SCT and TRT Performance from Cosmic Ray Runs

H. Sandaker[a],
On behalf of the ATLAS Inner Detector collaboration

[a] CERN, 1211 Geneva 23, Switzerland

Heidi.Sandaker@cern.ch

Abstract

The ATLAS SCT and TRT detectors have been integrated into one barrel and two end-cap parts. Cosmic ray runs of the combined detectors are used to study the individual and combined detector integration and performance. This has taken place both in the surface building (SR1) and after installation in the ATLAS cavern. This article focuses on the most resent results, which includes timing in and synchronisation procedures, noise studies as well as initial efficiency, tracking and alignment results.

I. Introduction

The Inner Detector (ID) [1] is the central tracker of the ATLAS experiment, built at one of the interaction points of the Large Hadron Collider (LHC). LHC will provide 14 TeV centre-of-mass p-p collisions at the design luminosity of $10^{34} cm^{-2}s^{-1}$ with a 25 ns bunch crossing time. The ID provides tracking of charged particles and consists of three detectors centered around the interaction point inside a 2 T magnetic field. The innermost detector is the Pixel detector surrounded by the SemiConductor Tracker (SCT) and the Transition Radiation Tracker (TRT). Each of the detectors consists of one barrel and two end-cap parts (A and C), one on each side of the barrel. Whereas the SCT and TRT are integrated together into these three parts, the Pixel detector is installed in one piece and tested separately from the two other detectors. For this reason the Pixel detector and its commissioning are described elsewhere in this proceedings.

The SCT detector [2] is a silicon microstrip detector (pitch $\sim$ 57-90 μm) with $\sim$ 6 million readout channels distributed over four concentric cylinders in the barrel part and nine disks in each of the end-caps. The intrinsic measurement accuracy is required to be $\sigma(r\phi) = 17\ \mu m$ and $\sigma(rz) = 580\ \mu m$. The TRT detector [2] consists of drift tubes (4 mm diameter) filled with $Xe/CO_2/O_2$ with transition radiation material in between 73 straw layers in the barrel and 160 in each end-cap region. The accuracy of the TRT detector is of $\sigma(r\phi) = 170\ \mu m$. The full size of the ID is 6.8 m length and 1.15 m in radius. The radiation levels are expected to be of $1 - 2 \times 10^{14}\ n_{eq}/cm^2$ over the lifetime of the SCT [3]. To limit increased noise in the detector due to high radiation the SCT is required to operate at sensor temperatures of approximately -5 to 10°C whereas the TRT will operate at room temperature.

The integration of the combined TRT & SCT barrel and end-caps took place in the CERN SR1 surface building [4]. Cosmic ray runs were part of the commissioning of the combined detectors to gain confidence in their performance before installation in the ATLAS underground cavern. A large sample of cosmic data from $\sim$ 450 000 events was recorded and the results are presented below. Underground in the ATLAS cavern, the first commissioning period has been completed for the barrel and cosmic ray studies for the TRT barrel are ongoing. Both end-caps are installed, cabled and the commissioning is ongoing.

Test	Description	Detectors
ID cosmic (SR1)	Test with random and cosmic triggers for both SCT and TRT	SCT+TRT (barrel and end-cap)
ID standalone (Cavern)	Standalone and combined commissioning	SCT+TRT (barrel)
ATLAS integration (Cavern)	Combined integration and cosmic runs for several ATLAS subdetectors combined	TRT only (barrel)

Table 1: Overview of the tests made and their locations.

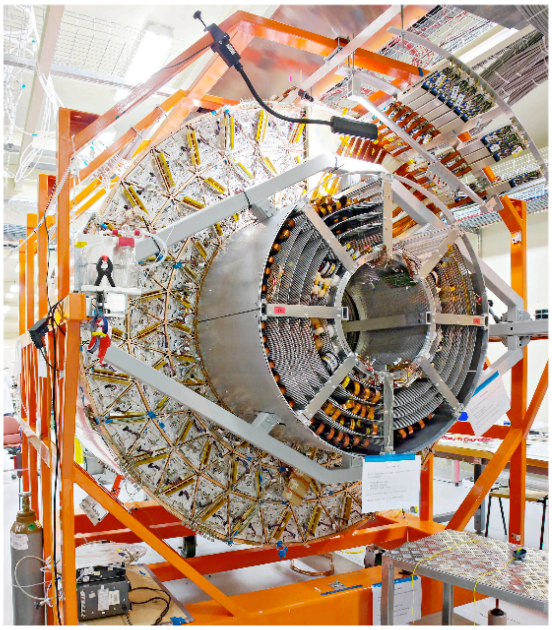

Figure 1: SCT and TRT barrel setup in SR1 for the cosmic ray runs [2].

