ATLAS Silicon Microstrip Tracker Operation

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On behalf of the ATLAS collaboration

Abstract

The ATLAS experiment at the CERN Large Hadron Collider (LHC) has started taking data last autumn with the inauguration of the LHC. The SemiConductor Tracker (SCT) is the key precision tracking device in ATLAS, made up from silicon microstrip detectors. The completed SCT has been installed inside ATLAS. Since then the detector was operated for many months under realistic conditions. Calibration data has been taken and analysed to determine the noise performance of the system. In addition, extensive commissioning with cosmic ray events has been performed both with and without magnetic field. The current status of the SCT will be reviewed, including results from the latest data-taking, and from the detector alignment.

I. INTRODUCTION

ATLAS (A Toroidal LHC ApparatuS) [1] is an experiment designed to explore the 14 TeV, 40 MHz proton-proton collisions at the Large Hadron Collider [2] in CERN, Geneva. The unprecedentedly high collision energy and the designed luminosity of 10^{34} cm^{-2}s^{-1} at LHC will eventually allow discovery of possible *new physics* at the TeV scale. ATLAS will exploit the full physics potential of LHC but will mainly focus on the discovery of the Higgs boson, Super Symmetry (SUSY) and extra dimensions. A complete study of the expected ATLAS physics discovery performance can be found in Ref. [3].

ATLAS is the largest ever built high-energy physics experiment. It has a cylindrical shape with 44 m in length and 25 m in diameter and weighs ~ 7000 t. It comprises of three basic subsystems: the Inner Detector, housed in a solenoid creating magnetic field of 2 T, the Calorimetry system (hadronic and electromagnetic) and the Muon Spectrometer with its associated superconducting toroidal magnets applying magnetic field of 0.5 T. A cut-away view of the ATLAS experiment is presented in Fig. 1; the various subdetectors are labeled.

The ATLAS Inner Detector (ID) [4] has to provide excellent momentum and vertex resolution for particles with pseudorapidity $|\eta| \leq 2.5$. At the same time it must cope with the high interaction rates and particle fluxes at the interaction region. For this it is designed to incorporate high granularity, radiation hardness and fast responsiveness. As shown in Fig. 2, the ID is composed of three subsystems placed in the 2 T solenoid: the Pixel detector, the SemiConductor Tracker (SCT) and the Transition Radiation Tracker (TRT). The Pixel detector (silicon pixels) forms the inmost, closest to the interaction point layer of the ID, followed by the SCT (silicon microstrips) and the TRT (arrays of gaseous straw drift-tubes). Each of the three ID systems has a central barrel section and two end-caps in the forward regions.

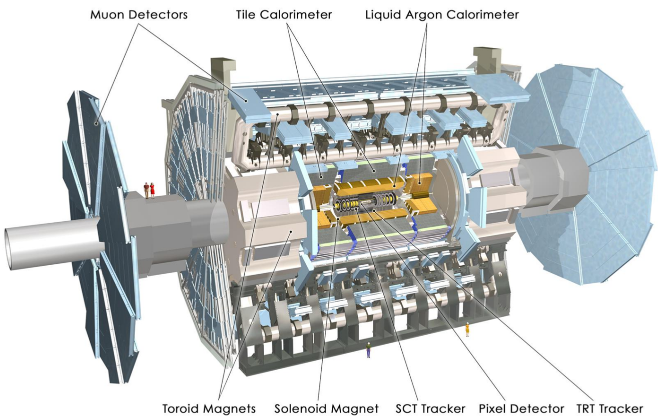

Figure 1: The ATLAS experiment.

