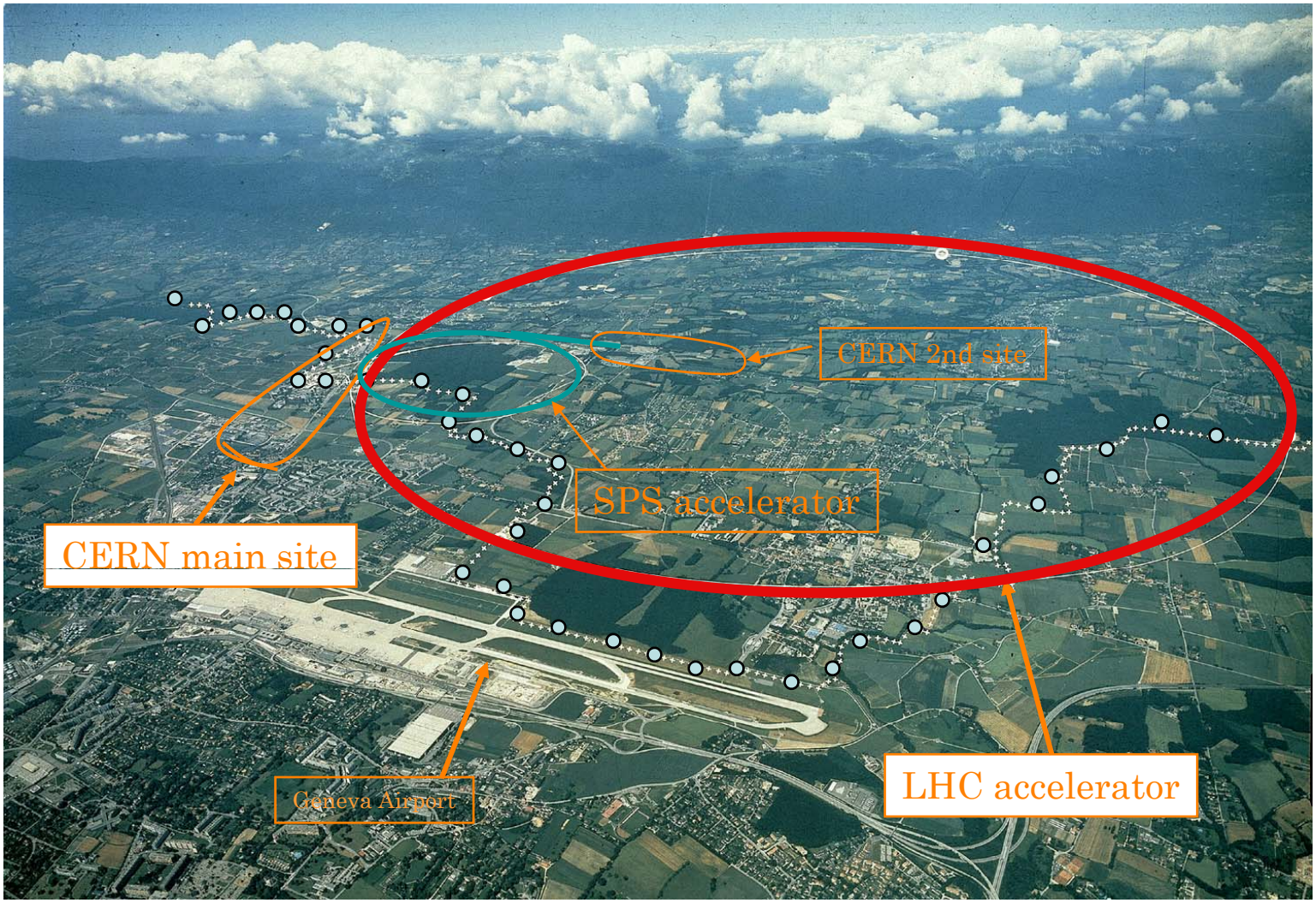
The ATLAS Inner Detector

Steve McMahon / RAL

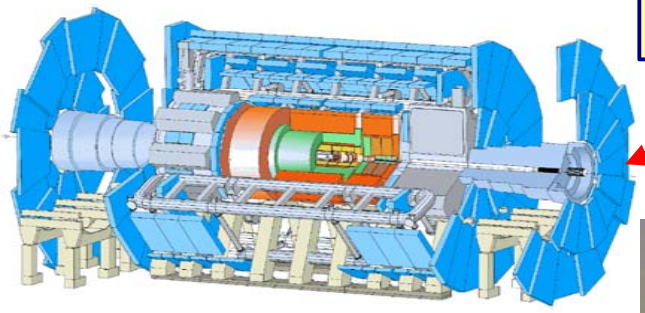
Welcome to CERN



It is your laboratory

LHC Experiments & Detectors

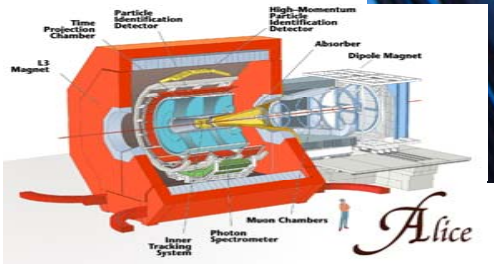
General purpose detectors (good for everything...)



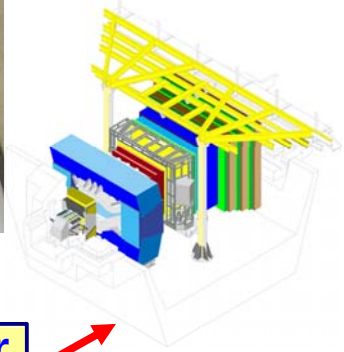
ATLAS

CMS

ALICE



LHCb



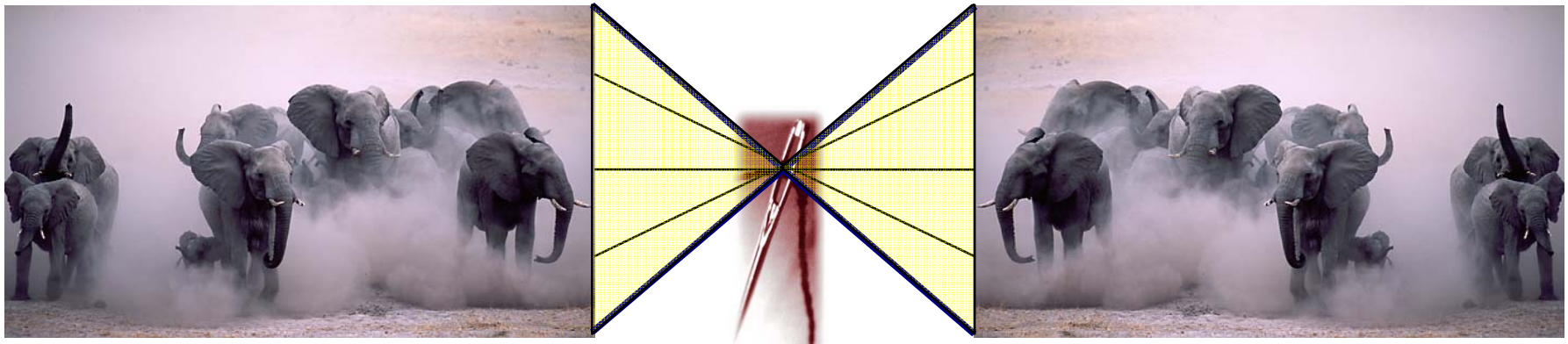
dedicated for Heavy Ion collisions

dedicated for b-physics

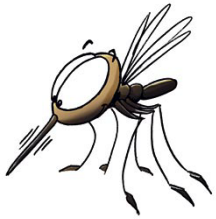
LHC Beam Stored Energy & Density

- 2808 bunches, 1.1 x 10^{11} protons/bunch @ 7 TeV
  - 350 MJ stored energy per proton beam

Same as colliding 2 x 120 elephants...