II. Cosmic rays

Cosmic rays at sea level [5] are dominated by cosmic muons with a mean energy of $\sim$2 GeV and arrives at a rate of $\sim 3 \times 10^{-3} muons\ cm^{-2}s^{-1}$. Characteristic for cosmic ray runs is that only few muons passes close to the interaction point and that multiple scattering also occurs from material surrounding the detector (e.g. building, equipment).

Underground, in the ATLAS cavern, the cosmic muon rates are significantly lower than on the surface. The flux is dominated by the muons traveling in the shafts. Their energies are of a few GeV and their angular spread is limited. They also have the smallest energy loss due to the absence of material in the shafts. Estimated (preliminary) cosmic muon rates underground are shown in table 2.

Cosmic rays studies are a powerful tool to test the detector both at the surface and in underground with real particles before LHC starts. Some of the main areas taking advantage of the cosmic ray studies are the following:

- Software integration (DAQ, Online, Offline, DCS)
- Tuning of readout parameters
- Detector time-in and synchronisation
- Track reconstruction and alignment
- Detector performance studies
- Trigger studies with the ATLAS trigger system
- Combined detector runs building ATLAS events

Muon volume :	O (kHz)	$\rightarrow$	O (100 000) tracks
TRT Barrel :	O (10 Hz)	$\rightarrow$	O (1 000) tracks
Pixel detector :	O (Hz)	$\rightarrow$	O (100) tracks

Table 2: Estimated cosmic event rates per day from simulation studies.

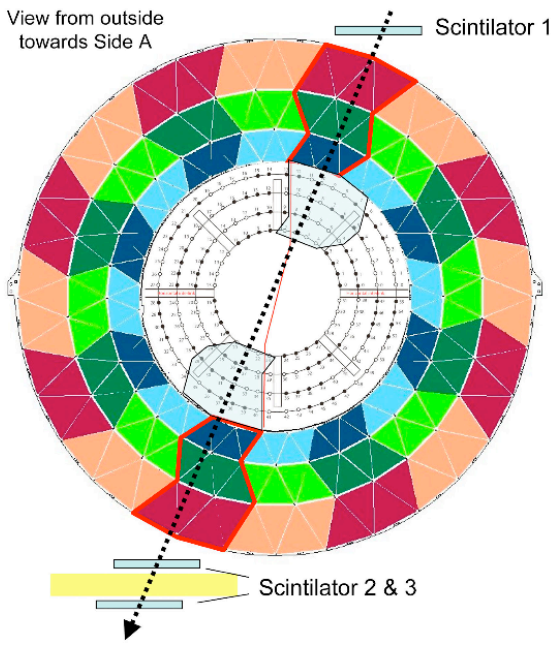

Figure 2: Schematic figure of the scintillator distribution and active detector parts for the SR1barrel cosmic ray runs [2].

III. Experimental Setup

On the surface, both barrel and end-cap cosmic ray runs were successfully completed [6]. For the barrel the experimental setup consisted of operating two opposite sectors of the SCT and the TRT corresponding to 1/8th of the TRT and 468 modules of the SCT ($\sim$ 11 %). The setup was as close to the final setup in the pit as possible including the final service routing and grounding. The end-cap tests were done using 1/16th of the TRT end-cap and one quadrant (247 modules) of the SCT. Scintillators (see Figure 2) were used as triggers, one above (1) and one below (2) the detector. Hits in both scintillators were required for a passing muon. A third scintillator (3) separated from the second by 15 cm of concrete provided a cut of around 170 MeV on the energy of the incident muon.

Some of the main achievements of the surface tests were to verify the noise performance of the two combined detector and the absence of cross talk. It was also important to gain experience with the combined operation and to test the full reconstruction chain. In addition, a first study of the detector performance with cosmic ray was successfully made. A typical clean event (no showering) at the surface consisted of 2 $\times$ 4 SCT space-points (4 in top and 4 in bottom sector) and more than 2 $\times$ 30 drift circles on a track for the TRT.

