Perspectives on Higgs Physics

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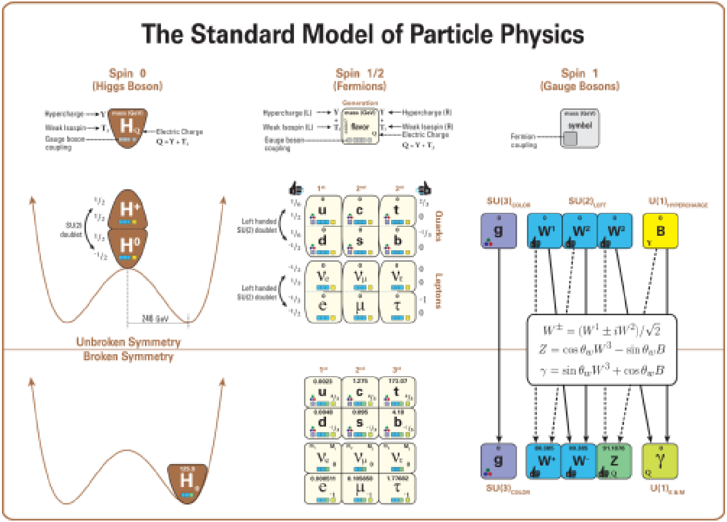

The Standard Model of Particle Physics
Spin 0
(Higgs Boson)
Spin 1/2
(Fermions)
Spin 1
(Gauge Bosons)
Unbroken Symmetry
Broken Symmetry
246 GeV
Left handed SU(2) doublet
Quarks
Leptons
u c t d s b
ν_e ν_μ ν_τ e μ τ
H^+ H^0 H
g W¹ W² W³ B
$SU(3)_{COLOR}$
$SU(2)_{LEFT}$
$U(1)_{HYPERCHARGE}$
$W^\pm = (W^1 \pm iW^2)/\sqrt{2}$
$Z = \cos\theta_W W^3 - \sin\theta_W B$
$\gamma = \sin\theta_W W^3 + \cos\theta_W B$
g W⁺ W⁻ Z γ
$U(1)_{E\&M}$

G t Hooft and the Standard Model

Recollections and reflections

Theme:

- Nature is more beautiful than we think

- Nature is smarter than we are

K. Symanzik

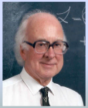
"Spontaneous symmetry breaking does not affect renormalizability"

"You have to understand the small distance structure of a theory"

What is the small distance structure of a massive Yang-Mills theory ?

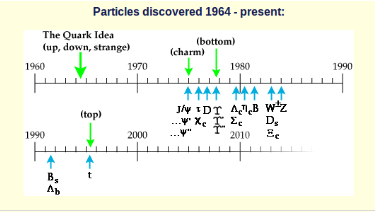
The gauge symmetry becomes *exact*, and the longitudinal mode of the vector boson behaves as a *scalar particle* – the *Higgs* !

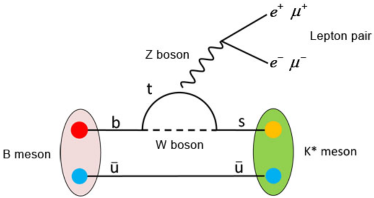
Only the Brout – Englert - Higgs mechanism can generate renormalizable massive vector particles such as the Intermediate Vecor Bosons of the weak interactions.



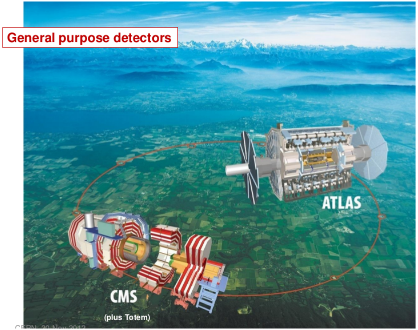
Tests del Modelo Estandar (SM)

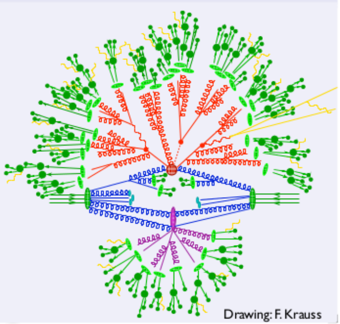
- Prediccion de los corrientes neutras (detectado en 1973),
- Prediccion del quark charm (detectado en 1974)
- Prediccion del W,Z (detectados en 1983),
- Prediccion del quark top (detectado en 1995),
- Prediccion del Higgs (detectado en 2012),

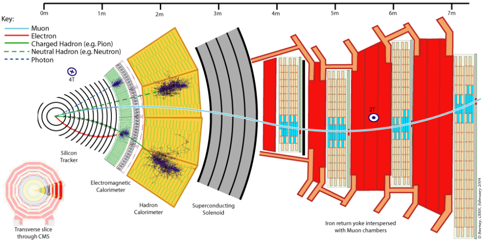




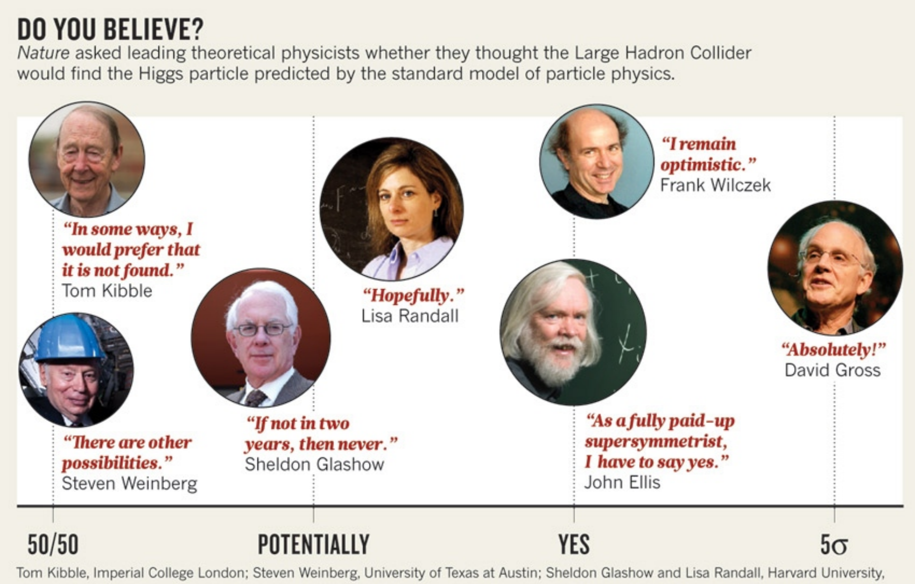
Higgs Hunting







What everybody was expecting? May be not..



