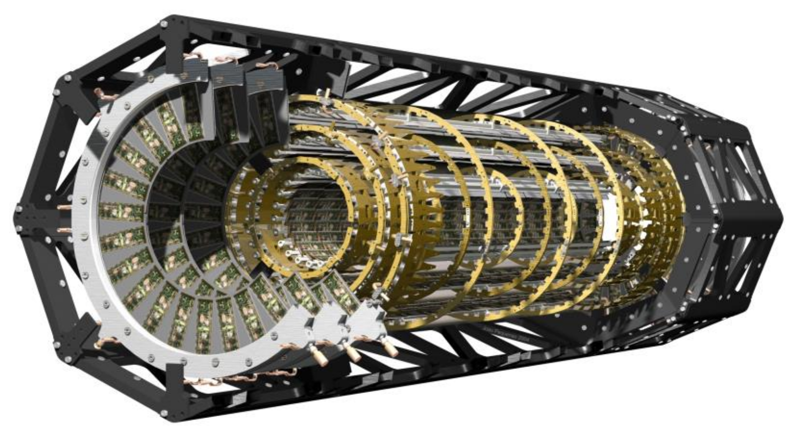
Status of the ATLAS Pixel Detector at the LHC after three years of operation

Kerstin Lantzsch (CERN)
for the ATLAS collaboration

RD13, Firenze, 03-07-2013



Outline

I. Introduction
- *The Large Hadron Collider*
- *The ATLAS Detector*
- *The ATLAS Pixel Detector*

II. Detector Performance and Operation
- *Operating Parameters, Performance*
- *Monitoring Radiation Damage*
- *Operations*

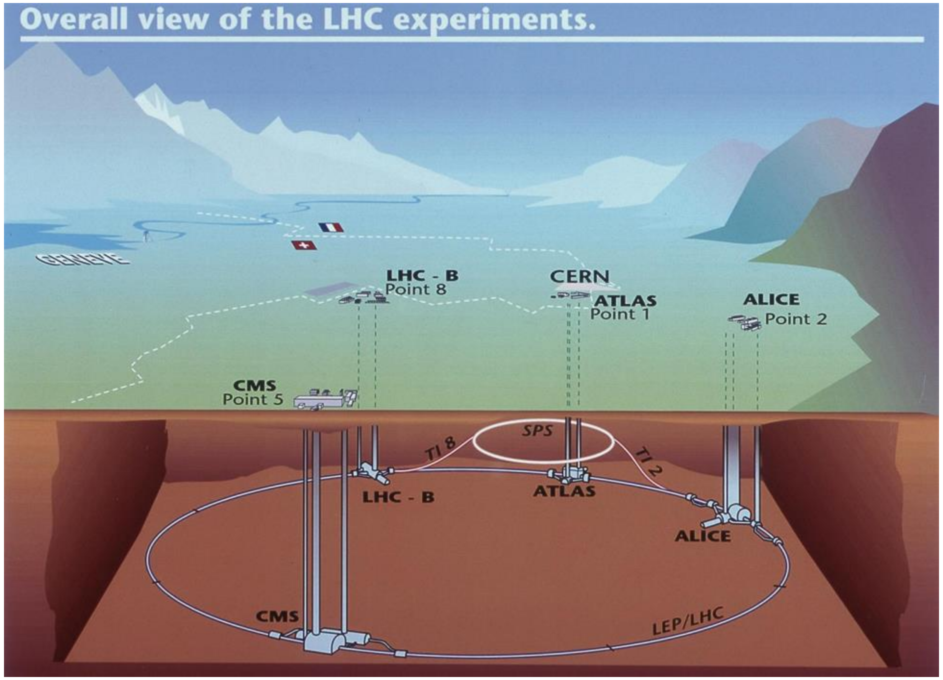
III. Shutdown work
- *Planned Upgrades*
- *Status*

IV. Conclusion

LHC

2012 operating parameters:
4 TeV beam energy, 1374 bunches per beam (@ 50 ns bunch spacing)

- proton-proton collider
- 27 km ring
- 1232 superconducting dipole magnets
- 7 TeV nominal beam energy
- 10^{34} cm^{-2} s^{-1} nominal luminosity
- 2808 proton bunches per beam
- 25 ns bunch spacing (40 MHz)

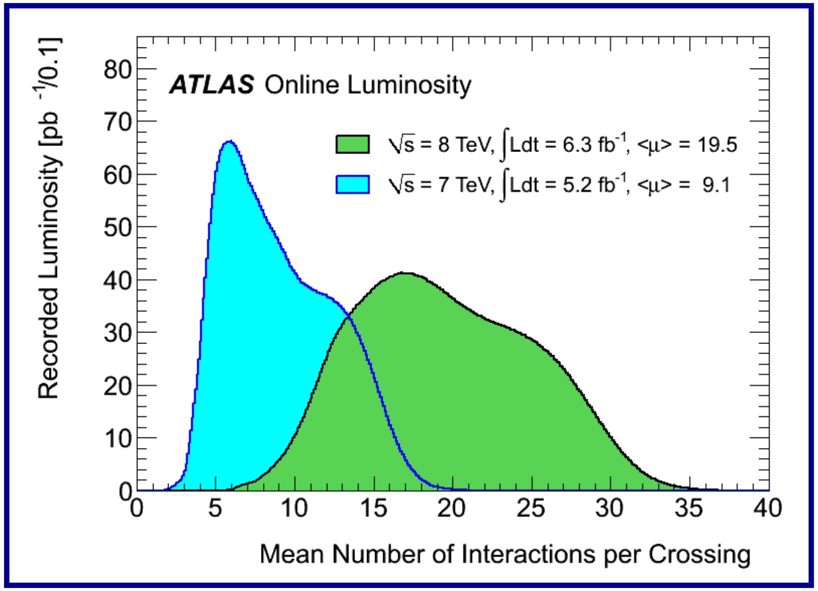


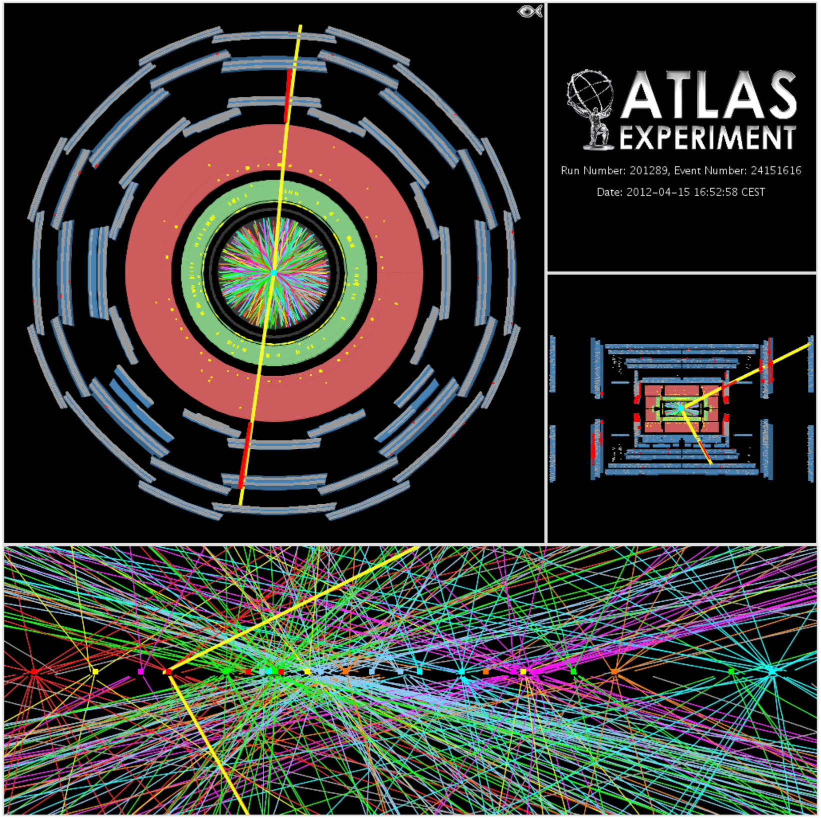
2012 Peak Luminosity: 7.73 10^{33} cm^{-2} s^{-1} — Total Delivered Luminosity: 23.3 fb^{-1}

LHC

2012 operating parameters:
4 TeV beam energy, 1374 bunches per beam (@ 50 ns bunch spacing)

LHC is performing extremely well
- Lumi > 7.7e33
- 50 ns bunch spacing → a lot of Pile-Up





