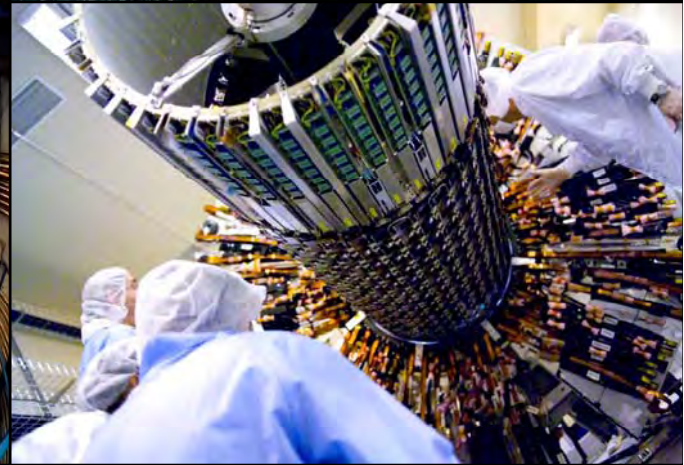
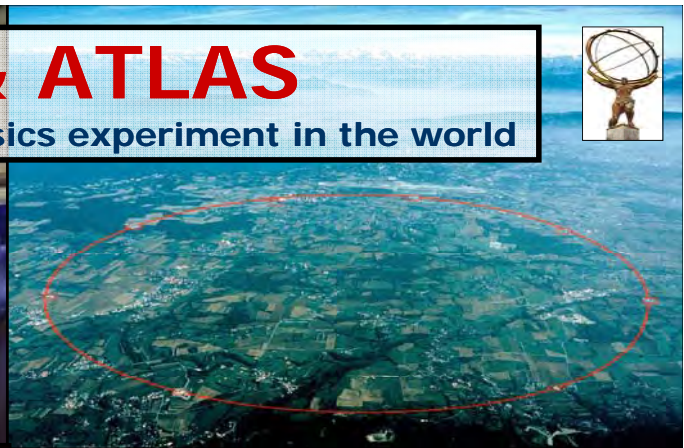
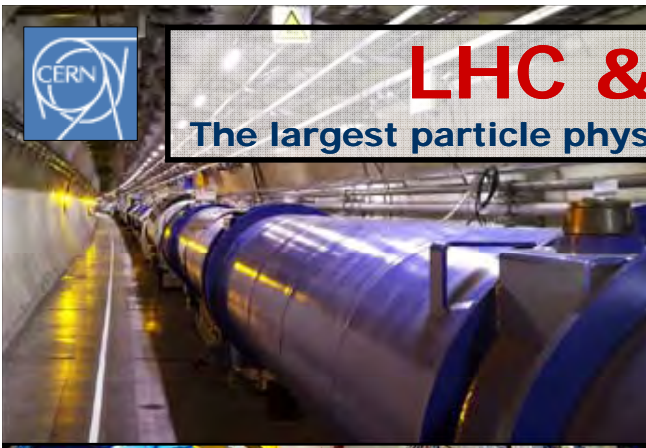




# LHC & ATLAS

The largest particle physics experiment in the world



Vincent Hedberg - Lund University

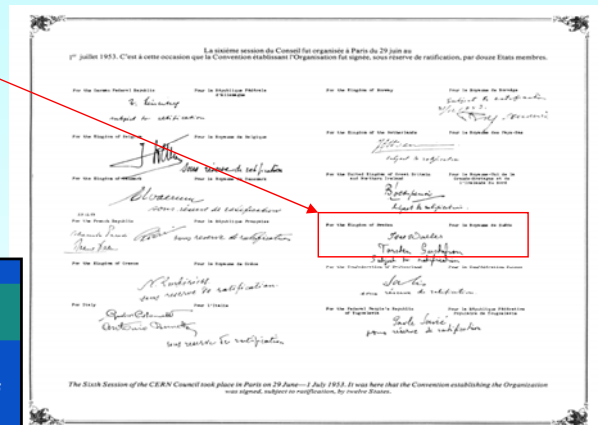


## CERN – A laboratory for the world



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



## OBSERVERS:

- UNESCO
- EU
- Israel
- Turkey

## SPECIAL OBSERVERS (for the LHC):

- USA
- Japan
- Russia
- India



### Member States (Dates of Accession)

AUSTRIA (1959)	DENMARK (1953)	GREECE (1953)	NORWAY (1953)	SPAIN (1/1961-12/1968-1/1983)
BELGIUM (1953)	FINLAND (1991)	HUNGARY (1992)	POLAND (1991)	SWEDEN (1953)
BULGARIA (1999)	FRANCE (1953)	ITALY (1953)	PORTUGAL (1986)	SWITZERLAND (1953)
CZECH FR (1993)	GERMANY (1953)	NETHERLANDS (1953)	SLOVAK FR (1993)	UNITED KINGDOM (1953)

CERN ACC/DIR/M/ES/1993-13/0-98



# 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



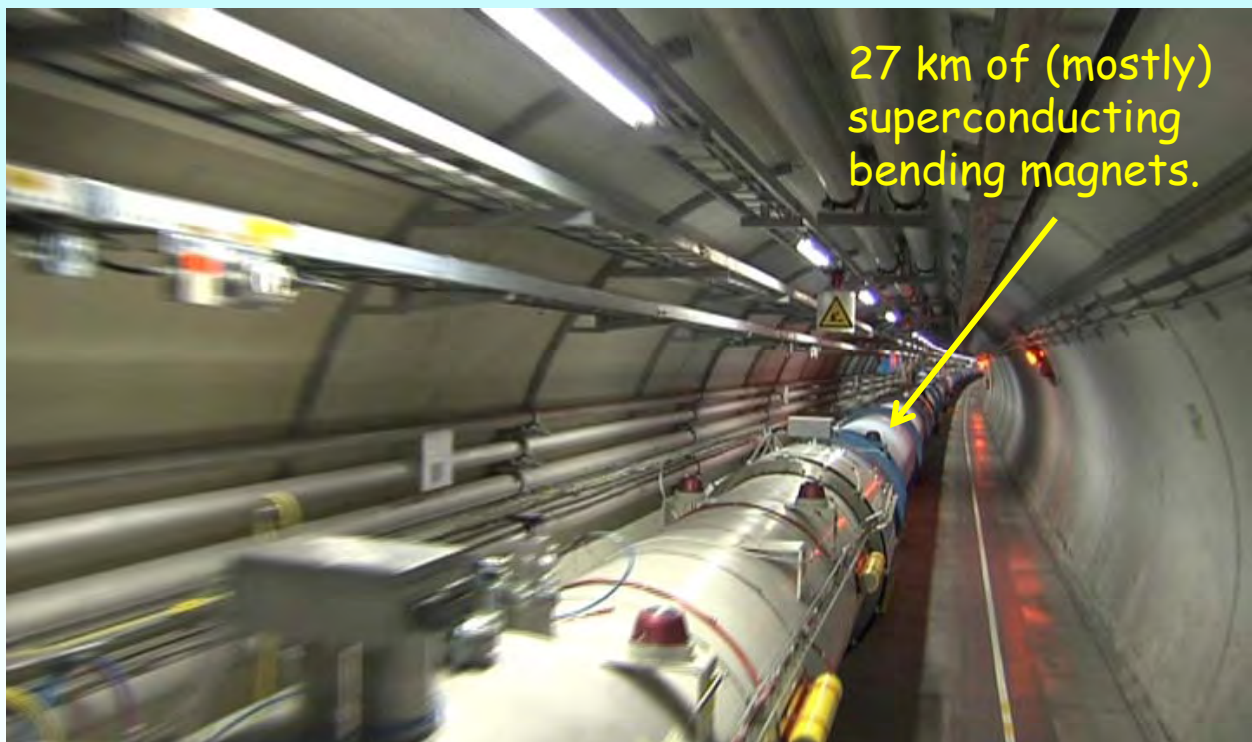
The protons are first accelerated in a linear accelerator. They are then accelerated in the booster to 1.4 GeV, in the PS to 25 GeV, in the SPS synchrotron to 450 GeV and finally injected into the 27 km long LHC tunnel.



