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LHC 2010-2012: HIGGS e NUOVA FISICA DIETRO L'ANGOLO?

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Oppure e' piu'giusto il titolo

LHC : NUOVA FISICA =

L'UBRIACO CHE RINCASA :

CHIAVI DI CASA

$M_w = 10^2$ GeV **$M_{PLANCK} = 10^{19}$ GeV**

Fin dove conosciamo **Di sicuro qui c'e' nuova fisica**

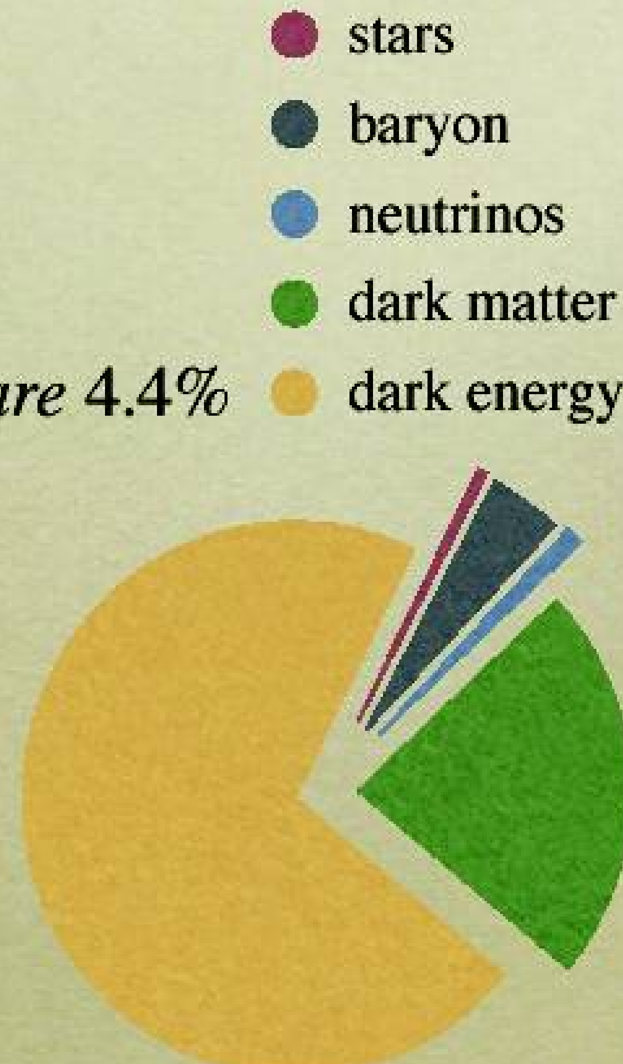
Perche' la Nuova Fisica dovrebbe stare proprio attorno a 10^3 GeV ?

Piano del seminario

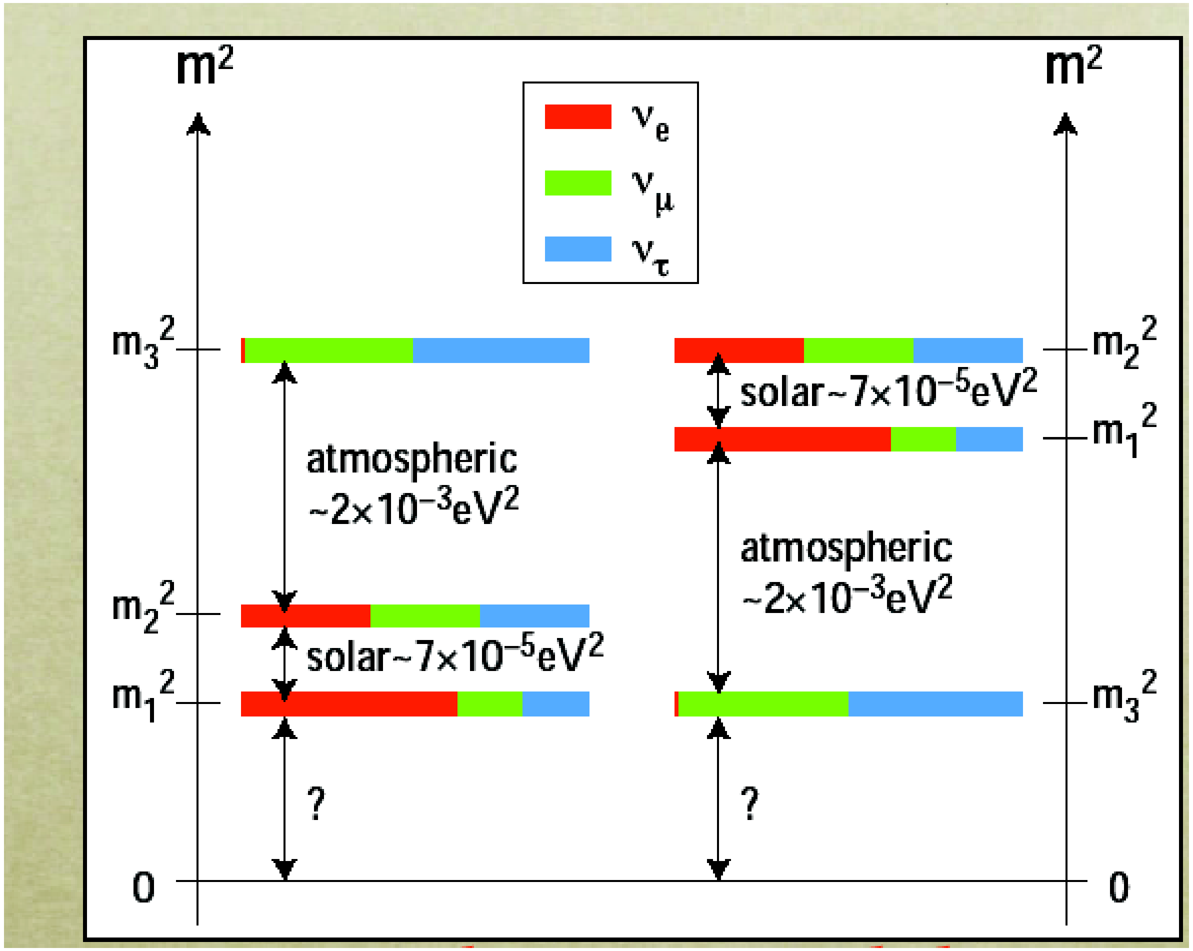
- La **Nuova Fisica** oltre il Modello Standard **esiste** (evidenze osservative e teoriche)
- Almeno parte di questa **Nuova Fisica “deve” essere** presente ad una scala di energia **vicino al TeV**
- Questa **Nuova Fisca** alla scala elettrodebole e’ **visibile a LHC**
- Nel decennio che si apre LHC (via dell’ **alta energia**), la via **astroparticellare** e la via dell’ **alta intensita**’ (fisica del flavor e della violazione di CP) concorreranno a mostrare che e’ cosi’ e ci faranno anche capire di quale Nuova Fisica si tratti (**scoperta e comprensione**)

LE GRANDI DOMANDE 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 ~10^{62}%??*



Neutrinos are MASSIVE: New Physics IS there!



THE FATE OF LEPTON NUMBER

L VIOLATED

υ Majorana ferm.

L CONSERVED

υ Dirac ferm.

(dull option)

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

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

SMALLNESS of m_υ

PRESENCE OF A NEW PHYSICAL MASS SCALE

NEW HIGH SCALE

NEW LOW SCALE

SEE - SAW MECHAN.

Minkowski; Gell-Mann, Ramond, SlansKy, Vanagida

ν_R ENLARGEMENT OF THE FERMIONIC SPECTRUM

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

$$\begin{array}{ccc} & \upsilon_L & \bar{\upsilon}_R \\ \upsilon_L & \sim O & h\langle\bar{\phi}\rangle \\ \upsilon_R & h\langle\bar{\phi}\rangle & M \end{array}$$

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!

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***

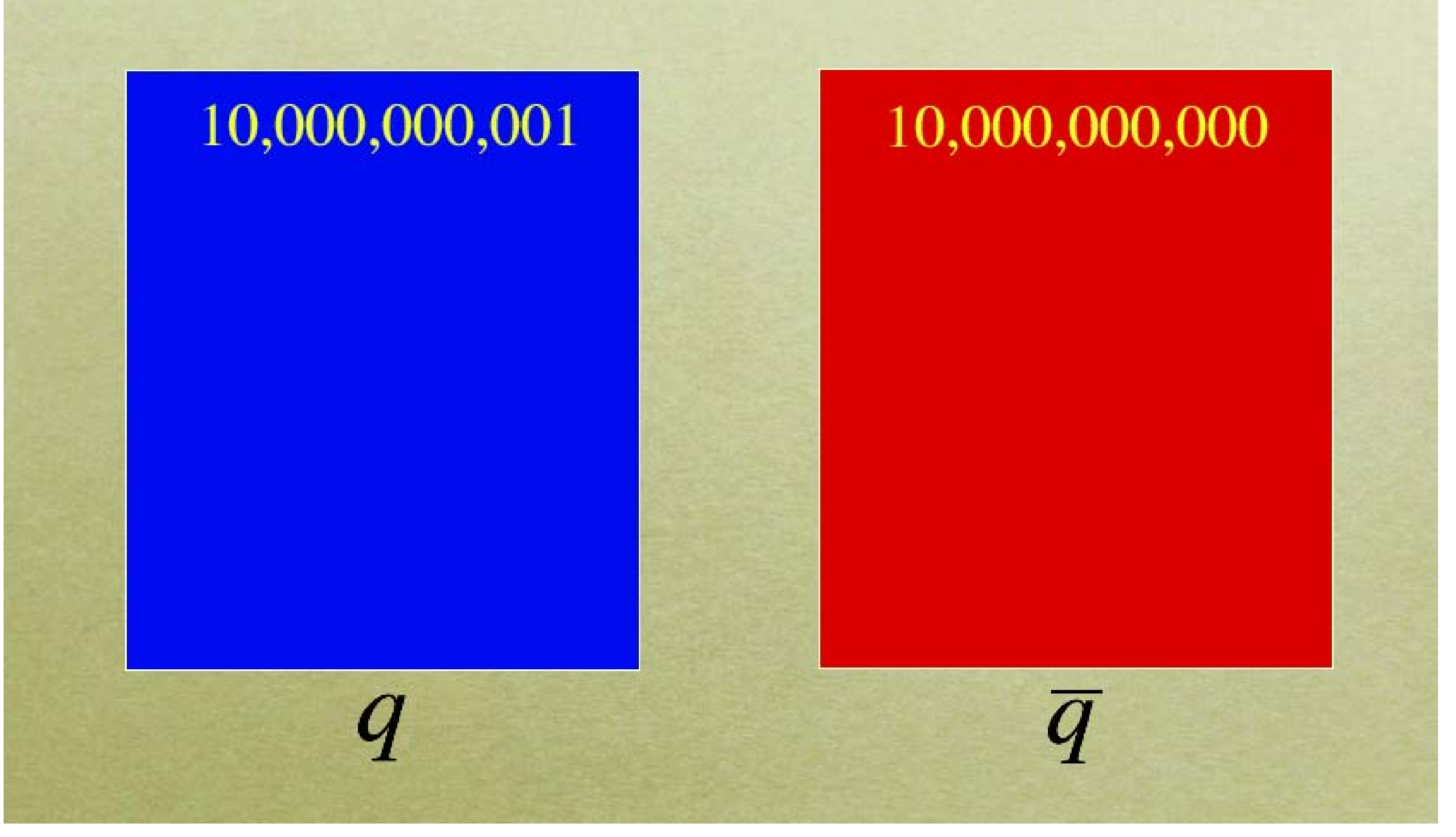
- DARK MATTER + DARK ENERGY

NEW PARTICLES AND INTERACTIONS

"OBSERVATIONAL" EVIDENCE FOR NEW PHYSICS

BEYOND THE (PARTICLE PHYSICS) STANDARD MODEL

COSMIC MATTER-ANTIMATTER ASYMMETRY



Murayama

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**)

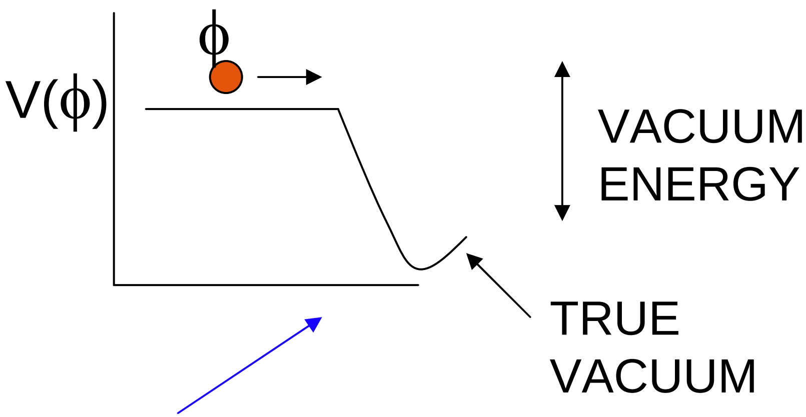
INFLATION

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 $\gg$ Mw

DIFFICULT BUT NOT IMPOSSIBLE TO OBTAIN ELECTROWEAK INFLATION IN SM EXTENSIONS

For some inflationary models → large amount of primordial gravitational waves

DM → NEW PHYSICS BEYOND THE (PARTICLE PHYSICS) SM - if Newton is right at scales>size of the Solar System

- $\Omega_{DM} = 0.233 \pm 0.013$ *
- $\Omega_{baryons} = 0.0462 \pm 0.0015$ **

*from CMB (5 yrs. of WMAP) + Type I Supernovae + Baryon Acoustic Oscillations (BAO)

**CMB + TypeI SN + BAO in agreement with Nucleosynthesis (BBN)

DM: the most impressive evidence at the "quantitative" and "qualitative" levels of

