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Status and experience with construction and integration of the ATLAS SemiConductor Tracker for the CERN LHC

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Abstract

This paper describes some of the essential features of the SemiConductor Tracker (SCT) of the ATLAS experiment at the CERN Large Hadron Collider (LHC), and the September 2006 status and experience with its construction and integration.

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Keywords: ATLAS; SCT; Silicon; Microstrip; Tracker; LHC

1. Introduction

The ATLAS experiment [1] is being constructed to explore the physics of 14 TeV proton–proton collisions at the CERN Large Hadron Collider (LHC) [2], with first beam expected in 2008. At the centre of ATLAS is an Inner Detector (ID) [3], whose function is to track charged particles coming from the interaction region. The ID is formed from a Pixel detector (PIXEL), surrounded by a Semiconductor Tracker (SCT), with a gaseous/polypropylene-foil transition radiation tracker (TRT) as the outer component, as illustrated in the quadrant view of Fig. 1. The overall ID is 2.3 m in diameter and 7 m in length. For analysing the momenta of charged particles, a 2 T solenoidal magnetic field is provided by a superconducting central solenoid [4], which is integrated inside the cryostat of a liquid argon electromagnetic calorimeter. Because of the high-energy proton–proton collisions, large numbers of particles are generated in one interaction and multiple interactions are expected in one collision of the proton bunches. The main requirements for the ID are precision tracking of charged particles in the environment of numerous tracks, capability of bunch-crossing identification, tolerance to large radiation doses, construction with minimal material, and a capability for electron identification within the ID.

The ID consists of barrel and endcap regions. The barrel is made of co-axial cylindrical layers and the endcap of disk layers. The Pixel and SCT detectors use silicon semiconductor technology for precision digitisation. In the SCT there are four barrel layers and nine disks in each of two endcaps. Each layer is able to read out a position in two dimensions, and the SCT provides at least four layer tracking coverage up to an η value of 2.5 [1]. This paper describes the status of the construction and integration of the SCT components in September 2006.

2. The SCT barrel and endcap silicon modules

The detecting modules of the SCT [5,6] are formed from single-sided, 280 μm thick, p-in-n silicon microstrip sensors [7,8], glued back-to-back around a thermo-mechanical baseboard [9] or a spine [6]. A module has 768 sensor readout strips at ~80 μm pitch on each side, with a total strip length of normally ~12 cm. The strips are AC-coupled to binary readout electronics, with the ABCD3TA custom application-specific integrated circuit (ASIC) [10] providing the front-end amplification, discrimination and pipeline functions. A binary threshold of around 1 fC will be used in the experiment to detect the charge deposited on a strip. The ASICs are attached to kapton hybrids mounted on

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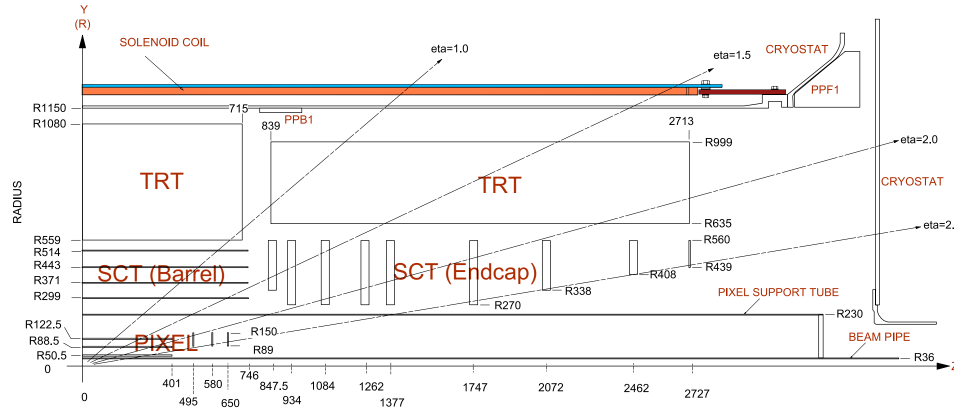

Fig. 1. A quadrant view of the Inner Detector, together with the central solenoid inside the cryostat of the ATLAS liquid argon electromagnetic calorimeter.

