ATLAS SCT Commissioning – TWEPP-07

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Abstract

The Barrel and End-Cap SCT detectors are installed in the ATLAS cavern. This paper will focus on the assembly, installation and first tests of the SCT in-situ. The thermal, electrical and optical services were tested and the results will be reviewed. Problems with the cooling have led to a modification for the heaters on the cooling return lines. The first tests of the SCT in-situ will be described using the calibration scans. The performance of the SCT, in particular the fraction of working channels and the noise performance, is well within the ATLAS specification.

I. Introduction

The ATLAS detector [1] is one of the two general purpose experiments currently under construction for the Large Hadron Collider (LHC [2]) at CERN. The LHC is a proton-proton collider with a 14-TeV center-of-mass energy and a design luminosity of 10^{34} cm^{-2}s^{-1}. The main detector components of ATLAS are the Inner Detector (ID), the electromagnetic and the hadronic calorimeters, and the muon spectrometer. The ID [3] is a system designed for tracking, particle identification and vertex reconstruction, and it will operate in the 2-Tesla field of a superconducting solenoid. The ID consists of a pixel detector at the innermost layer, the Semiconductor Tracker (SCT) in the middle layer and the transition radiation tracker (TRT) at the outermost layer.

This paper focuses on the SCT assembly and installation as well as the first tests of the SCT in its final position in the ATLAS cavern and its performance so far.

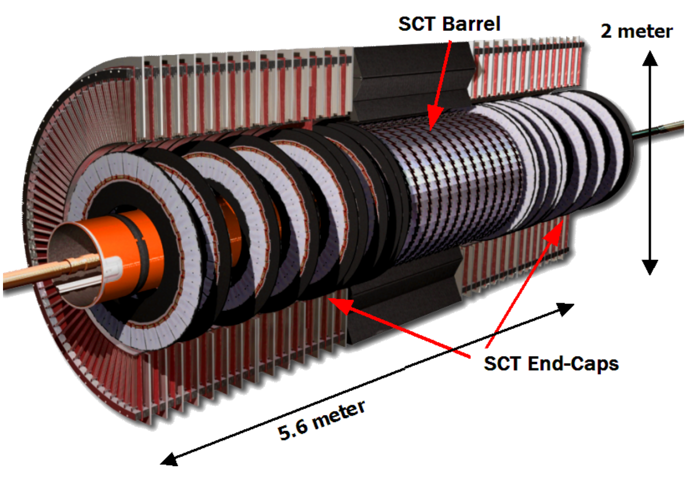

Figure 1: Layout of the ATLAS Inner Detector with indications to the Semi-Conductor Tracker barrel and end-caps

A. Lay-out

The ATLAS SCT was designed to measure at least four space-points for all charged particles tracks with $\eta < 2.5$ coming from the interaction region. For this purpose the SCT [3] consists of four cylindrical barrel layers, covering the region for $0 < |\eta| < 1.1 - 1.4$, and two end-caps composed of nine disks each that cover the region for $1.1 - 1.4 < |\eta| < 2.5$. Figure 1 shows the lay-out of the ATLAS ID with the the SCT barrel and end-caps indicated. The total SCT has length of 5.6 m, an outer radius of 56 cm and an inner of radius of 27 cm. This results in an area of 61 m^2 of silicon strip sensors divided over 2112 detection modules in the barrel region and 1976 modules in the end-cap region.

B. SCT modules

All SCT modules are similar in functionality but come in five different types that mostly differ in shape and size. The SCT barrel utilizes one type of module [4] which has a rectangular shape and a strip pitch of 80 μm pitch. The SCT end-cap contains four different trapezoidal shaped modules [5] that have a strip pitch of 57 to 94 μm.

Each SCT module is composed of 2 planes of single-sided p-in-n micro-strip sensors [6] glued back-to-back at a 40-mrad stereo angle to provide a two-dimensional position measurement. Each module has 1536 channels in total, which are readout by the ABCD3TA chips [7]. Twelve ABCD3TA chips are mounted on the copper/kapton hybrid of each module and each chip is wire-bonded to 128 channels. The ABCD3TA chip is an Application Specific Integrated Circuit (ASIC) that shapes, amplifies and converts the strip signals into a binary output signal. The ABCD3TA chip also contains a charge injection circuitry, which is used for calibration, and a pipeline memory that stores hits for 132 bunch crossings, while awaiting a Level 1 trigger signal.

