The ATLAS Pixel Detector: Overview & Commissioning

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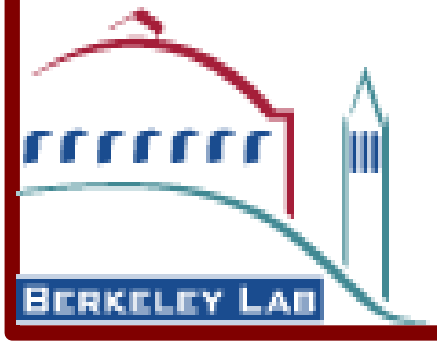
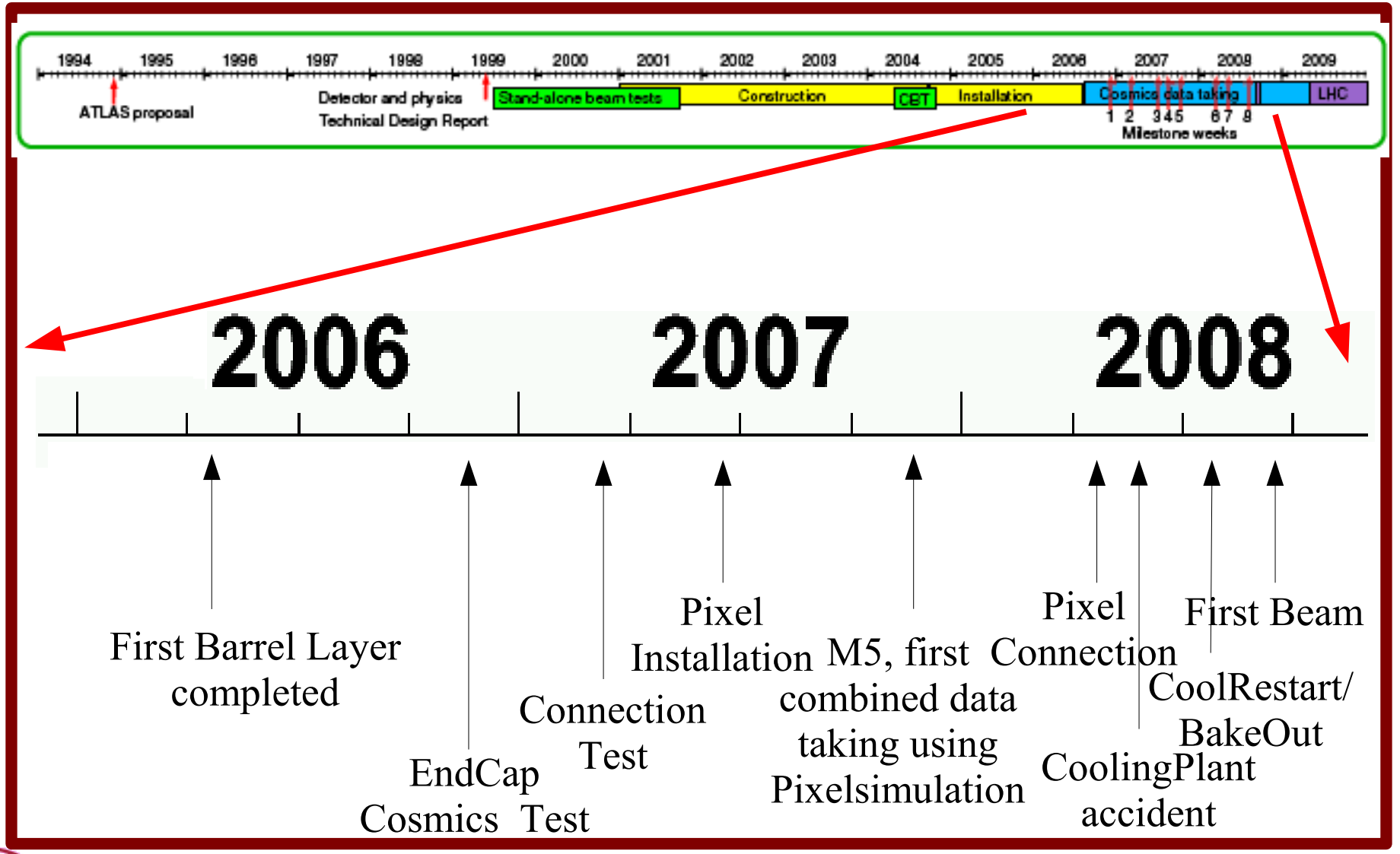
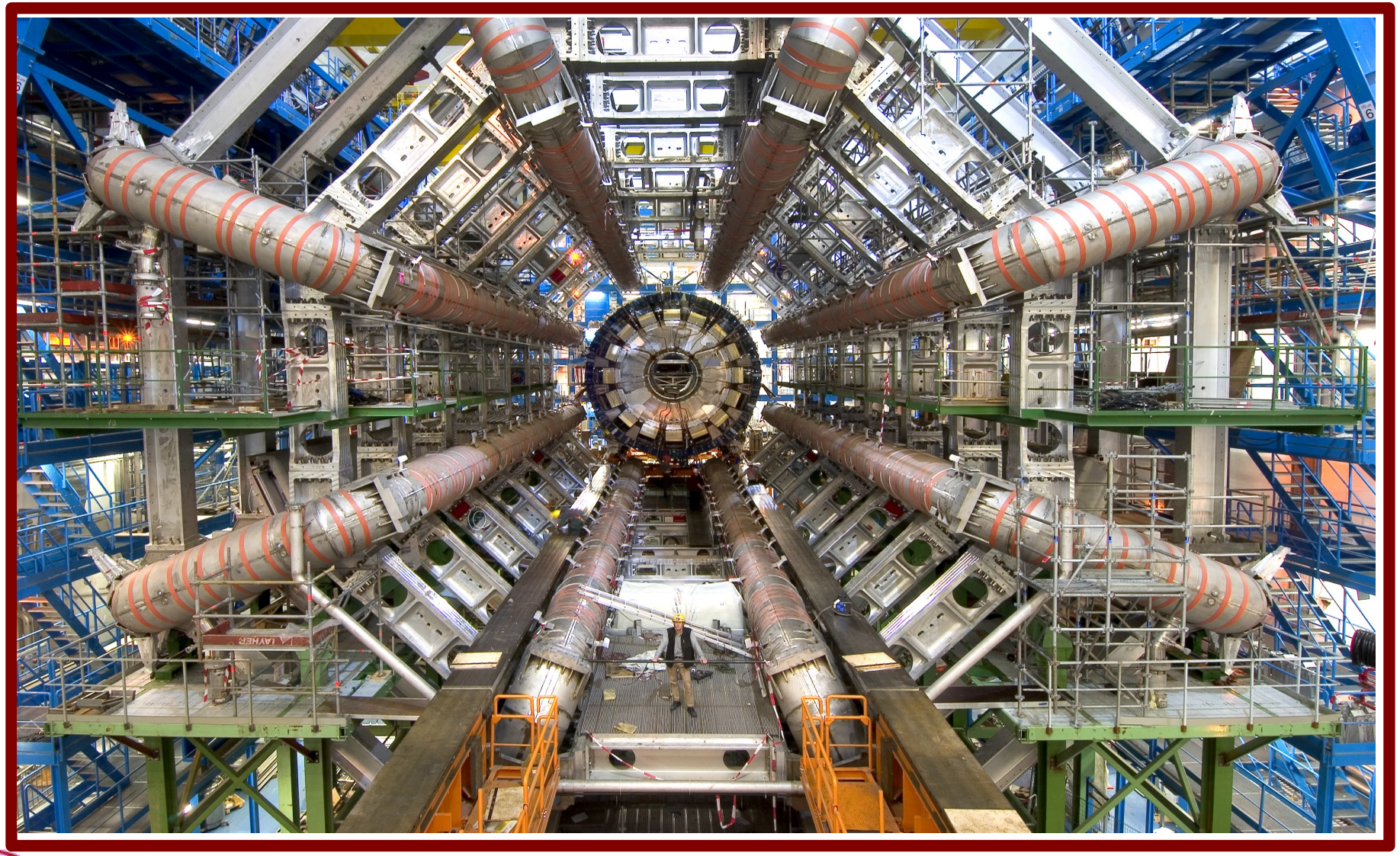


on behalf of the
ATLAS Pixel Collaboration

ATLAS ID timeline Overview



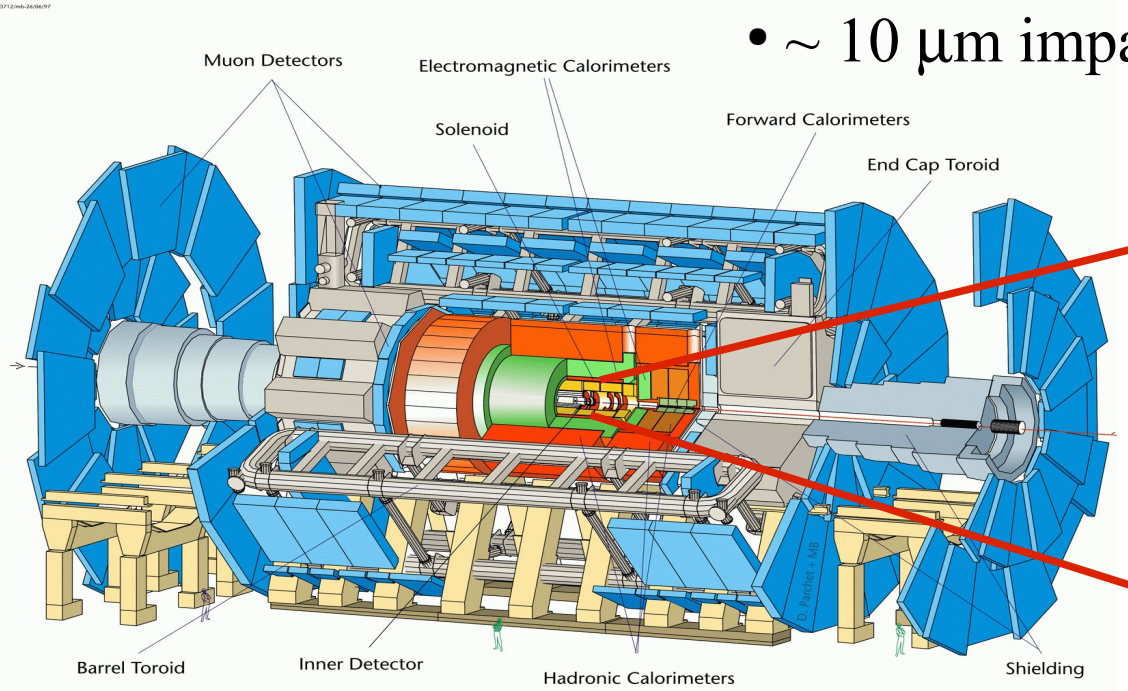
ATLAS Overview

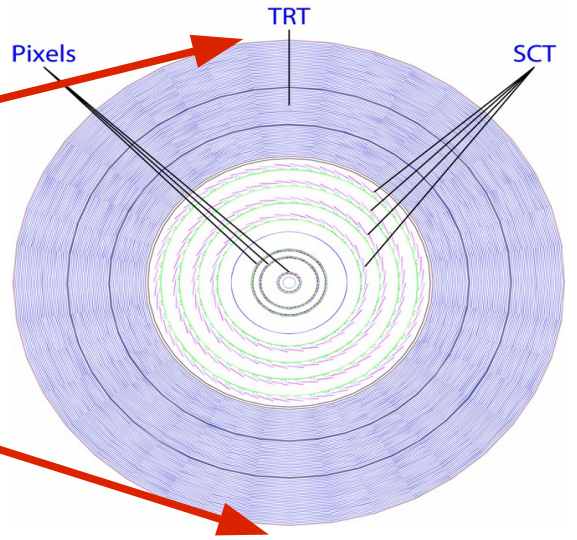


ATLAS Inner Detector

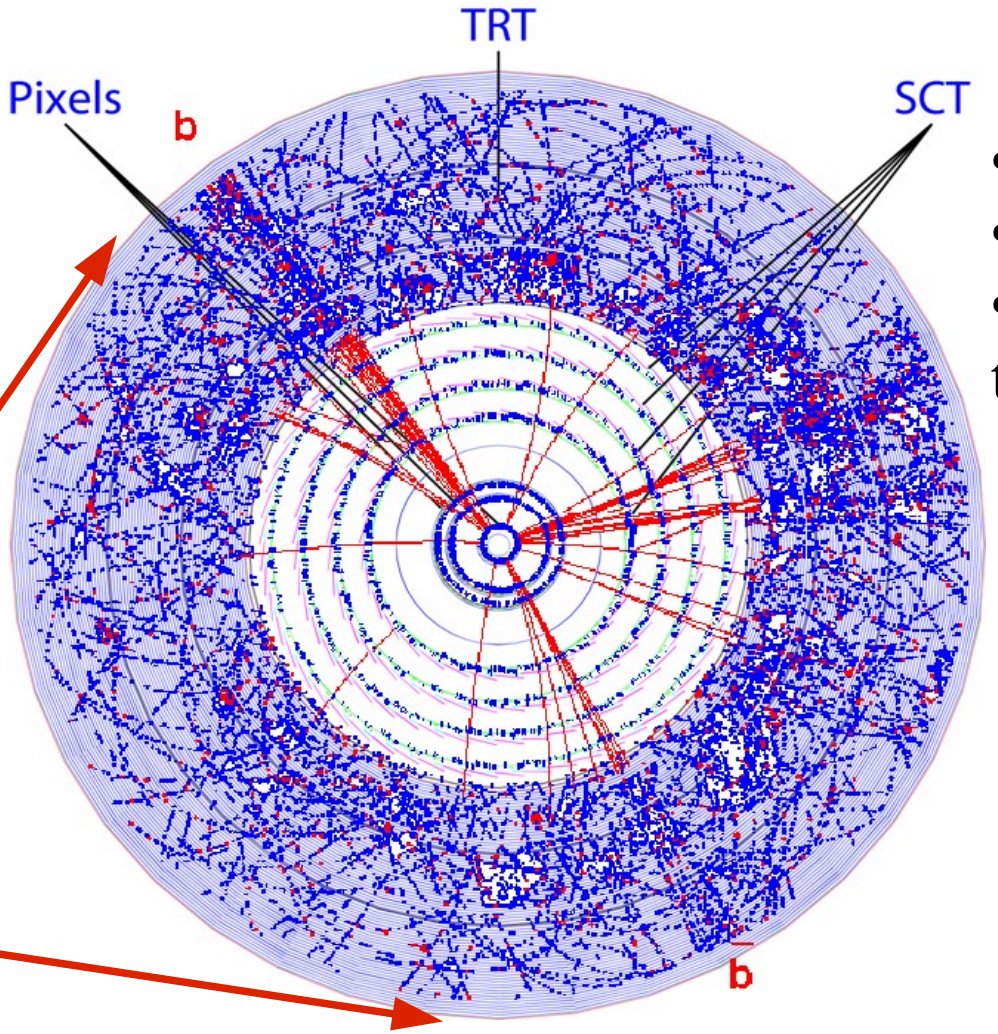
- 1.2m radius, 7m long
- coverage to $|\eta| \leq 2.5$
- inside 2T magnetic field
- 40MHz bunch crossing

- Transition Radiation Tracker (TRT) : 36 space points
- SemiConductor Tracker (SCT): 8 space points
- Pixel Detector: 3 Layers
- ~ 10 μm impact parameter resolution





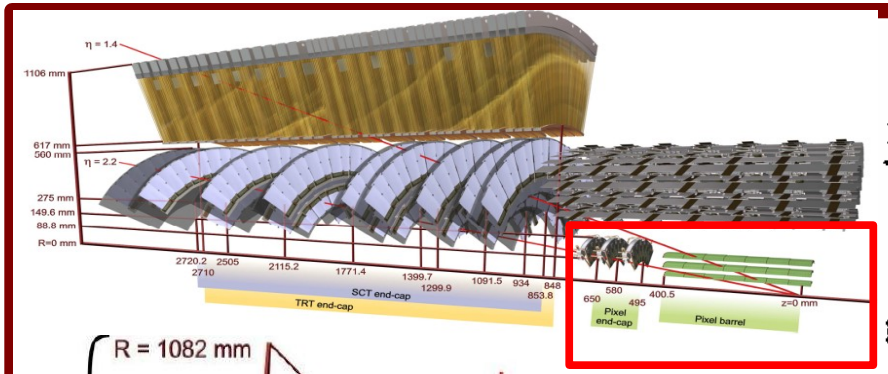
Physics Motivation

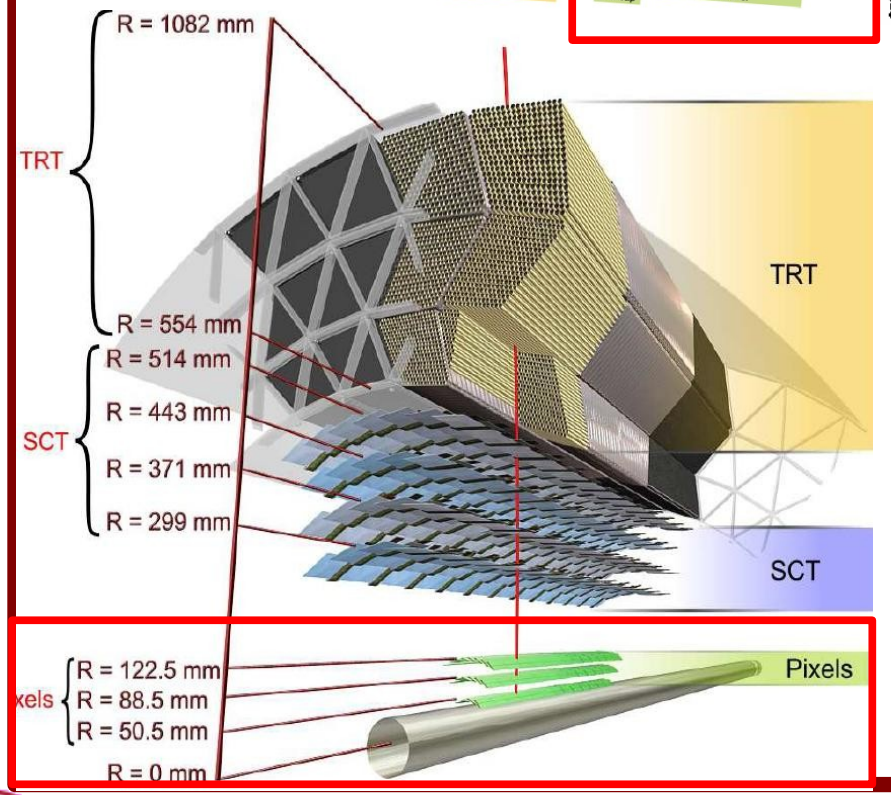


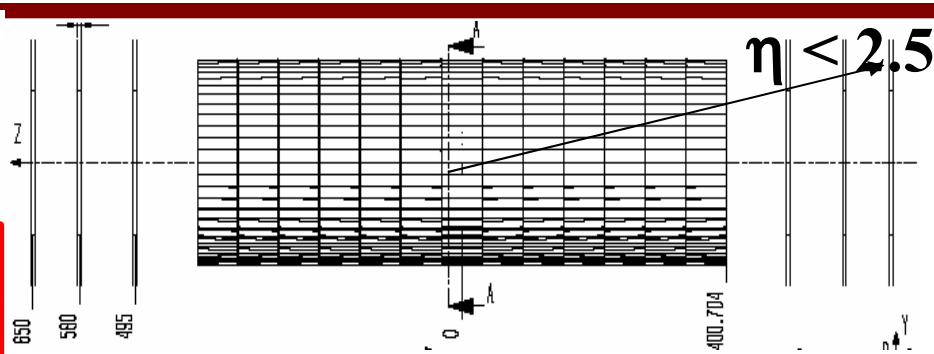
- reconstruct tracks
- measure their momenta
- identify b-hadrons by their displaced vertices

