Boson de X: Elucidating EWSB

Fawzi BOUDJEMA

boudjema@lapp.in2p3.fr

Higgs Meeting, LPSC, Grenoble, March 2013

Sent: 14 March 2013 15:26
To: Fawzi Boudjema
Subject: true?

Is this true?

http://www.independent.co.uk/news/science/have-they-found-the-higgs-boson-at-last-cern-scientists-say-theyre-confident-of-god-particle-breakthrough-8534012.html

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Have they found the Higgs boson at last? Cern physicists say they're confident of breakthrough

STEVE CONNOR | THURSDAY 14 MARCH 2013

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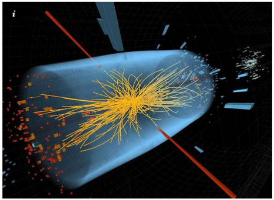

A new sub-atomic particle that could explain one of the great mysteries of the Universe – why matter has mass – has almost certainly been found according to further evidence supporting the discovery of the elusive Higgs boson.

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- Michael Bywater:

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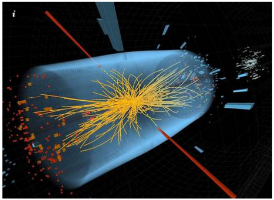

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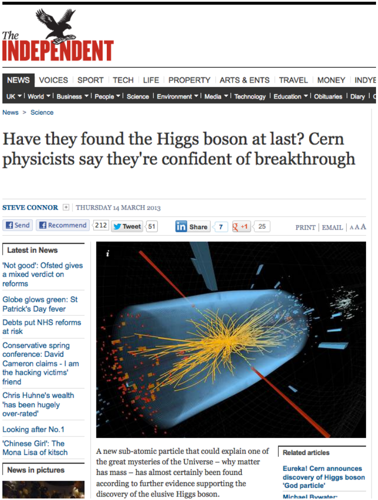
Michael Bywater:

It looks more and more likely that we really have found the Higgs particle, although it?s always difficult to say this with absolute certainty. Most physicists would now agree that this is probably the Higgs. Professor Charlton said.



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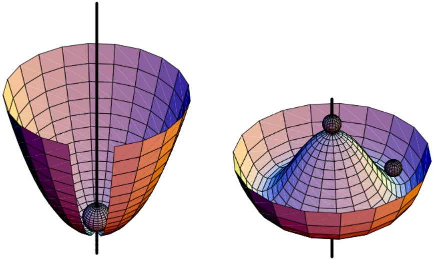
Michael Rywater:

The preliminary results with the full 2012 data set are magnificent and to me it is clear that we are dealing with a Higgs boson though we still have a long way to go to know what kind of Higgs boson it is, said Joe Incandela, a spokesman for the CMS experiment on the LHC

Higgs-Kibble in the SM model

Higgs Kibble Mechanism



$V = \lambda(|\Phi|^2 - v^2/2)^2$

$(\lambda > 0)$

$\langle 0|\phi|0\rangle = v/\sqrt{2}$

$Q_{em}|0\rangle = |0\rangle$

$y_\Phi = Y_\Phi = \frac{1}{2}$

$$\Phi = \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}(v+H) \end{pmatrix} e^{i\frac{\omega^j\tau^j}{2v}}$$

$$\mathcal{L}_{\text{Higgs}} = (D^\mu\Phi)^\dagger(D_\mu\Phi) - V(\Phi^\dagger\Phi), \quad V(\Phi^\dagger\Phi) = \lambda\left(\Phi^\dagger\Phi - \frac{v^2}{2}\right)^2$$

$$\mathcal{L}_{m_f} = -\left(y_u\bar{u}_R\tilde{\Phi}^\dagger Q_L +^{y}_{d} \bar{d}_r\Phi^\dagger Q_L\right) + h.c, \quad \tilde{\Phi} = i\tau_2\Phi^* \quad m_{d,u} = y_{d,u}\frac{v}{\sqrt{2}}$$

Weakly coupled extensions (MSSM, NMSSM,...) construction is similar, more multiplets, perhaps mixing

More fun and more papers:

- h and H. For H reanalyze your $H_{\rm SM}$ search
- $H^{\pm}$, A, reinterpretation of *MSSM* studies, perhaps some new things.
- Beware of Flavour constraints

in the SM, Higgs and Mass are "ONE"

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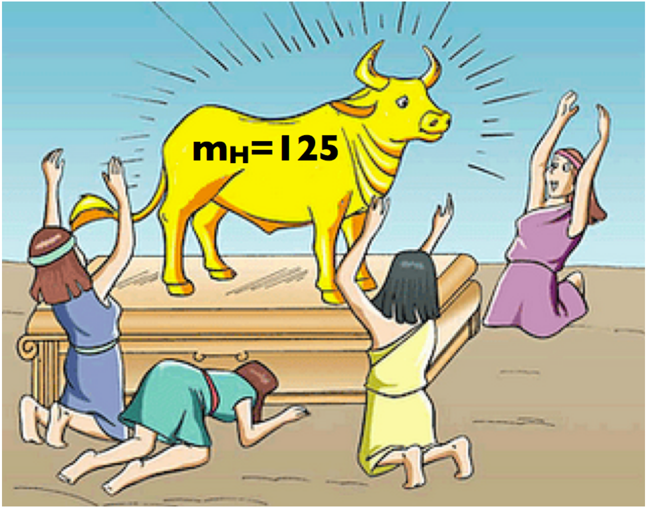
- Spin: Spin can only be 0 in this picture. A particle with a v.e.v can only by of spin-0 (angular momentum....)

