16TH Yukawa International Seminar (YKIS),

Particle physics *beyond* the Standard Model,

Yukawa Institute Colloquium, KYOTO, FEBR. 3, 2009

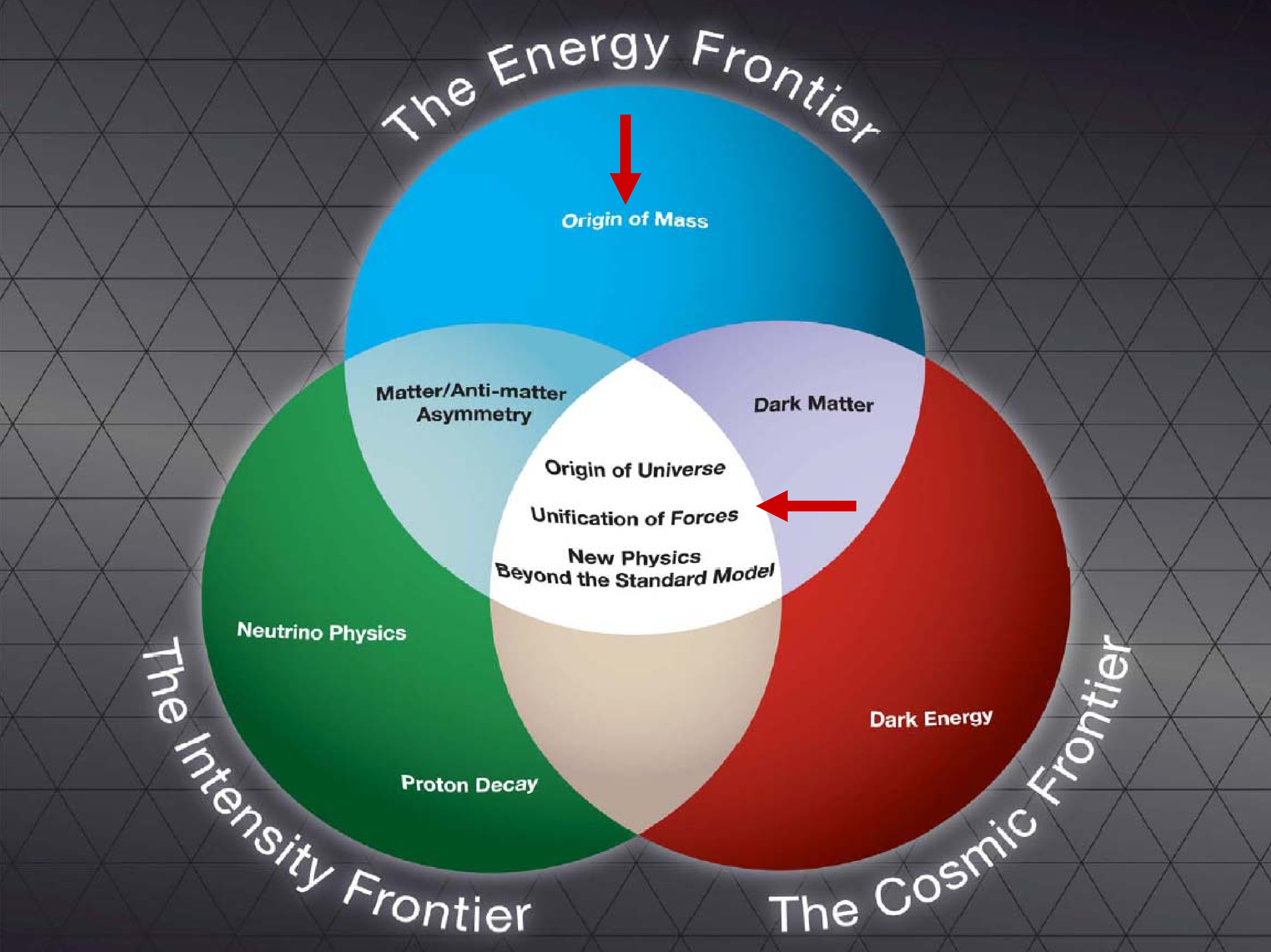
THE FLAVOR BET

ON

NEW PHYSICS

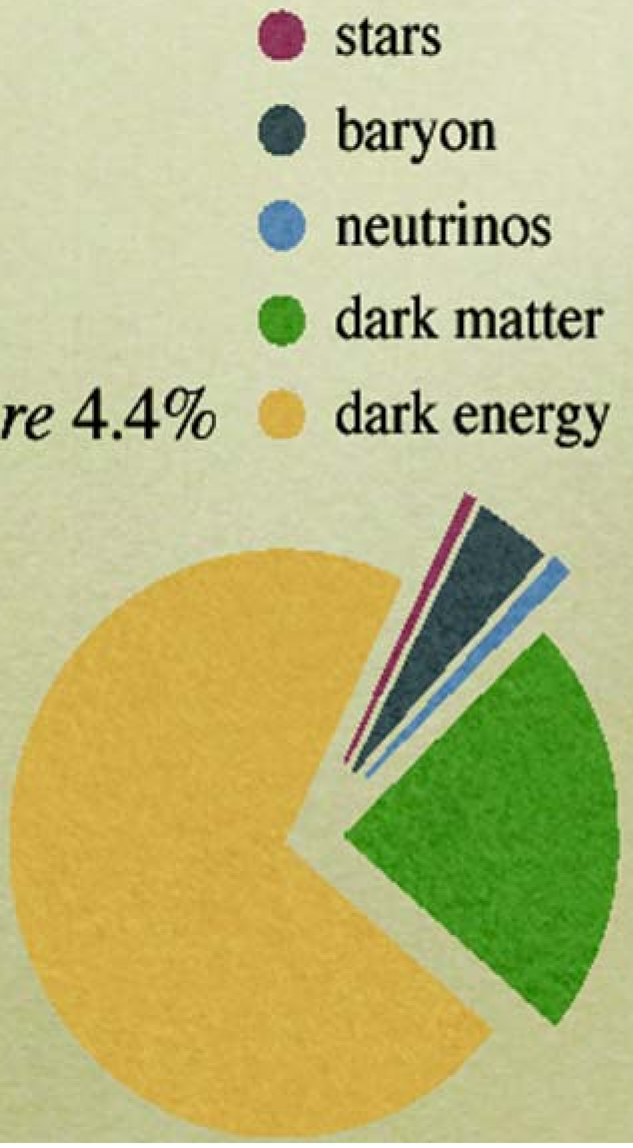
Antonio Masiero

Univ. of Padova and INFN, Padova


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
Proton Decay
Dark Energy
The Intensity Frontier
The Cosmic Frontier

MASS PUZZLES IN THE UNIVERSE

- *Stars and galaxies are only ~0.5%*
- *Neutrinos are ~0.1–1.5%*
- *Rest of ordinary matter (electrons, protons & neutrons) are 4.4%*
- *Dark Matter 23%*
- *Dark Energy 73%*
- *Anti-Matter 0%*
- *Higgs Bose-Einstein condensate ~10^{62}%??*



MICRO

PARTICLE PHYSICS

GWS STANDARD MODEL

MACRO

COSMOLOGY

HOT BIG BANG
STANDARD MODEL

HAPPY MARRIAGE
Ex: NUCLEOSYNTHESIS

BUT ALSO

POINTS OF
FRICTION

-**COSMIC MATTER-ANTIMATTER ASYMMETRY**

-INFLATION

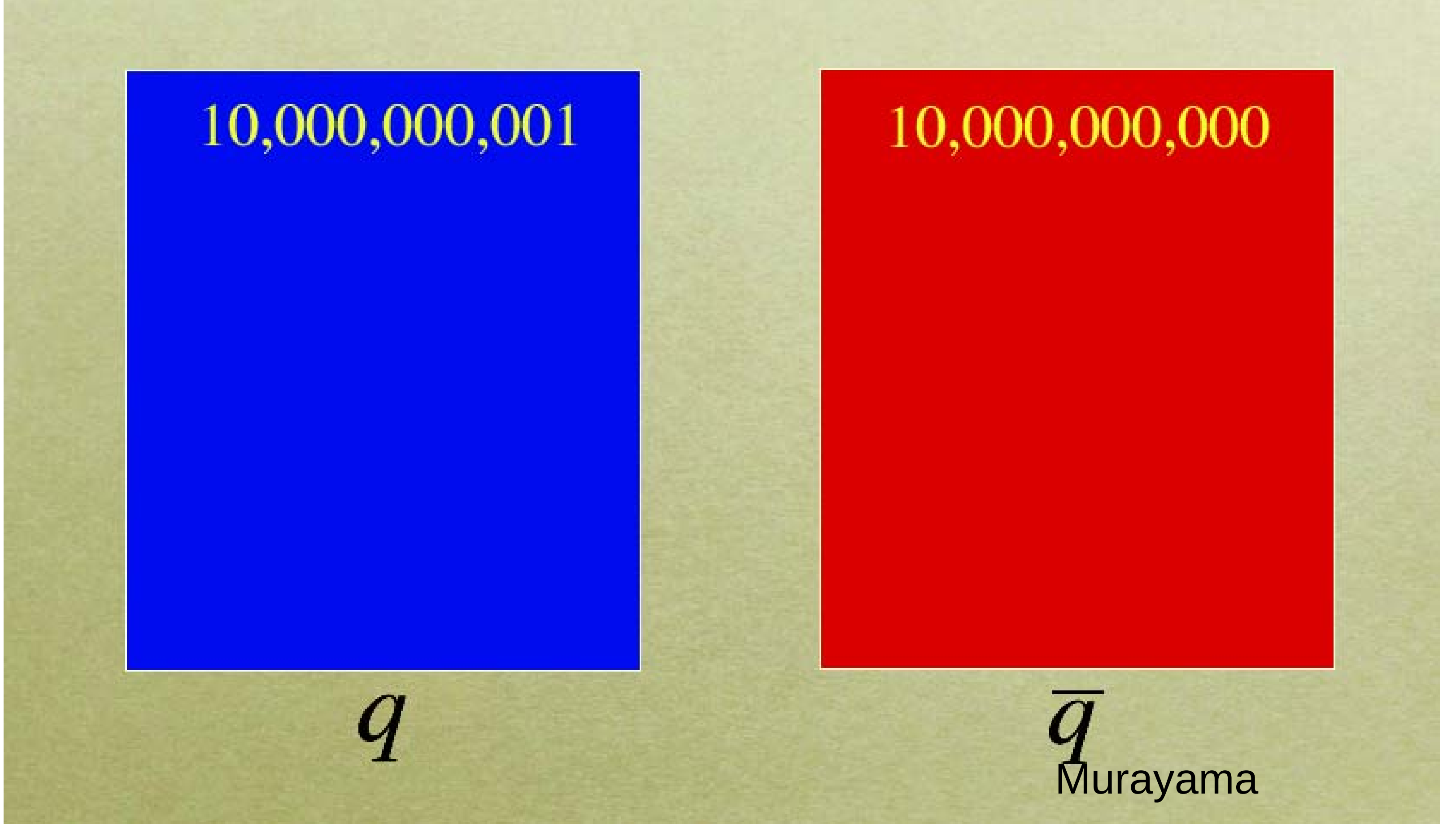
- **DARK MATTER** + DARK ENERGY

“OBSERVATIONAL” EVIDENCE FOR NEW PHYSICS BEYOND
THE **(PARTICLE PHYSICS)** STANDARD MODEL

THE COSMIC MATTER-ANTIMATTER ASYMMETRY PUZZLE:

