LC 09, PERUGIA, Sept. 21-24, 2009

DARK MATTER and FLAVOR PHYSICS in the LINEAR COLLIDER ERA?

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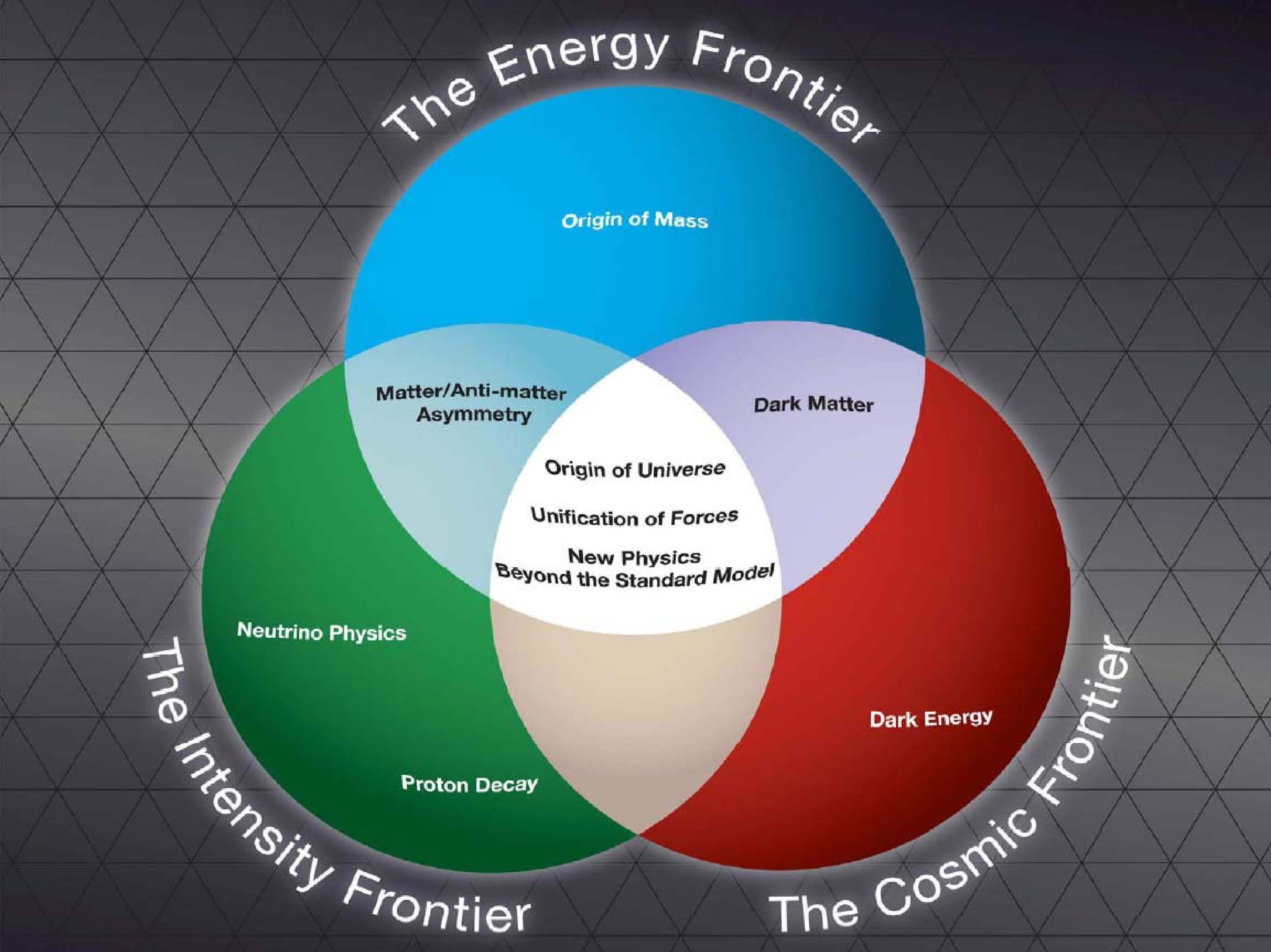

The Energy Frontier
Origin of Mass
Matter/Anti-matter
Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics
Beyond the Standard Model
Neutrino Physics
Dark Energy
Proton Decay
The Intensity Frontier
The Cosmic Frontier

WHY TO GO BEYOND THE SM

"OBSERVATIONAL" REASONS

- HIGH ENERGY PHYSICS

NO (but $A_{FB}^{Z \longrightarrow bb}$......)

- FCNC, CP$\neq$

NO (but $b \rightarrow s\bar{q}q$ penguin ...)

- HIGH PRECISION LOW-EN.

NO (but $(g\text{-}2)_\mu$ ...)

- **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 "FUNDAMENTAL" THEORY

YES **(hierarchy, unification, flavor)**

Present "Observational" Evidence for New Physics

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

LEPTON NUMBER and ***LEPTON FLAVOR NUMBERS*** ***<u>CONSERVATION</u>*** in the ***SM***

- *BARYON (B) AND LEPTON (L) numbers are* ***<u>AUTOMATICALLY</u>*** *conserved in the SM* (at all orders of the perturbation expansion), i.e. with the fields of the SM particle spectrum it is not possible to write any operator of dim. ≤ 4 which respects the SM gauge symmetry and violates B or L
- Given that neutrinos are massless in the SM, together with L (total Lepton number), also the partial **LEPTON FLAVOR** ***numbers, i.e.*** L_e, L_μ ***and*** L_τ ***are separately conserved as automatic global symmetries of the SM***

B and L VIOLATIONS in the *SM* as an *EFFECTIVE LOW-ENERGY THEORY*

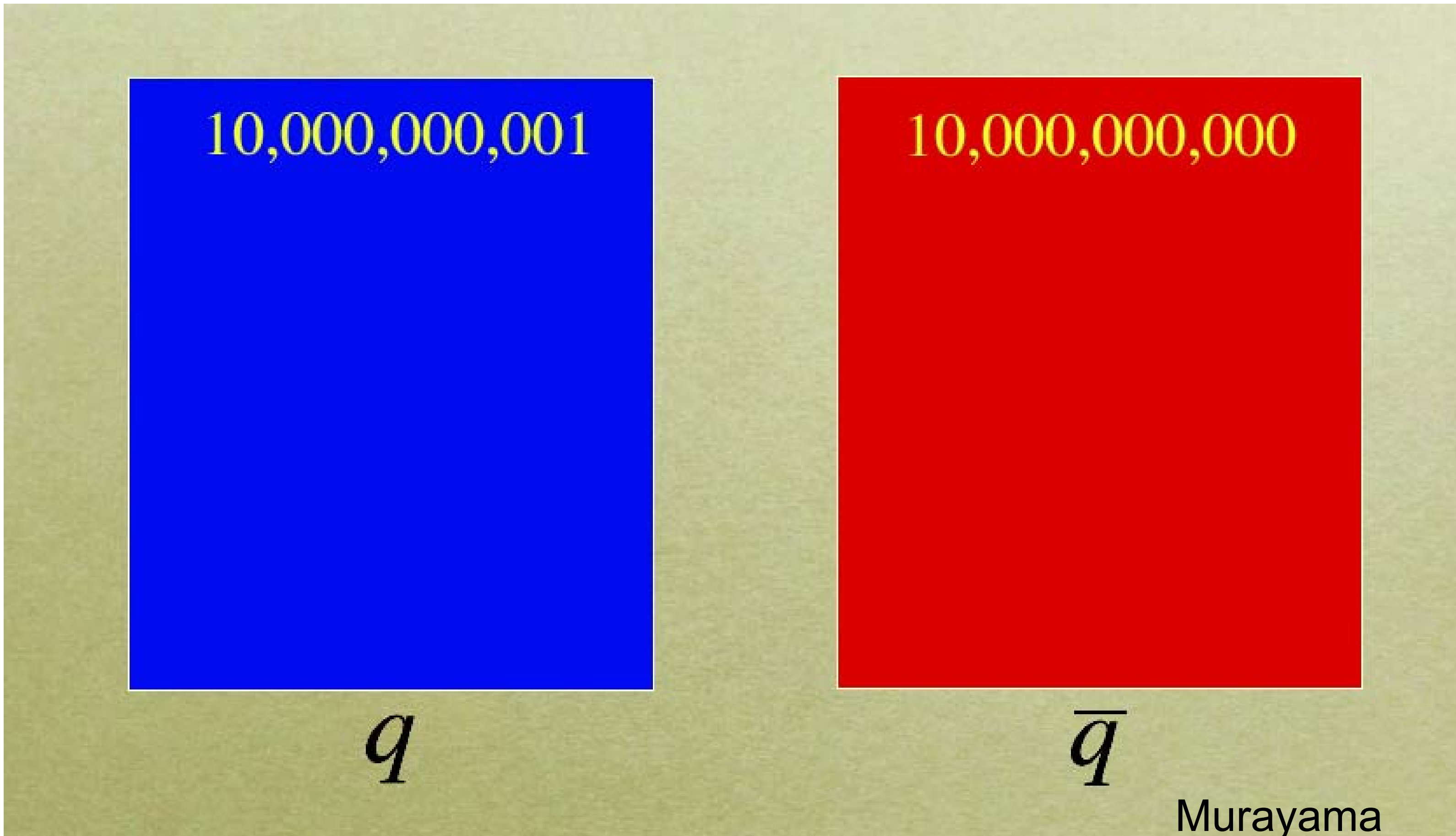
- **LLHH / Λ** → ΔL = 2 , ΔB = 0 (Majorana mass for the LH neutrino when H gets a VEV)
- **QQQL / Λ^2** → ΔB = ΔL = 1 (proton decay)
- **Λ** → Energy scale at which a new physics theory sets in (the SM is its low-energy effective theory valid up to the scale Λ)
- Ex: for **$\Lambda = 10^{16}$ GeV** → $m_\nu = \langle H\rangle^2 / 10^{16}$ GeV ~ 0.1 eV and $\tau_p \sim 10^{34}$ yrs.

but *B and L are NOT conserved at the QUANTUM LEVEL in the SM*

- B and L are NOT conserved at the quantum (non-perturbative) level.
- However, there are **no visible implications (like proton decay**) since all the ensuing physical processes are exponentially suppressed by a typical tunneling effect. This is true nowadays with a a very low temperature Universe
- but at early epochs when such temperature exceeded the electroweak energy scale (i.e. T > 100 GeV) the "tunneling toll" could be avoided so that B and L violating transitions could proceed at large rates possibly larger than the expansion rate of the Universe at that time (relevant observation for the discussion of a dynamical mechanism of originating the cosmic matter-antimatter asymmetry.

COSMIC MATTER-ANTIMATTER ASYMMETRY

FINE-TUNED INITIAL CONDITION



OR DYNAMICAL MECHANISM ?

