Recent Discovery of Higgs Boson

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Goddamn Particle ---- Leon Lederman

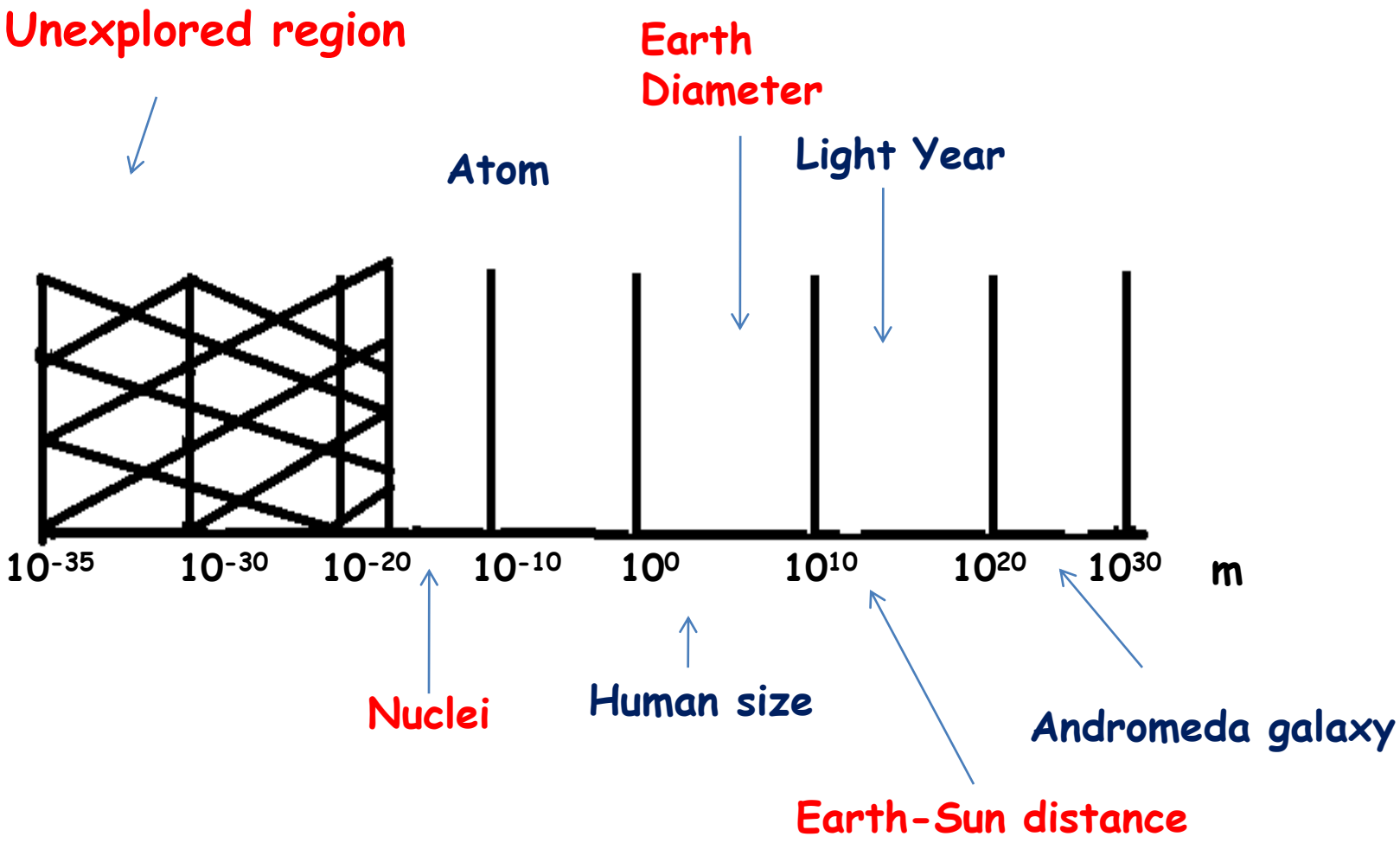
Very important discovery in particle physics

