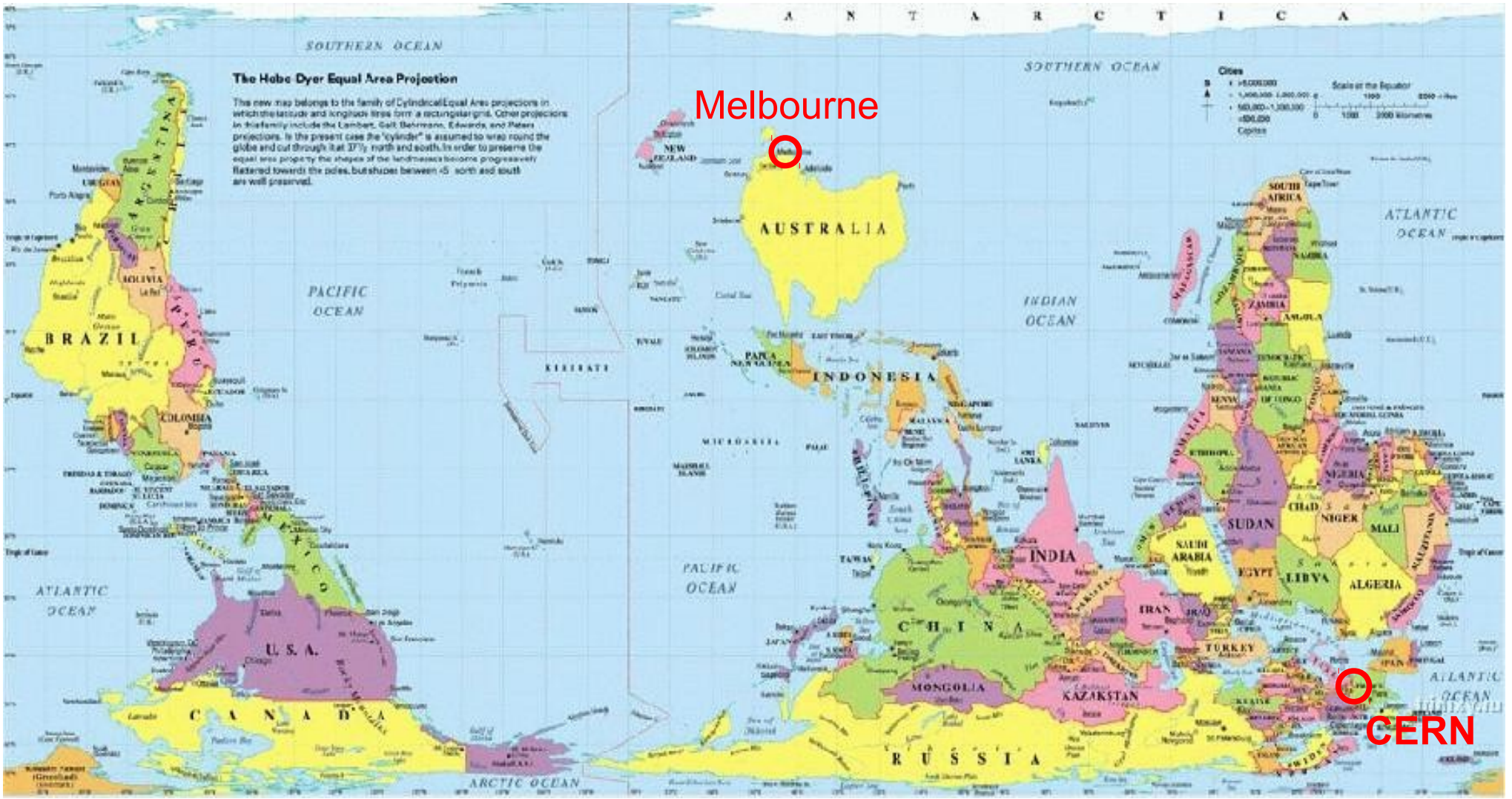
Hitchhikers Guide to Accelerators

Ralph J. Steinhagen, CERN
ICHEP'12, Melbourne, 2012-07-06

To put things into perspective

- … Melbourne at the top of the High-Energy-Physics World



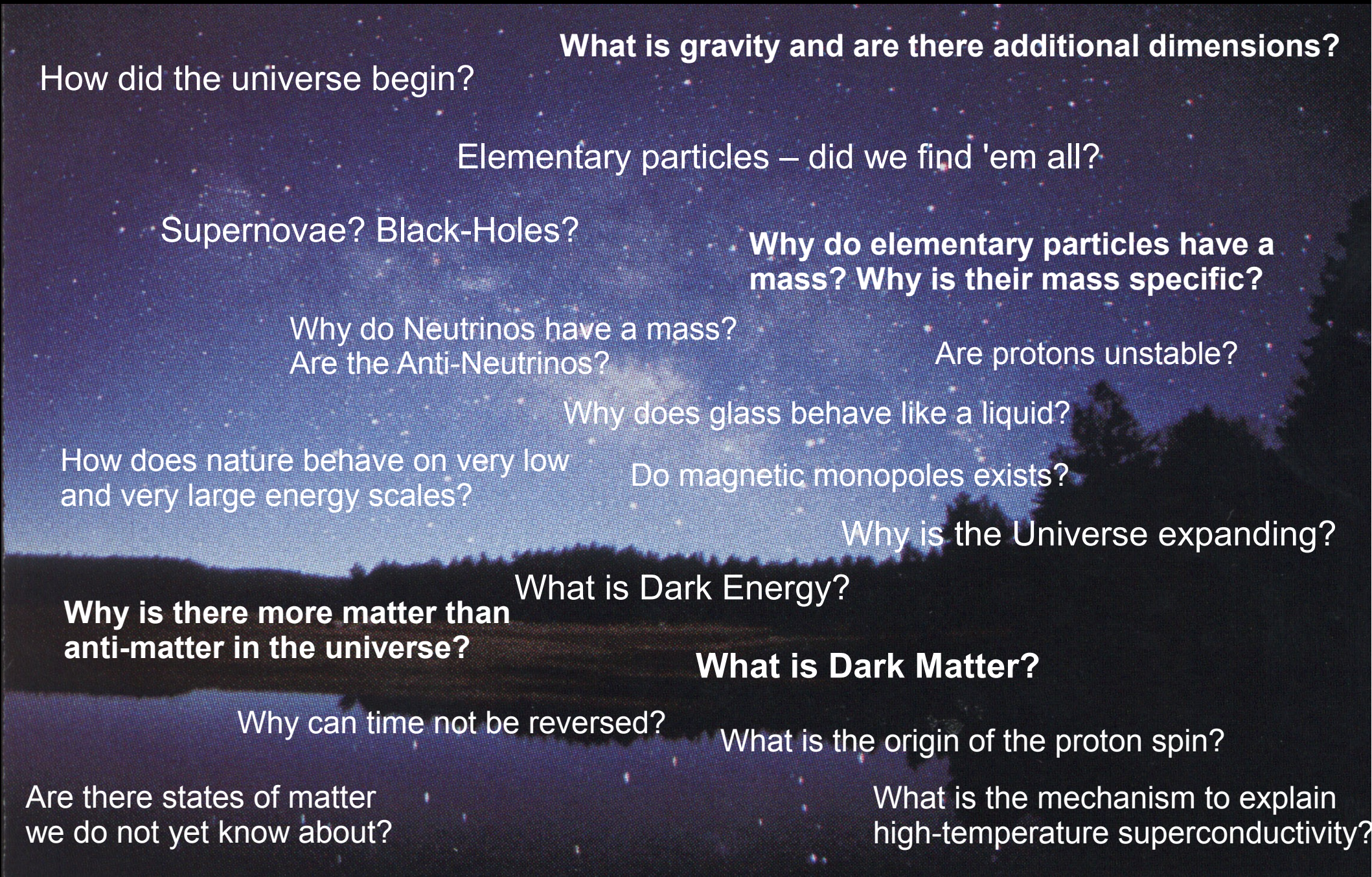
Physics is not about finding 'truths' ...

…but about discovering how nature works.

Physicists' fundamentals:

What, When, Why, How (exactly)...

Physicists' fundamentals:
What, When, Why, How (exactly)...



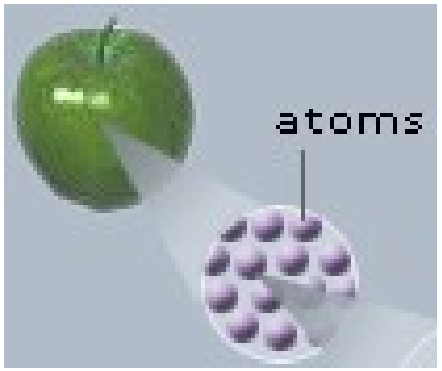
ICHEP'12 → … High-Energy-Physics
Understand the World in its most fundamental form ...

- Very ancient Greek idea ... world is made out of

  Atoms (ἄτομος, atomos, "indivisible")

- To set the scale:

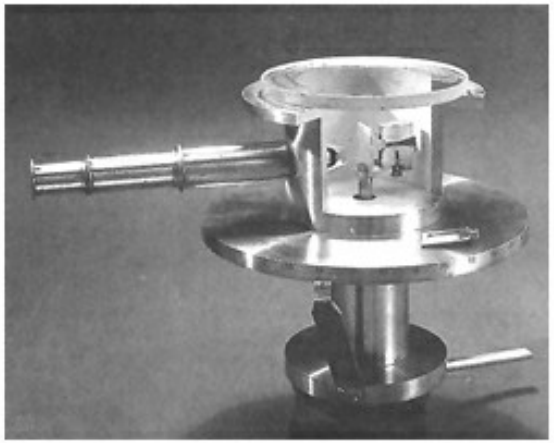
Human Hair
~ 100 μm = 0.0001 m or
= 100 ·10^{-6} m

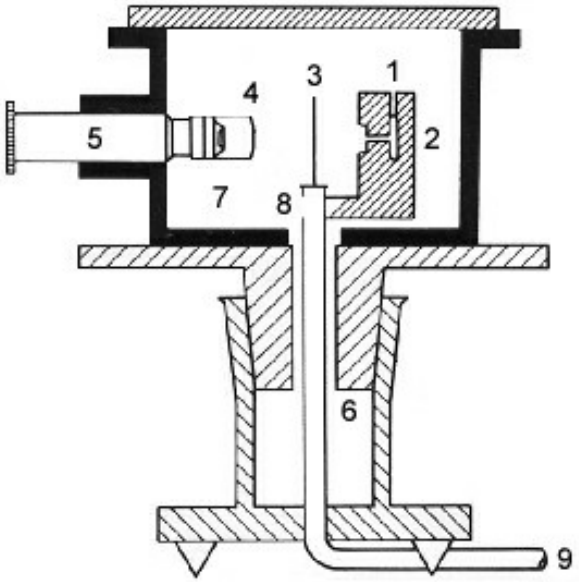


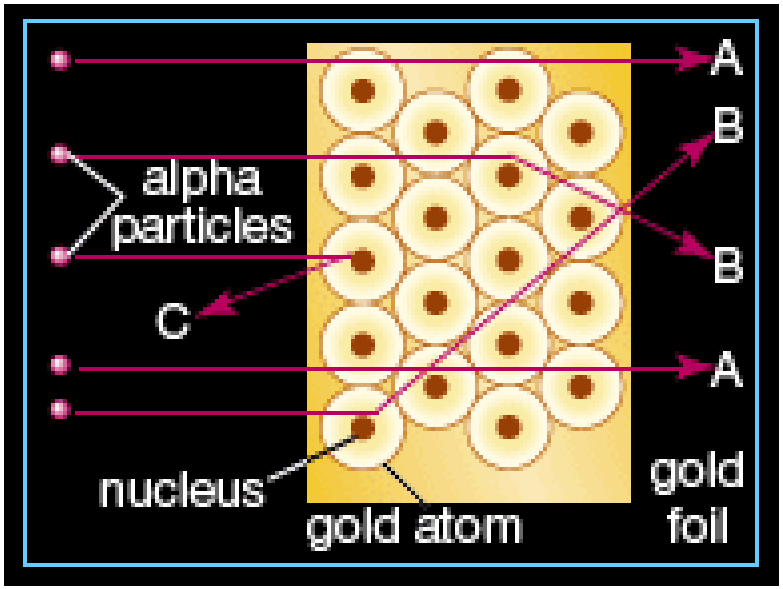
Atom ~ 10^{-10} m
= 0.0000000001 m

First Particle Physics Experiment: 'Atoms' are not fundamental Particles

1911
Rutherford-Geiger–Marsden experiment: found nuclei in the atom by firing alpha particles at gold and observing them to bounce back

