The ATLAS Detector at LHC Part 1: How to build a giant - and why ?

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on behalf of the ATLAS collaboration

The Actual Problems of Microworld Physics - GOMEL09

July 17, 2009

Outline

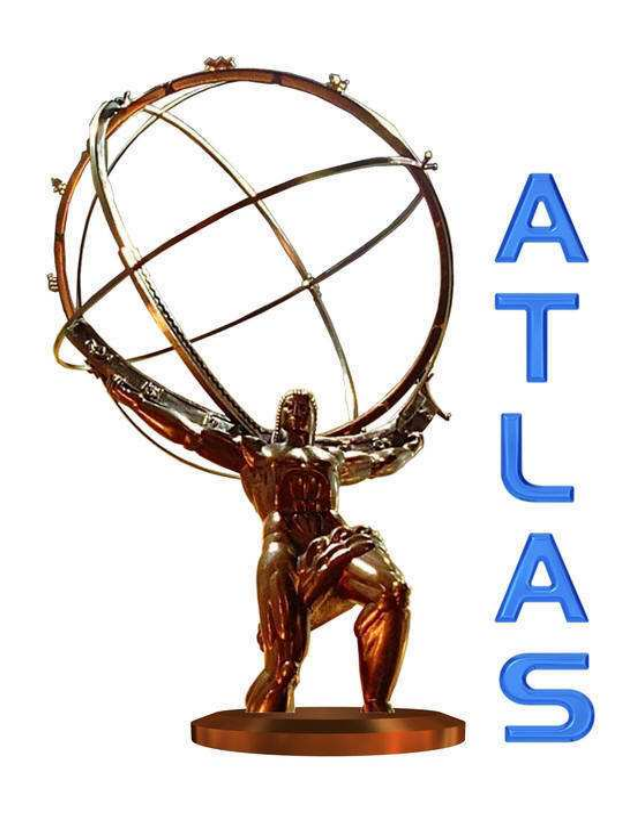
Why ATLAS?

A Subdetectors Tour

Putting it together

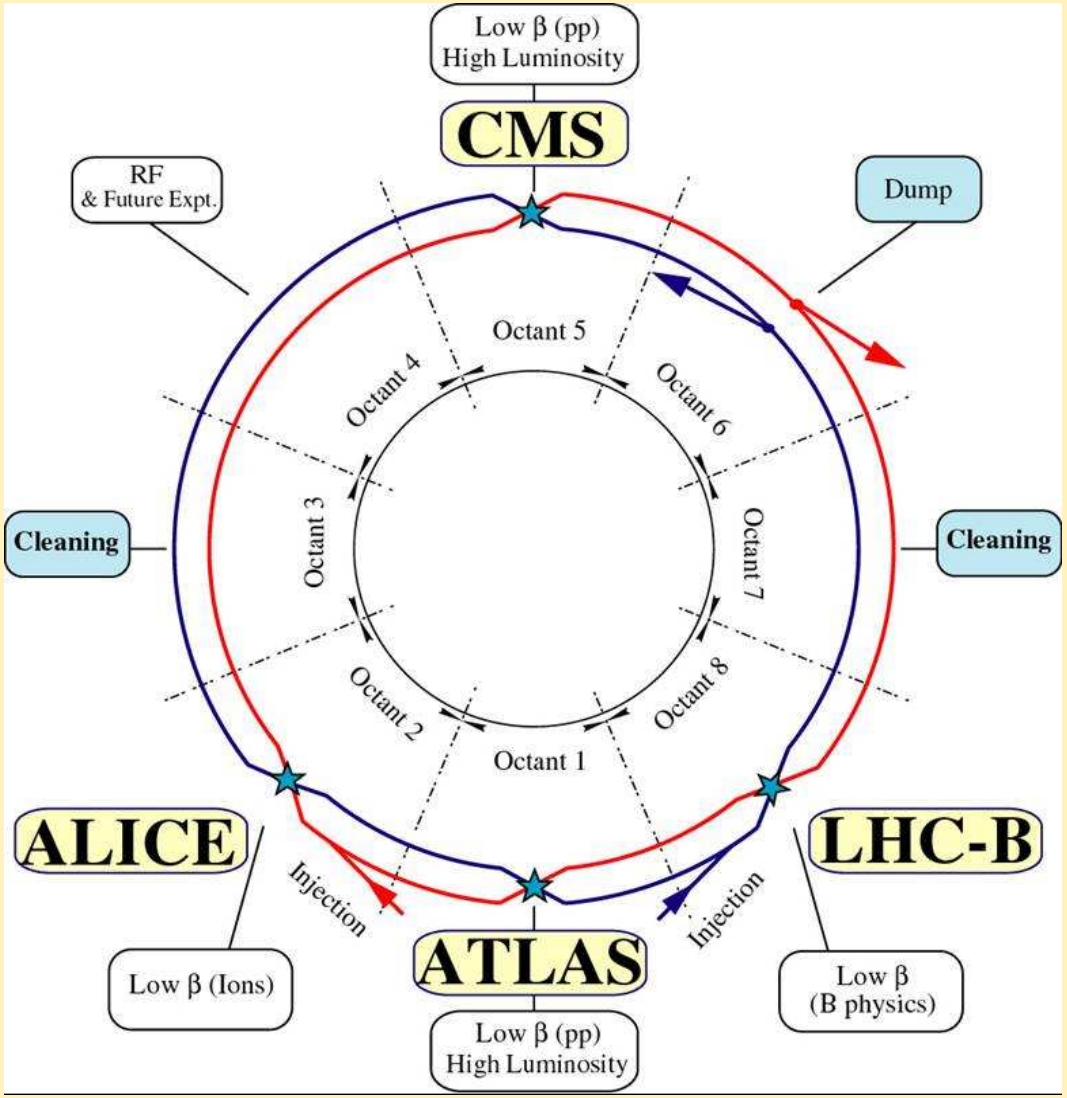
How does it run?

Summary



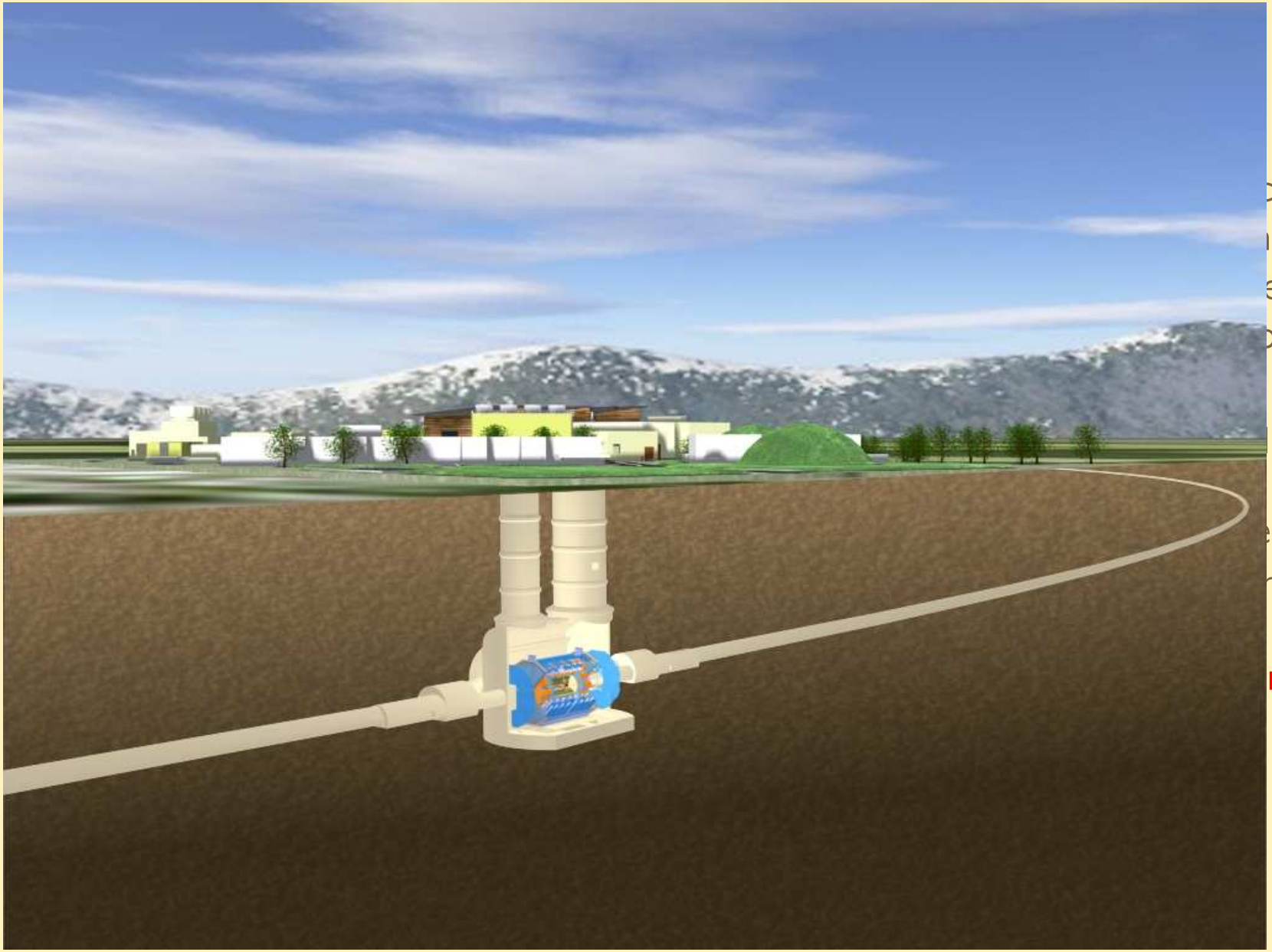
Why ATLAS?

The short answer: LHC



- pp (and Pb ion) collisions at design center-of-mass energy of 14 TeV (1150 TeV)
- Design Luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$
- Bunch crossing frequency of 40 MHz (25 ns)
- 26.7 km circumference
- 2808 bunches of $\sim 10^{11}$ protons each
- Pile up of $\sim$20 events at peak luminosity

