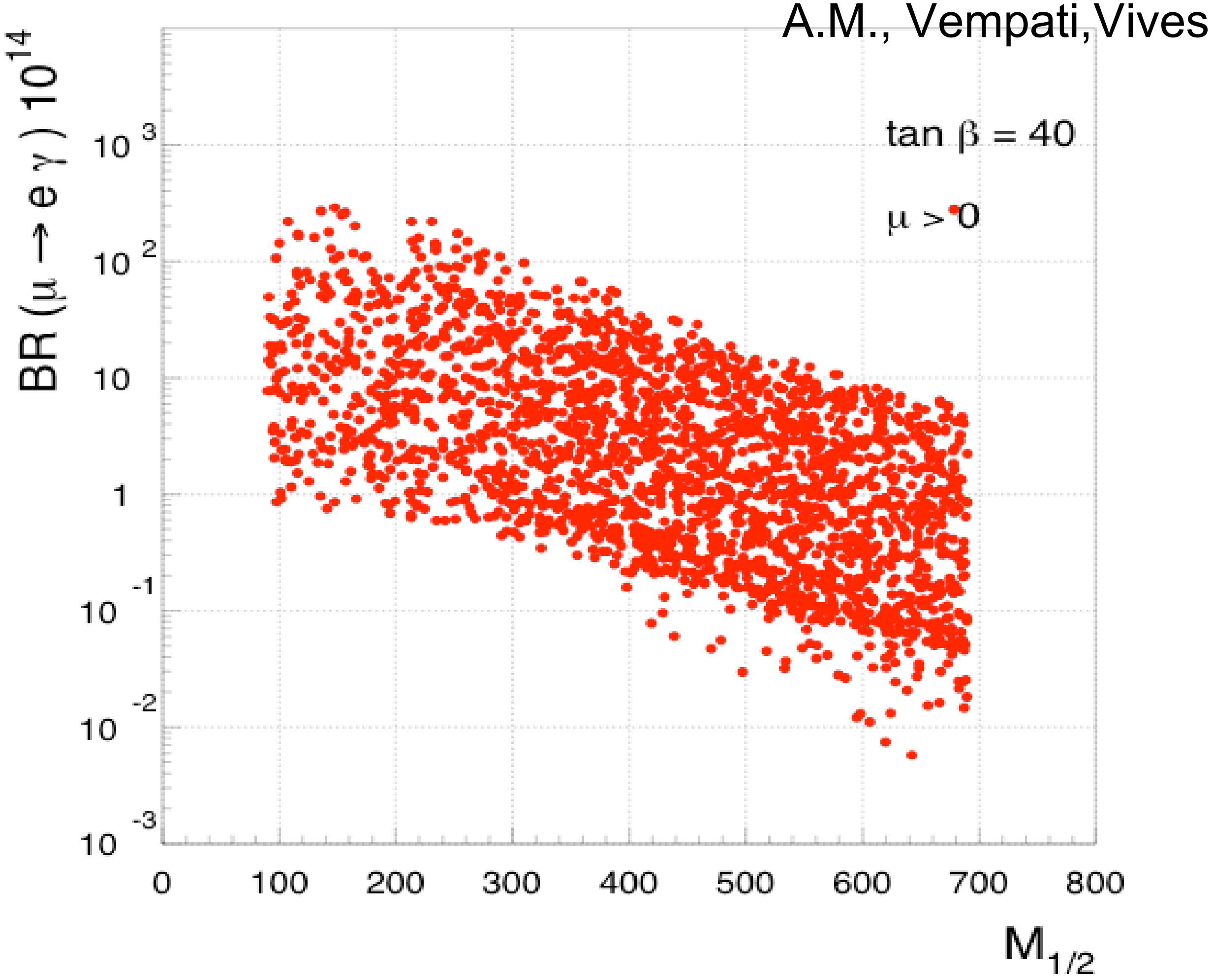


$\tau \longrightarrow \mu\gamma$ in SUSY SO(10) : PMNS case (No dependence on U_{e3})