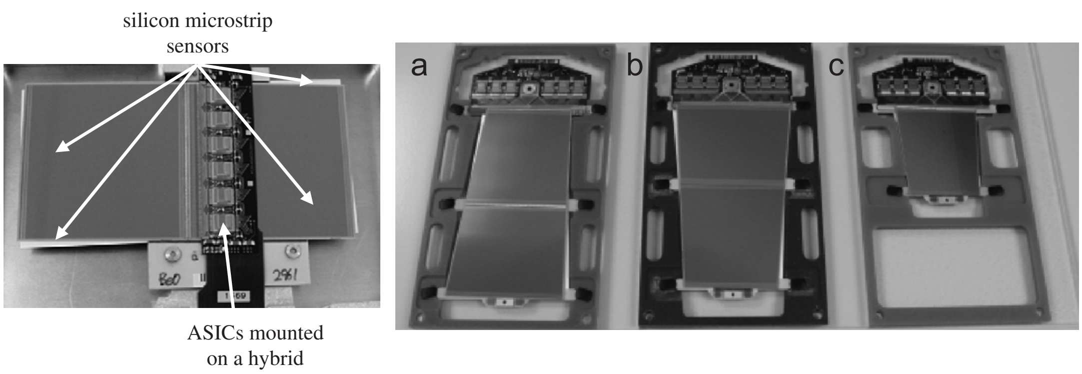

Fig. 2. Left: layout of the four sensors (two on the top surface, two on the bottom, with stereo rotation of 40 mrad) in the SCT barrel module. The arrangement provides a digitising precision of 17 μm perpendicular to the strips and 580 μm in the strip direction. The readout ASICs are mounted on a hybrid bridged over the sensors [5]. Right: the three distinct types on endcap module, showing the layout of the five different wedge geometries of the endcap sensors: (a) outer module, (b) middle module, and (c) inner module. The readout ASICs are mounted on hybrids at the ends of the endcap modules [6].

carbon-carbon substrates [6,11]. The ASIC power dissipation per module is 5.5 W nominal, 7.5 W maximum, and these figures have determined many of the critical design parameters of the SCT, and of its C_3F_8 evaporative cooling system. The modules are required to survive an integrated fluence of $\sim 2 \times 10^{14}$ 1 MeV neutron-equivalent/cm^2, corresponding to 10 years of LHC operation, and will be operated with the silicon at $\sim -7\,^{\circ}$C to limit the increase in depletion voltage due to reverse annealing following type inversion. A maximum value of 500 V is specified for the sensor bias voltage.

The layout of one of the 2112 identical rectangular barrel SCT modules is shown in Fig. 2, together with the configuration of the wedge-shaped sensors in the distinct types of endcap module. In total 1976 endcap modules are required to populate the disks. Photographs of modules mounted on a barrel and on an endcap disk are shown in Fig. 3.

The construction of all the barrel and endcap modules required for the SCT, with spares, was completed during 2005, and was not a limiting factor in the overall SCT construction schedule. The production was distributed over SCT institutes. The tight electrical and mechanical module specifications [5,6] were fully met with a yield of $>90\%$, albeit with some difficulty in certain of the sites. The module designs were made more intricate by the need for low mass, to minimise the multiple scattering of particles. The average module material at normal incidence represents 1.2% of a radiation length for barrel modules, and 1.4% for outer and middle endcap modules. It is actually the services, rather than the modules themselves, that dominate the material budget, and the total radiation length per barrel layer is $\sim 3\%$.

3. Assembly of modules to structures

The modules are individually mounted on light carbon fibre structures; cylinders for the barrel and disks for the endcaps. The module services are delicate and their arrangements complex. For the barrels they include thin-walled (70 μm) Cu–Ni cooling pipes, module cooling blocks, aluminium on kapton low mass tapes for power distribution, optical fibres for data and control signal transmission, opto-packages containing Vertical Cavity Surface Emitting Lasers (VCSELs), an epitaxial Si p-i-n diode and custom ASICs [12]. The services on an endcap