LHC: status of the art

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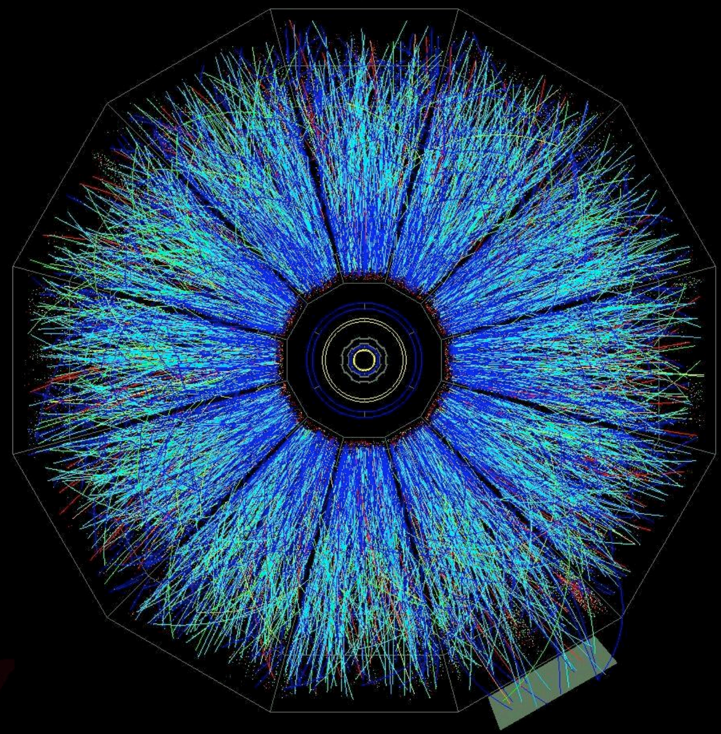
Outline

- What is LHC ?
  - Hadron collider physics
- Why LHC ?
  - The physics program
- The LHC challenge
  - The accelerator and the experiment
- The status of the art
  - September, 10th 2008
  - The incident
- Perspective

What is LHC?

Hadron Collider Physics

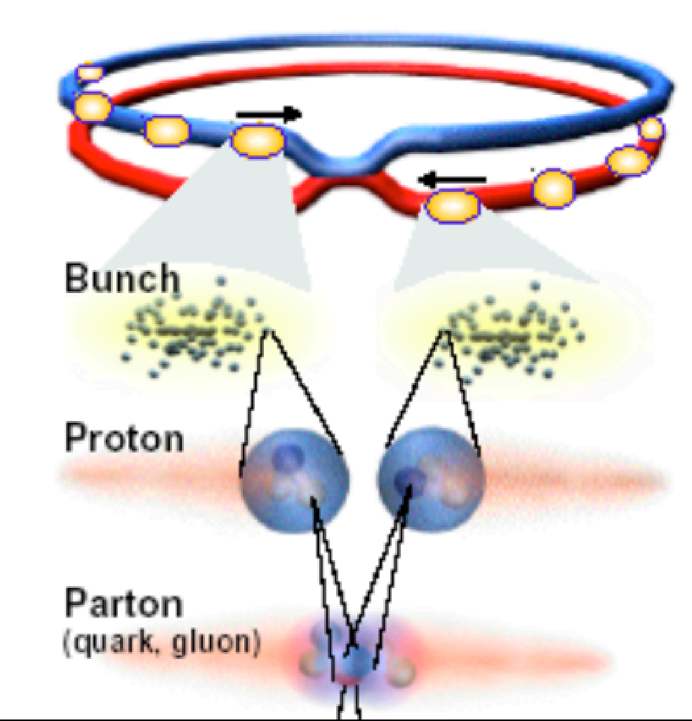


Large Hadron Collider

The Large Hadron Collider is a proton-proton collider

- Two proton beams of 7 TeV each will collide in 4 interaction points
- An experiment is installed at each interaction point (ATLAS, CMS, LHCb ALICE)
- Proton beams are organized in bunches
- The elementary interaction is a parton-parton interaction

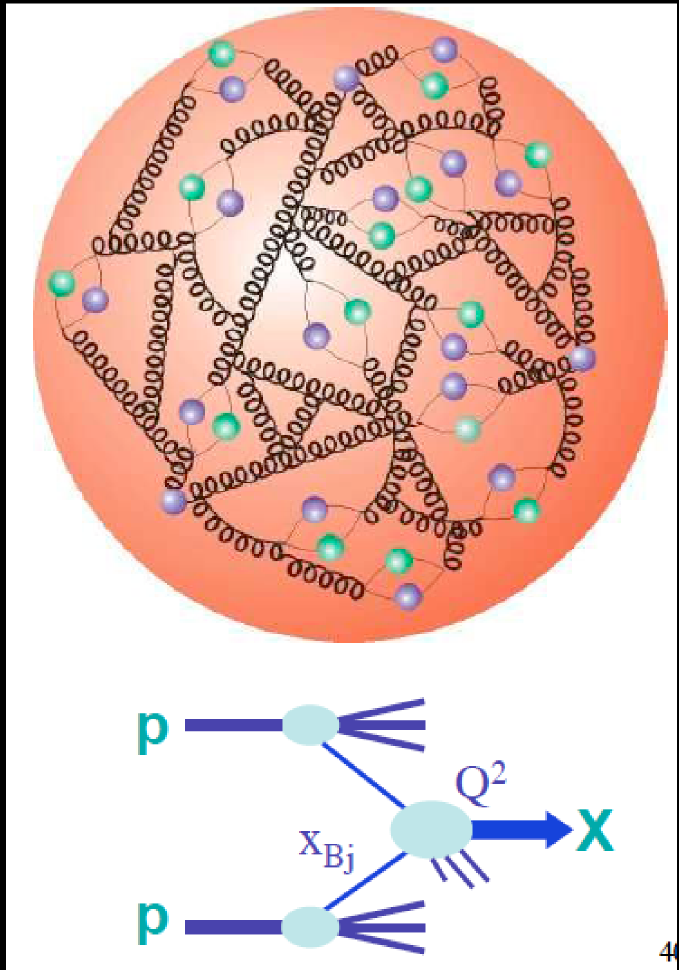
	LHC (design)	Tevatron (achieved)
Centre-of-mass energy	**14 TeV**	1.96 TeV
Number of bunches	**2808**	36
Bunch spacing	**25 ns**	396 ns
Energy stored in beam	**360 MJ**	1 MJ
Peak Luminosity	**10^{33}-10^{34} $cm^{-2}s^{-1}$**	3 x 10^{32} $cm^{-2}s^{-1}$
Integrated Luminosity / year	**10-100 fb^{-1}**	~2 fb^{-1}



Luminosity gives the number of particles per unit time per unit area

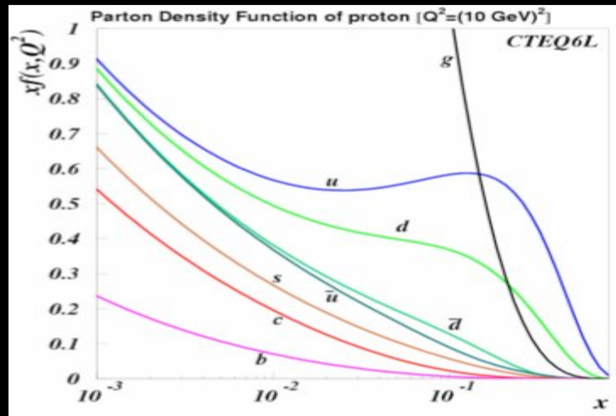
$$L = f\, n \frac{N_1 N_2}{A} \left[cm^{-2} s^{-1}\right]$$

Proton structure



A proton is made of:

- Valence quark (u,u,d)
- Sea quark
- gluons



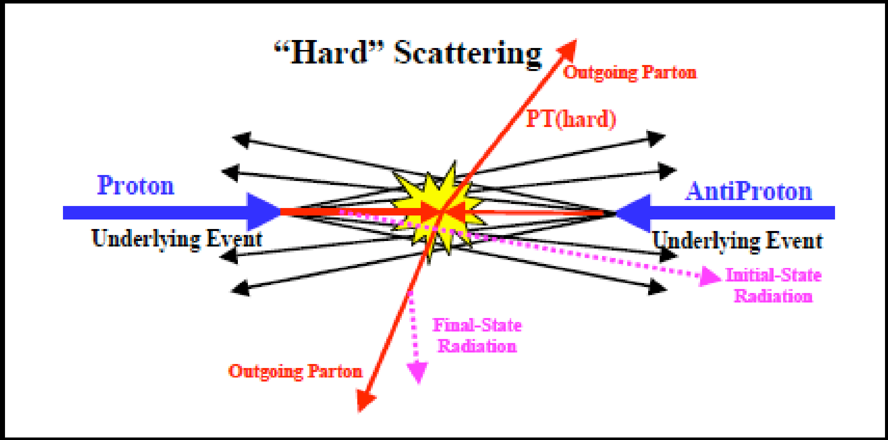
Center-of-mass energy of parton-parton collision

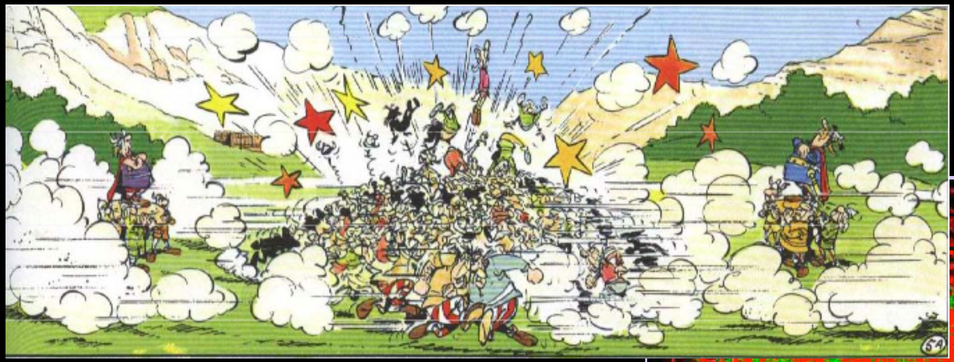
$$\sqrt{\hat{s}} = \sqrt{x_1 x_2 s}$$

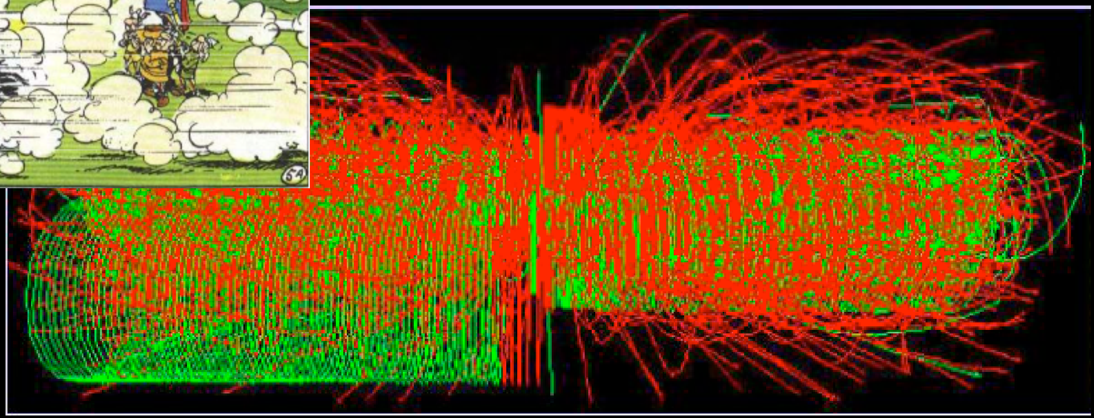
The proton-proton interaction

It's a superposition of:

