LCWS 07, DESY May 30, 2007

UPDATE on NEW PHYSICS AT COLLIDERS

ANTONIO MASIERO
UNIV. OF PADUA
and
INFN, PADUA

WHY TO GO BEYOND THE SM

"OBSERVATIONAL" REASONS

- HIGH ENERGY PHYSICS

NO (but $A_{FB}^{Z \to bb}$……)

- FCNC, CP≠

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

- HIGH PRECISION LOW-EN.

NO (but $(g-2)_\mu$ …)

- NEUTRINO PHYSICS

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

- COSMO - PARTICLE PHYSICS

YES (DM, ΔB_{cosm}, INFLAT., DE)

THEORETICAL REASONS

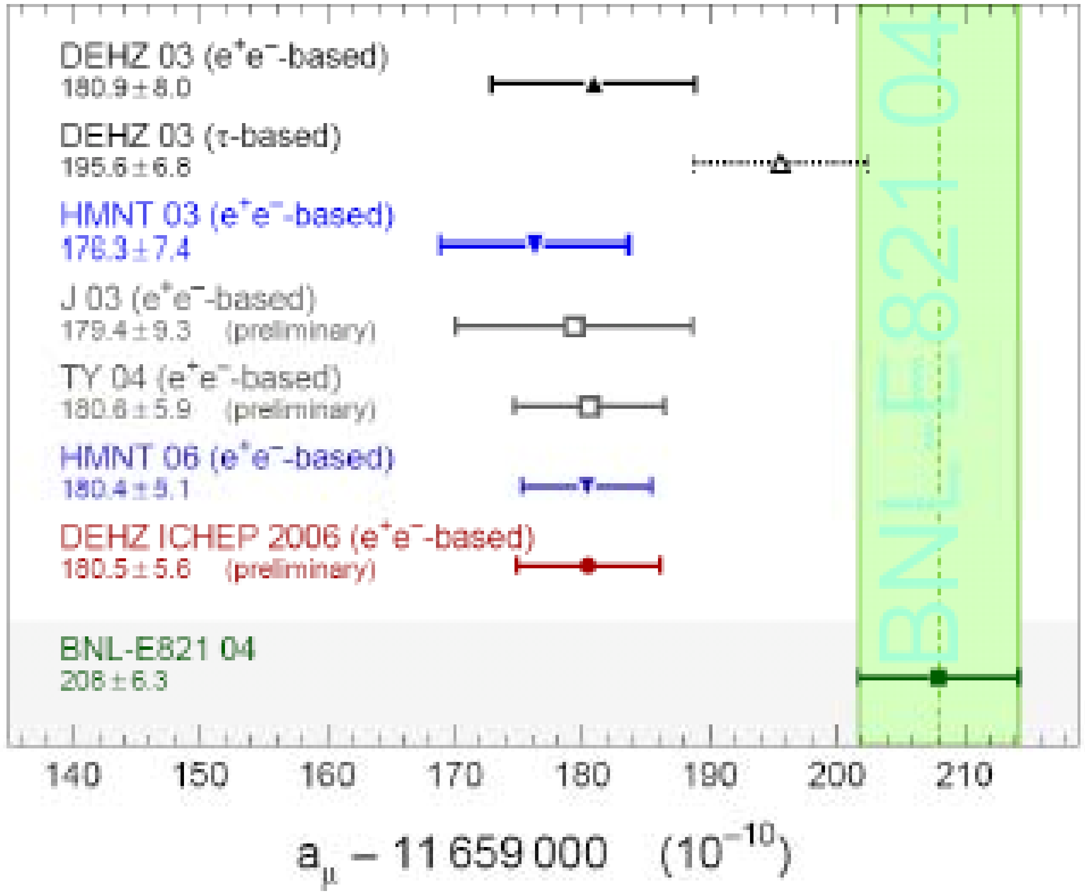
- INTRINSIC INCONSISTENCY OF SM AS QFT

NO (spont. broken gauge theory without anomalies)

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

YES (hierarchy, unification, flavor)

Status of g_μ-2



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

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.

Reference Unitarity Triangle and UUT (CMFV)

$(R_b)_{CMFV} = 0.363 \pm 0.016$

$(R_b)_{true} = 0.428 \pm 0.027$

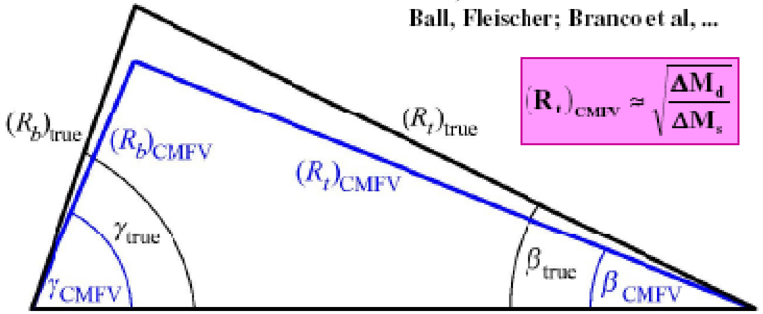
$\gamma_{true} = (82 \pm 20)^\circ$

$\sin 2\beta_{CMFV} = 0.675 \pm 0.026$

$\sin 2\beta_{true} = 0.749 \pm 0.063$ "true"= RUT

Blanke, AJB, Guadagnoli, Tarantino
Utfit, CKMfit
Ball, Fleischer; Branco et al, ...

$(R_t)_{CMFV} \approx \sqrt{\frac{\Delta M_d}{\Delta M_s}}$



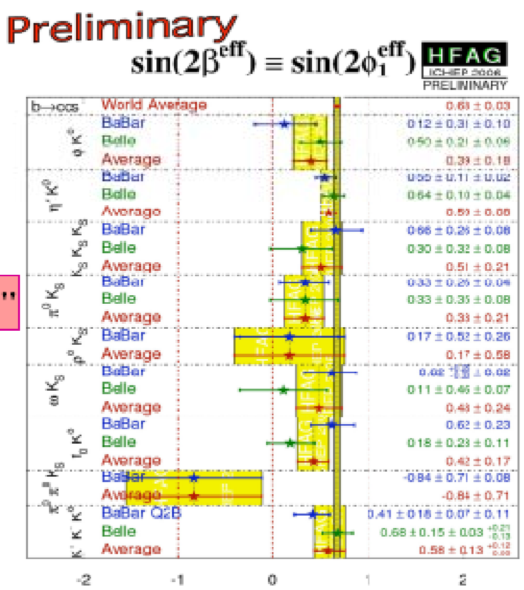
$\beta_{CMFV} = \beta_{\psi K_s}$

"$\sin 2\beta$ Problem"

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

second

"$\sin 2\beta$ Problem"



Single channels understood?

Allowed to take the avg.?

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

▪ 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 <10 -20% in the “flavor observables” which have already been observed!

What a SuperB can do in testing CMFV

L. Silvestrini at SuperB IV

Minimal Flavour Violation

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

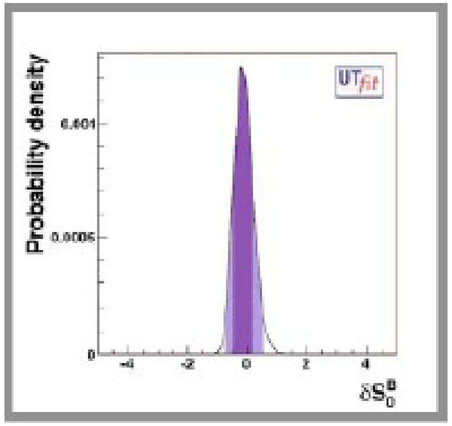
$$S_0(x_t) \to S_0(x_t) + \delta S_0(x_t)$$

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

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

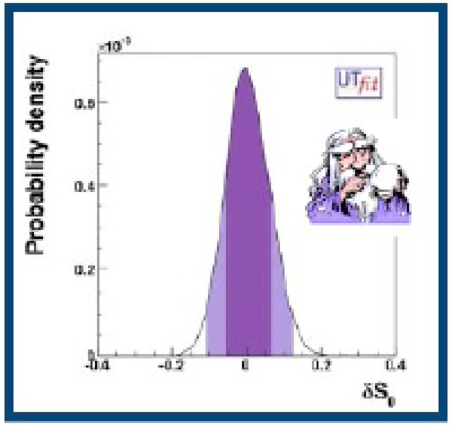
(D'Ambrosio et al., hep-ph/0207036)

$$\delta S_0^{\,B} = \delta S_0^{\,K}$$



$\delta S_0 = -0.16 \pm 0.32$

$\Lambda > 5.5$ TeV @95%



$\delta S_0 = 0.004 \pm 0.059$

$\Lambda > 28$ TeV @95%

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

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

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

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

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)

$h\,\bar{\upsilon}_L H\,\upsilon_R \rightarrow m_\upsilon = h\,\langle H\rangle$ $M_\upsilon < 5$ 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

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

$$\begin{array}{c|cc} & \upsilon_L & \upsilon_R \\ \hline \upsilon_L & \sim O & h\langle\phi\rangle \\ \upsilon_R & h\langle\phi\rangle & M \end{array}$$

LR Models?

