SULTAN QABOOS UNIVERSITY (SQU)

College of Engineering
Department of Mechanical and Industrial Engineering
Muscat, Oman

The European Organization for Nuclear Research (CERN)

Large Hadron Collider (LHC)
The Compact Muon Solenoid (CMS)
Resistive Plate Chambers (RPC)
Geneva, Switzerland

The Phase-2 Upgrade of the CMS RPC Detectors

CERN Summer Student Report - Summer 2019

Student Name	Gamal Talal Amer
SQU ID	117418
CERN ID	160856
Supervisors	Gabriella Pugliese - CMS RPC Project Manager, CERN Nikolaos Zaganidis Ian Martyn Crotty Mehar Ali Shah

Table of Contents

1. Abstract

For 8 weeks, I did an internship program at The European Organization for Nuclear Research (CERN) which is one of the world's largest and most respected centers for scientific research and is located in Geneva, Switzerland. CERN's primary research is in fundamental particle physics but the Laboratory also plays a vital role in developing the technologies of tomorrow.

The aim of this report is to illustrate in more details the institute profile, and to share my experience and the technical knowledge that I gained as a Summer Student at CERN through the tasks that were assigned to me. Finally, since this report is addressed mainly to future Summer Students and young people interested in science and work at CERN, the report is concluded with a discussion of some challenges that I have encountered during my program along with giving some recommendations that will hopefully be beneficial for future summer students here at CERN.

2. Introduction

2.1 A Brief introduction to LHC and CMS

The Large Hadron Collider (LHC) is the world's largest and most powerful accelerator and it is installed at CERN in the LEP tunnel, 100m underground in Geneva, Switzerland. It accelerates and collides the two high energy particle beams coming at speeds relative and close to the speed of light. These beams that come from different tubes are kept at ultrahigh vacuum guided by superconducting electromagnets [1]. Four experiments (ALICE, ATLAS, CMS, and LHCb) are installed at four interaction points where the high energy particles' collisions (like proton-proton collisions) occur.

The Compact Muon Solenoid (CMS) is a general purpose experiment (that has proven to be very successful) for measuring proton-proton and heavy-ion collisions at the Large Hadron Collider (LHC) at CERN [2]. The physics motivation is to test and to complete the Standard Model (SM), especially for what concerns the search for the Higgs boson and the exploration of new physics beyond SM. CMS has already produced many excellent scientific results. By mid-2017, CMS has published more than 600 papers in refereed journals. The highlight was the discovery of the 125 GeV Higgs boson by the ATLAS and CMS experiments in 2012. CMS is looking for answers to fundamental questions in particle physics and beyond: Are there more particles than the well-established fermions and gauge bosons of the Standard Model (SM)? Are all properties of the 125 GeV neutral boson consistent with the SM Higgs particle? Is nature supersymmetric? Can we explain the Dark Matter in the universe by particles that can be produced at the LHC? [2]

The CMS detector consists of various sub-detector systems. The Muon system located outside of the magnetic coil is designed for Muon triggering and tracking. It consists of three technologies:
The Drift Tube in barrel region, the Cathode Strip Chamber (CSC) in Endcap region, and Resistive Plate Chamber (RPC) in both regions [1].

2.2 RPC Working Principle

Fig. 1 below shows the internal layout of RPC detector. It is mainly composed of two high resistive plate (usually Bakelite), separated by a thin gap of consistent thickness. Electrodes are placed outside the plates to apply high voltage. The pickup strips are placed outside the plates with insulator between them to read out the induced signals. Spacers are inserted between two plates to maintain the right distance between the plates and proper gas mixture fill the gap region. By applying high voltage (about 6-9 KV) between the two plates, RPC can be operated as an ionization detector. [3]

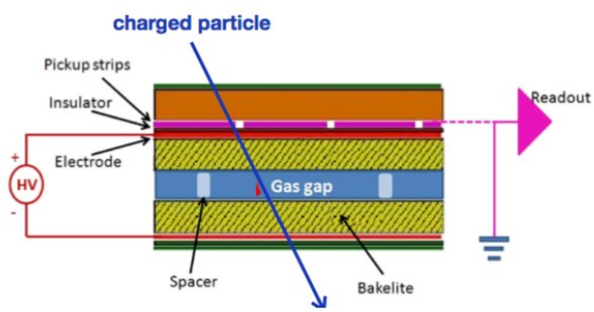


Figure 1: Overview of RPC Detector [3]