The short answer: LHC



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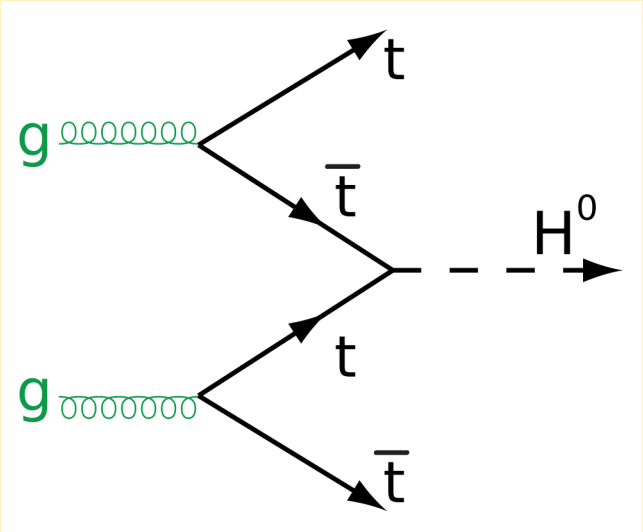
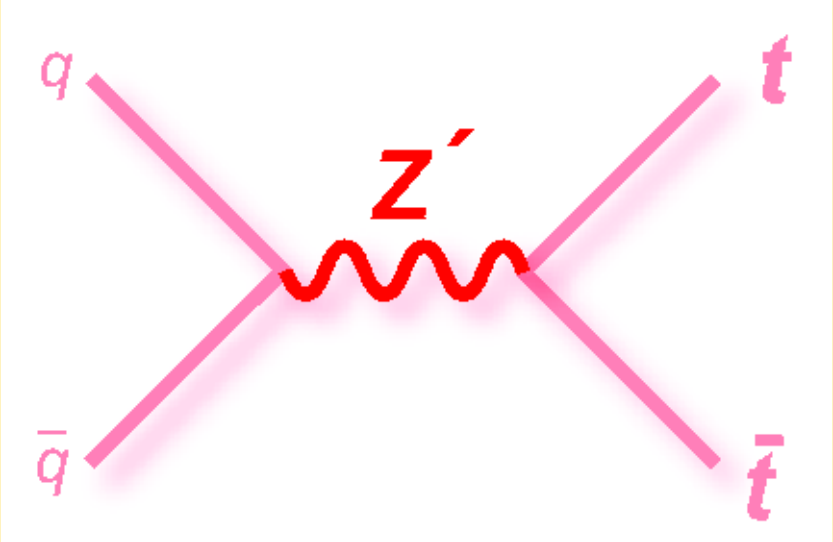
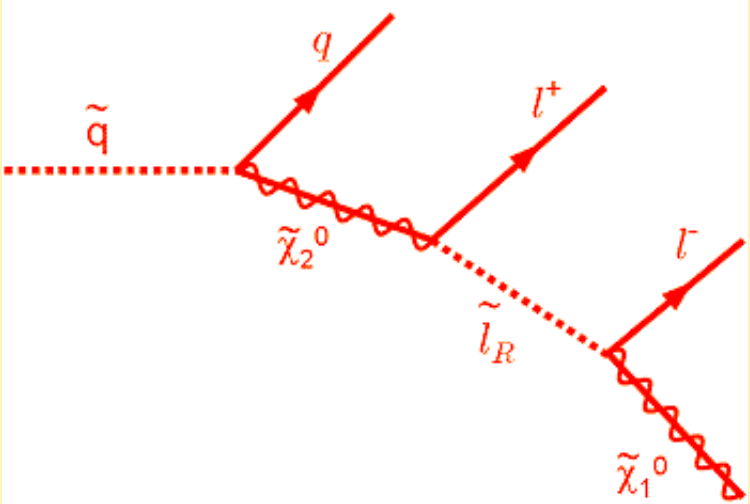
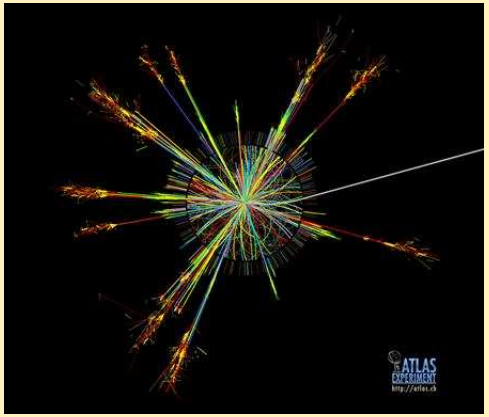
A longer answer

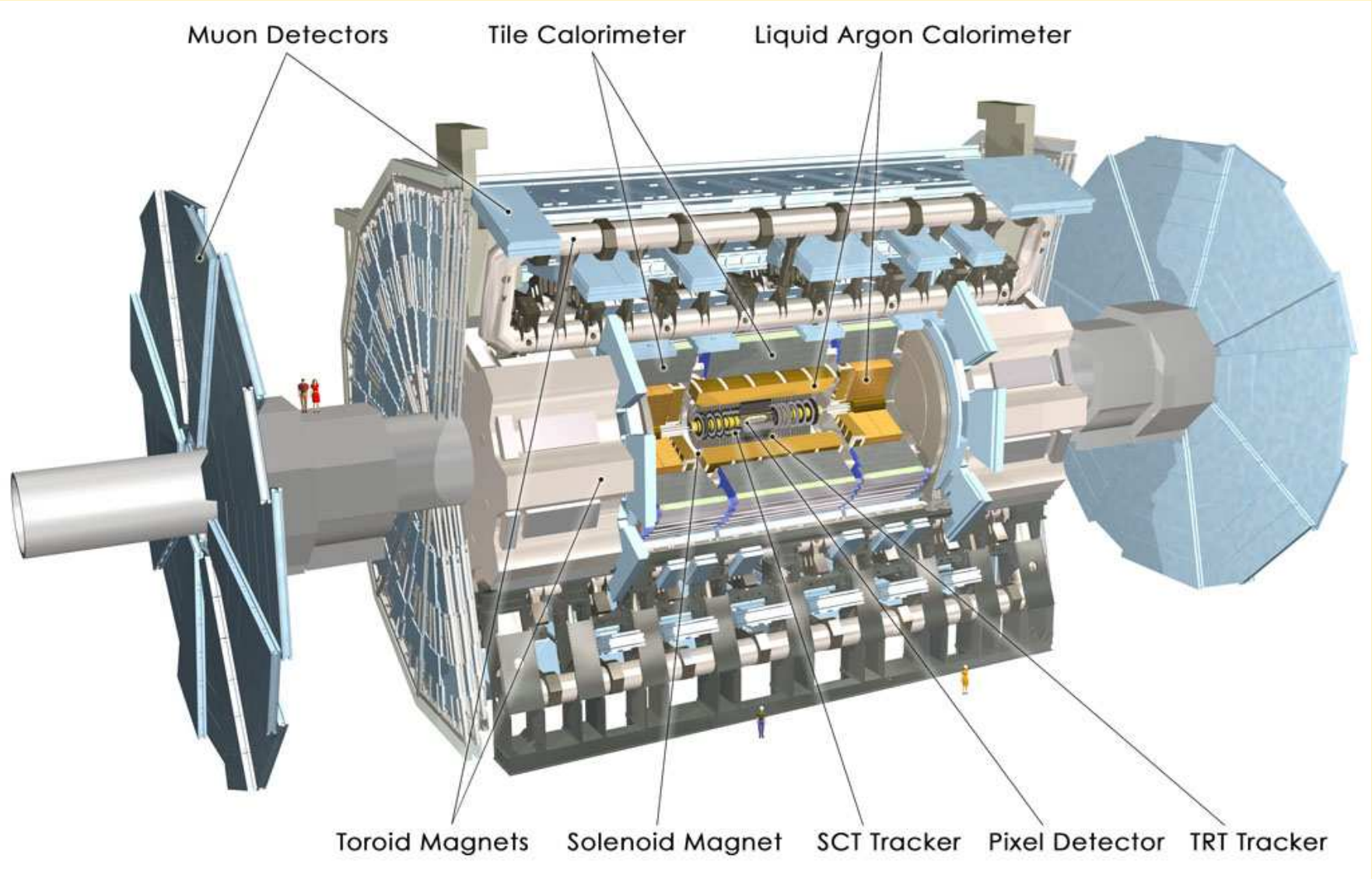
Frontiers of the Standard Model will be challenged by the physics range of the LHC (see M. Aharrouche's talk for more details)



