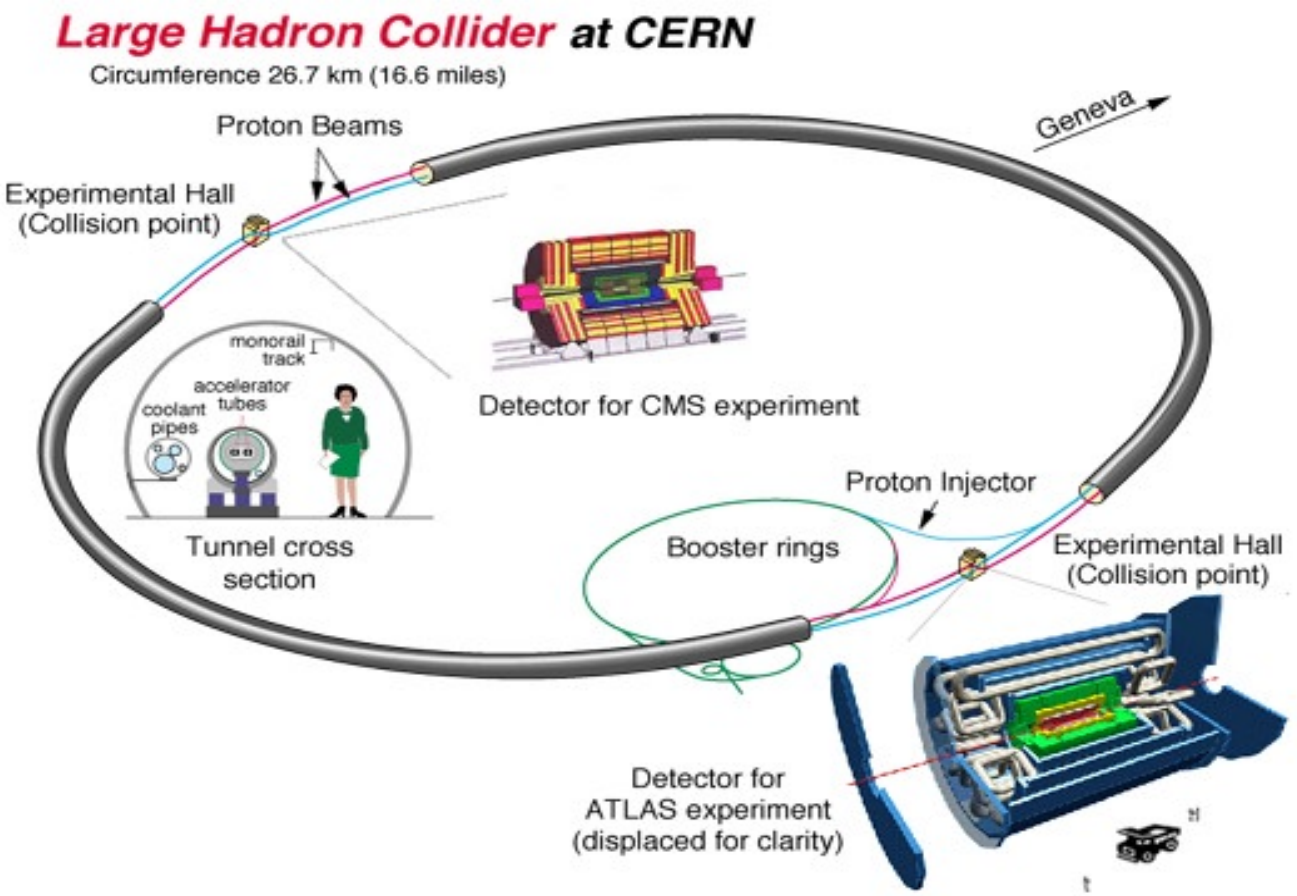
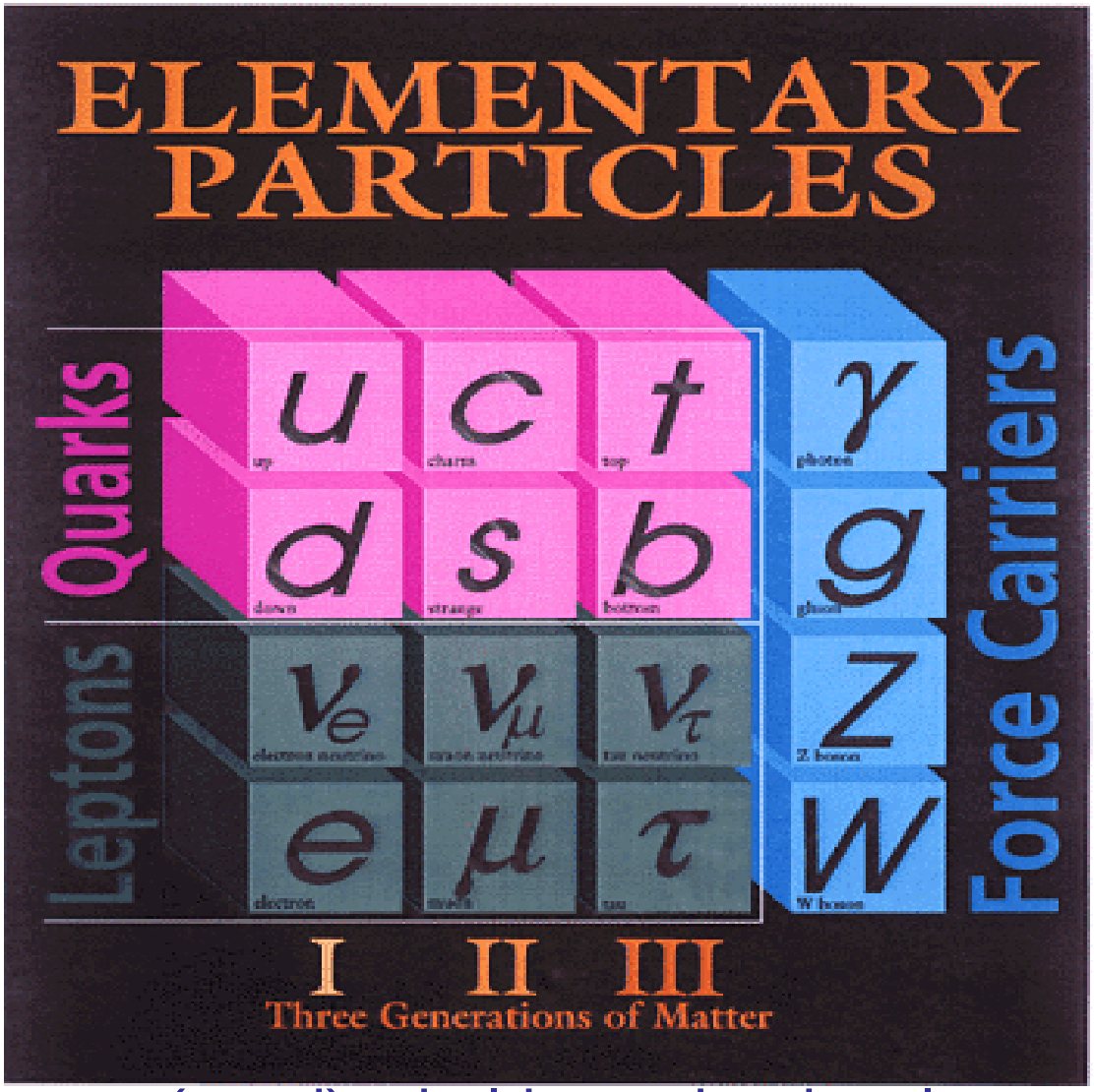
First some Introductory Stuff => On The Web

http://hep.physics.utoronto.ca/~orr/wwwroot/phy357/PHY357S.htm

PHY357 = What is the Universe Made Of?



Is the Universe Made of These?



