THE HIGGS BOSON

WINDOW ON THE BIG BANG

Jim Brau U. Oregon, Eugene October 29, 2012

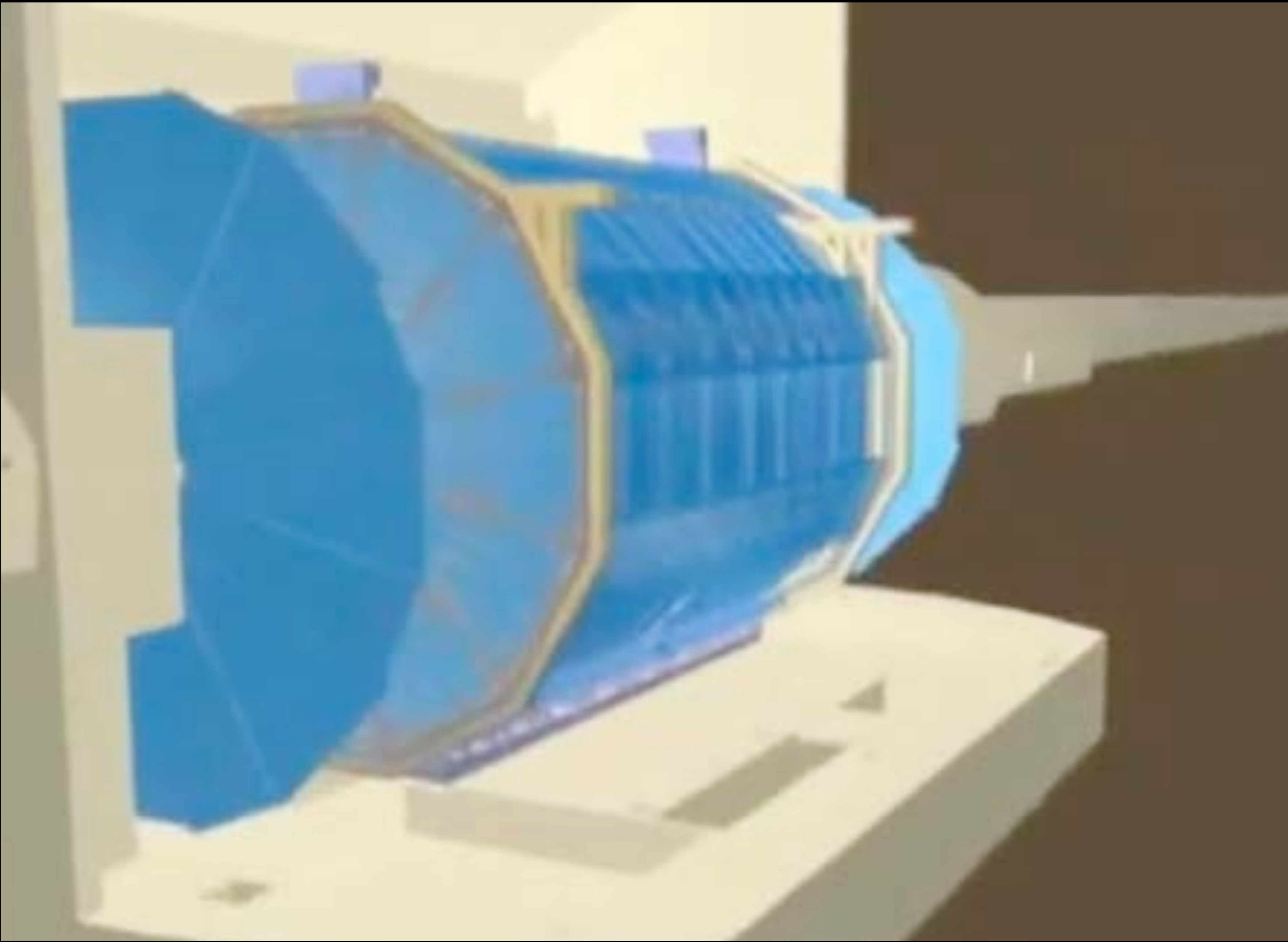
University of Oregon experimental high energy physics

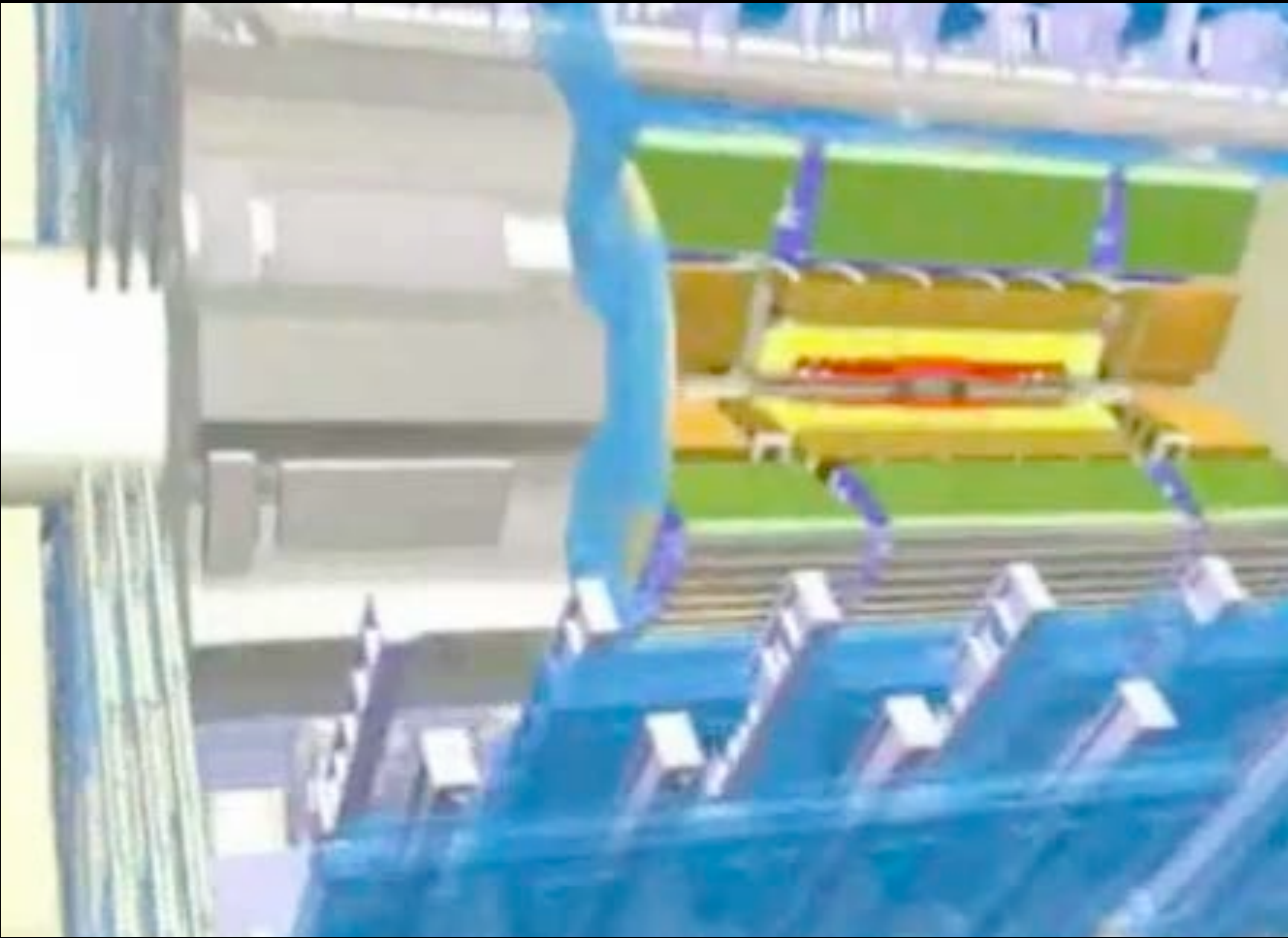
- Liza Brost, Ray Frey, Craig Gallagher, Emelie Harstad, Stephanie Majewski, Chris Potter, Elizabeth Ptacek, Ryan Quitzow-James, Peter Radloff, Andreas Reinsch, Robert Schofield, Jake Searcy, Mansoora Shamim, Nick Sinev, David Strom, Dipongkar Talukder, Eric Torrence

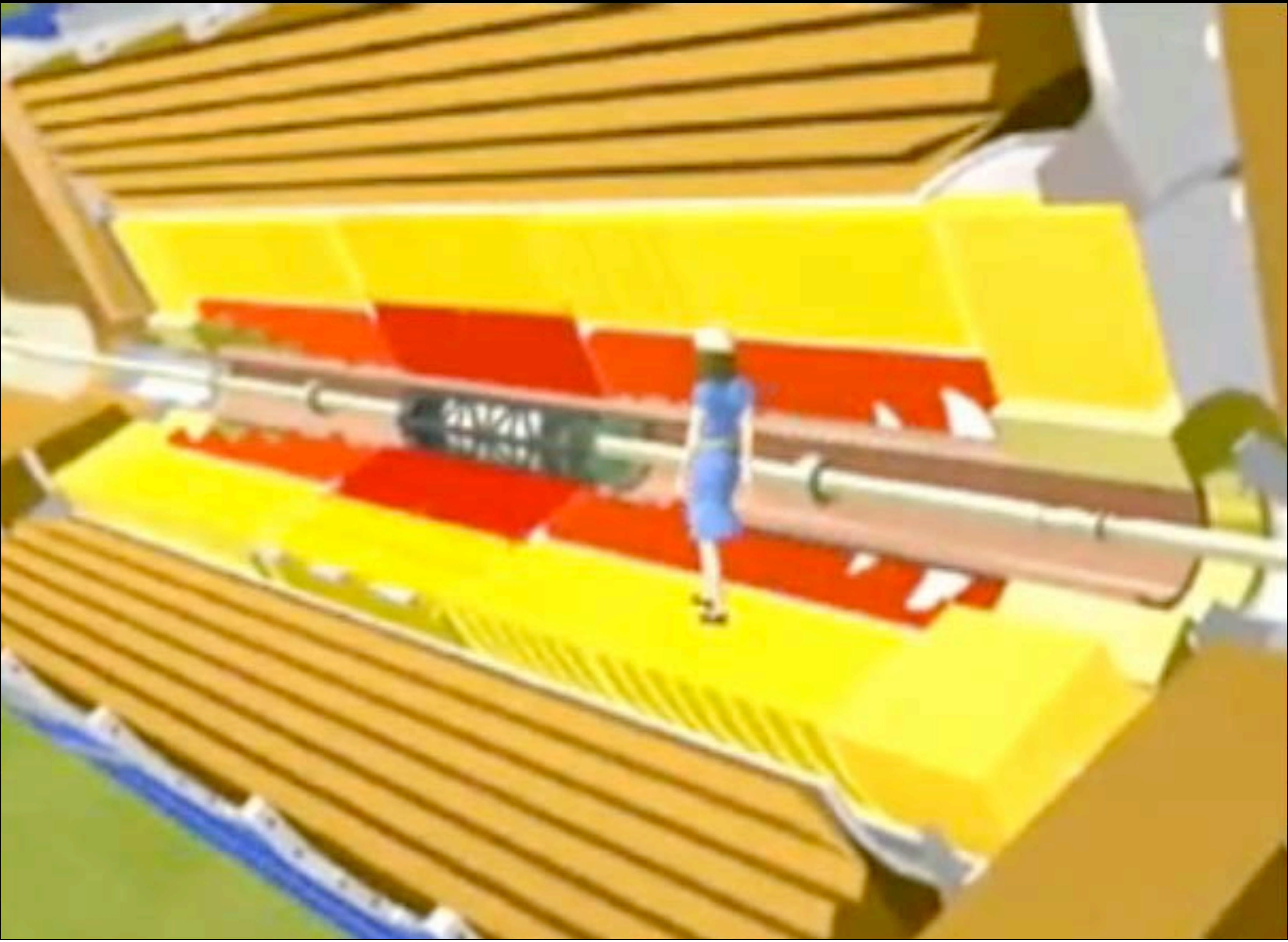
Wally Pacholka / AstroPics.com

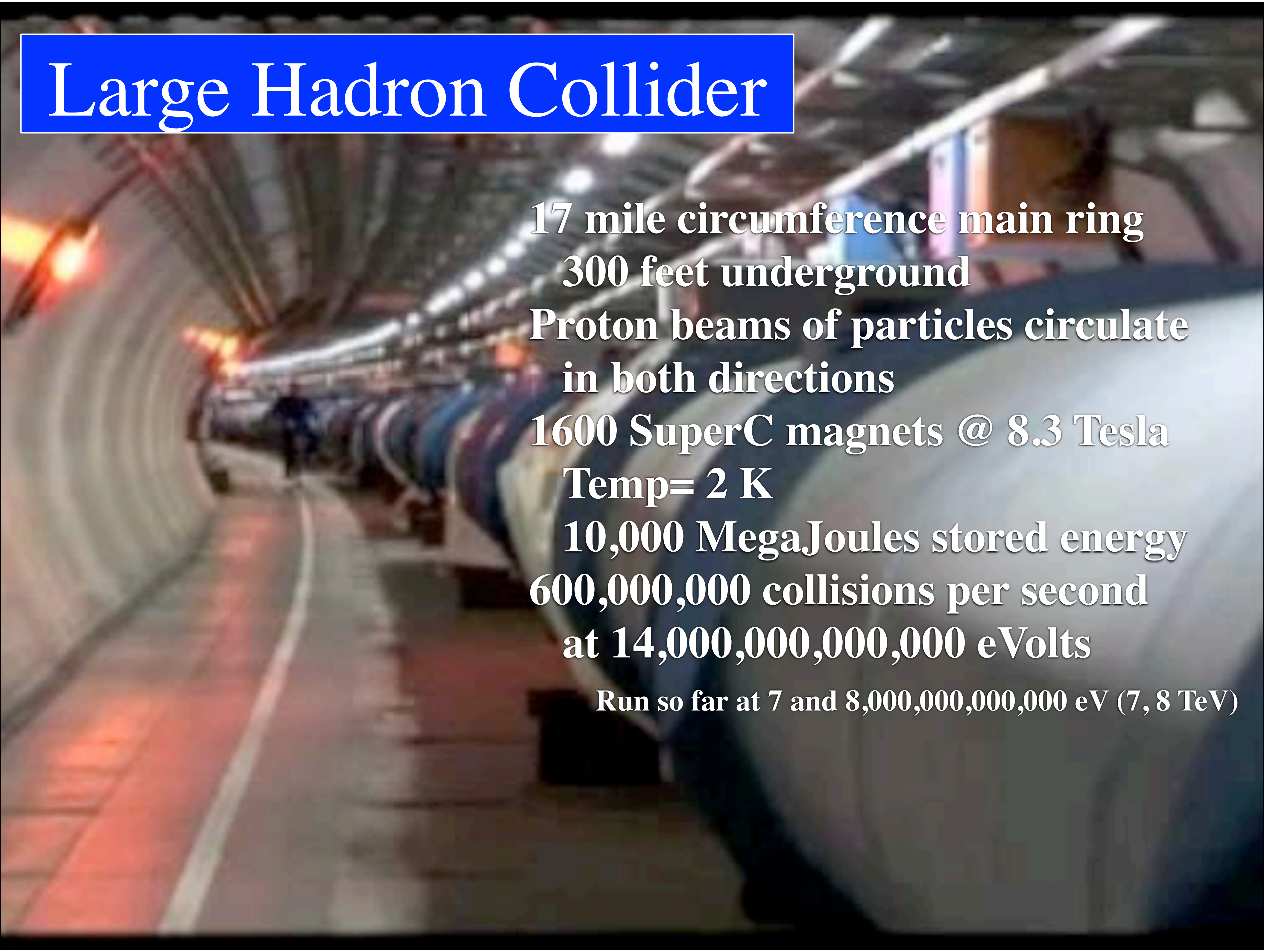
http://www.AstroPics.com

Large Hadron Collider (LHC)
Geneva, Switzerland









Large Hadron Collider

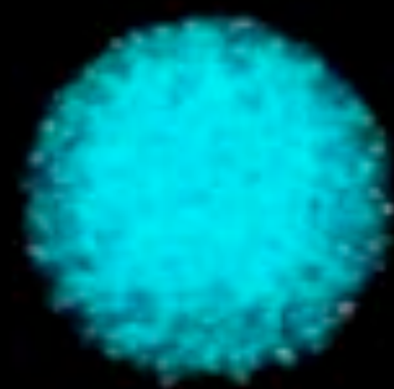
17 mile circumference main ring
300 feet underground
Proton beams of particles circulate
in both directions
1600 SuperC magnets @ 8.3 Tesla
Temp= 2 K
10,000 MegaJoules stored energy
600,000,000 collisions per second
at 14,000,000,000,000 eVolts

Run so far at 7 and 8,000,000,000,000 eV (7, 8 TeV)

Large Hadron Collider

Proton beam stores 700 MegaJoules
equiv. to 747 energy on take-off
enough to melt 1/2 ton copper

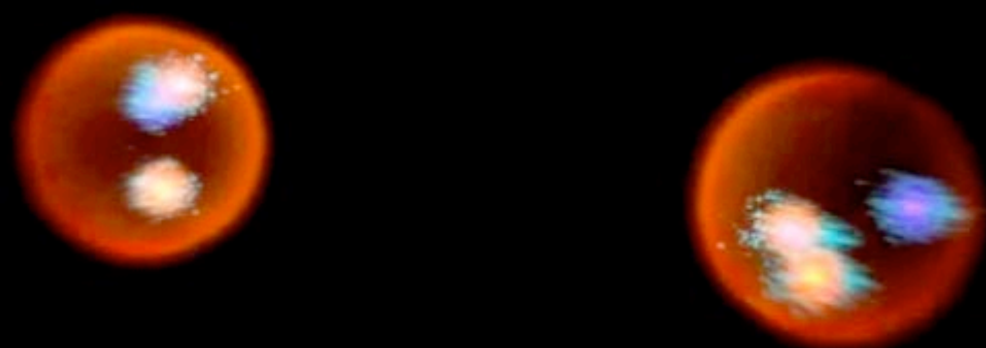
Search for the Higgs Boson at the LHC



Higgs Boson is VERY HEAVY
Candidate equivalent to 133 Hydrogen atoms
or one Cesium atom
126,000,000,000 eV = 126 GeV

Search for the Higgs Boson at the LHC

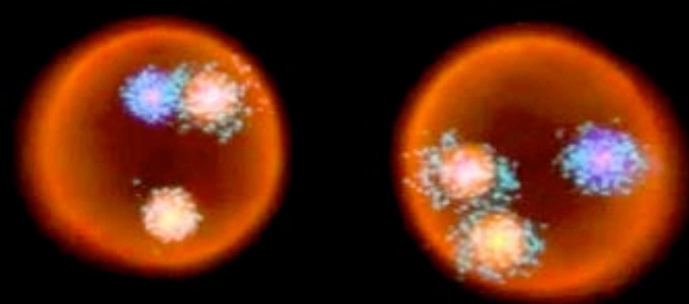
slow motion



Jim Brau U. Oregon, Eugene October 29, 2012

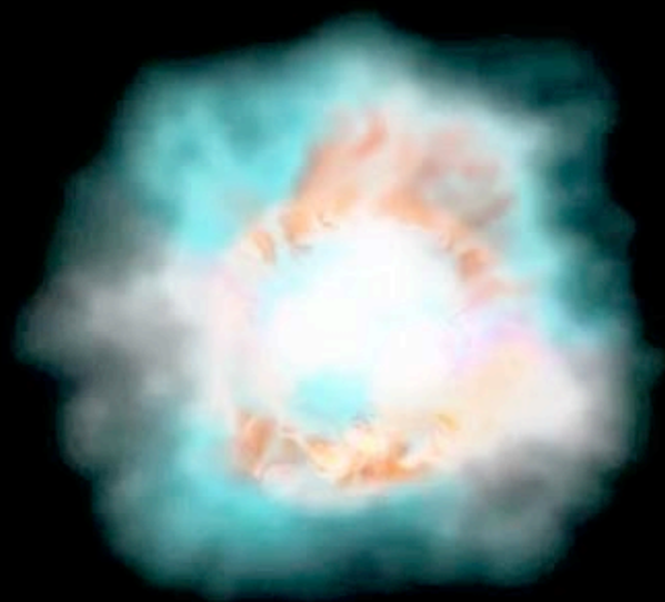
Search for the Higgs Boson at the LHC

slow motion



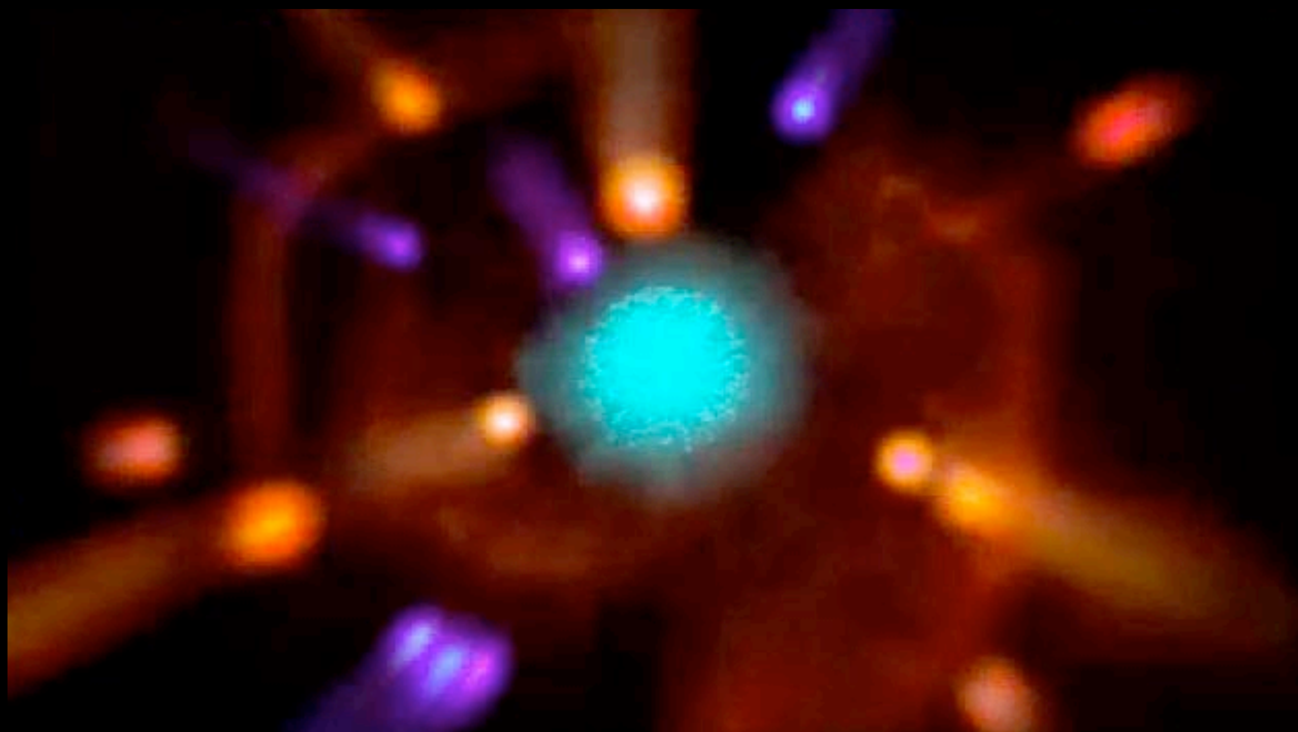
$E=mc^2$
or Energy equals Mass

Producing the Higgs Boson at the LHC



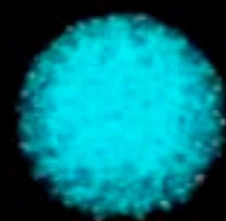
Jim Brau *U. Oregon, Eugene* *October 29, 2012*