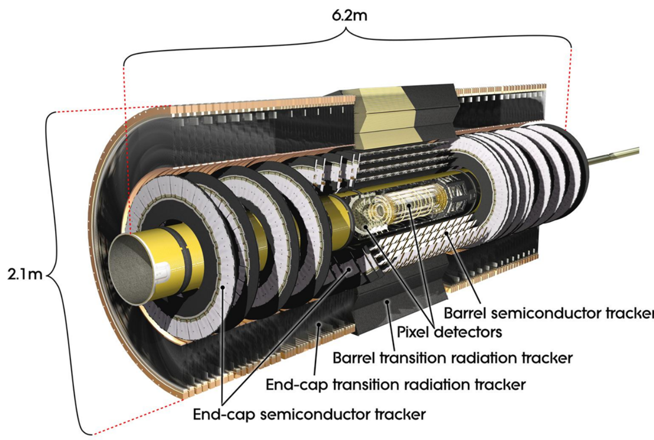

Figure 2: The Inner Detector of ATLAS.

II. THE SEMICONDUCTOR TRACKER

The ATLAS SemiConductor Tracker is built of 4088 silicon modules arranged in 4 cylindrical barrel layers, and 18 endcap discs. The pseudorapidity region covered by the SCT barrel part, consisting of 2112 modules, includes $|\eta| < 1.1$ to 1.4, depending on the layer, whereas the end-caps, with 1976 modules in total, extends this region up to $|\eta| < 2.5$. The barrel innermost radius is 30 cm and the outermost, common for both the barrel and the end-caps is 56 cm. Along the beam axis (the z-direction) the barrel takes 80 cm from both sides of the collision point. The two symmetrical groups of 9 end-cap discs, labeled as end-cap *A* and end-cap *B*, are positioned along z between 85 cm and 272 cm. In total, SCT integrates 61 m^2 of silicon micro-strip sensors with 6.3 million readout channels.

The design of the barrel and end-cap SCT modules is similar. The difference is mostly in the shape. The barrel modules are completely identical [5], whereas the end-cap ones are in 4 variations [6]. A typical SCT module, see Fig. 3, is built of 2 pairs of silicon (p-on-n) microstrip sensors, glued back-to-back at an angle of 40 mrad. There are 768 silicon strips per module side (1536 per module) at a pitch of 80 μm for the barrel and from 57 μm to 94 μm for the end-cap modules. This module architecture allows achievement of space-point resolution of 17 μm in the $R\phi$ and 580 μm in z directions. A nominal bias voltage of 150 V is applied to the silicon strips. The module power consumption is 5.6 W (without irradiation).

The readout is performed by 6 128-channel ADCD3TA chips [7] on each side of the module, fabricated in radiation hard technology DMILL. The data signals, processed by the chips are pre-amplified, shaped, discriminated (compared to a nominal threshold of 1 fC) and finally digitized; binary output is delivered. The communication of the module with the off-detector electronics is realized through optical links. The opto-electronics used for this includes VDC chip [8] (drives the laser diodes) and DORIC4A chip [8] (receives the clock and command data from the light-sensitive diode).

For a successful 10 years operation at the harsh radiation environment at LHC, the SCT modules must withstand a 1 MeV neutron equivalent fluence of 2×10^{14} cm^2. To limit the radiation damage effects, such as reverse annealing and leakage current, and to decrease the noise levels, the SCT detector is cooled to $-7°$C. The cooling is performed by evaporative C_3F_8-based system.

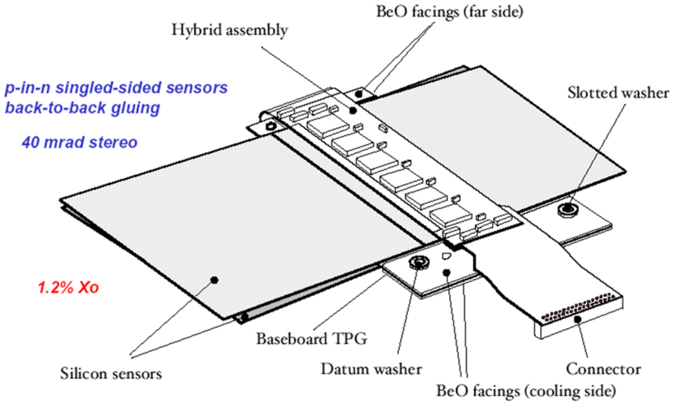

Figure 3: A drawing of the SCT barrel module.

