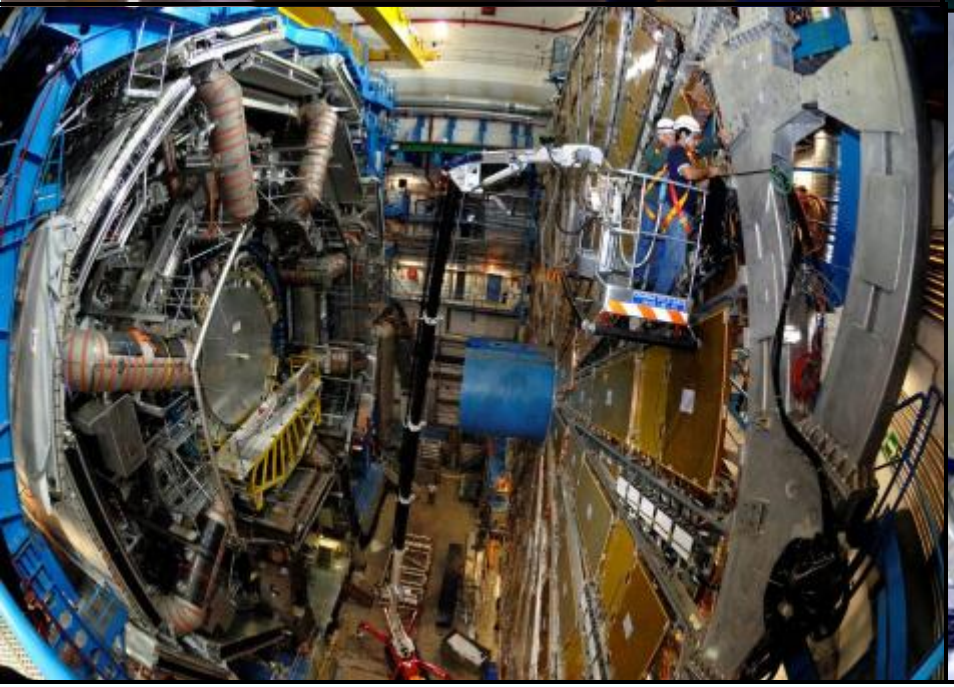
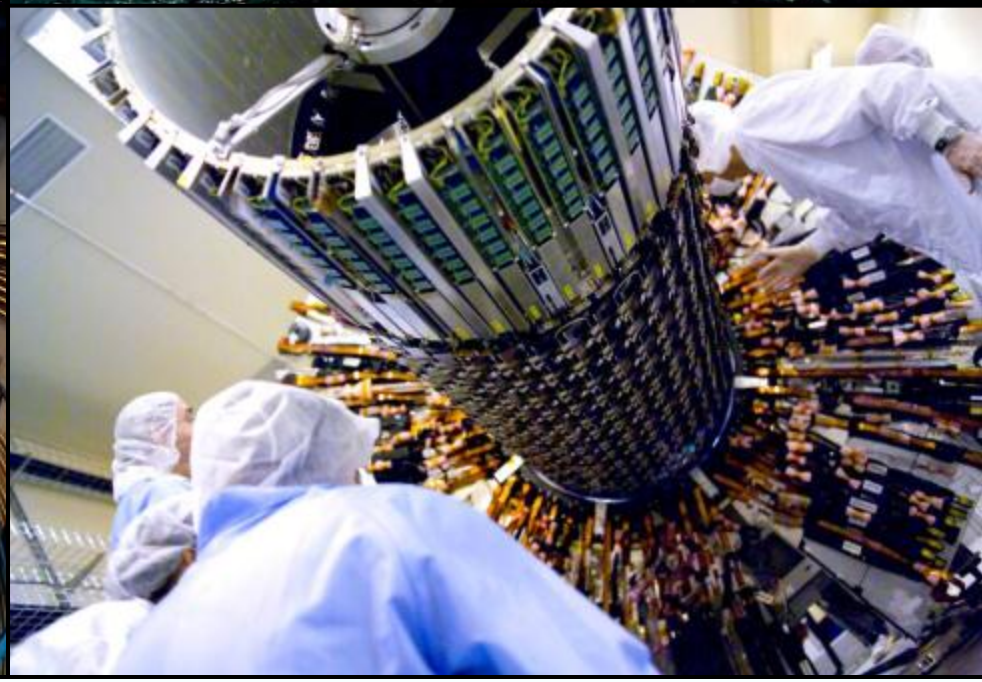
LHC & ATLAS

The largest particle physics experiment in the world

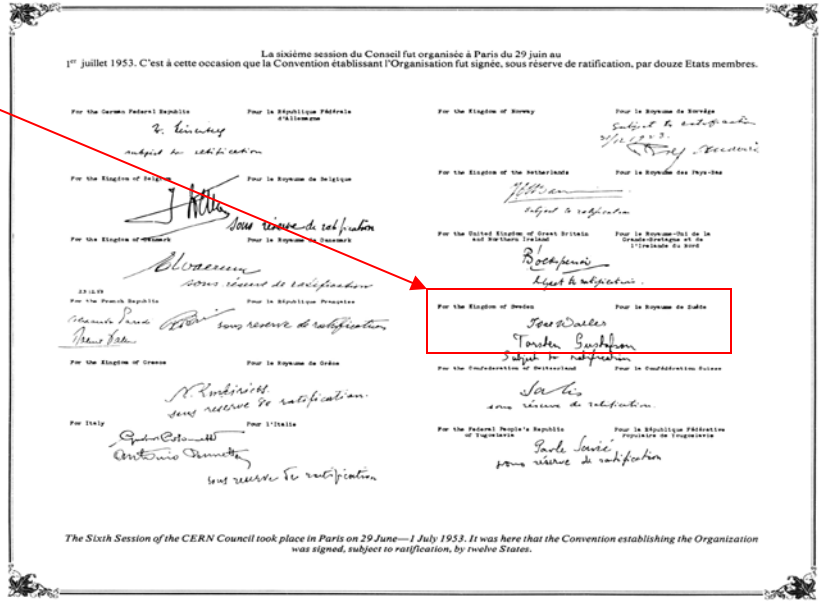




CERN – A laboratory for the world

Torsten Gustavson

CERN was founded in 1954



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)

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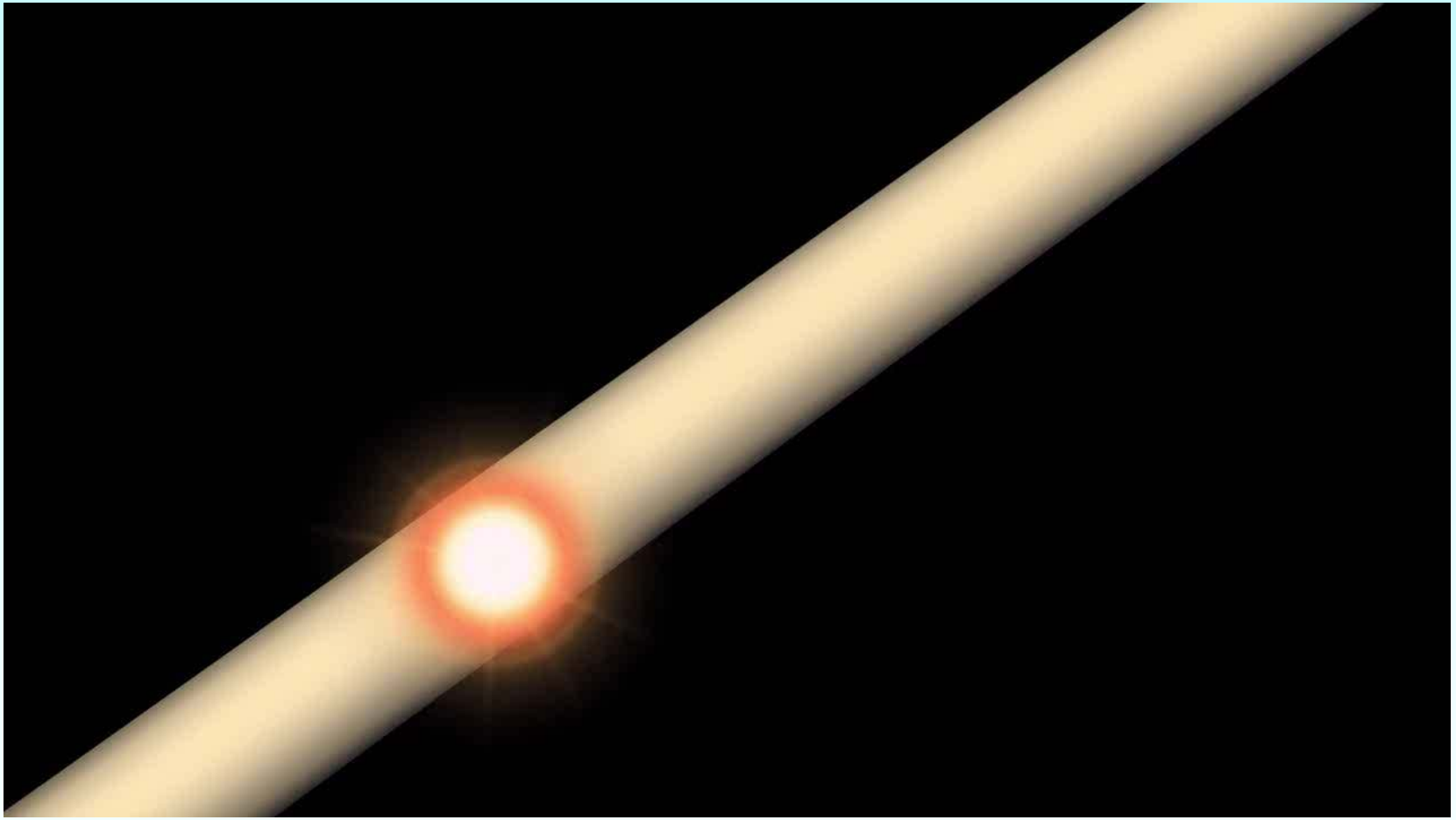
- The proton velocity is 99,999999991% of the speed of light.
- One billion collisions per second.
- The stored energy in one beam is 360 MJ. (360MJ ~ energy of a train travelling at 150 km/h or of an explosion of 77 kg of TNT).

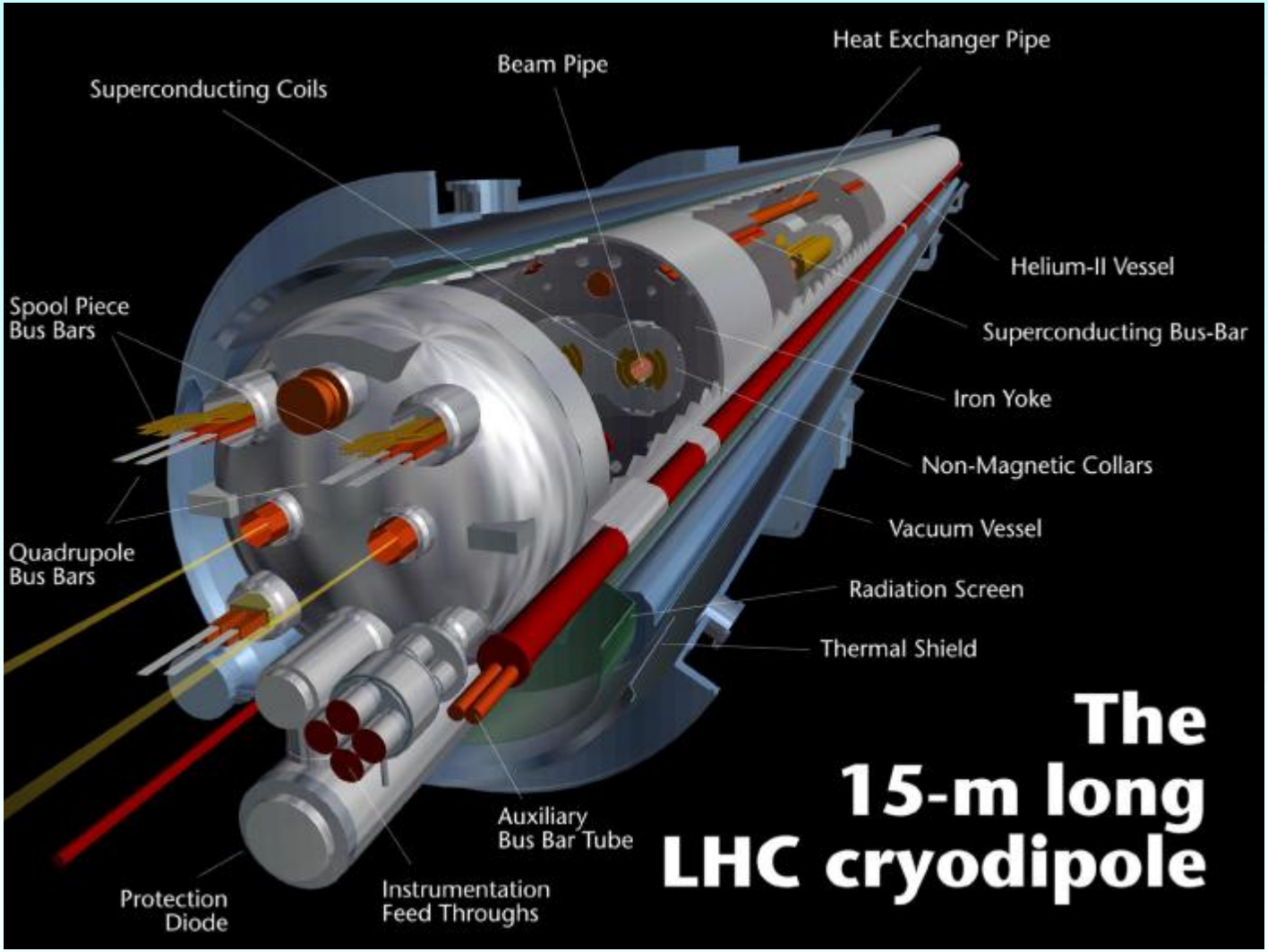
The accelerator complex at CERN



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

In the LHC accelerator tunnel

The magnets that bend the proton beams.



1232 dipole magnets

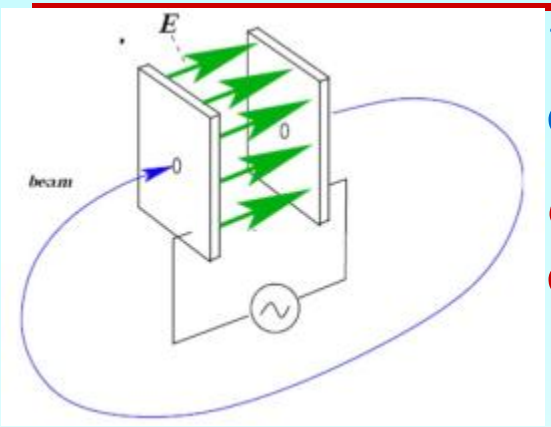
15 m long
35 ton heavy

Magnetic field:
8.3 Tesla

120 tonnes of liquid helium (1.9 K)

Current:
11800 Ampere

The cavities provide the energy.



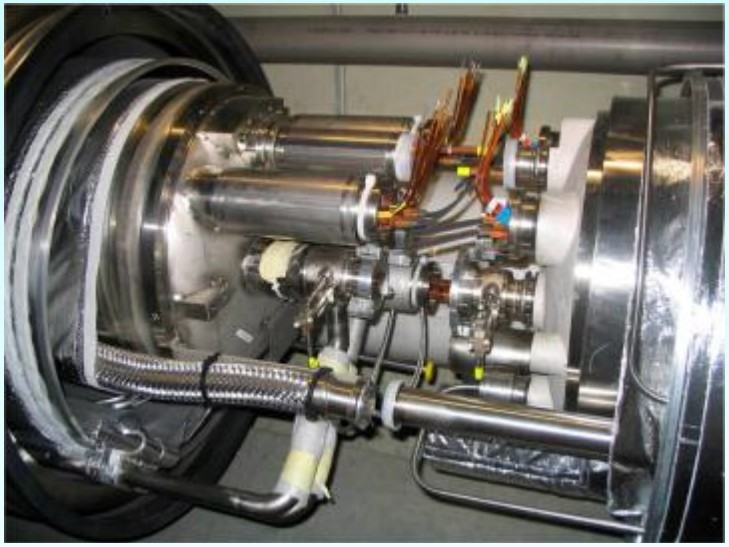
The magnets are used to bend the proton trajectories and to focus the beams.