Hare Higgsna, Hare Hare...



from Adam Martin, from?

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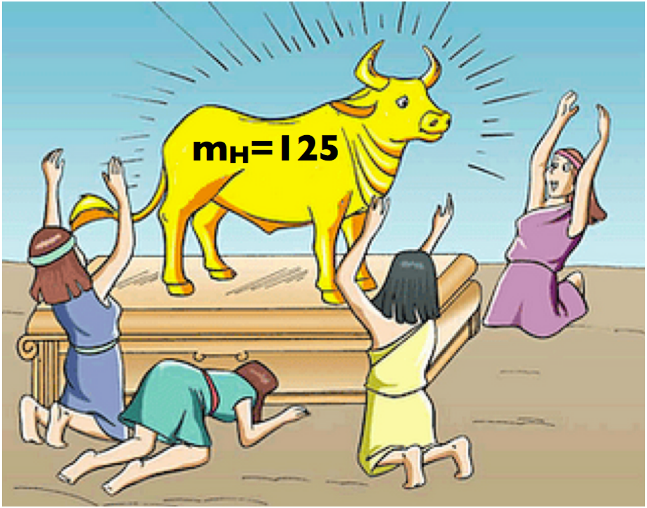
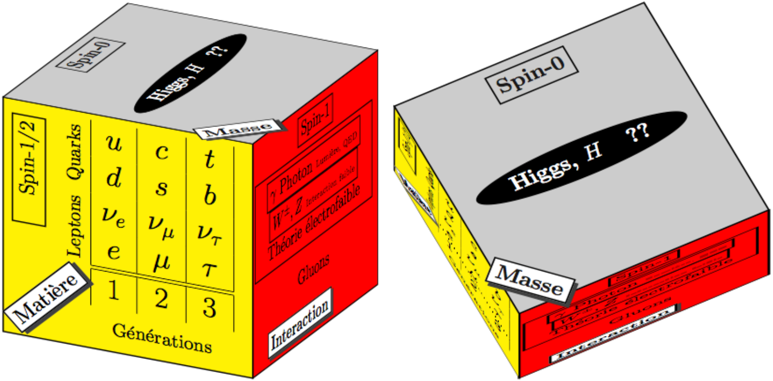


why not just praise the Lord and the SM

The holy cow has got 4 legs: 3 Goldstones and one scalar

SM Matter



Spin-0
Higgs, H ??
Masse
Spin-1/2
Quarks
Leptons
u c t
d s b
ν_e ν_μ ν_τ
e μ τ
1 2 3
Générations
Matière
Spin-1
γ Photon Lumière, QED
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Théorie électrofaible
Gluons
Interaction
Spin-0
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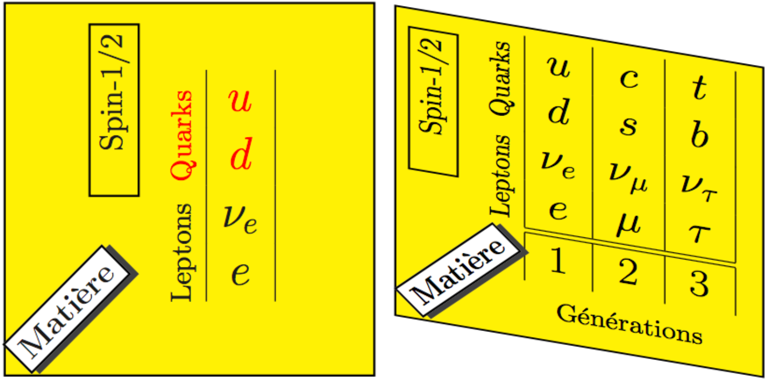
Matter and Forces: 3 families, why 3?



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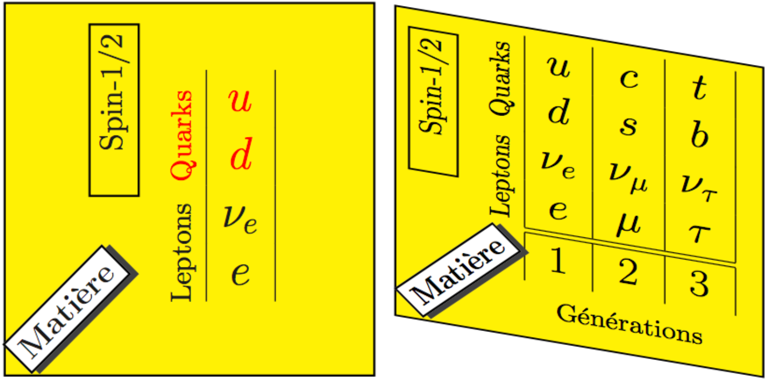

What difference between the 3 generations?

