Evaluation of Characteristics of Silicon Pixel Detectors for the ATLAS experiments

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Abstract—

The LHC will be upgraded to an increased luminosity by about 2025. Therefore the detector has to be upgraded. The detector system of the tracking detector of the ATLAS experiment will be upgraded by Silicon detectors, namely a silicon pixel and silicon strip detector. During my summer student project, I engaged in the evaluation of Silicon Pixel detectors using ITk Pixel SR1 System Setup, a Climate chamber setup and the Cell Test setup. The tests conducted during the project are NTC temperature readout, and electrical characterisation of modules. The details of the demonstrations and the analyzed readings are presented in this report.

1 Introduction

The intuition of the human imagination leads to many questions. One such a great question is what are we made of? What all the matter in universe made up with? Aristotle believed that matter was continuous, such that one could divide a piece of matter into smaller and smaller bits without any limit. Such that there were many ideas from great minds regarding this question. For several centuries the arguments continued without any real evidence. But now we stand in a position with real evidence for the great question. What all the matter in universe is made up with?

In the journey of observing the matter in smaller dimensions, particle accelerators play a major role by providing real evidence for the theories predicted. The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator. It consists of a 27 km ring of superconducting magnets with a number of accelerating structures to boost the energy of the particles. The proton beams inside the LHC are made to collide at four locations around the accelerator ring, corresponding to the positions of four particle detectors ATLAS, CMS, ALICE and LHCb.

In order to get more accurate and resolved data, the LHC needs to increase its luminosity. Such that the resolution, hit rate and capability radiation hardness of the detectors have to be further developed. Therefore pixel detector of the ATLAS experiment will be upgraded using new Silicon Pixel Detectors.

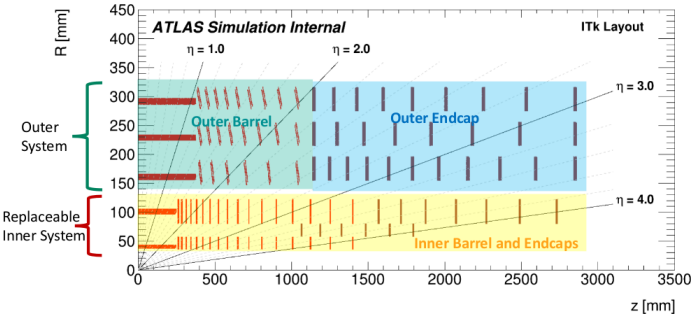


Figure 1: Layout of ATLAS Pixel Detector

2 Silicon Pixel Detectors

Silicon is a semiconductor element in the 4^{th} group of the periodic system. Characteristics of silicon such as band gap and very low intrinsic conductivity, are important for the operation as

particle detector and detection of charged particles. Silicon detectors can be viewed as solid-state ionisation chambers and they are used in most high energy physics experiments as innermost high-precision tracking devices.

3 Commissioning of Silicon Pixel detector using ITk Pixel SR1 System Setup

The ATLAS ITk Pixel group has a system setup in SR1. It consist of

- Demonstrator Setup Box
- Readout Hardware and software (with three systems)
- CO_2 Temperature Control plant
- Detector Control System (DCS)
- Dry airflow supply
- power supplies

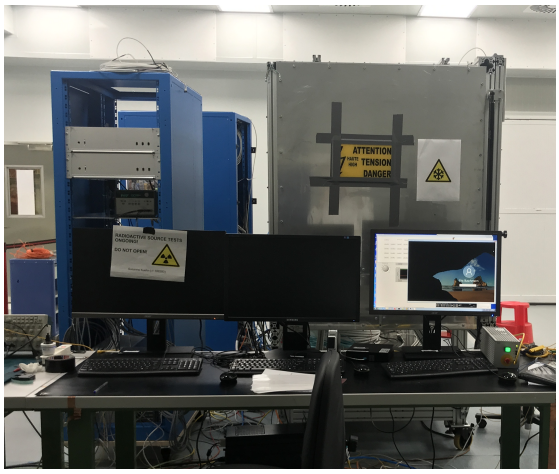


Figure 2: SR1 demonstration setup

The prototype is installed inside the setup. It is built of seven quad silicon pixel modules and eight dual modules. They were configured inside the demonstrator box and I worked on evaluation of quad modules. Following are the tests conducted during the program. The pyBar hardware and software was used to readout the outputs and analyze the results. The conducted tests are,