UNIFICATION — THEN AND NOW

Sheldon Lee Glashow

*A Talk delivered at CERN on 4 December 2009**

On this multiply celebratory occasion I shall describe various incidents of travel on the road to electroweak unification. Three quotations will serve to introduce my talk. The epigram to my 1958 doctoral thesis was taken from Galileo's *Dialogo sopra i due Sistemi: "The poetic imagination takes two forms: as those who can invent fables, and as those who are inclined to believe them."* My advisor, Julian Schwinger, invented the fable of electroweak unification, but hardly anyone was disposed to believe it. When he entrusted the matter to me, as his graduate student I had little choice.

My second quotation is from Hamlet: *"And thus do we by indirections find directions out."* It introduced a section of my thesis which tried, and failed, to explain a puzzling property of strange particles. In the course of my tale, I shall mention several other false starts and bumbling blunders (mostly mine) and a few brilliant insights (mostly by others). I apologize to the many colleagues whose work I do not cite and for not offering a more systematic and balanced account of a long and multifaceted tale.

Aging Nobel Laureates are sometimes regarded as authority figures. For example, I am often asked what the lessons of the past can teach us about the future of our discipline. I wish I knew, but instead I offer my last quotation. As it is written in the bible: *"Many are in high place and of great renown, but mysteries are revealed unto the meek"* ...and perhaps, unto my experimental colleagues at the Large Hadron Collider.

Martin Veltman and the Higgs

Higgs hunting

In 1974 I asked myself: if the Higgs is all around us in the vacuum we should really be able to see it. Since the Higgs field in the vacuum is an energy distribution at least gravity should see it.

The answer to that is that the Higgs field generates a curvature of the universe, corresponding to some value for the cosmological constant (Linde, MV).

This can be calculated from the expectation value of the Higgs field in the vacuum according to the Standard Model.

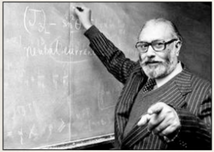
The result is about 45 orders of magnitude different from the observed rather small value.

I then stopped believing in a Higgs. Of course one may also question the cosmological part of Einstein's theory of gravity.

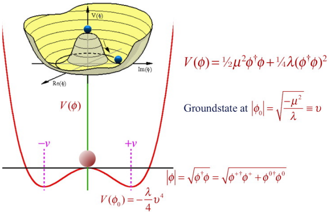
Naturally the next question is where Higgs mass dependent terms could be observed experimentally. This required investigation of the radiative corrections in the Standard Model.

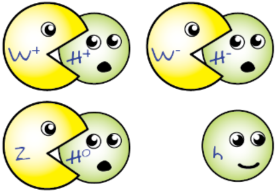
Weinberg, Salam (1967)

the Electroweak Standard Model



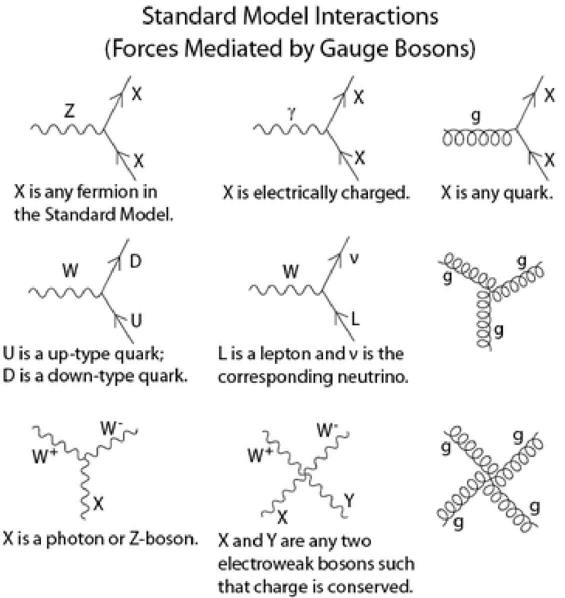
- An $SU(2)_L \times U(1)_Y$ nonabelian gauge theory with chiral fermions
- Spontaneously broken by a complex doublet scalar field with self-interactions
- Three of the four real scalar components are eaten to give mass to the W^+, W^-, and Z, leaving one neutral Higgs boson and a massless photon
- ***The fermions also get mass*** from their Yukawa couplings to the scalar field



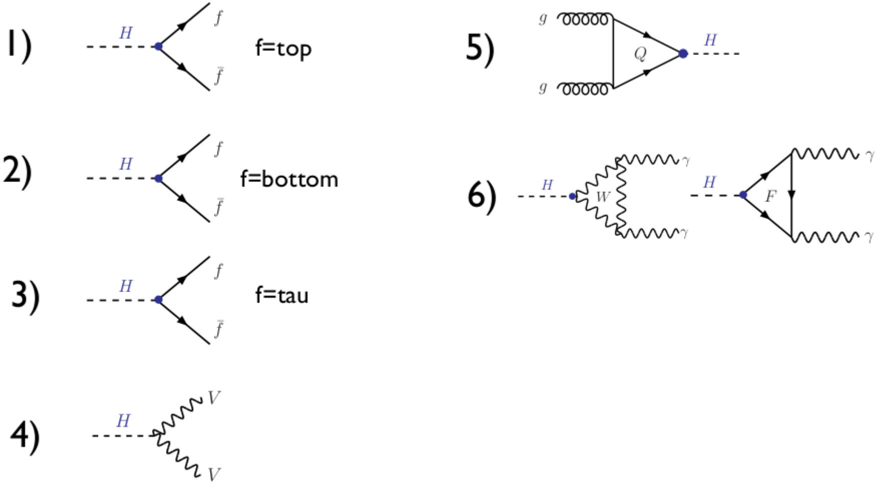


The SM QFT and its Parameters (19)

Parameters of the Standard Model			[hide]
Symbol	Description	Renormalization scheme (point)	Value
m_e	Electron mass		511 keV
m_μ	Muon mass		105.7 MeV
m_τ	Tau mass		1.78 GeV
m_u	Up quark mass	$\mu_{\overline{MS}}$ = 2 GeV	1.9 MeV
m_d	Down quark mass	$\mu_{\overline{MS}}$ = 2 GeV	4.4 MeV
m_s	Strange quark mass	$\mu_{\overline{MS}}$ = 2 GeV	87 MeV
m_c	Charm quark mass	$\mu_{\overline{MS}} = m_c$	1.32 GeV
m_b	Bottom quark mass	$\mu_{\overline{MS}} = m_b$	4.24 GeV
m_t	Top quark mass	On-shell scheme	172.7 GeV
θ_{12}	CKM 12-mixing angle		13.1°
θ_{23}	CKM 23-mixing angle		2.4°
θ_{13}	CKM 13-mixing angle		0.2°
δ	CKM CP-violating Phase		0.995
g_1 or g'	U(1) gauge coupling	$\mu_{\overline{MS}} = m_Z$	0.357
g_2 or g	SU(2) gauge coupling	$\mu_{\overline{MS}} = m_Z$	0.652
g_3 or g_s	SU(3) gauge coupling	$\mu_{\overline{MS}} = m_Z$	1.221
θ_{QCD}	QCD vacuum angle		~0
v	Higgs vacuum expectation value		246 GeV
m_H	Higgs mass		~ 125 GeV (tentative)