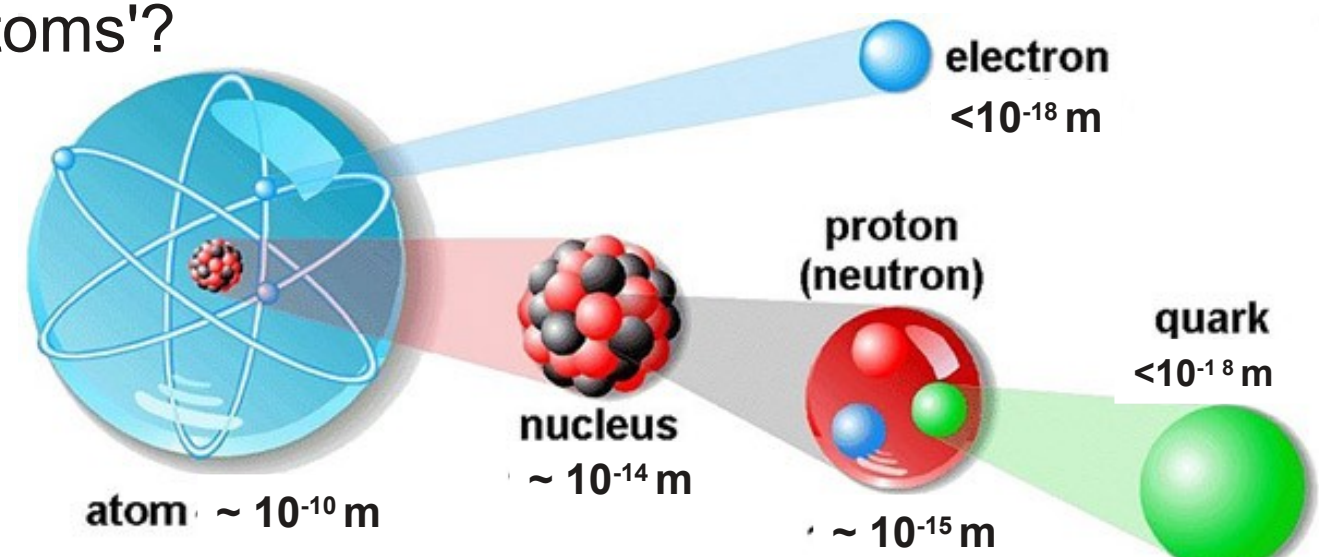






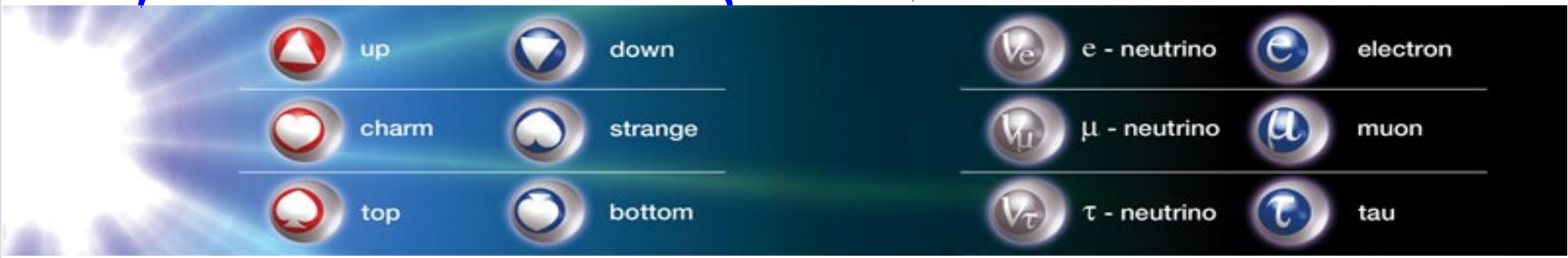
Leading to an Avalanche of New Discoveries and Scientific and Technological Advances

- What are the true 'Atoms'?



Hadrons
(greek: heavy particle)

Leptons
(greek: light particle)

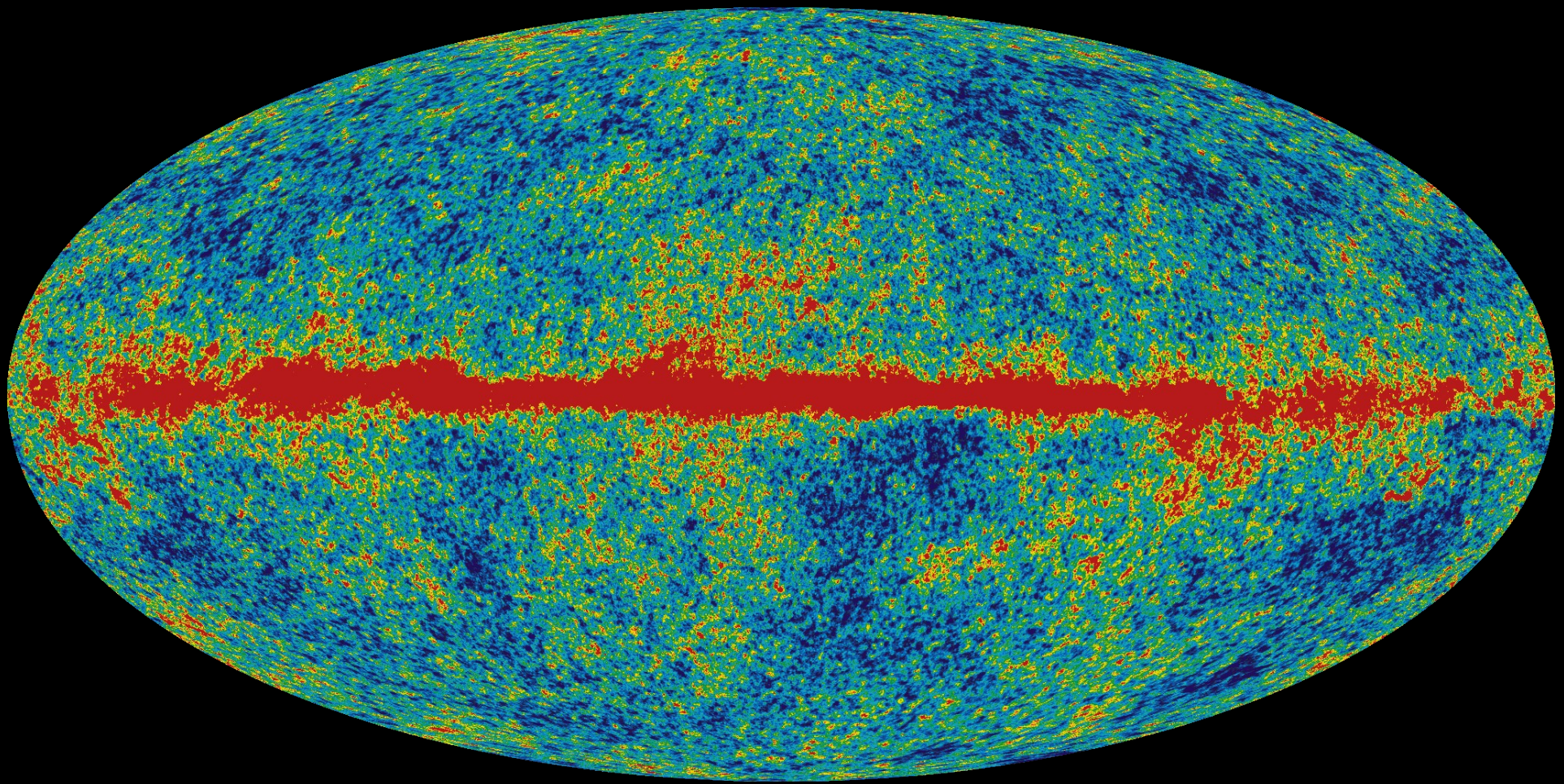


+ binding forces: γ (photons, x-rays, gamma), W, Z, gluons & H

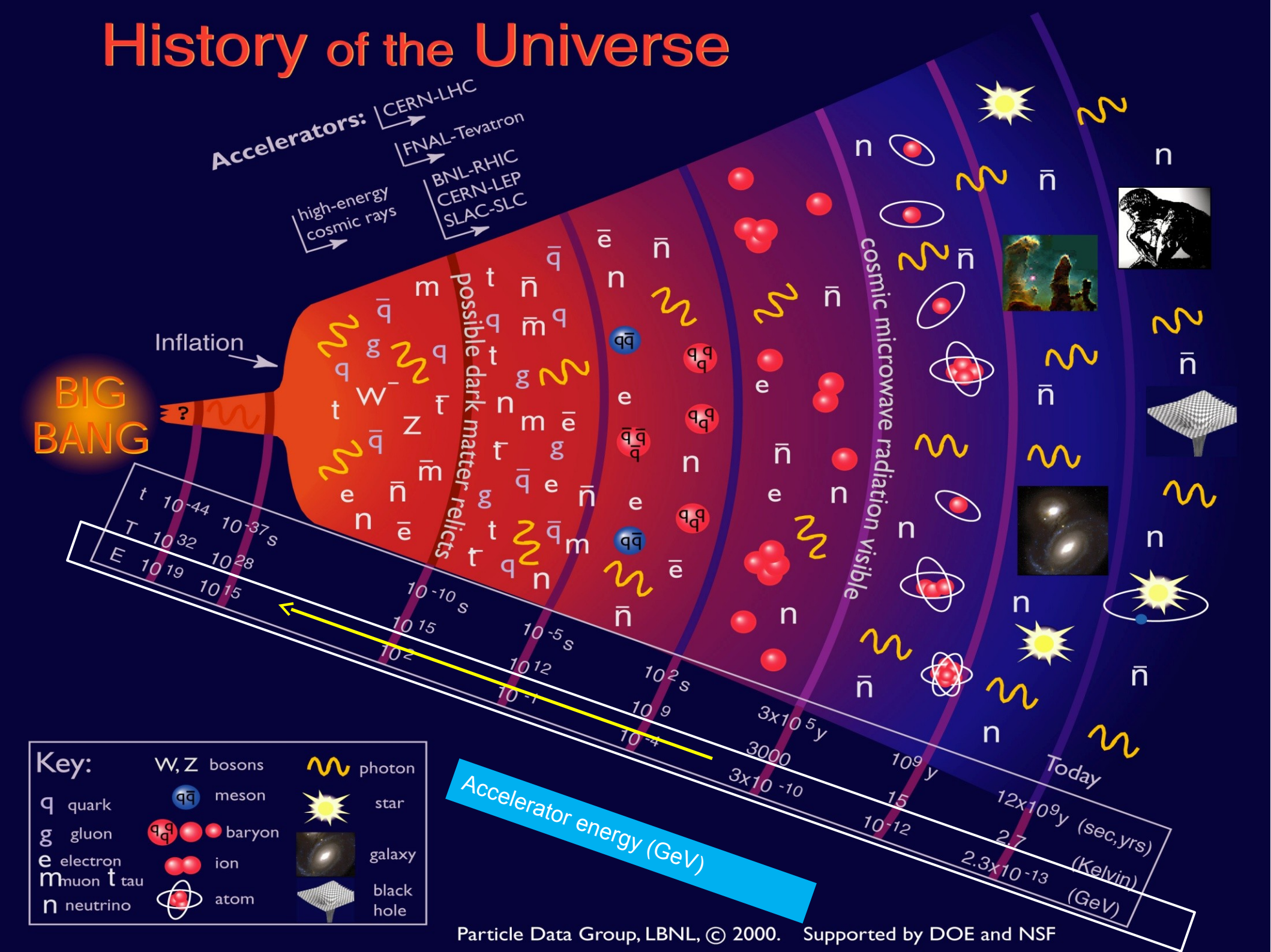
- Still, many open question remain....

Dark Matter, the Age of the Universe, ...
… and why there was a “Big Bang”

Dark Matter, the Age of the Universe, ...
… and why there was a “Big Bang”



History of the Universe



Dark Matter, the Age of the Universe, ...
… and why there was a “Big Bang”

Anti-Matter does exist …

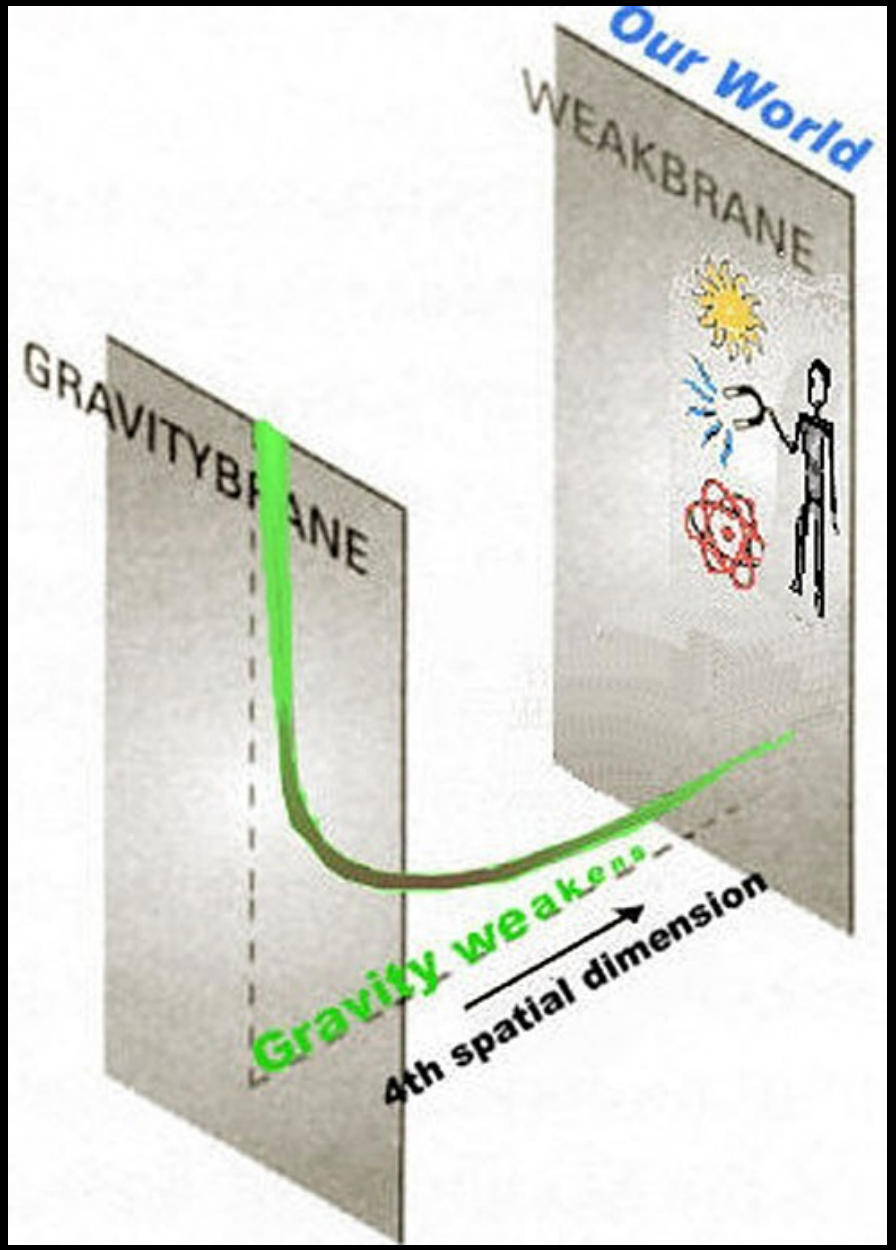
… but why is it so rare in the Universe?

