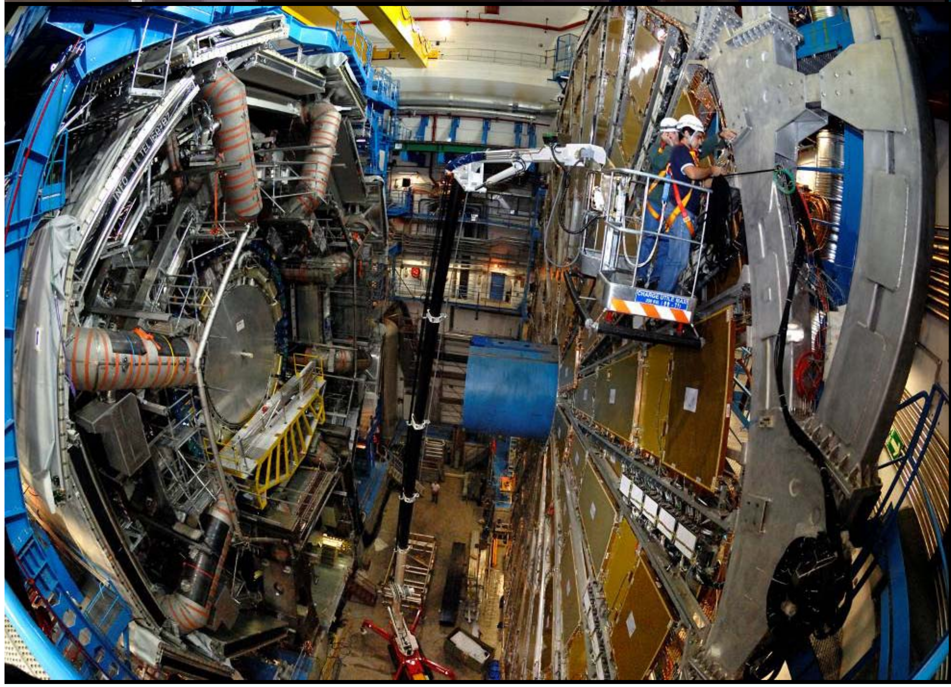
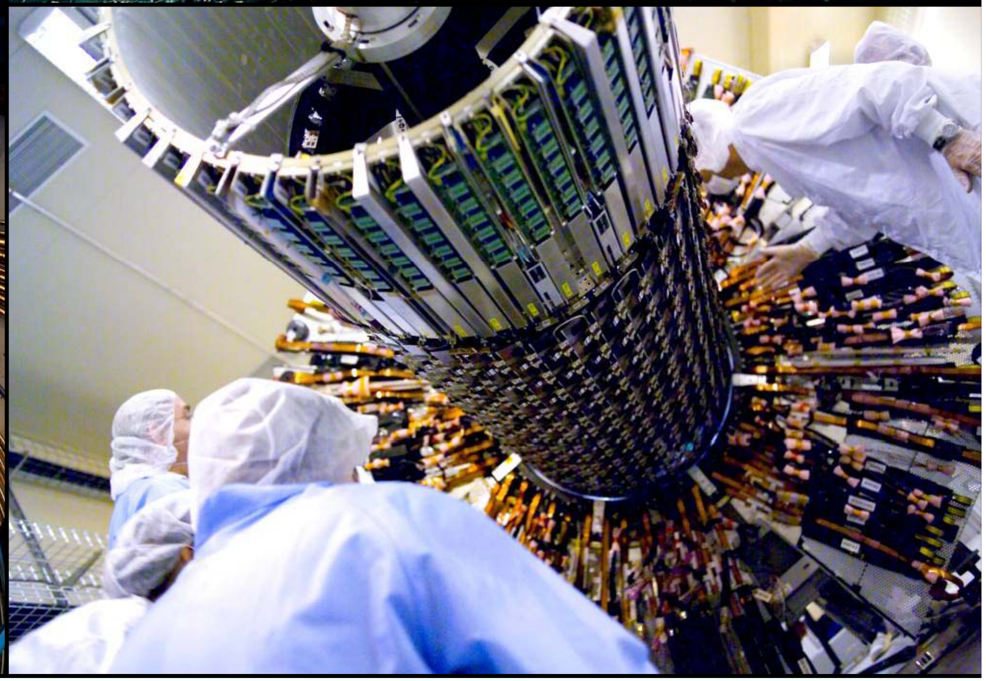
LHC & ATLAS

The largest particle physics experiment in the world

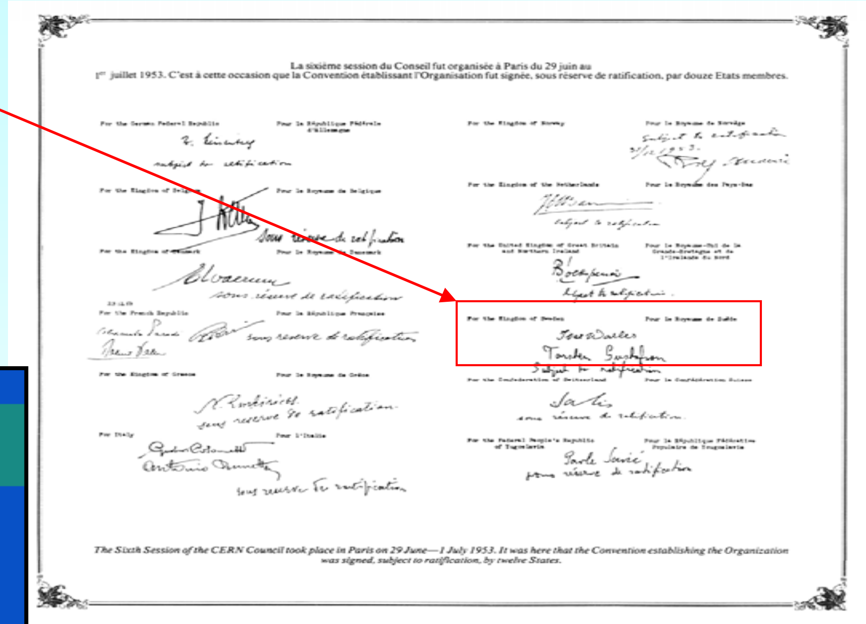




CERN – A laboratory for the world

CERN was founded in 1954

Torsten Gustavson



La sixième session du Conseil fut organisée à Paris du 29 juin au 1er juillet 1953. C'est à cette occasion que la Convention établissant l'Organisation fut signée, sous réserve de ratification, par douze Etats membres.

The Sixth Session of the CERN Council took place in Paris on 29 June—1 July 1953. It was here that the Convention establishing the Organization was signed, subject to ratification, by twelve States.

- The first proposal (De Broglie, 1949)

"...a laboratory or institution where it would be possible to do scientific work, but somehow beyond the framework of the different participating states.

...this body could be endowed with more resources than national laboratories and could, consequently, undertake tasks...beyond their scope..."

Collaboration could be easier due to the "true nature of science"

This kind of cooperation would serve also other disciplines

There were 12 member states in the beginning.

The 20 member states

OBSERVERS:
- UNESCO
- EU
- Israel
- Turkey

SPECIAL OBSERVERS (for the LHC):
- USA
- Japan
- Russia
- India

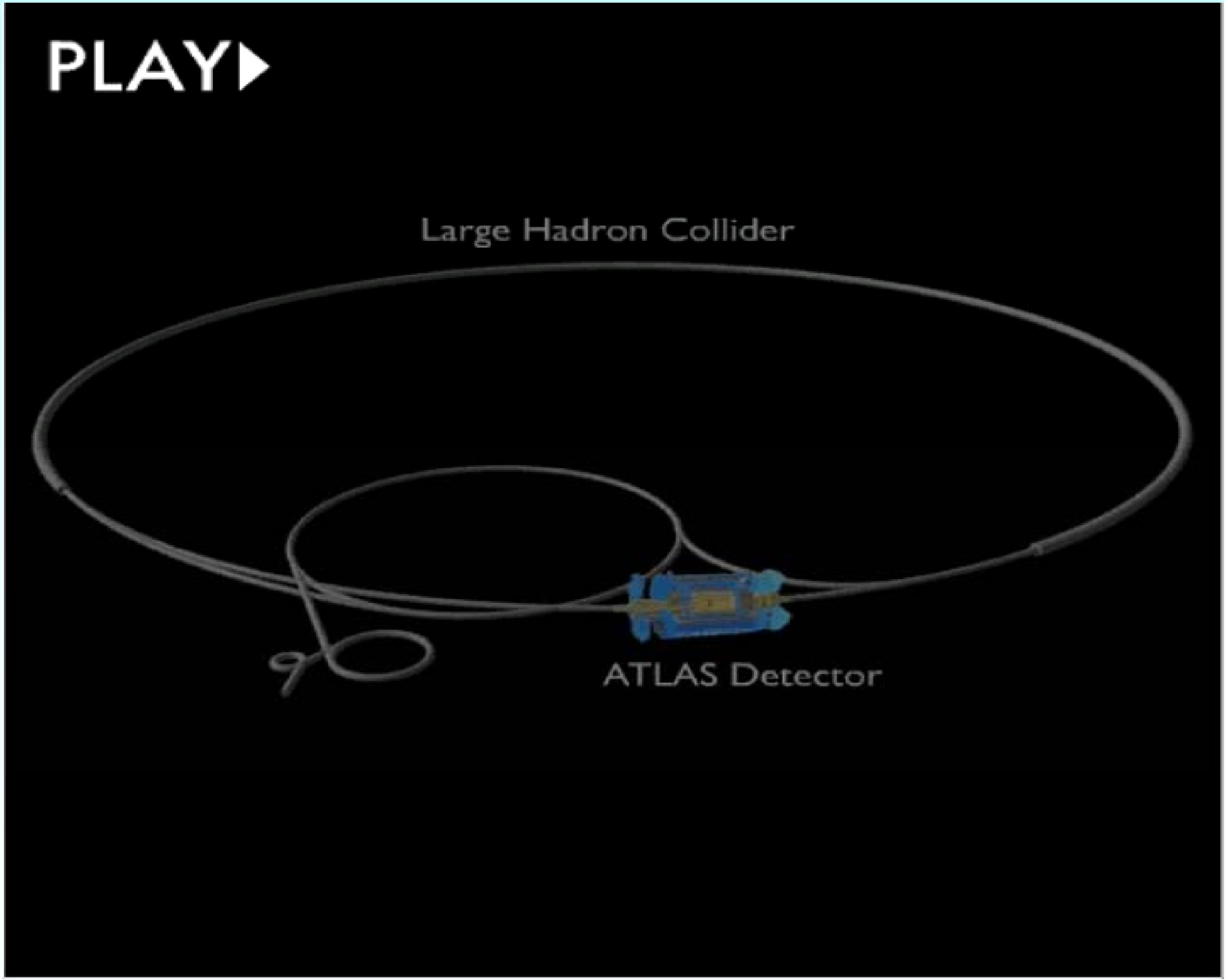
The Large Hadron Collider (LHC)

- The 27 km long proton-proton collider was ready to start in the autumn of 2008.
- It consists of 1232 + 392 superconducting magnets.
- The maximum collision energy: 14 TeV

  However, the collision energy is 1150 TeV when Pb-atoms are used.
- The proton velocity is 99,999999991% of the speed of light.
- One billion collisions per second.
- The stored energy in one beam is 360 MJ. (360MJ ~ energy of a train travelling at 150 km/h or of an explosion of 77 kg of TNT).

The Large Hadron Collider (LHC)

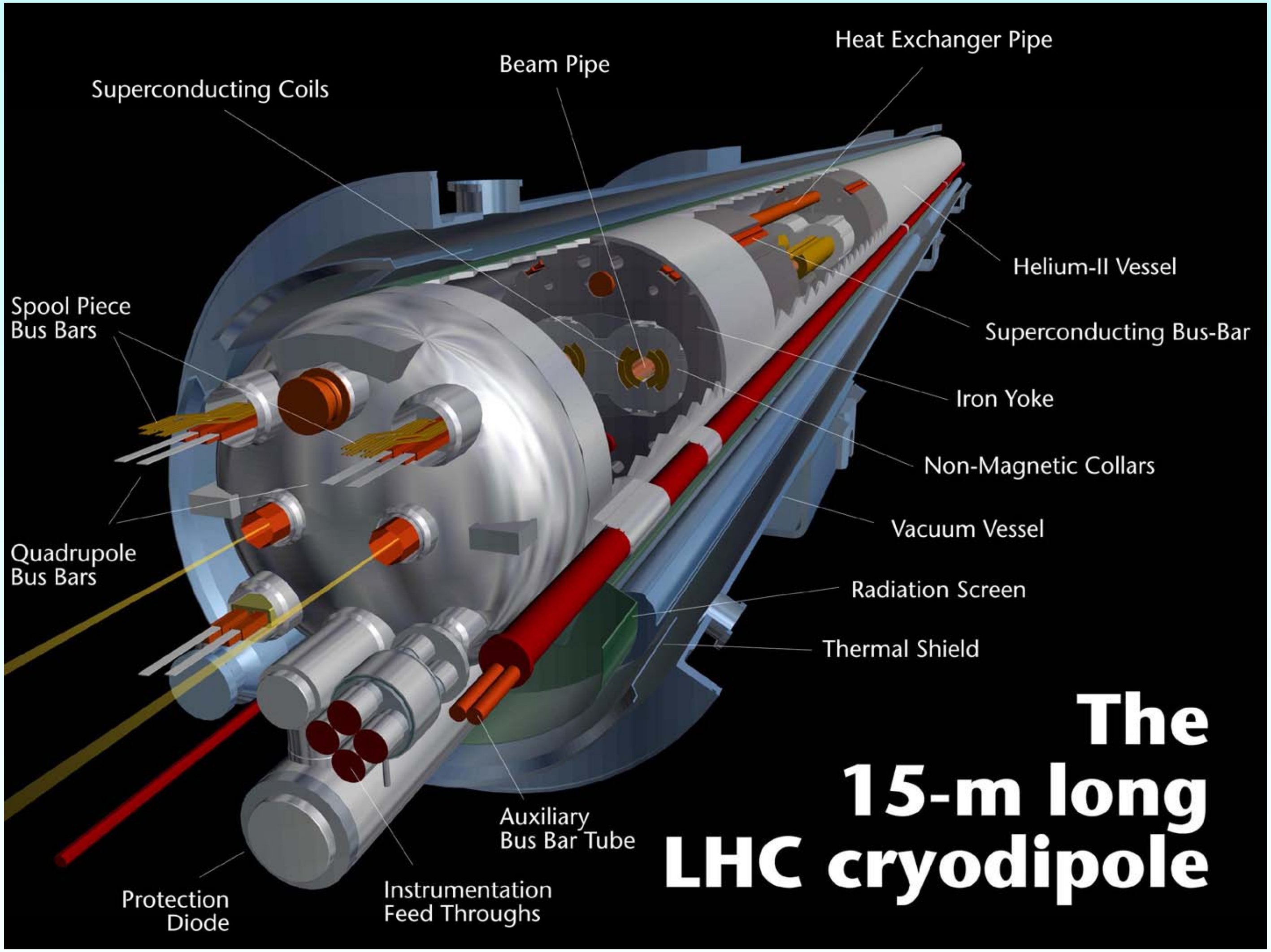
The protons are first accelerated in a linear accelerator. They are then accelerated in the PS and SPS synchrotrons and finally injected into the 27 km long LHC tunnel.



The protons are travelling in 2808 bunches that each contain 10^{11} protons.

In the LHC accelerator tunnel

The magnets that bend the proton beams.



1232 dipole magnets

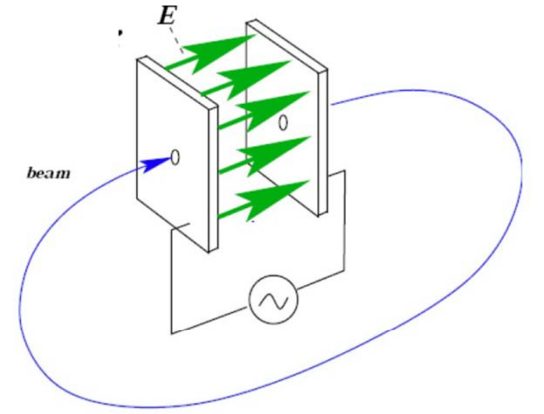
15 m long
35 ton heavy

Magnetic field:
8.3 Tesla

120 tonnes of liquid helium (1.9 K)

Current:
11800 Ampere

The cavities that provide the energy.



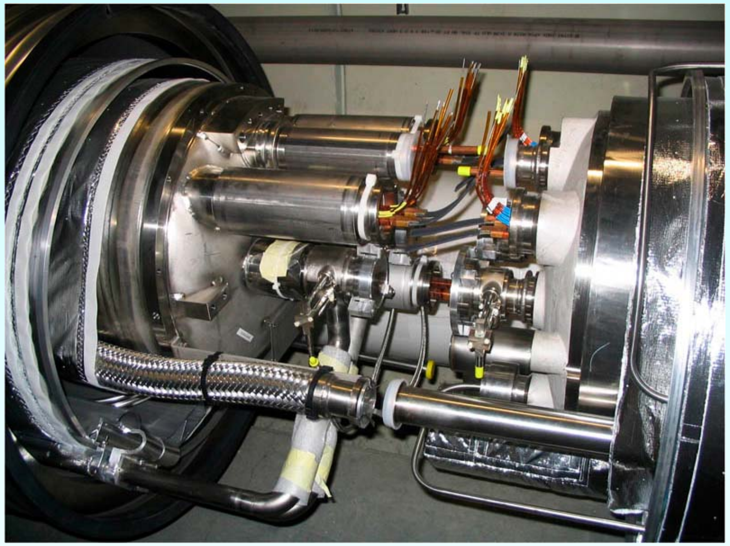
The magnets are used to bend the proton trajectories and to focus the beams.

Cavities with strong high-frequency electric fields are used to provide the energy to the beams. The LHC has 2x8 cavities that give 16 MV at 400 MHz.

The building of the LHC

10 September 2008 – Champagne !

19 September 2008 – Hangover !



A shortcut burned a hole in the helium enclosure and a pressure wave damaged about 50 magnets. Several tonnes of liquid helium leaked out.

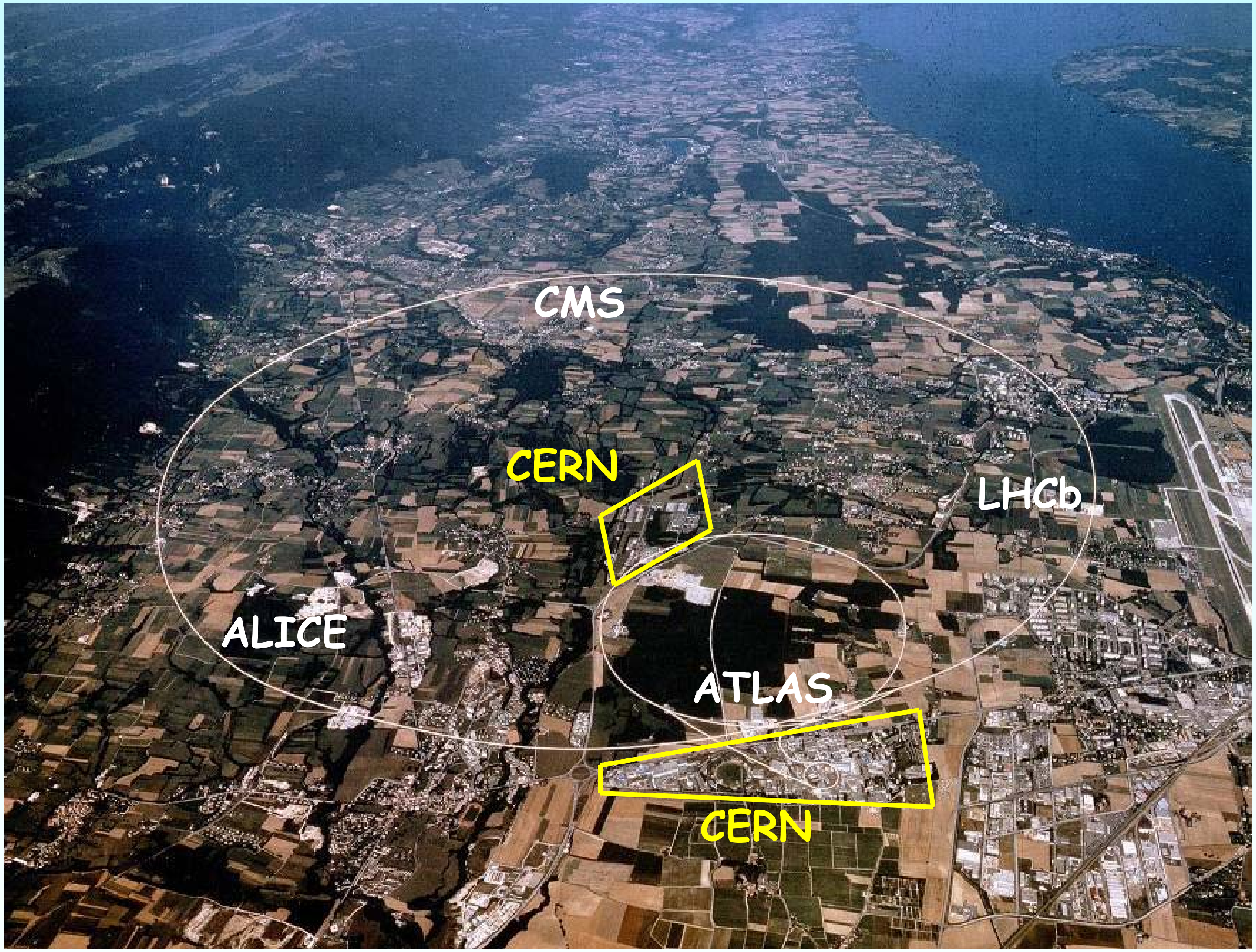
Same procedure as last year !