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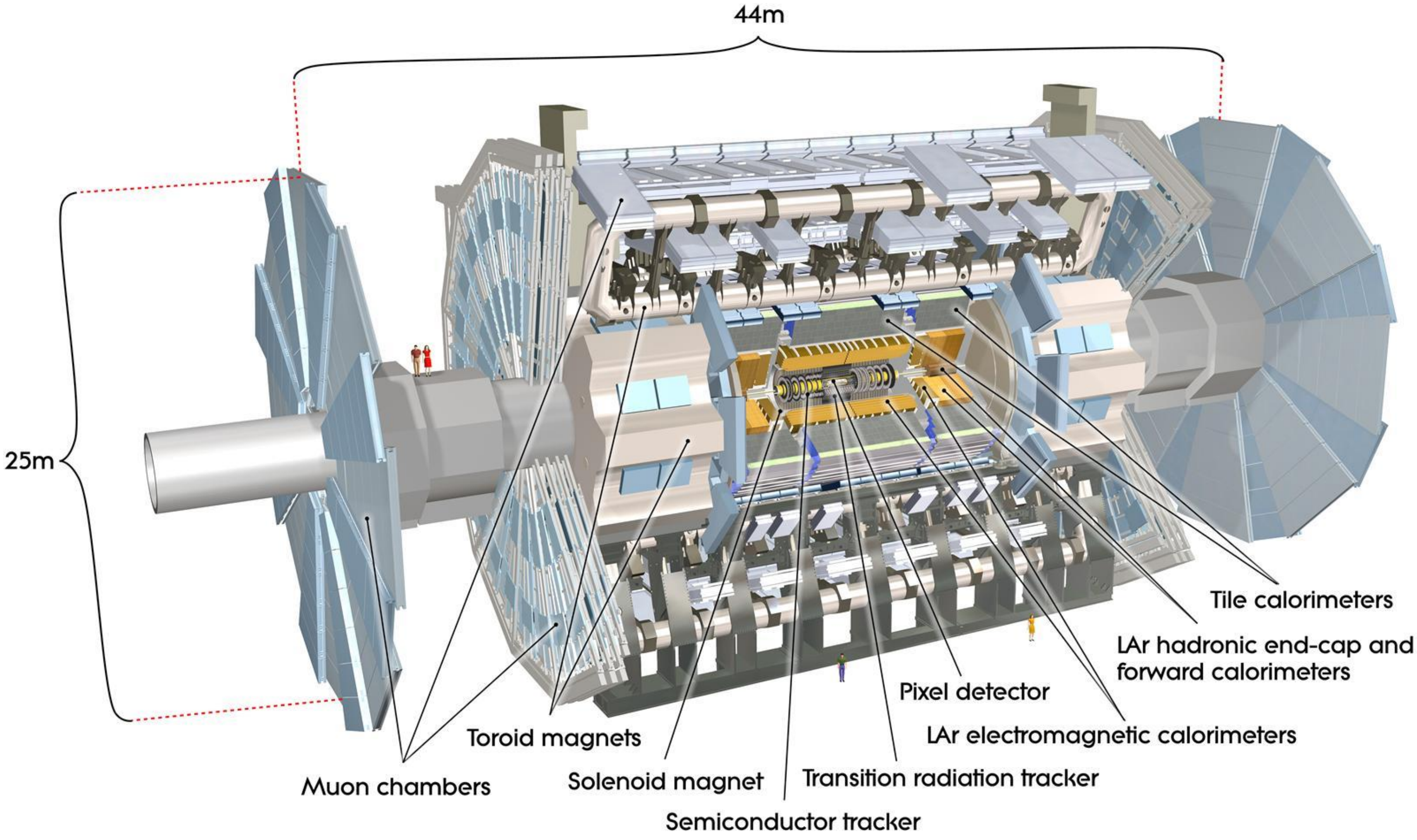
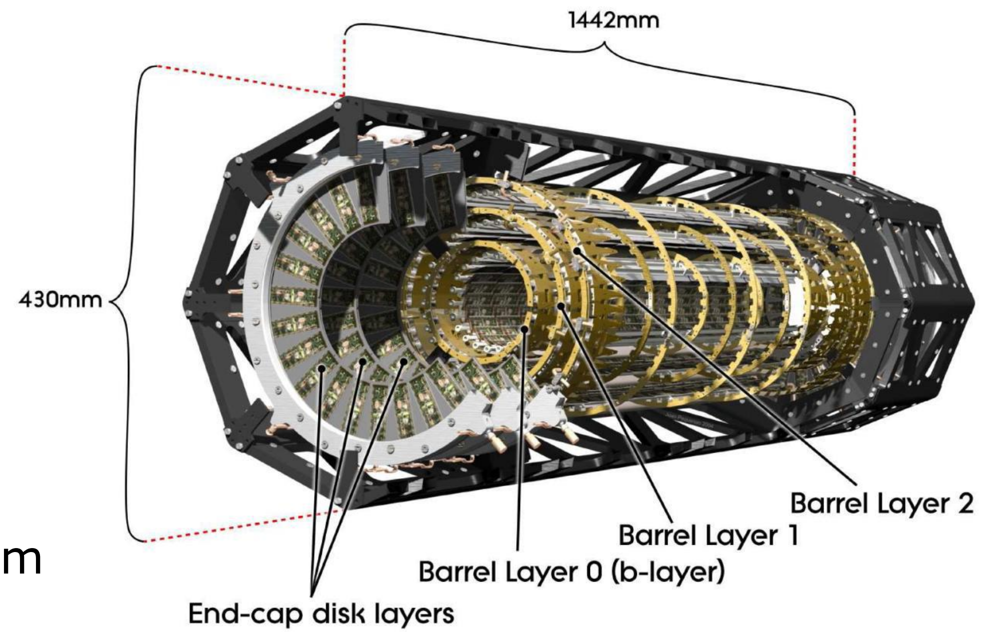
ATLAS

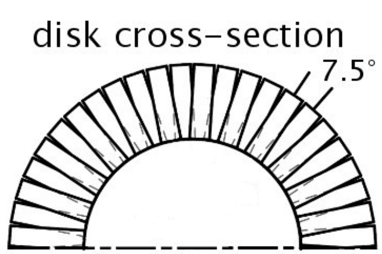


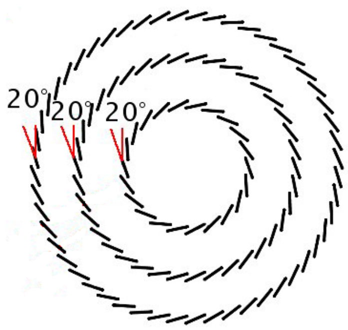
44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

The Pixel Detector

- 3 hit-system for $|\eta| < 2.5$
  - 3 barrel layers
  - 3 disks per end-cap
- Resolution in r-φ < 15 μm
- 1744 modules,
  80M readout channels
- Innermost barrel layer at 50.5 mm
  - Radiation tolerance
    500 kGy / 10^{15} 1MeV n_{eq} cm^{-2}
- Evaporative C_3F_8 cooling integrated in local support structures
  - set temperature -20°C (2 bara)
  - Average module temperature -13°C, warmest module at -5 °C

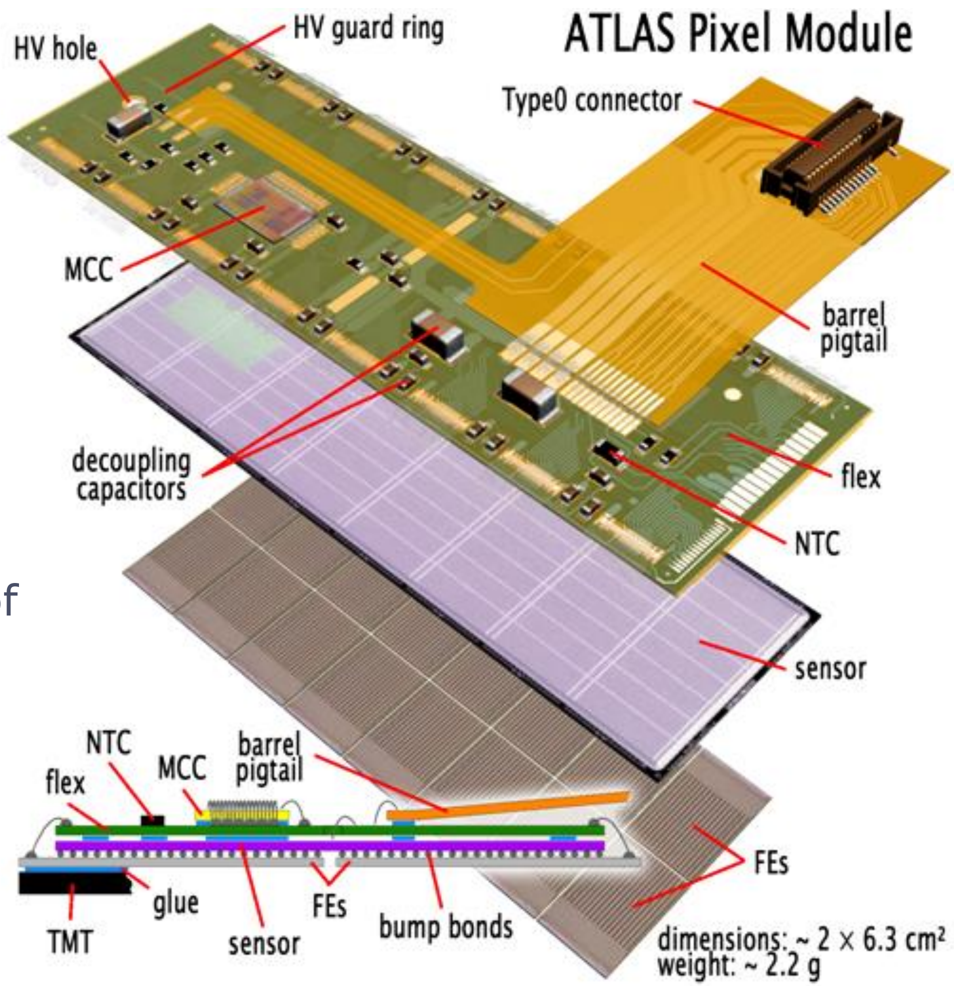






The ATLAS Pixel Module

- Sensor:
  - 250 µm thick n-on-n sensor
  - 47232 (328 x 144) pixels
  - Typical pixel size 50 x 400 µm^2 (50 x 600 µm^2 pixels in gaps between FE chips)
  - Bias voltage 150 – 600 V



