PPC 2010, TORINO, July 16, 2010,

OUTLOOK from the PARTICLE PHYSICS VIEWPOINT

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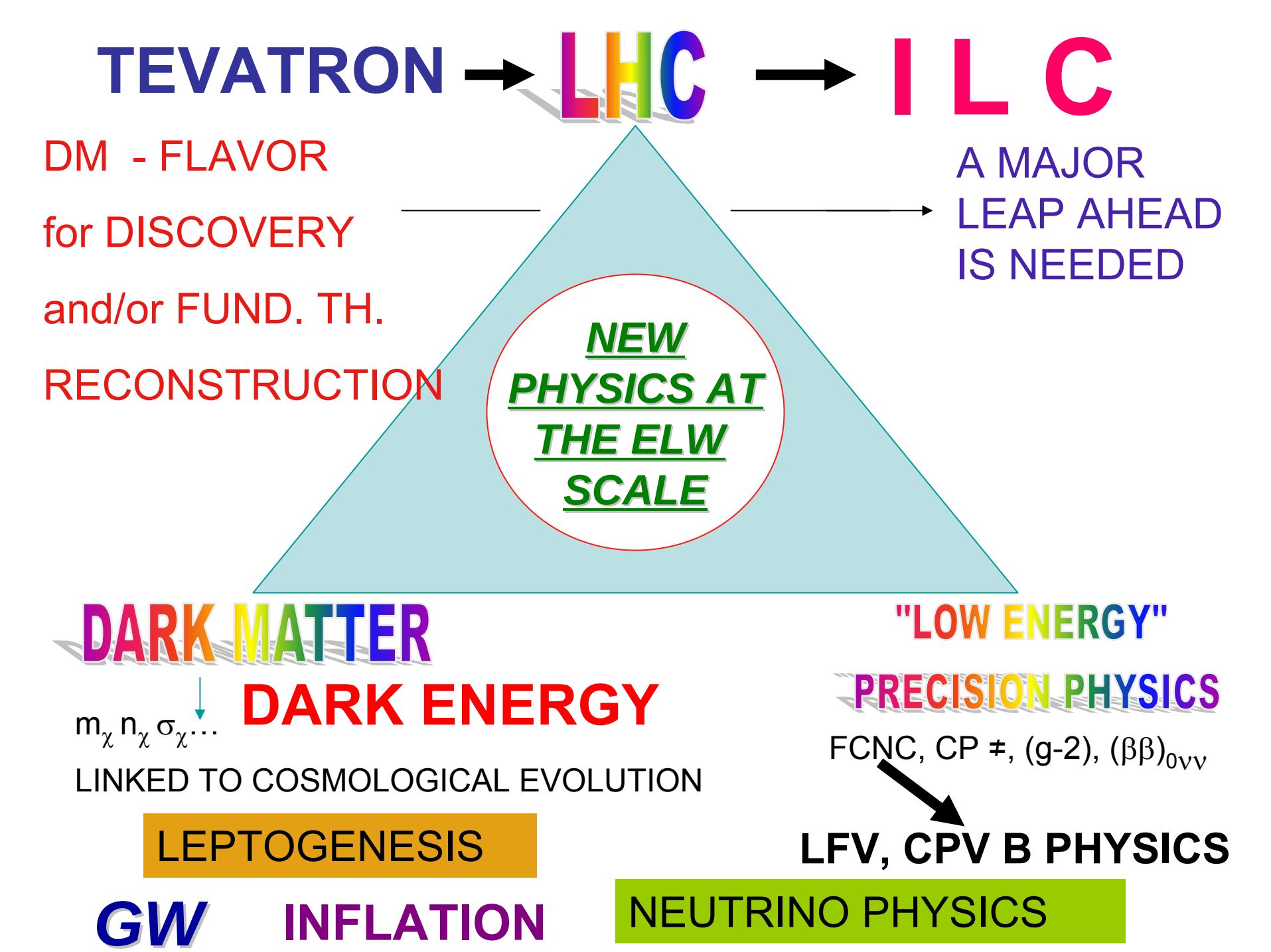

TEVATRON → LHC → I L C
DM - FLAVOR
for DISCOVERY
and/or FUND. TH.
RECONSTRUCTION
A MAJOR
LEAP AHEAD
IS NEEDED
NEW
PHYSICS AT
THE ELW
SCALE
DARK MATTER
DARK ENERGY
m_χ n_χ σ_χ…
LINKED TO COSMOLOGICAL EVOLUTION
"LOW ENERGY"
PRECISION PHYSICS
FCNC, CP ≠, (g-2), $(\beta\beta)_{0\nu\nu}$
LFV, CPV B PHYSICS
LEPTOGENESIS
NEUTRINO PHYSICS
GW
INFLATION

0. PROLOGUE

… no firm indication that some NEW PHYSICS sets in at the electroweak scale (i.e., with new particles and phenomena at the TeV mass scale) and

… yet, we are strongly convinced that **TeV New Physics** is present

WHY TO GO BEYOND THE SM

"OBSERVATIONAL" REASONS

- HIGH ENERGY PHYSICS

NO (but $A_{FB}^{Z \to bb}$……)

- FCNC, CP≠

NO (but CPV in the Bs…)

- 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

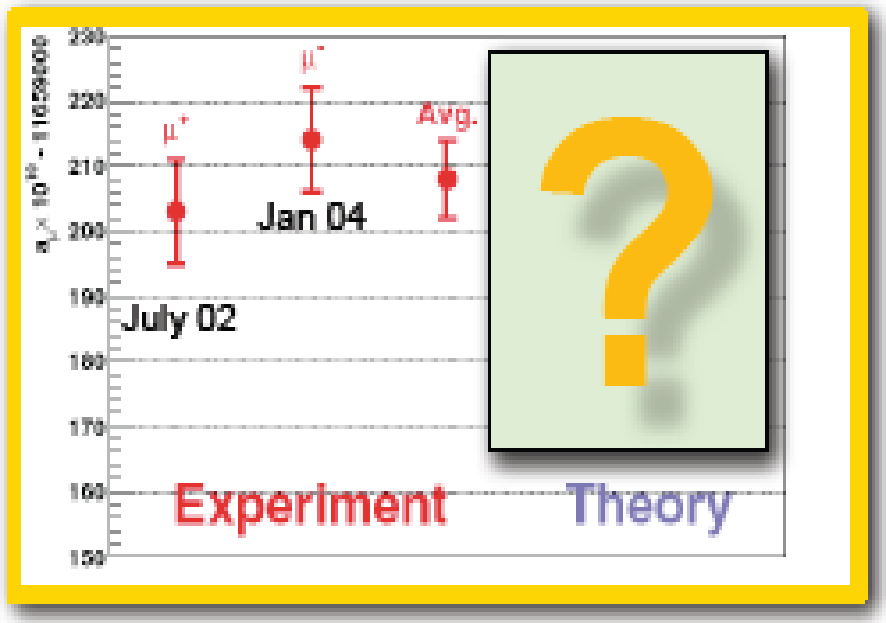
- INTRINSIC INCONSISTENCY OF SM AS QFT

NO (spont. broken gauge theory without anomalies)

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

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

The muon g-2: the experimental result



- Today (E821): $a_\mu^{EXP} = (116592089 \pm 54_{stat} \pm 33_{sys}) \times 10^{-11}$ [0.5ppm].
- Future: new muon g-2 experiments proposed at:
  - Fermilab (E969), aiming at 0.14ppm
  - J-PARC, aiming at 0.1 ppm

  [D. Hertzog & N. Saito, Paris meeting, Feb 2010]
- Are theorists ready for this (amazing) precision? [not yet]

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:

$a_\mu^{EXP} = 116592089\ (63) \times 10^{-11}$

E821 – Final Report: PRD73 (2006) 072
with latest value of $\lambda = \mu_\mu/\mu_p$ (CODATA'06)

	$a_\mu^{SM} \times 10^{11}$	$(\Delta a_\mu = a_\mu^{EXP} - a_\mu^{SM}) \times 10^{11}$	σ
[1]	116 591 782 (59)	307 (86)	3.6
[2]	116 591 834 (49)	255 (80)	3.2
[3]	116 591 773 (48)	316 (79)	4.0
[4]	116 591 929 (52)	160 (82)	2.0

with $a_\mu^{HHO}(lbl) = 105\ (26) \times 10^{-11}$

[1] F. Jegerlehner, A. Nyffeler, Phys. Rept. 477 (2009) 1
[2] Davier et al, Eur.Phys.J.C66 (2010) 1 (includes BaBar)
[3] HLMNT09: Hagiwara et al, arXiv:1001.5401
[4] Davier et al, Eur.Phys.J.C66 (2010) 127 (τ data).

Note that the th. error is now about the same as the exp. one

MICRO
PARTICLE PHYSICS

GWS STANDARD MODEL

MACRO
COSMOLOGY

HOT BIG BANG STANDARD MODEL

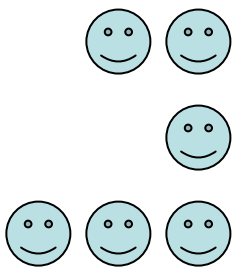
HAPPY MARRIAGE

Ex: **NUCLEOSYNTHESIS**

NUCLEAR ASTROPHYSICS

BUT ALSO

POINTS OF FRICTION



NEW SOURCE OF CP VIOLATION

- COSMIC MATTER-ANTIMATTER ASYMMETRY

- INFLATION ***NEW SCALAR POTENTIAL***

- DARK MATTER + DARK ENERGY

NEW PARTICLES AND INTERACTIONS

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

THEORETICAL REASONS TO GO BEYOND THE SM

- ***FLAVOR PUZZLE*** → **RATIONALE FOR FERMION MASSES AND MIXINGS**

- ***UNIFICATION PROBLEM*** → **NO REAL UNIF. OF ELW.+STRONG INTERACTIONS +GRAVITY LEFT OUT OF THE GAME**

- ***HIERARCHY PROBLEM(S)*** →
- **ULTRAVIOLET COMPLETION OF THE SM TO (NATURALLY) STABILIZE THE ELW. BREAKING SCALE**
- **TUNING OF THE COSMOLOGICAL CONSTANT**
- **STRONG CP PROBLEM (TUNING OF THE QCD θ ANGLE)**

SOMETHING is needed at the TeV scale to enforce the unitarity of the electroweak theory

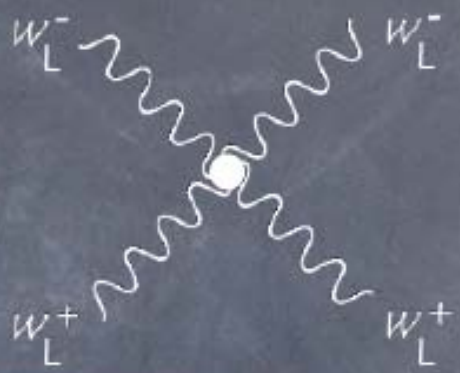
What is the mechanism of EWSB?

susy, LH... models assume that we already know the answer to

What is unitarizing the WW scattering amplitudes?

W_L & Z_L part of EWSB sector ⊃ W scattering is a probe of Higgs sector interactions

$$\epsilon_l = \left(\frac{|\vec{k}|}{M}, \frac{E}{M} \frac{\vec{k}}{|\vec{k}|} \right)$$



$$\mathcal{A} = g^2 \left(\frac{E}{M_W} \right)^2$$

loss of perturbative unitarity around 1.2 TeV

Weakly coupled models

prototype: Susy

susy partners ~ 100 GeV

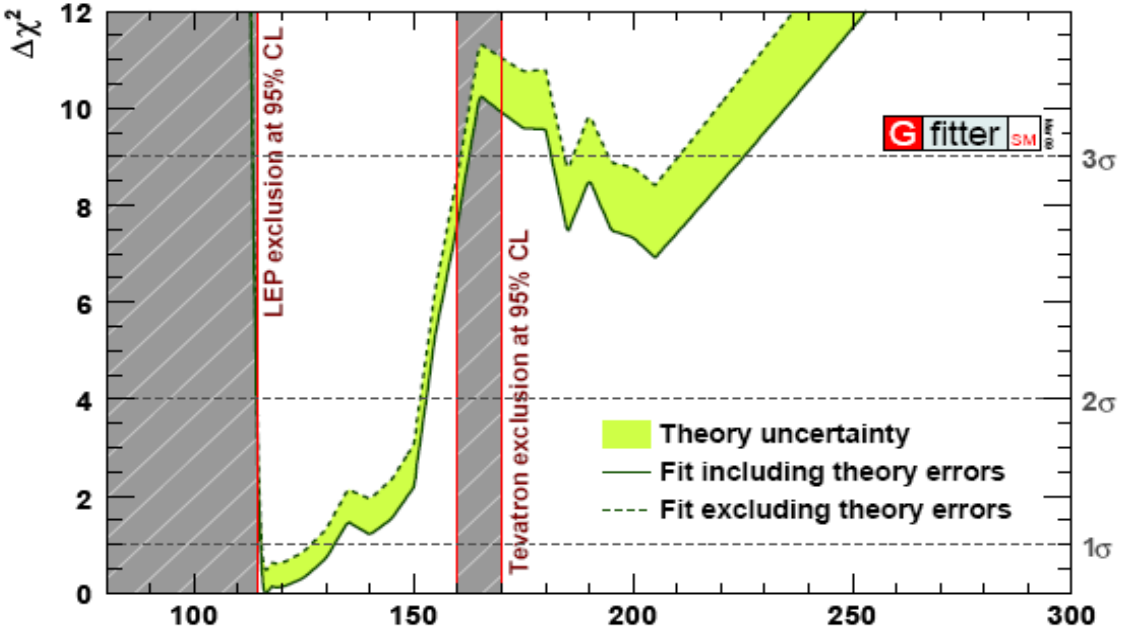
Strongly coupled models

prototype: Technicolor

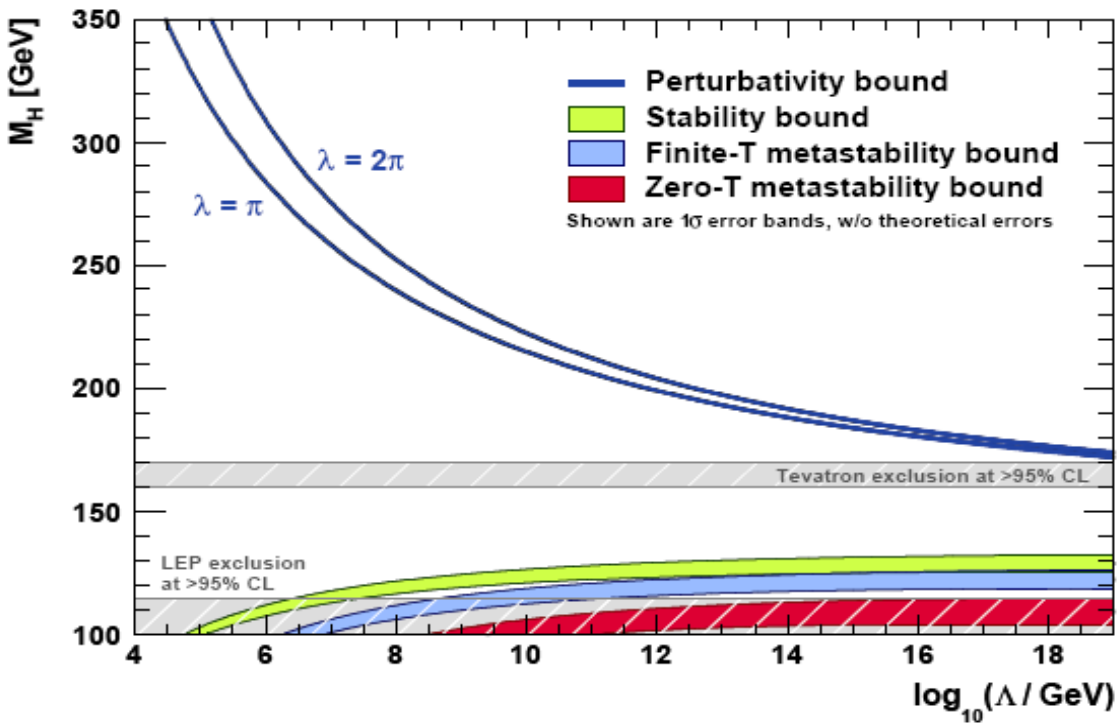
rho meson ~ 1 TeV

Different signatures at the LHC!

Grojean



a light higgs (or something mimicking it) is definitely favored



the big desert between the TeV and the GUT scales only if the higgs is a narrow band between 130 and 180

Ellis, Espinosa, Giudice, Hoecker, Riotto

Is it possible that there is "only" a light higgs boson and no NP?