First collisions in ATLAS on the 23rd of November 2009.

So far no explosions….. but collisions at 450 GeV and a new world record in beam energy (1118 GeV)…..it is looking good.

However, maximum a 7 TeV collision energy in 2010 and at low collision rate.

Experiments at the LHC



Experiments

ATLAS:
Proton-proton collisions

CMS:
Proton-proton collisions

ALICE:
Atom-atom collisions

LHCb:
Proton-proton collisions giving b quarks

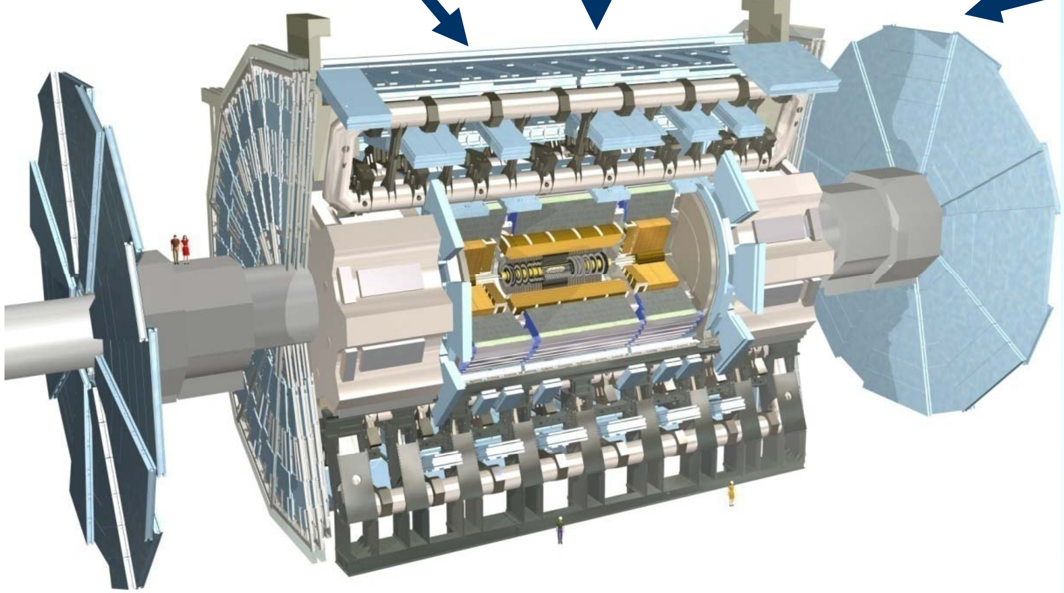
Swedish research groups

Uppsala Universitet

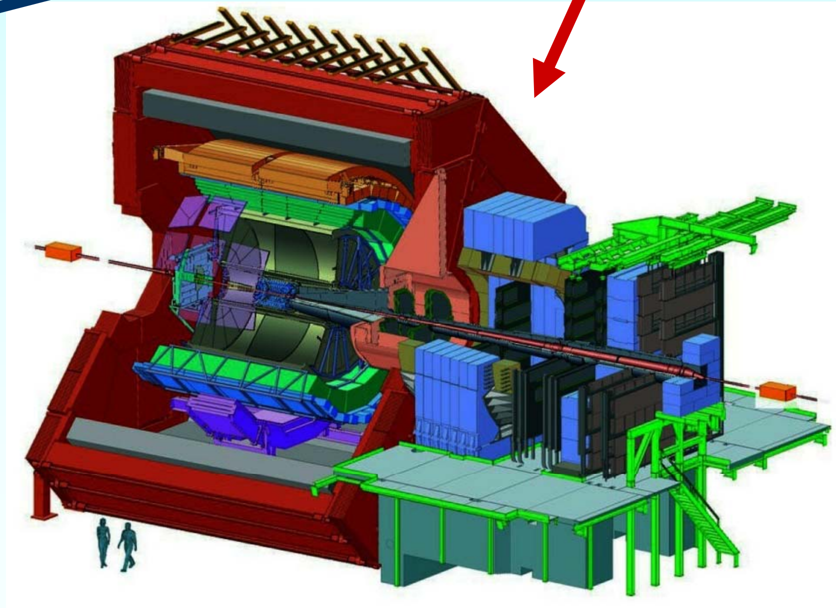
Kungl Tekniska Högskolan

Stockholms universitet

Lunds Universitet

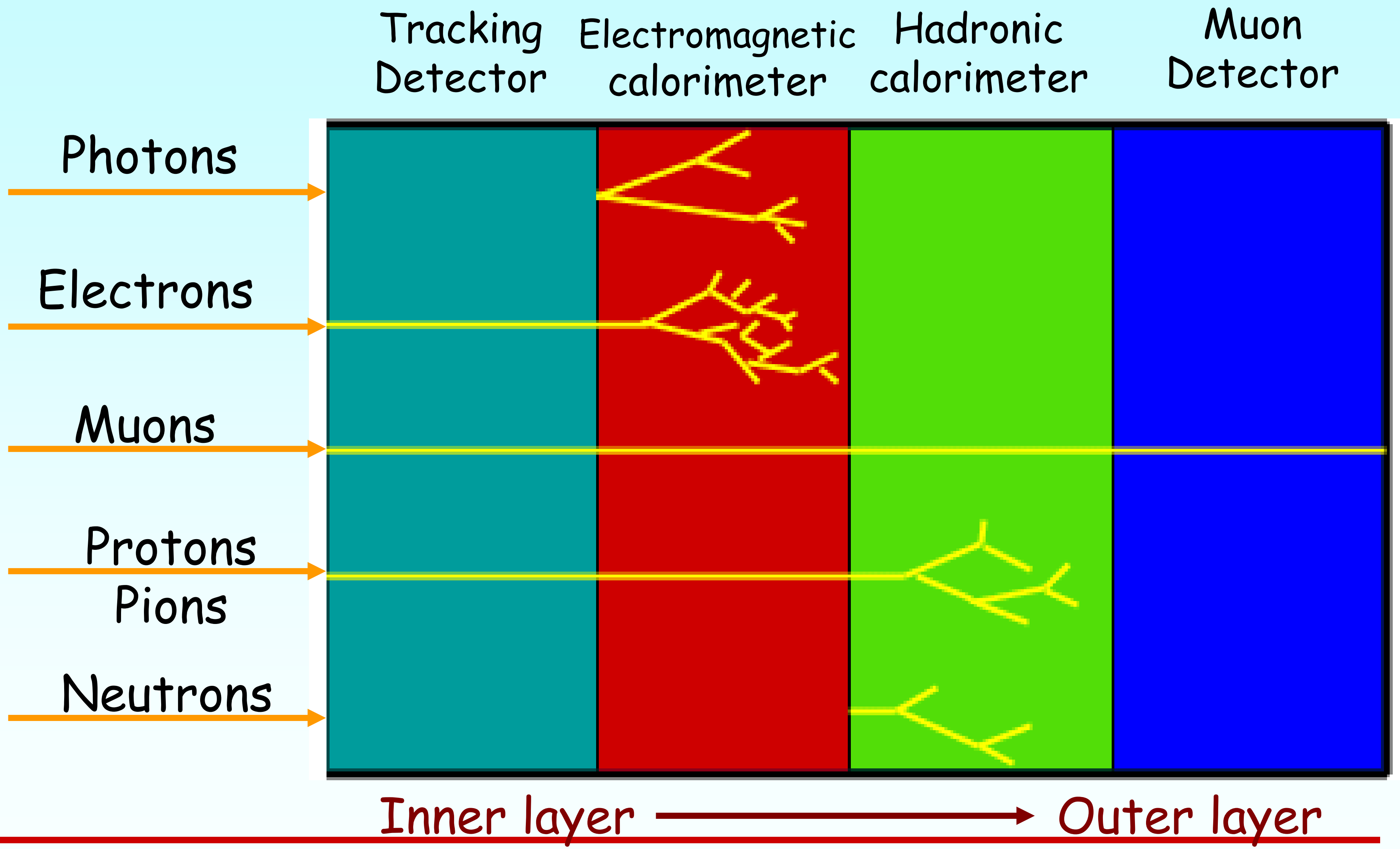


The ATLAS experiment

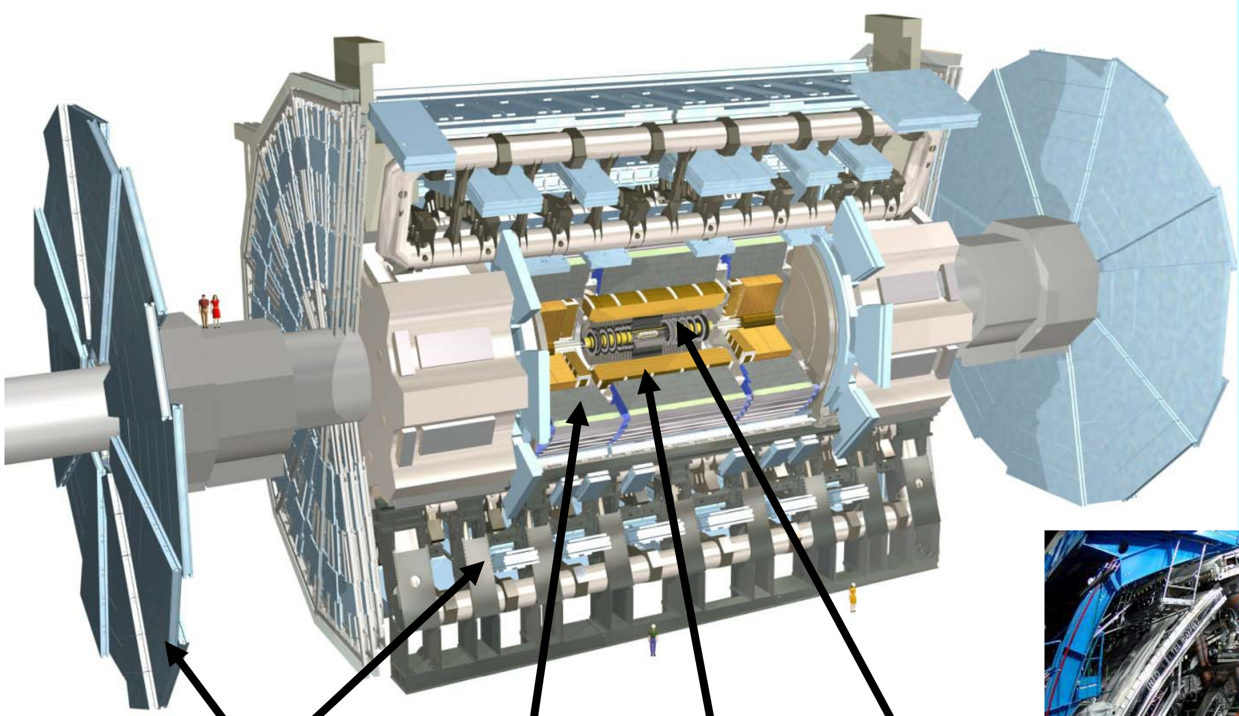


The ALICE experiment

Detection of particles



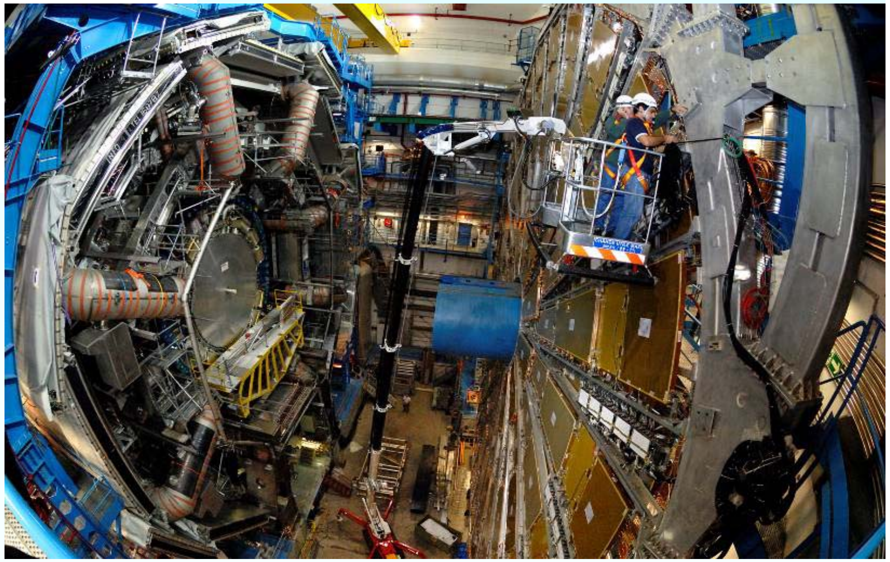
The ATLAS experiment



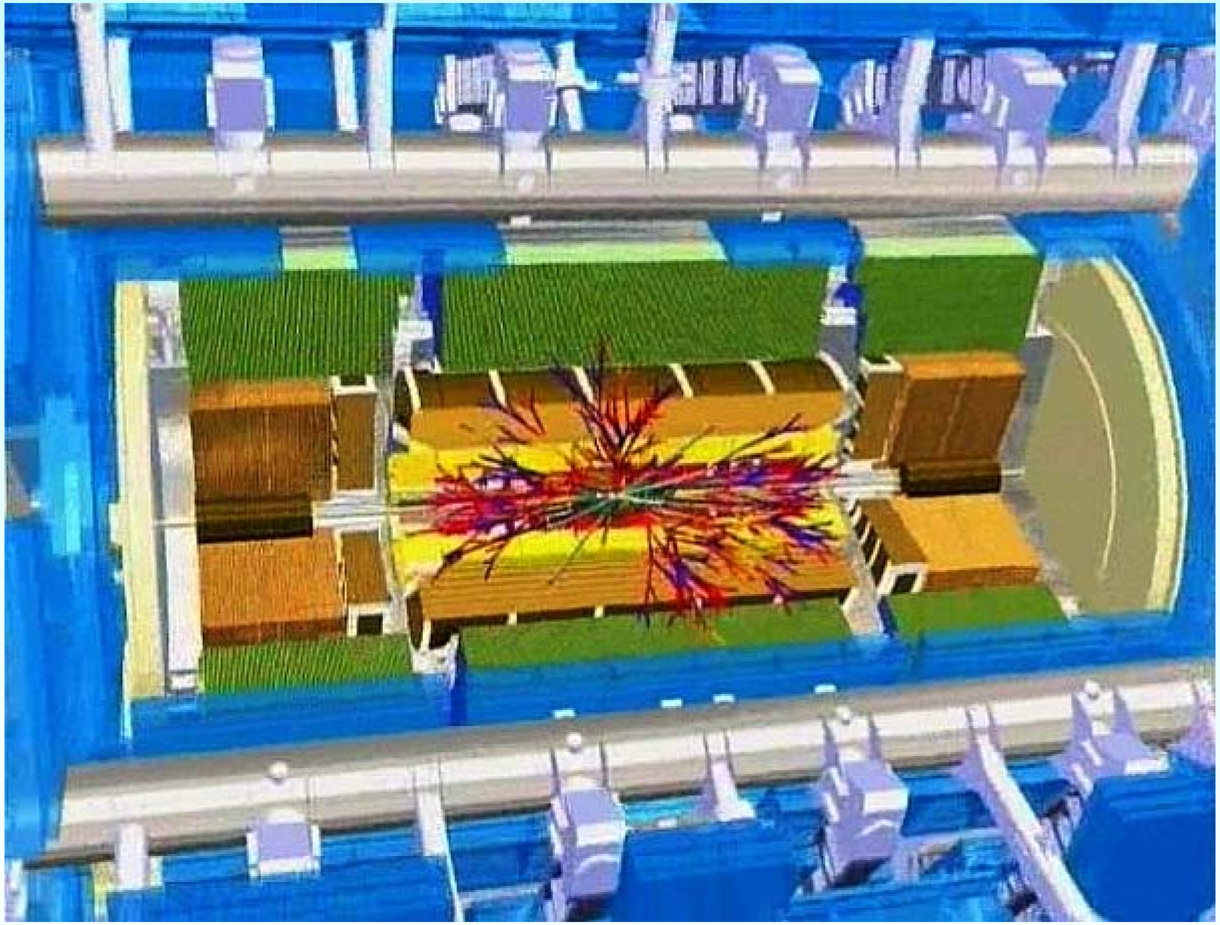
- Muon detector
- Hadron calorimeter
- Electromagnetic calorimeter
- Tracking detector

The ATLAS Experiment

- Length: 44m
- Diameter: 22m
- Weight: 6000 tonnes
- The collaboration 1800 physicists (>160 Univ., 34 Countries)



