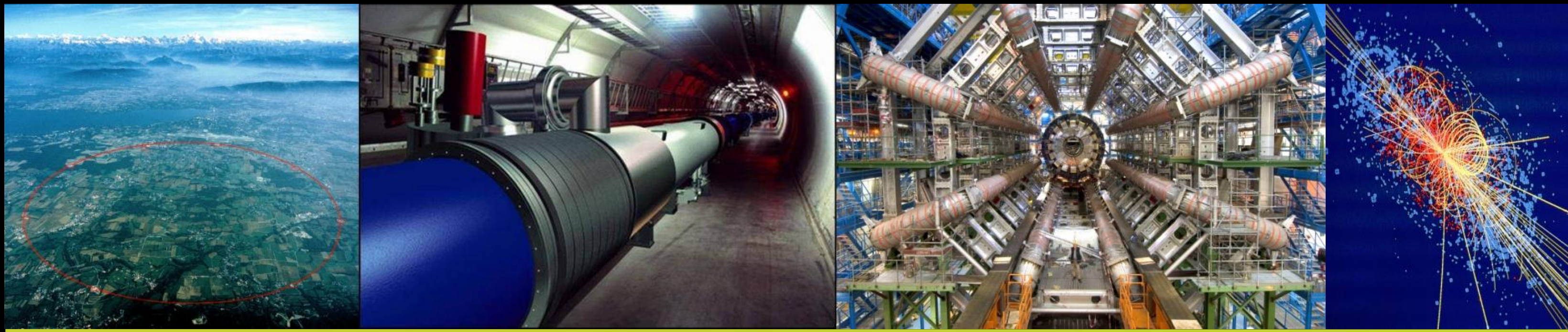


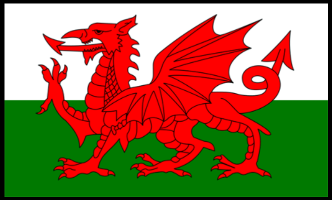
CROESO i CERN

Welcome to CERN

Labordy Ffiseg Mwya'r Byd

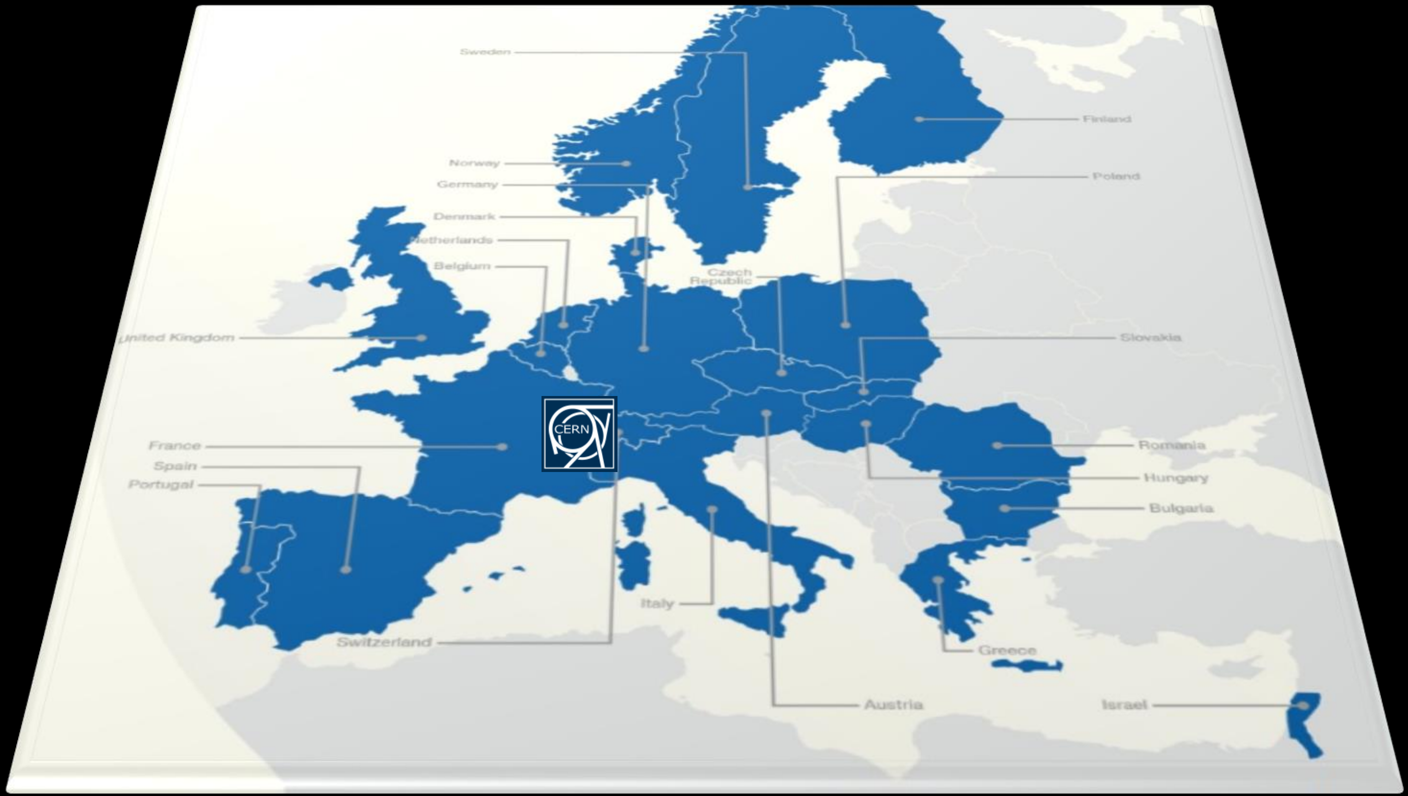
The World's Largest Particle Physics Laboratory

Dr. Rhodri Jones (*CERN*)



Rhaglen Athrawon Cymru
Welsh Teachers Programme
Chwefror / February 8 2017

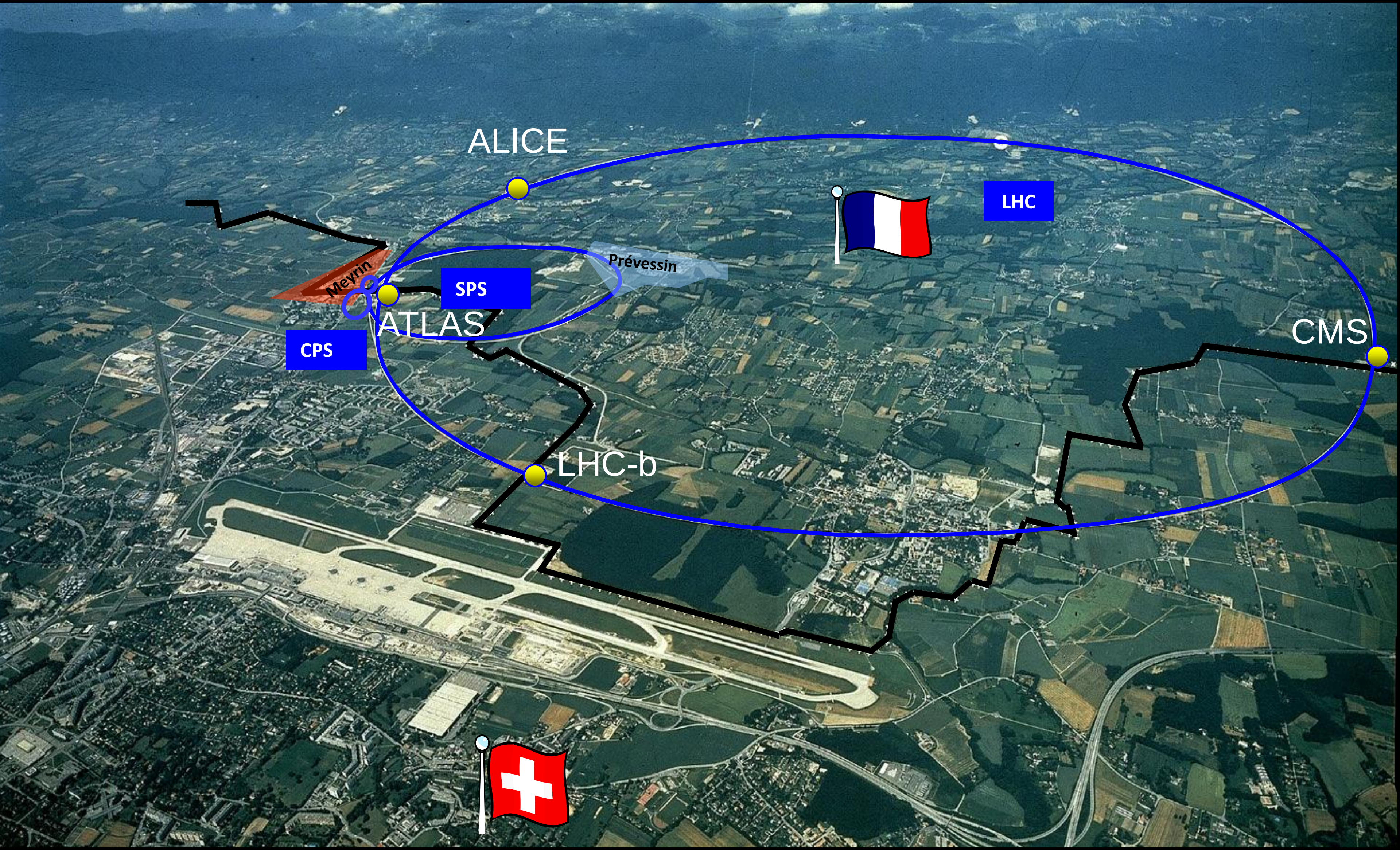
CERN & its Member States



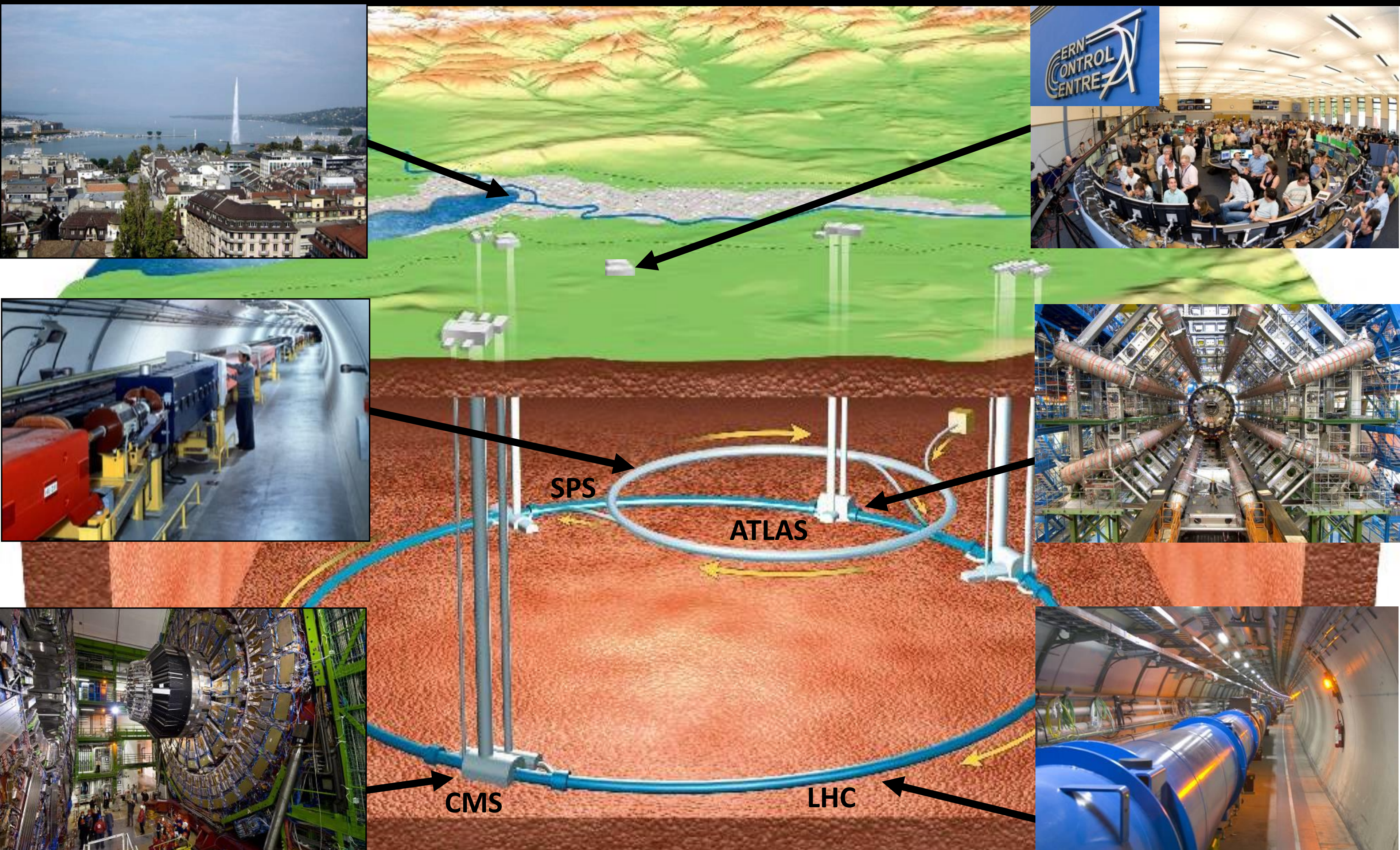
CERN’s Aims

- Research, Technology, Collaboration, Education
- Created in 1954 with the following aims
  - Scientific collaboration within Europe which has now become Worldwide
  - No military work and results available to all
- Personnel: staff ~2500 ; fellows ~550 ; students ~500 ; over 10,000 users