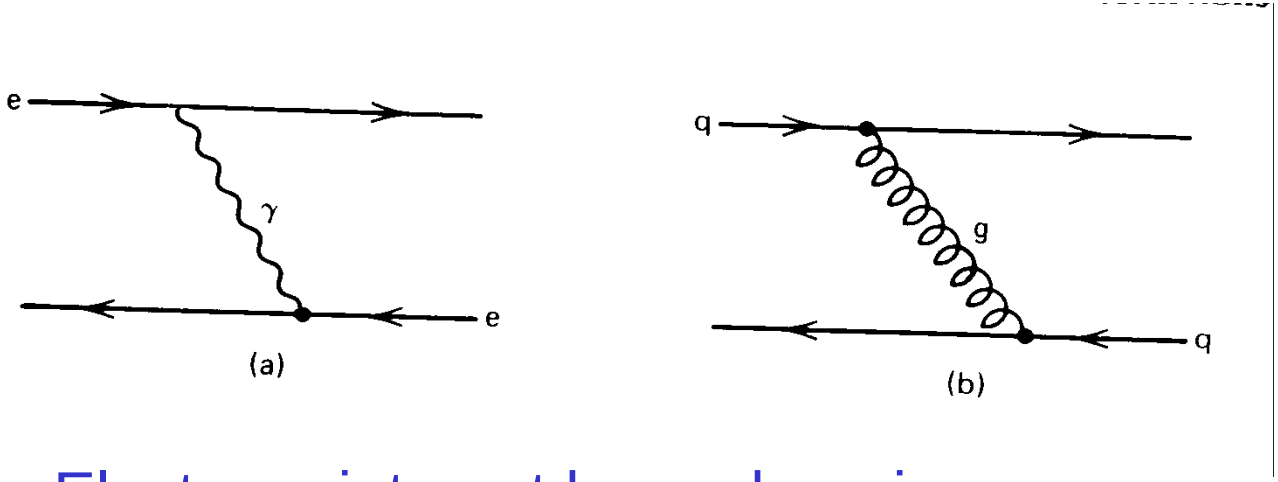
Proton = (u u d) – held together by gluons

Neutron = (u d d)

Quantum Forces

- In Quantum Field Theory, particles interact via:

Exchange of virtual particles



Electrons interact by exchanging:

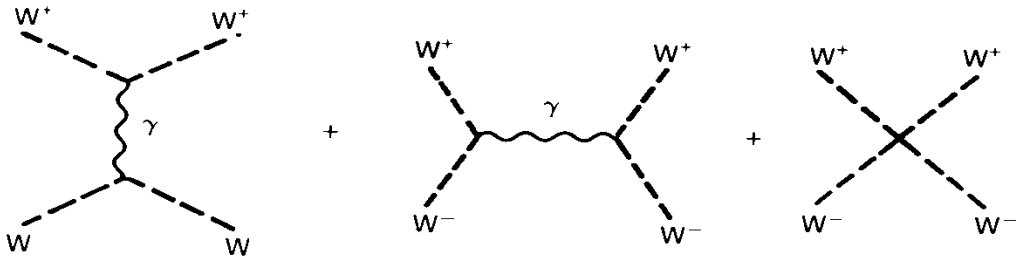
Virtual Photons - EM Force

Quarks interact by exchanging:

Virtual Gluons – Color Force

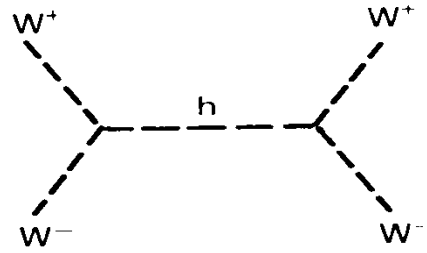
Higgs Boson

- Electromagnetism on its own can be made to give finite results for all calculations.
- Unified Electroweak theory gives infinite results for process like:



- Become finite if include new particle

Higgs



Spontaneous Symmetry Breaking

Renormalizable Gauge Theory

- Higgs makes $W^{\pm}$ Z^{0} massive, and actually generates masses of fundamental particles. It is a quantum field permeating the universe.

How Does Higgs Generate Mass?

- In vacuum, a photon:
  has velocity c and has zero mass

- In glass, a photon:
  has velocity < c , same as an effective mass

Refractive Index

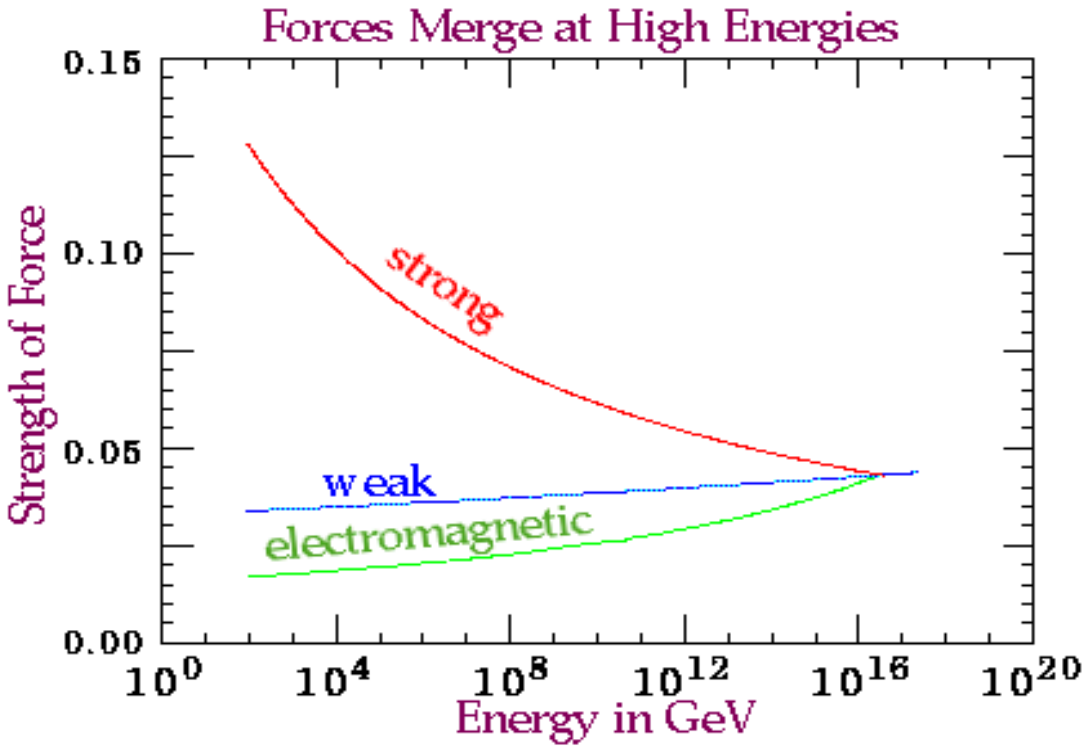
- This is due to photon interacting with
  electromagnetic field in condensed matter

- By analogy can understand masses of particles
  generated by Higgs Field in vacuum

Grand Unification.

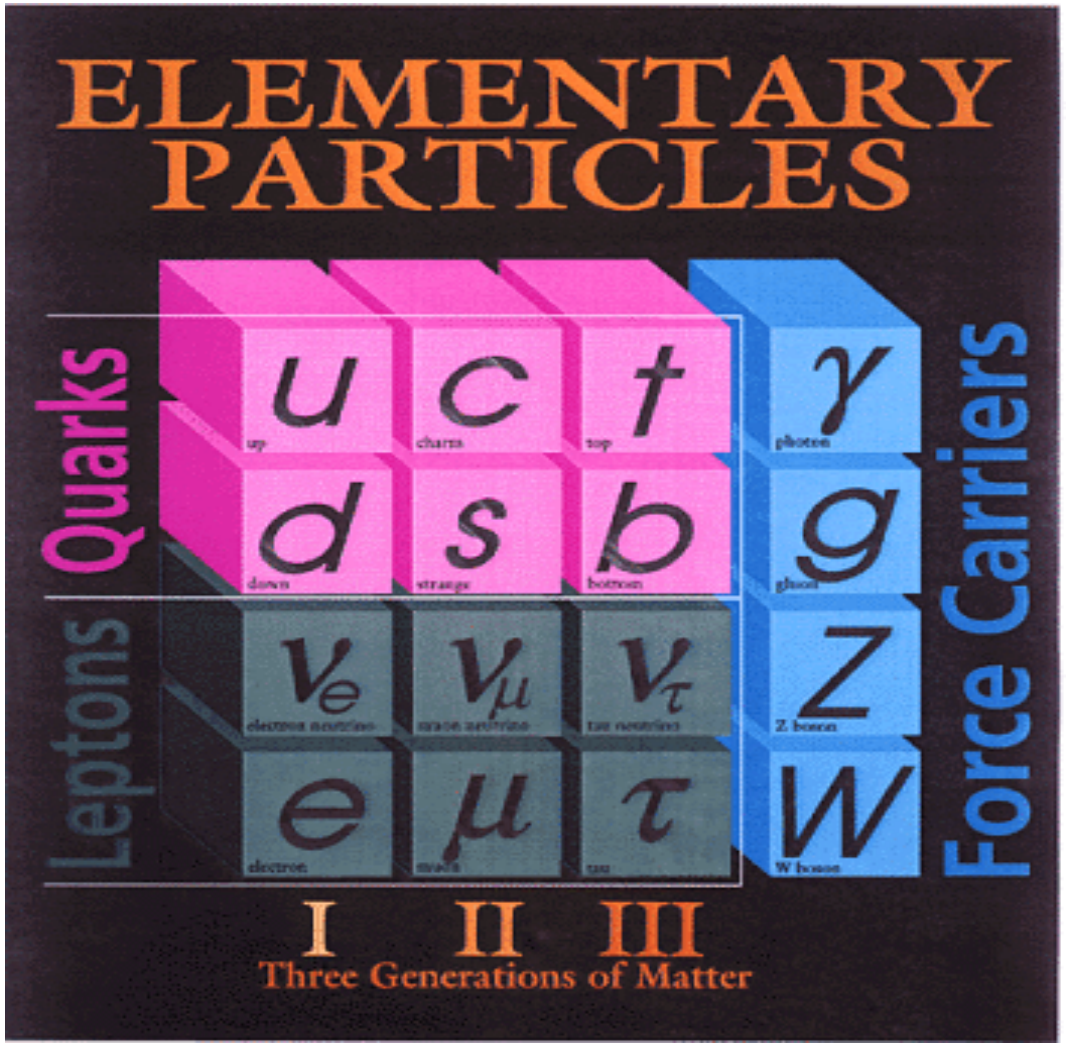
- At a high enough energy
  electromagnetism
  weak force
  strong (colour) force