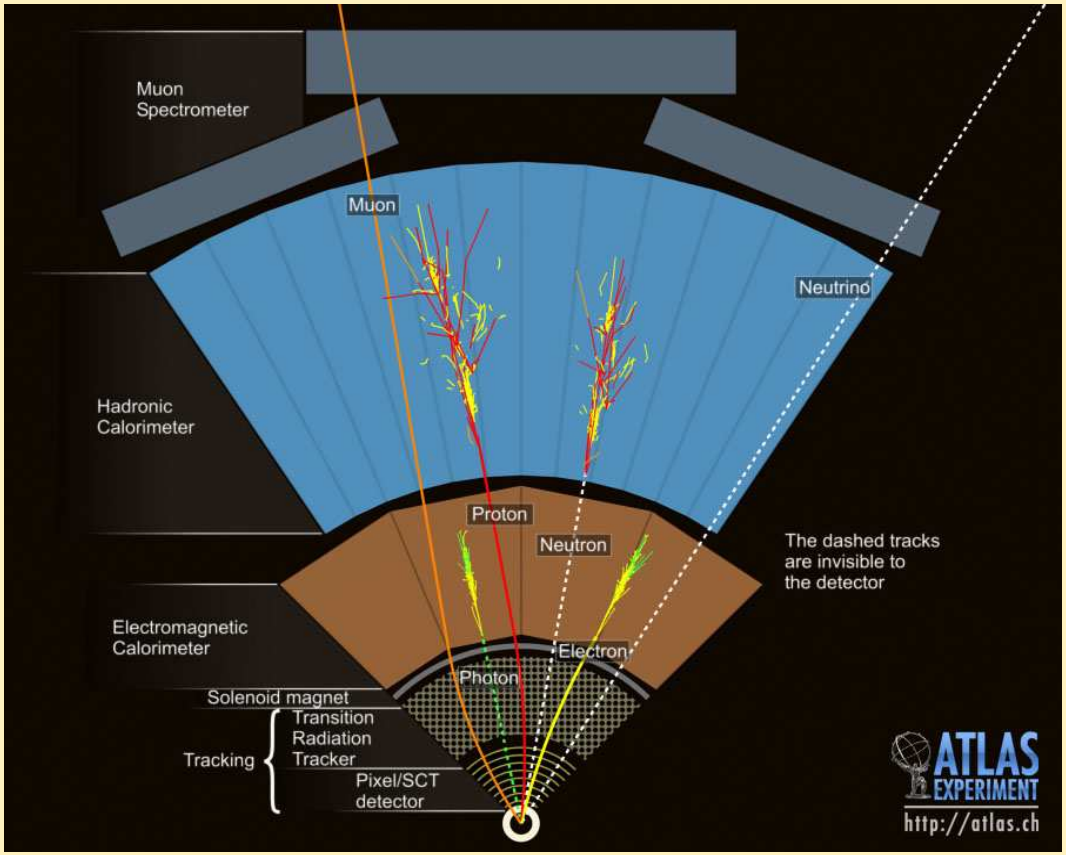







Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker

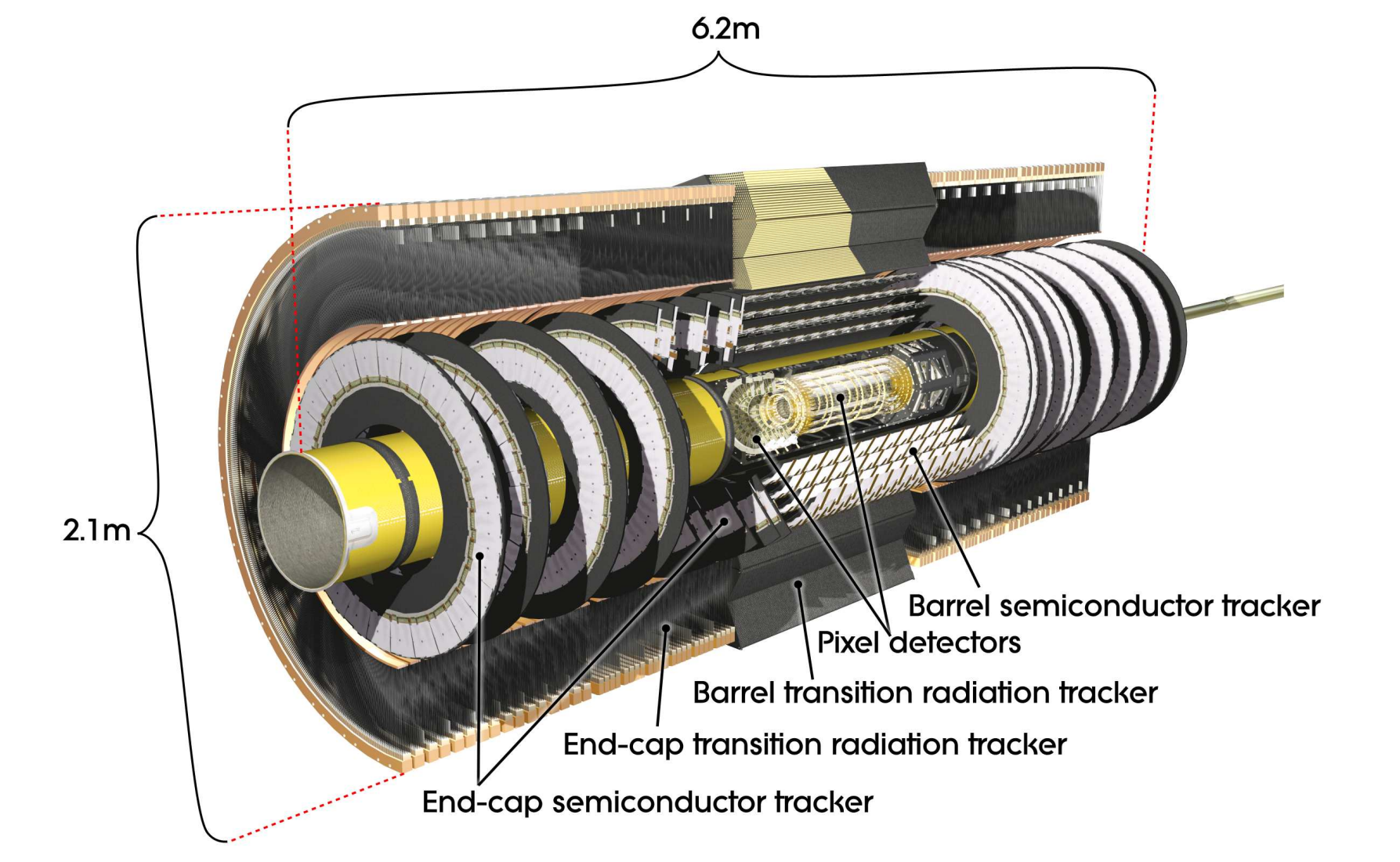
What can we see?



- Tracks from charged particles (Inner detector)
- Energy deposition from electromagnetic and hadronic particles (Calorimeter)
- Tracks from high energy muons (Muon spectrometer)

A Subdetectors Tour

The Inner Detector



In numbers...

From the beamline towards the calorimeter:

- Pixel
  - Absolute position measurement (Si pixels)
  - 3 barrel layers of active material, 2 x 3 end-cap wheels
  - $5.05 < R < 12.25$ cm
  - Covers the range $|\eta| < 2.5$
- SemiConductor Tracker (SCT)
  - Double-sided modules of Si strips
  - 4 cylindrical barrel layers, 2 x 9 disks in the end-caps
  - $25.5 < R < 54.9$ cm ($25.1 < R < 61.0$ cm for the end-caps)
  - Covers the range $|\eta| < 2.5$
- Transition Radiation Tracker (TRT)
  - Straw tube detector (Xe used as the active gas)
  - 73 straw planes in barrel, 160 straw planes in the end-caps
  - $55.4 < R < 108.2$ cm ($61.7 < R < 110.6$ cm)
  - Covers the range $|\eta| < 2.0$

Radiation

The Pixel detector lives dangerously:

- Very high radiation dose
  - F_{neq} of $\sim$8x10^{14} cm^{-2} for 2 outmost pixel layers
  - 3 years of lifetime at design luminosity for innermost layer (b-layer)

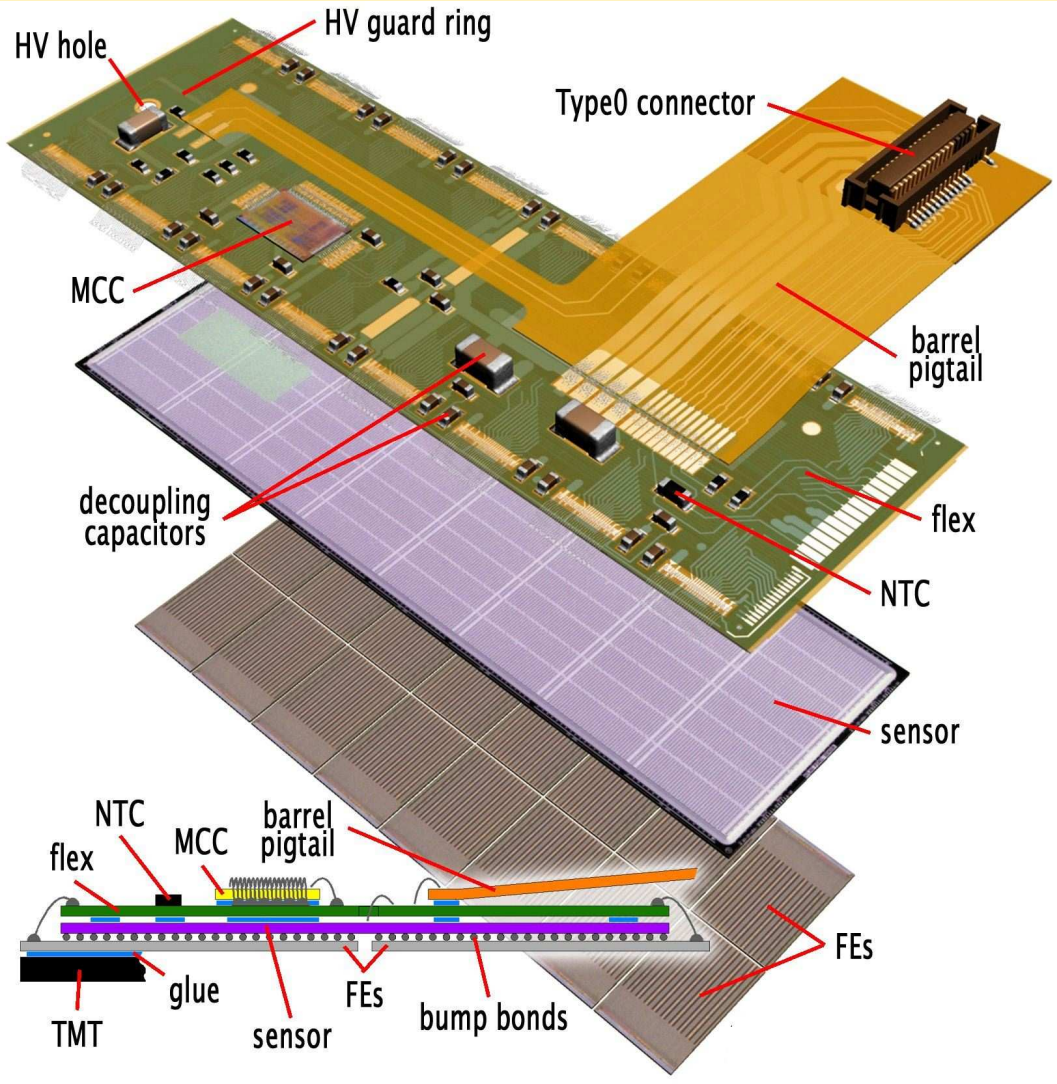
The SCT will also suffer from radiation damage:

- As for the Pixel outer layers, designed to survive for the LHC lifetime
- Innermost layer should receive $F_{neq} \leq$2x10^{14} cm^{-2}

Due to this, Pixel and SCT sensors are chosen to resists to radiation, with the help of:

- Silicon sensors designed with radiation-hardness properties
- Increasing depletion voltage (due to type inversion)
- Cold operation (to reduce leakage current and also type inversion effects)

Pixel module



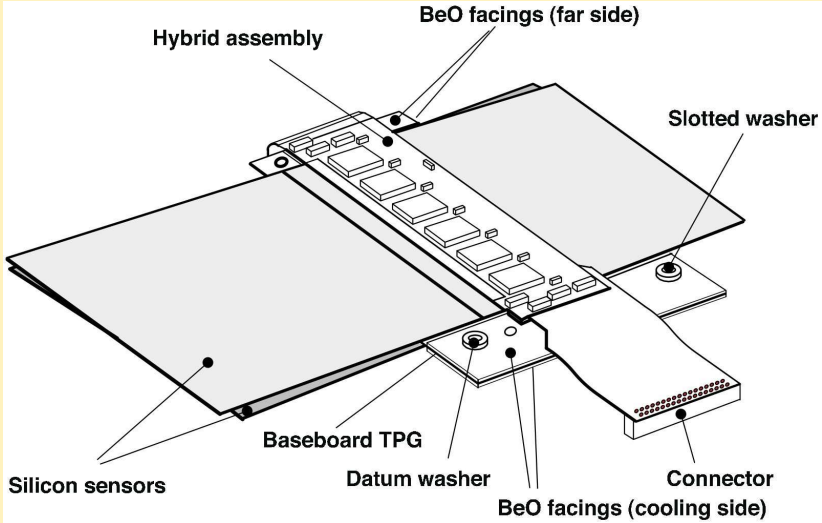
- 1744 identical modules in the Pixel detector
- 46080 channels per module, ~80 million channels total
- Bump-bonded chip on the Si sensor
- 250 μm thick sensors
- Pixel size 50 x 400 μm (also 50 x 600 μm on the edge)
- Operates at 150-600 V, -20° C nominally
- Arranged in ladders along the beam-pipe (barrel) and in wheels perpendicular to the beam (end-cap)

SCT

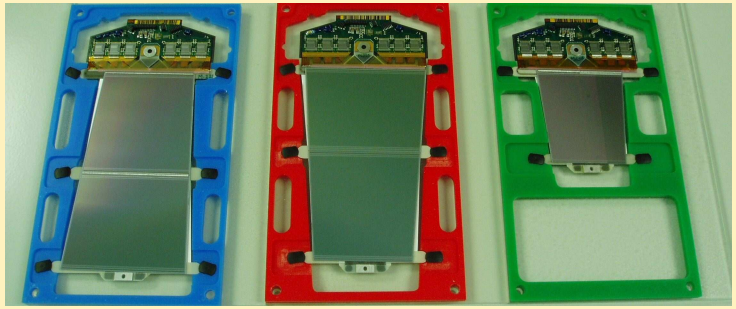
- 4088 double-sided modules of four different geometries (barrel, end-cap inner, end-cap middles, end-cap outer).
- 1536 channels per module, $\sim$6 million channels
- 63 m^2 of Si
- Wire-bonded chips to the strips
- 285$\pm$15 μm thick sensors
- Stereo angle between each side = 40 mrad
- Operates at 150-500 V, -7° C

Adds at least 4 space points (up to 9 in the end-caps) to the track

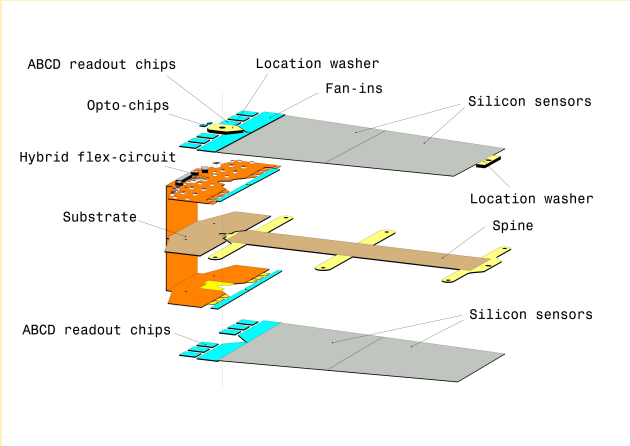
SCT module(s)