A.M., Vempati, Vives

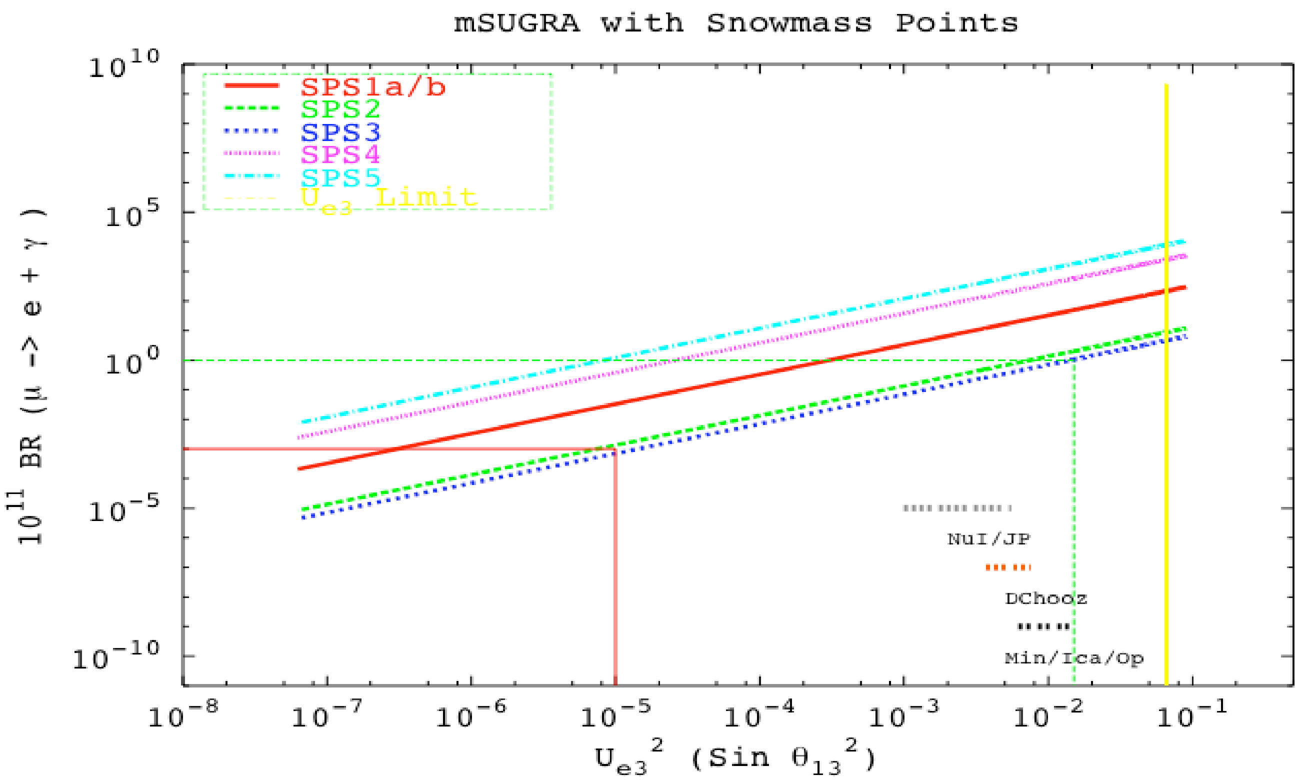


$\mu \longrightarrow e\gamma$ in SUSY SO(10) : CKM case

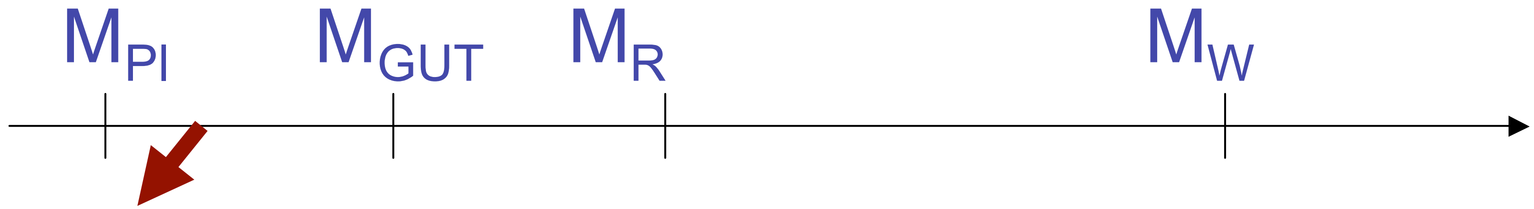


Sensitivity of $\mu \to e\gamma$ to U_{e3} for various Snowmass points in mSUGRA with seesaw

A.M., Vempati, Vives



LFV in SUSYGUTs with SEESAW



Scale of appearance of the SUSY soft breaking terms resulting from the spontaneous breaking of supergravity

Low-energy SUSY has “memory” of all the multi-step RG occurring from such superlarge scale down to M_W

$\longrightarrow$ potentially large LFV

Barbieri, Hall; Barbieri, Hall, Strumia; Hisano, Nomura, Yanagida; Hisano, Moroi, Tobe Yamaguchi; Moroi; Carvalho, Ellis, Gomez, Lola; Calibbi, Faccia, A.M, Vempati (in preparation)

LFV in MSSMseesaw: $\mu \to e\gamma$ Borzumati, A.M.

$\tau \to \mu\gamma$ Blazek, King;

General analysis: Casas et el; Lavignac, Masina, Savoy

Large ν mixing $\leftrightarrow$ large b-s transitions in SUSY GUTs

In SU(5) $d_R \longleftrightarrow l_L$ connection in the 5-plet
Large $(\Delta^l_{23})_{LL}$ induced by large f_ν of $O(f_{top})$
is accompanied by large $(\Delta^d_{23})_{RR}$

In SU(5) assume large f_ν (Moroi)
In SO(10) f_ν large because of an underlying Pati-Salam symmetry
(Darwin Chang, A.M., Murayama)

See also: Akama, Kiyo, Komine, Moroi; Hisano, Moroi, Tobe, Yamaguchi, Yanagida; hisano, Nomura; Kitano,Koike, Komine, Okada

SCKM basis

SUPER CKM: basis in the LOW - ENERGY phenomenology where through a rotation of the whole superfield (fermion + sfermion) one obtains DIAGONAL Yuhawa COUPL. for the corresponding fermion field

$\Delta_{ij}^{f} \longrightarrow \delta_{ij}^{f} \equiv \Delta_{ij}^{f} / m_{\tilde{f}}^{ave}$

$f \longrightarrow Uf = f^{0}$

$\tilde{f} \longrightarrow U\tilde{f} = \tilde{f}^{|}$

Unless m_f and $m_{\tilde{f}}$ are aligned, $\tilde{f}^{|}$ is not a mass eigenstate

Hall, Kostelecki, Raby

Constraints on δ_{ij} from Δm_K , ε_K, Δm_d

Gabbiani, Gabrielli, A.M., Silvestrini;
Ciuchini et al.; Becirevic et al.

Table 1. Maximum allowed values for $|\mathrm{Re}\,(\delta^d_{12})_{AB}|$ and $|\mathrm{Im}\,(\delta^d_{ij})_{AB}|$, with $A, B = (L, R)$ for an average squark mass $m_{\tilde{q}} = 500$ GeV and for different values of $x = m^2_{\tilde{g}}/m^2_{\tilde{q}}$. The bounds are given at tree level in the effective Hamiltonian and at NLO in QCD corrections as explained in the text. For different values of $m_{\tilde{q}}$ the bounds scale roughly as $m_{\tilde{q}}/500$ GeV.

