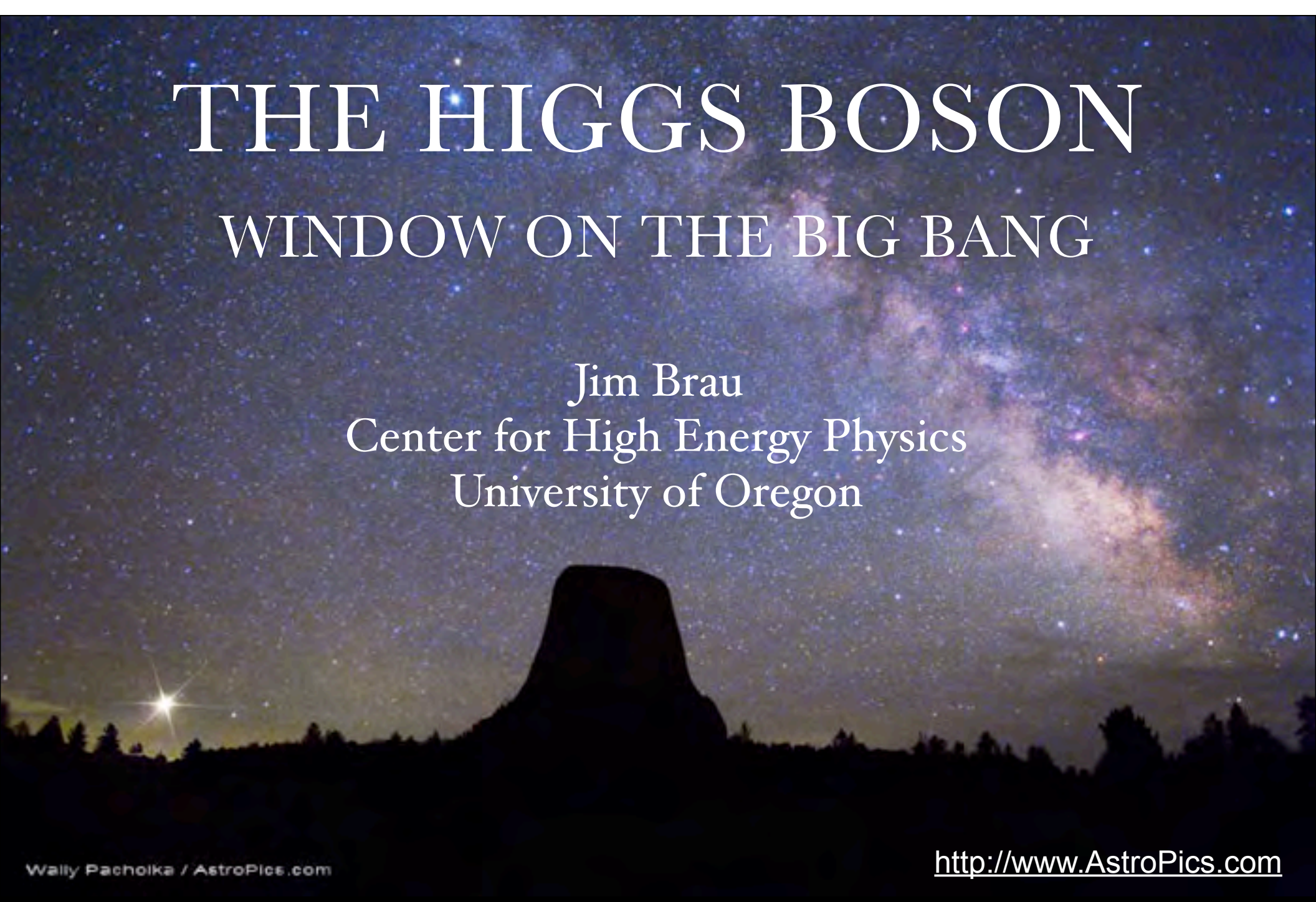
THE HIGGS BOSON

WINDOW ON THE BIG BANG

Jim Brau
Center for High Energy Physics
University of Oregon



http://www.AstroPics.com

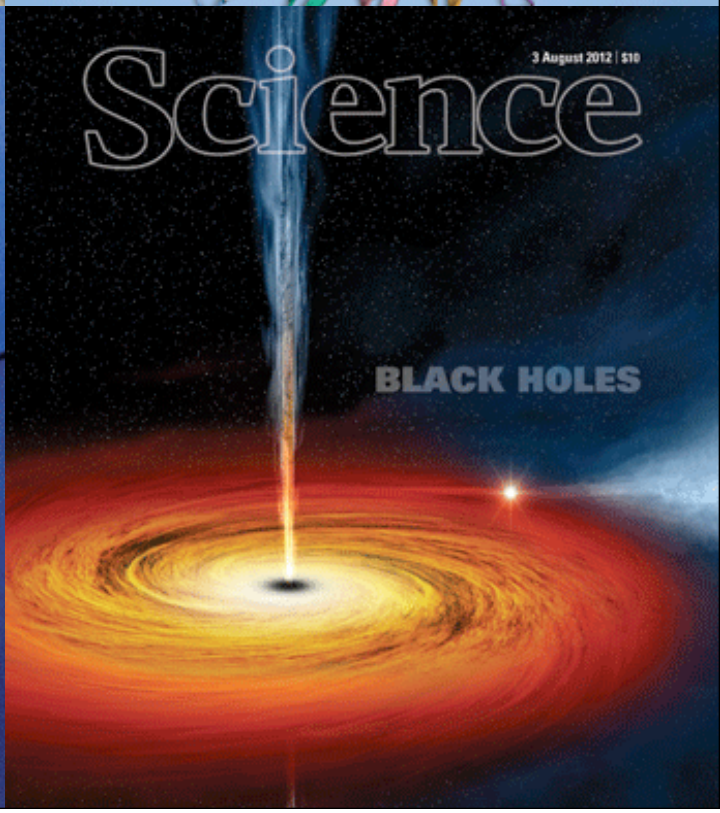

Science
14 December 2012 | $10


Science
4 January 2013 | $10


Science
7 December 2012 | $10


Science
23 November 2012 | $10


Science
12 October 2012 | $10
Forces in Development


Science
3 August 2012 | $10
BLACK HOLES

Science

21 Dec 2012

BREAKTHROUGH OF THE YEAR

Jim Brau *Wright State University* *February 7, 2014*

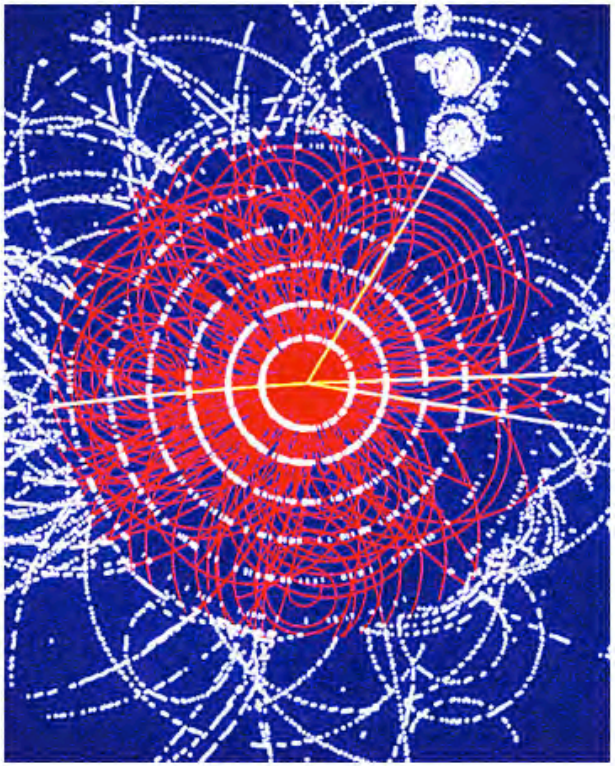
Time's 2012 Person of the Year: *the Higgs Boson was among nominees!*

THE CANDIDATES

18 of 40

The Higgs Boson

By Jeffrey Kluger | Monday, Nov. 26, 2012



SSPL/GETTY IMAGES

Simulation of a Higgs-Boson decaying into four muons, CERN, 1990.

What do you think?

Should **The Higgs Boson** be TIME's Person of the Year 2012?

19.74% **Definitely** 80.26% **No Way**

Take a moment to thank this little particle for all the work it does, because without it, you'd be just inchoate energy without so much as a bit of mass. What's more, the same would be true for the entire universe. It was in the 1960s that Scottish physicist Peter Higgs first posited the existence of a particle that causes energy to make the jump to matter. But it was not until last summer that a team of researchers at Europe's Large Hadron Collider — Rolf Heuer, Joseph Incandela and Fabiola Gianotti — at last sealed the deal and in so doing finally fully confirmed Einstein's general theory of relativity. The Higgs — as particles do — immediately decayed to more-fundamental particles, but the scientists would surely be happy to collect any honors or awards in its stead.

Time's 2012 Person of the Year: *the Higgs Boson was among nominees!*

Name	Definitely	No Way
Kim Jong Un	5,635,941	137,986
Jon Stewart	2,366,324	63,213
Undocumented Immigrants	1,554,085	328,710
Gabby Douglas	1,515,215	79,167
Aung San Suu Kyi and Thein Sein	1,487,945	56,021
Stephen Colbert	1,446,656	270,675
Chris Christie	1,368,767	401,011
Hillary Clinton	1,317,815	485,059
Ai Weiwei	1,151,120	456,897
Mohamed Morsi	874,486	2,032,540
Bashar Assad	857,339	353,982
E.L. James	782,583	245,593
Roger Goodell	691,870	99,026
Sheldon Adelson	618,678	427,300
Malala Yousafzai	340,205	48,453
The Mars Rover	102,477	294,597
Psy	100,722	100,308
Barack Obama	89,182	100,584
[illegible]	82,316	83,570
The Higgs Boson Particle	73,558	299,051
[illegible]	56,881	374,714
Bill Clinton	48,323	86,134
Michael Phelps	42,825	91,954
Sandra Fluke	42,133	83,803
Mitt Romney	30,764	541,059
Joe Biden	29,576	103,127

Time's 2012 Person of the Year:
the Higgs Boson was among nominees!

THE CANDIDATES

The Higgs Boson

18 of 40

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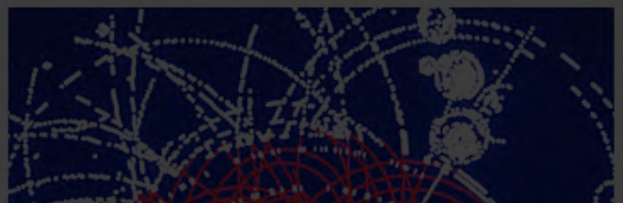

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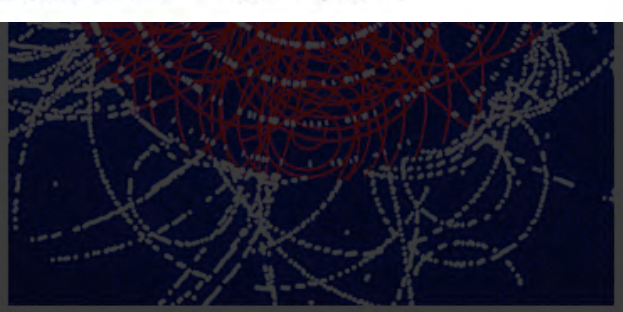
The Higgs Boson: Particle of the Year

Forget Person of the Year – the discovery this summer by the Large Hadron Collider of the Higgs Boson particle was one of science's greatest achievements

By TIME Staff @TIME Dec. 19, 2012



SSPL/GETTY IMAGES

Simulation of a Higgs-Boson decaying into four muons, CERN, 1990.

a particle that causes energy to make the jump to matter. But it was not until last summer that a team of researchers at Europe's Large Hadron Collider — Rolf Heuer, Joseph Incandela and Fabiola Gianotti — at last sealed the deal and in so doing finally fully confirmed Einstein's general theory of relativity. The Higgs — as particles do — immediately decayed to more-fundamental particles, but the scientists would surely be happy to collect any honors or awards in its stead.

The Nobel Prize in Physics 2013

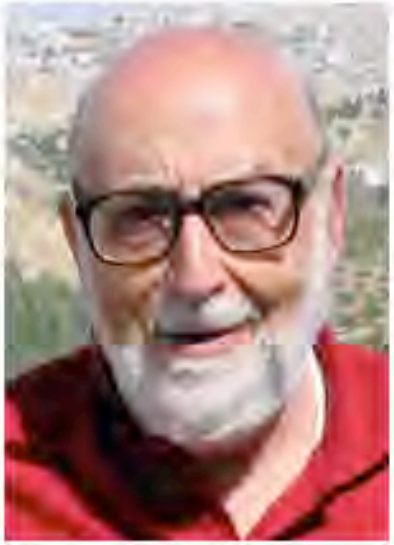


Photo: Pnicolet via Wikimedia Commons

François Englert

Photo: G-M Greuel via Wikimedia Commons

Peter W. Higgs

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"*

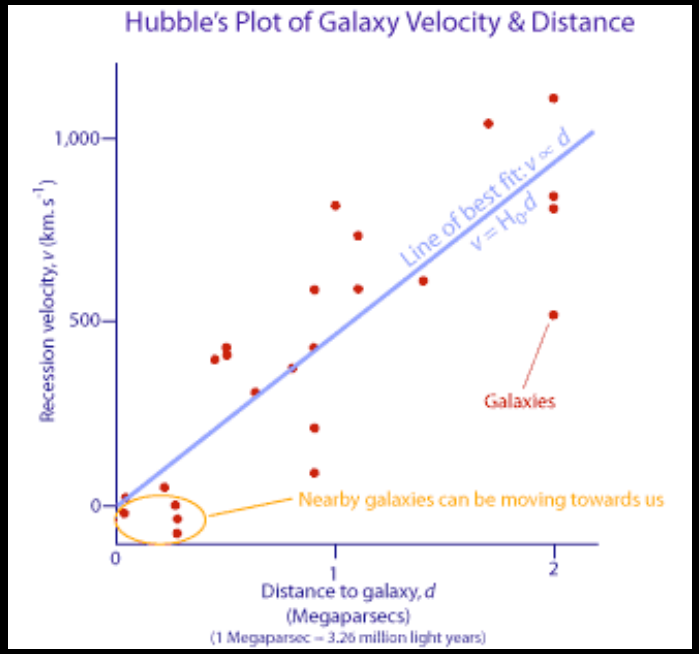
Higgs Boson

- What is the Higgs Boson?
- Why is it important?
- What was its role in the early universe (the Big Bang)?

1929 - Hubble Discovered Universe is Expanding

First evidence that Universe began with a Big Bang

Edwin Powell Hubble
(1889-1953)



1929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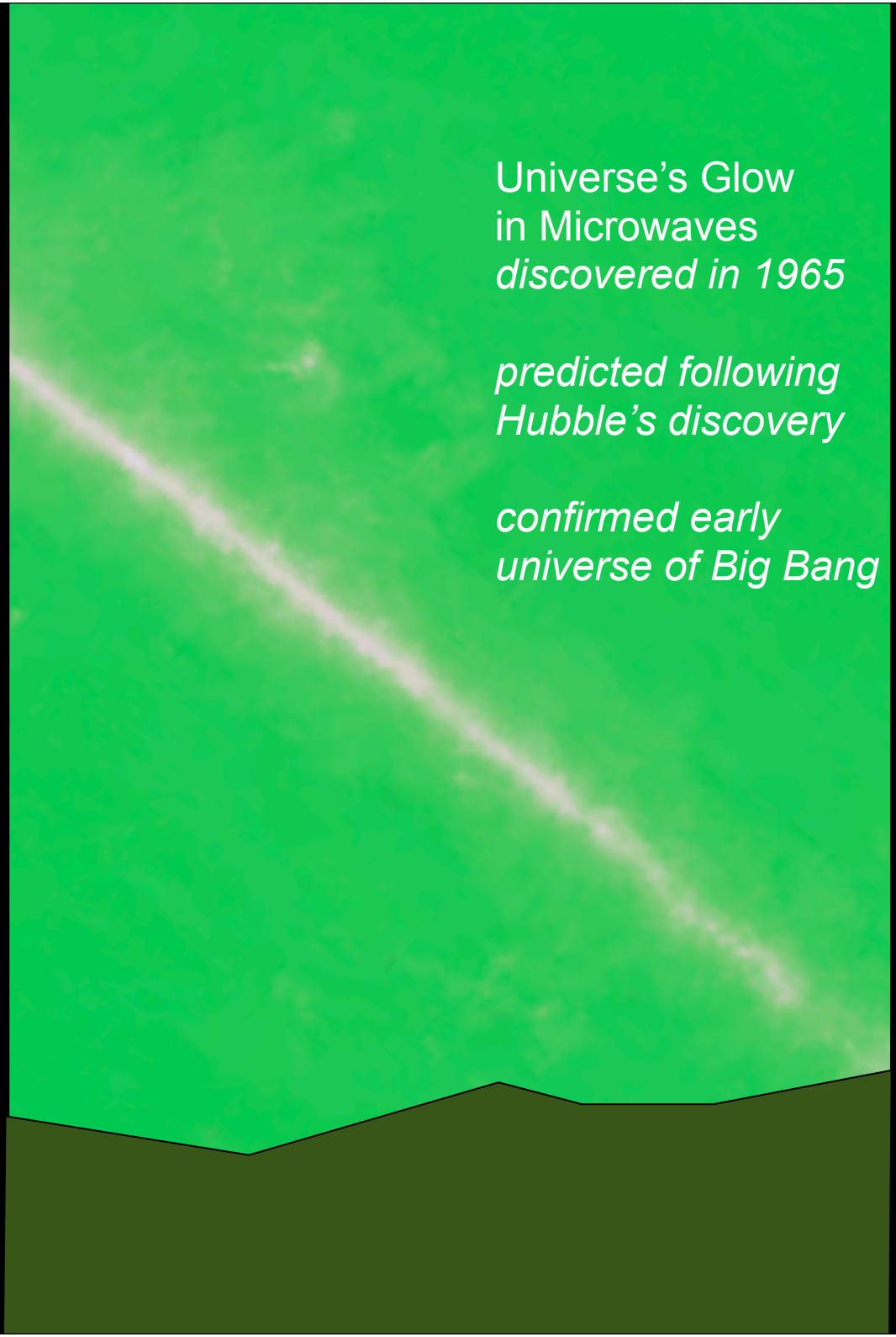
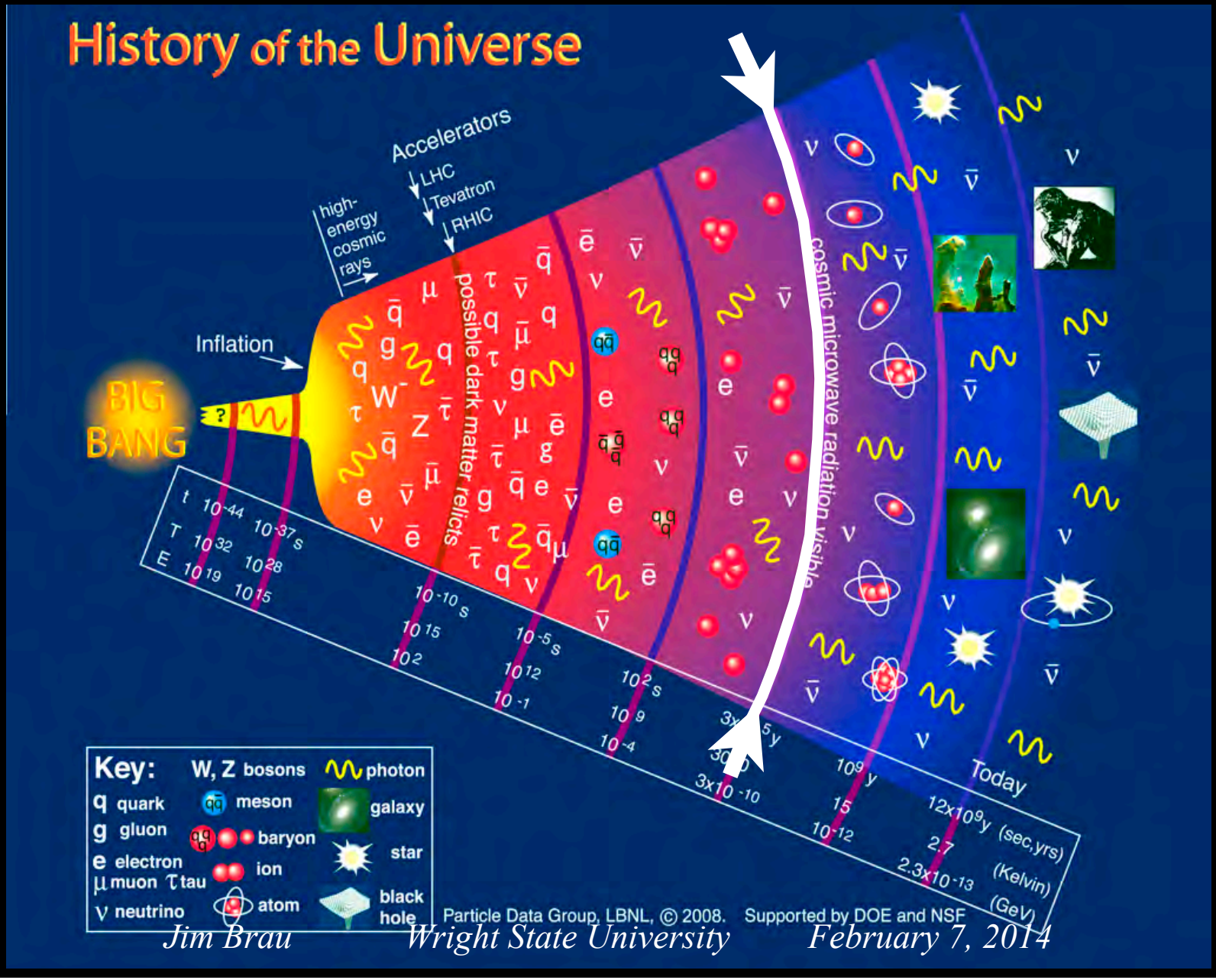
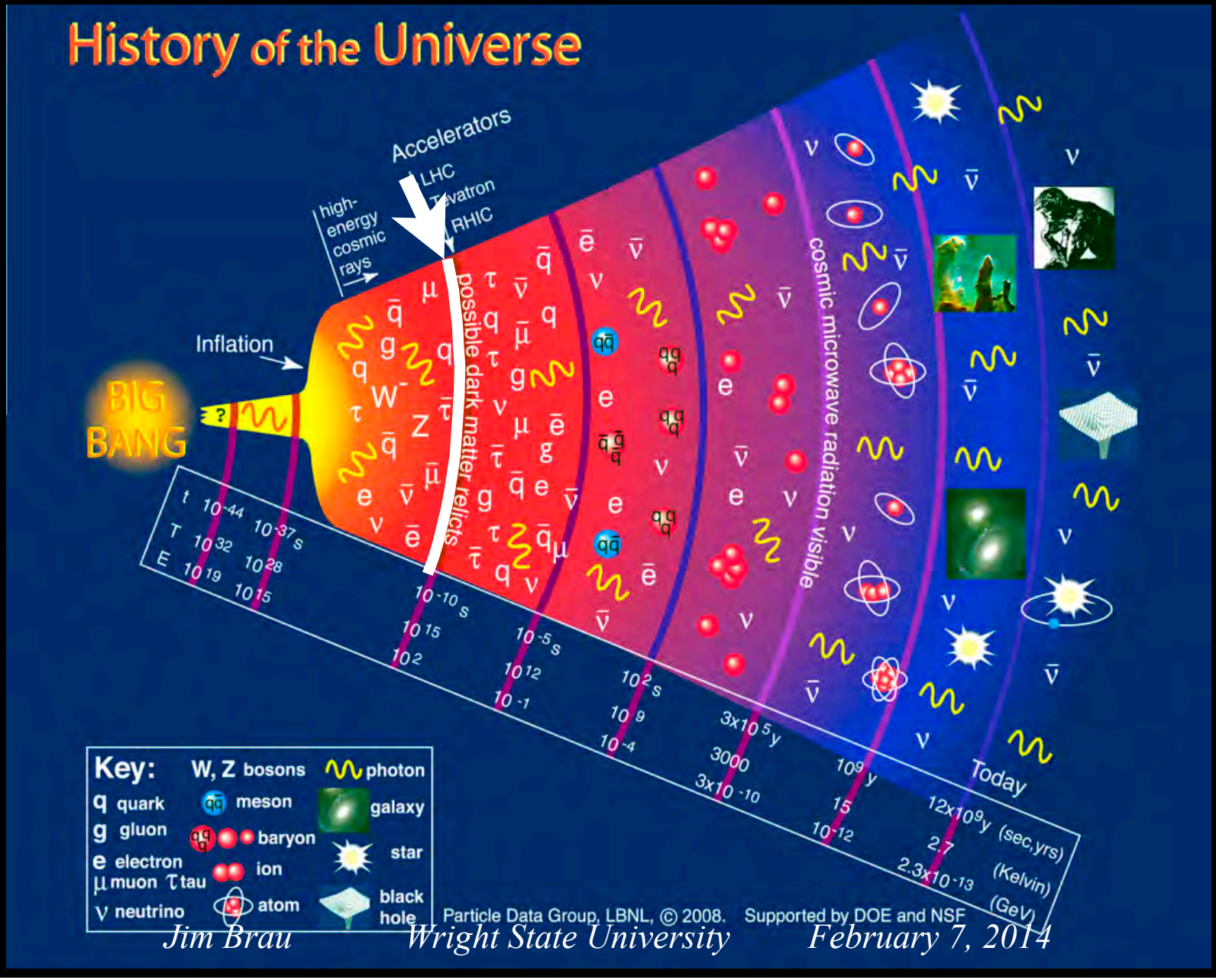