After installation of the ID barrel in the ATLAS cavern standalone tests were made to check the performance of the barrel before the insertion of the end-cap which blocks the access to the barrel services. For the standalone test the ID barrel was run with all the final equipment and grounding configuration. For the cosmic ray test and the combined ATLAS commissioning, parts of the TRT barrel are operational. During the last cosmic test period 19 barrel segments (of 64 in total) were operational.

IV. Timing and Synchronisation

A critical issue in a pipelined system is to time-in all the detectors correctly. During all tests a 40 MHz clock was used equal to what will be used in ATLAS. Mainly two issues affect the timing when working with cosmic muons, that the muons are not produced in the centre of the ID and that the particles are randomly generated and not synchronised with the readout clock. Both issues were addressed for the cosmic ray studies and resulted in software modifications.

The basic method for timing in of the ATLAS detectors [7] underground is to synchronise the trigger signal (Scintillator or ATLAS trigger signal) with the Beam Crossing (BC) time. The trigger signal is accorded a BCID (0-4095) depending on which 25 ns window the signal falls into. The SCT or TRT Level-1 trigger delay is then adjusted in 25 ns steps to take into account the total delay (e.g. due to L1 pipeline, cables and other equipment).

For the SR1 test, a two-side-coincidence method was developed to easily time-in the SCT during the cosmic ray runs. When receiving a hit in a ABCD chip [8] in the top layer of a module this method checks if there is a corresponding hit in either of the three neighbouring chips on the bottom layer. Since the final ATLAS trigger system was not available the scintillator trigger signal was delayed $\sim$3 μs to arrive to the chip with the correct latency. This delay was tuned (in steps of 25 μs) to ensure that all hits were contained within the three read out bins and then again (in fine steps of ∼ns) to optimise the occupancy distribution in those same bins to 01X. In addition the propagation time on the fibres were calibrated to account for the different fibre length for the SCT. Figure 3 shows a prelim- inary plot for the hit efficiency against the timing delay were the pulse shape can be seen and how well the detector can be timed-in.

Another critical issue for pipelined systems is to ensure that different detectors remain synchronized during a run. During the combined testing in SR1 the SCT and TRT were synchronised using custom (not final) equipment. Dedicated software tools in the online monitoring software were set up to verify continuously the synchronisation using the difference in track segments between the SCT and the TRT. Figure 4 shows the result for when the two detectors are synchronised (left) and when the syncronisation was lost (right) due to a failure of the custom equipment.

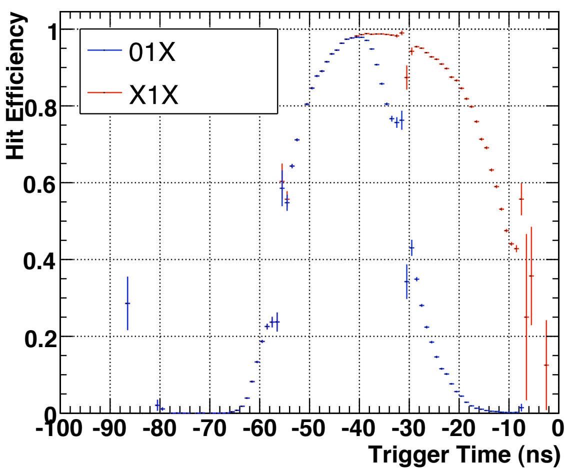

Figure 3: Preliminary plot of the efficiency vs timing delay where 01X and X1X are two different compression criteria (slightly modified)

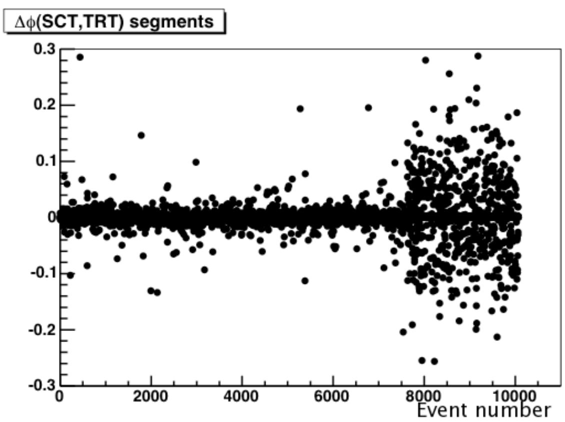

Figure 4: Example of synchronisation monitoring, a loss is detected after ∼ 8000 events [4].