A proton-proton collision in ATLAS



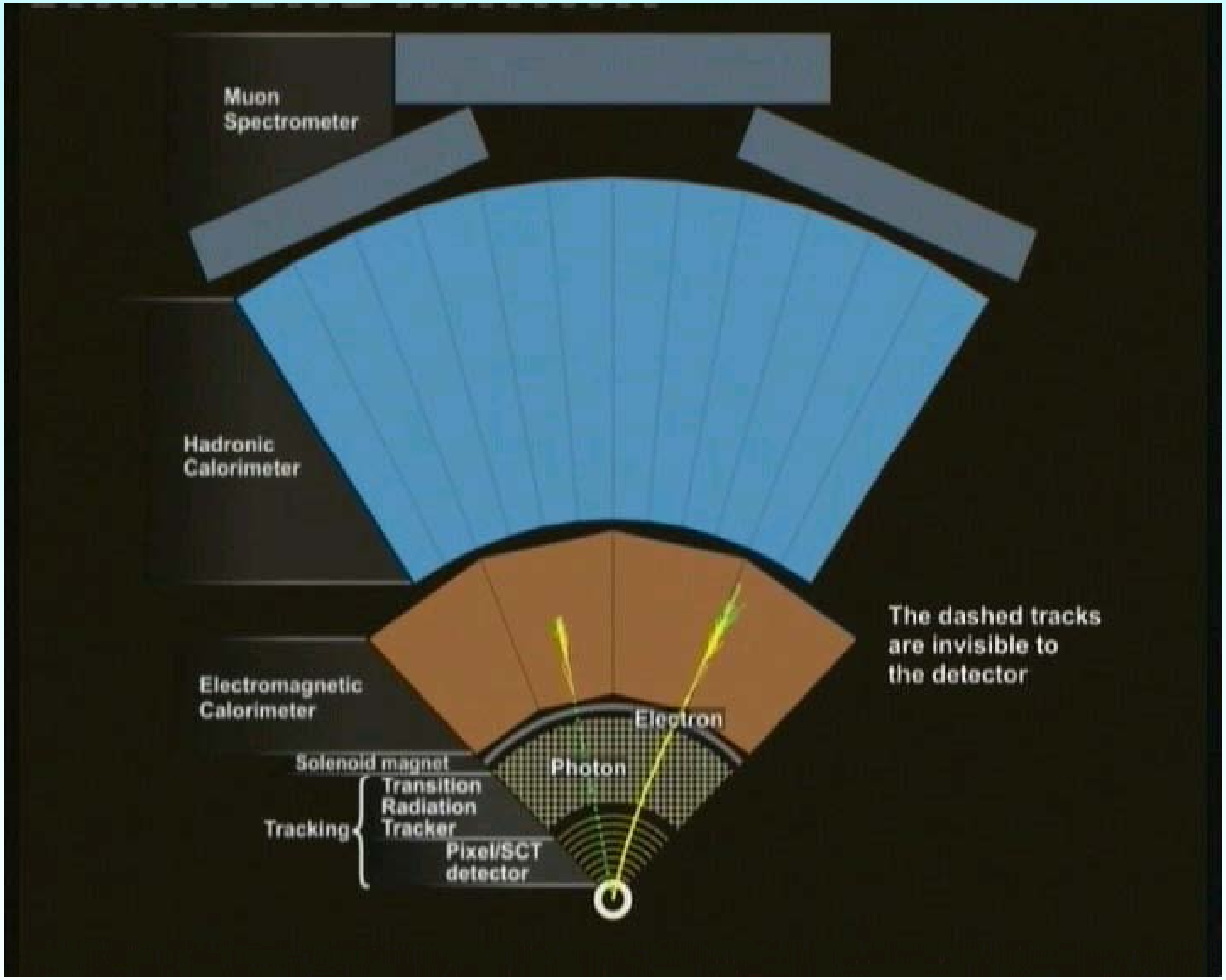
Detection of photons and electrons

Muon detector

Hadronic calorimeter

Electromagnetic calorimeter

Tracking detector



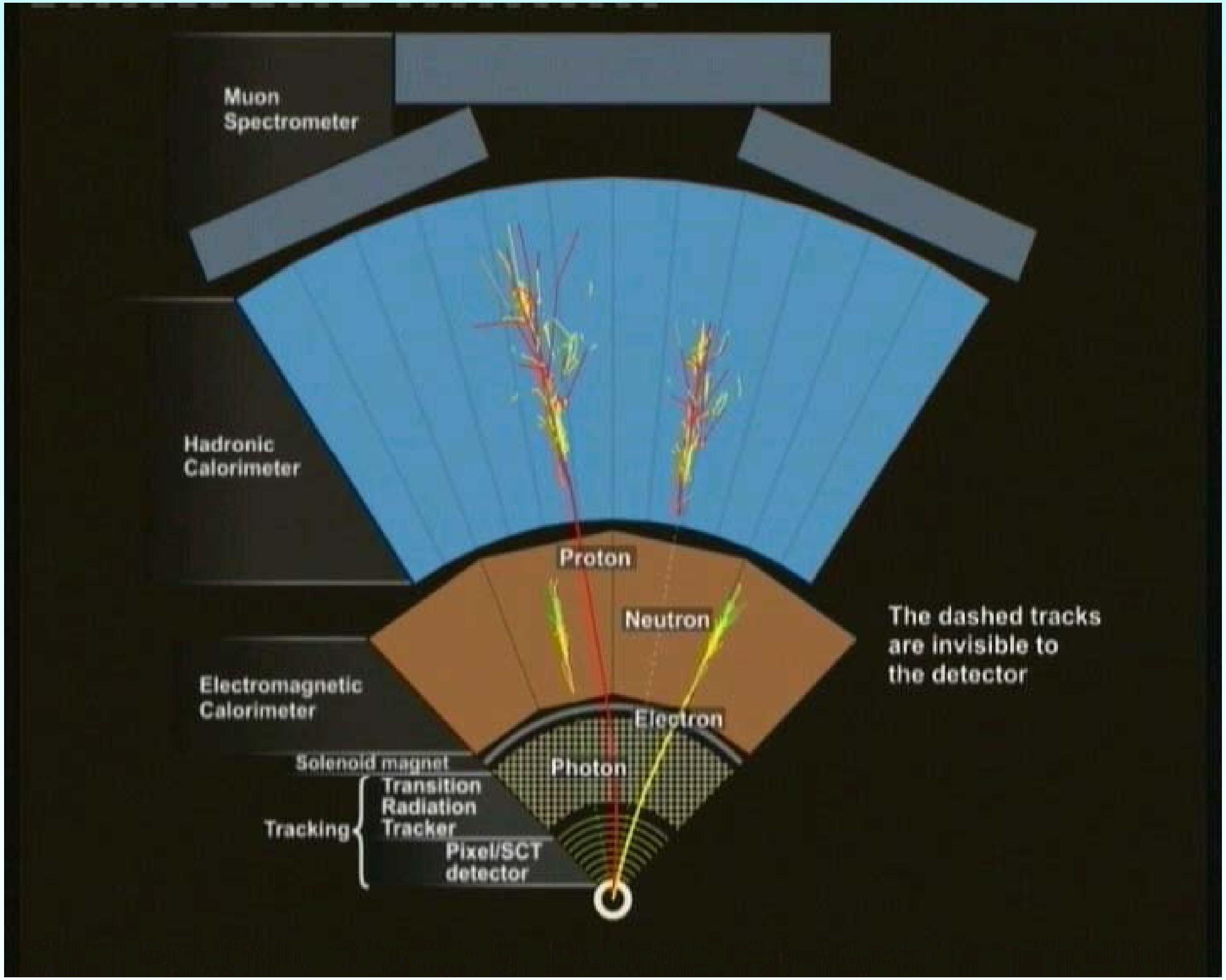
Detection of protons and neutrons

Muon detector

Hadronic calorimeter

Electromagnetic calorimeter

Tracking detector



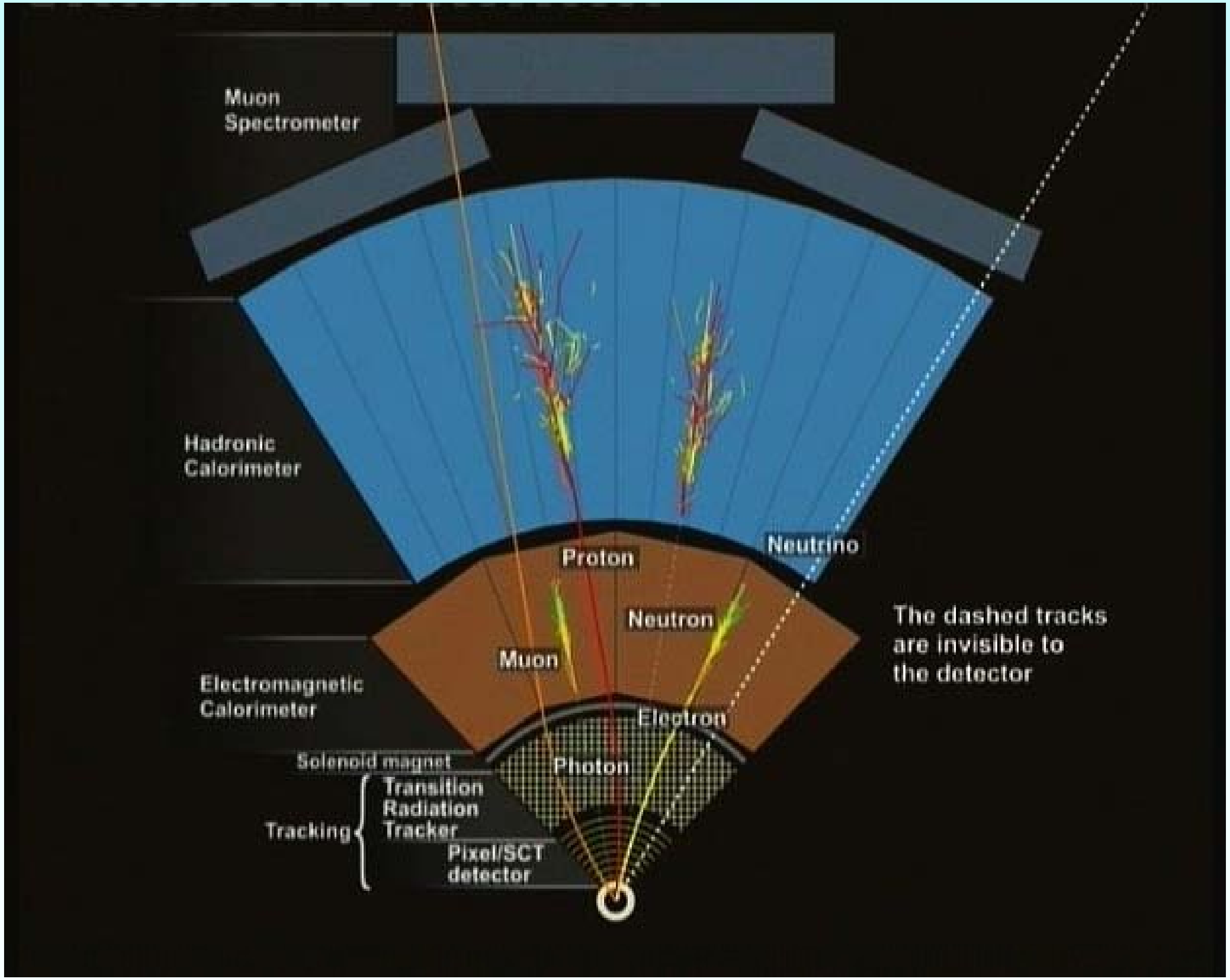
Detection of muons and neutrinos

Muon detector

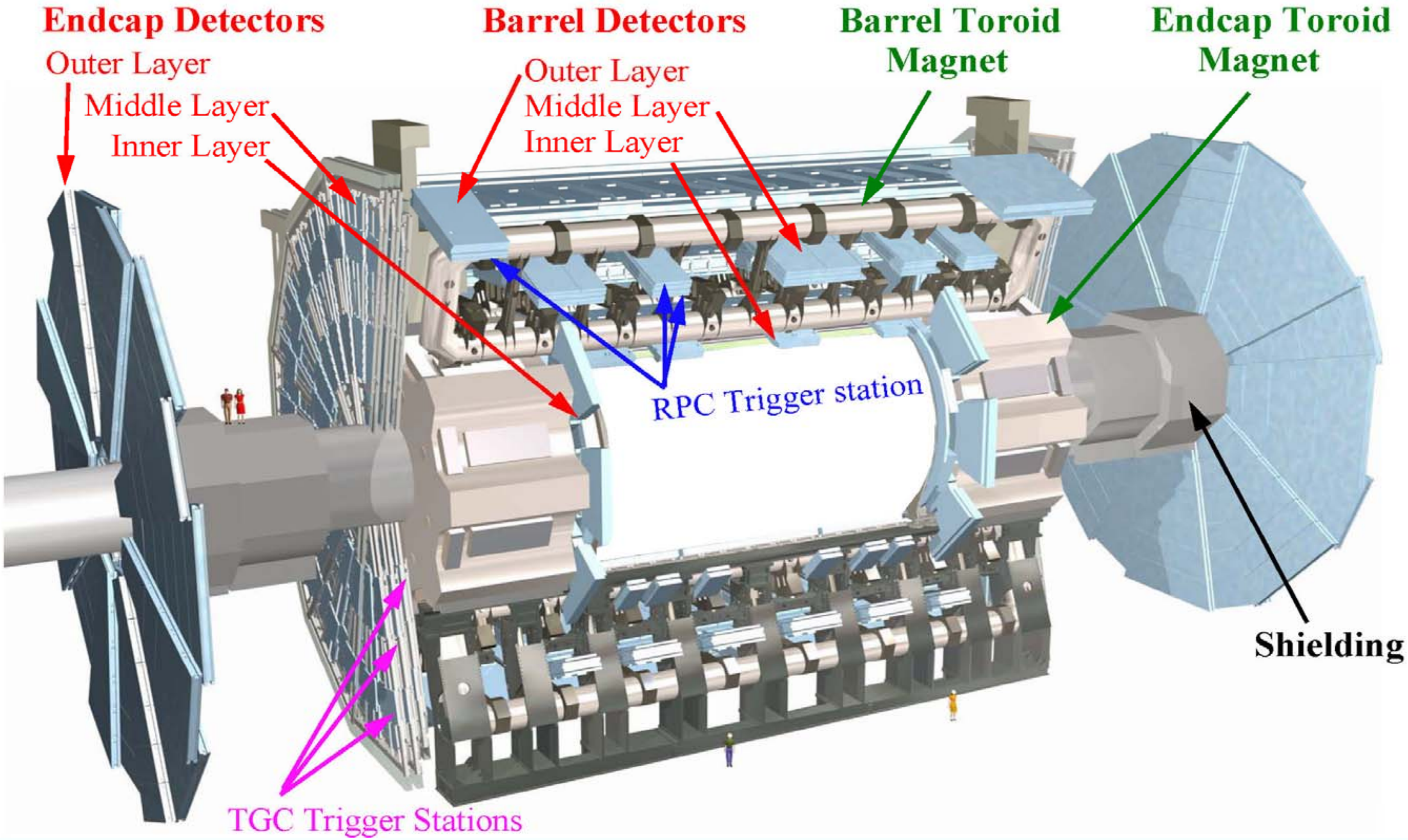
Hadronic calorimeter

Electromagnetic calorimeter

Tracking detector



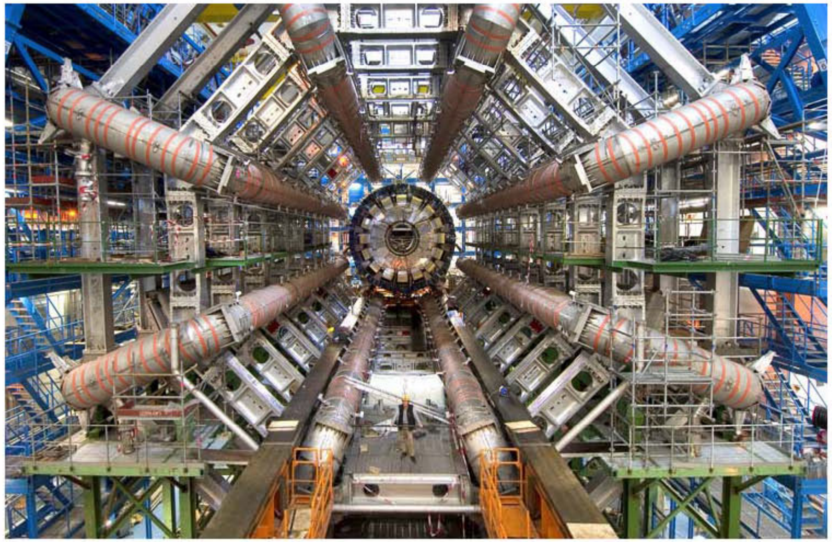
ATLAS: the muon detector

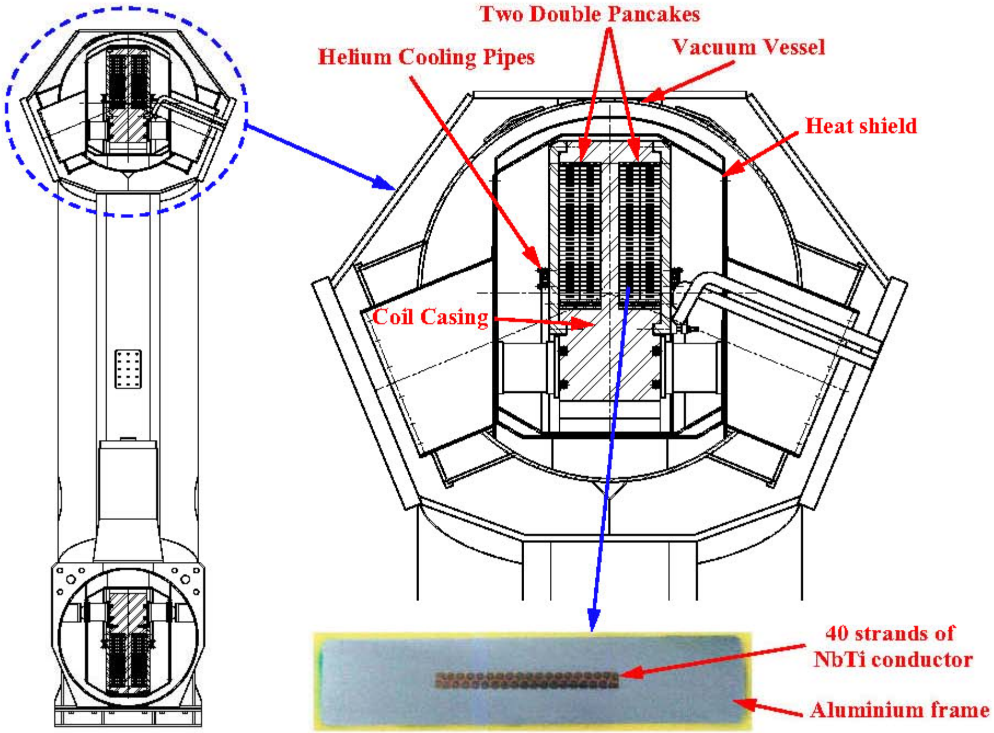


ATLAS: The 3 large toroidial magnets

The barrel magnet

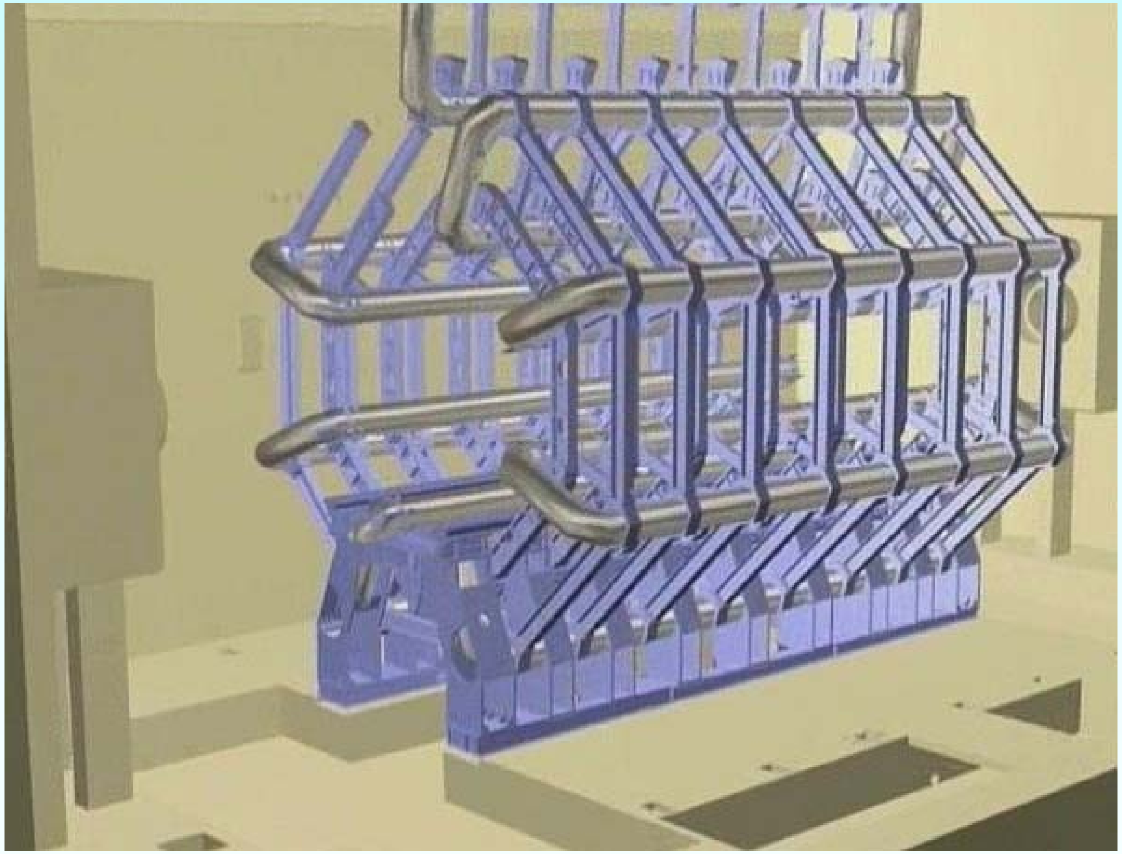
ATLAS has the worlds largest superconducting toroidal magnet that gives a peak field of 4 Tesla.