- Hard parton-parton collision
- Soft interaction among spectator partons (pile-up ~ 20 at nominal luminosity)
- Initial State Radiation (ISR) and Final State Radiation (FSR) (underlying event)





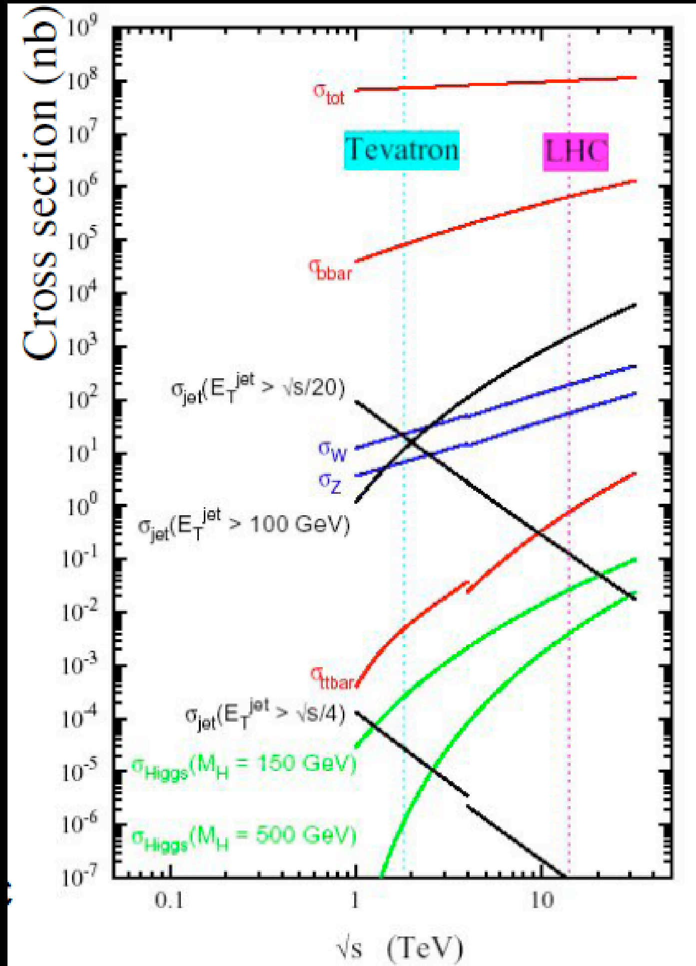


Why choosing an hadron collider ?

- Hadron colliders can access higher energy (wrt lepton colliders)
  - In e+e- collider syncrotron radiation reduces energy of particles
  - Cross sections grow with energy
- It's variable center-of-mass energy accelerator
- Proton-proton collider allows for higher luminosity

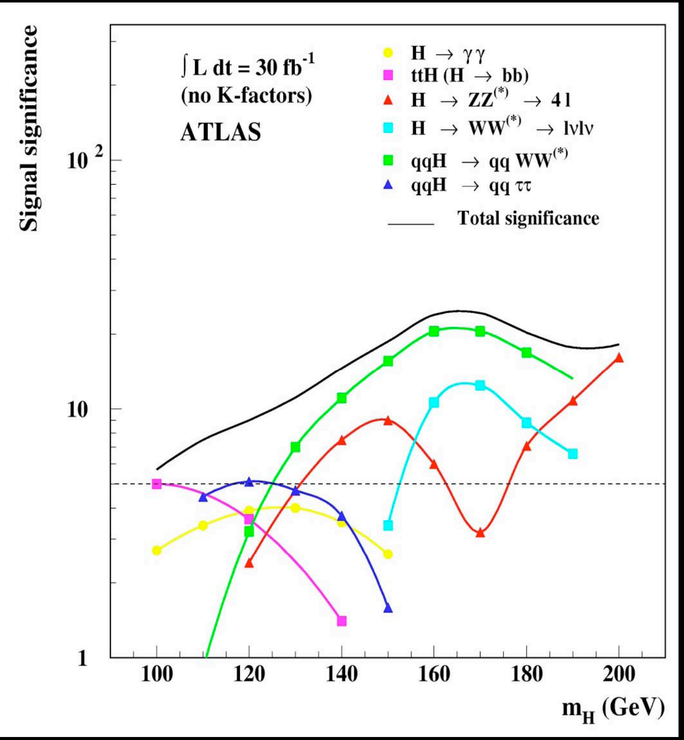
N_{event} = cross section x $\int Ldt$ x Efficiency

- Given by Nature (calculated by theorists)
- accelerator
- Detector (Experimentalist)



Why LHC?

The Physic Program

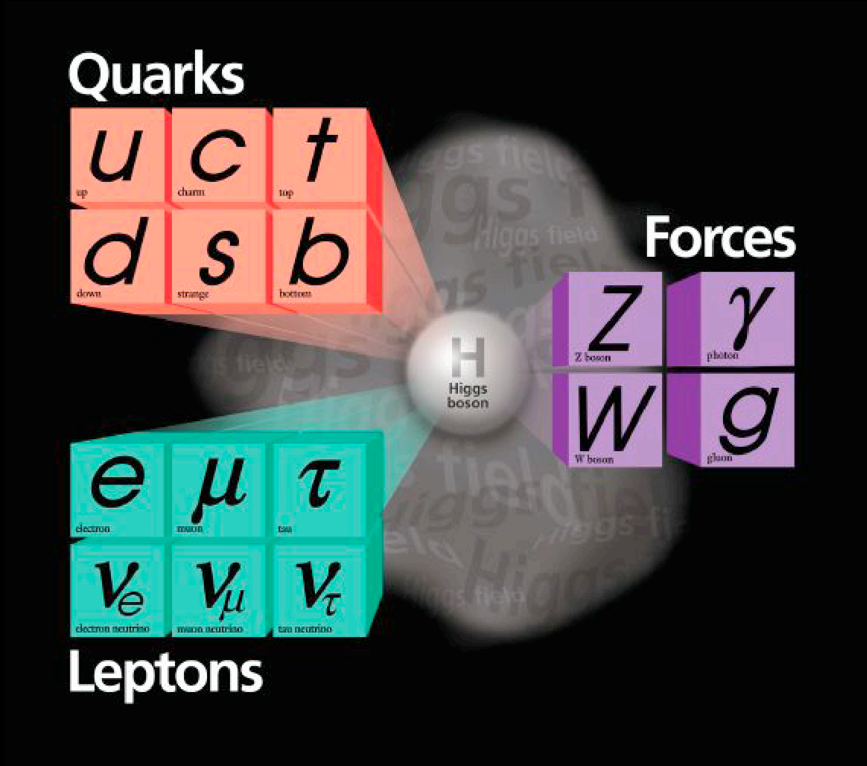


The Standard Model in a nutshell

- Matter is made of fermions (quarks and leptons)
- Forces are mediated by gauge bosons
- Higgs boson breaks the symmetry and gives mass to fermion and weak gauge bosons

Open questions:

- No Higgs boson found so far
- What is the dark matter? SM accounts for only 20% of the matter of the Universe
- Where did all the antimatter go? Not explained by SM
- Hierarchy problem
- Forces Unification (not in SM)

