The Search for New Particles at Particle Collider

Hossain Ahmed
Assistant Professor
DR. W. F. James Research Scholar
Department of Physics, Saint Francis Xavier University
Antigonish, Nova Scotia, Canada, B2G 2W5

Abstract: Higgs boson discovery is one of the best scientific achievements in the early 21st century. It quenches lot of our understanding of the universe through the Standard Model. However, many theoretical models and astronomical observations predict the dark matter and dark energy that Standard Model particles can't explain. There are dark matter searches in space, in the ground, and underground. I will give a roadmap of the Higgs boson and the dark matter particles search in the energy range up to 10 GeV in this talk.

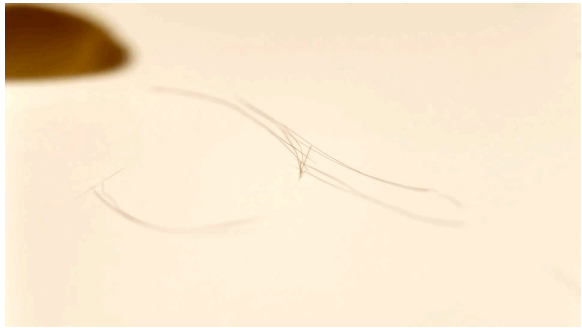
Introduction (460 BC to 1850 AD)

Our ancestors, like us, were surprised by

- Lightning in thunderbolt

- Shock in touching electric fish

- Attracting of small objects by amber while rubbing with fur



Introduction (460 BC to 1850 AD)

Democritus (460 -370 BC)

- Famous student of Leucippus
- Most influential pre-socratic philosopher studying many fields
- Concept of the atom, an indivisible object that made the universe
- Said that atoms are in constant motion

Introduction (460 BC to 1850 AD)

John Dalton (1766 -1844)

- An English Chemist as well as Physicist, gave an evidence-based atomic theory
- All the elements are made of tiny particles called atoms
- Atoms are indivisible, and they are alike for the same element and different for different elements
- Atoms can perform chemical reactions

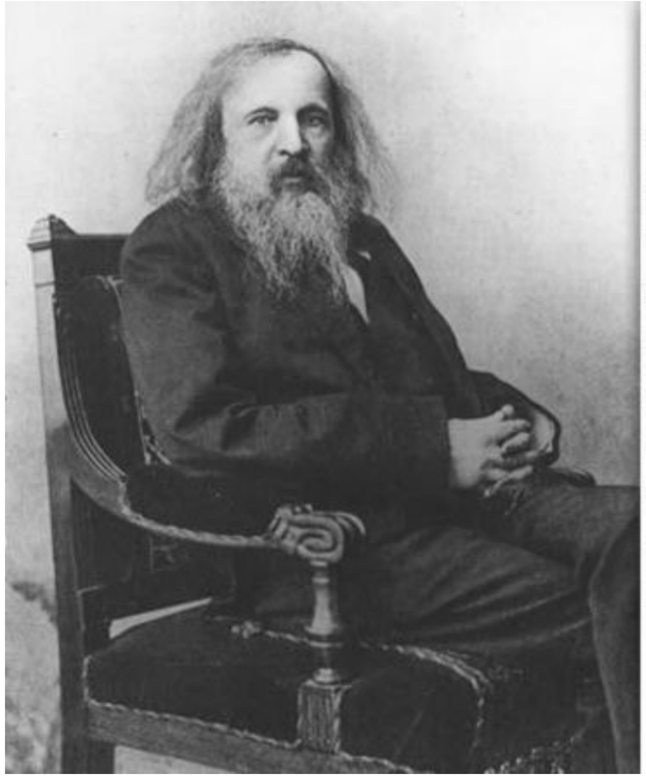
Introduction (460 BC to 1850 AD)

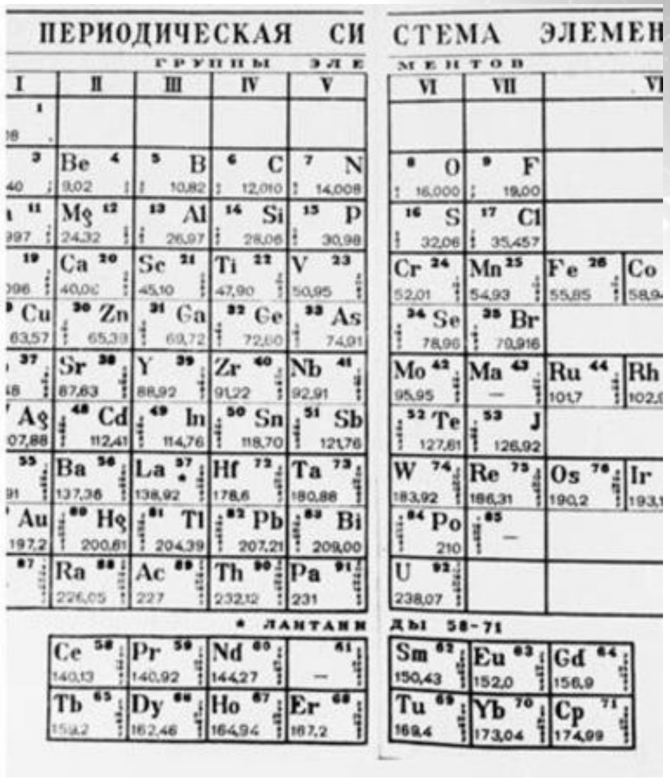
Amedeo Avogadro (1776 – 1856)

- N_A = 6.02 x 10^{23} /mol
- Equal volumes of gases under the same conditions of temperature and pressure will contain equal numbers of molecules
- Basis of our understanding that matter is not continuous as it appears, but it quantized (i.e., discrete) on the microscopic scale!

Introduction (460 BC to 1850 AD)

Dmitri Mendeleev (1834 – 1907)





- Invented periodic table
- Organized elements by properties
- Arranged elements by atomic mass
- Predicted existance of several unknown elements
- Elements 101

Introduction (460 BC to 1850 AD)

Alessandro Volta (1745 – 1827)

- Pioneeer of electricity
- Inventor of electric battery

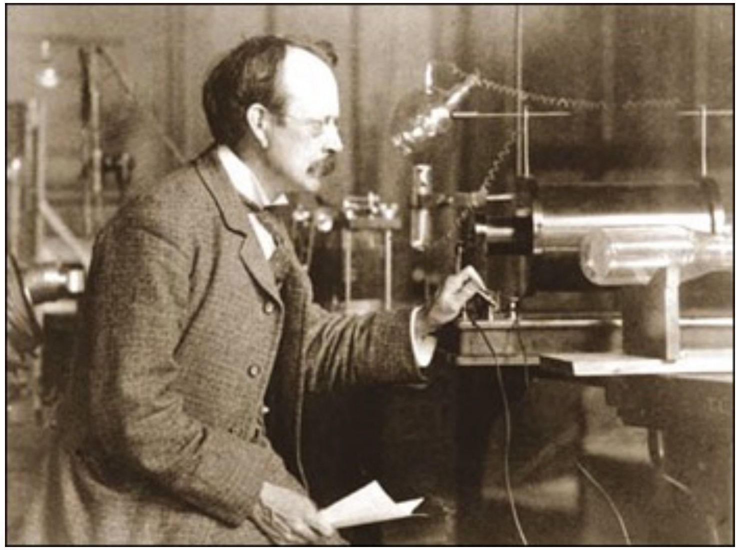
Introduction (460 BC to 1896 AD)

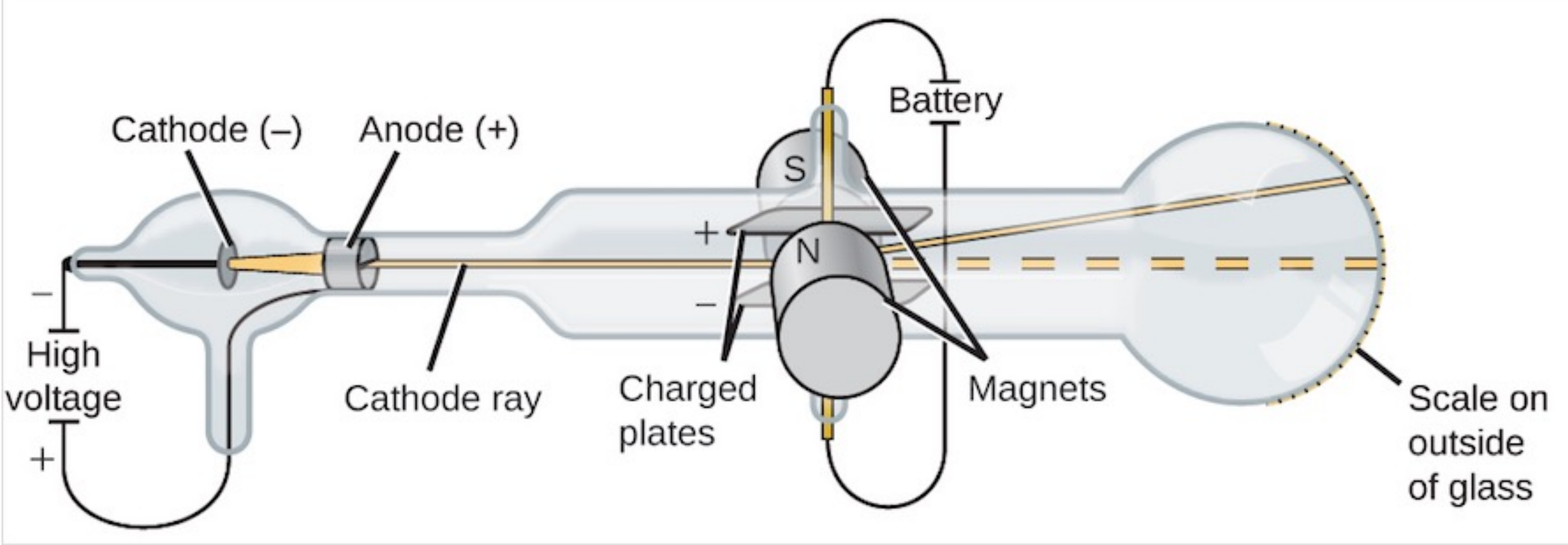
- From 1869 – 1896 many physicists studied about electric conductivity, discovered the glow from cathode, named them cathode ray, studies their deflection in electric and magnetic fileds …

➢ We couldn’t modeled it quite well untill Joseph J. Thomson named it as electron in 1897

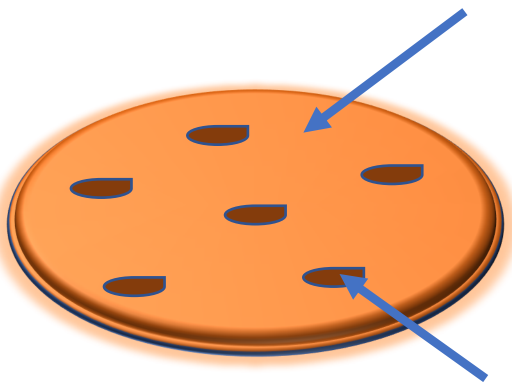
Divisible atom (1897)

J. J. Thompson (1856 – 1940)



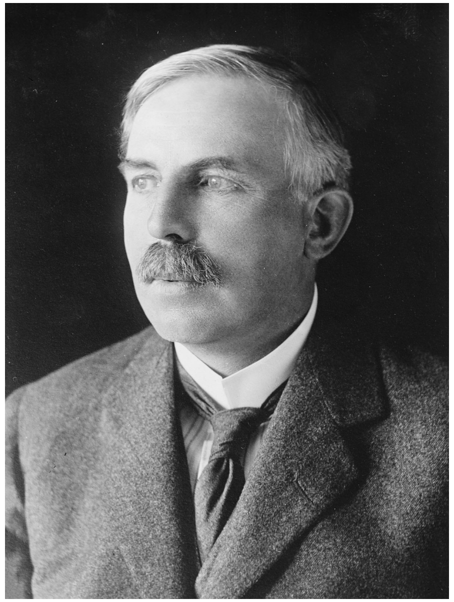


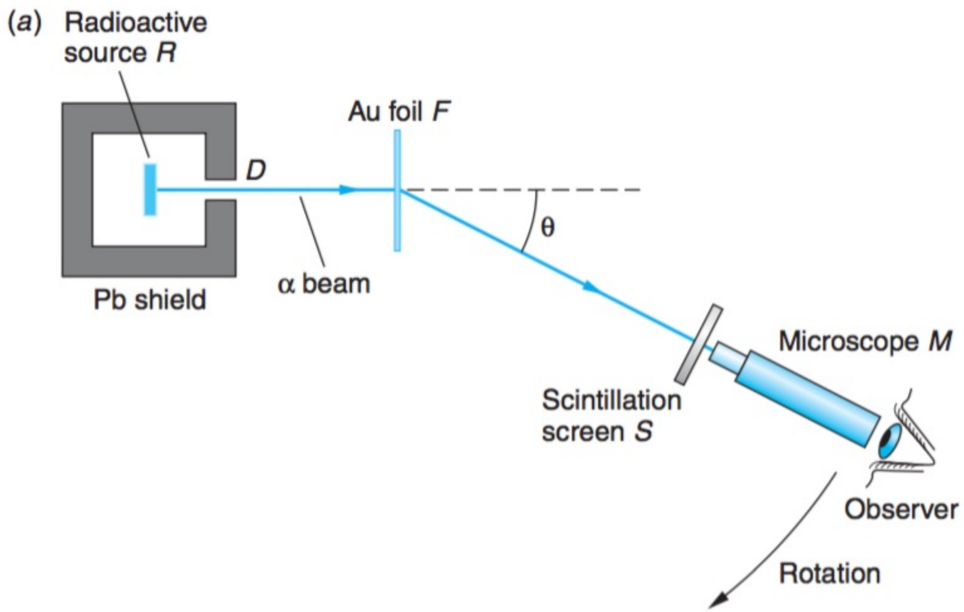
- Pioneer particle physicist @ Cavendish laboratory at the Cambridge University
- Inventor of first ever sub-atomic particle "electron"
- Developed "Plum Pudding" model
- Awarded Nobel prize in 1906
- At least eight of his direct students and researchers awarded Nobel prize in Physics and Chemistry!



