The ATLAS Silicon Microstrip Tracker

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The ATLAS experiment will contain a large scale silicon microstrip tracker (SCT). The pseudo-rapidity range $|\eta| < 2.5$ will be equipped with a total of $61\mathrm{m}^2$ of silicon microstrip sensors. System design and the status of the SCT are reviewed.

The ATLAS[1] experiment will study proton proton interactions of 14TeV centre-of-mass energy at the large hadron collider (LHC) at CERN. The expected cross-sections for many of the interesting processes are very small. Therefore the LHC is designed to provide a high luminosity of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, with bunch crossings every 25ns. The large cross-section for hadronic "minimum bias" interactions on the other hand leads to an average of 23 interactions per bunch crossing or about 10^9 events per second, out of which the very few interesting events have to be selected and reconstructed. The ATLAS tracking system is designed to provide high-p_t lepton momentum measurements, electron and photon identification as well as heavy flavour and τ lepton identification at high luminosity, and full event reconstruction during the initial low luminosity ($10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) running of LHC. At design luminosity about 1000 particles will pass through the tracking system every 25 ns. This high particle flux requires tracking techniques which are fast and have high granularity. In addition, the detectors have to be radiation hard as the high particle flux causes significant radiation damage. The ATLAS tracking system is composed of three different sub-detectors. At the innermost radius, close to the interaction region, a pixel detector with about 140 million channels provides 3 space points along the particle track with a resolution of 12μm and 66μm in the transverse plane and along the beam axis, respectively. It is surrounded by the silicon microstrip tracker (SCT), which is described in detail below. The outermost system in the inner tracker is a transition radiation straw tube tracker (TRT) with 0.42 million channels, which provides typically 36 measurements along a particle track with a resolution of 170μm per straw. All systems cover the pseudo-rapidity range $|\eta| < 2.5$. The inner tracker is surrounded by a super-conducting solenoid which provides a magnetic field of 2 T.