Barrel SCT module

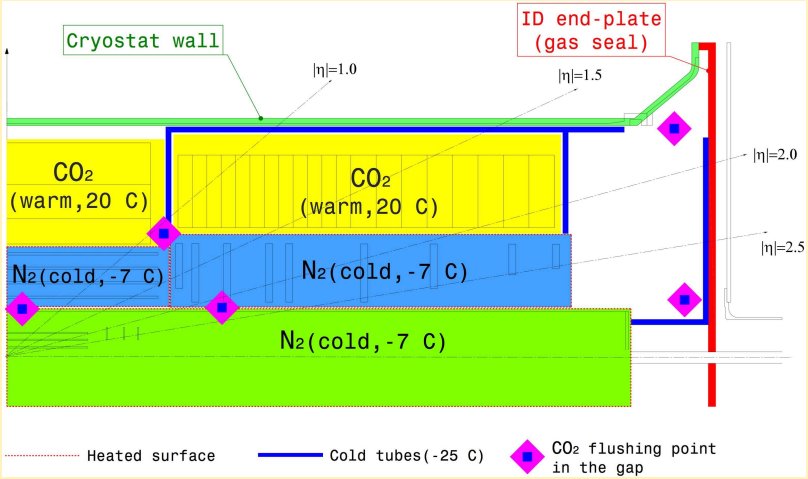


3 different end-cap module geometries



Layout of the End-Cap module

ID cooling system & environment



ID Environmental gas

- Different gases are used throughout the ID volume (for safety reasons)
  - N_2 in Pixel and SCT to avoid condensation
  - CO_2 to protect TRT active gas from N_2 contamination
  - All gases being non-flammable

ID Evaporative cooling system

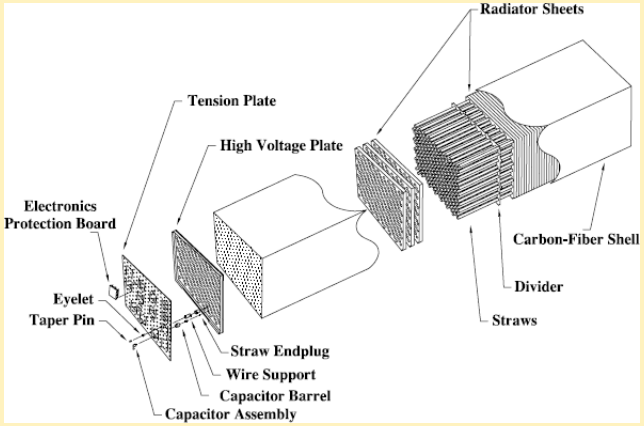
- About 85 kW of heat needs to be removed from the ID
- C_3F_8 is used as coolant for all the Silicon sensors in ATLAS
- Pressure drop used to boil the two-phase fluid in the copper pipes
- Subcooling through counter-flow heat exchangers
- Heaters to bring the outgoing liquid above the cavern dewpoint - back to the plant

TRT

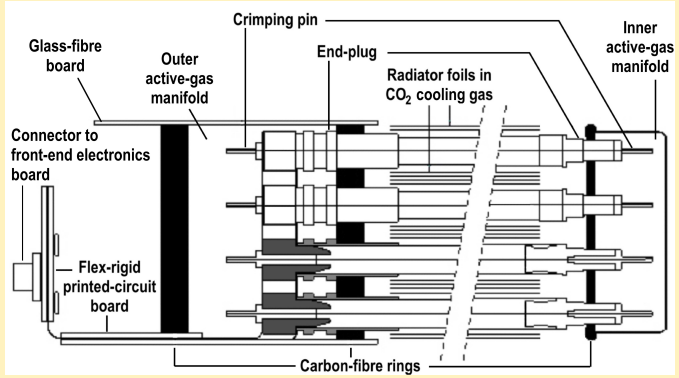
- Using Straw tubes interleaved with thin foil for Transition Radiation detection
- 3 rings, 32 modules in each ring (Barrel), 40 wheels (End-Cap)
- Straws parallel to beam axis for barrel, perpendicular for end-cap
- 351 000 channels
- Provides $R - \phi$ information
- 4 mm straw tubes (cathode), 31 μm gold-plated tungsten wires (anode)
- Gas mixture in the straw: 70% Xe, 27% CO_2, 3% O_2.
- Operation at -1530 V on the cathode (anode grounded)

Adds at least $\sim$36 space points to the track (22 in the end cap)

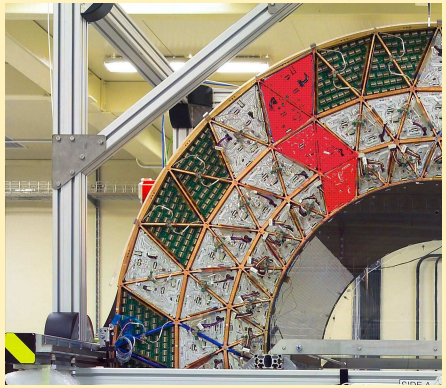
TRT modules & straws

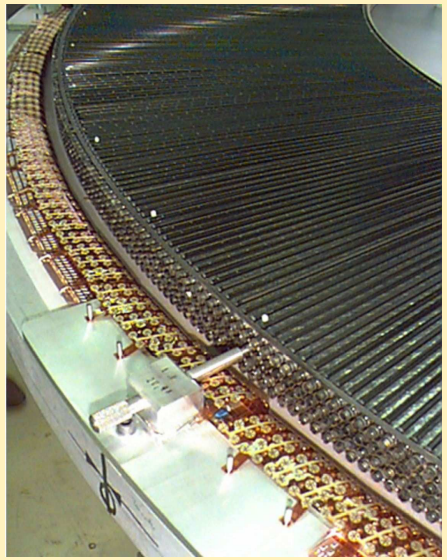


Barrel module layout



End-Cap straw plane diagram

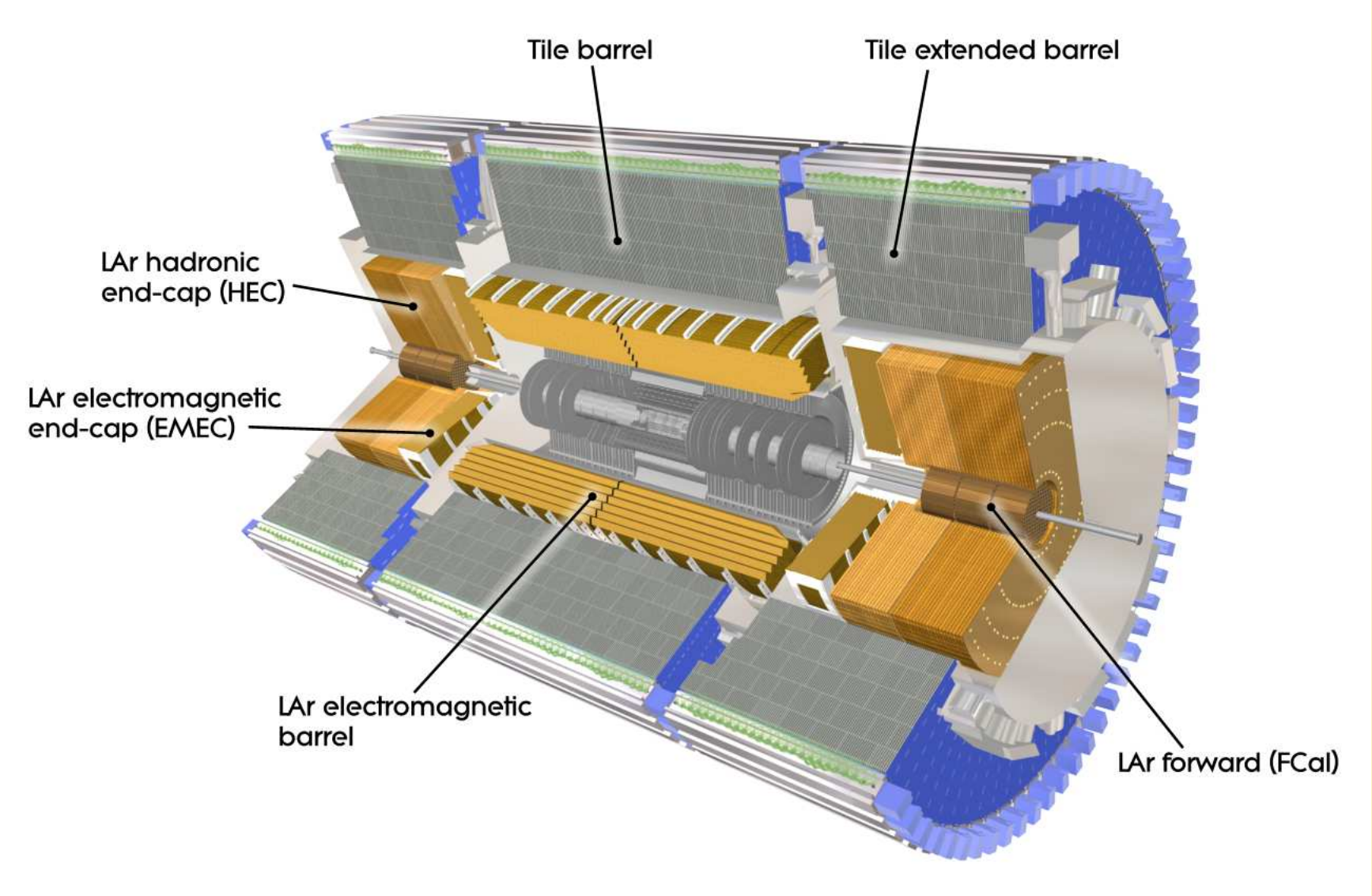




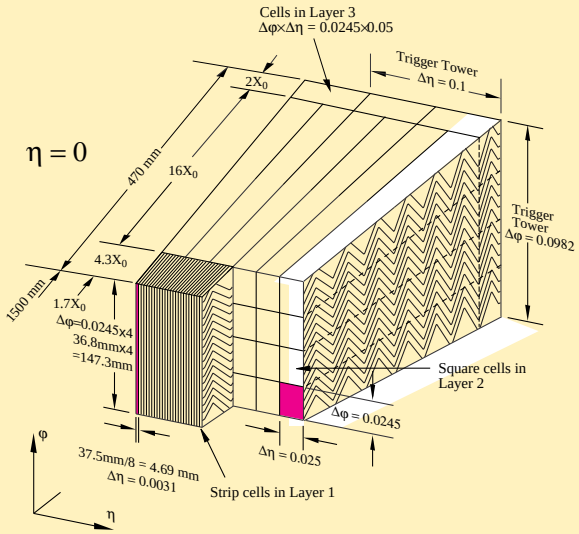
Solenoid: B field for the Inner Detector

- Longitudinal (axial) B field of 2 T provided by the Solenoid
- Solenoid enclosed inside the Calorimeter cryostat, to reduce material (see Calorimeter section)
- Superconducting solenoid made of Al-stabilised NbTi wires
- Cooled to 4.5 K using liquid Helium (within one day)
- Stores 40 MJ of energy (absorbed by the cold mass in case of quench)