Optical links [8] provide communication between the module and the off-detector electronics. An opto-package connects to each module and contains a *p-i-n* diode to receive the Timing, Trigger and Commands (TTC) signals and two VCSELs to return data from each side of one module. Redundancy options are available in case of broken links, which allow the TTC signals to be sent via a neighboring module or the data from both sides of one module to be read-out via one link.

The module performance has been extensively studied in beam tests using irradiated SCT modules [9]. The SCT has been designed to be able to be operated during 10 year of LHC running, requiring a radiation hardness of $\approx 2 \times 10^{14}$ 1-MeV-neutrons/cm^2. To minimize radiation damage and to minimize noise from the leakage current it is foreseen to keep the sensors cooled at $\sim$ -10°C.

C. Assembly and installation

In order to ensure that the SCT modules will perform within specification once installed in the ATLAS cavern,the module performance is fully tested and re-tested during many stages of the assembly and installation process.
The main test stages of the SCT modules are after:

1. Production (at module assembly sites)
2. Reception at macro-assembly site
3. Macro-assembly
4. Reception of single barrel or end-cap at CERN
5. Installation in ATLAS cavern

The module performance tests are composed of digital tests to check the functionality of the ABCD3TA chips and analogue tests to check the performance of all channels. The analogue performance tests are described in section III. All 4 SCT barrels were assembled by the University of Oxford, while one SCT end-cap was assembled by NIKHEF and another by the University of Liverpool. A carbon-fiber support structure forms the basis for the disks/barrels on which the SCT services and modules are mounted. The SCT services are composed of the cooling lines, the Low Mass Tapes (supplying power to the modules), the optical communication system and the Frequency Scanned Interferometry (FSI) alignment system. Each assembly site had their own test-setup that allowed to dry, cool-down and power one disk or barrel at a time to verify the performance of the assembled system. These tests started by verifying and finding the optimized settings for the optical communication before repeating the module performance tests.
Each completed end-cap and each single barrel was sent to CERN in the course of 2005 where they underwent an intensive series of reception tests in the surface reception area (SR1). The test setup in SR1 used a cooling setup similar to final ATLAS cooling and allowed the DAQ and DCS software to be debugged in a setup similar to the final setup in the ATLAS cavern. The four single barrels were integrated into one single SCT barrel after the single barrel reception tests and the full SCT barrel was inserted into the TRT barrel. Similarly, the SCT end-caps were retested upon reception and inserted into the TRT end-caps.
Cosmic test data was taken for the SCT+TRT barrel [10] and one of the SCT+TRT end-caps so the performance of the simultaneous running of the detectors could be tested and the detectors could be operated in physics mode for the first time.
The SCT+TRT barrel was installed in august 2006 and had to be connected and fully tested before the end-caps could be inserted, as further access to the connections were blocked from that point onward. The SCT+TRT end-caps were installed in May 2007, which followed after a delay in the installation schedule as problems with the SCT cooling system (described in section E.) required a longer period of access to the SCT barrel.

D. SCT in-situ tests

With the SCT barrel and end-caps in their final position in the ATLAS cavern, the SCT is now being operated with the final services that will be employed during LHC data taking. It was important at this point to ensure the correct mapping of all connections to the detector. The SCT barrel has finished its connection tests successfully and performed a series of performance tests while being cooled. At the time of writing, the connection tests for the SCT end-caps were finishing.

E. Cooling system

The module cooling is based on a evaporative system employing C3F8 to remove up to 40kW of heat. Any liquid in the exhaust pipes must be evaporated and raised above the cavern dew point to avoid condensation, therefore heaters were installed in the exhaust lines. During the first tests of running the SCT barrel with its final cooling services, a short occurred in the power connector of these heaters. The heater in question had a history of non-conformity and vulnerability to moisture ingress was assumed. When all non-conformities, permeability to moisture as well as geometrical non-conformity, were found and corrected, the cold SCT barrel tests continued. After 5 days of operation another power connector shorted. This connector had no history on non-conformity. After the second heater incident it was decided to move the heaters into a more serviceable area on the backplate of the SCT-end-cap detectors. The new “far-end” heater design allowed the end-caps to be inserted while a solution for the heater connector problems was under investigation. An improved design for the heater connector has been developed since then.