Producing the Higgs Boson at the LHC

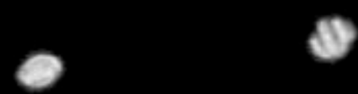


Jim Brau U. Oregon, Eugene October 29, 2012

Producing the Higgs Boson at the LHC



Producing the Higgs Boson at the LHC



July 4, 2012

- The experiments ATLAS and CMS announced evidence for the Higgs Boson

University of Oregon
experimental high energy physics

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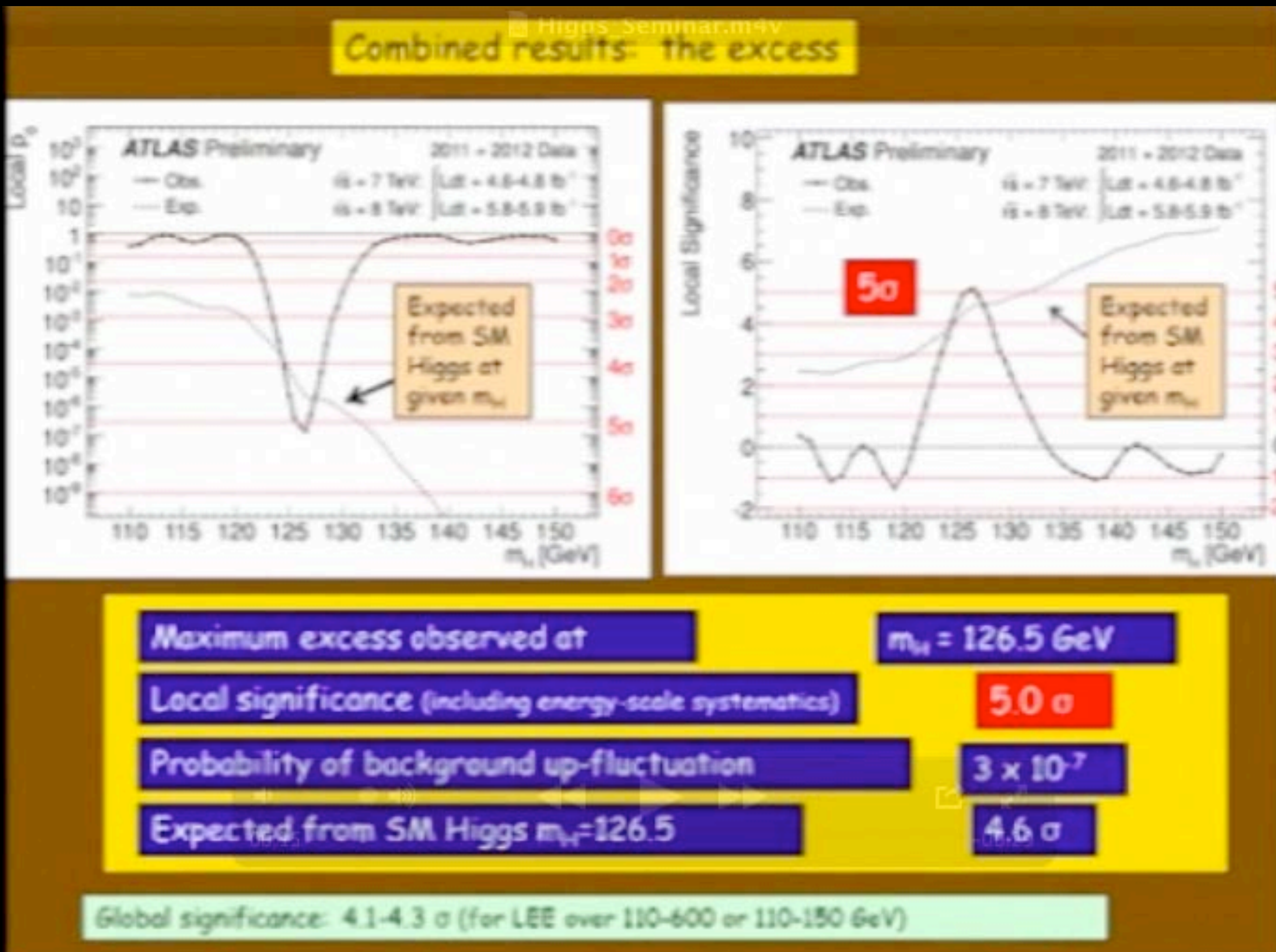
Combined results: the excess
ATLAS Preliminary
2011 + 2012 Data
Local p_0
Local Significance
Obs.
Exp.
Expected from SM Higgs at given m_H
5σ
m_H [GeV]
Maximum excess observed at
m_H = 126.5 GeV
Local significance (including energy-scale systematics)
5.0 σ
Probability of background up-fluctuation
3 x 10^{-7}
Expected from SM Higgs m_H=126.5
4.6 σ
Global significance: 4.1-4.3 σ (for LEE over 110-600 or 110-150 GeV)

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July 4, 2012

ATLAS

CMS

July 4, 2012

University of Oregon
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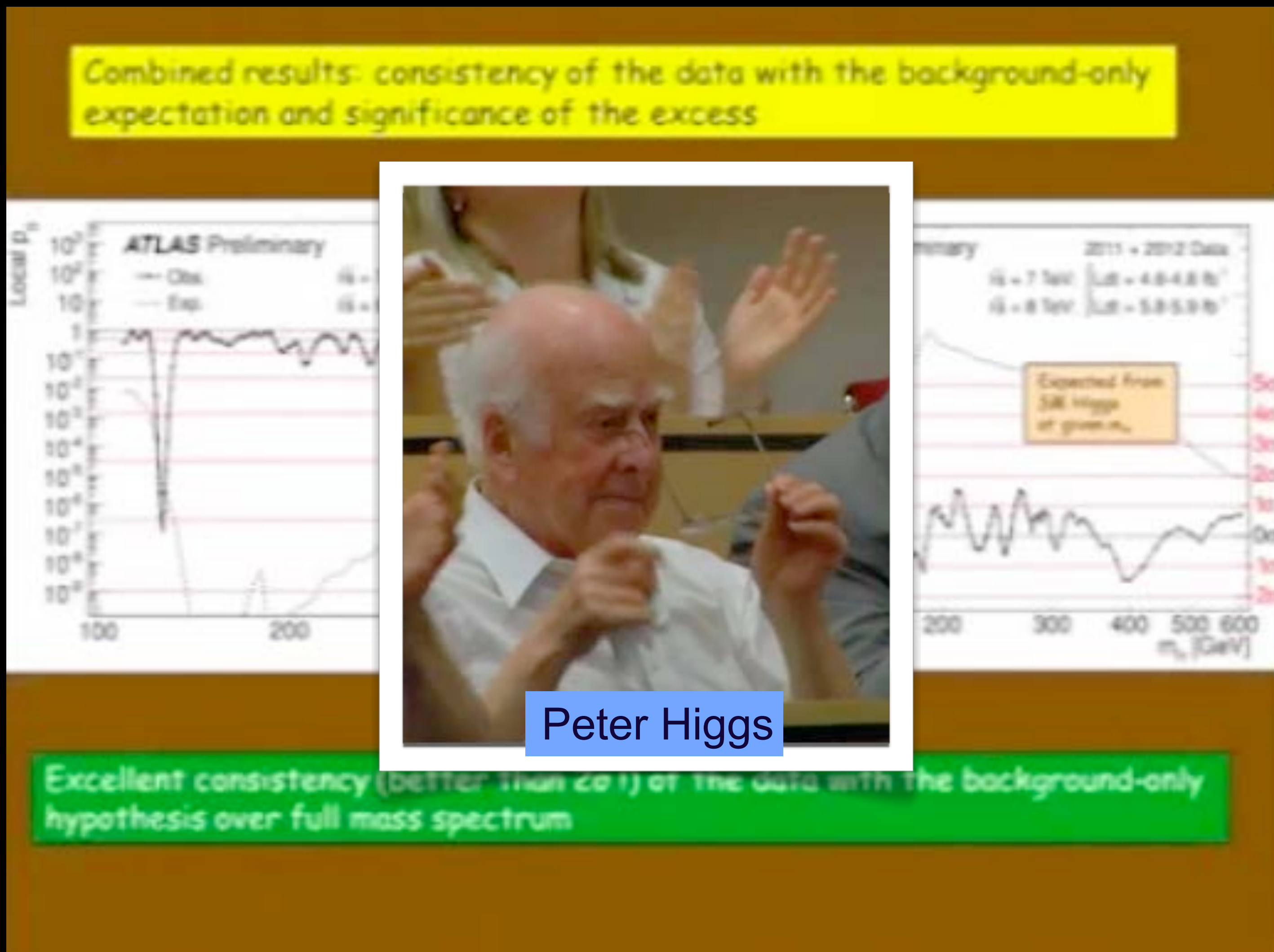
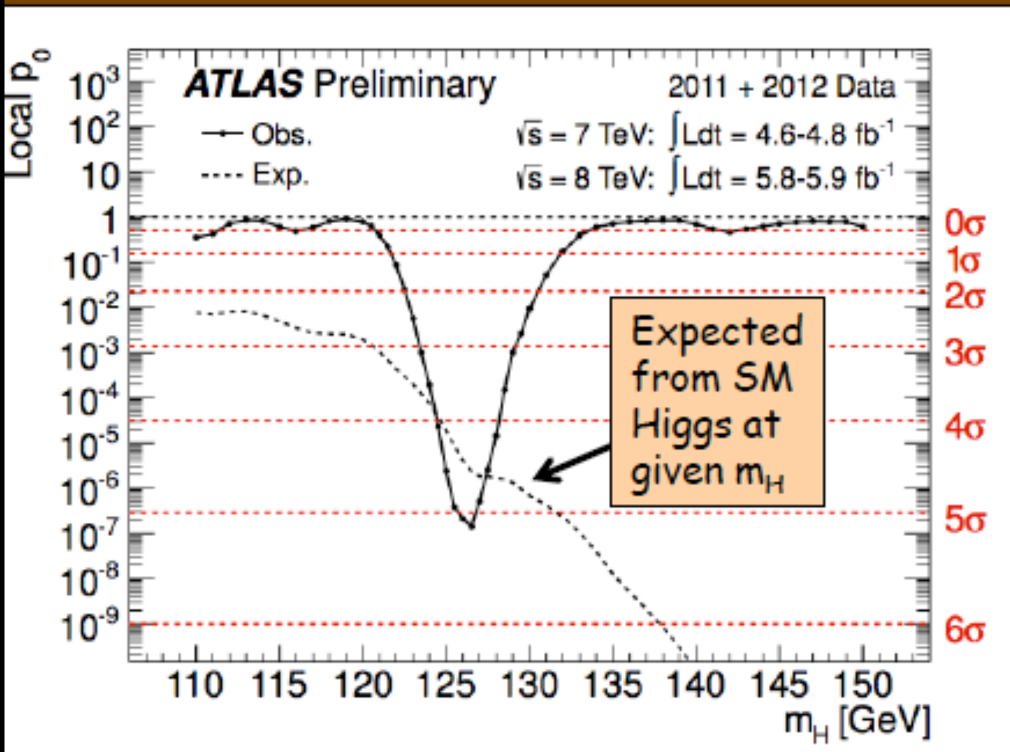
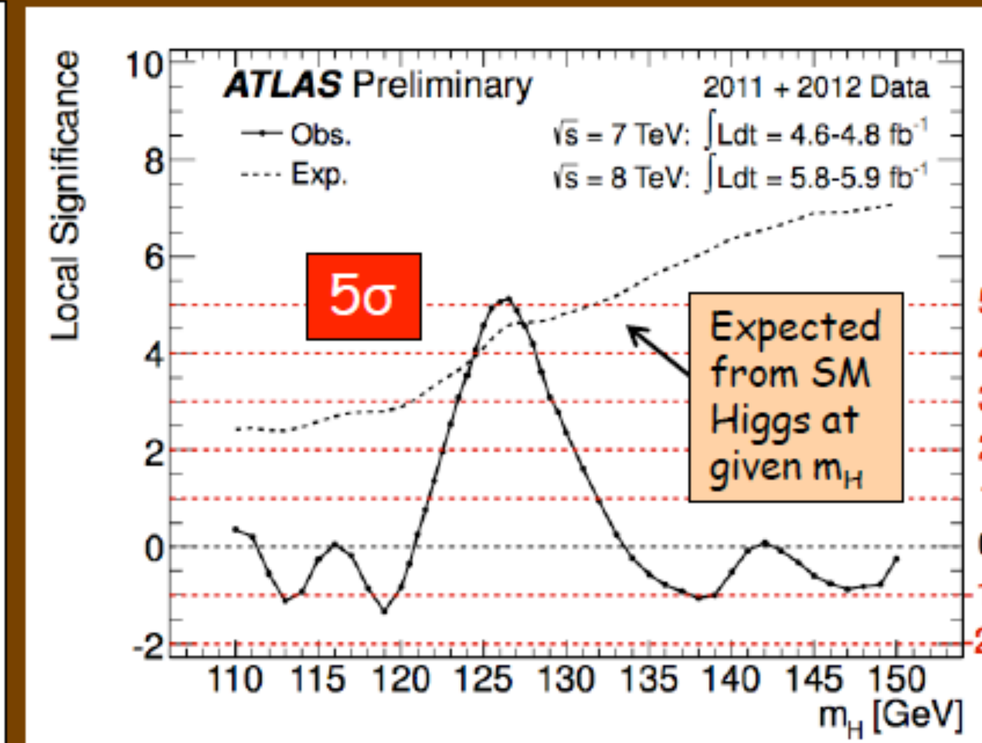
July 4, 2012



Combined results: consistency of the data with the background-only expectation and significance of the excess
ATLAS Preliminary
Peter Higgs
Excellent consistency
the background-only
hypothesis over full mass spectrum

Combined results: the excess

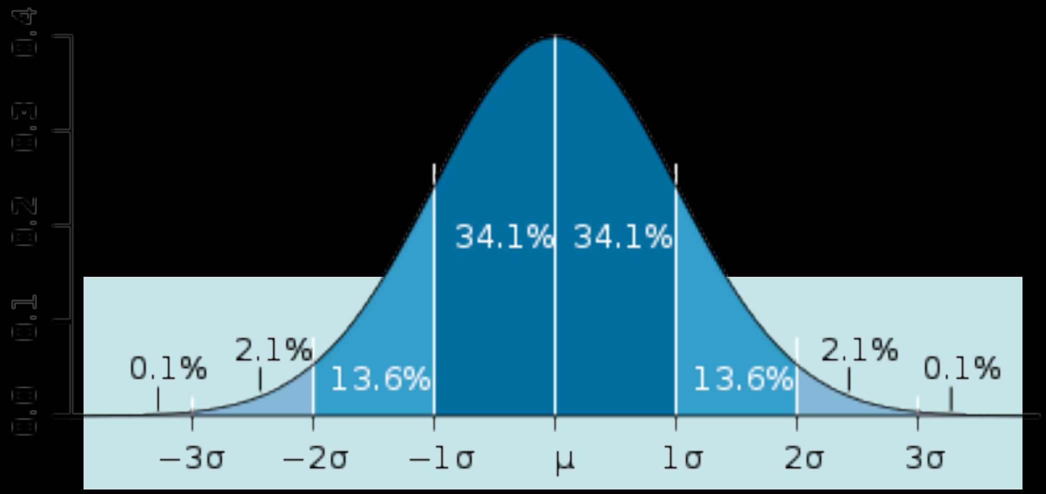




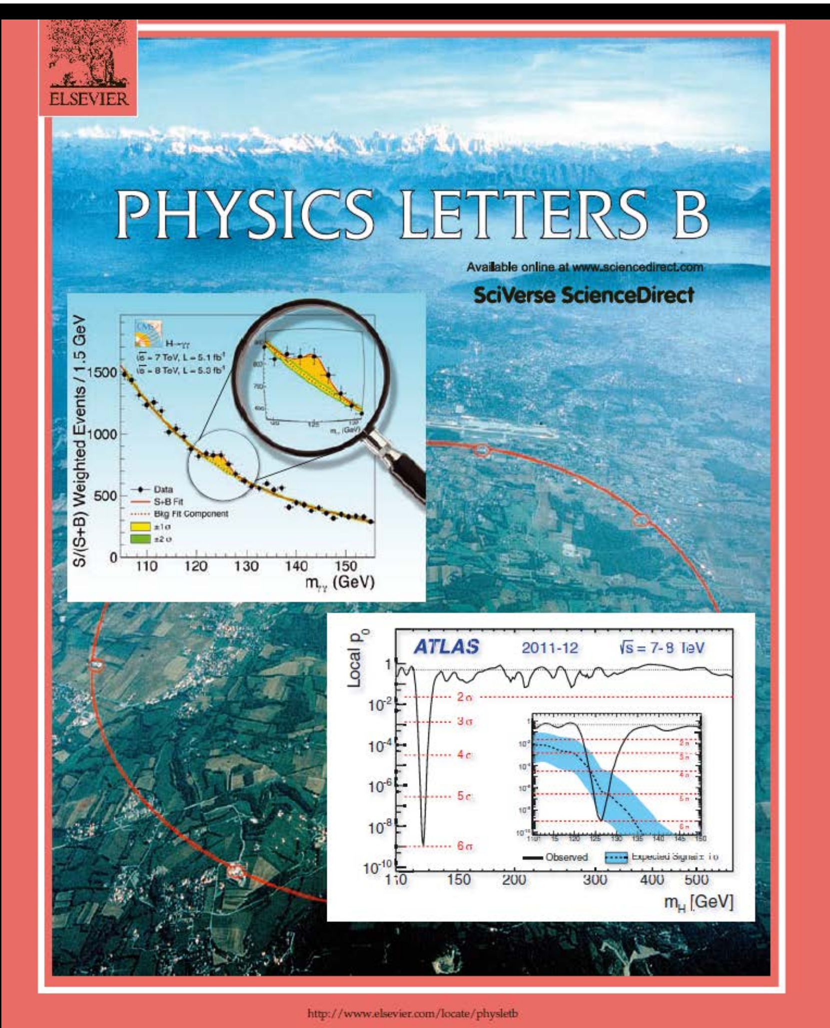
Maximum excess observed at	m_H = 126.5 GeV
Local significance (including energy-scale systematics)	5.0 σ
Probability of background up-fluctuation	3×10^{-7}
Expected from SM Higgs m_H=126.5	4.6 σ

Global significance: 4.1-4.3 σ (for LEE over 110-600 or 110-150 GeV)

Five Sigma Confidence



- Five sigma is the threshold particle physics requires for DISCOVERY (very high standard)
- THEN, randomness could produce the same result ONLY once in 3.5 million times
- Example - flip a coin 22 times and get heads EVERY time - not likely - but possible



