

CERN & LHC

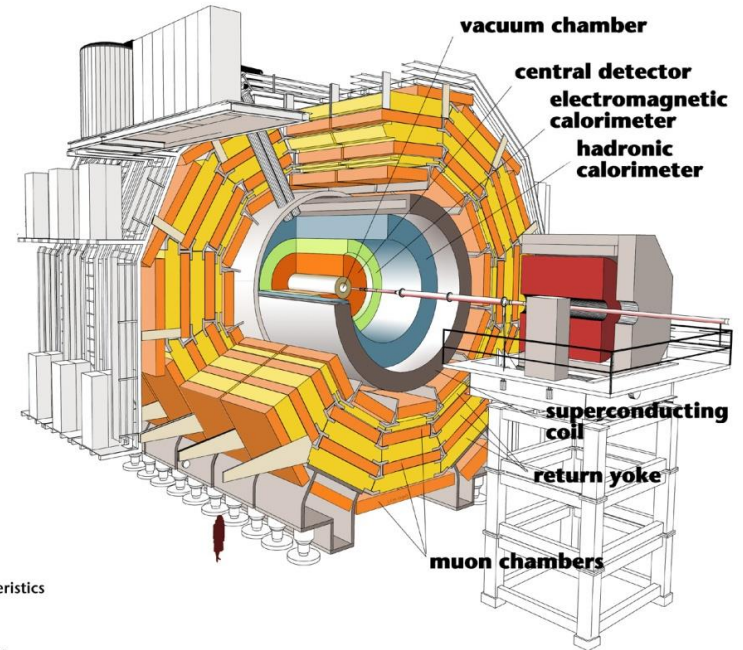
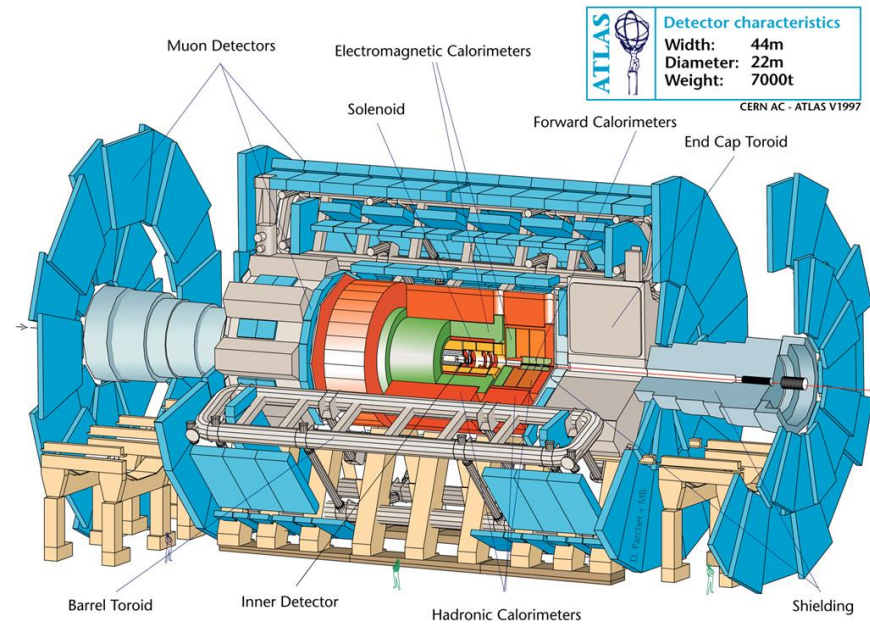




**WITHOUT
ENGINEERS**

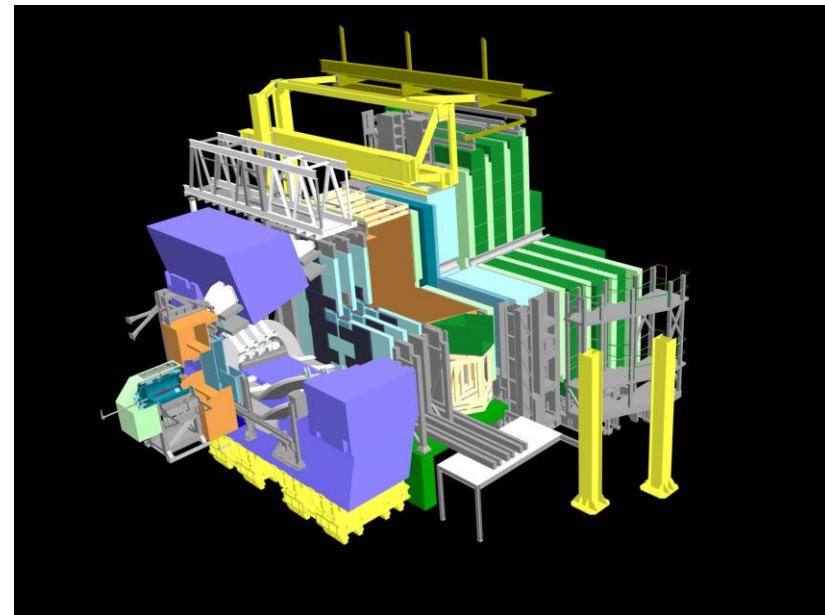
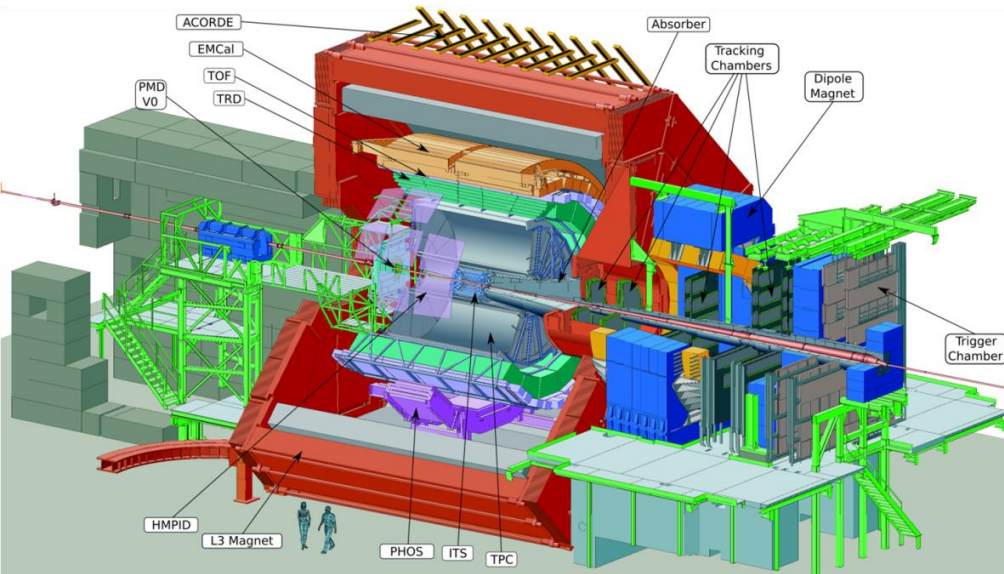
**SCIENCE IS JUST
PHILOSOPHY**