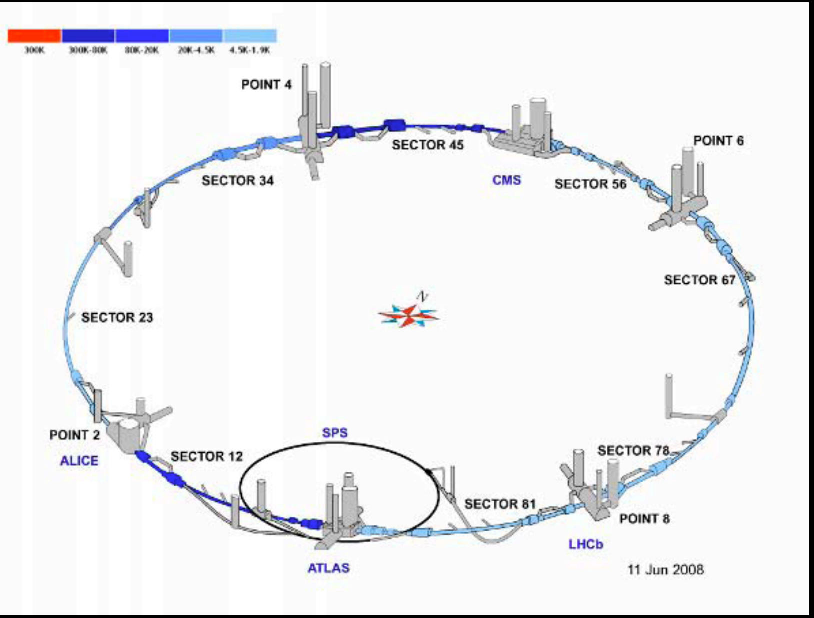


Physics program at LHC

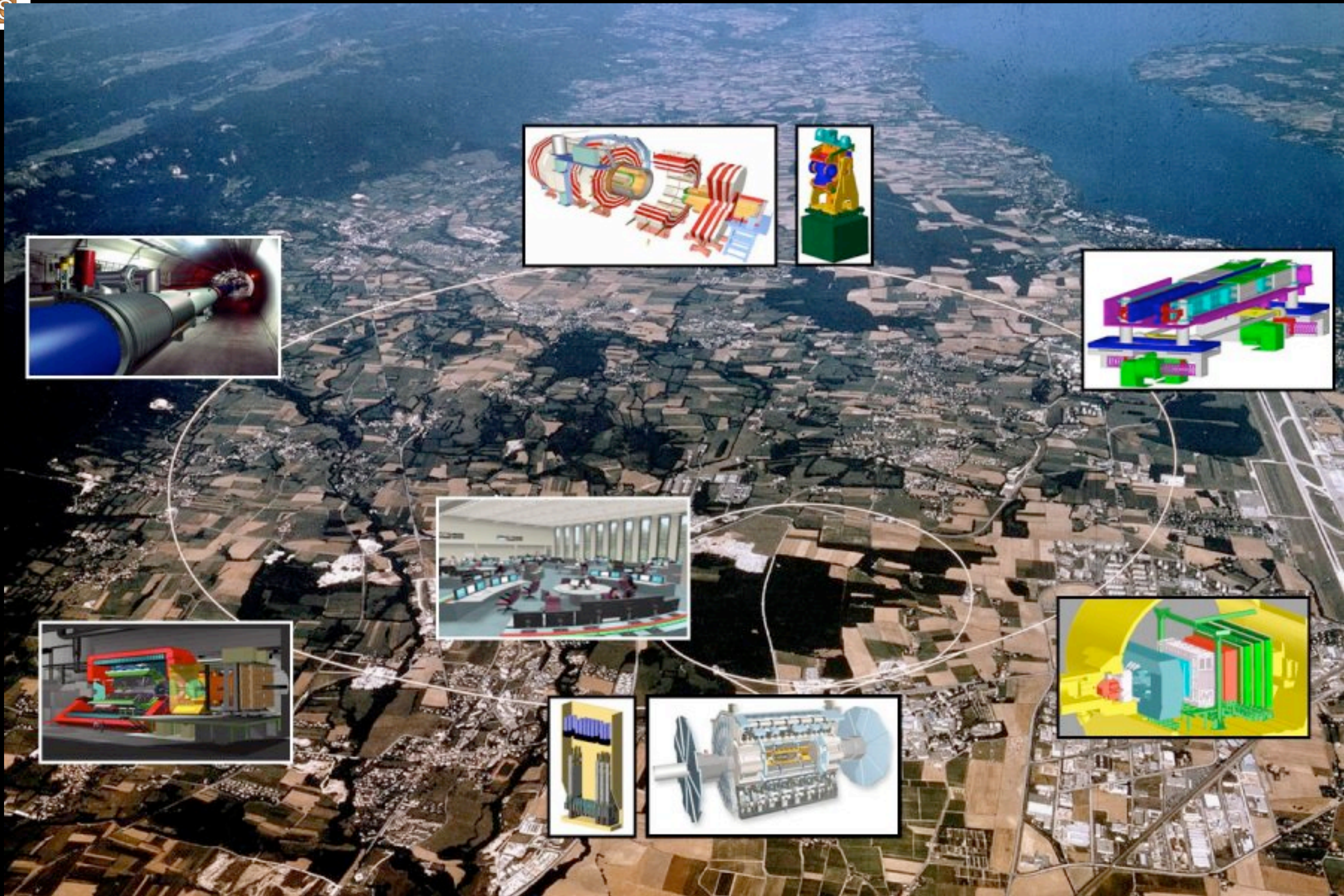
- Standard Model (SM) precision measurements
  - re-discovery W, Z, top
  - QCD in the TeV region
  - B-physics measurements (low luminosity)
- Higgs search
  - advocated as mechanism for giving mass to all particles
- Searches beyond the SM
  - A number of theories have been proposed in order to extend SM
    - Supersymmetry
    - Extra Dimensions
    - Technicolor
    - …

The LHC challange

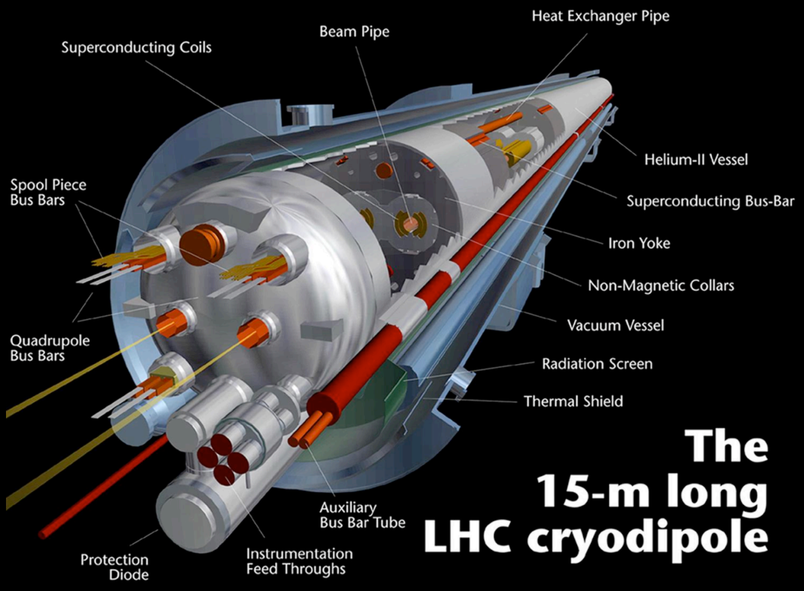
The accelerator
The experiments



LHC @ CERN



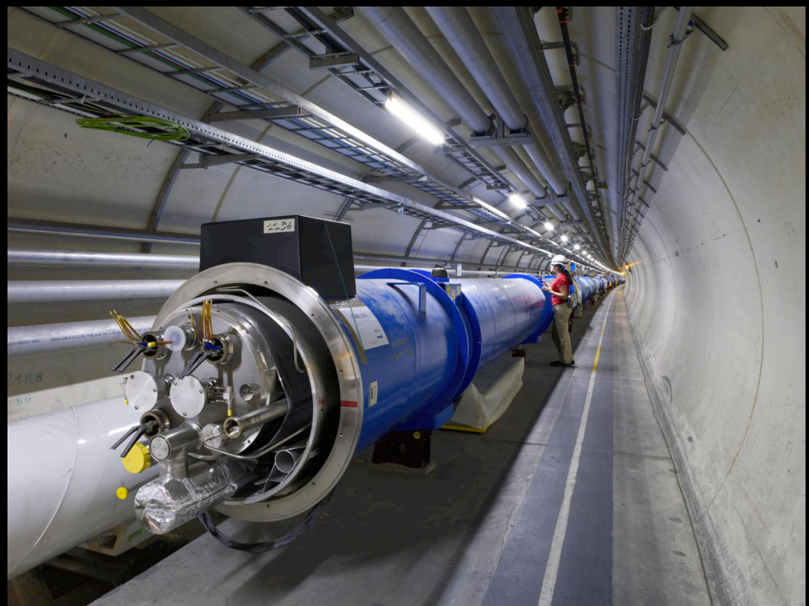
LHC: the magnets



LHC uses superconducting magnets

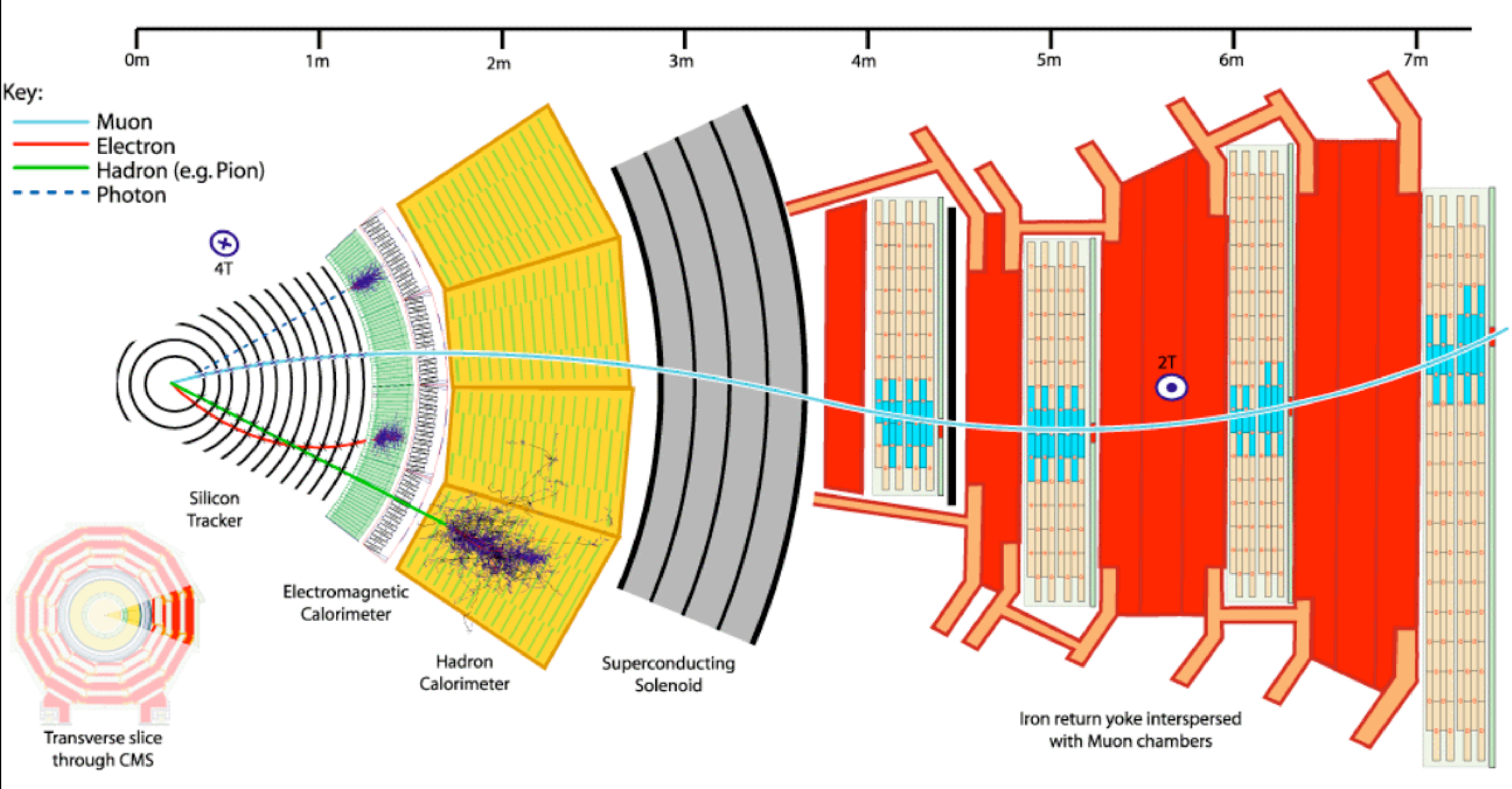
- 27 km of magnets cooled at 1.9°K
  - Uses liquid helium
- 1232 dipoles (9T each)

How does it work?