Standard Model Interactions
(Forces Mediated by Gauge Bosons)
Z
X
X
X is any fermion in the Standard Model.
γ
X
X
X is electrically charged.
g
X
X
X is any quark.
W
D
U
U is a up-type quark;
D is a down-type quark.
W
ν
L
L is a lepton and ν is the corresponding neutrino.
g
g
g
W⁻
W⁺
X
X is a photon or Z-boson.
W⁻
W⁺
Y
X
X and Y are any two electroweak bosons such that charge is conserved.
g
g
g
g

Higgs couplings



How the Higgs hunt started?

- After Snowmass-1982 the hadron collider got momentum $\rightarrow$ SSC,
- At U of Michigan, a series of seminars were arranged around 1987,
- Tiny Veltman claimed it should be difficult to extract Higgs mass from RadCor due to "Screening theorem", but it was the best hope,
- G. Kane, talked about our work on Intermediate Mass region $(m_z < m_h < 2m_z)$, I told him Okun's book has the calculation of $h \rightarrow \gamma\gamma$, and made first plots of BR's for that region: it turned out this is how the Higgs was detected! (GKW paper),
- Then, it was the turn of Ruddy Thun, an experimentalist, who said that detector design needs to improve in order to make realistic all of the above,

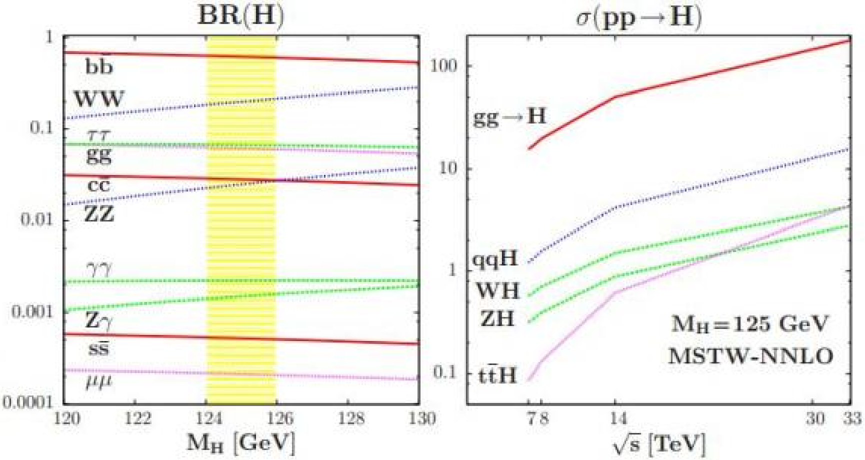
Busqueda directa del Higgs - B.R.'s

Interesting decay modes for a light Higgs:

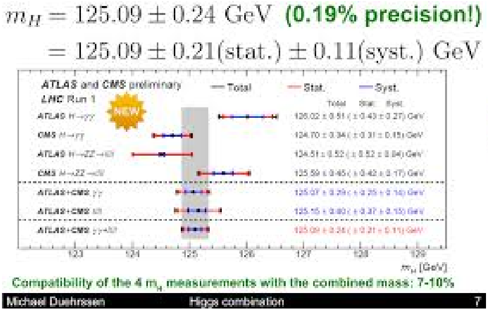
- $h \to b\bar{b}$,
- $h \to \tau^+\tau^-$,
- $h \to c\bar{c}$,
- $h \to \gamma\gamma$ (top and W loops) (Ellis, Gaillard, Nanopoulos),
- $h \to gg$ (top loop) (Georgi, Glashow, Machacek, Nanopoulos)
- $h \to WW^*, ZZ^*$ (Keung, Marciano)
- $h \to t\bar{t}$
- $h \to (c\bar{c}) + \gamma/Z$

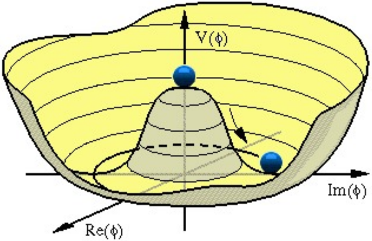
$$B.R.(h \to XX) = \frac{\Gamma(h \to XX)}{\Gamma_{total}} \tag{1}$$

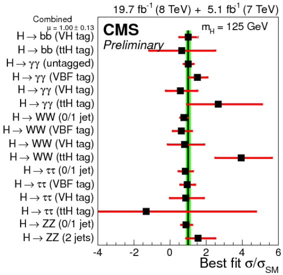
Higgs cross sections and branching ratios

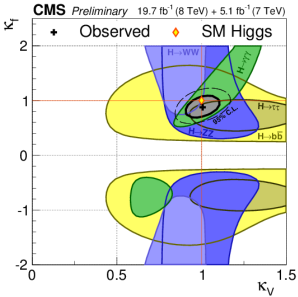


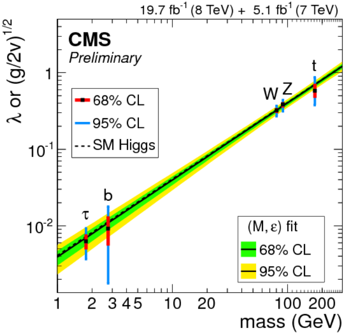
Higgs signal at LHC

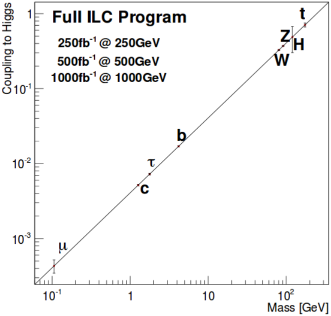





19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
Combined
μ = 1.00 ± 0.13
CMS
Preliminary
mH = 125 GeV
H → bb (VH tag)
H → bb (ttH tag)
H → γγ (untagged)
H → γγ (VBF tag)
H → γγ (VH tag)
H → γγ (ttH tag)
H → WW (0/1 jet)
H → WW (VBF tag)
H → WW (VH tag)
H → WW (ttH tag)
H → ττ (0/1 jet)
H → ττ (VBF tag)
H → ττ (VH tag)
H → ττ (ttH tag)
H → ZZ (0/1 jet)
H → ZZ (2 jets)
Best fit σ/σSM