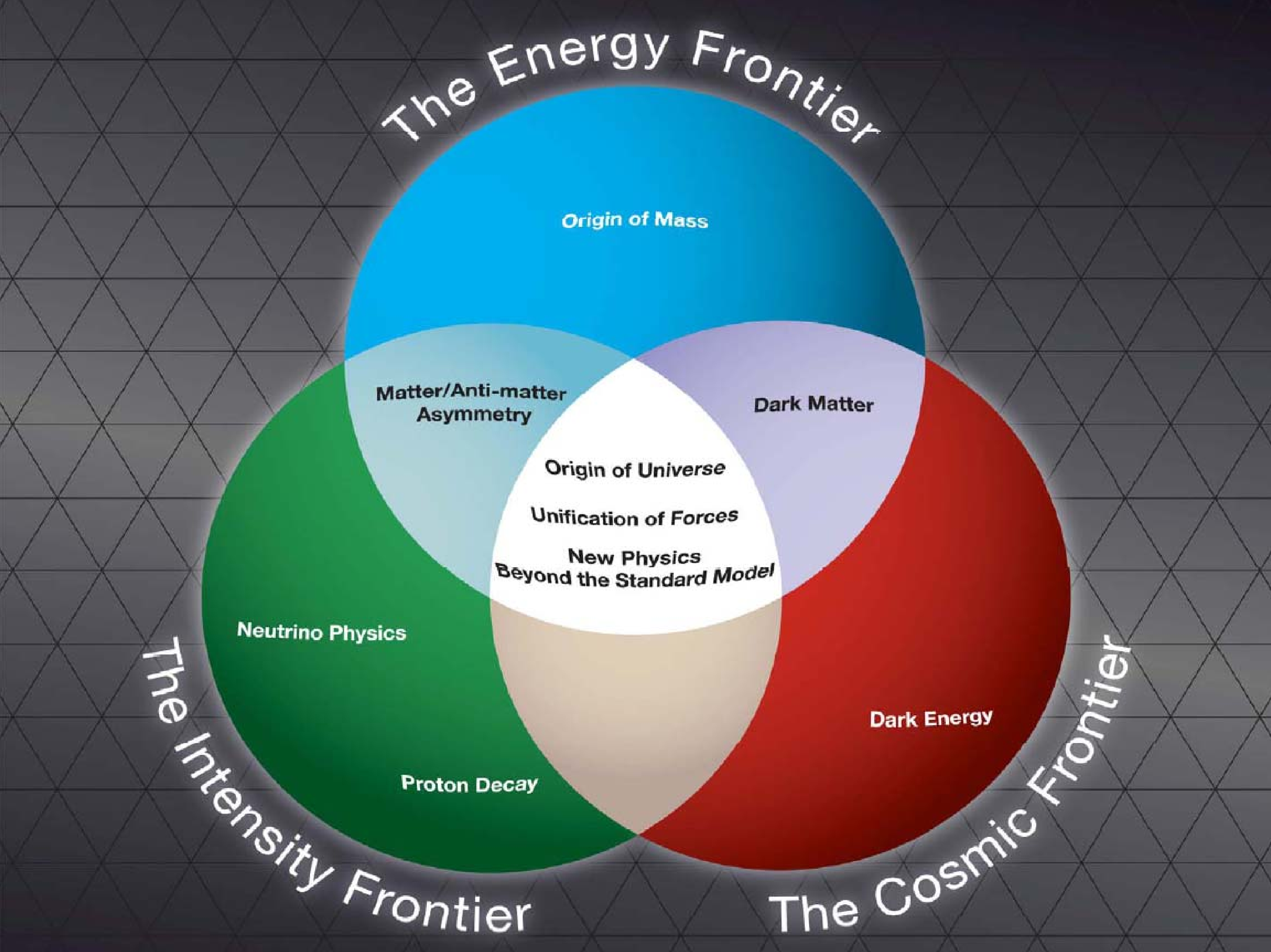
New Physics beyond SM

- 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 !**

Present "Observational" Evidence for New Physics

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



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

PERCHE' OLTRE IL MODELLO STANDARD

"OBSERVATIONAL" REASONS

- HIGH ENERGY PHYSICS

NO (but $A_{FB}^{Z \to bb}$……)

- FCNC, CP$\neq$

NO (but $b \to s q\bar{q}$ penguin …)

- 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

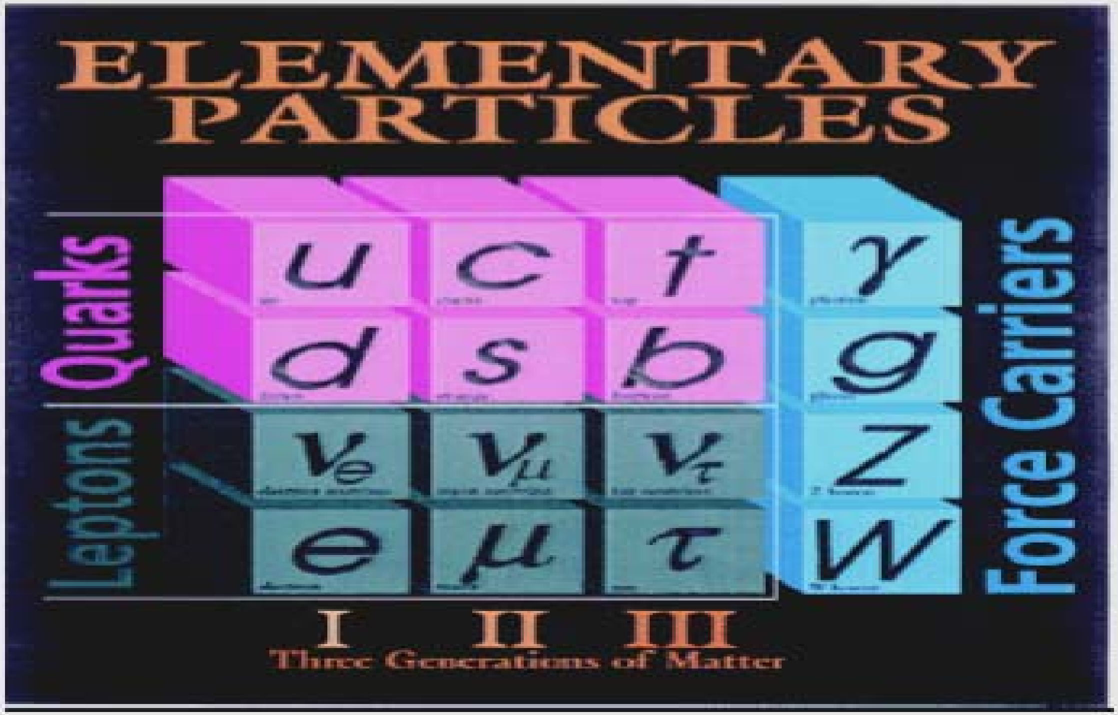
- INTRINSIC INCONSISTENCY OF SM AS QFT

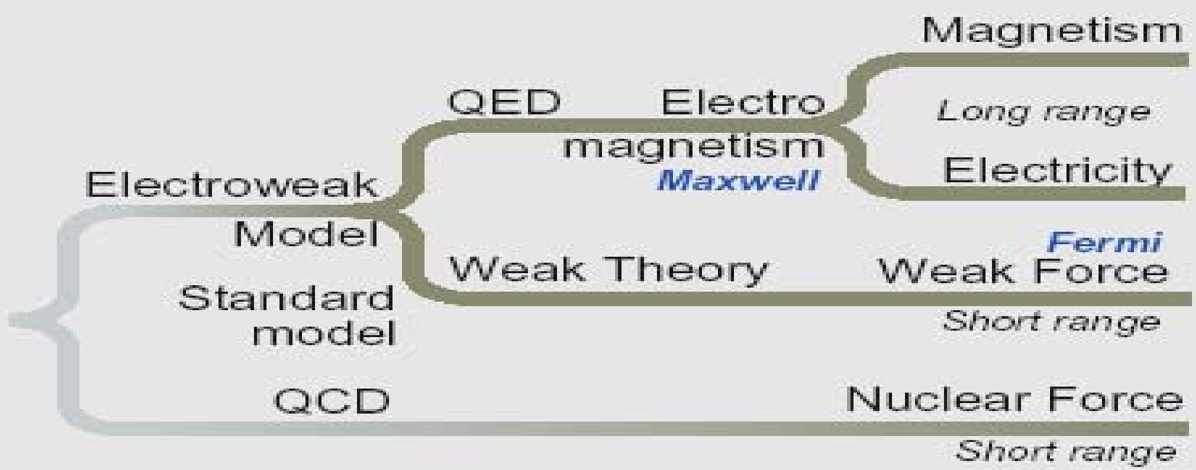
NO (spont. broken gauge theory without anomalies)

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

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

THE G-W-S STANDARD MODEL





PROLOGUE

… **no firm experimental 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**

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

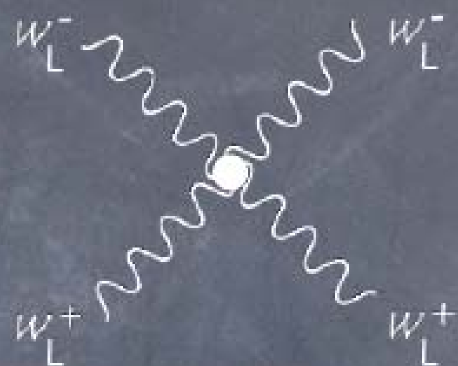
What is the mechanism of EWSB?

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

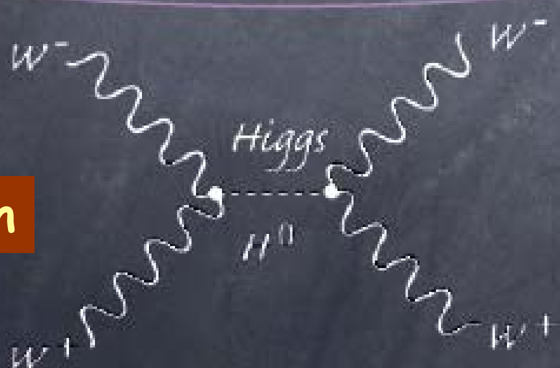
$$\epsilon_l = \left(\frac{|\vec{k}|}{M}, \frac{E}{M} \frac{\vec{k}}{|\vec{k}|} \right)$$



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

loss of perturbative unitarity
around 1.2 TeV

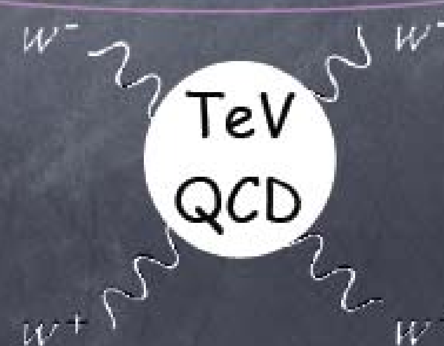
Weakly coupled models



prototype: Susy

susy partners ~ 100 GeV

Strongly coupled models



prototype: Technicolor

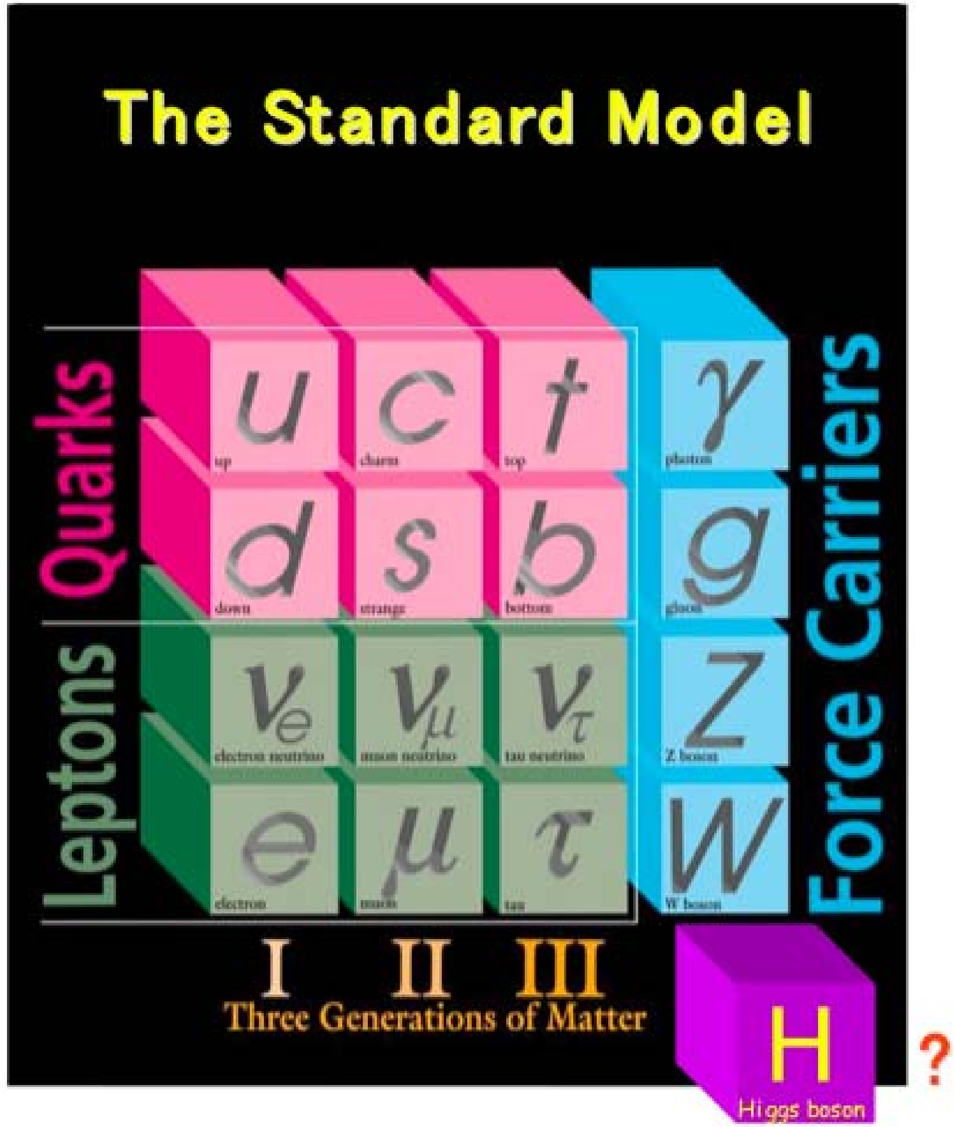
rho meson ~ 1 TeV

Different signatures at the LHC!