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.

Three years of successful running!

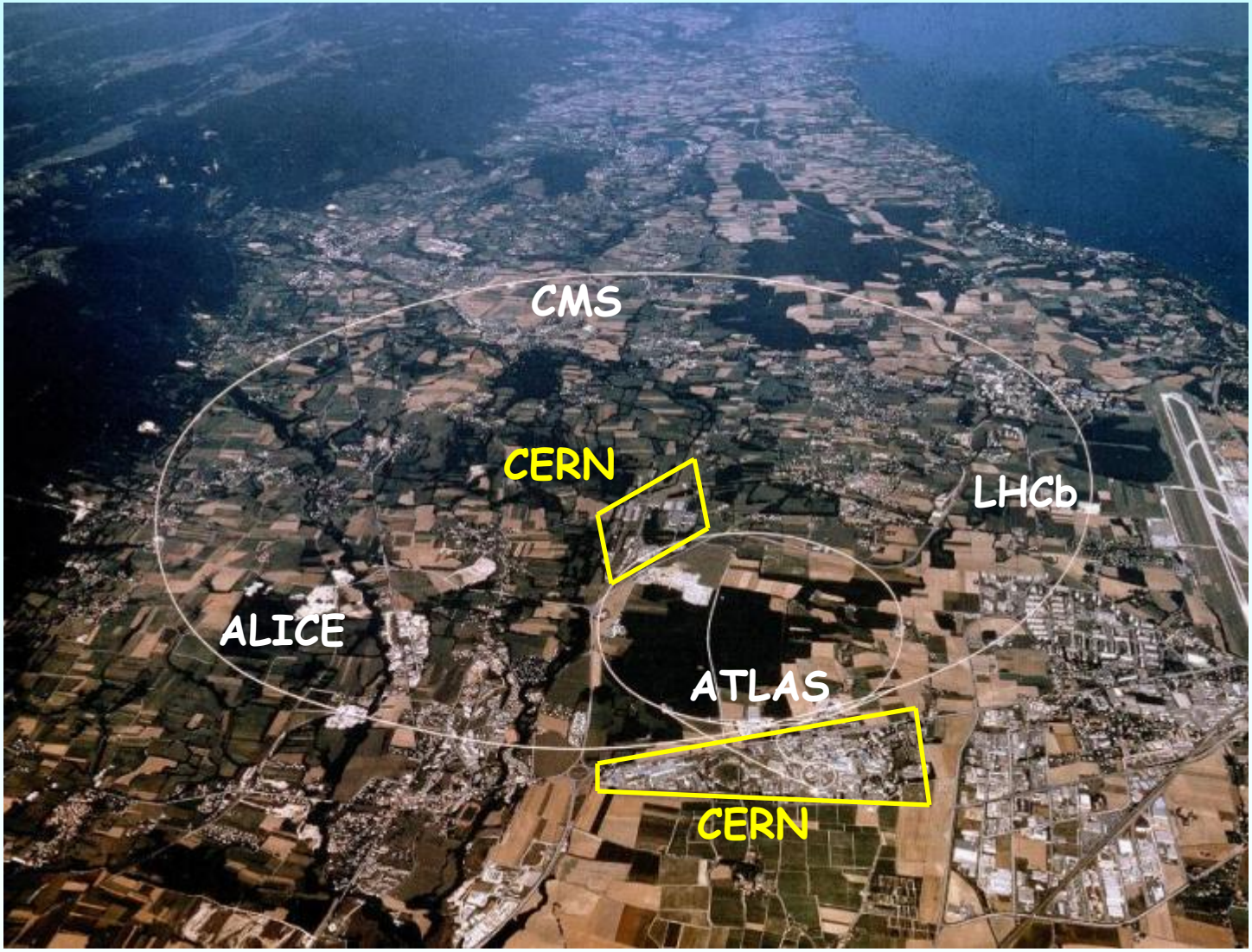
First collisions in ATLAS on the 23rd of November 2009.

Collision rate

Collision energy

Year	Energy (TeV)	Luminosity ($10^{34}cm^{-2}s^{-1}$)
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

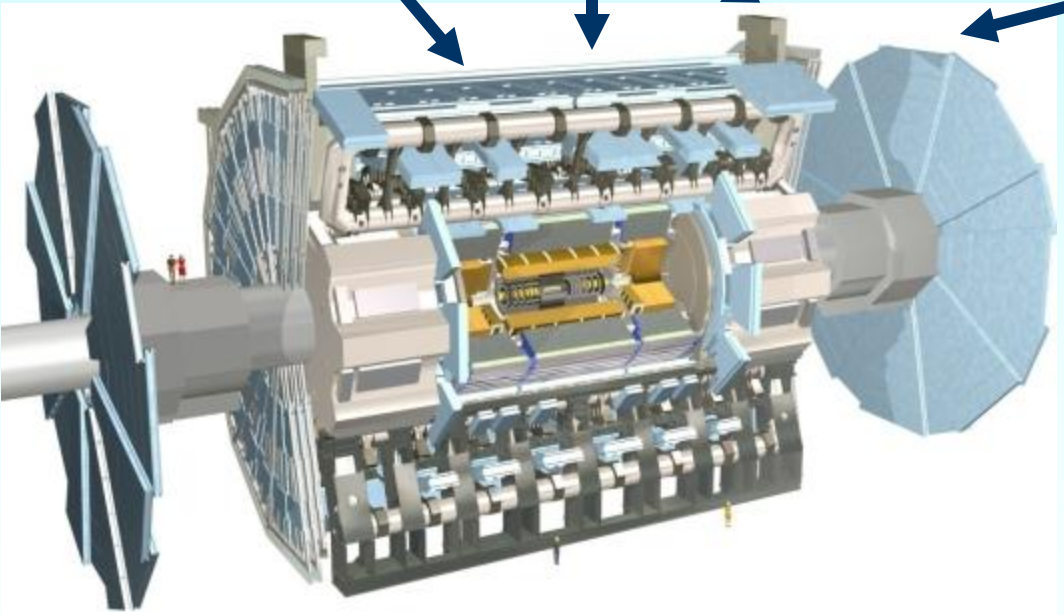
Swedish research groups

Uppsala Universitet

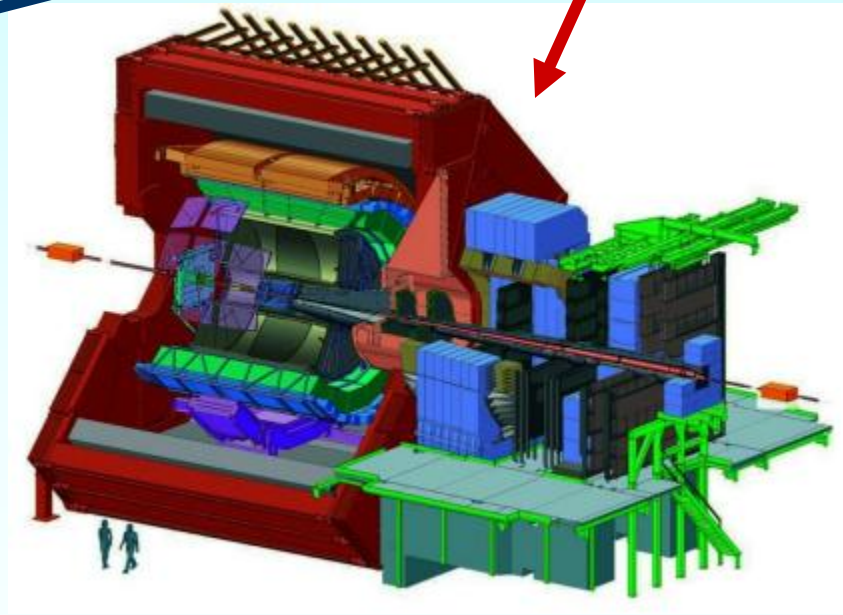
KUNGL TEKNISKA HÖGSKOLAN

Stockholms universitet

LUNDS UNIVERSITET

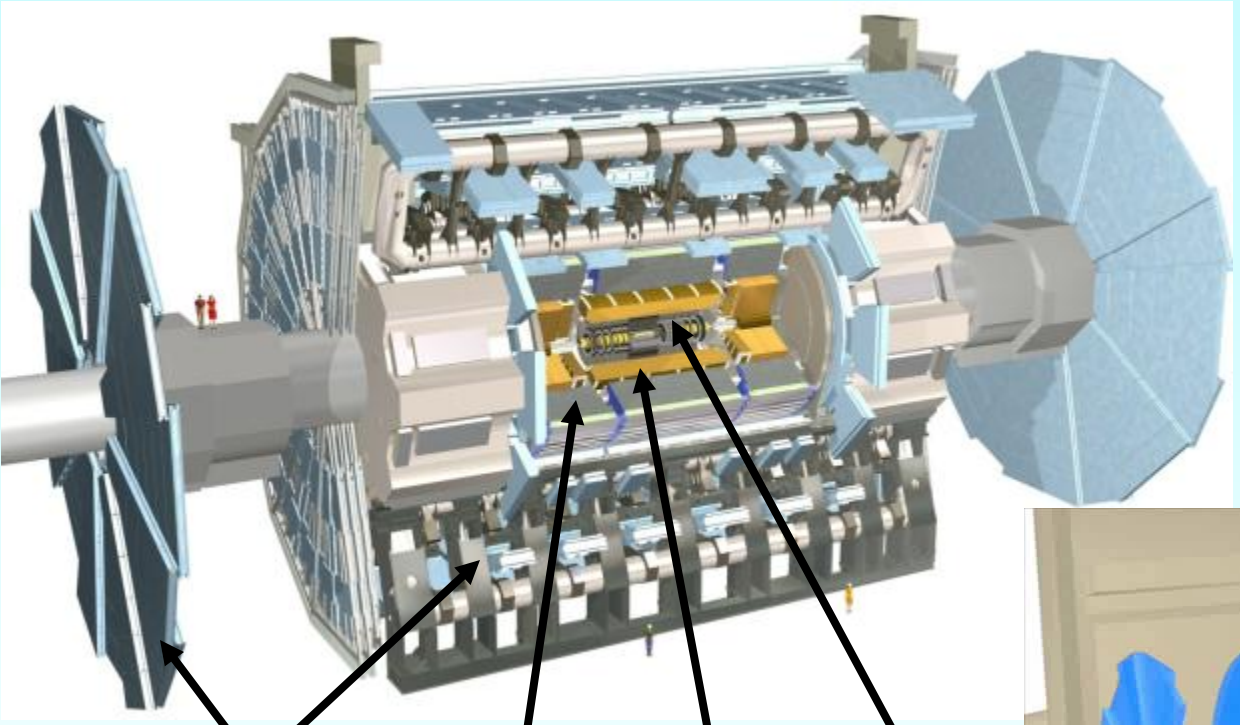


The ATLAS experiment



The ALICE experiment

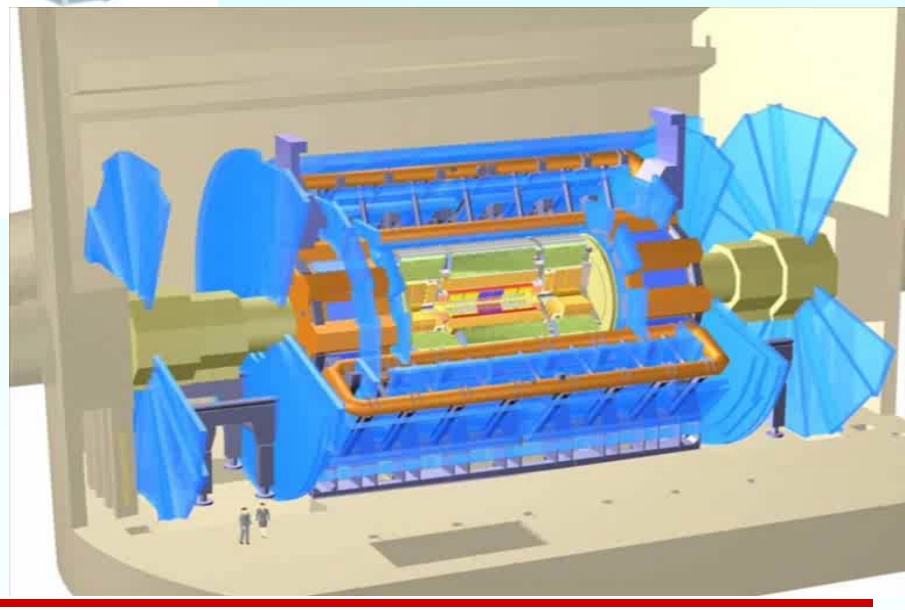
The ATLAS experiment



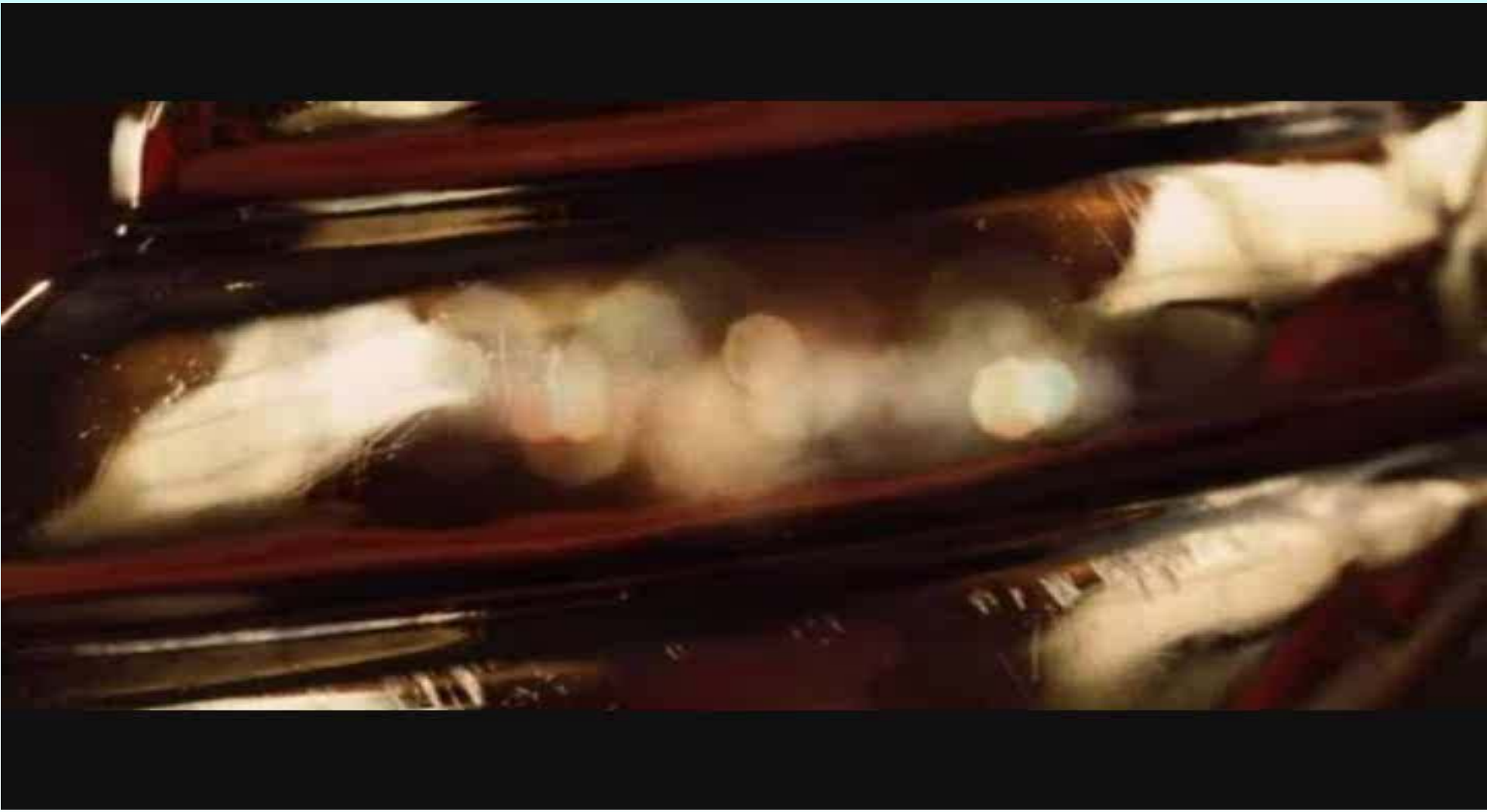
- Muon detector
- Hadron calorimeter
- Electromagnetic calorimeter
- Tracking detector

