ATLAS Pixel Detector System Test

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Abstract

On June 25th of 2007 the ATLAS collaboration lowered the pixel detector into place, however before this the detector had to be qualified through a series of tests. Prior to assembly, each individual piece of the detector and services chain passed a set of quality controls. This was followed by the construction and test of the whole pixel detector. This test of the full chain of services -including the voltage supplies, opto-boards, cooling, temperature monitoring, control software, and the pixel modules themselves- is referred to as the Pixel System Test. The System Test took place in an above-ground laboratory setting at CERN and consisted of two main parts. The first half of the test focused on one of the pixel detector's endcaps. This endcap consists of 144 modules, making up roughly 10% of the total pixel detector. For the pixel endcap test, most of the 144 modules were operated simultaneously which required that the pixel endcap's cooling system be functioning as well[1]. Additionally, four scintillators were added above and below the detector which trigged on cosmic muons. As a result, the pixel detector measured its first cosmic tracks during this test. After the cosmic test the pixel collaboration connected the entire pixel detector a few modules at a time. The cooling for the pixel detector could not be used in this setting, and to prevent overheating any componants only one chip was powered on at a time. This half of the system test is referred to as the connectivity test[3].

I. The Pixel Detector

The ATLAS pixel detector has a strict set of design requirements. First, due to its proximity to the beam pipe, it must be able to operate under a lifetime dose of radiation of at least 50 Mrad. Second, in order to perform B-tagging, the detector needs a high resolution in $\eta\phi$ which translates into a requirement for a high granularity and low mass pixel detector. With its 80 million pixel channels in three concentric layers covering a total of $1.8m^2$ and mass of $0.10\chi_0$, the ATLAS pixel detector achieves an impact resolution of $12\mu m$. Finally, the high rate of bunch crossings and slow trigger latency mean that the pixel detector must store the hits from 100 beam crossings in each on chip buffer and distinguish which of those hits pertain to each bunch crossing[2].

The 80 million pixels are located on 1744 identical modules. Each module consists of 16 pixel front end sensor chips which each contain 2880 pixels. While the pixel detector itself is quite small, measuring 1.3 meters in length and .33 meters in diameter, a large number of external services are needed to operate it. Nearest of these to the detector is a set of 'opto-boards' which translate the electrical signals to and from the modules into optical ones. These signals are then sent through fiber cables into the counting room about 100 meters away. The pixel modules also need a high voltage supply to deplete the sensors and a low voltage supply to operate the electronics; these power supplies are also located in the counting rooms. The length of the electrical cables causes a significant voltage drop, which requires that voltage regulators be placed about 10 meters from the pixel detector in order to measure and compensate for the drop.

II. Services Test

A host of electrical and cooling services are needed for the operation of the pixel detector, and these are shown in Figure 1 for one pixel module. The service cables pass through a series of patch panels between the pixel detector and the counting room. Patch Panel 0 (PP0) is the interface from the pixel modules to pixel services and is integrated into the pixel detector assembly. The interface between the pixel assembly and the rest of the world is Patch Panel 1 (PP1). The low voltage regulators are located at PP2, approximately 10 meters from the detector center. PP3 is a cable interface located on the scaffolding of the atlas cavern. The final step is PP4, in the counting room itself, where the cables are routed to the proper power supplies and interlocks.

