Status of the ATLAS Pixel Detector at the LHC and its performance after three years of operation.

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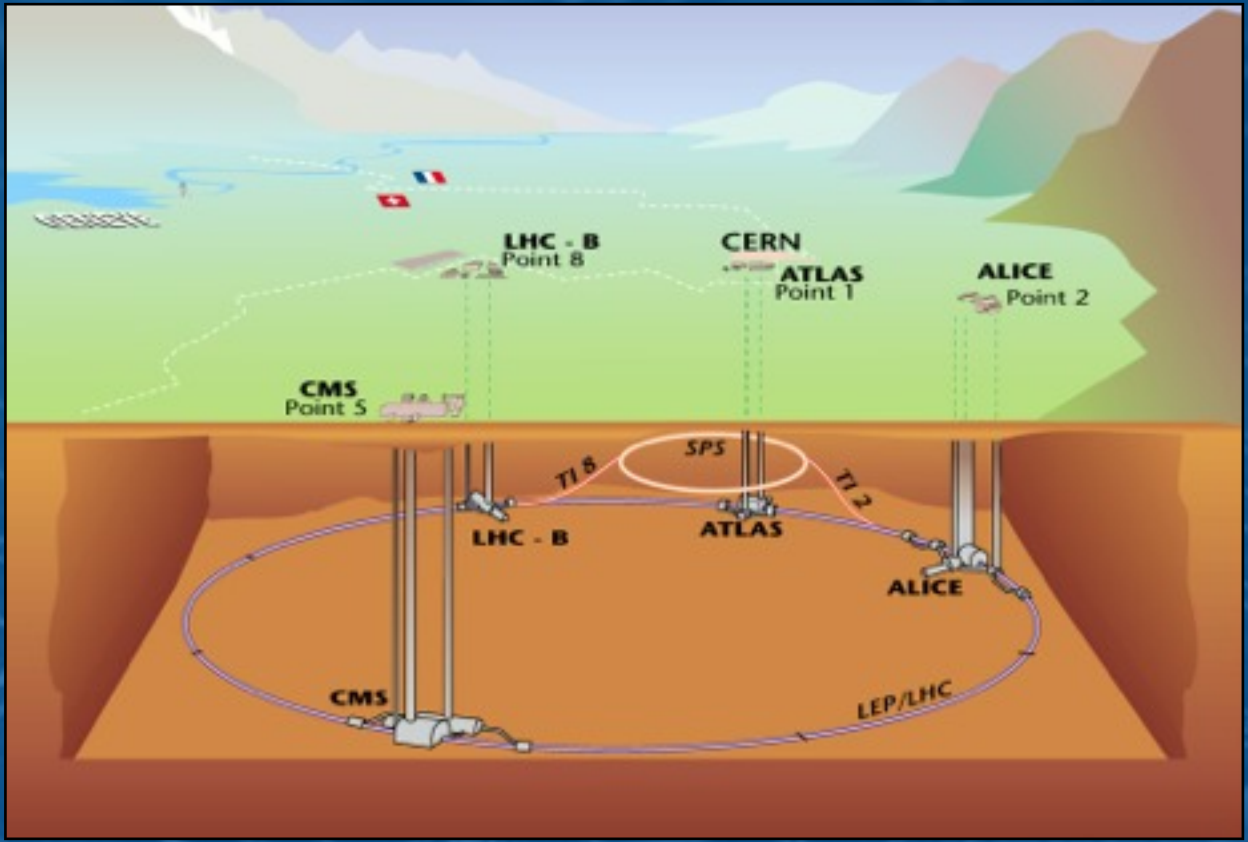
Outline

- Introduction
  - The Large Hadron Collider
  - The ATLAS Detector
  - Timeline
- The ATLAS Pixel Detector
- Performance over 3 years of operation
  - Calibration
  - Data Quality
  - Tracking
  - Radiation Damage
- Upgrade and repairs in the Long Shutdown 1

The LHC at CERN

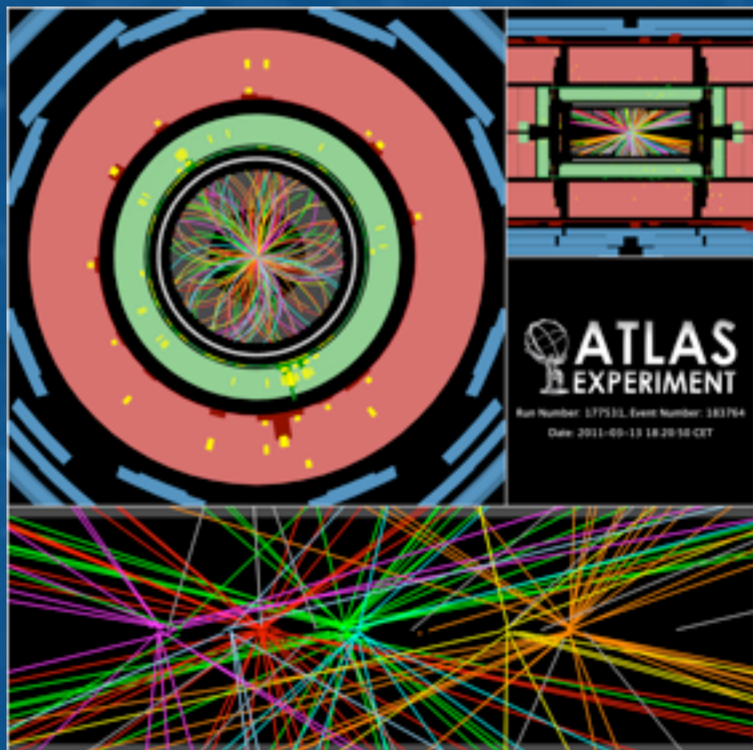
- pp - collider
- 27km circumference
- 1232 superconducting dipoles
- Design parameters:
    - $\sqrt{s}$ = 14 TeV
    - $10^{34} \frac{1}{\mathrm{cm}^2\mathrm{s}}$ luminosity
    - 2808 proton bunches per beam
    - 25ns bunch spacing

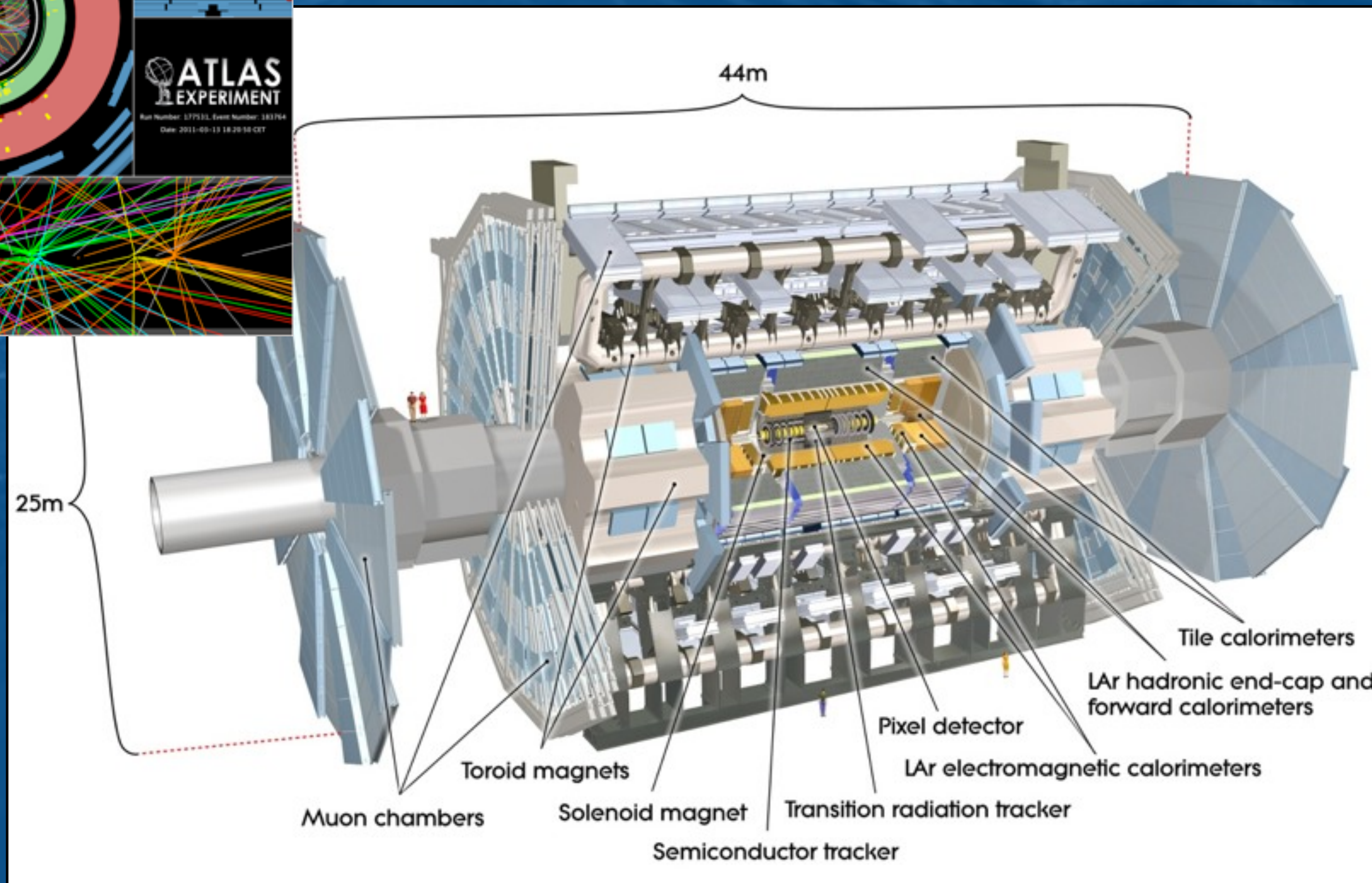


2012 run parameters:

