ATLAS SemiConductor Tracker Operation and Performance

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On behalf of the ATLAS Collaboration

RD11

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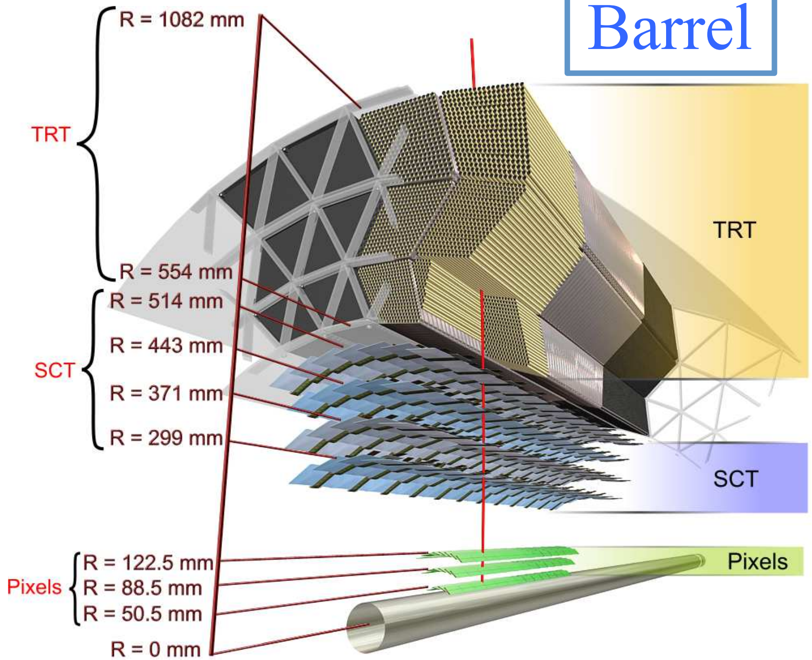
SCT – SemiConductor Tracker

- SCT in ATLAS Inner Detector
  - 2 T solenoid B-field
  - In between Pixels and TRT (Transition Radiation Tracker)
  - 1 Barrel (4 layers) and 2 Endcaps (9 disks on each side)
- SCT specification

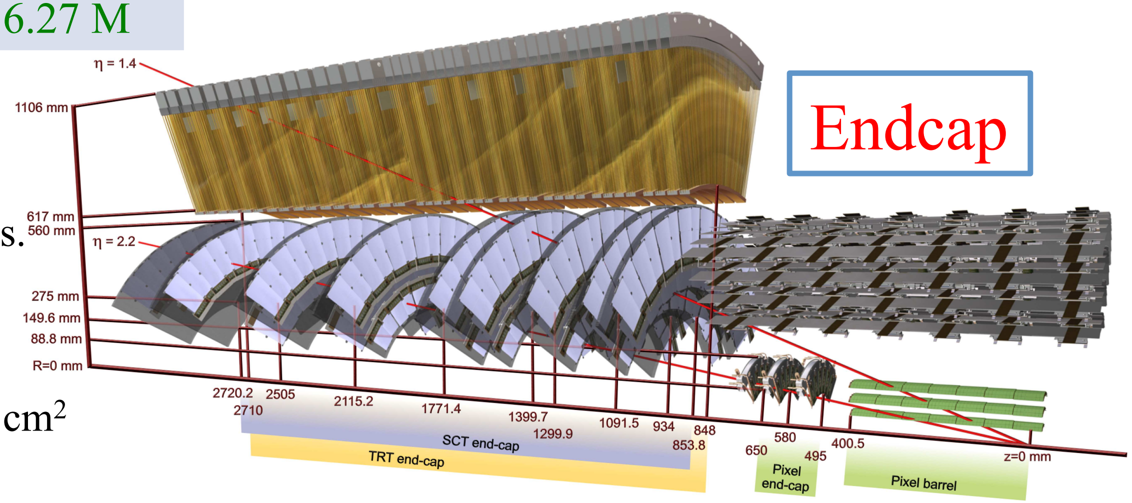
	Barrel	Endcaps	Total
Layer	4	2 × 9	22
Module	2,112	2 × 988	4,088
Strip	3.24 M	2 × 1.52 M	6.27 M

  - Silicon active area of 61 m^2
  - Hermetic in $|\eta| < 2.5$
    - Track with $p_T > 1$ GeV/c passes 4 layers.
  - Radiation hardness for 10-year operation
    - Non-ionized radiation : $< 2 \times 10^{14}$ n_{eq} / cm^2
    - Ionized radiation : < 10 Mrad