become aspects of Grand Unified Force

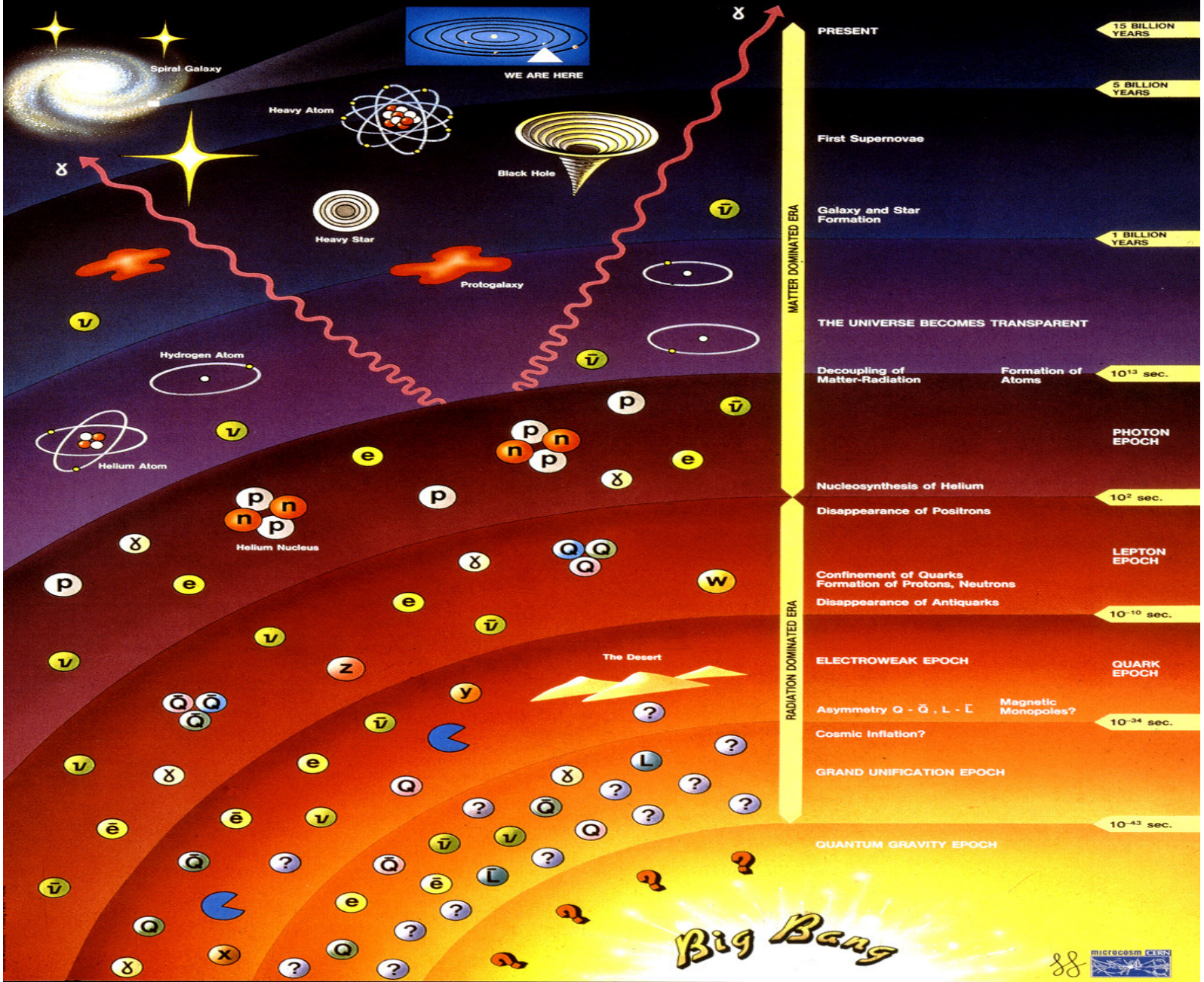


Understand History of Universe?

- What we think (thought?) visible matter is made of.



