



Dept of Physics

Pradipta
Ghosh

AN INTERVIEW WITH GOLD "Particle"



12th March, 2019

March 12, 2019

1 / 30

THE
HIGGS
BOSON



The Birth of God Particle
Traveling Back In Time



The Birth of God Particle: **Meet the Creators**



Englert, Brout, Phys. Rev. Lett. 13, 321, 31 August 1964
Broken Symmetry and the Mass of Gauge Vector Mesons



Higgs, Phys. Rev. Lett. 13, 508, 19 October 1964
Broken Symmetries and the Masses of Gauge Bosons

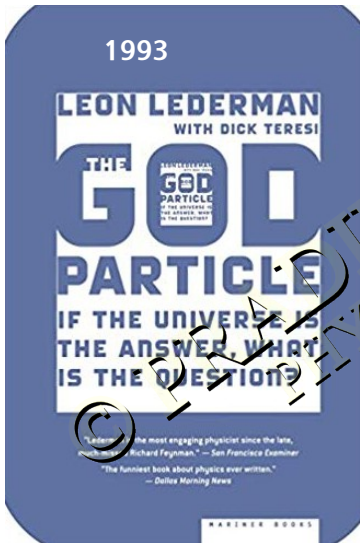


Guralnik, Hagen, Kibble, Phys. Rev. Lett. 13, 585, 16 November 1964
Global Conservation Laws and Massless Particles

Contributors over years: Anderson, Brout, Englert, Guralnik,
Hagen, Higgs, Kibble, and 't Hooft

Peter Higgs: It's not **Higgs** boson but **ABEGHHK'tH** boson

The Birth of God Particle: The Man Behind the Myth



Leon Max Lederman 1922 - 2018

“the effort to reduce all the operations of nature to a small number of laws governing a small number of primordial objects”



Asgard for God Particle?

Asgard of God Particle

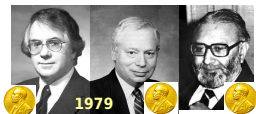
The Standard Model (SM) of Particle Physics

Asgardians

Elementary Particles

Basic Interactions and mediators

Theory: Glashow, 1961, Weinberg, 1967, Salam, 1968



Sheldon Glashow Steven Weinberg Abdus Salam

Theory: Greenberg, 1964, Han, Nambu, 1964, Bardeen, Fritzsche, Gell-Mann, 1973



David Gross H. D. Politzer F. Wilczek

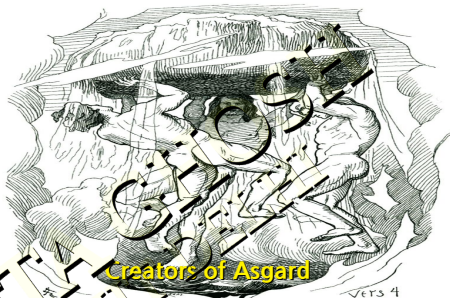
Theory: Nambu, Jona-Lasinio 1961



Yoichiro Nambu



Gerard 't Hooft Martinus J. G. Veltman

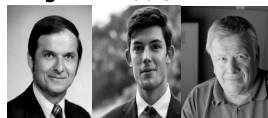


Peter Higgs François Englert



2013

C. R. Hagen Tom Kibble Gerald Guralnik



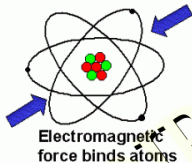
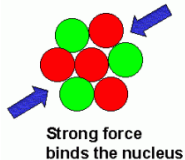
Robert Brout