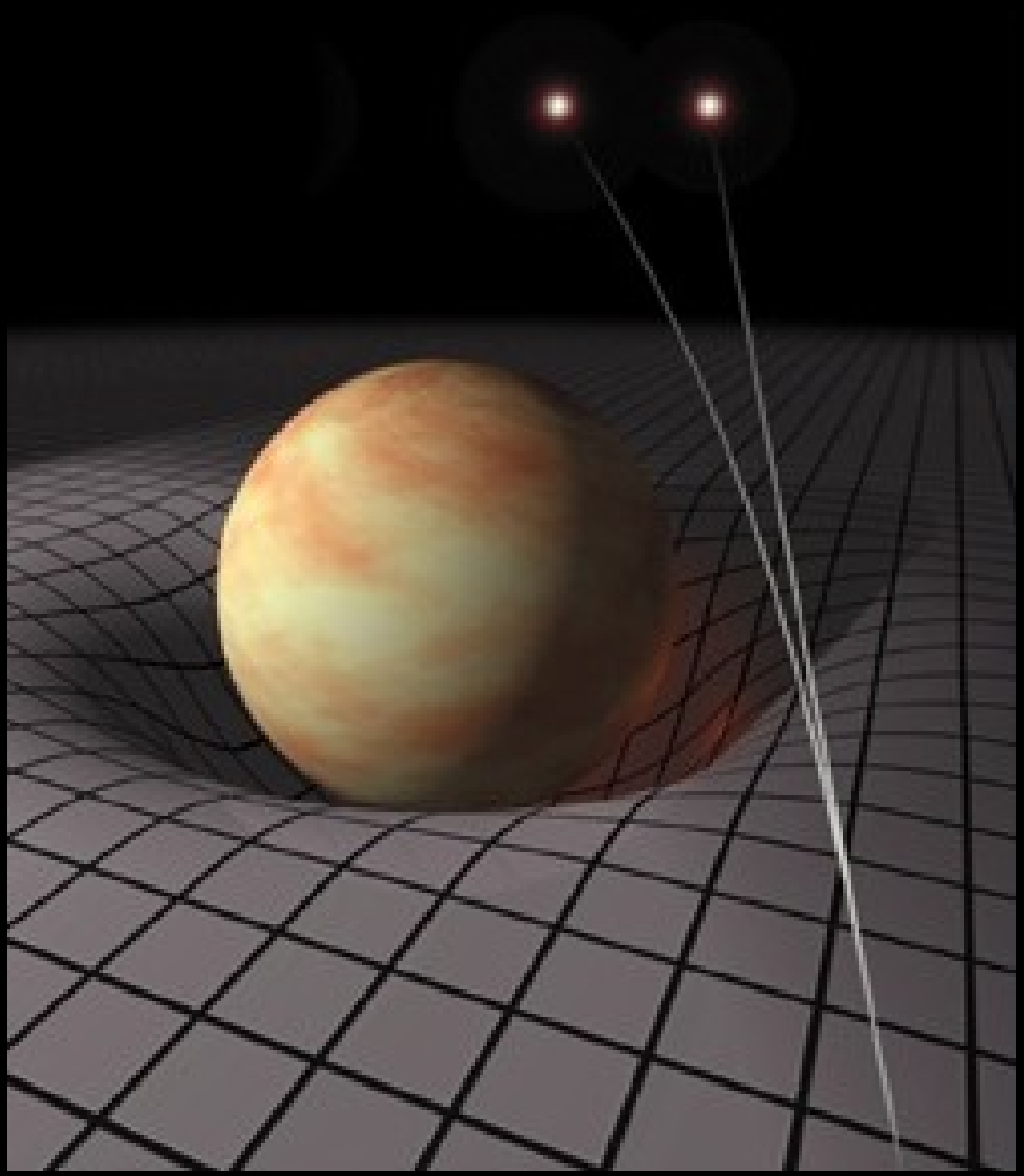
Why do elementary particles have a mass?

… what's behind the 'Higgs©' particle?

Does our world have more than 3+1 dimensions?
How does gravity work? Or:

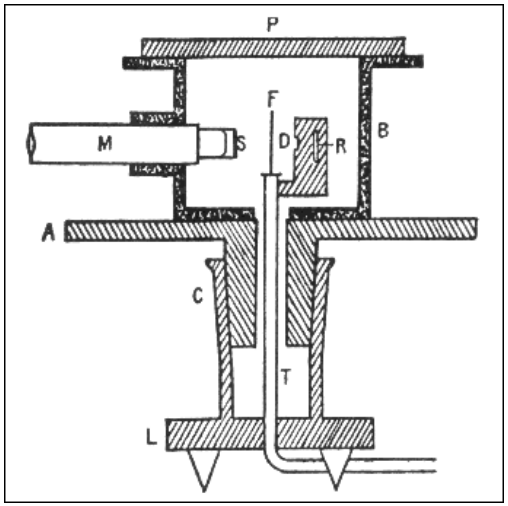
What the … are “micro-black-holes” and why we are excited about (even worse) unstable ones?





Main Outcome of Rutherford's experiment (my personal view)

- 'Atoms' are not Atoms → 'Elementary Particles'
- Need to use particles that are smaller than the structure to be investigated
- Need a microscope, <u>patience</u> and <u>persistence</u>
  (… and a lot of students)



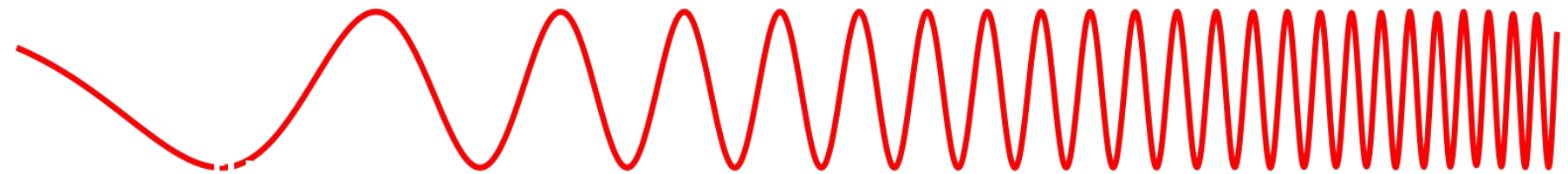
- Later: De Broglie's 'Particle – Wave' dualism (1924):

$$\lambda = \frac{h}{p}$$

h: Planck's constant
p: momentum of particle
λ: equivalent wavelength

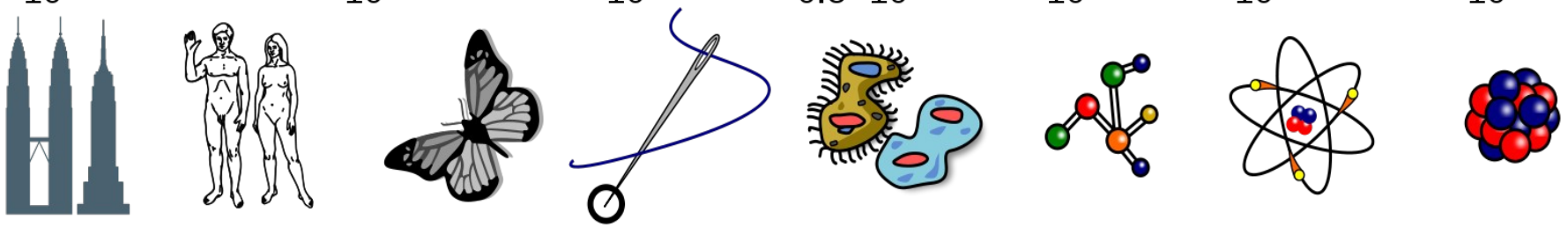
… So high momentum (energy) gives us short wavelengths so we can make out small details
or High-Energy-Physicists credo: we want to see smallest particles, thus need the highest energy particle sources → accelerators

De Broglie: Wavelength and Scales

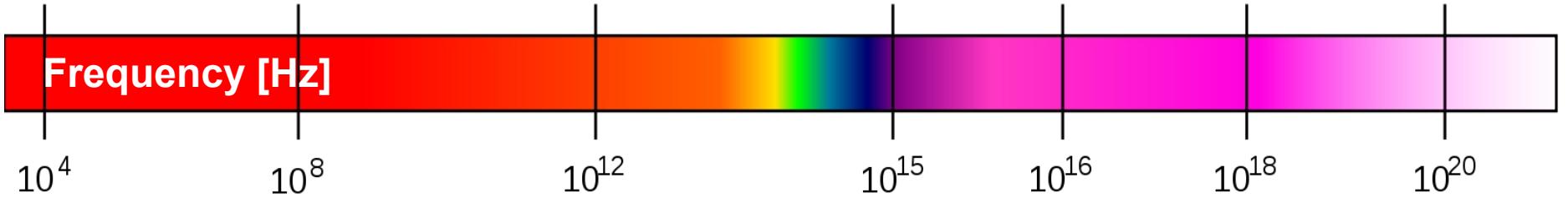


Wavelength [m]

Radio	Microwave	Infrared	Visible	Ultraviolet	X-ray	Gamma ray
10^{3}	10^{-2}	10^{-5}	0.5×10^{-6}	10^{-8}	10^{-10}	10^{-12}



Buildings	Humans	Butterflies	Needle Point	Protozoans	Molecules	Atoms	Atomic Nuclei



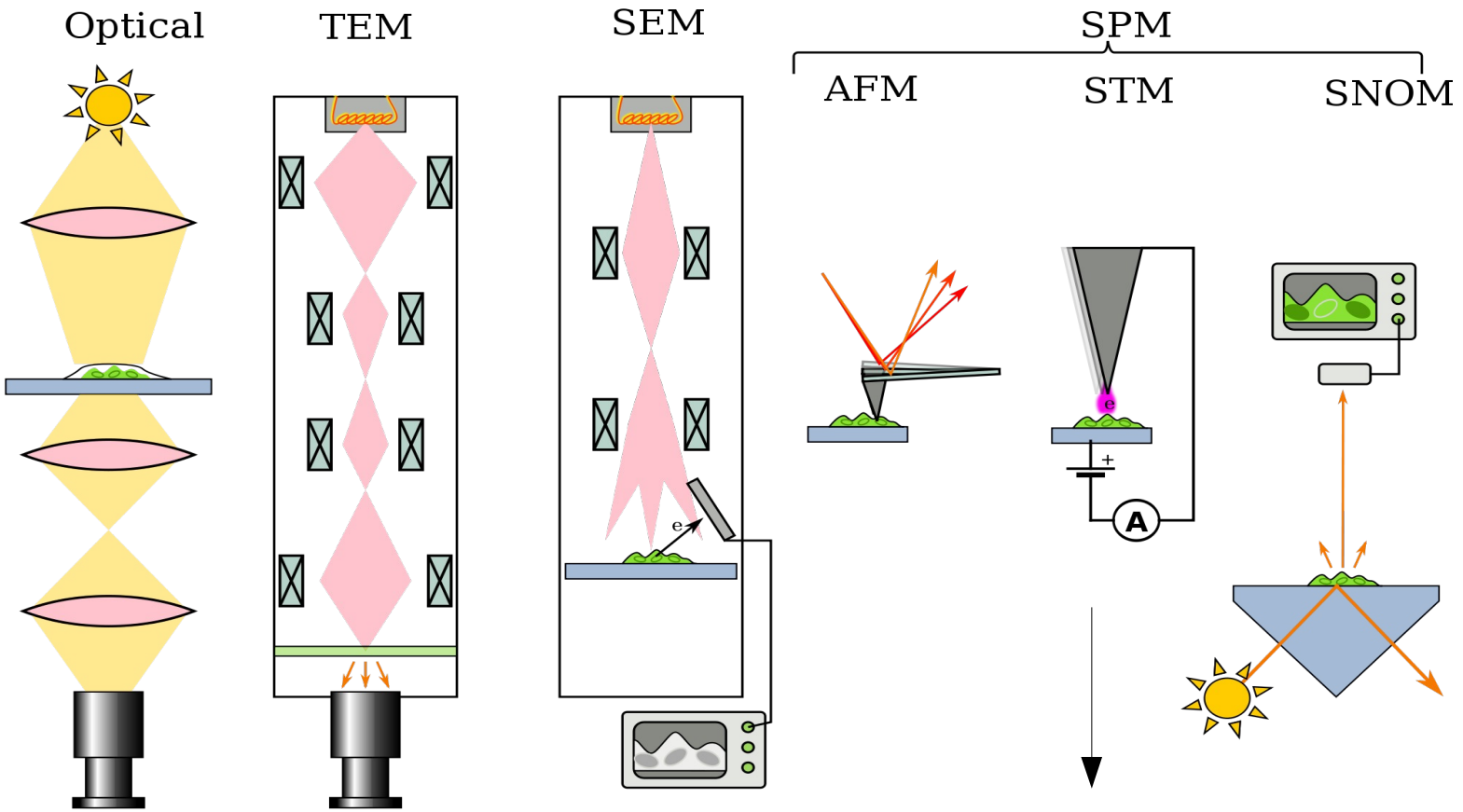
Energy/Momentum Electron Volt [eV]

