MARCH 2007

XLII ND RENCONTRES DE MORIOND - ELW. SESSION THEORY SUMMARY

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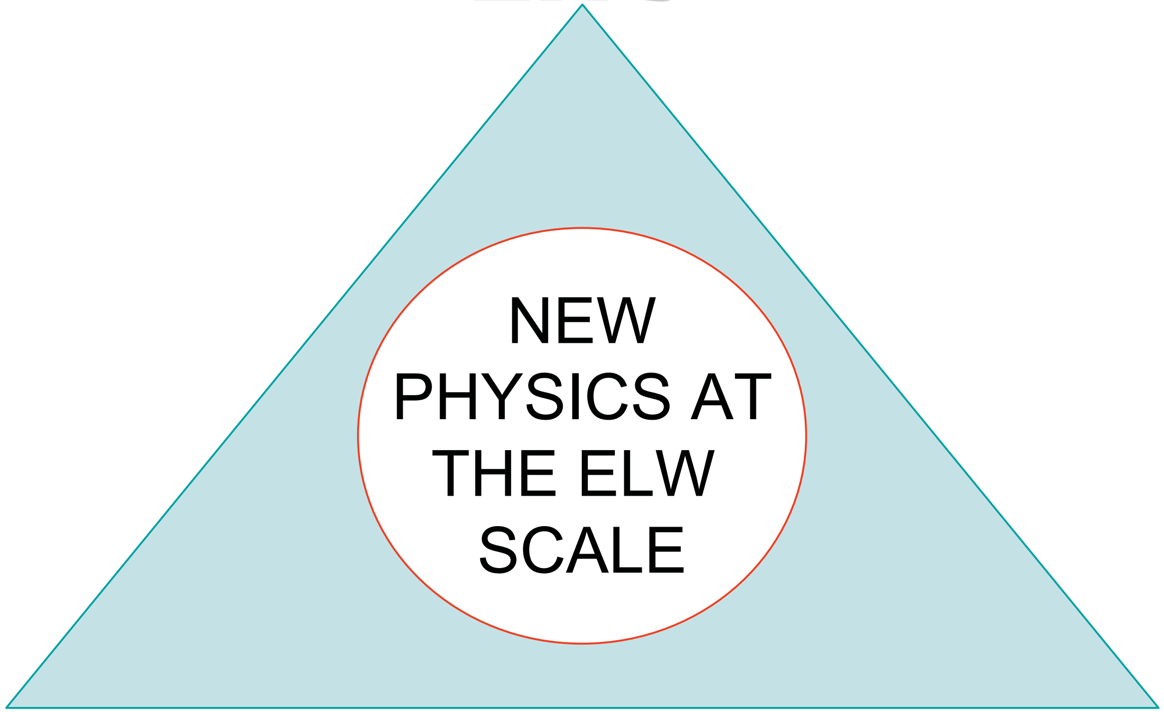
UNIV. OF PADOVA

AND

INFN, PADOVA

TEVATRON -- LHC



DARK MATTER

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

LINKED TO COSMOLOGICAL EVOLUTION

→ Possible interplay with dynamical DE

"LOW ENERGY"

PRECISION PHYSICS

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

WHY TO GO BEYOND THE SM

"OBSERVATIONAL" REASONS

- HIGH ENERGY PHYSICS

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

- FCNC, CP≠

NO (but $b \to s\bar{q}q$ 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

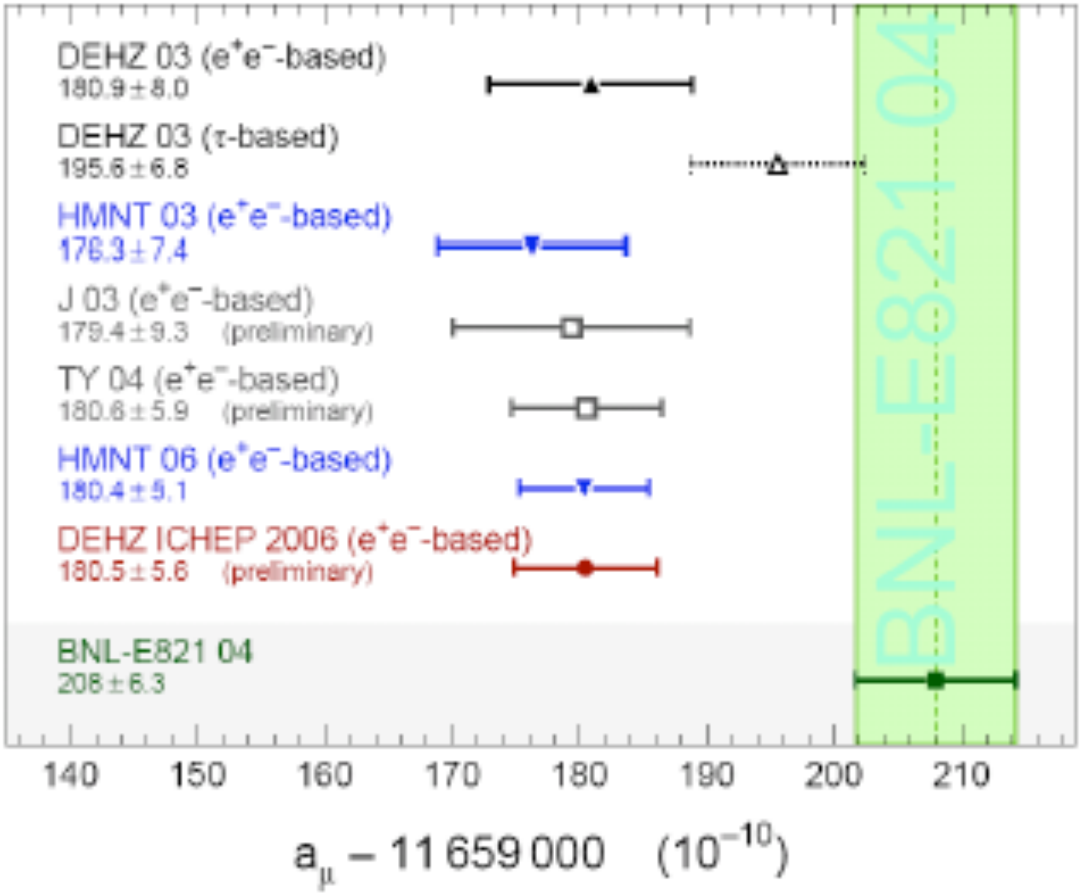
NO (spont. broken gauge theory without anomalies)

- 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

ZHIQUING ZHANG



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

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 (?)

SEARCHING FOR AN ULTRAVIOLET COMPLETION OF THE SM AT THE ELW. SCALE

The SM, as we know it today, is not a complete theory:

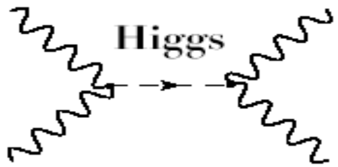
$$\propto \frac{E^4}{m_W^4}$$

First priority at the LHC:

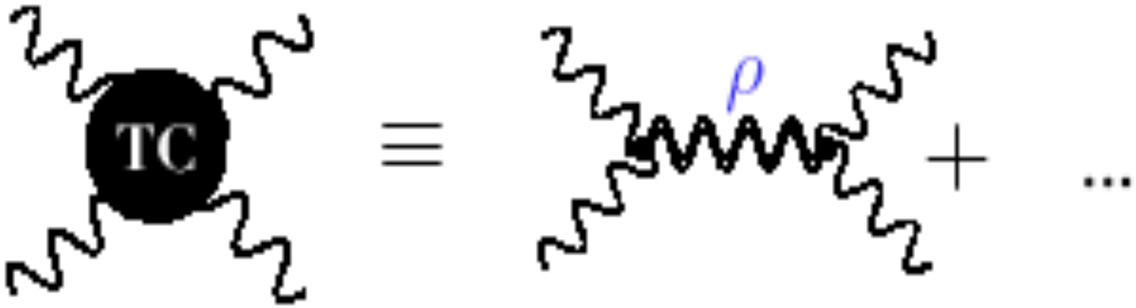
What unitarize it ?

As in $\pi\pi \longrightarrow \pi\pi$, a strong sector

Technicolor: repetition of QCD at $m_\rho \sim 1\ TeV$



Supersymmetry needed for naturalness (hierarchy problem)



NEW SUSY PARTICLES AT THE ELW. SCALE

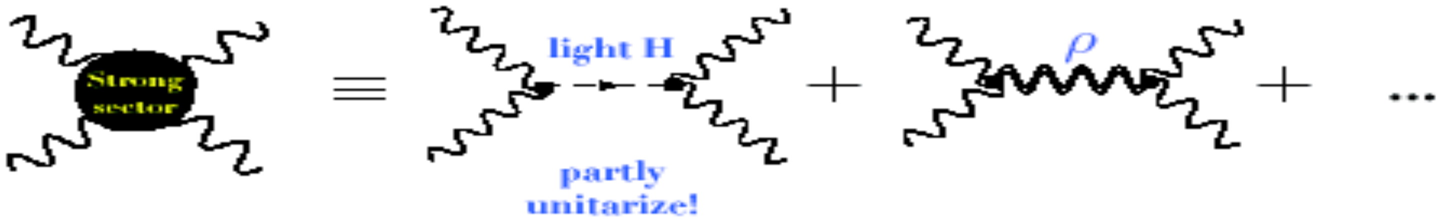
A 3rd way is possible: explored in the recent years

There is a Higgs but it is not elementary: it is composite particle

Georgi,Kaplan 80s

no naturalness problem

WW unitarity:



H **is "almost" a Higgs (its couplings deviate from a point-like scalar)**

Giudice, Grojean, ALEX POMAROL,Rattazzi

What we gain?

heavy states ρ are needed to unitarize WW at an energy slightly higher that 1 TeV so they can have bigger masses and give smaller effects on the self-energies of the SM gauge bosons

Why the Higgs mass will be smaller than m_ρ ?

Higgs can appear as a Pseudo-Goldstone boson from a "strong" sector

global symmetry breaking: G → H

example: SO(5) → SO(4)

4 Goldstones= a doublet of SU(2) = Higgs

Higgs Mass protected by the global G-symmetry

Alex Pomarol

Generically:

$$\mathcal{L}_{\rm SM}(f, A_\mu) \quad + \quad \mathcal{L}_{\rm BSM}(H, \rho, ...) \quad + \quad \mathcal{L}_{int}$$

symmetries:	SM Group	G → H e.g. SO(5) → SO(4)	G-breaking terms
parameters:	$g_{\rm SM}$	g_ρ	$\frac{g_{\rm SM}}{g_\rho}$

$$g_\rho \gg g_{\rm SM}$$

↓ responsible for V(H/f) and Yukawas

$$\langle H \rangle \equiv v \sim f$$

Physics of two scales: $\begin{cases} f = \text{decay constant} \\ m_\rho = \text{"hadron" mass} \end{cases}$

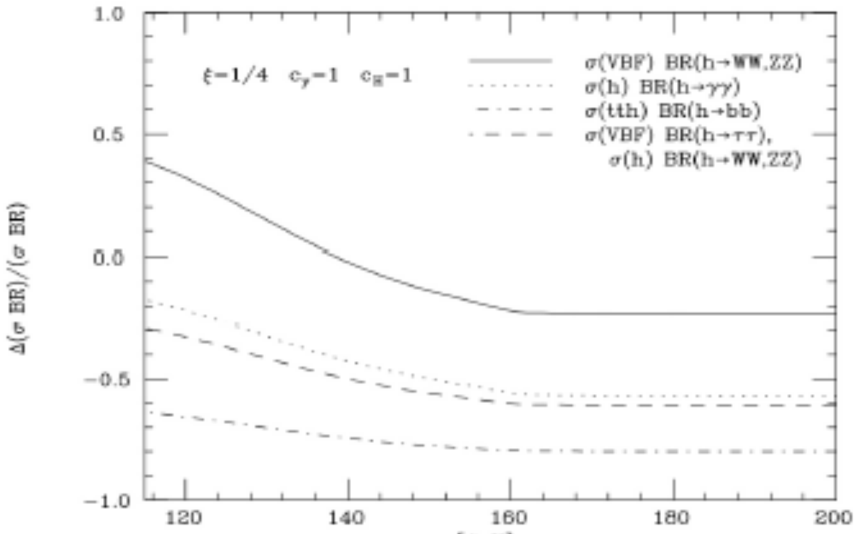
general relation: $m_\rho = g_\rho f$

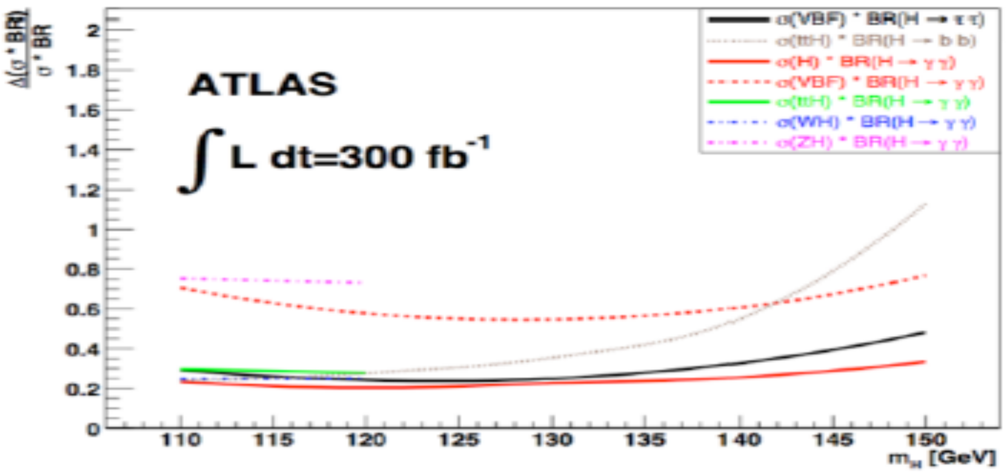
$$\hookrightarrow \quad m_\rho \gg v \quad \hookleftarrow$$