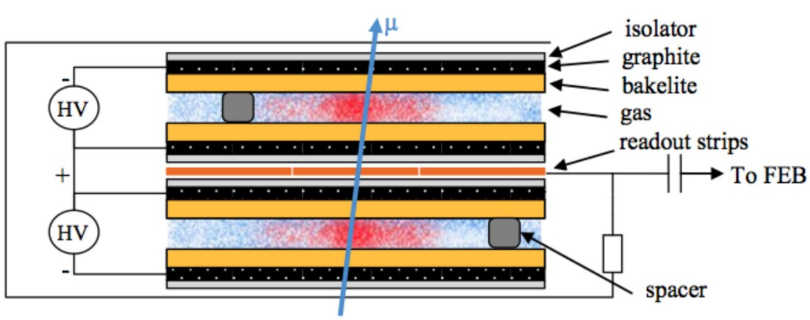
When a charged particle passes through the gap region, it can ionize the gas molecule, creating electrons and ions, which get accelerated by the electric field. When the electrons become fast enough, they can generate a secondary ionization. The secondary ionized electrons can also generate another ionization again. This process repeats many times and finally the multiplication factor can be 107. One of the biggest features of RPC is that since the plates are highly resistive, by choosing proper voltage, cascade multiplication decreases down by itself and it does not expand all over the detector. Due to this localization mechanism, RPCs can be operated at high rate such as 1 kHz/cm2. This operation mode is called avalanche mode. In addition, since the electric field is constant between the two plates, cascade multiplication occurs in all the gas volume. RPCs do not have a drift volume, which is the main contribution to low time resolution in other gaseous detectors. [3]

2.3 Gas Mixture of RPC

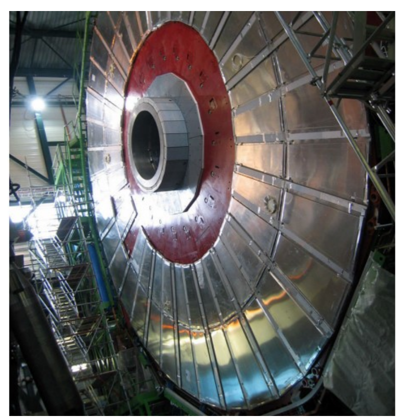
The RPCs in ATLAS and CMS use a gas mixture that is composed of 95.2% $C_2H_2F_4$, 4.5% i-C_4H_{10}, and 0.3% SF_6. $C_2H_2F_4$ is to be ionized by the incident particle, i-C_4H_{10} is a quenching gas used to absorb soft X-ray which can induce streamer mode, and SF_6 is an electronegative gas to prevent too high multiplication process which will result in streamer mode [3]. This gas composition of the RPC was optimized with respect to gas gain, drift time, quenching, aging, and they have proven to work very well. However, the European regulations of 2014 [4] call for restricting the use of fluorine-based gases to one-fifth of their consumption in 2014 by 2030. The regulation is due to the undesired environmental impact of such gases, notably because of their greenhouse effect, leading to global warming. Studies of RPC detector operation with alternative, ecologically friendlier gas compositions are underway. In case a complete elimination of F-gases is not feasible, several measures to stop the release of these components into the atmosphere are being explored: preventing leakage, efficient recuperation, and burning of the exhaust gas into harmless compounds. Thus, the new environmental regulations can be handled, and a significant performance loss of the CMS muon chambers will be avoided [2].

2.4 CMS RPCs

RPCs in CMS are double-gap chambers operated in avalanche mode, at high electric field. They use High Pressure Laminate (HPL, commonly known as Bakelite) electrodes with a high bulk resistivity. RPCs are mainly used for accurate timing and fast triggering, with an excellent intrinsic resolution of about 1.5 ns for a double-gap chamber. This allows in particular the identification of the corresponding bunch crossing. In Fig. 2 the schematic layout and a photo of endcap RPCs are shown.



(a)



(b)

Figure 2: (a) Working principle of the double gap RPCs in CMS, (b) RPC endcap chambers RE1/2 and RE1/3 after installation. The iron yoke is shown in red [2]

3. CMS RPC Upgrade Project (improved RPC - iRPC)

New improved RPC (iRPC) chambers made of thinner Bakelite and a narrower gas gaps with respect to the existing detectors (both reduced from a thickness of 2 mm in the current design to 1.4 mm), will be installed in stations 3 and 4 (RE3/1 and RE4/1), complementing the already existing CSC chambers installed there. This detector upgrade is driven by the necessity to increase the number of hits per muon track up to $|\eta| = 2.4$. By reading out signals from both ends of the RPC strips, excellent time resolution of approximately 1.5 ns, and much improved hit localization in the radial direction (about 2 cm) can be achieved [2].

3.1 Services and Quality Control

Most of my summer program (besides attending the lectures) was focused on the services and quality control aspects of the CMS RPC Upgrade Project (iRPCs). I have been a member of several groups that implemented the required services and quality control tests to insure the quality and functionality of several systems such as the optical fibers, some electronics, and the high and low voltage cables. That included (for instance) handling, labeling, testing, and preparing the optical fibers to be later installed in P5 (LHC Access Point 5 - the location of the CMS experiment). Fig. 3 illustrates the process of connecting the optical fibers according to a given map for first testing them and then to prepare them to be moved to P5 for installation.