Barrel



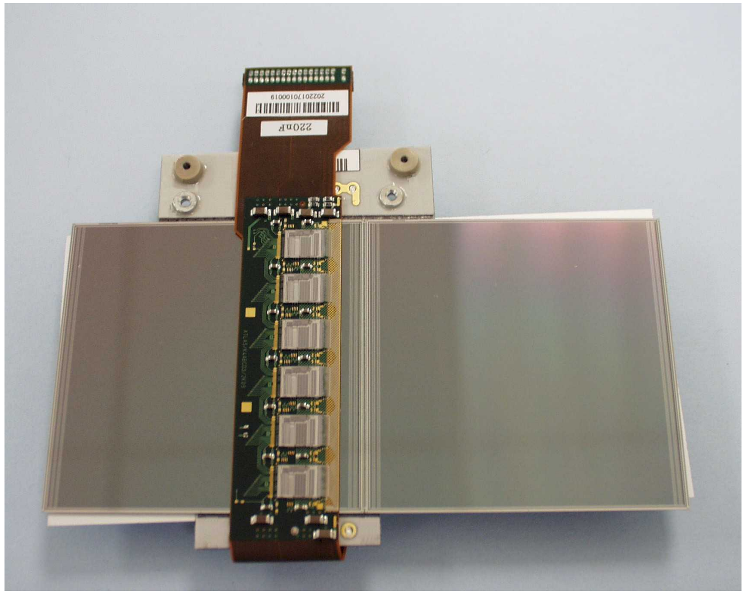
Endcap



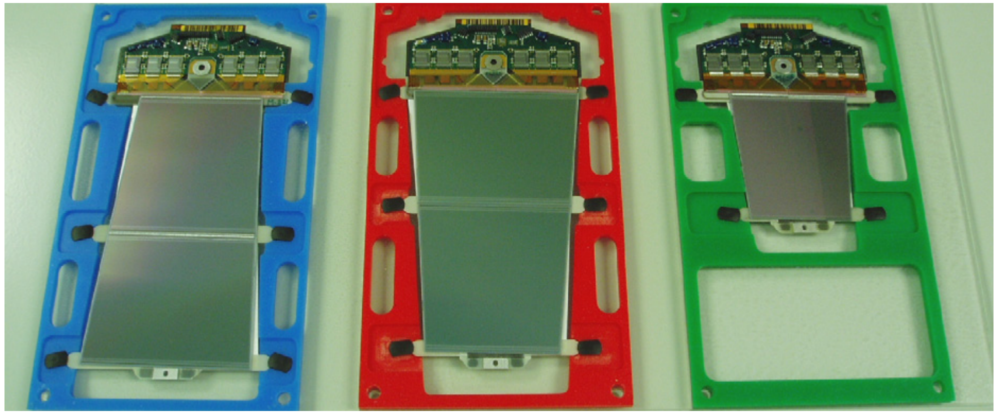
SCT Modules

- Silicon strip sensor
  - p-in-n single-sided & AC-coupled sensor
  - 6 types of sensor geometries
    - Barrel : 1, Endcap : 1 (inner), 2 (middle), 2 (outer)
  - 285 μm thick
  - 80 μm (barrel), 56.9 – 94.2 μm (endcap) pitch
- Readout chip : ABCD3TA
  - DMILL BiCMOS rad-hard process
  - 128 ch/chip
  - Binary readout at a nominal threshold of 1 fC
  - Clocked at 40 MHz
  - 132-cell deep pipeline
- Module
  - 2 sensors glued back-to-back w/ 40 *m*rad stereo angle
  - 6 chips/side on a Cu-Kapton flex hybrid
  - V_{bias} = 150 V (< 500 V)
  - Resolution : 17 μm (rϕ), 580 μm (z)

Barrel

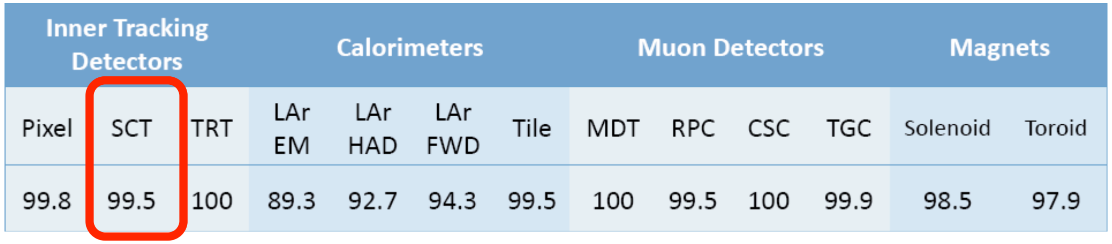


Endcap

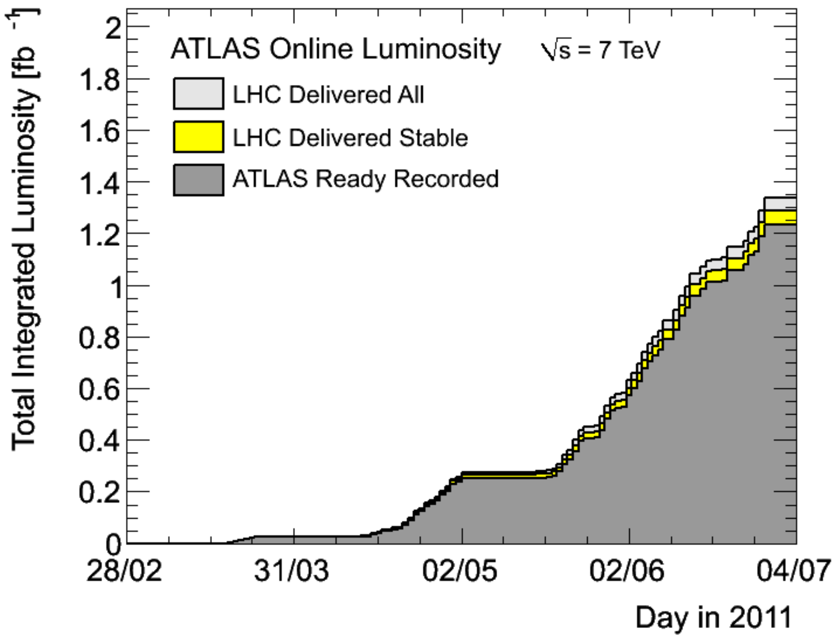


SCT Operation

- LHC/ATLAS operation
  - Recorded 1.2 fb^{-1}
  - Move from 75 ns to 50 ns bunch trains
  - **A very high data-taking efficiency in ATLAS/SCT**

