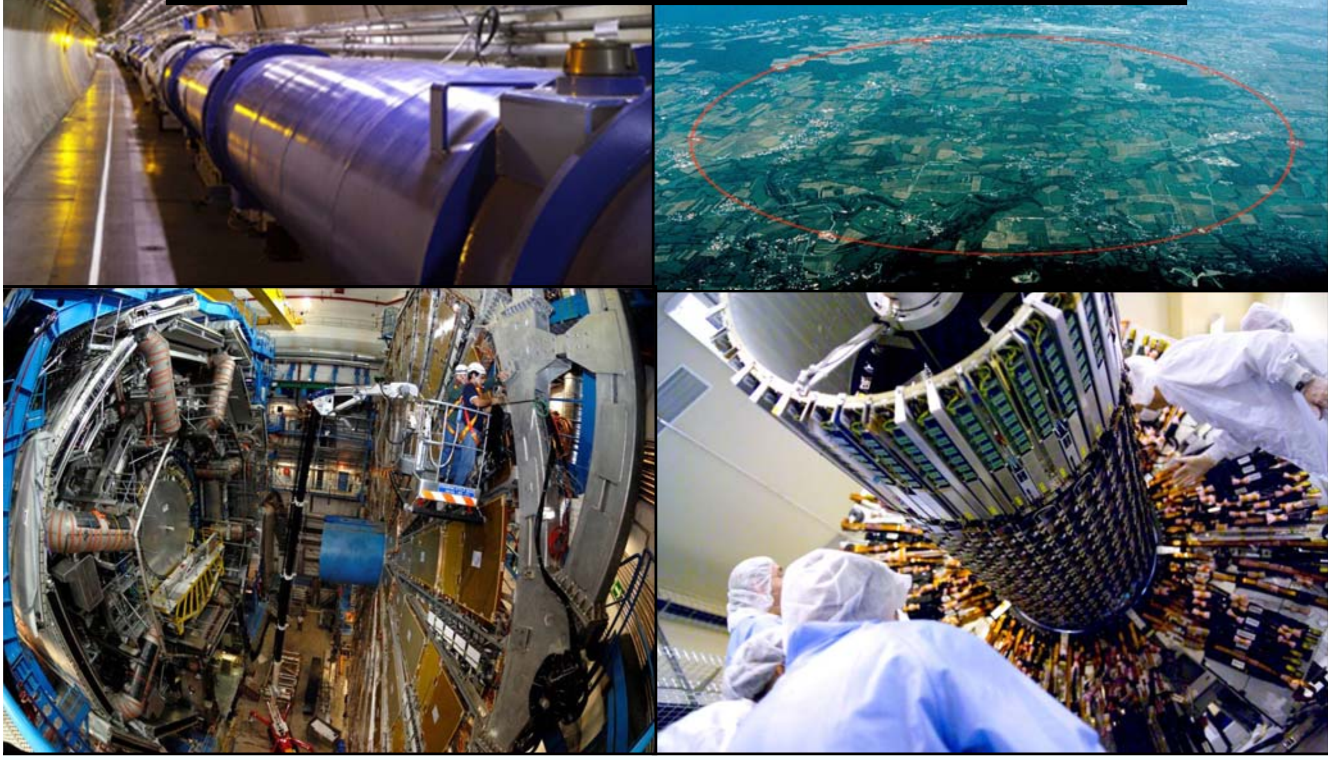
LHC & ATLAS

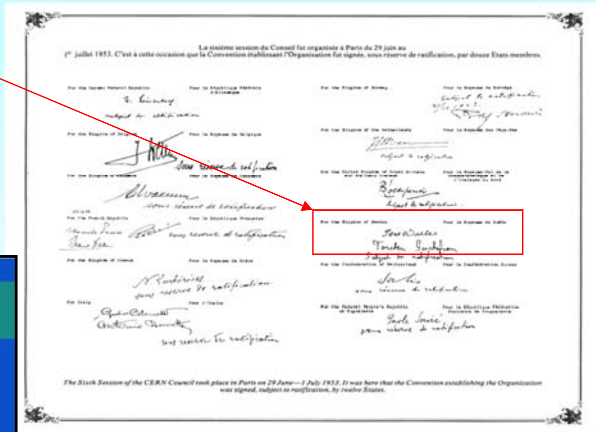
The largest particle physics experiment in the world



CERN – A laboratory for the world

Torsten Gustavson

CERN was founded in 1954



- 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

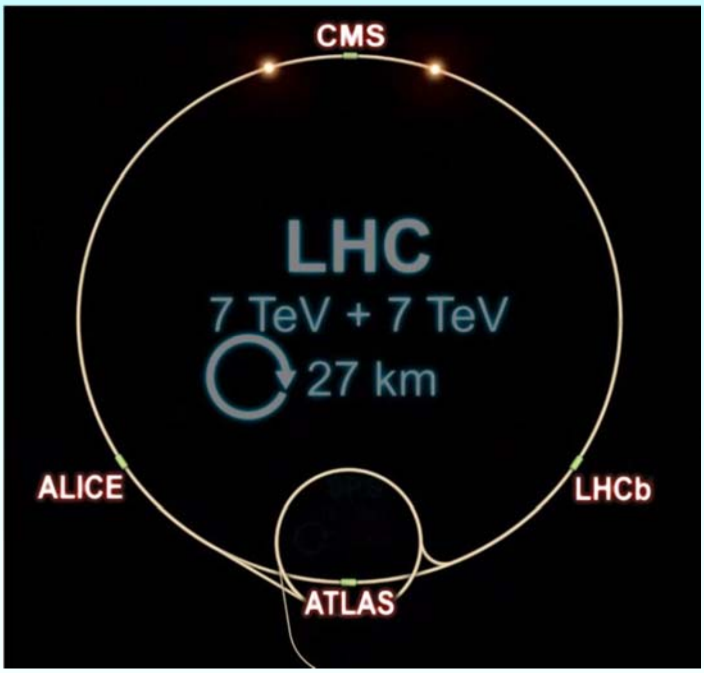
The Large Hadron Collider (LHC)

- 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).

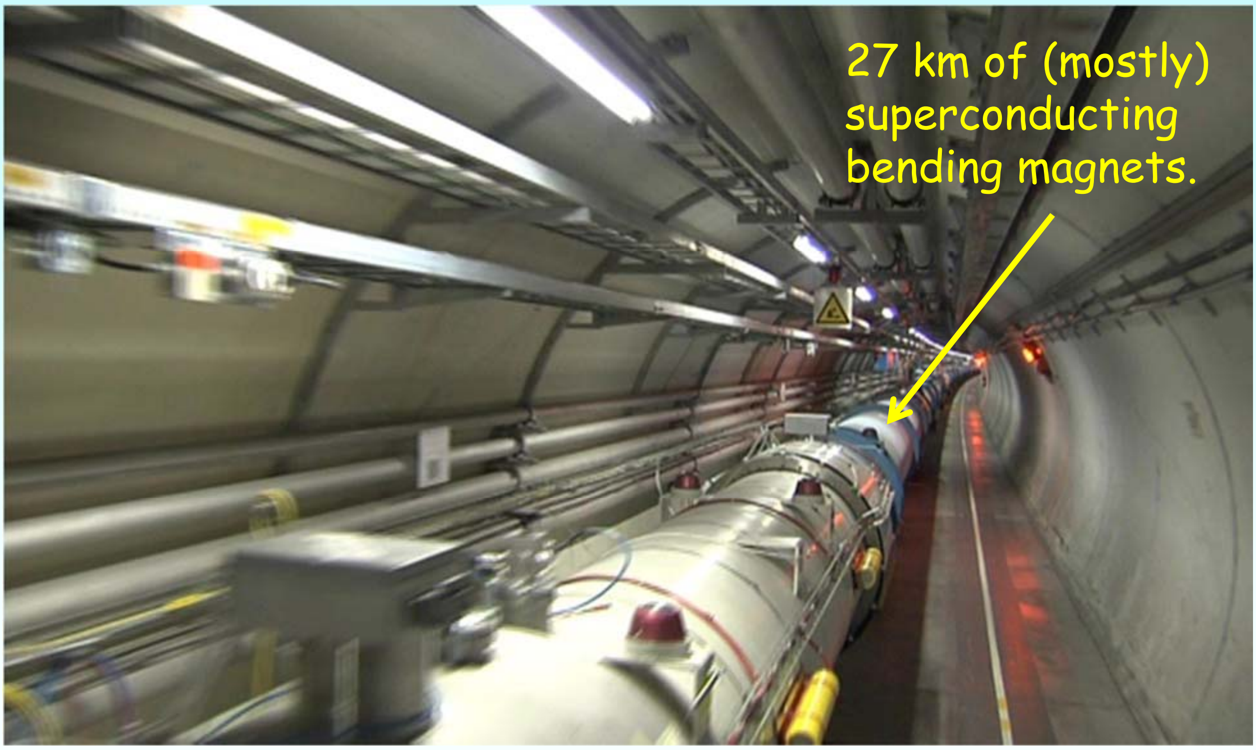
The accelerator complex at CERN

The protons are first accelerated in a linear accelerator. They are then accelerated in the booster to 1.4 GeV, in the PS to 25 GeV, in the SPS synchrotron to 450 GeV and finally injected into the 27 km long LHC tunnel.

