Abstract

In this project as a CERN summer student, I worked at the GEM QC7 lab where we test all the electronic components of the GEM Chamber after the production. In QC7 we want to make sure that all the electronics are communicating with each other and working properly. The GEMs are the gaseous ionization detector that are one of the upgrades for CMS muon endcap. The high spatial and time resolution and the outstanding aging resistance of this technology make it stand out.

1. Introduction

1.1 The GE1/1 project

Currently the CMS detector uses three technologies of gaseous detectors. A longitudinal view of the a quarter of CMS can be seen in figure 1.1 where these three technologies are shown in colors.

- the Drift Tubes (DTs) are present in the barrel of CMS,
- the Cathode Strip Chambers (CSCs) are in the endcaps and
- the Resistive Plate Chambers (RPCs) are found in both regions, complementing the DTs and CSCs.

To withstand LHC performance during its high luminosity phase, a region in the CMS endcap that was reserved for RPCs will be equipped with a more suitable technology thanks to the GE1/1 project.

The aim of the GE1/1 project is to implement a new technology of gaseous detector for muon tracking and is expected to be added to the CMS endcaps during the current long shutdown 2019 and 2021. As a matter of fact, this project had to meet major constraints, in particular in terms of:

**Geometry** The space available in the endcaps is very small, only a few centimetre along z-axis and the detector has to cover the whole area to ensure hermeticity for the muon detector.

**Hit rate** The detector needs to support rates of up to 10 kHz cm⁻².
Efficiency  A detection efficiency of at least 97% is required to detect a maximum of particles.

Angular resolution  At least 300 μrad resolution is needed to precisely determine the angular muon positions. Time resolution  To participate to the LV1 trigger, a time resolution of 10 ns or better is requested. To fulfill those constraints, triple-GEM technology has been chosen for the detector.

1.2 The triple-GEM detector

Three GEM (Gas Electron Multiplier) foils surrounded by gas are used to make Triple-GEM detector. Figure 1.6 shows a foil and its typical dimension. Free electrons are created in the gas when a muon passes thorough the detector. Each foil is drilled with holes all over the surface and is formed by two thin copper sheets isolated by a dielectric layer and a high electric field (order of 10 kV cm$^{-1}$) is created between those two surfaces, as shown on figure 1.5. These free electrons later accelerated by this electric field in these small holes, and this ionizes other gas molecules and resulting in the avalanche.

By triplicating this phenomenon, the gas gain, which is typically defined as the ratio between the number of electrons exiting the GEM hole and the number of electrons entering it, goes from about 20 for one foil up to 8000 for the triple-GEM configuration. As shown on figure 1.4, a particle passing through the detector ionizes the gas and the three GEM foils provoke an avalanche process multiplying the number of electrons until the readout board, collecting a readable electric signal.

1.3 VFAT3 Chip

The VFAT chip has been originally designed to be used in the TOTEM experiment. It is built in a 0.25μm CMOS technology and is a synchronous chip working with the LHC master clock at 40 MHz. A block diagram of the VFAT is presented on figure 1.5. The
VFAT3 has 128 input channels. That is why the readout board has been shaped accordingly by gathering 128 strips in 24 different sections. Each channel has a preamplifier, a shaper, and a constant fraction discriminator (CFD). CFD is a technique to provide amplitude-independent information about arrival time of an event. After the CFD there is Synchronisation unit which synchronises the comparator result with the 40 MHz clock. The synchronised data then splits into two paths, one with the fixed latency for trigger signals, and the second for tracking data which is asynchronous. VFAT3 is designed in the way to accommodate the future operation conditions of the high luminosity LHC as well as new constraints of the upgraded CMS detector.

VFAT3 does all its communication via the Comm-Port. This includes Slow Commands and response as well as fast trigger commands, clock and calibration signals. In order to offer maximum flexibility this chip is highly programmable.

1.4 The Opto-Hybrid (OH)

The connection between the VFAT and the off-detector electronics is ensured by the Opto-Hybrid. It also compress and synchronise the data from the 24 VFATs, and send them via the optical fiber and ensure the transmission of all the command signal to the VFAT such as the master clock, the reset or the LV1A signal. It is well known from the figure 1.2 that the large area of the GEB is occupied by the Opto-Hybrid.

A field programmable gate array (FPGA), three Gigabit Transceiver (GBT) modules and one 8b/10b module are the main elements in the Opto-Hybrid. The FPGA job is to synchronise and compress the trigger data coming from the 24 VFATs. The bidirectional communication by optical fiber developed by the CERN is formed by the combination of the GBTx ASIC and Versatile link modules (VTTx and VTRx). Three VTXs are used to transmit the tracking data out of the detector to the off-detector electronics. Two VTTxs transmit trigger data, one to the GEM back end, and the second to the neighbouring CSC OTMB.

