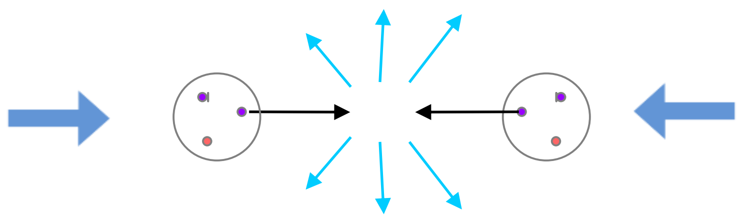
The ATLAS detector at LHC

We study new physics by colliding high energy particles

New particles are produced from the energy released when they collide head on.

If we collide protons the probability (cross section) for this is very small

Not only must the protons collide head on but also their constituent quarks.



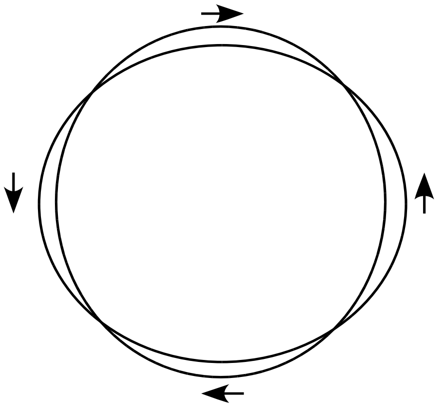
We have done this for a long time, so if we look for something new, it is a very rare such event.

And if we find it, we want many such events to believe the results

Thus,

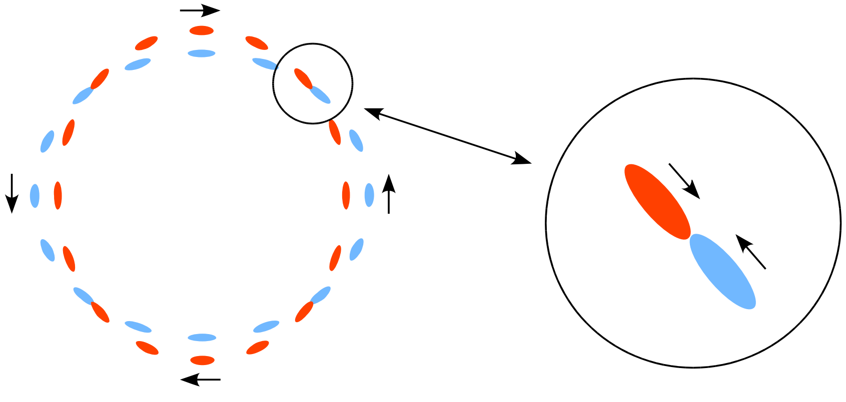
- Must collide many protons each time – high luminosity proton beams
- Must repeat collisions many times – high collision rates

One solution is to circulate the protons in two ring accelerators that cross in regions where the particles can collide



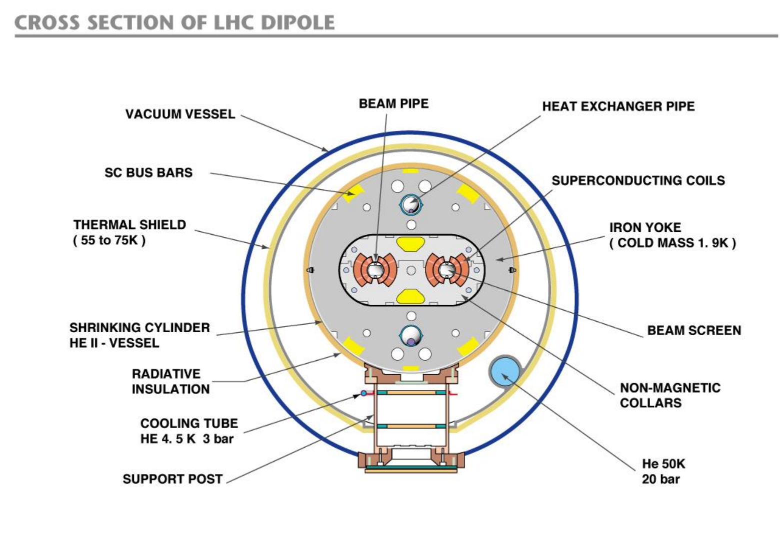
- Most protons will pass through and continue to recirculate, but some would collide
- Eventually all protons will be lost, but before that they will pass each other many times

A more practical solutions is to group the protons in bunches and let the bunches collide



The Large Hadron Collider

- 27km circumference double ring collider
- 13 TeV (6.5+6.5) – 0.999999991 times c, i.e. 3m/s less than c
- 4 interaction points with detectors – ATLAS, CMS, LHC-B and ALICE
- 10^{34} protons/cm^2/sec focused into 16 μ beams that collide
- 1600 superconducting magnets (up to 9T) to bend and focus the beams
- Bunches with about 10^{11} protons collide every 25 ns
- The total beam energy is 562 MJ
- Start of operations 2010 (2008)