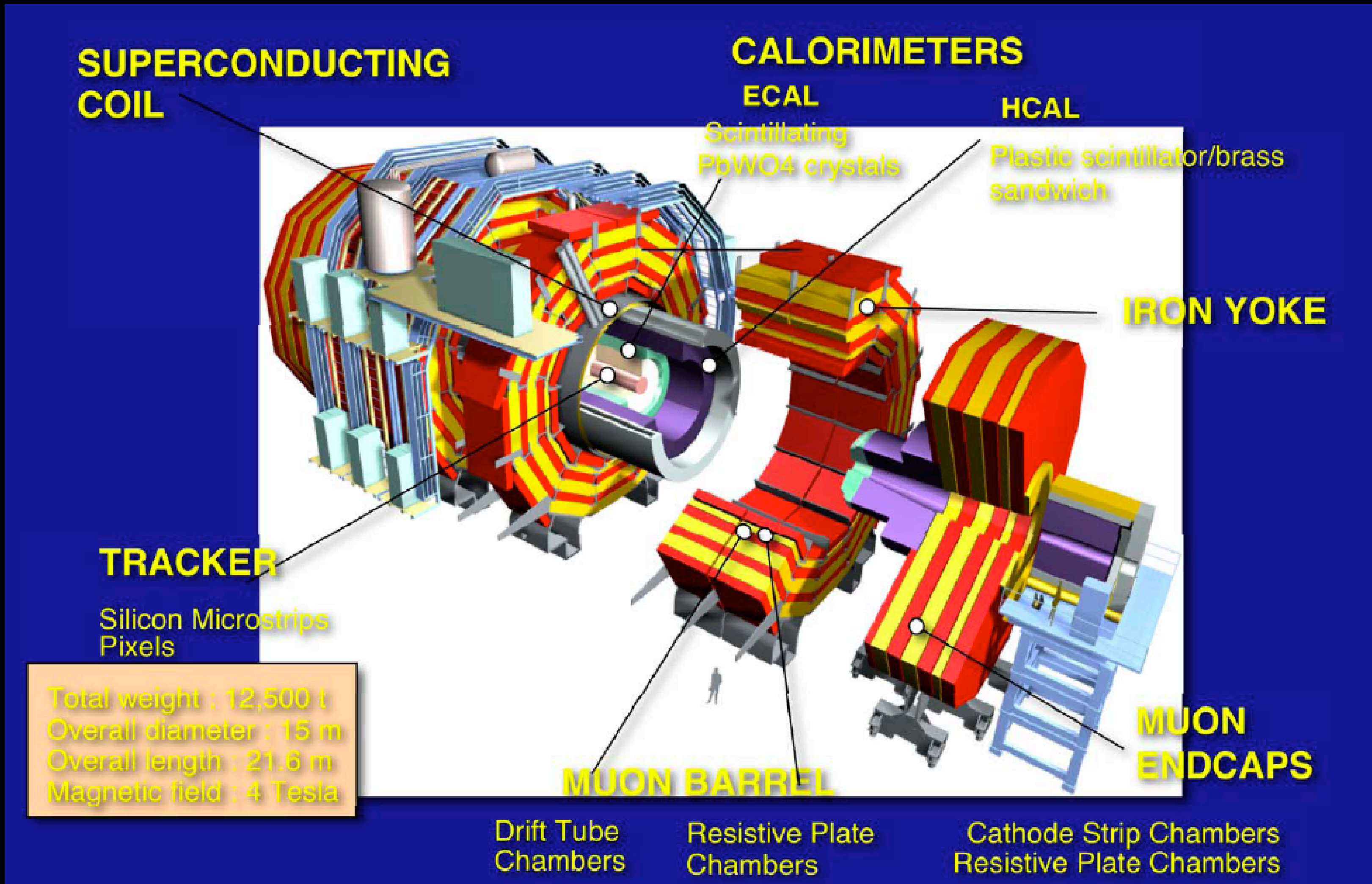


High Energy Physics Experiment

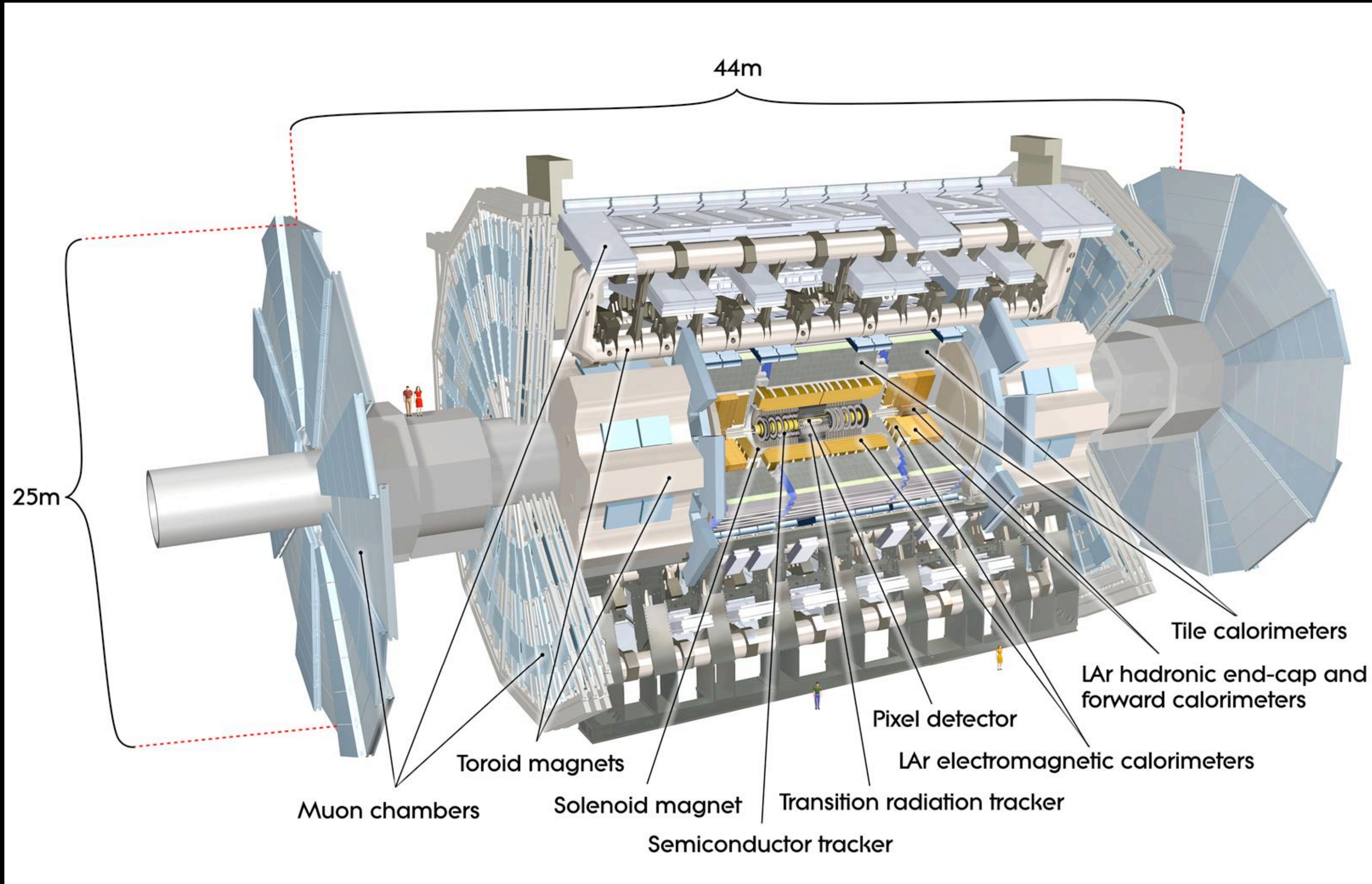
A “Generic” experimental setup



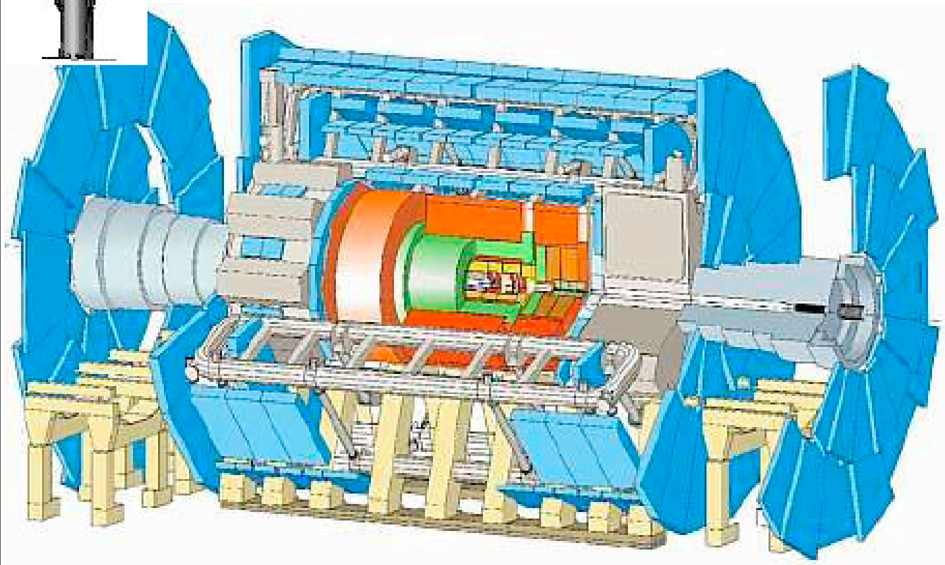
The CMS Experiment

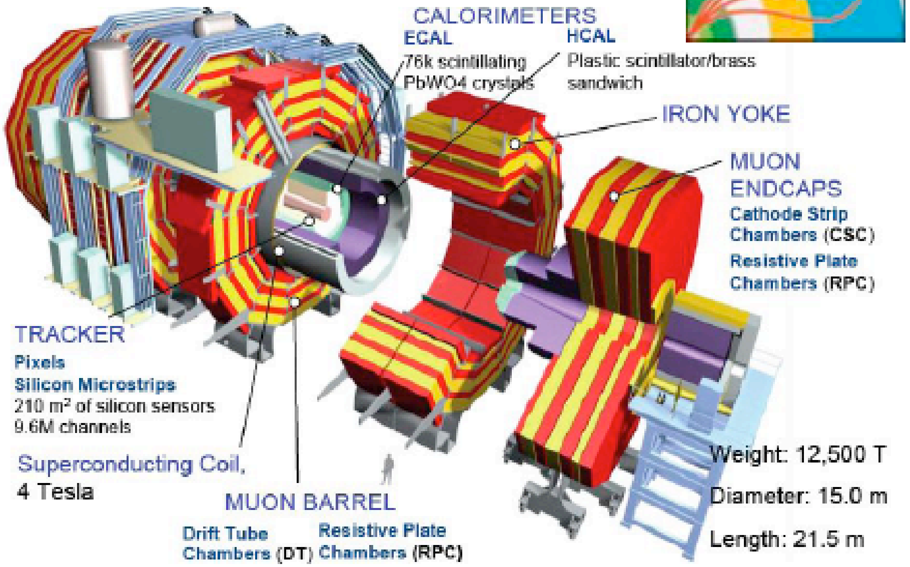


The Atlas Experiment



ATLAS and CMS Detectors





	Weight (tons)	Length (m)	Height (m)
ATLAS	7,000	42	22
CMS	12,500	21	15

ATLAS and CMS in Berlin

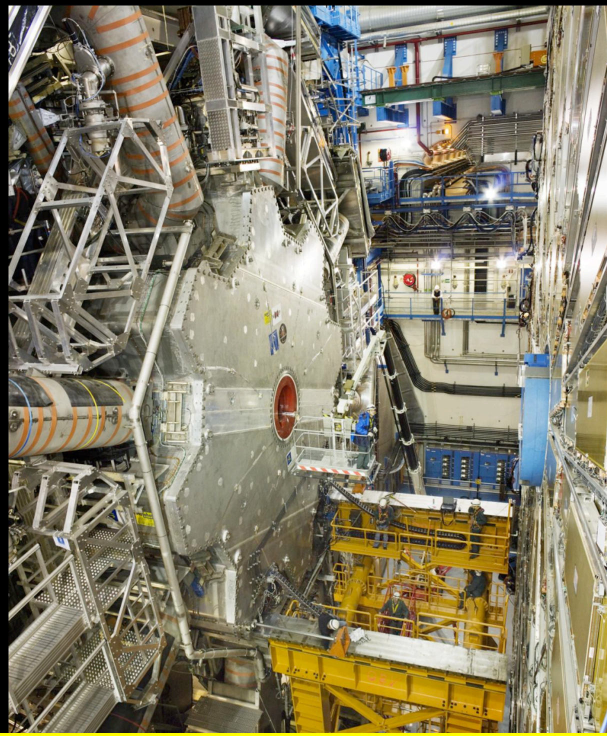
The Atlas Cavern

- The Atlas cavern excavation started in 2000 and finished in April 2002
  - 35 m wide, 55 m long and 40 m high
  - The Canterbury Cathedral would fit in it
- Large civil engineering work
  - Starting excavation from the top
  - Top part was concreted and the vault was suspended with rods anchored in the gallery
  - The floor of the cavern is about 100 m under sea level
- As you'll see in a while, the ATLAS experiment fill almost the whole cavern

Atlas assembly in the cavern: a 3-years story

- Detectors and magnets built and tested on surface
- Piece after piece, all the parts have been downloaded in the cavern and positioned

