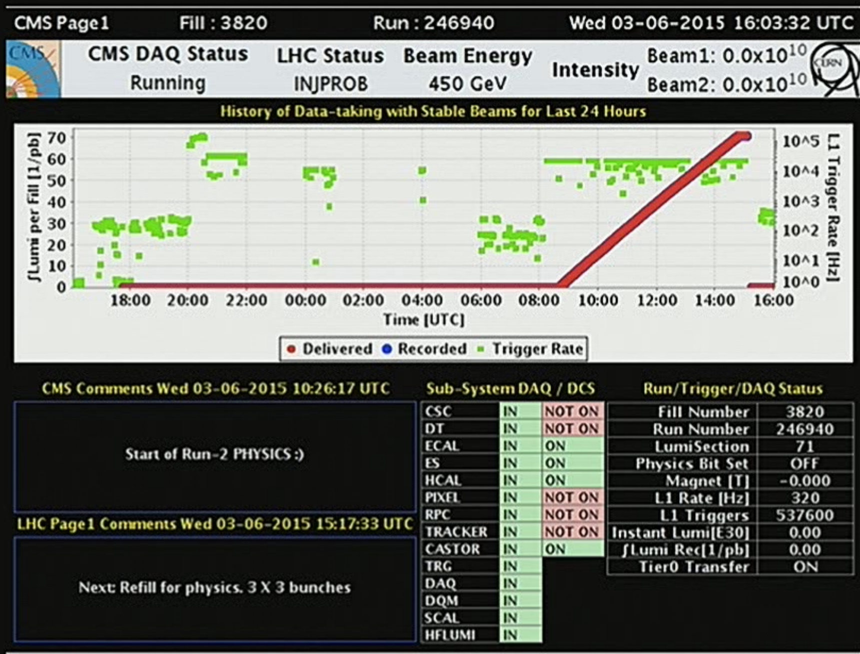
Title: The richness of particle physics

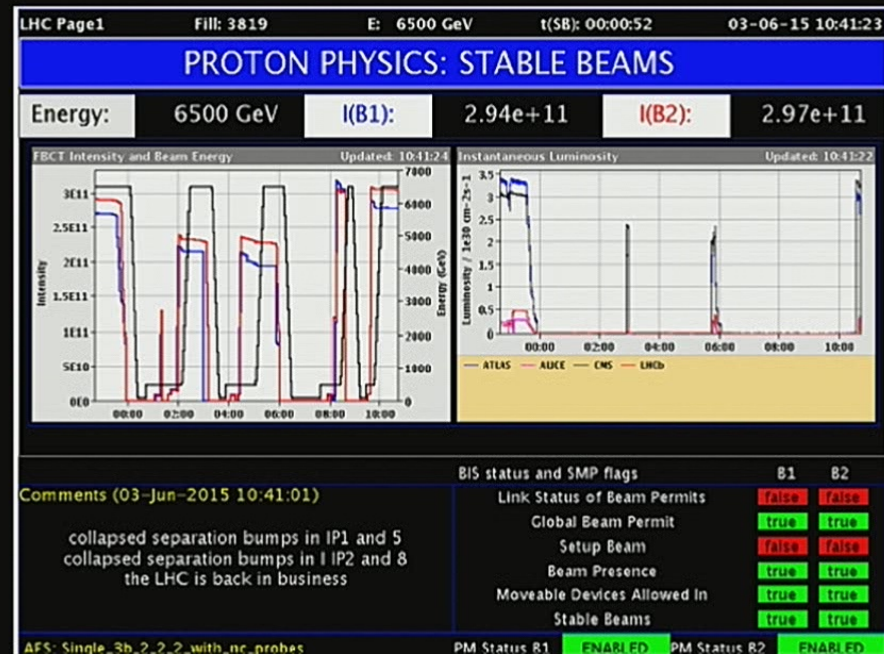
Date: Jun 22, 2015 10:00 AM

URL: http://pirsa.org/15060044

Abstract: I will discuss the state of particle physics today and emphasize the implications of the discovered H-boson in high energy physics and cosmology and the connections with the future discovery and precision machines and observatories world-wide.

JUNE 3: LHC 13 TEV RUN2 BEGINS





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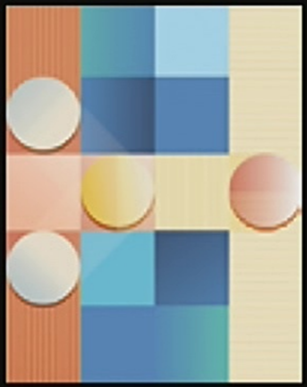

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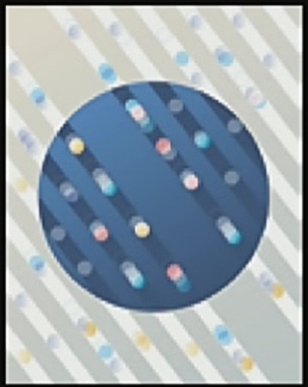

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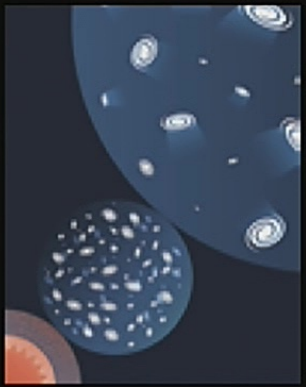

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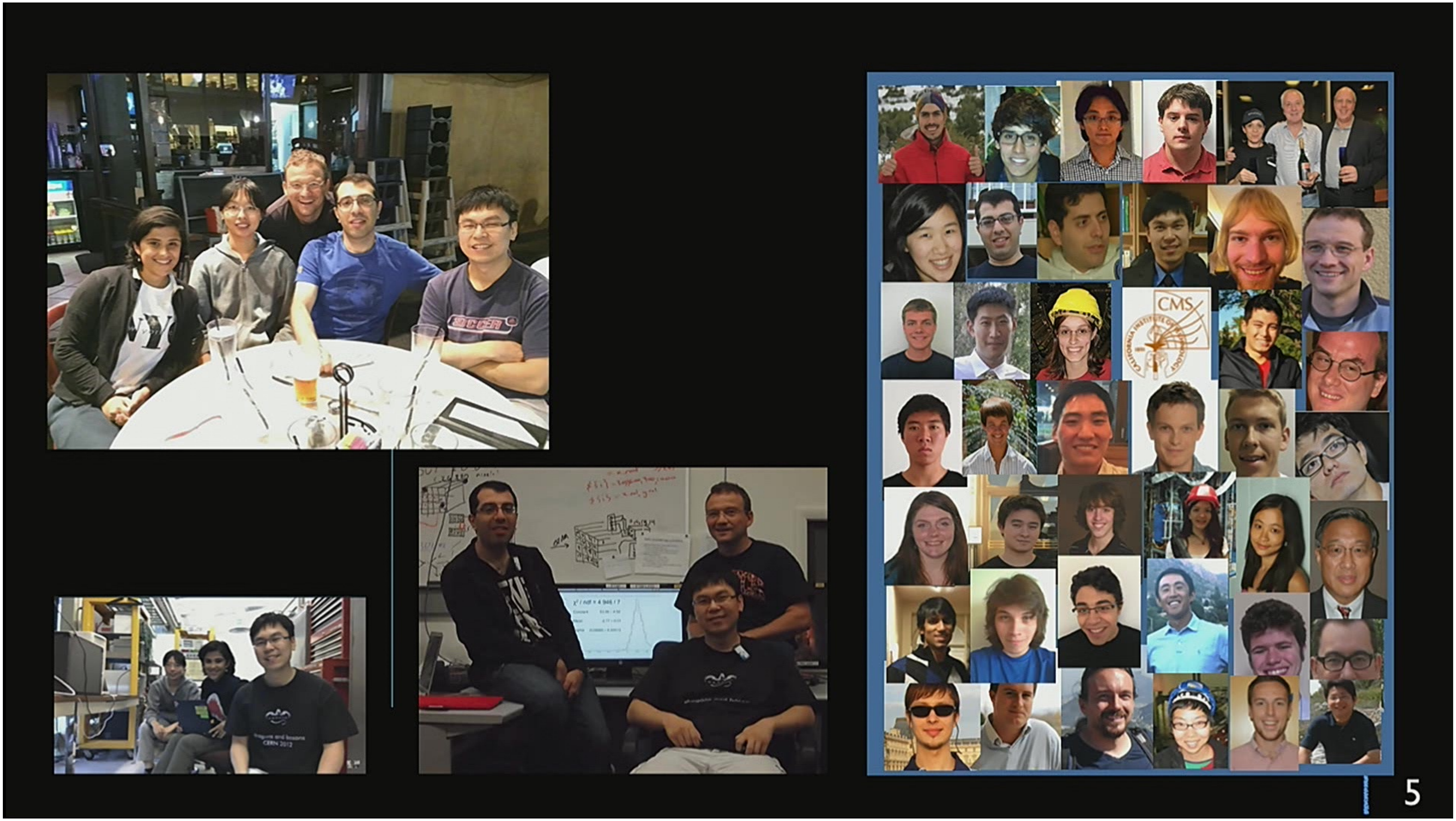
CMS
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A New Era for United States Cooperation with CERN
Posted by Jo Handelsman and Saul Gonzalez on May 07, 2015 at 05:19 PM EDT
E-Mail Tweet Share +
Question: What do the Higgs boson and the World Wide Web have in common? Answer: Not much, except that both trace their origins to the world's leading particle physics organization: the European Laboratory for Nuclear Research (CERN), located near Geneva, Switzerland. Today, at a brief ceremony led by OSTP Associate Director for Science Jo Handelsman, the United States signed an agreement for renewed cooperation with this prominent institution.
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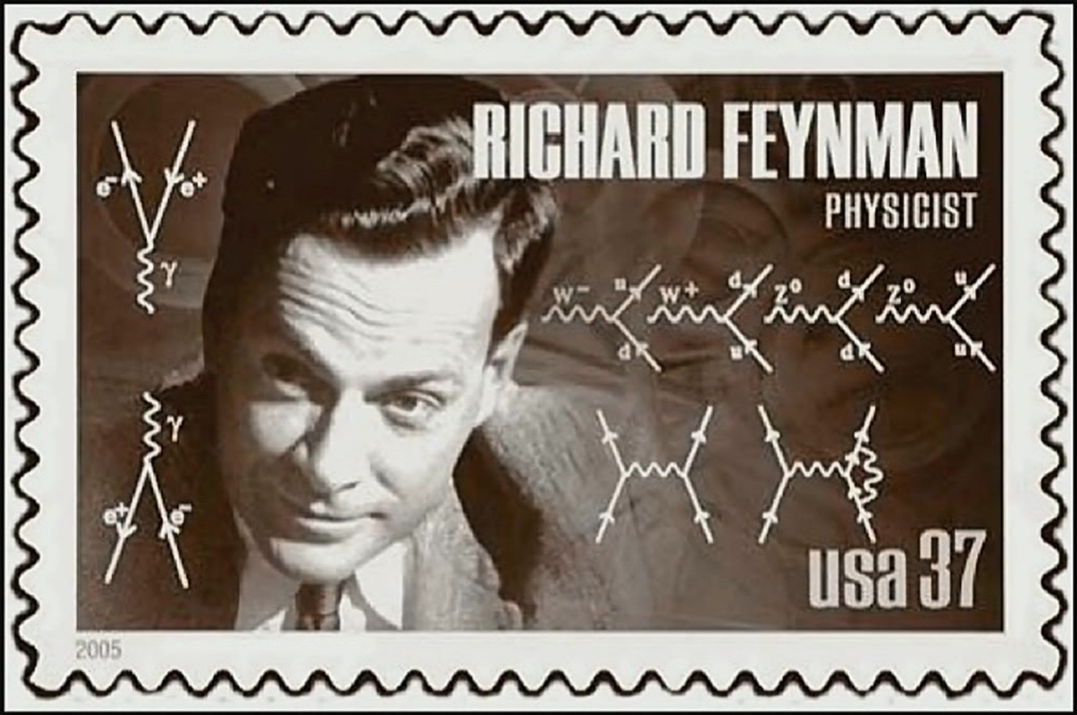
THE STANDARD THEORY OF PARTICLES AND FORCES

