Automatization of the measurement of temperature dependent gain and noise in ATLAS SCT modules.

DESY Summer Student Programme, 2012

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31th of August 2012

Abstract

In this work it is explained the automatization of the measurement of temperature dependent gain and noise for the SCT modules. Some tests were made to verify the compatibility with the SCTDAQ software. The analysis of the measurements has reveled an interesting behaviour of the modules.

Contents

1 Introduction

This work describes measurements performed on ATLAS silicon strip detector during the course of the Summer Student Programme in 2012 at DESY Zeuthen. ATLAS is a particle physics experiment at the Large Hadron Collider (LHC) at CERN. The ATLAS detector is searching for new discoveries in head-on proton-proton collisions at center of mass energies of up to 8 TeV. One of the principal goals at the LHC is to search for the existence of the Higgs boson and measure its properties. This can be a discriminator for the validity of theories beyond the SM like SUSY and extra-dimension theories. In 2013 a long shutdown is planned to prepare for an increase of the total center of mass energy towards 14 TeV. Because of the limited life time of the detectors, mainly due to the high radiation environment, an upgrade of the LHC and the detectors is planed to be done in 2022. This is also to enable the detector to be operated at the so-called HL-LHC, which puts higher demands on the performance, granularity and radiation hardness of the detector components.

2 ATLAS detector

The ATLAS detector (shown in Figure 1) consists of four major components: The inner detector measures the momentum of each charged particle, the calorimeters measure the energies carried by the particles, the muon spectrometer identifies and measures the momenta of muons and the magnet system is used to bend charged particles for momentum measurement.

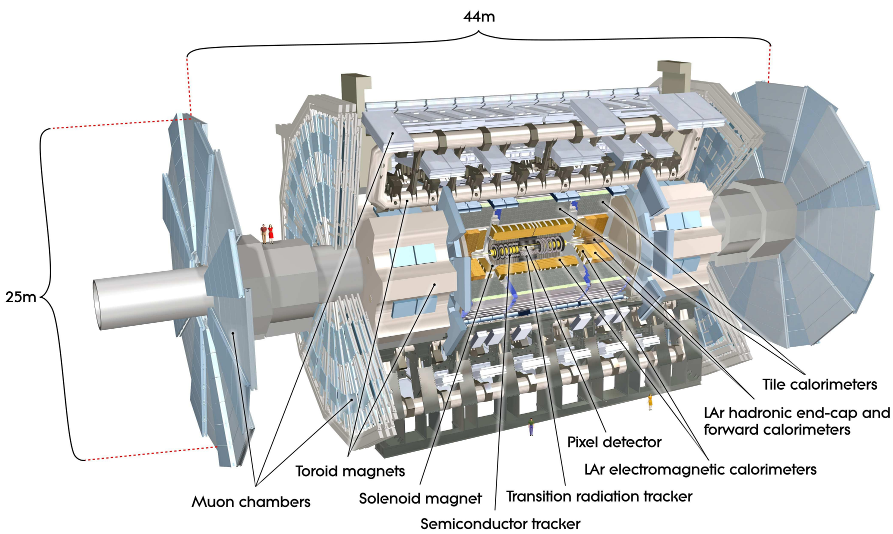

Figure 1: Cut-away view of the ATLAS detector.

2.1 Inner detector

The inner detector (ID) consists of three independent but complementary sub-detectors. At inner radii, high-resolution pattern recognition capabilities are available using discrete space-points from silicon pixel layers and stereo pairs of silicon microstrip (SCT) layers. At larger radii, the transition radiation tracker (TRT) comprises many layers of gaseous straw tube elements interleaved with transition radiation material.