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2012-218

Accepted by: Physics Letters B

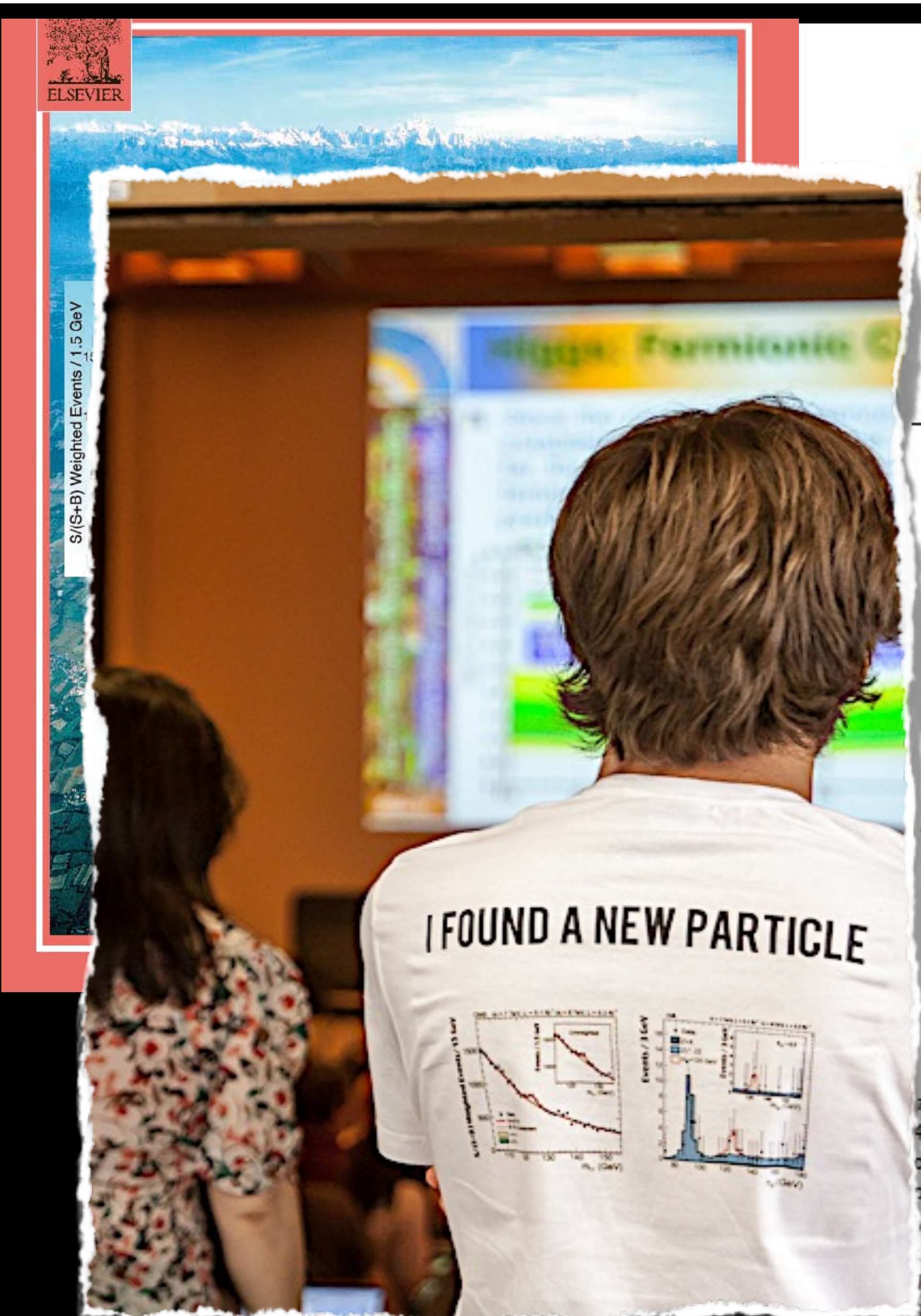
Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

The ATLAS Collaboration

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

Abstract

A search for the Standard Model Higgs boson in proton-proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s}$ = 7 TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s}$ = 8 TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 $\pm$ 0.4 (stat) $\pm$ 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

ATLAS

CERN

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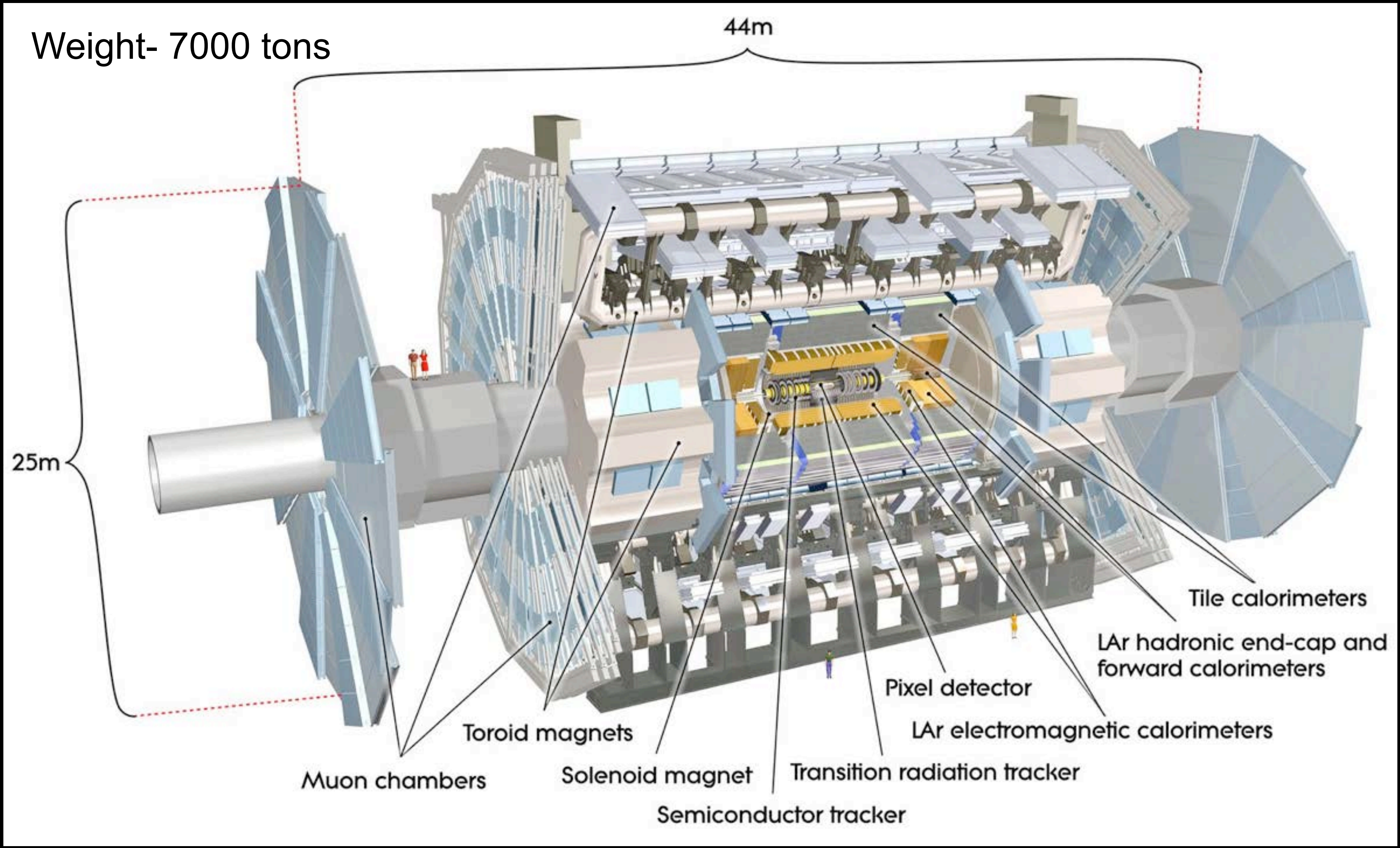
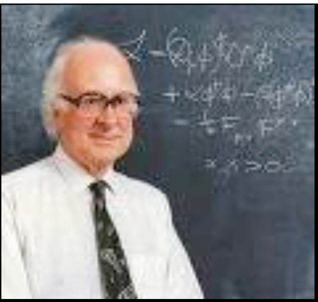
ATLAS Detector



July 4, 2012

- Evidence for the Higgs Boson that ATLAS and CMS resulted from:
  - 1 in 1,000,000,000,000 collisions appear to produce two photons from a new particle
  - data collected in 2011 and early 2012



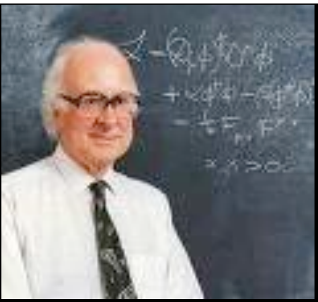
Peter Higgs
(1929-)

What is the Higgs Boson?

Satyendra
Nath Bose
(1894-1974)

- Theory postulated in 1964

by P. Higgs,
R. Brout , F. Englert,
G. S. Guralnik, C. R. Hagen,
and T. W. B. Kibble



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Satyendra
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- Theory postulated in 1964
  – historical era

by P. Higgs,
R. Brout , F. Englert,
G. S. Guralnik, C. R. Hagen,
and T. W. B. Kibble

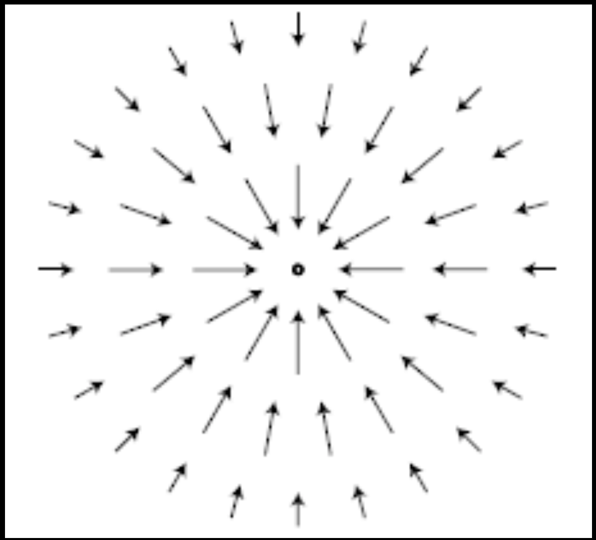
The Beatles arrive in USA,
Kennedy Airport, Feb 1964

President Johnson
signs Civil Rights Act,
July, 1964

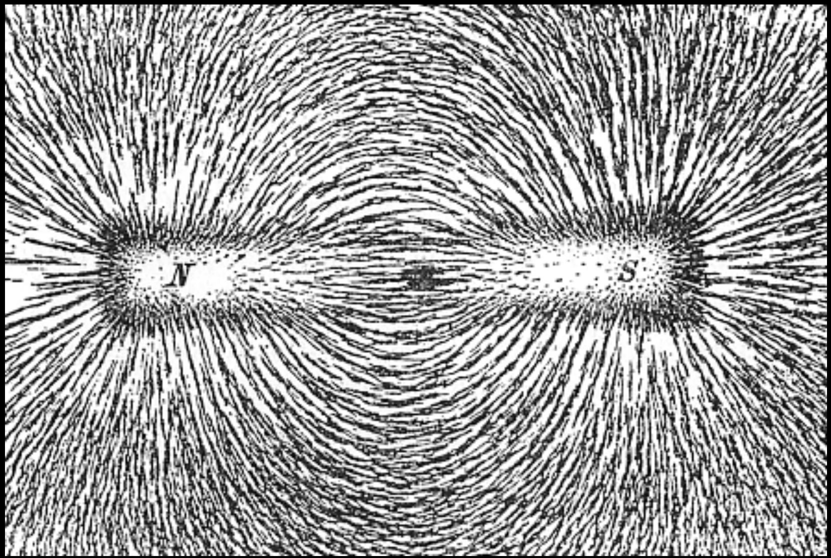
Mad Men, AMC

The Higgs Field

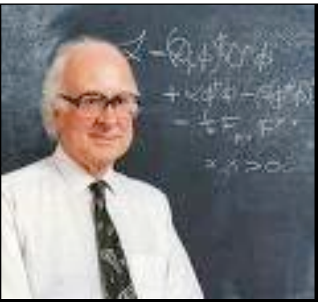
- The Higgs is both a field and a particle
- Familiar fields



Earth's gravity



Magnetism



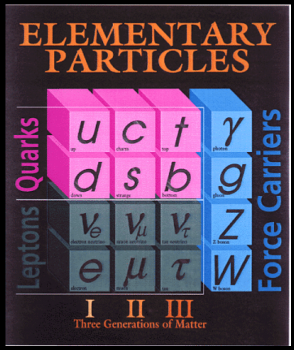
Peter Higgs

Higgs Boson Theory

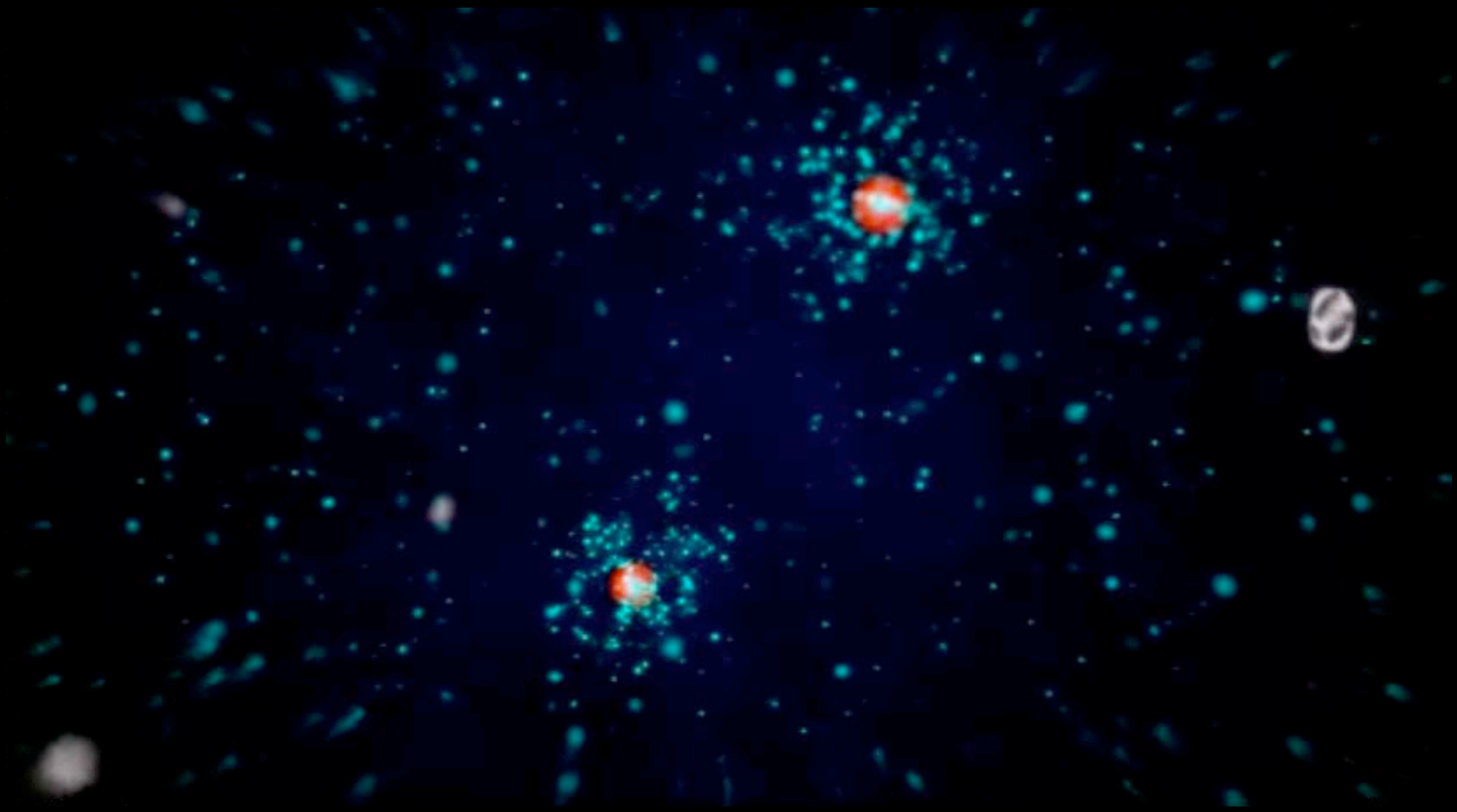
Kibble, Guralnik, Hagen, Englert, Brout

- Higgs field fills the universe

- Interacts with fundamental particles to give them mass



- Separates electromagnetism and the <u>weak</u> nuclear force
  - –photon remains massless



Why is the Higgs Important?

PARTICLE PHYSICS

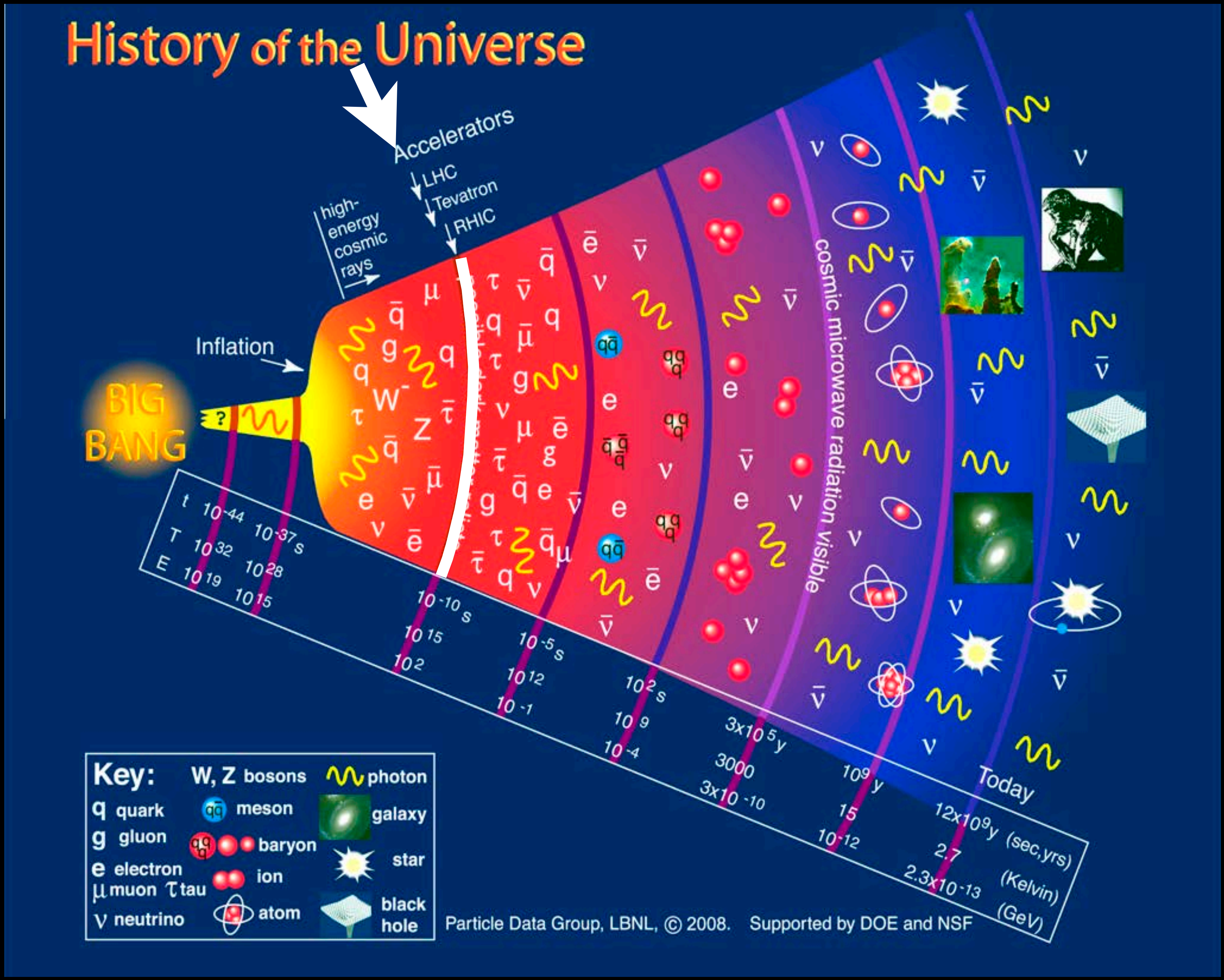
- It gives mass to the fundamental particles of Nature
  - quarks, leptons, fundamental bosons, ...

- It produces differences in the fundamental forces
  - electromagnetism and the weak nuclear force

Why is the Higgs Important?