7

THE STANDARD FRAMEWORK: QUANTUM FT

— **QUANTUM FIELD THEORY** is the language of particle physics and condensed matter physics



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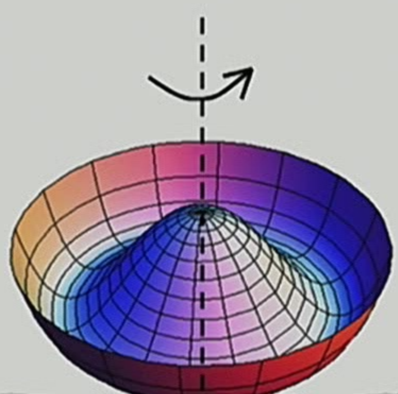
THE STANDARD MODEL & PARTICLE CONTENT

The Standard Model

A blueprint for the universe

$$\mathcal{L} = -\tfrac{1}{4}F^{\mu\nu i}F_{\mu\nu i} - \tfrac{1}{4}B^{\mu\nu}B_{\mu\nu} - \left(D_\mu\phi\right)^\dagger D_\mu\phi - \tfrac{1}{2}\lambda\left(\phi^\dagger\phi - v^2\right)^2$$
$$+i\bar{l}_L\gamma^\mu D_\mu l_L + i\bar{e}_R\gamma^\mu D_\mu e_R + i\bar{q}_L\gamma^\mu D_\mu q_L + i\bar{u}_R\gamma^\mu D_\mu u_R + i\bar{d}_R\gamma^\mu D_\mu d_R$$
$$-G_e\bar{l}_L.\phi e_R - G_d\bar{q}_L.\phi d_R - G_u\bar{q}_R.\phi^c u_R + \text{h.c.}$$



Three Generations of Matter (Fermions)

		I	II	III	Bosons (Forces)
	mass→ / harge→ / spin→ / name→	2.4 MeV, ⅔, ½, u, up	1.27 GeV, ⅔, ½, c, charm	171.2 GeV, ⅔, ½, t, top	0, 0, 1, γ, photon
Quarks		4.8 MeV, -⅓, ½, d, down	104 MeV, -⅓, ½, s, strange	4.2 GeV, -⅓, ½, b, bottom	0, 0, 1, g, gluon
		<2.2 eV, 0, ½, ν_e, electron neutrino	<0.17 MeV, 0, ½, ν_μ, muon neutrino	<15.5 MeV, 0, ½, ν_τ, tau neutrino	91.2 GeV, 0, 1, Z^0, weak force
Leptons		0.511 MeV, -1, ½, e, electron	105.7 MeV, -1, ½, μ, muon	1.777 GeV, -1, ½, τ, tau	80.4 GeV, ±1, 1, $W^\pm$, weak force

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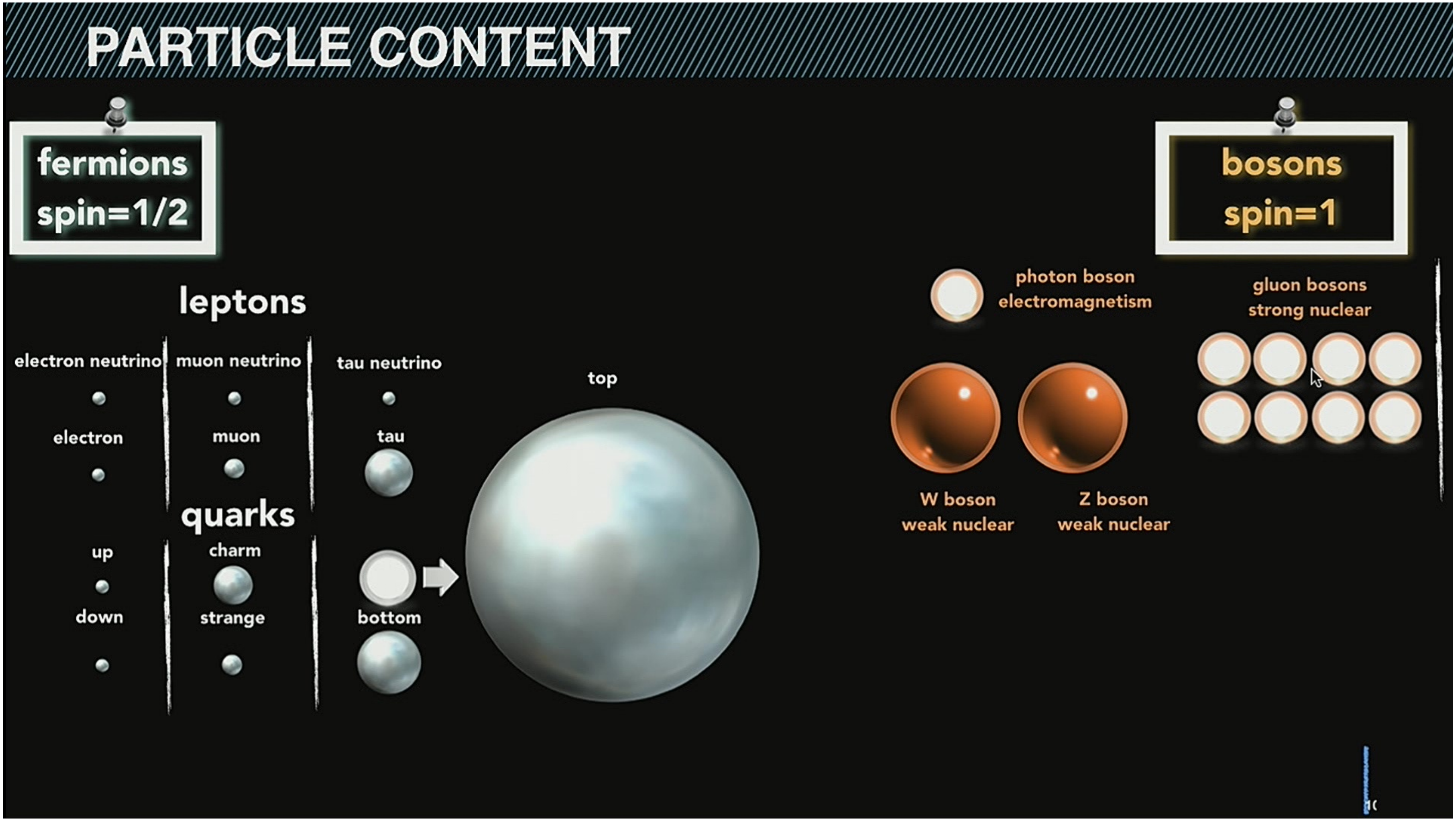
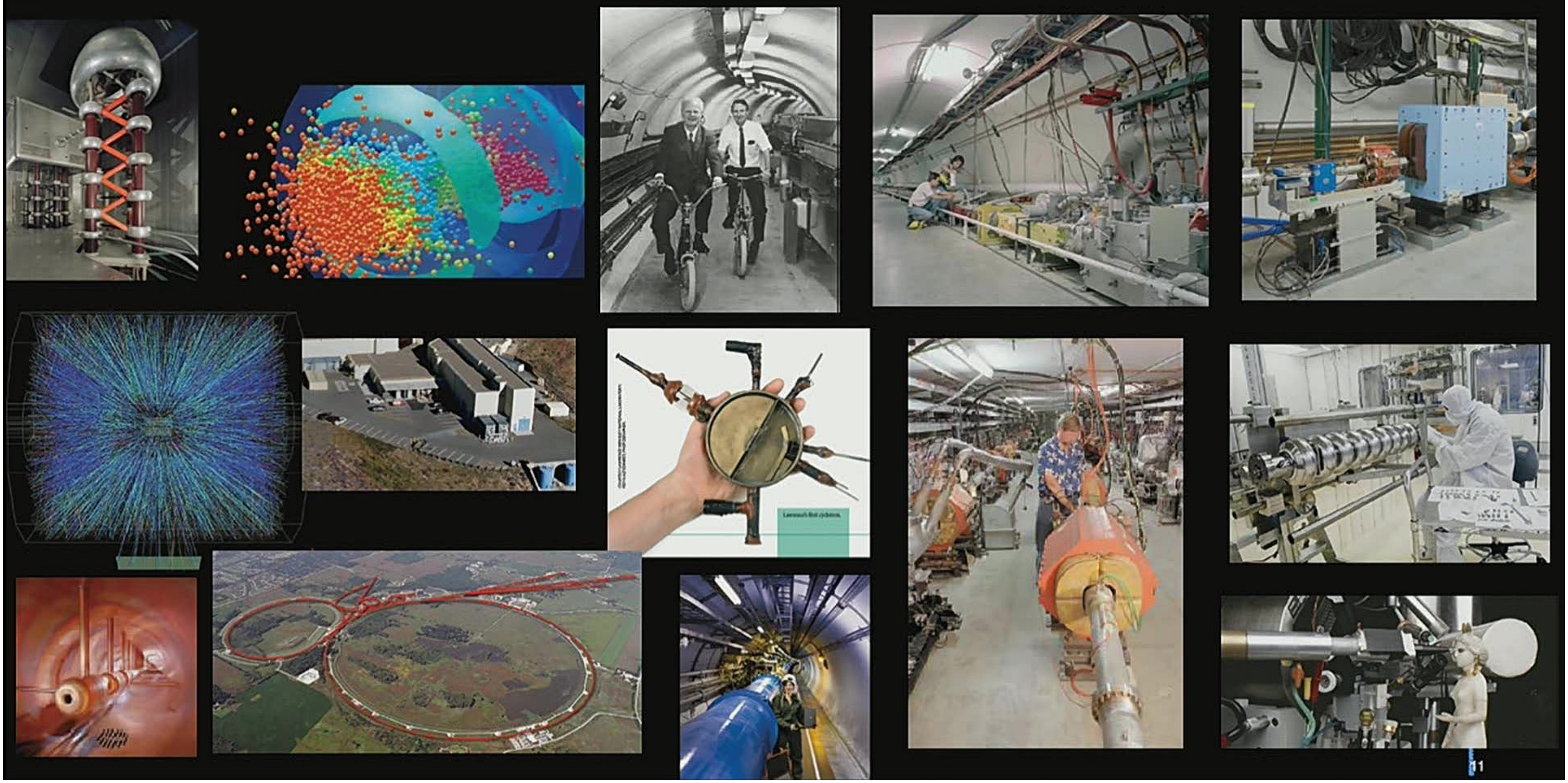
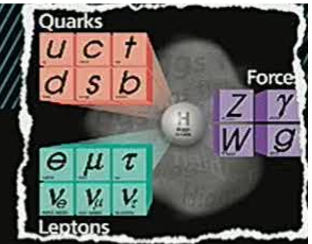