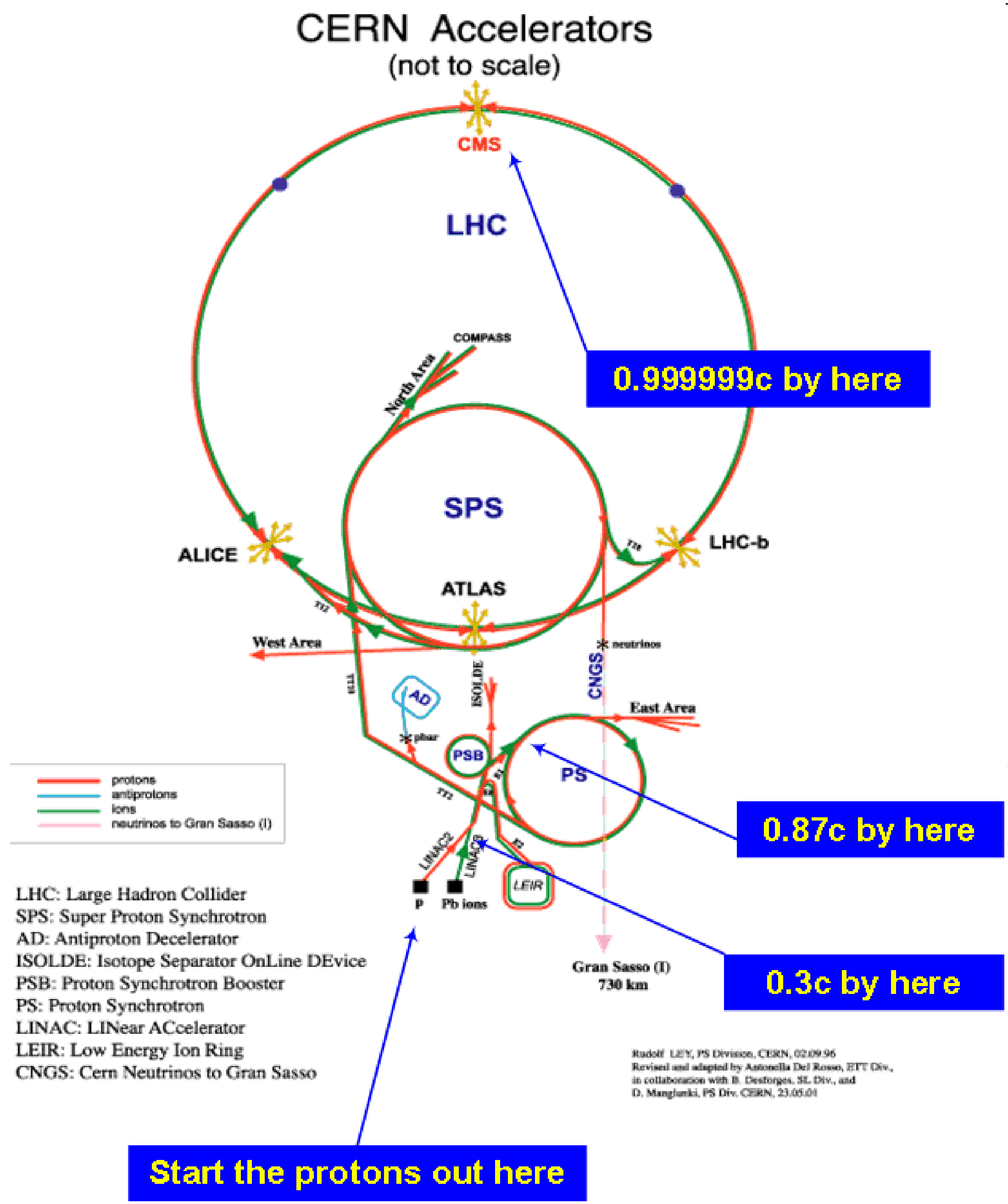
A hierarchical system of accelerators

Lineac 2 → PS Boster → PS → SPS → LHC

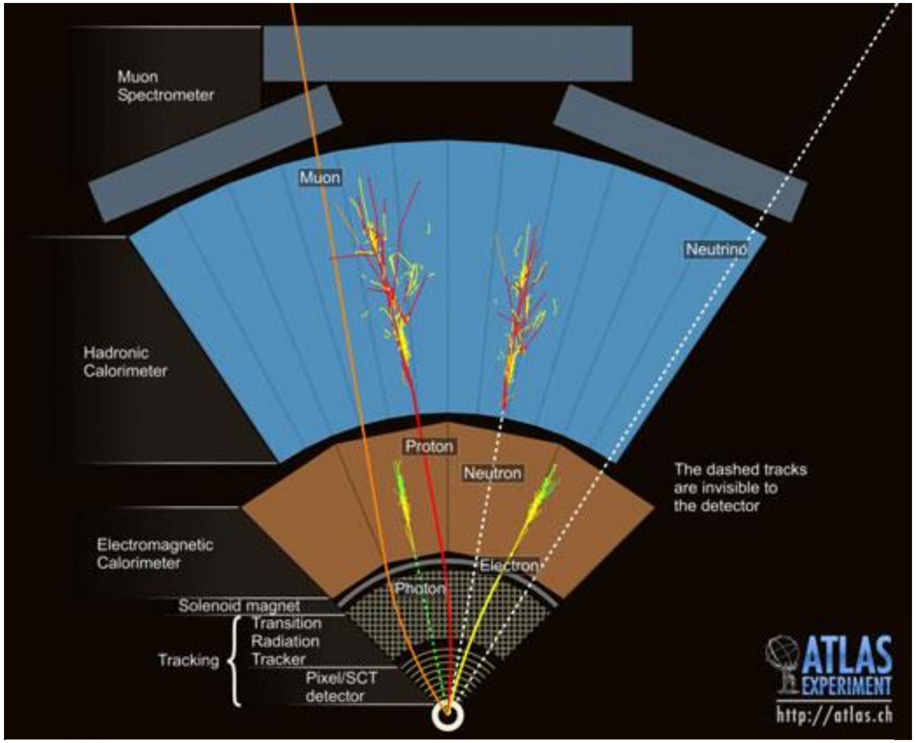
50 MeV I.4 GeV 25GeV 450GeV 6.5TeV

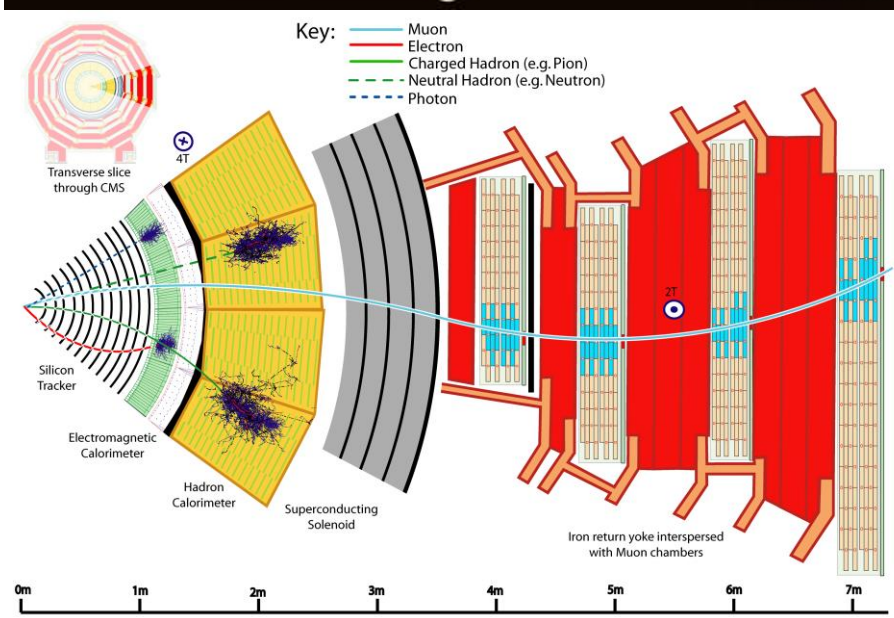
One or two injections into LHC per day

450 GeV injected protons accelerate to 6.5 TeV during 20 minutes

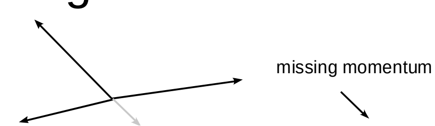


Identifying the collision event





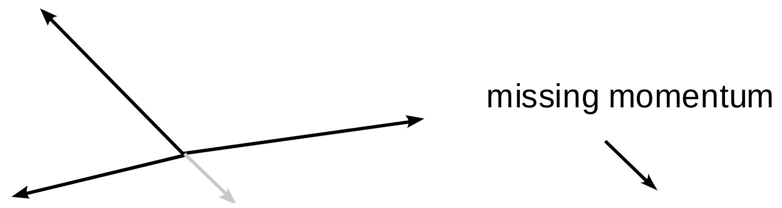
- All short-lived particles decay before entering the detector itself
- Remaining particles: e-, e+, γ, hadrons (p, n..., jets), μ+, μ-, ν, ?
- A high energy quark will pick up other quarks as it leaves, creating a hadron je
- Onion-like construction with multiple subdetector and magnet shells:
  - Inner detector – tracker
  - Magnets to deduce charge
  - Electromagnetic calorimeter
  - Hadron calorimeter
  - Muon detector
  - Missing momentum



- Group particles from the same interaction point – deduce source particle: e+e- ->Z μ+μ- ->Z   2Z-> H

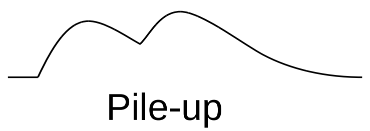
Inner detector information geometrically precise, but no amplitude information needed

Good energy information in calorimeters and muon detector to determine missing momentum



Only transverse momenta considered, but all particles should be present – hermeticity

Detector signals are long, many bunch crossings, but must be associated with correct bunch crossing – pile-up problem at high count rates



Broken detector parts must be corrected for

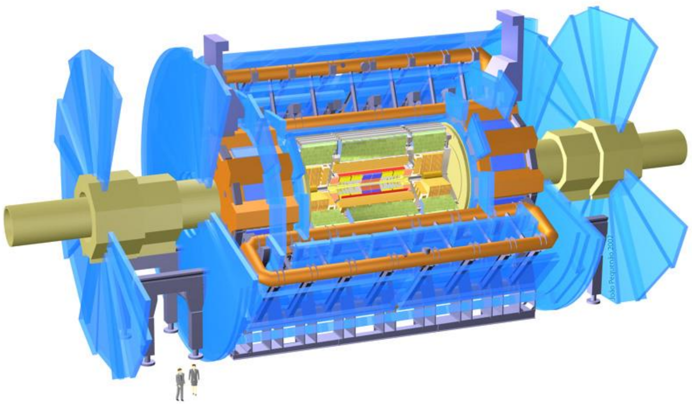
E/M calorimeter should be deep enough to contain electrons and γ

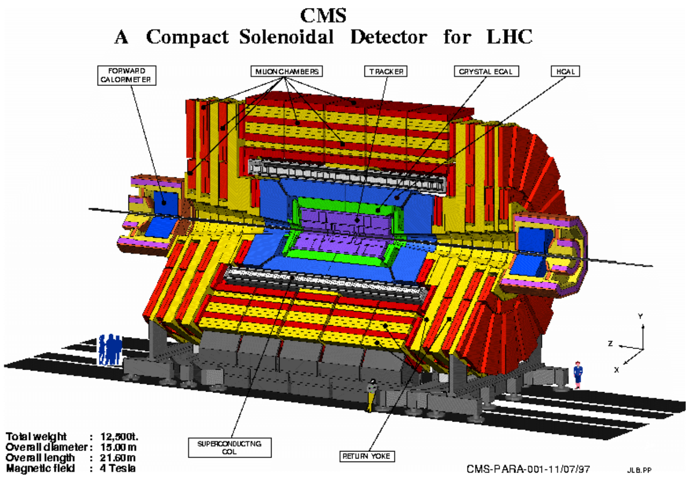
Hadron calorimeter should be deep enough to contain hadrons