Universe's Glow
in Microwaves
discovered in 1965
*predicted following
Hubble's discovery*
*confirmed early
universe of Big Bang*

Big Bang


History of the Universe
Accelerators
LHC
Tevatron
RHIC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
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
atom
black hole
ν neutrino
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF
(sec,yrs)
(Kelvin)
(GeV)

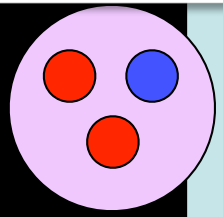
Particles and Forces

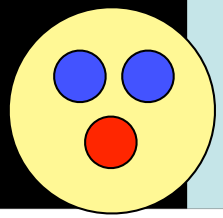
"interactions"



Fundamental Particles

PROTON

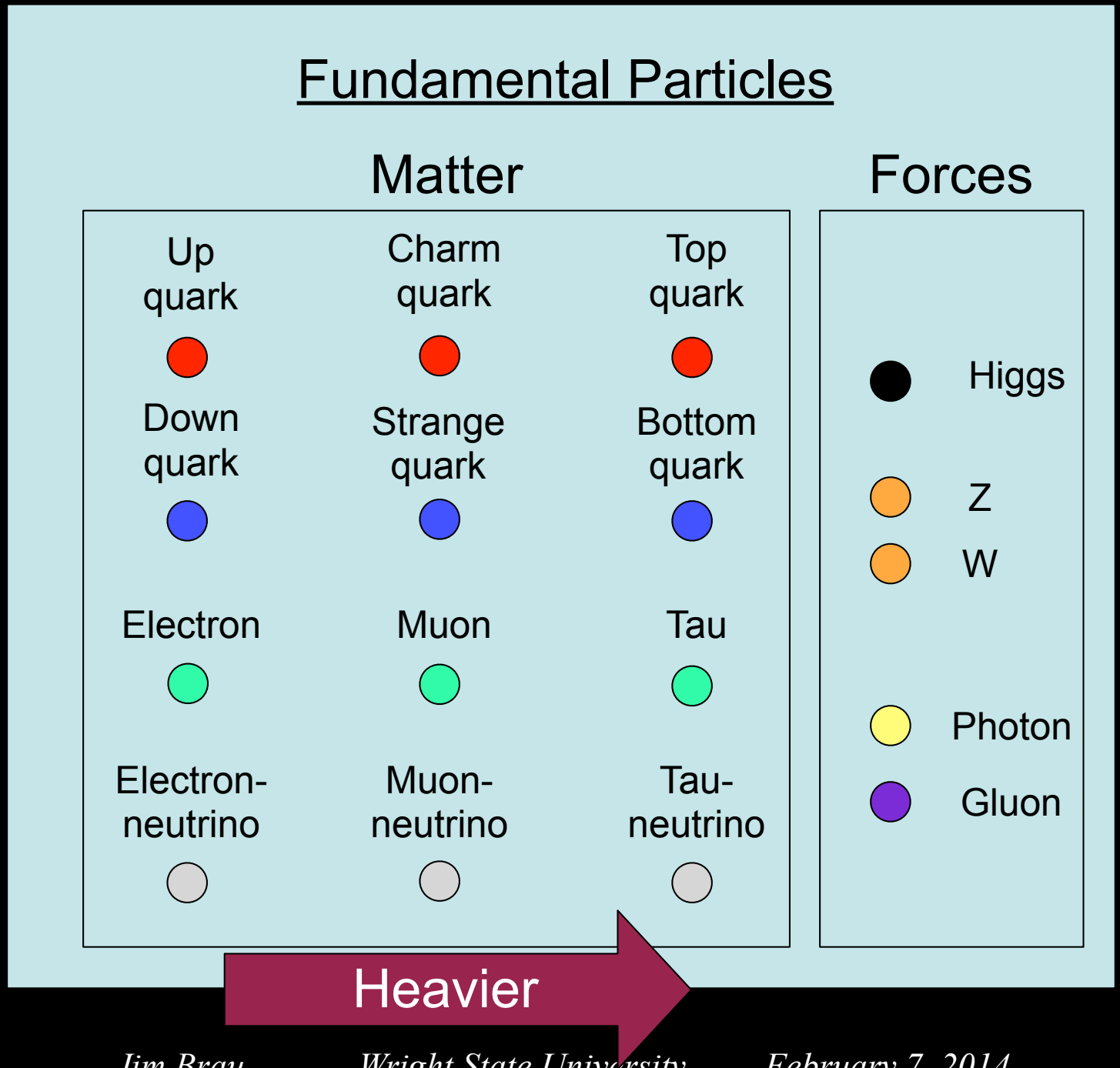


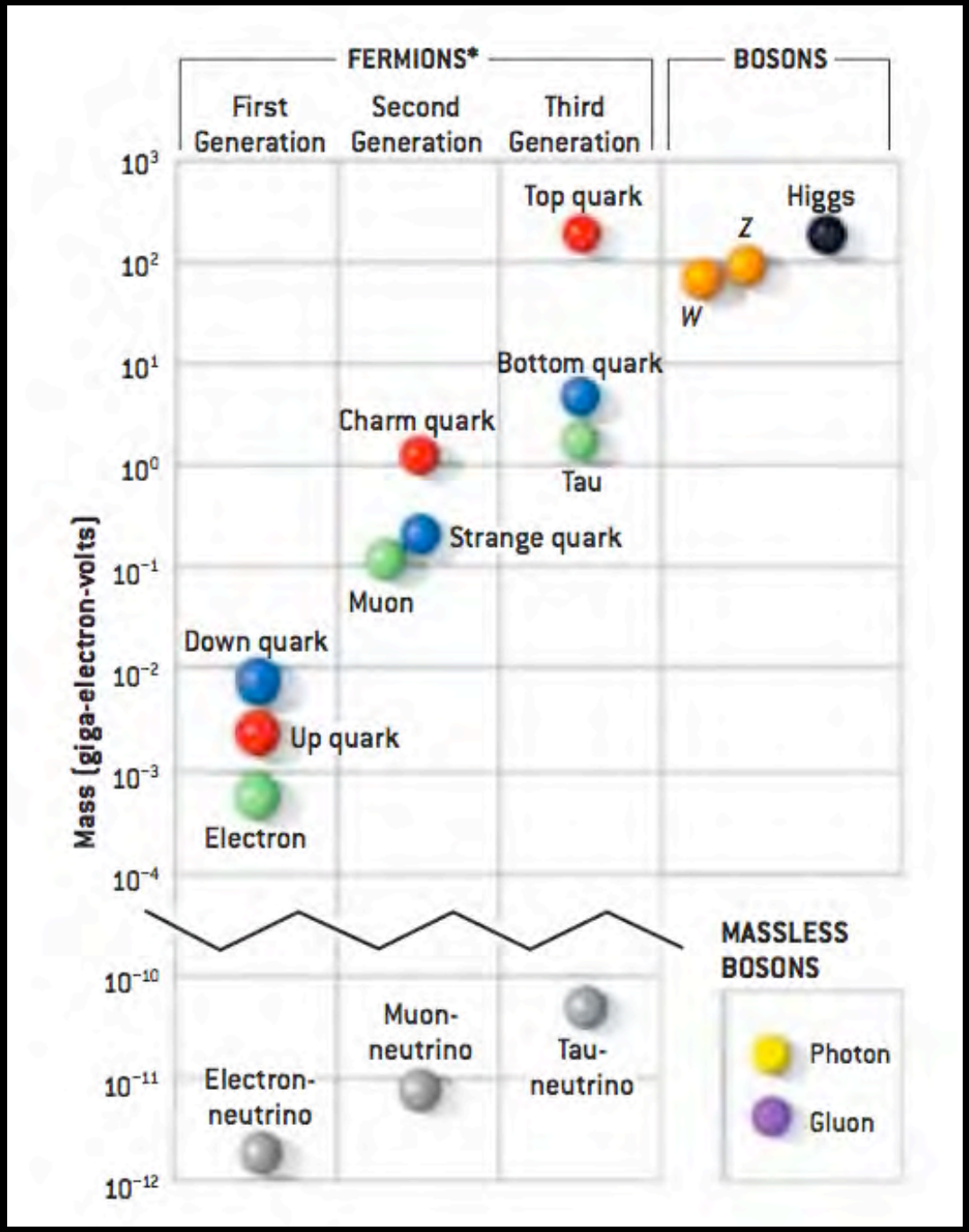


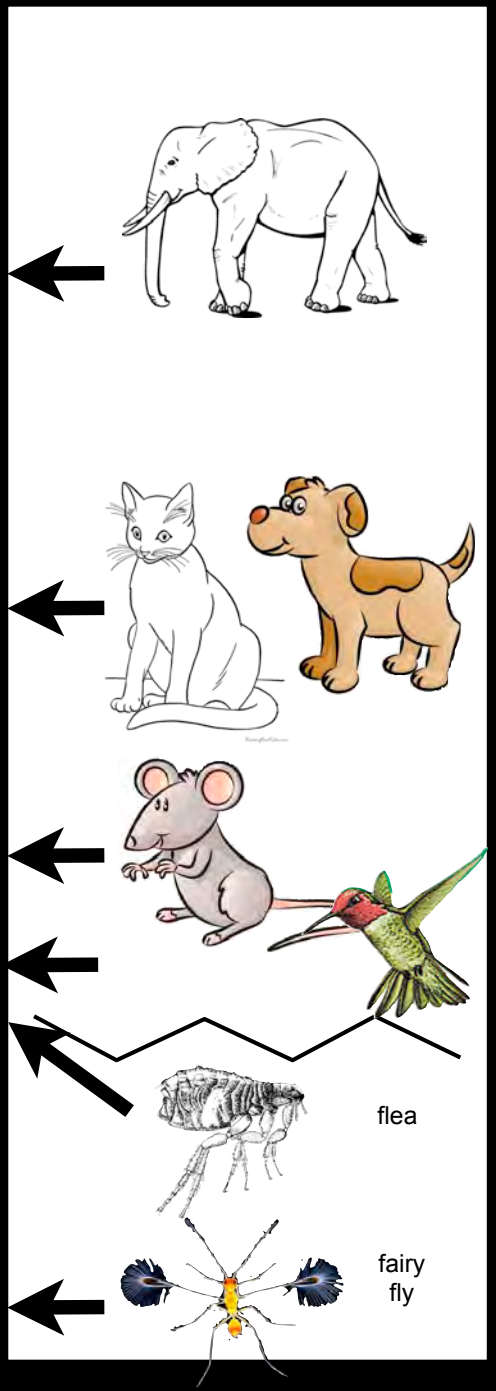
NEUTRON

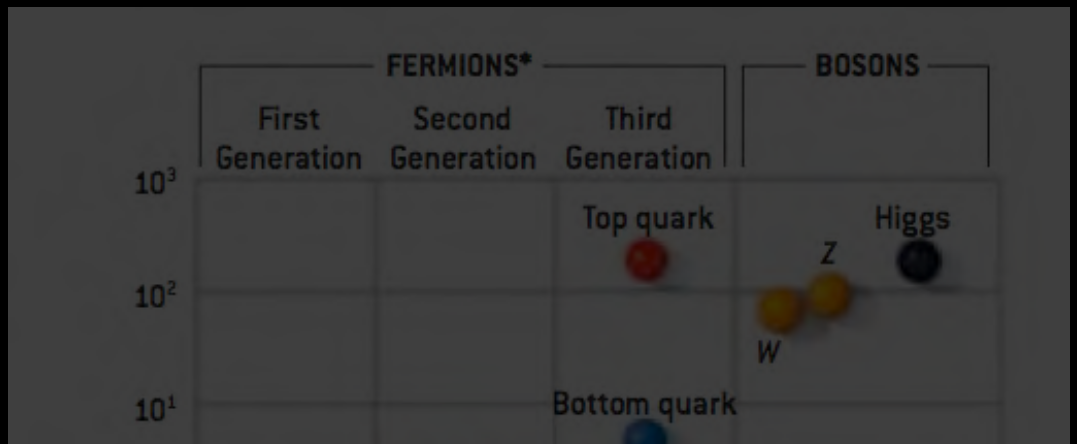
Matter	Forces
Up quark	
Down quark	
Electron	
Electron-neutrino	

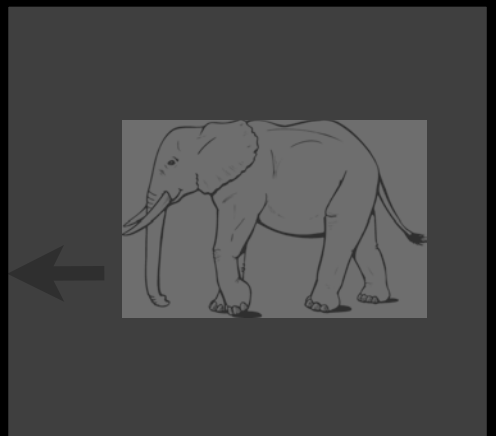
Fundamental Particles




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

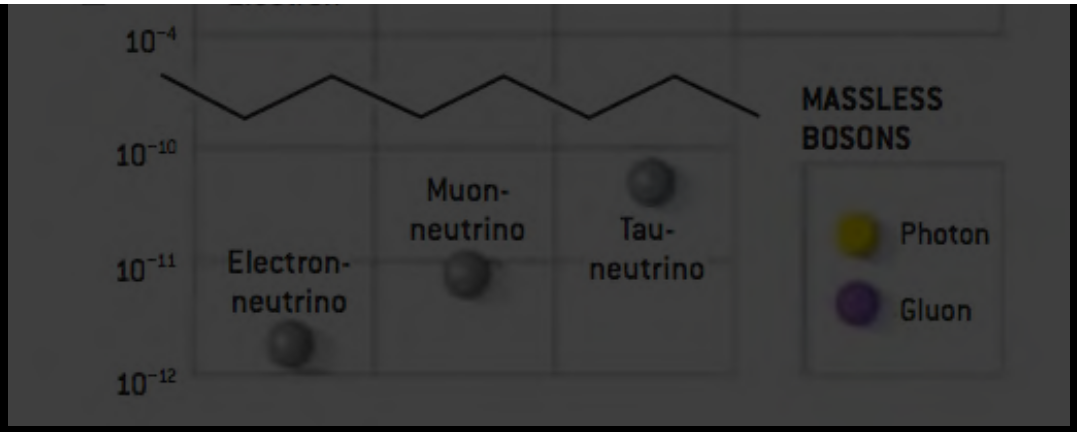

flea
fairy fly

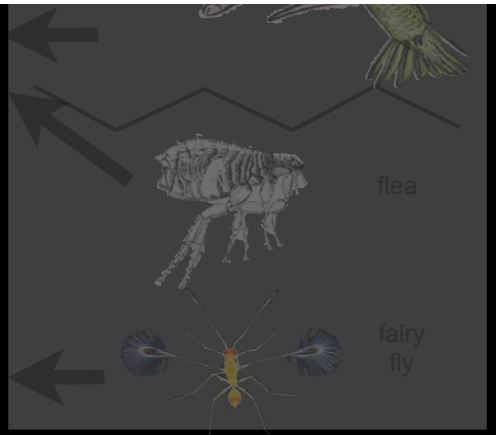




Why are masses of each of these <u>fundamental</u> particles so different?