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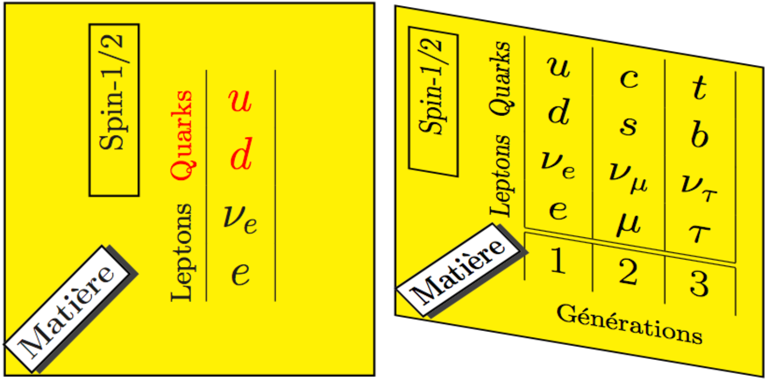

What difference between the 3 generations? MASS

What puzzles when one talks about MASS: Flavour

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- Neutrinos special?
- CKM fits that have become more and more precise over the years have still not help draw an underlying model or theory of flavour. More luck with Higgs couplings fits?

More puzzling

If Higgs last piece of a model of interactions below 1TeV or even valid all the way to the Planck scale (see later),

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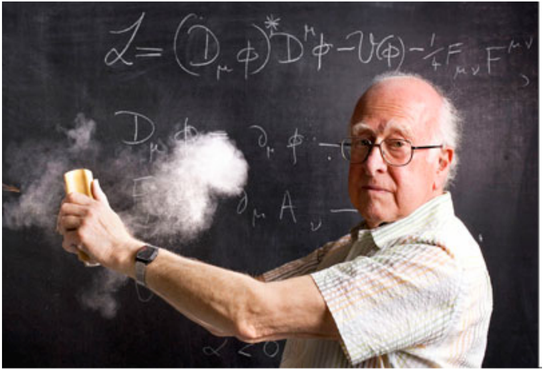
- The vacuum of the SM stable up to Planck scale?
- A glimmer of hope, M_{125GeV} maximised so that a large number of couplings are accessed! Allows more test.

Higgs? Is this all smoke then?



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- Technicolour revamped, larger symmetries (modern parlance Composite Higgs)

Mass, dynamical generation?

Forces	Theory	mediators	rel. strength	long dist.	range (m)
Strong	QCD	gluons	10^{38}	1	10^{-15}
Electromagnetic	QED	photons	10^{36}	$1/r^2$	∞
Weak	QEW	W/Z	10^{25}	$1/r\ e^{-M_W}$	10^{-18}
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Weak force, has massive mediators!

No quantum theory of gravity (yet)

but a fundamental scale is introduced:

$$M_P = \Lambda_P = \sqrt{\frac{\hbar c}{8\pi G}} \sim 2.5\ 10^{18} GeV$$

Masses in a Gauge Invariant Way without Higgs

The W, Z, γ kinetic pure gauge term still of the same origin but

mass and longitudinals through a system of Goldstones without the Higgs (still gauge invariant): Non-Linear realisation of SB

$$\Sigma = exp(\frac{i\omega^i\tau^i}{v}) \quad (v = 246\ GeV \text{ is the vev}) \quad \text{and} \quad \mathcal{D}_\mu\Sigma = \partial_\mu\Sigma + \frac{i}{2}\left(g\boldsymbol{W}_\mu\Sigma - g' B_\mu \Sigma\tau_3\right)$$

$$\mathcal{L}_M = \frac{v^2}{4}\mathrm{Tr}(\mathcal{D}^\mu\Sigma^\dagger\mathcal{D}_\mu\Sigma) \equiv -\frac{v^2}{4}\mathrm{Tr}\left(\mathcal{V}_\mu\mathcal{V}^\mu\right) \quad \text{with} \quad \mathcal{V}_\mu = (\mathcal{D}_\mu\Sigma)\,\Sigma^\dagger$$

Replaces all of the Higgs sector, potential and all.

Not renormalisable? and so what...!

Higgsless

$$\begin{aligned} \mathcal{L}_{\rm GB} &= \frac{1}{2}(\partial_\mu \omega^i)^2 - \frac{1}{6v^2}\left((\omega^i\partial_\mu\omega^i)^2 - (\omega^i)^2(\partial_\mu\omega^i)^2\right) + \cdots \\ \omega^i\omega^j \to \omega^k\omega^l &\Longrightarrow \mathcal{A}^{ijkl}(s,t,u) = \text{Sym}\;\; \tilde{A}(s,t,u)\delta^{ij}\delta^{kl} \\ \tilde{A}(s,t,u) &= \frac{s}{v^2} \qquad \text{Weinberg LET} \end{aligned}$$

breaks for energies beyond $4\pi v$

The "chirally coupled" Higgs, composite Higgs

Chivukula and Koulovassilopoulos ('93,94)

FB+Chopin, '95

Grojean et al.

Coupling the Higgs X, to the chiral Lagrangian

$$\Sigma = exp(\frac{i\omega^i\tau^i}{v})$$

$$\mathcal{L}_{M,X} = \frac{1}{2}(\partial_\mu X)^2 - \frac{1}{2}M_X^2 X^2$$

$$+ \frac{v^2}{4}\mathrm{Tr}(\mathcal{D}^\mu\Sigma^\dagger\mathcal{D}_\mu\Sigma)\left(1+2a\frac{X}{v}+b\frac{X^2}{v^2}+\cdots\right) - Y_{ij}\overline{\psi}_L^i\Sigma\psi_R^j(1+c_{ij}\frac{X}{v}+\cdots)$$

$$- \frac{1}{2}M_X^2 X^2\frac{X}{v}\left(h_3+h_4\frac{X}{4v}\right)+\cdots$$

$$\text{for } X = H, \qquad a=b=c=1, \qquad h_3=h_4=1$$

Composite X better have $c_{ij}=c$ else FCNC

X Boson, Le Boson 2 X

Le Monde diplomatique – Septembre 1991

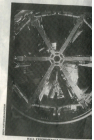
Supplément

Quelle recherche pour l'Europe ?

