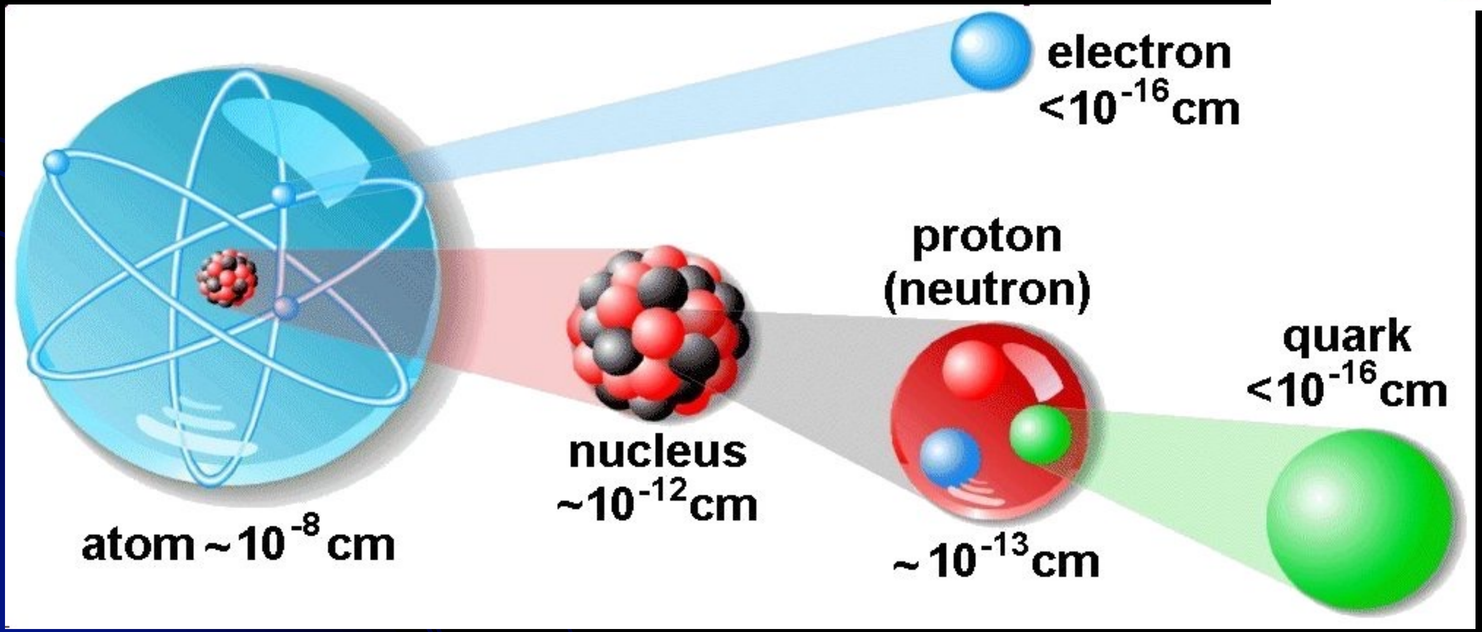
Particle Physics at OU

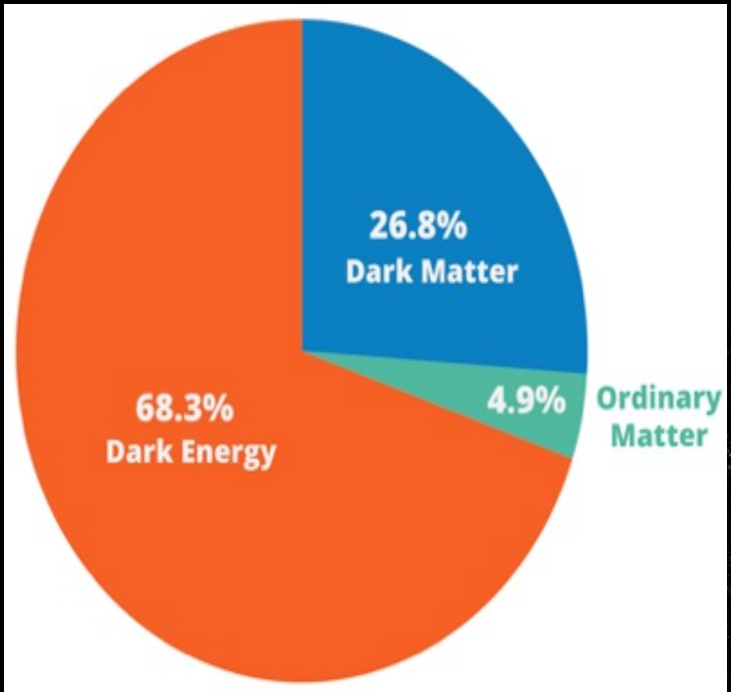
Brad Abbott
Department of Physics and Astronomy
The University of Oklahoma

The Structure of Matter

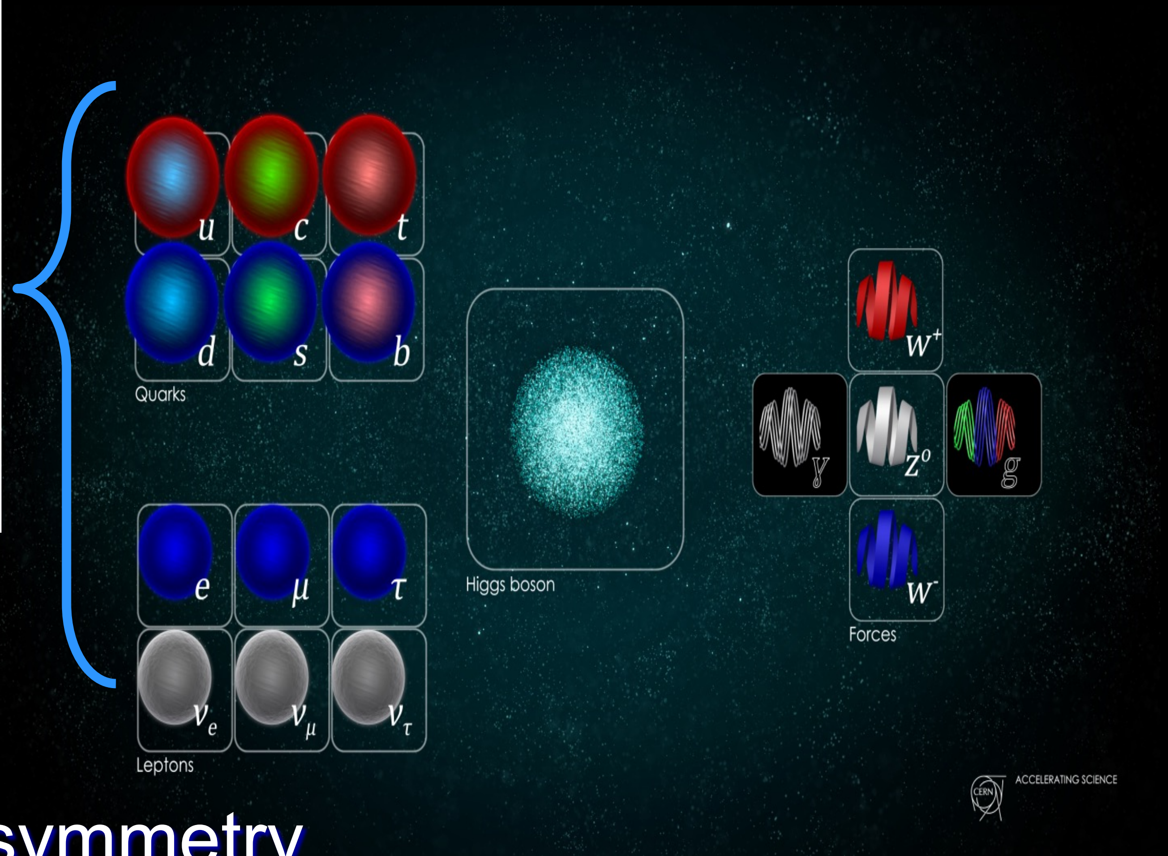
- What are the fundamental building blocks of matter?
- What the fundamental forces that cause those entities to interact?



Something is Missing



The Standard Model (SM)



- Dark Matter
- Hierarchy Problem
- Matter-antimatter asymmetry

Professors doing theoretical or phenomenological research

Chung Kao

Howie Baer

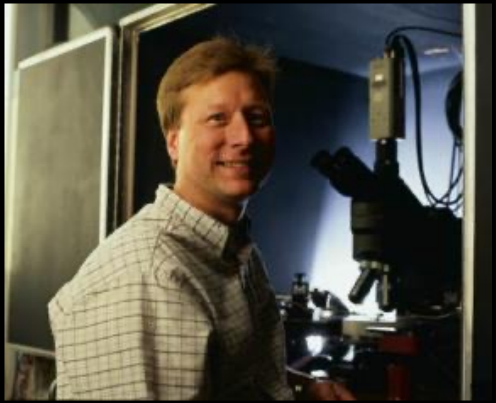
Kuver Sinha

Professors doing experimental research

Phil Gutierrez

Brad Abbott

John Stupak



Mike Strauss

CERN: The Large Hadron Collider

Research Facilities

Tevatron, Fermilab
Chicago Illinois
No longer colliding beams
g-2 experiment
Neutrino physics (DUNE)

LHC, CERN
Geneva, Switzerland

The Accelerator

The accelerator runs 24 hours per day, except for maintenance periods. At CERN the beams interact every 25 ns and data is written to disk at ~1000 Hz.

The LHC Tunnel

Large Hadron Collider

The LHC ring will store a beam energy of 360 megajoules.

$$2\,808 \text{ bunches} \times 1.15\ 10^{11} \text{ protons @ 7 TeV each} =$$

$$2\,808 \times 1.15 \times 10^{11} \times 7 \times 10^{12} \times 1.602 \times 10^{-19} \text{ joules} = 362 \text{ MJ per beam}$$

This can be compared to:

Kinetic energy
- 1 small cruise ship of 10 000 tonnes moving at 30 km/hour
- 450 automobiles of 2 tonnes moving at 100 km/hour

Chemical energy
- 80 kg of TNT
- 16 kg of chocolate (counting the calories)

Thermal energy
- melt 500 kg of copper
- raise 1 cubic meter of water 85° C: "a tonne of tea"

Milk chocolate is 520 calories per 100 g , which gives 350 MJ = 16 kg of chocolate.

The energy in chocolate is released a bit more slowly than in TNT!

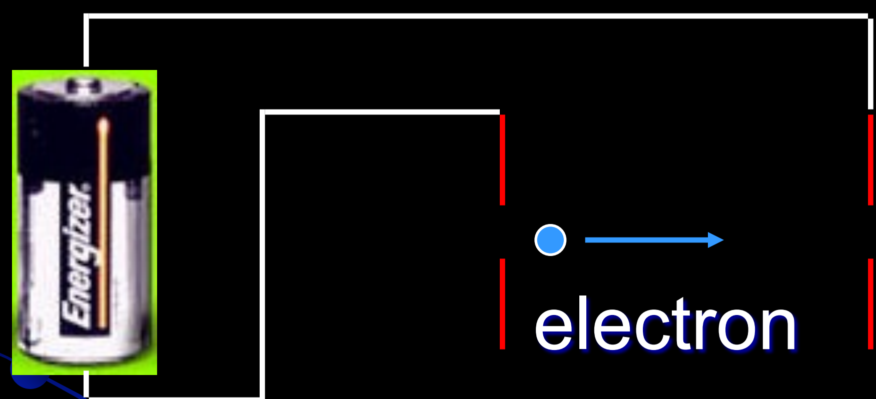
ATLAS Data

About 20 petabytes (1,000,000 gigabytes) of data, or more, per year

Particle *Acceleration*

<u>Vocabulary</u>

1 eV (electron volt) is the amount of energy carried by a particle with the same charge as an electron, when accelerated by a 1 volt battery.



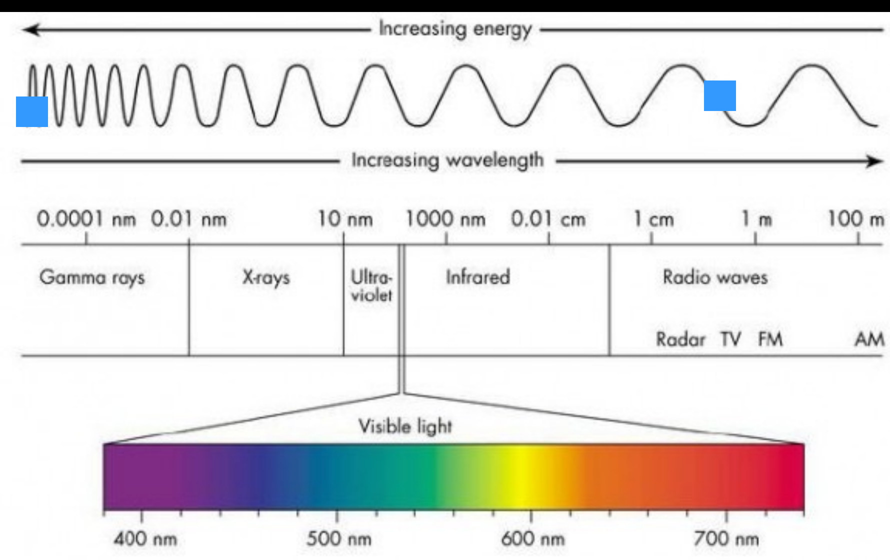
1 keV (kilo electron volt) 1,000 x-rays, TV
1 MeV (mega electron volt) 1,000,000 Gamma rays
1 GeV (giga electron volt) 1,000,000,000 Big gamma rays
1 TeV (tera electron volt) 1,000,000,000,000 Fermilab
7 TeV (tera electron volt) 7,000,000,000,000 LHC!

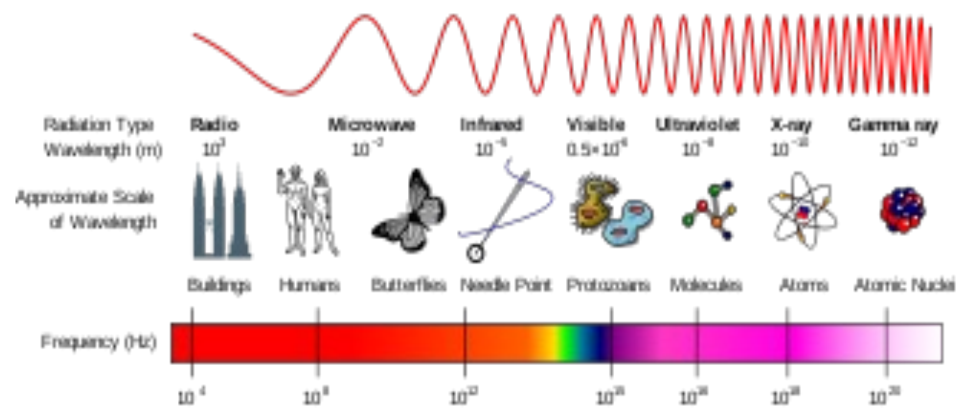
When objects collide, they break up into smaller pieces and you get to see the structure of the object.

So smashing objects together can reveal the structure of matter which is why this field of science is called both "Elementary Particle Physics" and "High Energy Physics."

How do we "see" these particles?

