Did we discover the Higgs?

*UTA Physics Public Symposium*
*July 6, 2012*

*Dr. Jaehoon Yu*

**Outline**

- What is High Energy Physics?
- What is the Higgs particle and what does it do?
- What did we see? (some scientific plots…)
- Did we find the Higgs?
- What’s coming next?
- Are we done yet?
We always wonder…

• What is the universe made of?
• How does the universe work?
• What are the things that holds the universe together?
• What are the governing principles of the universe?
• How can we live in the universe well?
• Where do we all come from?
• HEP looks into the smallest possible things to find the answers to these deep questions
High Energy Physics

• Definition: A field of physics that pursues understanding the fundamental constituents of matter and basic principles of interactions between them.

• Known interactions (forces):
  – Gravitational
  – Electro-Weak
  – Strong

• Current theory: The Standard Model of Particle Physics
  – Unified Weak and Electromagnetic: SU(2)xU(1)
  – Strong Interaction: SU(3)
  – Currently: SU(3)xSU(2)xU(1)
  – Meaning: 8+4 mediators for forces
## The forces in Nature

<table>
<thead>
<tr>
<th>TYPE</th>
<th>INTENSITY OF FORCES (DECREASING ORDER)</th>
<th>BINDING PARTICLE (FIELD QUANTUM)</th>
<th>OCCURS IN:</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRONG NUCLEAR FORCE</td>
<td>~ 1</td>
<td>GLUONS (NO MASS)</td>
<td>ATOMIC NUCLEUS</td>
</tr>
<tr>
<td>ELECTRO-MAGNETIC FORCE</td>
<td>~ $10^{-3}$</td>
<td>PHOTONS (NO MASS)</td>
<td>ATOMIC SHELL ELECTROTECHNIQUE</td>
</tr>
<tr>
<td>WEAK NUCLEAR FORCE</td>
<td>~ $10^{-5}$</td>
<td>BOSONS $Z^0, W^+, W^-$ (HEAVY)</td>
<td>RADIOACTIVE BETA DESINTEGRATION</td>
</tr>
<tr>
<td>GRAVITATION</td>
<td>~ $10^{-38}$</td>
<td>GRavitons (?)</td>
<td>HEAVENLY BODIES</td>
</tr>
</tbody>
</table>

**THE EXCHANGE OF PARTICLES IS RESPONSIBLE FOR THE FORCE**

Is the Higgs particle discovered?  
Dr. Jaehoon Yu
Total of 16 particles make up the matter in the universe! → Simple and elegant!!!

Tested to a precision of 1 part per million!
Accelerators are **Powerful Microscopes**.

They make high energy particle beams that allow us to see small things.

seen by low energy beam (poorer resolution)

seen by high energy beam (better resolution)
Accelerators are also *Time Machines.*

They make particles last seen in the earliest moments of the universe.

Particle and anti-particle annihilate.

\[ E = mc^2 \]
Fermilab Tevatron and LHC at CERN

- World’s Highest Energy proton-anti-proton collider
  - 4km circumference
  - $E_{cm} = 1.96$ TeV ($= 6.3 \times 10^{-7} J/p \Rightarrow 13$ M Joules on the area smaller than $10^{-4} m^2$)
  - Equivalent to the kinetic energy of a 20t truck at the speed 81mi/hr $\Rightarrow 130$ km/hr
    - ~100,000 times the energy density at the ground 0 of the Hiroshima atom bomb
  - Was shut down at 2pm CDT, Sept. 30, 2011
  - Vibrant other programs running!!

