THE HIGGS BOSON

WINDOW ON THE BIG BANG

http://www.AstroPics.com
University of Oregon
experimental high energy physics

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Nick Sinev, David Strom,
Dipongkar Talukder, Eric Torrence

http://www.AstroPics.com

Jim Brau         U. Oregon, Eugene         October 29, 2012
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 14,000,000,000,000,000 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
Search for the Higgs Boson at the LHC

slow motion

$E=mc^2$
or Energy equals Mass
Producing the Higgs Boson at the LHC
Producing the Higgs Boson at the LHC
Producing the Higgs Boson at the LHC
Producing the Higgs Boson at the LHC
The experiments ATLAS and CMS announced evidence for the Higgs Boson.
July 4, 2012

Combined results: the excess

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

Global significance: 4.1-4.3 $\sigma$ (for LEE over 110-600 or 110-150 GeV)
July 4, 2012

University of Oregon
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- Liza Brost, Ray Frey, Craig Gallagher, Emilie Haestad,
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Combined results: consistency of the data with the background-only expectation and significance of the excess

Excellent consistency (better than 2011) of the data with the background-only hypothesis over full mass spectrum

Peter Higgs
**Combined results: the excess**

Maximum excess observed at $m_H = 126.5$ GeV  
Local significance (including energy-scale systematics) 5.0 $\sigma$  
Probability of background up-fluctuation $3 \times 10^{-7}$  
Expected from SM Higgs $m_H=126.5$ 4.6 $\sigma$  
Global significance: 4.1-4.3 $\sigma$ (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
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 \(H \rightarrow ZZ^{(*)} \rightarrow 4\ell\), \(H \rightarrow \gamma\gamma\) and \(H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu\) in the 8 TeV data are combined with previously published results of searches for \(H \rightarrow ZZ^{(*)}, WW^{(*)}, b\bar{b}\) and \(\tau^+\tau^-\) in the 7 TeV data and results from improved analyses of the \(H \rightarrow ZZ^{(*)} \rightarrow 4\ell\) and \(H \rightarrow \gamma\gamma\) 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 \(1.7 \times 10^{-9}\), is compatible with the production and decay of the Standard Model Higgs boson.
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ATLAS Detector

Weight - 7000 tons
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
What is the Higgs Boson?

- Theory postulated in 1964

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

Peter Higgs (1929 - )

Satyendra Nath Bose (1894-1974)
What is the Higgs Boson?

- Theory postulated in 1964 — historical era

Peter Higgs (1929-)

Satyendra Nath Bose (1894-1974)

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

Jim Brau U. Oregon, Eugene October 29, 2012
The Higgs Field

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

Earth’s gravity

Magnetism
Higgs Boson Theory

- Higgs field fills the universe
- Interacts with fundamental particles to give them mass
- Separates electromagnetism and the weak 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
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 both 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
20th Century Particle Physics Laboratories

electron linear accelerator at Stanford (SLAC)

proton synchrotron at Fermilab (near Chicago)
1969

Stanford Linear Accelerator Center

electrons

proton
1969 - Quarks discovered (inside atomic nucleus) Stanford
1969 - Quarks discovered (inside atomic nucleus) Stanford
1995 - Top Quark Discovered at Fermilab
1995 - Top Quark Discovered at Fermilab
1995 - Top Quark Discovered at Fermilab

Creation of massive matter \((E=mc^2)\)
ELEMENARY PARTICLES

Quarks

Leptons

Force Carriers

u c t f y γ

V_e V_μ V_τ

W Z

I II III

Three Generations of Matter

Jim Brau  U. Oregon, Eugene  October 29, 2012
Particles and Forces

“interactions”

- Gravity - weakest
Particules and Forces

“interactions”