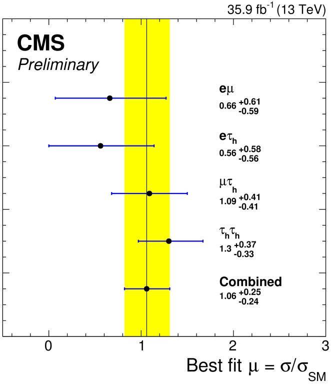

CMS Preliminary 19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
Observed
SM Higgs
H→WW
H→γγ
H→ττ
H→ZZ
H→bb̄
95% C.L.
κf
κV

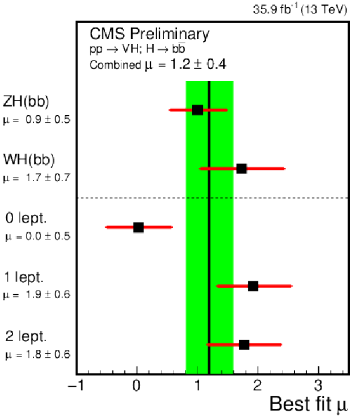

19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
CMS
Preliminary
68% CL
95% CL
SM Higgs
(M, ε) fit
68% CL
95% CL
τ
b
W Z
t
λ or (g/2v)1/2
mass (GeV)


Full ILC Program
250fb-1 @ 250GeV
500fb-1 @ 500GeV
1000fb-1 @ 1000GeV
Coupling to Higgs
Mass [GeV]
μ
c
τ
b
W
Z
H
t

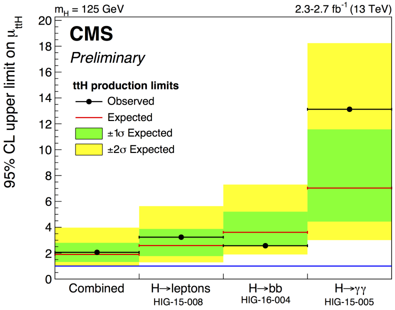
LHC13 and the Higgs

- En 2015 el LHC alcanzo una energia de 13 TeV,
- Permitió medir mejor los acoplos del Higgs con tau, bottom (FC),

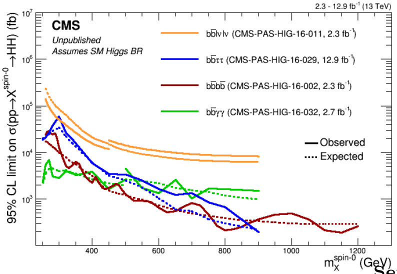




- Falta medir acoplo del Higgs con top, charm, muon...



- Medir el auto-acoplo del Higgs (hhh vertex)

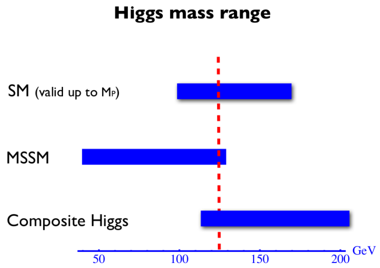


Further questions about the Higgs nature

- Is it the SM Higgs? All couplings lay on a single line?
- How can we test the Higgs couplings with 2nd generation fermions?
($B.R.(h \to \mu^+\mu^-) \simeq 2 \times 10^{-4}$, $B.R.(h \to (c\bar{c}) + \gamma) \simeq 10^{-6}$)
- Are Higgs signal affected by new physics?
(Is $h \to \gamma\gamma$ consistent with SM?)
- Signals of Flavor Violating Higgs Couplings
(LFV Higgs decays: $h \to \tau\mu$?)
(Top FCNC decay: $t \to c + h$?)
- Could the Higgs couplings with light quarks be extracted from:
$\tau \to \mu + (s\bar{s})$?, $e - \mu$ conversion? DM search?
- Is the 125 GeV Higgs part of an extended Higgs Spectrum?

Problemas abiertos - Que es el Higgs?

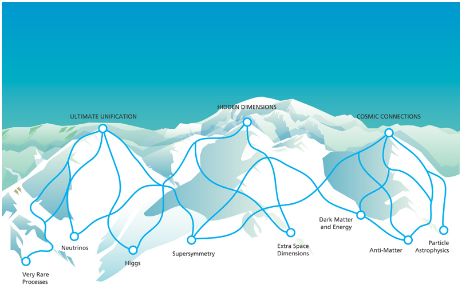
- Un nuevo estado compuesto?,
- Realizacion de una nueva simetria? (supersimetria?),
- Una manifestacion de dimensiones extra?,
- Un estado asociado con Materia oscura? (JLDC, PRL, 2008),



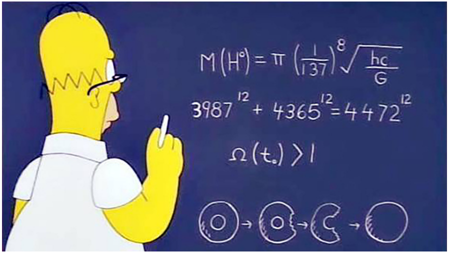
Models for BSM Physics

SM structure (Flavor parameters, gauge group, families) as well as the problems of DM, BAU, etc, motivates extensions of the SM.
In particular, Models with an extended Higgs sector have been studied extensibly:

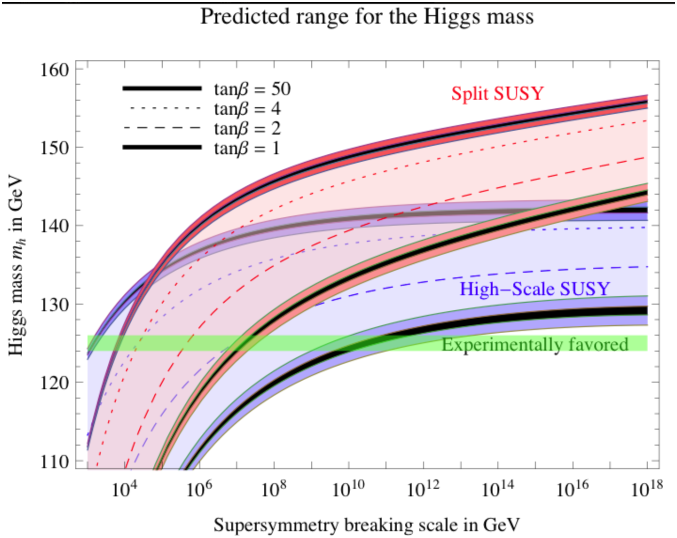
- NHDM: SM+1s, 2HDM, 3HDM, 4HDM ($\rho = 1$)
- Triplets, LR models, .. ($\rho \neq 1$ or $\rho \simeq 1$ with some tunning)
- IDM, stable septet, etc.. ($\rightarrow$ DM candidate)
- Hierarchy problem: MSSM, Composite Higgs, XD, ..