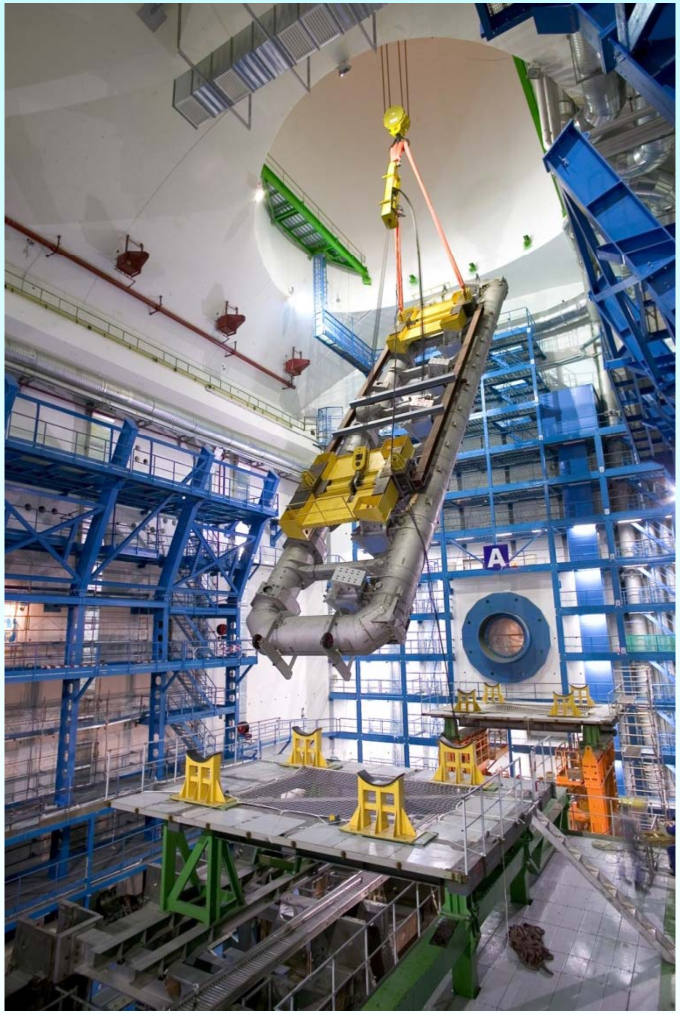




ATLAS: The 3 large toroidial magnets

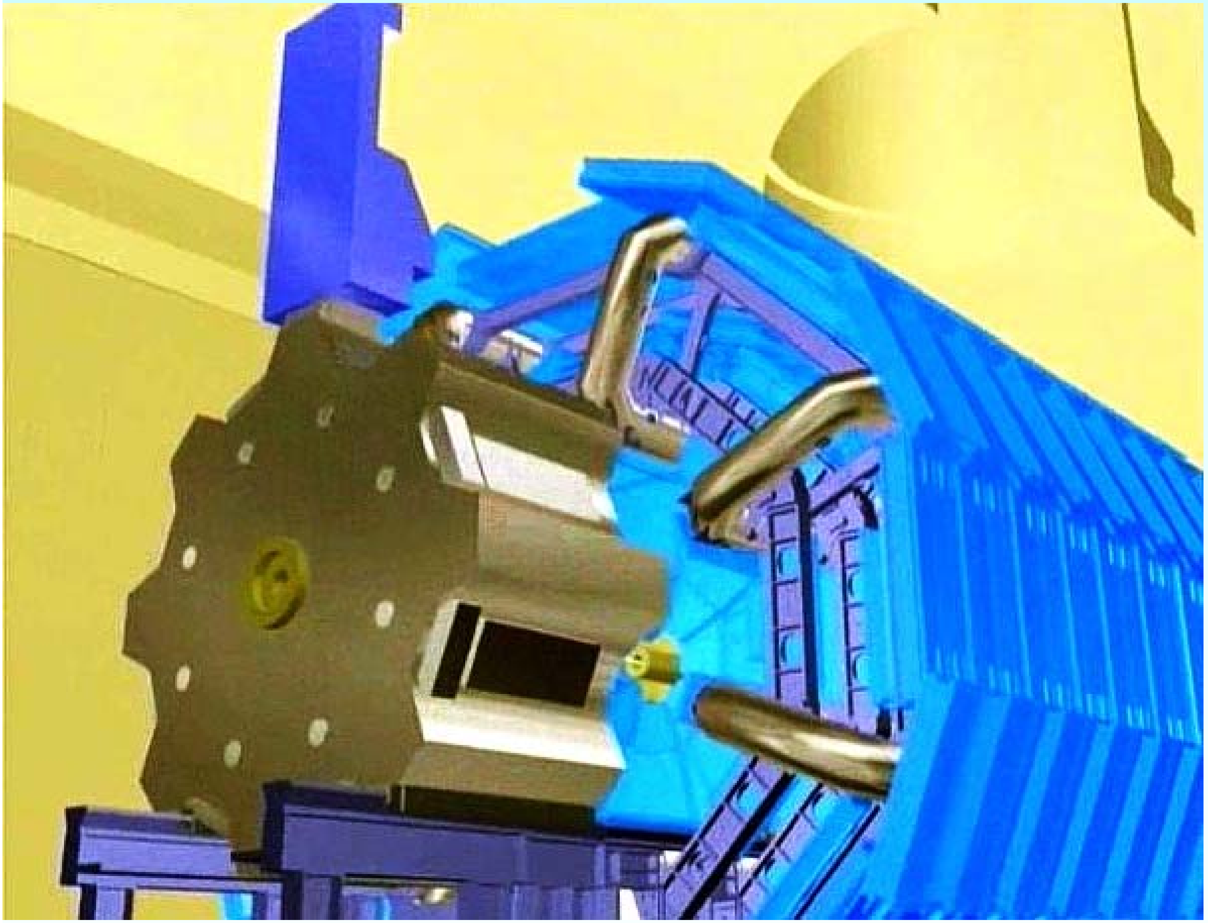
Installation of the first central magnet

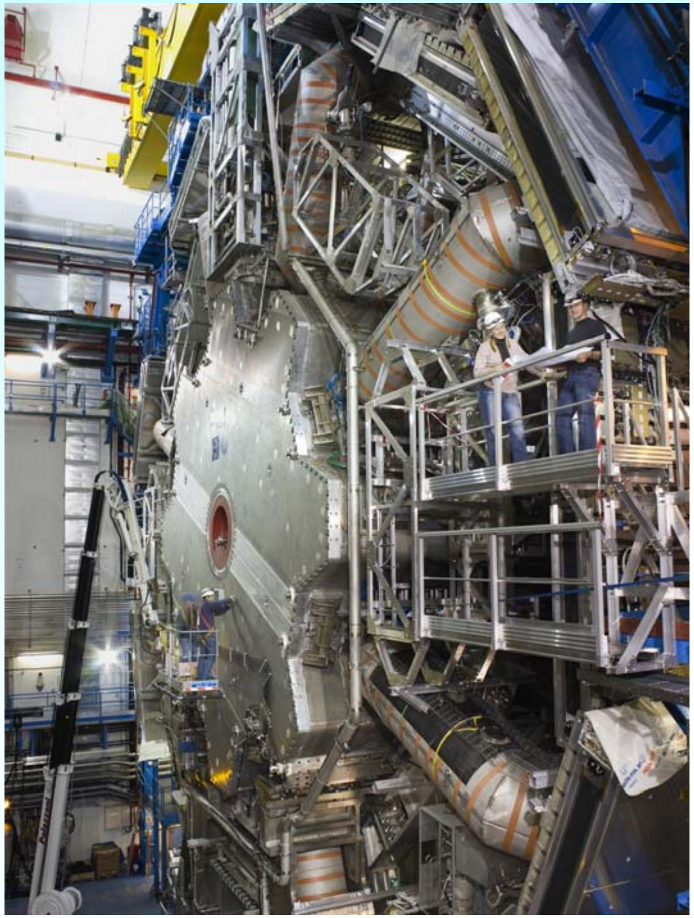




ATLAS: The 3 large toroidial magnets

Installation of the two endcap magnets

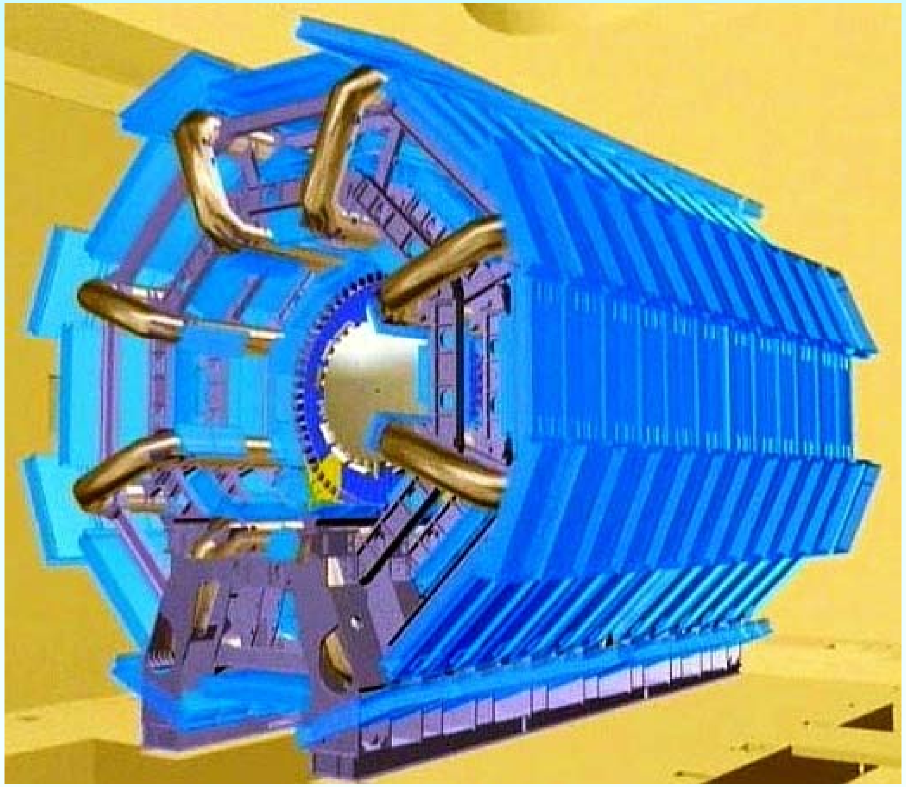




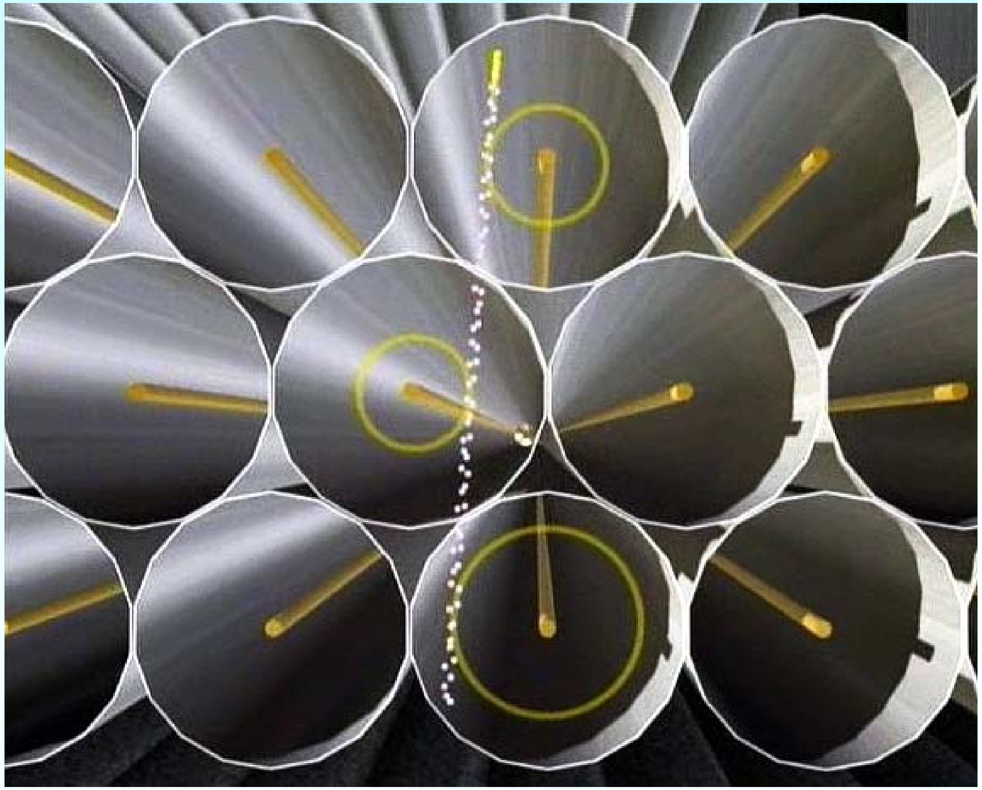
Construction of the magnets

ATLAS: the muon detector

Installation of the muon detectors.



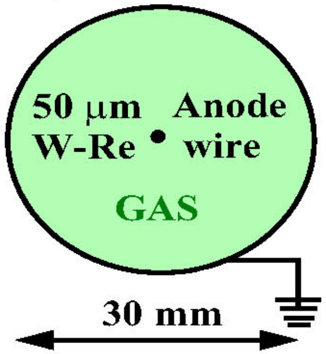
How do they work ?



ATLAS: the muon detector

DRIFT TUBES
1170 chambers
354 000 channels

Alumimium
Cathode tube

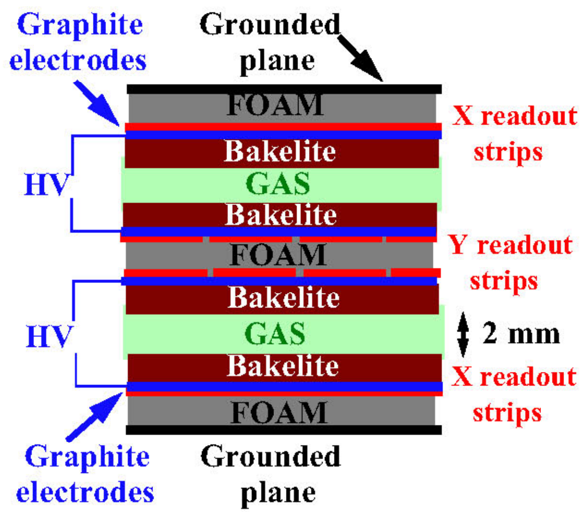


GAS (at 3 bar):
93% Ar + 7% CO_2

Max drift: 710 ns

Spatial Resolution:
80 µm

RESISTIVE PLATE CHAMBERS
1112 chambers
374 000 channels



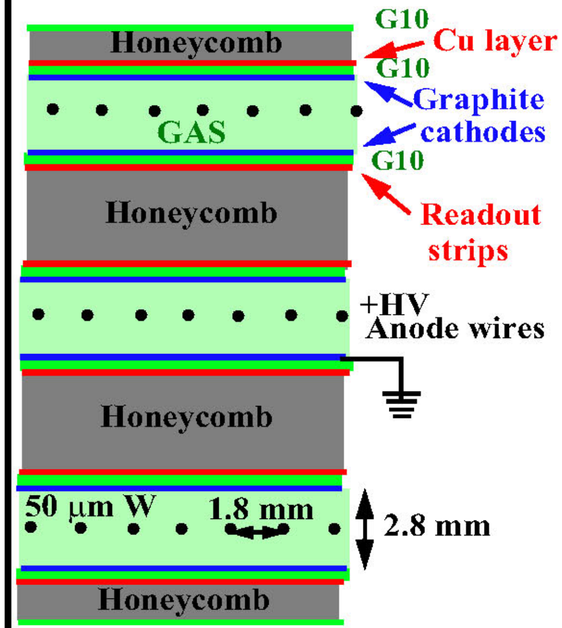
GAS: 94.7% $C_2H_2F_4$+5%C_4H_{10}+0.3%SF_6

Avalanche mode

Time resolution: 1-2 ns

Spatial resolution: 5-10 mm

MULTI-WIRE CHAMBERS
1578 chambers
320 000 channels



GAS: 55% CO_2 + 45% n-Pentane
Saturated mode

Contributions by Lund: The muon shielding

Muons are particles that can pass through many meters of matter.

There are 2800 tonnes of shielding in ATLAS to stop other types of particles so that the muons can be identified.

Copper shielding was cast in Armenia.

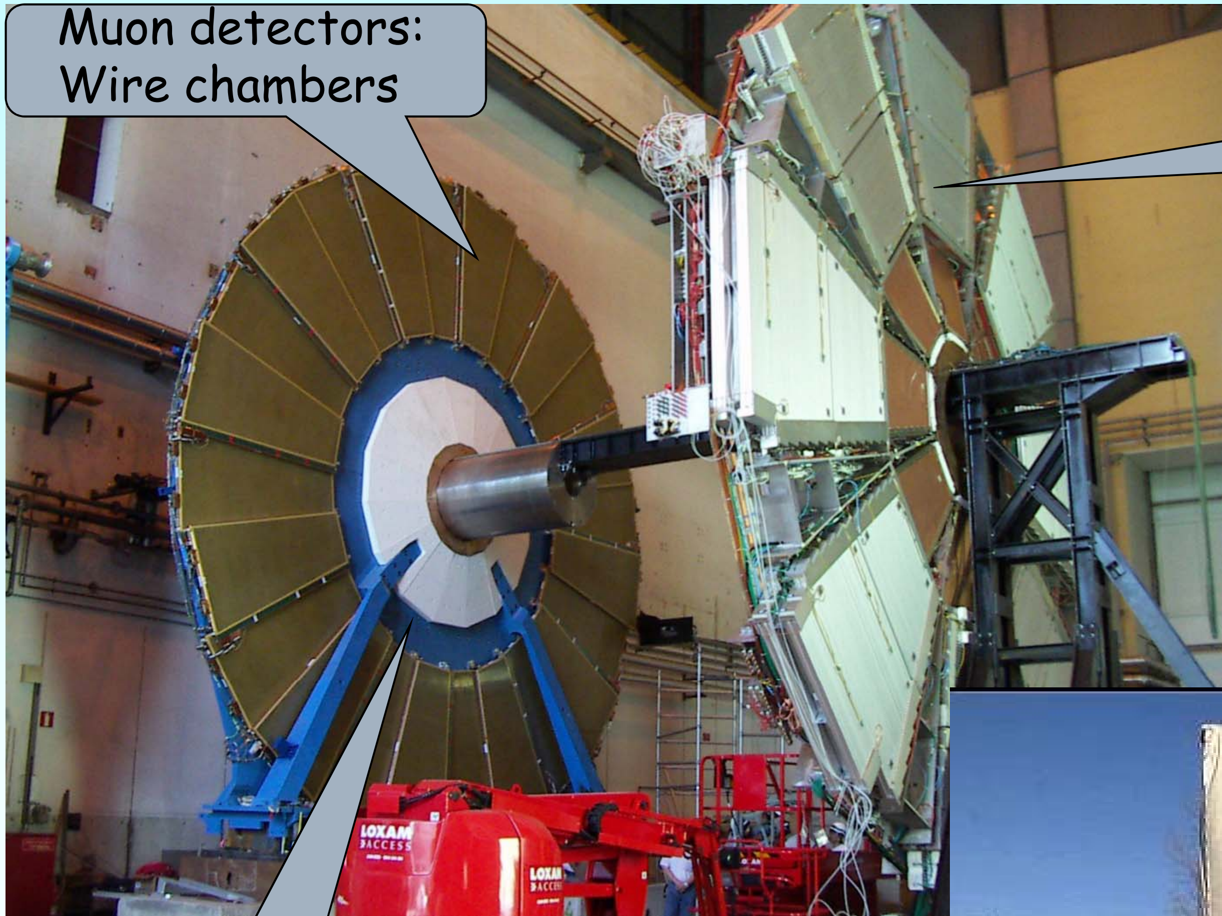
100 tonne heavy iron pieces were cast in the Czech republic.

Large steel plates were manufactured in Serbia.

10 m high transport frames were made in Bulgaria.