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



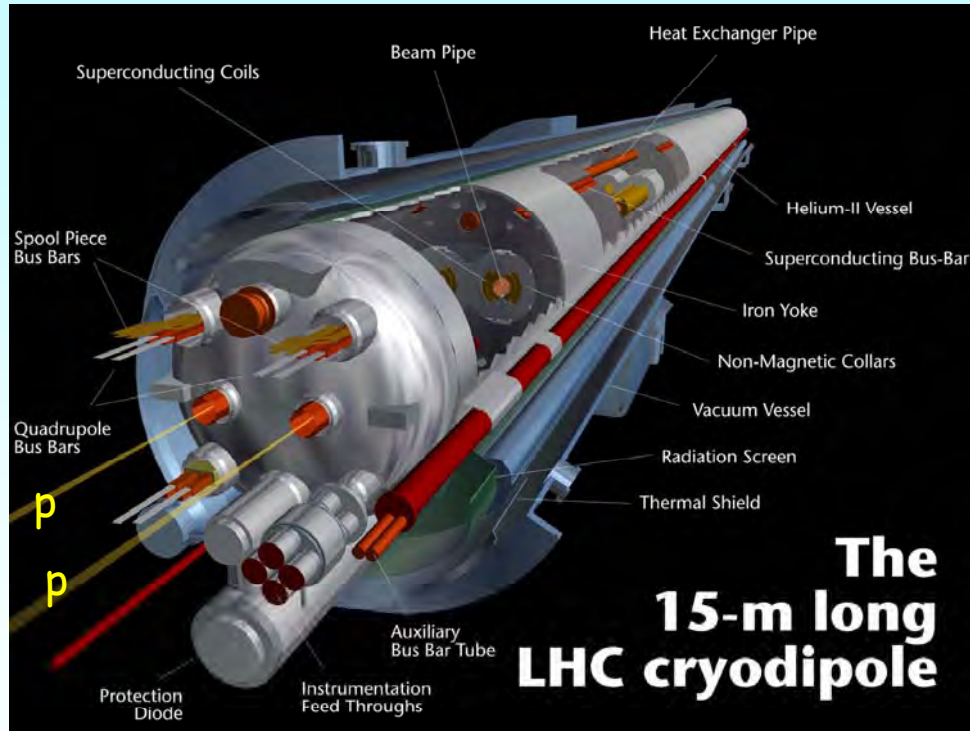
# In the LHC accelerator tunnel



27 km of (mostly) superconducting bending magnets.



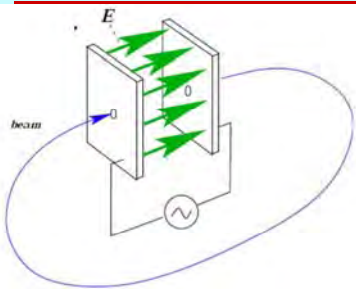
# The magnets that bend the proton beams.



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 !

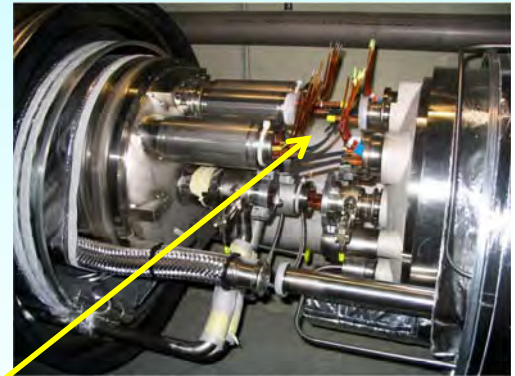


On the 10<sup>th</sup> of September 2008 it was for the first time possible to make a 450 GeV proton beam go around the whole of the LHC.





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.



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



Collision energy  
Collision rate

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

Predicted values      Design values



# 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



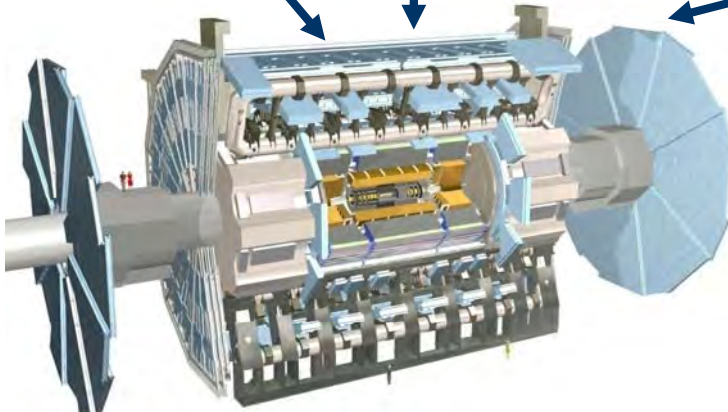
KUNGL  
TEKNISKA  
HÖGSKOLAN



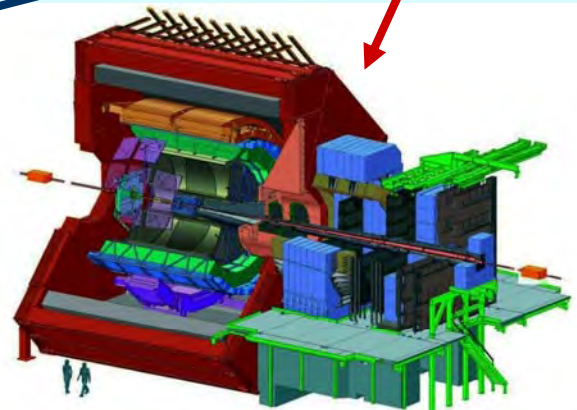
Stockholms  
universitet



LUNDS  
UNIVERSITET



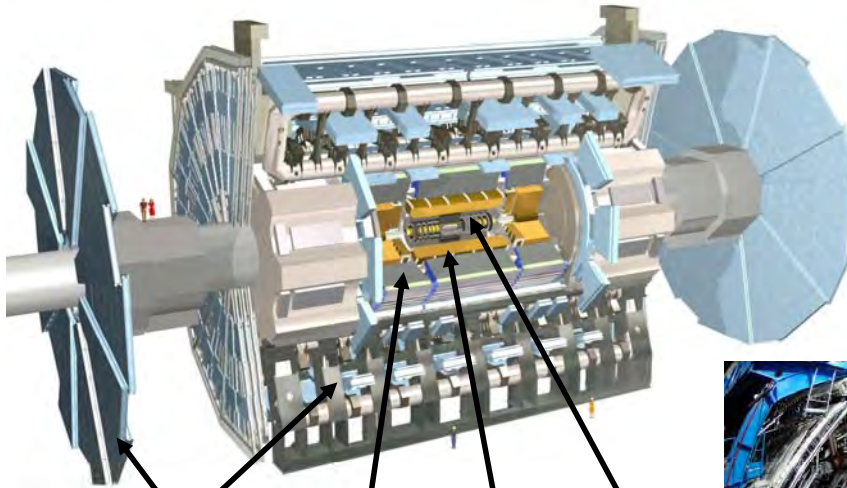
The ATLAS experiment



The ALICE experiment



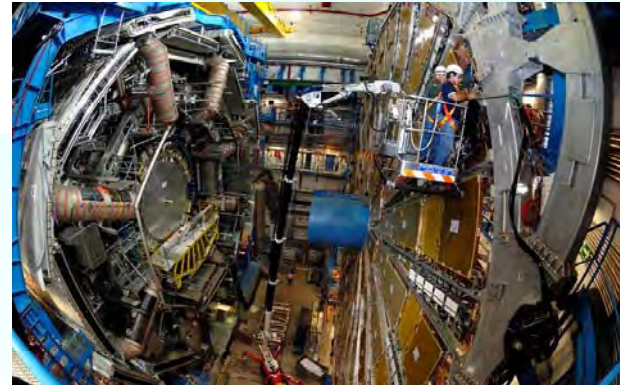
# The ATLAS experiment



## 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

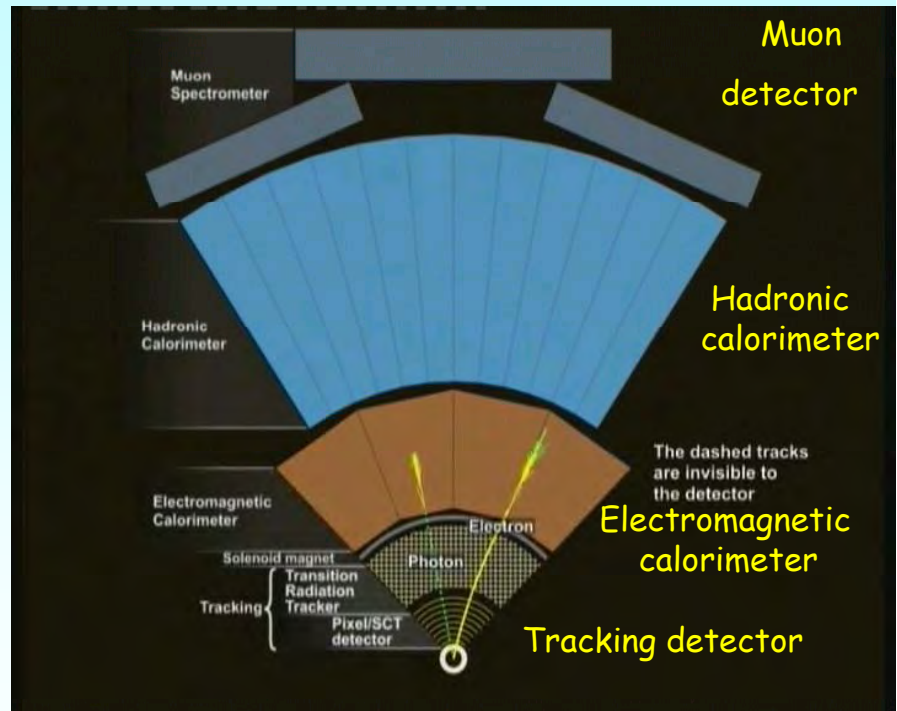


Electron:

Track in tracker & Shower in electromagnetic calorimeter

Photon:

No track in tracker & Shower in electromagnetic calorimeter



# Detection of protons and neutrons

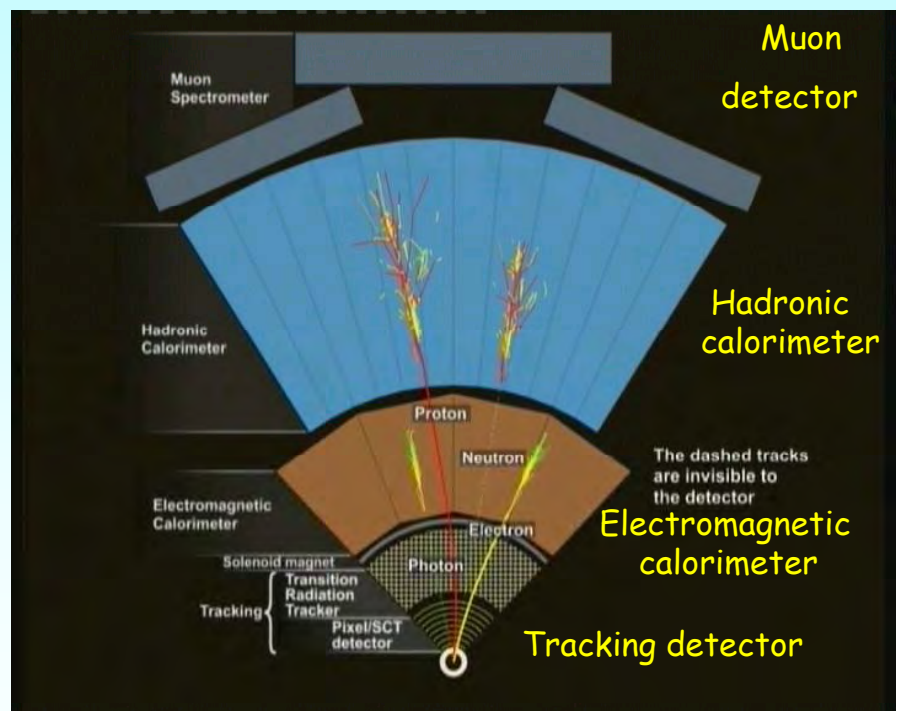


Proton:

Track in tracker & Shower in hadronic calorimeter

Neutron:

No track in tracker & Shower in hadronic calorimeter





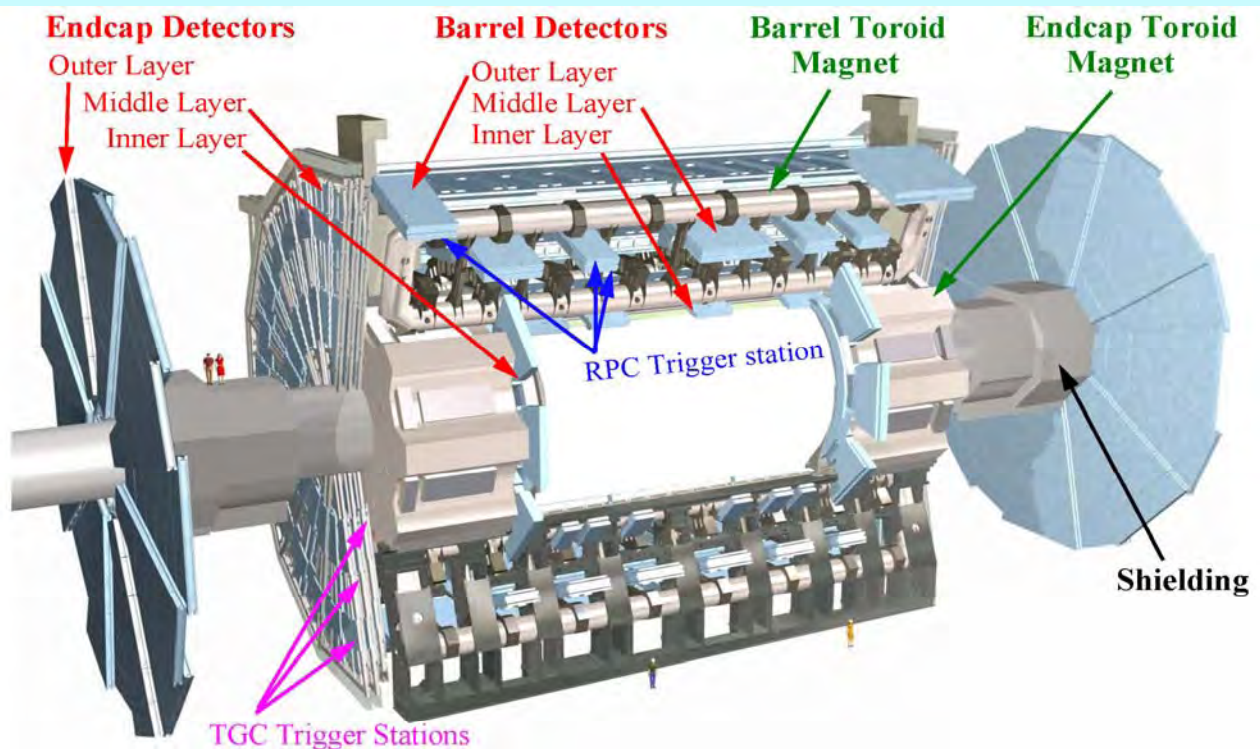
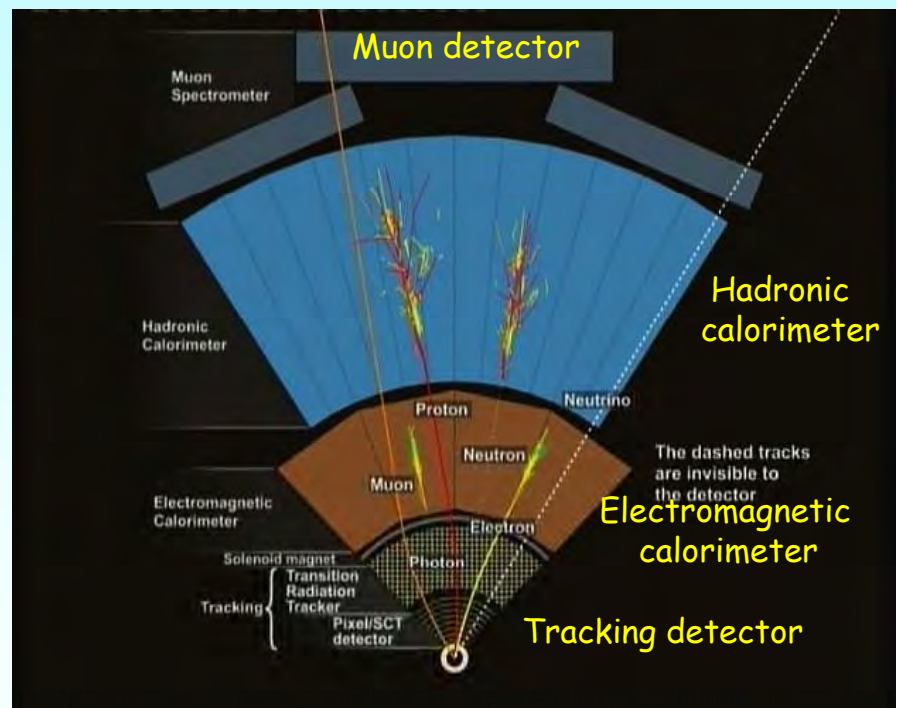
**Muon:**

Track in tracker &  
Track in muon detector

**Neutrino:**

No signals anywhere

Shows up as missing energy and missing momentum



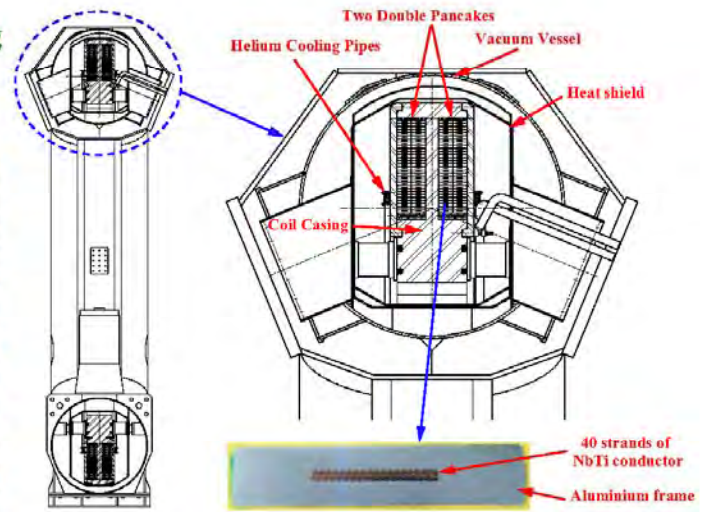
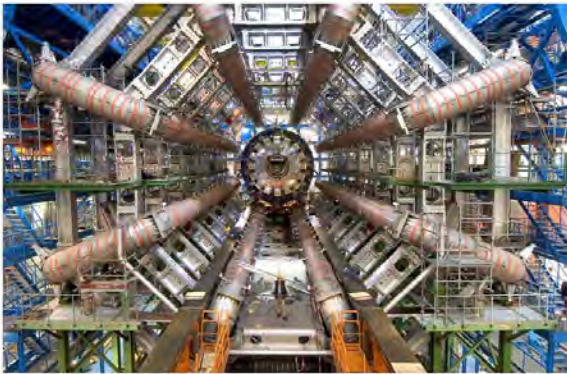