V. Noise Studies and Grounding

Extensive noise and grounding studies were made to verify the absence of excess noise and cross-talk at several stages during the SCT and TRT integration and underground installation. These results provide the first determination of the SCT and TRT noise performance, in-situ with the final electrical grounding scheme implemented. Random triggers were used for these noise studies.

One of the first verifications after the integration of the SCT into the TRT was to check that the number of faulty channels had not increased. This total number after integration was found to be approximately 0.3 % of the SCT channels and less than 2% for the TRT, which is in accordance with previous results. So far no increase in these numbers has been found after the installation of the detectors in the pit.

During the surface tests the SCT was tested warm, with hybrid temperatures between 25-30°C. Previous tests of the SCT before integration has shown a mean noise occupancy of 4.5 $\times 10^{-5}$. After integration the mean noise occupancy remained below 5.0×10^{-5} and the e^- ENC below 1900, which is well below the specifications for warm running (5×10^{-4} and 1900 e^- ENC). Several tests were performed to check the noise performance but no increase was detected:

- At different trigger rates (5 to 50 Hz)
- At different thresholds
- During TRT operation and readout
- With different grounding schemes
  - With and without shorting cards
  - SCT and TRT isolated or shorted
  - Heaters on, off or switching

Similar tests with the TRT in SR1 after integration show no effect on the straw noise occupancy, which remained around 2%. No cross-talk between the two detectors was observed.

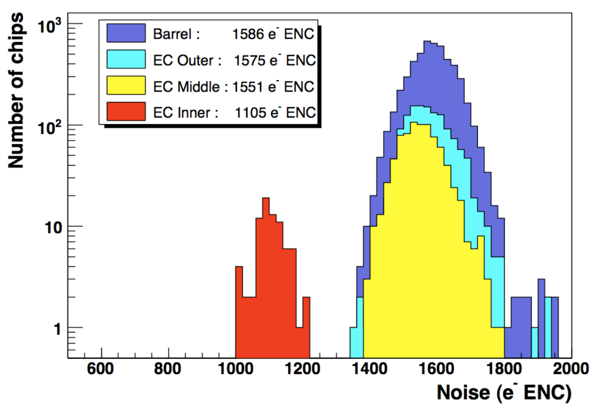

Figure 5: The SCT ENC noise levels for both barrel and end-cap C as measured in the SR1 surface building [2]. The EC inner modules shows lower noise values due to different geometry.

After installation of the barrel in the pit, these noise tests were repeated with either detector checking noise while the other detector was in operation. Figure 6 shows the difference in noise for six of the TRT barrel sectors ($\sim$ 20% of the barrel) when the SCT was on and off. The mean noise for the SCT was found to be less than 1900 e^- ENC and the TRT noise occupancy remained below $\sim 2\%$, well below the maximum noise limit (3%).

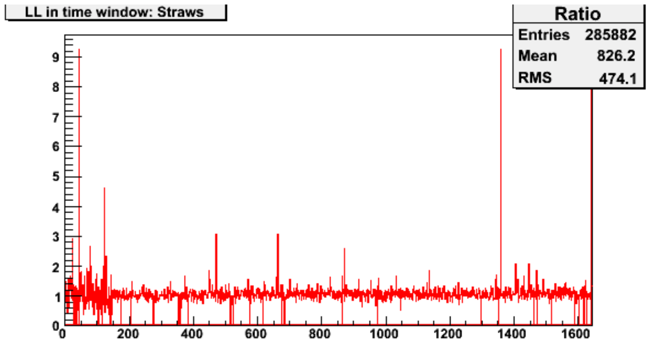

Figure 6: The difference in TRT noise occupancy between the noise when the SCT was off or operating.

VI. Hit Efficiency

A first determination of SCT module and TRT straw efficiency was possible using the data from the SR1 cosmic ray runs. Reconstructed tracks have been used to calculate hit efficiencies in the SCT and TRT. During cosmic ray tests the TRT is using an Ar/CO_2 gas mixture for economical and practical reasons instead of the Xenon mixture to be used when LHC starts. This results in a shorter drift time and a loss of sensitivity due to the poor transition radiation absorption. Figure 7 shows the hit efficiency for the SCT detector. After alignment the hit efficiency for the SCT is $> 99\%$ and for the TRT ~ 90 %, which are well within specifications (taking into account the use of Ar/CO2).