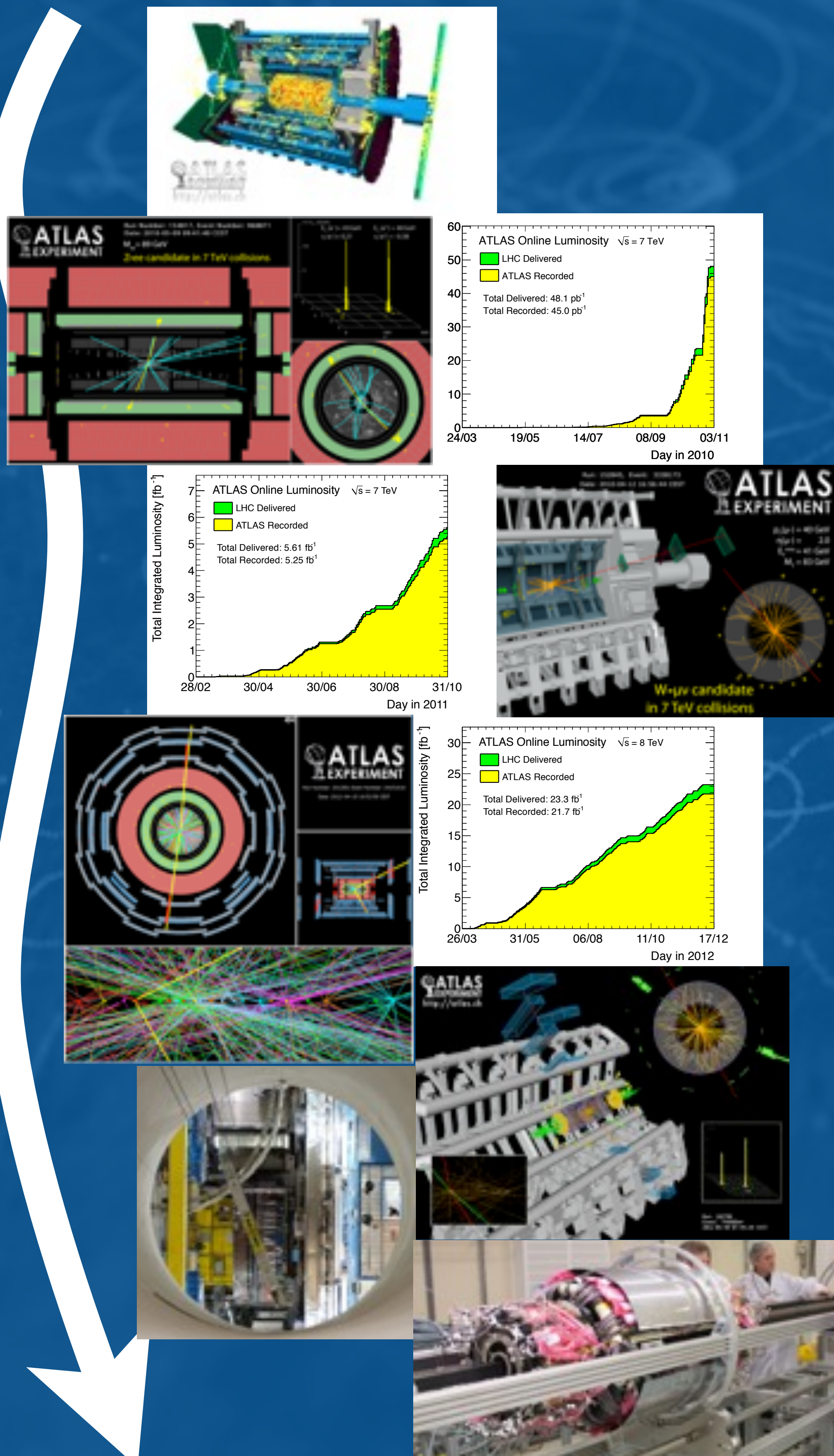
- $\sqrt{s}$ = 8 TeV
- 7.73 $10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ peak luminosity
- 1374 bunches per beam (50ns spacing)
- 23.3 fb^{-1} total delivered luminosity

The ATLAS Detector



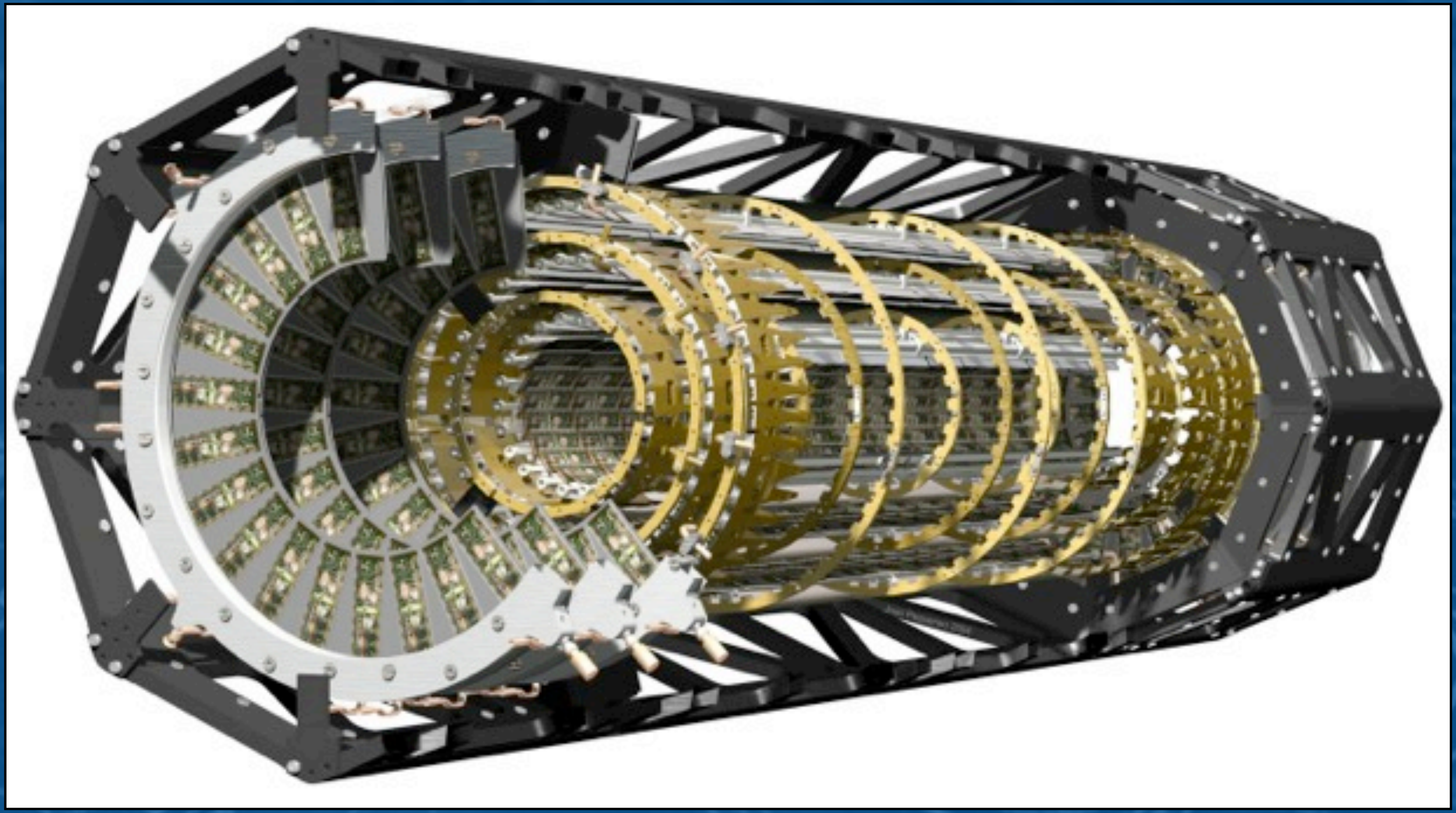


Timeline



- 2009 Nov: First 450 GeV beams
- 2010 Mar: 7 TeV collisions
- 2010: 45 pb^{-1} recorded
- 2011 May: Peak luminosity of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- 2011: 5.25 fb^{-1} recorded
- 2012 Mar: 8 TeV collisions
- 2012 Dec: 25ns bunch spacing physics runs
- 2012: 21.7 fb^{-1} recorded
- 2013 Feb: Start of Long Shutdown 1
- 2013 April: Pixel detector on surface