To "see" object, need wavelength ~ size of object

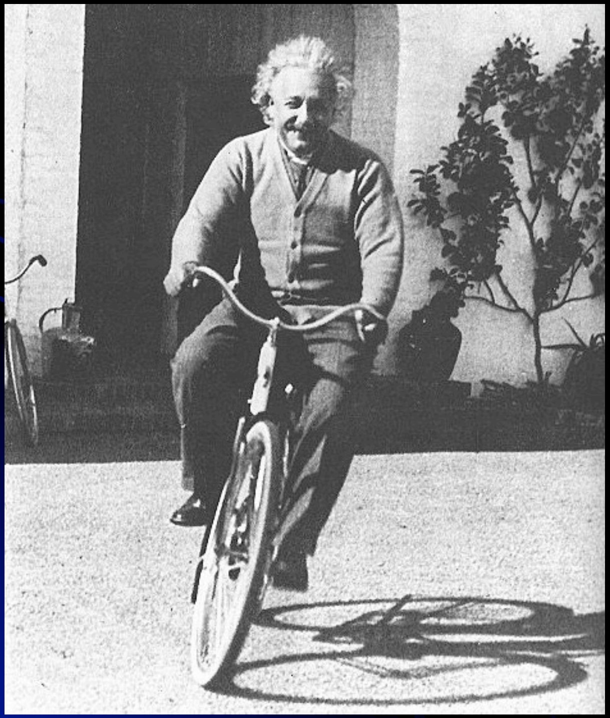




Two physics principles involved in colliders

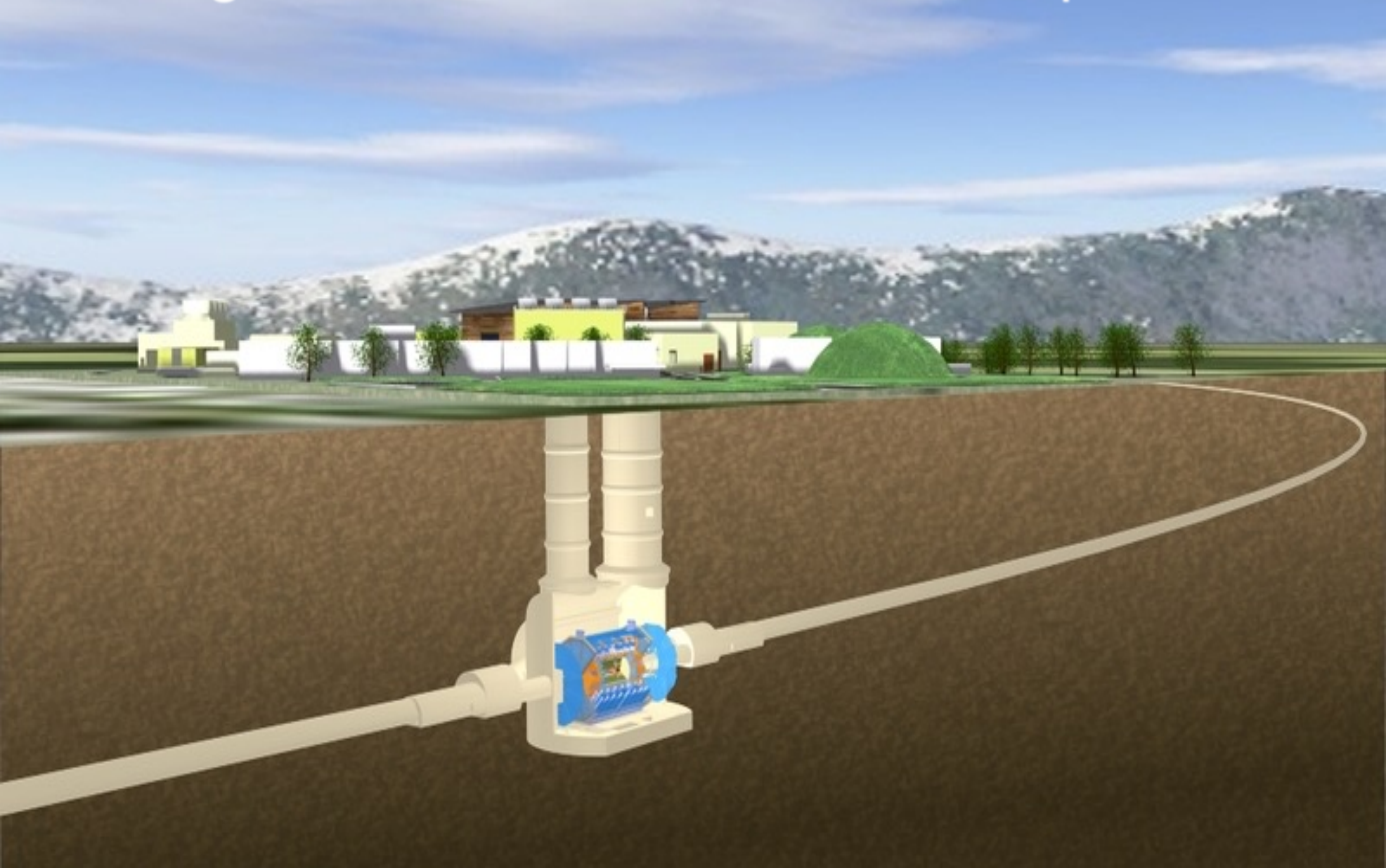
De Broglie wavelength

$\lambda = h/p$

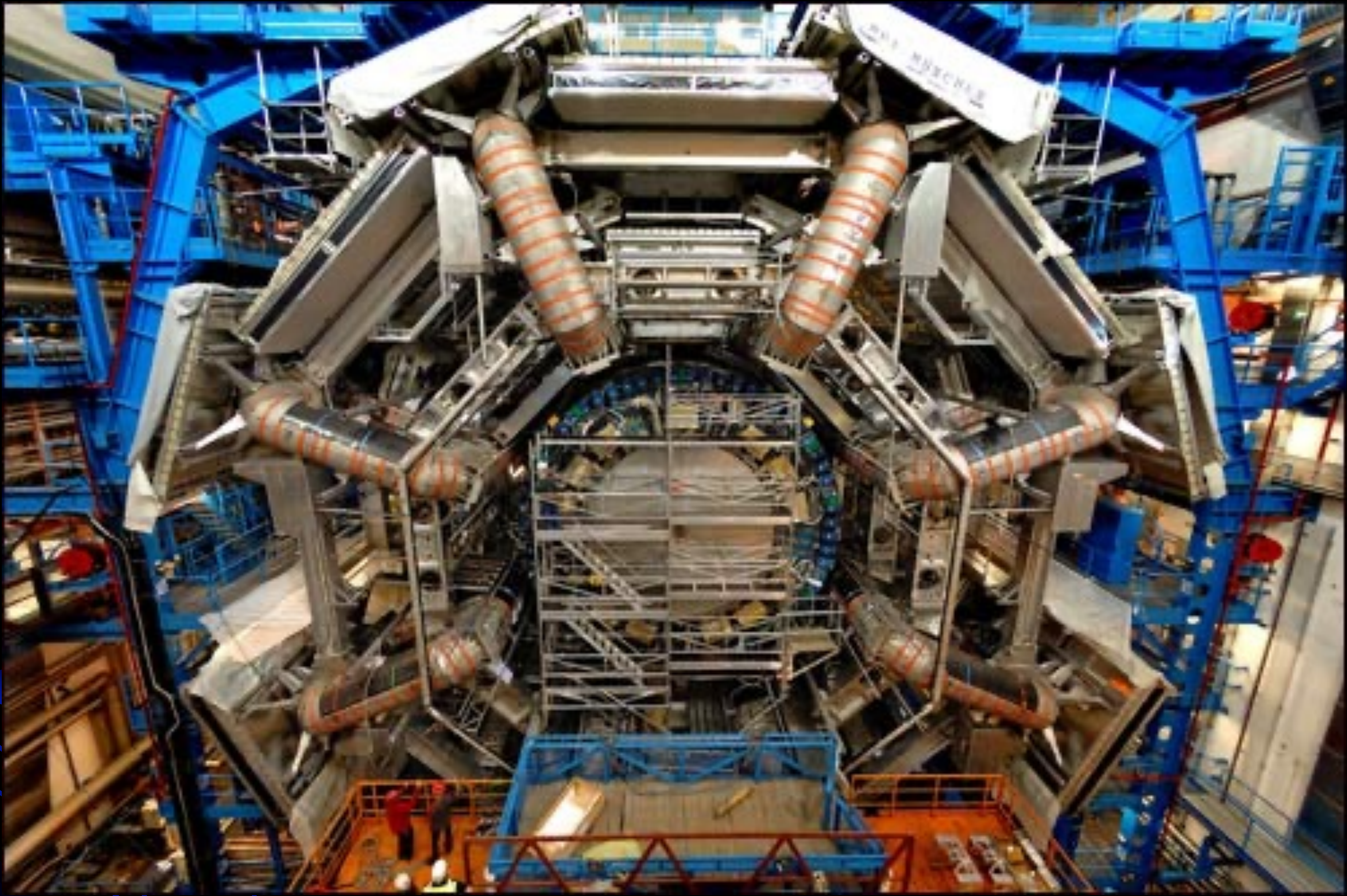


$E = mc^2$

The ATLAS detector:
A large camera to “see” subatomic particles.



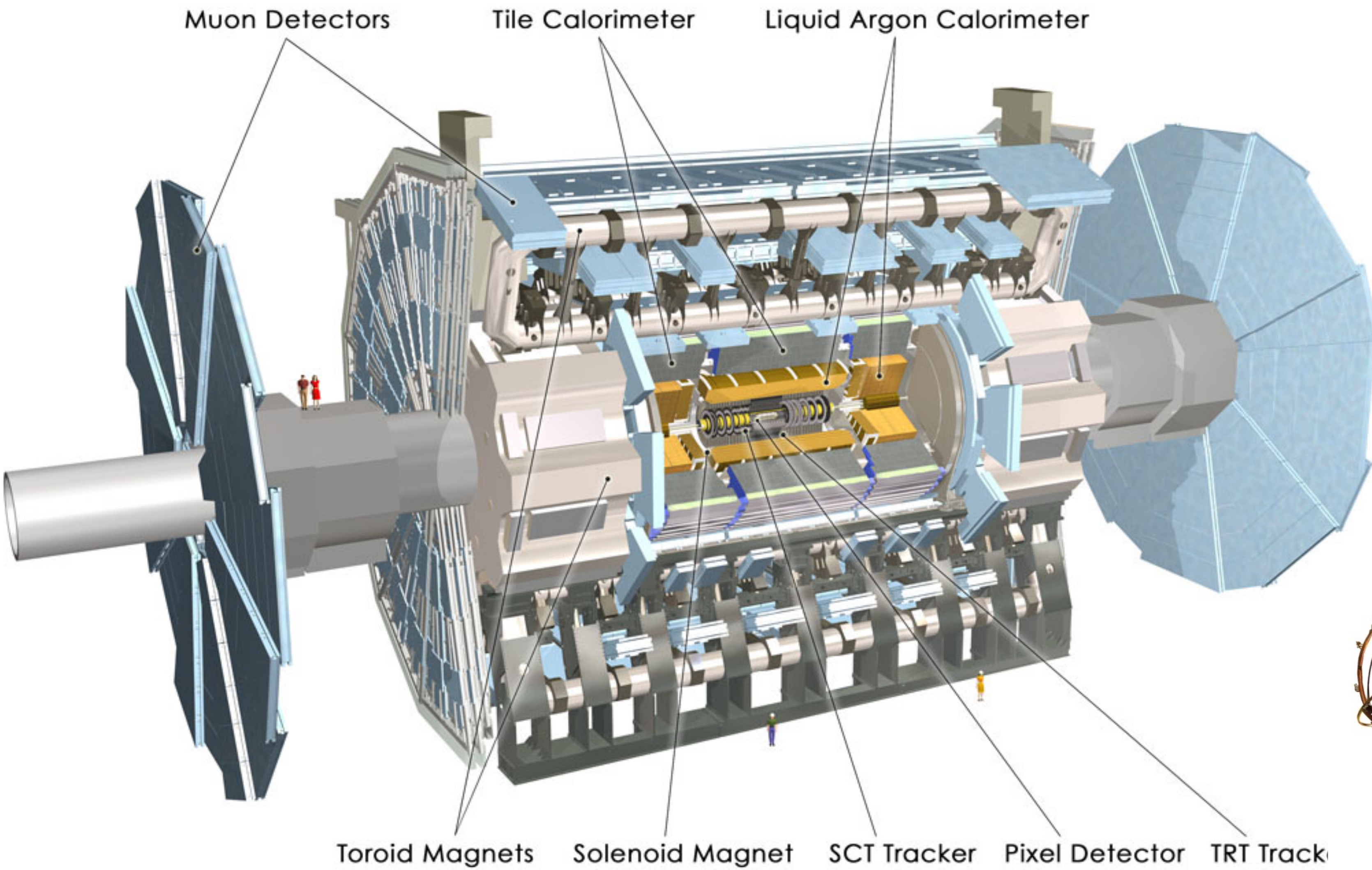
The Detector



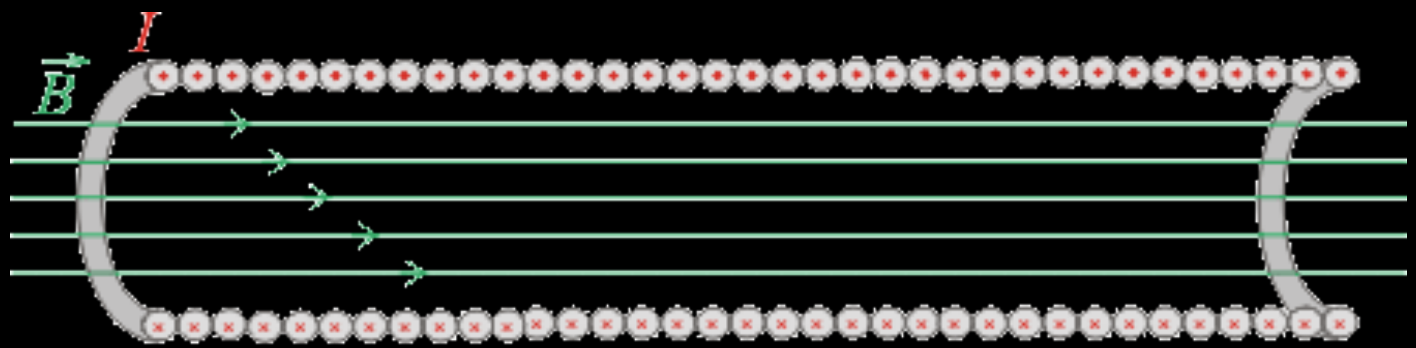
ATLAS at CERN

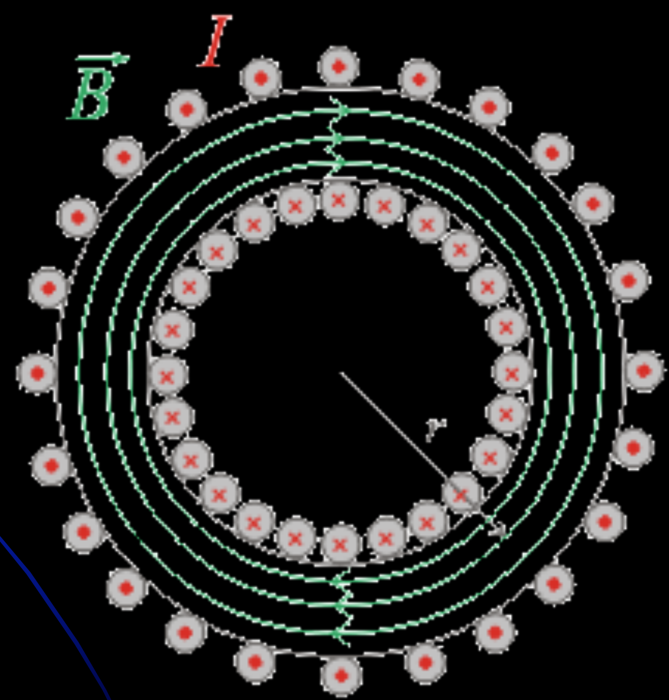
Width: 44 m
Diameter: 22 m
Weight: 7000 tons

