COMMISSIONING OF THE ATLAS PIXEL DETECTOR WITH COSMICS DATA

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Abstract

This paper presents results from the commissioning periods of the ATLAS Pixel Detector in 2008 and 2009. Internal detector calibration is described as well as calibration with cosmic ray data.

The paper is aimed to layout the way from interpreting and tuning the detector response to actual data taking and studies on first data. The current status and readiness of the detector is also summarized.

INTRODUCTION

The ATLAS Pixel Detector is the innermost part of the ATLAS Detector. It is a tracking device and it is split in three detector layers to cover three hits per particle track. A solenoid magnet delivers a 2T field, which is necessary to bend the particle tracks and allow a momentum measurement.

A Pixel Detector module is composed of an n-in-n silicon sensor bump bonded to front end electronics. The front end chips are wire bonded to a circuit board which contains the module control chip (MCC) and the power and read out connections [1].

The Pixel Detector consists of 1744 such modules with 46080 readout channels each. In total, this results in approximately 80 million readout channels, each of which has to be calibrated. The front end electronics is subdivided into 16 readout chips. Figure 1 shows an exploded schematic view of a module.

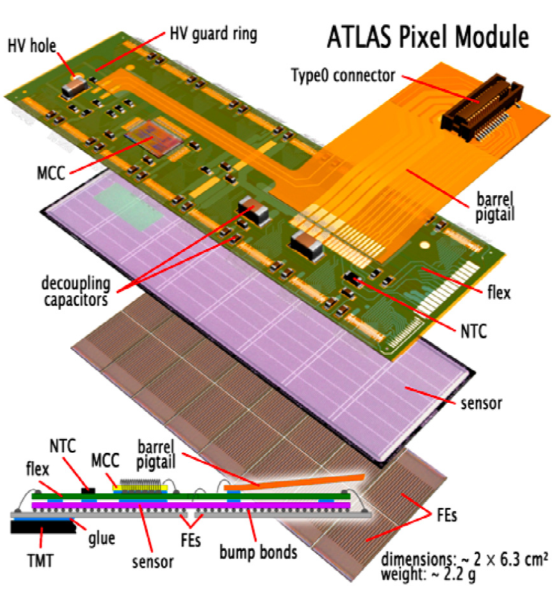

Figure 1: Exploded schematic view of a module.

The readout chips of the Pixel Detector have the capability to inject adjustable charges for each readout channel [3]. This allows calibration without depending on physics data, like cosmic ray data or beam collision data.

Since the Pixel Detector is a tracking device, it has to be very efficient while at the same time having a low noise. It also has to deliver a good spatial resolution and coverage. These requirements were considered in the design and the following sections present the current status of the detector performance.

The detector was operated from August 2008 to December 2008 and, after a shutdown for cooling consolidation, from May 2009. After describing threshold related tunings done during these operation periods, studies conducted with cosmic ray data are described. The last section gives an overview of the current detector status and the readiness for data taking with LHC collisions.

THRESHOLD CALIBRATION

To control the signal efficiency and the noise, the channels of the Pixel detector were individually tuned. The following subsections describe the tuning and the detector response.

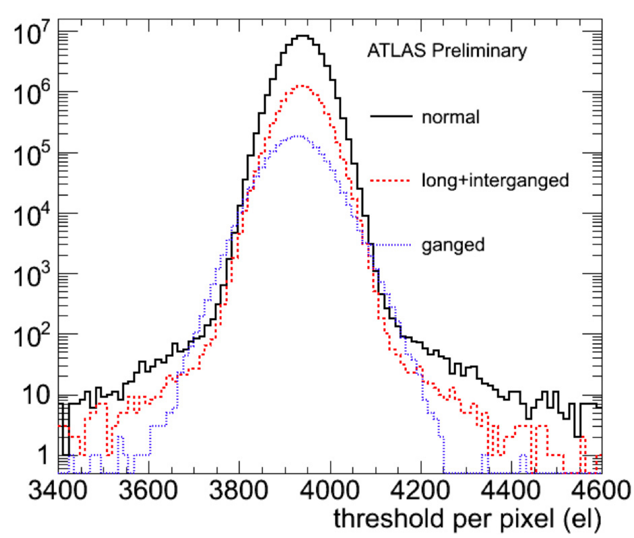

Figure 2: Calibrated threshold for the different pixel types. Non normal pixel types are geometric artefacts of the module layout.