Des programmes en quête d'un nouveau souffle

Le troisième programme-cadre communautaire (1990-1994) de recherche et développement technologique, adopté après bien des difficultés, est le reflet des contradictions qui traversent la Commission et les Douze. Bien que significativement doté (5,7 milliards d'écus pour cinq ans, soit 4 % du total des budgets de recherche des Etats membres), il ne satisfait pleinement ni les néolibéraux – qui récusent un volontarisme technologique réputé perturber les « lois » du marché – ni les tenants d'une véritable politique industrielle européenne, qui, eux, déplorent les tergiversations dans les prises de décision politiques et la lourdeur des procédures administratives de Bruxelles.

Mais, au-delà des acquis indiscutables de ses programmes, en particulier la montée en puissance d'une véritable « identité européenne » chez les scientifiques et les ingénieurs, n'est-il pas grand temps, pour la Communauté, de cesser d'assigner à la recherche l'unique objectif de renforcer la compétitivité industrielle de l'Europe ? C'est, en effet, la notion même de compétitivité qui, si on l'étend à l'échelle d'une planète caractérisée par sa finitude (voir, page 32, l'article de Riccardo Petrella), mérite pour le moins examen. D'où la nécessité, pour une Europe qui ne limiterait pas son ambition à la conquête de marchés, de mettre également la recherche au service de nouvelles formes de solidarité mondiale centrées sur les besoins de l'homme. Et d'en faire un très grand projet, comme ceux dans lesquels elle est déjà engagée aux côtés des Etats-Unis et du Japon.



HALL EXPERIMENTAL DU CERN

Une présence affirmée dans les grands projets

Par HERVÉ LE TELLIER*

CLIMAT et environnement, sciences de la vie, grands instruments. Autant de grands programmes scientifiques qu'aucune nation ne peut mener seule. […]

humain. Son budget est de 15 milliards de dollars sur quinze ans, et, en 1991, 155 millions de dollars ont déjà été dégagés, dont plus de 30 pour les seuls aspects informatiques. En 1988, les Américains ont ouvert le pro- […]

en 1995. Pour 2 milliards de francs suisses, l'Europe devrait pouvoir « chasser » le boson 2x.

Face à cette reconquête, le projet américain de collisionneur proton-proton SSC doit faire […]

Chasser le boson

Les Japonais, de leur côté, y investissent 25 millions de dollars. […]

Favoriser l'émergence d'une industrie commune

Par CHRISTIAN DAMBRINE*

Fusionner les tokamaks

Décrypter le génome

Les Éditions de l'INED — INSTITUT NATIONAL D'ÉTUDES DÉMOGRAPHIQUES — *La collection des Congrès et Colloques*

(Lire la suite page 28.)

X Boson, Le Boson 2 X

...% financé
Japon), et de 120 millions
cs en 1991.
physique fondamentale,
peut néanmoins redres-
ête : « Nous avons mis
ans pour rattraper les
ins, pour former une
de physiciens, explique
Darriulat, directeur des
mes du CERN (1), et il
s question de refaire de
ue aux Etats-Unis. » Les
ntermédiaires W+, W-,
nt valu aux Européens
Nobel, ont en effet été
ts dans le tunnel de
etres de circonférence
au CERN, en 1983. Le
eur de la prochaine
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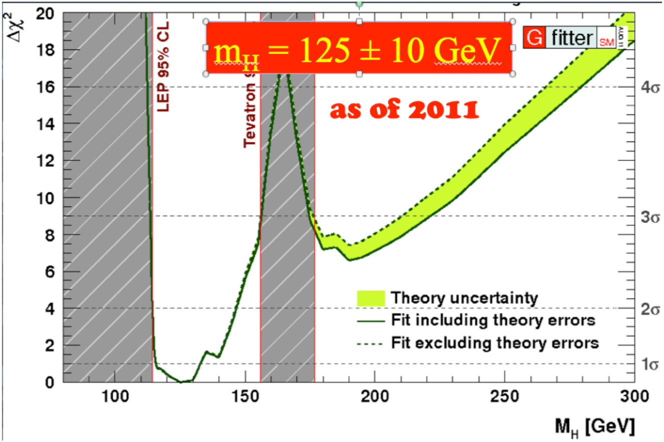
More implementations, *X* as pseudo-scalars and other dynamics

- $SO(5)/SO(4) \to 4\mathrm{PGB} : \omega^{\pm}, \omega^3, H$ Agashe,Contino,Pomarol
- 5PGB + H,A, Gripaiois, Pomarol,Riva, Serra '09
- ...
- more dynamics? updated walking technicolour (X+dilaton, resonances, 60(!) PGB): Bando, Kamawaki, Ken Lane and friends,...

Beware of Indirect limits (M_H, S, T, U)



X-Couplings to watch for

-Possible from X_{125} fits? -Indirectly? -Other manifestations, new particles?