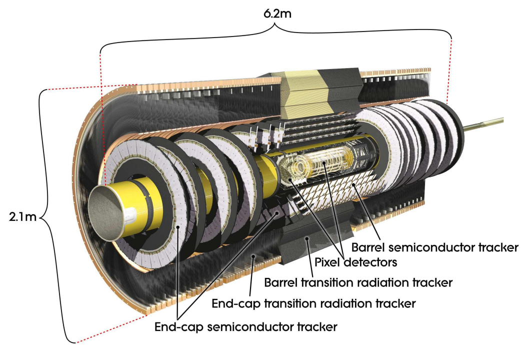

Figure 2: Cut-away view of the inner ATLAS detector.

The layout of the ID is illustrated in Figure 2. The precision tracking detectors (Pixels and SCT) cover the region $|\eta| < 2.5$ (The pseudorapidity $|\eta|$). In the barrel region, the components of the tracking detector are arranged on concentric cylinders around the beam axis while in the end-cap regions they are located on disks perpendicular to the beam axis.

2.1.1 Semiconductor tracker (SCT)

The SCT system is designed to provide eight precision measurements per track in the intermediate radial range, contributing to the measurement of momentum, impact parameter and vertex position. In the barrel SCT eight layers of silicon microstrip detectors provide precision point in the r-ϕ and z coordinates, using small stereo angle to obtain the z-measurement. Each silicon detector is 6.36 x 6.40 cm^2 in size and contains 780 readout strips of 80 μm pitch. The barrel modules are mounted on carbon-fibre cylinders at radii of 30.0, 37.3, 44.7, and 52.0 cm. The end-cap modules are very similar in construction but use tapered strips aligned radially.

3 ATLAS detector upgrade

In 2022 a radical upgrade for the ID is planned. In particular the SCT will be replaced by and improved detector. This change is primarily due to the need for higher granularity for the HL-LHC phase and the limited life-time of the detector. The TRT detector will be replaced by the new silicon tracker, as the TRT cannot handle the anticipated particle densities. The group of ATLAS at DESY is involved in the development and construction of the new generation of the silicon tracker that is going to substitute major parts of the actual inner detector. Figure 3 illustrates one of the motivation to increase the particle collision rate and thus the recorded amount of data. At high invariant dimuon masses the spectrum currently available runs cut of Statistics. An increase of the dataset will allow to explore the high-mass range further.

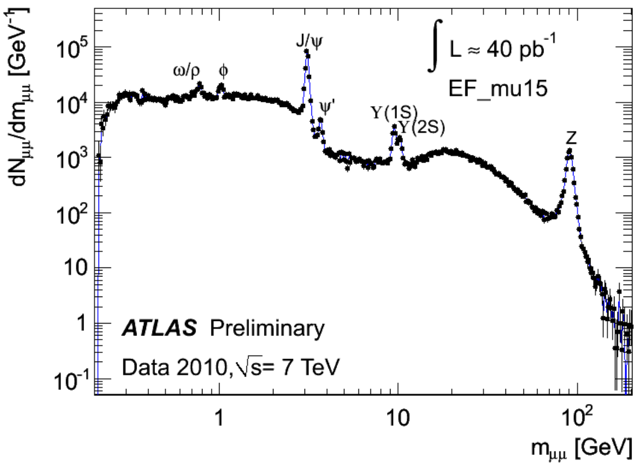

Figure 3: Dimuon mass spectrum. With the increase in the luminosity and brilliance of the LCH and the improvement in the detector we are going to be able of measure the properties of the particles at higher energies ($m_{\mu\mu}[GeV] > 10^2$).

3.1 Description of the new generation of the silicon strip modules

The new modules (Figure 4) have a size of about 10cm x 10cm. Each module consist of a sensor, which has 4 columns of silicon strips which are read-out by 4 columns of 10 read-out chips. Two columns of read-out chips are placed on a common hybrid, a flex-circuit which contains all the necessary power and data lines to control the chips and send the data off the module to the data-taking systems outside of the detector.

