Lessons from the LHC: SM Higgs and beyond

J. Lorenzo Diaz Cruz [a]

jldiaz@fcfm.buap.mx

FCFM-BUAP and DUAL-CP IHEP

(Mexico)

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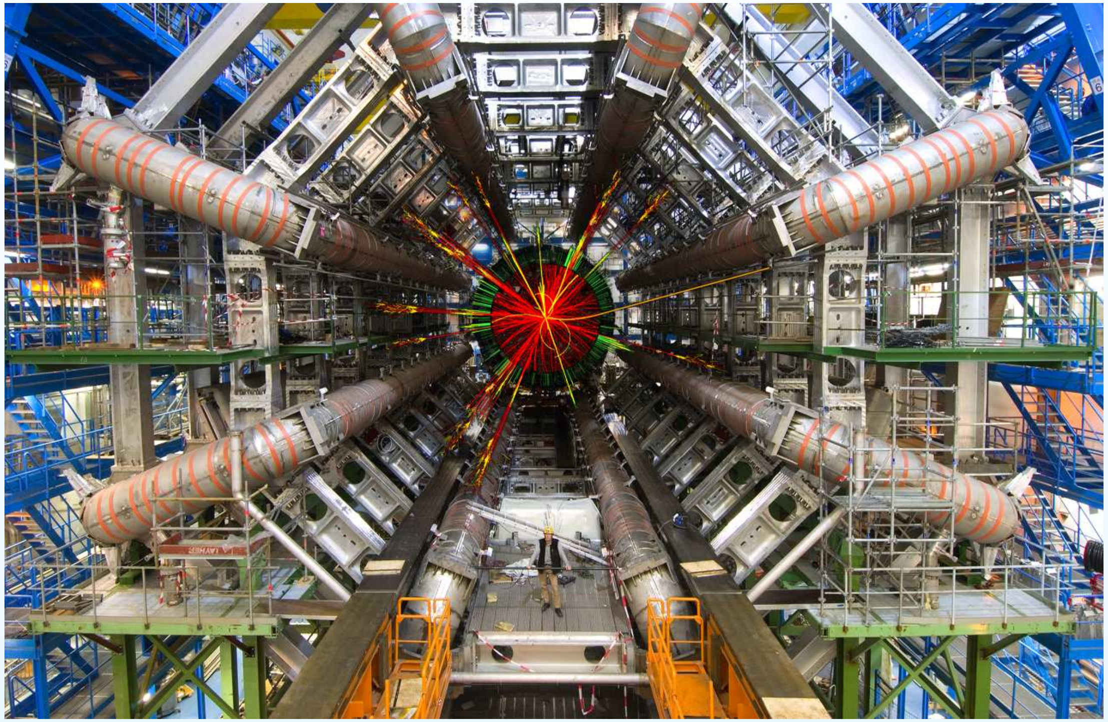
[a] Puebla and DF talks, 2012

Outline

1. Testing the SM at the LHC
2. EWSB and Scalars
    SM Higgs with $m_h = 125$ GeV?
3. Implications for SUSY (and DM)
4. Implications for Composite Higgs (and DM)
5. Conclusions - PROTEUS

1.



1.0 El SM es una gran teoria

El SM es una teoria grandiosa (a la Penrose),

- Teorias Grandiosas:
  Mec. Clasica (Newton), Termodinamica, ED (Maxwell), Mec. Q, Rel. Gen., Teoria electrodebil (GWS), QCD,
- Teorias Utiles:
  Modelo de Quarks-Partones, Modelo Cosmologico, ...
- Teorias Tentativas:
  SUSY, Gran Unificacion, ...
- Teorias mal encaminadas:
  ?????

1.1 El SM es una teoria cuantica de campos (QFT)

QFTs se basan en la Mecanica Cuantica y la Relatividad Especial:

- Es util,
- Hace sentido,
- Es dificil modificar,

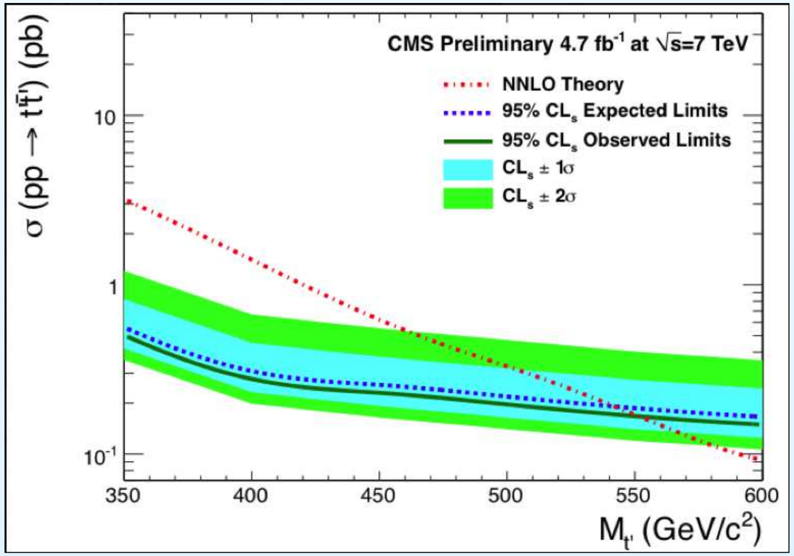
QFT se debe a muchos teoricos (Heisenberg, Pauli, Bethe, Feynman, Schwinger, Tomonaga, Yang, Nambu, Higgs, Coleman, t Hooft, Veltman,...)

SM debe tambien a muchos fenomenologos (Gell-Mann, CKM, Fritzsch, Bjorken,...) y algunos experimentales,

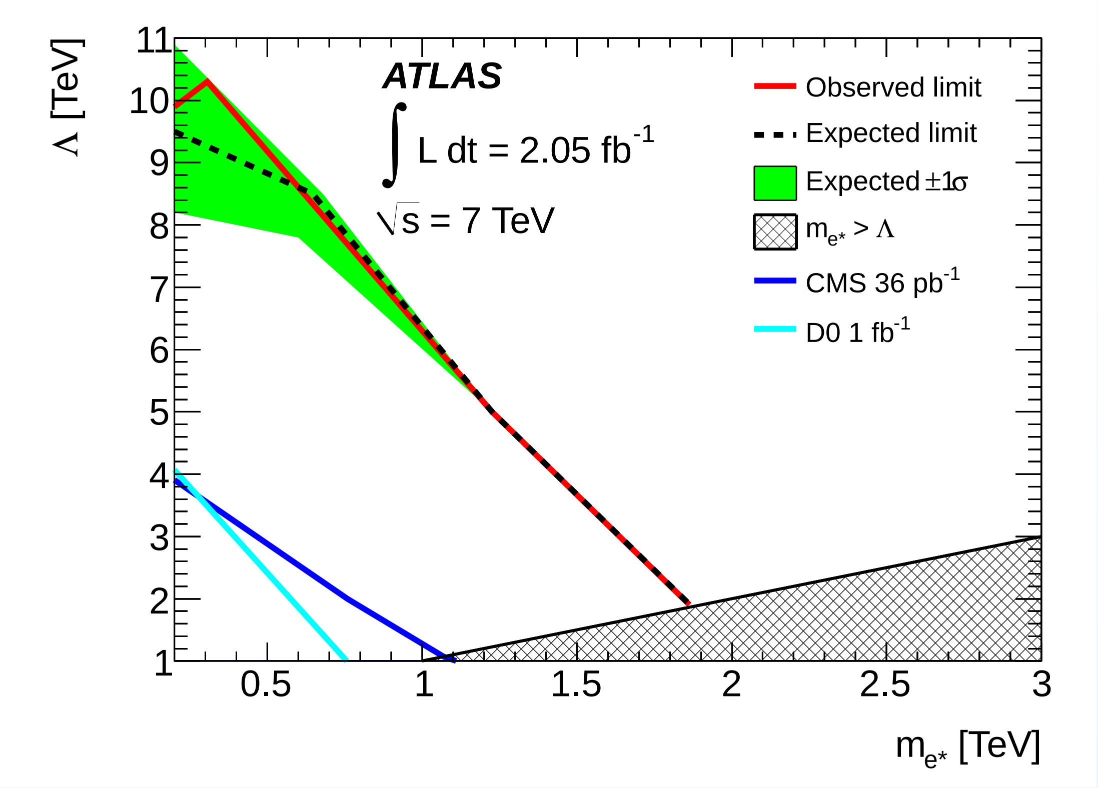
Todos ellos guiados por el sagrado principio (D. Gross): "Shut up and calculate!"

1.2 El Modelo Estandar (SM)

- La materia esta formada al nivel fundamental por: quarks y leptones, que aparecen en 3 familias
  $(u, d), (c, s), (t, b)$,
  $(\nu_e, e), (\nu_\mu, \mu), (\nu_\tau, \tau)$,
- Las familias se distingen solo por su masa,
- LHC no ha encontrado: 4ta familia, ni nuevos quarks, ni fermiones excitados o en representaciones exoticas,



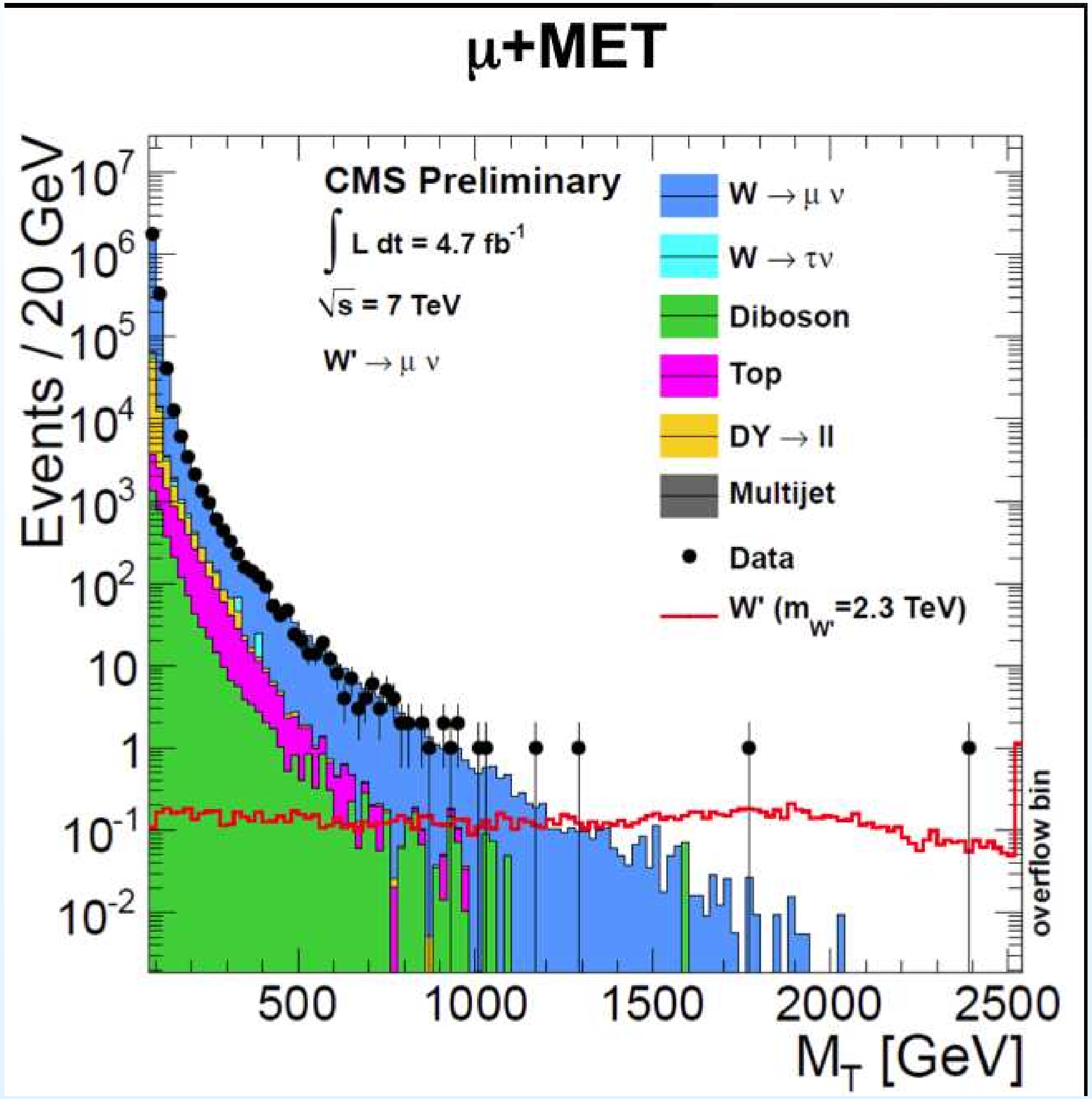
1.2


ATLAS
$\int L\,dt = 2.05\ \mathrm{fb}^{-1}$
$\sqrt{s} = 7$ TeV
Observed limit
Expected limit
Expected ±1σ
$m_{e*} > \Lambda$
CMS 36 pb^{-1}
D0 1 fb^{-1}
Λ [TeV]
11
10
9
8
7
6
5
4
3
2
1
0.5
1
1.5
2
2.5
3
m_{e*} [TeV]

1.2b El Modelo Estandar (SM)