# ATLAS: The large toroidal magnets



## The barrel magnet

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

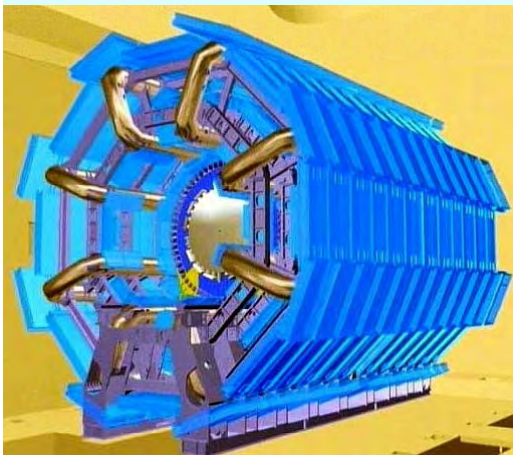


# ATLAS: the muon detector

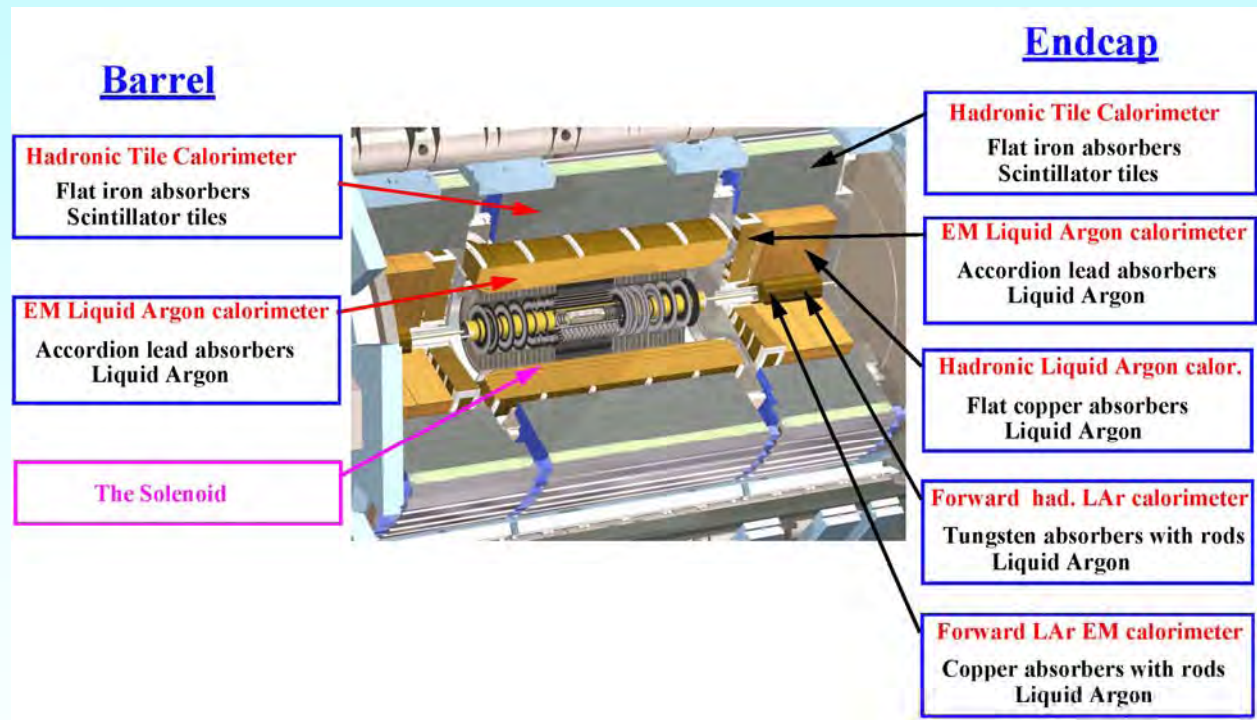


The muon detector consists of three layers of tracking detectors.

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.

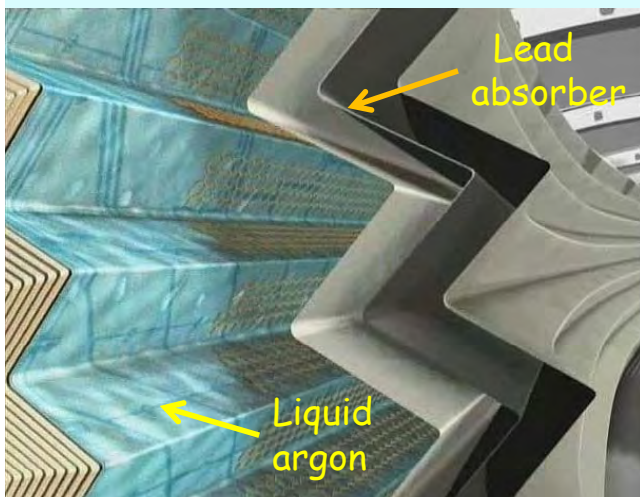


<b>DRIFT TUBES</b>
1170 chambers
354 000 channels
<b>Aluminium Cathode tube</b>
50 $\mu\text{m}$ Anode W-Re $\bullet$ wire
GAS
30 mm
GAS (at 3 bar): 93% Ar + 7% CO <sub>2</sub>
Max drift: 710 ns
Spatial Resolution: 80 $\mu\text{m}$