120 elephants with 40 km/h **120 elephants with 40 km/h**



The energy of a single 7 TeV proton is equivalent to a flying mosquito (1 µJ)

eye of a needle: 0.3 mm diameter

proton beams at interaction point are 10x smaller: 0.03 mm diameter

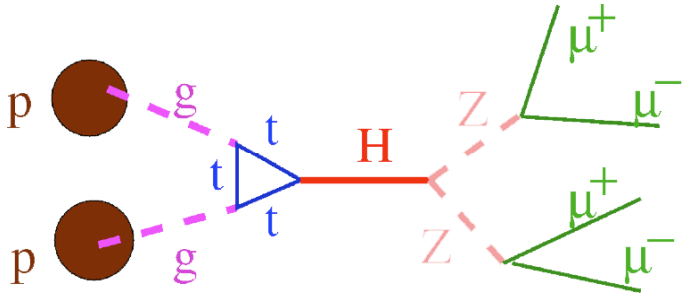
main problem at LHC is to control the stored energy and to avoid any damages
Currently install Beam Loss Monitors developed at FHWN to abort beam before damage occures

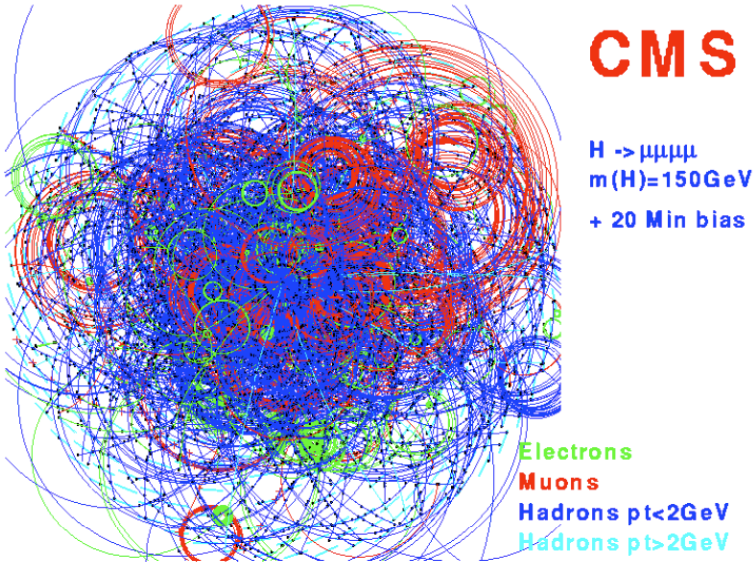
An LHC Particle Detector...

- Should
  - Reconstruct the 4-vectors of all particles produced in a 14Tev pp collision
    - Particle trajectory, charge, momentum vector, energy, particle species
    - Point of origin of particle (beam spot or displaced vertex)
    - Have good 4pi solid angle coverage
  - Have a good efficiency for reconstructing the debris from pp collisions
  - Must be efficient at recognizing interesting physics from backgrounds and able to reject the latter.
  - …have fast electronics as events are coming in at 40MHz
  - … not be sensitive too or generate too much electronic noise
  - .. be cooled adequately and not cool its environment (thermally neutral)
  - … work in a 2T magnetic field (static and dynamic)
  - …be light (transparent to particles) in some places and heavy (absorbing) in others
  - …be radiation hard (long term and instantaneous)
  - …often operate at low temperatures often contains strange gasses
  - …last 10 years (often in continuous operation without access)
  - …be maintainable, upgradeable
  - …not cost too much…
  - .. BE SAFE

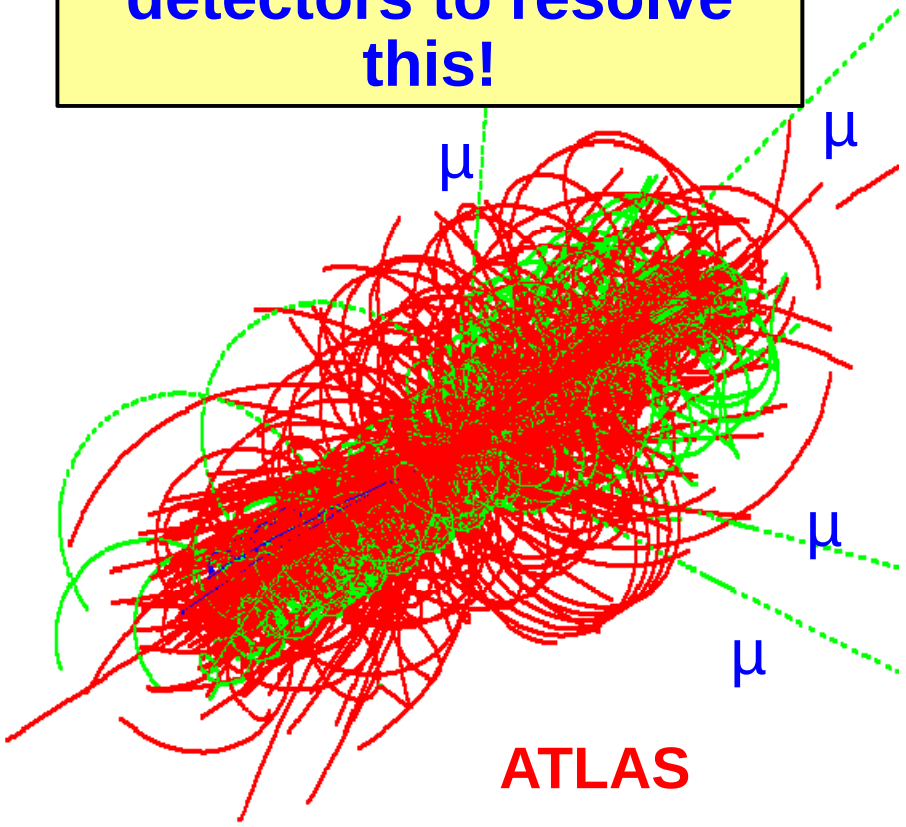
What do we expect

- One bunch crossing every 25ns with up to 20 interactions
  - ~1000 tracks per bunch crossing

