Results from the commissioning of the ATLAS Pixel Detector

L. Masetti[a] for the ATLAS Pixel Collaboration

[a] Physikalisches Institut der Universität Bonn, Nußallee 12, 53115 Bonn, Germany

Lucia.Masetti@cern.ch

Abstract

The Pixel Detector is the innermost detector of the ATLAS experiment at the Large Hadron Collider at CERN. It is an 80 million channel silicon tracking system designed to detect charged tracks and secondary vertices with very high precision.

After connection of cooling and services and verification of their operation, the ATLAS Pixel Detector is now in the final stage of its commissioning phase. Calibration of optical connections, verification of the analog performance and special DAQ runs for noise studies have been performed and the first tracks in combined operation with the other subdetectors of the ATLAS Inner Detector were observed. The results from calibration tests on the whole detector and from cosmic muon data are presented.

I. INTRODUCTION

In order to fulfill the requirements of coverage up to $|\eta| < 2.5$, vertex resolution below 15 μm in the $R\phi$ plane and below 1 mm in z, high efficiency with low material budget and radiation hardness to operate after a total dose of 500 kGy or about $10^{15} n_{eq}$ cm^{-2}, the ATLAS Pixel Detector provides three hits over the full rapidity range, has the innermost layer at a radius of 5 cm and a pixel size of 50×400 μm^2. The sensitive area of 1.6 m^2 is covered by 1744 modules distributed over three layers in the barrel and three disks for each endcap, containing a total of 80 million electronic channels. Only the basic features of the modules and of the read-out system are presented here, a detailed description can be found elsewhere [1].

A. *The pixel module*

Modules are the basic building blocks of the active part of the Pixel Detector. Each module consists of the silicon sensor with a volume of 60.8 mm $\times$ 16.4 mm $\times$ 250 μm, 16 front-end electronic chips bump bonded to one side of the sensor and a flex-hybrid glued to the other side of the sensor containing a Module Control Chip (MCC) to receive and transmit digital data out of the module (see Figure 1). The front-end chips are about 200 μm thick and the flex-hybrid 100 μm. During production the radiation hardness of the modules was tested and they are expected to be fully operational after the expected lifetime dose.

The readout chip contains 2880 pixel cells arranged in a 18 $\times$ 160 matrix, each (see Figure 2) with an analogue and a digital block. The analogue block contains a charge sensitive preamplifier and a discriminator in which the amplified charge signal from the sensor is compared to a tunable threshold. The digital read-out part transfers for each hit the address, the timestamp of the leading edge and the timestamp of the trailing edge to the buffers at the chip periphery where the Time-over-Threshold (ToT) is computed by subtracting the leading from the trailing edge timestamp. A feedback circuit in the preamplifier causes a nearly linear return of the pulse to the baseline, so that the ToT can be used to measure the signal amplitude and therefore the deposited charge.

The threshold and the feedback current are tunable globally for each chip and by a fine adjustment for each pixel.

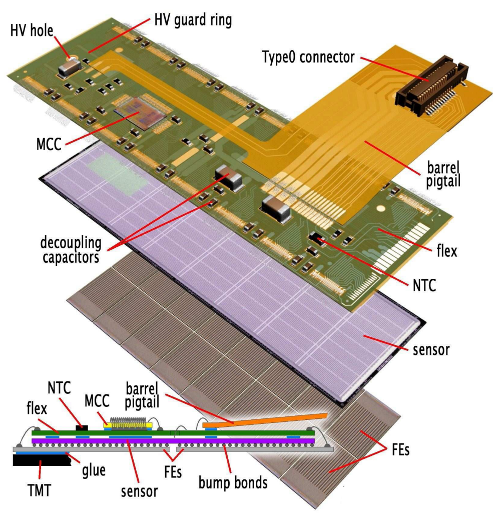

Figure 1: Exploded view of a pixel barrel module.

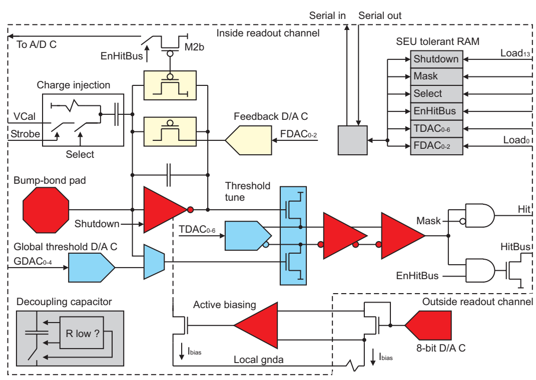

Figure 2: Block diagram of a pixel read-out cell.