MAJORON MODELS

Gelmini, Roncadelli

Δ ENLARGEMENT OF THE HIGGS SCALAR SECTOR

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

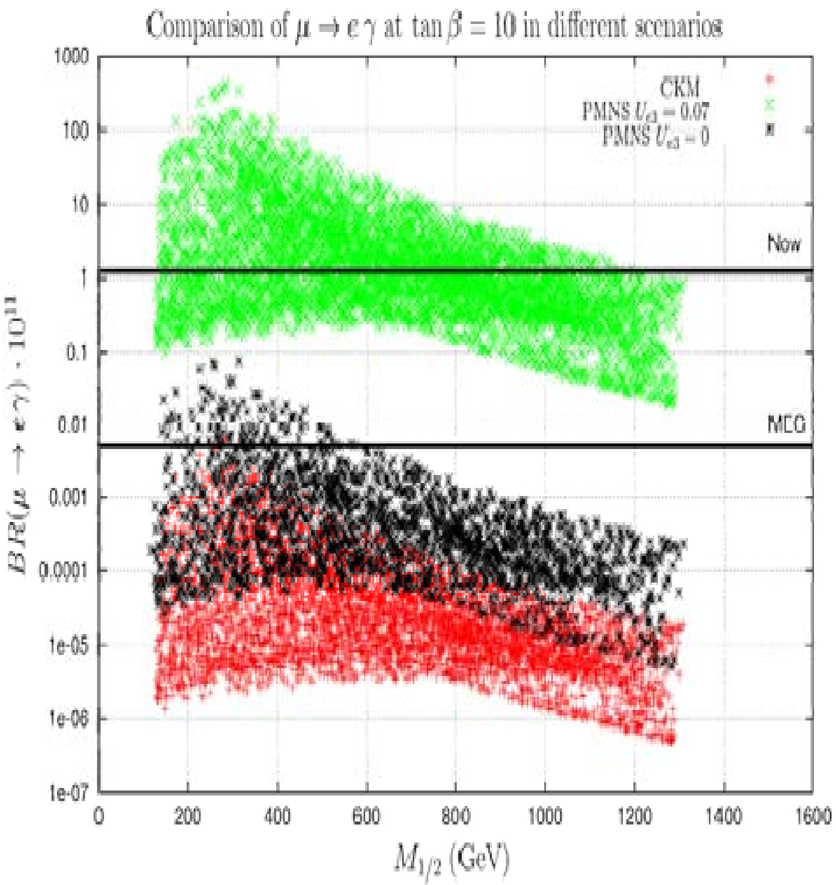
$m_\upsilon = h\,\langle\Delta\rangle$

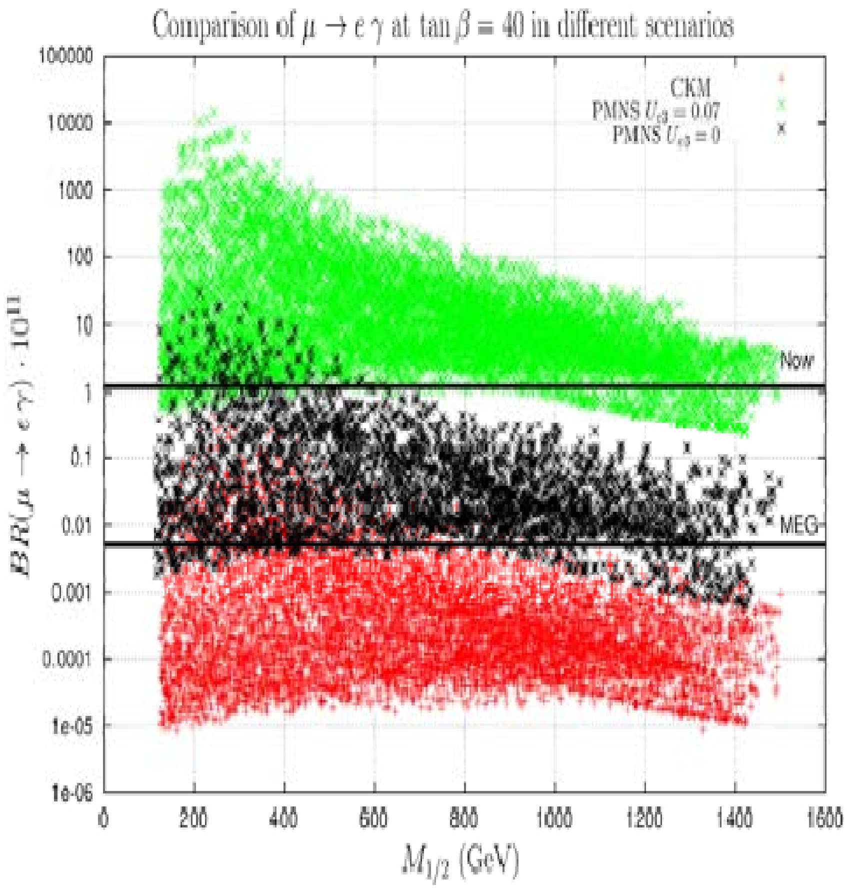
N.B.: EXCLUDED BY LEP!

SUSY SEESAW AND LARGE LFV ENHANCEMENT

μ → e+γ in SUSYGUT: past and future

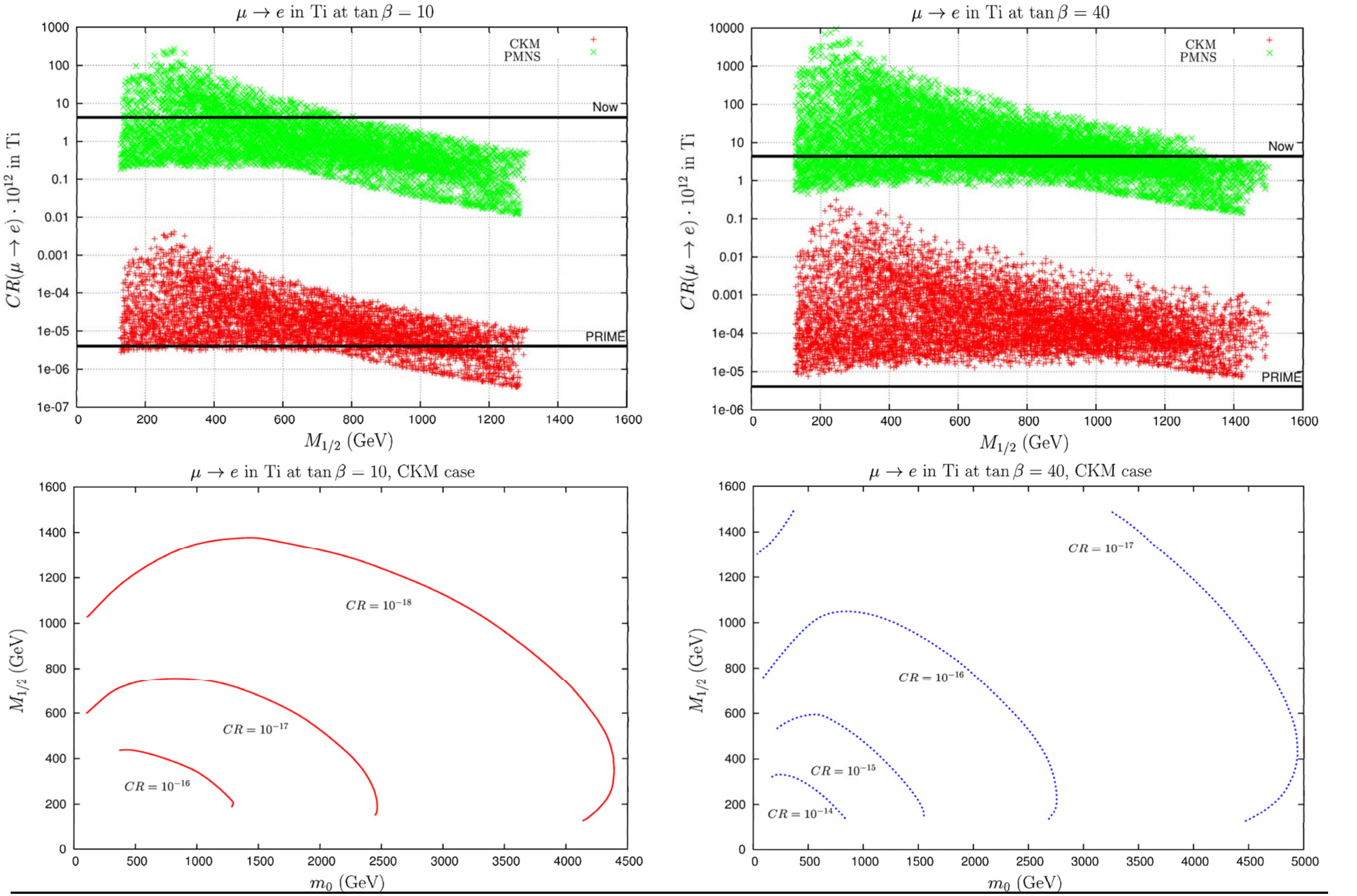
$\mu \to e\,\gamma$ in the $U_{e3} = 0$ PMNS case