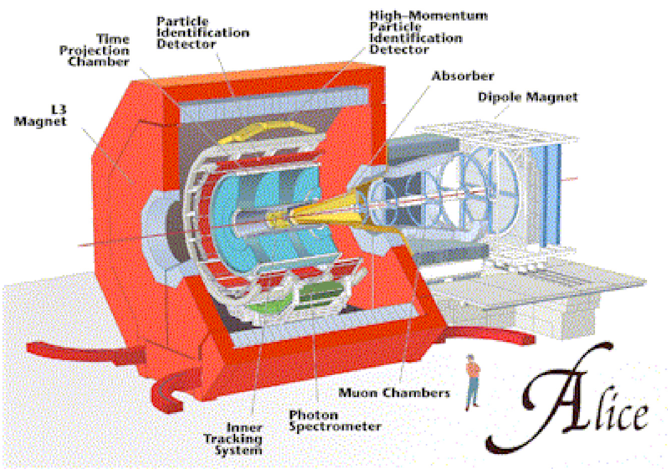
Radiation levels determin choice of detectors and electronics

Design compromises necessary for economical reasons

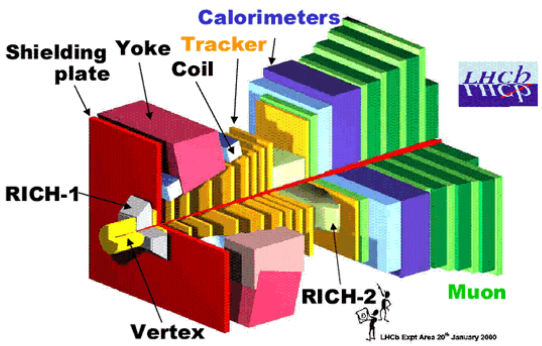
LHC Detectors







Pb - Pb



ATLAS -CMS

Similar but different – magnet system, detector solutions, TDAQ system

Competition – Collaboration

LHC results and cost

RESULTS so far

Higgs particle discovered 2012 July 4th (Nobel prize 2013)