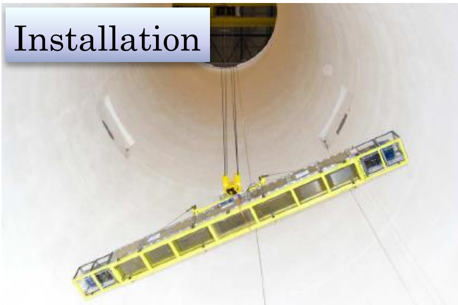
- Readout:
  - 16 FE chips, 2880 pixels each
  - Pulse height measured by means of Time over Threshold
  - Zero suppression in the FE chip, MCC builds module event
  - Data transfer 40 – 160 MHz depending on layer (80 m optical link from PP0 to counting room)

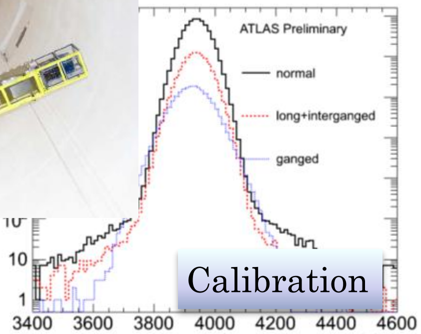
Timeline

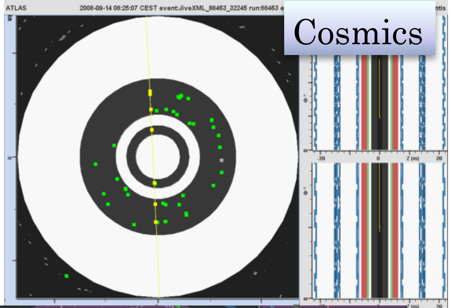
- May 2007 – Installation in ATLAS
- Sept 2008 – First cosmic events
- Oct 2008 – LHC incident

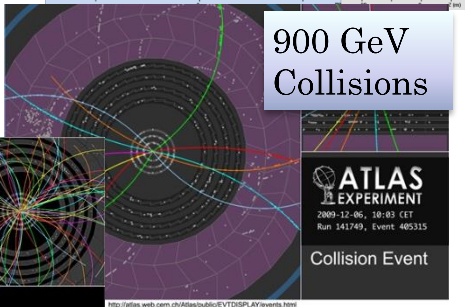
- Nov 2009 – First beam 450 GeV
- Dec 2009 – 0.9 TeV and 2.36 TeV collisions
- March 2010 – 7 TeV Collisions
- May 2011 – Luminosity 10^{33} cm^{-2} s^{-1}
- Apr 2012 – 8 TeV Collisions
- Dec 2012 – First physics runs with 25 ns bunch spacing

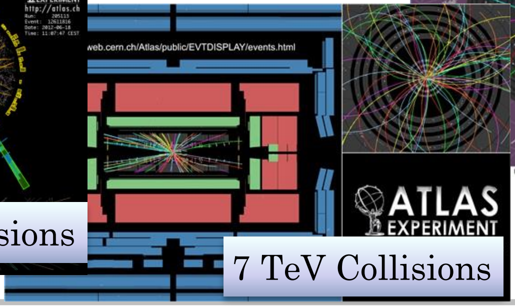
- Feb 2013 – Start of Long Shutdown 1
- April 2013 – Pixel Detector back on the surface

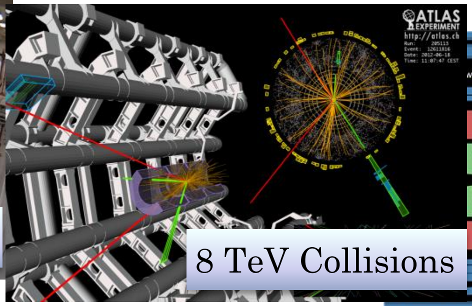






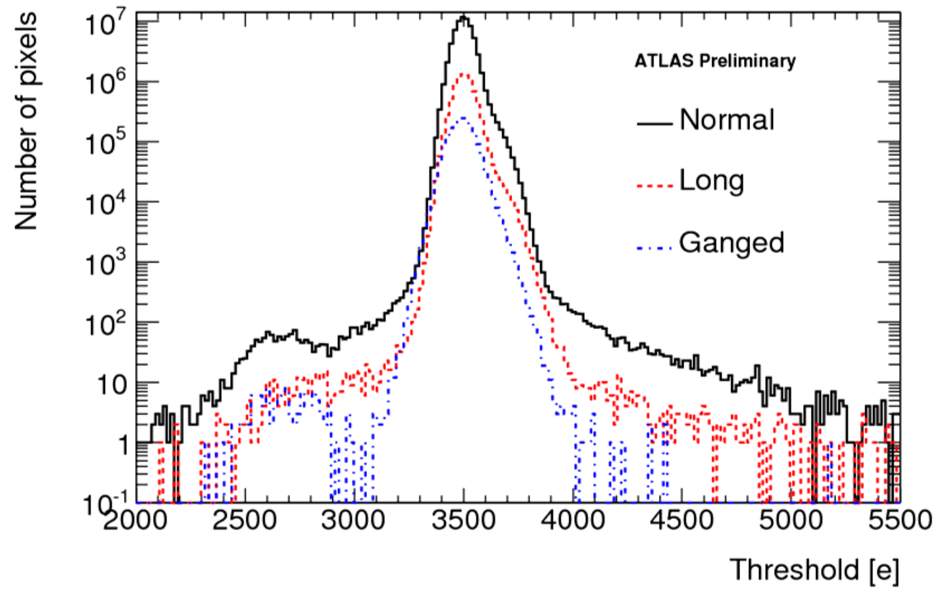




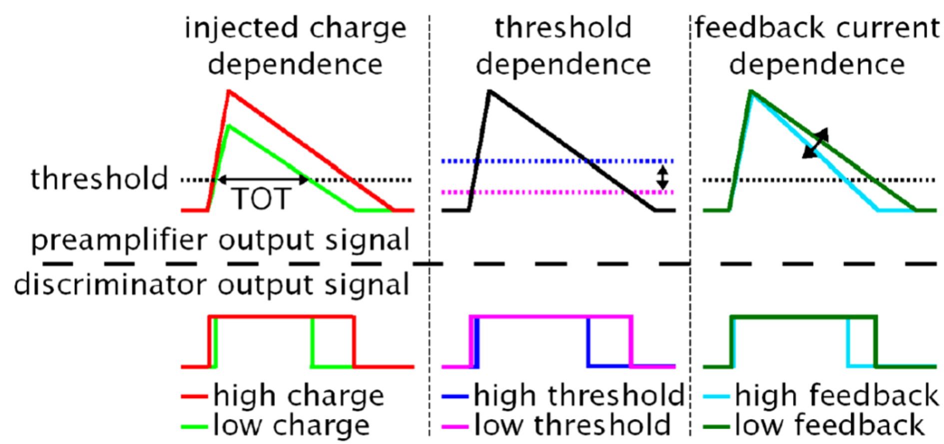


Operating Parameters

- **Threshold** and **noise** is determined by measuring the discriminator activation curve as a function of the injected charge
  - The Pixel Detector is operated at a threshold of 3500 e$^-$, typical dispersion 40 e$^-$.
  - Typical noise is since the beginning below 200 e$^-$ for regular sized pixels.
  - Online Noise Mask of Pixels with noise occupancy > 10^{-6} hits/event



- **Time-over-threshold** (ToT, length of discriminator signal) depends on:
  - deposited charge
  - discriminator threshold
  - feedback current



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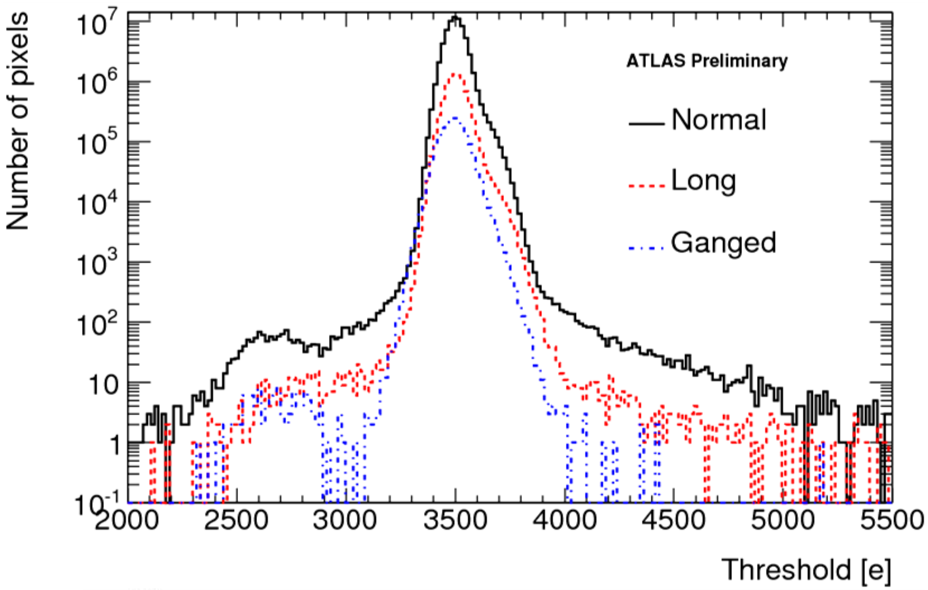