Divisible atom (1911)

Ernest Rutherford (1871 – 1937)



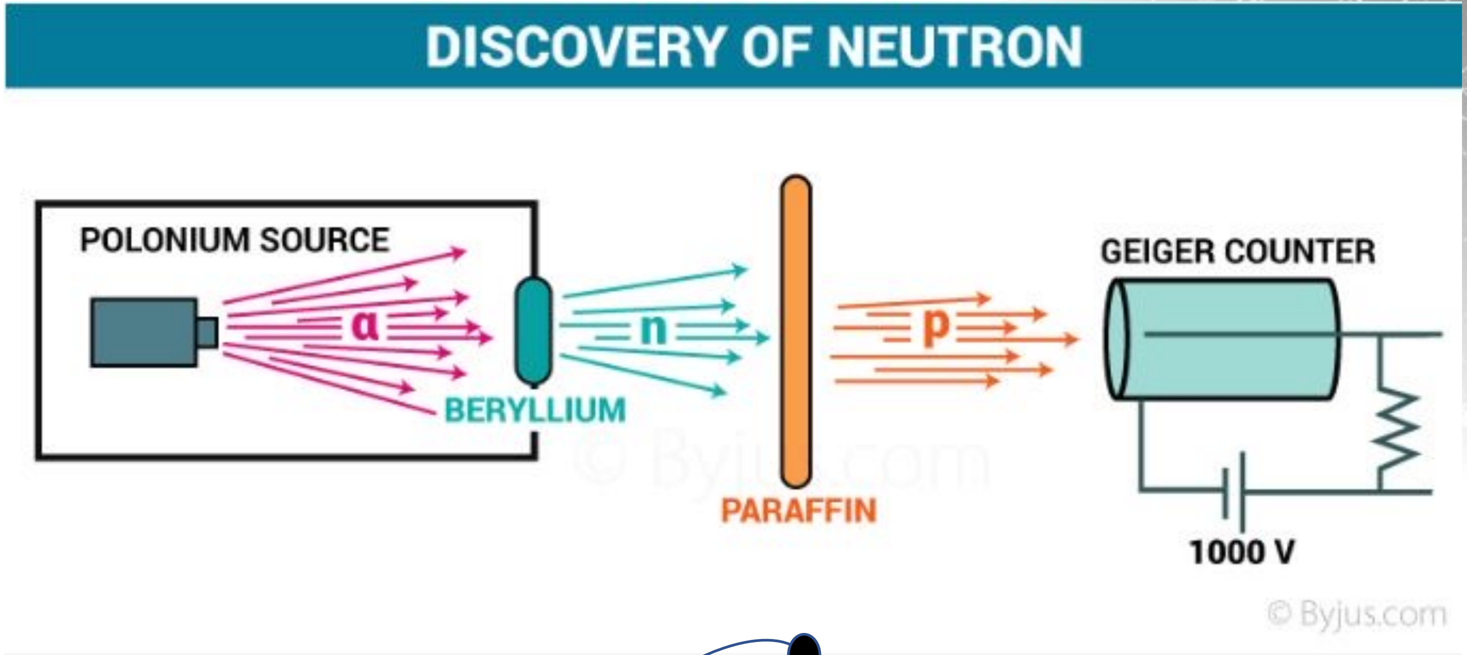


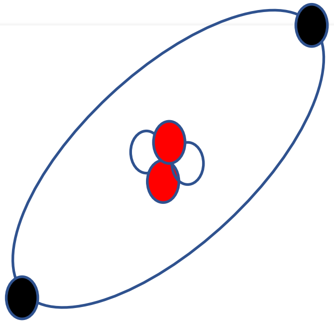
- Studied radiation, classify them and discovered the concept of radioactive half-life
- Studied interaction of radiation with matter
- Discovered "nucleus" in 1911 with famous alpha particle scattering
- Pioneer particle accelerator who performed first ever nuclear reaction: $N^{14} + \alpha \rightarrow O^{17} + p$
- Rutherford named this building block of nucleus as "proton" (Proton means first in Greek) in 1920

Divisible atom (1932)

James Chadwick (1891 – 1974)

- Discovered neutron in 1932

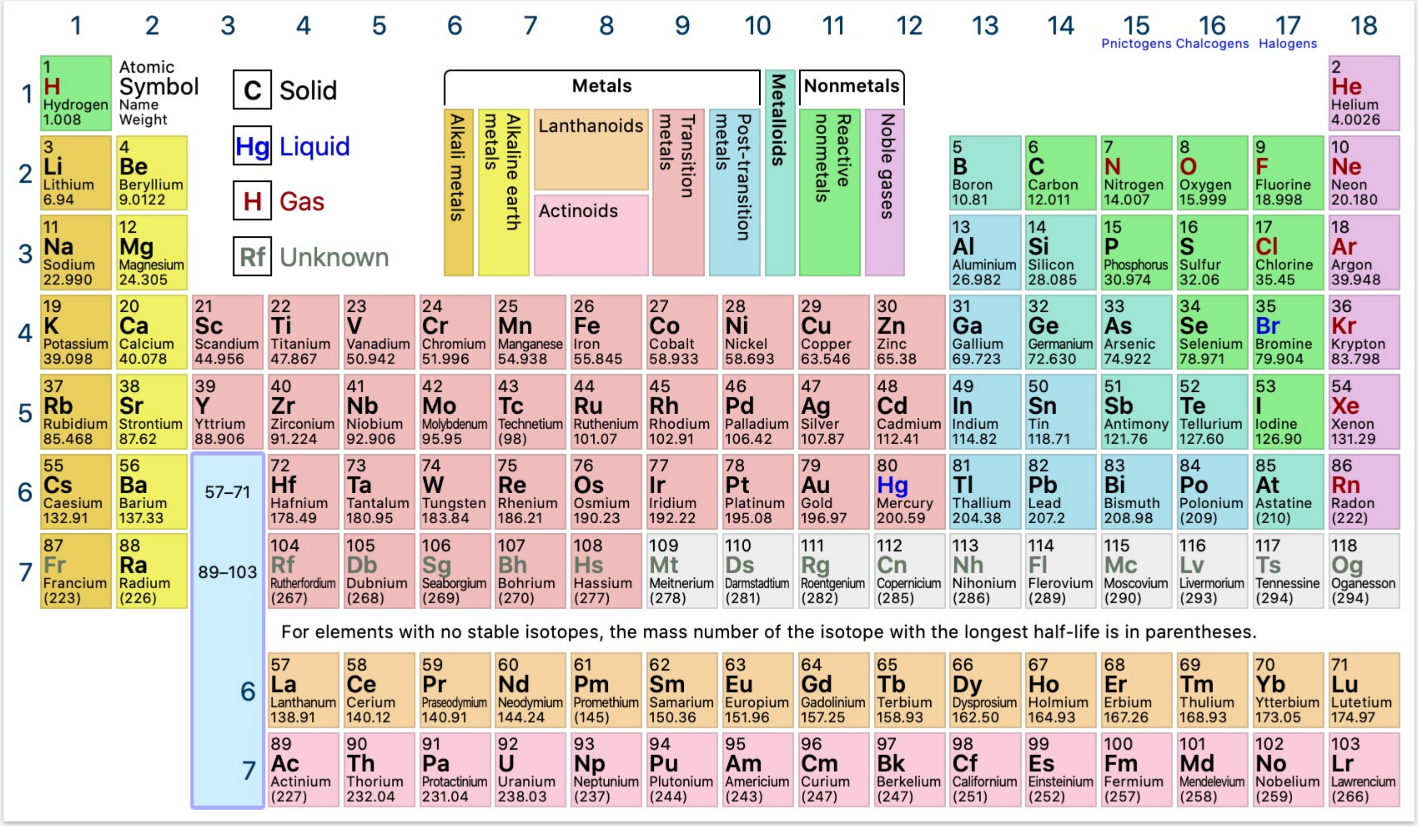




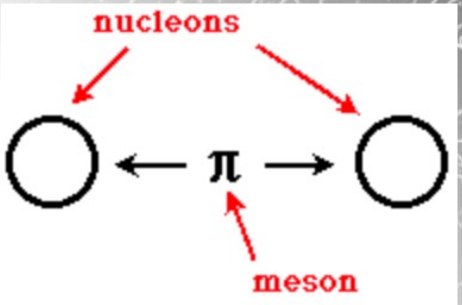
Helium atom

Subatomic era (1932-1964)

➢ Less than a century after Mendeleev publish his periodic table, scientists have arrived in a beautiful simplification that all things around us are made from three fundamental particles (electron, proton, and neutron)

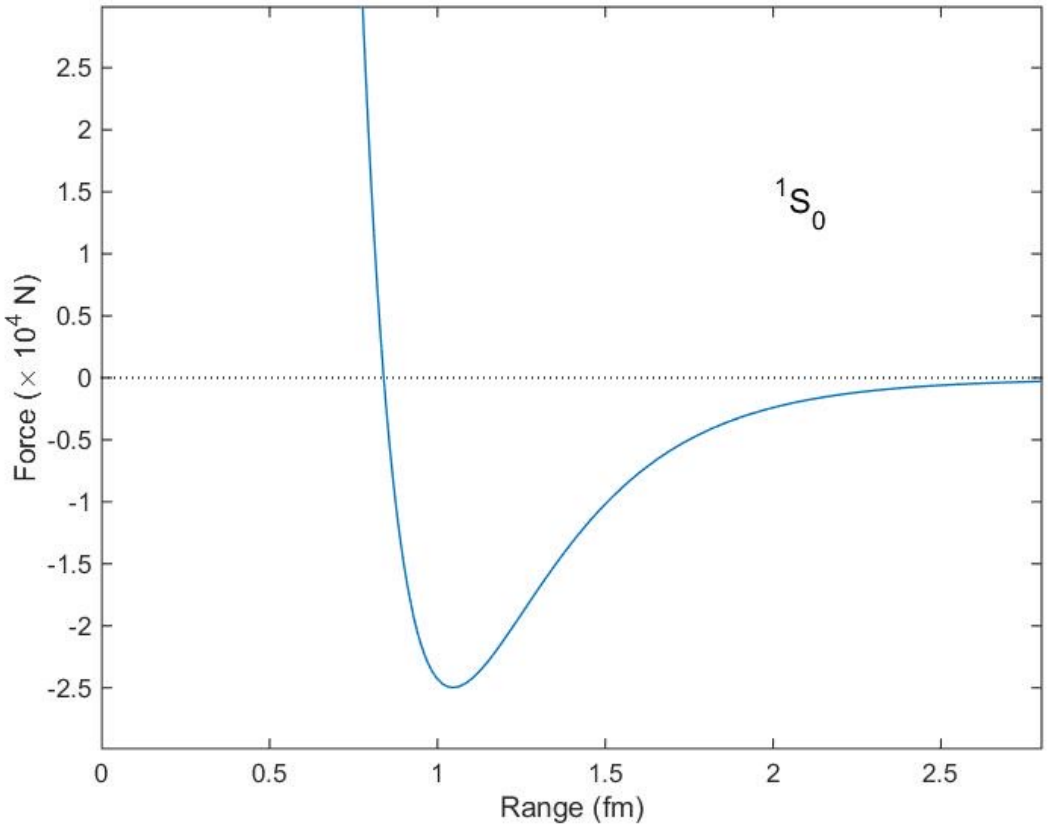


Subatomic era (1932-1964)