COSMOLOGY

- Big Bang produced massless particles
  - 13.7 billion years ago
- Higgs field appeared everywhere
- Universe expanded and cooled
- Fundamental particles of Nature, initially massless, acquired mass from the Higgs field
- Particles slowed, bunched up and eventually formed atoms


History of the Universe
Accelerators
LHC
Tevatron
RHIC
high-energy cosmic rays
Inflation
BIG BANG
cosmic microwave radiation visible
Today
Key:
W, Z bosons
photon
q quark
meson
galaxy
g gluon
baryon
star
e electron
ion
μ muon τ tau
ν neutrino
atom
black hole
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF
(sec,yrs)
(Kelvin)
(GeV)

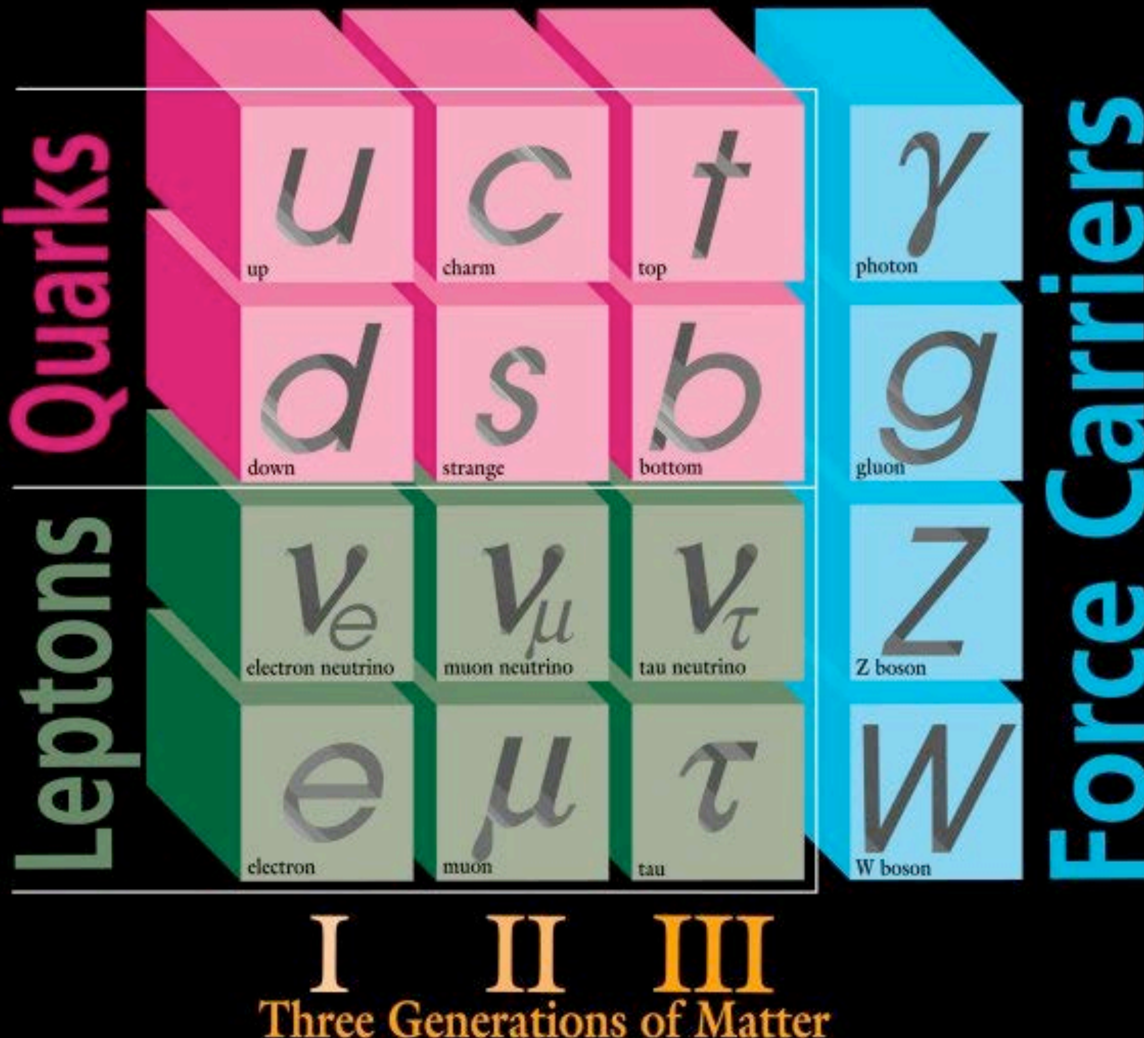
Higgs Boson

- Higgs bosons carry no spin - unique!
- Distributed throughout space, they create a Higgs condensate - a pure vacuum with energy
- This very stable vacuum field results from the mutual interactions of Higgs bosons
- To make them visible we must create a disturbance in the uniform Higgs field

The Higgs Boson is Different

- The Higgs is <u>both</u> force and matter particle
- Particle properties unique to known fundamental particles
  - –- spinless
- Possible key to discovering unity of forces and the underpinnings of the universe
- Could be the first discovered member of a new form of matter

ELEMENTARY PARTICLES

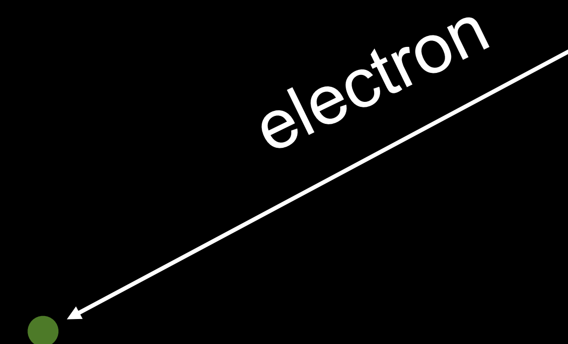


20th Century Particle Physics Laboratories

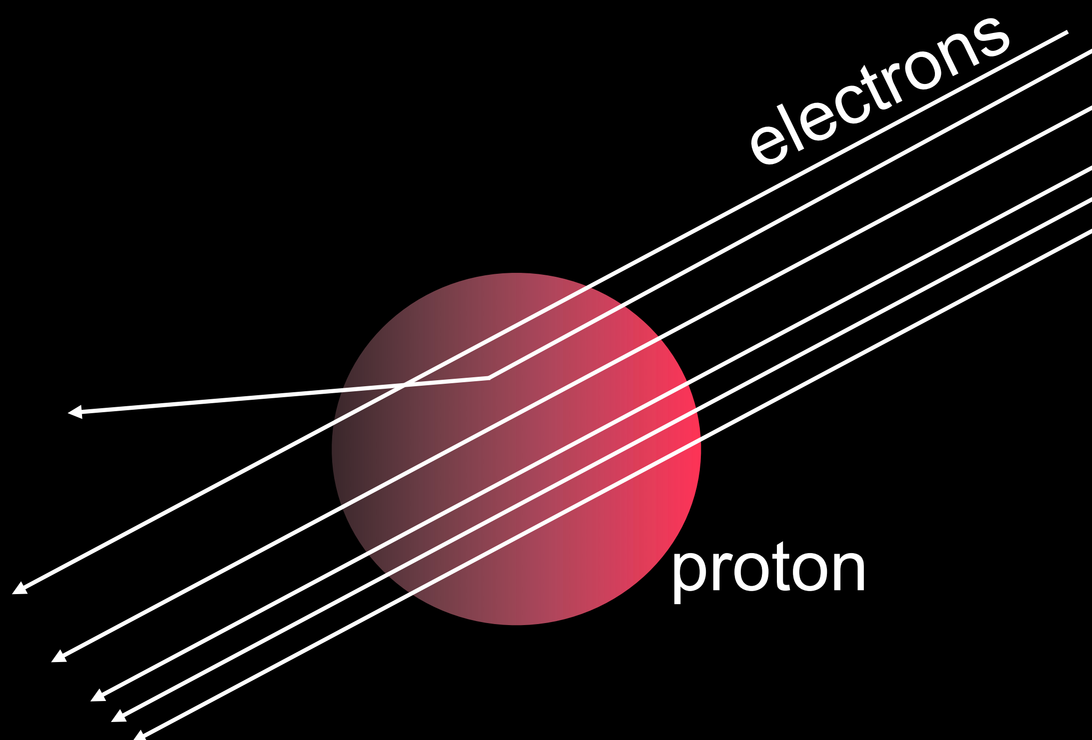
electron linear accelerator at Stanford (SLAC)

proton synchrotron at Fermilab (near Chicago)

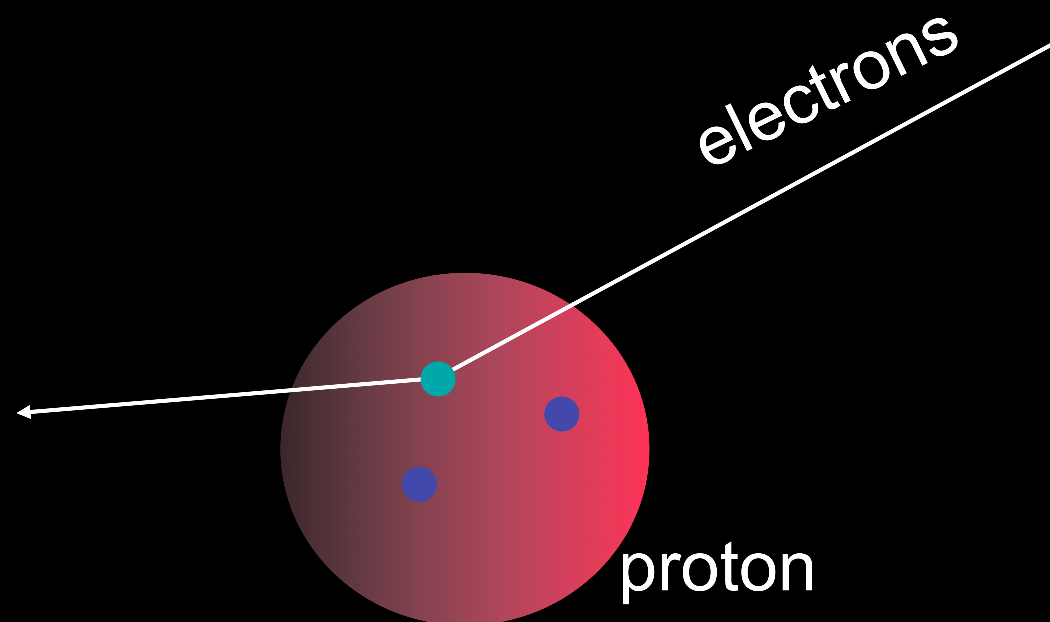

Stanford
Linear Accelerator
Center


electron

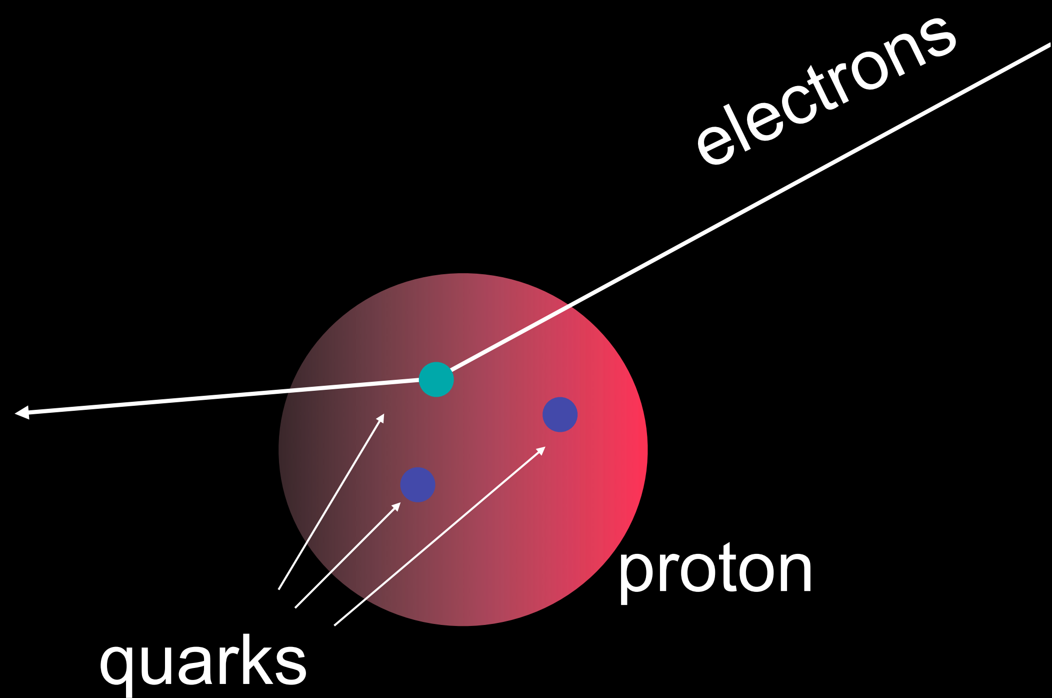
1969



1969



1969 - Quarks discovered (inside atomic nucleus) Stanford



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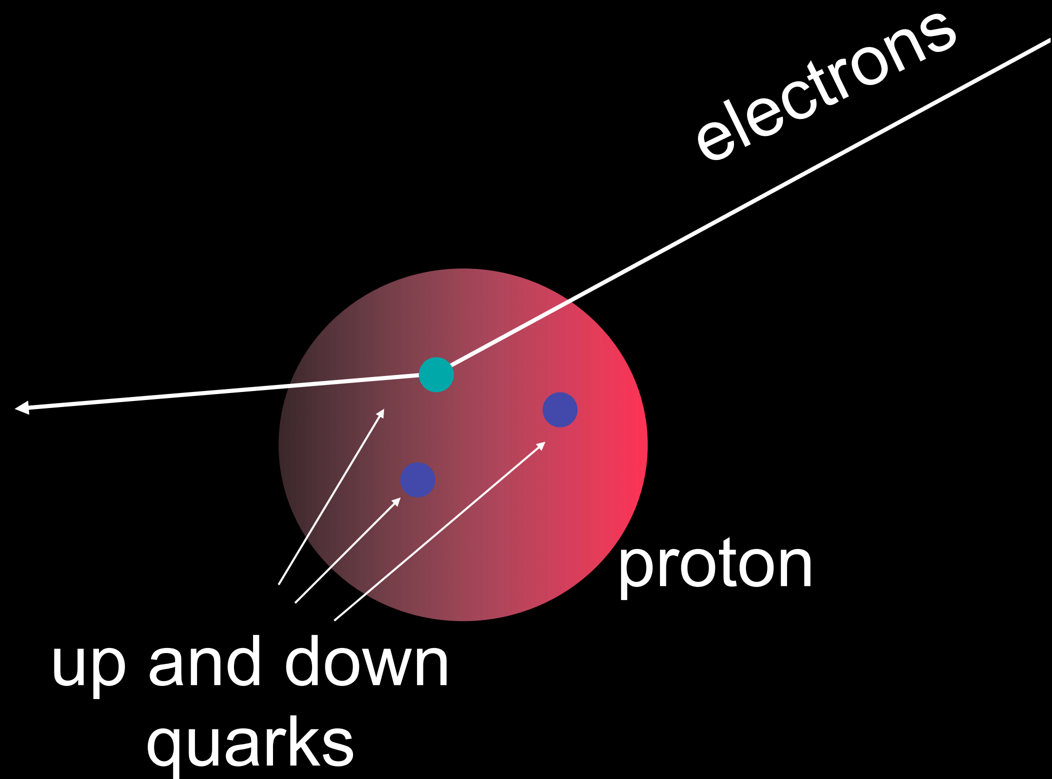
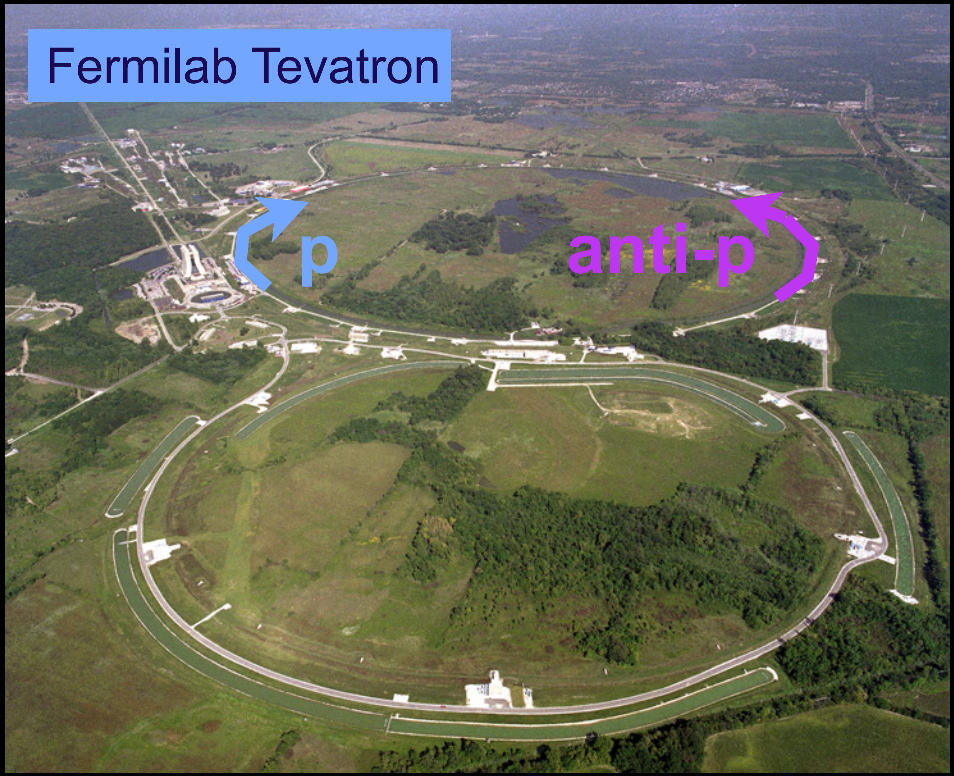


1995 - Top Quark Discovered at Fermilab



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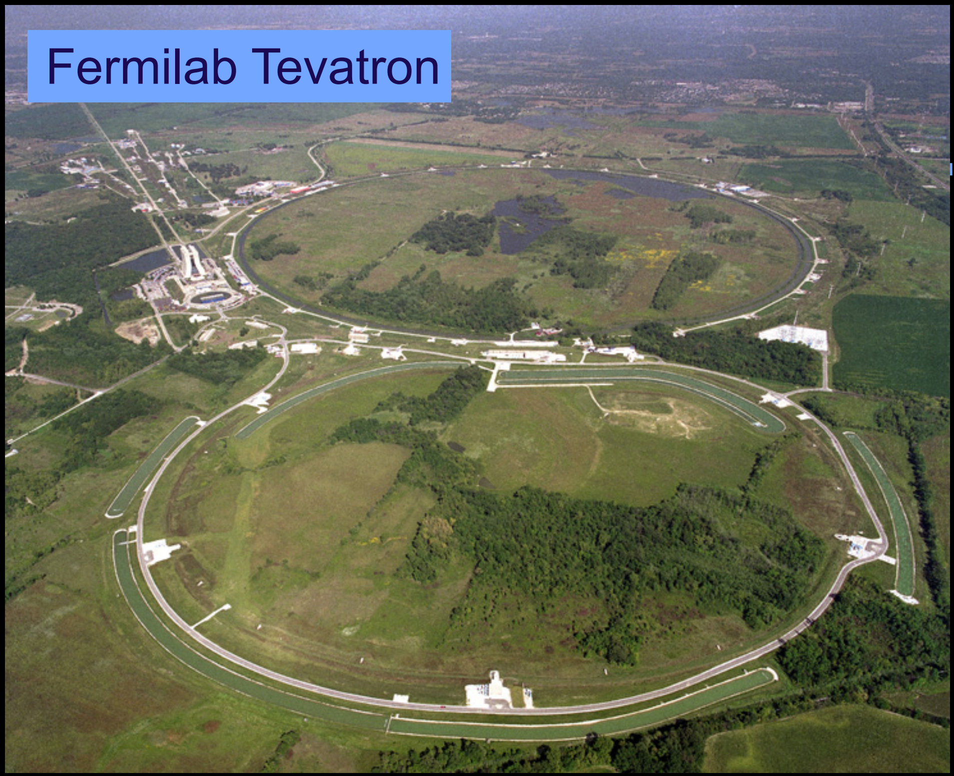
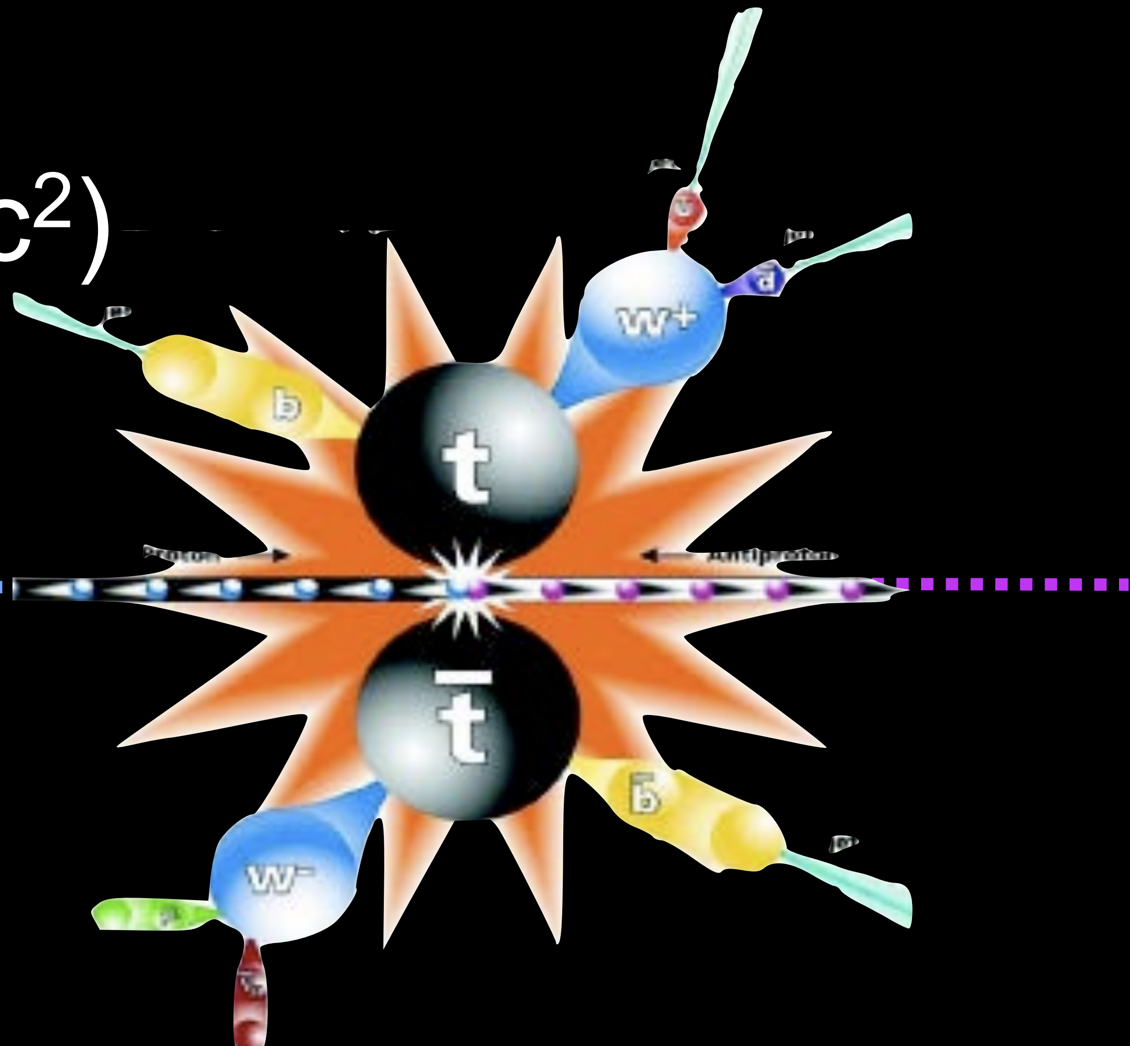
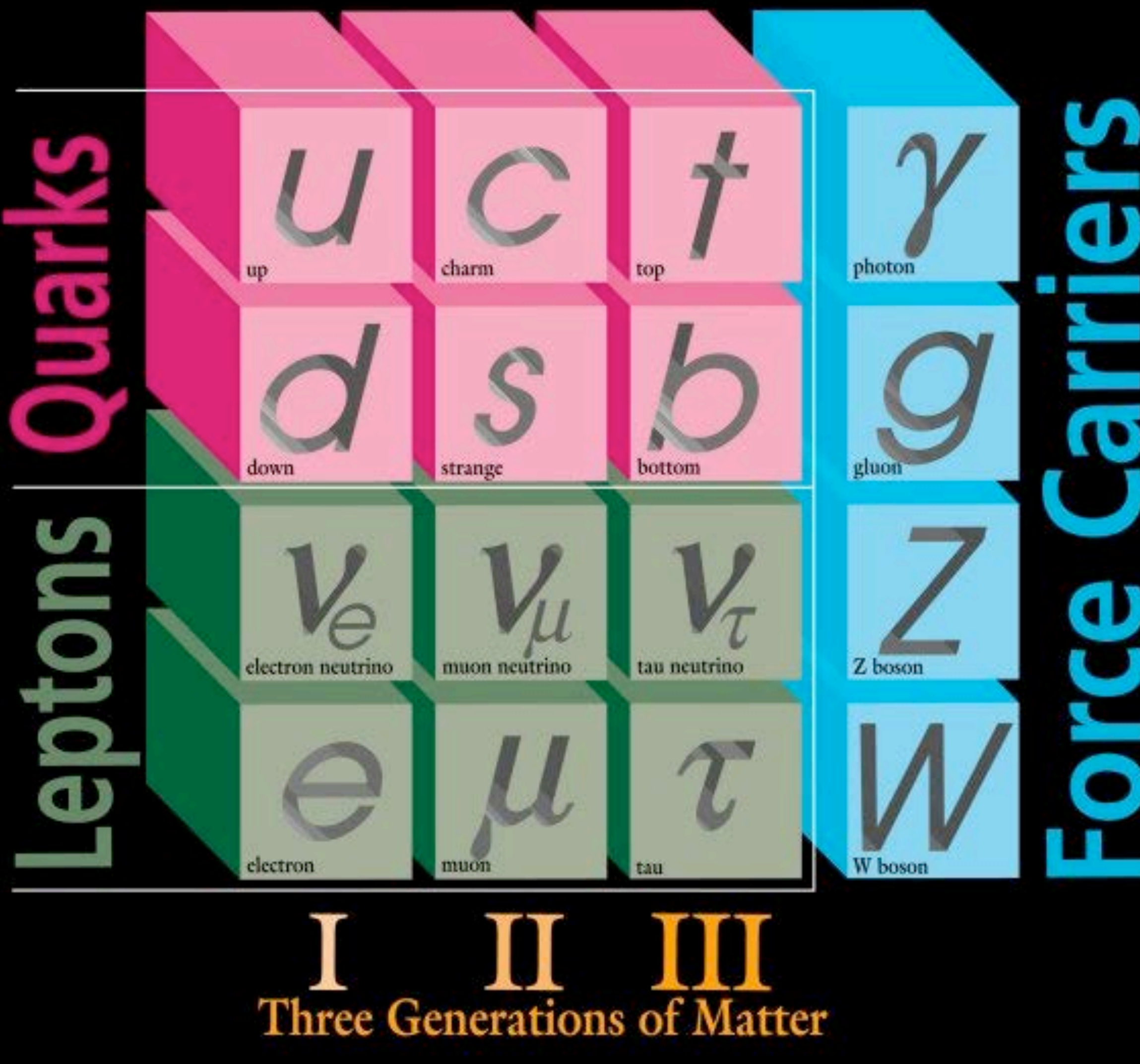