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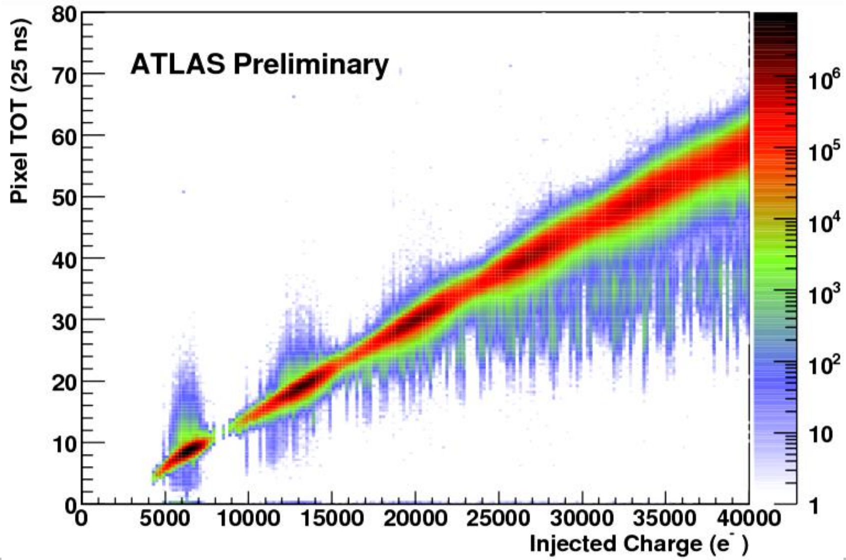
- ToT Information (in units of 25 ns) is read out together with the hit information → measurement of the deposited charge
  - Time-over-threshold tuned pixel by pixel to 30 BC @ 20ke



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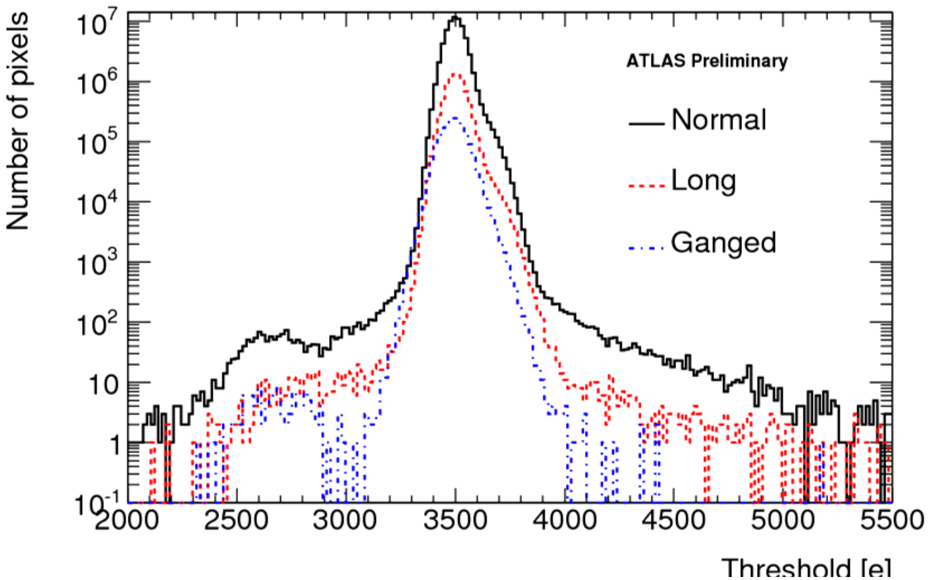
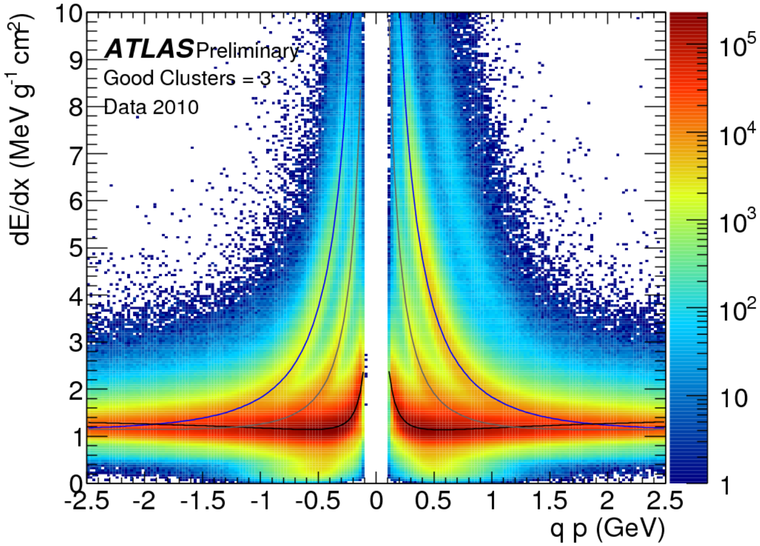
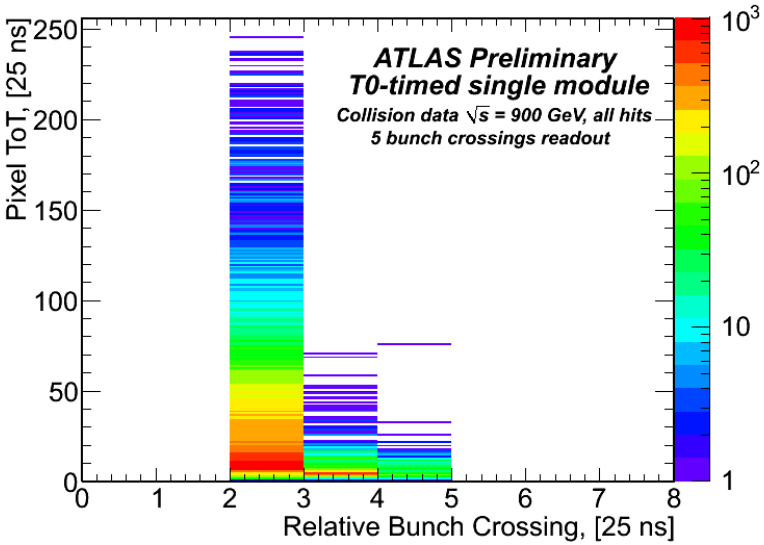
  - Time-over-threshold tuned pixel by pixel to 30 BC @ 20ke
  - *The ToT resolution achieved with the internal calibration is sufficient to distinguish p from K in minimum bias events below 1 GeV/c.*
    The dE/dx resolution is 12%.



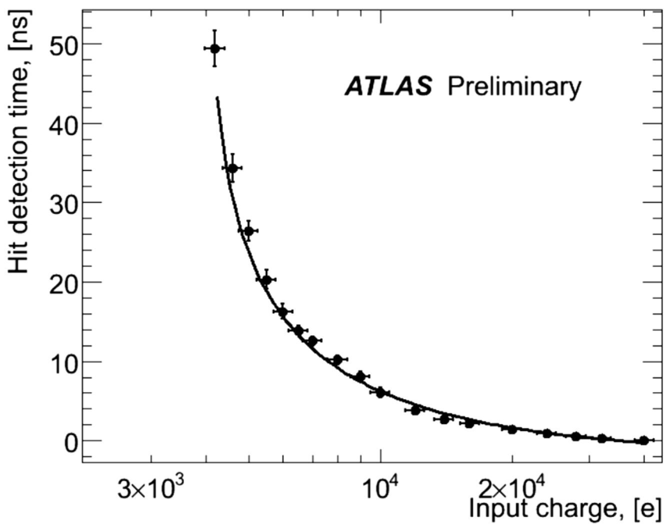


Readout window and Timing

- Operating with 1 BC readout window since September 2010
  - Re-done Timing scan with collision data in 2012 to check stability after exchange of all off-detector optical transmitters → timing well under control



- Account for timewalk of low charge hits with hit doubling
  - Doubling of hits with ToT ≤ 7