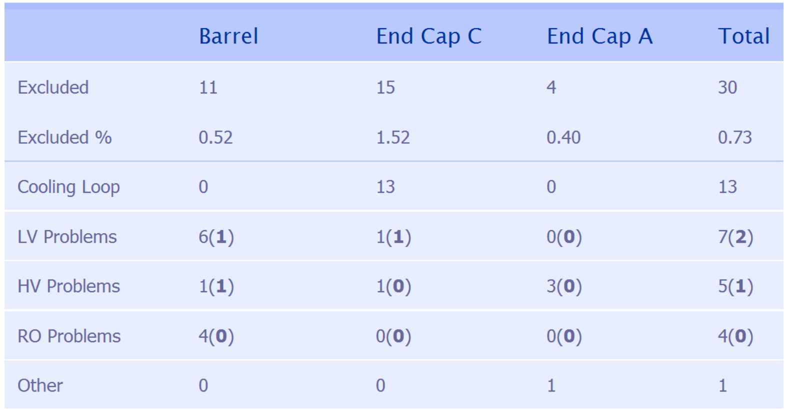


Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.5	100	89.3	92.7	94.3	99.5	100	99.5	100	99.9	98.5	97.9



- SCT
  - Modules disabled in physics running
    - **Nominally 0.73 % (30 modules out of 4088 modules)**
  - **"Warm start" operation**
    - Standby at V_{bias} = 50 V (Full depletion ~65 V)
    - Goes to **a nominal V_{bias} = 150 V** in a few minutes after :
      - Stable beams are declared by LHC,
      - Beam backgrounds are confirmed to be low (by Beam Conditions Monitor)
      - LHC component settings (such as collimators position and magnet currents) are within expected values.

Modules disabled in DAQ
(A nominal condition in 2010)



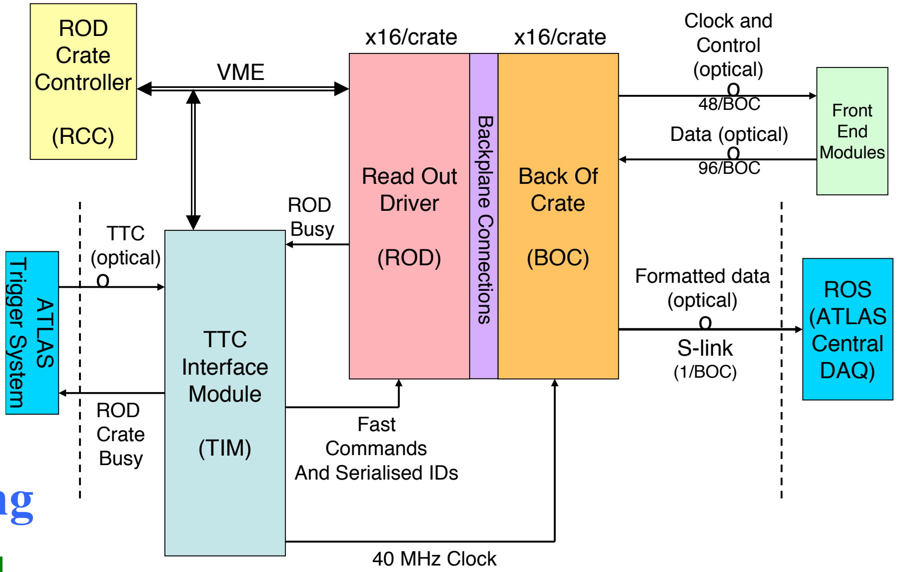
	Barrel	End Cap C	End Cap A	Total
Excluded	11	15	4	30
Excluded %	0.52	1.52	0.40	0.73
Cooling Loop	0	13	0	13
LV Problems	6(**1**)	1(**1**)	0(**0**)	7(**2**)
HV Problems	1(**1**)	1(**0**)	3(**0**)	5(**1**)
RO Problems	4(**0**)	0(**0**)	0(**0**)	4(**0**)
Other	0	0	1	1

() : unfixable

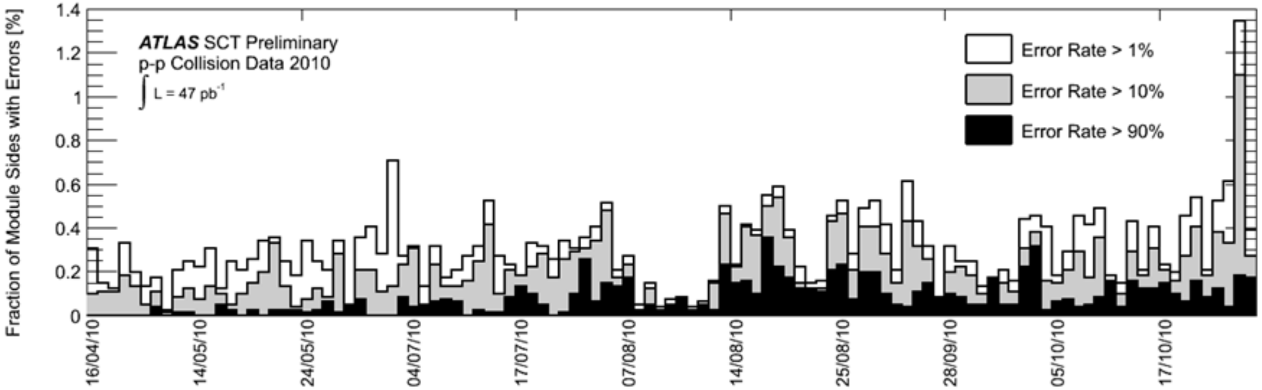
Data Taking

- **Read Out Driver (ROD)** in DAQ system
  - 48 modules per ROD
  - 1 optical fiber per module to send clock and control
  - 2 optical fibers per module to read out data
  - **ROD busy (as rare case)**