A Toroidal LHC ApparatuS



Solenoids and Toroids

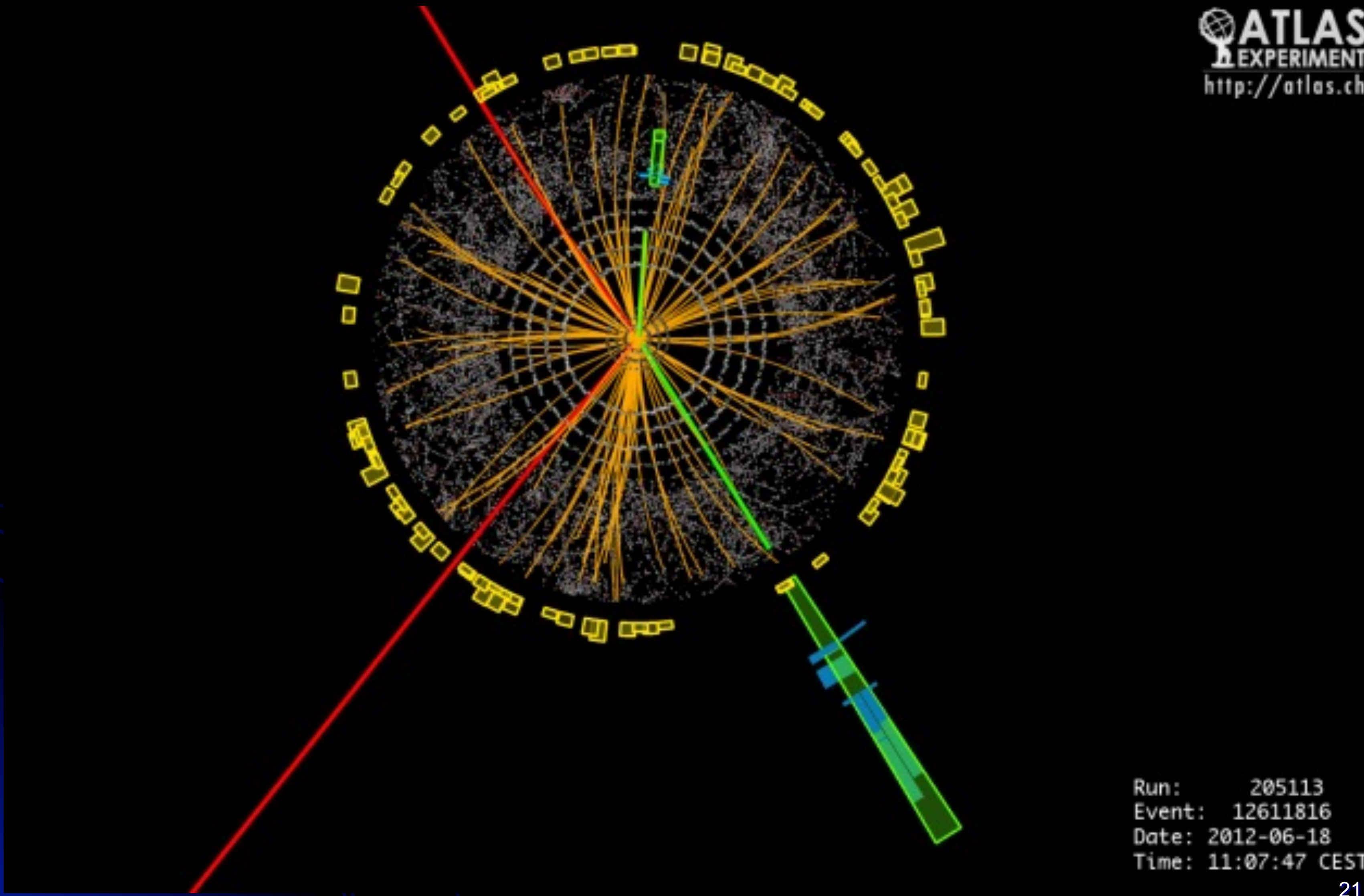


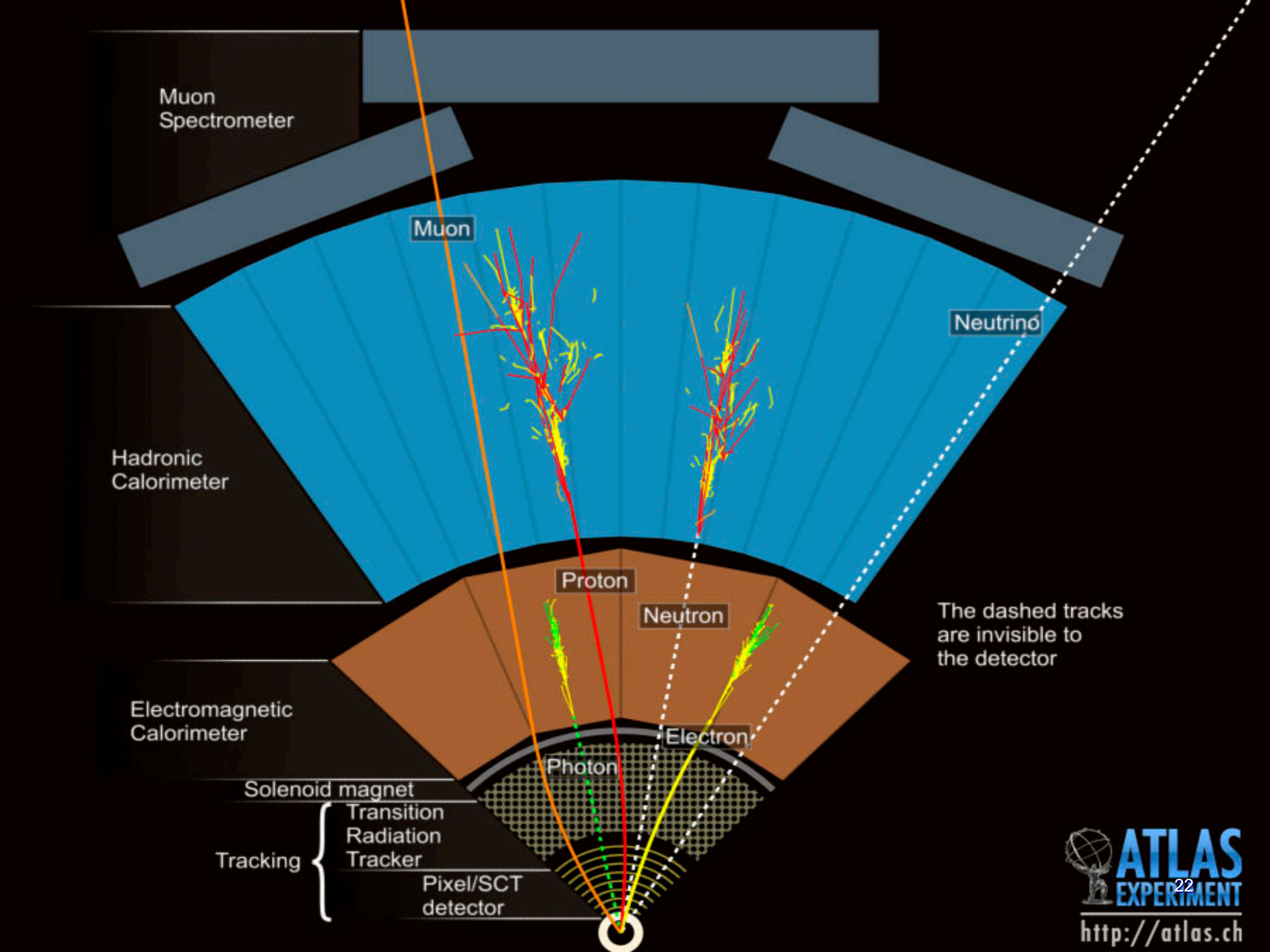


Magnetic fields

- F=qvxB Lorentz Force
- $F=mv^2/r$ Centripetal force
- $qvB=mv^2/r$ -> p=qBr
- Measure radius of curvature-> momentum

Real Event from ATLAS

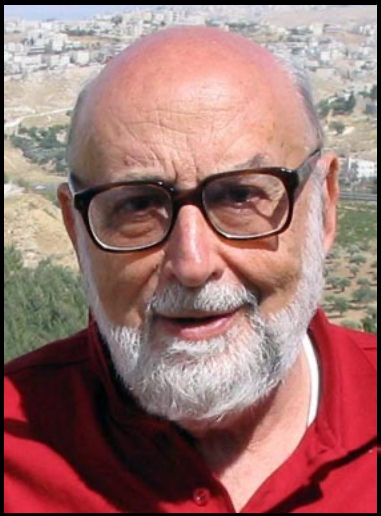


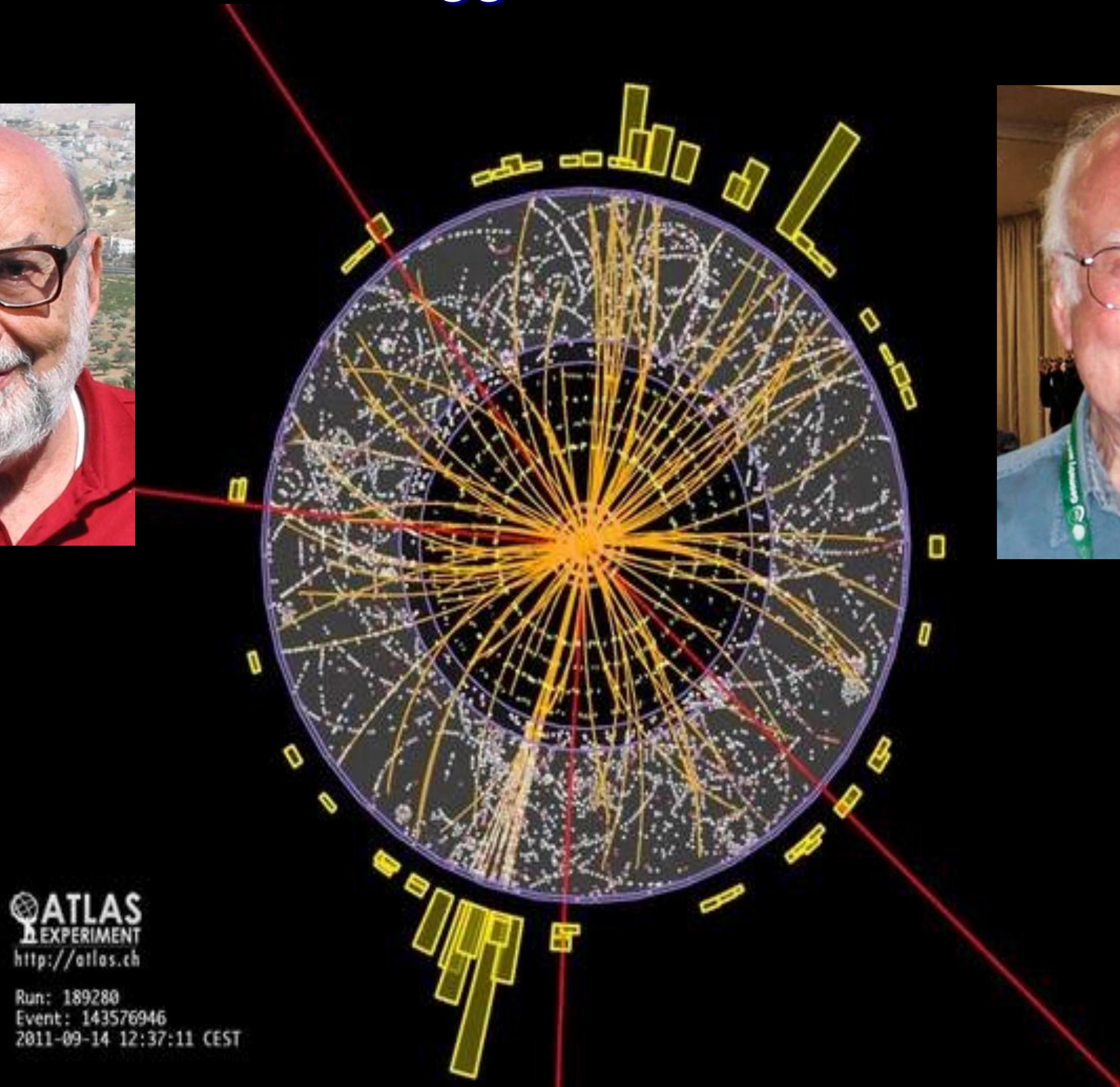

Muon Spectrometer
Hadronic Calorimeter
Electromagnetic Calorimeter
Solenoid magnet
Tracking
Transition Radiation Tracker
Pixel/SCT detector
Muon
Neutrino
Proton
Neutron
Electron
Photon
The dashed tracks are invisible to the detector
ATLAS EXPERIMENT
http://atlas.ch

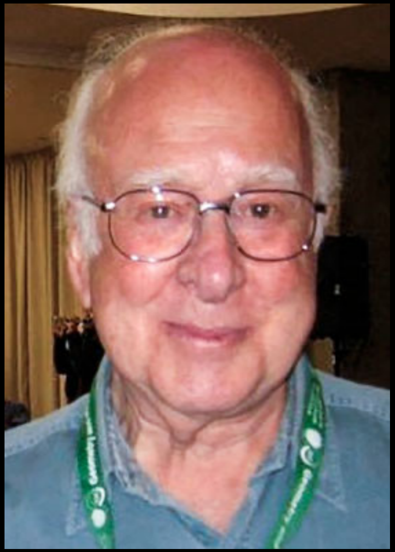
- 3000 physicists
- 37 countries
- 137 institutions

What questions are currently being investigated by particle physicists?

One of the two experiments that discovered the Higgs Boson in 2012





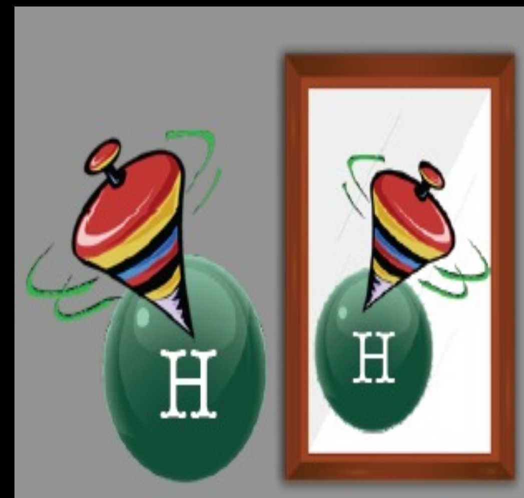


Testing the Higgs Discovery

Is the discovered particle a standard model Higgs?