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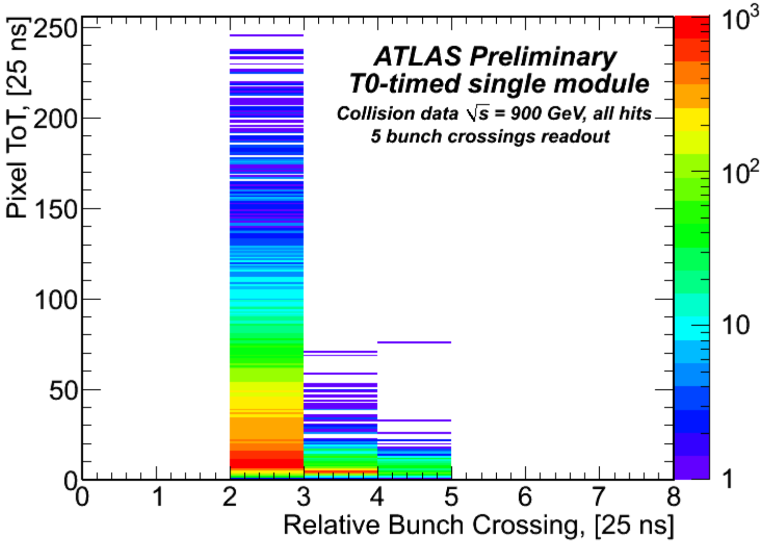
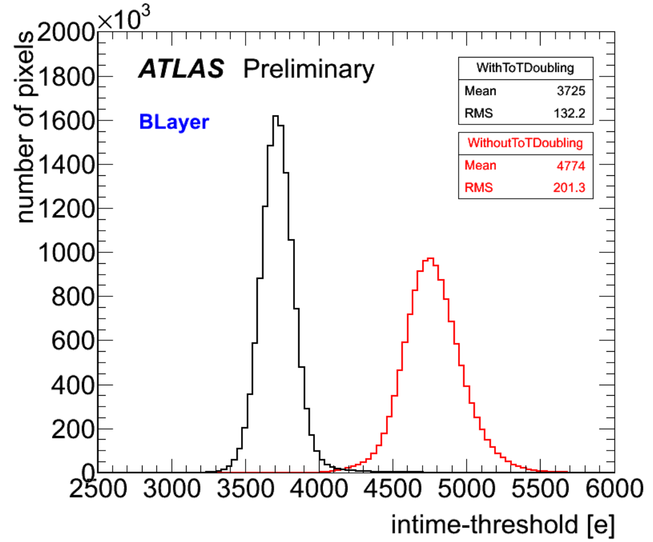
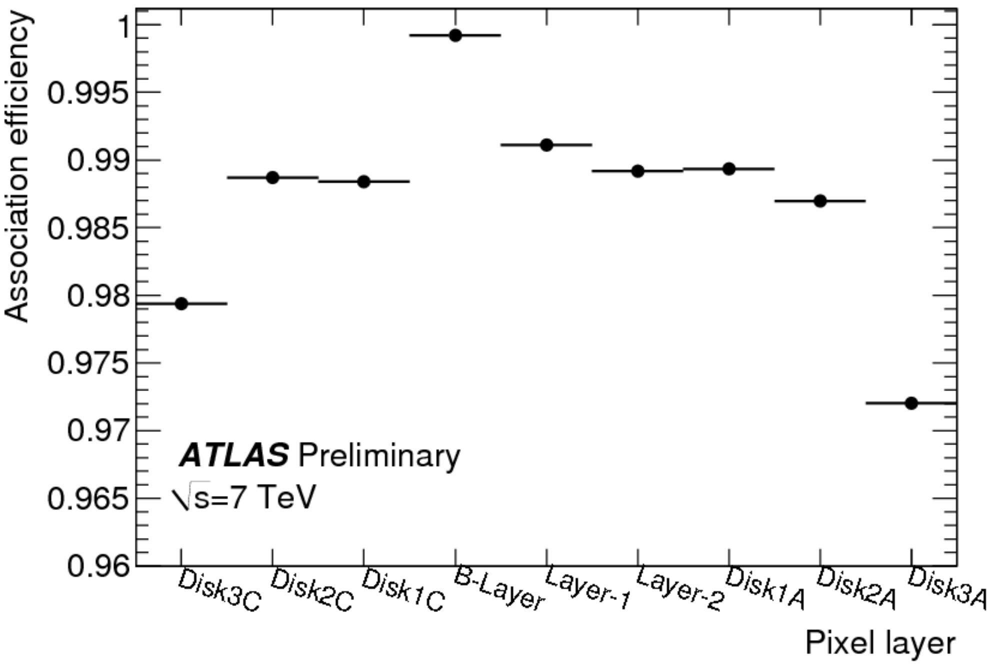


- Account for timewalk of low charge hits with hit doubling
  - Doubling of hits with ToT ≤ 7
  - Intime Threshold at 3700 e^- , only 200 e^- overdrive.
  - Would be 4800 e^- without hit doubling.

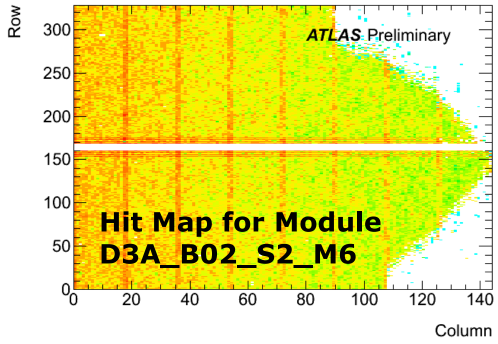


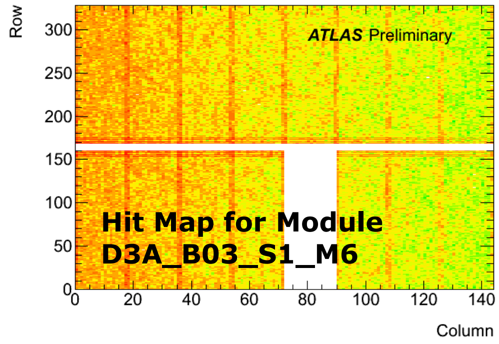
Hit-to-Track Association Efficiency

- Hit-to-track association efficiency for the different parts of the detector
  - Disabled modules have been excluded, dead regions not
  - Full efficiency of the B-layer due to track selection



- Efficiency ~99% for nearly all parts
  - Slightly lower efficiency in the outermost disks due to individual modules, e.g.
    - disconnected bumps
    - disabled front ends





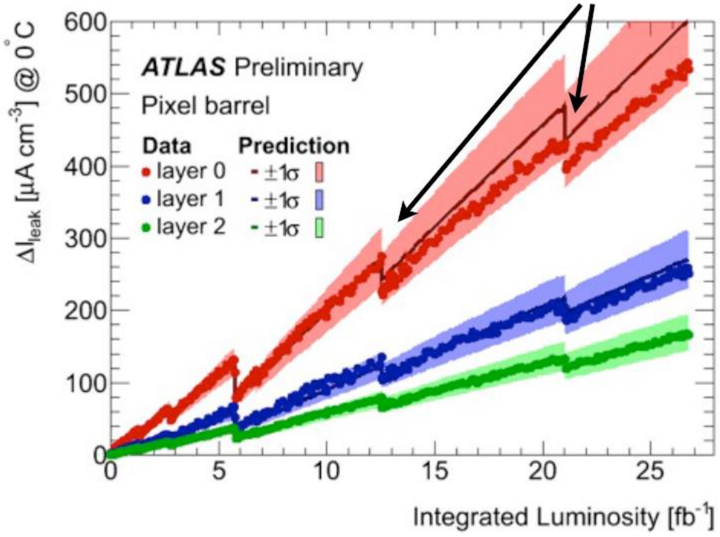
Radiation Damage

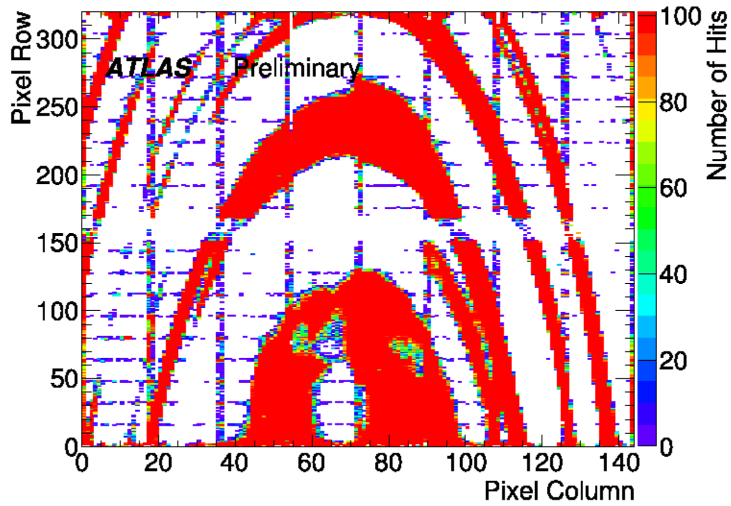
Bulk damage resulting in crystal defects will alter the physical properties of the sensor.

Monitoring of radiation damage:

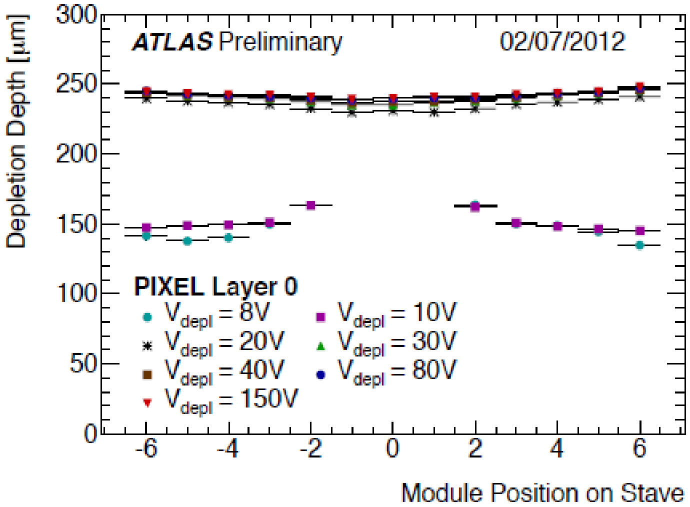
- Leakage current is measured
  - on the HV power supply level → per 6 or 7 modules
  - on the module level (for selected modules), special current measurement boards.
  - on the pixel level in special scans
- Depletion Voltage and Depth
  - Crosstalk Scan at different voltage settings (injected charge will induce crosstalk in neighbouring pixel in case of undepleted sensor → will not work after type inversion)
  - Track based depletion depth scan with collisions