  ➔Stop-less removal & recovery to continue data-taking w/ ATLAS running



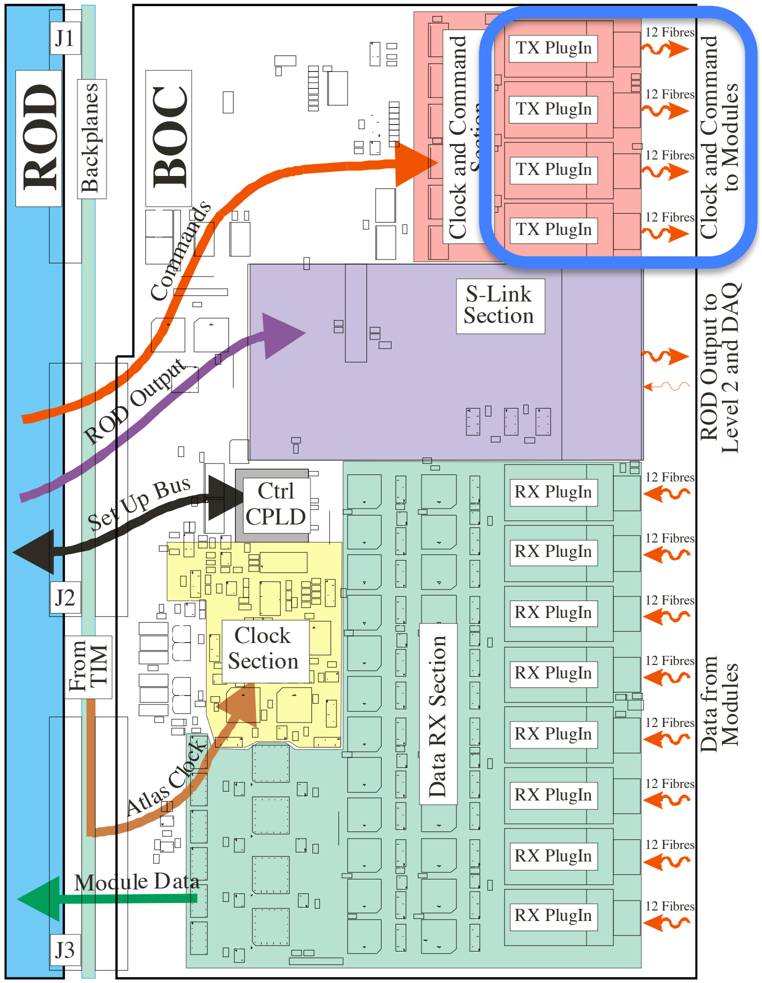
- **A very low error rate in DAQ system and RAW data recording**



Excellent performance of the SCT data taking

An Issue – TX Plugin in ROD

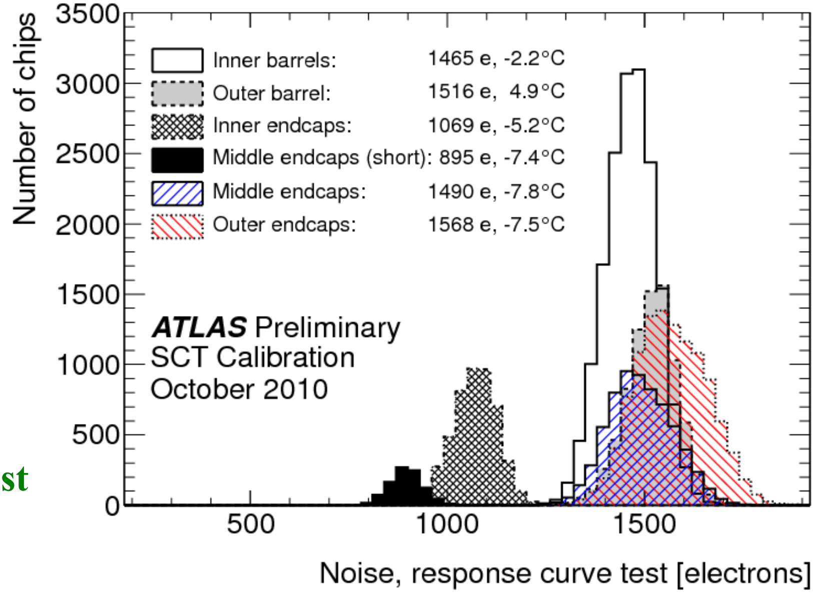
- TX plugin
  - Optical transmitter to modules
  - 12 VCSELs per TX plugin
  - 1 VCSEL transmits the optical clock/control signals into a module via the optical fiber
  - 4 TX plugins per ROD
  - 360 TX plugins in the entire SCT
- **The issue – TX death**
  - The issue before : ESD
    In 2010, rebuilt all TXs with better ESD precaution
  - **The issue now : less humidity-resistant**
    ~10 TXs dying per week
  - (Temporary) solutions
    - Utilize redundancy : Send signals from neighbors
    - Replacement of TX plugins
    - Humidity control in racks with additional dry air

