Operational Experience with the ATLAS Pixel Detector

Laura Jeanty, Lawrence Berkeley National Lab for the ATLAS Collaboration

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The Pixel Detector in ATLAS
The Pixel Detector in ATLAS

1744 modules arranged into 3 barrel and 3 endcap layers

46080 Pixels per module → 80 million readout channels

1.4 m
The Pixel Detector in ATLAS

Sensor
- 250 μm thick n-in-n Si planar sensor
- 50 x 400 typical μm pixel size
- Bias voltage: 150 - 600 V
- Resolution: 10 μm in Rφ and 80 μm in z
- Radiation tolerance: 500 kGy $10^{15}$ 1 MeV neutron equiv. cm$^{-2}$

Readout
- 16 Front ends chips bump-bonded to sensor
- Module Control Chip (MCC) builds event
- Data transfer 40 – 160 MHz, layer dependent
2007 May: Installation in ATLAS
2008 Sept: First cosmic data
2009 Nov: First 450 GeV beam
2010 March: First 7 TeV collisions
2011 May: Luminosity reaches $10^{33}$ cm$^{-2}$ s$^{-1}$
2012 March: First 8 TeV collisions
2013 Feb: End of Run I, 27 fb$^{-1}$ total data recorded
2013 April: Pixel detector on surface
2013 Dec: Pixel detector re-installed into ATLAS
2014 May: Insertable B-Layer inserted in cavern
2015 May: First 13/14 TeV collisions
Data Taking Overview during Run I

High operational efficiency and performance achieved with regular calibrations

Slight increase in disabled modules over time

Luminosity-dependent de-synchronization of front ends

Rate limitations

Radiation damage as expected

Addressed during Long Shutdown
Data taking efficiency in Run I

Detector ready for data taking: 99.9%

Operational fraction of Pixel detector: 95%
98% at beginning of Run I

Noise occupancy: $10^{-9}$ per pixel
0.1% of noisy pixels masked online (occupancy > $10^{-6}$)

Hit efficiency for association to track: 97 – 99%
Disabled modules excluded, inefficiency mostly due to disconnected bumps and disabled front-ends

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**Noise occupancy, per layer**

**Efficiency of associating hit to track, per layer**
Detector Calibration

- Detector regularly re-tuned
- Threshold
  - Measure the discriminator activation curve as function of injected charge
  - Tuned to 3500 e-
  - Dispersion of 40 e-
  - Noise around threshold 200 e-
Detector Calibration

Time over threshold (ToT) regularly measured and tuned

ToT tuned to 30 bunch crossings (25 ns) for injected charged of 20k e-

ToT linear with injected charge for most of range

ToT used for de/dx measurement, particle ID

Improved position resolution with weighted clustering and neural networks
Data taking issues in Run I: Module De-synchronization

Module timeouts and de-synchronizations
  Increased as luminosity increased
  caused by single event upsets

Real-time recovery actions implemented
  Automatic reconfiguration of module implemented on SBC first then ROD
  reduced dead-time from seconds to ms

*ATLAS* Pixel Preliminary

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**Modules affected by desynchronisation (ROD level)**

- Number of bad modules (bad+active) per event per LB, barrel layer 2

  - Run 208811
  - Fill 2984
  - Peak Lumi $7.42 \times 10^{33}$
  - 19 h stable beams

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**Modules affected by desynchronisation (Module level)**

- # errors/event

  - without auto-recovery
  - with auto-recovery

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Data taking issues in Run I: Rate Limitations

Bandwidth between module and ROD depends on Layer

B-layer: 160 Mb/s (2 x 80) on two optical fibers
Layer 1 + disks: 80 Mb/s on one optical fiber
Layer 2: 40 Mb/s on one fiber
Data taking issues in Run I: Rate Limitations

Layer 2 will saturate at and above $2 \times 10^{34}$
Layer 1 will follow at $3 \times 10^{34}$

Expected Link occupancy at 100 kHz L1 Trigger, 13 TeV, and 25 ns bunch spacing

<table>
<thead>
<tr>
<th>Lumi</th>
<th>B-Layer</th>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Disks</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \times 10^{34}$</td>
<td>47%</td>
<td>42%</td>
<td>65%</td>
<td>37%</td>
</tr>
<tr>
<td>$3 \times 10^{34}$</td>
<td>95%</td>
<td>97%</td>
<td>148%</td>
<td>75%</td>
</tr>
</tbody>
</table>
Data taking issues in Run I: Rate Limitations

Address rate limitation in two ways:

1) New service quarter panels (NSQP) and external optoboards installed on detector during Long Shutdown I to double optical fibers and optical channels

Layer 1: New 160 (2 x 80) Mb/s on two fibers
Layer 2: New 80 Mb/s on one fiber
Data taking issues in Run I: Rate Limitations

Address rate limitation in two ways:

2) Replace existing ROD/BOC system for Layers 2 (early 2015) and 1 (2016) with ROD/BOCs designed for IBL

Boards provided bandwidth support and protection at higher pileup
New Service Quarter Panels

Rebuilt services of detector on surface

Optical electronics moved to off-detector location
  Increased data bandwidth from modules to back-end electronics
  Easier to access for future repairs

8 new service quarter panels installed

electrical → optical conversion
  moved farther from collision point
Repair of Disabled Modules

During Run 1, 2.5% → 5% of modules became disabled (correlated with thermal cycles)

All modules tested and repairs attempted on surface during Long Shutdown I

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(B-Layer disabled modules: 18 / 286)
Repair of Disabled Modules

During Run 1, 2.5% → 5% of modules became disabled (correlated with thermal cycles)

More than 60% of disabled modules repaired on surface during Long Shutdown I

Remaining issues mostly problems with HV

Disabled Modules by Failure Type (End of Run 1)

Modules to be disabled (After LS1 Re-installation)

ATLAS Pixel Preliminary
Re-installing the Pixel Detector

Cold tests in June, July, and Sept → 98% of detector working well and ready for IBL! (see Francesco Guescini’s talk next)
Radiation damage monitored in 2 ways:

1) Leakage current measured
   • Customized current measuring boards monitor the current on selected modules
   • HV power supply monitored, per 6-7 modules
   • Short cooling stops allow annealing effect, leakage current reduces
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1) **Leakage current measured**
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2) **Depletion Voltage**
   - Cross talk scans used before type inversion to measure depletion voltage
   - Type inversion:
     • B-layer: early 2012
     • Layer 1: late 2012
     • Layer 2: not yet
   - Track depth studied after type inversion to measure depletion depth
The ATLAS pixel detector showed excellent performance in the first data taking run

Improvements during the long shut down:

- Repaired modules
- New service quarter panels
- Increased optical links and readout bandwidth
- Insertable B-Layer (next talk)

The detector is back in the cavern, connected and tested with 98% coverage ready for Run 2