- many interesting physics modes with b-quarks
  - $t \rightarrow Wb$
  - $H \rightarrow b\bar{b}$

ATLAS Pixel Detector Overview

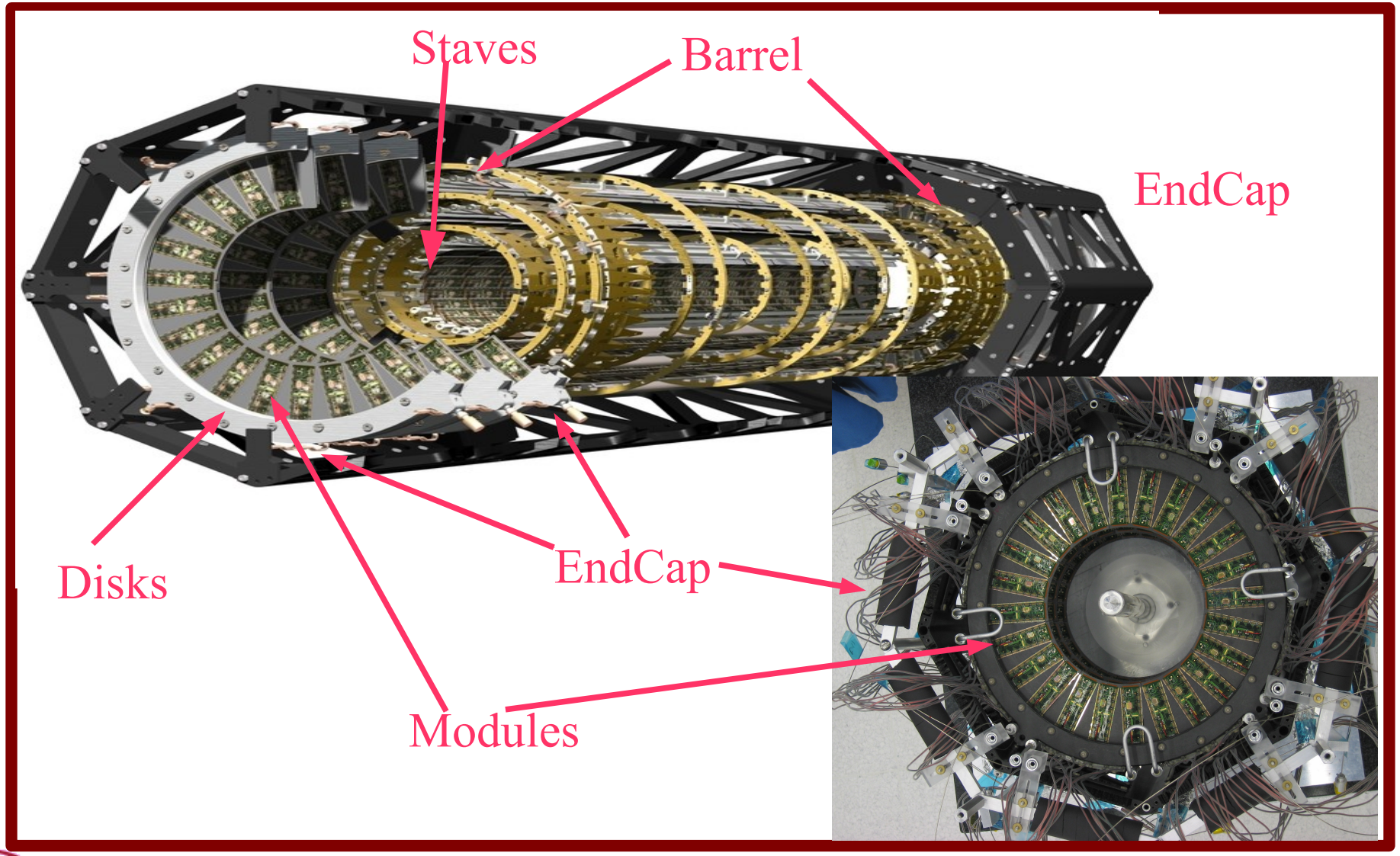






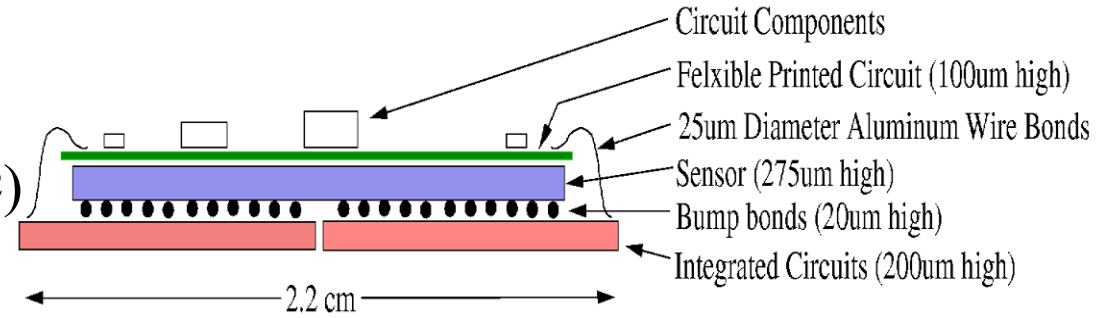
- 3 Barrels, 2x3 disks
- Total of 1744 Modules, organized in Staves and Sectors
- 46080 channels per Module, total ~80 million channels
- minimize confusion during pattern recognition (Occupancy 10^{-4}, Noise $<10^{-6}$)
- B-Layer at 5 cm ↔ good impact parameter resolution

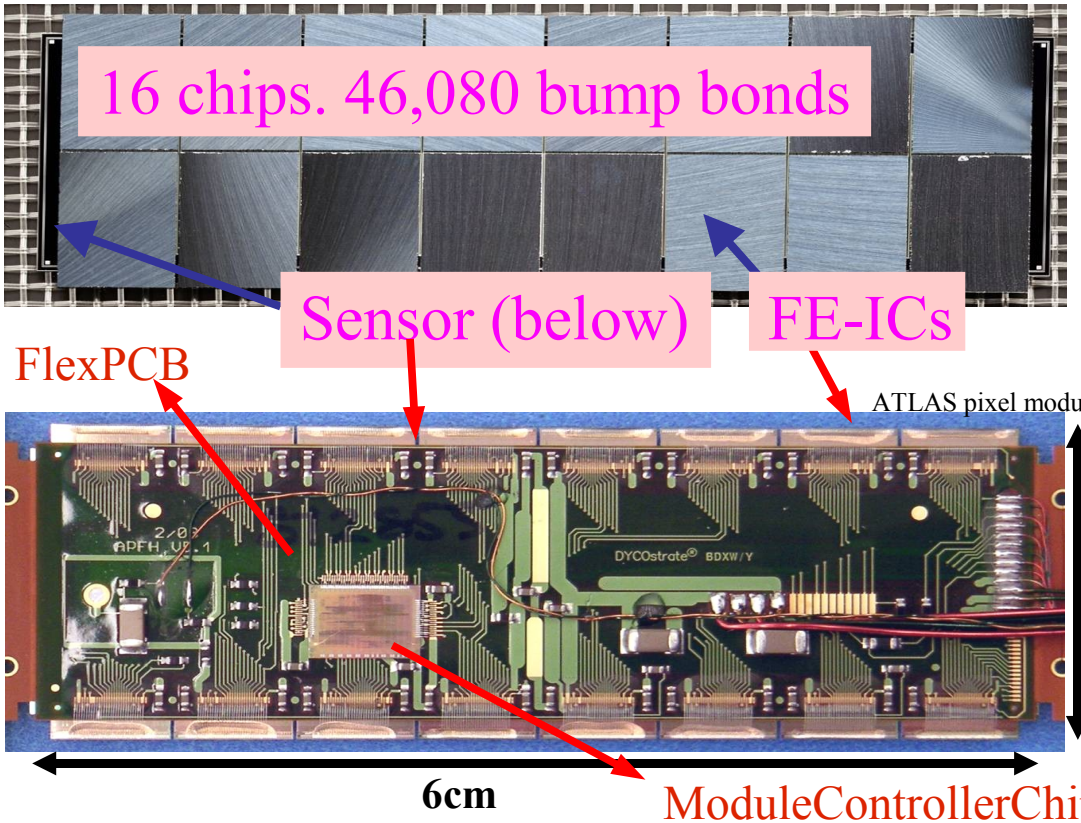
Pixel Overview



Pixel Module

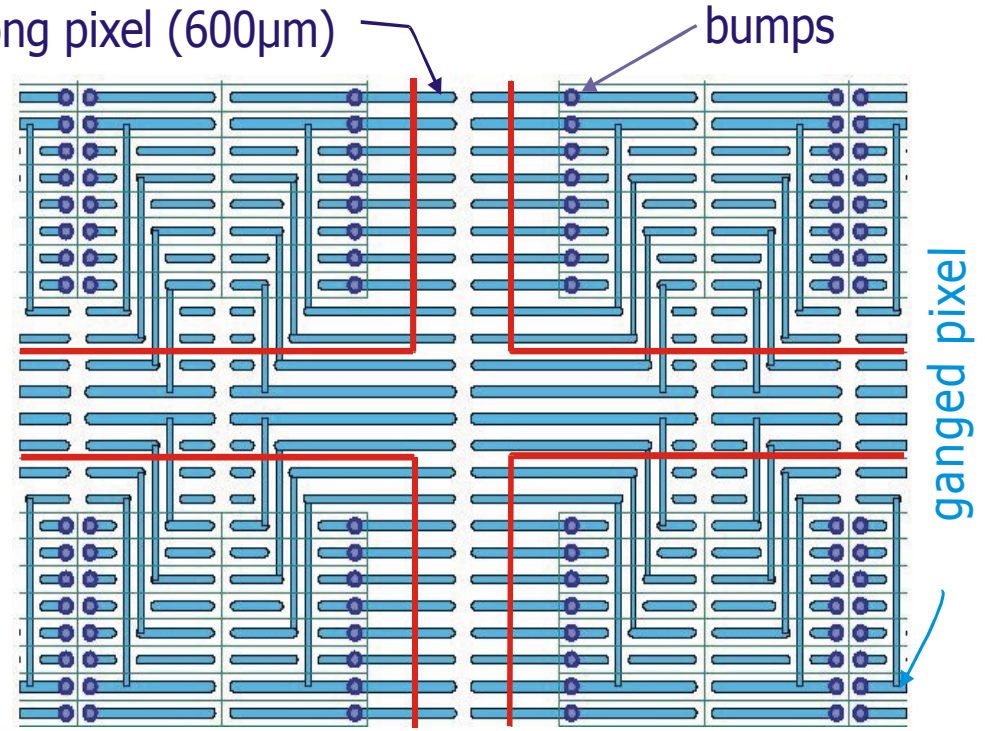
- radiation hard to 50MRad (NIEL > 10^{15} 1 MeV n_{eq}/cm^2)
- fast readout (25ns beam crossing, 3.2µs latency)
- Hybrid chip technology
- 0.25µm CMOS FrontEnd
- 1 Sensor bump bonded to 16 FrondEnd chips
- FrondEnd chips connect to ModuleControllerChip
- Zero suppression and first event building

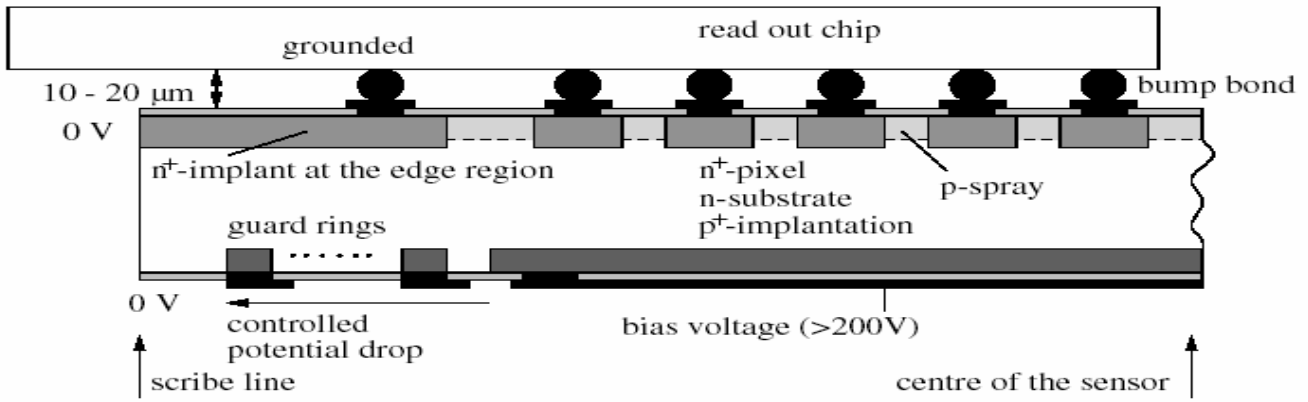




Pixel Sensor

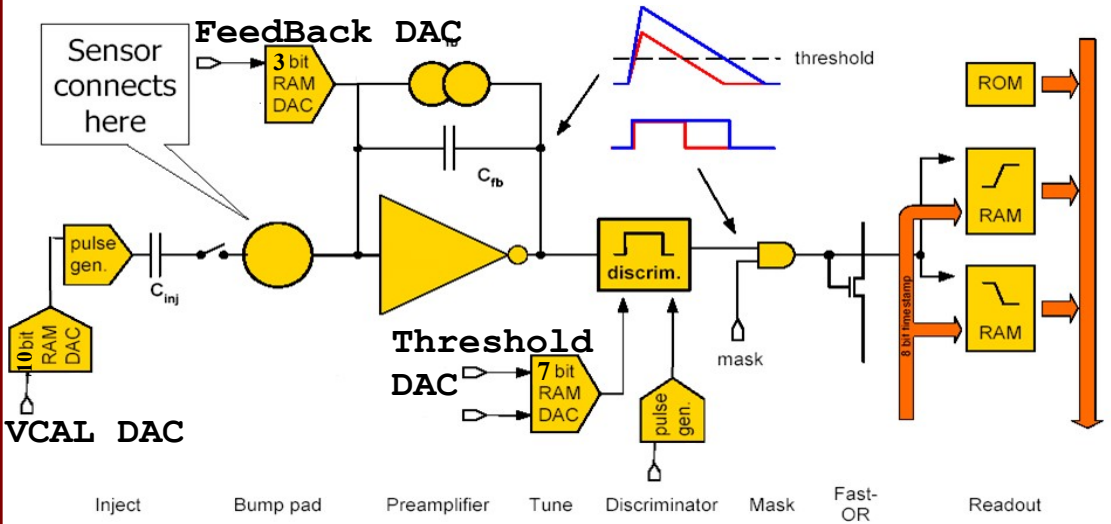
- n-substrate
- active area 60.8 x 16.2 mm^2
- total area ~1.8 m^2
- 41984 50µm x 400µm Pixels
- special Pixels for chip overlapp regions:
  - 5284 "long" 50µm x 600µm
- after radiation:
  - 97.8% eff
  - 9.7 µm Rϕ resolution

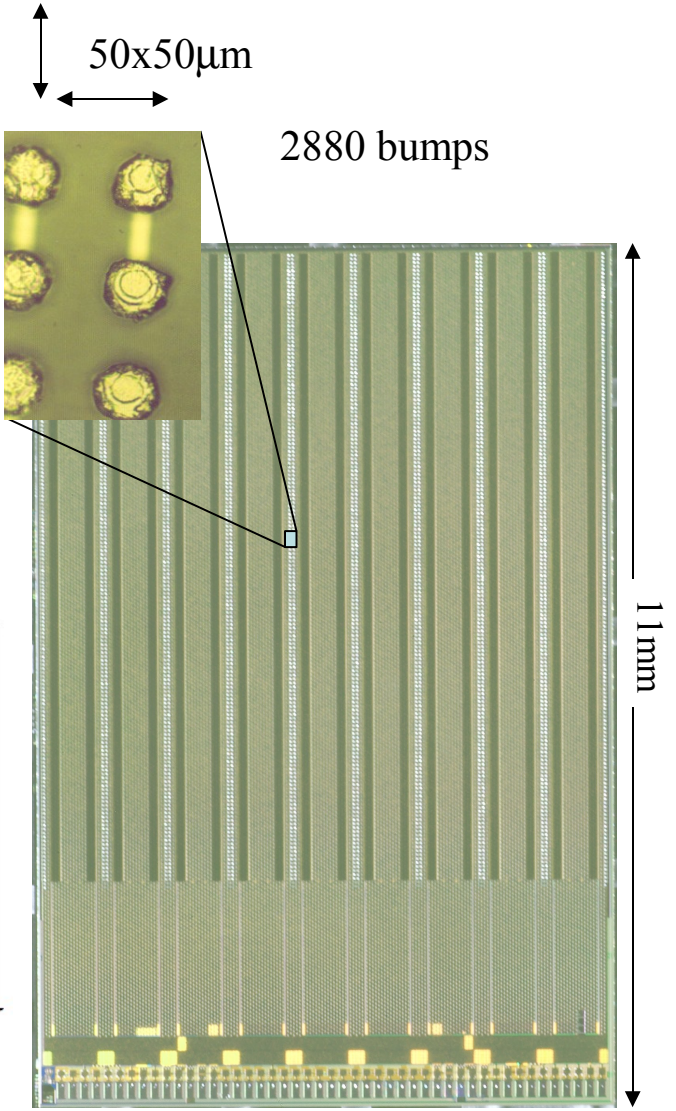




Pixel FrontEnd Chips

- 2880 channels organized in 18 columns and 160 rows
- connected to sensor via 50 µm pitch bump bonds
- buffering + time stamp logic
- converts charge into Time over Threshold (ToT)
- charge injection
- detailed monitoring