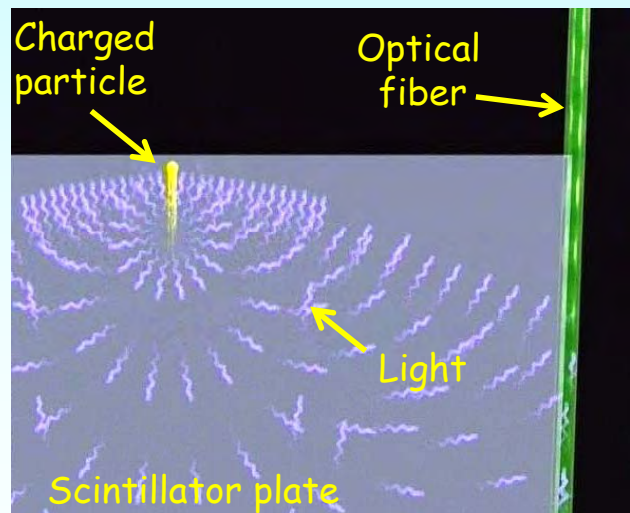
### The electromagnetic calorimeter

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

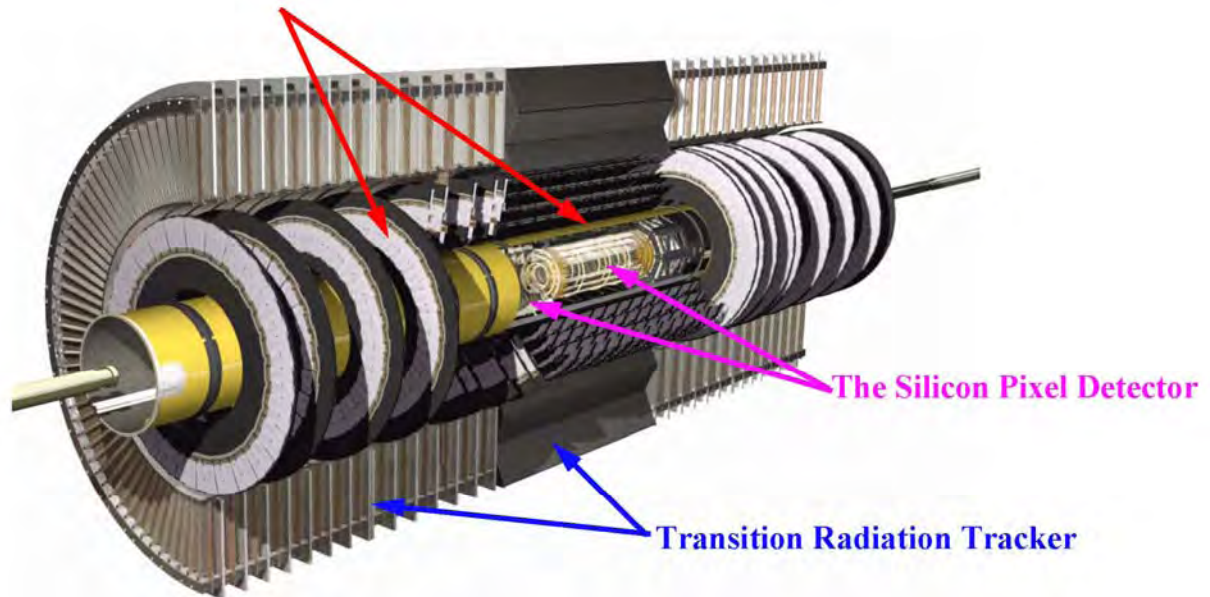


### The hadronic calorimeter

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



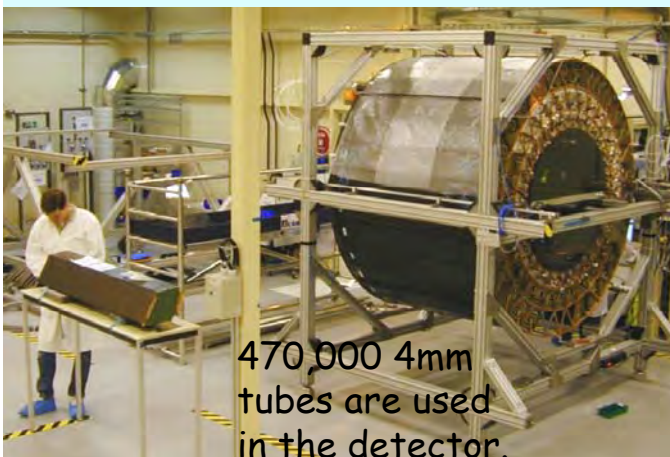
## The Silicon Strip Detector (The SemiConductor Tracker)



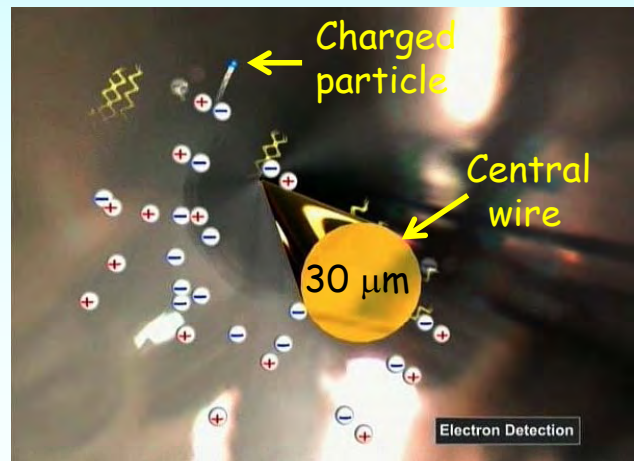
## The Transition Radiation Tracker

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.

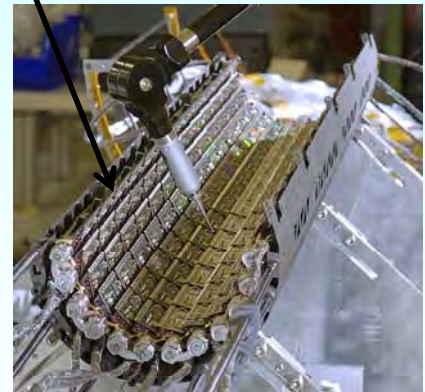
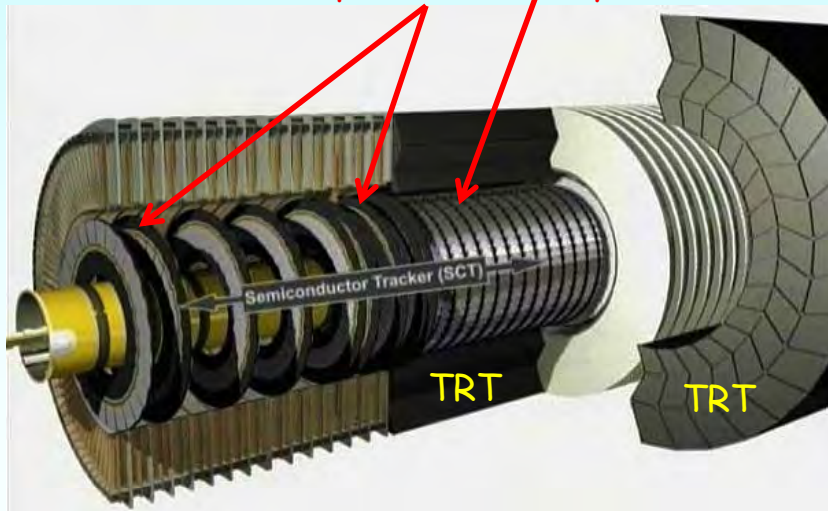


470,000 4mm tubes are used in the detector.

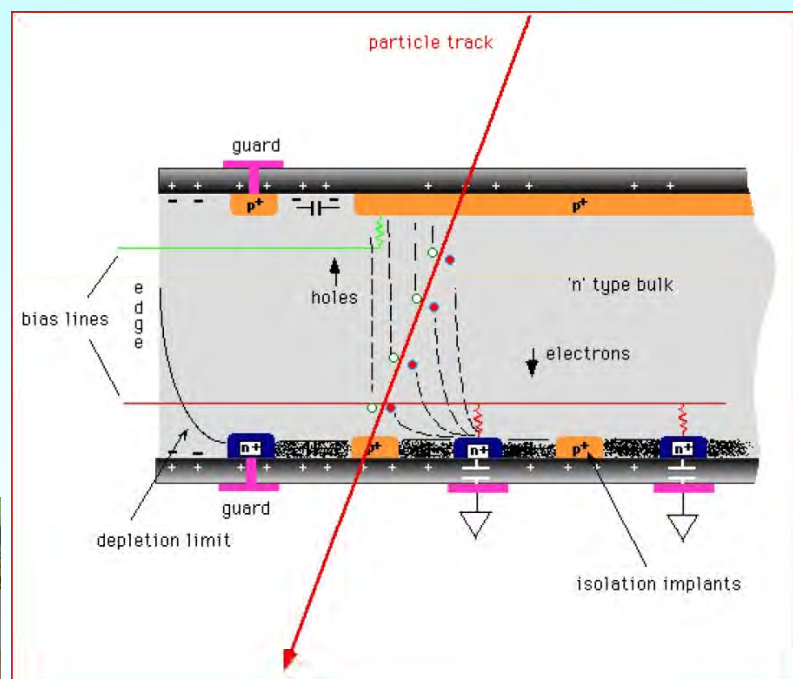
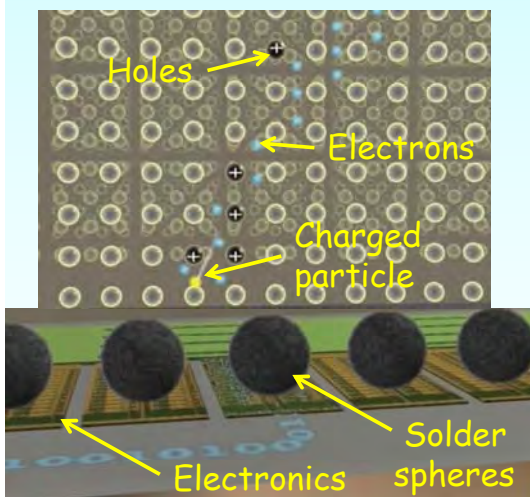


The pixel detector is closest to the collision point. It has 80 million  $50 \times 400 \mu\text{m}$  pixels in 3 layers.

The semiconductor tracker has 6.3 million  $2 \times 63 \text{ mm}$  silicon strips in 9 and 4 layers.