- why only baryons
- why $N_{baryons}/N_{photon} \sim 10^{-10}$

COSMIC MATTER-ANTIMATTER ASYMMETRY as an *INITIAL CONDITION*



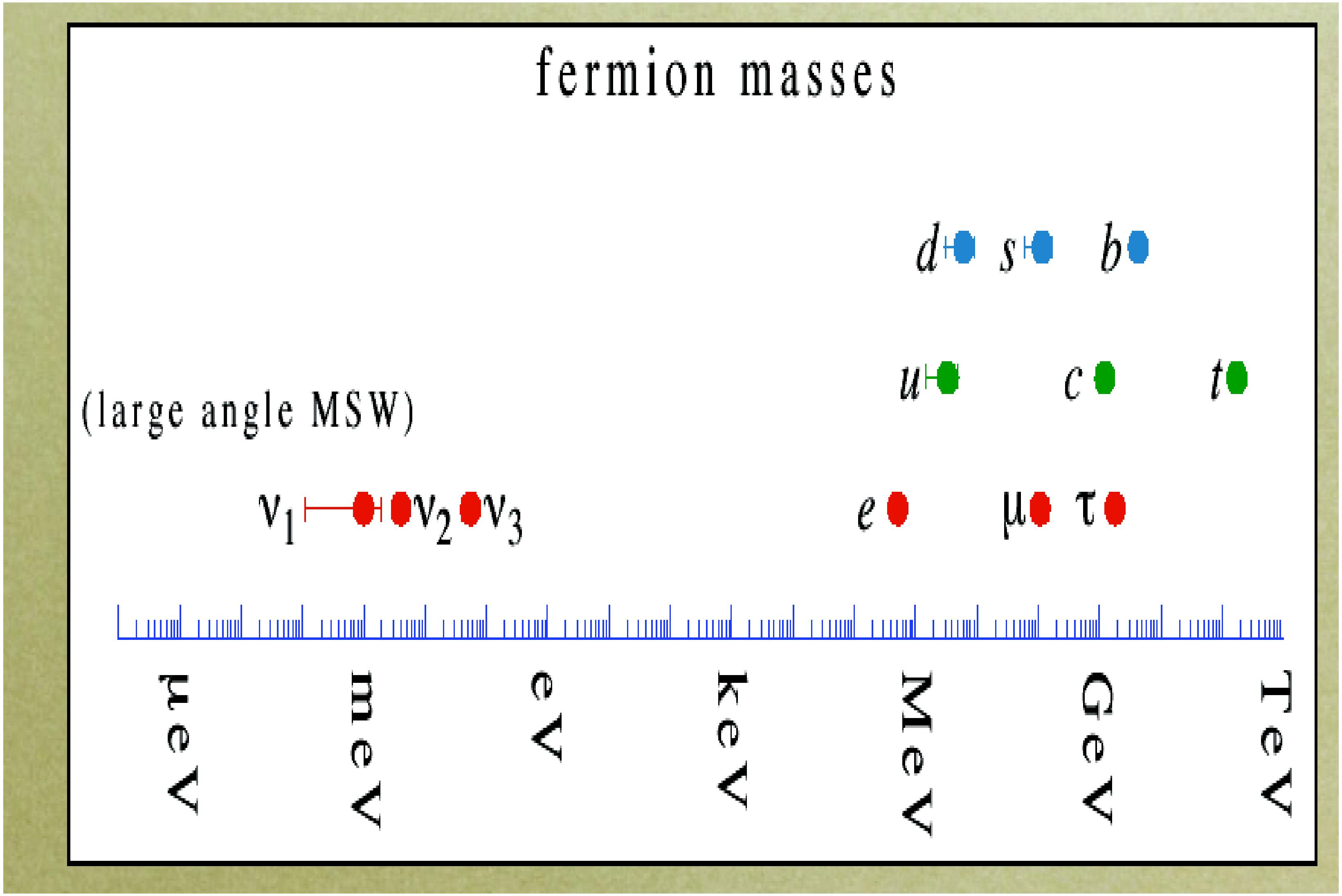
DYNAMICAL MECHANISM

TO ORIGINATE A COSMIC MATTER-ANTIMATTER ASYMMETRY STARTING FROM A MATTER-ANTIMATTER SYMMETRIC UNIVERSE:

NECESSARY CONDITION

CP VIOLATION

THE FERMION MASS PUZZLE



The First Problem

From the Feynman — Gell-Mann paper...

PHYSICAL REVIEW VOLUME 109, NUMBER 1 JANUARY 1, 1958

Theory of the Fermi Interaction

R. P. FEYNMAN AND M. GELL-MANN
California Institute of Technology, Pasadena, California

(Received September 16, 1957)

To account for all observed strange particle decays it is sufficient to add to the current a term like $(\bar{p}\Lambda^0)$, $(\bar{p}\Sigma^0)$, or $(\bar{\Sigma}^- n)$, in which strangeness is increased by one as charge is increased by one. For instance, $(\bar{p}\Lambda^0)$ gives us the couplings $(\bar{p}\Lambda^0)(\bar{e}\nu)$, $(\bar{p}\Lambda^0)(\bar{\mu}\nu)$, and $(\bar{p}\Lambda^0)(\bar{n}p)$. A direct consequence of the coupling $(\bar{p}\Lambda^0)(\bar{e}\nu)$ would be the reaction

$$\Lambda^0 \rightarrow p + e + \bar{\nu} \qquad (14)$$

at a rate 5.3×10^7 sec^{-1}, assuming no renormalization of the constants.[18] ..... we should observe process (14) in about 1.6% of the disintegrations. This is not excluded by experiments. If a term like $(\bar{\Sigma}^- n)$ appears, the decay $\Sigma^- \rightarrow n + e^- + \nu$ is possible at a predicted rate 3.5×10^8 sec^{-1} and should occur .....
... in about 5.6% of the disintegrations of the Σ^-.

S → U

TRANSITIONS

Around 1962 it became clear than these rates were $\approx$ 20 times smaller!

The Second Problem

The radiative corrections tended to worsen the disagreement between the Fermi constant as measured in beta decay and in muon decay, making it serious.

> The result decreases the universal coupling constant obtained from O^{14} to $G = (1.37 \pm 0.02) \times 10^{-49}$ erg cm^3 and increases the value of the predicted value of the muon lifetime from the value given above to $(2.33 \pm 0.05) \times 10^{-6}$ sec, while the experimental value is $(2.22 \pm 0.02) \times 10^{-6}$ sec. The disagreement between experiment and theory appears to be outside of the limit of experimental error and might be regarded as an indication of the lack of universality even by the strangeness-conserving part of the vector interaction. However, it is very difficult to understand the mechanism for such a slight deviation from universality; that is, if universality is to be broken at all why should it be by such a small amount?

Taking muon decay as the standard we have beta decay a few % weaker and hyperon semileptonic decays about 20 times weaker.

N. CABIBBO

In 1962 R. Gatto and I proposed that weak currents be classified in an SU(3) octet. This made the puzzle worse: the weakness of semileptonic $\Delta S = 1$ could not be a renormalization effect. The missing clue, which I found the next year, was that one should not compare the strength of the two components of the hadronic weak current to the $\mu - \nu_\mu$ or $e - \nu_e$ current separately but together,

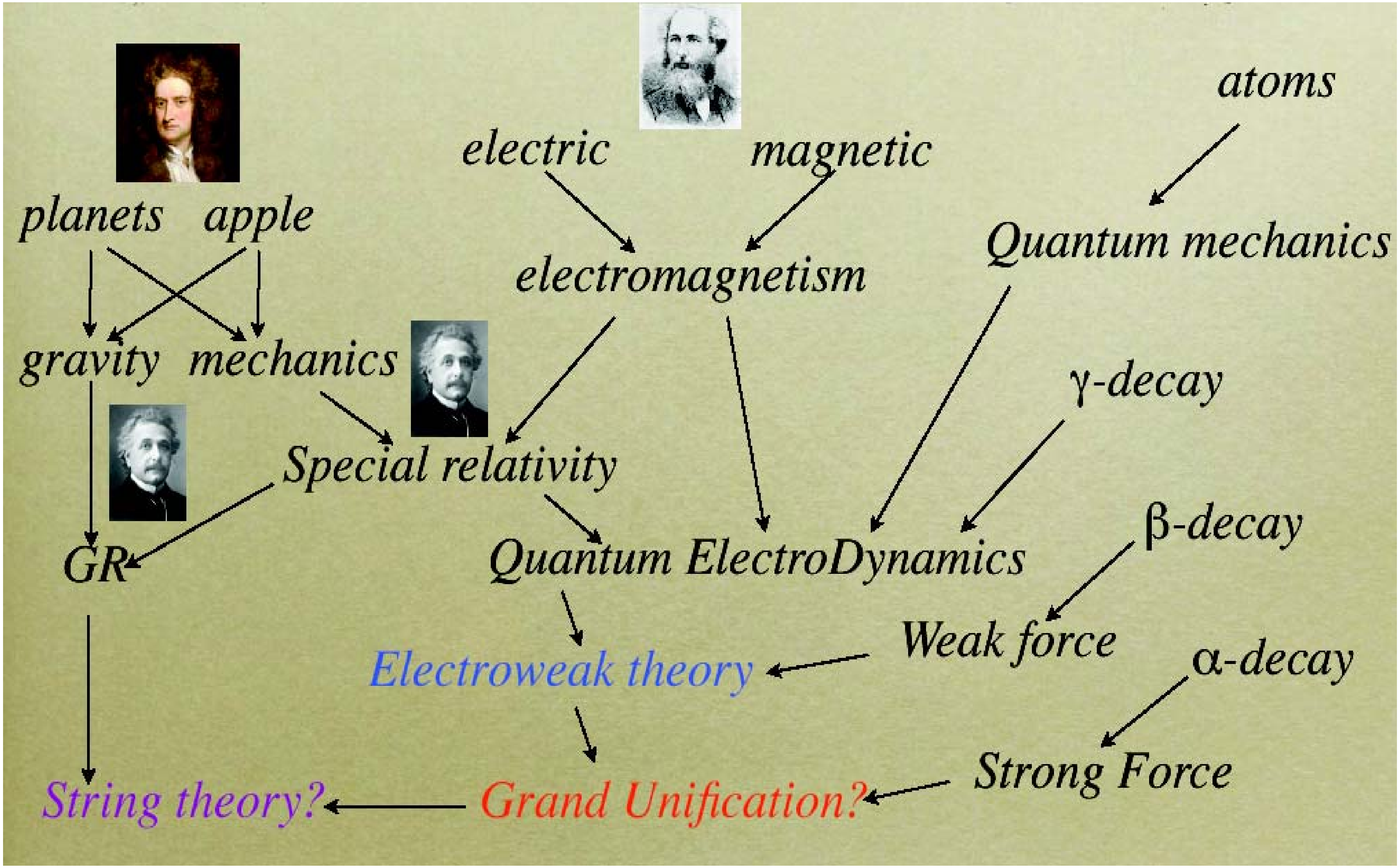
$$J^{\text{weak}} = J^{\mu-\nu_\mu} + J^{e-\nu_e} + \left(aJ^{\Delta S=0} + bJ^{\Delta S=1}\right) + \ldots$$

This led to the condition

$$a^2 + b^2 = 1 \qquad \text{or} \qquad a = \cos\theta, \qquad b = \sin\theta$$

and to a simultaneous solution of both problems: the $\Delta S = 1$ decays feed from a small decrease of the $\Delta S = 0$ beta decay.