	$\sqrt{\lvert\mathrm{Re}(\delta^d_{12})^2_{LL}\rvert}$		$\sqrt{\lvert\mathrm{Im}(\delta^d_{12})^2_{LL}\rvert}$	
x	TREE	NLO	TREE	NLO
0.3	1.4×10^{-2}	2.2×10^{-2}	1.8×10^{-3}	2.9×10^{-3}
1.0	3.0×10^{-2}	4.6×10^{-2}	3.9×10^{-3}	6.1×10^{-3}
4.0	7.0×10^{-2}	1.1×10^{-1}	9.2×10^{-3}	1.4×10^{-2}
	$\sqrt{\lvert\mathrm{Re}(\delta^d_{12})_{LL}(\delta^d_{12})_{RR}\rvert}$		$\sqrt{\lvert\mathrm{Im}(\delta^d_{12})_{LL}(\delta^d_{12})_{RR}\rvert}$	
x	TREE	NLO	TREE	NLO
0.3	1.8×10^{-3}	8.6×10^{-4}	2.3×10^{-4}	1.1×10^{-4}
1.0	2.0×10^{-3}	9.6×10^{-4}	2.6×10^{-4}	1.3×10^{-4}
4.0	2.8×10^{-3}	1.3×10^{-3}	3.7×10^{-4}	1.8×10^{-4}
	$\sqrt{\lvert\mathrm{Re}(\delta^d_{13})^2_{LR}\rvert}$		$\sqrt{\lvert\mathrm{Im}(\delta^d_{13})^2_{LR}\rvert}$	
x	TREE	NLO	TREE	NLO
0.3	3.1×10^{-3}	2.6×10^{-3}	4.1×10^{-4}	3.4×10^{-4}
1.0	3.4×10^{-3}	2.8×10^{-3}	4.6×10^{-4}	3.7×10^{-4}
4.0	4.9×10^{-3}	3.9×10^{-3}	6.5×10^{-4}	5.2×10^{-4}

Table 2. Maximum allowed values for $|\,\mathrm{Re}\left(\delta^d_{13}\right)_{AB}|$ and $|\,\mathrm{Im}\left(\delta^d_{ij}\right)_{AB}|$, with $A, B = (L, R)$ for an average squark mass $m_{\tilde{q}} = 500$ GeV and different values of $x = m^2_{\tilde{g}}/m^2_{\tilde{q}}$. with NLO evolution and lattice B parameters, denoted by NLO. The missing entries correspond to cases in which no constraint was found for $|\left(\delta^d_{ij}\right)_{AB}| < 0.9$.

	$\|\mathrm{Re}(\delta^d_{13})_{\mathrm{LL}}\|$		$\|\mathrm{Re}(\delta^d_{13})_{\mathrm{LL=RR}}\|$	
x	TREE	NLO	TREE	NLO
0.25	4.9×10^{-2}	6.2×10^{-2}	3.1×10^{-2}	1.9×10^{-2}
1.0	1.1×10^{-1}	1.4×10^{-1}	3.4×10^{-2}	2.1×10^{-2}
4.0	6.0×10^{-1}	7.0×10^{-1}	4.7×10^{-2}	2.8×10^{-2}
	$\|\mathrm{Im}(\delta^d_{13})_{\mathrm{LL}}\|$		$\|\mathrm{Im}(\delta^d_{13})_{\mathrm{LL=RR}}\|$	
x	TREE	NLO	TREE	NLO
0.25	1.1×10^{-1}	1.3×10^{-1}	1.3×10^{-2}	8.0×10^{-3}
1.0	2.6×10^{-1}	3.0×10^{-1}	1.5×10^{-2}	9.0×10^{-3}
4.0	2.6×10^{-1}	3.4×10^{-1}	2.0×10^{-2}	1.2×10^{-2}
	$\|\mathrm{Re}(\delta^d_{13})_{\mathrm{LR}}\|$		$\|\mathrm{Re}(\delta^d_{13})_{\mathrm{LR=RL}}\|$	
x	TREE	NLO	TREE	NLO
0.25	3.4×10^{-2}	3.0×10^{-2}	3.8×10^{-2}	2.6×10^{-2}
1.0	3.9×10^{-2}	3.3×10^{-2}	8.3×10^{-2}	5.2×10^{-2}
4.0	5.3×10^{-2}	4.5×10^{-2}	1.2×10^{-1}	—
	$\|\mathrm{Im}(\delta^d_{13})_{\mathrm{LR}}\|$		$\|\mathrm{Im}(\delta^d_{13})_{\mathrm{LR=RL}}\|$	
x	TREE	NLO	TREE	NLO
0.25	7.6×10^{-2}	6.6×10^{-2}	1.5×10^{-2}	9.0×10^{-3}
1.0	8.7×10^{-2}	7.4×10^{-2}	3.6×10^{-2}	2.3×10^{-2}
4.0	1.2×10^{-1}	1.0×10^{-1}	2.7×10^{-1}	—

Table 3. Limits from $\varepsilon'/\varepsilon < 2.7 \times 10^{-3}$ on $\mathrm{Im}\left(\delta^d_{12}\right)$, for an average squark mass $m_{\tilde{q}} = 500\mathrm{GeV}$ and for different values of $x = m^2_{\tilde{g}}/m^2_{\tilde{q}}$. For different values of $m_{\tilde{q}}$, the limits can be obtained multiplying the ones in the table by $\left(m_{\tilde{q}}(\mathrm{GeV})/500\right)^2$.

x	$\left\|\mathrm{Im}\left(\delta^d_{12}\right)_{\mathrm{LL}}\right\|$	$\left\|\mathrm{Im}\left(\delta^d_{12}\right)_{\mathrm{LR}}\right\|$
0.3	1.0×10^{-1}	1.1×10^{-5}
1.0	4.8×10^{-1}	2.0×10^{-5}
4.0	2.6×10^{-1}	6.3×10^{-5}

How large can the SUSY contribution to b $\longrightarrow$ s transitions still be?