ATLAS, CMS, ALICE, LHCb

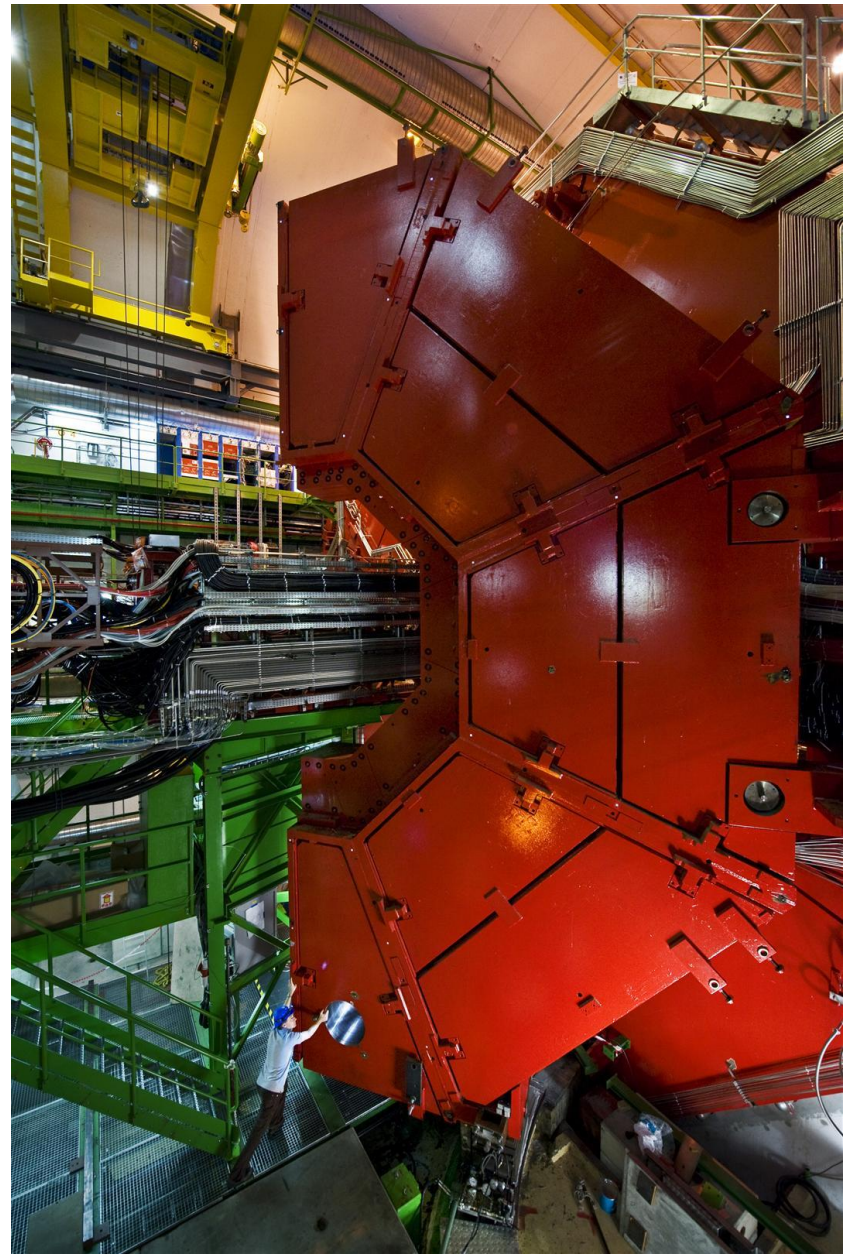


Detector characteristics

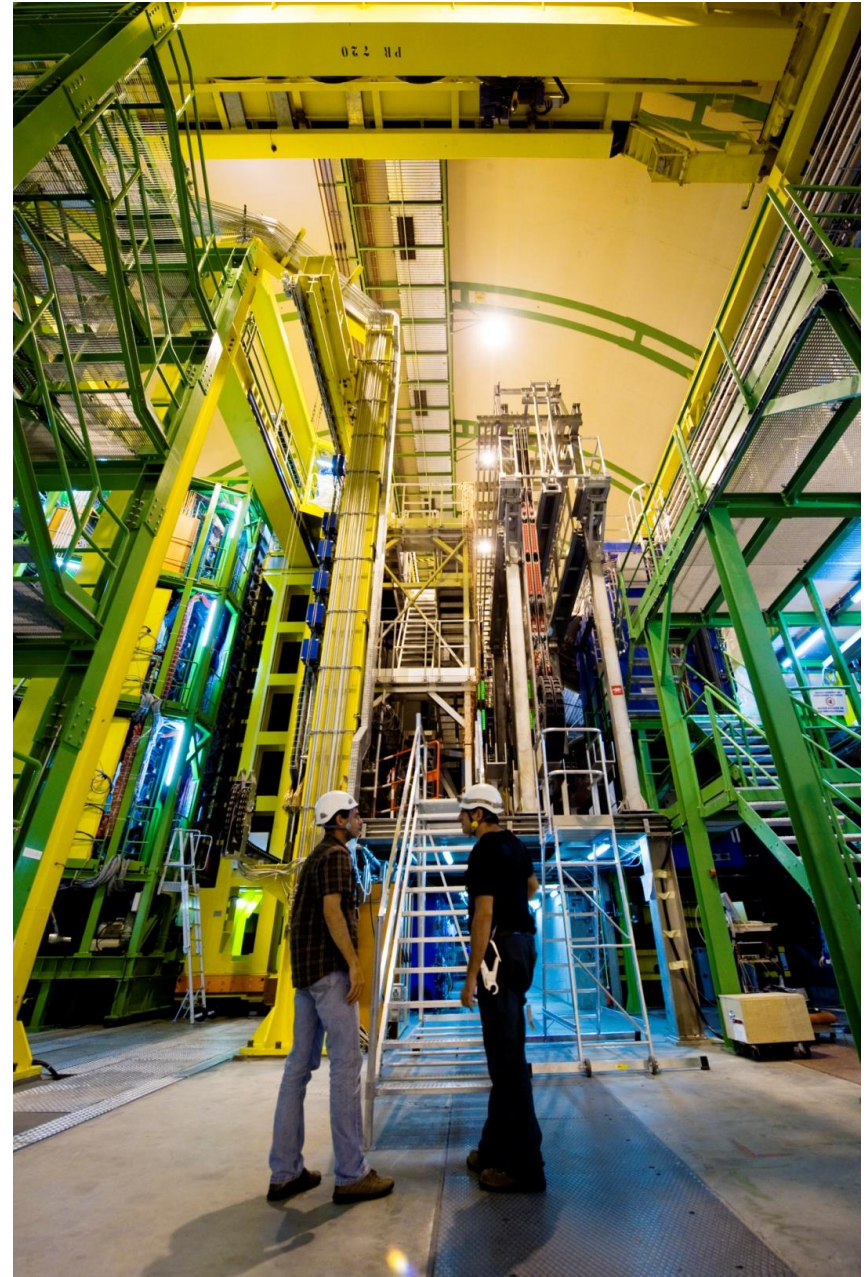
Width: 22m
Diameter: 15m
Weight: 14500t



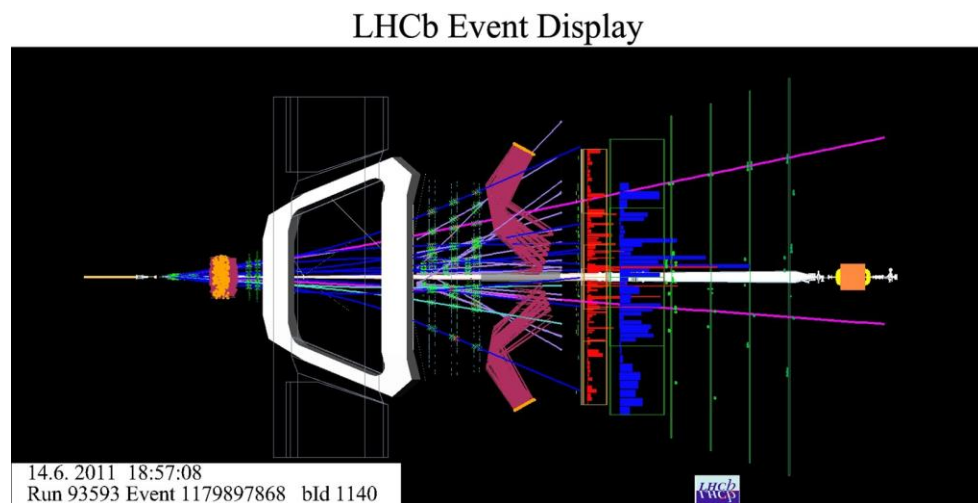
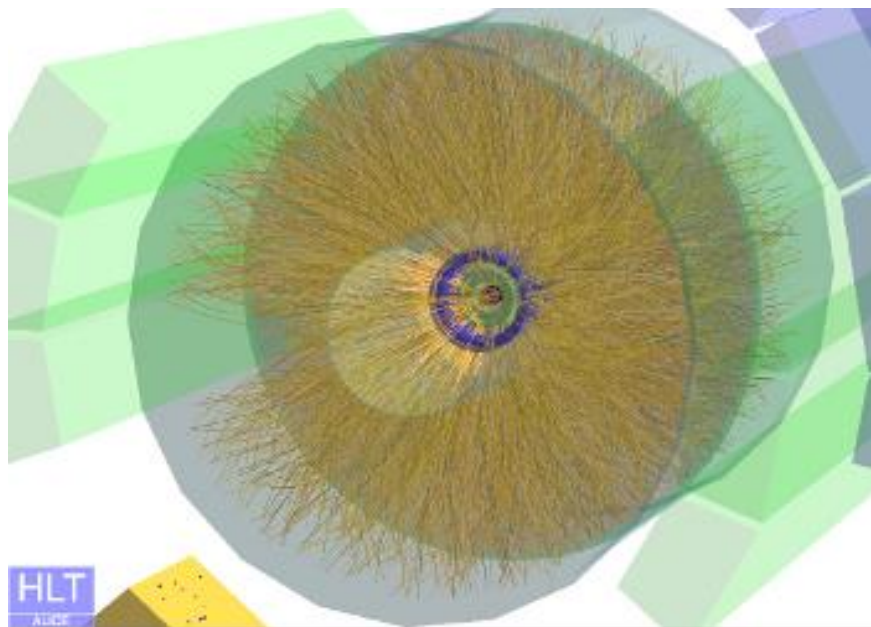
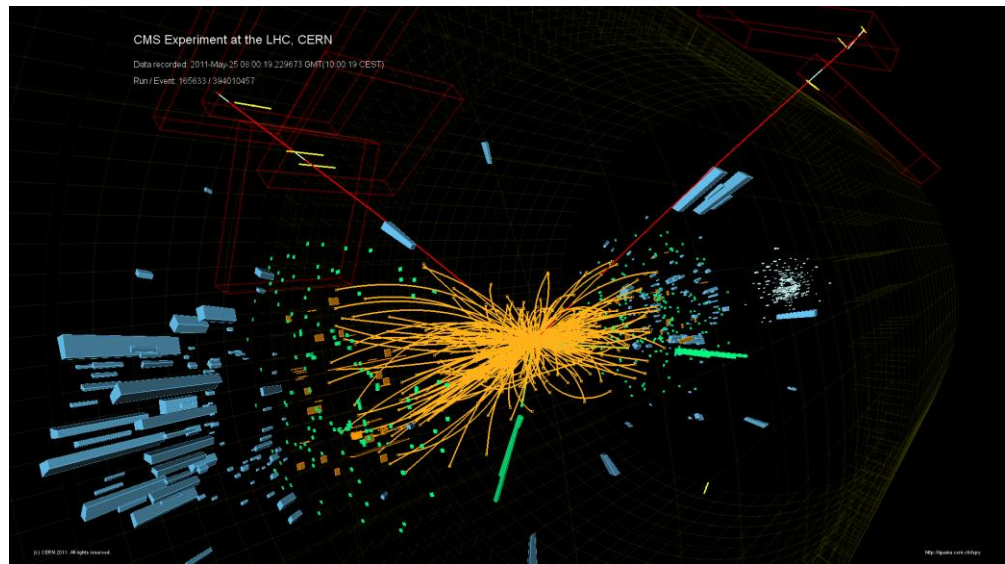
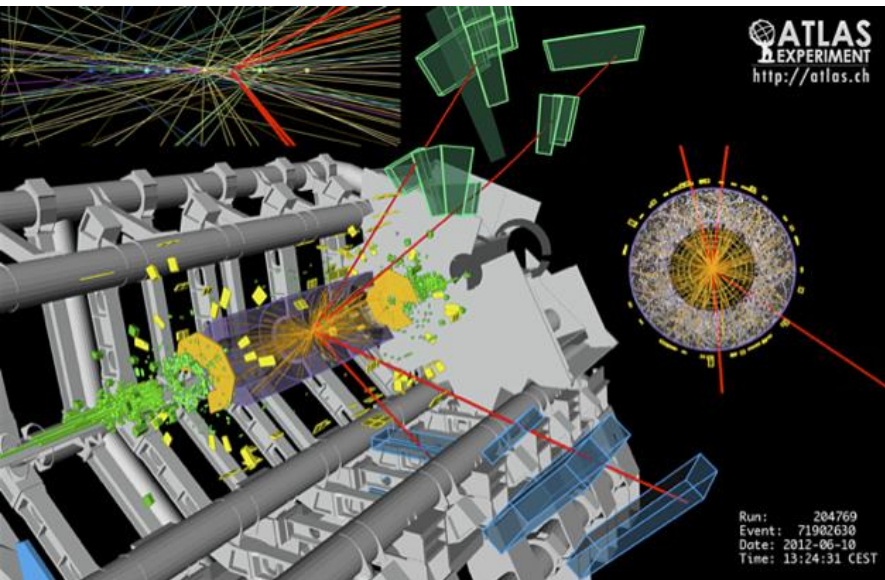
ATLAS, ALICE