Does it have appropriate mass couplings?

Is it composite?



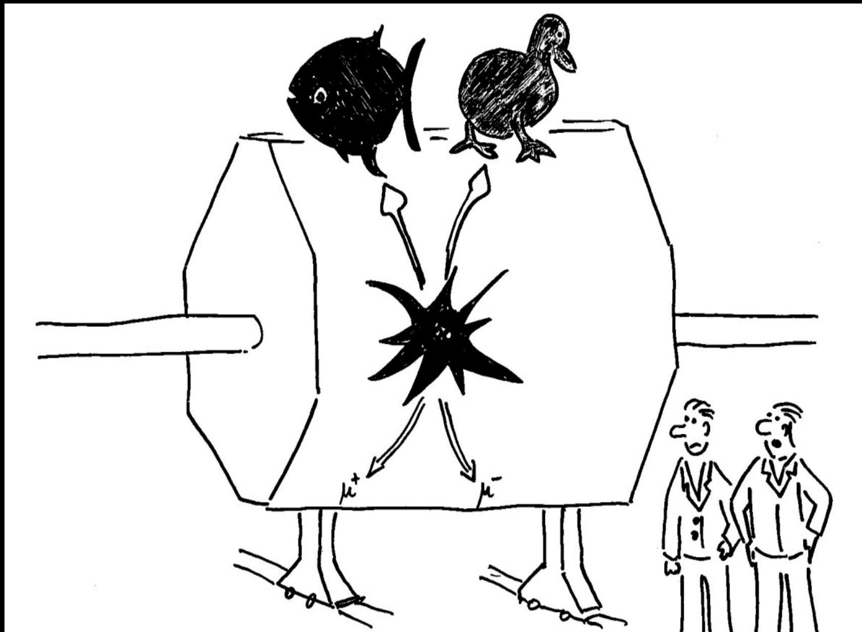
Does it have the correct spin and parity?

Is its mass appropriate?

Discovering Particles

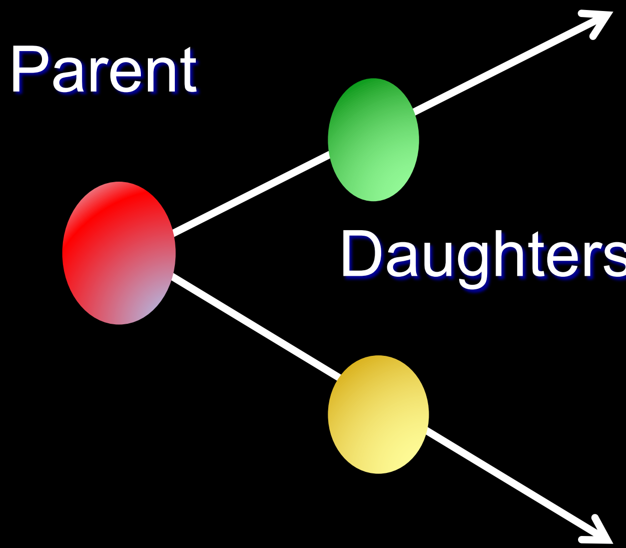
- Most particles produced from the proton collisions exist for a very brief period of time then decay into two or more particles. We see the decay products.

- The Higgs Boson exists for about 10^{-22} s.
- The ATLAS detector sees the decay particles. We have to show that they came from a Higgs Boson.



"This is not exactly, what theory predicted for the Higgs decay!"

Particle Decay



$$m_P^2 = E_P^2 - p_P^2$$

$$m_P^2 = (E_1 + E_2)^2 - (\mathbf{p}_1 + \mathbf{p}_2)^2$$

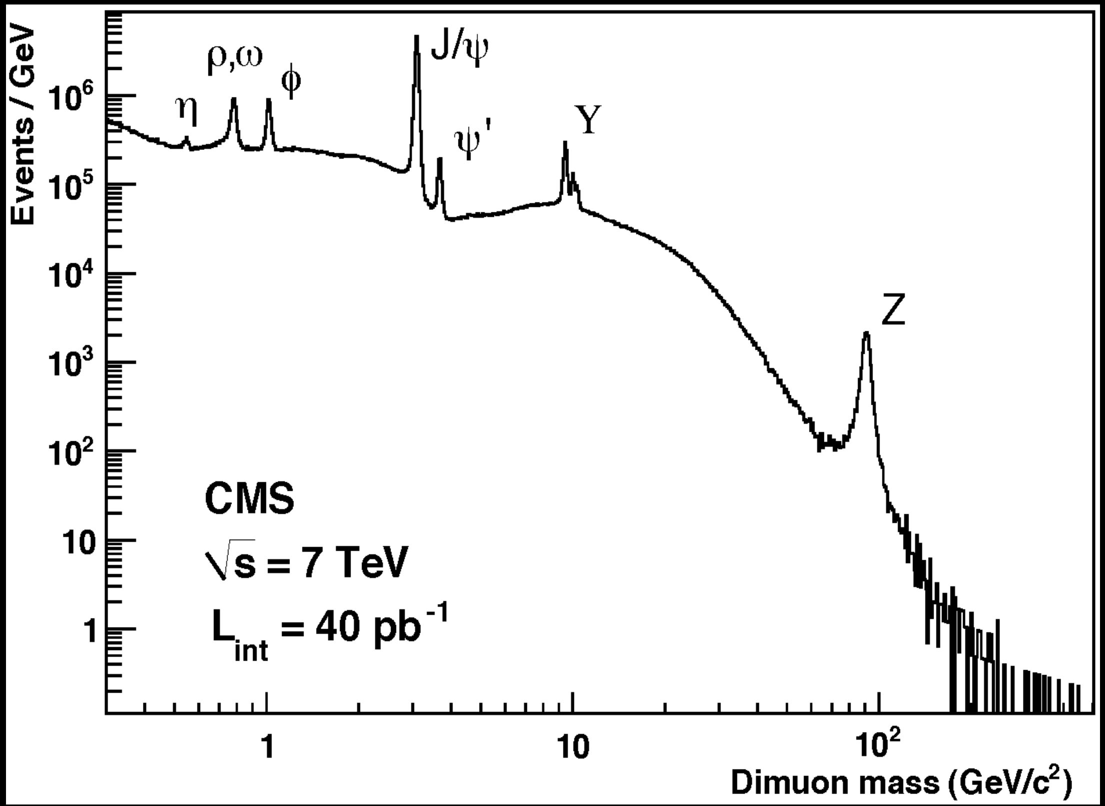
$$E_P = E_1 + E_2$$

$$\mathbf{p} = \mathbf{p}_1 + \mathbf{p}_2$$

$$E^2 = p^2c^2 + m^2c^4$$

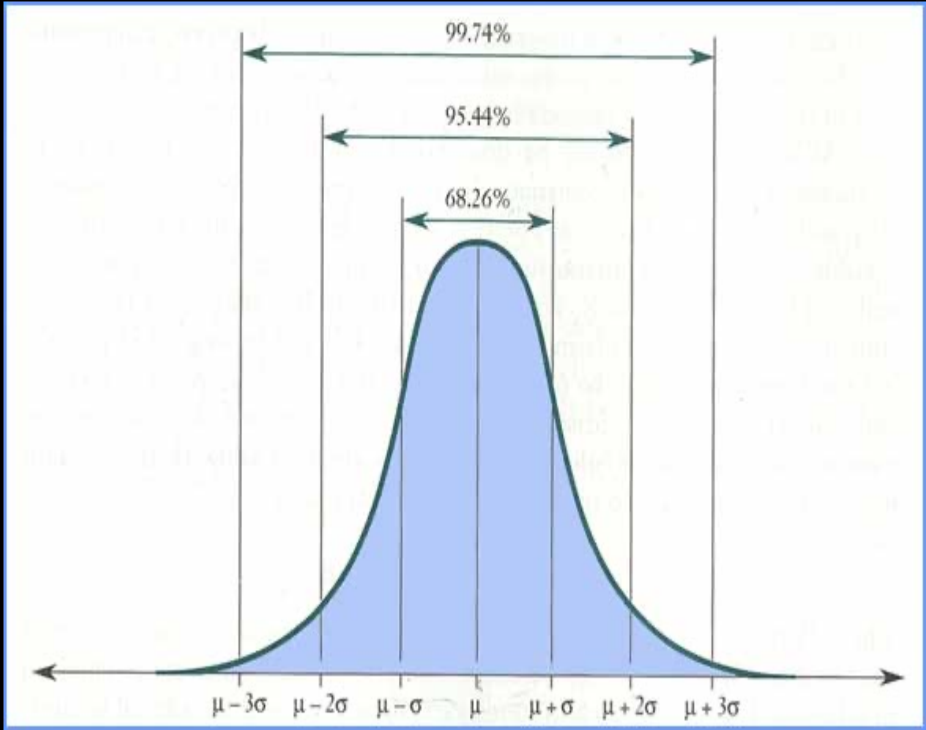
$$E^2 = p^2 + m^2$$

$$m^2 = E^2 - p^2$$



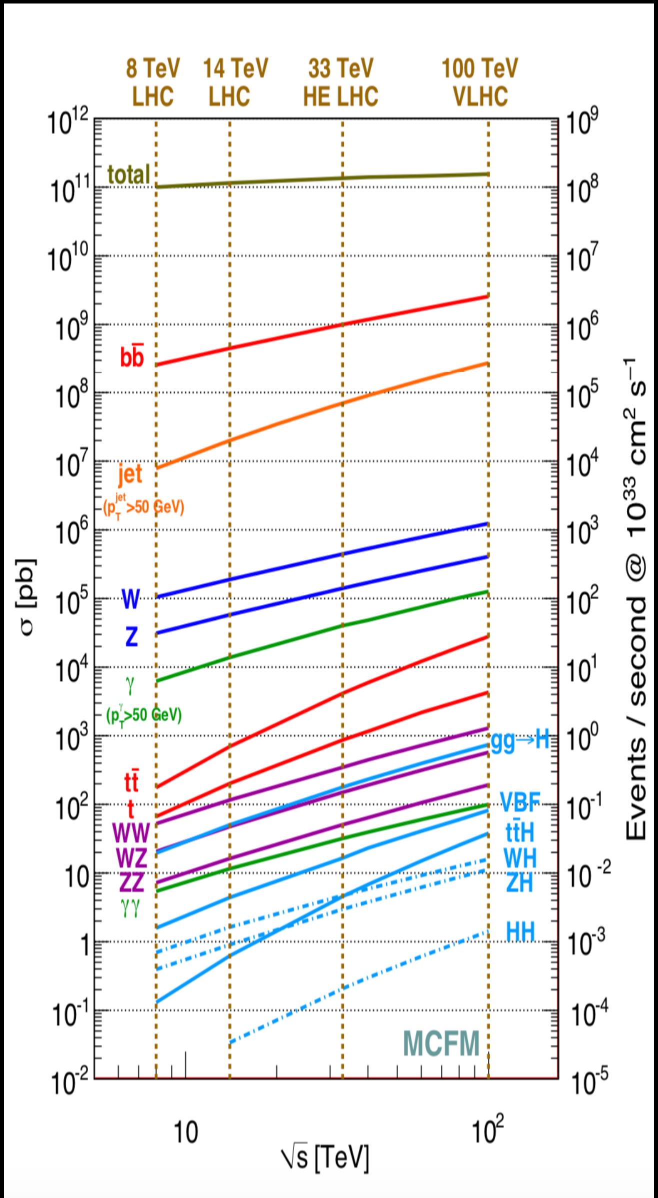
Statistics

- For a Gaussian (normal) distribution
  - 1σ deviation: 32% probability
  - 2σ deviation: 5% probability
  - 3σ deviation: 0.3% probability
  - 5σ deviation: 0.00006% probability
- In particle physics, we say that a 3σ effect gives us "evidence" for a process and 5σ effect is a "discovery."

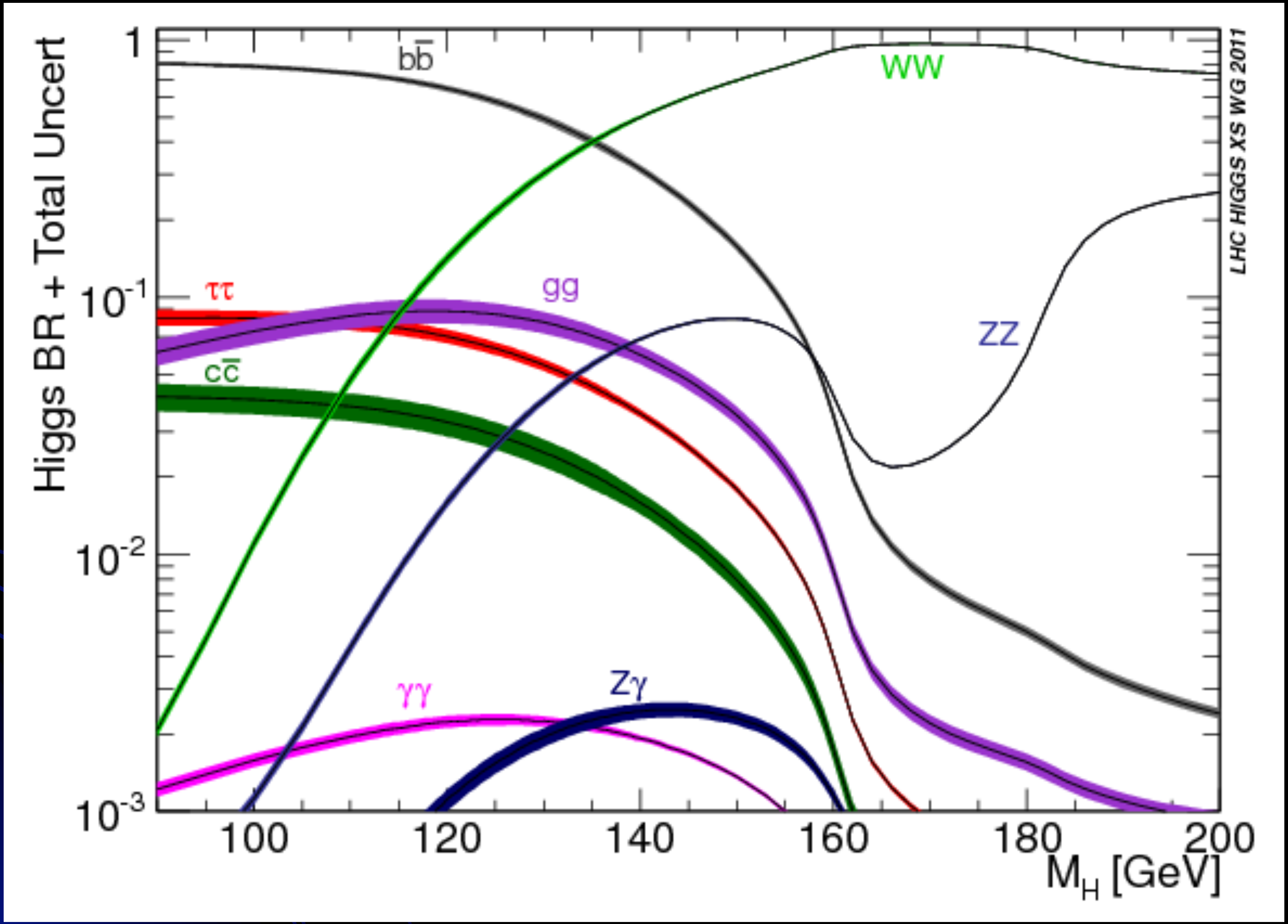


Backgrounds

- Many other processes can decay to the same final particles as the Higgs, with much higher probabilities
- About 1 Higgs particle is produced every 10 billion collisions