II. Electric and optical connection

A large number of power supply crates are needed to house the HV and LV cards that supply the power to 4088 modules and the same number of power cables have to be connected correctly at power supplies. A simple electrical test system is used to check the continuity of all electrical connections to the modules. This allowed broken tracks on the Low Mass Tapes, connector problems and shorted wires to be discovered and repaired in-situ while access was still possible.
The control and read-out of the modules require ROD (Read Out Driver) and BOC (Back Of Crate) cards that interpret and send the optical communication signal. The BOC sends the clock (at 40.08 MHz) and command signal and receives data from the 2 optical streams from each module. In calibration mode, the ROD can run a series of tests in which the events from the modules are decoded and put into histograms. In physics mode the ROD decodes data from the modules, before sending to the BOC the event fragment to send up the ATLAS read-out chain.
Optical ribbons, each serving 12 optical streams, connect to the BOCs. A total of 354 ribbons are needed for the TTC signals and 708 ribbons are need for the optical data returned by the detector. Powering one module and checking that the module is configured and returning data, ensures that all the connections are in the right place, as well as providing a way in which to debug possible mapping errors.
The current induced in the *p-i-n* diode by light from the BOC

with V_{pin}=6 Volt is measured to check if the light from the BOC arrives at the module. The threshold for operating the module is I_{pin} = 0.02 mA. All modules that were tested so far see clock and commands signals and are configured. However, approximately 25% of the modules have I_{pin} < 0.1 mA while to reduce single event upsets caused by the diode during high luminosity runs, I_{pin} > 0.1 mA would be required. It has been found that employing Micro Lense Arrays (MLA) to focus the light from the BOC increases the pin-current for all problematic channels, and in the future all TXs might be replaced by channels with MLA's.
To test, without cooling, if each module was able to return a stream of test data required a scan to be run in a short time as the module could overheat in less than 10 seconds when being powered.
The light output performance of each VCSEL-link is measured during a fast (< 7 seconds) scan where each VCSEL-link returns an optical data pattern which is read at a range of BOC settings for the threshold and the delay. Figure 2 shows an atypical example of the output of 2D BOC scan where the light from link0 is well below average. The current measured by the power supplies indicates if the module is correctly powered and configured.
The connection tests made after installation of the SCT barrel and end-caps, showed that almost all modules could be powered correctly and that the optical communication between the modules could be correctly established. The only exceptions were one SCT barrel module, which did not receive its HV bias voltage and one SCT end-cap module, where a short on the line supplying V_{VCSEL} prevents the module from returning data.

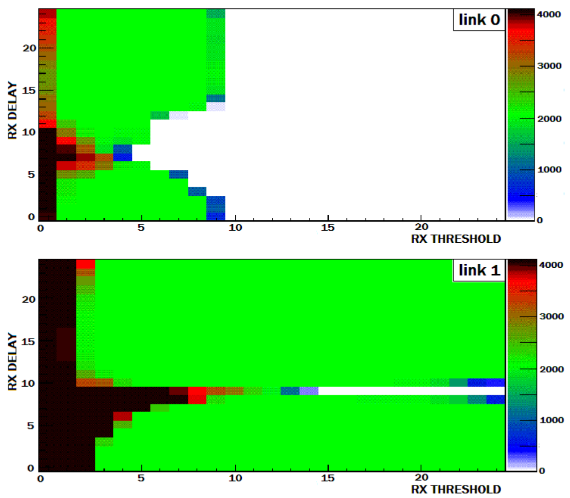

Figure 2: Example of the output of a 2D BOC scan for a module with low light from VCSEL link 0

III. Analogue performance

Analogue tests are needed to quantify the performance of the modules but since the SCT modules employ a binary read-out system, the analogue information has to be extracted by checking the module responses at a different thresholds.

At the time of writing only the SCT-barrel has been tested in-situ. Running any analogue test requires the modules to be powered for a long period and as such, the analogue performance of the SCT end-caps can not to be tested until the cooling problems are solved.

A. Input noise

The input noise is measured using the gain test. During the gain test increasing values of charge are injected on each channel and the number of hits for a given number of triggers is measured over a range of thresholds, to produce an S-curve for each channel. For each injected charge, the threshold at which 50% of the triggers are measured as hits, corresponds to the average channel output for that charge. Figure 3 shows a typical example of an S-curve as it is measured on each SCT channel. The standard deviation from the error function fitted to the S-curve is a measure of the output noise in mV. The gain of each channel is calculated from a fit to the scan points. The input noise of each channel is determined by the output noise at 1 fC divided by the gain.