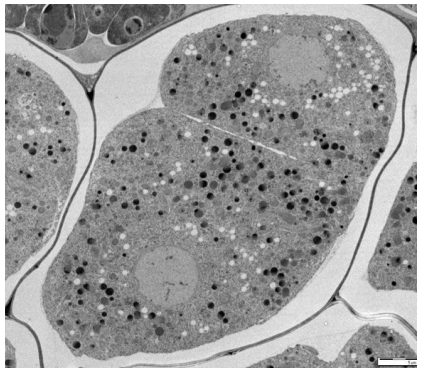
~1 μeV **~1 eV** **~1 MeV**

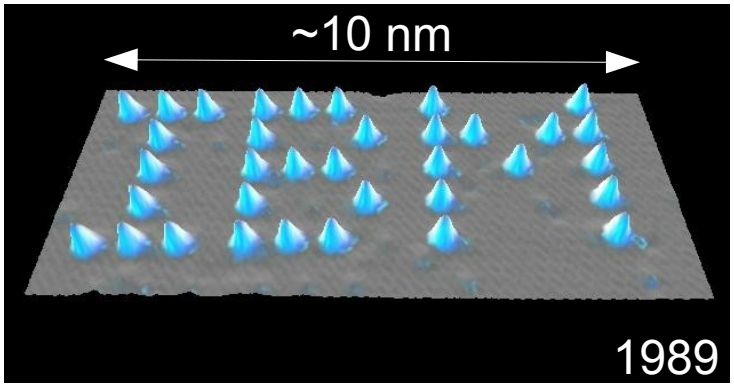
LHC (Higgs)
few hundred GeV/7 TeV

How to resolve Small Structures I
Cells, Molecules, Semiconductors ...

- … use a microscope – only a few electron-volt (eV) needed

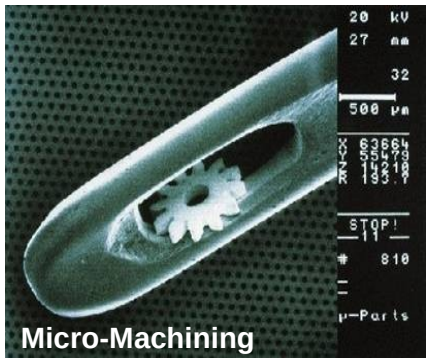


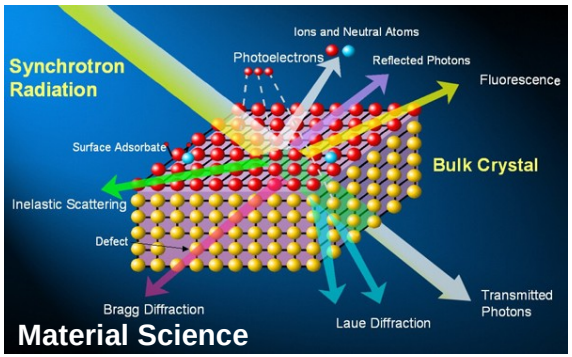


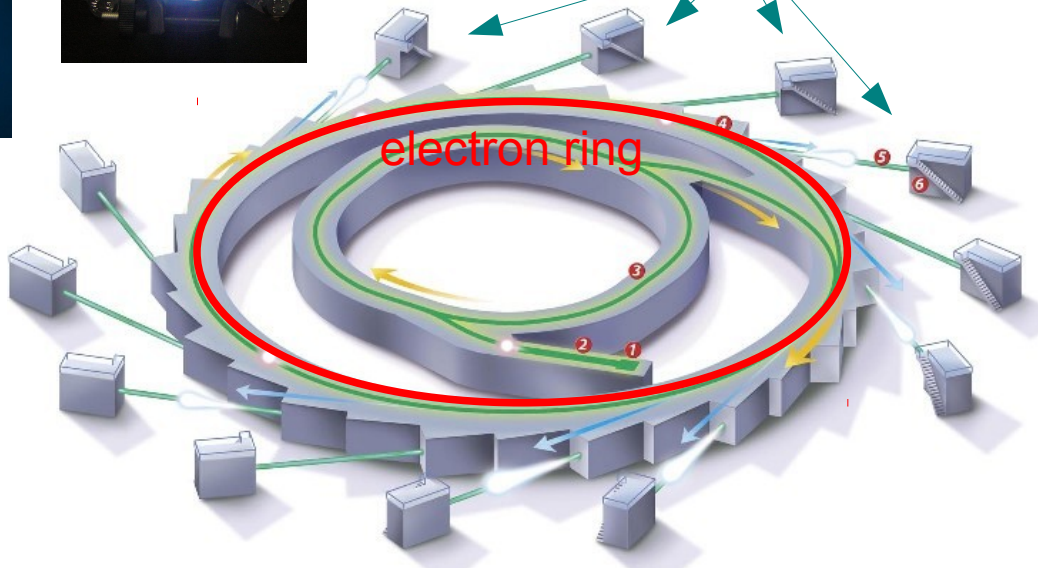


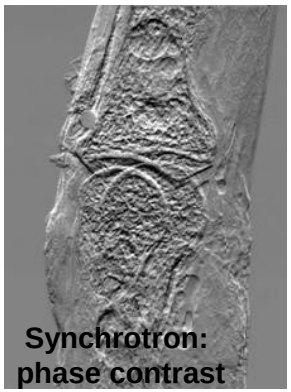
How to resolve Small Structures II
State-of-the Art Biology, Chemistry & Material Science ...

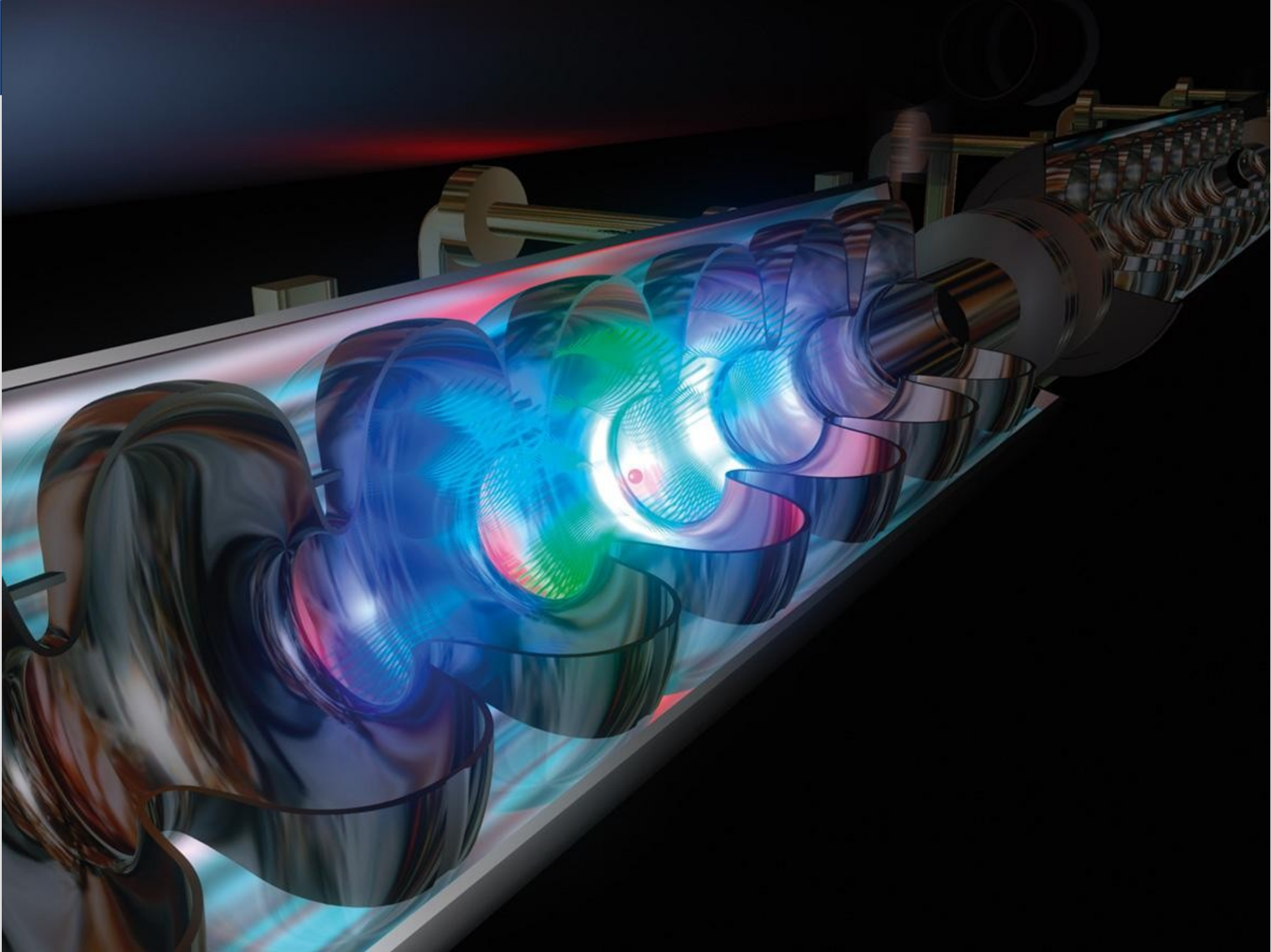
- … a synchrotron light source – few kilo-electron-volt (keV)