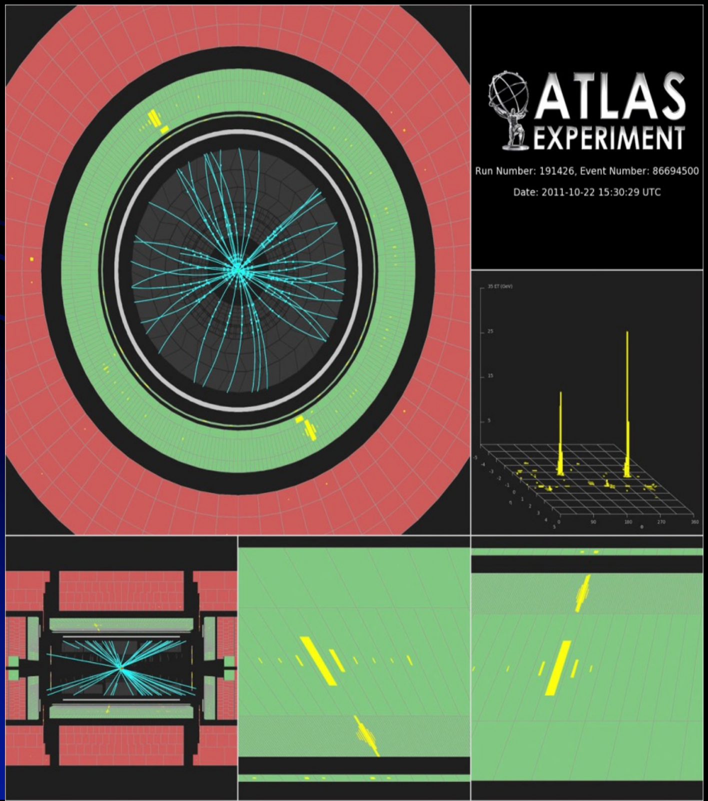
Higgs Decay

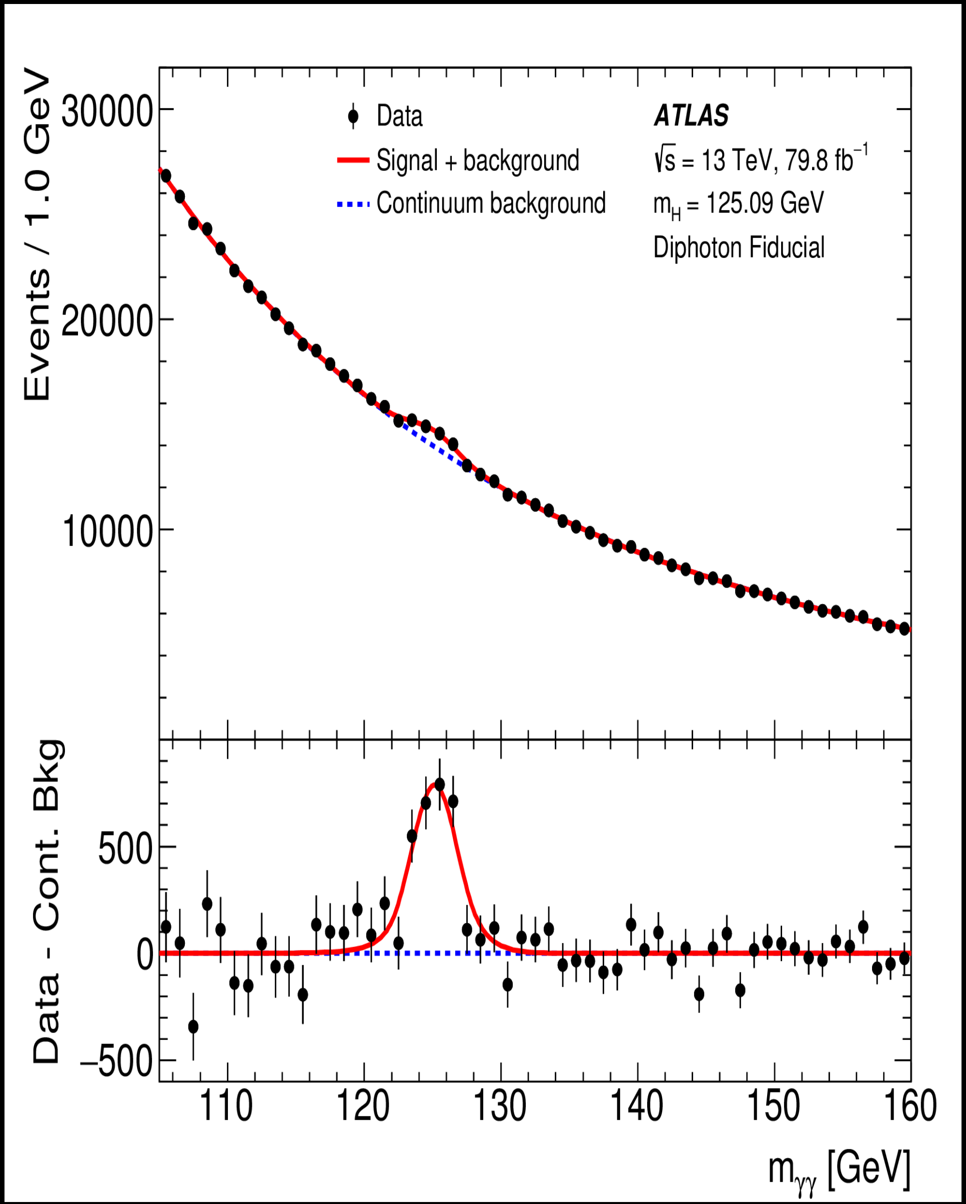


Higgs BR + Total Uncert
1
10^{-1}
10^{-2}
10^{-3}
100
120
140
160
180
200
M_H [GeV]
$b\bar{b}$
WW
$\tau\tau$
gg
$c\bar{c}$
ZZ
$\gamma\gamma$
$Z\gamma$
LHC HIGGS XS WG 2011