1995 - Top Quark Discovered at Fermilab

Creation of massive matter ($E=mc^2$)

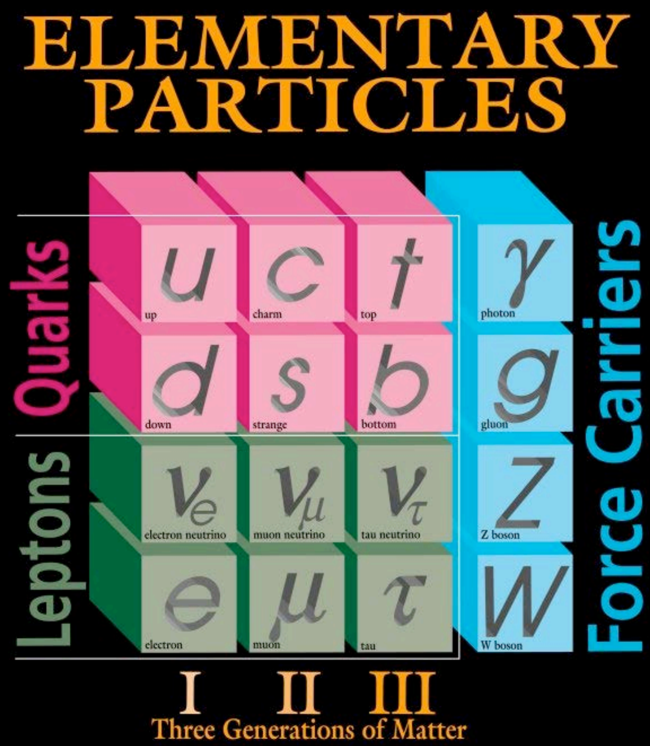


ELEMENTARY PARTICLES



Particles and Forces

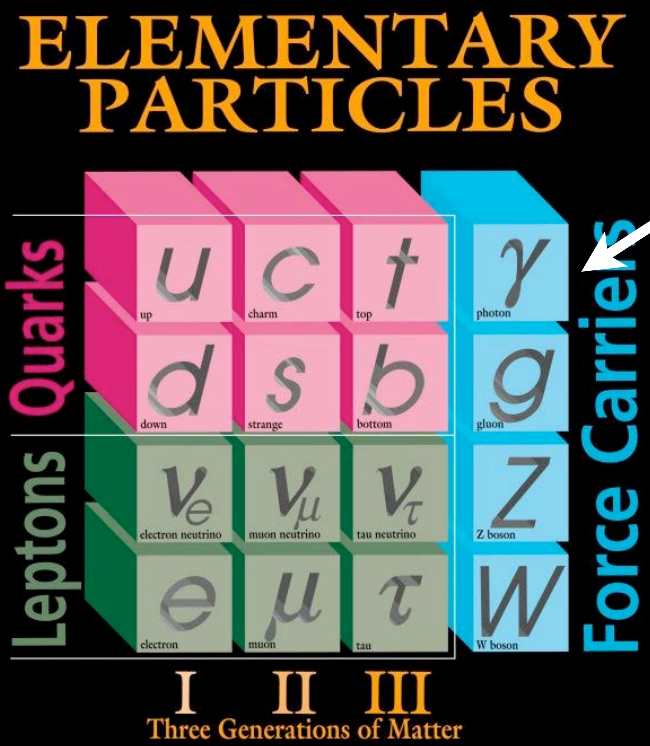
"interactions"



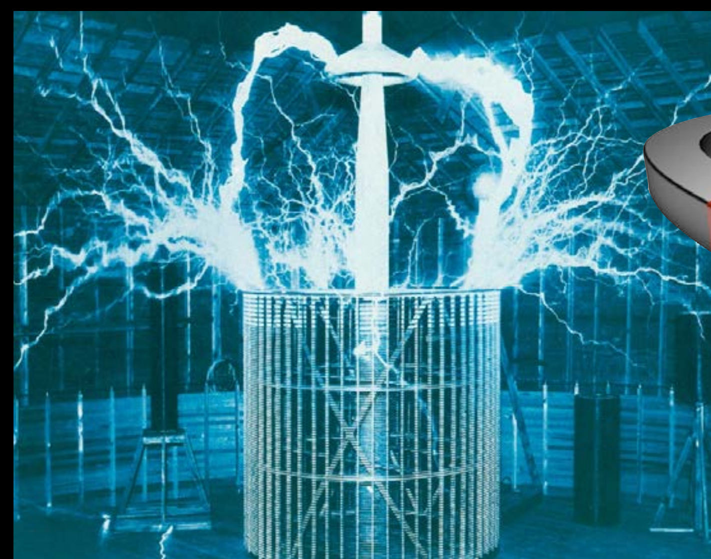
- Gravity - weakest

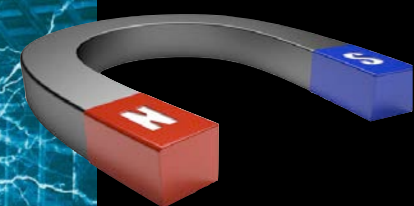
Particles and Forces

"interactions"



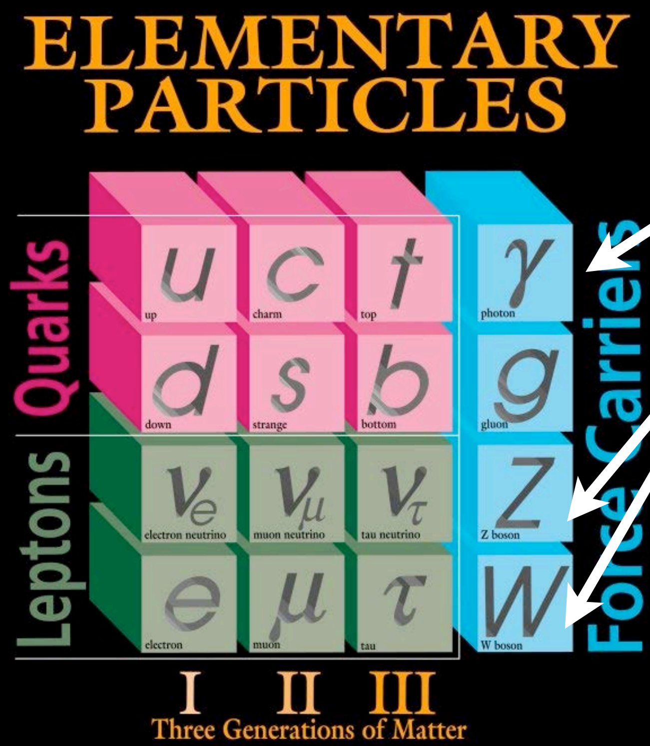
- Gravity - weakest
- Electromagnetism





Particles and Forces

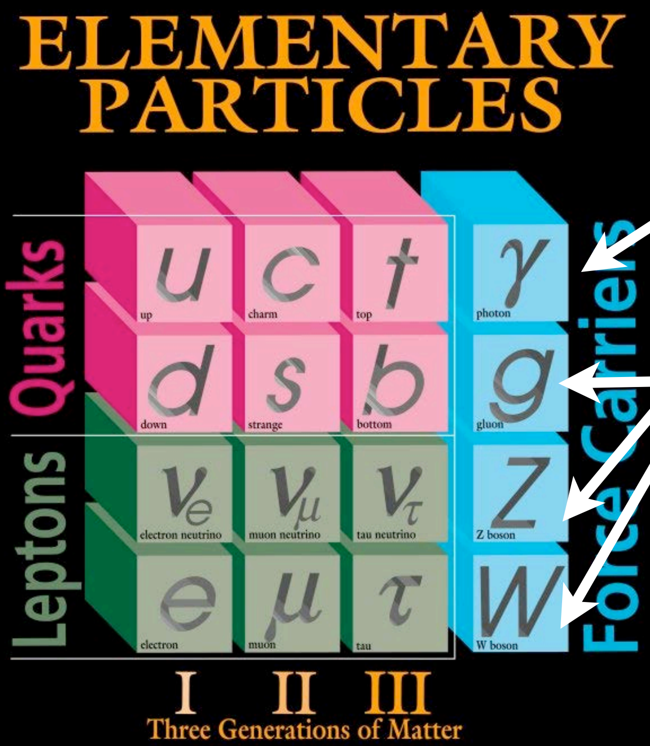
"interactions"



- Gravity - weakest
- Electromagnetism
- Weak Nuclear

Particles and Forces

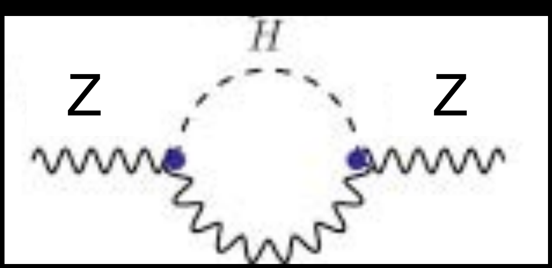
"interactions"

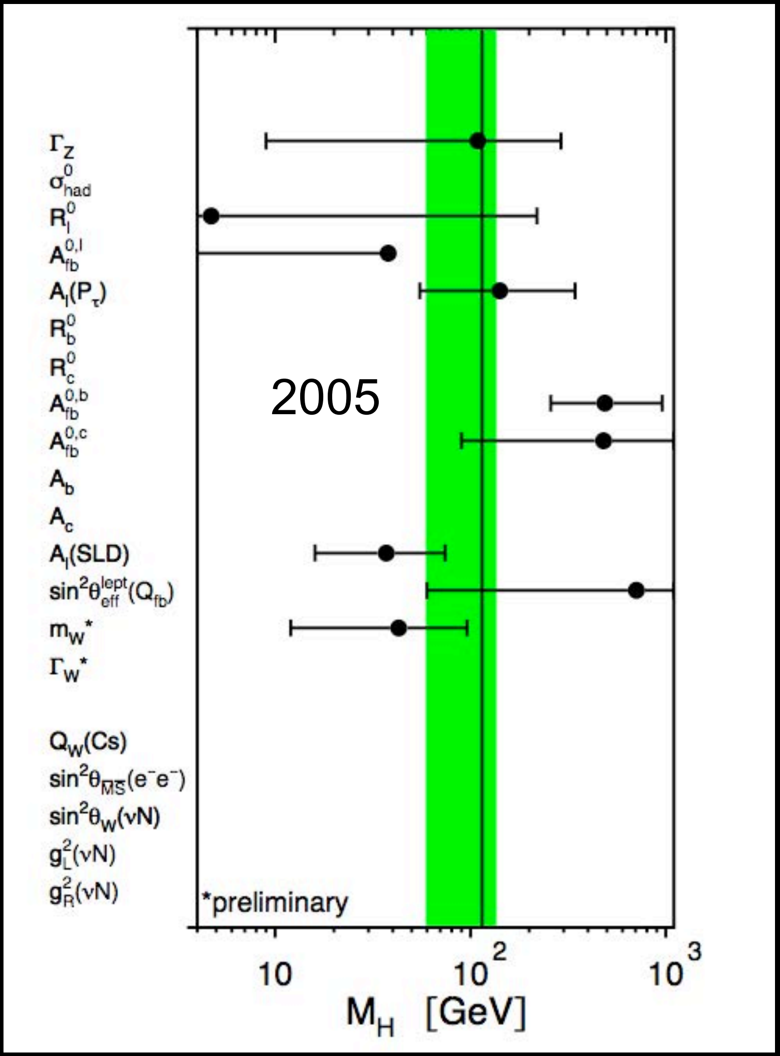


- Gravity - weakest
- Electromagnetism
- Weak Nuclear
- Strong Nuclear

Indirect evidence of Higgs Before the LHC

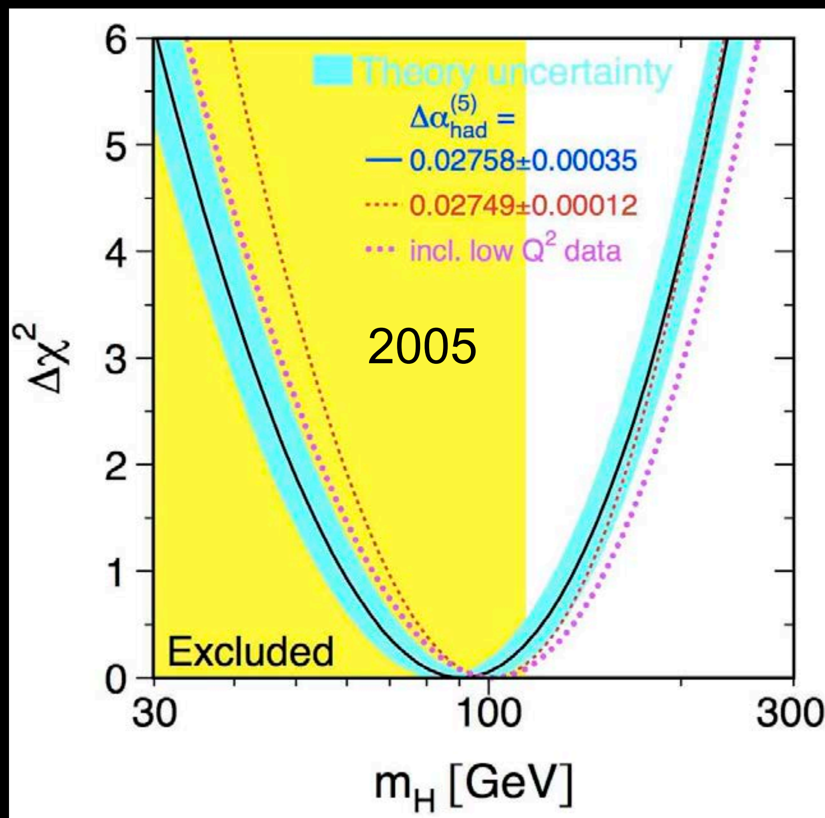
- Since the Higgs boson interacts with fundamental particles (in theory) experiments can detect indirect evidence for it and "measure" its mass

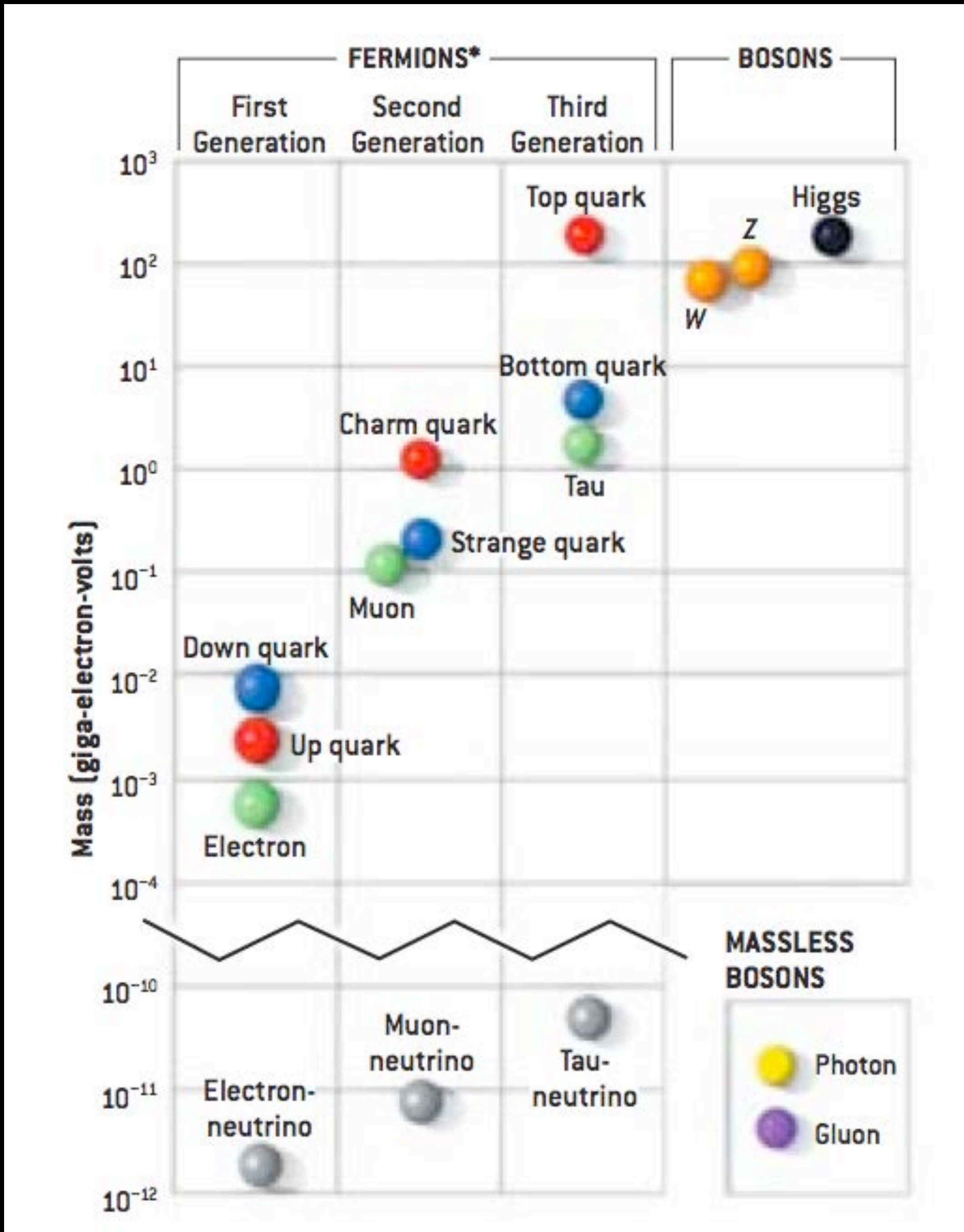


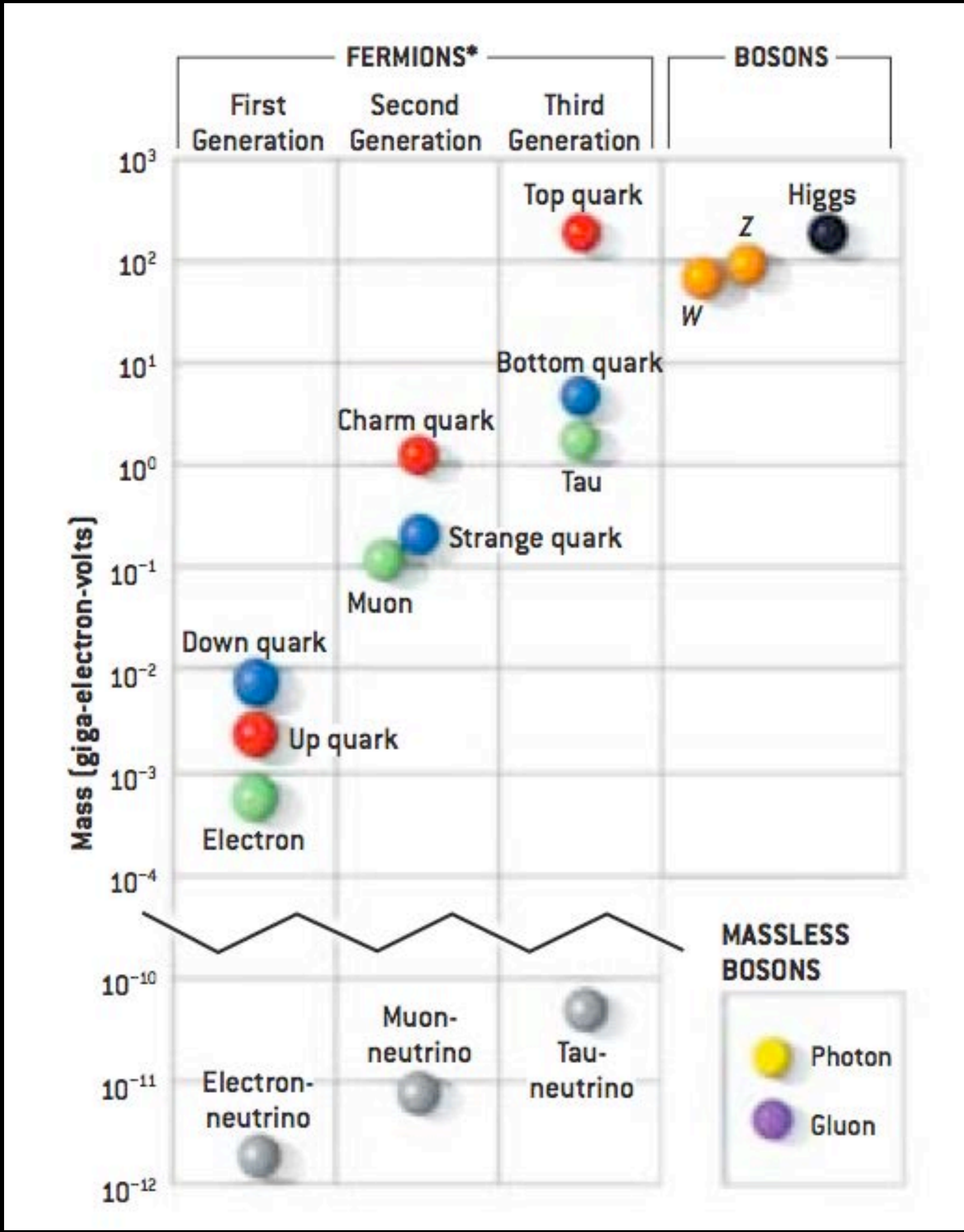


Indirect evidence for Higgs Before the LHC

- Those experiments find that the mass is less than 186 GeV (95% confidence)