- **This is acceptable if one argues that no ultraviolet completion of the SM is needed at the TeV scale** simply because there is **no actual fine-tuning related to the higgs mass stabilization** (**the correct value of the higgs mass is "environmentally" selected**). This explanation is similar to the one adopted for the cosmological constant

- Barring such wayout, **one is lead to have TeV NP to ensure the unitarity of the elw. theory at the TeV scale**

THE LITTLE HIERARCHY PROBLEM

SUSY CASE

$$m_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \ln \frac{m_{stop}^2}{m_t^2}$$

$$m_h > 115 \text{ GeV} \quad \Rightarrow \quad m_{stop} \geq O(1 \text{ TeV})$$

$$\frac{1}{2}M_Z^2 \approx -(m_{H_u}^2 + \mu^2)|_{tree} + 0.1 M_{SUSY}^2 \ln \frac{\Lambda_{MSSM}}{M_{SUSY}}$$

10^{-2}TeV vs $O(1)\text{TeV}|_{tree} + O(1)\text{TeV}$

% FINE-TUNING FOR THE NEW PHYSICS AT THE ELW. SCALE

- **Elementary Higgs** →In the **MSSM** % fine-tuning among the SUSY param. to avoid light SUSY particles which would have been already seen at LEP and Tevatron

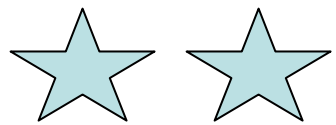
- **Elementary Higgs** → **PSEUDO-GOLDSTONE boson in the LITTLE HIGGS model** → Λ^2 div. cancelled by new colored fermions, new W,Z, γ, 2Higgs doublets… → % fine-tuning to avoid too large elw. Corrections

- **COMPOSITE HIGGS** in **a 5-dim**. holographic theory (Higgs is a PSEUDO-GOLDSTONE boson and the elw. symmetry breaking is triggered by bulk effects (in 5 dim. the theory is **WEAKLY** coupled, but in 4 dim. the bulk looks like a **STRONGLY** coupled sector) → also here % fine-tuning needed to survive the elw. precision tests

GENERAL FEATURES OF NEW PHYSICS AT THE ELW. SCALE

- Some amount of **fine-tuning** (typically at the % level) is required to pass unscathed the elw. precision tests, the higgs mass bound and the direct search for new particles at accelerators.
- The **higgs is typically rather light** (<200 GeV) apart from the extreme case of the “Higgsless proposal”
- All models provide **signatures which are (more or less) accessible to LHC physics** (including the higgsless case where new KK states are needed to provide the unitarity of the theory)

1. Present "Observational" Evidence for New Physics

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

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. Connection to LFV, too?

- 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**)

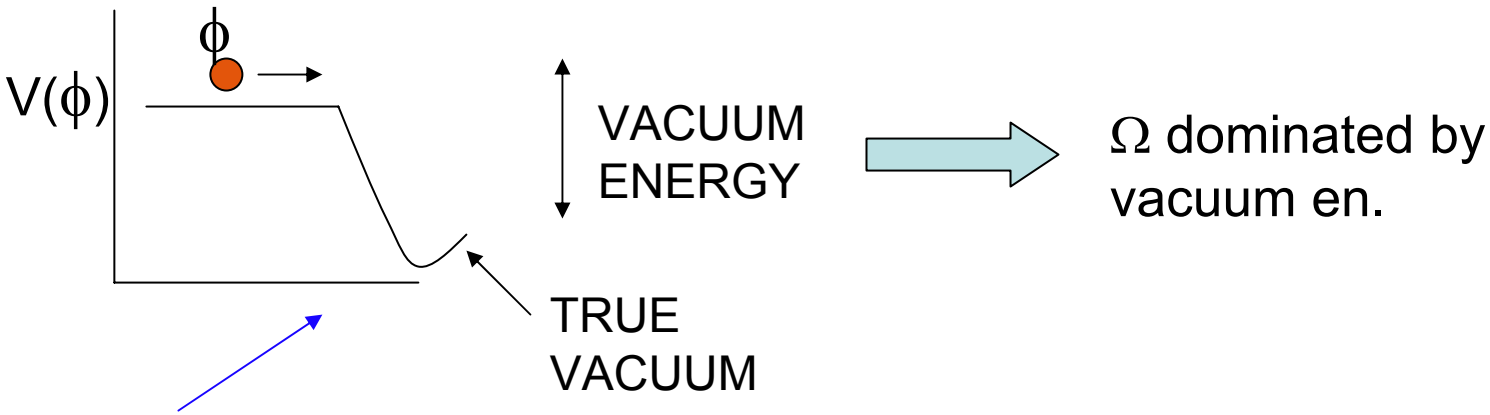
INFLATION

SEVERE COSMOGICAL PROBLEMS

- **CAUSALITY** (isotropy of CMBR)
- **FLATNESS** (Ω close to 1 today)
- **AGE OF THE UNIV.**
- **PRIMORDIAL MONOPOLES**

COMMON SOLUTION FOR THESE PROBLEMS

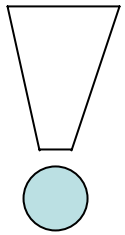
VERY FAST (EXPONENTIAL) EXPANSION IN THE UNIV.



Ω dominated by vacuum en.

NO WAY TO GET AN "INFLATIONARY SCALAR POTENTIAL" IN THE STANDARD MODEL

NO ROOM IN THE PARTICLE PHYSICS STANDARD MODEL FOR INFLATION



$V=\mu^2 \phi^2 + \lambda\phi^4 \longrightarrow$ no inflation

Need to extend the SM scalar potential

Ex: GUT's, SUSY GUT's,…

ENERGY SCALE OF "INFLATIONARY PHYSICS":

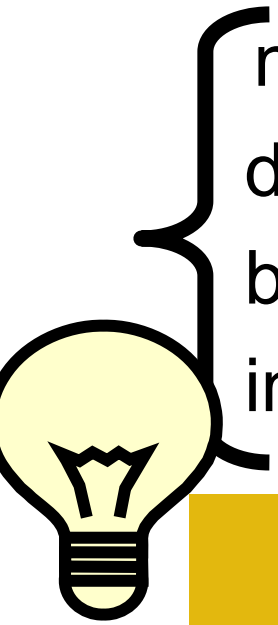
LIKELY TO BE » Mw

DIFFICULT BUT NOT IMPOSSIBLE TO OBTAIN ELECTROWEAK INFLATION IN SM EXTENSIONS

For some inflationary models → large amount of primordial gravitational waves

2. COULD (AT LEAST SOME OF) THE "OBSERVATIONAL" NEW PHYSICS BE LINKED TO THE ULTRAVIOLET COMPLETION OF THE SM AT THE ELW. SCALE ?

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**

3. THE DM ROAD TO NEW PHYSICS BEYOND THE SM:

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

CONNECTION DM – ELW. SCALE

THE WIMP MIRACLE :STABLE ELW. SCALE WIMPs

	SUSY	**EXTRA DIM.**	**LITTLE HIGGS.**
1) **ENLARGEMENT OF THE SM**	(x^μ, θ) Anticomm. Coord.	(x^μ, j^i) New bosonic Coord.	SM part + new part 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

IS THE "*WIMP MIRACLE*" AN **ACTUAL MIRACLE?**

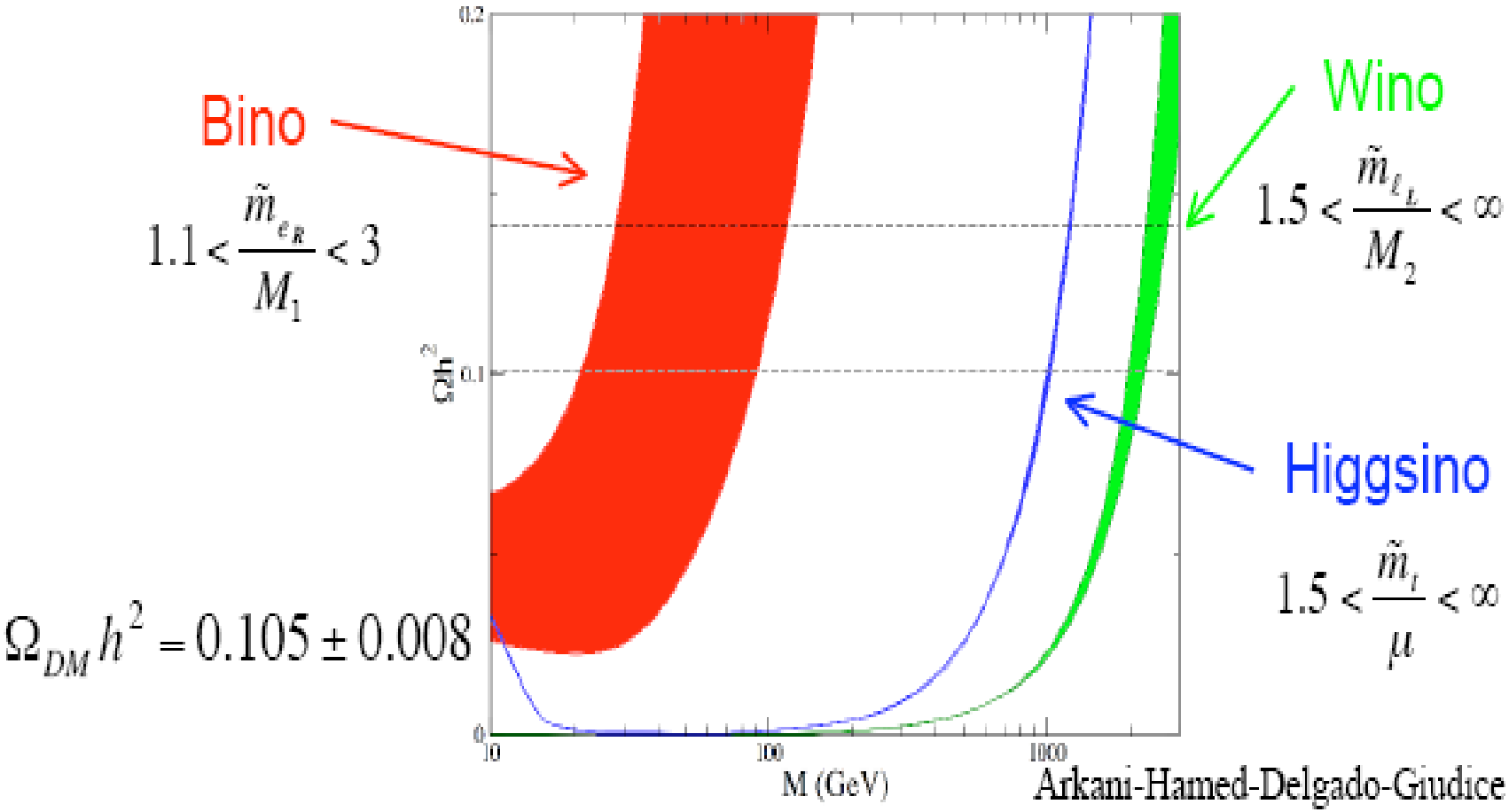
USUAL STATEMENT

Many possibilities for DM candidates, but WIMPs are really special: peculiar coincidence between particle physics and cosmology parameters to provide a VIABLE DM CANDIDATE AT THE ELW. SCALE

HOWEVER

when it comes to quantitatively reproduce the precisely determined DM density → once again the fine-tuning threat…

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



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

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**

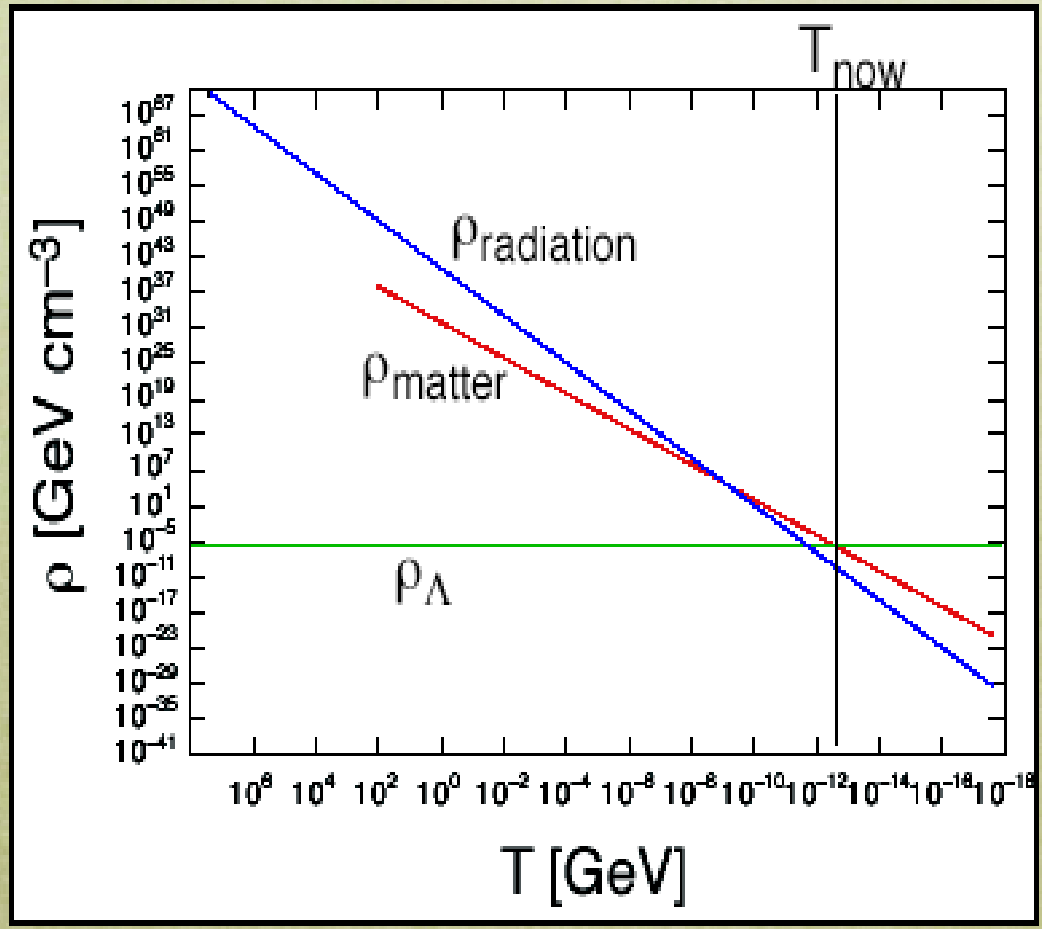
Modifications of the standard picture of
WIMPs FREEZE - OUT

