The ATLAS Pixel Detector

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1 Introduction

The Pixel Detector is the innermost part of the ATLAS tracking system. It is subdivided into three barrel layers in its centre, one of them around the beam pipe ($r = 5$ cm), and three disks on either side for the forward direction. The main components are approx. 1700 identical sensor-chip-hybrid modules, corresponding to a total of $8 \cdot 10^7$ pixels. The modules have to be radiation hard to an ATLAS life time dose of 50 MRad or 10^{15} neutron-equivalent.

2 Module layout

A pixel module consists of a single n-on-n oxygenated silicon sensor, approx. $2{\times}6$ cm^2 in size. The sensor is subdivided into 47,268 pixels, the "standard" pixels being 50 μm in azimuth ($r\phi$) by 400 μm parallel to the LHC beam (z), providing a high space-point resolution of approx. 12 μm in $r\phi$ and approx. 90 μm in z. The sensor pixels are connected individually to 16 front-end (FE) chips via lead-tin or indium "bumps". These chips are connected to a module-control chip (MCC) mounted on a kapton-flex-hybrid glued onto the back-side of the sensor. The MCC communicates with the off-detector electronics via opto-links, whereas power is fed into the chips via cables connected to the flex-hybrid.

The FE chips contain 2880 individual charge sensitive analogue circuits with a digital read-out that operates at 40 MHz clock. The analogue part consists of a high-gain, fast preamplifier followed by a DC-coupled second stage and a differential discriminator. The threshold of the discriminator ranges up to 7000 e, its nominal value being 3000 e. When a hit is detected by the discriminator the pixel address is provided together with the time over threshold (ToT) information which allows reconstruction of the charge seen by the preamplifier. The precision in assignment of the time-stamp is nominally better than 25 ns for charges above 5000 e.

3 Module prototype tests

The final generation of radiation-hard chips in 0.25 μm-technology now available had remaining problems fixed and brought module performance into specifications. Several prototype modules have been built with these chips. In order to assure full functionality of the modules in the later experiment, measurements at the production sites, after irradiation, in a testbeam, and in systemtests are performed.

3.1 Laboratory tests

On-chip injection circuits for each pixel allow to measure the threshold of the discriminator and the equivalent noise charge as seen by the preamplifier. A set of such injection-scans is used to reduce the threshold dispersion by adjusting a DAC-parameter individually for each channel. After threshold tuning, a threshold dispersion less than 100 e across a module and a noise value of below 200 e for standard pixels is achieved, well below what is required for good performance. In a similar fashion, the cross-talk is measured to be approx. 1 per cent for standard pixels.

A measurement of the timewalk, i.e. the variation in the time when the discriminator input goes above threshold, is an issue since hits with a low deposited charge have an arrival time later than those with high charges. With the latest version of FE chips, this dependency was largely reduced such that in-time thresholds within 25 ns are now

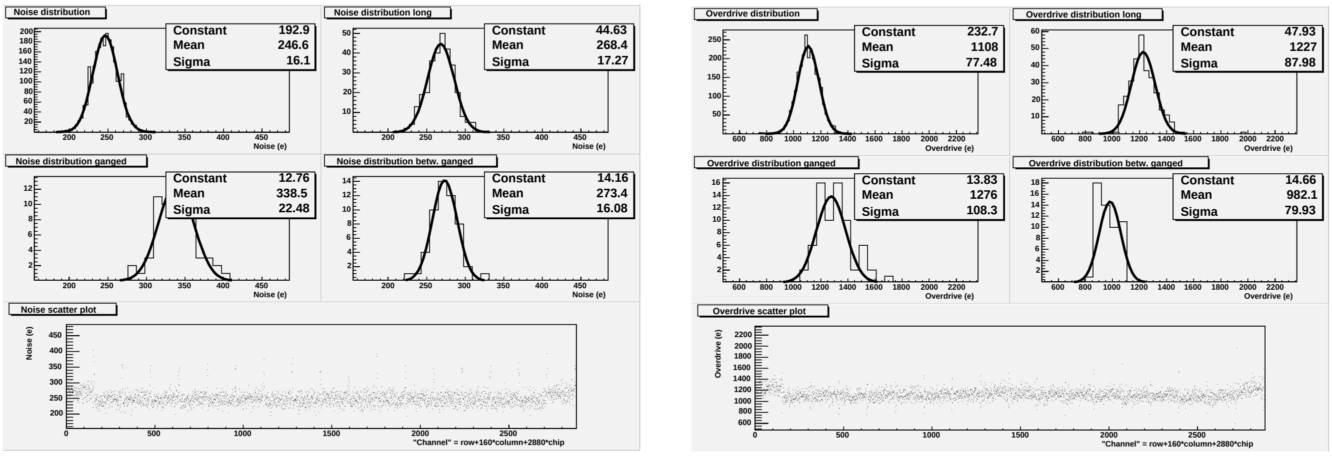

Figure 1: Distribution of noise (left) and overdrive, i.e. the difference in in-time threshold and discriminator threshold (right) of a randomly selected chip on a module after irradiation with 100 MRad.

measured to be below 4500 e for a discriminator threshold of 3000 e.

Data taken when illuminating the sensor with a radioactive source allows in-laboratory detection of defective channels. The source-spectrum reconstructed from the ToT-readings is in agreement with expectations.

3.2 Modules after irradiation

Some of the prototype modules have been irradiated to a dose of up to 100 MRad, approx. twice the dose expected after 10 years of ATLAS operation. The radiation damage is monitored reading the leakage current individually for each pixel. The threshold dispersion and the noise after irradiation is only modestly increased to 200 e and 400 e, respectively, which still well in agreement with requirements for operation in ATLAS. The cross-talk and timewalk performance hardly changes after irradiation. Noise and timewalk measurement results are shown in figure 1.

3.3 Testbeam studies

Tests have been performed in the beam line of the SPS at CERN using 180 GeV/c hadrons. The fraction of defective channels is observed to less than 10^{-3} and the efficiency is measured to be better than 99%. Detailed timing studies show a uniform behaviour of all pixels across a module and the timewalk is measured to values similar to those from lab tests (see above).

Modules irradiated as described above have been tested in the beam line and the bias voltage needed for full depletion is measured to be below 700 V for the full dose of 100 MRad and between 400 and 500 V for approx. half that dose. The deposited charge is measured via the ToT readings and no significant changes in the uniformity when compared to unirradiated modules are observed.

3.4 Systemtests

First small-scale systemtests have been performed with six modules on a disk sector and six modules on a barrel-stave. The noise behaviour on the disks or staves shows no significant differences compared to similar measurements with the same modules individually.

4 Conclusions

Prototype ATLAS Pixel modules built with the final generation of radiation hard chips show fully satisfying performance in laboratory-test, in test beam studies, after irradiation to 100 MRad, and in first systemtests. In particular, charges down to 4500 e can be efficiently detected with a timing-precision of better than 25 ns. Production of pixel modules has thus started.