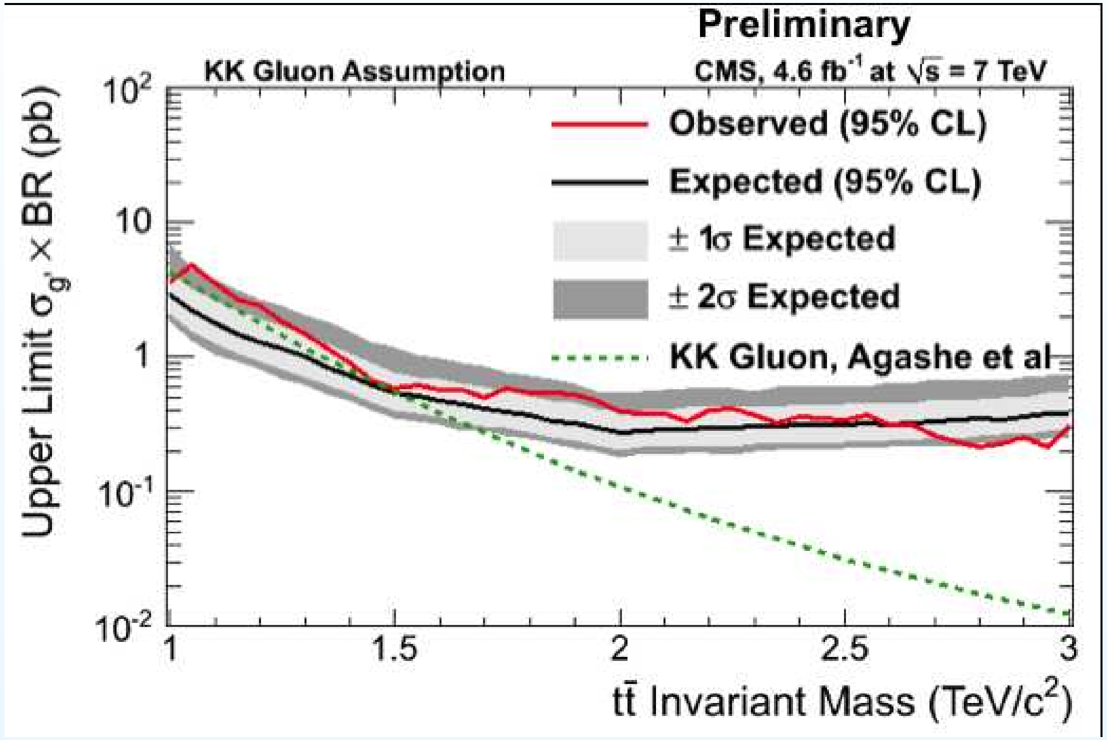
- Las fuerzas se describen por grupos de norma: $SU(3)_c \times SU(2)_L \times U(1)_Y$,
- Existe un campo de fuerza por cada generador del algebra de Lie,
  - 8 gluones de $SU(3)$,
  - 2 bosones cargados $W^{\pm}$ + 1 neutro W_3 de $SU(2)$,
  - 1 boson neutro B asociado con $U(1)_Y$.
- Los fermiones izquierdos (derechos) aparecen como dobletes (singletes) de $SU(2)_L$,
- Porque la naturaleza solo eligio dobletes de $SU(2)$ y tripletes de $SU(3)_C$? Es un misterio...
- El LHC no ha encontrado nuevos bosones de norma con una masa menor que aprox. 2 TeV,

1.2



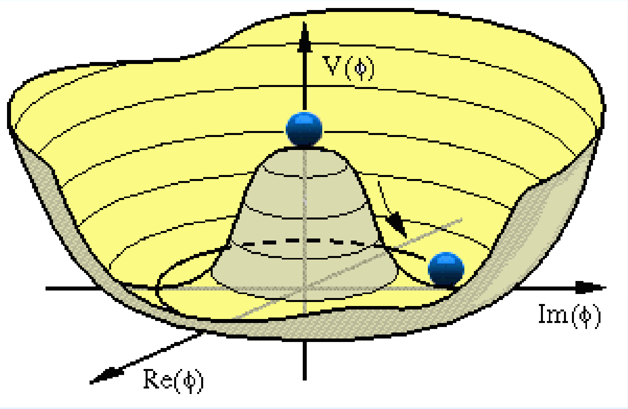
μ+MET
CMS Preliminary
$\int L\,dt = 4.7\ \mathrm{fb}^{-1}$
$\sqrt{s} = 7$ TeV
W' → μ ν
W → μ ν
W → τν
Diboson
Top
DY → ll
Multijet
Data
W' ($m_{W'}$=2.3 TeV)
Events / 20 GeV
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
500
1000
1500
2000
2500
M_T [GeV]
overflow bin

1.2


Preliminary
KK Gluon Assumption
CMS, 4.6 fb^{-1} at $\sqrt{s}$ = 7 TeV
Observed (95% CL)
Expected (95% CL)
± 1σ Expected
± 2σ Expected
KK Gluon, Agashe et al
Upper Limit $\sigma_{g'} \times$ BR (pb)
10^2
10
1
10^{-1}
10^{-2}
1
1.5
2
2.5
3
$t\bar{t}$ Invariant Mass (TeV/c^2)

1.2c El Modelo Estandar (SM)

- Se necesita para romper: $SU(2)_L \times U(1)_Y \to U(1)_{em}$,
- La masa aparece como consecuencia del Mecanismo de Higgs (SSB)
  $\phi \to < \phi > + h$,
- En el modelo minimo se incluye un solo doblete escalar: $\Phi = (\phi^+, \phi^0)$, que deja una particula remanente, el boson de Higgs,



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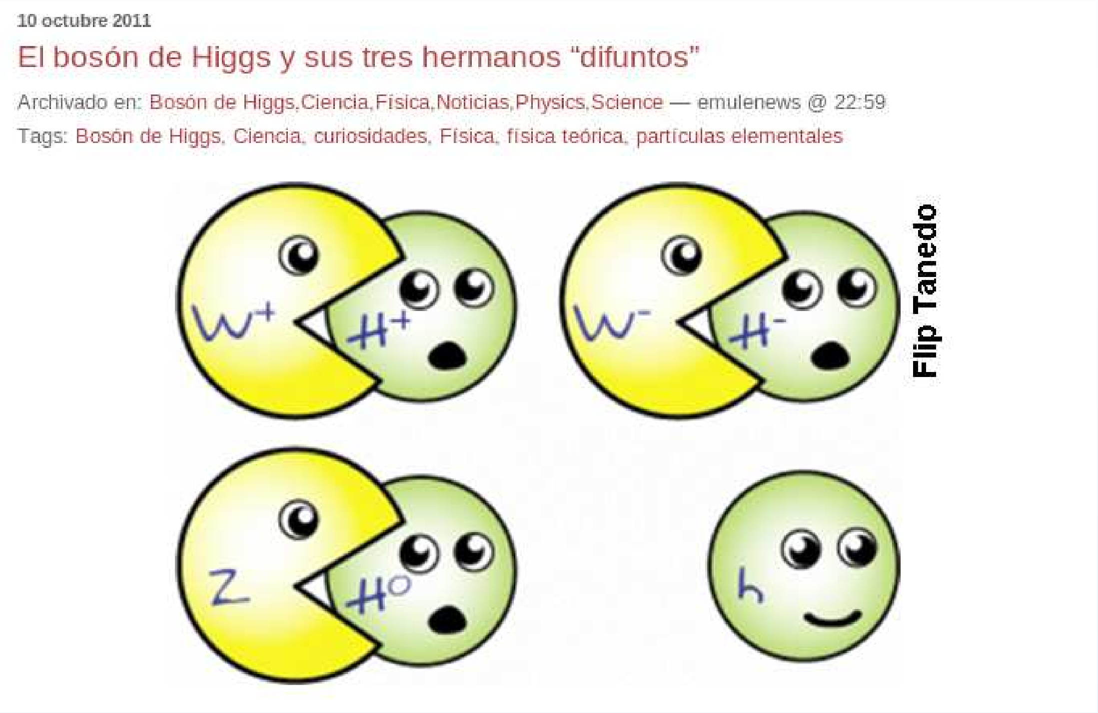


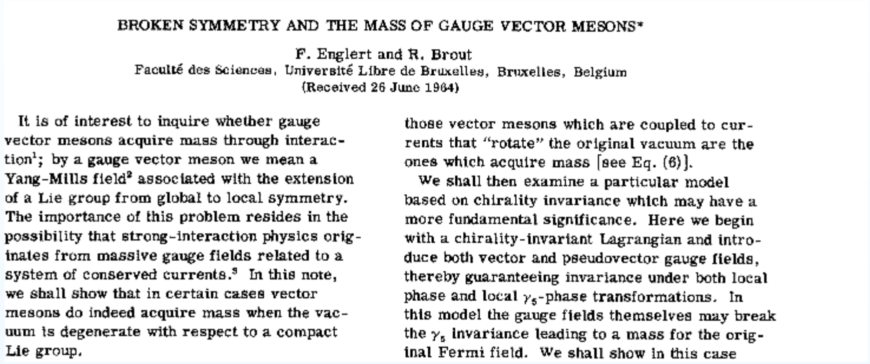
10 octubre 2011

El bosón de Higgs y sus tres hermanos “difuntos”

Archivado en: Bosón de Higgs,Ciencia,Física,Noticias,Physics,Science — emulenews @ 22:59

Tags: Bosón de Higgs, Ciencia, curiosidades, Física, física teórica, partículas elementales

2.



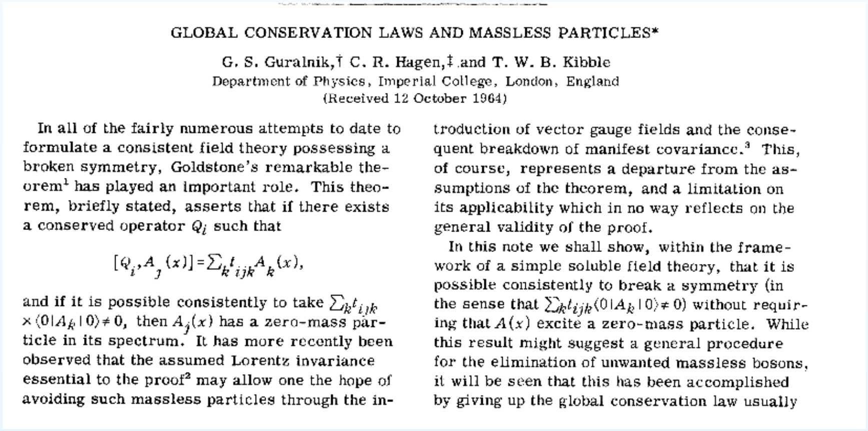
BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

It is of interest to inquire whether gauge vector mesons acquire mass through interaction[1]; by a gauge vector meson we mean a Yang-Mills field[2] associated with the extension of a Lie group from global to local symmetry. The importance of this problem resides in the possibility that strong-interaction physics originates from massive gauge fields related to a system of conserved currents.[3] In this note, we shall show that in certain cases vector mesons do indeed acquire mass when the vacuum is degenerate with respect to a compact Lie group.

those vector mesons which are coupled to currents that "rotate" the original vacuum are the ones which acquire mass [see Eq. (6)].

We shall then examine a particular model based on chirality invariance which may have a more fundamental significance. Here we begin with a chirality-invariant Lagrangian and introduce both vector and pseudovector gauge fields, thereby guaranteeing invariance under both local phase and local γ_5-phase transformations. In this model the gauge fields themselves may break the γ_5 invariance leading to a mass for the original Fermi field. We shall show in this case



GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

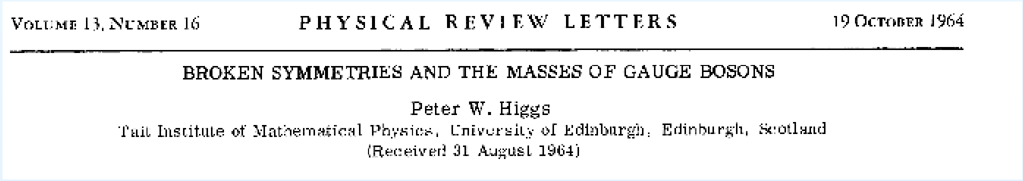
G. S. Guralnik,† C. R. Hagen,‡ and T. W. B. Kibble
Department of Physics, Imperial College, London, England
(Received 12 October 1964)

In all of the fairly numerous attempts to date to formulate a consistent field theory possessing a broken symmetry, Goldstone's remarkable theorem[1] has played an important role. This theorem, briefly stated, asserts that if there exists a conserved operator Q_i such that

$$[Q_i, A_j(x)] = \sum_k t_{ijk} A_k(x),$$

and if it is possible consistently to take $\sum_k t_{ijk} \times \langle 0|A_k|0\rangle \neq 0$, then $A_j(x)$ has a zero-mass particle in its spectrum. It has more recently been observed that the assumed Lorentz invariance essential to the proof[2] may allow one the hope of avoiding such massless particles through the introduction of vector gauge fields and the consequent breakdown of manifest covariance.[3] This, of course, represents a departure from the assumptions of the theorem, and a limitation on its applicability which in no way reflects on the general validity of the proof.

In this note we shall show, within the framework of a simple soluble field theory, that it is possible consistently to break a symmetry (in the sense that $\sum_k t_{ijk}\langle 0|A_k|0\rangle \neq 0$) without requiring that $A(x)$ excite a zero-mass particle. While this result might suggest a general procedure for the elimination of unwanted massless bosons, it will be seen that this has been accomplished by giving up the global conservation law usually



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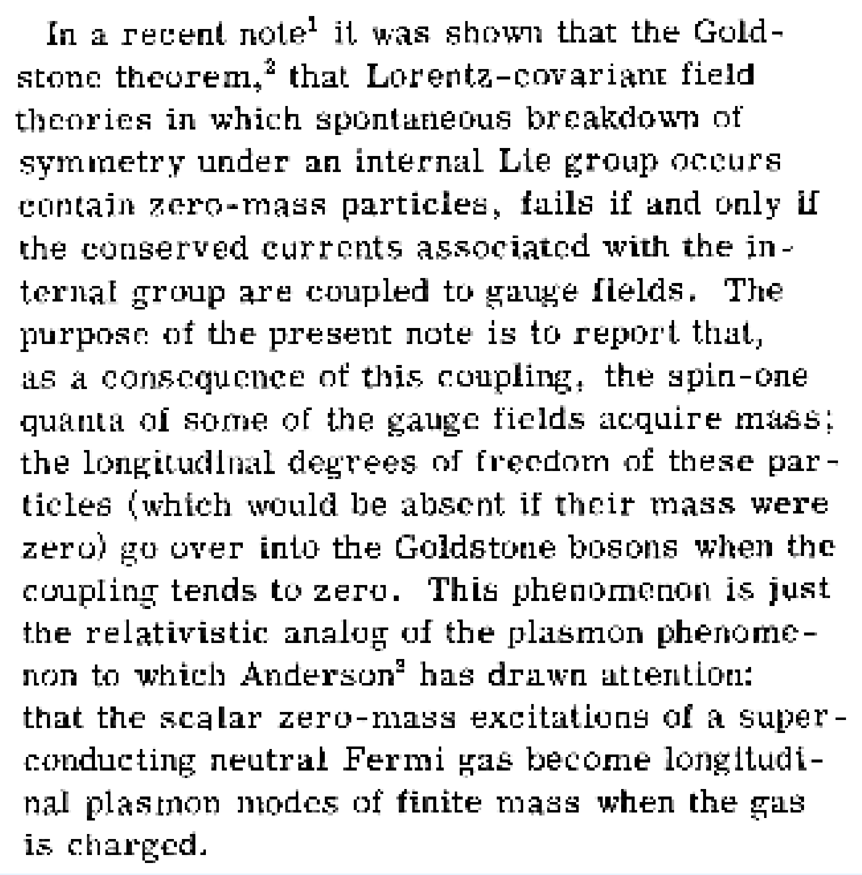
BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

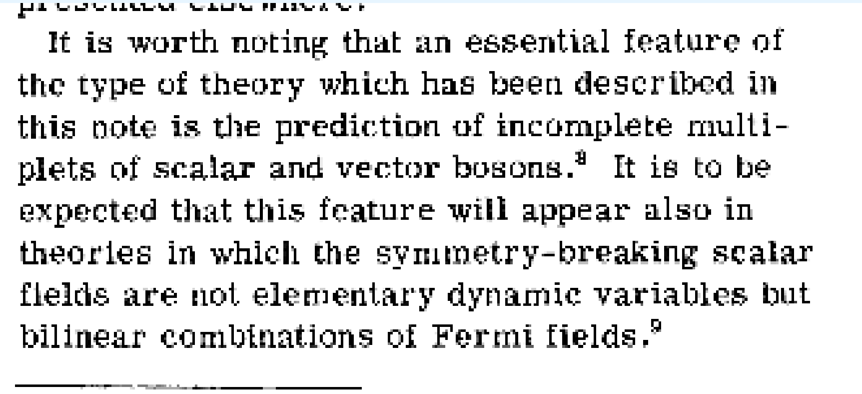
Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

Why call it *THE HIGGS*???