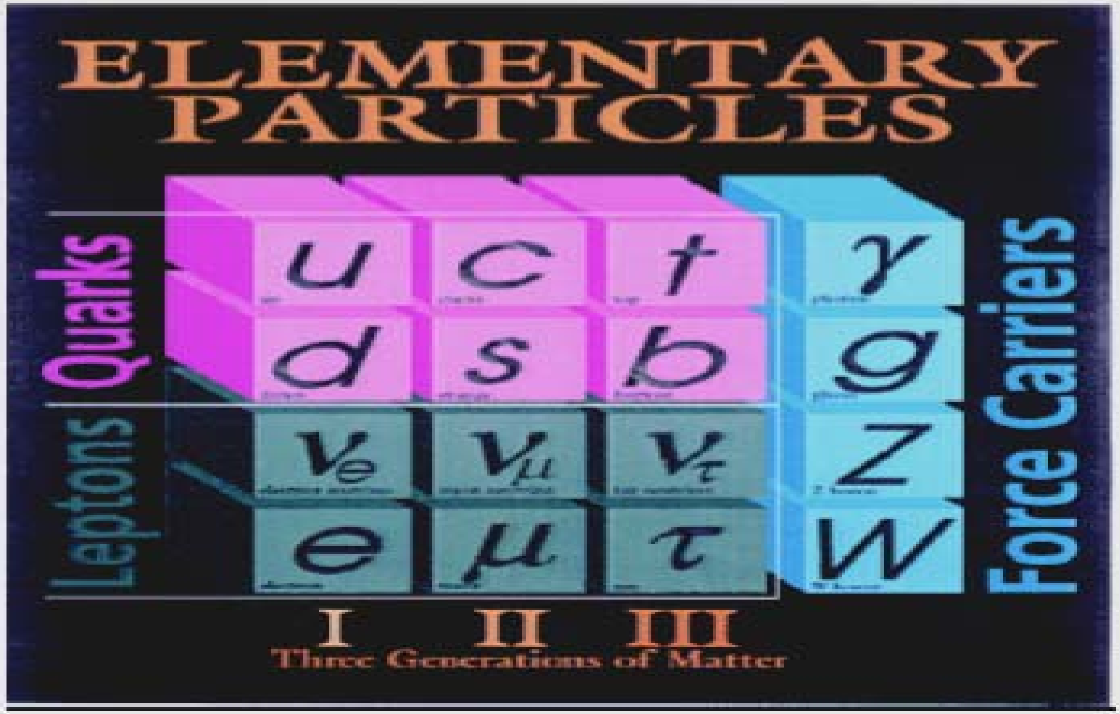
UNIFICATION of FUNDAMENTAL INTERACTIONS

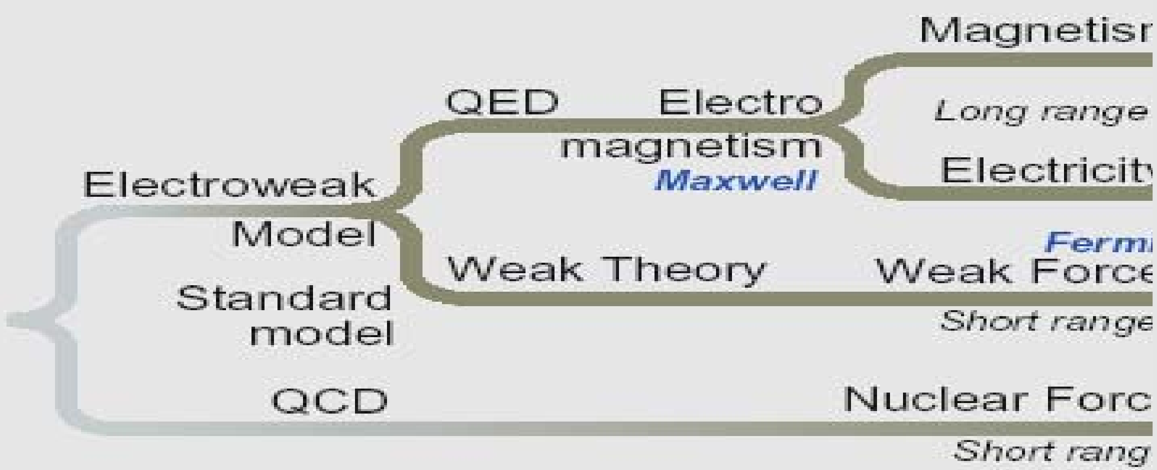


THE G-W-S STANDARD MODEL

SYMM

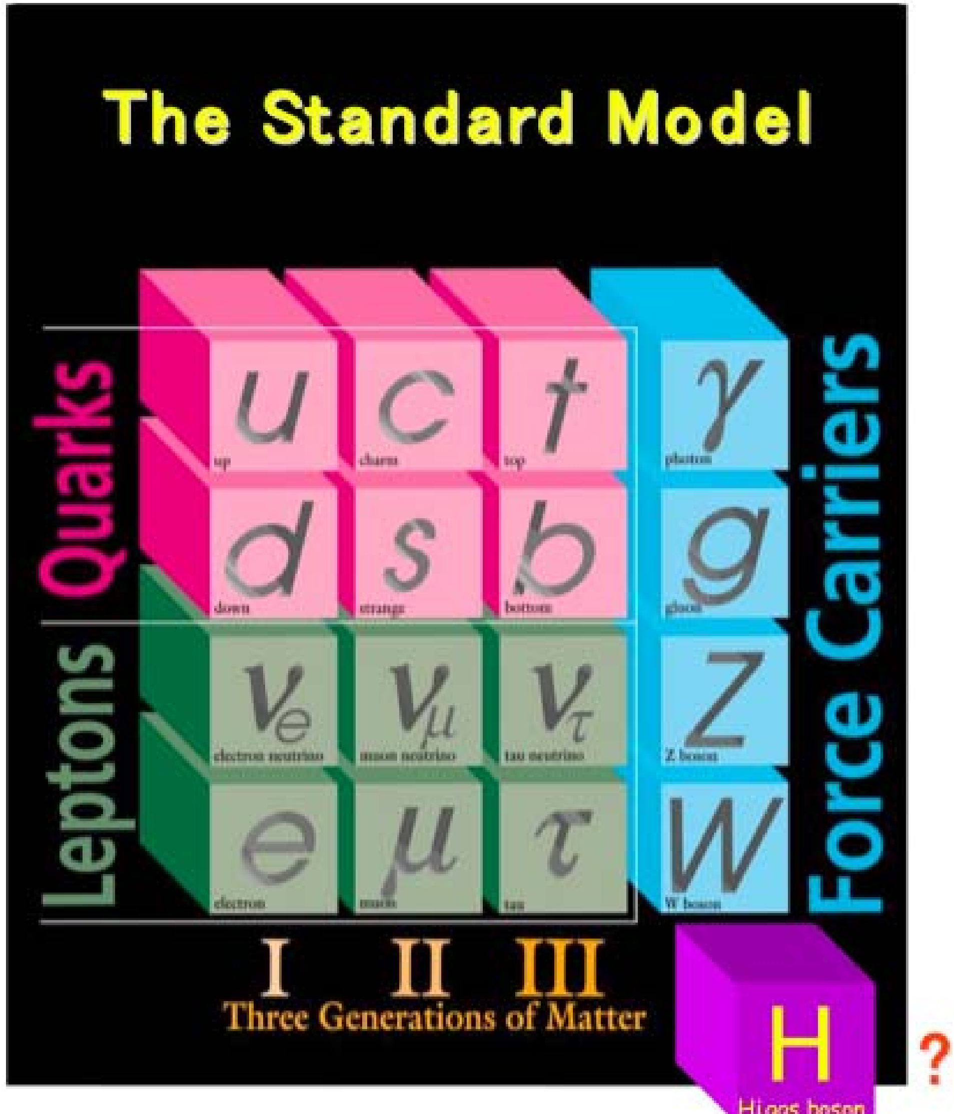
-





Gravity

?



SYMM?

CKM AND THE UNITARITY TRIANGLE

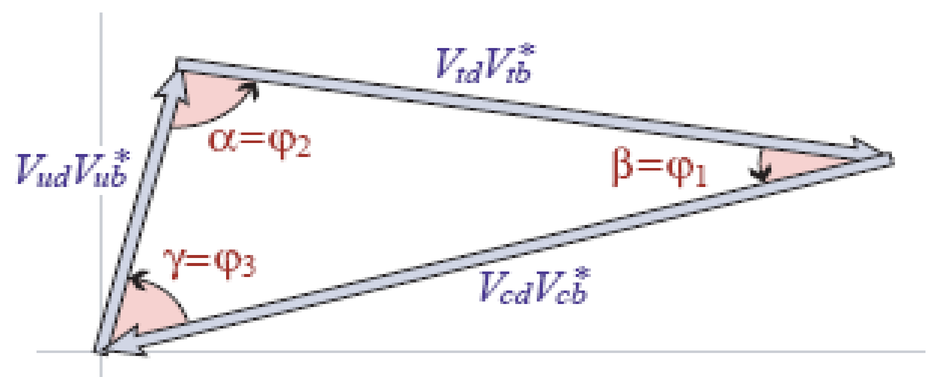
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$V = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

UNITARITY OF THE CKM

$$\begin{cases} V_{ud}V_{us}^* + V_{cd}V_{cs}^* + V_{td}V_{ts}^* = 0, \\ V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0, \\ V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0. \end{cases}$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \;\rightarrow$$



UNTIL 2002

IS V UNITARY ?

from CKM Unitarity and $|V_{ud}|$ $\rightarrow$ $|V_{us}| = 0.2265 \pm 0.0022$

PDG value, from $K_{\ell 3}$ $\rightarrow$ $|V_{us}| = 0.2196 \pm 0.0026$

V_{us} from $K_{\ell 3}$ decays.

Until 2002 $K_{\ell 3}$ decays seemed to point to a lower value for V_{us} than required by unitarity. The discrepancy started to clear in 2003 with new results from KTeV and then NA48. The most complete results come from the KLOE experiment in Frascati. Making use of both $K_{\mu\nu}$ and $K_{\ell 3}$, and a new determination of the K^+ lifetime, as well as the most recent Lattice computations of SU(3) breaking effects, KLOE obtains

$$|V_{us}| = 0.2249 \pm 0.0010$$

$$1 - |V_{us}|^2 - |V_{ud}|^2 = 0.0004 \pm 0.0007 \ (\sim 0.6\,\sigma)$$

There is now no hint of a violation of unitarity at the 0.1% level!

WOLFENSTEIN parametrization of V

V as an expansion in powers of the Cabibbo angle λ

$$\mathbf{V} = \begin{vmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix} = \begin{vmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{vmatrix} + O(\lambda^4)$$