Reconstructing the SM from Unitarity Arguments: Probability is always < 1

For QED the cross section $e^+e^- \to \mu^+\mu^-$ behaves as

$$\sigma \propto \alpha^2/s \quad \left(\mathcal{L}_{\text{eff.}} = -\frac{e^2}{2}\frac{J_\mu^{em}(e^+,e^-)J_\mu^{em}(\mu^+,\mu^-)}{k^2}\right)$$

decreases as the energy decreases.
Probability, $\mathcal{P}$, to produce muons is $\mathcal{P} < 1$ and decreases with energy

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But $\mathcal{P} < 1$, unitarity must be preserved.

This means something must happen at some energy to restore $\mathcal{P} < 1$

or theory not good!

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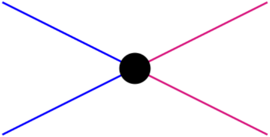
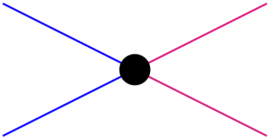


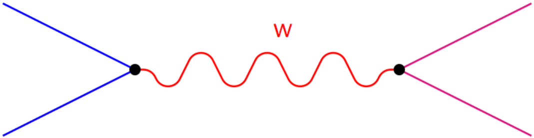
Fermi Contact interaction

Reconstructing the SM from Unitarity Arguments

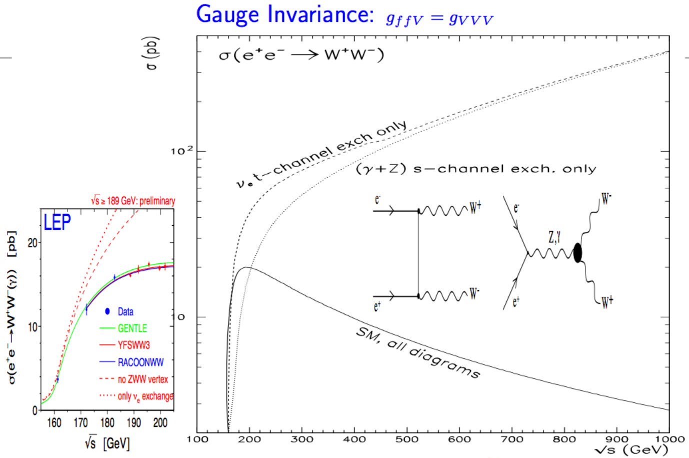


Fermi Contact interaction

Where is the underlying fundamental interaction?



Unitarity and the Higgs:

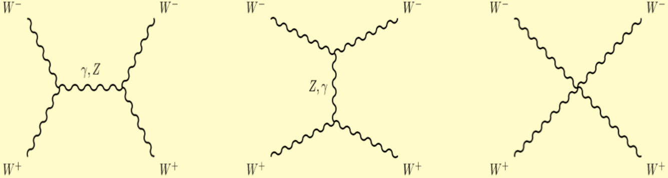


- LEP legacy: We know that WWV can not deviate too much (10%) from SM gauge value.
- But slightest deviations are revealed at higher energies (LHC?)

Unitarity and the Higgs

Self-couplings: the Higgs and Symmetry Breaking Connection

$W_L^+ W_L^- \rightarrow W_L^+ W_L^-$ *Without Higgs*



If $g_{VVVV} \neq g^2_{VVV} \Longrightarrow \mathcal{M}_{LLLL} \propto E_W^4$

In the SM $\mathcal{M}_{LLLL} \sim \sqrt{2} G_F u \propto E_W^2$

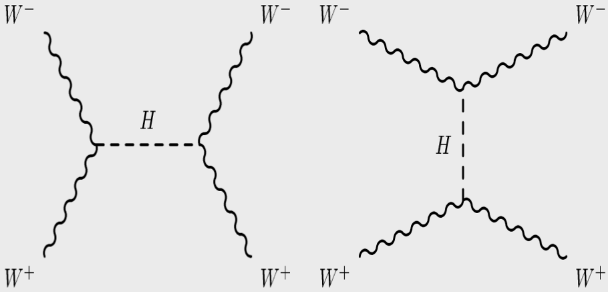
Unitarity without Higgs requires $\sqrt{s_{WW}} \leq 1.2\mathrm{TeV}$

Slight departure of the vector bosons self-couplings from SM values is enhanced at high energies

Delayed Unitarity, High energy high luminosity LHC

Higgs and Delayed Unitarity

Higgs in SM



$$\mathcal{M}_{LLLL} \sim -\sqrt{2} G_F M_H^2 \left(\frac{s}{s - M_H^2} + \frac{t}{t - M_H^2} \right)$$

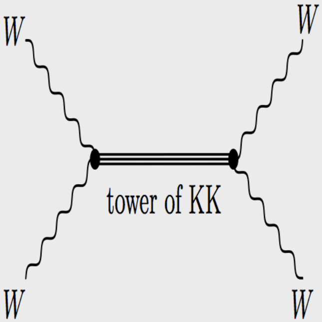
Unitarity implies $M_H \leq \frac{4\pi\sqrt{2}}{3 G_F} \sim 700\mathrm{GeV}$

- expect some collective modes to effectively affect the self-interaction of the gauge bosons
- watch out for the longitudinal modes

Example of Extra-dim

Higgs and Delayed Unitarity

Extra-dim with special boundary cdts



Unitarity is delayed up to a few TeV

cancellation from underlying

5-d gauge symmetry.

