Commissioning of the ATLAS Pixel Detector with Cosmics Ray Data

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The ATLAS Pixel Detector is the innermost detector of the ATLAS experiment at the Large Hadron Collider at CERN. It consists of silicon sensors equipped with approximately 80 million electronic channels and will allow to detect particle tracks and secondary vertices with very high precision. After connection of cooling, services and verification of their operation, the ATLAS Pixel Detector is now in the final stage of its commissioning phase. Prior to the first beams expected in Autumn 2009, a full characterization of the detector was performed. Calibrations of optical connections, verification of the analog performance and special DAQ runs for noise studies were done. Combined operation with other sub-detectors in ATLAS allowed to qualify the detector with physics data from cosmic muons. This paper will show all aspects of detector operation, including the monitoring and safety system, the DAQ system and calibration procedures. A summary of calibration tests on the whole detector as well as analysis of physics runs with cosmics data will be presented.

Keywords: LHC; ATLAS; Pixel Detector; Commissioning

ATL-INDET-PROC-2009-017
28 October 2009

1. Introduction

Many physics analyses of the ATLAS experiment[1] at the Large Hadron Collider (LHC) will require precise pattern recognition for the precise determination of vertices near the collision point. To meet this condition a vertex resolution less than 12 μm, high granularity and efficiency combined with low mass of the detector material are required. The Pixel Detector, the innermost tracking detector of ATLAS, plays a critical role in the identification and reconstruction of secondary vertices from the decays of b-quarks. The Pixel Detector contains more than 80 million channels, which provide excellent spatial resolution to meet the pattern recognition requirements for track reconstruction at the LHC design luminosity of L = 10^{34} cm^{-2} s^{-1}.

It uses silicon pixel technology designed to withstand the high radiation environment expected inside the Inner Detector.

2. Pixel Detector

The Pixel Detector consists of three barrel layers at radii 5, 9 and 12 cm and two endcaps of three disks each. This geometry guarantees at least three pixel hits in the pseudorapidity range of interest of $|\eta| < 2.5$. The 1744 identical modules are mounted on a carbon support structure with the integrated C_3 F_8 evaporative cooling.[2] The detector building elements are a stave with 13 modules for the barrel and a sector with six modules for the disks. Two neighboring staves (or sectors) share a cooling loop. During operation the module temperature will be kept at about -10^o C to minimize irradiation effects. To achieve the required transverse impact parameter resolution of 15 μm, each module contains 47232 pixels, the majority of them having a size of $50{\times}400$ μm. A pixel module is read out by 16 front-end (FE) chips. Each readout channel in the 16 FE chips is bump-bonded to a pixel on the sensor using either an In or a PbSn bump. A more detailed description of the pixel module and readout system can be found elsewhere.[3]

3. Commissioning

The assembly of the Pixel Detector package was installed in the center of ATLAS in June 2007. The connections of the electrical, optical and cooling services, together with validation tests was performed from February to April 2008. Commissioning was resumed in summer 2008, after a cooling incident, when the detector was calibrated for the first time and tested with simulated raw data input and cosmic data taking in standalone and in global ATLAS combined runs. On September 10^{th} of 2008 the Pixel Detector was ready for the first LHC beam, with HV turned off and the FE preamplifiers disabled to protect the FE chips from large charge deposits during unstable beam conditions. After the shut down in December 2008 the Pixel Detector was re-calibrated beginning of 2009 and signed-off with global cosmic runs from August 2009 to present.

3.1. *Tuning of Optical Connections*

The calibration of the optolink parameters is necessary to establish and maintain reliable communication to and from the pixel modules and to keep timing adjustments of the detector constant. The optical commissioning and tuning program consists of three parts: verification of the downlink, verification of the uplink and tuning of the uplink. In 2008, $\sim$97% of the detector was automatically tuned, while for a few modules the correct parameters had to be set manually.

3.2. *Analogue Tuning*

To limit the amount of data transfered from the modules to the readout crates, a pixel is only read out if the signal size is above a predefined threshold. This threshold can be set on a pixel-by-pixel basis, and in order to obtain a uniform efficiency of the detector, a tuning of the FE parameters determining the threshold is performed. The current tuning algorithm injects a charge exactly at the aimed threshold and then alters the settings of the readout channel in the FE chip until the 50 % efficiency point of the S-curve conforms to the desired threshold. The most probable charge deposition in a pixel from a minimum ionizing particle (mip) is 20,000 electrons, and the threshold is currently tuned to 4,000 electrons. Figure 1 (left plot) shows the threshold distribution of nearly all pixels in the detector for different pixel types. The threshold follows a Gaussian distribution with an average of $\sim$4,000 electrons and a width of 40 electrons. For standard pixels the threshold-to-noise ratio is approximately 25.