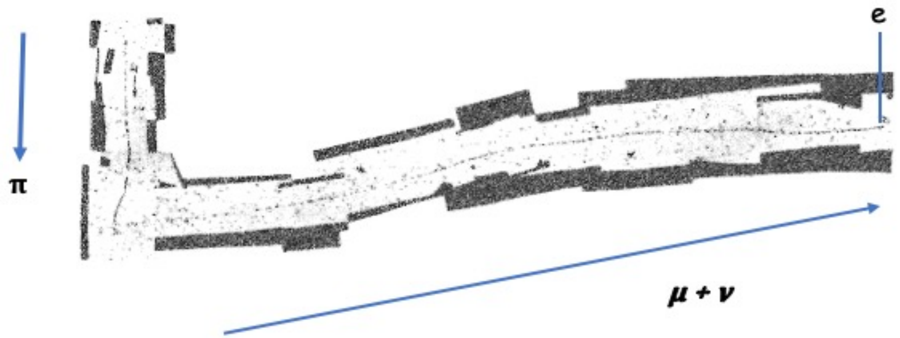
Hideki Yukawa (1907 - 1981)

Q. What holds nucleons together?

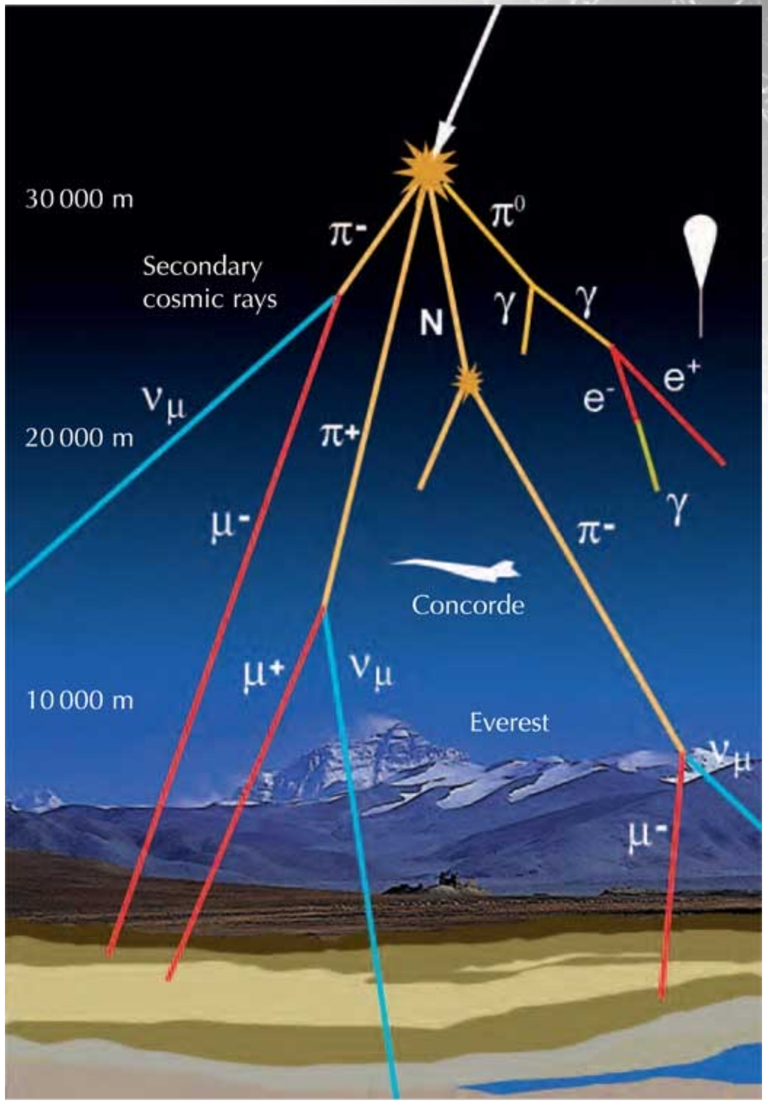


Subatomic era (1932-1964)

- Problem arises when scientists discovered many new particles in cosmic rays and in the particle accelerators



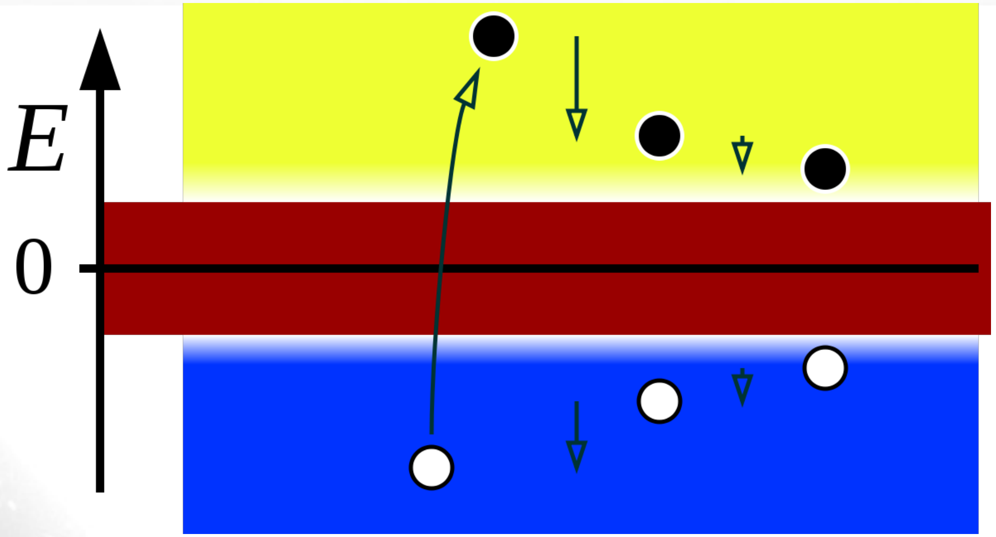
Powell's group exposed their photographic emulsions on mountain tops



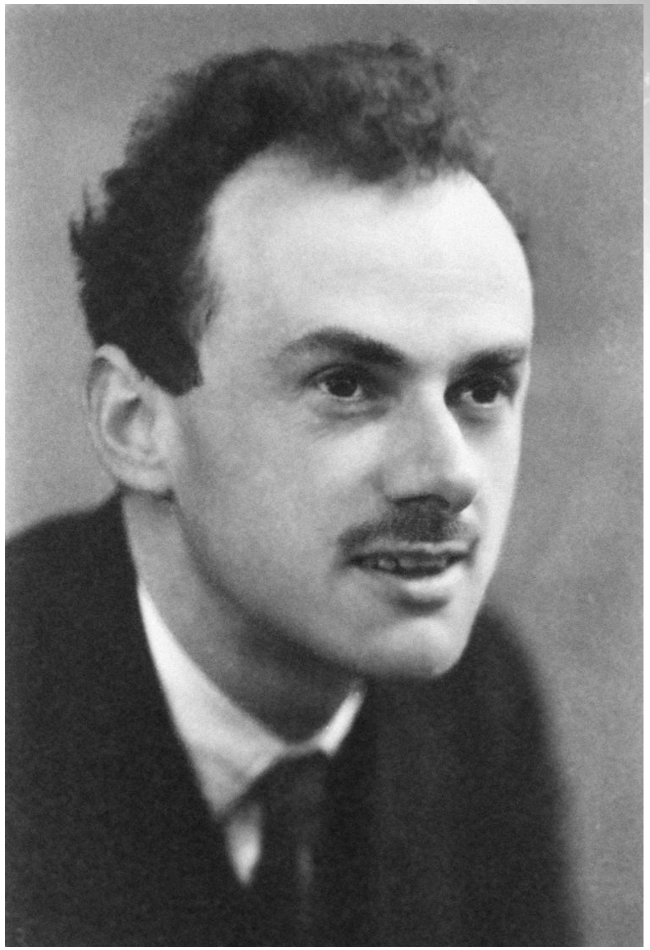
- Those particles can't be explained by the there fundamental particles; the proton; the neutron; and the electron

Subatomic era (1932-1964)

$$\left(\beta mc^2 + \sum_{k=1}^{3} \alpha_k p_k\, c\right) \psi(\mathbf{x}, t) = i\hbar \frac{\partial \psi(\mathbf{x}, t)}{\partial t}$$



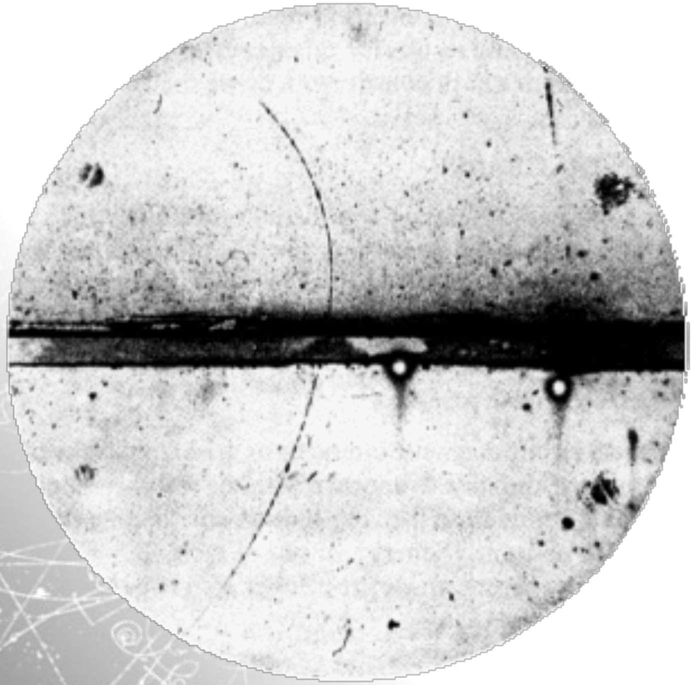
Paul Dirac (1902 - 1984)

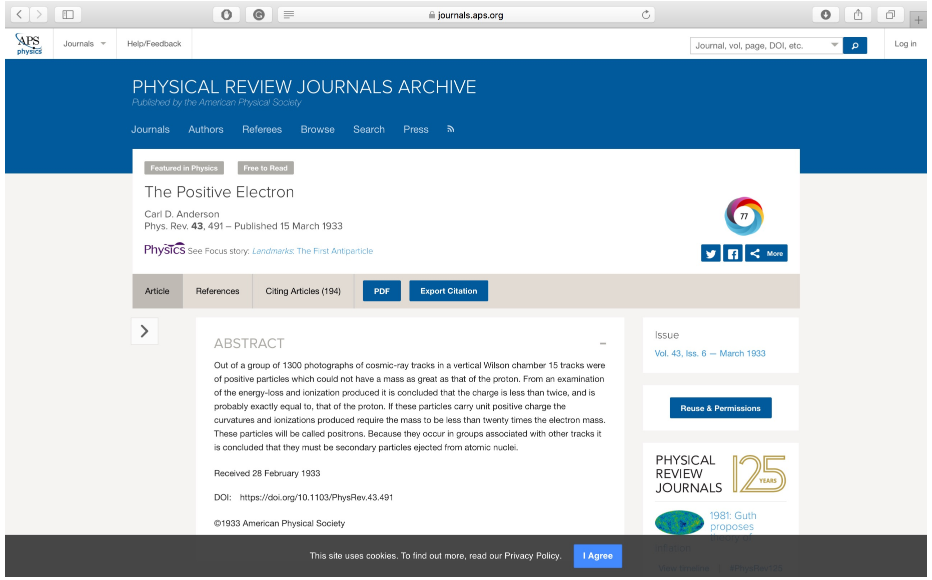


Subatomic era (1932-1964)

- While studying "cloud-chamber” photographs of cosmic rays, Anderson found a number of tracks whose orientation suggested that they were caused by positively charged particles-- but particles too small to be protons.