KOBAYASHI – MASKAWA **Progr. Theor. Phys., Vol. 49 No. 2 (1973) pp. 652-657**

FROM 2 TO 3 FERMION FAMILIES: CP VIOLATION

→ **phase in some elements of V, i.e. η different from zero**

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

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

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

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

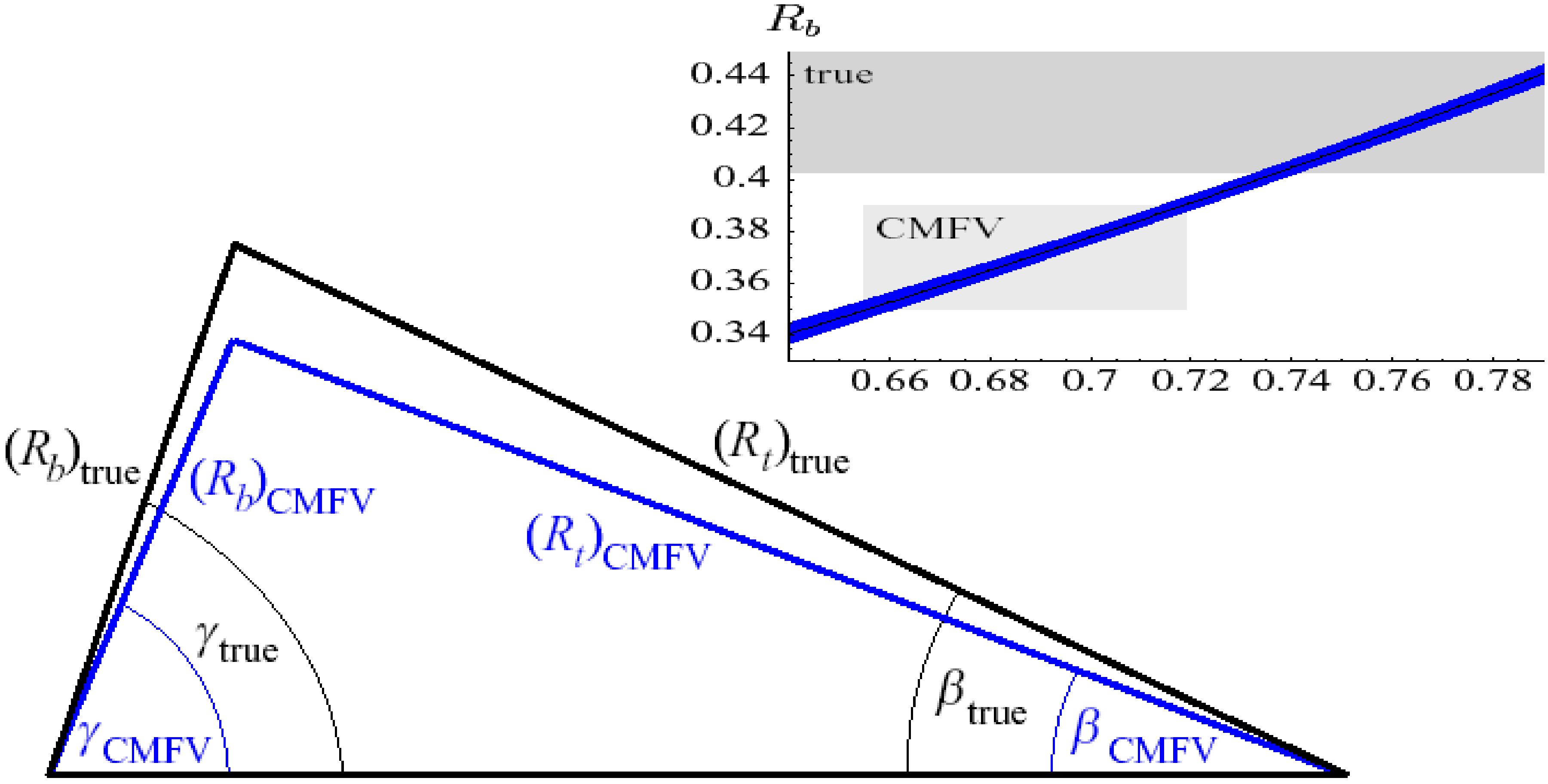
$$R_b = \sqrt{1 + R_t^2 - 2R_t\cos\beta}, \qquad \cot\gamma = \frac{1 - R_t\cos\beta}{R_t\sin\beta},$$

A. BURAS et al.

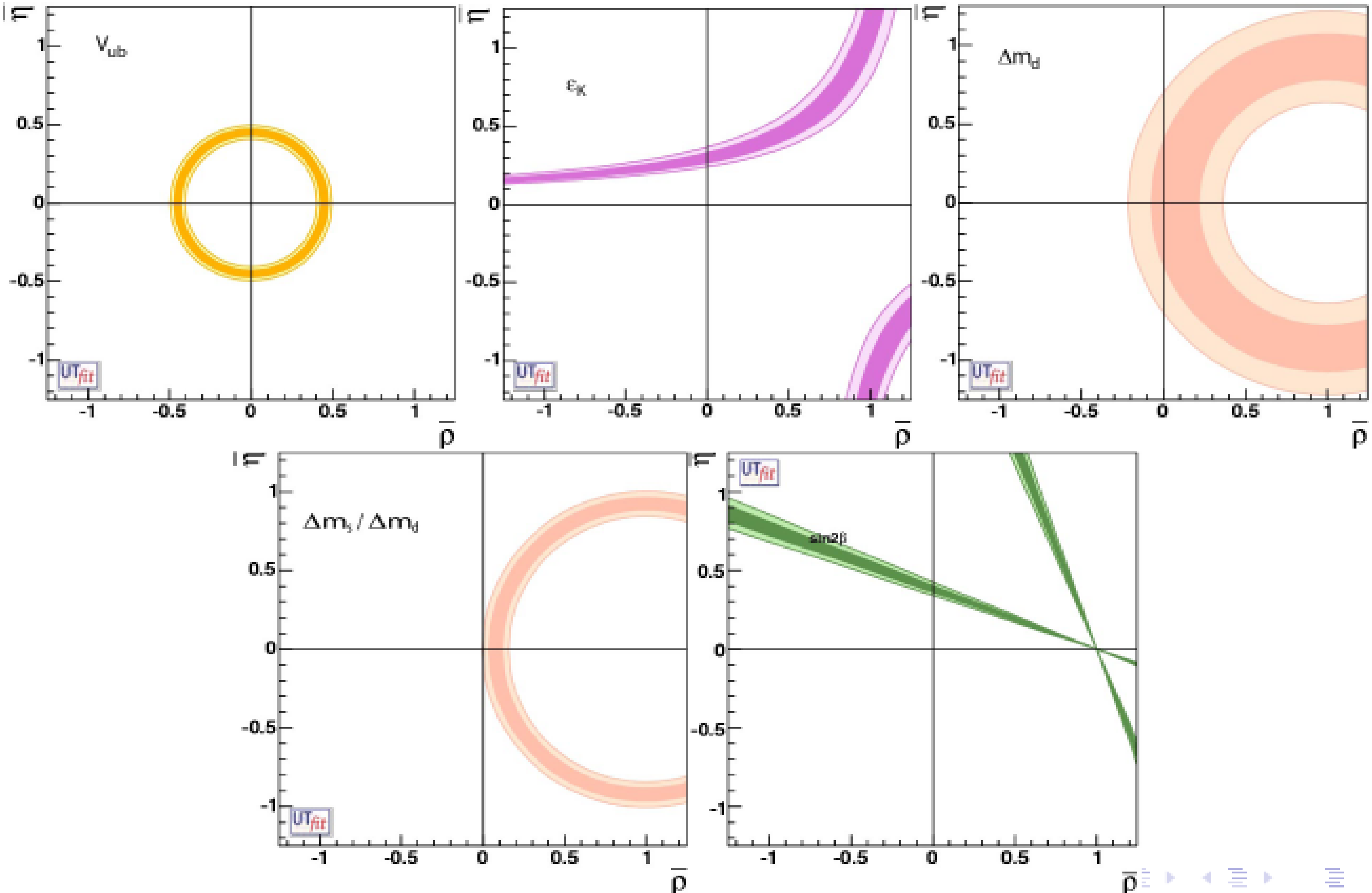
THE UT - UUT OVERLAP

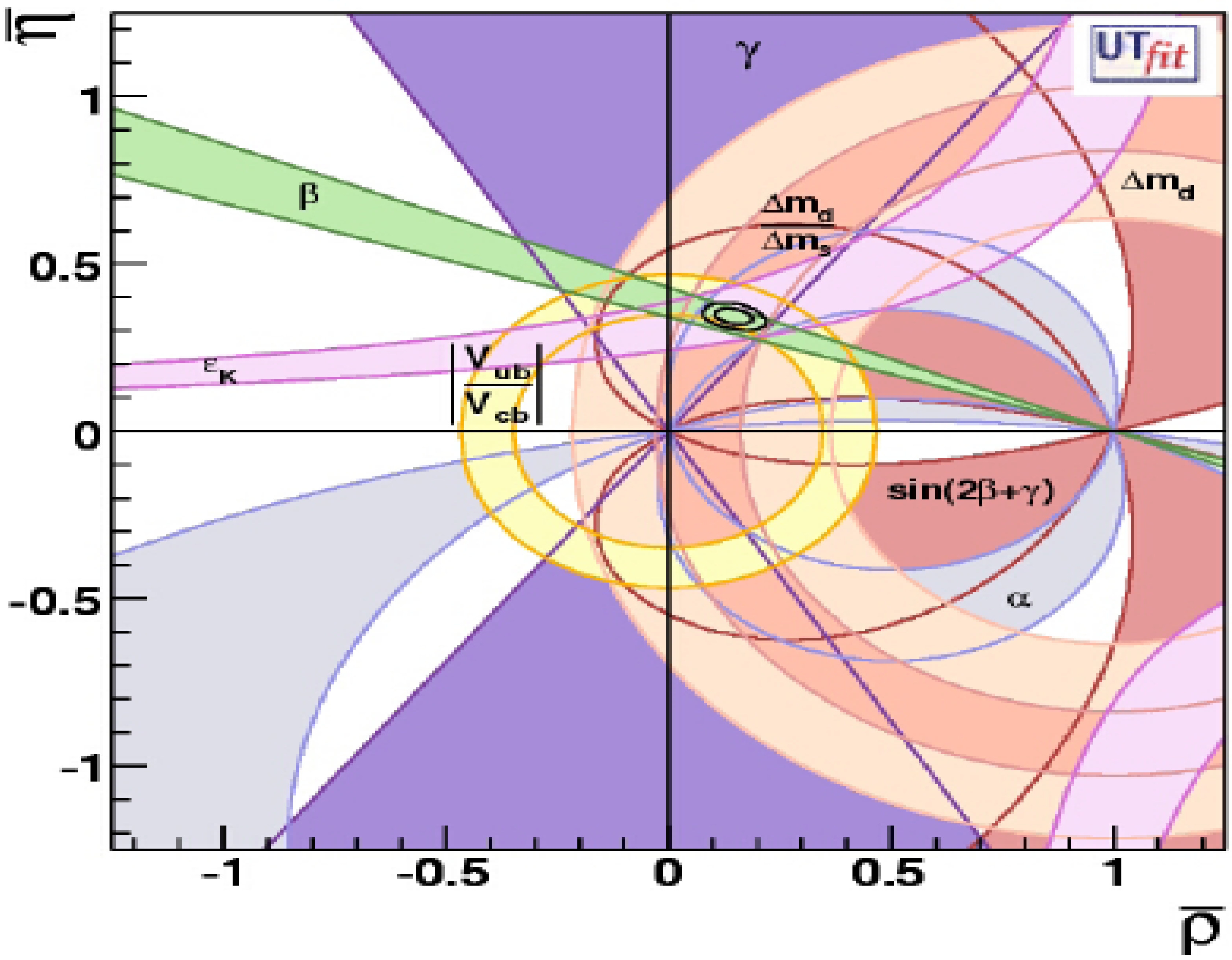
$$(R_b)_{\rm CMFV} = 0.370 \pm 0.020, \qquad \gamma_{\rm CMFV} = (67.4 \pm 6.8)^\circ$$

$$(R_b)_{\rm true} = 0.440 \pm 0.037, \qquad \gamma_{\rm true} = (71 \pm 16)^\circ.$$



BLANKE, BURAS, GUADAGNOLI, TARANTINO


V_{ub}
ε_K
Δm_d
$\Delta m_s / \Delta m_d$
sin2β
UTfit
$\bar{\eta}$
$\bar{\rho}$

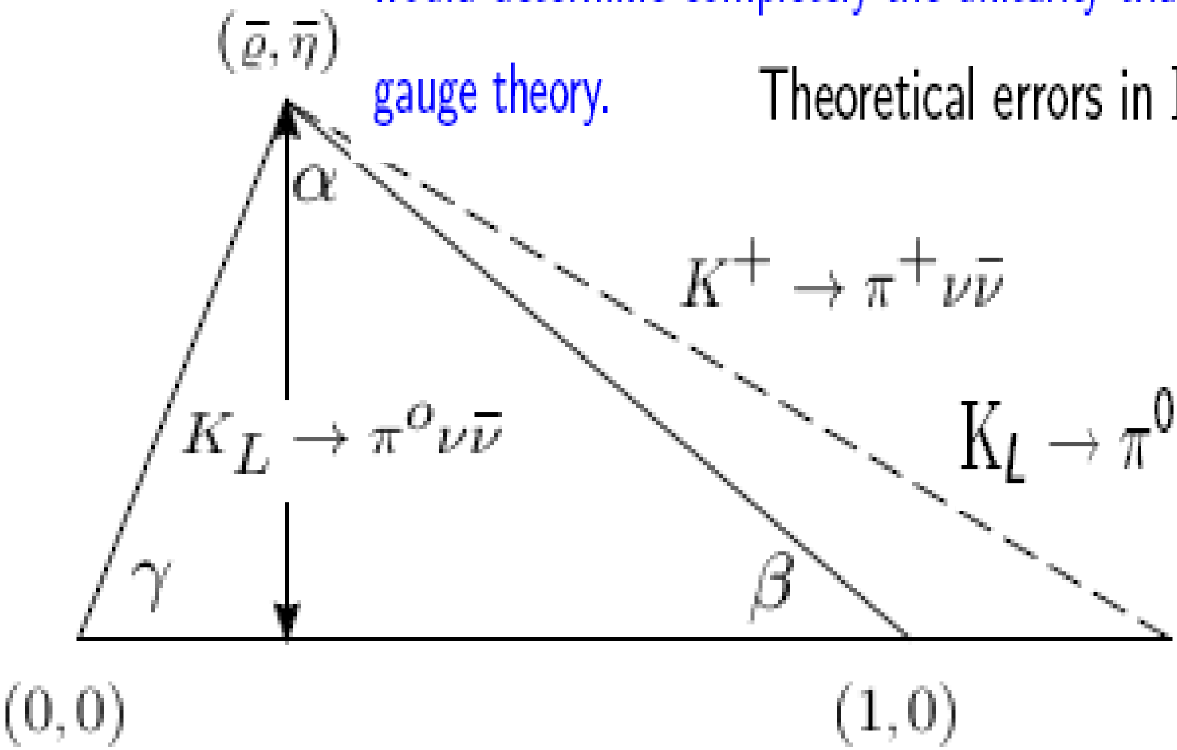


$\bar{\eta}$
$\bar{\rho}$
UTfit
γ
β
Δm_d
$\frac{\Delta m_d}{\Delta m_s}$
ε_K
$\left|\frac{V_{ub}}{V_{cb}}\right|$
$\sin(2\beta+\gamma)$
α
1
0.5
0
-0.5
-1
-1
-0.5
0
0.5
1