2.



In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.



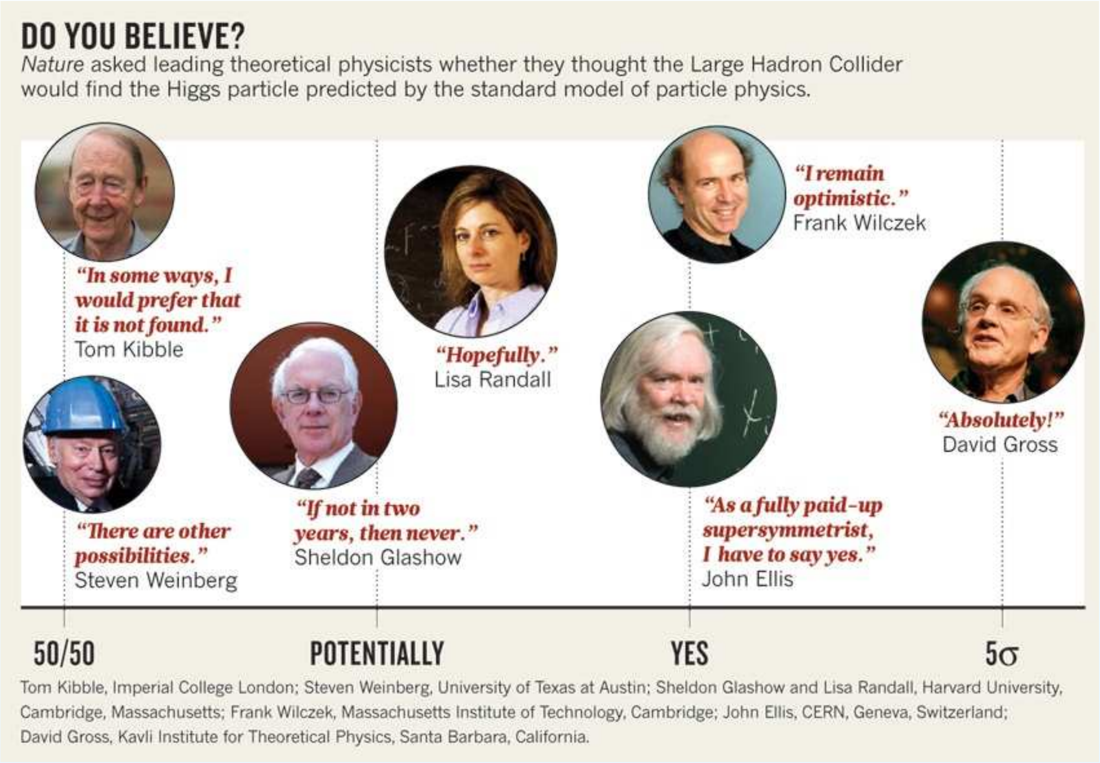
It is worth noting that an essential feature of the type of theory which has been described in this note is the prediction of incomplete multiplets of scalar and vector bosons.[8] It is to be expected that this feature will appear also in theories in which the symmetry-breaking scalar fields are not elementary dynamic variables but bilinear combinations of Fermi fields.[9]

2.1 Higgs search at LHC

- The distinctive characteristic of the Higgs boson is that it couples to the mass of the particles,
- Rad. Corrs. prefere a light Higgs, with a mass of order of the EW scale ($m_{\phi_{SM}} \simeq v$).
- LHC is already probing the Higgs sector of the SM,
- It seems that LHC has found events that could come from a Higgs with mass $m_h = 125$ GeV,
  really?

(Most interesting time I have seen in physics in my life, so far)

2.



DO YOU BELIEVE?

Nature asked leading theoretical physicists whether they thought the Large Hadron Collider would find the Higgs particle predicted by the standard model of particle physics.

"In some ways, I would prefer that it is not found."
Tom Kibble

"There are other possibilities."
Steven Weinberg

"If not in two years, then never."
Sheldon Glashow

"Hopefully."
Lisa Randall

"I remain optimistic."
Frank Wilczek

"As a fully paid-up supersymmetrist, I have to say yes."
John Ellis

"Absolutely!"
David Gross

Tom Kibble, Imperial College London; Steven Weinberg, University of Texas at Austin; Sheldon Glashow and Lisa Randall, Harvard University, Cambridge, Massachusetts; Frank Wilczek, Massachusetts Institute of Technology, Cambridge; John Ellis, CERN, Geneva, Switzerland; David Gross, Kavli Institute for Theoretical Physics, Santa Barbara, California.

2.2 SM Higgs interactions

SM lagrangian for a Higgs doublet $\Phi = (\phi^+, \phi^0)$ includes:

- Gauge ints. $\rightarrow$ Gauge boson masses,
  i.e. $\mathcal{L}_{HV} = (D^\mu \Phi)^\dagger (D_\mu \Phi)$
- Yukawa sector $\rightarrow$ fermion masses,
  i.e. $\mathcal{L}_Y = Y_u Q_L \Phi u_R$, etc.
- Higgs potential $V(\Phi) \rightarrow$ SSB and Higgs mass,
  i.e. $V(\Phi) = \lambda(|\Phi|^2 - v^2)^2$,
- One unknown parameter λ,
  - it determines Higgs mass m_h

2.3 Higgs couplings:

- $(hVV): \quad \frac{2m_V^2}{v}$
- $(hff): \quad \frac{m_f}{v}$
- $(hhh): \quad \frac{3}{2}\lambda v$
- $(hhhh): \quad \frac{3}{2}\lambda$

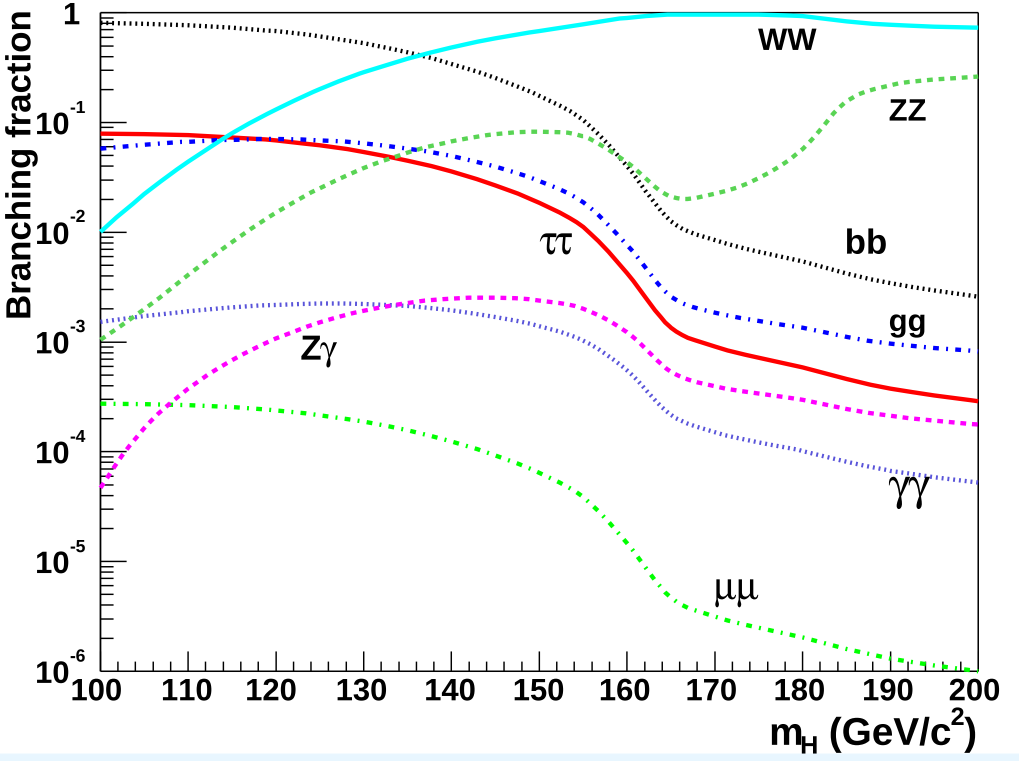
2.4 SM Higgs B.R.'s

Interesting decay modes:

- $h \to b\bar{b}$,
- $h \to \tau^+\tau^-$,
- $h \to \gamma\gamma$ (top and W loops),
- $h \to gg$ (top loop)
- $h \to WW, ZZ$
- $h \to t\bar{t}$

$$B.R.(h \to XX) = \frac{\Gamma(h \to XX)}{\Gamma_{total}} \tag{1}$$

2.5 Higgs B.R.'s

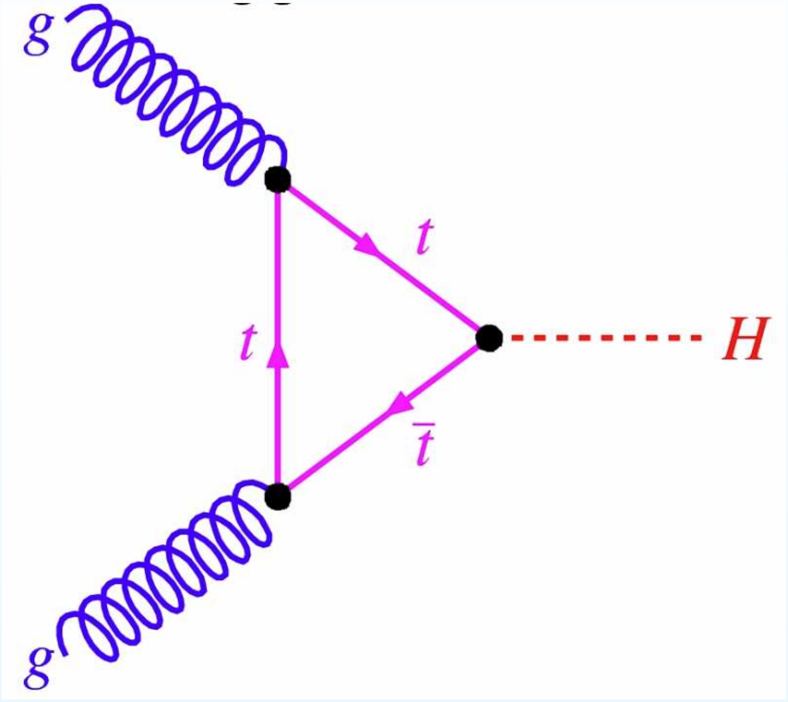

Branching fraction
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
100
110
120
130
140
150
160
170
180
190
200
m_H (GeV/c^2)
WW
ZZ
bb
ττ
gg
Zγ
γγ
μμ

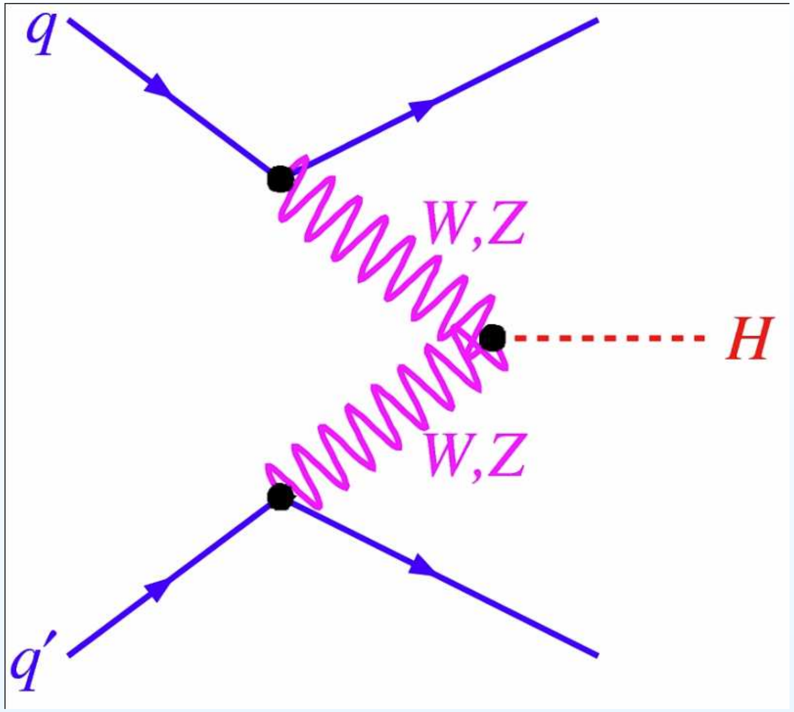
2.6 SM Higgs cross sections

Relevant mechanisms at Hadron colliders:

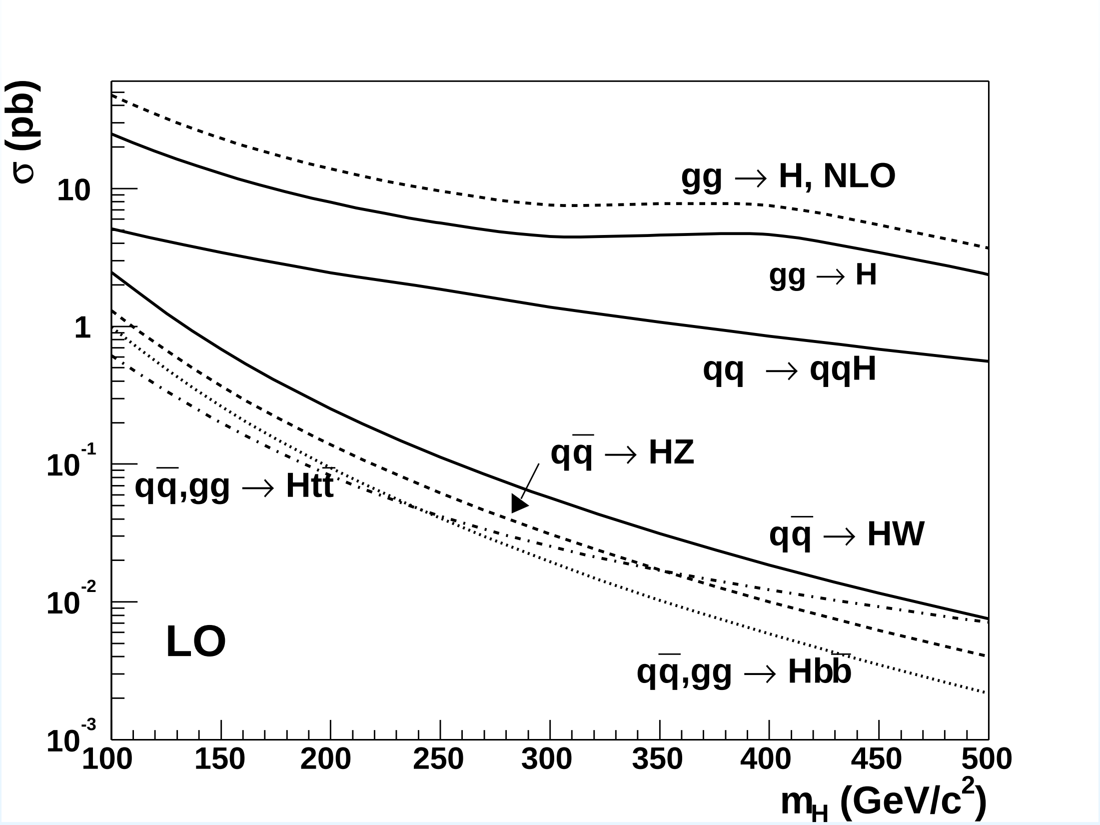
- Gluon fusion (top loop),
- quark fusion,
- Assoc. production hW, hZ,
- Assoc. production htt, hbb,
- W/Z vector fusion,

2.7 SM Higgs cross sections





2.7b Higgs cross sections



2.8 SM Higgs mass bounds

- Higgs boson mass limits from LEP,

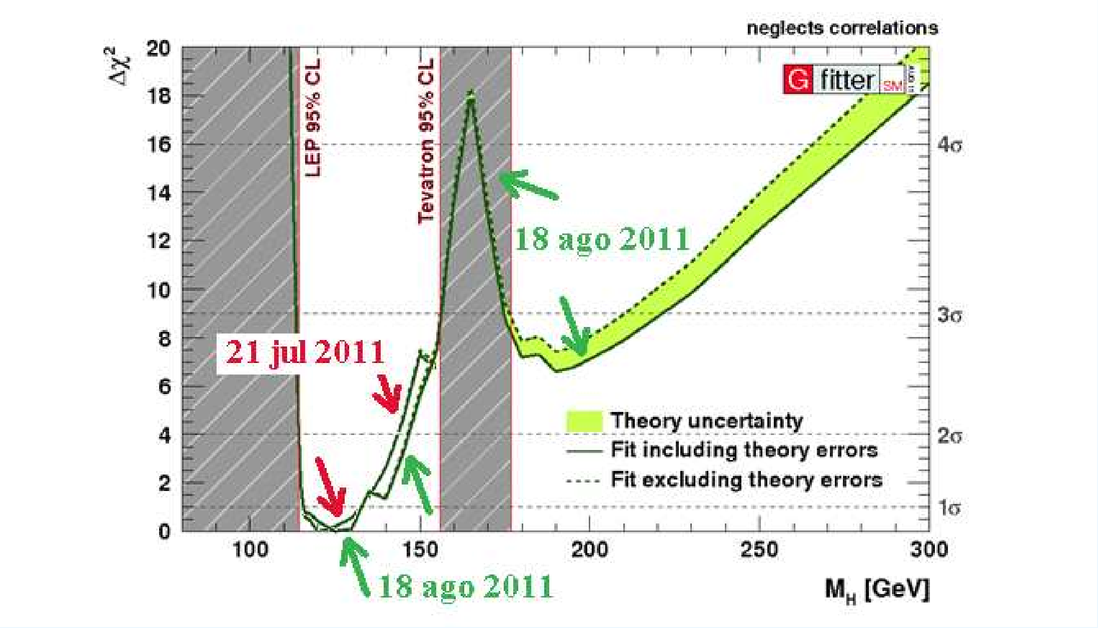
  $$e^+e^- \to Z + h$$

  $\to m_h > 114$ GeV.
- Higgs boson mass limits from Tevatron,

  $$p\bar{p} \to h(\to WW^*)$$

  $\to 160 < m_h < 170$ GeV.
- But Radiative Corrs. prefer a light, with a mass of order of EW scale ($m_{\phi_{SM}} \simeq v$).

2.10 Radiative Constraints on m_h:

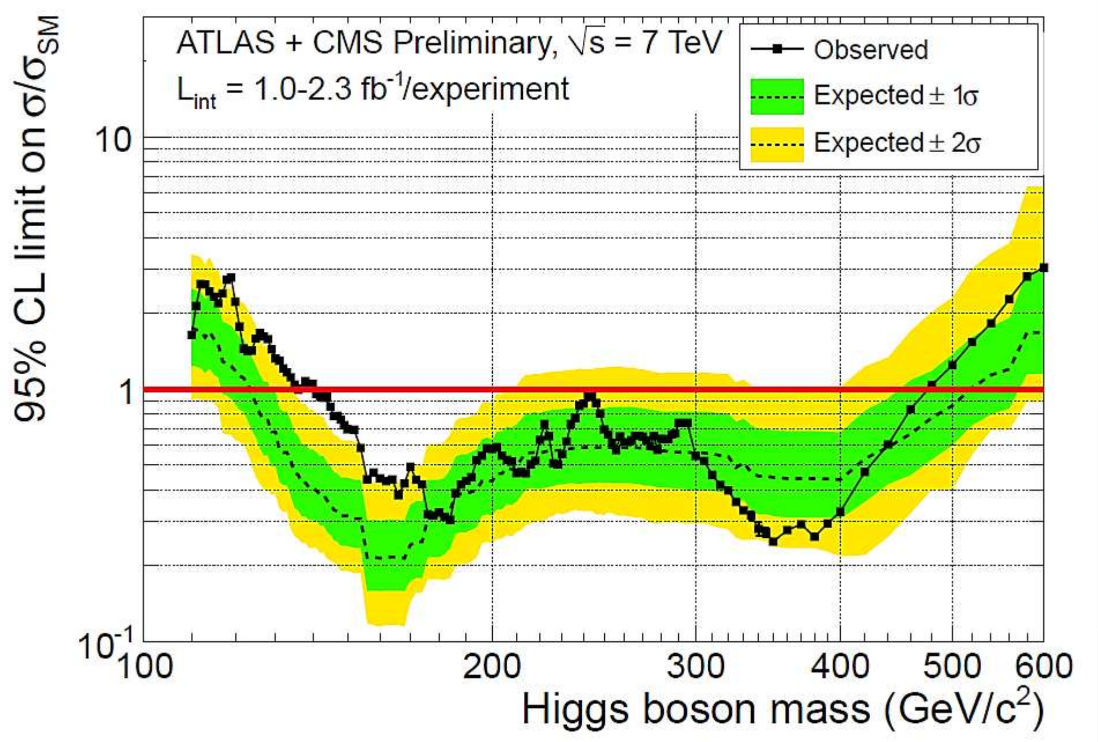


2.11 LHC search for SM Higgs

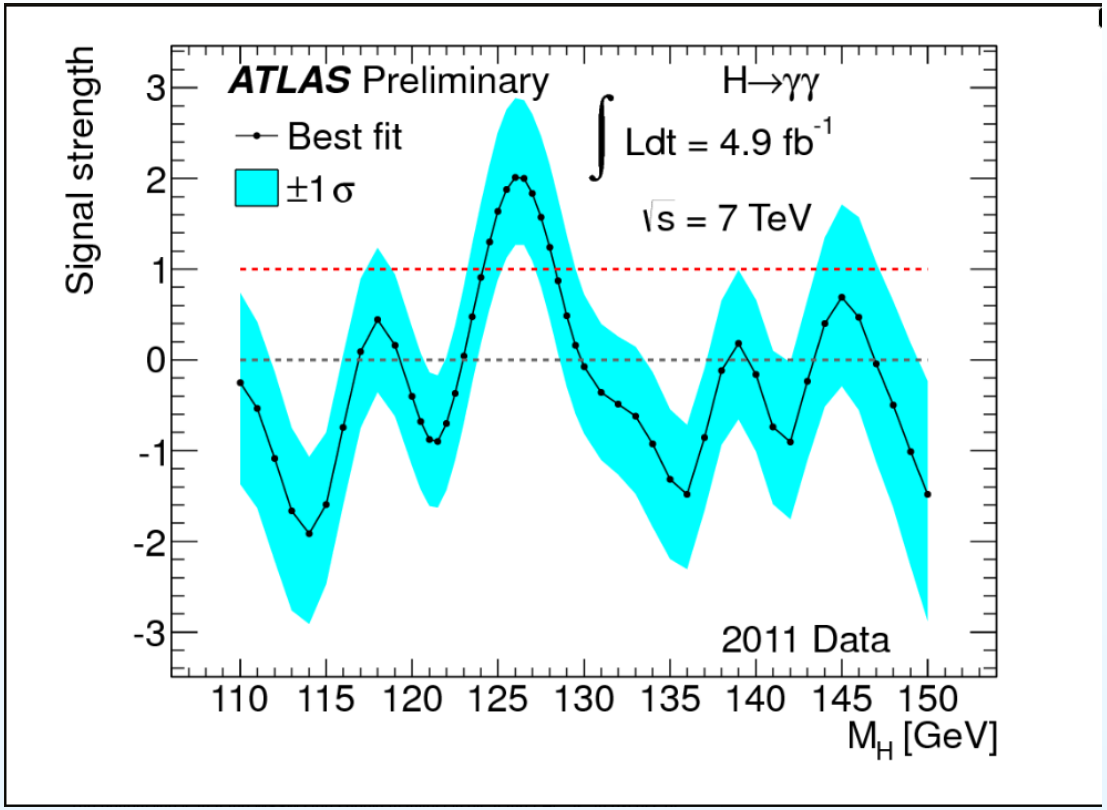
Expected discovery signals, include:

- Gluon fusion + $h \to \gamma\gamma$, for $m_h \simeq 120$ GeV,
- Assoc. $t\bar{t}h$ with $h \to b\bar{b}$ for $m_h \simeq 100$ GeV,
- Gluon fusion+$h \to ZZ \to 4l$, for $m_h \simeq 130 - 200$ GeV,
- Gluon fusion+$h \to WW \to 2l + 2\nu' s$, for $m_h \simeq 150 - 190$ GeV,
- Vector fusion+$h \to WW$, for $m_h \geq 120$ GeV,
- Vector fusion+$h \to \tau\tau$, for $m_h \simeq 115 - 140$ GeV,