No strong indications for BSM physics (Beyond Standard Model) yet

No SUSY (SuperSymmetry) yet

750 GeV bump exciting – could be something – BSM inthat case – more next month

COSTS

LHC material costs 3.1 G€

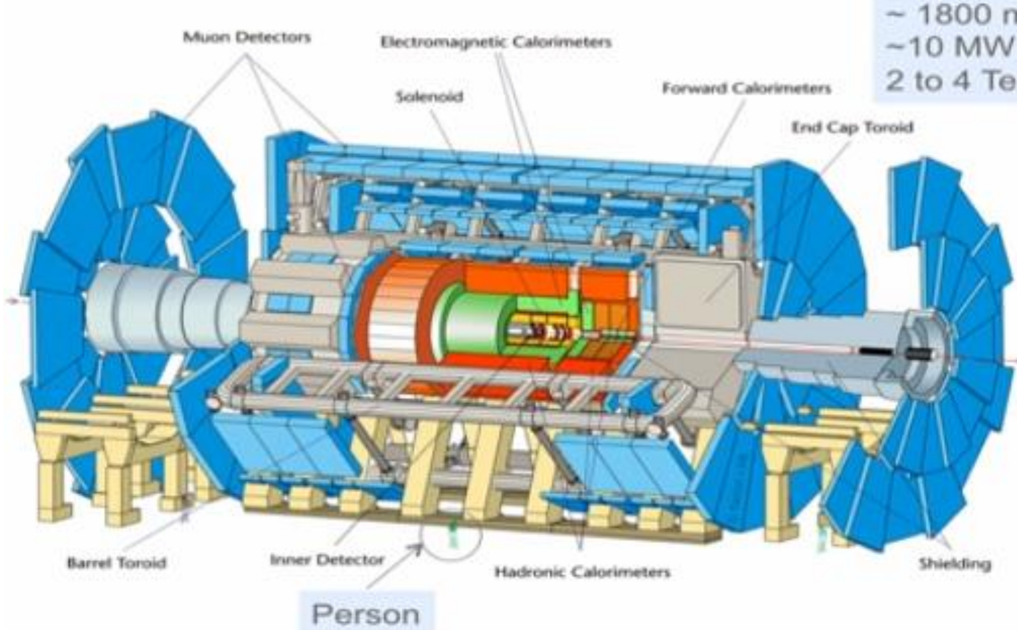
ATLAS material costs .3 G€

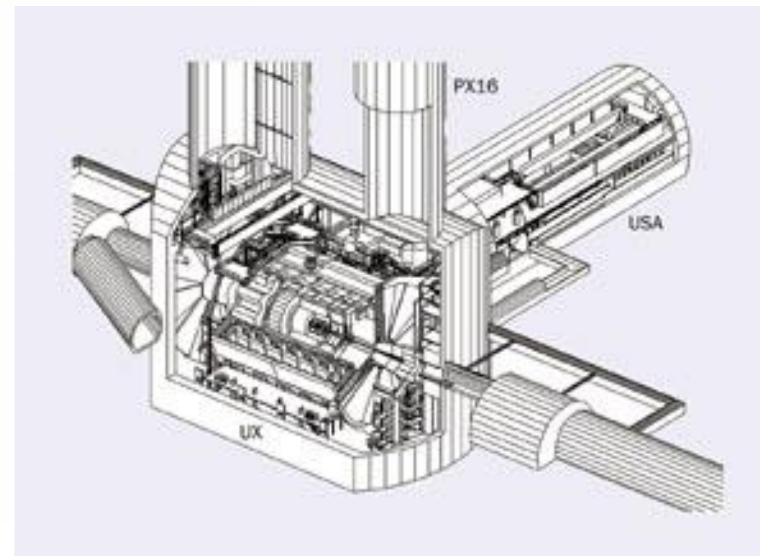
A ToroidaL ApparatuS - ATLAS

46 meters

~ 1800 miles of cables
~10 MW of electric power
2 to 4 Tesla mag. field

25 meters





USA = Underground Storage Area
100m below surface

Inner detector 1 bit? - ~86 Mch

E/M calorimeter 16 bit - ~300 kch

Hadron calorimeter 16 bit ~10kch

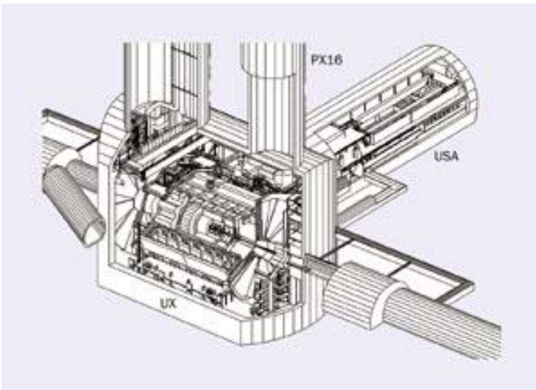
Muon detector x bit ~100 kch

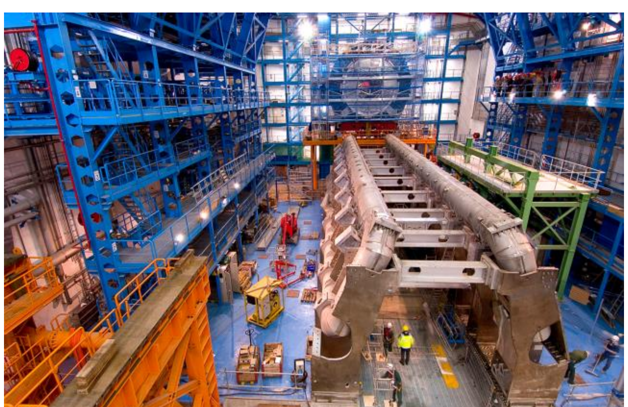
3000 physicists + x engineers

174 institutes from

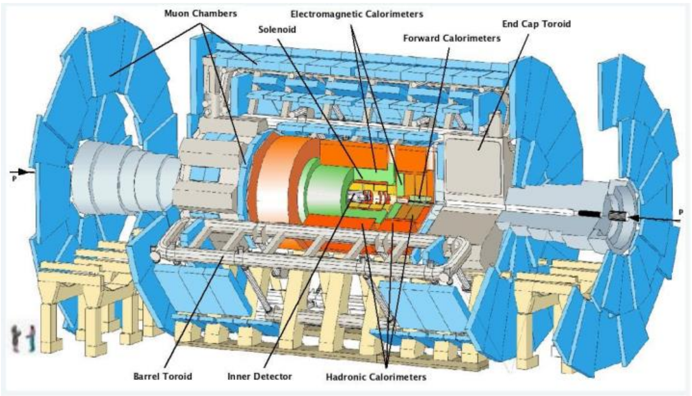
38 countries

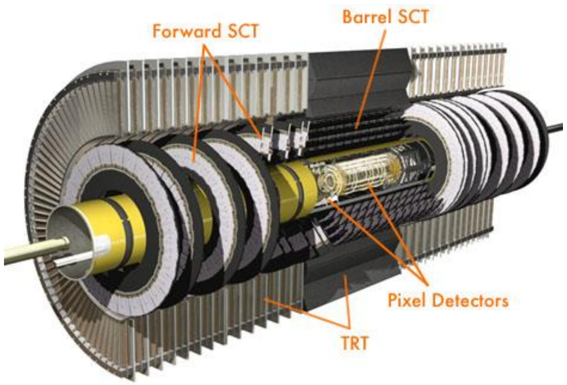
ATLAS installation





ATLAS inner detector





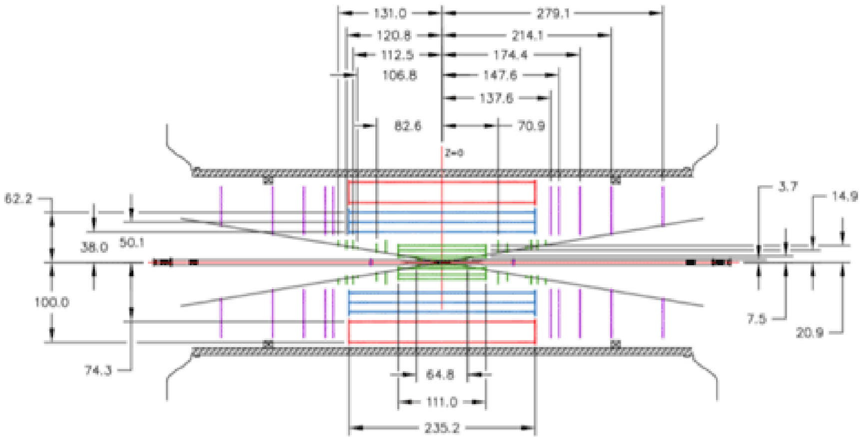
Magnetic field 2T
3 different detector types

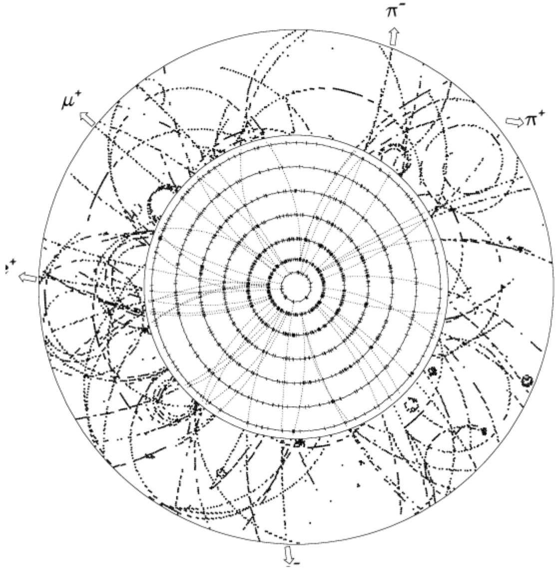
Pixel detector 80 Mch
Silicon pad detector 2D resolution 12 mx110m

Strip detector 6 Mch
Silicon detector (1D)
Double layers Resolution 23 m x800m

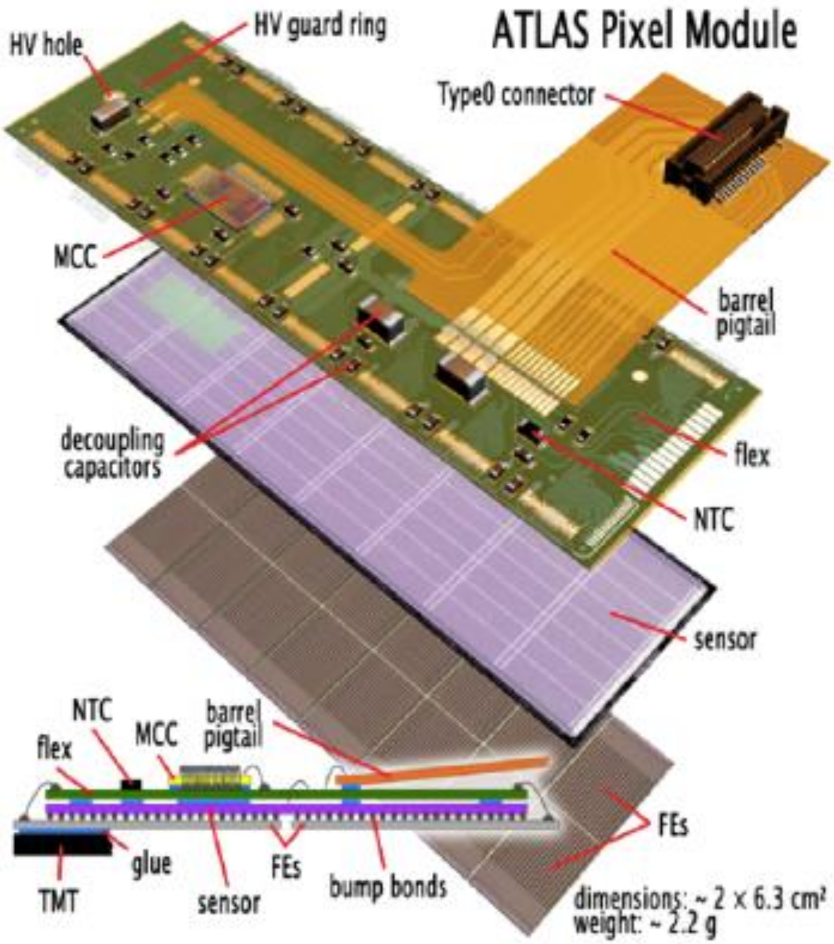
Transition Radiation Tracker 300kch
Gaseus detector – straw tubes
Elevtron identification

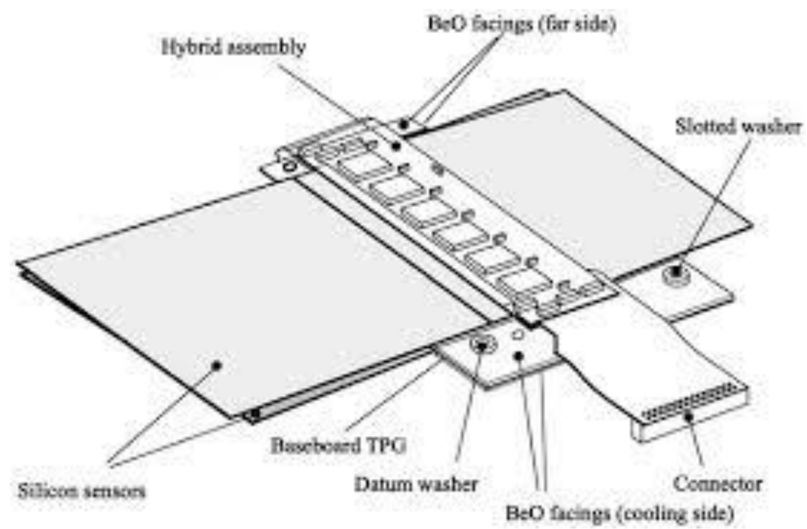
Pixel detector 3 sample points
Strip detector 4 sample points
TRT 36 sample points