SM FAILS TO GIVE RISE TO A SUITABLE COSMIC MATTER-ANTIMATTER ASYMMETRY

:

- **NOT ENOUGH CP VIOLATION IN THE SM**

  NEED FOR ***NEW SOURCES OF CPV IN ADDITION TO THE PHASE PRESENT IN THE CKM MIXING MATRIX***

- FOR M_{HIGGS} > 80 GeV THE ELW. PHASE TRANSITION OF THE SM IS A SMOOTH CROSSOVER

NEED *NEW PHYSICS BEYOND SM*. IN PARTICULAR, FASCINATING POSSIBILITY: THE ENTIRE MATTER IN THE UNIVERSE ORIGINATES FROM THE SAME MECHANISM RESPONSIBLE FOR THE EXTREME SMALLNESS OF NEUTRINO MASSES

MATTER-ANTIMATTER ASYMMETRY ⟷ NEUTRINO MASSES CONNECTION: BARYOGENESIS THROUGH LEPTOGENESIS

- Key-ingredient of the SEE-SAW mechanism for neutrino masses: **large Majorana mass for RIGHT-HANDED neutrino**
- In the early Universe the heavy RH neutrino decays with Lepton Number violatiion; if these decays are accompanied by a new source of CP violation in the leptonic sector, then

→ it is possible to create a lepton-antilepton asymmetry at the moment RH neutrinos decay. Since SM interactions preserve Baryon and Lepton numbers at all orders in perturbation theory, but violate them at the quantum level, such **LEPTON ASYMMETRY** can be converted by these purely quantum effects into a BARYON-ANTIBARYON ASYMMETRY (**Fukugita-Yanagida mechanism for leptogenesis**)

The Energy Scale from the "Observational" New Physics

- neutrino masses
- dark matter
- baryogenesis
- inflation

→ NO NEED FOR THE NP SCALE TO BE CLOSE TO THE ELW. SCALE

The Energy Scale from the "Theoretical" New Physics

☆ ☆ ☆ Stabilization of the electroweak symmetry breaking at M_W calls for an ***ULTRAVIOLET COMPLETION of the SM already at the TeV scale*** +

☆ ***CORRECT GRAND UNIFICATION "CALLS" FOR NEW PARTICLES AT THE ELW. SCALE***

In conclusion

From Altarelli's summary talk at LP09

Is it possible that the LHC does not find the Higgs particle?

Yes, it is possible, but then must find something else

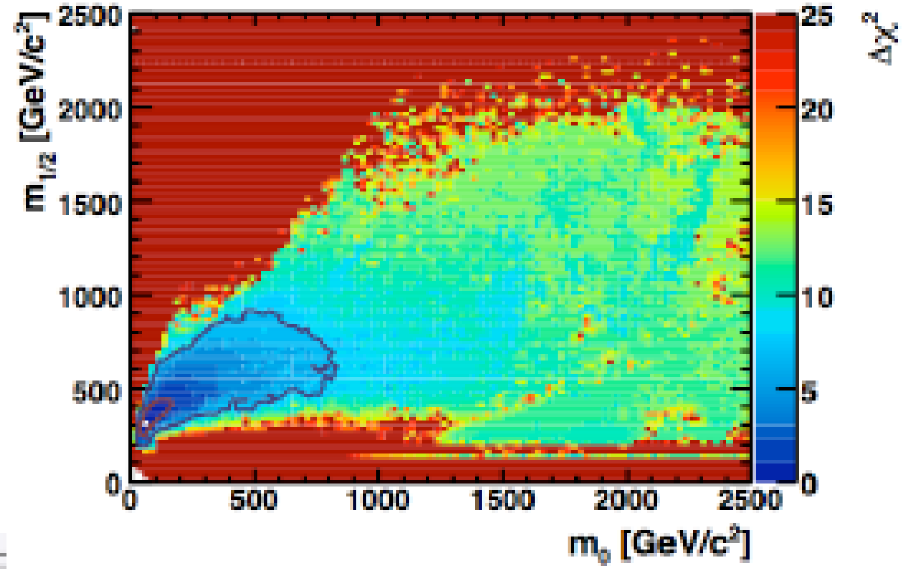
Is it possible that the LHC finds the Higgs particle but no other new physics (pure and simple SM)?

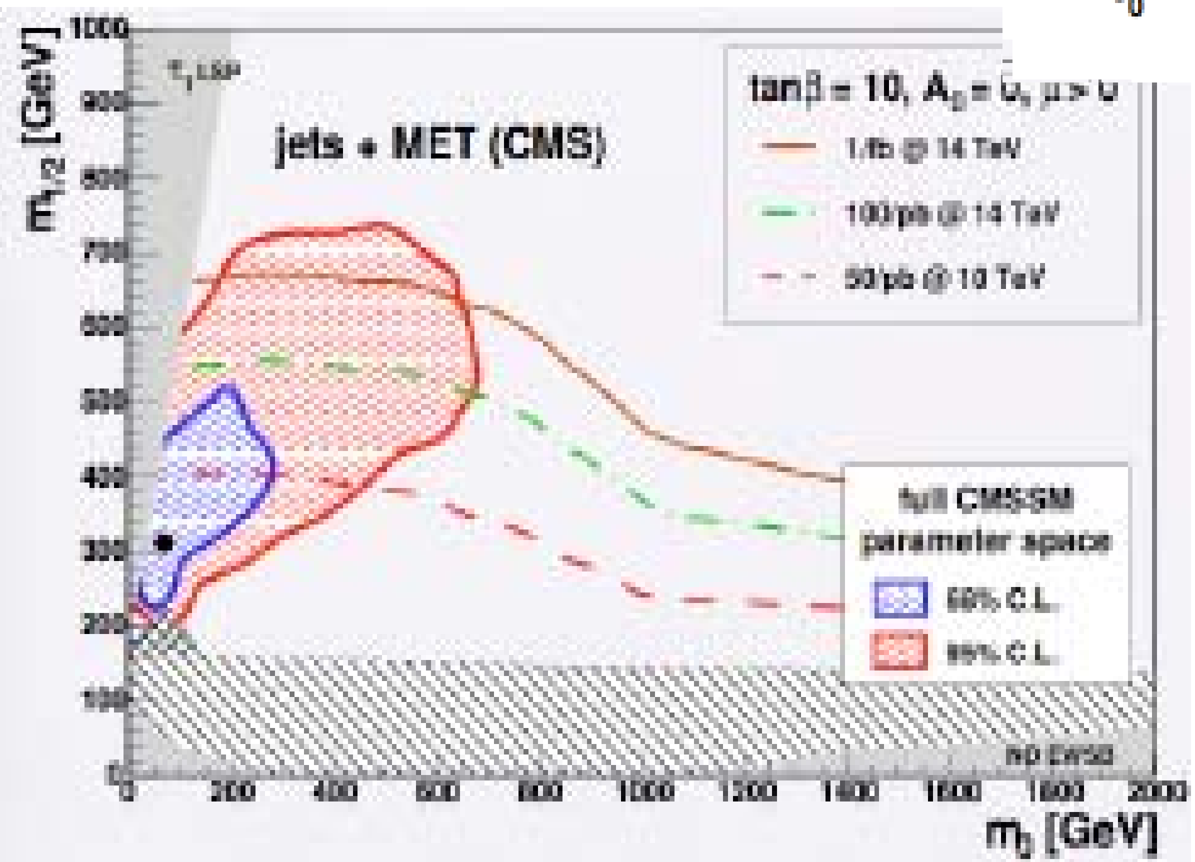
Yes, it is technically possible but it is not natural

Is it possible that the LHC finds neither the Higgs nor new physics?

No, it is "approximately impossible"

LIGHT SUSY IS PREFERRED BY DATA!



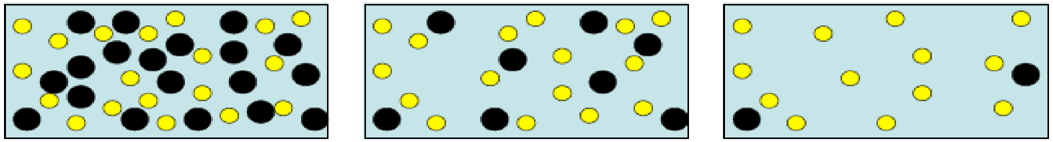


LIGHT SUSY IS TESTABLE AT THE LHC

ELLIS ET AL.

***THE DM ROAD TO NEW PHYSICS BEYOND THE SM*:**

IS **DM** A PARTICLE OF THE ***NEW PHYSICS AT THE ELECTROWEAK ENERGY SCALE*** **?**



$T \gg M$ $\quad$ $T \approx M$ $\quad$ $T \ll M$

WIMPS (Weakly Interacting Massive Particles)

$\#\chi \sim \#\gamma$ $\quad$ m_χ

$\#\chi$ $\exp(-m_\chi/T_\chi)$

$\#\chi$ does not change any more

$T_{decoupl.}$ typically ~ m_χ /20

Ω_χ depends on particle physics ($\sigma_{annih.}^{\chi}$) and "cosmological" quantities (H, T_0, …

$$\Omega_\chi h^2 \simeq \frac{10^{-3}}{\underbrace{\langle(\sigma_{annih.}) V_\chi\rangle}_{\sim \alpha^2 / M^2_\chi} \ \mathrm{TeV}^2}$$

TeV² → From $T^0 M_{Planck}$

COSMO – PARTICLE

CONSPIRACY

$\Omega_\chi h^2$ in the range 10^{-2} -10^{-1} to be cosmologically interesting (for DM)

$m_\chi \sim 10^2 - 10^3$ GeV (weak interaction) $\quad$ $\Omega_\chi h^2 \sim 10^{-2}$ -10^{-1} !!!

THERMAL RELICS (WIMP in thermodyn.equilibrium with the plasma until $T_{decoupl}$)

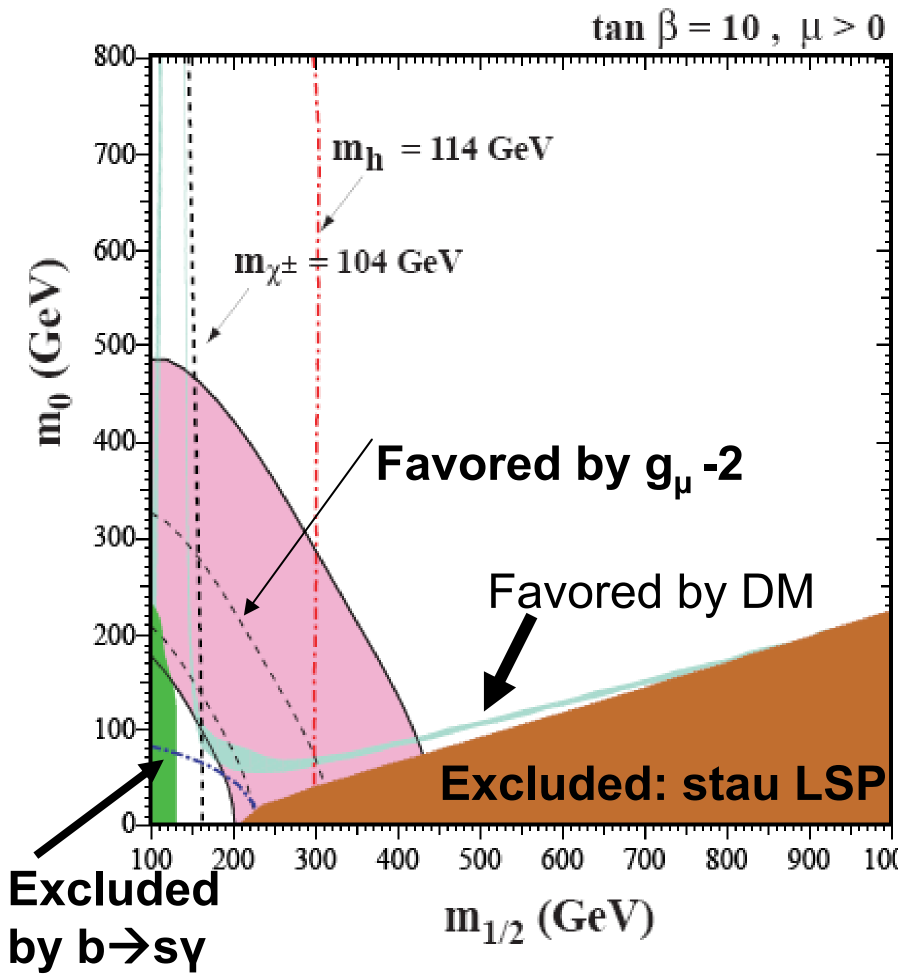
STABLE ELW. SCALE WIMPs from PARTICLE PHYSICS