Contributions by Lund: The forward muon system

Muon detectors:
Wire chambers

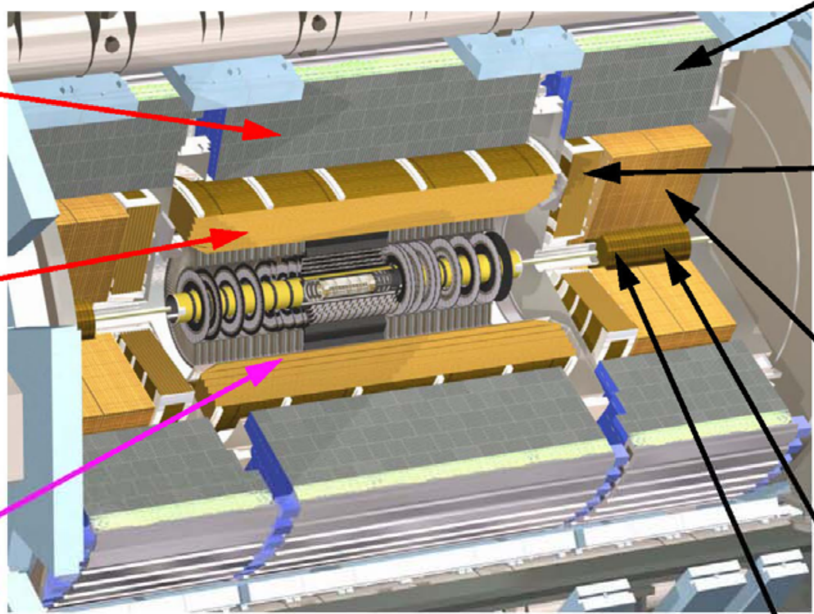


Muon detectors:
Drift tubes

Muon detectors:
Installation in ATLAS

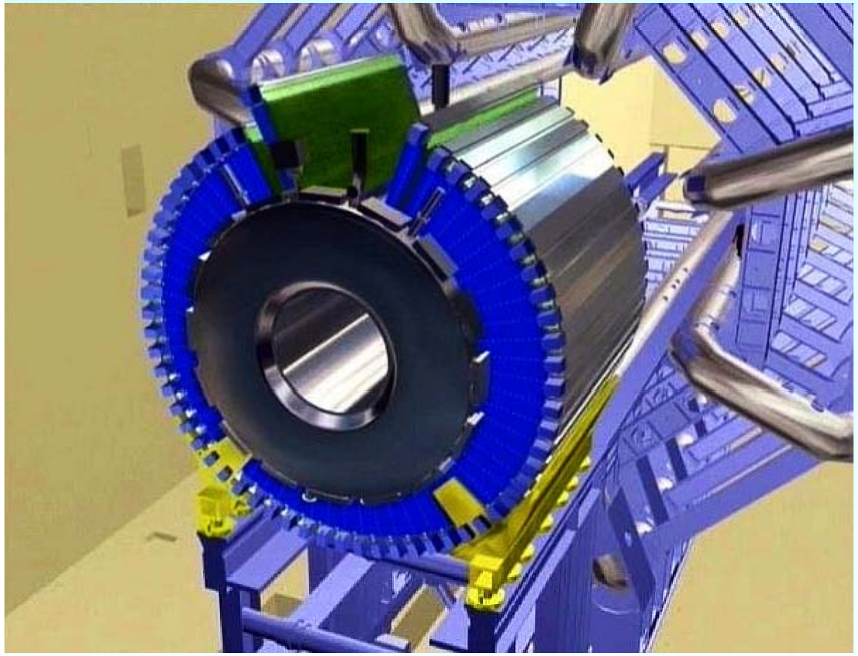
Shielding

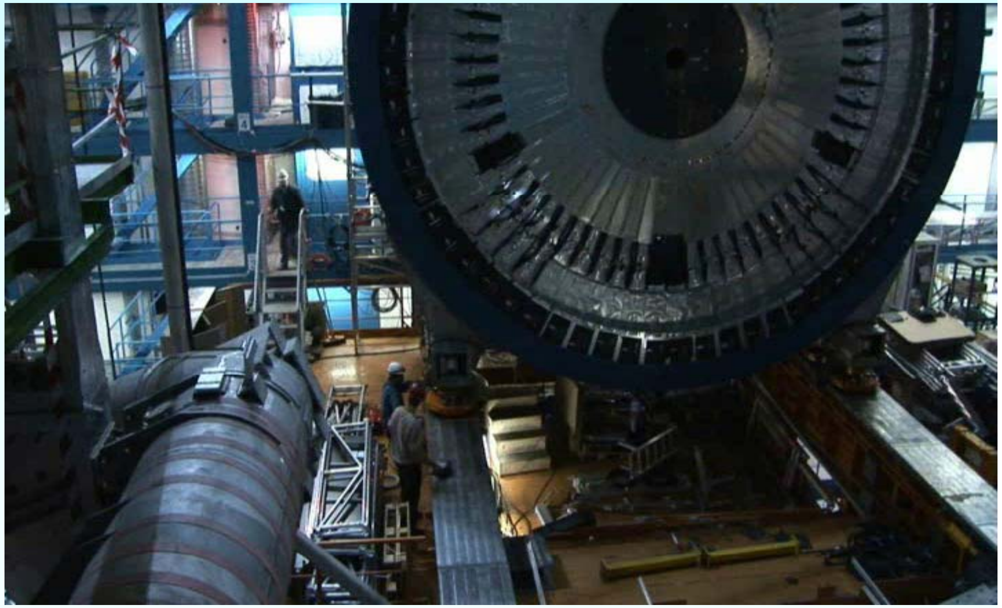
ATLAS: Calorimeters



ATLAS: Calorimeters

The calorimeters were installed in three parts.
First the barrel and then the two endcaps.

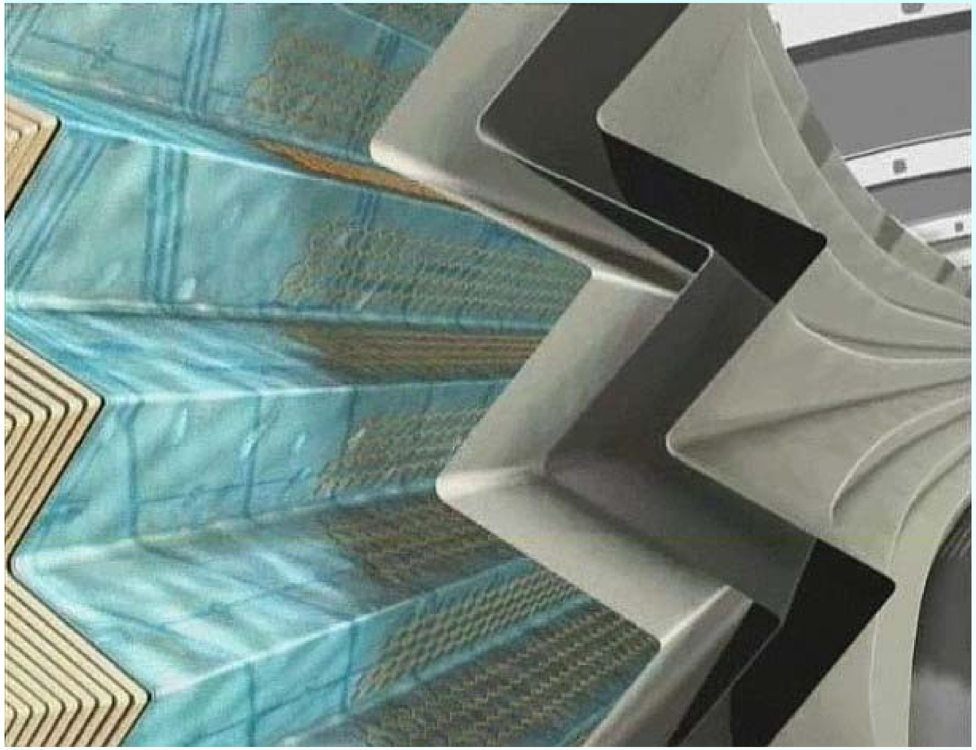


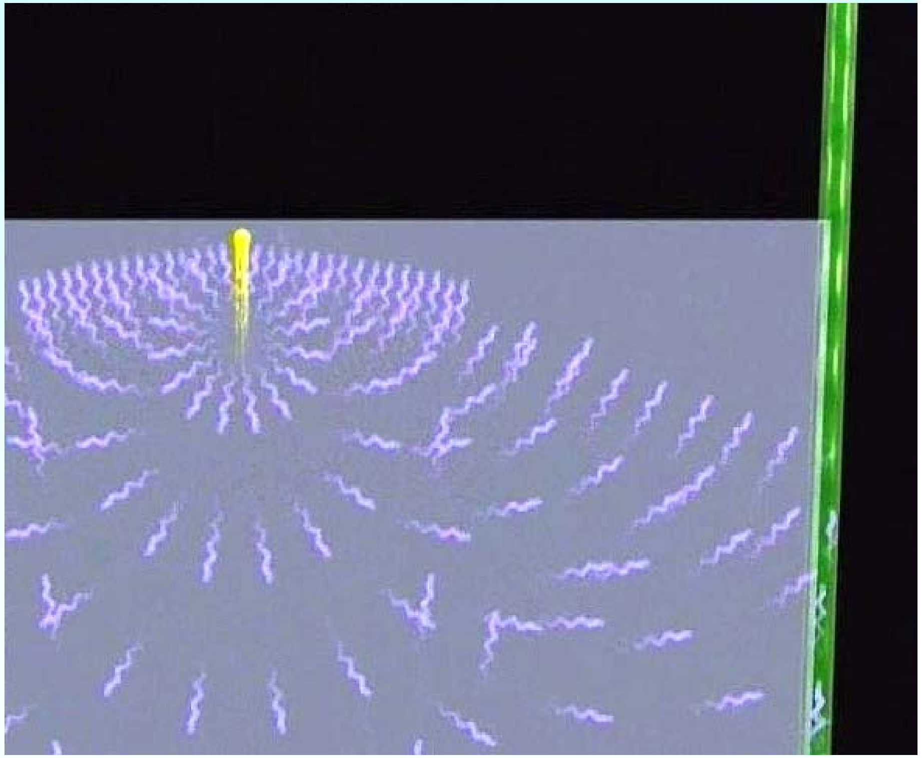


How does the calorimeter work ?

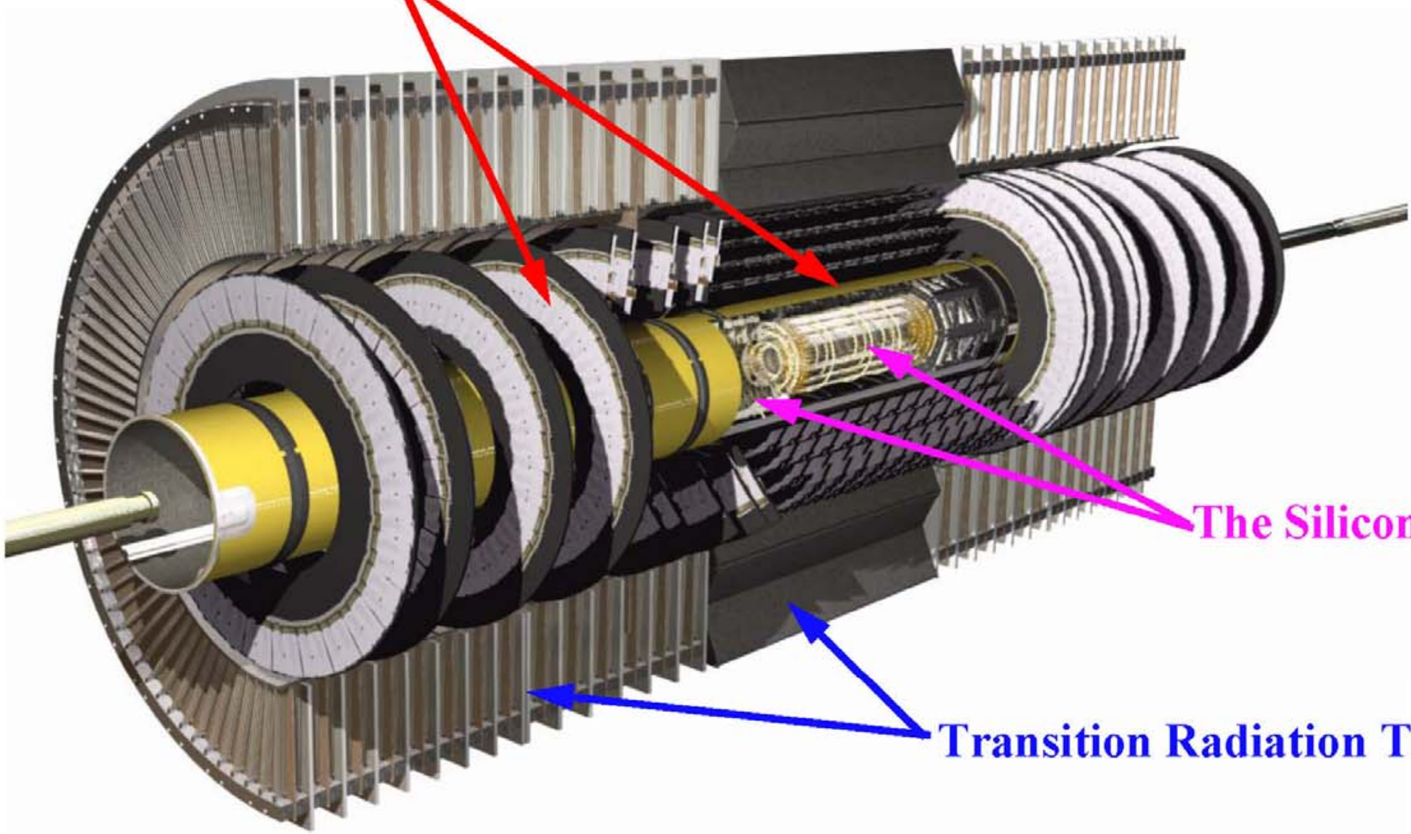
The electromagnetic calorimeter
is used to study photons and electrons.

The hadronic calorimeter
is used to study hadrons, i.e. particles that contains quarks such as protons and neutrons.





ATLAS: The Inner Detector

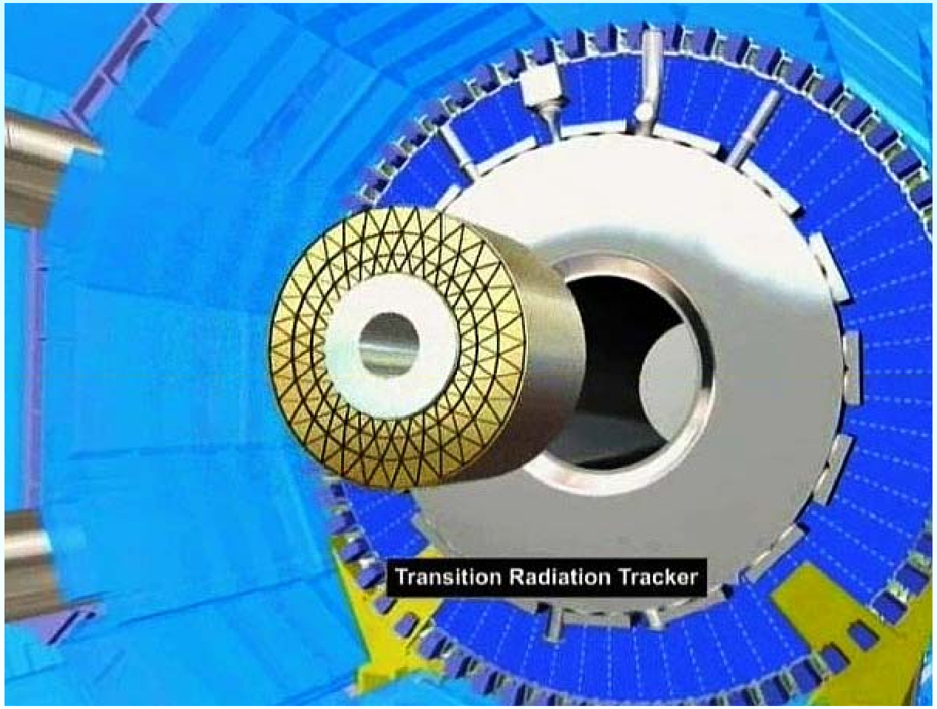


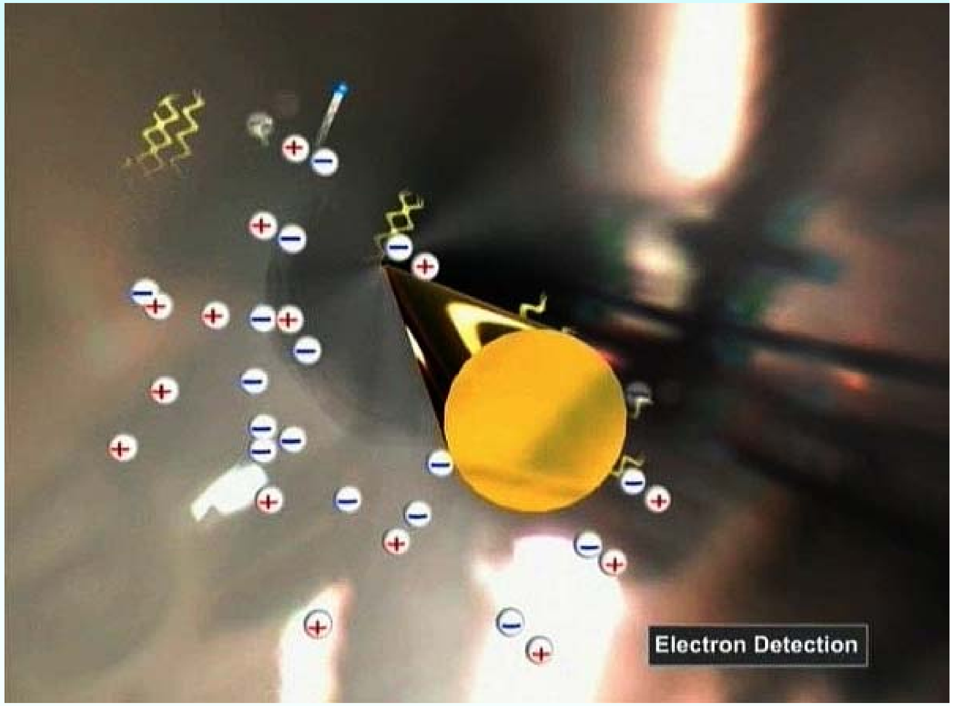
The Transition Radiation Tracker

The Transition Radiation Tracker (TRT) is used to measure the tracks of charged particles and to identify electrons.

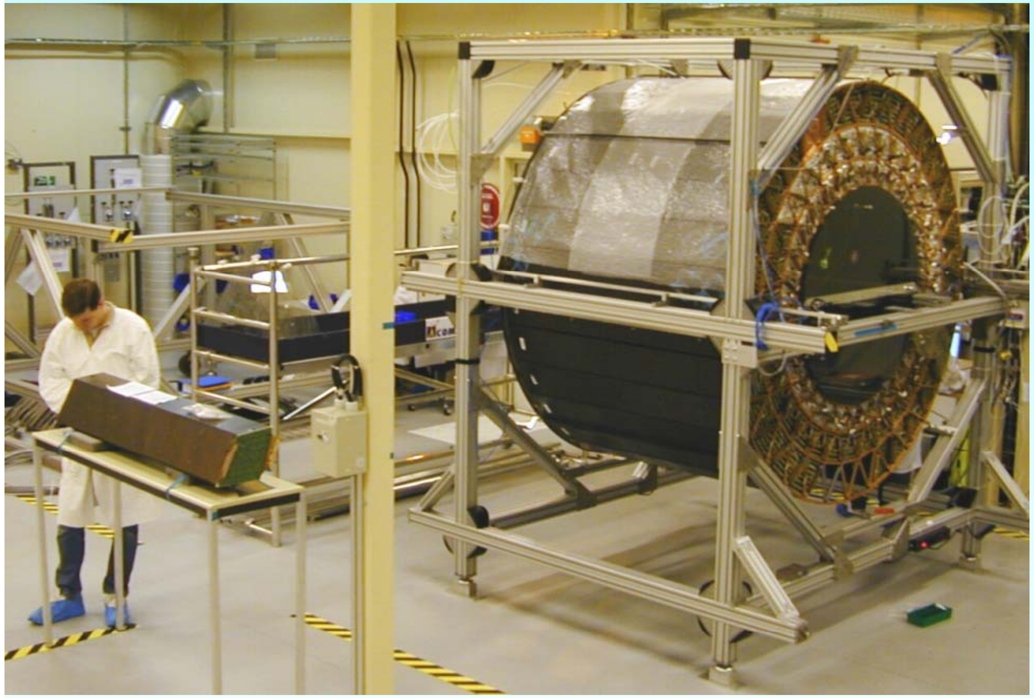
Installation of the detector.