Carl Anderson (1905 - 1991)





The Positive Electron

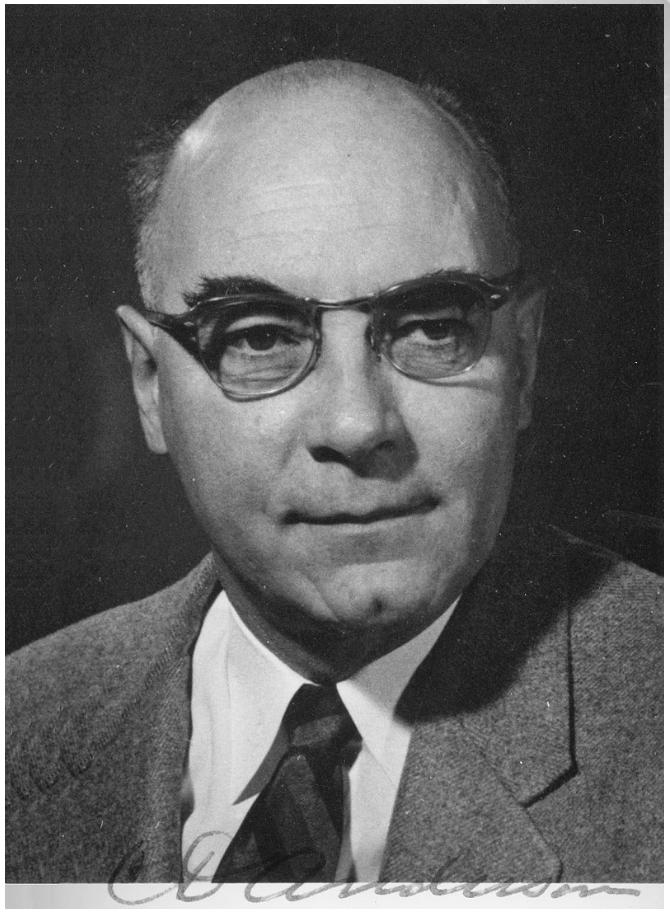
Carl D. Anderson
Phys. Rev. **43**, 491 – Published 15 March 1933

ABSTRACT

Out of a group of 1300 photographs of cosmic-ray tracks in a vertical Wilson chamber 15 tracks were of positive particles which could not have a mass as great as that of the proton. From an examination of the energy-loss and ionization produced it is concluded that the charge is less than twice, and is probably exactly equal to, that of the proton. If these particles carry unit positive charge the curvatures and ionizations produced require the mass to be less than twenty times the electron mass. These particles will be called positrons. Because they occur in groups associated with other tracks it is concluded that they must be secondary particles ejected from atomic nuclei.

Received 28 February 1933

DOI: https://doi.org/10.1103/PhysRev.43.491



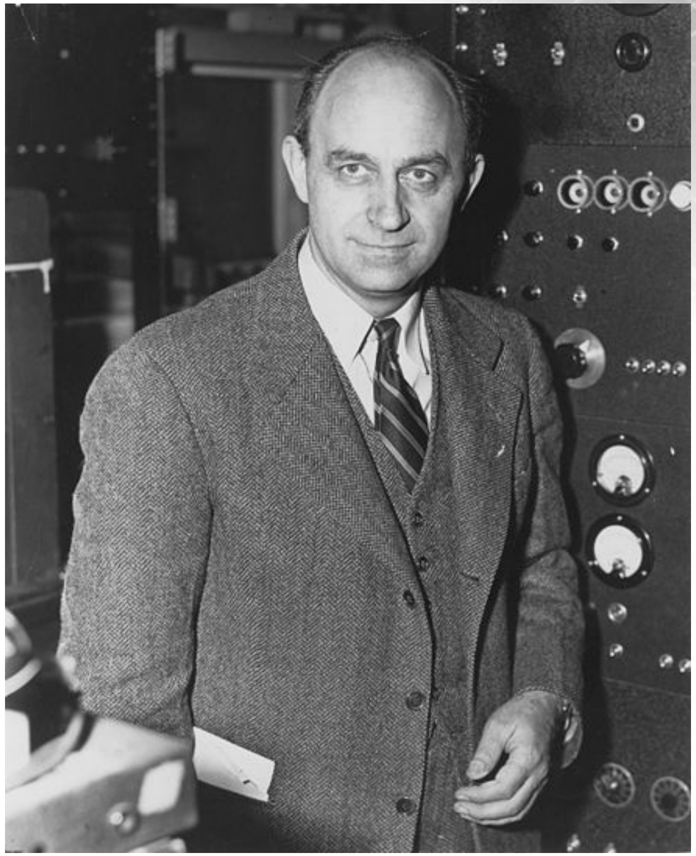
Subatomic era (1932-1964)

$$A \rightarrow B + e^-$$

e.g. ${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$

1.008665 u → 1.007825u (1.007276u + 0.00054858u)

Enrico Fermi (1901 - 1954)



- On 4 December 1930, Austrian theorist Wolfgang Pauli wrote a famous letter in which he dared to hypothesize the existence of new particle - the particle now known as the neutrino ($\boldsymbol{\nu}$).
- Fermi called this missing energy particles is “neutrino”

$$n \rightarrow p + e^- + \bar{\boldsymbol{\nu}}$$

- In the mid 1950's, Fred Reines & Clyde L. Cowan, Jr. came up with an experiment to verify the existence of the neutrino and discovered it in 1956.

Subatomic era (1932-1964)

- So far, we learn about, 1. Electron 2. Proton 3. Neutron 4. Muon 5. Pion 6. Positron 7. Neutrino
- We are now familiar with forces, which are three out of four basic forces in nature: Electromagnetic, Strong, and Weak force
- In 1950's physicists thought all the predictions are observed and the particle physics more or less complete:

  a) Yukawa's middle weight particle was found (Pion or pi-meson)
  b) Dirac's negative energy puzzle was solved by finding the positron
  c) Neutrino problem was also addressed!

One tiny question on MUON!

Isidor Isaac Rabi (1898-1988)

Who ordered that?

Subatomic era (1932-1964)

- Within a decade (1950-1960) particle accelerator established and several new particles are discovered, e.g. Kaons, Lamda, Rho, Phi, Omega, and many more
- Scientists were running out of symbol to name them
- Willis Lamb began his Nobel Prize acceptance speech in 1955 with the words:

Willis Lamb (1913-2008)

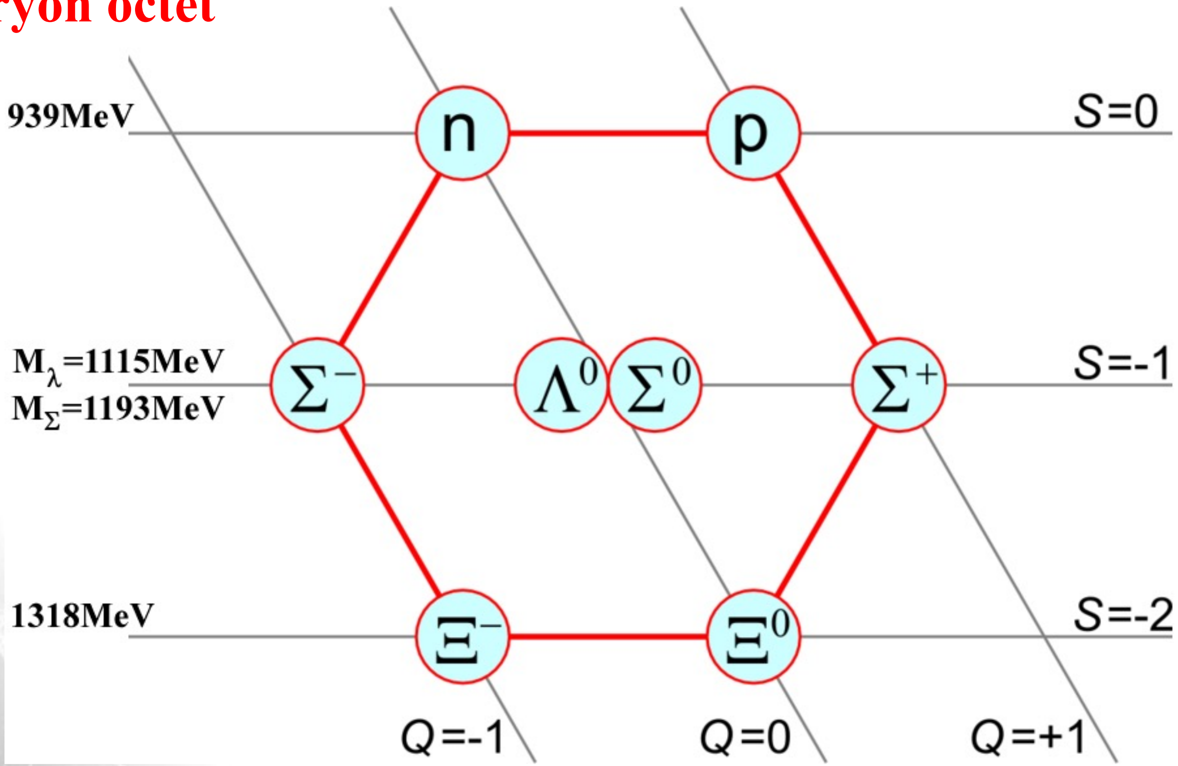
When the Nobel Prizes were first awarded in 1901, physicists knew something of just two objects which are now called "elementary particles": the electron and the proton. A deluge of other "elementary" particles appeared after 1930; neutron, neutrino, meson, heavier mesons, and various hyperons. I have heard it said that "the finder of a new elementary particle used to be rewarded by a Nobel Prize, but such a discovery now ought to be punished by a $10,000 fine". [Source: Les Prix Nobel 1955, The Nobel Foundation, Stockholm.]

Subatomic era (1932-1964)

- Murray Gell-Mann is known as the Mendeleev of elementary particle
- He introduce eight-fold way in 1961 where he arranged eight lightest baryons in a hexagonal array with two particles at the centre:

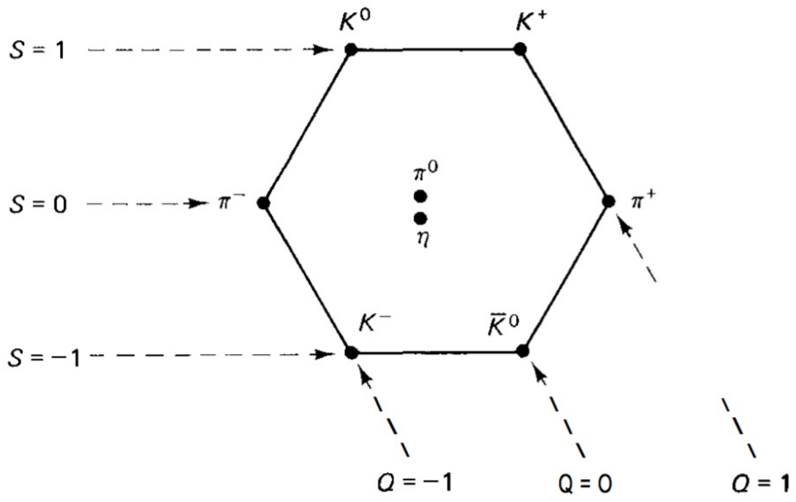
Murry Gell-Mann (1929-2019)

The baryon octet

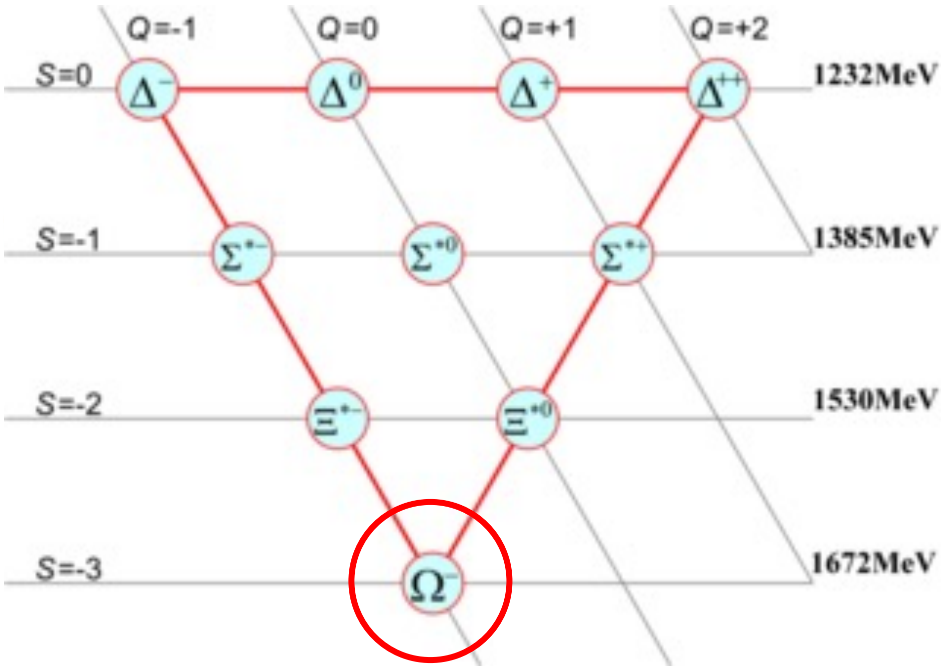


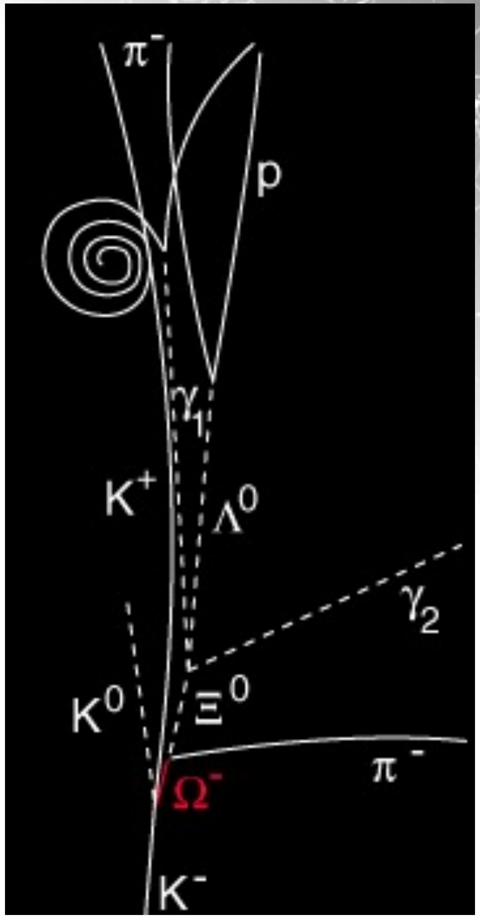
Subatomic era (1932-1964)

