FUTURE FLAVOUR PHYSICS, Abingdon, June 21-22, 2007

NEW PHYSICS AND FLAVOUR

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A FUTURE FOR FLAVOR PHYSICS IN OUR SEARCH BEYOND THE SM?

- The traditional **competition** between direct and indirect (FCNC, CPV) searches to establish who is going **to see the new physics first** is no longer the priority, rather

- **COMPLEMENTARITY** between direct and indirect searches for New Physics is the key-word

- Twofold meaning of such complementarity:

i) synergy in “reconstructing” the “fundamental theory” staying behind the signatures of NP;

ii) **coverage of complementary areas of the NP parameter space** (ex.: multi-TeV SUSY physics)

WHY TO GO BEYOND THE SM

"OBSERVATIONAL" REASONS

- HIGH ENERGY PHYSICS

NO (but $A_{FB}^{Z \rightarrow bb}$……)

- FCNC, CP≠

NO (but $b \rightarrow s q\bar{q}$ penguin, V_{ub} …)

- HIGH PRECISION LOW-EN.

NO (but $(g-2)_\mu$ …)

- NEUTRINO PHYSICS

YES $m_\nu \neq 0$, $\theta_\nu \neq 0$

- COSMO - PARTICLE PHYSICS

YES (DM, ΔB_{cosm}, INFLAT., DE)

THEORETICAL REASONS

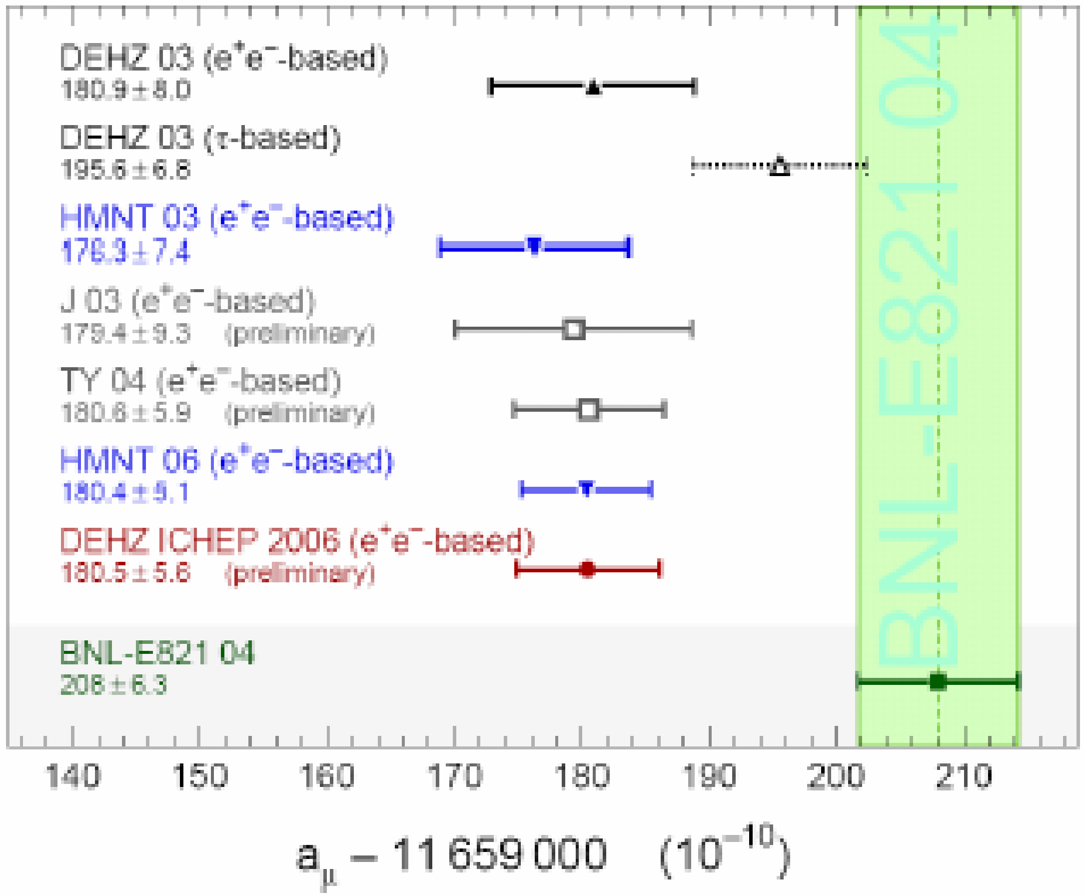
- INTRINSIC INCONSISTENCY OF SM AS QFT

NO (spont. broken gauge theory without anomalies)

- NO ANSWER TO QUESTIONS THAT "WE" CONSIDER "FUNDAMENTAL" QUESTIONS TO BE ANSWERED BY A "FUNDAMENTAL" THEORY

YES (hierarchy, unification, flavor)

Status of g_μ-2



Whereas τ based prediction agrees with the measurement within 1σ
all recent e+e- based predictions have a deviation with data at over 3σ

Present "Observational" Evidence for New Physics

- NEUTRINO MASSES ★★★
- DARK MATTER ★★★
- MATTER-ANTIMATTER ASYMMETRY ★★
- INFLATION ★

THE FATE OF LEPTON NUMBER

L VIOLATED → υ Majorana ferm.

L CONSERVED → υ Dirac ferm. (dull option)

$h\,\bar{\upsilon}_L H\,\upsilon_R \rightarrow m_\upsilon = h \langle H \rangle$ $\quad M_\upsilon < 1$ eV $\rightarrow$ $h < 10^{-11}$

EXTRA-DIM. ν_R in the bulk: small overlap?

SMALLNESS of m_υ

↓

PRESENCE OF A NEW PHYSICAL MASS SCALE

NEW HIGH SCALE | NEW LOW SCALE

SEE - SAW MECHAN.

Minkowski; Yanagida;Gell-Mann, Ramond, Slansky; Mohapatra-Senjanovic

↓

ν_R ENLARGEMENT OF THE FERMIONIC SPECTRUM

$M\upsilon_R\,\upsilon_R + h\,\bar{\upsilon}_L\,\bar{\phi}\,\upsilon_R$

	υ_L	υ_R
υ_L	~O	$h \langle \bar{\phi} \rangle$
υ_R	$h \langle \bar{\phi} \rangle$	M

LR Models?

MAJORON MODELS

Gelmini, Roncadelli

↓

Δ ENLARGEMENT OF THE HIGGS SCALAR SECTOR

$h\,\upsilon_L\,\upsilon_L\,\Delta$

$m_\upsilon = h \langle \Delta \rangle$

N.B.: EXCLUDED BY LEP!

STABLE ELW. SCALE WIMPs from PARTICLE PHYSICS

	SUSY	EXTRA DIM.	LITTLE HIGGS.
1) ENLARGEMENT OF THE SM	(x^μ, θ)	(x^μ, j^i)	SM part + new part
	Anticomm. Coord.	New bosonic Coord.	to cancel Λ^2 at 1-Loop
2) SELECTION RULE	R-PARITY LSP	KK-PARITY LKP	T-PARITY LTP
→ DISCRETE SYMM.	Neutralino spin 1/2	spin1	spin0
→ STABLE NEW PART.	↓	↓	↓
3) FIND REGION (S) PARAM. SPACE WHERE THE "L" NEW PART. IS NEUTRAL + $\Omega_L h^2$ OK	m_{LSP} ~100 - 200 GeV *	m_{LKP} ~600 - 800 GeV	m_{LTP} ~400 - 800 GeV

* But abandoning gaugino-masss unif. → Possible to have m_{LSP} down to 7 GeV

Bottino, Donato, Fornengo, Scopel

ELW. SYMM. BREAKING STABILIZATION VS. FLAVOR PROTECTION: THE SCALE TENSION

$$M(B_d\text{-}\bar{B}_d) \sim c_{SM} \frac{(y_t V_{tb}^* V_{td})^2}{16\pi^2 M_W^2} + c_{new} \frac{1}{\Lambda^2}$$

If $c_{new} \sim c_{SM} \sim 1$

Isidori

$\Lambda > 10^4$ TeV for $O^{(6)} \sim (\bar{s}\, d)^2$
[K^0-$\bar{K}^0$ mixing]

$\Lambda > 10^3$ TeV for $O^{(6)} \sim (\bar{b}\, d)^2$
[B^0-$\bar{B}^0$ mixing]

UV SM COMPLETION TO STABILIZE THE ELW. SYMM. BREAKING: $\Lambda_{UV} \sim O(1\ \text{TeV})$

FLAVOR BLINDNESS OF THE NP AT THE ELW. SCALE?

