EUROPEAN COUNCIL FOR NUCLEAR RESEARCH
CONSEIL EUROPÉEN POUR LA RECHERCHE NUCLÉAIRE
CMS Collaboration

Quality Control and certification of GEM detectors for the CMS GE2/1 station

CERN Summer Student Programme 2023

Riana Shaba

Supervisors: Ashok Kumar, Pieter Everaerts

June - August 2023

Abstract

The Compact Muon Solenoid (CMS) experiment at CERN's most powerful particle accelerator, the Large Hadron Collider (LHC), is a detector where proton-proton collision events are observed and studied by particle physicists.

The undergoing upgrades of the LHC will increase the instantaneous luminosity up to $\mathcal{L} = 5 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$, and therefore the experiments will need further developments as well. The CMS GEM Collaboration is working on upgrading the muon end-caps with the installation of Gas Electron Multipliers (GEM) detectors such as their second ongoing project, the GE2/1 chambers. GE2/1 will be the second station in the forward region of the muon end-caps in CMS installed by the end of 2023 and beginning of next year. The main goal of the muon system upgrade is to maintain the Level 1 trigger rate with maximum selection efficiency.

The GEM technology is very useful in High-Energy Physics experiments. The triple-layer gaseous detectors with their microscopic structures are capable to provide the needed detection properties required by the CMS experiment for such an upgrade.

This report focuses on the qualification tests done for the validation of GE2/1 detector for installment in CMS.

Contents

1 Introduction

The main goal of experimental physics is to detect particles based on particle-matter interaction processes. At CERN ambitious High-Energy Physics experiments are carefully planned and carried out in order for physicists to conduct their research and study the matter that makes up our universe.
The upcoming High-Luminosity (HL) LHC will allow for more precise measurements and a step further into the findings of new physics beyond the Standard Model.
To serve this purpose the CMS GEM Collaboration is currently working on the GE2/1 station, after the successful first muon station GE1/1 that is already installed in CMS.
The GE2/1 detector is going through the required steps for qualification during its development, where all the characteristics of the detector and electronics are measured, tested and validated.
My work in this project is focused on two out of the eight quality control tests named QC7 and QC8 as part of a professional team, that deal with the front-end electronics and the efficiency test of the chambers.

1.1 The GEM Technology

The Gas Electron Multipliers (GEM) detectors are an upgrade to the muon system in CMS. These detectors use gaseous technology of detectors to detect high energy muons via Coulomb interactions between charged particles and atomic electrons. They are also subject to high energy photons in the endcaps.
In order to better understand them and the way they operate, it's best if a brief introduction is given on gaseous detectors.

1.1.1 Gaseous Detectors

In HEP experiments identifying infinitesimal objects and studying their respective properties requires powerful detectors, and a well-suited option are gaseous detectors. Gaseous detectors are suitable because they are very light devices and they have a high level of flexibility when it comes to geometry, composition and performance. They also have a reasonable cost, which makes them great options for muon chambers because muon chambers need to cover large surfaces, so it is necessary to find a good balance between accuracy and cost. GEM detectors specifically have the advantage that compared to other gaseous detectors, they have a separate multiplication and readout part which makes them great for an environment with high background rates. But because of the very low density of the detection medium, the total amount of primary charges produced by a particle in the gaseous detectors is relatively small to other types

of detector technologies, and therefore they often need an amplification stage before the particle signals are collected from them.
So in principle, a chain reaction called an *avalanche* is responsible for the amplification of the primary charge. This happens when electrons pass through electric fields of the order of kV/cm, and they acquire sufficient energy between two collisions to provoke the excitation and/or the ionization of the gas, and then produce free charges that can ionize further atoms.

- **Structure**
A simple example of a gaseous detector is a parallel plate detector, which means that there is a cathode called the drift electrode, and an anode called the readout electrode that establish an electric field. The chamber is filled with a gas mixture and the choice of the gas is crucial because things like the right operation of the detector, the number of primary charges and the amplification factor all depend on the gas properties. Connected to the anode there's a readout system for all the electronics that can transfer the electrical signal produced. This is illustrated in the figure below.

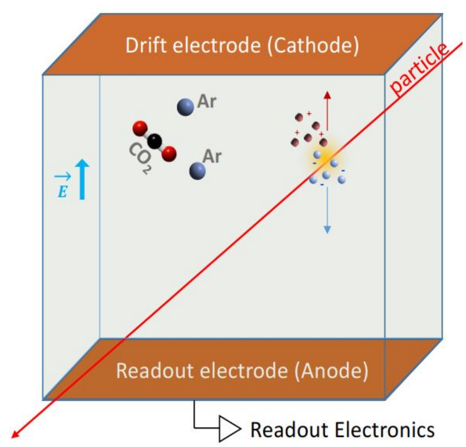

Figure 1: Structure of Gaseous Detectors. Figure from [4].