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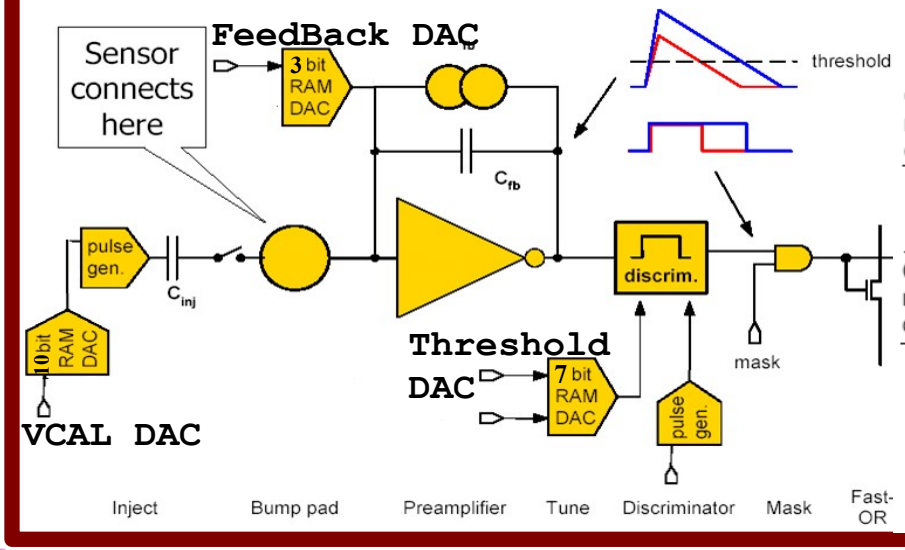
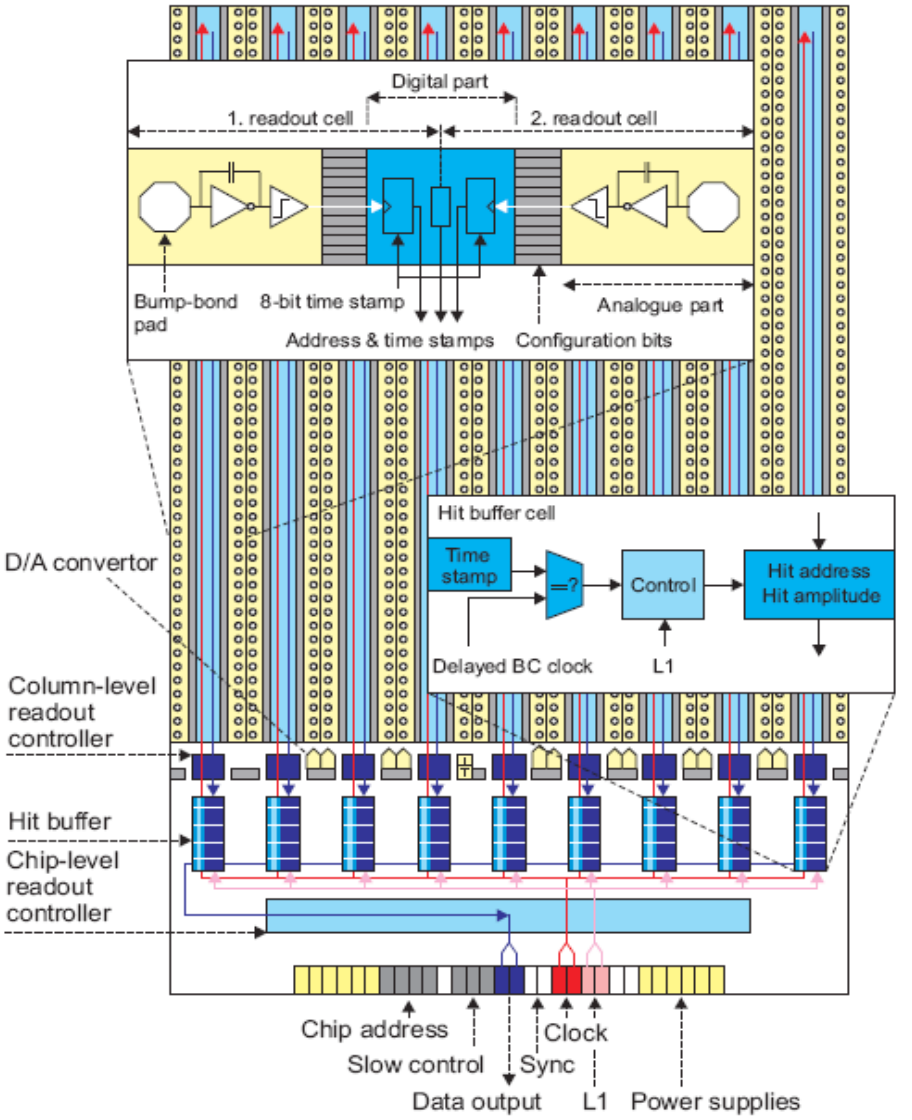
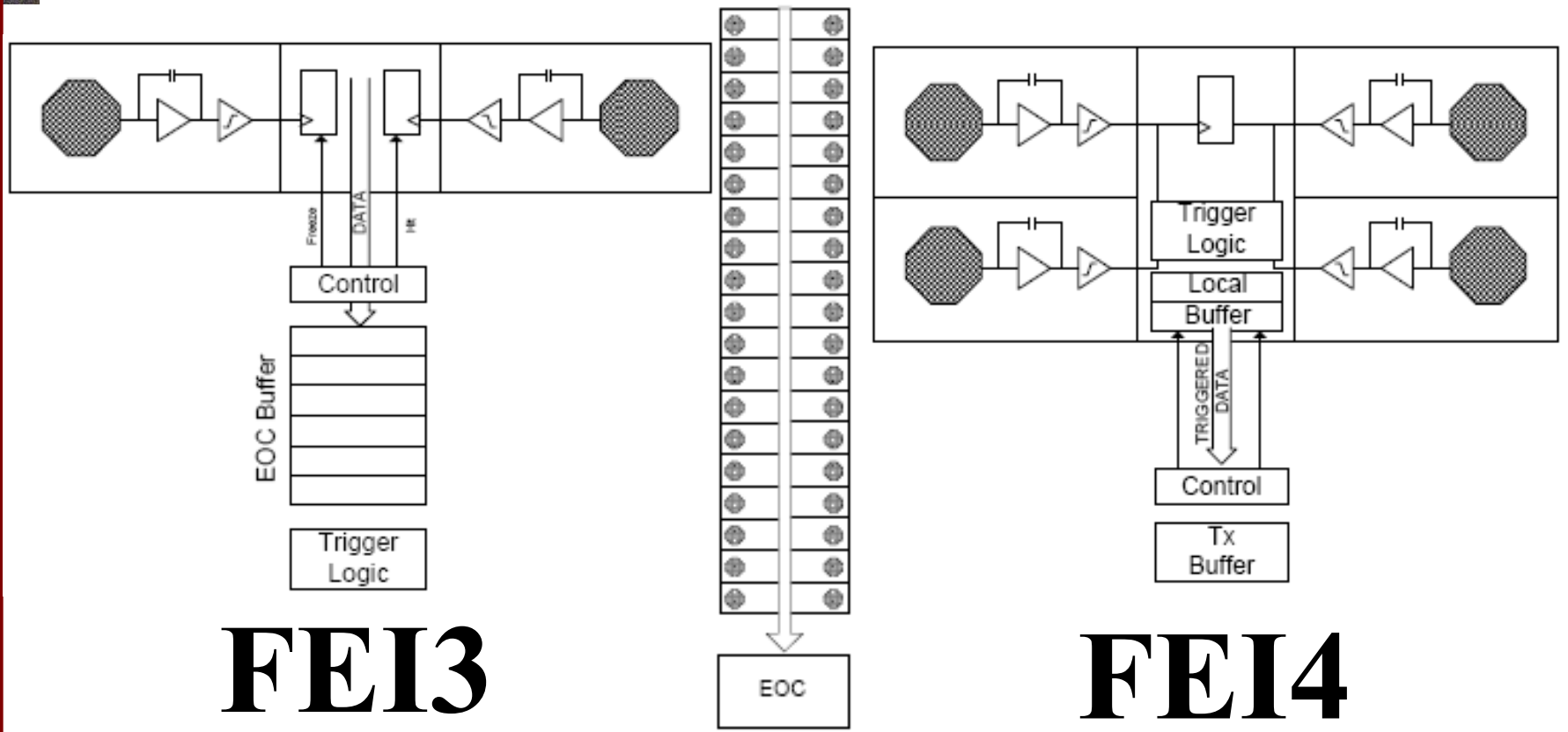


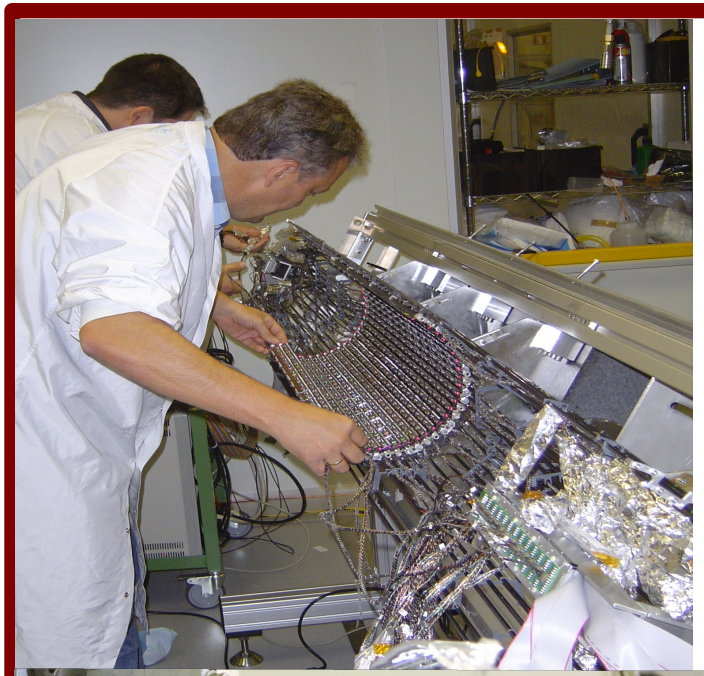


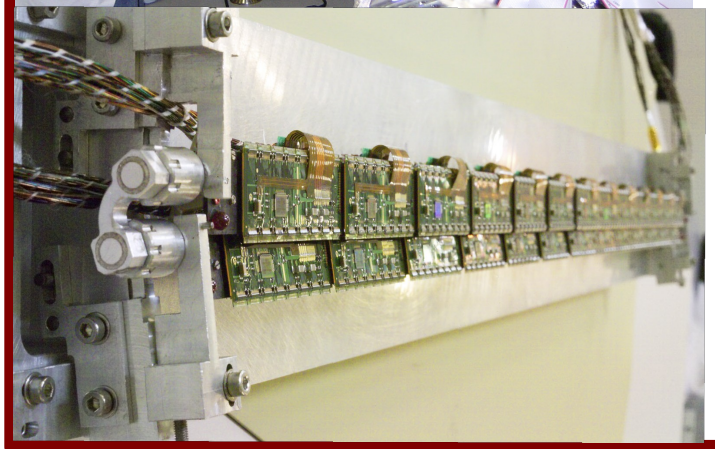
Upgrade: Pixel FrontEnd Chip FEI4



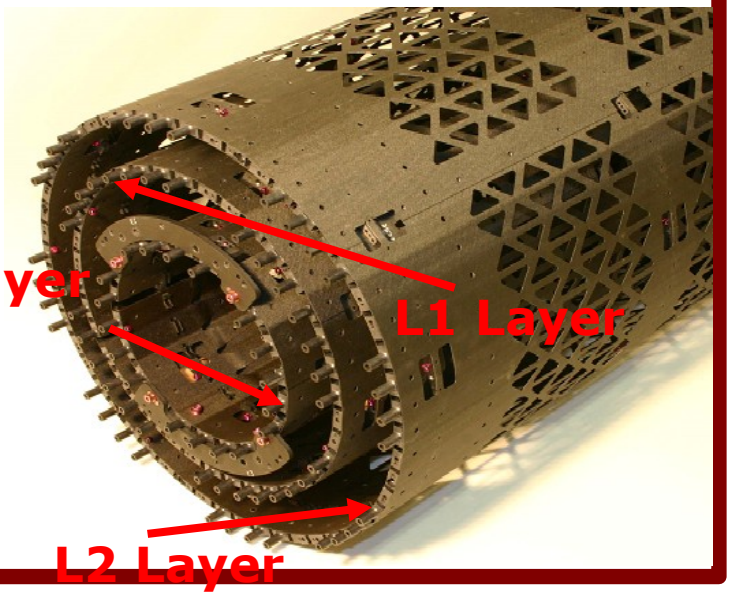
- FEI3 design has limitations at high occupancy
- Possible solution in FEI4:
  local storage + readout only triggered hits
- New concept: cluster timing (larger hits have better timing)

Pixel Barrel

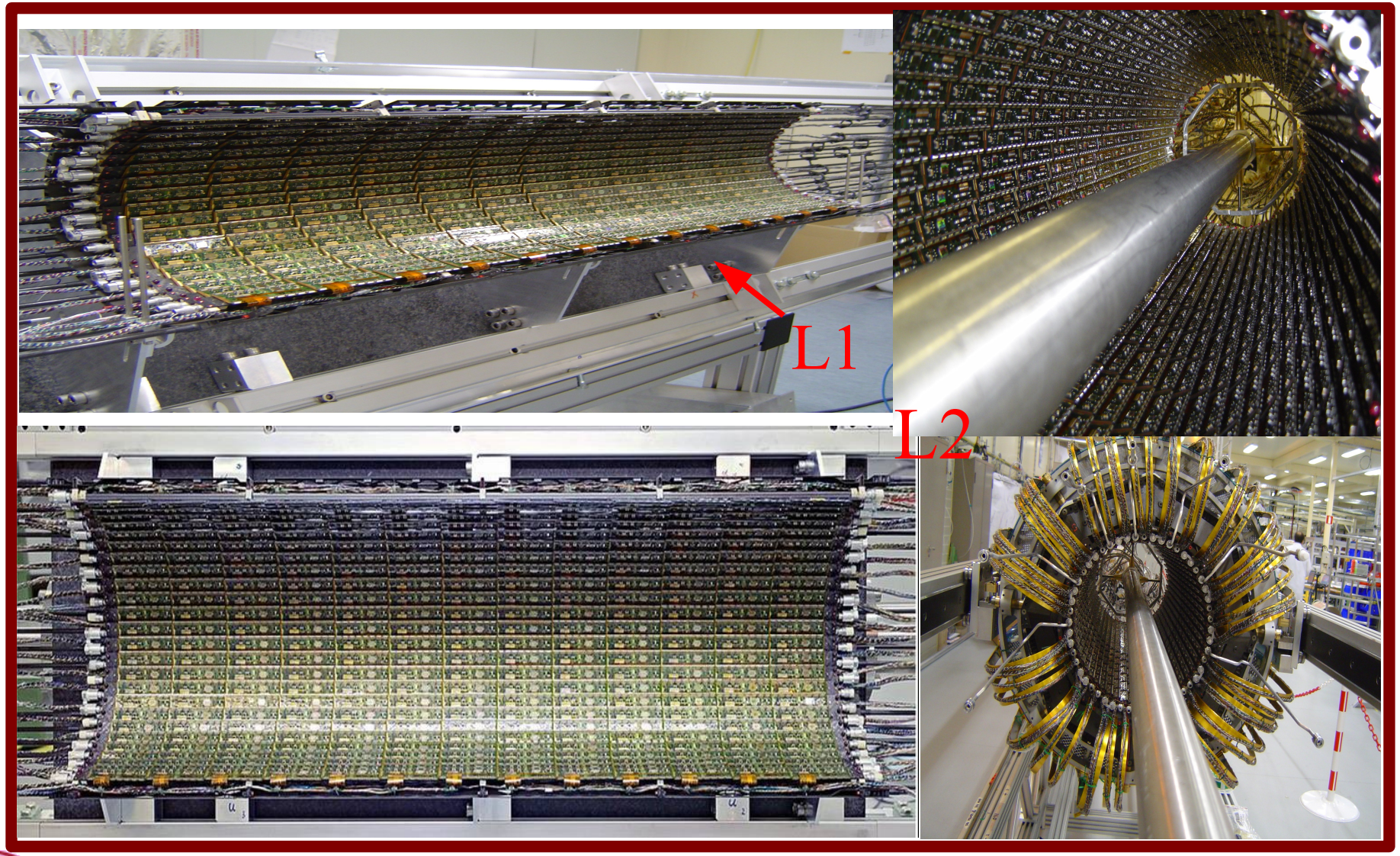




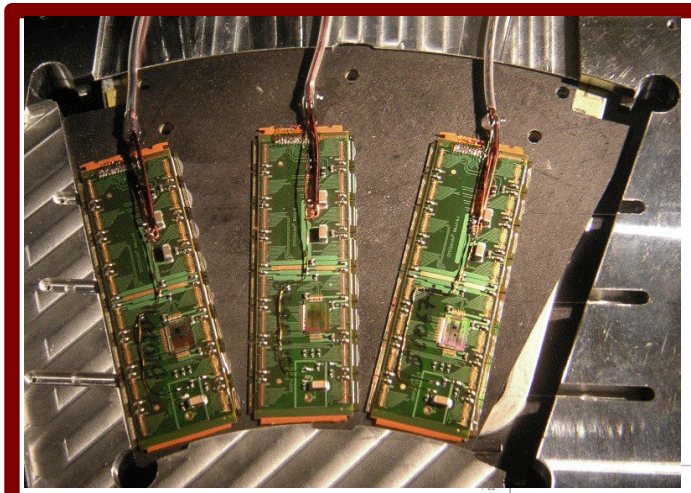
- carbon-carbon support ladder
- integrated cooling pipe
- 13 modules per stave
- bi-staves with cooling U-Link are inserted into half-shells
- finally clamping of half-shells