- THREE DECADES OF FLAVOR TESTS (Redundant determination of the UT triangle → verification of the SM, theoretically and experimentally “high precision” FCNC tests, ex. $b \rightarrow s + \gamma$, CP violating flavor conserving and flavor changing tests, lepton flavor violating (LFV) processes, …) clearly state that:
- A) in the **HADRONIC SECTOR** the CKM flavor pattern of the SM represents the main bulk of the flavor structure and of CP violation;
- B) in the **LEPTONIC SECTOR**: although neutrino flavors exhibit large admixtures, LFV, i.e. non – conservation of individual lepton flavor numbers in FCNC transitions among charged leptons, is extremely small: once again the SM is right (to first approximation) predicting negligibly small LFV

FROM DETERMINATION TO VERIFICATION OF THE CKM PATTERN FOR HADRONIC FLAVOR DESCRIPTION

$$|V_{us}| \equiv \lambda, \qquad |V_{cb}|, \qquad R_b, \qquad \gamma,$$

TREE LEVEL

$$|V_{us}| \equiv \lambda, \qquad |V_{cb}|, \qquad R_t, \qquad \beta.$$

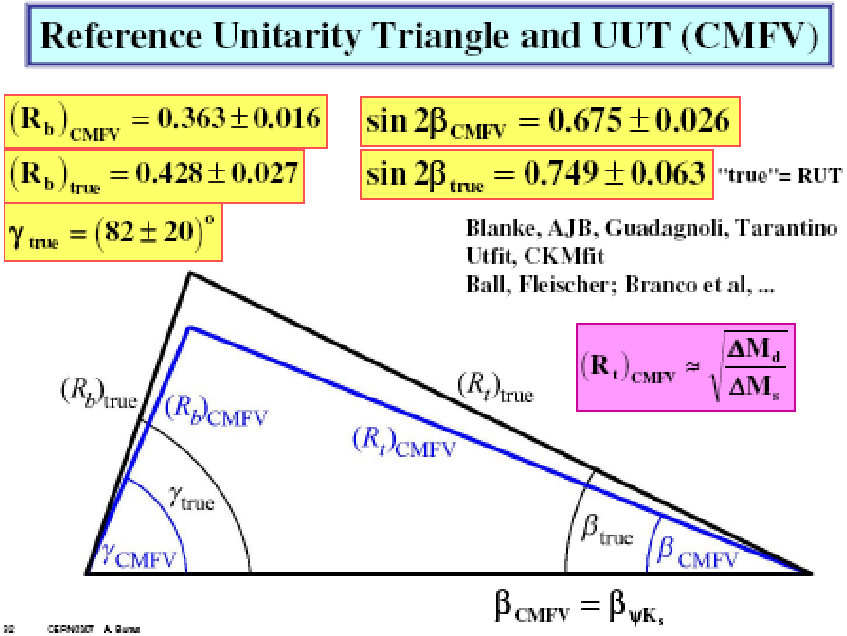
ONE - LOOP

$$R_b \equiv \frac{|V_{ud}V_{ub}^*|}{|V_{cd}V_{cb}^*|} = \sqrt{\bar{\varrho}^2 + \bar{\eta}^2} = \left(1 - \frac{\lambda^2}{2}\right)\frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right|$$

$$R_t \equiv \frac{|V_{td}V_{tb}^*|}{|V_{cd}V_{cb}^*|} = \sqrt{(1-\bar{\varrho})^2 + \bar{\eta}^2} = \frac{1}{\lambda}\left|\frac{V_{td}}{V_{cb}}\right|.$$

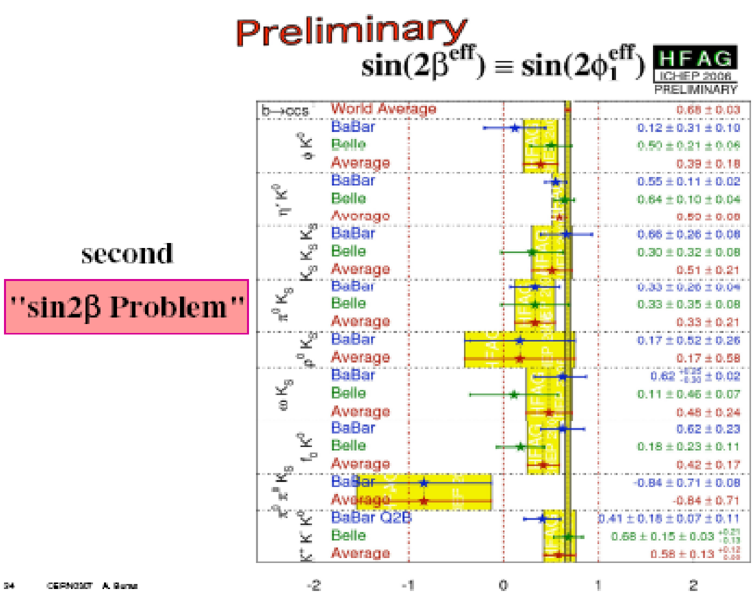
$$R_b = \sqrt{1 + R_t^2 - 2R_t\cos\beta}, \qquad \cot\gamma = \frac{1 - R_t\cos\beta}{R_t\sin\beta},$$

A. BURAS et al.



"sin 2β Problem"

Is this a $|V_{ub}|$ Problem?



Single channels understood?

Allowed to take the avg.?

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-$\bar{B}_d$ 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 →

MINIMAL FLAVOR VIOLATION

MFV : Flavor originates only from the SM Yukawa coupl.

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!

What a SuperB can do in testing CMFV

L. Silvestrini at SuperB IV

Minimal Flavour Violation

In **MFV models** with **one Higgs doublet** or **low/moderate tanβ** the NP contribution is a shift of the Inami-Lim function associated to top box diagrams

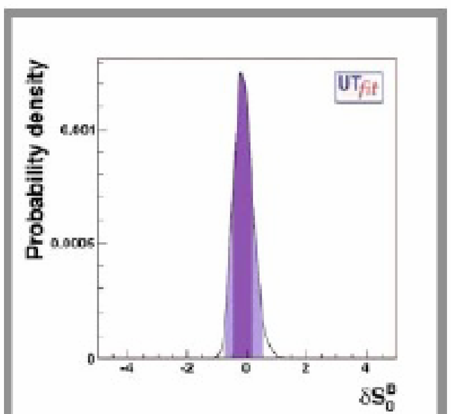
$$S_0(x_t) \rightarrow S_0(x_t) + \delta S_0(x_t)$$

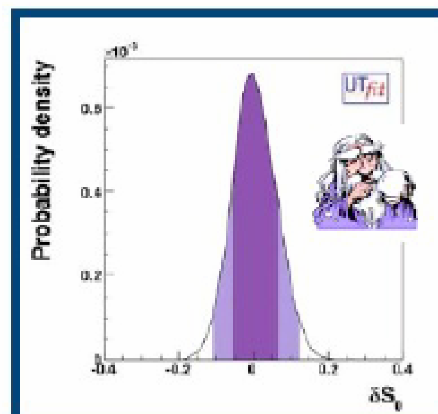
$$\delta S_0(x_t) = 4a\left(\frac{\Lambda_0}{\Lambda}\right)^2$$

$$\Lambda_0 = \frac{\lambda_t \sin^2 \vartheta_W M_W}{\alpha} \simeq 2.4 \text{ TeV}$$