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

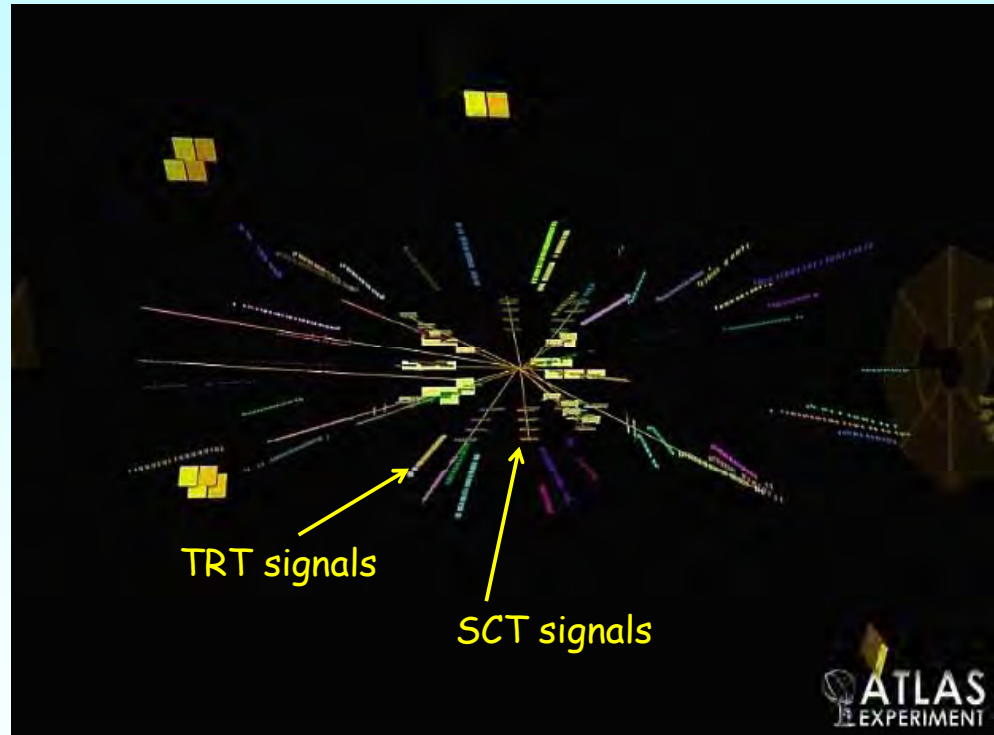




# One of the first collision in ATLAS



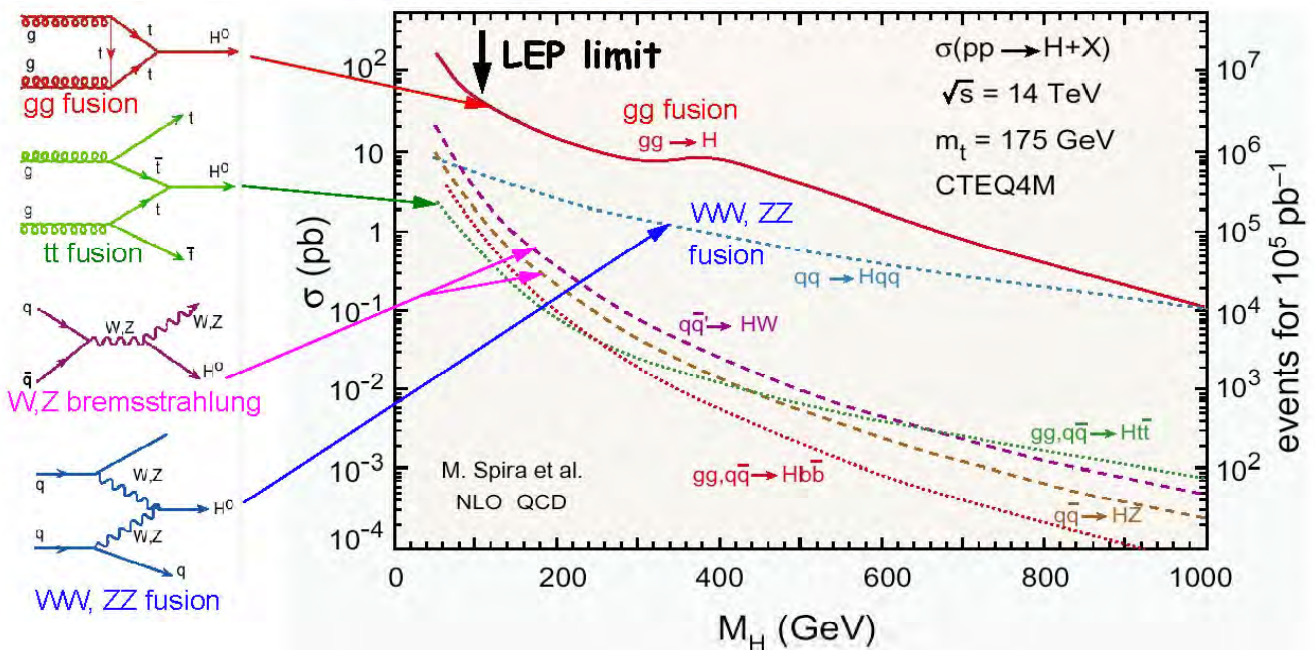
One 900 GeV collision recorded by the ATLAS experiment.



# Physics studies: Search for the Higgs particle



## → Higgs boson production



## → Higgs boson decays

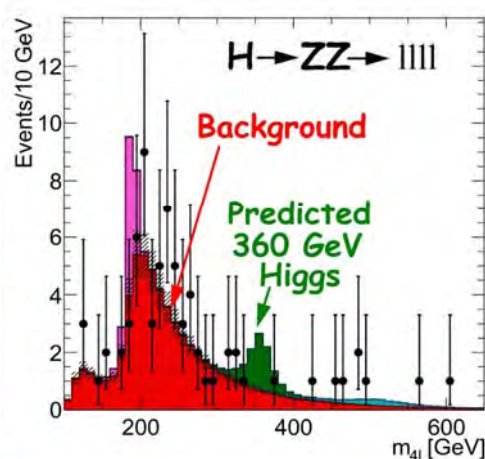
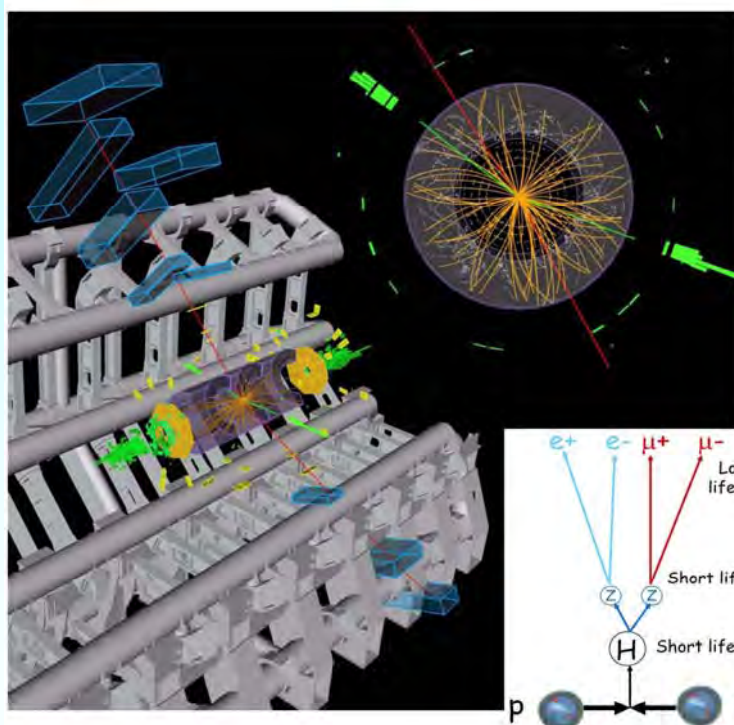
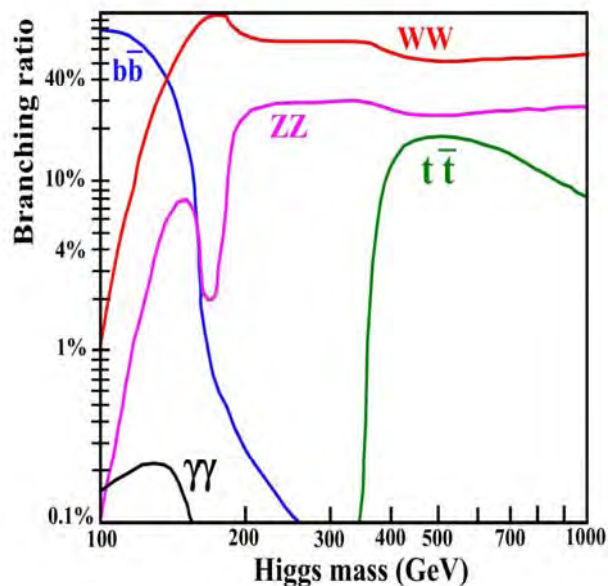
$10^9 - 10^{10}$  inelastic interactions  
for every Higgs boson.

