Beyond the Standard Model

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Lecture 2

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What do we learn from $m_H = 125-126$ GeV?

Do we live on the verge of a cosmic catastrophe?

When the universe was $10^{-10}$ second old, it underwent a phase transition.

Is a new phase transition going to happen?
Extrapolate the SM up to very high energies

\[ V = \frac{\lambda}{4} \left( |h|^2 - v^2 \right)^2 \]

- Higgs mass
- Top quark mass
- Quantum tunneling
- Thermal tunneling
We seem to live near a critical condition.
What do we learn from measuring the Higgs couplings?

$m_h = 125.5$ GeV
Discovering the Higgs is not *just* finding a new particle: it is unveiling a fundamental element of nature’s scheme

- GR & YM are elegant structures dictated by symmetry, have few free parameters, and fare marvelously with exp. data
- The Higgs sector looks like a provisional structure

⇒ the LHC may find surprises
Sensitivity to quantum fluctuations

\[ M_Z \propto \frac{\Lambda}{4\pi} \]

No separation of scales: why \( M_Z << M_{Pl} \) \((G_N << G_F)\)?
Having $M_Z << M_{Pl}$ requires tuning up to 34$^{th}$ digit.

Poising a pencil as long as the solar system on a tip 0.1 mm wide!
The “stability” of the hierarchy $M_Z / M_{Pl}$ requires an explanation.

Higgs is “screened” at energies larger than TeV $\Rightarrow$ new forces and new particles within LHC energy range.

What is the new phenomenon? Enter pure speculation…

These speculations created remarkable conceptual discoveries.
Some of the new ideas about naturalness and EW breaking revolutionize our concepts of space-time, matter and forces.

Supersymmetry emerges from the search for new space-time symmetries.

The new coordinates have a quantum character and cannot be described by ordinary numbers.
\[ \theta \times \eta = -\eta \times \theta \implies \theta^2 = 0 \]

\[ \text{SUSY} \times \text{SUSY} = \text{Translation} \]
Taylor expansion of superfields:

\[ \varphi(x, \theta) = \sum_{n} \varphi_{n}(x) \theta^{n} = \varphi_{0}(x) + \varphi_{1}(x) \theta \]

What is the physical meaning of superspace?

This new space has unfamiliar geometric properties (but it is mathematically consistent)

Fields: \( \psi(x) \) \( \rightarrow \) particles
What happens to particles propagating in superspace? Superparticle!

Superparticle

Supersymmetry
particle spin $S$
particle spin $S+1/2$

Special relativity & quantum mechanics
particle charge $Q$
antiparticle charge $-Q$

4-d space

superspace

superparticle

boson
(integer spin)

fermion
(half-integer spin)