(a) (b)

Figure 3: (a) Connecting the optical fibers to the control unit, (b) Preparing the optical fibers to be transferred to P5

Furthermore, the service work that I did included some tasks that were part of my studies as a mechanical engineering student. For instance, the water chilling unit shown in Fig. 4 below was previously used to heat/cool the water that is to be fed to somewhere else. Unfortunately, this unit was no longer operating and hence, I was assigned with a task to extract some of its critical components (such as the pump) so that they can be later used for other purposes if they can operate normally. Also, I had the chance to work on the maintenance of an XY-coordinate system machine fixed to a table. That machine can be used to carry and move any attached detector in the XY-plane to observe and analyze the detected signal at different locations. The main advantage of such an automated system is that it can be used in some locations of the LHC experiment where people should not enter for safety precautions.

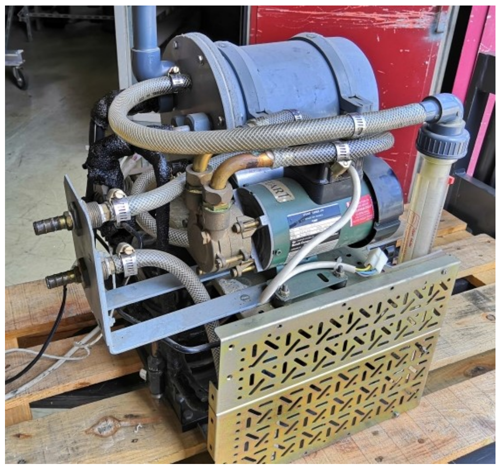
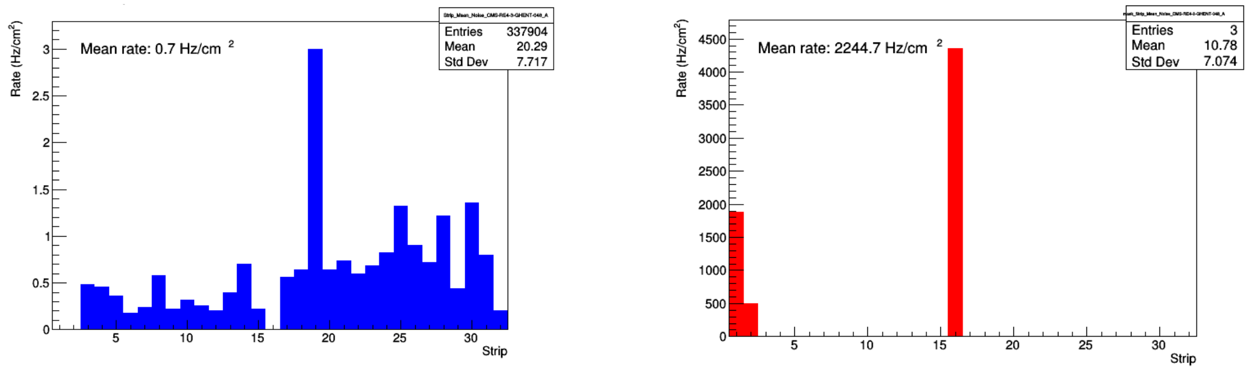


Figure 4: Water chilling unit

3.2 RE4 Current Studies

72 super chambers (RE+4 and RE-4 stations) were dismounted in March 2019 to free up space for CSC extraction for electronic refurbishment. RE+4 station is going to be reinstalled inside the CMS in November 2019. Several quality control tests were performed in a newly built lab with controlled environmental conditions in order to re-validate all the detectors. This included performing the noise scan on the detectors to confirm the functionality of the detector's front end boards (FEBs), to spot any dead or noisy readout channels, based on the noise rate histogram results. Fig. 5 below illustrates the noise scan results for one of the RPC detectors, namely: CMS-RE4-3-GHENT-048_A. Strip number 16 in this detector represents an example of a single noisy strip. This is due to the very high noise rate in that strip per unit area which was approximately 4400 Hz/cm2.



(a) (b)

Figure 5: (a) Strip mean noise rate CMS-RE4-3-GHENT-048_A, (b) Masked strip mean noise rate CMS-RE4-3-GHENT-048_A

Moreover, the high voltage was turned and kept on at 6 kV for each of the 6 super modules carried on a single trolley and the current readings were recorded regularly using the web detector control system (web DCS). Table 1 below shows a sample result for current readings from trolley 02 at different dates. In this table, SMs stands for Super Modules and P_O is the expected Ohmic current that was determined by extrapolating the slope of the decreasing currents by the end of RUN-2. All SMs were kept at a constant voltage of 6kV.