Grojean

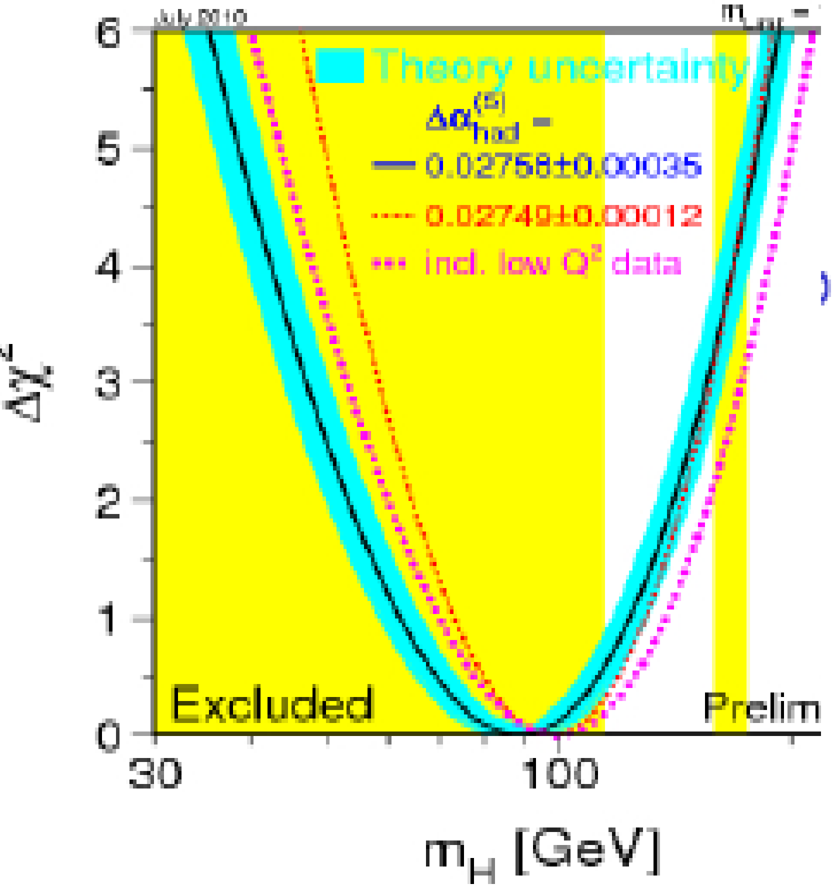
Gravity

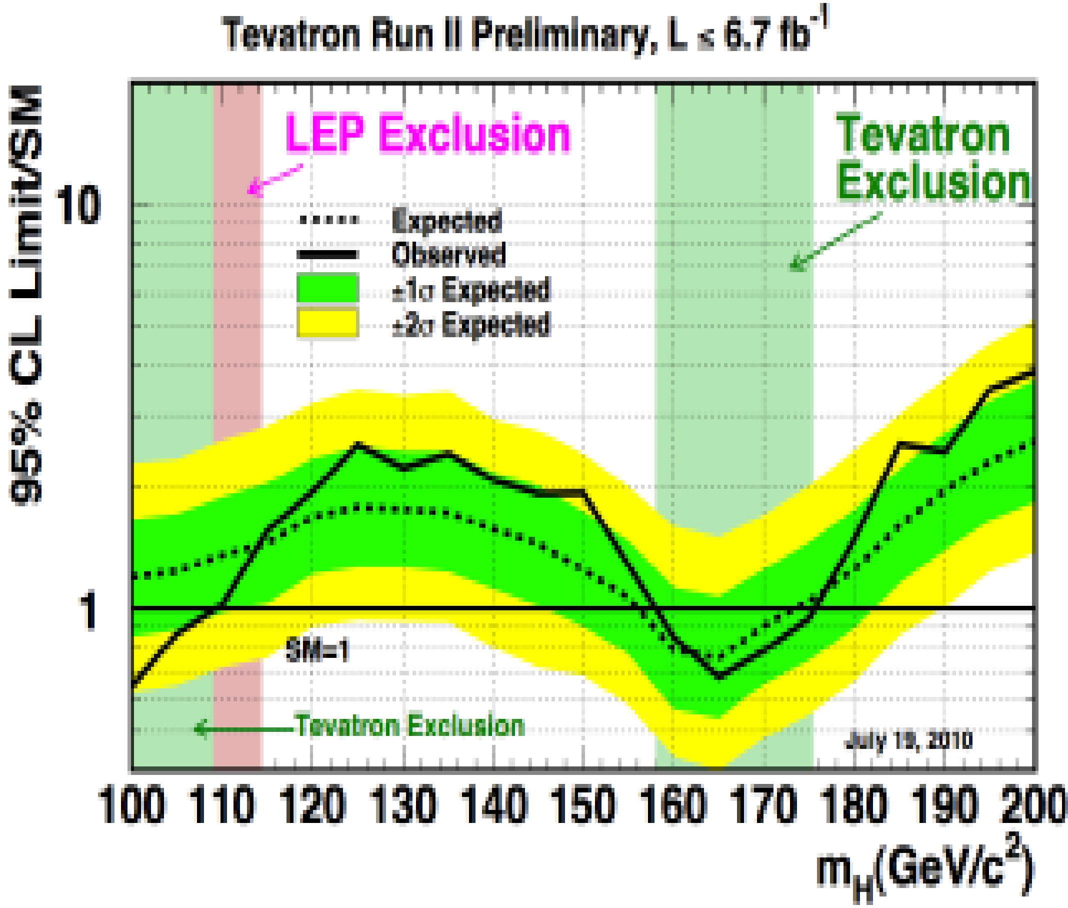
?

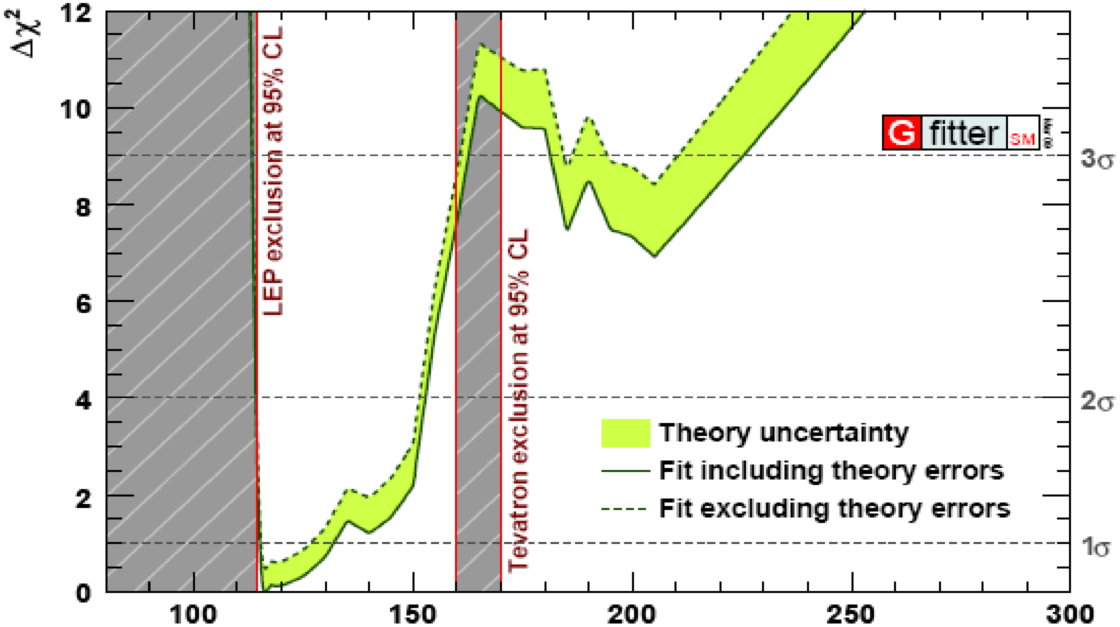


The Standard Model
Quarks
Leptons
Force Carriers
u
up
c
charm
t
top
d
down
s
strange
b
bottom
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
e
electron
μ
muon
τ
tau
γ
photon
g
gluon
Z
Z boson
W
W boson
I II III
Three Generations of Matter
H
Higgs boson
?

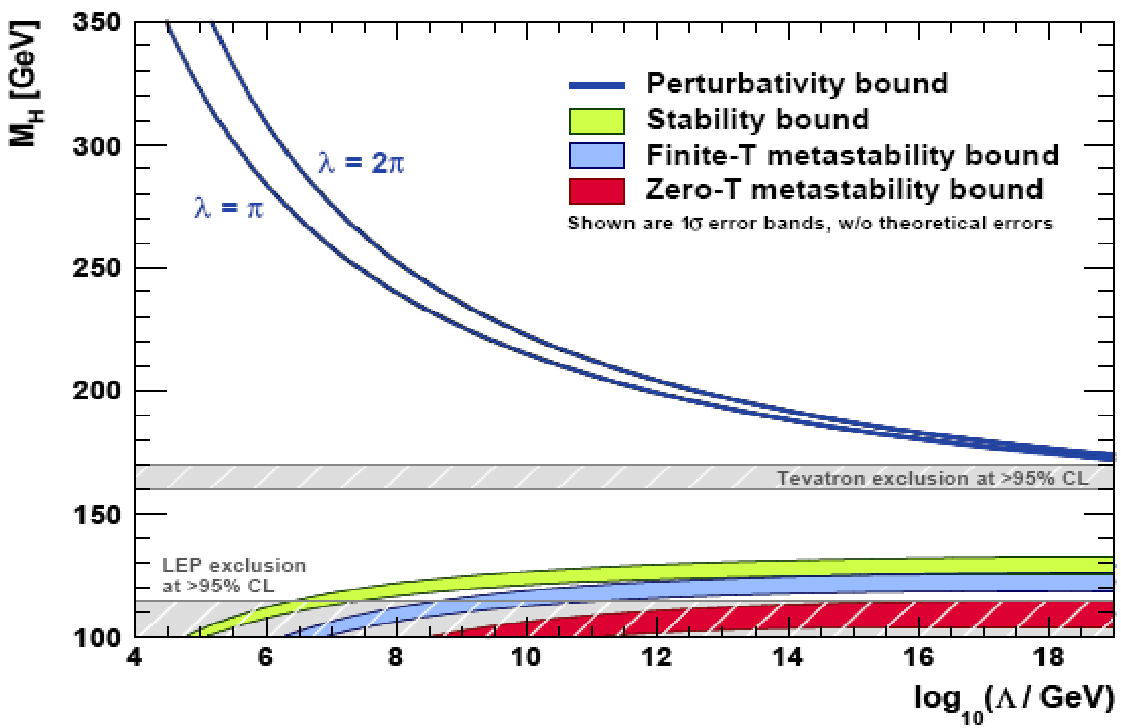
Higgs, particella elementare e leggera?





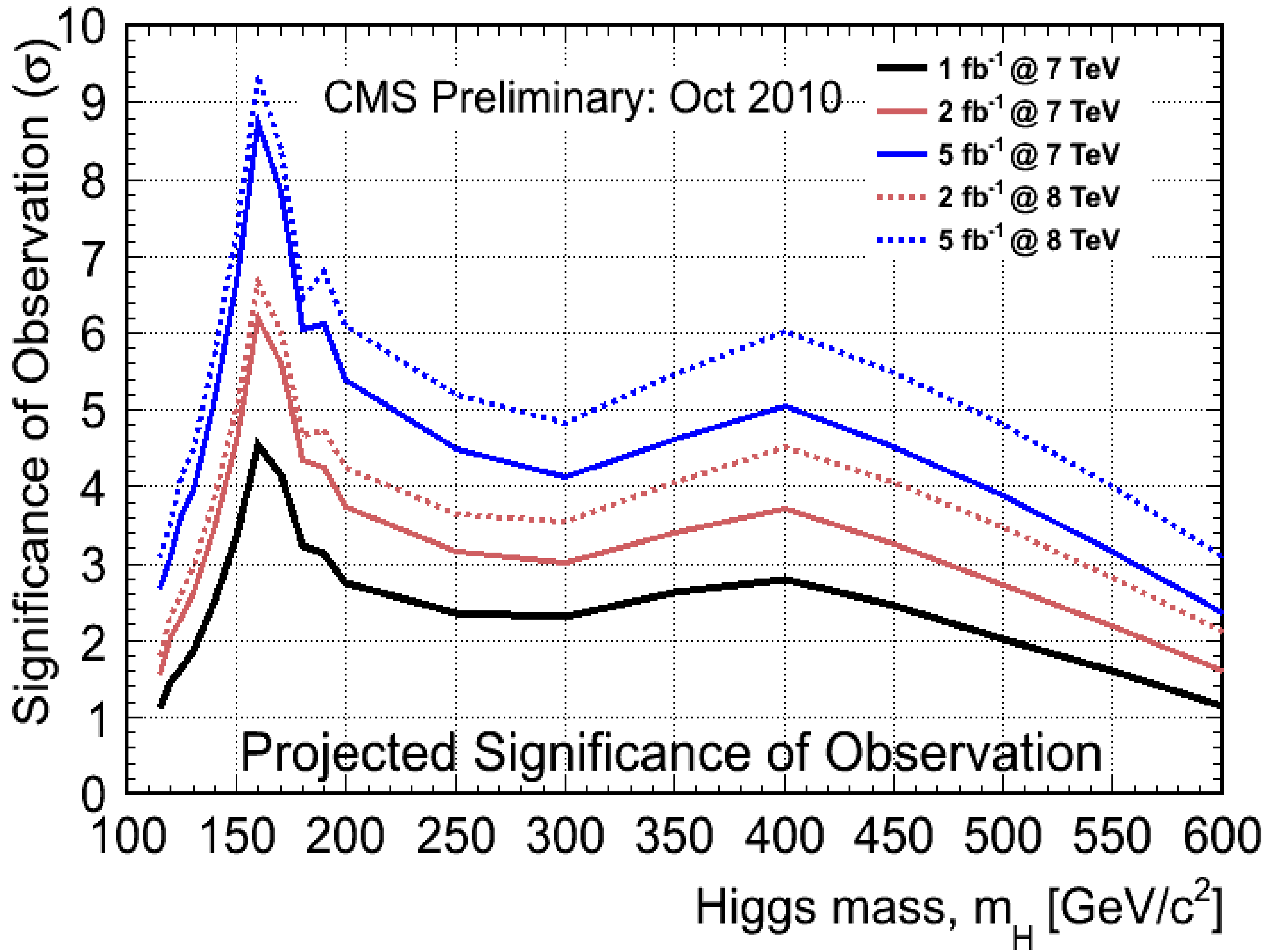


a light higgs (or something mimicking it) is definitely favored



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


CMS Preliminary: Oct 2010
1 fb-1 @ 7 TeV
2 fb-1 @ 7 TeV
5 fb-1 @ 7 TeV
2 fb-1 @ 8 TeV
5 fb-1 @ 8 TeV
Projected Significance of Observation
Significance of Observation (σ)
Higgs mass, mH [GeV/c2]
0
1
2
3
4
5
6
7
8
9
10
100
150
200
250
300
350
400
450
500
550
600

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

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

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

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

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

% 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: the 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)

"*MASS PROTECTION*"

For FERMIONS, VECTOR (GAUGE) and SCALAR BOSONS

SIMMETRY PROTECTION
- -FERMIONS $\longrightarrow$ chiral symmetry

  $f_L\, f_R$ not invariant under SU(2)x U(1)
- -VECTOR BOSONS $\longrightarrow$ gauge symmetry

$\longrightarrow$ FERMIONS and W,Z VECTOR BOSONS can get a mass only when the elw. symmetry is broken m_f, $m_W \leq \langle H \rangle$

NO SYMMETRY PROTECTION FOR SCALAR MASSES

POSSIBLE SOLUTION ⬇

"INDUCED MASS PROTECTION"

$\longrightarrow$ Create a symmetry (SUPERSIMMETRY)
Such that FERMIONS $\longleftrightarrow$ BOSONS

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)

$\longrightarrow$ LOW ENERGY SUSY

DESTABILIZATION OF THE ELW. SYMMETRY BREAKING SCALE

For $\Lambda = M_{\mathrm{Pl}}$:

$$\Sigma_H^f \approx \delta M_H^2 \sim M_{\mathrm{Pl}}^2 \quad \Rightarrow \quad \delta M_H^2 \approx 10^{30}\, M_H^2$$

(for $M_H \lesssim 1$ TeV)

SCALAR MASSES ARE "UNPROTECTED" AGAINST LARGE CORRECTIONS WHICH TEND TO PUSH THEM UP TO THE LARGEST ENERGY SCALE PRESENT IN THE FULL THEORY

EX: Grand Unified Theory (GUT): $\delta M_H^2 \approx M_{\mathrm{GUT}}^2$

THE FINE-TUNING PROBLEM
OR
NATURALNESS PROBLEM

When SM is embedded in a larger theory where a new scale M>> the electroweak scale $\longrightarrow$ the SM higgs mass receives corrections of O(M), i.e.