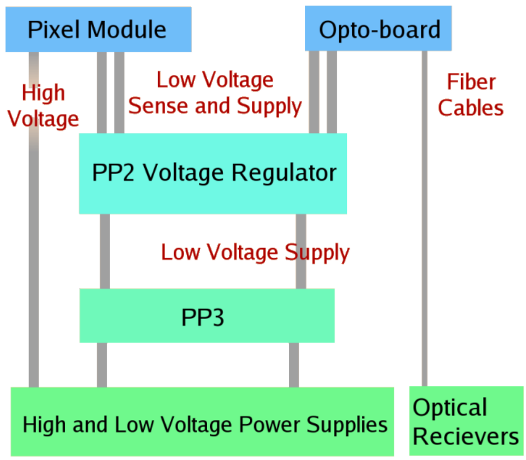

Figure 1: Electrical and optical services for one module

Before connecting the service cables to the pixel end cap for the system test, it was essential to test the full chain of services from PP1 to the power supplies. This pre-test was essential in order to test for malfunctioning voltage regulators. If a voltage regulator was measuring an incorrect voltage on a module while the built in protection circuit was not working correctly, a pixel module could have been damaged. Additionally, testing the services and their control systems before connecting to the pixel detector made it much easier to find and correct any problems.

In order to perform the services test, two parts were needed. First, a dummy pixel detector had to be to plugged into Patch Panel 1. This dummy detector consisted of an active resistive load (to mimic the resistances of the pixel module), a multimeter (to measure the voltages and currents supplied by the regulator boards), and a switching circuit (to switch the load to each of the module channels). The second half of the service test setup was a software package which connected to both the dummy pixel detector and to the services control software. This software activated the power supplies, adjusted the active load, measured the supplied voltages, and ensured that everything fell within accepted parameters. This process provided a test of the control software, as well as of the services themselves. These tests also ensured that the interlock and protection circuts functioned properly in order that the pixel detector would not be damaged when it was connected. Over the course of the services test, some problems were found and corrected, which led to a smooth transition into the system test as a whole. The services test setup is now being used in the ATLAS cavern to test the services for the full pixel detector.

III. Module Calibration

The next phase of the system test involved calibrating the modules and opto-boards. The light output of the opto-board is dependent on supply voltages, threshold levels, and board temperature. To obtain a uniform light output across all channels, each board needed to be tuned. Secondly, the discriminator thresholds and preamplifier feedback currents for each chip were tuned such that the average Time over Threshold (ToT) for an event was uniform over the entire detector. Finally, data was taken on the endcap using random triggers. From the randomly triggered data, noisy and dead pixels were observed. Overall, 0.074% of the pixels were found to be bad, but 90% of these bad pixels had already been discovered to be problematic during the chip production. After removing the noisy pixels from analysis, the average noise occupancy for random triggers is $2 * 10^{-7}$[1].

IV. Cosmic Data Taking

Surrounding the pixel endcap were four scintillators. These were used to trigger on cosmic muons which passed through the endcap. The pixel endcap's three layers of modules were oriented so that each layer was directly above the previous layer. This arrangement was such that it was possible to measure cosmic tracks passing through the endcap. Each layer on the endcap is composed of 48 modules arranged into a ring. Due to these overlapping modules, cosmic tracks could have had three to six hits in the pixel endcap. Because of the ability to trigger on events and record tracks and clusters, the cosmic data-taking setup provided a realistic test of the full chain of hardware and software.

Shortly after the start of cosmic data taking, the first evidence of real reconstructed tracks appeared. This appeared in the form of the module trigger timing and in the ToT distribution, shown by Figure 2. In both cases, a clear difference could be seen between events with random triggers and events with cosmic triggers. The reconstructed tracks from the cosmic data were then compared with those from the Monte Carlo data as shown in Figure 3. The agreement was good, except for the presence of a few noisy pixels which caused false tracks to appear. Once the dead and noisy pixels were taken int account the data matched the Monte Carlo as expected[4].