Threshold

Each channel of the Pixel Detector is read out by a preamplifier / comparator combination [3]. The threshold of the comparator can be adjusted individually for each readout channel and globally for each readout chip. The tuning procedure was done [4] and the resulting thresholds are presented in figure 2.

A peak at approximately 4000 electrons is clearly visible. This threshold charge was chosen to effectively register signals from charged particles, which are expected at ~19000 electrons, while at the same time avoiding having a high noise. The width of the threshold distribution is ~40 electrons (note the logarithmic scale) and the threshold over noise ratio is ~25.

Time over Threshold

The threshold controls, which charge deposition in the sensor is needed to register a hit. The magnitude of the deposited charge is correlated to the time over threshold (ToT). The time over threshold of a deposited charge of 20000 electrons was tuned to be 30 bunch crossings (BC). A bunch crossing corresponds to a time of 25 ns.

Figure 3 shows the effect of the ToT tuning. A tuned ToT guarantees a uniform detector response. It also defines the maximum measurable charge, since the maximum measurable ToT value is 255 bunch crossings.

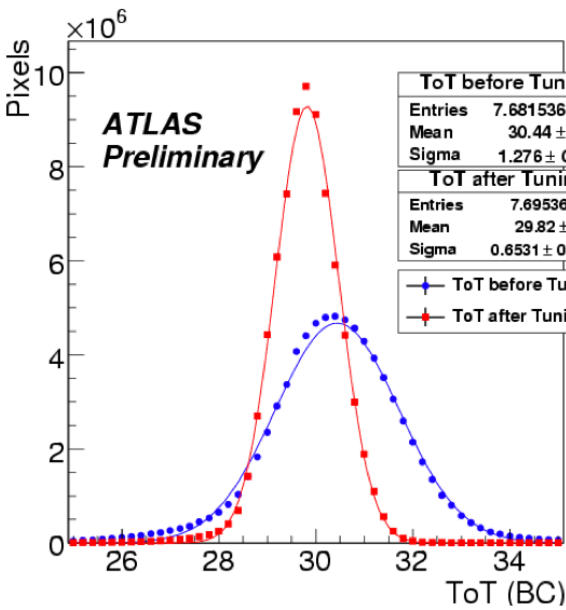

Figure 3: ToT tuning per channel. The blue curve shows the ToT tuning from module production data. The red curve shows the new tuning.

With the tuned ToT, a ToT-charge calibration curve was taken. The curve is shown in figure 4. The dependence of ToT on injected charge is expected to be linear and the measured calibration confirms this behaviour. More threshold related studies can be found in [4].

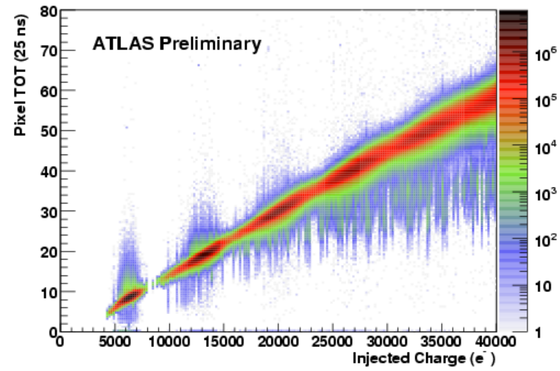

Figure 4: ToT-charge calibration curve per channel. Note the logarithmic scale. The spread at high injected charges may arise from badly tuned pixels.

