# Being Excited about The LHC Higgs Search

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LEPP Experiment/Theory Seminar, 28 Oct 2011

Cornell University

# The “must show” pictures

in the easy old times...

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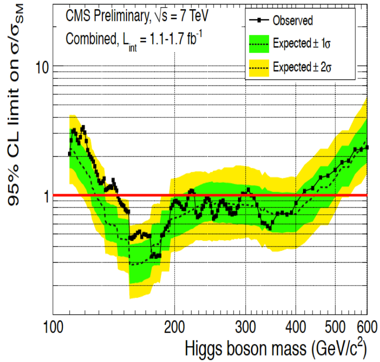
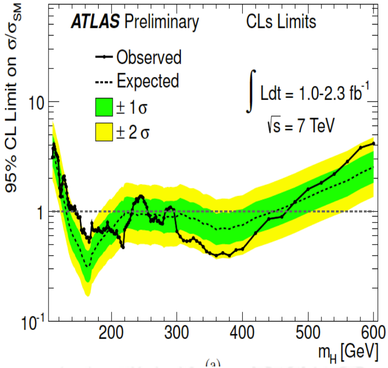
after the experimentalist friends push us so much...



# Look at the exclusion bounds

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We are forced to have a very light or heavy Higgs.

# Look at the exclusion bounds

**Are we doomed?**

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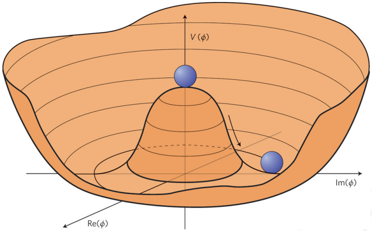
**No! We are not**

SM / MSSM prefer light ($\sim$ 120 GeV) Higgs.

# The jobs of Higgs

- Generates EW symmetry breaking, gives $M_W$ and $M_Z$
- Maintains the calculability in a higher energy scale
- Gives fermion masses



# The basic framework

## Higgs in the SM

$$\mathcal{L}_H = \frac{1}{2}(D_\mu H)^\dagger D^\mu H + \frac{1}{2}\mu^2 H^\dagger H - \frac{1}{4}\lambda(H^\dagger H)^2 + y\overline{\psi}_L H \psi_R$$

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$$H = \begin{pmatrix} w_1 + i\, w_2 \\ (h + v) + i\, w_3 \end{pmatrix}, \quad v = \sqrt{\frac{\mu^2}{\lambda}}, \quad M_h = \sqrt{2\lambda}\, v$$

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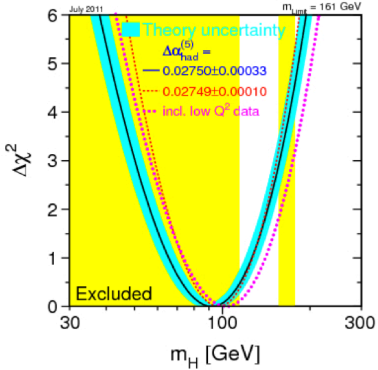
$$M_f = y_f \frac{v}{\sqrt{2}}$$

# Previous Experimental Constraints on $m_H$

By "Gfitter" (A Generic Fitter Project for HEP Model Testing)

- Indirect: Electroweak precision measurement by LEP and SLD
- Direct: CDF and D0

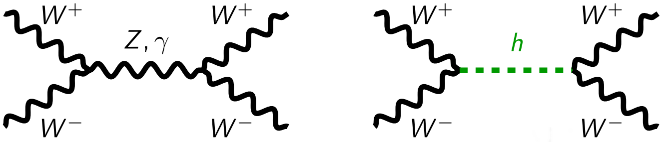


# The theory constraints on $m_H$

## The unitarity constraint

**Without the Higgs**

The EW sector becomes non-perturbative around TeV scale.




$$A(W_L^+ W_L^- \to W_L^+ W_L^-) = -\sqrt{2} G_F M_H{}^2 \left[ \frac{s}{s - M_H{}^2} + \frac{t}{t - M_h^2} \right]$$

Higgs needs to come in around 1 TeV, which means $M_H \lesssim 1$ TeV.