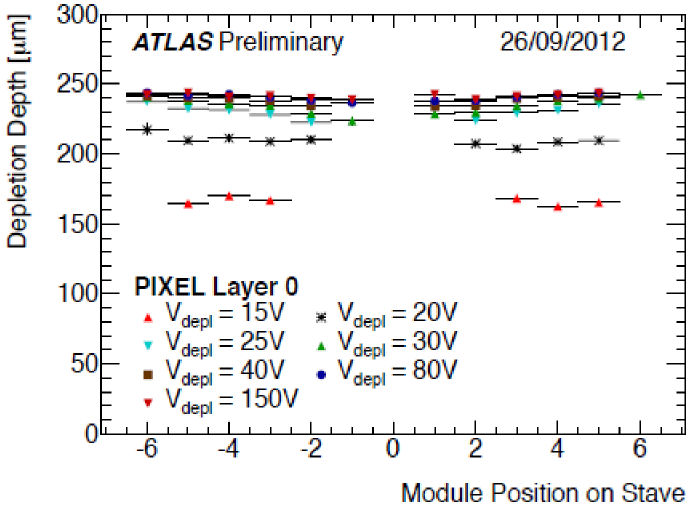
Cooling Stops

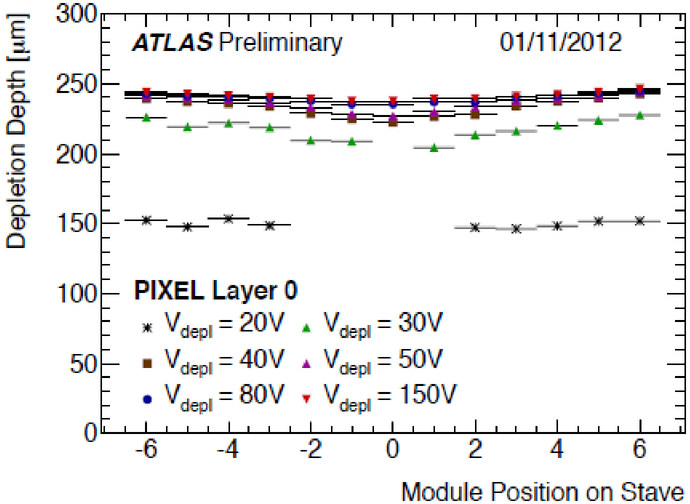


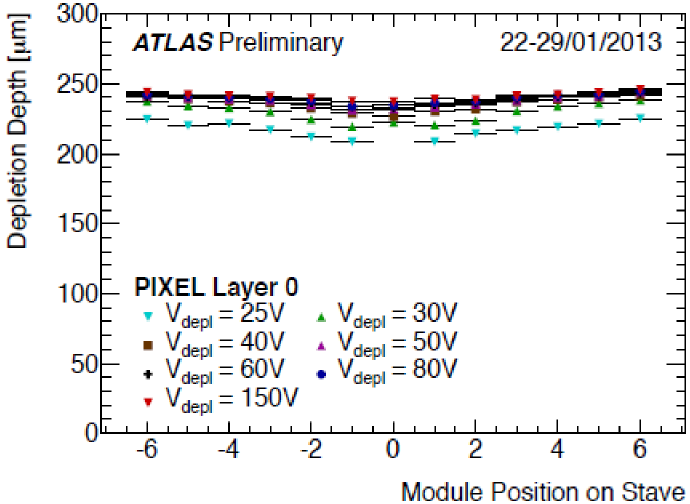


Depletion depth measurement

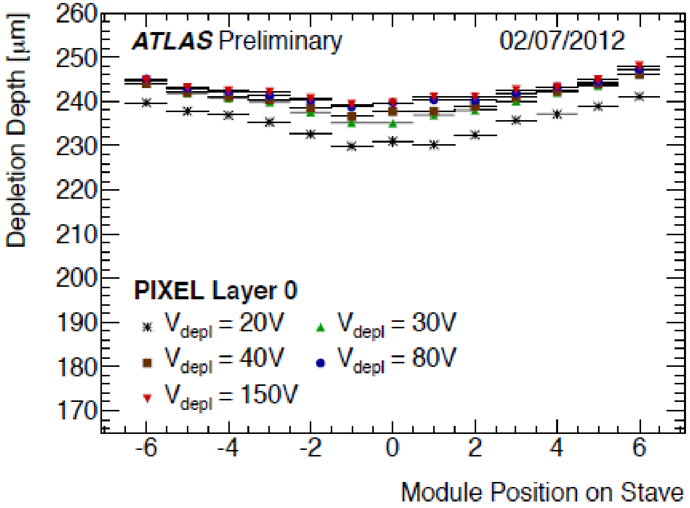


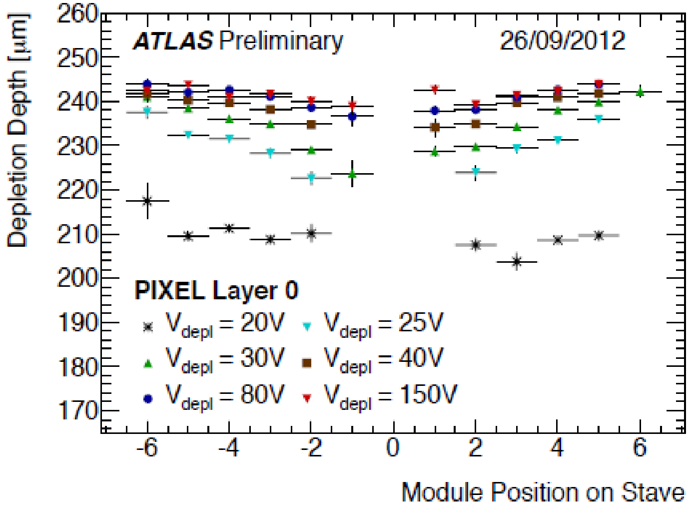


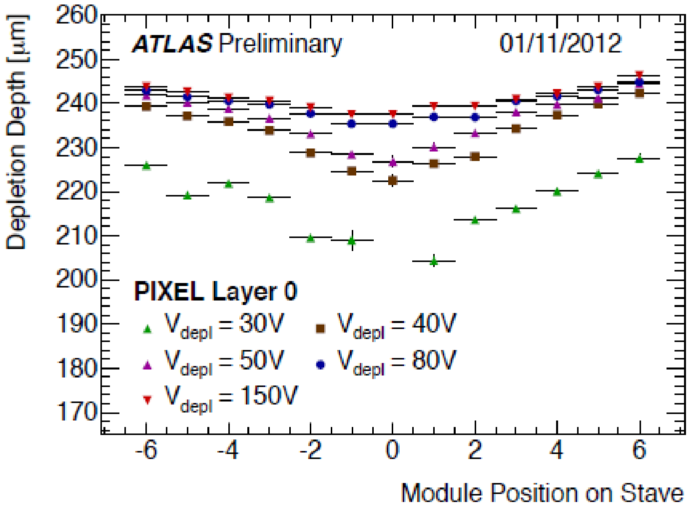


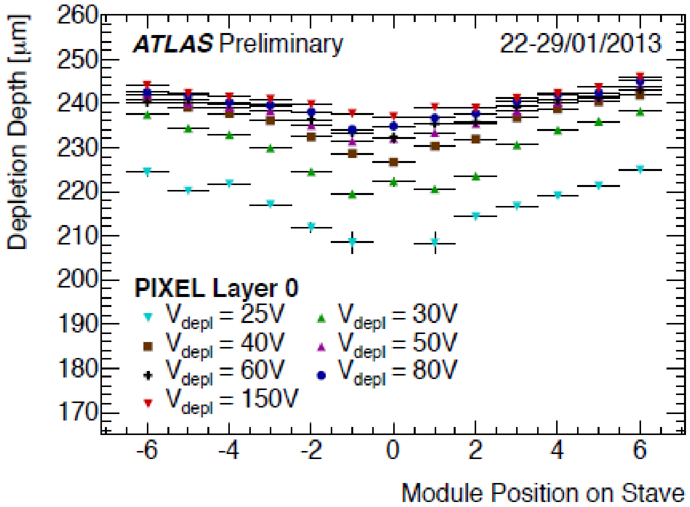


Depletion Voltage









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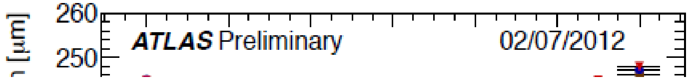
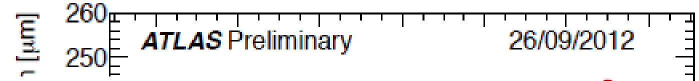
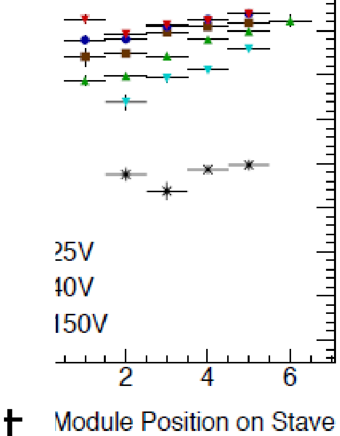
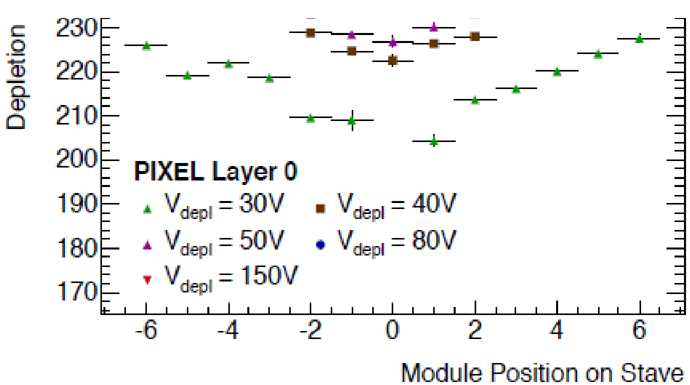
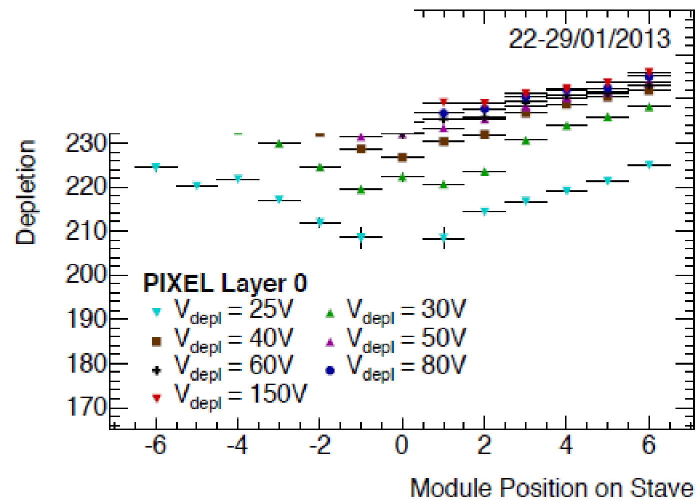




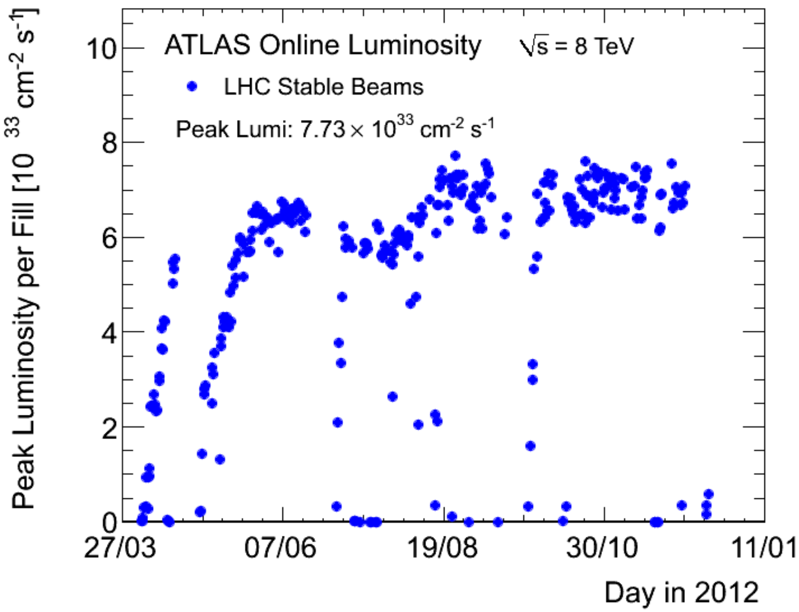


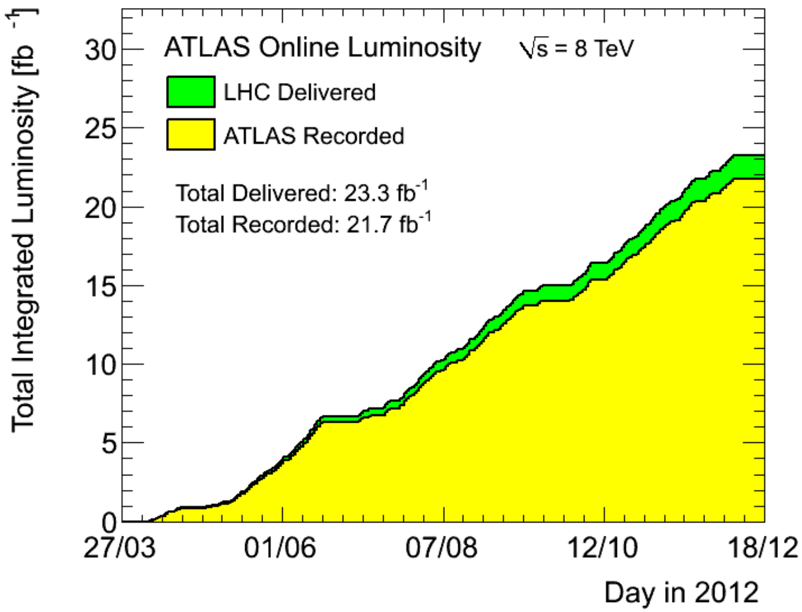
- Radiation damage effects and annealing are clearly visible in the data
- Use cross talk scans to measure depletion voltage up to type inversion
- Track based measurement shows subsequent rise in depletion voltage





Data taking efficiency





Pixel data taking efficiency is 99.9%!

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	99.4	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5