III. SCT Commissioning and Calibration

The installation of the SCT detector in the ATLAS setup ran in two stages. First, the SCT barrel was inserted in the ATLAS cavern in August 2006, then in April 2007 the end-caps were added. Post-installation and commissioning tests took place after the positioning of the SCT. The electrical connections (high and low voltage, temperature readings) were tested. The optical connections (p-i-n current, light from fiber at the Readout Driver, fiber connections and module mappings) and the cooling performance were examined. Finally, the SCT barrel was signed-off in April 2007 and the end-caps in February 2008, respectively.

In March 2008 the SCT joined the ATLAS combined M6 Milestone run with most other sub-detector systems and with all trigger levels. After successful integration with the central DAQ, SCT started taking cosmic data.

In May 2008 a cooling plant failure occurred, which put the SCT out of operation. The incident affected three out of the six compressors of the ID cooling plant, which is common for the Pixels and SCT. Three months later, at the end of August 2008, the damaged compressors were replaced, and since then the cooling is functional and works without problems.

For the launch of the LHC on 10^{th} of September 2008 with circulating proton beams in both directions at an injection energy of 450 GeV, the SCT was calibrated again and ready for operation. First detected beam events, see Fig. 4, were caused by splashes of the protons at a collimator close to ATLAS. For safety reasons the SCT barrel was turned off and only the end-caps were left to function at a decreased voltage (20 V) and a raised threshold (1.2 fC).

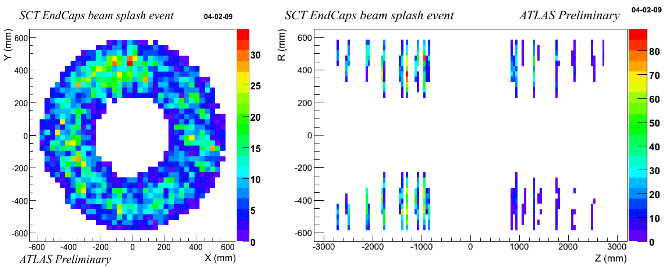

Figure 4: An LHC beam splash event from 10^{th} of September 2008 as detected by the SCT end-caps. The number of reconstructed space-points is shown.

From October until December 2008 SCT took part in the extensive ATLAS global cosmic run. All ATLAS subsystems were on and collected data synchronously. Different magnetic field configurations were applied (solenoid - on/off, toroids - on/off). In addition, there were also dedicated ID-only runs in which SCT worked in conjunction solely with the Pixels and the TRT. In total more than 7 million cosmic muon tracks were accumulated in ATLAS during this period, both with magnetic field on and off. Out of these, 2 million tracks (1.15 million with solenoid switched on and 0.88 million with solenoid off) crossed and were reconstructed in the SCT. An example of a cosmic ray event traversing the SCT, Pixels and the TRT is given in Fig. 5.

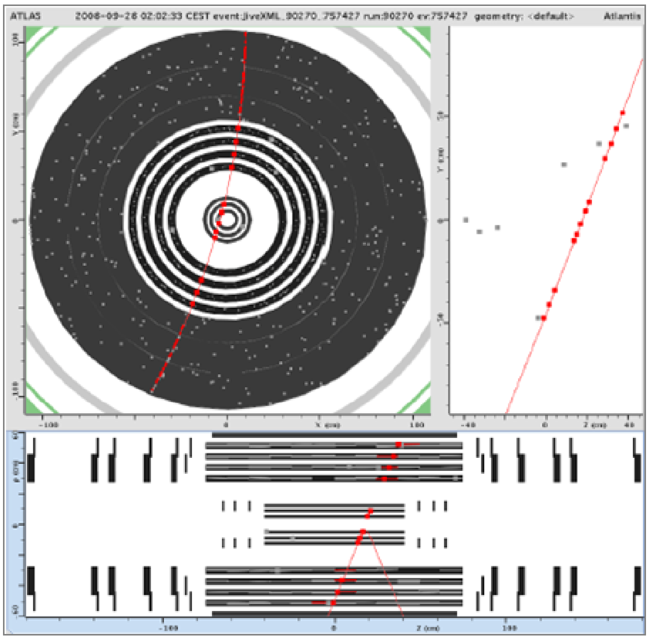

Figure 5: A cosmic ray event with hits in the SCT, Pixels and the TRT.