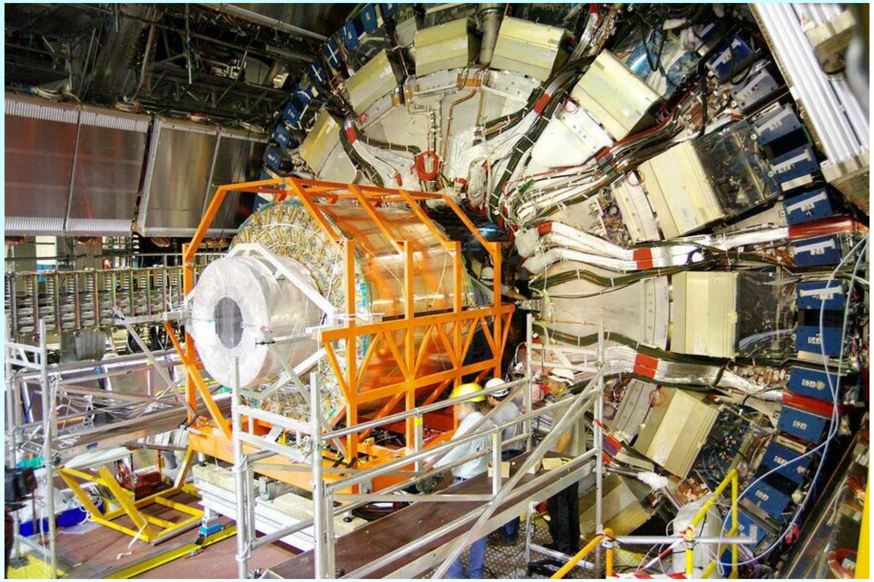
How does it work ?





Contributions by Lund: The Transition Radiation Tracker

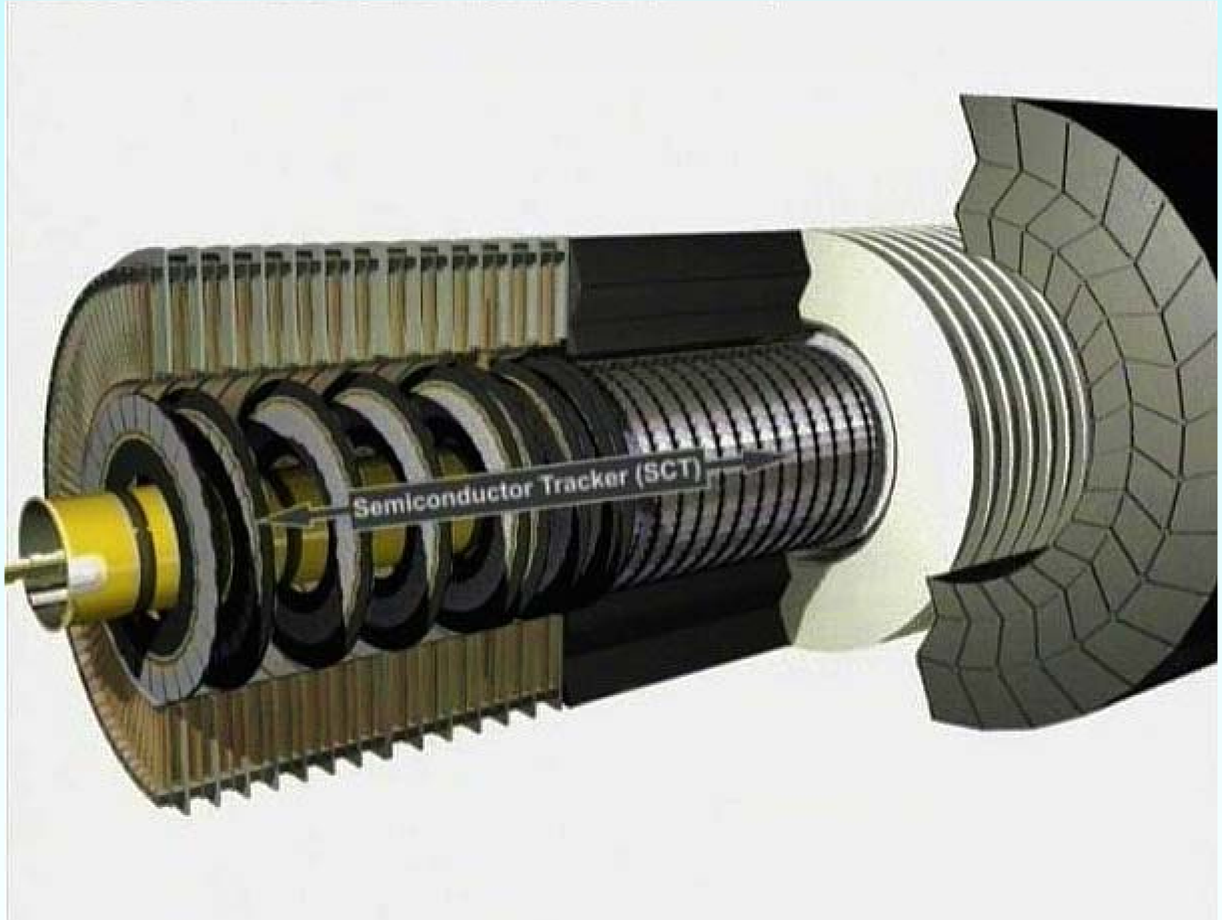


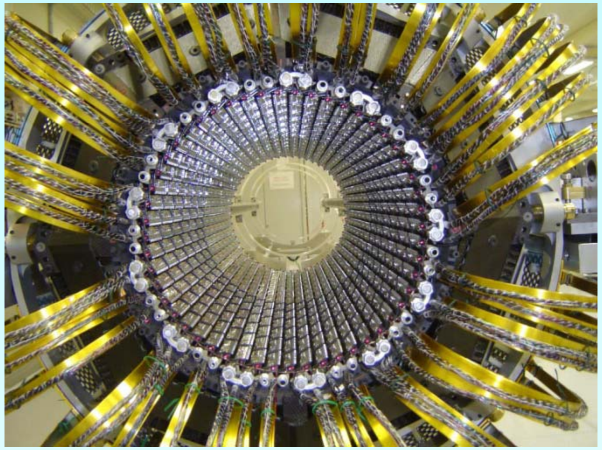


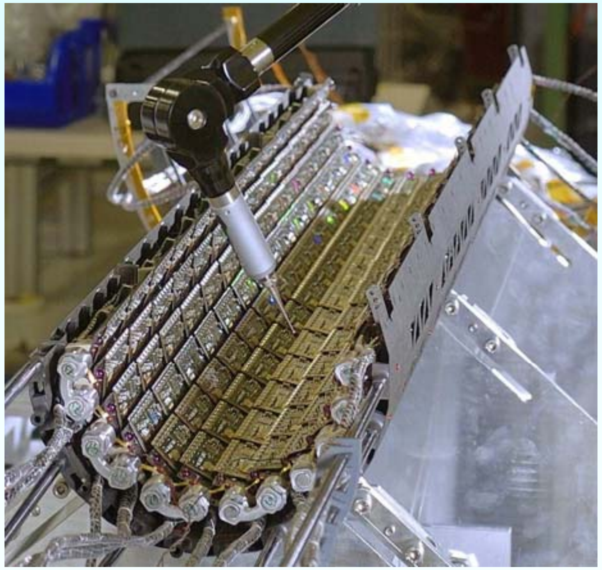
The TRT detector consists of thousands of gas-filled straws with a thin wire in the center. Particles that traverse the straws, produce signals that can be used to reconstruct the particles tracks.

Electrons produce a special type of radiation in the detector that is called transition radiation and that can be used to identify the electrons.

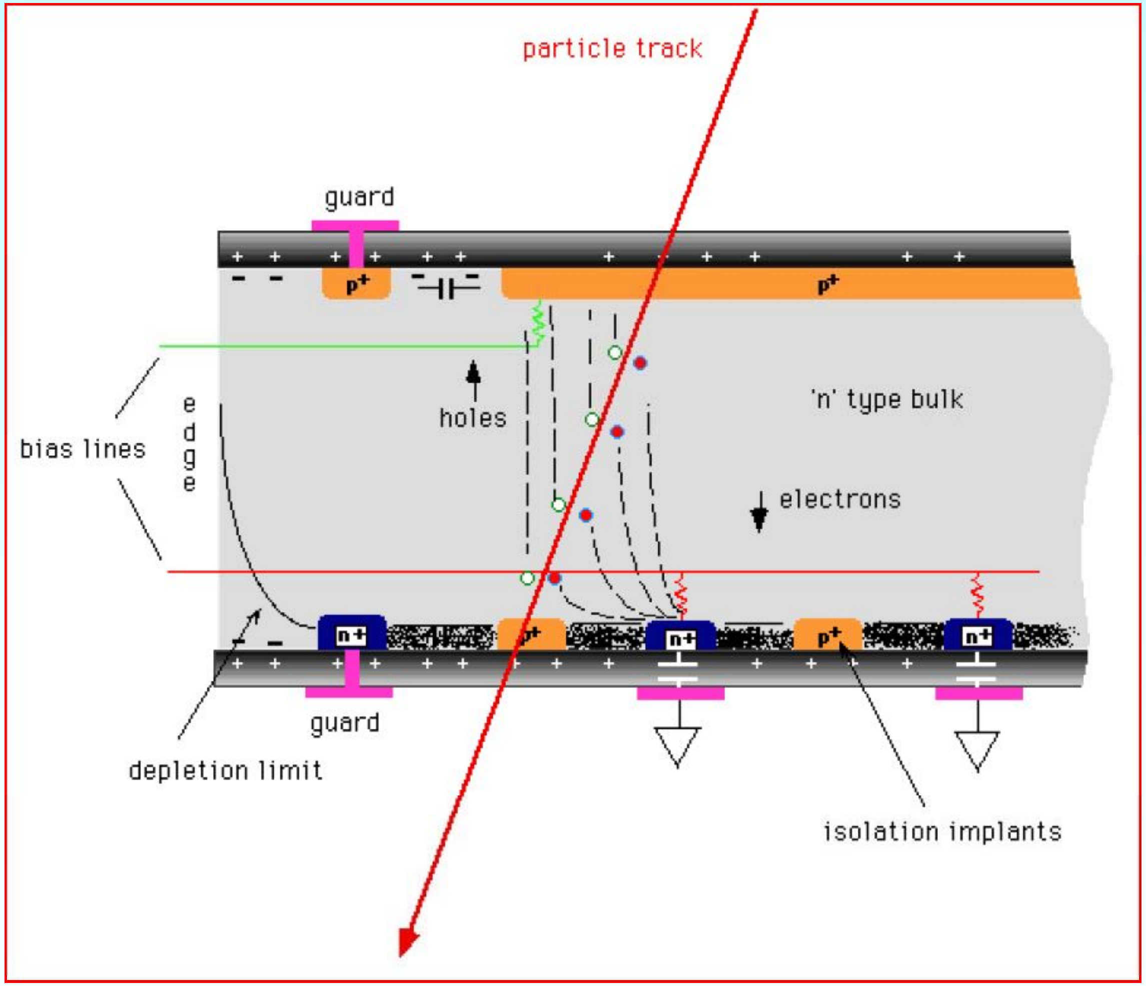
Silicon detectors in ATLAS

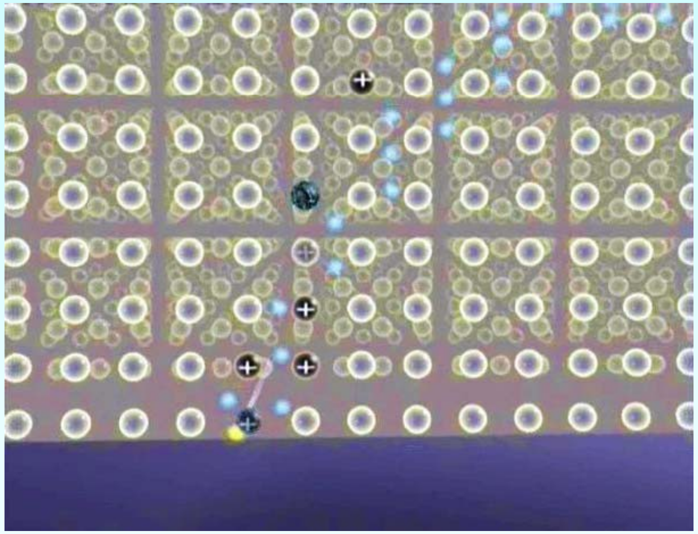




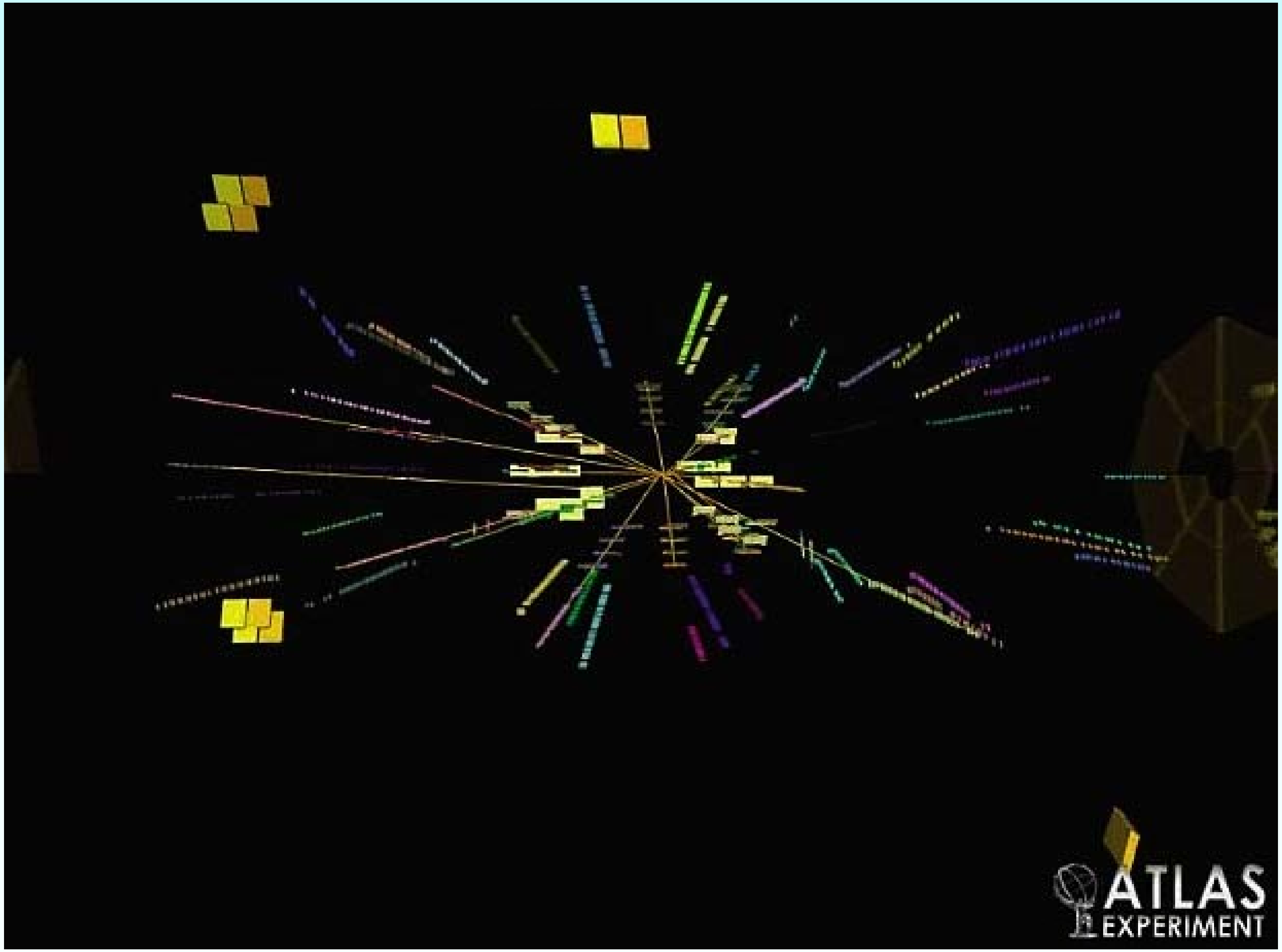


Silicon detectors: How do they work ?