B. *The read-out system*

The communication between modules and off-detector read-out electronics occurs via optical links (see Figure 3), whose architecture was inherited from the ATLAS SCT [2]. The electrical-optical interfaces are the opto-board on the detector side and the Back Of Crate card (BOC) in the counting room racks, where the Read Out Drivers (RODs) are housed in 9 VME crates, each connected to a BOC at the crate back-plane. Each opto-board serves the six or seven modules building a barrel half-stave or a disk sector. A BOC can be connected to up to four opto-boards at a readout speed of 40 Mb/s, which is sufficient for the outermost layer. For the middle layer and the end-caps two opto-boards are connected to the same BOC, allowing a maximum speed of 80 Mb/s, while the innermost layer must be read at up to 160 Mb/s, so that only one opto-board can be connected to each BOC.

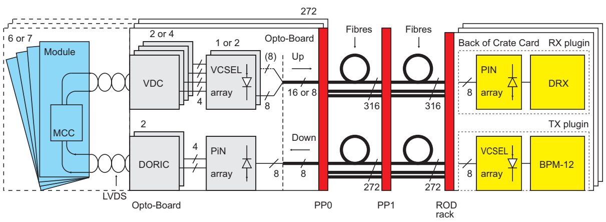

Figure 3: Arichitecture of the readout system

In the trasmitter (TX) plug-ins of the BOC, the clock signal and the commands sent by the ROD to the modules are Bi-Phase Mark (BPM) encoded and converted into an optical signal by a Vertical-Cavity Surface-Emitting Laser (VCSEL) array connected to one fiber per module. On the opto-board a PiN diode array receives the optical signal and a Digital Optical Receiver Integrated Circuit (DORIC) decodes it and extracts the clock.

The data sent by the modules are encoded in non-return-to-zero (NRZ) format and converted to an optical signal on the opto-board in a VCSEL Driver Chip (VDC) followed by the VCSEL array. Depending on the rate, one or two fibers per module are used and the number of VCSEL arrays and VDCs per opto-board varies accordingly. The receiver (RX) plug-in of the BOC performs the conversion from optical to electrical signal and the decoding with a PiN diode array and a Data Receiver ASIC (DRX).

The amplitude of the VCSEL current in the opto-board is driven by the I_{set} current, that depends on a tunable voltage ($V_{I_{set}}$). Once the optimal laser power for the whole opto-board has been determined, threshold and data delay can be adjusted for each RX-channel of the BOC.

In the ROD (see Figure 4) two different paths are used for data and for calibration, due to the different occupancy. At the typical occupancy of noise or physics data ($\leq 10^{-4}$) the data fragments can be sent to the ATLAS common part of the Read-Out System (ROS) [3] via the S-Link. During calibration scans up to 1/32 of the pixels can be injected at the same time, so that the information on each single hit has to be summarised into histograms and only these are transferred out of the ROD to the Single Board Computer (SBC) of each crate via VME connection. A further reduction of the exported data can be obtained by performing a fit on the slave DSPs and histogramming only the resulting fit parameters, as is done for the determination of the discriminator threshold and noise of each pixel with an S-curve fit to the pixel response as a function of the injected charge.

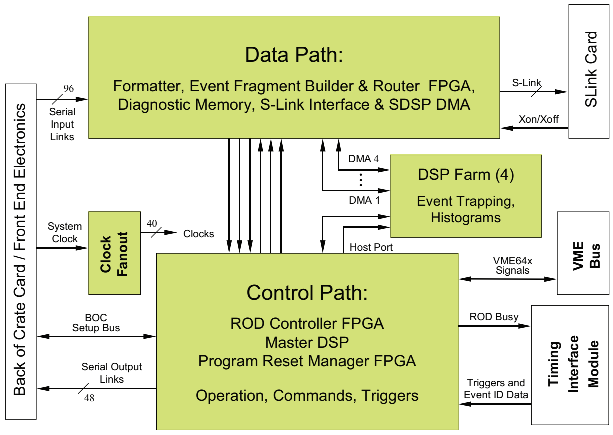

Figure 4: Block diagram of the ROD.

II. Calibration

The calibration of the ATLAS Pixel Detector cannot take place during normal data taking and needs dedicated software packages, due to the different data path that has to be used. In order to steer the whole system from a single GUI, a distributed system was developed, based on Inter Process Communication (IPC). A block diagram of the calibration infrastructure is shown in Figure 5.