IV. Performance

Throughout the cosmic data-taking in October - November 2008 SCT operated with 99.6% of its barrel and 97.8% of its end-cap modules. The main reason for the inefficiency were 2 problematic cooling loops. As of today, one of the colling loops is completely recovered; the other one is affected by a non-accessible leak and consequently 13 end-cap modules will stay permanently non-operational.

A part of the disabled modules were down due to issues with the off-detector transmitter boards. It is believed that the problem is now understood; it was caused by electro-static discharges at the VCSEL boards (used to transmit clock and commands to the modules). Currently all broken VCSELs are replaced.

A. Efficiency

Figure 6 shows the intrinsic hit efficiency of the SCT barrel measured with magnetic field. The muon tracks were required to have 10 SCT hits, 30 TRT hits and a $\chi^2/\mathrm{DoF} < 2$. On average the barrel hit efficiency is found to be 99.75%. The end-caps showed lower averaged efficiency values of $\sim 99\%$ because of unproper timing with respect to the trigger.

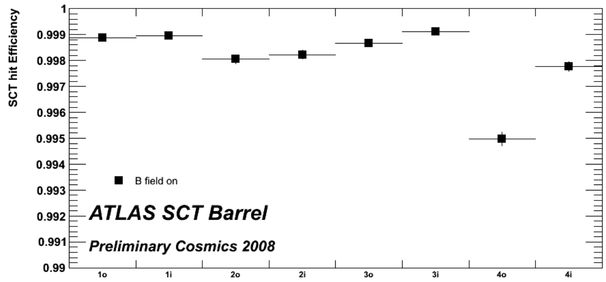

Figure 6: SCT barrel hit efficiency (4 layers, 2 sides - inner and outer).

B. Noise

The noise performance of the SCT is illustrated on Fig. 7 where the distribution of the ($\log_{10}$ of) average noise occupancy per chip of the SCT barrel, middle and outer end-caps is presented with nominal values of the threshold (1 fC) and bias voltage (150 V). The dashed line indicates the TDR noise-occupancy requirement limit of 5×10^{-4}. It can be seen that all the measured values are well below this limit. The inner and middle short end-cap modules are not shown since for them the average noise occupancy was below the sensitivity of the performed tests.

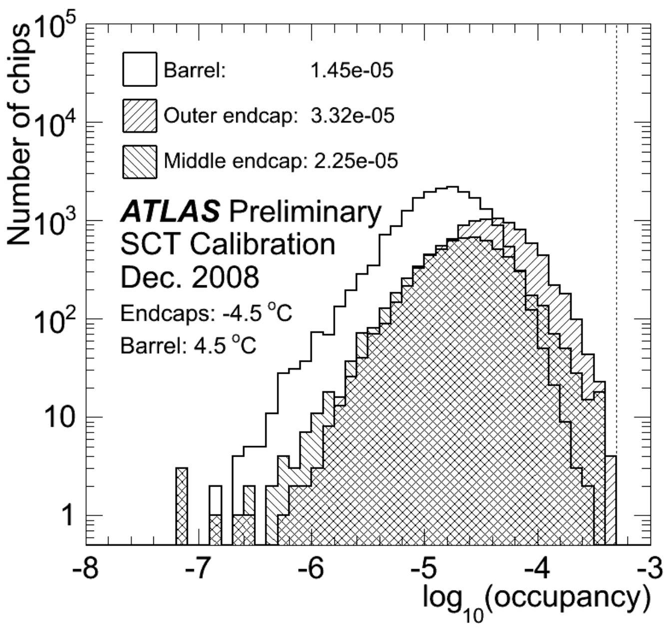

Figure 7: Noise occupancy averaged over chips in SCT barrel, SCT middle and outer end-caps. The specification limit of 5×10^{-4} is indicated with dashed line at the right-hand side of the plot.