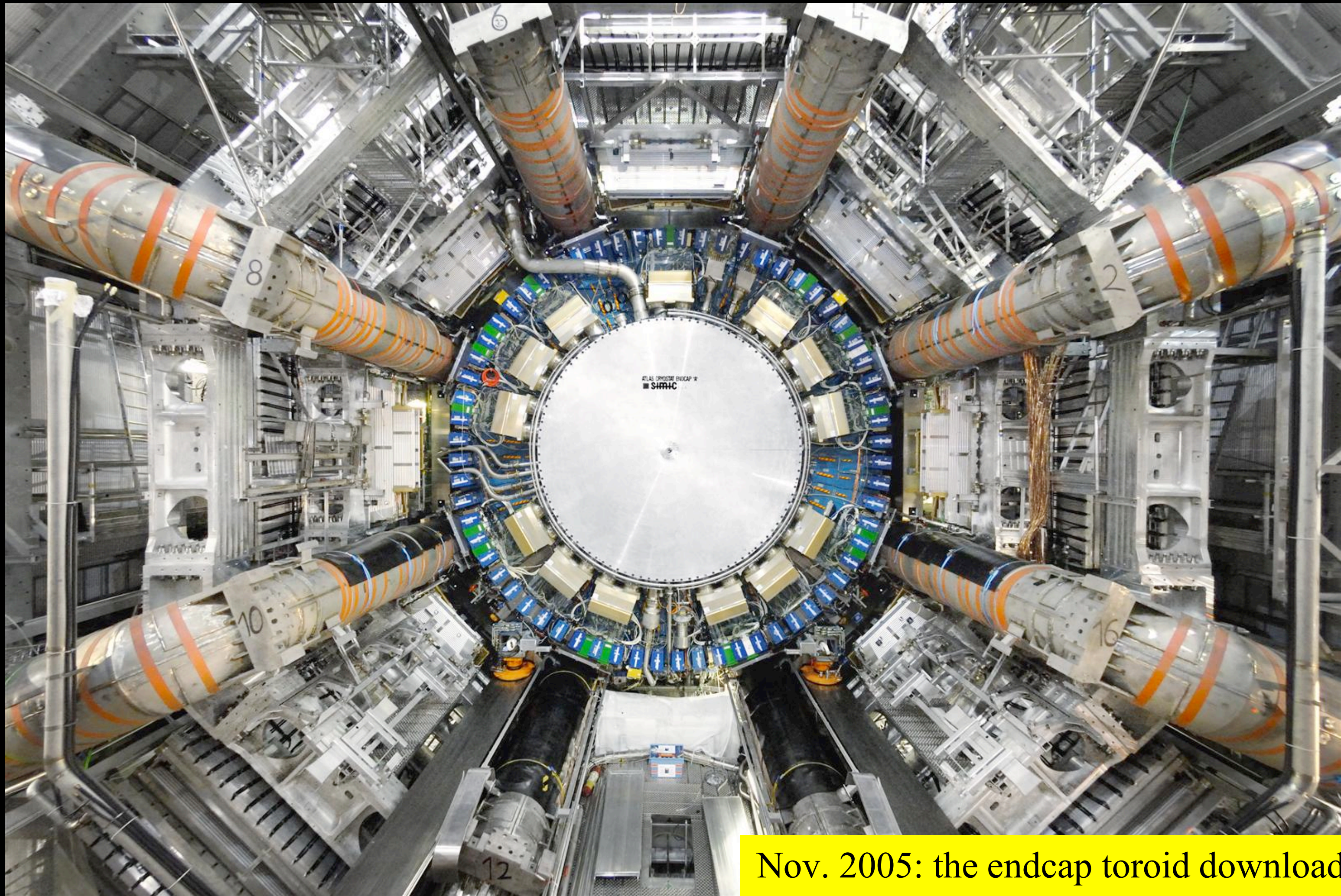
Oct. 2004: the first toroid magnet



Nov. 2007: the endcap toroid downloaded

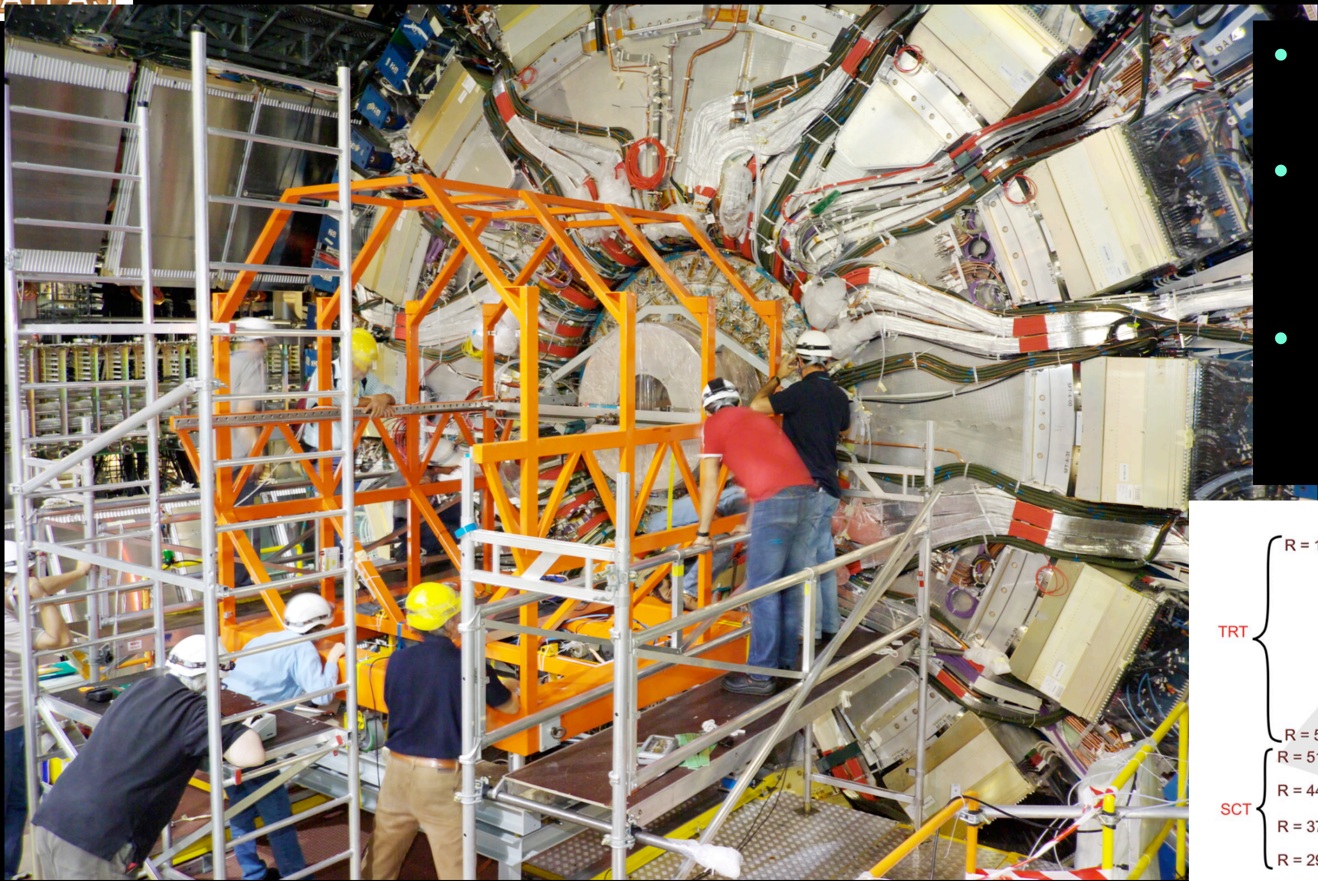
Assembling: the movie

Atlas: Calorimeters & Muon Spectrometer

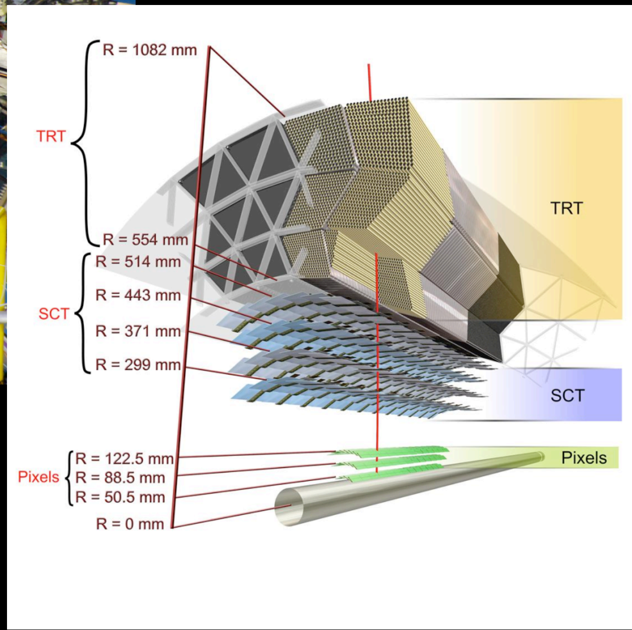


Nov. 2005: the endcap toroid downloaded

The inner detector



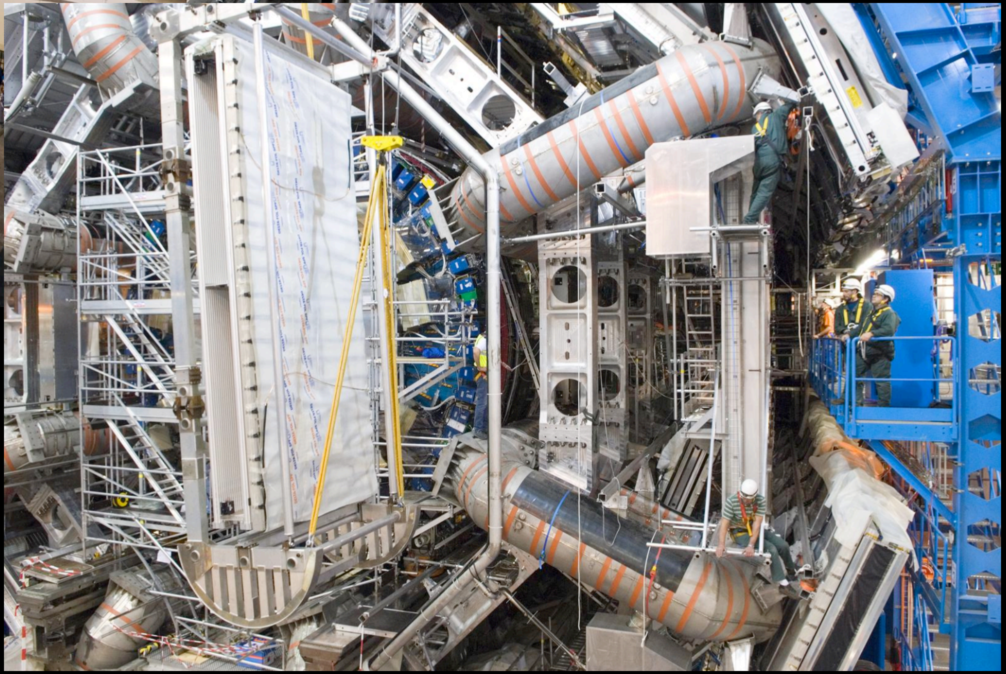
