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Abstract

The aim of this report is sharing my experience as a Summer Student at CERN. It is addressed mainly to future Summer Students and young people interested in science. In the introduction a brief description of the CMS muon system is given. The next two paragraphs provide more details about the two type of detectors I could work on and about my work as a Summer Student. The main activities I was involved in were Quality Control in RPC production and starting a DCS for the new GEM production facility. Finally an evaluation of the whole experience is made.

1. Introduction

The CMS muon chambers are located in the external part of the detector. The barrel region is instrumented with Drift Tubes and Resistive Plate Chambers (RPCs), while the endcap is currently equipped with four layers of Cathode Strip Chambers and RPCs. During the first run of LHC three layers of RPC detectors were in the endcap in the \( \eta \) region from 0.9 to 1.6. A fourth disk of RPCs was added during the first long shut down period, the chambers were successfully installed in the spring of 2014. The CMS muon system is designed to accomplish four main goals: bunch crossing identification, muon identification, momentum measurement and triggering. RPCs both in the barrel and the endcap are used in addition to the other muon detectors to ensure unambiguous bunch crossing identification and to build up a redundant system. The high \( \eta \) region from 1.6 to 2.4 will be instrumented during the second long shutdown (2017 – 2018) with Gas Electron Multiplier detectors (GEMs), to ensure redundancy of measurement and match the current Cathode Strip Chambers system. GEM detectors are faster than RPCs and radiation harder, so they are fit to work in the hostile environment of the high \( \eta \) region at LHC peak instantaneous luminosity. During my time at CERN I was able to work in the main facility where RPCs are built and tested before being shipped to CMS experiment. I was also able to work in the TIF laboratory which is planned to be used for assembly and testing of GEM detectors.

Figure 1: CMS transverse section showing the existing gaseous detector for muon tracking and triggering RPCs in red, future GEM stations in yellow.

2. RPCs assembly and Quality Control

The RPCs used in CMS are made of two gas gaps read out by a unique set of copper strips placed in between the two gaps. Each gas gap is made out of two Bakelite resistive plates filled with a gas mixture of \( \text{C}_2\text{H}_2\text{F}_4 \), \( \text{C}_4\text{H}_{10} \) and \( \text{SF}_6 \) (95.2: 4.5: 0.3 relative percentages). Water vapour is added to obtain a mixture with a relative humidity of 40 – 50 %, in order to maintain a constant Bakelite resistivity, thus avoiding degradation of RPC performance.
The outer surface of the Bakelite plates is covered by a thin graphite layer, through which a voltage of about 9.6 kV is applied. RPCs are operated in avalanche mode, gas mixture around 3 mbar overpressure.

The main facility for detector assembly and testing of RPCs used in CMS is located in building 904, inside the CERN Prevessin site.

When I arrived at CERN all the chambers commissioned for the fourth ring of the endcap had been assembled and tested. I worked mainly on gap testing and detector assembly of some spare pieces, which could substitute bad working chambers in CMS. The chamber design was the same of the existing RPC endcap chambers.

The bottom layer of the double gap is a single piece while the top layer of the double gap is segmented in two parts. A chamber is made of three kinds of different gap geometries.

2.1. Quality control on gaps

A rigid protocol for chamber building aims to ensure that detectors work as expected. Raw material preliminary controls and four quality control are foreseen for standard chamber production. Bakelite panels are preliminarily validated before the being cut and cleaned. After these procedures the panels are sent to the gap assembly site. The gap manufacturing site performs several measurements on the panels to ensure the correct resistivity, thickness, colour and roughness.

Once gaps are fabricated, the manufacturing site performs a gas leak and spacer test. Gaps are also subjected to a high voltage scan to measure the dark current and to a current monitoring at the expected operating voltage (about 9.7 kV) over one week. After this validation, called Quality Control 1 (QC1), gaps are dispatched to chamber assembly sites. The second quality control (QC2) is performed on the assembly site. Gaps undergo visual inspection, gas tightness, spacer test, and electrical dark current measurement for the second time.

Each gap is characterized and the information is stored into a database, which allows to track the history of detector components.