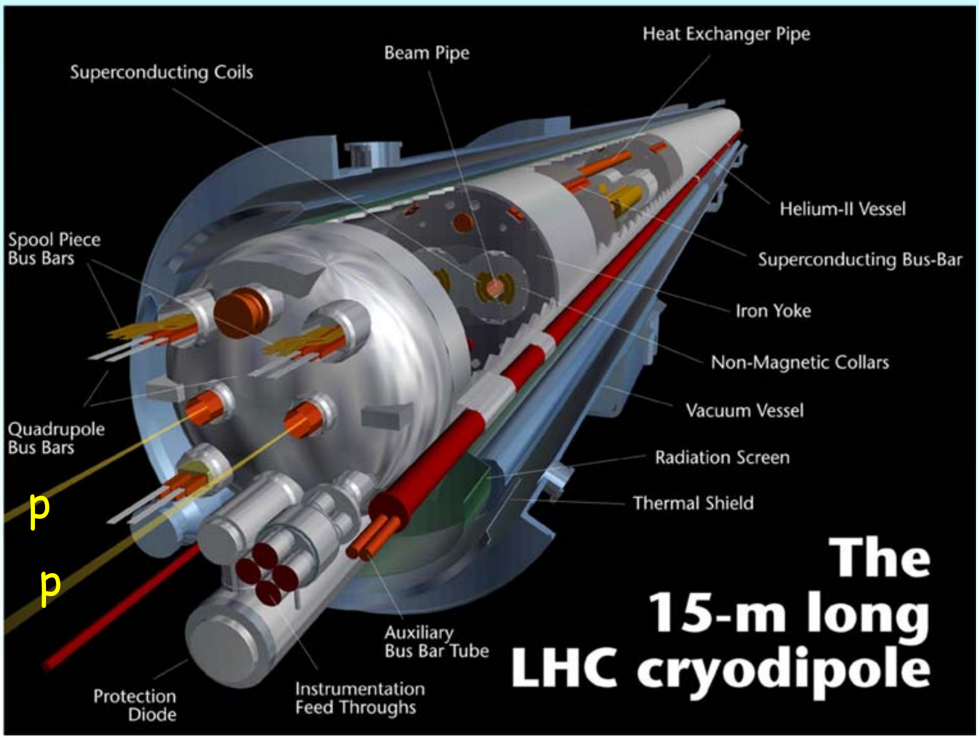


The protons are travelling in 2808 bunches with 10^{11} protons each.

In the LHC accelerator tunnel



The magnets that bend the proton beams.



1232 dipole magnets

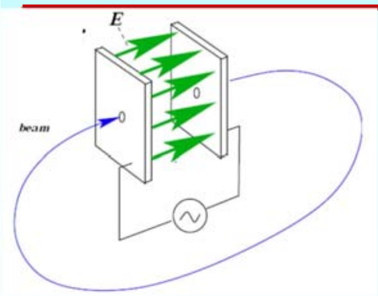
15 m long
35 ton heavy

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

The tunnel for the LHC accelerator had previously been built for the LEP accelerator.

The dipole magnets were produced by European industry and then shipped to CERN where they were tested.

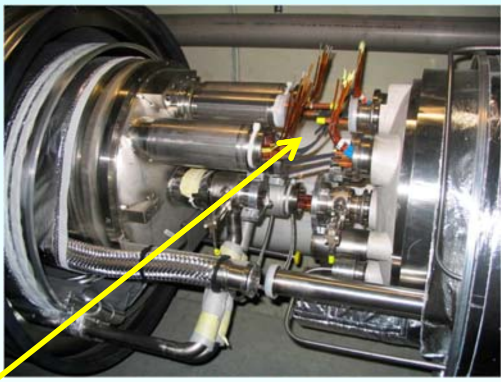
It was a major work to transport them around the 27km long tunnel and to install them with high precision.

10 September 2008 – Champagne !

On the 10th of September 2008 it was for the first time possible to make a 450 GeV proton beam go around the whole of the LHC.

19 September 2008 – Hangover !

The news about an accident at the LHC reached the press before many physicists.



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

Three years of successful running!

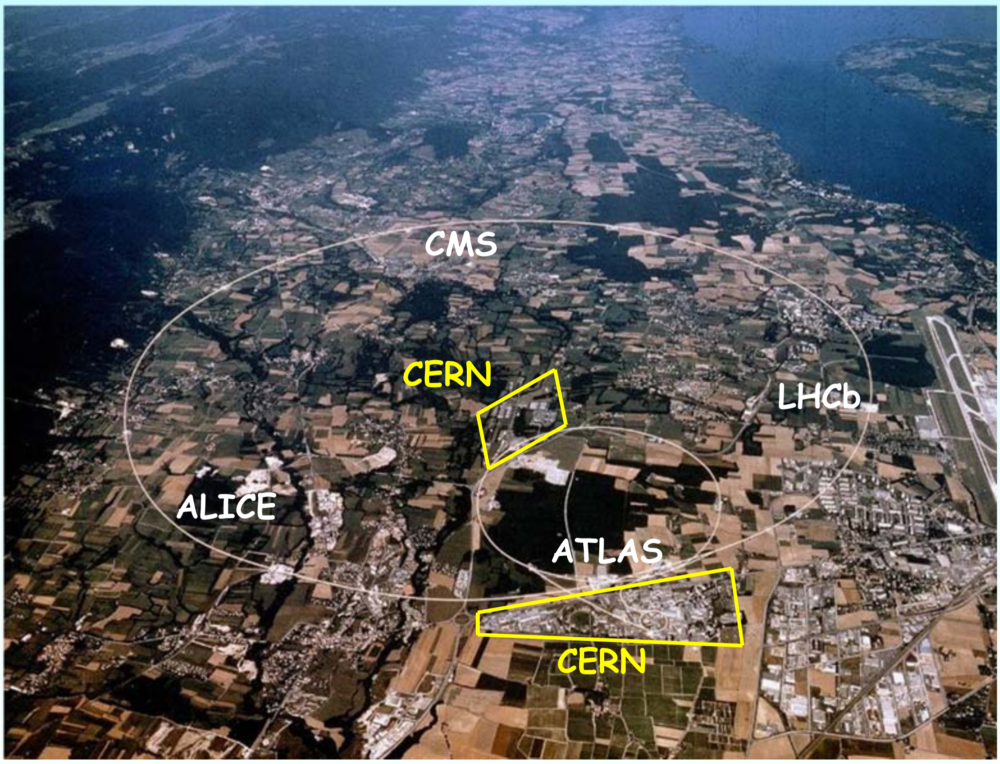
First collisions in ATLAS on the 23rd of November 2009 (after a one-year repair).

Collision rate

Collision energy

Year	Energy	Luminosity
	(TeV)	($10^{34}cm^{-2}s^{-1}$)
2009	2.4	0.00000003
2010	7	0.02
2011	7	0.37
2012	8	0.7
2013	shutdown	
2014	shutdown	
2015	14	1

Experiments at the LHC



Experiments

ATLAS:
Proton-proton collisions

CMS:
Proton-proton collisions

ALICE:
Atom-atom collisions

LHCb:
Proton-proton collisions giving b quarks

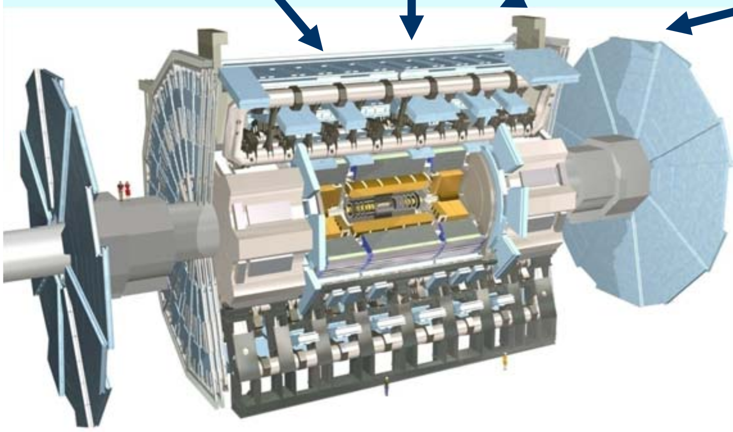
Swedish research groups

Uppsala Universitet

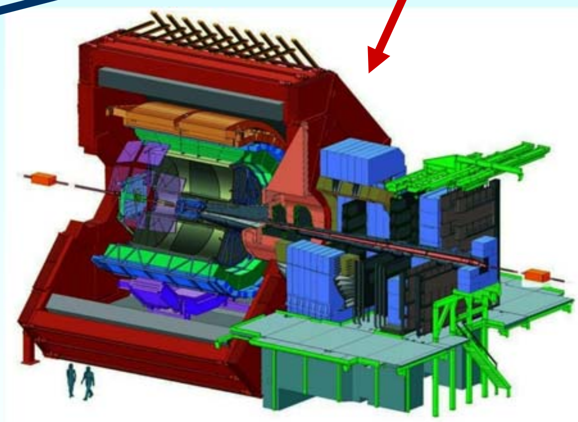
Kungl Tekniska Högskolan

Stockholms universitet

Lunds universitet

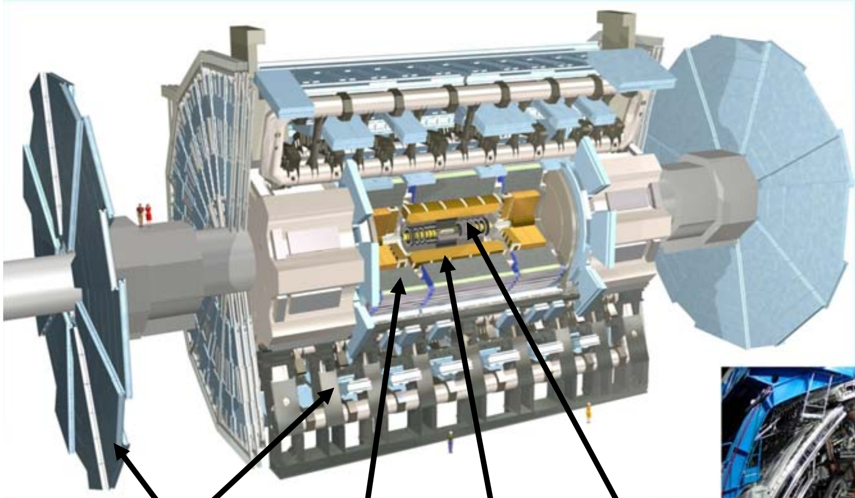


The ATLAS experiment



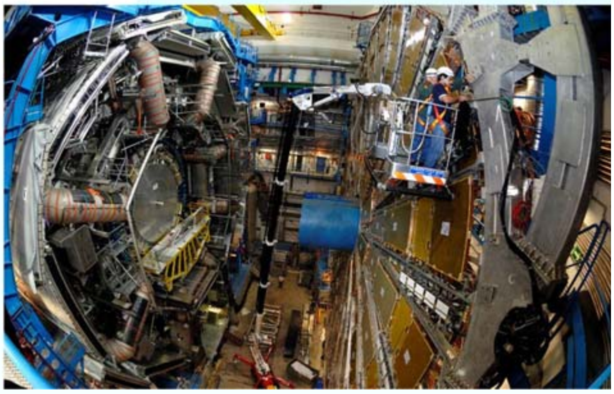
The ALICE experiment

The ATLAS experiment



The ATLAS Experiment

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



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

ATLAS in the movies

The film Angels and Demons contains a few minutes of footage from ATLAS and the LHC.