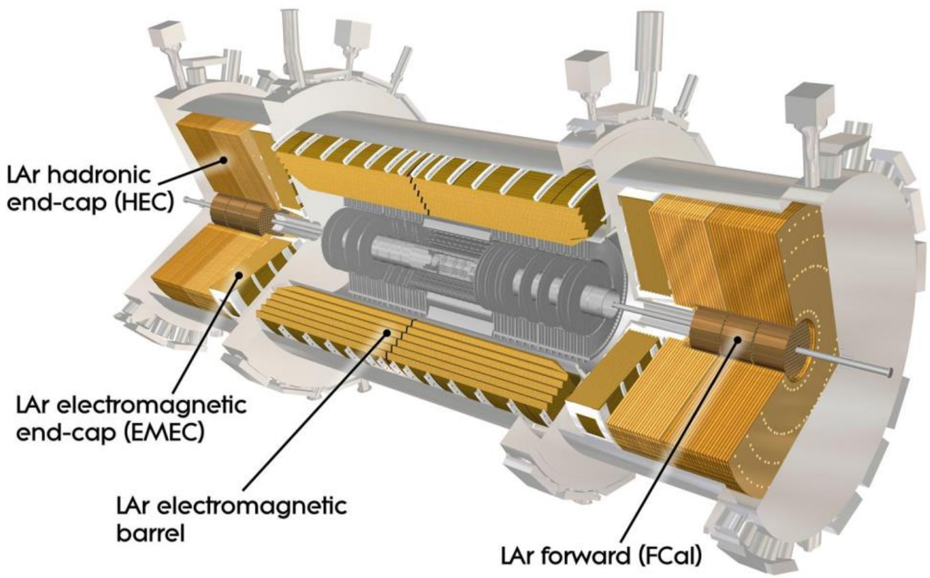
About 1000 particles

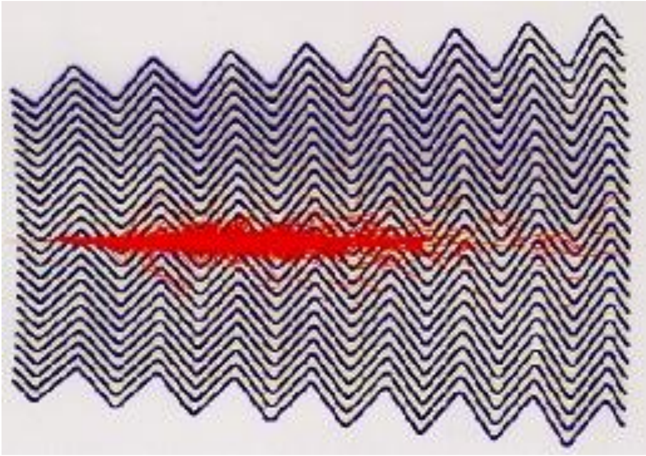




Radiation tolerance, power and cooling problems

Liquid Argon e-m calorimeter



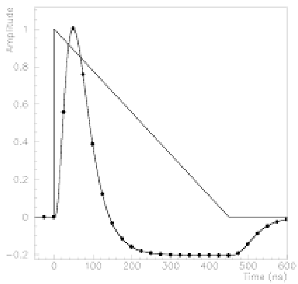


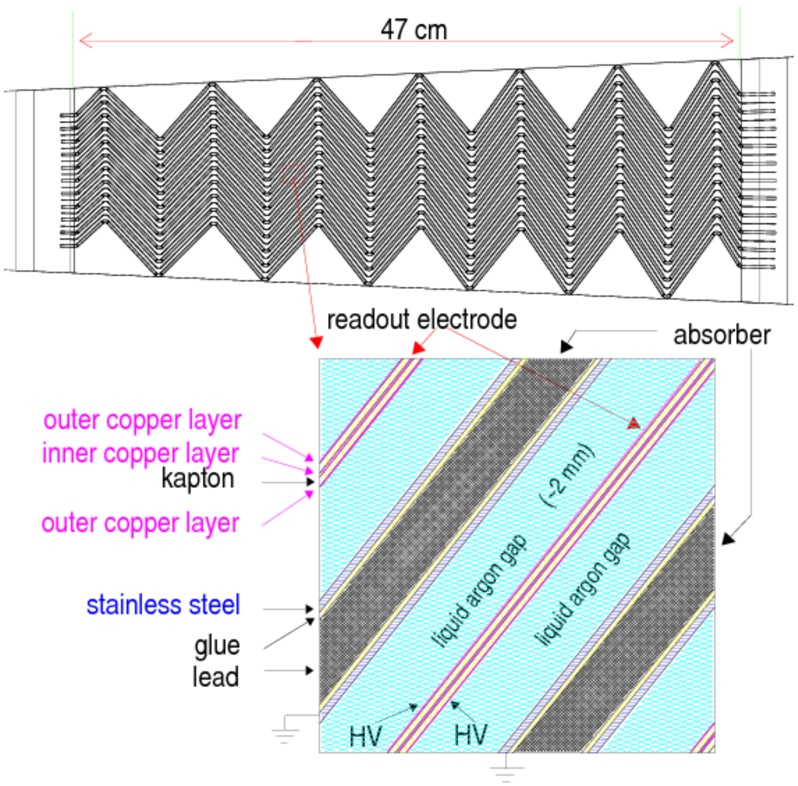
Liquid Argon-Lead/stainless steel calorimeter (87^{o}K)