UNITARITY TRIANGLE AND RARE KAON DECAYS

A combination of $K^+ \to \pi^+ \nu\bar{\nu}$ and the $\sin(2\beta)$ measurement in $B^0 \to \Psi K_S$ would determine completely the unitarity triangle without any recourse to lattice gauge theory.

Theoretical errors in $K^+ \to \pi^+ \nu\bar{\nu}$ are $\sim 5 \div 7\%$



$K_L \to \pi^0 \nu\bar{\nu}$ } **Theoretically even cleaner → direct determination of the area of the trinagle**

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"**

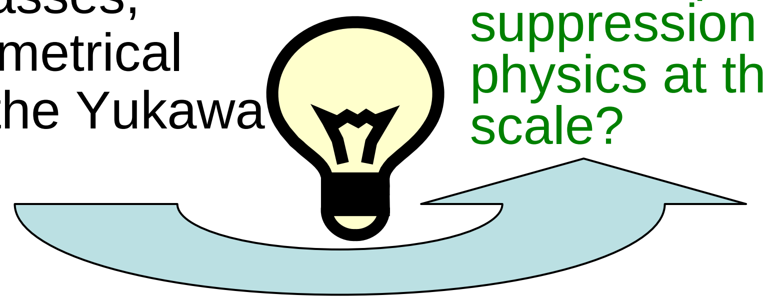
(new flavour – horizontal symmetry, radiatively induced lighter fermion masses, dynamical or geometrical determination of the Yukawa couplings, …?)

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?



PROBING NEW PHYSICS THROUGH FLAVOR CHANGING NEUTRAL CURRENTS (FCNC) , i.e. HOW TO SEE "REALITY" THROUGH ITS "VIRTUAL"EFFECTS

- Examples: the CHARM and TOP quarks were first "seen" not by producing and observing them as "real" or physical particles, but, rather, via their effects in FCNC processes in K and B physics, respectively (for instance, the large mass difference in the $B - \bar{B}$ mass difference was the first clear indication of the heaviness of the top quark)

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 $\longrightarrow$ verification of the SM, theoretically and experimentally "high precision" FCNC tests, ex. b $\rightarrow$ s + γ, 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

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 →

MINIMAL FLAVOR VIOLATION

MFV : Flavor originates only from the SM Yukawa coupl.

New Physics introduces

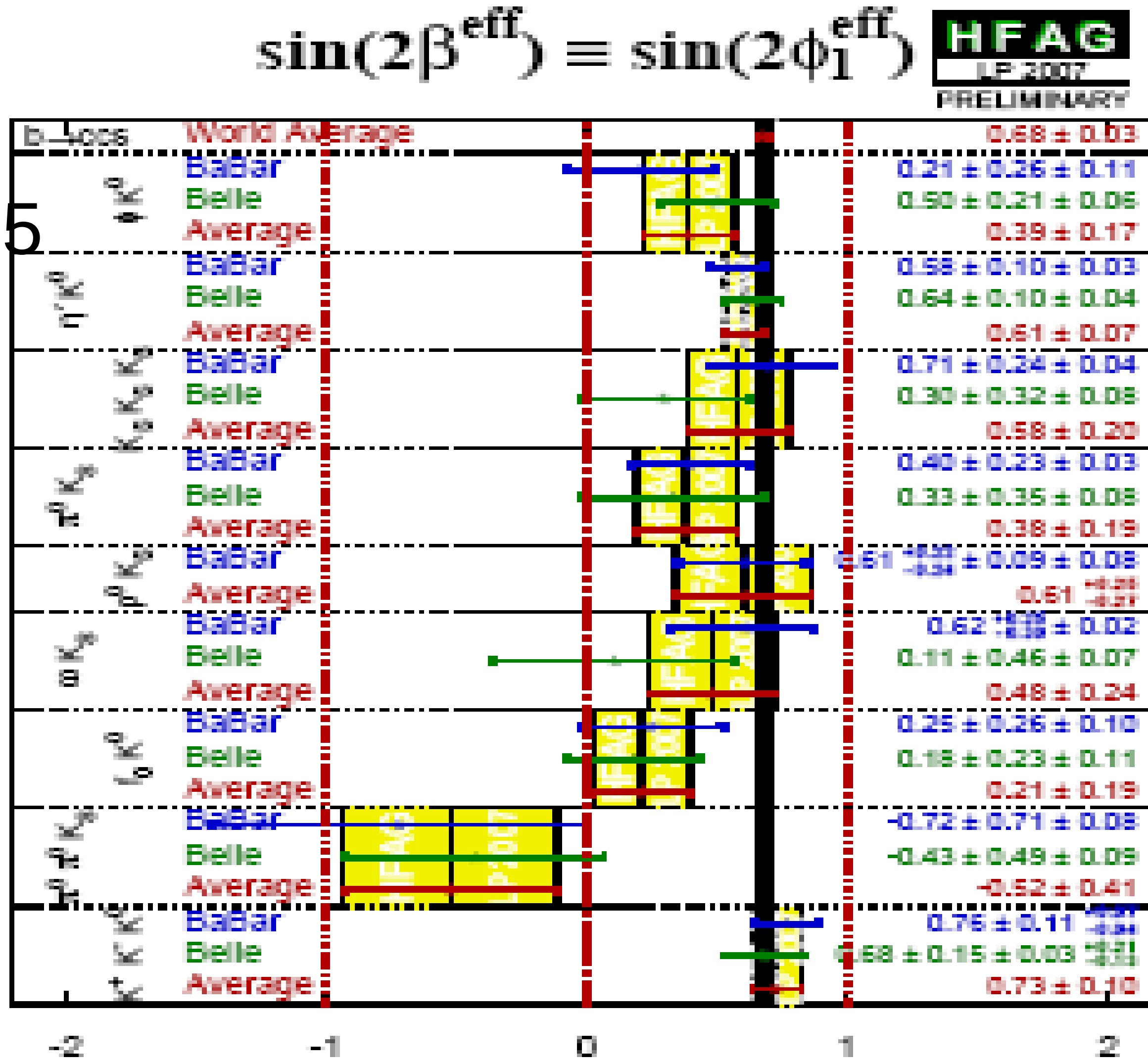
NEW FLAVOR SOURCES in addition to the CKM pattern. They give rise to contributions which are <20% in the “flavor observables” which have already been observed!

Δ S Problem

$S_{ccs} = 0.681 \pm 0.0225$

$S_{sqq} = 0.56 \pm 0.05$

naïve mean, what is important is the persistence of the result over the years + theory predicting the opposite trend

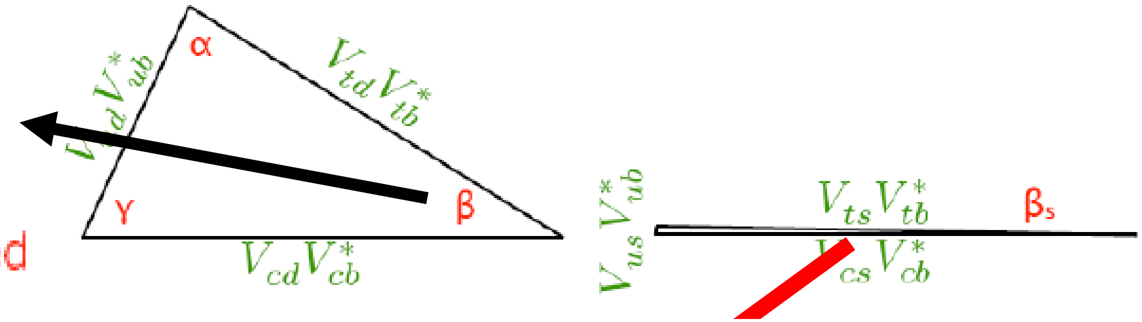


HINTS FOR NEW PHYSICS IN CP VIOLATION IN b → s

No evidence for NP

but still sizable NP

contributions allowed



- HFAG combination: 2.2σ

D0$(2.8 fb^{-1})$ CDF$(1.35 fb^{-1})$

2D hypothesis, no constraints

$0.24 \prec \beta_s \prec 0.57$ or

$0.99 \prec \beta_s \prec 1.33$ at 68% CL

- CDF update

$(1.35 fb^{-1} \rightarrow 2.8 fb^{-1})$:

significance at CDF increases

$1.5\sigma \rightarrow 1.8\sigma$

FIRST EVIDENCE OF NEW PHYSICS IN b ↔ s TRANSITIONS

(UT*fit* Collaboration)

$$2\beta_s^{SM} = -arg\left((V_{ts}V_{tb}^*)^2 / (V_{cs}V_{cb}^*)^2\right) = 0.0183 \pm 0.0009$$

CKMfitter,2008

K π Puzzle: hint for NP?

$$A_{CP}(\bar{B}^0 \to K^-\pi^+) \equiv \frac{N(\bar{B}^0 \to K^-\pi^+) - N(B^0 - K^+\pi^-)}{N(\bar{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)}$$

$$A_{CP}(B^0 \to K^+\pi^-) = -9.7 \pm 1.2\%,$$

$$A_{CP}(B^+ \to K^+\pi^0) = +5.0 \pm 2.5\%,$$

$$(\Delta A_{CP})_{\text{exp}} = (14.7 \pm 2.8)\% \qquad (\Delta A_{CP})_{\text{th}} = (2.1 \pm 1.6)\%$$

NON-VANISHING DIFFERENCE AT MORE THAN 5 σ

Is there a hope to see NP with MFV in H.I. Physics?

- In **FCNC** experiments the best (maybe, actually the only) chance is:

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

SM:	$Br(B_s \to \mu^+\mu^-)_{SM} = (3.37 \pm 0.31) \cdot 10^{-9}$	$< 6 \cdot 10^{-8}$
	$Br(B_d \to \mu^+\mu^-)_{SM} = (1.02 \pm 0.09) \cdot 10^{-10}$	$< 2 \cdot 10^{-8}$

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)

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

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!
- If BaBar's prelim. results are used instead, Δa_μ drops to ~1.7σ.