All good for physics: 95.8%										

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 21.6 fb^{-1} of recorded data.

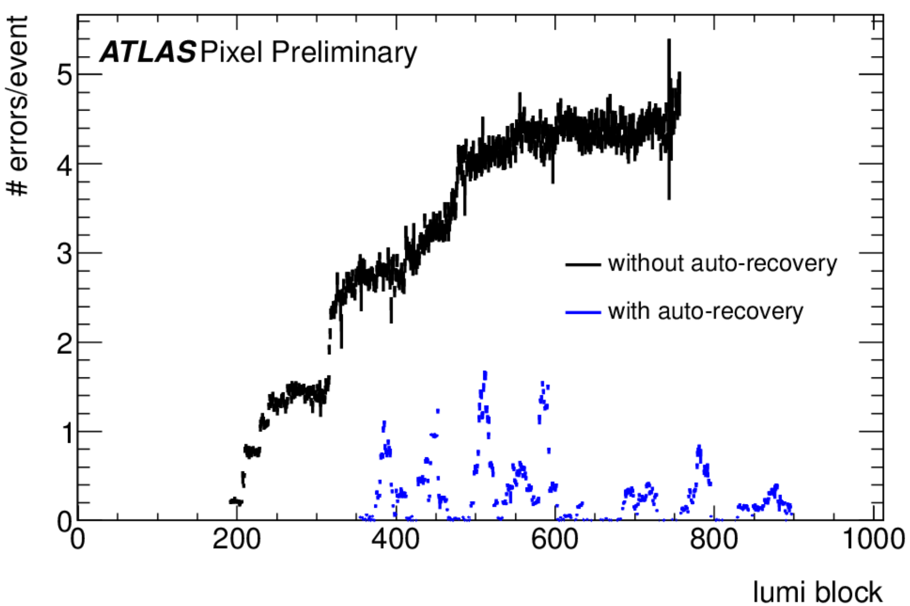
Limitations

- Start to suffer from problems with module busies, timeouts and desynchronization (caused by **Single Event Upsets**), affecting ATLAS data taking efficiency by induced dead time. Desynchronization renders the data of the affected modules partially useless.

- Effects of busy and timeout are mitigated by real-time recovery actions, moved from an SBC task (0.2 Hz) to the ROD-level (2.5 kHz), resulting in great reduction of dead time: O(s) → O(ms)

- Module level desynchronization, that is most frequent in the B-Layer, is addressed by automatic reconfiguration of the affected module, keeping the number of errors low throughout a run.

Modules affected by desynchronisation (Module level)

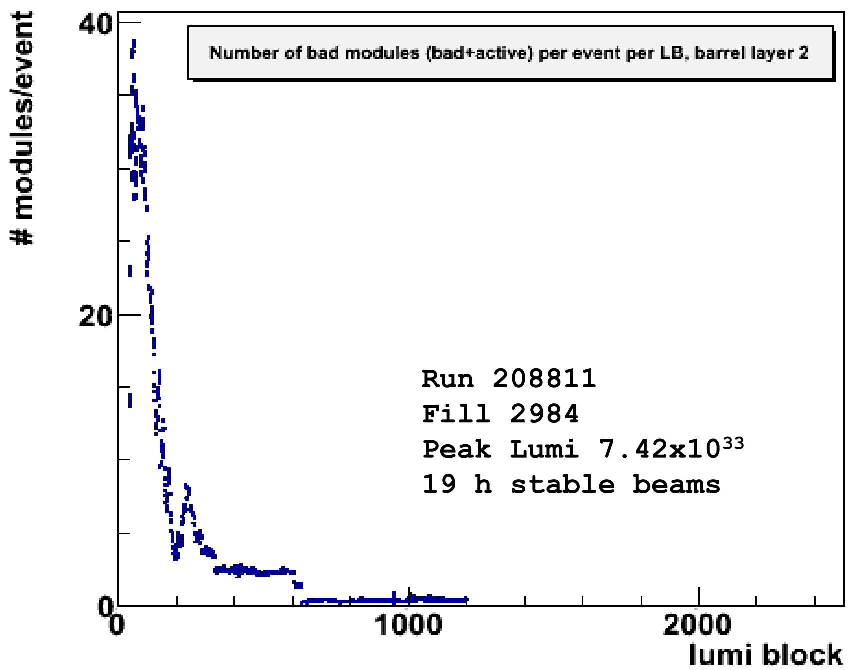


Limitations

- We clearly see **bandwidth limitations in Layer 2** (40 MHz data transfer rate) at high trigger rates/luminosity at the start of run, visible in ROD level desynchronization