CERN & its Accelerators

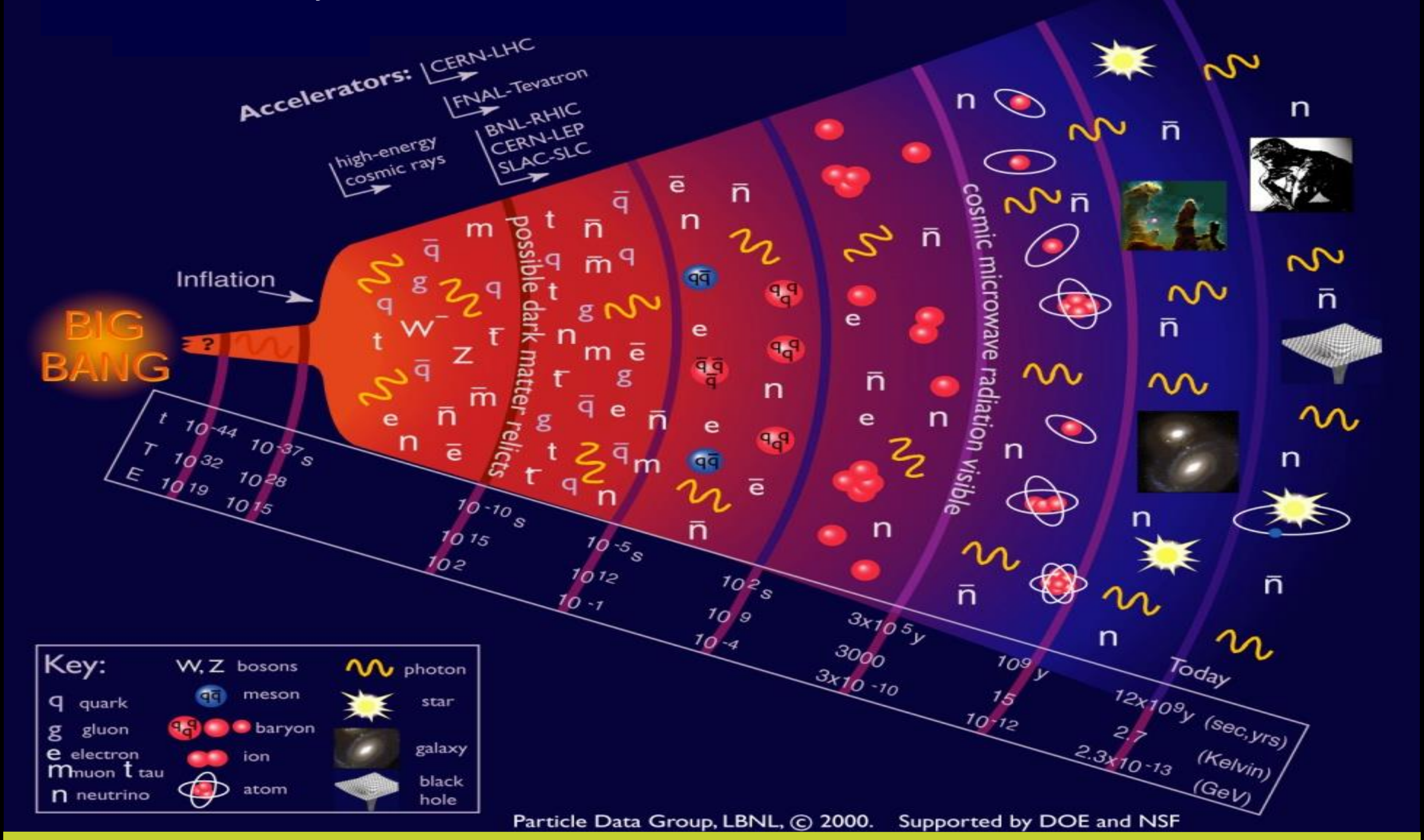


CERN & its Accelerators

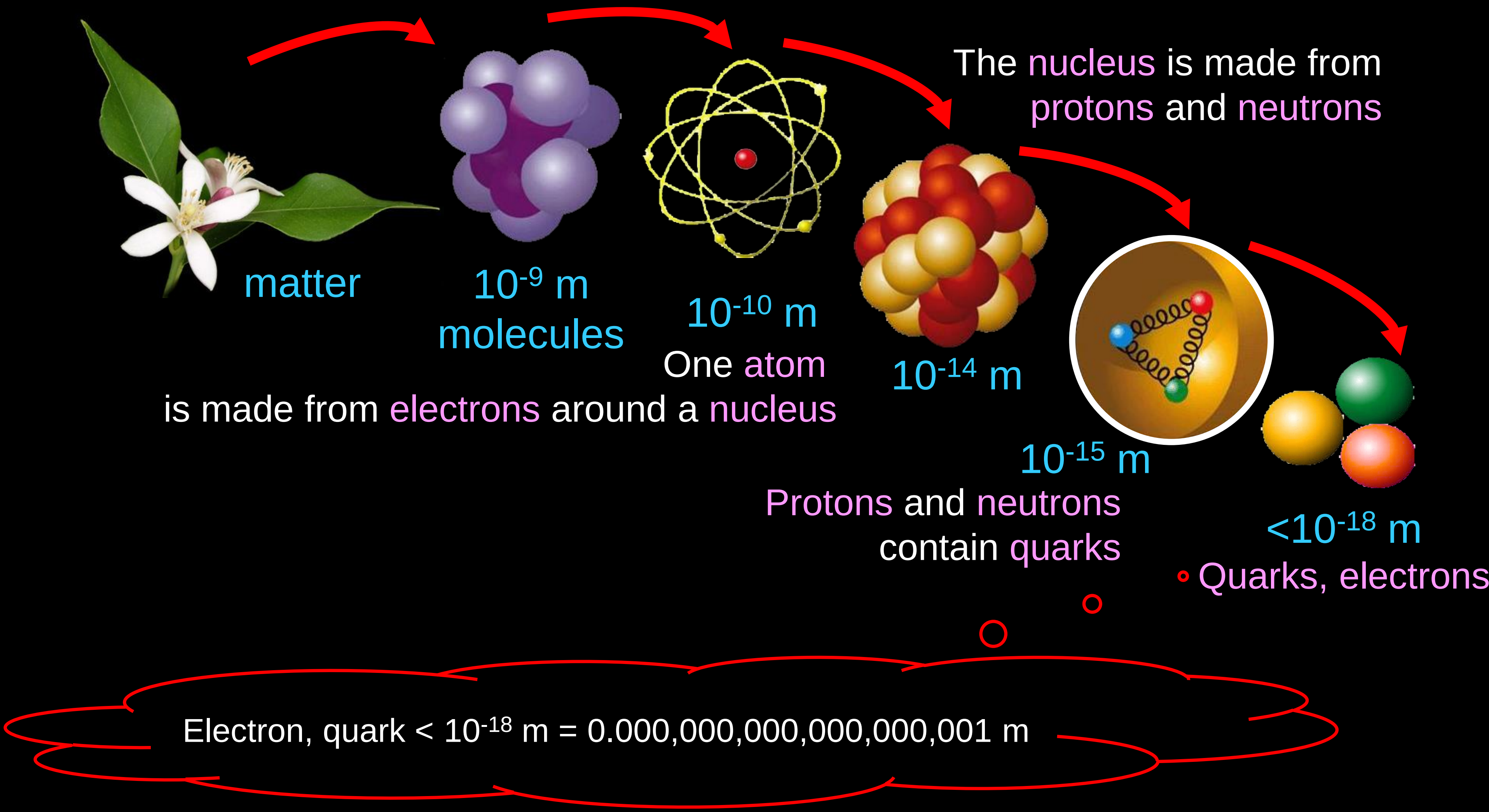


What are we trying to achieve?

History of our Universe



What is matter made from?

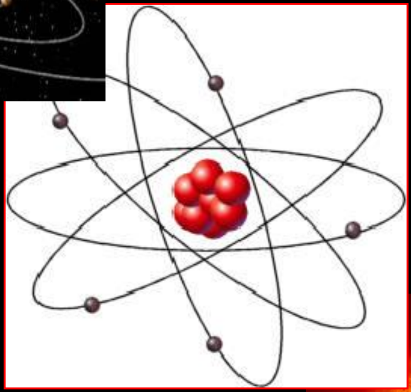


The Fundamental Forces

Gravity

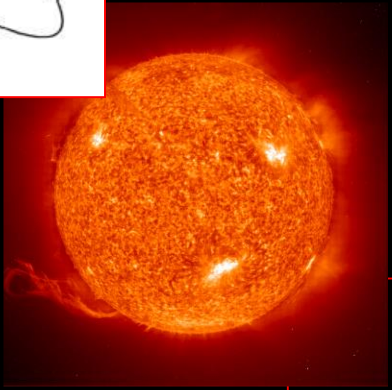
Graviton ?

The forces act through their associated particles



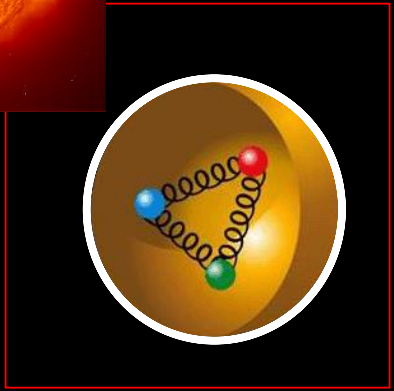
Electromagnetic Force

Photon



Weak Force

W, Z



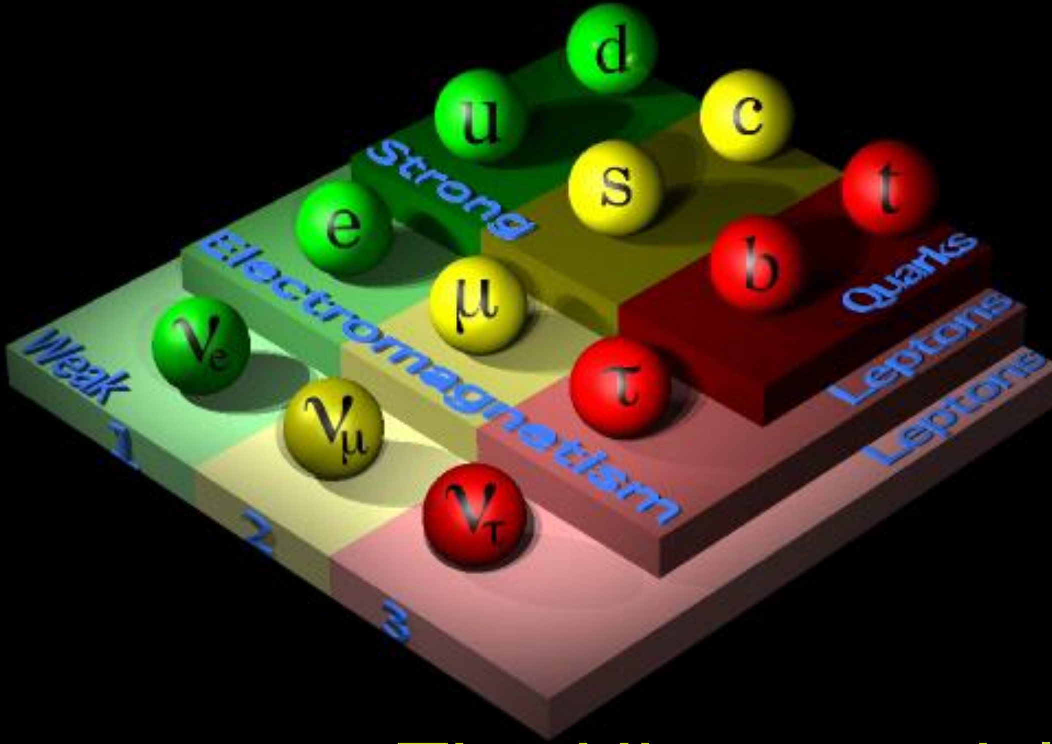
Strong Force

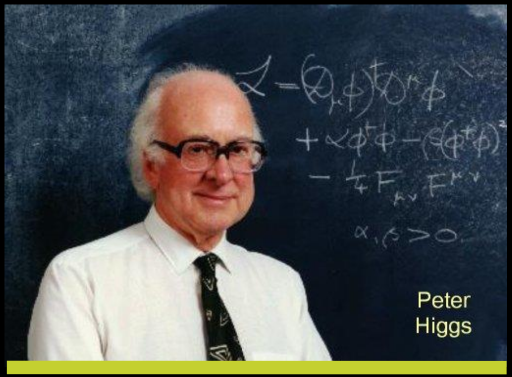
Gluon

The ambition is to describe all these forces as one

The Standard Model

We have a Model but for it to work we need the Higgs particle





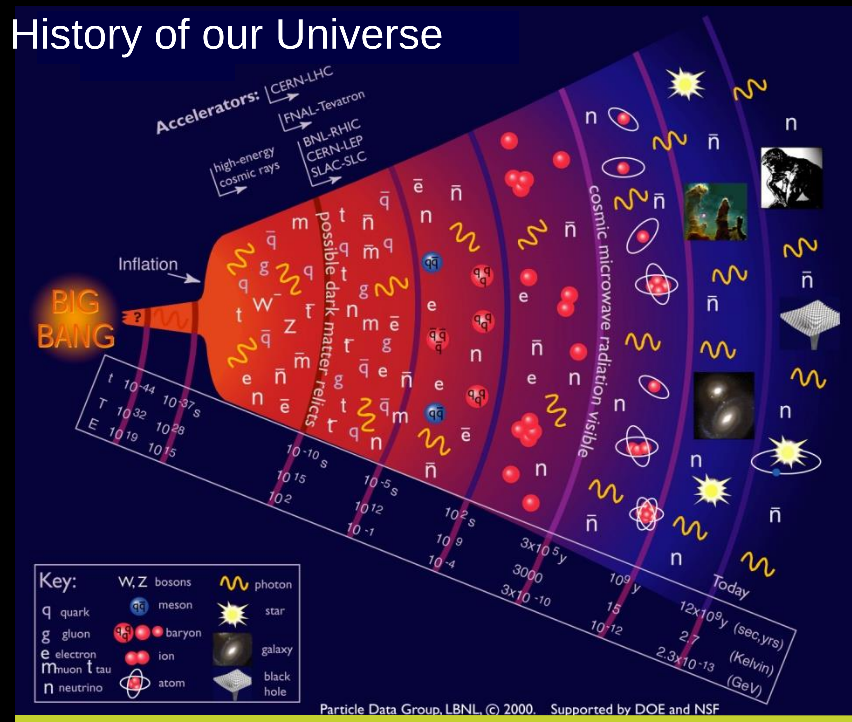
The Higgs particle is "heavy" so to discover it we need a high energy

The Higgs Particle

More Questions ....

BIG BANG

The same amount of matter & antimatter was created



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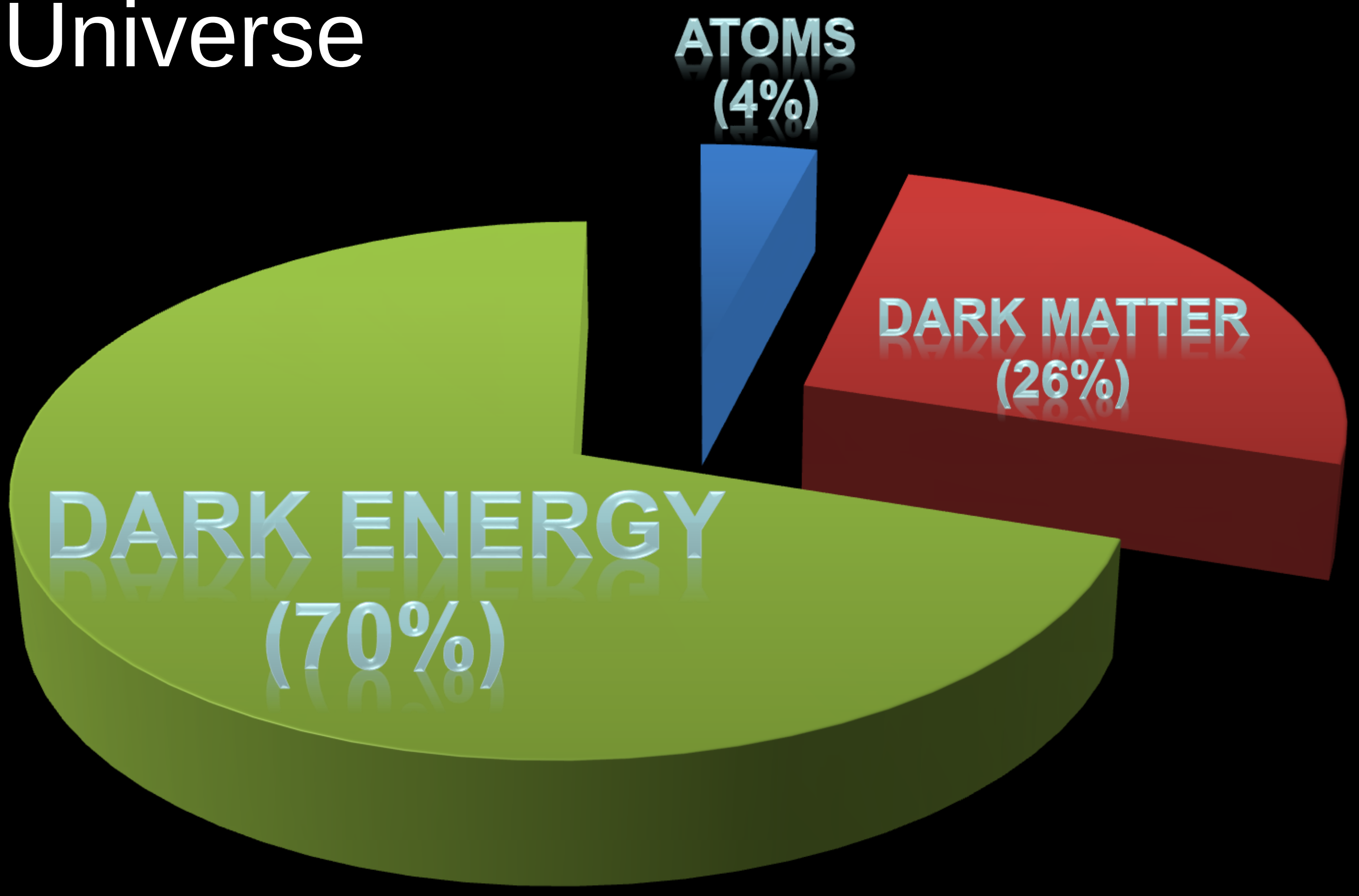
NOW

Only matter (us) survives

Why?

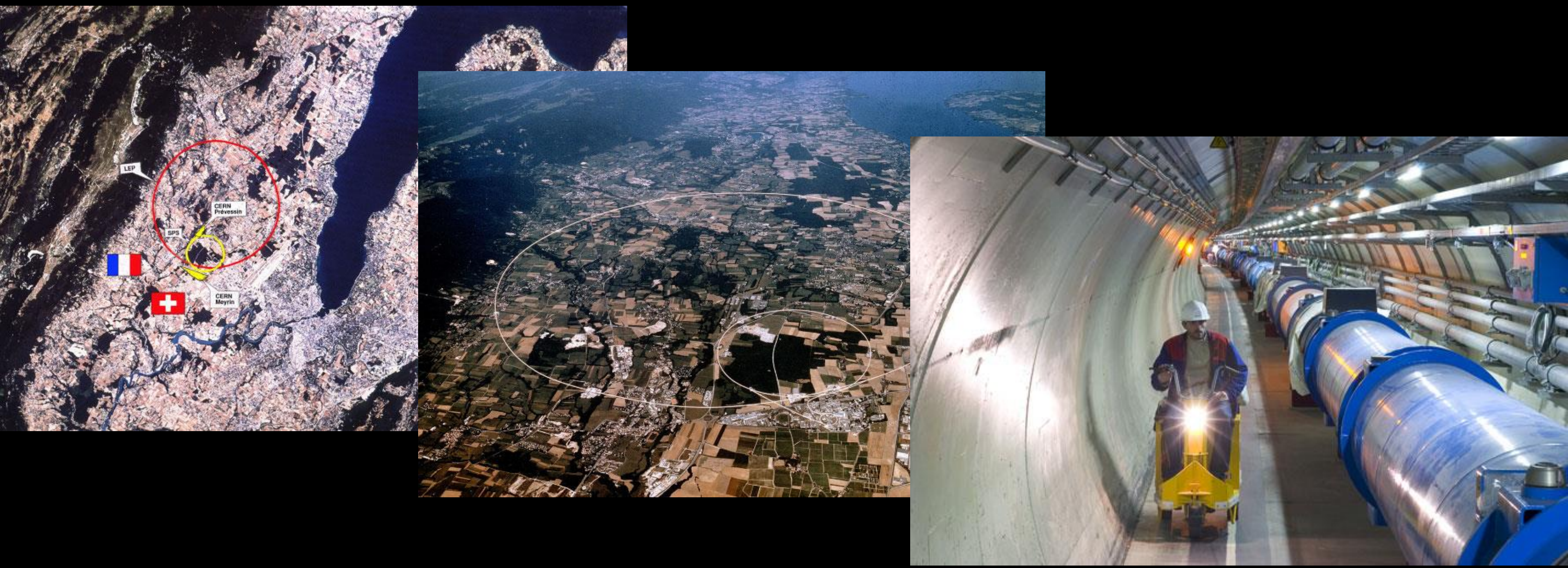
More Questions ....