The meson octet



The Baryon Decuplet



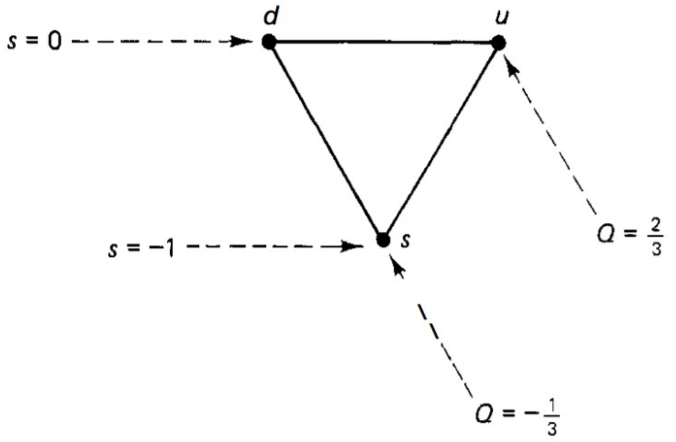


Predicted particle and discovered at BNL in 1964 (within very short time!)

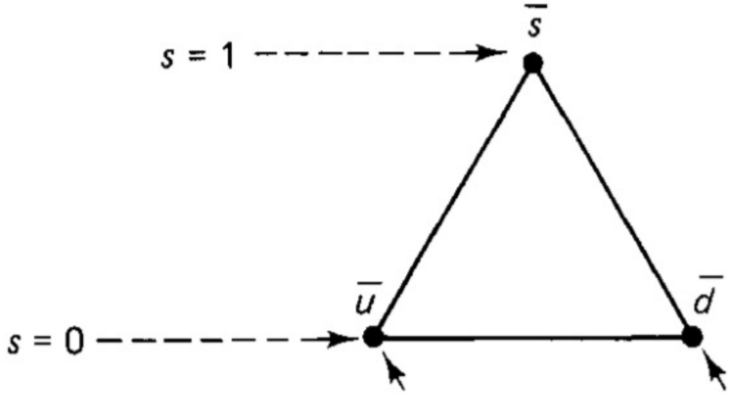
$$K^- + p \rightarrow \Omega^- + K^0 + K^+$$

Subatomic era (1932-1964)

- Success of the Eightfold Way begs the question: Why do the hadrons fit into these curious patterns?
- Gell-Mann and Zweig independently proposed that all hadrons are in fact composed of even more elementary constituents, which Gell-Mann called “***quarks*”.**



The Quarks



The Antiquarks

The Quark Model

Subatomic barren time (1964-1974)

- Why no free quarks observe in nature?
- Inconsistency with Pauli principle (three identical up quarks are in Δ^{++} etc.)
- Within few years proton structure discovered at SLAC

Journals | Help/Feedback | Journal, vol, page, DOI, etc. | Log in

PHYSICAL REVIEW LETTERS

Highlights | Recent | Accepted | Collections | Authors | Referees | Search | Press | About

Featured in Physics | PRL Milestone | Free to Read

High-Energy Inelastic $e-p$ Scattering at 6° and 10°

E. D. Bloom, D. H. Coward, H. DeStaebler, J. Drees, G. Miller, L. W. Mo, R. E. Taylor, M. Breidenbach, J. I. Friedman, G. C. Hartmann, and H. W. Kendall

Phys. Rev. Lett. **23**, 930 – Published 20 October 1969

Physics See Focus story: *Landmarks*—Discovery of Particles inside the Proton

An article within the collection: Letters from the Past - A PRL Retrospective

Article | References | Citing Articles (343) | PDF | Export Citation

ABSTRACT

Cross sections for inelastic scattering of electrons from hydrogen were measured for incident energies from 7 to 17 GeV at scattering angles of 6° to 10° covering a range of squared four-momentum transfers up to 7.4 $(\mathrm{GeV}/c)^2$. For low center-of-mass energies of the final hadronic system the cross section shows prominent resonances at low momentum transfer and diminishes markedly at higher momentum transfer. For high excitations the cross section shows only a weak momentum-transfer dependence.

Received 19 August 1969

DOI: https://doi.org/10.1103/PhysRevLett.23.930

Issue

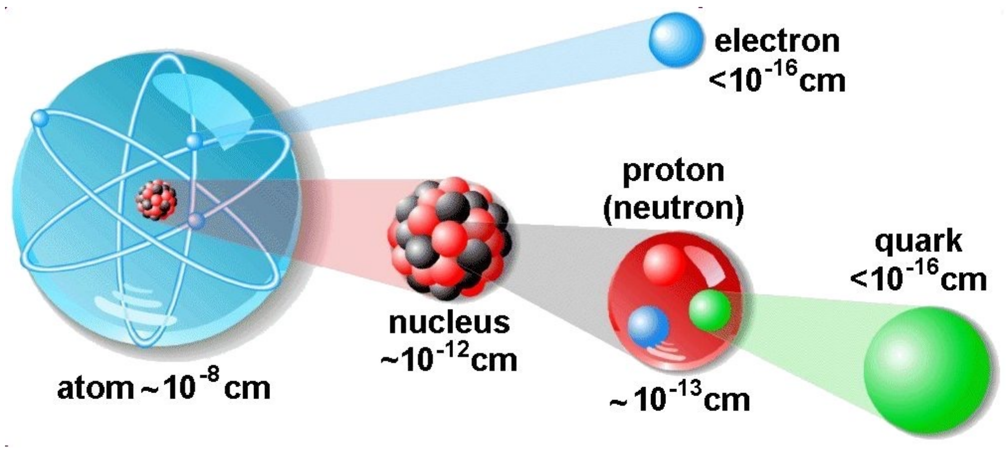
Vol. 23, Iss. 16 — 20 October 1969

Reuse & Permissions

PHYSICAL REVIEW JOURNALS 125 YEARS

Subatomic final era (1974-1995)

- In 1964, 0 . W. Greenberg proposed a way out of this dilemma: He suggested that quarks not only come in three flavors (u, d, and s) but each of these also comes in three colors (“red,” “green,” and “blue”).
- Since the exclusion principle only apply to the identical particles the problem solved.
- In 1974 J/Ψ particle discovered at BNL and SLAC by Burton Richter and Samuel C.C. Ting, which is the bound state of “Charm” quarks
- In 1975 tau lepton was discovered at SLAC by Martin Lewis Perl and his team
- In 1977 bottom or “beauty” quark was discovered by Leon M Laderman
- In 1995 top quark was discovered at Fermilab by CDF and D0 collaboration