- Gravity - weakest
- Electromagnetism

**Elementary Particles**

- Leptons
- Quarks

<table>
<thead>
<tr>
<th>Generation</th>
<th>Leptons</th>
<th>Quarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$e^-$, $e^+$, $\mu^-$, $\mu^+$, $\tau^-$, $\tau^+$</td>
<td>$u$, $d$, $s$, $b$, $c$, $t$, $g$</td>
</tr>
<tr>
<td>II</td>
<td>$\nu_e$, $\nu_\mu$, $\nu_\tau$, $\bar{\nu}<em>e$, $\bar{\nu}</em>\mu$, $\bar{\nu}_\tau$</td>
<td>$\omega$</td>
</tr>
<tr>
<td>III</td>
<td>$\nu_e$, $\nu_\mu$, $\nu_\tau$, $\bar{\nu}<em>e$, $\bar{\nu}</em>\mu$, $\bar{\nu}_\tau$</td>
<td>$\tau$, $W$, $Z$</td>
</tr>
</tbody>
</table>

Three Generations of Matter

**Force Carriers**
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)
The diagram illustrates the classification of fermions and bosons, with their respective mass scales. Fermions are further divided into first, second, and third generations, each containing different quarks and leptons. Bosons, on the other hand, are shown to have massless states, with photons, muon neutrinos, tau neutrinos, and gluons distinctively represented.
Are Forces Related?

1850
- Gravity
- Electricity
- Magnetism
Forces

“interactions”

Are Forces Related?

1864
Unified theory
• Electromagnetism
• Light (photons)

1850
• Gravity
• Electricity
• Magnetism

J.C. Maxwell

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Are Forces Related?

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• Light (photons)

J.C. Maxwell

Forces
“interactions”

• Gravity
• Electromagnetism

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Are Forces Related?

2000
• Gravity
• Electromagnetism
• Weak Nuclear
• Strong Nuclear

Forces
“interactions”
Are Forces Related?

Forces
“interactions”

2000
• Gravity

{ • Electroweak
• Strong Nuclear

• Gravity

1950

2000
Are Forces Related?

Anticipated - discovery of the Higgs Boson at accelerators

- Gravity
- Electroweak
- Strong Nuclear

Forces "interactions"

2000

- Gravity
- Electroweak
- Strong Nuclear

P. Higgs
Are forces related?
New particles would be involved in any unification

Forces
"interactions"

• Gravity
• Electroweak
• Strong Nuclear

2000
1929 - Hubble Discovered Universe is Expanding

Edwin Powell Hubble (1889-1953)

Hubble's Plot of Galaxy Velocity & Distance

Nearby galaxies can be moving towards us

Line of best fit: \( v = H_0 d \)

(1 Megaparsec = 3.26 million light years)
1929 - Hubble Discovered Universe is Expanding

First evidence that Universe began with a Big Bang

Edwin Powell Hubble
(1889-1953)
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

Key:
- W, Z bosons
- Photons
- q quark
- g gluon
- e electron
- μ muon
- τ tau
- ν neutrino
- galaxy
- atom
- black hole
- ion
- baryon
- star

Accelerators:
- LHC
- RHIC

High-energy cosmic rays

Possible dark matter relics

Cosmic microwave radiation, visible

Inflation

Big Bang

T 10^32
E 10^19
10^15
10^10
10^6
10^3
10^1
10^-1
10^-2
10^-5
10^-6
10^-7
10^-10
10^-12
10^-14
3x10^-5
10^-4
10^-3
10^-2
10^-1
3000
3x10^-10
10^-15
10^-16
12x10^8 (sec, yrs)
2.7 (Kelvin)
2.3x10^13 (GeV)

Today

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

M31 - Andromeda
Halo of Dark Matter
How we know dark halos surround galaxies?

Expected-based on stellar mass

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How we know dark halos surround galaxies?

Expected - based on stellar mass

Observed - reveals invisible ("dark") mass

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Dark Matter Dominates Atomic Matter

- Dark Matter of the Universe outweighs 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

This pie represents all the “stuff” in the universe
Acceleration Component called “Dark Energy”

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

![Pie chart showing 74% Dark Energy, 22% Dark Matter, and 4% Atoms]
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
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?
1897 - J.J. Thomson  Electron

Credit: American Institute of Physics

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J.J. Thomson, On 1897 Discovery

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
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

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OFFICE OF SCIENCE

NATIONAL SCIENCE FOUNDATION

Philip H. Knight

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