CDM CANDIDATES

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

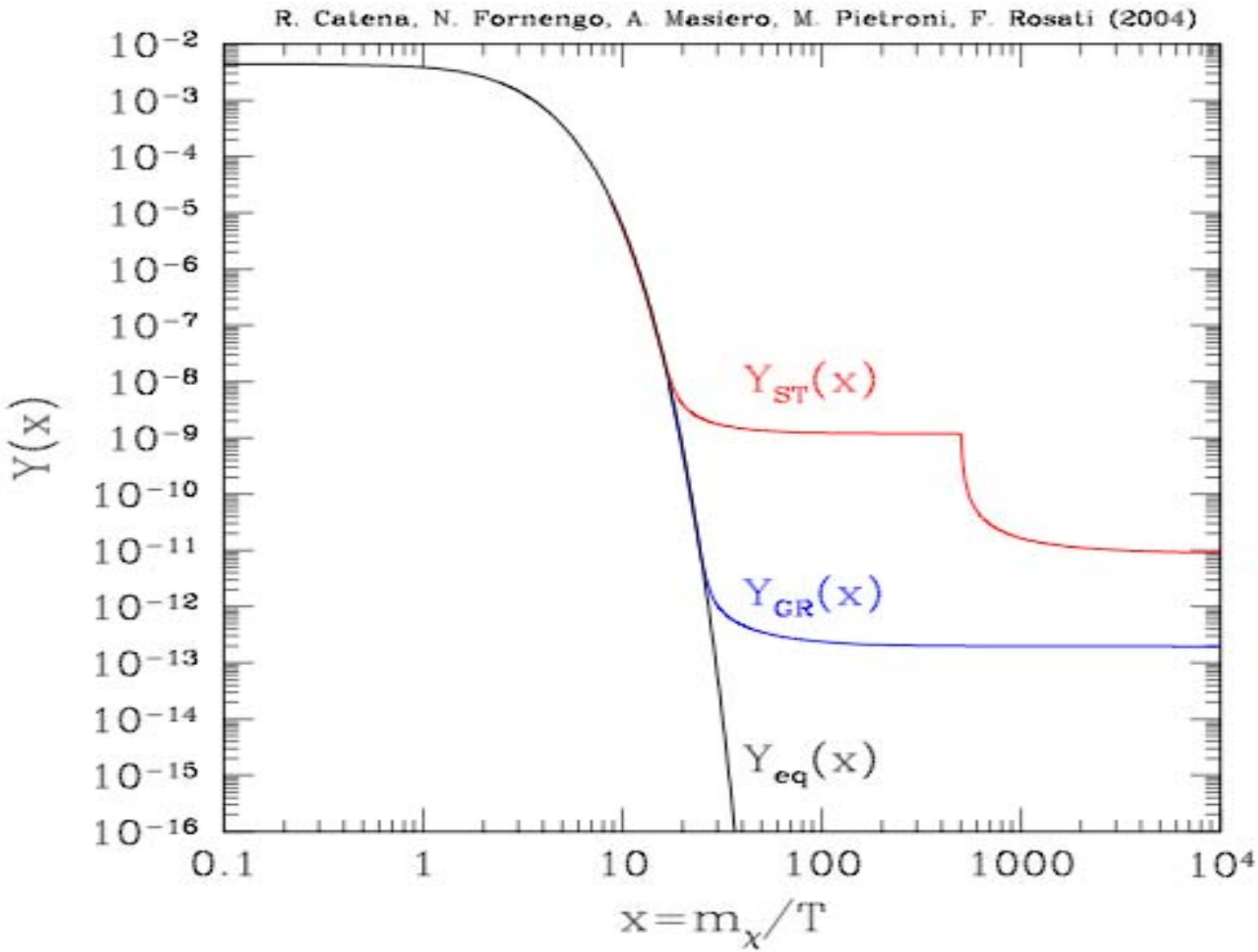
THE "WHY NOW" PROBLEM

- *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

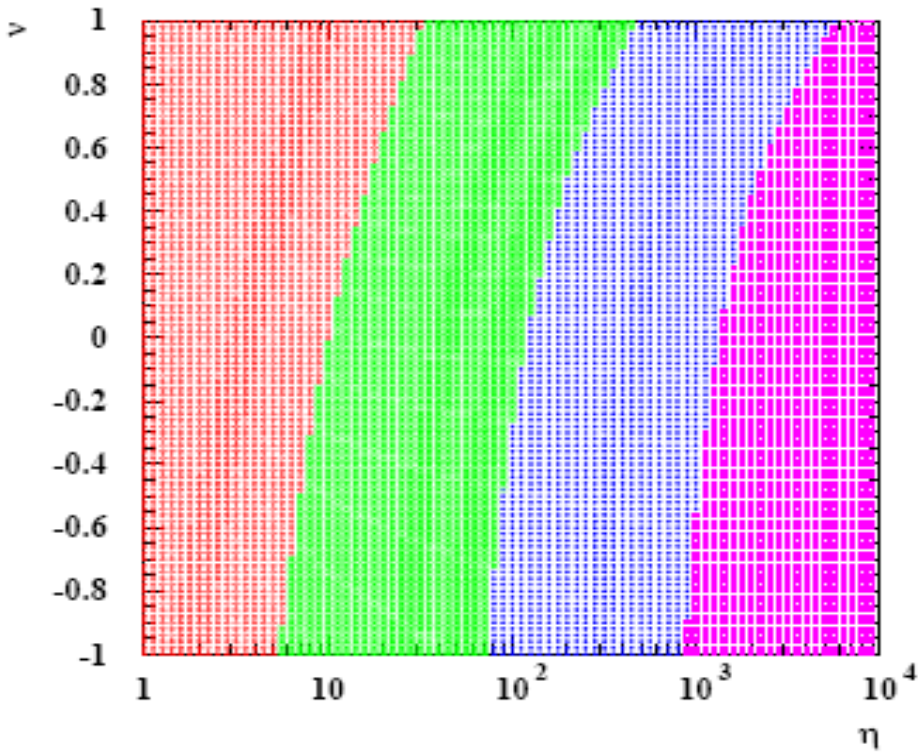
NEUTRALINO RELIC ABUNDANCE IN GR AND S-T THEORIES OF GRAVITY

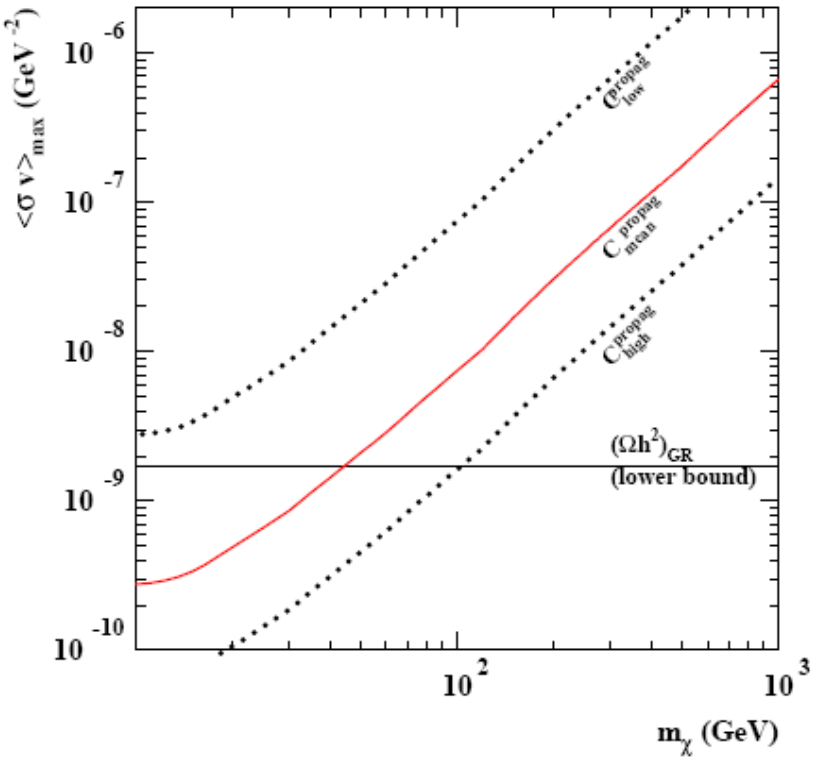


$$H = A(T) H_{\rm std} \qquad \text{at early times}$$

$$H = H_{\rm std} \qquad \text{at later times}$$

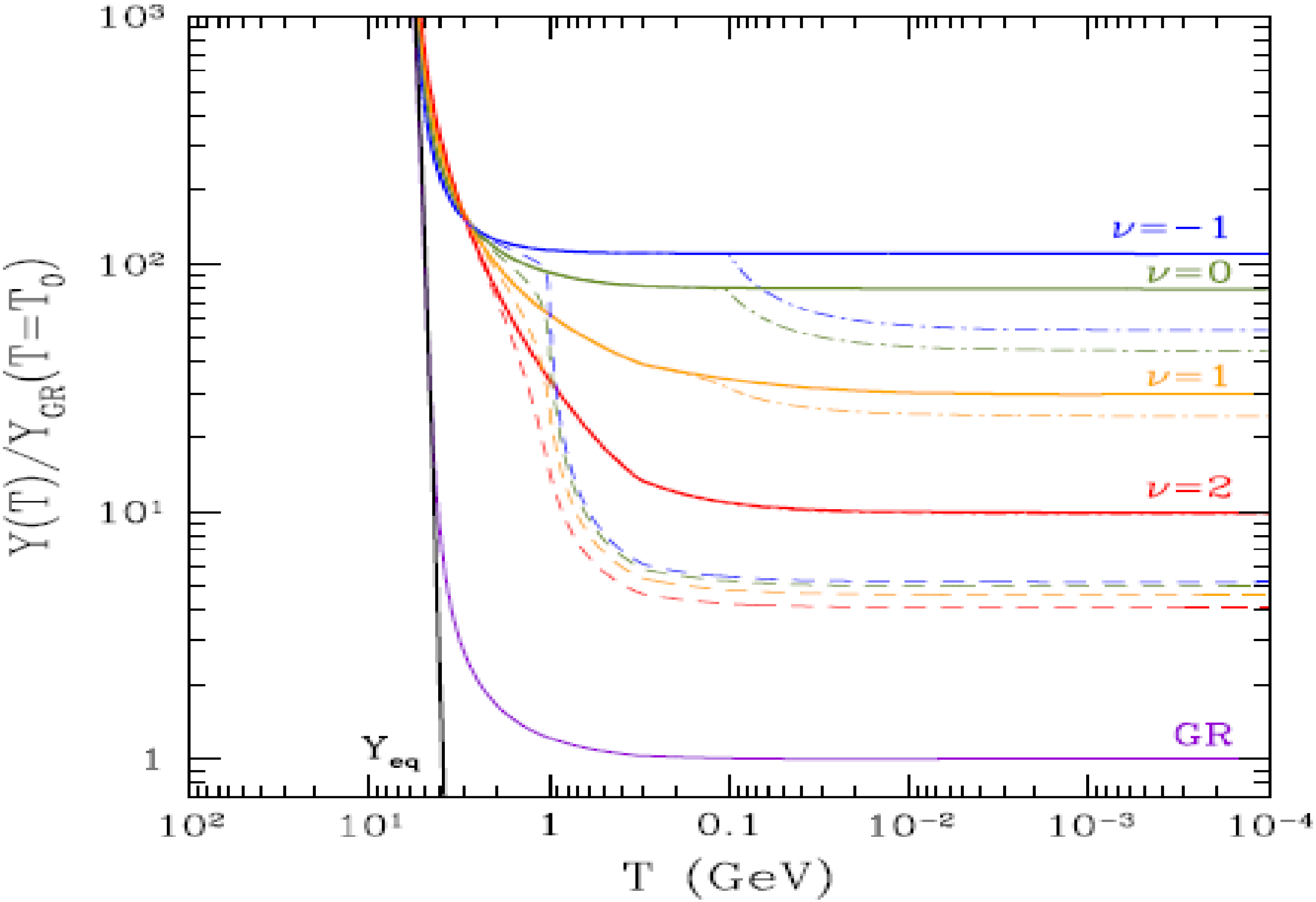
$$A(T) = 1 + \eta \left(\frac{T}{T_{\rm f}} \right)^{\nu} \tanh \left(\frac{T - T_{\rm re}}{T_{\rm re}} \right)$$



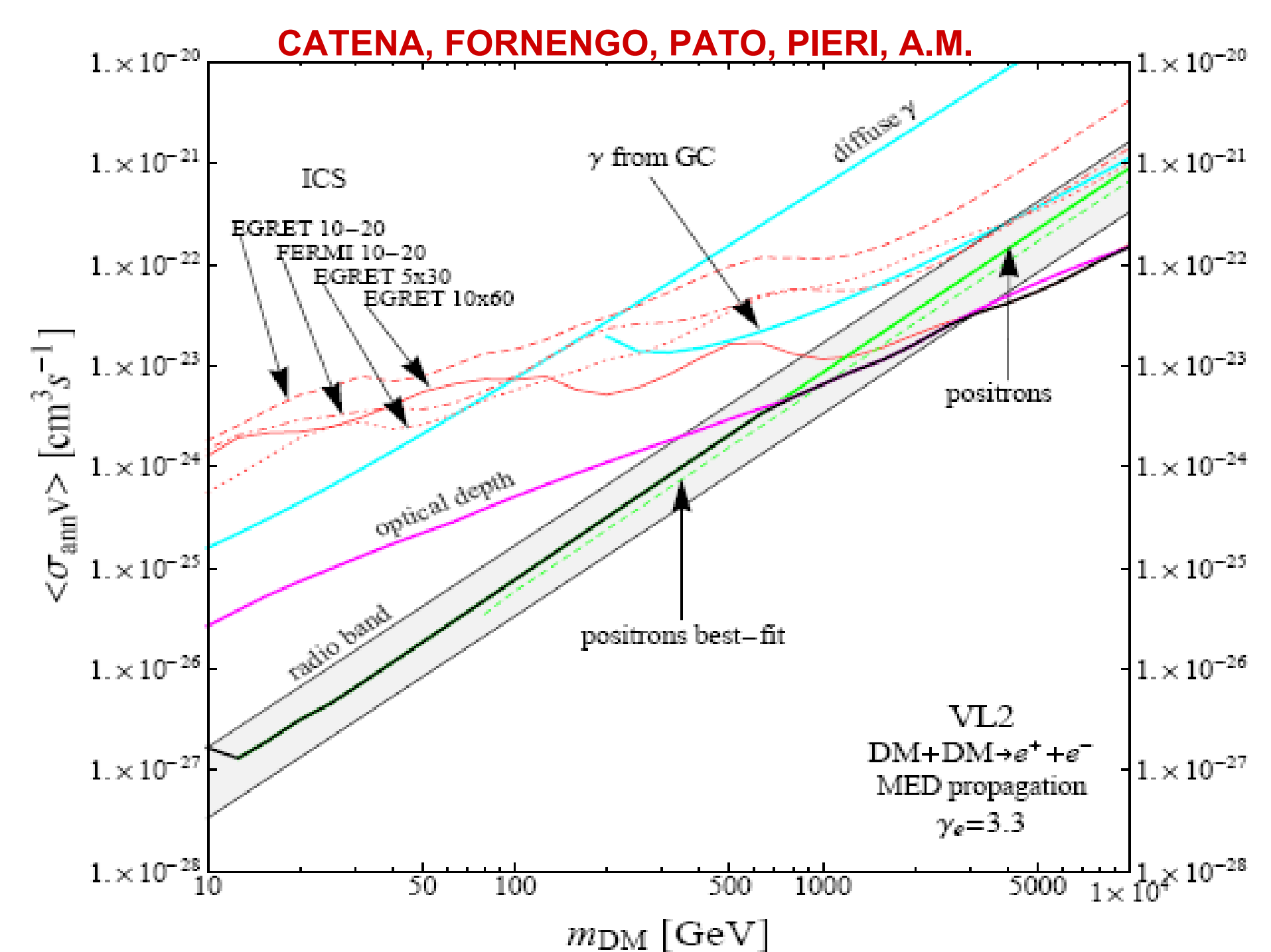


SCHELKE, CATENA, FORNENGO, A.M., PIETRONI

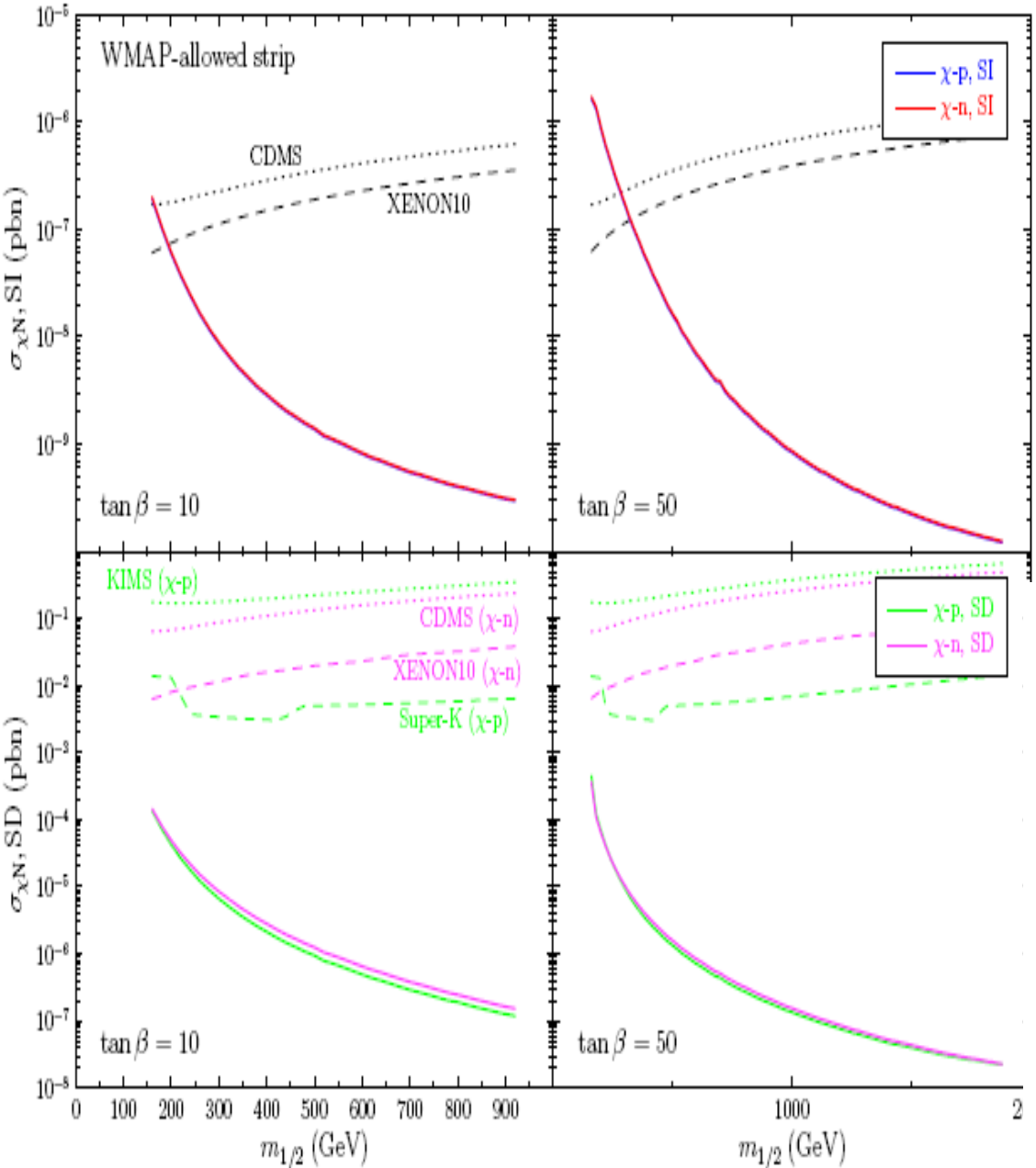
CATENA, FORNENGO, PATO, PIERI, A.M.



CATENA, FORNENGO, PATO, PIERI, A.M.