Barrels: L2, L1



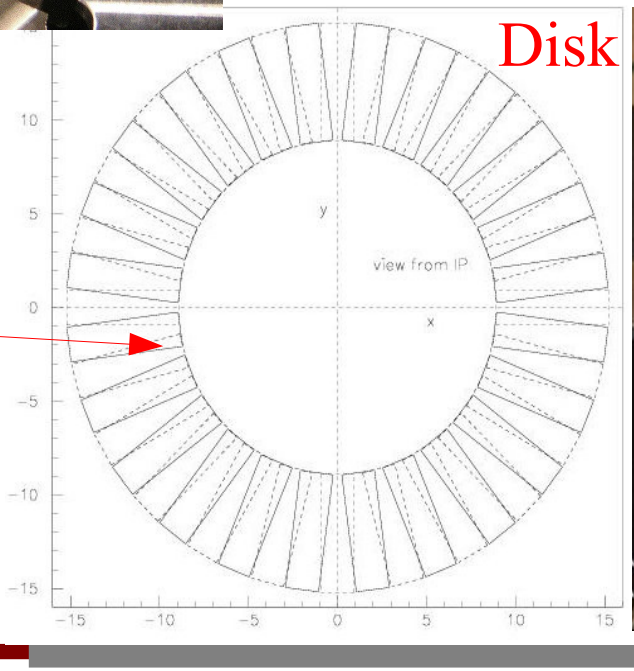
Pixel EndCaps



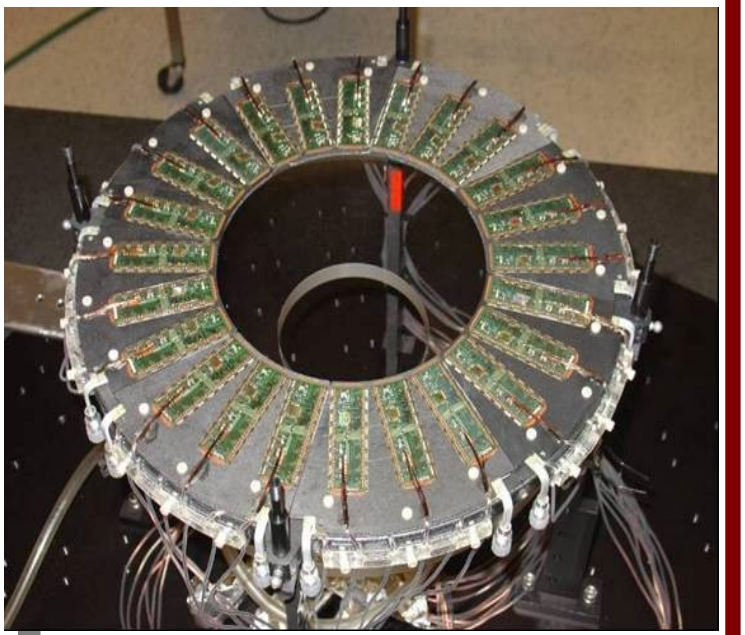
Sector

- 3 modules on each side of a sector, 6 modules total
- cooling pipe sandwiched between carbon-carbon plates
- 8 sectors to form a disk
- 3 disks per EndCap

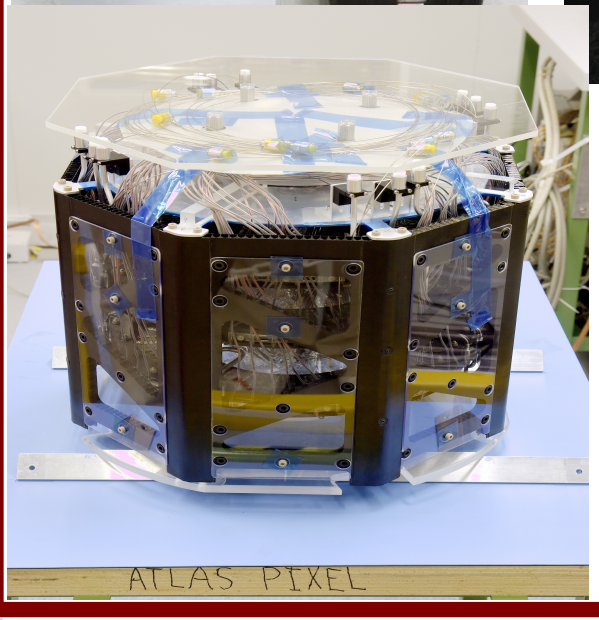
Disk



Overlapp region between modules

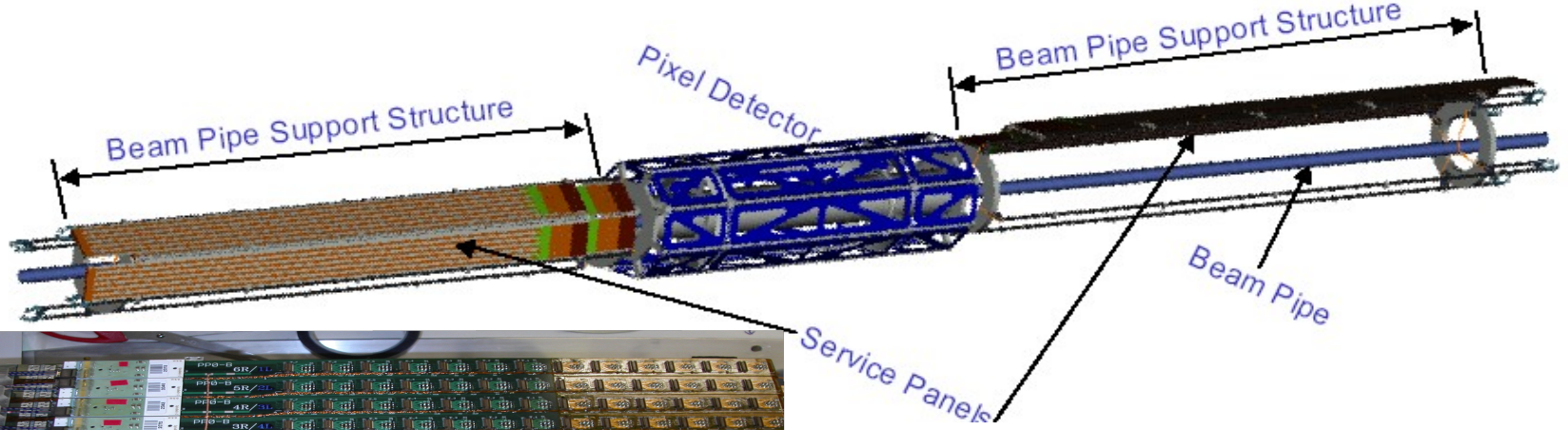


How to Transport an EndCap



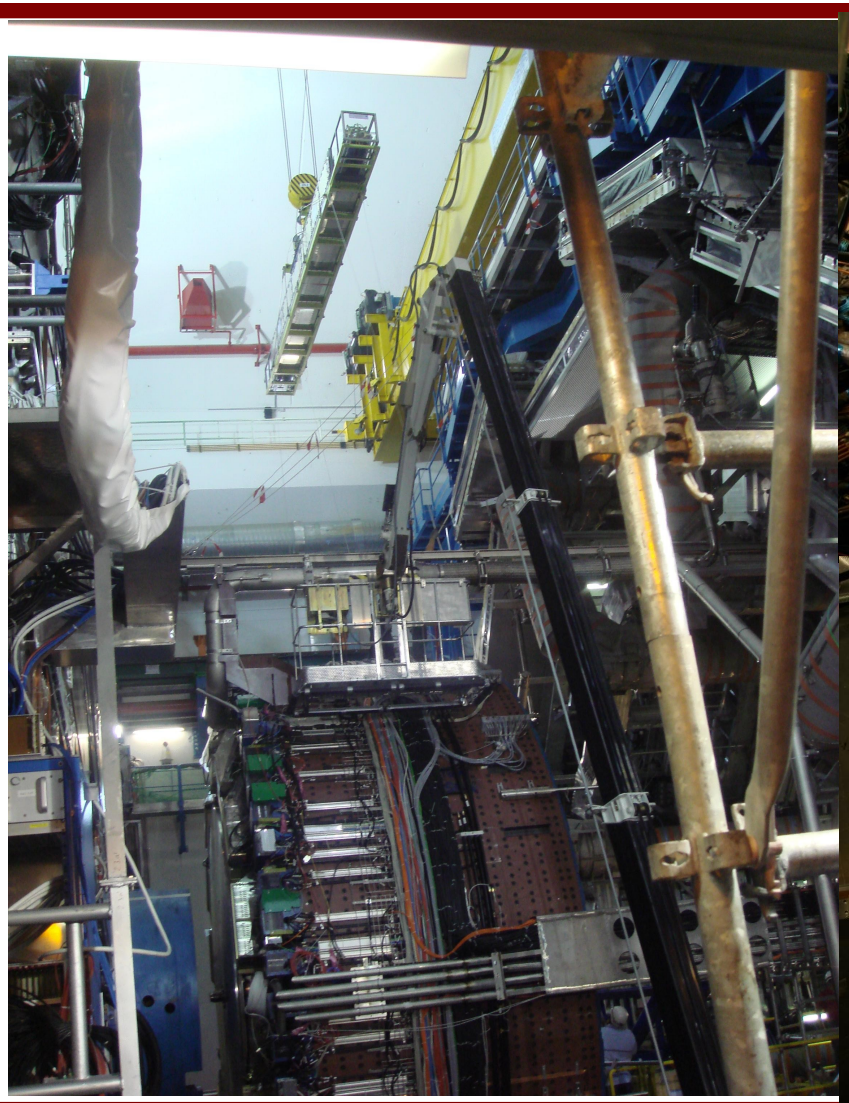
- transported from Berkeley by plane
- both EndCaps delivered safely to CERN
- underwent detailed reception testing
- < 0.2 % dead pixels in EndCaps!

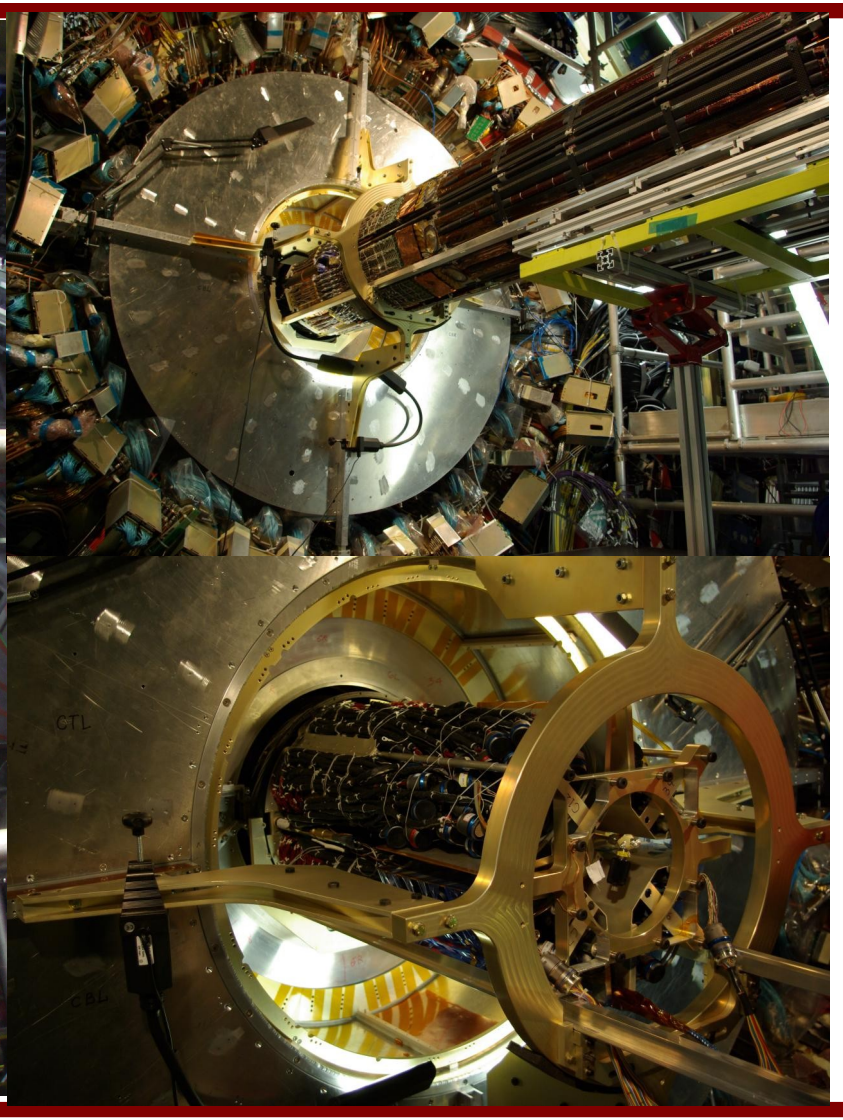
PixelPackage



- total pixel package 7m long
- data conversion to optical
- Service Quarter Panels to extract services to the outside of the Inner Detector Volume
- Pixel package to be inserted into Pixel Support Tube
- last detector installed in ATLAS

Pixel Insertion

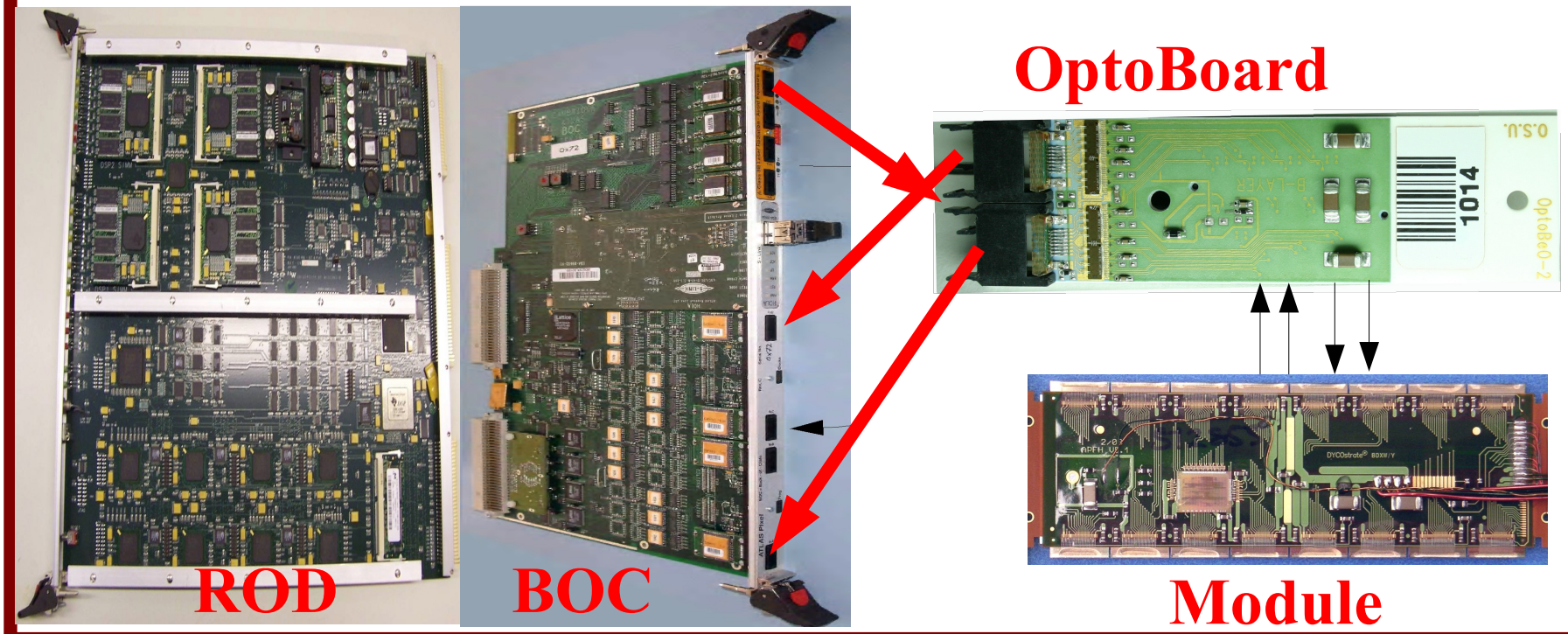




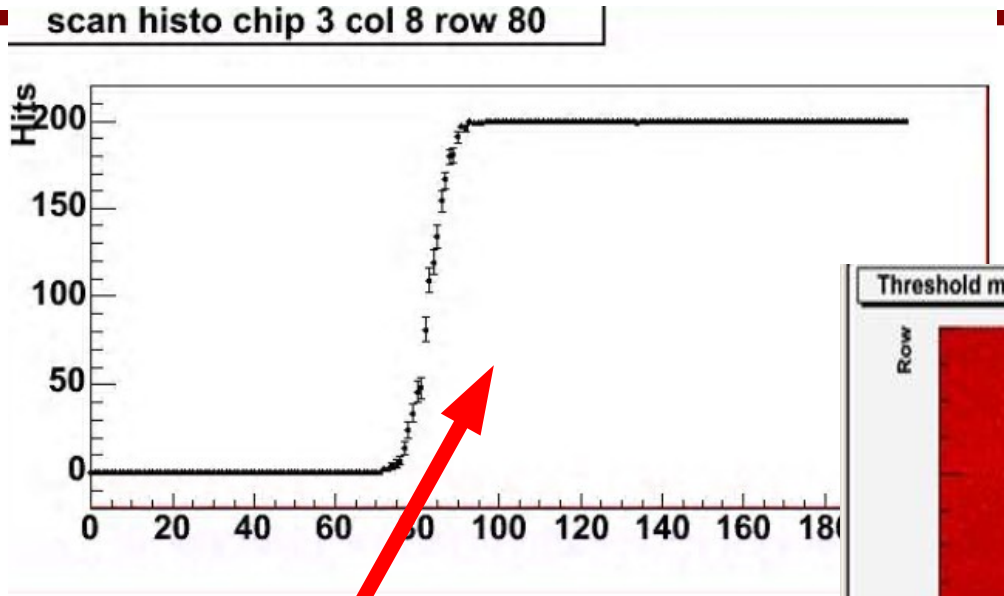
Pixel Connection

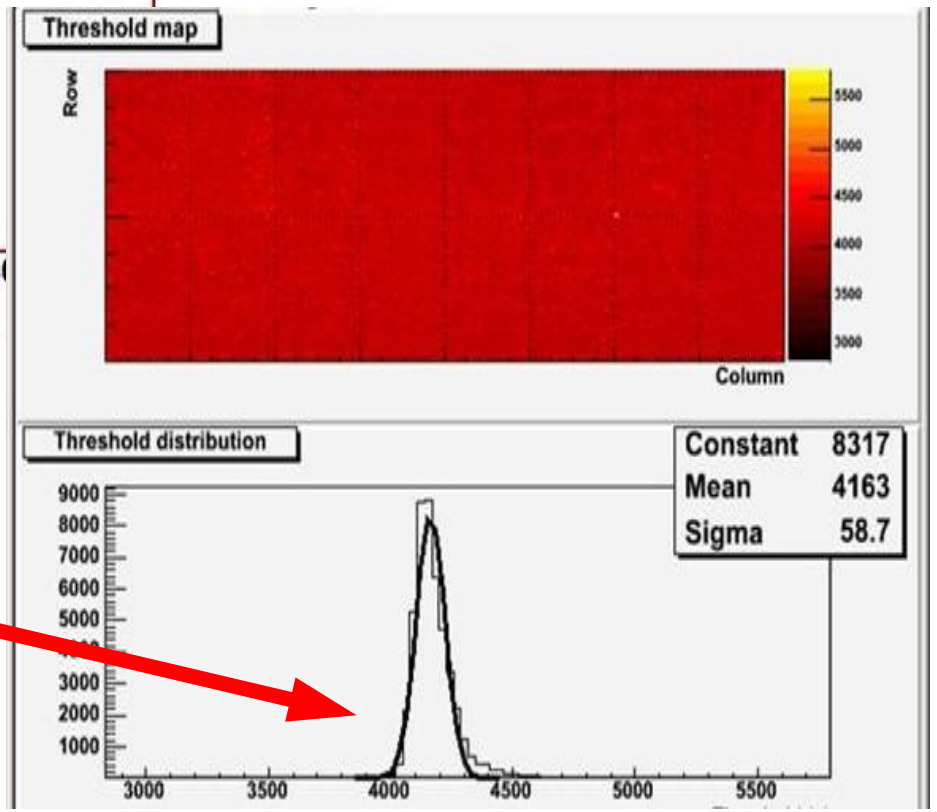
Pixel ReadOut

- Module can send data with 40(L2), 80(L1, Disk) or 160 Mbit(B)
- 4 LVDS connections to Module: Clock, DataIn, 2 x DataOut
- optoBoard services 6/7 modules, converts electrical to optical
- BackOfCrate card encodes clock/data, decodes in 40MHz streams
- ReadOutDrive with 4+1 DigitalSignalProcessors and 1GB RAM