The real ATLAS control room was not impressive enough, so a new one was created.

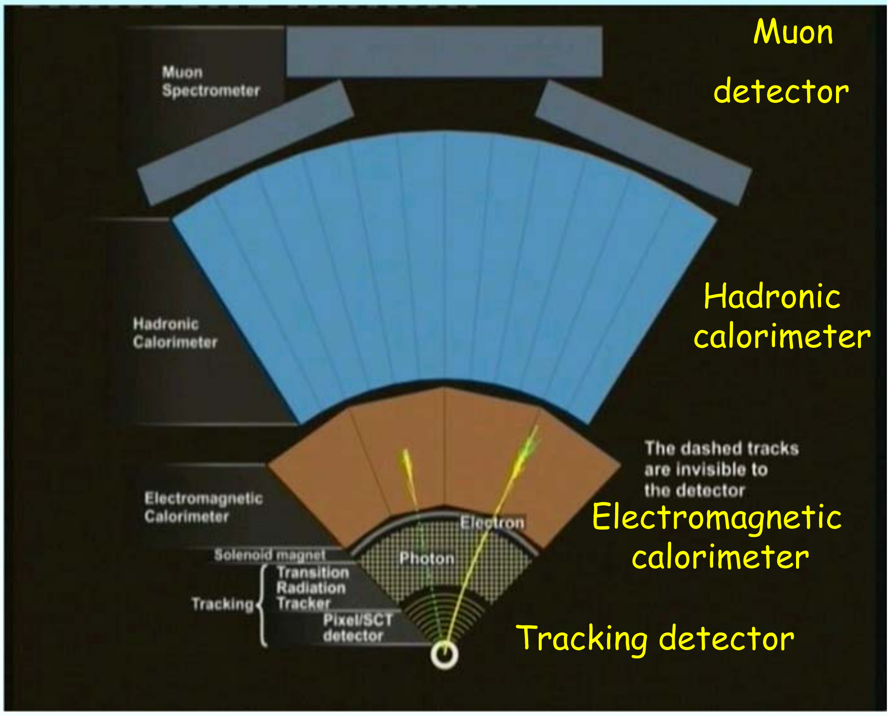
Detection of photons and electrons

Electron:

Track in tracker &
Shower in electro-
magnetic calorimeter

Photon:

No track in tracker &
Shower in electro-
magnetic calorimeter



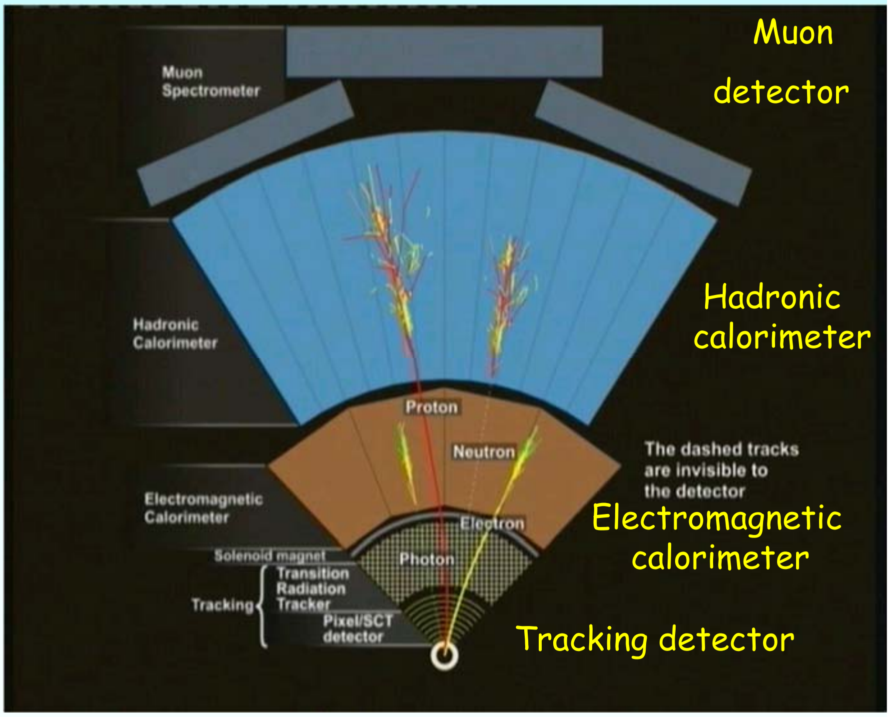
Detection of protons and neutrons

Proton:

Track in tracker &
Shower in hadronic
calorimeter

Neutron:

No track in tracker &
Shower in hadronic
calorimeter



Detection of muons and neutrinos

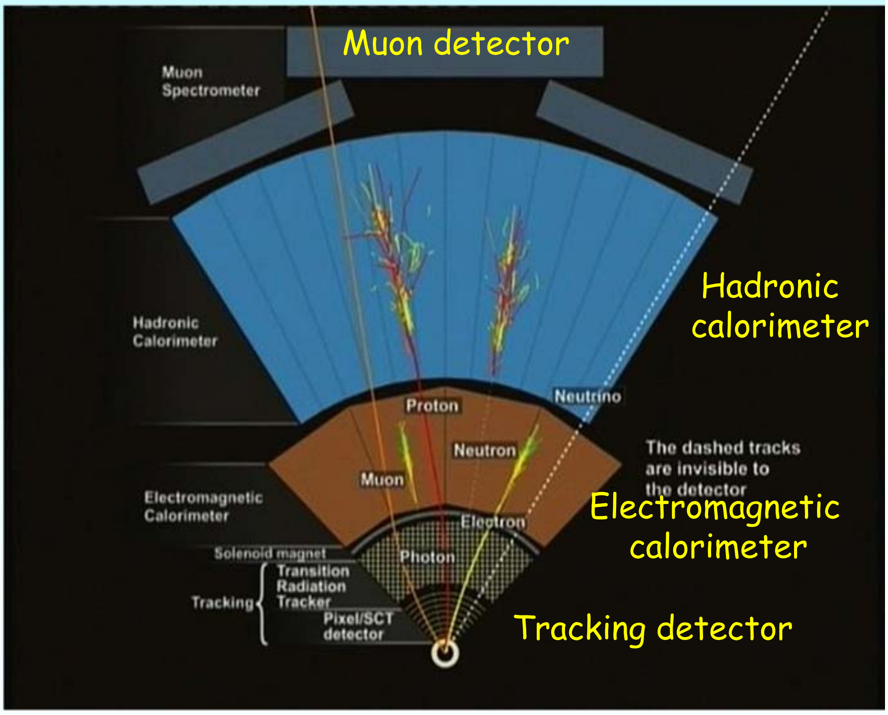
Muon:

Track in tracker &
Track in muon detector

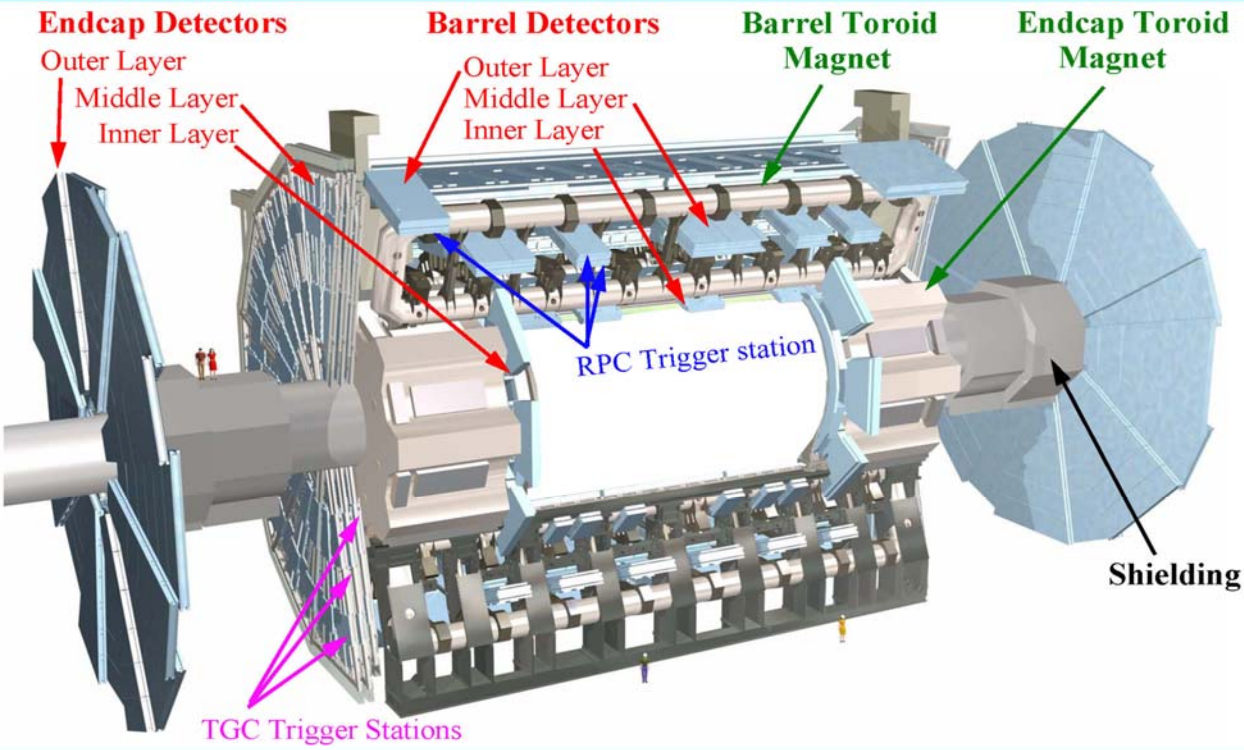
Neutrino:

No signals anywhere

Shows up as missing energy and missing momentum



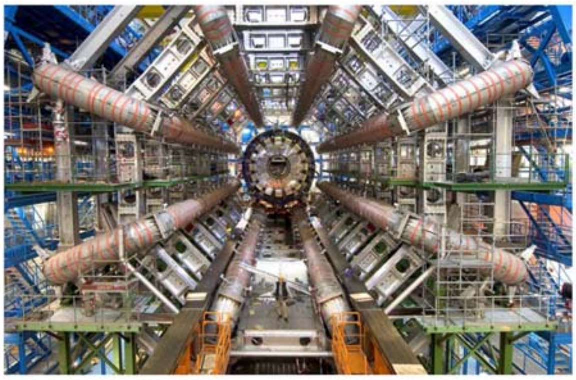
ATLAS: the muon detector

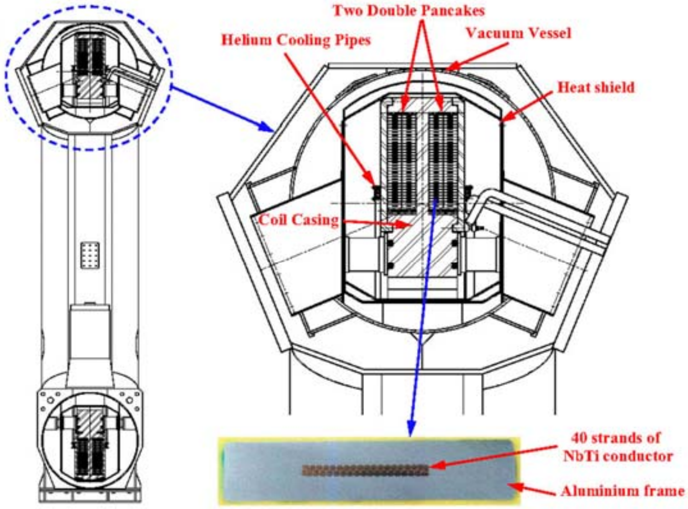


ATLAS: The large toroidial magnets

The barrel magnet

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

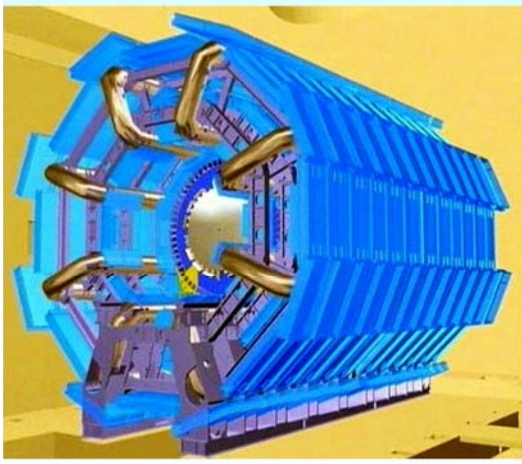


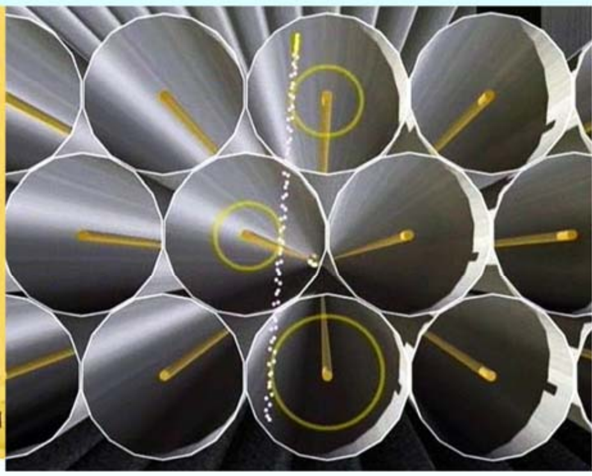


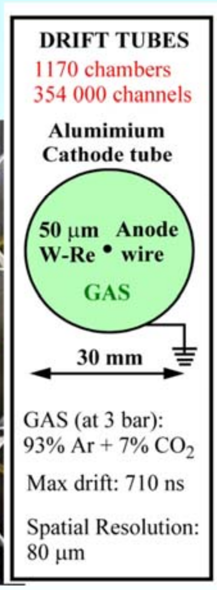
ATLAS: the muon detector

The muon detector consists of three layers of tracking detectors.

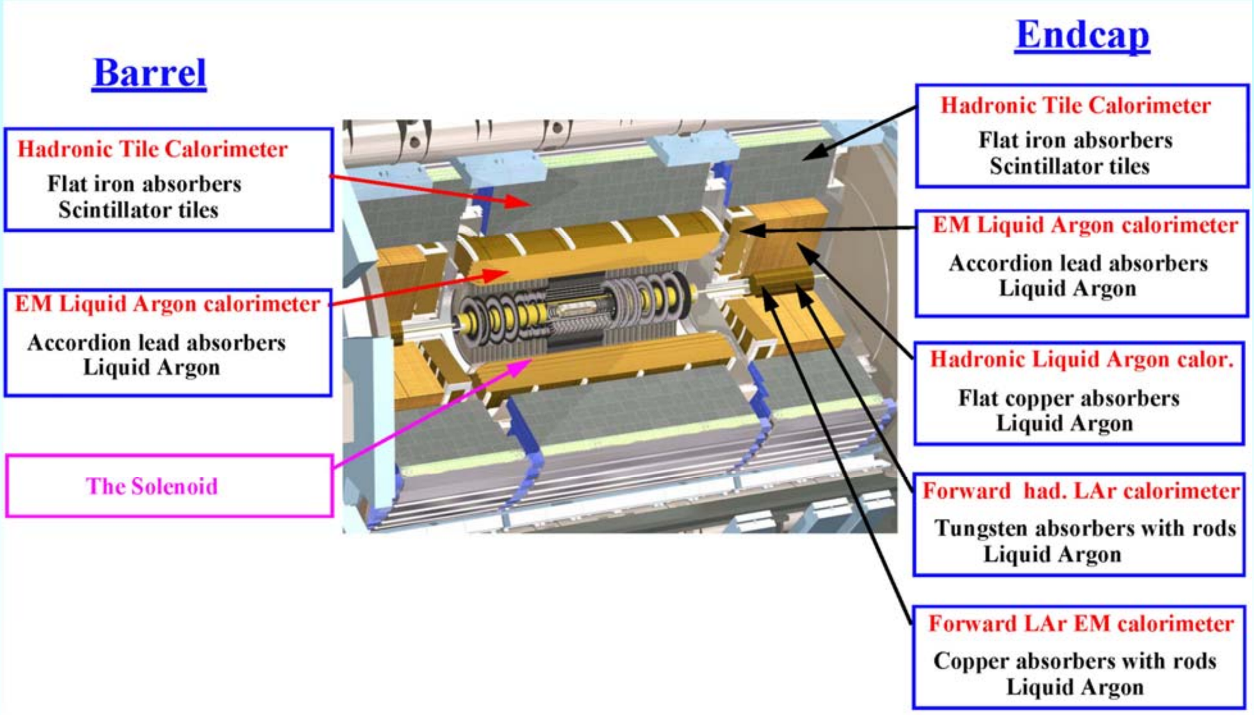
The main tracking is done with cylindrical gas filled drift tubes. A muon will ionize the gas and the electrons and ions will drift in an electric field. The drift time is measured and provides the position of the muon.







ATLAS: Calorimeters



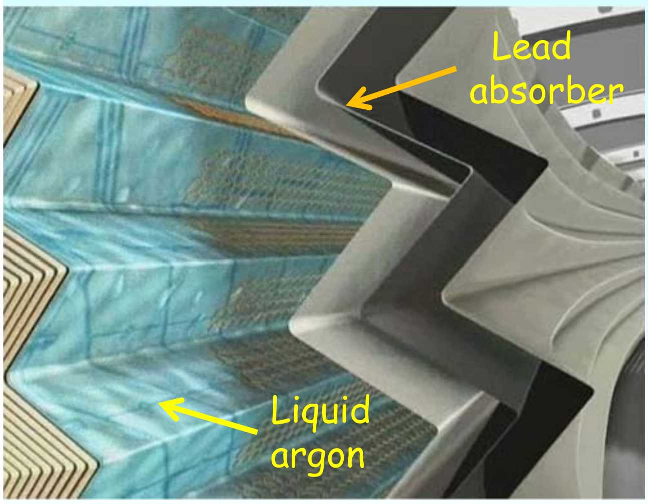
How does the calorimeter work ?

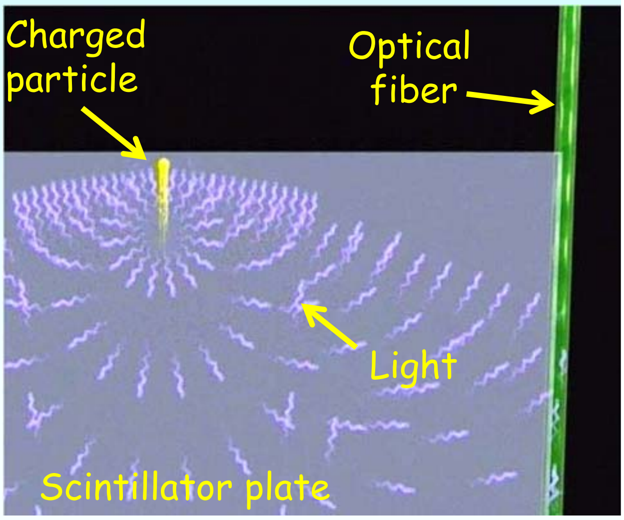
The electromagnetic calorimeter

An electron or a photon creates electro-magnetic showers in lead plates. Electrons in the shower ionize liquid argon which creates signals on electrodes.