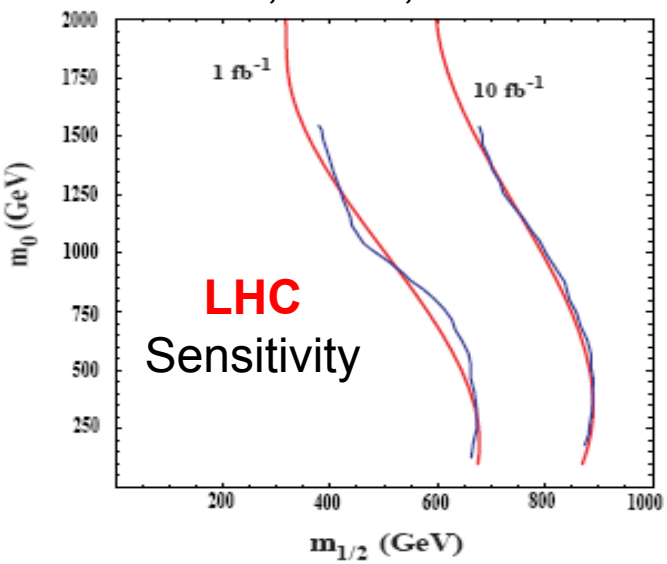
Neutralino-nucleon scattering cross sections along the WMAP-allowed coannihilation strip for tanbeta=10 and coannihilation/funnel strip for tanbeta=50 using the hadronic parameters



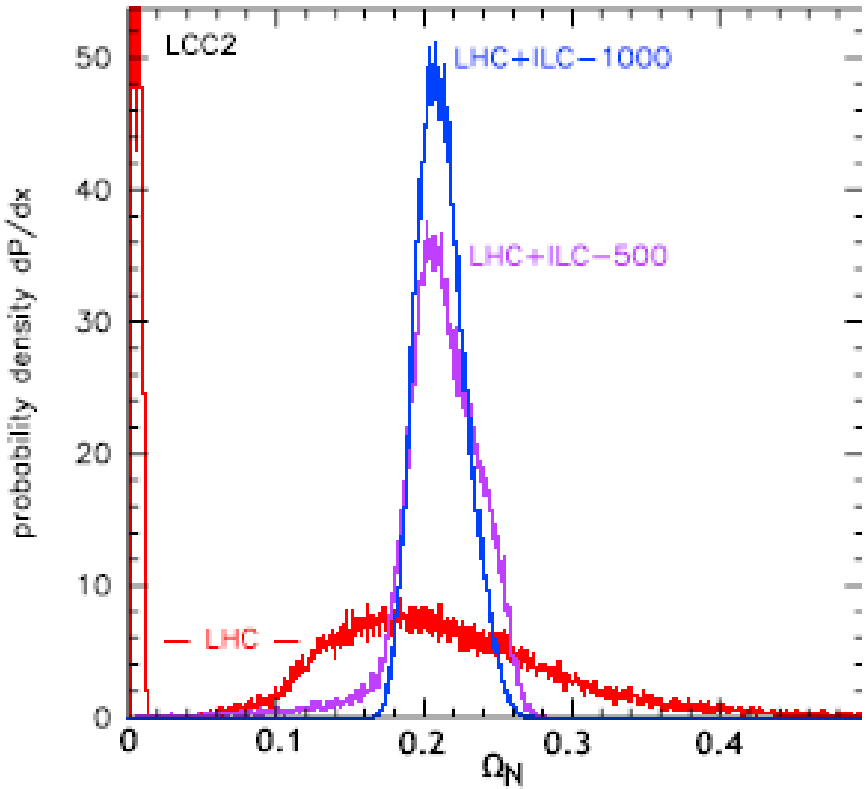
ELLIS. OLIVE. SAVAGE

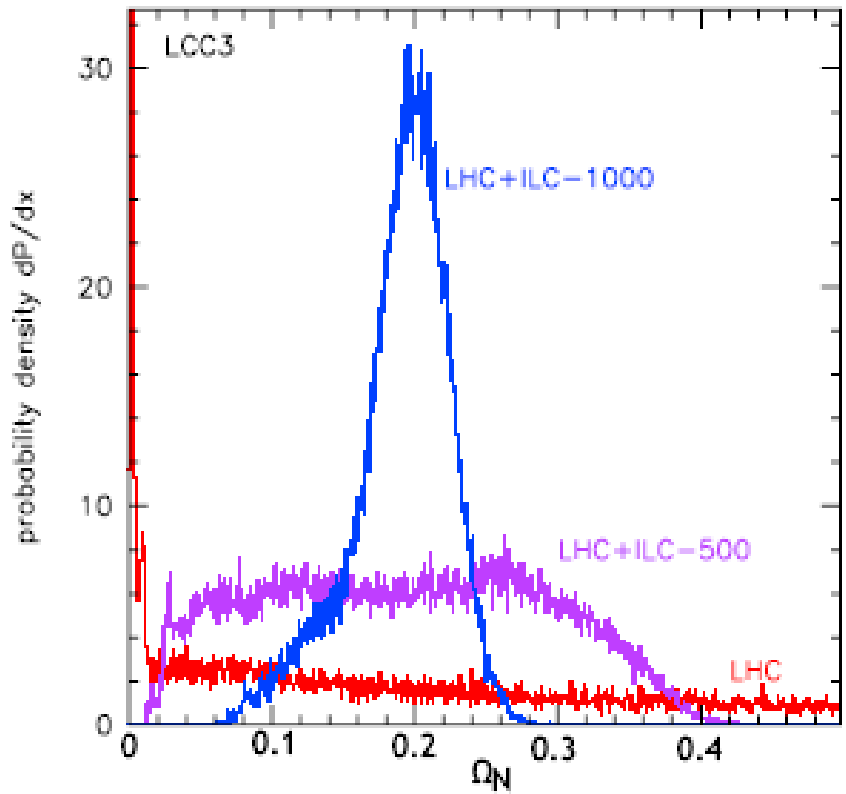
m_u/m_d	0.553	± 0.043
m_d	5	± 2 MeV
m_s/m_d	18.9	± 0.8
m_c	1.25	± 0.09 GeV
m_b	4.20	± 0.07 GeV
m_t	171.4	± 2.1 GeV
σ_0	36	± 7 MeV
$\Sigma_{\pi N}$	64	± 8 MeV
$a_3^{(p)}$	1.2695	± 0.0029
$a_8^{(p)}$	0.585	± 0.025
$\Delta_s^{(p)}$	-0.09	± 0.03

Ellis, Olive, Sandick

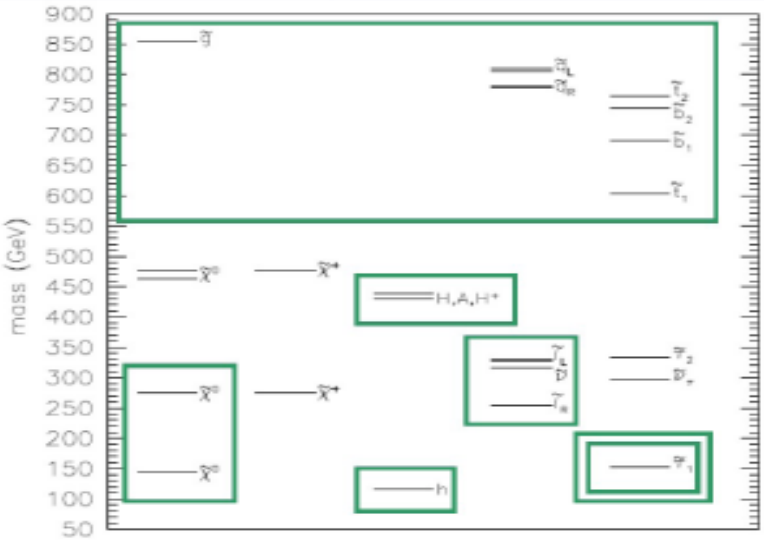


PREDICTION OF Ω DM FROM LHC AND ILC FOR TWO DIFFERENT SUSY PARAMETER SETS



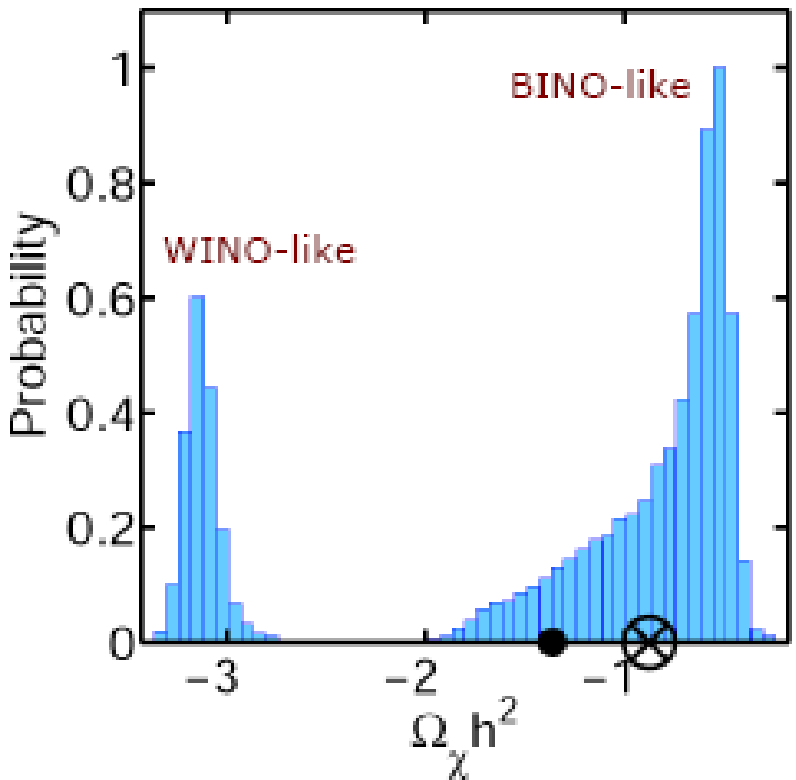


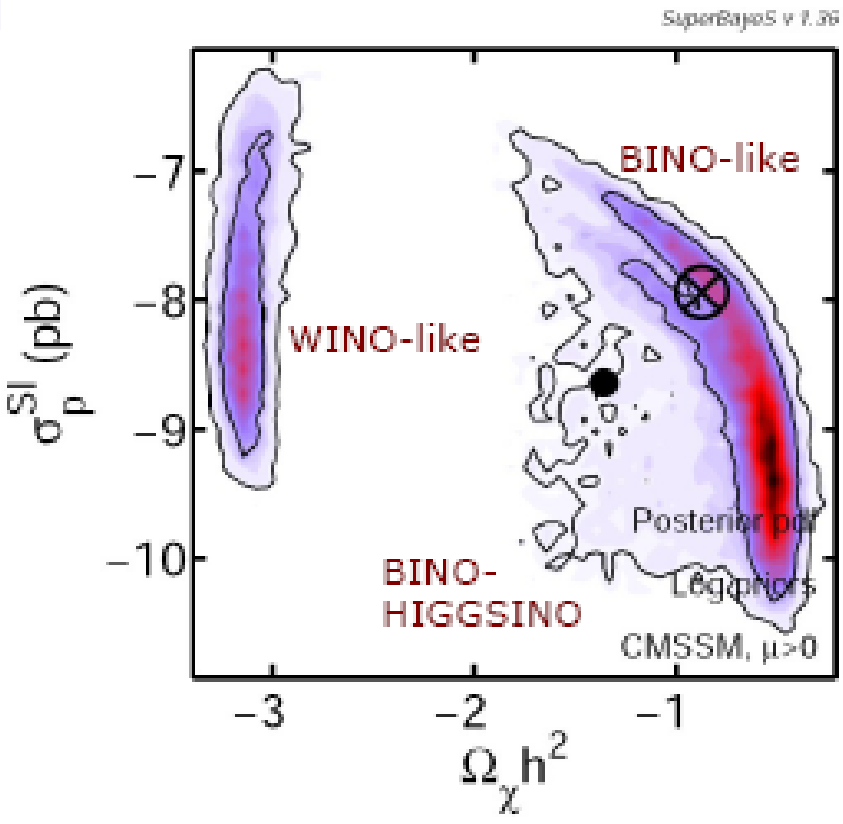
BALTZ, BATTAGLIA, PESKIN, WIZANSKY



Let's suppose to find part of the SUSY particle spectrum at LHC: will we be able to reconstruct then which s-particle is going to be the

LSP?





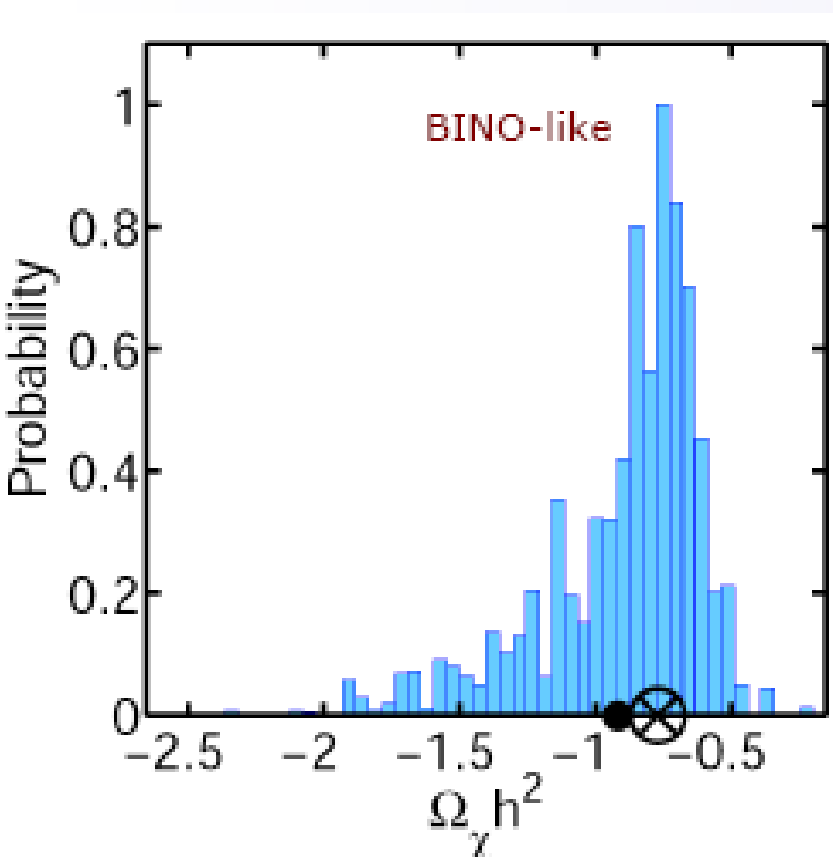
…but if we succeed to find the DM

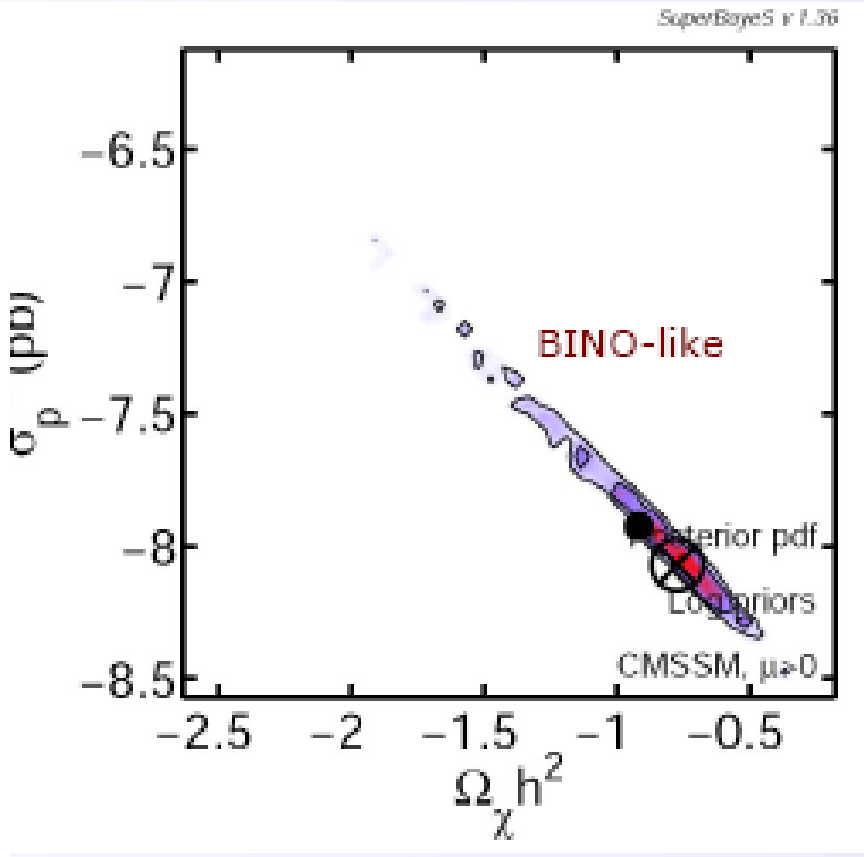
synergy LHC - DM

The combination of LHC data with Direct Detection data can resolve the degeneracy

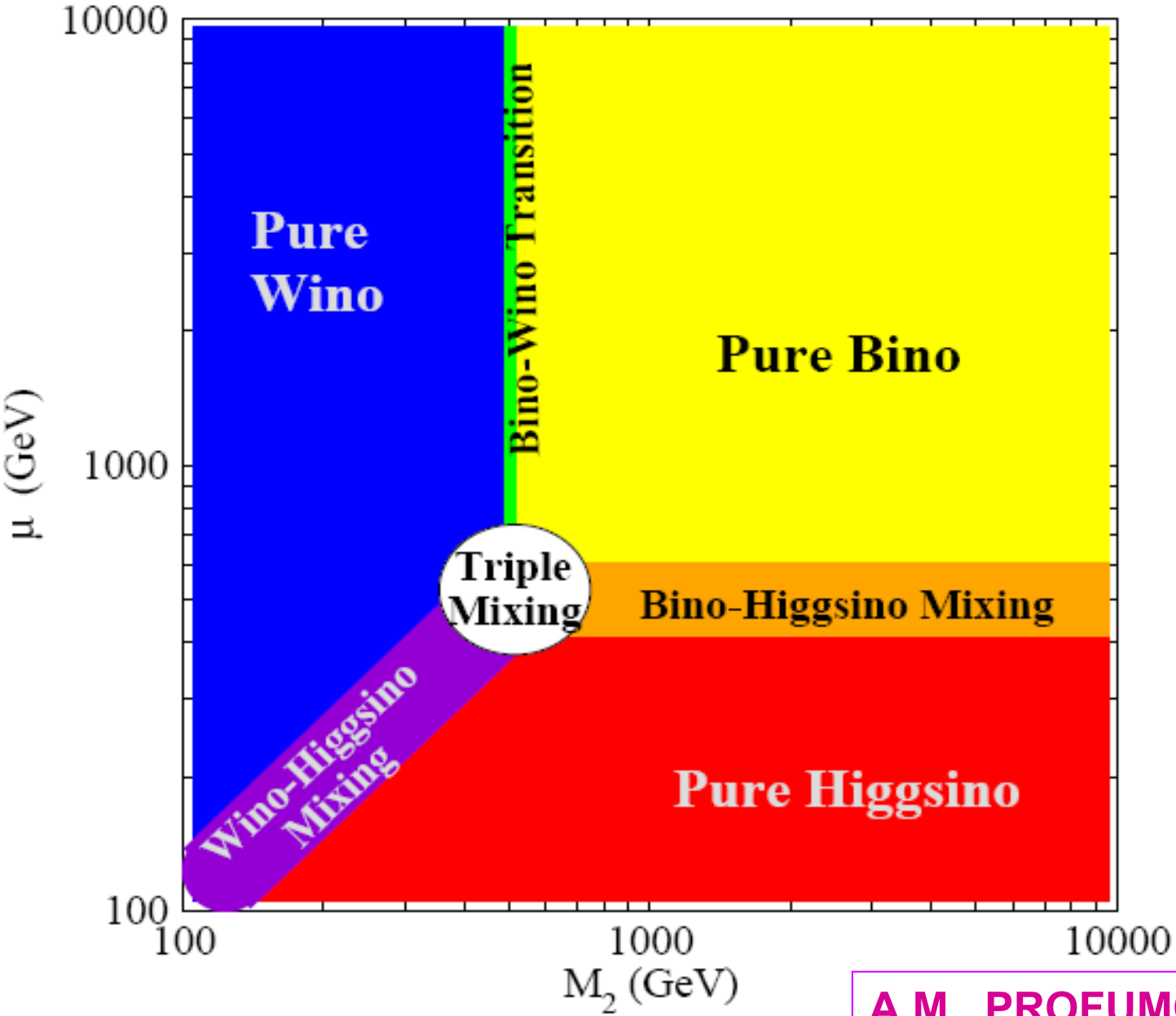
The reconstruction of the relic abundance has a similar accuracy but spurious maxima disappear