In spite of the constraints on

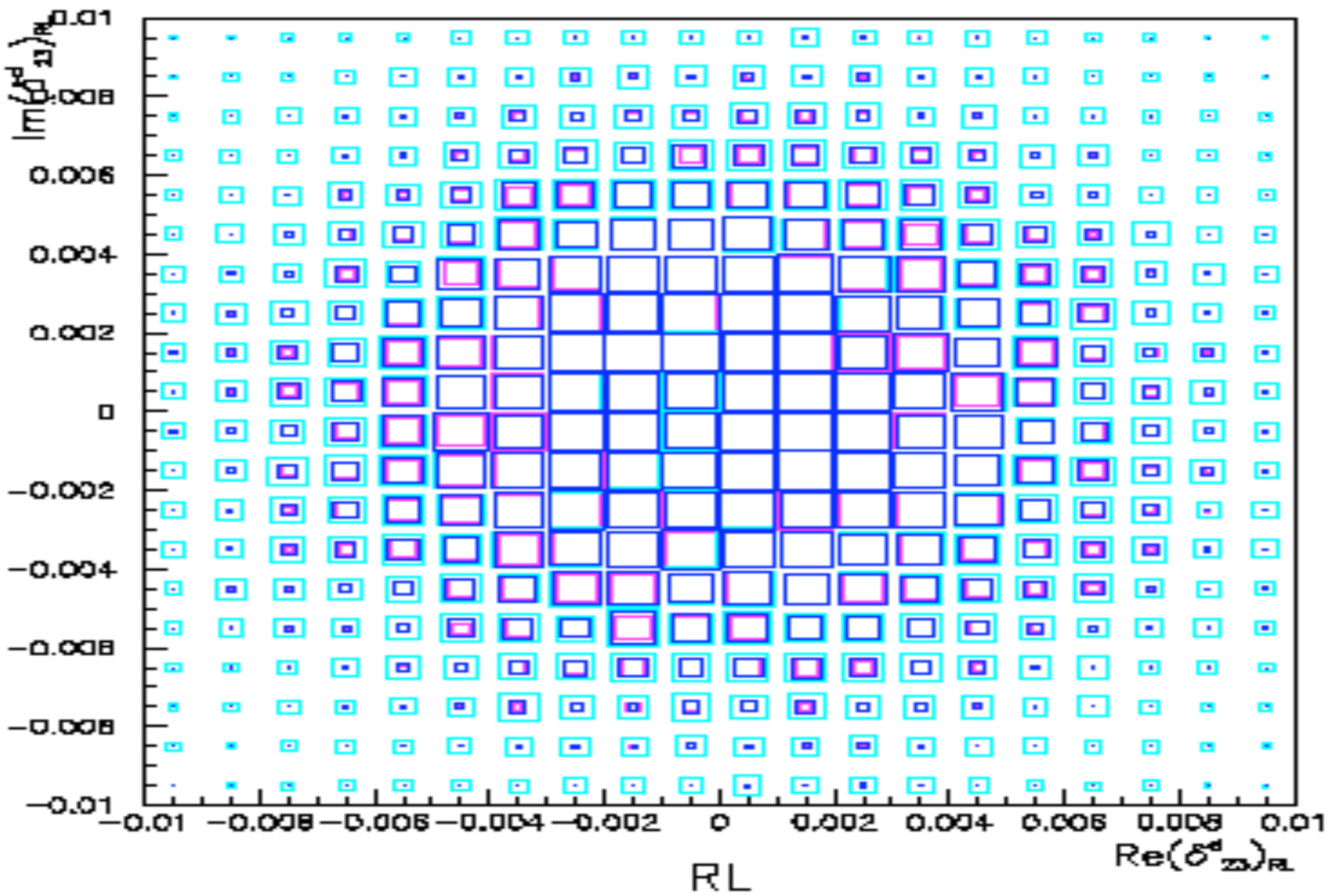
$B \longrightarrow X_s \gamma$ and $B \longrightarrow X_s l^+ l^-$,

there is still ample room for large values of some of the $(\delta^d)_{23}$ insertions (e.g., possible surprises in $B_s \longrightarrow J/\psi\ \Phi$ or measuring γ in $B_s \longrightarrow D_S^+ K^-$, etc.)