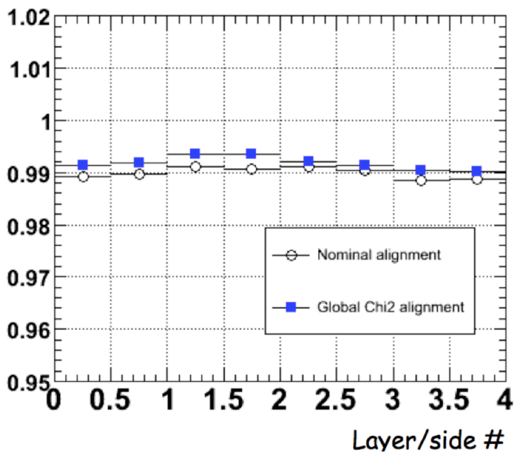

Figure 7: Hit efficiencies for the SCT detector [4].

VII. Tracking and Alignment

From the cosmic ray data it has also been possible to do the first tracking and alignment studies of the SCT and TRT detectors. A special detector description has been used taking into account that no magnetic field is applied. Several alignment methods were tested, including a combined algorithm for aligning the SCT and TRT simultaneously. Figure 8 shows the TRT residual without alignment applied. Figure 9 shows the typical residual for the SCT detector before and after applying the alignment. The results from the study can be found in Table 3 and is consistent with Monte-Carlo simulations.

TRT resolution	$\sim$190 μm (expected)
SCT resolution	96 μm
SCT resolution after alignment	59 μm

Table 3: The different resolutions found for the SCT and the TRT from the SR1 tracking and alignment studie.

In addition, a verification of the global misalignment of the two detectors with respect to each other was performed. There was no misalignment check in z since TRT only measures track parameters in the xy plane. Since tracks were more vertical than horizontal, Δx, Δrot-y and Δrot-x were obtained and the displacement of the SCT with respect to the TRT is shown in Table 4. Comparing the misalignment with the the survey results made after the integration (mechanical precision of $\sim 250\ \mu m$) one find a good correspondence between the two results.

Cosmic runs	Δx [mm]	Δrot-y [mrad]	Δrot-z [mrad]
3007	-0.290	0.277	0.254
3099	-0.289	0.293	0.226
Survey	-0.3	0.221	-

Table 4: The misalignment values for two cosmic runs and the survey.

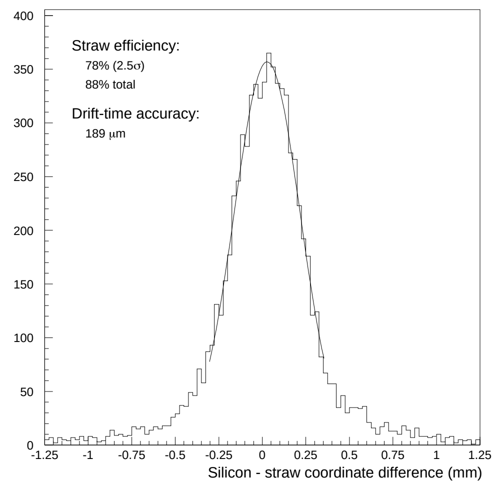

Figure 8: The TRT track residual without alignment.

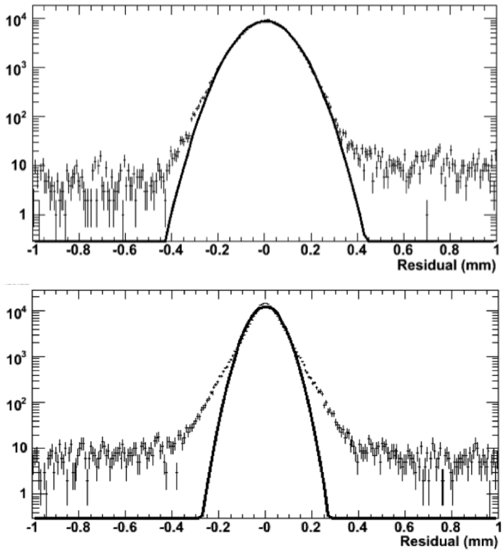

Figure 9: The SCT residual without alignment (top) and with alignment (bottom).