- The whole detector downloaded together
- A complex of three detectors integrated on surfaces
- The hardest environment of the whole experiment



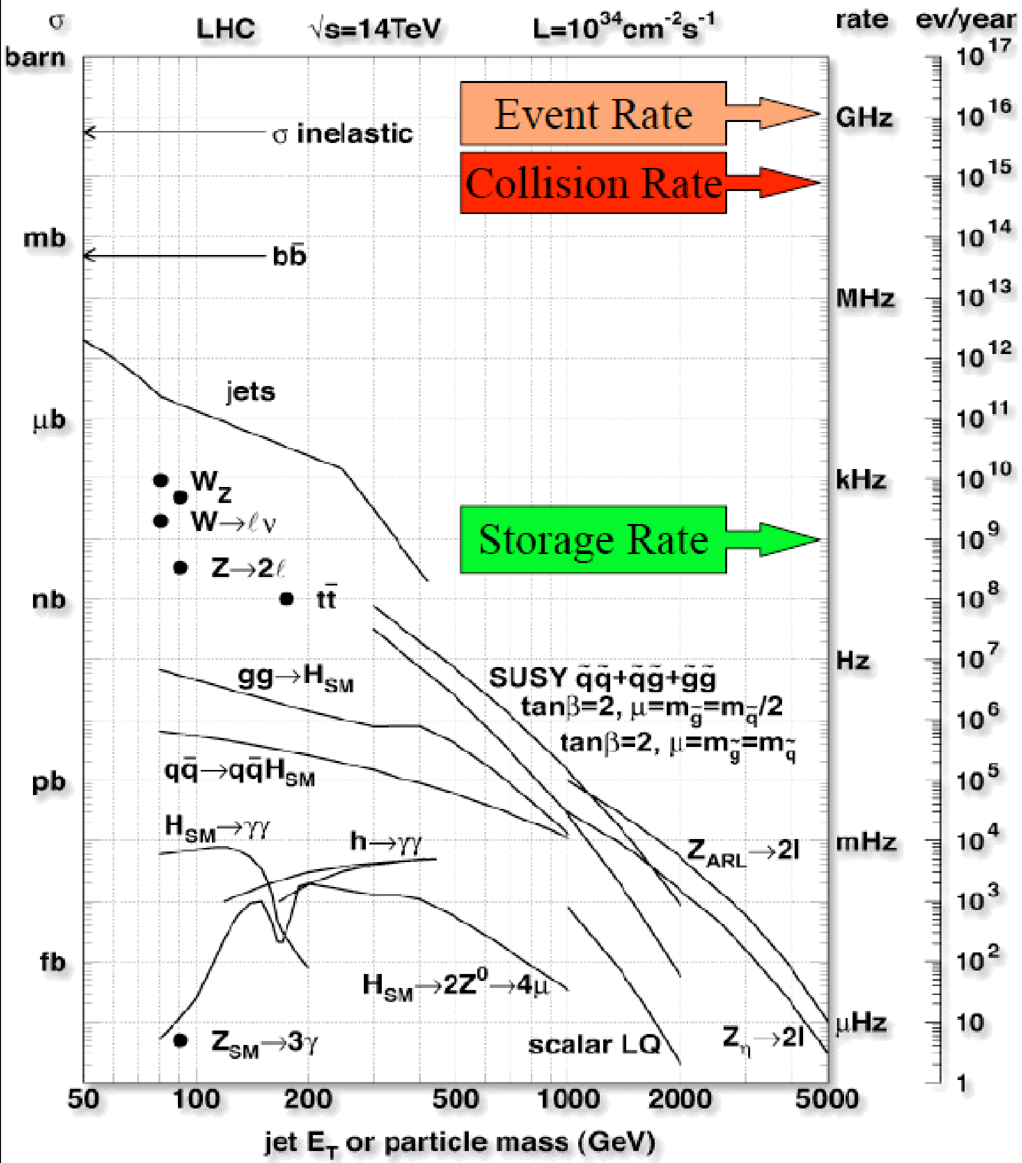
The Muon Chambers

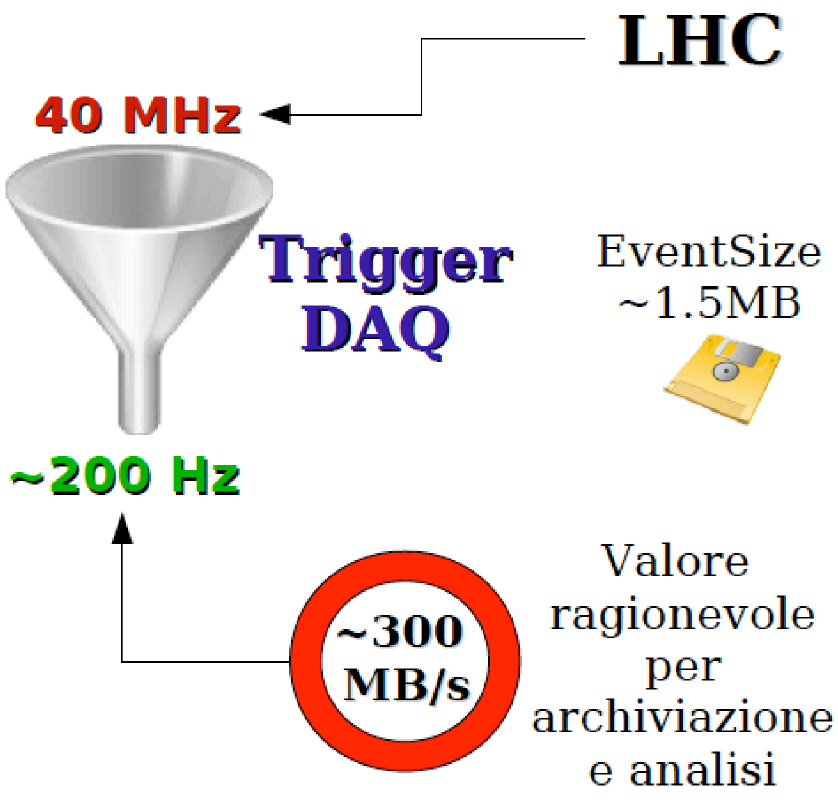
The small wheel have been downloaded after integration of all the muon chambers .