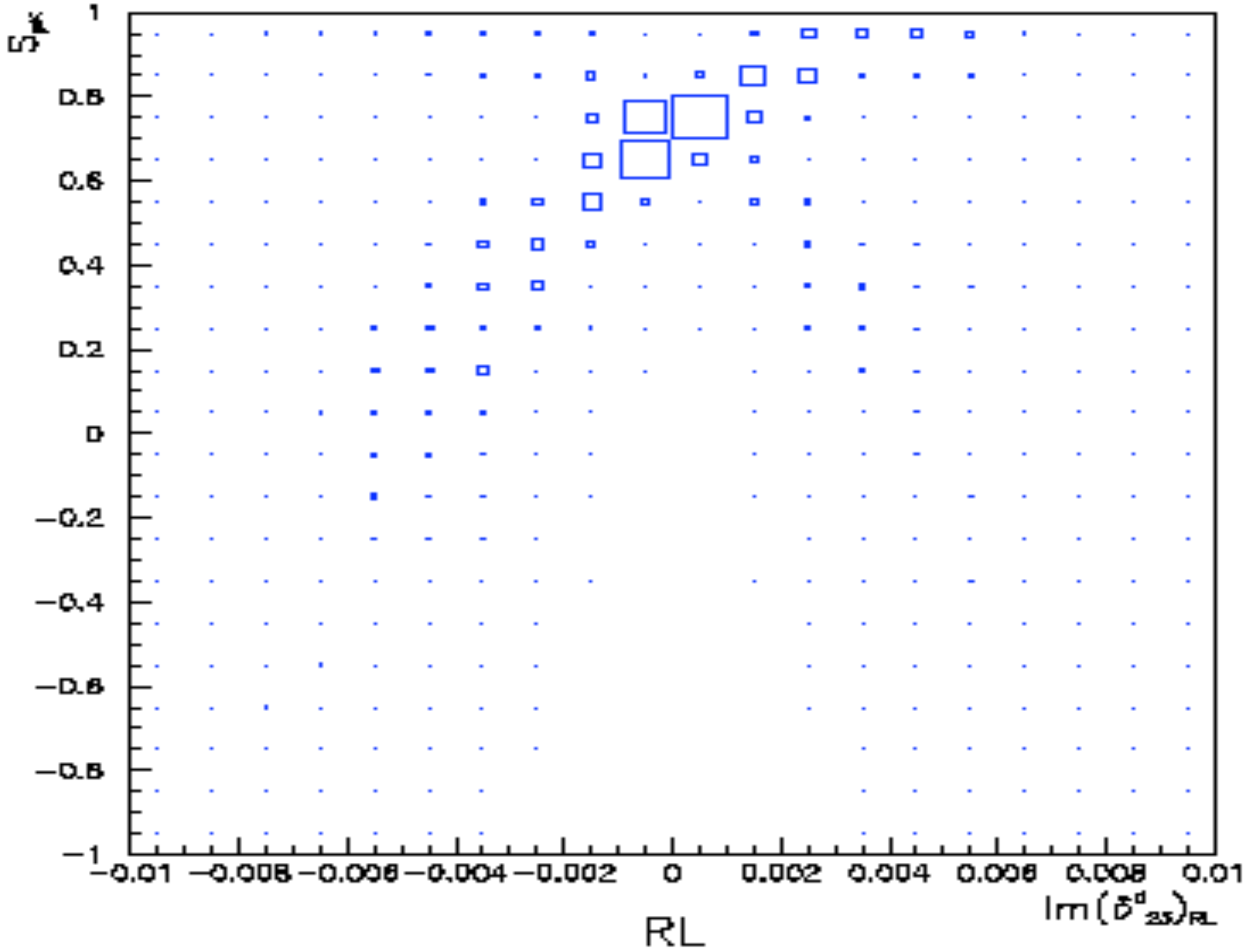
Ciuchini, Franco, Martinelli,A.M., Silvestrini;