Theory: Brout, Englert, Higgs, Guralnik, Hagen, Kibble, 1964

Asgardians for God Particle

Basic Interactions and mediators

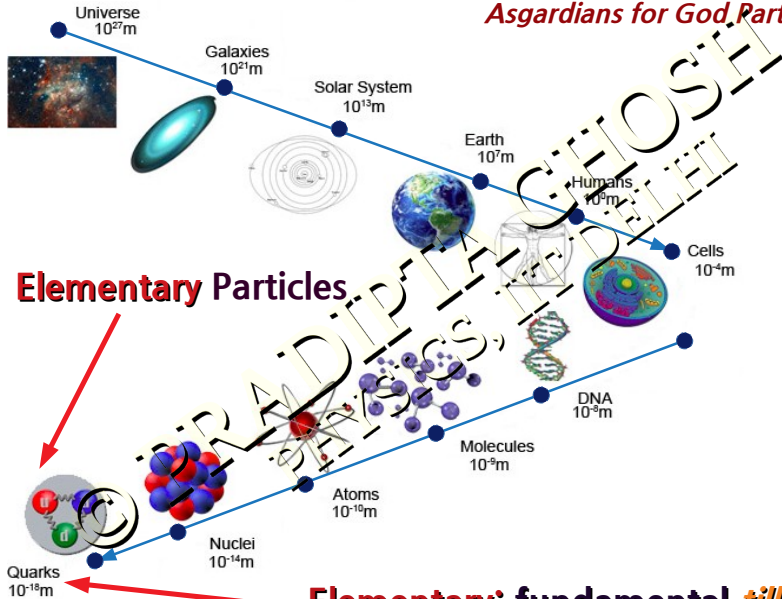


Gravity is not included in the SM

Force	Strength	Range (m)	Mediated by
strong	1	10^{-15}	Gluons (g)
electromagnetic	$1/137$	infinite	Photon (γ)
weak	10^{-6}	10^{-18}	W^+, W^-, Z
gravity	6×10^{-39}	infinite	Graviton (?)

Interactions are different

Asgardians for God Particle



Elementary: fundamental *till date*

Asgardians for God Particle

Elementary Particles

QUARKS	mass → $\approx 2.3 \text{ MeV}/c^2$ charge → $2/3$ spin → $1/2$  up	mass → $\approx 1.275 \text{ GeV}/c^2$ charge → $2/3$ spin → $1/2$  charm	mass → $\approx 173.07 \text{ GeV}/c^2$ charge → $2/3$ spin → $1/2$  top	 gluon	 Higgs boson
	mass → $\approx 4.8 \text{ MeV}/c^2$ charge → $-1/3$ spin → $1/2$  down	mass → $\approx 95 \text{ MeV}/c^2$ charge → $-1/3$ spin → $1/2$  strange	mass → $\approx 4.18 \text{ GeV}/c^2$ charge → $-1/3$ spin → $1/2$  bottom	 photon	ATTENTION In SM neutrinos are massless
	mass → $0.511 \text{ MeV}/c^2$ charge → -1 spin → $1/2$  electron	mass → $105.7 \text{ MeV}/c^2$ charge → -1 spin → $1/2$  muon	mass → $1.777 \text{ GeV}/c^2$ charge → -1 spin → $1/2$  tau	 Z boson	$1 \text{ eV}/c^2 = 1.783 \times 10^{-36} \text{ kg}$ $C = 1$ in natural unit system
LEPTONS	Massless 0 1/2  electron neutrino	Massless 0 1/2  muon neutrino	Massless 0 1/2  tau neutrino	 W boson	GAUGE BOSONS

Electron (1897)



J. J. Thomson

Muon (1936)



S. Neddermeyer



C. D. Anderson

Tau (1975)



Martin
Lewis Perl

The Particle Hunters

Theory: Pauli, 1930

e-Neutrino (1956)

Clyde
Cowan



Frederick
Reines

μ -Neutrino (1962)

Theory: 1940



Leon M.
Lederman



Melvin
Schwartz



Jack
Steinberger

Theory: 1970

τ -Neutrino (2000)

DONUT Coll.



Carlo Rubbia



Simon van
der Meer

W, W, Z UA1, UA2 (1983) CERN

Theory: Glashow, Weinberg, Salam, 1968



T. Maskawa M. Kobayashi

Bottom quark Top quark
FermiLAB CDF & D0
(1977) (1995)

Gluons

DORIS (1978)
PETRA (1979)
DESY

Theory: Gell-Mann, 1962

Light quarks (up, down, strange) SLAC (1968)



Murray
Gell-Mann

George
Zweig
Theory: 1964



Burton
Richter



Samuel
Ting

Charm quark SLAC, BNL (1974)