Our Universe



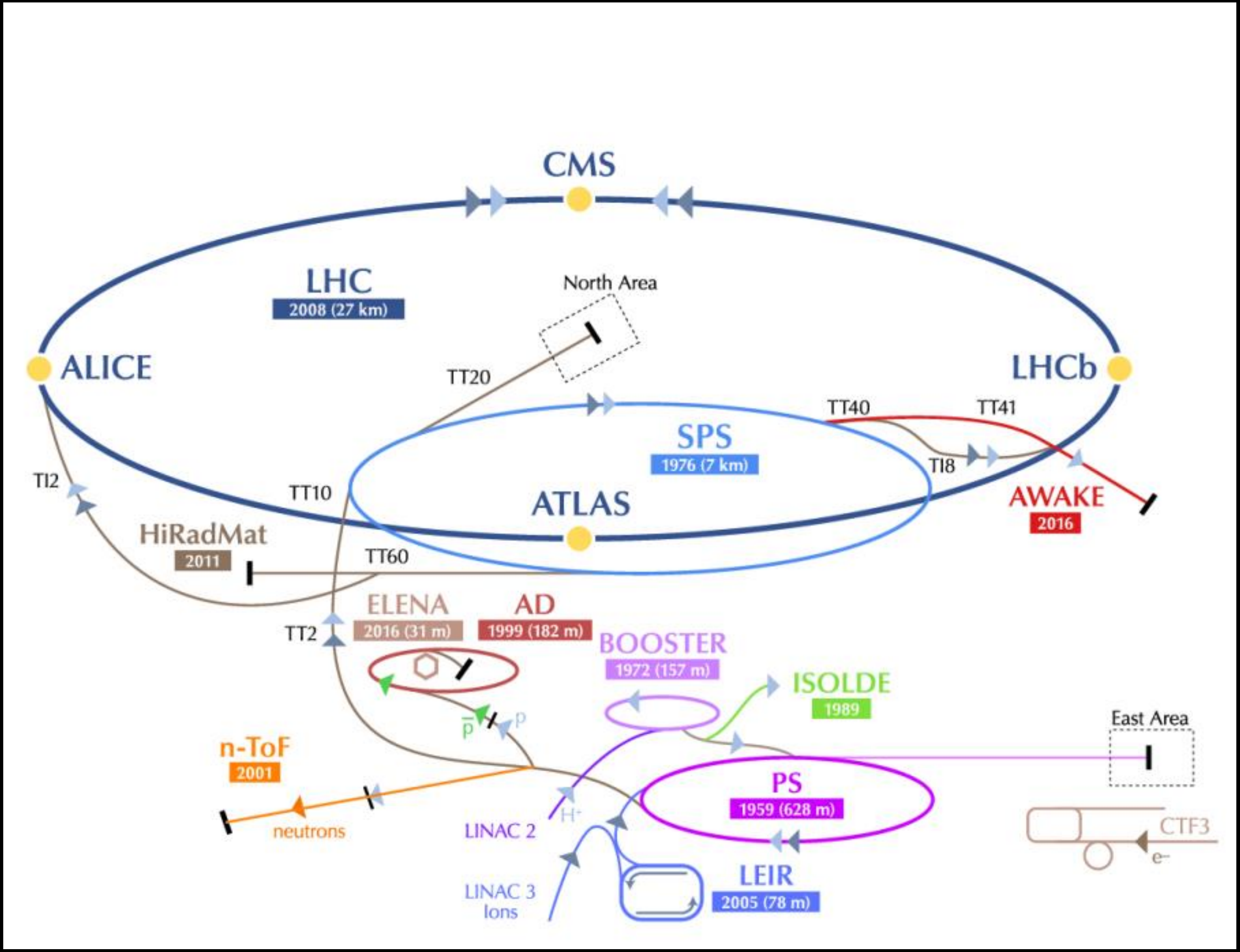
What is this other 96%?

LHC an accelerator to answer some of these questions?

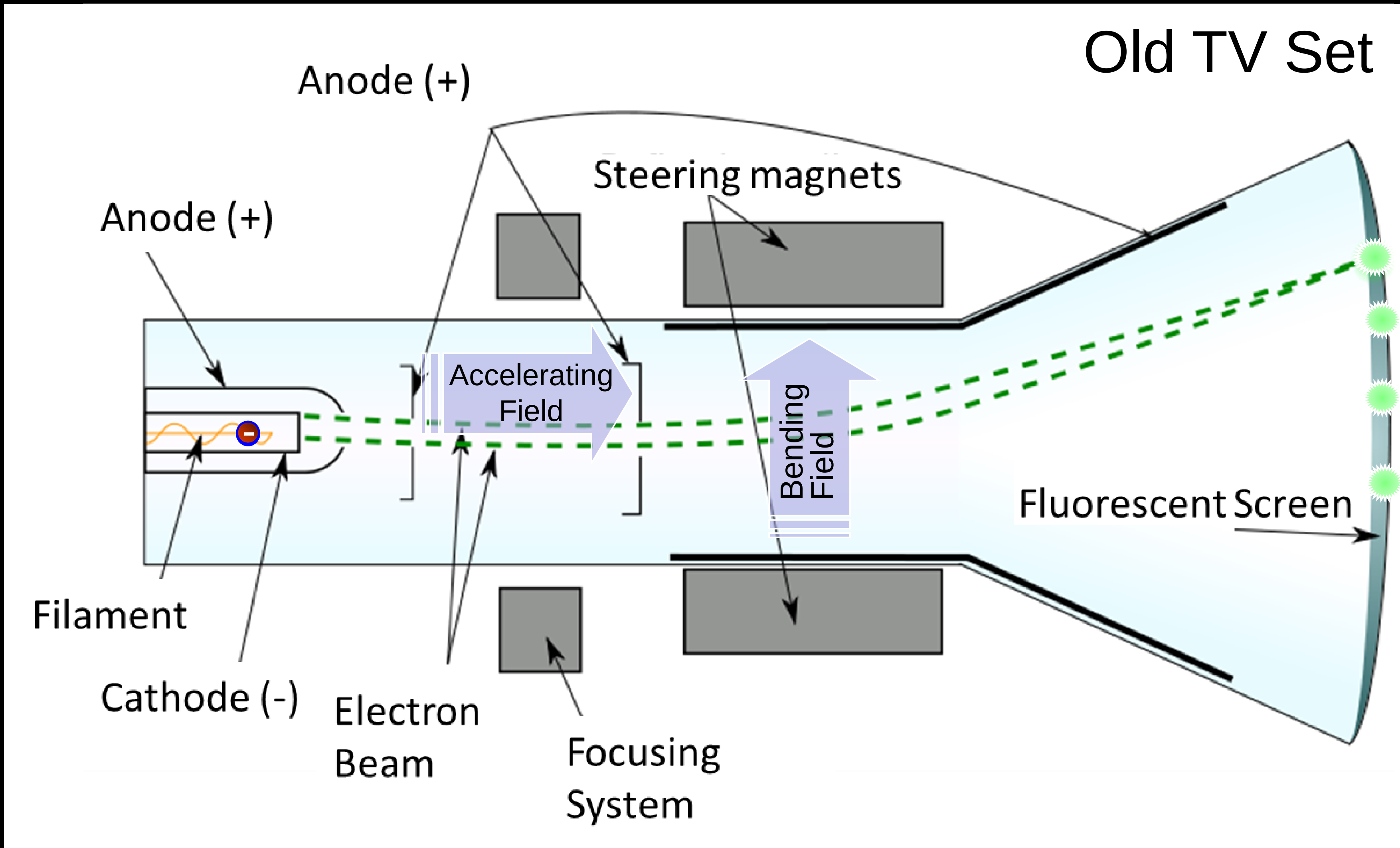


2 beams made up of trillions of protons flying around a 27km ring at 0.999999991 times the speed of light in opposite directions ....

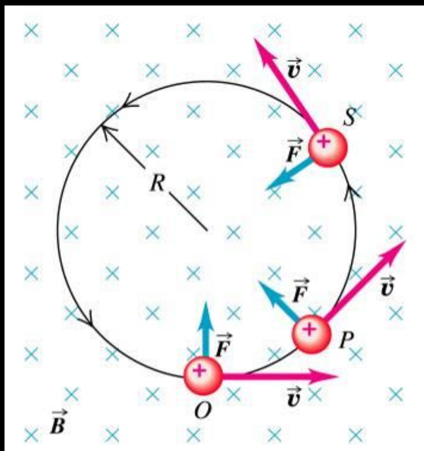
The CERN Accelerator Complex

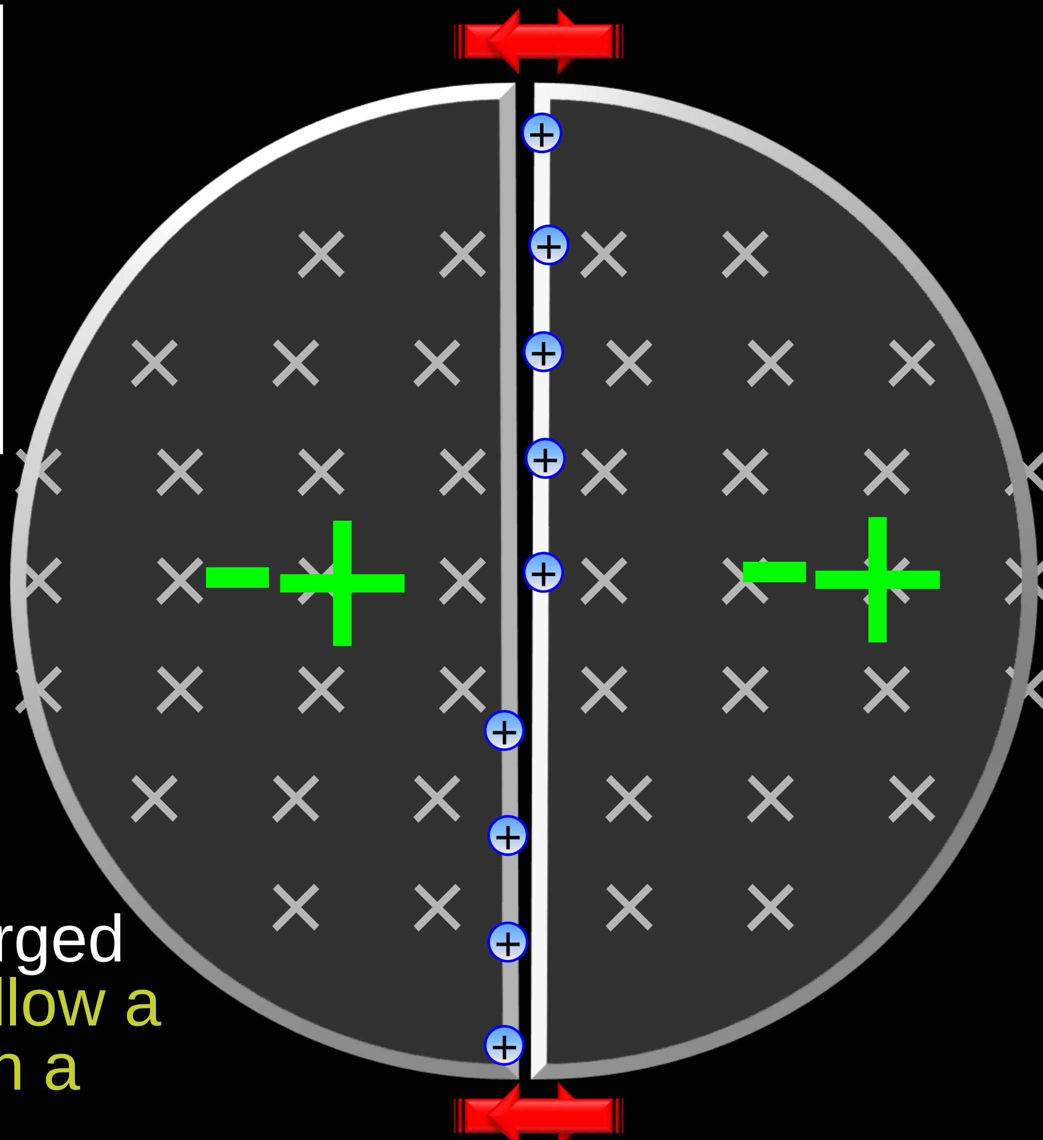


How does an accelerator work?



Circular Accelerators

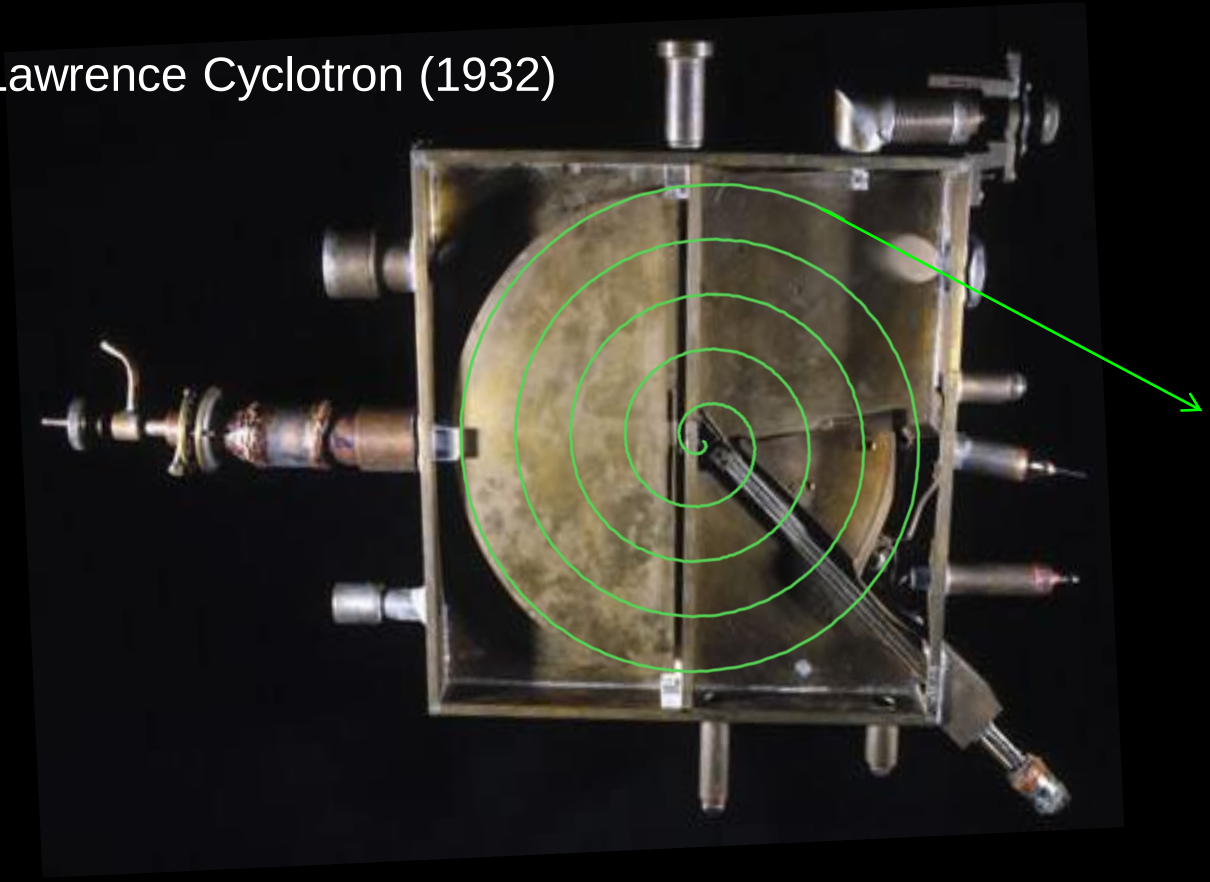




A moving charged particle will follow a circular path in a magnetic field

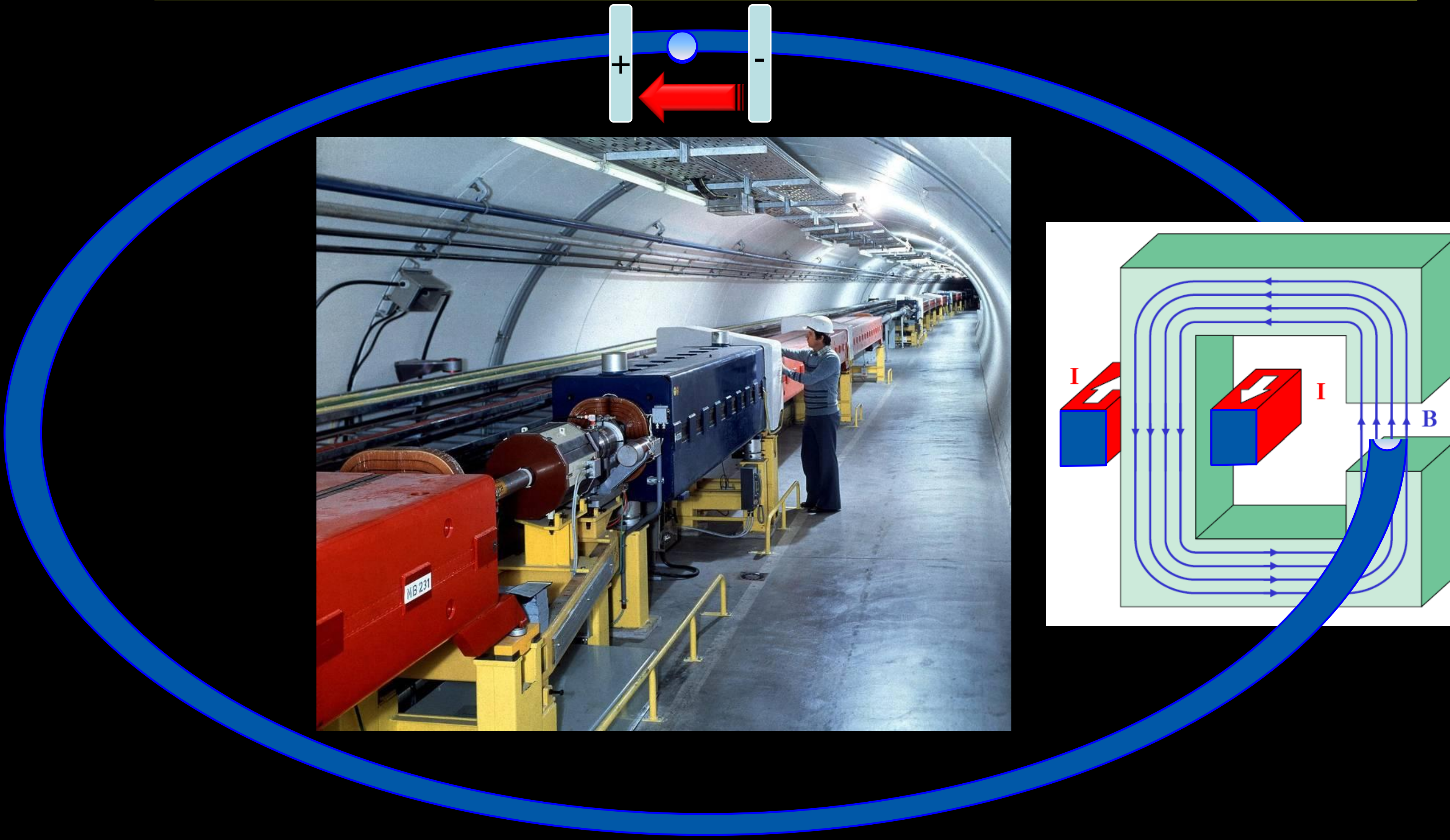
The First Circular Accelerator

Ernest O. Lawrence Cyclotron (1932)



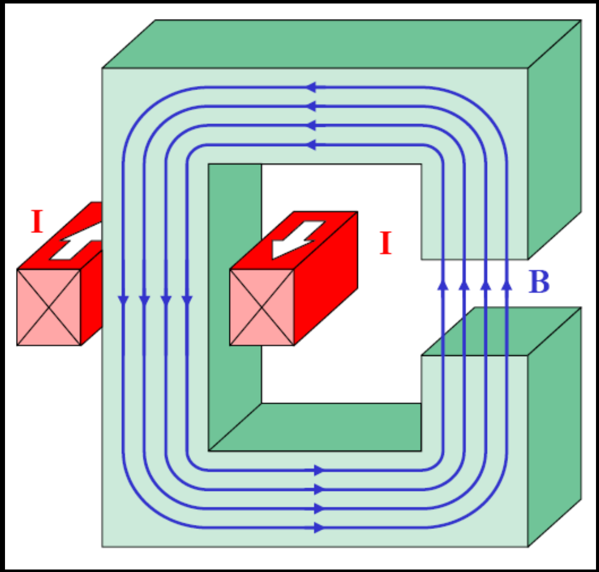
- This 5” version reached an energy of 80keV using only a 1800V acceleration potential
  - As if hydrogen ions (protons) accelerated by 80,000V

Synchrotron Accelerators

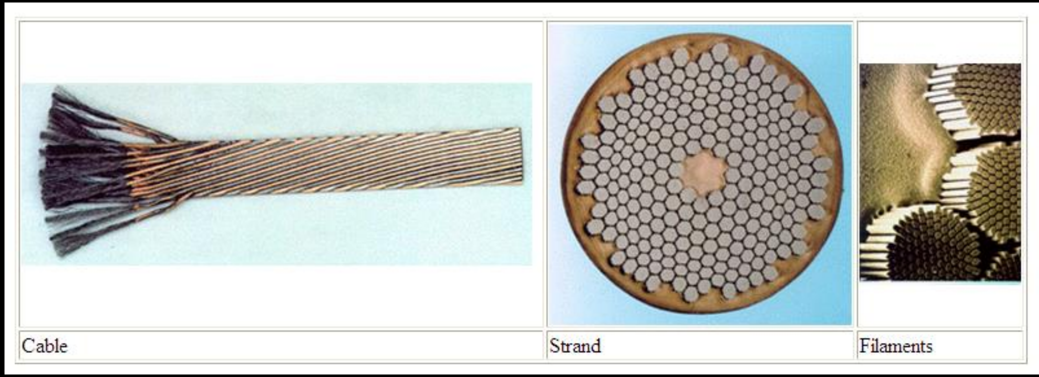


Why use Superconducitivity?