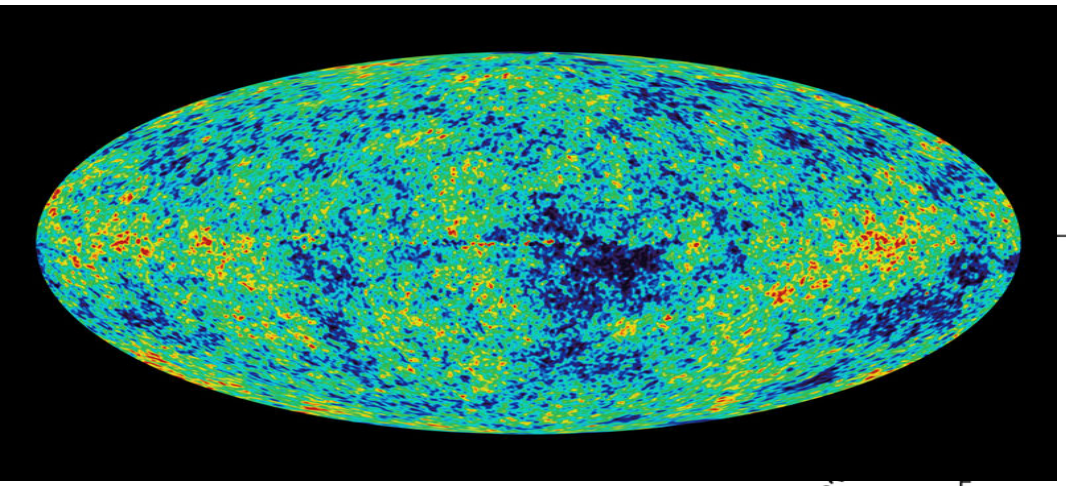
History of the Universe



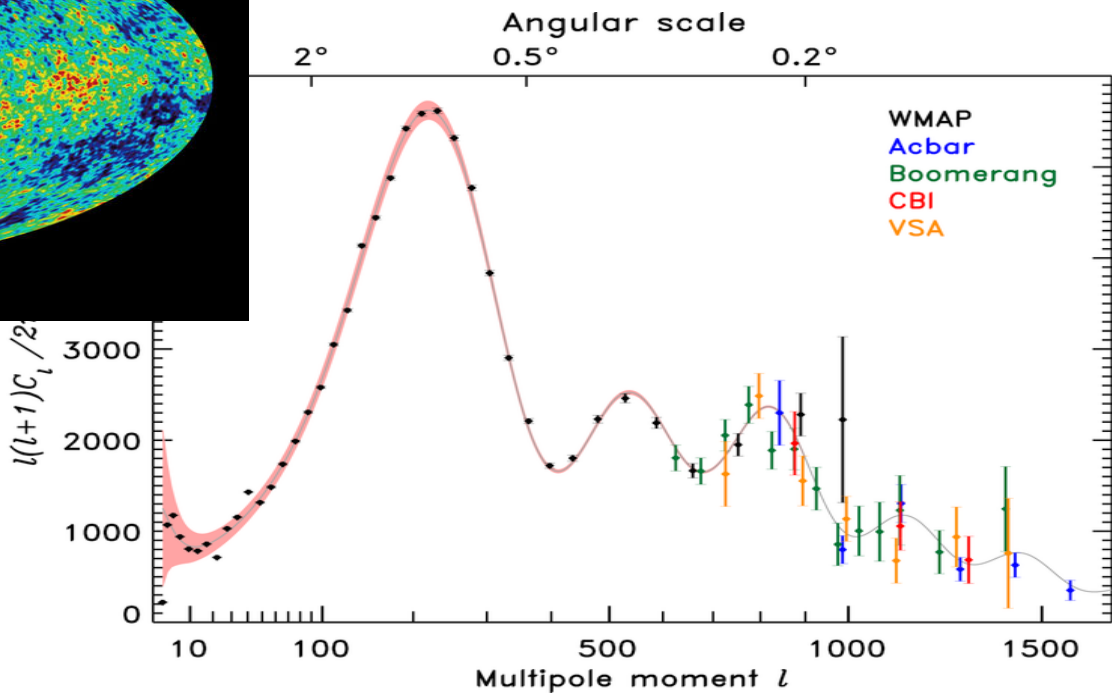
Measuring $\Omega_0 = \rho_0 / \rho_C$

- Amazingly enough can measure
  - Total matter/energy density in universe
    - Seems equal to critical density for flat space/time
- Measure temperature fluctuations in remnant of fireball from Big Bang.

$$\Omega_0 = 1.003 \pm 0.013$$



Map of sky temp
~ 3 Kelvin



Density of Standard Model Matter

- Referred to as Baryonic Matter
- Density is Ω_B
- If Universe is made of quarks & leptons

$$\Omega_B = \Omega_0 = 1$$

- Ω_B measured from abundance of elements produced in nucleosynthesis of Big Bang.

  Deuterium, Helium, Lithium

$$\Omega_B = 0.044$$

$$\Omega_B \neq \Omega_0$$

- Most of Universe is not Standard Model matter. Some kind of Dark Matter

Density of All Matter Ω_M

- Can measure density of all matter, whatever its nature, Ω_M ,by looking at gravitational motion

  rotation curves of galaxies

  motion of galactic clusters

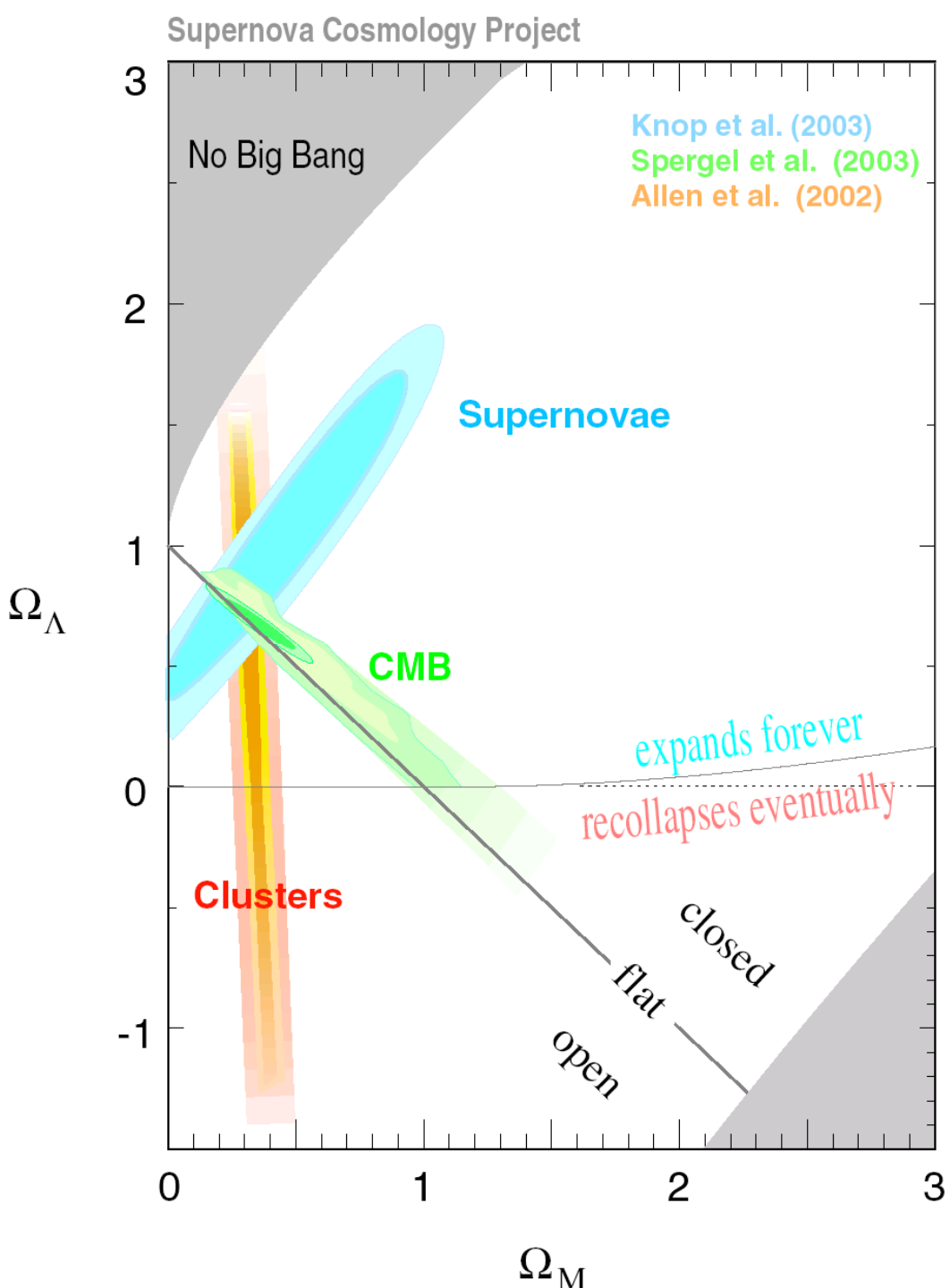
  Fit to global parameters of Universe

$$\Omega_M = 0.26 \pm 0.012$$

- There is indeed Dark Matter

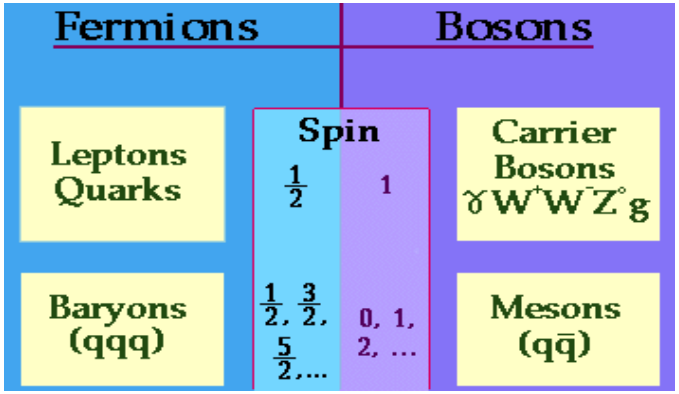
$$\Omega_0 = 1$$

- So even with this Dark Matter, cannot account for
- Universe must be 75% Something Else


Supernova Cosmology Project
No Big Bang
Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
3
2
1
0
-1
0
1
2
3
Ω_Λ
Ω_M

Need for Supersymmetry

- In Grand Unified Theories cannot Unify forces, unless postulate unseen form of matter
  - Higgs mass runs away to Plank Scale
  - Three forces never have same strength
- Unless all particles have supersymmetric sparticle partners (of higher mass)



+

Sleptons Bosinos

Squarks

Spin 1 Spin1/2

SUSY + Dark Matter

- Supersymmetric Particles are unstable

$$Susy \rightarrow Normal + Susy$$

- Eventually decay chain ends in Normal matter + lightest SUSY particle
- Lightest SUSY particle cannot interact with normal matter
- Lightest SUSY particle good candidate for