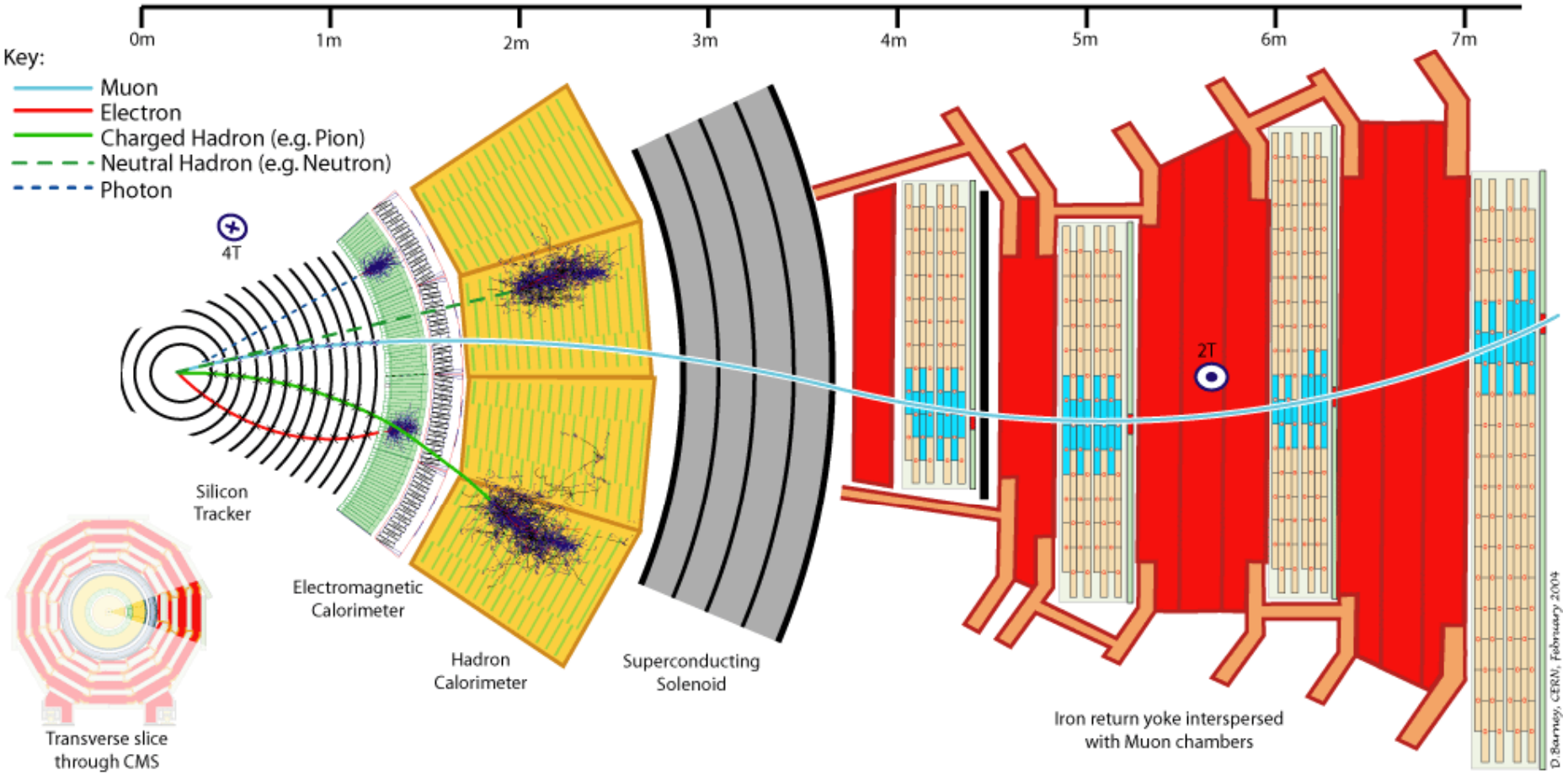




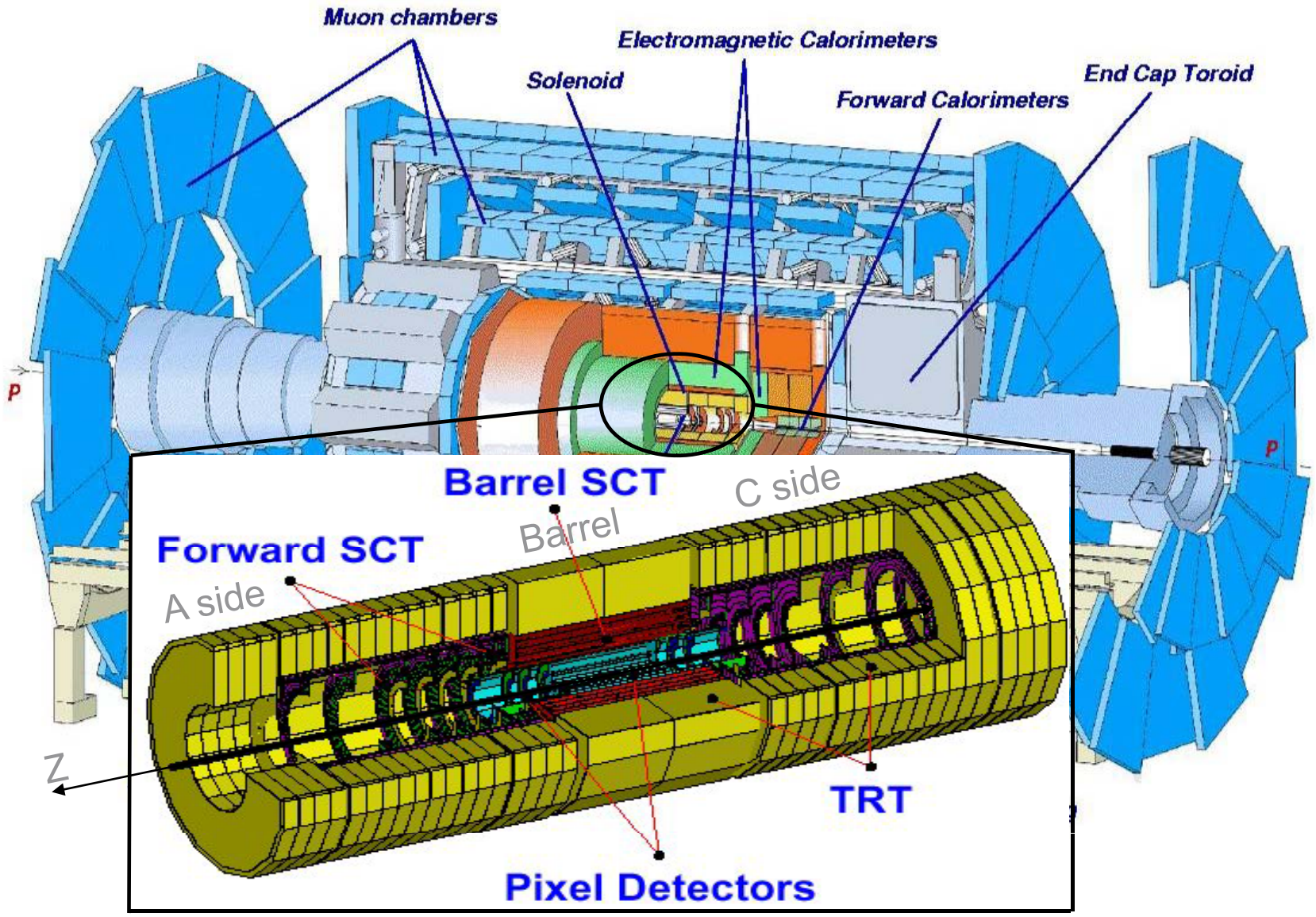
need very powerful detectors to resolve this!



Collider detector arrangement



> 100 Million Electronics Channels, 40 MHz ---> TRIGGER and Event selection


Muon chambers
Electromagnetic Calorimeters
Solenoid
End Cap Toroid
Forward Calorimeters
P
P
Barrel SCT
C side
Barrel
Forward SCT
A side
Z
TRT
Pixel Detectors

ATLAS Inner Detector

ATLAS Inner Detector

Tracking and Vertex reconstruction

Axial magnetic field 2T

Enclosed in a thermal envelope inside the solenoid

Pixel Detector (Silicon pixel detector)

3 layers, 8 disks

r = 4.8 - 16 cm, 140 M channels

SemiConductor Tracker (SCT)

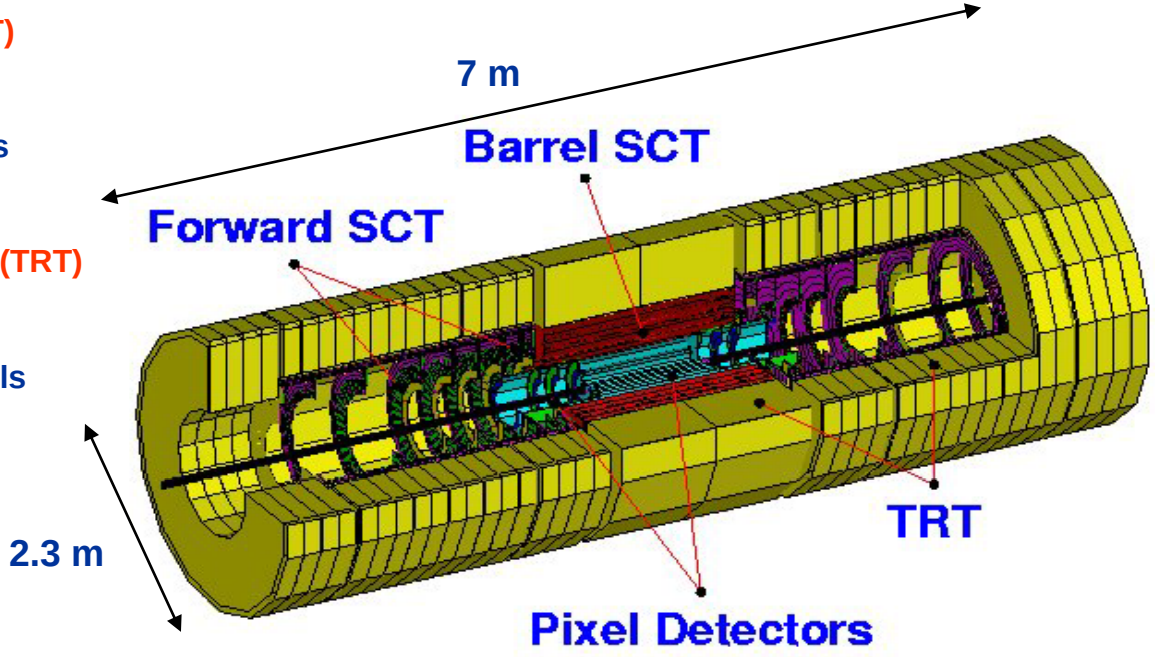
(Silicon strip detector)

r = 27 - 52 cm, 6.3 M channels

Transition Radiation Tracker (TRT)

(Straw tube detector)

r = 56 - 107 cm, 330 k channels



SCT General

Layout:

4 Barrel cylinders, 2 x 9 End-cap disks

4088 Silicon modules (2112 Barrel and 1976 Forward (four different kinds))

61 m^2 silicon, 6.2 M channels

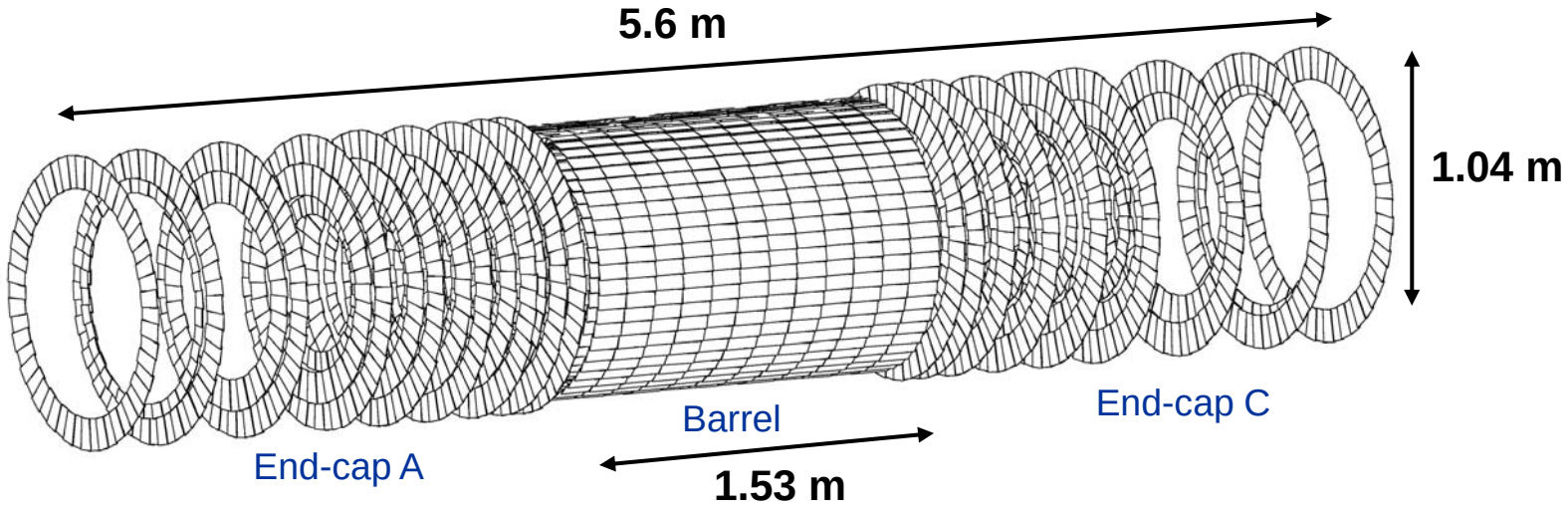
Coverage: pseudorapidity $|\eta| < 2.5$ ($|\eta| < 1.4$ for Barrels & $1.4 < |\eta| < 2.5$ for End-caps

providing 4 space points per track

Resolution Barrel: $\sigma(R\phi) = 16\ \mu m$ Forward: $\sigma(R\phi) = 16\ \mu m$

