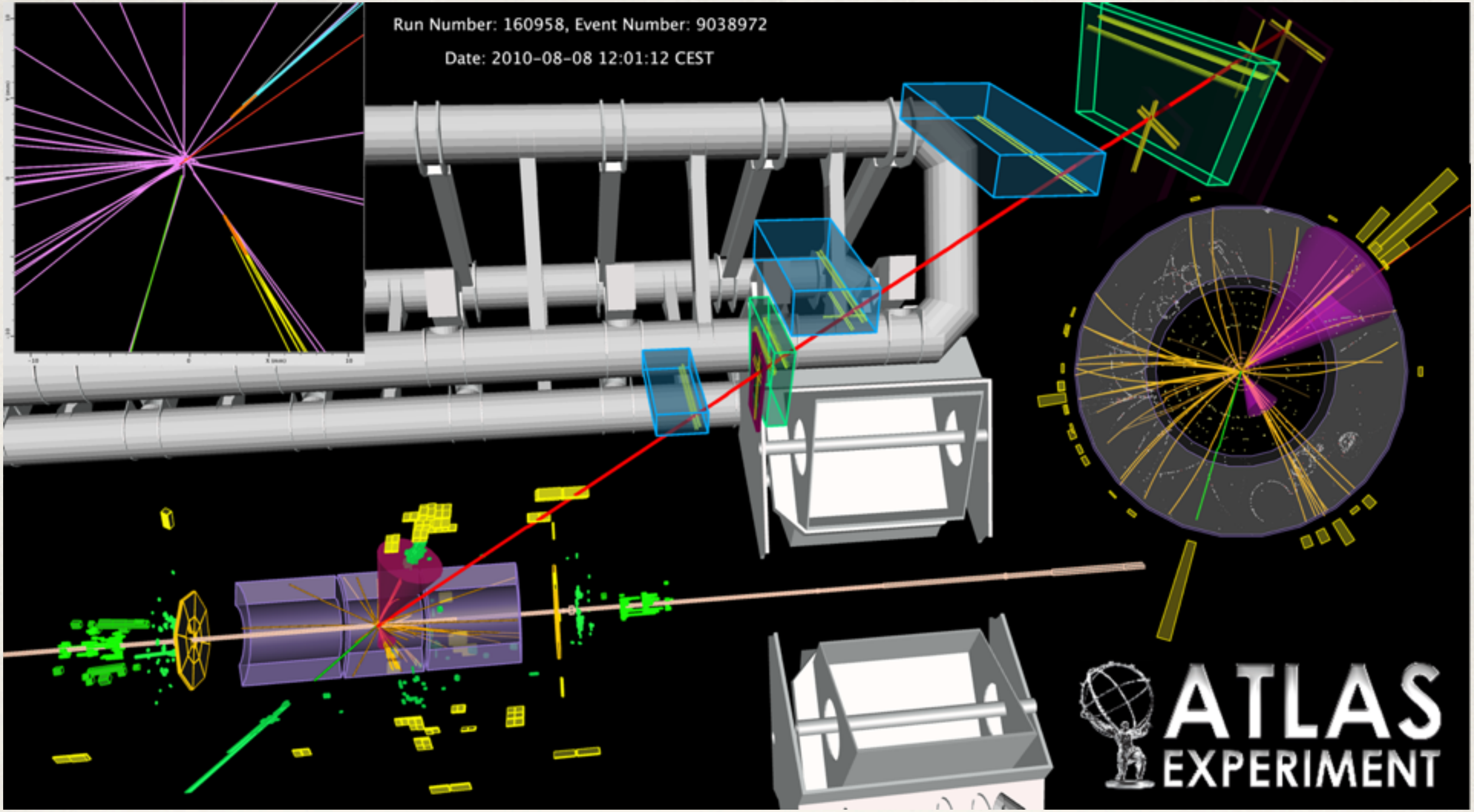


The Physics of the LHC

Maximilian Swiatlowski

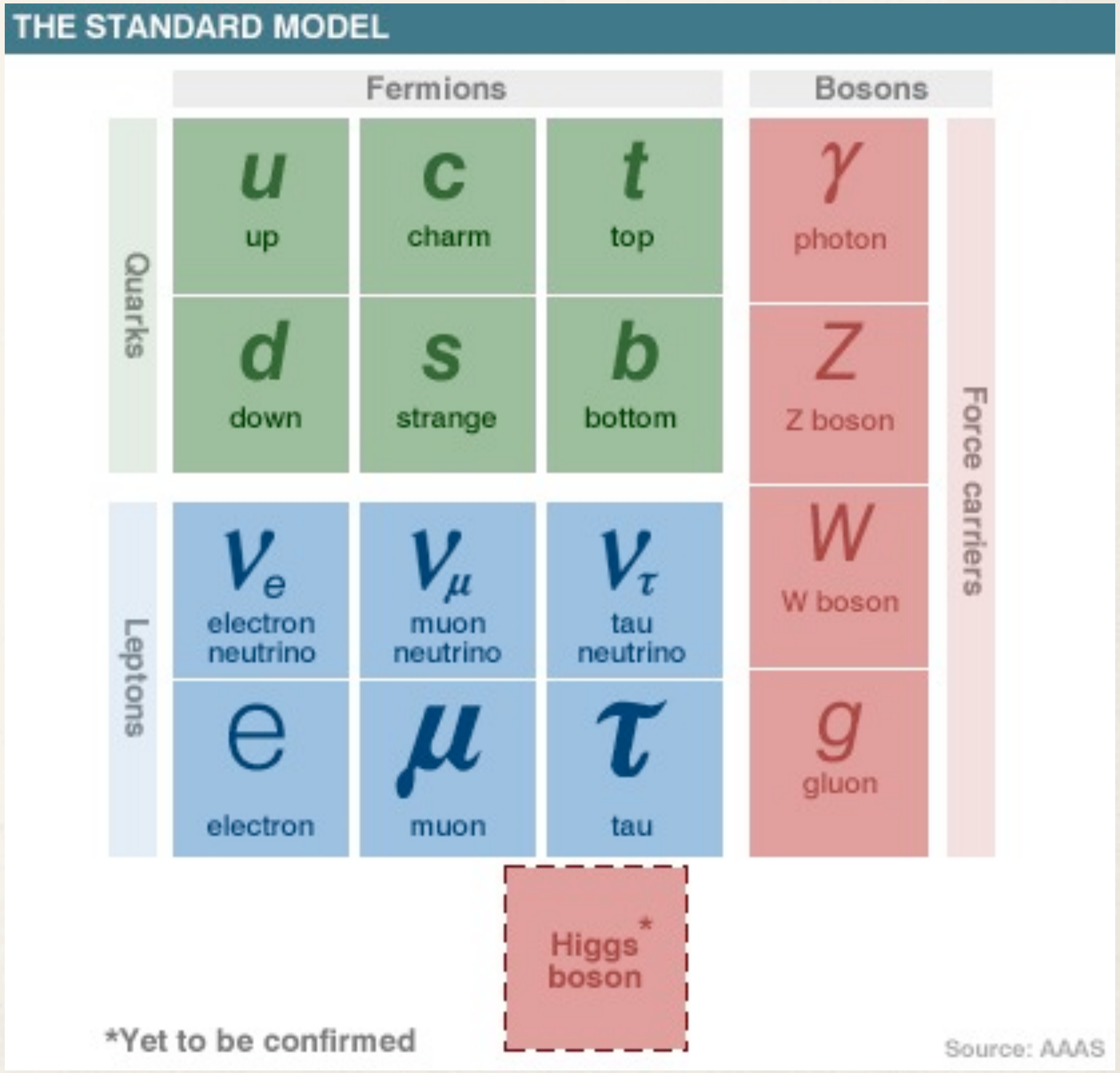
SPLASH Spring 2011, April 17

What are we doing here today?

- Our goal: to understand the basic ideas behind particle colliders:
  - Why do we build them?
  - How do they tell us about the universe?

What are we doing here today?

- Four main topics today
  - Particle physics so far: the Standard Model
  - What's wrong with the Standard Model?
  - How do you build an accelerator?
  - How do you understand the data?



The Standard Model

What does the Standard Model Say?

- The SM is a quantum field theory
    - Quantum Mechanics (really small!) + Special Relativity (really fast!)
- Incredibly, incredibly successful
    - Accurate to 13 digits in some calculations!
- What kind of universe does it describe?

Matter: what are we made of?

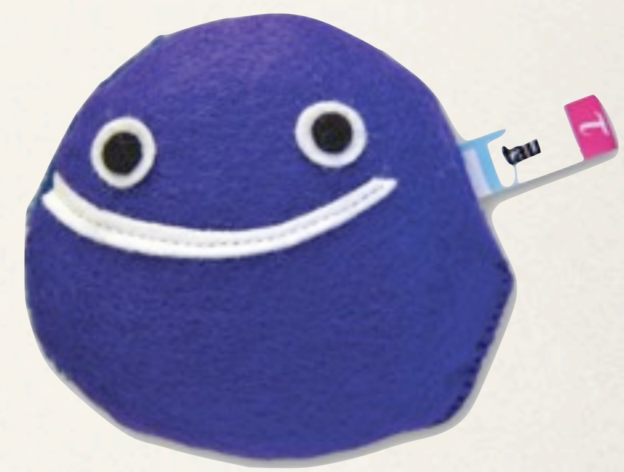
- Two main categories of matter: leptons and quarks
  - Protons and neutrons are made of quarks
  - Electrons are leptons

Leptons

ELECTRON

MUON

TAU



ELECTRON-NEUTRINO

MUON-NEUTRINO

TAU-NEUTRINO

Images courtesy particlezoo.net

Quarks

UP QUARK

CHARM QUARK

TOP QUARK

DOWN QUARK

STRANGE QUARK

BOTTOM QUARK

Forces: what moves us?

- Force particles go between particles and make things happen
- A photon from the light bounces off the projector screen, hits your eye
    - Your eye senses the photon: vision happens!
- All interactions between matter involve **forces**

Forces

Weak Nuclear Force

Strong Force

EM Force

Who's missing?

Things to remember!