PARTICLE CONTENT
fermions
spin=1/2
leptons
electron neutrino
muon neutrino
tau neutrino
electron
muon
tau
quarks
up
charm
top
down
strange
bottom
bosons
spin=1
photon boson
electromagnetism
gluon bosons
strong nuclear
W boson
weak nuclear
Z boson
weak nuclear

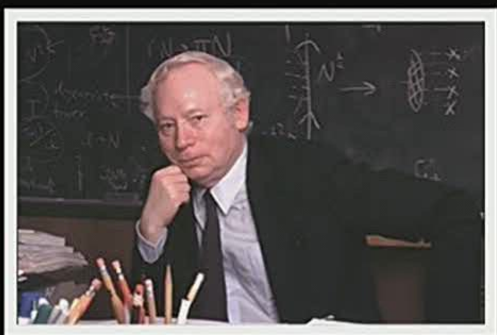
ACCELERATORS FOR DISCOVERY

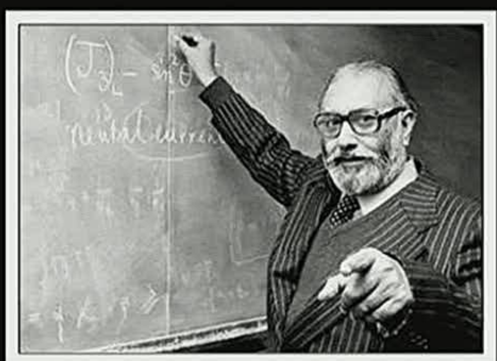


MY TRAJECTORY UNDERGROUND

THE FULL STANDARD MODEL (1967)

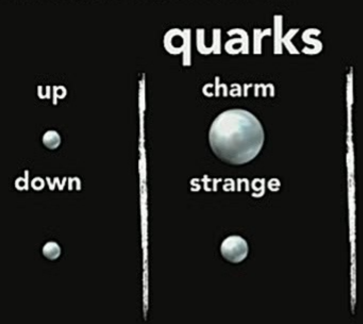






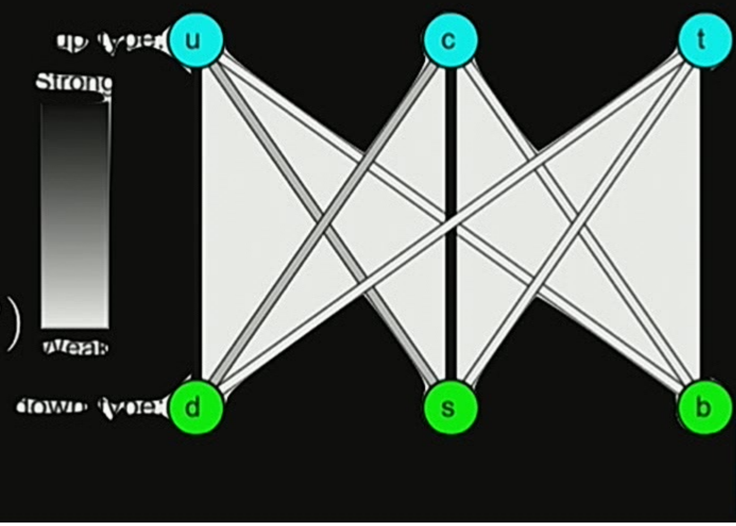
- Elementary particles do not naturally have mass
- They can acquire mass through dynamics
- For gauge bosons, **the Higgs mechanism is how this works**
- Quarks and charged leptons also get mass from different interactions with the Higgs field
- **<u>The mass generation for the diverse "flavors" of fermions is still a big mystery...</u>**

QUARK QUANTUM MIXING



Cabibbo–Kobayashi–Maskawa

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



3 mixing angels $(\theta_{12} \sim 13^\circ, \theta_{13} \sim 0.2^\circ, \theta_{23} \sim 2.4^\circ)$

1 CP-violating phase $\delta_{13} = 57^\circ$

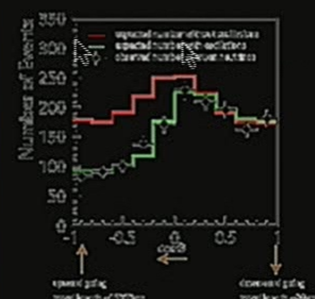
LEPTON QUANTUM MIXING

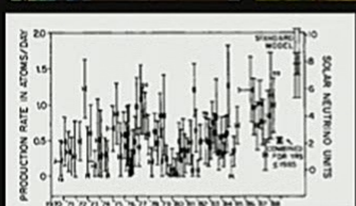
$$\begin{pmatrix} 0.8 & 0.5 & 0.15 \\ 0.35 & 0.7 & 0.6 \\ 0.4 & 0.45 & 0.8 \end{pmatrix}$$

> 50 years program and going

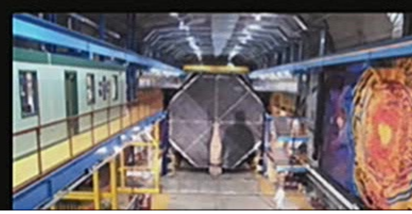
Ray Davis @Homestake Super-K @ Kamioka,Japan SNO @Sudbury,Canada