$\sigma(z) = 580\ \mu m$ $\sigma(R) = 580\ \mu m$

(From Technical Design Report, confirmed by Test Beams



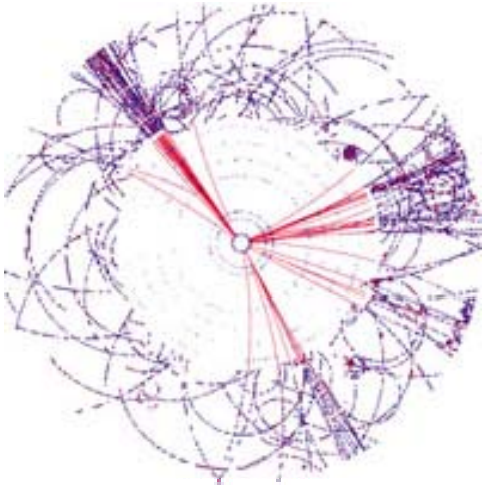
SCT Environment

Requirements:

- 40 MHz Bunch-crossing frequency
- 3 μs trigger latency, 1 % occupancy
- 100 kHz Level 1 Trigger frequency
- Magnetic field 2T
- Low material < 0.4 X_0
- No alignment needed within the detector module
- Hit efficiency 98%, noise occupancy < $5*10^{-4}$

Radiation Environment:

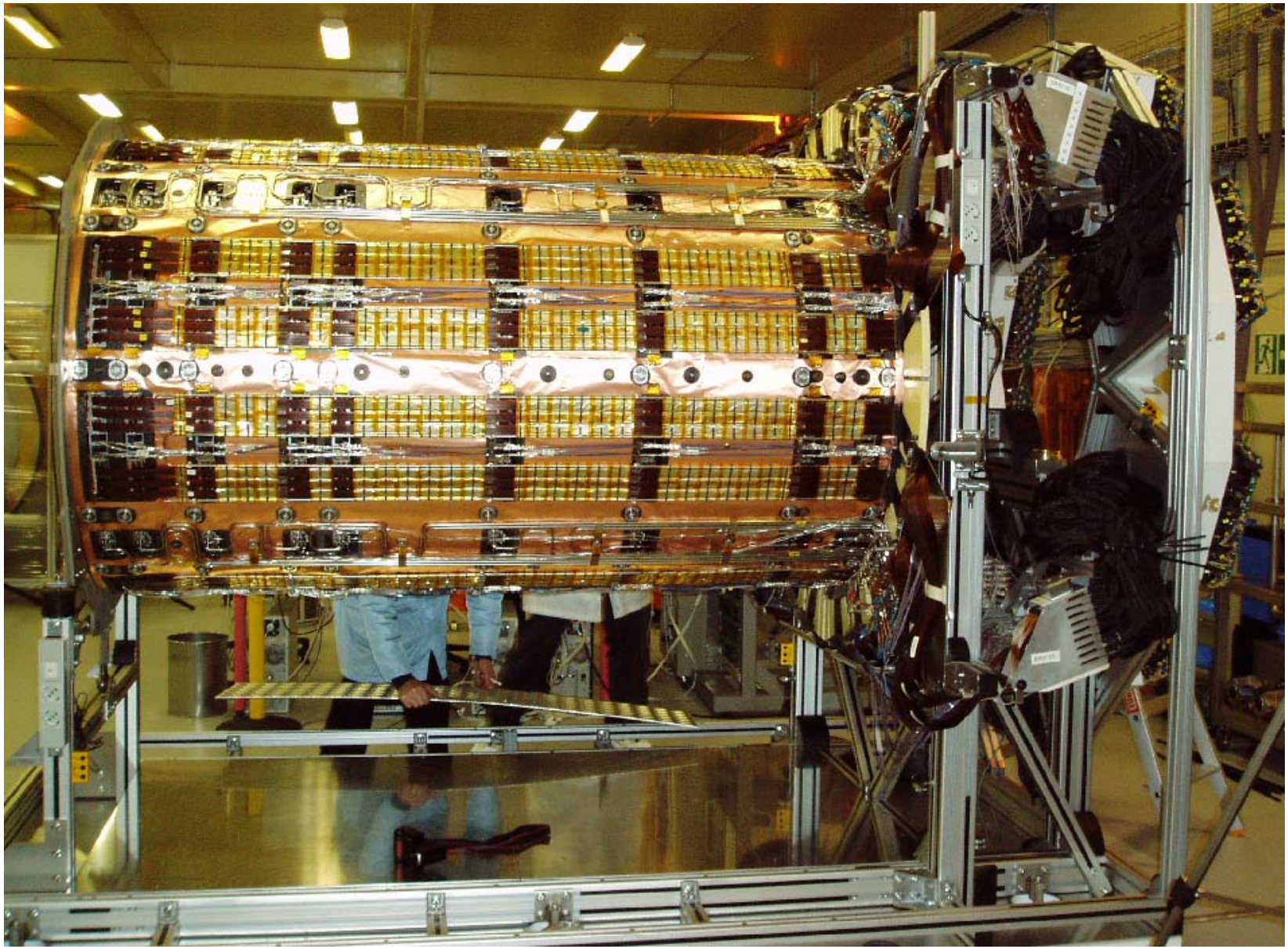
- Maximum values for SCT
- Corresponding to 10 years of running @ LHC
- 10 MRad Ionising dose
- $2 * 10^{14}$ n/cm^2 1 MeV NIEL equivalent

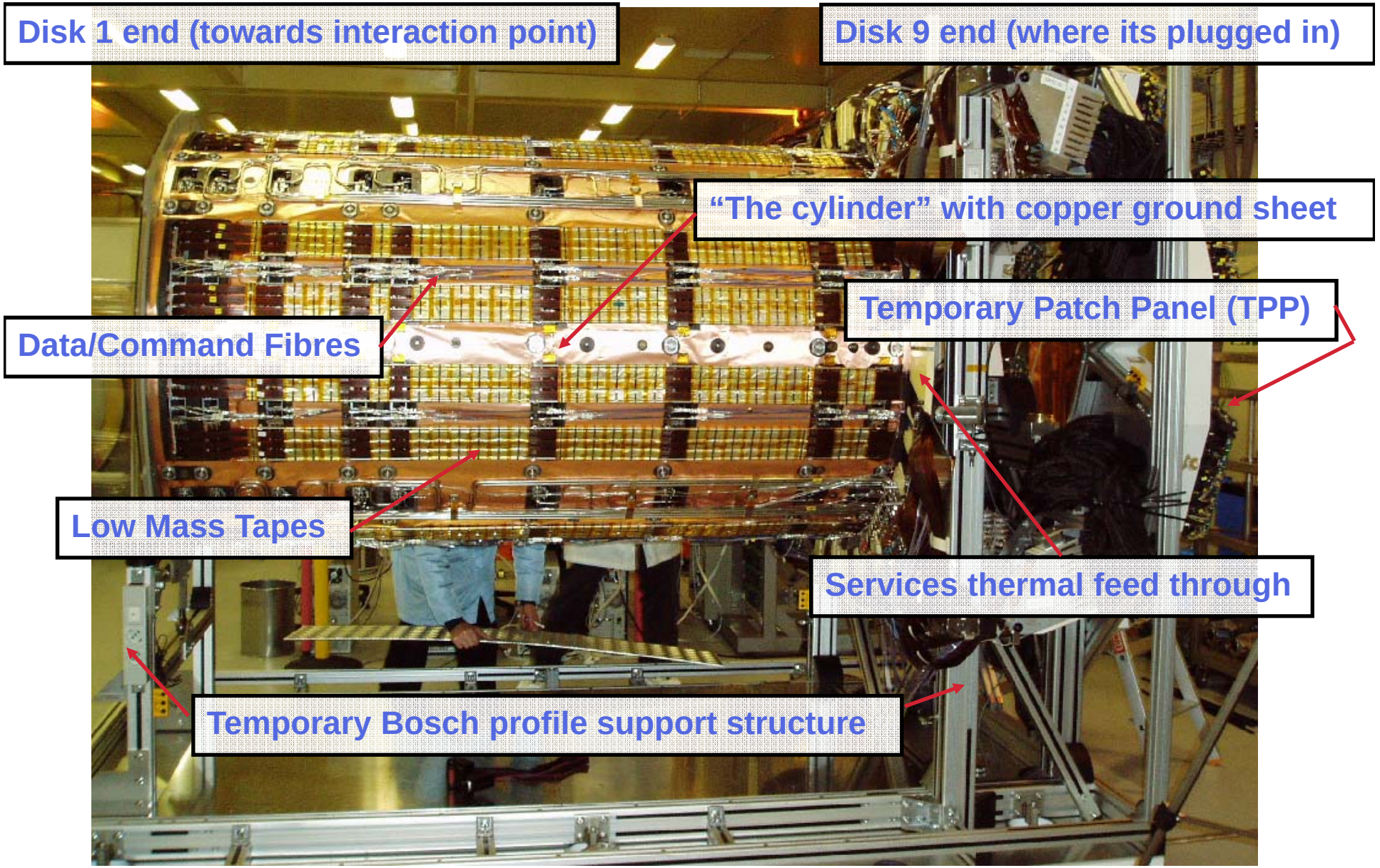


ATLAS event seen in the Inner Detector

Thermal Environment:

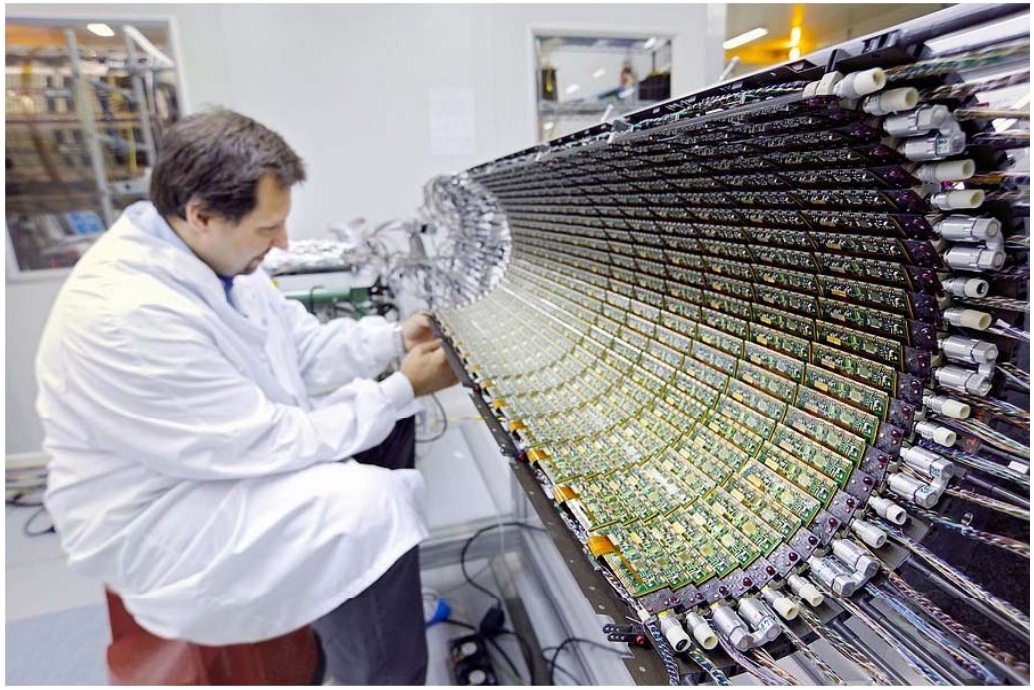
- Avoid reverse annealing of silicon detectors
- Limit leakage current in damaged silicon detectors
- ASICs power ~ 7 W per module
- Operating at $T_{DET} \approx$ -7 ºC

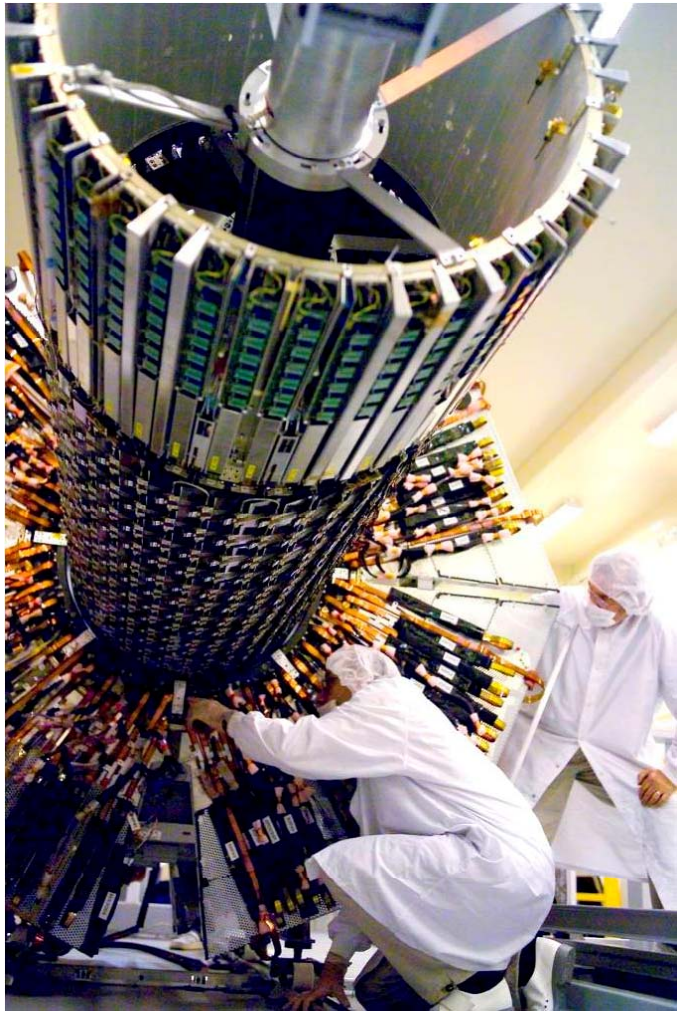



Disk 1 end (towards interaction point)
Disk 9 end (where its plugged in)
“The cylinder” with copper ground sheet
Temporary Patch Panel (TPP)
Data/Command Fibres
Low Mass Tapes
Services thermal feed through
Temporary Bosch profile support structure

Assembly of silicon detectors

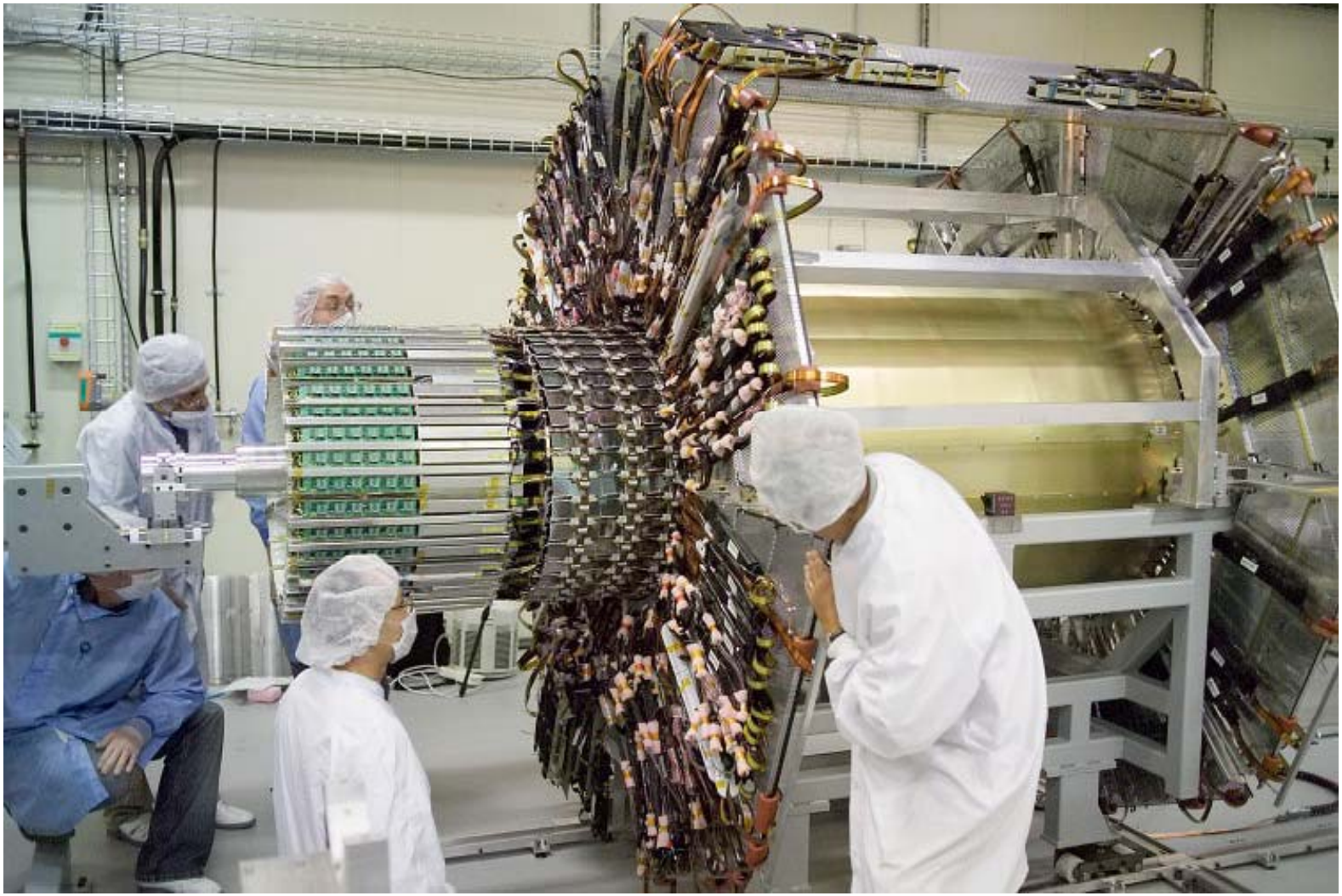
- Produced over 10 years by ~40 institutes