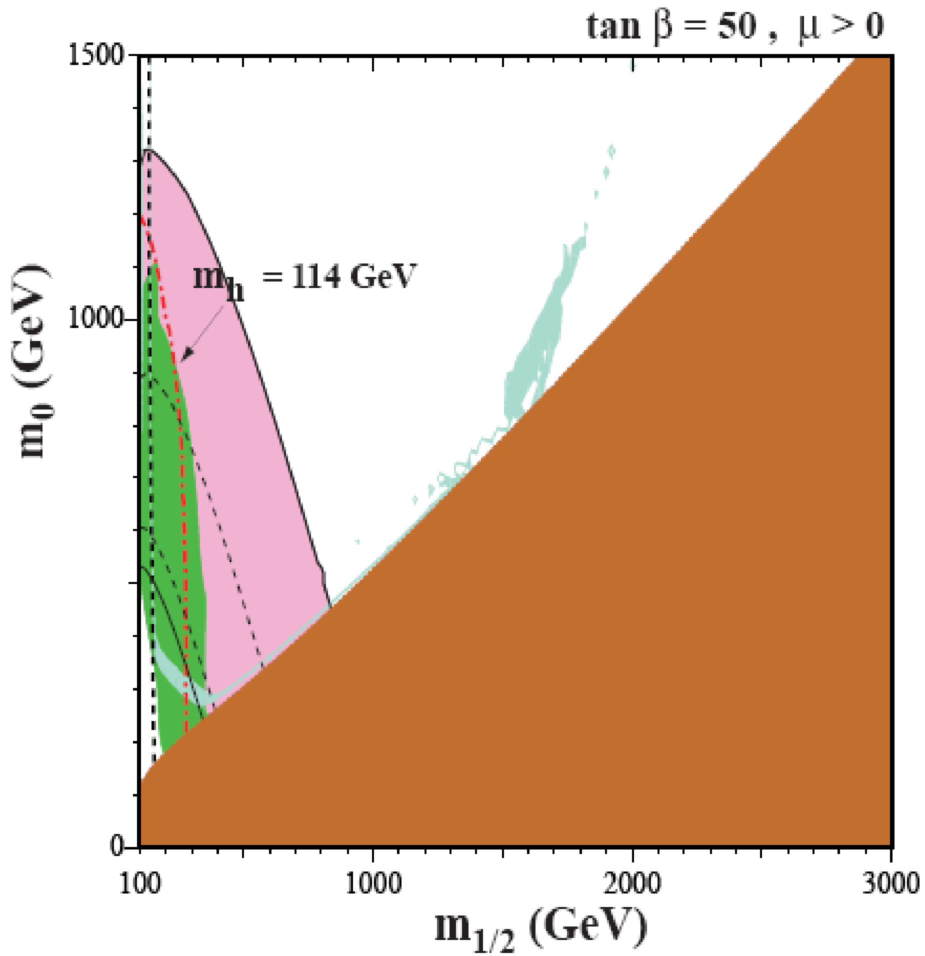
	SUSY	EXTRA DIM.	LITTLE HIGGS.
1) **ENLARGEMENT OF THE SM**	(x^{μ}, θ)	(x^{μ}, j^{i})	SM part + new part
	Anticomm. Coord.	New bosonic Coord.	to cancel Λ^2 at 1-Loop
2) **SELECTION RULE**	**R-PARITY LSP**	**KK-PARITY LKP**	**T-PARITY LTP**
→ **DISCRETE SYMM.**	Neutralino spin 1/2	spin1	spin0
→ **STABLE 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

NEUTRALINO LSP IN THE CONSTRAINED MSSSM: A VERY SPECIAL SELECTION IN THE PARAMETER SPACE?





Ellis, Olive, Santoso, Spanos

After LEP: tuning of the SUSY param. at the % level to correctly reproduce the DM abundance: NEED FOR A "WELL-TEMPERED" NEUTRALINO

Bino

$$1.1 < \frac{\tilde{m}_{e_R}}{M_1} < 3$$

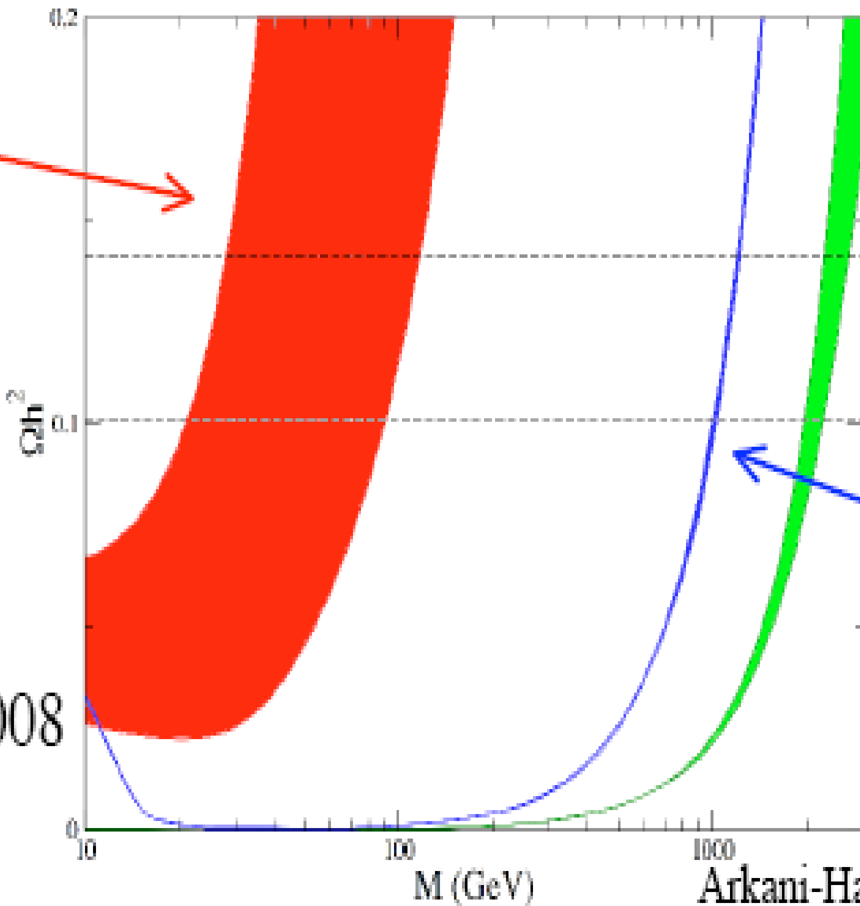
Wino

$$1.5 < \frac{\tilde{m}_{\ell_L}}{M_2} < \infty$$

Higgsino

$$1.5 < \frac{\tilde{m}_t}{\mu} < \infty$$

$$\Omega_{DM} h^2 = 0.105 \pm 0.008$$



Arkani-Hamed-Delgado-Giudice

DM and NON-STANDARD COSMOLOGIES BEFORE NUCLEOSYNTHESIS

- **NEUTRALINO RELIC DENSITY MAY DIFFER FROM ITS STANDARD VALUE**, i.e. the value it gets when the expansion rate of the Universe is what is expected in Standard Cosmology (EX.: **SCALAR-TENSOR THEORIES OF GRAVITY**, **KINATION**, **EXTRA-DIM. RANDALL-SUNDRUM TYPE II MODEL**, ETC.)

- **WIMPS MAY BE "COLDER",** i.e. they may have smaller typical velocities and, hence, they may lead to smaller masses for the first structures which form **GELMINI, GONDOLO**

LARGER WIMP ANNIHILATION CROSS-SECTION IN NON-STANDARD COSMOLOGIES

- **Having a Universe expansion rate at the WIMP freeze-out larger than in Standard Cosmology→ possible to provide a DM adequate WIMP population even in the presence of a larger annihilation cross-section** (**Catena, Fornengo, A.M., Pietroni**)

- **Possible application to increase the present DM annihilation rate to account for the PAMELA results in the DM interpretation** (instead of other mechanisms like the Sommerfeld effect or a nearby resonance)

El Zant, Khalil, Okada

DM DE

DO THEY "KNOW" EACH OTHER?

- DIRECT INTERACTION ϕ (quintessence) WITH DARK MATTER

DANGER:
ϕ Very LIGHT
$m\phi \sim H_0^{-1} \sim 10^{-33}$ eV

Threat of violation of the equivalence principle
constancy of the fundamental "constants",…

- **INFLUENCE OF ϕ ON THE NATURE AND THE ABUNDANCE OF CDM**

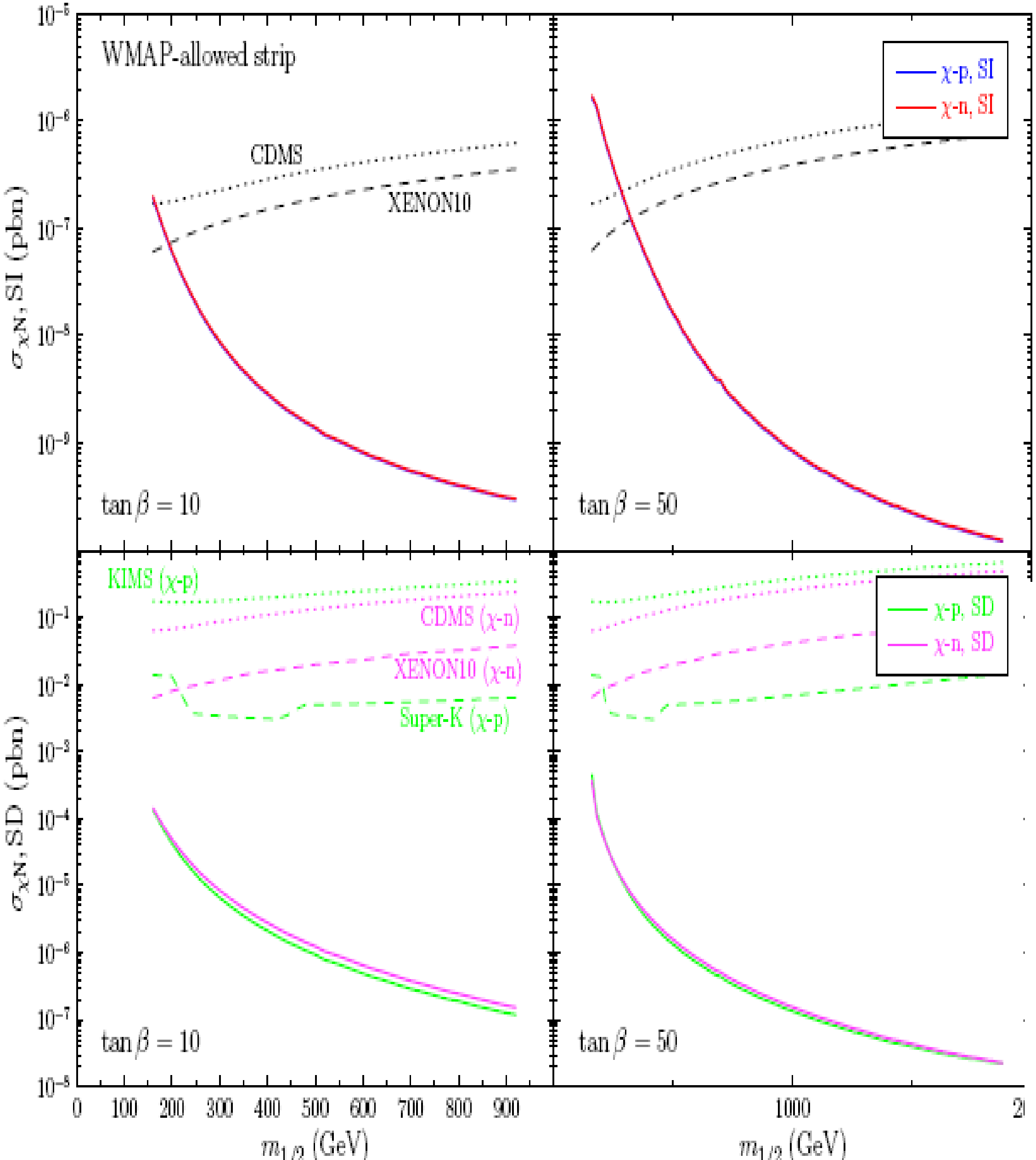
Modifications of the standard picture of
WIMPs FREEZE - OUT