Ciuchini, Franco, A.M., Silvestrini

Ciuchini, Franco, A.M.,Silvestrini;
Silvestrini, LP05

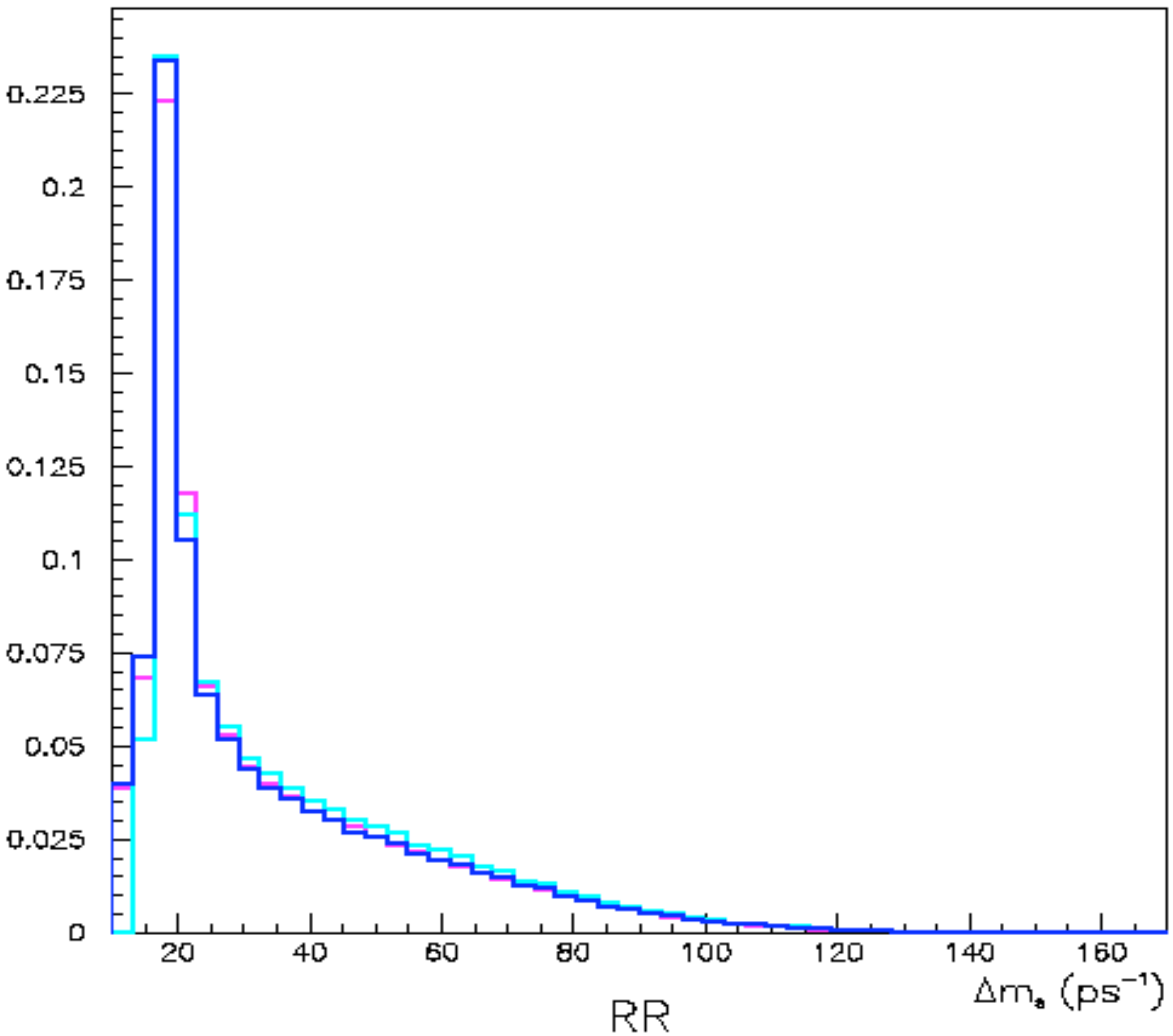


Ciuchini et al.; Silvestrini LP05

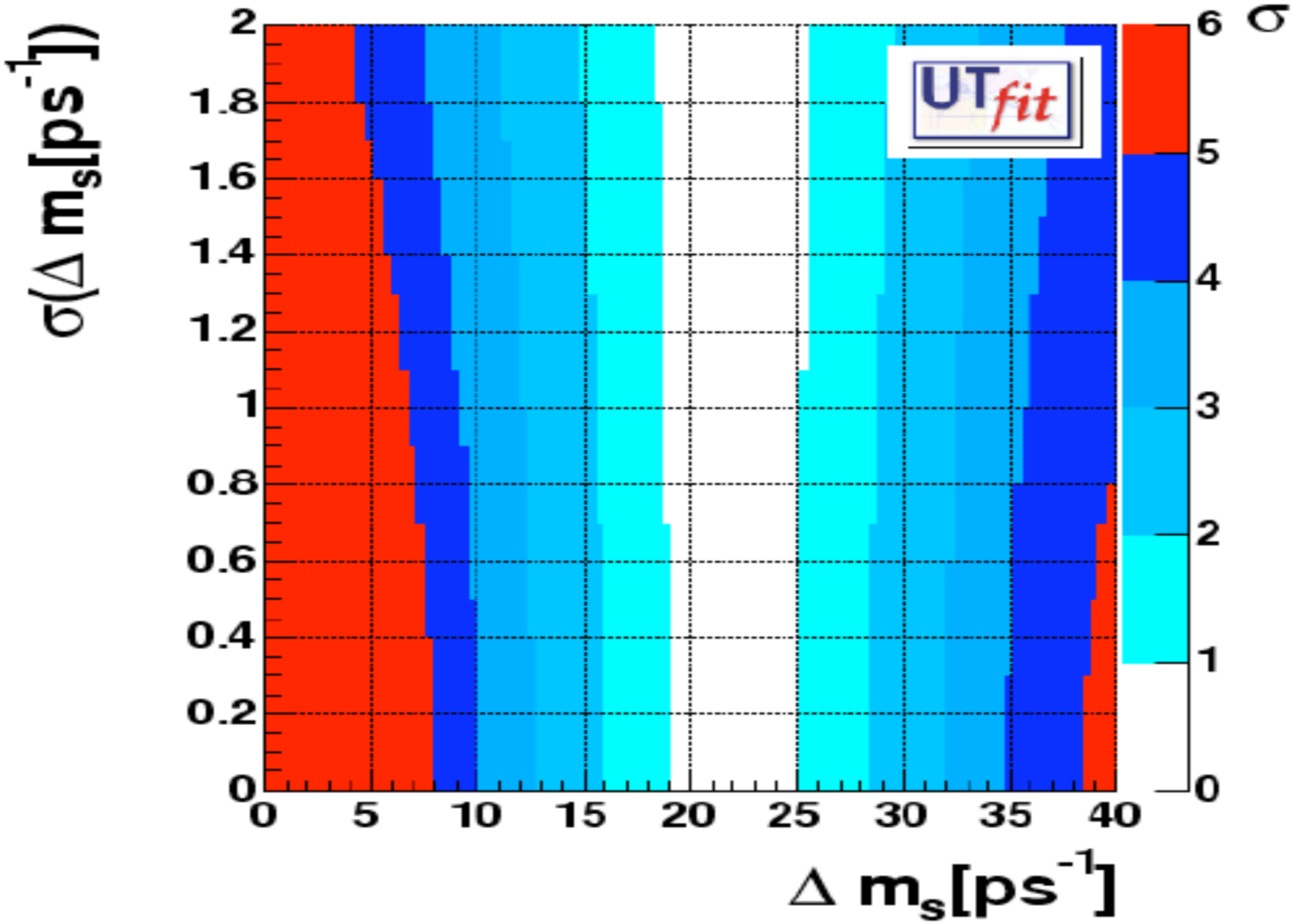


δ_{RR} contribution to Δm_S

Ciuchini et al.