This is the role of the Higgs boson.





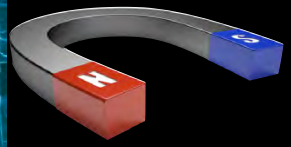
Forces

"interactions"

Are Forces Related?

1850

- Gravity
- Electricity
- Magnetism



Forces

"interactions"

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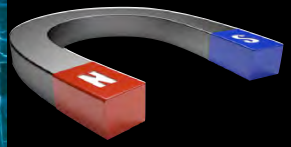
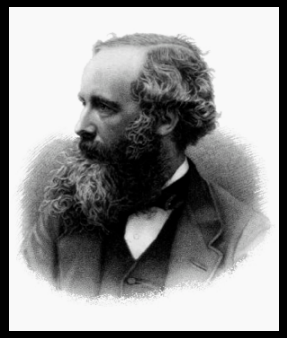


1864

Unified theory
- Electromagnetism
- Light (photons)



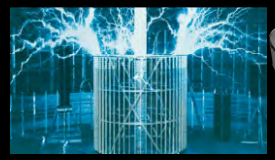
J.C. Maxwell

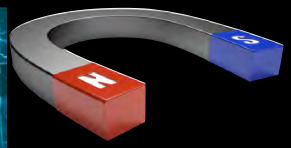
Forces

"interactions"

Are Forces Related?

- Gravity
- Electromagnetism





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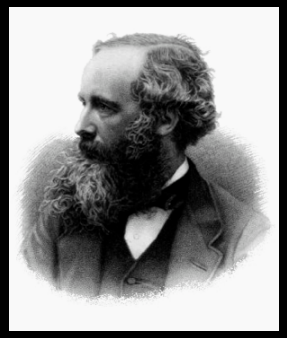


J.C. Maxwell

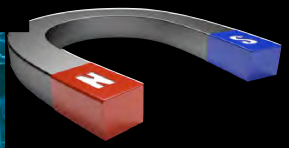
Forces

"interactions"

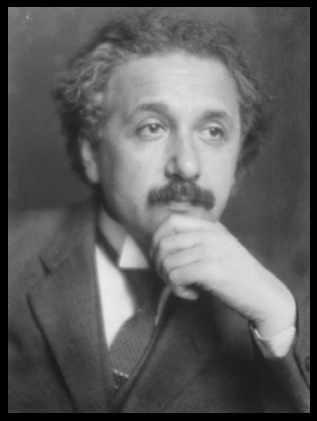
Are Forces Related?

Early 20th Century

- Gravity
- Electromagnetism



Einstein worked for years on a unified theory of Electromagnetism and Gravity **UNSUCCESSFULLY**



Albert Einstein

Forces

"interactions"

Are Forces Related?

1950

- Gravity
- Electromagnetism
- Weak Nuclear
- Strong Nuclear

Forces

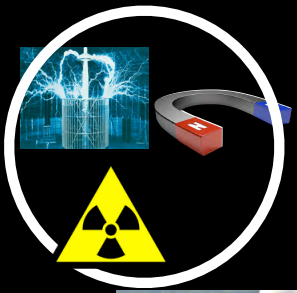
"interactions"

Are Forces Related?

2000

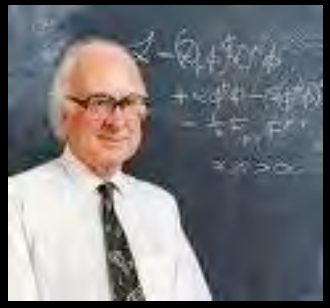
- Gravity

- Electroweak



- Strong Nuclear

Anticipated
- discovery of
  the Higgs Boson
  at accelerators



P. Higgs

Forces

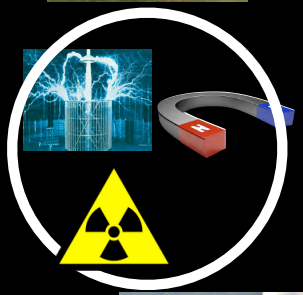
"interactions"

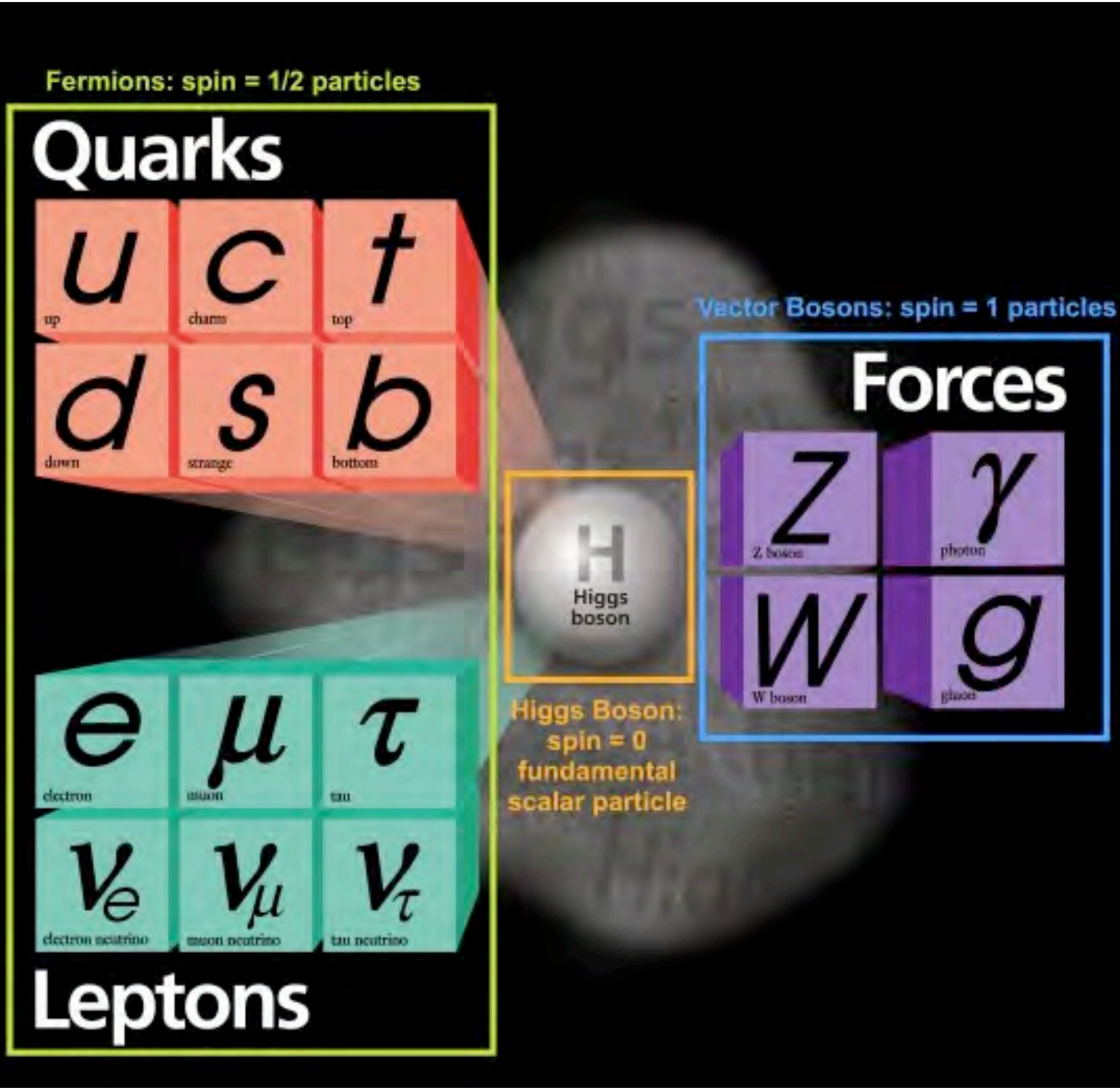
Are Forces Related?

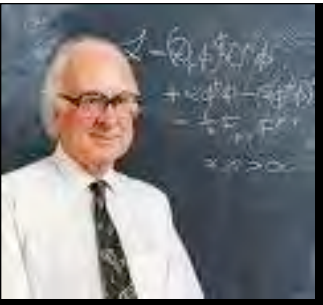
2000

- Gravity
- Electroweak
- Strong Nuclear

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




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



Peter Higgs
(1929-)

What is the Higgs Boson?

Satyendra
Nath Bose
(1894-1974)

- Theory postulated in 1964
  –historical era

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

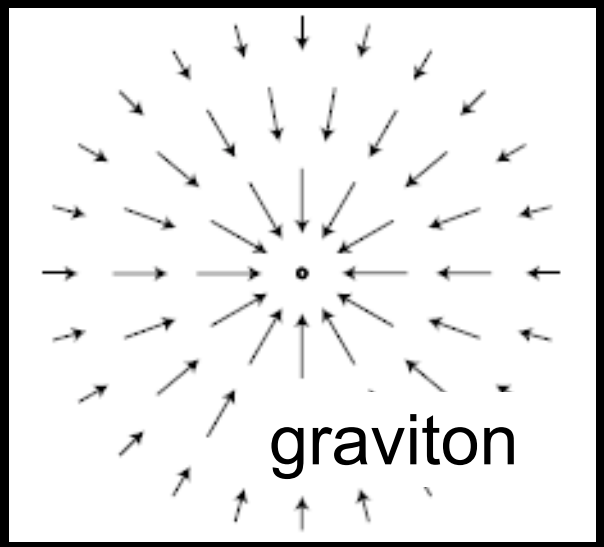
The Beatles arrive in USA,
Kennedy Airport, Feb 1964

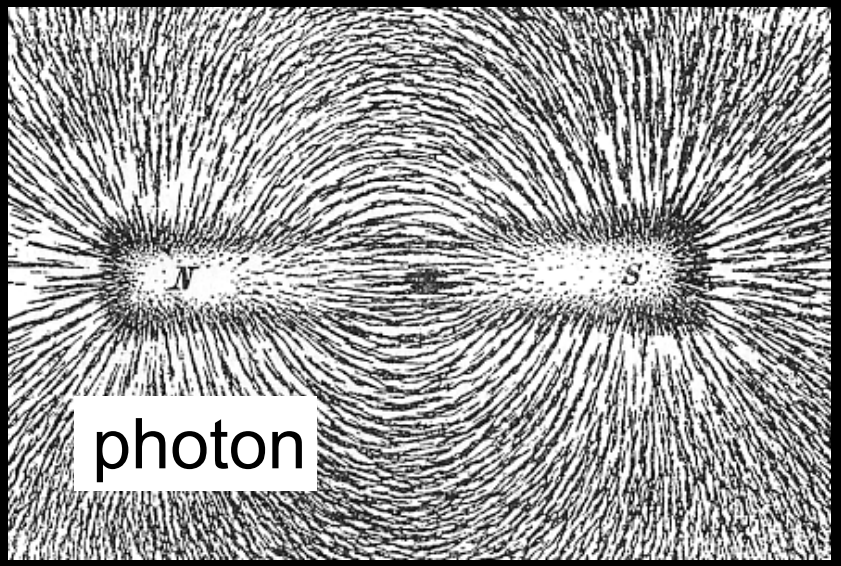
President Johnson
signs Civil Rights Act,
July, 1964 -
Voting Rights in 1965

Mad Men, AMC

The Higgs Field

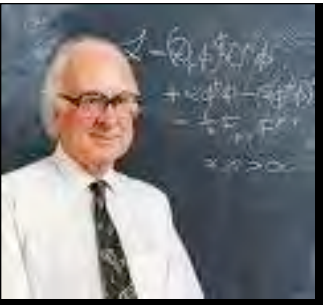
- Familiar fields





Earth's gravity Magnetism

- The Higgs is both a field and a particle

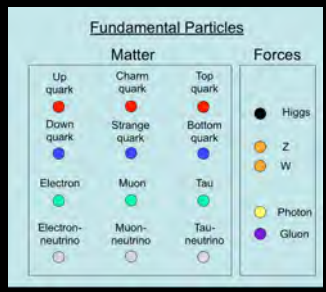


Peter Higgs

Higgs Boson Theory

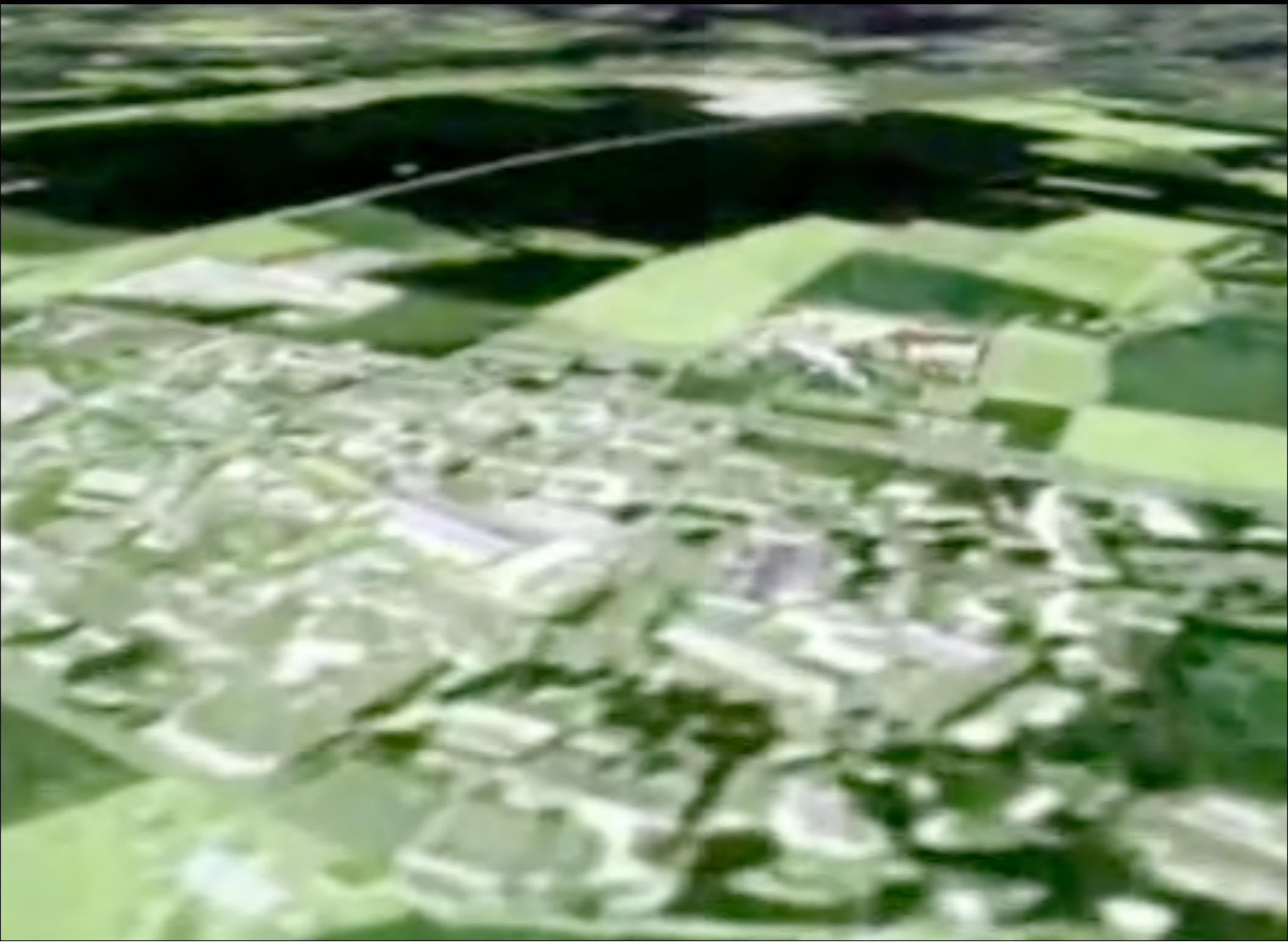
Kibble, Guralnik, Hagen, Englert, Brout

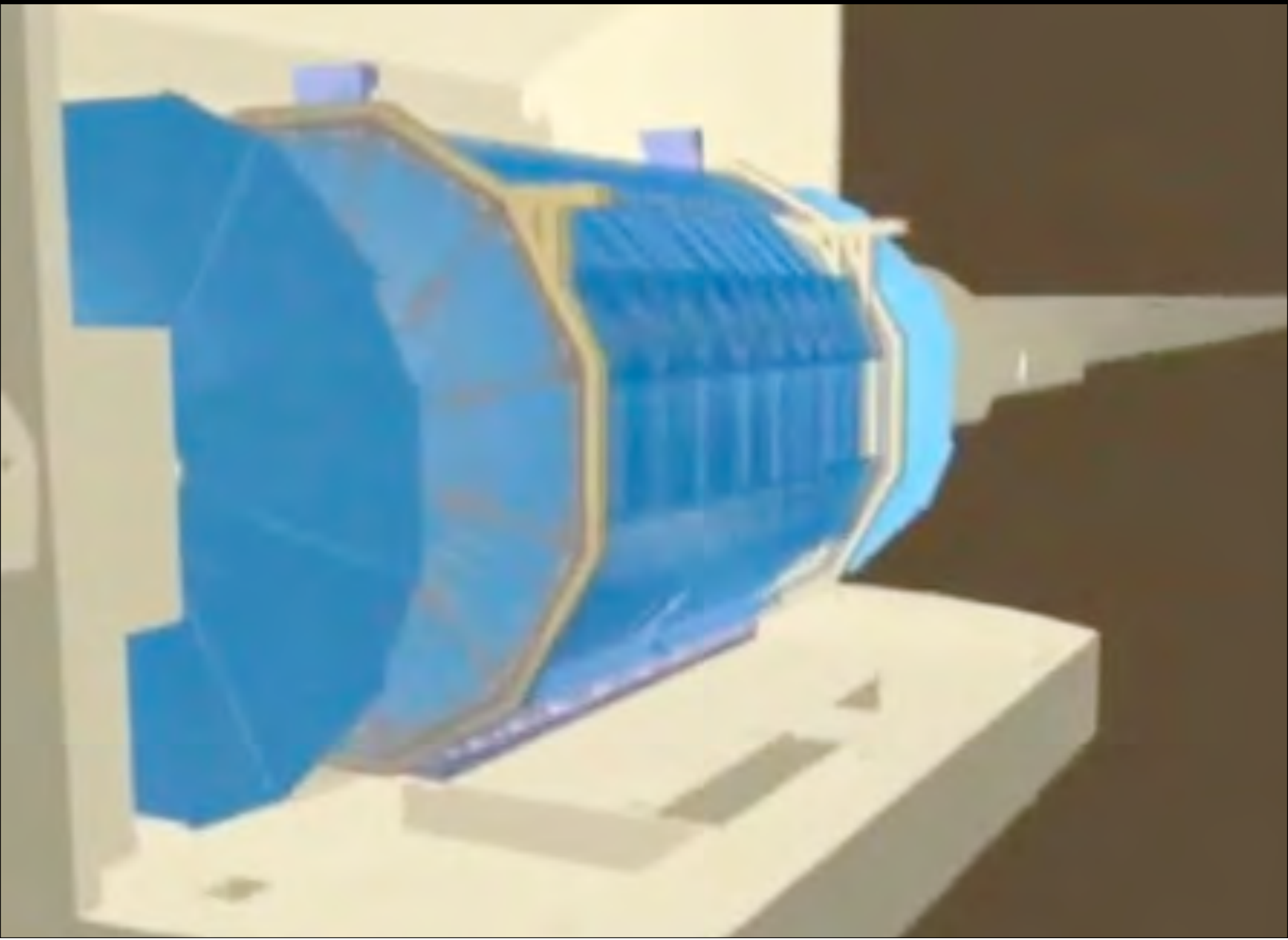
- Higgs field fills the universe
- Interacts with fundamental particles to give them mass
- Separates electromagnetism and the <u>weak</u> nuclear force
  - –photon remains massless