- World’s Highest Energy p-p collider
  - 27km circumference, 100m underground
  - Design $E_{cm} = 14$ TeV ($= 44 \times 10^{-7} J/p \Rightarrow 362$ M Joules on the area smaller than $10^{-4} m^2$)
  - Equivalent to the kinetic energy of a B727 (80tons) at the speed 193mi/hr $\Rightarrow 312$ km/hr
    - ~3M times the energy density at the ground 0 of the Hiroshima atom bomb
  - First 7TeV collisions on 3/30/10 $\Rightarrow$ The highest energy humans ever achieved!!
  - First 8TeV collisions in 2012 on April 5, 2012

Is the Higgs particle discovered? Dr. Jaehoon Yu
LHC @ CERN Aerial View

Is the Higgs particle discovered? — Dr. Jaehoon Yu.
The ATLAS and CMS Detectors

- Fully multi-purpose detector with emphasis on lepton ID & precision E & P
- Weighs 7000 tons and 10 story tall
- Records 200 – 400 collisions/second
- Records approximately 350 MB/second
- Record over 2 PB per year ➔ 200*Printed material of the US Lib. of Congress
Amount of ATLAS Data

**ATLAS Online Luminosity**

- **2010** pp $\sqrt{s} = 7$ TeV
- **2011** pp $\sqrt{s} = 7$ TeV
- **2012** pp $\sqrt{s} = 8$ TeV

<table>
<thead>
<tr>
<th>Year</th>
<th>Luminosity [fb$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0.05</td>
</tr>
<tr>
<td>2011</td>
<td>5.6</td>
</tr>
<tr>
<td>2012</td>
<td>6.6</td>
</tr>
</tbody>
</table>

July 6, 2012 Is the Higgs particle discovered? Dr. Jaehoon Yu
Step one: Understanding the ATLAS Detector

Allows detailed understanding of the detector material via location of interactions.

July 6, 2012
Step two: Verify SM \( \rightarrow \) Weak Bosons

- Important first steps are the verification of the Standard Model physics at \( \sqrt{s} = 7 \) TeV
- W/Z weak vector boson are powerful tools to constrain PDF’s and to understand detector
Here are some nice $Z \to ee$ and $\mu\mu$!!

**$Z \to ee$ candidate**

- Total efficiency: $\sim 30\%$
- Main background: QCD
- $S/B \sim 100$

**$Z \to \mu\mu$ candidate**

- Total efficiency: $\sim 40\%$
- Main background: $tt$, $Z \to tt$
- $S/B \sim 400$
Step 3: Understanding Fakes to the Higgs!!

Validation of theoretical predictions!!

W x-sec vs CMS Energy

W+Njet x-sec

ATLAS

Data 2010 ($\sqrt{s} = 7$ TeV)

$\int L dt = 310-315$ nb$^{-1}$

$\sigma(W \rightarrow \mu \nu)$
$\sigma(W \rightarrow e \nu)$

NNLO QCD

$\sigma(W + N_{jet}$ [pb])

ATLAS Preliminary

$\int L dt = 33$ pb$^{-1}$

Theory/Data

Inclusive Jet Multiplicity, N$_{jet}$

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Is the Higgs particle discovered?

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What is the Higgs and What does it do?

- When there is perfect symmetry, one cannot tell directions!
- Only when symmetry is broken, can one tell directions.
- Higgs field works to break the perfect symmetry and give mass.
  - This field exists right now amongst us so that we have mass.
- Sometimes, this field spontaneously generates a particle, the Higgs particle.
- So the Higgs particle is the evidence of the existence of the Higgs field!
How do we look for the Higgs?

• Higgs particle is so heavy they decays into some other particles very quickly

• When one searches for a new particle, you look for the easiest way to get at them

• Of these the many signatures of the Higgs, some states are much easier to find, if it were the Standard Model one

  – $H \rightarrow \gamma\gamma$
  – $H \rightarrow ZZ^* \rightarrow 4e, 4\mu, 2e2\mu, 2e2\nu$ and $2\mu2\nu$
  – $H \rightarrow WW^* \rightarrow 2e2\nu$ and $2\mu2\nu$
  – And many more complicated signatures
How do we look for the Higgs?

- Identify the Higgs candidate events
- Understand fakes (backgrounds)
- Look for a bump!!
What does Tevatron tell us on Higgs?