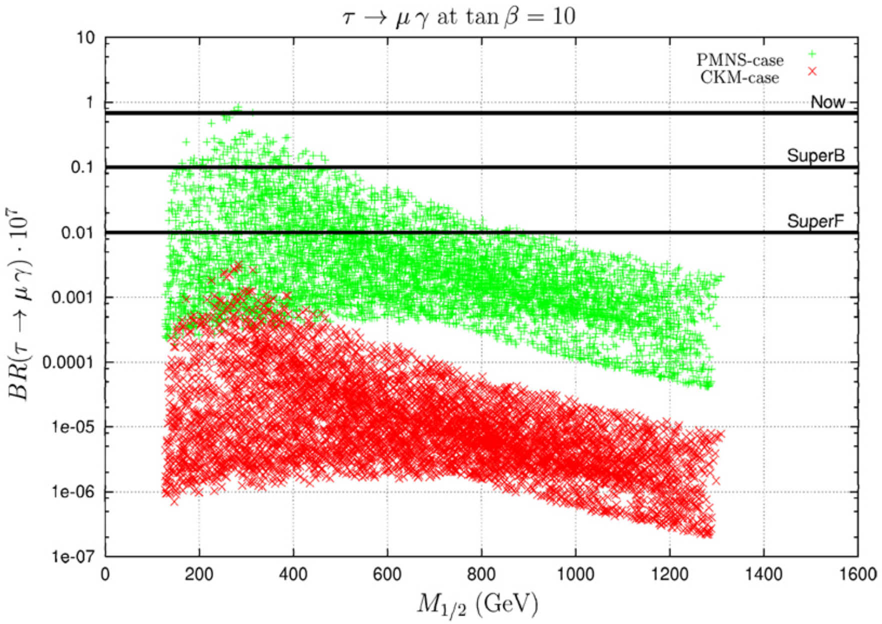


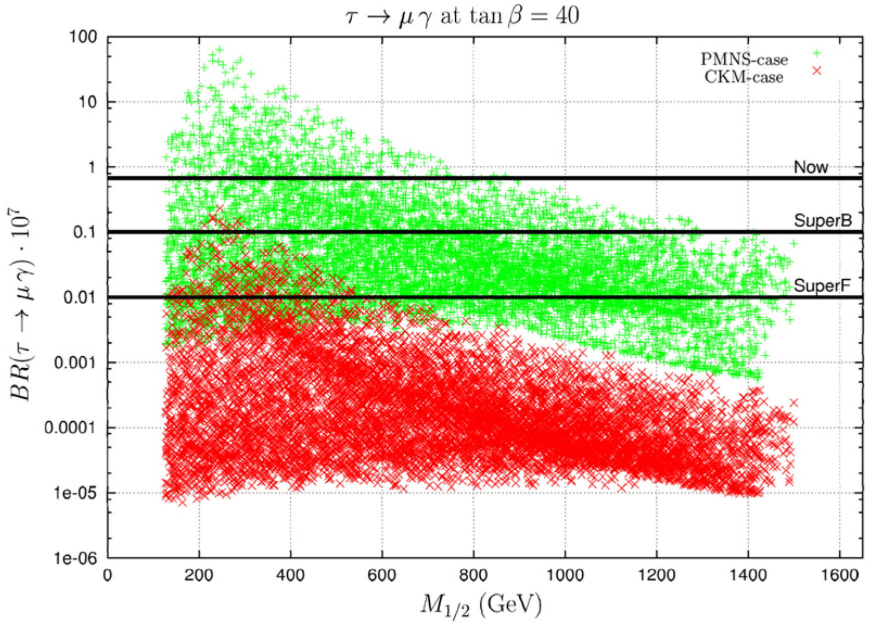
CALIBBI, FACCIA, A.M., VEMPATI

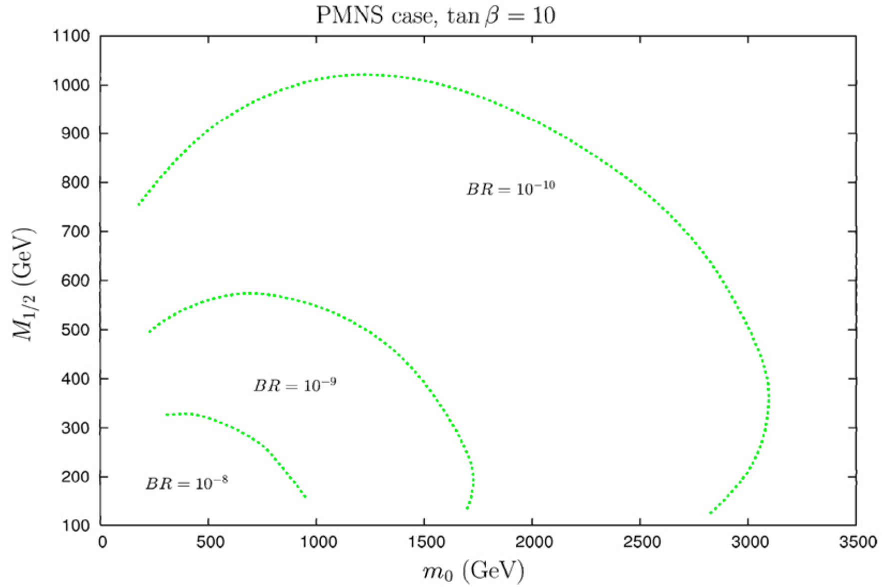
$\mu \to e$ in Ti and **PRISM/PRIME** conversion experiment

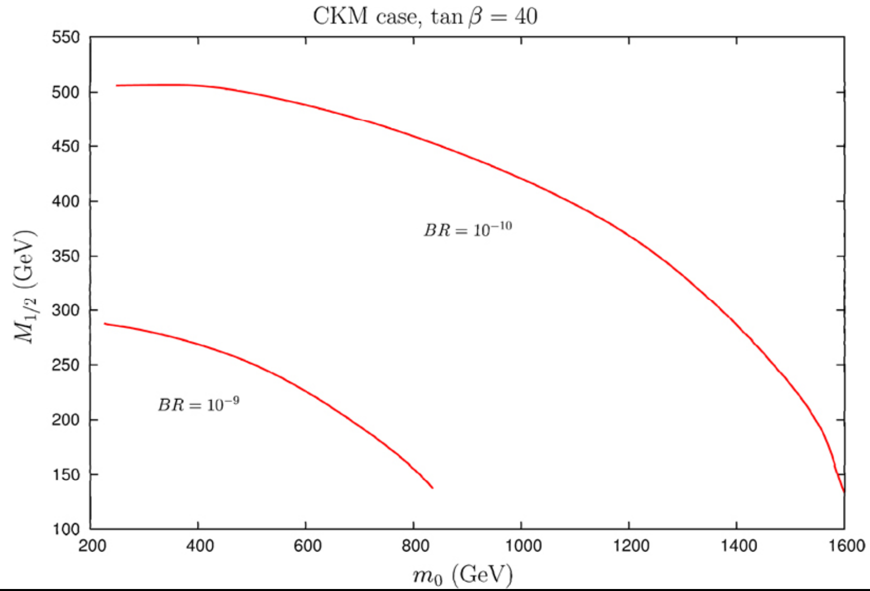


$\tau \to \mu\,\gamma$ and the **Super B** (and **Flavour**) factories





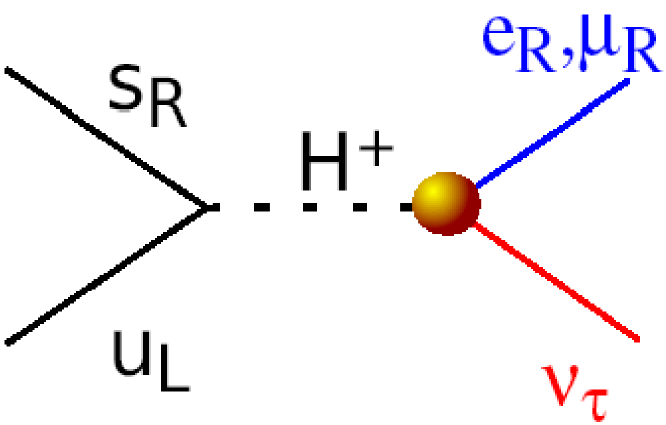




H mediated LFV SUSY contributions to R_K

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

PARADISI, A.M.,PETRONZIO



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

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

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

$$\Downarrow$$

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

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

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)