- Threshold Scans
- Tuning of the modules (noise occupancy tuning, stuck pixel tuning, hot pixel tuning)
- Analog and Digital scans

3.1 Time over Threshold (ToT)

For the threshold scans a sample electrical signal was injected to the silicon pixel modules and observed the outputs using the pyBar readout system. All the properly operating quad modules were tested by threshold scans and one of the parameter we considered in the threshold scan is the Time over Threshold value.

ToT is the time interval during which the corresponding pre-amplifier output is greater than the threshold. This value is recorded in units of the bunch crossing clock. The ToT value is an important parameter because it can be used to interpret the charge deposited by a passing particle. Also during the establishment of the communication between the detector module and the off- detector electronics the ToT values plays a major role. Since the links need to be tuned using the ToT and the sampling phase of the up-link.

In the existing system the ToT results for each front end was generated separately. A python code was generated to gather all the front end readings into one histogram as showed in figure 3.

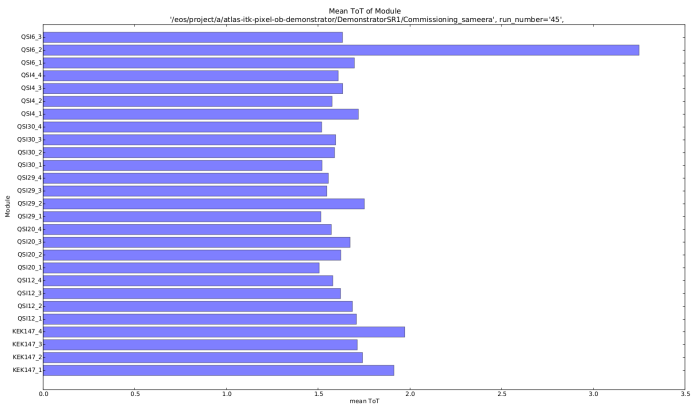


Figure 3: Mean ToT variation of the front ends

In the above figure one of the front ends shows a greater mean ToT value than the other front ends. The ToT variation of that front end (QSI16 - 2) and ToT variation of other front end were compared. By comparing the ToT variation of the QSI16-2 and the other ToT distributions, the QSI16-2 ToT distribution resulted in not only a

greater Mean ToT but also a greater standard deviation.

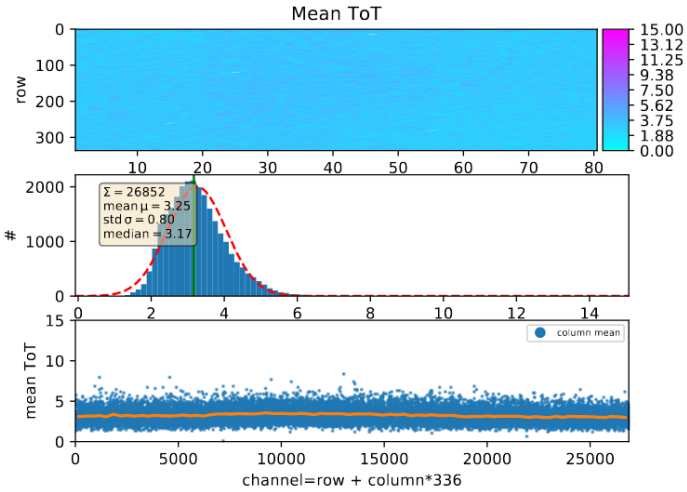


Figure 4: ToT variation of QSI16-2

The figure 5 shows the ToT variation of the KEK147-1 front end. Most of the front ends resulted in similar distributions other than the QSI16-2 front end.