Courtesy of M. Passera

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

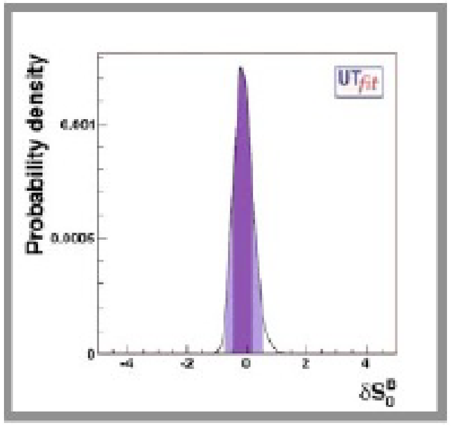
$$S_0(x_t) \rightarrow S_0(x_t) + \delta S_0(x_t)$$

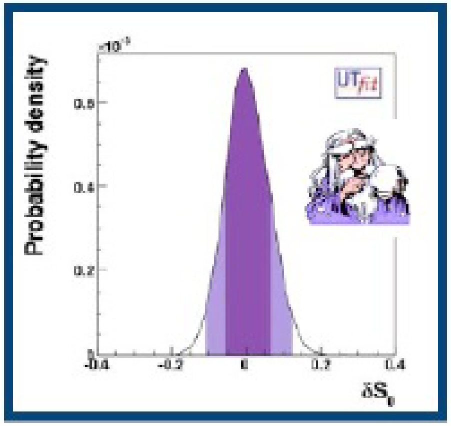
$$\delta S_0(x_t) = 4a\left(\frac{\Lambda_0}{\Lambda}\right)^2$$

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

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

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





$\delta S_0 = -0.16 \pm 0.32$

Λ > 5.5 TeV @95%

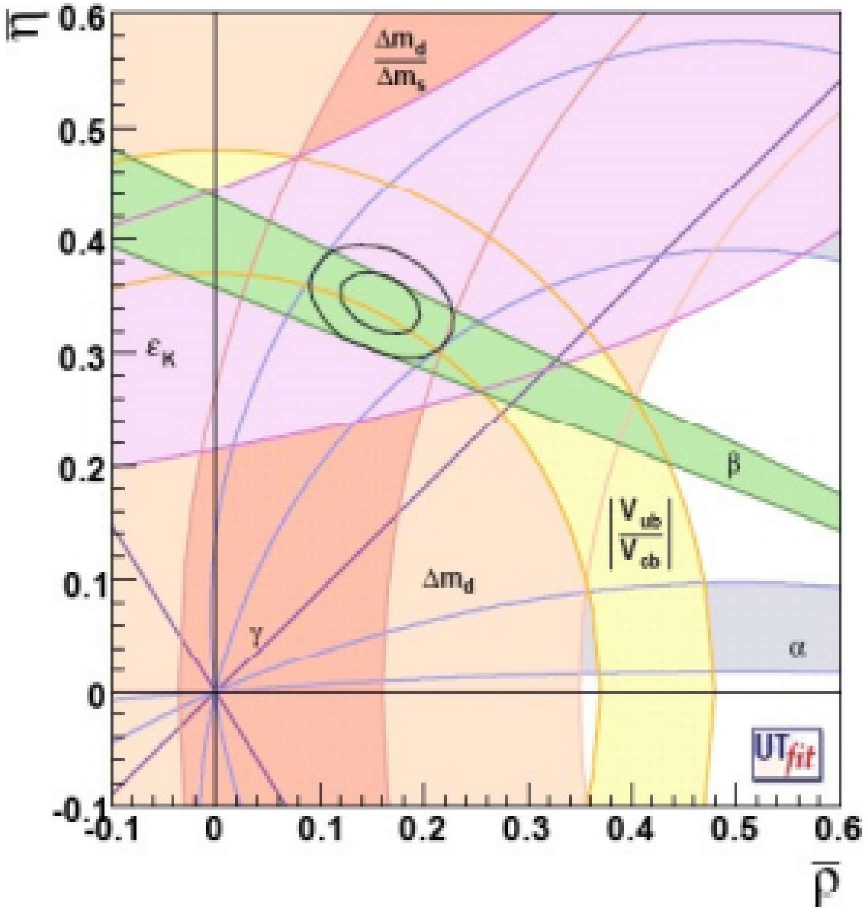
$\delta S_0 = 0.004 \pm 0.059$

Λ > 28 TeV @95%

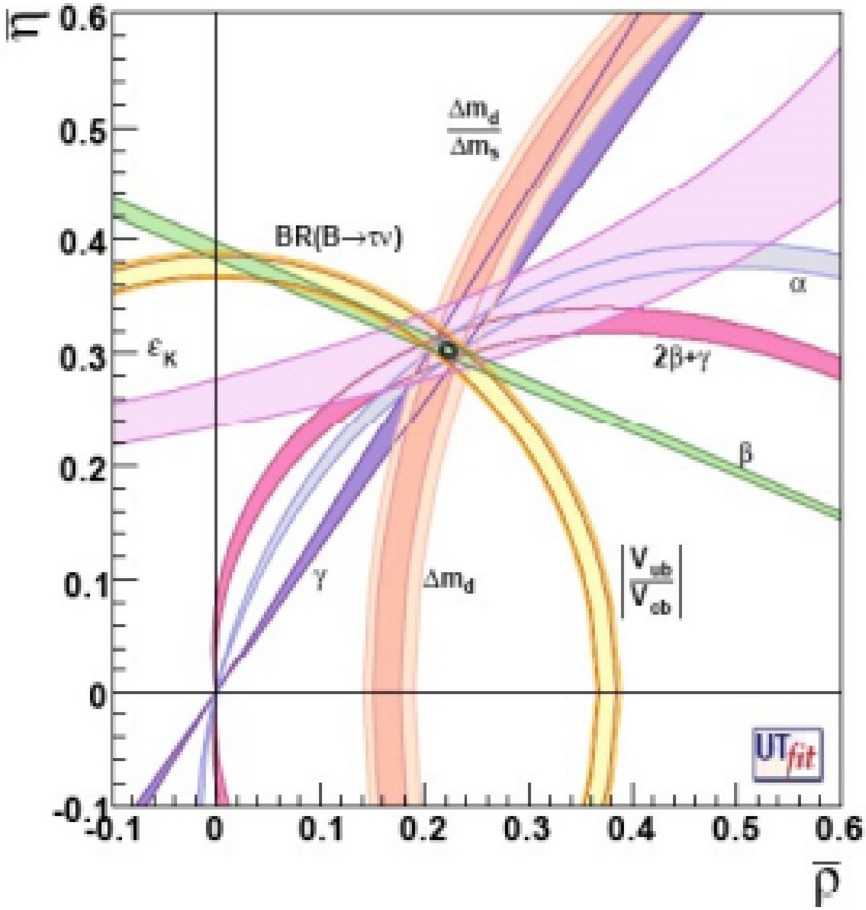
The "worst" case: we still probe virtual particles with masses up to ~12 M_W ~1 TeV

Unitarity Triangle

2008



2015



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

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

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

Ciuchini, Isidori, Silvestrini

SUSY SEE-SAW

- **UV COMPLETION OF THE SM TO STABILIZE THE ELW. SCALE:**

LOW-ENERGY SUSY

- **COMPLETION OF THE SM FERMIONIC SPECTRUM TO ALLOW FOR NEUTRINO MASSES**: NATURALLY SMALL PHYSICAL NEUTRINO MASSES WITH RIGHT-HANDED NEUTRINO WITH A LARGE MAJORANA MASS

SEE-SAW

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**)

LFV IN CHARGED LEPTONS FCNC

L_i - L_j transitions through W - neutrinos mediation

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

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

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

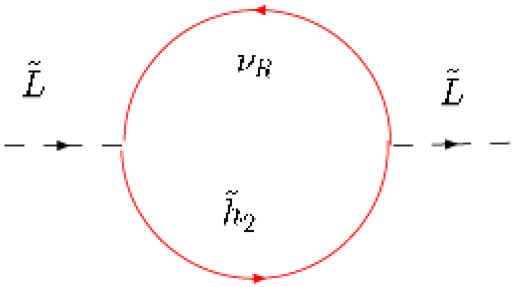
BUT in CMSSM (MSSM with flavor universality in the SUSY breaking sector) $\Delta M_{sleptons}$ is $O(m_{leptons})$, hence GIM suppression is still too strong.

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)

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



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

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

How Large LFV in SUSY SEESAW?

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

In **MSSM seesaw** or in **SUSY SU(5)** (Moroi): not possible to correlate the neutrino Yukawa couplings to know Yukawas;

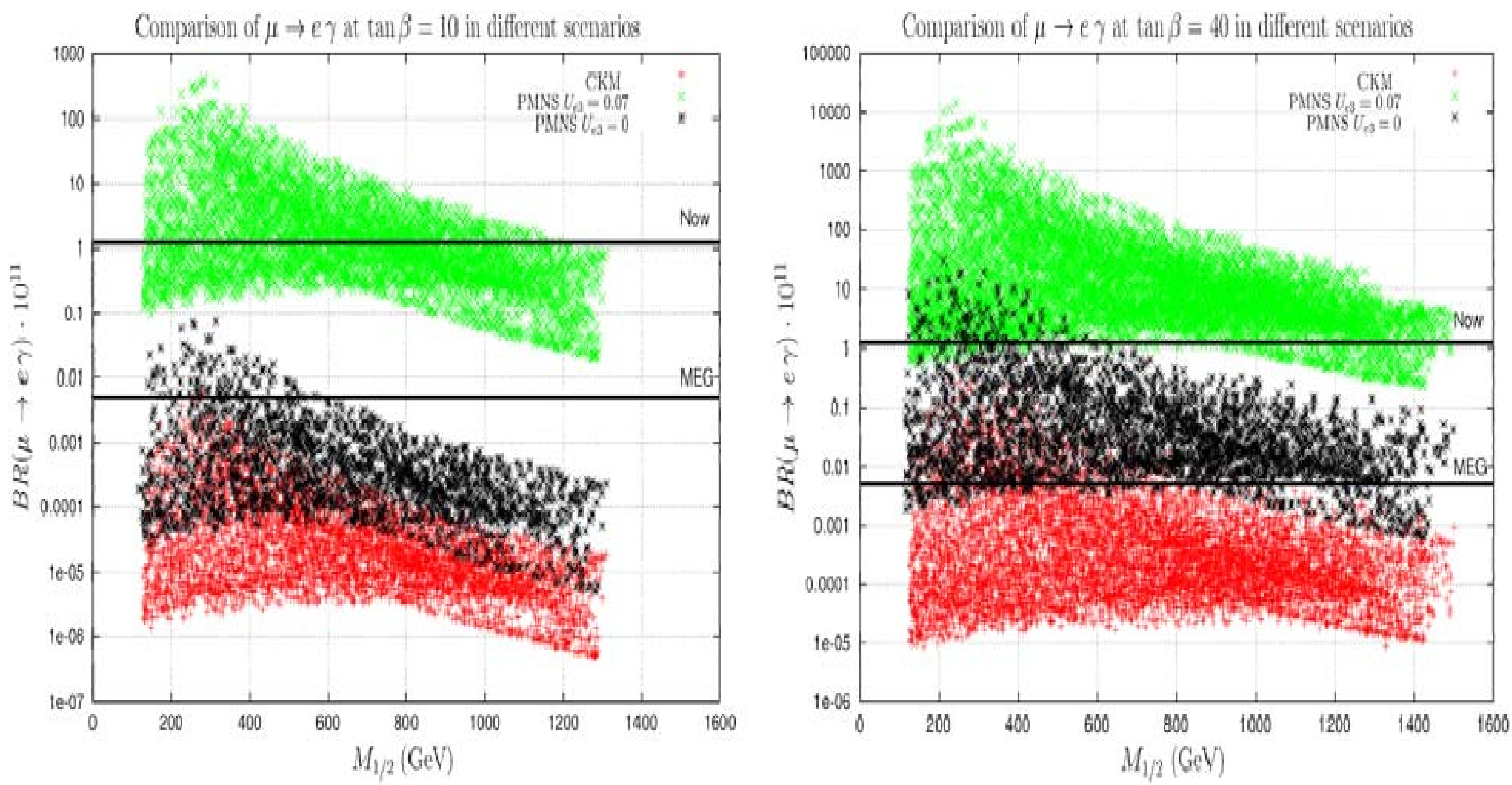
In **SUSY SO(10)** (A.M., Vempati, Vives) at least one neutrino Dirac Yukawa coupling has to be of the **order of the top Yukawa coupling** → one large of O(1) f_ν