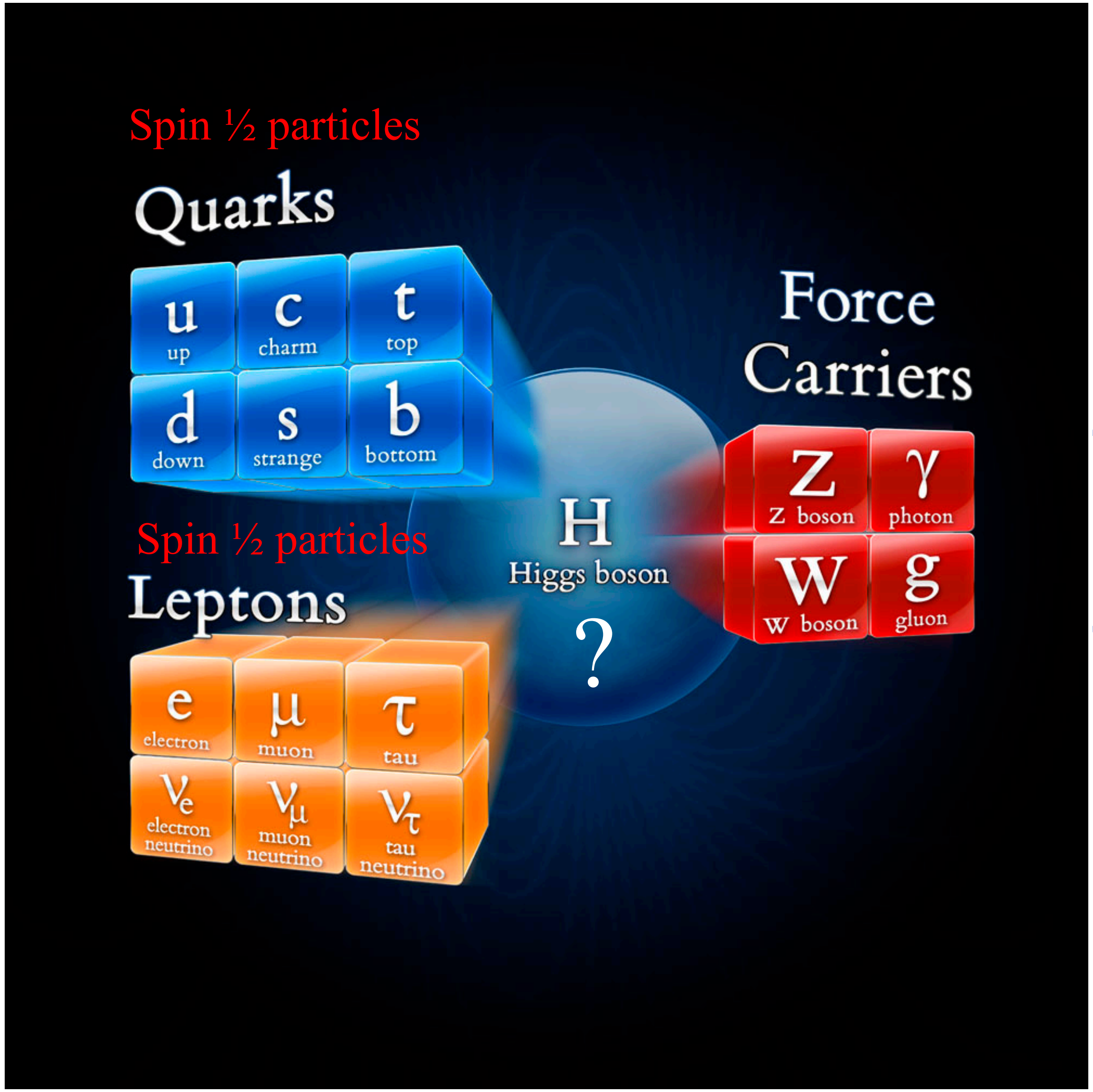


The Standard Model

Strong Interaction

EM Interaction

Weak Interaction



Vector Bosons
Spin 1 particles

- Particles
- Forces
- Fields

Higgs Mechanism

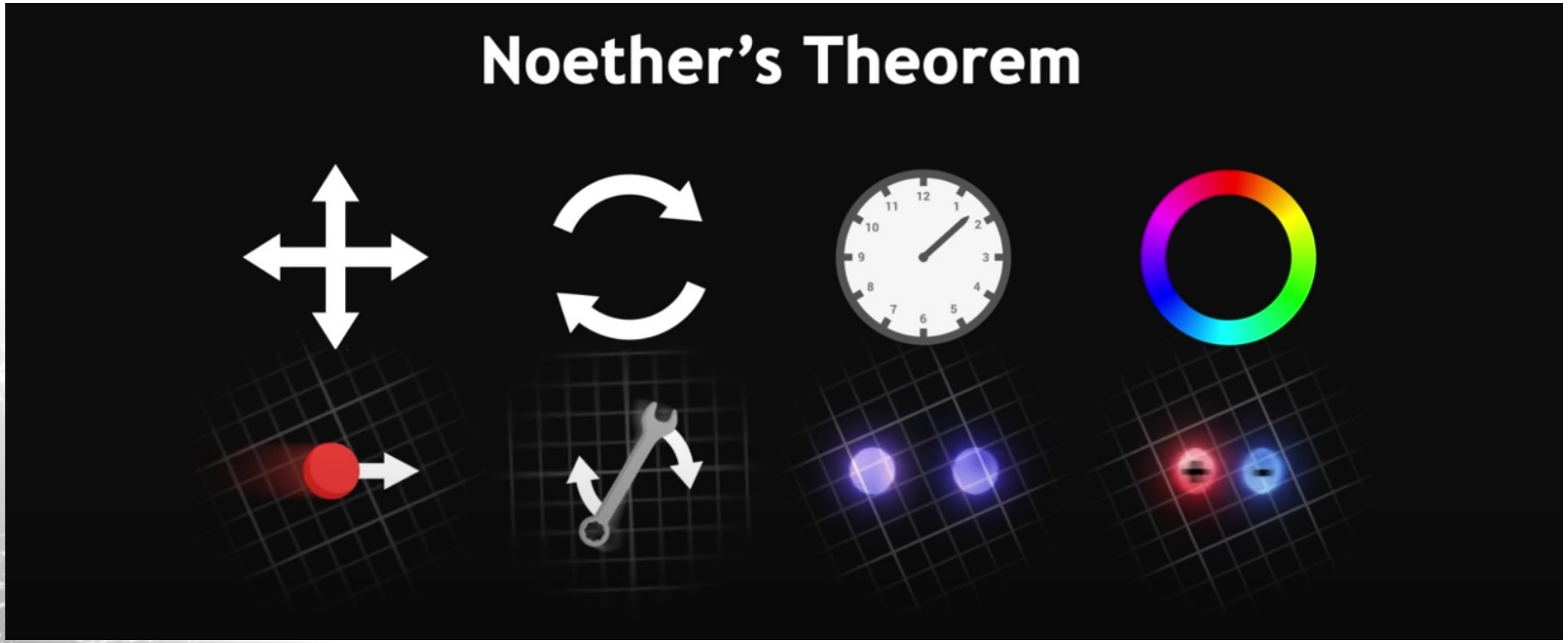
- How the elementary particles acquired masses? Why do they have different masses for different particles?
- In the 1960s, a group of physicists, including Peter Higgs, worked independently on explaining the above question.
- Peter Higgs idea: all the space in the Universe is uniformly filled with the invisible substance. The invisible substance sort of like molasses, which is also called “The Higgs Field.”
- A particle interacts with these molasses and gains mass. Different particles have different resistance in molasses and acquired different masses.
- Peter Higgs’s first submitted paper on this idea was rejected for publication, but he finally was able to convince the scientific community by providing his beautiful mathematical calculation.

Particle	Mass(GeV)
Photon, gluon	0
Neutrinos	~ 0
Electron	0.0005
Muon	0.105
Tau	1.77
Up quark	0.002
Down quark	0.004
Strange quark	0.100
Charm quark	1.27
Bottom quark	4.18
Top quark	172
W boson	80.3
Z boson	91.2
Higgs	125

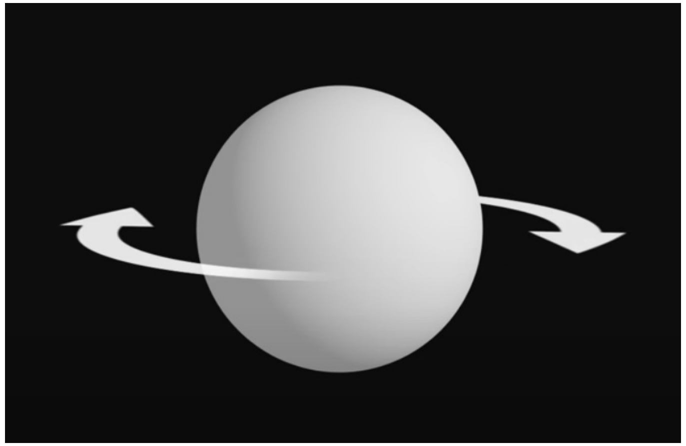
Higgs Mechanism

- The Standard Model is a paradigm of the "Quantum Field Theory".
- The Standard model is described using group theory $SU(3)\times SU(2)\times U(1)$. SU(3) is the gauge group of the strong interaction and SU(2) x U(1) is the group of electroweak interaction

Symmetry



Example



Higgs Mechanism (Lagrangian)

Lagrangian (an example)

$$\mathcal{L} = \frac{1}{2} m\dot{x}^2 - \frac{1}{2} m\omega^2 x^2$$

$$S = \int_{t_0}^{t_f} \mathcal{L} dt \,;\, \delta S = 0; \frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{x}} = \frac{\partial \mathcal{L}}{\partial x} ; m\ddot{x} = -m\omega^2 x$$

Fields

a) Fermion field (spin ½ particles)
b) Vector field (spin 1 particles (vector bosons))
c) Scalar field (spin zero boson)

Lagrangian (with respect to the field)

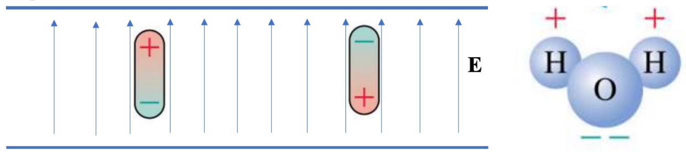
$$\phi(x,t) = \phi(x^\mu)$$

$$\partial_\nu \phi \equiv \frac{\partial \phi}{\partial x^\nu} ; \partial^\nu \phi \equiv g^{\nu\mu} \frac{\partial \phi}{\partial x^\mu} ; S = \int \mathcal{L}(\phi, \partial_\nu \phi) d^4 x$$

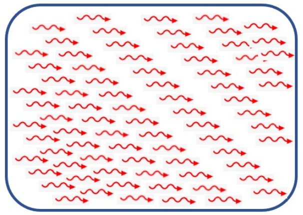
$$\partial_\mu \left(\frac{\partial \mathcal{L}}{\partial \phi_\mu} \right) = \frac{\partial \mathcal{L}}{\partial \phi}$$

$$-E^2\phi + p^2\phi + m^2\phi = 0$$

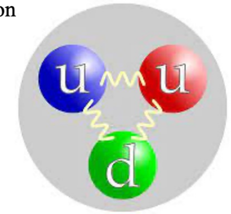
Water molecule dipole in electric field



Photon box



Proton



Standard Model (Lagrangian)

1

$$-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \frac{1}{2}ig_s^2(\bar{q}^\sigma_i \gamma^\mu q^\sigma_j)g^a_\mu + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu$$

2

$$- \partial_\nu W^+_\mu \partial_\nu W^-_\mu - M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+\phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h\left[\frac{2M^2}{g^2} + \frac{2M}{g}H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)\right] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] - \frac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2 H^2] - gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \frac{1}{2}ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \frac{1}{2}g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)] + \frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_w MA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac{1}{4}g^2 W^+_\mu W^-_\mu[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] - \frac{1}{4}g^2\frac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-] - \frac{1}{2}g^2\frac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) + \frac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c_w^2 - 1)Z^0_\mu A_\mu\phi^+\phi^- - g^1 s_w^2 A_\mu A_\mu\phi^+\phi^-$$

3

$$- \bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \bar{\nu}^\lambda\gamma\partial\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + m_u^\lambda)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial + m_d^\lambda)d^\lambda_j + igs_w A_\mu\left[-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)\right] + \frac{ig}{4c_w}Z^0_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(\frac{4}{3}s_w^2 - 1 - \gamma^5)u^\lambda_j) + (\bar{d}^\lambda_j\gamma^\mu(1 - \frac{8}{3}s_w^2 - \gamma^5)d^\lambda_j)] + \frac{ig}{2\sqrt{2}}W^+_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \frac{ig}{2\sqrt{2}}W^-_\mu[(\bar{e}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa}\gamma^\mu(1+\gamma^5)u^\lambda_j)] +$$

4

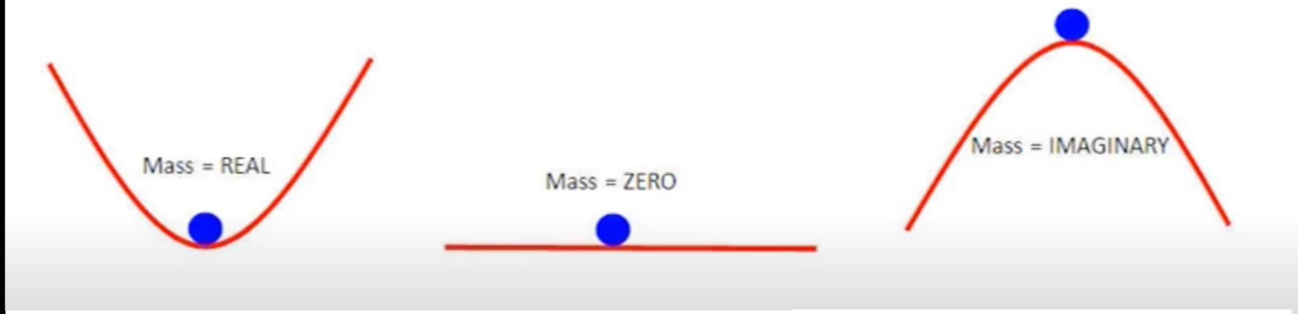
$$\frac{ig}{2\sqrt{2}}\frac{m_e^\lambda}{M}[-\phi^+(\bar{\nu}^\lambda(1-\gamma^5)e^\lambda) + \phi^-(\bar{e}^\lambda(1+\gamma^5)\nu^\lambda)] - \frac{g}{2}\frac{m_e^\lambda}{M}[H(\bar{e}^\lambda e^\lambda) + i\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}}\phi^+[-m_d^\kappa(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m_u^\lambda(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j] + \frac{ig}{2M\sqrt{2}}\phi^-[m_d^\lambda(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m_u^\kappa(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j] - \frac{g}{2}\frac{m_u^\lambda}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \frac{g}{2}\frac{m_d^\lambda}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m_u^\lambda}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) - \frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) +$$

5

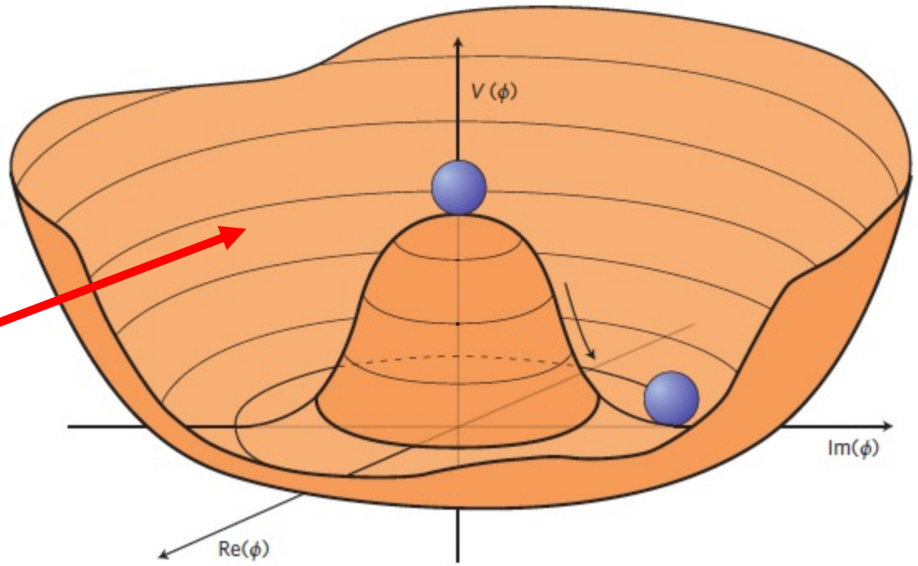
$$\bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \frac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y - \partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) - \frac{1}{2}gM[\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2}\bar{X}^0 X^0 H] + \frac{1-2c_w^2}{2c_w}igM[\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-] + \frac{1}{2c_w}igM[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + igMs_w[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + \frac{1}{2}igM[\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0]$$

Standard Model (Lagrangian)