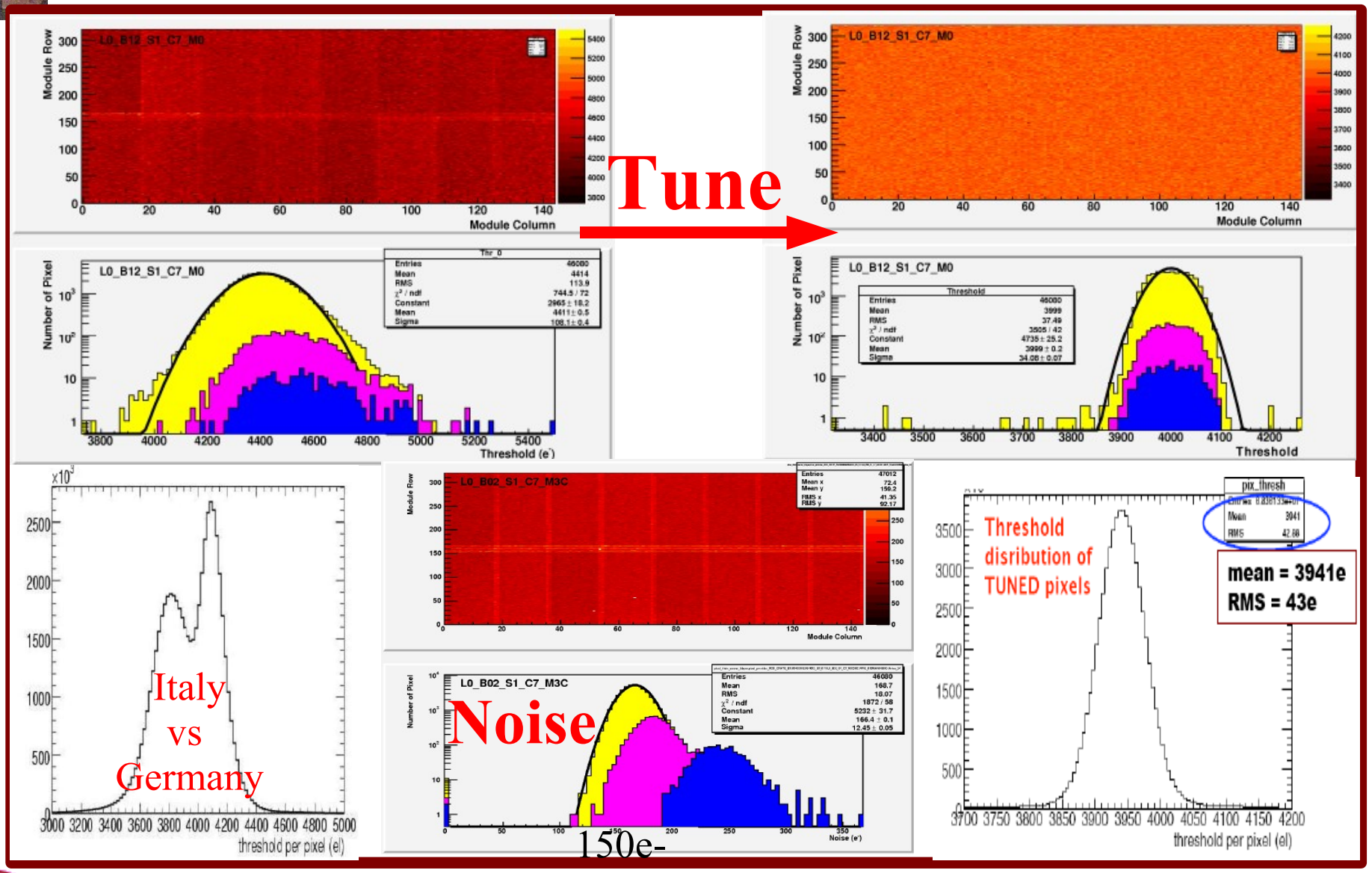
Calibration Challenges





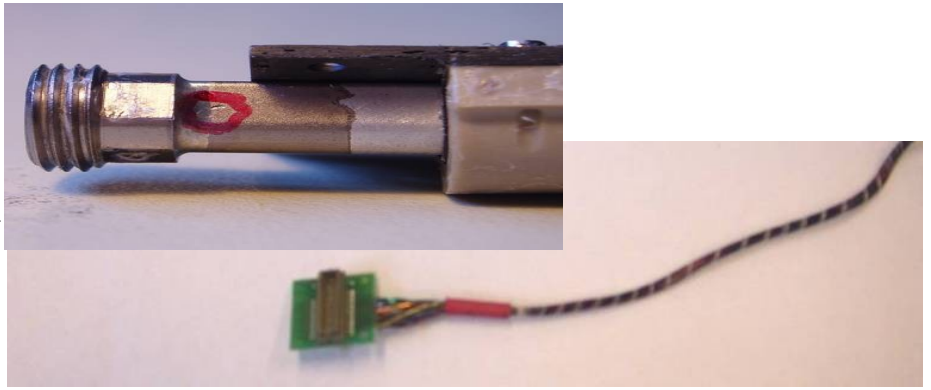
- Threshold Scan for each pixel
- fitted threshold
- fit 80 million Pixels!
- TB ! of data

Threshold & Noise



Service Challenges and Problems

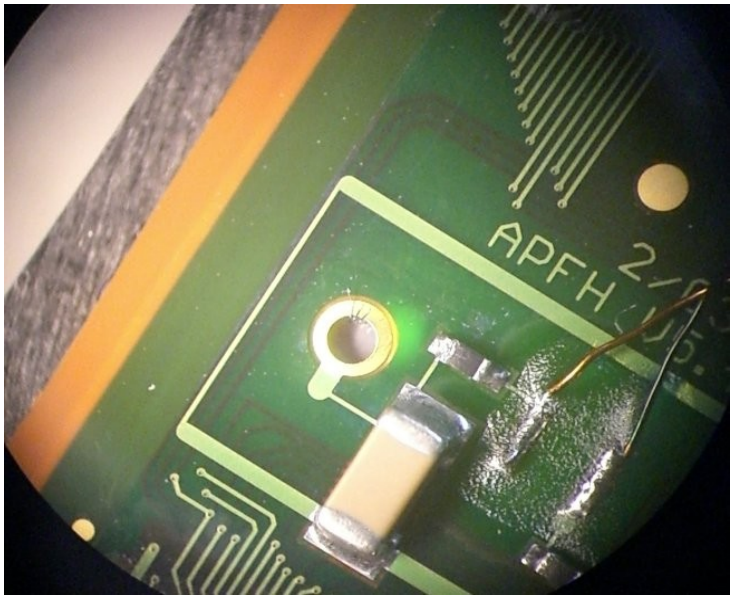
- Service Challenges:
  - power: operation at ~2V, 1A over 100m cables require additional radition hard voltage regulators close to the detector
  - 6kW of heat removed with C3F8 evaporative cooling
- Problems overcome:
  - cooling pipe corrosion
  - breaking cables



- never underestimate the “simple” parts

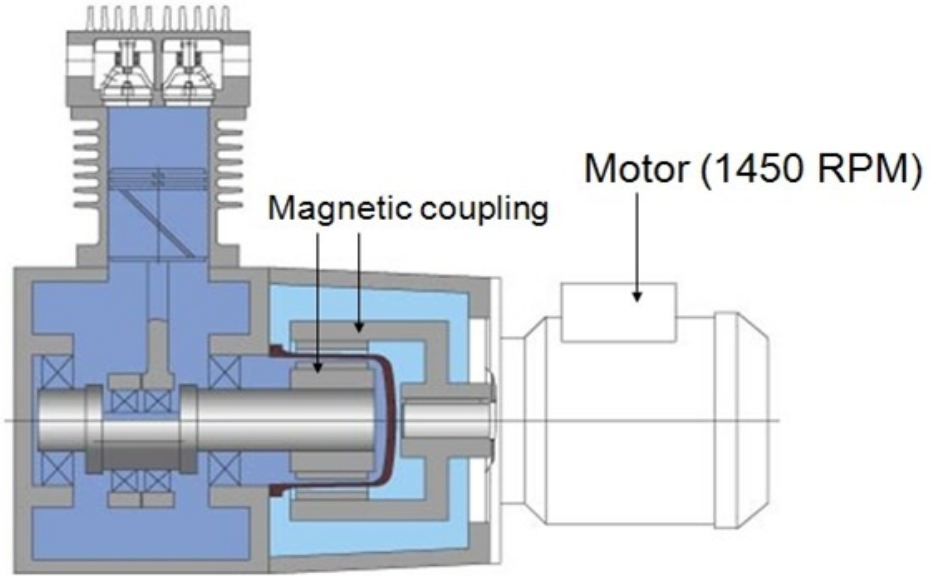
Problems: HV

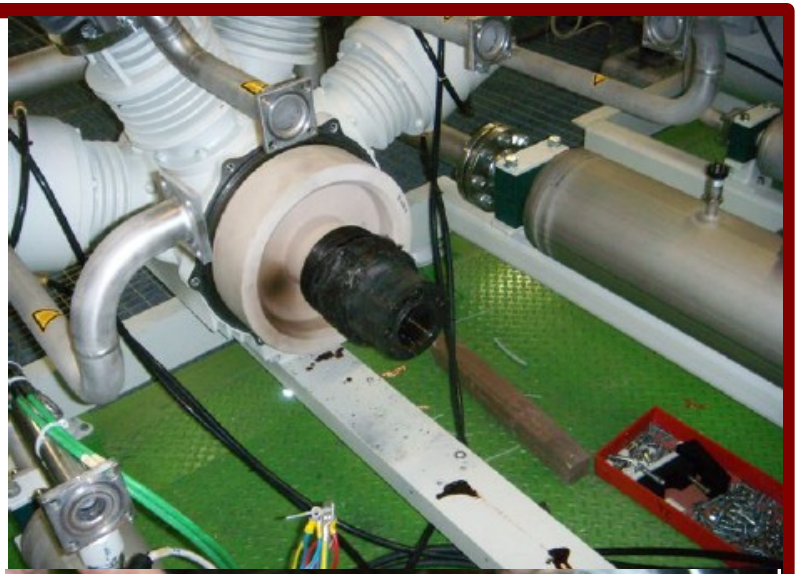
- Problems
  - HV opens are the larges source of irrecoverably lost modules (11)
  - There are three different sources
    - Broken wire bonds (likely due to flex bow)
    - Broken cables
    - Open module connectors
  - Some might have slipped through a fault in the connection test



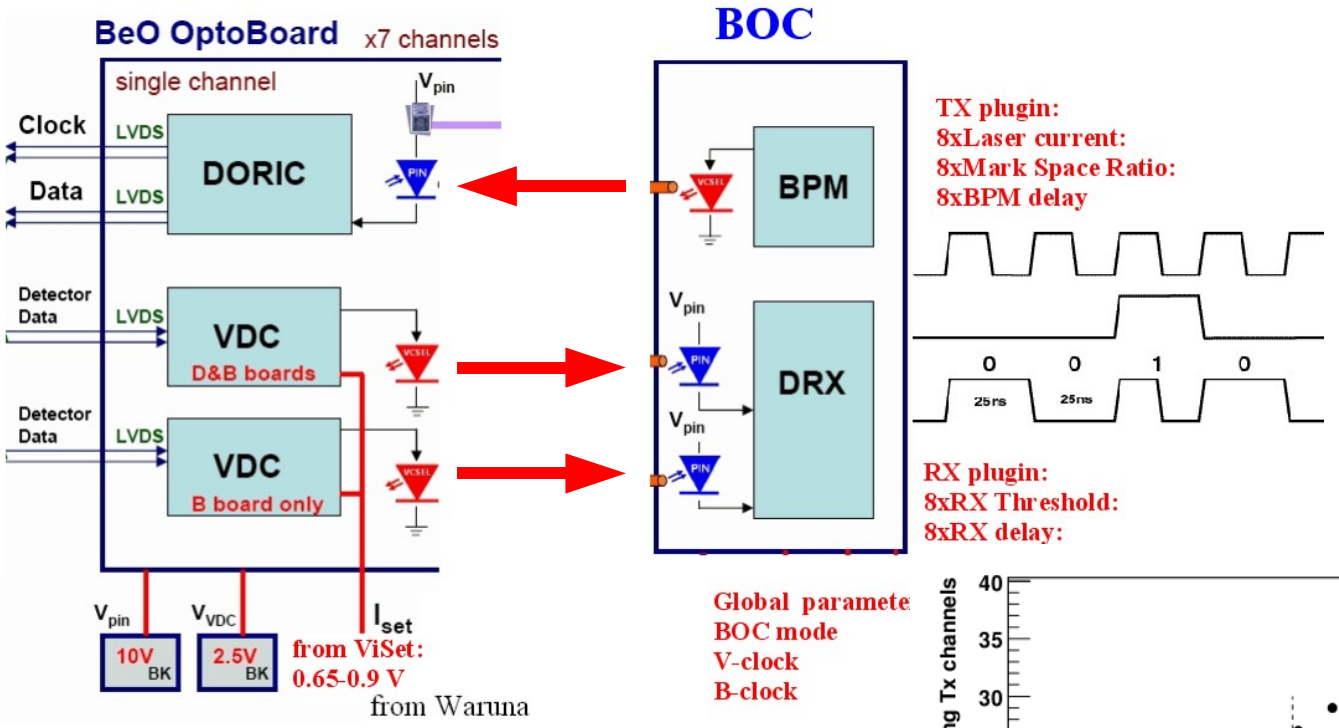
Problems: Cooling

- Incident May 1st
  - caused serious delay
  - 3 compressors damaged
  - Coupler housing cracked
  - Cooling fluid contaminated
  - Showed a lack of monitoring

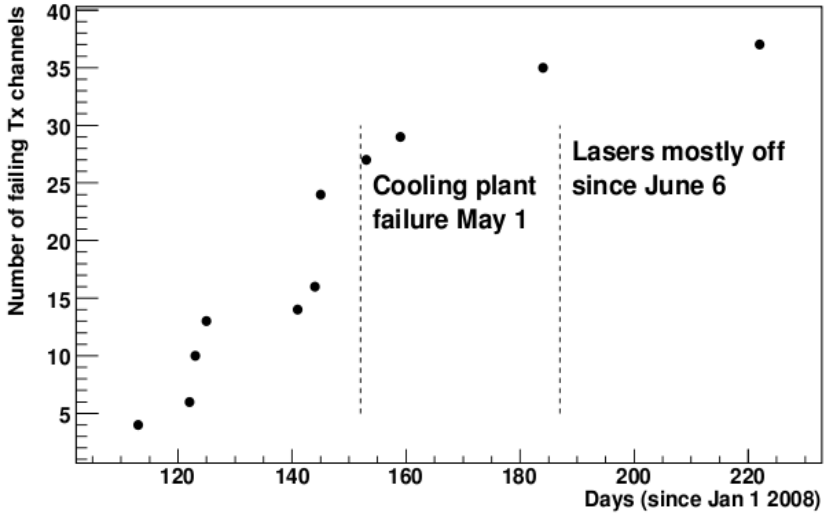




Problems: Optical Transmission

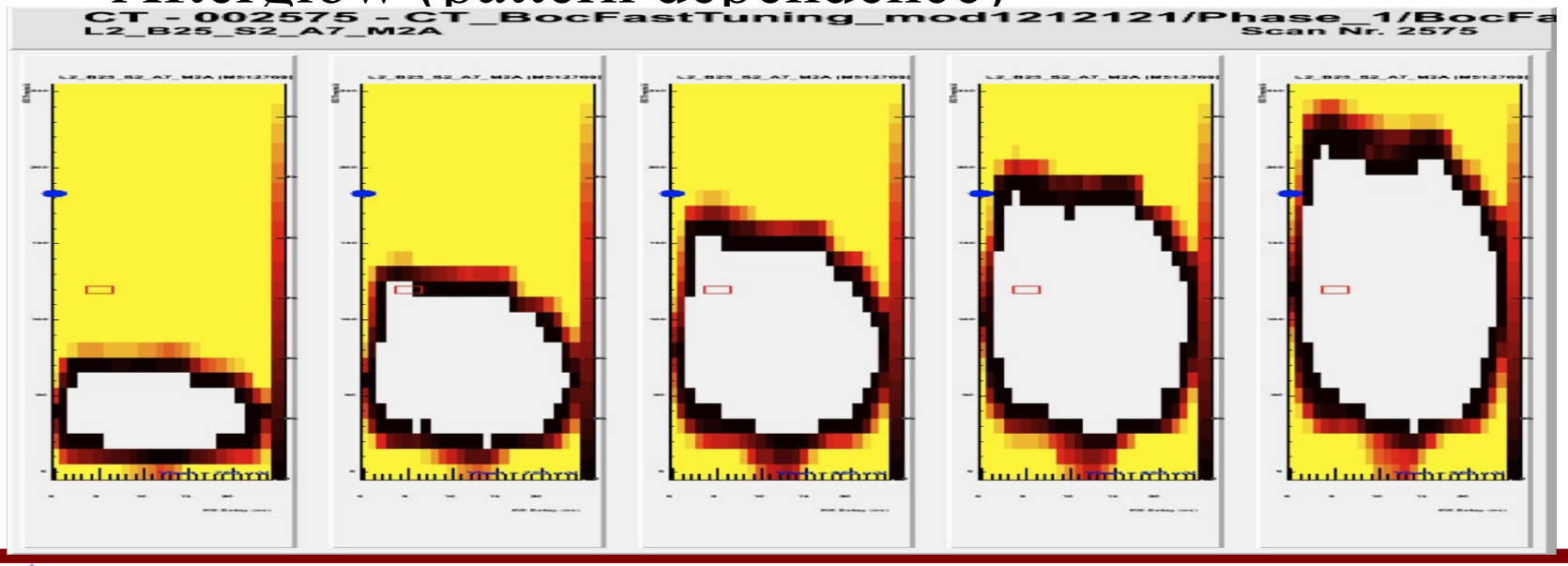


- Transmission towards modules very stable, but observe dying channels due to ESD