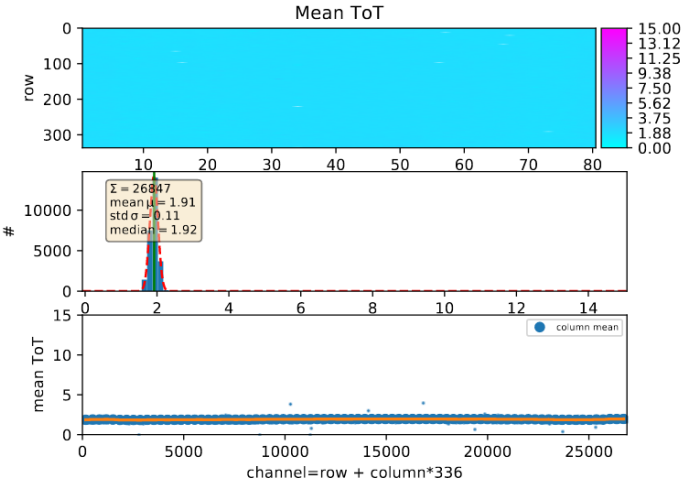


Figure 5: ToT variation of KEK147-1

4 NTC Temperature measurements using Climate Chamber

A NTC Thermistors is a negative temperature coefficient resistor that significantly reduces its resistance value as the heat/ ambient temperature rises. Four Quad modules with NTC thermistors were tested using the Climate chamber setup to observe the NTC reading variation with the ambient temperature. This measurement is important to quantify the temperature variation of modules. The Quads were placed inside the climate chamber one by one and the resistance of the NTCs were measured at several temperatures set by the climate chamber. With the following equation (equation 01) which is given in the catalogue, the temperature was calculated using the measured resistance values.

$$R = R_0 \exp^{B(\frac{1}{T} - \frac{1}{T_0})} \quad (1)$$

where R is the resistance at temperature T, R_0 is the resistance at standard temperature T_0 (298.15 K) and B is the Thermistor constant which depends on the type of thermistor.
Source : Panasonic Thermal Management Solutions (2019 catalog)

Figure 6 shows the NTC resistance variation of the QSI19 quad module with respect to temperature set by Climate Chamber while the low voltage is OFF.

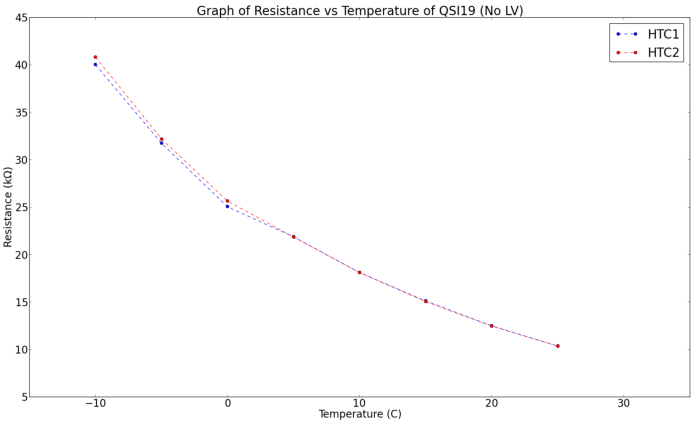


Figure 6: NTC resistance variation with respect to temperature set by Climate Chamber

Like wise the Resistances of the NTCs were measured at several temperatures $(0^0C, -5^0C, -10^0C)$ while the low voltage is OFF, low voltage is ON and while threshold scan is running. It is observed that the temperature of the quad module rises to a temperature around 24^0C when the Low Voltage is turned ON. To get a stable Resistance reading after a transition

from low voltage OFF to ON or ON to OFF it took around 5 minutes.Figure 7, 8 and 9 show the calculated temperatures correspondingly.