M higgs= M higgs tree-level+ aM +bM +…

Need a and b to cancel each other with a precision of O(elw. scale / M)

The Higgs problem is central in particle physics today

Altarelli LP09

The main problems of the SM show up in the Higgs sector

$$V_{Higgs} = V_0 - \mu^2 \phi^\dagger \phi + \lambda\left(\phi^\dagger \phi\right)^2 + [\overline{\psi}_{Li} Y_{ij} \psi_{Rj} \phi + h.c.]$$

Vacuum energy
$V_{0exp} \sim (2.10^{-3}\ \mathrm{eV})^4$

Origin of quadratic divergences.
Hierarchy problem

Possible instability depending on m_H

The flavour problem: large unexplained ratios of Y_{ij} Yukawa constants

HOW TO COPE WITH THE HIERARCHY PROBLEM

- LOW-ENERGY SUSY
- LARGE EXTRA DIMENSIONS
- DYNAMICAL SYMMETRY BREAKING OF THE ELW. SYMMETRY
- LANDSCAPE APPROACH (ANTHROPIC PRINCIPLE)

ROADS TO GO BEYOND THE STANDARD MODEL (I)

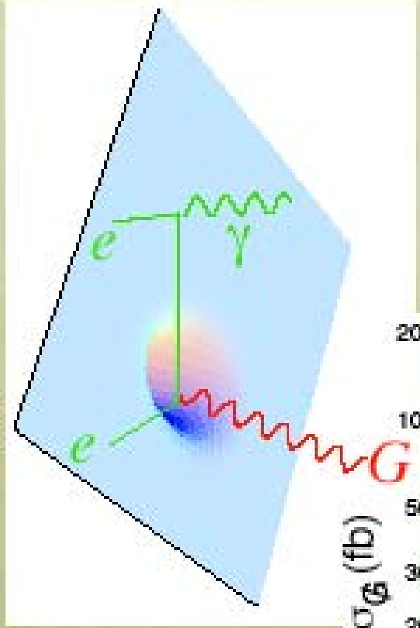
1) **THERE EXISTS NO NEW PHYSICAL ENERGY SCALE ABOVE THE ELW. SCALE**: gravity is an extremely weak force not because of the enormous value of the Planck scale, but because of the existence of **NEW DIMENSIONS** beyond the usual 3+1 space-time where (most of) the gravity flux lines get “dispersed”

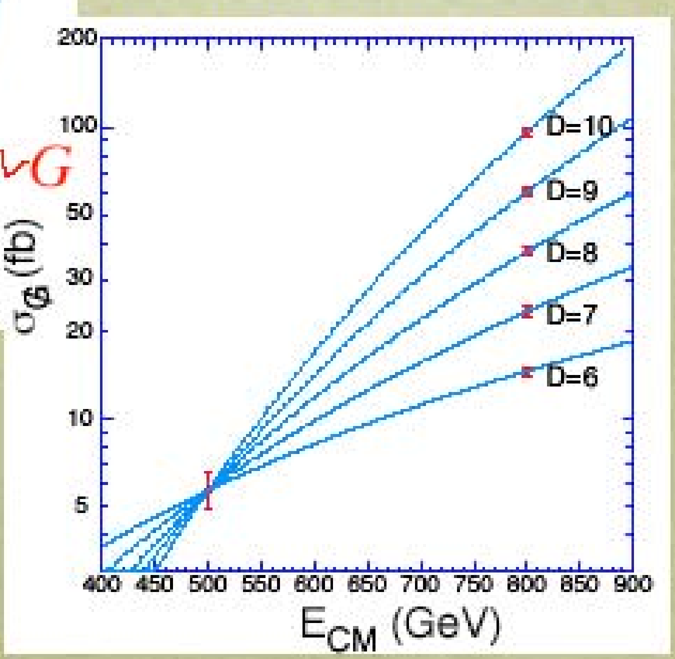
→ **VISIBILITY AT LHC**: there exist “excited” states of the ordinary particles (**Kaluza-Klein states**) and some of them are accessible at LHC (the lightest KK state may be a stable particle and it can constitute the DM)

Hidden Dimensions

- *Hidden dimensions*
- *Can emit graviton into the bulk*
- *Events with apparent energy imbalance*

How many extra dimensions are there?





ROADS TO GO BEYOND THE STANDARD MODEL (II)

- **2) NO NEED TO "PROTECT" THE HIGGS MASS AT THE ELW. SCALE: THE HIGGS IS A COMPOSITE OBJECT (for instance, a fermion condensate) WHOSE COMPOSITENESS SCALE IS THE ELW. SCALE (cfr. the pion mass case)**

$\longrightarrow$ **VISIBILITY AT LHC**: **THERE EXIST NEW (STRONG) INTERACTIONS AT THE ELW. SCALE WHICH PRODUCE THE HIGGS CONDENSATE** (new resonances,, new bound states, a new rescaled QCD at 1 TeV)

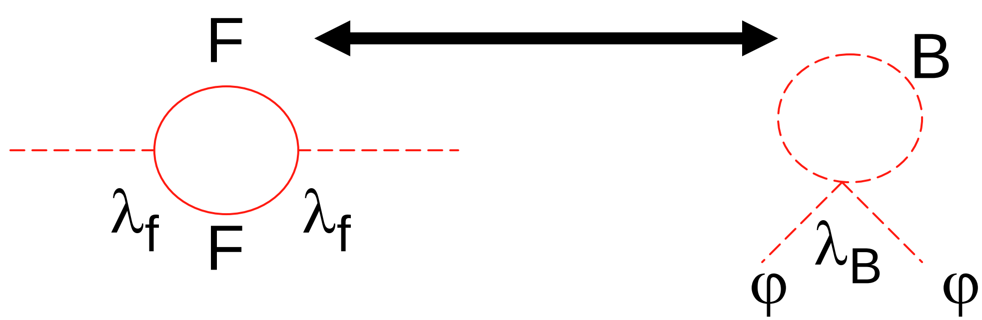
ROADS TO GO BEYOND THE STANDARD MODEL (III)

- **3) THE MASS OF THE ELEMENTARY HIGGS BOSON IS "PROTECTED" AT THE ELW. SCALE BECAUSE OF THE PRESENCE AT THAT ENERGY OF A NEW SYMMETRY, THE SUPERSYMMETRY (SUSY)**
  → **VISIBILITY AT LHC**: WE'LL SEE (SOME OF) THE **SUSY PARTICLES AND THEIR INTERACTIONS**. THE LIGHTEST SUSY PARTCILE (**LSP**) IS LIKELY TO BE STABLE AND PROVIDE THE **DM**. **AT THE SAME TIME, WE COULD DISCOVER SUSY AND THE SOURCE OF 90% OF THE ENTIRE MATTER PRESENT IN THE UNIVERSE.**

HIERARCHY PROBLEM: THE SUSY WAY

SUSY HAS TO BE BROKEN AT A SCALE CLOSE TO 1TeV $\longrightarrow$ LOW ENERGY SUSY

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



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

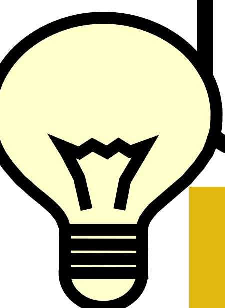
$$\longrightarrow [m^2{}_B - m^2{}_F]^{1/2} \sim 1/\sqrt{G_F}$$

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

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

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**

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

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

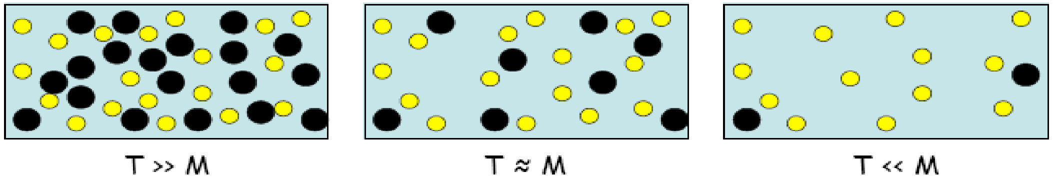
THE "*WIMP MIRACLE*"

Bergstrom

Table 1. Properties of various Dark Matter Candidates

Type	Particle Spin	Approximate Mass Scale
Axion	0	μeV-meV
Inert Higgs Doublet	0	50 GeV
Sterile Neutrino	1/2	keV
Neutralino	1/2	10 GeV - 10 TeV
Kaluza-Klein UED	1	TeV

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



WIMPS (Weakly Interacting Massive Particles)

$\#\chi \sim \#\gamma$ m_χ

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

$\#\chi$ does not change any more

$T_{decoupl.}$ typically ~ m_χ /20

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

$$\Omega_\chi h^2 \simeq \frac{10^{-3}}{\underbrace{<(\sigma_{annih.}) V \chi>}_{\sim\, \alpha^2 / M^2_\chi} \quad TeV^2}$$

TeV^2 → From T^0 M_{Planck}

COSMO – PARTICLE CONSPIRACY

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

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

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

STABLE ELW. SCALE WIMPs from PARTICLE PHYSICS

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

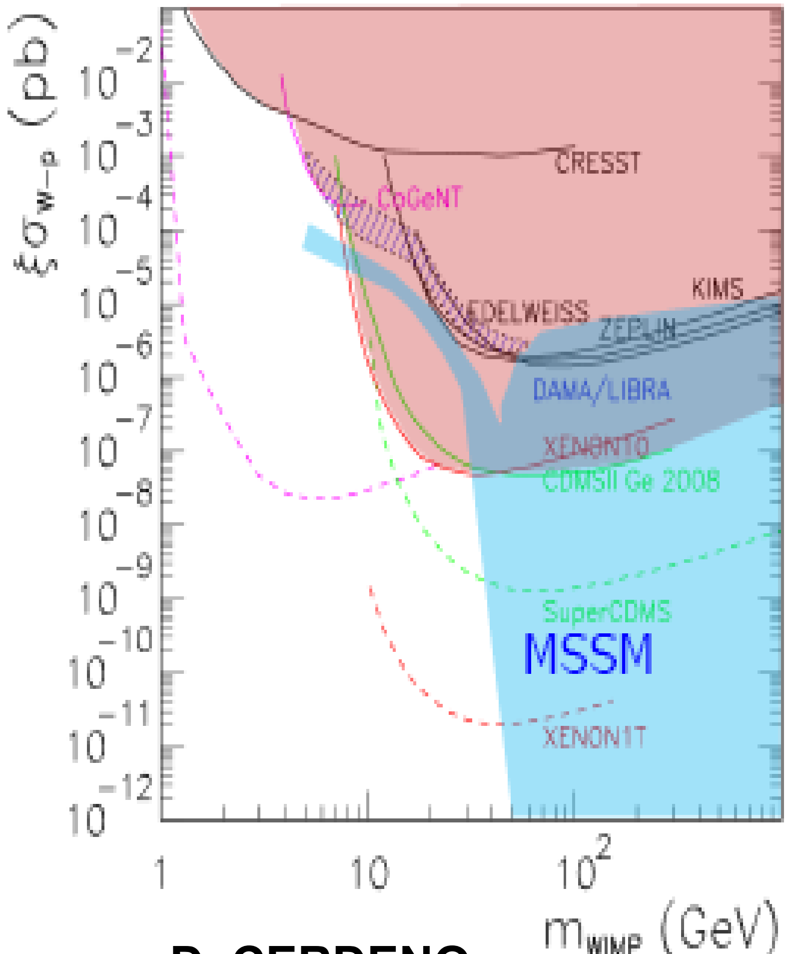
* But abandoning gaugino-masss unif. → Possible to have m_{LSP} down to 7 GeV

