Uncovering the Universe with the LHC
Uncovering the Universe with the LHC

BIG BANG

NOW

History of the Universe

Key:
- W, Z, bosons
- γ, photon
- q, quark
- g, gauge
- η, electron
- η, electron
- φ, photon
- ν, neutrino
- m, meson
- b, baryon
- β, ion
- α, atom
- η, black hole
quarks

leptons
Uncovering the Universe with the LHC

quarks: $u, c, t, d, s, b$

leptons: $e, \mu, \tau, \nu_e, \nu_\mu, \nu_\tau$

Weak bosons: $W, Z$
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quarks

u c t

d s b

leptons

e μ τ

ν_e ν_μ ν_τ

EM:

bosons

γ

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Quarks: u, c, t, d, s, b
Leptons: e, μ, τ, νₑ, νᵤ, νₜ

Strong: g

Bosons
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Quarks: u, c, t, d, s, b
Leptons: e, μ, τ, νe, νμ, ντ

(and gravity)
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quarks: u, c, t, d, s, b
leptons: e, μ, τ, ν_e, ν_μ, ν_τ

Mass: H, Higgs
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\[ L = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \text{i} F^\mu_{\nu\lambda} D^\lambda \phi + h.c. \\
+ \lambda \left( y_{ij} x_i x_j \phi + h.c. \right) \\
+ \lambda \partial^2 \phi - V(\phi) \]
nice ...

BUT
(0) is the Higgs .... really the Higgs?
Big Bang: equal amounts of matter and antimatter created

Now: we (matter) exist

Why?
(2) and the other 96%?
Many questions....

What is mass?

What about gravity?

How many dimensions?

4 forces?

12 matter particles?

Mini black holes?

What about the other 96% of the universe .....
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QUARKS

- **up** (mass ≈ 2.3 MeV/c², charge 2/3, spin 1/2)
- **charm** (mass ≈ 1.275 GeV/c², charge 2/3, spin 1/2)
- **down** (mass ≈ 4.8 MeV/c², charge -1/3, spin 1/2)
- **strange** (mass ≈ 95 MeV/c², charge -1/3, spin 1/2)
- **bottom** (mass ≈ 4.18 GeV/c², charge -1/3, spin 1/2)

GAUGE BOSONS

- **electron** (mass 0.511 MeV/c², charge -1, spin 1/2)
- **muon** (mass 105.7 MeV/c², charge -1, spin 1/2)
- **tau** (mass 1.777 GeV/c², charge -1, spin 1/2)
- **Z boson** (mass 91.2 GeV/c²)
- **W boson** (mass 80.4 GeV/c²)

LEPTONS

- **electron neutrino** (mass < 2.2 eV/c², charge 0, spin 1/2)
- **muon neutrino** (mass < 0.17 MeV/c², charge 0, spin 1/2)
- **neutrino** (mass 0, charge 0, spin 1/2)

Gluon (mass 0, charge 0, spin 1/2)


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European Laboratory for Particle Physics

Founded in 1954

20 member countries

More than 9,000 scientists

Over 100 nationalities
1991 - 2000

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LHC:
2 beams of protons collide 40 million x a second at near light speed 100m underground

Recreating conditions when universe was a billionth of a second old ……
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Higgs?
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ATLAS Preliminary

H → ZZ(∗) → 4l channel

\( \sqrt{s} = 7 \text{ TeV} \int Ldt = 0.05 \text{ fb}^{-1} \)  
Apr 24, 2011
A Higgs? The Higgs?

\~1,000 papers / year.
Antimatter - CERN: LHCb
1 number

Measure of matter / antimatter difference
And beyond the Standard Model?