[1] http://atlasinfo.cern.ch/Atlas

The ATLAS silicon microstrip tracker SCT is designed to provide eight precision measurements per tack, contributing to the measurement of momentum, impact parameter and vertex position, as well as providing good pattern recognition. The system is an order of magnitude larger in surface area than previous generations of silicon microstrip detectors. A major design consideration is the high level of radiation. For ten years of operation, the radiation fluence in the SCT volume reaches an expected ionising dose of 55 kGy and a non-ionising energy loss equivalent to 1.3×10^{14} of $1-\mathrm{MeV}-\mathrm{neutrons/cm}^2$. The SCT is divided into a barrel section with 4 double-layers of sensors, and two end-caps with 9 disks each. They occupy the radial region between 25 cm and 55 cm. The sensors are single sided strip detectors and have p-type diodes in an n-type bulk of initially $2-8\mathrm{k}\Omega\mathrm{cm}$, $\langle 111 \rangle$, $285\mu\mathrm{m}$ thick silicon, with an N^+ ohmic contact on the backside. The radiation changes the effective doping and will turn the n-type bulk after a few years of operation into p-type, thus moving the junction to the backside. The radiation also creates trapping centres in the silicon. Both effects require a significant over-depletion of the sensors in order to obtain efficient charge collection. The over-depletion also minimises the noise by minimisation of the backplane and interstrip capacitance, the latter being affected by increased fixed charges in the oxide between the strips. Testbeam measurements show that about 400V bias voltage is required for full charge collection if the sensors are irradiated to 3×10^{14} of $24-\mathrm{GeV}-\mathrm{protons/cm}^2$, which is equivalent to 15% more than the expected fluence. By the creation of energy states in the middle of the band gap, the radiation also strongly increases the detector leakage current, which after 10 years will reach about half a milliampere at $-10°\mathrm{C}$ for a sensor of $\approx 40\mathrm{cm}^2$ surface. AC coupling is implemented in the sensors in order to protect the read-out electronics from this current. The leakage current is strongly temperature dependent and doubles about every 7°C. The high bias voltage in combination with the high leakage currents lead to a significant self-heating of the sensors, which, in conjunction with heat loads by the electronics, can lead to thermal run-away, when the positive feedback of temperature and current is not limited by an efficient cooling. Not all radiation damage is stable and both the depletion voltage and the leakage current show a substantial annealing. The depletion voltage, however, also shows a reverse effect which leads to a significant increase of depletion voltage with time. It can be suppressed by keeping the sensors below 0°C. In order to limit the leakage current and make best use of the annealing, the sensor temperature will be kept around $-7°\mathrm{C}$. Recently it has been shown that the use of oxygen enriched silicon does slow down the increase of depletion voltage with irradiation and also the reverse annealing. A part of the innermost sensors which receive the highest radiation dose will be fabricated on oxygen enriched silicon. The manufacturers for the SCT sensors have been qualified and series production is under way. The total required sensor area is $61.1\mathrm{m}^2$. The sensors are read out by ABCD chips, which provide 128 channels of preamplification, shaping with a time constant of around 25 ns, comparators with thresholds which are trimmable for each channel, a digital pipeline which is 132 cells deep to allow for data storage while the first level trigger decision is made, data compression and read-out buffers. In this way the signals from the sensor are converted to binary hit information in the front-end chip and binary optical links are sufficient to transmit the data to the counting room. The chips are fabricated in the radiation tolerant DMILL process and irradiation tests show satisfactory results. The chips are fully functional after irradiation equivalent to more than 10 years of operation. Process optimisation for reduced power consumption and improved yield are under way and the start of series production is expected soon. In total, the SCT has 6.3 million read-out channels. To form detector modules, the sensors are glued back-to-back onto highly heat conductive structures, with a 40 mrad stereo rotation to allow for the reconstruction of the second co-ordinate. In the barrel modules two pairs of rectangular sensors of $6.36 \times 6.40\text{cm}^2$ with 80μm strip pitch are used. Given the binary read-out scheme, the position resolution per detector module is 16μm perpendicular to the strips, and 580μm along the strips by means of the stereo rotation. The electronics hybrid carrying the read-out chips is mounted "centre-tapped" across the surface of the sensors, folded around the module. In the end-caps, three different types of modules are used. They carry wedge shaped sensors in such a way that on one side the strips are radial, while the second side is rotated by a 40 mrad stereo angle. The modules for the inner ring on the disks carry two sensors and have 6 cm long strips, while the middle and outer ring modules have 12 cm long strips, composed of two sensors on each side. The strip pitch varies between 50μm and 90μm. In the end-cap modules the electronics hybrid is "end-tapped". All SCT modules have 768 channels on each side, corresponding to a total of 12 chips per module. The hybrids for barrel and end-cap modules use the same technology. A flexible circuit with 4 layers of copper traces embedded into polyimide foils is laminated onto highly heat conducting carbon substrates. Comparative studies have shown that this technology ensures optimum performance and it keeps the material budget low. For the barrel hybrid the flex circuit is folded around the module to supply both sides, and is laminated to an individual substrate on each side. In the end-caps the flex circuit is laminated onto both sides of one substrate. The hybrid substrate removes the 7.5W dissipated by each hybrid into a cooling contact. The SCT will be cooled by an evaporative C_3F_8 cooling system, running at approximately $-20°$C. The SCT detector modules are close to the final design review. Prototype modules have been tested in the lab, in multi-module system tests and also in testbeams. In all three environments the electronics noise is consistently around or below 1500 e for 12 cm strip length. Some modules have been irradiated to a fluence equivalent to 15% more than expected for 10 years of operation. They show full functionality with an electronics noise at or slightly above 2000 e. For the operational threshold setting the hit efficiency is greater than 97% at a noise occupancy level below 10^{-4}.