New Physics and the Higgs nature



SUSY and Higgs



The Higgs portal

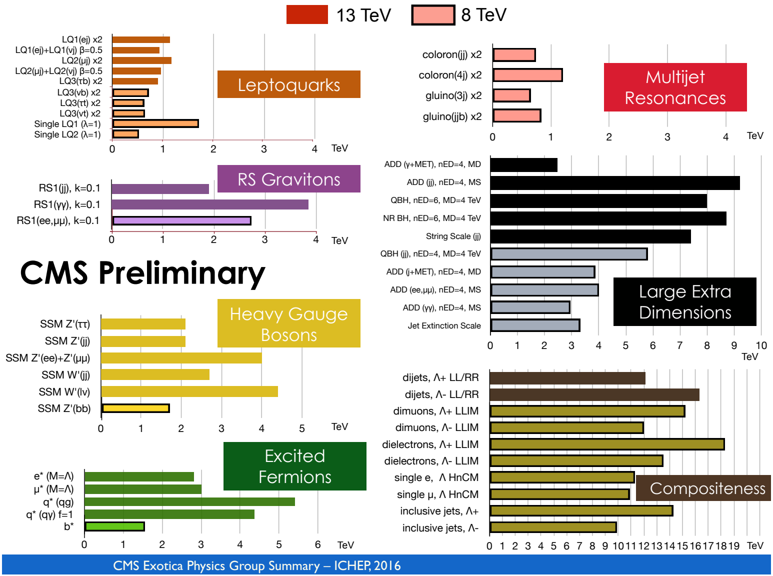
The possibility to write:

$$\mathcal{L}_{\Phi X} = \lambda_x(\Phi^\dagger\Phi)(X^\dagger X) \tag{2}$$

allows to connect the SM(Higgs) with some hidden X sector:

- X = Dark Matter ex. Inert doublet,
- X = Flavon field (FN) (our most recent work)
- X = Susy sfermion,
  ($\rightarrow$ EW phase transition, gravitational waves from early universe)
- X = Inflaton,

El problema : LHC esta comprobando el SM



Desviaciones del SM Higgs - ex. 2HDM (S.F. Su et al)

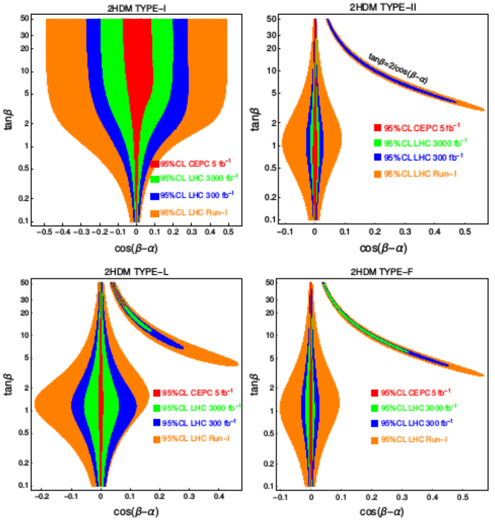


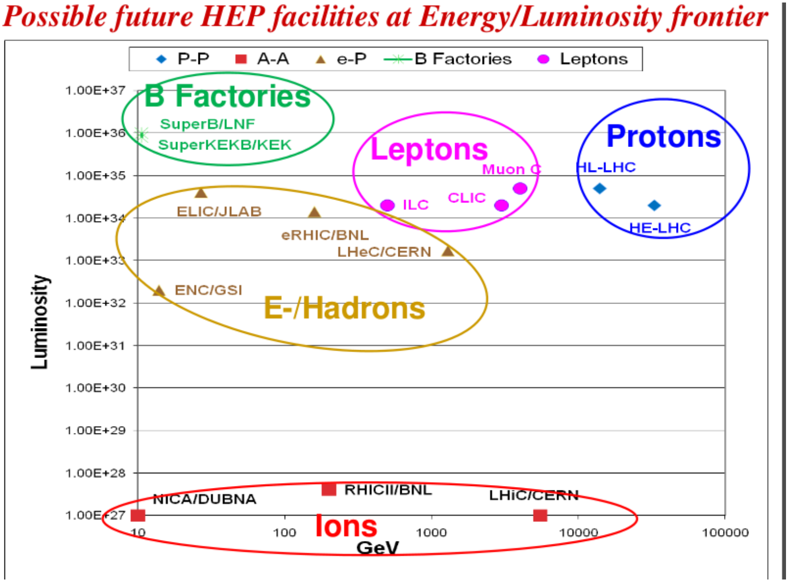
Figure 2. The allowed region in the plane of $\tan\beta$ vs. $\cos(\beta-\alpha)$ at 95% C.L. for the four types of 2HDM, given LHC and CEPC Higgs precision measurements. For future measurements, we have assumed that the measurements agree with SM predictions. The special "arm" regions for the Type-II, L and F are the wrong-sign Yukawa regions. See text for more details.

Keep searching and ...

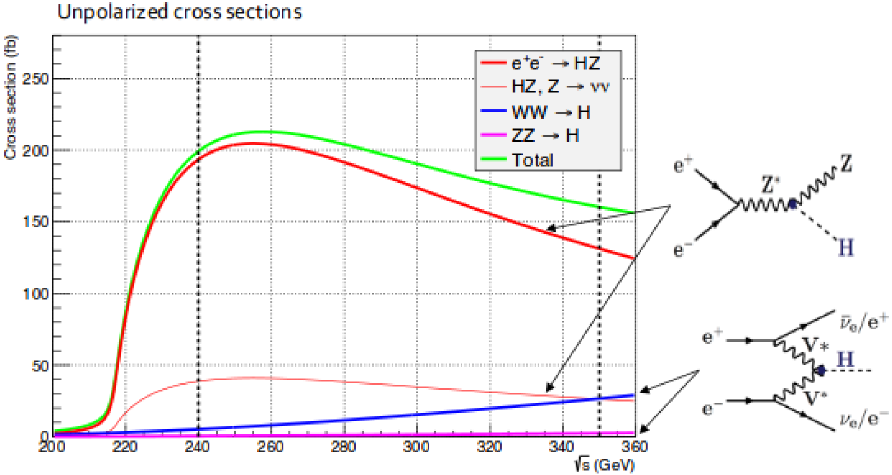
Let us be patient …

- If you have a problem, postulate a new particle:
  - QM and Special Relativity: Antimatter
  - Nuclear spectra: Neutron
  - Continuous spectrum in β decay: Neutrino
  - Nucleon-nucleon interactions: Pion
  - Absence of lepton number violation: Second neutrino
  - Flavour SU(3): Ω^-
  - Flavour SU(3): Quarks
  - FCNC: Charm
  - CP violation: Third generation
  - Strong dynamics: Gluons
  - Weak interactions: $W^{\pm}$, Z^0
  - Renormalizability: H (48 years)
  - **Naturalness: Supersymmetry? (40 years)**

