The Higgs mechanism is the heart of the Standard Model:

- Provides masses to W and Z by breaking electroweak symmetry.
- Implies existence of a single neutral scalar.
- Gives masses to all other particles (fermions).

"The" Higgs boson is the only undiscovered piece of the Standard Model.

If no Higgs, there must be something else to control large divergences that are controlled by Higgs (non-unitarity).
The BEH Mechanism & the Quest for the Scalar Higgs Potential

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961/11/61</td>
<td>CFS Quarterly CR: Higgs and Twin Higgs</td>
</tr>
<tr>
<td>1961/08/01</td>
<td>Phys. Rev. Lett. 18 (1967)</td>
</tr>
</tbody>
</table>

Higgs vacuum expectation value (vev)

\[ \langle 0 \rangle = \frac{\Lambda}{\sqrt{2}} \]

\[ 0 = \langle \phi \rangle = 0 \]

\[ 0 > m^2 \]

\[ 0 < m^2 \]
We don't know which minimum is chosen.

Higgs Field in the SM

No difference between u and d quarks.
No difference between electron and neutrino.
Perfect symmetry

At point O, bulk, very unstable

Our world

Symmetric Higgs Potential: We don't know which one, A or B, is chosen. But once one of two states is chosen, the state is no longer symmetric.
Higgs Interaction

Electron field
Muon field

Electromagnetic field + electron field [propagation of EM force]

Fundamental Interaction

Electromagnetic field + electron field [propagation of EM force]

Higgs field’s vacuum expectation is non-zero everywhere in the universe. Higgs field can “interact” with particles in the universe. Higgs field gives masses to all other particles (fermions).
SUSY is:

a) Supersymmetrized Standard Model ("Democratic" solution between Fermions and Bosons);

b) An elegant solution to solve the problem associated with the Higgs mass around 1 TeV;

c) Beautifully connecting the Standard Model with an ultimate unification of the fundamental interactions around 1 TeV;

d) Cosmologically consistent with a Dark Matter candidate – stable neutralino.

e) There must be a light Higgs boson below ~150 GeV.
SUSY is:

- Supersymmetrized Standard Model ("Democratic" solution between Fermions and Bosons);
- An elegant solution to solve the problem associated with the Higgs mass around 1 TeV;
- Beautifully connecting the Standard Model with an ultimate unification of the fundamental interactions around 1 TeV;
- Cosmologically consistent with a Dark Matter candidate around 1 TeV;
- Discovery of a Higgs-like boson: ~125 GeV;
Dark Matter Interactions

Standard Model, SUSY/Higgs & Cosmology
Minimal Supergravity (mSUGRA)

- $m_0$ (spin 0)
- $m_{1/2}$ (spin 1/2)

(We choose $\mu > 0$ and $A_0 = 0$ for simplicity)

$	an\beta = \frac{\Delta H_u}{\Delta H_d}$ at $M_Z$

$A_0 = \text{Trilinear coupling at } M_{	ext{GUT}}$

$m_{1/2} = \text{Common gaugino mass at } M_{	ext{GUT}}$

$m_0 = \text{Common scalar mass at } M_{	ext{GUT}}$

$\text{sign}(\mu) = \text{sign of } \mu in \mu H_u H_d$

In $2$ Higgs Doublet + Supersymmetrized Standard Model + Universality

Minimal Supergravity (mSUGRA)
Group Higgs couplings into "vectorial" and "fermionic" sets. Attach a modifier to the SM prediction to each of those ($c^V$ and $c^F$).

Use LO theoretical prediction for loop-induced $H \rightarrow VV$, $H \rightarrow /g74/g74$ couplings.

In agreement with the SM within the 95% confidence range within the 95% confidence range.

Solid contour: 68% CL

Dashed contour: 95% CL

Solid contour: 95% CL

Dashed contour: 68% CL

Need more data!
Production and decay rates could be deviated from the SM expectation through SUSY particles in loop-induced processes.

See, for example, Howard, Baer, Mustafayev, "Neutrino (Higgsino) LSP and neutralinos below 200 GeV, with mass splittings of order 10 GeV: It is very difficult for LHC to observe these lightest SUSY particles.

Higgsino LSP, charginos and neutralinos.

[Lightest SUSY Particles]

Mixed higgsino-axion DM

Mixed bino-axion DM

Flavor DM

Mixed higgsino-axion DM


What I am hearing are...

Marcela Carena, SUSY 2012
Pheno #11: Stop with M3

Pheno #10: Stop with M3
My advisor, Kunitaka Kondo, was smiling and exciting, saying "Kamon-kun, there is an interesting theory." It was "Supersymmetry." In the 1980s, Supersymmetry at Snowmass Workshop, there was Supersymmetry theory. It was an interesting and exciting theory. By October 1986: First p-pbar collisions at 1.6 TeV. Supersymmetry papers (1982).
My theory colleagues, R. Arnowitt and D. Nanopoulos, suggested to search for “tri-lepton” events at the Tevatron. My first SUSY analysis at CDF was cancelled (’93) → TRIPLER (’94) → Tripler (’01). March 1995: Discovery of top quark. SSC was cancelled (’93) → Tevatron (’94) → Tripler (’01). My first SUSY analysis at CDF (’99). Possible indication of grand unification with MSSM based on LEP data. 

Possible indication of grand unification with MSSM based on LEP data.

Possible indication of grand unification with MSSM based on LEP data.

Possible indication of grand unification with MSSM based on LEP data.

Possible indication of grand unification with MSSM based on LEP data.
My theory colleagues, R. Arnowitt and B. Dutta.

**Selected References**

- R. Arnowitt and B. Dutta, suggested (i) B -+ H search at the Tevatron (2002); (ii) stau-neutralino coannihilation search at the LHC (2005).
- WMAP results (2002) \( \Omega_{W0} = 23\% \)
- Pheno papers (2002, 2006, ...)
- Interconnection between Particle Physics and Cosmology.
- December 2005: Joined CMS
The maximum gluino and 1st- and 2nd-squark masses are excluded by current LHC limits are ~1.5 TeV.

Long-Term Planning

I hope we see any sign of SUSY before I retire...

2020 and Beyond