Higgs

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Higgsteria

How the field feels about the potential Higgs discovery

Replace “trapped antimatter” with “discovered Higgs”
Let me spend a few slides trying to emphasize why this is so interesting
Jim’s talk showed we know a lot about the Standard Model, but that the Higgs is still to be confirmed.

Let me try to address the question: What is so special about finding the Higgs?
Standard Answer: It is a key to determining how W/Z gauge bosons get mass or in more technical terms the mechanism which breaks electroweak symmetry
Short intro to gauge theories

Gauge theories describe interactions mediated by spin-1 bosons (gauge bosons)

examples
  E&M (photon)
  Weak Interactions (W,Z)
  Strong Interactions (gluons)
Gauge symmetries

Gauge theories have symmetries which forbid a mass for the gauge boson so having mass $\Leftrightarrow$ breaking symmetry

For E&M (or QED), for the symmetry, you can think of this as a complex phase dependent on charge

$$e^- \rightarrow e^{iqe\alpha} e^-$$
Familiar in Materials

Photons in free space move at speed of light

In material, light moves slower due to absorption and reemission by atoms

This gives the photon an effective mass in the material
Mass in a Vacuum

Photon could be given a mass if scalar with charge gets a vacuum expectation value (vev)

This is a Lorentz-invariant ether which slows down photons
More masses

In Standard Model, all fundamental particles get mass from Higgs vev

Heavier things get larger mass by interacting more frequently
So what?

Symmetry breaking where a gauge boson gets a mass isn’t something new

In fact, superconductivity is a well known example and serves as a good analogy of why the Higgs is special
Superconductivity

Cooper pairs

Due to interactions in superconductor quasiparticles of electron pairs form with charge -2 and spin 0
In a superconductor, Cooper pairs get a vev giving the photon a mass inside of it explaining Meissner effect (magnetic field exclusion) Flux quantitization Zero resistance
Meissner Effect = Short Range Force

Massless photon
has a coulomb potential

$$V \propto \frac{1}{r}$$

Massive photon
has a Yukawa potential

$$V \propto \frac{1}{r} e^{-m\gamma r}$$

This makes magnetic fields in superconductor
go to zero deep inside of it
## Comparison

<table>
<thead>
<tr>
<th>Superconductivity</th>
<th>Standard Model Higgs</th>
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<tbody>
<tr>
<td>Quasiparticle gets vev</td>
<td>Fundamental Scalar gets vev?</td>
</tr>
<tr>
<td>Special materials in specific conditions (e.g. low Temp)</td>
<td>Applies in vacuum in low temperature universe</td>
</tr>
<tr>
<td>Simple Gauge Theory</td>
<td>Complex Gauge Theory</td>
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Hierarchy Problem

This is a theoretical argument that a Standard Model Higgs and nothing else is extremely unlikely.

Incredibly important in particle theory as it has motivated most of the theories proposed to extend the Standard Model.

However, it could be wrong...
Higgs Potential

\[ V(\phi) = m^2 |\phi|^2 + \lambda |\phi|^4 \]

If \( m^2 < 0 \), origin is unstable leading to a vev

\[ < |\phi|^2 > = \frac{-m^2}{\lambda} \]

Original symmetry was rotation of \( \phi \) by a phase, but vev has to choose a certain phase, breaking symmetry
Superconductor Temperature Phase Transition

\[ V(\phi) = m^2|\phi|^2 + \lambda|\phi|^4 \]

As one turns down the temperature, one finds that goes \( m^2 \) negative

\[ m^2 = c(T - T_c) \]

In practice, we can make the material superconducting by cooling it down to \( T < T_c \)
Hierarchy Problem

If it just, the Standard Model with a Higgs, what is the natural scale for EWSB?

Using dimensional analysis is a disaster!

Only relevant scale is Planck scale which much much larger!

\[ m_{\text{Planck}} = 10^{19} \text{ GeV} \]

\[ m_W \sim 100 \text{ GeV} \]
Hierarchy Problem

\[ m^2 = c_1 m^2_{\text{Planck}} + c_2 m^2_{\text{Planck}} \]

Can tune two values to get observed

\[ c_1 = c_2 (-1 + 10^{-36}) \]

Equivalent to tuning temperature of superconductor to

\[ T = T_c (1 - 10^{-36}) \]

An incredibly tuned value! Higgs would much rather be a “high T_c” superconductor
We are faced with this issue, because higher order corrections to this parameter are sensitive to the Planck scale.

\[
\delta m^2 = - \left( \frac{m_t}{m_W} \right)^2 m_{Planck}^2
\]

Choose \( m^2 \) to get right value

Solving this need for tuning is what motivates supersymmetry, large extra dimensions, technicolor.
Higgs is actually radical!

Would be first fundamental scalar in nature

Without anything else, theory requires an incredible fine-tuning

(This is fine in superconductors, but in vacuum?)

(We know God does play dice, but does God dial knobs?)
It also isn’t the simplest

Without Higgs, strong interactions would break electroweak symmetry

Strong interactions get strong at 1 GeV, confining quarks into hadrons

This also breaks electroweak symmetry giving a mass to $W$ of 30 MeV
It has happened before

Standard Model is not creative in its matter content

Generations are just replicated version of higher mass

Simplest way to get EWSB is to have a copy of strong interactions technicolor

It should get strong at a higher energy to get W mass

Has been disfavored by fits to precision data
I’ve tried to highlight why the Higgs is exciting by arguing that it is an extremely radical idea.

It tests our scientific priors of naturalness and minimality.

Let’s look ahead to see how the story will unfold in the future.
Higgs Outline

- Is there a Higgs?
  - Yes!
  - No!
- Is the Higgs Fundamental?
  - Yes!
  - No!
- Is there supersymmetry?
- Is EWSB due to technicolor?
  - Yes!
  - No!
- Is it a composite particle?
Long road ahead

First, find the Higgs and then measure its interactions with the Standard Model

Along the way, find what else is in the TeV scale (supersymmetry, extra dimensions, technicolor, something yet to be proposed)