Tevatron Run II Preliminary, $L \leq 10.0 \text{ fb}^{-1}$

95% CL Limit/SM

- Observed
- Expected w/o Higgs
- $\pm 1$ s.d. Expected
- $\pm 2$ s.d. Expected

LEP Exclusion

Tevatron + ATLAS + CMS Exclusion

June 2012

$10^0 \, , \, 10^1 \, , \, 10^2 \, , \, 10^3 \, , \, 10^4 \, , \, 10^5 \, , \, 10^6 \, , \, 10^7 \, , \, 10^8$

$m_H (\text{GeV/c}^2)$

$\pm 1$ s.d. Expected
$\pm 2$ s.d. Expected

Expected

Observed

SM=1

ATLAS + CMS Exclusion

June 2012

$10^0 \, , \, 10^1 \, , \, 10^2 \, , \, 10^3 \, , \, 10^4 \, , \, 10^5 \, , \, 10^6 \, , \, 10^7 \, , \, 10^8$

$m_H (\text{GeV/c}^2)$

$1\sigma \, , \, 2\sigma \, , \, 3\sigma$

$10^0 \, , \, 10^1 \, , \, 10^2 \, , \, 10^3 \, , \, 10^4 \, , \, 10^5 \, , \, 10^6 \, , \, 10^7 \, , \, 10^8$

$m_H (\text{GeV/c}^2)$

$1\sigma \, , \, 2\sigma \, , \, 3\sigma$
ATLAS and CMS Mass Bump Plots

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ATLAS

CMS Preliminary

CMS Preliminary

CMS Preliminary

CMS Preliminary

LOO K, Ma! B bumps!!

Jaehoon Yu
ATLAS Higgs – All $M_H$

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Is the Higgs particle discovered?    Dr. Jaehoon Yu

ATLAS and CMS Higgs – low $M_H$
So have we seen the Higgs particle?

• The statistical significance of the finding is to 5 standard deviation
  – Level of significance: 99.99994%
  – We can be wrong once if we perform the same experiment 1,740,000 times

• So did we find the Higgs particle?
  – We have discovered a new particle, the heaviest boson we’ve seen thus far
  – It has some properties consistent with the Standard Model Higgs particle
  – We, however, do not have enough data to precisely measure all the properties – mass, life time, the rate at which this particle decays to certain other particles, etc – to definitively determine
So why is this discovery important?

- This is the giant first in completing the Standard Model
- Will help understand the origin of mass and the mechanism at which mass is acquired
- Will help understand the origin and the structure of the universe and the inter-relations of the forces
- Will help us make our lives better
- Generate excitements and interests on science and train the next generation
What next? Future Linear Collider

- Now that we have found a new boson, precision measurement of the particle’s properties becomes important.
- An electron-positron collider on a straight line for precision measurements.
- 10~15 years from now (In Dec. 2011, Japanese PM announced that they would bid for a LC in Japan).
- Takes 10 years to build the detector.
Bi-product of High Energy Physics Research

Can you see what the object is?

WWW Came from HEP!!!

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GEM Application Potential

Using the lower GEM signal, the readout can be self-triggered with energy discrimination:

F. Sauli, Nucl. Instr. and Meth.A 461(2001)47

FAST X-RAY IMAGING

9 keV absorption radiography of a small mammal (image size ~ 60 x 30 mm²)
And in not too distant future, we could do ...
So are we done yet?

- Why are there three families of quarks and leptons?
- Why is the mass range so large ($0.1m_p – 175 m_p$)?
- How do matters acquire mass?
  - Higgs mechanism but where is the Higgs, the God particle?
- Why is the matter in the universe made only of particles?
  - What happened to anti-particles? Or anti-matters?
- Do neutrinos have mass & what are the mixing parameters?
- Why are there only three apparent forces?
- Is the picture we present the real thing?
  - What makes up the 96% of the universe?
  - How about extra-dimensions?
- How is the universe created?
- Are there any other theories that describe the universe better?
- Many more questions to be answered!!