FERMIONS*
BOSONS
First Generation
Second Generation
Third Generation
Mass (giga-electron-volts)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-10}
10^{-11}
10^{-12}
Top quark
Higgs
Z
W
Bottom quark
Charm quark
Tau
Strange quark
Muon
Down quark
Up quark
Electron
MASSLESS BOSONS
Muon-neutrino
Tau-neutrino
Electron-neutrino
Photon
Gluon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10^1
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10^-1
10^-2
10^-3
10^-4
10^-10
10^-11
10^-12
Top quark
Higgs
Z
W
Bottom quark
Charm quark
Tau
Strange quark
Muon
Down quark
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Electron
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Muon-neutrino
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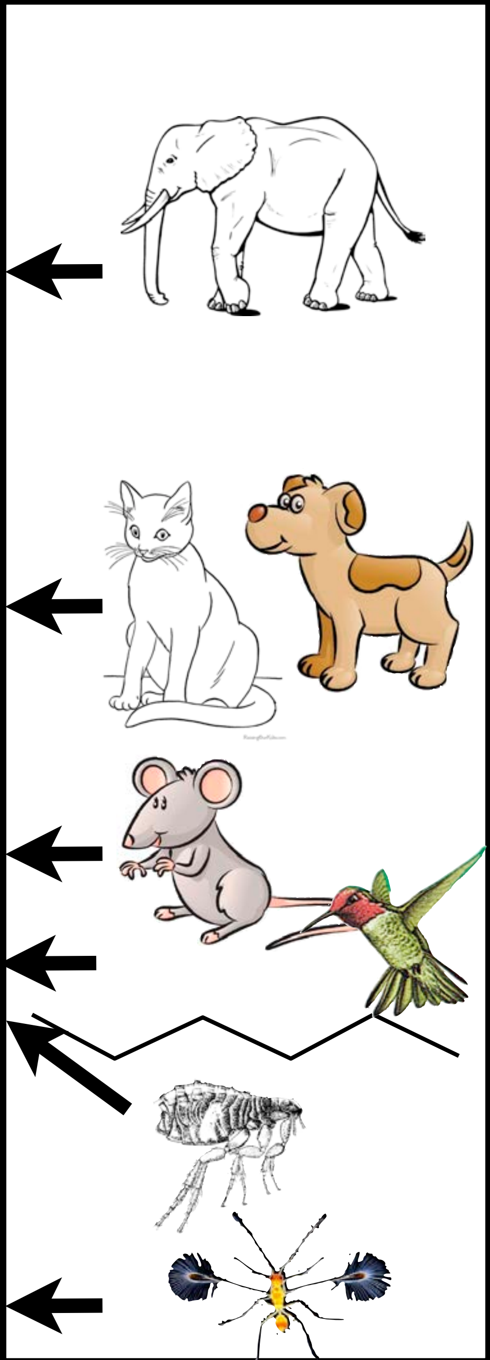
Gluon



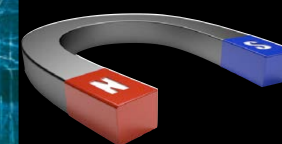
Forces

"interactions"

Are Forces Related?

1850

- Gravity
- Electricity
- Magnetism



Forces

"interactions"

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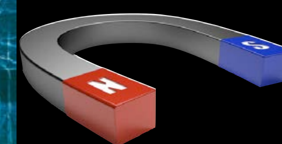
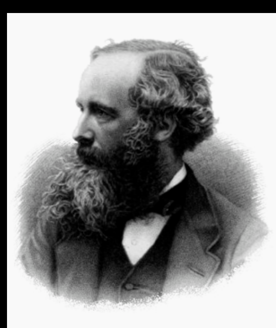


1864

Unified theory

- Electromagnetism
- Light (photons)



J.C. Maxwell

Forces

"interactions"

Are Forces Related?

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Unified theory

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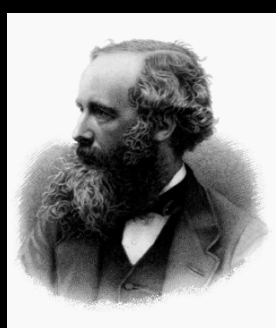
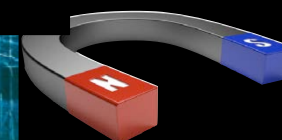


J.C. Maxwell

- Gravity
- Electromagnetism



Are Forces Related?

Forces

“interactions”

2000

- Gravity
- Electromagnetism
- Weak Nuclear
- Strong Nuclear

Forces

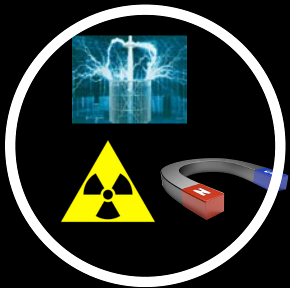
"interactions"

Are Forces Related?

2000

- Gravity

- Electroweak



- Strong Nuclear

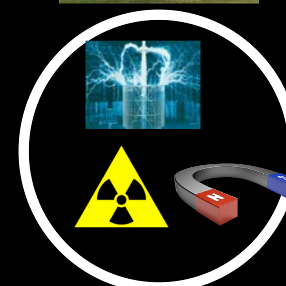
Forces

"interactions"

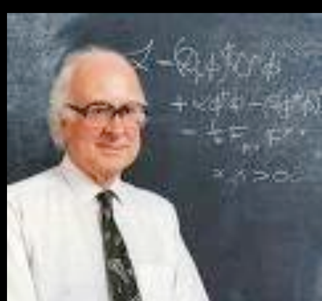
Are Forces Related?

2000

- Gravity
- Electroweak
- Strong Nuclear



Anticipated
- discovery of the Higgs Boson at accelerators



P. Higgs

Forces

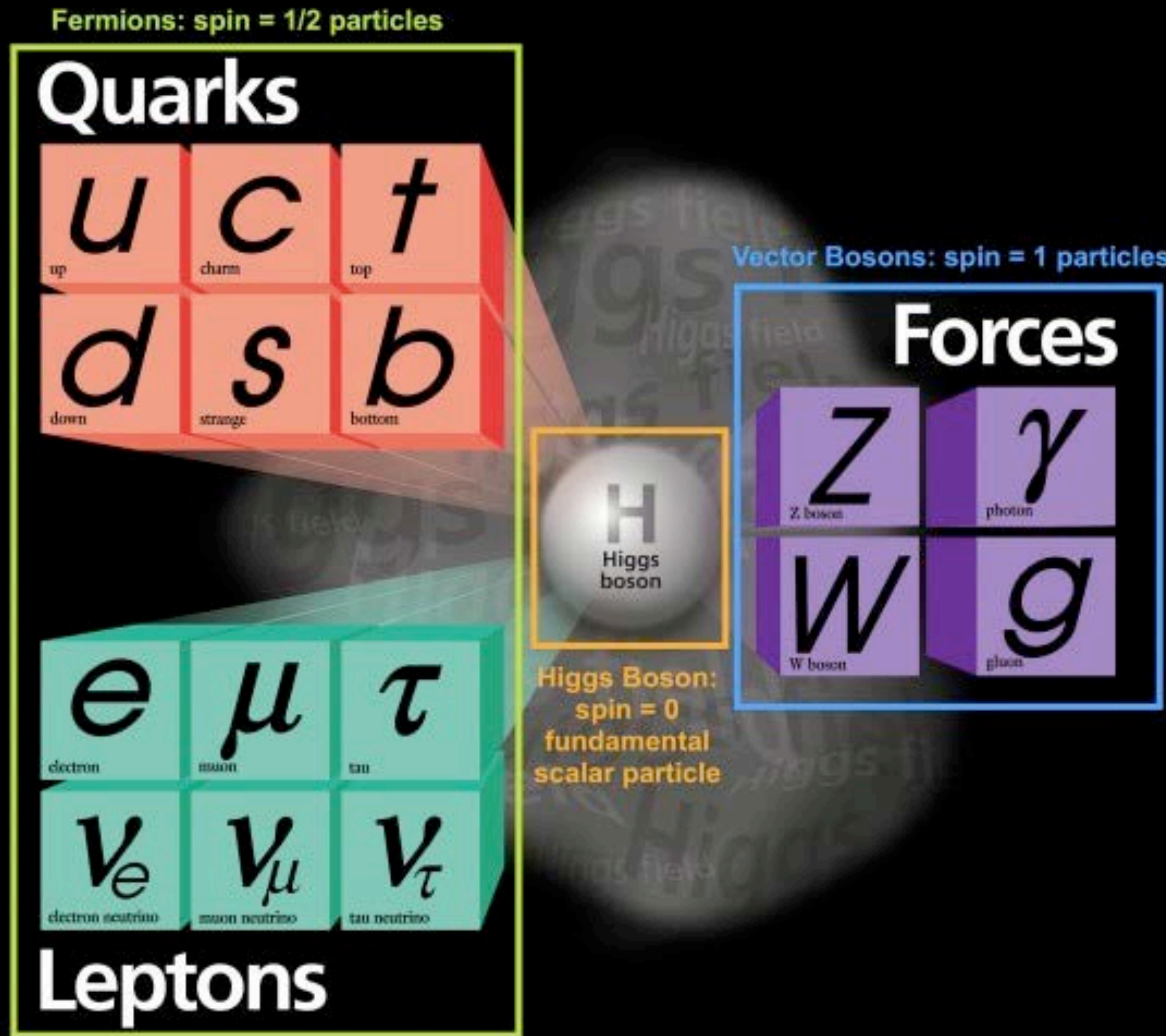
"interactions"

Are Forces Related?

2000

Are all forces related?
New particles would be involved in any unification

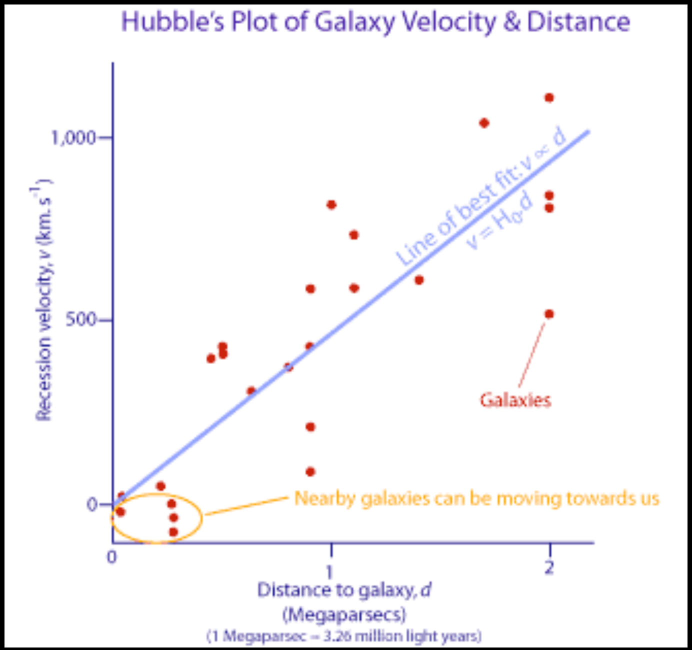
- Gravity
- Electroweak
- Strong Nuclear

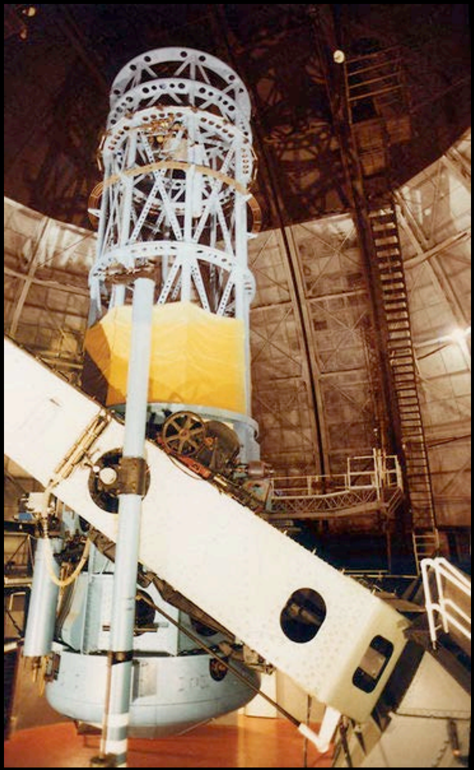


Fermions: spin = 1/2 particles
Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
e
electron
μ
muon
τ
tau
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
Leptons
H
Higgs boson
Higgs Boson: spin = 0 fundamental scalar particle
Vector Bosons: spin = 1 particles
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon

1929 - Hubble Discovered Universe is Expanding

Edwin Powell Hubble
(1889-1953)



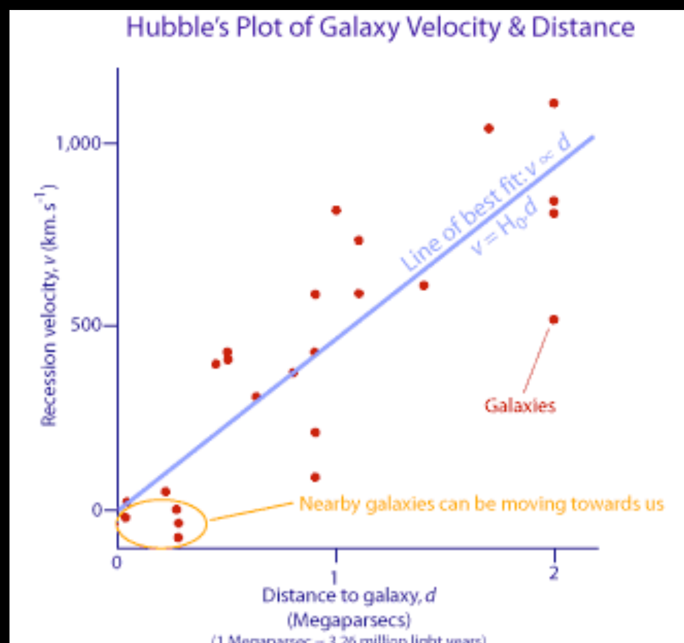


1929

1929 - Hubble Discovered Universe is Expanding

<u>First</u> evidence that Universe began with a Big Bang

Edwin Powell Hubble
(1889-1953)



1929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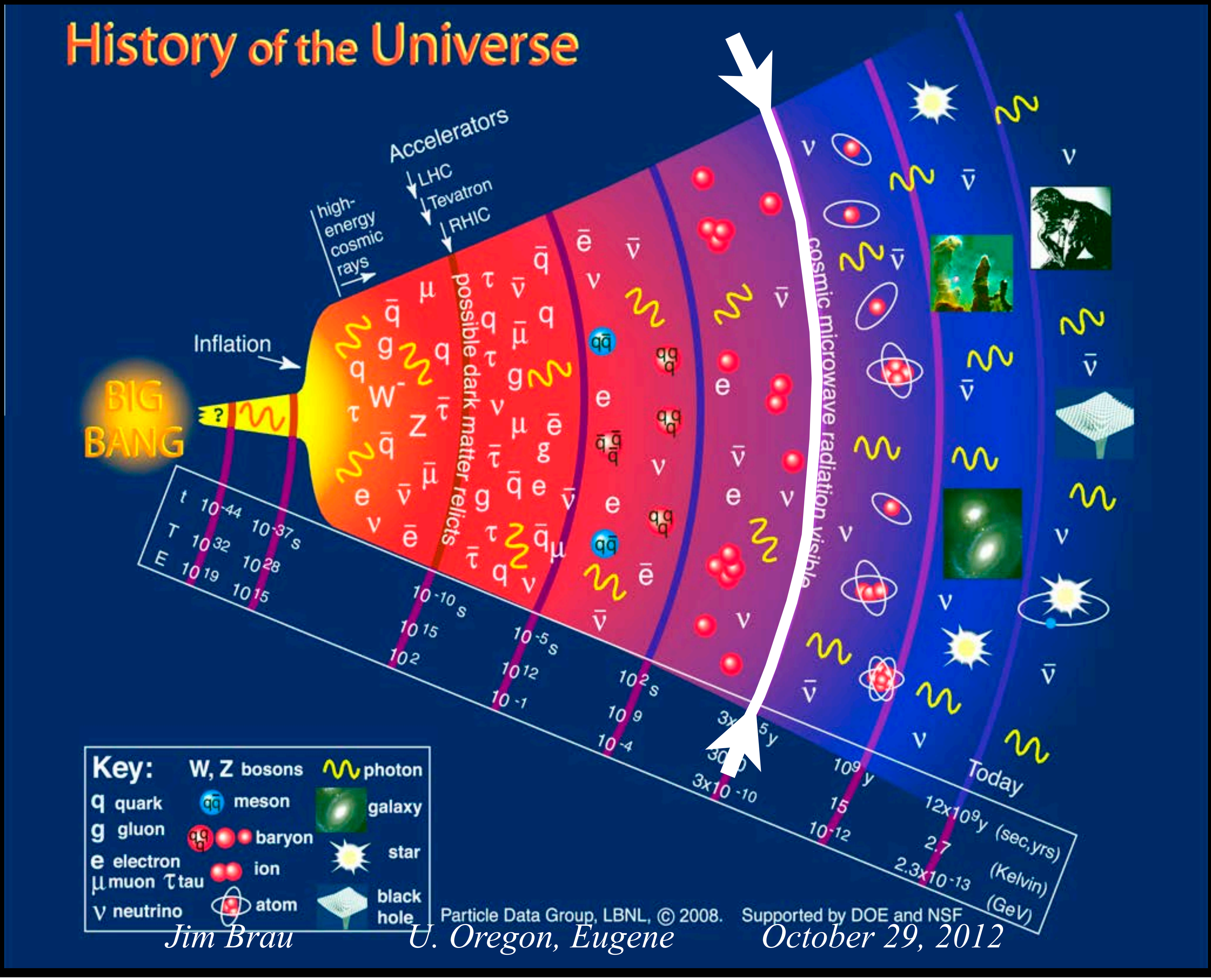
www.MrEclipse.com