CMS, LHCb



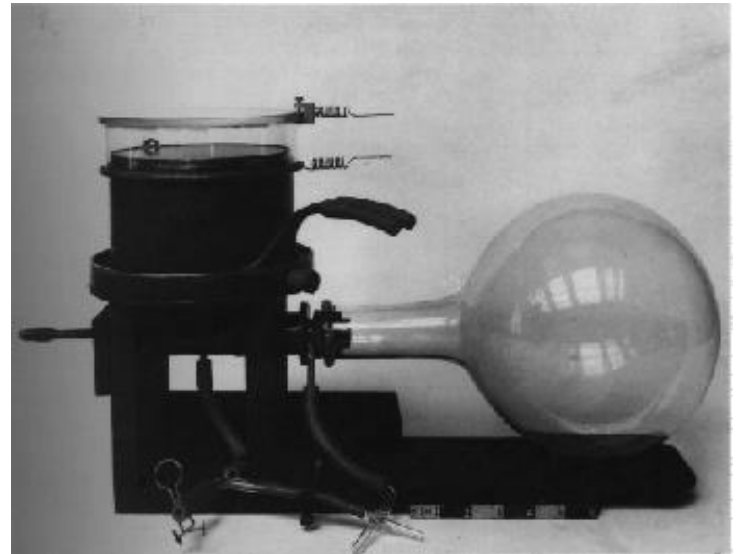
ATLAS, CMS, ALICE, LHCb



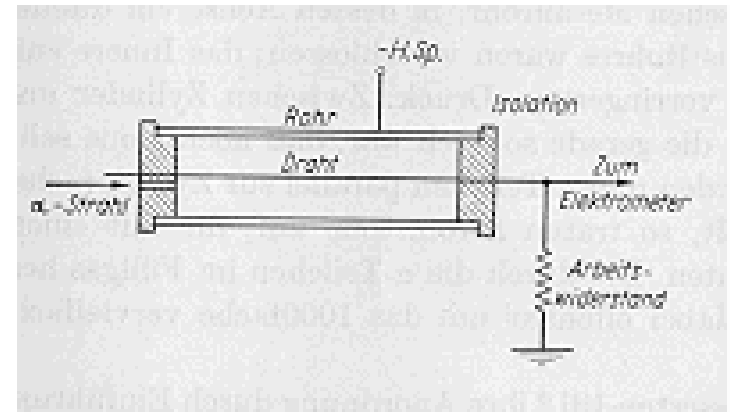
Detectors for Astronomy and Particle Physics



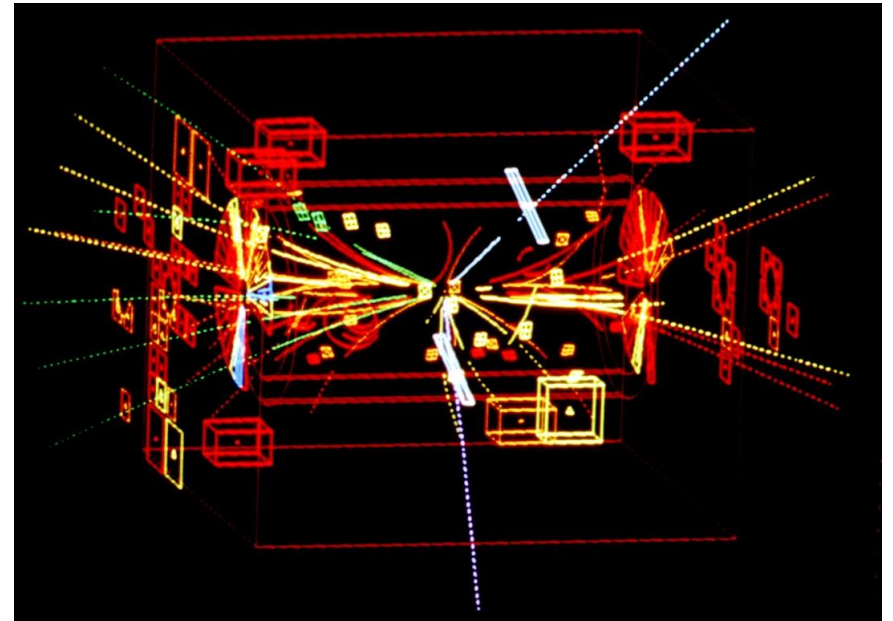
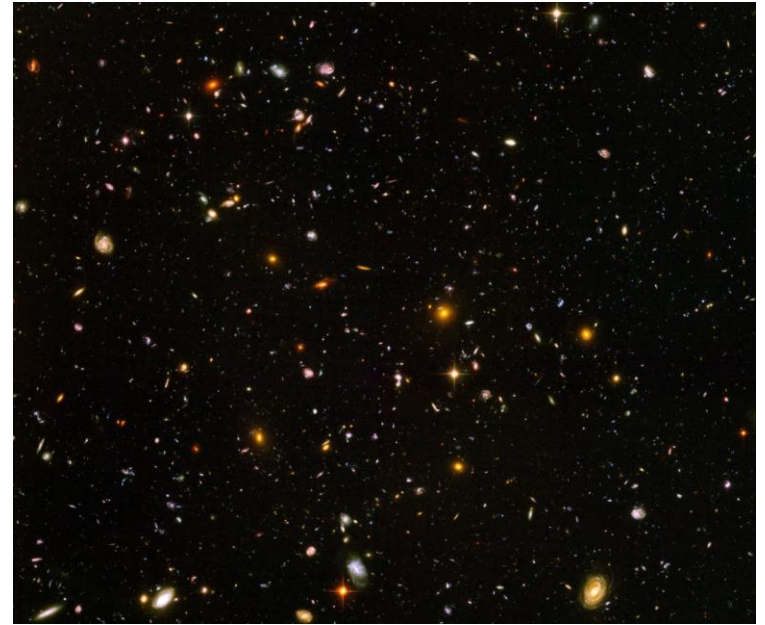
Galilei, 1610



Wilson 1910, Cloud Chamber



Rutherford and Geiger 1908
'Geiger Counter'



Images: Bubble Chamber, Cloud Chamber

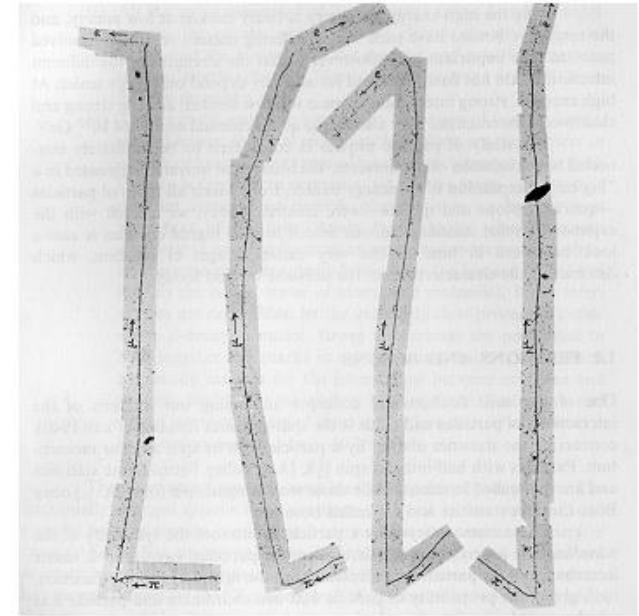
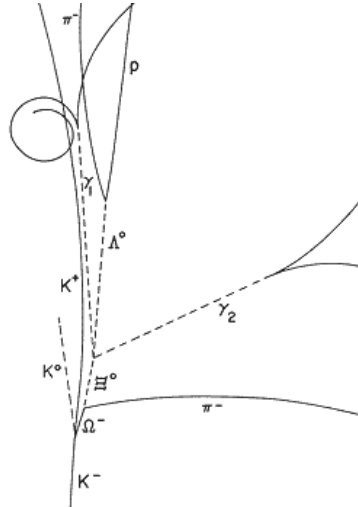
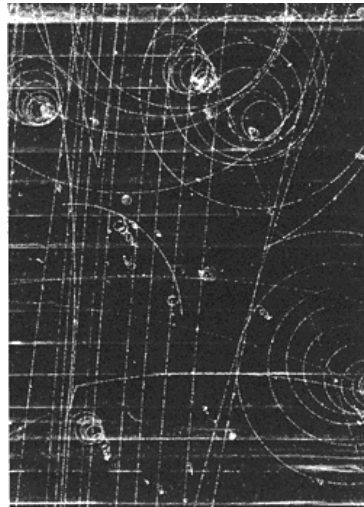
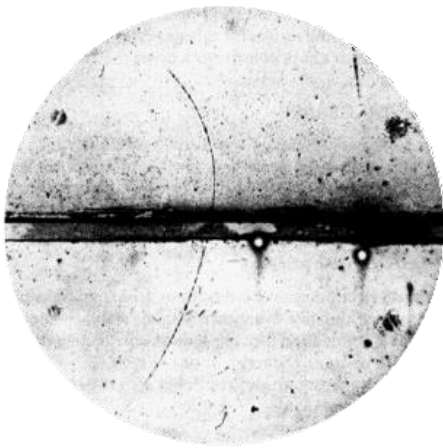


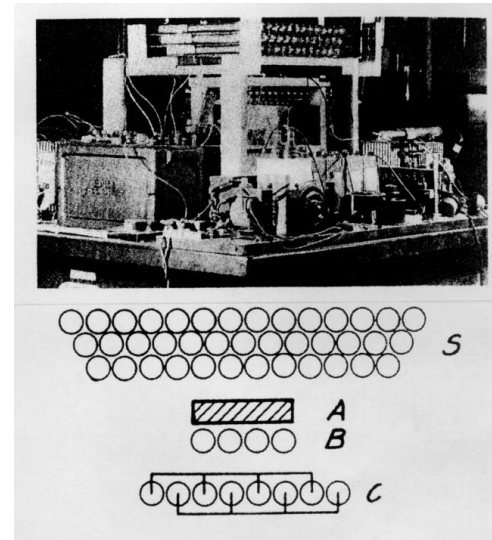
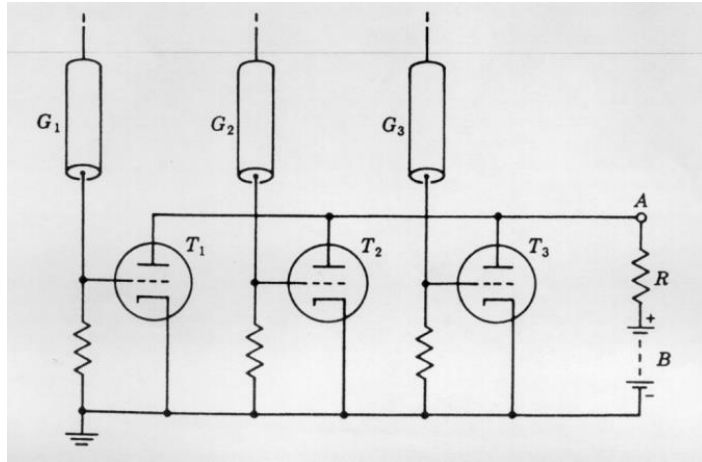
Image ,Tradition‘:

Cloud Chambers from 1910 to 1950 and Bubble Chambers from 1950 to 1980 and photographic plates since 1940 were taking photographic images of the particle tracks.