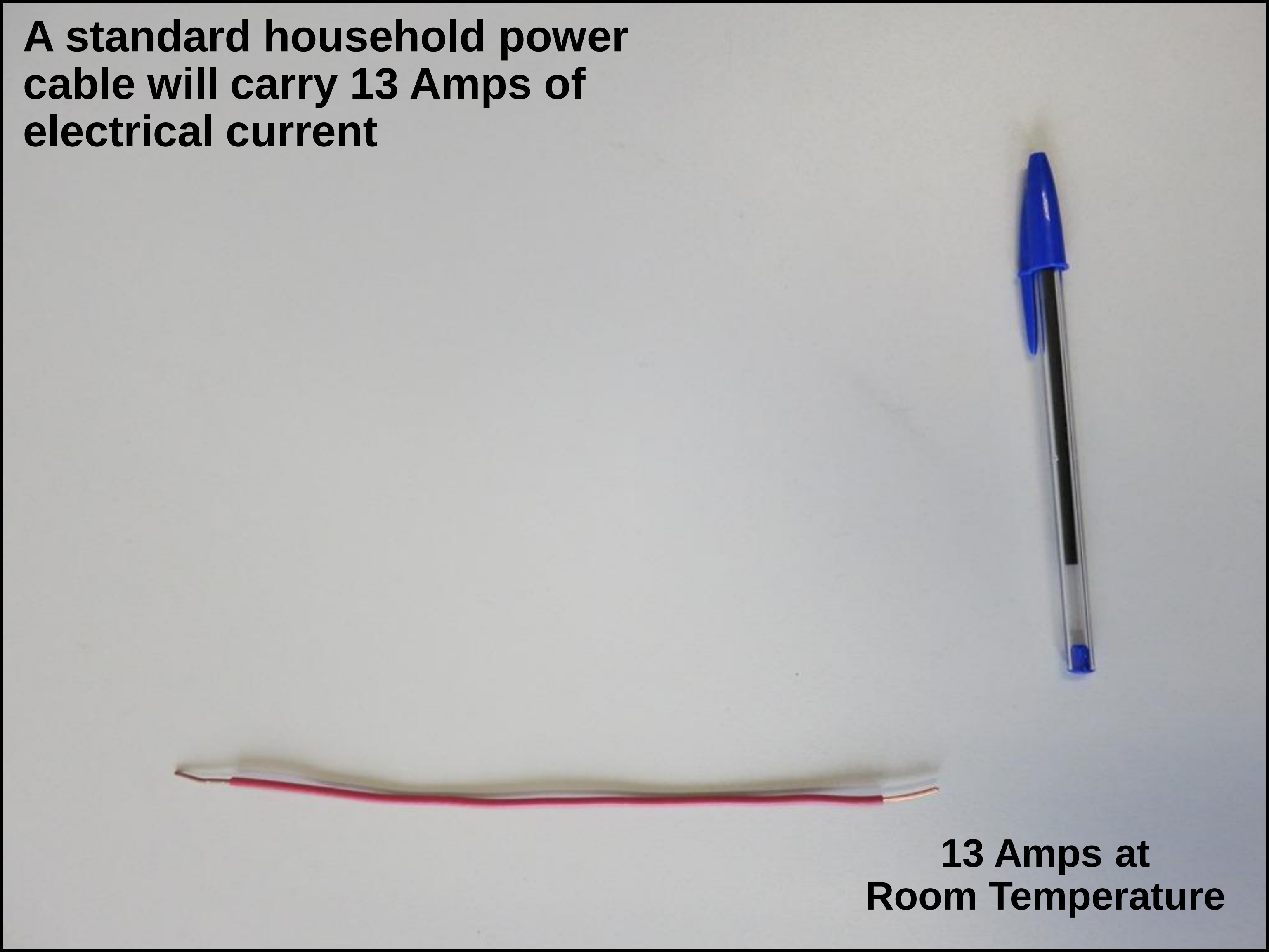
- Iron Yoke Magnets
  - Good to reduce current required
  - Iron guides the magnetic field
  - BUT – iron saturates at around 2T
    - For an accelerator with fixed magnetic field
      - Increasing the energy = increasing the size



- Superconducting Magnets
  - Virtually lossless (no resistance)!
    - Can carry very high currents to create high magnetic fields
      - 8T in LHC
    - BUT the wire needs to be cooled to near absolute zero

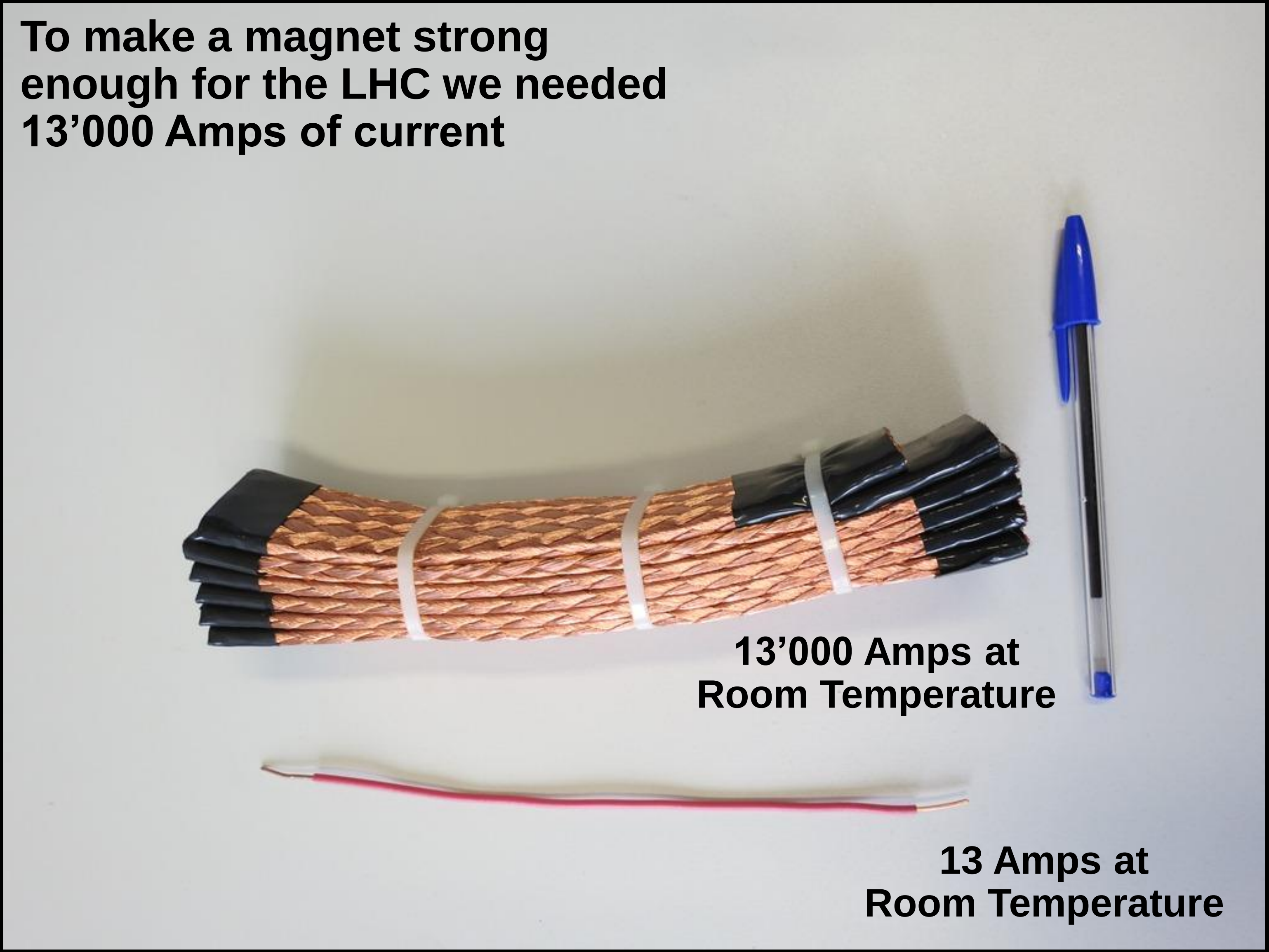


Why is the LHC Superconducting?

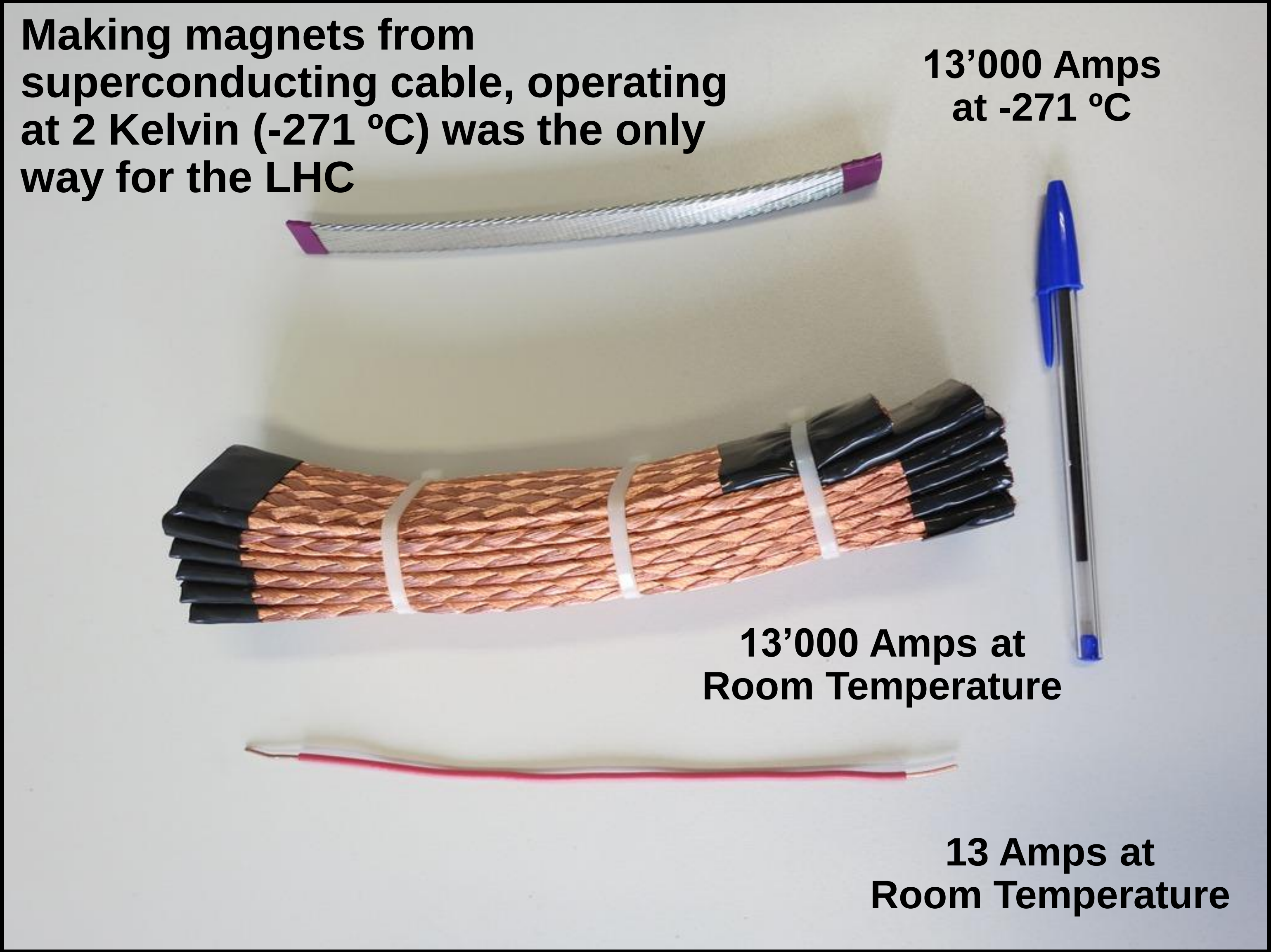


Why is the LHC Superconducting?

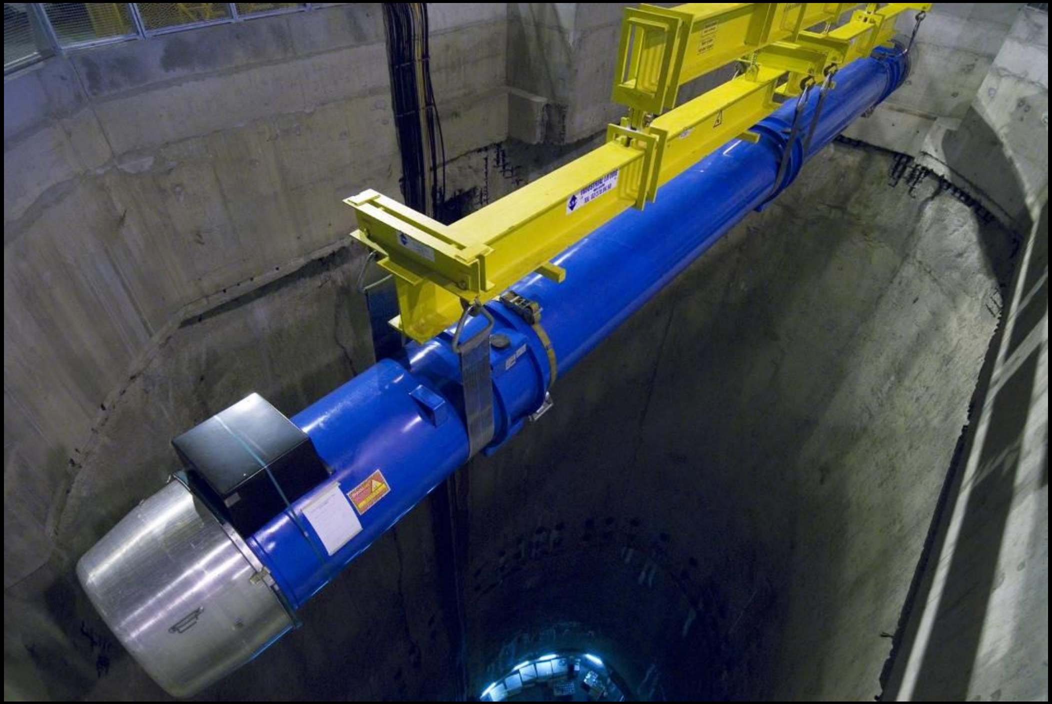
To make a magnet strong enough for the LHC we needed 13’000 Amps of current



Why is the LHC Superconducting?