Theory: Glashow,
Iliopoulos, Maiani, 1970

Higgs boson ATLAS, CMS (2012) LHC-CERN

Theory: Brout, Englert, Higgs, Guralnik, Hagen, Kibble, 1964

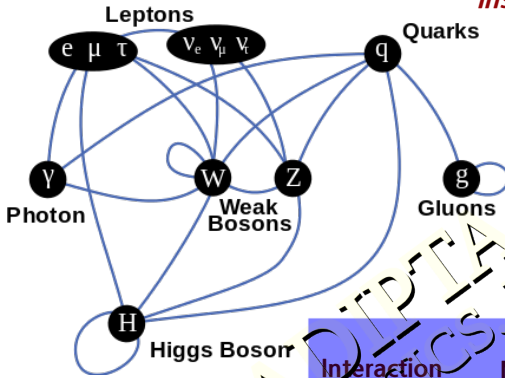


Peter
Higgs

François
Englert

Inside Asgard of Particle Physics

The Standard Model



Letters

	Interaction	Mediators	Acts on
Strong	Strong	Gluons	Quarks & Gluons
Electromagnetic	Electromagnetic	Photon	Charged leptons, W , quarks
Weak	Weak	W, Z	Leptons, Quarks, W, Z , Higgs

Postman (points to Mediators)

Clients (points to Acts on)



The need of God Particle

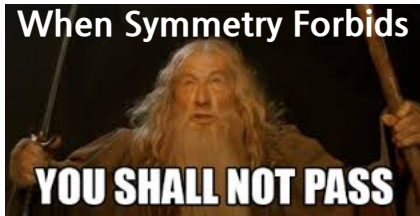
*Asgard of Particle Physics
is ruled by symmetry laws*

Those laws forbid mass terms

*Most of the elementary particles
are massive in nature !!*

*Asgard of Particle Physics seeks protection
from symmetry Demons*





Consider the following
English alphabets: M, N, O, P



1. Vertical mirror
Reflection symmetry
M, O survive

2. Horizontal mirror
Reflection symmetry
Only O survives



Symmetry does Kill

Observation:

Asgard of Particle Physics is ruled by Gauge symmetries

Mass terms are forbidden



**our
Saviour**

Crisis:

**Most of the elementary particles and
force mediators are massive**

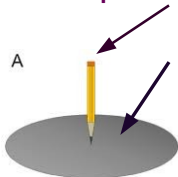
Solutions:

Spontaneous symmetry breaking and ABEGHHK'tH mechanism

Thanks to God Particle

Spontaneous symmetry breaking

Not the place of minimum Energy



Place of minimum Energy: Ground State

Will remain same under rotations

All directions on this Grey circle are the same from Pencil's viewpoint

Ground State is not unique

The ground state now has a SPECIFIC direction

B



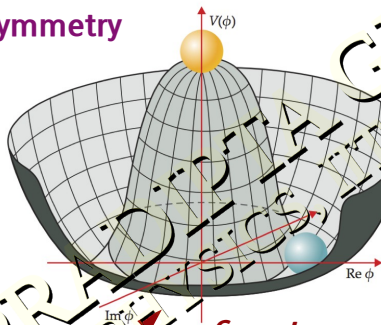
The Rotational symmetry is Broken Spontaneously

without any external influence

Spontaneous symmetry breaking in the SM

GOD is Here

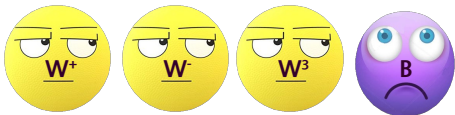
Unbroken symmetry



Spontaneously broken symmetry

"GOD Particle's" Potential

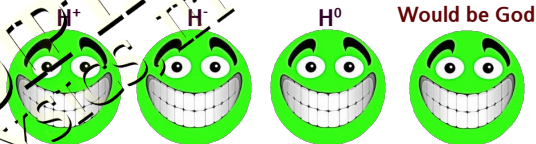
When Massless becomes Massive: ABEGHHK'tH mechanism