Our main task in the RPC production laboratory was performing leak tests on gaps. Leak tests were performed at around 5 and 15 mbar pressure over ten minutes time. If leak exceeded 0.4 mbar, the gap would be rejected. The main challenge of this work was making sure that the gaps were properly sealed and that leak measurement was not biased by leaks in the sensor pipe.
After the leak test and other visual inspections a gap characterization sheet was completed and the information was recorded in the Laboratory database.

### 2.2. Chamber assembly

Once three gaps of the required geometry were tested and recorded in the database the task was using them to build a full chamber. Besides the gaps, a large number of components is needed to build the chamber structure and for signal readout. The assembly was carried out according to the standard procedure.

- Aluminium frame was prepared for gap installation
- Copper sheet was laid onto the frame and carefully cleaned
- Bottom gap was prepared: gas pipes were installed, HV cable at the bottom
- Bottom gap was sled into the frame
- Read out strips were laid onto the bottom gap
- Top wide gap was sled onto readout strips, HV connection on top
- Top narrow gap was sled onto readout strips, HV connection on top
- Top gaps were covered with a second copper sheet
- Openings for HV were cut, copper sheet was closed
- Gas pipes were connected from top narrow gap to top wide (left, right)
- Ground pins of cables were attached to ground (copper sheet)
- Cables were soldered to readout strips
- Aluminium frame was placed on top

Once the chamber was closed, Front End Board (FEB) and cooling circuit were installed.

- Mylar sheet was cut of the same dimension as FEB and applied to the copper pad
- Cooling circuit was installed and FEB was mounted on the copper pad
- Frame was closed with screws
- Patch panel was fixed: signal cables from FEB, gas pipes, HV cables were attached to the patch panel.

Finally all the connections were double checked and the front end panel was covered in aluminium.

### 2.3. Quality control on chambers

Quality control of full chambers (QC3) foresees chamber visual inspection, gas leak test, electrical and dark current measurement and cosmic muon testing.

The leak test measures the chamber gas leak in order to check whether, during chamber manufacturing, the gap gas inlet are correctly connected to chamber service panel.

In the electric test the front end boards are powered and checked while the gaps are subjected to a high voltage scan.

Finally the high voltage scan aims to measure the main detector performance parameters such as efficiency, cluster size and noise.

Each detector undergoes three independent efficiency scans using three different configurations: double-gap, top single-gap, bottom single-gap.

During one efficiency scan, 7 runs at different effective HV are taken, from 8.5 up to 10 kV.

The cosmic telescope is equipped with two scintillator layers (top and bottom) serving as a trigger. The routine analysis performs a tracking algorithm to reconstruct cosmic muon tracks using three reference chambers installed in the telescope.

After cosmic test, every chamber is powered on and monitored for about three weeks in order to check its stability over time (QC4).
My work after building a full chamber consisted in testing the overall gas leak and testing the electronic components. HV scan and cosmic test will be performed later this year. The chamber will subsequently be stored and its data will be recorded in the CMS database.

3. Initial DCS for GEM CERN assembly facility

GEM detectors are planned to be installed during the second long shutdown. At present the GEM collaboration is getting ready for large scale production while testing GEM prototypes. Several decisions will be made in the upcoming years in order to optimize detector performance. GEM foils are made out of a 50 μm thick kapton foil coated with a 5 μm copper layer on each side, that is chemically drilled to create a pattern of holes. The holes have a diameter of 70 μm on both ends and a diameter of 50 μm in the middle. They are separated by 140 μm. Three GEM foils are stretched and spaced by a few millimetres (1 to 3 mm) using a frame to form a Triple–GEM detector. A cathode plane is placed on one side and a series of anode strips for the readout on the other. Once the detector is assembled, the proper gas mixture is injected into the chamber. A voltage difference is applied between the two copper layers of each GEM foil to create a strong electric field inside the holes that act as multipliers. The presence of three layers allows to generate detectable signals through multiple amplification stages.

![Figure 6: Electric field induced by the GEM foils, pattern view.](image)

As the GEM collaboration was getting ready for large scale production and the TIF laboratory was being equipped with all the necessary instruments, I had the possibility to get acquainted with the concept of DCS. DCS, Distributed Control System, is a control system wherein control elements are not only in the central location but are also distributed throughout the system with each subsystem controlled by one or more controllers. It is often used in industrial plants and is suited to big laboratories such as the TIF, which will be used for serial detector production. My task was to establish a connection with the HV power supply which will be used for the GEM detectors during cosmic tests and to develop a web application for remote control. The application can be integrated in a complex project which allows to control all the devices in the laboratory, monitor environmental conditions, gas lines etc.