Bubble chambers synchronized with the accelerator, every event to be photographed. No possibility of selective ,triggering‘

Many millions of Bubble Chamber images had to be analyzed.

Logic: Geiger Counters, Scintillators



Logic ,Tradition':

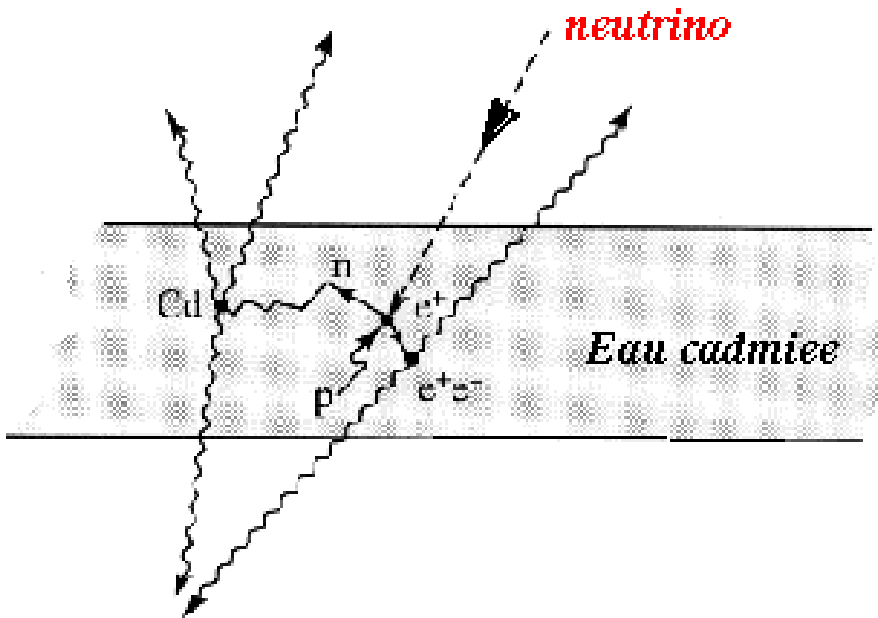
Coincidences of Geiger Counters or scintillators including timing, pulseheight measurements etc. were selectively measuring particle events.

Anti Neutrino Discovery 1959

Reines and Cowan experiment principle consisted in using a target made of around 400 liters of a mixture of water and cadmium chloride.

The anti-neutrino coming from the nuclear reactor interacts with a proton of the target matter, giving a positron and a neutron.

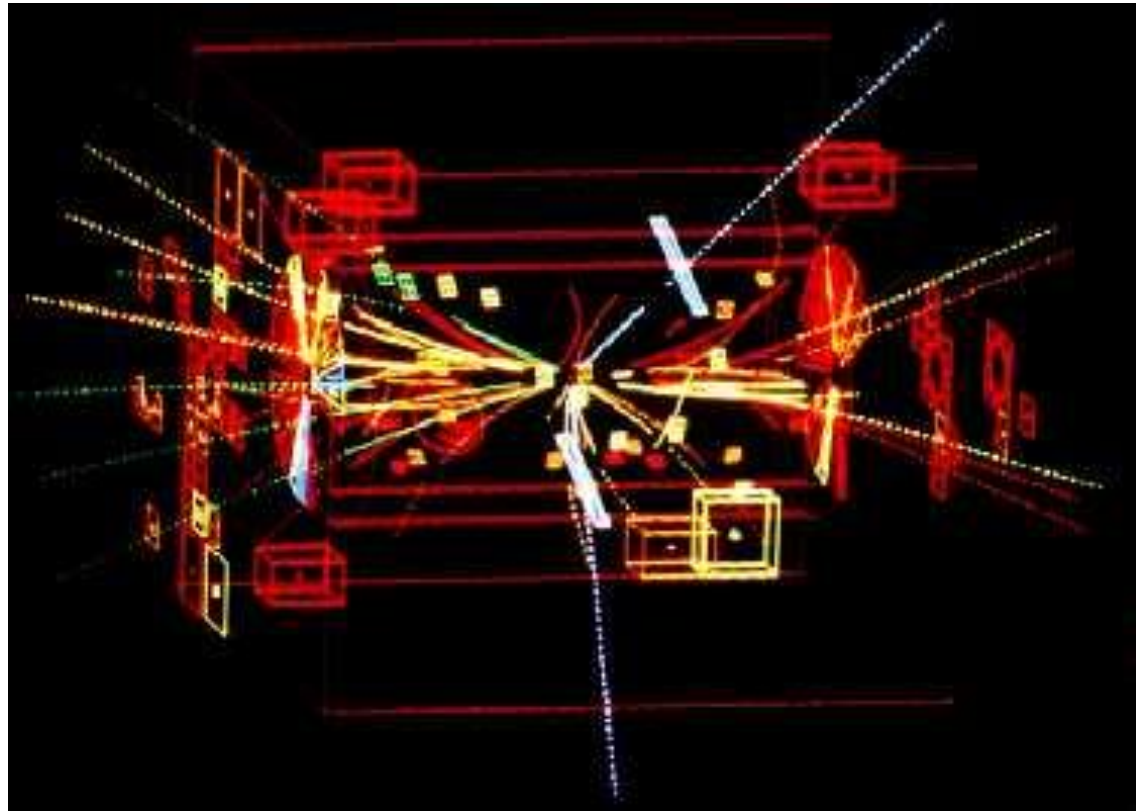
The positron annihilates with an electron of the surrounding material, giving two simultaneous photons and the neutron slows down until it is eventually captured by a cadmium nucleus, implying the emission of photons some 15 microseconds after those of the positron annihilation.



The electronics image: W, Z-Discovery 1983/84

UA1 used a very large
wire chamber.

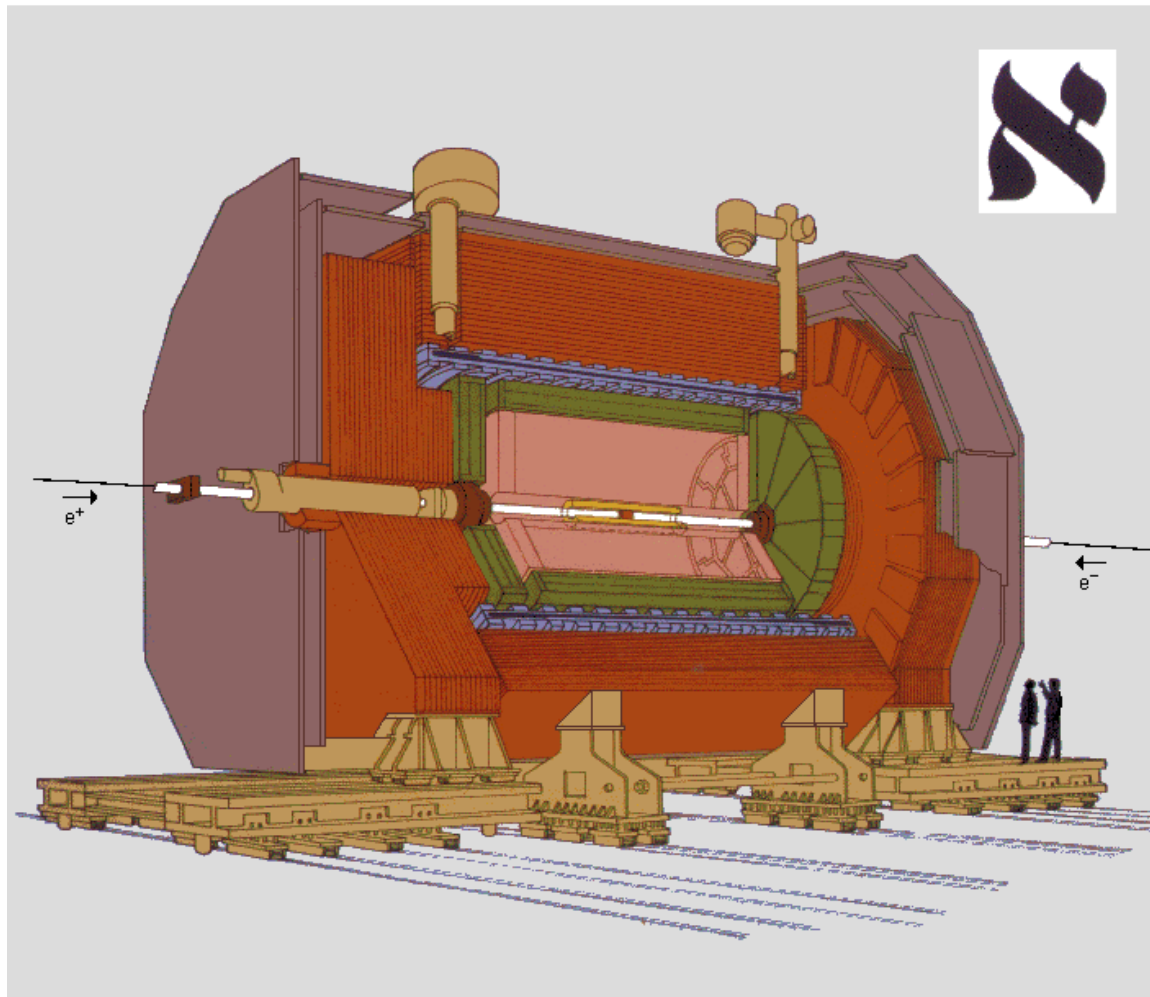
Can now be seen in
the CERN Microcosm
Exhibition



Electronic detectors to 'trigger' the readout of an events
AND to reconstruct the particle tracks.