Heavy states ~ 2-4 TeV

Deviations from the SM:

GGPR





Duhrssen 03

...certainly if they are of order 20-40%

ILC would be a perfect machine to test these scenarios:
effects could be measured up to a few %

Jochum's WARNING   J. Van der Bij

…and if at LHC we don't see anything?…

M(inimal) N(on) M(inimal) S(tandard) M(odel)

with: T. Binoth

Stealth model

$$\mathcal{L} = -\partial_\mu \phi^+ \partial_\mu \phi - \lambda(\phi^+\phi - v^2/2)^2$$
$$- \frac{1}{2} \partial_\mu \vec{\varphi}\, \partial_\mu \vec{\varphi} - \frac{1}{2} m^2 \vec{\varphi}^2 - \frac{\kappa}{8N}(\vec{\varphi}^2)^2 - \frac{\omega}{2\sqrt{N}}\vec{\varphi}^2 \phi^+\phi$$

$\vec{\varphi}$ N scalar real fields; singlets under SU(3) × SU(2) × U(1)

O(N)-symmetry, renormalizable, few extra parameters

$\langle\vec{\varphi}\rangle = 0$ $\langle\phi\rangle = v \neq 0$

$\frac{\omega}{\sqrt{N}}$ invisible decay

$$\Gamma_H = \frac{\omega^2}{64\pi^2}\frac{v^2}{m_H}$$

ω can be large

$N \to \infty$ possibility non-perturbative $1/N$-expansion

"MASS PROTECTION"

For FERMIONS, VECTOR (GAUGE) and SCALAR BOSONS

SIMMETRY PROTECTION

- -FERMIONS → chiral symmetry

  $f_L\, f_R$ not invariant under SU(2)x U(1)

- -VECTOR BOSONS → gauge symmetry

→ FERMIONS and W,Z VECTOR BOSONS can get a mass only when the elw. symmetry is broken m_f, $m_w \leq$ <H>

NO SYMMETRY PROTECTION FOR SCALAR MASSES

↓

"INDUCED MASS PROTECTION"

→ Create a symmetry (SUPERSIMMETRY)

Such that FERMIONS ⟷ BONUS

So that the fermion mass "protection" acts also on bosons as long as SUSY is exact

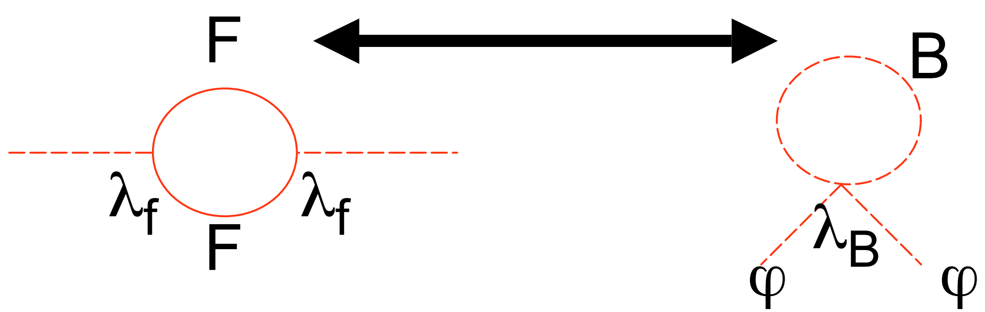
⇨ SUSY BREAKING ~ SCALE OF 0 (10^2-10^3 Gev)

→ LOW ENERGY SUSY

HIERARCHY PROBLEM: THE SUSY WAY

SUSY HAS TO BE BROKEN AT A SCALE CLOSE TO 1TeV ⟶ LOW ENERGY SUSY

$m_\varphi^2 \propto \Lambda^2$ ⟶ Scale of susy breaking



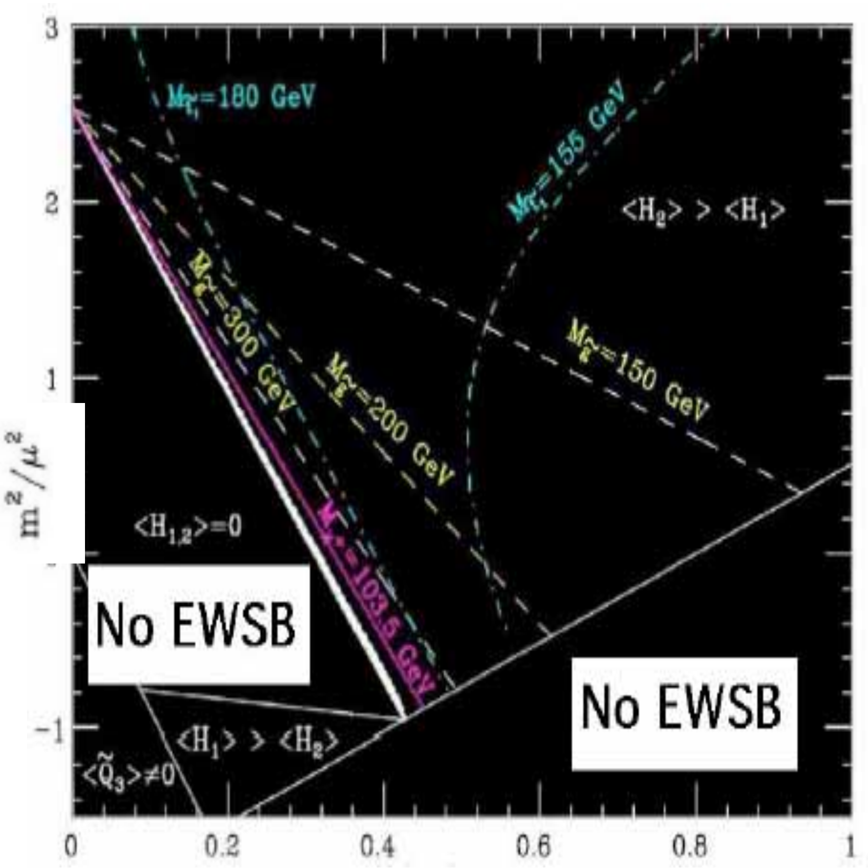
$$Sm^2_\varphi \sim \frac{(\lambda_B - \lambda^2_f)}{16\pi^2} \Lambda^2$$

⟶ $[m^2_B - m^2_F]^{1/2} \sim 1/\sqrt{G_F}$

$\begin{pmatrix} B \\ F \end{pmatrix}$ In SUSY multiplet

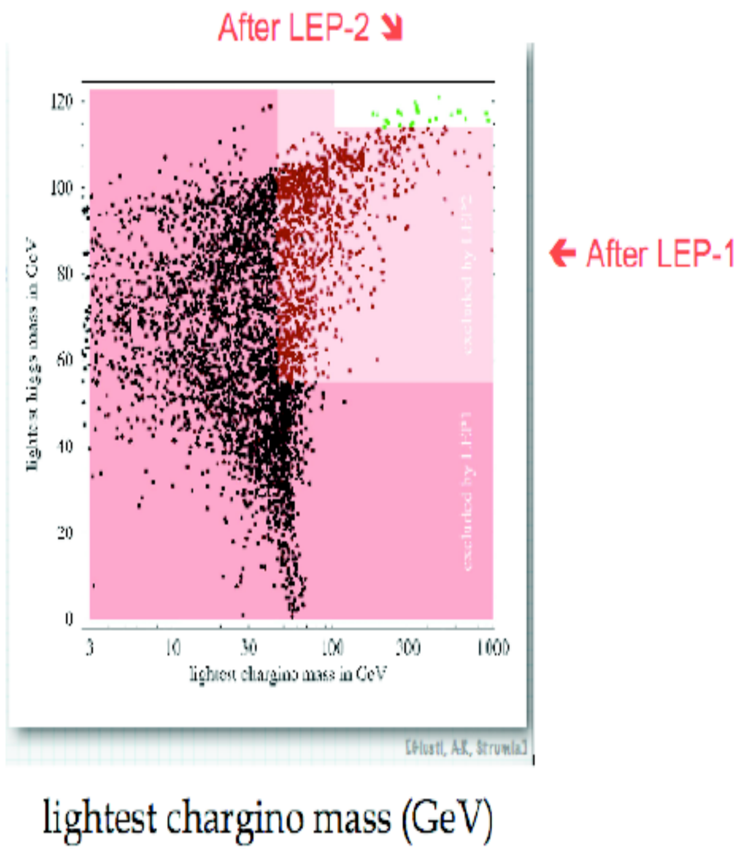
SPLITTING IN MASS BETWEEN B and F of O (ELW. SCALE)

THE LOW-ENERGY SUSY TENSION between the UV COMPLETION SCALE and the POST-LEP SUSY EXCLUSIONS



Giudice, Rattazzi

M^2/μ^2



Zwirner

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

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

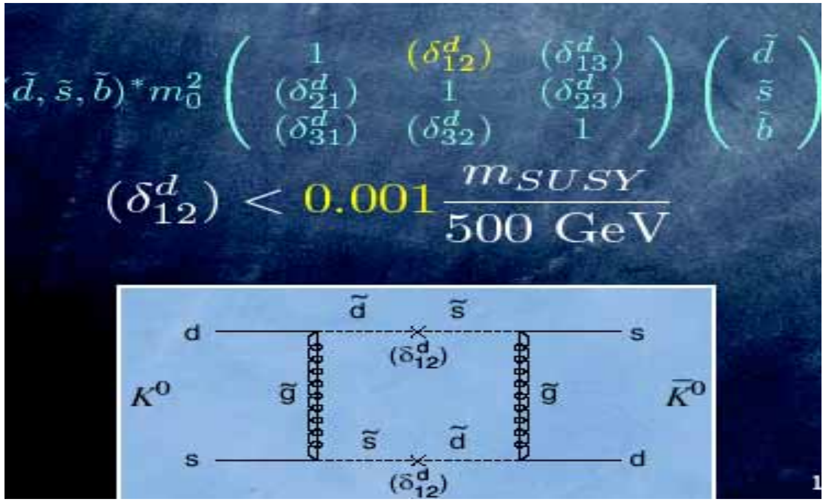
Isidori

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

$\Lambda > 10^4$ 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]

SUSY →



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

WHICH SUSY

HIDDEN SECTOR SUSY BREAKING AT SCALE $\sqrt{F}$

MESSENGERS

$F = M_W M_{Pl}$

GRAVITY

$M_{gravitino} \sim F/M_{Pl} \sim$ $(10^2 - 10^3)$ GeV

$F = (10^5 - 10^6)$ GeV

GAUGE INTERACTIONS

$M_{gravitino} \sim F/M_{Pl} \sim$

$(10^2 - 10^3)$eV

OBSERVABLE SECTOR
SM + superpartners
MSSM : minimal content of superfields

Hitoshi Murayama

Choice

- Accept heavy SUSY > 100 TeV — **Defeatism**
  - the hierarchy problem fine-tuned > 10^6!
- Tune SUSY breaking flavor-blind, CP — **Self-righteous**
  - probability for viable parameter set $10^{-3}{}_{K} \times 10^{-3}{}_{B} \times 10^{-3}{}_{\mu \to e\gamma} \times 10^{-2}{}_{EDM} \times \cdots$?
- Build an elaborate model to get flavor-blind and CP-conserving SUSY breaking — **Intelligent Design**
  - elaborate model = delicate artwork = unlikely choice by Mother Nature (?)