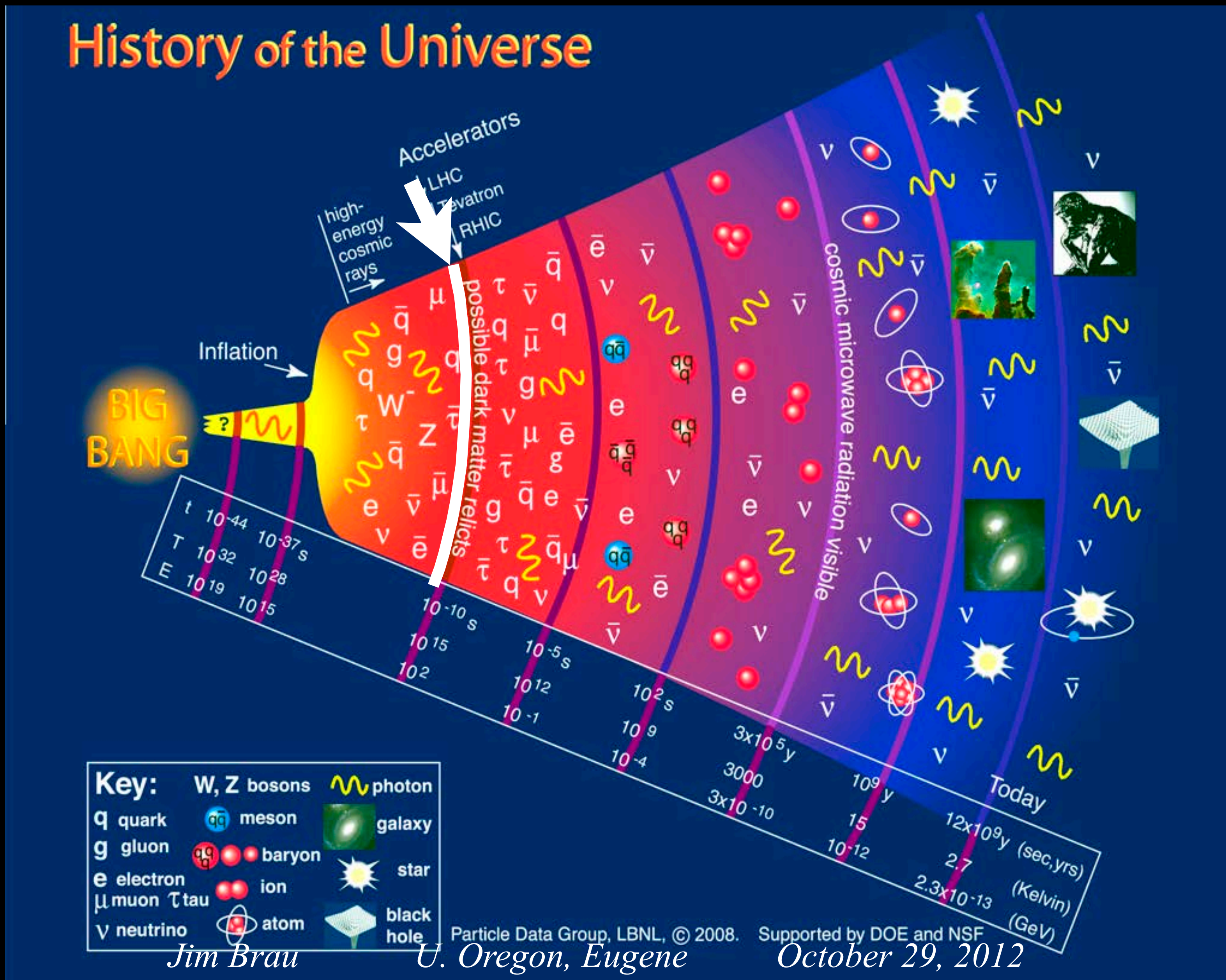

Universe's Glow
in Microwaves
discovered in 1965

predicted following
Hubble's discovery

confirmed early
universe of Big Bang

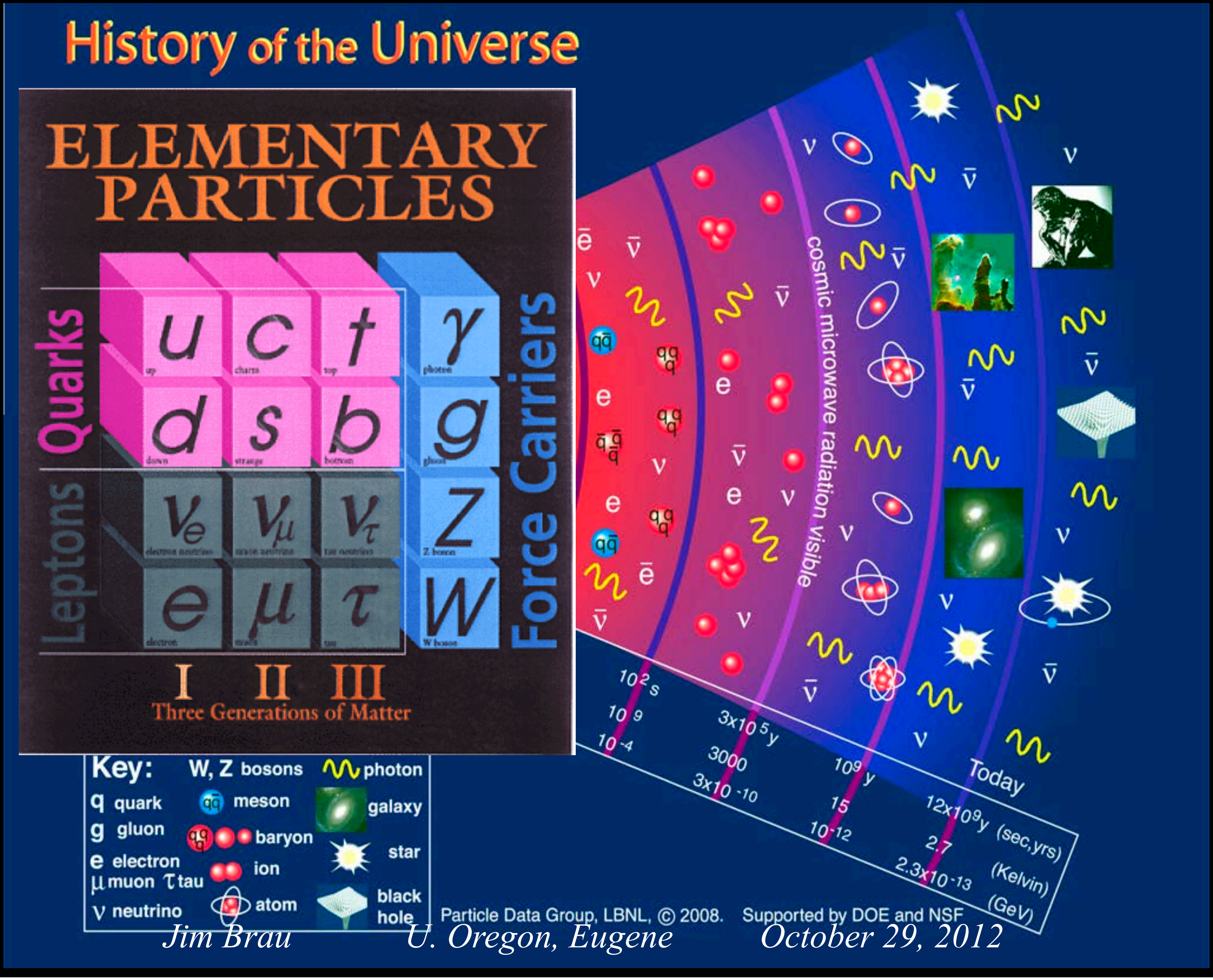
Big Bang


History of the Universe
BIG BANG
Inflation
high-energy cosmic rays
Accelerators
LHC
Tevatron
RHIC
possible dark matter relicts
cosmic microwave radiation visible
Today
Key:
q quark
g gluon
e electron
μ muon τ tau
ν neutrino
W, Z bosons
meson
baryon
ion
atom
photon
galaxy
star
black hole
(sec,yrs)
(Kelvin)
(GeV)
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF

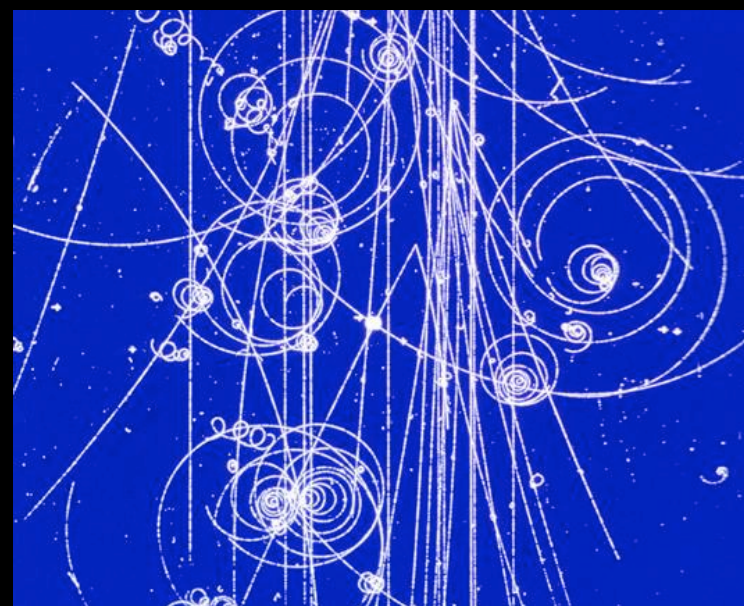

History of the Universe
Accelerators
LHC
Tevatron
RHIC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37s 10-10 s 10-5 s 10 2 s 3x10 5 y 10 9 y 12x10 9 y (sec,yrs)
T 10 32 10 28 10 15 10 12 10 9 3000 15 2.7 (Kelvin)
E 10 19 10 15 10 2 10 -1 10 -4 3x10 -10 10 -12 2.3x10 -13 (GeV)
Today
Key:
q quark
g gluon
e electron
μ muon τ tau
ν neutrino
W, Z bosons
meson
baryon
ion
atom
photon
galaxy
star
black hole
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF

Particles and Forces

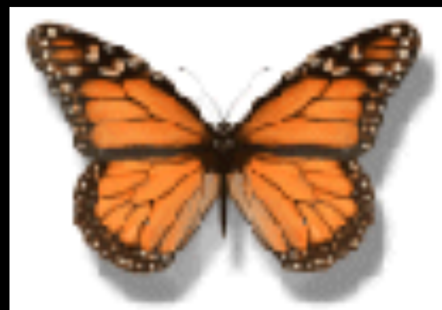
"interactions"



What is Matter?

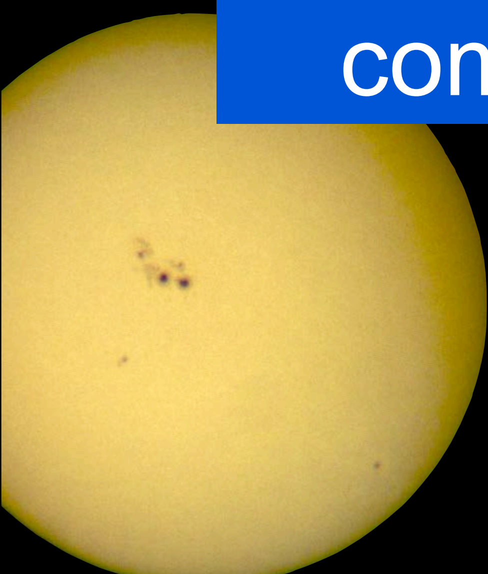


What is Matter?

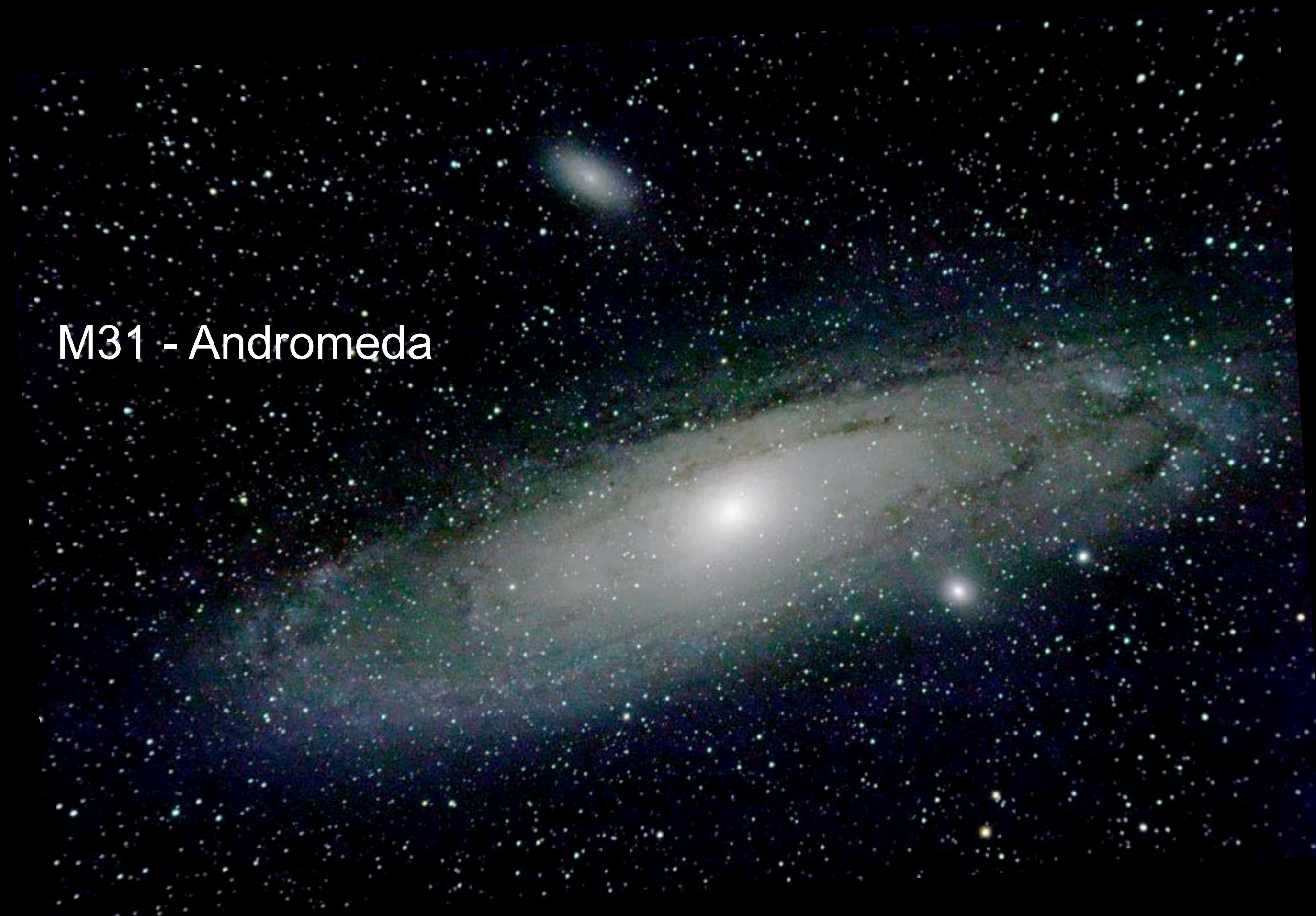



all Atomic

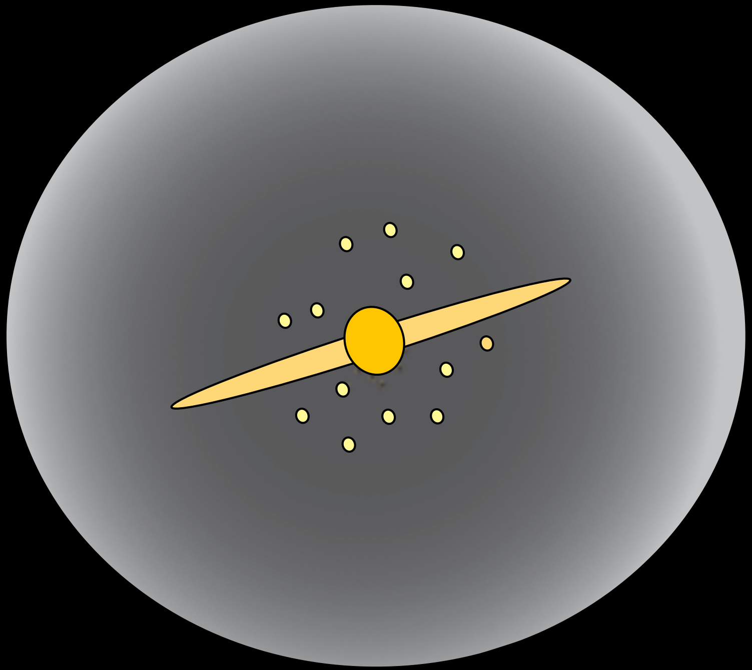
composed of quarks and leptons



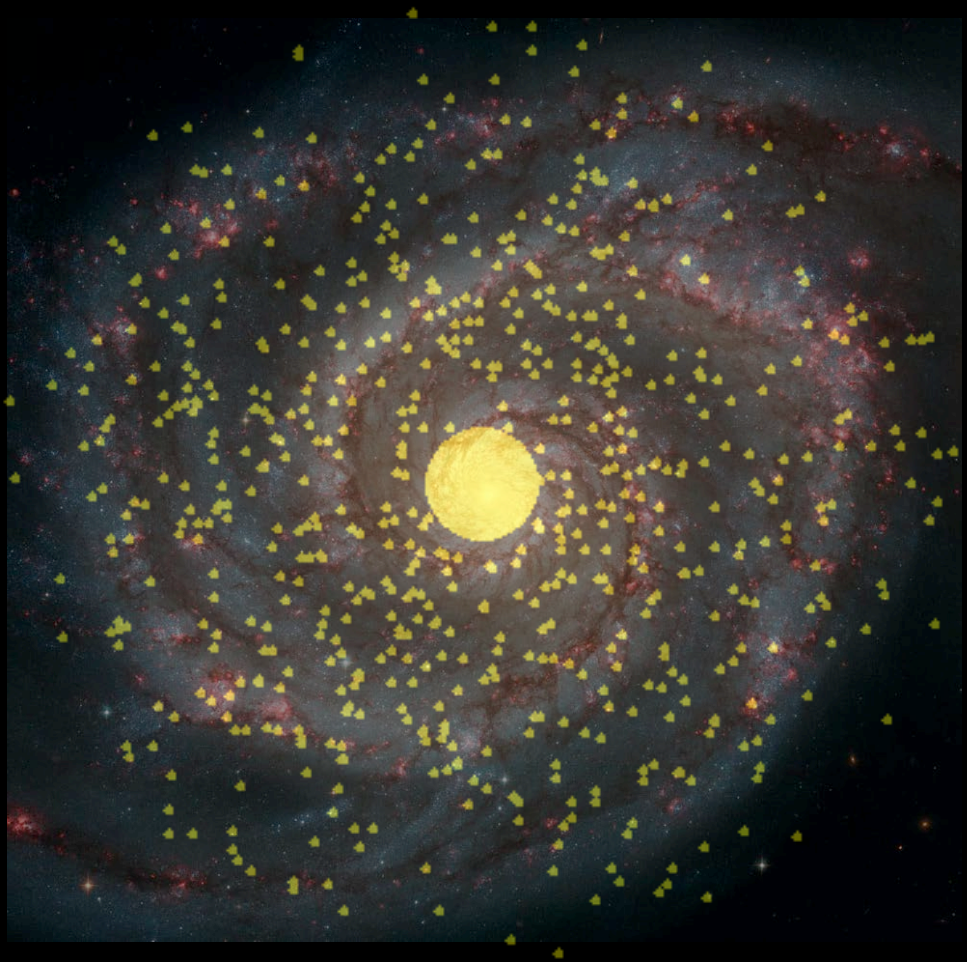
Halo of Dark Matter



Halo of Dark Matter



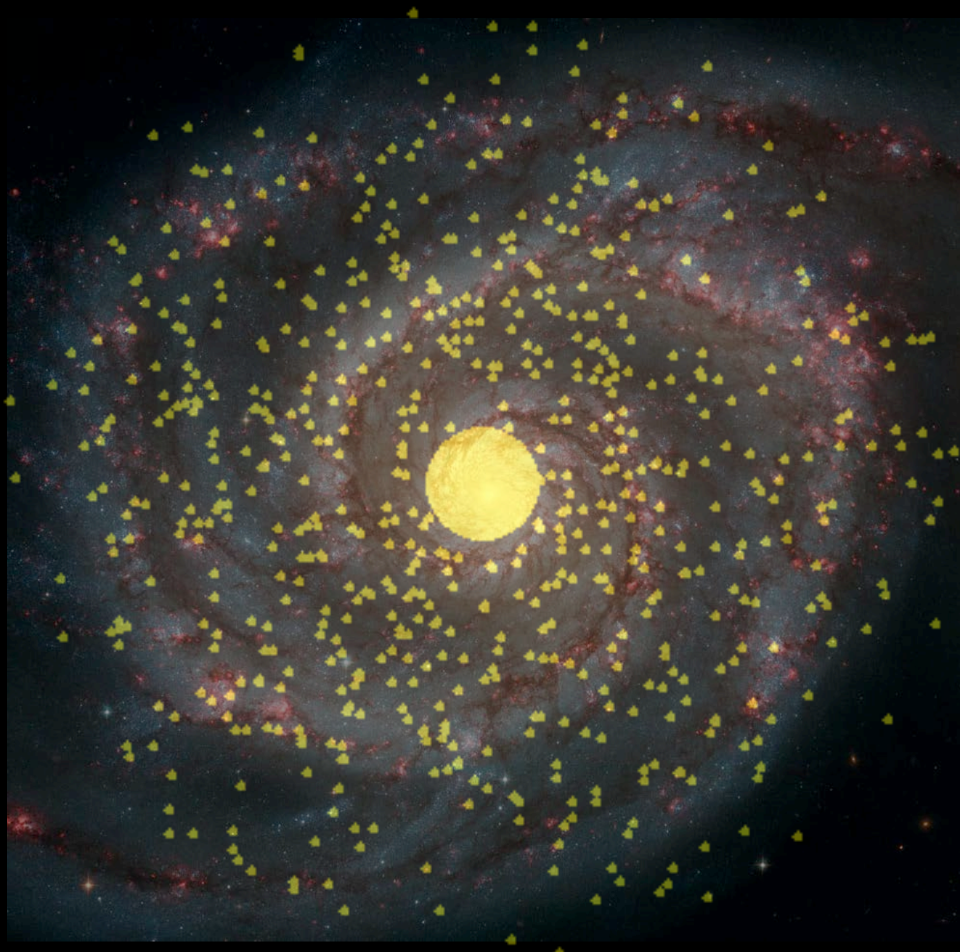
How we know dark halos surround galaxies?

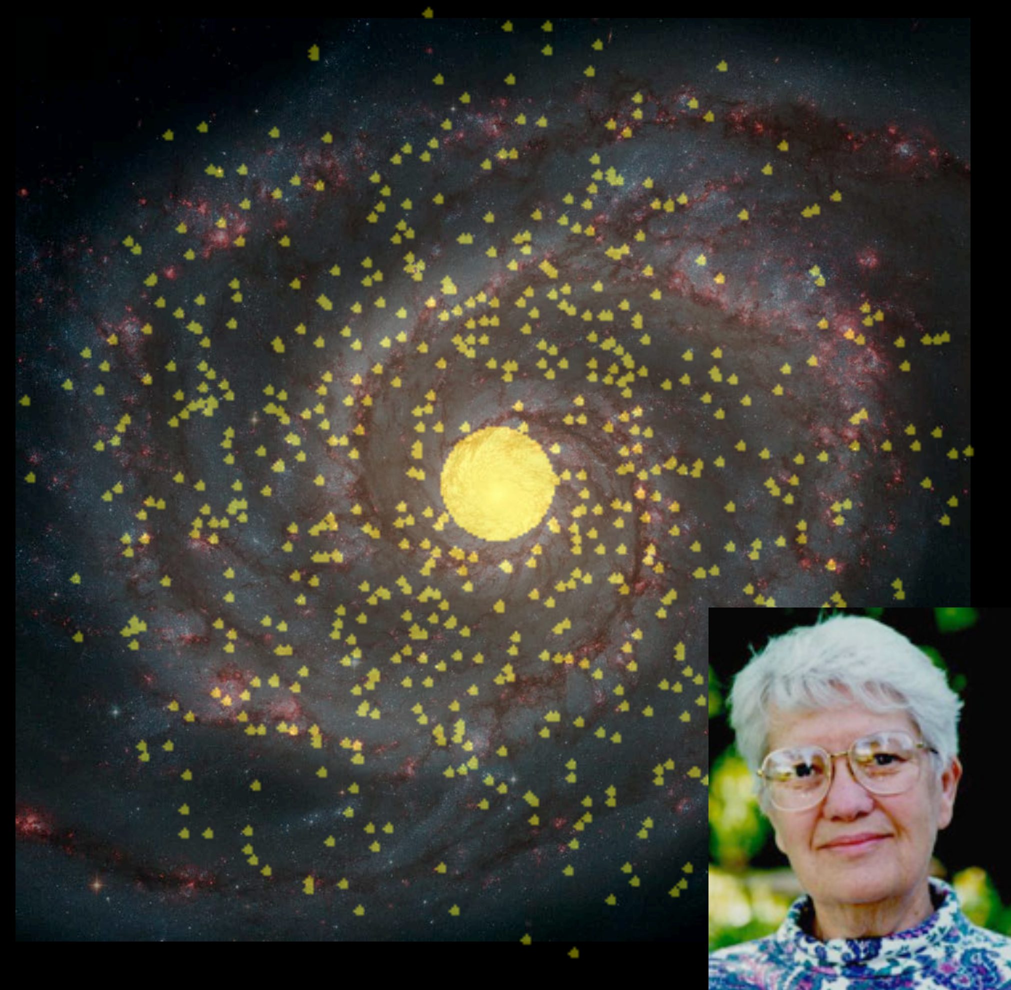


Expected-

based on stellar mass

How we know dark halos surround galaxies?