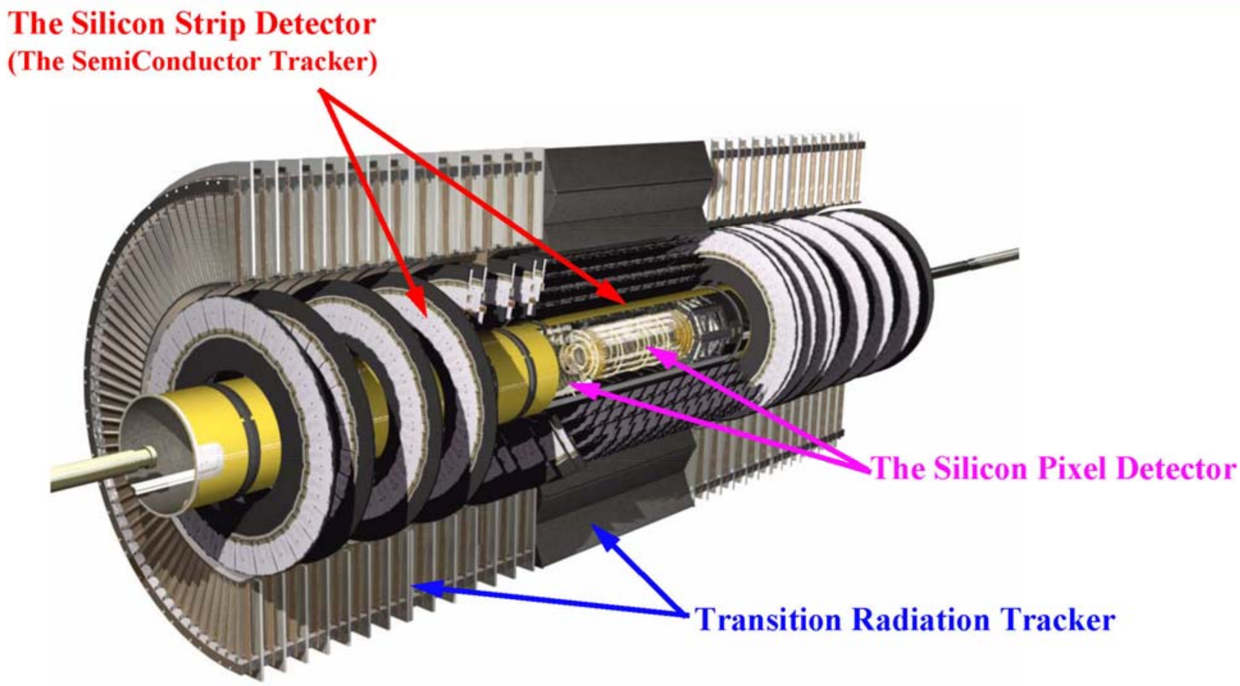
The hadronic calorimeter

Hadrons produce showers in steel plates. The charged particles in the shower creates light in scintillator plates that is read out by fibers.





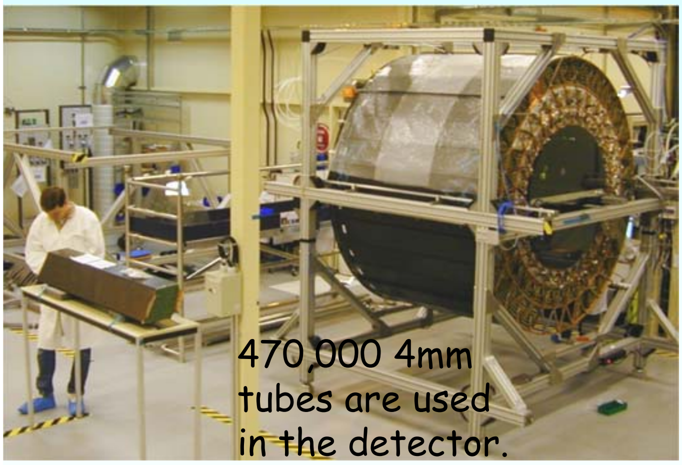
ATLAS: The Inner Detector

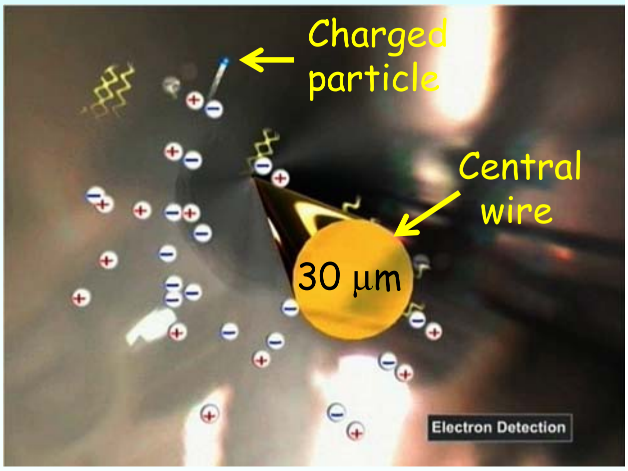


The Transition Radiation Tracker

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

It consists of gas filled tubes with a central wire. Electrons (but not pions) will produce photons in thin plastic sheets located between the tubes. Charged particles and the TRT photons will ionize the gas and produce signals on the wires. Large signals for electrons and small ones for hadrons.

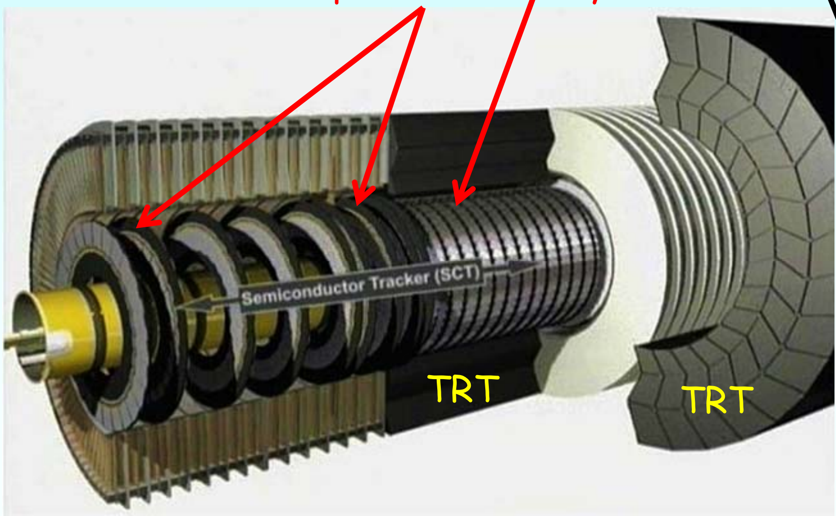


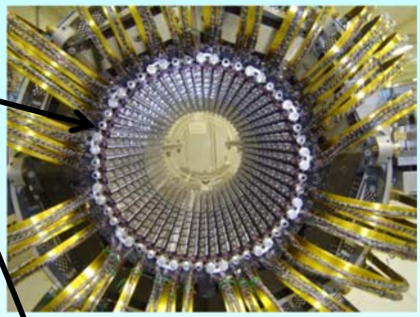


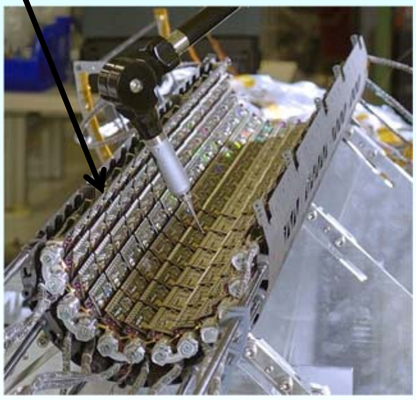
Silicon detectors in ATLAS

The pixel detector is closest to the collision point.
It has 80 million 50x400 μm pixels in 3 layers.

The semiconductor tracker has 6.3 million
2x 63 mm silicon strips in 9 and 4 layers.

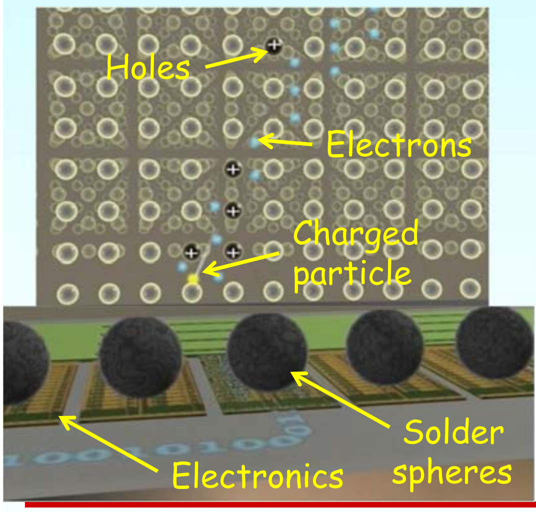


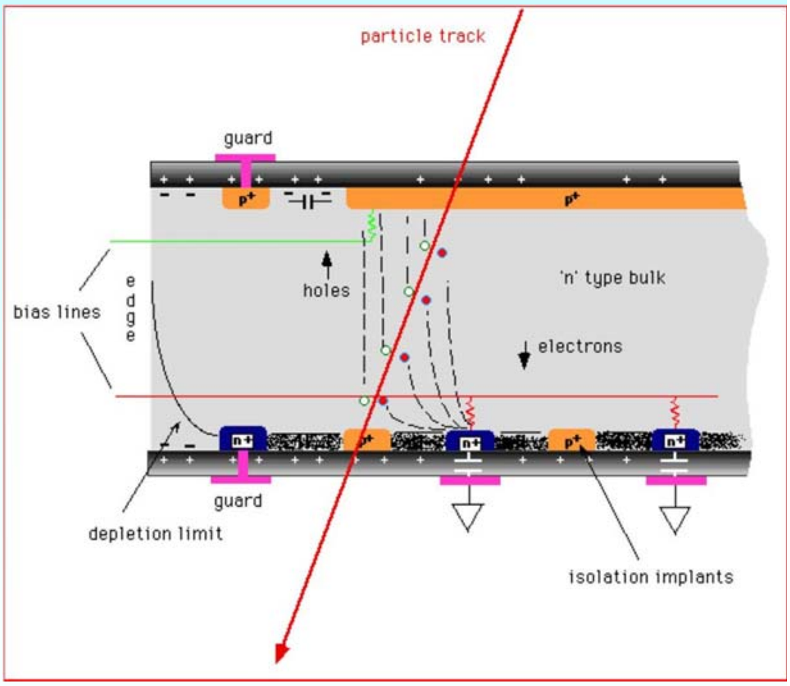




Silicon detectors: How do they work ?