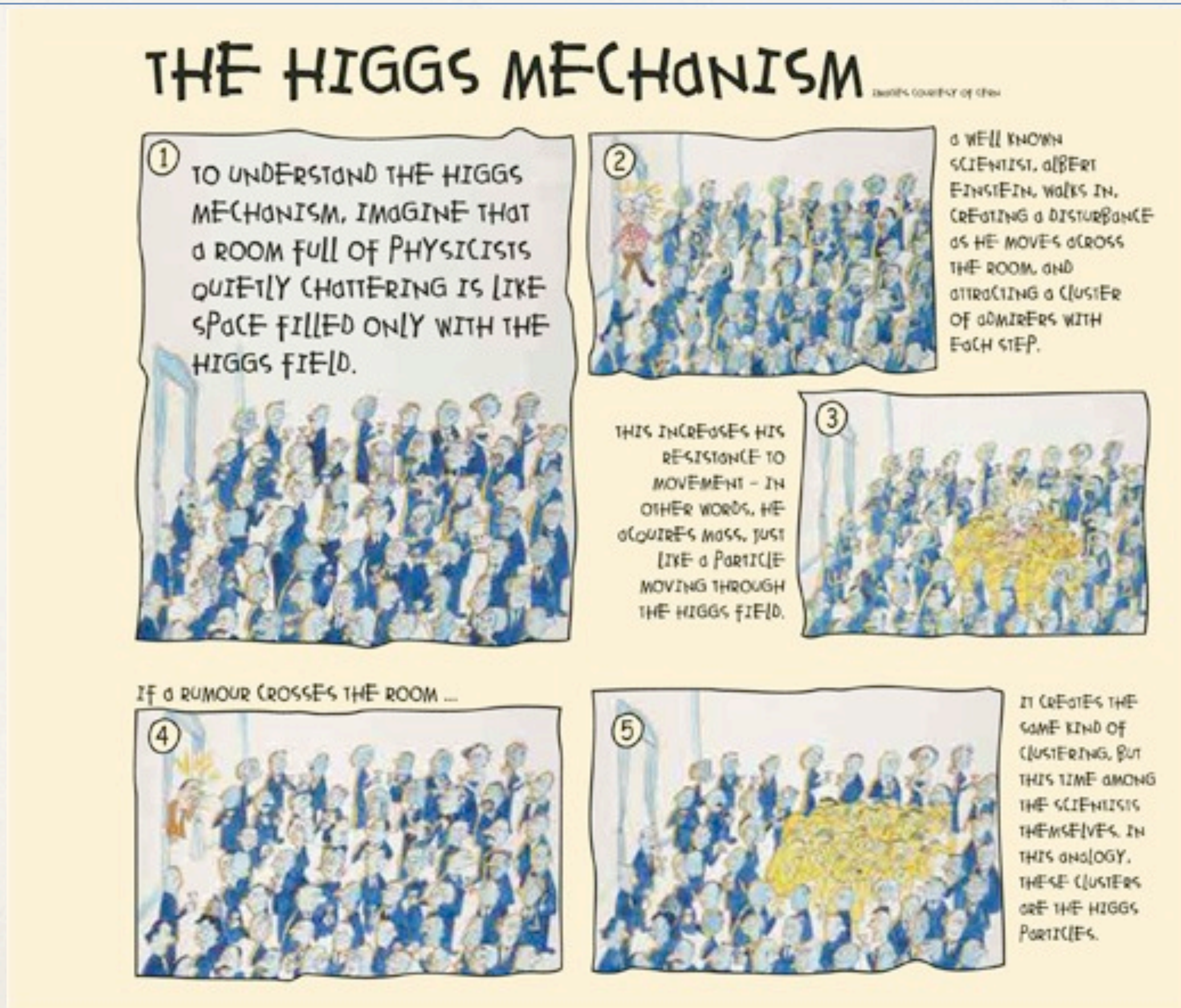
- Particles have **masses** and **lifetimes**
- Six types of leptons, six types of quarks, plus antimatter
- Force particles let matter **interact**
  - Strong force is the strongest! Then EM, then Weak

What’s wrong with this?

Where do we start...

- Lots of problems with the Standard Model, even if it's so accurate!
- For us, three main issues:
  - Where's the Higgs Boson?
  - What is Dark Matter?
  - Where is gravity?

The Higgs Boson



The Higgs Boson

- The Higgs Boson gives mass to all particles
  - Except the unpopular particles (like the photon or the gluon) that don't gather a lot of attention
- Without the Higgs Boson, everything in the Standard Model should be massless! So it has to exist...
  - Or does it?

Dark Matter

- Astrophysicists tell us we can’t see 75% of the matter in the universe
    - They “see” it with gravity: how gravity bends light, spins galaxies

Dark Matter

- If dark matter exists, it should be a particle!
  - But nothing in the Standard Model fits...

Where's Gravity?

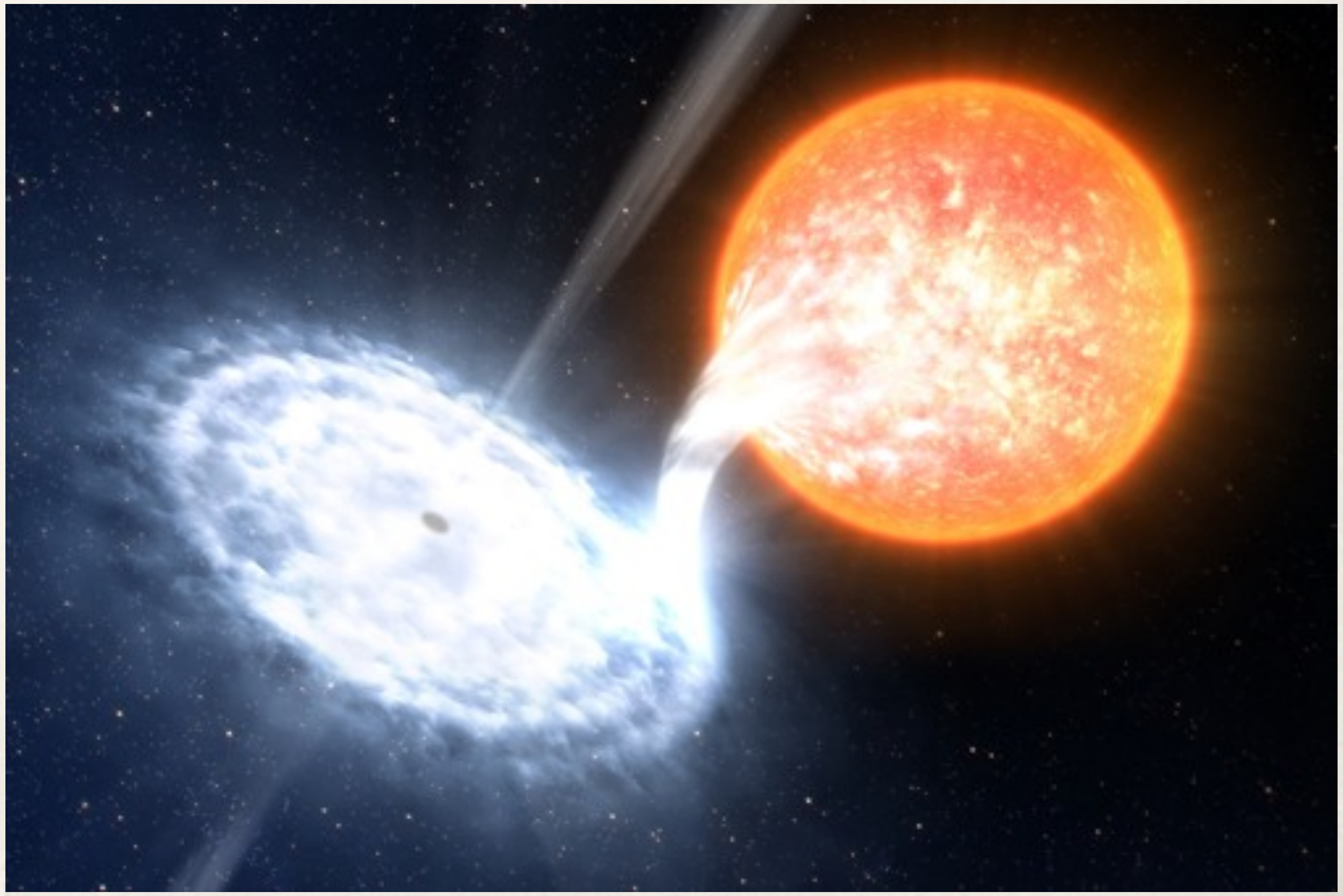
- Why isn't gravity included in the forces of the Standard Model?
  - So much weaker: but why is that? Feels strong to us...
- One possible answer: gravity works in extra dimensions!
  - It has to run further-- through 6 dimensions-- and the rest of the forces only have to go through 3, so it seems slower

Extra Dimensions and Black Holes

- Is a Black Hole created at the LHC going to destroy the world?
- Extra dimensions mean that gravity is stronger when things get realllllly close together: things might get close enough to form a black hole!
  - Should we be worried?

Extra Dimensions and Black Holes

- Cosmic rays (higher energy than the LHC!) hit the sun all of the time!
  - Why does this mean that we're safe?



Extra Dimensions and Black Holes

- Answer: if the LHC can make a black hole, so can the cosmic rays-- but the sun is still here!
  - And so are all the stars in the sky-- that means we must be safe
  - Small black holes probably evaporate through **Hawking Radiation**

Things to remember!

- Where's the Higgs Boson?
- What is Dark Matter?
- Why is gravity so weak?
- … and more and more…

HIGGS BOSON

DARK MATTER

GRAVITON

How do we study this?

How do we study this?