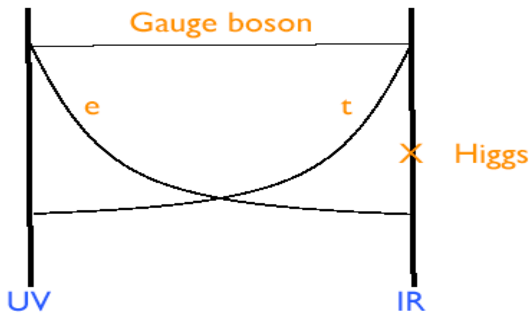
Toni Gheghetta

Warped Extra Dimension ➡ Explain hierarchies

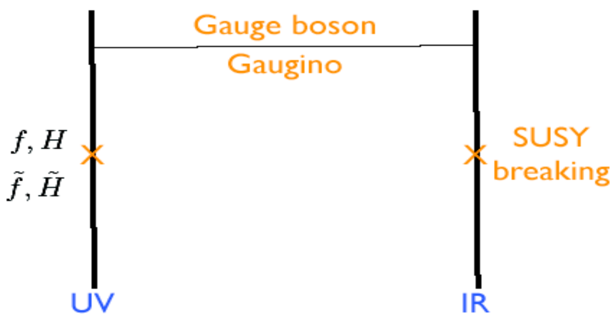
5D metric ➡ IR = UV $e^{-\pi k R}$

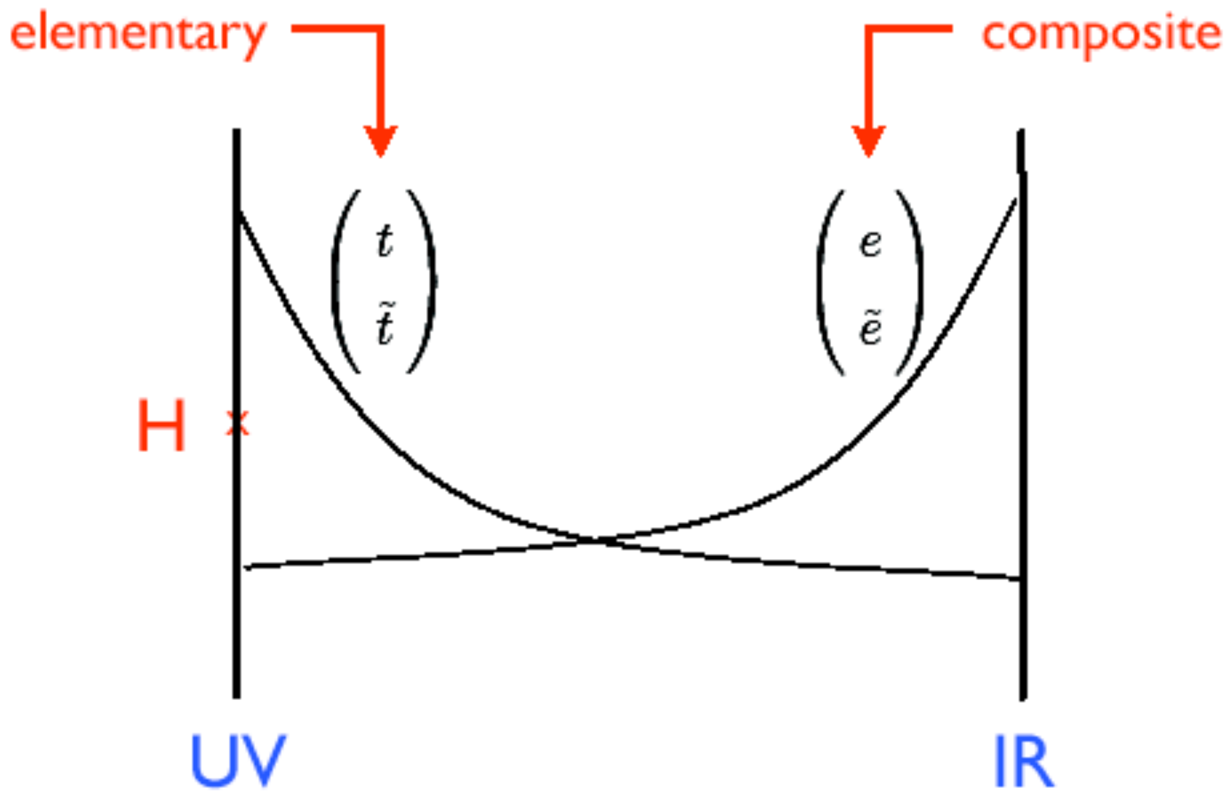
- Gauge hierarchy problem: Higgs mass [Randall, Sundrum 99]

- **Fermion masses:**
  e.g. electron, top
  [TG, Pomarol 00]



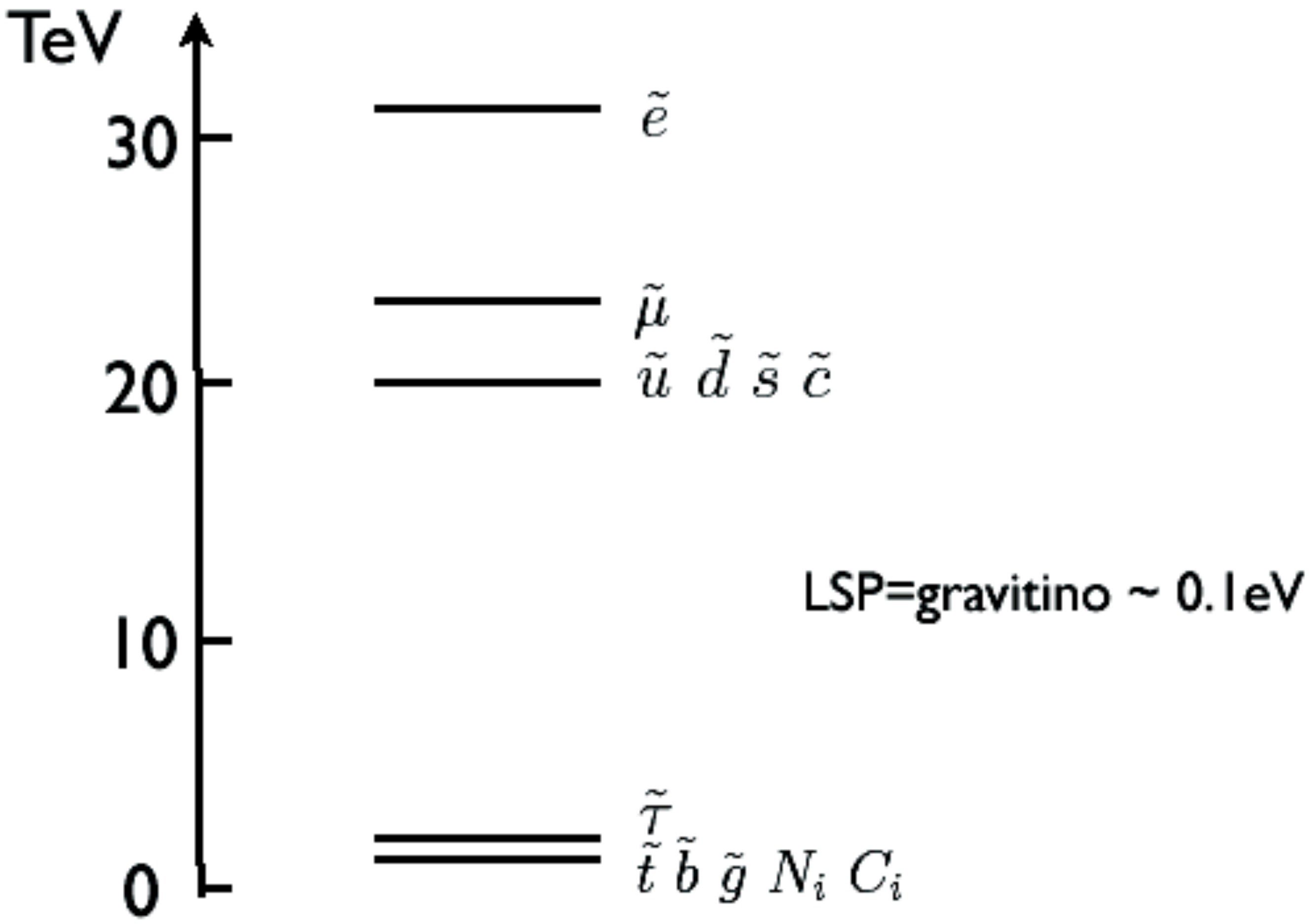
- **SUSY-breaking scale**
  e.g.Warped MSSM
  [TG, Pomarol 00]





Sparticle spectrum determined by fermion mass spectrum!

Mass Spectrum



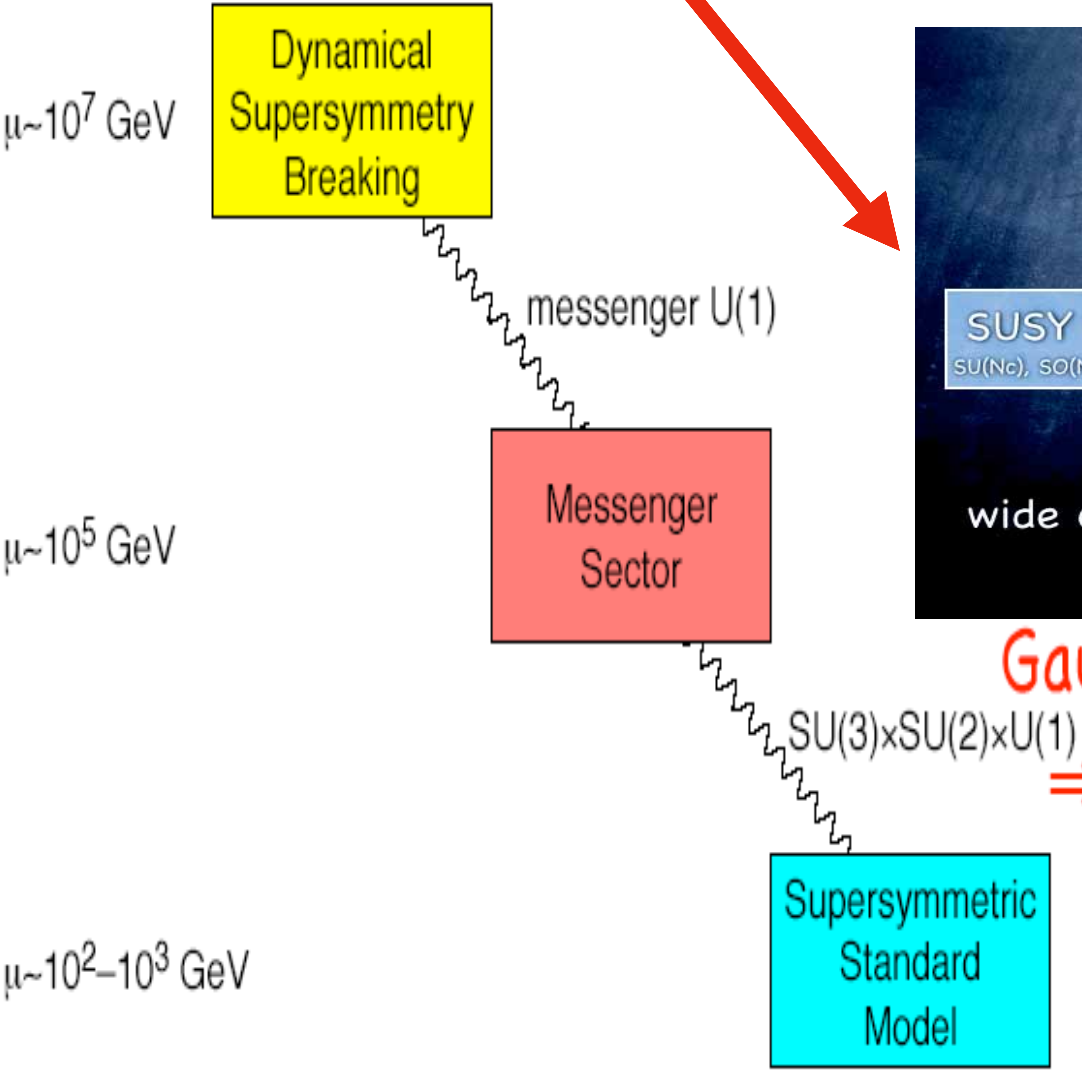
LHC signal : $pp \to 2\gamma + \not{E}_T$

Since $\tilde{m}_{1,2}$ very heavy diphoton rates reduced → At least 10 times more data than conventional gauge mediation needed