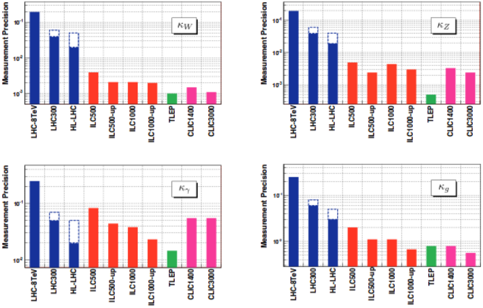
Futuros Aceleradores-



Futuros Aceleradores- TLEP



Future Higgs couplings



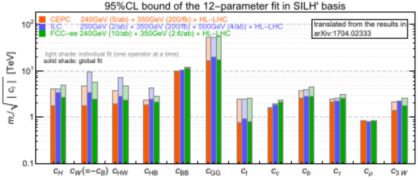
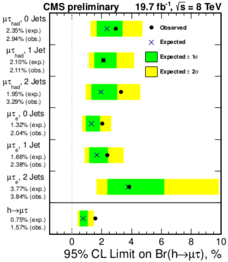
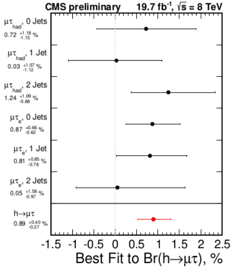


Figure 12. The 95% C.L. constraints on the overall coefficient of $\mathcal{O}_i$ from Ref. [34], which are translated into the SILH basis and presented in the form $m_*/\sqrt{c_i}$. Estimated Higgs measurement precision from CEPC, ILC, and FCC-ee are used with the inclusion of HL-LHC Higgs precision.

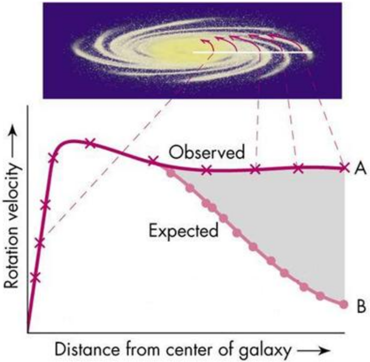
Mexico and the Higgs

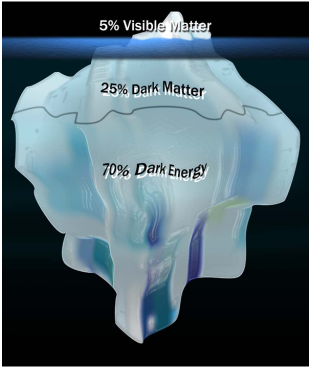
- En lo que va de 2017 se han publicado del orden de 715 papers sobre Higgs (CMS/Atlas, Pheno, Models, Theory) ,
- Los más recientes desde Mexico: Chamorro et al (1707.00100), Barradas et al (1706.00054), Garcia-Jimenez et al (1705.02637), J.I. Aranda et al (1703.07893), etc...
- LFV Higgs decay: $h \to \tau\mu$
  (Diaz-Cruz et al: 2HDM-III, MSSM, ...) ,





Dark Matter - WIMPS

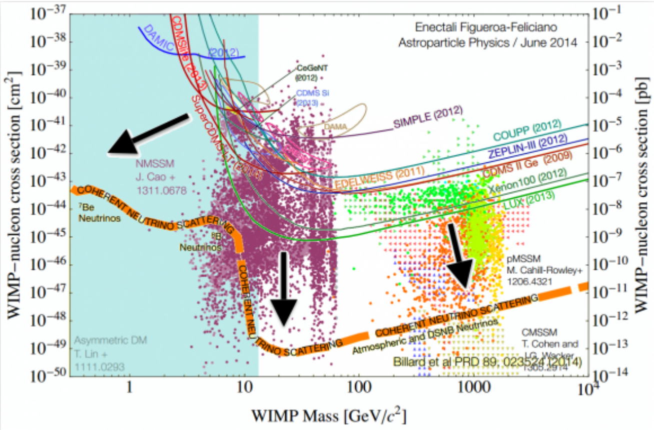




Many models of Physics Beyond the SM are motivated because they include a discrete symmetry (ex Z_2), such that a Z_2-odd particle is stable and could be a viable DM candidate (WIMP).

Dark Matter searches (wimp-direct)

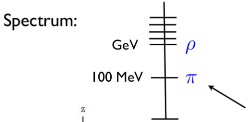
The search for WIMPS involves both cosmology and energy frontiers.

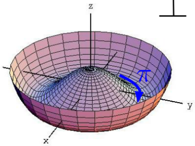


Higgs- Dark matter connection

Composite PGB Higgs

Inspired by QCD where one observes
that the (pseudo) scalars are the lightest states





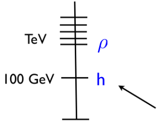
Are Pseudo-Goldstone bosons (PGB)

Mass protected by the global QCD symmetry!

$$\pi \to \pi + \alpha$$

The light Higgs can be a kind of pion from a new strong sector

The spectrum of the new strong sector could be:



Pseudo-Goldstone bosons (PGB)

Mass protected by the global symmetries!

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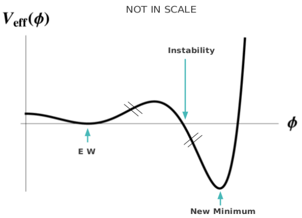
Holographic Dark Matter and Higgs Models

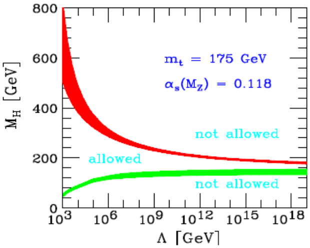
J. Lorenzo Díaz-Cruz

Phys. Rev. Lett. **100**, 221802 – Published 5 June 2008

Is our universe stable?