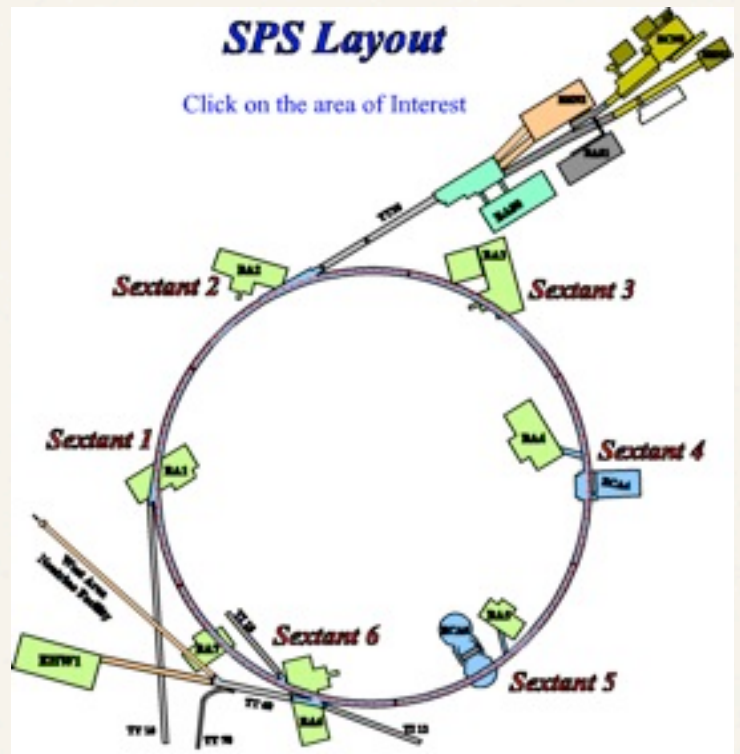
- How do we build accelerators?
- How do we build detectors?

Accelerator Outline

Hydrogen

v = 0.000000…9 %
speed of light

+



Boosters
(smaller accelerators)

v = 99.9995 %
speed of light

+

The LHC!

v = 99.9999999 %
speed of light

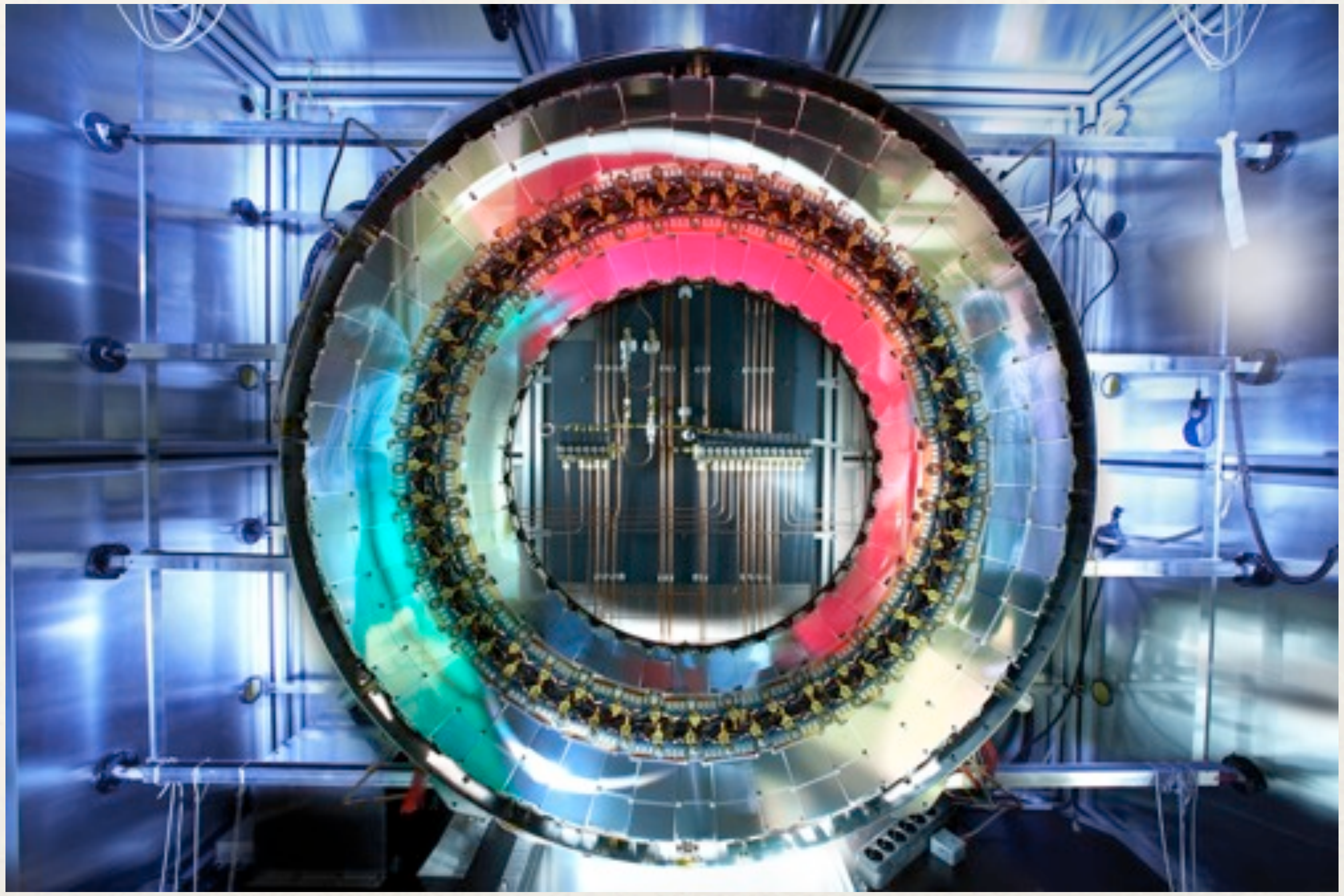
Detecting Particles

- How do you detect a particle?
- Close your eyes: say I throw a lot of tennis balls at you
  - How do you detect them?
  - You feel the collisions: they hit you!
- Same thing in detectors: look for where the particle 'hits' stuff as it passes!

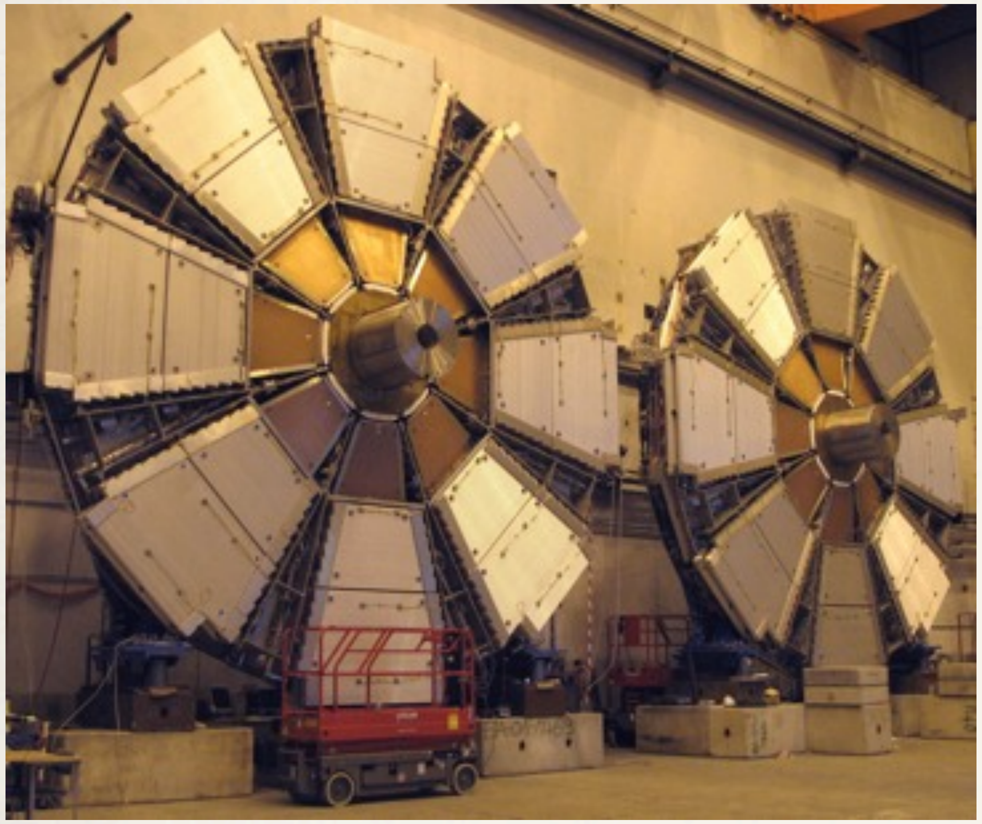
Detecting Particles

- Look for **ionization:** bumping an atom so hard it knocks out an electron
  - See those electrons, and you know something passed through!

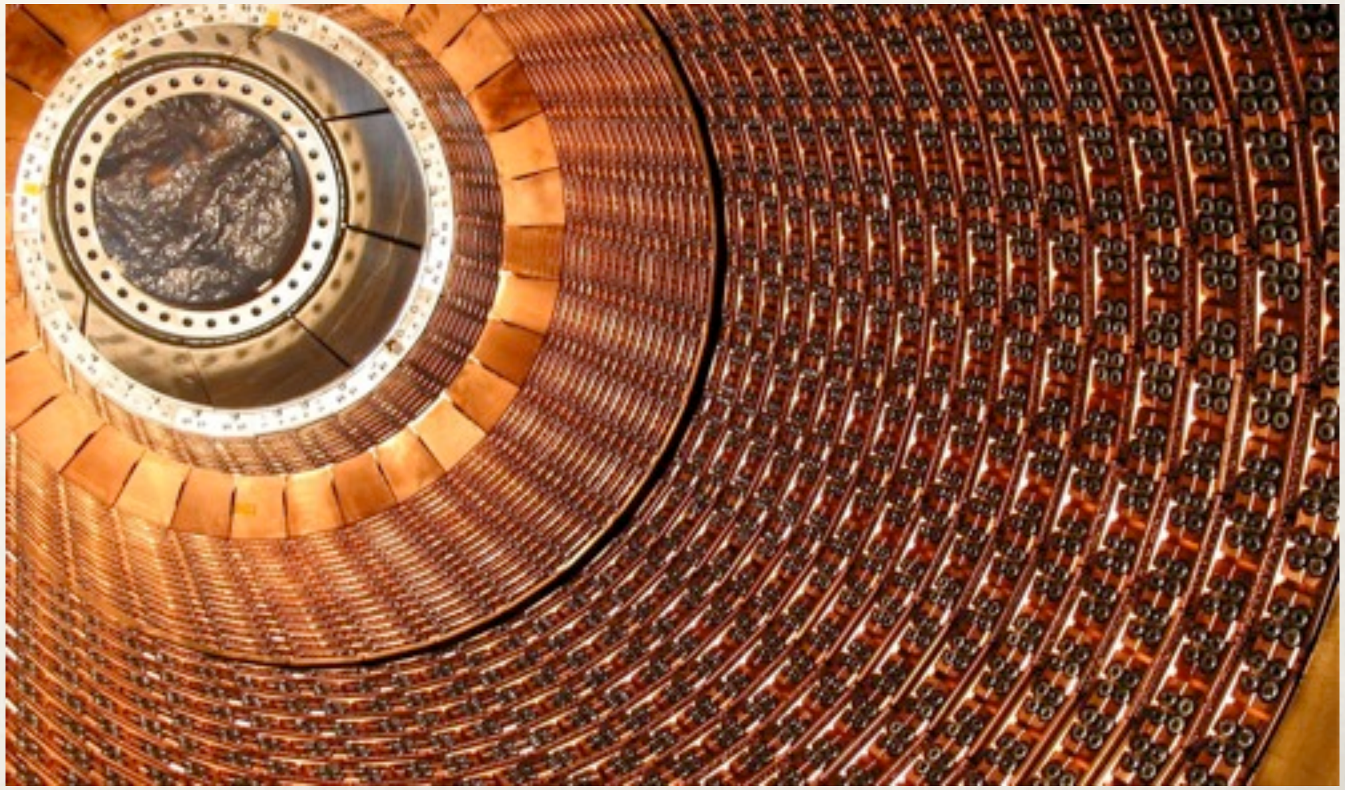
ATLAS Silicon Control Tracker: Looks for ionization in silicon computer chips