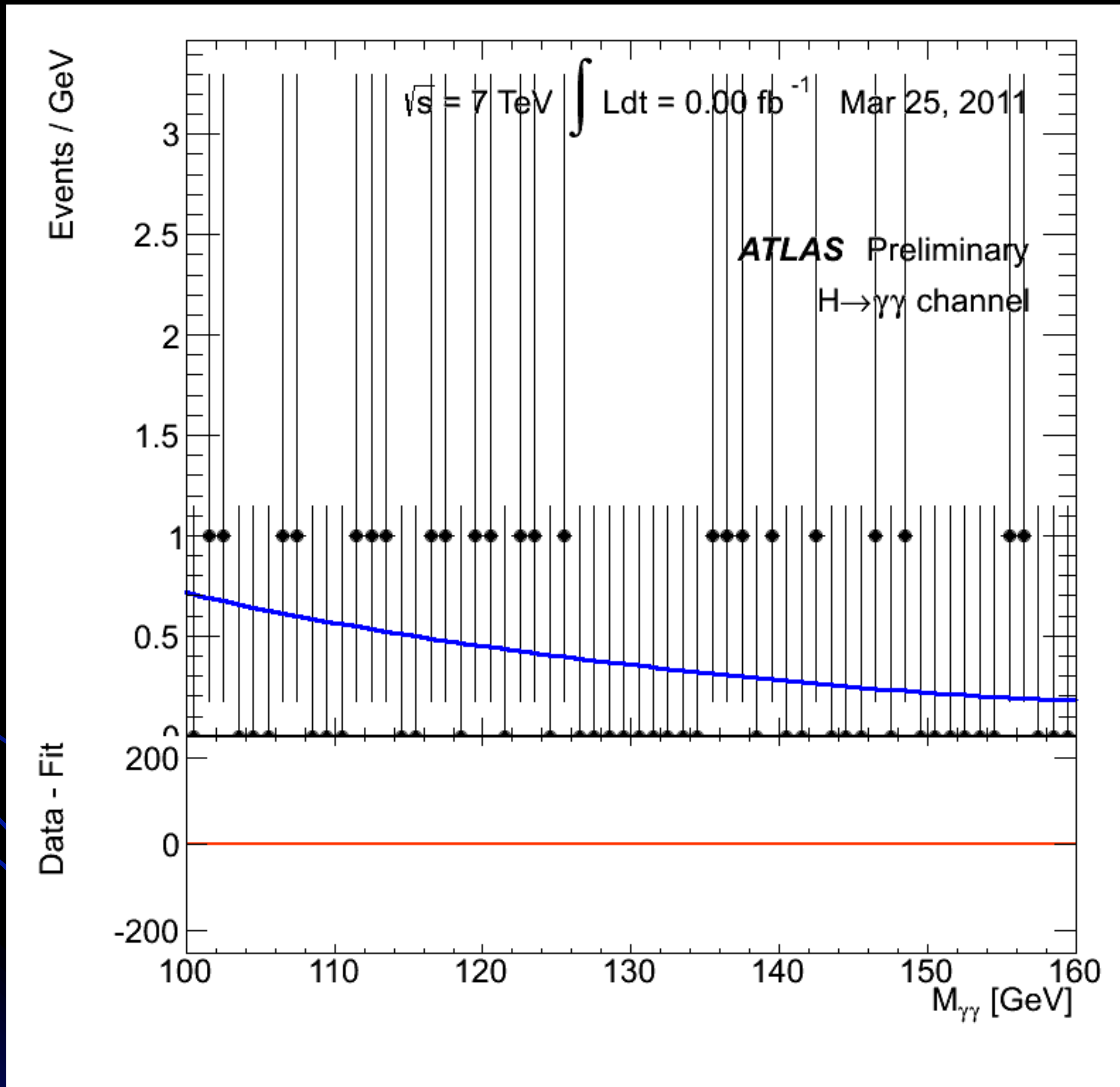
ATLAS Data: H → γγ

- Small Higgs decay rate
- Huge backgrounds
- Clean signal

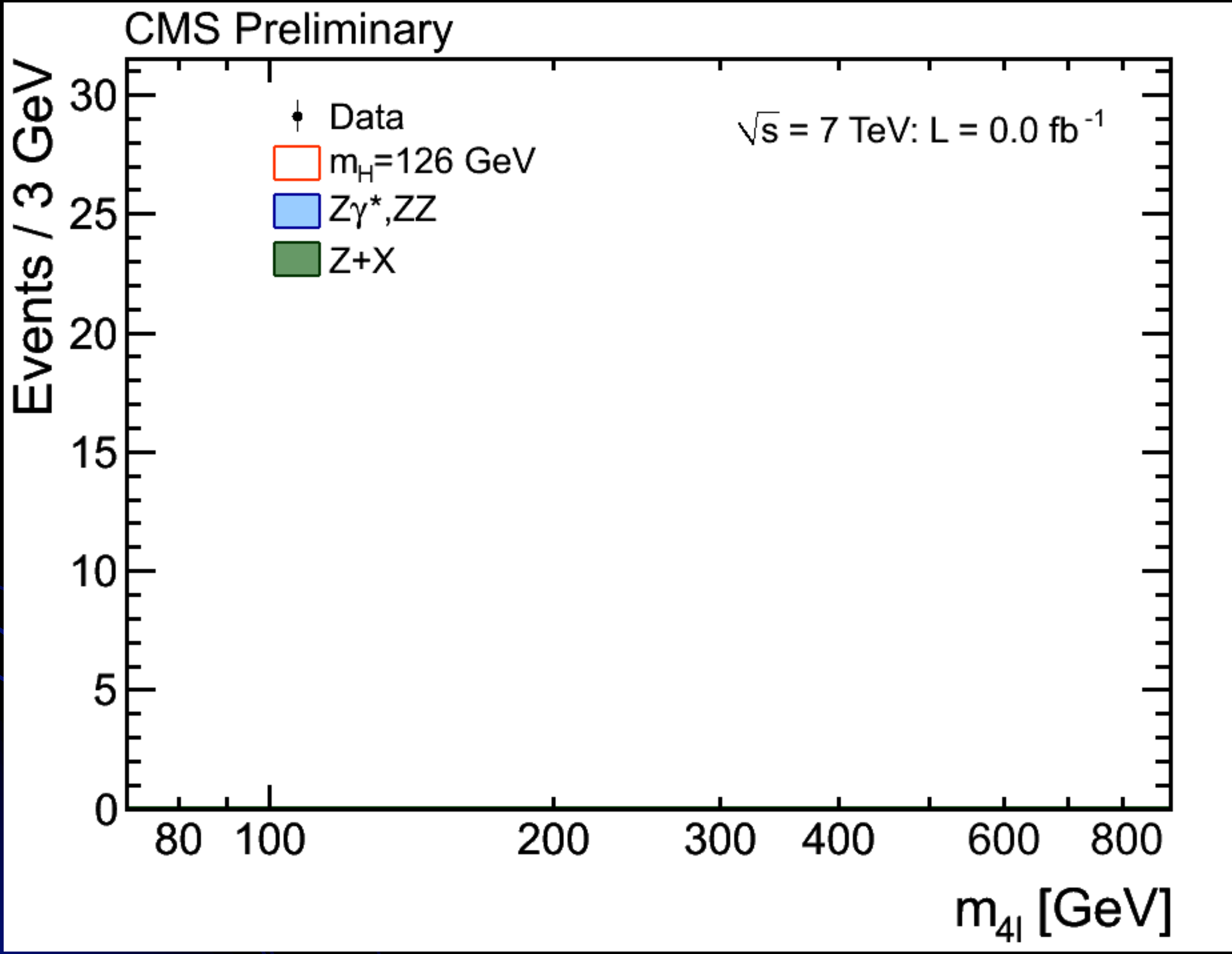




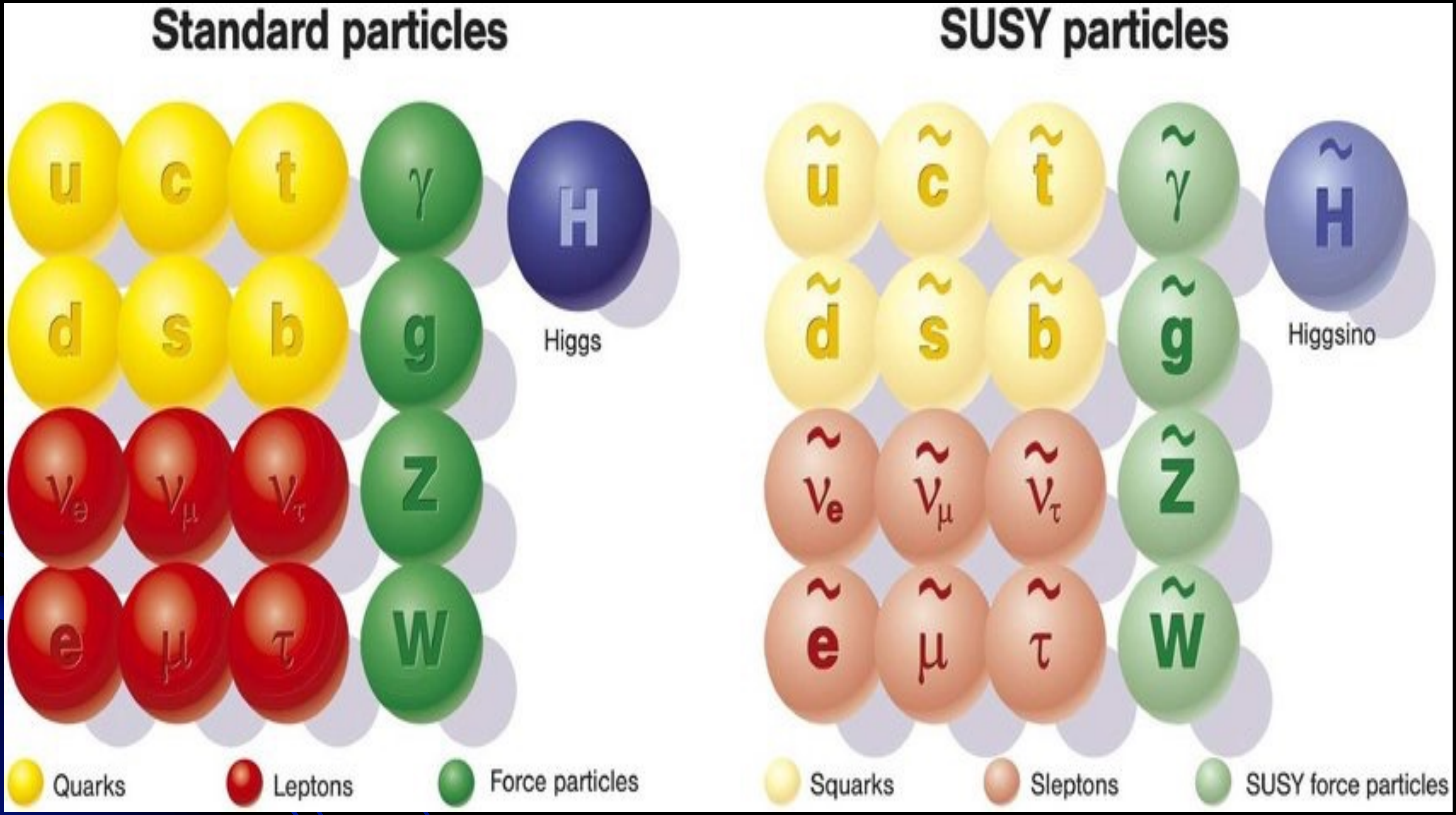
Time Evolution of 2 Photon Signal



Higgs-> 4 leptons

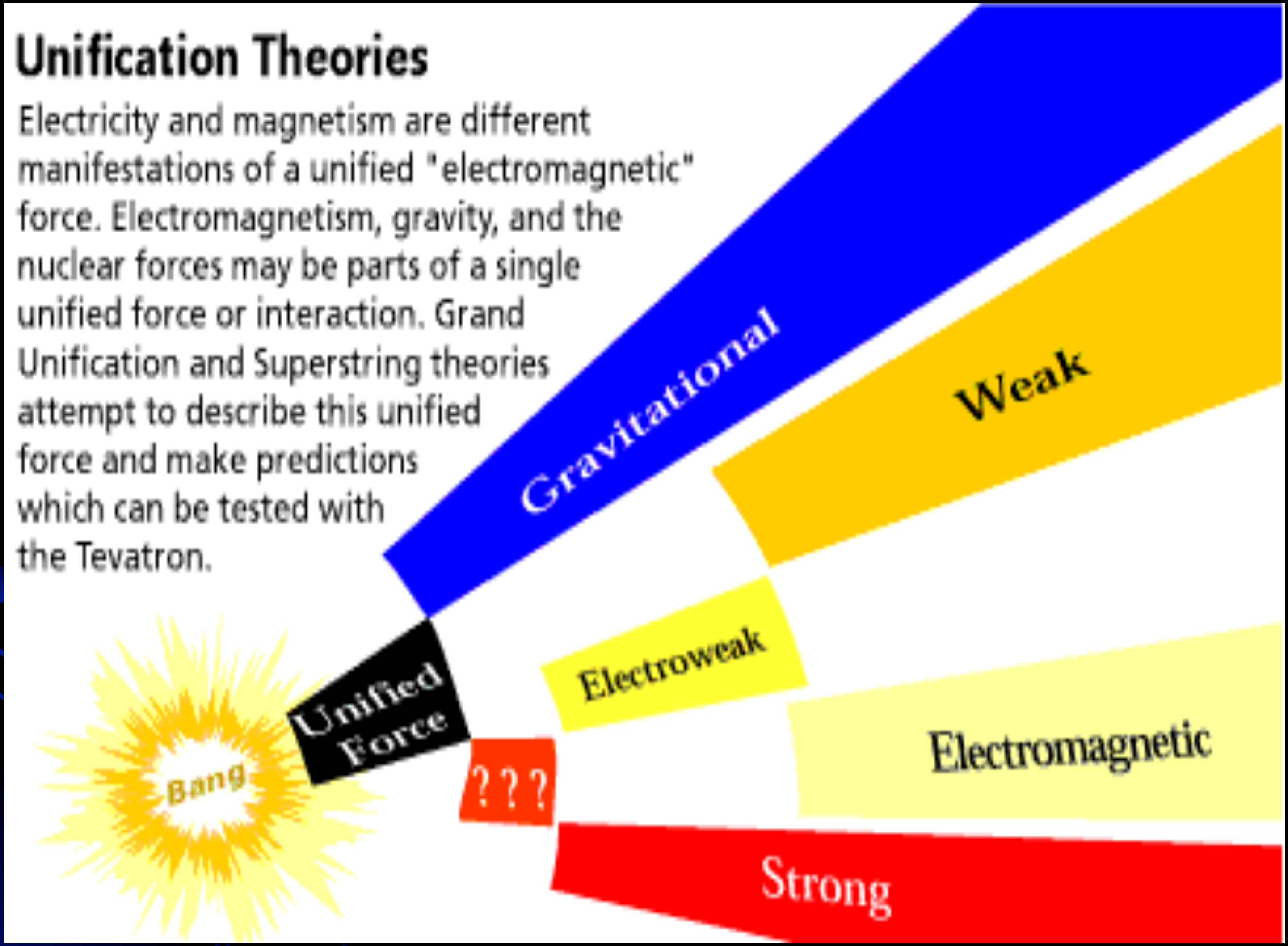


SuperSymmetry is Minimally a 2HDM



SUSY has the potential of solving many problems

Are The Three Forces Really One Super Force?



Why is the Universe Almost All Matter and No Antimatter?

Now
(15 billion years)

Stars form
(1 billion years)

Atoms form
(300,000 years)

Nuclei form
(180 seconds)

Nucleons form
(10^{-10} seconds)

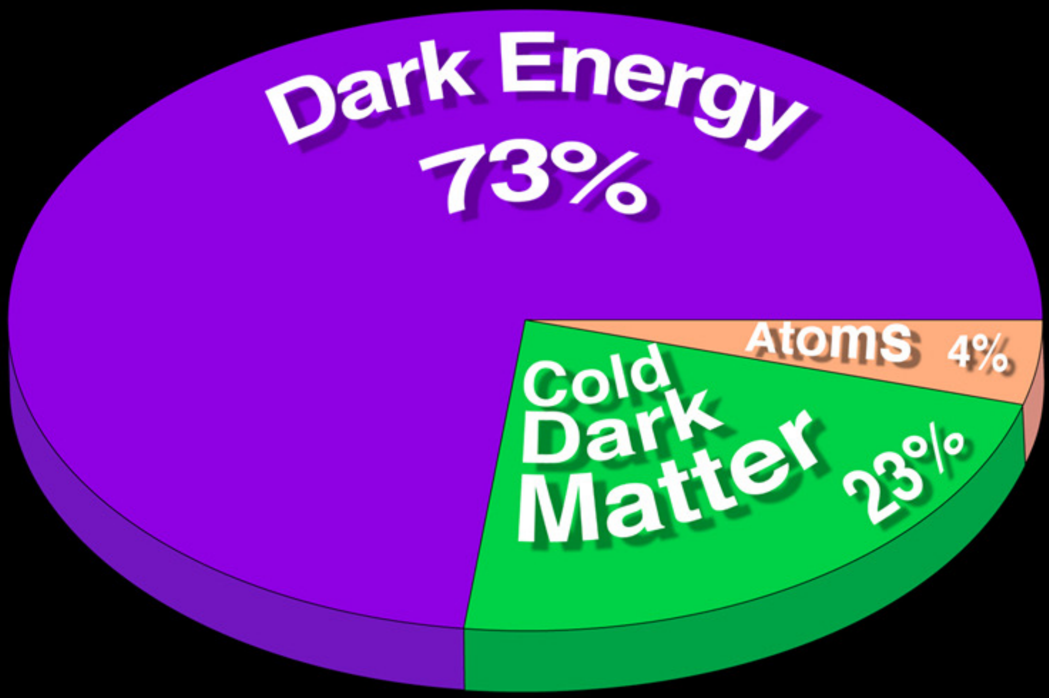
CERN

$3x10^{-13}$ seconds

Quarks differentiate
(10^{-34} seconds?)

??? (Before that)

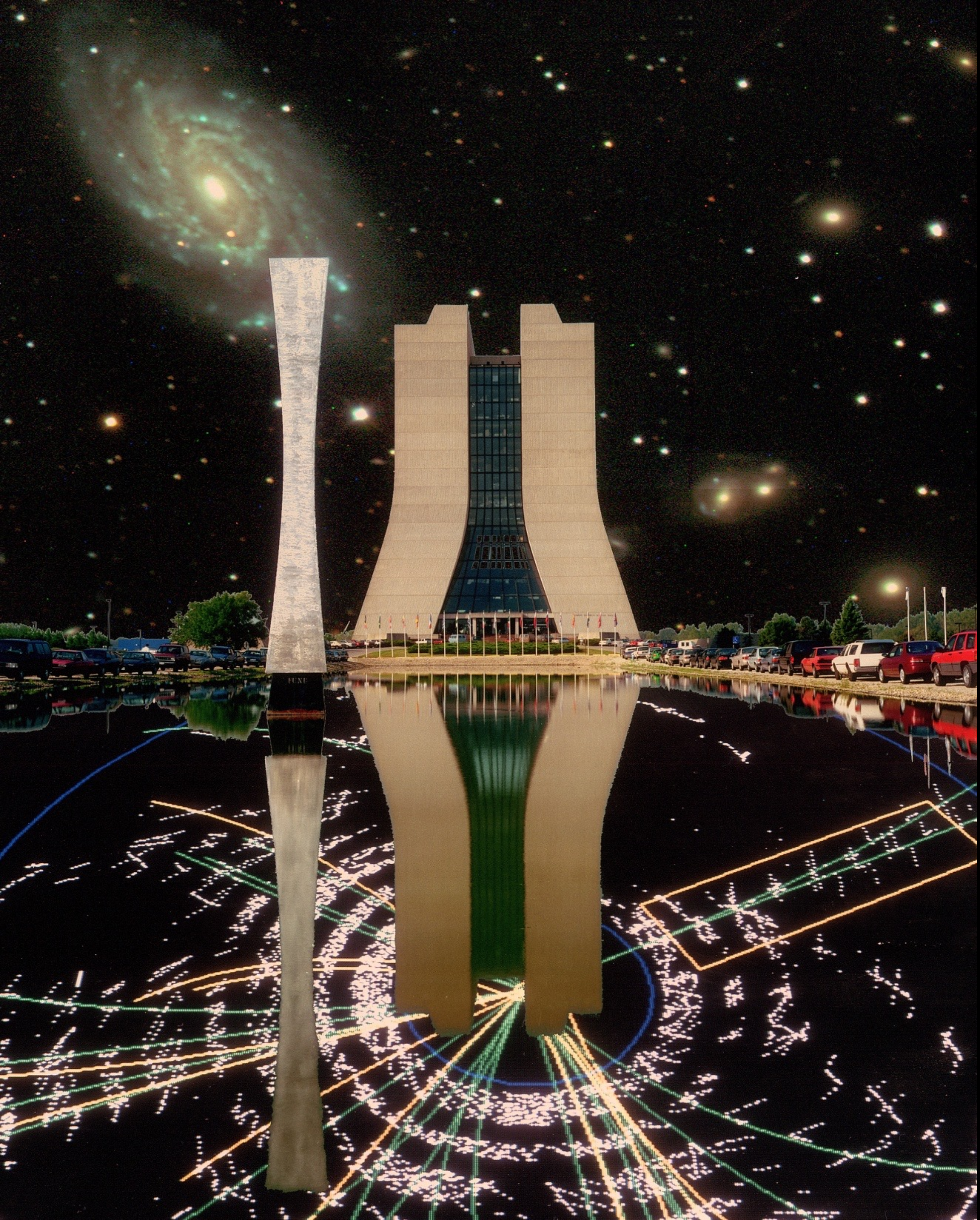
The Energy Composition of the Universe



No Clue

Discovered Matter

Undiscovered Matter



Is There A More Fundamental Theory? What Surprises Await Us?

“The most exciting phrase to hear in science, the one that heralds new discoveries, is not ‘Eureka!’ (I found it!), but ‘That's funny...’ ”

-- Isaac Asimov

Career Path

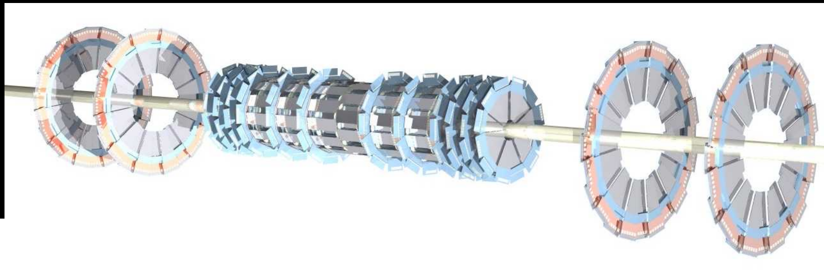
- Graduate Student
  - Classes/Qualifiers (~2 years)
  - Research/Dissertation (~4 years)
    - at CERN/Fermilab for about 2 years as an experimentalist

- Postdoctoral Researcher (4-6 years)
  - Usually full time at the lab
- Permanent Position
  - Professor at research university
  - Researcher at national lab
  - Professor at teaching university

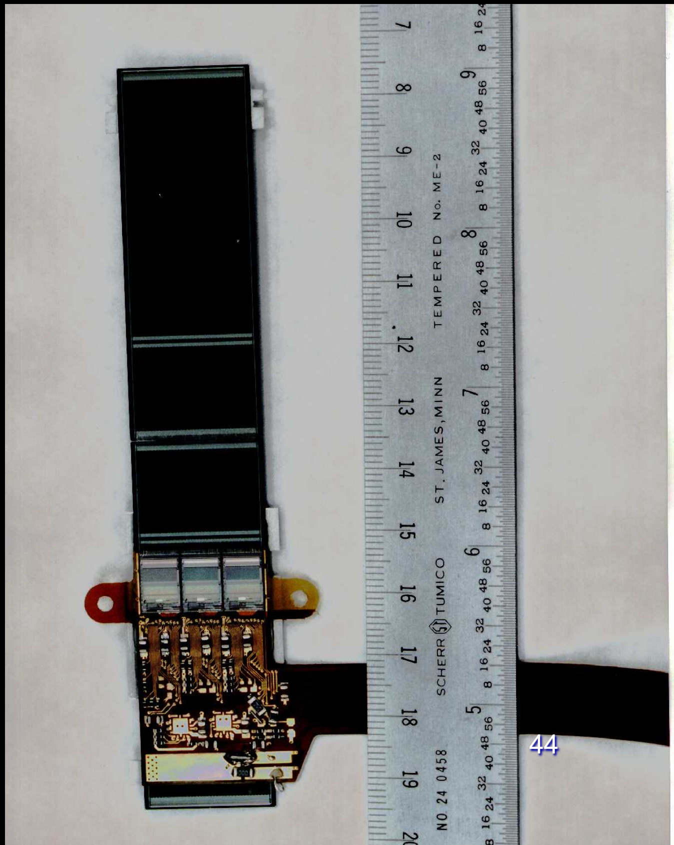
- Permanent industry job
  - About half of experimental students