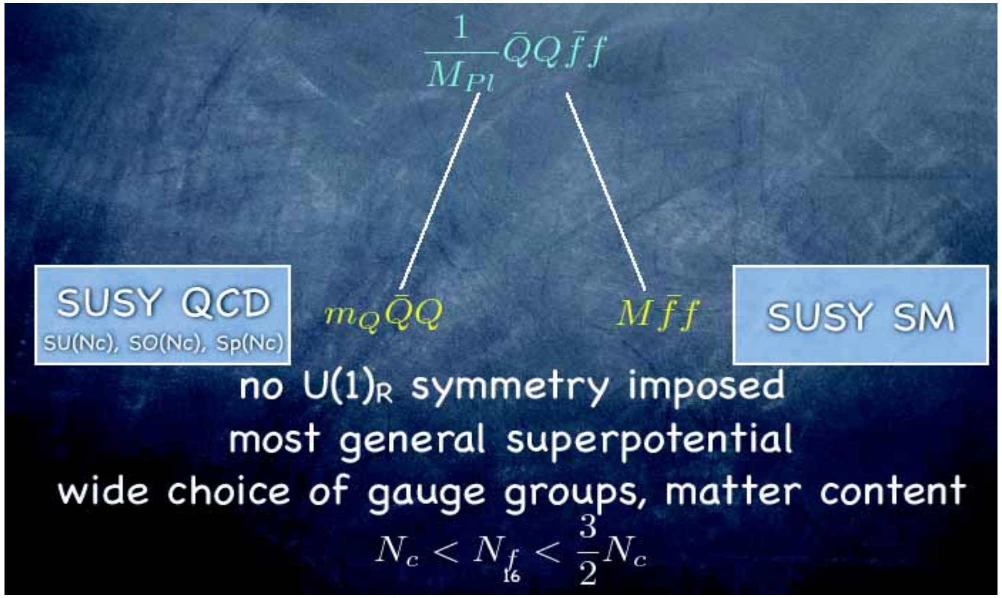
Impose cuts to reduce background:

$$p_{T,\gamma} \geq 40 \text{ GeV}, \quad \not{E}_T \geq 60 \text{ GeV}$$

A NEW MECHANISM FOR SUSY BREAKING IN GAUGE MEDIATED SUSY MODELS



Dine-Nelson-Nir-Shirman



Gauge Mediation
⇒flavor blind

Hitoshi MURAYAMA

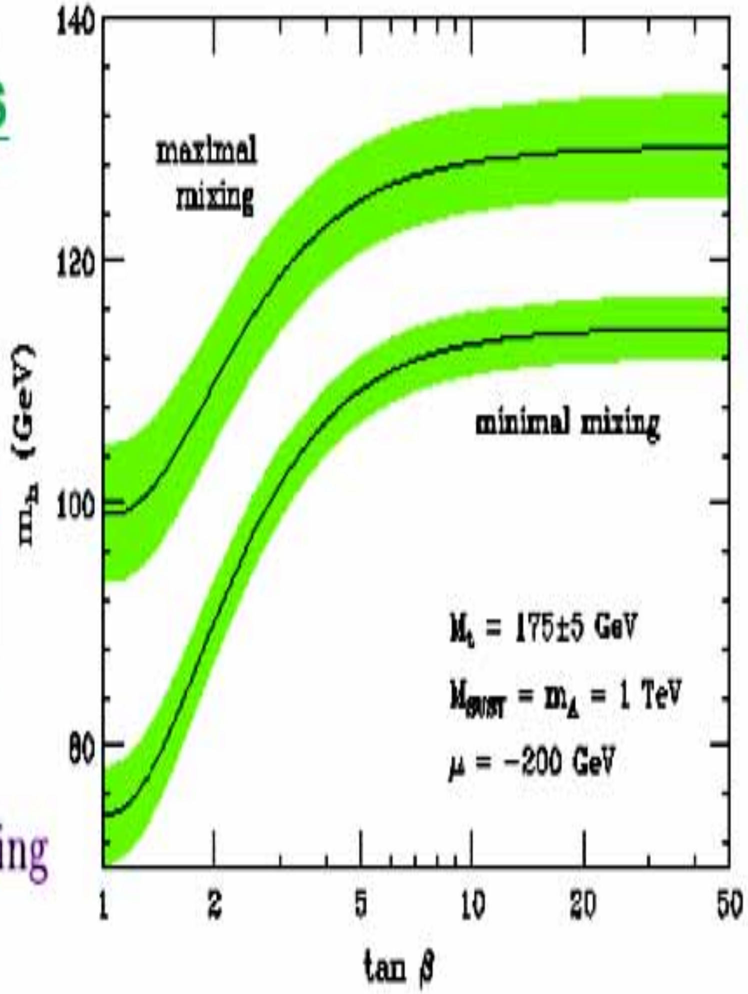
Carena

Radiative Corrections to Higgs Boson Masses

Important effects due to incomplete cancellation of particles and superparticles in the loops

$$m_h^2 = M_Z^2 \cos^2 2\beta + \frac{2\, g_2^2\, m_t^4}{8\pi^2\, M_W^2}\left[\ln(M_S^2/m_t^2) + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12\, M_S^2}\right)\right]$$

$M_S^2 = \frac{1}{2}(m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2)$ and $X_t = A_t - \mu/\tan\beta \longrightarrow$ stop mixing



After 2 -loop corrections $m_h \leq 135\,\mathrm{GeV}$ **==> stringent test of the MSSM**

Stefano RIGOLIN

Mechanism for HIDING the Extra Dim:

No experimental evidence of E.D. at energies presently available: $1/R >> 1$ TeV;

Mechanism for BREAKING Gauge Sym:

No scalar potential to drive Electro-Weak symmetry breaking;

For model building reasons one has to start from larger gauge group.

- Symmetry Breaking from 't Hooft Fluxes;
- Chirality from Magnetic Fluxes (background).

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

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

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

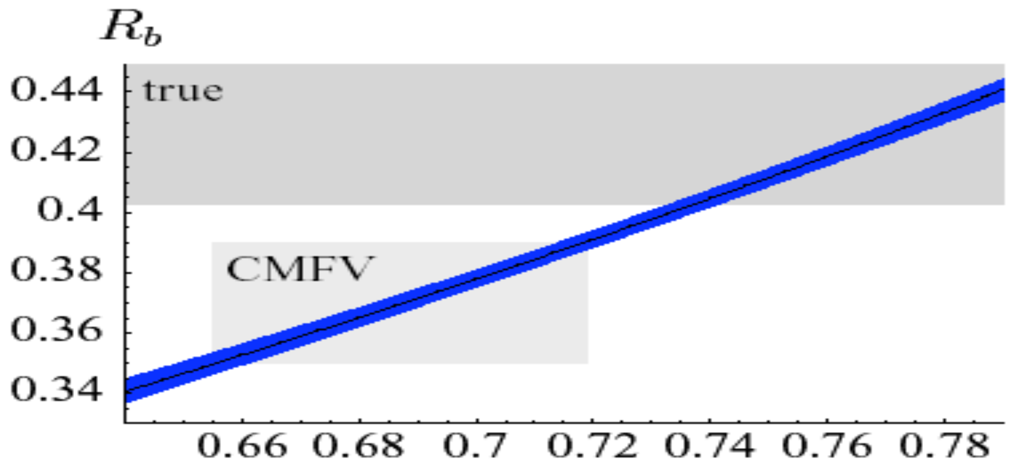
$$R_b = \sqrt{1 + R_t^2 - 2R_t\cos\beta}, \qquad \cot\gamma = \frac{1 - R_t\cos\beta}{R_t\sin\beta},$$

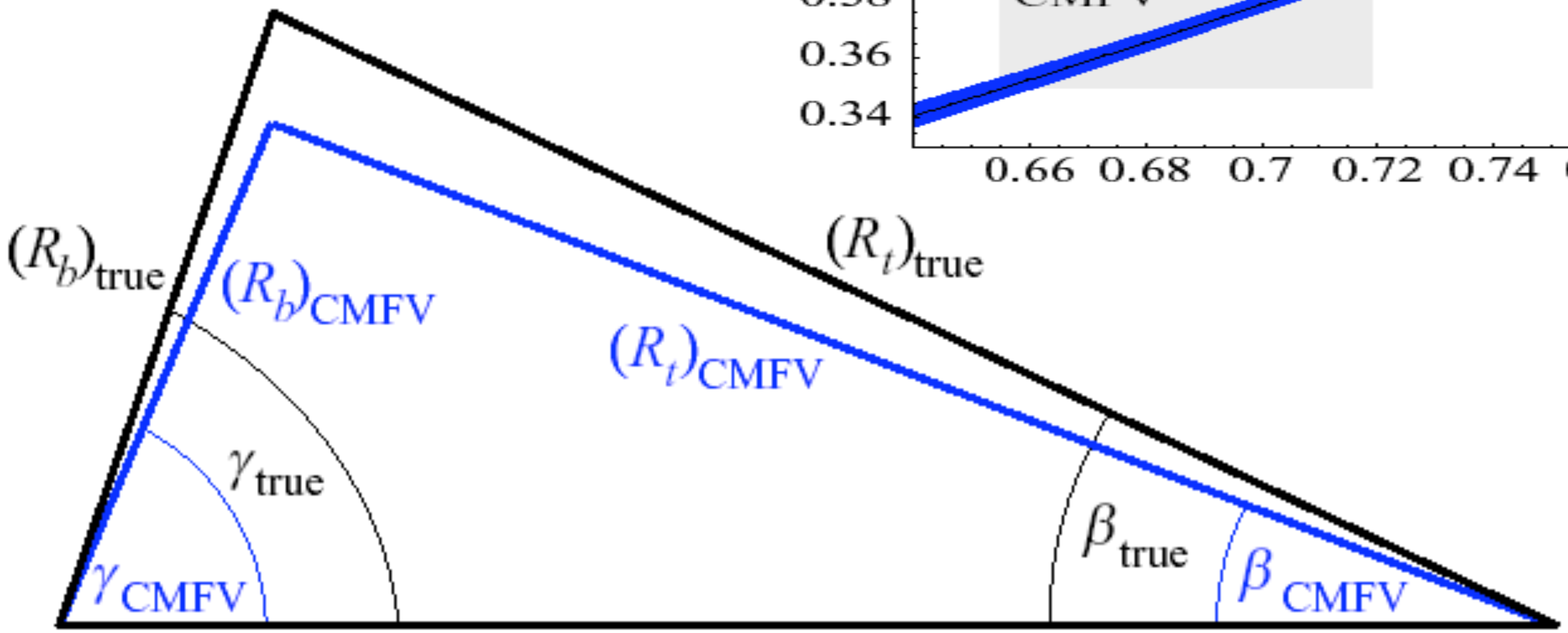
A. BURAS et al.

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

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!

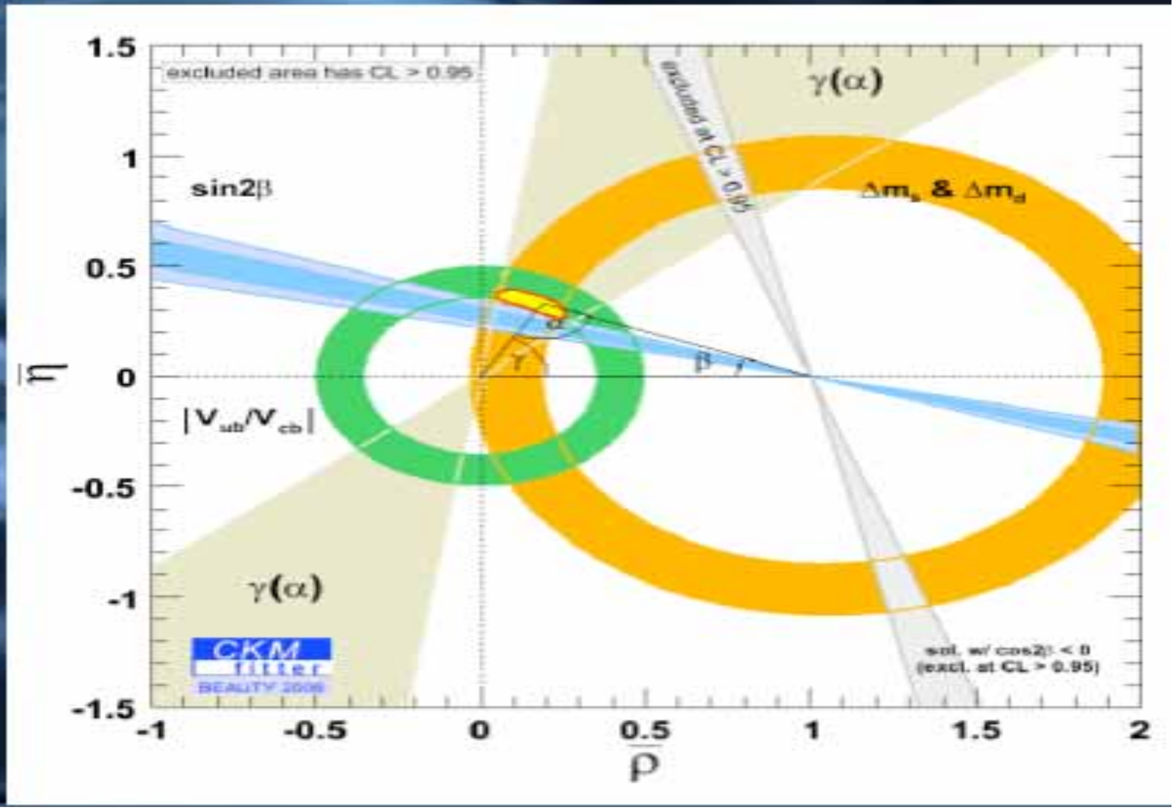
B physics (several intriguing effects):

- $\sin 2\beta$: tree vs. penguin (2.6σ)
- $\sin 2\beta$ vs. UT fit (2.9σ)

Matthias Neubert

Impact of precise $|V_{ub}|$

- Combined average $\sin 2\beta = 0.647 \pm 0.024$ below "tree" value $\sin 2\beta = 0.794 \pm 0.045$ deduced from $|V_{ub}|$ and $|V_{td}|$
- Deviation 2.9σ (!)
- Increased precision in $|V_{ub}|$ and recent measurement of B_s-$\overline{B}_s$ mixing (D0, CDF) crucial



B_s and NEW PHYSICS

SM predictions:

Patricia Ball

$$\Delta M_s|_{\rm JLQCD} = (16.1 \pm 2.8)\,{\rm ps}^{-1}, \quad \Delta M_s|_{\rm HPQCD} = (21.3 \pm 3.2)\,{\rm ps}^{-1}$$

recall CDF result: $(17.77 \pm 0.12)\,{\rm ps}^{-1}$

$\Delta M_s|_{\rm th}$ not yet known accurately enough to exclude even $|M_{12}^{s,{\rm NP}}| \approx |M_{12}^{s,{\rm SM}}|$ (i.e. $\kappa_s < 1$)

improved predictions expected in due course thanks to recent breakthrough in lattice algorithms to reduce the cost of simulations of light quark masses for Wilson fermions

(Del Debbio, Lüscher 06)

$$M_{12}^s = M_{12}^{s,{\rm SM}}(1 + \kappa_s e^{i\sigma_s})$$

LENZ-NIERSTE

Using theory predictions for the B_d contribution to $A_{\rm SL}^{\mu\mu}$ (instead of exp. data from the B factories), and the D0 data for $B_s \to J/\psi\phi$, LN find

$$\sin\phi_s = -0.77 \pm 0.04({\rm th}) \pm 0.34({\rm exp}): \ \phi_s \neq 0 \text{ at } 2\sigma$$

Paolo Gambino

Why a NNLO calculation?