Detecting Particles



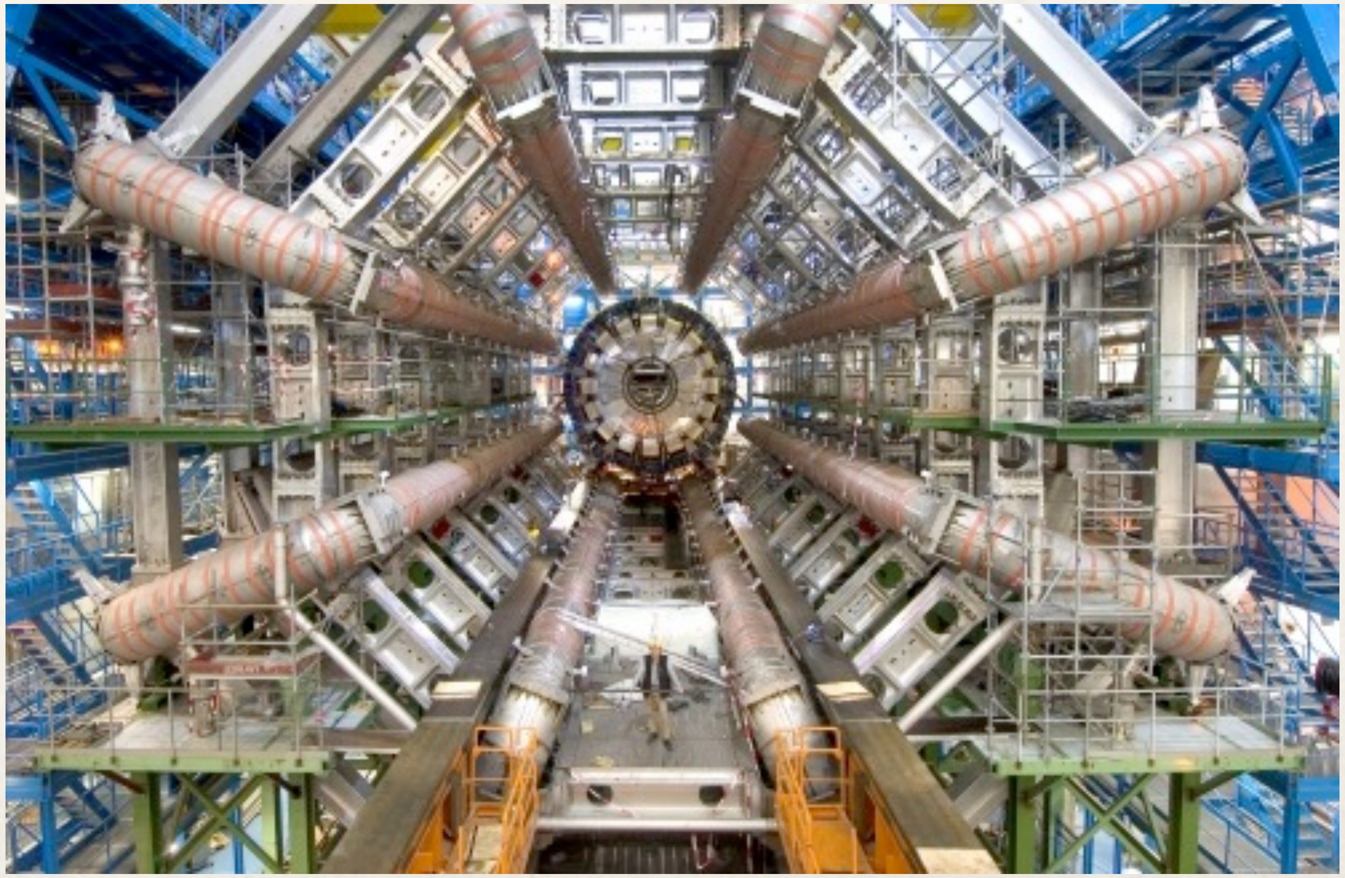
ATLAS Muon Drift Tube: Gas tubes that look for ionization!



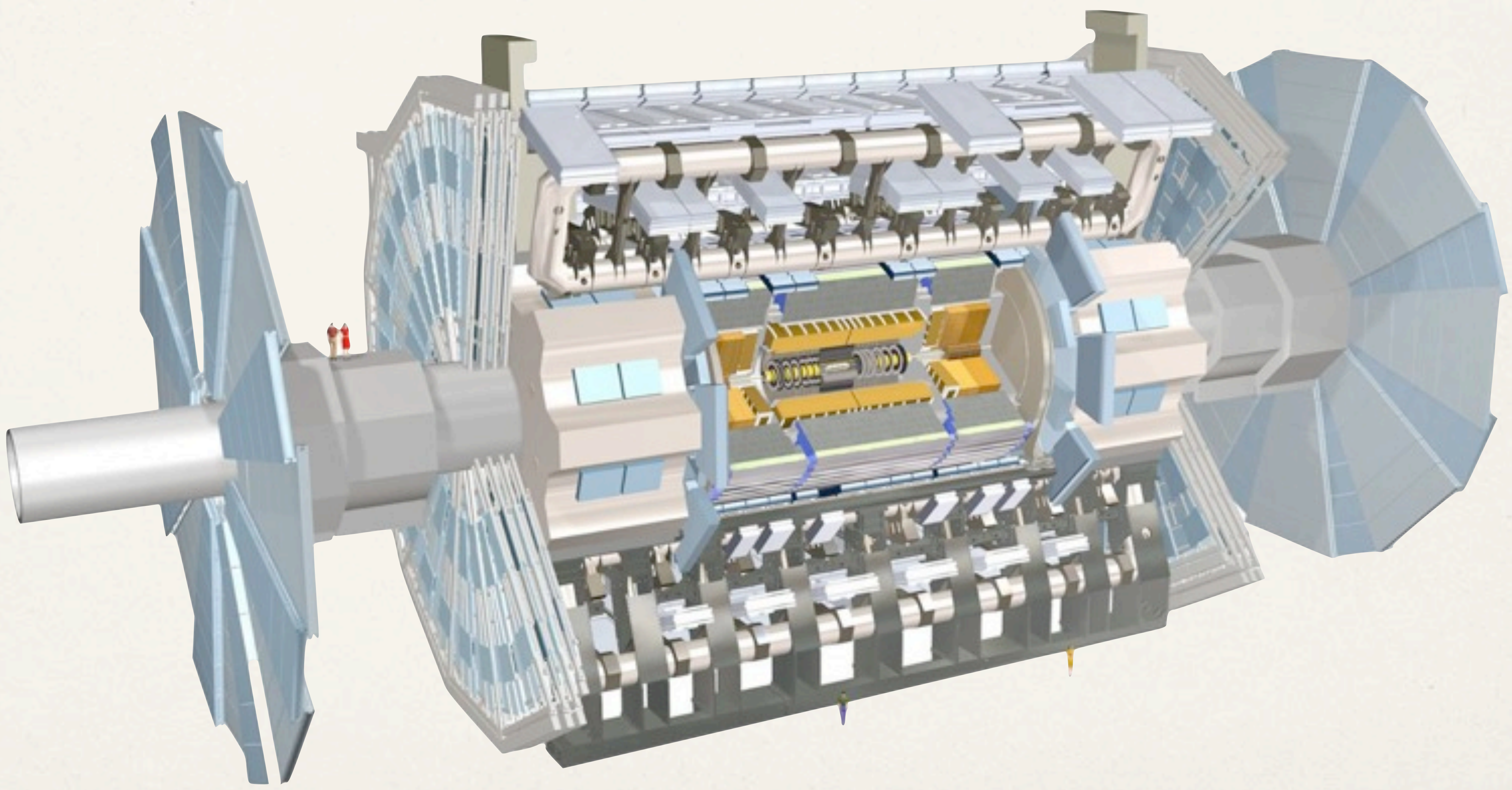
ATLAS Liquid Argon Calorimeter: Looks for ionization (and light caused by ionization) in liquid!

Detecting Particles

- Detecting charge: ionization doesn't tell you *what* charge hit
- How can we tell the difference between + and -?
  - Magnets: huge magnets bend charged particles in opposite directions



Putting it all together...