Dark Matter

- Hope to produce

(SUSY - antiSUSY) pairs and Higgs

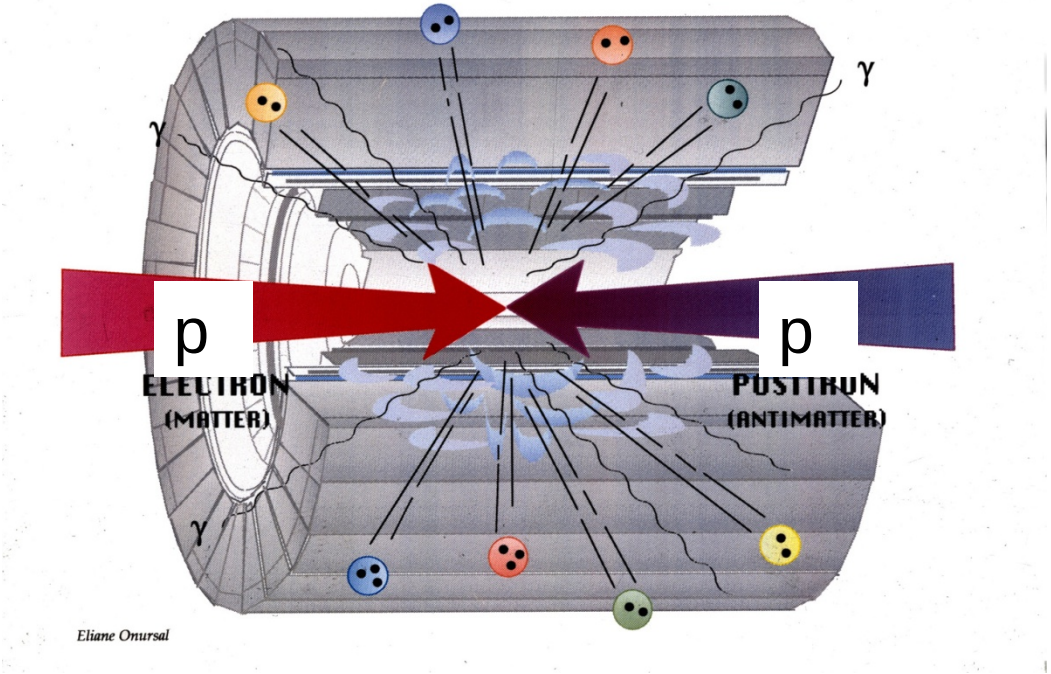
at

Large Hadron Collider

How to Make Matter / AntiMatter?

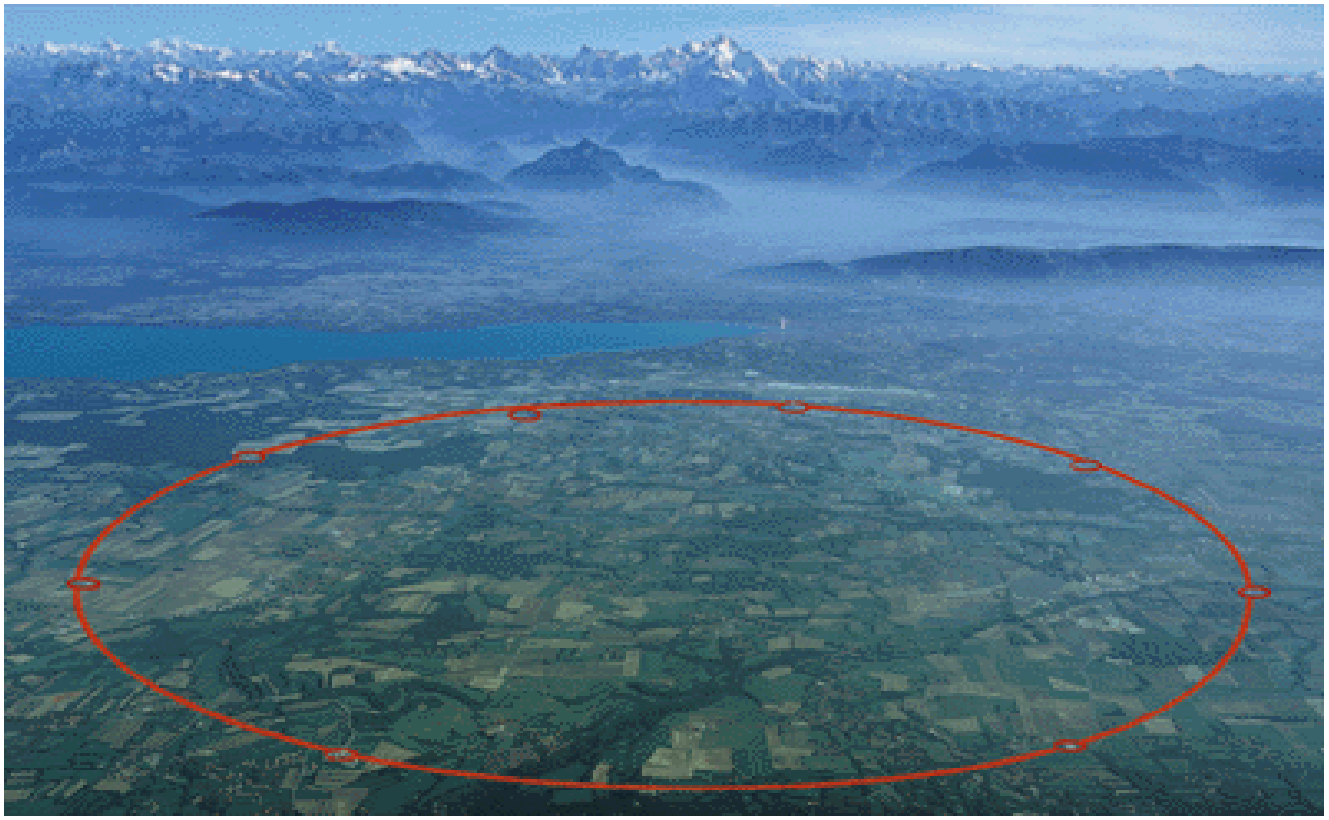
Colliding high energy beams

Energy of beams transformed into mass of new particles



- LHC will be proton - proton collider
- For SUSY observation must contain ALL visible energy, in order to infer invisible SUSY

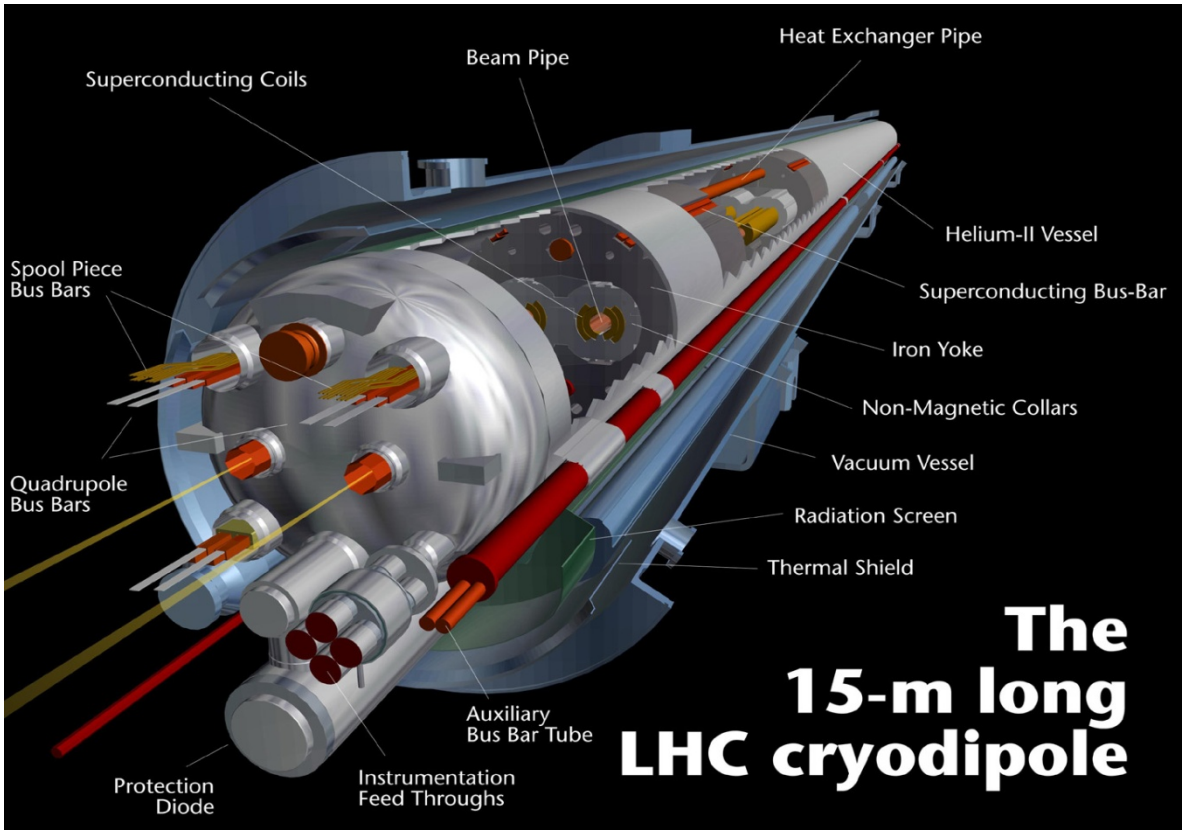
CERN Seen from the Air



- Tunnels of CERN accelerator complex superimposed on a map of Geneva.
- Accelerator is 50 m underground
- 25 km in circumference