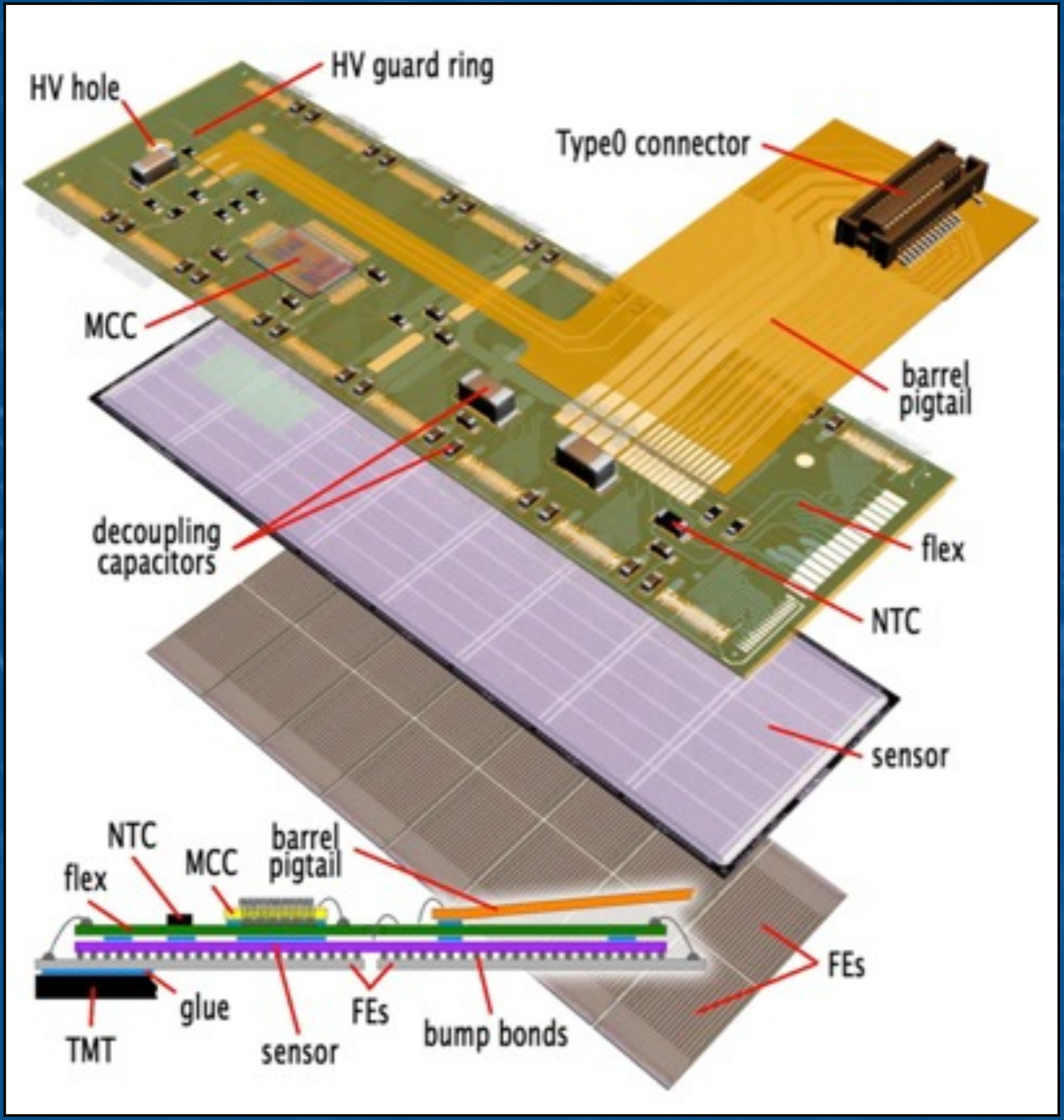
The ATLAS Pixel Detector



- 3 barrel & 3 disk layer covering $|\eta| < 2.5$
- 46080 pixels per Pixel Module
- 1744 Pixel Modules with a total of 80M readout channels

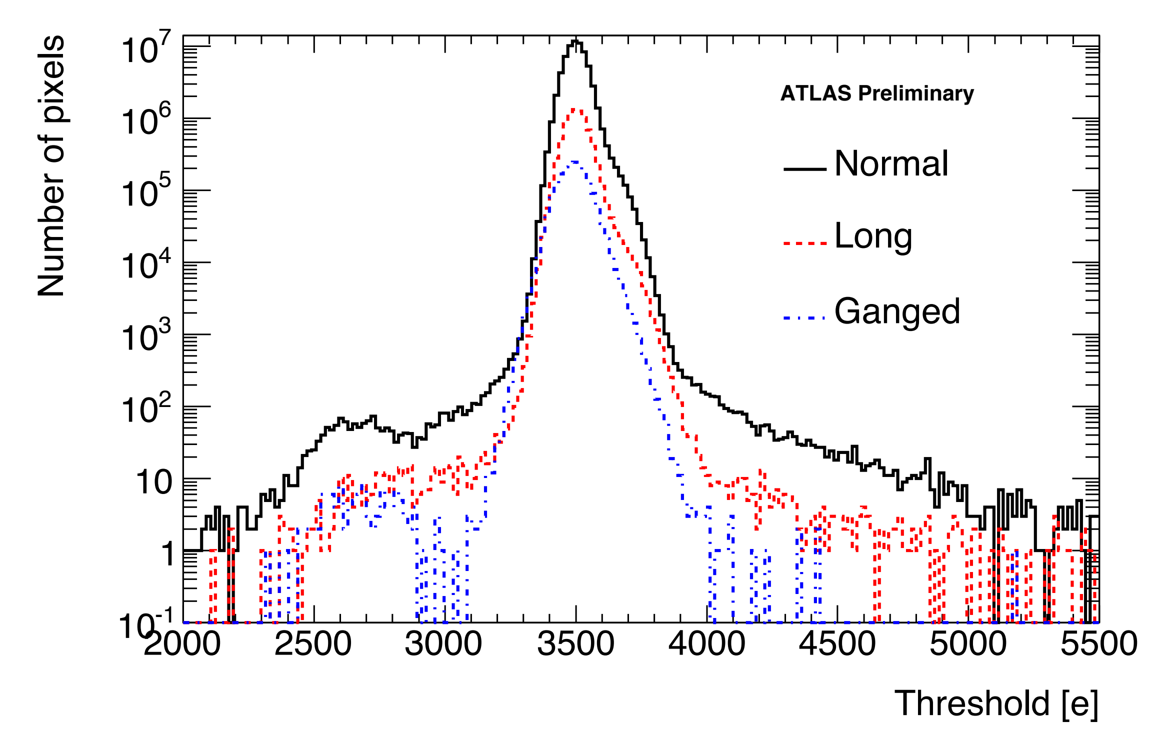
The ATLAS Pixel Module

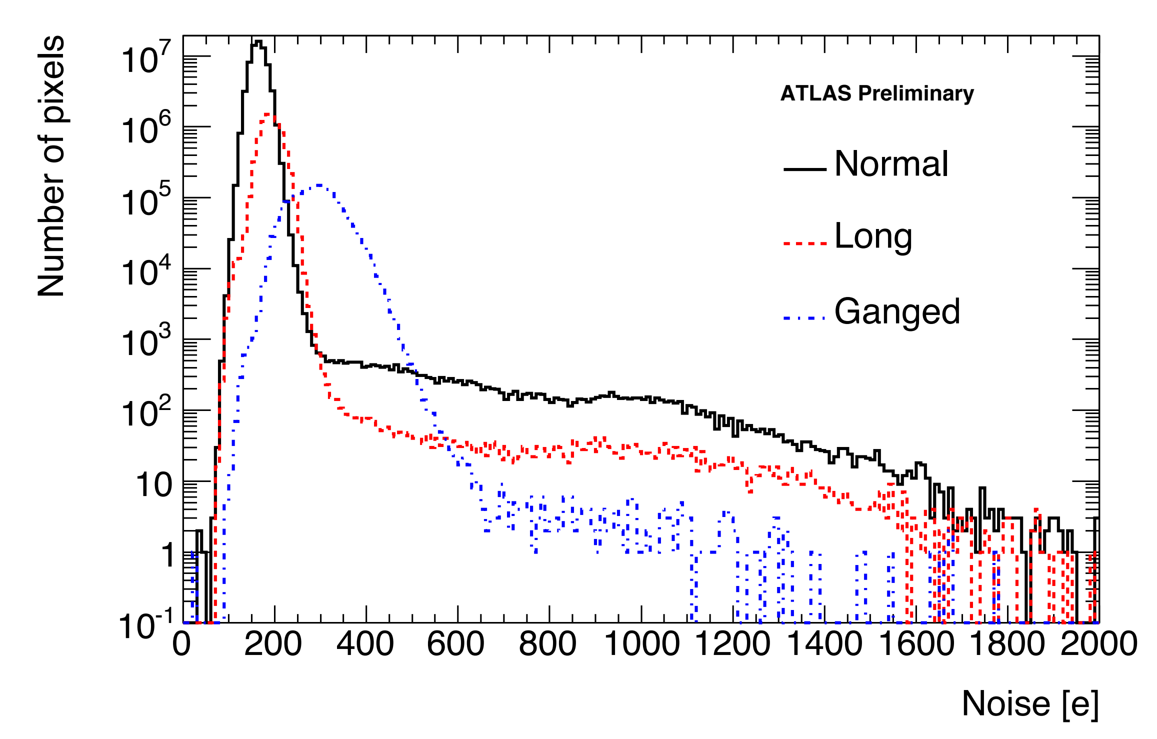
- 250µm thick, n-in-n, Si planar pixel sensor technology with 50x400 µm pixel size (slightly bigger pixels in FE interconnection regions and edges)
- Radiation tolerance of 50MRad/ 500kGy/10^{15} $1\mathrm{MeV}\ \mathrm{N_{eq}cm^{-2}}$
- Resolution of 15 and 115µm, in Rϕ and z respectively
- Pixel Module consists of 1 sensor bump bonded to 16 Front-End chips (FE-I3)