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi} \not{D} \psi + h.c. + \psi_i y_{ij} \psi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$



$$V(\phi) = -|\mu^2||\phi|^2 + \lambda(|\phi|^2)^2$$

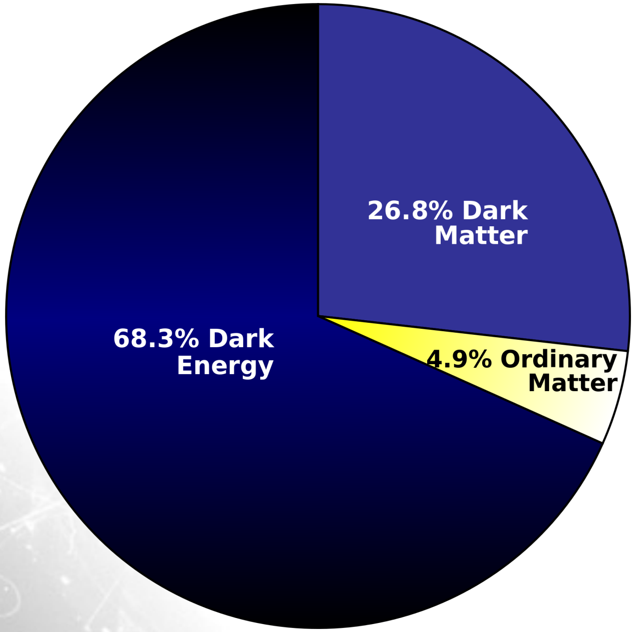


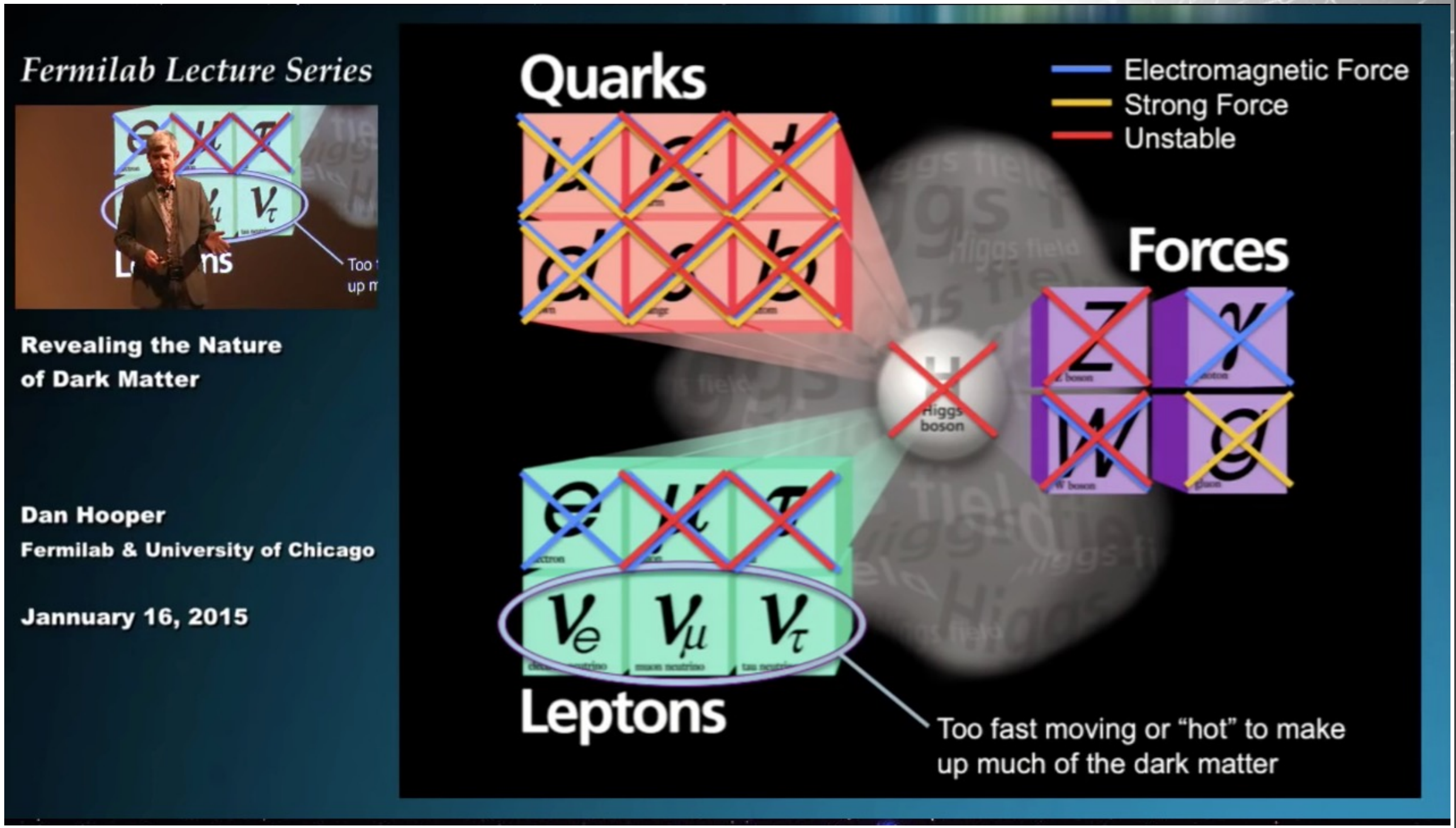
Higgs Boson

To observe the Higgs field, we must produce its quantum particle, the Higgs Boson, as like as a photon in the electromagnetic field

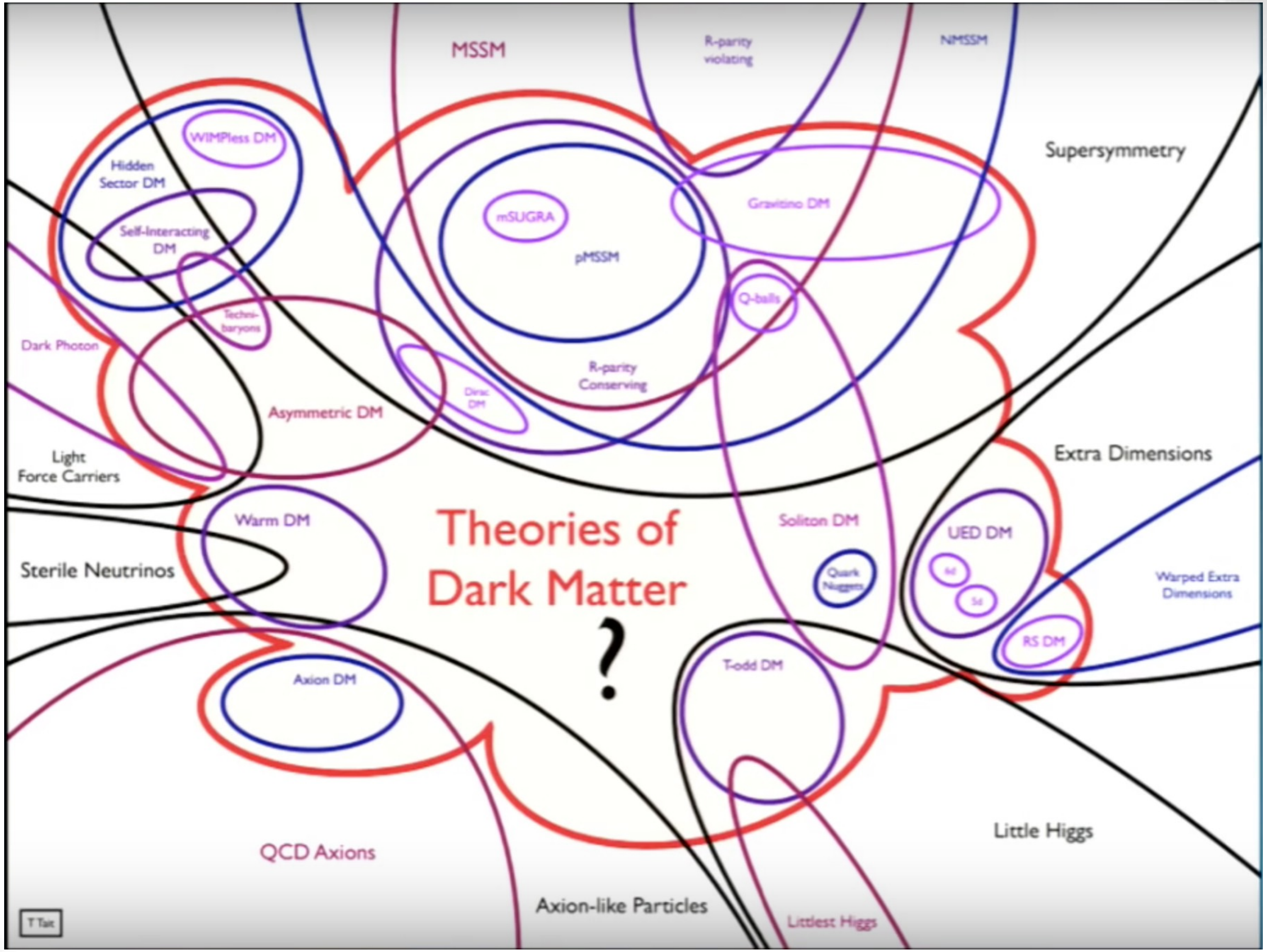
July 2012 @ ATLAS and CMS at the Large Hardon Collider

Beyond Standard Model





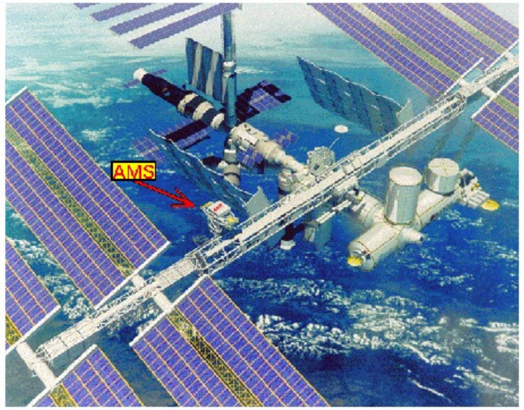
Beyond Standard Model



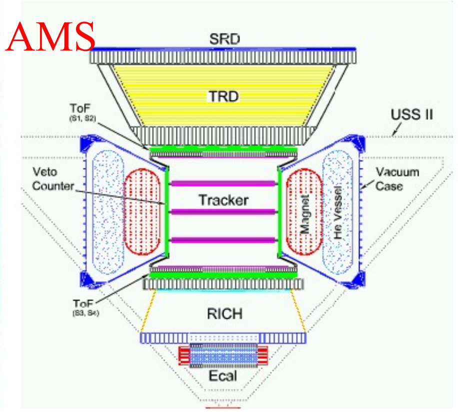
Dark matter Search

- Satellite base

AMS



AMS-02 on International Space Station (Oct.2003)