Last of crucial piece of the jigsaw puzzle of standard model

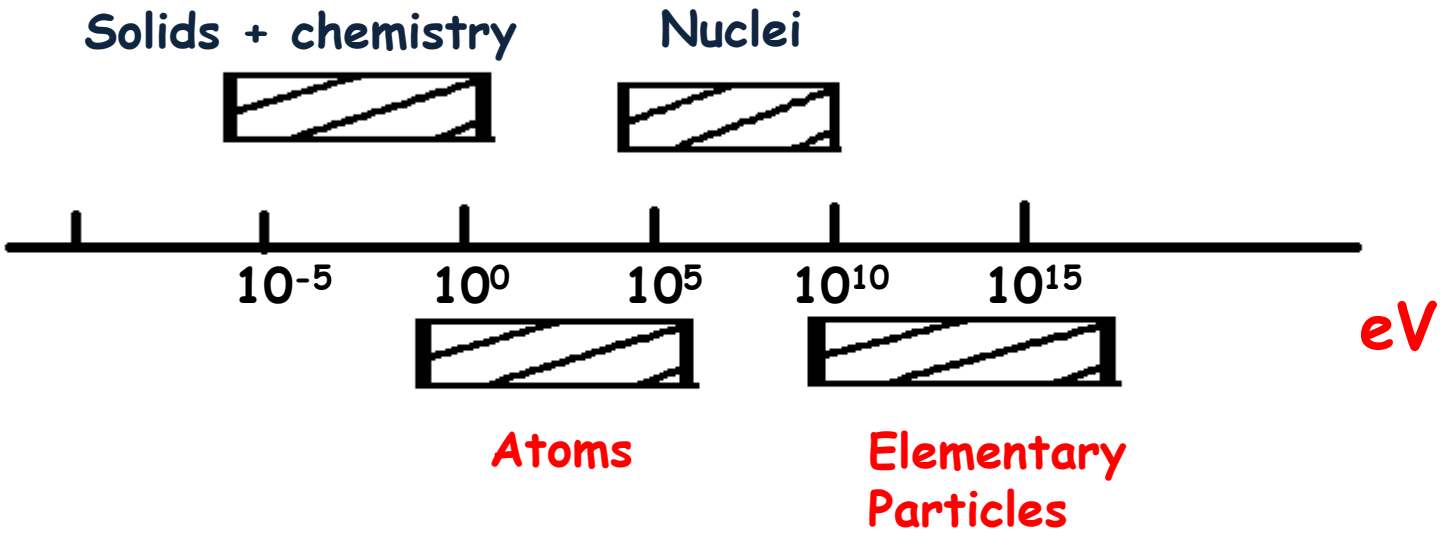
(Theory of evolution in biology)

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?


Unexplored region
Earth
Diameter
Atom
Light Year
10-35
10-30
10-20
10-10
100
1010
1020
1030
m
Nuclei
Human size
Andromeda galaxy
Earth-Sun distance

Excitation Energies



1 eV = 1.6×10^{-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
π, K, Λ, Σ,….. Discovered

SLAC (1969):
$e^- + p \rightarrow e^- +$ anything

Experiment similar to the Rutherford Expt.

α+ Gold file ➔ large angle scattering

p and n made of quarks

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

u, d, e^-, γ our world

Basic Constituents of matter (as of Today)

Quarks	Leptons
(u,d)	(ν_e, e_-)
(c,s)	(ν_μ, μ_-)
(t,b)	(ν_T, T^-)

ν_e …… Electron Neutrino

+ anti-particles (e^+ (positron), $\bar{u}$ ….)
  (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

Force	Range	Strength
1. Strong (nuclear)	$\sim 10^{-15}$ m	~ 1
	(Why protons stay in nucleus)	
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 ~10^{-15} 10^{-5}

β 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)

$$F = GmM/r^2$$

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 ~ 10^{-15} m ➔

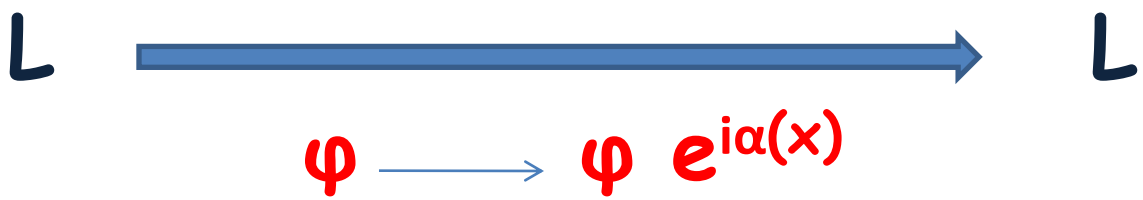
Massive mediating particles ($W^{\pm}$, Z^{0})

Massive gauge theory not renormalizable

Higgs Mechanism :

$$V(\varphi) = \lambda\,(\varphi^*\varphi - a^2)^2$$

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 elecromagnetic 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: $\vec{F} = e\vec{E} + e/c\ \vec{V}\times\vec{B}$