Pixel Calibration

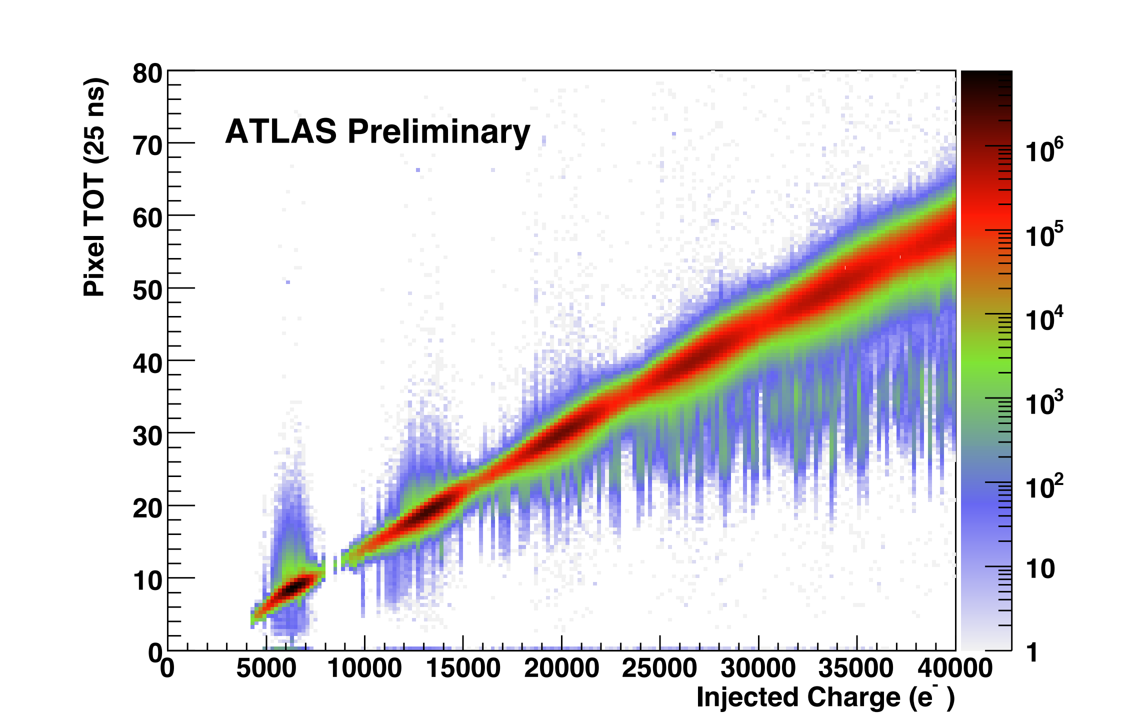
- Threshold used to distinguish between noise and signal
- Tuned to 3500e
- Threshold noise in the order of less than 200e (~300e for larger pixels)
- Comfortable signal/noise ratio of around 20
- Noise occupancy O(10^{-9}) hits/pixel/bc, while the physics occupancy is O(10^{-4}) hits/pixel/bc

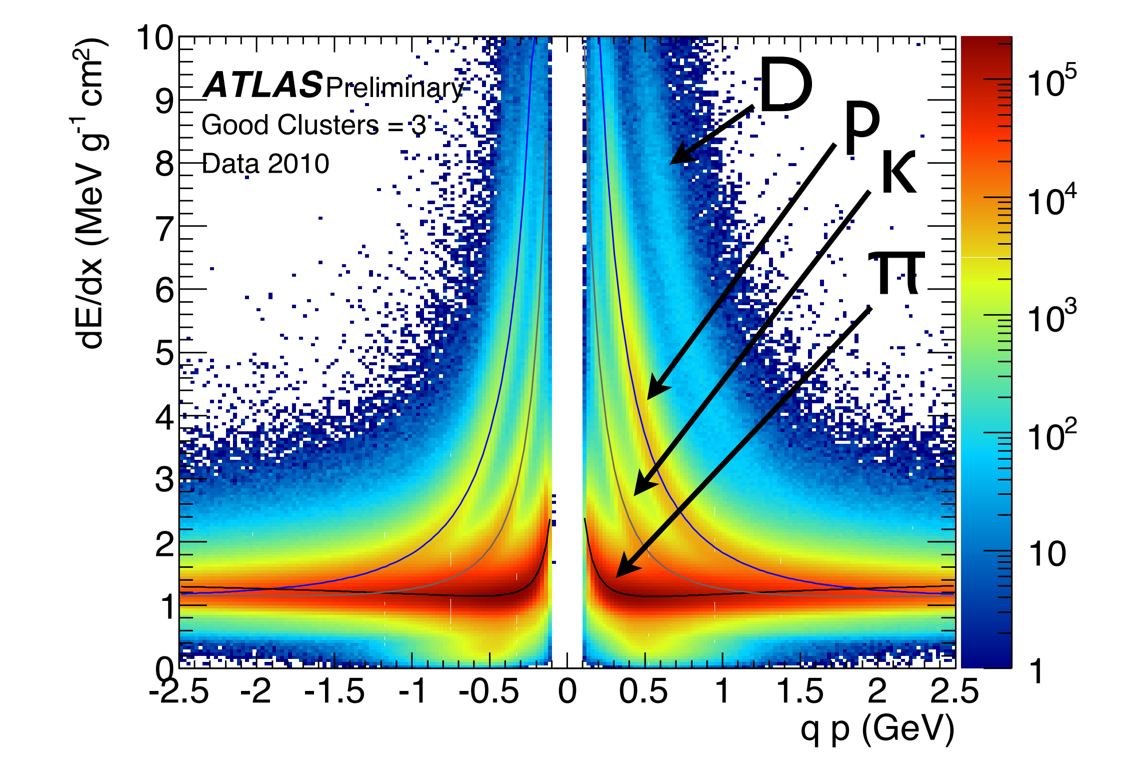




Pixel Calibration

- Deposited charge measured in Time-over-Threshold (ToT) in units of bunch crossings
- Tuning point: 30 ToT @ 20 ke
- Near linear dependency of ToT and deposited charge
- ToT used to refine cluster position for tracking (instead of binary hits)
- ToT resolution good enough to measure dE/dx and distinguish between different types of particles