(D'Ambrosio et al., hep-ph/0207036)

$\delta S_0^B = \delta S_0^K$





$\delta S_0 = -0.16 \pm 0.32$

$\Lambda > 5.5$ TeV @95%

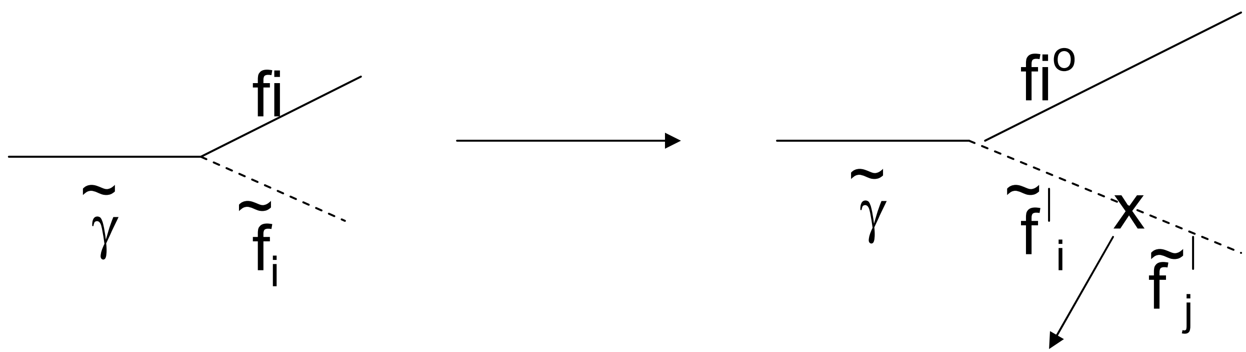
$\delta S_0 = 0.004 \pm 0.059$

$\Lambda > 28$ TeV @95%

The "worst" case: we still probe virtual particles with masses up to ~12 M_W ~1 TeV

SCKM basis

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



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

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

Hall, Kostelecki, Raby

BOUNDS ON THE HADRONIC FCNC: 1 - 3 DOWN GENERATION

	$\|\Re(\delta^d_{13})_{LL}\|$		$\|\Re(\delta^d_{13})_{LL=RR}\|$	
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}
	$\|\Im(\delta^d_{13})_{LL}\|$		$\|\Im(\delta^d_{13})_{LL=RR}\|$	
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}
	$\|\Re(\delta^d_{13})_{LR}\|$		$\|\Re(\delta^d_{13})_{LR=RL}\|$	
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}	—
	$\|\Im(\delta^d_{13})_{LR}\|$		$\|\Im(\delta^d_{13})_{LR=RL}\|$	
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}	—

SuperB vs. LHC Sensitivity Reach in testing Λ_{SUSY}

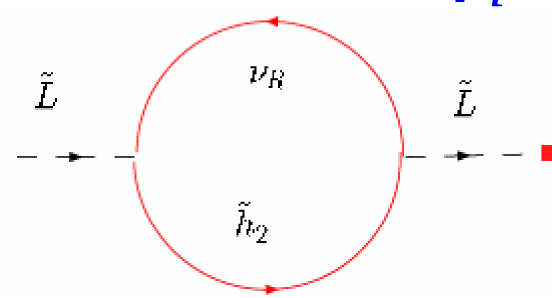
	superB	general MSSM	high-scale MFV
$\left\|\left(\delta^d_{13}\right)_{LL}\right\|$ $(LL \gg RR)$	$1.8 \cdot 10^{-2}\frac{m_{\tilde{q}}}{(350\mathrm{GeV})}$	1	$\sim 10^{-3}\frac{(350\mathrm{GeV})^2}{m_{\tilde{q}}^2}$
$\left\|\left(\delta^d_{13}\right)_{LL}\right\|$ $(LL \sim RR)$	$1.3 \cdot 10^{-3}\frac{m_{\tilde{q}}}{(350\mathrm{GeV})}$	1	$-$
$\left\|\left(\delta^d_{13}\right)_{LR}\right\|$	$3.3 \cdot 10^{-3}\frac{m_{\tilde{q}}}{(350\mathrm{GeV})}$	$\sim 10^{-1}\tan\beta\frac{(350\mathrm{GeV})}{m_{\tilde{q}}}$	$\sim 10^{-4}\tan\beta\frac{(350\mathrm{GeV})^3}{m_{\tilde{q}}^3}$
$\left\|\left(\delta^d_{23}\right)_{LR}\right\|$	$1.0 \cdot 10^{-3}\frac{m_{\tilde{q}}}{(350\mathrm{GeV})}$	$\sim 10^{-1}\tan\beta\frac{(350\mathrm{GeV})}{m_{\tilde{q}}}$	$\sim 10^{-3}\tan\beta\frac{(350\mathrm{GeV})^3}{m_{\tilde{q}}^3}$

SuperB can probe MFV (with small-moderate tanβ) for TeV squarks; for a generic non-MFV MSSM → sensitivity to squark masses > 100 TeV ! L. Silvestrini

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

Borzumati, A. M. 1986 (after discussions with W. Marciano and A. Sanda)