Low mass  $\Rightarrow H \rightarrow b\bar{b}$   
(huge background)

Low mass  $\Rightarrow H \rightarrow \gamma\gamma$   
(small branching ratio)

High mass  $\Rightarrow H \rightarrow WW \rightarrow l\nu l\nu$   
(neutrinos)

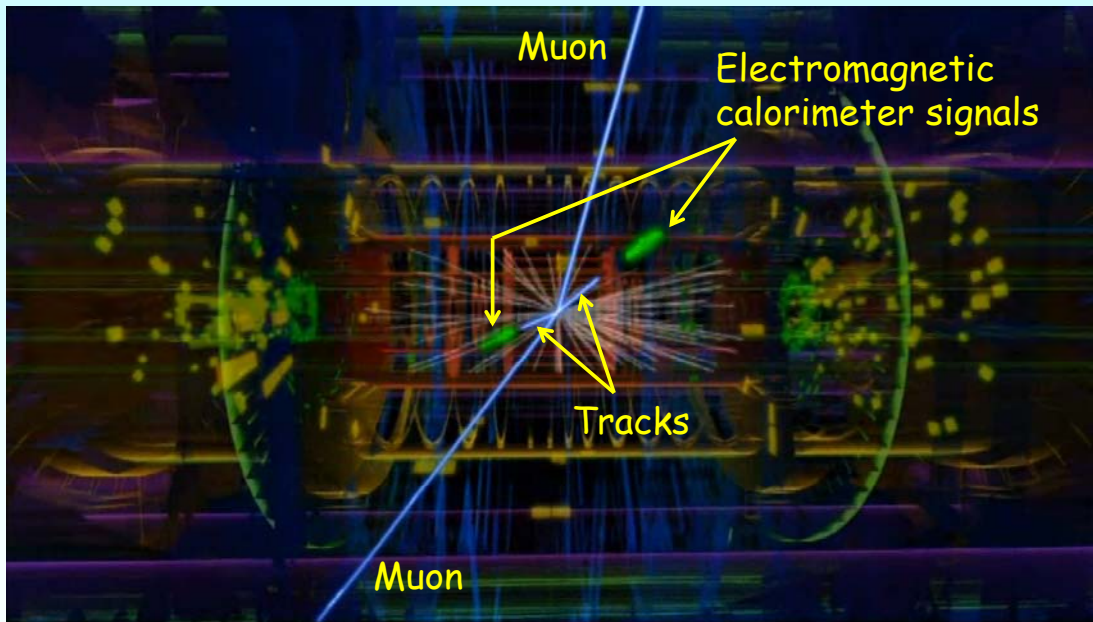
High mass  $\Rightarrow H \rightarrow ZZ \rightarrow llll$   
(gold-plated decay)



**ATLAS + CMS:**  
No Higgs with mass  
between 141 and 476 GeV

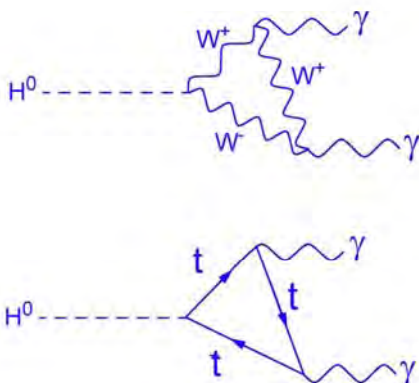


$$pp \rightarrow ZZ + X \rightarrow ee + \mu\mu + X$$

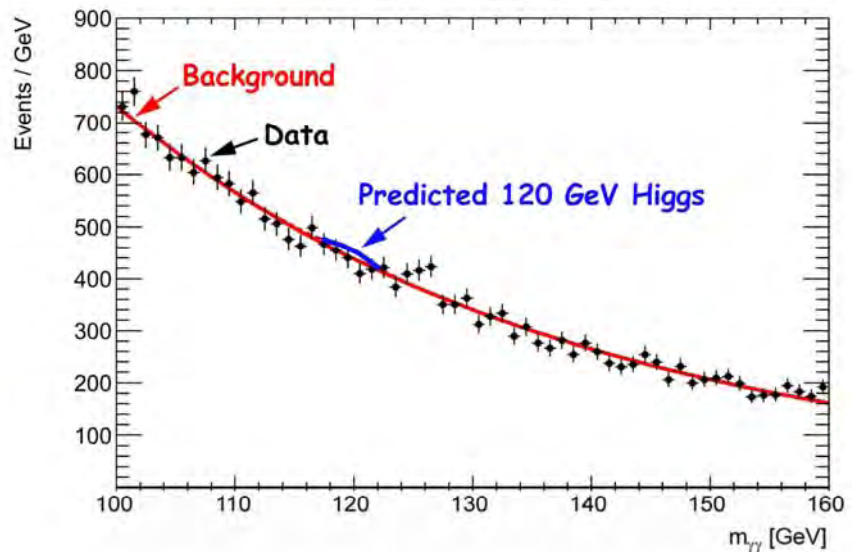


$$H^0 \rightarrow \gamma\gamma$$

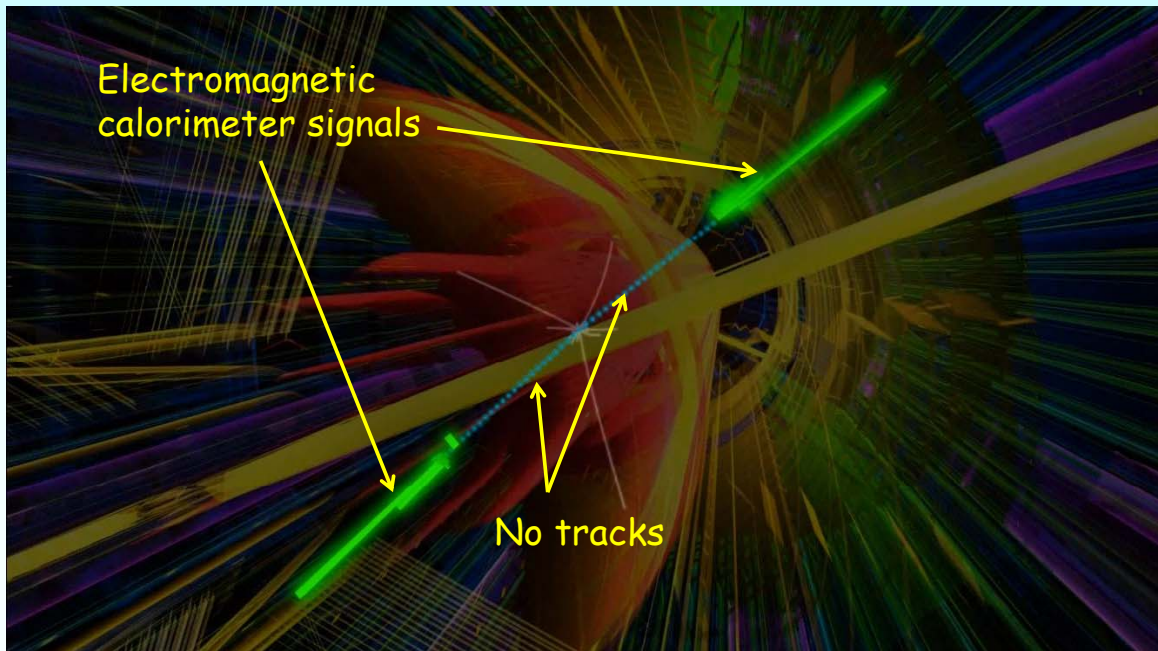
$$\text{Br} = 1-2 \times 10^{-3}$$



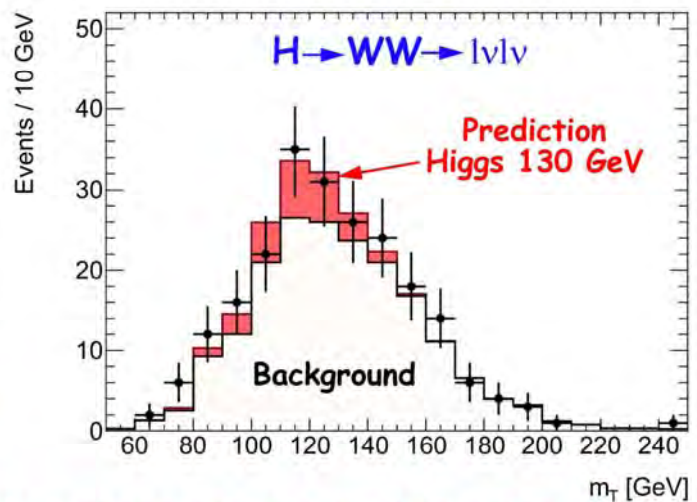
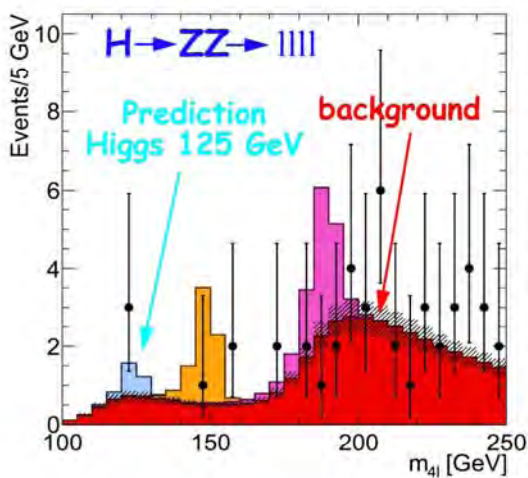
## ATLAS 2011 Data



$$pp \rightarrow \gamma\gamma + X$$



One can use the  $H \rightarrow ZZ$  or  $WW$  channel for low Higgs masses ( $m_H < 2m_Z$ ) if the Higgs decays to one real and one virtual  $Z, W$



**A small excess (fluctuation) is observed at 125 GeV when all channels are combined.**



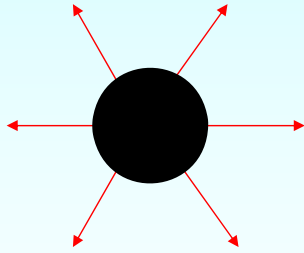
# Physics studies: Search for black holes



