Discovery of a New Particle

Experimental High-Energy Physics Group
McGill

Homer’s Physics 101
2012.September.28

"GOD PARTICLE"

YOU KEEP USING THAT WORD, I DO NOT THINK IT MEANS WHAT YOU THINK IT MEANS

http://nonsensibleshoes.com
My brother & sister-in-law asked me to explain the Higgs Boson. It was one of those Homer Simpson moments where he shrieks and runs away.
Leon Lederman Quotations

“god particle” nickname: because the particle
“...is so central to the state of physics today, so
crucial to our final understanding of the structure of
matter, yet so elusive…”

A second reason: because “…the publisher wouldn’t let
us call it the Goddamn Particle, though that might be a
more appropriate title, given its villainous nature and the
expense it is causing.”

http://wikipedia.org
Reductionism Epitomised

Condensed-Matter & Atomic Physics

Nuclear Physics

Low Energies

High-Energy Particle Physics
The (known) Fundamental Particles & Forces

Note: gravity is (temporarily) omitted
What gives masses to fundamental particles such as quarks and electrons, and why are they so different?

Important Distinction:

We already know how composite matter (e.g., atoms, fish, pizza, planets, people) gets most of its mass:

binding $E = mc^2$
So why should you care about the fundamental stuff?

Q: If your fundamental particles had no mass, what would they be doing?

A: They’d all be zipping around at the speed of light.
- no fish
- no pizza
- no planets

No us…
But the issue of masses of fundamental particles really takes its origins from the time of Rutherford.

Radioactivity: atoms transmute

Force is weak because W particle is massive!
Theory devised in 1964 to explain how W (also Z) particle gets its mass

“Simplest” idea: add a new “Higgs field” to the theory (i.e., to the Universe…)

Changes the symmetry of the equations, spontaneously allowing certain types of particles to have nonzero mass
Different fundamental particles experience different amounts of resistance when interacting with the Higgs field.

All-pervasive Higgs field
Think: **Electric and Magnetic Fields**

Look at them closely and you see little “chunks”:

- Quantum chunks
- photon particles
- \( \gamma \)

Same idea for a **Higgs Field**:

- Different Quantum chunks
- Higgs particles!
- Discover particle to discover a new field!
- (Contrast: top quark discovery)

Think of fields like fabrics:
- Waves & ripples
- Look closely, see threads
- Chunky particles…

http://www.spreadshirt.co.uk

http://labman.phys.utk.edu
So, where do you look for Higgs particles?

1. **Make** them in particle colliders

2. **Study** them using particle detectors (“experiments”)

**Challenges:**
- Need a lot of energy to make them
- They’re pretty rare but look a lot like common stuff
- They only exist for 0.000000000000000000016 seconds
CERN Laboratory, Geneva, Switzerland

Large Hadron Collider (LHC)

ATLAS Detector

proton

proton
The Large Hadron Collider (LHC)

proton $\rightarrow$ $E$ $\rightarrow$ proton

$E = M \, c^2$
ATLAS (A Toroidal LHC ApparatuS)
“Higgs seen by ATLAS already in 2008...”
(part of) The McGill ATLAS Group

2012.June.27         CLUMEQ Site Visit, ETS, Montréal
The LHC assaults ATLAS with about 600 million collisions every second.

McGill group has contributed to development of the ATLAS trigger:

- Designed to select interesting collisions, reject boring ones
- Keep recording rate well under 1000 collisions per second
- Without throwing away any Higgs (or other interesting) candidates…
July 2010: Canadian High-Level Trigger Computers Delivered to ATLAS Experiment

Surface building, above ATLAS cavern
Many thanks to CLUMEQ-McGill
High Performance Computing Centre

• Host site for ATLAS data files

• Computing power
  - Data analysis
  - Simulated LHC collisions

• Special thanks:
  - Steven Robertson
  - Bryan Caron, Simon Nderitu
  - Nik P., Sangyong J., Brigitte V.

McGill Physics
Paul Mercure
Juan Gallego
July 4, 2012

• First day of ICHEP 2012 (International Conference on High Energy Physics), Melbourne, Australia

• Specially timed CERN Seminars by ATLAS and CMS Experiments

• Both experiments announced discovery of a new particle
Much media attention...
One of the harder questions...
Attempting to explain the discovery to my 8-year-old niece

Sandra Sousa Julia says she wants to know what the particle looks like
4 July at 16:46 via mobile · Like

Andreas Warburton Julia, it's too small to see with your own eyes, so we built a big machine to try to take a picture of it (like a giant microscope with a camera attached to it). The machine actually makes the particle, but then the particle falls apart almost right away, breaking into smaller particles. The machine takes pictures of these smaller particles, so that's how we know the new particle existed. It's like when you find something in Kookie's/Smoukkie's litter box. It tells you that the cats are somewhere in the house, even if you don't see them. :)
4 July at 17:04 · Like · 6
How do we find the signal? Look for a bump!