(Bertone, Cerdeño, Fornasa, Trotta, de Austri – in preparation)



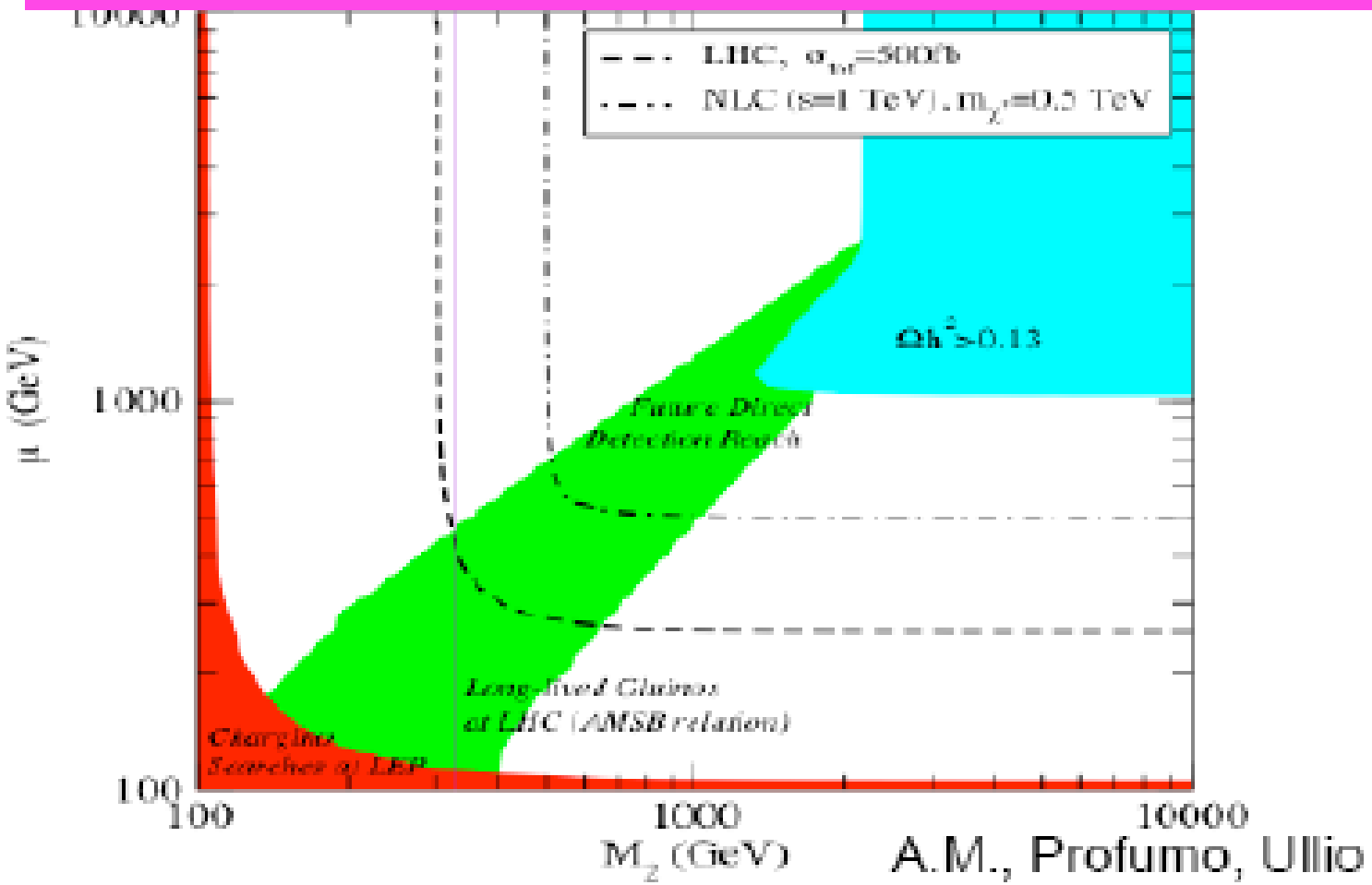


NEUTRALINO LSP IN SUPERGRAVITY



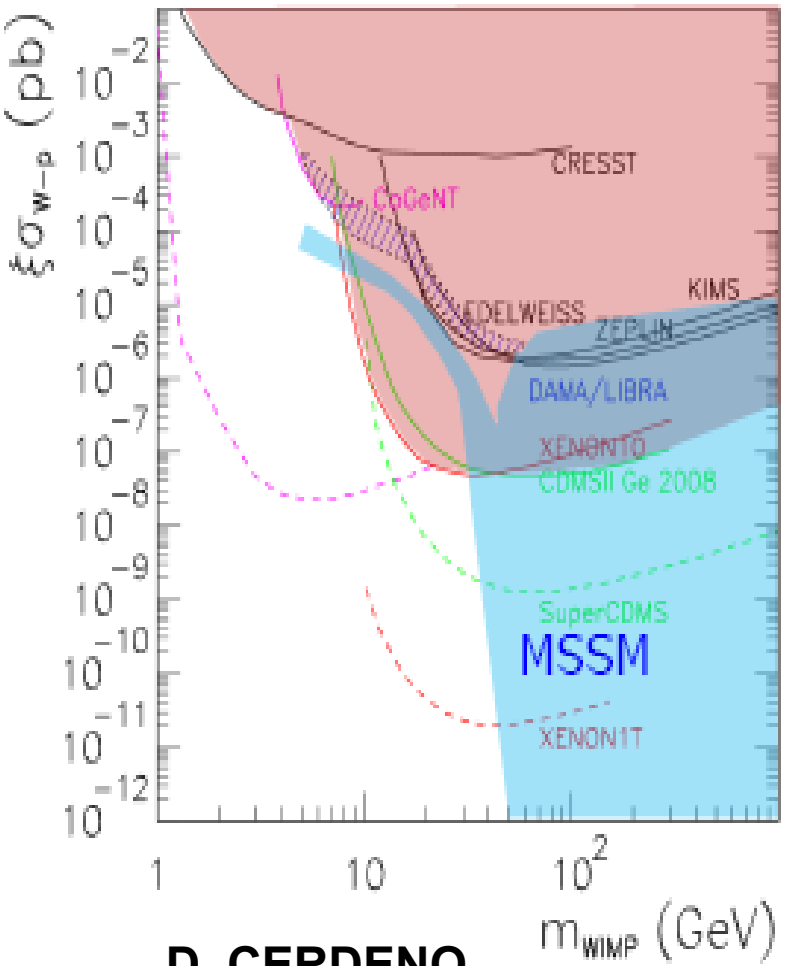
A.M., PROFUMO, ULLIO

LHC, ILC, DM SEARCHES SENSITIVITIES

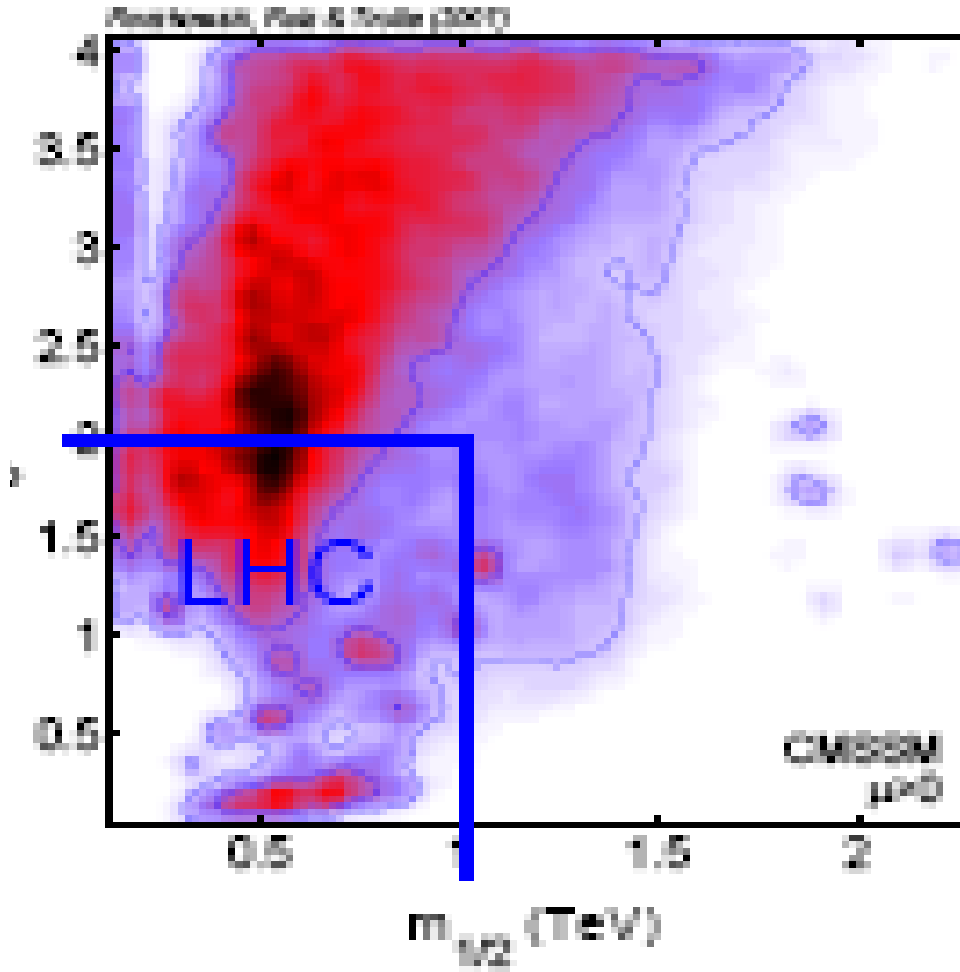


A.M., Profumo, Ullio

On the LHC – Direct DM searches coverage of the MSSM parameter space



D. CERDENO
WONDER10



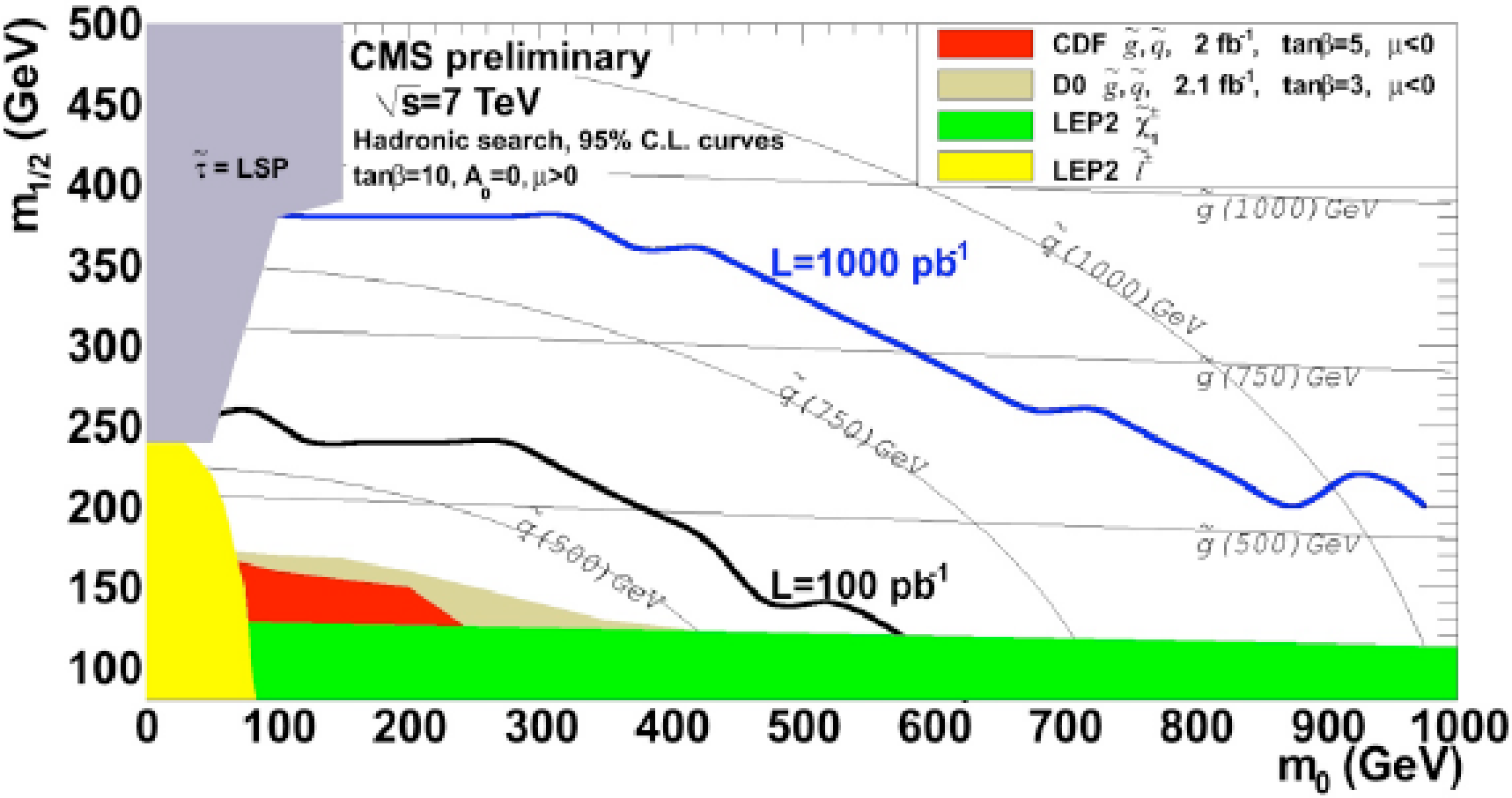
L. Roszkowsk et al.

SUSY: jets + missing E_T

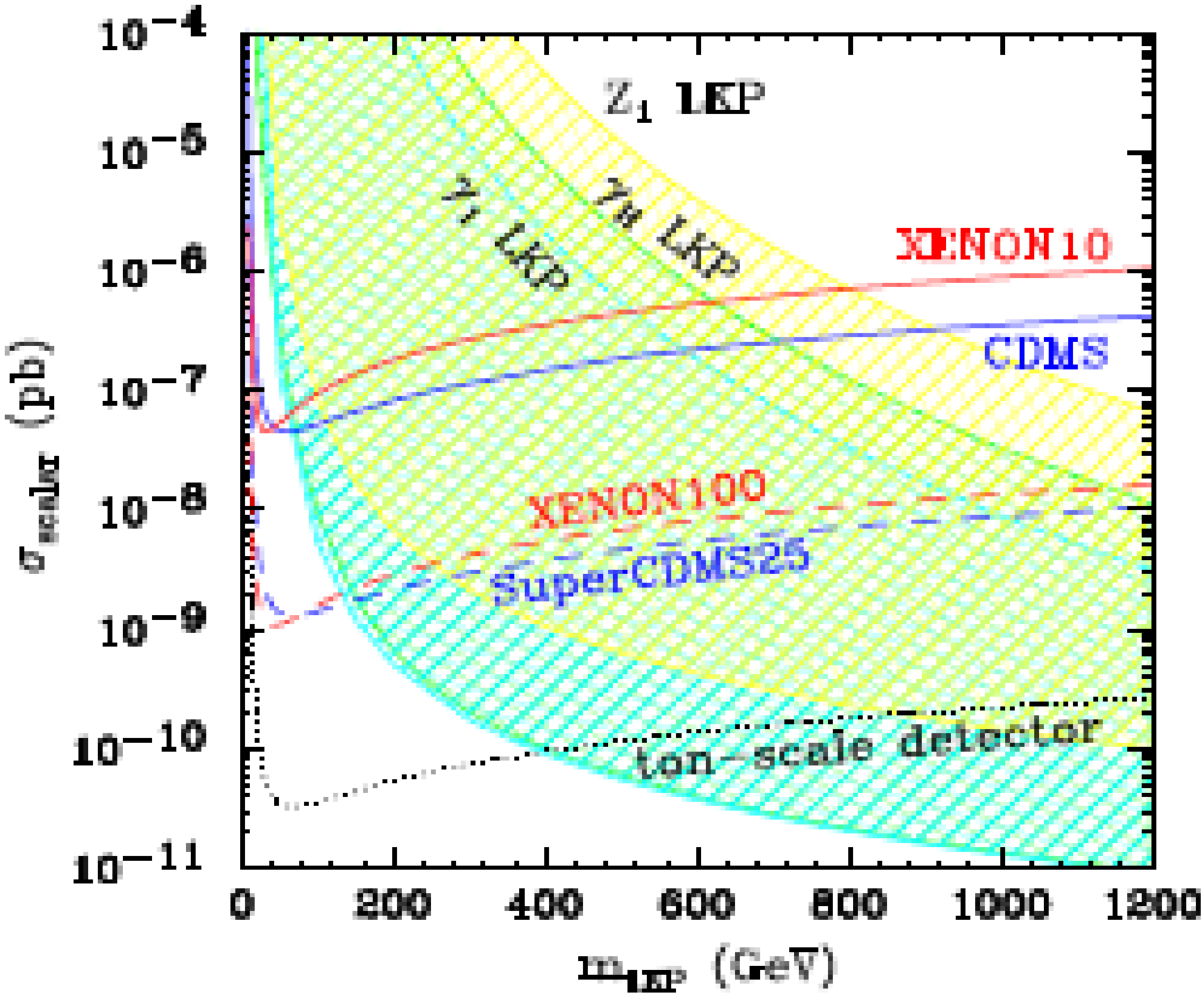
"Classic" all-jets search:

- 3 or more jets, E_T > 50 GeV
- missing E_T > 250 GeV
- no leptons

J. CONWAY
PHENO10



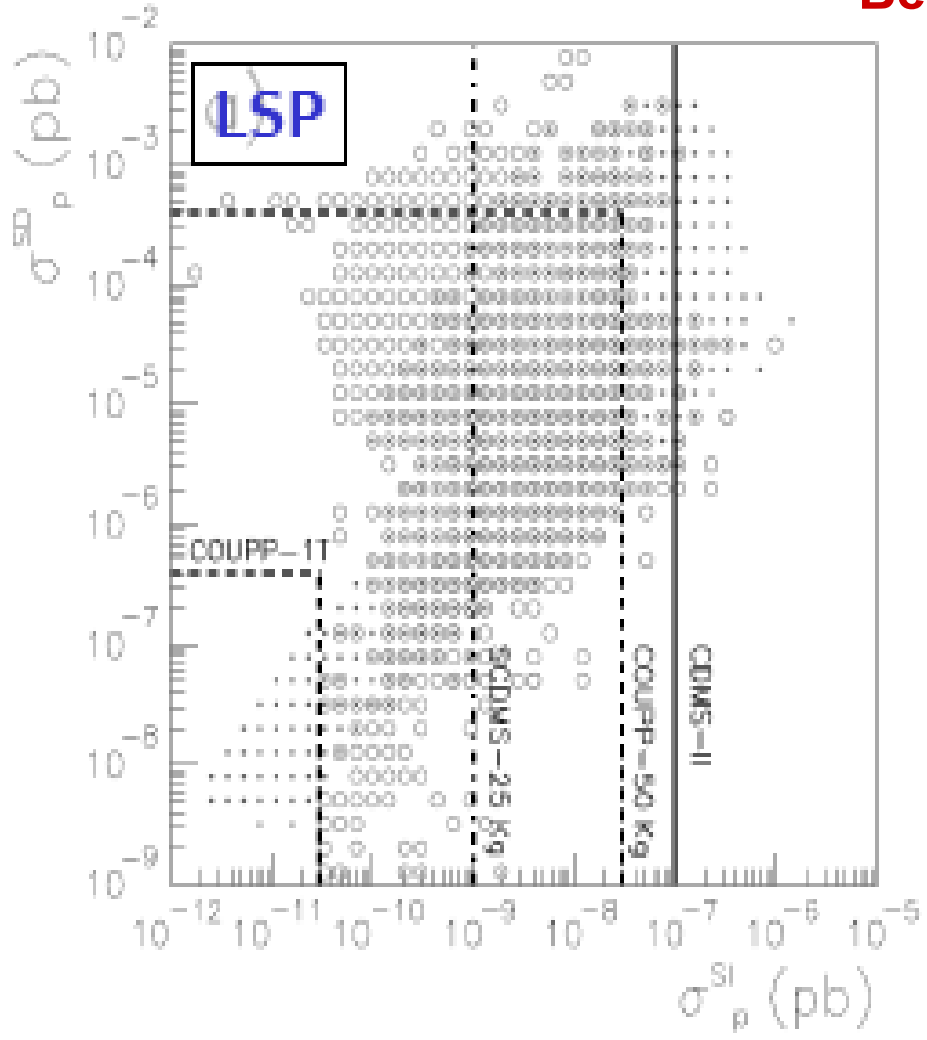
Arrenberg, Baudis, Kong, Matchev, J. Yoo

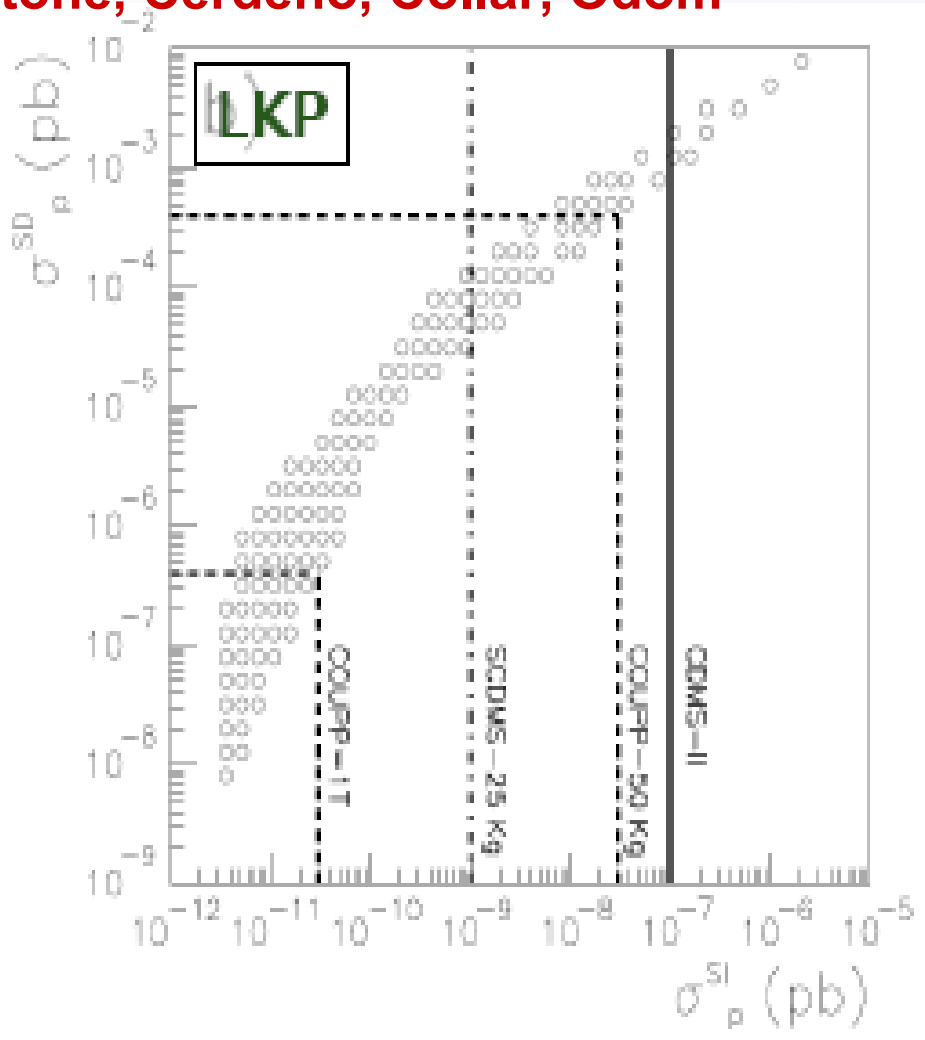


ON THE DISCRIMINATION AMONG WIMP CANDIDATES:

useful to measure both the SI and SD cross-sections

Bertone, Cerdeno, Collar, Odom





4. 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 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}

SMALLNESS OF THE NP COUPLINGS IF THE NP SCALE IS 1 TEV

$$Y_t \sim 1, \quad Y_c \sim 10^{-2}, \quad Y_u \sim 10^{-5}$$
$$Y_b \sim 10^{-2}, \quad Y_s \sim 10^{-3}, \quad Y_d \sim 10^{-4}$$
$$Y_\tau \sim 10^{-2}, \quad Y_\mu \sim 10^{-3}, \quad Y_e \sim 10^{-6}$$
$$|V_{us}| \sim 0.2, \quad |V_{cb}| \sim 0.04, \quad |V_{ub}| \sim 0.004, \quad \delta_{\rm KM} \sim 1$$

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"**

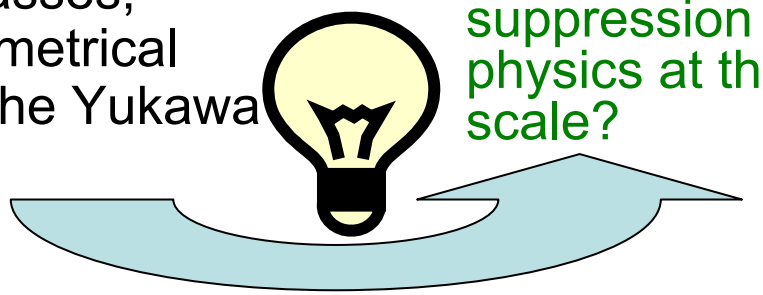
(new flavour – horizontal symmetry, radiatively induced lighter fermion masses, dynamical or geometrical determination of the Yukawa couplings, …?)

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.**

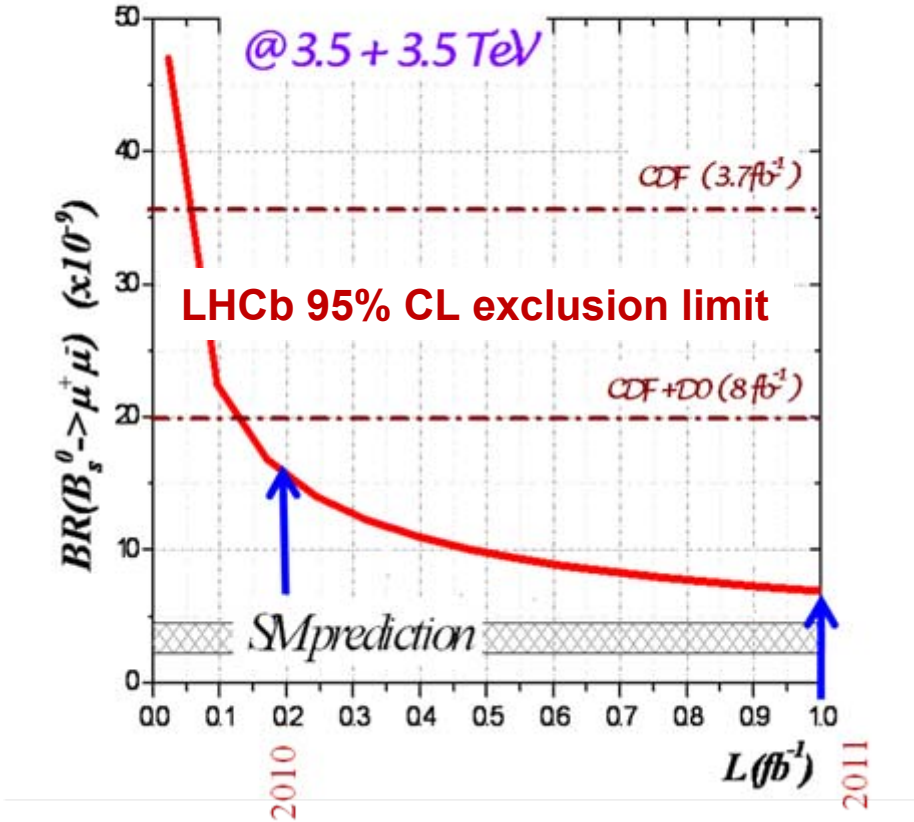
How to cope with such delicate suppression if the there is new physics at the electroweak scale?

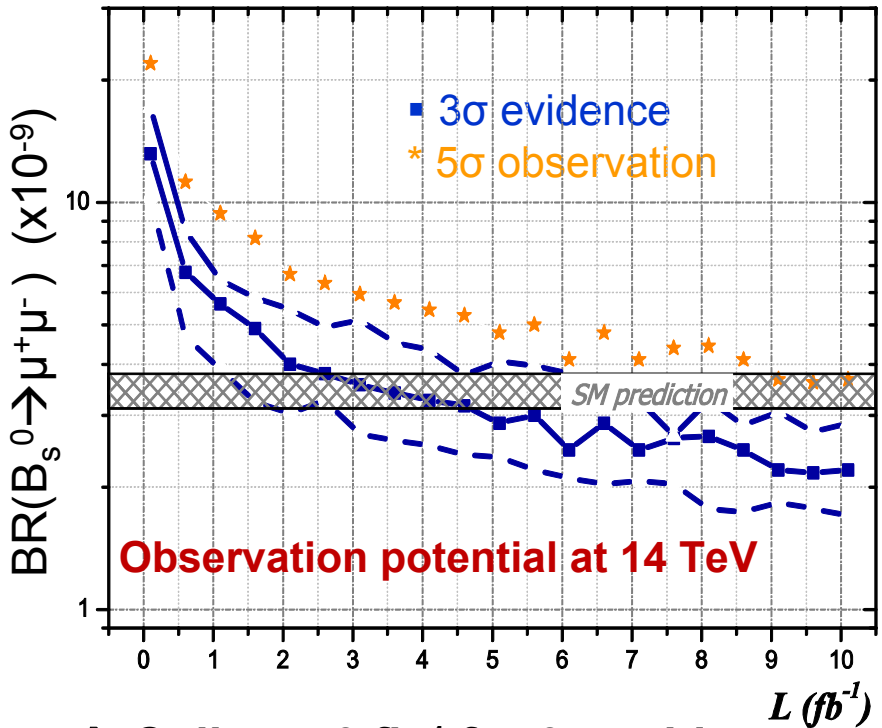


FLAVOR BLINDNESS OF THE NP AT THE ELW. SCALE?

- **THREE DECADES OF FLAVOR TESTS** (Redundant determination of the UT triangle ⟶ verification of the SM, theoretically and experimentally "high precision" FCNC tests, ex. b ⟶ 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

Physics reach for BR($B_s^0 \to \mu^+\mu^-$) as function of integrated luminosity (and comparison with Tevatron)





With ~0.2 fb^{-1} LHCb should improve on expected Tevatron limit

→ **Collect ~3 fb^{-1} for 3σ evidence of SM value and ~10 fb^{-1} for 5σ observation of SM**

(Note: ATLAS/CMS will be competitive)

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

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

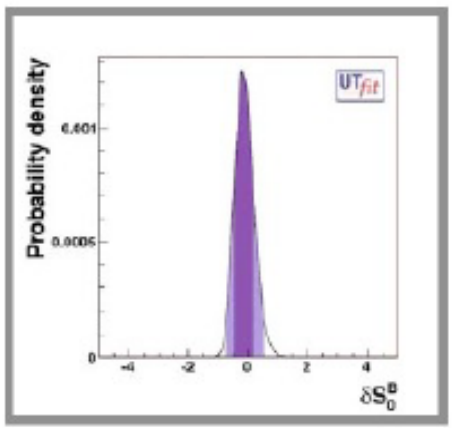
$$\delta S_0(x_t) = 4a\left(\frac{\Lambda_0}{\Lambda}\right)^2$$