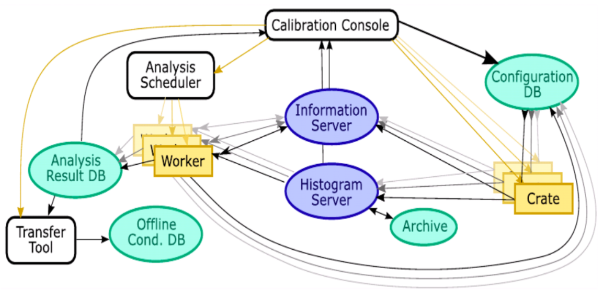

Figure 5: Block diagram of the calibration infrastructure.

From the GUI, called Calibration Console, the user can start a scan, which is actually executed on the SBC of each crate by sending commands to the RODs. In this way the time consumption to run a scan on the whole detector is not much higher than for one of the slowest RODs (connected to 26 modules). The scan configuration can be customised from the Console and is saved to a database before starting the scan, from where it is read by the crates. The Console monitors the progress of the scan, reading the information published about each ROD on the Information Server (IS). The histograms produced by the scan are available for fast reading in the Histogram Server and are automatically archived to a file on disk.

A scan only collects the data for which the hardware is necessary, while, whenever possible, the analysis of the histograms, computing the actual calibration constants, is run separately, leaving the hardware free for physics data or for the next scan. The analysis is started by the user from the Calibration Console, where the cut values can be customised, and the processes, one per ROD, are queued by the Analysis Scheduler and executed by the next free worker in the analysis farm. The analysis configuration is saved to a database, the monitoring of the analysis progress is based on IS and the histograms to be analysed are retrieved from the histogram server. The calibration constats are saved into the Analysis Result database and can be converted into the format necessary for the Offline Conditions database, to be used for data reconstruction and simulation.

Additional monitoring tools were developed, e.g. the ROD Status Monitor, that displays the ROD status presently published in IS as well as the errors per ROD and per module during scans and data taking, or the SBC Monitor, showing CPU and memory consumption of the SBCs.

III. Commissioning

The detector was assembled with its mechanical support between March and June 2007. During assembly tests were performed to check the connections between the modules, the optoboards and the low and high voltage supply lines in the Patch Panel on the support (PP0). Procedure and results of the connectivity test can be found elsewhere [4].

A. *Installation and connectivity test*

The Pixel-package was installed in the ATLAS cavern in July 2007, but remained unconnected for a few months, waiting for the outer parts of the Inner Detector (ID) to finish their cabling. Until December, the services were connected from the counting rooms up to PP2, inside the muon detector, and they were tested to detect malfunctioning as well as discrepancies between the actual connections and the connectivity database. Furthermore the cooling exhaust pipes at PP1 (at the ID endplates) were replaced, since they had beed damanged by corrosion.

The connection of services and optical fibres at PP1 could only start in February 2008 and also in this case tests were performed during connections to check for damages and differences from the database. The cables and fibres after connection at PP1 are shown in Figure 6. A general fibre swap at the BOC side was found and most of the fibres had to be reconnected in a few days.

The light transmission to and from the detector was tested: the light power on the TX channels was found to be lower than during assembly, as expected considering the different fibre attenuation. During the test period TX channels have been dying at the very high rate of a few per month. Their behaviour was found to be compatible with ElectroStatic Discharge (ESD) damage during production and the higher number of dead channels with respect to SCT could be explained by the fact that the SCT lasers were kept off when not in operation, while the Pixel ones were on all the time. New TX plug-ins are being produced both for Pixel and SCT, with particular care to avoid ESD damage.

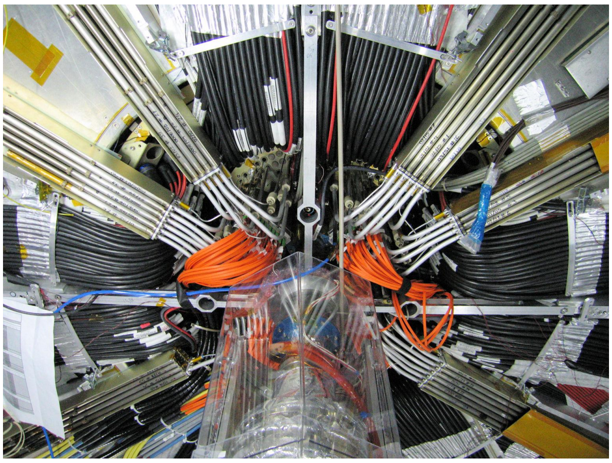

Figure 6: Connections at PP1.