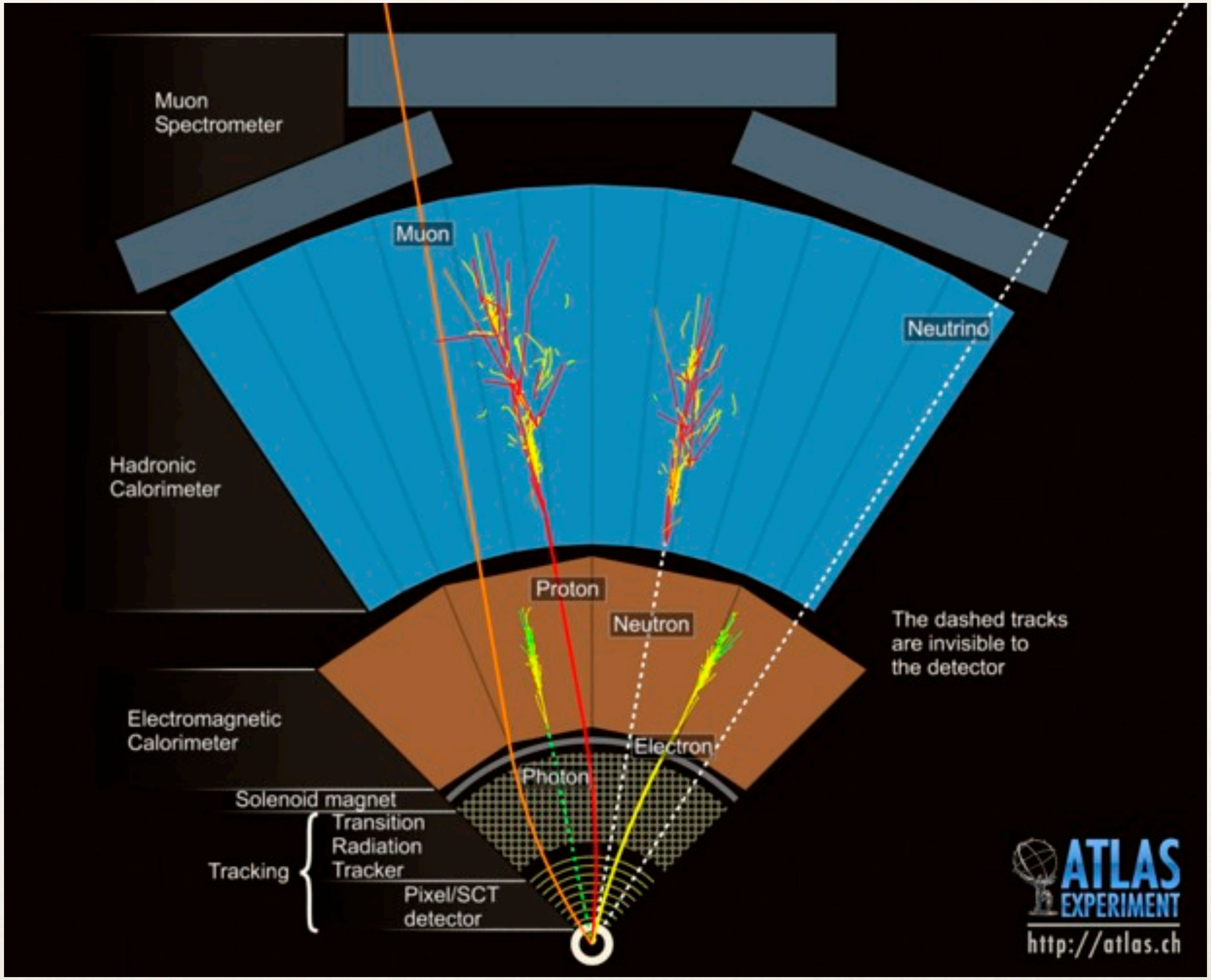


Going inside out...

- Inner Detector measures charged particles very accurately
- Electromagnetic calorimeter measures photons and electrons
- Hadronic calorimeter measures (and stops) everything else
- Muon chambers measure... muons

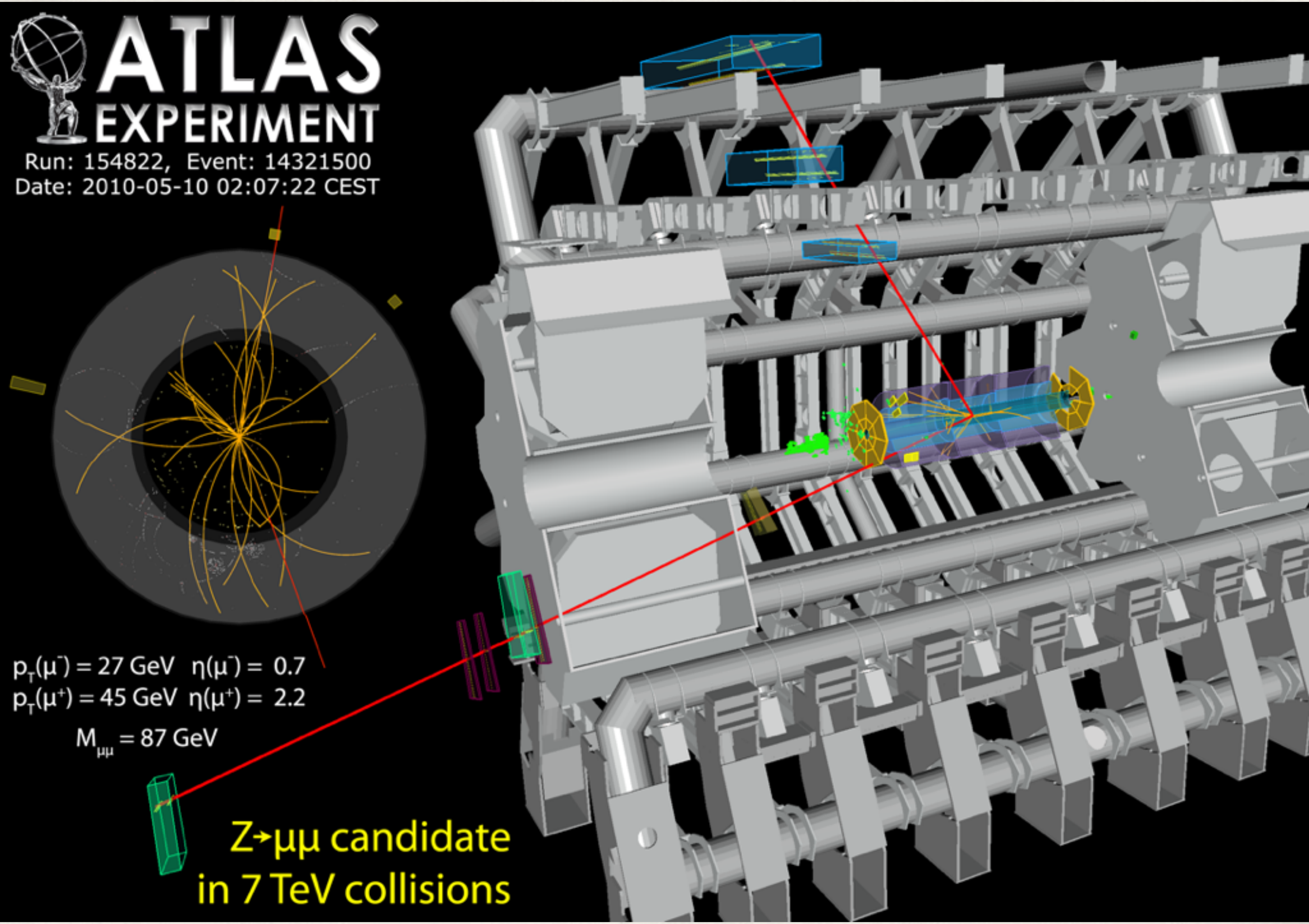
How do you understand the data?

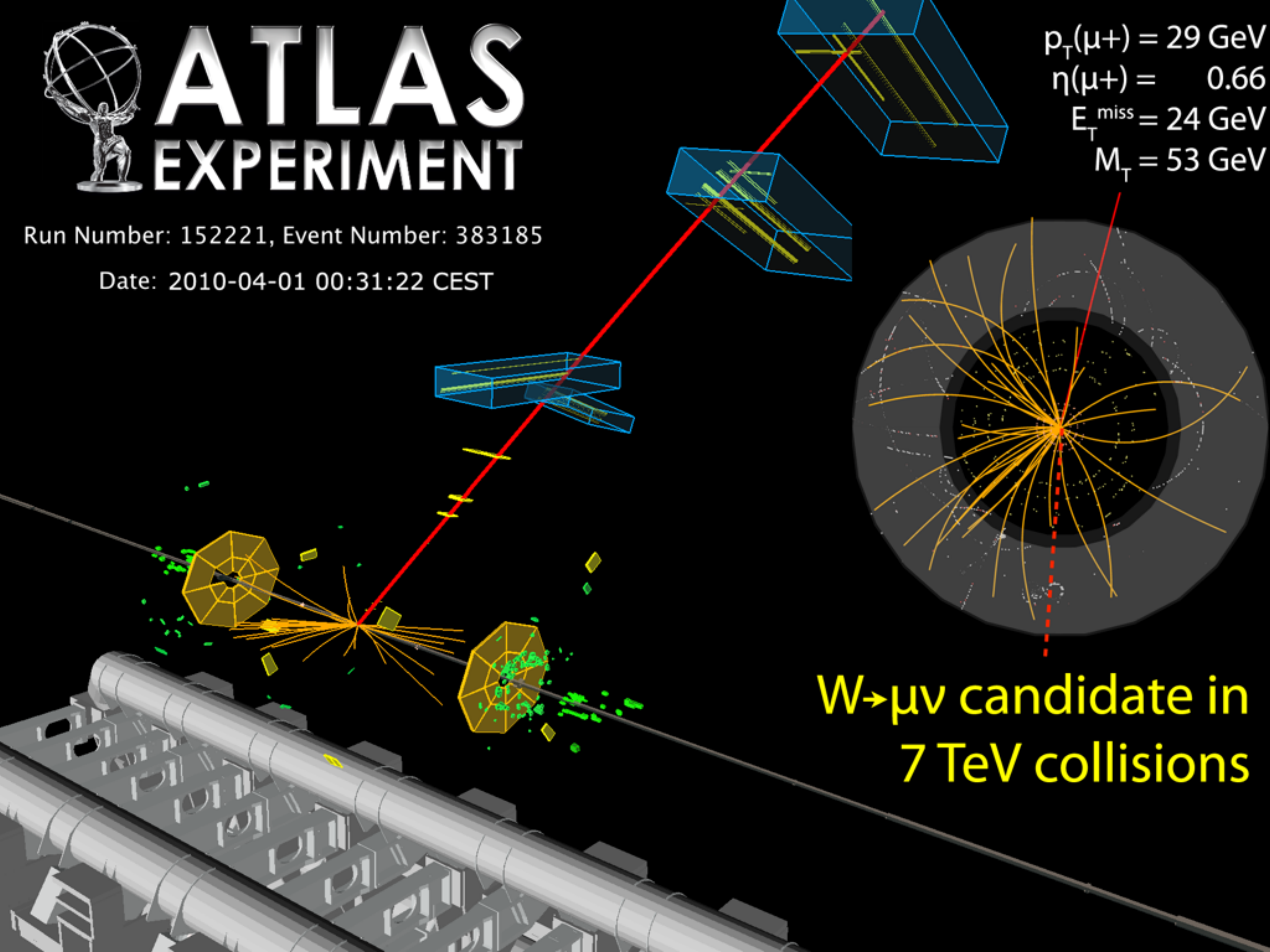
What is the detector telling us?