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

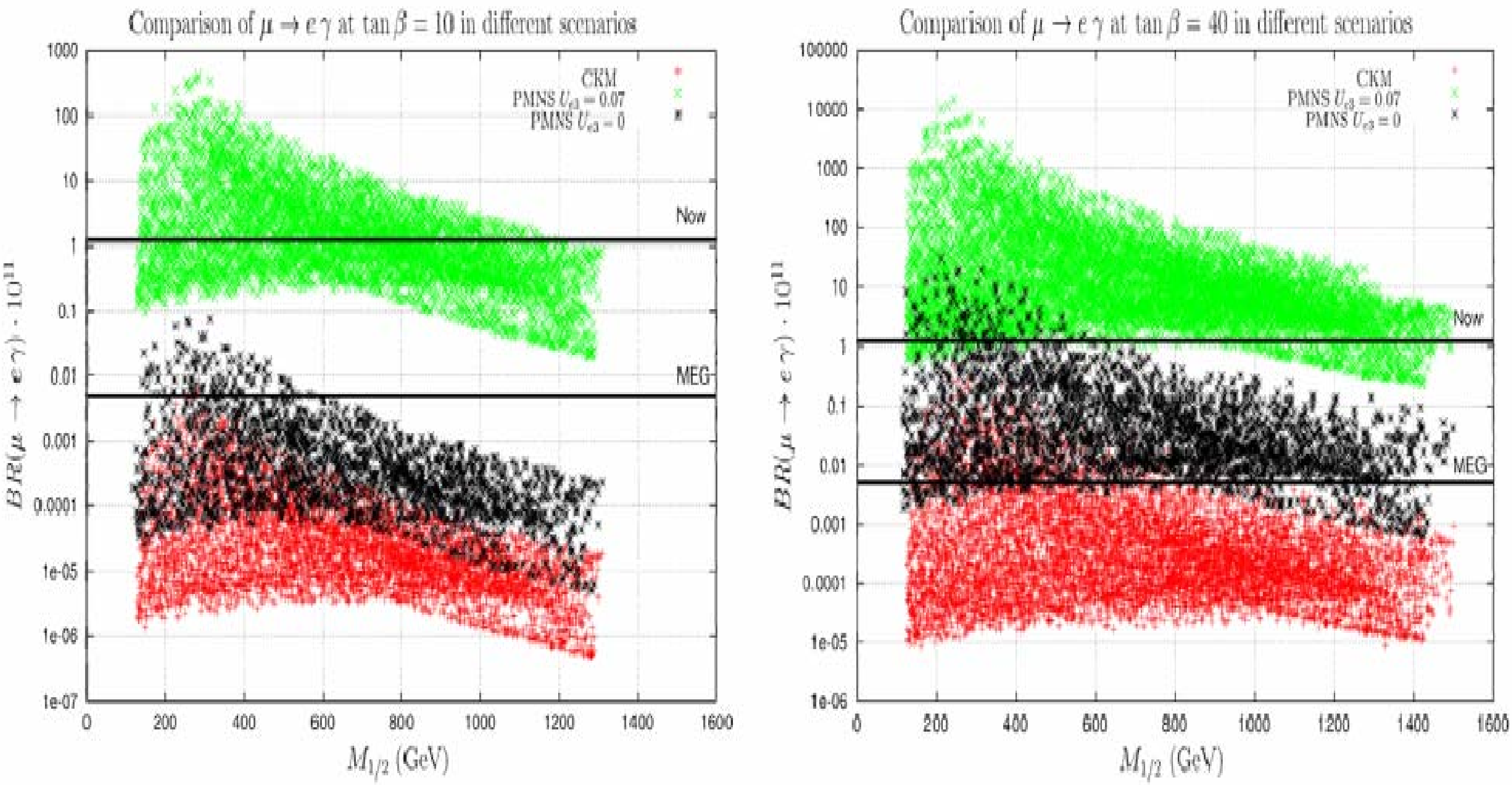


$$\left(m_{\tilde{L}}^2\right)_{ij} \sim \frac{1}{8\pi^2}(3m_0^2 + A_0^2)\left(f_\nu^\dagger f_\nu\right)_{ij} \log\frac{M}{M_G}$$

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

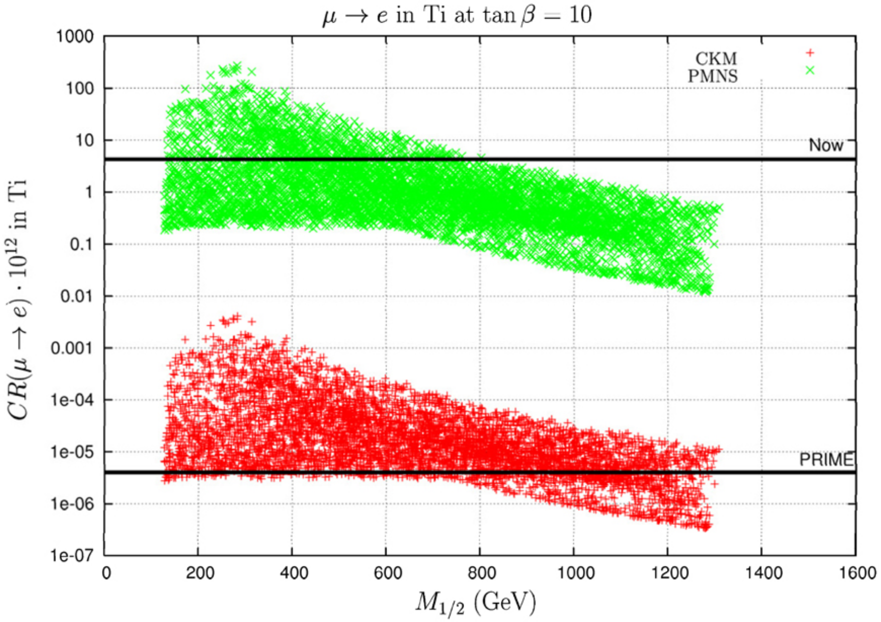
μ → e+γ in SUSYGUT: past and future

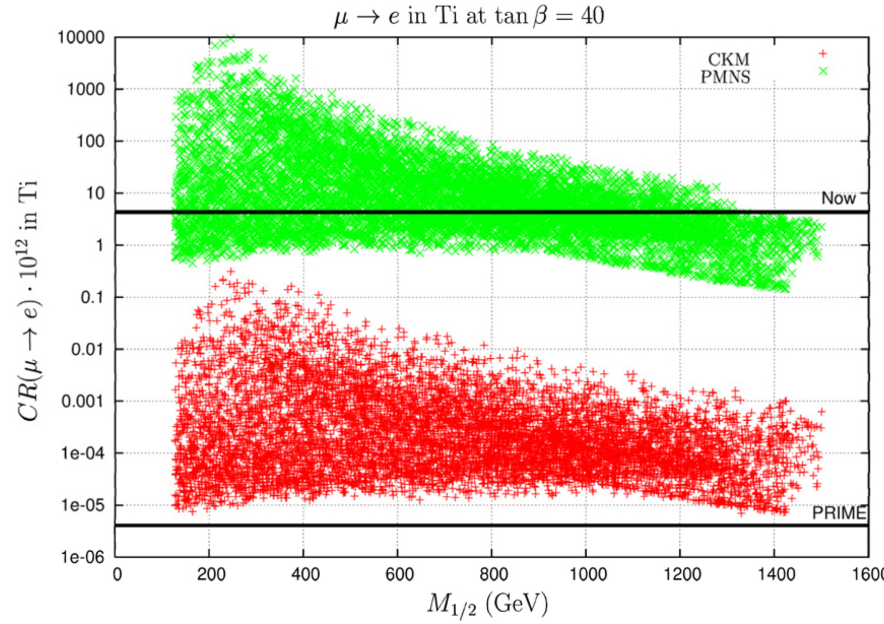
$\mu \to e\gamma$ in the $U_{e3} = 0$ PMNS case