C. Lorentz angle

Another important quantity measured during the 2008 cosmic tests was the Lorentz angle. This is the track incidence angle leading to a minimum cluster size. Cosmic muons traverse the silicon sensors at different angles, thus allowing precise determination of the Lorentz angle. The measured (with and without magnetic field) mean cluster size as a function of the incidence angle is fitted and plotted in Fig. 8. The Lorentz angle (for magnetic field on) is then defined by the position of the function minimum, resulting in the value of $3.93° \pm 0.03°$(stat.) $\pm 0.10°$(syst.). This value is in good agreement with the predicted by Monte-Carlo simulation value of $3.69° \pm 0.19°$(syst.). When there is no magnetic field applied, the Lorentz angle is found to be in the vicinity of 0 degrees, as expected.

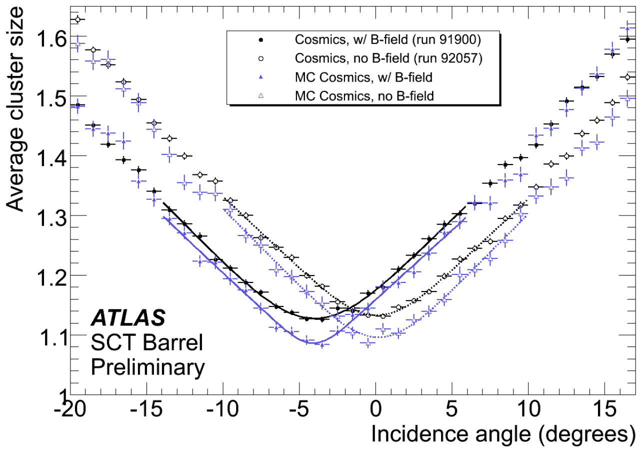

Figure 8: Mean cluster size versus incidence angle. Both measurements (2008 cosmic data) and Monte-Carlo predictions are plotted with and without magnetic field of 2 T.

V. ALIGNMENT

The SCT barrel alignment was significantly improved using the collected 2008 cosmic data. This is demonstrated in Fig. 9, where the x track residual distributions are shown before the alignment (nominal geometry), after the alignment (aligned geometry) and for a perfectly aligned (MC-simulated) geometry.

The residuals are constructed as the difference between the measured x hit position and the expected x position, as the latter is obtained via track extrapolation. From the plot it is evident that the newly aligned SCT geometry approximates closely the perfect, Monte-Carlo simulated geometry.

The alignment of the end-caps (module-to-module) was not possible because of the lower end-cap track statistics.

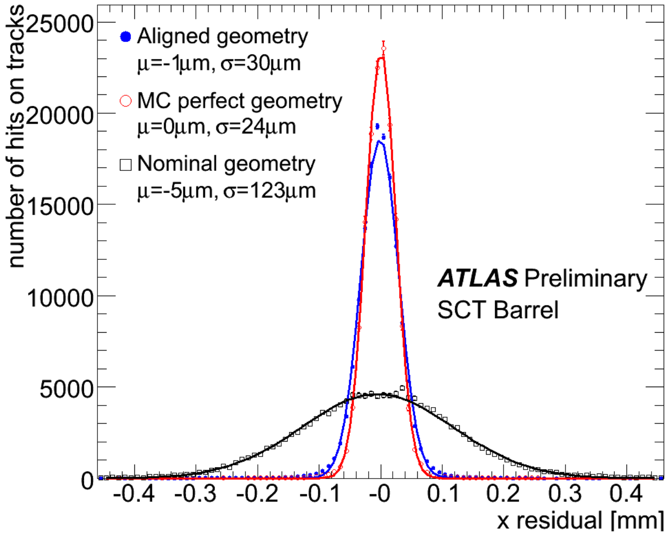

Figure 9: Track x-residuals for SCT nominal, aligned and perfect (MC) geometries.

VI. CONCLUSION

The ATLAS SemiConductor Tracker was successfully installed, commissioned and calibrated. Extensive tests with cosmic rays carried on in the autumn of 2008 proved that the detector is in excellent condition and meets the design specifications. The encountered problems were solved in due time. The SCT is now ready for the expected LHC restart in November 2009.

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