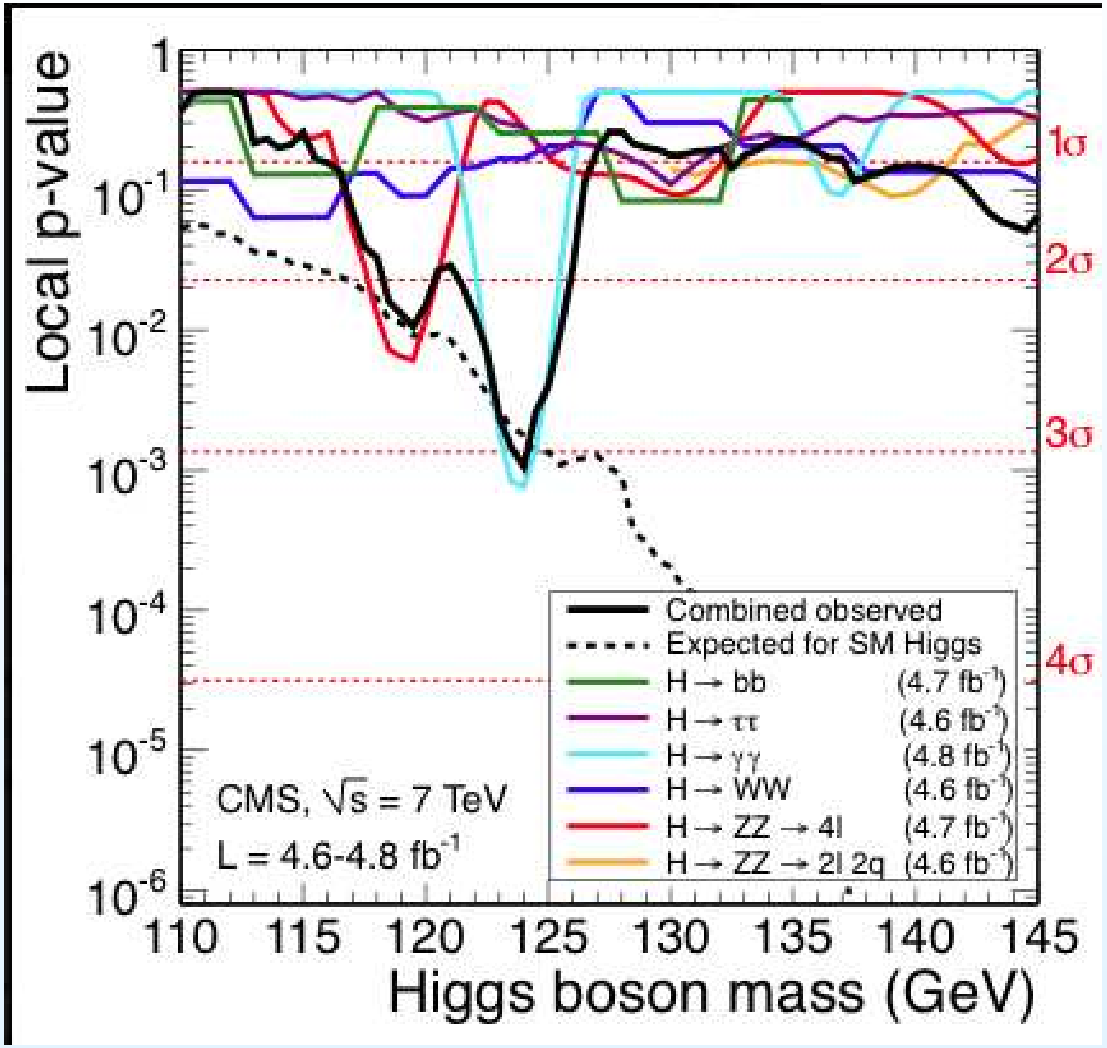
2.12 ATLAS Higgs search



2.12 ATLAS Higgs search- $\gamma\gamma$ mode

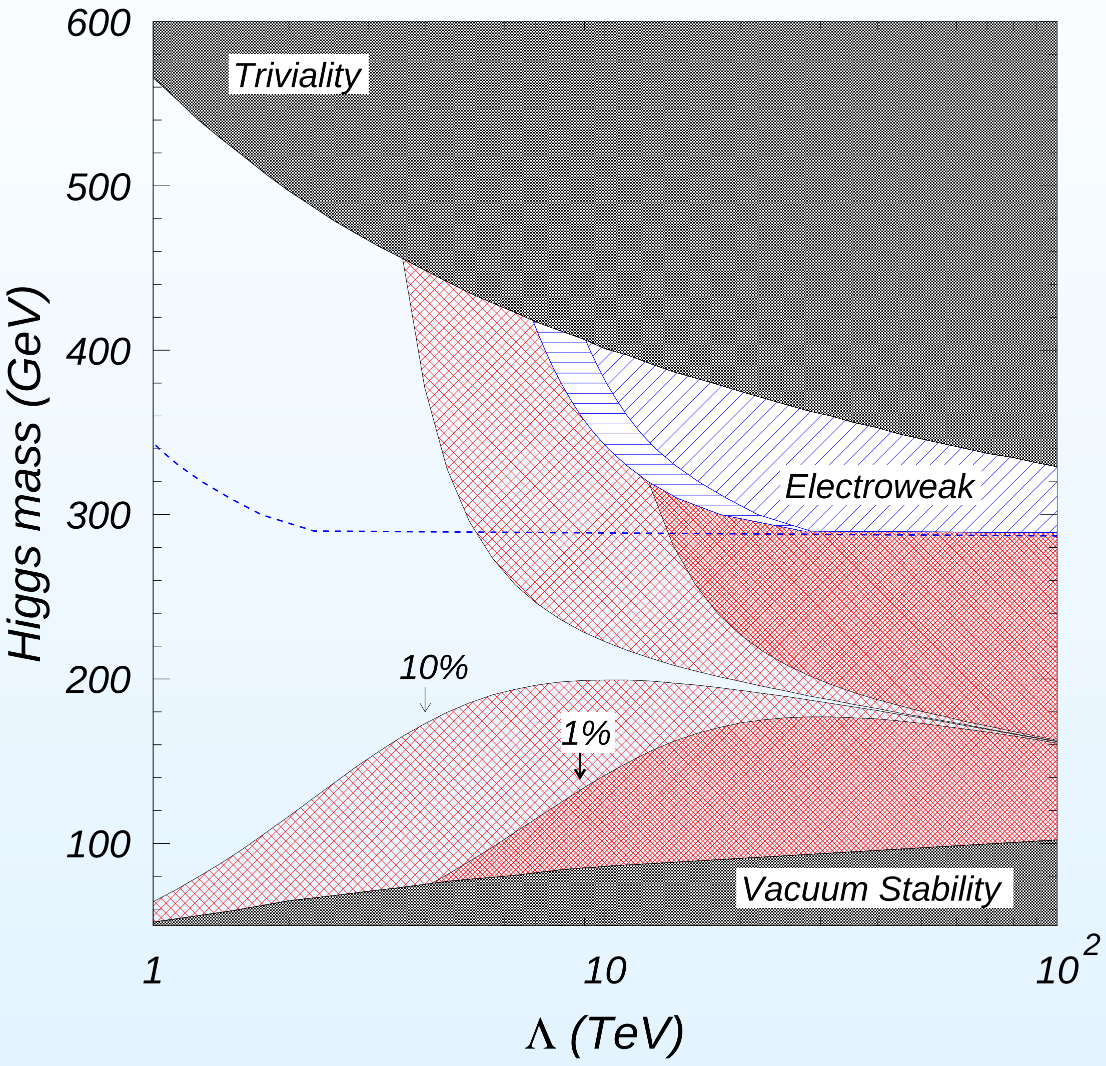


2.13 All LHC Higgs search



2.14 Then what?

2.15



600
500
400
300
200
100
Higgs mass (GeV)
Triviality
Electroweak
10%
1%
Vacuum Stability
1
10
10^2
Λ (TeV)

3.1 Spin (S) e Isospin (T)

Es el Higgs algo artificial? Si y no.

T / S	0	1/2	1	3/2	2
0	?	Neutrinos-R	gluon	?	?
1/2	Higgs	electron quarks	?	?	?
1	?	?	W, Z	?	?

$$Q_{em} = T_3 + Y \qquad (2)$$

3.2 Open problems in the SM

- Large/Little hierarchy problem,
- Neutrino masses,
- Strong CP problem,
- Dark Matter,
- Cosmological constant (Dark energy),
- Some deviations from the SM (a few std. dev.),
  e.g. Δa_μ, etc.
- Aesthetical questions,

They all suggest the need for New Physics.

3.3 The Hierachy problem

When SM is incorporated into a new theory with a heavy mass scale M, and UV cutoff Λ, the Higgs mass gest corrected, i.e.

$$m_h^2 = m_0^2 + \frac{y^2}{16\pi^2}[c_1\Lambda^2 + c_2 m_0^2 ln\frac{\Lambda}{m} + M^2] \tag{3}$$

Some solutions:

- Accidental cancelacion,

$$\lambda = y_t^2 - \frac{1}{8}[3g^2 + g'^2] \tag{4}$$

- Composite Higgs (as in QCD!),
- Cancelation between boson-fermion loops ($\rightarrow$ SUSY),
- Higgs is part of $D - dim$ vector field: $A_M = (A_\mu, A_i)$,

3.4 A modern view of Physics BSM

Physics BSM incorporates Extra Dimensions,

- Fermionic XD:
  $x^\mu \to Z^M = (x^\mu, Q, \bar{Q})$
- Bosonic XD:
  $x^\mu \to X^M = (X^\mu, X^i)$
- Curved Extra dimensions (RS):
  Ads/CFT duality means XD → Strong Ints.

3.5 SUSY without prejudice

Why is SUSY attractive?

- Offers the possibility to stabilize the Higgs mass and EWSB,
- Improves Unification and o.k. with proton decay,
- Favors a light Higgs boson, in agreement with EWPT and LHC?), i.e. $m_h \leq 180$ GeV,
- New sources of flavor and CP violation may help to get the right BAU,
- LSP is stable and Dark matter candidate.

3.6 The MSSM

The minimal extension of the SM consistent with SUSY, is based on:

- SM Gauge Group (→ gauge bosons and gauginos),
- 3 families of fermions and sfermions,
- Two Higgs doublets,
- Soft-breaking of SUSY,
- R-parity distinguish SM and their superpartners
  → LSP is stable and DM candidate.

3.7 The MSSM particle content

	SM	Superpartners
SM Bosons	$W^{\pm}, Z, \gamma$ gluon Higgs bosons	Wino,Zino, Photino gluino Higgsinos
SM Fermions	quarks leptons neutrinos	squarks sleptons sneutrinos

Mixing of gauginos and Higgsinos $\rightarrow$
Charginos ($\chi_i^{\pm}$, $i = 1, 2$) and
Neutralinos (χ_j^0, $j = 1, 4$),

Gravitino is also part of the spectrum.

3.9 The MSSM Higgs sector

At tree-level MSSM Higgs sector is a 2HDM of type-II, and becomes type-III after rad. corrs., with:

- CP-even neutral Higgs bosons h^0, H^0, at tree-level $m_h < m_Z$,
- CP-odd neutral Higgs A^0 with $m_H^2 = m_A^2 + m_Z^2 \sin^2 2\beta$,
- Charged Higgs $H^\pm$, with $m_{H^+}^2 = m_A^2 + m_W^2$,
- Masses and mixing angles fixed with: m_A and $tan\beta = v_2/v_1$,
- When $m_A \leq \tilde{m}$, Higgs search uses SM techniques.
- But $H^0, A^0, H^\pm$ may decay into SUSY modes; LHC search gets more complicated!,

3.9b MSSM Higgs couplings:

- $(hVV):\quad \frac{2m_V^2}{v}\cos(\beta-\alpha),\quad v^2=v_1^2+v_2^2,$
- $(huu):\quad \frac{m_u}{v}\left(\frac{\cos\alpha}{\sin\beta}\right),$
- $(hdd):\quad \frac{m_d}{v}\left(\frac{\sin\alpha}{\cos\beta}\right),$
- $(hll):\quad \frac{m_l}{v}\left(\frac{\sin\alpha}{\cos\beta}\right),$
- $(hhh):\quad \simeq\lambda v,\qquad \lambda=\frac{g^2+g'^2}{8},$
- $(hhhh):\quad \simeq\lambda.$

Similar expressions hold for H^0, A^0 and $H^\pm$.