Problems: Optical Transmission

- Data transmission to the off detector electronics
  - Opto board operating temperature (20C, now use heaters)
  - Only one parameter for 7 channels (ViSet)
  - Slow turn on
  - Afterglow (pattern dependence)

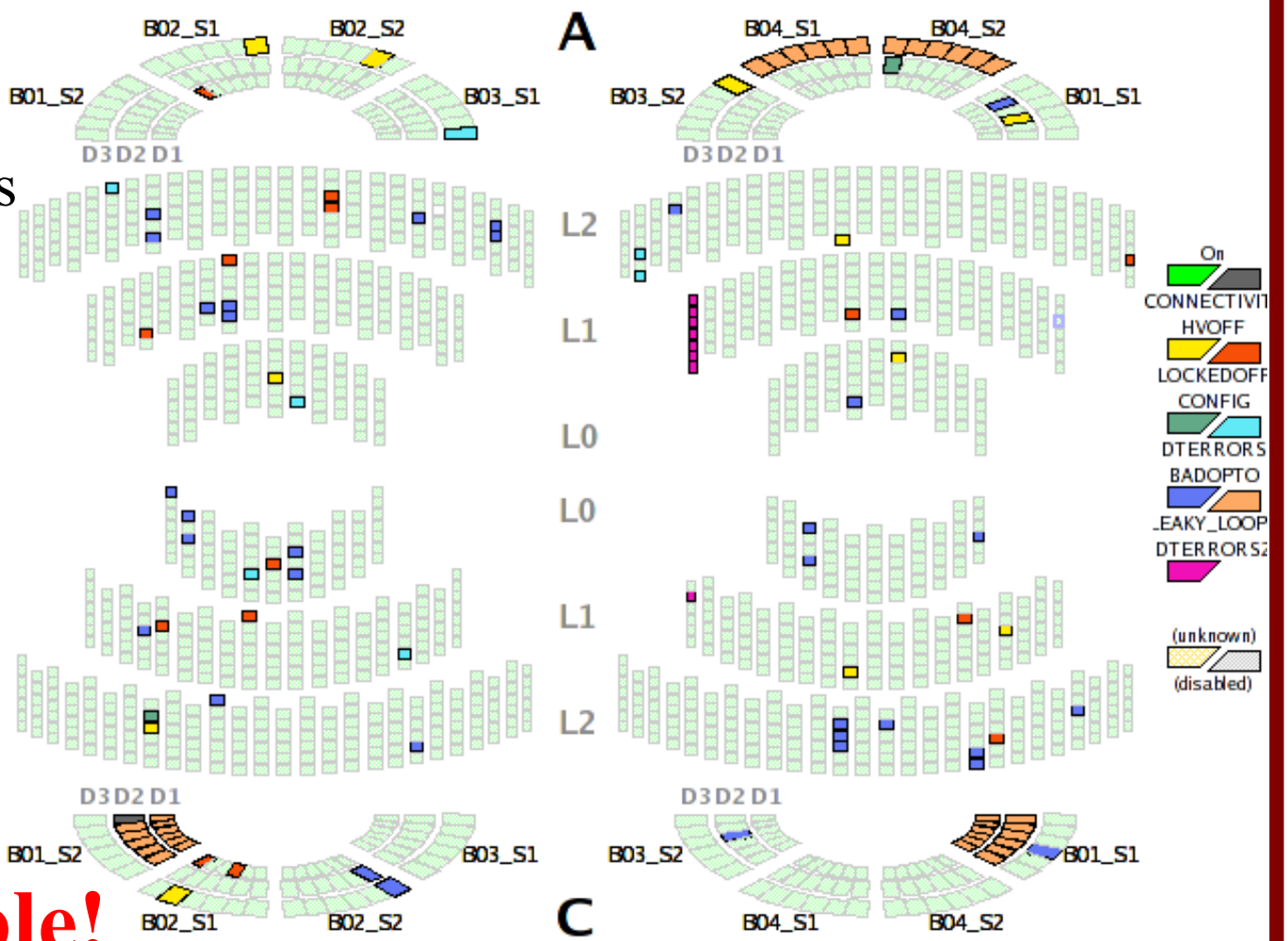


Pixel Status

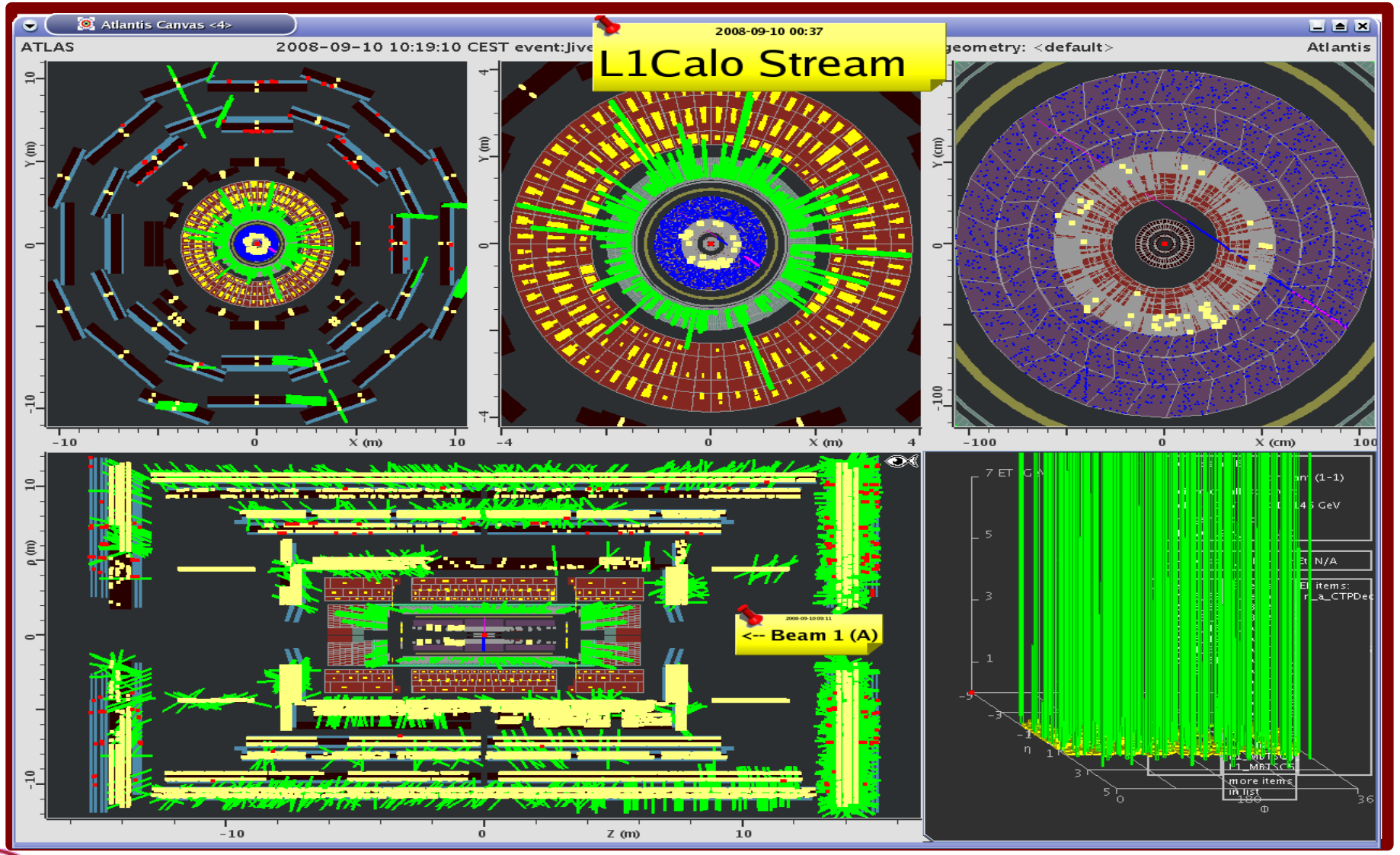
Disabled modules

Leaky Loops	36
Bad Opto	35
HV Open	11
BAD TX	2
Locked Off	14
Data Errors	15

Largely recoverable!



First Beam!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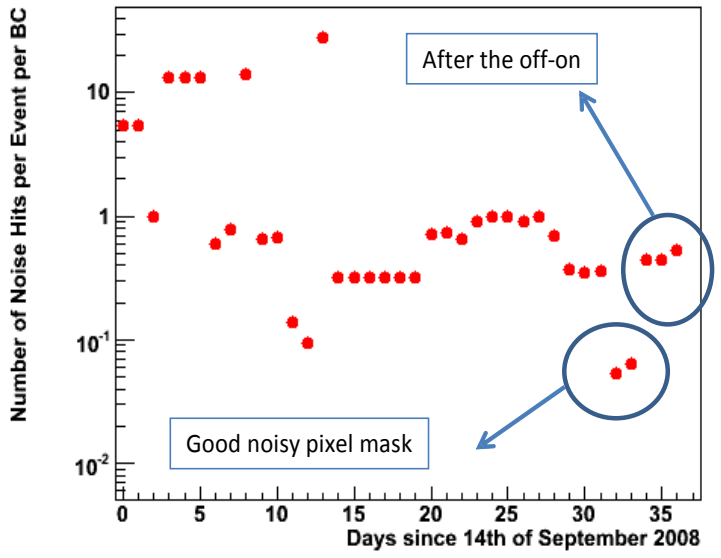
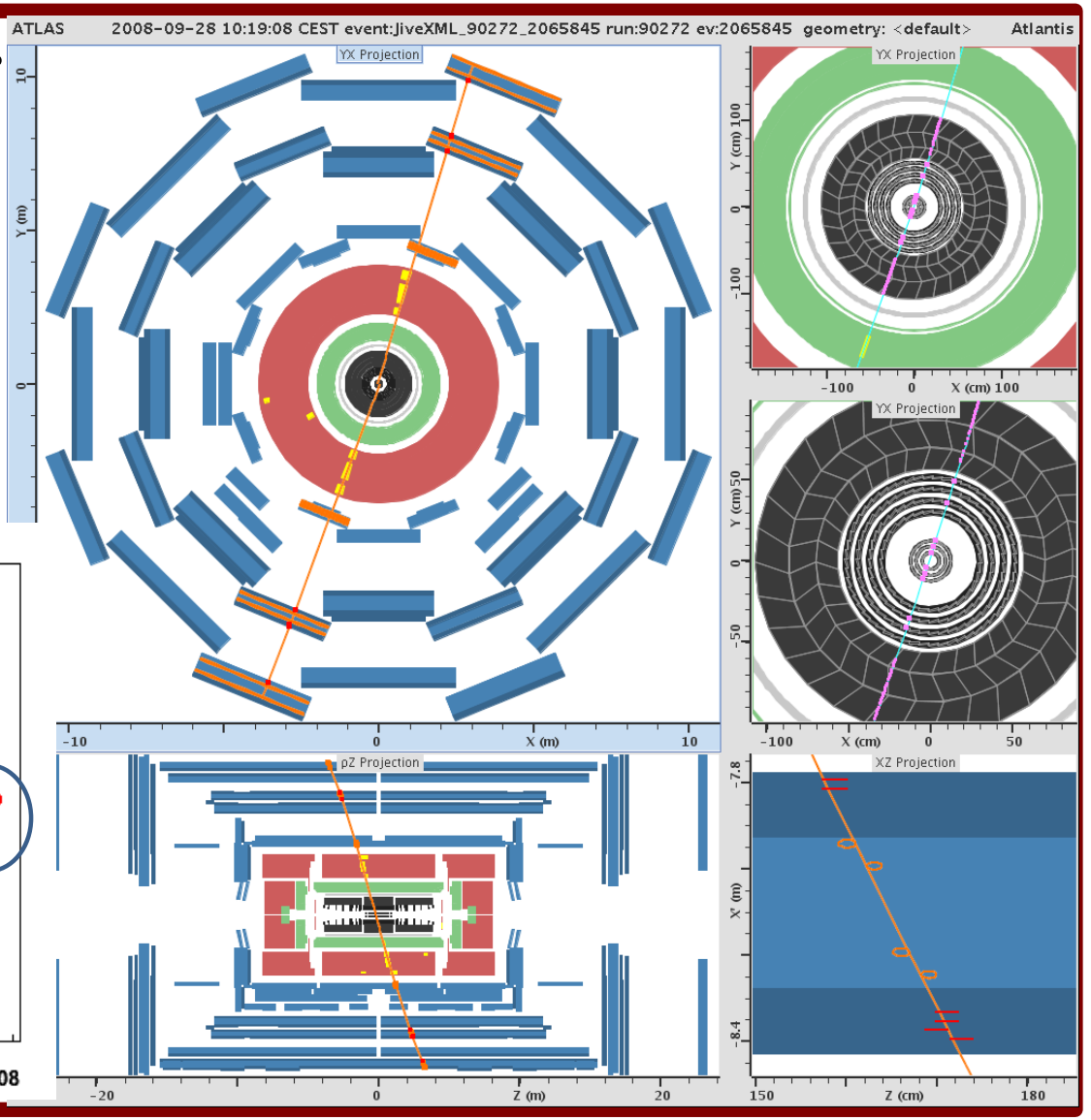
Data: Cosmics!

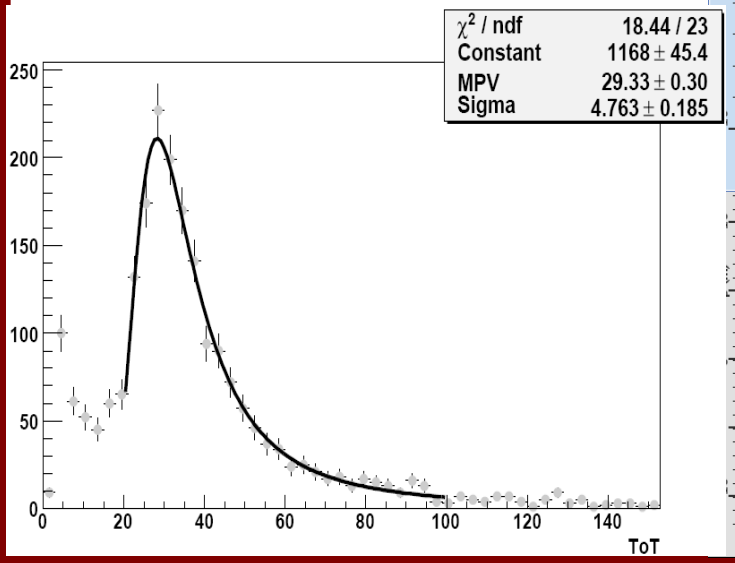
- **Cosmic rays used for**
  - Noise studies
  -
  -
  -

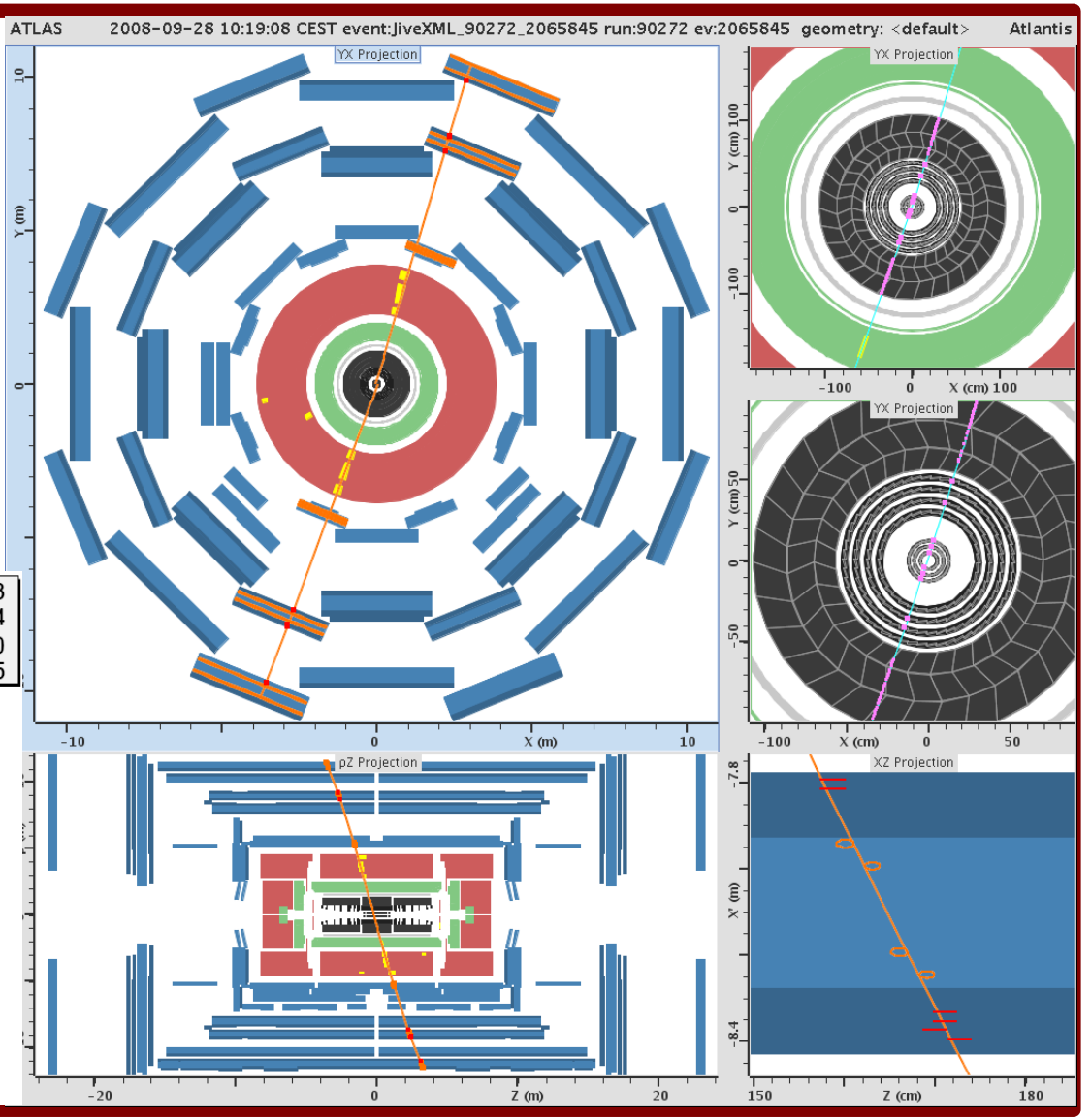




Data: Cosmics!