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

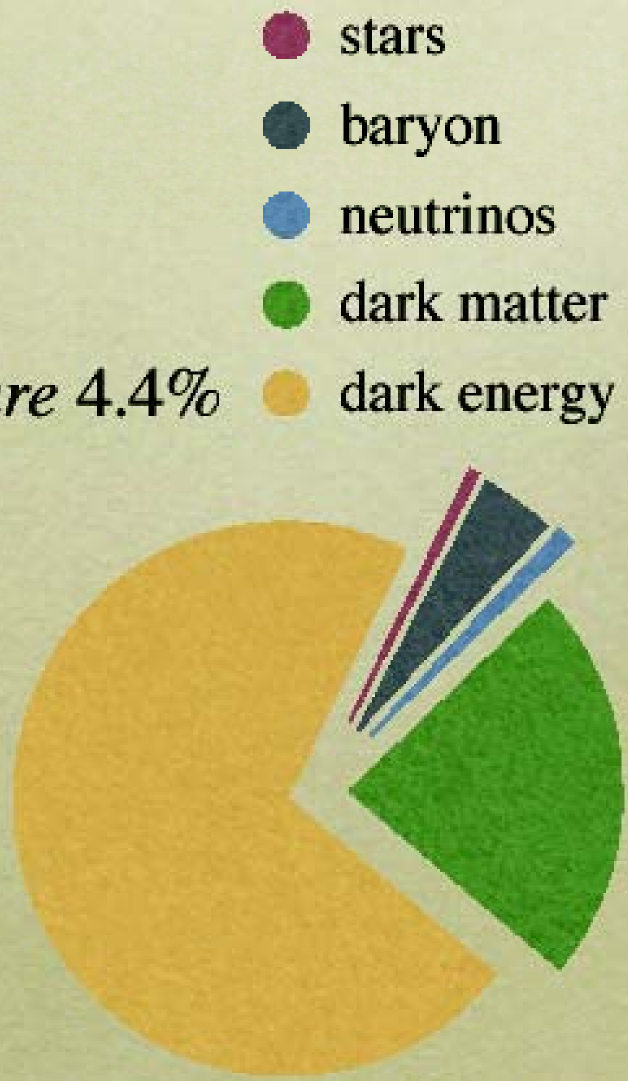
-INFLATION

- DARK MATTER + DARK ENERGY

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

The energy budget of 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}%??*



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 !

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

SEARCHING FOR WIMPs

WIMPS HYPOTHESIS

DM made of particles with mass $\underbrace{\text{10Gev - 1Tev}}_{\text{ELW scale}}$

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

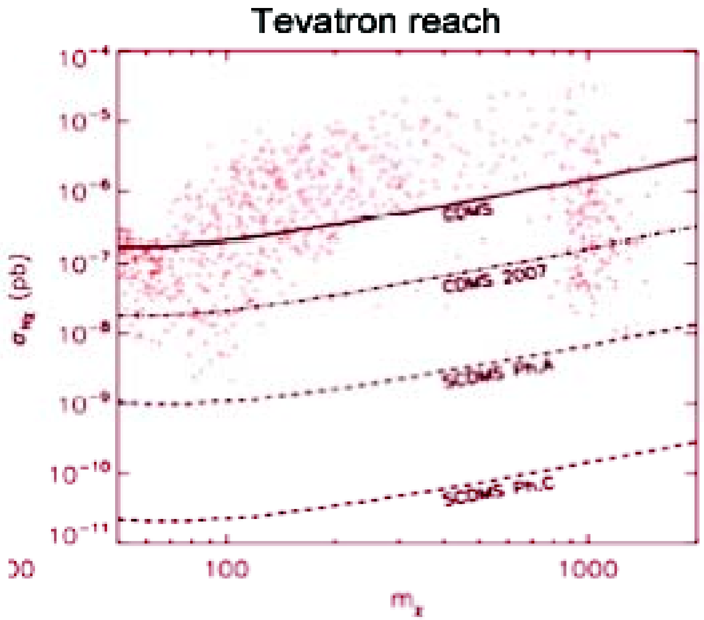
BIRKEDAL, MATCHEV, PERELSTEIN ,
FENG,SU, TAKAYAMA

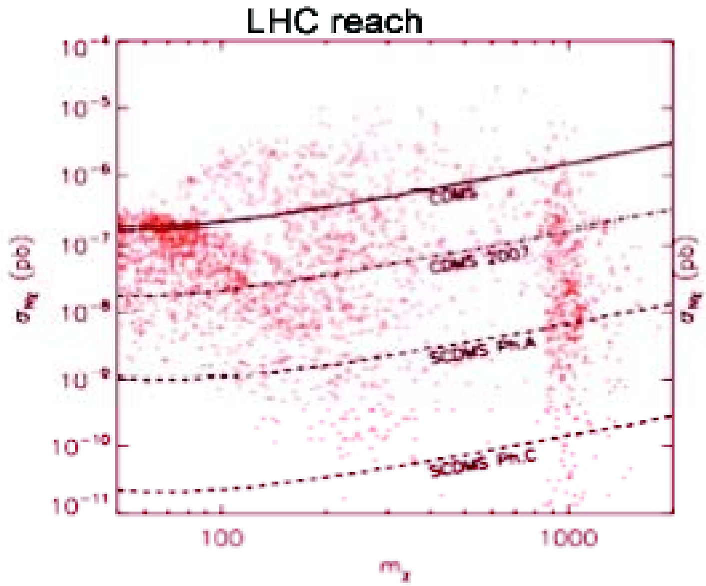
CDMS DM searches Vs the Tevatron and LHC H/A searches

- 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)