EX.: **SCALAR-TENSOR GRAVITY**

CATENA, FORNENGO, A.M., PIETRONI, SHELCKE

CDM CANDIDATES

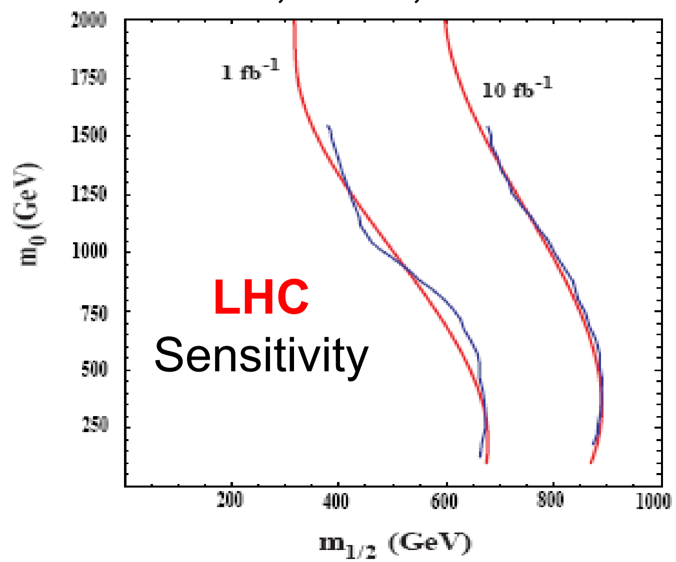
Neutralino-nucleon scattering cross sections along the WMAP-allowed coannihilation strip for tanbeta=10 and coannihilation/funnel strip for tanbeta=50 using the hadronic parameters



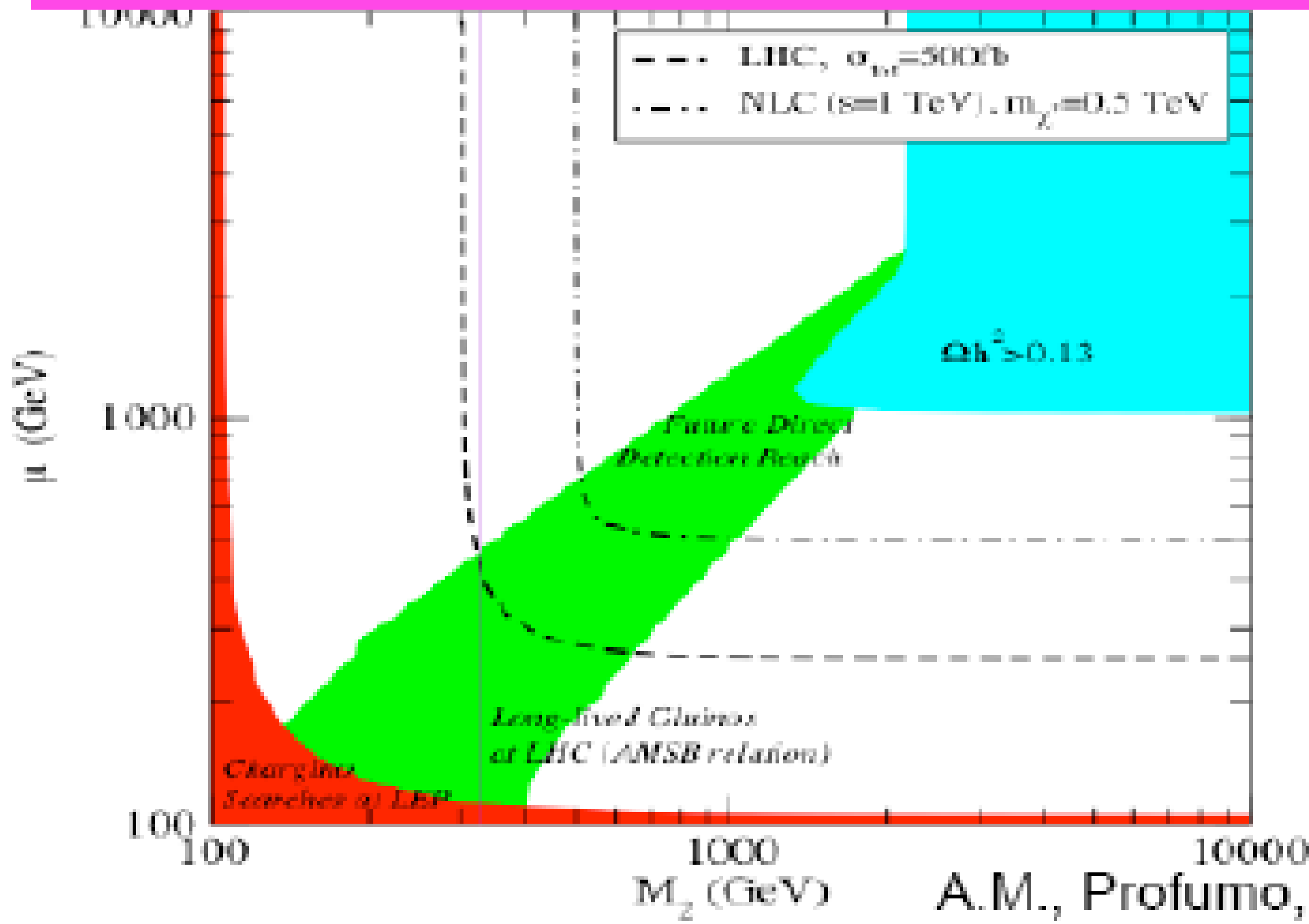
ELLIS. OLIVE. SAVAGE

m_u/m_d	0.553	±	0.043
m_d	5	±	2 MeV
m_s/m_d	18.9	±	0.8
m_c	1.25	±	0.09 GeV
m_b	4.20	±	0.07 GeV
m_t	171.4	±	2.1 GeV
σ_0	36	±	7 MeV
$\Sigma_{\pi N}$	64	±	8 MeV
$a_3^{(p)}$	1.2695	±	0.0029
$a_8^{(p)}$	0.585	±	0.025
$\Delta_s^{(p)}$	-0.09	±	0.03

Ellis, Olive, Sandick

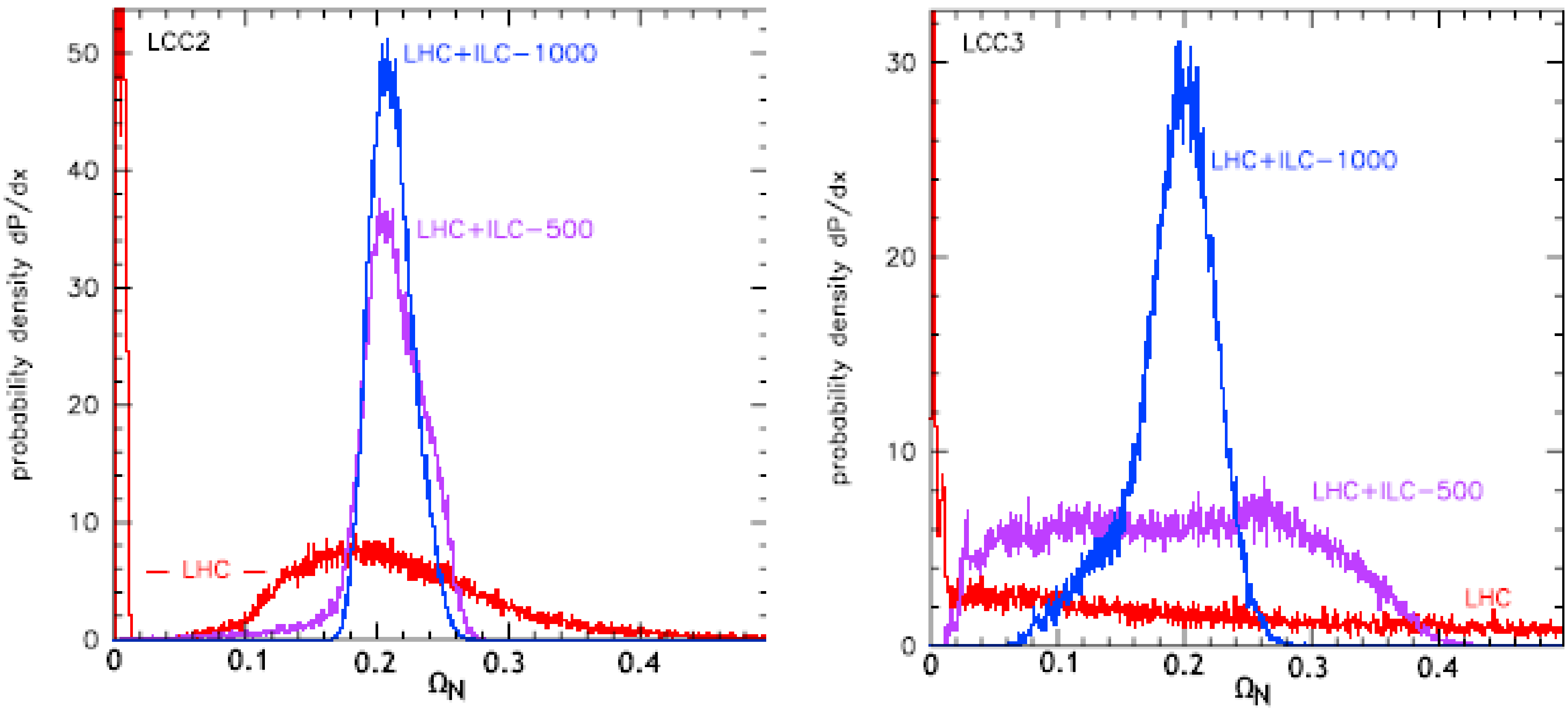


LHC, ILC, DM SEARCHES SENSITIVITIES



A.M., Profumo, Ullio

PREDICTION OF Ω DM FROM LHC AND ILC FOR TWO DIFFERENT SUSY PARAMETER SETS



BALTZ, BATTAGLIA, PESKIN, WIZANSKY

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


THE MAGNIFICENT SEVEN
S. Katsanevas
ASPERA
ET
AUGER
North
CTA
KM3
1 ton
DM
1 ton
NM
Megaton
scale
NNN
Common with
Astrophysics
ASTRONET
Common with
Particle Physics
CERN SG

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

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

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

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: $\Lambda_{UV} \sim O(1\ \mathrm{TeV})$

How large Λ NP and/or how small the "angles" of the Λ = 1 TeV NP couplings have to be to cope with the FCNC ?