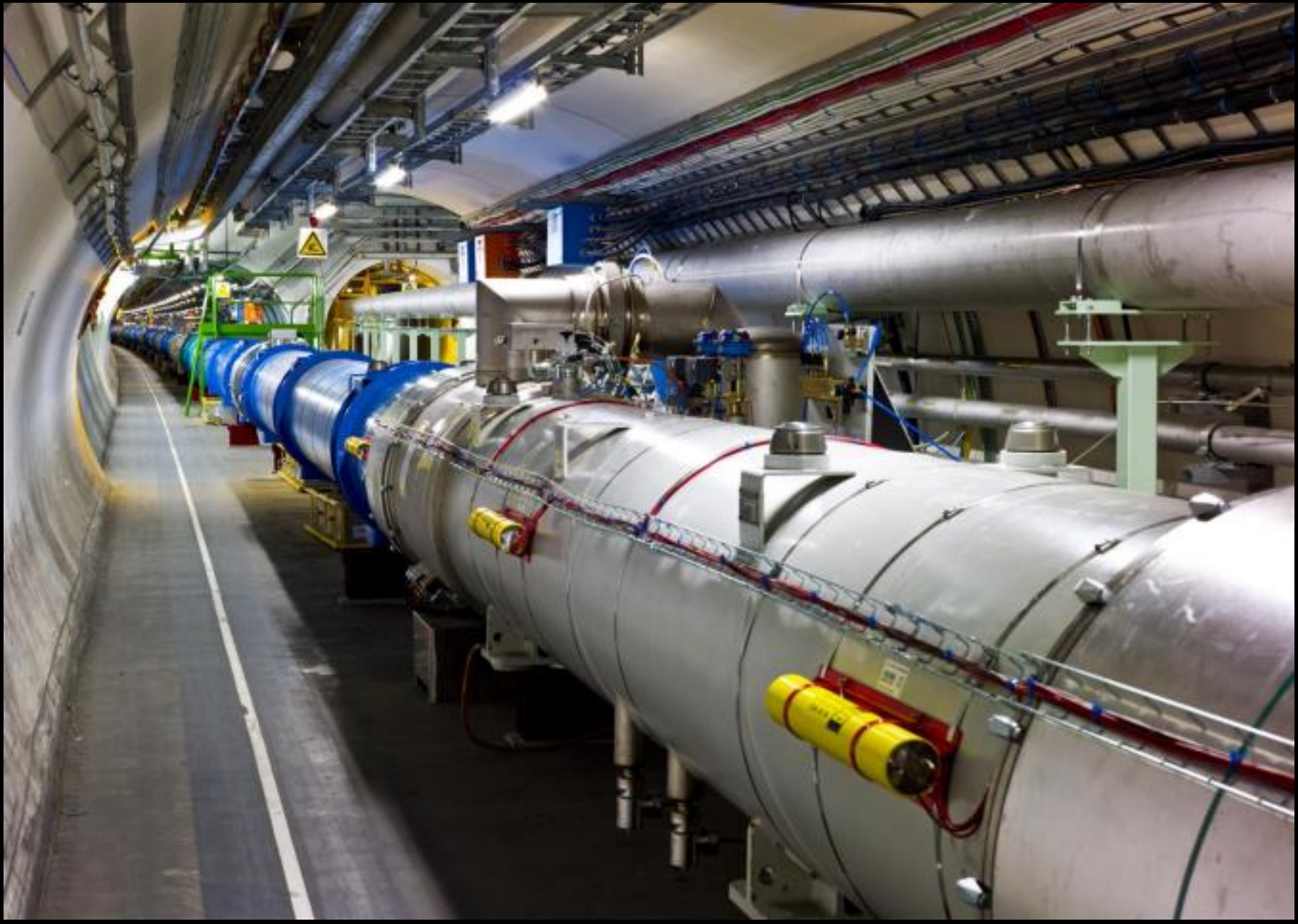


Last Magnet Lowered under Welsh Banner!

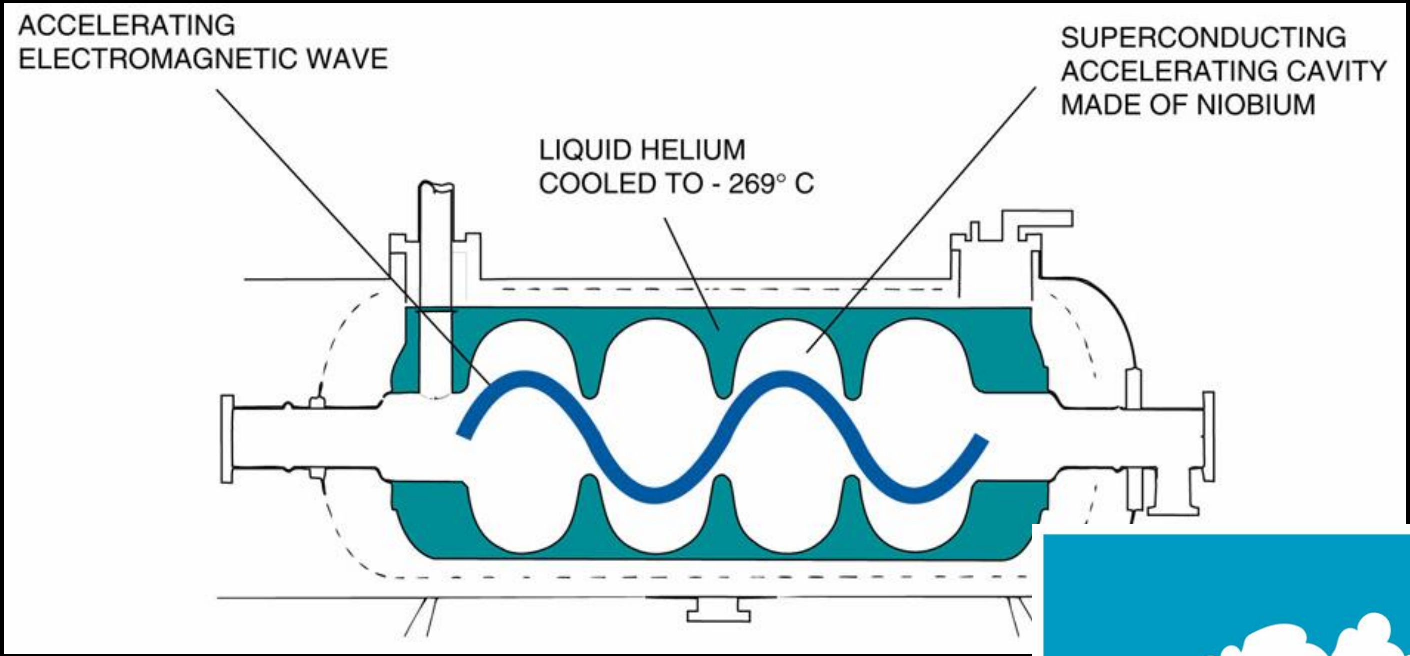


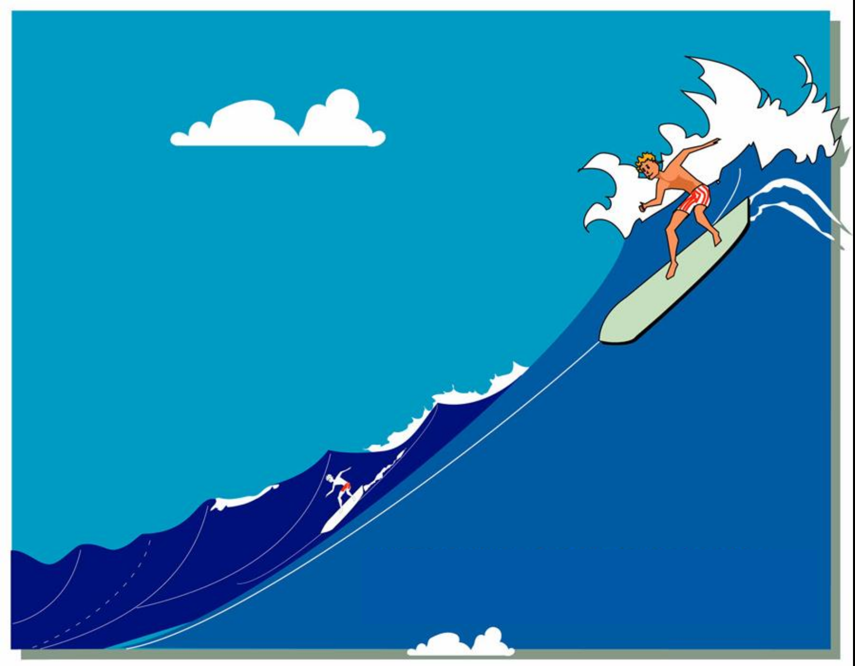
26 April 2007

The LHC Accelerator Ready



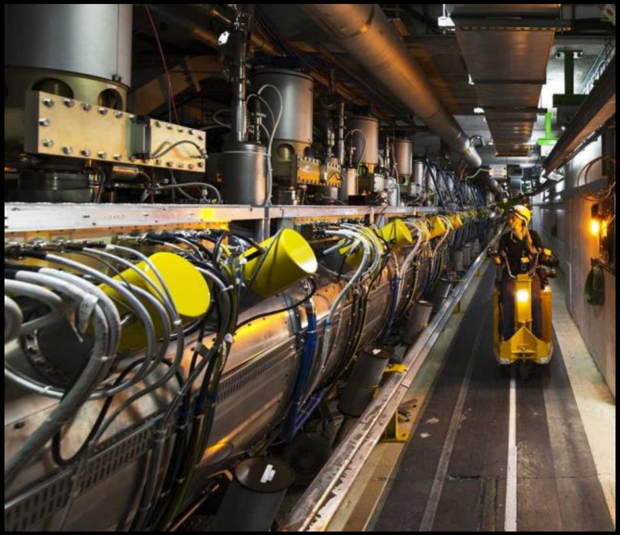
Accelerating in the LHC



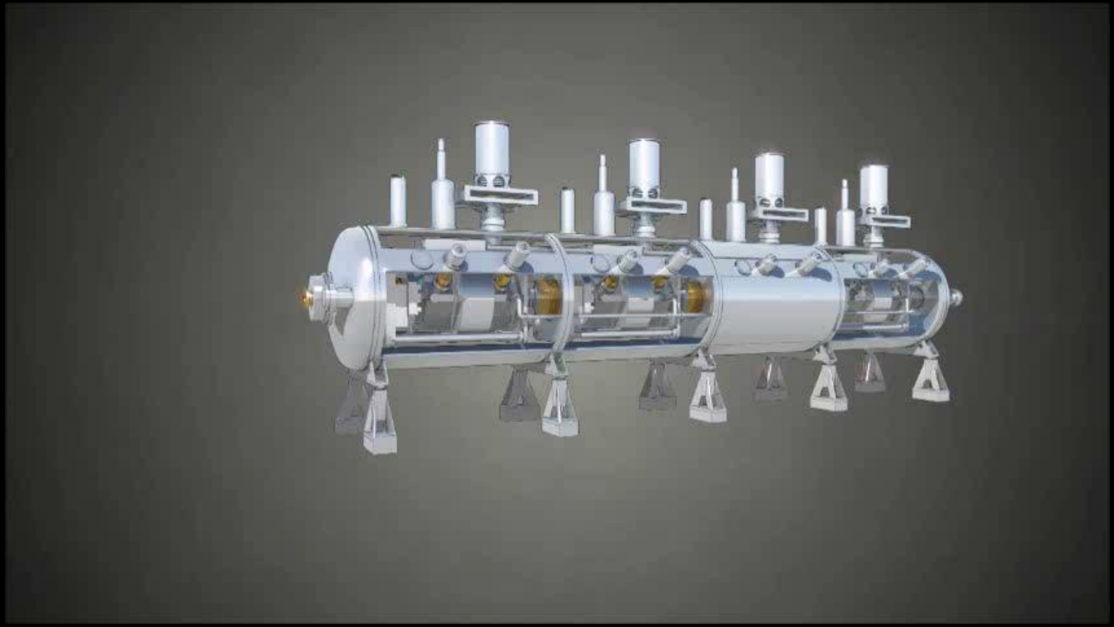


- In the same way that the wave pushes a surfer the electomagnetic wave gives energy to the particle
  - In a synchrotron the particle gains a small amount of energy each time it passes the accelerating structure
- In the LHC it takes ~30 minutes to go from injection energy to top energy (~20 million turns)

Accelerating in the LHC



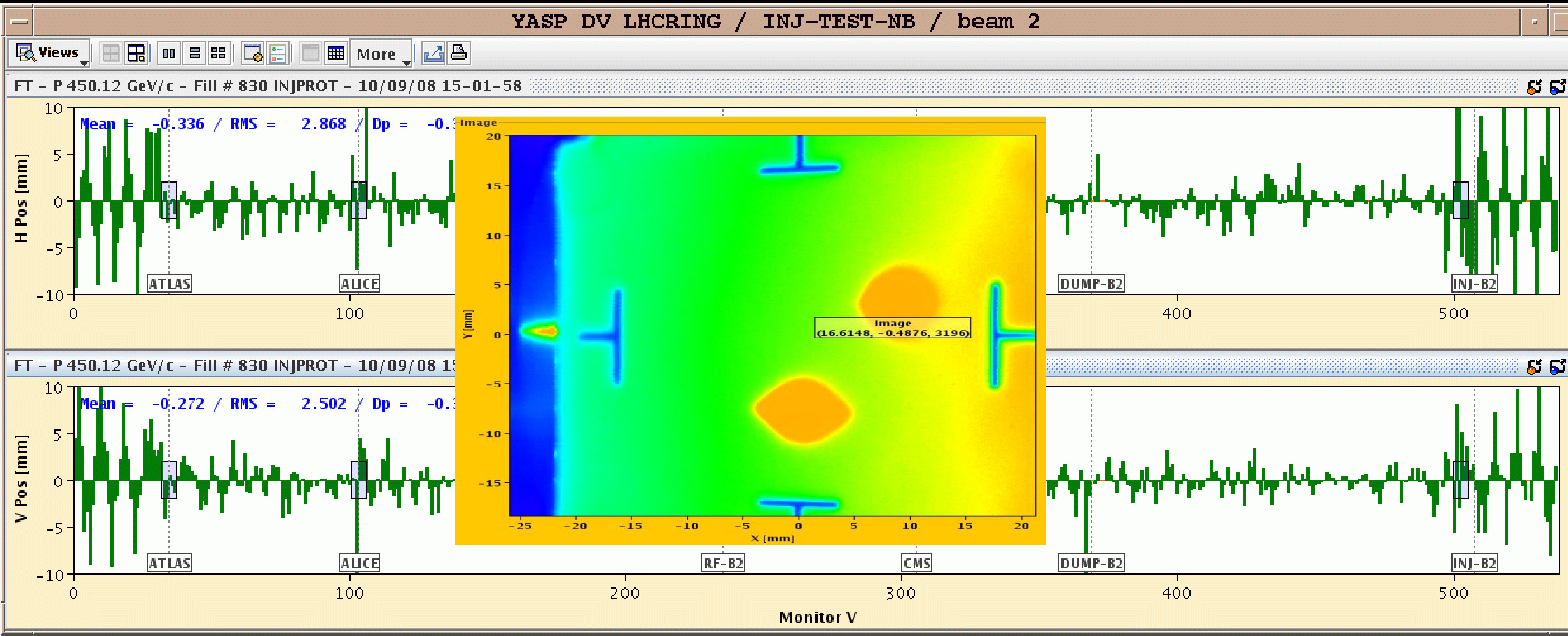
- LHC has 2 modules made of 4 cavities per beam
  - Providing 2 x 4 x 2 MV = 16 MV of accelerating gradient
- On each turn particles can gain 16 MeV of energy
- In one second particles can gain
  - (16 MeV/turn) x (11245 turns/s) = 0.18 TeV/s
- To go from 450GeV injection energy to 7 TeV
  - Time taken is (7 - 0.45) / 0.18 = 36.4 s
- In reality the LHC it takes ~30 minutes to go from injection energy to top energy (~20 million turns)
  - Driven by how fast the magnetic field can be ramped-up rather than how fast we can accelerate



Controlling the Beams

- Beam Instrumentation
- Over 500 position monitors per beam
  - Automatic feedback systems measure the beams & correct trajectories by adjusting magnetic field to keep them within 10 microns of desired position

27km

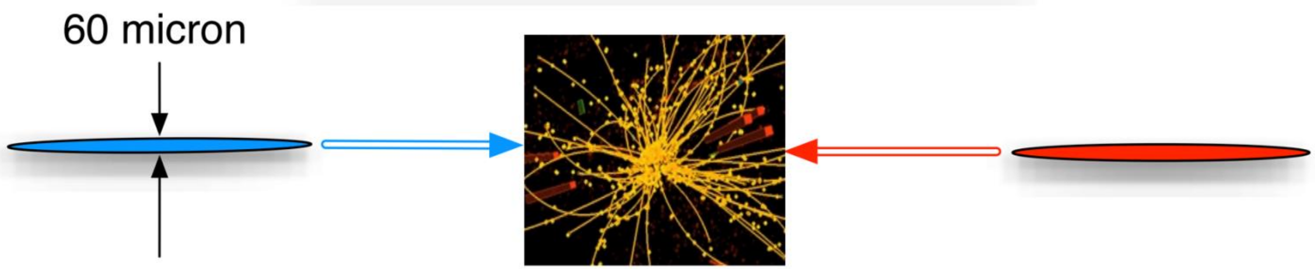


Controlling the Beams

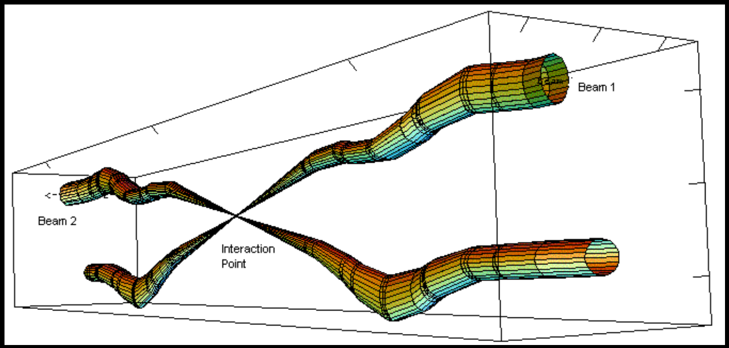
- Synchrotron light monitors
  - The protons have such a high energy that they emit light when bent by the magnetic field, so called “synchrotron radiation”
  - Looking at this light allows us to measure the size of the individual proton bunches in the LHC

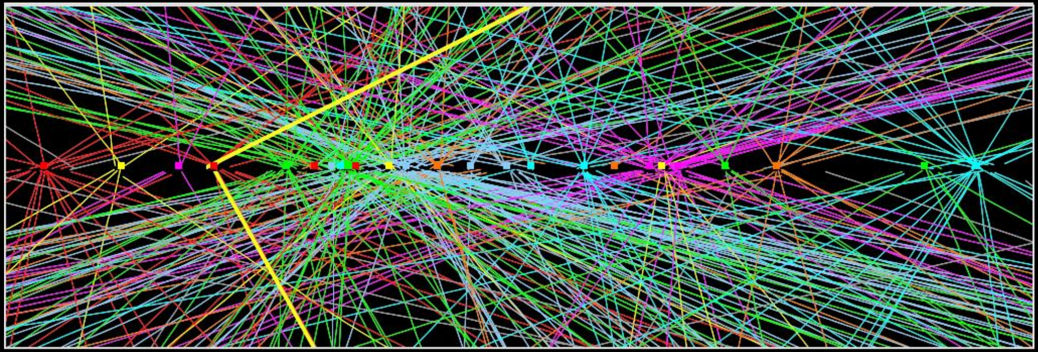
Collisions in the LHC

140,000,000,000 protons a bunch
~30 collide at each bunch crossing



~30 collisions per crossing
11,000 crossings per second per bunch
> 2000 bunches
~800 million collisions per second