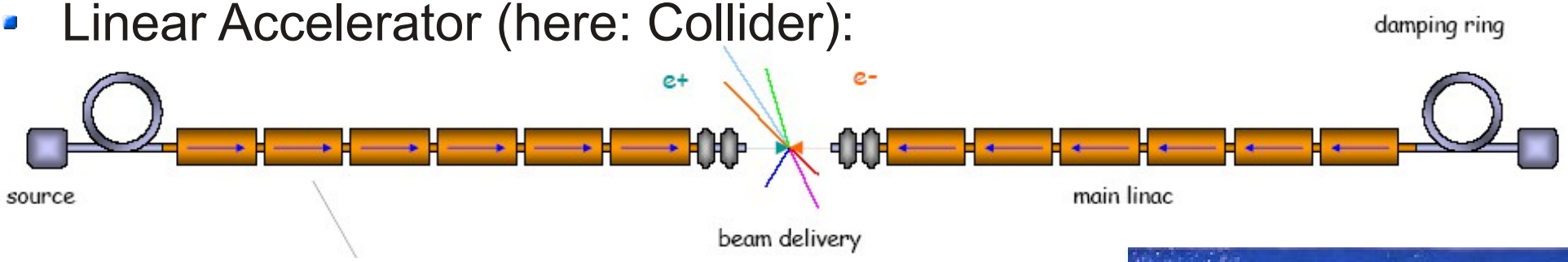




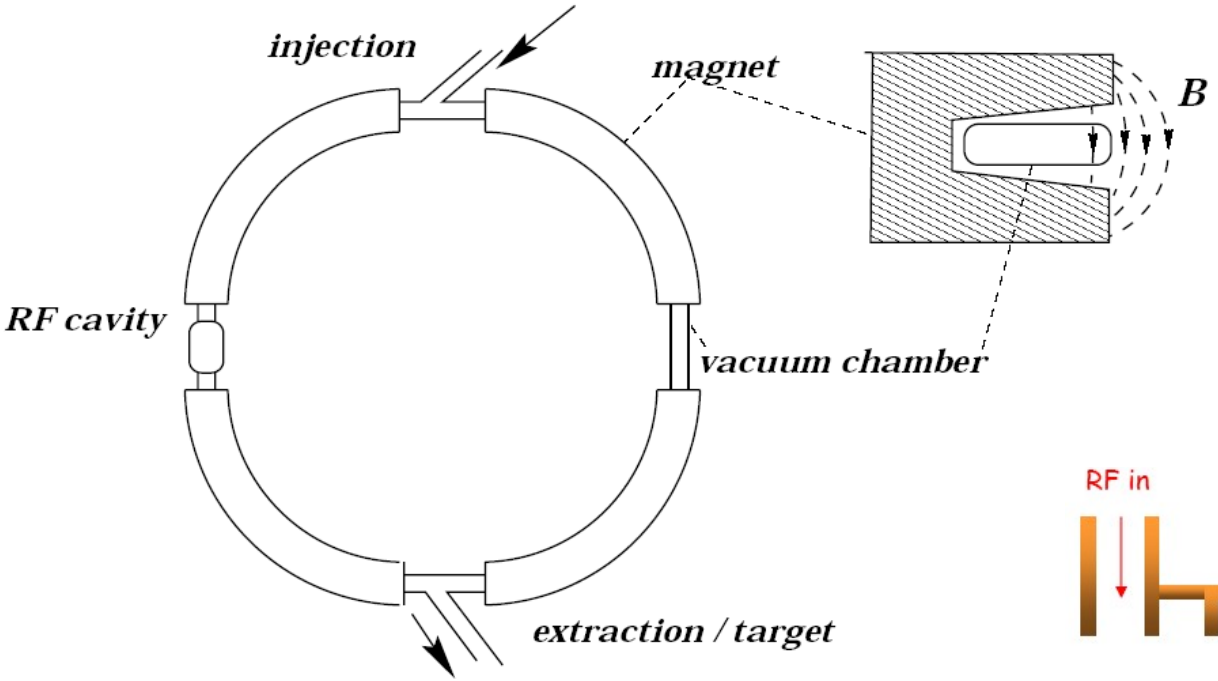


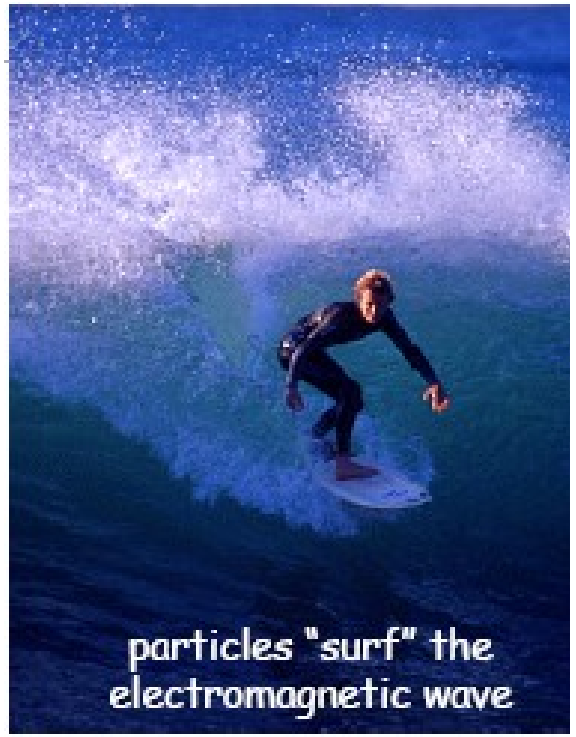
High-Energy Accelerators
To observer and study true 'Atoms'

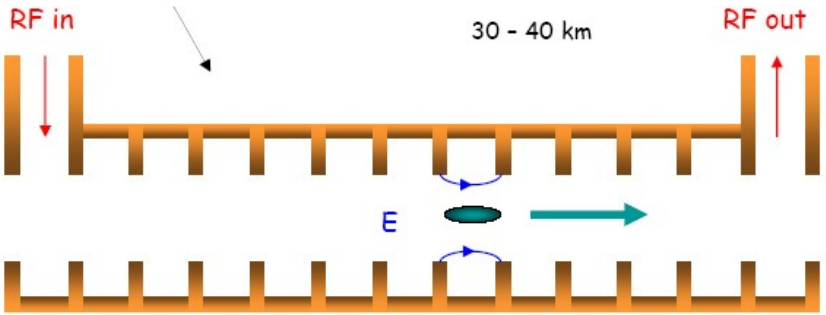
- Linear Accelerator (here: Collider):



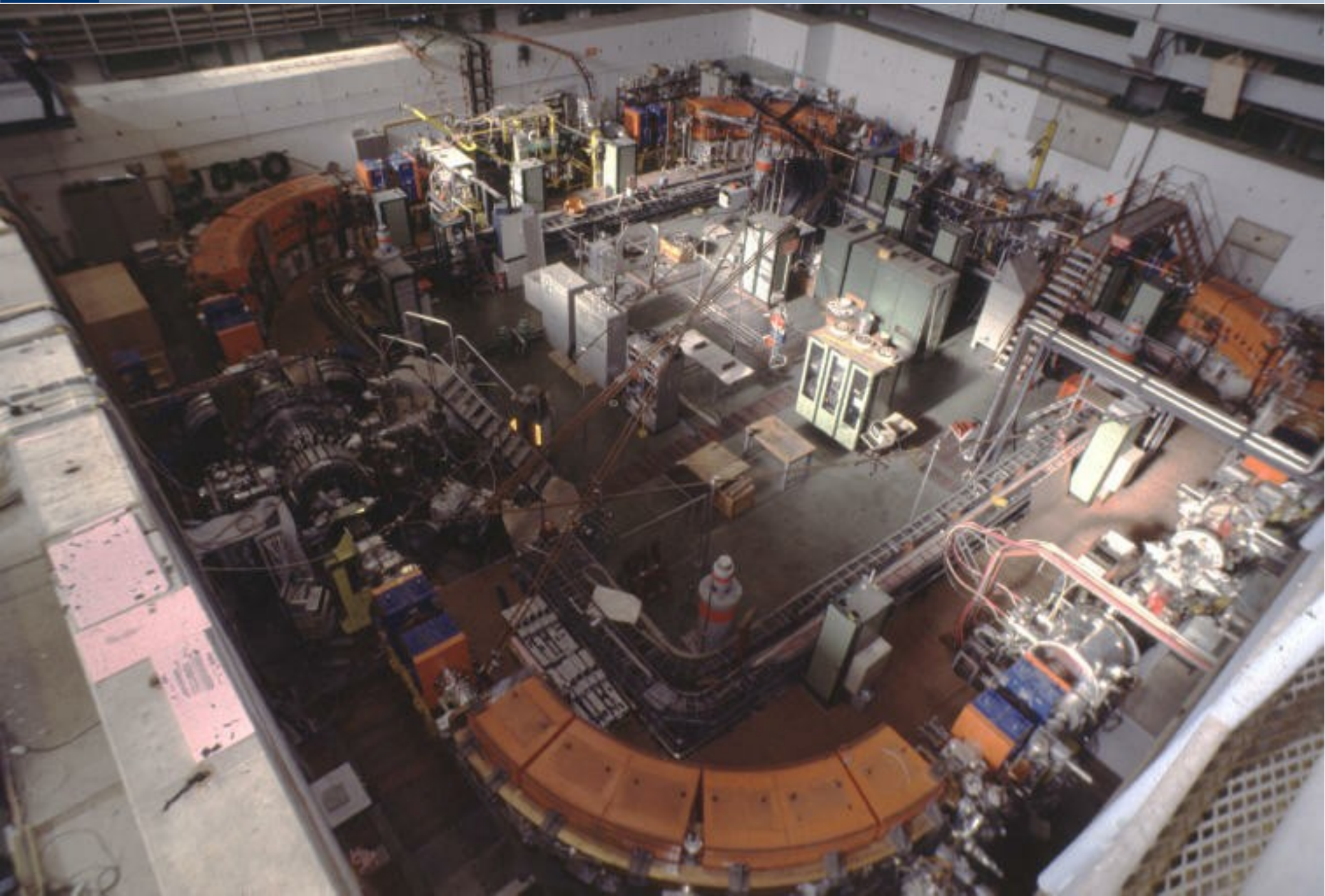
- Circular Accelerator:







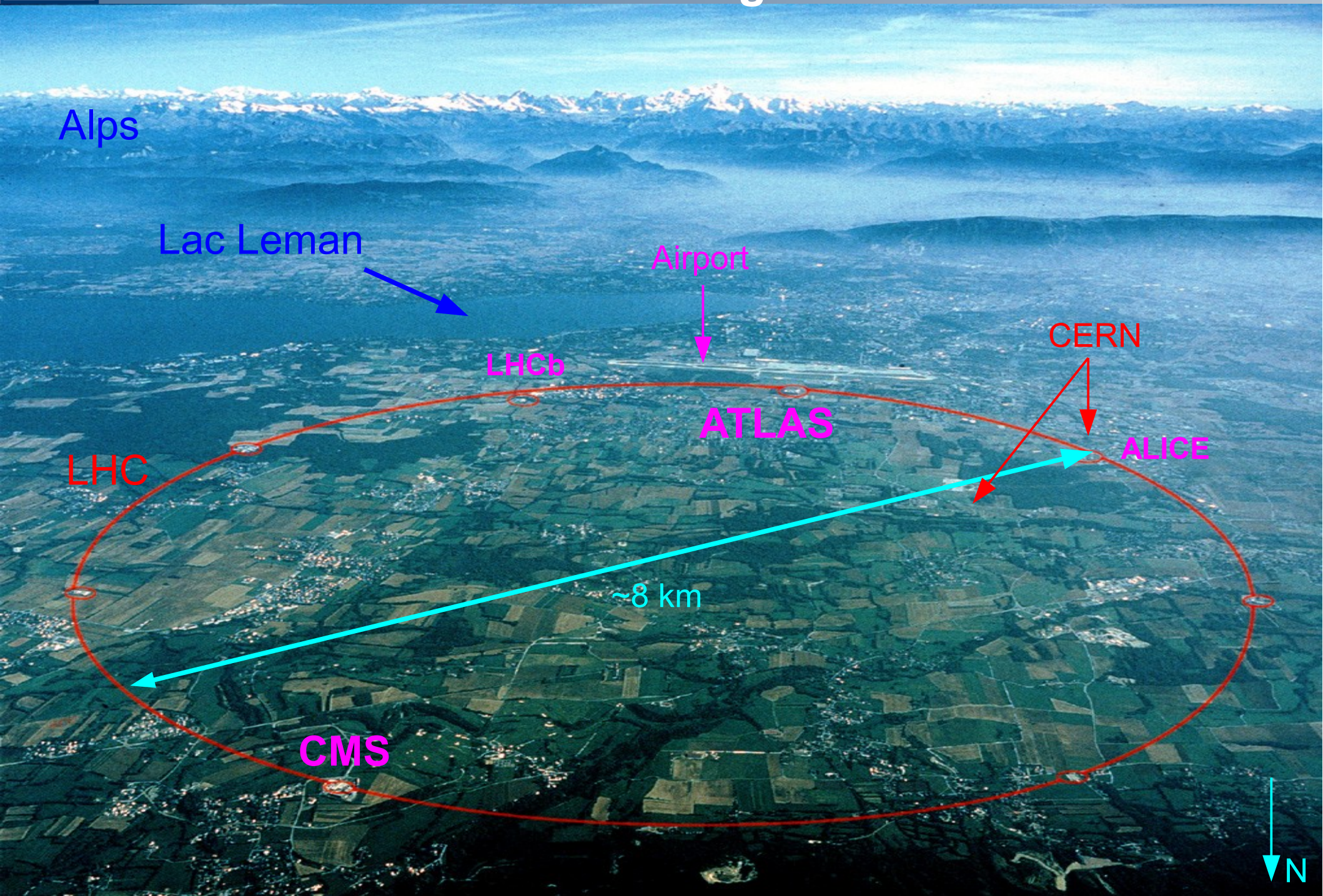
Low Energy Antiproton Ring (LEAR, CERN)



Super-Proton-Synchrotron (SPS, CERN)

- 7 km circumference, up to 450 GeV Energy
- Discovery of the W & Z Boson (Nobel prizes in 1979 & 1984)