- $$\mathrm{BR}(B \to X_s\gamma) = \left(3.55 \pm 0.24^{+0.09}_{-0.10} \pm 0.03\right) 10^{-4}$$

  latest HFAG E_γ>1.6 GeV

- Until recently: SM prediction at NLO in QCD + leading EW and non-perturbative effects with ~ 10% theory error
- Need to match ~ 5% exp error at end of B factories: first results of a collective effort for the NNLO calculation in **hep-ph/0609232**
- **authors**: M. Misiak, H.M. Asatrian, K. Bieri, M. Czakon, A. Czarnecki, T. Ewerth, A. Ferroglia, P. Gambino, M. Gorbahn, C. Greub, U. Haisch, A. Hovhannisyan, T. Hurth, A. Mitov, V. Poghosyan, M. Slusarczyk and M. Steinhauser.

Status of the NNLO enterprise

- **3-loop Wilson coefficients for O_7 and O_8**
  Misiak, Steinhauser, NPB 683 (2004) 277
- **3-loop mixing in $(O_1,...,O_6)$ & (O_7,O_8) sectors**
  Gorbahn, Haisch, NPB 713 (2005) 291
  Gorbahn, Haisch, Misiak, PRL 95 (2005) 102004
- **4-loop mixing $(O_1,...,O_6)$ into O_7 and O_8**
  Czakon,Haisch,Misiak, hep-ph/0612329
- **2-loop matrix elements of O_7 (real & virt), BLM for others**
  Bieri,Greub,Steinhauser, PRD 67 (2003) 114019
  Blokland, Czarnecki, Misiak, Slusarczyk,Tkachov, PRD 72 (2005) 033014
  Asatrian,Ewerth,Greub,Hurth,Hovhannisyan,Poghosyan, NPB 749 (2006)325
  Melnikov, Mitov, PLB 620 (2005) 69
  Asatrian, Ewerth, Ferroglia, PG, Greub, hep-ph/0607316
  Asatrian,Ewerth, Gabrielyan, Greub, hep-ph/0611123
- **3-loop matrix elements of O_1,O_2**
  Bieri, Greub,Steinhauser, PRD 67 (2003) 114019
  Misiak,Steinhauser,hep-ph/0609241 (**interpolation**)

NLLO "estimate" hep-ph/0609232

Including known power corrections, pure OPE result is at the moment

$$\mathcal{B}(\bar{B} \to X_s \gamma)^{\rm NNLO}_{E_\gamma > 1.6\ {\rm GeV}} = (3.15 \pm 0.23) \times 10^{-4}$$

Total error ~7% = ± 3% (interpolation) ± 3% (parametric)
± 3% (higher orders) ± 5% (non-pert)

At NLO: BR(E_g>1.6 GeV)=3.58 10^{-4} (Misiak, PG 2001) and
the NNLO error was 6% (m_c scale)+4% (other NNLO)

The present NNLO result (given the same inputs) is not far
from the edge of that range (-12%)

Various effects (notably but not only BLM, 4loop ADM) lower
the BR; charm scale is not set. Two scales (μ_c and μ_b) interplay.

$|V_{us}|(K_{l3}) = 0.2244(13)$

$|V_{us}|(\frac{F_K}{F_\pi}) = 0.222$

$|V_{us}|(\tau) = 0.2225(34)$

$|V_{us}|(\mathrm{Hyp}) = 0.$

$\Rightarrow$ **Average:** $|V_{us}| = 0.2240(11)$

Unitarity relation: $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 - \delta$.

$\Rightarrow$ $\delta = (1.58 \pm 0.72) \cdot 10^{-3}$ ≈ 2 diffe

Or vice versa: $|V_{us}|_{\mathrm{Unit}} = 0.2275(12)$

THE FATE OF LEPTON NUMBER

L VIOLATED

υ Majorana ferm.

SMALLNESS of m_υ

PRESENCE OF A NEW PHYSICAL MASS SCALE

L CONSERVED

υ Dirac ferm.

(dull option)

$h\, \bar{\upsilon}_L H\, \upsilon_R \rightarrow m_\upsilon = h \langle H \rangle$ $\quad M_\upsilon < 5$ eV $\rightarrow h < 10^{-11}$

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

NEW HIGH SCALE — NEW LOW SCALE

SEE - SAW MECHAN.

Minkowski; Gell-Mann, Ramond, SlansKy, Vanagida

ν_R ENLARGEMENT OF THE FERMIONIC SPECTRUM

$M \upsilon_R \upsilon_R + h\, \upsilon_L \bar{\phi}\, \upsilon_R$

	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!

THE FATE OF FLAVOR NUMBERS

HADRONIC FLAVOR NUMBERS: strangeness, charm, beauty.. ALL VIOLATED IN FLAVOR CHANGING CHARGED CURRENTS → mismatch in the simultaneous diagonalization of the up- and down- quark sectors allows for W intergenerational hadronic couplings

LEPTONIC FLAVOR NUMBERS: L_i i= e, μ, τ violated

in υ oscillations → massive neutrinos

→ mismatch in the simultaneous diagonalization of the up- (υ) and down- (l) sectors allows for W intergenerational leptonic couplings

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,

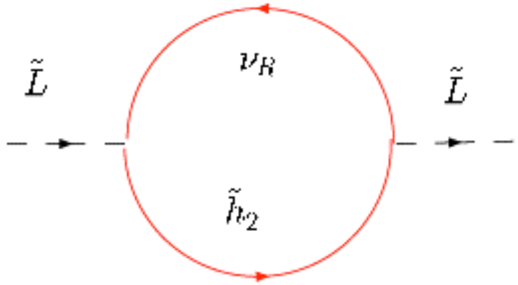
BUT in CMSSM (MSSM with flavor universality in the SUSY breaking sector) $\Delta M_{sleptons}$ is O($m_{leptons}$), hence GIM suppression is still too strong.

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 ($f_\nu^+ f_\nu$)

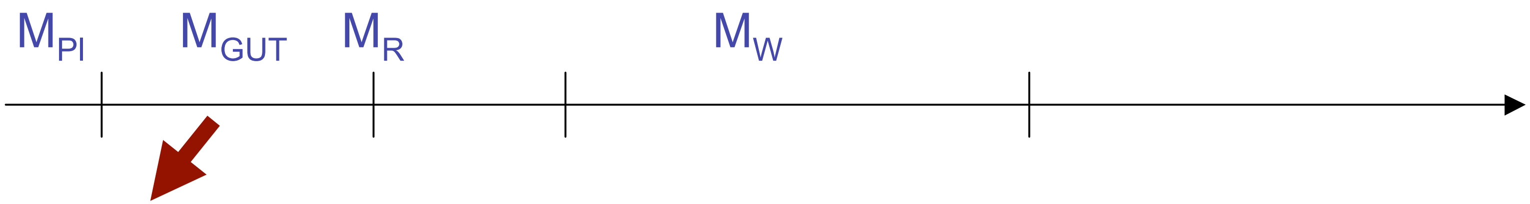
How Large LFV in SUSY SEESAW?

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

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) (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

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

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

→ potentially large LFV

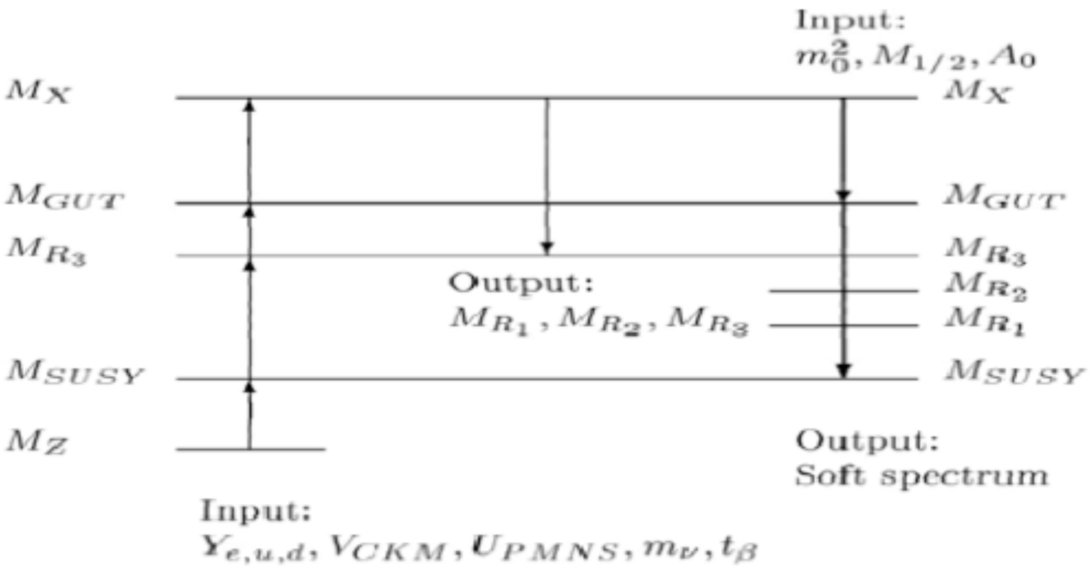
Barbieri, Hall; Barbieri, Hall, Strumia; Hisano, Nomura, Yanagida; Hisano, Moroi, Tobe Yamaguchi; Moroi;A.M.,, Vempati, Vives; Carvalho, Ellis, Gomez, Lola; Calibbi, Faccia, A.M, Vempati

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

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

General analysis: Casas Ibarra; Lavignac, Masina,Savoy; Hisano, Moroi, Tobe, Yamaguchi; Ellis, Hisano, Raidal, Shimizu; Fukuyama, Kikuchi, Okada; Petcov, Rodejohann, Shindou, Takanishi; Arganda, Herrero; Deppish, Pas, Redelbach, Rueckl; Petcov, Shindou

LFV with MULTIPLE RUNNING THRESHOLDS



CALIBBI, FACCIA, A.M., VEMPATI ;

For previous related work, see, in particular, HISANO et al.

GUT effect, e.g. SU(5), if $M_X > M_{GUT}$

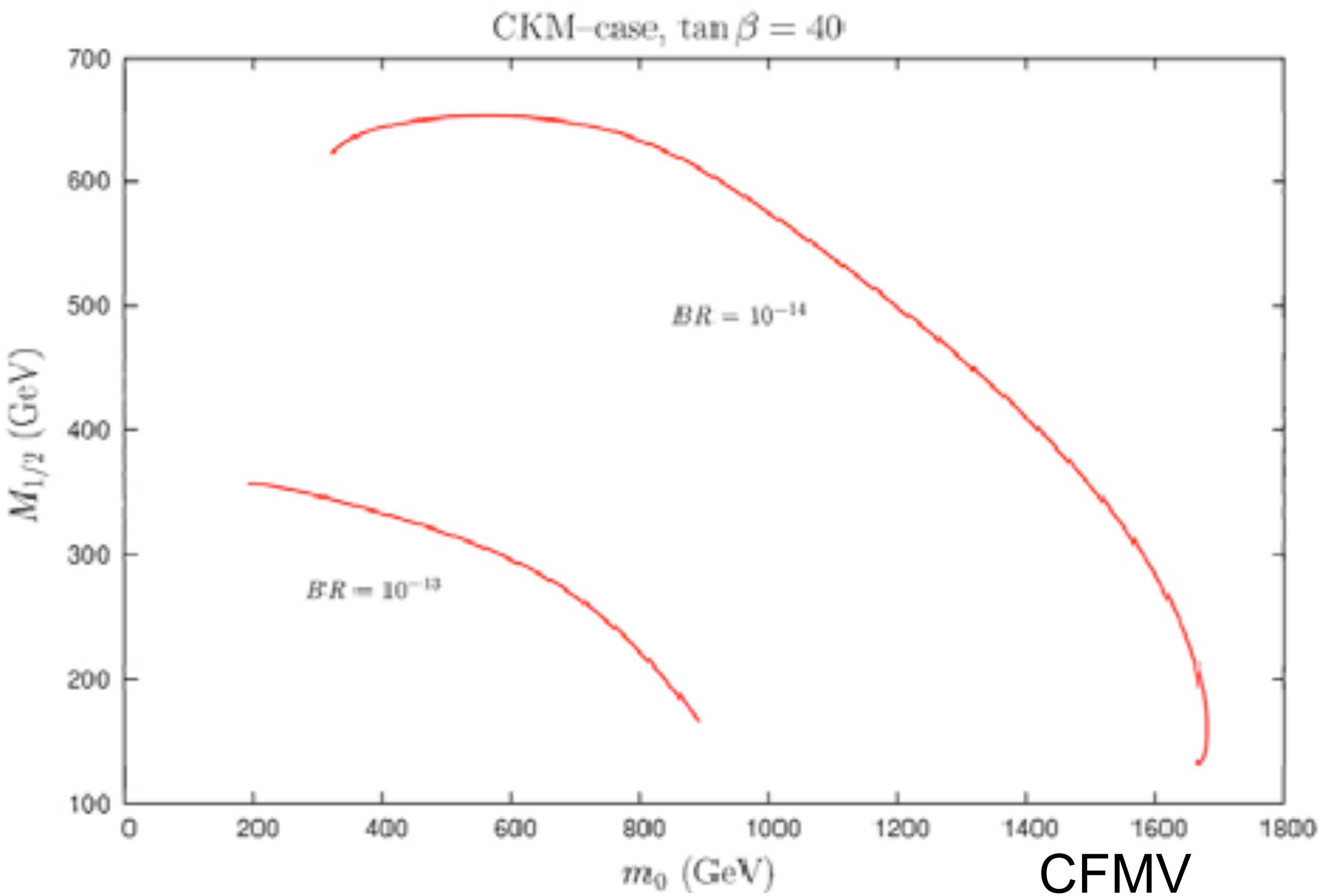
$$(\Delta_{RR})_{i\neq j} = -3 \cdot \frac{3m_0^2 + a_0^2}{16\pi^2} Y_t^2 V_{i3} V_{j3} \ln\left(\frac{M_X^2}{M_{GUT}^2}\right)$$

