Being Excited about The LHC Higgs Search

Yuhsin Tsai

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Cornell University
The “must show” pictures
in the easy old times...
The “must show” pictures

in the easy old times...
The “must show” pictures
in the easy old times...
The “must show” pictures
after the experimentalist friends push us so much...

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Being excited about the LHC Higgs search
Look at the exclusion bounds

Are we doomed?

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

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Are we doomed?
We are forced to have a very light or heavy Higgs.

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

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

- VEV and the Higgs mass
- Gauge boson mass and unitarity
- Fermion masses
The basic framework

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

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The basic framework

Higgs in the SM

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- VEV and the Higgs mass
- Gauge boson mass and unitarity
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\[ M_f = y_f \frac{\nu}{\sqrt{2}} \]
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.

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

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

$$V(H) = -\frac{1}{2} \mu^2 H^\dagger H + \frac{1}{4} \lambda (H^\dagger H)^2, \quad M_H^2 = 2\lambda \nu^2$$

one-loop correction of $\lambda$:

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

- $\lambda(\nu)$ too big $\rightarrow$ non-perturbative
- $\lambda(\nu)$ too small $\rightarrow$ no VEV
- Under control until $M_{pl}$:
  $$130 \text{ GeV} \lesssim M_H \lesssim 180 \text{ GeV}$$
Actually, can’t really have $\Lambda \rightarrow M_{\text{pl}}$ in SM

The naturalness of $m_H$ requires BSM physics

**Hierarchy Problem**

New physics must come in $\sim$ TeV scale

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

Many prominent ideas: SUSY, RS model, Little Higgs,...
The MSSM constraint on $m_H$
Which also prefers light Higgs

- **Two Higgs doublet:** light and heavy Higgs
The MSSM constraint on $m_H$

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- **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 MSSM constraint on $m_H$

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 $y_t$: $M_H \lesssim 130$ 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)

![Diagram of Higgs decays](image)

- $h \rightarrow b\bar{b}$
- $h \rightarrow \eta \{ \text{jet} \}$
- $h \rightarrow \eta \{ \text{jet} \}$

Graphs showing:

1. $\xi^2 \text{Br}(h \rightarrow b\bar{b})$ vs. $m_h$ [GeV] with lines for $f = 450, 400, 350$ GeV.
2. 95% CL limit on $\xi^2 \text{Br}(H \rightarrow b\bar{b})$ vs. $m_H$ (GeV/c^2) for LEP with $\sqrt{s} = 91-210$ GeV.
Higgsless model

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

- break EW symmetry
- fix the unitarity
- generate mass
Higgsless model

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Going from Higgs to Higgsless

The VEV and $M_H$ can be different:

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

<table>
<thead>
<tr>
<th>$\xi$</th>
<th>Fundamental Higgs</th>
<th>Composite Higgs</th>
<th>Technicolor (Higgsless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\xi = 0$</td>
<td>$h \rightarrow W^+ W^-$</td>
<td>$h \rightarrow W^+ W^-$</td>
<td>No $h \rightarrow VV$ decay</td>
</tr>
<tr>
<td>$0 &lt; \xi &lt; 1$</td>
<td>$\Gamma_{h \rightarrow VV}^{SM}$</td>
<td>$(1 - \xi) \Gamma_{h \rightarrow VV}^{SM}$</td>
<td>$0$</td>
</tr>
<tr>
<td>$\xi = 1$</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

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Being excited about the LHC Higgs search
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:

- Many clues for light Higgs in SM / MSSM
- 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?