→ The 'electronics image' selected by 'logic'

LEP 1988-2000

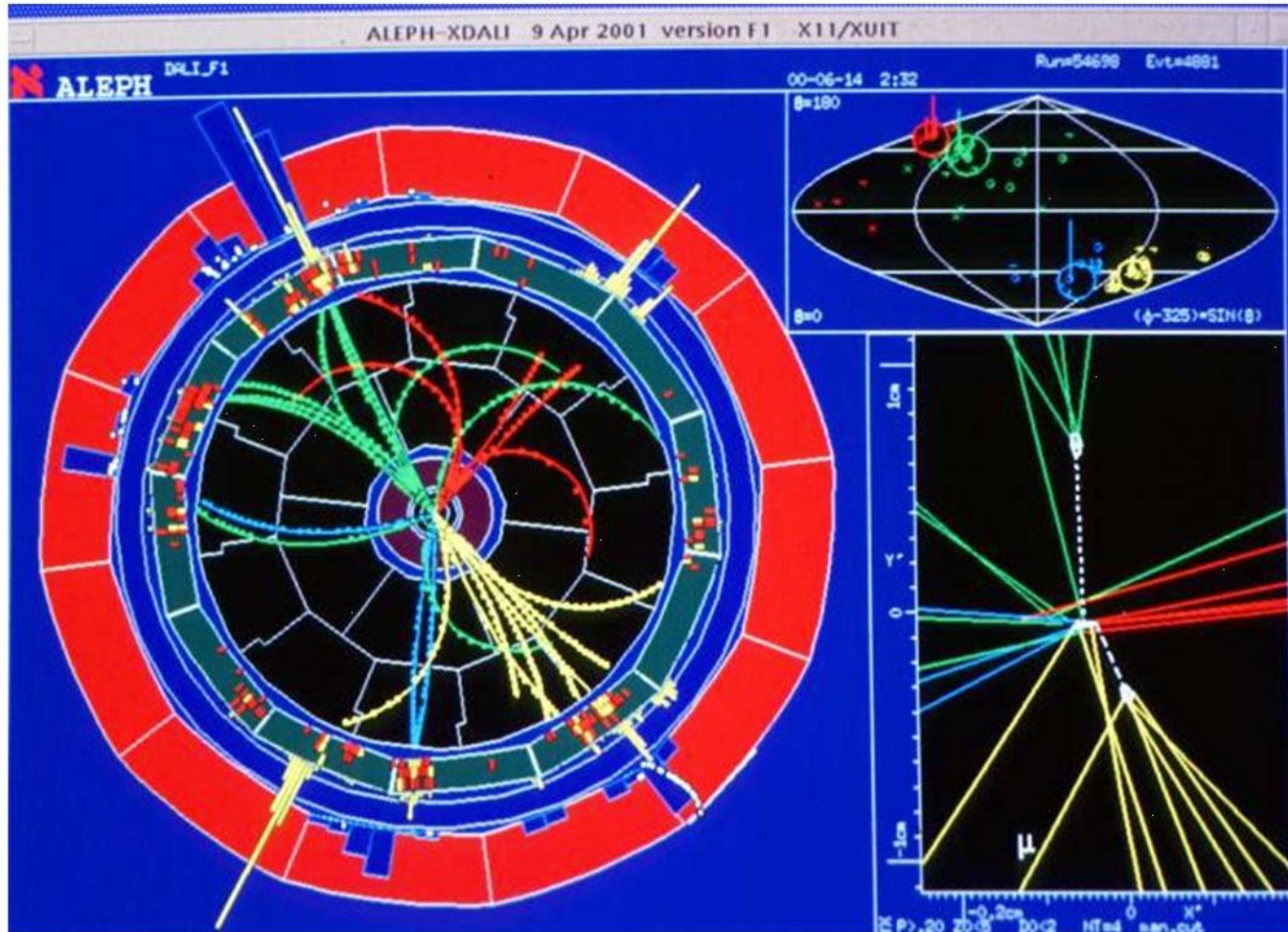


- Vertex Detector
- Inner Tracking Chamber
- Time Projection Chamber
- Electromagnetic Calorimeter
- Superconducting Magnet Coil
- Hadron Calorimeter
- Muon Chambers
- Luminosity Monitors

The ALEPH Detector
All Gas Detectors (Wire Chambers)

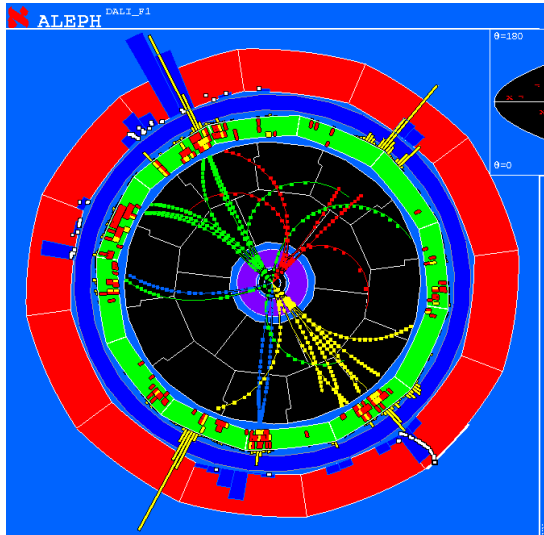
LEP 1988-2000

Aleph Higgs Candidate Event: $e^+ e^- \rightarrow HZ \rightarrow bb + jj$

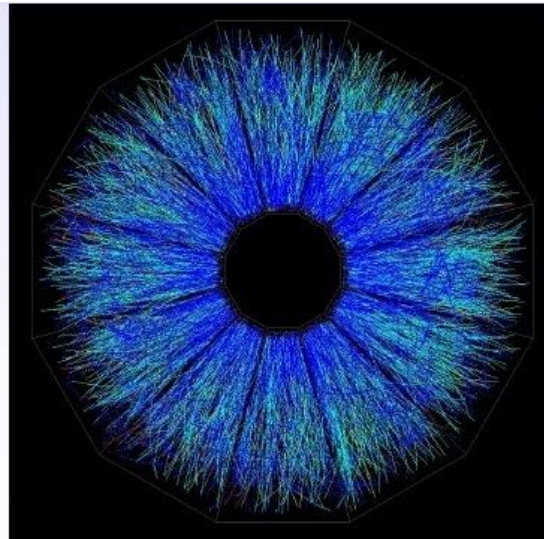


Increasing Multiplicities in Heavy Ion Collisions^{5/21/2014}

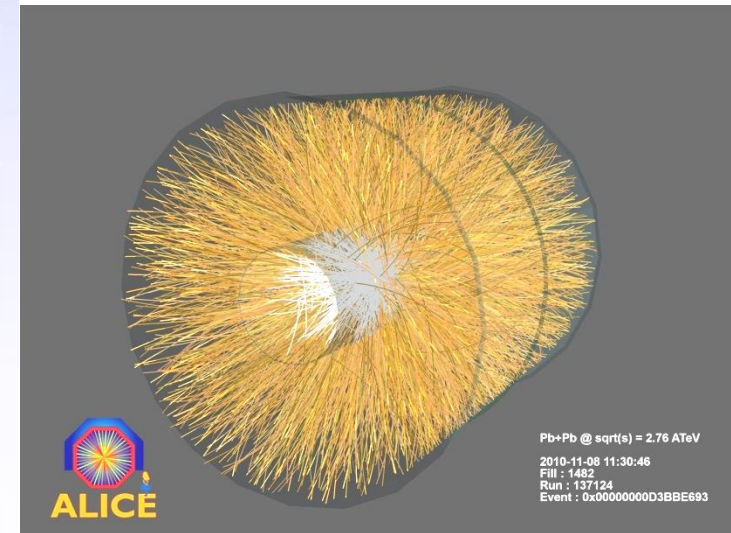
**e+ e- collision in the
ALEPH Experiment/LEP.**



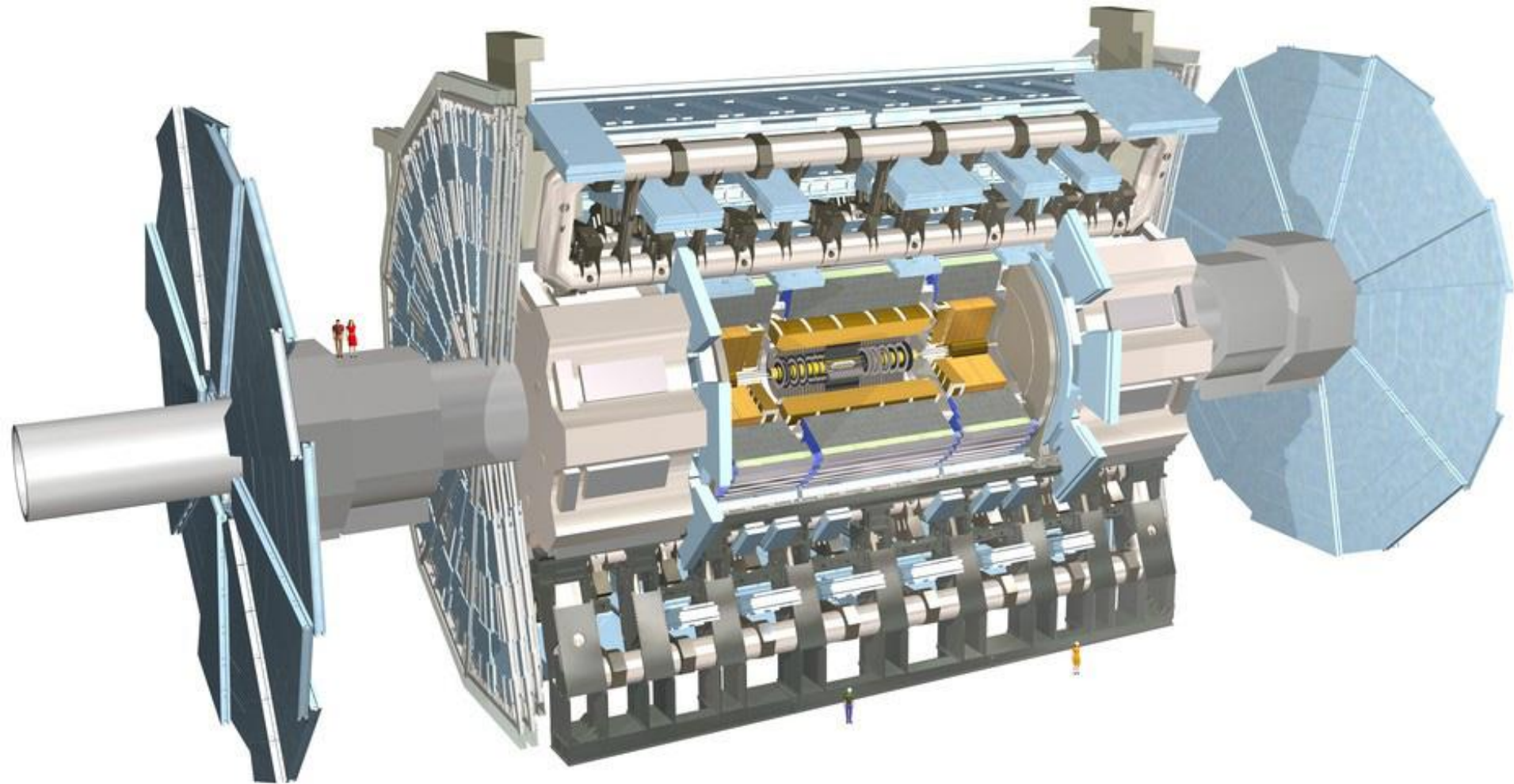
**Au+ Au+ collision in the
STAR Experiment/RHIC
Up to 2000 tracks**



**Pb+ Pb+ collision in the
ALICE Experiment/LHC
Up to 10 000 tracks/collision**



ATLAS at LHC



Large Hadron Collider at CERN.