Mixing	$\Lambda_{NP}^{CPC} \gtrsim$	$\Lambda_{NP}^{CPV} \gtrsim$
$K-\overline{K}$	1000 TeV	20000 TeV
$D-\overline{D}$	1000 TeV	3000 TeV
$B-\overline{B}$	400 TeV	800 TeV
$B_s-\overline{B}_s$	70 TeV	70 TeV

$K-\overline{K}$	8×10^{-7}	6×10^{-9}
$D-\overline{D}$	5×10^{-7}	1×10^{-7}
$B-\overline{B}$	5×10^{-6}	1×10^{-6}
$B_s-\overline{B}_s$	2×10^{-4}	2×10^{-4}

Y. NIR et al.

$K-\overline{K}$	8×10^{-7}	6×10^{-9}
$D-\overline{D}$	5×10^{-7}	1×10^{-7}
$B-\overline{B}$	5×10^{-6}	1×10^{-6}
$B_s-\overline{B_s}$	2×10^{-4}	2×10^{-4}

$\rightarrow$ **SMALLNESS OF THE NP COUPLINGS IF THE NP SCALE IS 1 TEV**

$$Y_t\sim1,\quad Y_c\sim10^{-2},\quad Y_u\sim10^{-5}$$

$$Y_b\sim10^{-2},\quad Y_s\sim10^{-3},\quad Y_d\sim10^{-4}$$

$$Y_\tau\sim10^{-2},\quad Y_\mu\sim10^{-3},\quad Y_e\sim10^{-6}$$

$$|V_{us}|\sim0.2,\quad |V_{cb}|\sim0.04,\quad |V_{ub}|\sim0.004,\quad \delta_{\rm KM}\sim1$$

$\rightarrow$ **SMALLNESS OF THE SM COUPLINGS**

THE FLAVOUR PROBLEMS

FERMION MASSES

What is the rationale hiding behind the spectrum of fermion masses and mixing angles (our "**Balmer lines**" problem)

LACK OF A FLAVOUR "THEORY"

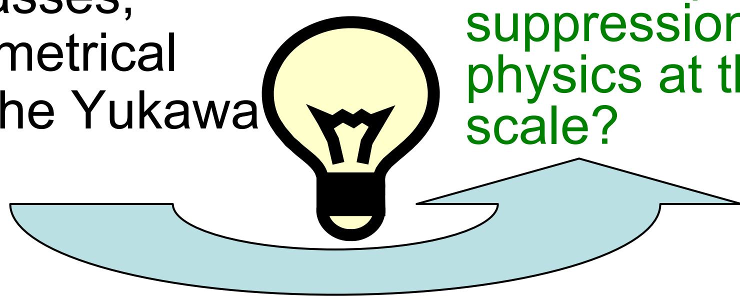
(new flavour – horizontal symmetry, radiatively induced lighter fermion masses, dynamical or geometrical determination of the Yukawa couplings, …?)

FCNC

Flavour changing neutral current (FCNC) processes are suppressed.

In the SM two nice mechanisms are at work: the **GIM mechanism** and the structure of the **CKM mixing matrix.**

How to cope with such delicate suppression if the there is new physics at the electroweak scale?



FLAVOR BLINDNESS OF THE NP AT THE ELW. SCALE?

- **THREE DECADES OF FLAVOR TESTS** (Redundant determination of the UT triangle $\longrightarrow$ verification of the SM, theoretically and experimentally "high precision" FCNC tests, ex. $b \to s + \gamma$, 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 (flavor violating) 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

The muon g-2: Standard Model vs. Experiment

- Adding up all the above contribution we get the following SM predictions for a_μ and comparisons with the measured value:

	$a_\mu^{SM} \times 10^{11}$	$\Delta a_\mu \times 10^{11}$	σ
[1]	116 591 793 (60)	287 (87)	3.3
[2]	116 591 778 (61)	302 (88)	3.4
[3]	116 591 807 (72)	273 (96)	2.8
[4]	116 591 828 (63)	252 (89)	2.8
[5]	116 591 991 (70)	89 (95)	0.9

2

with $a_\mu^{HHO}(lbl) = 110\ (40) \times 10^{-11}$. $\Delta a_\mu = a_\mu^{EXP} - a_\mu^{SM}$.

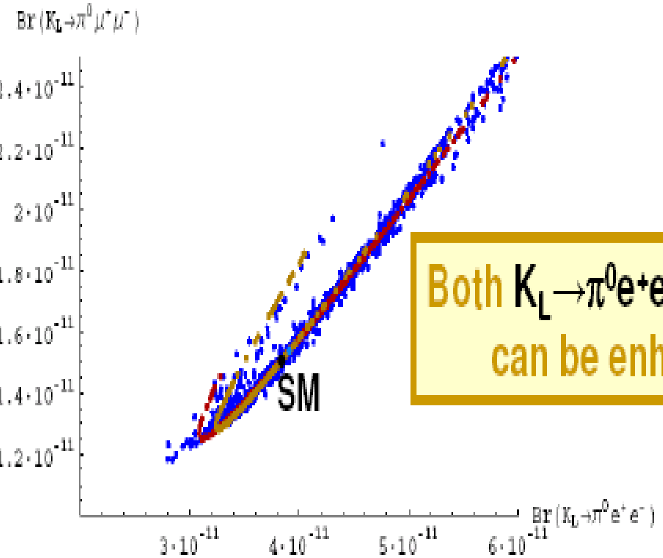
[1] Eidelman at ICHEP06 & Davier at TAU06 (update of ref. [5]).
[2] Hagiwara, Martin, Nomura, Teubner, PLB649 (2007) 173.
[3] F. Jegerlehner, PhiPsi 08, Frascati, April 2008.
[4] J.F. de Troconiz and F.J. Yndurain, PRD71 (2005) 073008.
[5] Davier, Eidelman, Hoecker and Zhang, EPJC31 (2003) 503 (τ data).

- The th error is now the same (or even smaller) as the exp. one!

FCNC SEMILEPTONIC K DECAYS

Decay	SM	Exp	TH
$K^+ \to \pi^+ \nu\bar{\nu}$	$(8.1\pm1.1)\cdot10^{-11}$	$(14.7^{+13.0}_{-8.9})\cdot10^{-11}$ (BNL)	±2-3%
$K_L \to \pi^0 \nu\bar{\nu}$	$(2.6\pm0.3)\cdot10^{-11}$	$< 2.1\cdot10^{-7}$ (KTeV,KEK)	±1-2%
$K_L \to \pi^0 e^+e^-$	$(3.5\pm1.0)\cdot10^{-11}$	$< 28\cdot10^{-11}$ (KTeV)	$\pm15\%$
$K_L \to \pi^0 \mu^+\mu^-$	$(1.4\pm0.3)\cdot10^{-11}$	$< 38\cdot10^{-11}$ (KTeV)	$\pm15\%$

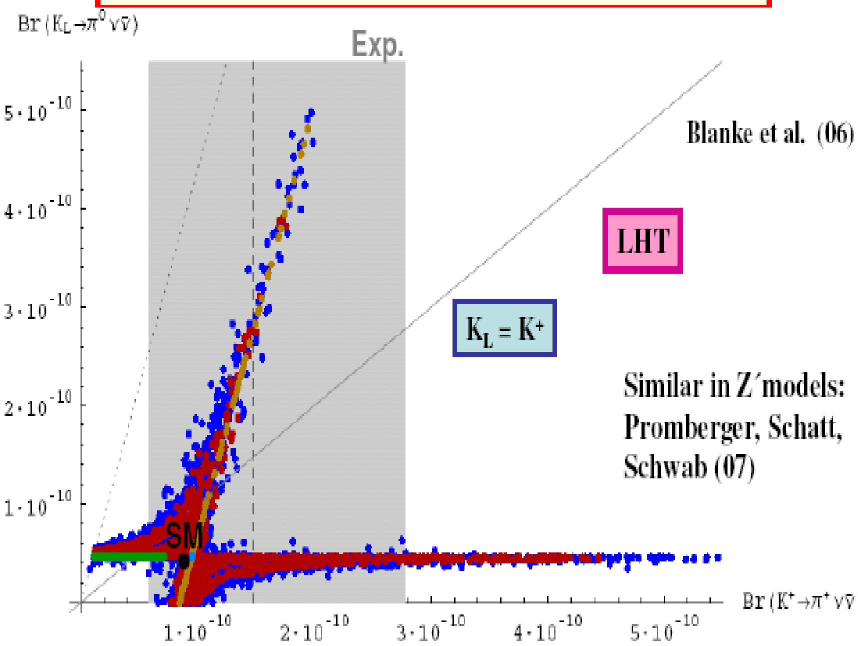
K-system: $K_L\to\pi^0 e^+e^-$ and $K_L\to\pi^0\mu^+\mu^-$



Friot, Greynat, de Rafael (04)
General correlation:
Isidori, Smith, Unterdorfer (04)
Mescia, Smith, Trine (06)

Both $K_L\to\pi^0 e^+e^-$ and $K_L\to\pi^0\mu^+\mu^-$ can be enhanced by ~2

K-system: $K_L\to\pi^0\nu\bar{\nu}$ vs $K^+\to\pi^+\nu\bar{\nu}$



Blanke et al. (06)