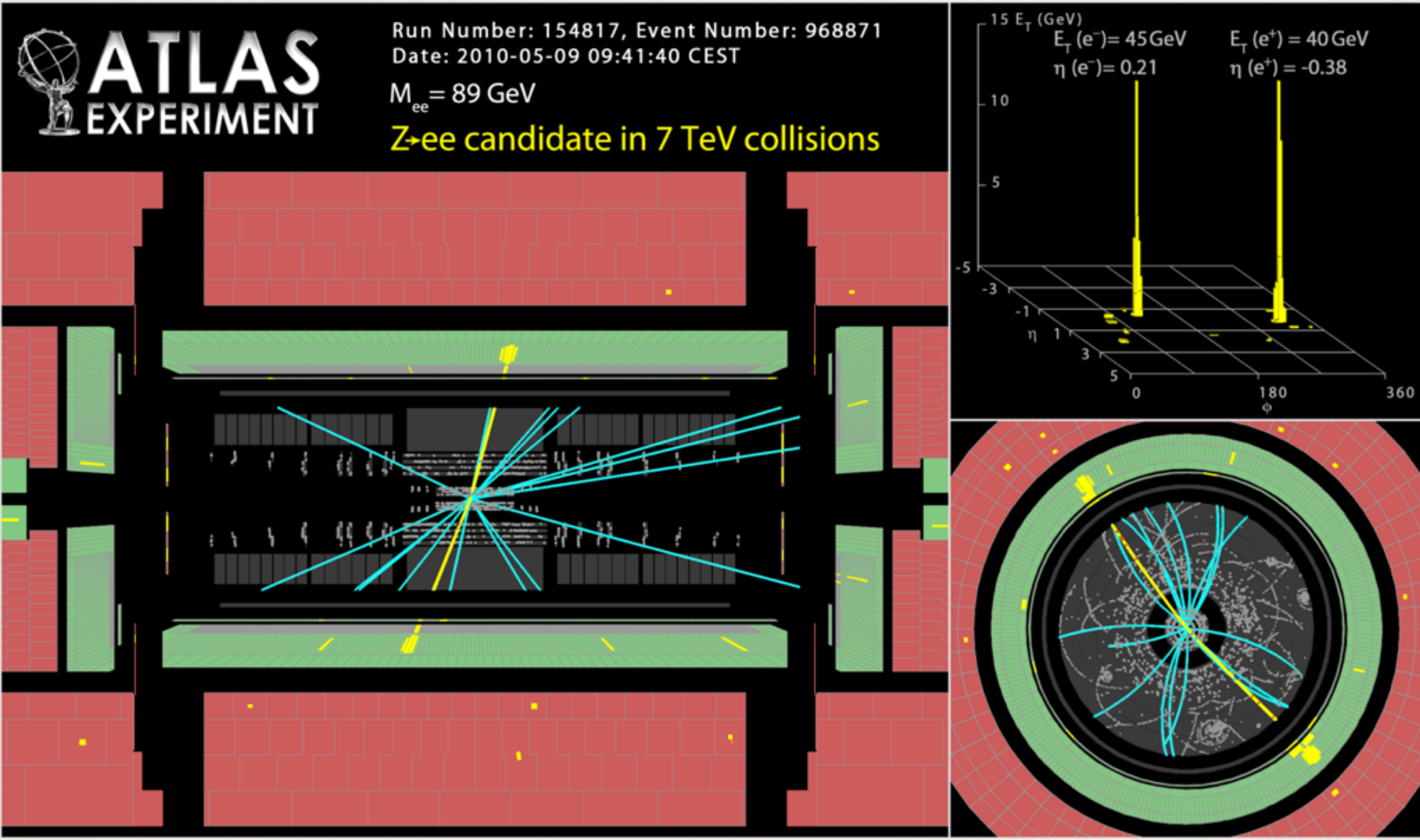


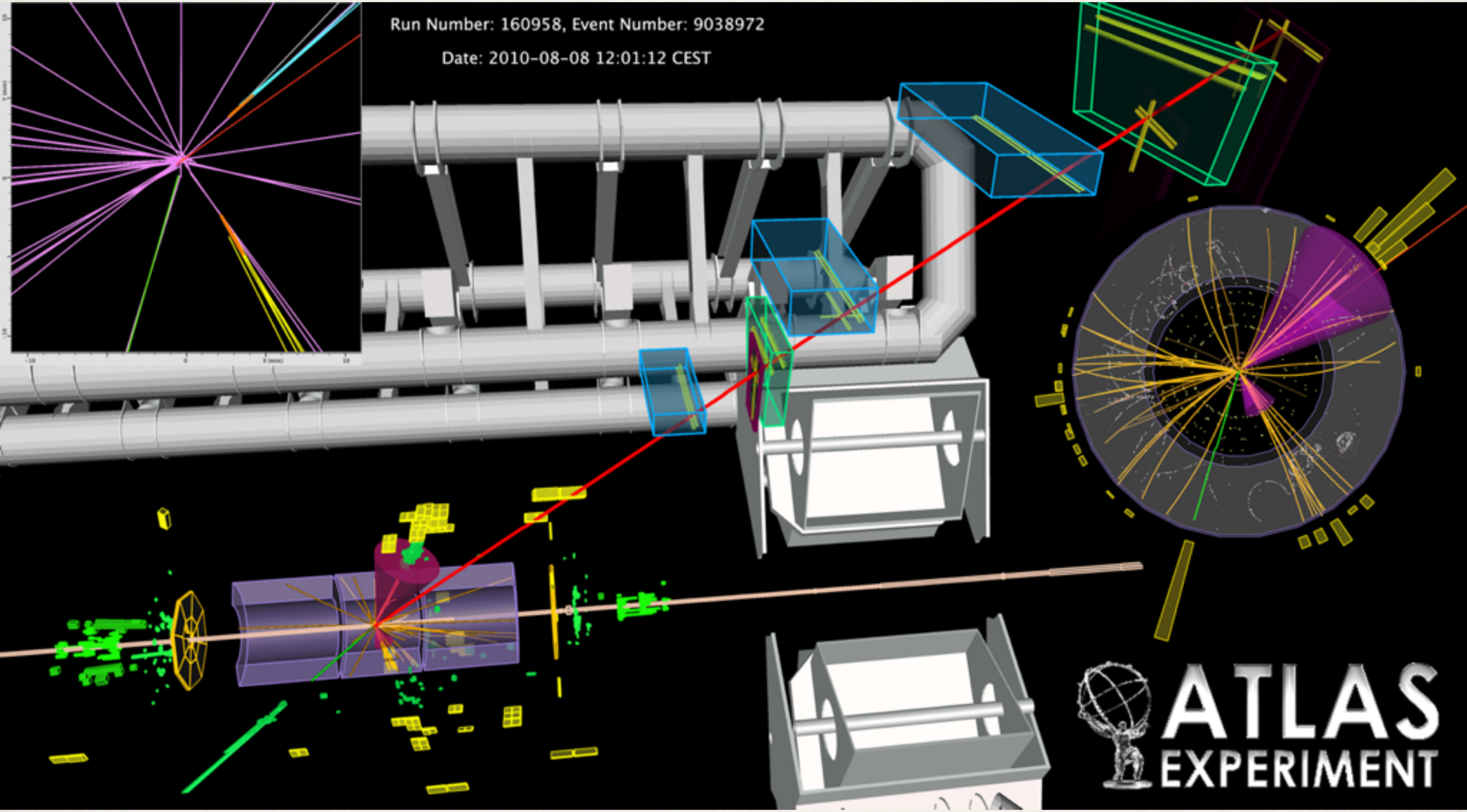
Looking at real event displays!