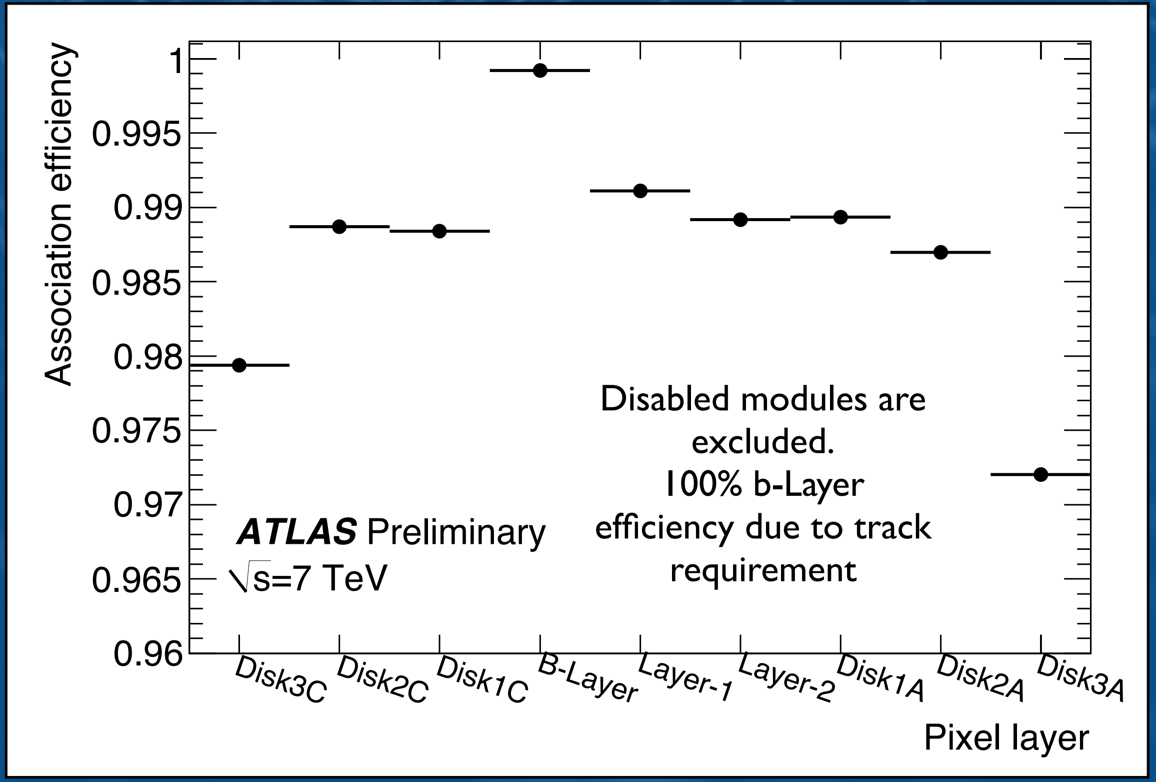
Pixel Data Quality

ATLAS p-p run: April-December 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.1	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5
All good for physics: 95.5%										

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and December 6th (in %) – corresponding to 21.3 fb^{-1} of recorded data.

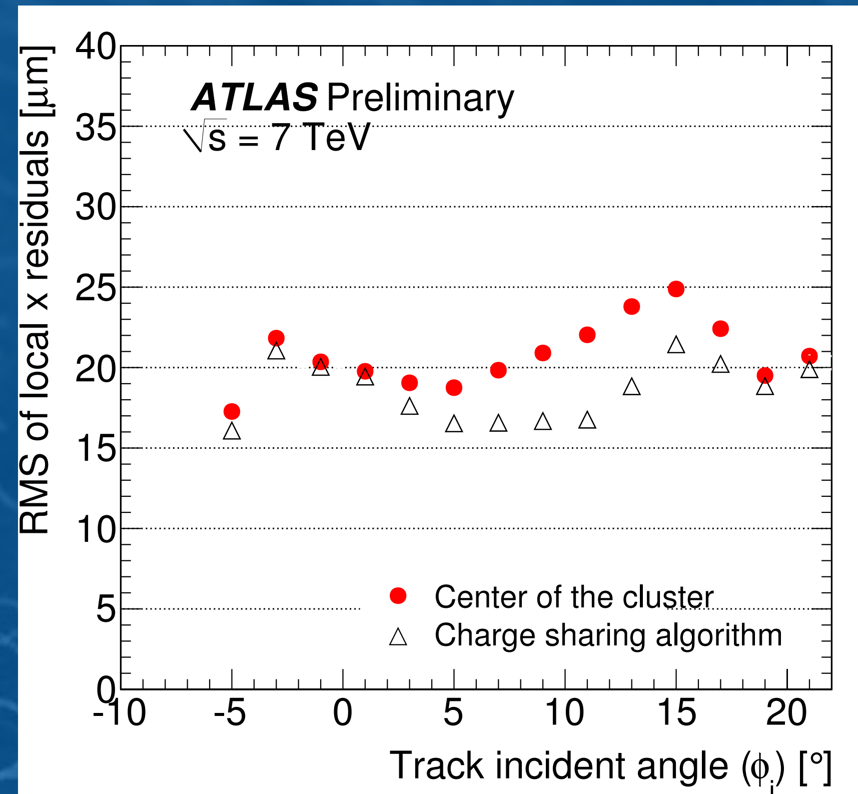
- 99.9% good quality data
- 95% operational fraction of the Pixel detector
- Inoperable fraction gets addressed in the LS1 repairs

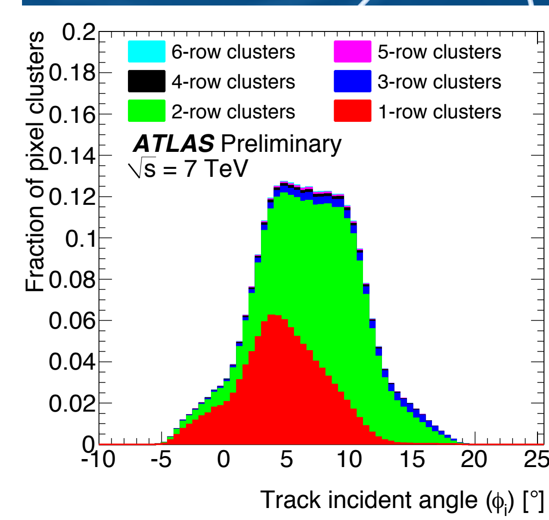
Efficiency of tracks having associated hits

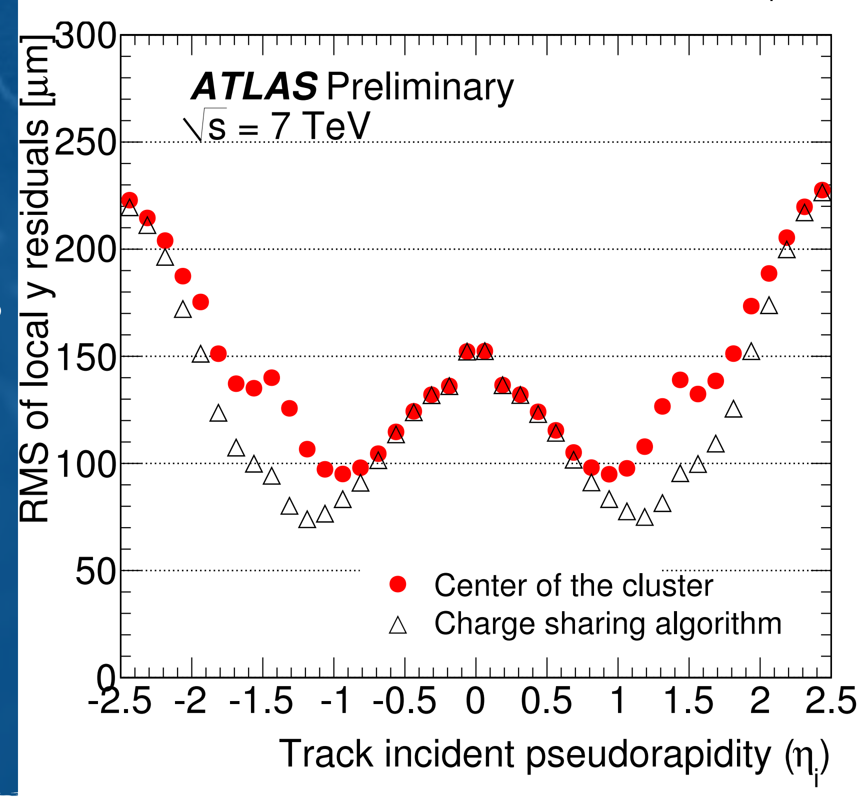


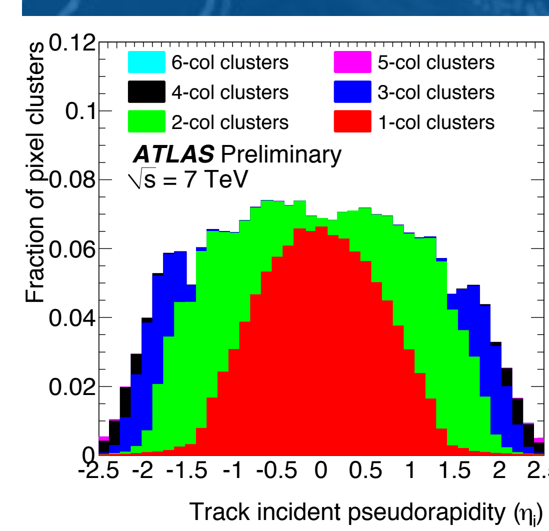
Tracking Performance

- Resolution given in local pixel coordinates, local x and y
- Early alignment shows typical resolution in local x and y with expected values of around 20 and 125µm, respectively
- Charge sharing algorithm improves resolution in regions with multi-hit clusters
- Most prominent in $5 < \phi_i < 15$ and $0.5 < |\eta_i| < 2$