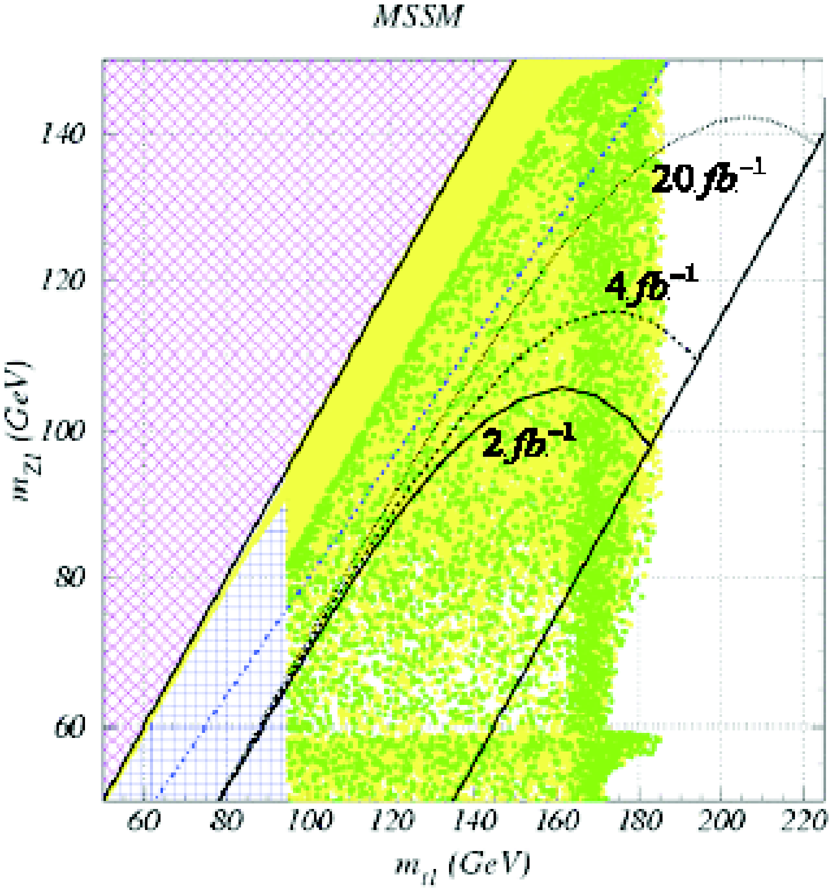




CARENA, HOOPER, VALLINOTTO 06

Tevatron stop searches and dark matter constraints

CARENA, BALAZS, WAGNER



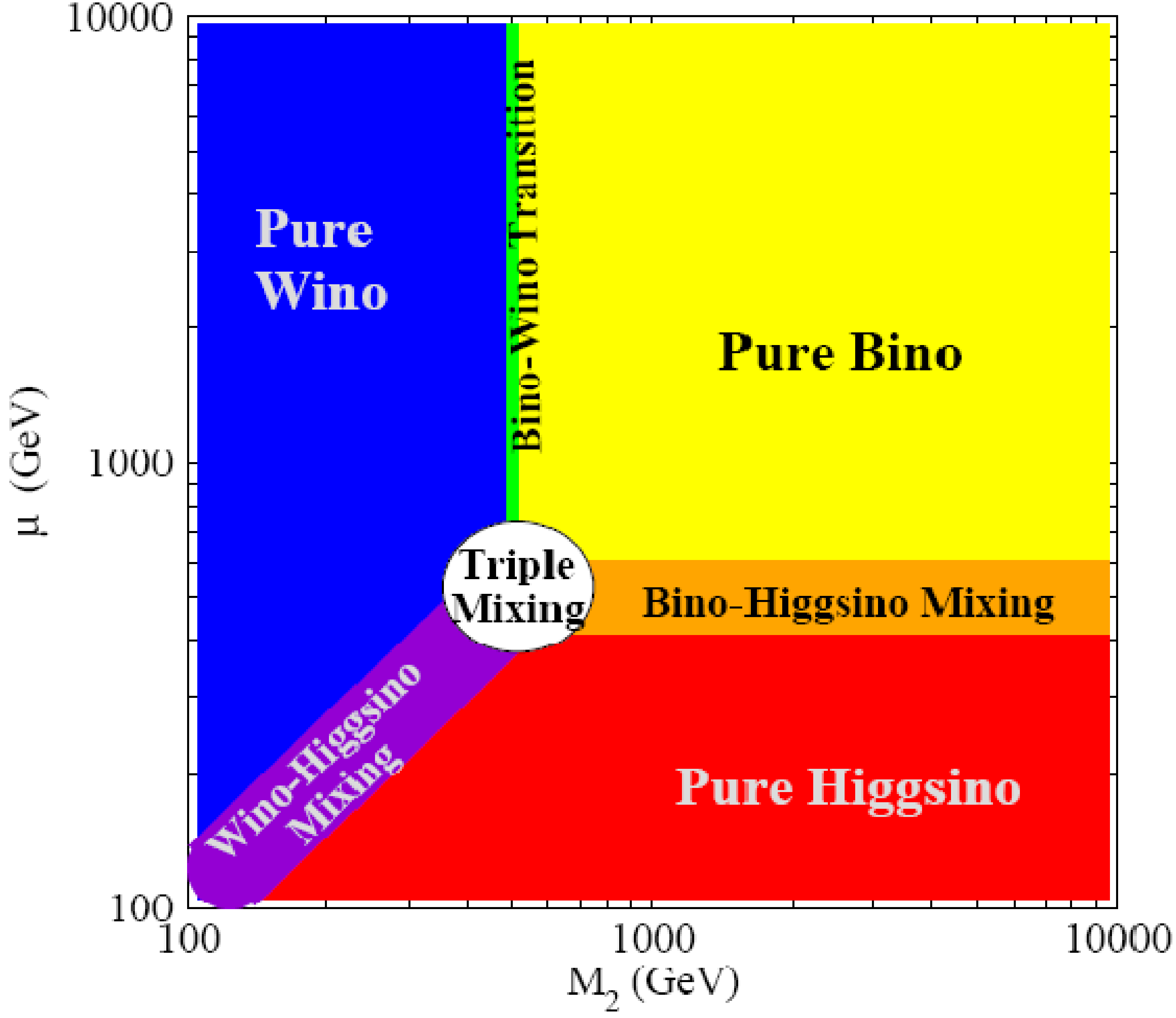
Green: Relic density consistent with WMAP measurements.

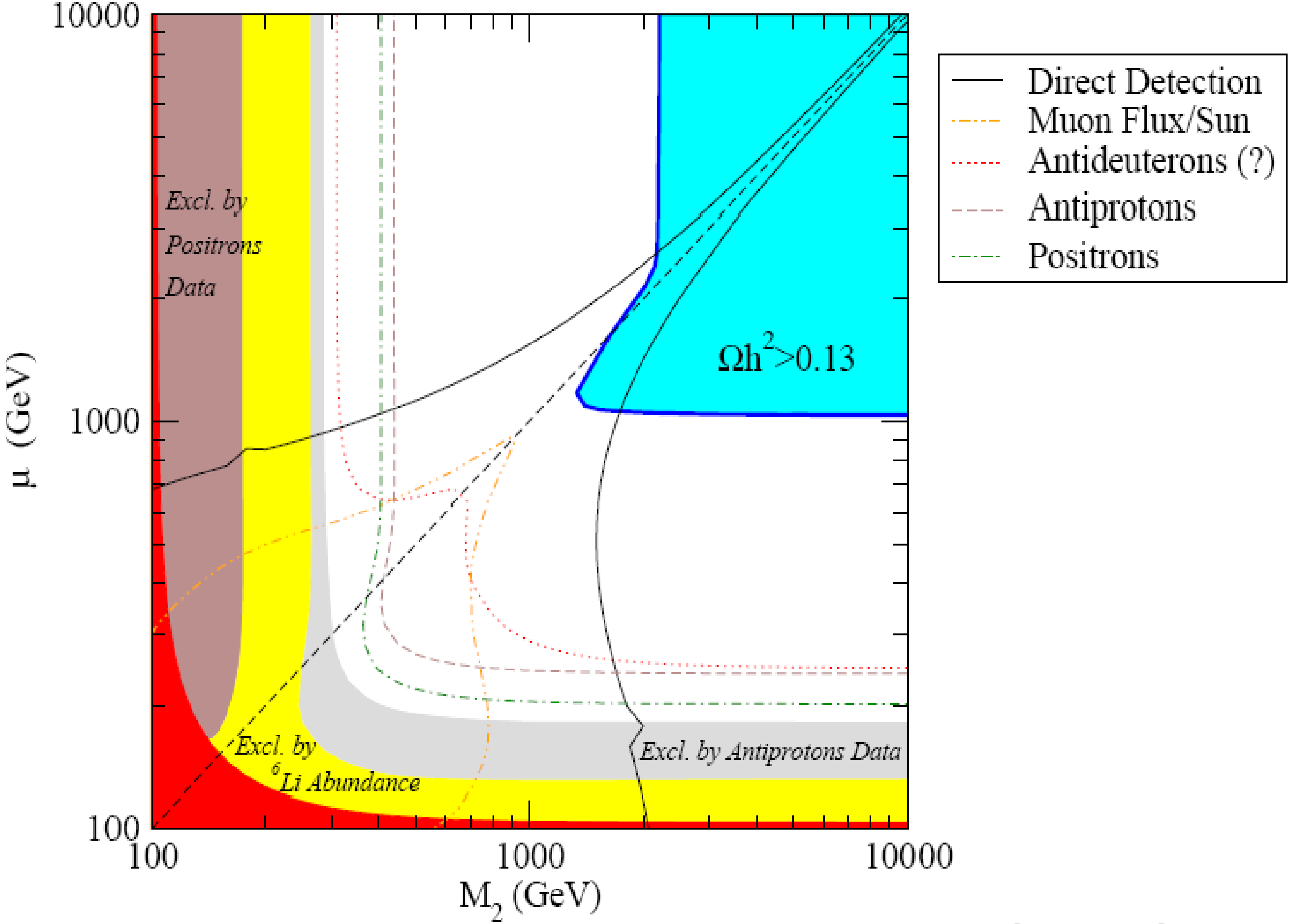
Searches for light stops difficult in stop-neutralino coannihilarion region.