The ATLAS detector uses more than 100 million detector channels.

Data of LHC Experiments

10^9 collisions/s

10^{16} collisions/year

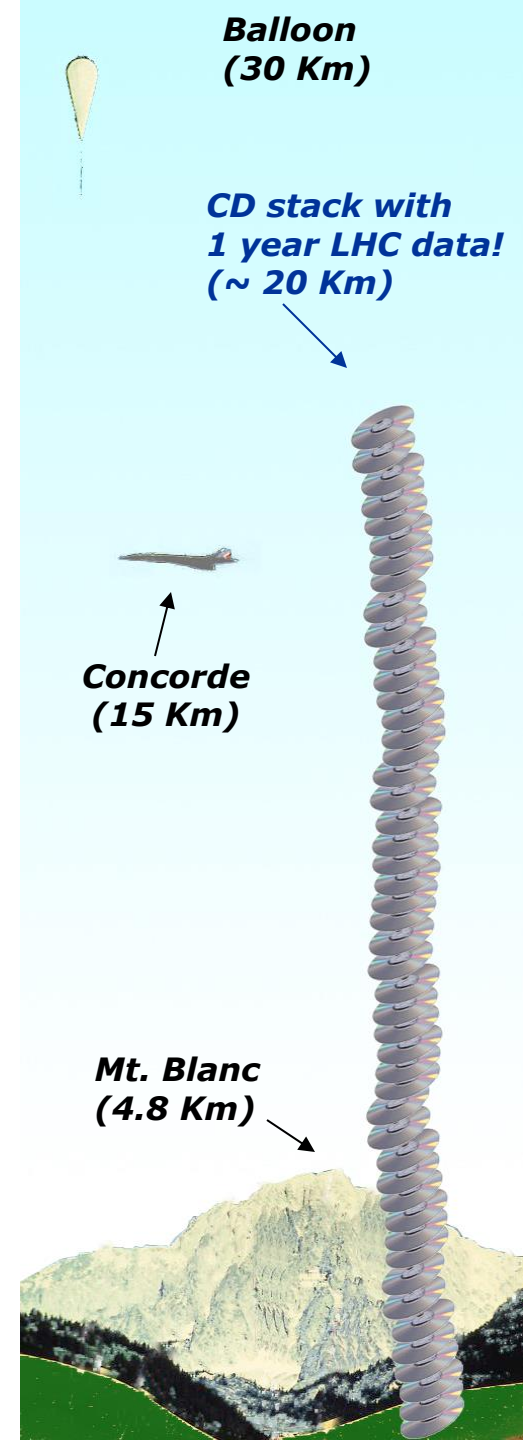
Among them, about 10 000 Higgs Particles

After filtering, about 100 collisions/s go to tape

10 MBegabyte of digitized data per event, 1 Gigabyte/sec to tape.

10 Petabyte/year

GRID: To manage the data analysis and storage through computing centers in the different institutes.



Challenges for Detectors for LHC

Large magnetic fields for momentum spectroscopy

- Superconducting magnets, cryogenics
- Heavy structures of iron yokes

Very large detector sizes momentum spectroscopy and Energy measurement (Calorimetry)

- Engineering of very heavy structures

Very high particle rates

- Radiation hard detectors and electronics
- Fast detectors and fast readout electronics

Need for high measurement precision

- Large granularity
- Large channel numbers and needs for massive data storage

Need for high selectivity of stored data

- Lots of clever actions needed on the detector in ,real time' to decide which event to store i.e. 1 in 10^7

Challenges for Detectors for LHC

Positive surprise for LHC detectors:

Detector technologies that can stand the high particle rates and radiation dose could be developed and constructed on such a large scale.

Availability of

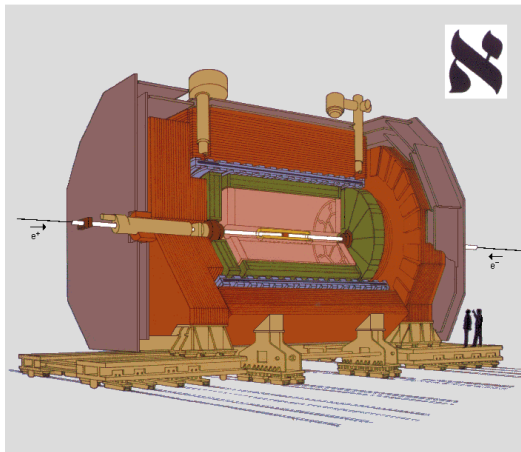
- deep submicron CMOS technology
- silicon technology in general
- powerful FPGAs
- massive computing power

played a key role for the success.

Underestimated difficulty:

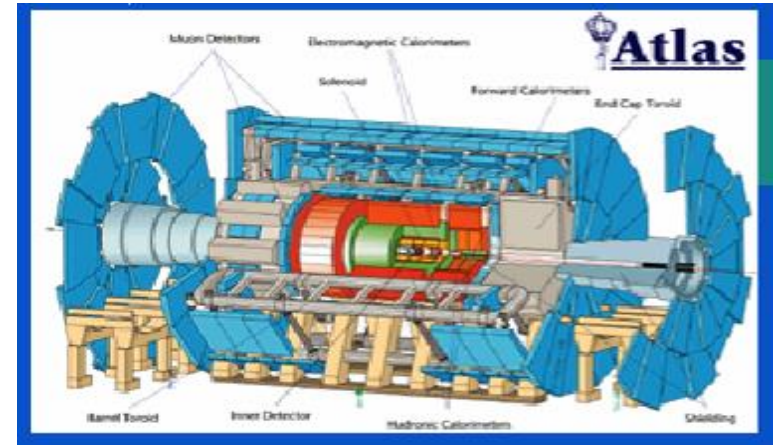
Communication and convergence in Mega-Collaborations

A sociological change from LEP to LHC



The ALEPH Detector

- Vertex Detector
- Inner Tracking Chamber
- Time Projection Chamber
- Electromagnetic Calorimeter
- Superconducting Magnet Coil
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- Luminosity Monitors



The Geiger counter reloaded: Drift Tube

Atlas Muon Spectrometer, 44m long, from $r=5$ to 11m.

1200 Chambers

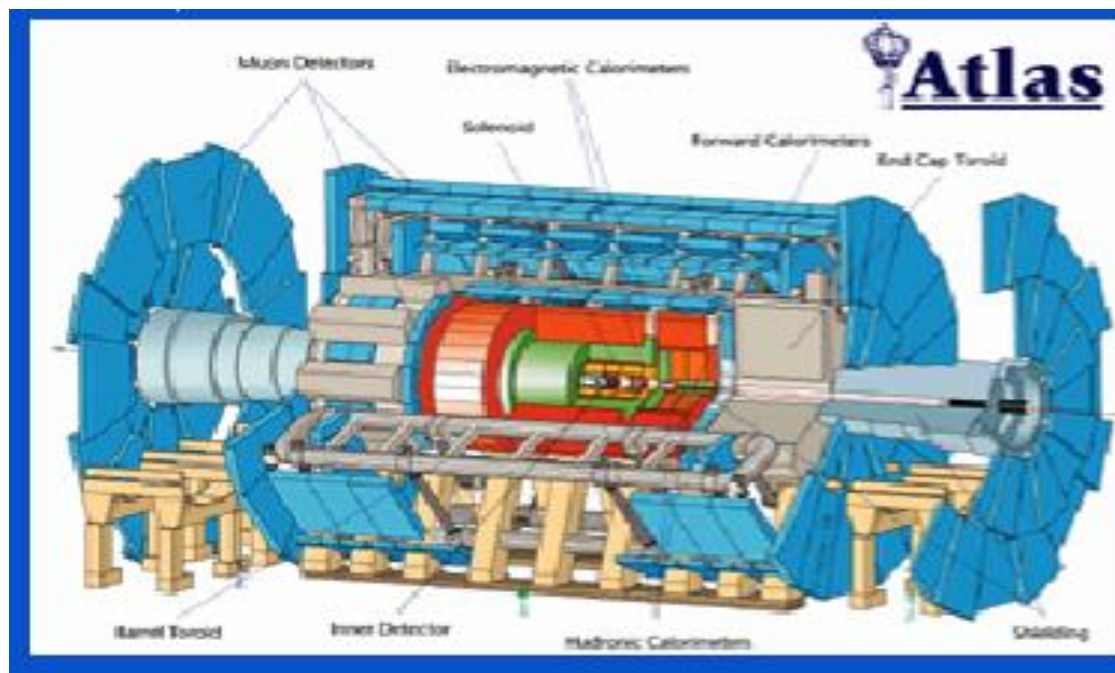
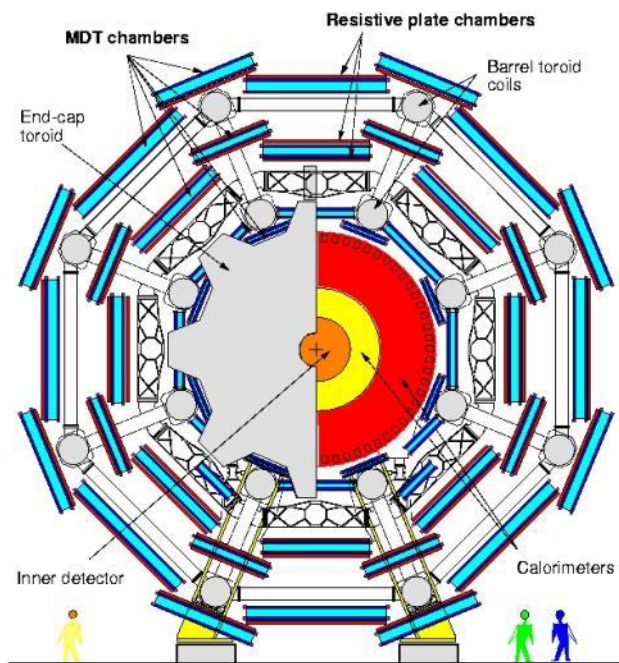
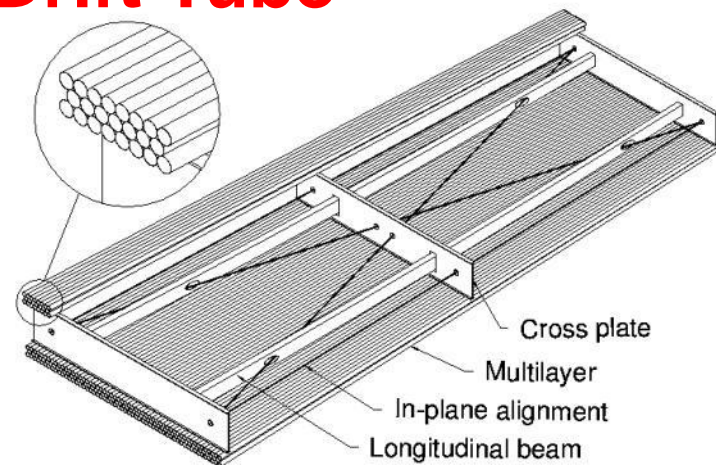
6 layers of 3cm tubes per chamber.