LHT

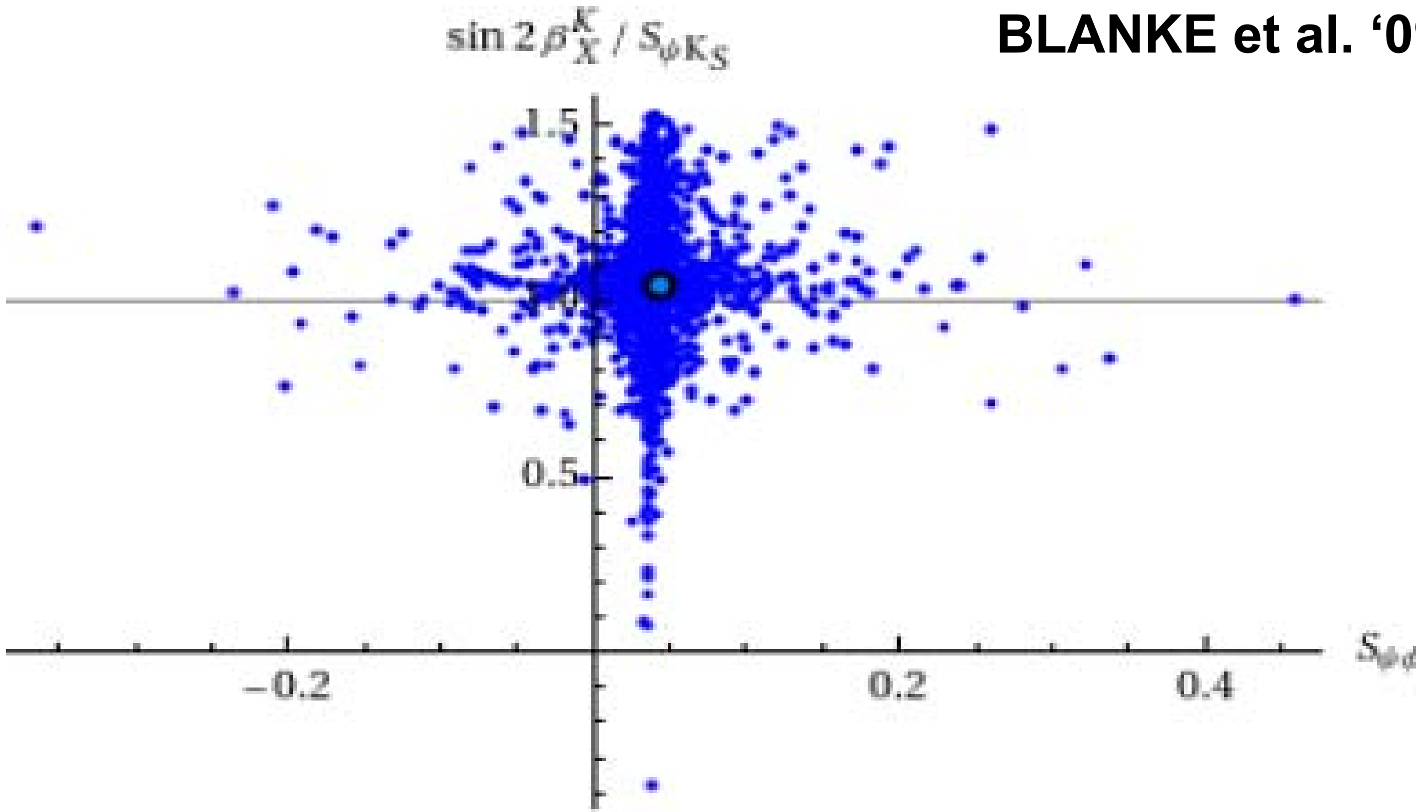
$K_L = K^+$

Similar in Z′models:
Promberger, Schatt, Schwab (07)

Two distinguished branches appear!
~10 times enhancement in $K_L\to\pi^0\nu\bar{\nu}$
~5 times enhancement in $K^+\to\pi^+\nu\bar{\nu}$

Sin2β from $K \rightarrow \pi \nu \bar{\nu}$ and the mixing induced CP asymmetry in $B_d \rightarrow \Psi K_S$

BLANKE et al. '09



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

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

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!

Is there a hope to see **NP with MFV** in **HIGH INTENSITY Physics**?

- In hadronic **FCNC** experiments the best chance is:

Measurement of Br ($B_{s,d} \to \mu^+\mu^-$)

SM:

$$Br(B_s \to \mu^+\mu^-)_{SM} = (3.37 \pm 0.31) \cdot 10^{-9}$$
$$Br(B_d \to \mu^+\mu^-)_{SM} = (1.02 \pm 0.09) \cdot 10^{-10}$$

$$< 6 \cdot 10^{-8}$$
$$< 2 \cdot 10^{-8}$$

CDF (95% C.L.)
DØ

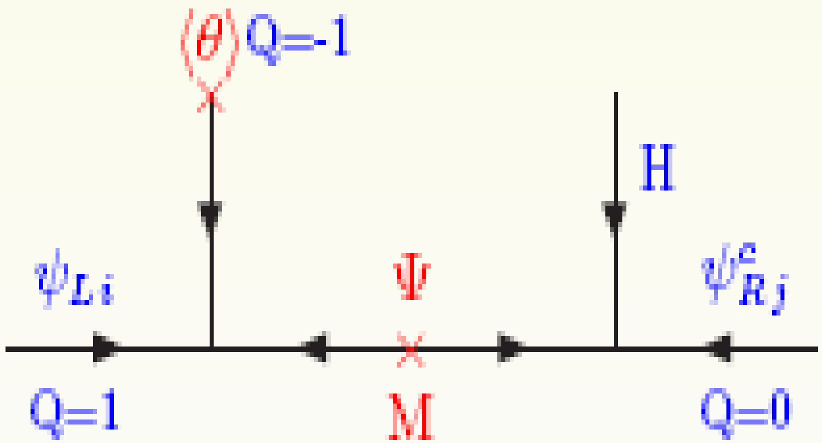
- In rare processes where the flavor does **not** change: **magnetic and electric dipole moments** (es. Muon magnetic moment, electric dipole moments of electron and nucleon)

MSSM ⊗ FAMILY SYMM.

- **AMBITION**: **simultaneously** accounting for the "correct" SM fermion masses and mixings (***SM Flavor Puzzle***) **and** a structure of the SUSY soft breaking masses allowing for adequate FCNC suppression + possible "explanation" of the alleged SM FCNC difficulties (***SUSY Flavor Puzzle***)

- Mechanism a la Frogatt – Nielsen with **abelian or non-abelian family symmetry**

- Froggatt-Nielsen mechanism and flavour symmetry to understand small Yukawa elements. Example: $U(1)_{fl}$



$$\Rightarrow Y_{ij} = \left(\frac{\langle\theta\rangle}{M}\right) \ll 1$$

Yukawa Textures

What we want:

$$Y_u \propto \begin{pmatrix} 0 & \varepsilon^3 & \varepsilon^3 \\ \varepsilon^3 & \varepsilon^2 & \varepsilon^2 \\ \varepsilon^3 & \varepsilon^2 & 1 \end{pmatrix} \qquad Y_d \propto \begin{pmatrix} 0 & \bar{\varepsilon}^3 & \bar{\varepsilon}^3 \\ \bar{\varepsilon}^3 & \bar{\varepsilon}^2 & \bar{\varepsilon}^2 \\ \bar{\varepsilon}^3 & \bar{\varepsilon}^2 & 1 \end{pmatrix}$$

$$\varepsilon = 0.05 \qquad \bar{\varepsilon} = 0.15$$

R. G. Roberts, A. Romanino, G. G. Ross, L. Velasco-Sevilla (hep-ph/0104088)

$SU(3)$ Flavour model

ROBERTS, ROMANINO, ROSS, VELASCO-SEVILLA;
ROSS, VELASCO-SEVILLA, VIVES

- $Q, L \sim \mathbf{3}$ and $d^c, u^c, e^c \sim \mathbf{3}$; flavon fields: $\theta_3, \theta_{23} \sim \overline{\mathbf{3}}$, $\overline{\theta}_3, \overline{\theta}_{23} \sim \mathbf{3}$

- Family Symmetry breaking: $SU(3) \xrightarrow{\langle\theta_3\rangle} SU(2) \xrightarrow{\langle\theta_{23}\rangle} \emptyset$

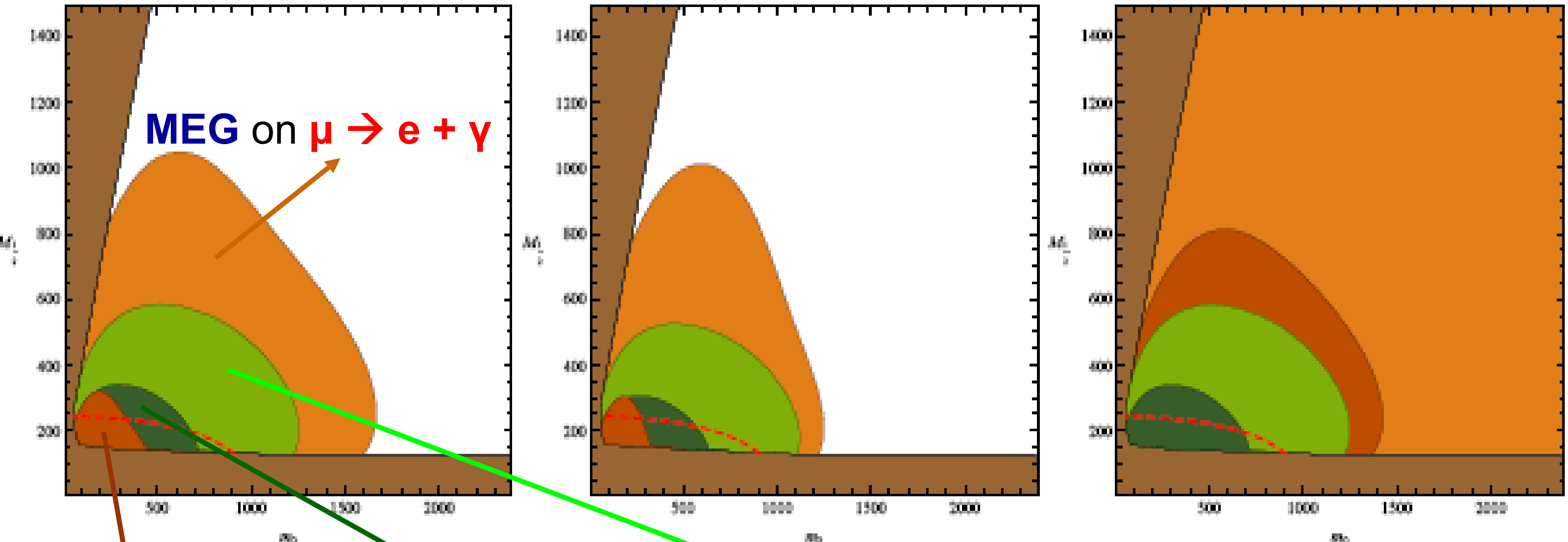
$$\theta_3, \overline{\theta}_3 = \begin{pmatrix} 0 \\ 0 \\ a_3 \end{pmatrix}, \quad \theta_{23}, \overline{\theta}_{23} = \begin{pmatrix} 0 \\ b \\ b \end{pmatrix} \text{ with } \left(\frac{a_3}{M}\right) \sim \mathcal{O}(1), \left(\frac{b}{M_u}\right) \simeq \left(\frac{b}{M_d}\right)^2 = \varepsilon \sim 0.05.$$

- Yukawa superpotential: $W_Y = H \psi_i \psi_j^c \left[\theta_3^i \theta_3^j + \theta_{23}^i \theta_{23}^j \left(\theta_3 \overline{\theta_3}\right) + \epsilon^{ikl} \overline{\theta}_{23,k} \overline{\theta}_{3,l} \theta_{23}^j \left(\theta_{23} \overline{\theta_3}\right)\right]$

$$Y^f = \begin{pmatrix} 0 & a\,\varepsilon^3 & b\,\varepsilon^3 \\ a\,\varepsilon^3 & \varepsilon^2 & c\,\varepsilon^2 \\ b\,\varepsilon^3 & c\,\varepsilon^2 & 1 \end{pmatrix} \frac{|a_3|^2}{M^2},$$

O. VIVES

LFV CONSTRAINTS IN THE $M_0 - M_{1/2}$ SUSY PLANE



PRESENT BOUND ON
τ → μ + γ

FUTURE BOUND ON τ → μ + γ
at SUPER B

PRESENT BOUND ON
μ → e + γ

CALIBBI, JONES, A.M., J-H. PARK, POROD and VIVES

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

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

SuperB can probe MFV (with small-moderate tanβ) for TeV squarks; for a generic non-MFV MSSM $\longrightarrow$ sensitivity to squark masses > 100 TeV !