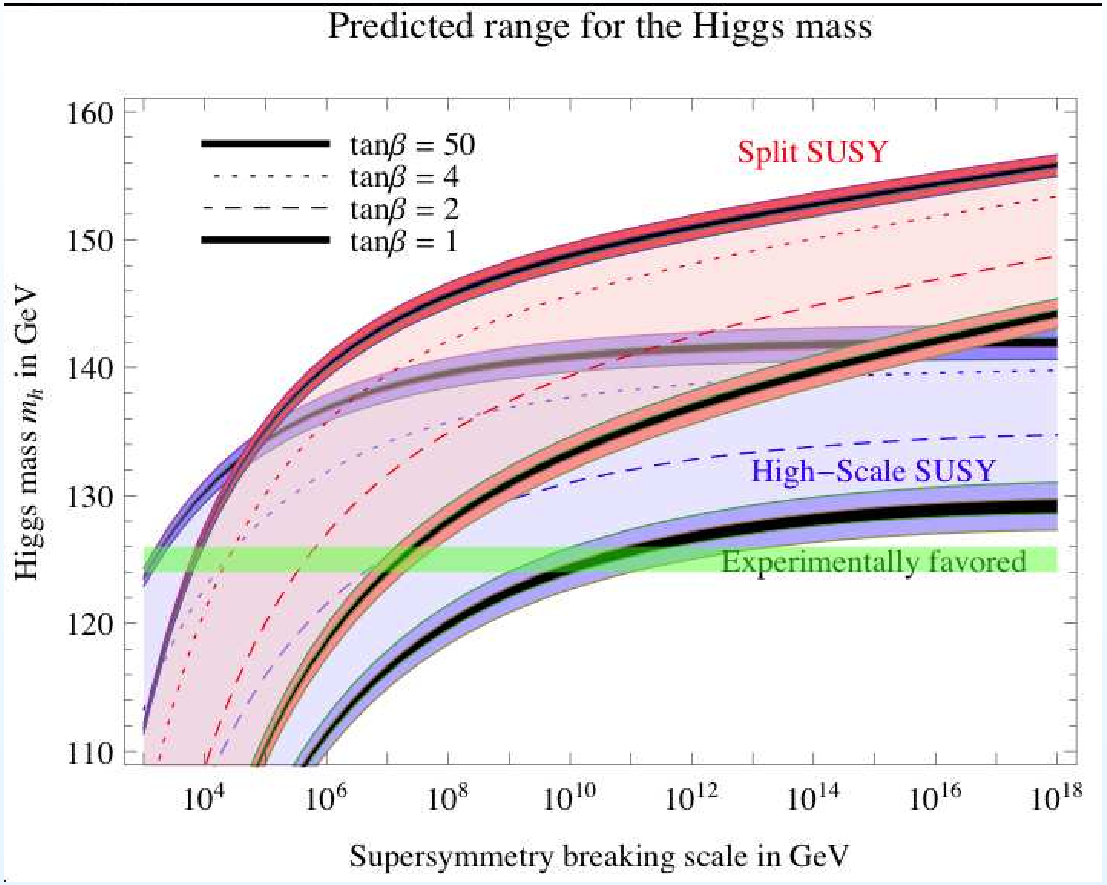
3.10 The MSSM Higgs mass

- Stop-top loops needed for LHC limits: $m_h > m_Z$,

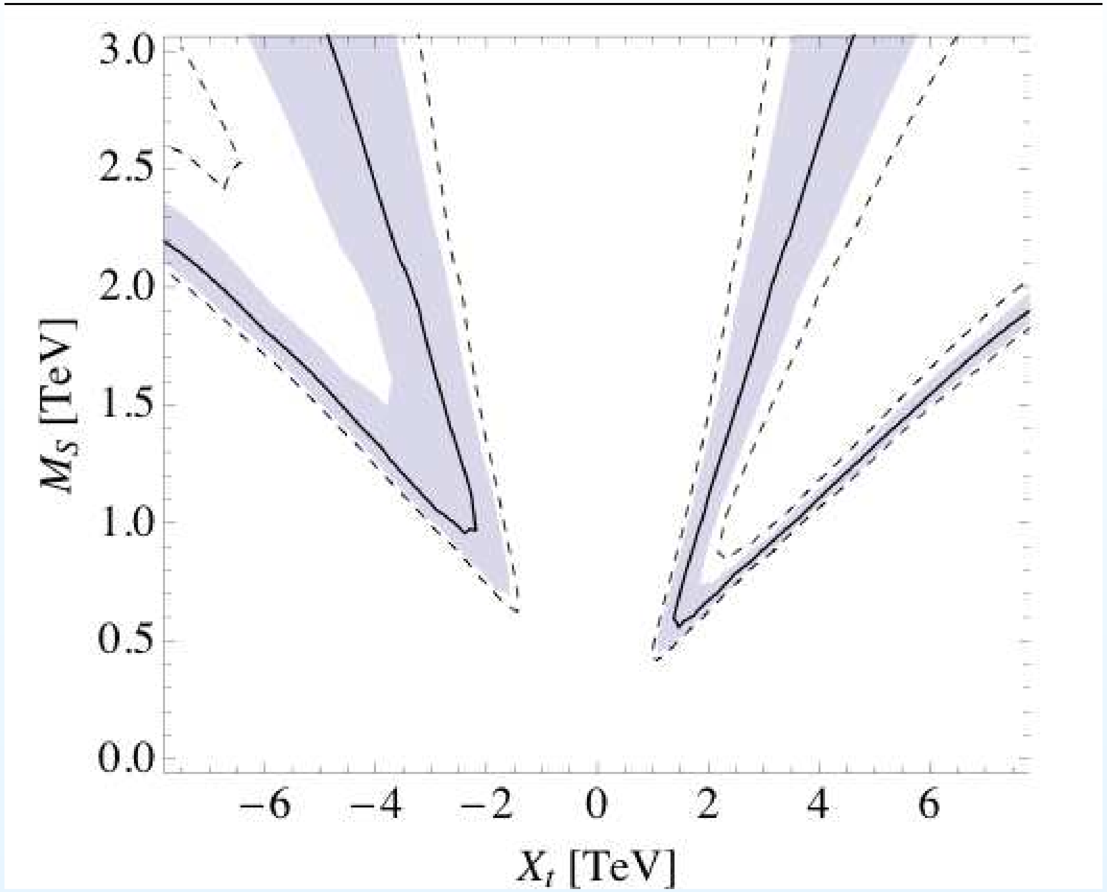
$$m_h^2 = m_Z^2[1 + \frac{3m_t^2}{2\pi^2 m_Z^2} log(\frac{m_{stop}}{m_t})] \tag{5}$$

- Large superpartner masses (and large $tan\beta$) needed in order to make it as heavy as $m_h = 125$ GeV, and with SM-like couplings,
- May imply large production of $H + bb$ at LHC,
- Only a few superpartners could be at the reach of LHC,
- Split SUSY?

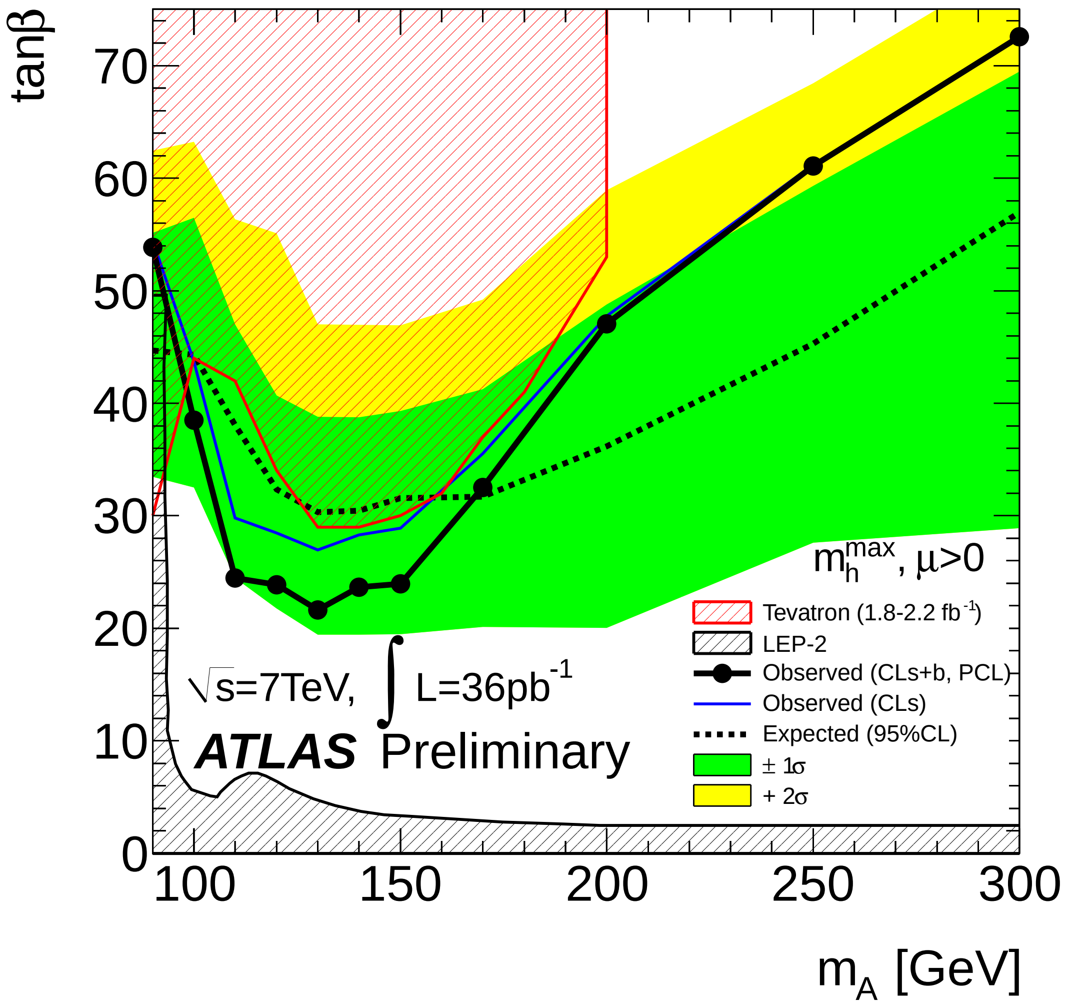
3.10b MSSM Higgs mass



3.10c MSSM Higgs mass



3.10c MSSM Higgs search at LHC



3.11 SUSY braking

- SUSY breaking is assumed to take place in a hidden sector (e.g. $< F_X > \neq 0$),
- Some mediator M communicates SUSY breaking to MSSM fields,
- In Supergravity, $M = M_{pl}$ gravitation. All SUSY masses are of order gravitino mass,

$$M_{susy} = \frac{< F_X >}{M_{pl}} \simeq m_{3/2} \simeq \frac{(10^{11}\,GeV)^2}{M_{pl}} \tag{6}$$

- In Gauge mediation, $X =$ SM gauge interactions. The gravitino mass is small,

$$M_{3/2} = \frac{< F_0 >}{M} \simeq 100\,GeV\,(\frac{\sqrt{F_0}}{10^{10}\,GeV})^2 \tag{7}$$

3.11b The parameters of the MSSM

In addition to SM parameters, the MSSM includes O(100) new ones:

- Scalar masses (Sleptons, squarks, Higgs),
- Gaugino masses ($\tilde{M}_G, \tilde{M}_W, \tilde{M}_B$),
- Trilinear terms ($A_{\tilde{f}}$ for squarks and sleptons),
- From Higgs sector: $\tan\beta = v_2/v_1$ and μ,

There are some relations (at tree-level):

(8) $$M_Z^2 = 2C_1 M_{H_1}^2 - 2t_\beta^2 M_{H_2}^2 - 2\mu^2$$

with $C_1 = 1/(t_\beta^2 - 1)$,

3.12 The models (a): CMSSM

To get MSSM parameters at TeV scale, one derive them from models at hgh scale (SUGRA/GUT) through RGE,

$\rightarrow$ CMSSM = Constrained Minimal Supersymmetric Standard Model.
In the CMSSM one takes (at M_{pl}):

- Universal scalar masses (=0)
- Universal gaugino masses (=$\tilde{m}_{1/2}$)
- Universal trilinear terms (=A_0)
- Also $\tan\beta = v_2/v_1$ and $sgn(mu)$.

3.12b The models (b): NUHM

- NUHM = Non-universal Higgs Masses Model.
- Same parameters as in CMSSM, except that the Higgs masses $m_{1,2}$ are not equal to m_0.
- We can trade $m_{1,2}$ with μ and m_A, as our free parameters through the electroweak symmetry breaking condition.
- Thus the NUHM parameters are: m_0,$m_{1/2}$ A_0, $\tan\beta = v_2/v_1$, μ and m_A,.

3.12b Mass spectrum in CMSSM

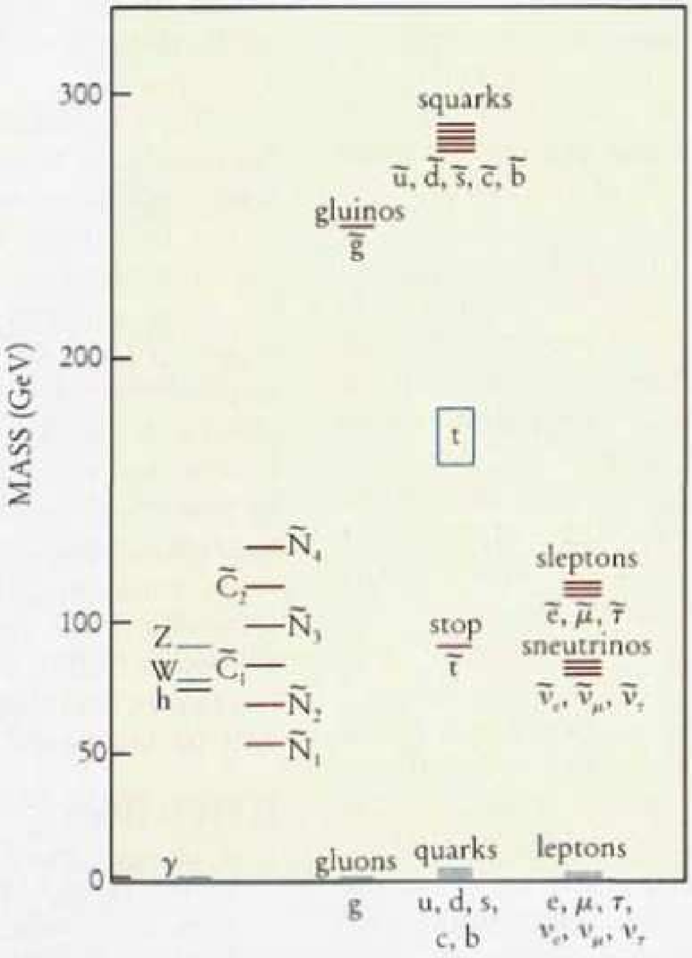
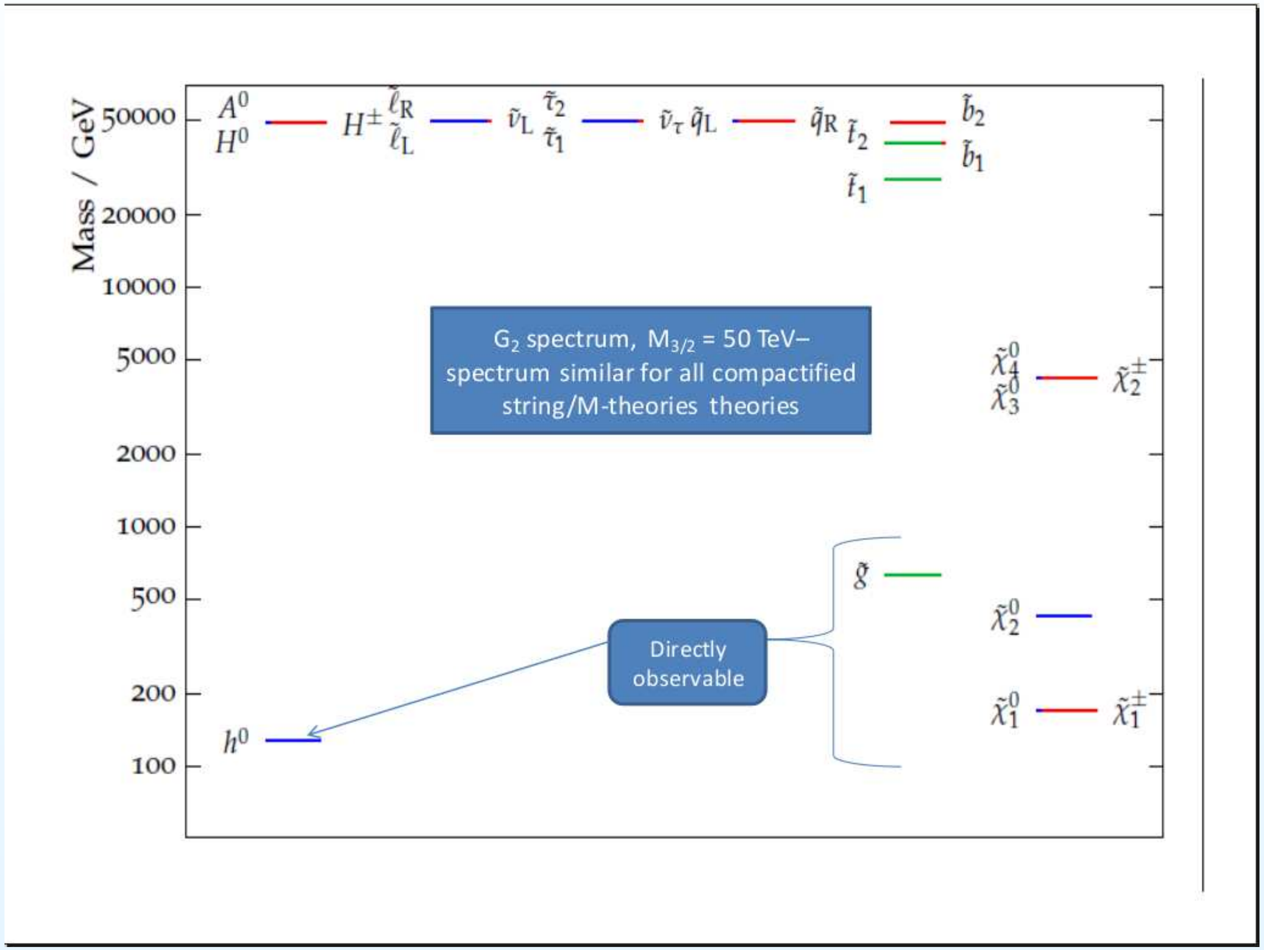


FIGURE 2. A POSSIBLE SPECTRUM of particles (blue) and their superpartners (red). The existence of superpartners is a prediction of supersymmetry, which, in turn, is a prediction of string models. The spectrum shown is consistent with all data at present. The neutralinos ($\tilde{N}_i$) and charginos ($\tilde{C}_i$) are mass eigenstates of the electroweak superpartners $\tilde{\gamma}$, $\tilde{Z}$, $\tilde{W}$ and so on. The Higgs boson (h, green) will be accompanied by three other Higgs boson states with higher mass. The primary theory would predict a specific spectrum of particles and superpartners that can be compared with experimental data.