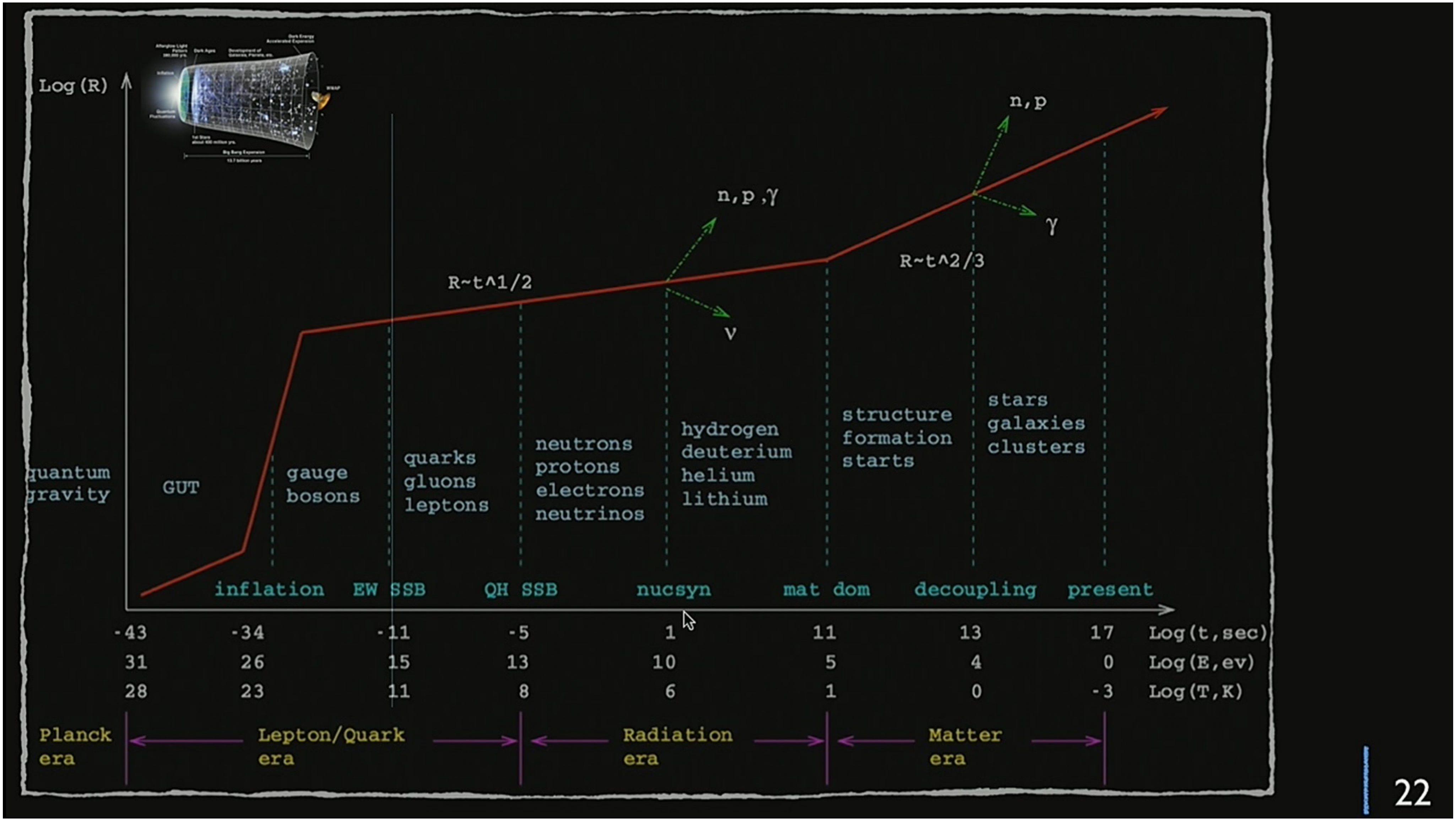


MINOS@FNAL+Minnesot





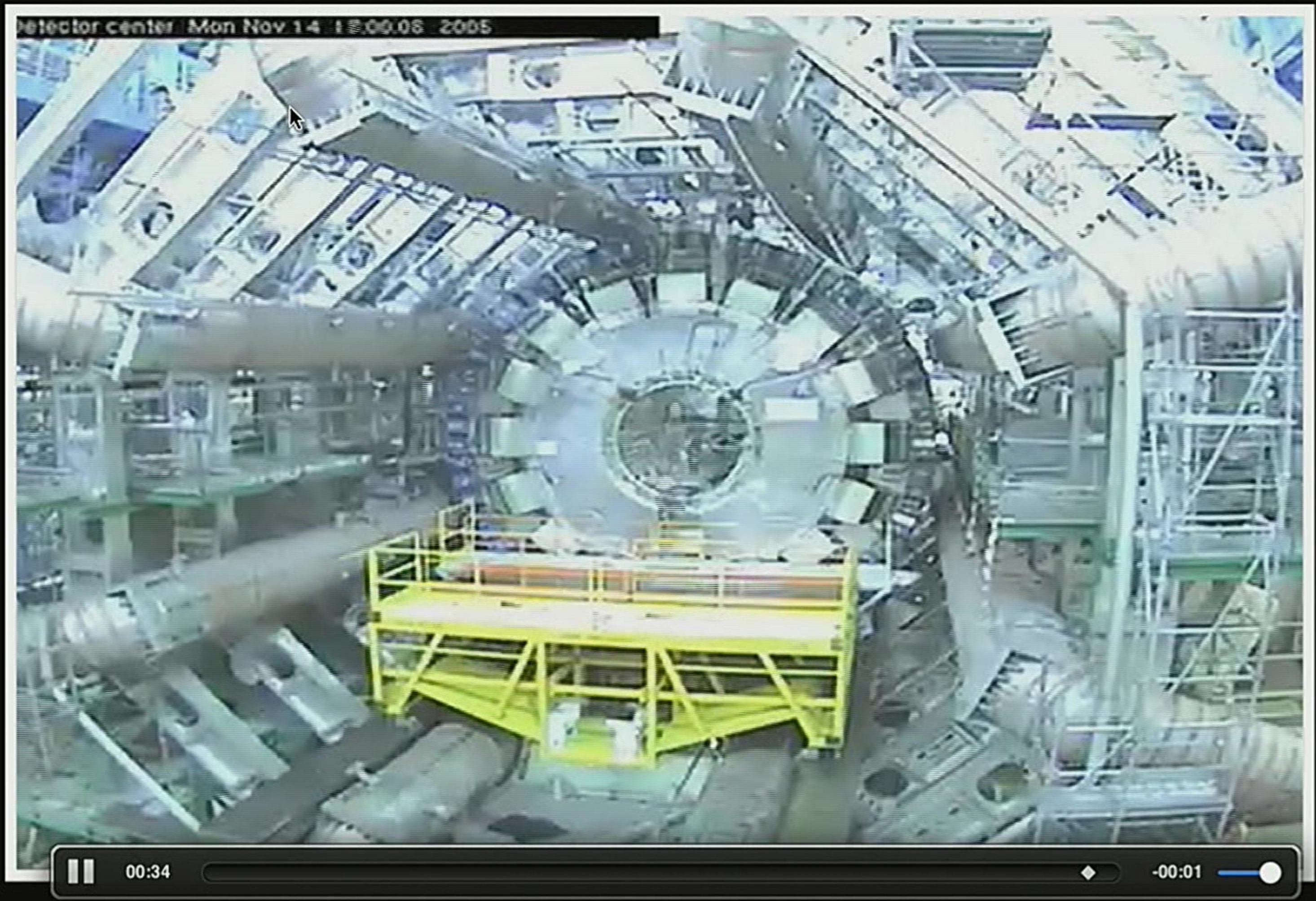
DUSEL Underground Lab
South Dakota
Minnesota
MINOS Neutrino Detector
Nebraska
Wisconsin
Iowa
Milwaukee
Fermilab
Chicago
Image © 2008 TerraMetrics



Log(R)
n,p
n,p,γ
γ
R~t^1/2
R~t^2/3
ν
quantum gravity
GUT
gauge bosons
quarks gluons leptons
neutrons protons electrons neutrinos
hydrogen deuterium helium lithium
structure formation starts
stars galaxies clusters
inflation
EW SSB
QH SSB
nucsyn
mat dom
decoupling
present
-43 -34 -11 -5 1 11 13 17 Log(t,sec)
31 26 15 13 10 5 4 0 Log(E,ev)
28 23 11 8 6 1 0 -3 Log(T,K)
Planck era
Lepton/Quark era
Radiation era
Matter era
22

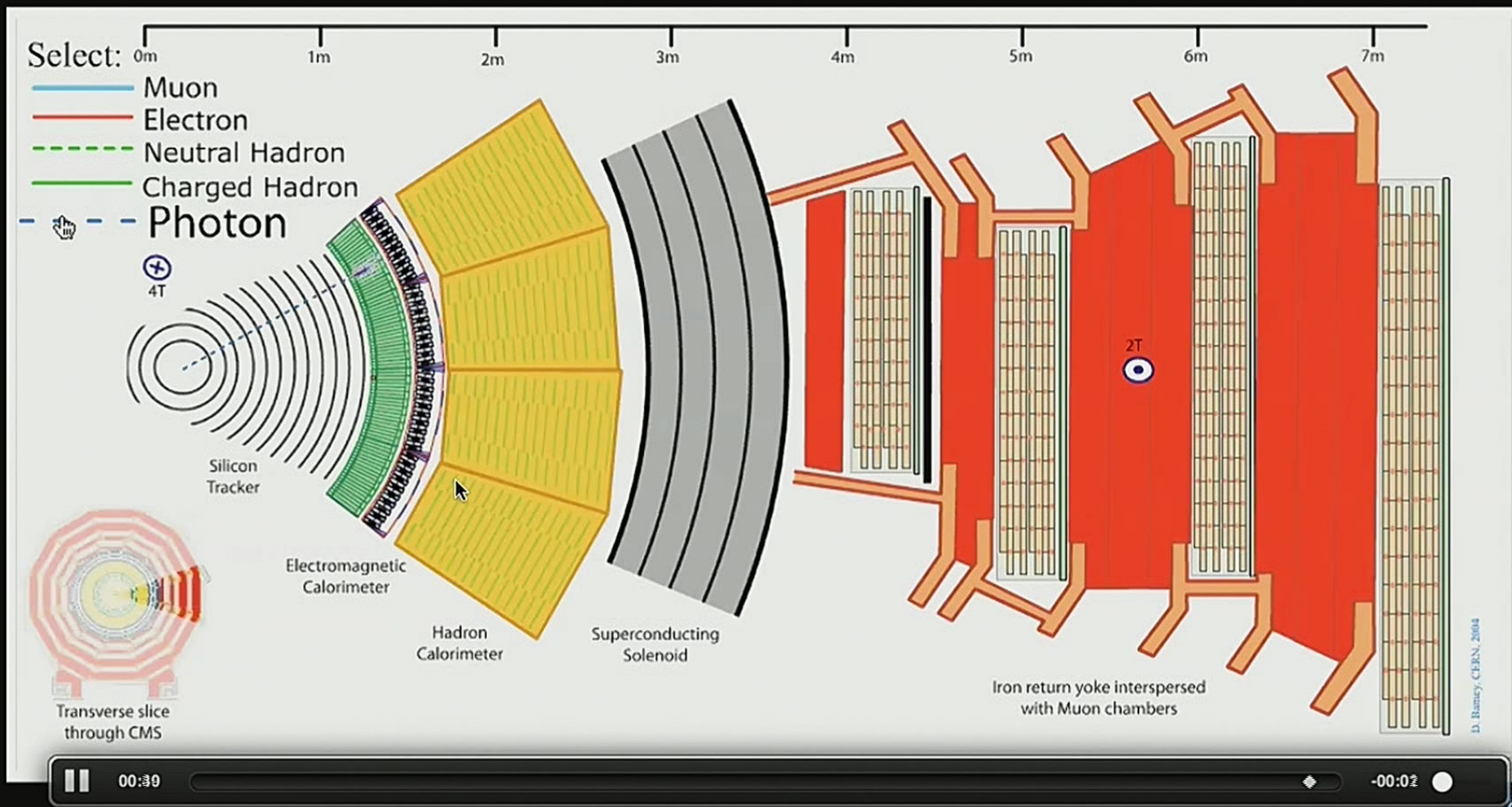
DISCOVERY MACHINE & DETECTION INSTRUMENTS