![Figure 1.6](image-url)
2. Methodology

2.1. Preparation Work

(a) Setting up CERN computing accounts and services
(b) Revising basic proficiency in Bash, Command prompt, Python, C++, ROOT.
(c) Reading documents of the GE1/1 project and its electronic components.
(d) Learning the procedure of testing electronics in QC7.
(e) Learning to distinguish between the fine plots and the worst.
(f) Learning how to fix the problem when we get bad plots.

2.2. Test Commands and Results:

In this project my task was to test electronics of the GEM chambers after the production. I used to run a pre written script to test the electronics. We basically test the following properties in the detector;

- a) Connectivity Test and Scurve Scan
- b) Sbit Scan
- c) Scurve Scan
- d) Threshold Scan

**a) Connectivity Test and Scurve Scan**

In the connectivity test we check the GBT communication before and after programming the GBTs, SCA communication, and will program FPGA and will check the Trigger Links. In this step we also select the best phases for each of the VFATs.

![Figure 2.1](image-url)
If any of the above mentioned communications and tests did not pass, we cannot move forward.

Plots in the figure 2.1 give us information about the response of the channels in each VFATs and the efficiency of each channel for the different CAL_DAC value. It is also shown in figure 2.1 that there are some fluctuations in the DAC value of each channel to have 100 percent efficiency. Sometimes this command winds up with the plot where some channels in some VFATs has zero efficiency for each of the DAC value where this will affect the efficiency of the detector and if more than three channels per row, is dead then it is not acceptable and we figure out how to fix it and run the test again.

b) Sbit Scan

In order to detect the signal we want to see by our detector, we have to reduce the noise in each of 24 VFATs by increasing the THR_ARM_DAC value. However, we let 100 Hz of noise for each of the VFATs and we will have 24 values of the DAC for 24 VFATs. This information is provided by the Sbit Scan test where we in this case we change the THR_ARM_DAC value and get the output from the trigger link which is the number of event from noise, because in this case we don’t inject charge. Therefore Sbit Scan gives us the relationship between the noise events and the THR_ARM_DAC value for each VFAT. An example of the Sbit Scan for one of the VFATs is shown in figure 2.2.

![Figure 2.2](image)

These Sbit Scans from all 24 VFATs looks good and we can move forward, but there are times that we do not get response from some of the VFATS and we do not get Sbit Scan plot for that particular VFAT, and sometimes we have broken Sbit Scans which are not acceptable and we need to fix the issue until we get the acceptable plots. After Sbit Scan we find the THR_ARM_DAC value for each VFAT corresponding to 100 events of noise.
c) **Scurve Scan**

Scurve is the overall response of a channel to the amount of injected charge from the calibration the preamplifier of the channel. As we increase the amount of the injected charge we expect to increase the response of the channel so there is a point where the efficiency become 100 percent. The shape of the this graph has shape of S as shown in figure 2.3 therefore it is called Scurve.

![Figure 2.3](image)

In this test we need the to have Scurve all 128 channels per VFAT which can be seen from the figure 1.7. They criterion for the acceptance of the Scurve Scan are the following:

- The threshold CAL_DAC value of all channels should be close.
- No more than 3 dead channels per row.
- The noise of each VFAT should be below 1 fC. as shown in figure 2.4 a.
- The Threshold of each VFAT should be below 10 fC as shown in figure 2.4 b.

![Figure 2.4 a](image) ![Figure 2.4 b](image)
If the detector is qualified enough to meet all the above mentioned criterion then we move to the next step. Otherwise, we take some actions as stated below to make the detector qualified to pass this step.

- Swapping the VFATs.
- Cleaning the connectors of the VFATs and reinstall them.
- Checking the Opto-Hybrid connection with the GEB.
- Other

d) **Threshold Scan**

In order to distinguish the muon signal from the noise. We want to find the lowest possible THR_ARM_DAC value to efficiently detect the muon signal.

There is no injecting charge, we send the trigger signal to readout the tracking data. By changing the values of THR_ARM_DAC we can find the point where the noise events are suppressed.

![Figure 2.5]( VFAT16 chipID 6955 )

**Figure 2.5**

### 3. Summary

In QC7 by using the procedures outlined in the section 2 we are able to qualify two detectors per day. Once the detector has been qualified it is passed to the assembly team to be assembled into a superchamber. Moreover, I would like to add that in this summer school I had been attending the lecture programs regularly which helped me develop my theoretical and experimental knowledge in the field of particle physics.