Length of the chambers 1-6m !

Position resolution: $80\mu\text{m}/\text{tube}$, $<50\mu\text{m}/\text{chamber}$ (3 bar)

Maximum drift time $\approx 700\text{ns}$

Gas Ar/CO₂ 93/7



A sociological change from LEP to LHC

Difference from LEP to LHC detectors:

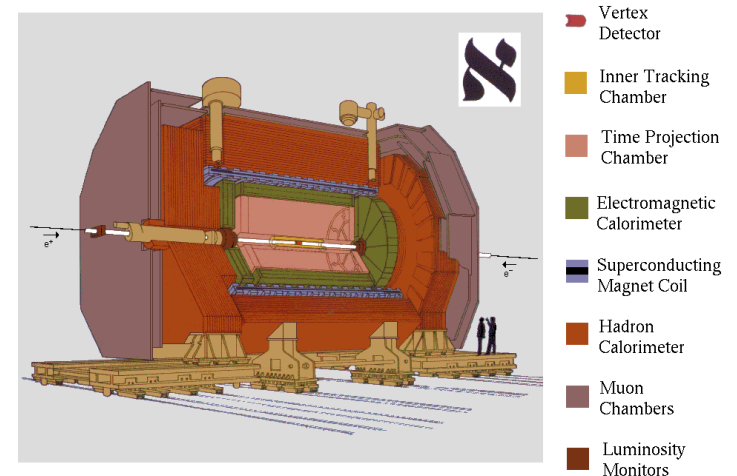
While for LEP detectors the subsystems were built by one or very few institutes, the subsystems of LHC had to be built by many institutes.

Decision was that a subsystem has to be homogeneous, i.e. to be built in the same way in all (around 10 institutes).

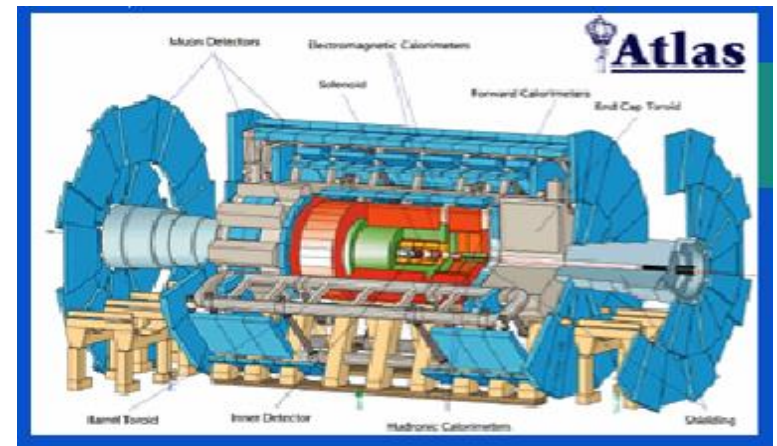
How to agree on the engineering solution between the different institutes ?

The only mechanism that forced a solution:

→ If we do not decide now we will not be finished in time → no experiment



The ALEPH Detector



Organization of an Experiment

An experiment is constructed and operated by a collaboration of institutes and laboratories that share the construction and funding of the detector (>150).

CERN just acts as one of the participating Institutes, but has a long tradition in building and developing particle detector technology.

The collaboration decides on the way it wants to operate i.e. each LHC experiment created it's own 'constitution' that is ratified by the collaboration board (heads of participating institutes).

The Technical Coordinator must be a CERN person, represents the link between CERN and the experiment and also has the responsibility that safety regulations are followed.

The detector is divided up into projects with individual project leaders. The projects are responsible for the construction, funding, calibration, maintenance and operation and eventually the disposal of the detector.

The experiment installation and operation is followed up through the Technical Board that is composed of all project leaders and convenors.

The experiment progress is continuously monitored by the LHCC and the finances are monitored by a scrutiny group.

Organization of an Experiment

CERN provides the accelerator, building infrastructure and the experimental cavern ...
The entire installation in the cavern is funded by the experiment collaboration.

CERN provides services that are paid by the experiment collaboration through so called 'Service level Agreements':

Gas systems, magnet control systems, detector cooling systems, electrical infrastructure, ventilation infrastructure and safety systems, cryogenics infrastructure together with on-call support.

The experiment is operated by the collaboration and shifts are shared by all institutes 3-8 people 24/7.

The detectors are developed by the participating university institutes and laboratories.

It is tradition that a particle physics institute participates in detector development, detector construction, software and data analysis.

CERN has a technical student program for diploma students and doctoral students that is just meant for detector development and not for physics exploitation.

→ A lot of detector development is done by students !

Organization of an Experiment

Detector development is driven by Physicists → Important

The 'desire' to do a particular physics measurement has to drive the effort !

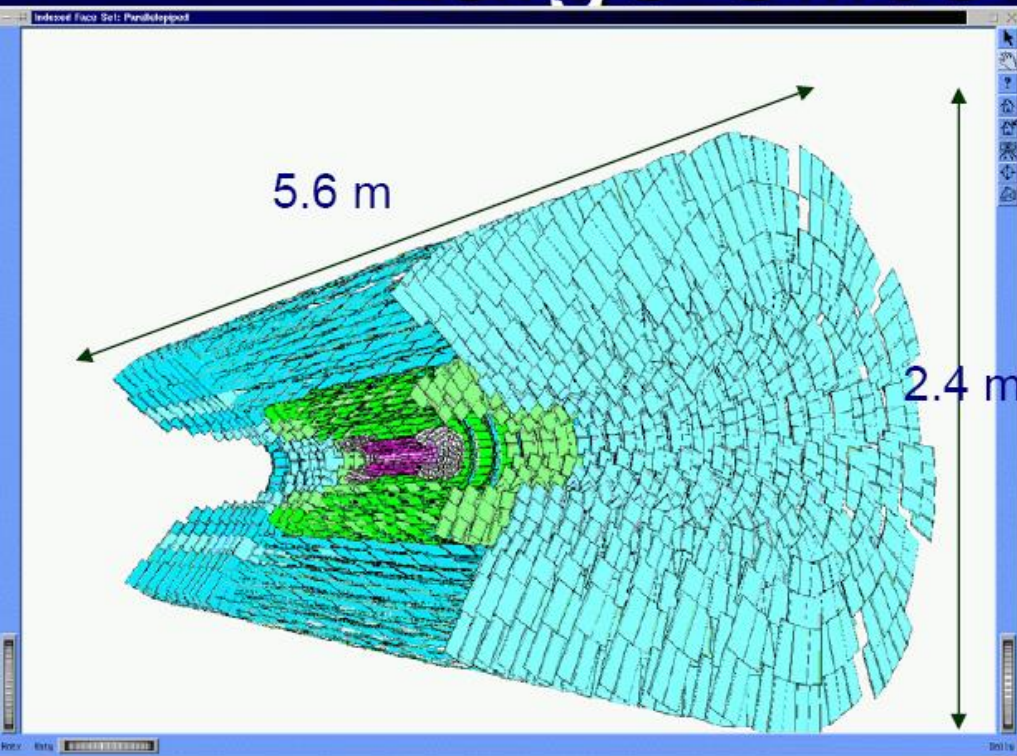
Very close collaboration with mechanics and electronics engineers.

Electronics has become a huge fraction of the particle detector effort.

While at LEP times the detector (e.g. wire chambers) and readout electronics were 'separate' objects, the development of silicon sensors has brought these disciplines much closer.

E.g. the development of monolithic silicon sensors is fully integrating sensor and electronics, and the developers are typically physicists with great affection for electronics or vice versa.

Large Silicon Systems



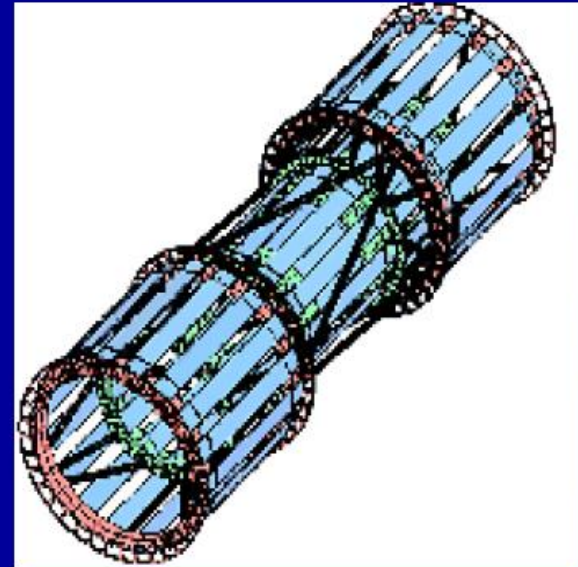
CMS tracker (~2007)