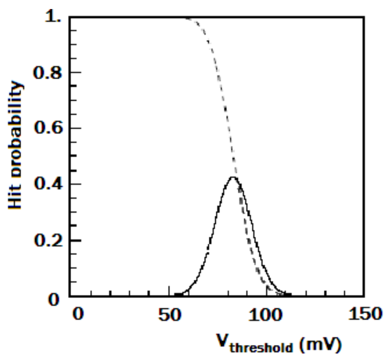

Figure 3: Typical example of an S-curve (dotted line) with the fitted error function (solid line) as measured on one SCT channel

For the SCT barrel in-situ tests, the detector was biased at 150 V, the amount of time the modules were biased varied between 30 minutes up to a maximum of 70 hours. In order to check that the input noise did not increase after installation in the cavern, the results of the in-situ tests were compared with the results from single barrel tests made during the assembly and CERN reception periods. The temperature dependence of the input noise was found to be of the order of 6 electrons per °C. Figure 4 shows the difference between the average chip noise between the in-situ tests and the single barrel reference tests, before and after the temperature correction. After temperature correction the average input noise per chip is approximately 60 electrons higher when compared to the reference data. Another peak can be seen in figure 4 at about -50 electrons difference, which comes from modules that were biased for up to 7 hours. Taking into account that the input noise decreases as the modules are biased longer, it can be concluded that the input noise measured in the ATLAS cavern is comparable to the single barrel reference data.
The lack of input noise or a very high value for the input noise in

some channels would indicate broken or problematic channels. No significant increase in problematic channels was found in the barrel in-situ tests, except that one SCT barrel module does not receive HV bias voltage, resulting in the loss of all 1536 channels for this module. This brings the total percentage of functioning channels in the SCT barrel down to 99.7 %, which is still well within the ATLAS required minimum of 99 %.

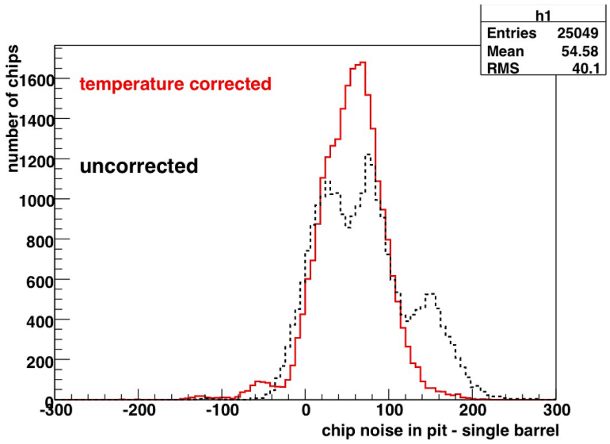

Figure 4: Comparison between the average input noise per chip for the ATLAS SCT barrel modules as measured in the ATLAS cavern and the the single barrel reference data.

B. *Noise occupancy*

The noise occupancy of each channel is measured by sending triggers and measuring the number of registered hits, without charge injection, over a range of thresholds. The value of the noise occupancy for each channel is determined at a threshold equivalent to 1 fC calibration charge. ATLAS specification requires a maximum noise occupancy of 5×10^{-4}. Figure 5 shows that the average noise occupancy per module in the SCT barrel in-situ calibration tests is approximately 7.4 10^{-5}. This is slightly higher than the result for the single barrel tests which measured a noise occupancy of 6.0×10^{-5}. For modules that were biased longer, the noise occupancy was lower than the average, indicating that the noise occupancy is still well within ATLAS specification.

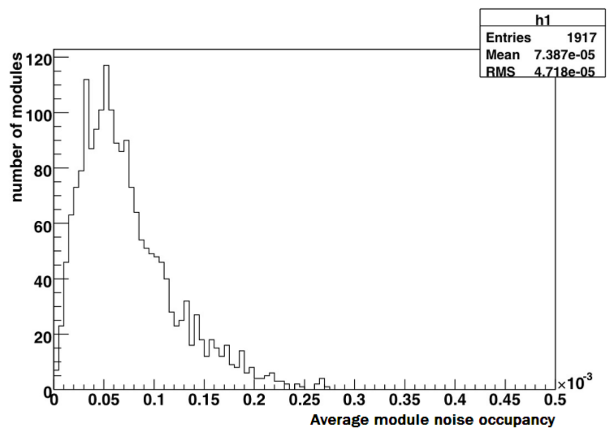

Figure 5: Average noise occupancy per module of the ATLAS SCT barrel as measured in the ATLAS cavern

IV. Conclusions

The SCT barrel and end-caps have been integrated with the TRT barrel and end-caps and are installed in their final position in the ATLAS detector. Problems with the heaters on the cooling return lines required the heaters to be moved into a more serviceable area. Tests of the electrical and optical connections of the SCT could be performed without cooling and show that all SCT modules can be powered and that the optical communication with all modules could be established. Calibration tests taken with the SCT barrel, before the cooling problems, show that the modules perform well within their specification requirements.

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