Amount of Data

Higgs Mass

Higgs-like excess???
(the ‘something’ in the litter box)

Discovery Mass?!
But Nature can sometimes be so cruel…

Simpson stature

Raw intelligence

Not the Higgs…
Real ATLAS Data: Clear Excess (Bump) Visible by Eye


Excess resembling Higgs expectations

ATLAS

Data S/B Weighted

Sig+Bkg Fit ($m_H=126.5$ GeV)

Bkg (4th order polynomial)

$\sqrt{s}=7$ TeV, $\int Ldt=4.8$ fb$^{-1}$

$\sqrt{s}=8$ TeV, $\int Ldt=5.9$ fb$^{-1}$

$H\rightarrow \gamma\gamma$
I happened to be doing a remote Trigger Monitoring Shift from Montréal on this day.
I happened to be *en route* to Calgary for the CAP Congress at this time.
Significance of the Findings

Current Standards in Particle Physics

“Evidence”:
- $3\sigma$ (three sigma) or greater
- Less than 1 chance in $\sim400$ that it’s a fluke

“Observation” or “Discovery”:
- $5\sigma$ (five sigma) or greater
- Less than 1 chance in $\sim3.5$ Million that it’s a fluke

This Summer’s Results:

2012.July.04 (ICHEP): CMS 4.9$\sigma$; ATLAS 5.0$\sigma$

2012.July.31 (papers): CMS 5.0$\sigma$; ATLAS 5.9$\sigma$

Less than 1 in $\sim588$ Million
An alternative indicator of significance?

Prevalence of fake David Letterman Top 10 lists…

Homer Simpson on the Higgs Boson – Top 10

July 6, 2012

A list of top 10 things that Homer Simpson might have to say on the recent discovery Higgs Boson à la David Letterman mode.

10 Higgs Boson? Wait a minute.. I thought it was Hog the Bison.

9 Since the universe has been explained, do we now get to play with lasers? Please, please, please..

8 I found an elementary particle once.. I named it Simps-on. Hee hee..

7 Now that Higgs Boson is found.. can we use the LHC for NASCAR?

6 If I were a particle physicist, my mass would be 86 terra yotta electron volts.

5 ..and the antiparticle is Higgs Bos-off?

4 Hey! I too have no charge, no spin and a hell load of mass.

3 God particle eh? Has Flanders been visiting the CERN?

2 Being the Nuclear Safety Inspector, I demand my Nobel Prize.

1 And all this while I had been thinking that the missing link was some kind of a monkey! Stupid formal education.
Wait, what about Fermilab?
Hunting down the Higgs Boson

- The “Holy Grail”, a missing link in Particle Physics.
- Theory: Higgs gives particles their masses.
- Can we find it at Fermilab before CERN/LHC/ATLAS does? Maybe.
- Our best bet right now: use b quarks!

The Golden Mode

Higgs Boson

b Quarks
Evidence for a Particle Produced in Association with Weak Bosons and Decaying to a Bottom-Antibottom Quark Pair in Higgs Boson Searches at the Tevatron

(*CDF Collaboration)
(†D0 Collaboration)

(Received 26 July 2012; published 14 August 2012)

We combine searches by the CDF and D0 Collaborations for the associated production of a Higgs boson with a W or Z boson and subsequent decay of the Higgs boson to a bottom-antibottom quark pair. The data, originating from Fermilab Tevatron $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, correspond to integrated luminosities of up to 9.7 fb$^{-1}$. The searches are conducted for a Higgs boson with mass in the range 100–150 GeV/$c^2$. We observe an excess of events in the data compared with the background predictions, which is most significant in the mass range between 120 and 135 GeV/$c^2$. The largest local significance is 3.3 standard deviations, corresponding to a global significance of 3.1 standard deviations. We interpret this as evidence for the presence of a new particle, consistent with the standard model Higgs boson, which is produced in association with a weak vector boson and decays to a bottom-antibottom quark pair.

DOI: 10.1103/PhysRevLett.109.071804

PACS numbers: 13.85.Rm, 14.80.Bn
Dr. Adrian Buzatu explains his McGill PhD thesis research to Professor Peter Higgs

Adrian’s work contributed to first evidence of Higgs particles coupling to beauty (bottom) quarks

St. Andrews, Scotland (2012.August.23)
What about this new particle’s properties?

Higgs mass or Homer’s mass?

http://spinor.info/weblog/?p=1591
Properties: What we know so far...

- Neutral electric charge
- Boson (integral spin, but not spin 1)
- CMS Measured mass: $125.3 \pm 0.4$ (stat.) $\pm 0.5$ (syst.) GeV
- ATLAS Measured mass: $126.0 \pm 0.4$ (stat.) $\pm 0.4$ (syst.) GeV
- ATLAS / CMS: Observed couplings to spin-1 bosons (photon, Z)
- CDF / D0 (Fermilab): Evidence of couplings to fermions ($b$ quarks)
Recommended Reading

GQ (Gentleman’s Quarterly)
Bruno Maddox
2012.September.11

Closing Remarks

• We (Humanity) have discovered a new particle

• The discovery was made while searching for the Standard Model Higgs Boson

• A Higgs boson has been predicted to exist if a Higgs field were to exist (but it may be in a “system” of multiple Higgs-related particles)

• Now we must extract this particle’s properties:
  • More LHC data
  • Upgrades to detectors (McGill: ATLAS muon detectors)
  • Another collider (International Linear Collider)

• Note: LHC was not built just to find this particle

• Other big questions need answering; surprises may lie ahead!
A good many thanks to many good people.

This discovery has been made possible by, literally, thousands of individuals and organizations worldwide:

- Scientific authors
- Technical personnel (many of you!)
- Institutional support staff (many of you!)
- Funding agencies (NSERC, FRQNT, CFI)