16-bit dynamic range

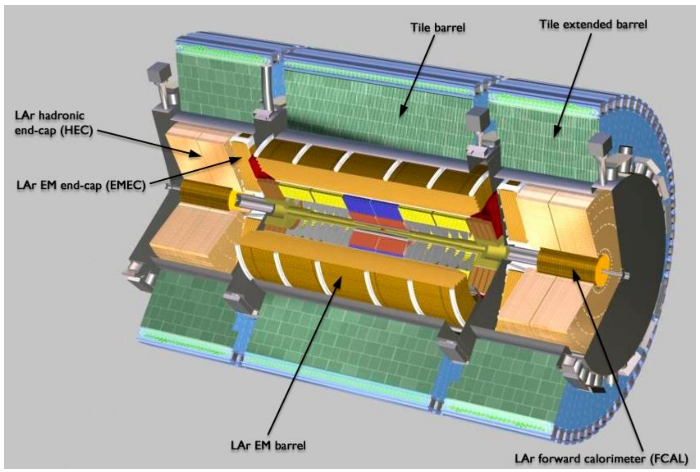
Cooled preamplifiers

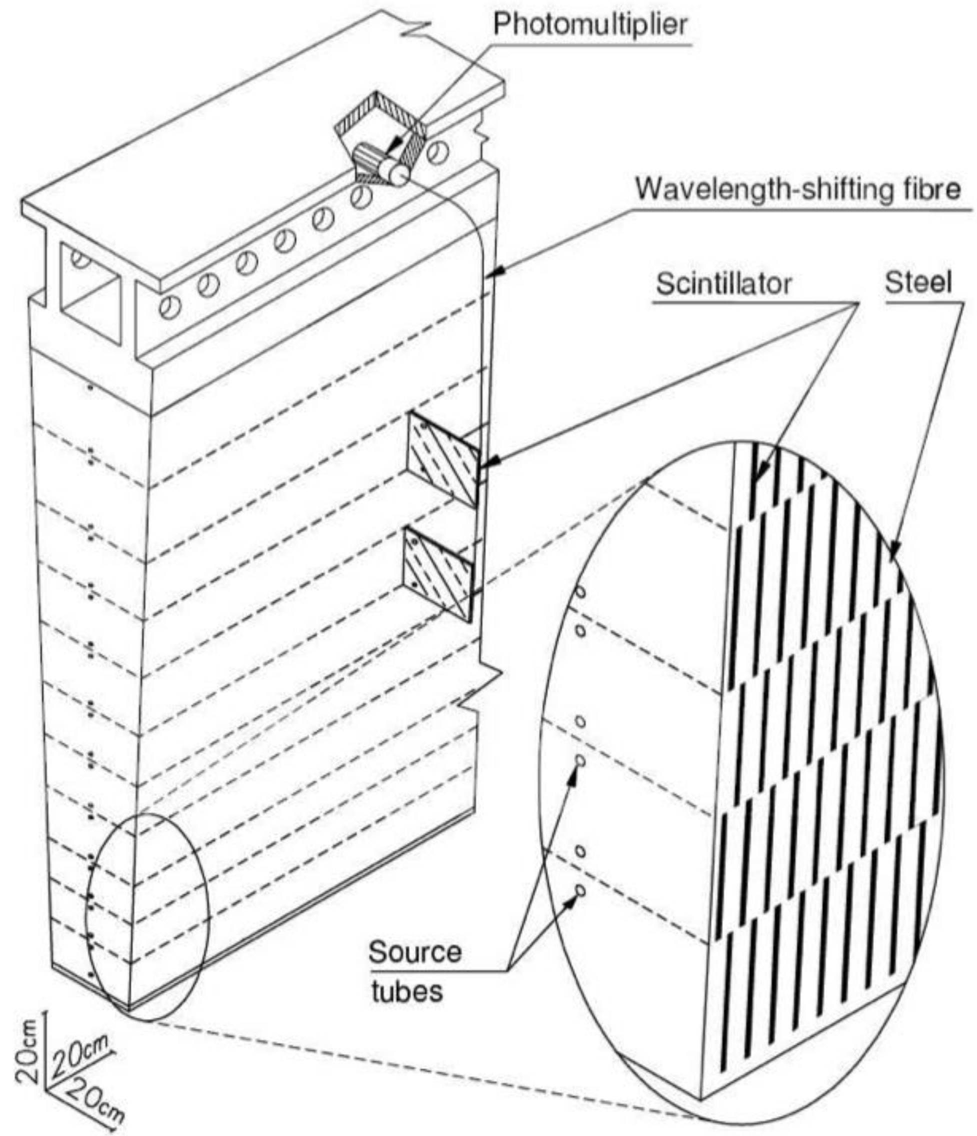
4 layers + presampler





TileCal hadron calorimeter





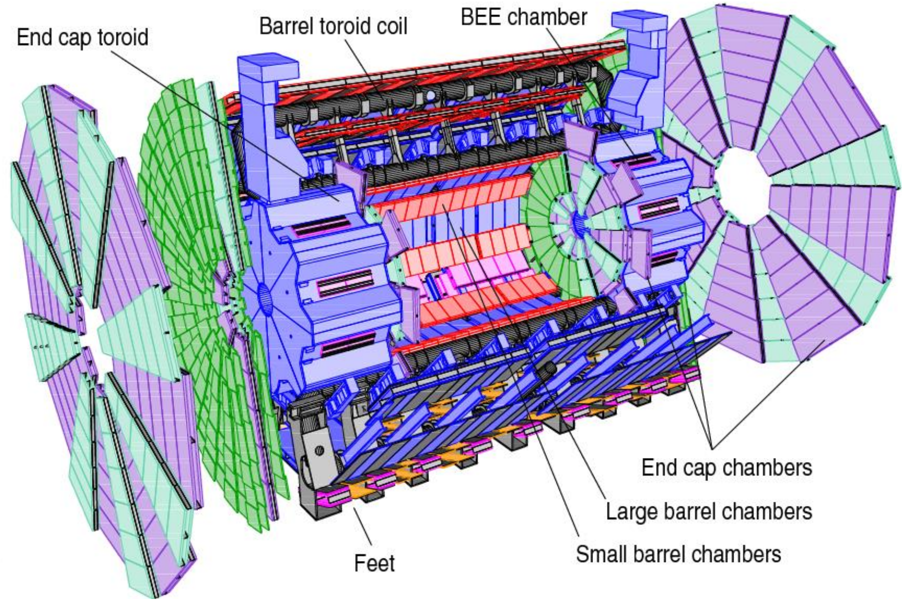
Interleaved steel and scintillator tiles

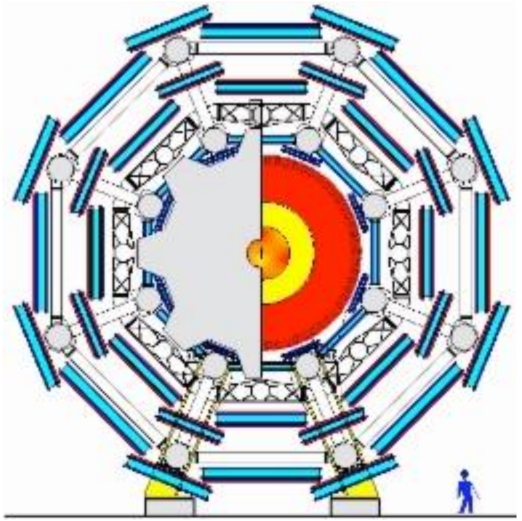
256 modules, each weighing 10 tons

4 depth layers

Coarse spatial but good amplitude resolution

The Muon Detector





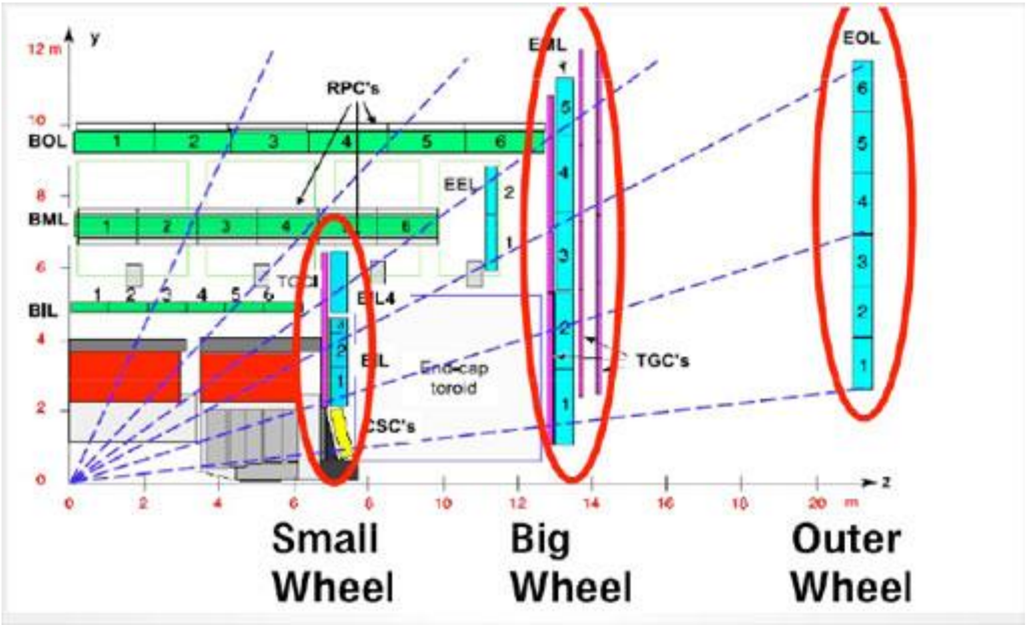
Geometrical alignment precision 30 μm

Alignment can change due to temperature change or deformations when the magnet field is changed

Cost → Use gas detectors different types for precision and trigger and different types for normal and high intensity regions – close to beam pipe

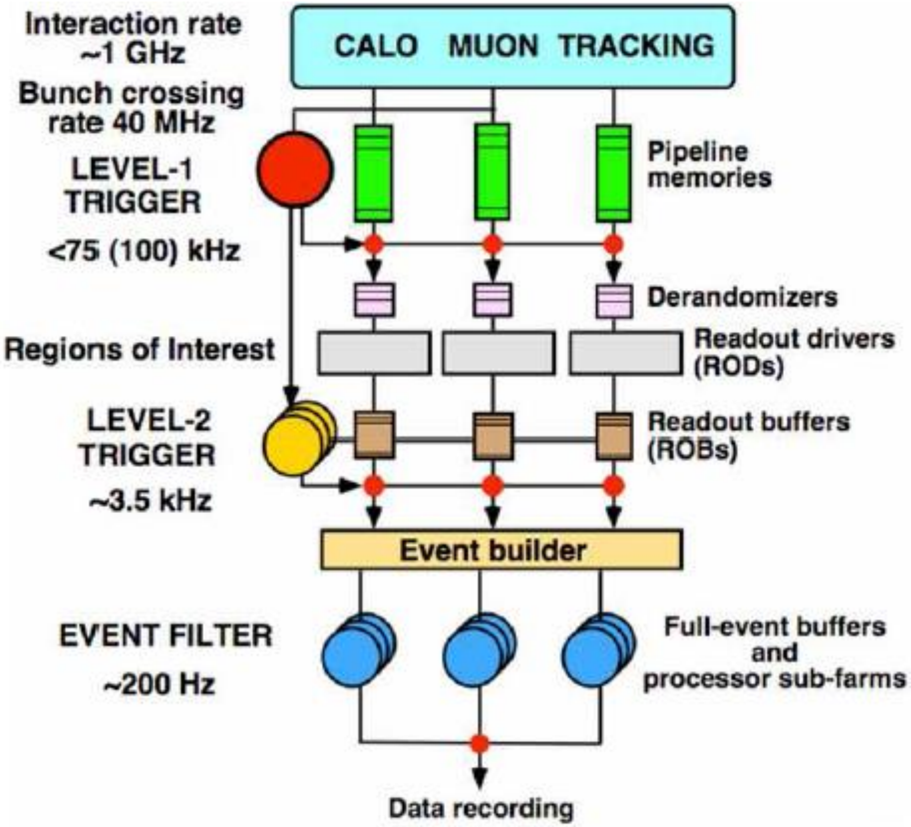
MDT(Monitored Drift Tubes) and CSC (Cathod Strip Chambers) for high precision. CSC for high intensity

RPC (Resistive Plate Chambers) and TGC (Thin Gap Chambers) for trigger. TGC for high intensity regions.