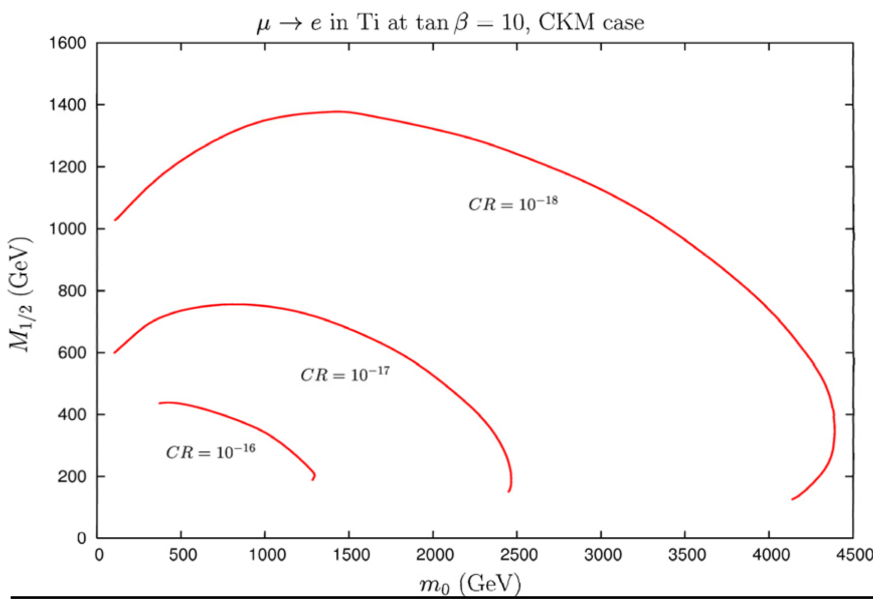


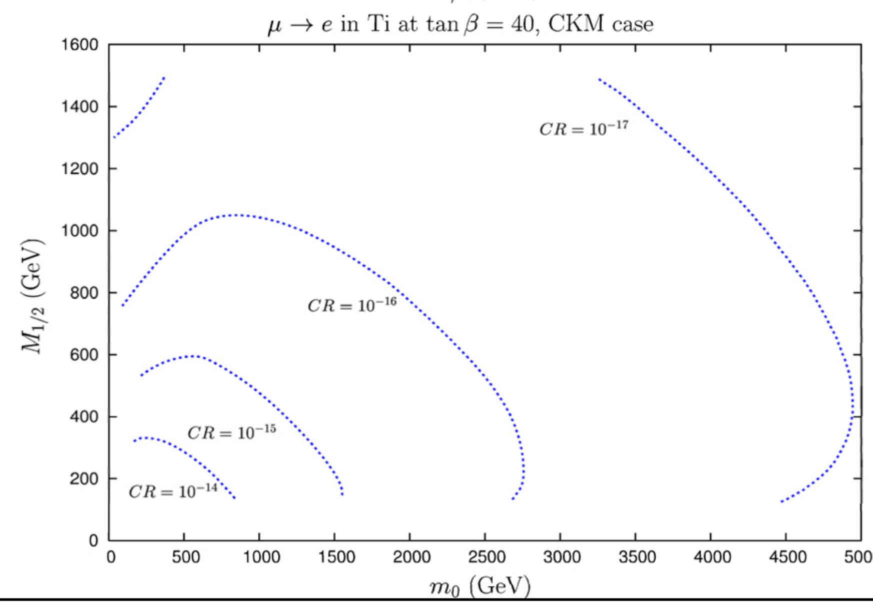
CFMV

$\mu \to e$ in Ti and **PRISM/PRIME** conversion experiment

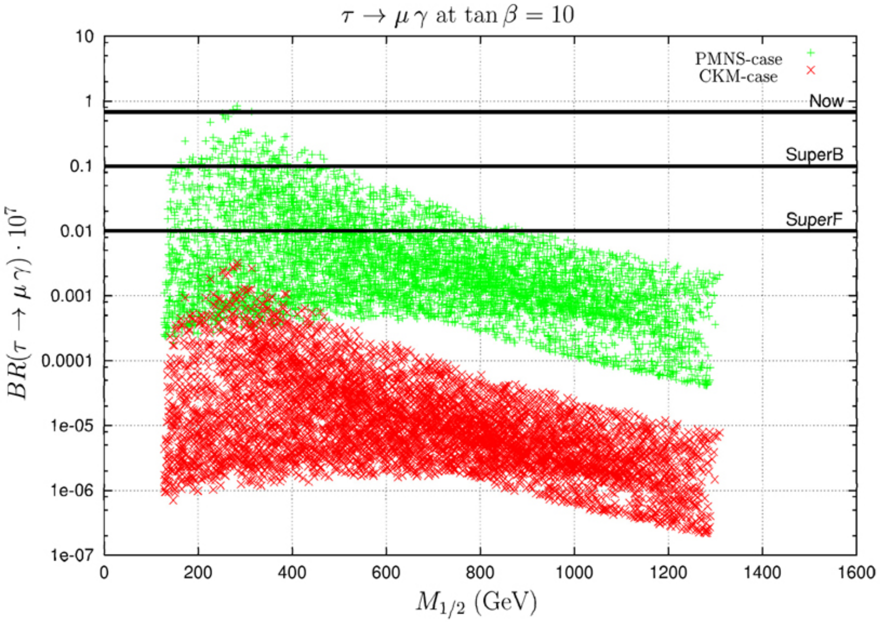


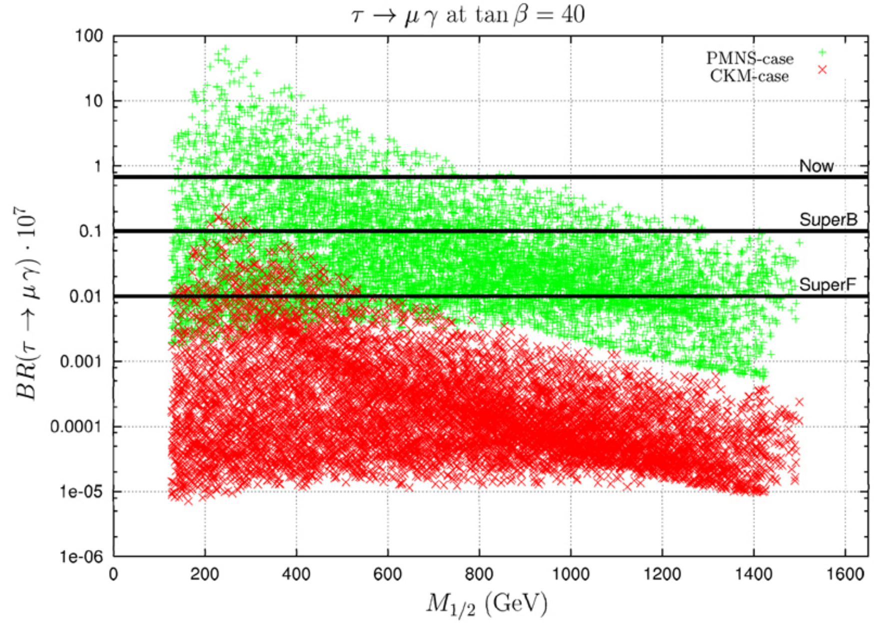


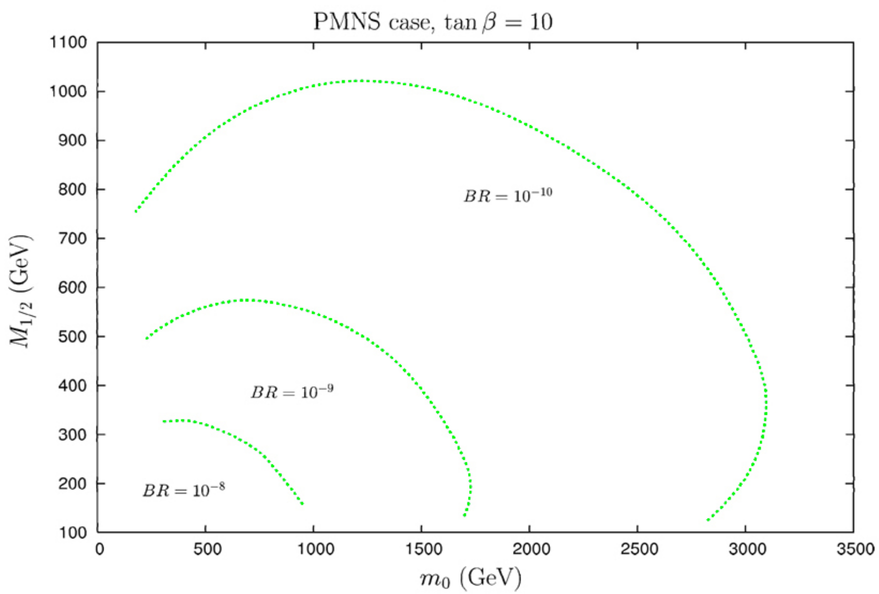


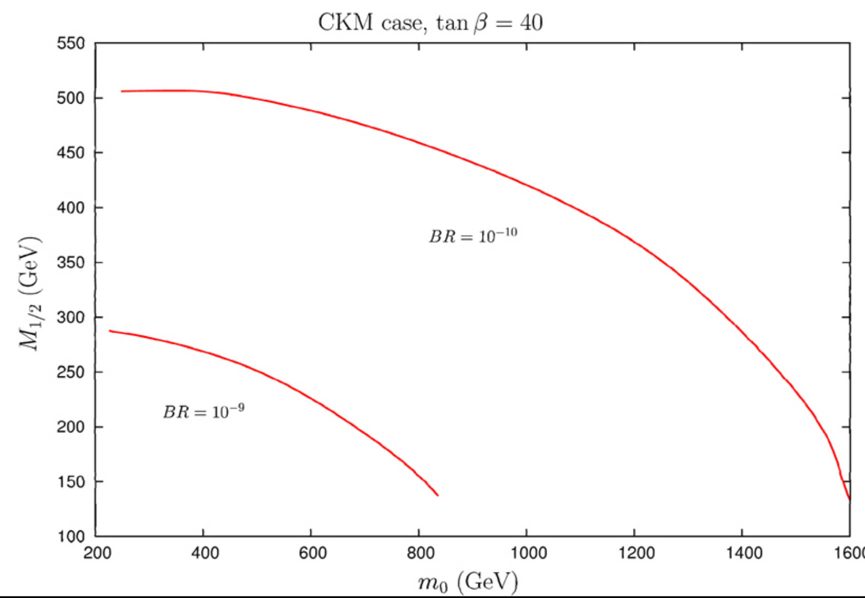


$\tau \to \mu\,\gamma$ and the **Super B** (and **Flavour**) factories









LFV ⟷ LHC SENSITIVITIES IN PROBING THE SUSY PARAM. SPACE

TABLE IX: Reach in $(m_0, m_{\tilde{g}})$ of the present and planned experiment from their $\tau \to \mu\gamma$ sensitivity.