The ATLAS Experiment

- Length: 44m
- Diameter: 22m
- Weight: 6000 tonnes
- The collaboration
  2900 physicists
  (173 Univ., 37 Countries)



ATLAS in the movies



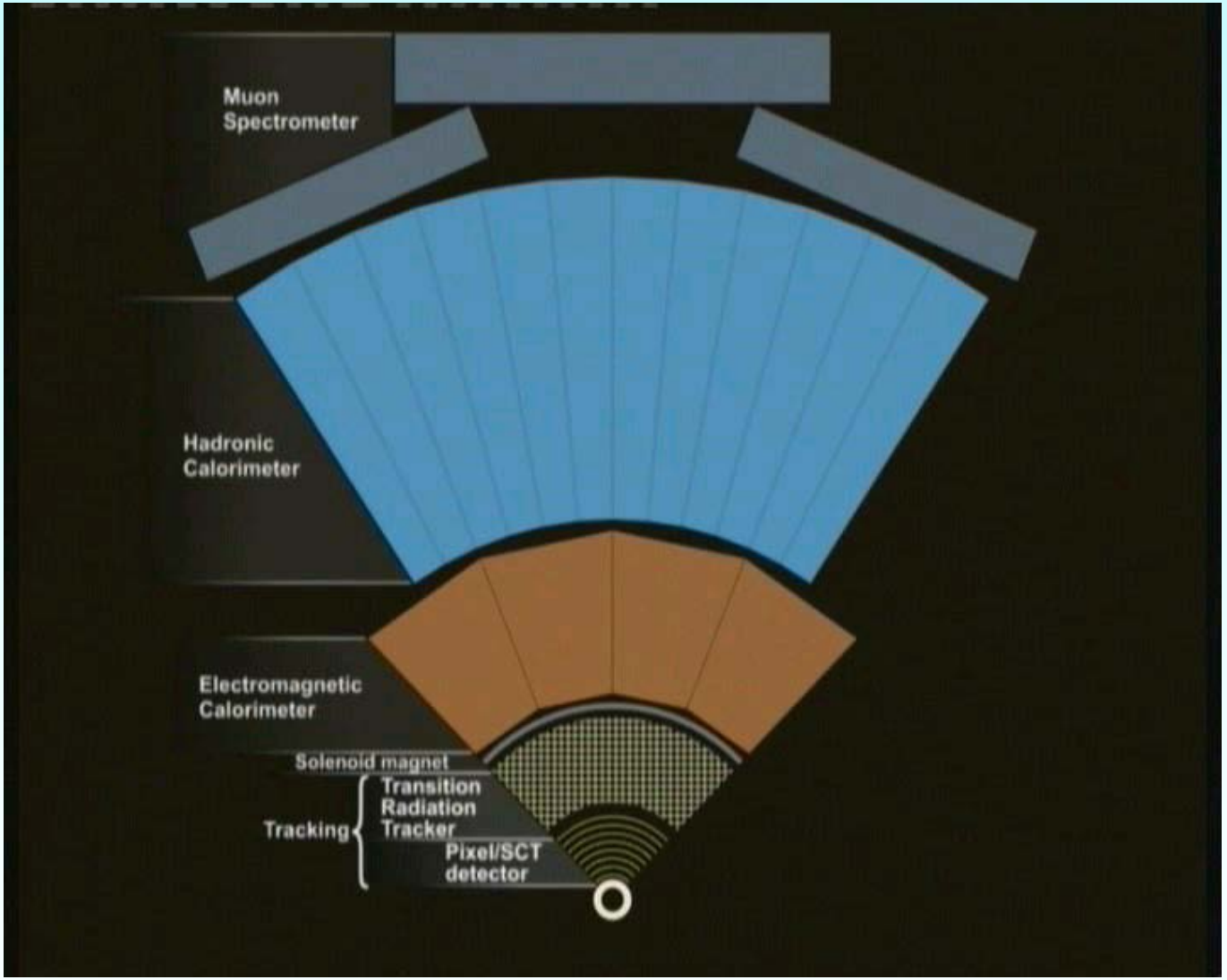
Detection of photons and electrons

Muon detector

Hadronic calorimeter

Electromagnetic calorimeter

Tracking detector



Detection of protons and neutrons

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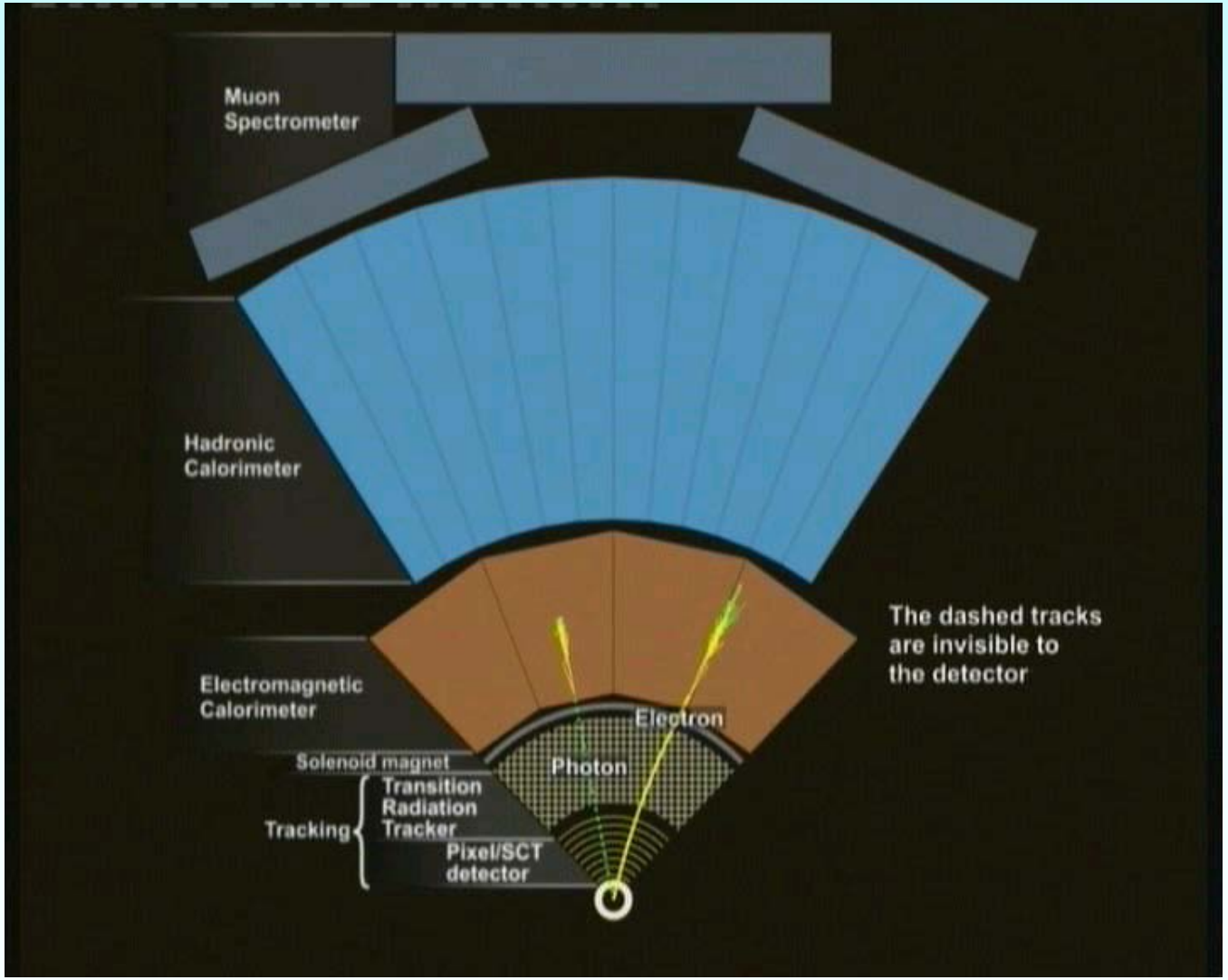
Electromagnetic calorimeter

Tracking detector



Detection of muons and neutrinos

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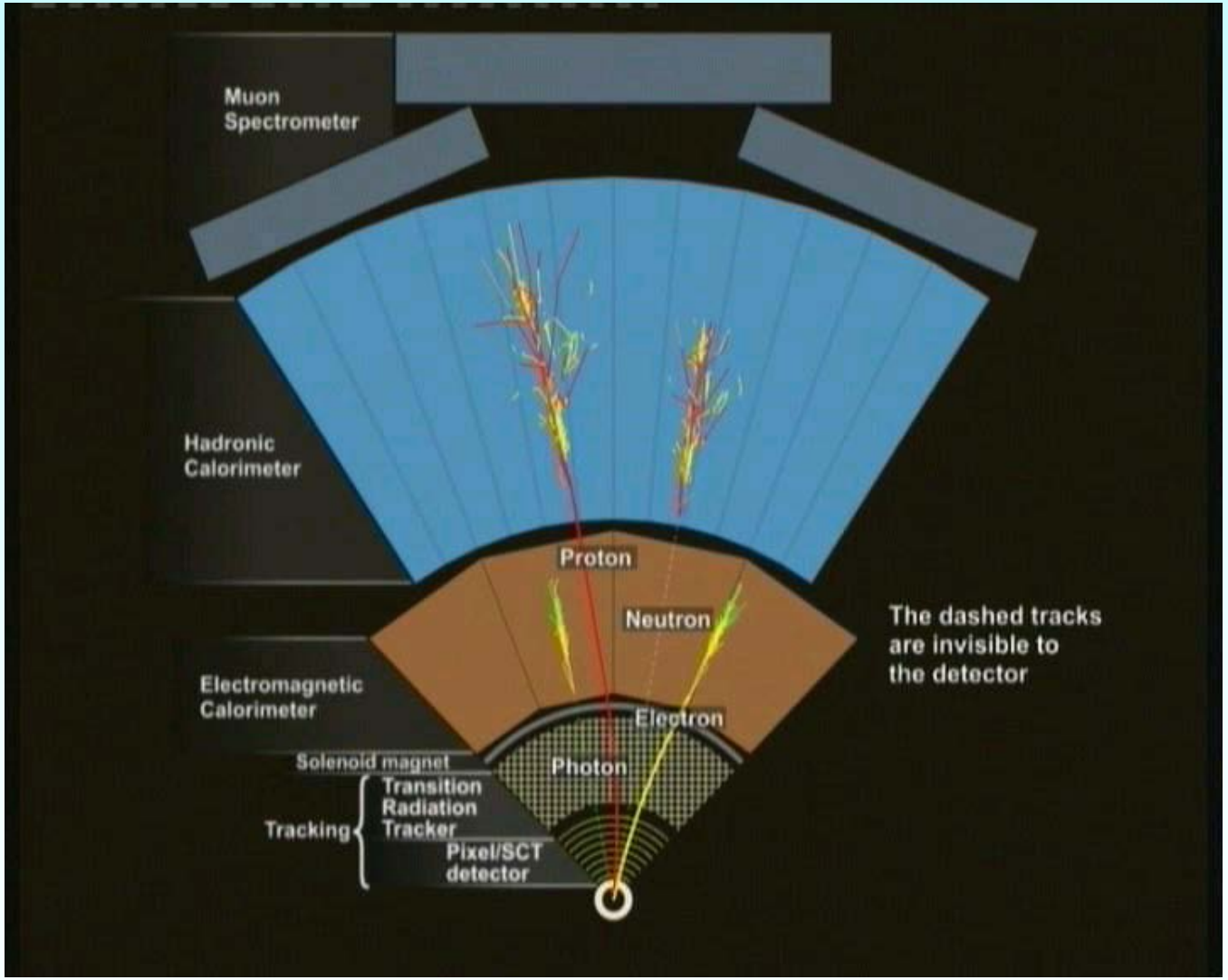
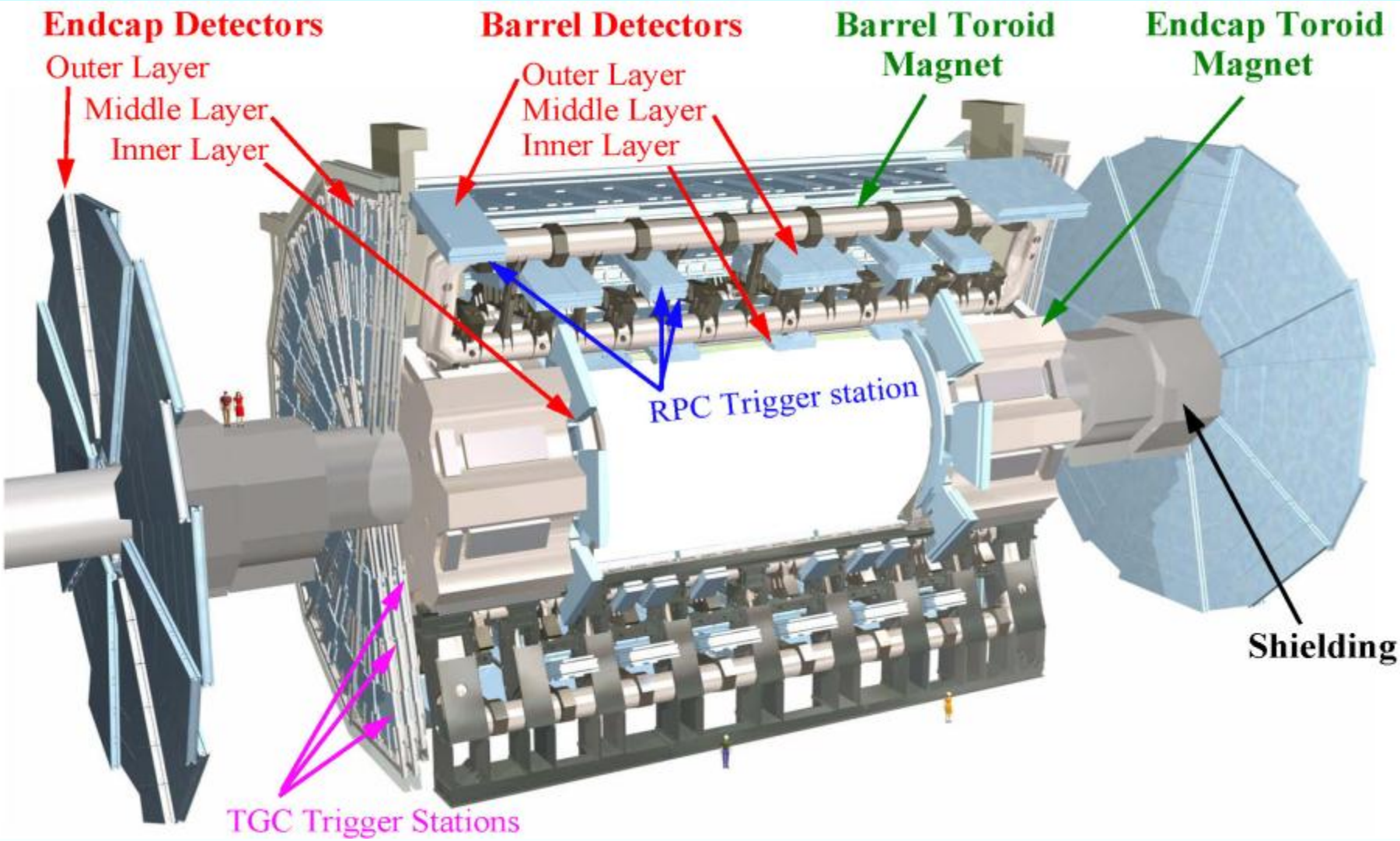