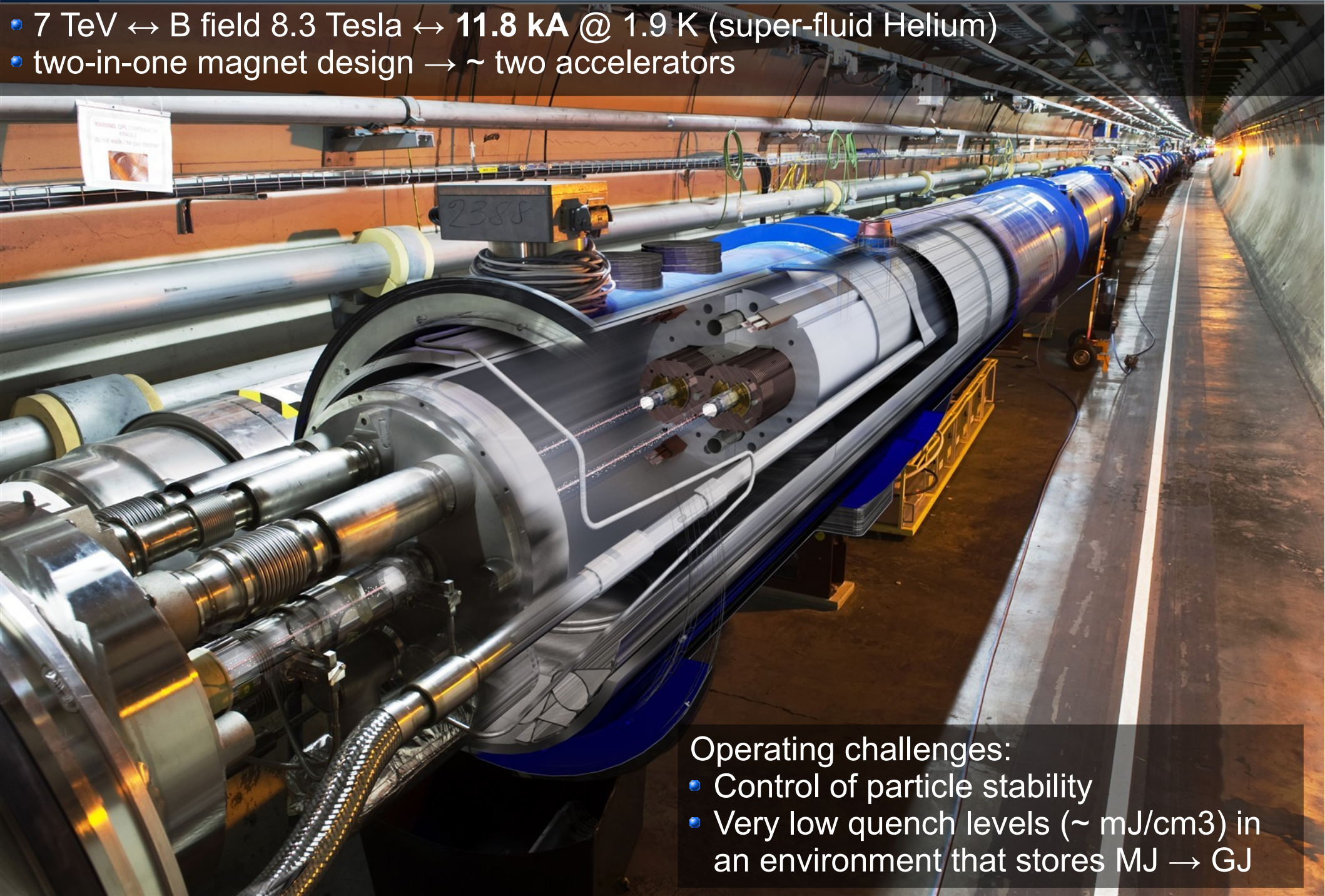
How to resolve Small Structures III
Sub-Atom Structures.... Large Particle Accelerators



It all looks so easy...

27 km Circumference – 1232 LHC dipole magnets

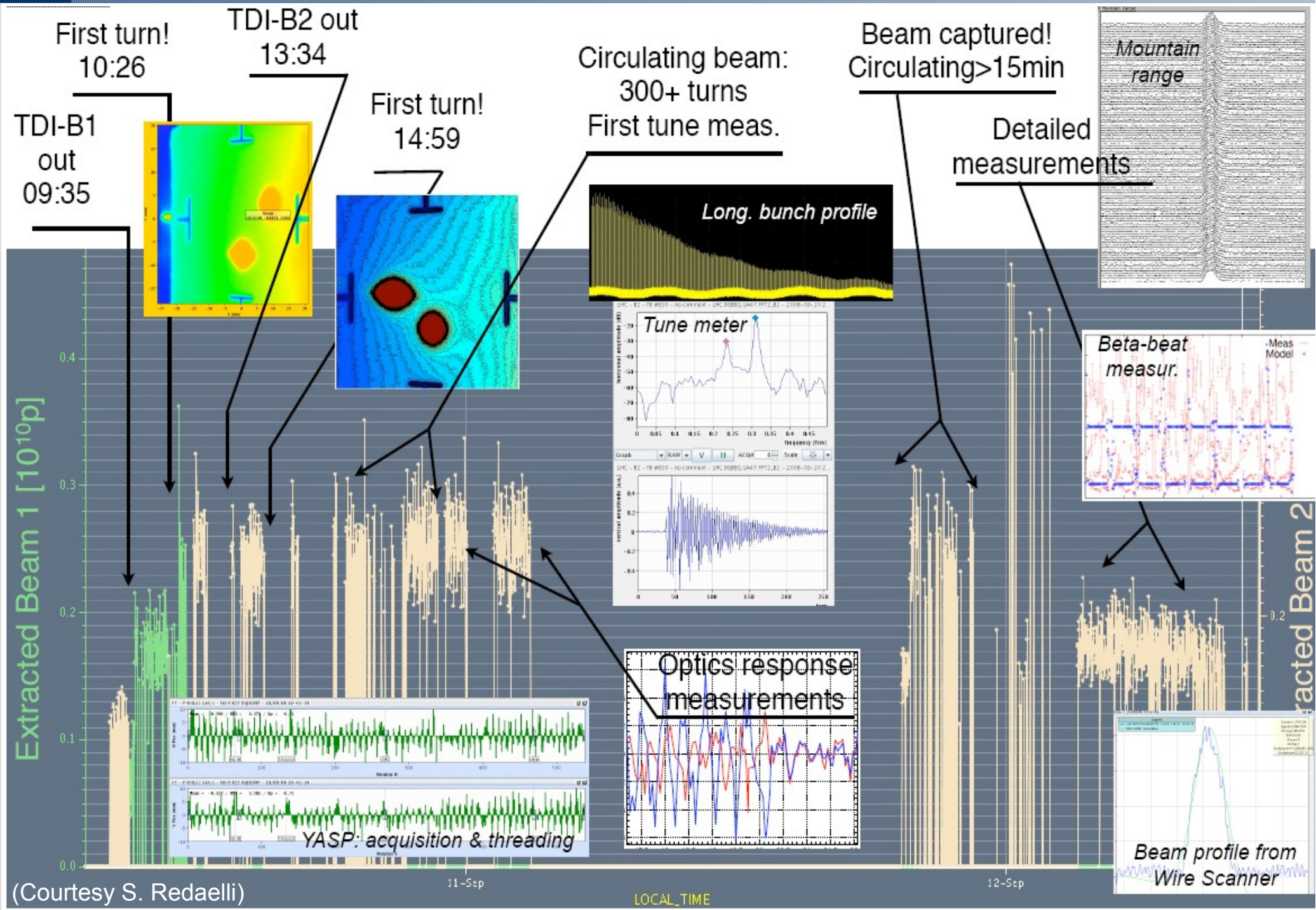
- 7 TeV ↔ B field 8.3 Tesla ↔ **11.8 kA** @ 1.9 K (super-fluid Helium)
- two-in-one magnet design → ~ two accelerators



Operating challenges:

- Control of particle stability
- Very low quench levels (~ mJ/cm3) in an environment that stores MJ → GJ

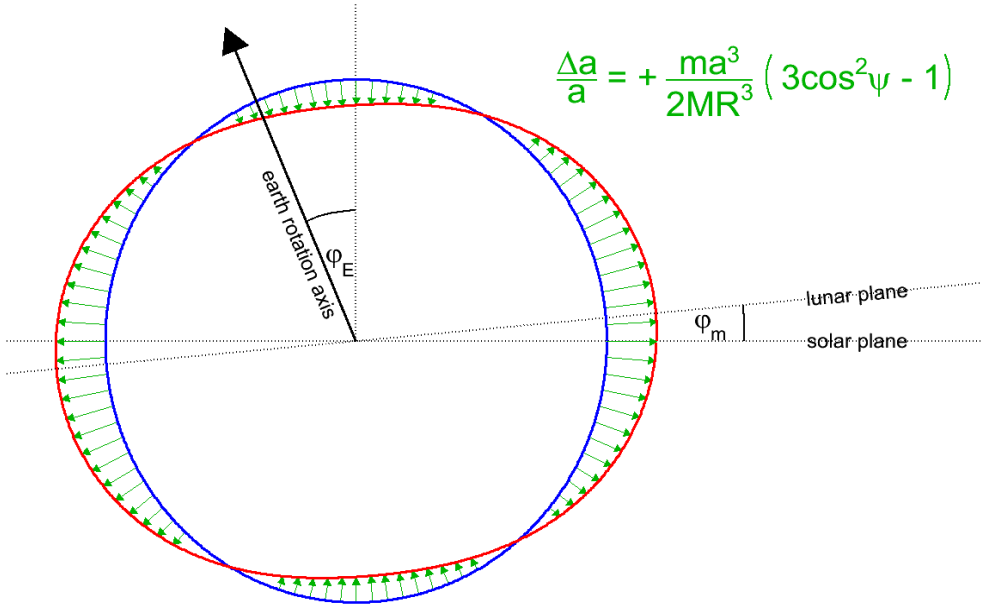
Beam Instrumentation provides the 'Eyes' and 'Ears' of an Accelerator
Example: 10th September 2008

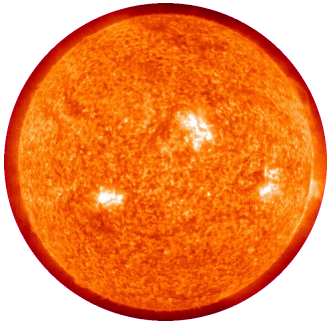


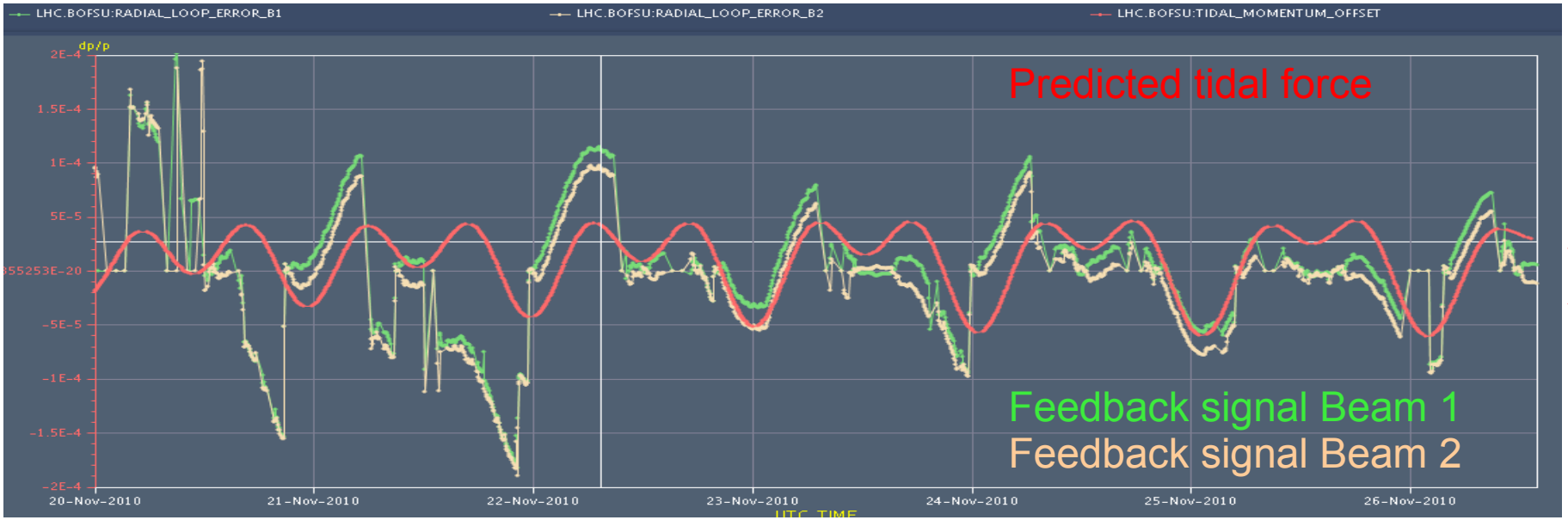
(Courtesy S. Redaelli)

Beam Orbit Stability and Tides ...