The Chiral Higgs

$$W^+W^- \to W^+W^- \Longrightarrow \mathcal{A} = \frac{1}{v^2}\left(s - \frac{a^2 s^2}{s - M_X^2}\right) \to a = \pm 1$$

The Chiral Higgs

$$W^+W^- \to t\bar{t} \Longrightarrow ac = 1$$

The Chiral Higgs

$$W^+W^- \to XX \Longrightarrow b = a^2$$

The potential: Stability up to which scale

the Higgs boson self-coupling $\lambda = M_H^2/2v^2$

$$\lambda = M_H^2/2v^2 = 0.118(M_H = 125GeV) \quad \lambda^2/4\pi \sim 1/900 \ll \alpha_{\rm em}$$

$$\lambda = M_H^2/2v^2 = 4.9(M_H = 800GeV).$$

$$\lambda > 0.$$

Behaviour of $\lambda(Q^2)$?

Running of couplings in the SM

At M_Z $g_i = \{0.46, 0.65, 1.2\}$

$$
\begin{aligned}
g_1 &= \sqrt{\frac{5}{3}}\frac{\sqrt{4\pi\alpha(m_Z)}}{\cos\theta_W} \simeq 0.46 \\
g_2 &= \frac{\sqrt{4\pi\alpha(m_Z)}}{\sin\theta_W} \simeq 0.65 \\
g_3 &= g_s = \sqrt{4\pi\alpha_3(m_Z)} \simeq 1.2
\end{aligned}
$$

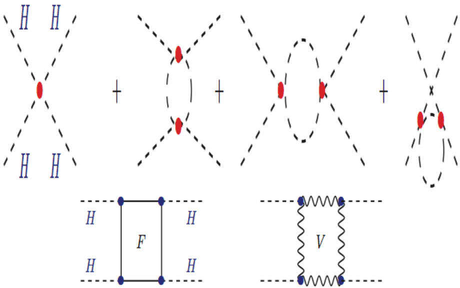
the top Yukawa coupling $y_t = \sqrt{2}m_t/v \simeq 1$,

$$
\begin{aligned}
\frac{dg_1}{dt} &= \frac{41}{10}\frac{g_1^3}{16\pi^2}, \quad \frac{dg_2}{dt} = -\frac{19}{6}\frac{g_2^3}{16\pi^2}, \quad \frac{dg_3}{dt} = -7\frac{g_3^3}{16\pi^2} \\
\frac{dy_t}{dt} &= \frac{y_t}{16\pi^2}\left(-\frac{17}{20}g_1^2 - \frac{9}{4}g_2^2 - 8g_s^2 + \frac{9}{2}y_t^2\right)
\end{aligned}
$$

$$
t \equiv \ln(Q/Q_0)
$$

Running of the quartic coupling (one-loop)

$$\frac{d\lambda}{dt} = \frac{1}{16\pi^2}\Big\{ +24\lambda^2 - \lambda\left(\frac{9}{5}g_1^2 + 9g_2^2 + 12y_t^2\right) - 6y_t^4 + \frac{9}{8}\left(\frac{3}{25}g_1^4 + \frac{2}{5}g_1^2 g_2^2 + g_2^4\right)\Big\}$$



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$+ \Rightarrow$ Coupling will increase until very large values and will no longer be perturbative.

$+ \Rightarrow$ like with em coupling, breaks at the Landau pole, Q_{LP}

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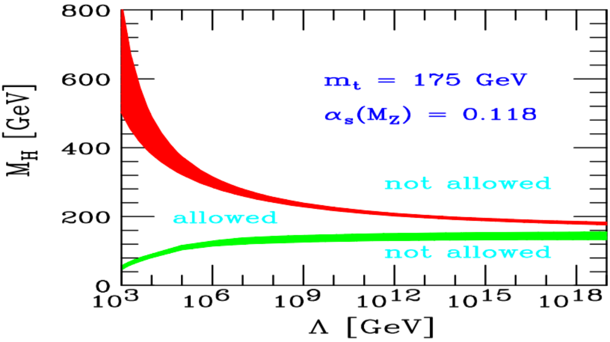
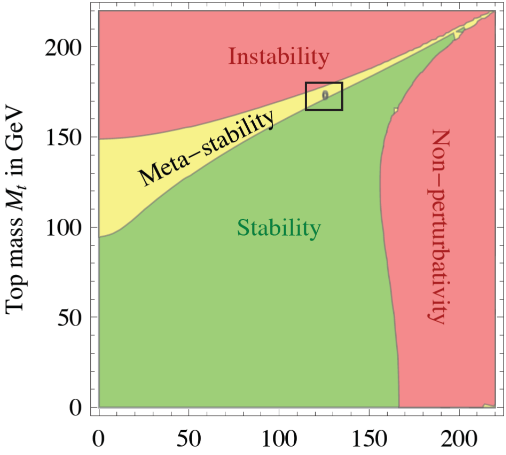
– ⇒ Coupling will decrease and may turn negative!

– ⇒ the Higgs potential will be unbounded from below: vacuum is no longer stable

Stability and Perturbativity



Stability: The Miracle (Strumia et al.,), 2loop,..