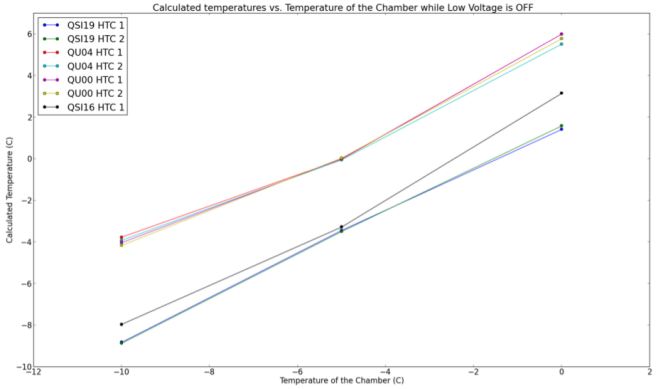


Figure 7: NTC temperature variation with respect to temperature set by Climate Chamber while the low voltage is OFF

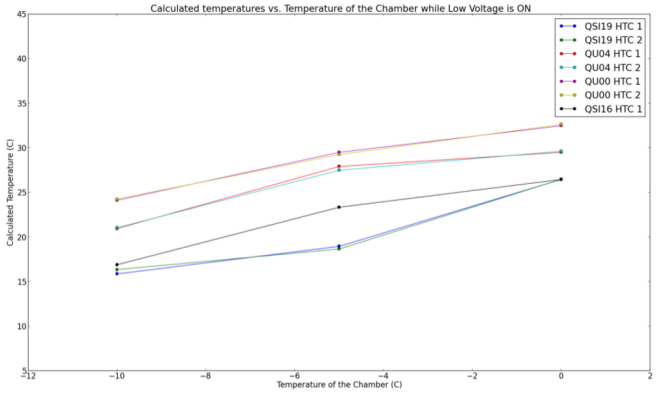


Figure 8: NTC temperature variation with respect to temperature set by Climate Chamber while the low voltage is ON

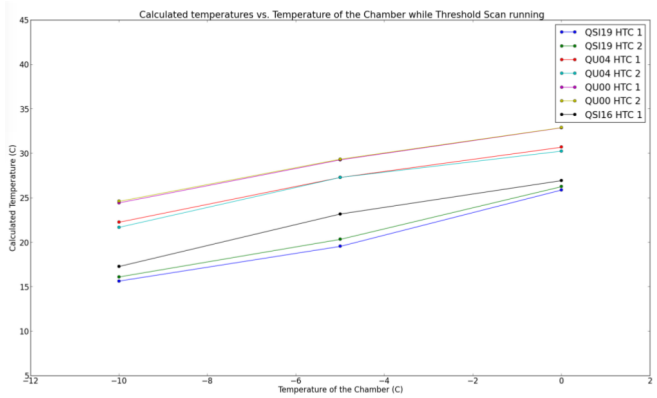


Figure 9: NTC temperature variation with respect to temperature set by Climate Chamber while threshold scan is running

In the climate chamber setup the ambient temperature variation was set all around the quad. There is no specific heat supplying location. After testing with the climate chamber, same quads were tested for NTC readings using the Cell test setup. In the Cell test set up the heat transit and cooling applied on the bottom of the module.

5 NTC Temperature measurements using Cell Test Setup

To test the NTC temperature measurements of the quads using the cell test setup, the quad is placed on the setup properly as shown in the figure 10 and vacuum was used to keep the quad in a stable position. Then the connections were established accordingly. The cooling and temperature of the quad was controlled using a chiller. The resistance of the NTC was measured as in the previous climate chamber setup and calculated the temperatures using the relationship of equation 01.

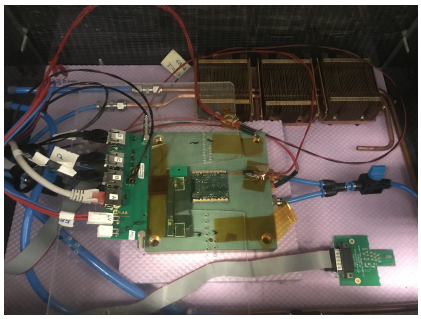


Figure 10: Quad placed inside the Cell test setup

The temperatures are calculated while the low voltage is OFF, low voltage is ON and while threshold scan is running.