... supersymmetry....
..dark matter?
### ATLAS SUSY Searches* - 95% CL Lower Limits

**Status:** Feb 2015

<table>
<thead>
<tr>
<th>Model</th>
<th>$e, \mu, \tau, \gamma$ Jets</th>
<th>$E_{T}^{miss}$</th>
<th>[F dL/df (fb)]</th>
<th>Mass limit</th>
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<td>2-6 jets</td>
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<td>$q\bar{q}, q\bar{q}t\bar{t}$</td>
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<td>2-6 jets</td>
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<td>2-6 jets</td>
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</tr>
<tr>
<td>$S \bar{S}, S \bar{S} \rightarrow q\bar{q}t\bar{t}$</td>
<td>1 $\gamma$</td>
<td>0-1 jet</td>
<td>Yes</td>
<td>20.3</td>
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<tr>
<td>GMSB (S NLSP)</td>
<td>1 $\gamma$</td>
<td>0-2 jets</td>
<td>Yes</td>
<td>20.3</td>
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<tr>
<td>GMSB (S NLSP)</td>
<td>2 $\gamma$</td>
<td>0-2 jets</td>
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<td>GMSB (S NLSP)</td>
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<td>0-3 jets</td>
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<td>Gravitino LSP</td>
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<td>3 $b$</td>
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<td>7-10 jets</td>
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<tr>
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<td>3 $b$</td>
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<td>20.3</td>
</tr>
<tr>
<td>$\tilde{g} \rightarrow b\bar{b}$</td>
<td>1 $\gamma$</td>
<td>3 $b$</td>
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<tr>
<td>$\tilde{b}_1, \tilde{b}_1 \rightarrow b\bar{b}$</td>
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<td>2 $b$</td>
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<tr>
<td>$\tilde{b}_1, \tilde{b}_1 \rightarrow b\bar{b}$</td>
<td>2 $\gamma$</td>
<td>0-2 jets</td>
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<tr>
<td>$\tilde{g} \rightarrow b\bar{b} \tilde{g}$</td>
<td>0-1 $\gamma$</td>
<td>1 $b$</td>
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<td>1 $b$</td>
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<td>$\tilde{g} \rightarrow b\bar{b} \tilde{g}$</td>
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<td>1 $b$</td>
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<tr>
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<tr>
<td>$\tilde{g} \rightarrow b\bar{b} \tilde{g}$</td>
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<td>1 $b$</td>
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<tr>
<td>$\tilde{g} \rightarrow b\bar{b} \tilde{g}$</td>
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<td>1 $b$</td>
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<td>$\tilde{t}_1, \tilde{t}_1 \rightarrow \tau\bar{\tau} \tilde{e}$</td>
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<td>2 $\gamma$</td>
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<tr>
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<td>2 $\gamma$</td>
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<td>$\tilde{t}_1, \tilde{t}_1 \rightarrow H \tilde{g}$</td>
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<td>2 $\gamma$</td>
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<tr>
<td>$\tilde{t}_1, \tilde{t}_1 \rightarrow W^+W^- \tilde{g}$</td>
<td>2-3 $\gamma$</td>
<td>0-2 jets</td>
<td>Yes</td>
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</tr>
<tr>
<td>$\tilde{t}_1, \tilde{t}_1 \rightarrow \tau\bar{\tau} \tilde{g}$</td>
<td>3 $\gamma$</td>
<td>0-2 jets</td>
<td>Yes</td>
<td>20.3</td>
</tr>
<tr>
<td>$\tilde{t}_1, \tilde{t}_1 \rightarrow \tau\bar{\tau} \tilde{g}$</td>
<td>4 $\gamma$</td>
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<td>20.3</td>
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<tr>
<td>Direct $\tilde{t}_1 \tilde{t}_1$ prod., long-lived $\tilde{t}_1$</td>
<td>Disapp. trk.</td>
<td>1 jet</td>
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<td>Stable $\tilde{R}$ hadron</td>
<td>0-1-5 jets</td>
<td>Yes</td>
<td>27.9</td>
<td></td>
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<tr>
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<td>trk.</td>
<td>-</td>
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<td>19.1</td>
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<tr>
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<td>0-1-5 jets</td>
<td>Yes</td>
<td>27.9</td>
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<tr>
<td>Stable $\tilde{g}$ hadron</td>
<td>trk.</td>
<td>-</td>
<td>Yes</td>
<td>19.1</td>
</tr>
<tr>
<td>Stable $\tilde{g}$ hadron</td>
<td>0-1-5 jets</td>
<td>Yes</td>
<td>27.9</td>
<td></td>
</tr>
<tr>
<td>LPV $pp+p+X, \gamma+e+\mu+\tau$</td>
<td>2 $\gamma$</td>
<td>0 $\gamma$</td>
<td>Yes</td>
<td>20.3</td>
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<tr>
<td>LPV $pp+p+X, \gamma+e+\mu+\tau$</td>
<td>3-4 $\gamma$</td>
<td>0 $\gamma$</td>
<td>Yes</td>
<td>20.3</td>
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<tr>
<td>LPV $pp+p+X, \gamma+e+\mu+\tau$</td>
<td>5-6 $\gamma$</td>
<td>0 $\gamma$</td>
<td>Yes</td>
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<td>LPV $pp+p+X, \gamma+e+\mu+\tau$</td>
<td>7-8 $\gamma$</td>
<td>0 $\gamma$</td>
<td>Yes</td>
<td>20.3</td>
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<tr>
<td>LPV $pp+p+X, \gamma+e+\mu+\tau$</td>
<td>9-10 $\gamma$</td>
<td>0 $\gamma$</td>
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<td>20.3</td>
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<tr>
<td>LPV $pp+p+X, \gamma+e+\mu+\tau$</td>
<td>11-12 $\gamma$</td>
<td>0 $\gamma$</td>
<td>Yes</td>
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<tr>
<td>Long-lived particles</td>
<td>2 $\gamma$</td>
<td>0-1-5 jets</td>
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<tr>
<td>Other</td>
<td>0 $\gamma$</td>
<td>2 $\gamma$</td>
<td>Yes</td>
<td>20.3</td>
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</table>