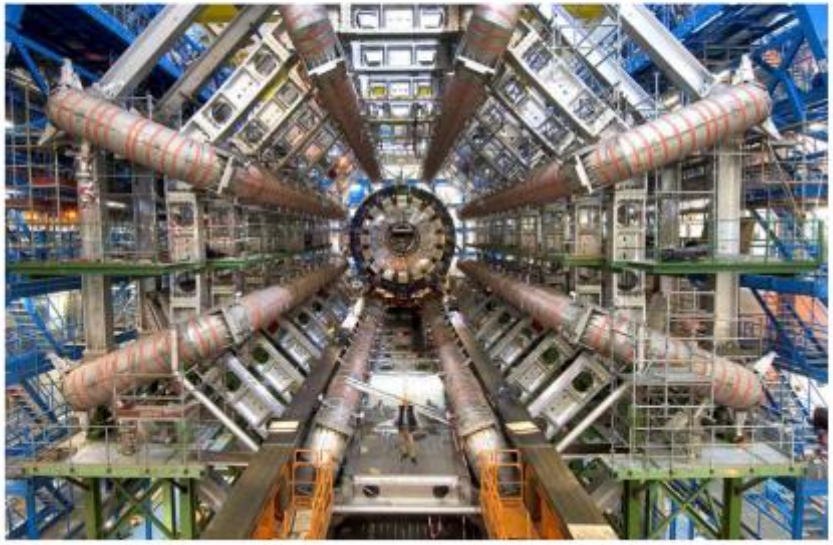
ATLAS: the muon system

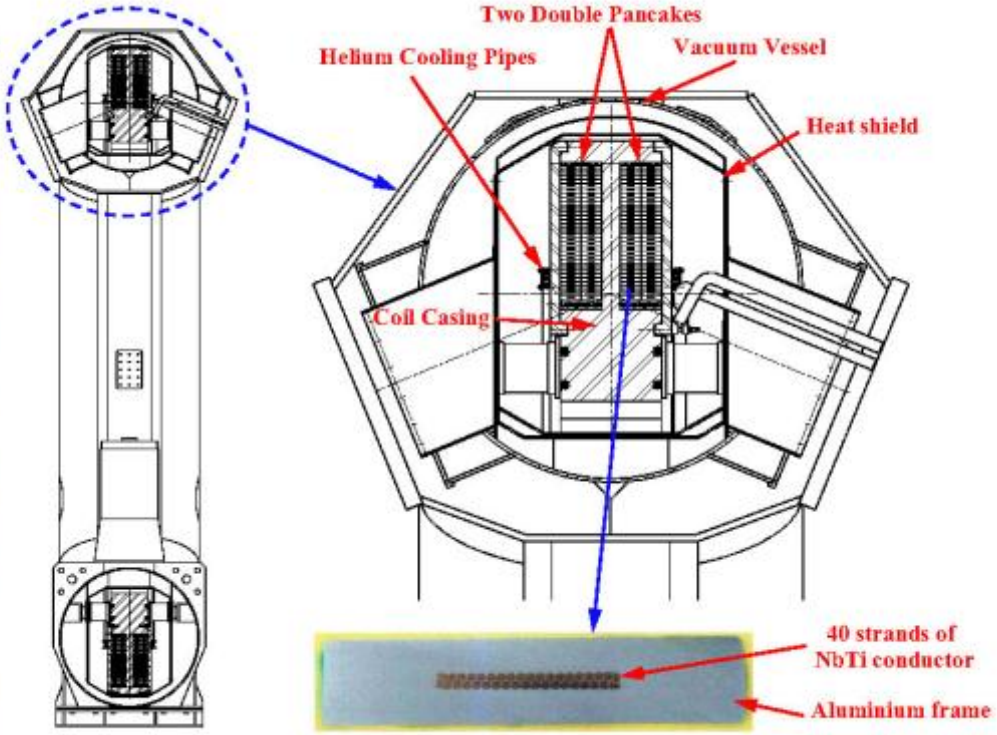


ATLAS: The 3 large toroidial magnets

The barrel magnet

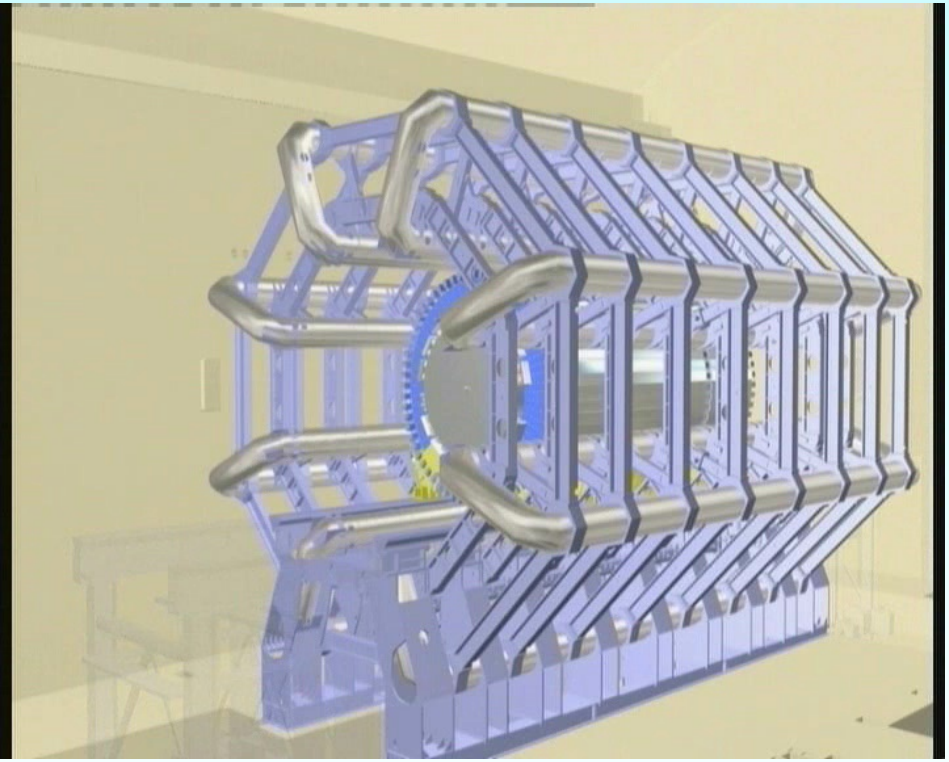
ATLAS has the worlds largest superconducting toroidal magnet that gives a peak field of 4 Tesla.



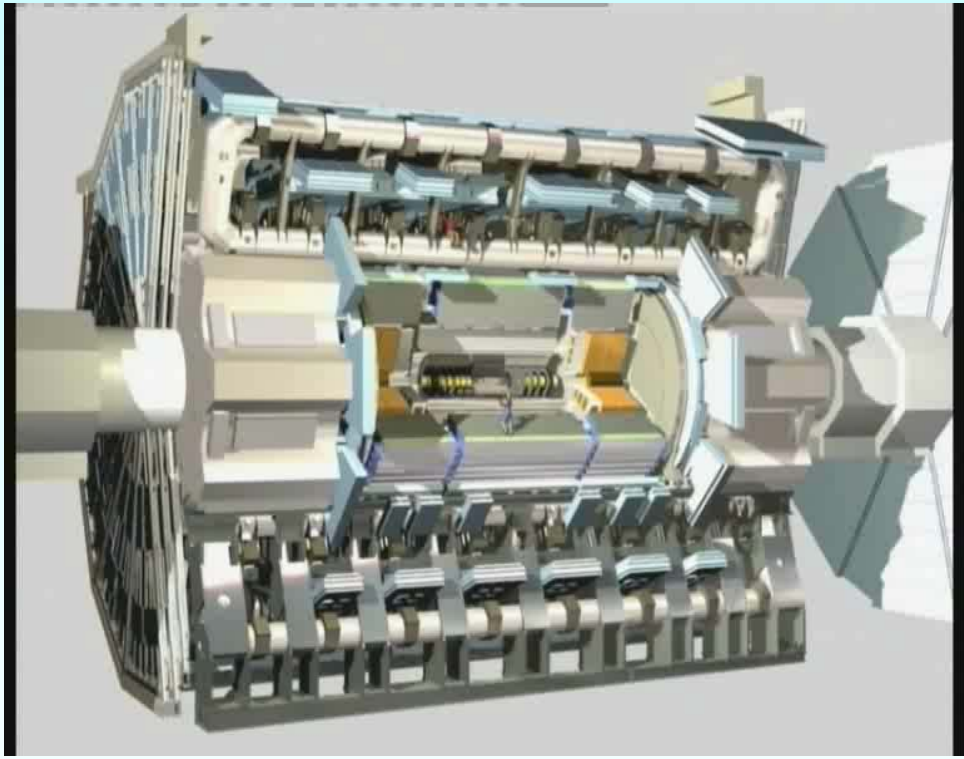


ATLAS: the muon detector

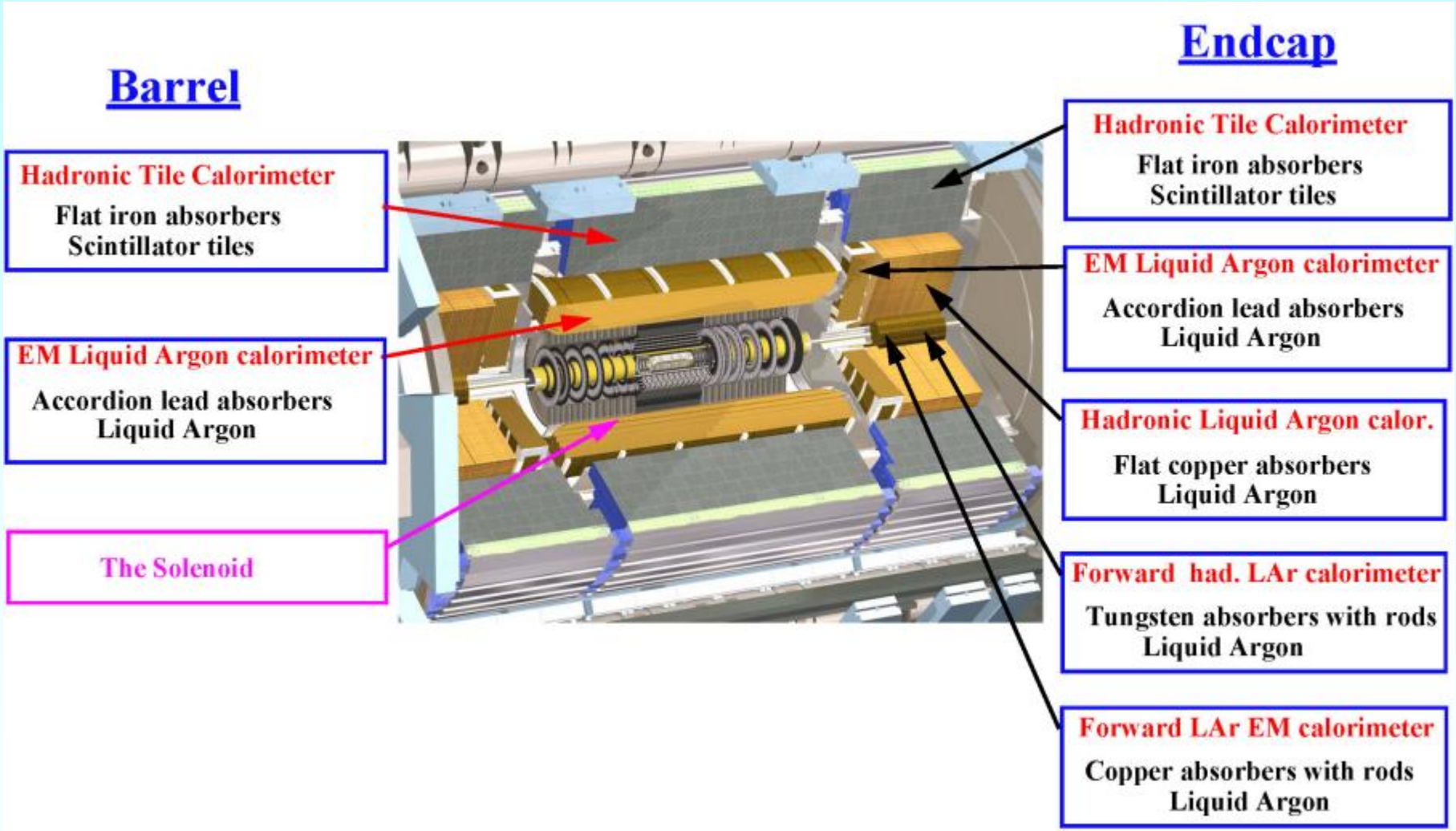
Installation of the muon detectors.



How do they work ?



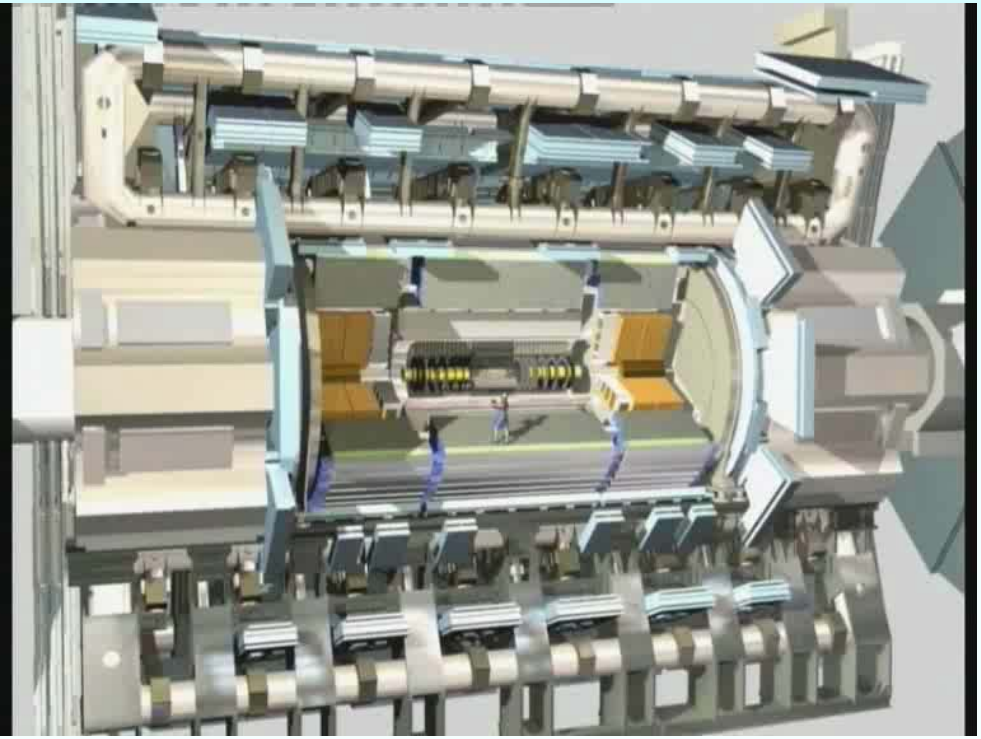
ATLAS: Calorimeters

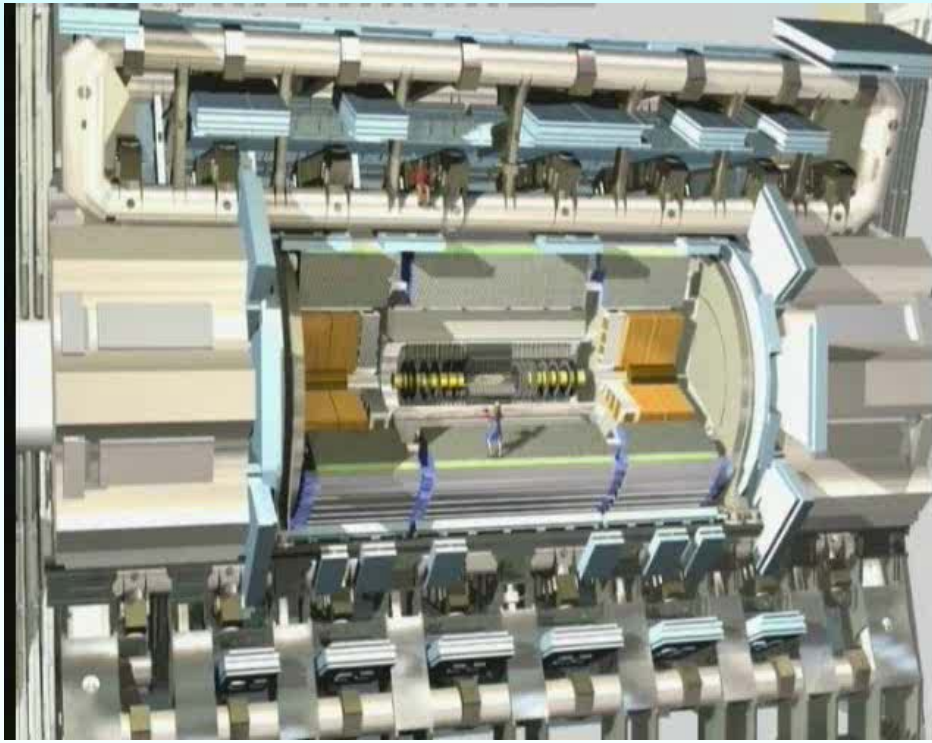


How does the calorimeter work ?