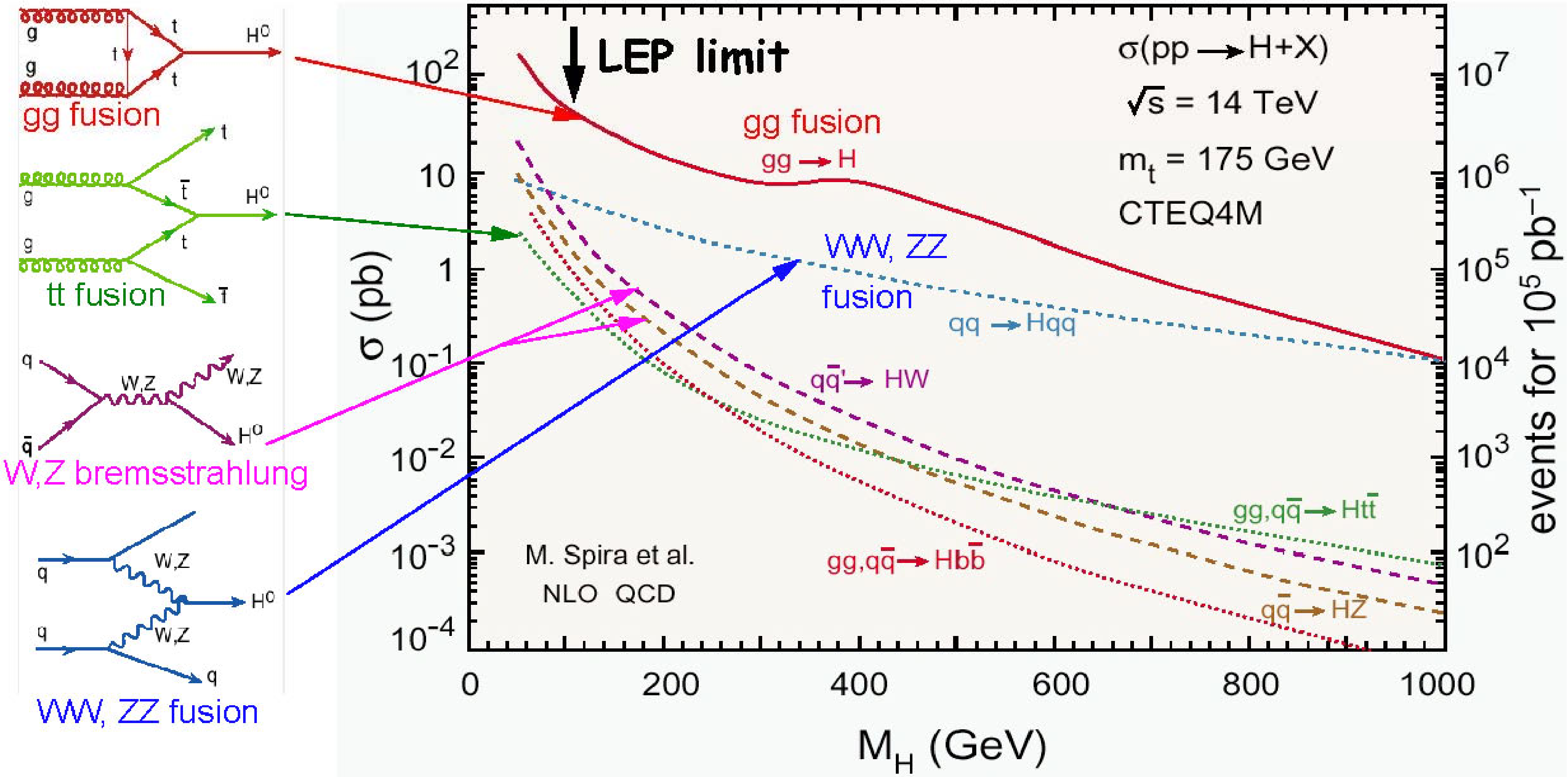


One of the first collision in ATLAS



Physics studies: Search for the Higgs particle

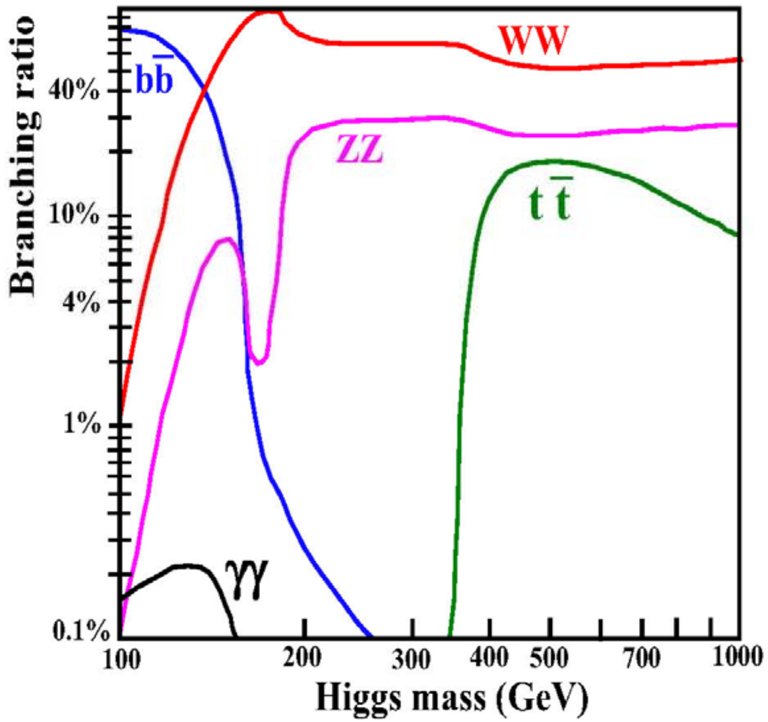
➡ Higgs boson production



Physics studies: Search for the Higgs particle

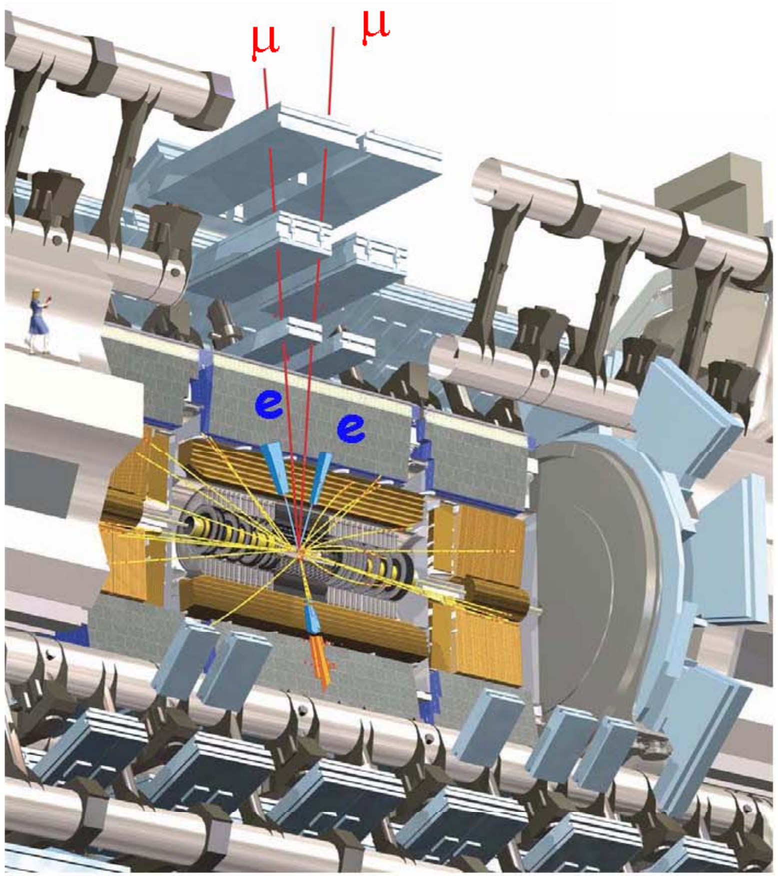
➡ Higgs boson decay

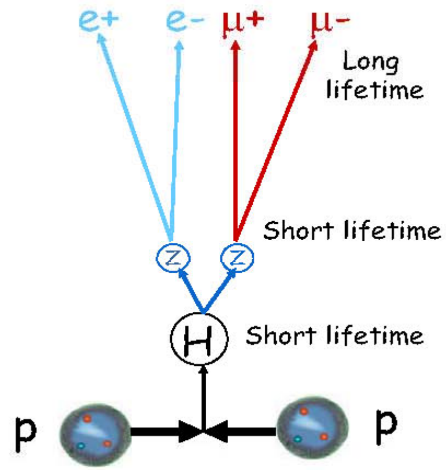
- There is 10^9-10^{10} inelastic interactions for every Higgs boson that is produced. At low mass most decay to $b\bar{b}$ and at high mass most decay to WW and ZZ.
- The background is huge and one has to select decays that are are visible above the background ($b\bar{b}$ are for example hopeless).
- The cleanest process is if the Higgs has a large enough mass so that it can decay to two Z^0 that then decay to leptons.

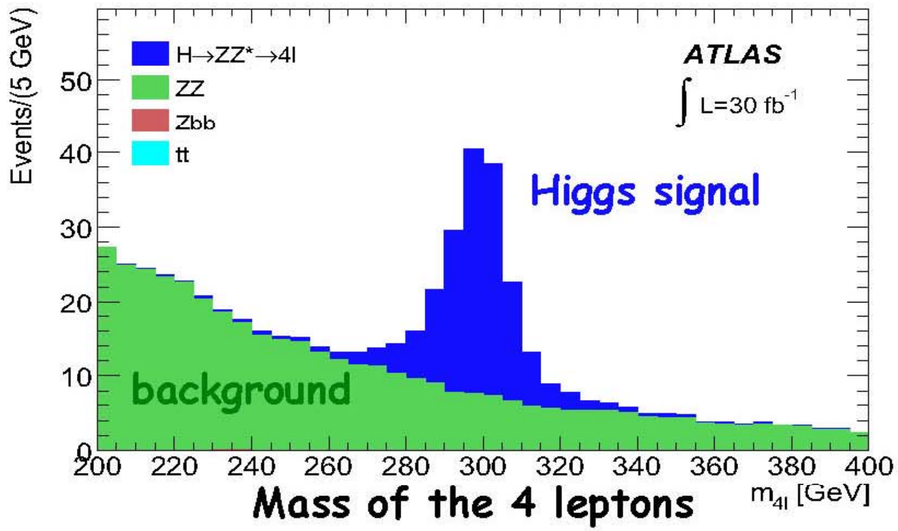


Physics studies: Search for the Higgs particle

- Computer simulations of collisions in which Higgs bosons are detected by finding **four leptons** show a very clear signal if the Higgs mass is 300 GeV.

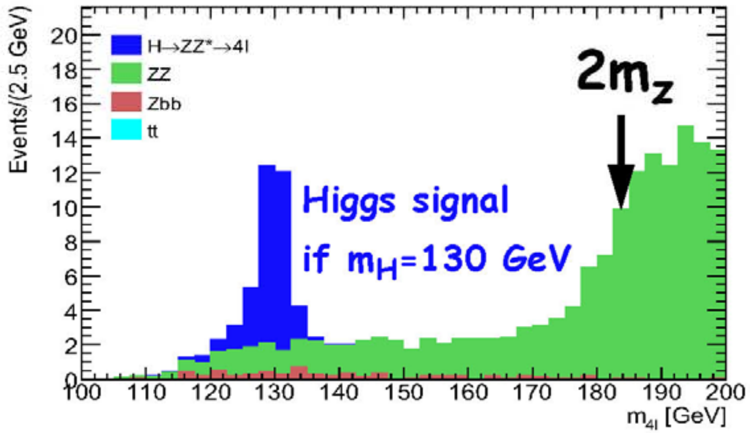






Physics studies: Search for the Higgs particle

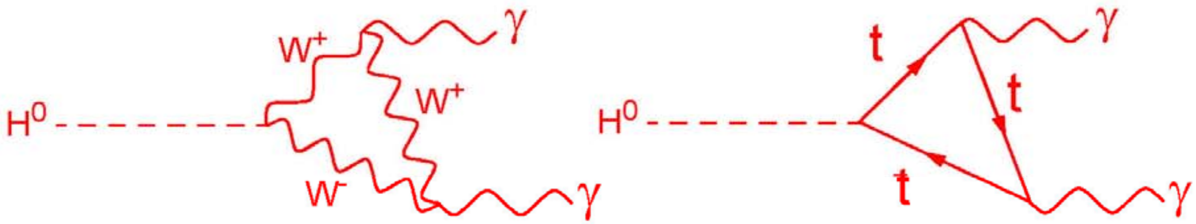
- It is possible to use the **4-lepton** channel also if $m_H < 2m_Z$, but then the Higgs decays to one real and one virtual Z^0.



- At a Higgs mass close to the LEP limit, the branching ratio for $H^0 \rightarrow ZZ \rightarrow$ leptons is very small and one is also considering using $H^0 \rightarrow \gamma\gamma$ but this process also has a minute branching ratio:

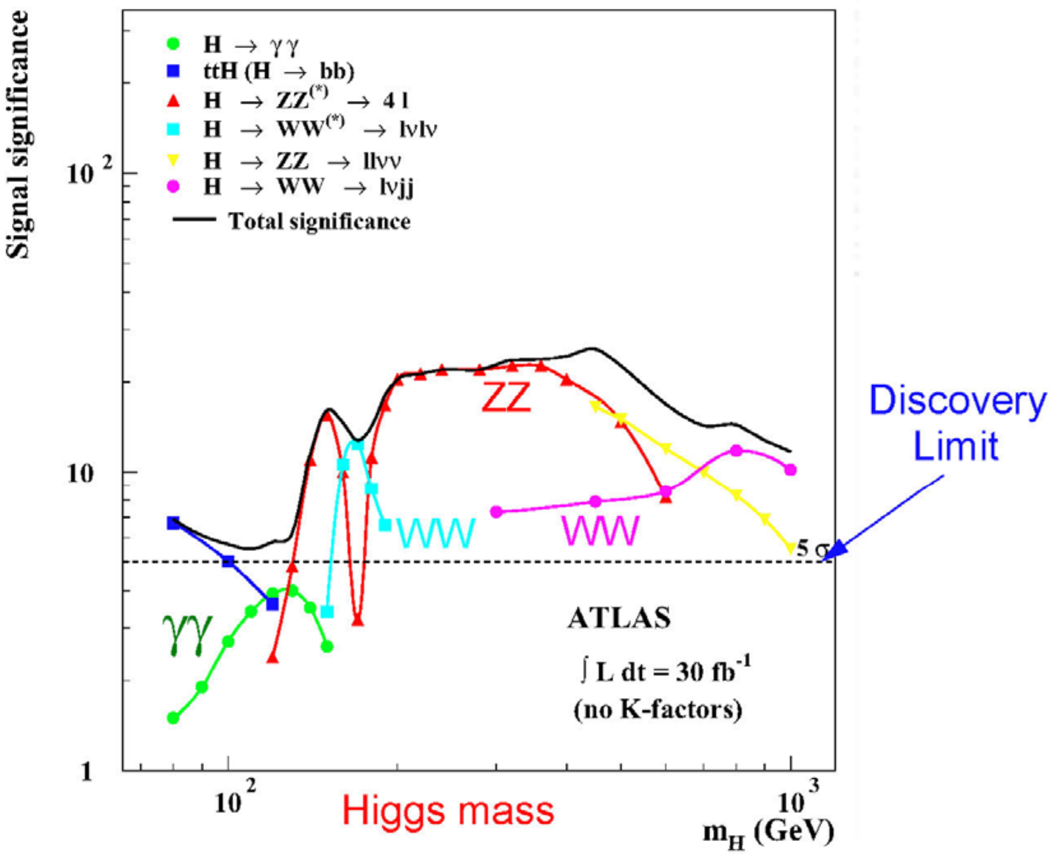
$$Br = 1\text{-}2 \times 10^{-3}$$

- Production diagrams:



Physics studies: Search for the Higgs particle

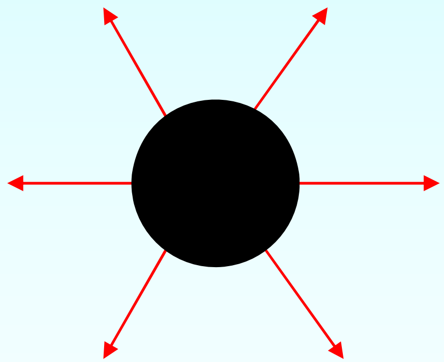
- One can estimate the **signal significance** for different search channels:

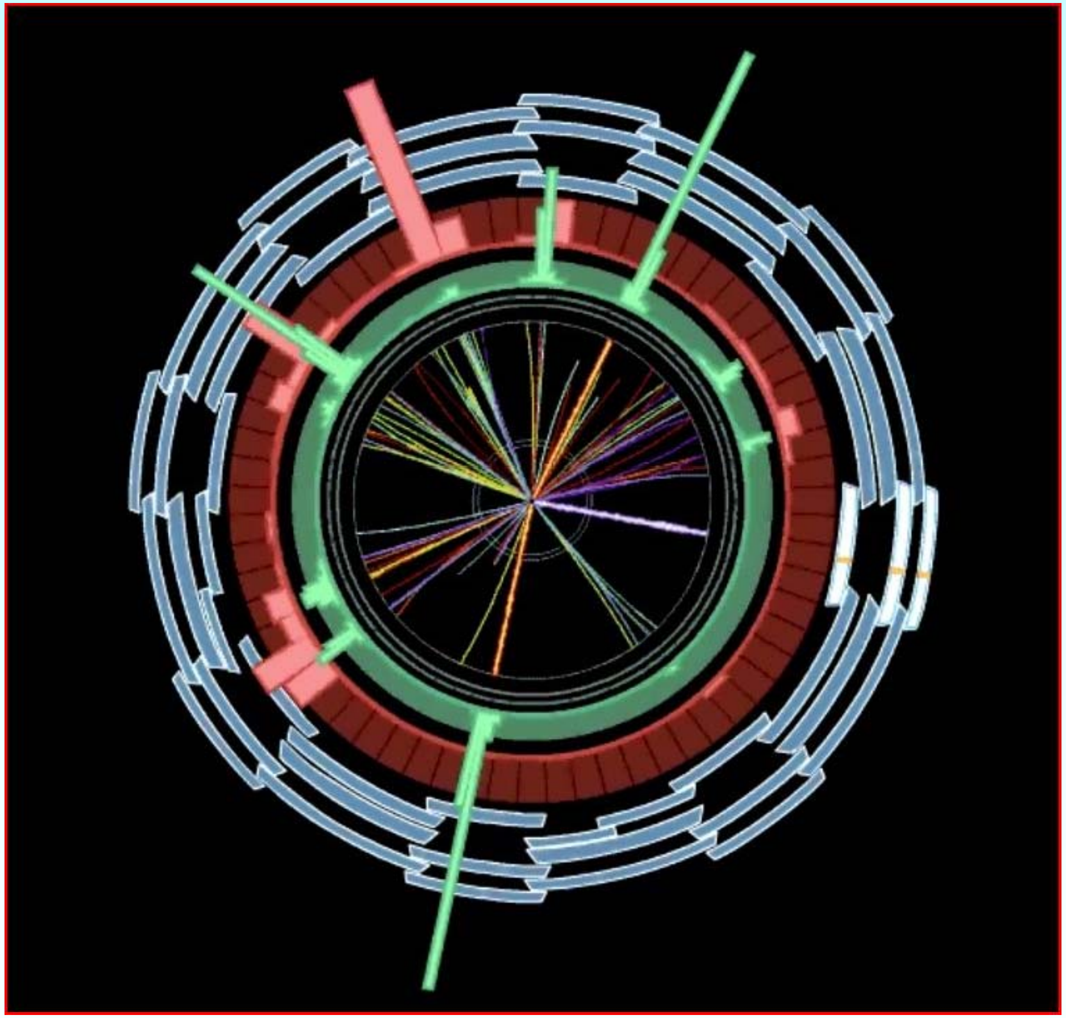


Black Hole

Signature:

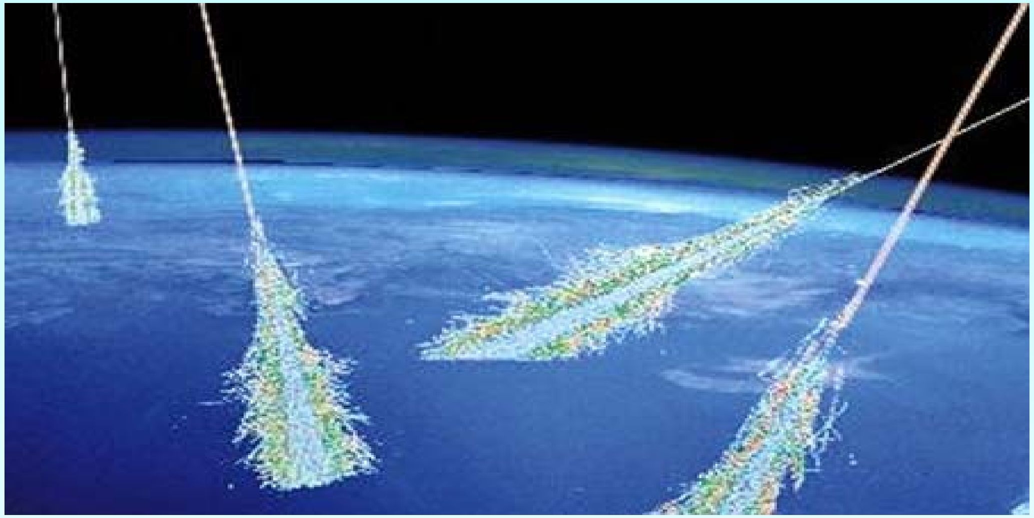
Many particles and particles with a high energy and with a large angle with respect to the proton direction.