Gauge Sector: All Massless with 2 DOF

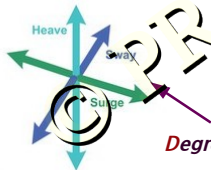
$$4 \times 2 + 4 = 12 \text{ DOF}$$

Unbroken gauge symmetries



Higgs sector: Each with 1 DOF

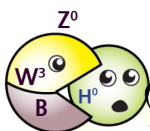
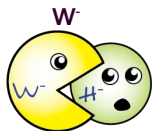
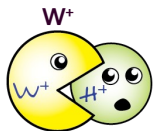
Translational Movement
in Three Perpendicular Axes



Surge: Moving forward/backward
Heave: Moving up/down
Sway: Moving left/right

Degrees Of Freedom: Independent Translation / Rotation / Vibration

When Massless becomes Massive: ABEGHHK'tH mechanism



Massless Photon with 2 DOF



Three Massive with 3 DOF each

Spontaneously broken
gauge symmetries



*Massive God Particle
with 1 DOF*

$$3 \times 3 + 2 + 1 = 12 \text{ DOF} \quad \text{match} \quad \checkmark$$

Leptons & Quarks masses through Yukawa interactions

Gluons remain massless



The Nobel Prize in Physics 1906

Joseph John Thomson

Electron (1897)

The Nobel Prize in Physics 1906 was awarded to J.J. Thomson "in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases".

J. J. Thomson

What took it so long?

Waiting...



115 Years



François Englert



Peter W. Higgs

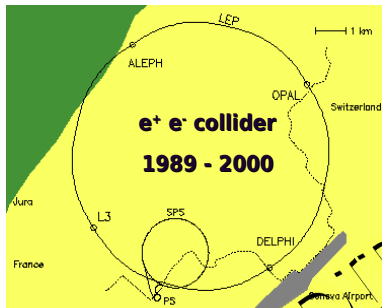
The Nobel Prize in Physics 2013

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

Higgs boson (2012)

Brout, Englert, Higgs, Guralnik, Hagen, Kibble

From LEP to LHC: The quest for God Particle



Large Electron Positron Collider a.k.a LEP

Energy ~200 GeV

Length probed ~ 10^{-18} m

Insufficient energy to detect God Particle

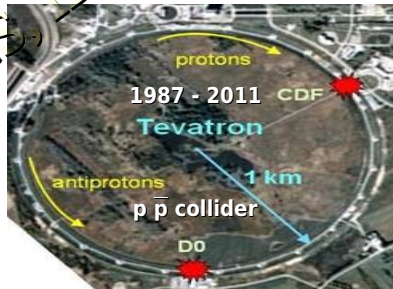
Predicted Lower bound ~ 114 GeV

Energy ~2000 GeV

Length probed ~ 10^{-19} m

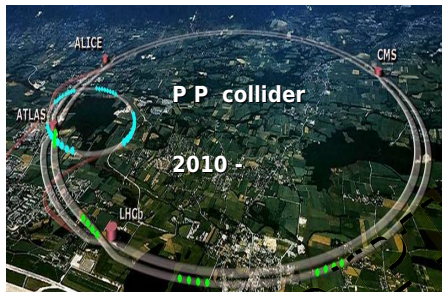
Not a correct probe for God Particle

Predicted Exclusion limits



With 1 GeV we can probe a distance of 10^{-15} m

From LEP to LHC: The quest for God Particle



Large Hadron Collider a.k.a LHC

Energy ~ 14000 GeV

Length probed ~ 10^{-20} m

Discovery Machine

Can not use for precision study

**4th July 2012: CMS & ATLAS announced
God Particle Discovery**



The Saga of the SM Ends here ?

How large is 14 TeV ~ Kinetic Energy of a Ping-Pong ball (~3 gm) moving with a speed of ~4 cm/sec



The standard model gives us an accuracy of ten decimal digits, this is an amazing success that has never been achieved before in science.