Δm_s in the SM



FCNC HADRON-LEPTON CONNECTION IN SUSYGUT

If

soft SUSY breaking terms arise

at a scale > M_{GUT}, they have to respect

the underlying quark-lepton GU symmetry

↓

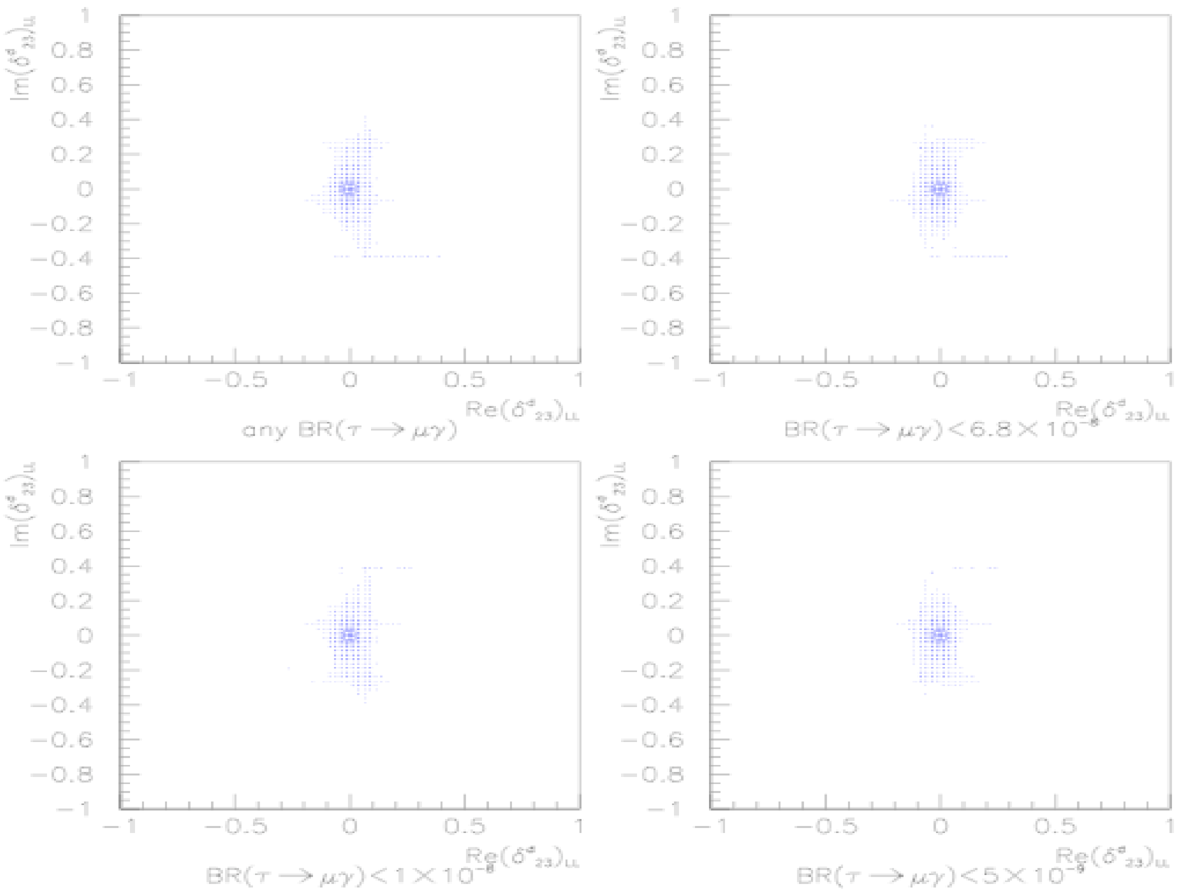
constraints on δ^{quark} from LFV and

constraints on δ^{lepton} from hadronic FCNC

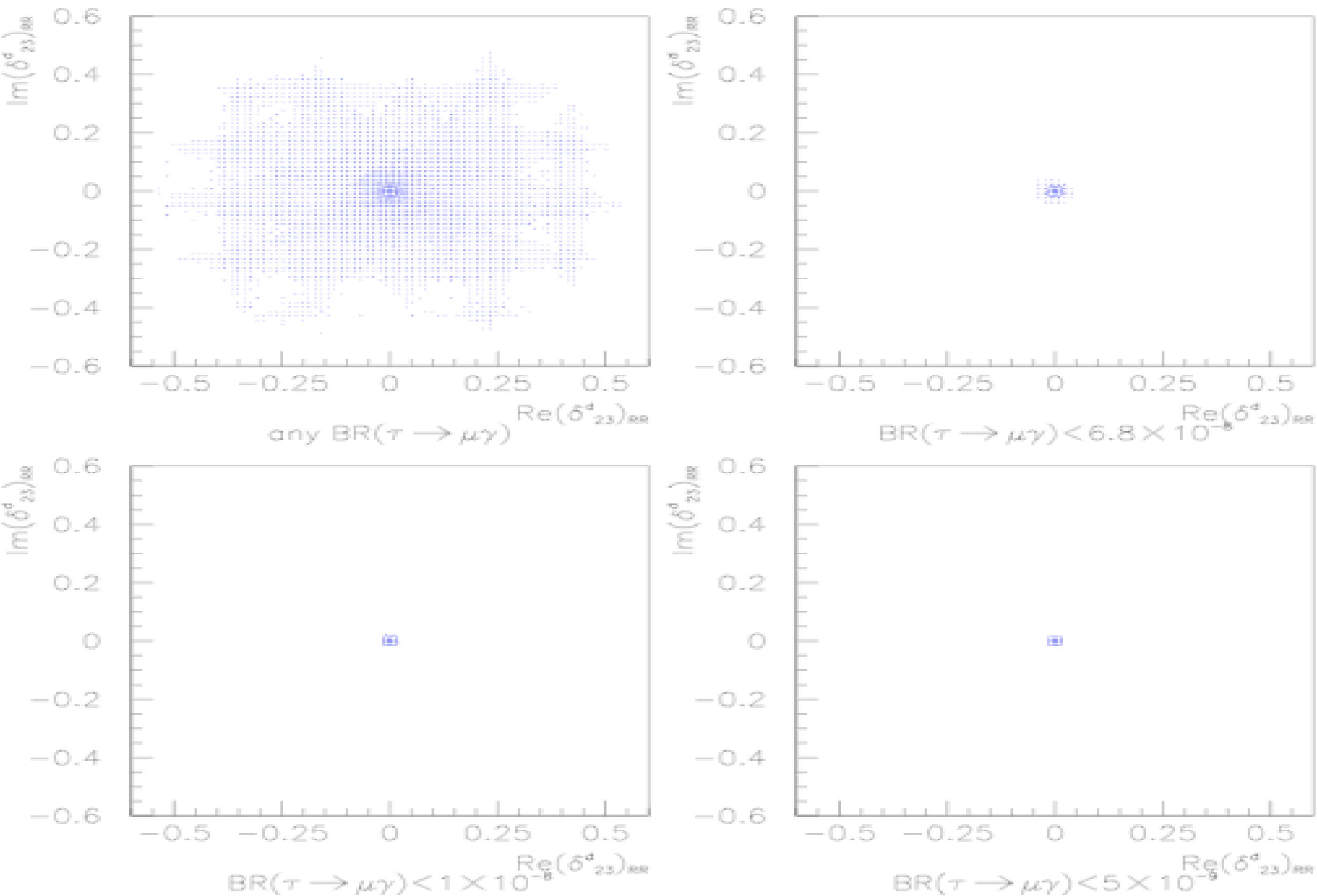
Ciuchini, A.M., Silvestrini, Vempati, Vives

