ATLAS Silicon Microstrip Tracker: Operation and Performance

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The ATLAS experiment
ATLAS Inner Detector

Inner Detector (ID):
- 2 T solenoid magnet; $|\eta| < 2.5$
- Transition Radiation Tracker (TRT) straw drift tubes - outer part
- SemiConductor Tracker (SCT) silicon micro-strip detector - middle part
- Pixel detector silicon pixel detector - inner part

- Robust pattern recognition
- Fast level-2 trigger
- Accurate momentum measurements
- Excellent vertex reconstruction
- Stand-alone electron identification

### Sub-detector Specifications

<table>
<thead>
<tr>
<th>Sub-detector</th>
<th># barrel layers</th>
<th># end-cap layers</th>
<th># channels</th>
<th>Operational fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixels</td>
<td>3</td>
<td>2×3</td>
<td>80 M</td>
<td>96.8%</td>
</tr>
<tr>
<td>SCT</td>
<td>4</td>
<td>2×9</td>
<td>6.3 M</td>
<td>99.1%</td>
</tr>
<tr>
<td>TRT</td>
<td>73</td>
<td>2×160</td>
<td>350 k</td>
<td>97.5%</td>
</tr>
</tbody>
</table>
SCT geometry

- 4 barrel layers
  - barrel radii: 300, 371, 443 and 514 mm; length 1530 mm
  - in total 2112 modules
- 2 × 9 forward disks
  - disk distance from z = 0: 835 - 2788 mm, radii: 259-560 mm
  - in total 1976 modules
    (3 rings: 40, 40, 52 modules each)
- 4088 double-sided modules
- 15,392 sensors of total 61.1 m²
- Total length of diode: 716 km
- 49,056 front-end chips
  - binary read-out
  - DMILL radiation-hard technology
  - total 6.3 millions channels
- Material: 0.03 $X_0$ per layer
SCT modules

- 2 planes of silicon detectors
  - stereo angle of 40 mrad to measure second coordinate
- Barrel
  - two $64 \times 64 \text{ mm}^2$ wafers chained together per module side
  - 80 $\mu$m pitch
- Forward
  - 5 different wedge-shaped sensors
  - 55-90 $\mu$m pitch

- Optical readout via 12 ABCD ASICs
  - mounted on a copper/kapton hybrid
  - each chip reads 128 channels
  - 2 data streams 768 channels each

End-cap: Radial strips for three different types

Barrel: Rectangular detectors with parallel strips
The early days …
* < 2005: test beams
* 2008 – 2009: cosmic rays
* Sep 2008: single-beam data

... and recent excitement!
* Dec 2009: Collisions @ 2.36 TeV
* Since March 2010: 7-TeV collisions
* 2011: Increasing luminosity

Excellent SCT performance during data taking
SCT operational status

- Stable configuration since December 2009
- Cooling plant working stably
  - Faulty connection to cooling loop discovered during commissioning; irreparable (behind the endplate)
- Unexpected failures of off-detector optical transmitters (TX-plugins)
  - 1 TX plugin holds 12 VCSELs → 12 modules
  - Losing ~10 TX plugins per week
  - Occur due to ingress of humidity into VCSEL
- Temporary fixes:
  - Use of module redundancy
  - Plugin replacement with spares
  - Humidity control in racks with additional dry air
- Long term fix: replace plugins with new units with better humidity resistance

> 99% of all SCT modules are operational
Noise level

- Noise measured by two methods
  1. Injection of calibration pulses ➔ noise from response-curve fit
  2. Measure noise occupancy as a function of threshold ➔ extract input noise

- Good agreement between them

Measured values well within the design specification

- noise occupancy < $5 \times 10^{-4}$
- noise < 1500 electrons
SCT hits

Good agreement between MC and 900-GeV data in number of hits per module side

* discrepancy at low N due to lower noise assumed in simulation compared to data by approximately a factor of 3
Three 25-ns time bins are read out around the trigger time (L1A)

Operation modes
- Early running: “XXX” = accept a hit in any of the 3 bins
- Now (50-ns LHC bunch train): “X1X” = require a hit in the correct bin
- Future (25-ns LHC bunch train): “01X”

Per-module adjustments are made for fibre length and time-of-flight from interaction point through timing scans

ATLAS SCT is well synchronized with trigger
Lorentz angle

- The magnetic field in the ID causes charge to drift before it is collected.

- Lorentz angle measured by minimum cluster size.

- Lorentz angle depends on:
  - Magnetic field
  - Bias voltage
  - Temperature
  - Radiation damage

Agreement between collision data, cosmics data and model prediction → good signal digitization in full simulation.
Intrinsic efficiency

Computed by counting missed hits in well-reconstructed tracks

- track $p_T > 1$ GeV
- at least 7 (6) hits for standalone (combined) tracks
- dead modules and chips taken into account

SCT hit efficiency well above specification (99%)
Radiation damage

- Radiation damage monitored through leakage current
- Comparison between measured values and FLUKA predictions
  - Good agreement in barrel region
  - Discrepancy in low-R forward region (under study)
- Leakage current evolution with time
  - So far, the measurements agree within 1σ with predictions (barrel)
  - Long-term monitoring of the effect during operation continues

Radiation effects on SCT well under control
Conclusions

- The ATLAS Semiconductor Tracker shows excellent performance
- 99.1% of the SCT modules are used for data taking
- Noise occupancy and hit efficiency well within design specifications
- Optical transmitter failures are understood and do not impair data taking efficiency
- MC simulation accurately reproduces detector geometry & material
- Radiation damage is being monitored and is in good agreement with expectations
- The SCT is a key precision tracking device in ATLAS and we are taking more and more good physics data every day
- see also Vicente Lacuesta’s talk on ATLAS ID Alignment