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

Carena, Freitas et al. '05

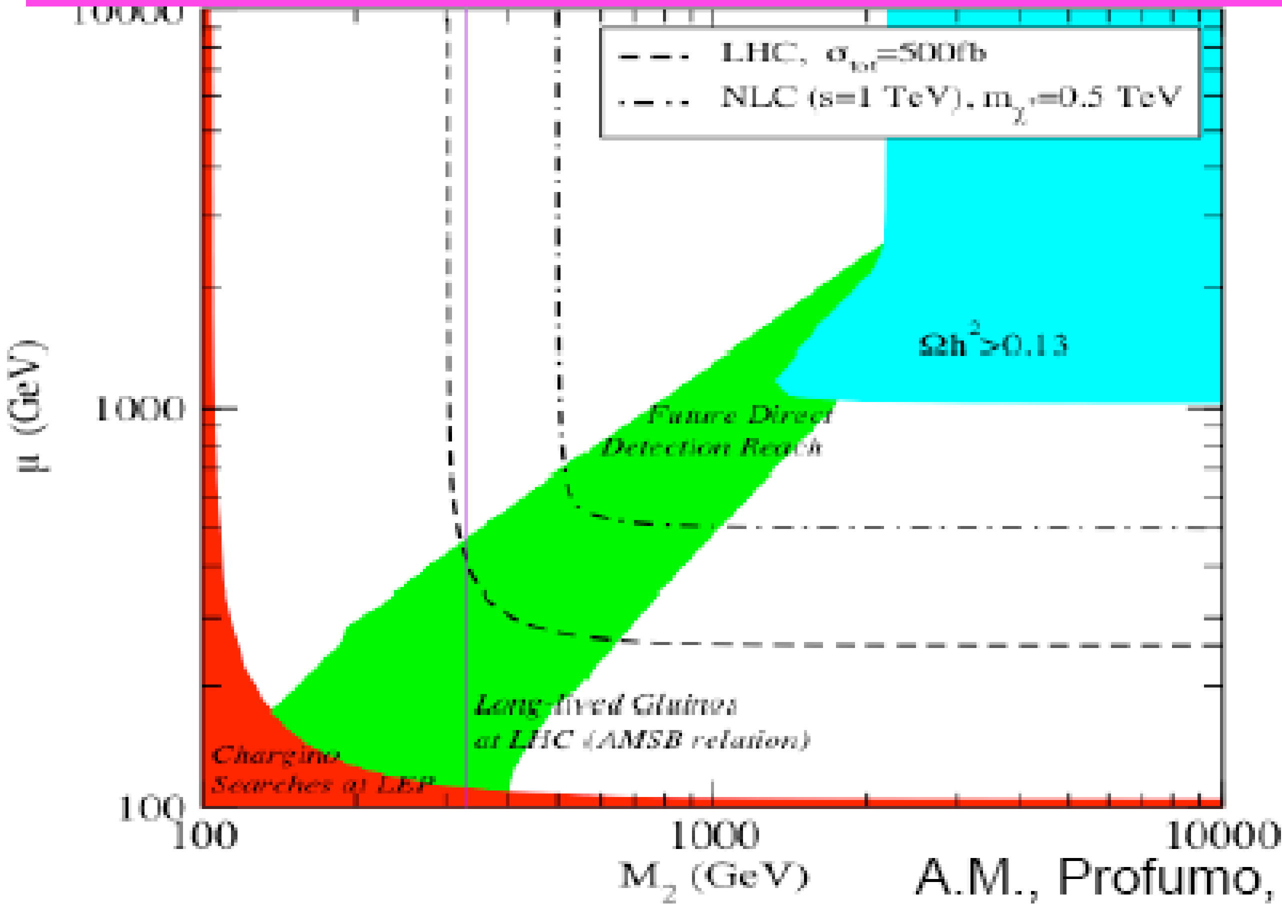
A.M., PROFUMO, ULLIO





A.M., PROFUMO,ULLIO

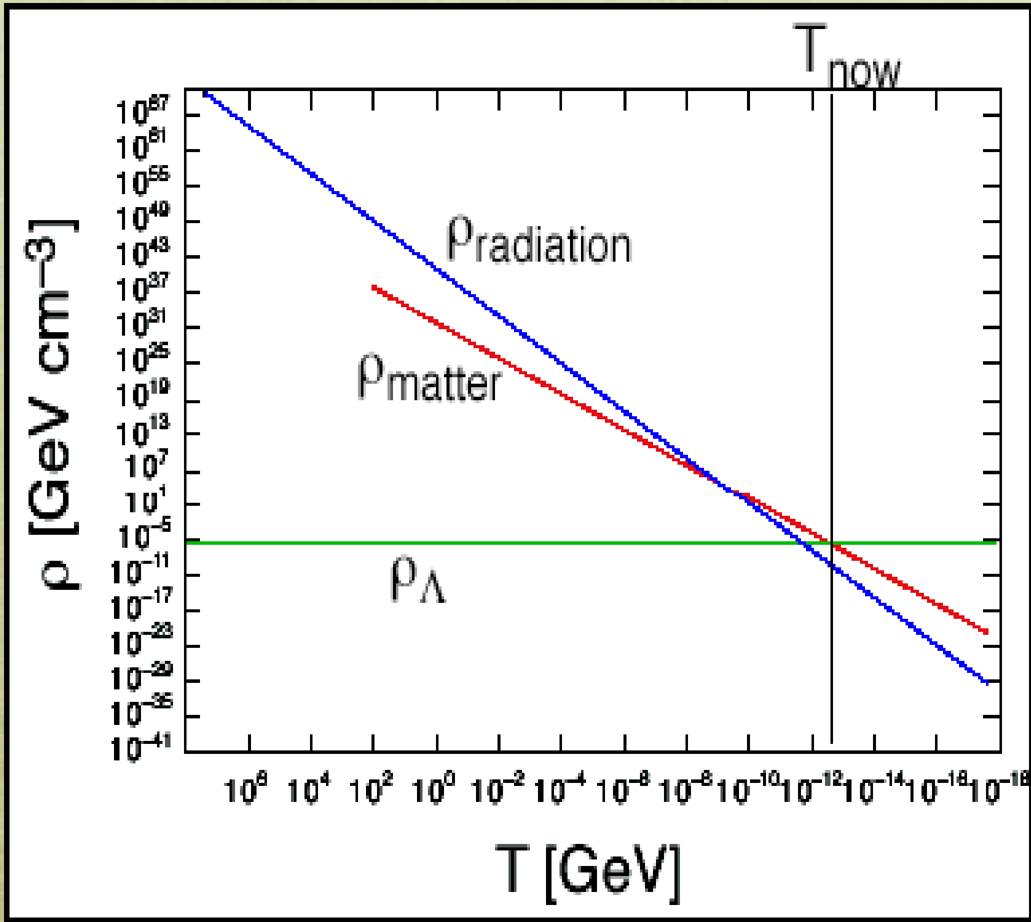
LHC, ILC, DM SEARCHES SENSITIVITIES



A.M., Profumo, Ullio

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

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

CDM CANDIDATES

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 (?)