Bottino, Donato, Fornengo, Scopel

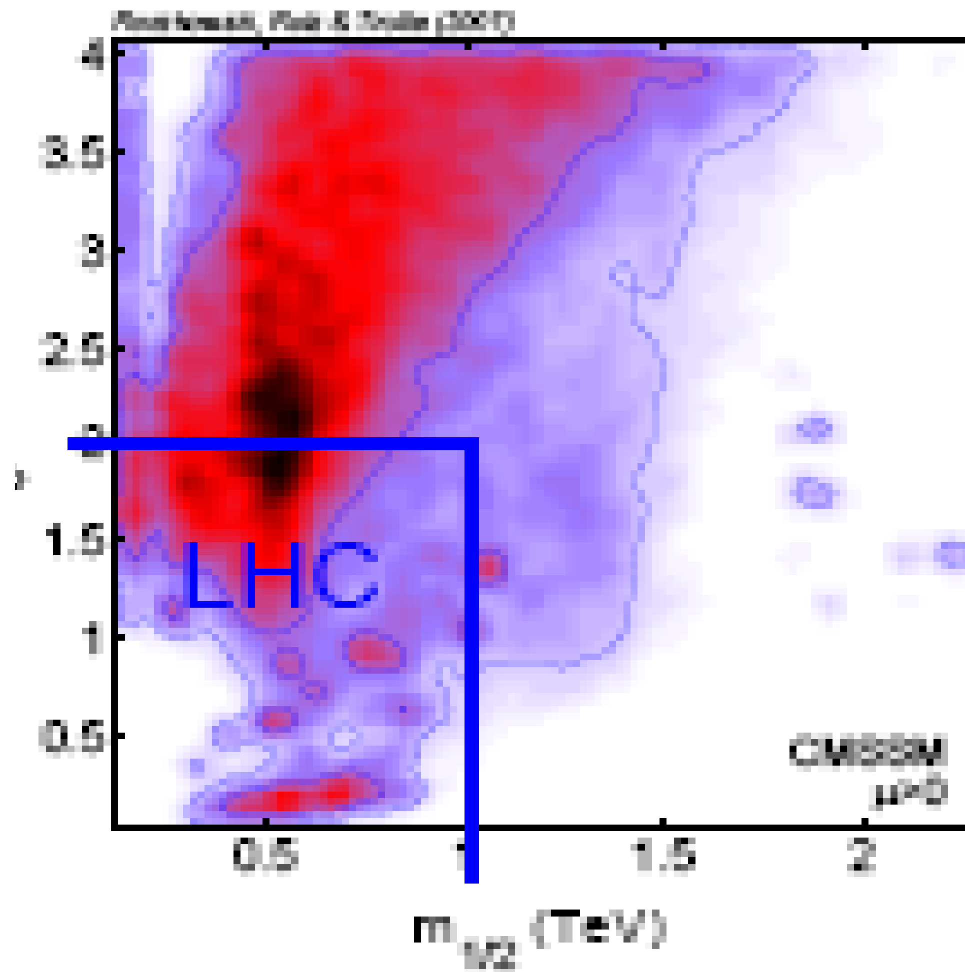
SUSY & DM : a successful marriage

- Supersymmetrizing the SM does not lead necessarily to a stable SUSY particle to be a DM candidate.
- However, the mere SUSY version of the SM is known to lead to a too fast p-decay. Hence, necessarily, the SUSY version of the SM has to be **supplemented with some additional (ad hoc?) symmetry to prevent the p-decay catastrophe.**
- Certainly the simplest and maybe also the most attractive solution is **to impose the discrete R-parity** symmetry
- MSSM + R PARITY $\longrightarrow$ LIGHTEST SUSY PARTICLE (LSP) IS STABLE .
- The LSP can constitute an interesting DM candidate in several interesting realizations of the MSSM (i.e., with different SUSY breaking mechanisms including gravity, gaugino, gauge, anomaly mediations, and in various regions of the parameter space).

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

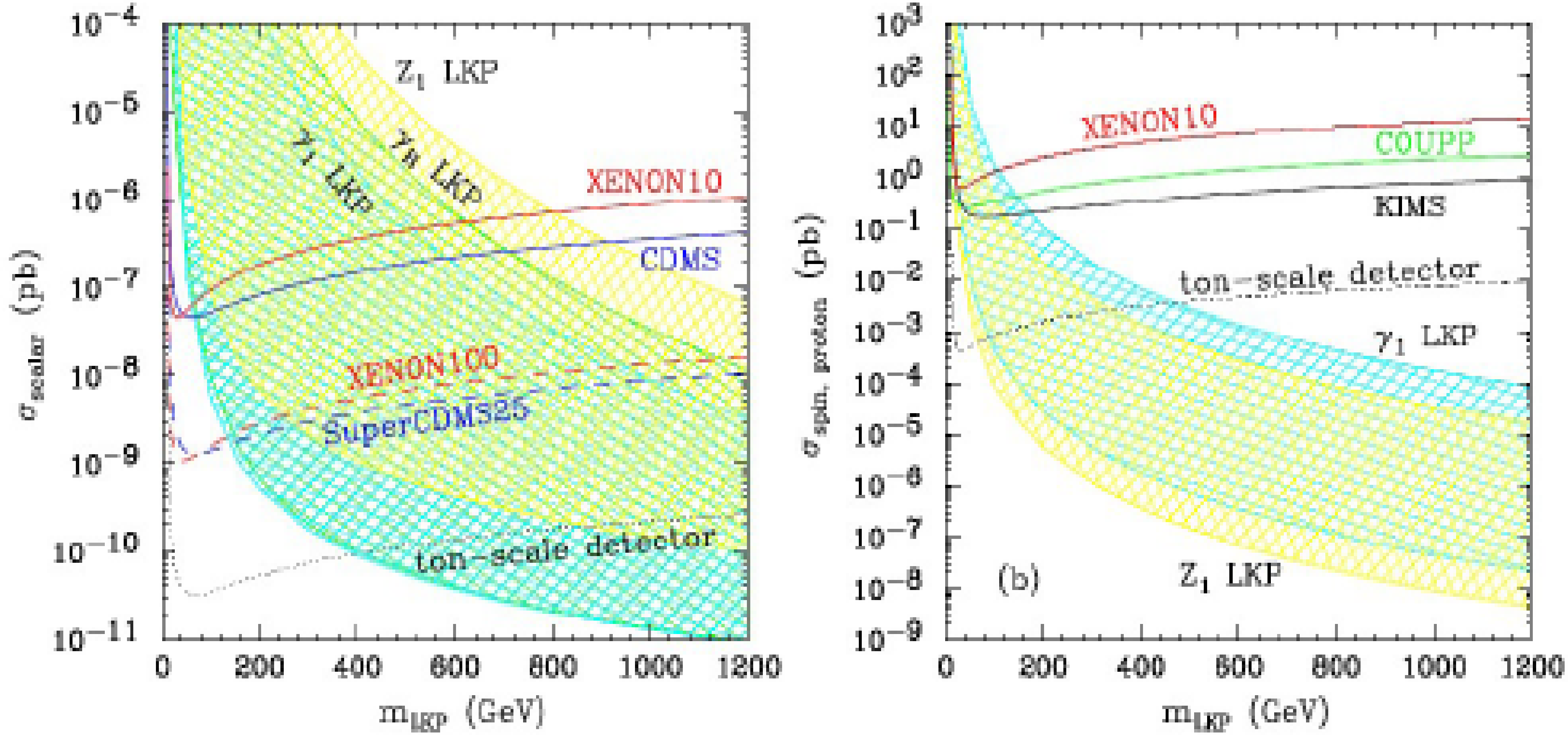


D. CERDENO
WONDER10



L. Roszkowsk et al.

DM and Extra Dimensions



(Arrenberg et al.'08)

HUMAN PRODUCTION OF WIMPs

WIMPS HYPOTHESIS

DM made of particles with mass 10Gev - 1Tev

ELW scale

With WEAK INTERACT.

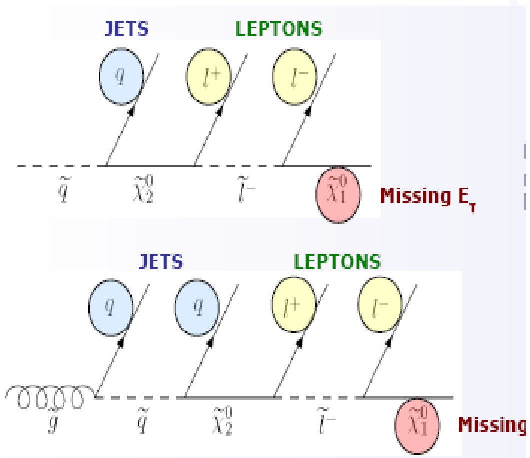
LHC, ILC may PRODUCE WIMPS

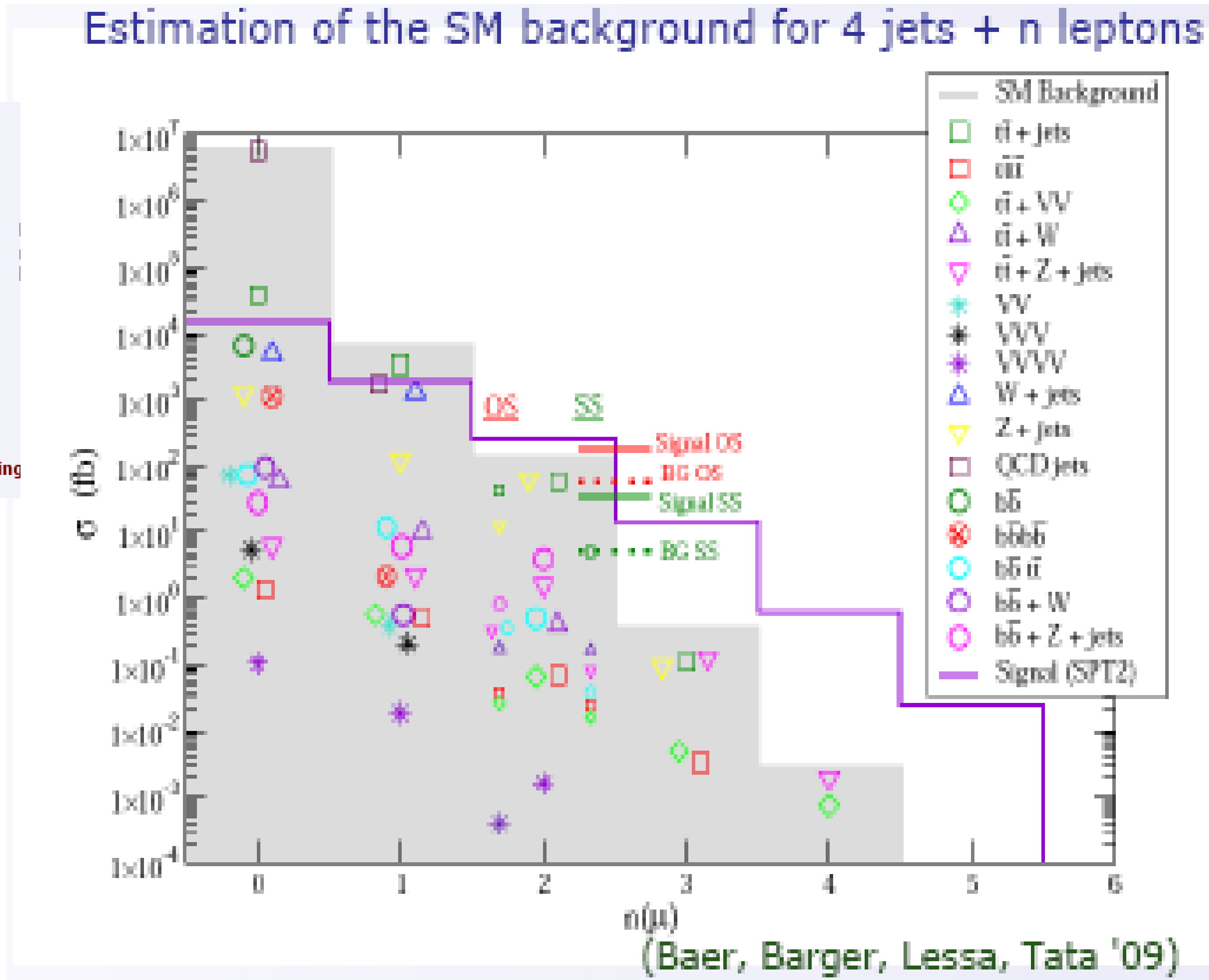
WIMPS escape the detector

→ MISSING ENERGY SIGNATURE

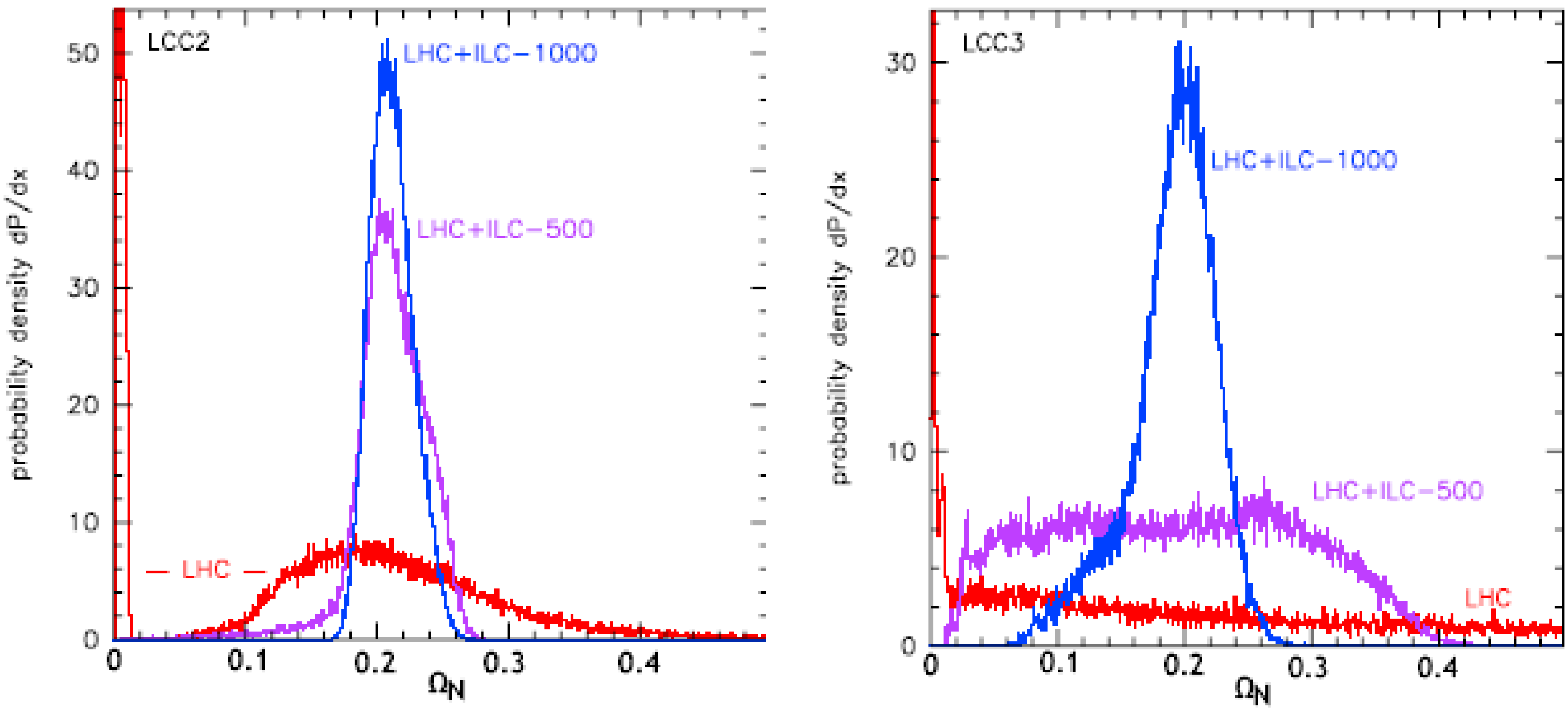
POSSIBILITY TO CREATE OURSELVES IN OUR ACCELERATORS THOSE DM PARTICLES WHICH ARE PART OF THE RELICS OF THE PRIMORDIAL PLASMA AND CONSTITUTE 1/4 OF THE WHOLE ENERGY IN THE UNIVERSE

