the **ATLAS Experiment**

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ATLAS Silicon Microstrip Tracker Operation and Performance

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The ATLAS Detector

- **Inner Detector**

Composite tracking system: Pixel detector, SemiConductor Tracker (SCT) and Transition Radiation Tracker (TRT)

Full coverage in ϕ and acceptance in pseudorapidity $|\eta| < 2.5$

Solenoid provides a 2T magnetic field

- **Calorimeters**

EM calorimeter: Liquid Ar

Hadronic calorimeter: Liquid Ar endcap Tile calorimeter (Fe scintillator) barrel

- **Muon Spectrometers**

- **Toroid**

provides a 4T field for muon tracking

- **Triggers**

3 level trigger system:

Level 1 (hardware) reduces the accept rate to 75 kHz.
2.5 μ s latency (decision time)

Level 2 and Event Filter (software) reduces the acceptance rate further to up to 200 Hz (latency of 10 ms and 2 s respectively)

The Inner Detector

Designed to accurately reconstruct vertices and charged particle tracks

- Pixel

3 cylindrical pixel-silicon layers and 2 x 3 endcap disks
1744 modules, each containing 47,232 pixels
Pixels mostly $50\text{ }\mu\text{m} \times 400\text{ }\mu\text{m}$

- SCT

Sandwiched between Pixel and TRT

- TRT

298,304 drift tubes (straws)
3 cylindrical layers with polypropylene fibres in the barrel between the straws
80 wheel-like endcap disks with polypropylene foils between the straws

Design Resolution

Transverse momentum resolution:

$$\sigma(p_T)/p_T = 0.05\% p_T \text{ GeV} \oplus 1\%$$

Transverse impact parameter resolution:

$$\sigma(d_0) = 10\text{ }\mu\text{m} \oplus 140\text{ }\mu\text{m} / p_T(\text{GeV}/c)$$

The SCT

- 4 concentric barrel layers and 2 x 9 endcap disks
- Barrel: $|z| < 805$ mm, $299 < R < 514$ mm
- Endcap: $810 < |z| < 2797$ mm, $251 < R < 610$ mm
- 4088 silicon strip detector modules
- 2112 Barrel Modules, 1976 Endcap Modules
- Cooled with C_3F_8 fluid delivered to detector with temp < 0 °C
- 2 x 768 strips per module, ~ 6.3 million strips total

SCT Modules

- p-in-n single sided silicon-strip sensors ($\sim 6\text{ cm}$ in length)
- Barrel module strip length $\sim 12\text{ cm}$, pitch $80\text{ }\mu\text{m}$
- Endcap strip length $\sim 5.5 - 12\text{ cm}$, pitch $57 - 95\text{ }\mu\text{m}$
- Sensors glued back-to-back at a stereo angle of 40 mrad , allowing for a 2-dimensional position measurement
- Sensors separated by a thermal pyrolytic graphite (TPG) base-board/spine
- The base-board/spine provides the thermal and mechanical structure
- Intrinsic accuracy per module: $17\text{ }\mu\text{m}$ ($R - \phi$) and $580\text{ }\mu\text{m}$ (z) for barrel, $580\text{ }\mu\text{m}$ (R) for endcap

SCT Module Readout

- Strips are read out by radiation-hard front-end readout chips (ABCD₃T)
- 6 readout chips on each side of module, each responsible 128 channels
- Readout is binary
- Hit or no hit (1 or 0) provided and stored for each of the 128 channels of the chip

- The threshold discriminator comparator detects signal when the amplitude is greater than a predefined threshold
- This threshold is determined by a differential voltage applied to one of its input pins and is common for all channels

Design Requirements

- Inner Detector tracking efficiency: Reconstruct isolated leptons with $p_T > 5$ GeV with 95% efficiency out to $|\eta| < 2.5$
- SCT strip efficiency $> 99\%$
- Noise Occupancy $< 5 \times 10^{-4}$ per bunch crossing
Required at a noise threshold of 1 fC (the nominal operational value of modules)
- Maximum of 1% of strips allowed to be defective