Ciuchini, Isidori, Silvestrini

SLOW-DECOUPLING OF NP IN FCNC

LFV IN CHARGED LEPTONS FCNC

L_i - L_j transitions through W - neutrinos mediation

GIM suppression $(m_\nu / M_W)^2 \longrightarrow$ forever invisible

New mechanism: replace SM GIM suppression with a new GIM suppression where m_ν is replaced by some $\Delta M \gg m_\nu$.

Ex.: in SUSY L_i - L_j transitions can be mediated by photino - SLEPTONS exchanges,

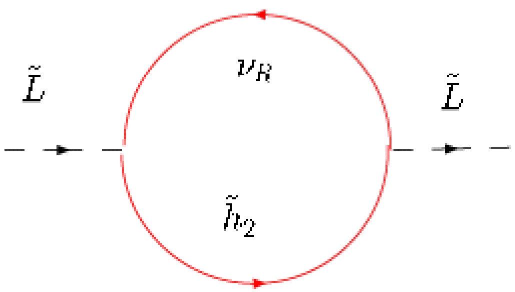
BUT in CMSSM (MSSM with flavor universality in the SUSY breaking sector) $\Delta M_{\text{sleptons}}$ is O(m_{leptons}), hence GIM suppression is still too strong.

How to further decrease the SUSY GIM suppression power in LFV through slepton exchange?

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

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

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

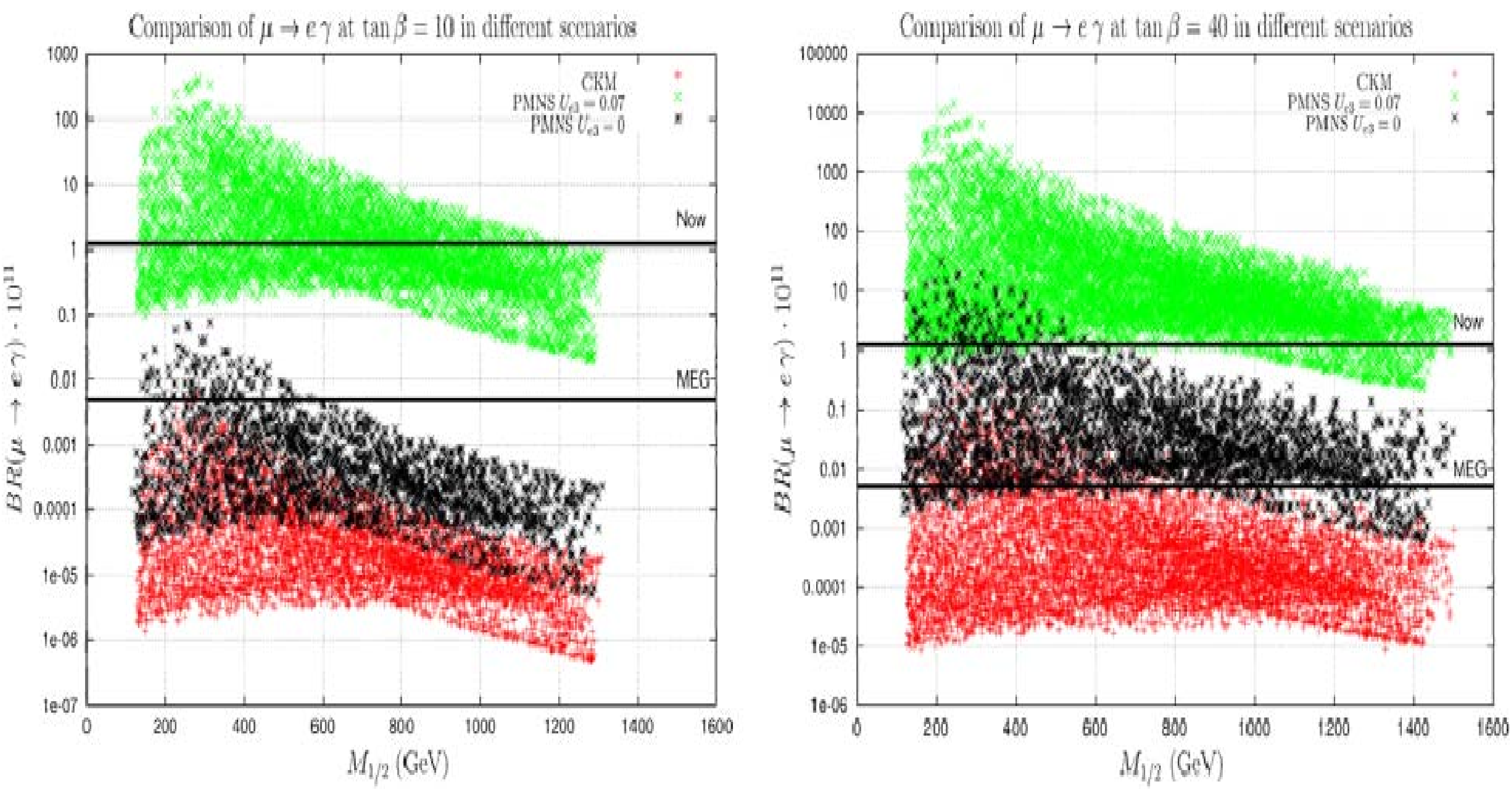


$$\left(m^2_{\tilde{L}}\right)_{ij} \sim \frac{1}{8\pi^2}\left(3m_0^2 + A_0^2\right)\left(f_\nu^\dagger f_\nu\right)_{ij} \log\frac{M}{M_G}$$

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

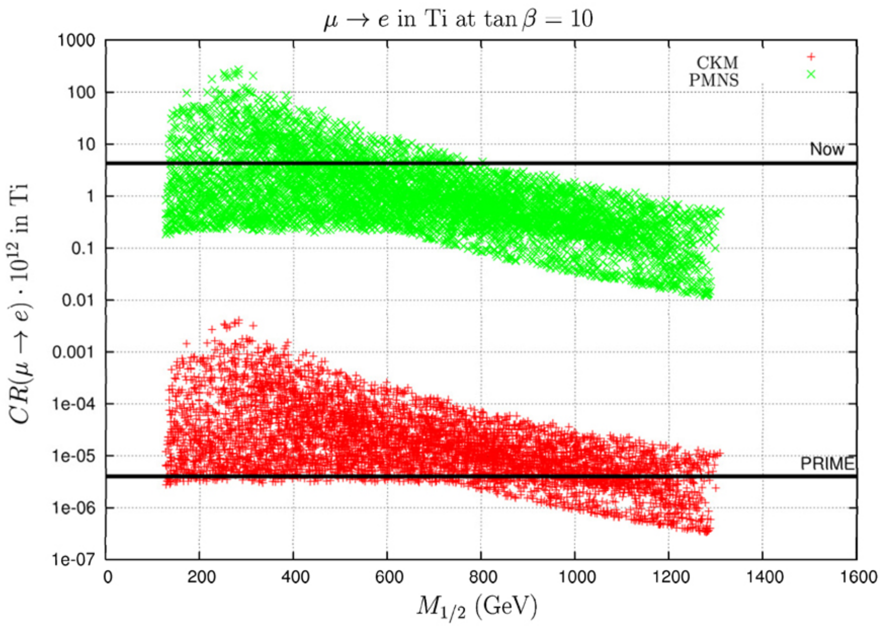
μ → e+γ in SUSYGUT: past and future

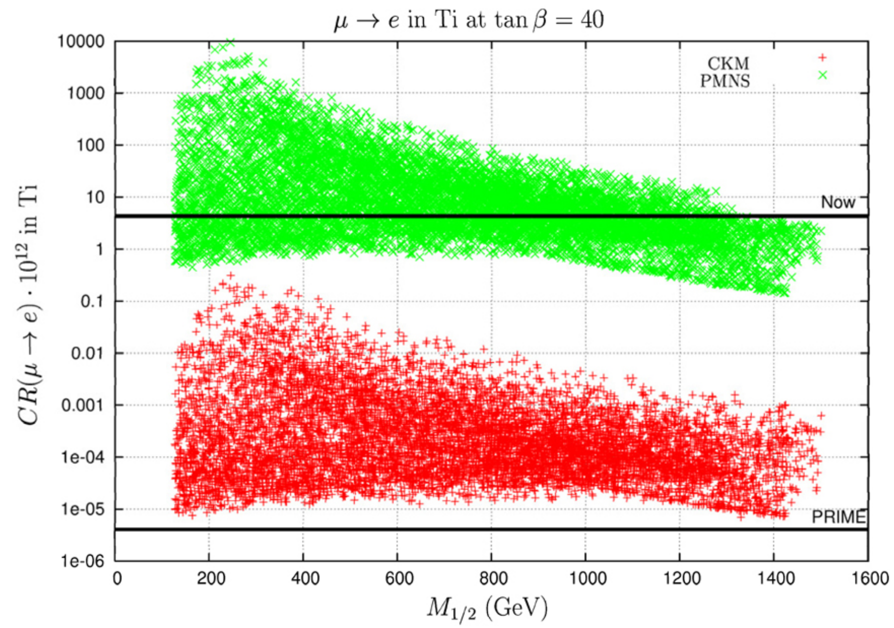
$\mu \to e\gamma$ in the $U_{e3} = 0$ PMNS case