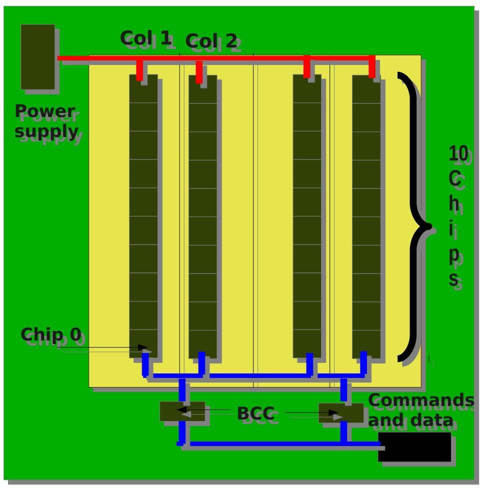

Figure 4: Schematic view of a module.

4 Experimental setup

4.1 Hardware

The experimental setup installed at DESY Zeuthen to test the new modules, depicted schematically in Figure 5 is described below: The goal is to measure the response of the

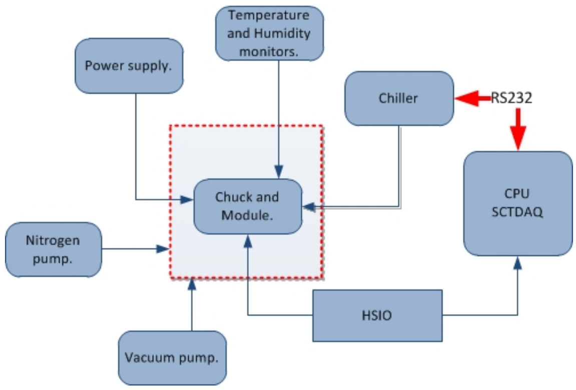

Figure 5: Scheme of the testing experiment.

module. In order to do this a charge is self-injected by a calibration circuit into the amplifier input in each channel of the test module. The module is fixed to a chuck (a metallic plate used to support and cool the module) inside a metallic box which is hermetically closed, hence air and light tight. Through the chuck a pipe coming from a kryostat. The cooling liquid is circulated through a heat exchanger to cool it. The voltage and current needed are supplied by two independent power supplies (TTI). The air temperature and the humidity conditions inside the box can be adjusted extracting air from the box and pumping in nitrogen, using two different pumps, to avoid condensation. The module under test is read out with the help of the high speed I/O interface board (HSIO) which is controlled with a computer software, called SCTDAQ.

4.2 Software

The principal aim of this project is the automatization of the measurements of noise and gain as a function of the temperature of the SCT detector module. In other words we had to write a macro to establish the communication between the interface of the chiller and the SCTDAQ. The SCTDAQ is a software based on ROOT which is a framework specially developed for data analysis. Together with collegues from DESU Hamburg we developed a dynamic library with a special dictionary to enable ROOT to call the methods inside the library. In order to make the library we followed the next steps (schematically shown in Figure 6):

1.- We wrote a class in c++ languages to establish communication with a device by the serial port.

2.- Using the class, a pre-configured link file and the ROOT interpreter (CINT), we created a dictionary file which include the definition of the class header files that the dll have to be included to be correctly interpreted by ROOT.

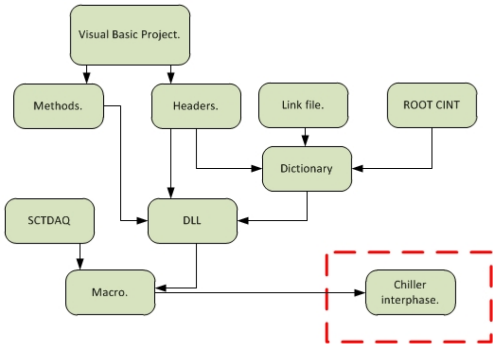

Figure 6: Scheme of the testing experiment.

3.- We use the methods, headers and dictionary files to create the dynamic library, this library can be directly called from a macro and is fully compatible with the SCTDAQ.