3.12c The models (c): String inspired?



G_2 spectrum, $M_{3/2}$ = 50 TeV– spectrum similar for all compactified string/M-theories theories

Directly observable

3.13 What is the LSP?

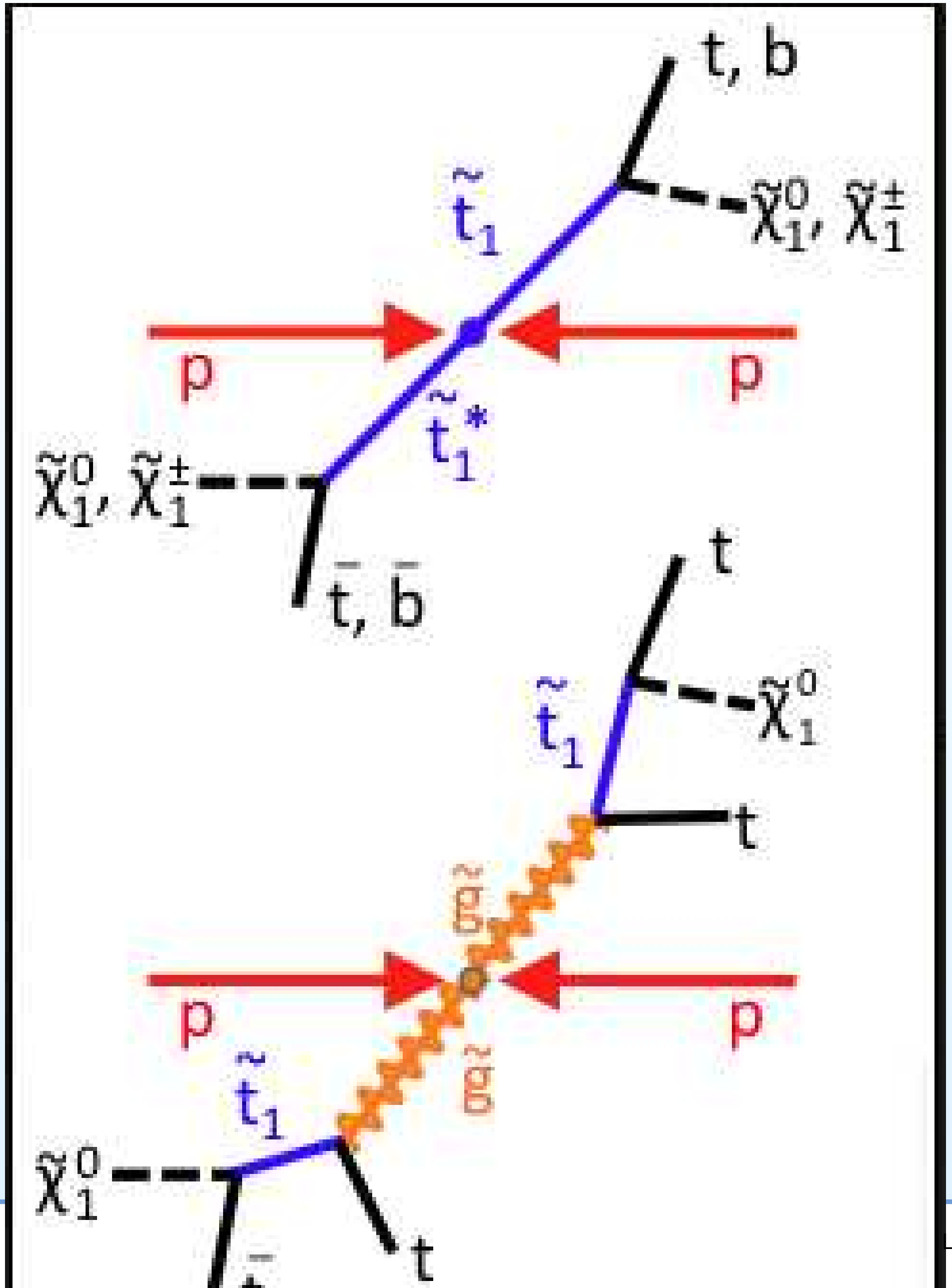
- Most popular choice Neutralino LSP,
  - Higgsino-like, Bino-like, wino-like
- Another possibility: sneutrino LSP,
  $\tilde{\nu}_L$ is not favored by direct DM search,
  But $\tilde{\nu}_R$ is still allowed by direct DM search.
- Still another option is: Gravitino () LSP,

3.13b SUSY scenarios

With R-parity, LSP and NSP nature determine the exp. search for SUSY,

- Production: SM+SM $\rightarrow$ SP+SP
- SP decays into NSP+ SM
- NSP decays into LSP+SM
- Neutralino LSP most widely studied,
- Gravitino LSP gives very different phenomenology, For instance, with Stop as NSP, LHC will find new hadrons (Stop mesinos and stop baryons).

3.13b MSSM search at LHC



3.14 SUSY phenomenology

LSP (and NLSP) nature determines the signatures of SUSY at LHC.

- If $\chi_1^0 = LSP$, signal of SUSY is cascade decays and missing energy , e.g. $\chi_2^0 \to l^+ l^- + \chi_1^0$.
- If $= LSP$ within GMM, signals include photons from $\chi_1^0 \to +\gamma$.

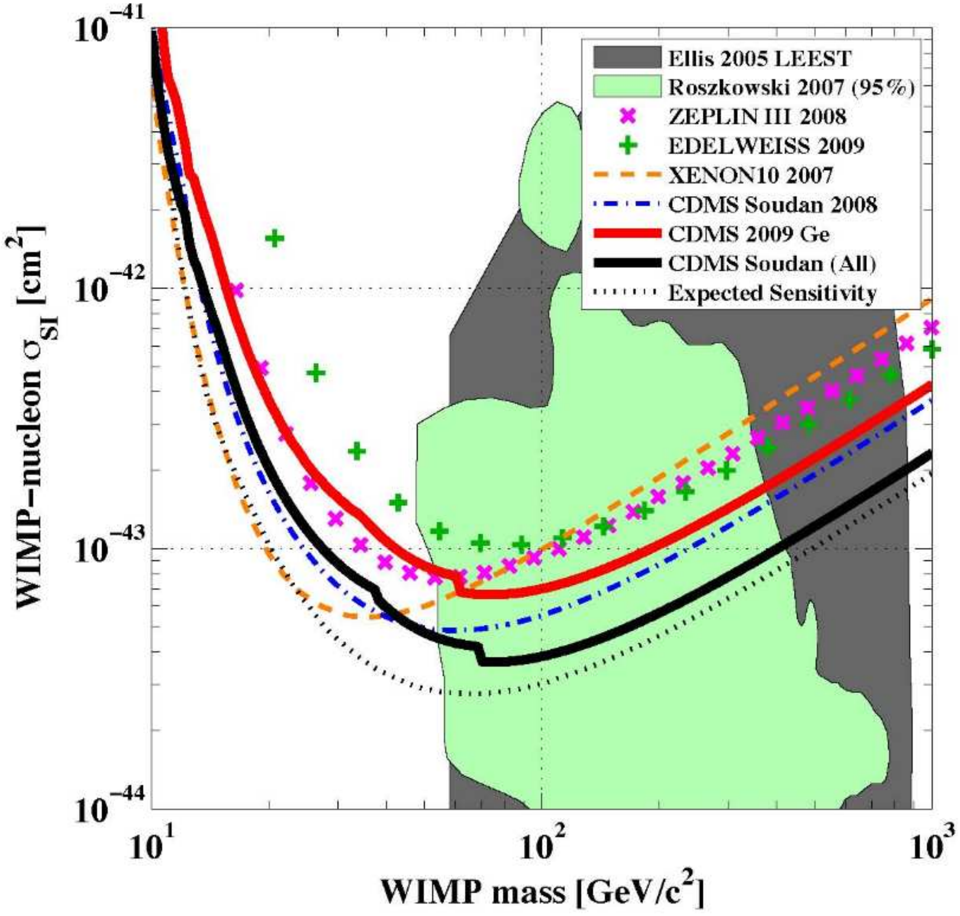
3.14b NLSP scenarios and Constraints

Several constraints are required for consistency of this scenario. SUSY parameters must satisfy:

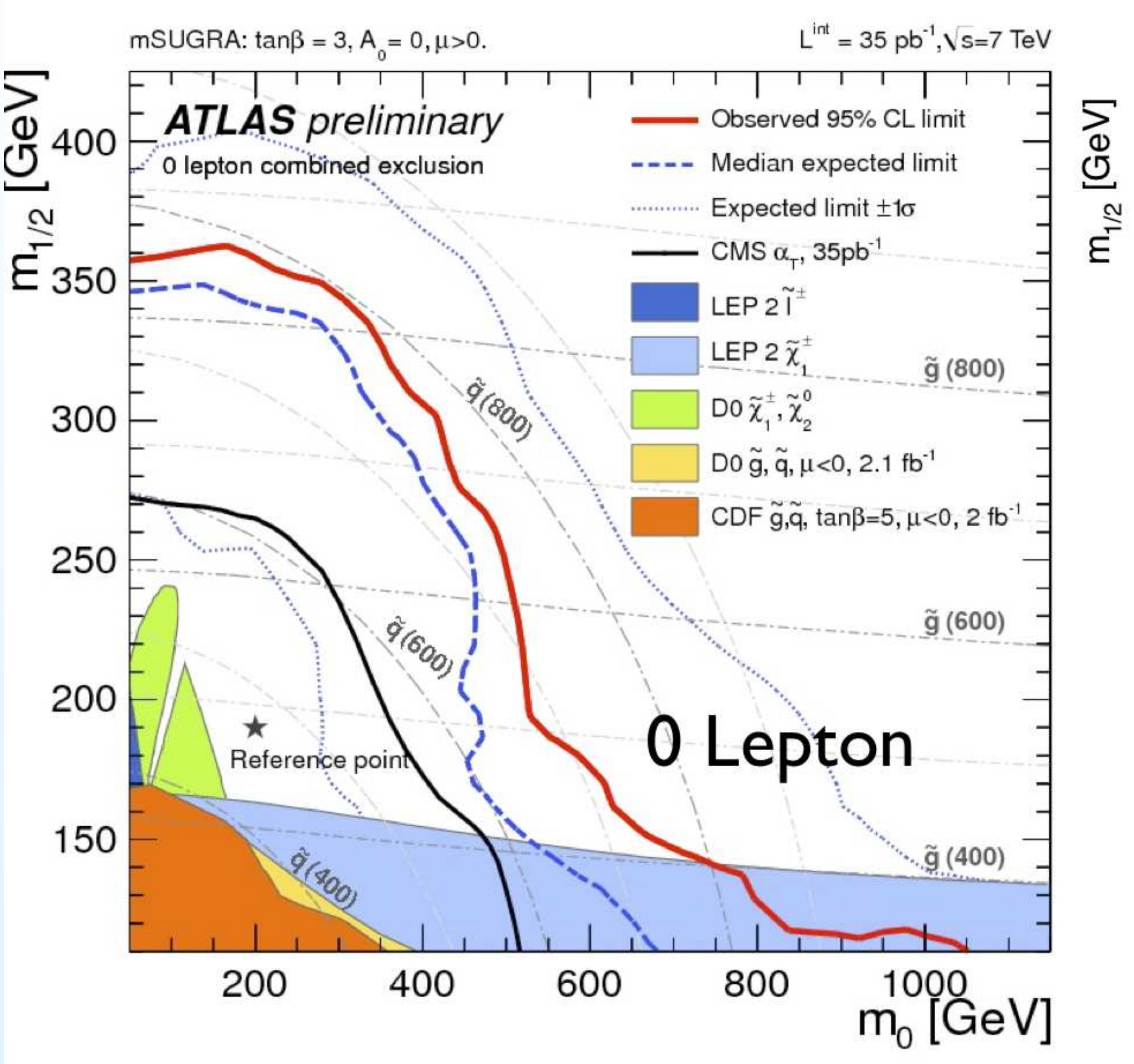
- LEP limits on Higgs mass ($m_h \geq 114$ GeV),
- Current bounds on $b \to s + \gamma$,
- Correct induced radiative EWSB,
- Tevatron and LHC limits on superpartners.
- Verify implications for cosmology (e.g. Relic density of DM),