general analysis Ciuchini, A.M., Paradisi, Silvestrini, Vempati, Vives (to appear soon)

LFV limiting the hadronic $(\delta_{23})_{LL}$



LFV limiting the hadronic $(\delta_{23})_{RR}$



TESTING LFV through μ - e UNIVERSALITY

- $\mu - e$ universality in $R_K = \Gamma(K \to e\nu_e)/\Gamma(K \to \mu\nu_\mu)$

$$R_K^{exp.} = (2.416 \pm 0.043_{stat.} \pm 0.024_{syst.}) \cdot 10^{-5} \quad \text{NA48/2 '05}$$

$$R_K^{exp.} = (2.44 \pm 0.11) \cdot 10^{-5} \quad PDG$$

$$R_K^{SM} = (2.472 \pm 0.001) \cdot 10^{-5} \quad SM$$

DEVIATION from μ - e UNIVERSALITY

A.M., Paradisi, Petronzio

- Denoting by $\Delta r_{NP}^{e-\mu}$ the deviation from $\mu - e$ universality in $R_{K,\pi}$ due to new physics, i.e.:

$$R_{K,\pi} = R_{K,\pi}^{SM}\left(1 + \Delta r_{K,\pi\, NP}^{e-\mu}\right),$$

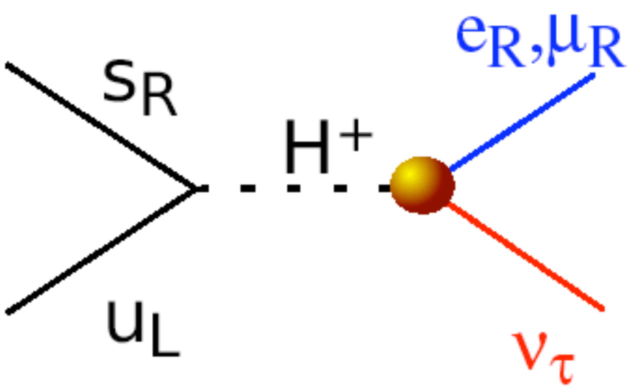
- we get at the 2σ level:

$$-0.063 \leq \Delta r_{K\, NP}^{e-\mu} \leq 0.017 \quad \text{NA48/2}$$

$$-0.0107 \leq \Delta r_{\pi\, NP}^{e-\mu} \leq 0.0022 \quad \text{PDG}$$

H mediated LFV SUSY contributions to R_K

$$R_K^{LFV} = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \simeq \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)} \quad , \quad i = e, \mu, \tau$$



$$eH^\pm \nu_\tau \to \frac{g_2}{\sqrt{2}} \frac{m_\tau}{M_W} \Delta_R^{31} \tan^2\beta$$

$$\Delta_R^{31} \sim \frac{\alpha_2}{4\pi} \delta_{RR}^{31}$$

$$\Delta_R^{31} \sim 5 \cdot 10^{-4} \quad t_\beta = 40 \quad M_{H^\pm} = 500\mathrm{GeV}$$

$$\Downarrow$$

$$\Delta r_{K\,SUSY}^{e-\mu} \simeq \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right) |\Delta_R^{31}|^2 \tan^6\beta \approx 10^{-2}$$

Extension to B ⟶ lν deviation from universality   Isidori, A.M., Paradisi

OUTLOOK

- We possess a robust Standard Model for Flavor Physics: from determining the CKM entries we entered the new era of (successful) precision tests of its consistency

- New physics at the elw. scale is likely to be either Flavor Blind or to account for deviations not larger than 10 - 20% from the SM predictions for the measured quantities.

- Still possible to have sizeable deviations in flavor observables to be measured (for instance CP violating B_s decays)

- Flavor universality in the mechanism for the SUSY breaking generally does NOT imply flavor blindness of Low-Energy SUSY (ex. SUSY seesaw) → great potentialities for exps. looking for LFV

- Flavor Physics plays a crucial role for "reconstructing" the New Physics discovered at LHC !

BRINDISI
to
the 20 successful years of La Thuile

When the toast
for the wedding of Flavor Physics with
New Physics?