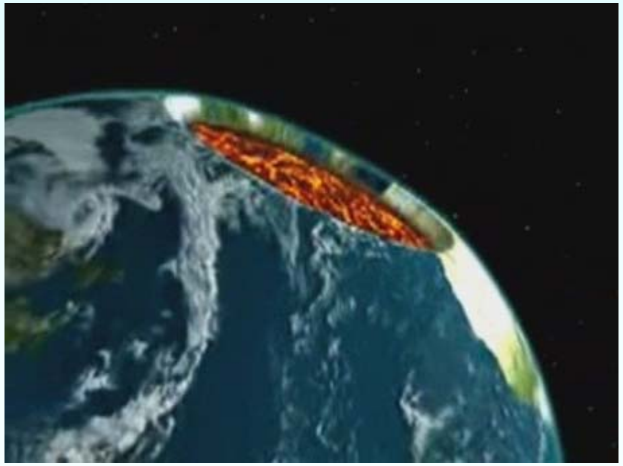




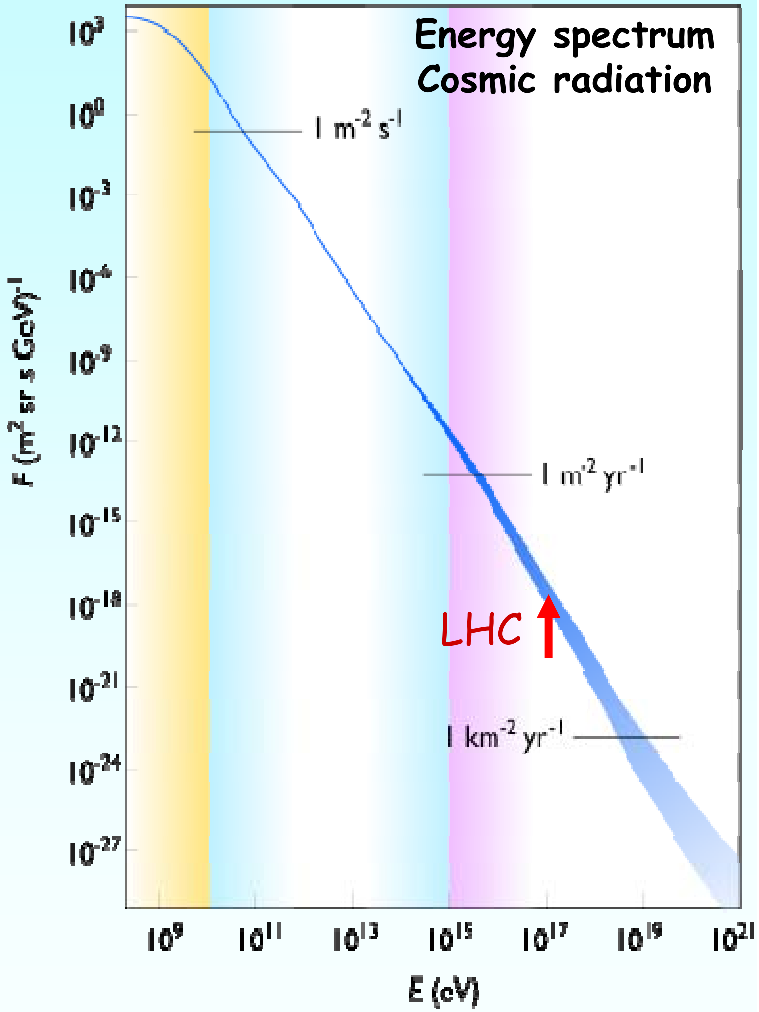
The holes will disappear after 10^{-26}s according to the theory (if they are produced).

Black holes = The end of the world ?





There are protons in the cosmic radiations with a higher energy than what can be produced by LHC. The number of collisions at LHC during one year corresponds to about 1000-10000 years of collisions in the atmosphere.



What other problems remain to be solved ?

Dark Matter

- The rotational speed of stars in some galaxies are too high to be explained by the known matter.
- This unknown matter could consist of new particles that can be discovered in ATLAS.

Dark Energy

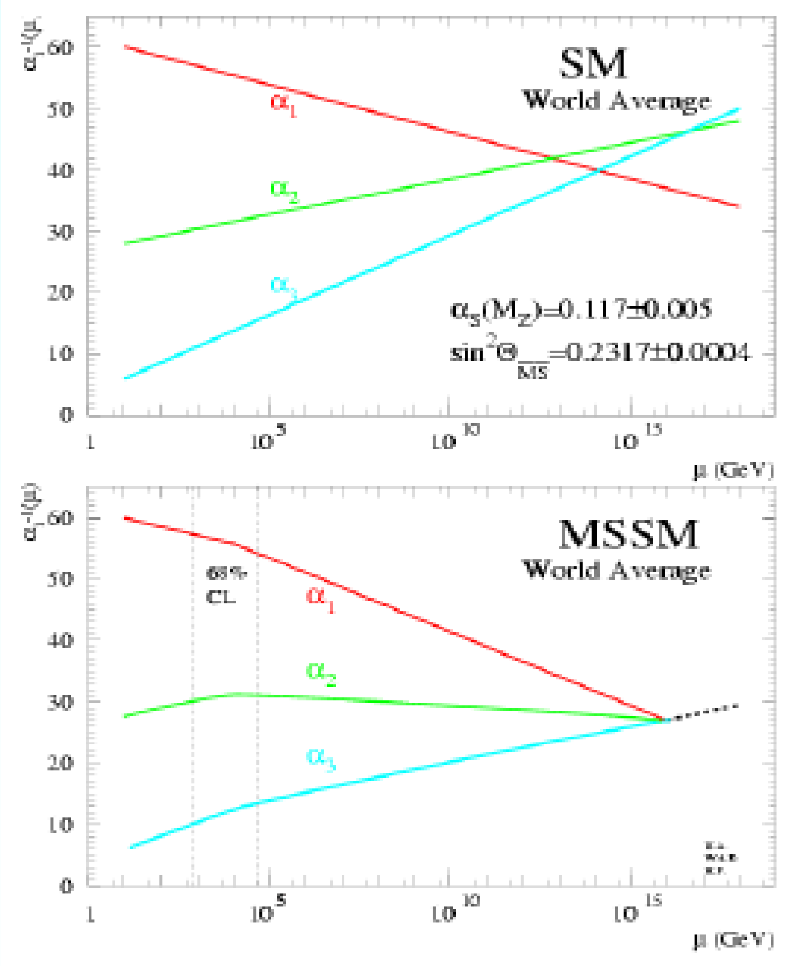
The universe is not expanding with a constant speed. It seems that there is an unknown repulsive force between the galaxies. This force is thought to be caused by a mysterious dark energy.

What other problems remain to be solved ?

Unification of the forces

Motivated by theory:

- ✓ The strength of a force depends on the energy in the interaction in which it is being studied.
- ✓ If the strength of the different forces is the same at some very high energy, then this could be due to all forces being parts of the same unified force.
- ✓ A similar phenomena is known from the theory that describes both the weak and the electromagnetic force.
- ✓ The known forces looks at the moment to be almost unified at some large energy.
- ✓ **The confirmation could be given by new particles discovered in ATLAS.**



What problems remain to be solved ?

- What is dark energy ?
- What is dark matter?
- What happened with the anti-matter ?
- How does particles obtain their mass ? (Higgs ?)
- Why is the gravitation so weak ? (Extra dimensions ? Black holes ?)
- Are the different forces the same thing ?

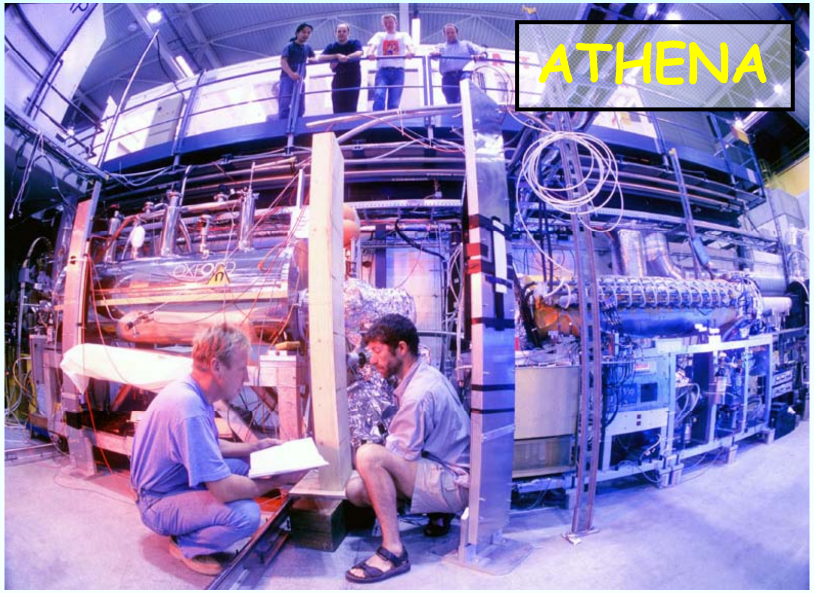
LHC can perhaps give the answer

Antimatter at CERN

- (1928) When Dirac constructed his relativistic quantum mechanical equation that described spin ½ particles, it had solutions for electrons with both a positive and negative energy.
- Conclusion: All particles have an anti-particle with opposite charge.

Paul Dirac

- (1932) The positron was observed experimentally in cosmic rays for the first time.
- Antiparticles are created routinely in high energy physics experiments. Beams of antiparticles e.g. positrons and antiprotons have been used in accelerators at CERN.
- (1995) CERN produces anti-hydrogen i.e. anti-matter.



Anti-hydrogen spectroscopy at CERN

How to use anti-particles

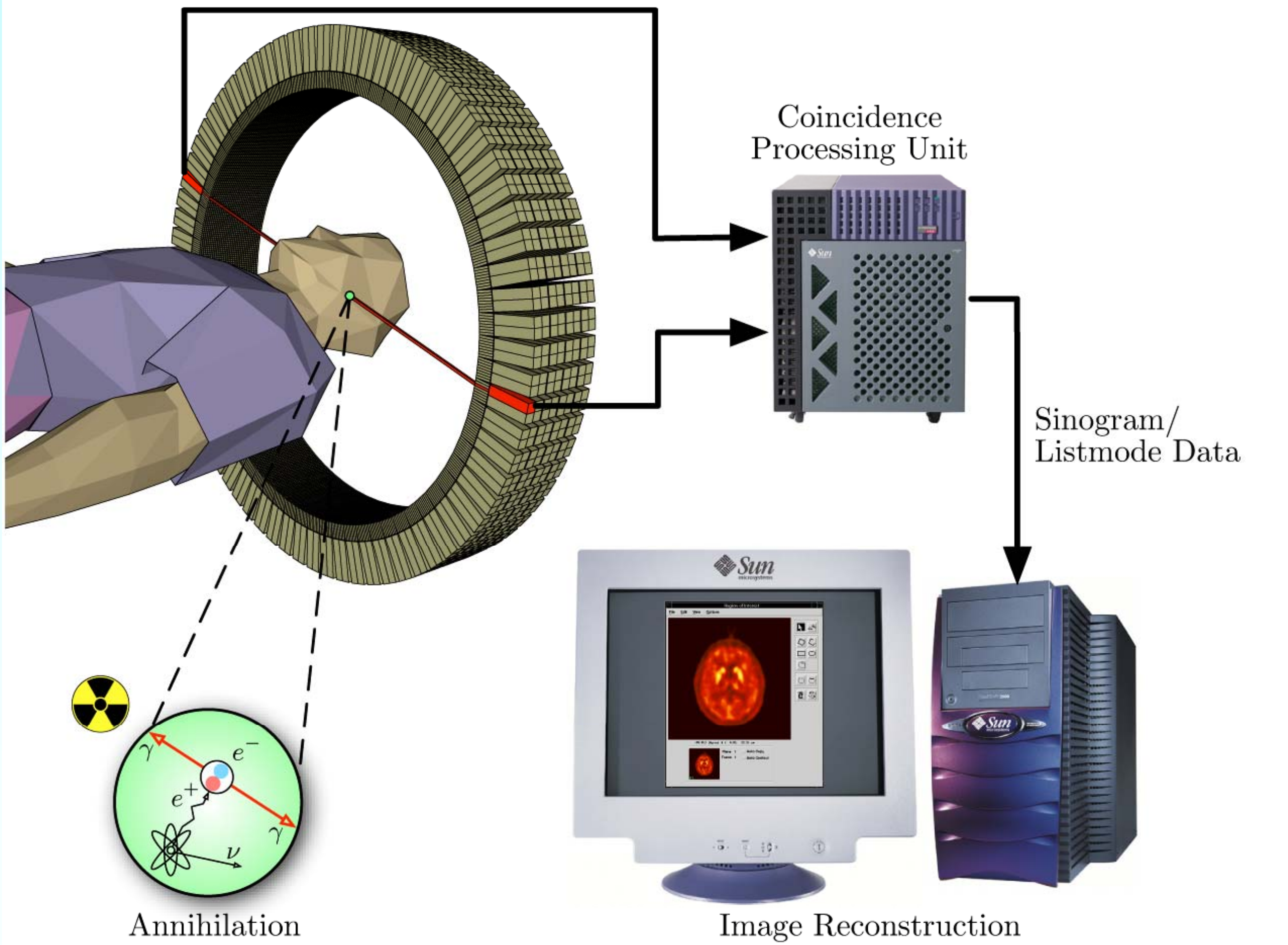
Positron Emission Tomography - PET

A radioactive isotope is injected.

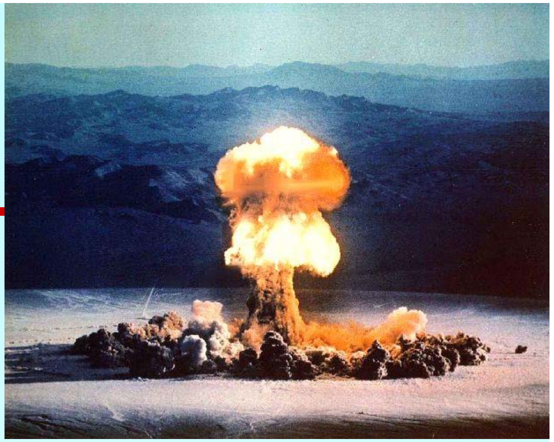
The radioisotope decays to positrons.

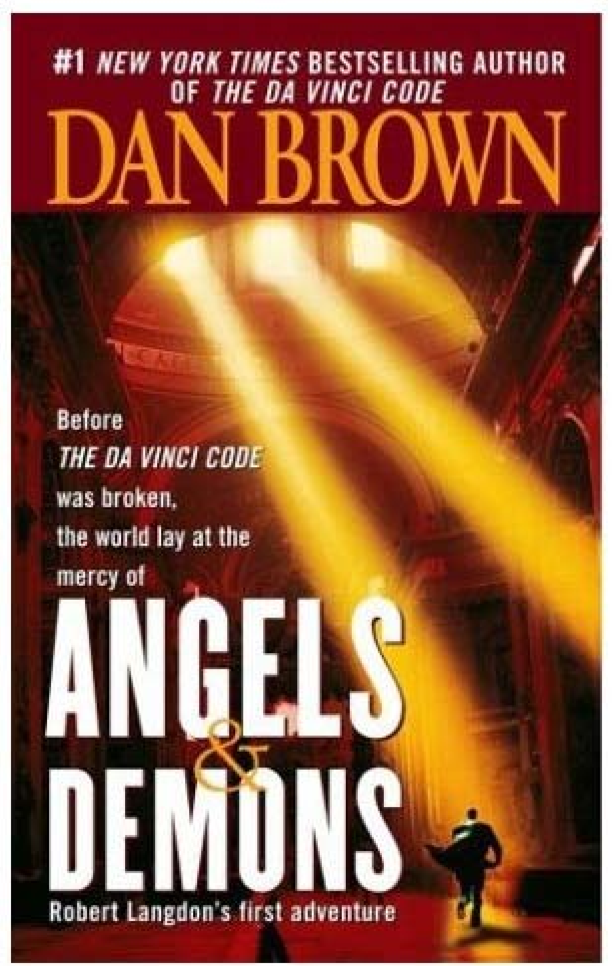
The positrons encounters electrons in the body and the pair then annihilates to a pair of photons.

The photons are detected.



Anti-matter for a bomb ?

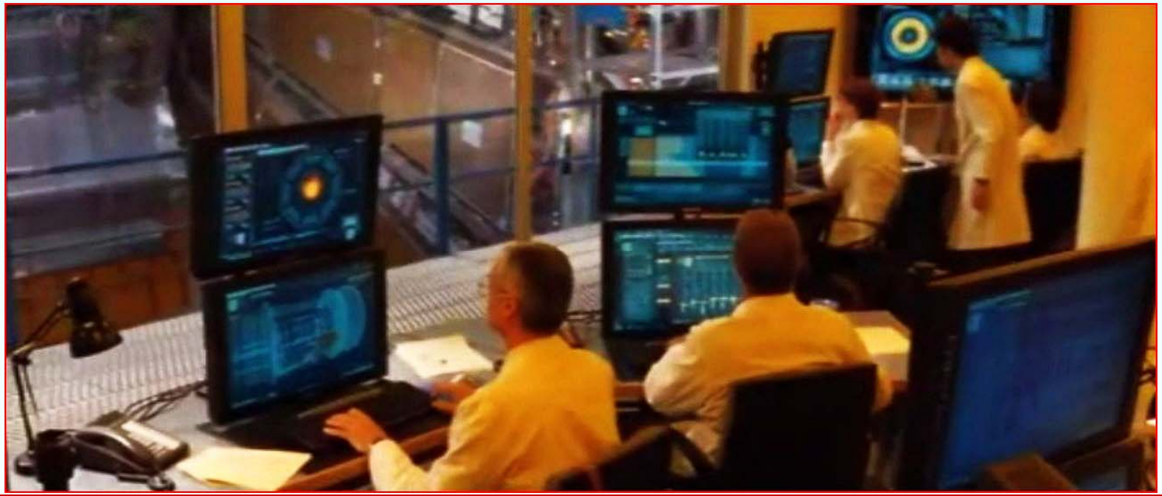




- One gram anti-matter contains energy equivalent to a Hiroshima bomb (20 kton TNT).
- However, it is not possible to store anti-matter and so the research will not lead to new weapons.

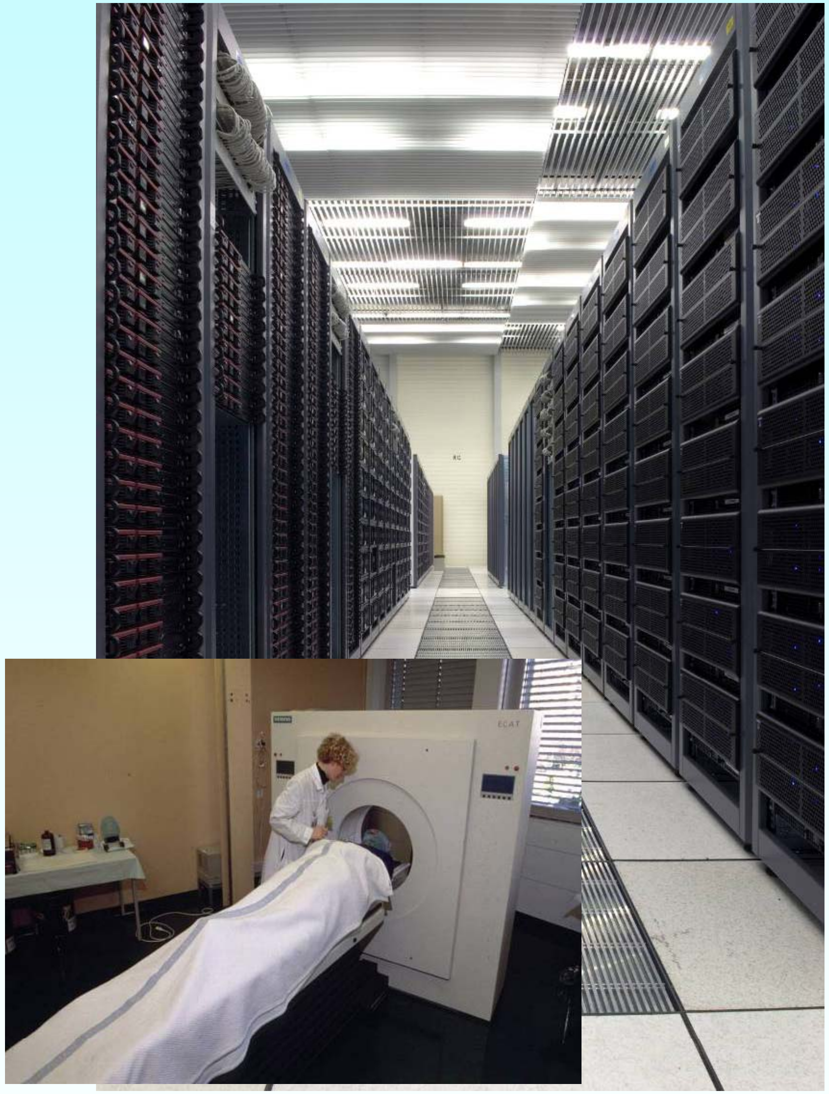
Hollywood at CERN

So do not believe everything you see at the movies………



No bombs... but one gets ....

- Computer technology
  - The World Wide Web
  - The Computer Grid
- Detector technology
  - Radiation treatments
  - Medical instrumentation
- Nuclear waste disposal
  - Transmutation
- Superconducting magnets
- Electronics
- ......



The World Wide Web

The most important spin-off from particle physics is the World Wide Web. It was invented at CERN as a way for physicists to share information on computers in different countries.

The worlds first web-server.

Tim Berners-Lee, the inventor of the World Wide Web.

The next large computer project is the grid.

The Worldwide LHC Computing Grid has been developed in order for physicist around the world to have sufficient computer power and in order for them to get hold of the 15 million Gigabytes of data that the LHC will produce each year.