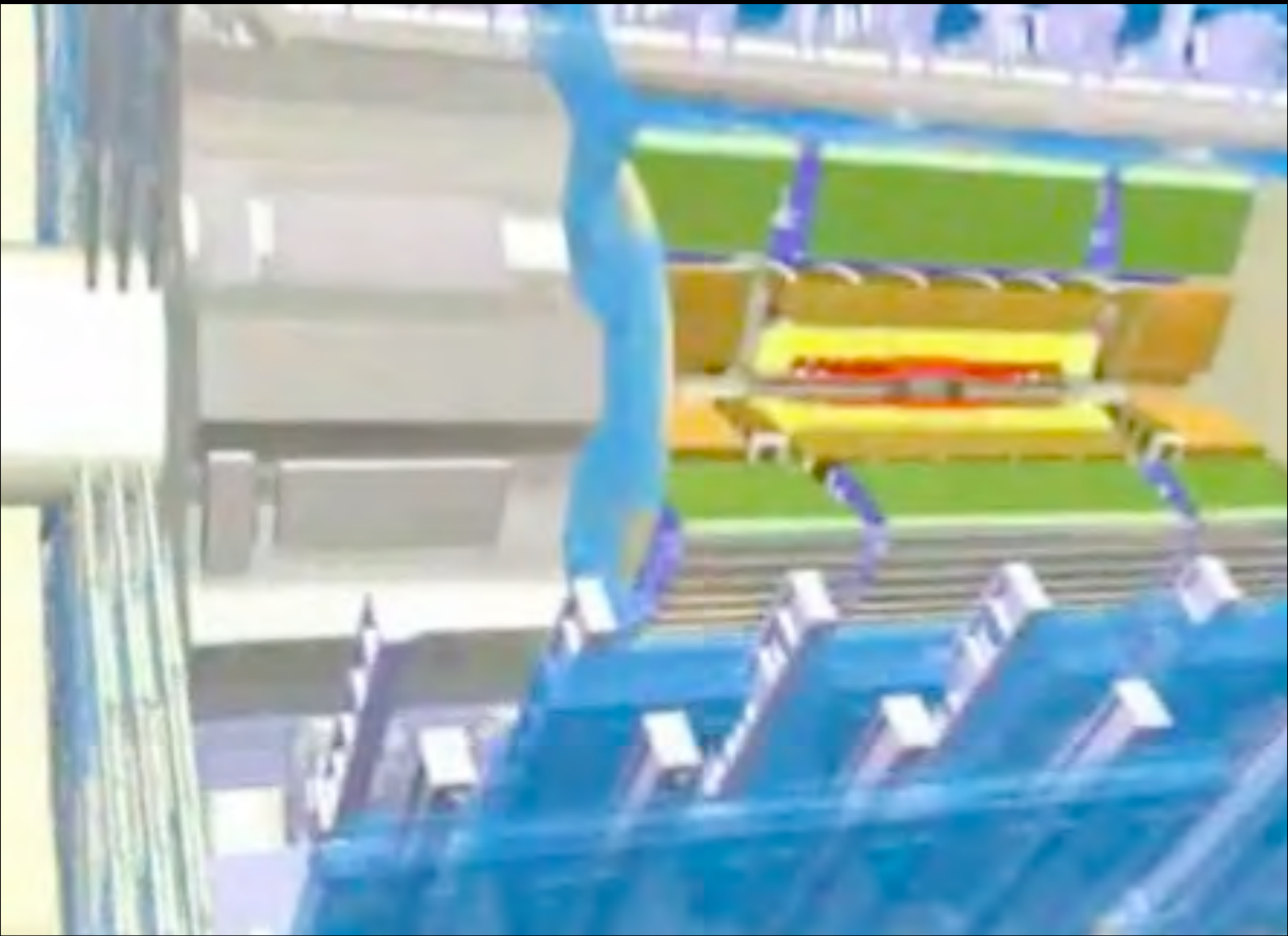


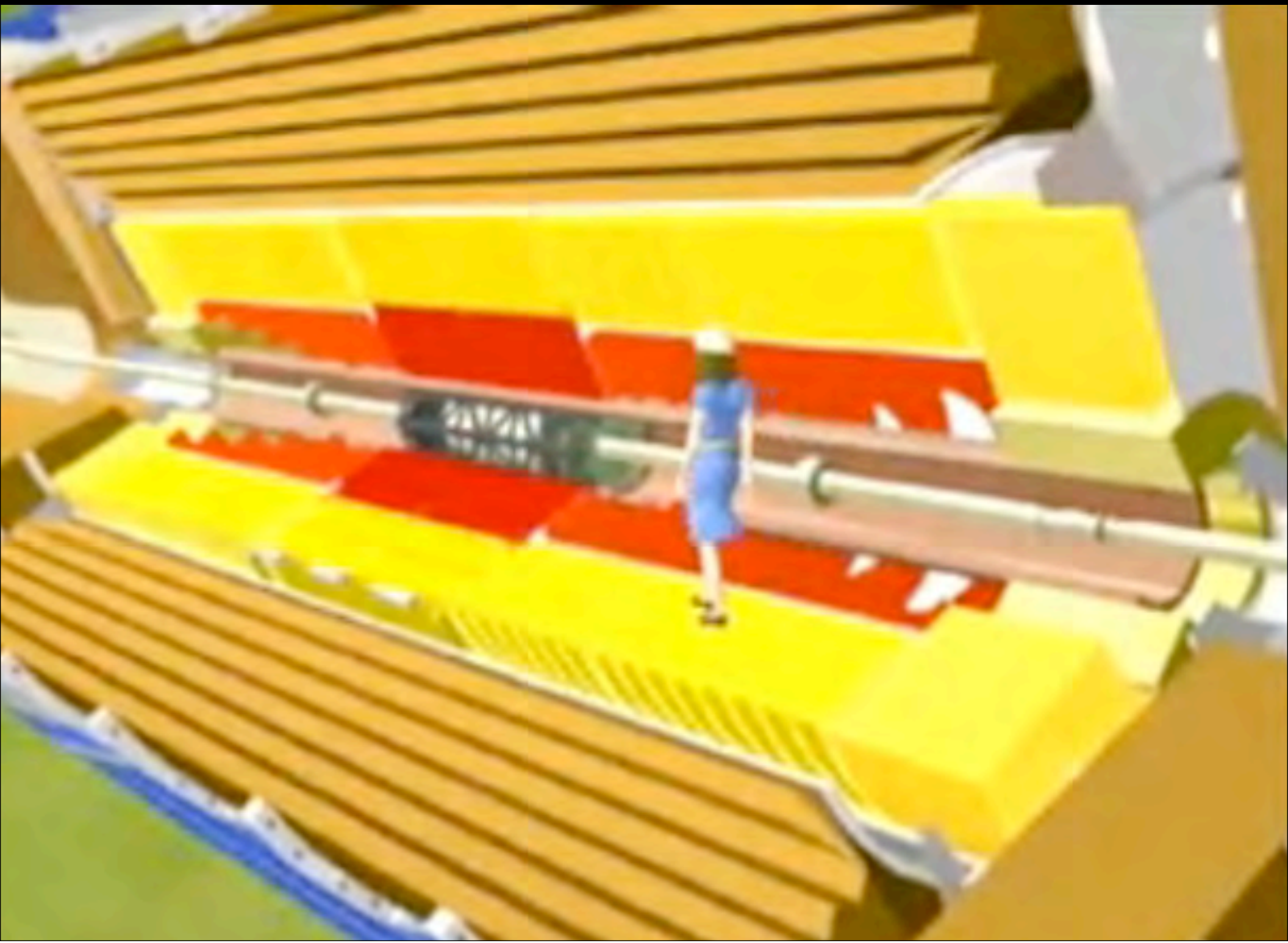
Large Hadron Collider (LHC)
Geneva, Switzerland

Jim Brau *Wright State University* *February 7, 2014*

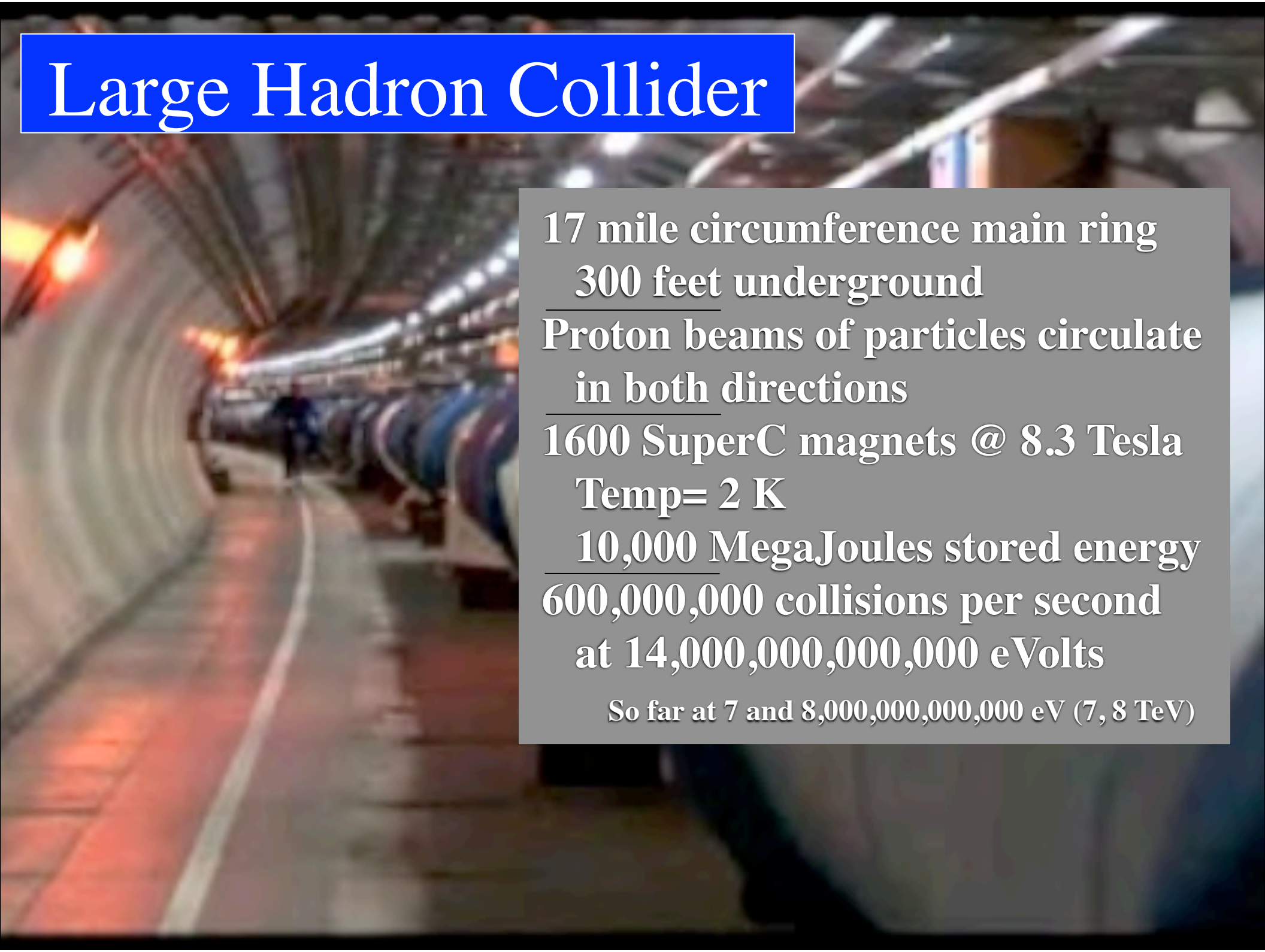








Large Hadron Collider



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

So far at 7 and 8,000,000,000,000 eV (7, 8 TeV)

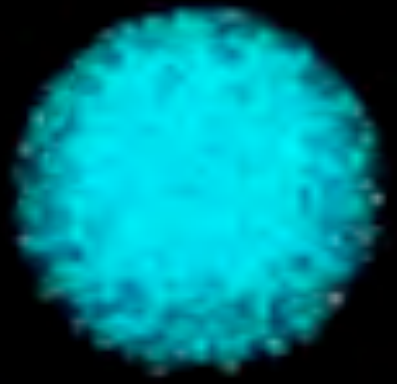
Large Hadron Collider

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

Search for Higgs Boson by ATLAS Collaboration[‡] at LHC

‡ ATLAS Collaboration = 3000 physicists

from 177 universities and laboratories in 38 countries

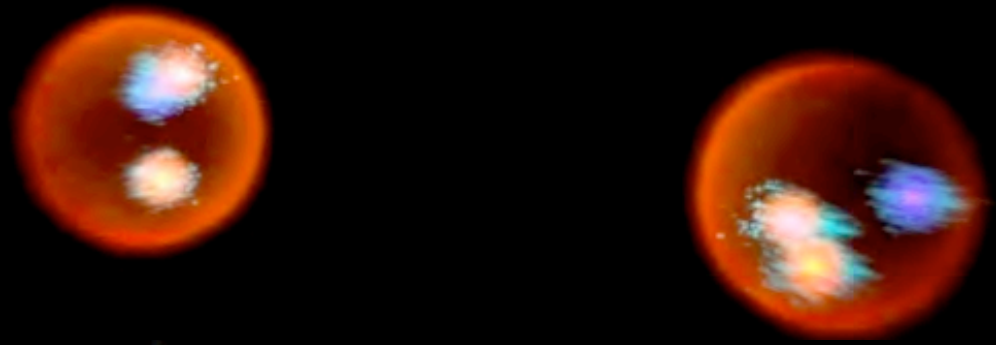


Higgs Boson is VERY HEAVY
Equivalent to 133 Hydrogen atoms
or one Cesium atom
126,000,000,000 eV = 126 GeV

Jim Brau *Wright State University* *February 7, 2014*

Search for the Higgs Boson at the LHC

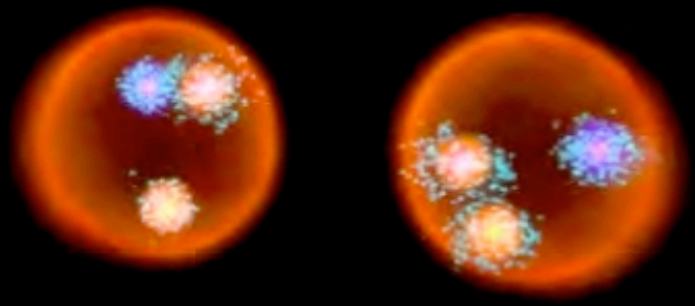
slow motion



Jim Brau *Wright State University* *February 7, 2014*

Search for the Higgs Boson at the LHC

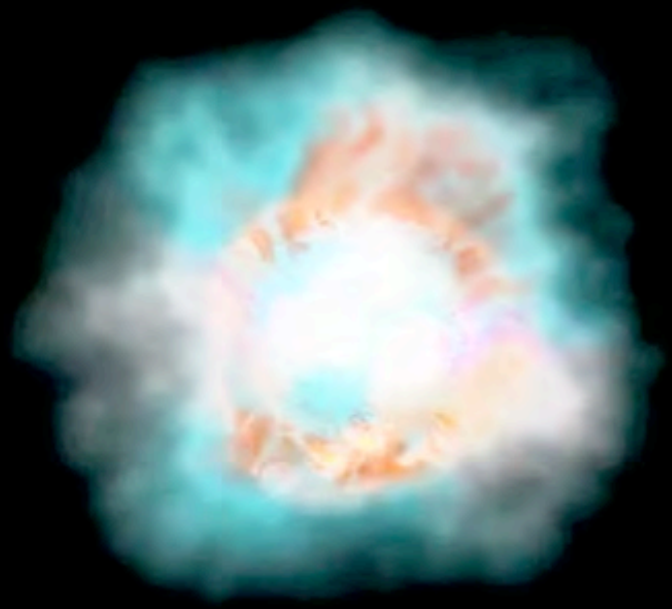
slow motion



$E=mc^2$
or Energy equals Mass

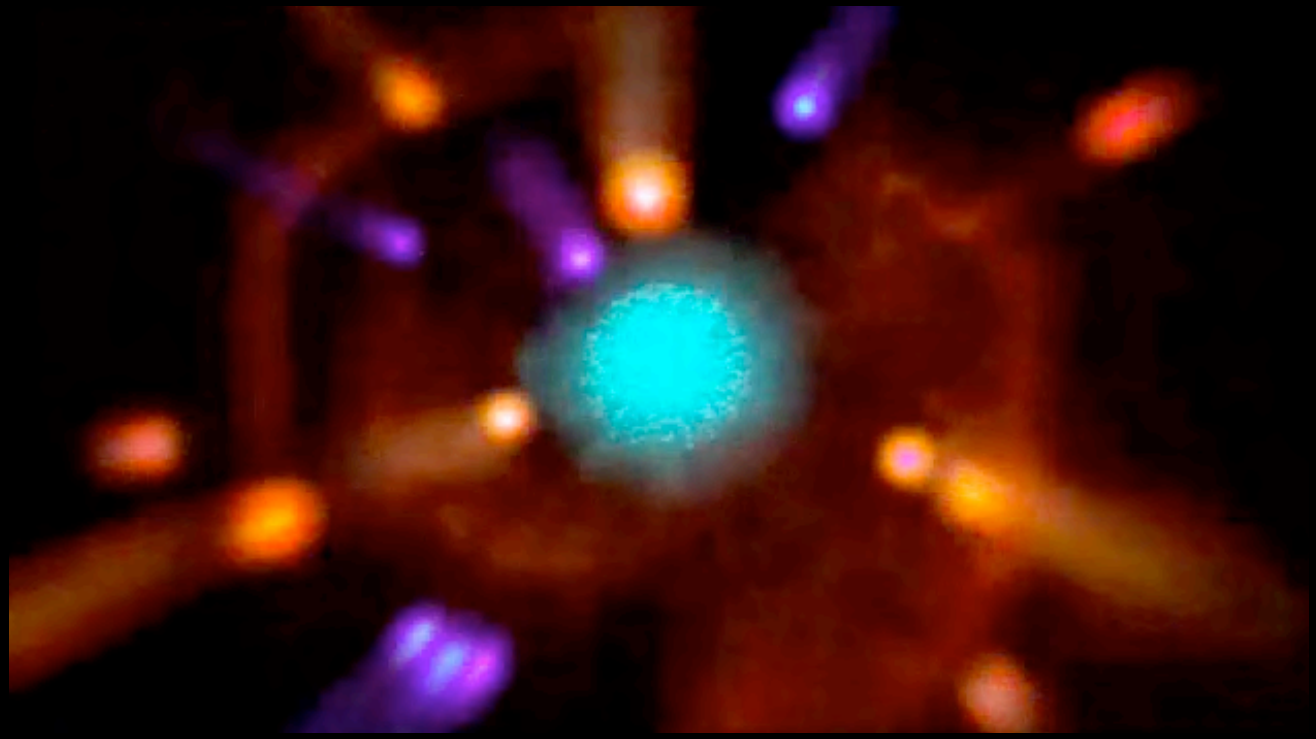
Jim Brau *Wright State University* *February 7, 2014*

Producing the Higgs Boson at the LHC



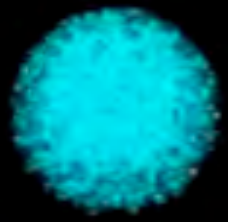
Jim Brau *Wright State University* *February 7, 2014*

Producing the Higgs Boson at the LHC



Jim Brau *Wright State University* *February 7, 2014*

Producing the Higgs Boson at the LHC



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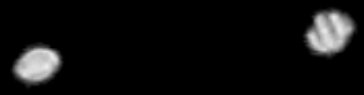
Producing the Higgs Boson at the LHC