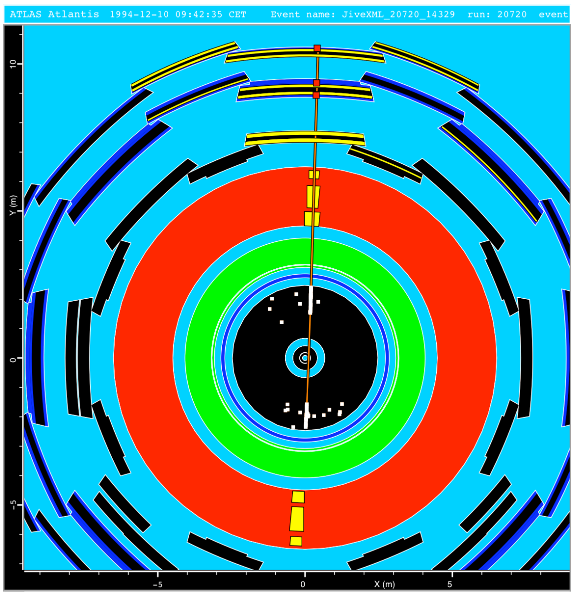

Figure 10: Typical cosmic ray track as seen by the online software.

VIII. ATLAS COSMIC RAY RUNS

The best indication of the performance of the SCT and TRT during ATLAS operation will come from the cosmic ray runs in the ATLAS cavern. First combined ATLAS tracks with the TRT were made in June. The trigger was provided by the Muon spectrometer and Tile calorimeter with 80 hits in total, including RPC hits, resulting in a straight line fit through the TRT and MDT (see Figure 10). First TRT residuals have been found without drifttime (no r-t calibration yet) and show promising results. Preliminary results are promising but work is ongoing to integrate material corrections for cosmic radiation. SCT will join the ATLAS combined cosmic ray runs once the current problems with the heater part of the evaporative cooling system have been overcome.

IX. CONCLUSION AND OUTLOOK

Using cosmic rays to study early detector performance has proven itself to be a powerful commissioning tool. During the initial cosmic ray studies of the SCT and the TRT the operation and readout has been finalised and both detectors have checked their calibration, noise levels and grounding scheme. Timing and synchronisation of the two detectors have been made and all software has been tested including the full reconstruction chain. The first track reconstruction and alignment studies were successful and the first combined tracking with other parts of ATLAS has been made with the TRT. Alignment results are comparable with surveys made of the ID and comparable with Monte-Carlo simulation studies.

Already these first cosmic results are a big step towards taking data from LHC collisions. However, more detailed studies will be possible now that the detectors are installed in their final locations. Any distortions measured will be representative of the operational system. As the muons will traverse the full SCT and TRT detectors, the alignment analysis will allow for the determination of some low frequency spatial modes of the detector which will not be constrained by pp data, such as sagitta distortions. Although the first cosmic ray runs have been very successful, the knowledge gained from future studies will be equally important.

REFERENCES

[1] ATLAS Collaboration, *ATLAS Technical Design Report - Inner Detector*, CERN/LHCC/97-16 and CERN/LHCC/97-17 (1997).

[2] ATLAS Collaboration, *The ATLAS experiment at the CERN Large Hadron Collider*, to be submitted, (2007).

[3] S. Baranov *et al.*, *Estimation of Radiation Background, Impact on Detectors, Activation and Shielding Optimization in ATLAS*, ATL-GEN-2005-001, (2005).

[4] M. J. Costa *et al*, *Combined SCT and TRT performance tests in the SR1 assembly area*, to be submitted (2007).

[5] O. C/ Allkofer *et al*, *The absolute cosmic ray muon spectrum at sea level*, Phys. Lett. B, 36 (1971).

[6] O. K. Øye, "Preparing the ATLAS experiment, SemiConductor Tracker commissioning and simulation studies of SUSY models", Dissertation (2007).

[7] ATLAS Collaboration, *ATLAS Technical Design Report - High-Level Trigger Data Acquisition and Controls*, CERN/LHCC/2003-22 (2003).

[8] F. Campabadal *et al.*, *Design and performance of the ABCD3TA ASIC for readout of silicon strip detectors in the ATLAS semiconductor tracker*, Nucl. Instrum. Meth. A, **552** (2005), 292-328.