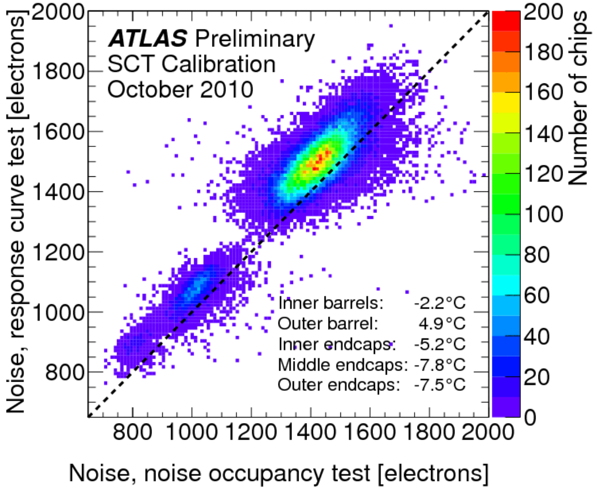

BOC Block Diagram

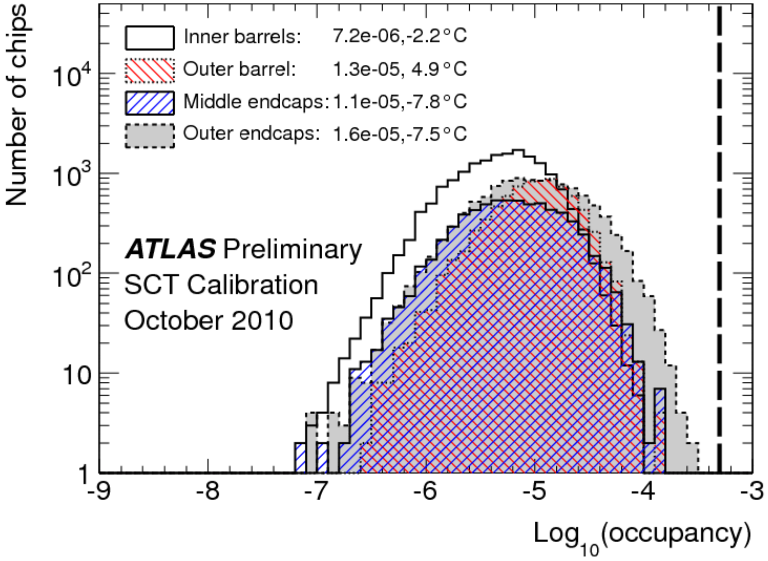
THE SOLUTION :
New productions of humidity-resistant TX plugins

Calibration

- Calibrations in between LHC fills
  - Response curve test : S-curve from threshold scan w/ charge injected
    - Extract **gain** and **input noise**
  - Noise occupancy (NO) test : Take NO as a function of threshold
    - Extract **NO and input noise**
    - **Noise consistent with that from the response curve test**
  - Defect chips/strips
    - **Detected by the above two calibration tests are masked in reconstruction.**