Calorimeters General layout



LAr Electromagnetic Calorimeter



Principles

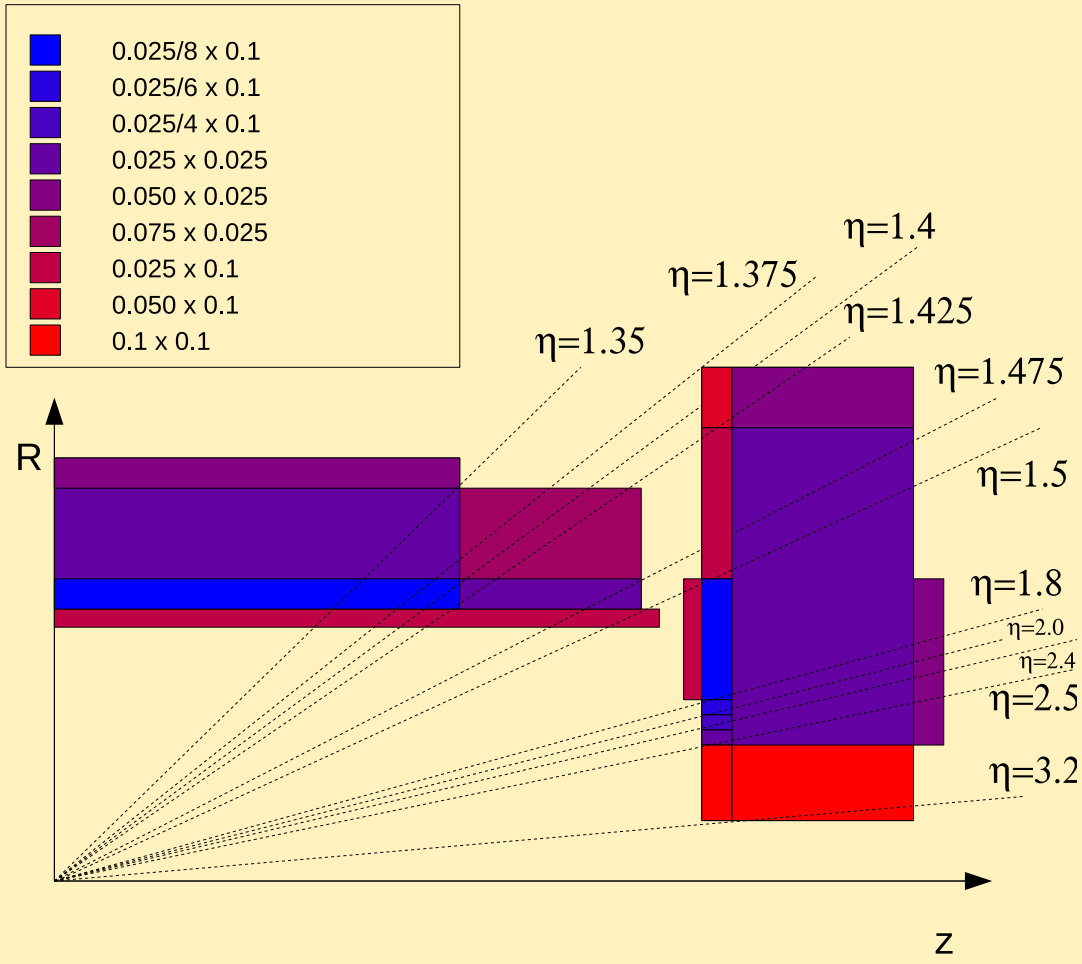
- Lead as absorber, interleaved with kapton electrodes
- Accordion geometry to provide full azimuthal coverage
- LAr as active detector material

Characteristics

- Sampling calorimeter
- 2 half-barrels and 2 end-cap wheels (with small gap at η=0 and 1.37< η <1.52)
- Detector material housed into a LAr cryostat, together with the Solenoid magnet
- 163 968 readout channels (cells)
- Presampler in front of Barrel and portion of the end-cap (see next page)
- 9 344 channels for the presampler
- Kept at approximately 87 K

EM Calo Cells Layout

- Careful: drawing not to scale!
- 2 or 3 layers of absorber with different granularity + presampler
- Many different $\Delta\eta$ x $\Delta\phi$ cell granularities throughout the calorimeter (see legend)

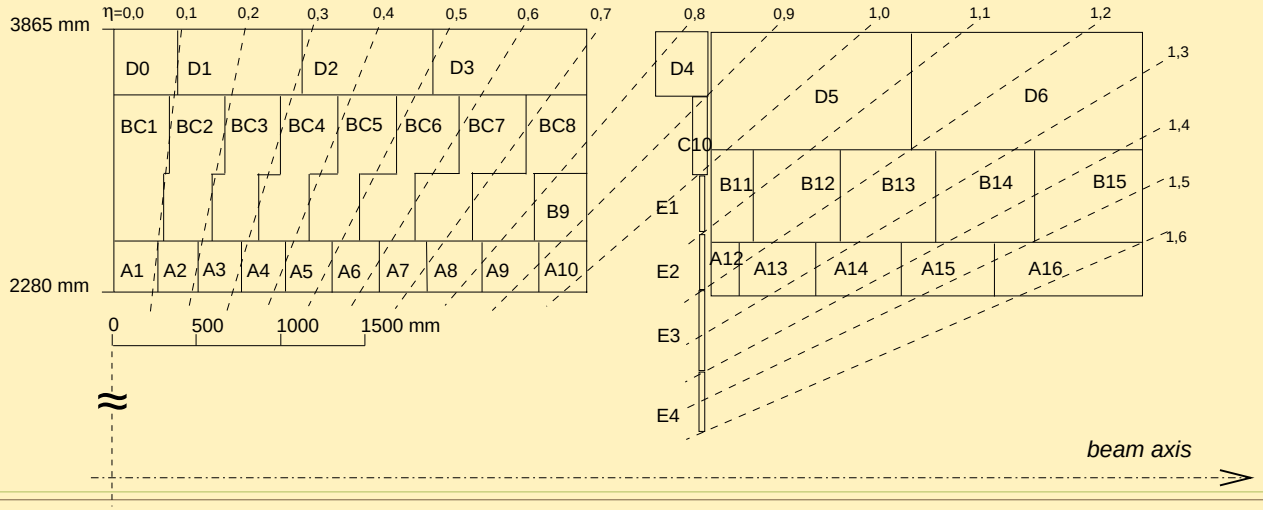


Hadronic Calo

Divided into two technologies: Tile and Liquid Argon.

Tile Calorimeter: Barrel and Extended Barrel

- Surrounds the LAr cryostats
- Made of steel plates (absorber) interleaved with scintillating tiles (active material)
- Read-out by wavelength-shifting fibres, connected to 9852 PMTs.
- $0 < |\eta| < 1.0$ (Barrel) ,$0.8 < |\eta| < 1.7$ (Extended Barrel)
- 64 wedge-shaped modules, covering $\Delta\phi \sim 0.1$
- Plug calorimeters in the gap region



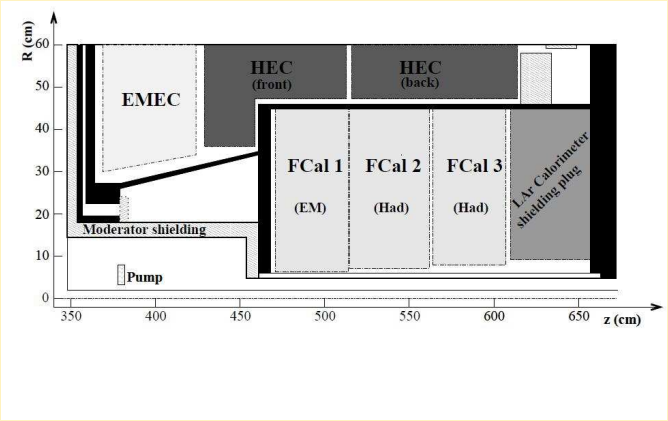
LAr Hadronic Calorimeters

Hadronic End-Cap (HEC)

- Cu plates as absorber material, LAr as active medium read-out by electrodes
- Made of 2 wheels, each equipped with 32 wedge-shaped modules
- Covers the range $1.5 < |\eta| < 3.2$

Forward Calorimeter (FCal)

- Closest to the beam pipe, covers the range $3.1 < |\eta| < 4.9$
- 3 layers with FCal1 using steel plate as absorbers (EM) and FCal2 and FCal3 using Tungsten plates (Hadronic)
- Uses small LAr gaps between plates to limit ion formation due to high particle flux at high η



Principle of the muon system in ATLAS

At such high energy and luminosity, muons are highly appreciated by the trigger system.

The muon system in ATLAS was designed with the following requirements in mind:

- Separate "trigger" (fast) and "precision" (slow) chambers
- Big toroidal magnets provide a strong bending power in a large empty volume, hence:
  - Better charge identification for high p_T muons
  - Minimization of multiple-scattering effects
- Good momentum resolution

The dimensions of the muon system determines the size of the ATLAS detector.

Toroidal Magnets

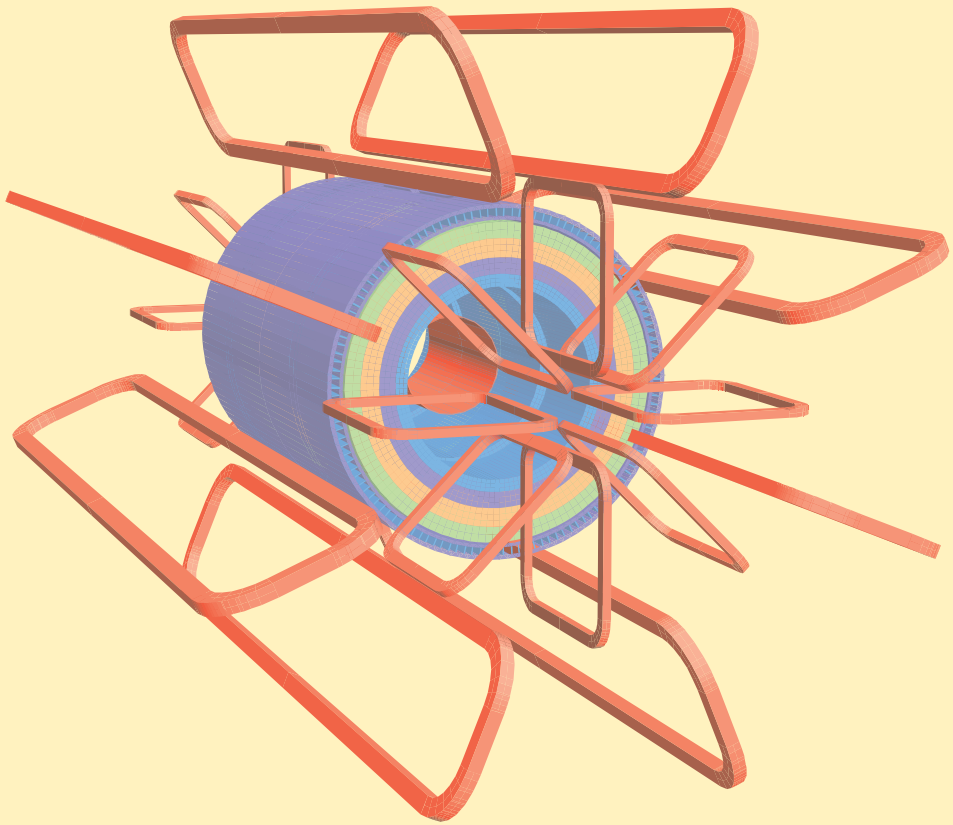
The skeleton of ATLAS

3 toroids in the system: barrel and two end-caps

Each is composed of 8 coils, with a 22.5° angle between the barrel and each end-cap. This is to provide radial overlap and to optimise the bending power in the transition region