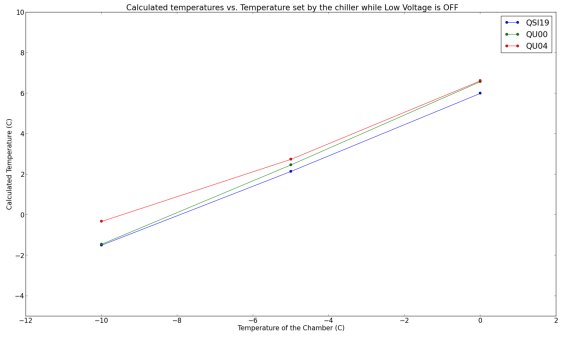


Figure 11: NTC temperature variation with respect to temperature set by Chiller while the low voltage is OFF

The temperature of the quad module rises by a temperature around 10^0C when the low voltage is turned ON. Also to get a stable Resistance reading after a transition from low voltage OFF to ON or ON to OFF it took around 5 minutes.

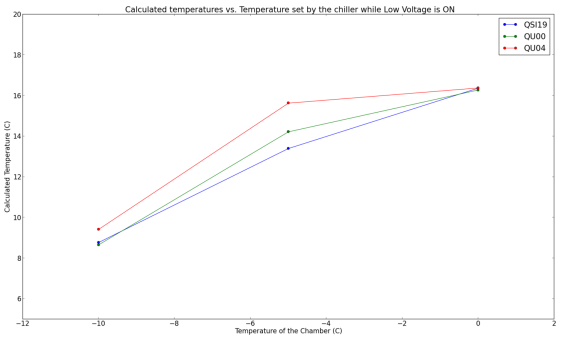


Figure 12: NTC temperature variation with respect to temperature set by Chiller while the low voltage is ON

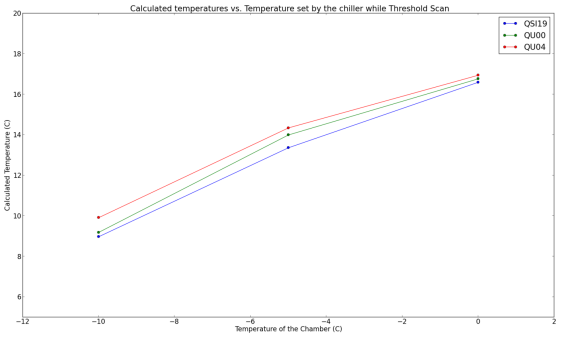


Figure 13: NTC temperature variation with respect to temperature set by Chiller while threshold scan is running

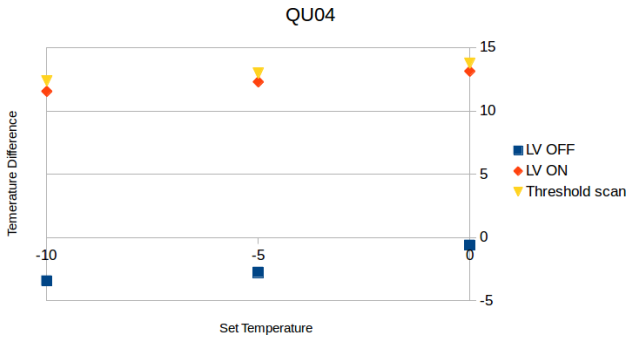


Figure 14: Calculated temperature differences between climate chamber temperature values and the cell test setup temperature values for the QU04 module

There is a difference in the temperature values in between the test setups. The temperature readings for tests inside the climate chamber while the low voltage is ON and while the threshold scan was running is greater than the temperature for test in the cell test setup readings from the cell test setup. Also while the low voltage is OFF the range of temperature values are greater in the climate chamber than in the cell test setup. In the climate chamber setup the cooling is not applied at a specific location for the quads but in the cell test setup the heat transit is mainly via the bottom of the quad. This could be the reason for the difference of the calculated temperatures.

Acknowledgement

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