The test to combine the library to control the temperature with a Strobe Delay and a Three Point Gain Test (explained later)from the SCTDAQ was successful. These test have revealed the following interesting aspects about the behaviour of the module:

a) The most natural aspect is that the noise depends on the temperature.

b) In the temperature range used in the tests the noise increase directly with temperature.

c) There is a column in the module that is more noisy. In both cases the col 2 is more noisy than the col 1 (see Figure 4).

4.2.1 Test StrobeDelay

The calibration strobe sets the timing (delay) of the injected calibration pulse with respect to the arrival time of the command to actually issue that pulse. This ensures that the discriminators, always firing at the clock frequency, will be synchronous with the calibration signal.

4.2.2 Threshold scan

The output of a channel for a given input of charge is measured systematically as the threshold is varied. The channel's response to an injected charge is to record a "1" (hit) or a "0" (no hit). The occupancy of the channel is measured for differing charges over a given range of thresholds settings sampling over a large number of events building up a statistical picture of how the channel behaves.

4.2.3 Three point gain

These tests are the threshold scan with 3 different levels of injected charge. The three points then can be fitted with a linear function to obtain a value for the gain (slope of fit) of the amplifiers. A fit of the s-shaped threshold-curves of each channel enable the calculation of the input noise per channel. There are two options of this tests: 3PointGain at 1fC and 3PointGain at 2fC, which refer to injected charge with 0.5fC, 1fC, 1.5fC and 1.5fC, 2fC, 2.5fC. The result plot is the Vt50 points wrt the injected charge.

5 Results

5.1 Behaviour of the chuck temperature over the time

In this test we changed the temperature in steps of three degrees from 15 °C to 24 °C and back to 15 °C again. In Figure 7 we can see that the values of the chiller temperature and chuck temperature are different, but the variation of 3 degrees is present in both devices. It took about 15 minutes for the chuck to reach each temperature. We also observe that the chuck temperature is always higher than the chiller temperature, this is due to the energy exchange between the chuck and the environment. As it was expected the decrease of the chuck temperature is exponential. On the other hand, the chiller change of temperature is almost linear at this range of temperatures and changes with faster time scales than the chuck (minutes).

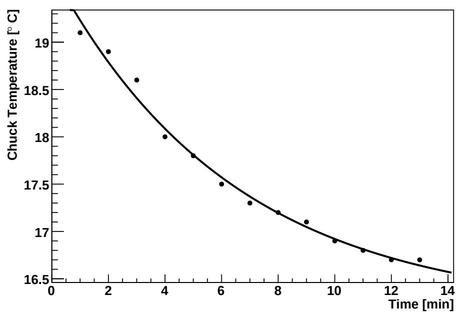

Figure 7: Time dependence of the chuck temperature. The chiller temperature goes from 18°C to 15°C.

5.2 Test of two different modules

Different test were made using two modules, called Module A and Module B. The most of the channels of the Module A are damaged, for this reason they has a high noise. The Module B is less noisy than the Module A but doesn't have yet enough quality mainly due to the problems with the wire bonding.

5.2.1 Test of module A

Module A was brought through a temperature cycle going from 15 °C to 30 °C and back to 15 °C (chiller temperature). The measured noise for each temperature is shown in Figure 8. Previous measurements performed in Freiburg showed a trend of increasing noise over time, this was not seen here.

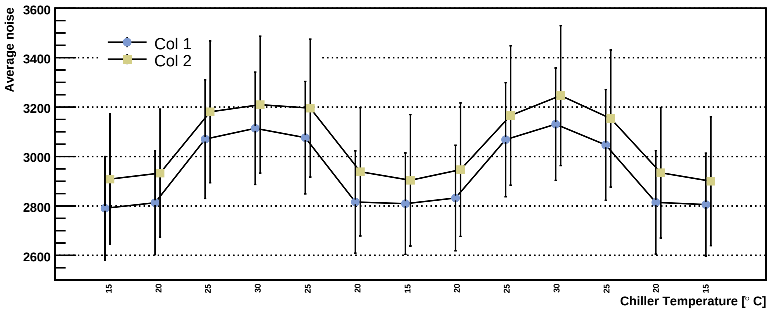

Figure 8: Module A: Noise vs Temperature to different columns of chips.(The measurements were made at same temperature, the points of the col 2 were displaced to appreciate the error bars.)