RG Improved Effective Potential $V_{eff}(\phi)$

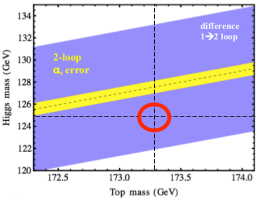


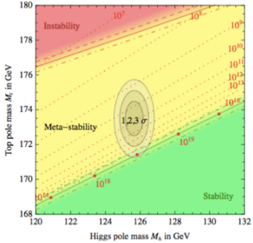


Is the Higgs Potential at M_{Planck} flat?

Buttazzo, Degrassi, Giardino, Giudice, Sala, Salvio, Strumia

Holthausen, ML, Lim

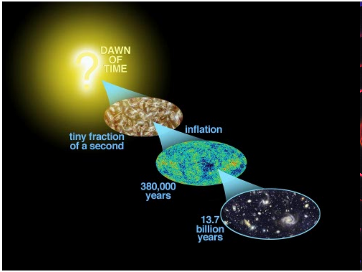


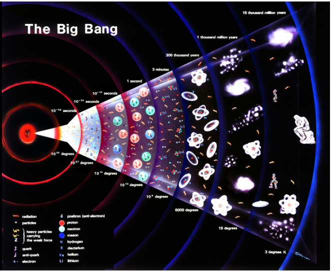


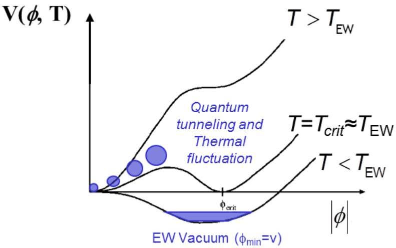
Notes:

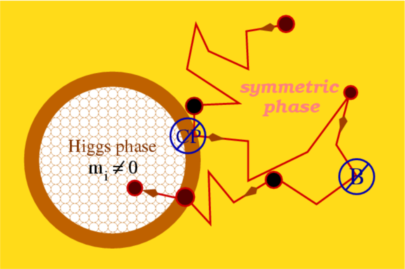
- remarkable relation between weak scale, m_t, couplings and M_{Planck} ↔ precision

The big-bang and the EWSB vacuum

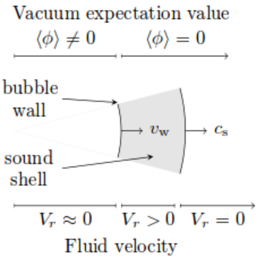


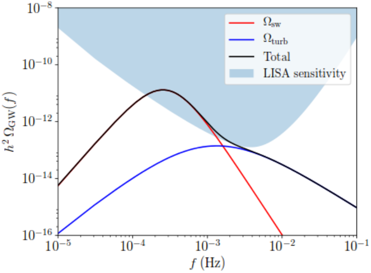


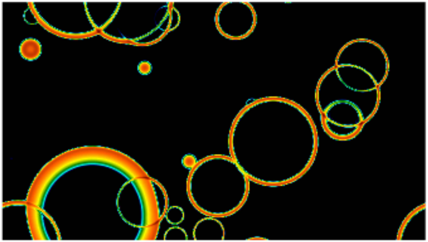


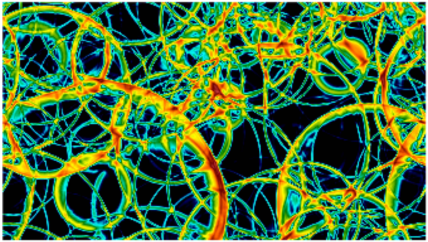


EWSB and gravitational waves









Conclusiones

- El SM es una teoria grandiosa (a la Penrose),
- Se ha encontrado evidencia de un nuevo boson con masa $m_h = 125 - 126$ GeV,
- Las medicions actuales apuntan a un boson de Higgs tipo-SM; se deben estudiar a detalle sus propiedades para saber si es asi o hay algo mas alla (LHC13),
- El SM deja preguntas sin resolver (Neutrino mass, Dark matter,..), que sugieren nueva fisica, la cual se debe buscar en LHC13,
- No entendemos el origen del SM, los valores de sus parametros, ni sus representaciones,
- Interesante medir el encuentro de Higgs y Einstein ...

The Hierachy problem

When an scalar interacts with a heavy fermion M, with $L_Y = y\bar{\Psi}\Psi\phi$, and UV cutoff Λ, the scalar mass gest corrected, i.e.

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

Some solutions:

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

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

NO LONGER WORKS! ($\rightarrow m_h \simeq 200$ GeV,)

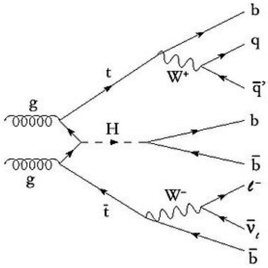
AT LOW ENERGIES....BUT WHAT ABOUT AT M_{pl}?

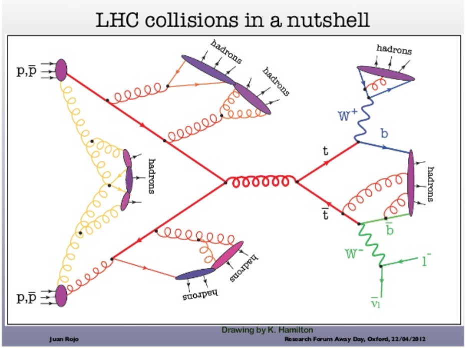
Beyond the SM (Open Problems)

- Large/Little hierarchy problem (what is the Higgs?),
- Neutrino masses and flavor problem,
- Strong CP problem,
- Some deviations from the SM (a few std. dev.), e.g. Δa_μ, etc.
- La asimetria materia- antimateria del universo,
- Dark Matter, Dark Energy (Cosmological constant),
- Quantum gravity,

They all suggest the need for New Physics

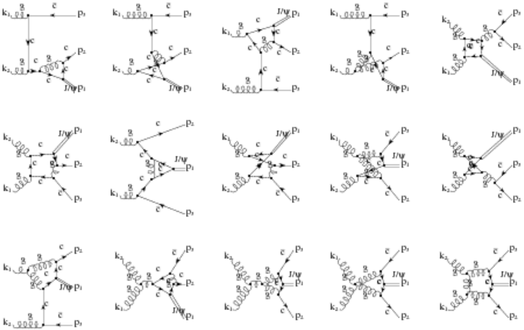
La detección del Higgs requirió un dominio de QCD