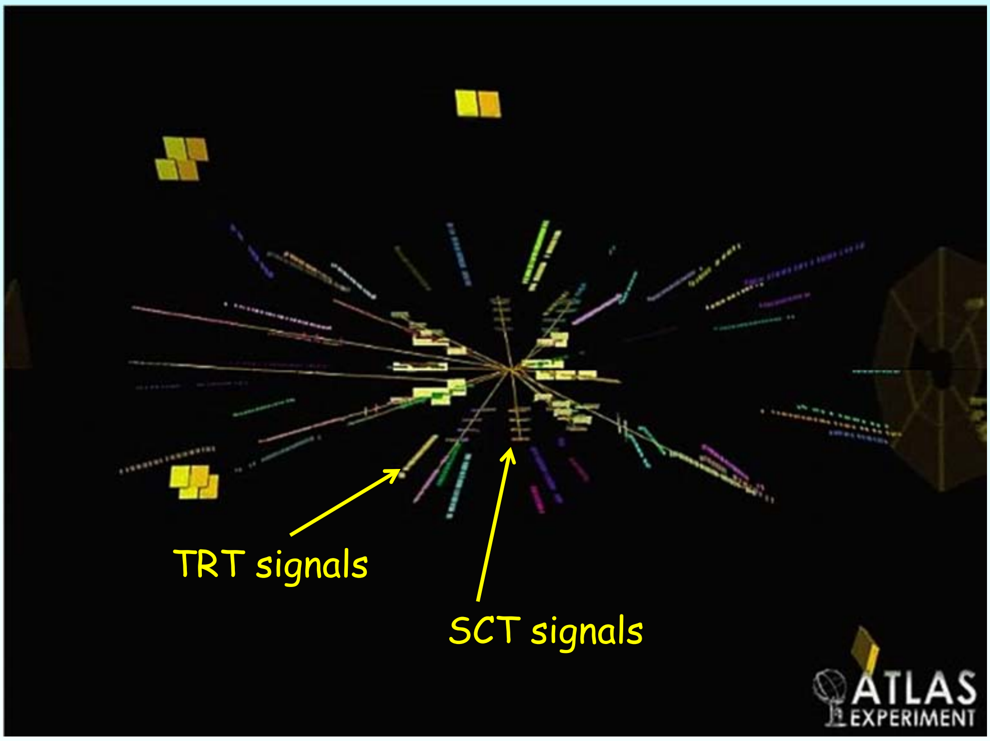
A charged particle creates electron-hole pairs. The charge drift to solder spheres which connects the silicon detector to a second layer with electronics.





One of the first collision in ATLAS

One 900 GeV collision recorded by the ATLAS experiment.

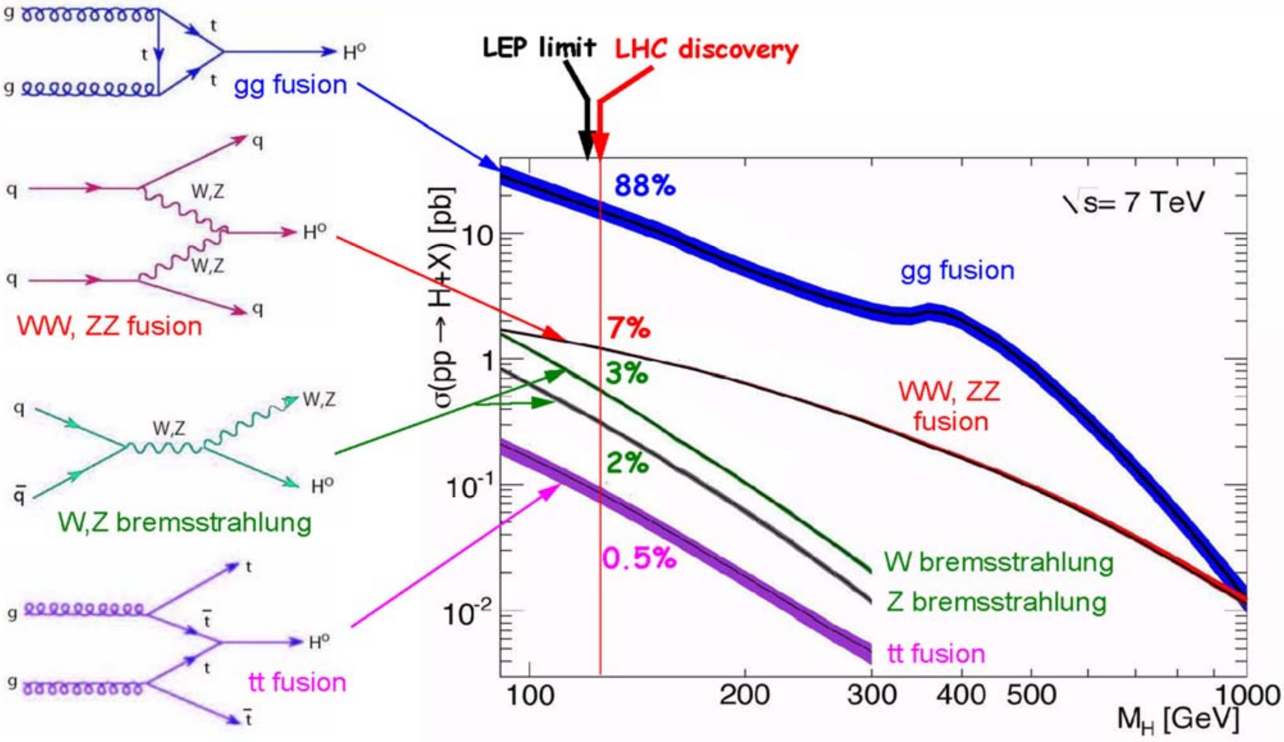


Physics studies: The Higgs particle

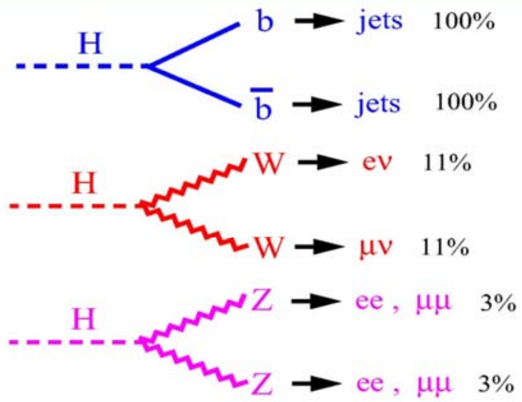
On the 4th of July 2012 the ATLAS and CMS experiments announced the discovery of a new particle at CERN.

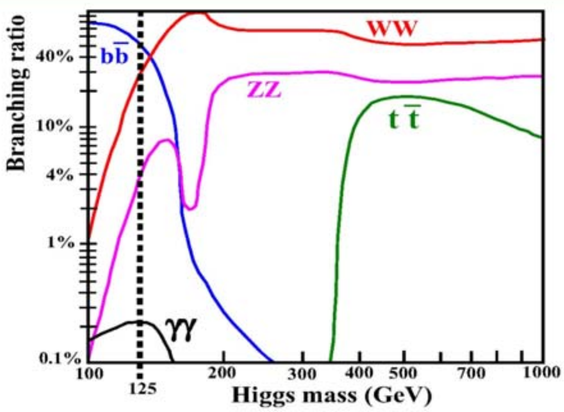
After the seminars Peter Higgs thanked the LHC experiments for discovering the Higgs boson in his lifetime ....

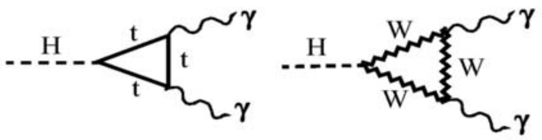
Higgs boson production



Higgs boson decay







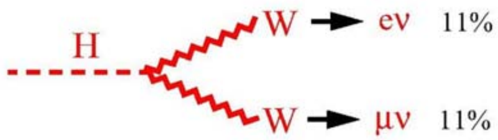
$H \to b\bar{b}$ ⇨ huge background

$H \to WW \to l\nu l\nu$ ⇨ neutrinos small W BR

$H \to ZZ \to llll$ ⇨ small Z BR

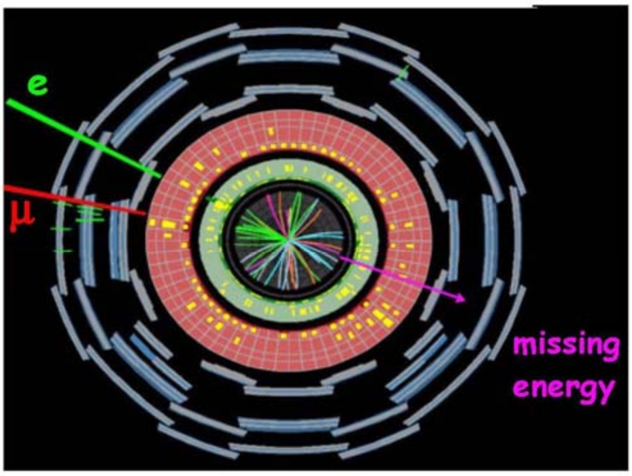
$H \to \gamma\gamma$ ⇨ small H BR

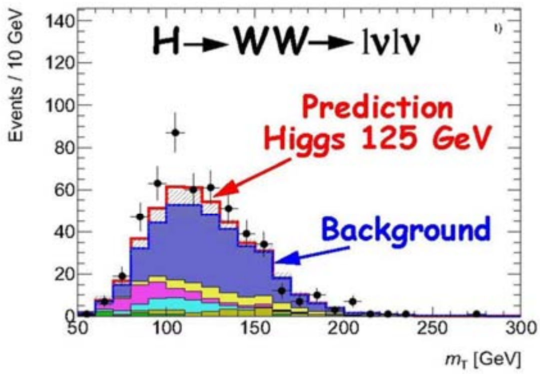
Higgs bosons to WW



Selection: One muon and one electron with large transverse momentum and opposite charge.

Large missing energy.