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

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

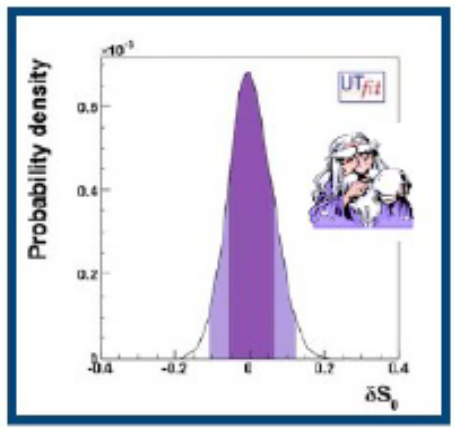
$$\delta S_0^B = \delta S_0^K$$

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



$\delta S_0 = -0.16 \pm 0.32$

$\Lambda > 5.5$ TeV @95%



$\delta S_0 = 0.004 \pm 0.059$

$\Lambda > 28$ TeV @95%

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

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

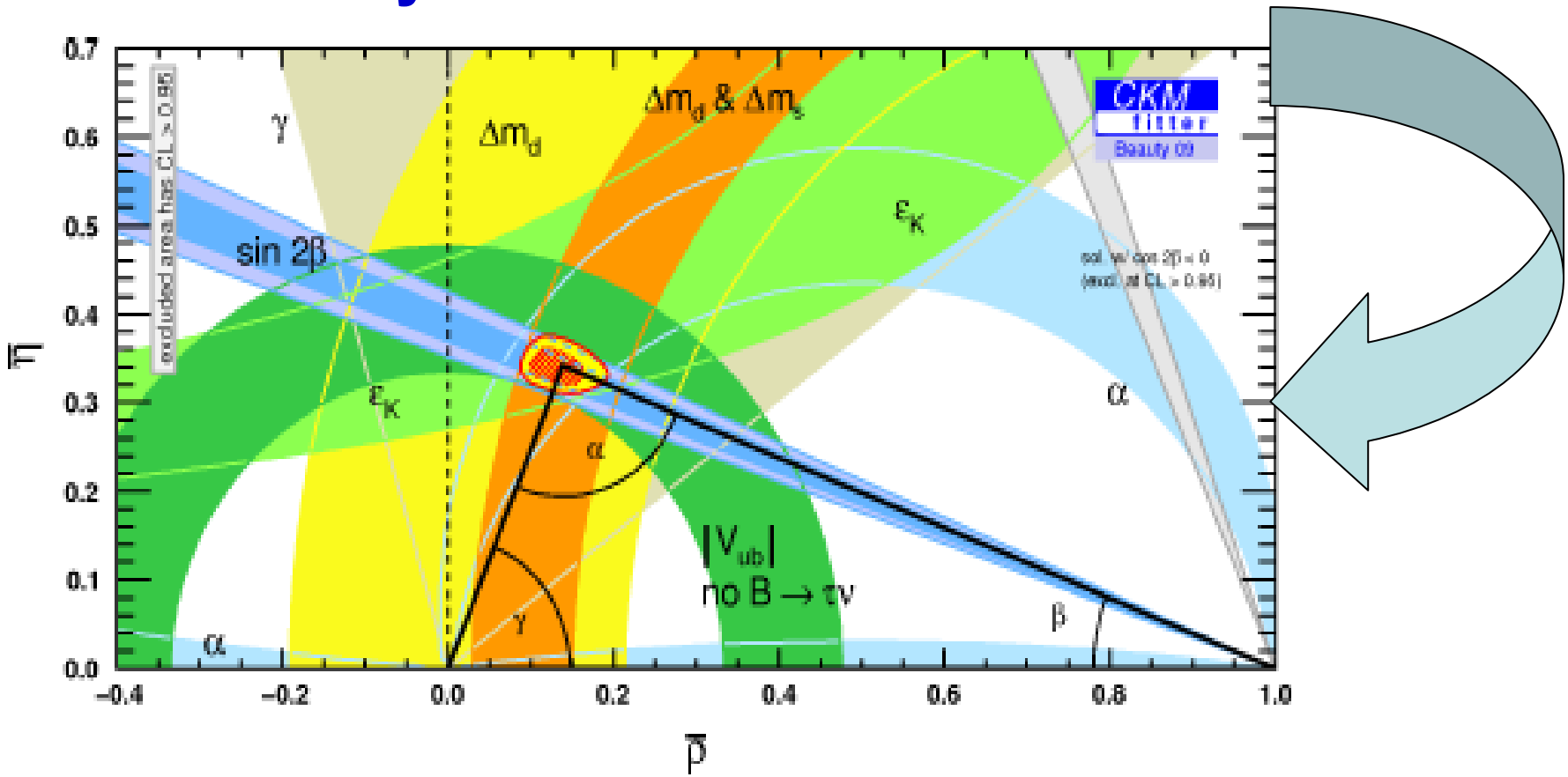
SuperB can probe MFV (with small-moderate tanβ) for TeV squarks; for a generic non-MFV MSSM → sensitivity to squark masses > 100 TeV !

Ciuchini, Isidori, Silvestrini ***SLOW-DECOUPLING OF NP IN FCNC***

Estimates of error for 2015

Hadronic matrix element	Current lattice error	6 TFlop Year	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9% (22% on 1-f_+)	0.7% (17% on 1-f_+)	0.4% (10% on 1-f_+)	**< 0.1% (2.4% on 1-f_+)**
$\hat{B}_K$	11%	5%	3%	**1%**
f_B	14%	3.5 - 4.5%	2.5 - 4.0%	**1 – 1.5%**
$f_{Bs}B_{Bs}^{1/2}$	13%	4 - 5%	3 - 4%	**1 – 1.5%**
ξ	5% (26% on ξ-1)	3% (18% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	**0.5 – 0.8 % (3-4% on ξ-1)**
$\mathcal{F}_{B\to D/D^*l\nu}$	4% (40% on 1-$\mathcal{F}$)	2% (21% on 1-$\mathcal{F}$)	1.2% (13% on 1-$\mathcal{F}$)	**0.5% (5% on 1-$\mathcal{F}$)**
$f_+^{B\pi}$,...	11%	5.5 - 6.5%	4 - 5%	**2 – 3%**
$T_1^{B\to K^*/\rho}$	13%	----	----	**3 – 4%**

THE STANDARD LORE :" the global fit of the CKM flavor pattern shows an excellent consistency of all the various observables…"



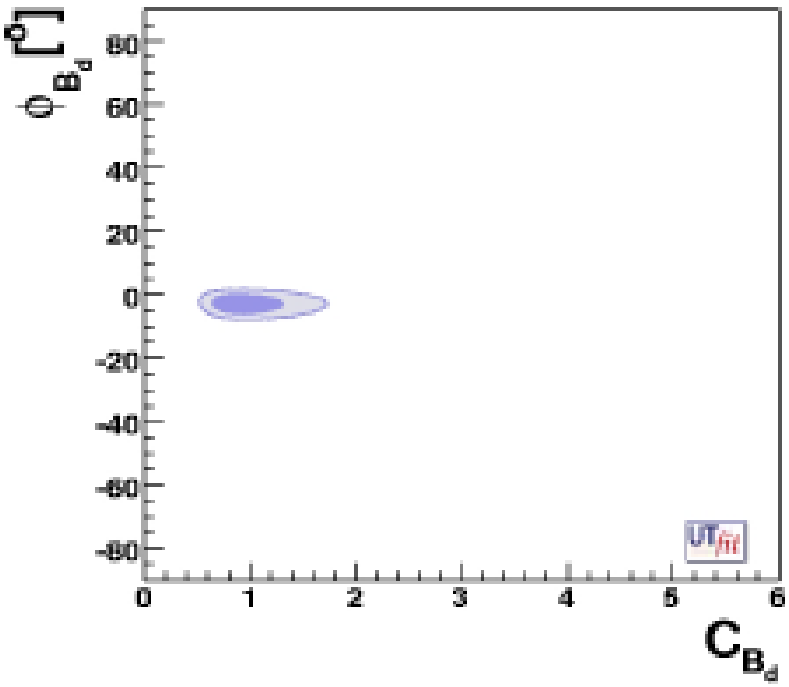
SOME CLOUDS ON A (TOO) CLEAR SKY ?

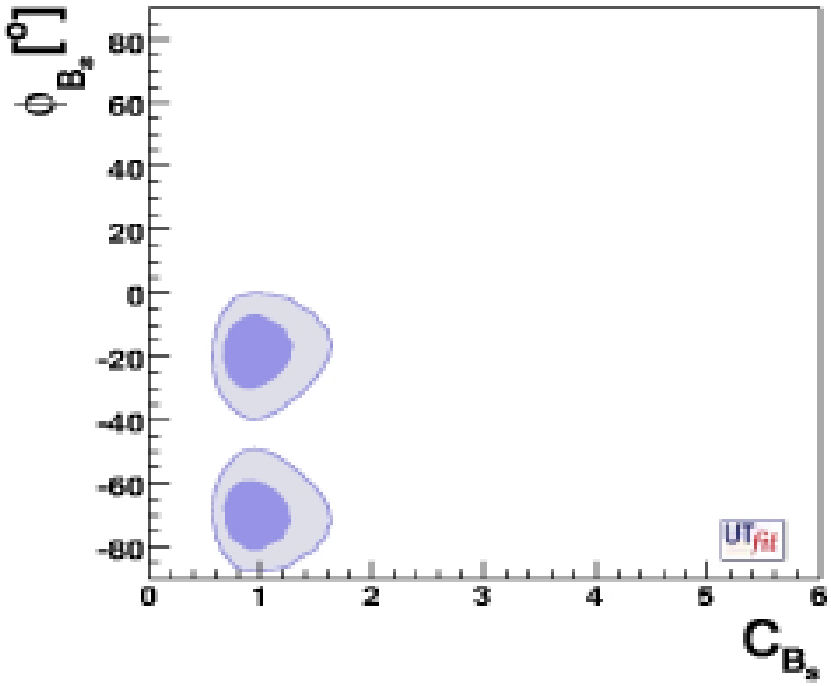
IS A NEW SOURCE OF CPV IN THE Bs SYSTEM NEEDED?

Taking as reference values the 2009 results, the two "anomalies" are both at the ~2σ level

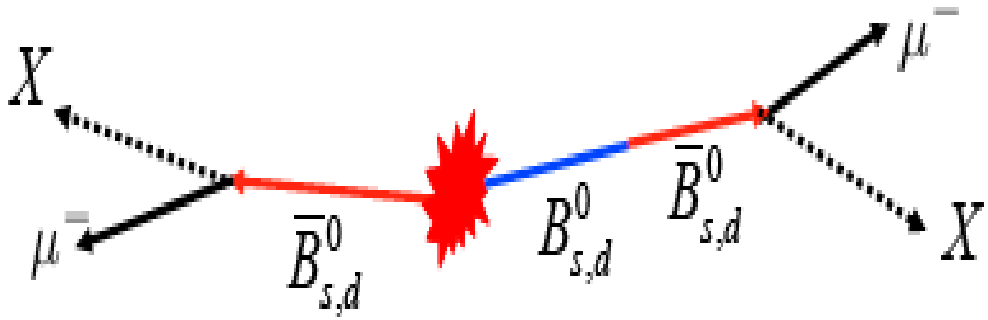
$$\langle B_q | M_{12}^{SM+NP} | \bar{B}_q \rangle = C_{B_q} e^{2i\phi_{B_q}} \langle B_q | M_{12}^{SM} | \bar{B}_q \rangle$$

G. ISIDORI, PLANCK10





DIMUON CHARGE ASYMMETRY FROM SEMILEPTONIC B DECAYS



$$A^b_{sl} = 0.506 a^d_{sl} + 0.494 a^s_{sl}$$

$$\left(a^b_{sl} \equiv \frac{\Gamma(\bar{B} \to \mu^+ X) - \Gamma(B \to \mu^- X)}{\Gamma(\bar{B} \to \mu^+ X) + \Gamma(B \to \mu^- X)} \right)$$

$$A^b_{sl} \equiv \frac{N^{++}_b - N^{--}_b}{N^{++}_b + N^{--}_b} = \left(-2.3^{+0.5}_{-0.6}\right) \times 10^{-4}$$

(Lenz & Nierste: hep-ph/0612167)

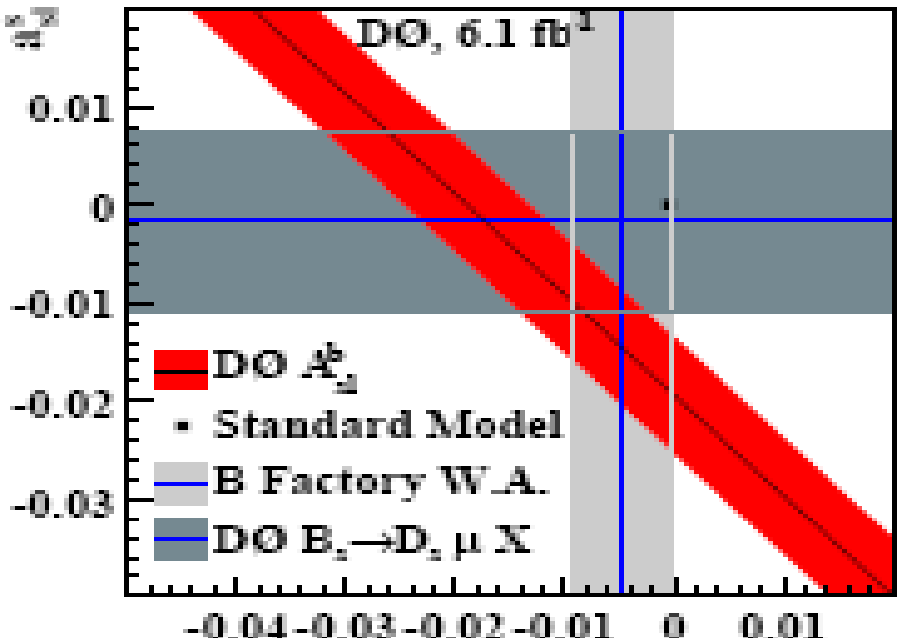
D0 analysis

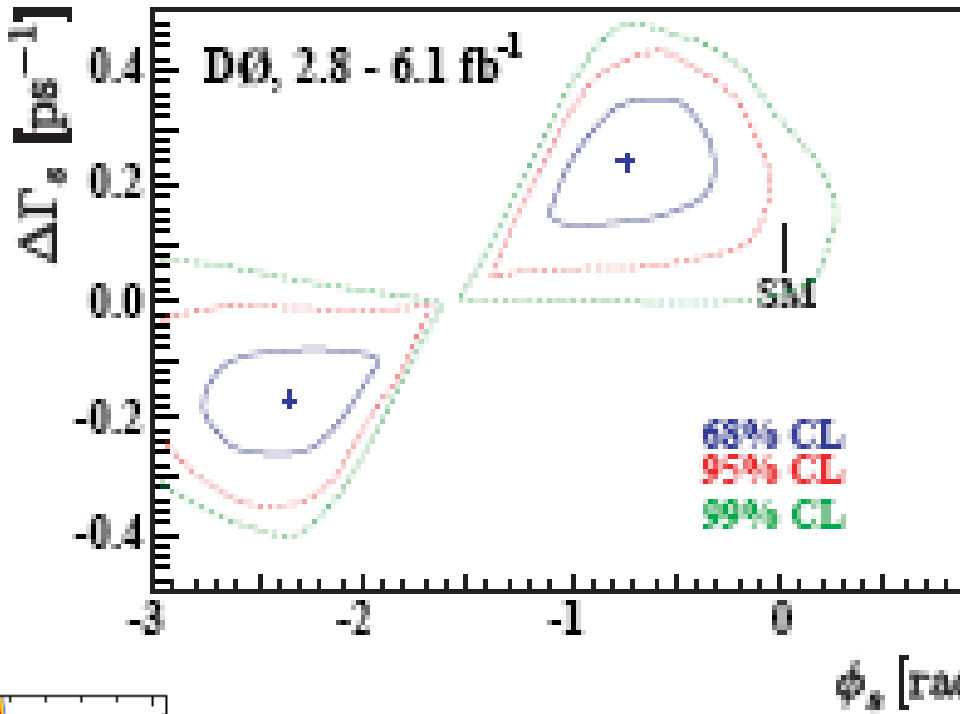
hep-ex 1005.2757

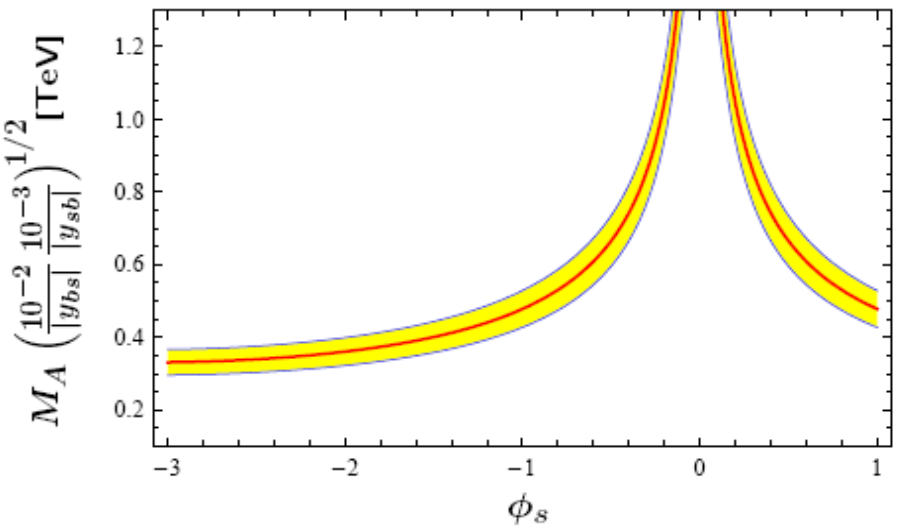
$$A^b_{sl} = \left[-0.957 \pm 0.251\,(\text{stat}) \pm 0.146\,(\text{syst})\right]\ \%$$

$$A^b_{sl}(SM) = \left[-0.023^{+0.005}_{-0.006}\right]\%$$

COMBINING CLOUDS I AND II





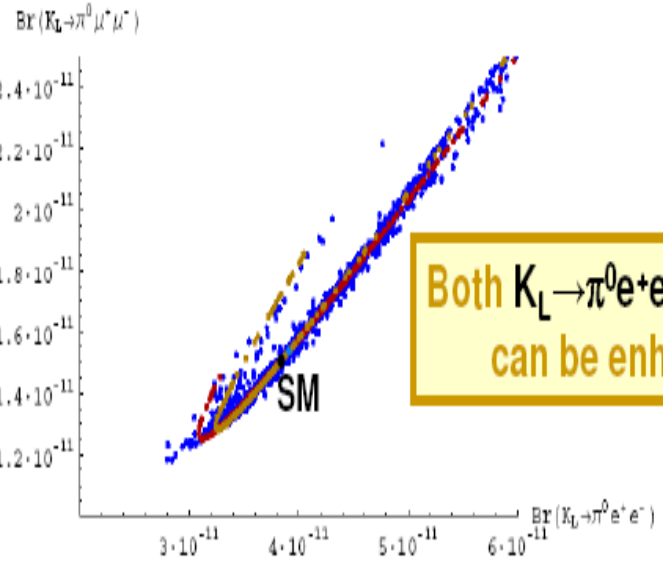


Dobrescu, Fox, Martin: CPV in the Bs mixing due to the interference between the SM and the A, H contributions in multi-higgs models

FCNC SL 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)	±15%
$K_L \to \pi^0 \mu^+ \mu^-$	$(1.4\pm0.3)\cdot10^{-11}$	$< 38\cdot10^{-11}$ (KTeV)	±15%