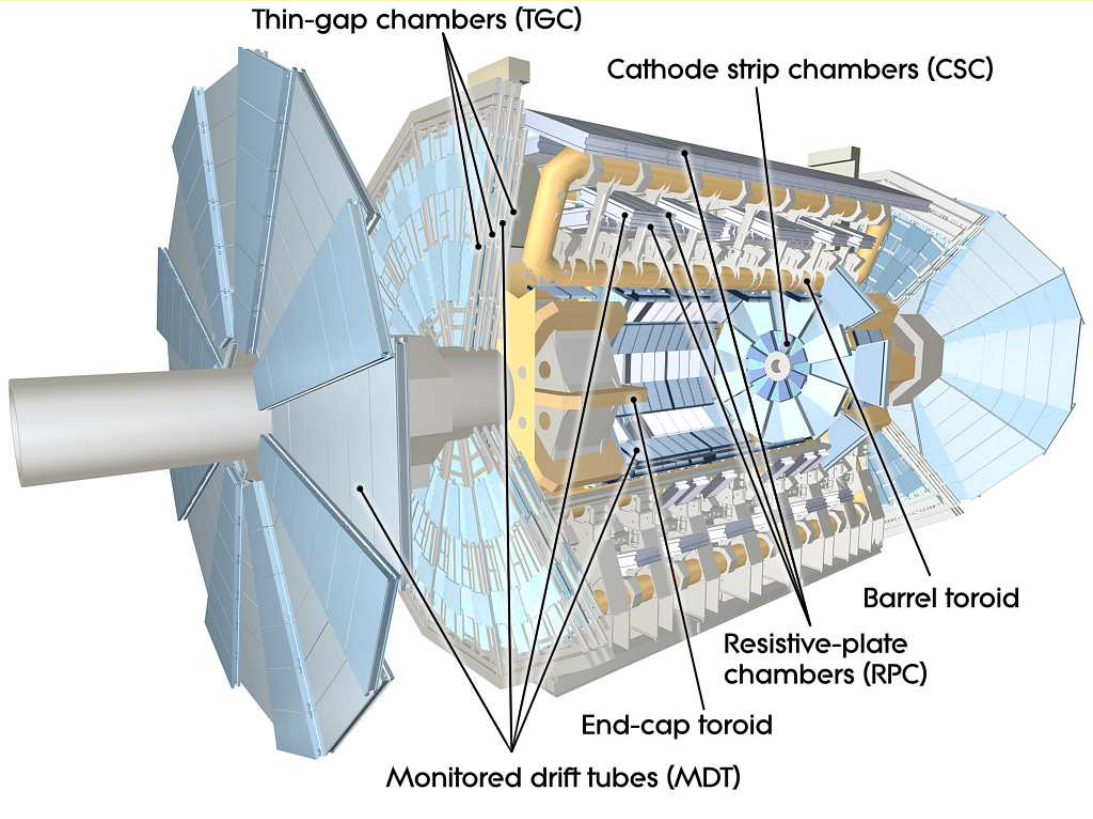
0.5 T for barrel and 1 T for end-caps, approximately

Made of Al-stabilised Nb/Ti/Cu superconducting wires, cooled with liquid helium (4.5 K)



Layout of the Muon system

ATLAS muon system is quite complex!



- Precision tracking
  - Monitored Drift Tubes
  - Cathode Strip Chambers
- Triggering
  - Resistive Plate Chambers
  - Thin Gap Chambers

MDT

- Covers up to $|\eta|$=2.7 (except innermost end-cap layer)
- 3 to 8 layers of drift tubes filled with 93% Ar/7% CO_2
- Installed in three concentric layers around and inside the barrel toroids, or on wheels before and after the end-cap toroids
- 354 000 channels
- Max counting rate of 500 Hz/cm^2

CSC

- Covers the range $2 < |\eta| < 2.7$
- Only in the innermost end-cap layer
- Multiwire proportional chamber filled with 80% Ar/20% CO_2 enclosed in cathode planes
- Both cathodes segmented in strips (one parallel to the wires, the other perpendicular)
- 30 700 channels
- Needed due to the high flux of particles in this pseudo-rapidity range
- Max counting rate of 1000 Hz/cm^2

Trigger Muon Chambers

RPC

- Covers up to $|\eta|$=1.05
- Gas-mixture filled chamber with two parallel plates with an electric field between them.
- $C_2H_2F_4$/Iso-C_4H_{10}/SF_6 (94.7/5/0.3)
- 373 000 channels

TGC

- Covers the range $1.05 < |\eta| < 2.4$
- Multi-wire proportional chamber with smaller wire-anode gap than wire-wire gap
- Filled with CO_2 and n-C_5H_{12}
- 318 000 channels

Forward detectors

Many other detectors are placed further down along the beampipe, at high values of η, to do specific tasks

LUCID

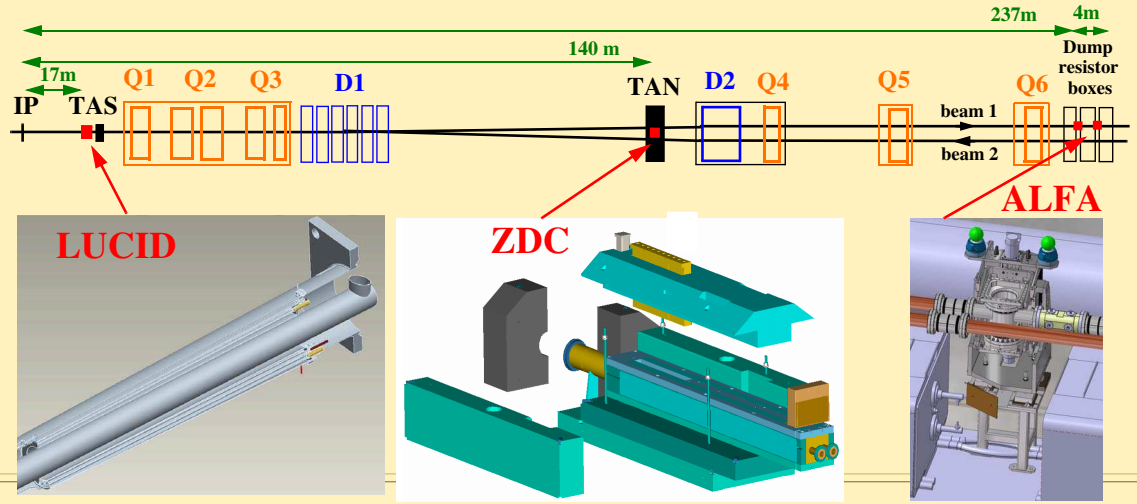
- To measure *relative* luminosity using inelastic $p-p$ scattering

ALFA

- To measure *absolute* luminosity using elastic $p-p$ scattering at small angles

ZDC

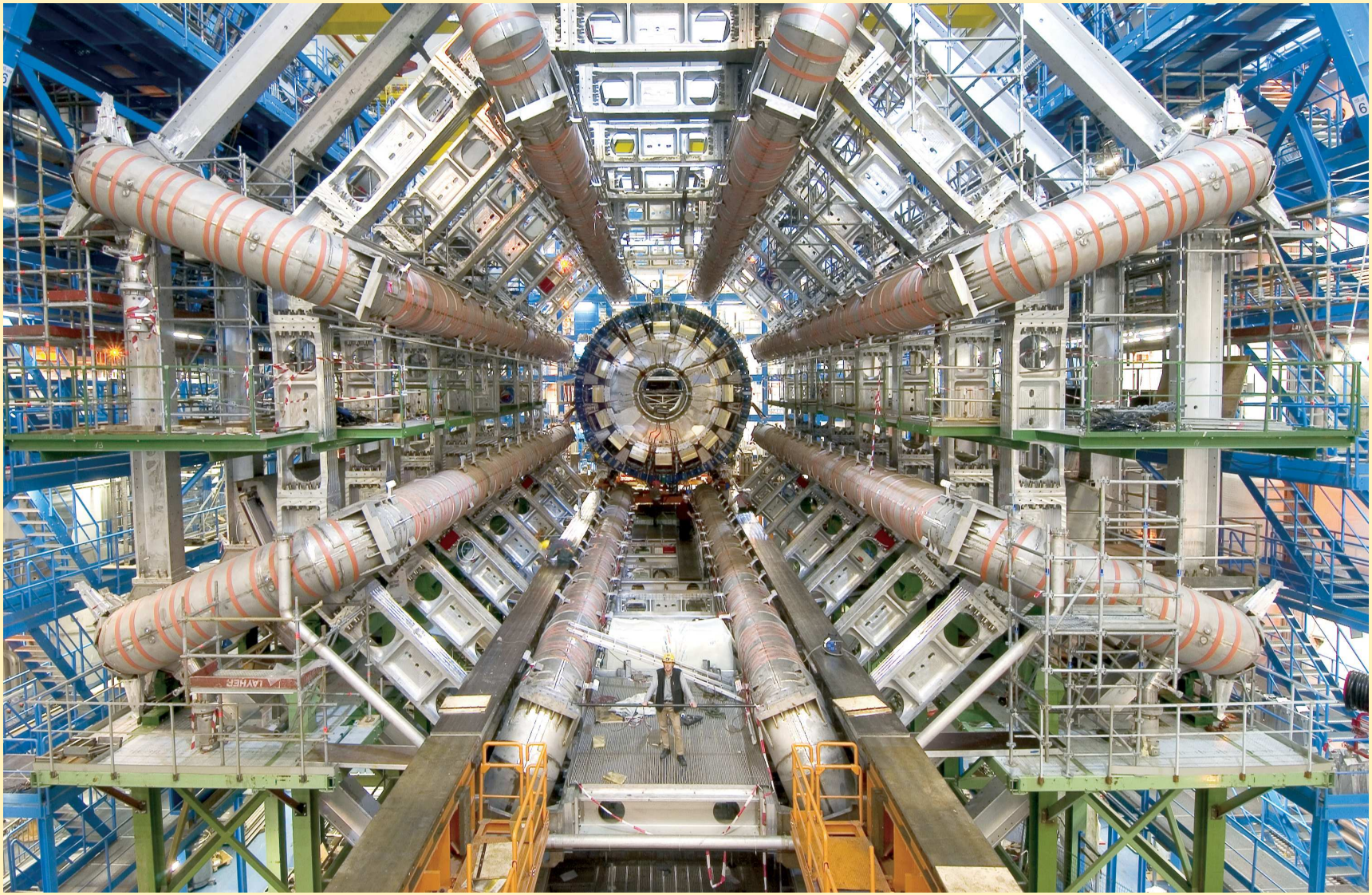
- To detect very forward neutrons for heavy-ions physics (also useful for minimum bias events measurements)