Calibration

- S curve (nHits vs threshold) produced by varying threshold whilst injecting a fixed signal
- Threshold at which occupancy is 50% = V_{t50}
- Distribution shows r.m.s spread of the threshold V_{t50} for each chip in SCT barrel.
- Trim range corresponds to TrimDAC setting which allows correction of individual channel thresholds in order to maintain uniformity of response
- Uniformity of response $\sim 4\%$
- S curve is described by a complementary error function
- Derivative of error function is the noise distribution
- σ of this distribution = noise after amplification

**Calibration carried out during
stand alone calibration runs
in 2008**

Calibration

Noise

- Input noise values for each chip as obtained in response curve tests
- SCT noise ~ 1500 e, well below typical threshold set at 1 fC (1fC $\sim 6,240$ e)

Calibration

- Noise occupancy specification:
 $< 5 \times 10^{-4}$
- Can be measured from noise using charge injection or directly counting hits using a random trigger
- Both methods show good agreement

- Occupancy better than 10^{-5} , less than specification of 5×10^{-4} (dotted line)
- Few strips ($< 0.2\%$) with occupancy greater than 5×10^{-4} are disabled
- Average silicon temperature estimated for the operation conditions

Path to Collisions

2008

- Single-beam LHC running
- September setback
- Combined ATLAS cosmic-ray run
- Standalone ID cosmic-ray run

Cosmics extremely useful for ID alignment and detector timing and for testing the triggers, tracking and data acquisition system

Inner Detector event display of a cosmic event

Path to Collisions

2009:

- More cosmic runs (November 23rd):
- First collisions at 900 GeV! (December 8th):
- 2.36 TeV collisions (world record)

2010

- 932 million 7 TeV collisions
- ATLAS recorded lumi: 16.02 nb^{-1}
as of 08/06/2010

Operating Conditions

- Detector Control System (DCS) controls and monitors the supply of powering, cooling and other control signals, ensuring a safe functionality
- Most of detector operational during cosmic runs
- Configuration stable since 2009
- **Currently** ~99.3% of all SCT modules are operational
- Operational strips better than specification

ATLAS SCT Configuration May 2010

Disabled Readout Components	Endcap A	Barrel	Endcap C	SCT	Fraction (%)
Disabled Modules	5	10	15	30	0.73
Disabled Chips	5	24	4	33	0.07
Masked Strips	3,364	3,681	3,628	10,673	0.17
Total Disabled Detector Region					0.97

ATLAS SCT Disabled Modules May 2010

	Endcap A	Barrel	Endcap C	SCT	Fraction (%)
Total	5	10	15	30	0.73
Fraction (%)	0.5	0.2	1.5	0.7	
Cooling	0	0	13	13	0.32
LV	0	6	1	7	0.17
HV	4	1	1	6	0.15
Readout	1	3	0	4	0.10

Performance

Timing

- Readout of the SCT is synchronized with the bunch-crossing time
- Ensures that the signal is sampled at the peak of the charge response curve
- SCT reads out three consecutive 25 ns time bins (0, 1 and 2). 25 ns corresponds to LHC bunch crossing spacing
- Readout is centered on time bin 1 (same bunch-crossing as level-1 accept)
- Hits corresponding to tracks from a collision should have nothing in the first bin and should be over the threshold in the second bin. No requirement on third bin
- Average of time bin value (0, 1 or 2) taken over all events for all layers

Performance

Timing

- Commissioned with a threshold of 1 fC
- The mean time bin should ideally be between 1 and 2
- For this plot individual module timing offsets were adjusted for optical fibre lengths
- Timing is very good/uniform without final adjustments from fine timing scan

Performance

Number of Strips per Module Side (Occupancy)

- Data vs simulation
- Normalised by number of events
- All SCT modules
- Good agreement
- Discrepancy at low N
(Due, in part, to there being more noise in data than Monte Carlo simulations)