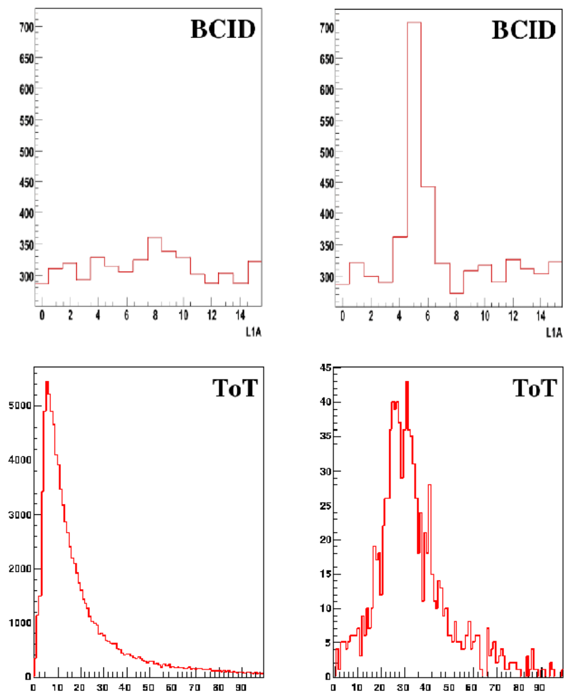

Figure 2: Left: noise triggers, Right: Cosmic triggers[2]

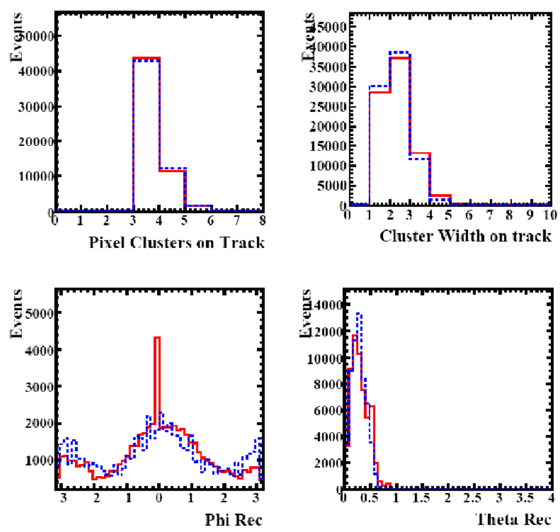

Figure 3: Solid: Cosmic data, Dashed: MC data[4]

Other analyses with the cosmic data have also been ongoing. The first alignment studies have obtained resolutions of $17.8\mu m$ in X and $117\mu m$ in Y. These compare well with expected values of $15.8\mu m$ and $117\mu m$ which were obtained from simulation. In the regions where the pixel modules overlap, it is possible to have 4 to 6 hits on a track. This allowed for a calculation of the pixel efficiency and was determined to be about 99% after removing dead and noisy pixels. In addition, once the dead and noisy pixels were removed from the analysis, the measured occupancy during the cosmic data taking was 10^{-9}[4]. These tests all demonstrated that the pixel endcap performed within specifications in all areas and is ready for integration into the ATLAS detector.

V. Connectivity Test

After the cosmic test, the pixel endcap was integrated into the pixel detector. Then, as the last stage in the system test, each pixel module in the entire detector was connected and operated in the above ground laboratory. However, the infrastructure to provide cooling to the entire detector was not available outside of the ATLAS cavern. In order to avoid overheating the modules, only one chip was operated at a time. The purpose of this test was to check that all of the modules and wiring were working properly before lowing the pixel detector to the ground, as this was the last time that the pixel detector will be accessible for repairs. Through the course this test, all of the modules were connected, tuned, and many problems were found and corrected. After all tests and repairs, the entire pixel detector is working properly, with the exception of two dead modules and 3 dead chips. None of these, however, exist in the innermost (and most critical) layer of the detector[5].

VI. Summary

The system test on the pixel detector has been completed and work is moving forward to installation of the detector in the ATLAS cavern. Not only did the system test verify the functionality of the pixel detector, it also provided the pixel collaboration with an invaluable experience working with the detector. The techniques used in testing the services and in operating the detector for the cosmic test are now being used in the installation of the full detector. In addition, the results from the cosmic endcap test provide a glimpse of the pixel detectors performance. These results are quite encouraging and show that the pixel detector should perform at or above expectations.

References

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