$$\frac{\Delta a}{a} = + \frac{ma^3}{2MR^3}\left(3\cos^2\psi - 1\right)$$



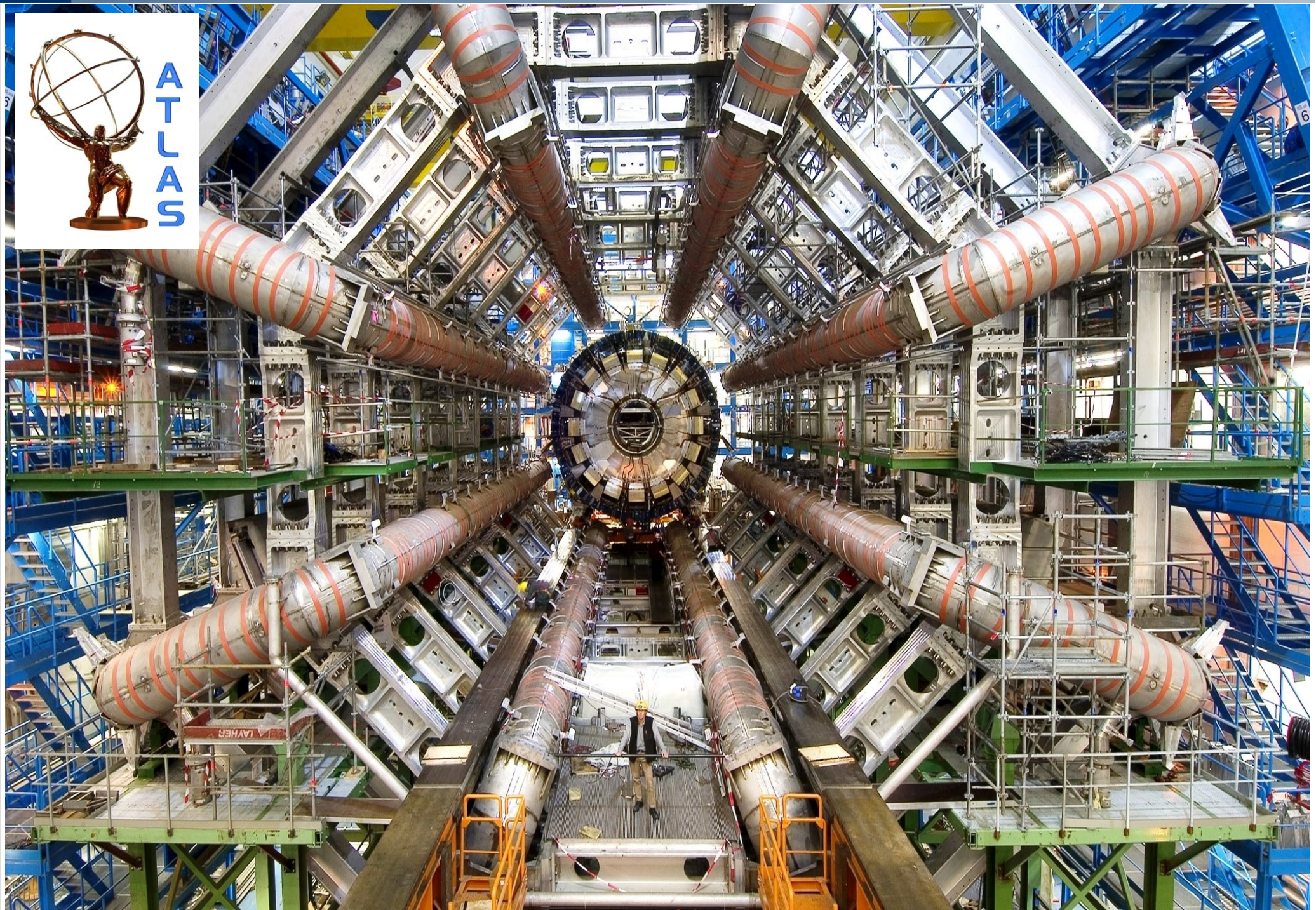


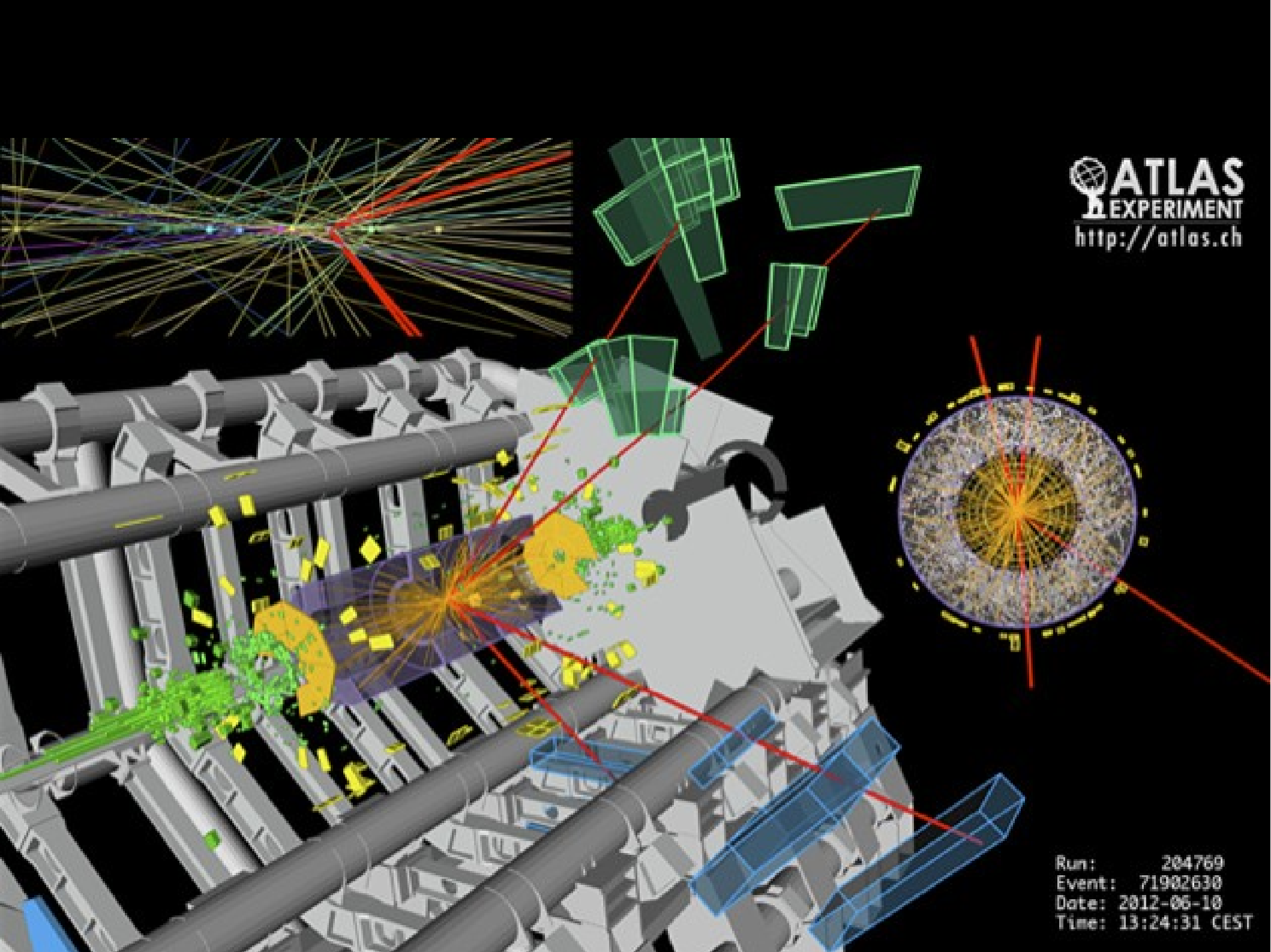


$\Delta x \approx 200\ \mu m$

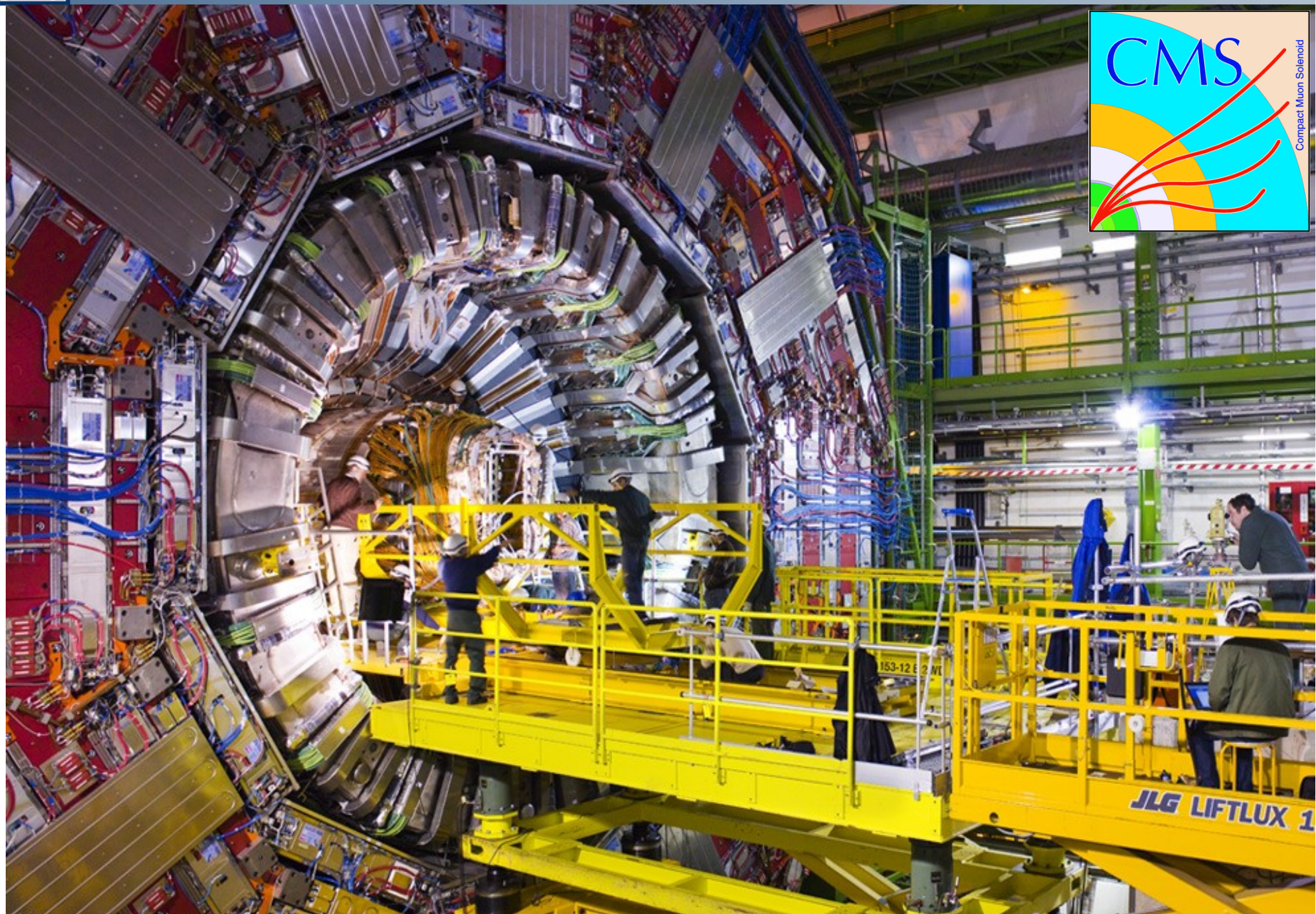
~ one week

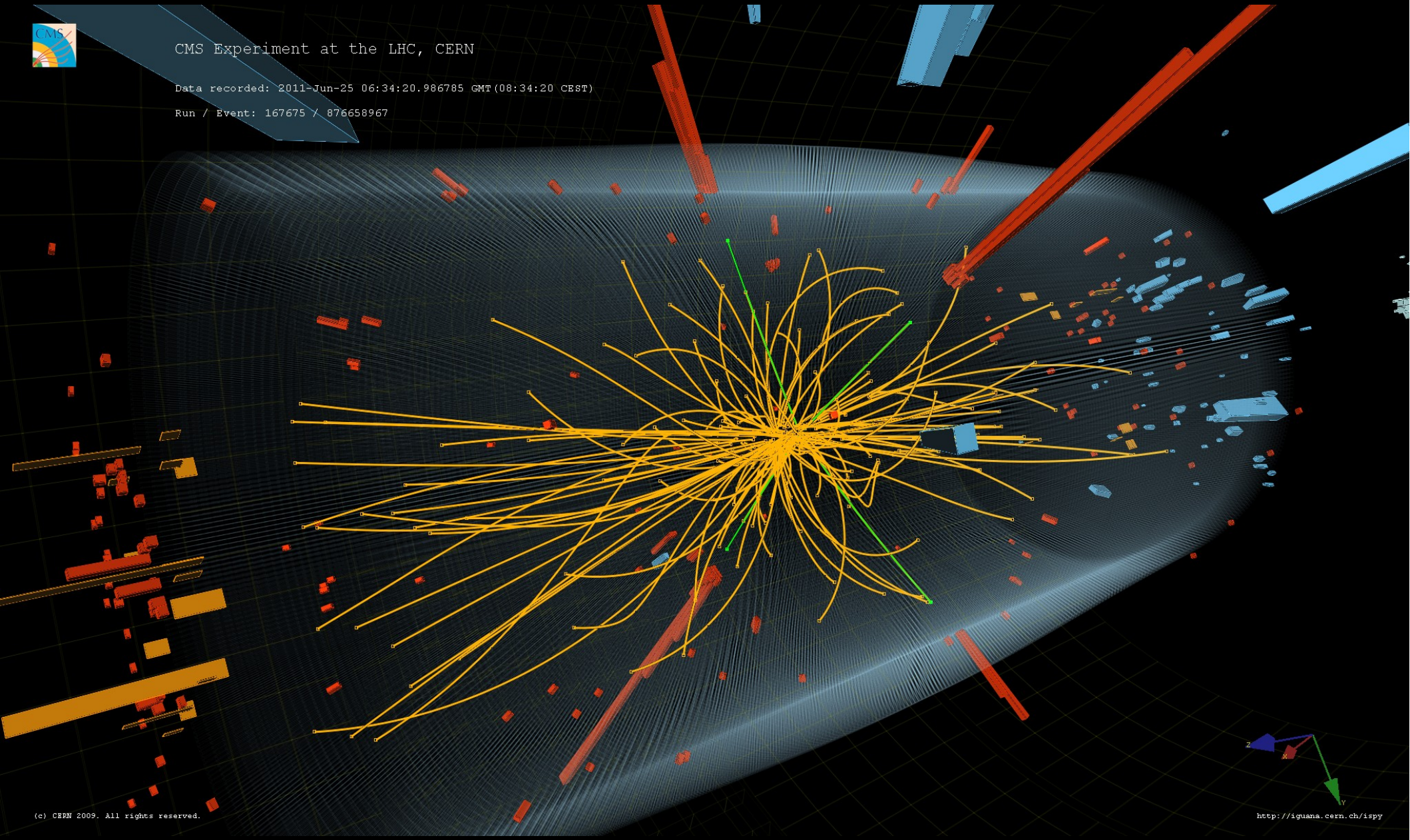
ATLAS



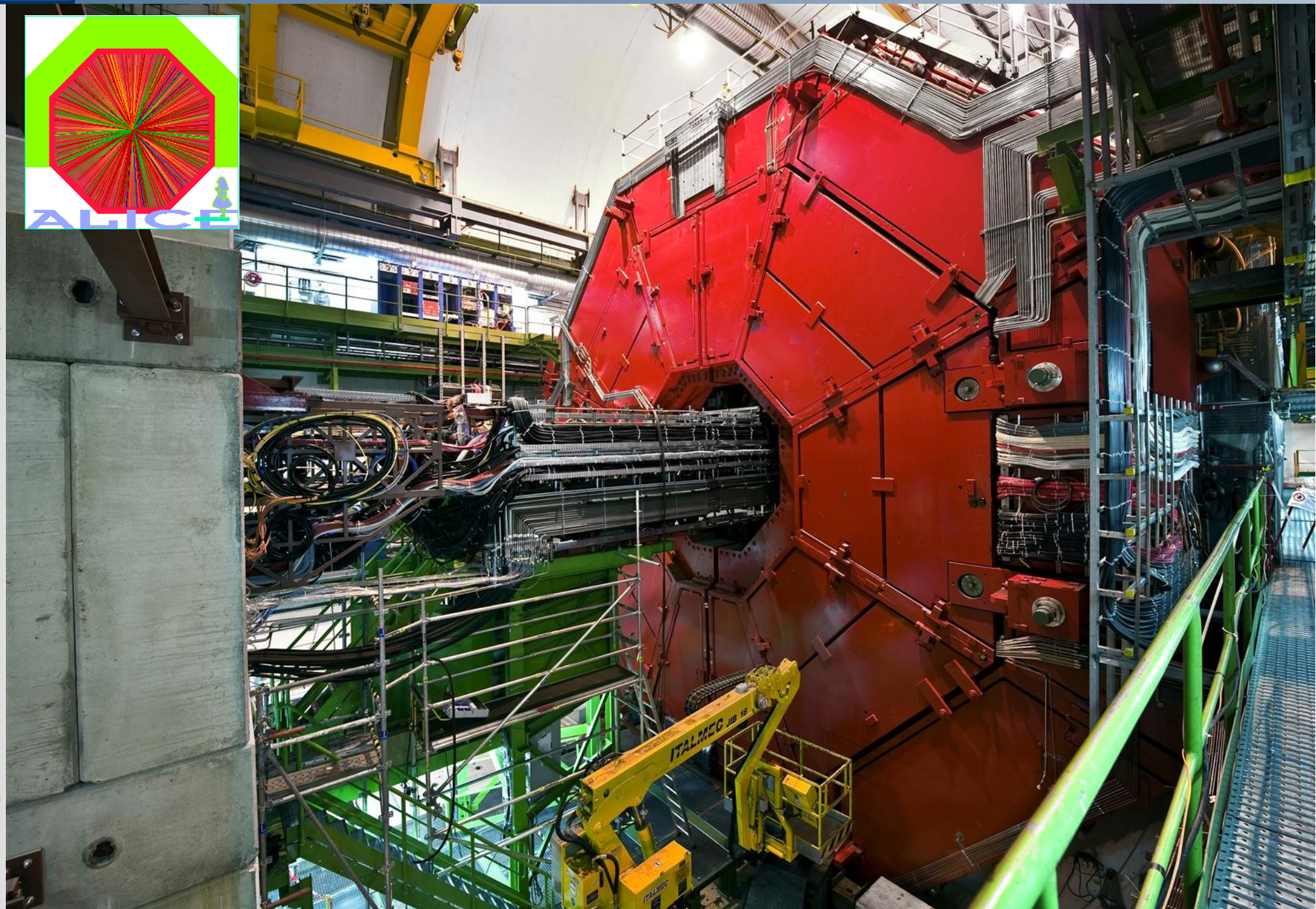

ATLAS
EXPERIMENT
http://atlas.ch
Run: 204769
Event: 71902630
Date: 2012-06-10
Time: 13:24:31 CEST

CMS

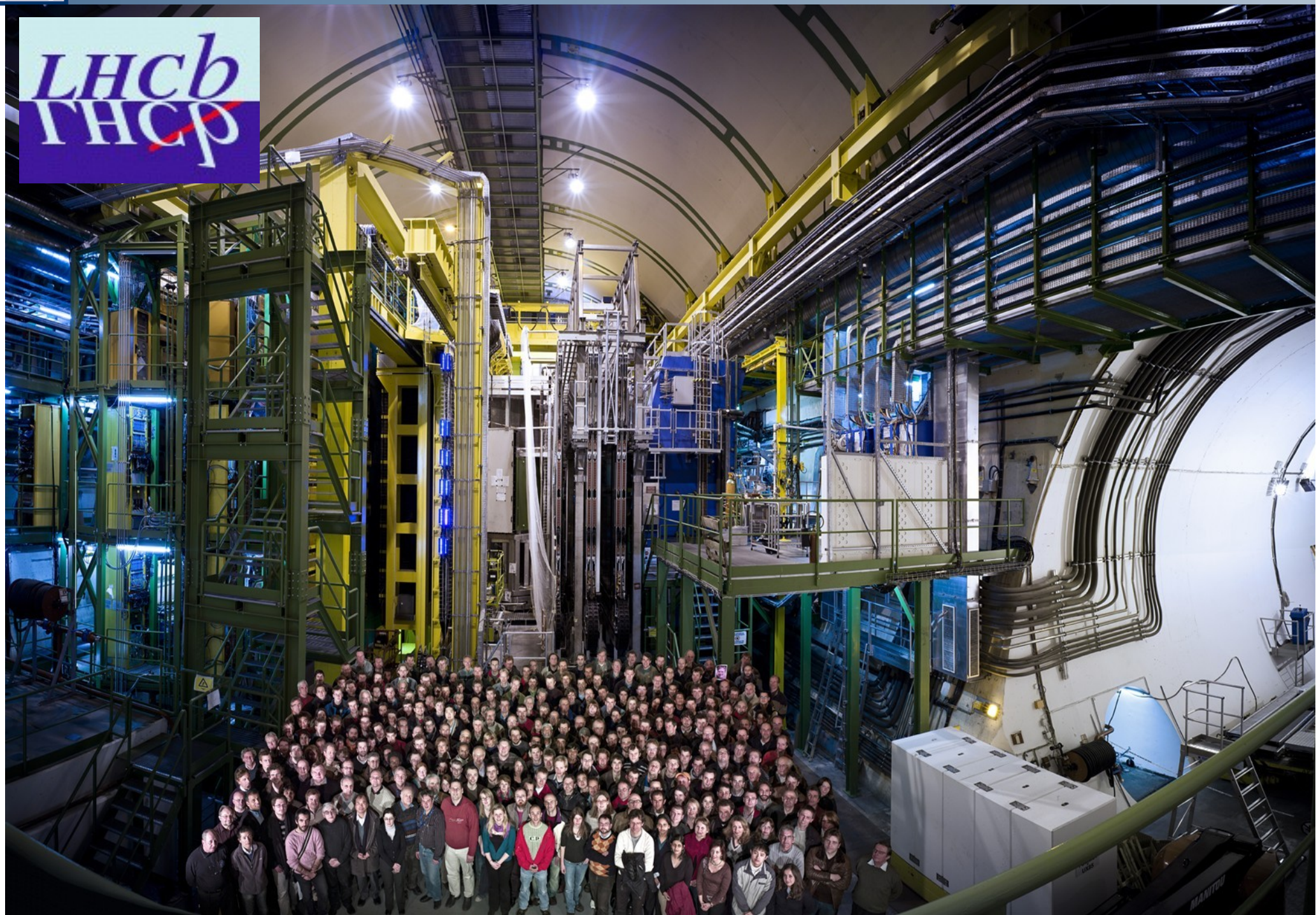



CMS Experiment at the LHC, CERN
Data recorded: 2011-Jun-25 06:34:20.986785 GMT(08:34:20 CEST)
Run / Event: 167675 / 876658967
(c) CERN 2009. All rights reserved.
http://iguana.cern.ch/ispy

ALICE

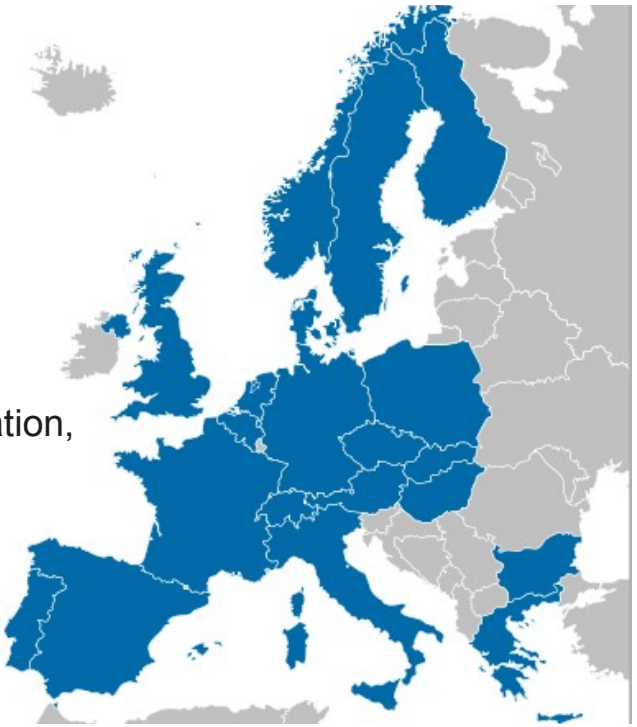


LHCb



CERN - Conseil Europeén pour la Recherche Nucléaire
Today: ~~European~~ Global Organization for Nuclear Research

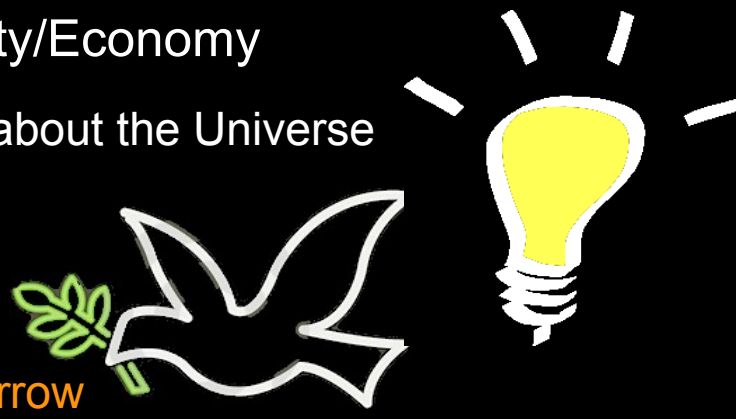
- 1951: CERN's mission:
  - provide resources and common infra-structure related to pure scientific and fundamental character
  - Promote peace and collaboration platform, education and sharing of scientific results among nations
- 20 member states + observers: India, Israel, Japan, Russian Federation, USA, Turkey, European Commission and UNESCO + Australia?
- One of Geneva's largest organisations:
  ~ 2500 full-time employers, > 9000 visiting scientists
- A small world of its own → extraterritorial (neither CH/FR)



- Cradle of the World-Wide-Web: http://www.cern.ch
- GRID - One of the world's most power-full data processing networks
- World's home of High-Energy Physics and Nobel-Prize Winners
- More info:

What are long-, medium- and short-term benefits? … why we must spend money for science?

Long-Term - World is becoming a Knowledge-based Society/Economy



- Research: Seeking and finding answers to questions about the Universe
- Technology: Advancing the frontiers of technology
- Collaborating: Bringing nations together through science
- Education: Training the scientists & engineers of tomorrow

Medium-Term: Fundamental Research enables applied Science, e.g.

- Quantum-Mechanics → Semi-Conductor → Transistors → Computer
- General Theory of Relativity (Einstein) → Satellites → GPS

Short-Term: Advancements in industry....

- Accelerator, Magnet, Cryogenics, Detectors & Instrumentation, Electronics, .
  → Biology and Medicine: NMR & PET scanners, Ion therapy/cancer treatme
- Information Technology: WWW, GRID, Genome Analysis, …

What we do today will impact and be in your life in 10-20 years...