Performance

- Hit Efficiency

Intrinsic hit efficiency of the SCT measures the fraction of hits per possible hit

For a well reconstructed track the number of hits (clusters) and the number of holes (where a hit is expected but not found) are counted

Efficiency defined as:

$$\varepsilon = N_{\text{clusters}} / (N_{\text{clusters}} + N_{\text{holes}})$$

- Dead modules and chips taken in to account
- Tracks require ≥ 20 TRT hits and ≥ 6 SCT hits

Performance

- Hit Efficiency for Endcaps A and C
- Dead modules and chips taken in to account
- Tracks require ≥ 20 TRT hits and ≥ 6 SCT hits

$$\epsilon = N_{\text{clusters}} / (N_{\text{clusters}} + N_{\text{holes}})$$

Performance

Alignment

- Residual = measured hit position - expected hit position (from the track extrapolation)
- As cosmics are $\sim$ vertical they are particularly useful to align the barrel
- With collision data the alignment of the endcaps are seen to improve (in particular SCT endcap C)

Unbiased residual distribution for barrel

Performance

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Unbiased residual distribution for endcaps

Performance

Alignment

- ID alignment further improved using 900 GeV and then 7 TeV collision data
- Alignment very close to ideal alignment (MC)

SCT Barrel:

Cosmics(42 μm), Cosmic MC(36 μm)

Collision Data(42 μm), MC(34 μm)

SCT Endcap:

EndcapA: Cosmics(83 μm), MC(46 μm)

EndcapC: Cosmics(122 μm), MC(46 μm)

Collision Data(44 μm), MC(38 μm)

Performance

- Good alignment allows for accurate tracking and invariant mass reconstruction
- Plot shows the invariant mass distribution of 2 track (opposite charge) vertices
- Accurate reconstruction of K short invariant mass

Performance

Lorentz Angle

- As charge carriers drift through the silicon wafer to the readout strips they are deflected by the magnetic field
- The Lorentz angle is the angular deflection relative to the electric field direction
- Depends on magnetic field strength, bias voltage across the wafer and temperature
- Model: $\theta_L = -3.69^\circ \pm 0.26^\circ$
  - Error on model from uncertainties in charge-carrier mobility
- From 2008 Cosmic data:
 $\theta_L = -3.93^\circ \pm 0.03^\circ \pm 0.10^\circ$
  - Dominant systematic error from fit range
  - Compatible with model

Performance

Lorentz Angle with collisions

- Number of strips in a cluster vs incident angle of the track has minimum displacement from zero equal to the Lorentz angle
- Layers operate at different temps

- Lorentz angle extracted from the cluster size vs angle distribution
- Shown for cosmic data, collision data and also the model prediction in yellow
- Measured value is higher than prediction by $\sim 1\sigma$ of error on model prediction

Conclusions

- The SCT has performed well during commissioning, cosmic data taking and collisions:
  - 99.3% of all SCT modules operational
  - Noise occupancy and hit efficiency exceed design specifications
  - Alignment very close to nominal, allowing for accurate track and invariant mass reconstruction
  - Resolutions consistent with expectations

**Exciting times ahead with greater luminosity,
beams at higher intensity and ultimately higher
energy collisions**

Bonus Material: The Barrel Modules

1. 4 Sensors

285 microns thick p-n
(Hamamatsu)
Strip length 12cm
Pitch 80 μ m
Vmax = 500V

2. 3rd Mounting point

3. Hybrid & Binary Readout chips

Flex circuit with 12 x ABCD chips.

7. Overlaps

Overlap in $r\phi$ and Z to adjacent modules

8. Stereo angle

Upper or lower detector pairs rotated by 40 mRad

4. Be Facing & Central TPG

TPG (thermal pyrolytic graphite) plate for sensor cooling

6. Connector

Power & Data

5. Module support & Location Holes

fix to brackets, one hole & one slot

Bonus Material: The Endcap Modules