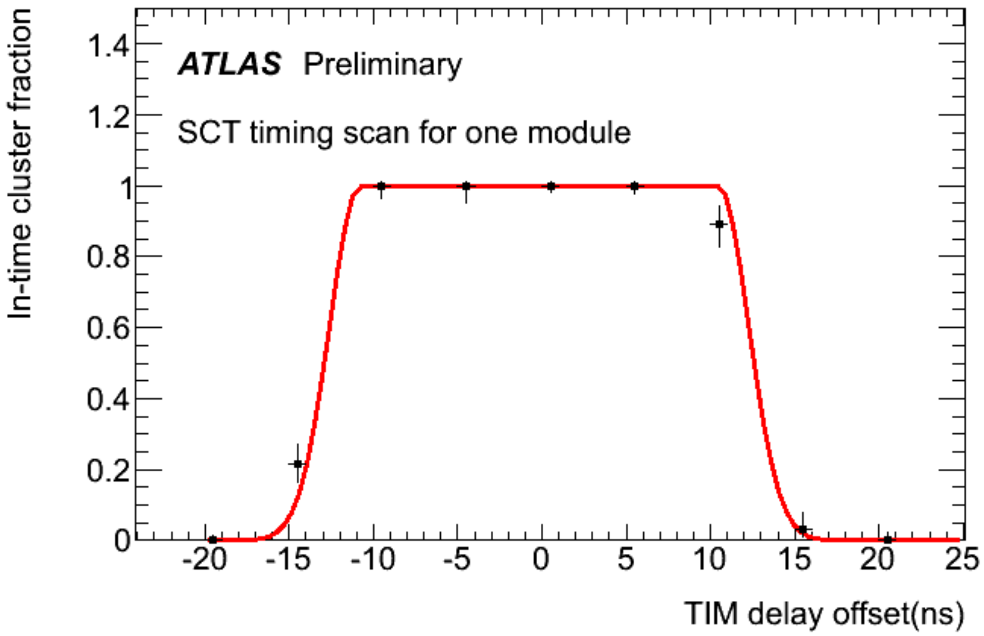


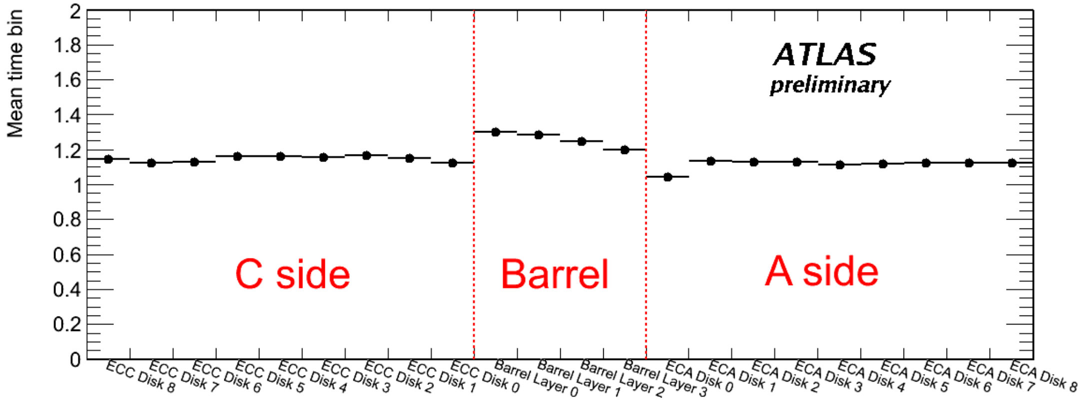
Noise occupancy < 5×10^{-4} and Noise < 1500 e^- fulfill the design requirements.

Timing

- 3 time bin readout
  - 1 time bin : 25 ns (40 MHz LHC clock)
  - Readout of 3 time bins centered on L1A

    e.g. 01X – 1st bin : no hit
    2nd bin : hit required (at L1A)
    3rd bin : no hit requirement
    X1X – hit required at L1A
    XXX – Any hit mode
- Time-in
  - Timing scan is done for each module using collision data (with special requests)
  - Maximizing 01X fraction of hit patterns
- Operation mode
  - Recently moved from XXX to X1X to deal with 50 ns LHC bunch trains
  - Plan to move to 01X when LHC moves to 25 ns bunch train operation

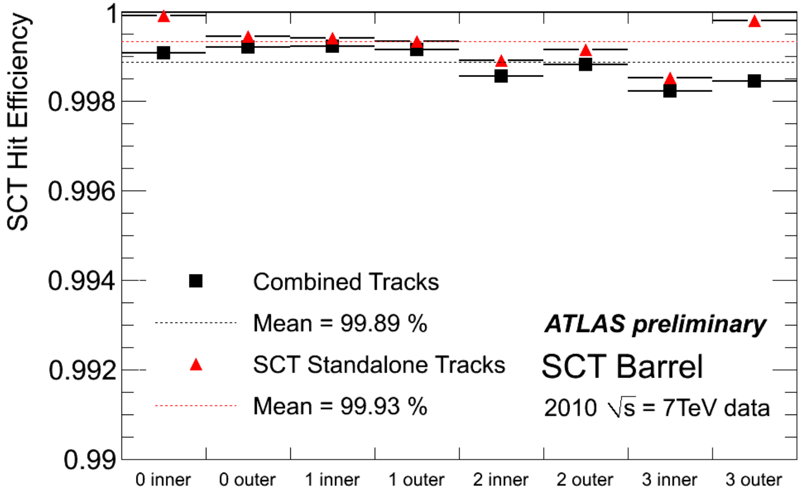


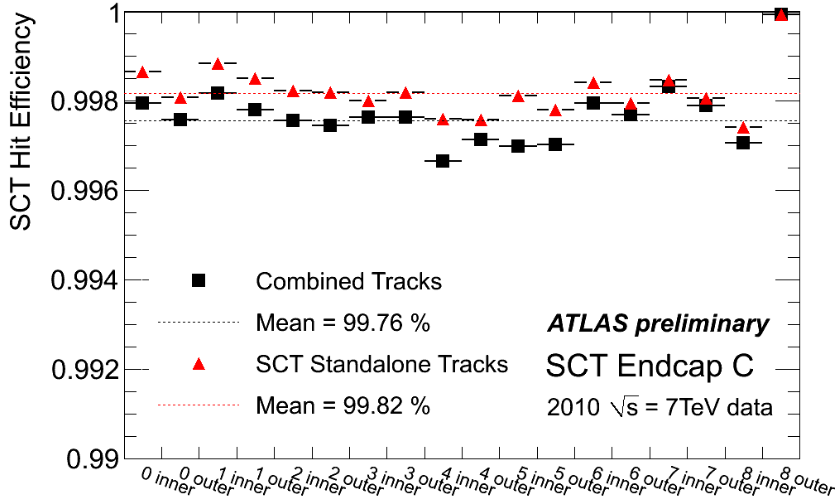


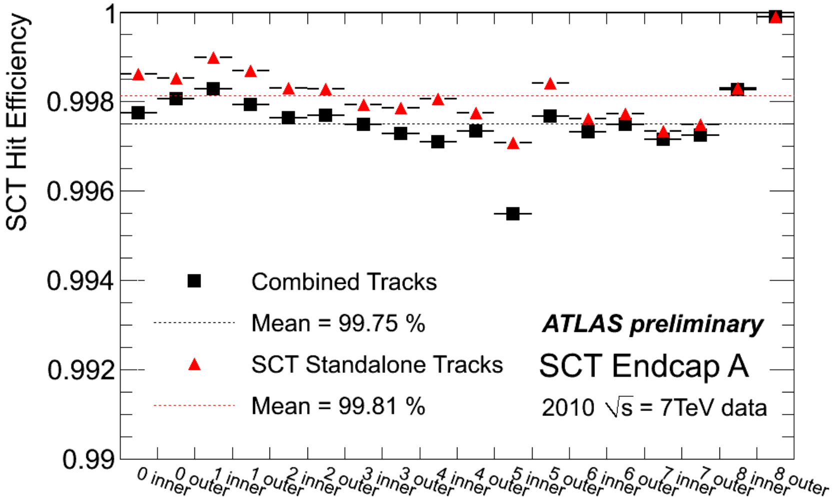
The SCT is well timed-in.