See-saw:

$$m_\nu = -Y_\nu \hat{M}_R^{-1} Y_\nu^T \langle H_u \rangle^2$$

$$(\Delta_{LL})_{i\neq j} = -\frac{3m_0^2 + A_0^2}{16\pi^2} Y_{\nu\, i3} Y_{\nu\, j3} \ln\left(\frac{M_X^2}{M_{R_3}^2}\right)$$

MEG POTENTIALITIES TO EXPLORE THE SUSY SEESAW PARAM. SPACE

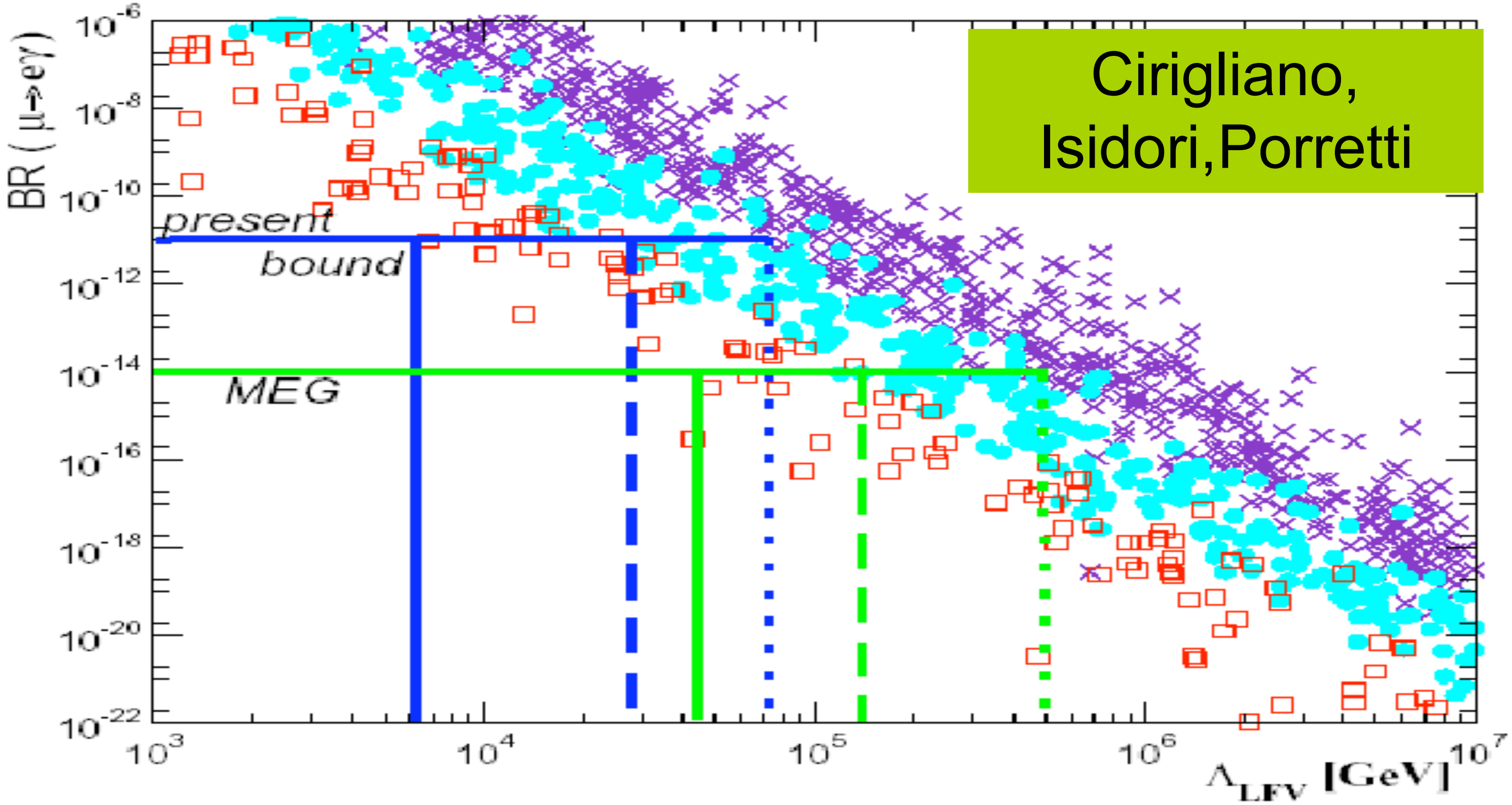


CFMV

Valentina Porretti

MFV in the lepton sector

we assume only Yukawa's break flavour as in the quark sector →
the Maiorana mass $M_D = 1$



$M_R =$ □ 10^{13} GeV ● 10^{14} GeV × 10^{15} GeV

❷ MFV as a restriction on *renormalizable* couplings [3]

F. Palorini

New renormalizable interactions can choose only one more basis in the L space

⇒ FV processes are not necessarily controlled by the U_{MNS} mixing matrix

MICRO

PARTICLE PHYSICS

GWS STANDARD MODEL

MACRO

COSMOLOGY

HOT BIG BANG
STANDARD MODEL

HAPPY MARRIAGE
Ex: NUCLEOSYNTHESIS

BUT ALSO

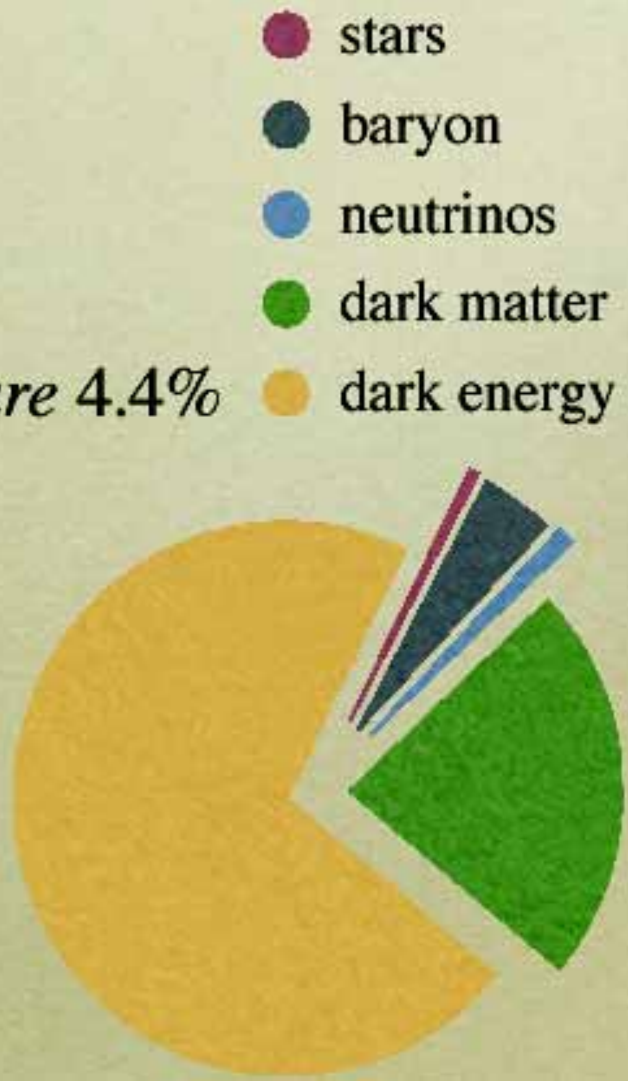
POINTS OF
FRICTION

- -COSMIC MATTER-ANTIMATTER ASYMMETRY
- -INFLATION
- - DARK MATTER + DARK ENERGY

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

Bilancio energetico dell’Universo

- *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* $\sim 10^{62}\%$*??*

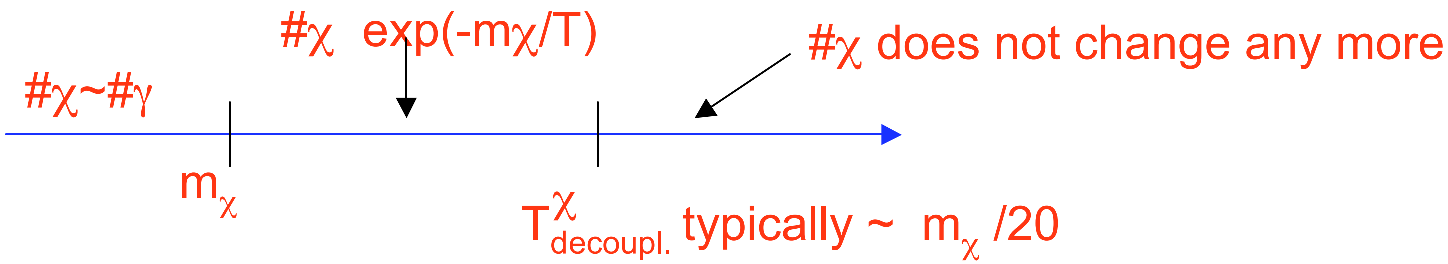


DM: the most impressive evidence at the "quantitative" and "qualitative" levels of New Physics beyond SM

- QUANTITATIVE: Taking into account the latest WMAP data which in combination with LSS data provide stringent bounds on Ω_{DM} and Ω_B → EVIDENCE FOR NON-BARYONIC DM AT MORE THAN 10 STANDARD DEVIATIONS!! THE SM DOES NOT PROVIDE ANY CANDIDATE FOR SUCH NON-BARYONIC DM

- QUALITATIVE: it is NOT enough to provide a mass to neutrinos to obtain a valid DM candidate; LSS formation requires DM to be COLD → NEW PARTICLES NOT INCLUDED IN THE SPECTRUM OF THE FUNDAMENTAL BUILDING BLOCKS OF THE SM !

WIMPS (Weakly Interacting Massive Particles)



Ω_χ depends on particle physics ($\sigma^{\chi}_{annih.}$) and “cosmological” quantities (H, T_0, …

$$\Omega_\chi h^2 \simeq \frac{10^{-3}}{\langle(\sigma_{annih.}) V \chi\rangle \;\; \mathrm{TeV}^2}$$

$\langle(\sigma_{annih.}) V \chi\rangle \sim \alpha^2 / M^2_\chi$

TeV^2 → From T^0, M_{PLANCK}

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

$m\chi \sim 10^2 - 10^3$ GeV (weak interaction) $\qquad \Omega\chi h^2 \sim 10^{-2}$ -10^{-1} !!!

Carena

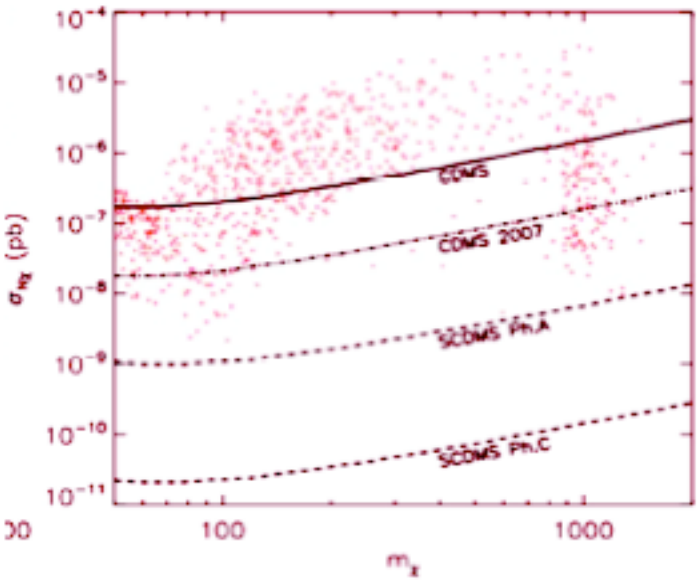
CDMS DM searches Vs the Tevatron and LHC H/A searches

•If the lightest neutralino makes up the DM of the universe

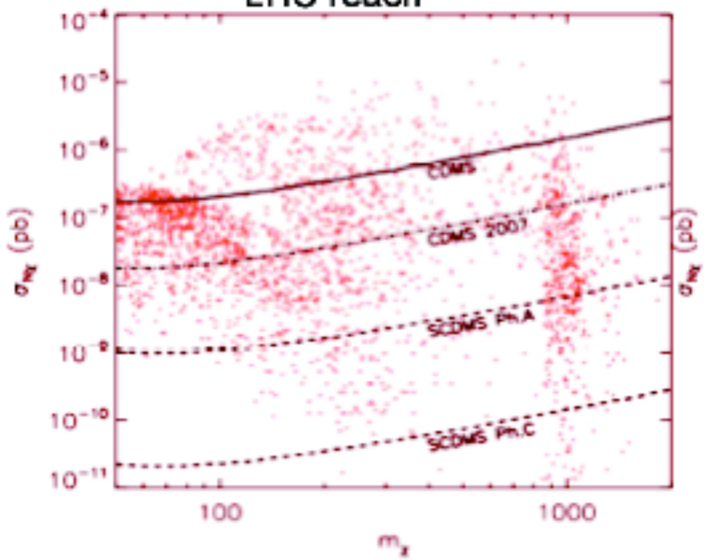
==> Evidence for H/A at the Tevatron (LHC) predict neutralino cross sections typically within the reach of present (future) direct DM detection experiments.