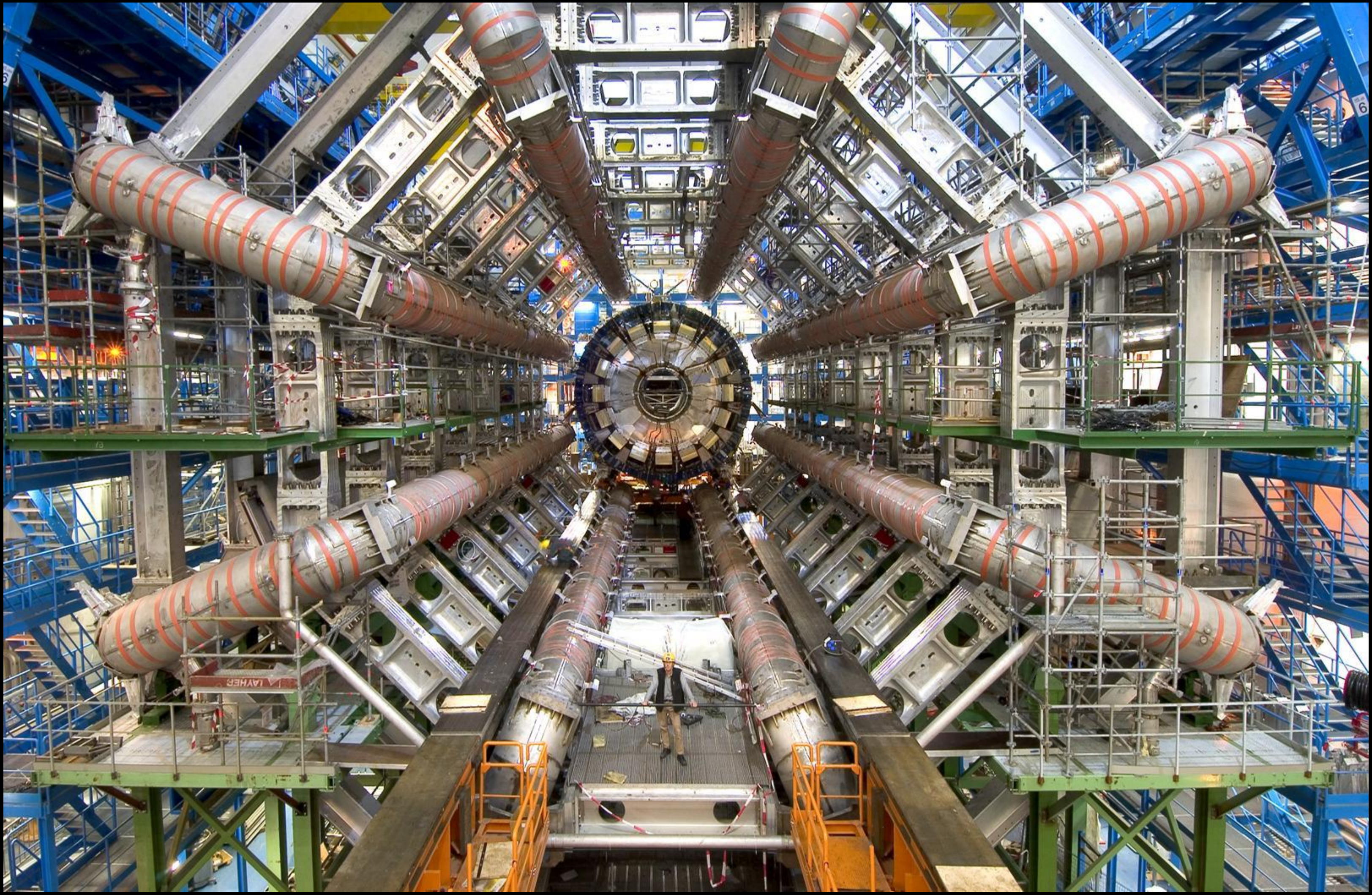




The LHC Experiments

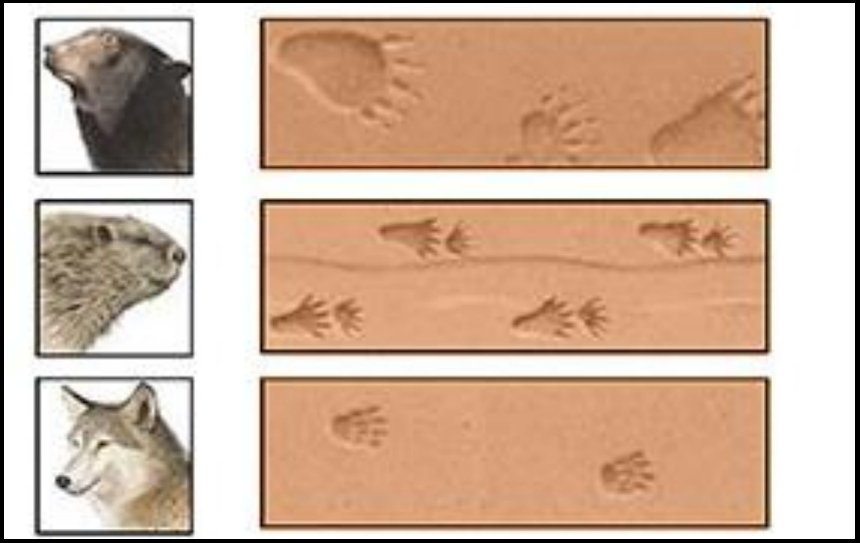
- A total of 7 experiments use LHC collisions
  - Over 100 different countries working together
- Each Experiment has own Specialised Detector
  - 2 large general purpose experiments
    - ATLAS – A Toroidal LHC ApparatuS
    - CMS – Compact Muon Solenoid
  - 2 large specialist experiments
    - ALICE concentrating on heavy ion physics
    - LHCb looking at B meson decays (matter / anti-matter asymmetry)
  - 3 smaller experiments
    - TOTEM & LHCf studying the physics of scattered protons
    - MoEDAL searching for magnetic monopoles

The ATLAS Experiment



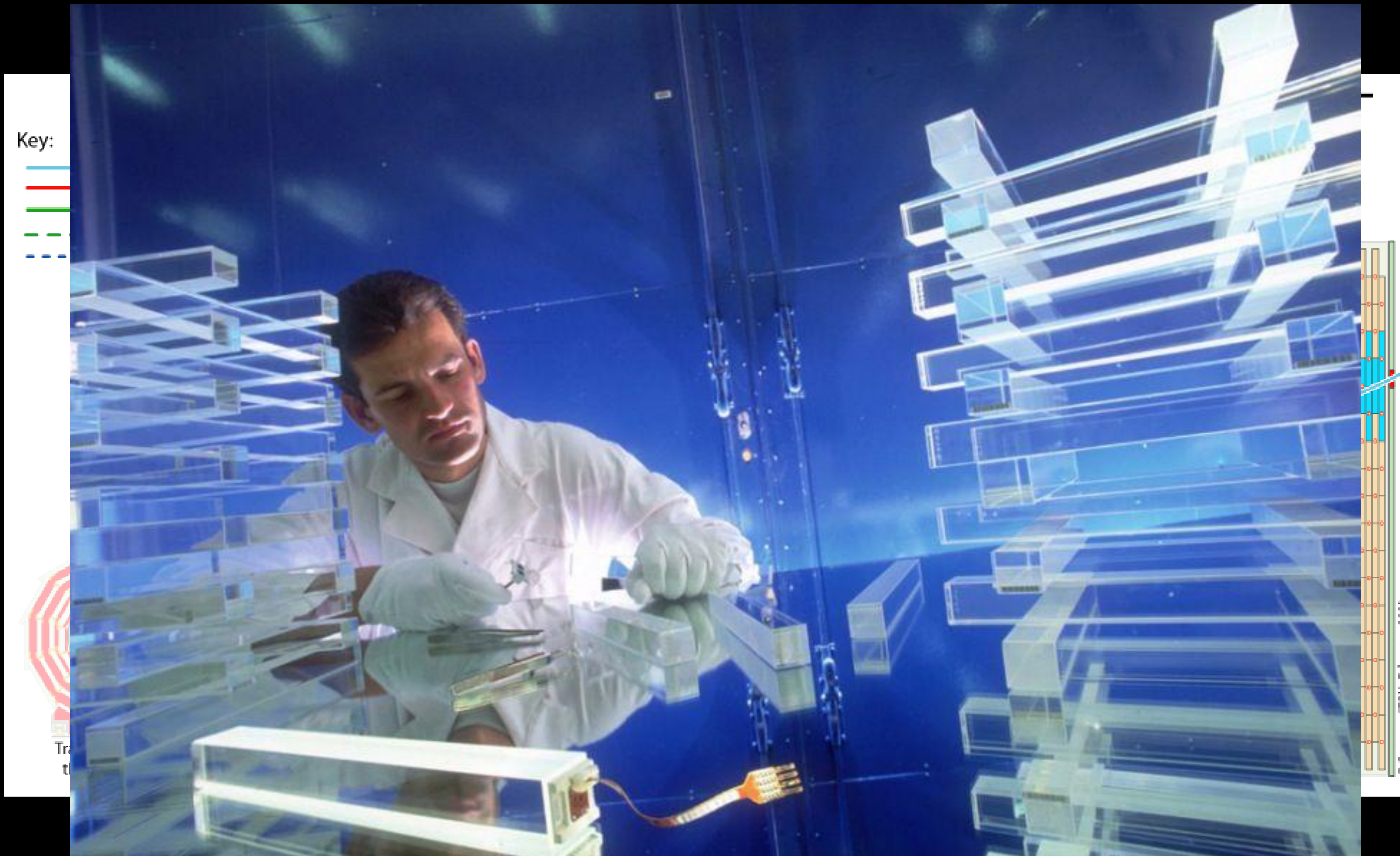
The CMS Experiment

How do the Detectors Work?



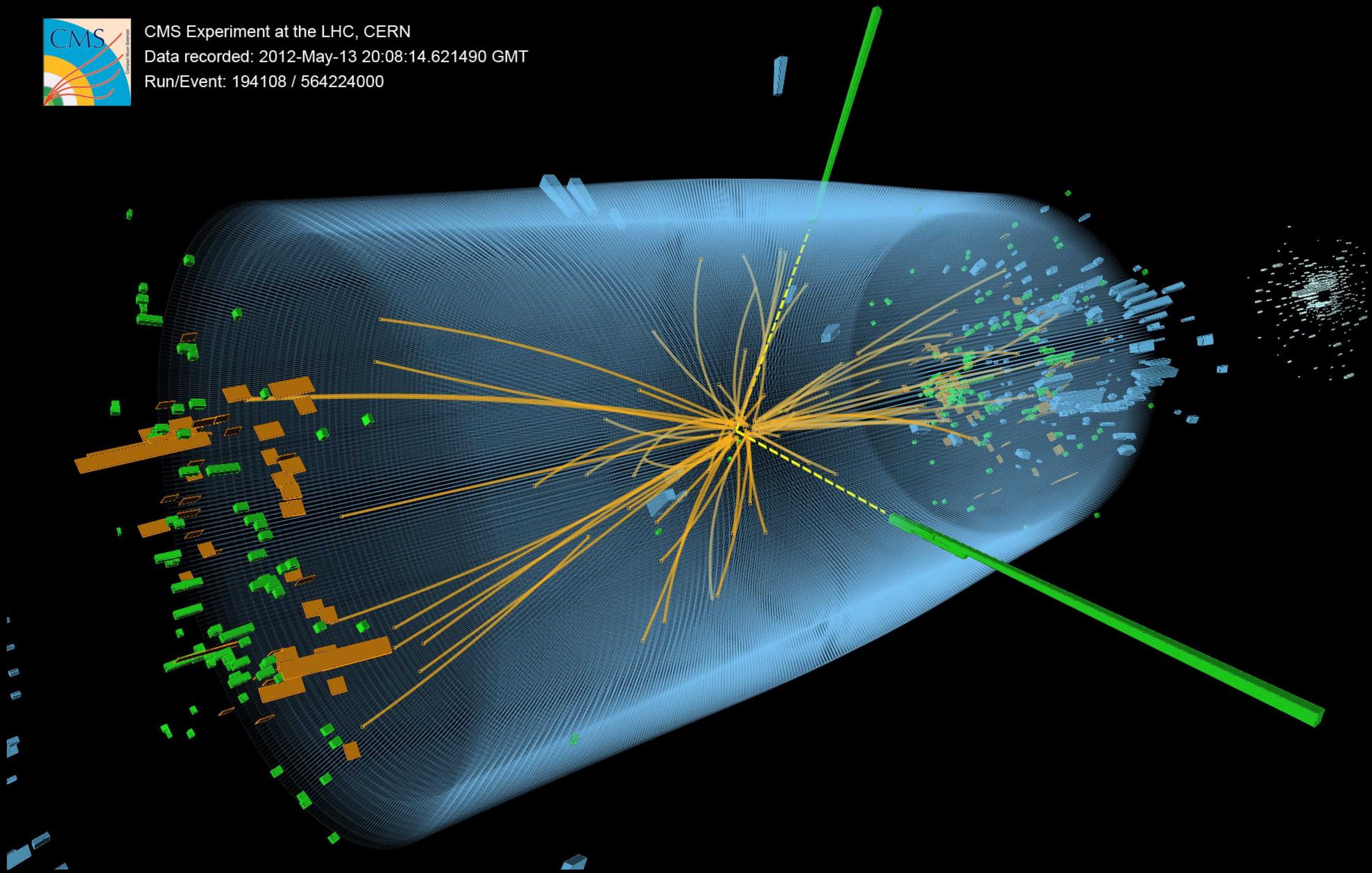
- In the same way as you study footprints in snow or mud
  - The shape, step size, direction, and depth of the footprints tells you which animal it was, how big it was and where it came from

How do the Detectors Work?