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

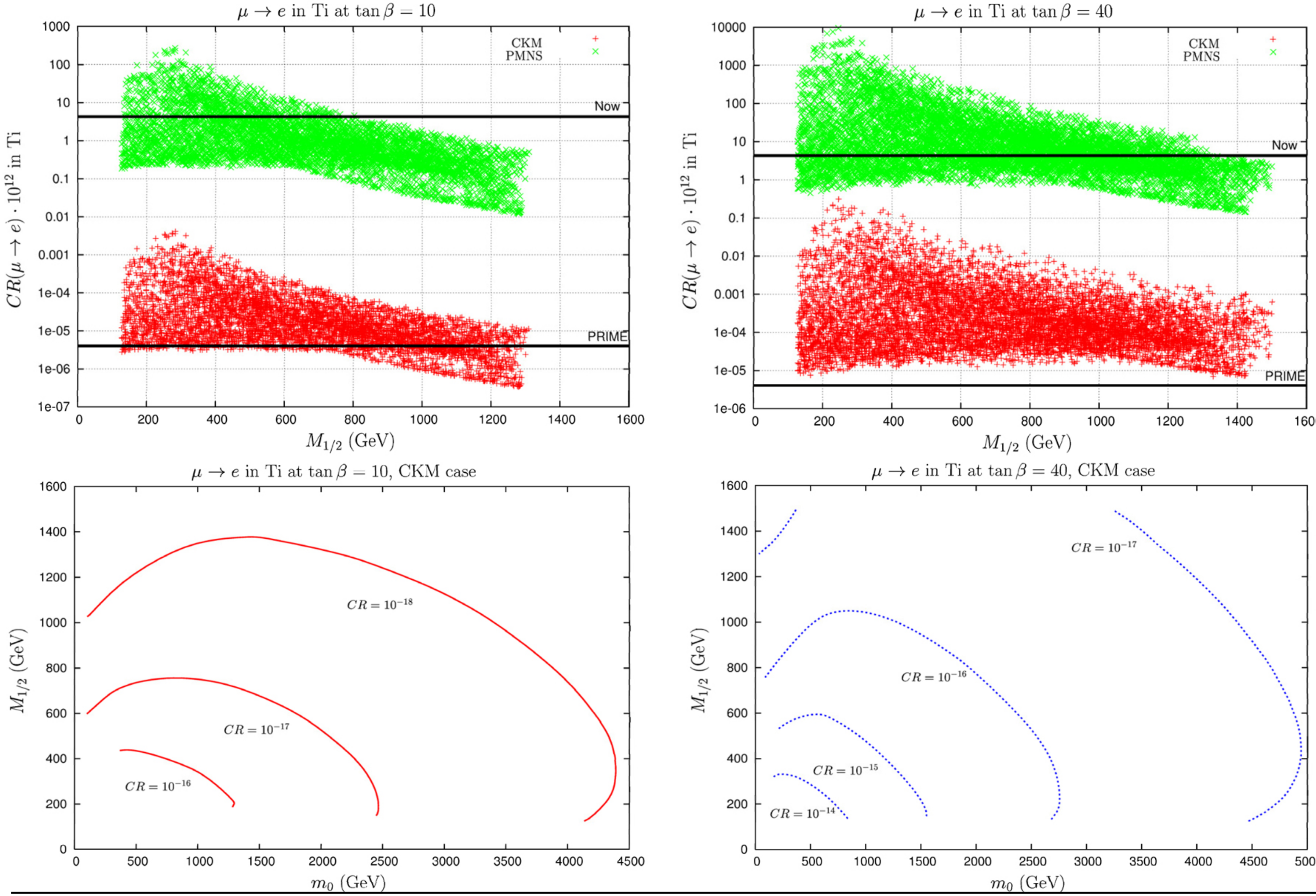
μ → e+γ in SUSYGUT: past and future

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



Calibbi, Faccia, A.M., Vempati

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



LFV vs. MUON (g – 2) in MSSM

Isidori, Mescia, Paradisi, Temes

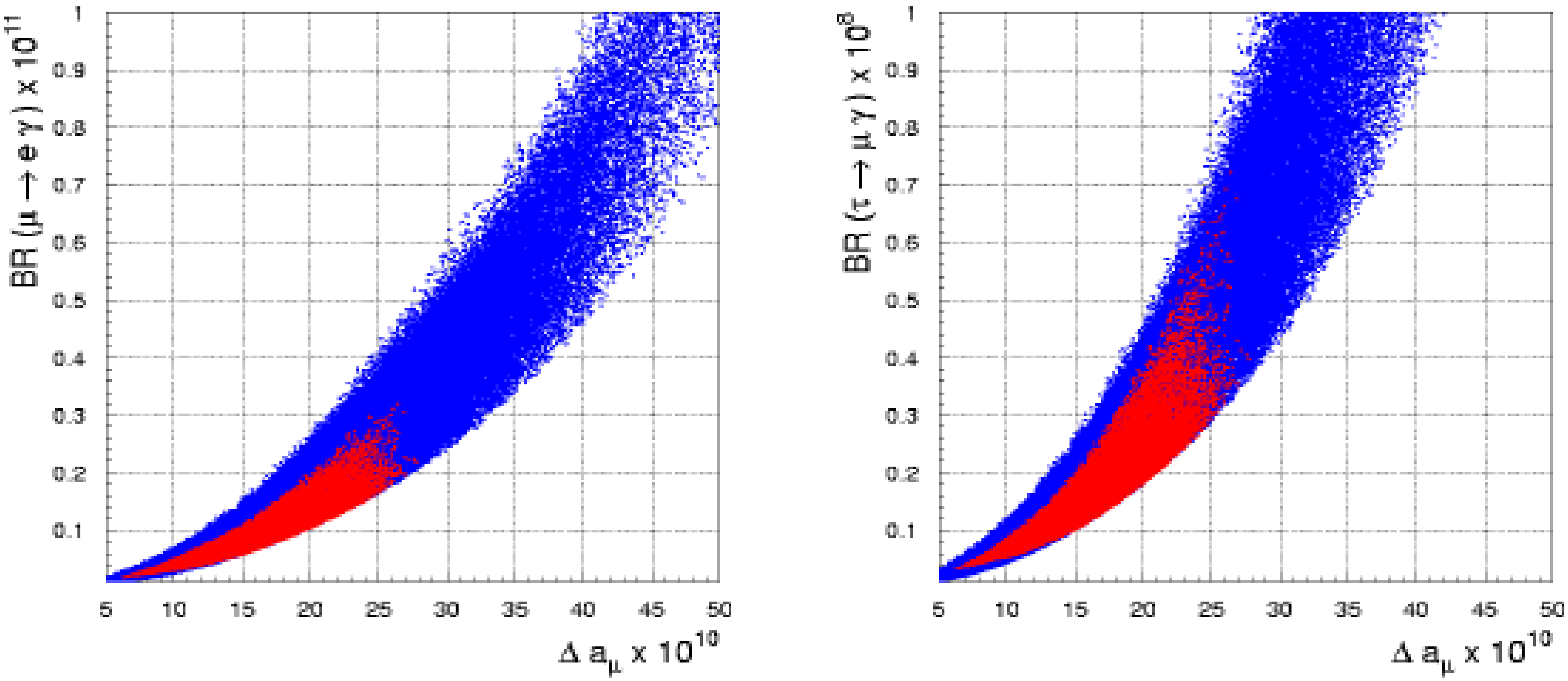


Figure 6: Expectations for $\mathcal{B}(\mu \to e\gamma)$ and $\mathcal{B}(\tau \to \mu\gamma)$ vs. $\Delta a_\mu = (g_\mu - g_\mu^{\rm SM})/2$, assuming $|\delta_{LL}^{12}| = 10^{-4}$ and $|\delta_{LL}^{23}| = 10^{-2}$. The plots have been obtained employing the following ranges: 300 GeV $\leq M_{\tilde\ell} \leq$ 600 GeV, 200 GeV $\leq M_2 \leq$ 1000 GeV, 500 GeV $\leq \mu \leq$ 1000 GeV, $10 \leq \tan\beta \leq 50$, and setting $A_U = -1$ TeV, $M_{\tilde q} = 1.5$ TeV. Moreover, the GUT relations $M_2 \approx 2M_1$ and $M_3 \approx 6M_1$ are assumed. The red areas correspond to points within the funnel region which satisfy the B-physics constraints listed in Section 3.2 [$\mathcal{B}(B_s \to \mu^+\mu^-) < 8 \times 10^{-8}$, $1.01 < R_{Bs\gamma} < 1.24$, $0.8 < R_{B\tau\nu} < 0.9$,

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:

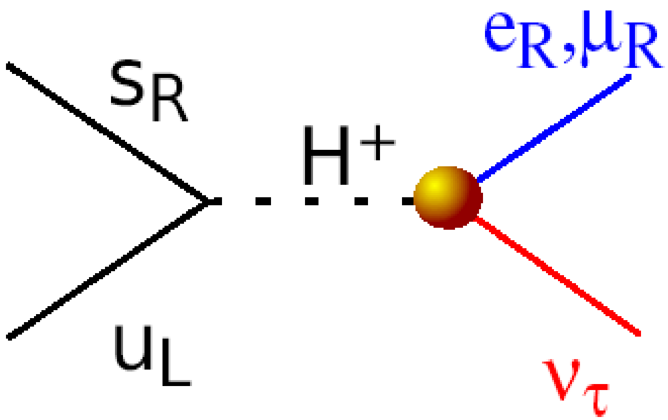
$$-0.063 \leq \Delta r_{K\,NP}^{e-\mu} \leq 0.017 \quad \mathrm{NA48/2}$$

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

Prospects: error on R_K down to the 1% level by KLOE and 0.3% in the 2007 dedicated run of the CERN-P326 Coll. (successor of NA48)

H mediated LFV SUSY contributions to R_K

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



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

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

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

$$\Downarrow$$

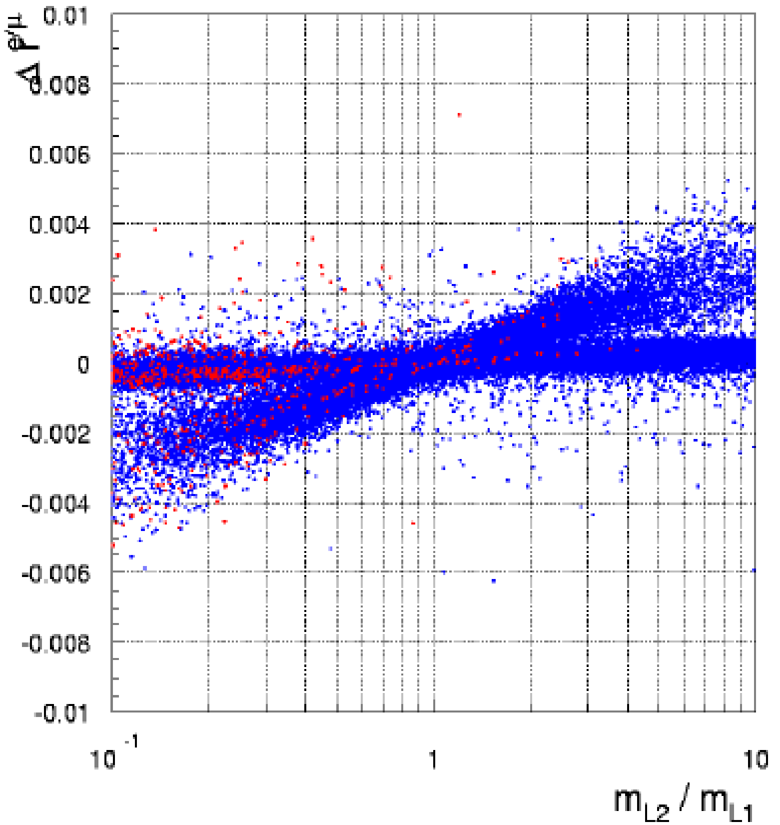
$$\Delta r_{K\ SUSY}^{e-\mu} \simeq \left(\frac{m_K^4}{M_{H^\pm}^4}\right) \left(\frac{m_\tau^2}{m_e^2}\right) |\Delta_R^{31}|^2 \tan^6\beta \approx 10^{-2}$$