# The theory constraints on $m_H$

## The perturbativity and vacuum stability constraints

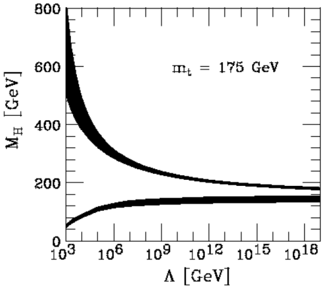
$$V(H) = -\frac{1}{2}\mu^2 H^\dagger H + \frac{1}{4}\lambda \left(H^\dagger H\right)^2, \qquad M_H^2 = 2\lambda\, v^2$$

one-loop correction of $\lambda$ :

$$\frac{d\,\lambda}{d\,\ln\mu} = 24\,\lambda^2 + 12\,\lambda\, {y_t}^2 - 6\,{y_t}^4 + \text{gauge contributions}$$

- $\lambda(v)$ too big $\rightarrow$ non-perturbative
- $\lambda(v)$ too small $\rightarrow$ no VEV
- Under control until $M_{\rm pl}$ :

  $130\ \mathrm{GeV} \lesssim \mathrm{M_H} \lesssim 180\ \mathrm{GeV}$



# Actually, can't really have $\Lambda \to M_{\rm pl}$ in SM

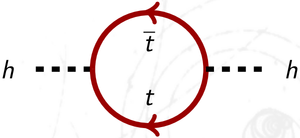
The naturalness of $m_H$ requires BSM physics

## Hierarchy Problem

New physics must come in $\sim$ TeV scale

$$M_H^2(v) = (M_H^2)_0 + \frac{kg^2}{16\pi^2}\Lambda^2$$

Many prominant ideas: SUSY, RS model, Little Higgs,...

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## Which also prefers light Higgs

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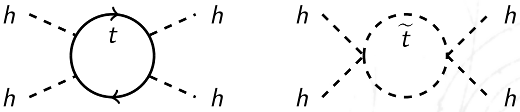
## Which also prefers light Higgs

- **Two Higgs doublet:** light and heavy Higgs
- **Hard to make the light Higgs heavy:**
  the $H^4$ term in the Higgs potential is proportional to the gauge coupling (from the D-term only)
- **The way out:** corrections from the (s)top loop

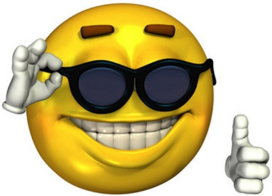



For perturbative $y_t$: $M_H \lesssim 130\,\text{GeV}$.

# So why remain optimistic?

**The LHC bounds move towards the expected $M_H$ region!**

- EWPM and CDF+D0: $114 < M_H < 156$ GeV
- Unitarity: $M_H \lesssim 1$ TeV
- Vacuum stability: $130 \lesssim M_H \lesssim 180$ GeV
- MSSM: $M_H \lesssim 130$ GeV



# How about if we don't see Higgs at LHC?

**This will be very interesting!**

There are two possibilities:

- The currently expected decay channels are NOT dominant:
  e.g. Buried Higgs
- Other stuff generates the masses and preserves the unitarity:
  Higgsless models

# Buried Higgs

B. Bellazzini, C. Csaki, A. Falkowski, and A. Weiler (09)

**As have discussed before**

SUSY prefers Higgs lighter than the LEP bound (114 GeV)

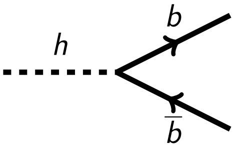
Ok, let's have it!

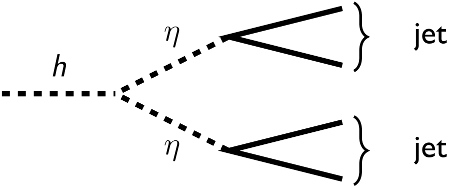
## In the buried Higgs model:

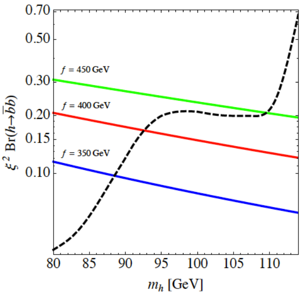
- Higgs is a pseudo-Goldstone boson from a global symmetry breaking.
- There is an even lighter pGB $\eta$ coupling to Higgs.
- $\eta$ mainly decays to gluon though a fermion loop.

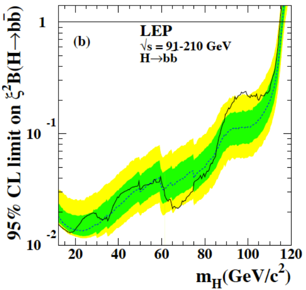
# Buried Higgs

B. Bellazzini, C. Csaki, A. Falkowski, and A. Weiler (09)



# Higgsless model

Do NOT have Higgs in the theory, need some other physics to

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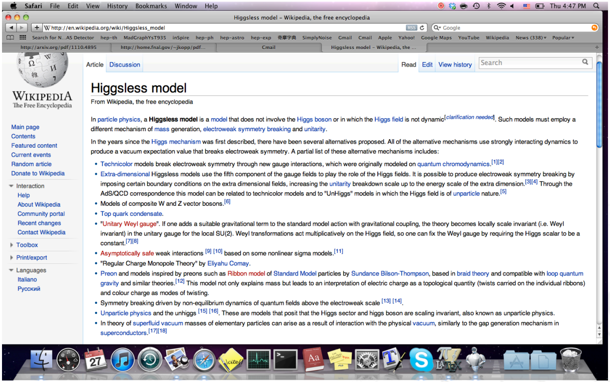


Higgsless model

From Wikipedia, the free encyclopedia

In particle physics, a **Higgsless model** is a model that does not involve the Higgs boson or in which the Higgs field is not dynamic[clarification needed]. Such models must employ a different mechanism of mass generation, electroweak symmetry breaking and unitarity.