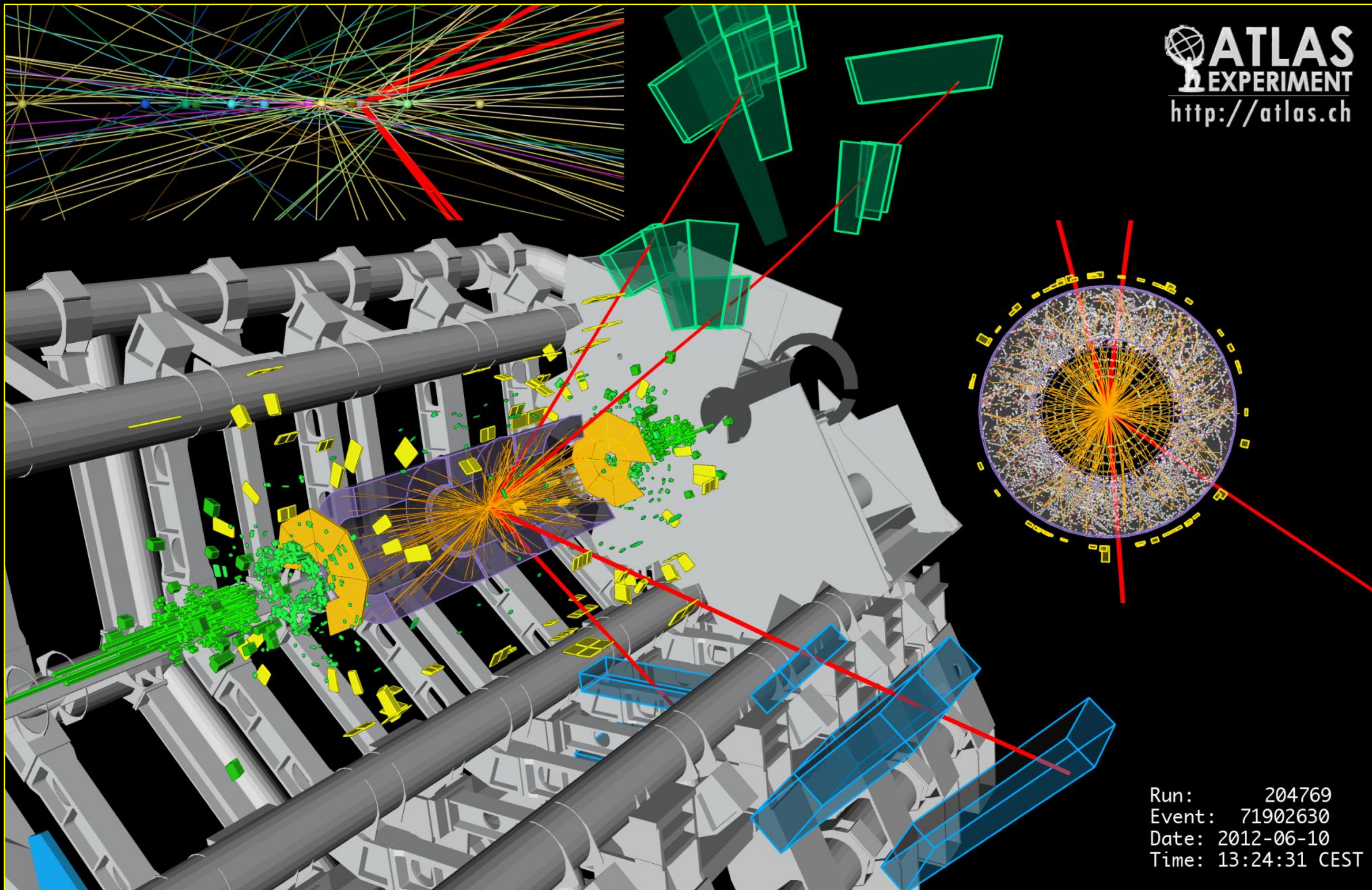


From the Bottle to the Experiment

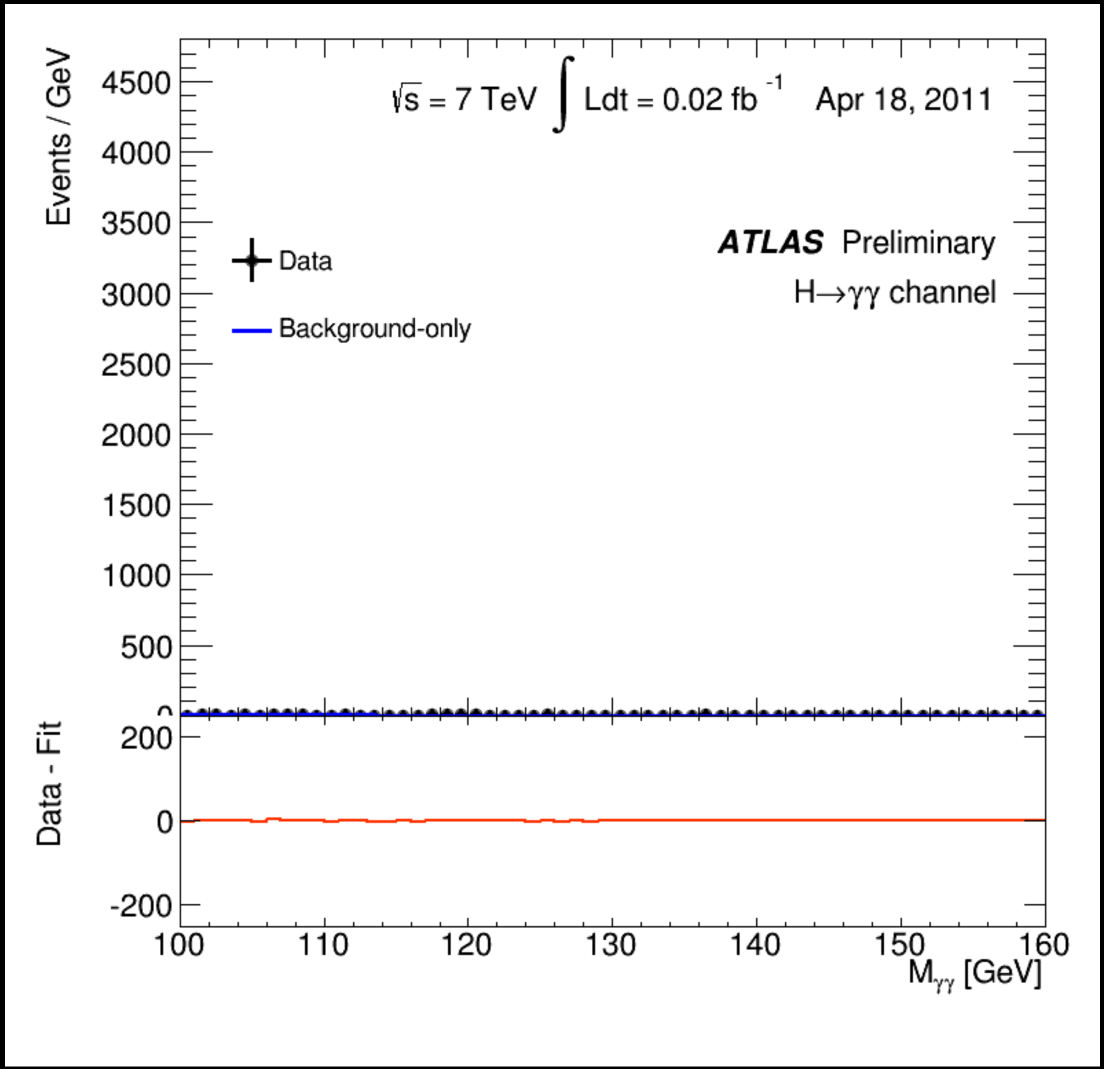
A Possible H → 2 Photon Decay



A Possible H → 4 Muon Decay

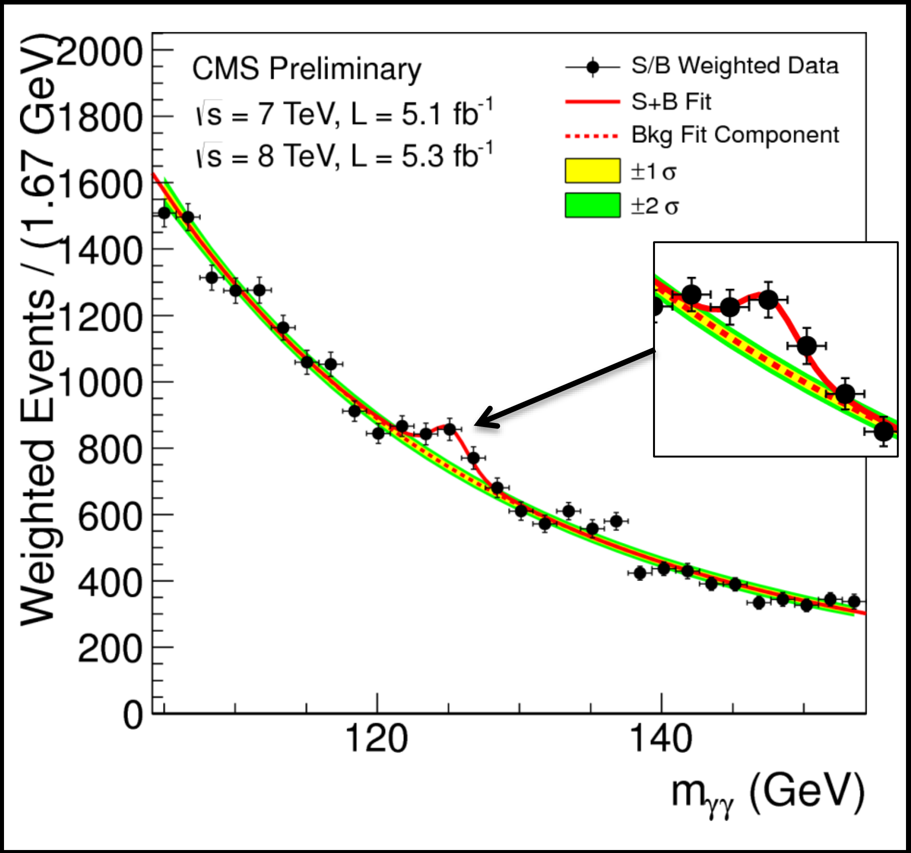


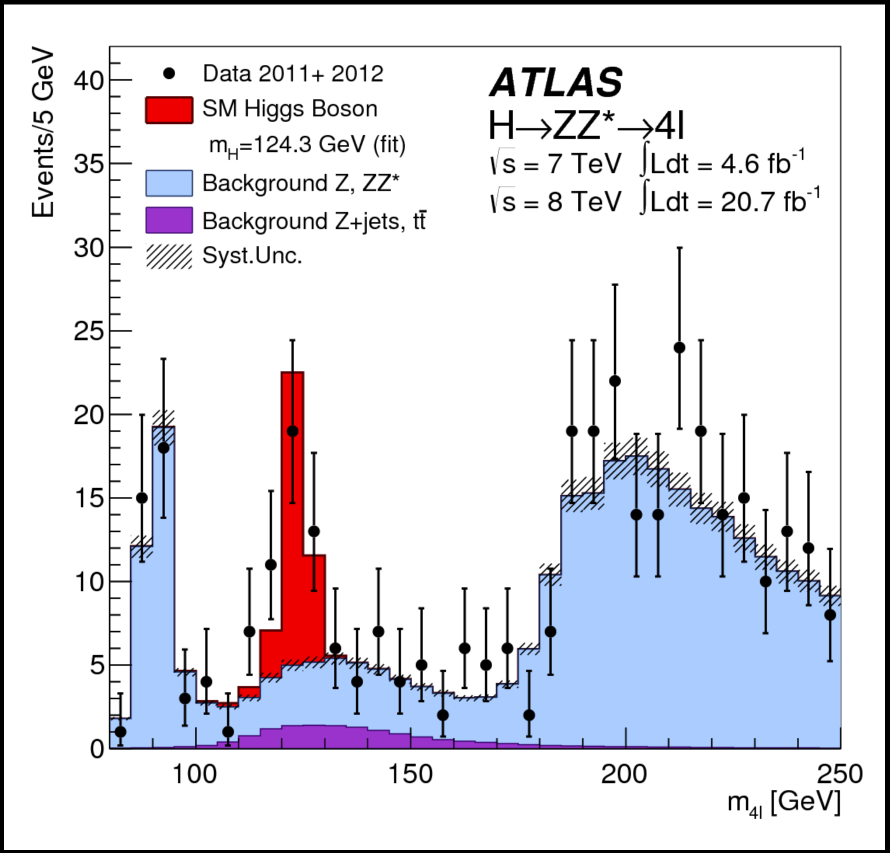
How do we discover new particles?



- Look for a bump on a smoothly falling "background" distribution

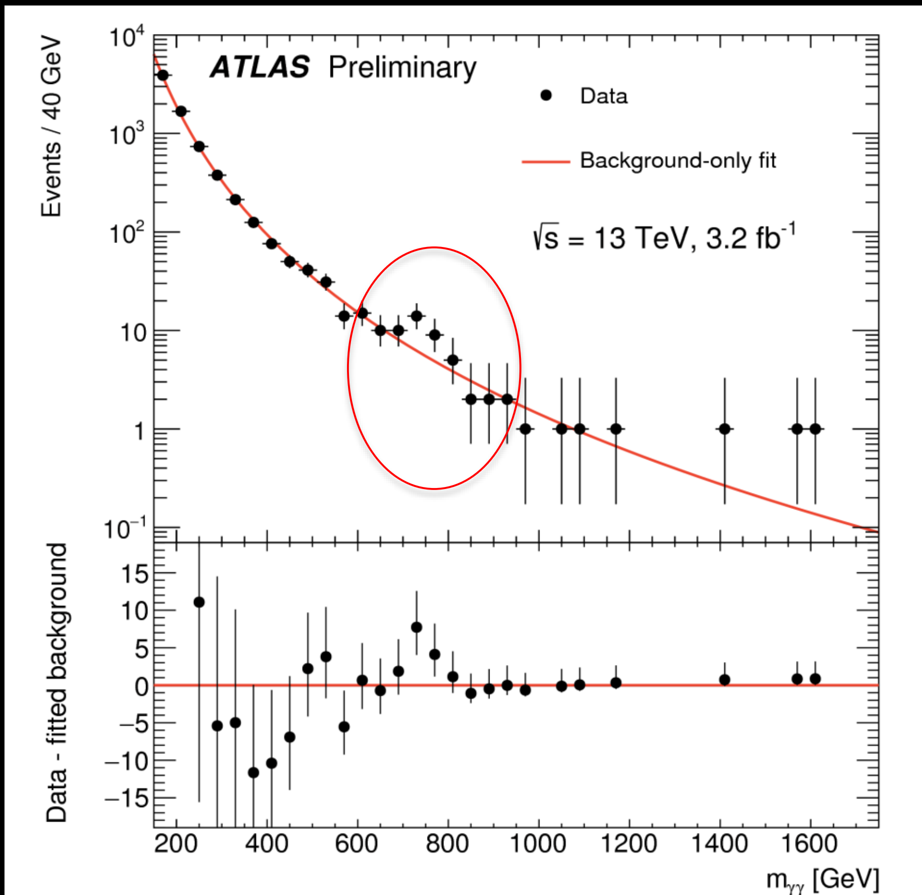
The Results so Far (Run 1)



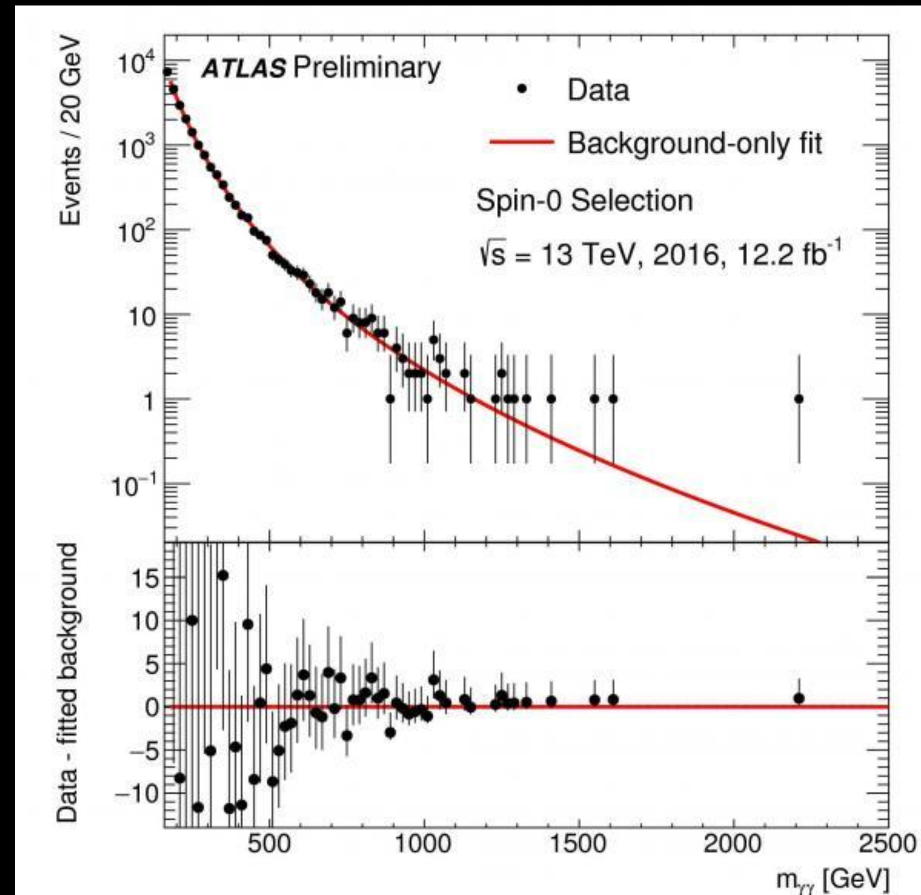


- Both ATLAS a CMS discover a new particle
  - The Higgs Boson Higgs is the heaviest particle to date
  - Nobel prize to F. Englert and P. Higgs in 2013

The Results so Far (Run 2)



2015
Excess of events over background observed at ~750 GeV



2016
Everything consistent with background

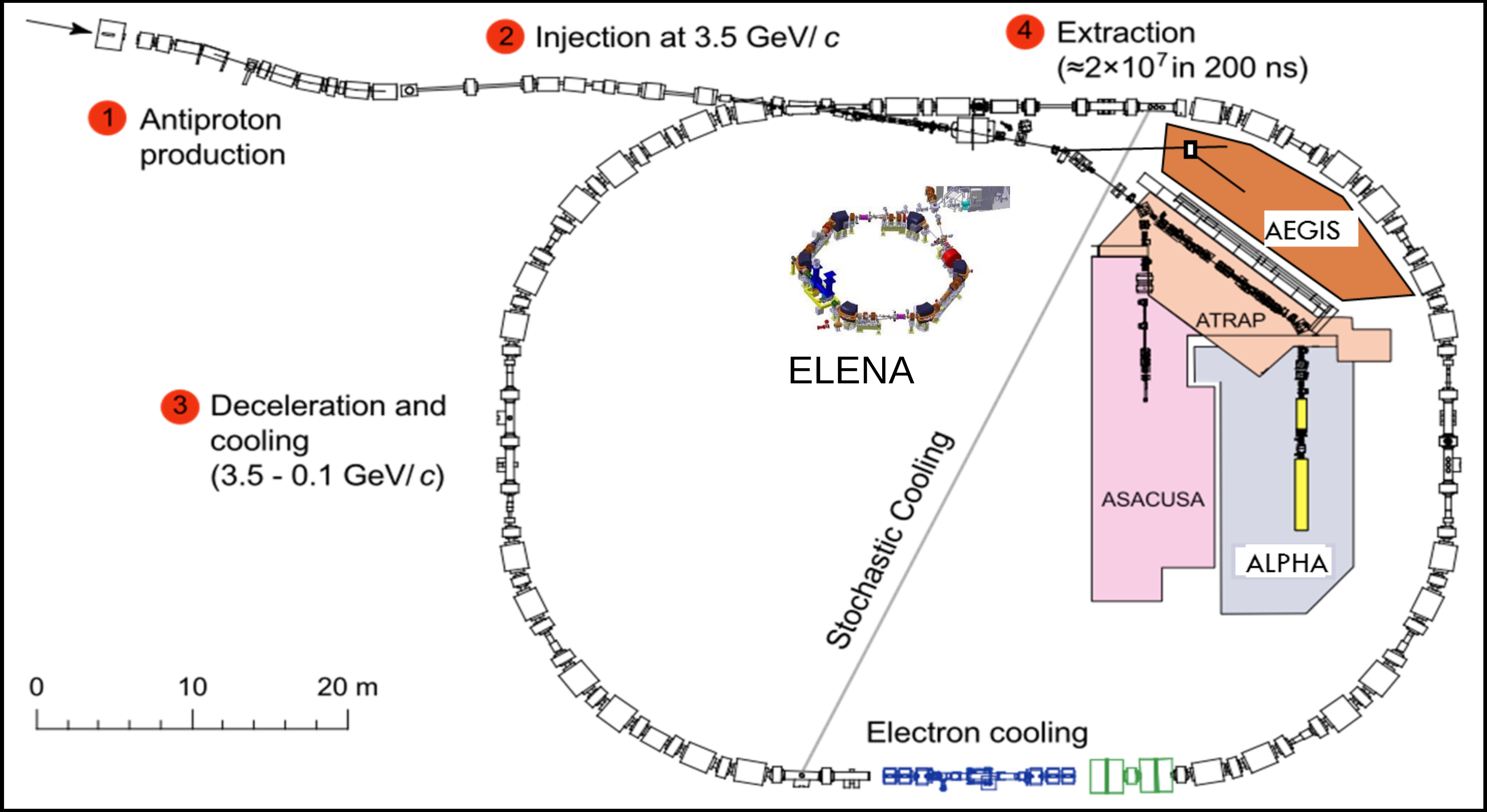
- Tantalising hints of a new particle turned out to be a statistical fluctuation

What next for the LHC?

- Studying the Higgs particle in detail
  - It will take time and much more data to verify that its properties are all that is expected of a standard model Higgs Boson
- Looking for new physics
  - Has another new particle already been discovered?
  - Constraining theoretical alternatives or extensions to the standard model
  - All this relies on much more data
- Upgrading to High Luminosity LHC
  - Foreseen for 2025
  - Aim to collect 10 times more data in the years 2025-2035 than with all runs up to 2023
  - Is there anything else to discover?

