Recent Discovery of Higgs Boson

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Goddamn Particle ---- Leon Lederman

Very important discovery in particle physics

Last of crucial piece of the jigsaw puzzle of standard model

(Theory of evolution in biology)
Plan of the talk

1. Pre-Standard Model
2. Standard Model
3. Why is Higgs particle so crucial?
4. How was it discovered?
5. What Next?
Excitation Energies

1 eV = 1.6 x 10^{-12} erg

1 MeV = 10^6 eV

1 GeV = 10^9 eV = 10^3 MeV

1 TeV = 10^3 GeV = 10^6 MeV
Past picture:

Democritus (400 BC):
Gave the word “atom”
In Greek it means “indivisible”

Dalton: Father of modern atomic theory
“All atoms of a particular element are identical”

Mendeleev: Periodic Table

Rutherford: α \( (2p + 2n) \) + Gold foil (nuclei)
Large angle scattering
Are $p$ and $n$ the smallest constituents?

50s and 60s: Subatomic Zoo
$\Pi$, $K$, $\Lambda$, $\Sigma$,..... Discovered

SLAC (1969):
$e^- + p \rightarrow e^- + \text{anything}$
Experiment similar to the Rutherford Expt.

$\alpha + \text{Gold file} \rightarrow \text{large angle scattering}$

$p$ and $n$ made of quarks

$p = u + u + d$
$n = d + d + u$

$u, \ d, \ e^{-}, \ \gamma$ our world
Basic Constituents of matter (as of Today)

<table>
<thead>
<tr>
<th>Quarks</th>
<th>Leptons</th>
</tr>
</thead>
<tbody>
<tr>
<td>(u,d)</td>
<td>(ν_e, e_-)</td>
</tr>
<tr>
<td>(c,s)</td>
<td>(ν_μ, μ_-)</td>
</tr>
<tr>
<td>(t,b)</td>
<td>(ν_τ, τ^-)</td>
</tr>
</tbody>
</table>

ν_e ...... Electron Neutrino

+ anti-particles (e^+ (positron), u ....) (same mass, opposite charge)

In our life time we have discovered one new layer of matter
Important point:

Quarks are permanently jailed inside p and n

One can not isolate a free quark.

Disturbing thought:

Basic constituents yet confined!

Clay Math Institute ➔
One million dollar prize for quark confinement
### Basic Interactions of Nature

<table>
<thead>
<tr>
<th>Force</th>
<th>Range</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Strong</strong></td>
<td>$\sim 10^{-15}$ m</td>
<td>$\sim 1$</td>
</tr>
<tr>
<td>(nuclear)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Why protons stay in nucleus)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Electromagnetic   Infinite   $\alpha = 1/137$

Relevant in biology, chemistry, atomic, molecular, and solid state physics

QED: Anomalous magnetic moment
(Theory and experiment agree to 7 decimal places)
3. Weak
\[\sim 10^{-15} \quad 10^{-5}\]
\(\beta\) decay: \(n \rightarrow p + e^- + \nu_e\)

4. Gravitational
Infinite
\[10^{-39}\]

Difference between quarks and Leptons:

Leptons do not experience strong interactions while quarks do.
Fundamental law of particle physics:

Law of Jungle!
Anything that can happen, does happen

Important corollary:

If something does not happen, there must be a reason for it

Conservation laws:
E, P, L conservation
Why does $e^-$ live for ever in free space?

Charge conservation

Why does $p$ live for ever?

Baryon number conservation
Difference between quarks and leptons

Leptons do not experience strong interactions while quarks do

Particle interaction:
Through a mediating particle
Idea of Unification of Forces:

Celestial gravity
Terrestrial gravity ---- Same (Newton) \[ F = G m M / r^2 \]

Electricity
Magnetic ------- Electromagnetic (Maxwell ~1856)

Electromagnetic
Weak -------- Electro weak interaction (Glashow, Salam, Weinberg ~1970)

Higgs ?
Why is Higgs particle so crucial?

Range of weak interaction $\sim 10^{-15}$ m

Massive mediating particles ($W^\pm$, $Z^0$)

Massive gauge theory not renormalizable
Higgs Mechanism:

\[ V(\phi) = \lambda (\phi^* \phi - a^2)^2 \]

Local Gauge symmetry spontaneously broken

Ground state (say \( \phi = a e^{i\beta} \)) not invariant!

Massive gauge particle + \( H^0 \)

Also gives masses to quarks & leptons (church)
Accelerators ➔ Like powerful microscopes

It is a device which makes use of electromagnetic fields to accelerate charged particles to higher and higher velocities and also to keep them focused as a sharp beam.
Charged Particles in Electric and Magnetic fields

Lorentz Force Law: \( F = eE + \frac{e}{c} V \times B \)

To probe smaller and smaller distances:

Need more and more powerful accelerators

(India: Delhi, Mumbai, Kolkata, Bhubaneswar……)

World's Largest accelerator (LHC) at CERN, Geneva, Switzerland

Circumference = 27 km
Indian teams:
CAT Indore, & also BARC Mumbai, are involved in building the accelerator & also in building the detectors (TIFR, BARC, VECC, IOP, Chandigarh, Delhi, Jaipur, ...) and in performing the experiment.
Many Spin-offs:

--- Cutting edge technology
--- Medical Cyclotron
--- X-rays
--- Proton beams (useful for cancer therapy)
--- Discovery of www (CERN-Tim-Berners-Lee in 1989)

Badly needed:
New concepts in accelerator technology
Primary Goal of LHC:

To detect Higgs Particles (God Particle)

Recent Indications: $M_{H^0} \sim 125 \text{ GeV}$
What Next?

Precision Measurements

Spin 0 or 2?

Spin 0 : SM Higgs or SUSY Higgs?
Electroweak
Strong (QCD) \( \longrightarrow \) Grand Unified Theory (GUT) \( T_p > 10^{33} \) years

Does proton decay?

Electroweak + strong + Gravitational \( \rightarrow \)
Superstring theory
String Theory:

Basic constituents of matter are strings (size ~ $10^{-35}$ m)

$q, l, \ldots$ Vibrational modes of string

Only consistent (perturbative) quantum theory of gravity.

Unifies all 4 interactions

Space-time dimensions: $9 + 1 = 10$
Requires supersymmetry:

Symmetry between Fermion and Boson

\( e^- \quad \text{SUSY} \quad e_{s}^- \)

Spin = \( \frac{\hbar}{2} \)

Spin = 0
Open Questions:

1. Correct direction beyond standard model (electroweak + QCD)?

2. GUT, string theory?

3. Does proton decay?

4. Supersymmetry?

5. Badly need help from experiments ➔ Real breakthrough in accelerator technology