Silicon Tracker (SCT)

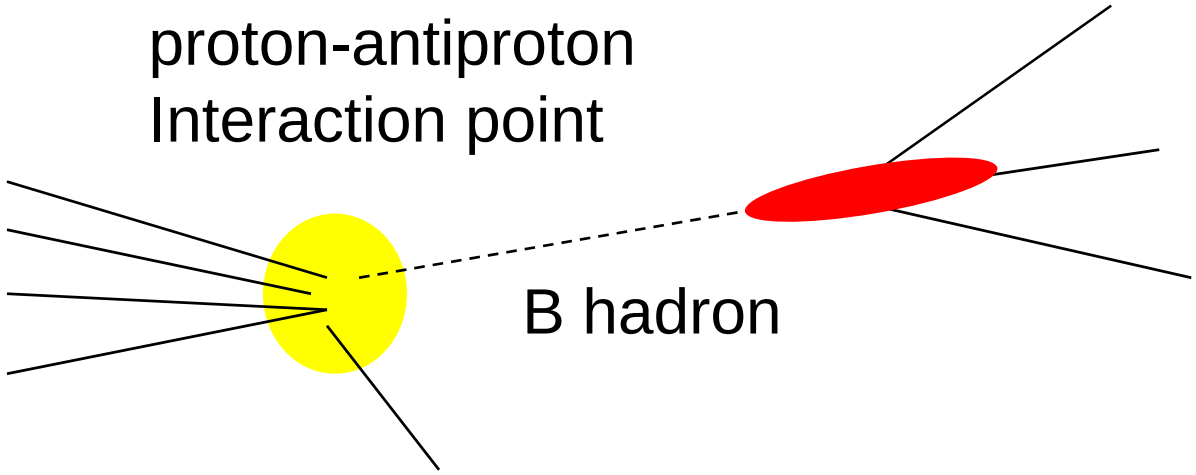
All four barrel cylinders are complete and at CERN, the integration into the cylindrical support structure has been recently completed



Insertion of the 3rd cylinder (out of the four) into the barrel SCT

Identifying b Quarks from Higgs

B hadrons have lifetimes of 1.5 ps: find the decay vertex!



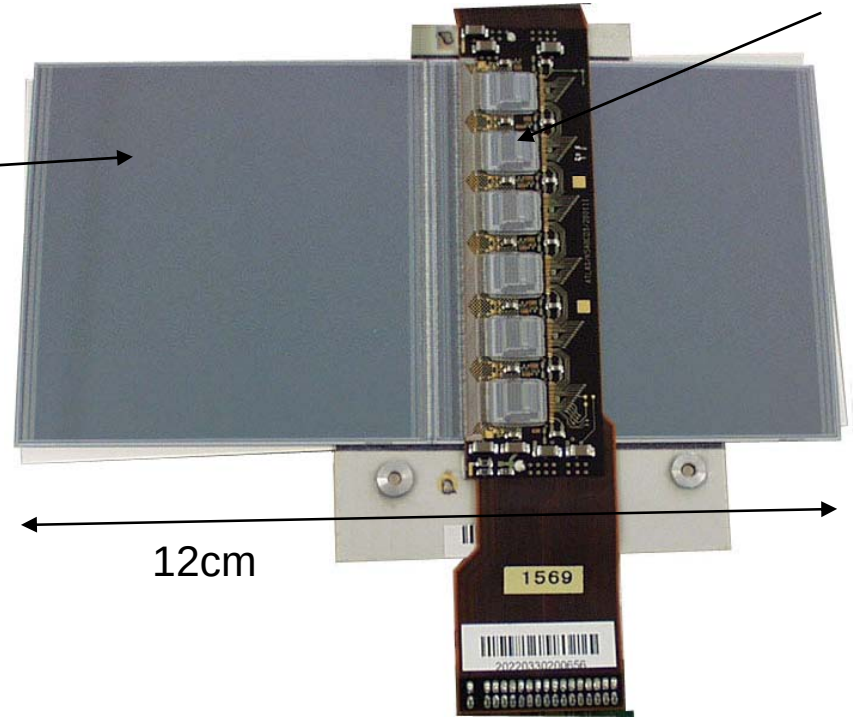
Fit tracks together to form secondary vertex

- measure flight distance of B hadron
- typical flight distance is 0.5 cm from interaction point
- close, precise measurement provided by silicon is crucial

(Silicon -) Trackers

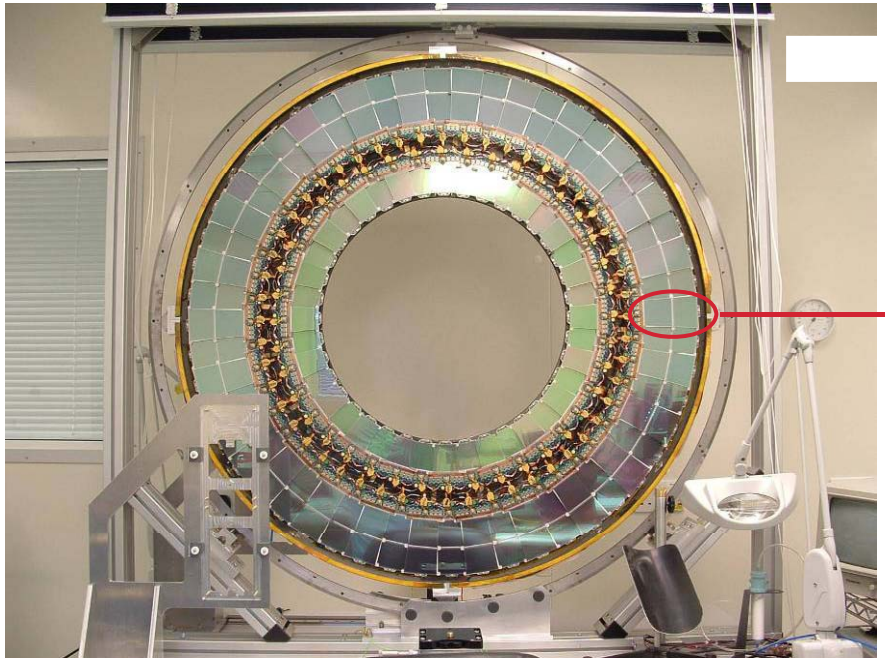
- Precise track position measurement based on low mass silicon detectors
  - Pixel to resolve the many tracks in center ~13μm /point
    - Active area ~1.5 m^2
  - Silicon strip detectors for precision track measurement ~16μm
    - Active area 60m^2 (Atlas) to 200m^2 (CMS)

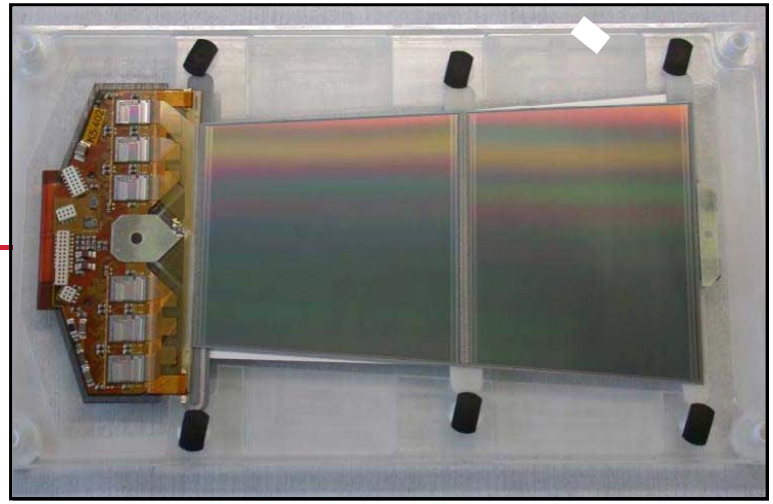
4 Sensors
280 microns thick p-n silicon sensors
Strip length 12cm
Pitch 80mm



Hybrid & Binary Readout chips
Flex circuit with 12 x ABCD chips.