Trigger and Data Acquistion (TDAQ)

Reading out all data, every bunch crossing, completely impossible - data transfer limitations
Solution -> use multilevel trigger – data storage limitations, radiation tolerance



First level trigger – pipe-lined processing (in FPGAs) of merged calorimeter and muon data with reduced spatial and amplitude information - delivers Regions Of Interest

Second level trigger – PC based software processing full resolution data from all subdetectors but only from RIOs

Third level trigger – Event Builder – PC farm to on-line analyze all data at highest precision

First level trigger

The Calorimeter trigger processor and the Muon trigger processor reports to the Central Trigger Processor (CTP)

CTP looks for characteristic signatures in the data that indicates that the data contains an interesting event e.g.

- 4 isolated electrons or
- 4 muons or
- 2 high energy electrons over a certain threshold and 2 jets
- etc.

The search criteria are defined in Trigger Menus

The current Trigger Menu selection is defined at the start of a run

All data can be stored on the detector for maximum 2.5 μs

Before this, a decision must made on saving or not saving that data

The specified data latency allows for sending the data from the detector to the trigger processor in USA-15 (Underground Storage Area), process it and send the result back to the detector for possible transmission

First level trigger

Each bunch crossing, i.e. each 25ns

4096 data values arrive from LAr and Tile

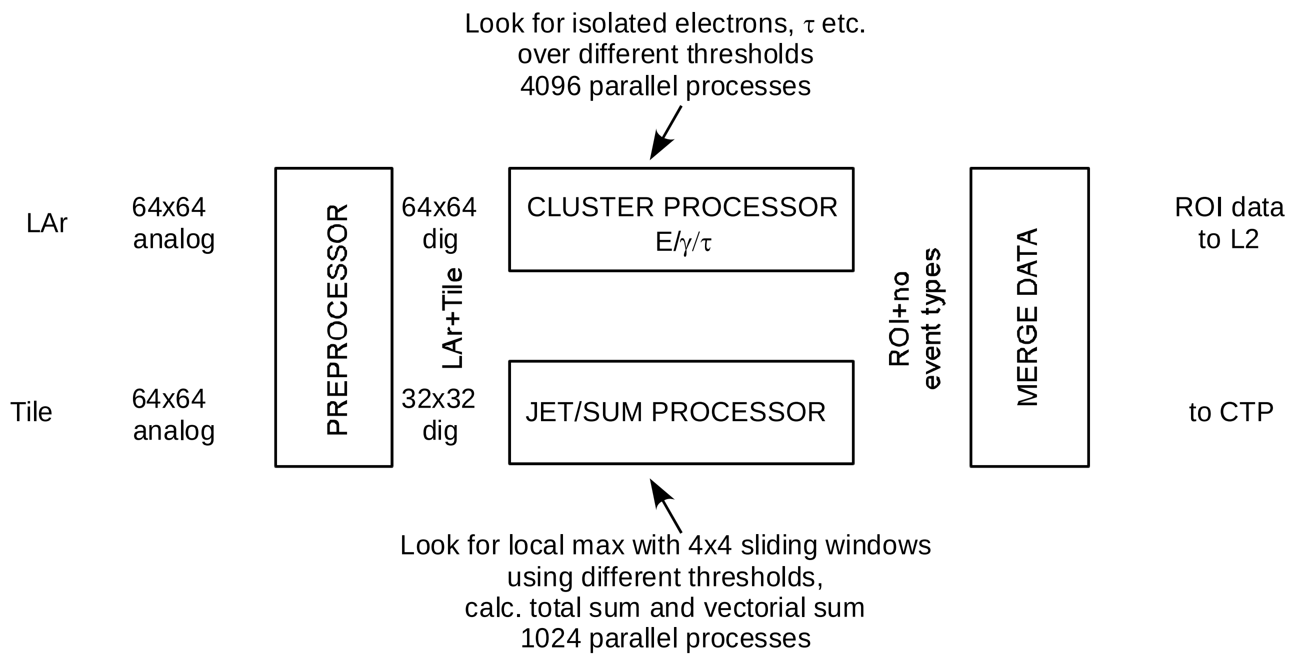
64 rows around the calorimeters and

64 along the detector

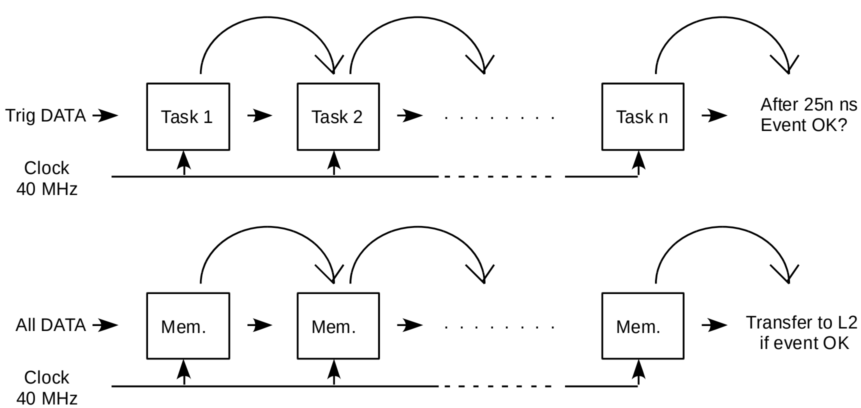
For each corresponding trigger cell one must study if it experienced an interesting event

4096 parallel processes start every 25ns and should be completed within 1 μs

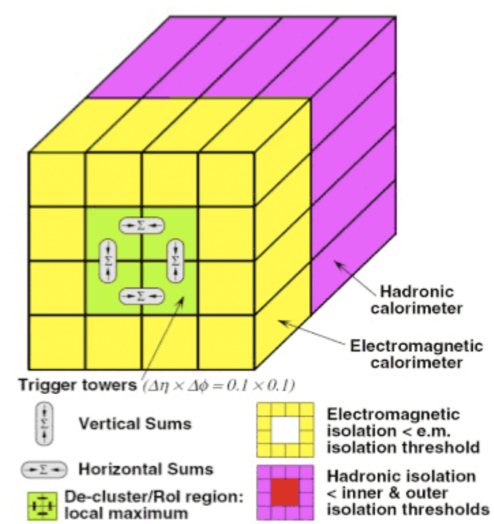
FPGAs widely used



PIPELINED PROCESSING



CLUSTER FINDING ALGORITHM



For each cell anf each set of thresh.

Vert. SUM or Hor. SUM > thresh.

Em isolation SUM< thresh.

Had isolation SUM < thresh.