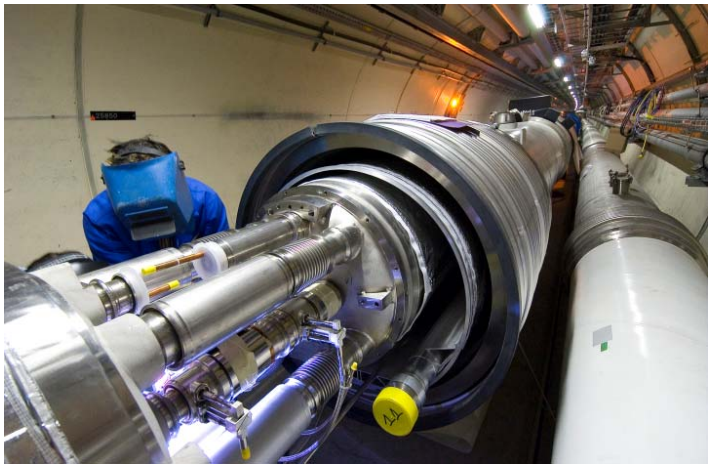
Superconducting Magnet

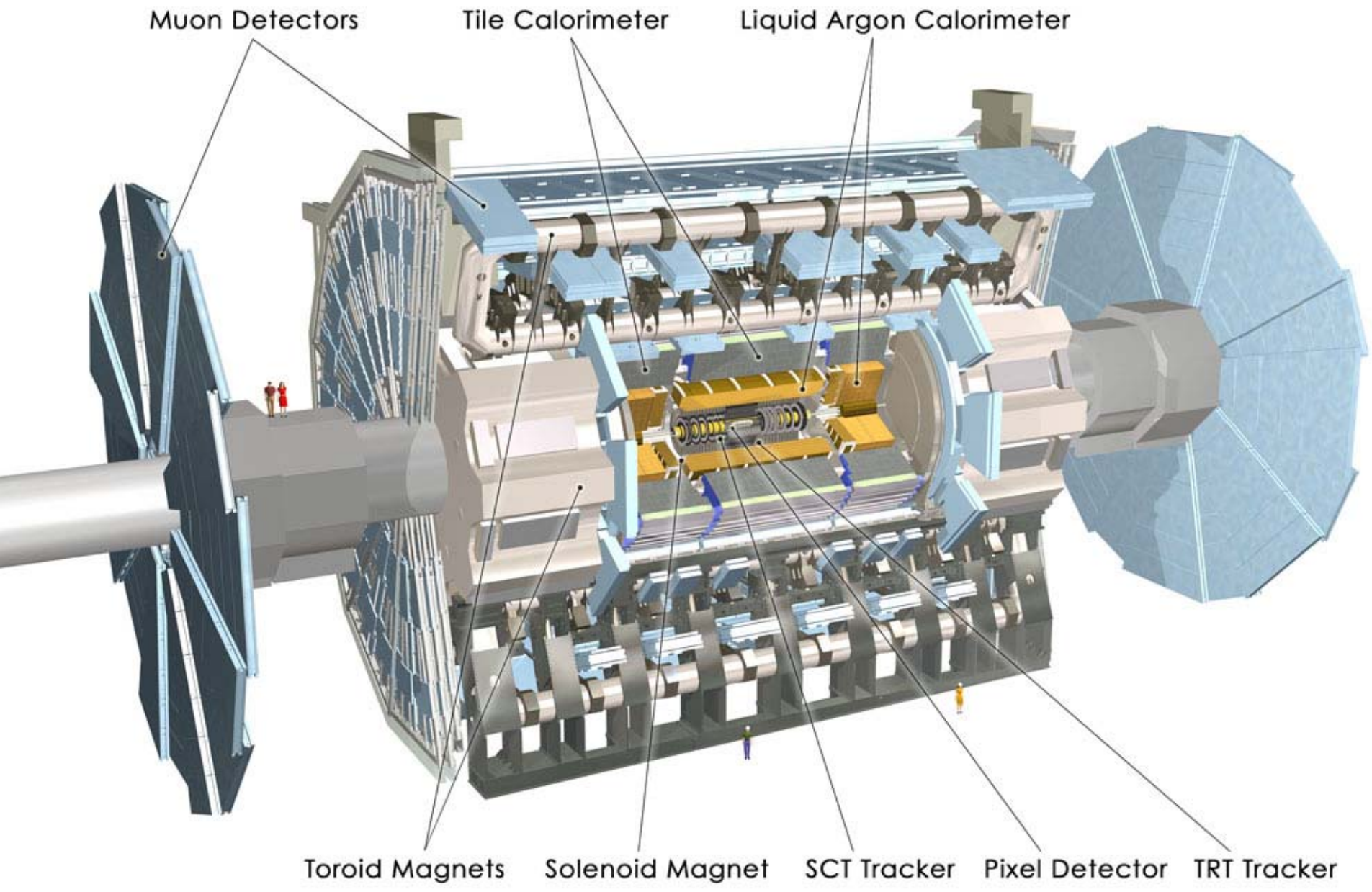
8 Tesla



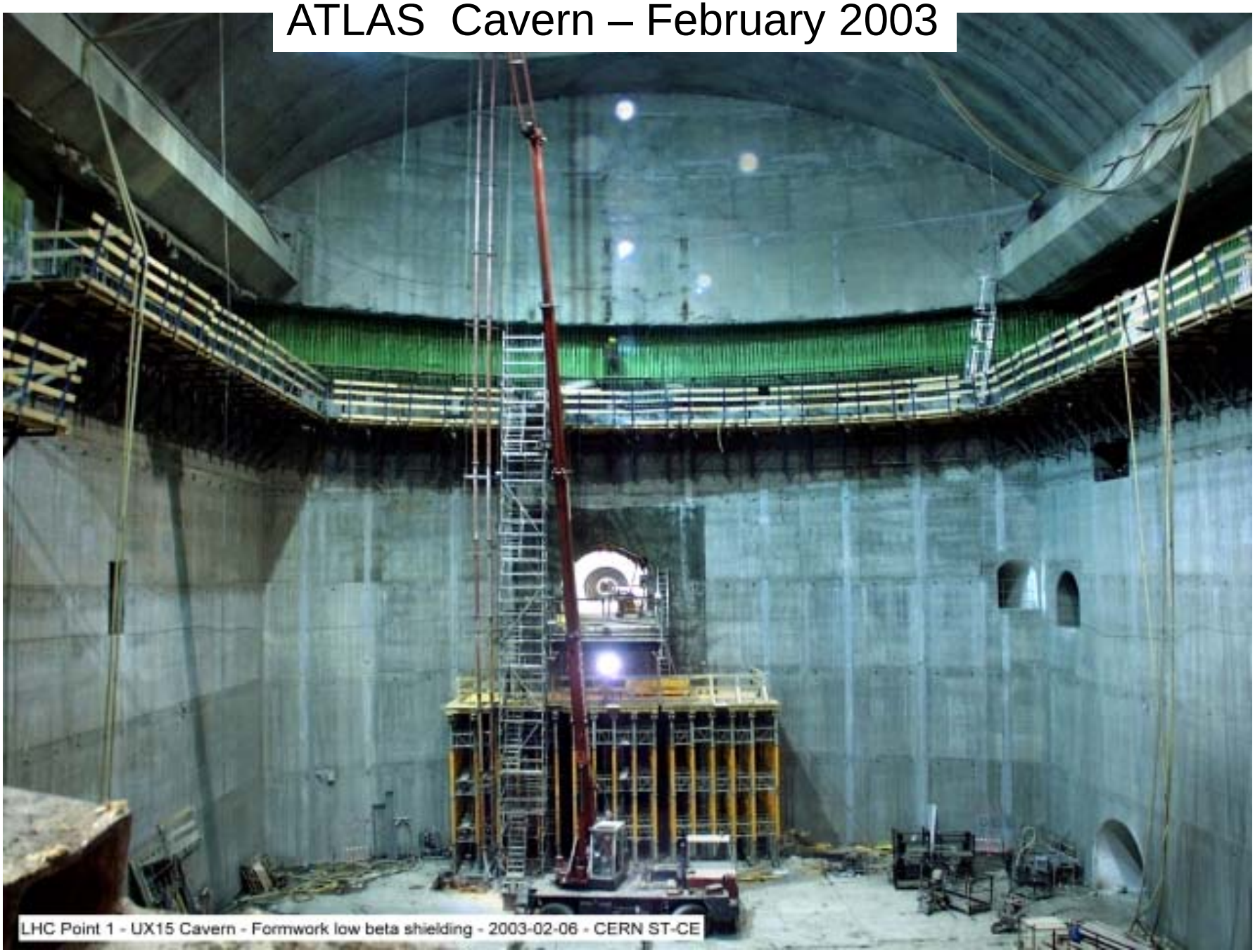
- In order to accelerate protons to high energy, must bend them in circular accelerator
- 7 TeV momentum needs intense magnetic field