UV COMPLETION OF THE SM AND THE ORIGIN OF THE ELW. SYMMETRY BREAKING

DYNAMICS RESPONSIBLE FOR ELW. SYMMETRY BREAKING

WEAKLY COUPLED

LIGHT HIGGS

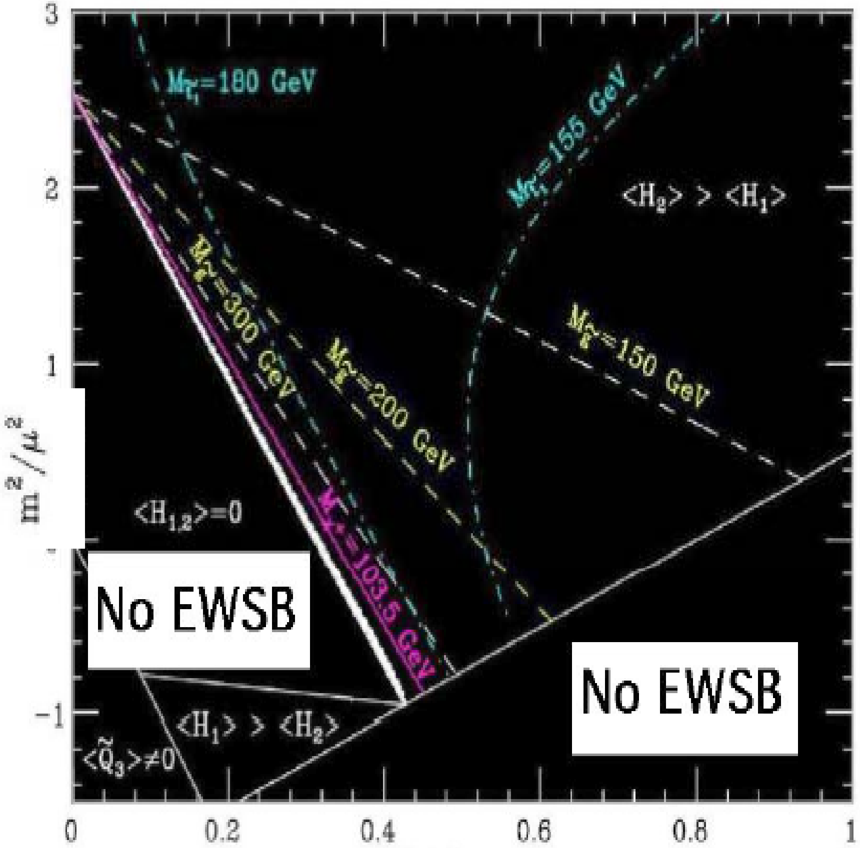
Favored by LEP1

STRONGLY COUPLED

NEW QCD SCALED AT 1 TEV

Disfavored by LEP1

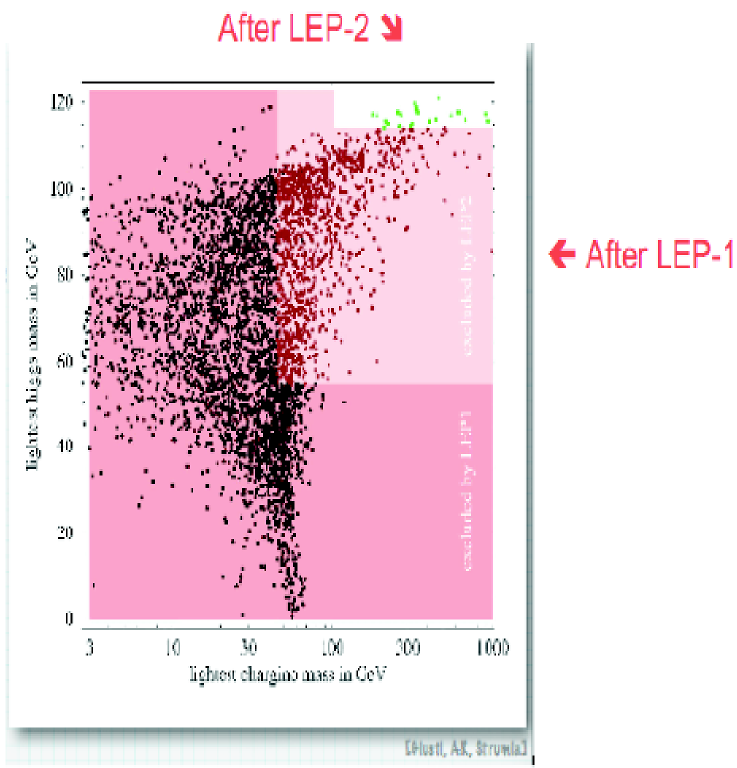
THE LOW-ENERGY SUSY TENSION between the UV COMPLETION SCALE and the POST-LEP SUSY EXCLUSIONS



M^2/μ^2

Giudice, Rattazzi

lightest Higgs mass (GeV)



lightest chargino mass (GeV)

Zwirner

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

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

Isidori

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

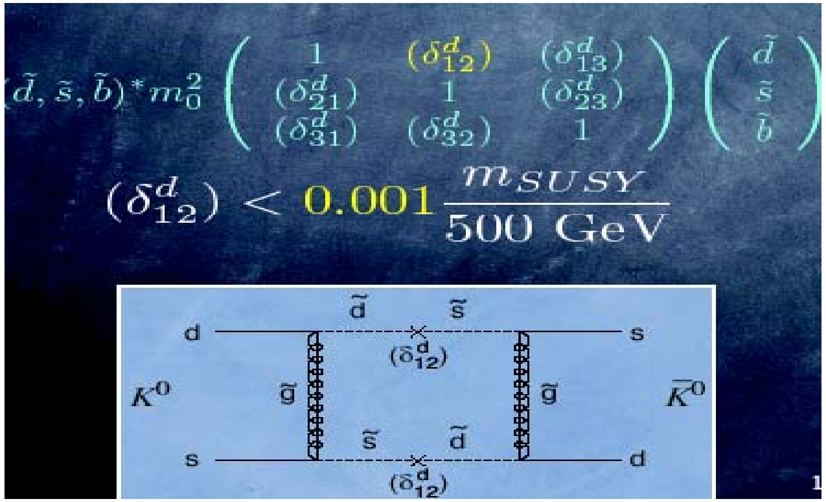
$\Lambda > 10^4\,\mathrm{TeV}$ for $O^{(6)} \sim (\bar{s}\,d)^2$

[K^0-$\bar{K}^0$ mixing]

$\Lambda > 10^3\,\mathrm{TeV}$ for $O^{(6)} \sim (\bar{b}\,d)^2$

[B^0-$\bar{B}^0$ mixing]

SUSY $\longrightarrow$



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

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 (?)

WHICH SUSY

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

$F = M_W M_{Pl}$

GRAVITY

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

MESSENGERS

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

GAUGE INTERACTIONS

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

OBSERVABLE SECTOR
SM + superpartners
MSSM : minimal content of superfields

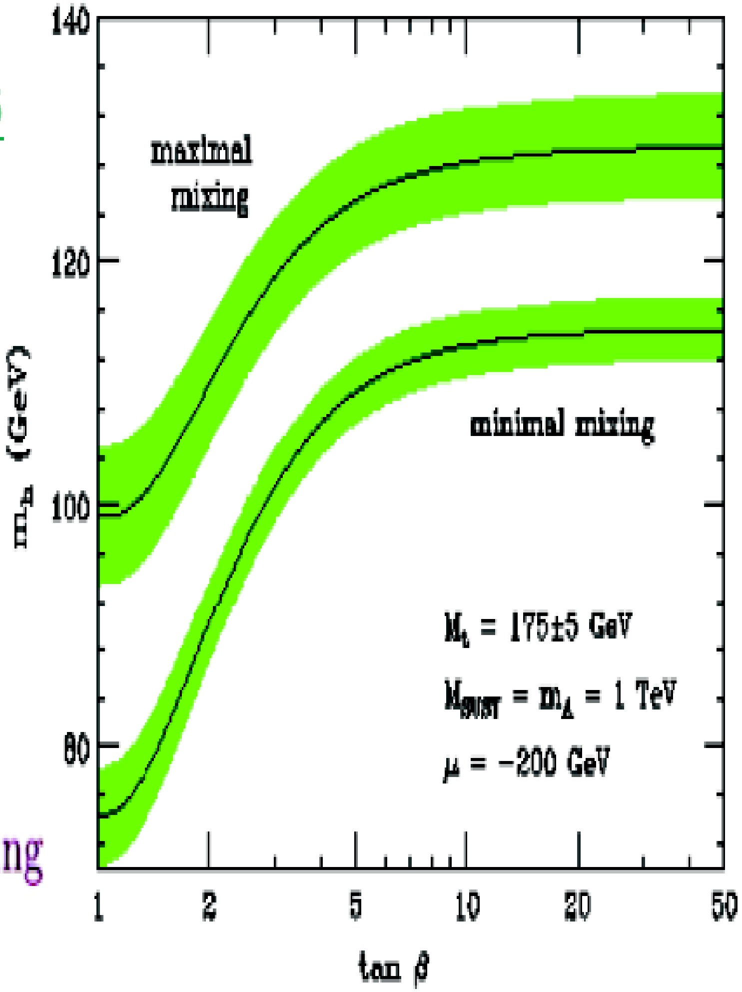
Carena

Radiative Corrections to Higgs Boson Masses

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

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

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



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

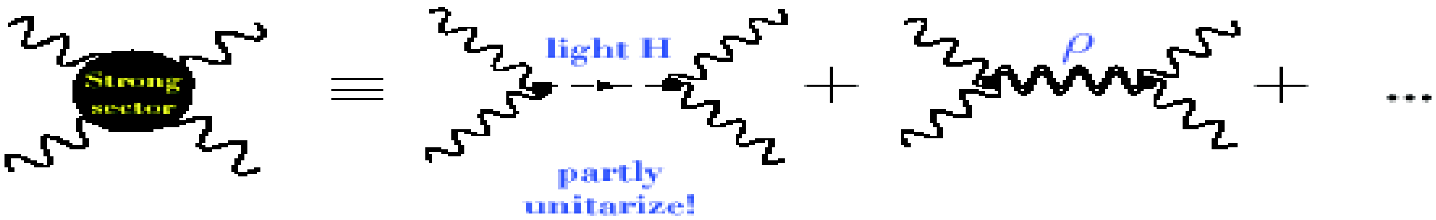
A 3rd way is possible: explored in the recent years

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)**

What we gain?