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Uncovering the Universe with the LHC

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LHC results put supersymmetry theory 'on the spot'

By Pallab Ghosh  
Science correspondent, BBC News

Results from the Large Hadron Collider (LHC) have all but killed the simplest version of an enticing theory of sub-atomic physics.

Researchers failed to find evidence of so-called "supersymmetric" particles, which many physicists had hoped would plug holes in the current theory.

Theorists working in the field have told BBC News that they may have to come up with a completely new idea.
And **beyond** SUSY?

... still looking....
One year on from the Higgs boson find, has physics hit the buffers?

Despite the success of the Large Hadron Collider, evidence for the follow-up theory - supersymmetry - has proved elusive.
Now what?
2015

Upgrade
Maintenance
Run 2: Energy increase
Run 2: Dataset increase

Uncovering the Universe with the LHC
# LHC Schedule 2015

Approved by the Research Board, December 2014

## January 2015

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<tr>
<th>Wk</th>
<th>Mo</th>
<th>Tu</th>
<th>We</th>
<th>Th</th>
<th>Fr</th>
<th>Sa</th>
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<td>9</td>
<td>16</td>
<td>23</td>
<td>2</td>
<td>9</td>
</tr>
</tbody>
</table>

- **January 28, 2015**
- **V1.1**

- **Controls maintenance**

## February 2015

- **Powering tests**

## March 2015

- **Sector test 23 78-67**
- **Sector test backup**
- **Machine checkout**

## April 2015

- **Easter Mon**
- **Recommissioning with beam**
- **G. Friday**

## May 2015

- **Ascension**
- **1st May**

## June 2015

- **TS1**
- **Intensity ramp-up with 50 ns beam**

- **Scrubbing for 50 ns operation**
- **Whit**
- **Special session**
What will we find?

.......... wait and see ..........
Reflections:

• Pick something you are interested in! Then you can’t go wrong.
Reflections:

- Don’t obsess (needlessly).
- Learn to be (self-) critical, so you can rely on your judgement.
Reflections:

• Don’t obsess (needlessly).

• Be realistic.

• Try new things, new avenues, when you have a chance. That way, you learn.
Reflections:

- Don’t obsess (needlessly).
- Be realistic.
- Be creative.
- Careers only look logical in retrospect...
Reflections:

• Don’t obsess (needlessly).
• Be realistic.
• Be creative.
• Be brave.

Good luck!!