Table 1: Trolley 02 current readings in μA

SMs	20 Jul 2019	30 Jul 2019	06 Aug 2019	P_O from fits 2018
26	4.7	3	2.8	2.5
28	12	7	6	4.1
22	15	7	4	4.5
24	6	4	4	4.7
18	7	5	4	2
20	6	4.3	4.2	4.4

It can be seen from the table that as the super modules are kept at high voltage for a long period of time, the resulting current value decreases and is expected to approach the corresponding value of P_0. It can also be observed that the SMs with a relatively high value of current initially, tend to have a significant rate of reduction in its value at the beginning and then this rate of reduction itself decreases as the current approaches the corresponding value of P_0. Finally, some other SMs have shown that the currents can be decreased much faster if higher voltage values were used.

Since the increase of currents appears to be reversible (as it decreases back to initial value over time as data taking stops), it can be concluded that there is no damage to the inner electrode surface and no permanent damage to the electrode resistivity. The current increases due to high concentration of pollutant (HF) which is not efficiently removed by gas flow and forms a thin conductive layer on the inner electrode surface and decreases surface resistivity. The RPC gas mixture is mainly composed of F-gas. The decomposition of this gas under electrical discharge produces Fluorine ions which can produce HF. Gas flux cleans this layer and HV helps burning any deposits, after data taking is stopped and system is kept flushing with gas. In conclusion, RPC system is performing stably after running in extreme conditions for more than 7 years and no obvious ageing effects has been observed and the system is ready to participate in upcoming High Luminosity-LHC program.

4. Challenges and/or Recommendations

4.1 Challenges

The main challenges that were encountered during the internship were as follows:

- The new environment: this opportunity allowed me to be in Switzerland for the first time in my life. It took me some time at the beginning to get adapted to the new culture but then everything went smoothly as people here were very friendly and helpful.
- Although I had the opportunity to have some tasks that were related to my mechanical engineering studies (which I have really enjoyed and benefited from), many of the tasks that I was given were relatively far from my own specialization as a mechanical engineering student. I felt that such tasks were closer to the work of a physicist or an electrical engineer. However, it was a really good chance to learn new things and develop my knowledge in these interesting areas.
- Working in a team of different nationalities, cultures, and educational levels would seem to be a challenge initially. However, everyone here was very friendly and, with time, it usually ends up being a good friendship and results in fruitful teamwork.

4.2 Recommendations

I would like to give the following recommendations to future summer students to have a better experience:

- Beside English, I would really recommend them to start learning some French because it is very common here and that would certainly benefit them a lot whether during their program or in their future in general.
- The student must always be punctual and committed to the rules whether in his training place or, more generally, anywhere he/she goes.
- In the training place, the student must be aware of the instructions and procedures of security and safety, and he/she must follow them strictly. All the online safety lectures and the relevant practical classes must be taken seriously.

- ❖ Always ask if you are not sure about something. The people here are friendly and helpful. And you should always remember that working together is the main key to success.
- ❖ The student should engage himself/herself into the work. Once he/she completes one task, he/she should ask for another one.

5. Conclusion

During this summer student program, I have attended lectures on various topics in physics, electronics, detectors, etc. Moreover, I had the possibility to see how much effort goes into detector development and production for huge experiments like CMS through working under the umbrella of the RPC upgrade project. This included working in the services and maintenance of some engineering systems as well as conducting quality control tests to make sure that the parts to be used have adequate functionality. Furthermore, I helped conducting some relevant current studies through applying high voltage and monitoring the current, creating warning signal when voltage or current have strange behavior, and extracting the desired results from the Web DCS. Overall, the Summer Student Programme at CERN was a huge learning experience for me that has made me feel enriched and motivated to continue and do my best in my studies

Acknowledgment

I would like to express my gratitude and give special thanks to the UK Science and Technology Facilities Council (STFC) for selecting me and funding my program, and CERN staff (especially the organizers of the summer student program and my supervisors and colleagues) for giving me this precious opportunity to have such an amazing experience which helped me improving my knowledge and skills.

References

[1] B. Batool, "CMS RPC performance study by using 2012 and 2015 data," CERN, Geneva, Switzerland, 2015.

[2] CMS Collaboration, "The Phase-2 Upgrade of the CMS Muon Detectors," CERN, Geneva, Switzerland, 2017.

[3] X. FAN, "Analysis of RPC Performance with DifferentGas Mixture," CERN, Geneva, Switzerland, 2015.

[4] The European Parliament and the Council of the European Union, "Regulation (EU) No 517/2014 of 16 April 2014 on fluorinated greenhouse gases," technical report, EU, 2014.