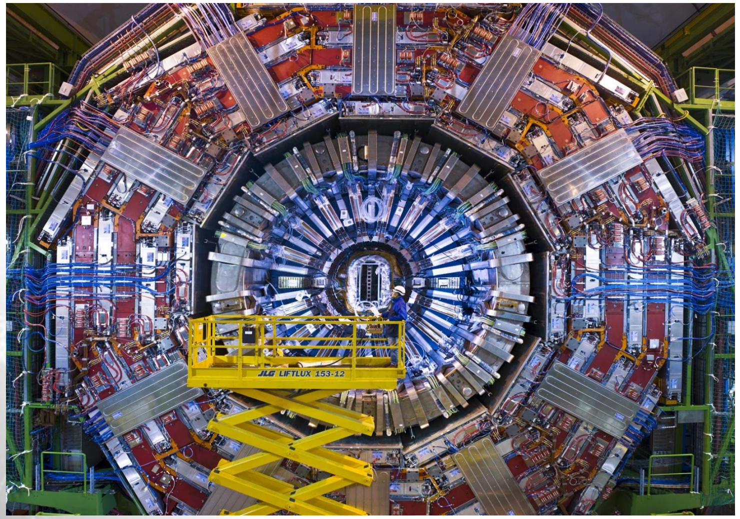


Main Components of AMS-02 Detector

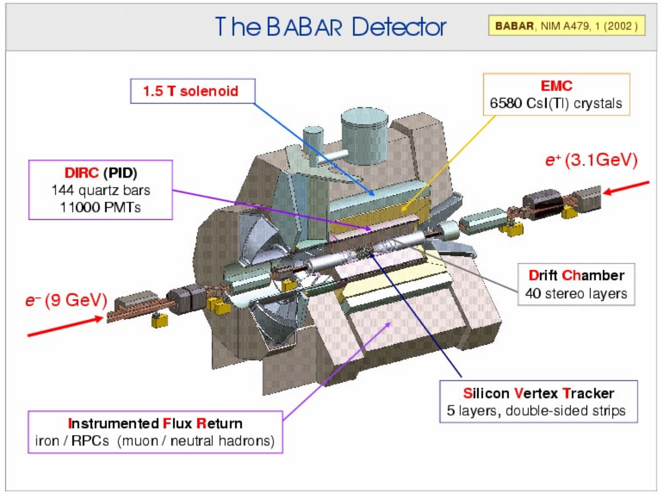
PAMELA

- Ground base

ATLAS



BABAR

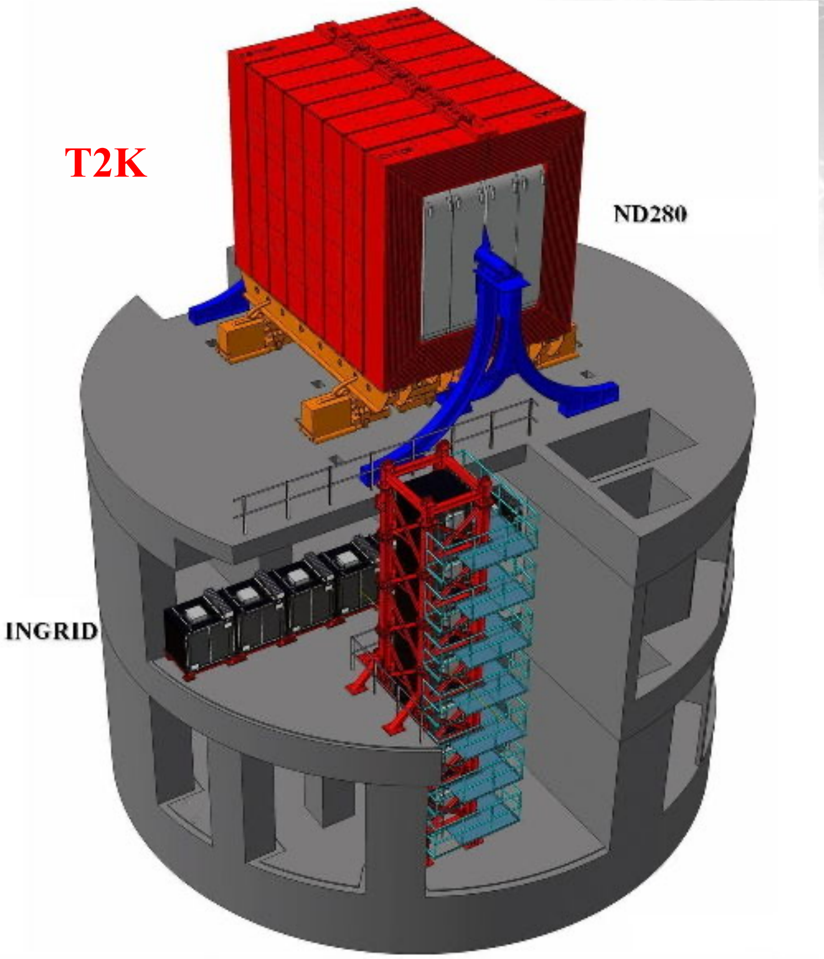


Dark matter Search

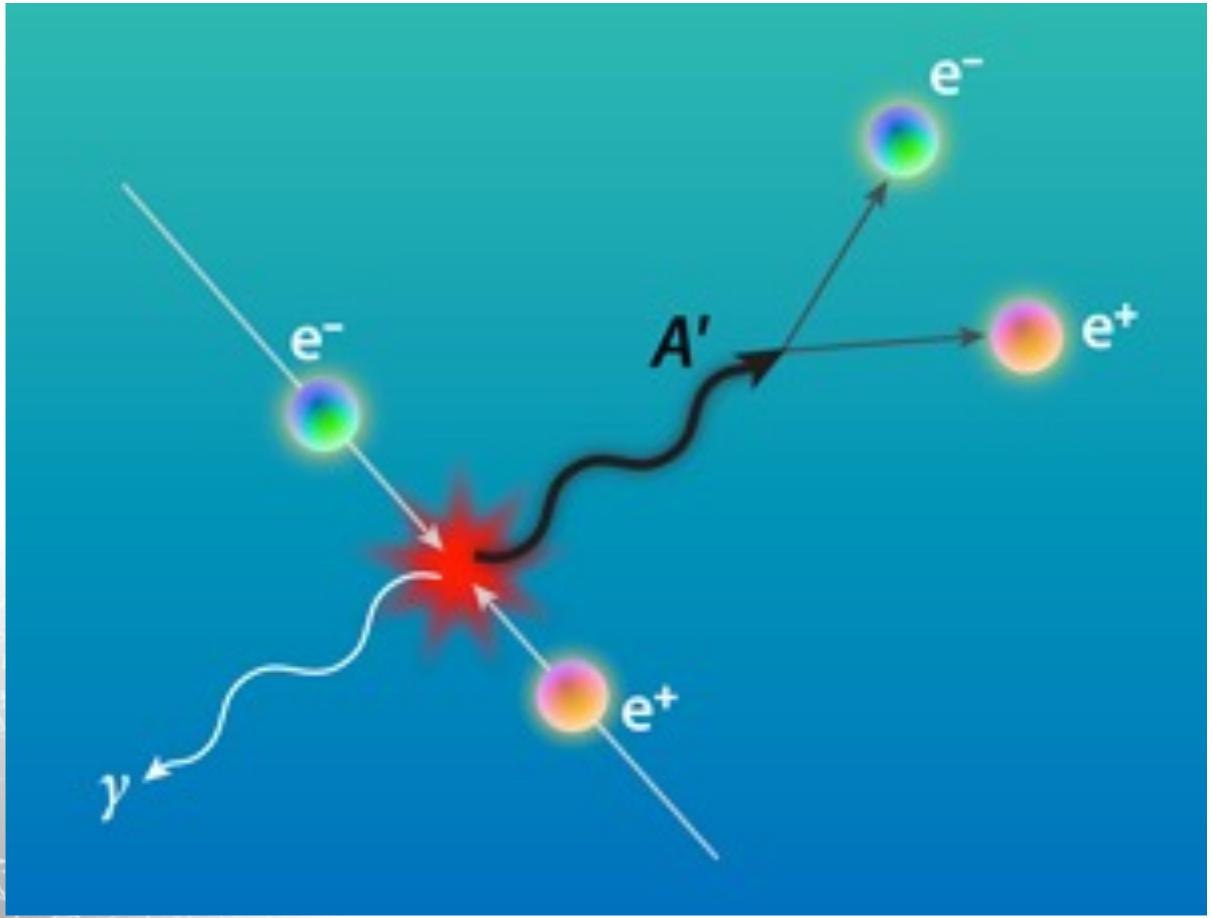
- ❑ Underground base

SNO

T2K



Dark matter Search



- The known particles and interactions in the SM are insufficient to explain dark matter.

- Many theoretical predictions and astronomical observations suggest dark sector – feebly coupled to the SM.

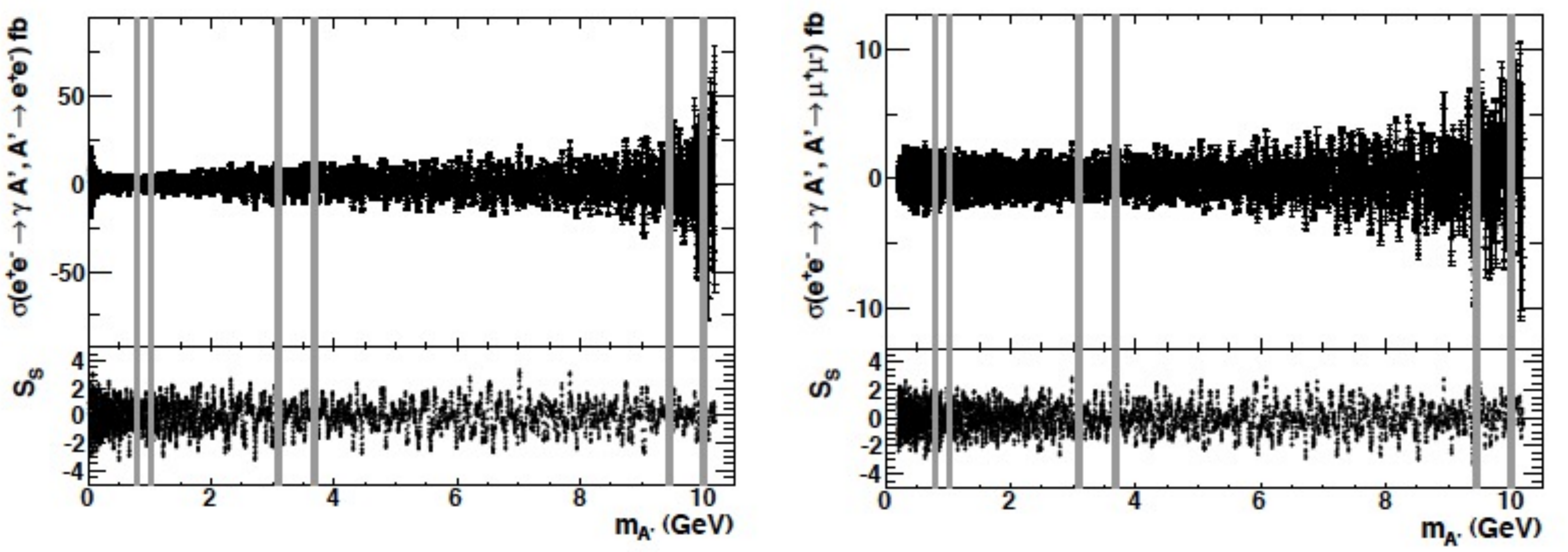
- Beyond Standard Model (BSM) scenario with new gauge bosons (dark photon (A′)/boson(Z′)) which are the mediators of the new $U(1)'$ interactions.

$$e^+e^- \to \gamma A', A' \to e^+e^-, \mu^+\mu^-$$

- 20 MeV to 10.2 GeV

- BABAR full dataset: 514 fb^{-1} (~ 514, 000000 events)

Dark matter Search



- No significant signal (A' →visible particles)
- **PRL 113 201801 (2014)**

Belle II experiment at KEK

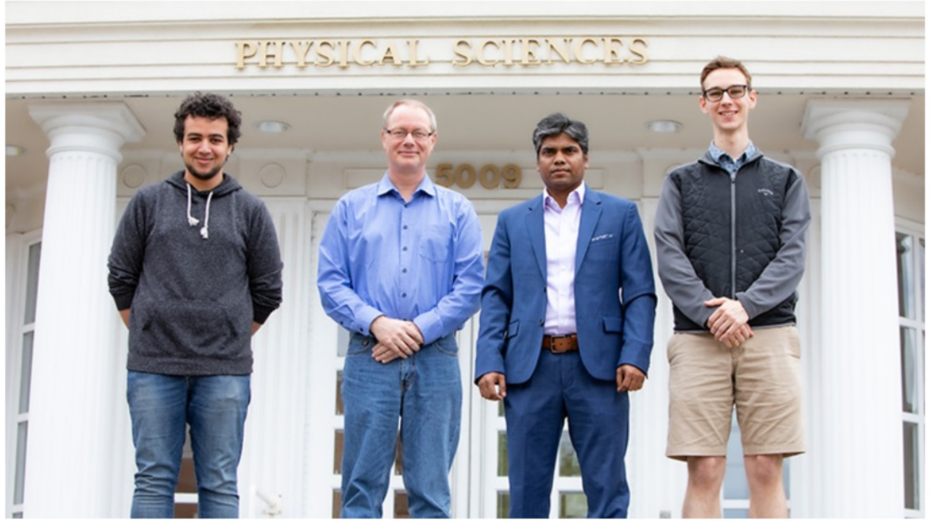
ACADEMICS WHY STFX ADMISSIONS STUDENT LIFE ST. FRANCIS XAVIER UNIVERSITY RESEARCH INTERNATIONAL COADY INSTITUTE ALUMNI

Home > About StFX > News >

StFX voted new member of Belle II collaboration; providing opportunity to work on potentially Nobel Prize winning research

STFX VOTED NEW MEMBER OF BELLE II COLLABORATION; PROVIDING OPPORTUNITY TO WORK ON POTENTIALLY NOBEL PRIZE WINNING RESEARCH

June 26th, 2019



L-r, Noah Tessema, Dr. Peter Marzlin, Dr. Hossain Ahmed and Patrick O'Brien

Acknowledgement

NSERC
CRSNG

INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

ST. FRANCIS XAVIER
UNIVERSITY