Jim Brau *Wright State University* *February 7, 2014*

July 4, 2012

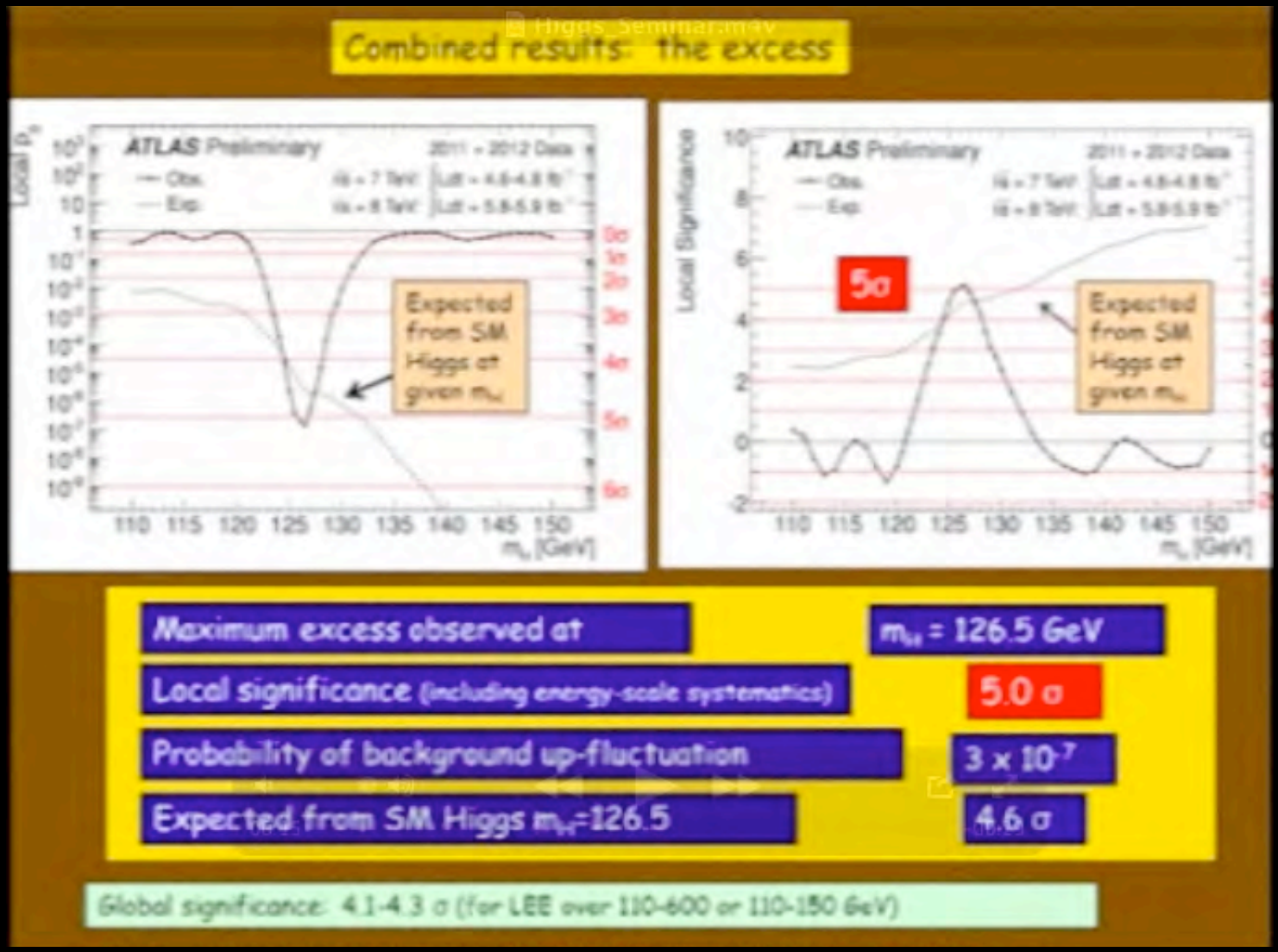
ATLAS Collaboration
(and CMS Collaboration)

Announced Discovery

July 4, 2012

Jim Brau *Wright State University* *February 7, 2014*

July 4, 2012


Combined results: the excess
ATLAS Preliminary
Expected from SM Higgs at given m_H
Local Significance
5σ
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)

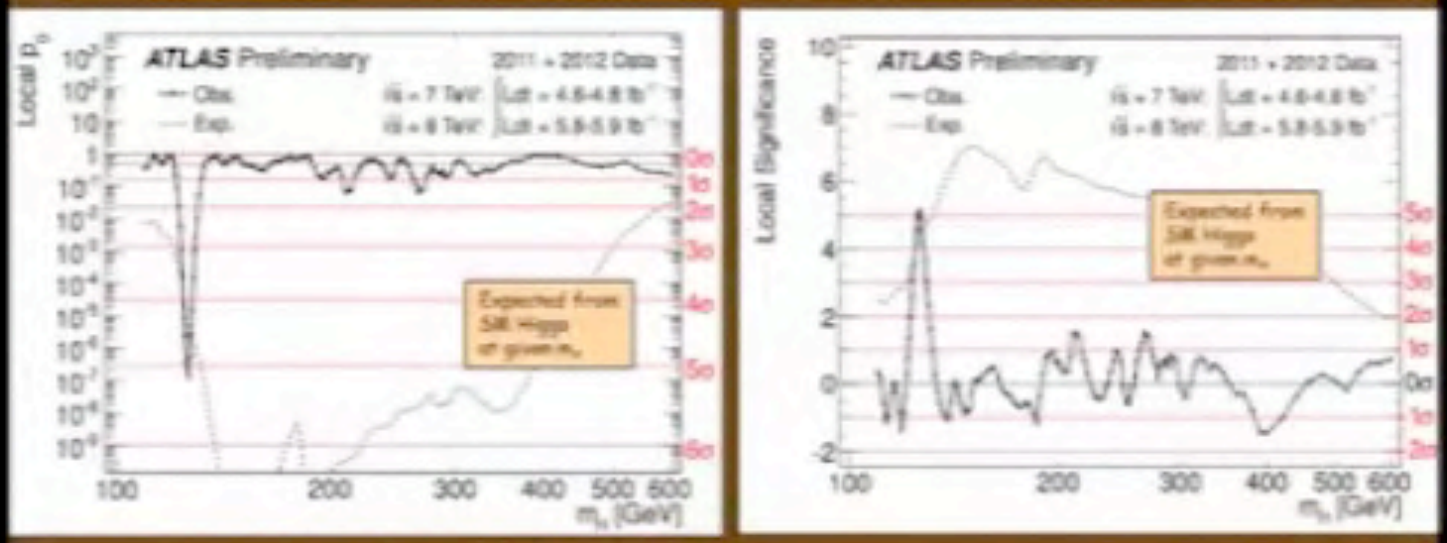
July 4, 2012

July 4, 2012

Jim Brau *Wright State University* *February 7, 2014*

July 4, 2012

Combined results: consistency of the data with the background-only expectation and significance of the excess



Excellent consistency (better than 2σ !) of the data with the background-only hypothesis over full mass spectrum

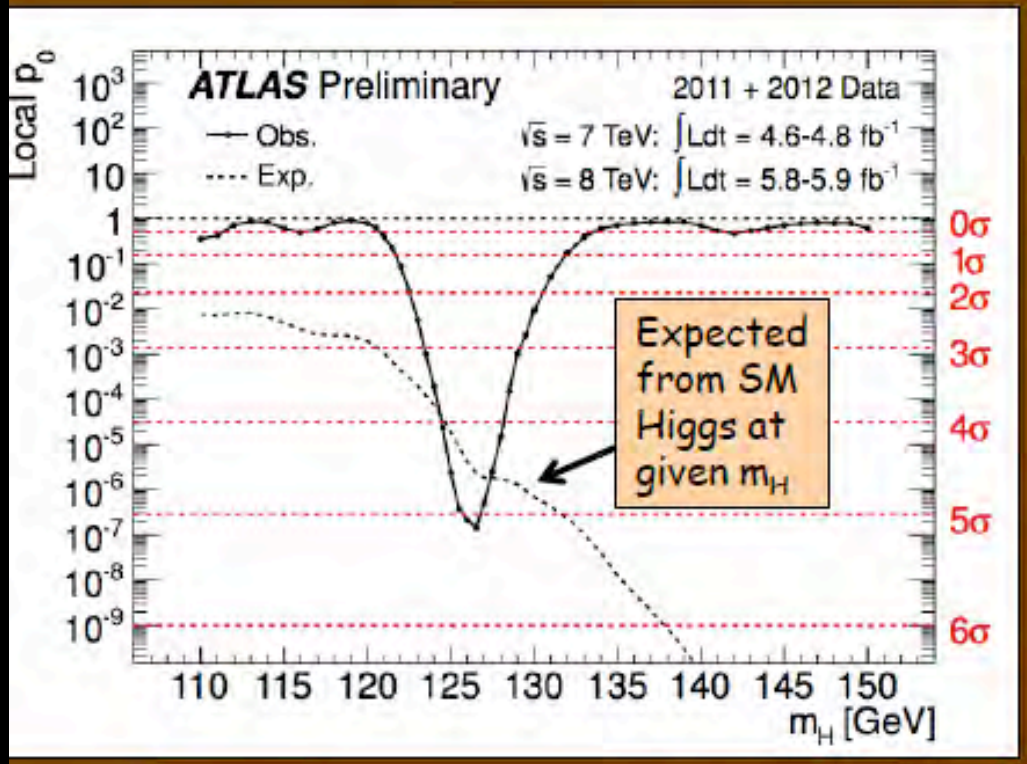
July 4, 2012

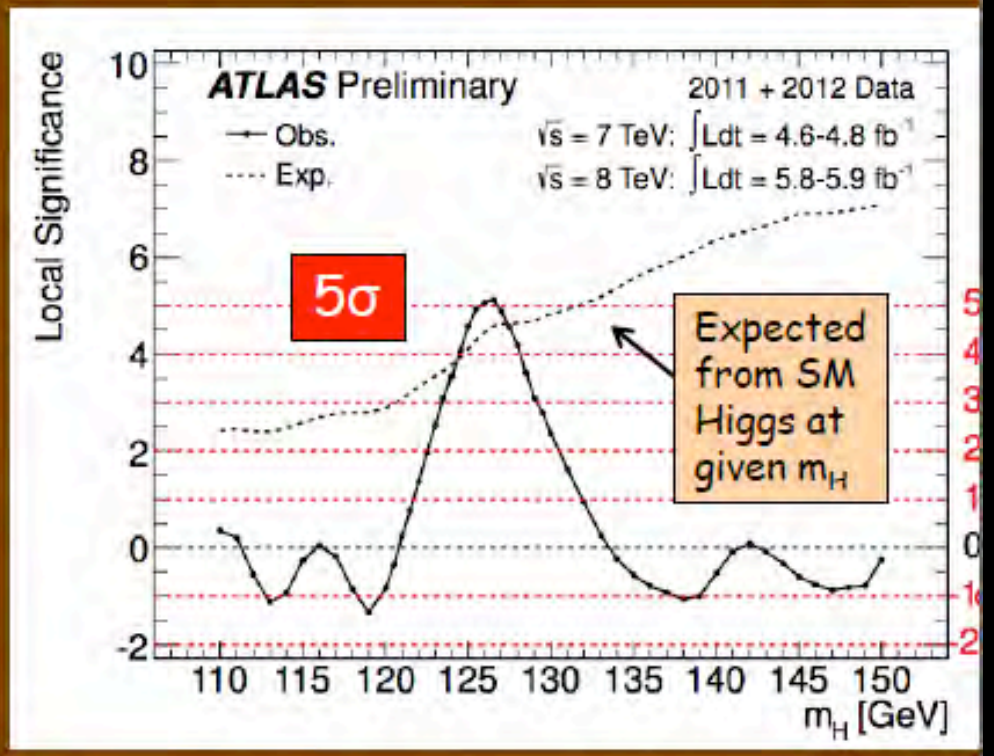
Combined results: consistency of the data with the background-only expectation and significance of the excess

Peter Higgs

Excellent consistency (better than 2σ) of the data with the background-only hypothesis over full mass spectrum

Combined results: the excess

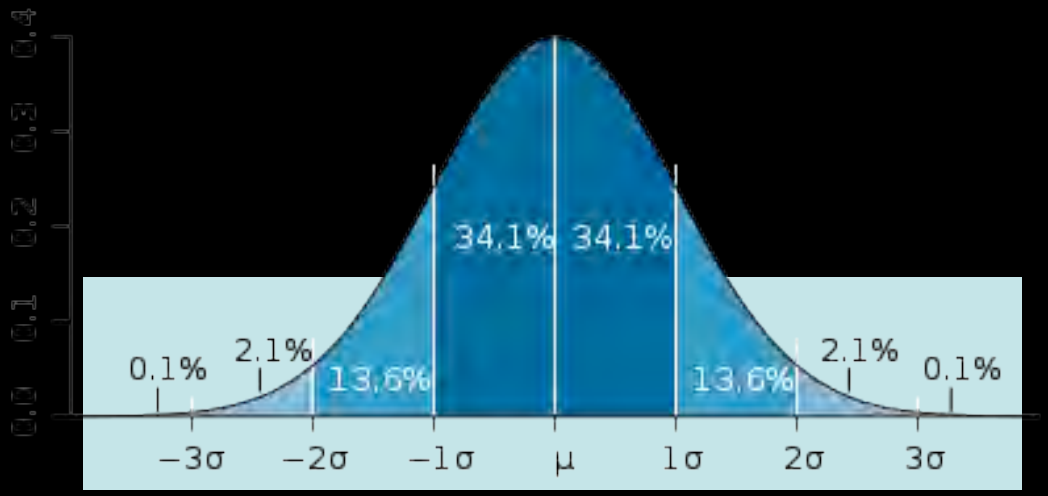




Maximum excess observed at	m_H = 126.5 GeV
Local significance (including energy-scale systematics)	5.0 σ
Probability of background up-fluctuation	3×10^{-7}
Expected from SM Higgs m_H=126.5	4.6 σ

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 coin 22 times and heads EVERY time

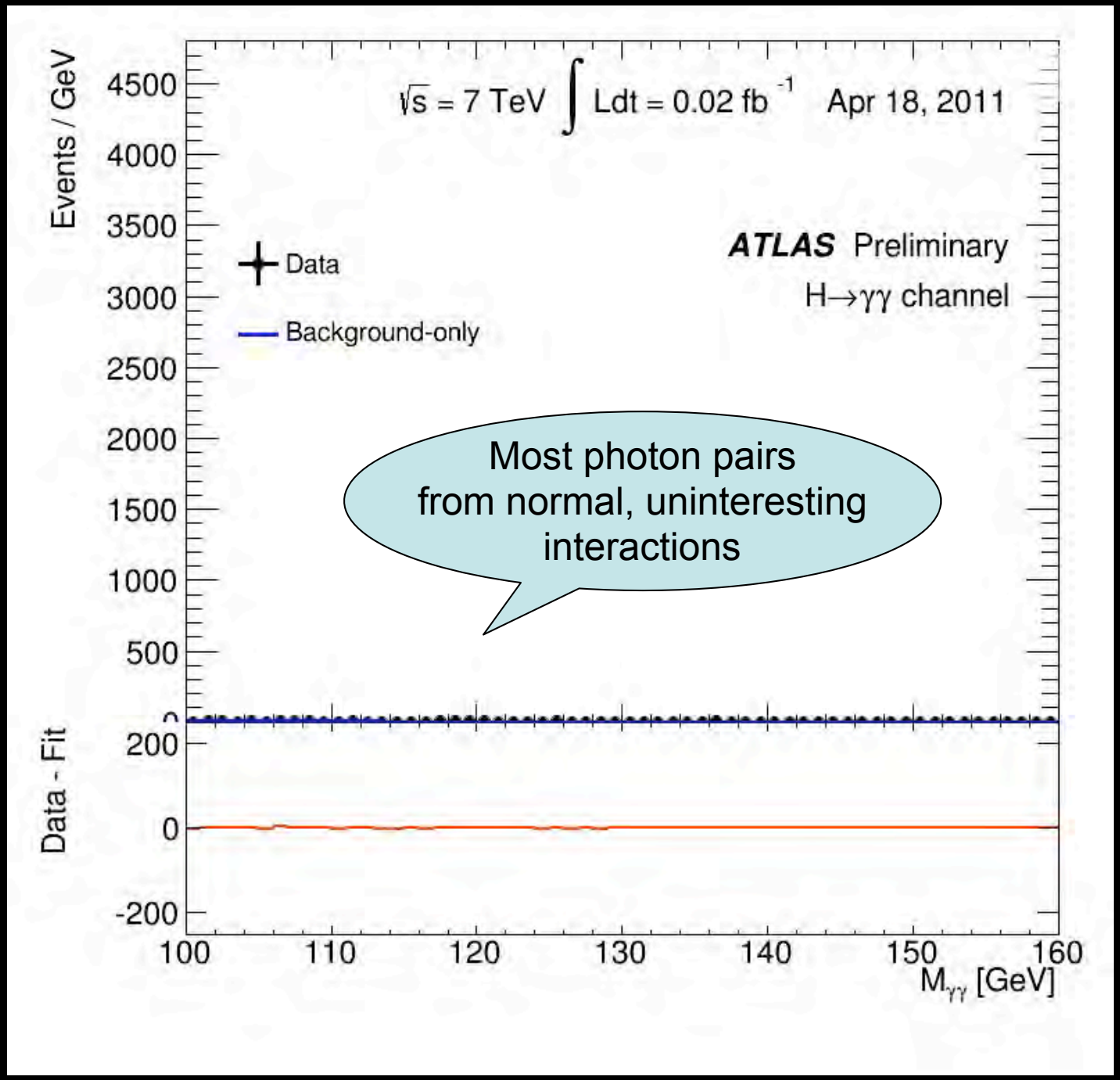
  You are now confident this is not a normal coin!