DISCOVERY MACHINE & DETECTION INSTRUMENTS

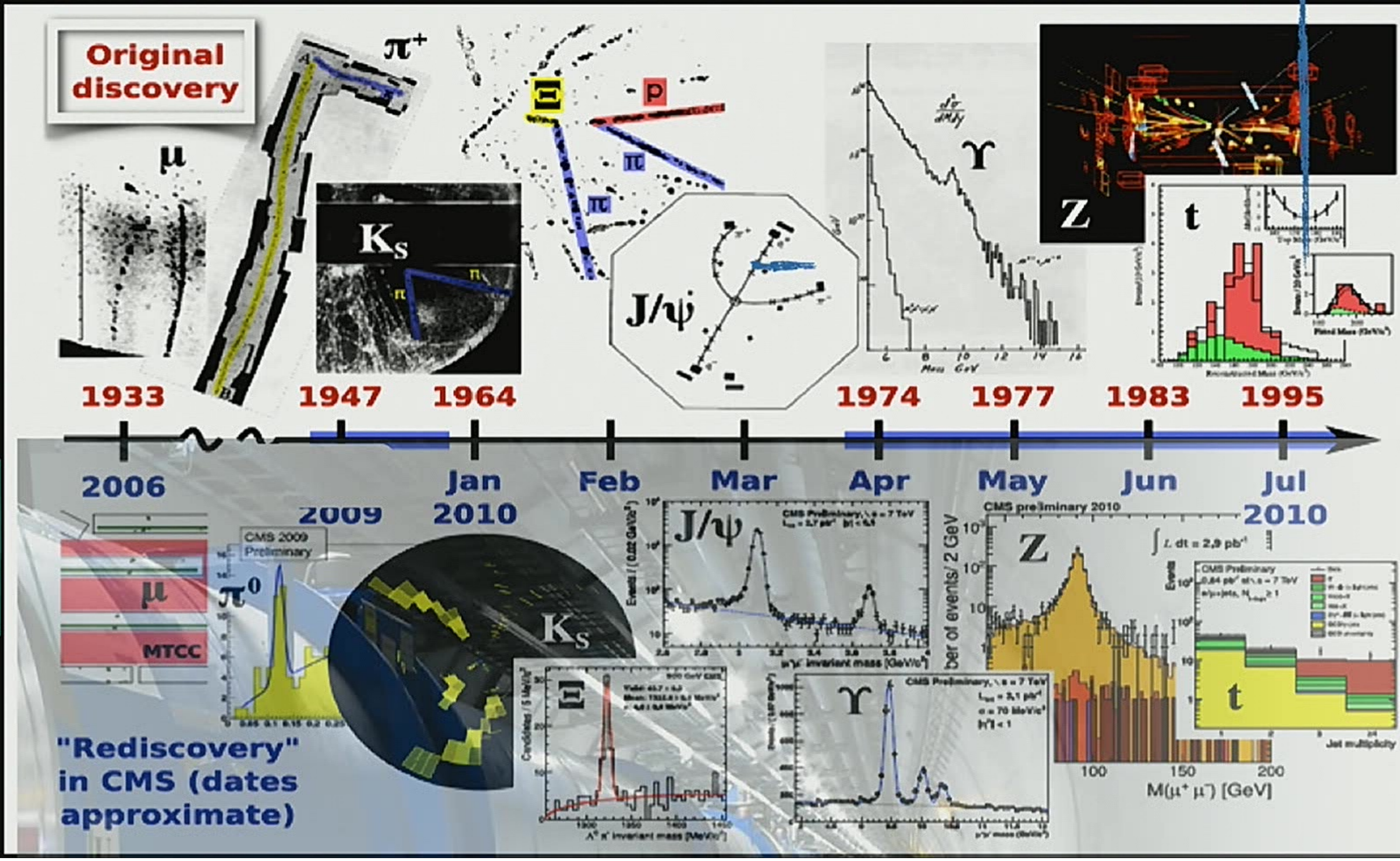


THE TUNNEL

PARTICLE DETECTOR

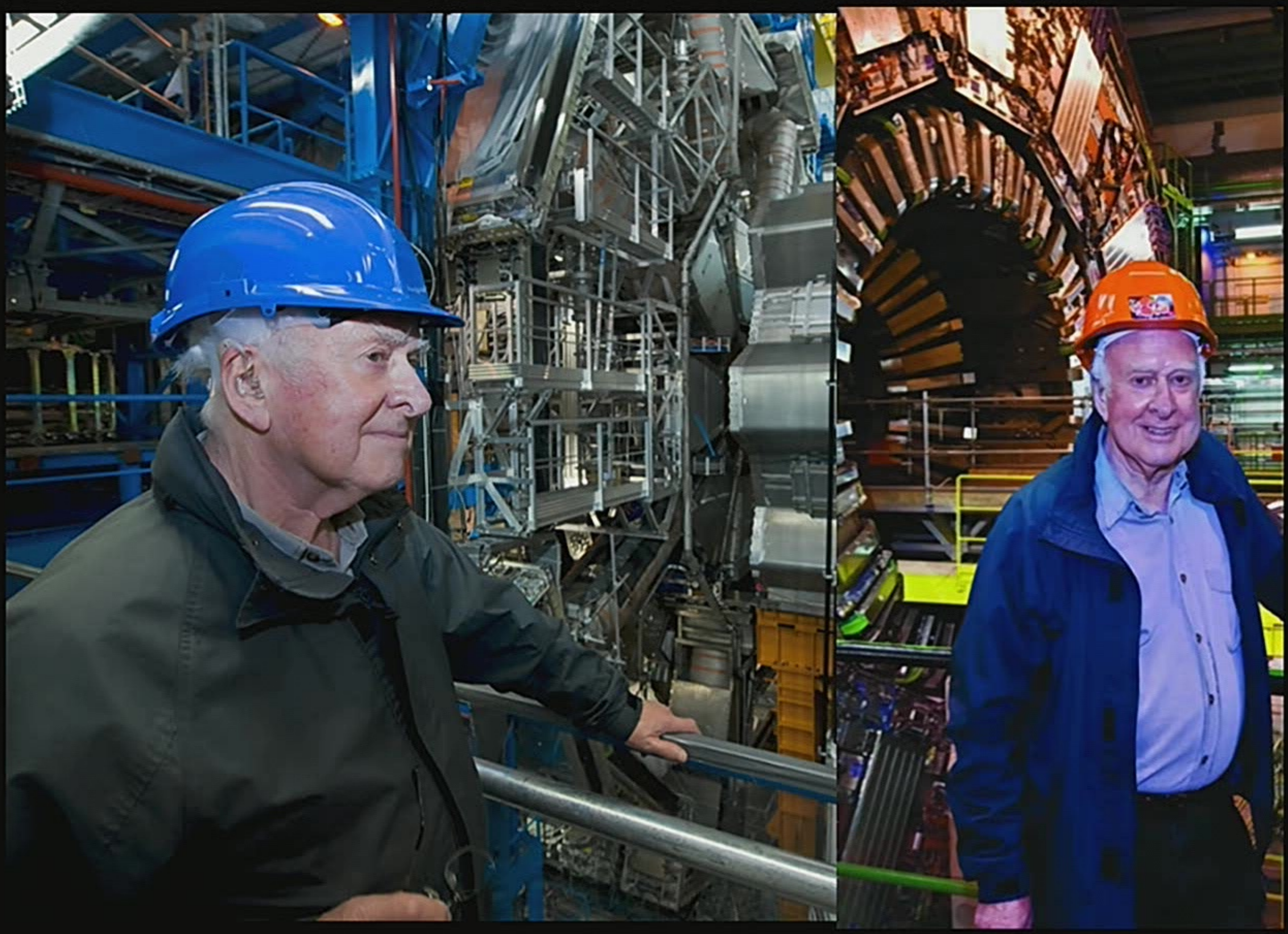


PARTICLE DISCOVERIES



9 mo
LHC
7TeV

PETER HIGGS AT ATLAS AND CMS



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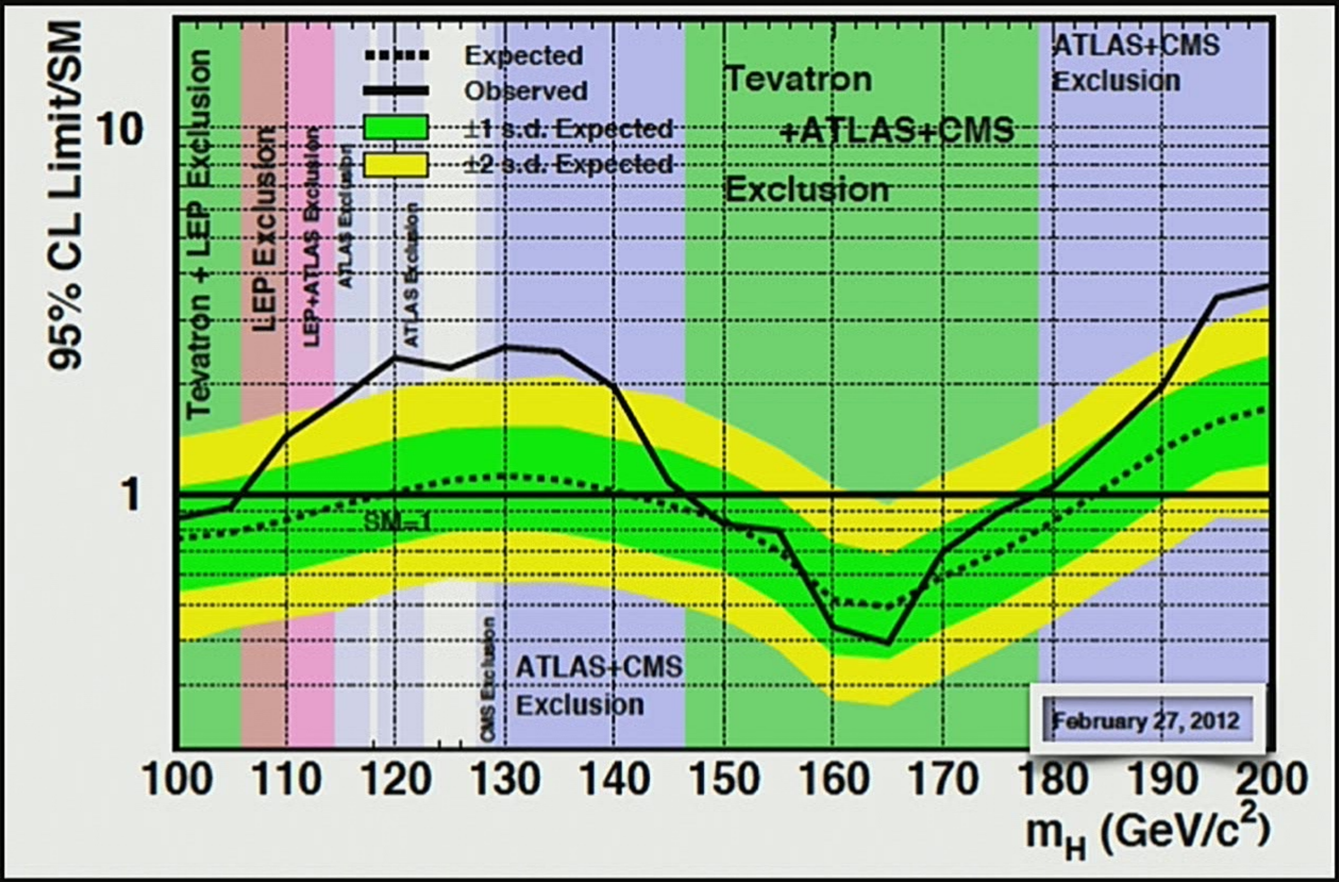
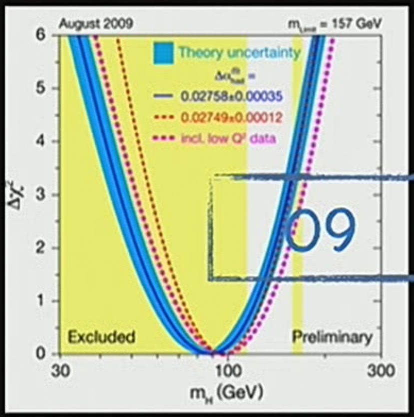
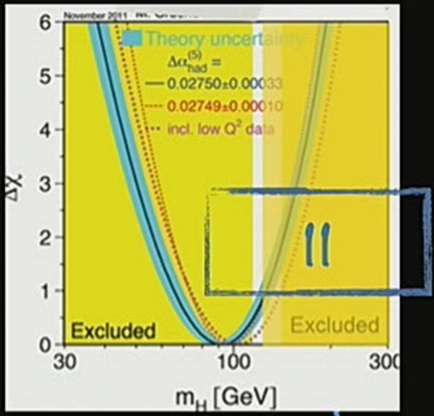
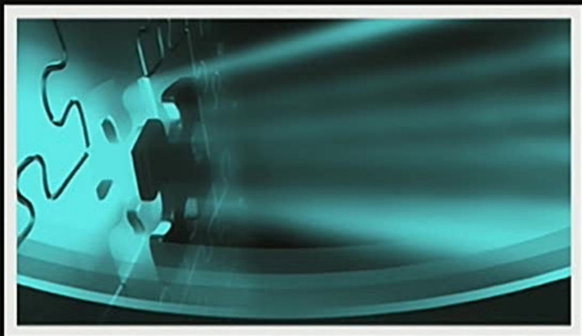
DECADES OF EXPERIMENTAL HUNTING







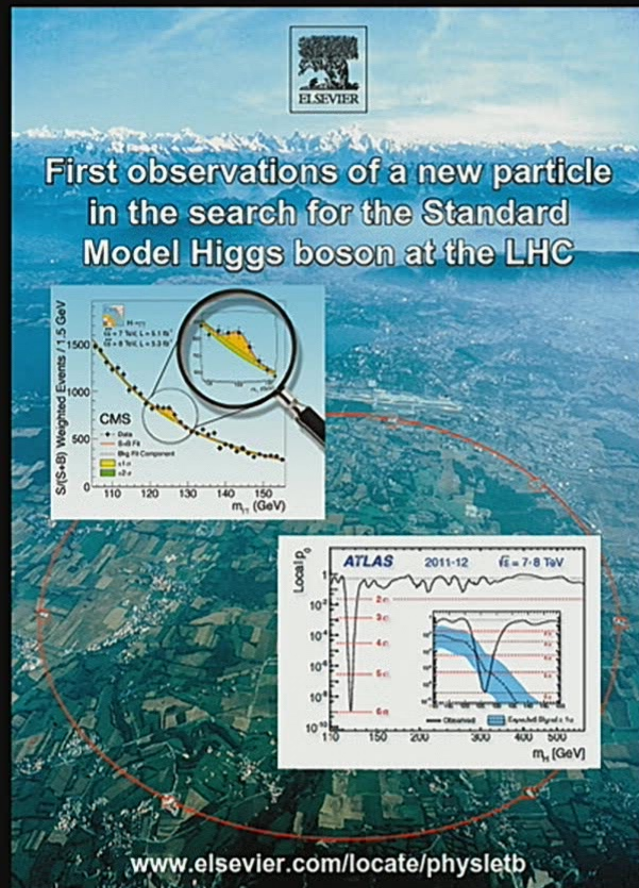
EUREKA



SCHOOL of PHYSICS and ASTRONOMY
The University of Edinburgh
James Clerk Maxwell Building
The King's Buildings
Mayfield Road
Edinburgh EH9 3JZ

Congratulations to both
Atlas and CMS Collaborations
and to the builders of the LHC
on a magnificent achievement!

Peter Higgs
30 August 2012



THE WHITE HOUSE
WASHINGTON
August 8, 2012

Dr. Joel N. Butler
Fermilab
P.O. Box 500
Batavia, IL 60510-5011

Dr. Butler:

On behalf of the Obama Administration, I would like to congratulate the US-CMS collaboration on the discovery of the Higgs boson. The successful culmination of the long quest for the Higgs boson represents a triumph for fundamental science and paves the way for a deeper understanding of the universe.

I note with great pride the role US scientists have had in the design, construction, and operation of the CMS detector as well as the leadership of collaboration. Clearly, the scientific expertise and ingenuity of US scientists have been essential components of the discovery. Furthermore, the astounding scientific achievement and the technological and educational benefits of your work demonstrate that our national investment in fundamental science has been well placed.

The discovery of the Higgs boson has captured the imagination of the American public, and along with our fellow citizens, I look forward to your continued exploration of the sub-microscopic universe.