All the others have been installed one-by-one



DAQ & Computing

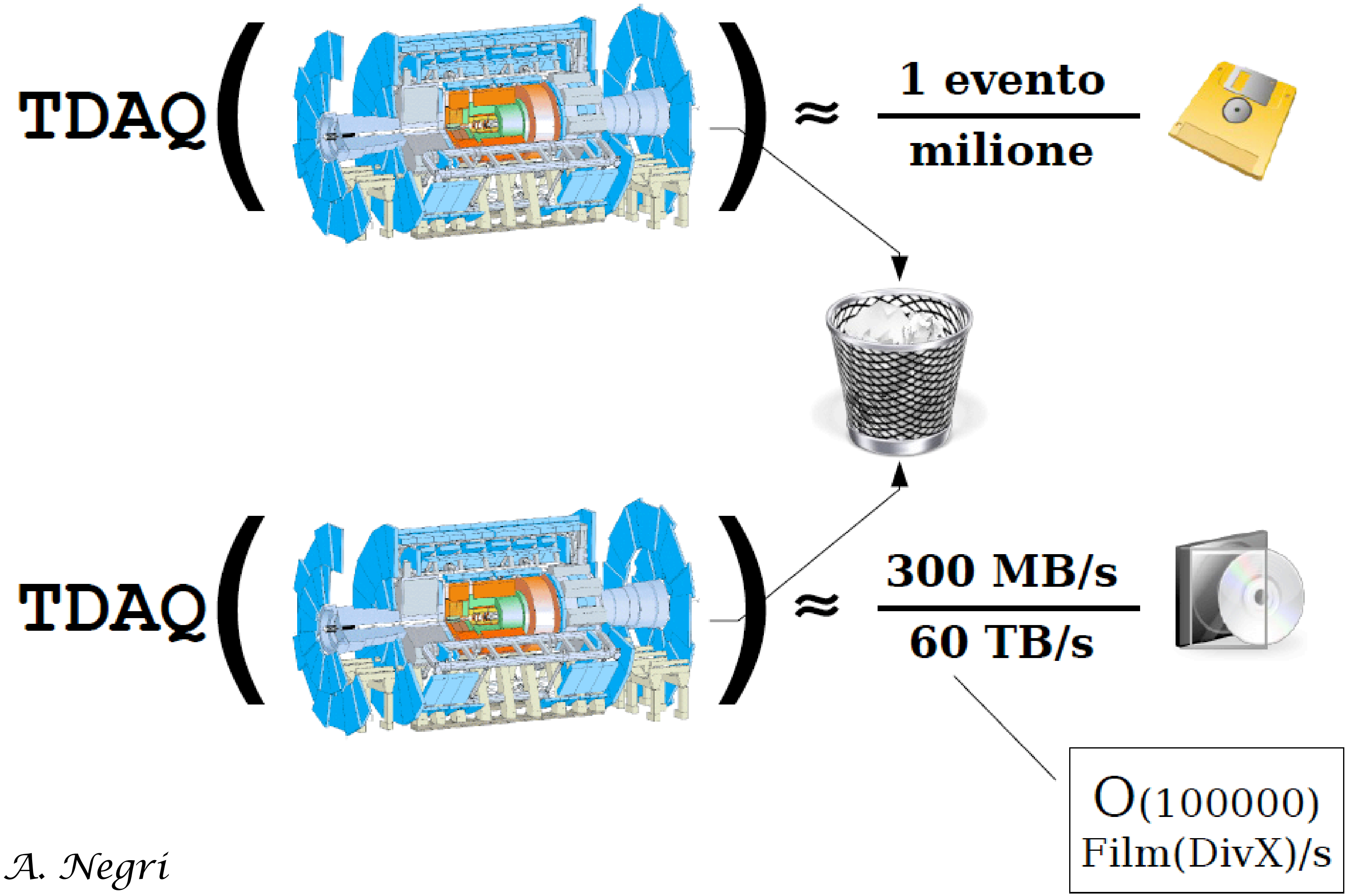




$$\frac{\text{Rate } H(120) \rightarrow \gamma\gamma}{\text{Rate collisioni}} \sim 10^{-13}$$

A. Negri

DAQ & Computing



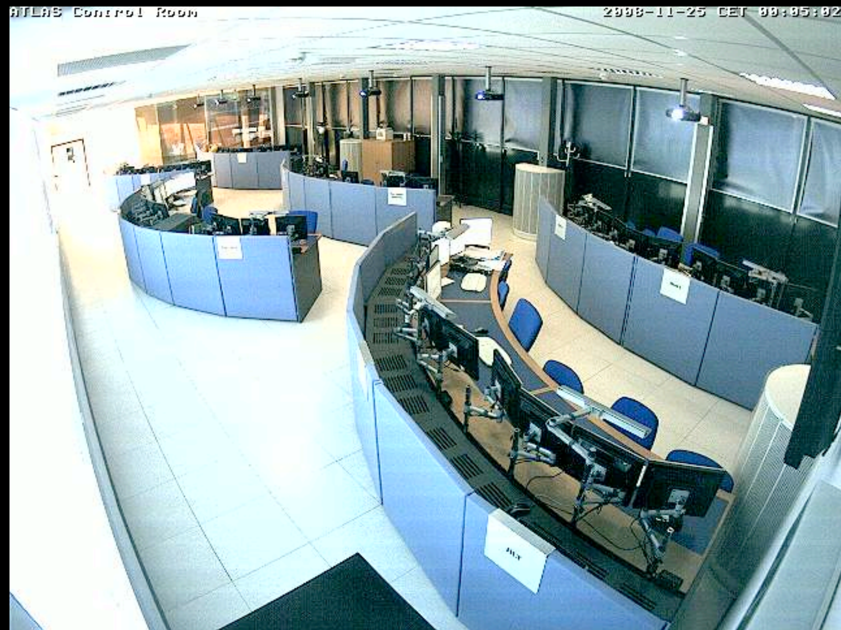
A. Negri

Atlas Control Room

Atlas has a main control room

- One desk for the run control
- One desk per detector subsystem (+ Trigger)
- One desk for the DataQuality
- One desk for SLIMOS (security)

One shift leader will overview the data taking



Waiting for the beam… we're already in data taking since spring 2008

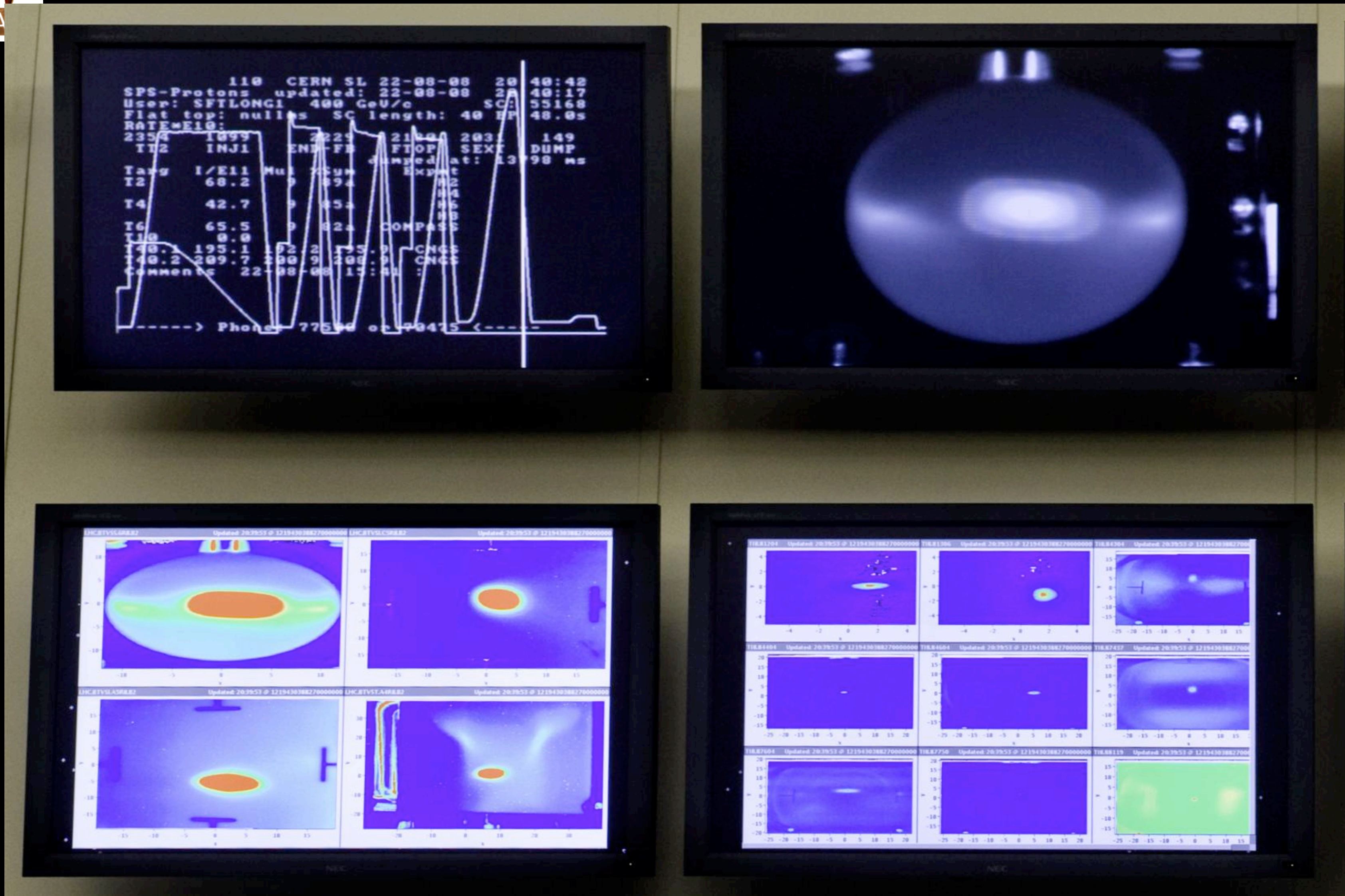
- Cosmic ray are always on and they are for free
- Extremely useful for detector and DAQ commissioning