Giudice, Grojean, ALEX POMAROL,Rattazzi

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: $G \longrightarrow H$

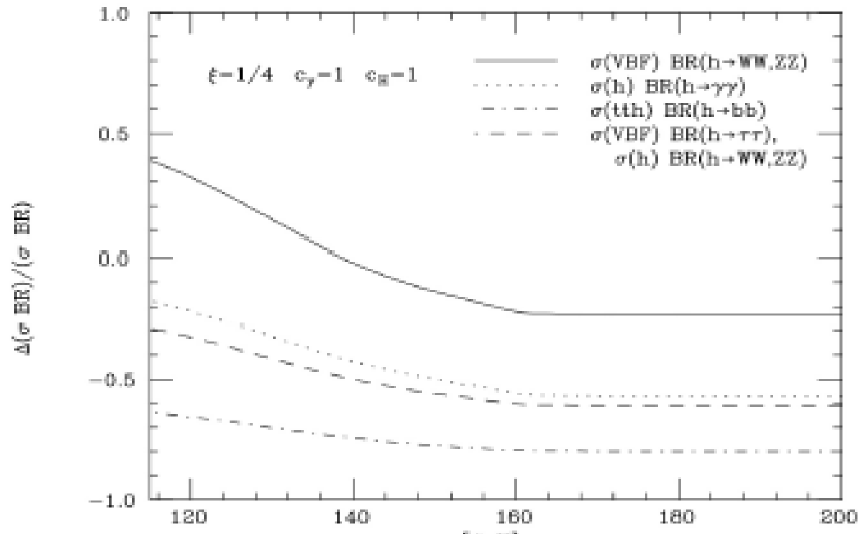
example: $SO(5) \longrightarrow SO(4)$

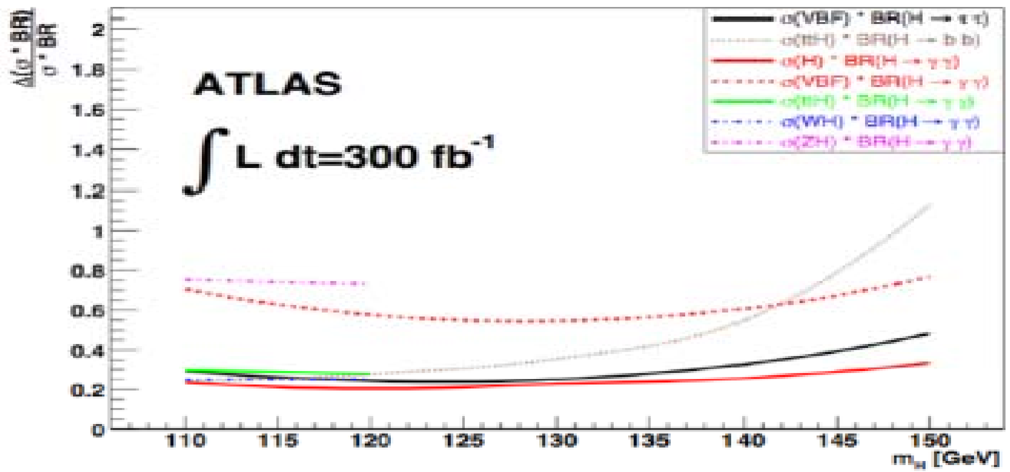
4 Goldstones= a doublet of SU(2) = Higgs

Higgs Mass protected by the global G-symmetry

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 %

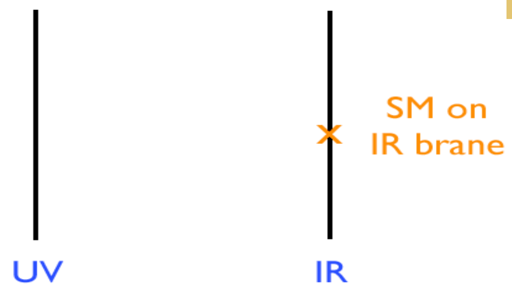
Warped Extra Dimension ➡ Explain hierarchies

5D metric ➡ IR = UV $e^{-\pi k R}$

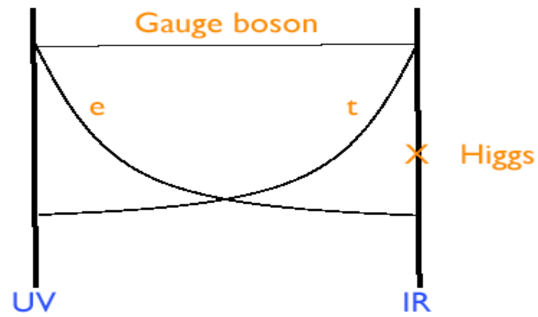
Toni Gheghetta

at Moriond 07

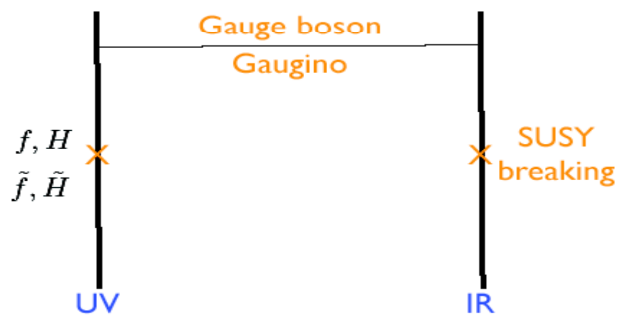
- Gauge hierarchy problem:
  Higgs mass [Randall, Sundrum 99]



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

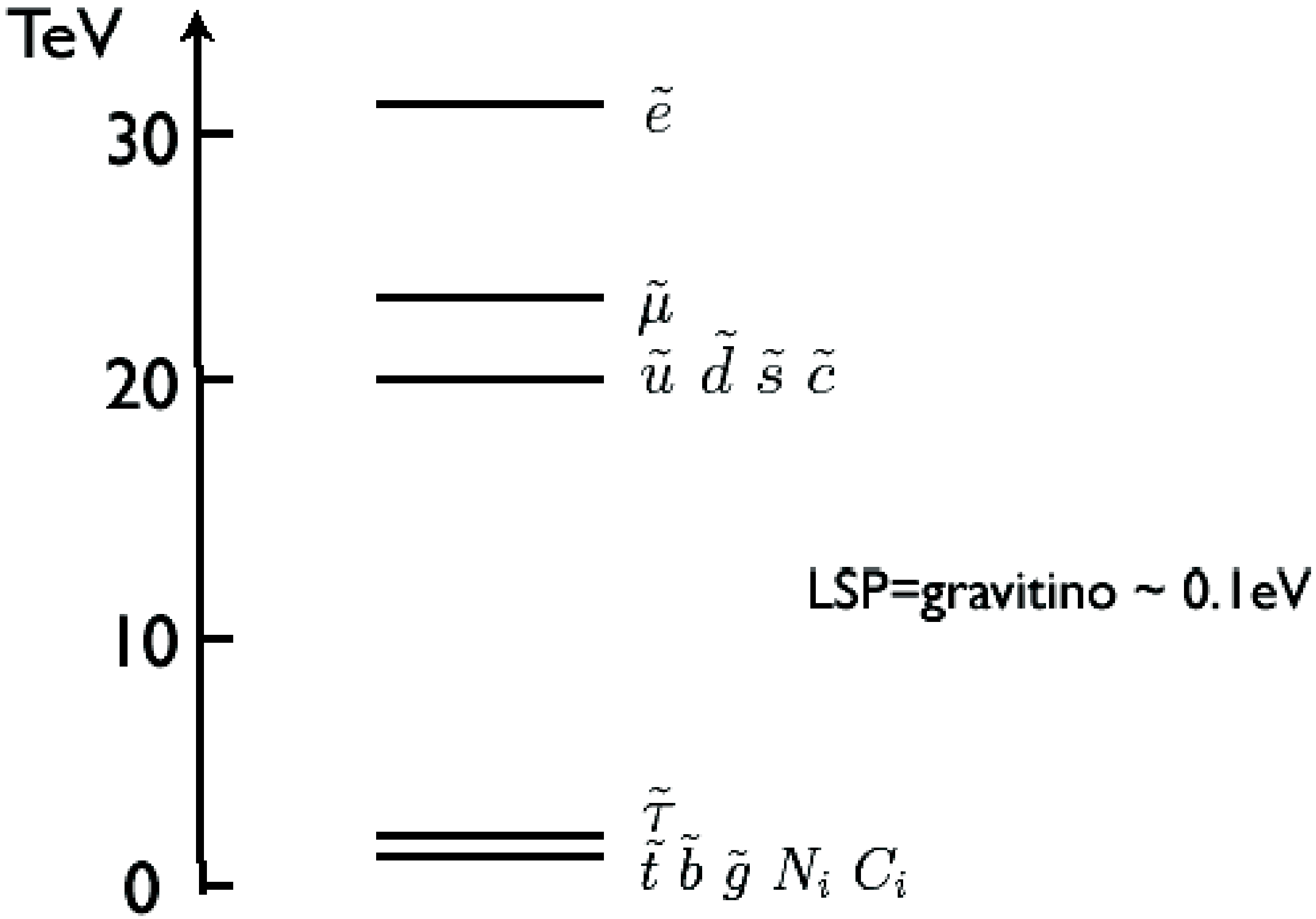


- SUSY-breaking scale
  e.g. Warped MSSM
  [TG, Pomarol 00]



GABELLA, GHERGHETTA, GIEDT

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:

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

Gabella et al.

TEVATRON → LHC → ILC

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 ≠, (g-2), $(\beta\beta)_{0\nu\nu}$

LFV