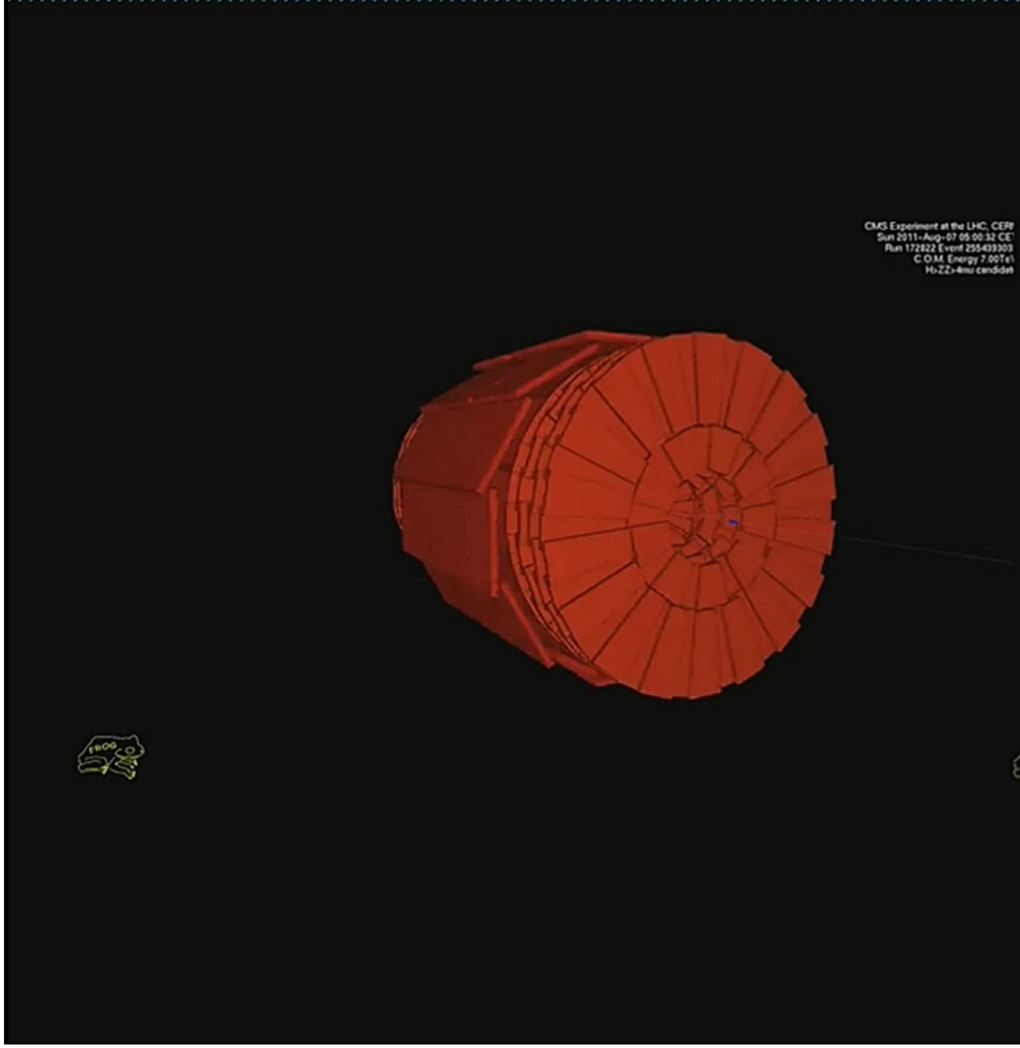
Sincerely,

John P. Holdren

John P. Holdren
Director, Office of Science and Technology Policy

cc: Professor Dan R. Marlow, Princeton University
Professor Nicholas J. Hadley, University of Maryland

4 LEPTONS FROM HIGGS



SYMMETRY BREAKING AND COMPLEXITY

Nambu (1960)

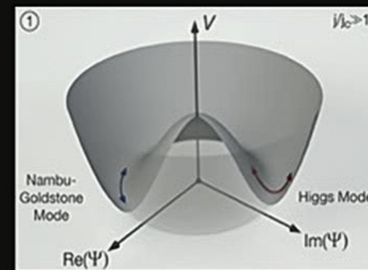
The importance of Spontaneous Symmetry Breaking

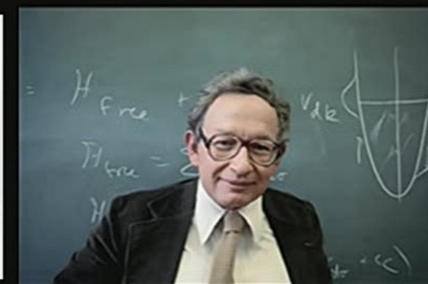
Nobel Lecture: Spontaneous symmetry breaking in particle physics: A case of cross fertilization*

Yoichiro Nambu

Physical system	Broken symmetry
Ferromagnets	Rotational invariance (with respect to spin)
Crystals	Translational and rotational invariance (modulo discrete values)
Superconductors	Local gauge invariance (particle number)

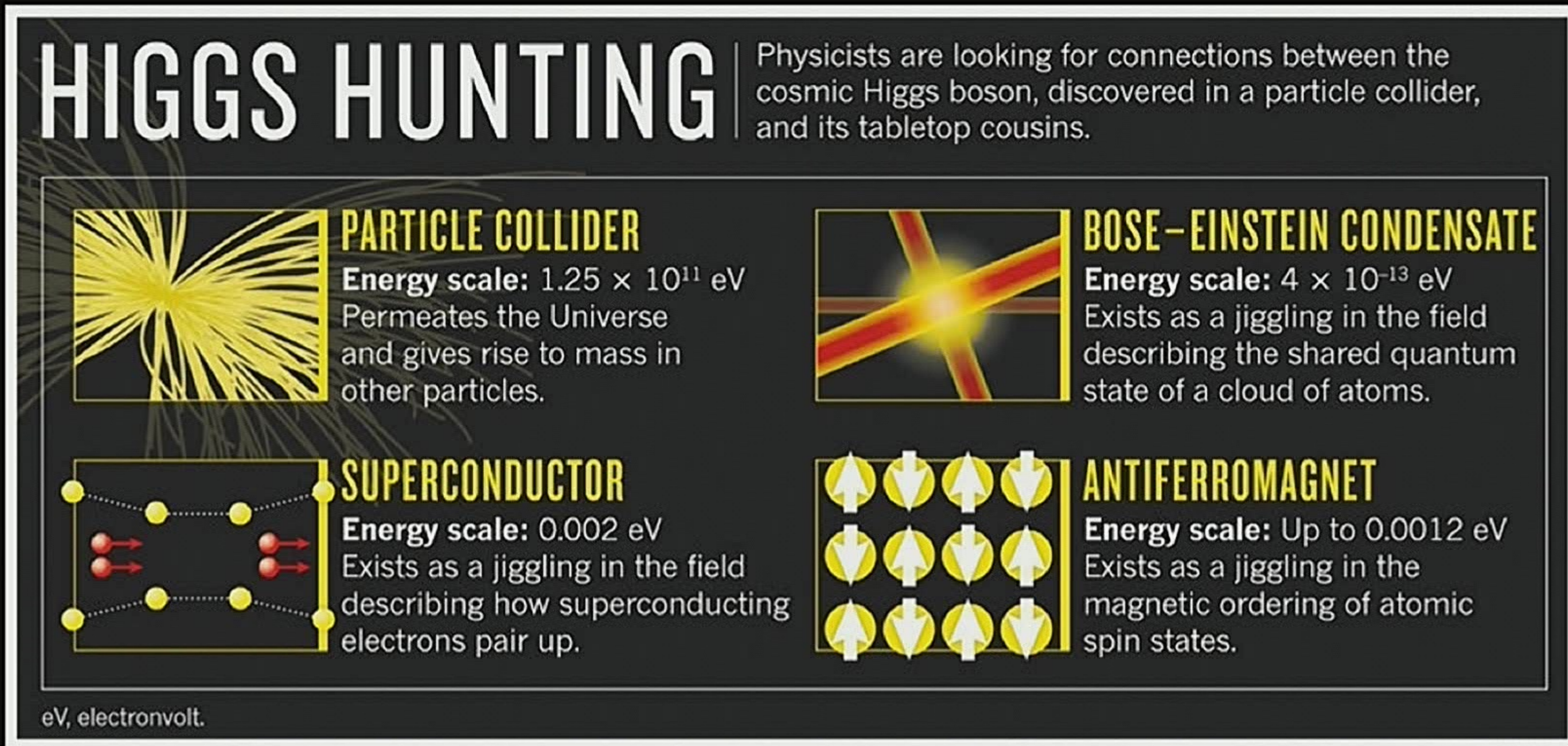
- Apply condensed matter ideas to **particle physics**
- **Now the quantum vacuum is the "medium"**





- The key difference is that in quantum field theory it is much more difficult to transition from one degenerate ground state to another
- ***The quantum vacuum*** is like a many-body system in this sense
- As Phillip Anderson emphasized in his 1972 article **"More is Different"**, spontaneous symmetry breaking is a property of "large" systems

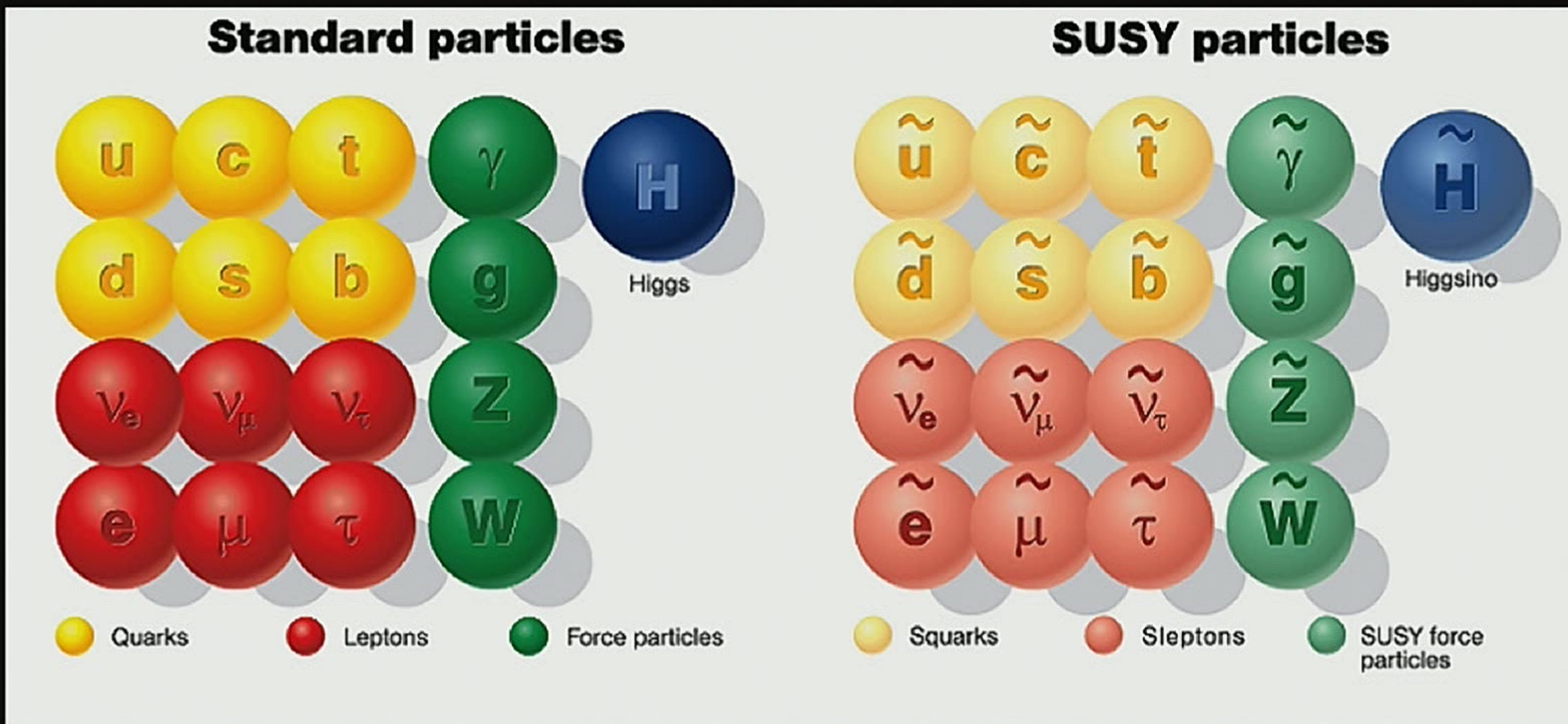
SYMMETRY BREAKING DYNAMICS



Peter Littlewood and Chandra Varma discovered "light" Higgs bosons states in niobium-selenide superconductors, 1981