3.3. *Time-Over-Threshold Tuning*

After the threshold tuning the detector must be tuned so that a mip (20,000 electrons) produces a Time-Over-Threshold (ToT) response of 30 bunch crossings (BC), as uniformly as possible across the entire detector. The charge is collected and amplified by a charge sensitive preamplier in the FE chip. Only pixels above a predefined threshold are readout. The deposited charge is measured using the ToT: the period of time during which the preamplifier output signal is above the threshold. The ToT increases almost linearly with the deposited charge and is digitised in clock cycles of the module controller chip. The ToT is converted to charge offline using functions obtained from fits to calibration data. To obtain a uniform response from all pixels, the ToT is tuned FE-by-FE and on a pixel-by-pixel basis. For initial operation the average ToT for a charge deposition of 20,000 electrons, close to the charge deposited by a mip, was tuned to 30 clock cycles. This ToT-to-charge relation ensures that the Pixel Detector can measure charges up to 8.5 times the charge of a mip. Figure 1 (right

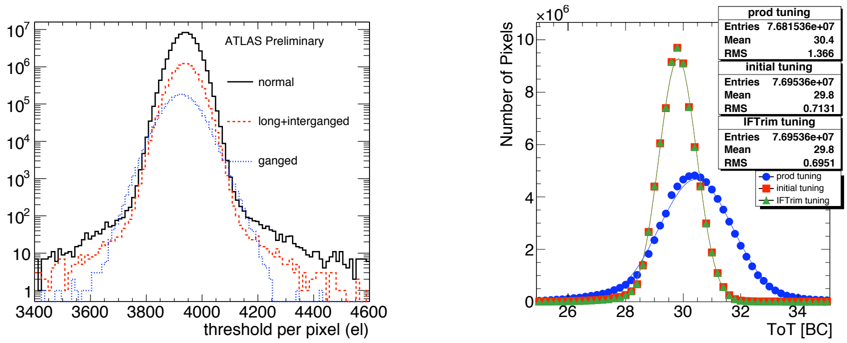

Fig. 1. The left plot shows the tuned threshold distribution for different pixel types. The right plot shows the ToT distribution for the whole detector before (blue) and after tuning (green).

plot) shows the ToT distribution for pixels with an injected charge of 20,000 electrons with tuning performed during module production (blue) and the new tuning performed (green). After tuning the mean value is about 30 with a resolution of 0.65.

3.4. *Cosmic Muon Ray Data Taking*

After the LHC incident of September 19$^{\text{th}}$, more than 400,000 tracks with hits in the Pixel Detector were collected over several months of data-taking with cosmic rays. After masking roughly 10^{-4} noisy pixels in the detector, a noise occupancy at the 10^{-10}-per-BC level was achieved, corresponding to roughly 0.05 noise hits per event in the whole detector. With the most recent aligned geometry, the efficiency of attaching a hit to a track traversing the barrel is 99.8 %, which is compatible with the test-beam value of 99.9 %.[4] The detector was reading out a window of 8 consecutive BCs in order to allow synchronization with the other ATLAS sub-detectors, which was quickly achieved. As the detector is currently timed-in to within 3 BCs. The readout window will be reduced to 5 BCs for initial LHC data, and ultimately to 1 to 3 BCs. To determine the position of clusters the pixel cluster width is measured versus the track incident angle, called the Lorentz angle. Figure 2 (left plot) shows the cluster width in the Pixel Detector versus incidence angle of the track for two different values of the solenoidal magnetic field in the Inner Detector. The minimum of the distributions occurs at the Lorentz angle, which reflects the deflection of the charge carriers in the magnetic field. This angle is consistent with zero when the

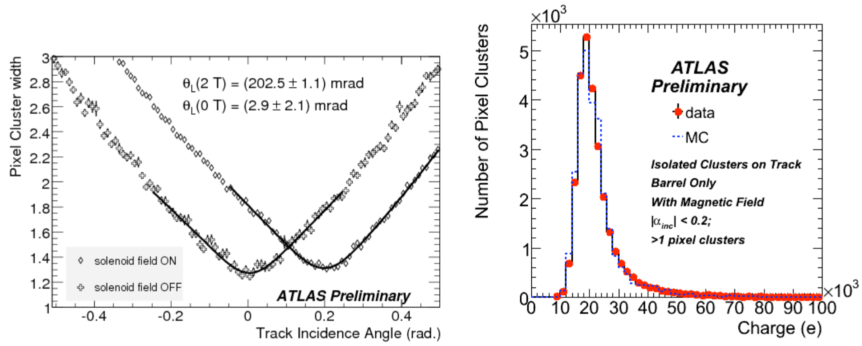

Fig. 2. The left plot shows the distribution of the cluster width versus the track incident angle for two values of the magnetic field. The right plot shows the distribution of the cluster charge distribution in data (points and fitted solid line) and Monte Carlo simulation (dashed).

magnetic field is off and about 214 mrad for the full magnetic strength of 2 T. This result is consistent with expectations from Monte Carlo simulations to within 5 %. The cluster-charge distribution for tracks with nearly normal incident agrees very well with Monte Carlo simulated events as shown in Fig. 2 (right plot).

4. Summary

An intensive commissioning and cosmic-ray data-taking period was performed over the year 2008, ~96 % of the Pixel Detector was tuned, calibrated, and ready to collect data. The cosmic-ray data sample has been used for extensive calibration, tuning of simulation input, and on-going studies of the detector performance. The Pixel Detector is currently being re-calibrated, with ~98 % of all modules working, in preparation for LHC collisions to be delivered by the end of 2009.

References

1. The ATLAS Collaboration, Aad, G. et al., The ATLAS Experiment at the CERN Large Hadron Collider, *JINST* **3**, (2008) S08003.
2. Attree, D. et al., The evaporative cooling system for the ATLAS Inner Detector, *JINST* **3**, (2008) P07003.
3. Aad, G. et al., ATLAS Pixel Detector electronics and sensors, *JINST* **3**, (2008) P07007.
4. Andreazza, A. et al., Test beam performance of the ATLAS Pixel Detector modules, *Nucl. Instr. Meth. A* **565**, (2006) 23-29.