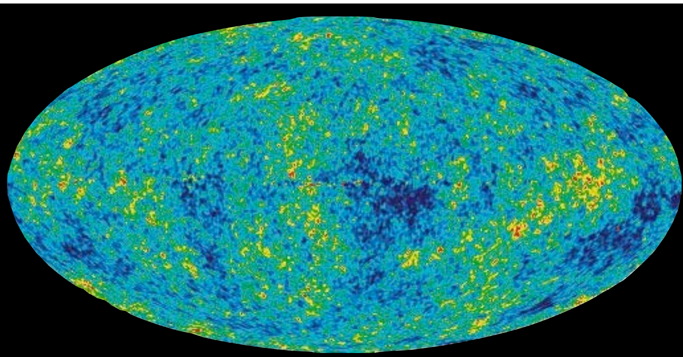
Vera Rubin
1950s

Expected-
based on stellar mass

Observed-
reveals invisible (“dark”) mass

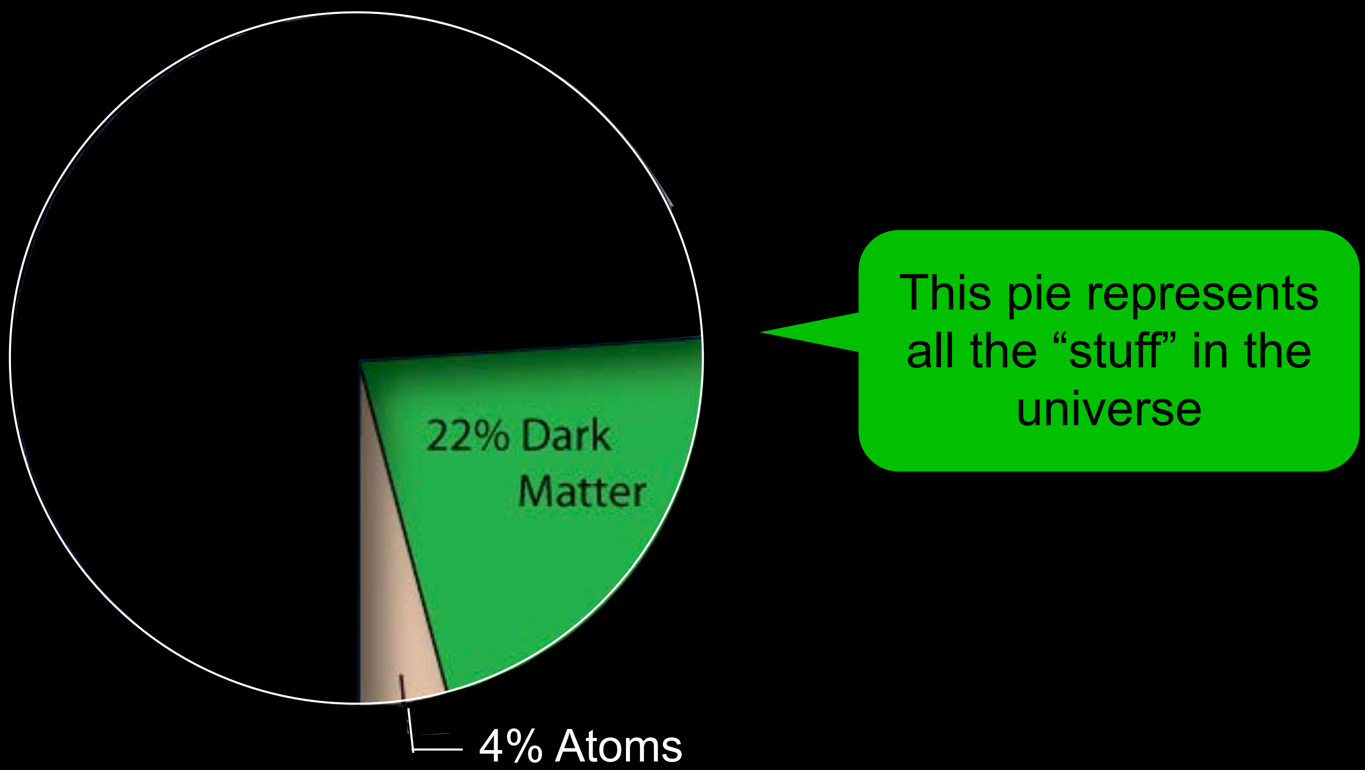
Dark Matter Dominates Atomic Matter

- Dark Mattter of the Universe out weighs Atomic Matter by about 6 to 1
- What is it?
- We have good ideas, but only direct evidence will be definitive
- Accelerator experiments may discover the Dark Matter



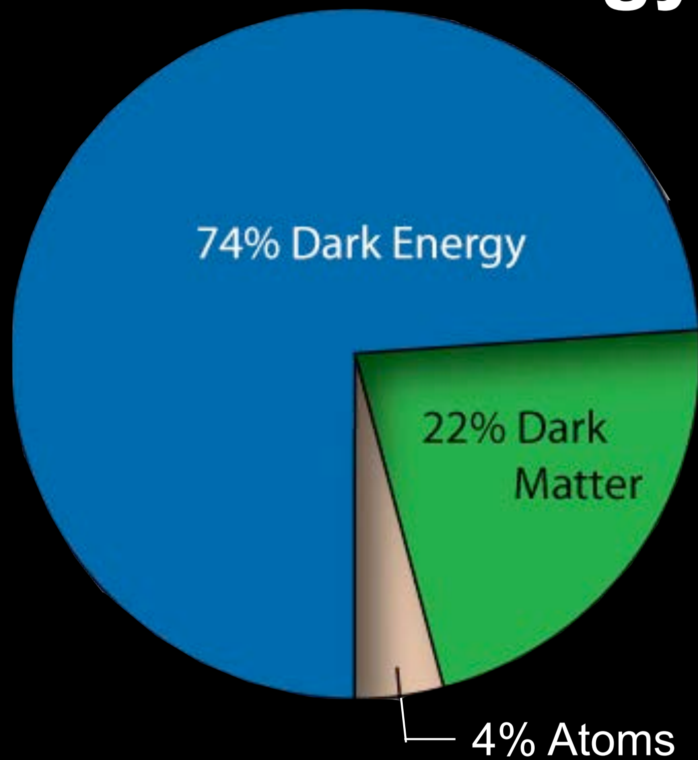
The Matter Crisis

- not enough matter (atomic or dark matter) to "make-up" known stuff of the Universe

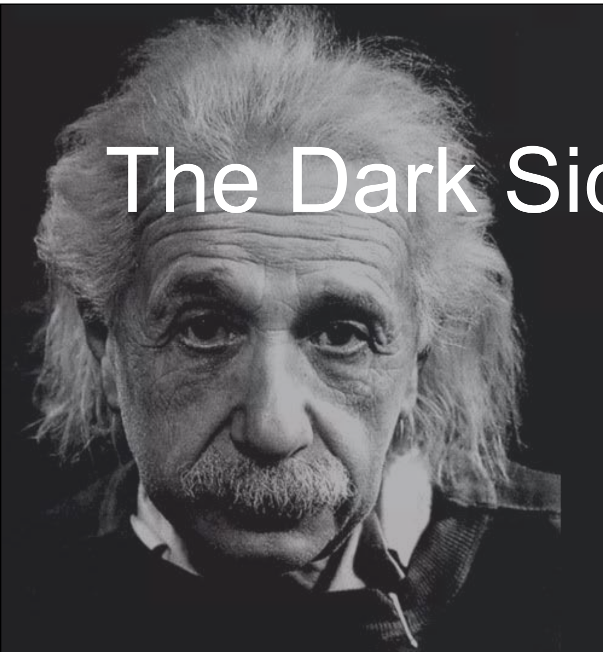


Acceleration Component called “Dark Energy”

- Solves “Matter” Crisis
- The dominant “stuff” of the universe is **dark matter** and **dark energy**



The Dark Side Controls the Universe

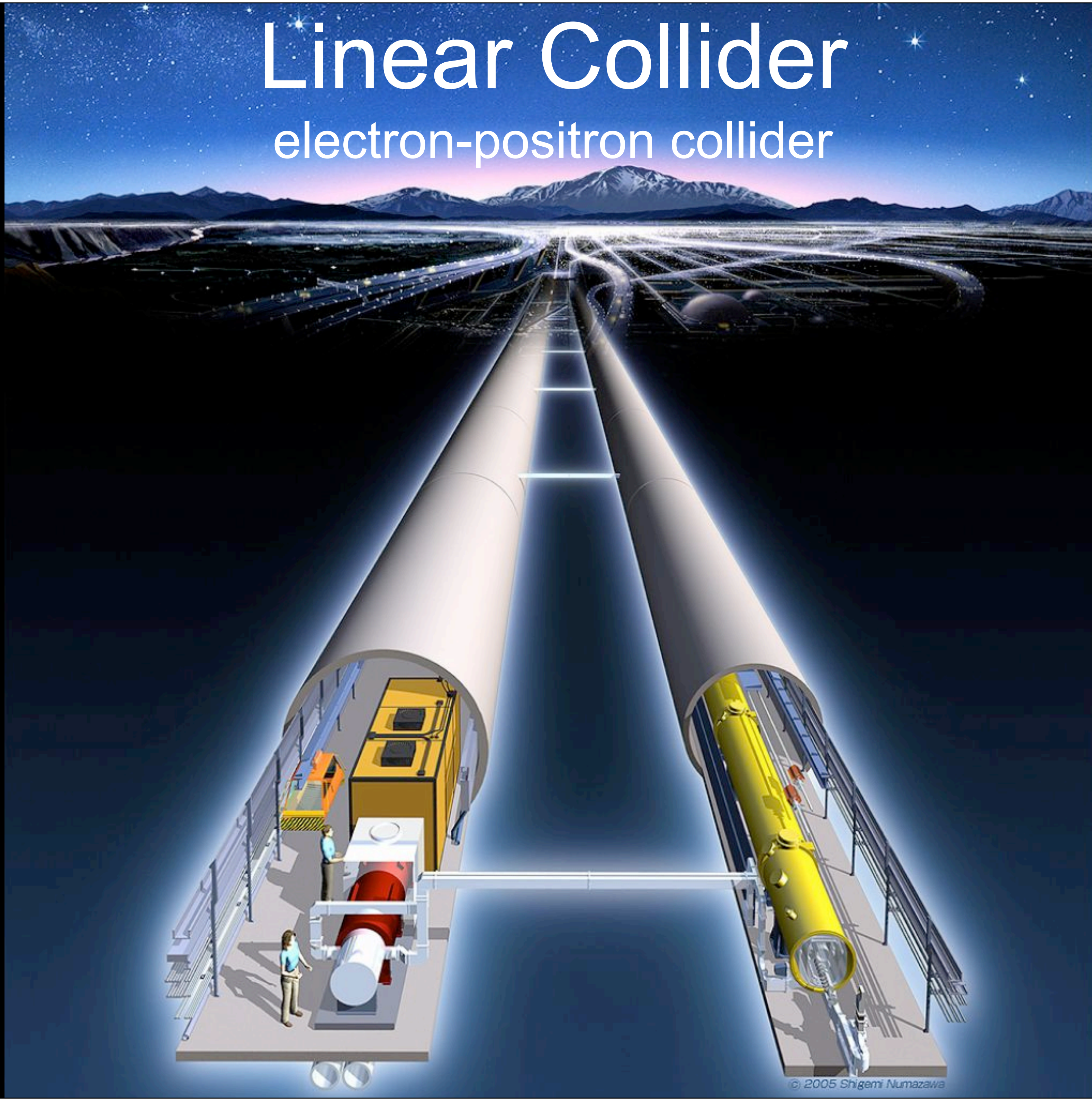


Dark Matter HOLDS IT TOGETHER

Dark Energy DETERMINES ITS DESTINY

Dark Matter is strange!

Dark Energy stranger?


Linear Collider
electron-positron collider
(c) 2005 Shigemi Numazawa

Linear Collider

electron-positron collider

FUTURE

Offers more precise studies of Higgs and other possible new physics

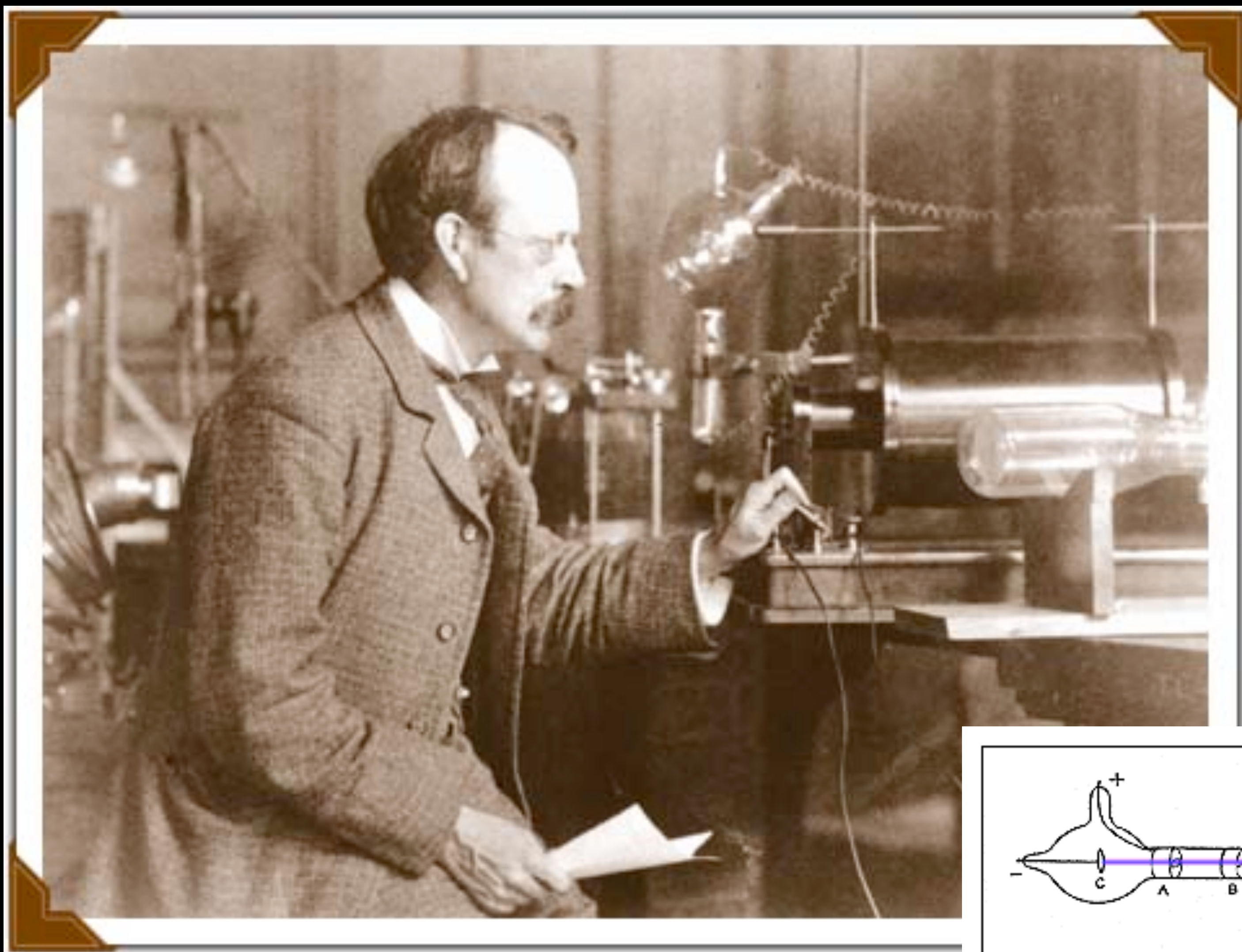
World-wide collaboration (including UO team) has developed the technology

Ready to start construction

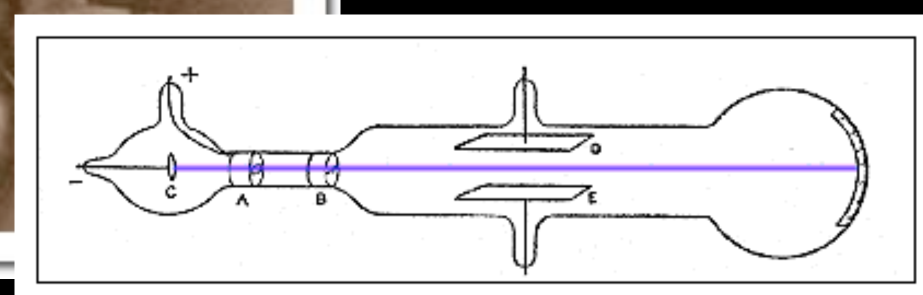
Are there any practical applications?

Credit: American Institute of Physics

1897 - J.J. Thomson   Electron



Credit: American Institute of Physics



J.J. Thomson, On 1897 Discovery

Speaking in 1934

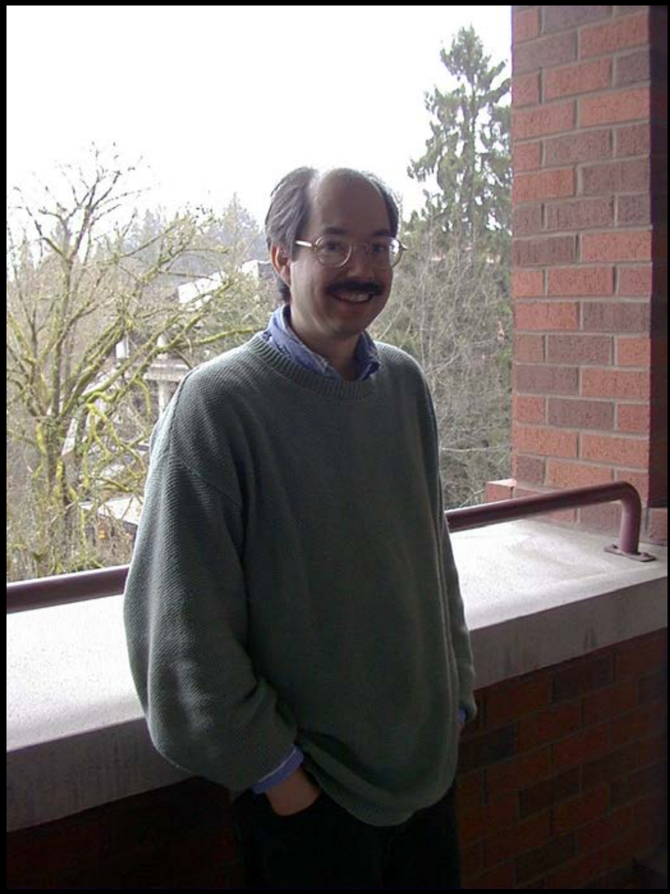
Could anything at first sight seem more impractical than a body which is so small that its mass is an insignificant fraction of the mass of an atom of hydrogen? -- which itself is so small that a crowd of these atoms equal in number to the population of the whole world would be too small to have been detected by any means then known to science.

Credit: American Institute of Physics

From the soundtrack of the film, Atomic Physics

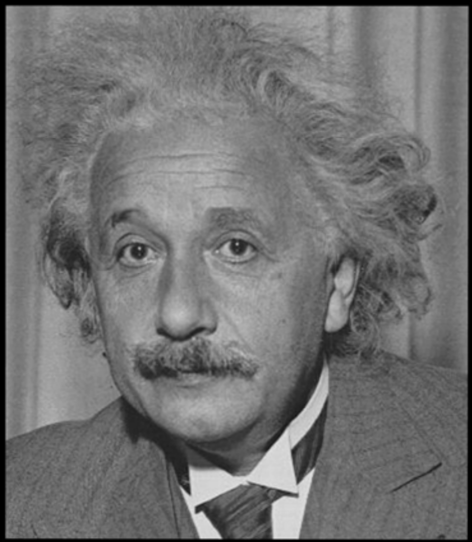
Learn More about the Higgs Boson at the LHC

- Physics Department Colloquium
- Professor David Strom
  - leader in UO's LHC research
  - ATLAS Trigger Coordinator (2010-2012)
- *Finding a Higgs Boson at the LHC*
  - 4 pm, November 1
  - 100 Willamette



One thing I have learned in a long life: that all our science, measured against reality, is primitive and childlike

—and yet it is the most precious thing we have.



The most beautiful experience we can have is the mysterious.

It is the fundamental emotion which stands at the cradle of true art and true science.

Acknowledgements

RESEARCH SUPPORTED BY

Department of Energy
OFFICE OF SCIENCE

NATIONAL SCIENCE FOUNDATION

Philip H. Knight

Acknowledgement: images from http://www.AstroPics.com