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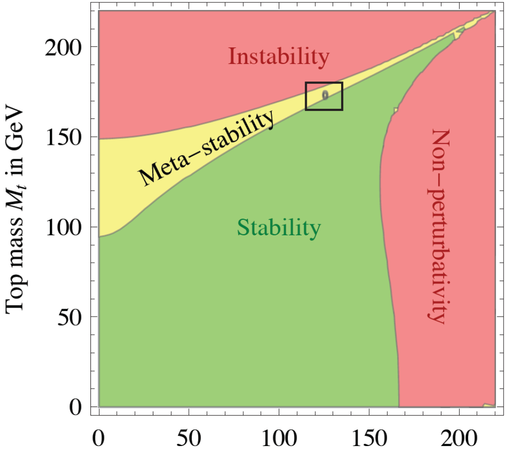

some new physics contribution could easily move us to a stable region

m_t essential (which m_t?)

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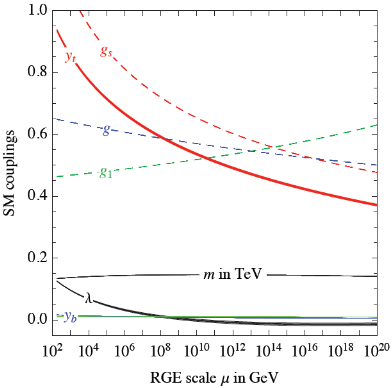

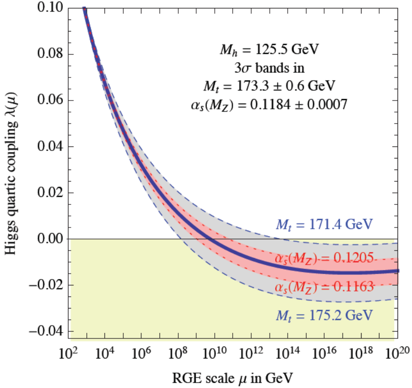

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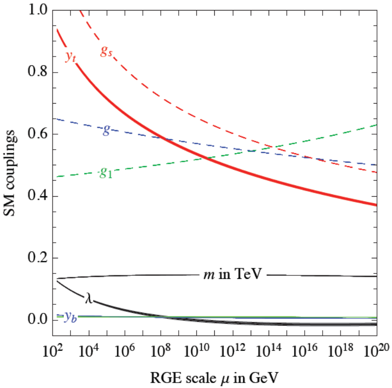
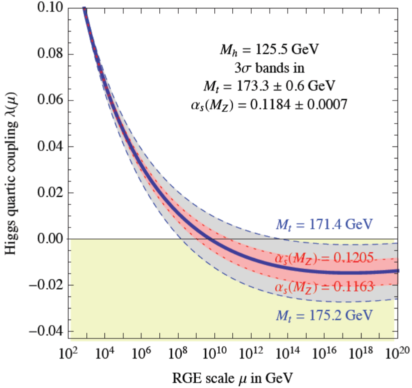
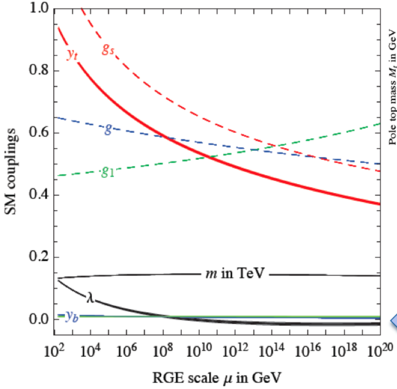
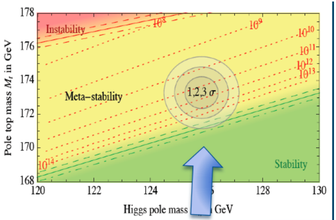




some new physics contribution could easily move us to a stable region and perhaps give gauge coupling unification

Vanishing of λ and its β function?

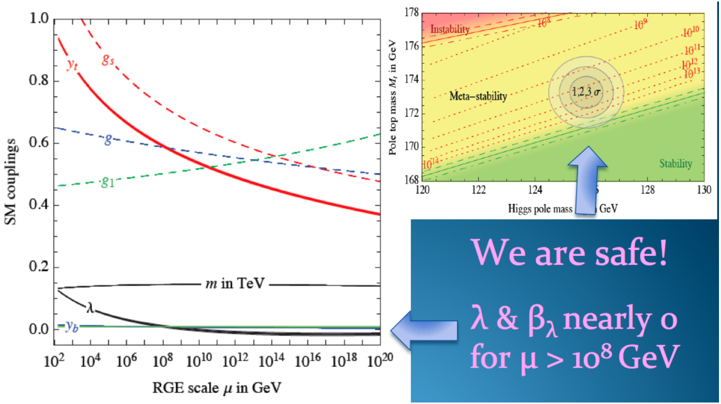




We are safe!

λ & β_λ nearly o for $\mu > 10^8$ GeV

Vanishing of λ and its β function?



Is there any meaning in this? M_h *vs* Planck Scale. Not to me. Let alone that λ and β_λ vanish over a wide range, starting from $\mu > 10^8$GeV.