Hit Efficiency

- Intrinsic hit efficiency measured
  - Track $p_T > 1$ GeV/c
  - SCT hits on track required
    - ≥ 6 for Inner Detector combined tracks
    - ≥ 7 for SCT standalone tracks
  - Dead module/chips are removed.



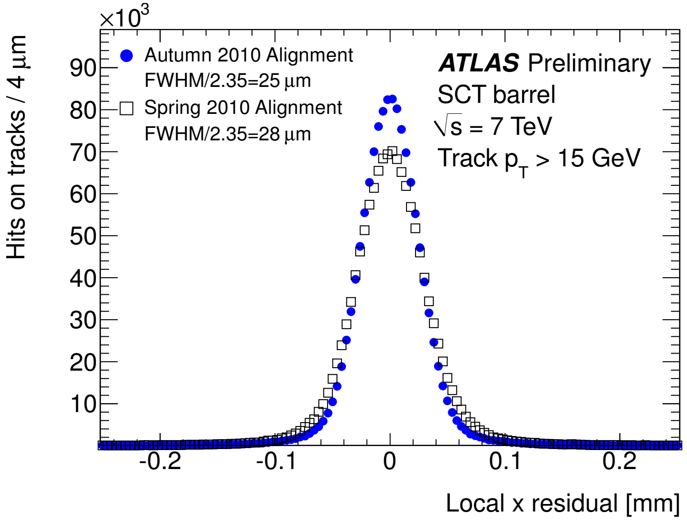


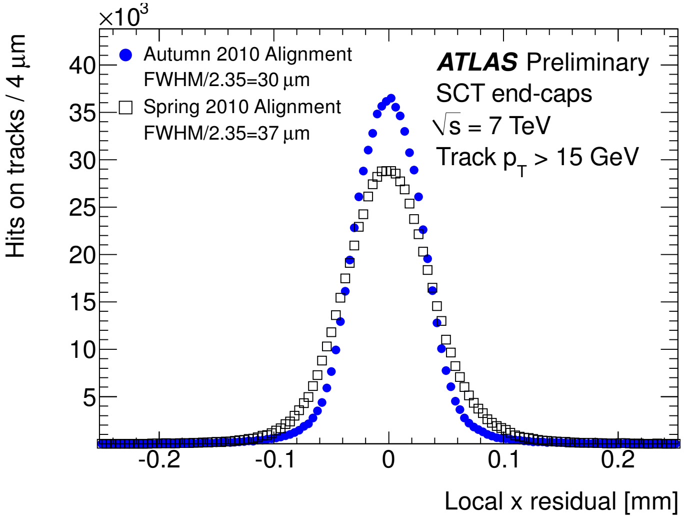


The SCT hit efficiency is well above the design requirement of more than 99.0% in all barrel layers and endcap disks.

Alignment

- The alignment performed by using a track-based algorithm
  - Minimize a χ^2 from track-hit residuals
- Dedicated samples to extract the alignment constants
  - Isolated high p_T tracks in collisions by the high-level trigger
  - Cosmic-ray tracks during physics running
- Alignment performance in a jet trigger sample
  - **A large improvement from the previous alignment (using 900 GeV collision data in 2009)**
- **Move to time-dependent studies using more statistics in 2011**





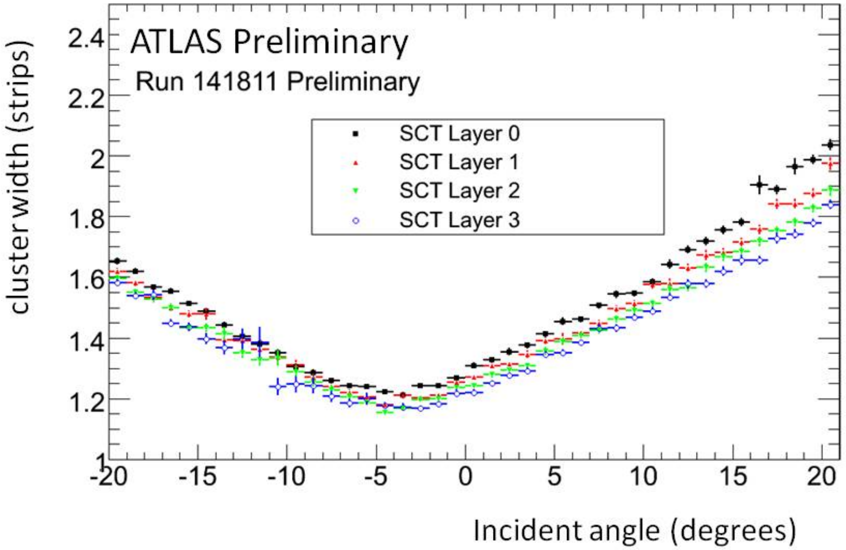
Alignment of the SCT at the module-level is under control and is approaching to the design value.