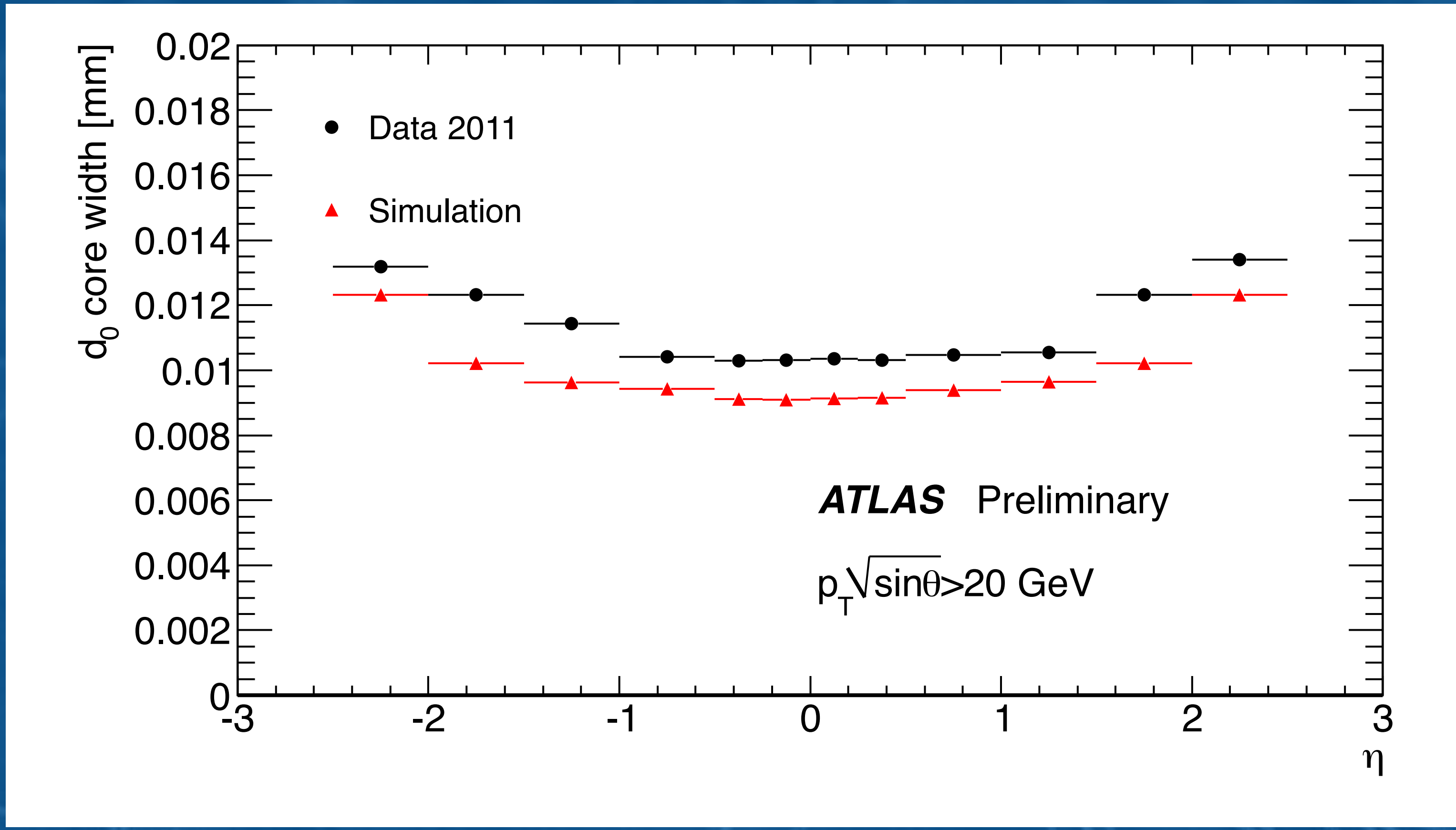


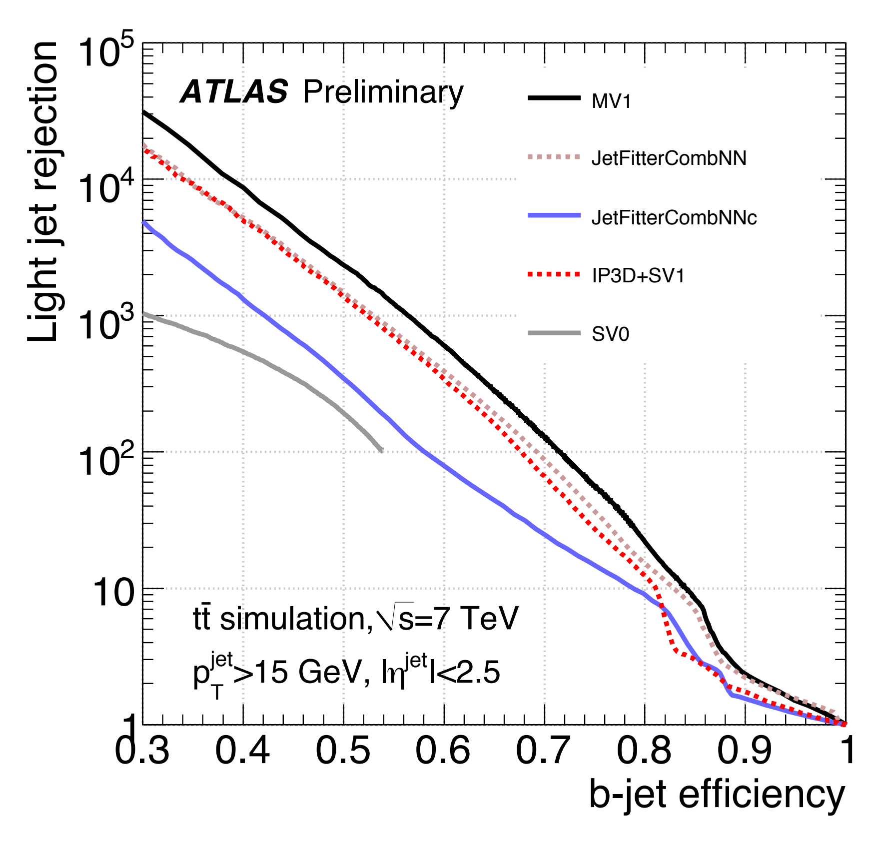






Impact Parameter

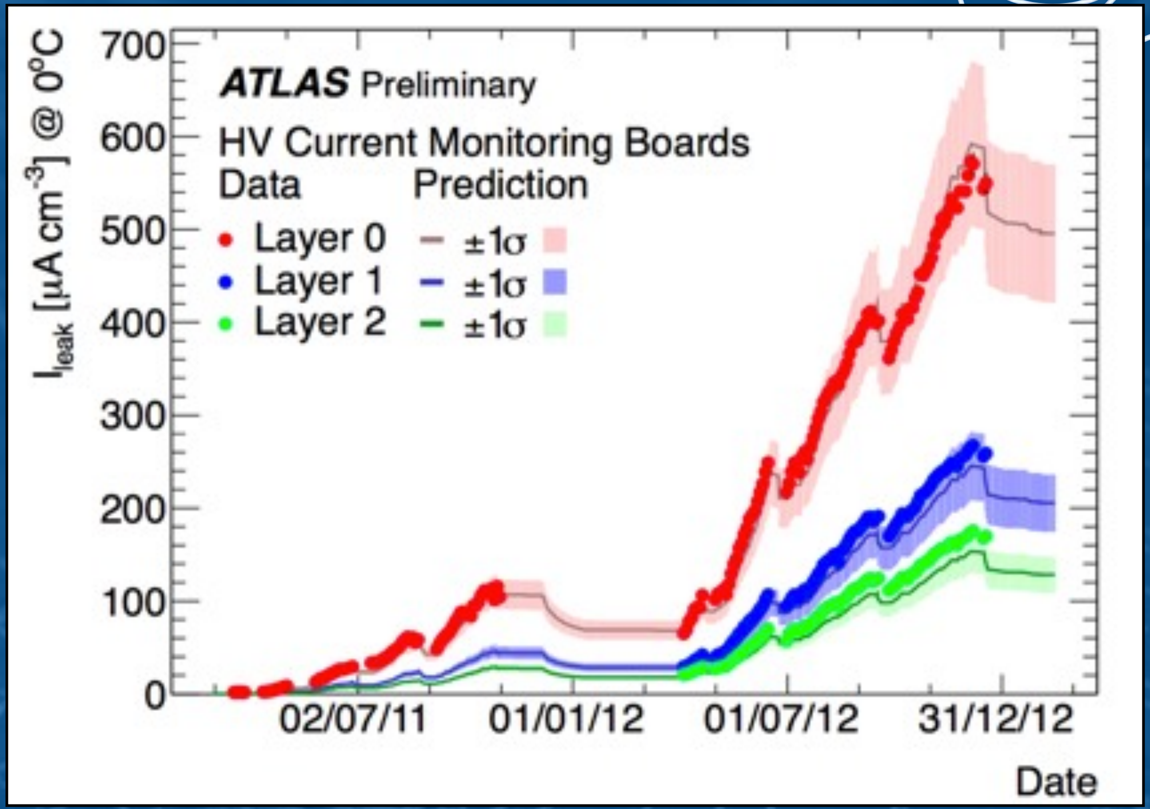


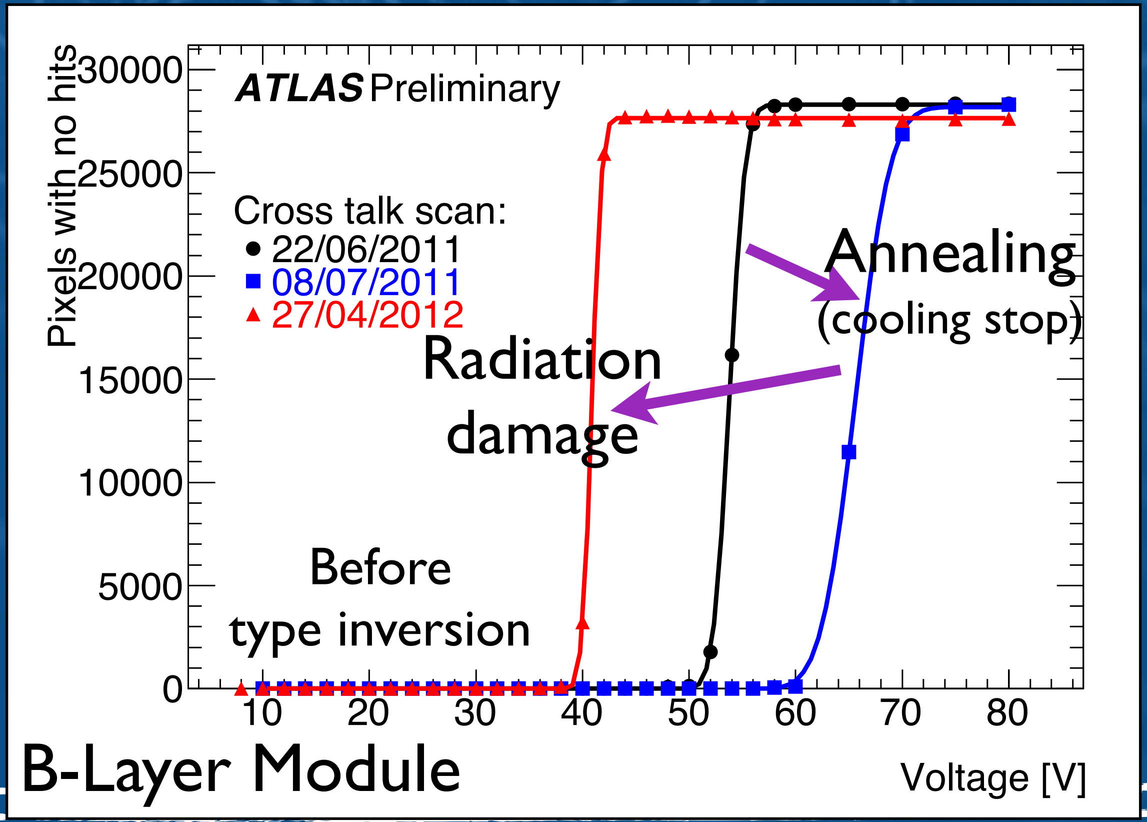


- Precise track resolution of the Pixel Detector together with the rest of the ATLAS Inner Detector result in an transverse impact parameter of O(10)μm
- Very good resolution of second vertices of B-Hadrons
- Very good B-tagging efficiency (~50%) with low mistag rate (0.5%) for high purity tagging

Radiation Damage

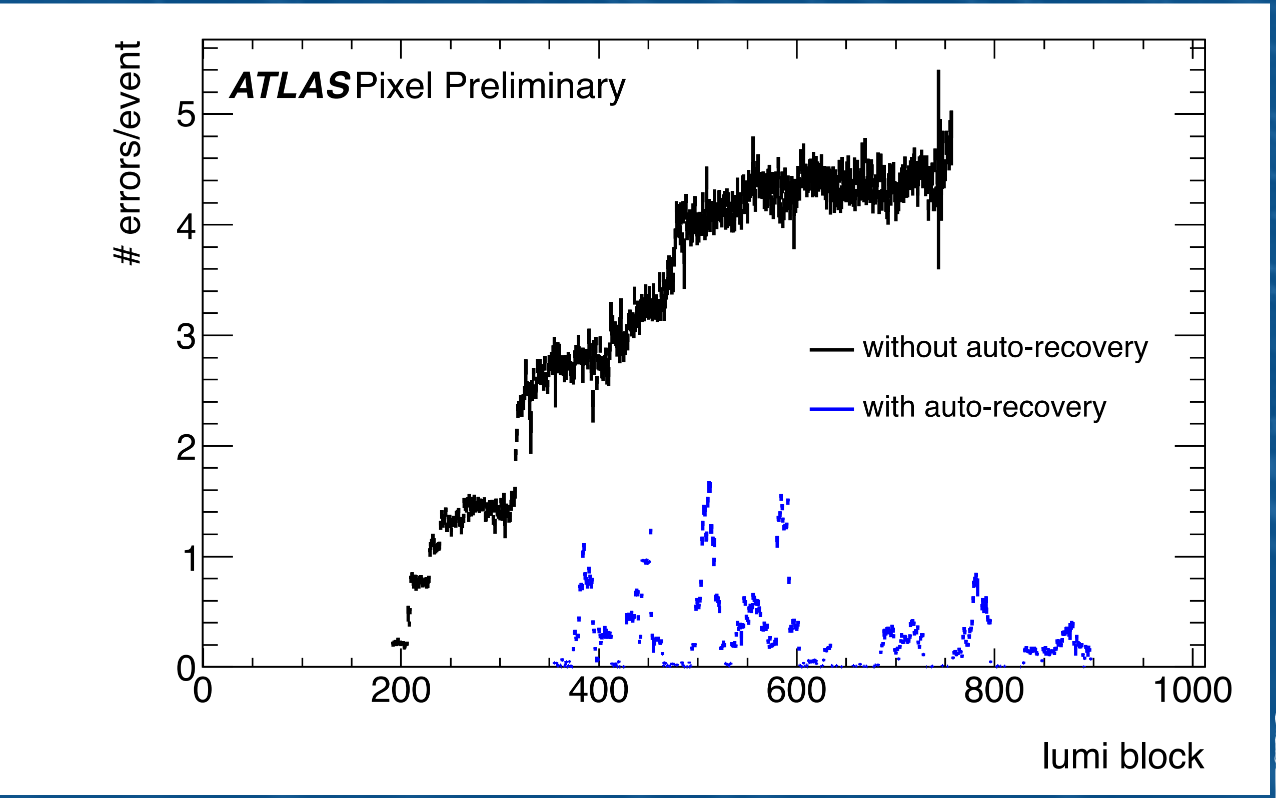
- Radiation damage in sensor visible in leakage current and shift of depletion voltage
- Leakage current behaves as predicted
- Short Cooling stops result in annealing effect and hence lower the leakage current
- Type inversion happened early 2012 for B-Layer, late 2012 for Layer 1 and not yet for Layer 2
- Depletion voltage/depth can be determined by using crosstalk method before type inversion and track depth method after type inversion





Synchronization Errors & Auto-Recovery

- In case of high burst data rate or SEUs module resynchronization is needed
- Highly correlated to instantaneous luminosity, more probable at the beginning of a run
- Auto-recovery implemented in DAQ, allows for single modules to be reconfigured (O(ms)) whilst data taking can continue on others
- Desynchronization seems to be connected to high bandwidth usage, especially on Layer 2