SUSY-PARTNERS = THE OTHER SPIN PARTNER

(Electron in superspace) = superelectron (spin 0) + electron (spin1/2)



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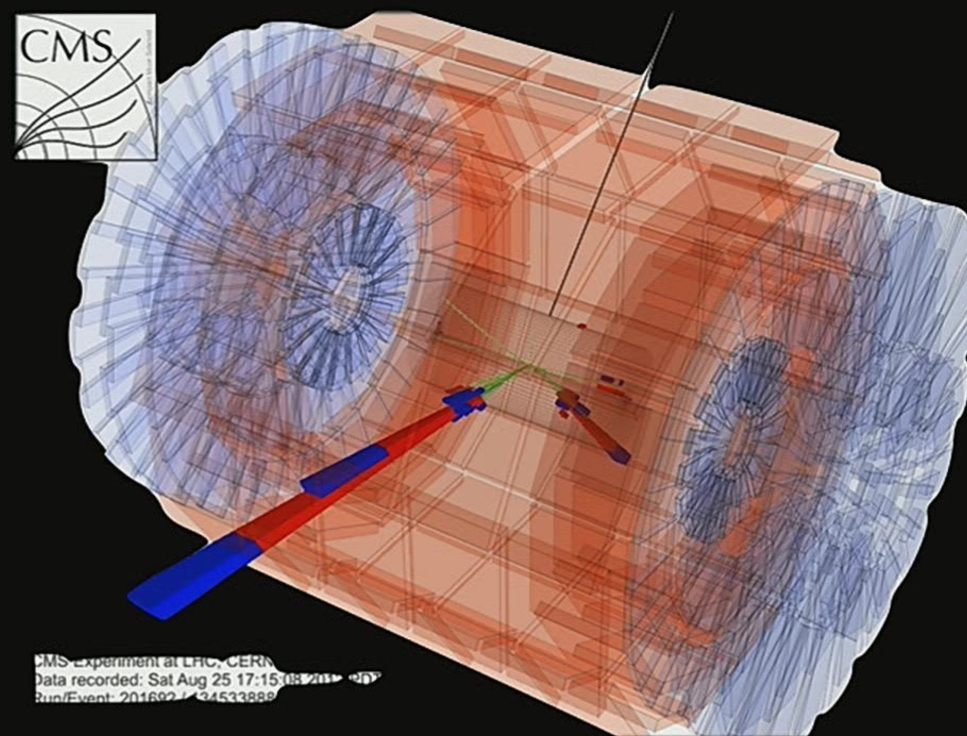
SUSY IN THE DETECTORS



BEYOND THE HIGGS

H boson : is it the Standard Model?

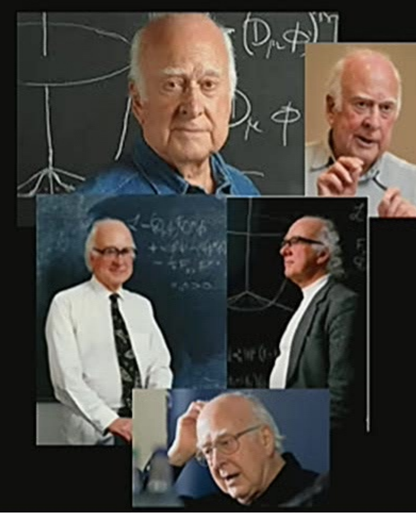
Does it behave as predicted?

Is there more than one?

how many more?

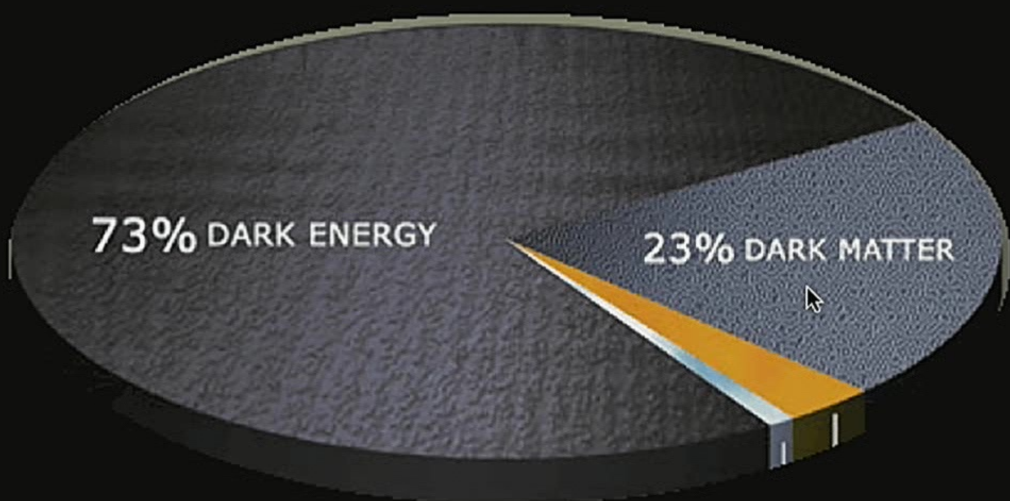
Finding heavy Higgs bosons with non-standard interactions is a major long-term challenge for the LHC

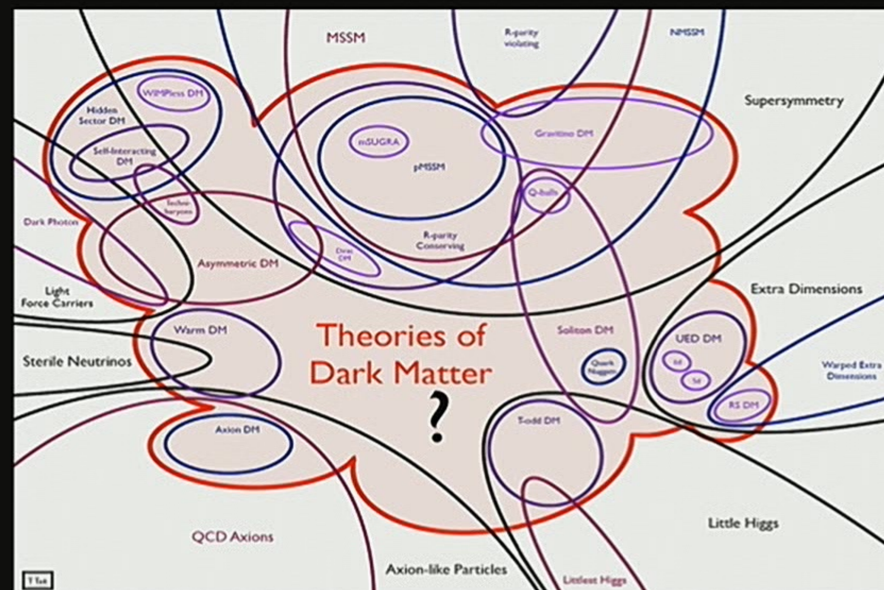
Supersymmetry predicts at least five kinds of Higgs bosons, differing in their mass and other properties



DARK MATTER

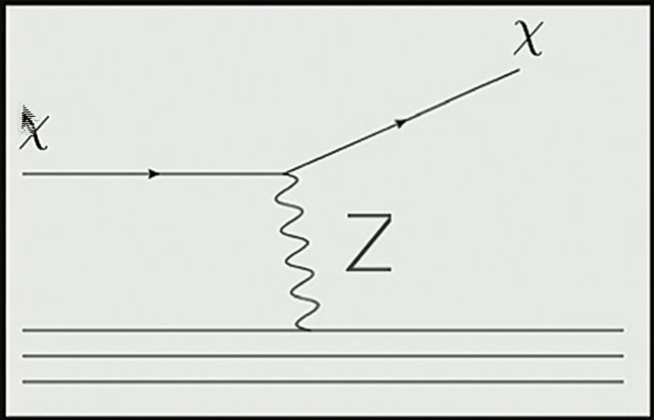
Early cosmology, BBN, CMB concordance that the picture of the mass-energy balance in the Universe today looks like



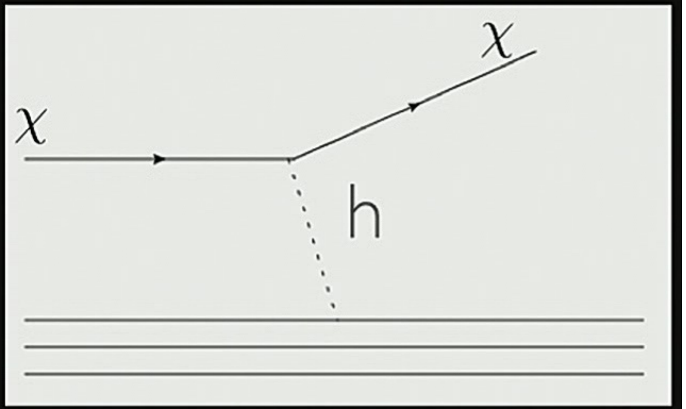


DARK MATTER INTERACTION WITH MATTER

via gravity



via weak interactions like neutrinos



via the newly discovered Higgs Boson