Dissecting the Higgs Discovery: The Anatomy of a 21st Century Scientific Achievement

Lecture 9
What’s next for the LHC?

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Arthur H. Compton Lectures
December 14th, 2013
Schedule of Lectures


[10/12] Accelerators: Creating particles out of (very) thin air

[10/19] Seeing the Higgs with light


[11/2] Seeing the Higgs with heavy particles


[11/16] Digesting the Data: Triggering, Data Processing


[11/30] No Lecture for Thanksgiving

[12/7] No Lecture for Physics with a Bang

[12/14] What's next for the LHC?
Outline

• Brief Review of the last lecture
• What’s happening during the shutdown?
• The state of the Higgs
• The Higgs signal emerges from the haystack
• Gaining Confidence
Last week

- We use detailed simulation as our prediction for what we should see in our data.

- Results are statistical in nature: we use histograms to display and analyze data.

- We have stringent statistical benchmarks for discovering new physics.
Last Week
LHC Run I

CMS Integrated Luminosity, pp

Data included from 2010-03-30 11:21 to 2012-12-15 22:00 UTC

Total Integrated Luminosity (fb⁻¹)

- 2010, 7 TeV, 44.2 fb⁻¹
- 2011, 7 TeV, 6.1 fb⁻¹
- 2012, 8 TeV, 23.3 fb⁻¹
Anatomy of Run

LHC Run Efficiency

Mode: Proton Physics
Fills: 2469 – 3271 [667 Fills]
SB Time: 64 days 15 hrs 33 mins

Run Availability
Based on LHC Physics Schedule
Total Run Time: 179 days 0 hrs 35 mins
Cryo Availability: 167 days 13 hrs 45 mins 93.6 %
Fault Downtime: 42 days 18 hrs 8 mins 23.9 %

Recent Availability
Total Run Time: 6 days 23 hrs 18 mins
Cryo Availability: 6 days 20 hrs 27 mins 98.3 %
Fault Downtime: 2 days 0 hrs 47 mins 29.2 %

Recent Faults: The top 5 list

<table>
<thead>
<tr>
<th>Fill</th>
<th>Duration</th>
<th>System</th>
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<tbody>
<tr>
<td>267</td>
<td>10:07</td>
<td>PS/No beam</td>
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<tr>
<td>265</td>
<td>8:34</td>
<td>PSB/No beam</td>
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<tr>
<td>260</td>
<td>4:25</td>
<td>QPS/Hardware</td>
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<tr>
<td>254</td>
<td>4:24</td>
<td>Beam instrumentation/BLM - hardware</td>
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<tr>
<td>263</td>
<td>4:03</td>
<td>RF/Transverse feedback</td>
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</table>

Access – No beam: 13.57%
Machine setup: 27.06%
Beam in: 15.06%
Ramp + squeeze: 8.19%
Stable beams: 36.11%

Why Shutdown?

- Shutdowns are routine:
  - One every year!
- This one is special:
  - Fix damage from 2008 magnet incident
Quenching is Big Deal
The main 2013-14 LHC consolidations

1. 1695 Openings and final reclosures of the interconnections
2. Complete reconstruction of 1500 of these splices
3. Consolidation of the 10170 13kA splices, installing 27000 shunts
4. Installation of 5000 consolidated electrical insulation systems
5. 300 000 electrical resistance measurements
6. 10170 orbital welding of stainless steel lines
7. 18 000 electrical Quality Assurance tests
8. 10170 leak tightness tests
9. 4 quadrupole magnets to be replaced
10. 15 dipole magnets to be replaced
11. Installation of 612 pressure relief devices to bring the total to 1344
12. Consolidation of the 13 kA circuits in the 16 main electrical feedboxes
• Run for 2.5 years at 14 TeV, with full intensity
• Shutdown for 1.5 years, then run another 2.5 years at 2x intensity
Where do we go in Run II and beyond?

• Map the landscape that Run I illuminated
  • Higgs!
  • Measure the Standard Model at 14 TeV

• Venture deeper into the waters of supersymmetry

• Hunt exotica
  • Extra dimensions, new quarks, and many more

• Strike out in new directions
State of Higgs Knowledge

- It has a mass of 125 GeV
- It can decay to photons, W bosons, Z bosons and tau leptons*
  - Still looking for b-quark decays!
- It very likely has spin 0

*not with the statistical certainty of the other measurements
What’s left to Measure?

- Can we see it interact with other particles?
- Does it decay in the probabilities we think it does?
- Does it decay to anything else?
  - Dark Matter?
- Is it the only one?

[Diagram showing percentages for different decay products: b (11%), tau (3%), W (22%), Z (6%), photon (0.2%), other (58%)]
Searching for New Physics

- Extra dimensions of space-time
Gravity in Extra Dimensions

Island Universes in Warped Space-Time

According to string theory, our universe might consist of a three-dimensional “brane,” embedded in higher dimensions. In the model developed by Lisa Randall and Raman Sundrum, gravity is much weaker on our brane than on another brane, separated from us by a fifth dimension. (Time is the unseen fourth dimension.)

Fifth dimension
Space is warped by energy throughout five-dimensional space-time. As a result, gravity is much weaker on our brane.

Gravitions, which transmit gravity, are closed strings, which are not confined to either brane.

Warped space-time
Because space-time is warped, things are exponentially bigger and lighter closer to our brane.

The ends of open strings, whose oscillations are particles and forces other than gravity, are stuck to our brane.
Extra Dimensions at the LHC

- See particles traveling in extra dimensions
- $E = mc^2!$
- $E^2 = m^2c^4 + p^2c^2$
Extra Dimensions at the LHC

- See particles traveling in extra dimensions
- Disappear!
Extra Dimensions at the LHC

- Create Black Holes!
Supersymmetry

- Each particle has a shadow partner
- Makes the Standard Model compatible with general relativity
• Shadow partners are more massive, so we haven’t seen them yet
SUSY at the LHC
Conclusions

- Thanks for a great series!