Synchronization

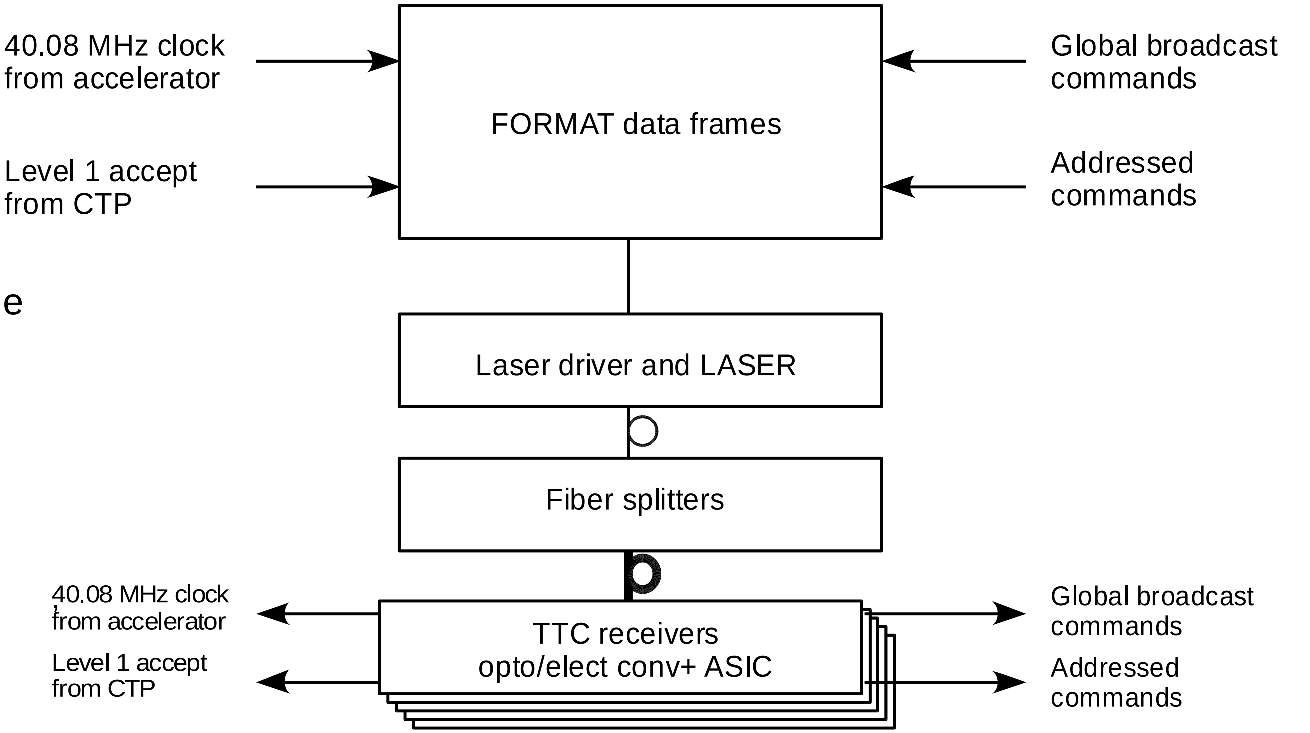
The Timing, Trigger and Control (TTC) system is responsible for synchronization

The same 40.08 MHz distributed to all Front-End units with local phase control

L1A distributed to all FE with programmable delay to maintain sync.

Addressed commands to configure FE

Maintains Bunch Crossing Identifier BCID to label events

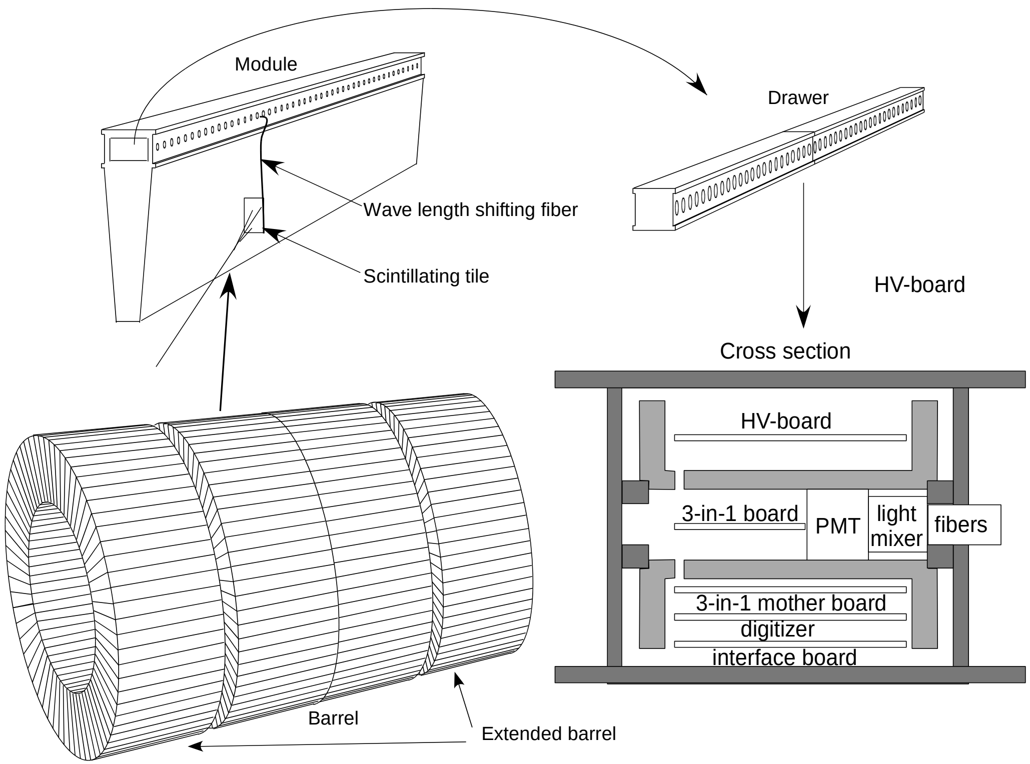


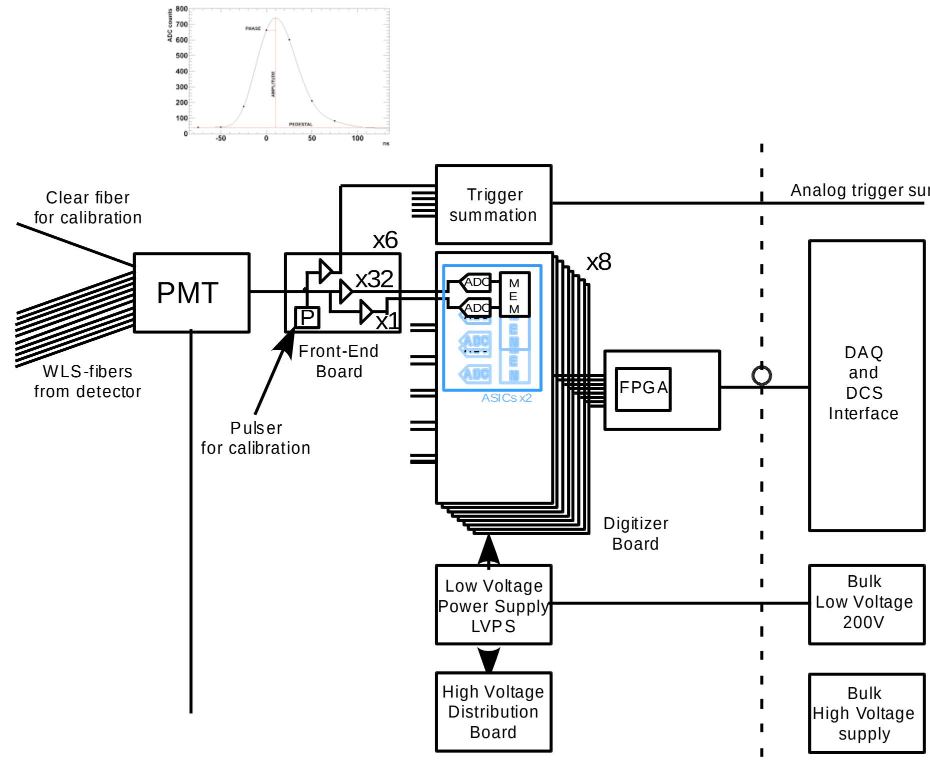
Detector Control - DCS

The Detector Control System or Slow Control, as it was called before, is responsble for initializing all system components incuding configuring the FPGAs

It is also responsible for safety functions

Front-End example - TileCal





4x64 modules (drawers) with 46 or 32 PMTs read out by 2 10 bit ADCs – high and low gain

256x8 Digitizer boards with 2 ASICs each containing digital pipeline and de-randomizer

Analog trigger signals – digitized in USA-15

3 calibration methods: Charge injection, Laser and circulating source through detector

ATLAS upgrades

LHC have regular stops for maintenance and upgrade
2013-2015 phase 0, 2018-2020 phase 1, 2024-2025 phase 2 - times might change
End 2035?

Phase 0
Prepare for full energy
Insertable B-layer – replace the inner pixel layer

Phase 1
3 times higher luminosity
New Small Wheel
Topological trigger – not only count event bur also consider where they occur
LAr fully digital trigger
New trigger architecture

Phase 2
10 times higher luminosity
New Trigger system – level 0/level 1
New inner detector – no TRT, track trigger?
New TileCal electronics – read out all data to USA-15 – fully digital trigger

General trends
More on-detector FPGAs – new FPGAs more radiation tolerant to hard but not soft errors – develop correction strategies
More high speed data transmission – 10 Gb/s or more

After 2035? FCC? ILC? CLIC?

BUT THIS IS FOR YOU!

Future Circular Collider
FCC
50+50TeV p – p
100 km circumference
New magnet technologies