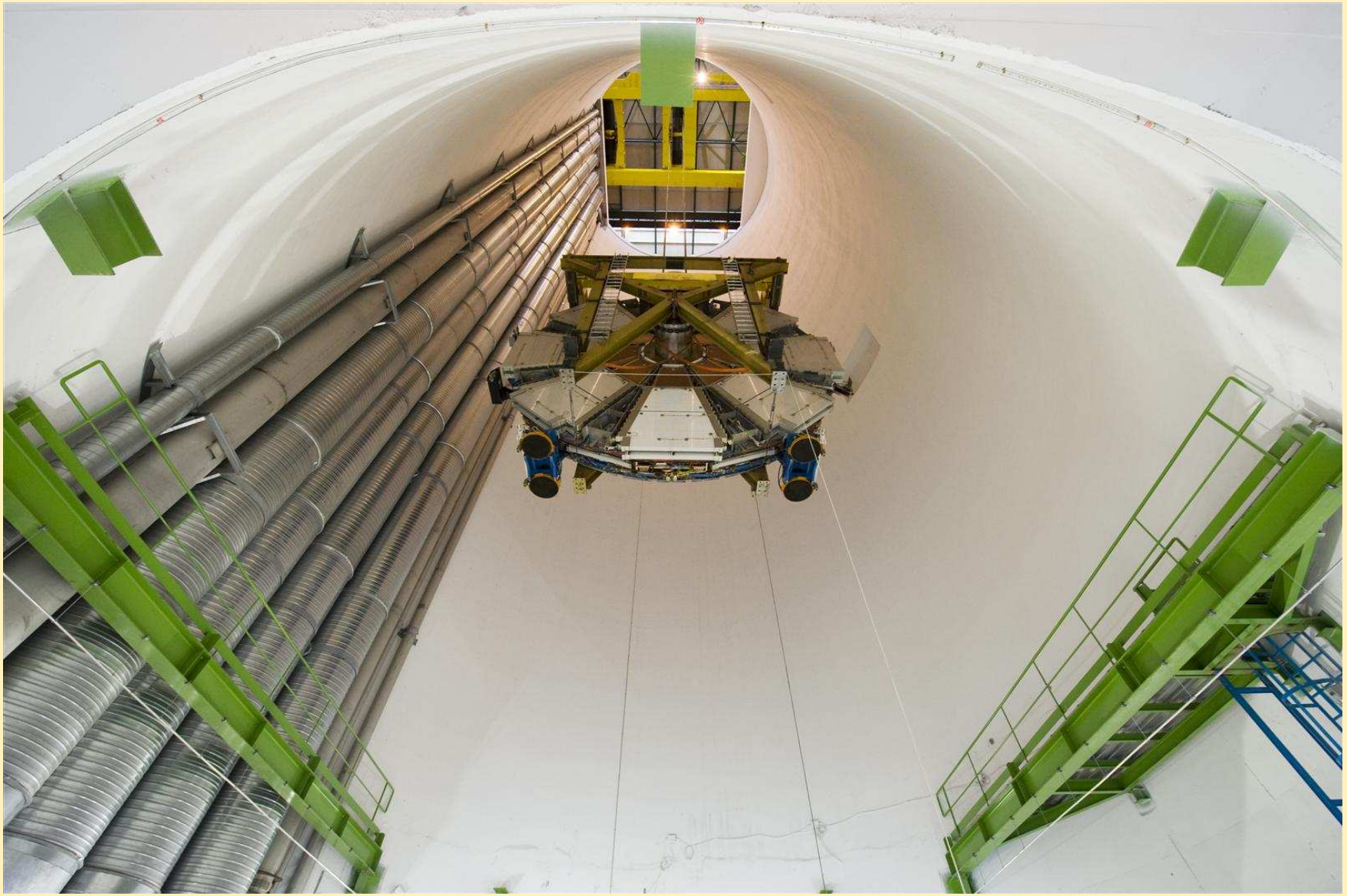
Putting it together

A jigsaw puzzle

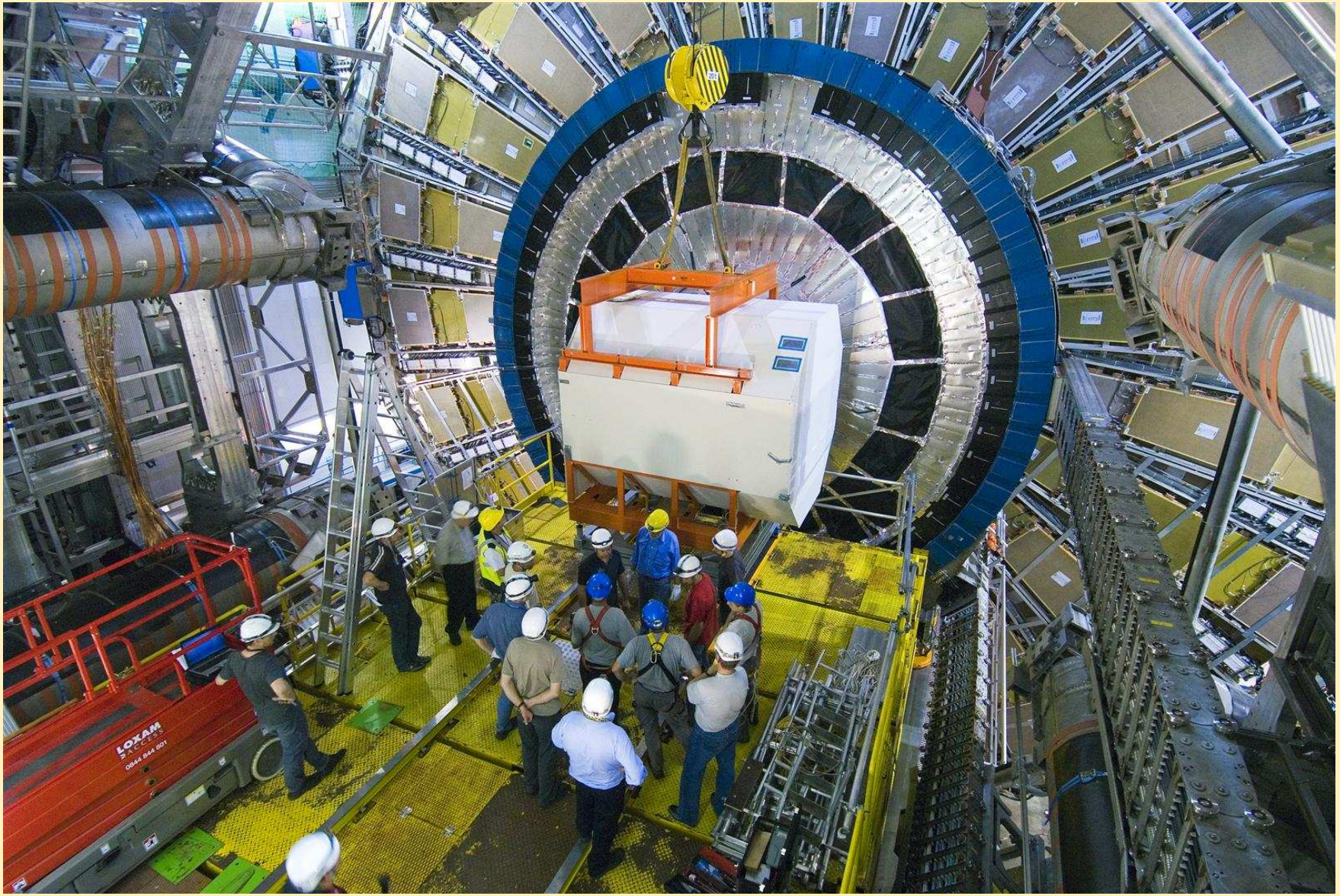
ATLAS was built by pieces and put together in the cavern



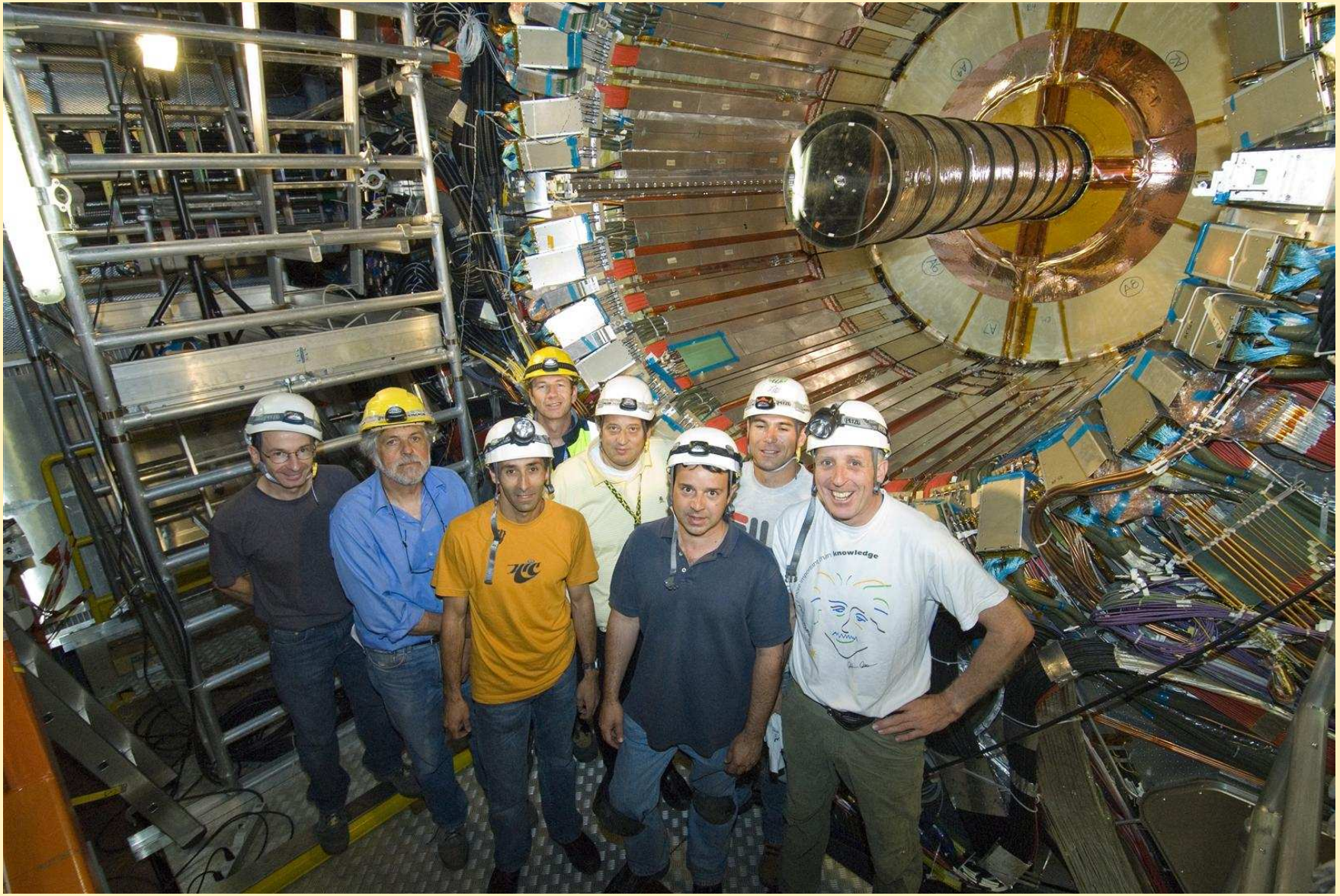
From the outside...