Underground

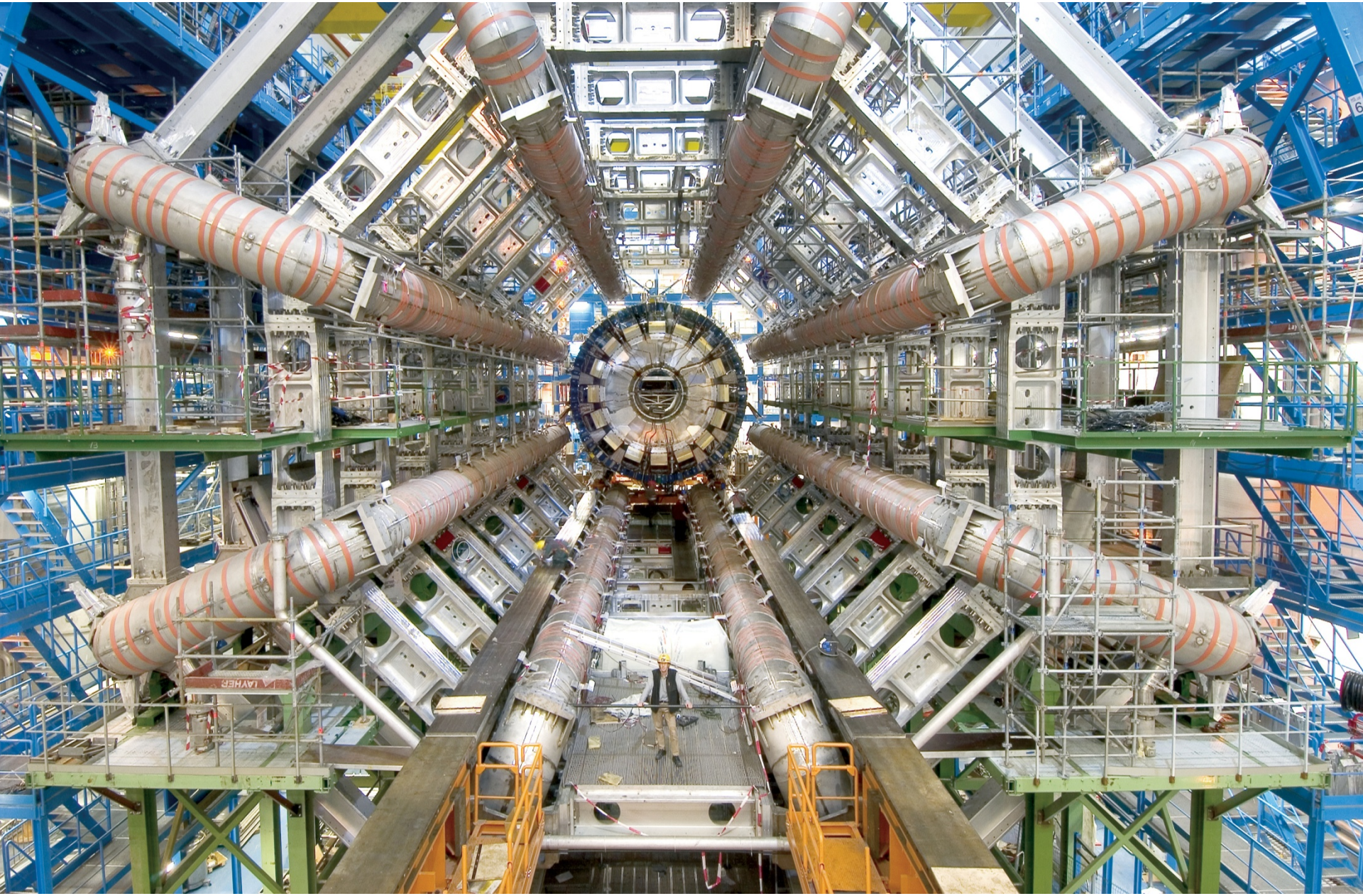



Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker

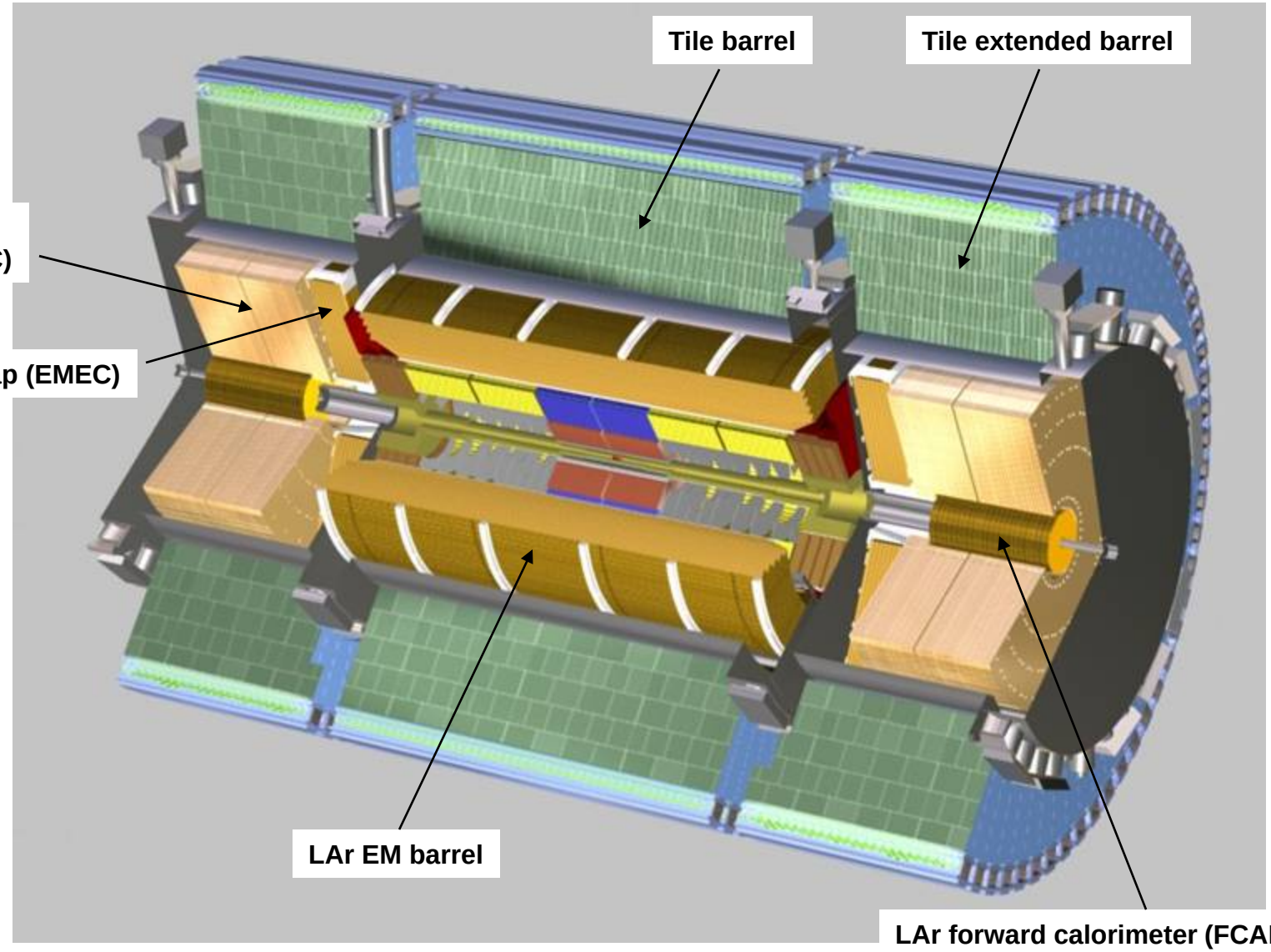
ATLAS Cavern – February 2003



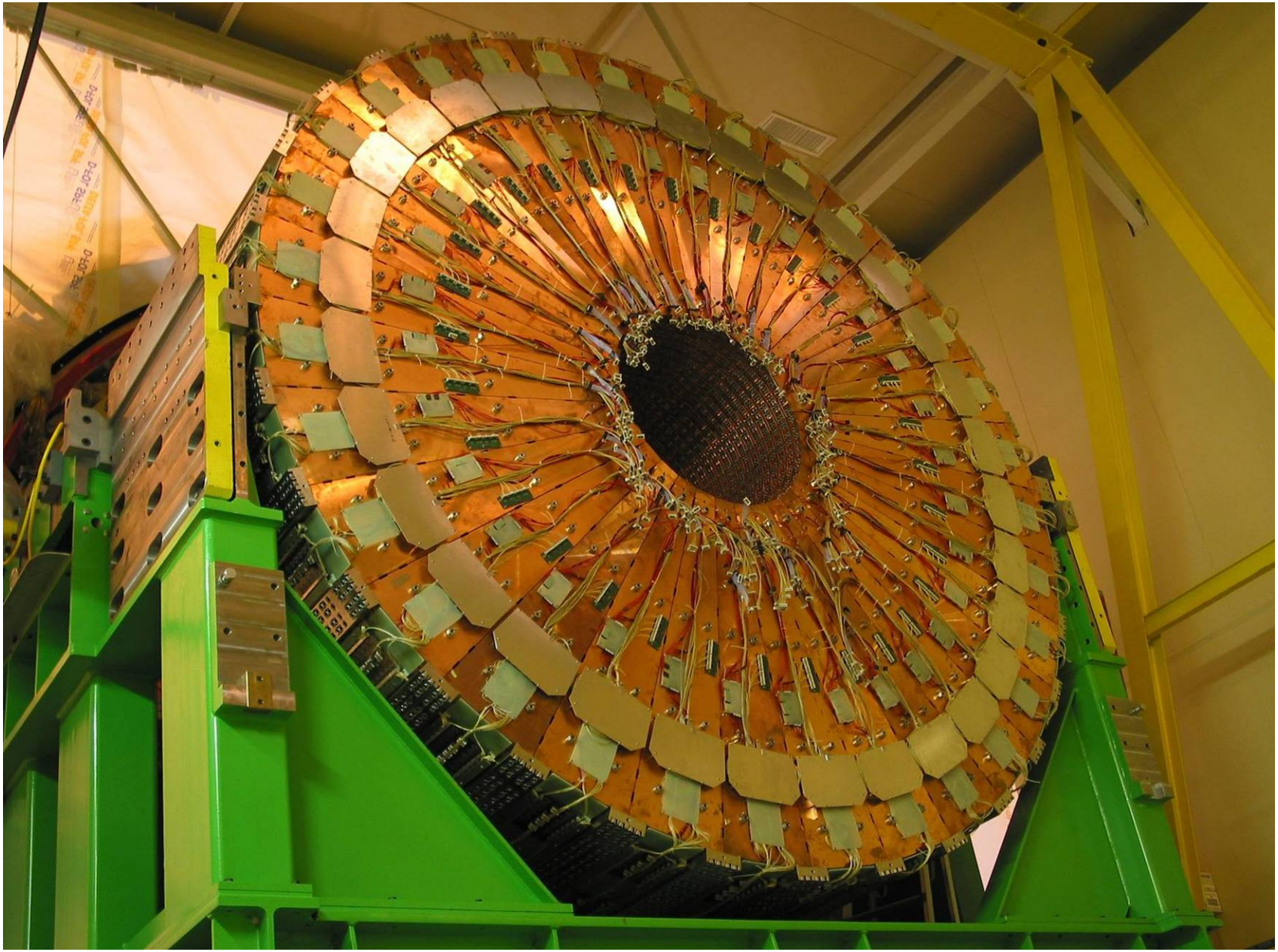
ATLAS Cavern – November 2004



LAr and Tile Calorimeters