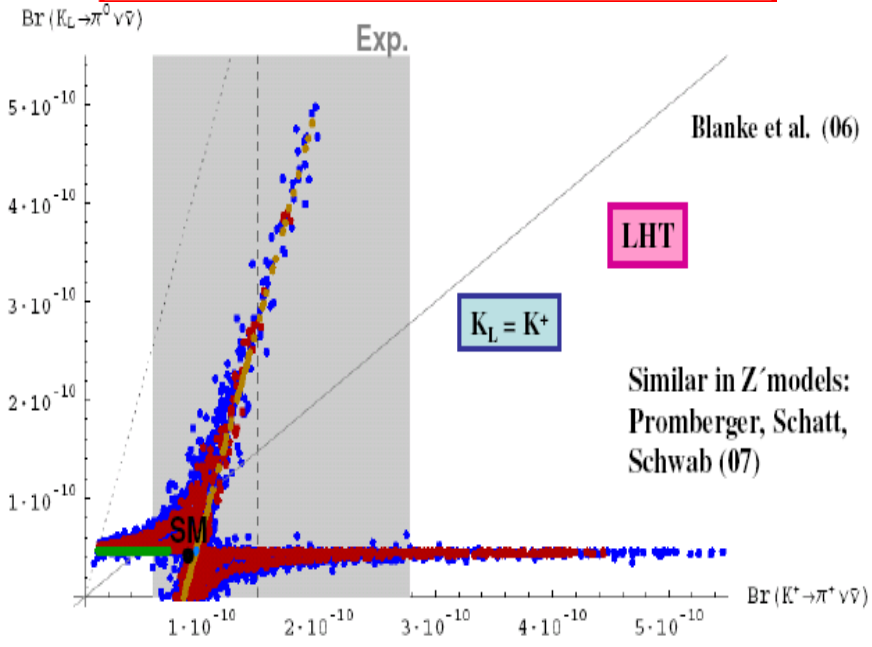
K-system: $K_L \to \pi^0 e^+ e^-$ and $K_L \to \pi^0 \mu^+ \mu^-$



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 $K^+ \to \pi^+ \nu\bar{\nu}$



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

SUSY SEE-SAW

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

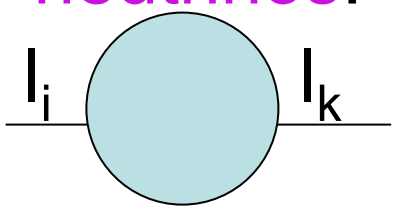
LOW-ENERGY SUSY

- **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

LFV and NEW PHYSICS

- Flavor in the HADRONIC SECTOR:
  CKM paradigm
- Flavor in the LEPTONIC SECTOR:
  - Neutrino masses and (large) mixings
  - Extreme smallness of LFV in the charged lepton sector of the SM with massive neutrinos:

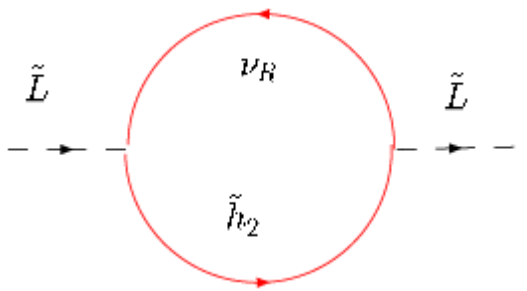


suppressed by $(m_{\nu_i}^2 - m_{\nu_k}^2) / M_W^2$

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

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

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



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

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***;

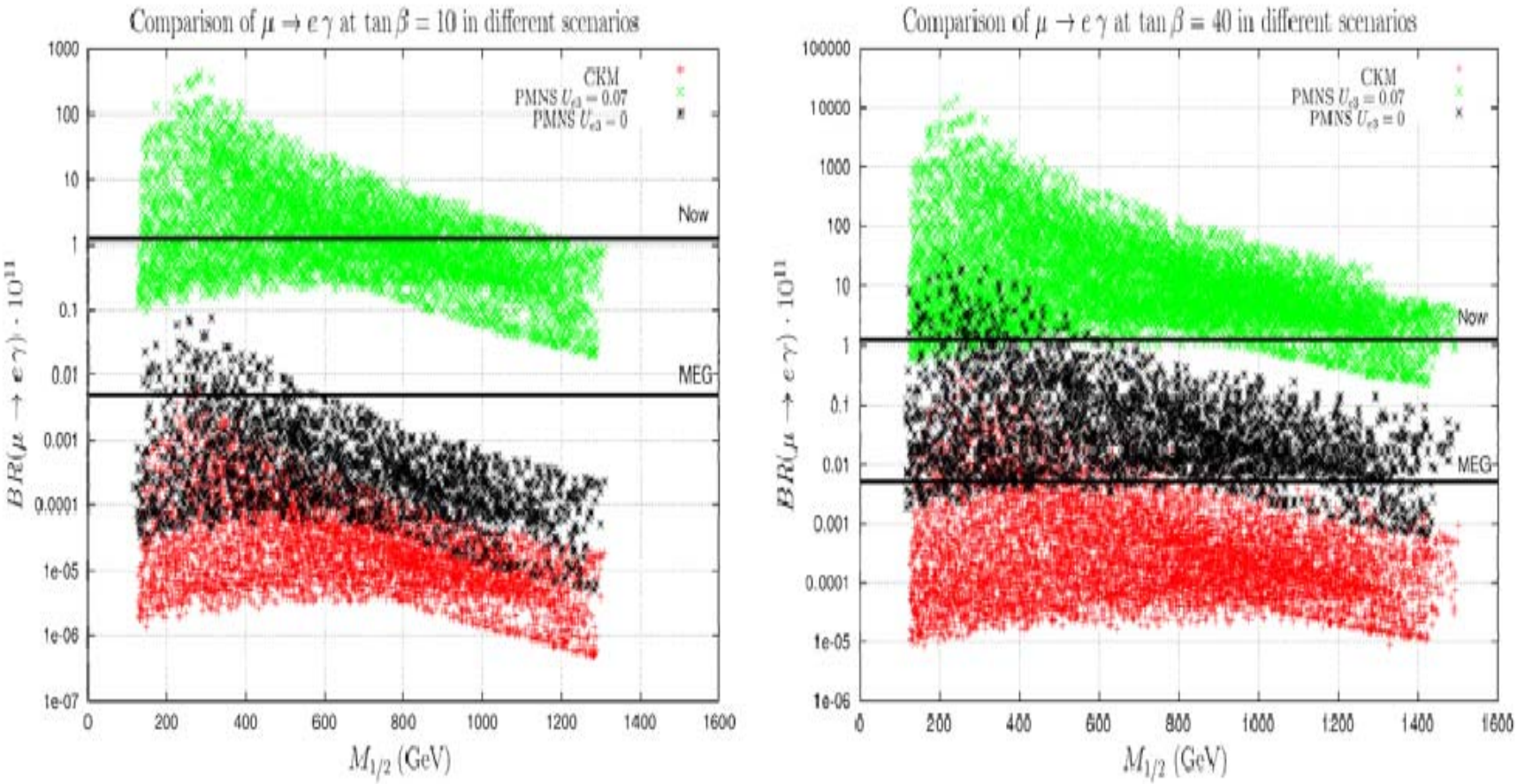
b) **U with "large" entries** with the exception of the 13 entry → ***U = PMNS*** matrix responsible for the diagonalization of the neutrino mass matrix

THE STRONG ENHANCEMENT OF LFV IN SUSY SEESAW MODELS CAN OCCUR

EVEN IF THE MECHANISM RESPONSIBLE FOR SUSY BREAKING IS ABSOLUTELY FLAVOR BLIND

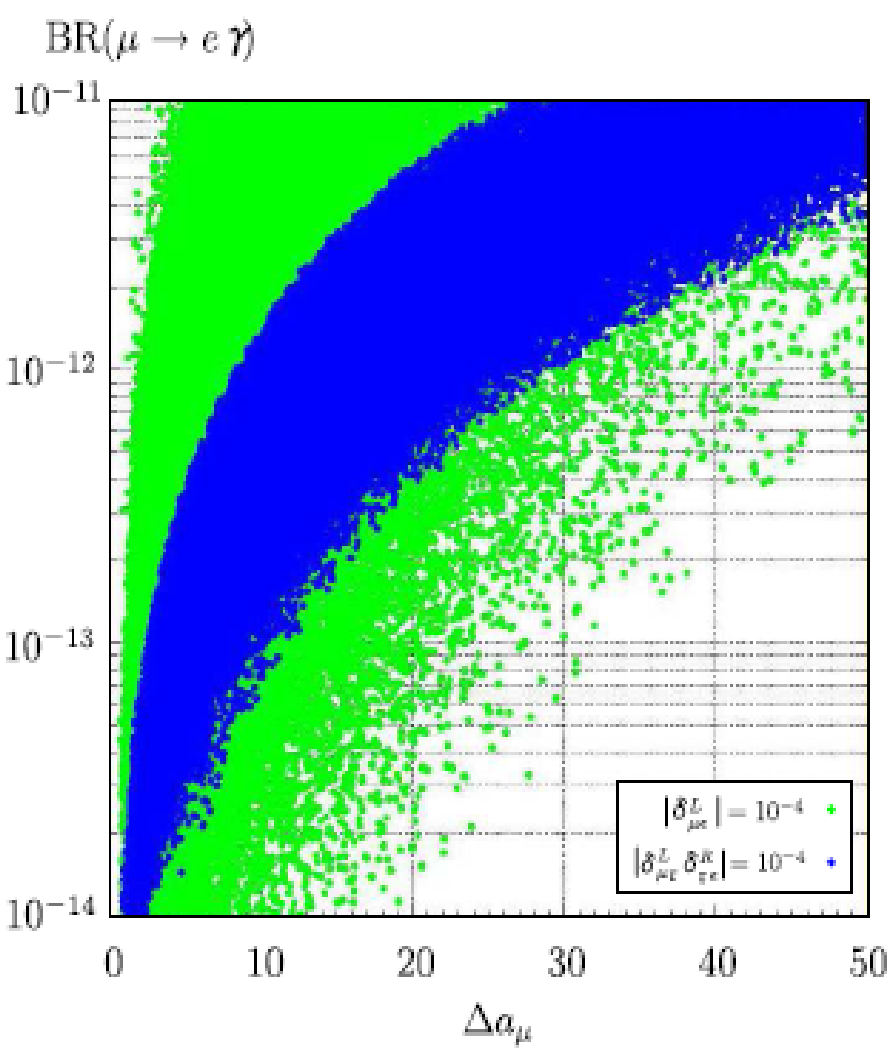
μ → e+γ in SUSYGUT: past and future

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

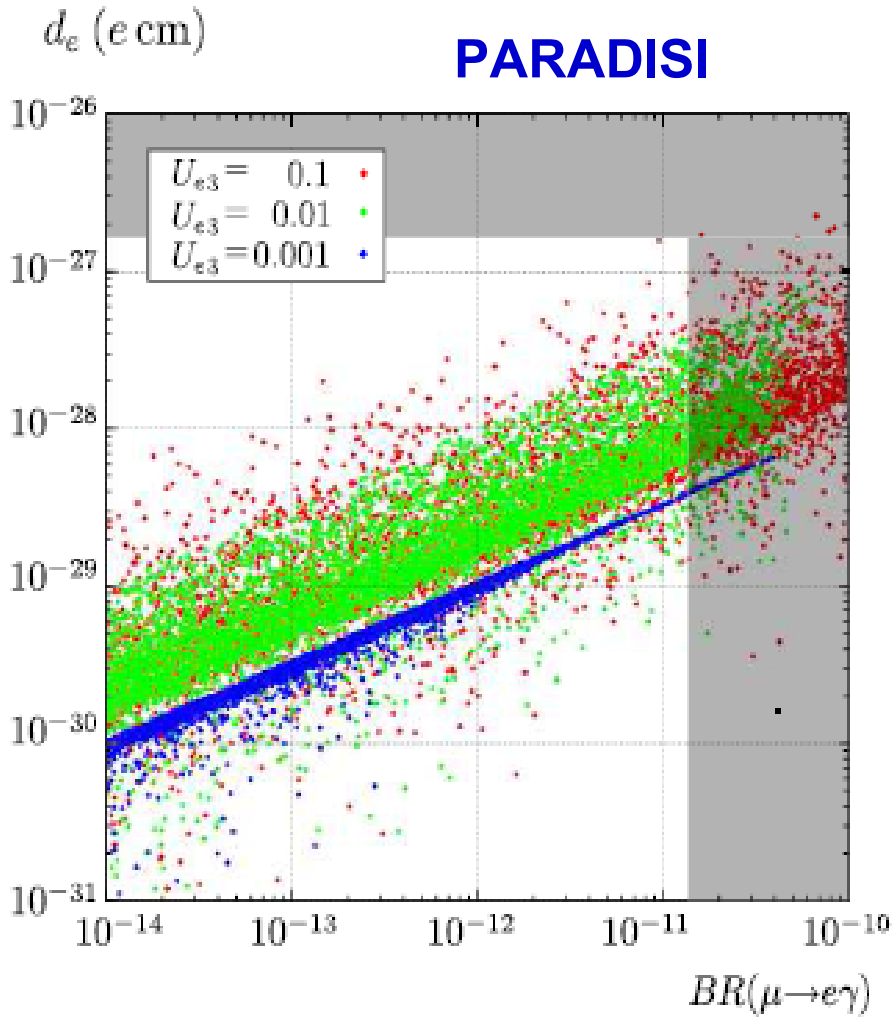


Calibbi, Faccia, A.M., Vempati

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



PARADISI

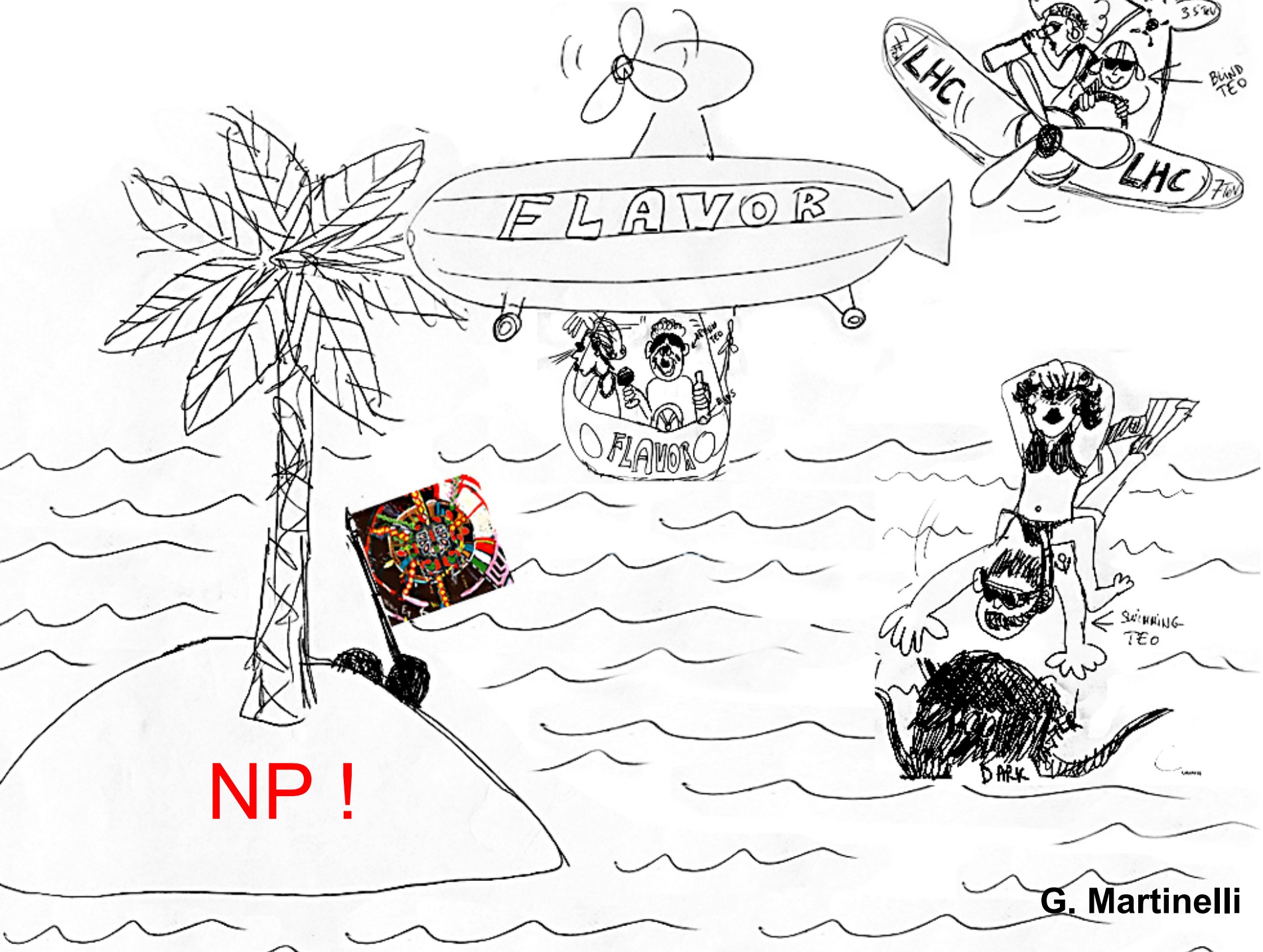


3 QUESTIONS

- **Are we sure that there is new physics (NP) at the TeV scale? YES (barring an antropic approach)**

- **If yes, are we sure that LHC will see something "new", i.e. beyond the SM with its "standard higgs boson"? YES**

- **If there is new physics at the TeV scale, what can flavor and DM physics tell to LHC and viceversa? (or, putting it in a less politically correct fashion: if LHC starts seeing some new physics signals, are flavor and DM physics still a valuable road to NP, or are they definitely missing that train? NO, actually to catch the "right train" it is highly desirable, though maybe strictly not necessary, to make use of all the three roads at the same time**



G. Martinelli