— Nathan Seiberg —

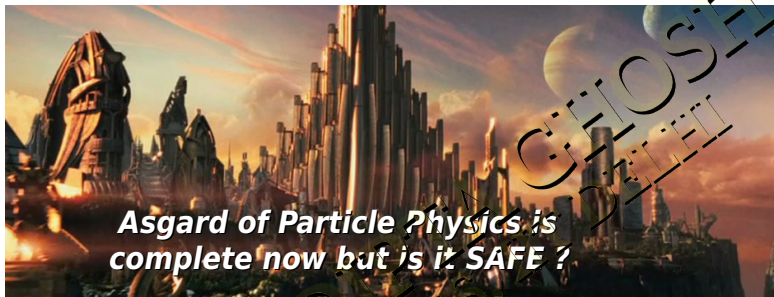
Eminence of the SM

© PNP Physics II Dipti Ghosh
Anomalous Magnetic Moment of muon

$$a_{\mu}^{\text{exp}} - a_{\mu}^{\text{SM}} = (28.7 \pm 8.0) \cdot 10^{-10}$$



God Particle is here... It's All Over or **NOT?**



No it's NOT !





God Particle itself is the most SERIOUS threat !

Suppose SM is the only theory for Particle Physics

It should work till 10^{19} GeV, a.k.a. Planck Scale, realm of GRAVITY

Quantum corrections Should make the Higgs much heavier than what it is

However, it's ~ 125 GeV !

UNNATURAL FINE TUNING for Higgs Mass

It's like a snowball surviving in hell





Another troublesome Asgardian: Neutrino

Neutrinos are Massless within the SM

Neutrinos oscillate in nature: Observed

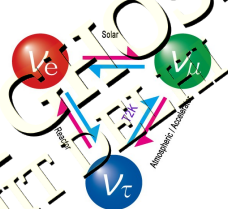
Arthur
McDonald

Takaaki
Kajita

Theory: Pontecorvo, 1957, 1967,
Maki, Nakagawa, Sakata, 1962



2015

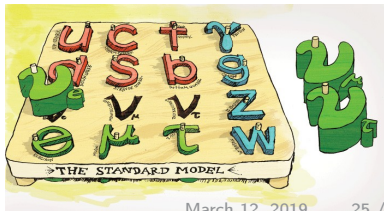


Oscillation impossible WITHOUT Neutrino mass



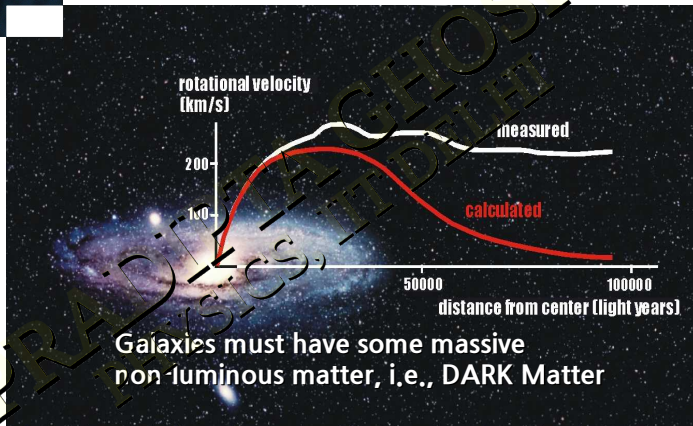
DOES THE HIGGS
GIVE MASS
TO NEUTRINOS?

Not within the SM





Dark Matter: Enemy 'beyond' Asgard

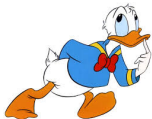


Beyond the LHC if anything matters, it is the Dark Matter which does matter... (anonymous)

THE QUANTUM UNIVERSE



We NEED to look for a "BETTER" Asgard



Life at the LHC after God Particle

God Particle discovered but **NOTHING ELSE** since 2012

LHC will be back with 14 TeV at 2021

High-Luminosity (HL) LHC from 2026

Proposed International Linear Collider (ILC)

500-1000 GeV, Precision studies

Proposed Compact Linear Collider (CLIC)

Upto 3000 GeV, Precision studies

Proposed Triple LEP Collider (TLEP)

80-100 km tunnel, 90-350 GeV, Precision studies

33 TeV, 100 TeV colliders

Discovery machines



God Particle discovery: Could be the beginning of a new journey



So far it seems like **THIS IS THE ONE** and **NOTHING ELSE** but who knows...

This may be the
tip of the iceberg...



125 GeV



Today is gone,
what's done is done.

Embrace your
dreams
through
the night,

Tomorrow comes with
a whole new light!



Thanks!