DM through the jets + missing energy signature at the LHC

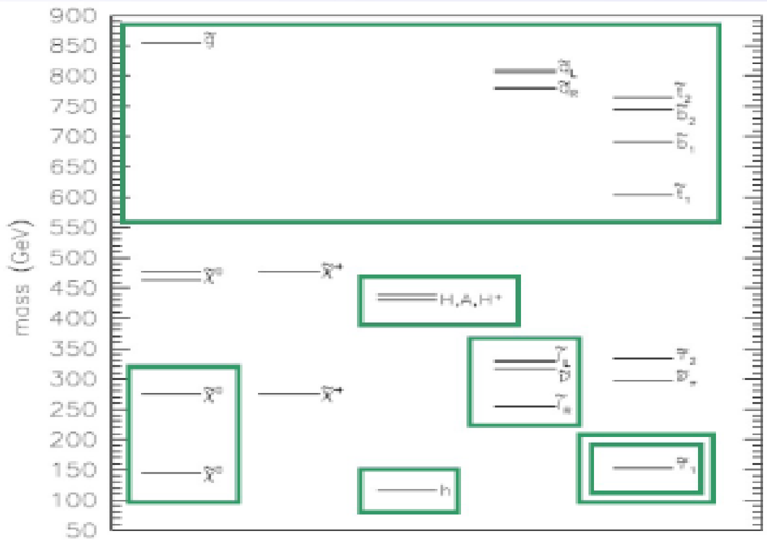




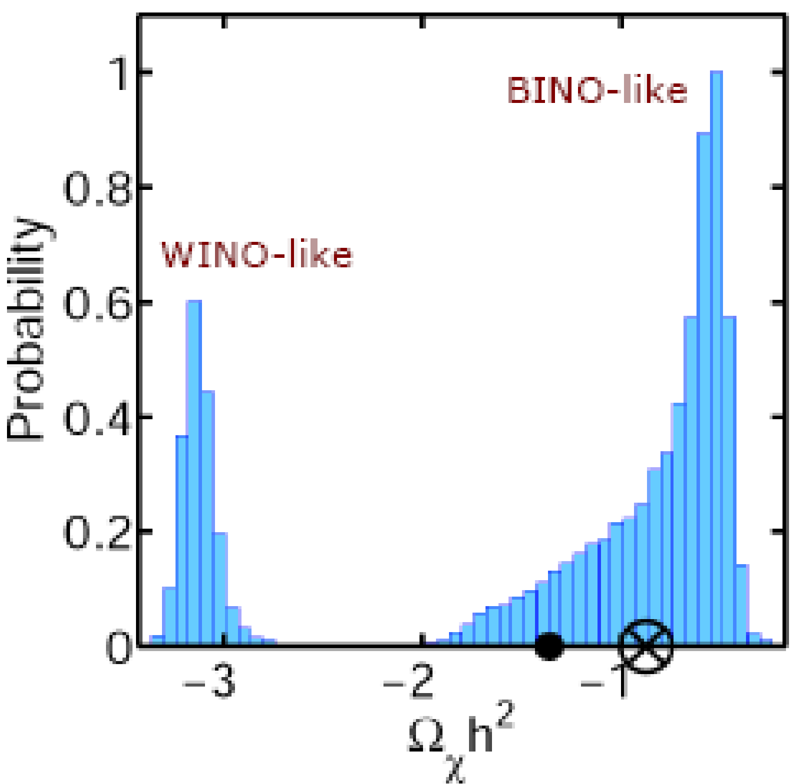
PREDICTION OF Ω DM FROM LHC AND ILC FOR TWO DIFFERENT SUSY PARAMETER SETS

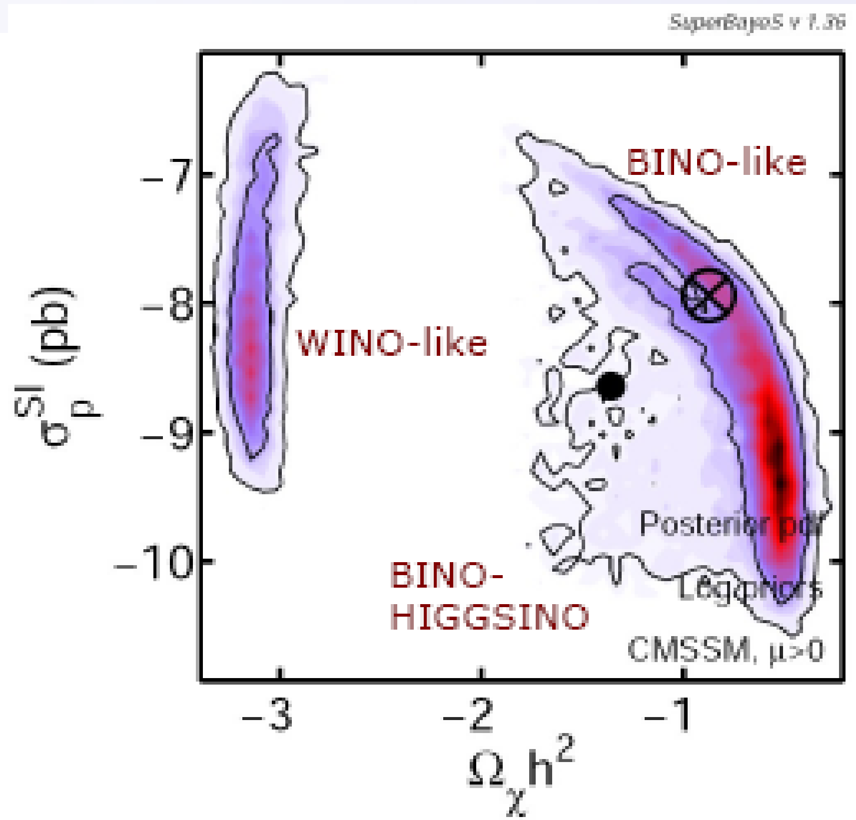


BALTZ, BATTAGLIA, PESKIN, WIZANSKY



Suppose we find some SUSY particles at LHC: will we be able to infer which s-particle is the LSP?





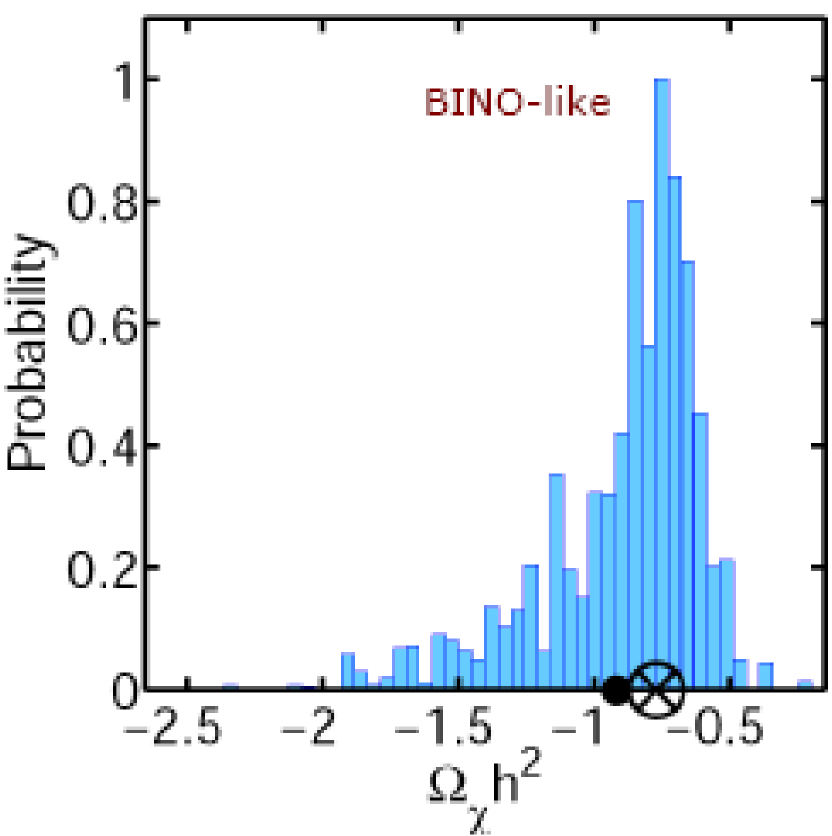
...but if at the same time we have some result from the DM searches

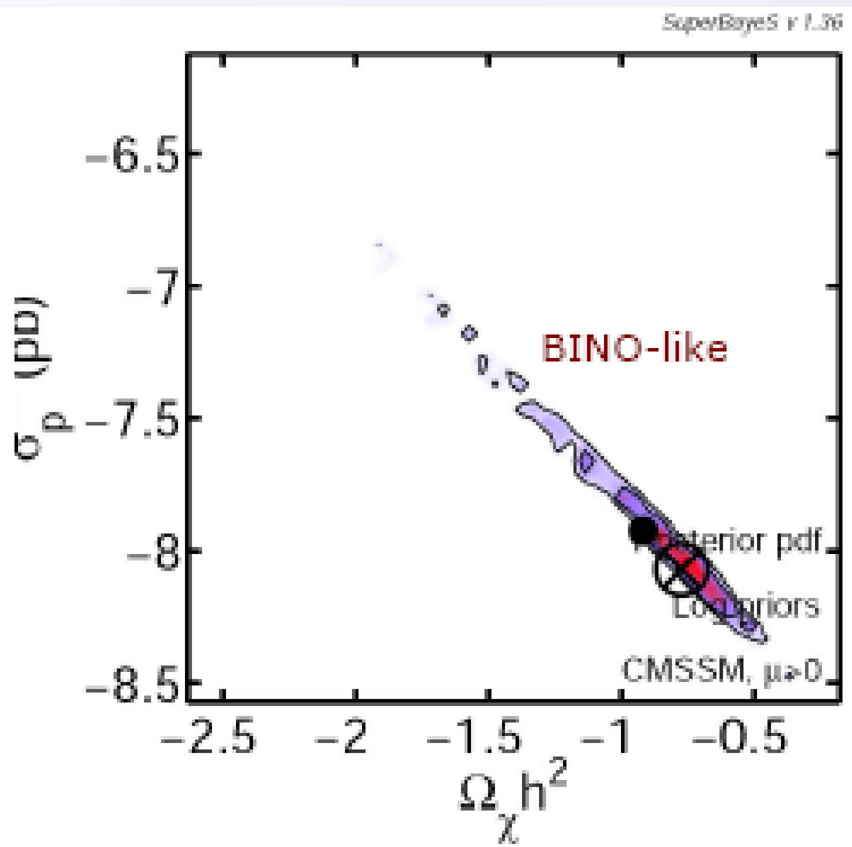
synergy LHC - DM

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

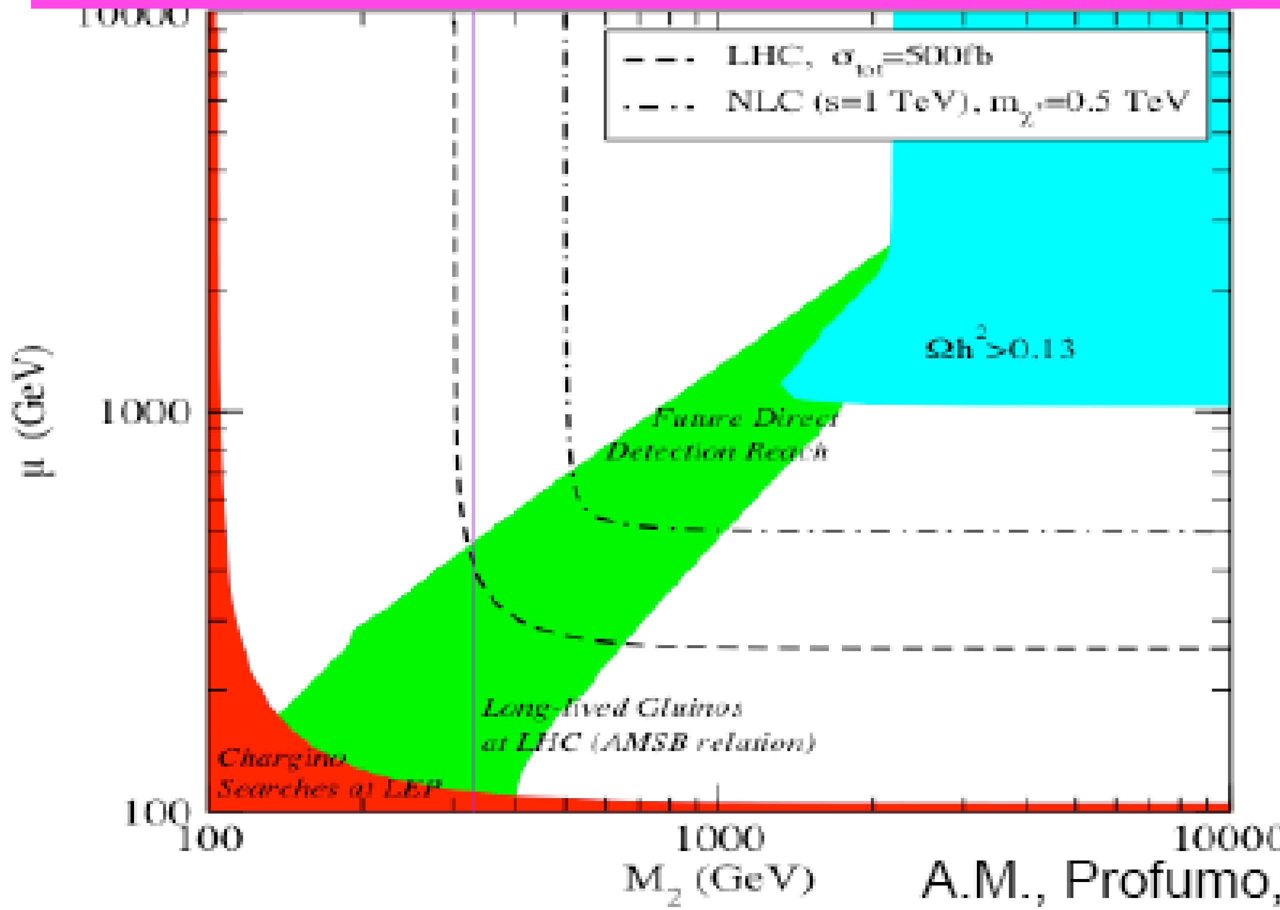
The reconstruction of the relic abundance has a similar accuracy but spurious maxima disappear