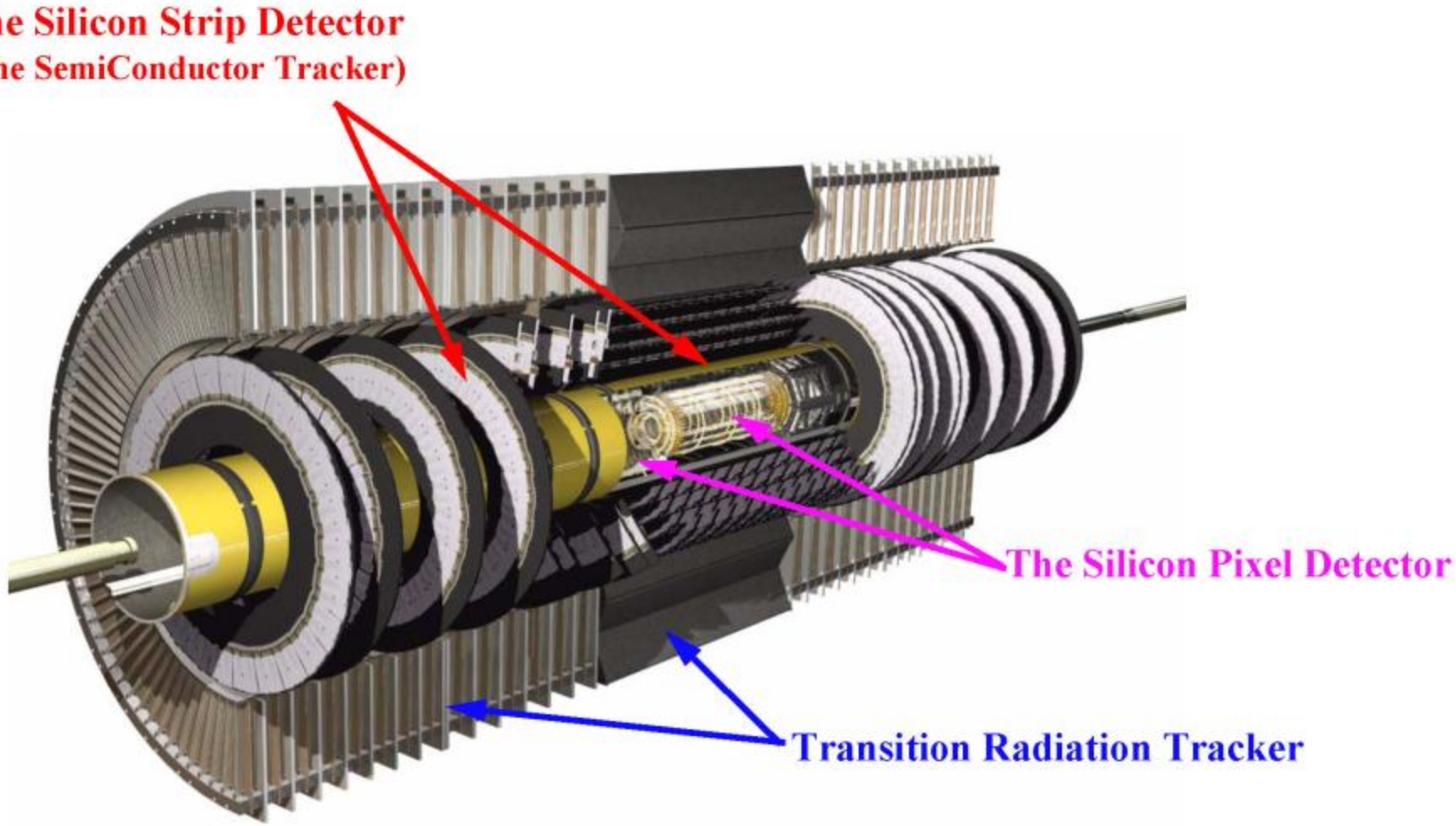
The electromagnetic calorimeter is used to study photons and electrons.

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





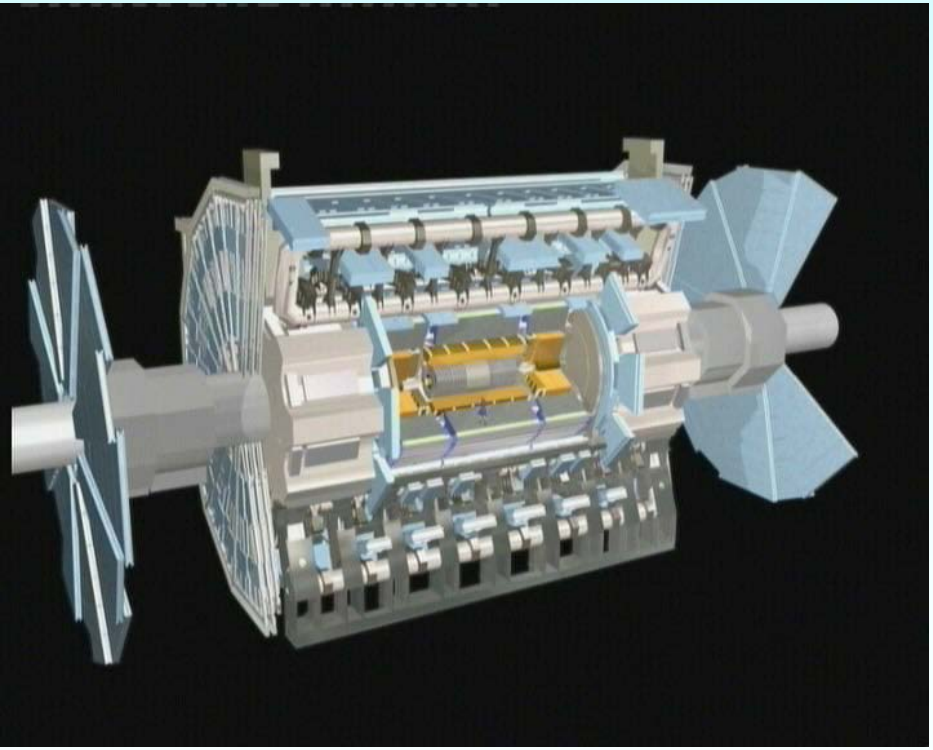
ATLAS: The Tracking Detector



The Transition Radiation Tracker

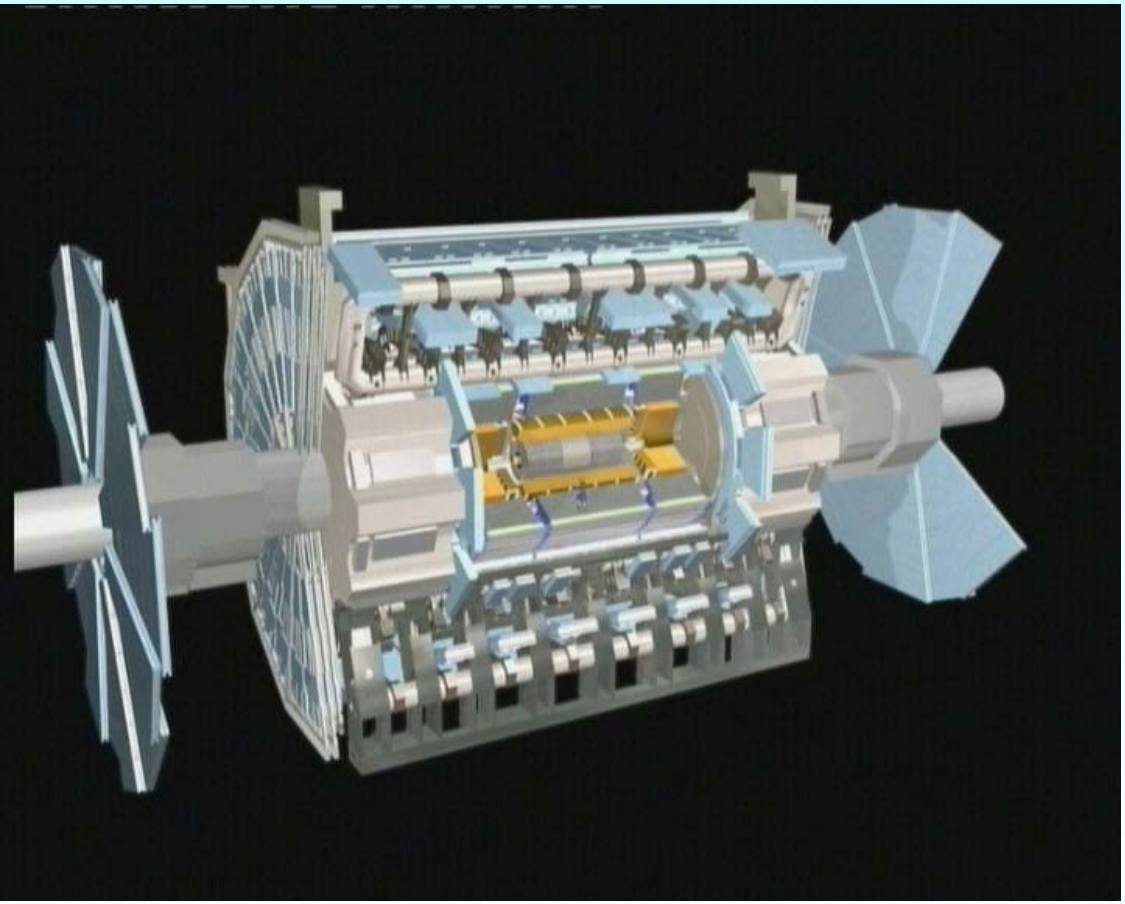
The Transition Radiation Tracker (TRT) is used to measure the tracks of charged particles and to identify electrons.

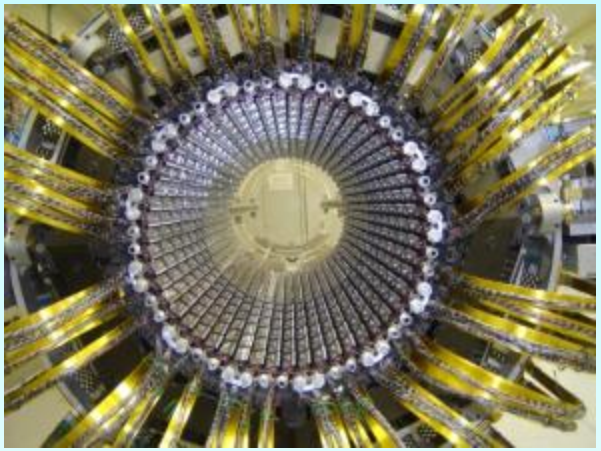
How does it work ?