Since in April the modules could not yet be cooled down, only one FE was configured per module and a threshold scan over 1/10 of the pixels of this FE was performed to make sure that the sensor was biased.

B. *Sign-off before Inner Detector closure*

Cooling was available starting from April 25th. Each loop, cooling 26 modules in the barrel or 12 modules in the endcaps, was tested singularly, measuring temperatures, back-pressure and heater power with different detector configurations, corresponding to different heat loads. While some loops were unstable with the detector off, most of them could be easily stabilised with configured modules, dissipating about 4 W each. Three endcap loops were found to be leaky and will not be operated for normal data taking, but could be kept on up to now, to complete the commissioning of all the modules. On May 1st, 77 of the 88 Pixel cooling loops had been tested, when the system had to be turned off due to a cooling plant accident and the Inner Detector was closed a few days later, before the foreseen sign-off could be completed.

Before the cooling accident, about 900 modules could be tested by performing a threshold scan on all the pixels: 8 modules with open high voltage connection and one without clock were identified and they cannot be recovered, two modules were swapped and the database was corrected accordingly, for 4 modules the threshold was not tuned in the configuration used at the moment and 3 modules show threshold scan results similar to those for an open high voltage connection, but a direct measurement was either not yet performed or it did not confirm the open line. The number of dead pixels in the tested modules did not increase significantly with respect to the measurements performed during module production. Based on a sample of 25 million pixels, the electronics noise was measured from the S-curve fit to be on average 166 electrons. Only about 1% of the pixels have noise higher than 200 electrons, while for a further 1% the fit did not converge.

C. Preparation for first data

In the cooling system three compressors were damaged due to prolonged slippage in the magnetic coupling between the motor and the compressor shaft. They could be repaired and the contamined coolant was replaced, so that the Pixel detector could be cooled again in time for the beam-pipe bake-out, that took place successfully at the end of August. The coolant loss was at the level of 1 kg/h during bake-out, so that further cooling commissioning, until the 11th of August, was necessary to find and possibly remove the leaks.

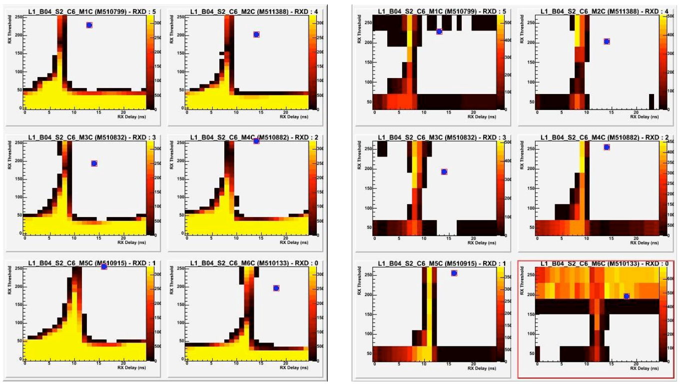

Figure 7: Communication errors as a function of threshold (y axis) and data-delay (x axis) settings in an RX plug-in at fixed opto-board laser power for six channels with clock (left) or pseudo-random pattern (right). The point indicates the chosen settings.

To restart operation with cooling, a new tuning of the opto-links was necessary. While modules have to be kept at about 0°C, opto-boards cannot operate stably at this temperature, therefore heaters were installed to keep the opto-boards at a higher temperature. In order to preserve the opto-board lasers from dying, it was first tried to tune the opto-links with the opto-boards at 10°C, but slow turn on effects were observed in some channels at this temperature, i.e. some channels reached the full power only after a few microseconds. The opto-link tuning is normally performed by sending clock to the modules and reading it back at different values of $V_{I_{set}}$ and for different settings of the threshold and data delay in the RX plug-in. The number of errors with respect to the expected signal is plotted versus the chosen parameters and values are chosen for which no communication errors were reported (see Figure 7, left). This method is fast enough to test the whole parameter space with the required granularity, but is not sensitive to slow turn on. A scan at fixed laser power and lower granularity, in which a pseudo-random pattern is sent to the modules and each returned bit is compared with the sent one, shows in case of slow turn on that the point chosen by the tuning algorithm is in a region with communication errors (see Figure 7, right). Most of the links could be tuned when the opto-boards were instead warmed up to 20°C, that was therefore chosen as the operating temperature.