3.1. TIF facility

TIF (Tracker Integration Facility) is a laboratory inside the CERN Meyrin site, building 186. It has one of the largest clean rooms (class 10000) and is planned to be used for assembly of the Triple–GEMs. GEM foils will be handled in the TIF clean room to avoid any contact with dirty environment. The TIF assembly facility will host the GEM assembly and the quality control of each detector. Gain uniformity measurements will be performed to validate the chamber response using a cosmic stand facility, before the chambers will be transported to CMS for installation.
3.2. Preparation of the Cosmic Stand

A Cosmic Stand facility is currently being prepared in the TIF clean room. The overall quality control of detectors will foresee an analogous protocol to the one described above for RPCs, the last step will be testing the GEMs using cosmic rays.

At the moment all the PMTs of the scintillators in use have been characterized. Next step will be triggering GEMs using scintillators. Finally a Data Acquisition system to measure GEM efficiency will be developed. A high voltage power supply (CAEN module SY1527) will be used to power the PMTs and the GEM detectors. CAEN SY1527 mainframe can host up to 16 boards which are connected to power stations. The mainframe can be controlled both locally using a keyboard and the mainframe screen and remotely.

In our case we want to use a TCP-IP connection for remote control, so that the mainframe will be connected to a modern computer. The remote control functions will be implemented in a similar fashion as the ones used for RPCs Cosmic Stand.

3.3. Power supply on line monitor

My task was to establish communication with a similar mainframe (the one which powers RPCs in the cosmic stand, currently unused) and to develop a web application through which online monitoring and parameter setting could be possible. The web application can be used for remote control by itself and could be integrated in a more complex DCS project.

The first steps of my work were:

- Becoming acquainted with the CAEN SY1527 functionalities by reading the manual
- Becoming acquainted with the CAEN HV wrapper library, a software produced by CAEN written in C language for communication with various CAEN devices
- Making a decision about the simplest way to start developing a web application

Together with my supervisor we decided to wrap the CAEN HV wrapper library in a Python script and further developing the web application using the Web framework Django. Django is a high-level Python Web framework that makes it easy to start developing simple applications even for beginners. Using Python language made it possible to embed the python scripts for remote control of the CAEN mainframe into the application.

The application was developed on SLC5 OS and tested on Mozilla Firefox. Python version 2.7.8 and Django version 1.7 were used.

It should be remarked that currently the application is just at prototype level. Further testing and upgrades are necessary to use this software extensively.

In order to develop the application I went through the following steps:

- Using Python to embed the CAEN HV wrapper library into a Python script. The compiled library (.so extension) was imported and data types were simulated using the ‘ctypes’ Python module
- Writing Python scripts for terminal interaction with the CAEN mainframe
- Developing of views which allowed to call these functions through the web application.
The web application allows the user to test board presence in the mainframe, read and set all the parameters relative to a board channel, monitor current voltage and status of the active channels. The application views and functionalities are represented in the map below.

Figure 8: Map of the web application

<table>
<thead>
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</tr>
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<tbody>
<tr>
<td>ch_name</td>
</tr>
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<td>---------</td>
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<tr>
<td>station5_TN</td>
</tr>
</tbody>
</table>

Figure 9: channel monitor view: status, voltage and current can be monitored; workflow can be checked on the terminal

4. Conclusions

The main targets of my Summer Student project were successfully reached: I was able to learn about detector construction and quality control in a practical way and to start a DCS project. As a physics student with little laboratory experience the main challenge for me was working in a field I was not familiar with, but perfectly complements my studies. I had the possibility to see how much effort goes into detector development and production for big high energy experiments like CMS. I also became aware of the engineering effort which is needed to get ready for detector serial production. For the first time I had the opportunity to learn software development for device control and to get started with web developing. Overall the Summer Student Programme was a huge learning experience for me. Leaving CERN I feel enriched and motivated to continue my studies.
Acknowledgments

I would like to thank my supervisor for introducing me to topics I was not familiar with and for being supportive throughout the learning process. I would like to thank the students I had the opportunity to work with for their friendship and support.

REFERENCES