COSMIC RAY DATA-TAKING

During the run periods in 2008 and 2009, a total of 700k cosmic ray tracks were taken. 310k of these were taken with the solenoid field turned on. The following subsections describe the techniques for successful data-taking and a first study on cosmic ray data.

Figure 5 shows an event display of a recorded track with applied noise mask.

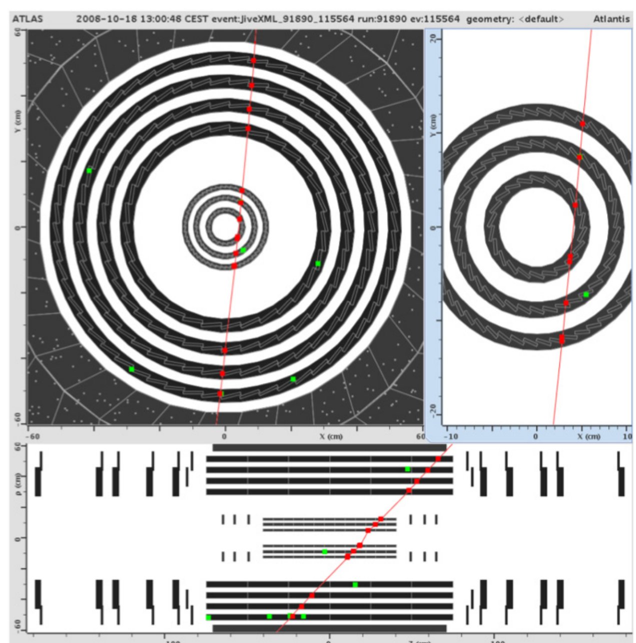

Figure 5: Event display for a particle track in the Pixel Detector (inner three layers) and the surrounding SCT Detector (outer four layers). The solenoid field is off. The red dots indicate hits in the corresponding layer of the subdetector and the red line shows the output of the tracking algorithm. The green dots indicate noise hits. The Pixel Detector registers one noise hit in this example.

Noise Occupancy

To reduce the noise hits registered by the Pixel Detector, a noise mask is applied. The noise mask is build from a dataset taken with a random trigger. After having taken a sufficient number of events, pixels with an amount of hits higher than a threshold were masked from data-taking. The random trigger guarantees that the recorded hits are not from particle tracks, but from noise.

After applying the noise mask, the noise occupancy of the Pixel Detector is $\sim 10^{-10}$ hits per BC and event.

Alignment

The Pixel Detector has been surveyed during installation and the locations of the different parts of the detector have been stored in a database. However, the survey was not sensitive to displacements on the order of 0.1mm. These displacements can be calculated from particle track data. Only tracks with a hit in the innermost detector layer are taken into account, so due to the nature of cosmic tracks mostly the upper and lower parts of the Pixel Detector barrel are considered.

The cosmic ray data can be used to test these alignment algorithms of the Pixel Detector. During the alignment process, the residual of the pixel hits is used to optimize the real module position with regard to the tracks hit positions. The residual is defined as the distance of a hit associated to a track to the track. The newly found geometry is then applied and the track finding is redone. Figure 6 shows the effect of alignment. The resolution is close to the simulated perfect resolution.

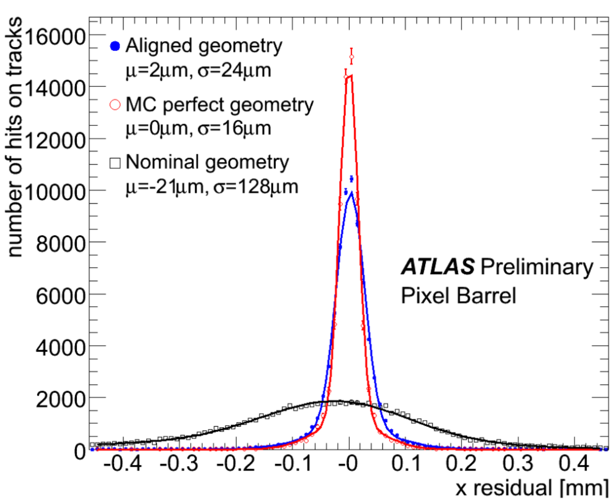

Figure 6: Aligned and non-aligned (nominal) residuals for a sample of cosmic ray tracks. The perfect geometry Monte Carlo (MC) residual distribution is also shown.