	PMNS		CKM	
Exp.	$t_\beta = 40$	$t_\beta = 10$	$t_\beta = 40$	$t_\beta = 10$
BaBar, Belle	1.2 TeV	no	no	no
SuperKEKB	2 TeV	0.9 TeV	no	no
Super Flavour [a]	2.8 TeV	1.5 TeV	0.9 TeV	no

[a] Post–LHC era proposed/discussed experiment

Calibbi, Faccia, A.M., Vempati

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.:

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

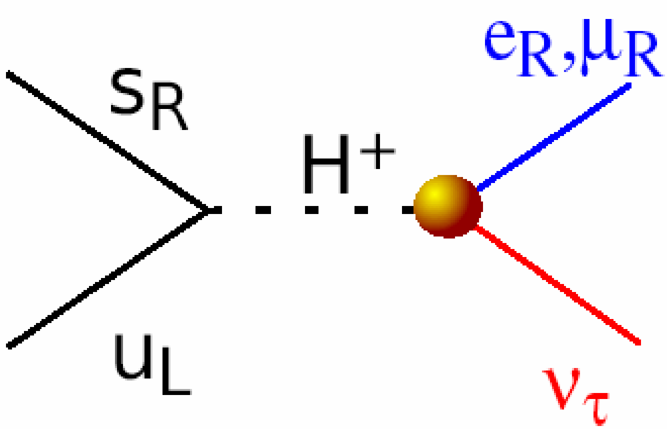
- we get at the 2σ level:

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

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

H mediated LFV SUSY contributions to R_K

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



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

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

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

$$\Downarrow$$

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

Extension to B ⟶ $l\nu$ deviation from universality

Isidori, Paradisi

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

FCNC HADRON-LEPTON CONNECTION IN SUSYGUT

If

M_{Pl} M_{GUT} M_W

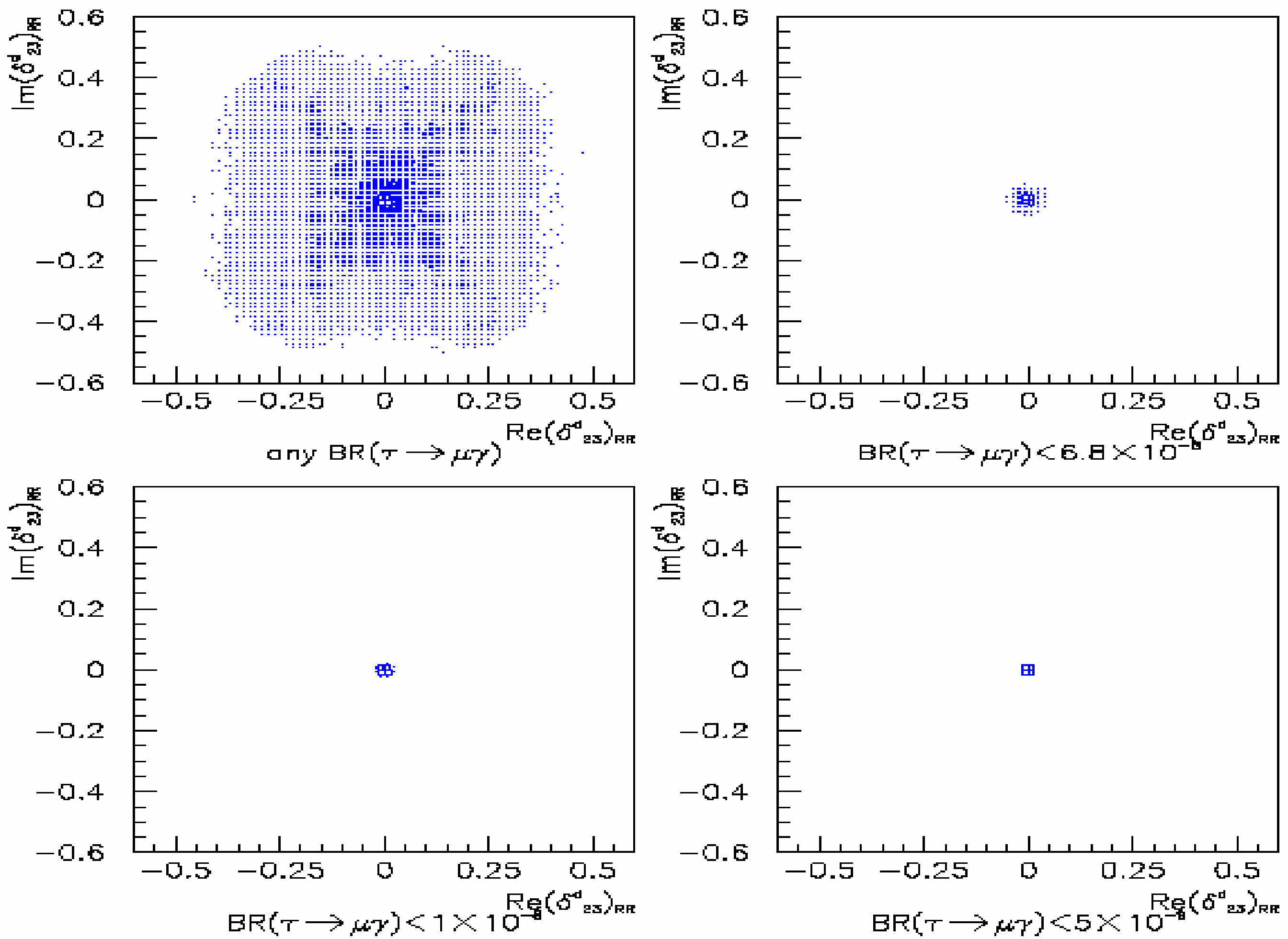
soft SUSY breaking terms arise
at a scale > M_{GUT}, they have to respect
the underlying quark-lepton GU symmetry

constraints on δ^{quark} from LFV and
constraints on δ^{lepton} from hadronic FCNC