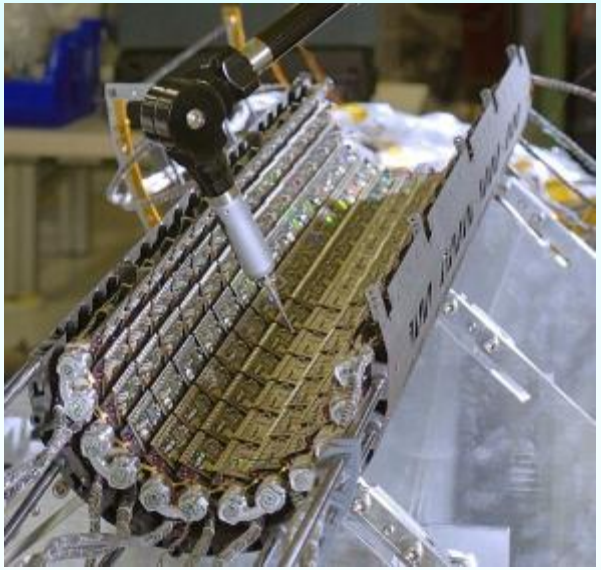


Building the detector

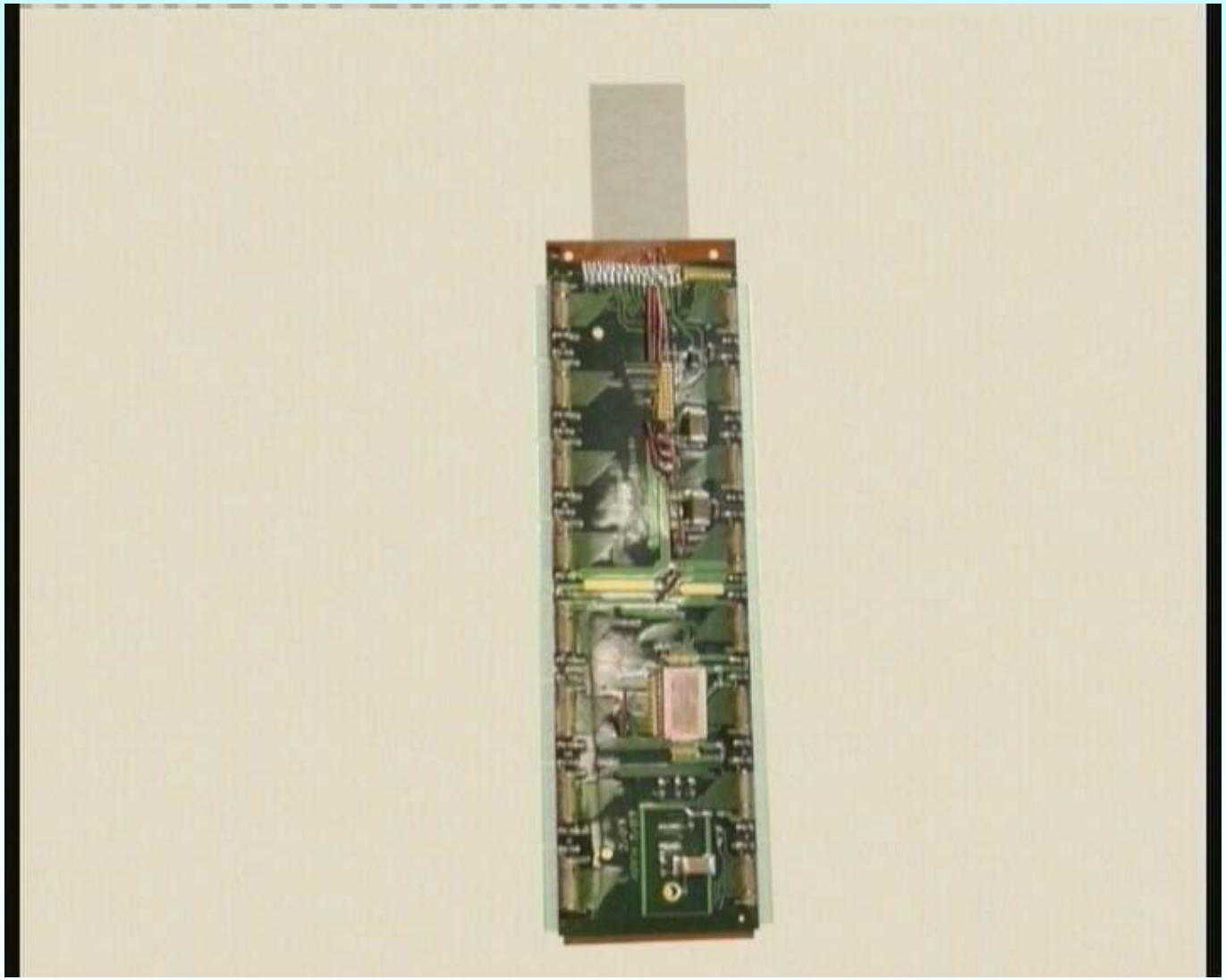
Silicon detectors in ATLAS



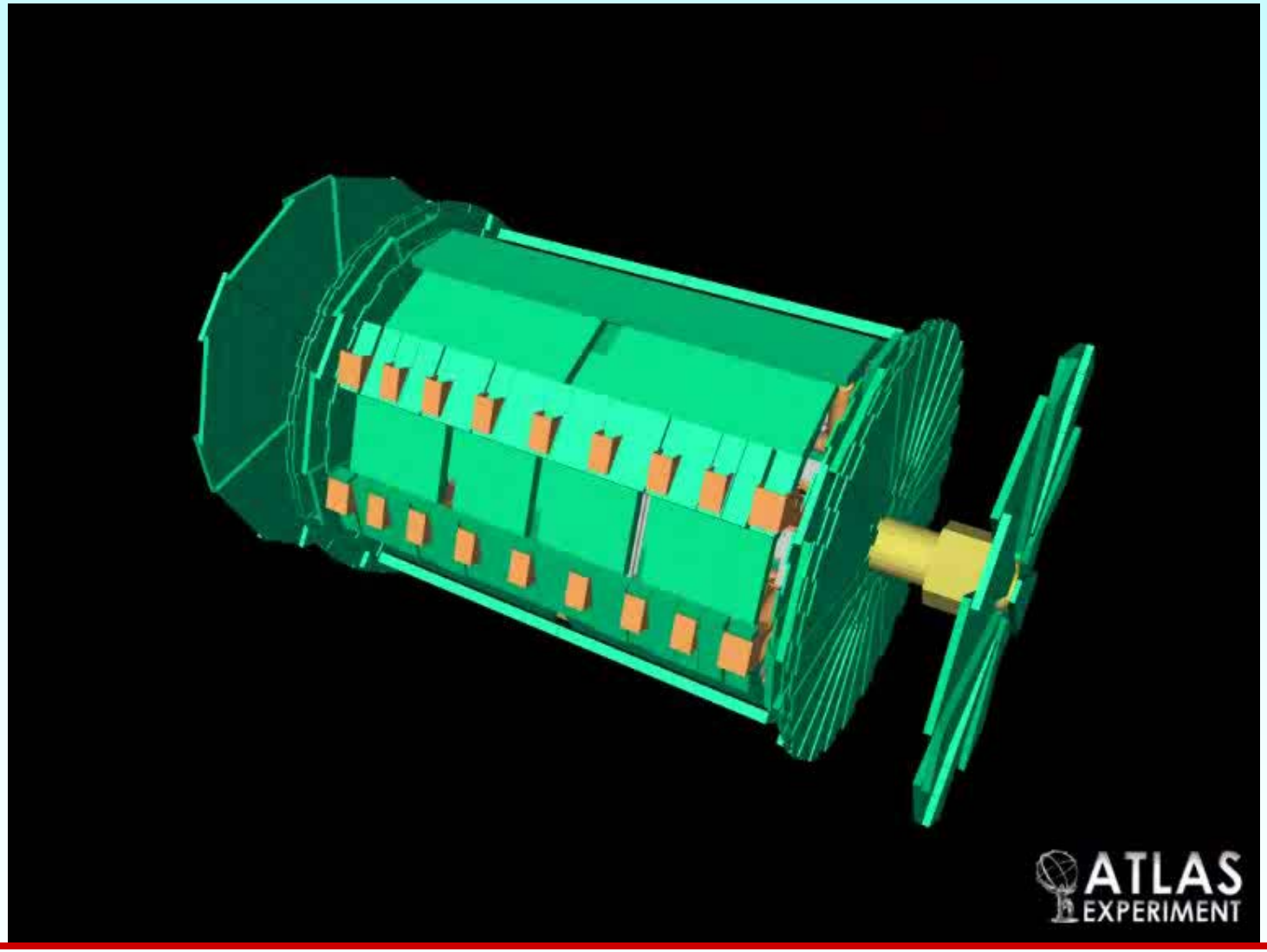




Silicon detectors: How do they work ?



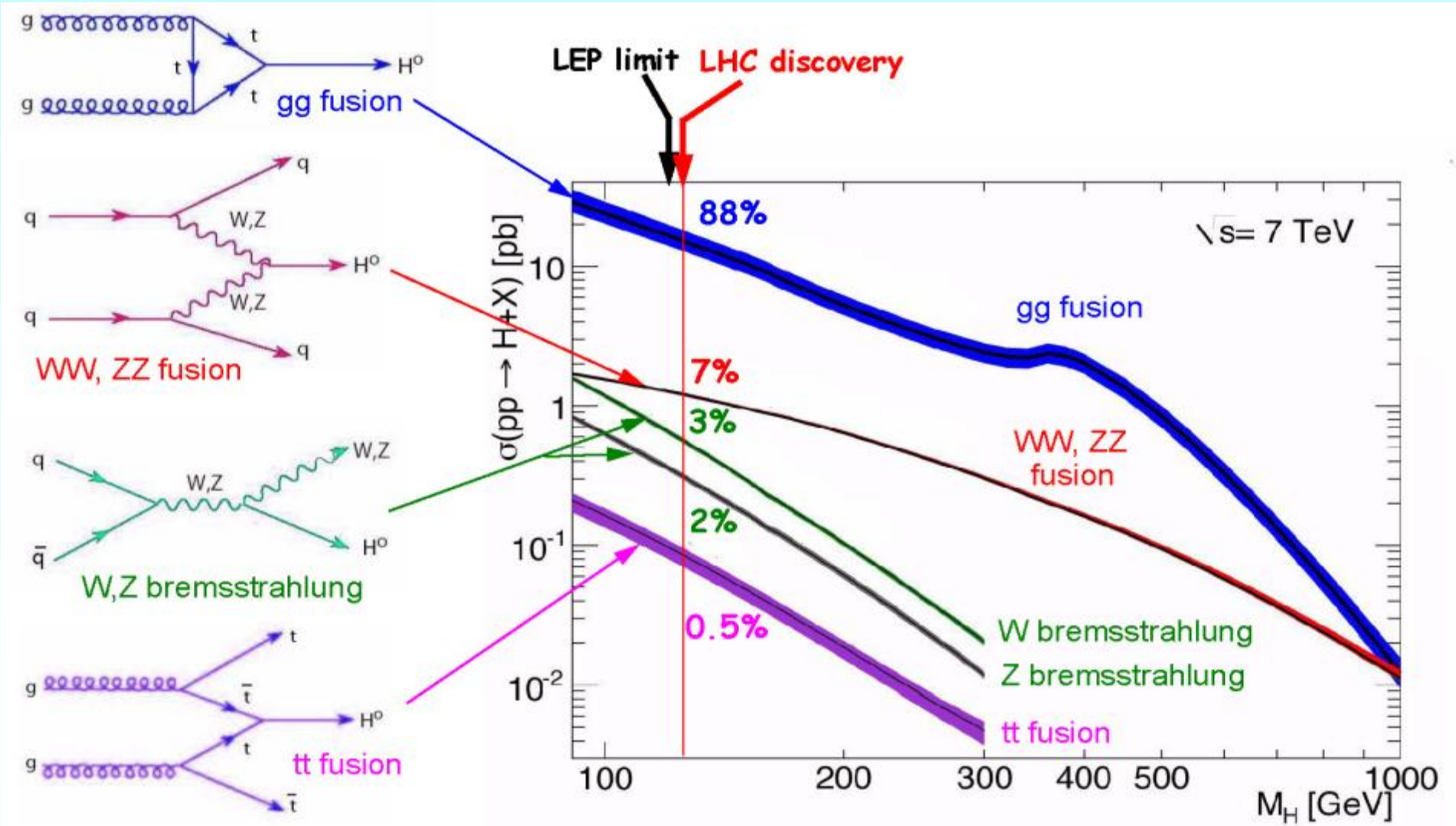
One of the first collision in ATLAS



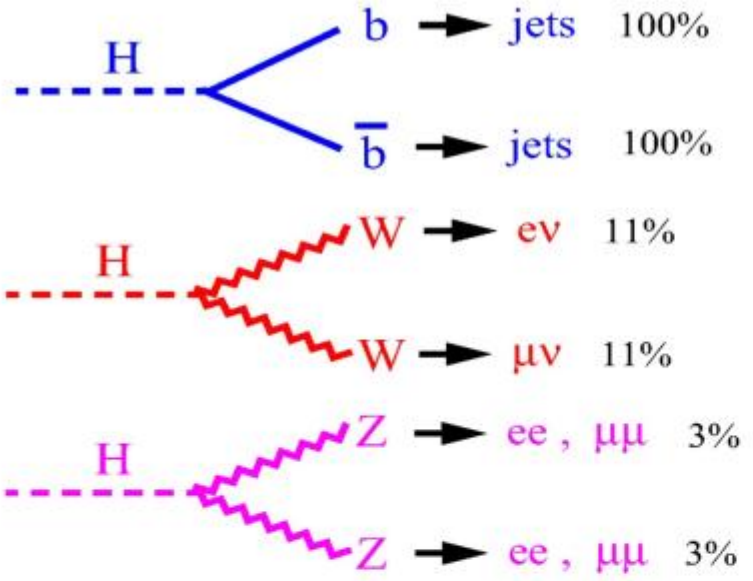
Physics studies: The Higgs particle

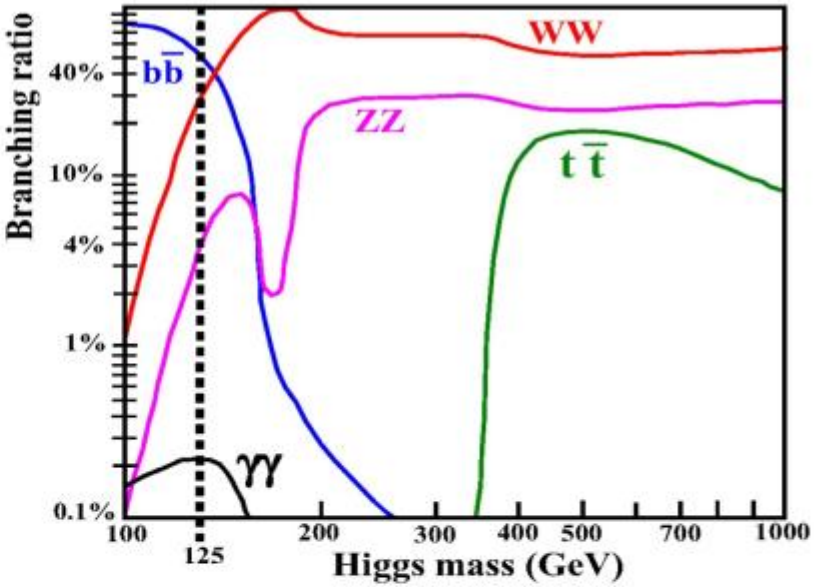
On the 4th of July 2012 the ATLAS and CMS experiments announced the discovery of a new particle at CERN.