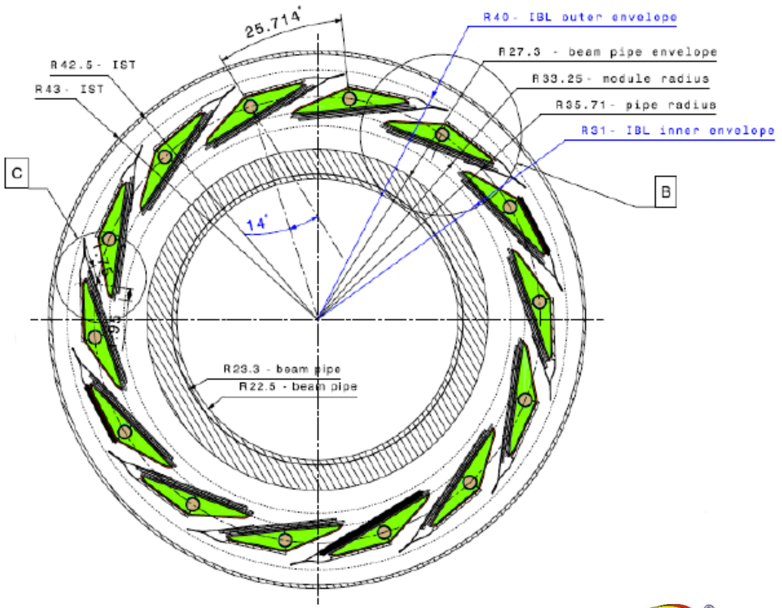
- In addition, we start to see occurrences of entire B-Layer RODs getting disabled during a run (aggravated by one hardware failure), a problem that needs to be understood and addressed for 2015. One disabled B-Layer ROD affects 6 or 7 modules, and is treated as an intolerable data quality defect.

Modules affected by desynchronisation (ROD level)



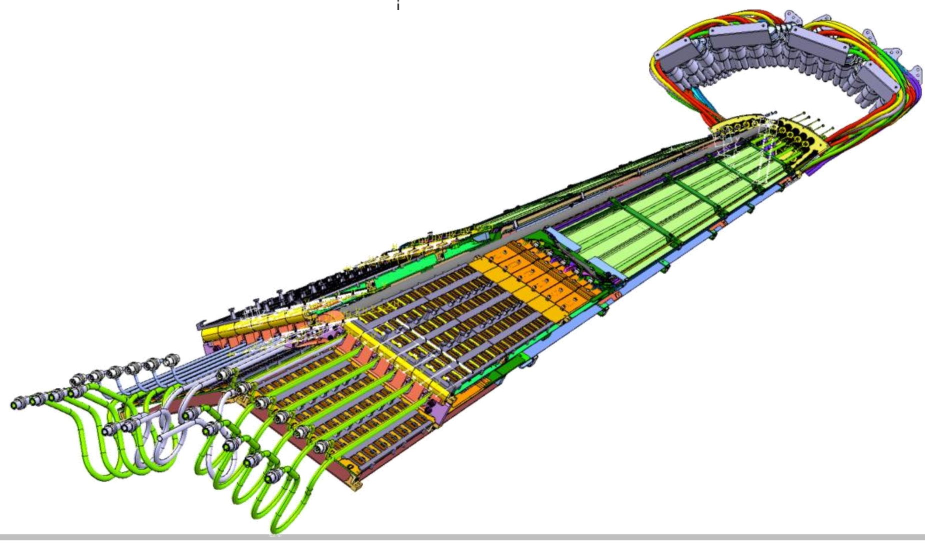
Upgrades in LS1

IBL:
- new innermost tracking layer for ATLAS; between new smaller beam pipe and the current B-Layer (IBL inner radius: 3.2 cm)
- 14 staves arranged in turbine-like fashion
- see tomorrow’s dedicated talk



nSQP:
- move on-detector opto-electrical transceivers (optoboards) to a serviceable location
- allow later Layer 1 readout speed upgrade to 160 Mbit/s

Layer 2 readout speed upgrade:
- operate single link at 80 Mbit/s
- additional off-detector hardware will be installed (ROD/BOC)



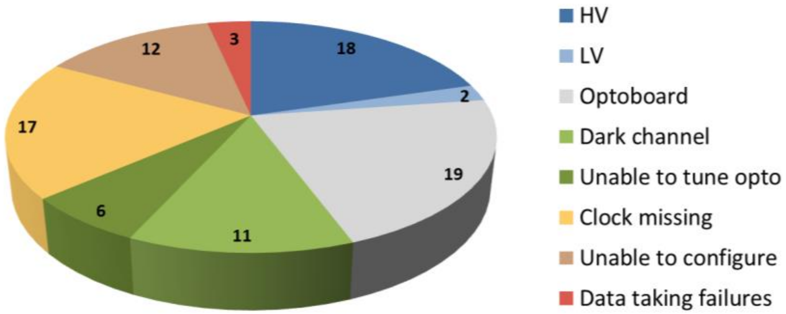
Pixel Detector Repairs

Pixel Detector Status 2012

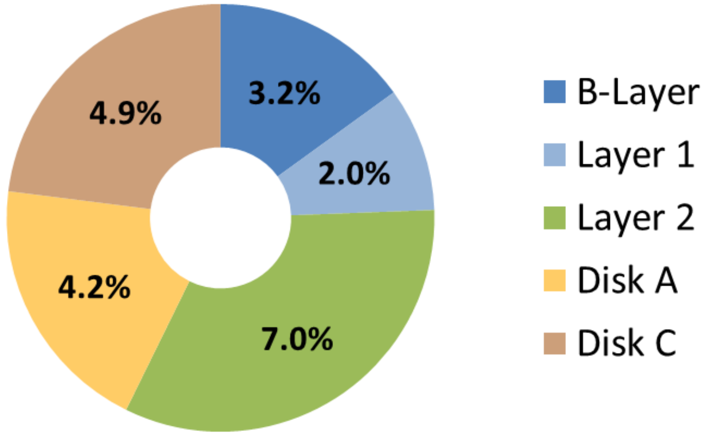
Status of the Pixel Detector End of 2012:
95% of the modules are active in data taking

- 88 modules are disabled or problematic
  - including 1 B-Layer optoboard with fluctuations in light output (supply voltage problem)
  - 2 B-Layer modules with low efficiency (HV problem)
- 2 additional RODs are operated at half speed
  - 1 B-Layer ROD at 80 Mbit/s (1 module w/o good second link)
  - 1 Disk ROD at 40 Mbit/s
- 60 dead FEs in 45 modules
- Failures are linked to thermal cyclings
  - Keep cooling operational whenever possible
  - Two step switch-on and switch-off, to reduce temperature gradient

Disabled Modules by Failure Type



Disabled Modules Fraction by Layer



Current Work: Locating the failures

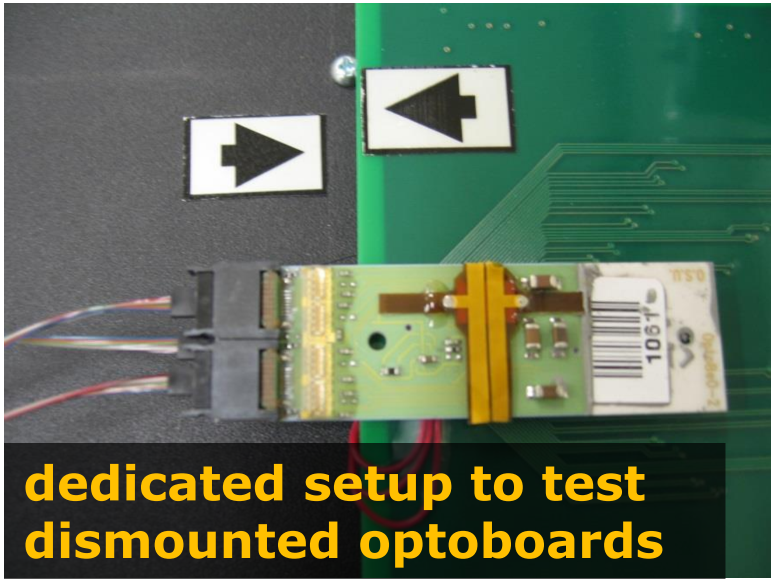
Direct Access to the Modules via type 0 cable

1 SQP with intact services

- On Detector
  - Module
  - Type 0
- SQP
  - PP0
  - Optoboard
    - DORIC Reset
    - VCSEL
  - PP1
- Services

Repair what is possible and locate the failures to learn for the future

Current Work:
Locating the failures



- On Detector
  - Module
  - Type 0
- SQP
  - PP0
  - Optoboard*
    - DORIC Reset
    - VCSEL
  - PP1
- Services →
  - exp. Cavern,
  - complete retesting

• none of the "complete optoboard" failures were located on the optoboard itself

Conclusion

- We had a very successful Run 1, the ATLAS Pixel Detector is still performing very well.
  - Detector is calibrated and tuned to a stable working point
  - high data taking efficiency
  - radiation damage effects agree well with prediction

- Main work in the next year:
  - Integration of IBL
  - Pixel reconnection

- Also:
  - address issues that have been emerging in 2012
  - working points for higher luminosity
  - achieve smooth operation and good data taking efficiency also for Run 2

- There is much work to face in LS1.
- We are looking forward to data taking in 2015!