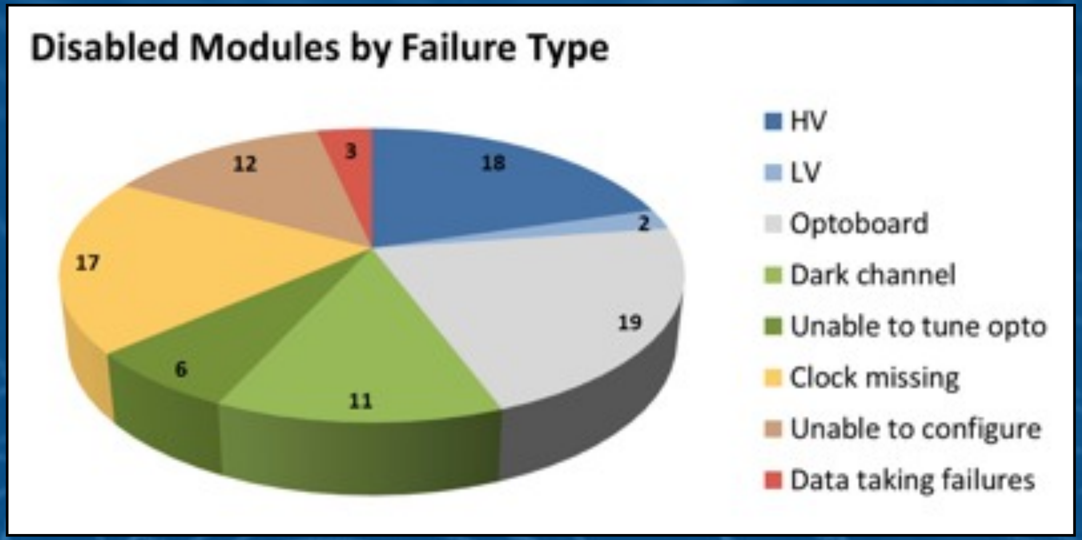


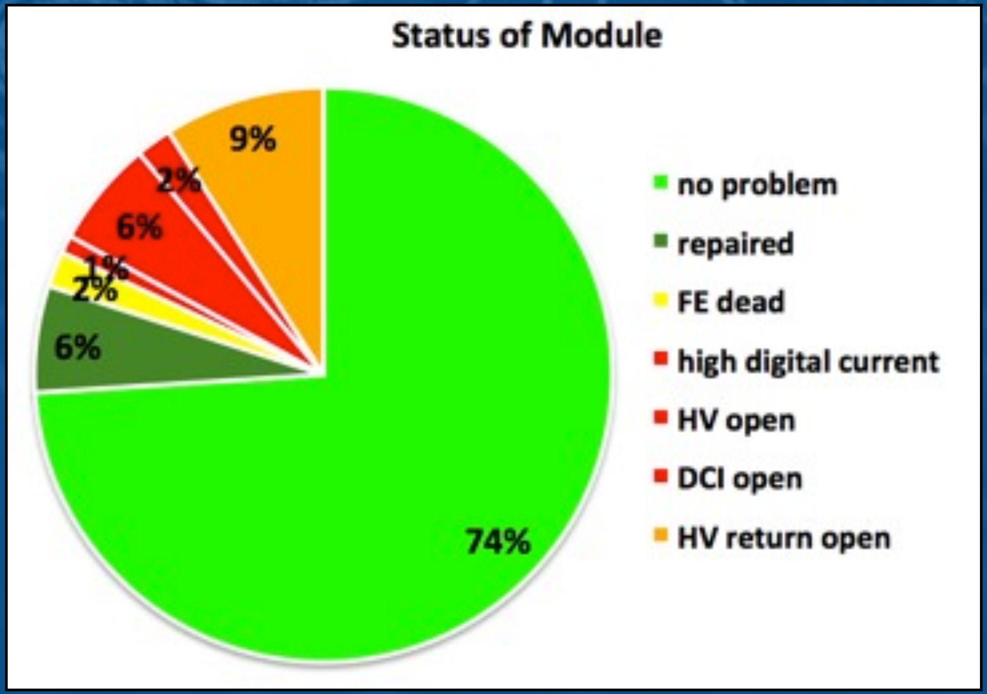
Status & Plans in LS1

- Pixel Detector was extracted from the ATLAS detector in the beginning of LS1and since April 2013 is in a lab on the surface for refurbishment
- Refurbishment will address the part of the 88 inoperable modules (5%), which failed due to damaged or disconnected services
- New services have been produced prior to extraction and will be integrated into the Pixel detector, after the old services have been dismounted

Pixel Refurbishment

- Parts of old services have been checked for failures and modules have been tested for functionality w/o services
- ~75% of the module failures caused by damaged/disconnected services
- ~25% are module failures
- ~8% are not recoverable
- Maximum of 92% can be recovered with installation of new services





Layer 2 DAQ Upgrade

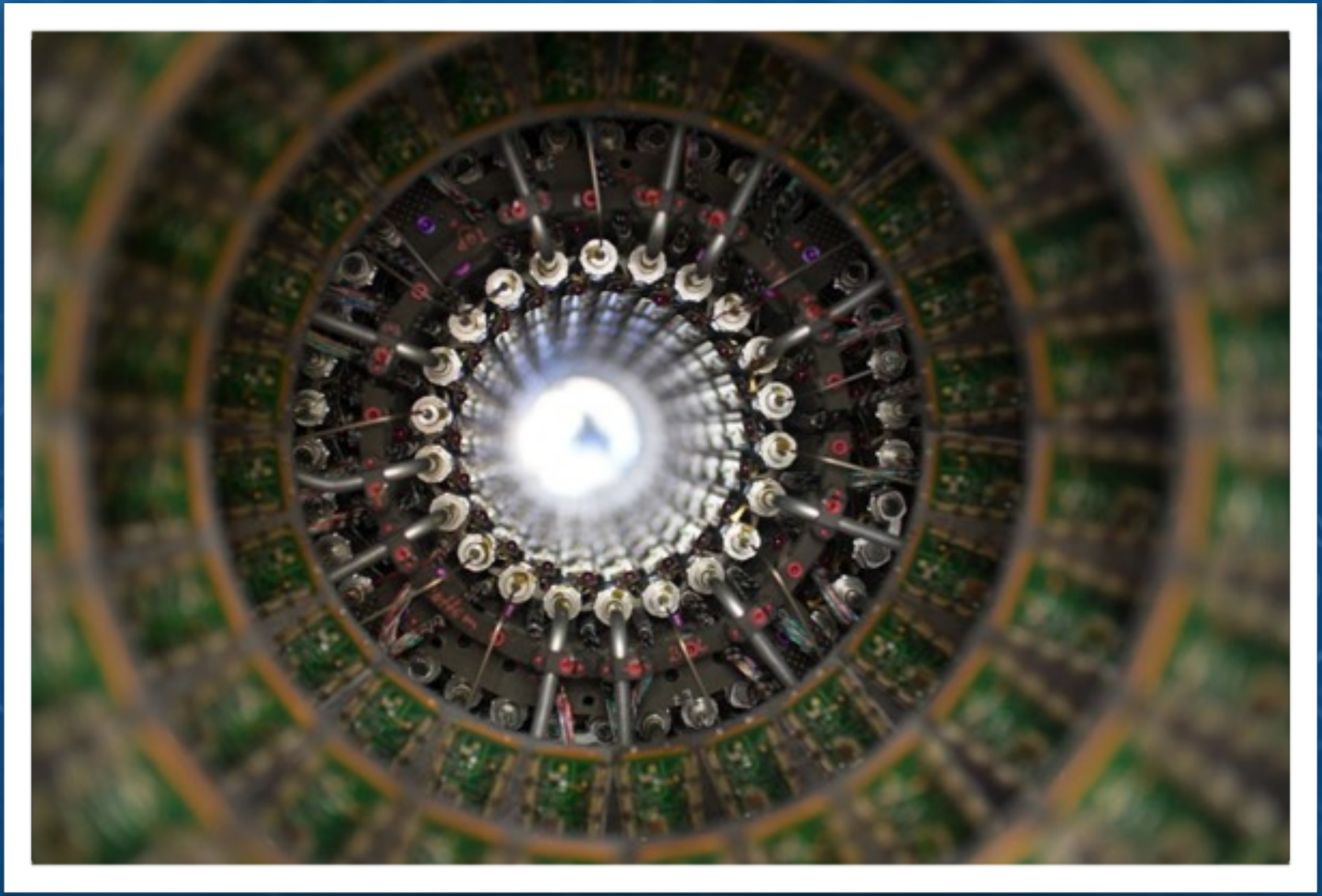
- New readout system currently under development for the 4th layer upgrade of the Pixel Detector
- Pixel Layer 2 will reach its readout bandwidth limitation for the expected luminosity after LS1
  - see Alessandro Gabrielli's talk in this session
- Plan to replace Layer 2 readout system with new one
- Increase bandwidth of Layer 2 from 40Mbit/s to 80Mbit/s per channel
- Layer 1 readout upgrade follows later (not as urgent)

Future Pixel Detectors

- The 4th layer Pixel Detector upgrade, the Insertable B-Layer (IBL), will be integrated into the Pixel Detector early 2014
    - see Daniel Dobos' talk on IBL in this session
    - IBL will profit from the data taking experience gathered with the Pixel detector and is optimized with state-of-the-art sensor and readout technology
    - IBL will compensate for arising inefficiencies in the B-Layer and improve the vertexing performance in high pile-up events
- A completely new Pixel Detector is planned for the Phase-II upgrade
    - Development of the components for this detector is ongoing
    - Employing new sensor and FE technology, with even smaller pixels and faster readout, while being even more lightweight

Conclusion

- The Pixel Detector is the innermost 3 layer pixel tracking system of the ATLAS Detector at the LHC at CERN
- Over the years 2010-2013 a total data sample of 27 fb^{-1} was taken
- Excellent data quality and tracking performance of the Pixel detector in this run
- Desynchronization and failing modules are quickly taken back into data taking via real-time reconfiguration
- The Pixel Detector was extracted from ATLAS in April 2013 and will be refurbished over the cause of the LS1
- Goal for 2015: A maximum of 92% of the 88 failed modules can be made operable again → 99.6% total operable Pixel detector



Thank you for your attention!

Pixel Hit Digitization

- FE-I3 allows pixel-calibration of discriminator threshold and amplification
- Pre-amplification controls signal shape
- Signal above threshold are digitized by discriminator
- Sampling of digitized signal with 40MHz clock allows conversion to time
- Charge is measured in units of 25ns as Time-over-Threshold (ToT)