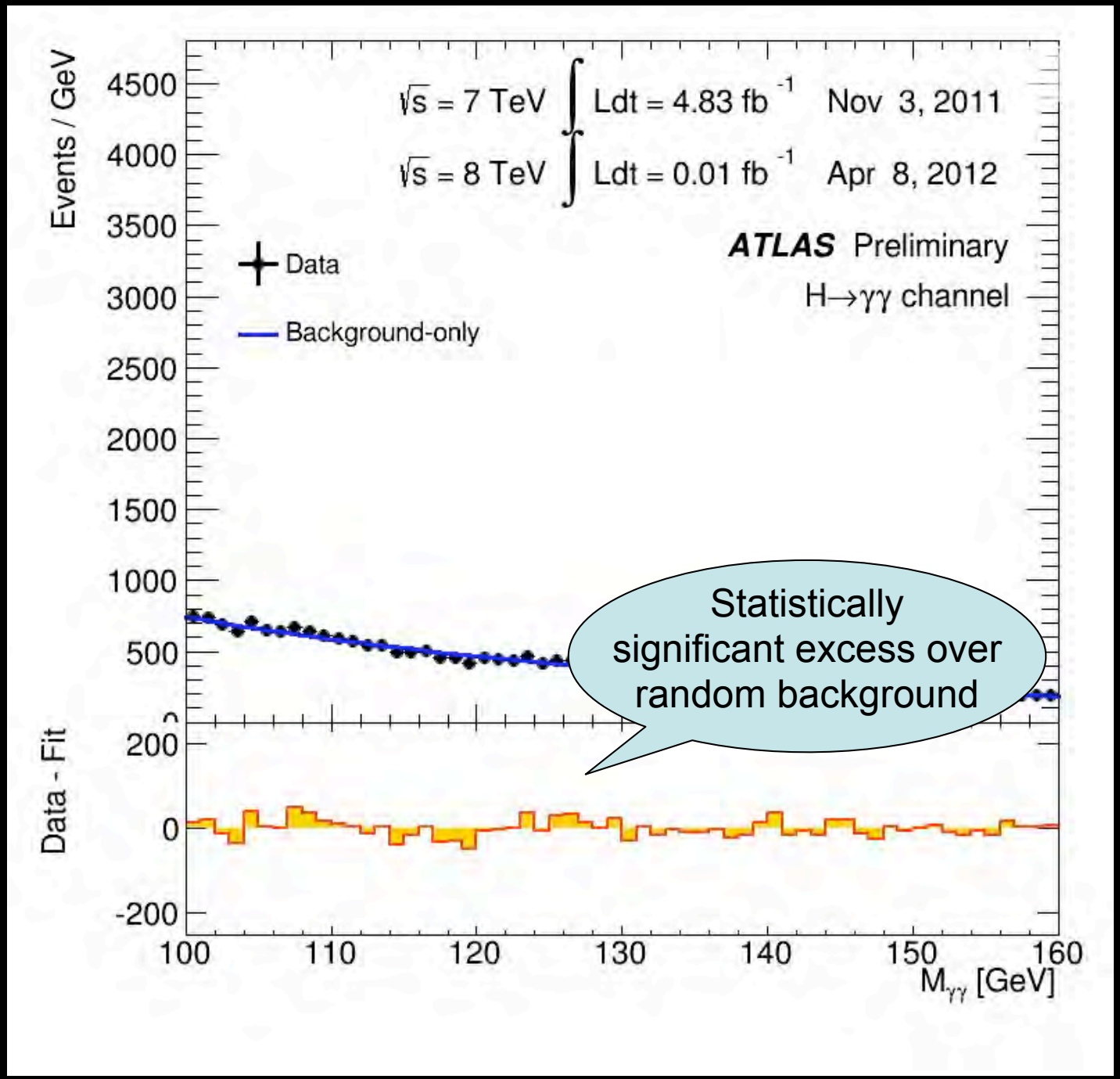
July 4, 2012

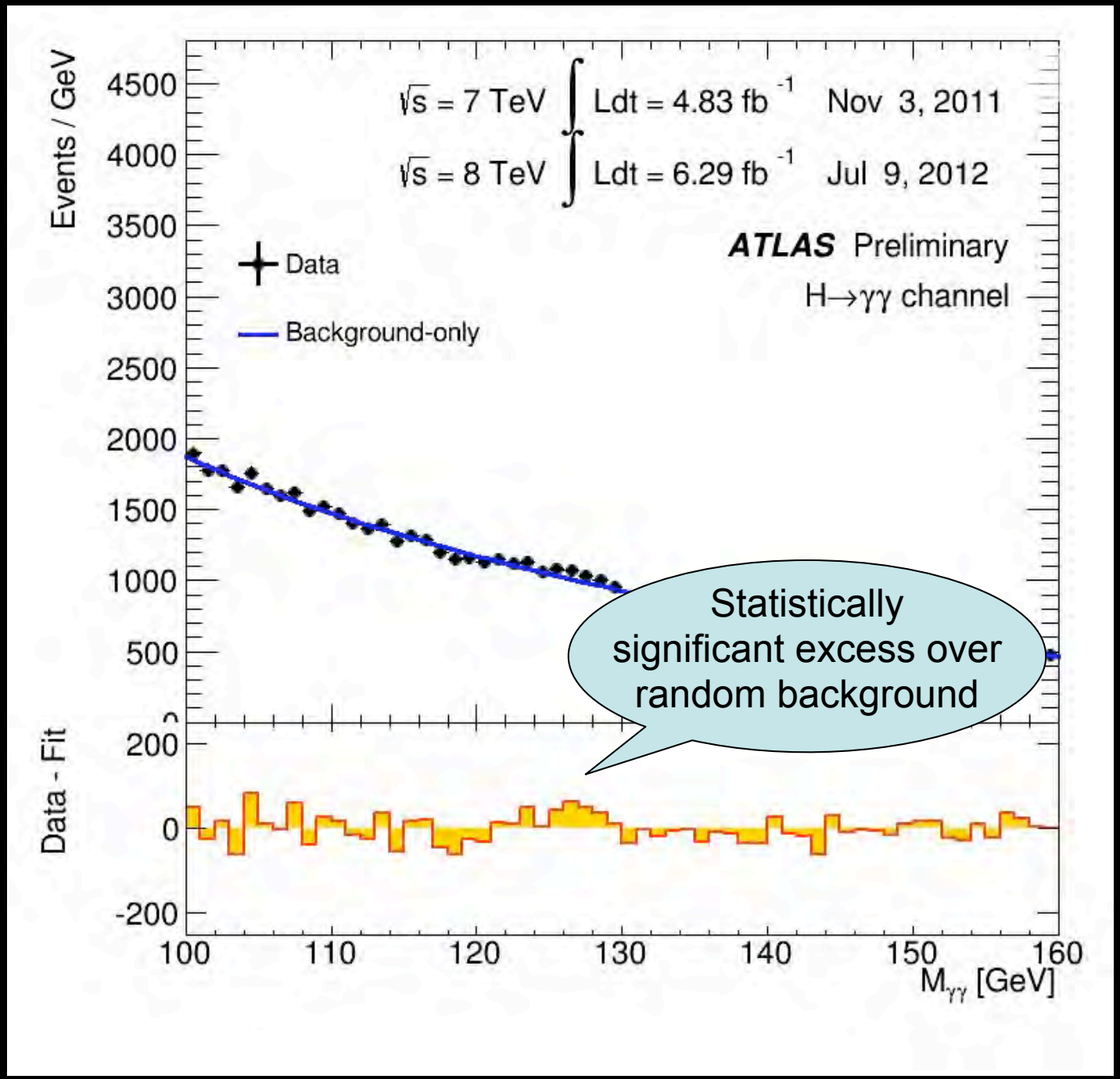
- Evidence for the Higgs Boson by ATLAS and CMS resulted from:
  - –about one in every 1,000,000,000,000 collisions produce two photons from the Higgs boson

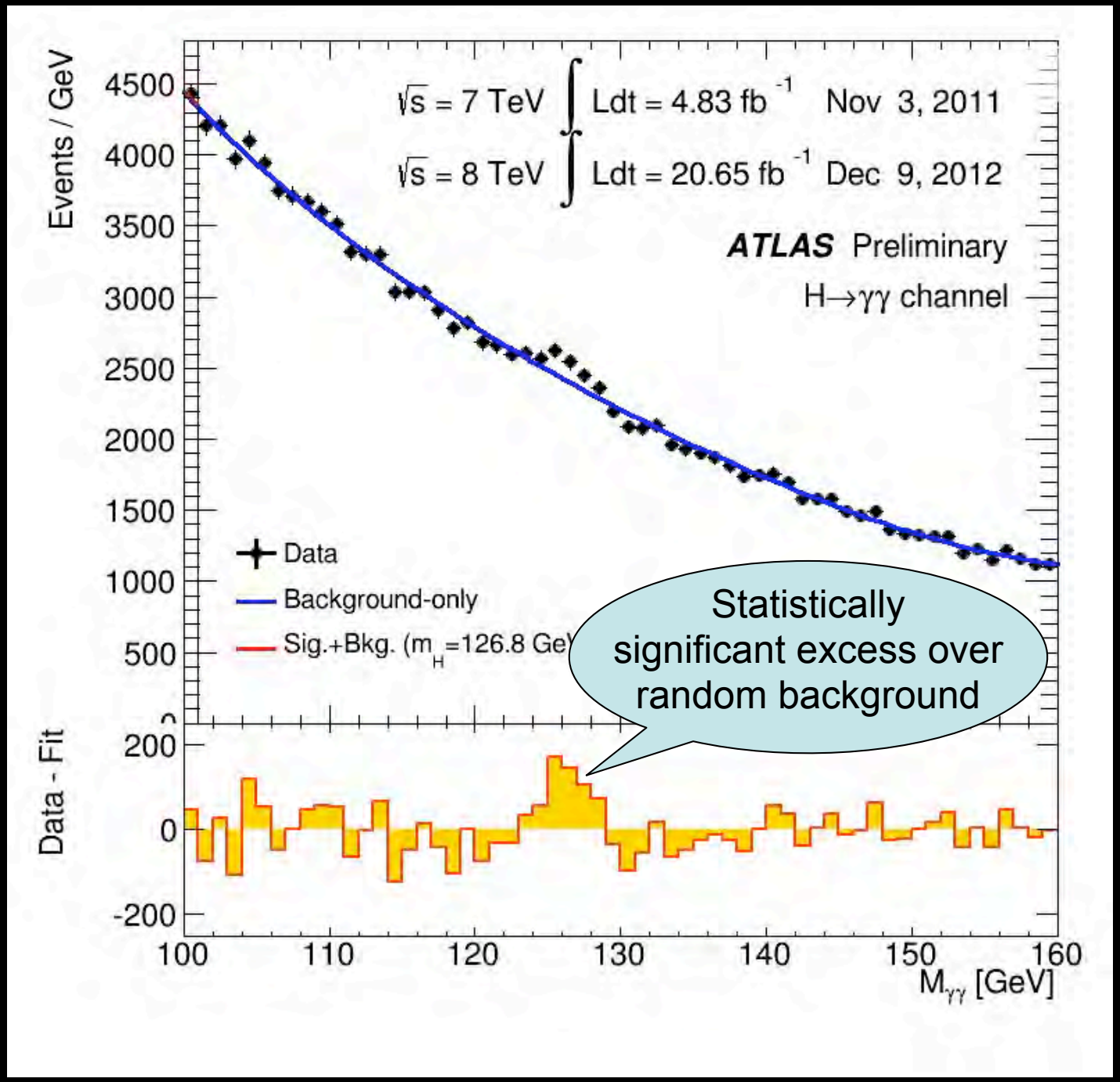
    - many more pairs of photons are produced by random unrelated processes

  - –data collected in 2011 and 2012

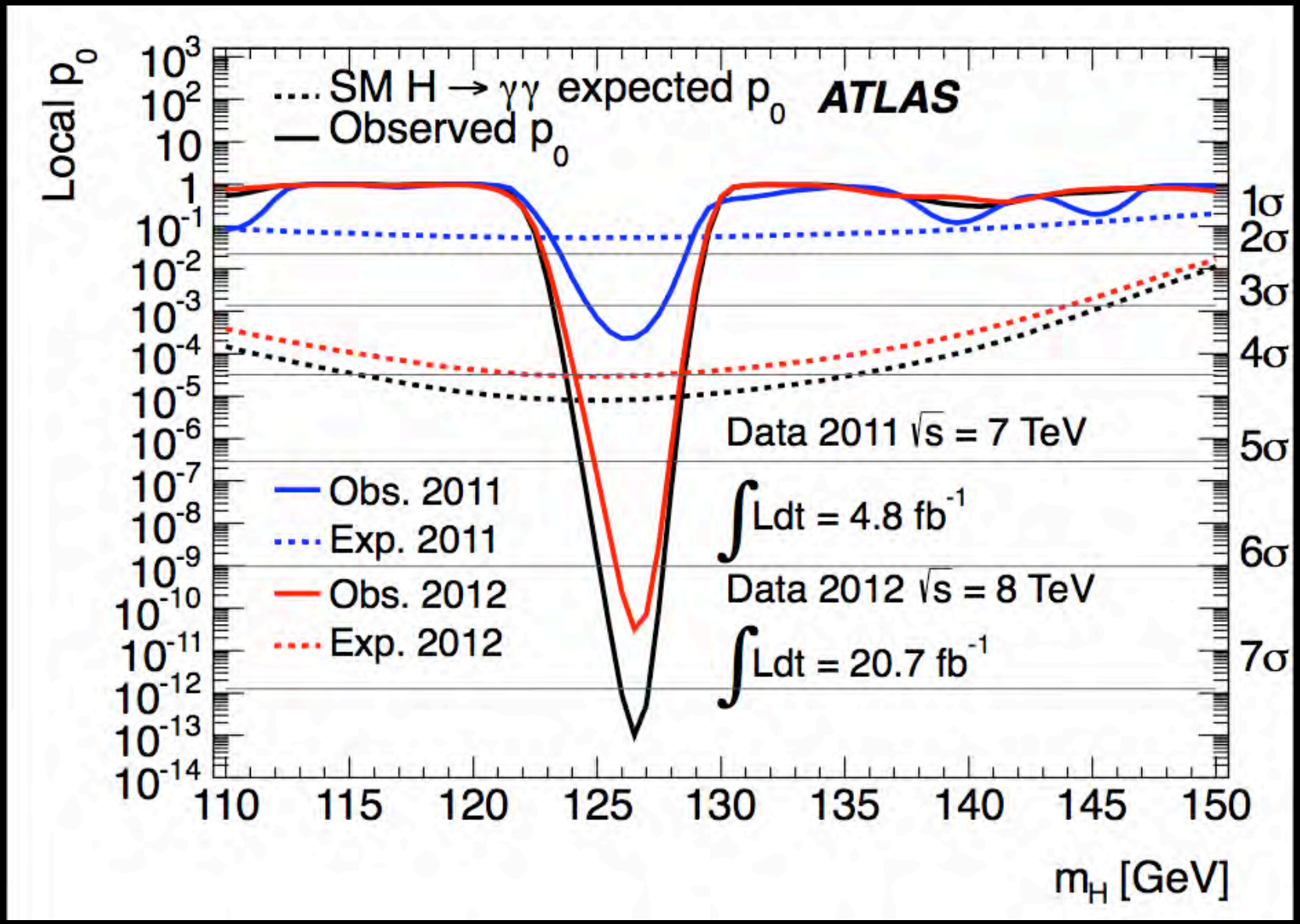

√s = 7 TeV ∫ Ldt = 0.02 fb -1 Apr 18, 2011
ATLAS Preliminary
H→γγ channel
Data
Background-only
Most photon pairs from normal, uninteresting interactions
Events / GeV
Data - Fit
4500
4000
3500
3000
2500
2000
1500
1000
500
200
0
-200
100
110
120
130
140
150
160
Mγγ [GeV]

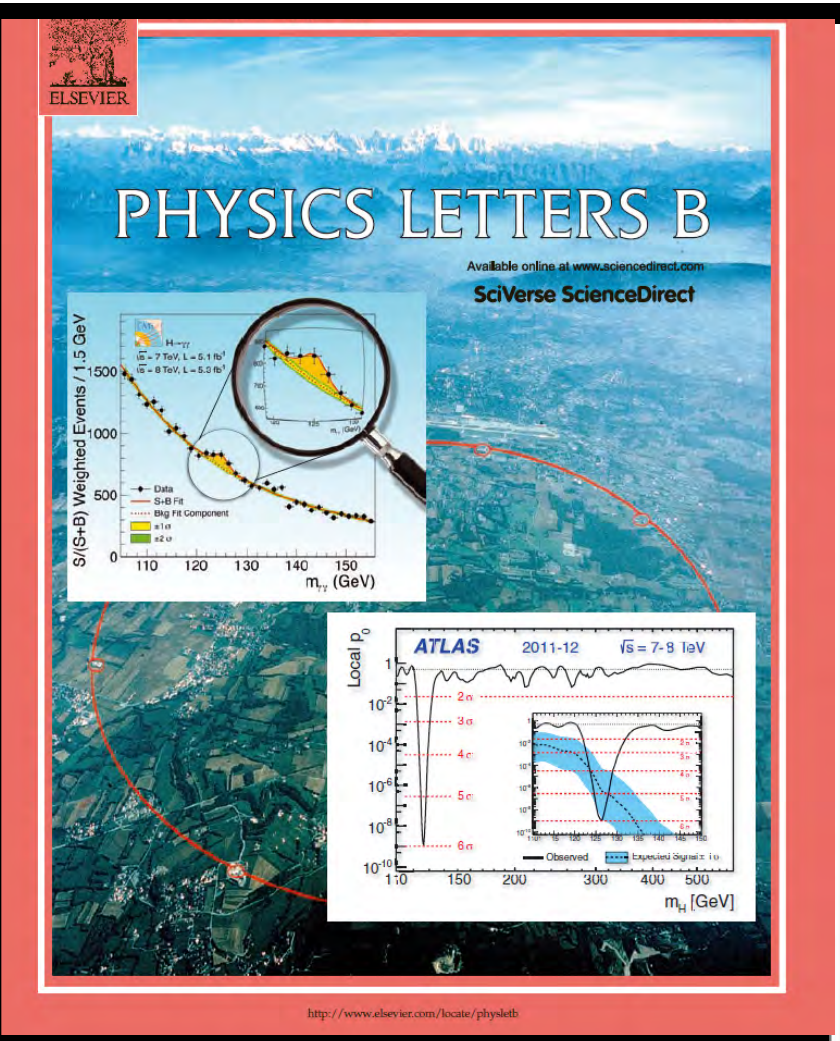

Events / GeV
4500
4000
3500
3000
2500
2000
1500
1000
500
√s = 7 TeV ∫ Ldt = 4.83 fb-1 Nov 3, 2011
√s = 8 TeV ∫ Ldt = 0.01 fb-1 Apr 8, 2012
ATLAS Preliminary
H→γγ channel
Data
Background-only
Statistically significant excess over random background
Data - Fit
200
0
-200
100
110
120
130
140
150
160
Mγγ [GeV]


Events / GeV
4500
4000
3500
3000
2500
2000
1500
1000
500
$\sqrt{s}$ = 7 TeV $\int$ Ldt = 4.83 fb^{-1} Nov 3, 2011
$\sqrt{s}$ = 8 TeV $\int$ Ldt = 6.29 fb^{-1} Jul 9, 2012
ATLAS Preliminary
H→γγ channel
Data
Background-only
Statistically significant excess over random background
Data - Fit
200
0
-200
100
110
120
130
140
150
160
$M_{\gamma\gamma}$ [GeV]


Events / GeV
4500
4000
3500
3000
2500
2000
1500
1000
500
√s = 7 TeV ∫ Ldt = 4.83 fb-1 Nov 3, 2011
√s = 8 TeV ∫ Ldt = 20.65 fb-1 Dec 9, 2012
ATLAS Preliminary
H→γγ channel
Data
Background-only
Sig.+Bkg. (m_H=126.8 GeV)
Statistically significant excess over random background
Data - Fit
200
0
-200
100
110
120
130
140
150
160
M_γγ [GeV]

Signal is not a random fluctuation!





arXiv:1207.7214v2 [hep-ex] 31 Aug 2012

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2012-218

Accepted by: Physics Letters B

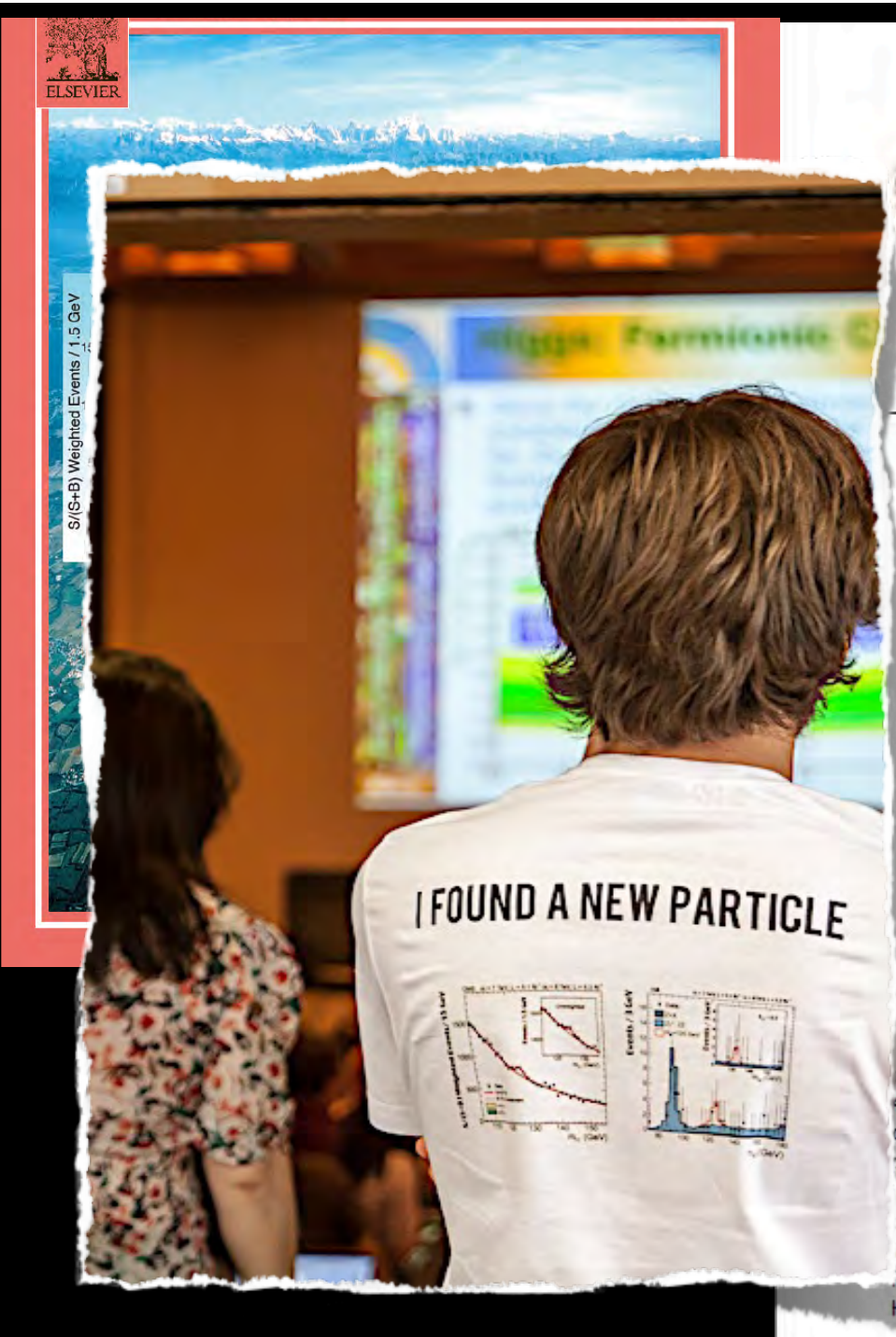
Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

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 ± 0.4 (stat) ± 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.