3.14c Dark Matter

CDMS



3.15 Recent results from LHC

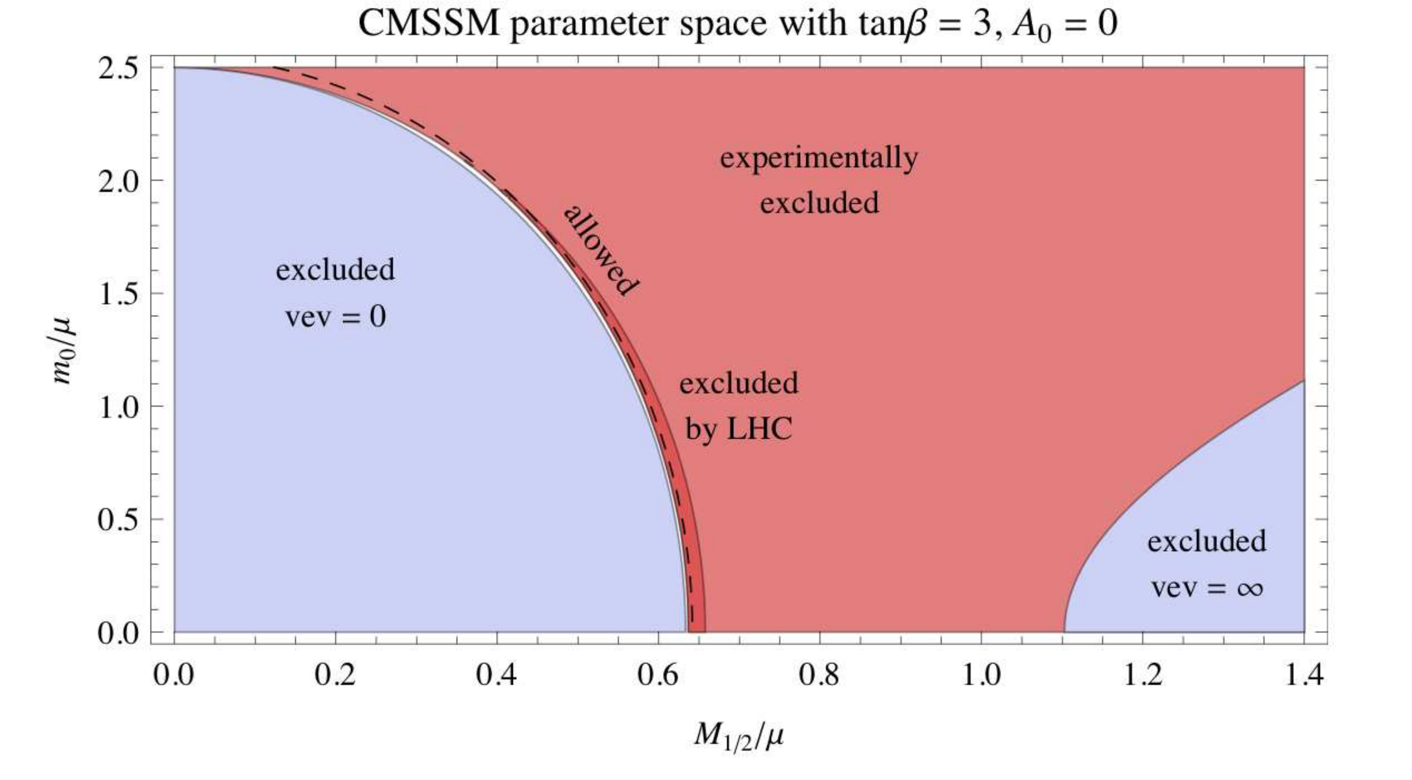


3.15b What are the bad news?

- The masses of superpartners have important implications for EWSB
- Correct radiative EWSB and LHC limits give (A. Strumia, ArXive:1101.2195 [hep-ph]):

$$M_Z^2 = 0.2m_0^2 + 0.7M_3^2 - 2\mu^2 \simeq (91GeV)^2 \times 50(\frac{M_3}{780})^2 + ... \tag{9}$$

3.15c Allowed SUSY parameters from LHC



3.16 Gravitino as LSP in SUGRA models

- Another candidate for DM is the gravitino.
  SUSY mass parameters are related to $O(m_{3/2})$,
  Take $m_{3/2}$ as a free parameter; lighter than other sparticle masses.
- Gravitino is a very weakly interacting particle, with coupling $\simeq 1/M_{Pl}$ (in supergravity).
  Practically undetectable. Only gravt. effect,
  The next lightest SUSY particle (NLSP) could be long lived.
- We have many possibilities for the NLSP: neutralino, stau, sneutrino, stop. Each with its own distinct phenomenology.

5. Conclusions

- LHC is already giving great results,
- Some evidence for a SM-like Higgs with $m_h = 125$ GeV,
- This is already pushing the SUSY scale to $O(10)$ TeV,
- Only a few superpartners may be detectable at LHC (gluino, chargino, LSP),
- Still possible to find evidence of SUSY Dark matter,
- Need to keep track of all fronts (LHC, AstroP, Cosmo,..),
- If no signal of BSM physics shows up at LHC, then what? ($\rightarrow$ PROTEUS)

5. PROTEUS

Proyecto Teorico-Experimental para la Unificacion de las Simetrias Fundamentales:

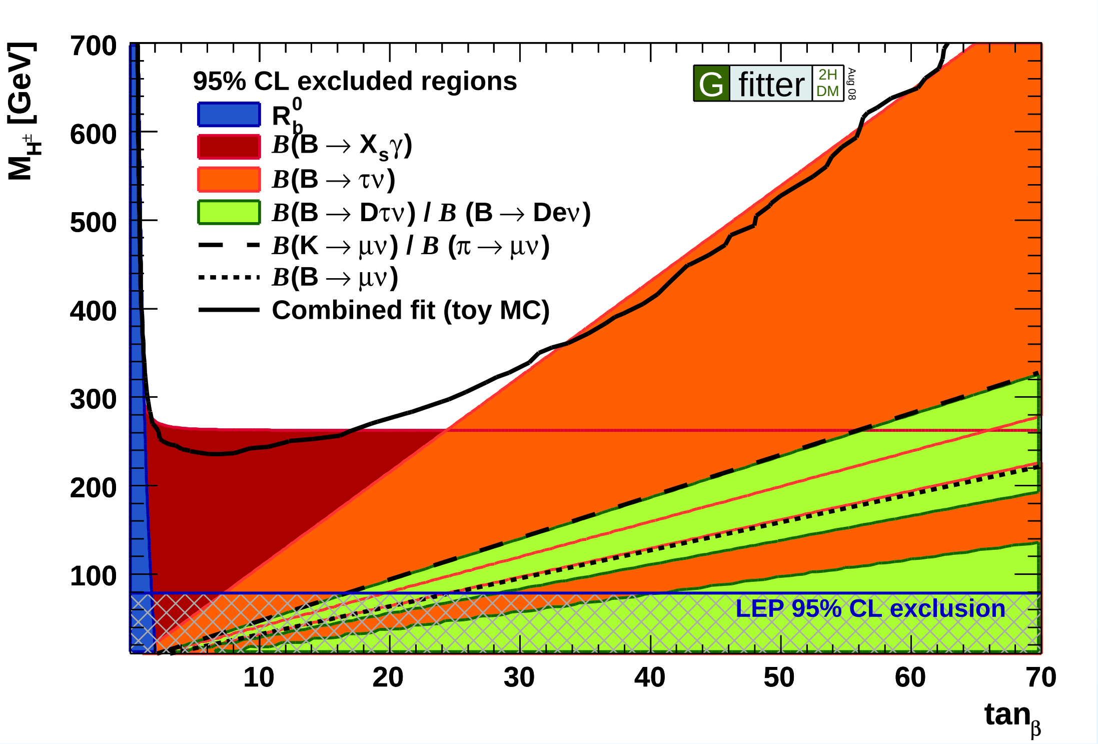
- Estudiar los principios basicos (teoricos) de BSM Physics,
- Estudiar las implicaciones experimentales de la violacion de estos principios,
- Proponer analisis para probar estos principios en los experimentos actuales de HEP-Mexico,
- Proponer un nuevo experimento (en Mexico) para probar la violacion de estos principios,

3.x Higgs and Flavor

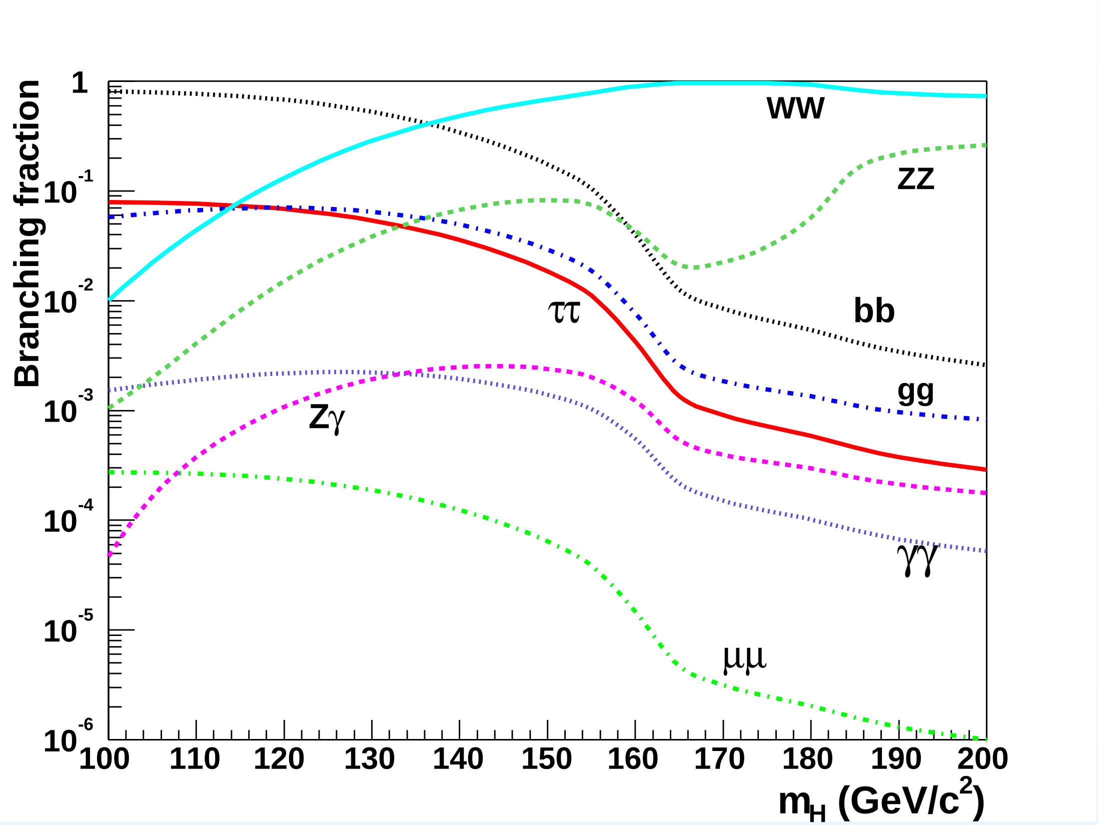
Rare B decays have been used to constrain the Neutral and Charged Higgs sector in THDM (and BSM)

- $B.R.(B \to X_s + \gamma)_{exp.} = (3.55 \pm 0.24)x10^{-4}$:
  (SM prediction: $B.R. = (3.15 \pm 0.23)x10^{-4}$)
- $B.R.(B_s \to \mu\mu)_{exp.} \leq 5.8x10^{-8}$:
  (SM prediction:$B.R.(B_s \to \mu\mu) = 3x10^{-9}$)
- $B \to \tau\nu$, $B \to \mu\nu$,
- $B \to D\tau\nu$
- $\tau \to \mu\nu\nu$

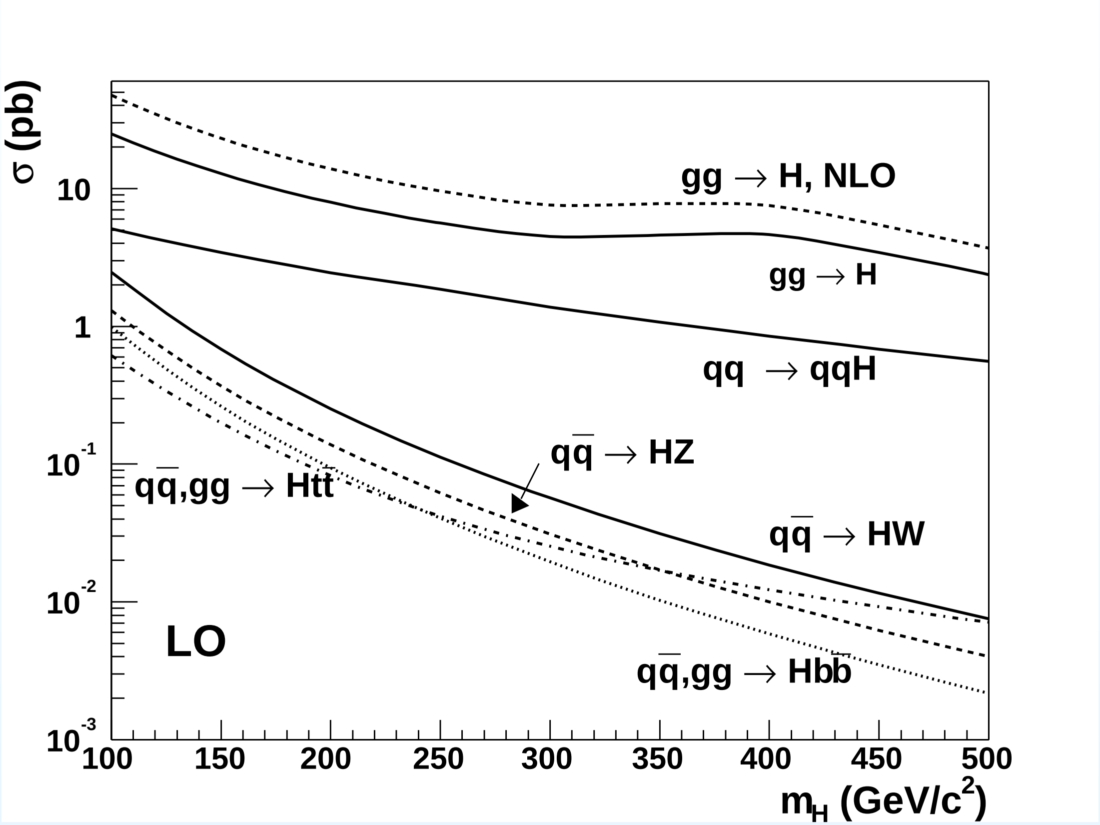
3.y Flavor and Higgs



1.2b Higgs B.R.’s



1.2c Higgs cross sections



2.x 4-Texture - 2HDMIII

(10) $$M^q = \begin{pmatrix} 0 & C_q & 0 \\ C_q^* & \tilde{B}_q & B_q \\ 0 & B_q^* & A_q \end{pmatrix} \qquad (q = u, d) \ ,$$

(11) $$\left[\tilde{Y}_n^q\right]_{ij} = \frac{\sqrt{m_i^q m_j^q}}{v} \ [\tilde{\chi}_n^q]_{ij} = \frac{\sqrt{m_i^q m_j^q}}{v} \ [\chi_n^q]_{ij} \ e^{i\vartheta_{ij}^q}$$