Build and Test New Hardware

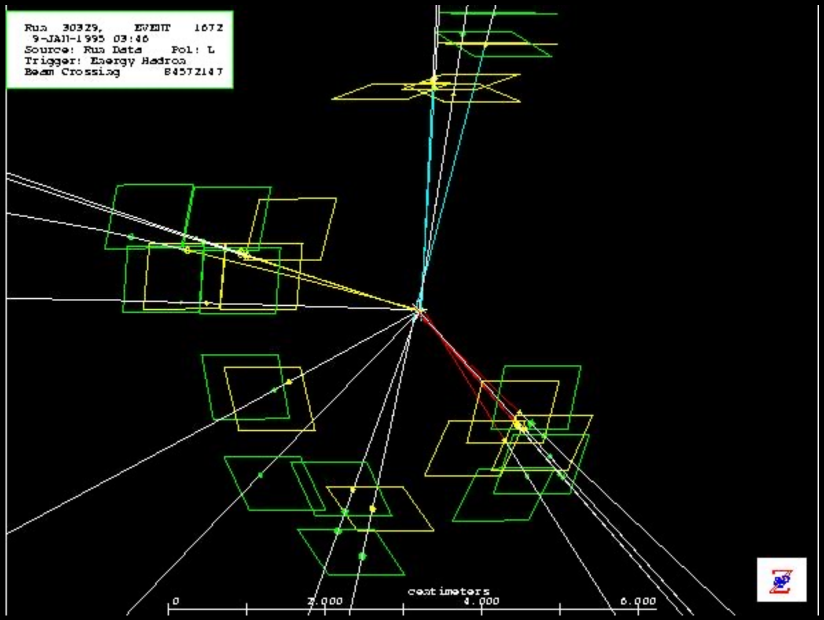
Take classes and learn physics

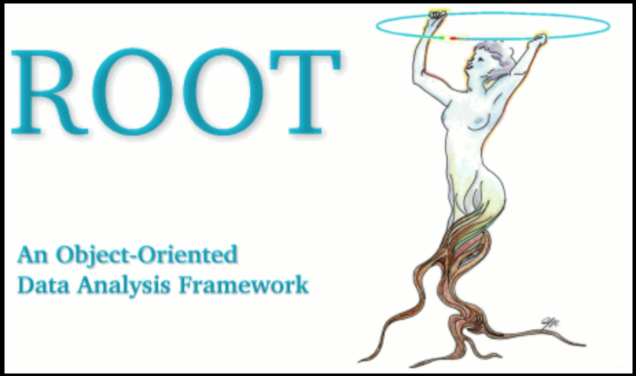


$$
\begin{aligned}
\mathcal{L}_{GWS} = & \sum_f (\bar{\Psi}_f (i\gamma^\mu \partial\mu - m_f)\Psi_f - eQ_f \bar{\Psi}_f \gamma^\mu \Psi_f A_\mu) + \\
& + \frac{g}{\sqrt{2}} \sum_i (\bar{a}_L^i \gamma^\mu b_L^i W_\mu^+ + \bar{b}_L^i \gamma^\mu a_L^i W_\mu^-) + \frac{g}{2c_w} \sum_f \bar{\Psi}_f \gamma^\mu (I_f^3 - 2s_w^2 Q_f - I_f^3 \gamma_5) \Psi_f Z_\mu + \\
& - \frac{1}{4} |\partial_\mu A_\nu - \partial_\nu A_\mu - ie(W_\mu^- W_\nu^+ - W_\mu^+ W_\nu^-)|^2 - \frac{1}{2} |\partial_\mu W_\nu^+ - \partial_\nu W_\mu^+ + \\
& - ie(W_\mu^+ A_\nu - W_\nu^+ A_\mu) + ig' c_w (W_\mu^+ Z_\nu - W_\nu^+ Z_\mu|^2 + \\
& - \frac{1}{4} |\partial_\mu Z_\nu - \partial_\nu Z_\mu + ig' c_w (W_\mu^- W_\nu^+ - W_\mu^+ W_\nu^-)|^2 + \\
& - \frac{1}{2} M_\eta^2 \eta^2 - \frac{g M_\eta^2}{8 M_W} \eta^3 - \frac{g'^2 M_\eta^2}{32 M_W} \eta^4 + |M_W W_\mu^+ + \frac{g}{2} \eta W_\mu^+|^2 + \\
& + \frac{1}{2} |\partial_\mu \eta + i M_Z Z_\mu + \frac{ig}{2c_w} \eta Z_\mu|^2 - \sum_f \frac{g}{2} \frac{m_f}{M_W} \bar{\Psi}_f \Psi_f \eta
\end{aligned}
$$

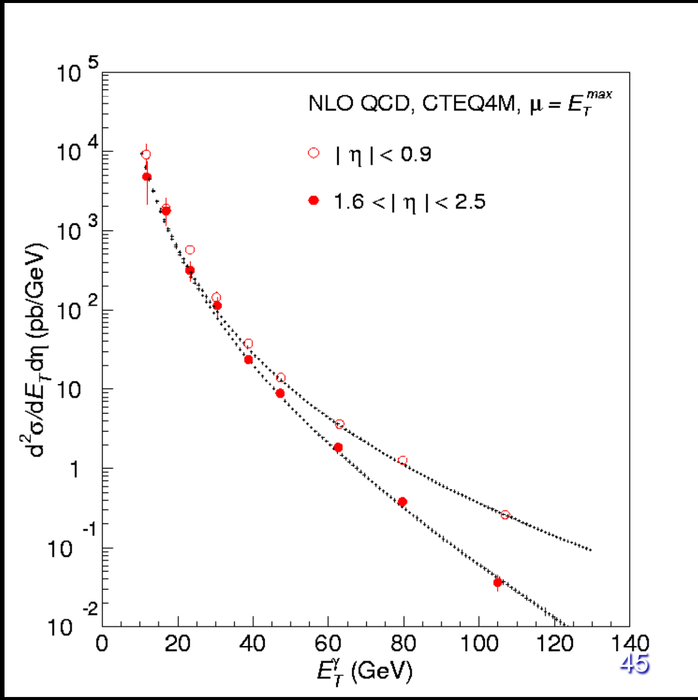


Write Software



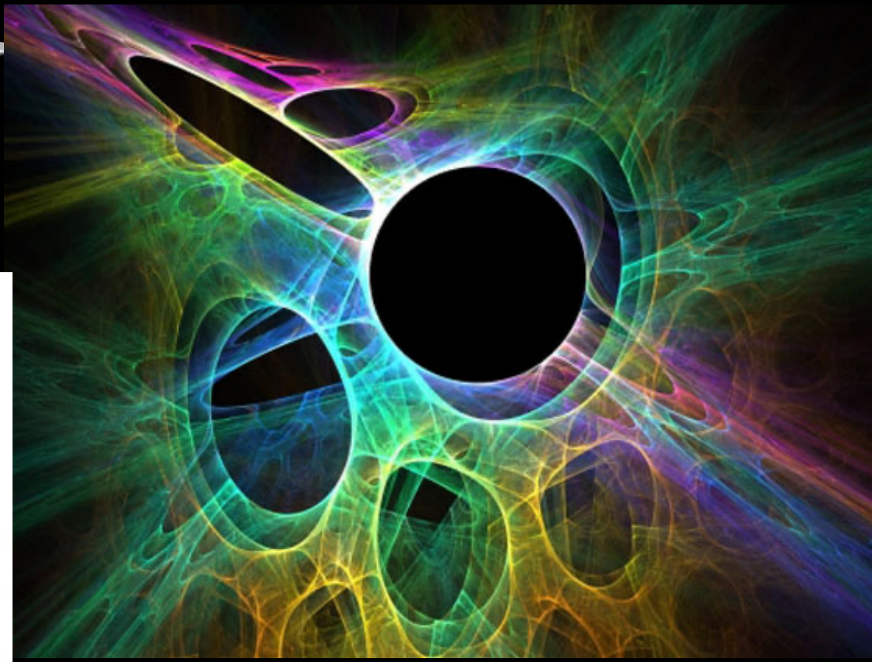


Analyze data



Run Software

Work with an international collaboration at Fermilab or CERN



Search for answers to fundamental questions about the universe that no one knows.

Questions?

Fun Videos

http://www.youtube.com/watch?v=iYRQpcJVQx8

Episode 2 – The Particles Strike Back

http://www.youtube.com/watch?v=j50ZssEojtM

Large Hadron Rap

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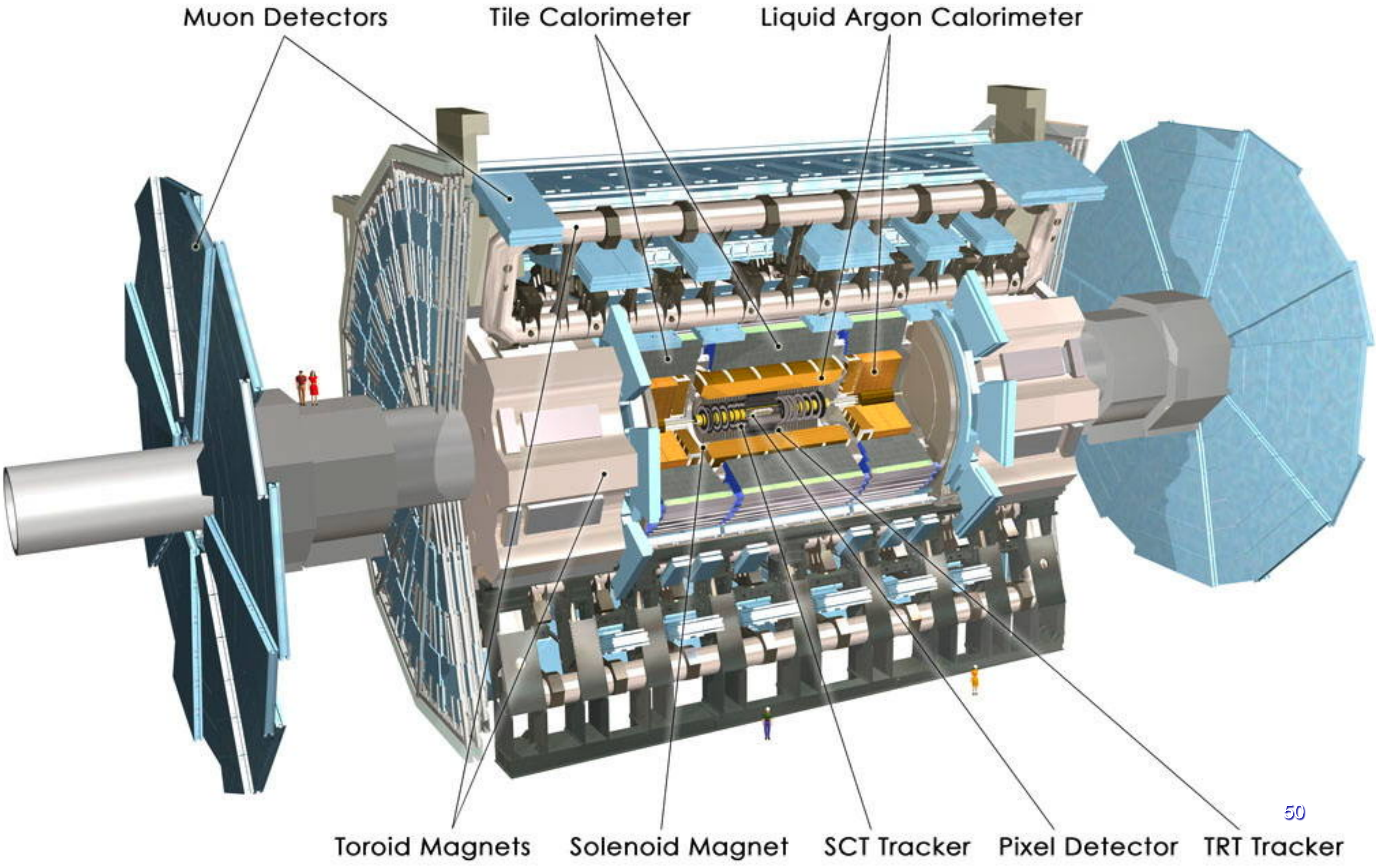
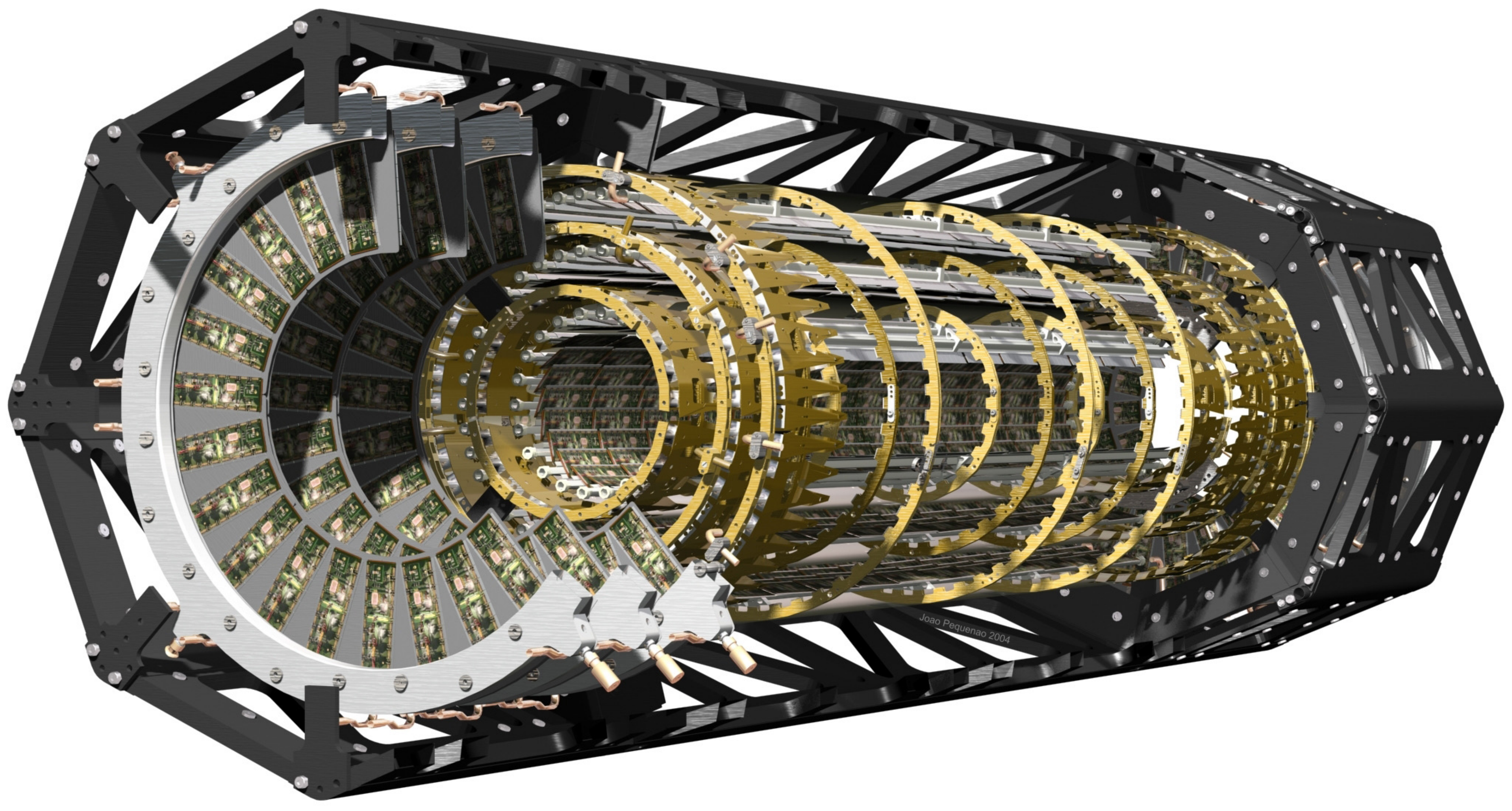
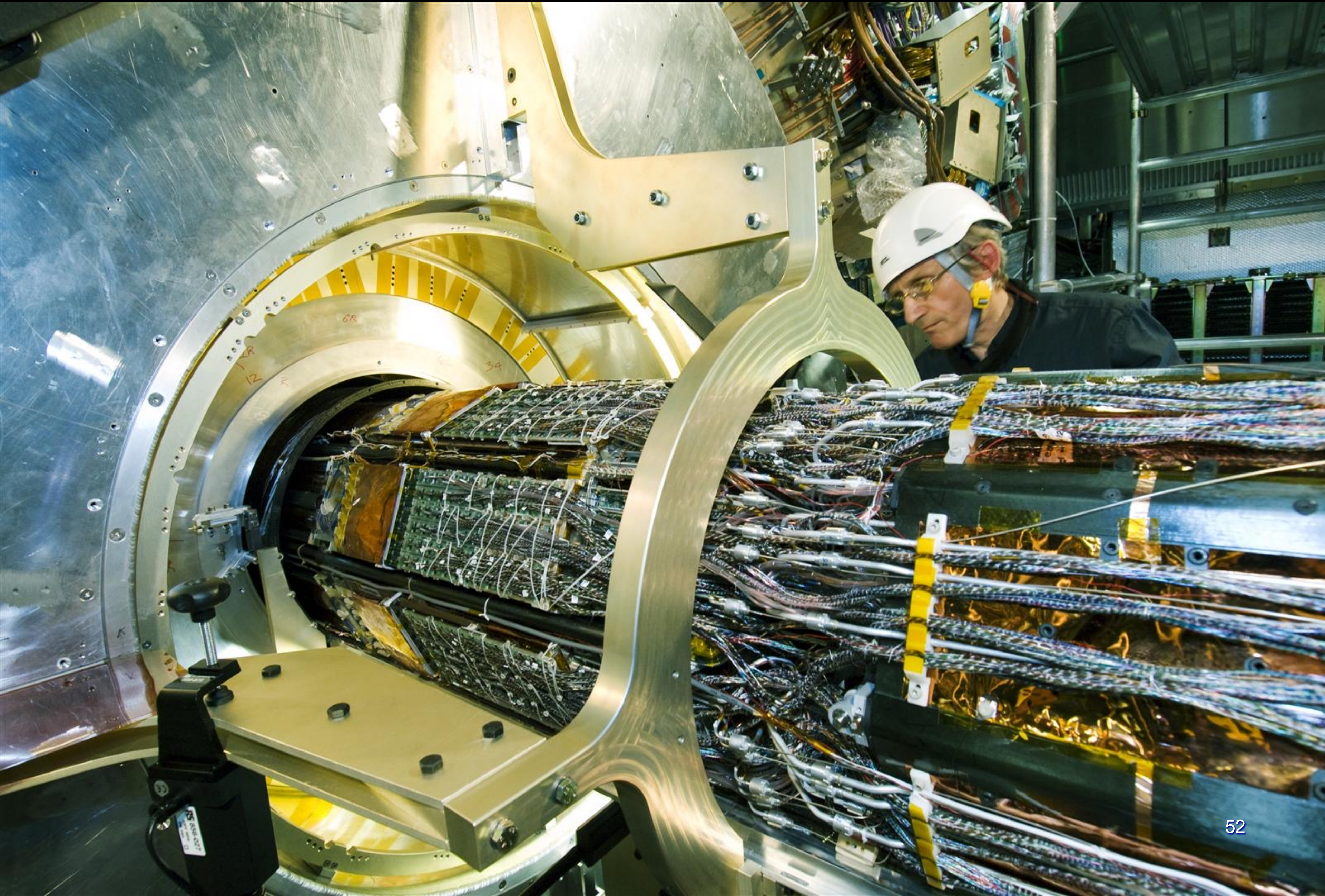
Large Hadron Rap