To probe smaller and smaller distances :

Need more and more powerful accelerators

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

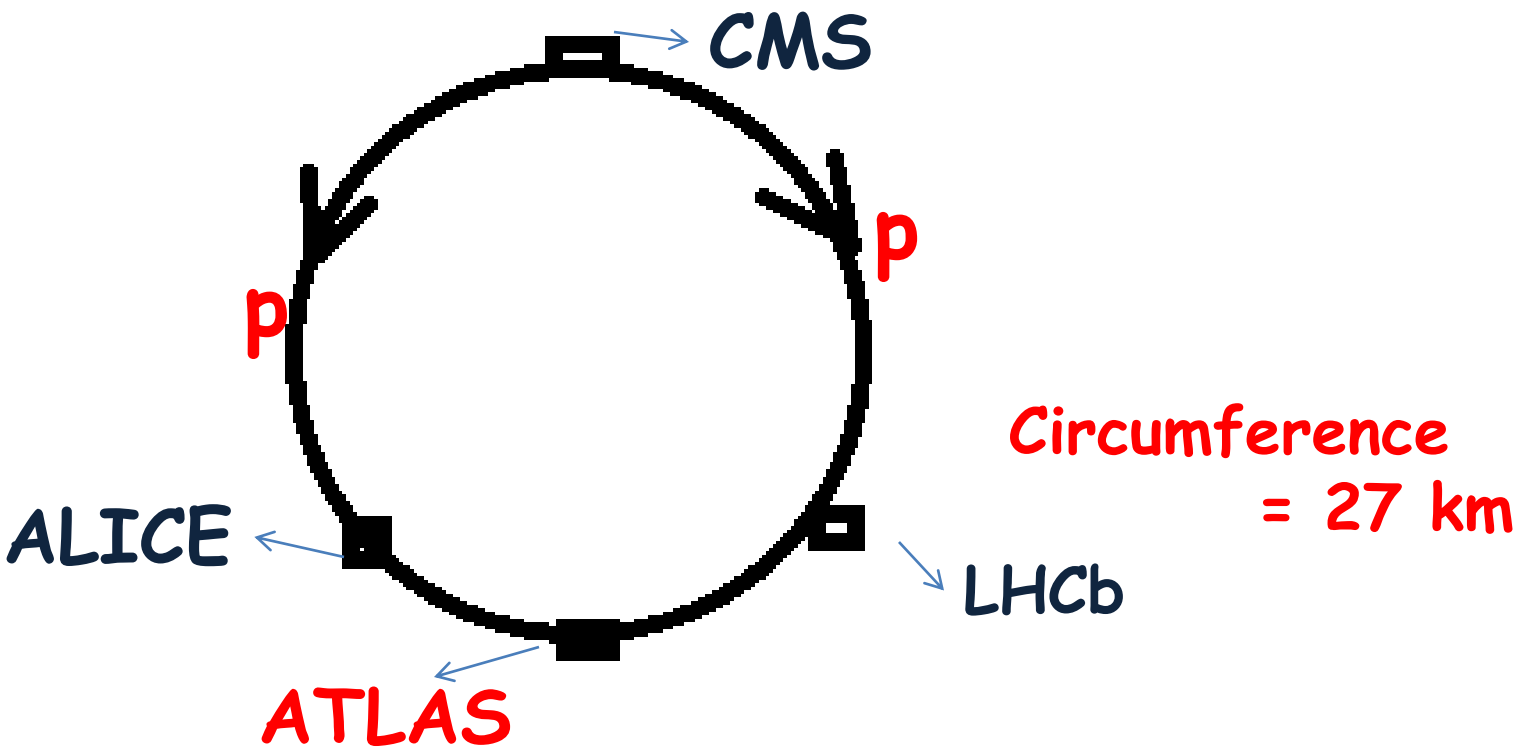
World's Largest accelerator (LHC) at CERN, Geneva, Switzerland

Circumference = 27 km

LHC ➔ World Accelerator

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: $M_{H^0} \sim 125$ GeV

What Next?

Precision Measurements

Spin 0 or 2?

Spin 0 : SM Higgs or SUSY Higgs ?

Electroweak

Strong (QCD) ------ Grand Unified Theory (GUT) $\tau_p > 10^{33}$ years

Does proton decay?

Electroweak + strong + Gravitational ➔ Superstring theory

String Theory :

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

q, l, ….. 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^- — Spin = $\hbar/2$

SUSY

e^-_s — 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