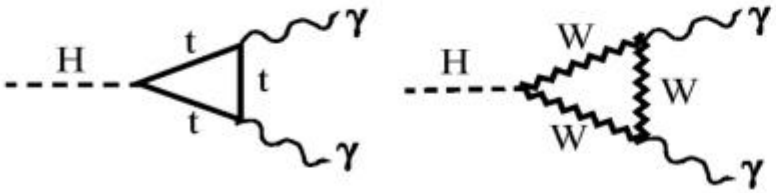
Higgs boson production



Higgs boson decay







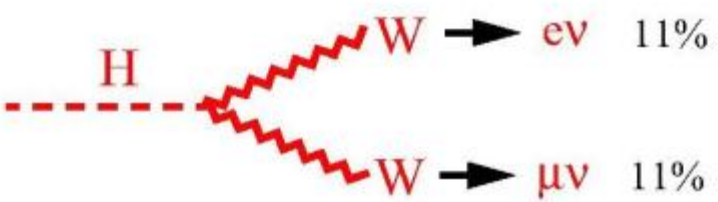
$H \to b\bar{b}$ ⇨ huge background

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

$H \to ZZ \to llll$ ⇨ small Z BR

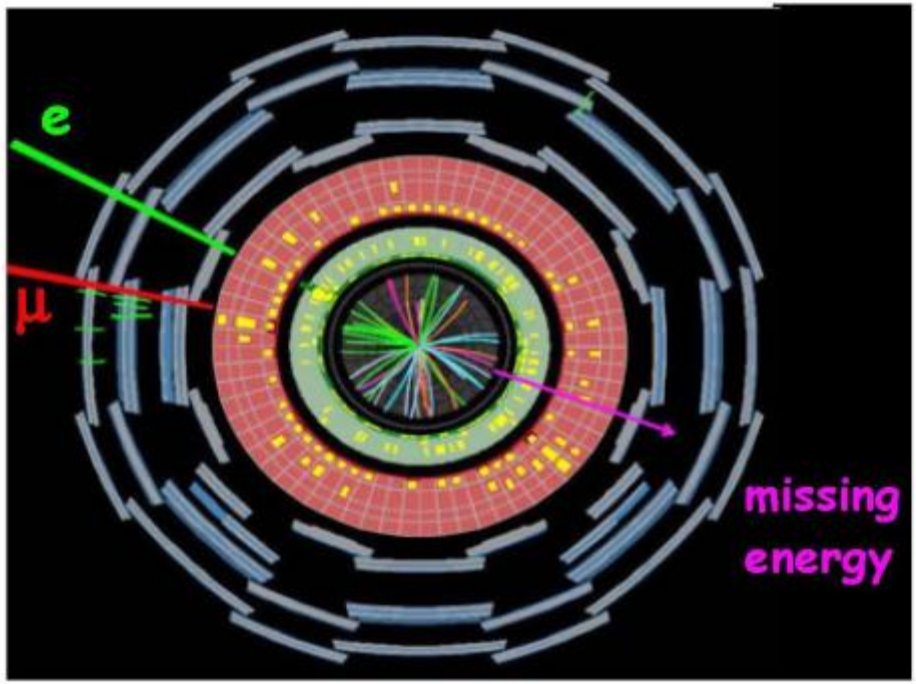
$H \to \gamma\gamma$ ⇨ small H BR

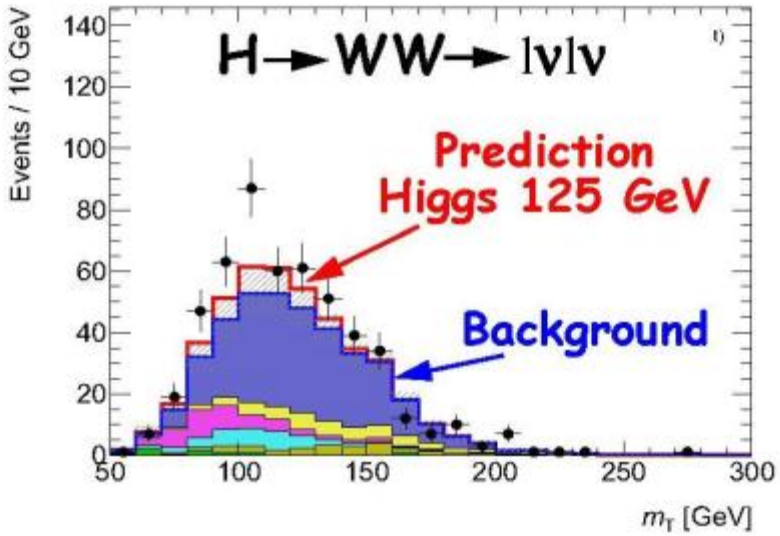
Higgs bosons to WW



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

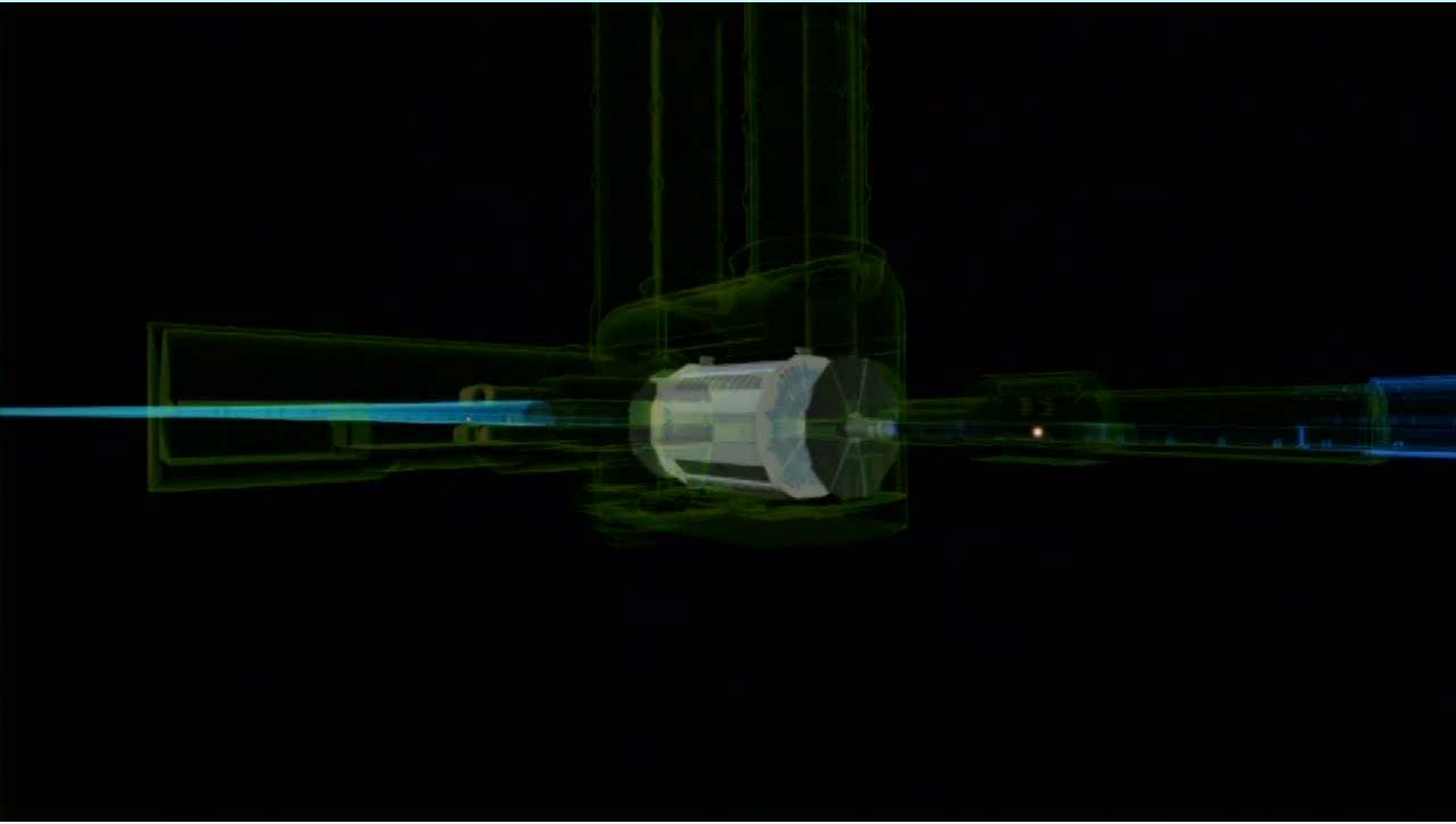
Large missing energy.



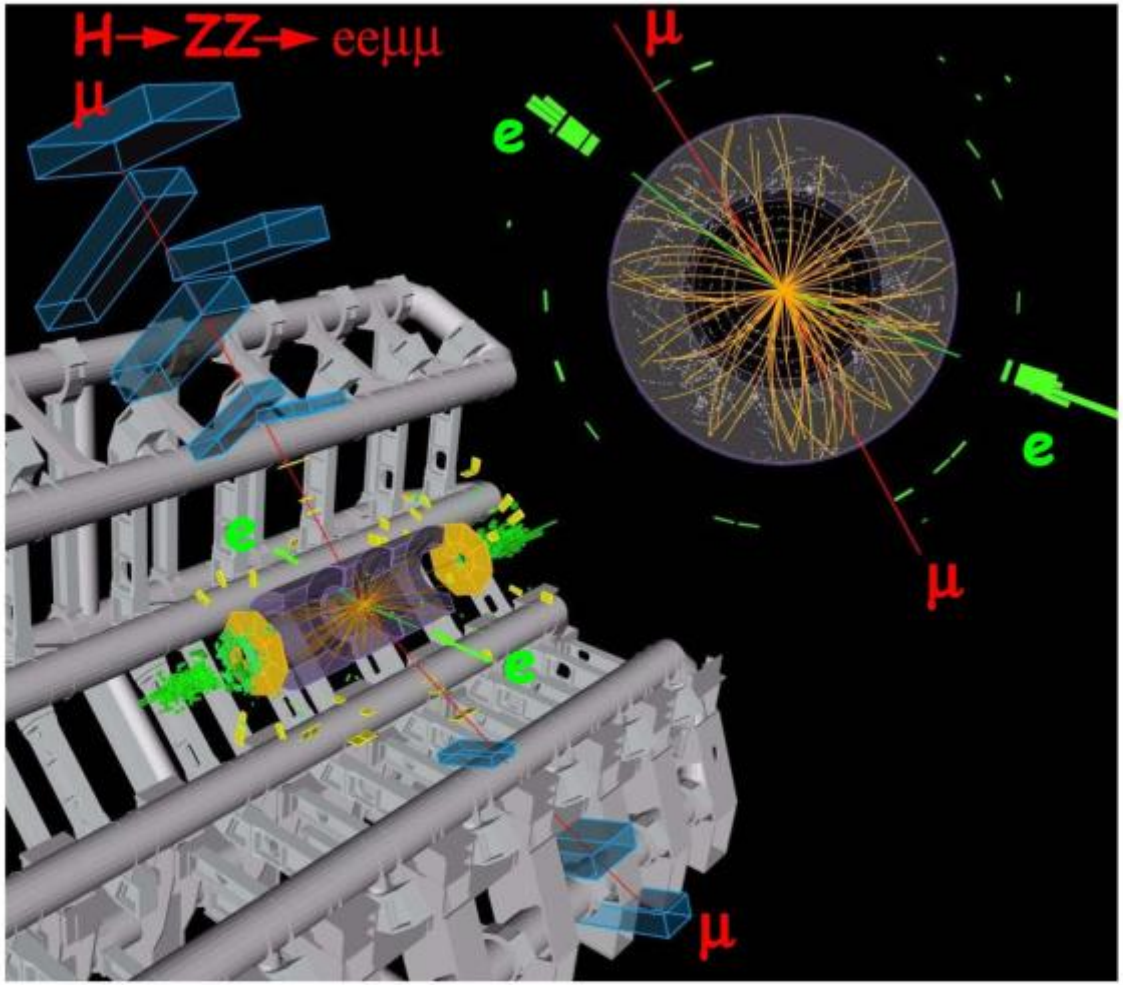


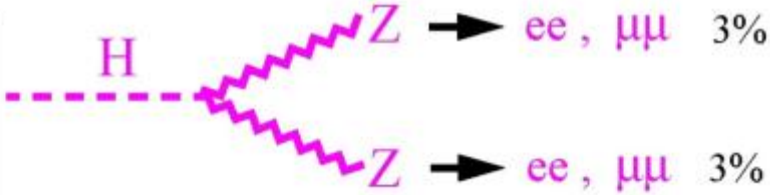
$$m_{\mathrm{T}} = \sqrt{(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - |\mathbf{p}_{\mathrm{T}}^{\ell\ell} + \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}|^2}$$

Higgs boson to ZZ ?

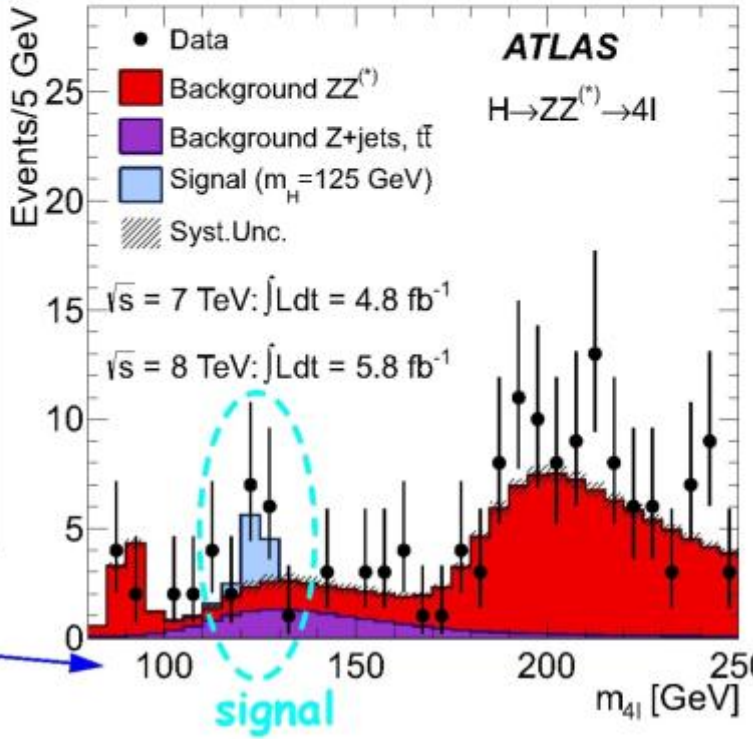


Higgs bosons to ZZ



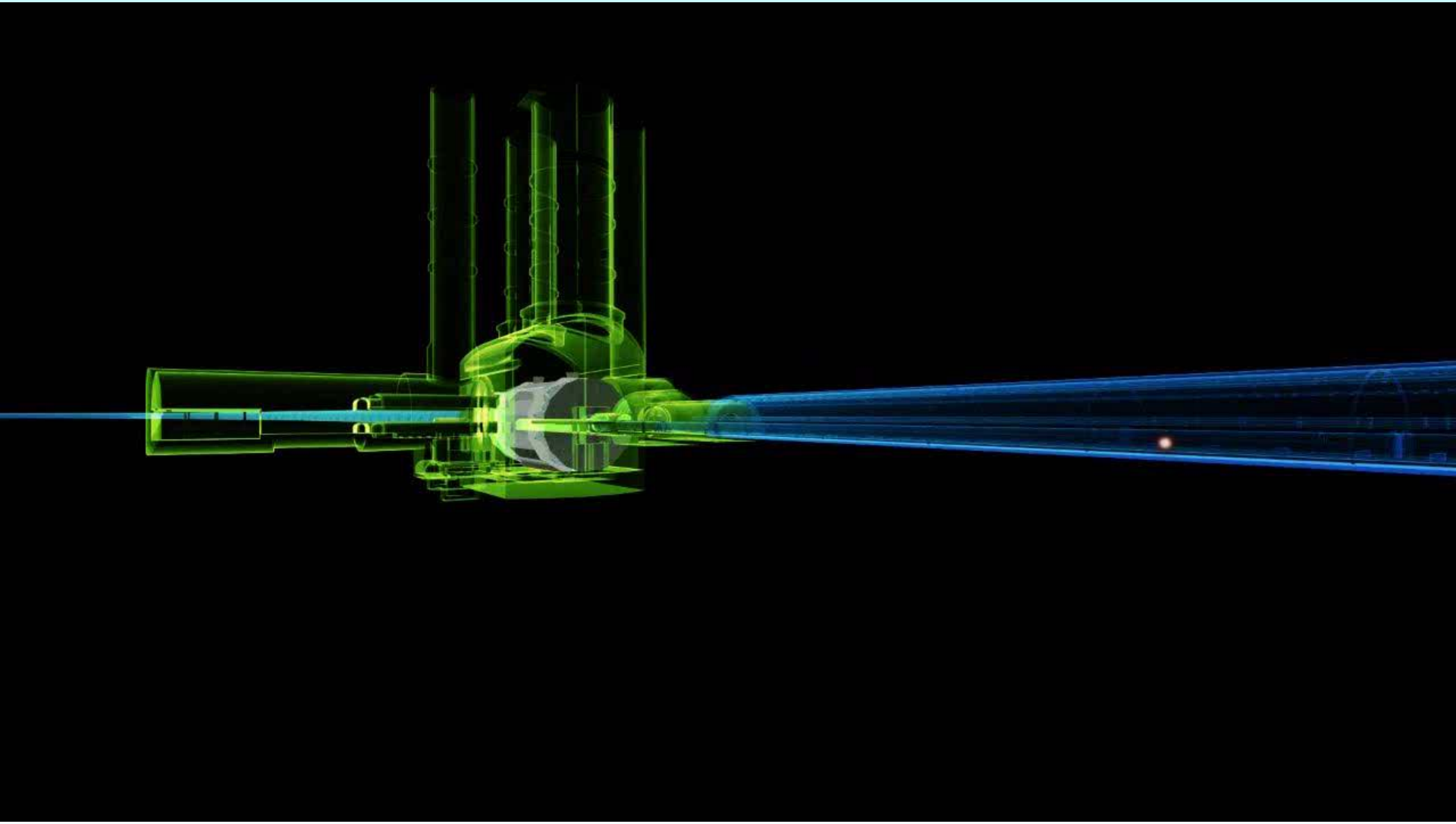


Selection: Two pairs of electrons and/or muons that each have the mass of a Z^0.

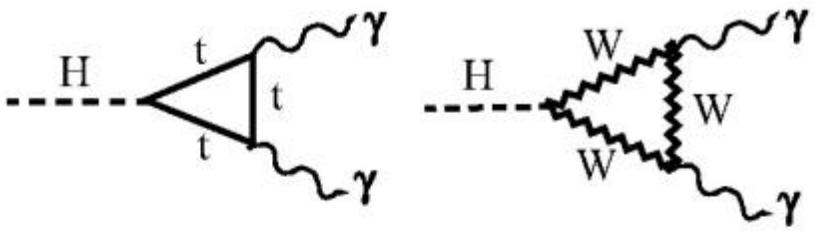


$$M_H^2 = (\vec{P}_{e^-} + \vec{P}_{e^+} + \vec{P}_{\mu^-} + \vec{P}_{\mu^+})^2$$

Higgs boson to γγ ?

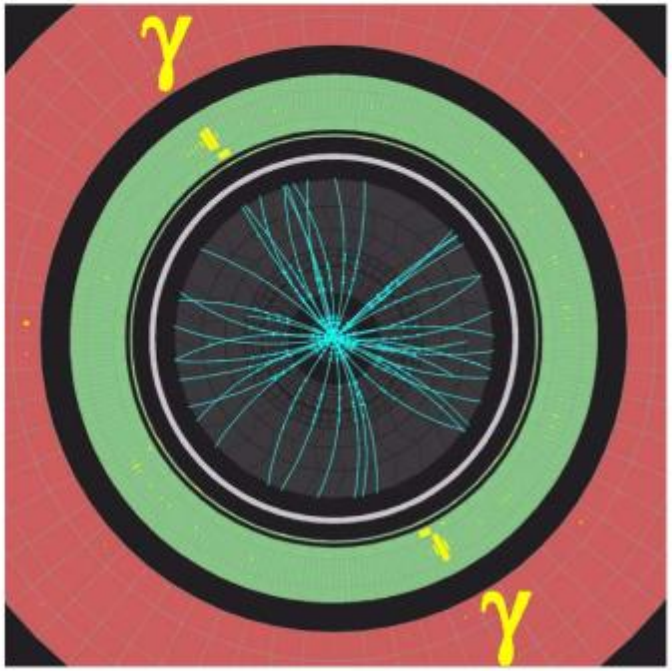


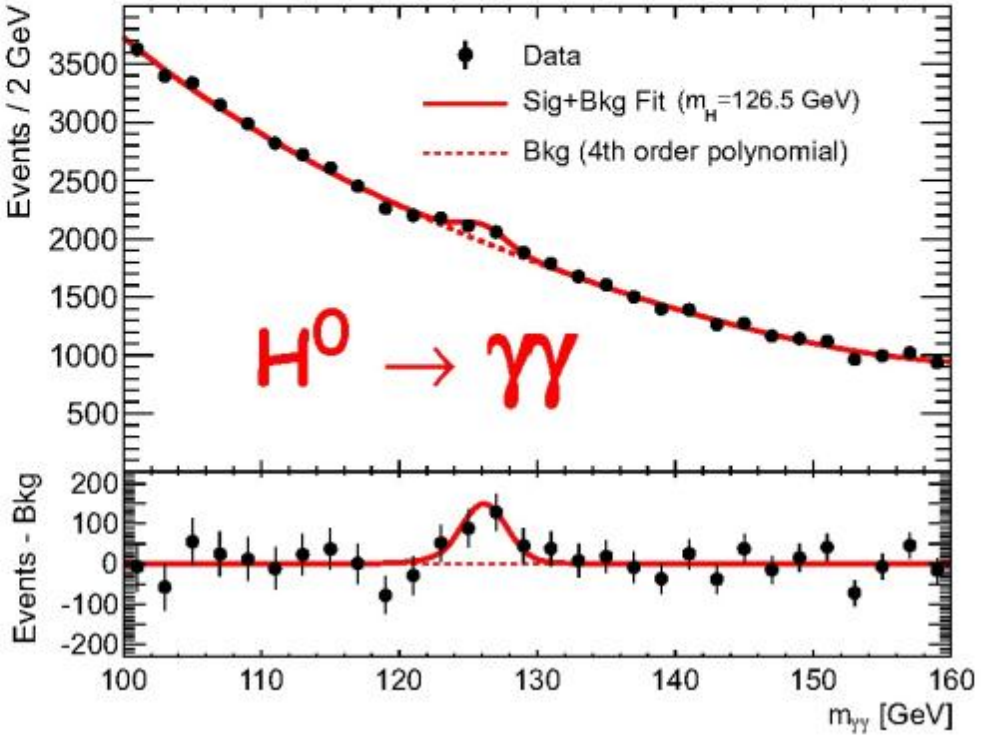
Higgs bosons to γγ



Selection: Two isolated photons with large transverse momentum.