Oklahoma and The ATLAS Detector

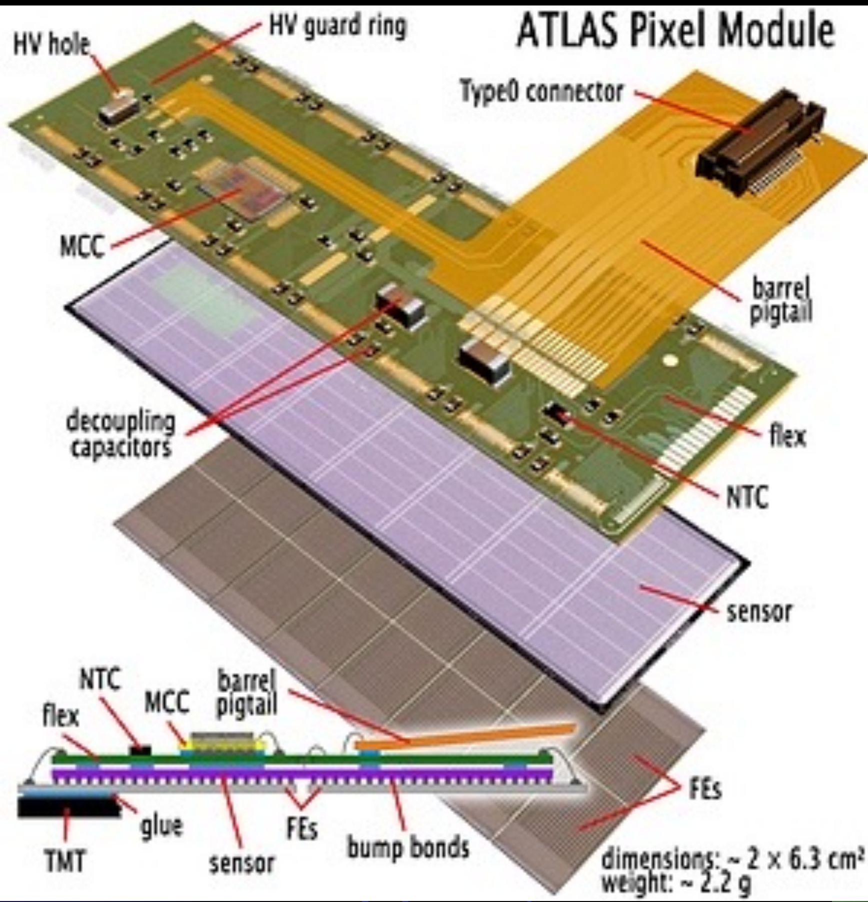


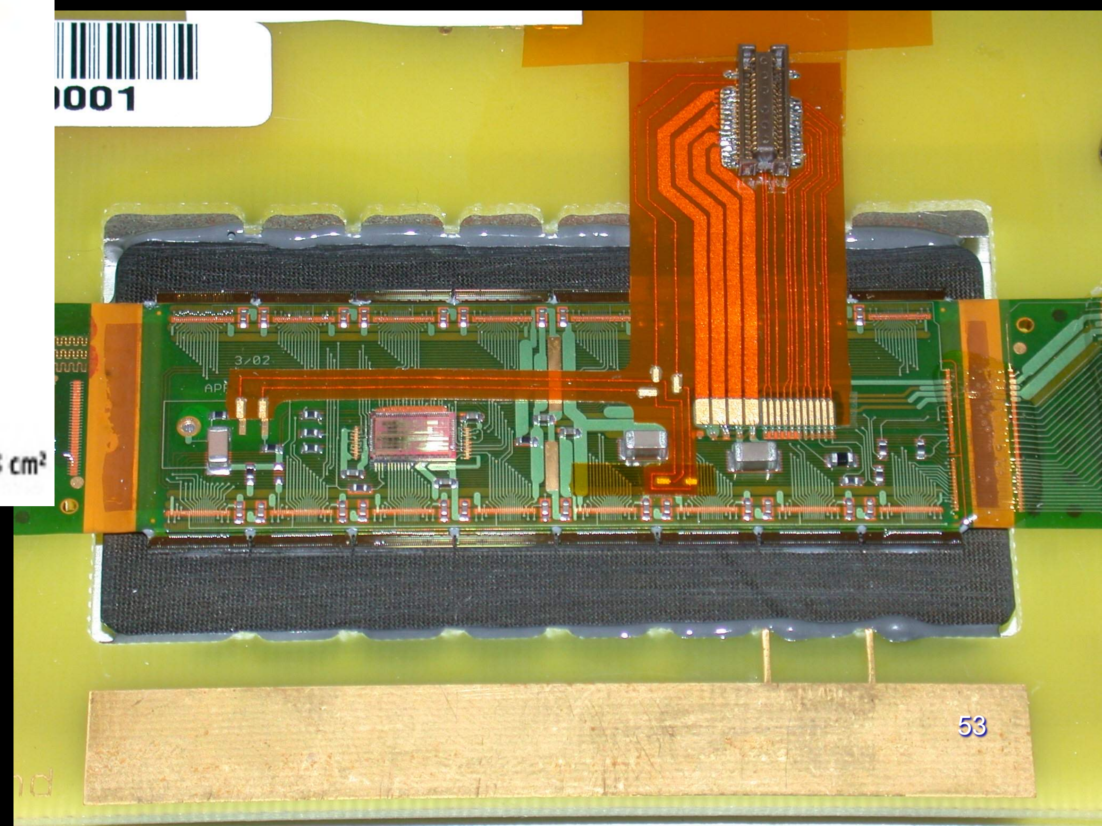
The Inner Detector



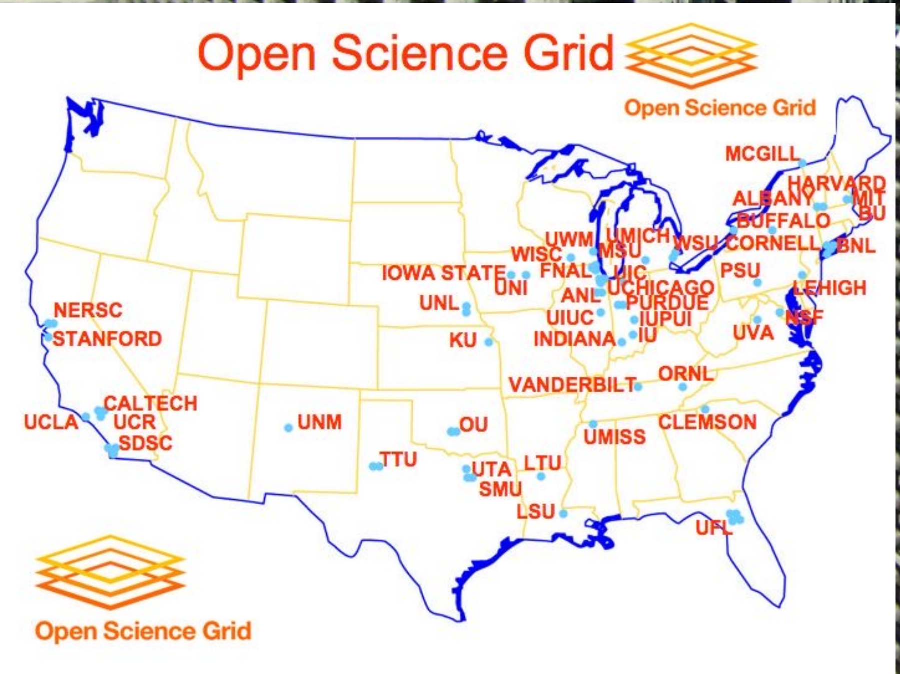


A single pixel module



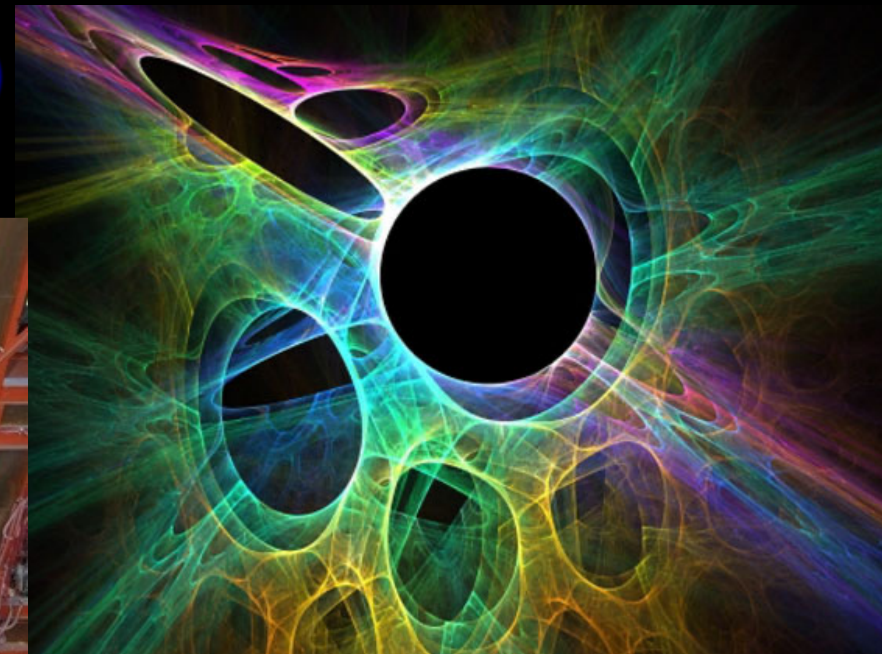


World-wide distributed computing


Open Science Grid
Open Science Grid
MCGILL
HARVARD
ALBANY
MIT
BU
BUFFALO
BNL
CORNELL
WSU
UMICH
MSU
UWM
WISC
FNAL
UIC
IOWA STATE
UNI
PSU
LEHIGH
ANL
UCHICAGO
PURDUE
UNL
NERSC
UIUC
IUPUI
NSF
STANFORD
KU
INDIANA
IU
UVA
VANDERBILT
ORNL
CALTECH
UCLA
UCR
SDSC
UNM
OU
CLEMSON
UMISS
TTU
UTA
LTU
SMU
LSU
UFL
Open Science Grid

OU ATLAS Tier 2 Cluster

Work with an International Collaboration (in Switzerland?)



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