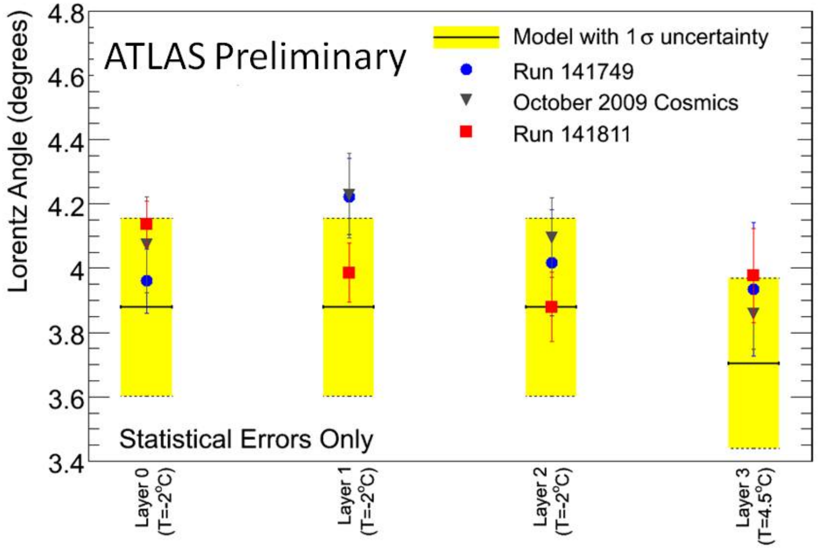
Lorentz Angle

- Lorentz (Hall) angle
  - A carrier drift direction is deflected by Lorentz force in a B-field.
  - The Lorentz angle is measured to be the track incident angle at minimum cluster width.
  - Depends on B-field, bias voltage and temperature
- Sensitive to :
  - Model of signal digitization in full simulation
  - Radiation damage

Successful measurement in collision data, consistent with cosmic data and model prediction including temperature dependence

- **Improvement of the full simulation model is under way and plan to monitor in a long term operation**



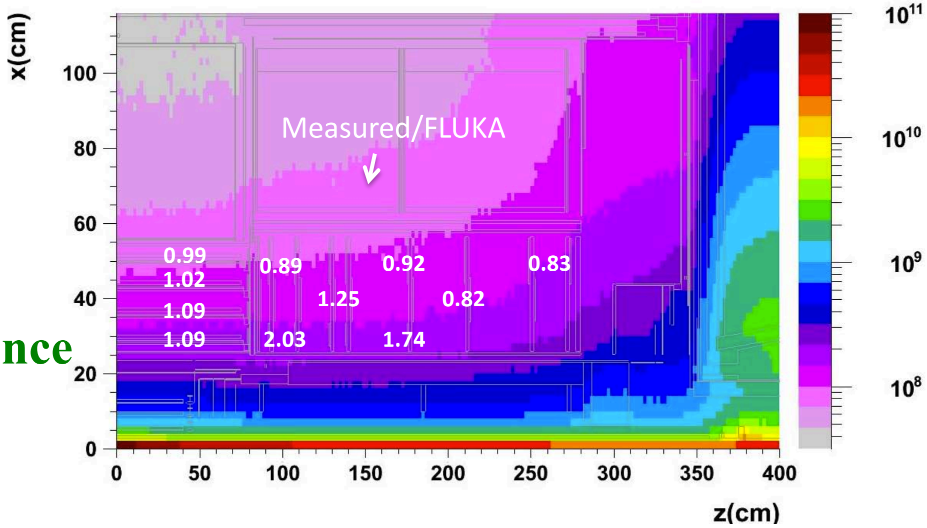


Radiation Damage

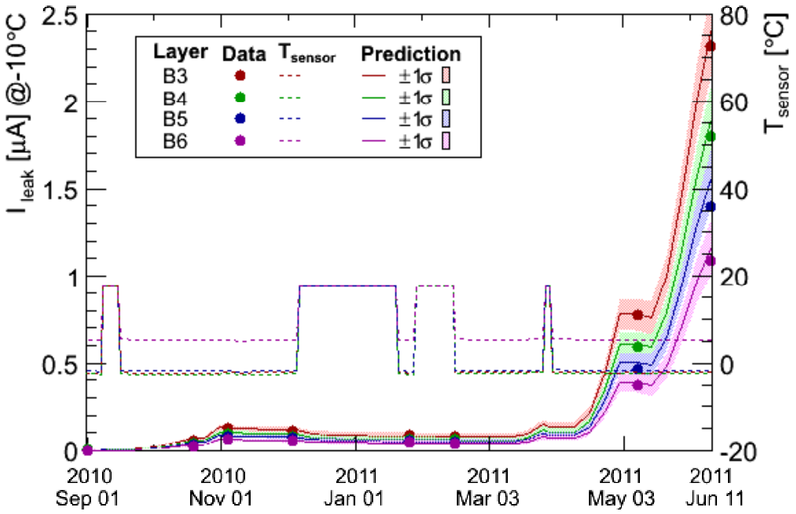
- NIEL : 1 MeV neutron equivalent fluence
  - Measurement from SCT leakage current
  - **Comparison with FLUKA predictions**

Barrel : Consistent

Endcap : A slightly different radial dependence



- Leakage current increase
  - Converted values at -10 deg C
  - Predictions based on NIEL from FLUKA simulation, time-dependent annealing effects and delivered luminosity
  - **Consistent with the prediction within 10% level**



The first effect of radiation damage is seen and understood.
Continue monitoring the effect for a long term operation.

Summary

- A successful operation of the SCT together with LHC/ATLAS
  - 99.5 % data-taking efficiency in 2011
  - 99.3 % of modules in a nominal operation

- The issue is in TX death : solutions exist
  - Redundancy and replacements
  - New productions

- Excellent performance
  - Fulfilling the design requirements for noise and hit efficiency
  - Alignment is approaching to the design value.

- The first effect of radiation damage is seen and understood.

Backup Slides

Alignment

- Comparison with a Monte-Carlo sample (PYTHIA dijet)
- **The alignment is approaching to the ideal value.**