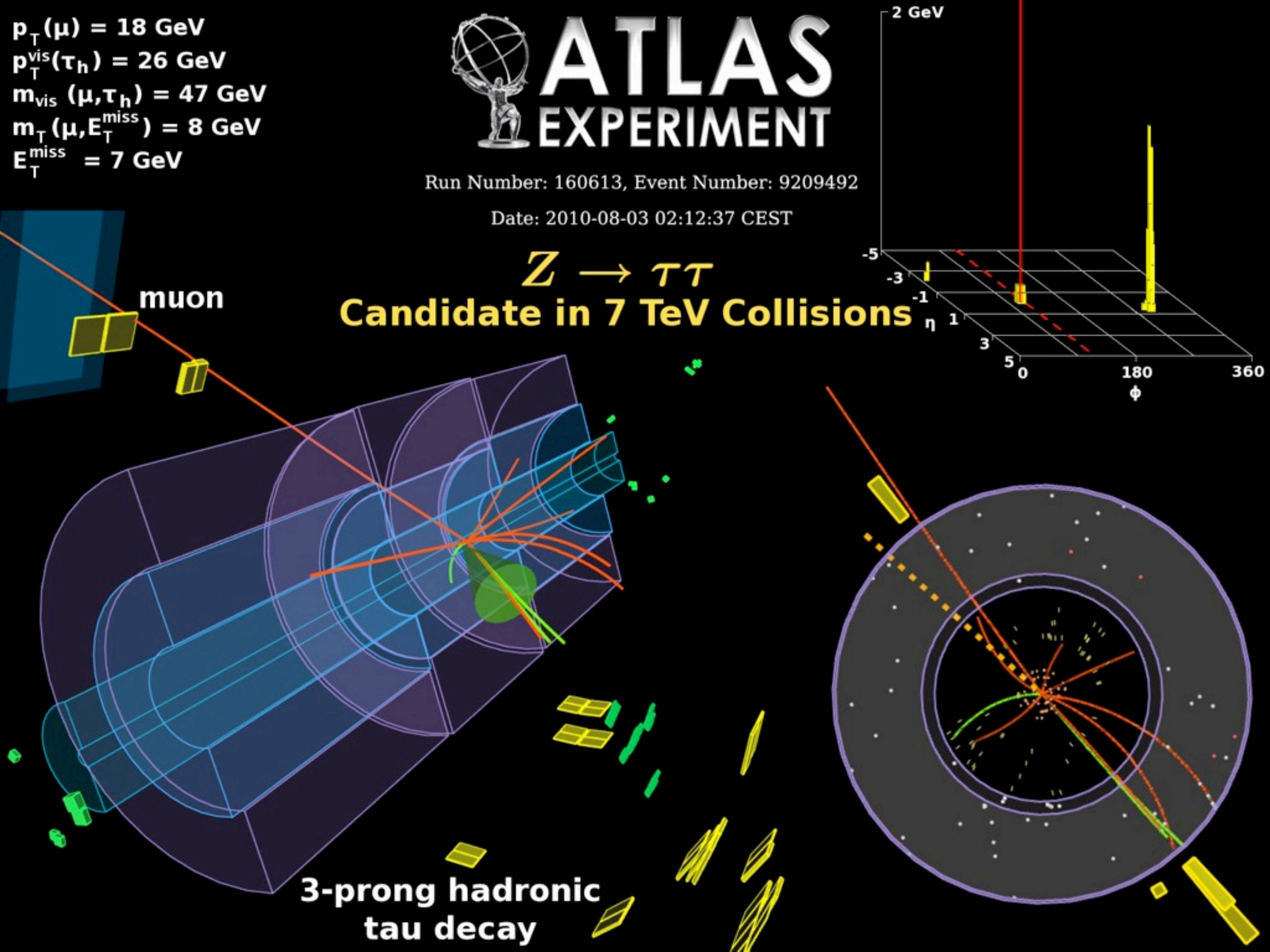
- Remember: it's all the same as the cut-out on the previous slide
- Just... a lot more stuff going on at the same time!


ATLAS EXPERIMENT
Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST
$p_T(\mu^-) = 27$ GeV $\eta(\mu^-) = 0.7$
$p_T(\mu^+) = 45$ GeV $\eta(\mu^+) = 2.2$
$M_{\mu\mu} = 87$ GeV
Z→μμ candidate
in 7 TeV collisions


ATLAS EXPERIMENT
Run Number: 152221, Event Number: 383185
Date: 2010-04-01 00:31:22 CEST
$p_T(\mu+) = 29$ GeV
$\eta(\mu+) = 0.66$
$E_T^{miss} = 24$ GeV
$M_T = 53$ GeV
W→μν candidate in
7 TeV collisions


ATLAS
EXPERIMENT
Run Number: 154817, Event Number: 968871
Date: 2010-05-09 09:41:40 CEST
M_ee = 89 GeV
Z→ee candidate in 7 TeV collisions
15 E_T (GeV)
E_T (e⁻)= 45GeV
η (e⁻)= 0.21
E_T (e⁺) = 40GeV
η (e⁺) = -0.38
10
5
-5
-3
-1
η
1
3
5
0
180
360
φ

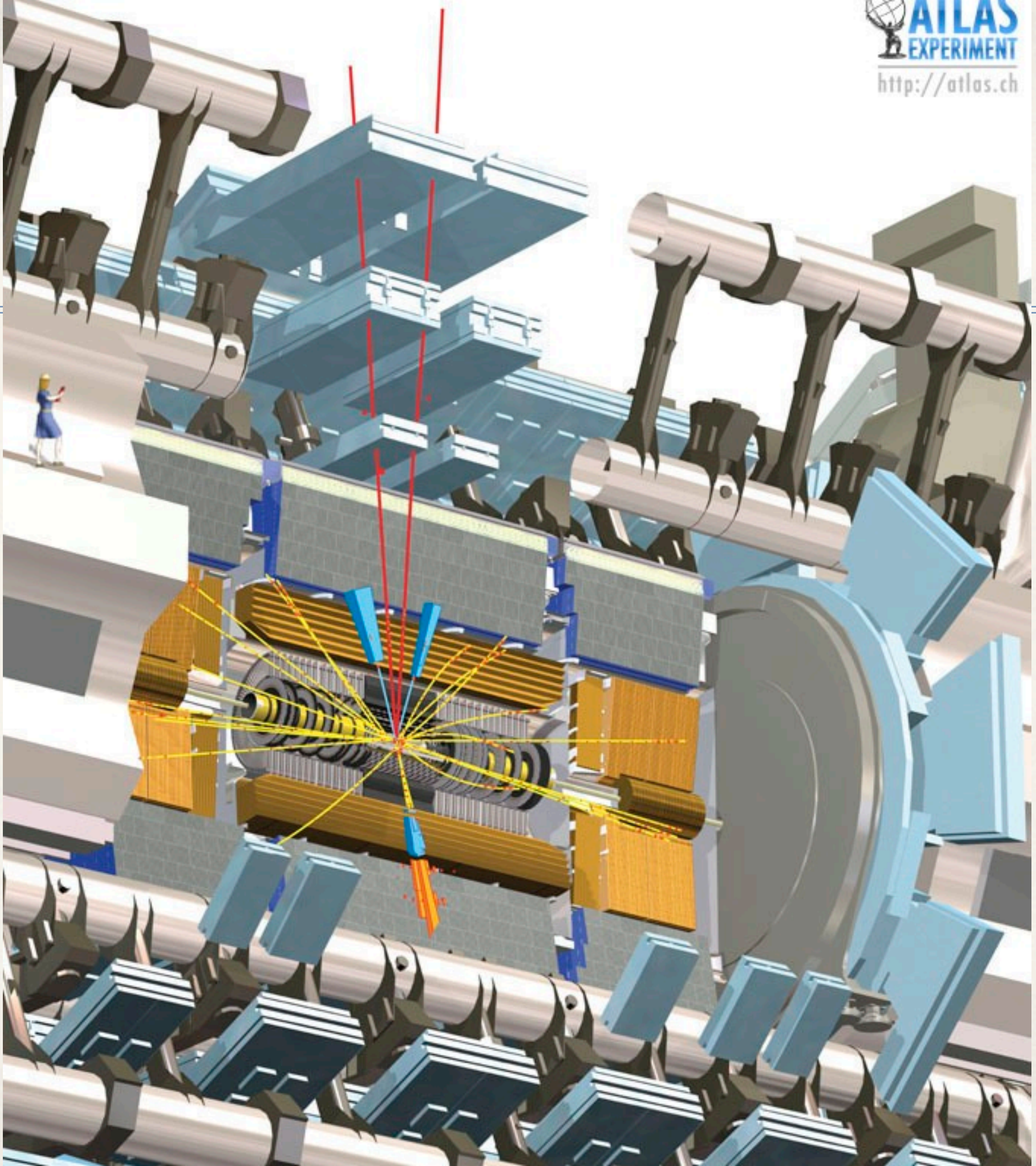

Run Number: 160958, Event Number: 9038972
Date: 2010-08-08 12:01:12 CEST
ATLAS
EXPERIMENT