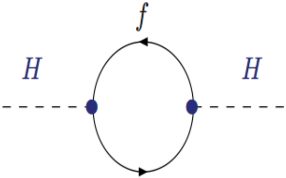
Reconstruct the Higgs potential, or part of it

- Measure H^3 at LHC???
- Through double Higgs production
- Can not rely on total rate. Too uncertain
- "spin 0" nature of $H^\star \to HH$ (FB +Chopin 95) to pin-down the H^3 coupling

The trouble with the SM Higgs: $\Lambda\phi^2$

why is then $M_H \ll \Lambda$

Unnaturalness and fine-tuning



Take a fermion f with Yukawa coupling $\lambda_f = \sqrt{2} m_f / v$. (Assume for simplicity that the fermion is very heavy so that one can neglect the external Higgs momentum)

$$\Delta M_H^2 = \frac{\lambda_f^2}{8\pi^2}\left[-\Lambda^2 + 6 m_f^2 \log\frac{\Lambda}{m_f} - 2 m_f^2 \right] + \mathcal{O}(1/\Lambda^2)$$

$$\Delta M_H^2 \propto \Lambda^2$$

if $\Lambda = \Lambda_P$ tuning of contributions at the level of 30 digits

Calls for BSM

What is problematic about the Higgs in the SM:
A pathological description: why $M_H < 1TeV$??

at one-loop:

Spin-1, Local gauge symmetry (Current is conserved, locally)

$$\mathbf{M}^2_\gamma = M^2_{\gamma,0} = 0$$

Spin-1/2, Chiral symtrie (global)

$$\mathbf{m_e = m_e^0 \left(1 + \frac{3}{2}\frac{\alpha}{\pi}\log(\Lambda^2/m_e^2)\right) \quad \Lambda = \Lambda_P \Longrightarrow \delta_m \sim 30\%}$$

Spin-0, a lone spin-0 has no symmetry

$$\mathbf{M_H^2 - M_{H,0}^2 \sim \frac{\alpha}{\pi}\Lambda^2}$$

Fine-tuning, hierarchy problem

Ways beyond the SM Higgs

The New Physics must explain why:

$$\mathbf{M_H} \,, \quad \ll \quad \mathbf{\Lambda}_{\text{Planck}}$$

3 Solutions

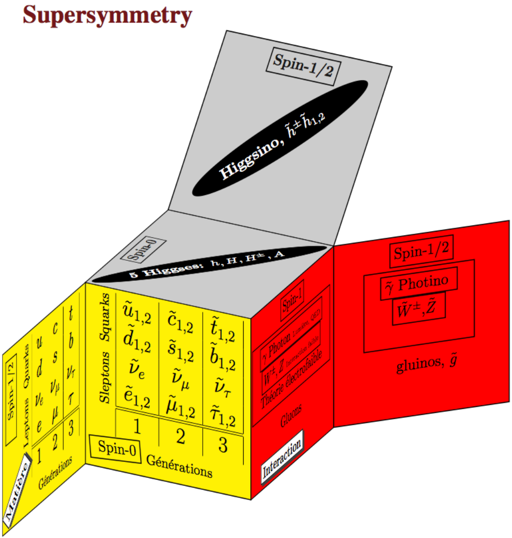
- Higgsless models (equality has no sense, a term M_H is missing
- $\Lambda \sim 1, 10, , , 100$TeV: Extra-Dimensions: Λ large or G_{Newton} small because gravity is diluted in a much larger space! , ,..
- $\ll$: symmetry=supersymmetry is one implementation

This argument certainly implies New Physics with New Particles

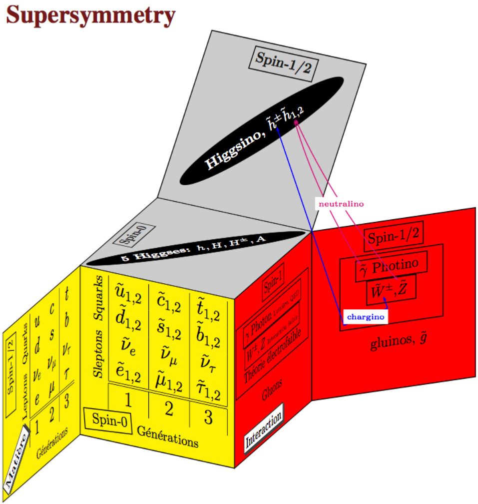
One of these particles: neutral and stable is a Dark Matter candidate: Higgs as a Portal

(new philopsophy: reject the fine-tuning argument, anthropic principle, ex: Tides)

Example of a weakly coupled solution: Supersymmetry



Supersymmetry and the Higgs



but the MSSM at the edge, too simple

Some already tested, not much is seen

Fits of couplings

- Rescaled SM couplings, no higher order operators

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  - this assumes this new particles must have been produced at higher rates

We may have been too naive: SUSY as an example

- SUSY provides nice solutions (Naturalness, DM,) but the MSSM may have been too simple and naive
- Supersymmetric Effective Approach: encapsulates effects from different implementations. Higgs is a very good window.
- Effective approach: what do we learn from discovering the first Higgs, h. Importance of accessing as many channels of h as possible
- Signatures depend not only on the different implementations but also on the role of the stops.
- The role of Higgsinos and naturalness
- What about the other Higgses, keep analyzing the data in a wide range of Higgs masses
- Flavour observables important: $B \to X_s \gamma^*$
- Direct Detection important

Higgs is incomplete, but will we know?

"Higgs = emergency tire of the SM"

Altarelli @ Blois'10

[picture courtesy to Andreas Weiler]

and Christophe Grojean

Surprise, surprise

Many surprises!