On August 28th the whole detector could be turned on, 1662/1744 modules showed no communication errors after opto-link tuning and were further tested. From standalone data taking with a random trigger, the noise occupancy of each pixel was determined. The few modules limiting the data taking rate were disabled and about 5000 pixels with occupancy above 10^{-5} were masked out. In this way the average number of clusters per bunch crossing could be reduced from 100 to less than one. It was observed that most of the clusters are produced by single noisy modules and mostly concentrated on a small number of pixels inside them (see Figure 8).

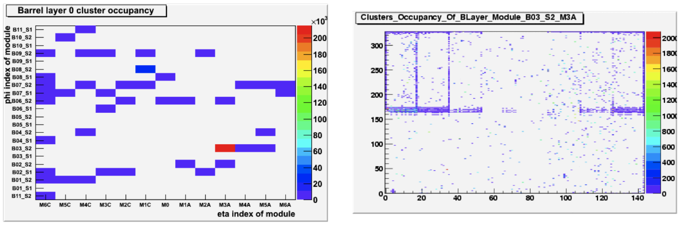

Figure 8: Noise hits per module in a layer (left) and per pixel in a module (right).

The plan for calibration in September was to collect a complete set of constants necessary for offline reconstruction and simulation, based on the threshold and ToT tuning performed during module production. Until September 20th the threshold scans were completed, while the ones involving timing and ToT were only partially done. The noise occupancy data were compared with the threshold scan results and a very good overlap was found between the pixels with high occupancy and the ones failing the S-curve fit after the scan. The threshold scan results confirmed the disconnection of some modules from the high voltage supply and the presence of one or two bad FEs in 8 modules, for which no pixels could be fitted.

D. Cosmics data

The Pixel detector was included in a combined ATLAS run for cosmic muons for the first time on September 4th, but since the timing was not tuned properly yet, no tracks with pixel hits were recorded. After changing the time window for read-out and extending it to 8 bunch crossings, on September 14th the first track with 7 Pixel hits and 16 SCT hits was recorded. The corresponding event display is shown in Figure 9.

The few tracks available after a few days of running could already be used to align the barrel layers with respect to the SCT, while smaller units, like the staves and maybe even the modules, need higher statistics, but could still be aligned with cosmics data.

Since the stability of the beam cannot be assured yet, the high voltage of the modules is not turned on during beam commissioning.

IV. Summary

Running the opto-boards at 20°C it was possible to tune the opto-links stably for about 95% of the modules, that could be further calibrated and used for data taking of cosmic muons with the threshold and ToT tuning obtained during module production. Three cooling loops, corresponding to 36 modules, will not be operated because they were found to be leaky, but the modules could be still calibrated and are kept on for commissioning. As long as the priority lies by stable running, there is no necessity to retune thresholds and ToTs and the modules failing calibration or giving errors during data taking will only be tested at a later time. The identification of bad pixels agrees well between calibration and data taking so that both methods can be combined. Cosmics tracks for alignment are being collected, but for the safety of the detector the high voltage cannot be kept on during beam commissioning.

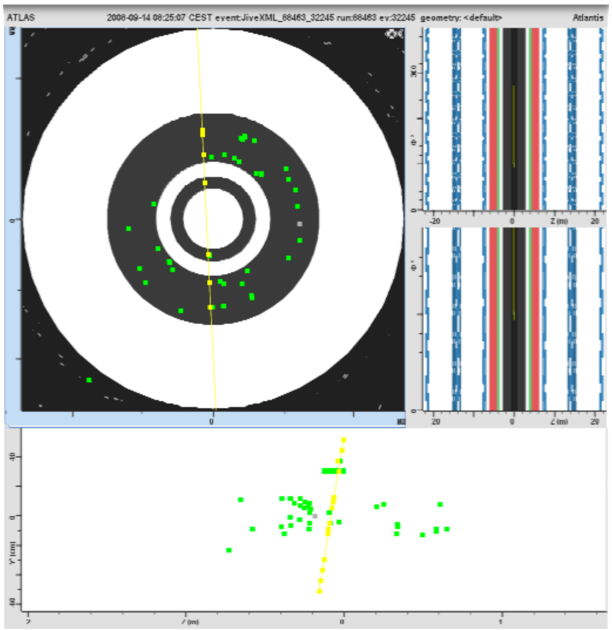

Figure 9: Event display of the first track with Pixel hits.

References

[1] G. Aad *et al.*, *JINST* **3** (2008) P07007.

[2] M. L. Chu *et al.*, *Nucl. Intrum. Meth.* **A 530** (2004) 293.

[3] J. Vermeulen *et al.*, *IEEE Trans. Nucl. Sci.* **53** (2006) 912.

[4] E. Anderssen *et al.*, CERN-ATL-COM-INDET-2008-016 (2008)