Extension to B $\longrightarrow$ lν deviation from universality
Isidori, Paradisi

LFU breaking occurs in a **LF conserving** case because of the splitting in slepton masses

A.M., PARADISI. PETRONZIO

LFU breaking occurs with LFV



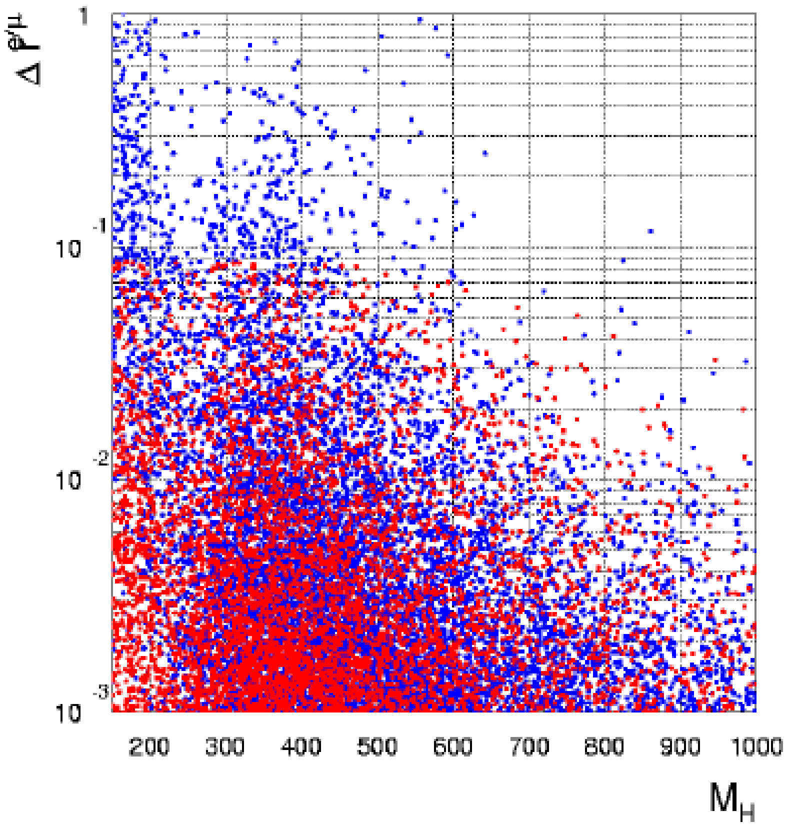


Figure 2: Left:$\Delta r_K^{e/\mu}$ as a function of the mass splitting between the second and the first (left-handed) slepton generations. Red dots can saturate the $(g-2)_\mu$ discrepancy at the 95% C.L., i.e. $1 \times 10^{-9} < (g-2)_\mu < 5 \times 10^{-9}$. Right: $\Delta r_K^{e/\mu}$ as a function of M_{H+}.

SUSY GUTs

- UV COMPLETION OF THE SM TO STABILIZE THE ELW. SCALE:

LOW-ENERGY SUSY

TREND OF UNIFICATION OF THE SM GAUGE COUPLINGS AT HIGH SCALE:

GUTs

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

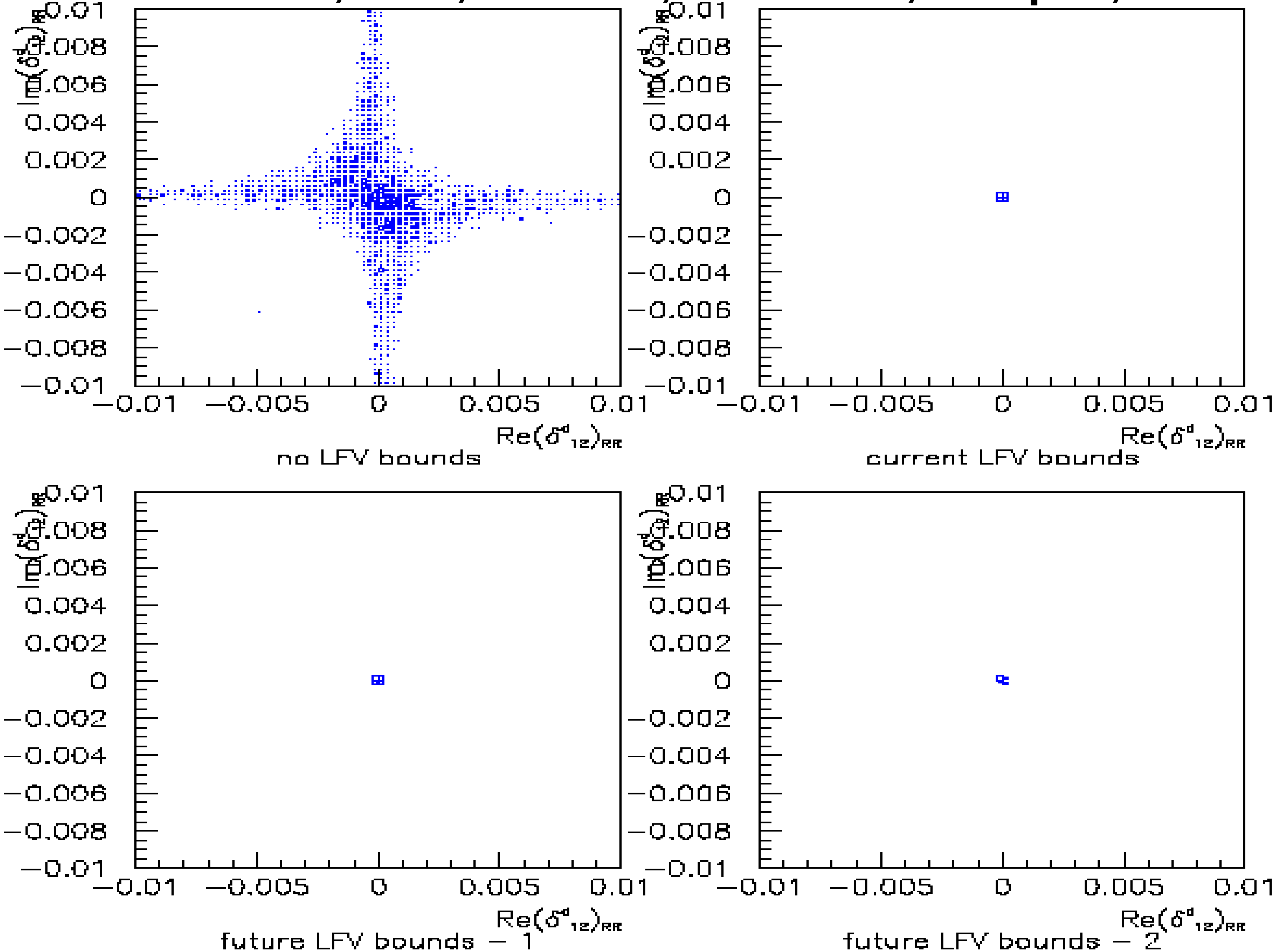
soft **SUSY breaking terms** arise
at a scale > M_{GUT}, they have to **respect the underlying quark-lepton GU symmetry**

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

Bounds on the hadronic $(\delta_{12})_{RR}$ as modified by the inclusion of the LFV correlated bound

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



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

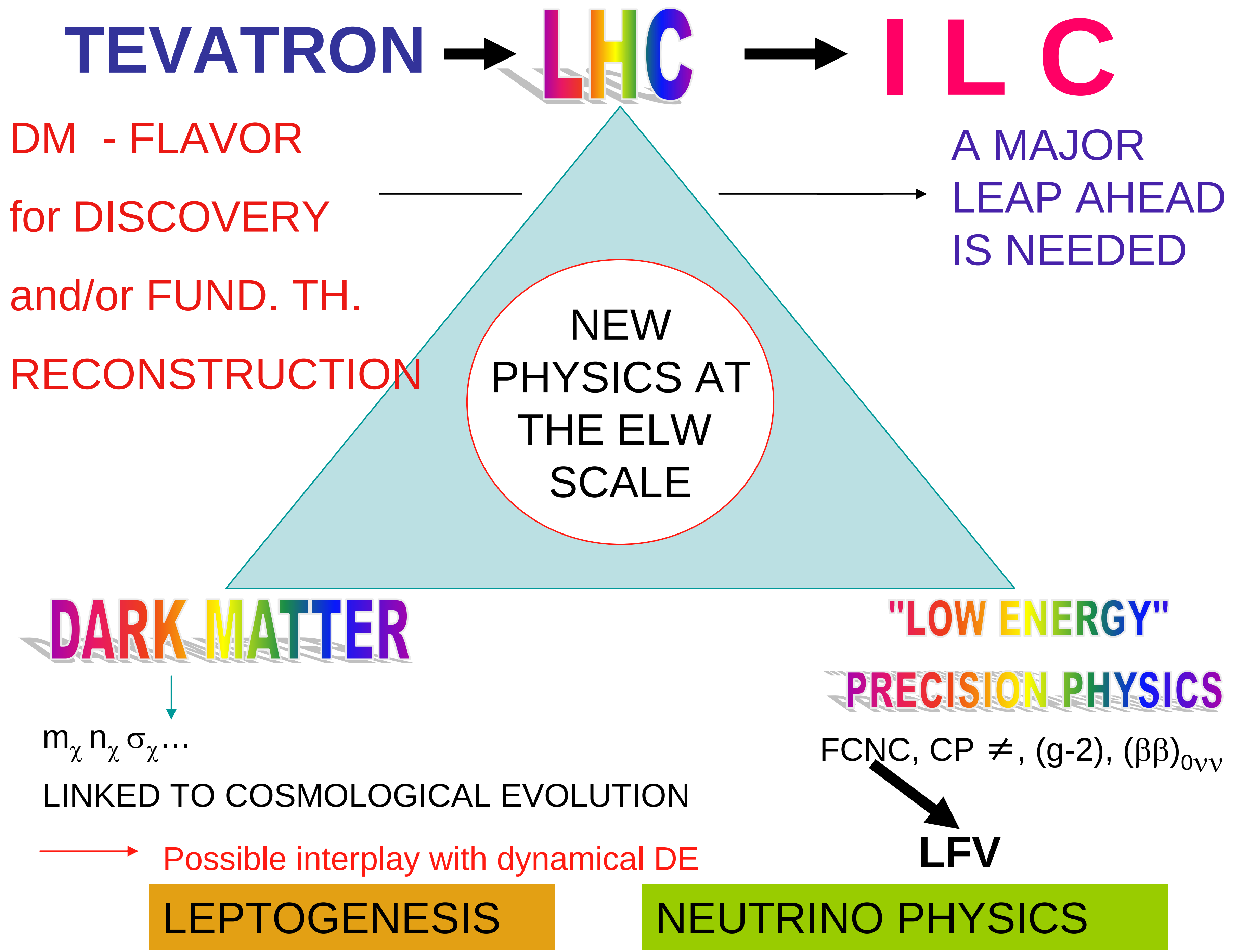
- The traditional **competition** between direct and indirect (FCNC, CPV) searches to establish who is going **to see the new physics first** is no longer the priority, rather

- **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)


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_χ n_χ σ_χ…
LINKED TO COSMOLOGICAL EVOLUTION
Possible interplay with dynamical DE
"LOW ENERGY"
PRECISION PHYSICS
FCNC, CP $\neq$, (g-2), $(\beta\beta)_{0\nu\nu}$
LFV
LEPTOGENESIS
NEUTRINO PHYSICS