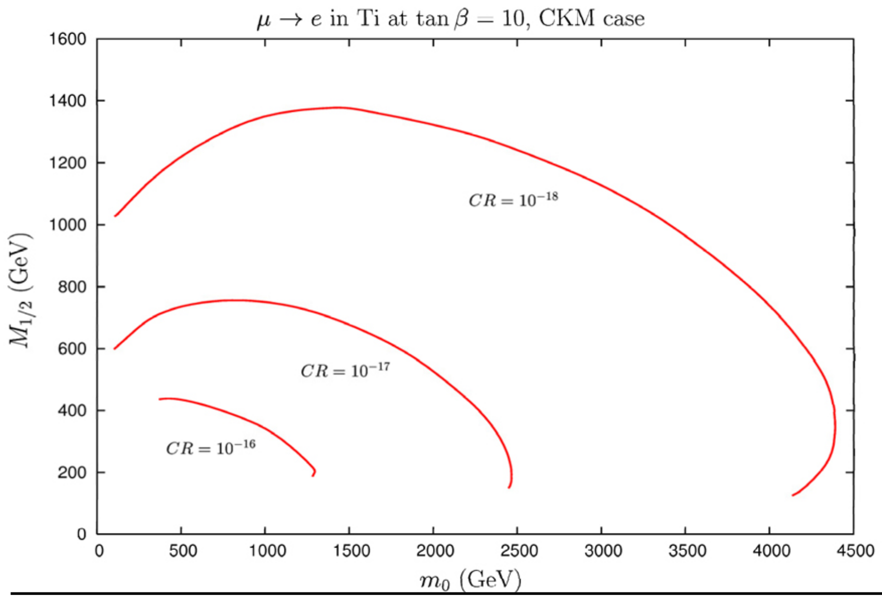


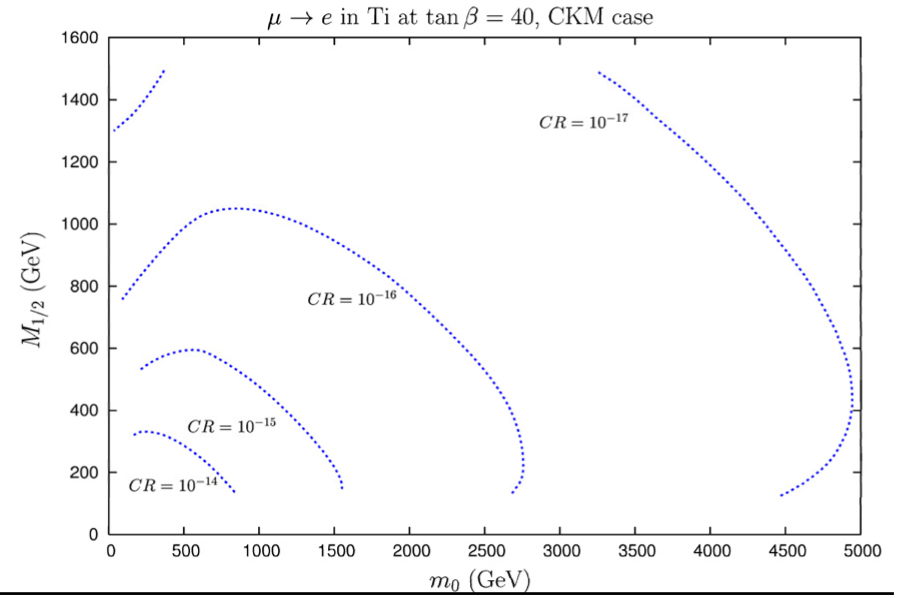
Calibbi, Faccia, A.M., Vempati

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

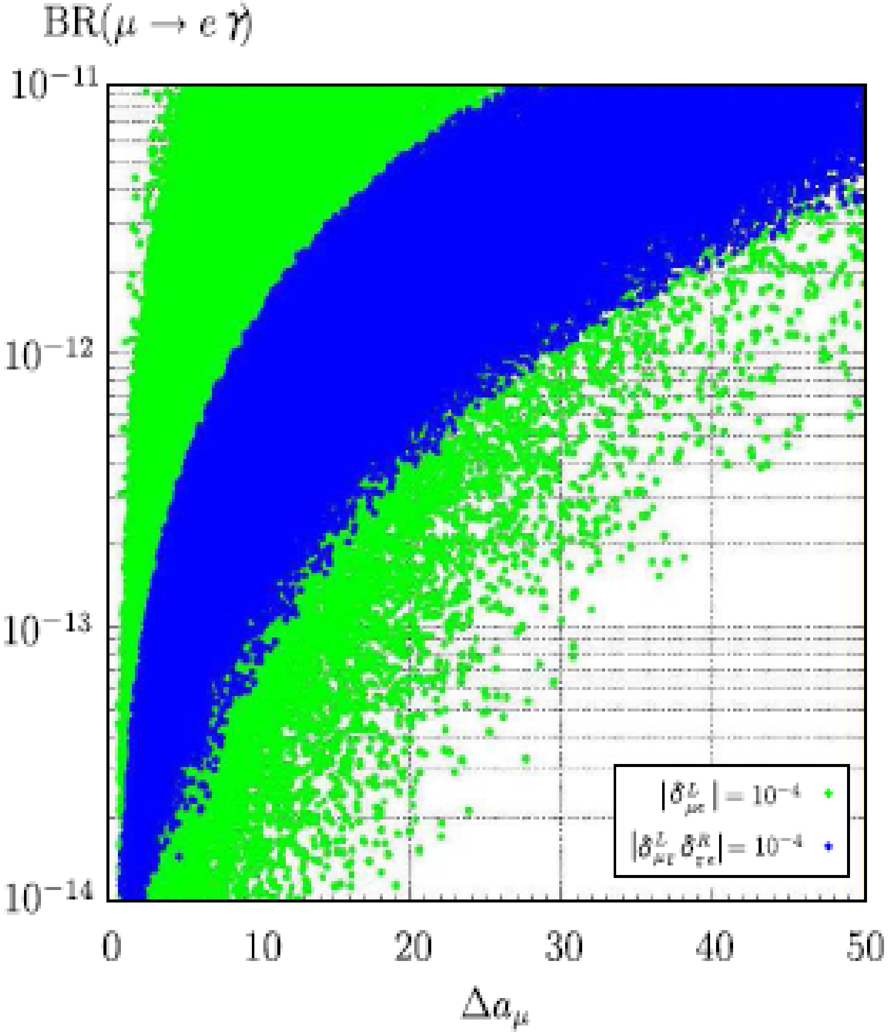




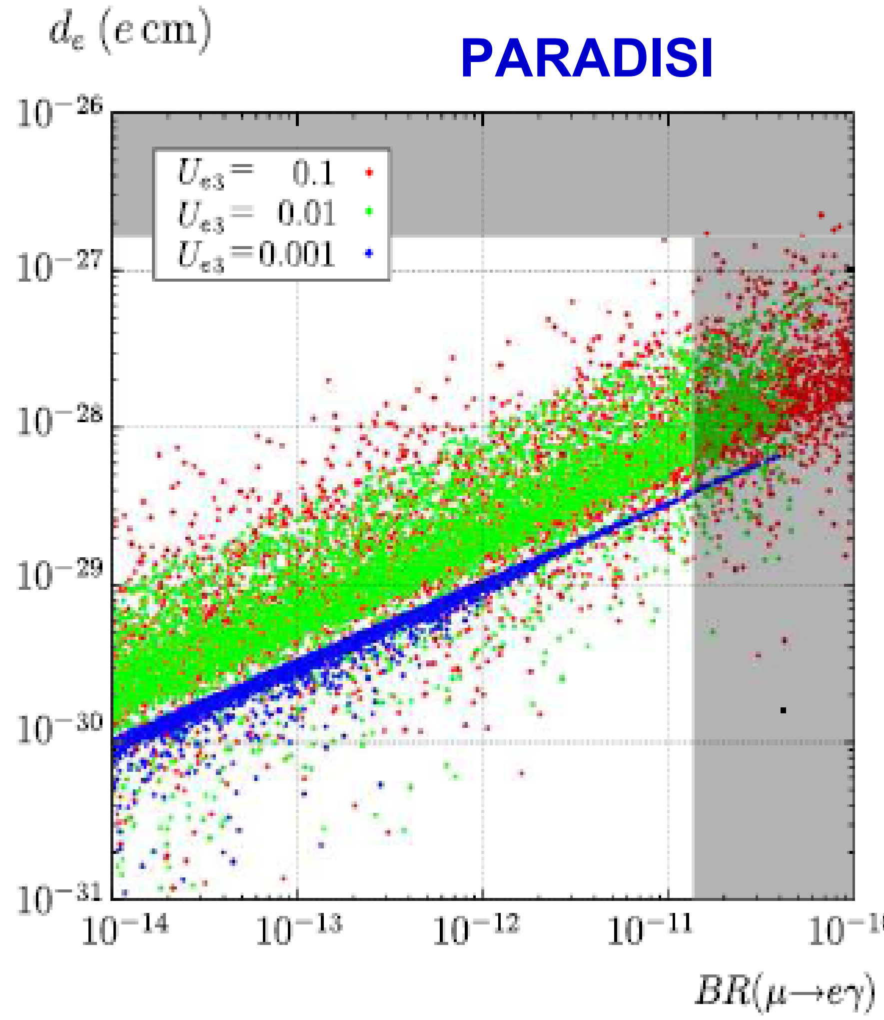




LFV, g – 2, EDM: a promising correlation in SUSY SEESAW



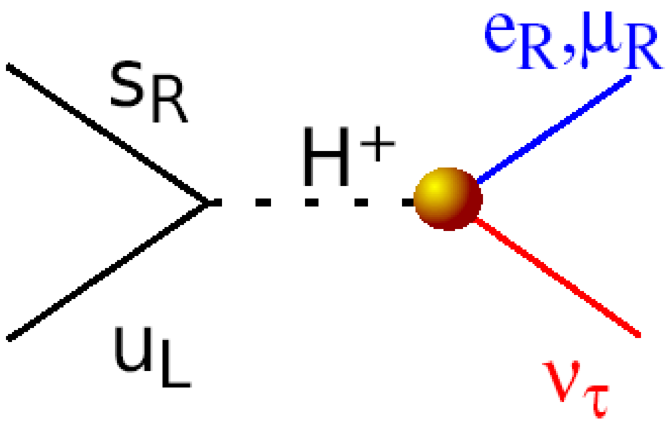
PARADISI



DEVIATION from μ - e UNIVERSALITY

A.M., Paradisi, Petronzio

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



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

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

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

$$\Downarrow$$

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

Exp: now at **0.7%** accuracy (NA62), **0.3%** will be reached when all NA62 data are analyzed

Large ν mixing $\longleftrightarrow$ 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 2004
general analysis **Ciuchini, A.M., Paradisi, Silvestrini, Vempati, Vives** NPB 2007
For previous works: Baek, Goto, Okada, Okumura PRD 2001;
Hisano, Shimizu, PLB 2003;
Cheung, Kang, Kim, Lee PLB 2007
Borzumati, Mishima, Yamashita hep-ph 0705:2664
For recent works: Goto, Okada, Shindou, Tanaka PRD 2008;
Ko, J-h. Park, Yamaguchi arXiv:0809:2784

GUT -RELATED SUSY SOFT BREAKING TERMS

$$m^2_Q = m^2_{\tilde{e}^c} = m^2_{\tilde{u}^c} = m^2_{\mathbf{10}}$$

$$m^2_{\tilde{d}^c} = m^2_L = m^2_{\bar{\mathbf{5}}}$$

$$A^e_{ij} = A^d_{ji} .$$

SU(5) RELATIONS

TO BE TESTED STUDYING THE SUSY SPECTRUM AT THE LC

	Relations at weak-scale	Relationss at $M_{\rm GUT}$
(1)	$(\delta^u_{ij})_{\rm RR} \approx (m^2_{e^c}/m^2_{u^c})\ (\delta^l_{ij})_{\rm RR}$	$m^2_{u^c{}_0} = m^2_{e^c{}_0}$
(2)	$(\delta^q_{ij})_{\rm LL} \approx (m^2_{e^c}/m^2_Q)\ (\delta^l_{ij})_{\rm RR}$	$m^2_{Q_0} = m^2_{e^c{}_0}$
(3)	$(\delta^d_{ij})_{\rm RR} \approx (m^2_L/m^2_{d^c})\ (\delta^l_{ij})_{\rm LL}$	$m^2_{d^c{}_0} = m^2_{L_0}$
(4)	$(\delta^d_{ij})_{\rm LR} \approx (m^2_{L_{avg}}/m^2_{Q_{avg}})\ (m_b/m_\tau)\ (\delta^l_{ij})^\star_{\rm LR}$	$A^e_{ij_0} = A^d_{ji_0}$

ON THE LHC – LC – DM – FCNC COOPERATION TO CORNER TeV NEW PHYSICS

- **The traditional competition between direct and indirect (DM,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)

SLOW "DECOUPLING" of NEW PHYSICS EFFECTS in DM and FCNC SEARCHES w.r.t. the DIRECT ACCELERATOR SEARCHES.

TEVATRON → LHC → I L C

DM - FLAVOR

for DISCOVERY

and/or FUND. TH.

RECONSTRUCTION

A MAJOR
LEAP AHEAD
IS NEEDED

NEW PHYSICS AT THE ELW SCALE

DARK MATTER

$m_\chi\ n_\chi\ \sigma_\chi \ldots$

LINKED TO COSMOLOGICAL EVOLUTION

Possible interplay with dynamical DE

LEPTOGENESIS

"LOW ENERGY"

PRECISION PHYSICS

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

LFV

NEUTRINO PHYSICS