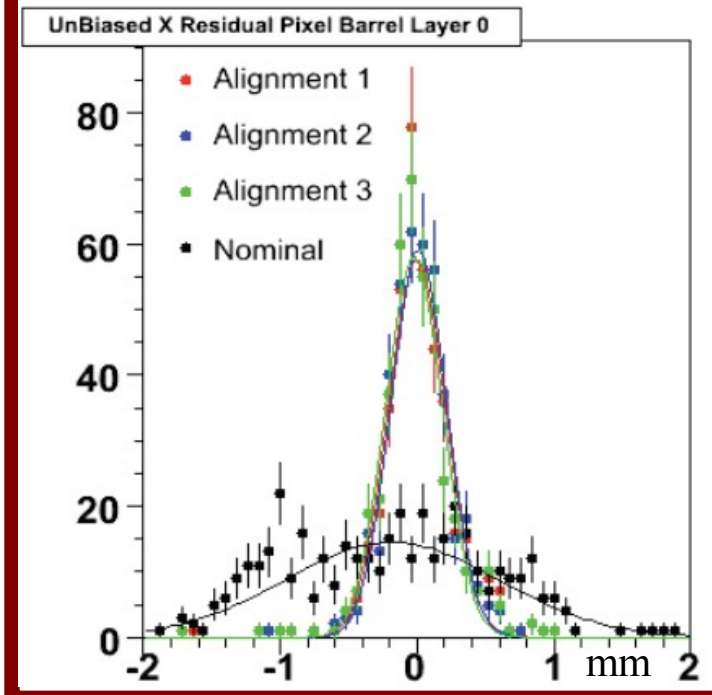
- **Cosmic rays used for**
  - Noise studies
  - Cluster studies
  -
  -

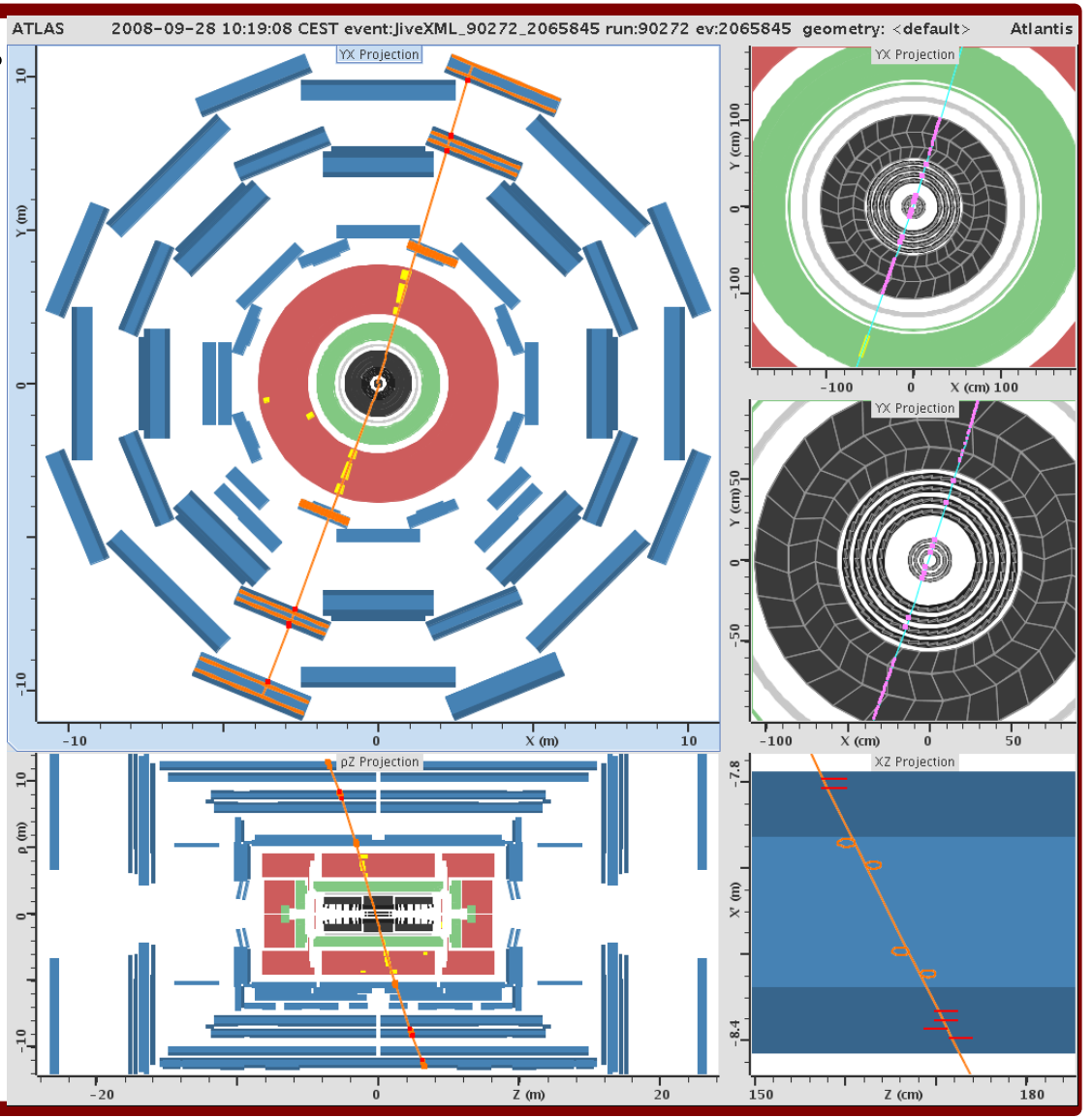




Data: Cosmics!

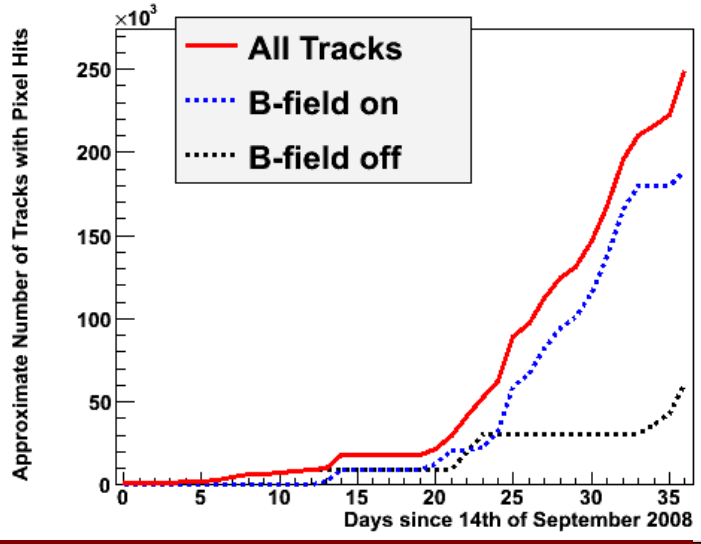
- **Cosmic rays used for**
  - Noise studies
  - Cluster studies
  - Alignment

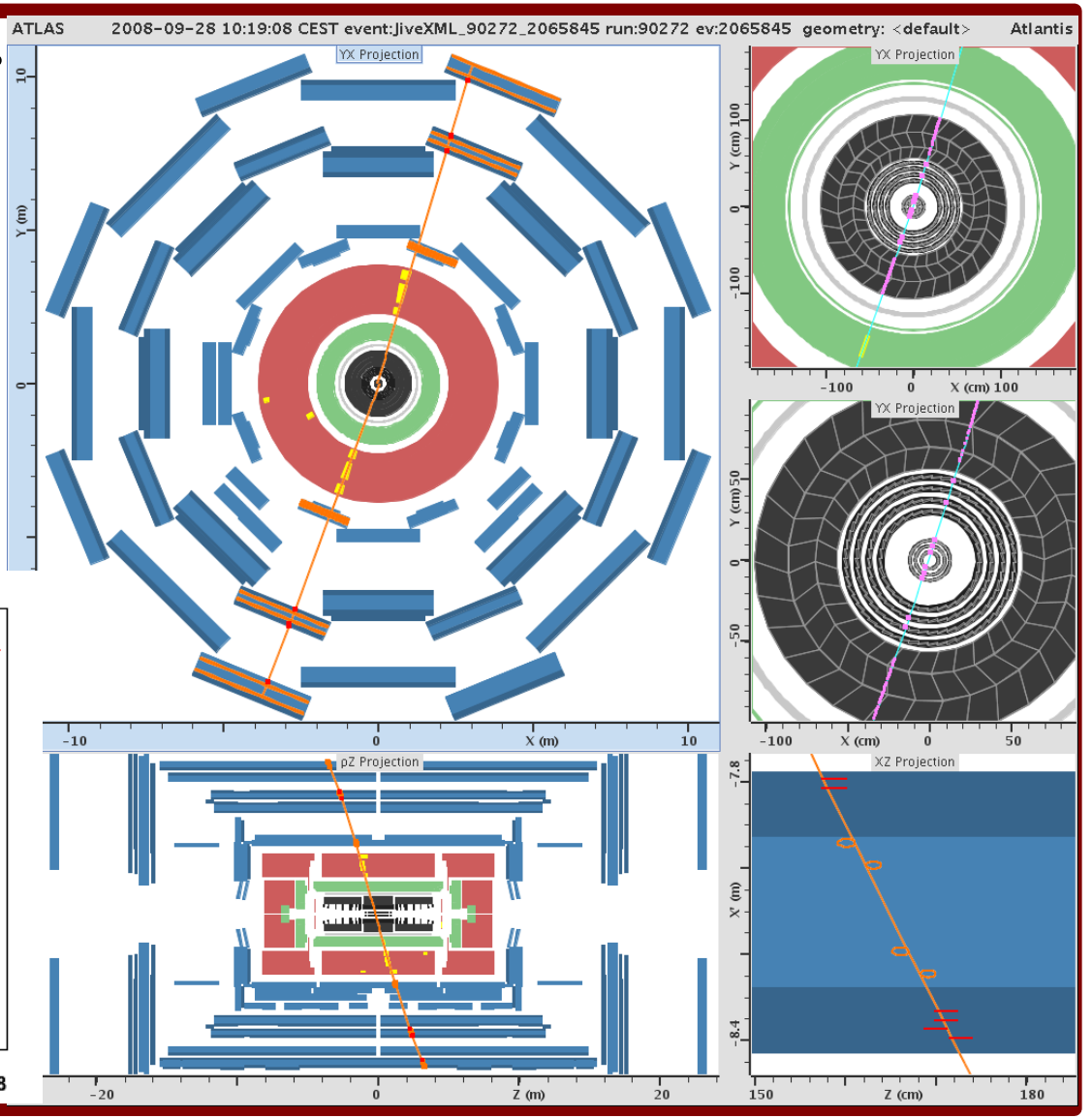




Data: Cosmics!

- **Cosmic rays used for**
  - Noise studies
  - Cluster studies
  - Alignment
  - Physics?

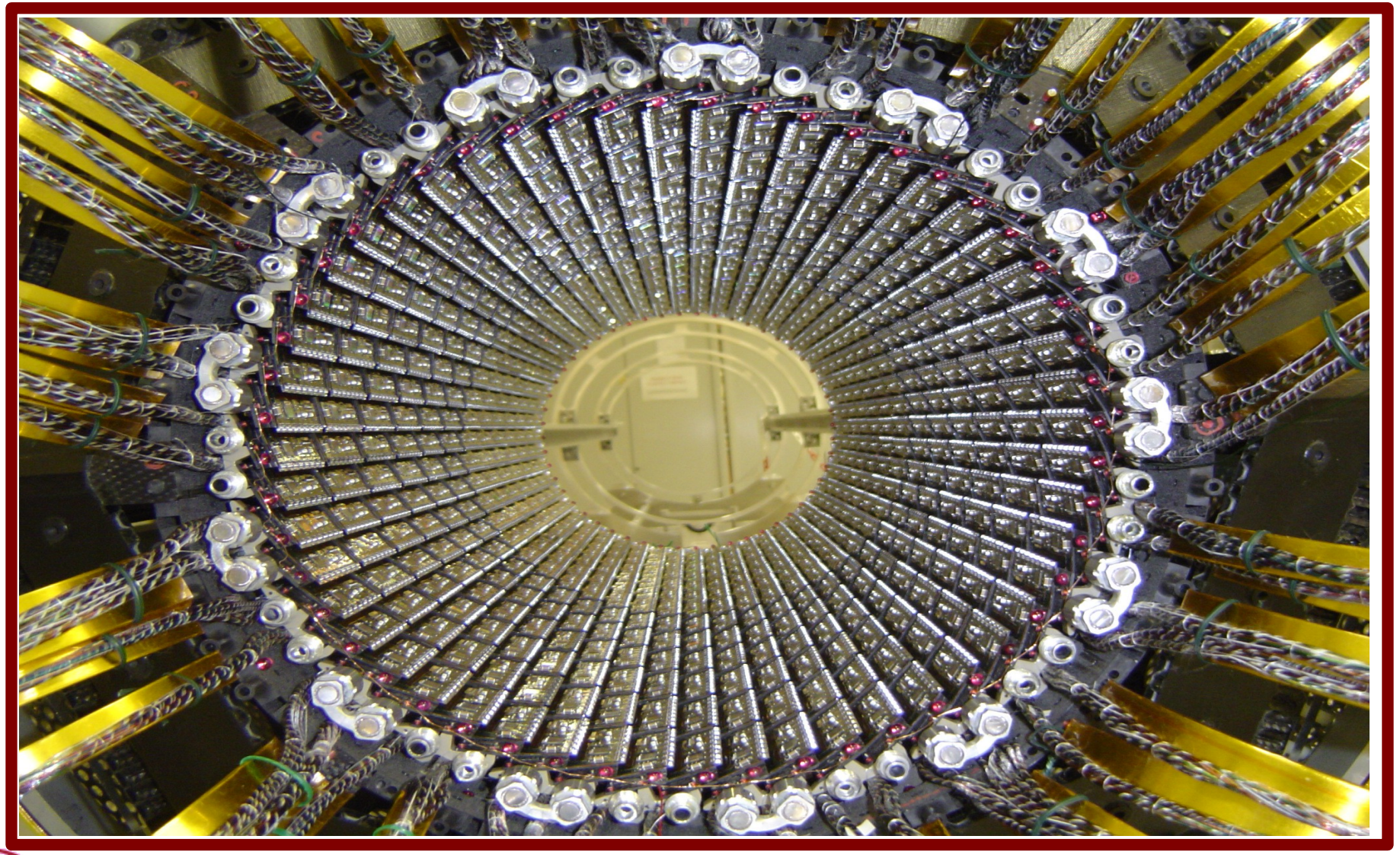




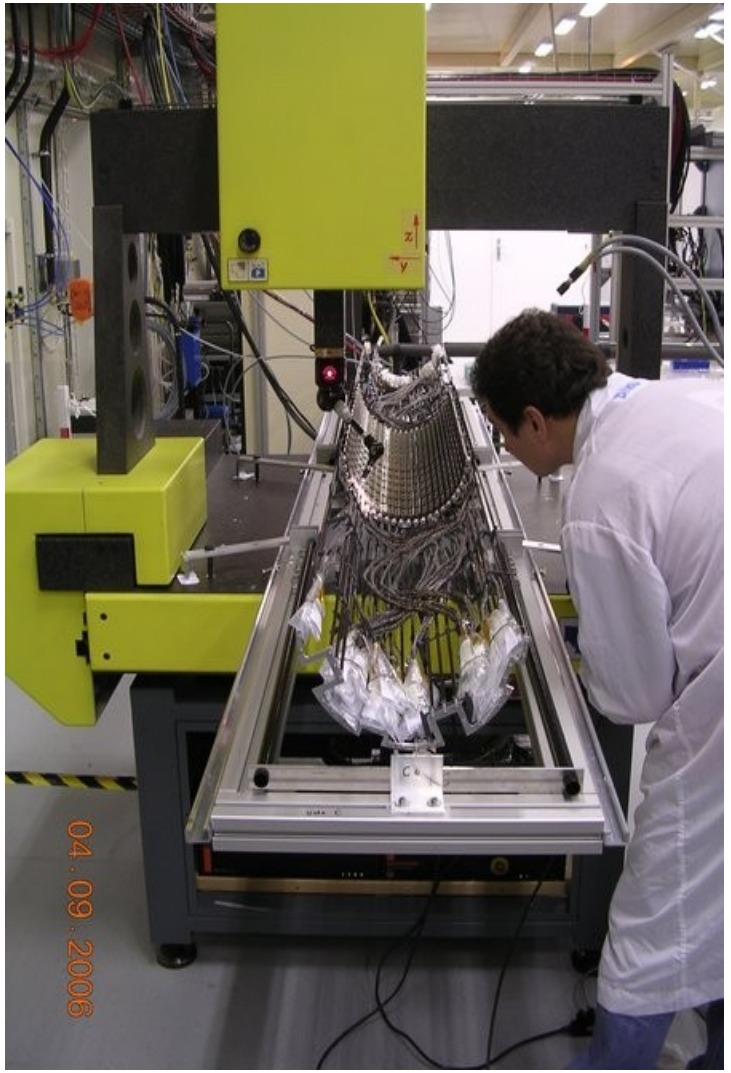
Summary

- Full Pixel Detector construction completed
- installed in the Inner Detector since 27th June 07
- Complex system, many challenges overcome
- Operation & Commissioning with Cosmic Rays ongoing
- Waiting for stable LHC beams and full collisions in ATLAS!!