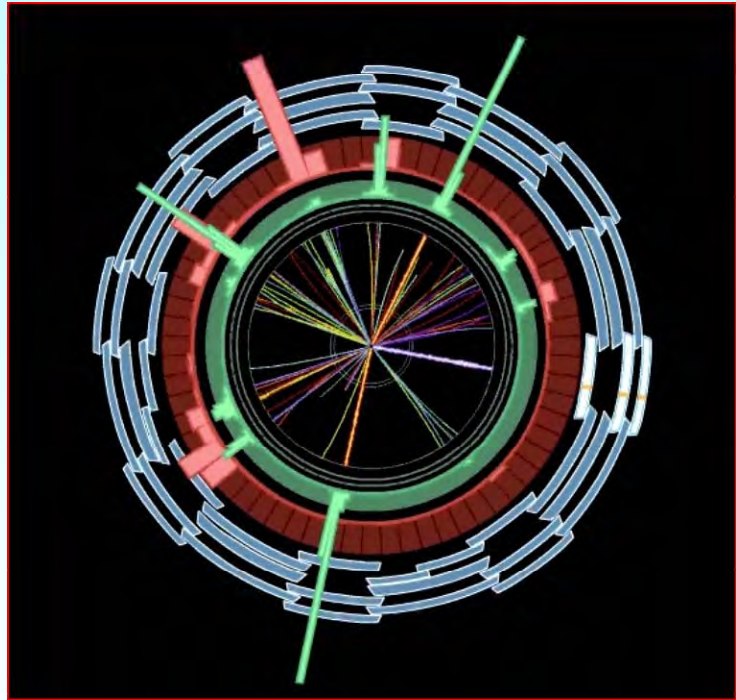
## Black Hole

Signature:

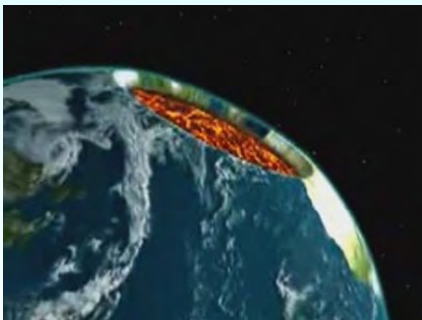
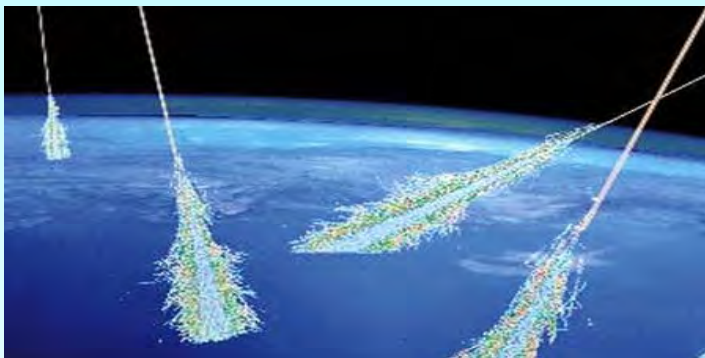
Many particles and particles with a high energy and with a large angle with respect to the proton direction.



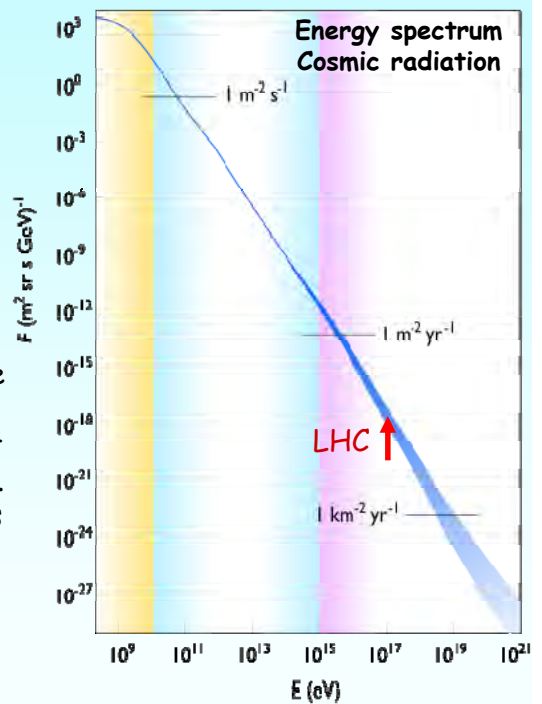
The holes will disappear after  $10^{-26}$ s according to the theory (if they are produced).

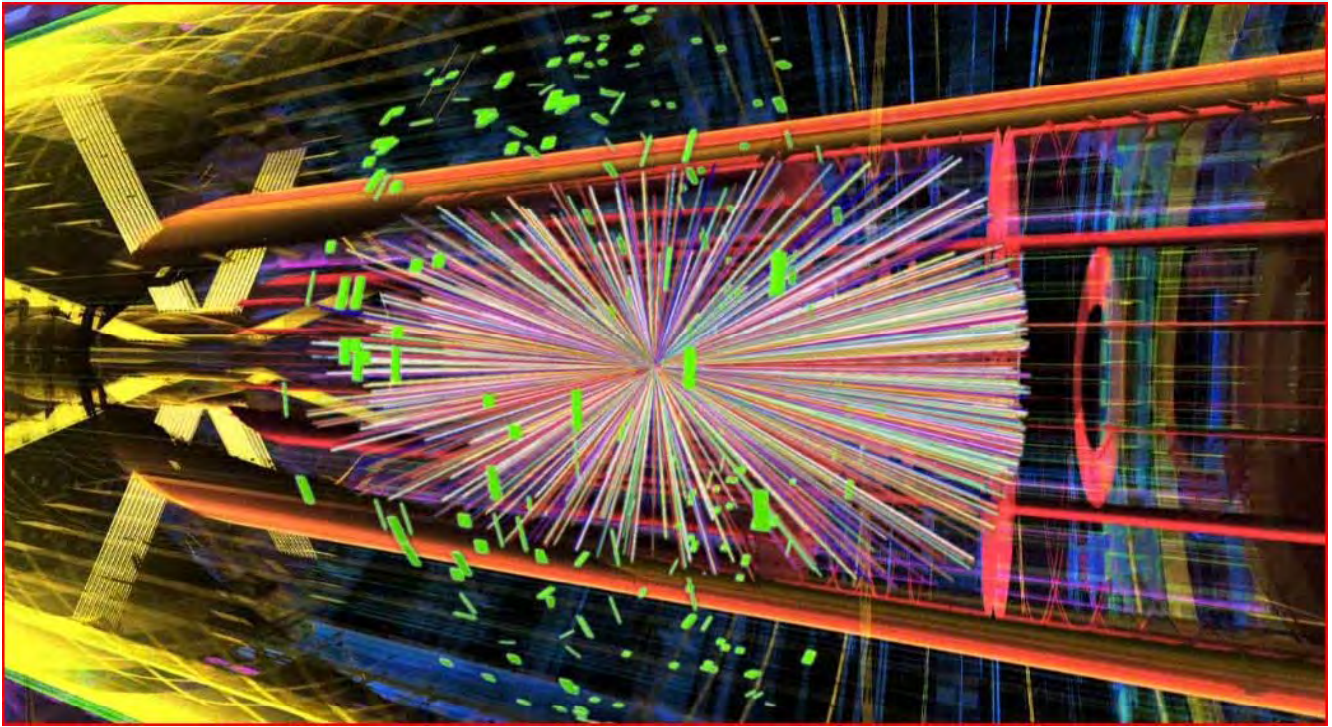


## Black holes = The end of the world ?



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.





### 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** ?

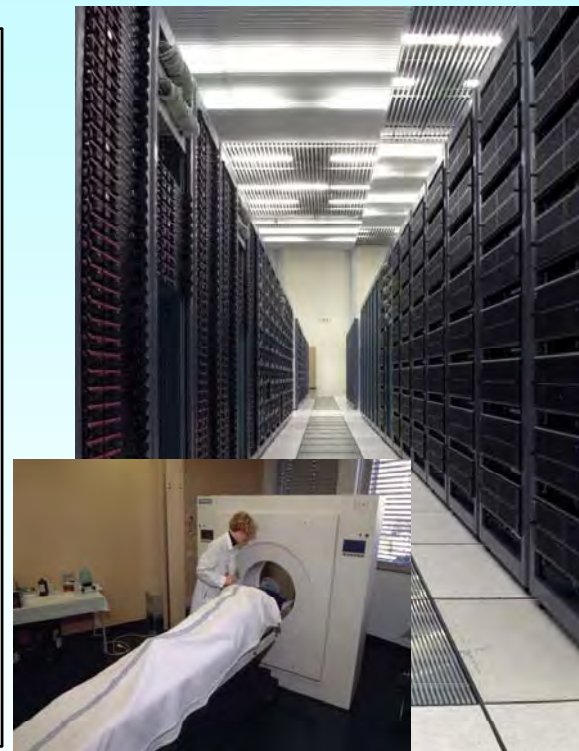
LHC can perhaps give the answer



## 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 world's 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.