(Bertone, Cerdeño, Fornasa, Trotta, de Austri –

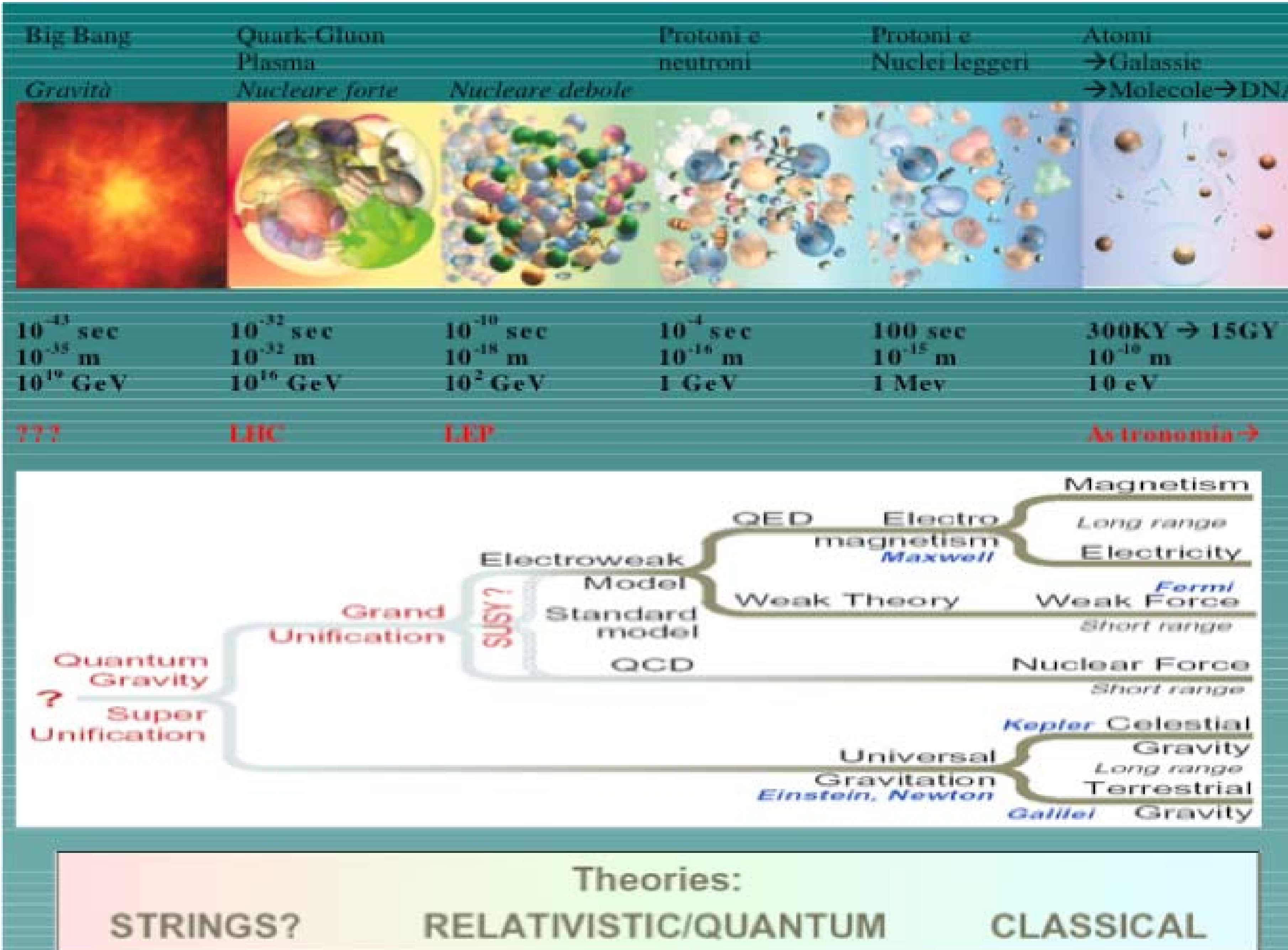




LHC, ILC, DM SEARCHES SENSITIVITIES



A.M., Profumo, Ullio

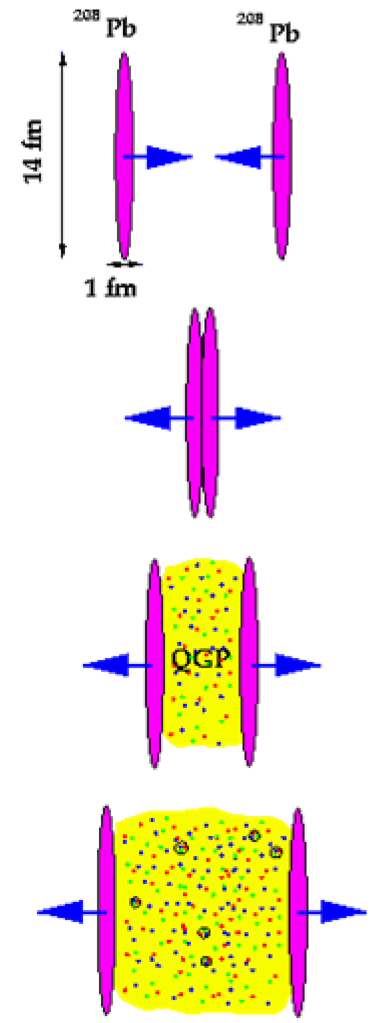

Big Bang
Gravità
Quark-Gluon Plasma
Nucleare forte
Nucleare debole
Protoni e neutroni
Protoni e Nuclei leggeri
Atomi
→Galassie
→Molecole→DNA
10^{-43} sec
10^{-35} m
10^{19} GeV
10^{-32} sec
10^{-32} m
10^{16} GeV
10^{-10} sec
10^{-18} m
10^{2} GeV
10^{-4} sec
10^{-16} m
1 GeV
100 sec
10^{-15} m
1 Mev
300KY → 15GY
10^{-10} m
10 eV
???
LHC
LEP
Astronomia →
Magnetism
Long range
Electricity
QED
Electro magnetism
Maxwell
Electroweak Model
Weak Theory
Fermi
Weak Force
Short range
Grand Unification
SUSY ?
Standard model
QCD
Nuclear Force
Short range
Quantum Gravity
?
Super Unification
Kepler
Celestial Gravity
Long range
Universal Gravitation
Einstein, Newton
Galilei
Terrestrial Gravity
Theories:
STRINGS?
RELATIVISTIC/QUANTUM
CLASSICAL

Collisioni tra nuclei ad LHC

- facendo collidere due nuclei a energia ultrarelativistica ad LHC, si produce una “fireball” a una temperatura superiore a 2000 miliardi di gradi, rincreando, seppure per un tempo brevissimo, le condizioni appropriate per il “deconfinamento”

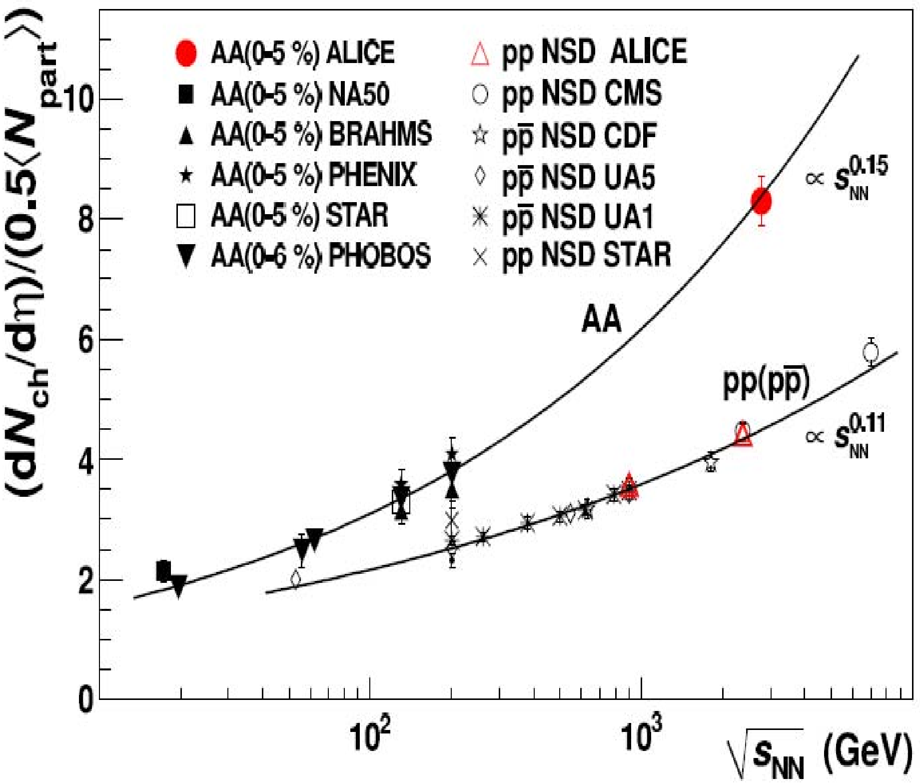
- si ottiene così un Plasma di Quark e Gluoni (Quark-Gluon Plasma, QGP) in cui i quark (e i gluoni che ne mediano l’interazione) sono “liberati”

- studiando le proprietà del QGP, speriamo di capire meglio come si comportava l’Universo nei suoi primi istanti di vita, e di comprendere più in dettaglio il fenomeno del confinamento e come vengano generate le masse dei protoni, neutroni e altri adroni



F. Antinori

La più alta densità di energia…



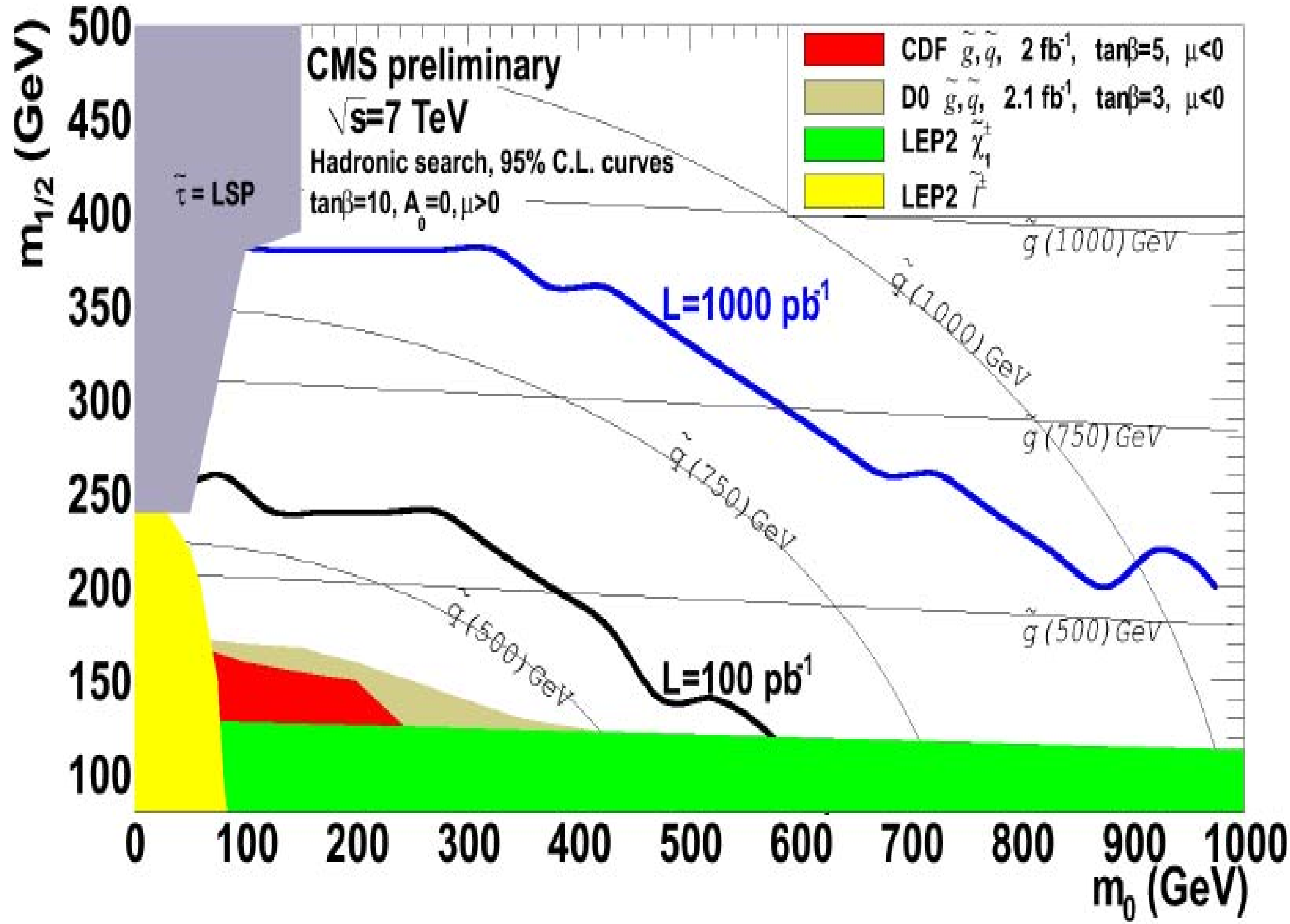
… mai raggiunta artificialmente

- ε = energia per unità di volume:

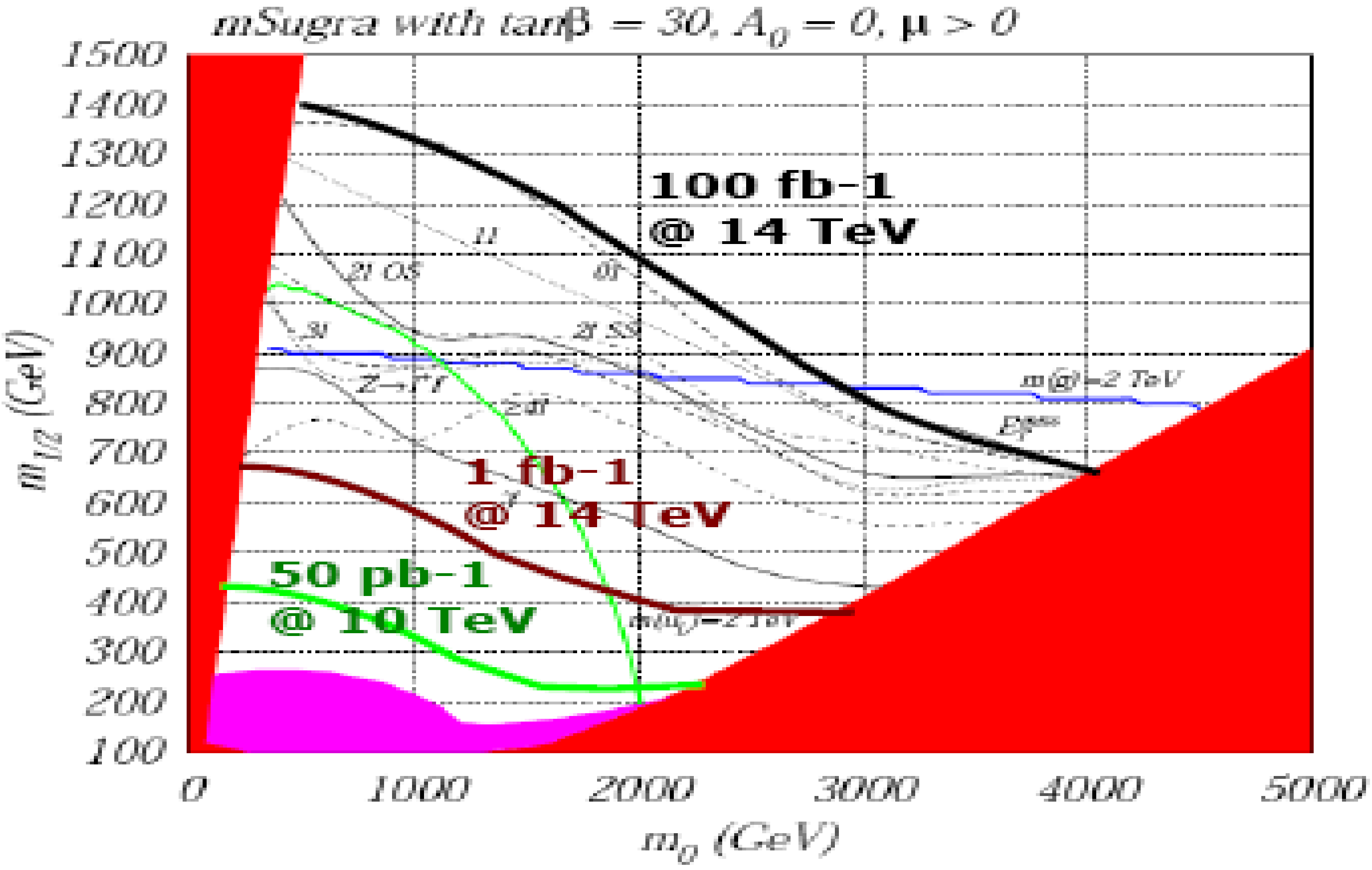
$$\varepsilon = \frac{E}{V} = A \cdot \frac{dN_{ch}}{d\eta} \cdot \left\langle \sqrt{m^2 + p_T{}^2} \right\rangle$$

- **ε ~ alcuni GeV/fm³**
  - **alcuni miliardi di tonnellate/cm³** !
- **~ 3 volte più alta che a RHIC**

F. ANTINORI



CMS preliminary
$\sqrt{s}$=7 TeV
Hadronic search, 95% C.L. curves
tanβ=10, A_0=0, μ>0
$\tilde{\tau}$ = LSP
CDF $\tilde{g}, \tilde{q}$, 2 fb^{-1}, tanβ=5, μ<0
D0 $\tilde{g}, \tilde{q}$, 2.1 fb^{-1}, tanβ=3, μ<0
LEP2 $\tilde{\chi}_1^{\pm}$
LEP2 $\tilde{l}^{\pm}$
L=1000 pb^{-1}
L=100 pb^{-1}
$\tilde{g}$ (1000) GeV
$\tilde{q}$ (1000) GeV
$\tilde{g}$ (750) GeV
$\tilde{q}$ (750) GeV
$\tilde{g}$ (500) GeV
$\tilde{q}$ (500) GeV
$m_{1/2}$ (GeV)
m_0 (GeV)



(Baer, Belyaev, Kuprovnikas, o'Farrill ' 04)

(Buchmüller et al. '08)

Baer, Barger, Lessa, Tata (2009)

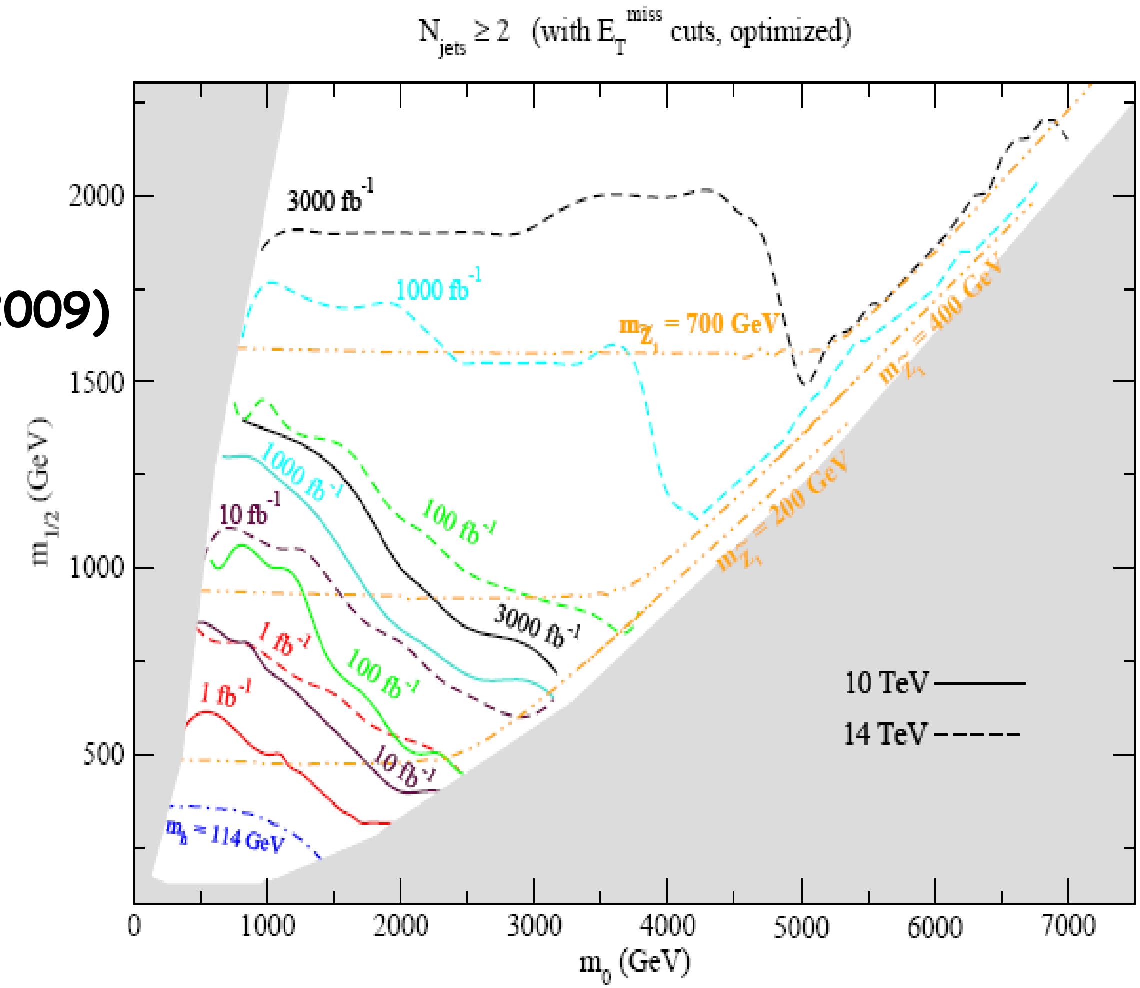


Figure 21: The ultimate SUSY reach of LHC within the mSUGRA framework for $\sqrt{s} = 10$ TeV (solid) and $\sqrt{s} = 14$ TeV (dashed) for various values of integrated luminosities. The fixed mSUGRA parameters are $A_0 = 0$, $\tan\beta = 45$ and $\mu > 0$. Isomass contours for the LSP (double dot-dashed) and for a 114 GeV light Higgs scalar (dot-dashed) are also shown. The shaded areas are excluded

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 $O^{(6)} \sim (\bar{s}\, d)^2$

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

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

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

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

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.

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

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

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

Ciuchini, Isidori, Silvestrini

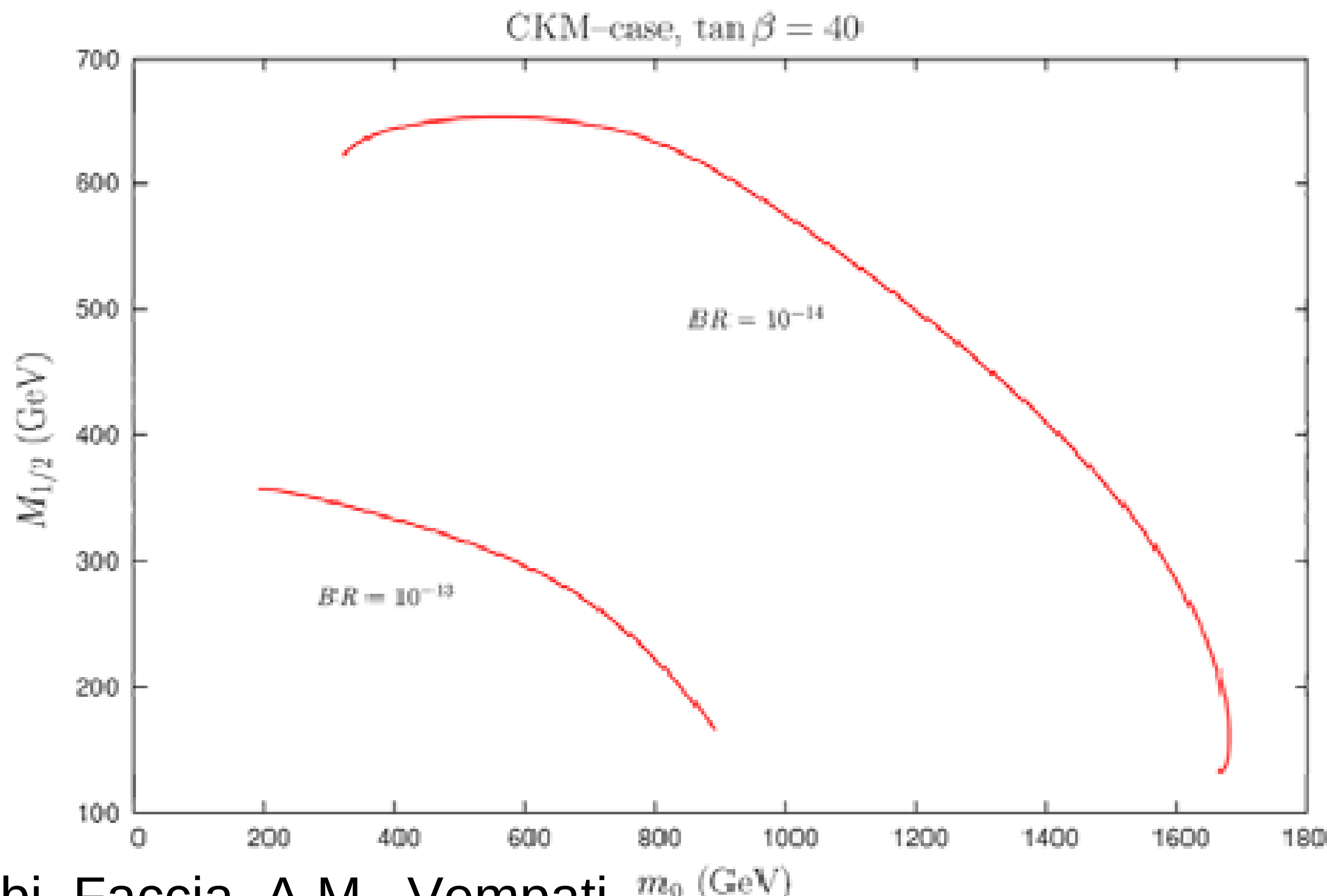
SLOW-DECOUPLING OF NP IN FCNC

V. Lubicz, SuperB_Padova 2008

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-$\mathcal{F}$)**
$f_+^{B\pi},\ldots$	11%	5.5 - 6.5%	4 - 5%	**2 – 3%**
$T_1^{B\to K^*/\rho}$	13%	----	----	**3 – 4%**

MEG POTENTIALITIES TO EXPLORE THE SUSY SEESAW PARAM. SPACE



Calibbi, Faccia, A.M., Vempati

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

LHC and “LOW-ENERGY” NEW PHYSICS

- **LHC discovers NP**: difficult, if not impossible, to “reconstruct” the fundamental theory lying behind those signals of NP;

- **LHC does not see any signal of NP**: still a NP related to the stabilization of the elw. scale may be present, but with particles whose masses are in the multi-TeV range.

TEVATRON → LHC → I L C

DM - FLAVOR

for DISCOVERY

and/or FUND. TH.

RECONSTRUCTION

A MAJOR
LEAP AHEAD
IS NEEDED

NEW PHYSICS AT THE ELW SCALE

DARK MATTER

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

DARK ENERGY

LINKED TO COSMOLOGICAL EVOLUTION

LEPTOGENESIS

GW

INFLATION

"LOW ENERGY"

PRECISION PHYSICS

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

LFV, CPV B PHYSICS

NEUTRINO PHYSICS

G. Martinelli