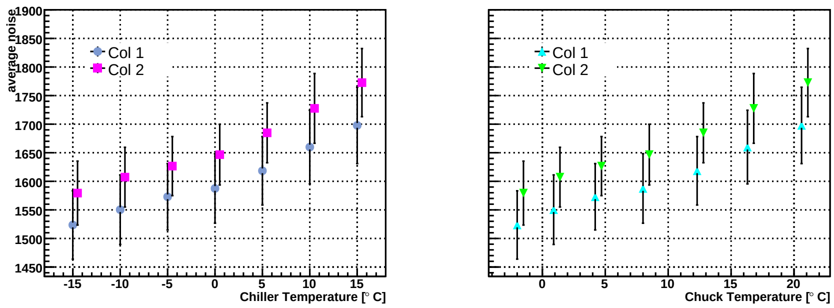

Figure 9: Module B: Noise vs Temperature to different columns of chips.(The measurements were made at same temperature, the points of the col 2 were displaced to appreciate the error bars.)

5.2.2 Test of module B

In the measurements on the Module B (shown in Figure 9) at the range of temperatures (in the chiller) from −15 °C to 15 °C we can observe a nearly linear dependence of the noise on the temperature, if we plot the noise vs the chuck temperature the dependence seems to be linear as well.

The observed noise difference between the columns is not caused by temperature, since Column 1 is at a higher temperature that Column 2, but the first one shows lower noise than the latter. The difference in the noise could be due to the setup of the experiment or the design of the module itself (position of the hybrids on sensor), but probably not due to the quality of the chips.

5.3 Channel noise

The noise of 400 ENC (number of charges measured) counts some channels. Figure 10 shows the noise measurements for the chip in col 1 of the module A. is only due to the chip noise, in other words the channel is not connected to any strip by a wire bond. The

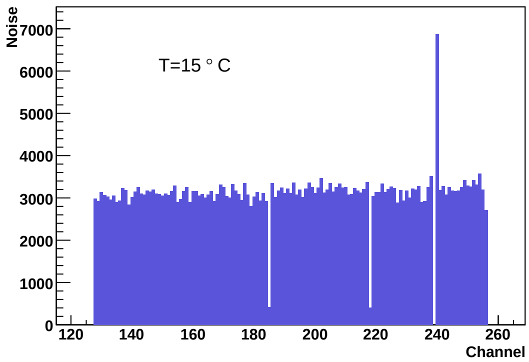

Figure 10: Module A: Noise vs channel number for one chip in col 1.

highly noisy channels are principally due to the faults in the wire bonding or a bad metallic contact.

6 Conclusions

The main goal to establish communication between the chiller interface and the SCTDAQ was successfully done. In the way of testing the this communication we figured out some interesting properties of the modules and the components of the experimental setup.

The first property is the linear dependence of the noise measurements. The second property is the exponential change on the chuck temperature in the time. The third and most interesting property is the noise difference between two columns in the module, that in the to cases that we explored shown behaviuor opposite to that we expected, been the warmer column less noisy than the coolest one.

Acknowledgements

First of all I would like to thank my supervisor Ingo Bloch, this project would not have been possible without his kind support and help during my stay at Zeuthen, I learnt a lot discussing with him. To Valentina Ferrara who worked with me in most of the experimental test and analisis and who shared all of her experience so we could achieve my goals. To Friedrich Conrad who always had answers to the technical issues. Richard Peschke who gave me the programming tools to finish the work. I would like to express my special gratitude and thanks to Karl Jansen and all the Summer Student Programme team for giving me such opportunity. At last but not least Elin Bergeeas who helped me even before my arrival to Zeuthen.

References

[1] The ATLAS collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, J. Instrum., 437 p. (2008) S08003.