H decay mode	H production	Exclusive final states	No. of channels	m_H range [GeV]	m_H resolution
$WW \to \ell\nu\ell\nu$	untagged	$(ee, \mu\mu, e\mu)$ + (0 or 1 jets)	4	145–1000 [a,b]	20%
	VBF tag	$(ee, \mu\mu, e\mu) + (jj)_{VBF}$	2	145–1000 [a,b]	20%
$WW \to \ell\nu qq$	untagged	$(e\nu, \mu\nu) + (jj)_W$	2	180–600	5–15%
	untagged	$(e\nu, \mu\nu) + (J)_W$ + (0+1-jets)	2	600–1000 [b]	5–15%
	VBF tag	$(e\nu, \mu\nu) + (J)_W + (jj)_{VBF}$	1	600–1000 [b]	5–15%
$ZZ \to 2\ell 2\ell'$	untagged	$4e, 4\mu, 2e2\mu$	3	145–1000	1–2%
	VBF tag	$(4e, 4\mu, 2e2\mu) + (jj)_{VBF}$	3	145–1000	1–2%
	untagged	$(ee, \mu\mu) + (\tau_h\tau_h, \tau_e\tau_h, \tau_\mu\tau_h, \tau_e\tau_\mu)$	8	200–1000	10–15%
$ZZ \to 2\ell 2\nu$	untagged	$(ee, \mu\mu)$ + (0 or $\geq$ 1 jets)	4	200–1000	7%
	VBF tag	$(ee, \mu\mu) + (jj)_{VBF}$	2	200–1000	7%
$ZZ \to 2\ell 2q$	untagged	$(ee, \mu\mu) + (jj)_Z^{0,1,2\,b\text{ tags}}$	6	230–1000 [c]	3%
	untagged	$(ee, \mu\mu) + (J)_Z^{0,1,2\,b\text{ tags}}$	6	230–1000 [c]	3%
	VBF tag	$(ee, \mu\mu) + (jj)_Z^{0,1,2\,b\text{ tags}} + (jj)_{VBF}$	6	230–1000 [c]	3%
	VBF tag	$(ee, \mu\mu) + (J)_Z^{0,1,2\,b\text{ tags}} + (jj)_{VBF}$	6	230–1000 [c]	3%

QCD perturbtiva ($\alpha_s << 1$)



SM Physics basis

- Gauge Bosons Mixing: $W^3_\mu, B_\mu \;\; \rightarrow \;\; A_\mu, Z_\mu \;\; (\theta_W \text{ rotation})$
- Through SSB scalar gets a vev: $< \phi >= \frac{v}{\sqrt{2}}, \quad e = g_2 \sin\theta_w,$
- Gauge boson masses: $M_W = \frac{gv}{2}, \quad M_Z = \frac{gv}{2\cos\theta_w},$
- Veltman ρ parameter: $\rho = \frac{M_W^2}{M_Z^2 \cos^2\theta_w} = 1 + \delta\rho$
- Fermion masses: $m_f^0 = \frac{1}{\sqrt{2}} y_f v,$
- Fermion mass diag.: $M_f = V_R M_f^0 V_L^\dagger \rightarrow V_{ckm} = V_L^u V_L^{d\dagger},$
- Higgs mass: $m_h = \lambda v, \quad (\;\; V \simeq \mu^2\phi^2 + \lambda\phi^4 \;\;),$

SM Parameters

- Gauge couplings: $g_1, \quad g_2, \quad g_3 \;, \quad \theta_{qcd},$

  $\rightarrow \alpha_{em} = \frac{e^2}{4\pi} = \frac{1}{137}, \quad \sin^2\theta_w = 0.223, \quad \alpha_s = 0.118,$

- Higgs Potential: μ^2, $\lambda \rightarrow v = 246$ GeV, $m_h = \lambda v = 125$ GeV

- leptons: $m_e = 0.511$ Mev, $m_\mu = 105$ Mev, $m_\tau = 1705$ Mev,

- u-type quarks: $m_u = 5 - 7$ MeV, $m_c = 1300$ MeV, $m_t = 173$ GeV,

- d-type quarks: $m_d = 5 - 10$ MeV, $m_s = 300$ MeV, $m_b = 4.5$ GeV,

- CKM elements: V_{ij} (3x3 matrix) $\rightarrow$ 3 angles + 1 phase (CPV)

A total of: 4+2+3+3+3+3+1= 19 parameters (plus neutrinos!)

SM Parameters

- Gauge couplings: g_1, g_2, g_3 , θ_{qcd},

  $\rightarrow \alpha_{em} = \frac{e^2}{4\pi} = ?$, $\sin^2\theta_w = ?$, $\alpha_s = ?$,

- Higgs Potential: μ^2, $\lambda \rightarrow v = ?$, $m_h = \lambda v = ?$

- leptons: $m_e = ?$, $m_\mu = ?$, $m_\tau = ?$,

- u-type quarks: $m_u = ?$, $m_c = ?$, $m_t = ?$,

- d-type quarks: $m_d = ?$, $m_s = ?$, $m_b = ?$,

- CKM elements: V_{ij} (3x3 matrix) $\rightarrow$? angles + ? phase (CPV)

A total of: ?? parameters (plus neutrinos!)

Supersimmetry (SUSY)

Why is SUSY attractive? It is a new simmetry that relates fermions and bosons,

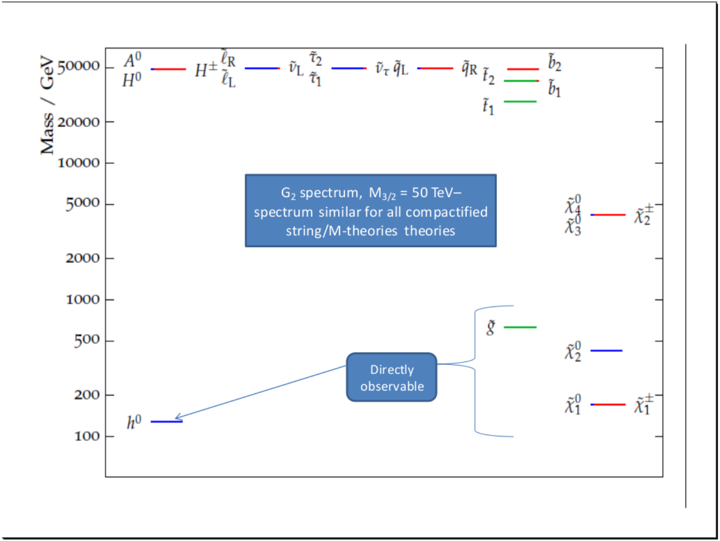
- Offers the possibility to stabilize the Higgs mass and EWSB,
- Improves Unification and o.k. with proton decay,
- Favors a light Higgs boson, in agreement with EWPT (and LHC?), i.e. $m_h \leq 160$ GeV,
- New sources of flavor and CP violation may help to get the right BAU,
- LSP is stable and a possible Dark matter candidate.

The MSSM

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

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

SUSY Spectrum (String inspired)



(See G.l. Kane et al, arXive)

Slim Susy and Heavy Higgses (JLDC et al, PLB,2013)