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

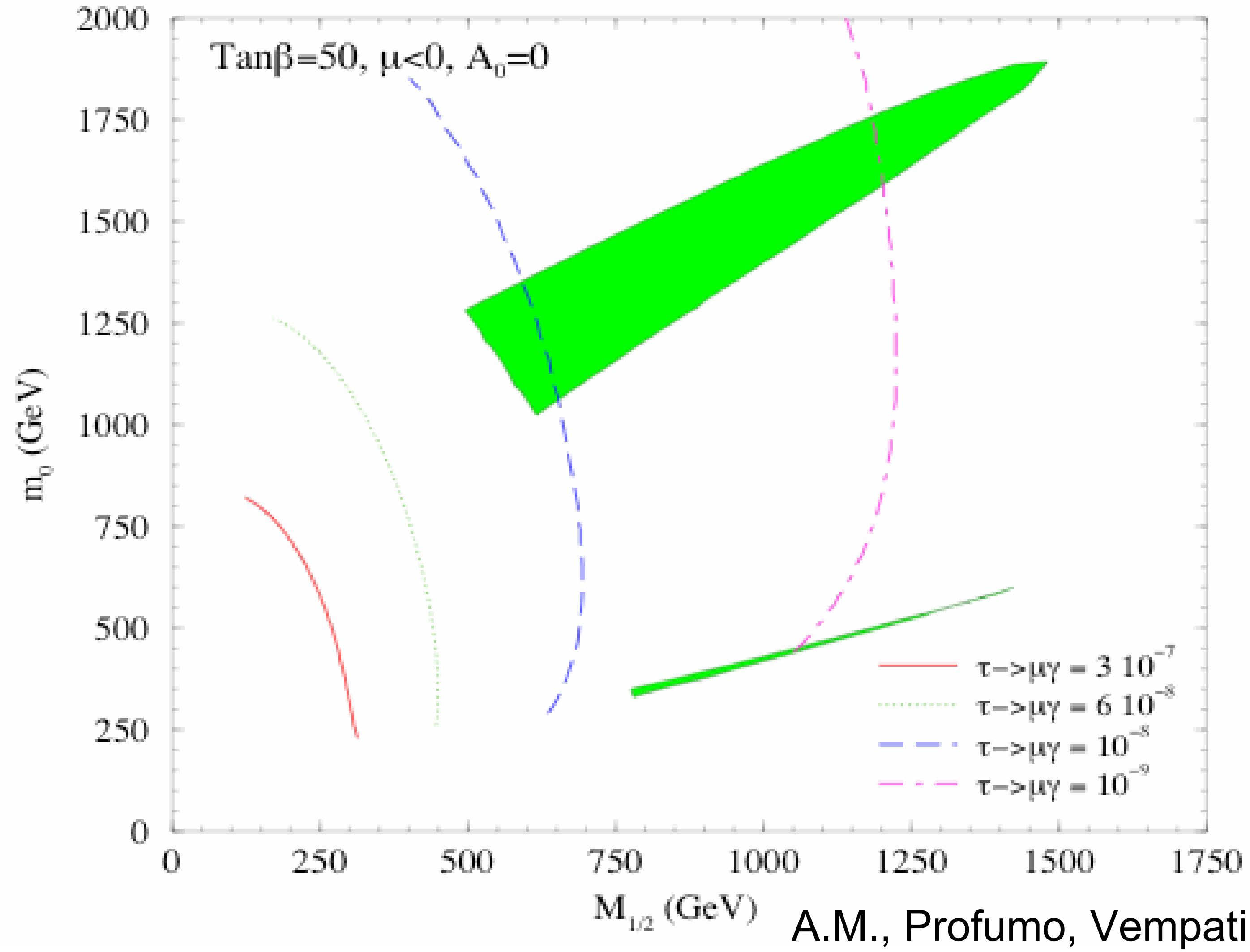
general analysis Ciuchini, A.M., Paradisi, Silvestrini, Vempati, Vives (to appear next week)

Bounds on the hadronic $(\delta_{23})_{RR}$ as modified by the inclusion of the LFV correlated bound



CMPSVV

LFV - DM CONSTRAINTS IN MINIMAL SUPERGRAVITY



A.M., Profumo, Vempati, Yaguna

SEARCHING FOR WIMPs

WIMPS HYPOTHESIS

DM made of particles with mass 10Gev - 1Tev

ELW scale

With WEAK INTERACT.