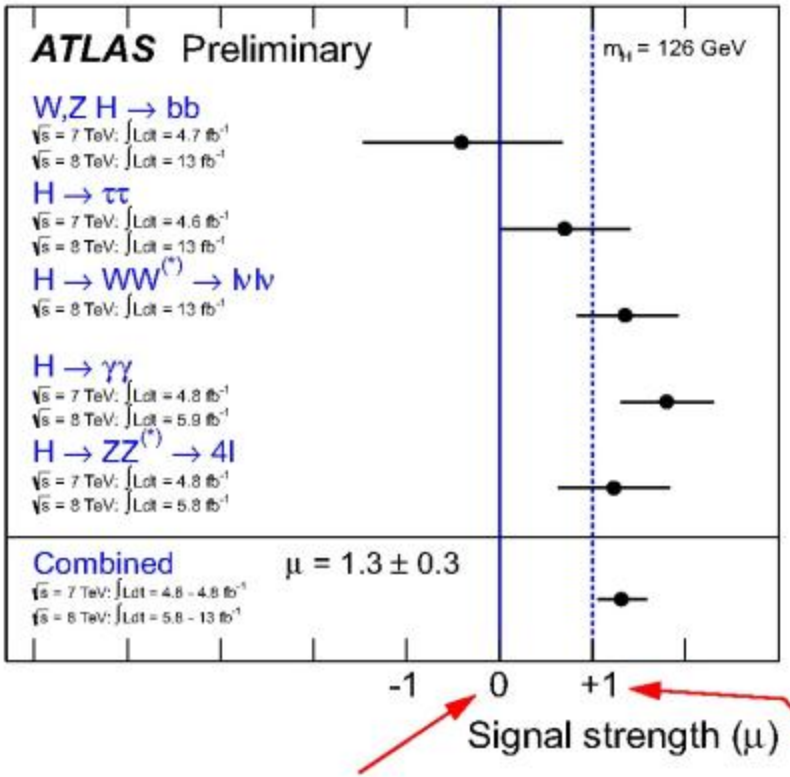
$$M_H^2 = (\vec{P}_\gamma + \vec{P}_\gamma)^2$$



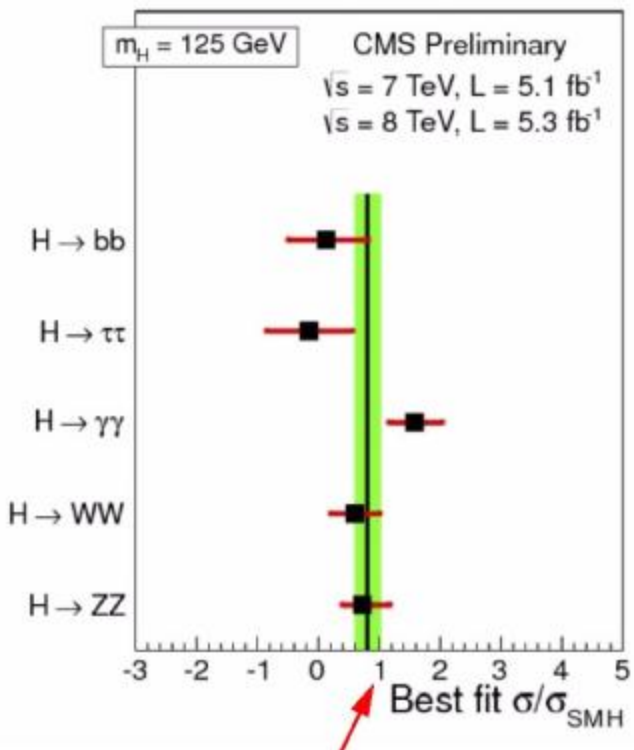


Summary of Higgs measurement

ATLAS
$M_H = 126.0 \pm 0.4$ GeV



CMS
$M_H = 125.8 \pm 0.4$ GeV



No signal

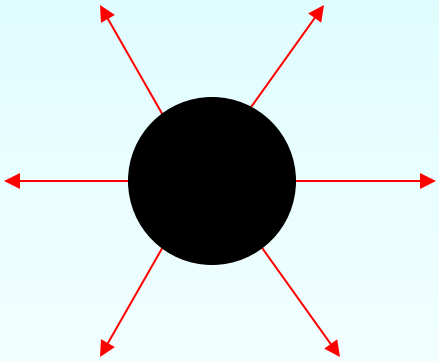
Signal in perfect agreement with standard model

Physics studies: Search for black holes

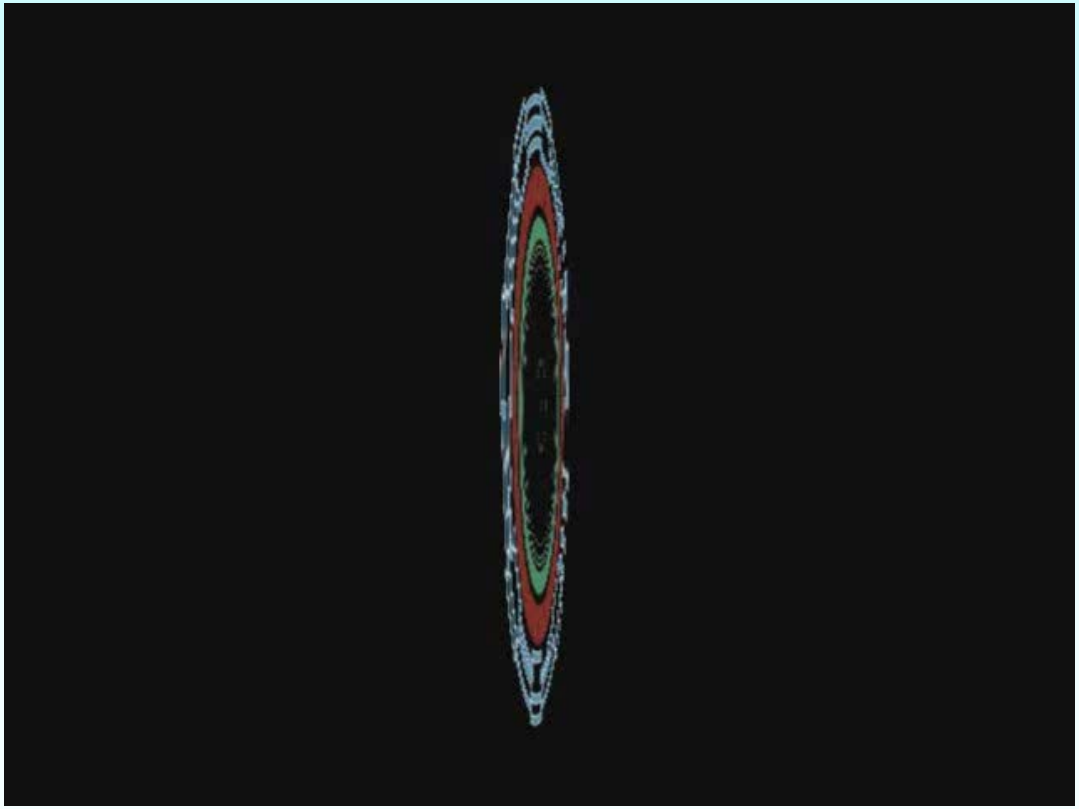
Black Hole

Signature:

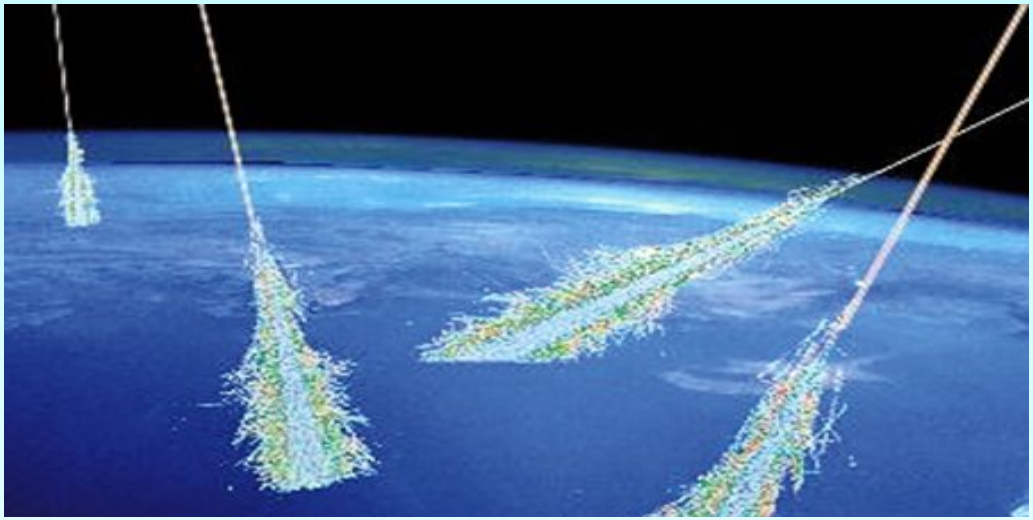
Many particles and particles with a high energy and with a large angle with respect to the proton direction.



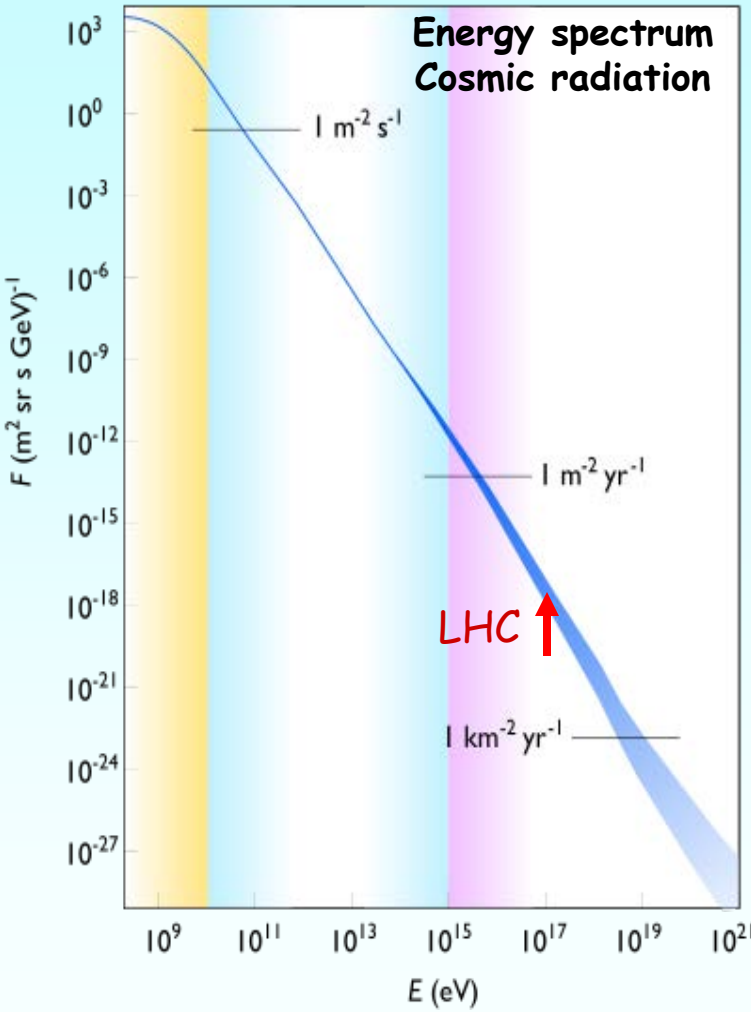
The holes will disappear after 10^{-26}s according to the theory (if they are produced).



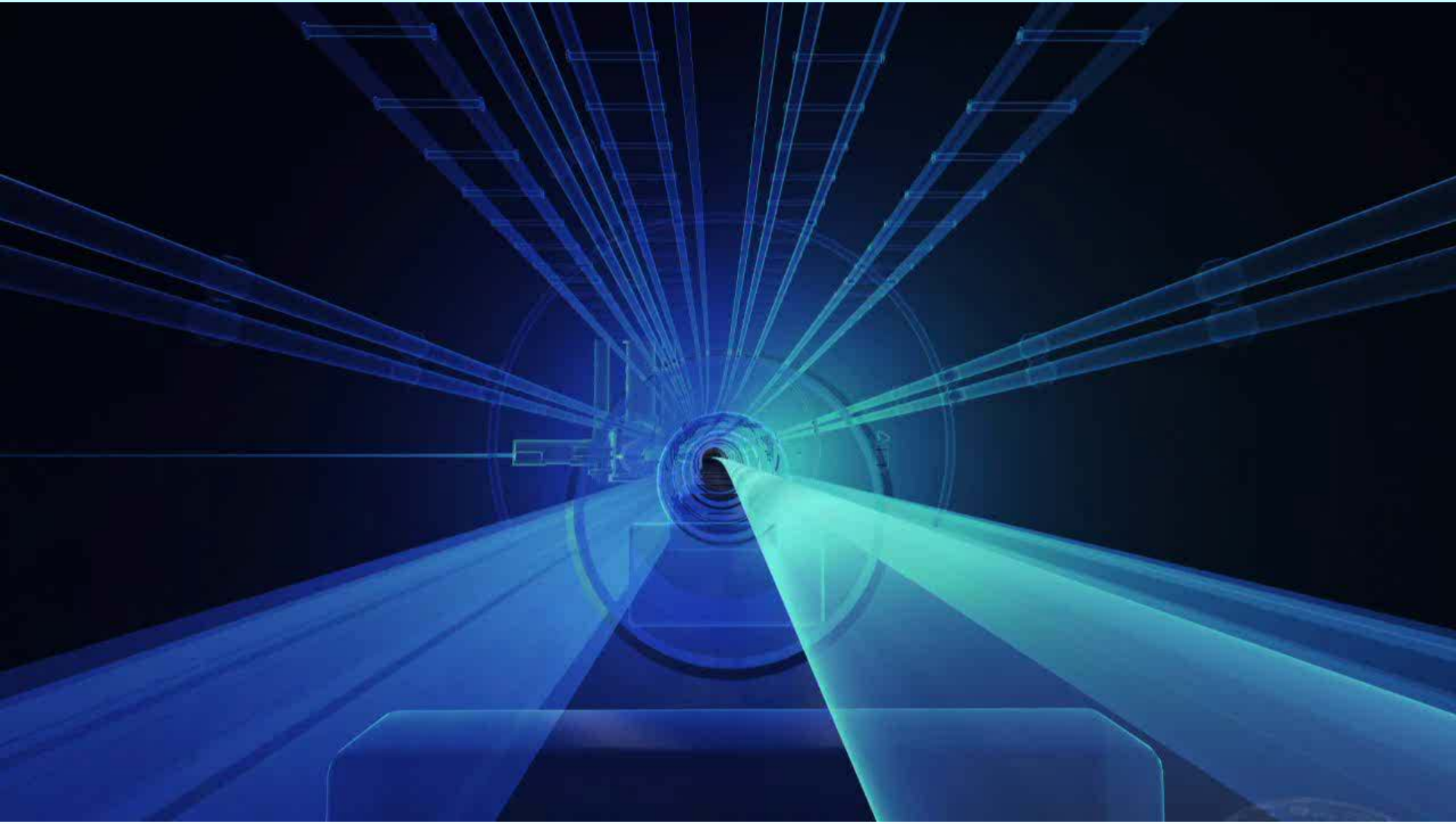
Black holes = The end of the world ?



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 new 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.