The status of the art

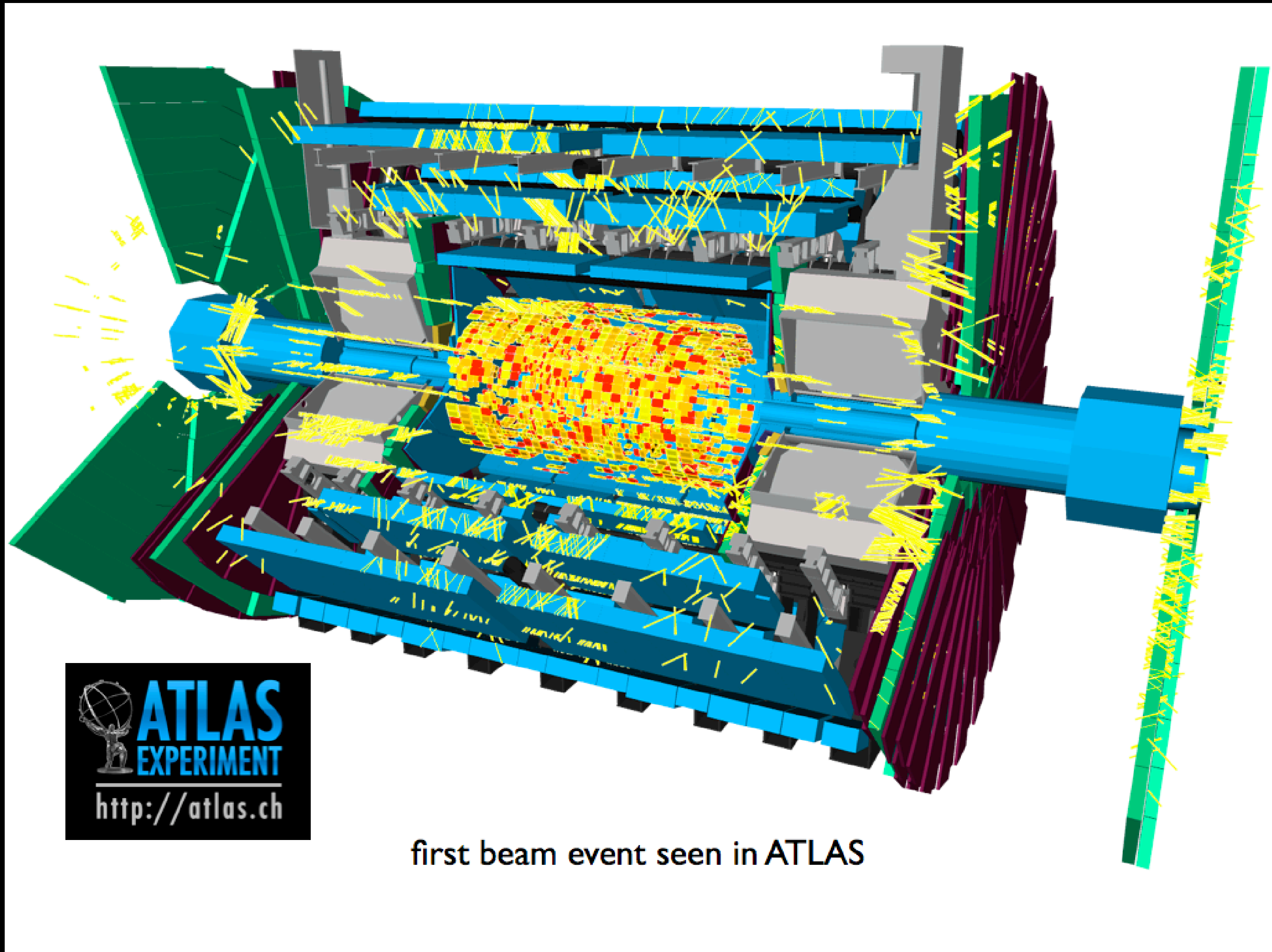
September, 10th
The incident

The Accelerator Control Room

Monitoring the first beam

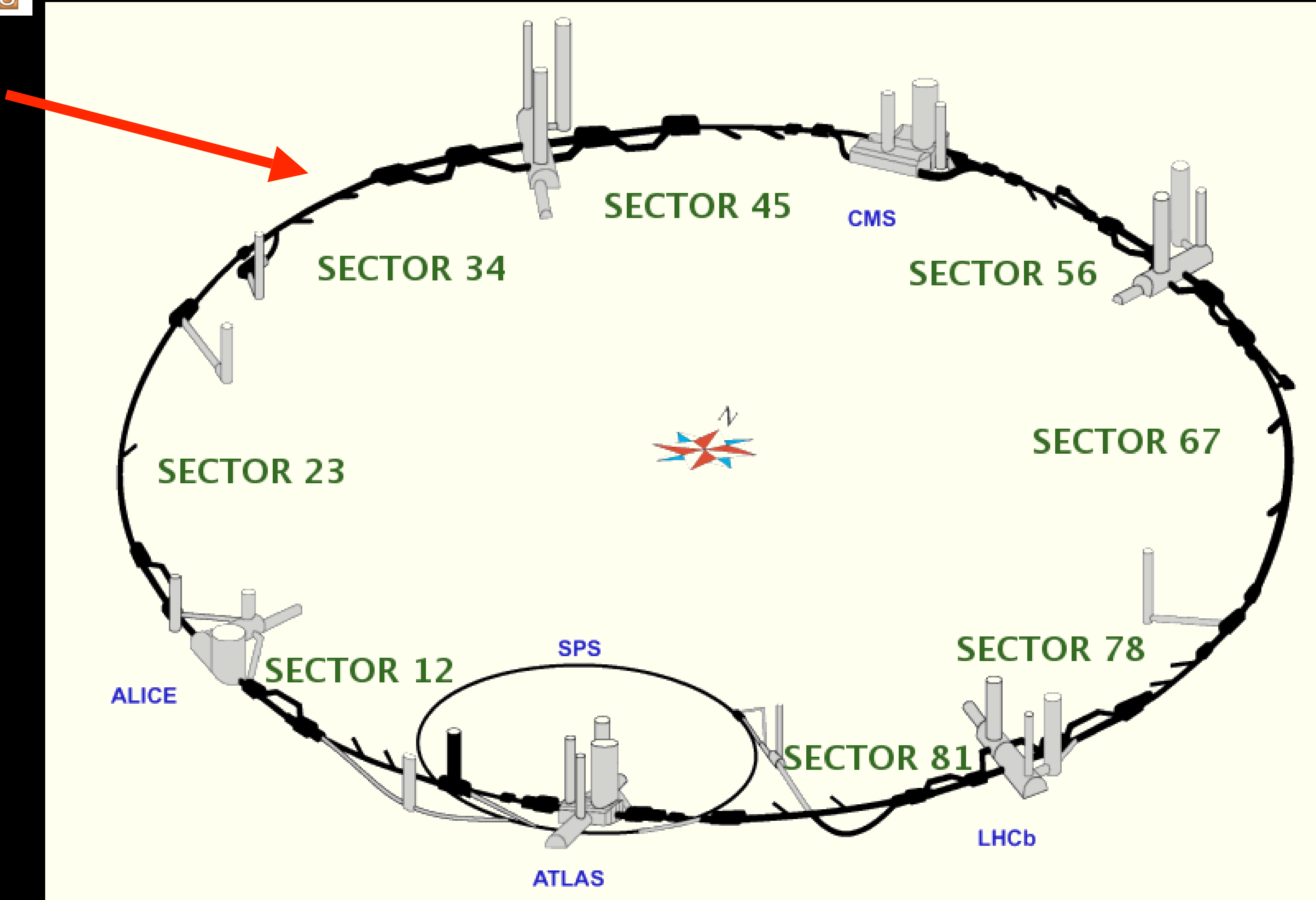


The first beam as seen by ATLAS



The first beam as seen by ATLAS

The incident on Sept. 19th 2008

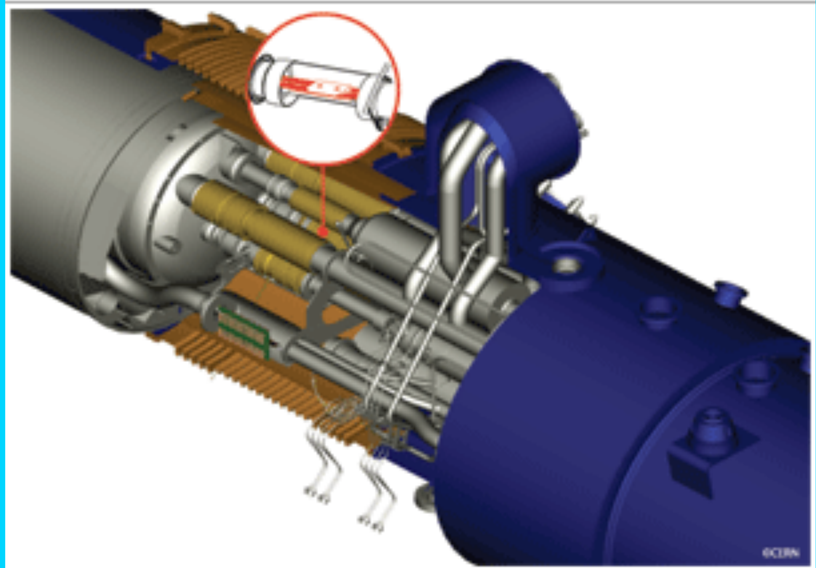


The incident on Sept. 19th 2008

Details on the incident analysis can be found here:

http://press.web.cern.ch/press/PressReleases/Releases2008/PR14.08E.html

"… Investigations at CERN1 following a large helium leak into sector 3-4 of the Large Hadron Collider (LHC) tunnel have confirmed that cause of the incident was a faulty electrical connection between two of the accelerator's magnets. This resulted in mechanical damage and release of helium from the magnet cold mass into the tunnel…."



Investigations have shown that a faulty electrical connection between two magnets (shown in red) was the cause of the incident in sector 3-4 of the LHC on 19 September.

The incident on Sept. 19th 2008 (cont'd)

- A fault occurred in the electrical bus connection in the region between a dipole and a quadrupole, resulting in mechanical damage and release of helium from the magnet cold mass into the tunnel
- After a period during which the temperature of the magnets in question was allowed to rise close to room temperature, inspections started and a number of clear findings have now been established
  - During the ramping-up of current in the main dipole circuit at the nominal rate of 10 A/s, a resistive zone developed leading in less than one second to a resistive voltage of 1 V at 9 kA. The power supply, unable to maintain the current ramp, tripped off and the energy discharge switch opened, inserting dump resistors into the circuit to produce a fast current decrease
  - Within one second, an electrical arc developed, puncturing the helium enclosure and leading to a release of helium into the insulation vacuum of the cryostat. After 3 and 4 seconds, the beam vacuum also degraded in beam pipes 2 and 1, respectively

The incident on Sept. 19th 2008 (cont'd)

- The spring-loaded relief discs on the vacuum enclosure opened when the pressure exceeded atmospheric, thus releasing helium into the tunnel, but they were unable to contain the pressure rise below the nominal 0.15 MPa in the vacuum enclosure of the central subsector, thus resulting in large pressure forces acting on the vacuum barriers separating the central subsector from the neighbouring subsectors
- the number of magnets to be repaired is at most 5 quadrupoles and 24 dipoles from the three subsectors involved. But it is possible that more magnets will have to be removed from the tunnel for cleaning and exchange of multilayer insulation. Spare magnets and spare components appear to be available in adequate types and sufficient quantities to allow replacement of the damaged ones during the forthcoming shutdown
- The extent of contamination to the beam vacuum pipes is not yet fully mapped, but is known to be limited

Perspective

✓ Winter shutdown ongoing
✓ Expert are working to repair the accelerator
✓ Detector people take profit to continue to test/repair experiments
✓ Official date for LHC (re)start-up foreseen for early spring

CERN General Director R. Aymar:

"…The time necessary for the investigation and repairs precludes a restart before CERN's obligatory winter maintenance period, bringing the date for restart of the accelerator complex to early spring 2009. LHC beams will then follow…."