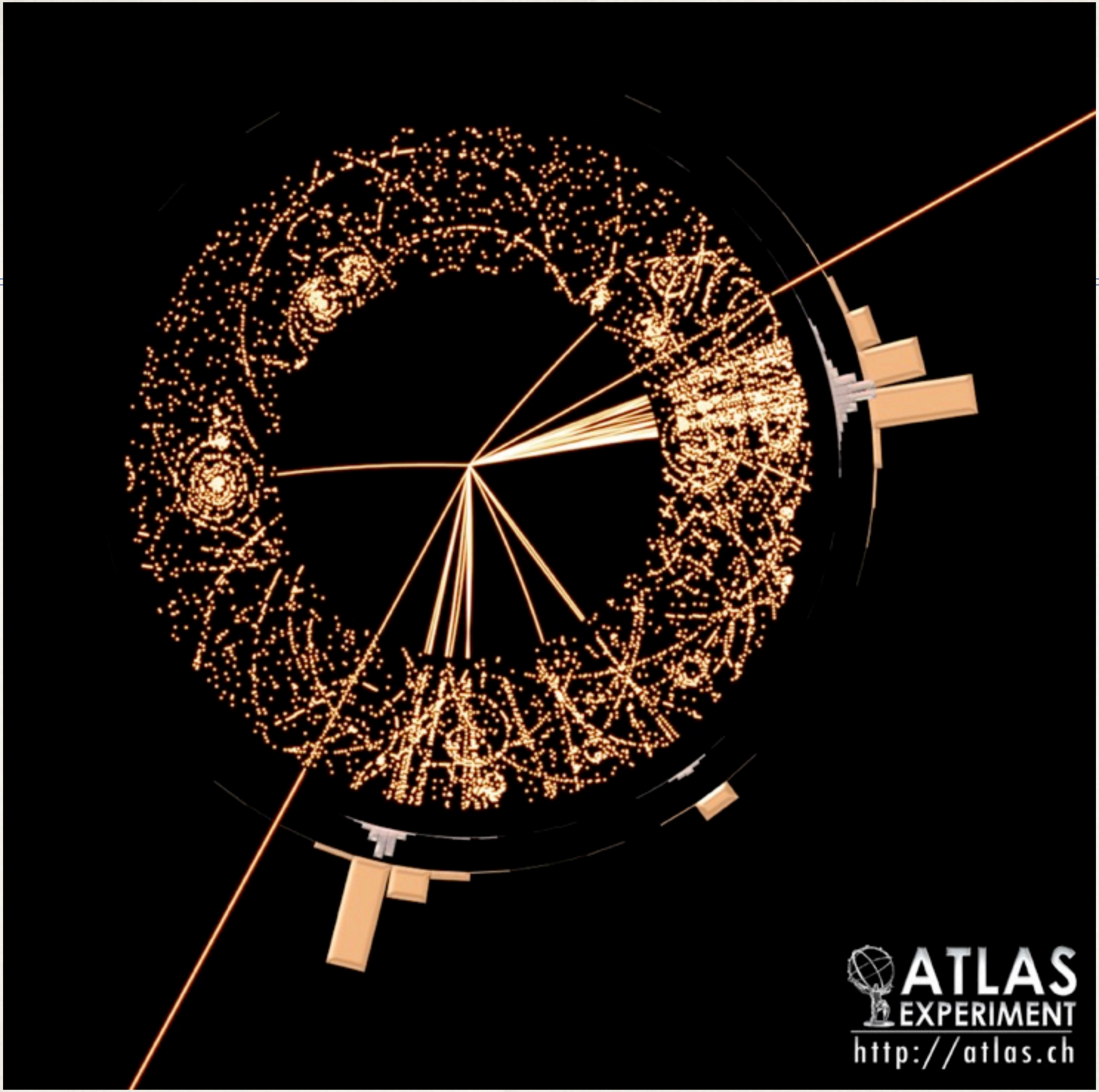


$p_T(\mu) = 18$ GeV
$p_T^{vis}(\tau_h) = 26$ GeV
$m_{vis}(\mu,\tau_h) = 47$ GeV
$m_T(\mu,E_T^{miss}) = 8$ GeV
$E_T^{miss} = 7$ GeV
ATLAS EXPERIMENT
Run Number: 160613, Event Number: 9209492
Date: 2010-08-03 02:12:37 CEST
$Z \rightarrow \tau\tau$
Candidate in 7 TeV Collisions
muon
3-prong hadronic tau decay
2 GeV
-5
-3
-1
1
3
5
η
0
180
360
φ

Simulations

- What do the things we look for look like?
- Make simulations using the theory you think exists, so you know what to look for!


ATLAS
EXPERIMENT
http://atlas.ch


ATLAS
EXPERIMENT
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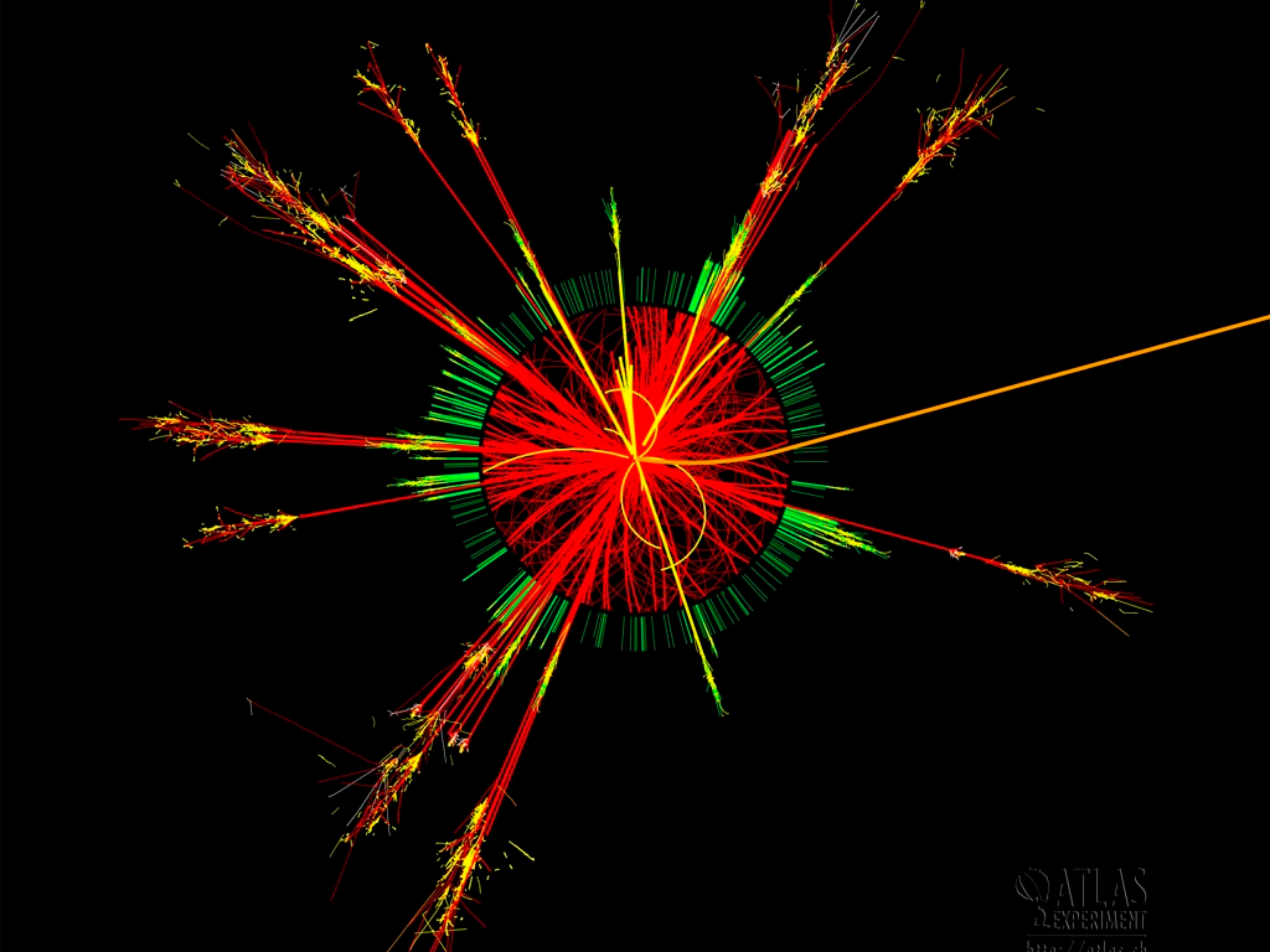
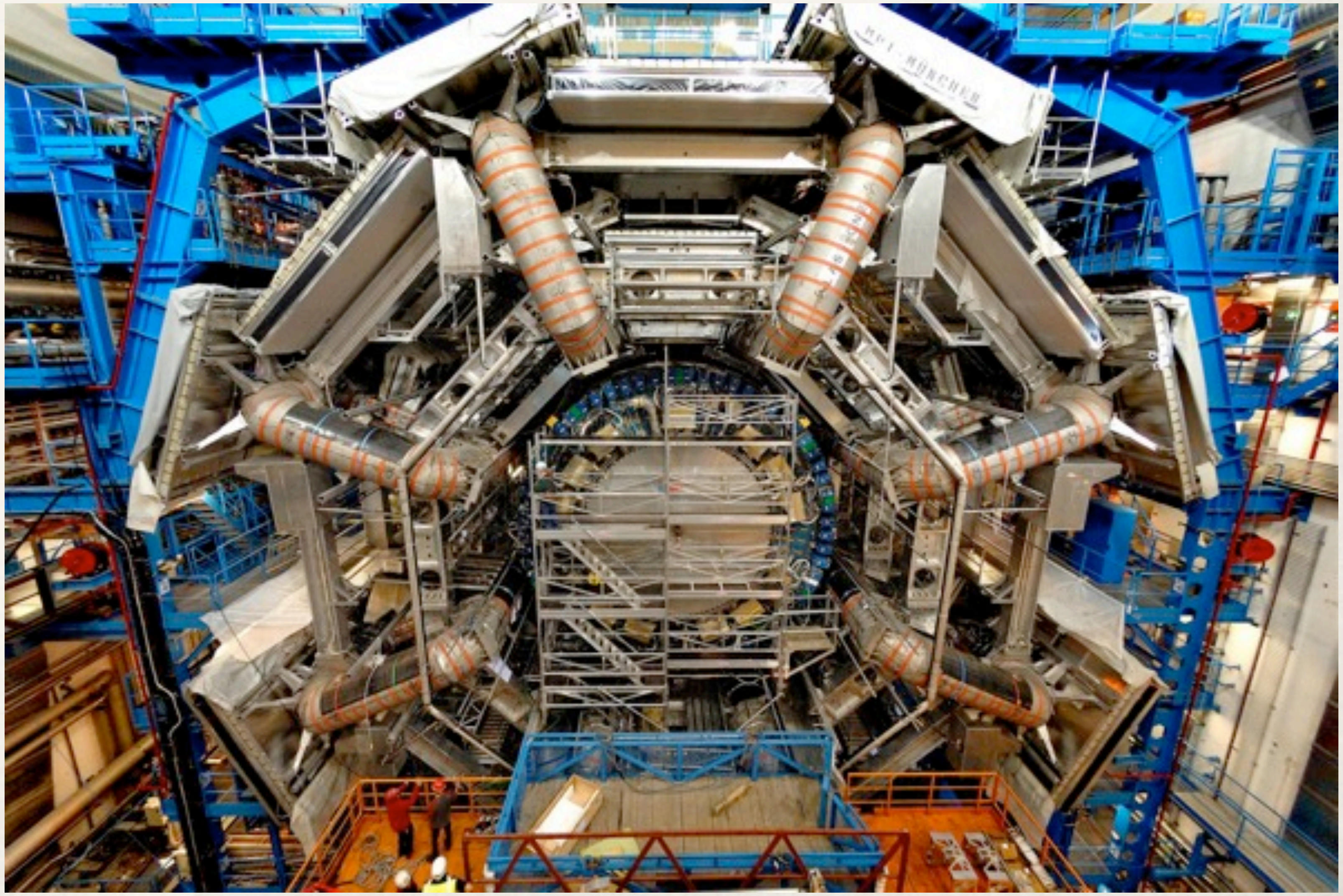

ATLAS
EXPERIMENT

Closing Thoughts

- Why do we build them?
- How do they tell us about the universe?



Backup

Matter: what are we made of?

- Cells? Molecules? Atoms? What's in an atom?
    - Electrons, neutrons, protons
- What's different between protons/neutrons from electrons?
    - Protons and neutrons are not fundamental!