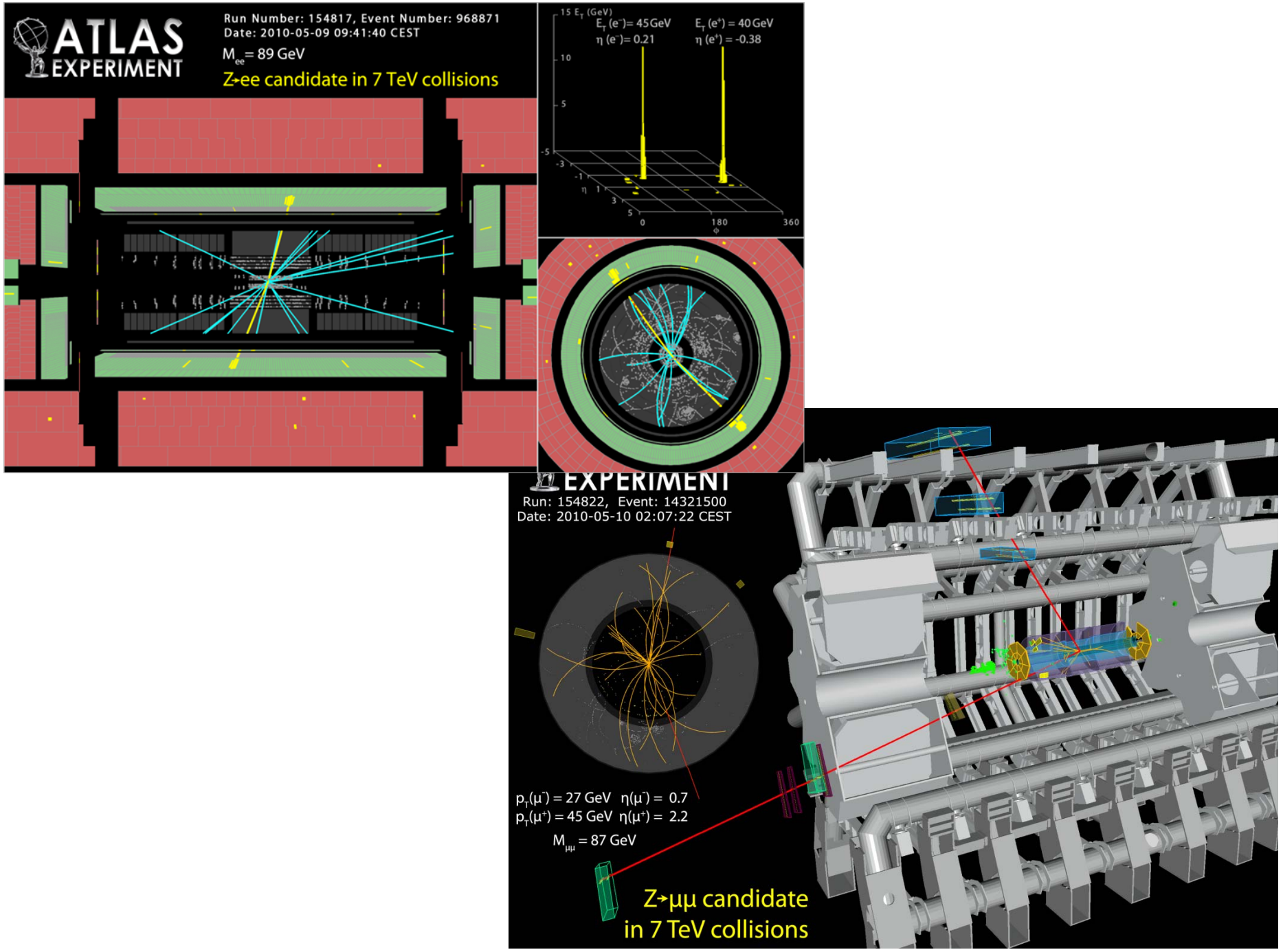


HEC 2 A-wheel on the insertion stand, Aug. 2004



LAr Forward Calorimeters

- FCAL C assembly into tube – Fall 2003


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
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