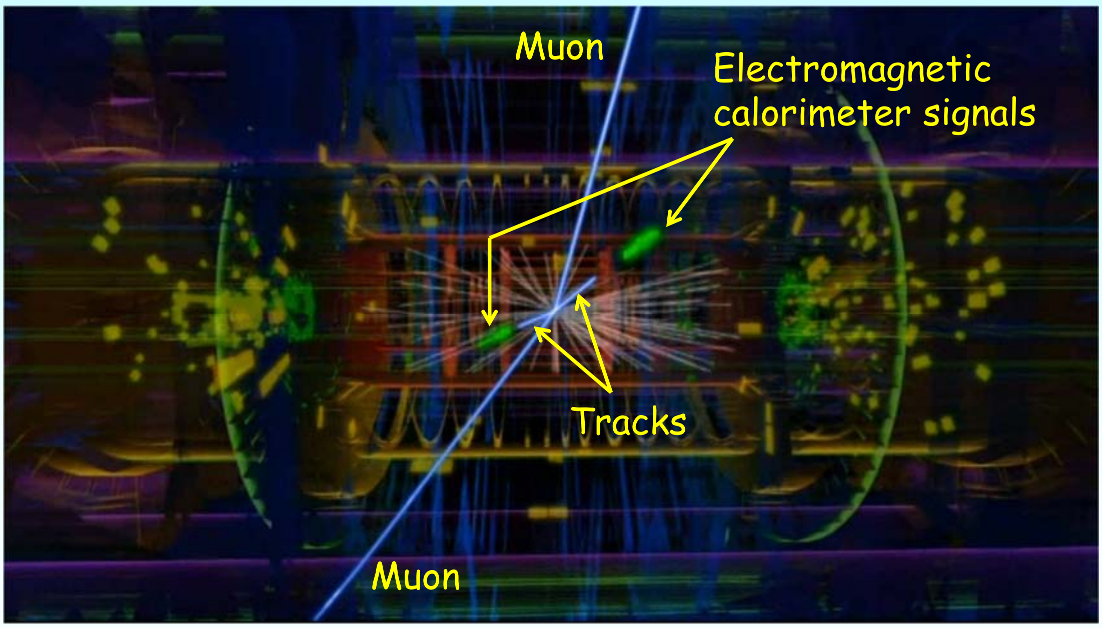




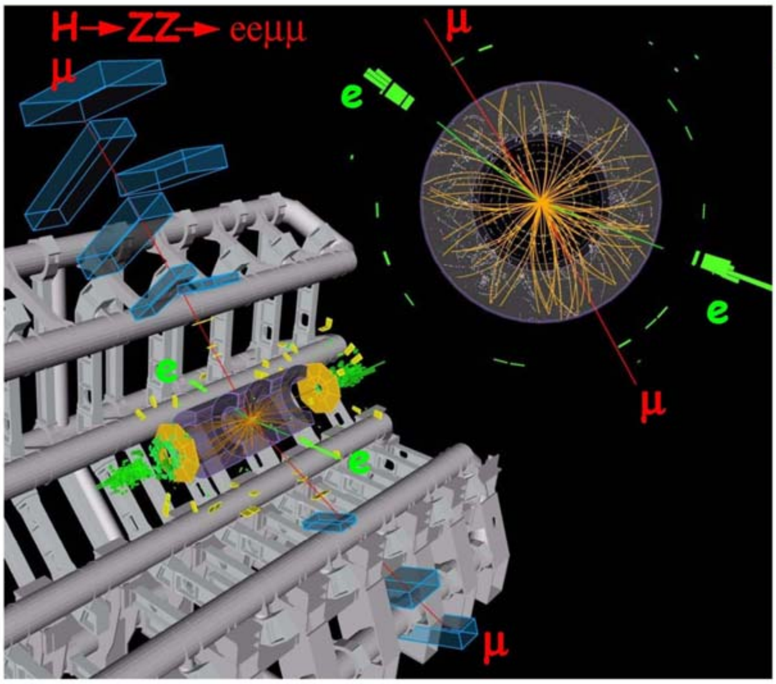
$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - |\mathbf{p}_T^{\ell\ell} + \mathbf{E}_T^{miss}|^2}$$

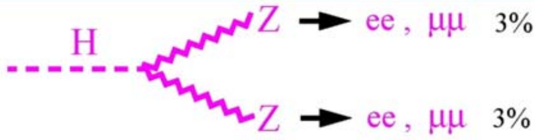
Higgs particle to ZZ ?

$$pp \longrightarrow ZZ + X \longrightarrow ee + \mu\mu + X$$



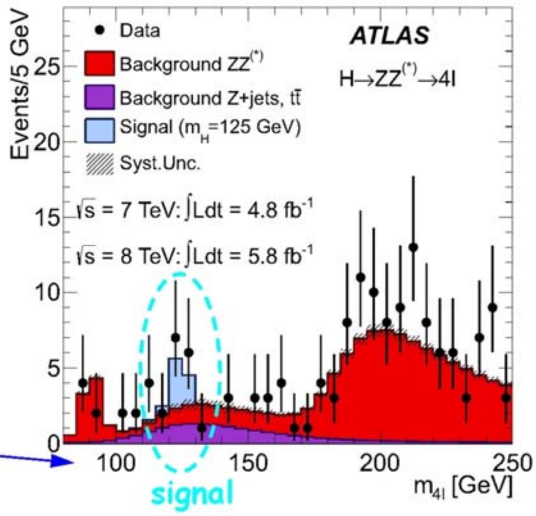
Higgs bosons to ZZ





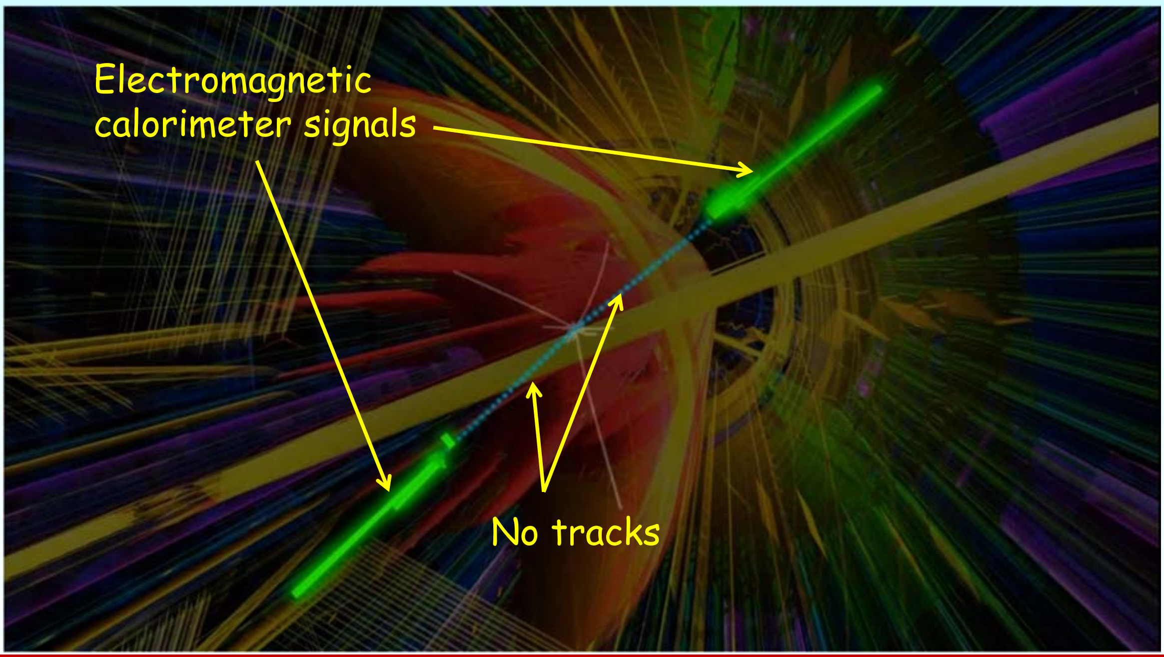
Selection: Two pairs of electrons and/or muons that each have the mass of a Z^0.

$$M_H^2 = (\vec{P}_{e^-} + \vec{P}_{e^+} + \vec{P}_{\mu^-} + \vec{P}_{\mu^+})^2$$

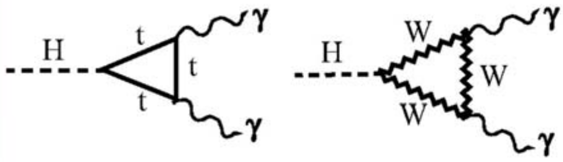


Higgs particle to γγ ?

$$pp \longrightarrow \gamma\gamma + X$$

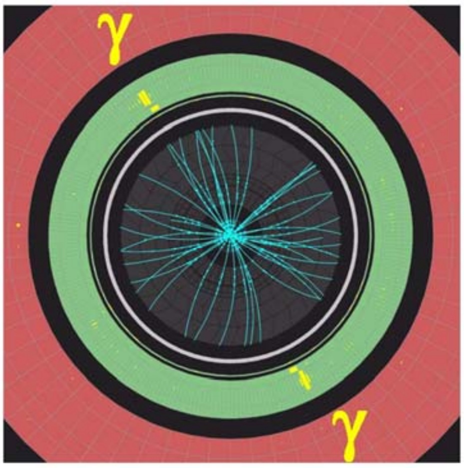


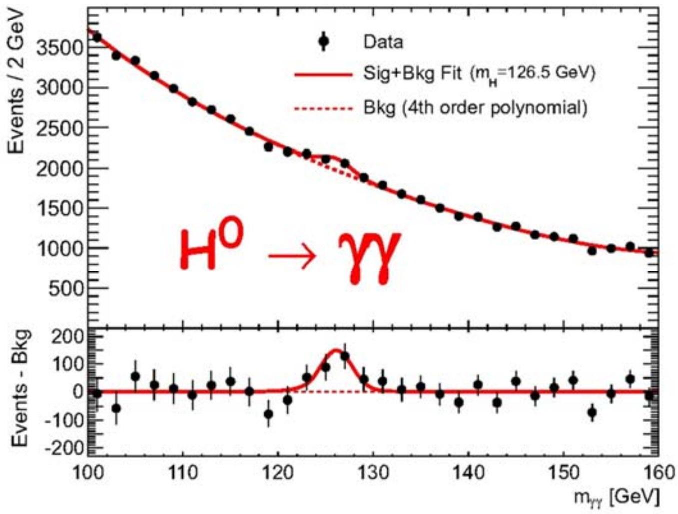
Higgs bosons to $\gamma\gamma$



Selection: Two isolated photons with large transverse momentum.