Pixel Outlook

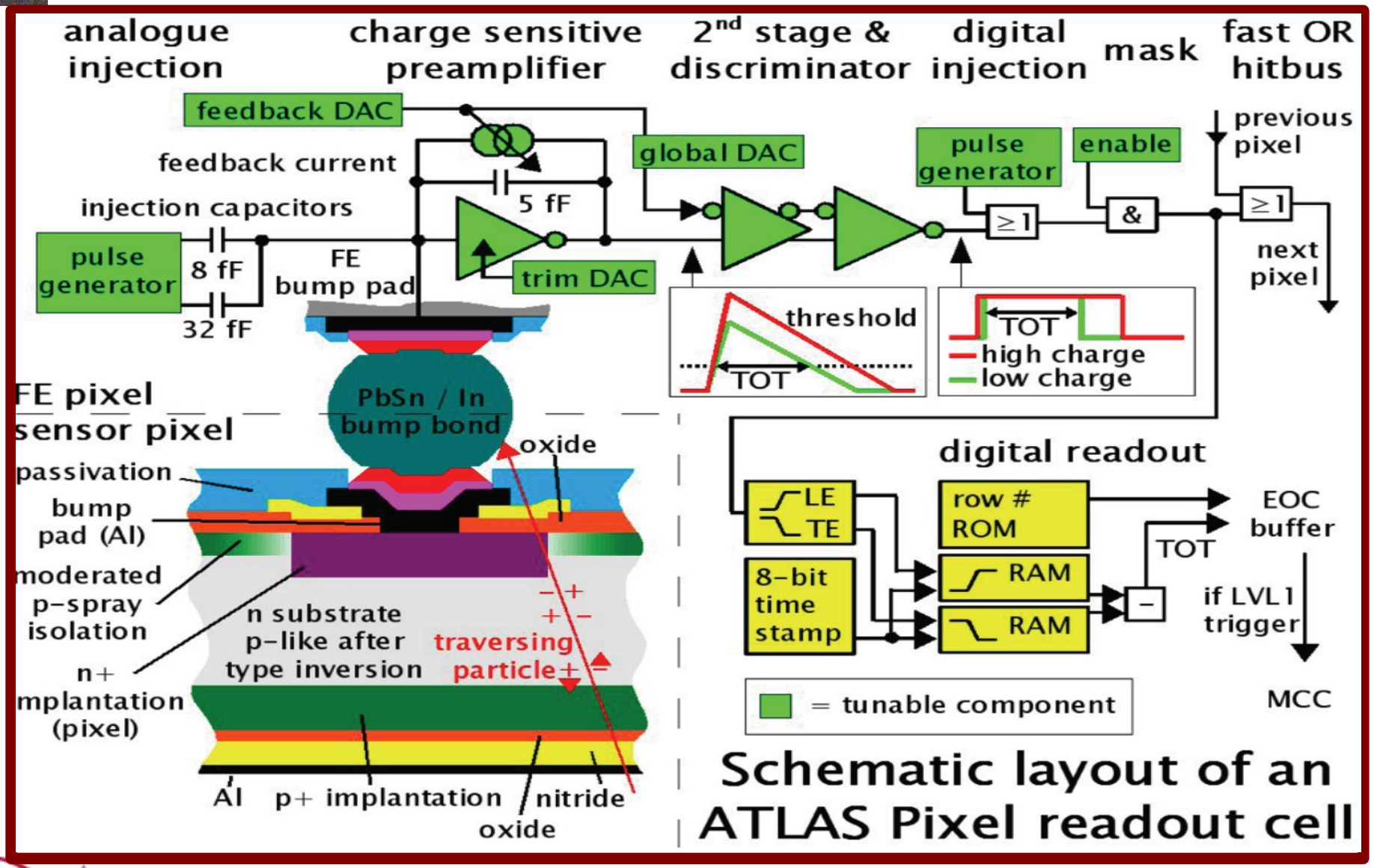


Metrologie

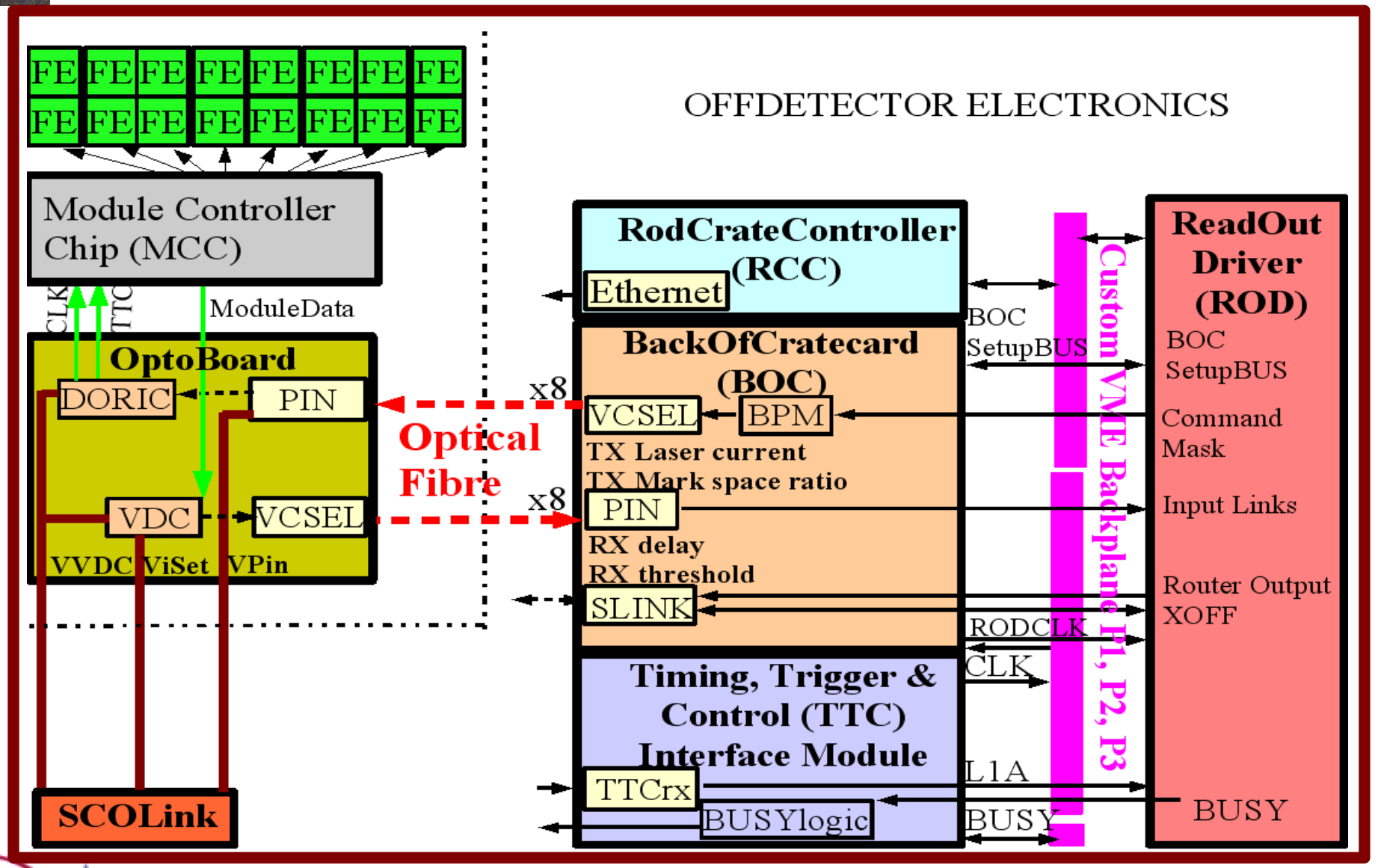


- careful survey of all components
- survey dots on sectors
- measurements on each module to record distortions (bow, twist)
- ruby ball targets on each stave
- survey of half-shells
- detailed material recording
- used as input for “as build” detector description and alignment constraint

PixReadOut


analogue injection
charge sensitive preamplifier
2nd stage & discriminator
digital injection
mask
fast OR hitbus
feedback DAC
feedback current
injection capacitors
5 fF
global DAC
pulse generator
enable
previous pixel
pulse generator
8 fF
32 fF
FE bump pad
trim DAC
≥1
&
≥1
next pixel
threshold
TOT
TOT
high charge
low charge
FE pixel sensor pixel
PbSn / In bump bond
oxide
passivation
bump pad (Al)
moderated p-spray isolation
n+ implantation (pixel)
n substrate p-like after type inversion
traversing particle
digital readout
LE
TE
row # ROM
EOC buffer
TOT
8-bit time stamp
RAM
RAM
if LVL1 trigger
= tunable component
MCC
Al
p+ implantation
nitride
oxide
Schematic layout of an ATLAS Pixel readout cell

PixReadOut

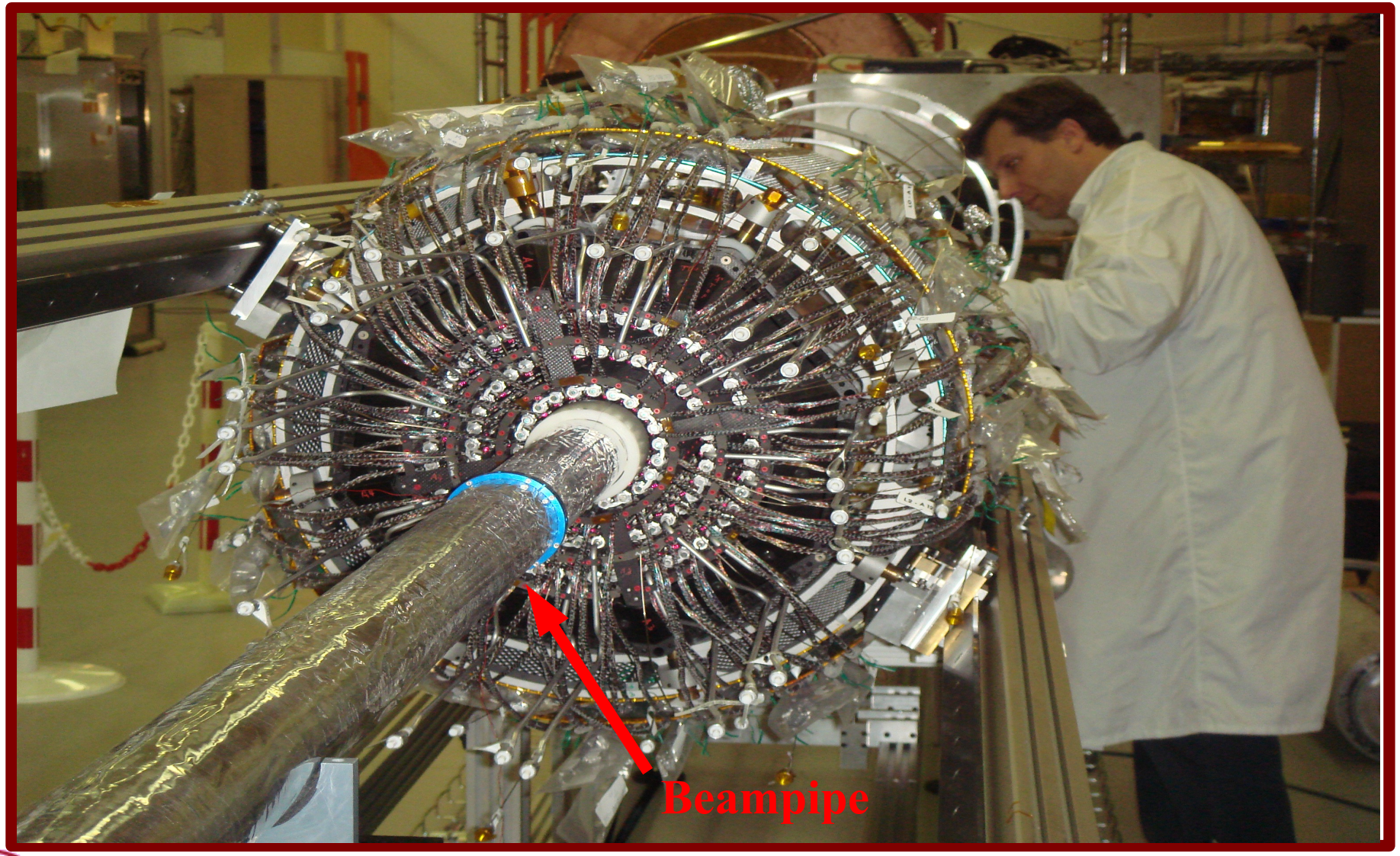

FE FE FE FE FE FE FE FE
FE FE FE FE FE FE FE FE
Module Controller Chip (MCC)
CLK
TTC
ModuleData
OptoBoard
DORIC
PIN
VDC
VCSEL
VVDC ViSet VPin
SCOLink
x8
Optical Fibre
x8
OFFDETECTOR ELECTRONICS
RodCrateController (RCC)
Ethernet
BackOfCratecard (BOC)
VCSEL
BPM
TX Laser current
TX Mark space ratio
PIN
RX delay
RX threshold
SLINK
Timing, Trigger & Control (TTC) Interface Module
TTCrx
BUSYlogic
BOC SetupBUS
RODCLK
CLK
L1A
BUSY
Custom VME Backplane P1, P2, P3
ReadOut Driver (ROD)
BOC SetupBUS
Command Mask
Input Links
Router Output XOFF
BUSY

DAQ Crates

Cosmic Test

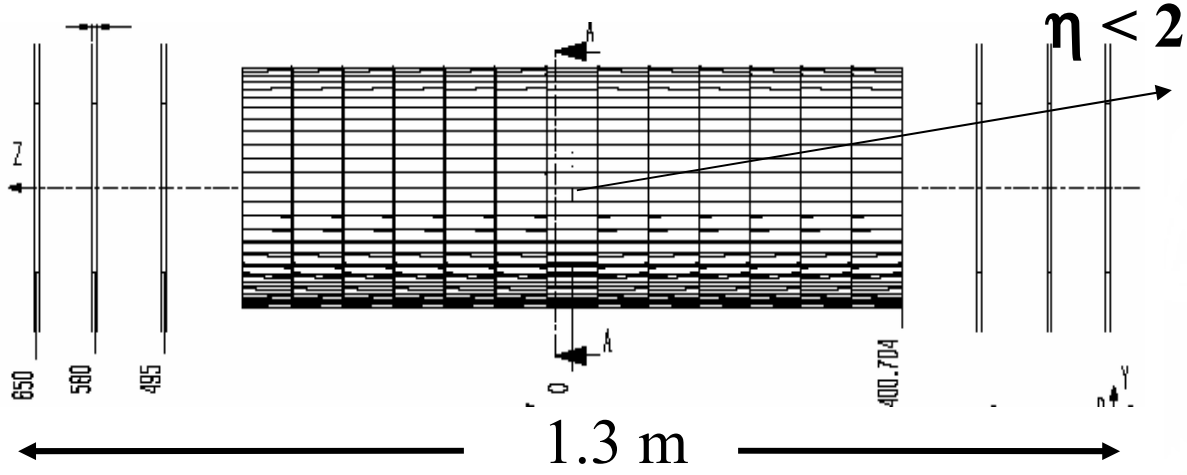
- large scale (10%) system test
- emphasis on service and DAQ test
- uses final service and cooling setup, including Service Quarter Panel
- EndCap A (144 Modules)
- EndCap 90 degrees rotated for better coverage
- scintillator system as trigger
- verified efficiency (> 99%) and noise level (< 10^{-6})

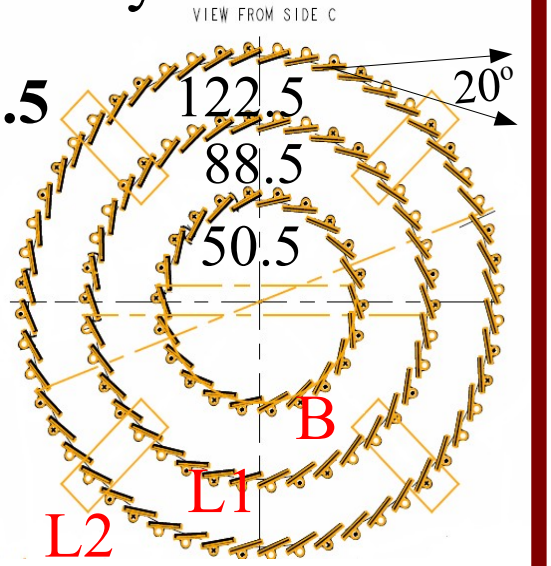
Finished Barrel



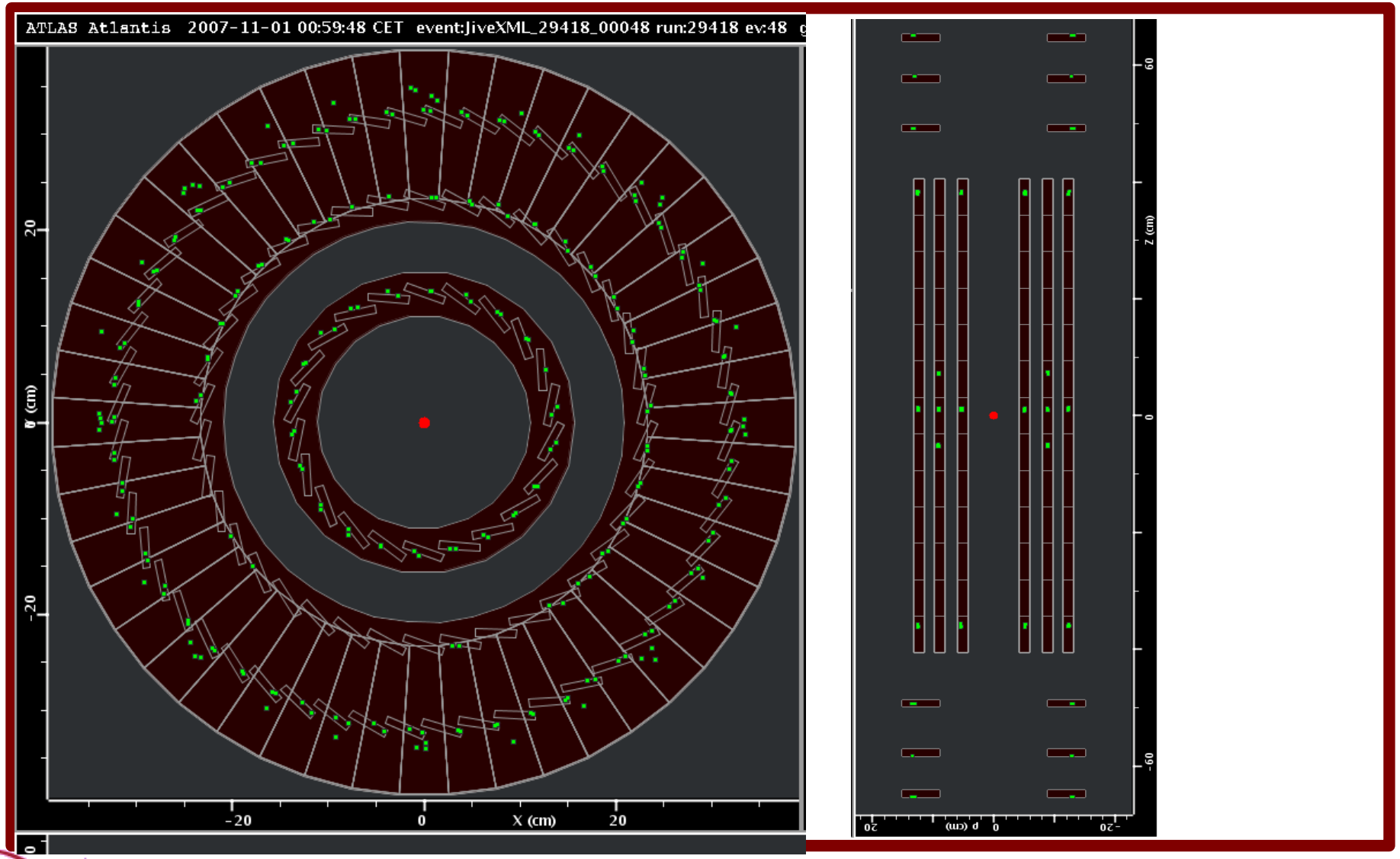
Pixel Overview

- 3 Barrels, 2x3 disks
- Total of 1744 Modules, organized in Staves and Sectors
- 46080 channels per Module, total ~80 million channels
- minimize confusion in pattern recognition
(Occupancy 10^{-4}, Noise $<10^{-6}$)
- good impact parameter resolution due to B-Layer at 5 cm





Pixel Hit Map



ATLAS Trigger/DAQ Overview