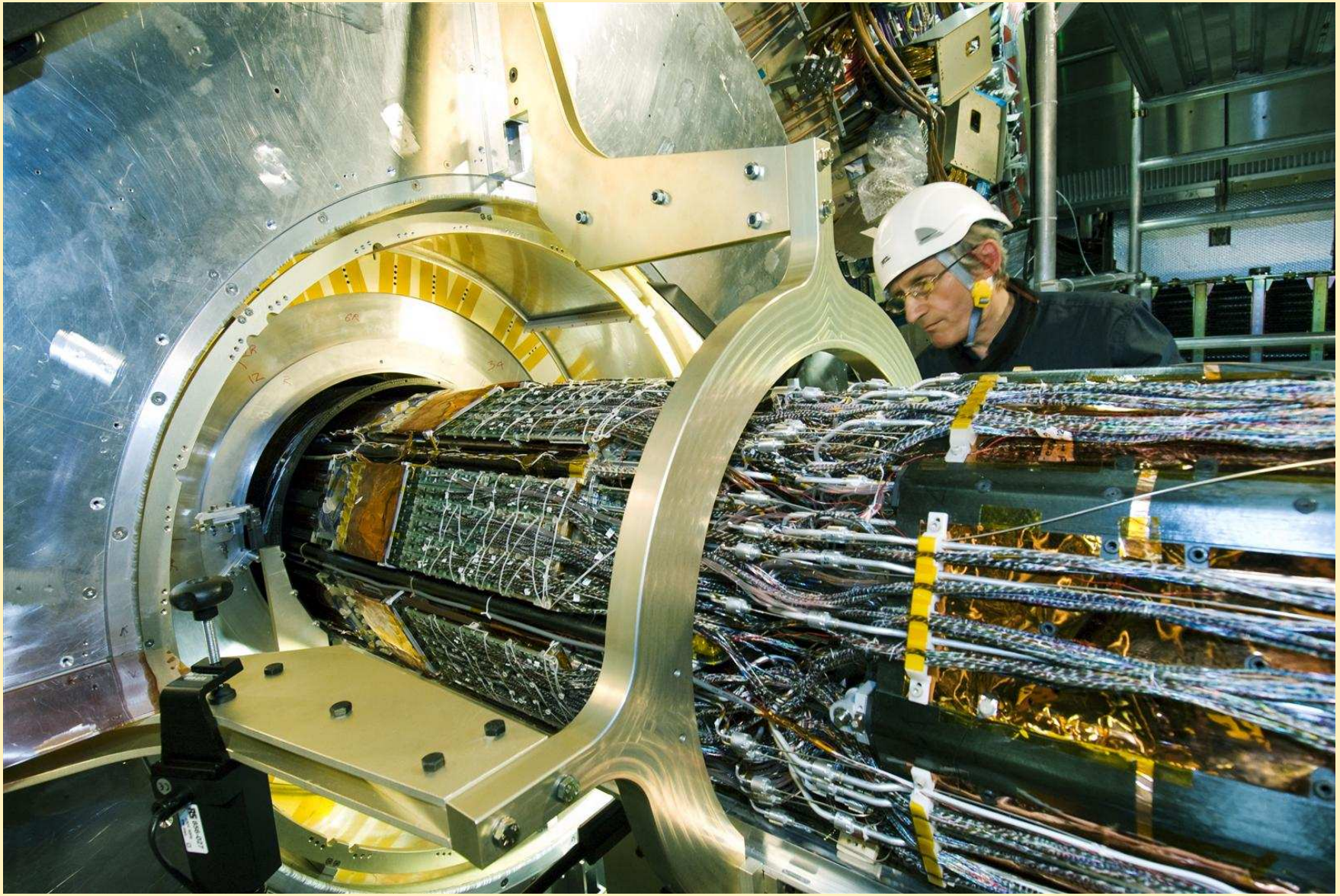
From the outside...



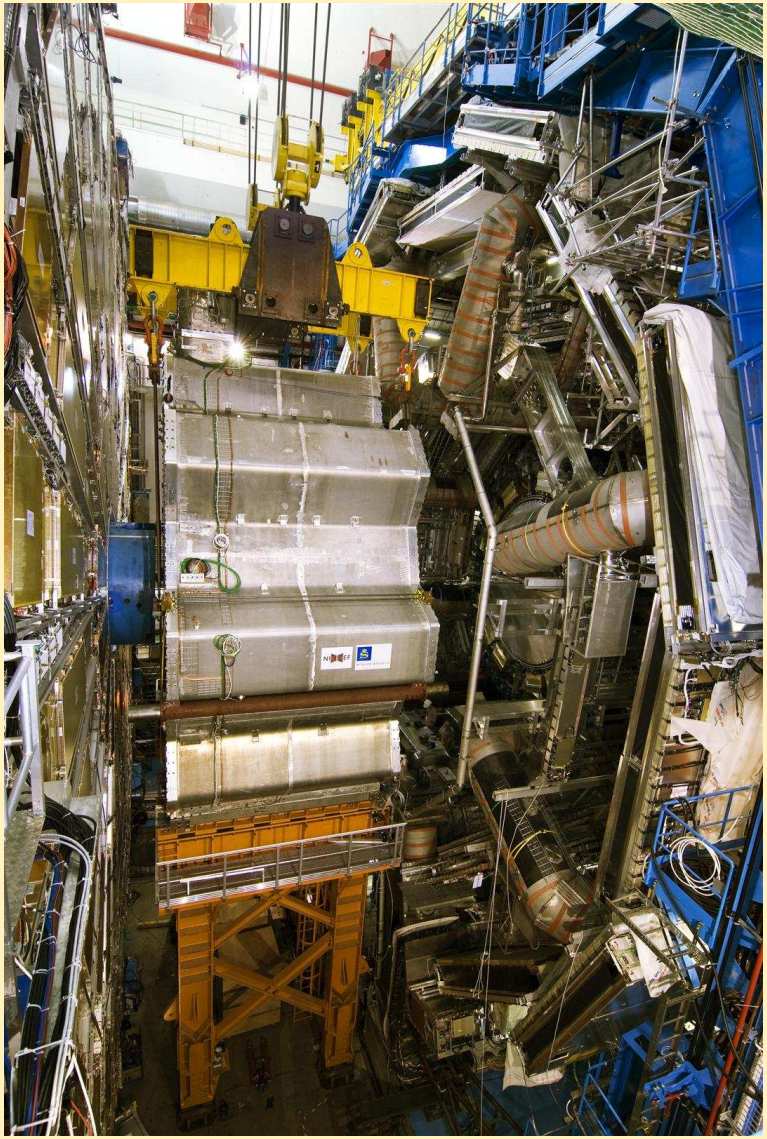
... to the inside



... to the inside



Not forgetting the final "cap"



A colossal effort from hundreds of men and women, just about as big a human experience as a technical challenge!

How does it run?

How much data, exactly?

If all collisions delivered by the LHC were recorded, it is common to say that we would fill enough CDs to pile them to the moon and back.

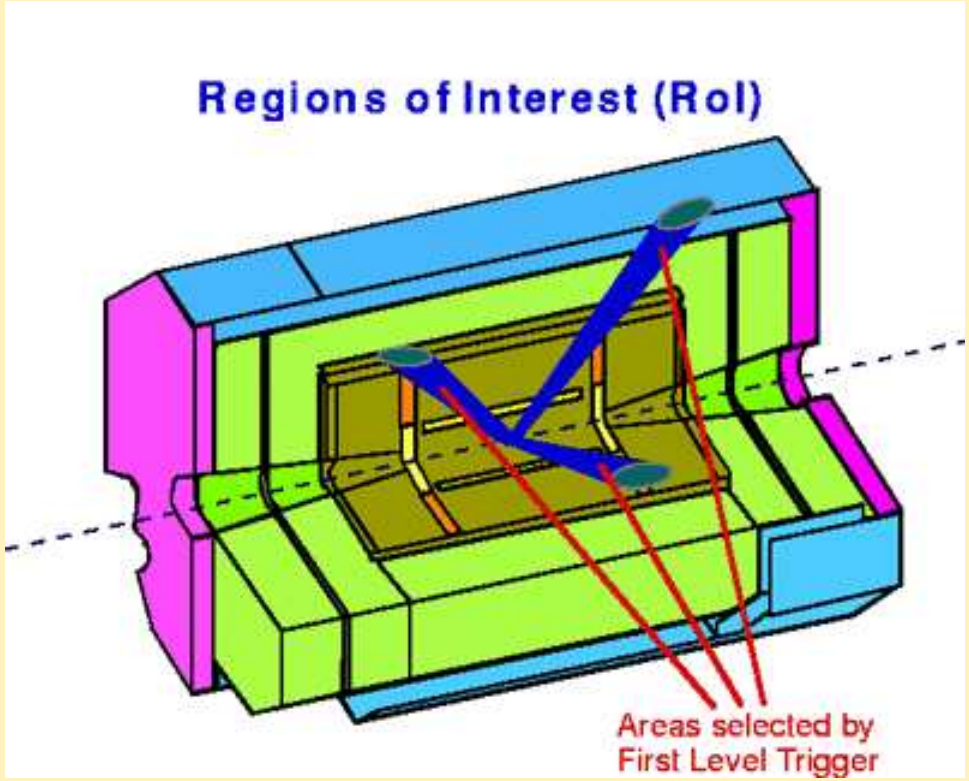
We need to filter this data, which is mostly made of non-interesting events (minimum bias)

From 40 MHz, we need to reach a rate of $\sim$200 Hz

Filtering the data: the trigger system

Principles

- 3-level trigger system:
  - Hardware Level 1 (L1) takes a decision in <2.5 μs
  - High Level Trigger (HLT) divided into two levels: Level 2 (L2) and Event Filter (EF)
- L1 & L2 use Regions-of-Interest (RoI): $\Delta\phi$ x $\Delta\eta$ = 0.1 x 0.1
- L2 uses the full granularity of the detector *within the RoI* to make a decision in 40 ms on average
- EF uses the full event information to classify them into chains and has 4 s on average to do so.
- HLT works in steps and rejection is made as early as possible



Data acquisition

DAQ and HLT are designed closely together with a common data flow system

Principles and Operation

- Data is first stored in Front-End electronics, waiting in pipe-lines for a L1 decision
- When L1 accepts the event, the data is moved to ReadOut Drivers (ROD) in the standard ATLAS format
- Data is then sent to the ReadOut System (ROS) which buffers it into ReadOut Buffers (ROB)
- ROB can then deliver data on request to L2
- Upon a L2 accept, the event is built by the Event Builder (EB) and sent to the Event Filter (EF)

Powering it all up

Together with the DAQ, the Detector Control System (DCS) is required to operate the detector and to ensure its safety.

- Provides the power for the high voltage and low voltage systems of the different subdetectors
- Monitors operation parameters (voltages, currents, etc)
- Monitors environmental parameters (temperature, humidity, etc)
- Allows for automatic and manual safety operations on the different systems
- Shares this information with the DAQ through DAQ-DCS Communication (DDC) protocol
- Stores some of the information in offline database which can be used for reconstruction
- Based upon a common hardware part, the Embedded Local Monitor Board (ELMB)

Recap

- ATLAS is not only a giant in Greek mythology, also in underground Geneva!
- Silicon+straw tube tracking covering $|\eta| < 2.5$
- LAr electromagnetic calorimetry (with an accordion geometry)
- LAr and steel tile hadronic calorimeter covering $|\eta| < 4.9$
- Complex muon system with trigger chambers and precision tracking chambers
- A huge magnet system made of a solenoid for inner tracking and 3 toroids for muon tracking, which determines the size of ATLAS.
- RoI-based trigger system
- All of this installed and running in the ATLAS cavern

What we really want to know now is: how well does it work?