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Why is the Higgs Important? (1)

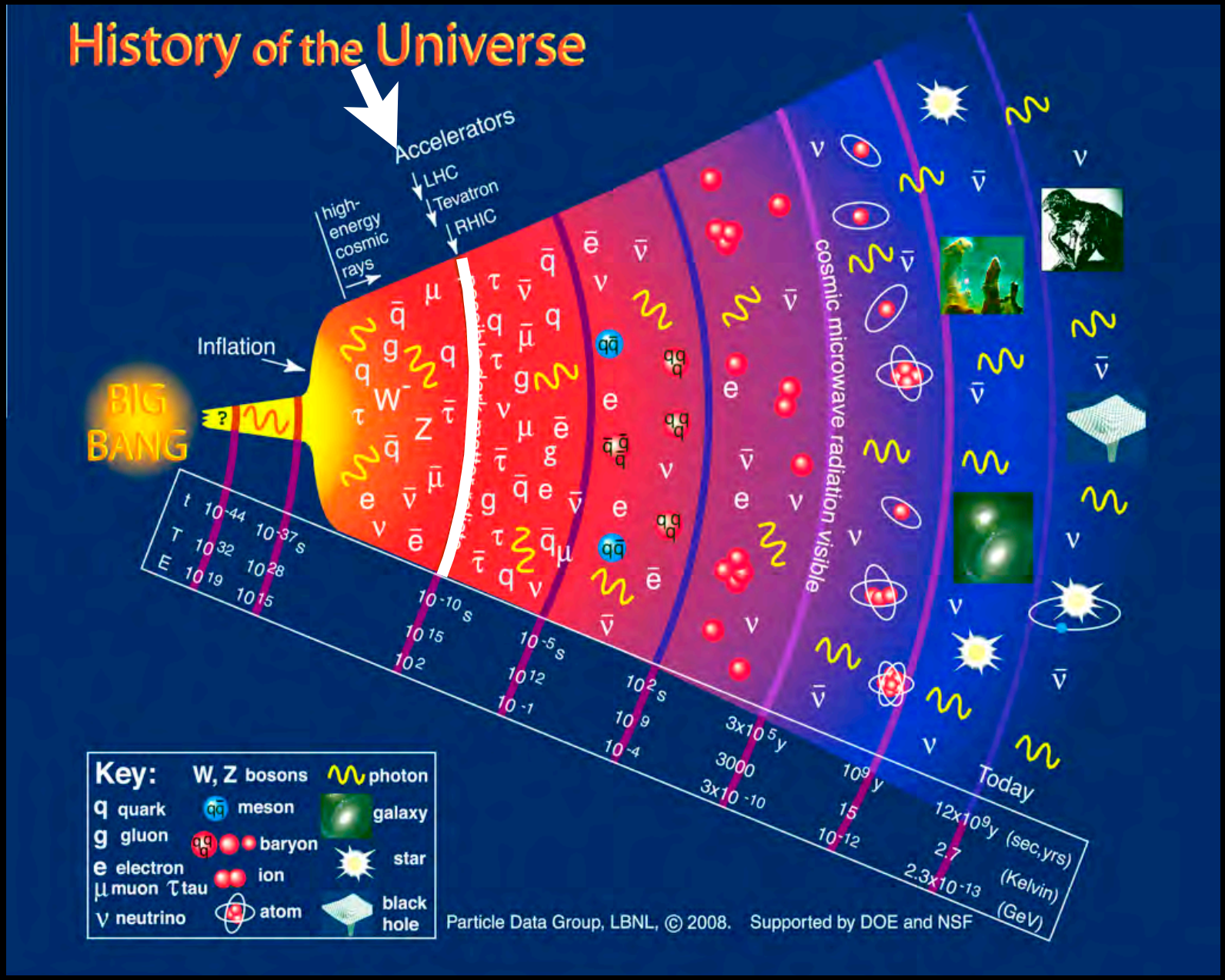
PARTICLE PHYSICS

- 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, as photon remains massless and weak bosons (W and Z) acquire mass

Why is the Higgs Important? (2)

COSMOLOGY

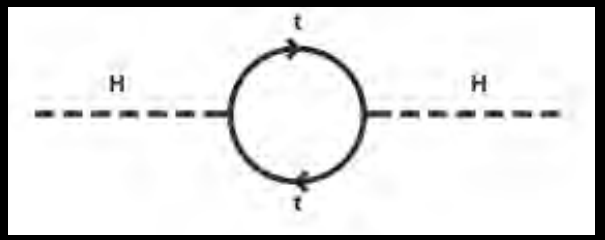
- Big Bang produced massless particles
  - 13.8 billion years ago
- Higgs field appeared everywhere
- Universe expanded and cooled
- Fundamental particles of Nature, initially massless, acquired mass from the Higgs field
- Particles slowed, bunched up and eventually formed atoms


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
atom
black hole
ν neutrino
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF

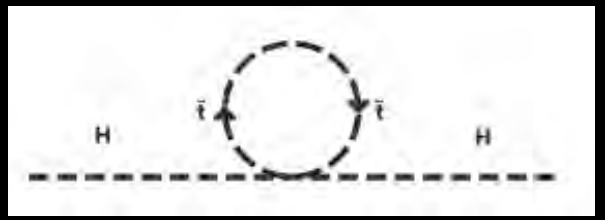
Hierarchy Problem

- Theory suggests the Higgs boson should be much, much heavier than it is ⇒ this is a problem
- Mass of the Higgs boson is affected by "radiative corrections" (very large effect)

  mass (H) should be very large



- New physics (ie. new particles) could limit mass through compensating "radiative corrections" which can cancel those we know

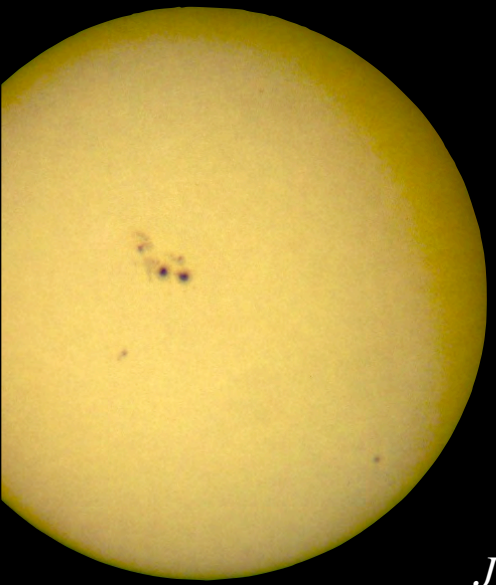


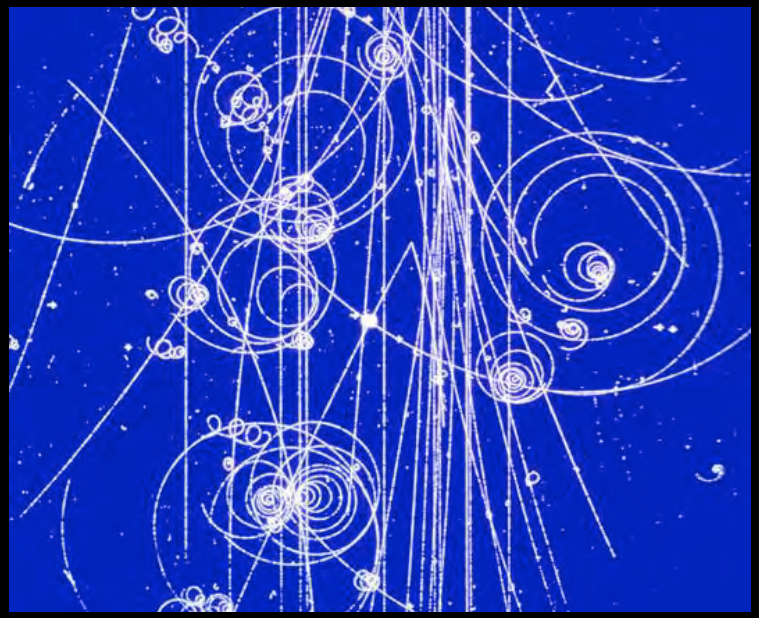
Possible solutions to Hierarchy Problem

- Supersymmetry
  - new particles truncate radiative corrections
- Extra dimensions
  - motivated by string theory
- Composite Higgs
  - not fundamental scalar - rather, composite particle
  - new force, eg. Technicolor, binds heavy particles into Higgs boson

NEW PHYSICS IS NEEDED FOR SOLUTION!

What is Matter?

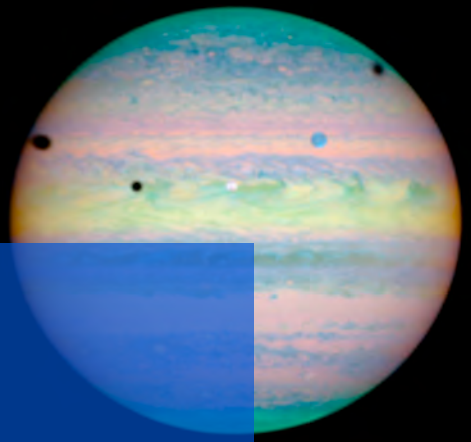




Jim Brau *Wright State University* *February 7, 2014*

What is Matter?



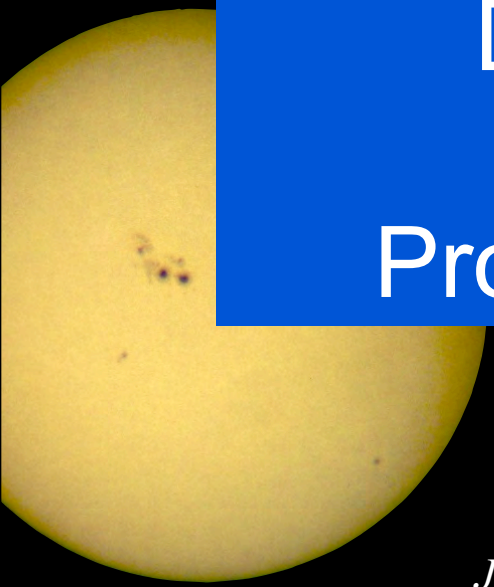
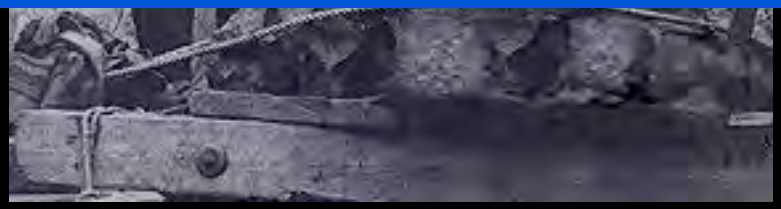



all Atomic

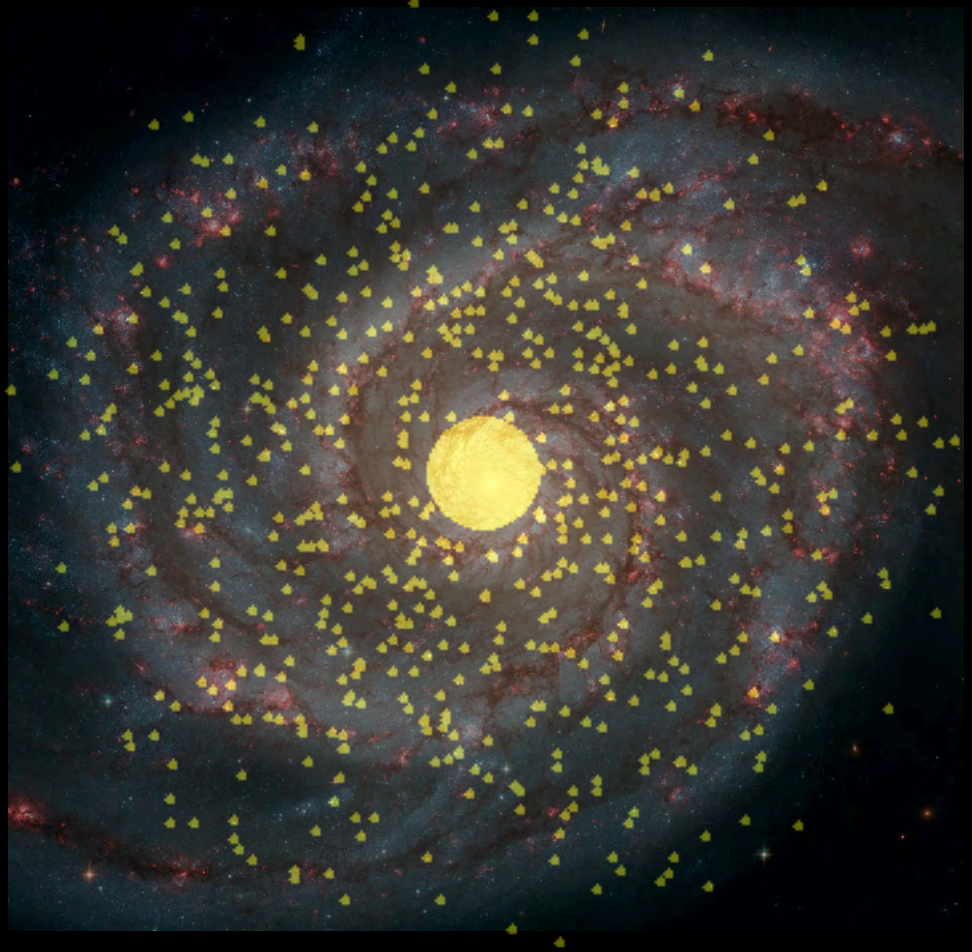
composed of quarks and leptons

Does the Universe contain another form of matter?

Probably yes - DARK MATTER


We know galaxies are surrounded by dark halos of mysterious, unidentified stuff (dark matter).



Expected-

based on stellar mass

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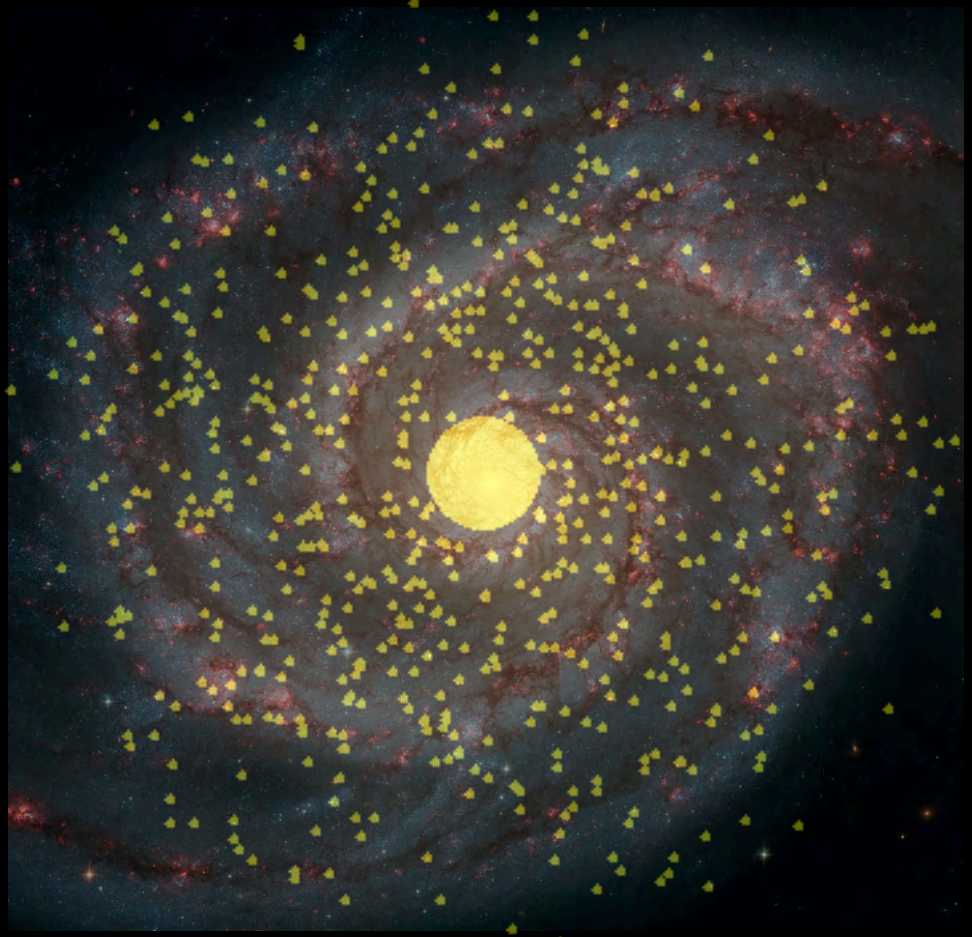
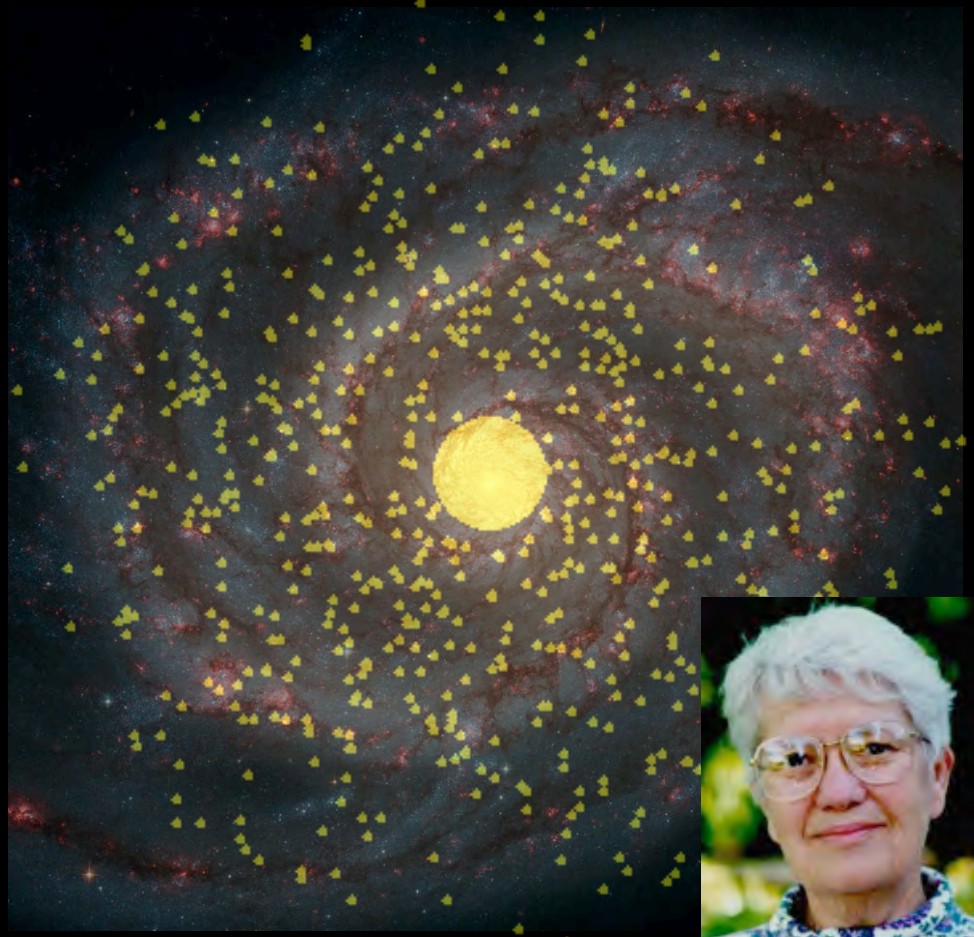
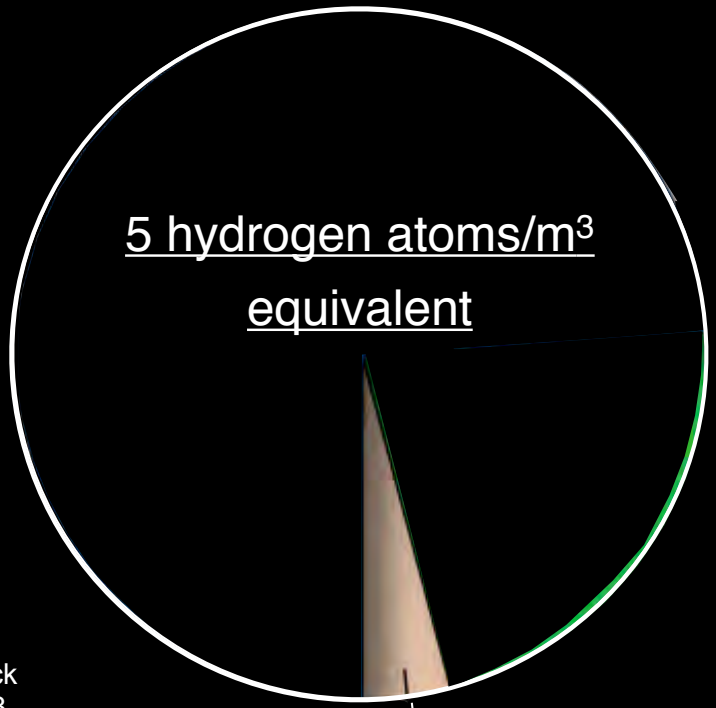