Radiation hard ASIC developed specifically for readout of silicon strips





• The 9 disks of each end-cap are tiled with a total of 986 modules

• Modules were constructed in different sites worldwide and shipped to Liverpool (Nikhef for EC-A) for assembly to disk, and for disk insertion to the carbon-fibre support cylinder

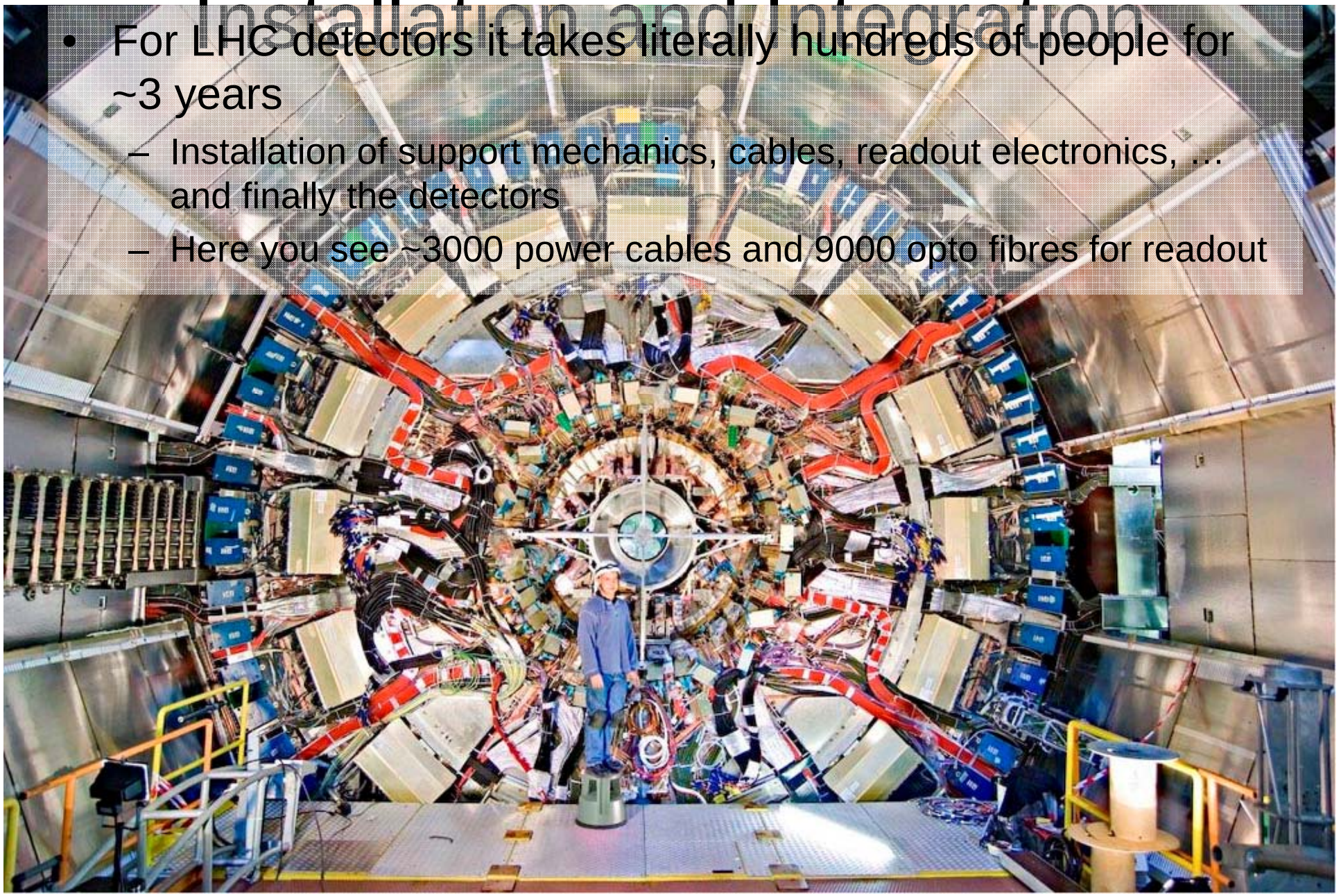
• Modules consist of two silicon wafers with 768 readout strips, back to back

• At one end, “hybrid” circuit holds FE chips which read out the strips

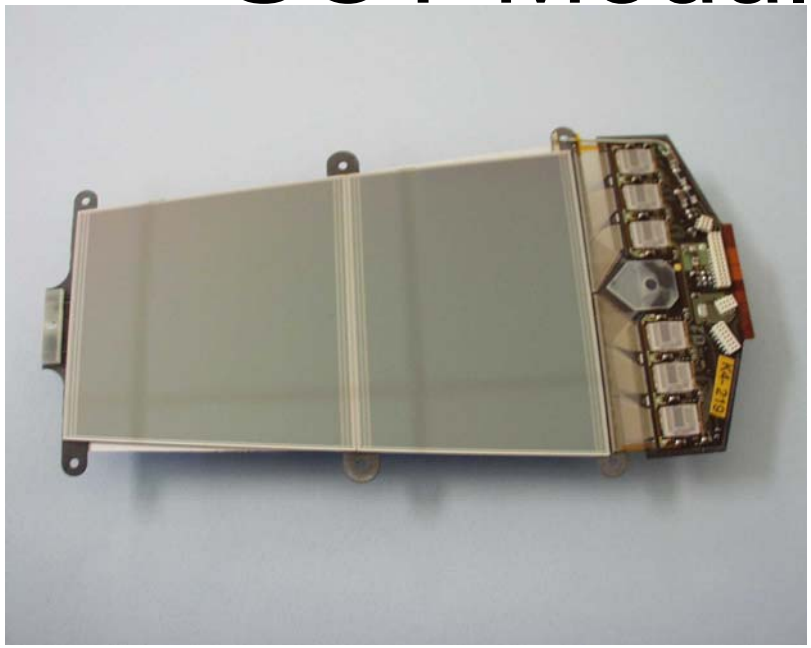
• Readout is binary: 6 chips per side (dealing with 128 channels each) providing shaping, amplification, discrimination against threshold and pipeline memory storage awaiting L1

Installation and Integration

- For LHC detectors it takes literally hundreds of people for ~3 years
  - Installation of support mechanics, cables, readout electronics, … and finally the detectors
  - Here you see ~3000 power cables and 9000 opto fibres for readout

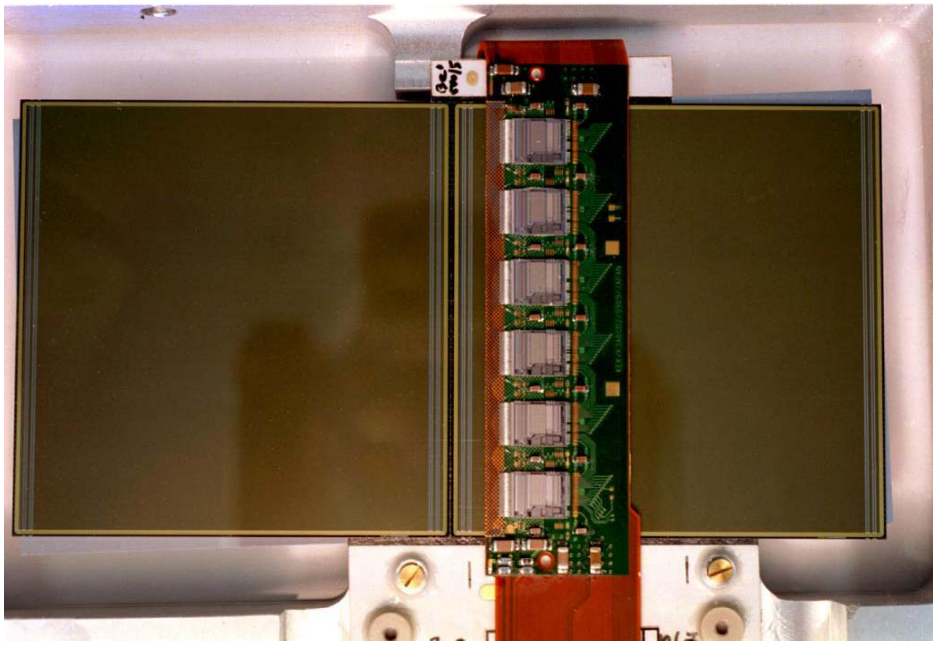


SCT Module — Pictures



Forward Middle detector module

Barrel detector module



SCT Module — Composition

Silicon detectors:

- Four single-sided detectors
- Mounted back to back with 40 mrad angle

Base boards:

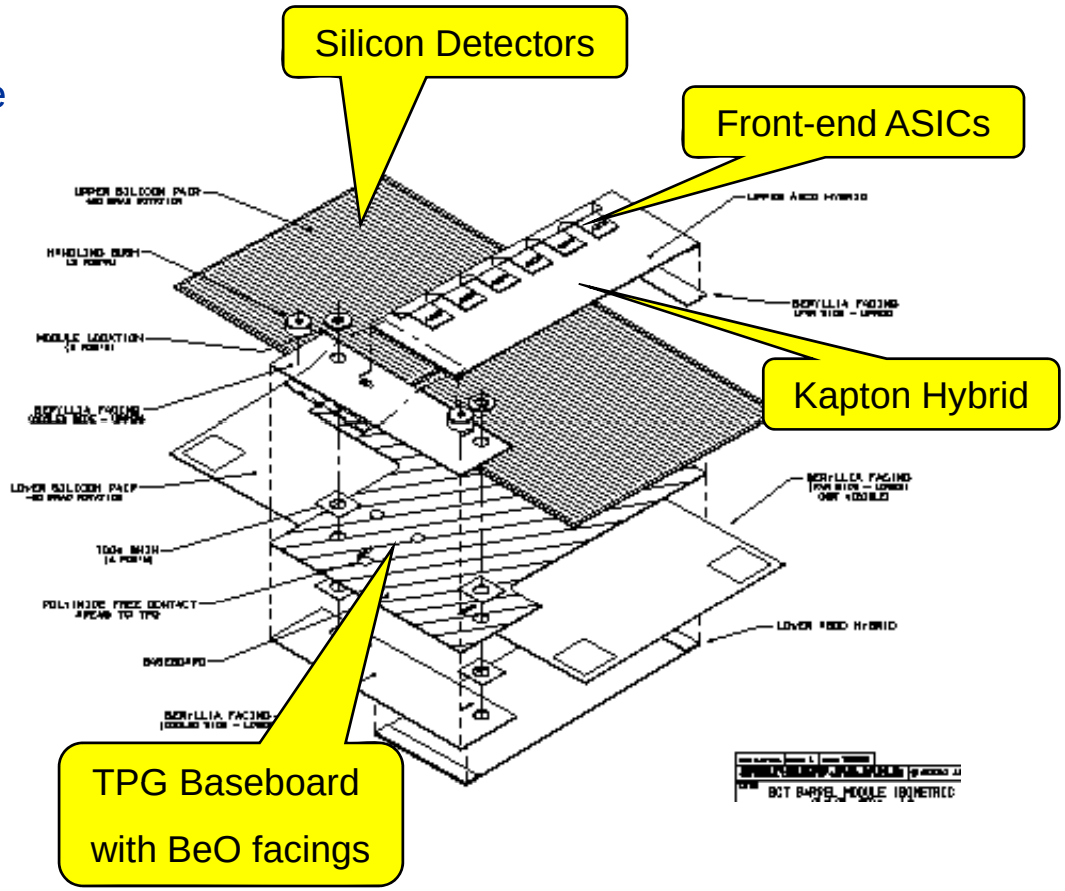
- TPG (Thermo Pyrolitic Graphite)
- Encapsulated with 20 μm epoxy
- Facings to cooling blocks of BeO

Kapton Hybrids

- Kapton printed circuit flex
- C-C bridge:
    - mechanical stability
    - good thermal conductivity
    - provides a gap between hybrid and detectors

ASICs:

- BiCMOS process
- Binary read-out



Exploded picture of a Barrel Module.

Design slightly modified

Front-end ASICs

- ATMEL DMILL BiCMOS process

(Digital CMOS, Analogue Bipolar)

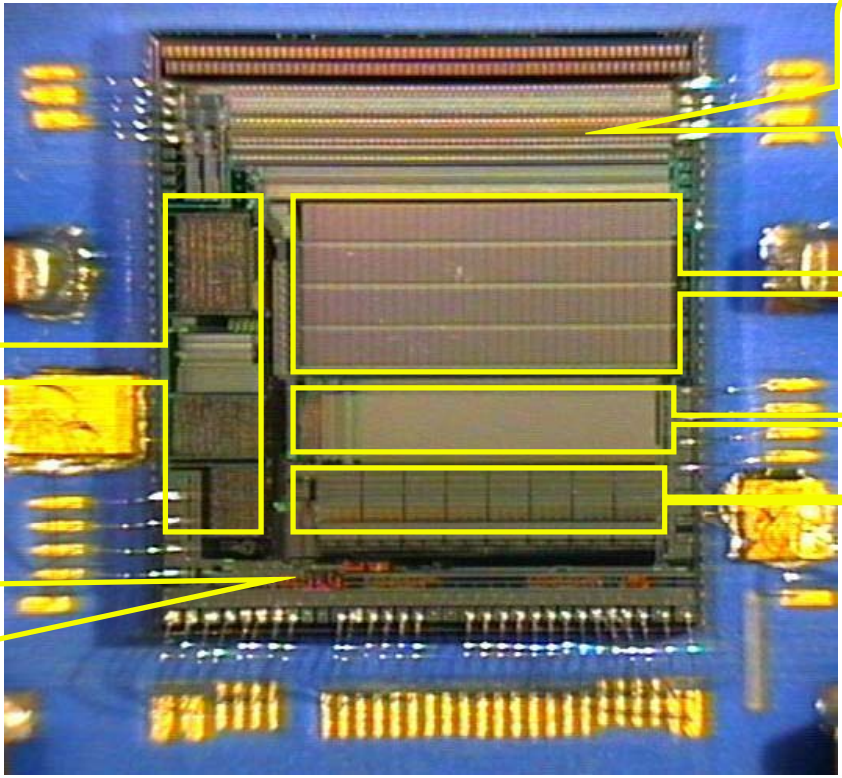
- Radiation Hard technology
- Binary read-out
- Optical links for CLK/COM and data.
- ~ 20 ns shaping time

128 Channels Bipolar front-end:

Preamplifier, Shaper & Discriminator

- Noise ~1400 ENC
- Gain ~ 55-60 mV/fC
- Noise Occupancy < $5*10^{-4}$

(@ 1 fC Threshold)



Built-in calibration circuitry for charge injection

132 cells pipeline

⇒ 3.3 μs latency for Level 1 Trigger

Read-out buffer

Data compression logic

Control circuitry

Double set of LVDS drivers/receivers for:

Clock, Commands, data & inter-chip communication

Thermal simulation of a Barrel Module

Z profile of a prototype module built in at Oslo University

Systems Test

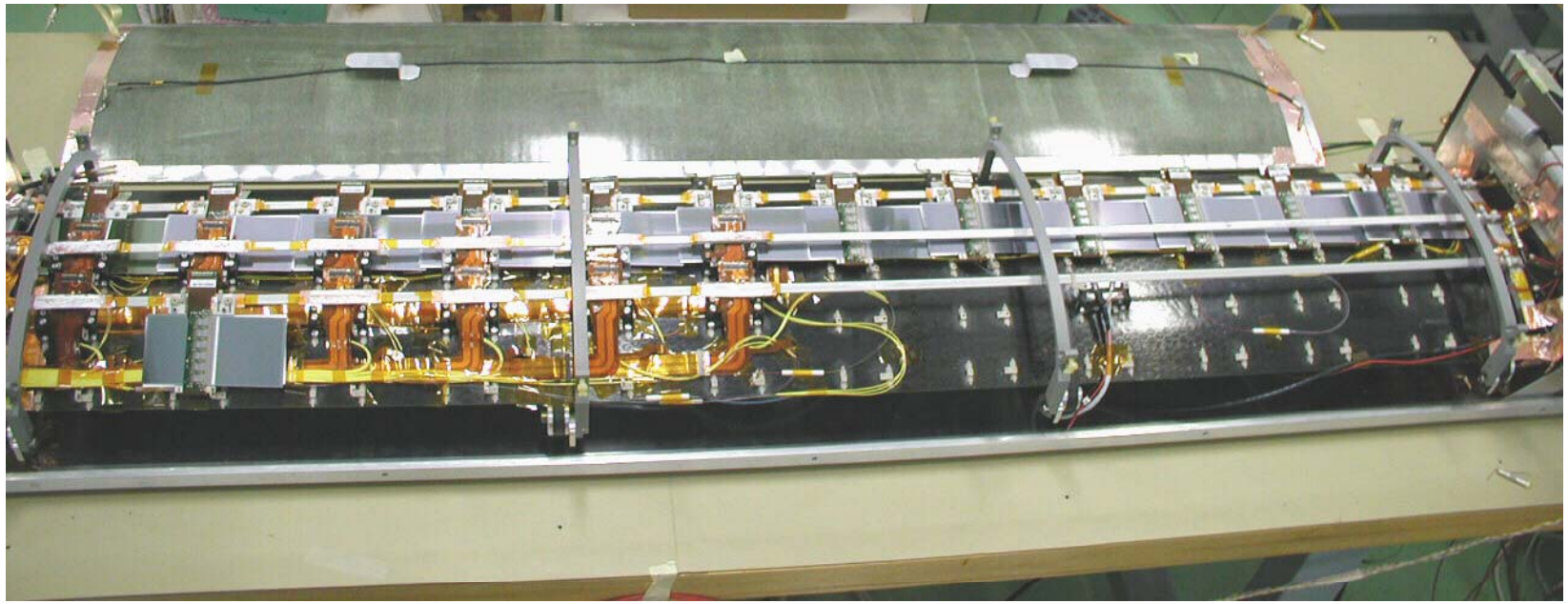
Small scale Systems Tests @ CERN:

Barrel ~ 15 modules

End-cap ~ 3 - 4 modules

Studies of (among many other things):

- Prototype Power Supplies
- Filtering
- Grounding / Shielding schemes
- Correlated noise
- Pick-up



Let’s fly though a detector!

- ATLAS Movie …

- http://www.youtube.com/user/TheATLASExperiment