Alignment

The efficiencies of the different parts of the Pixel Detector barrel are shown in figure 7. The efficiency is well above 99.5% for the barrel, but it has to be noted that disabled modules are not included in the calculation. The disk modules have very low statistics due to their position in the detector and are therefore not included in the efficiency measurement.

Lorentz Angle

The Lorentz angle is an effective angle for a charged particle passing a pixel module. Due to the Lorentz force, the charges induced in the silicon are deviated from their path to charge collection in the readout electronics. This results in an effective module tilt. The magnitude of this effect is shown in figure 8 and is in agreement with the expected value. Studies on the temperature dependence have also been conducted and results can be found in [5].

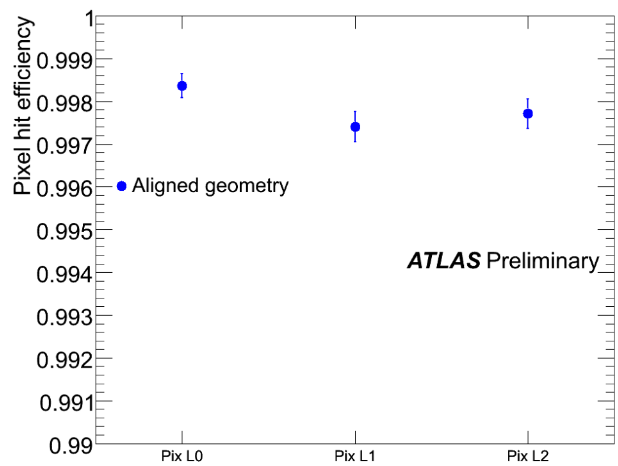

Figure 7: Efficiencies of the barrel layers. Disabled modules are not taken into account.

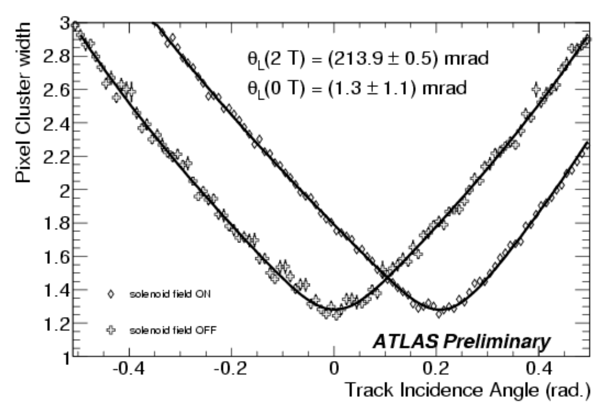

Figure 8: Lorentz angle measurement. The curve for solenoid field turned off is shown and the Lorentz angle is 0 as expected. The curve for solenoid field on is also shown and it yields a Lorentz angle of 214 mrad.

READINESS AND SUMMARY

Currently, 98% of the Pixel Detector modules are operable. It has been shown that a meaningful detector tuning was conducted, which resulted in a successful data-taking period.

The tuning results prove, that the detector response is understood and under control. The readout threshold is at 4000 electrons for most pixels with a spread of 40 electrons. A charged particle deposits a charge corresponding to ~30 BCs ToT in the detector.

The data confirms, that the alignment algorithms are in working and produce and alignment which is near perfect for the barrel. The detector meets the requirements for a high hit efficiency (>99.5%) and a low noise occupancy ($\sim 10^{-10}$ hits/BC/event). The Lorentz Angle was measured among other detector quantities (213.9 ± 0.5 mrad) and is in agreement with theoretical predicitons.

It can be concluded, that the ATLAS Pixel Detector is in good shape and ready for the LHC start up and first collisions.

REFERENCES

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