Vera Rubin
1950s

Expected-
based on stellar mass

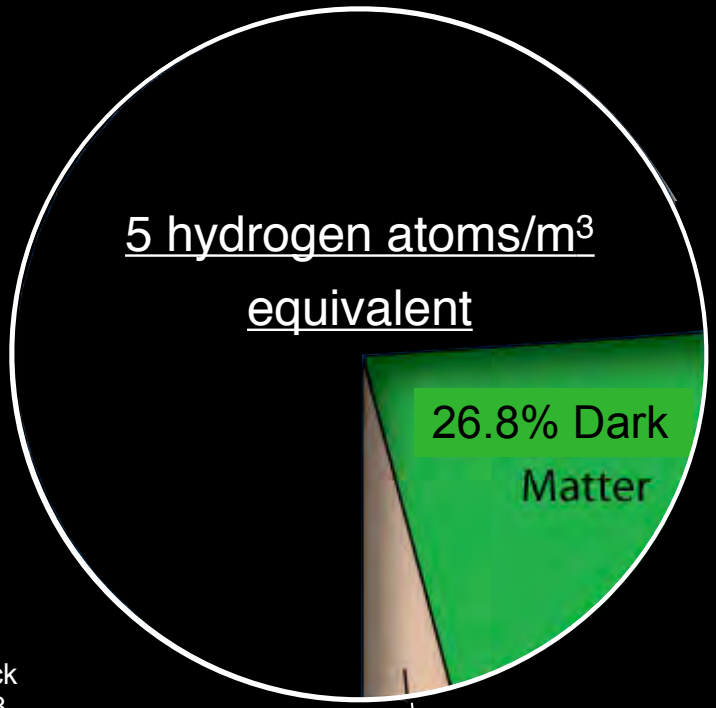
Observed-
reveals invisible ("dark") mass



This pie represents all the matter & energy in the universe

Planck 2013

4.9 % Atoms (1 hydrogen atom / 4 m^3)

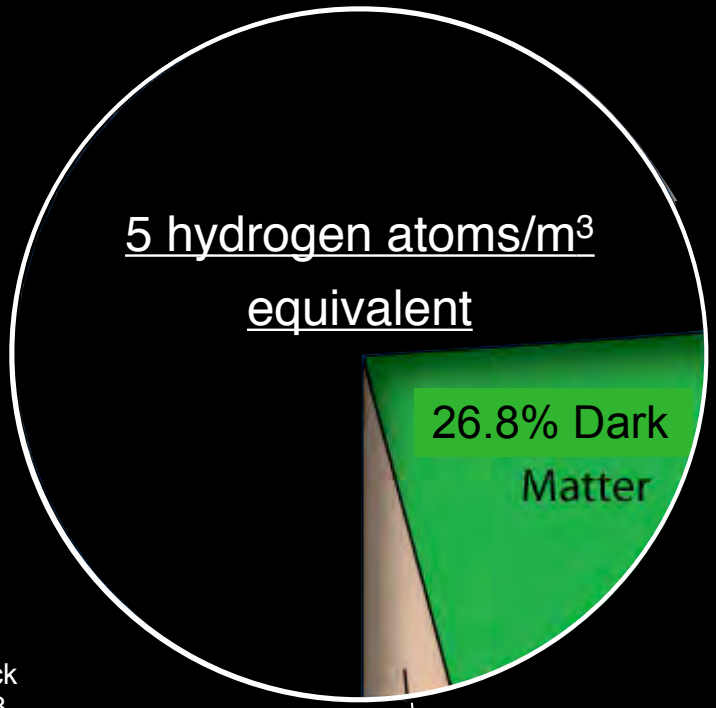


This pie represents all the matter & energy in the universe

Planck 2013

The Matter Crisis

- not enough matter
  to "make-up" known matter & energy of the Universe

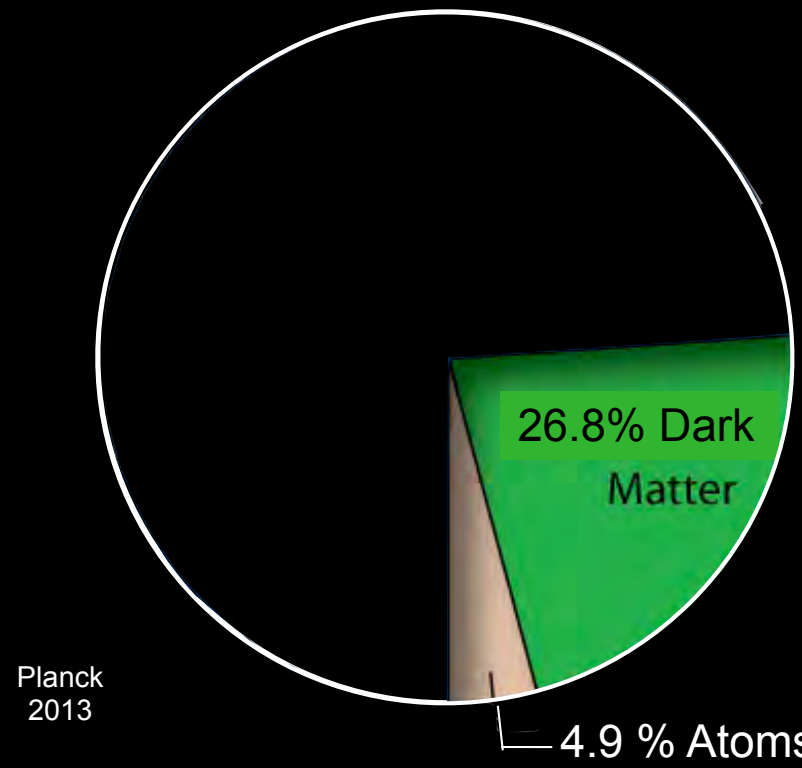


This pie represents all the matter & energy in the universe

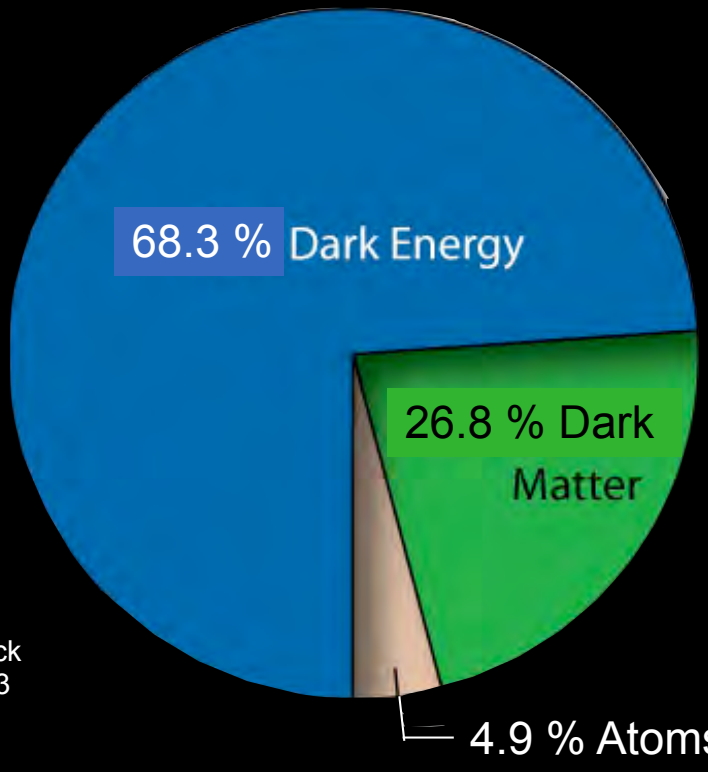
Planck 2013

Matter/Energy Budget Crisis

- What could account for the missing matter/energy of the Universe?



Acceleration Component called “Dark Energy”



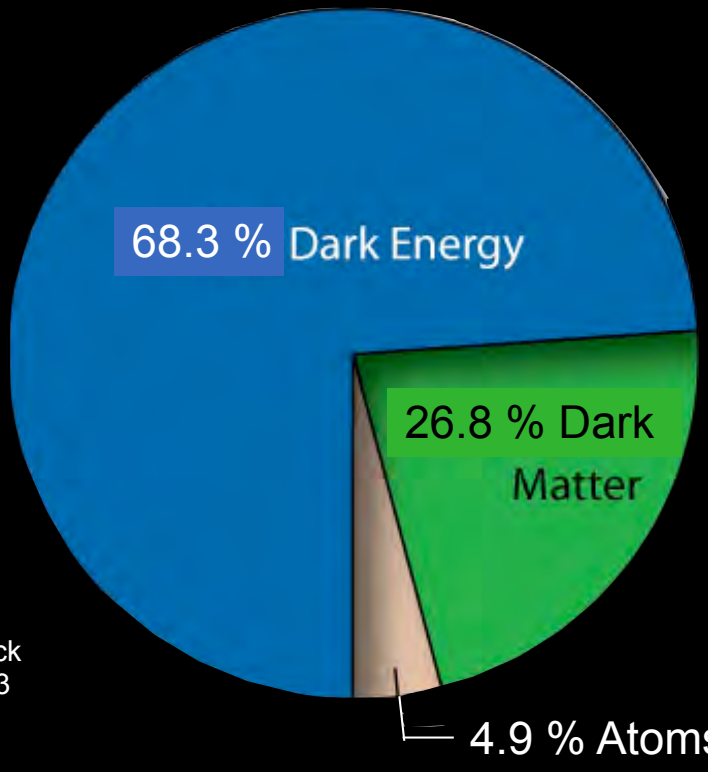
Planck 2013

This pie represents all the matter & energy in the universe

5 hydrogen atoms/m^3 equivalent

Acceleration Component called "Dark Energy"

- The dominant "stuff" of the universe is **dark matter** and **dark energy**



Planck 2013

This pie represents all the matter & energy in the universe

5 hydrogen atoms/m^3 equivalent


The Dark Side Controls the Universe
Dark Matter HOLDS IT TOGETHER
Dark Energy DETERMINES ITS DESTINY
Dark Matter is strange!
Dark Energy stranger?
Jim Brau
Wright State University
February 7, 2014

International Linear Collider

ILC (electron-positron collider)

International Linear Collider

ILC (electron-positron collider)

FUTURE

Higgs boson is such a fundamental addition to our understanding of Nature, it deserves our most precise and complete studies

ILC offers more precise studies of Higgs and other possible new physics

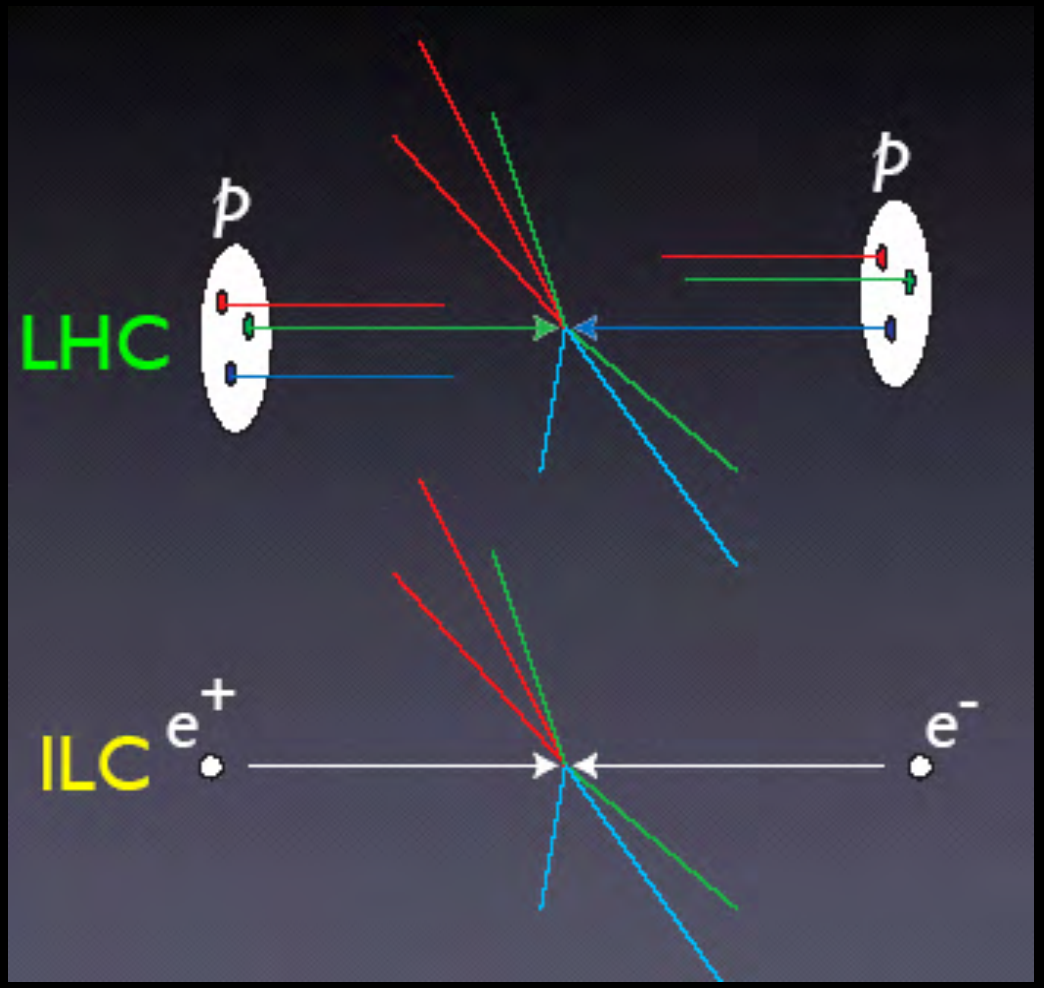
World-wide collaboration
has developed the technology

As of 2014, now ready to start construction
- governmental discussions underway

LHC / ILC comparison

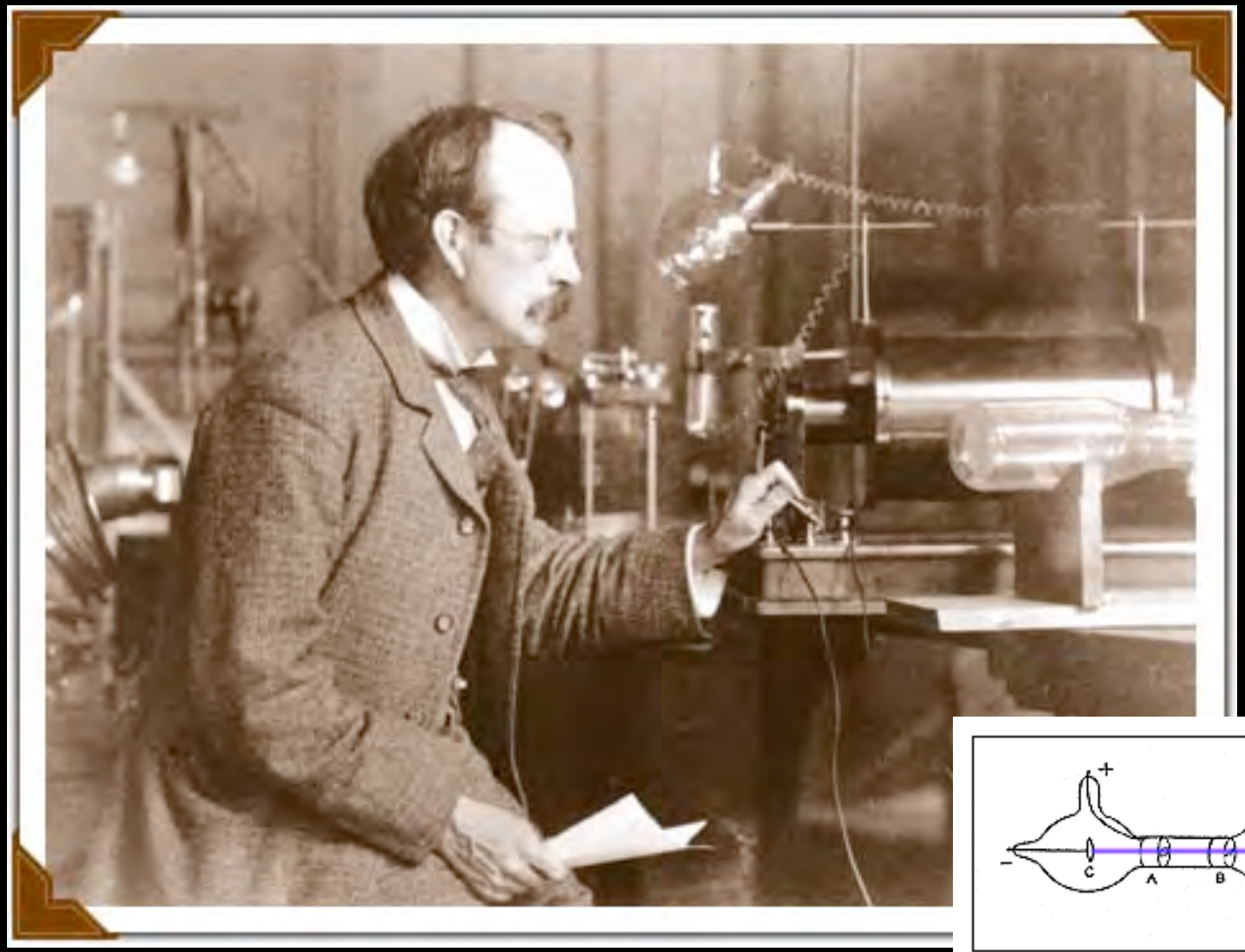
- ILC collisions are simpler
- an advantage for precision in Higgs boson measurements

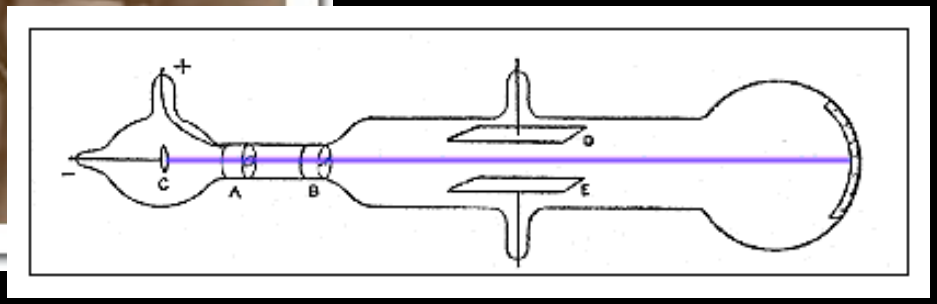
- Would be powerful complement to LHC



Are there any practical applications?

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
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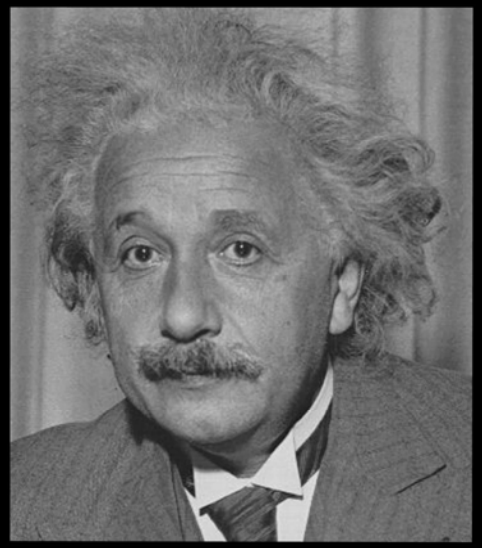
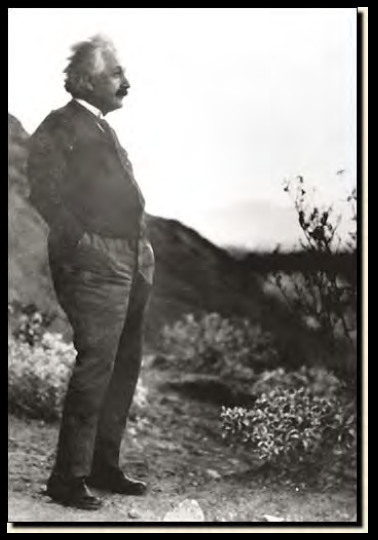
Summary:
Higgs Boson:
Window on the Big Bang

- Higgs boson discovery helps explain mysteries of physics and early universe
- Higgs boson particle was discovered in 2012 by large, international collaborations at the LHC in Switzerland
- Detailed properties of this Higgs boson will be measured in more detail to determine its full nature
  - –and search for evidence of “New Physics”
- LHC experiments search for more - eg. Dark Matter
- Future - International Linear Collider

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

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