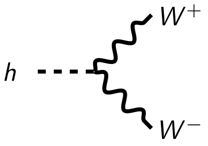
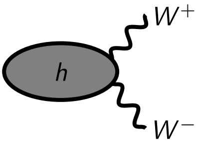
In the years since the Higgs mechanism was first described, there have been several alternatives proposed. All of the alternative mechanisms use strongly interacting dynamics to produce a vacuum expectation value that breaks electroweak symmetry. A partial list of these alternative mechanisms includes:

- Technicolor models break electroweak symmetry through new gauge interactions, which were originally modeled on quantum chromodynamics.[1][2]
- Extra-dimensional Higgsless models use the fifth component of the gauge fields to play the role of the Higgs fields. It is possible to produce electroweak symmetry breaking by imposing certain boundary conditions on the extra dimensional fields, increasing the unitarity breakdown scale up to the energy scale of the extra dimension.[3][4] Through the AdS/QCD correspondence this model can be related to technicolor models and to "UnHiggs" models in which the Higgs field is of unparticle nature.[5]
- Models of composite W and Z vector bosons.[6]
- Top quark condensate.
- "Unitary Weyl gauge". If one adds a suitable gravitational term to the standard model action with gravitational coupling, the theory becomes locally scale invariant (i.e. Weyl invariant) in the unitary gauge for the local SU(2). Weyl transformations act multiplicatively on the Higgs field, so one can fix the Weyl gauge by requiring the Higgs scalar to be a constant.[7][8]
- Asymptotically safe weak interactions [9] [10] based on some nonlinear sigma models.[11]
- "Regular Charge Monopole Theory" by Eliyahu Comay.
- Preon and models inspired by preons such as Ribbon model of Standard Model particles by Sundance Bilson-Thompson, based in braid theory and compatible with loop quantum gravity and similar theories.[12] This model not only explains mass but leads to an interpretation of electric charge as a topological quantity (twists carried on the individual ribbons) and colour charge as modes of twisting.
- Symmetry breaking driven by non-equilibrium dynamics of quantum fields above the electroweak scale [13] [14].
- Unparticle physics and the unhiggs [15] [16]. These are models that posit that the Higgs sector and higgs boson are scaling invariant, also known as unparticle physics.
- In theory of superfluid vacuum masses of elementary particles can arise as a result of interaction with the physical vacuum, similarly to the gap generation mechanism in superconductors.[17][18]

# Going from Higgs to Higgsless

The VEV and $M_H$ can be different:

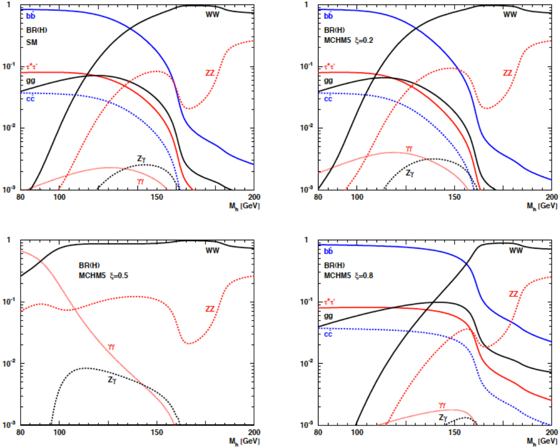
$$\xi \equiv \frac{v^2}{f^2}, \qquad v\text{: VEV,} \qquad f\text{: confinement scale in Higgs}$$

| $\xi = 0$ | $0 < \xi < 1$ | $\xi = 1$ |
|---|---|---|
| Fundamental Higgs | Composite Higgs | Technicolor (Higgsless) |
|   |   | No $h \to V\,V$ decay |
| $\Gamma^{SM}_{h\to VV}$ | $(1-\xi)\,\Gamma^{SM}_{h\to VV}$ | 0 |

# Go from Higgs to Higgsless

Take from J.R. Espinosa, C. Grogean and M. Muhlleitner (10)

Branching ratio for various $\xi$'s:




We may look at the wrong decay channels.

# Conclusion: The Theory Part

We're optimistic about the LHC Higgs search:

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- Even more interesting if the current searches don't see Higgs

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**So...**

What's the current status of the LHC Higgs search?