12000 modules

~ 445 m² silicon area

~ 24,328 silicon wafers

~ 60 M readout channels

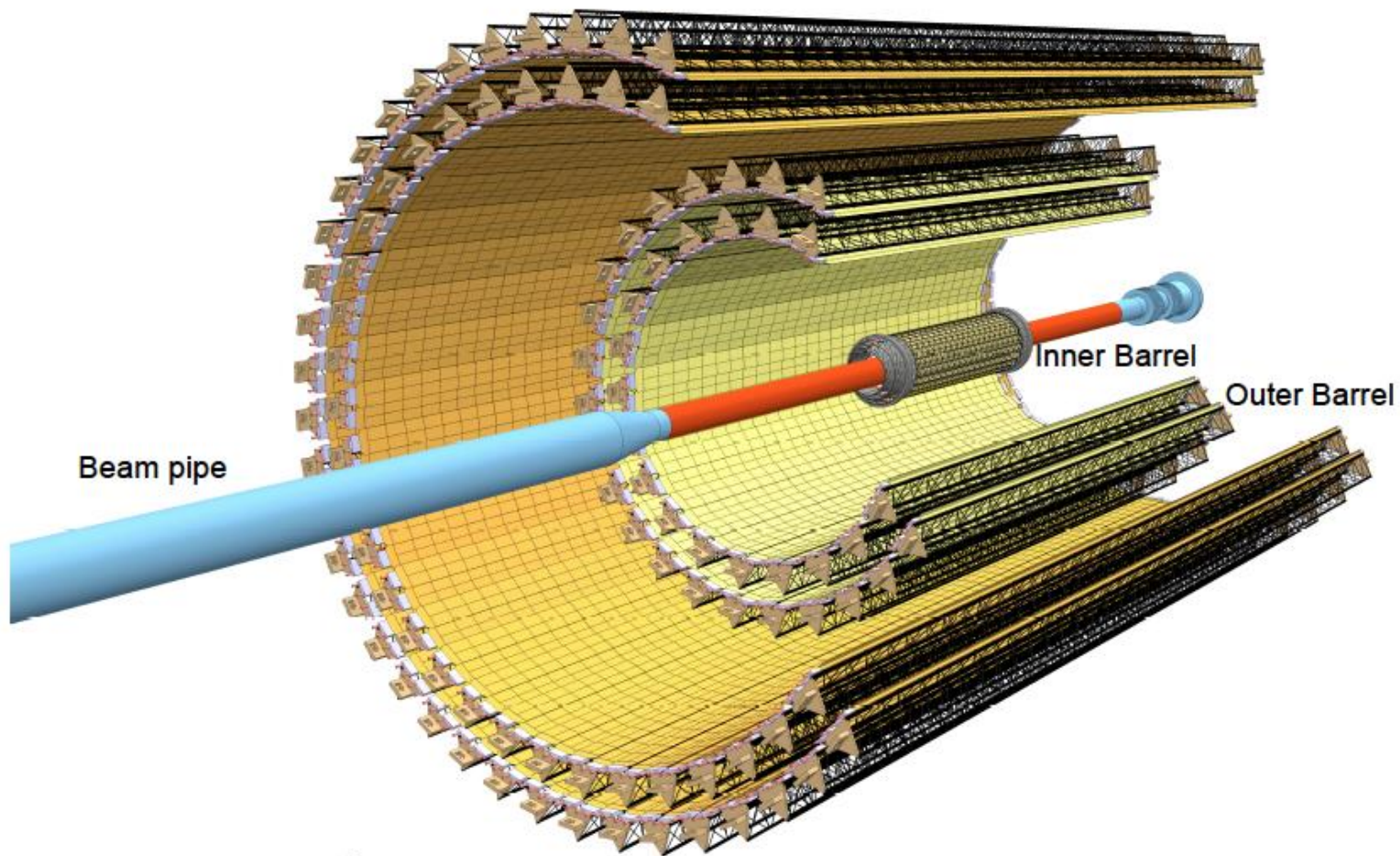


CDF SVX IIa (2001-)

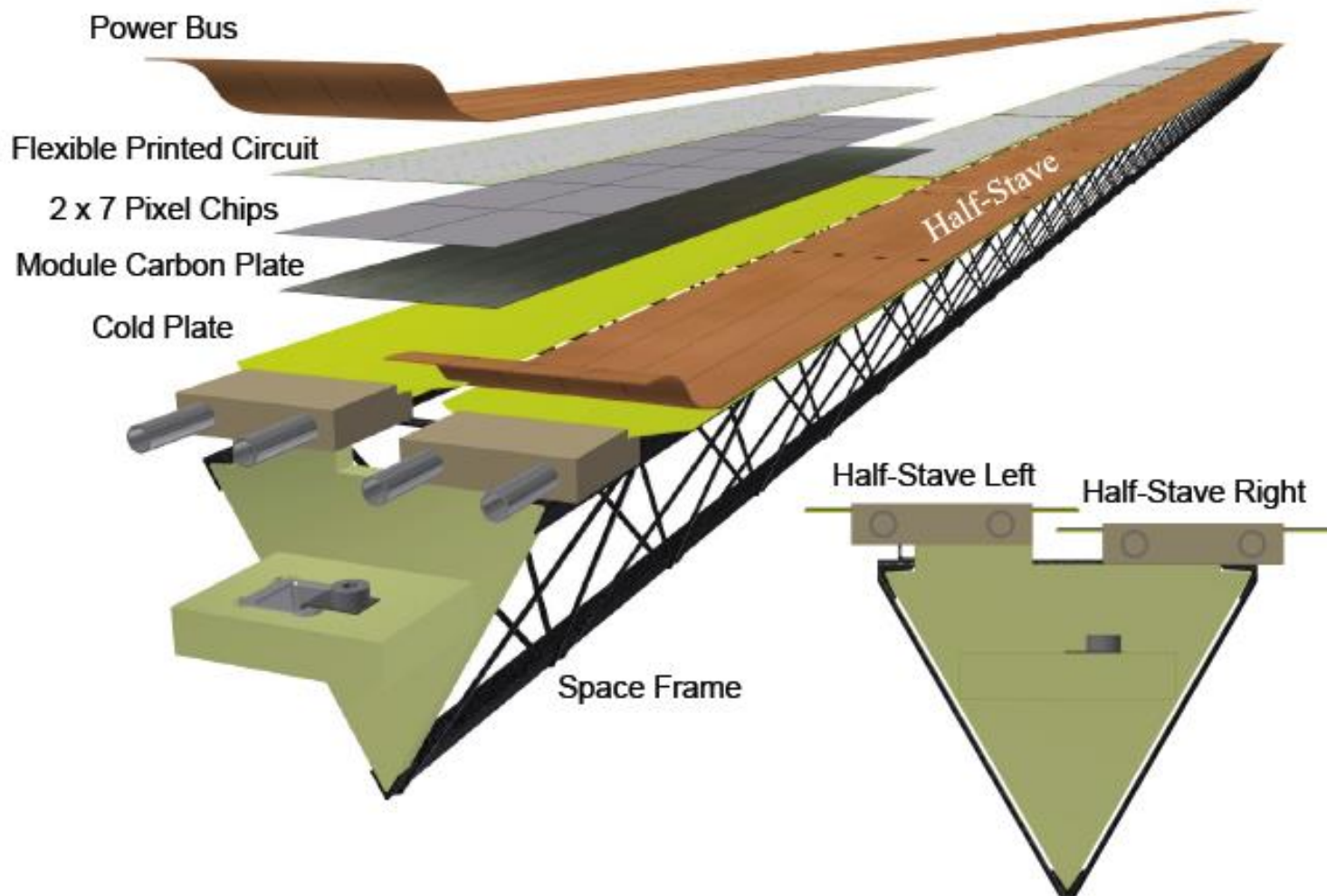
~ 11m² silicon area

~ 750 000 readout channels

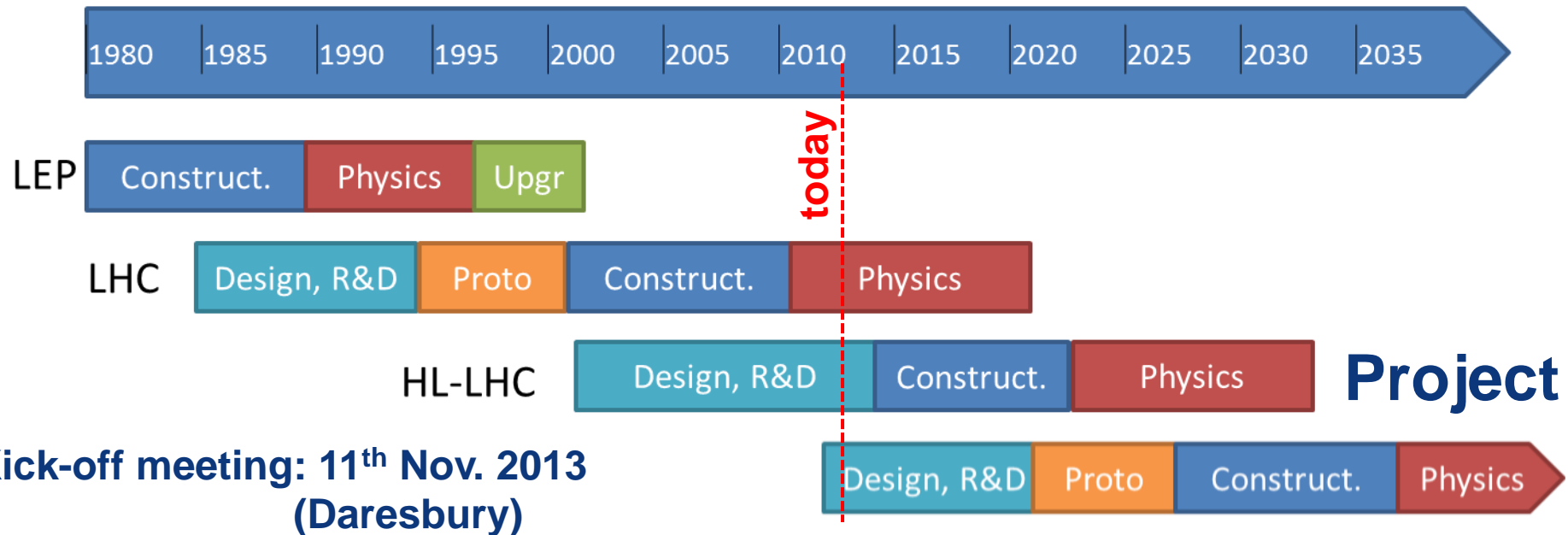
10m², 30GPixel 100-500kHz monolithic ,camera' for the upgrade of the ALICE detector



Development within the collaboration, production partially outsourced.



*“CERN should undertake design studies for accelerator projects in a global context, with emphasis on **proton-proton** and electron-positron **high-energy frontier machines**.”*



FCC Study : p-p towards 100 TeV
Kick-off meeting: mid-February 2014

FCC: Future Circular Colliders

Future Circular Collider Study (FCC)

100 km Tunnel for e^+e^- , pp collider

Such a machine will be done – questions are too big – only question is whether it is in Europe or e.g. Asia