LHC, ILC may PRODUCE WIMPS

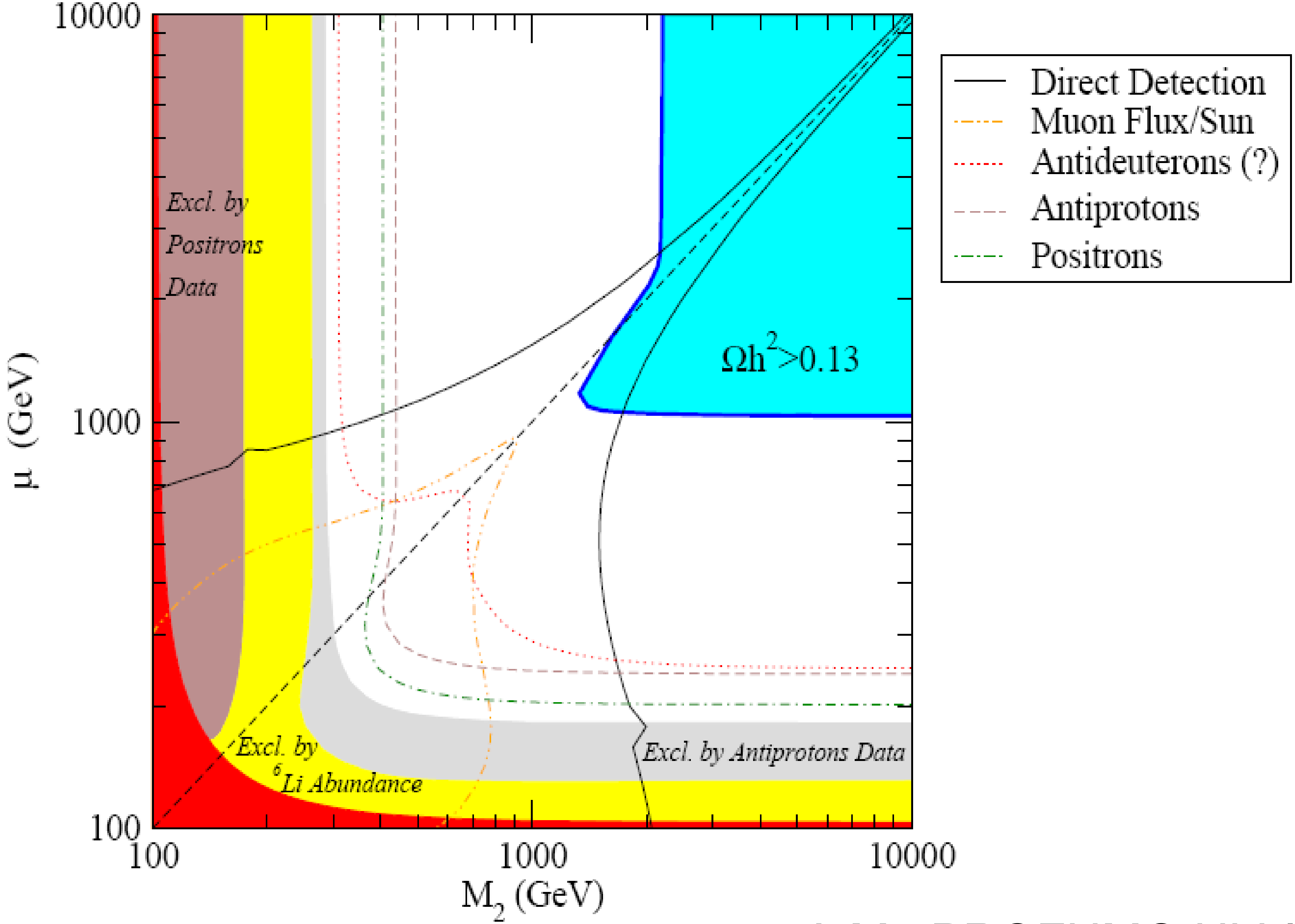
→ WIMPS escape the detector

→ MISSING ENERGY SIGNATURE

⇓

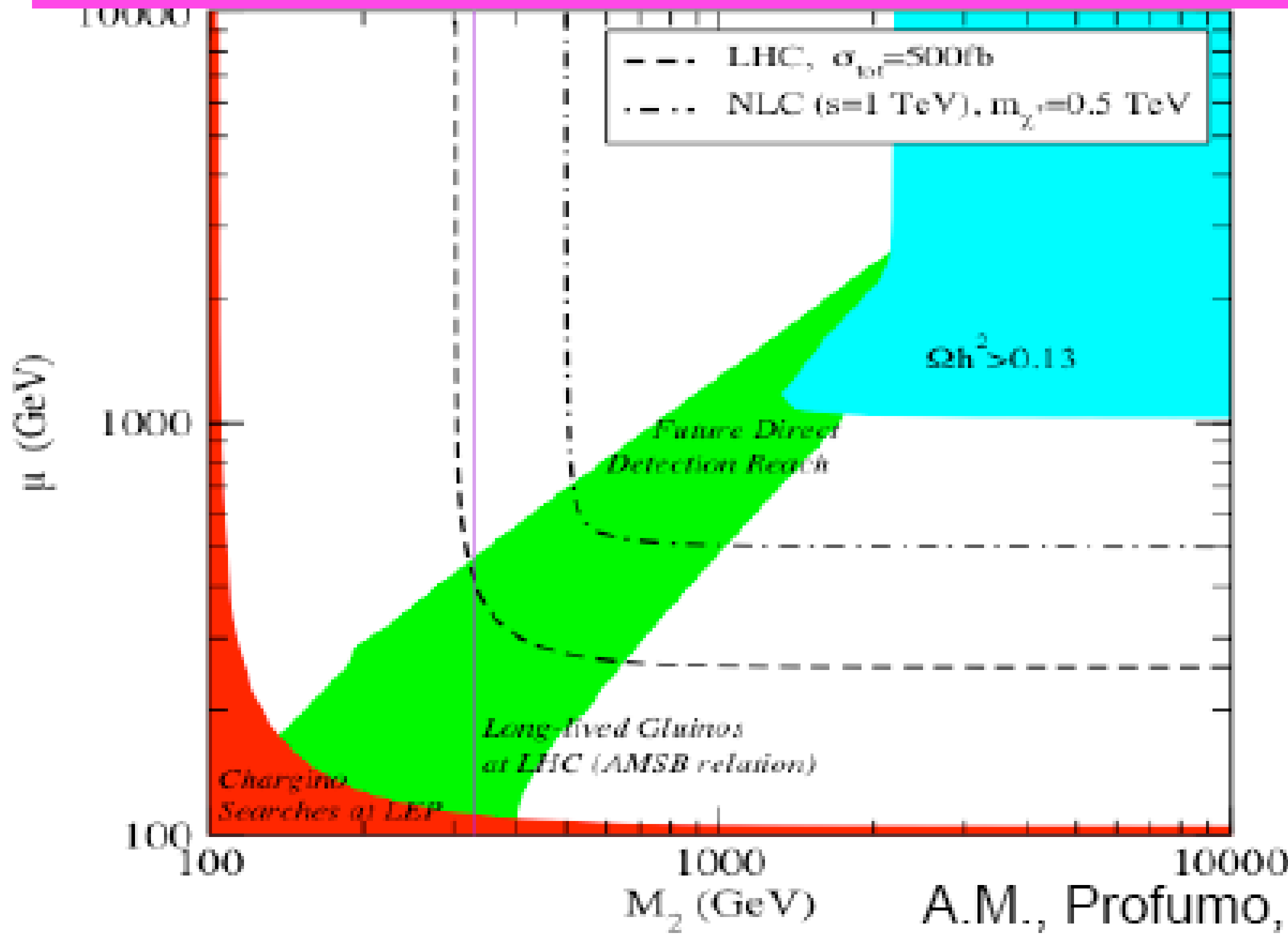
FROM "KNOWN" COSM. ABUNDANCE OF WIMPs → PREDICTION FOR WIMP PRODUCTION AT COLLIDERS WITHOUT SPECYFING THE PART. PHYSICS MODEL OF WIMPs

BIRKEDAL, MATCHEV, PERELSTEIN , FENG,SU, TAKAYAMA



A.M., PROFUMO,ULLIO

LHC, ILC, DM SEARCHES SENSITIVITIES



A.M., Profumo, Ullio

Final thoughts on the "complementarity" of flavor physics in our search for NP

- **"Slow" decoupling**: sensitivity to masses of NP larger than what can be explored with LHC (even in strict MFV "exploration power" of flavor physics is in the TeV range)

- At least in SUSY, it is possible, through low-energy FCNC effects induced by the running, to **get access to some large scale** (SUSY SeeSaw scale , Supergravity breaking scale)

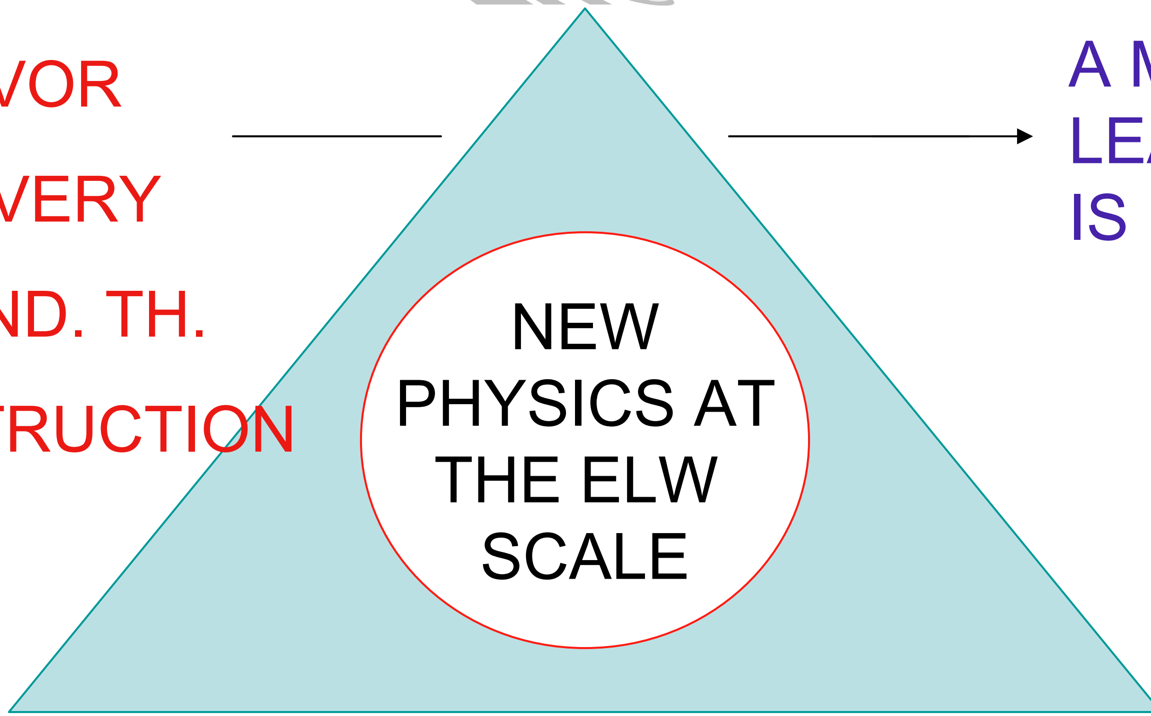
- Possible correlation of **hadronic and leptonic FCNC** in SUGRAGUTs

- "**Reconstruction of the fundamental theory**": ex., once LHC fixes the scale of the NP particles, we can go back to flavor knowledge and try to understand the flavor structure of such NP

TEVATRON → LHC → ILC

DM - FLAVOR for DISCOVERY and/or FUND. TH. RECONSTRUCTION

A MAJOR LEAP AHEAD IS NEEDED



DARK MATTER

m_χ n_χ σ_χ…

LINKED TO COSMOLOGICAL EVOLUTION

→ Possible interplay with dynamical DE

"LOW ENERGY"

PRECISION PHYSICS

FCNC, CP ≠, (g-2), $(\beta\beta)_{0\nu\nu}$

→ LFV

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