(strong μ dependence)

Tevatron reach

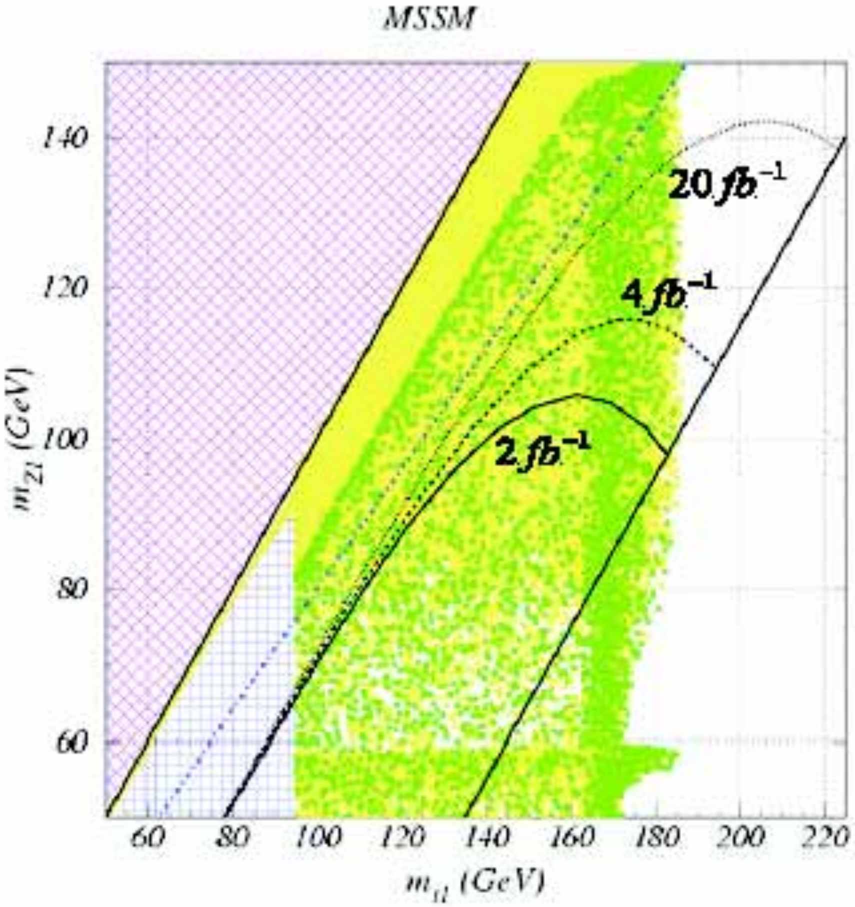


LHC reach



M.C, Hooper, Vallinotto 06

Tevatron stop searches and dark matter constraints



Carena, Balazs and C.W. '04

Green: Relic density consistent with WMAP measurements.

Searches for light stops difficult in stop-neutralino coannihilarion region.

LHC will have equal difficulties. Searches become easier at a Linear Collider !

Carena, Freitas et al. '05

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. → STABLE NEW PART.	Neutralino spin 1/2	spin1	spin0
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

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

Ana Texeira

SUSY dark matter beyond the MSSM - the NMSSM

Add **singlet** superfield $\boldsymbol{S}$ to the MSSM

Next-to-Minimal Supersymmetric Standard Model

⇒ Elegant **solution to the μ-problem** of the MSSM

$\mu H_1 H_2 \to \lambda S H_1 H_2$ ⇒ Dynamically generated μ: $\mu_{\text{eff}} = \lambda \langle S \rangle$

Scale-invariant superpotential: EW, SUSY scale only appearing via $\mathcal{L}_{\text{soft}}$

⇒ **Less severe** "Higgs - little fine tuning problem" of the MSSM

⇒ Formally...

NMSSM=MSSM + $\hat{\boldsymbol{S}}$ { 2 extra **Higgs** (CP-even, CP-odd); 1 additional **neutralino** }

$$\boldsymbol{W} = Y_u H_2 Q u + Y_d H_1 Q d + Y_e H_1 L e - \boldsymbol{\lambda} S H_1 H_2 + \tfrac{1}{3}\boldsymbol{\kappa} S^3$$

$$-\mathcal{L}_{\text{soft}}^{\text{Higgs}} = m_{H_i}^2 H_i^* H_i + \boldsymbol{m_S^2} S^* S + \left(-\boldsymbol{\lambda} \boldsymbol{A_\lambda} S H_1 H_2 + \tfrac{1}{3}\boldsymbol{\kappa} \boldsymbol{A_\kappa} S^3 + \text{H.c.}\right)$$

⇒ Richer and more complex **phenomenology** - extra Higgs, neutralino

⇒ Important implications for **dark matter analysis!**

NON-STANDARD WIMP DM

- LIGHT DM PRODUCING THE 511 KeV GAMMA LINE FROM THE GALACTIC CENTER Jean Orloff

  relevant for indirect searches of DM hunting for gammas emitted in DM annihilation: ditribution of DM in our galaxy ⟶ DM clumpiness Joerg Jaeckel
- LIGHT STERILE NEUTRINO WITH KeV MASS Takekiko Asaka
- TeV DARK STERILE NEUTRINO Alexey Anisimov
- KK Gravitinos David Gherson

Joern Kersten

Gaugino Mediation

$\Downarrow$

Neutralino LSP

Gravitino LSP

~~χ^0 NLSP~~

$\widetilde{\tau}$ NLSP

$\widetilde{\nu}$ NLSP

NATURALNESS AND DM

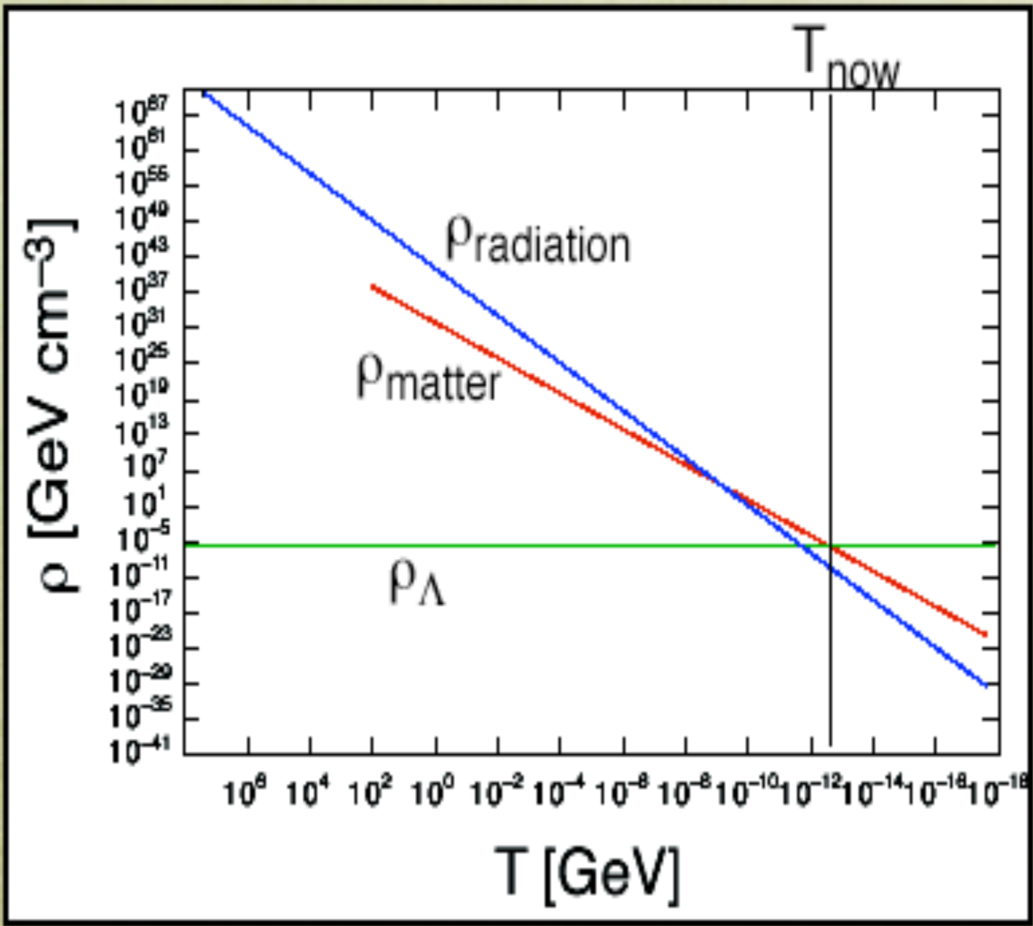
Jonathan Roberts

By relaxing our constraints we can find typical tuning scales across different dark matter annihilation channels.

Region	Typical Δ^{Ω}
Mixed bino/wino	~ 30
Mixed bino/higgsino	$30 - 60$
Mixed bino/wino/higgsino	$4 - 60$
Bulk region (t-channel $\tilde{f}$ exchange)	< 1
slepton coannihilation (low M_1, m_0)	$3 - 15$
slepton coannihilation (large M_1, m_0, $\tan\beta$)	~ 50
Z-resonant annihilation	~ 10
h^0-resonant annihilation	$10 - 1000$
A^0-resonant annihilation	$80 - 300$

THE "WHY NOW" PROBLEM

- *Why do we see matter and cosmological constant almost equal in amount?*
- *"Why Now" problem*
- *Actually a triple coincidence problem including the radiation*
- *If there is a deep reason for $\rho_\Lambda \sim ((\mathrm{TeV})^2/M_{Pl})^4$, coincidence natural*



Arkani-Hamed, Hall, Kolda, HM

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", …CARROLL

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

Modifications of the standard picture of WIMPs FREEZE - OUT

→ CDM CANDIDATES

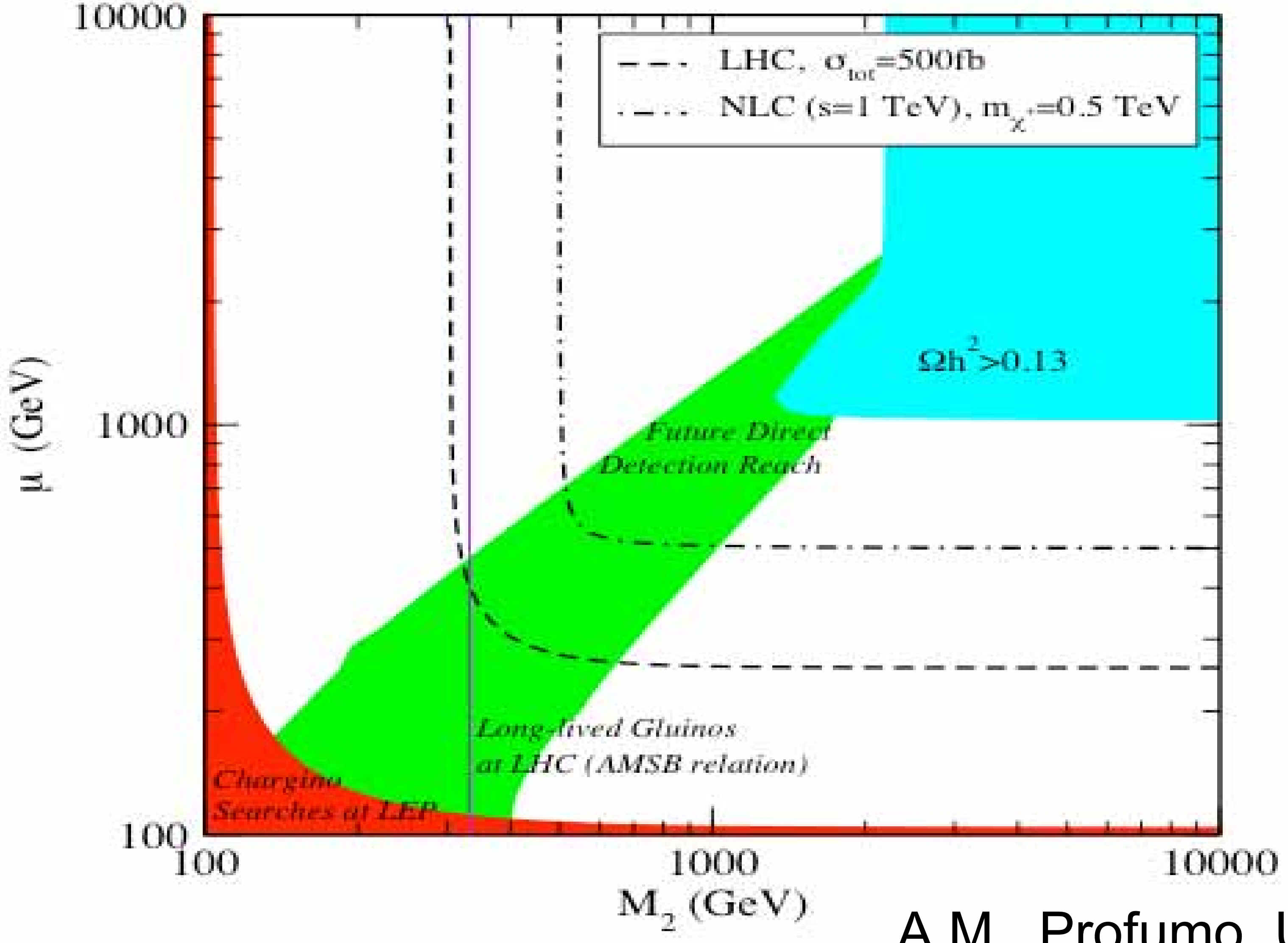
CATENA, FORNENGO, A.M., PIETRONI, ROSATI, SCHELKE