Antimatter Studies

- At the other end of the energy scale
  - The anti-proton decelerator (AD) & Extra Low ENergy (ELENA)

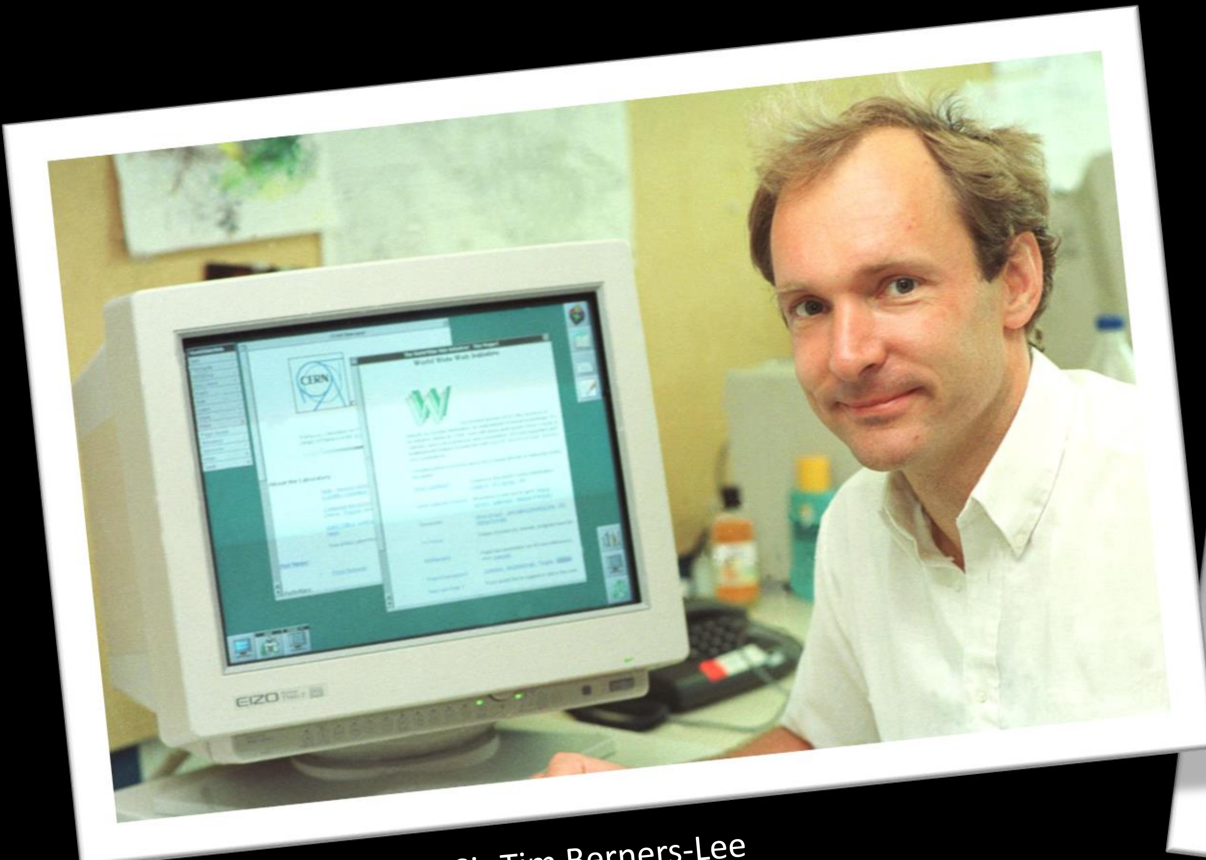


Trapping Anti-Hydrogen

- Does anti-matter behave the same way as matter?
  - Same energy levels (spectroscopy)? ALPHA, ATRAP, ASACUSA
  - Same under influence of gravity? AEgIS, GBAR, ALPHA-g
  - Magnetic moment? BASE

CERN and the Wider Community

World Wide Web



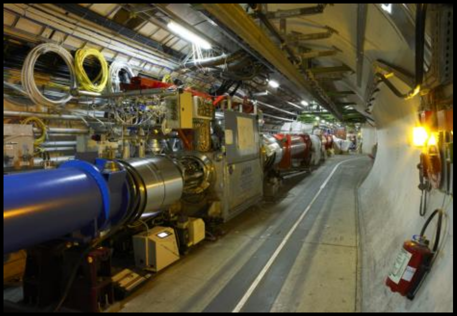
Sir Tim Berners-Lee

Developed in 1989 for sharing physics data

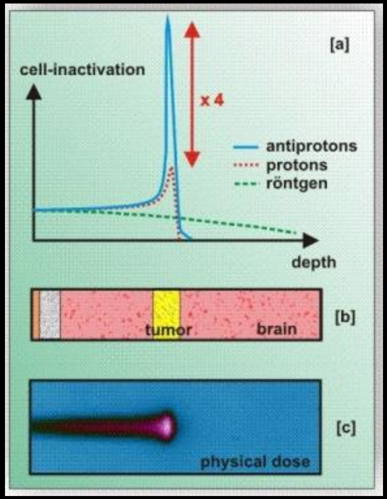
Given to the world for free

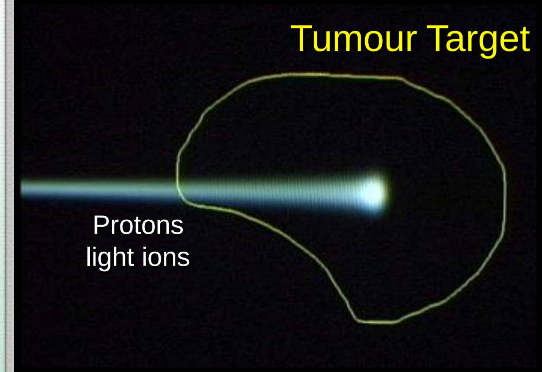
Medical Applications

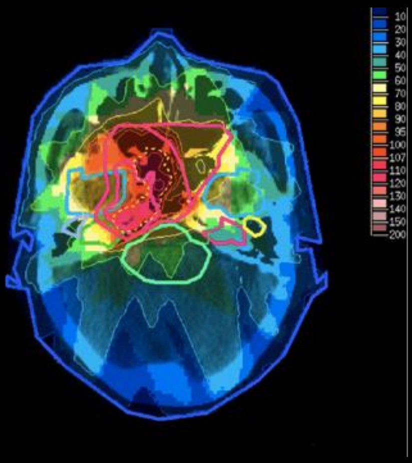
- Accelerating particle beams
  - ~30’000 accelerators worldwide
  - ~17’000 used for medicine



- Hadron Therapy
  - >70’000 patients treated worldwide (30 facilities)
  - >21’000 patients treated in Europe (9 facilities)
  - Leadership in Ion Beam Therapy now in Europe & Japan



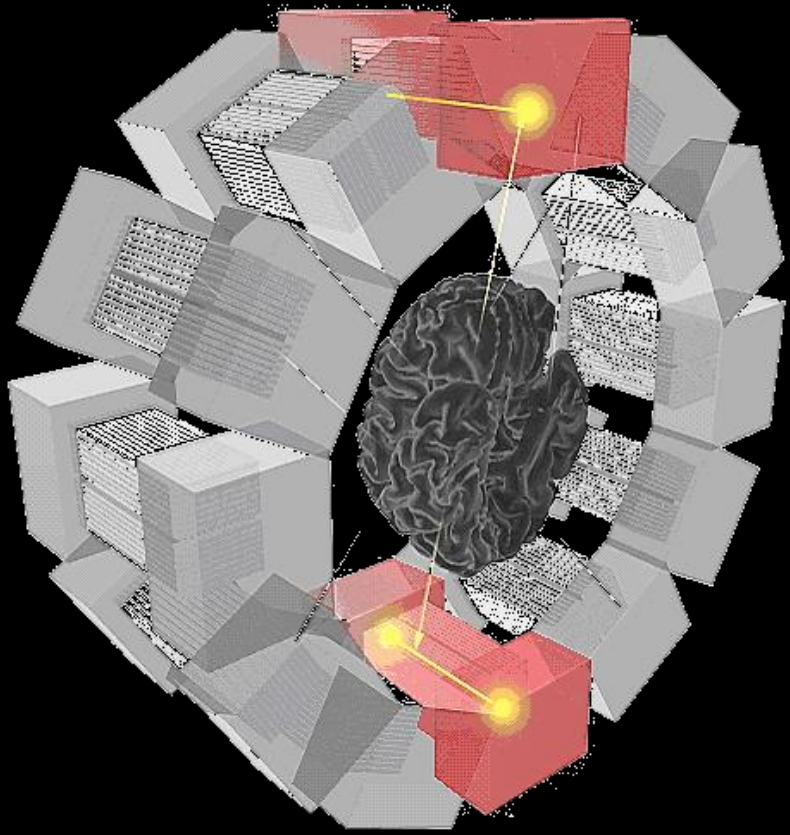


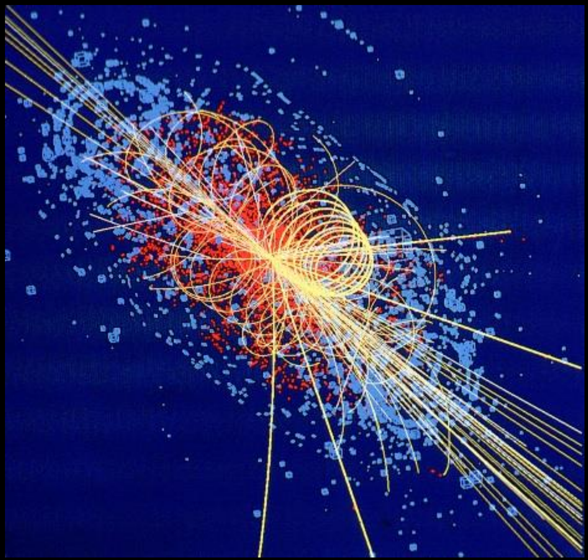

X-rays

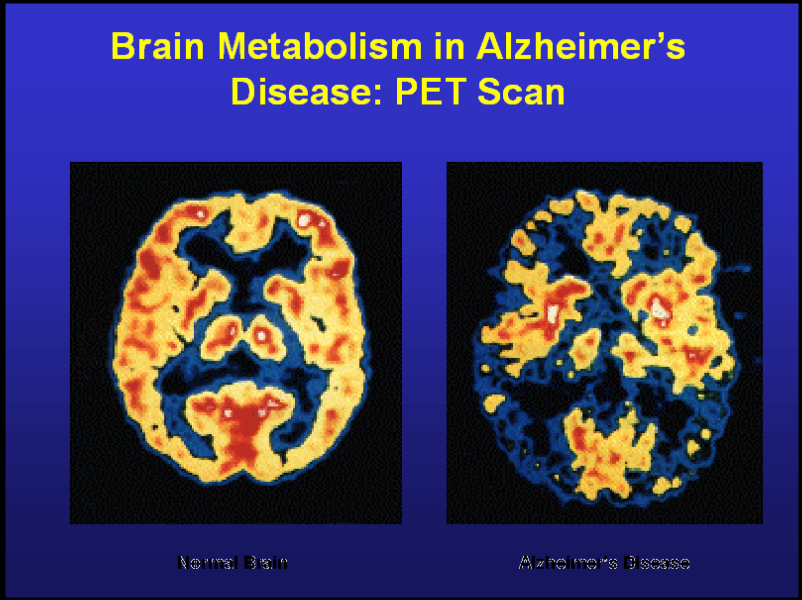

Protons

Medical Applications

- Detecting Particles
  - PET Scanners

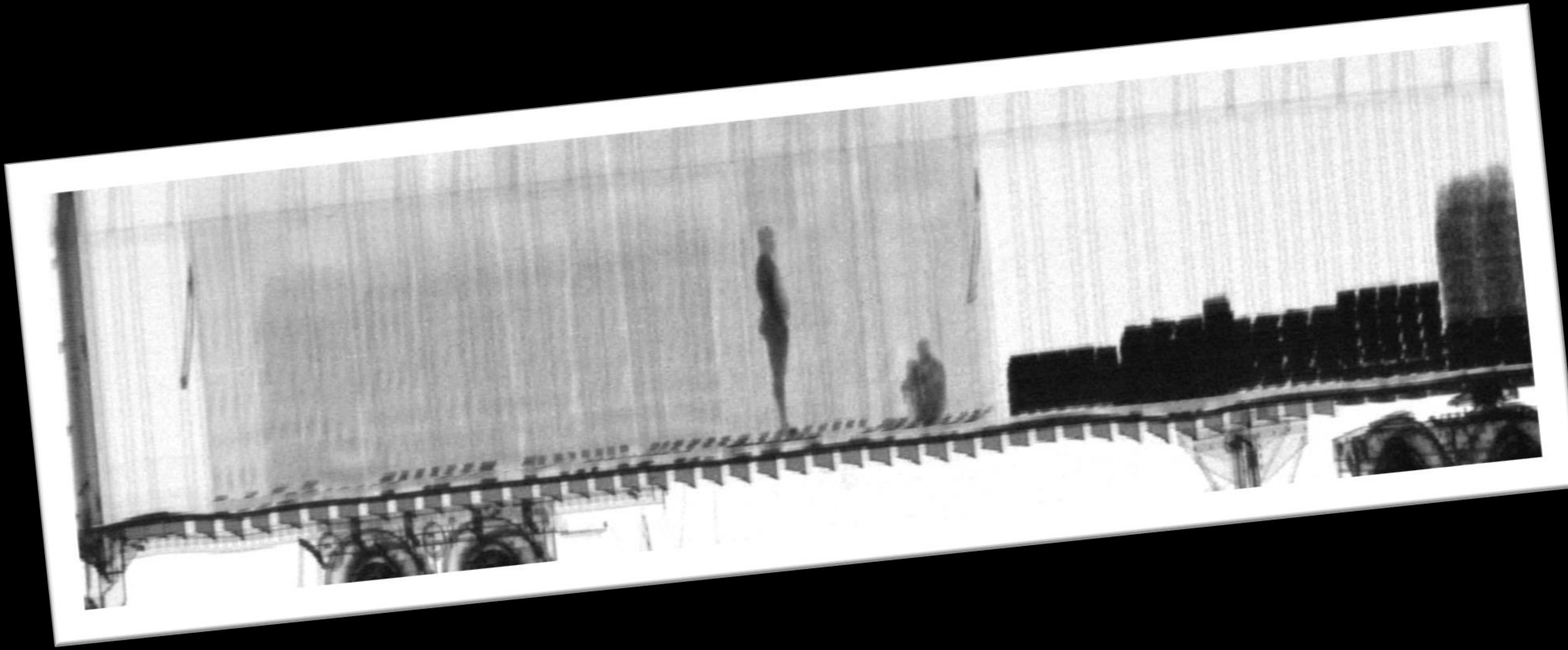






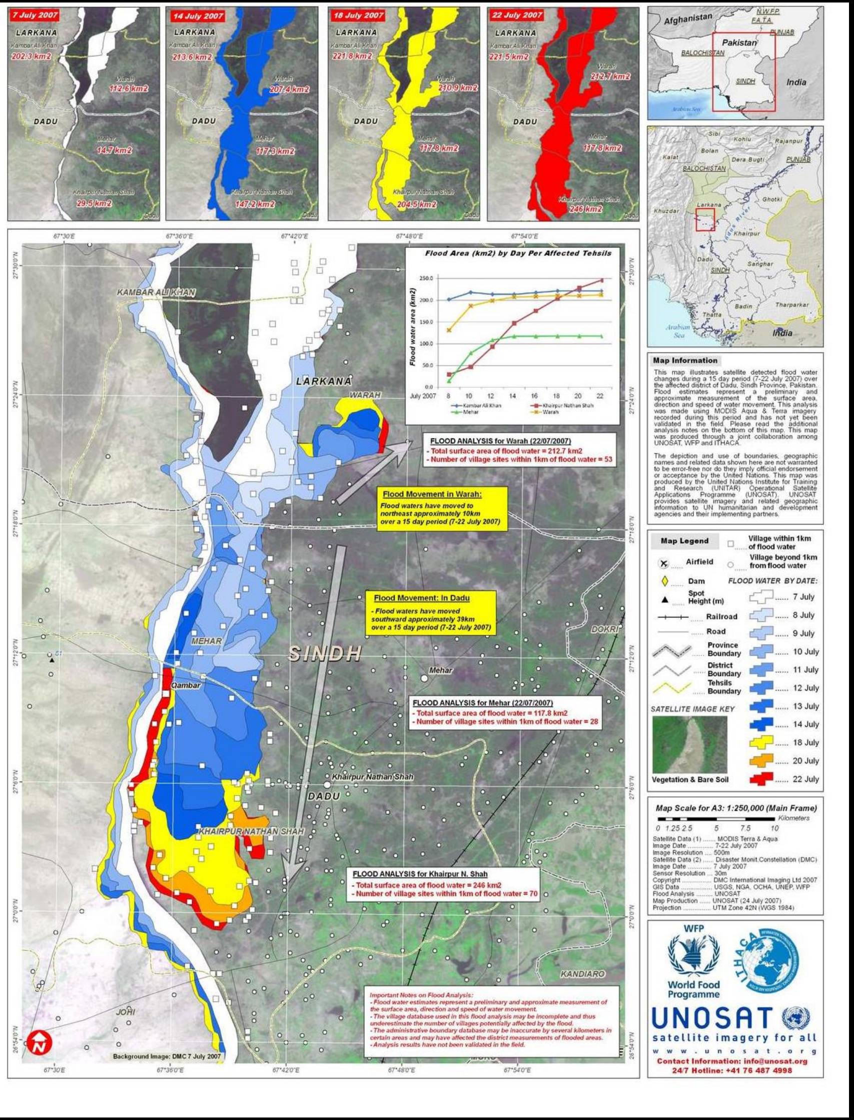
Security

Scanning lorries without offloading them!



The Computing “Grid”

- Processing large quantities of data at high speed
  - Medine / Health
  - Nanotechnology
  - Engineering
  - The Environment



Analysing satellite data after a natural disaster
(Floods in Pakistan)

Summary

- CERN – a fundamental science facility
  - Largest scientific collaborations in the world
  - Pushing boundaries of engineering & technology
  - Many practical “spin-offs” for everyday applications

- CERN depends on you to
  - provide the next generation of physicists and engineers
  - keep up tradition of Welsh contributions to this endeavour

Mwynhewch!