$$M_H^2 = (\vec{P}_\gamma + \vec{P}_\gamma)^2$$





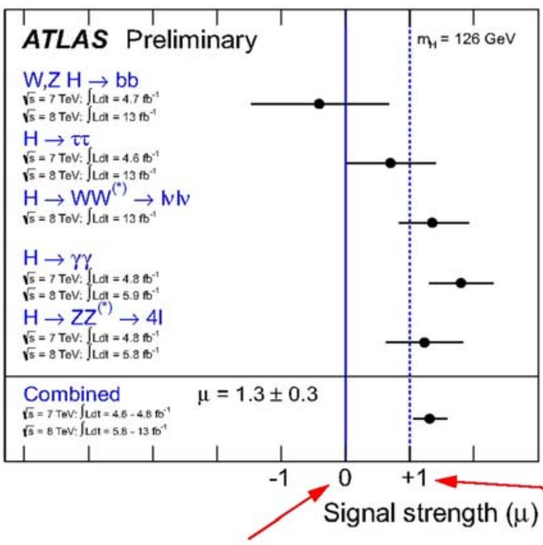
Summary of Higgs measurement

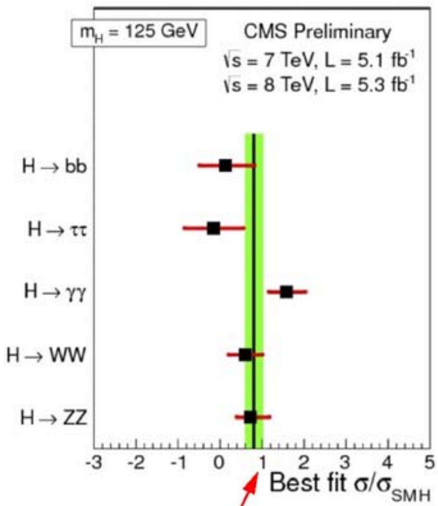
ATLAS

M_H = 126.0 ± 0.4 GeV

CMS

M_H = 125.8 ± 0.4 GeV





No signal

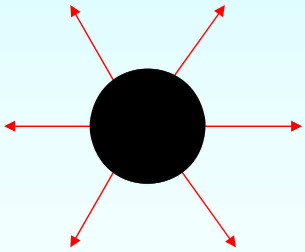
Signal in perfect agreement with standard model

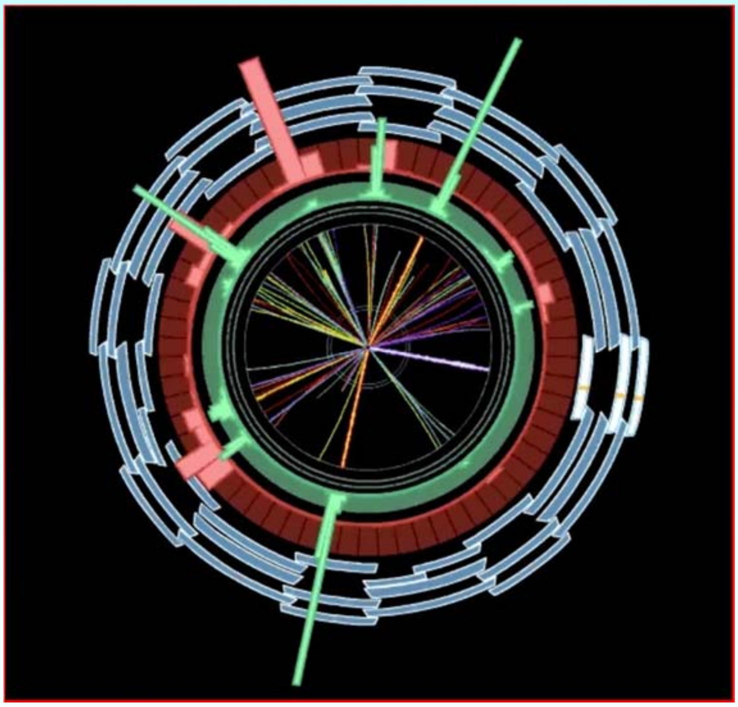
Physics studies: Search for black holes

Black Hole

Signature:

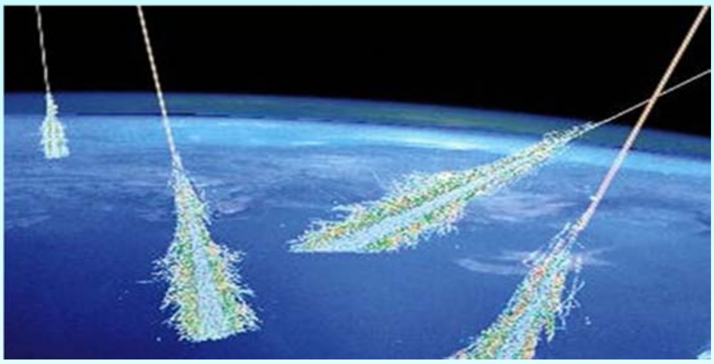
Many particles and particles with a high energy and with a large angle with respect to the proton direction.

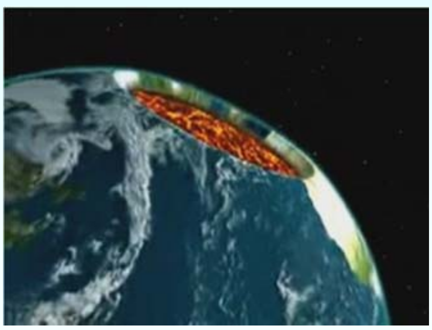




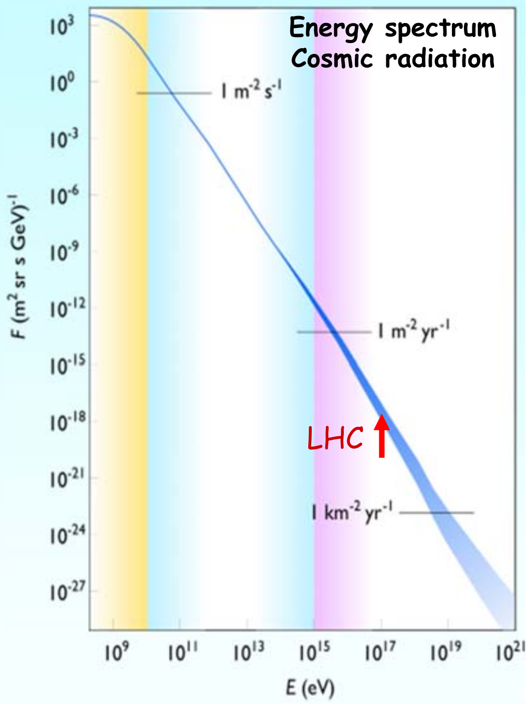
The holes will disappear after 10^{-26}s according to the theory (if they are produced).

Black holes = The end of the world ?

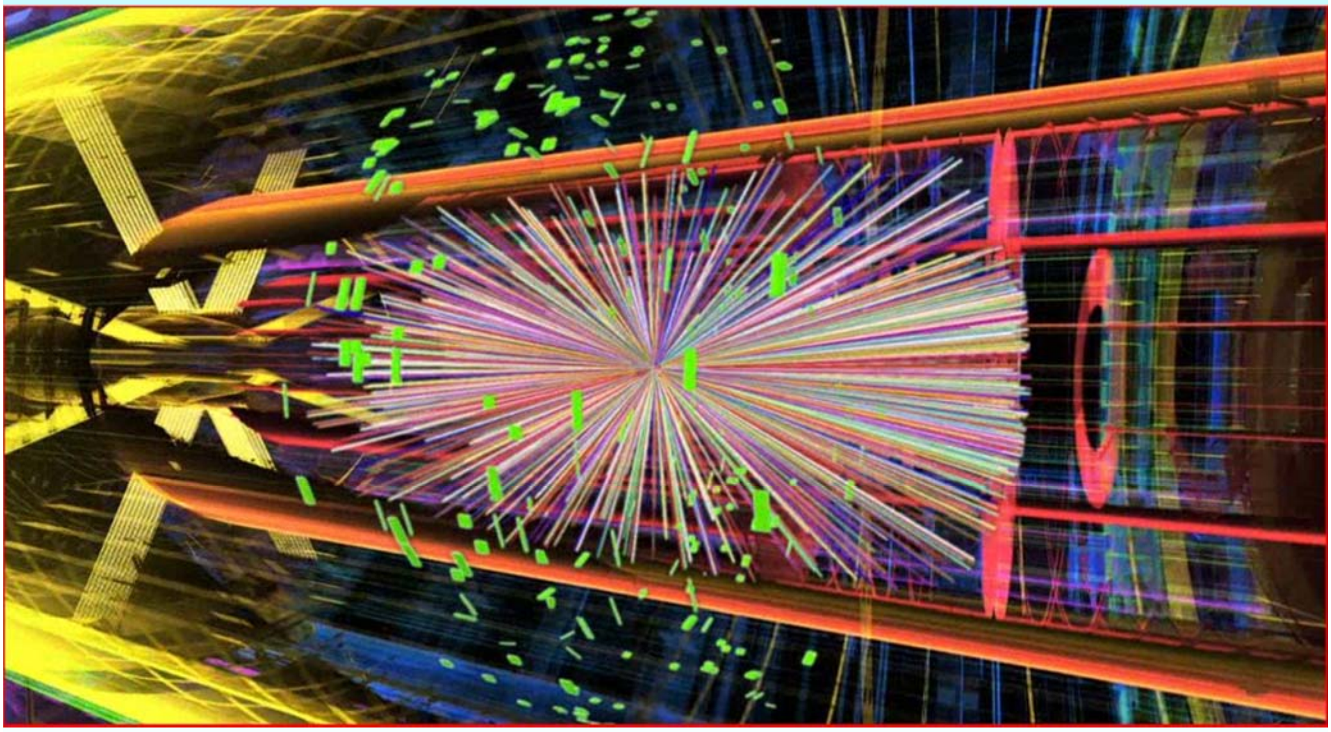




There are protons in the cosmic radiations with a higher energy than what can be produced by LHC. The number of collisions at LHC during one year corresponds to about 1000-10000 years of collisions in the atmosphere.



A lead-lead collision in ATLAS



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 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

Spin off technology ....

- 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.