DE AND LARGE EXTRA DIMENSIONS

Cliff Burgess

- Connection between the scale of DE and the scale associated to the presence of large extra dimensions
- Initial conditions for the scalar potential have to be fixed, but then there exists stability of the solution → stabilization of the extra dimensions

LHC, ILC, DM SEARCHES SENSITIVITIES



A.M., Profumo, Ullio

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

- SM DOES NOT SATISFY AT LEAST TWO OF THE THREE SACKAROV'S NECESSARY CONDITIONS FOR A DYNAMICAL BARYOGENESIS:

- 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 violation; 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)

Including Lepton Flavor Effects

ENRICO NARDI

Discussed also by FX Josse Michaux

$$-\mathcal{L} = \frac{1}{2} {N_1}^T M_1 N_1 + (\lambda_{1i} \bar{N}_1 \, \ell_i \, H + h_i \, \bar{e}_i \, \ell_i \, H^\dagger + \text{h.c.})$$

– For $T \gg 10^{12}$ GeV, no charged lepton Yukawa scattering has occured yet

– For $T < 10^{12}$ GeV, τ-Yukawa scatterings are in equilibrium; Basis: $(\ell_\tau, \ell_{\perp_\tau})$

– For $T < 10^9$ GeV, μ-Yukawa enters in equilibrium; Basis: $(\ell_\tau, \ell_\mu, \ell_e = \ell_{\perp_{\tau\mu}})$

The ℓ_1 ($\bar{\ell}'_1$) flavor content becomes important: $K_i = |\langle \ell_i | \ell_1 \rangle|^2$ $(\bar{K}_i = |\langle \bar{\ell}_i | \bar{\ell}'_1 \rangle|^2)$

- The flavor CP asymmetries: $\epsilon_1^i = \frac{\Gamma(N_1 \to \ell_i H) - \bar{\Gamma}(N_1 \to \bar{\ell}_i \bar{H})}{\Gamma_{N_1}} = K_i \epsilon_1$
- The (suppressed) flavor dependent washouts: $\Gamma^i_{wosh.} \sim K_i \, \tilde{m}_1$
- L-asymmetry enhancement: $Y_L \propto \sum_i \epsilon_1^i \frac{m_*}{K_i \, \tilde{m}_1} \approx n_f Y_L^{(n_f=1)}$

Julia GARAYOA

Soft Leptogenesis: soft breaking terms introduce new sources of CP and L violation. Mixing between the two sneutrinos of a single generation induces CP asymmetry in their decay.

- It works for relatively small values of the right-handed neutrino mass (10^5 - 10^8 GeV) →

POSSIBILITY TO AVOID THE GRAVITINO PROBLEM

EXAMPLE PROVIDED IN THE CONTEXT OF A SUSY INVERSE SEESAW MECHANISM

Garayoa, Gonzalez-Garcia, Rius

IS THE NEUTRINO MIXING MATRIX **UNITARY**

Belen GAVELA

Low-energy non- unitarity may result from new physics contributing to neutrino propagation.

i.e. a neutrino mass matrix larger than 3x3

Antusch, Biggio, Fernández-Martínez, López-Pavón, M.B.G. 06

→ Unitarity violations arise in models for ν masses with heavy fermions

Global fit

$$90\%\ \text{cl} \quad |NN^{+}| \approx \begin{pmatrix} 1.002 \pm 0.005 & < 7.2 \cdot 10^{-5} & < 1.6 \cdot 10^{-2} \\ < 7.2 \cdot 10^{-5} & 1.003 \pm 0.005 & < 1.3 \cdot 10^{-2} \\ < 1.6 \cdot 10^{-2} & < 1.3 \cdot 10^{-2} & 1.003 \pm 0.005 \end{pmatrix}$$

→ N is unitary at the % level

Can we measure the phases of N ?

E. Fdez-Martinez, J.Lopez, O. Yasuda, M.B.G.

➡ New CP-violation signals
even in the two-family approximation

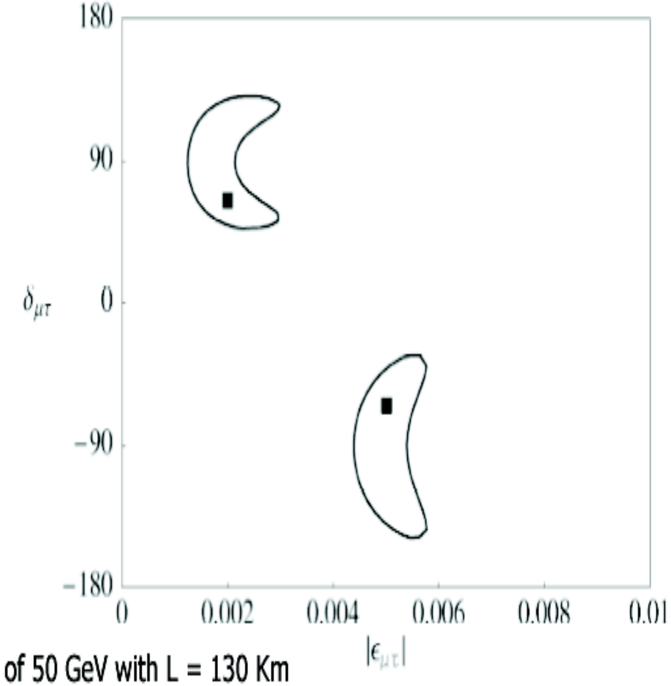
B. Gavela

i.e. $P(\nu_\mu \dashrightarrow \nu_\tau) \neq P(\bar{\nu}_\mu \dashrightarrow \bar{\nu}_\tau)$

$$N = (1+\varepsilon)\cdot U \quad \text{with} \quad U \approx U_{PMNS}$$

$$P_{\mu\tau} - P_{\bar{\mu}\bar{\tau}} = -4\,\mathrm{Im}(\varepsilon_{\mu\tau})\sin(2\theta_{23})\sin\left(\frac{\Delta m^2_{23} L}{2E}\right)$$

The CP phase $\delta_{\mu\tau}$ can be measured



At a Neutrino Factory of 50 GeV with L = 130 Km

Michele Maltoni

The situation until now:

- ν fluxes, Earth profile and ν cross-sections known with some accuracy;
- oscillation parameters were **not** known;

⇒ atmospheric data successfully used to extract info on oscillation parameters.

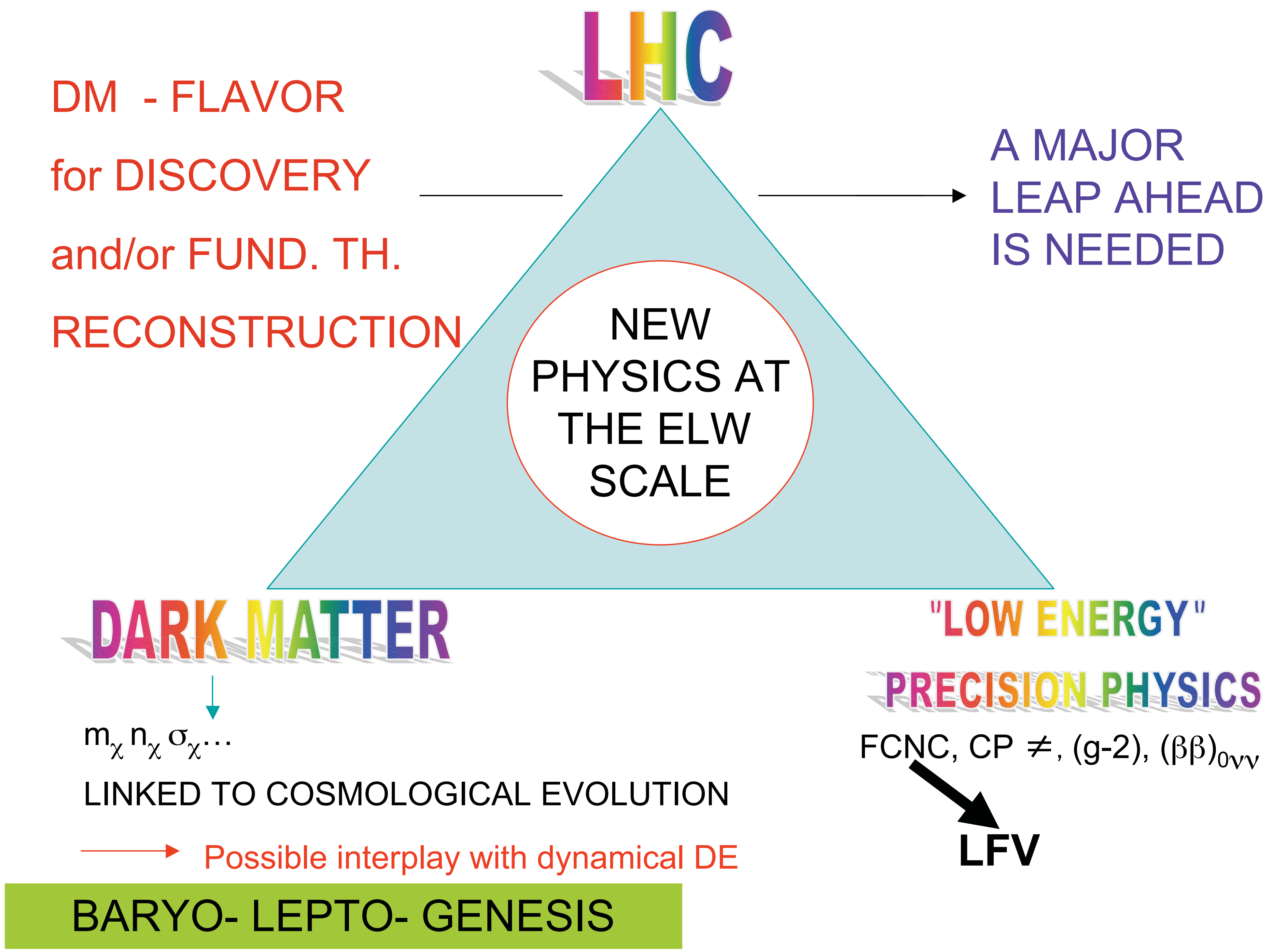
Possible future situation:

- oscillation parameters **may** be known with high accuracy;
- fix attention on other terms in the integral;

⇒ atmospheric data will provide info on fluxes, cross-sections, Earth matter...

- ATM and LBL data provide **complementary** information on neutrino parameters:
  - LBL data will accurately determine $|\Delta m^2_{31}|$ and θ_{23}, and measure/bound θ_{13};
  - ATM data will provide information on the mass hierarchy and on the octant.
- the sensitivity to neutrino parameters achievable with combined **ATM+LBL** is considerably stronger than that of ATM and LBL data taken separately;
- even if LBL will be so good to resolve degeneracies by themselves, ATM data will still:
  - provide a direct measurement of neutrino fluxes;
  - offer a unique window on physics beyond the Standard Model.

⇒ [Gonzalez-Garcia, MM, Smirnov, PRD 70 (2004) 093005, hep-ph/0408170]
[Huber, MM, Schwetz, PRD 71 (2005) 053006, hep-ph/0501037]
[Campagne, MM, Mezzetto, Schwetz, hep-ph/0603172]
[Gonzalez-Garcia, MM, Rojo, JHEP 10 (2006) 075, hep-ph/0607324]
[Akhmedov, MM, Smirnov, hep-ph/0612285]


LHC
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
BARYO- LEPTO- GENESIS
"LOW ENERGY"
PRECISION PHYSICS
FCNC, CP $\neq$, (g-2), $(\beta\beta)_{0\nu\nu}$
LFV