- **Principle of operation**
When particles cross the gas volume they may interact with the gas itself and this will release free charges, i.e. electron-ion pairs. Then, under the influence of the electric field the free charge moves toward the electrodes, where it induces a current, an electrical signal that is captured by the readout system connected to the anode. Nevertheless, it's a rather difficult task to readout the released charge without any losses because since it's so small, a part of it can be lost in the gas just like a part of the

signal can be lost in the noise of the electronics. In order to fix this issue, inside the gas volume a structure is added that can amplify the charge before it goes to the anode. The process of amplification that is due to the acceleration of the primary electrons in the high electric field and the excitation of the gas molecules, creates what is known as the electron avalanche, that is shown in the following figure.

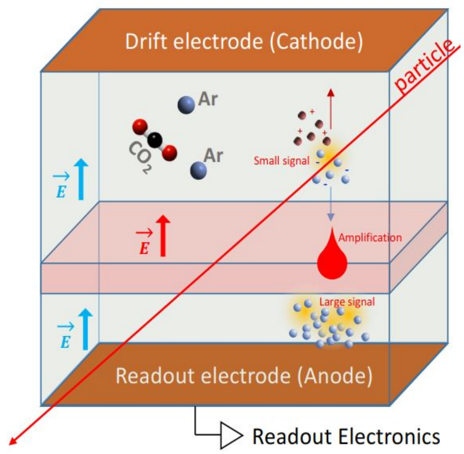

Figure 2: The amplification structure and the electron avalanche. Figure from [4].

1.2 Structure of GEMs

GEM is an amplification technology in a detector or in association with another detector structure to share the amplification and reach high gas gains. They are metal-clad foils consisting of an insulating polymer, 50 µm of Kapton which is a very expensive polyimide of high resistivity. It is coated on both sides with 5 µm of copper and is chemically perforated with high density microscopic holes that act as current gain channels or simply put, amplifiers of the electric current.

1.3 Principle of operation of GEMs

To better understand the operation of the detector, it is necessary to give an overview of the on-chamber front-end electronics that convert analog to digital signals and send the data outside of the cavern, to the Cathode Strip Chambers (CSC) through optical fibers cables.

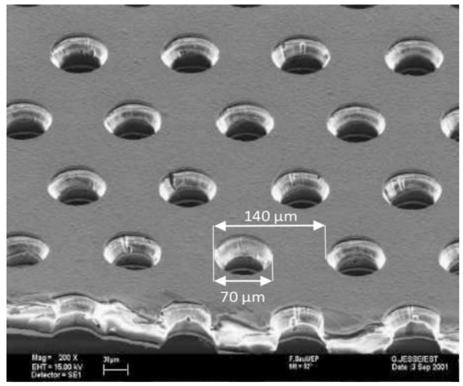

Figure 3: A microscopic view of the holes in the GEM foils. Figure from [5].

1.3.1 GE2/1 Front-end Electronics

The GEM GE2/1 chamber consists of four main components: the VFAT3 front-end chip, the OptoHybrid, the FEAST, and the GEM Electronics Board (GEB).
The VFAT3 is the front-end chip of the GE2/1 detector that has 128 readout channels, where each channel corresponds to a strip in the detector and has an independent data path. The chip is placed on a specialized board called VFAT3 hybrid to connect to the GE2/1 readout board and the GEB.
The OptoHybrid is placed at the center of GE2/1 chambers and is responsible for providing communication between the chambers and the outside world. This is done in the data path with three gigabit receivers called GBTs, where each of them is connected to a versatile link (VTRx) capable of sending and receiving optical signal, each taking care of data from a region of the detector. The OptoHybrid receives data from the tracking and trigger paths of the VFATs, and the GBTs send optical signals via the VTRxs to transmit the tracking data to the back-end electronics in the service cavern.
The FEASTs are radiation hard step-down DC to DC converters that deliver precise output voltages.
The GEB is placed on top of the G2/1 readout board, where all the electronics are found. It is a thin, multilayer PCB that helps keeping the detector compact and its main functions are to electrically shield the electronics from the detector, distribute power and ground for all of the front-end electronics, and provide a link for electric signals between the VFATs and the OptoHybrid. There is one GEB per module, where each module consists of four η-partitions.

The CMS muon GEM detectors essentially operate on argon-based mixtures, specifically Ar:CO_2 in respective proportions of 70:30%.

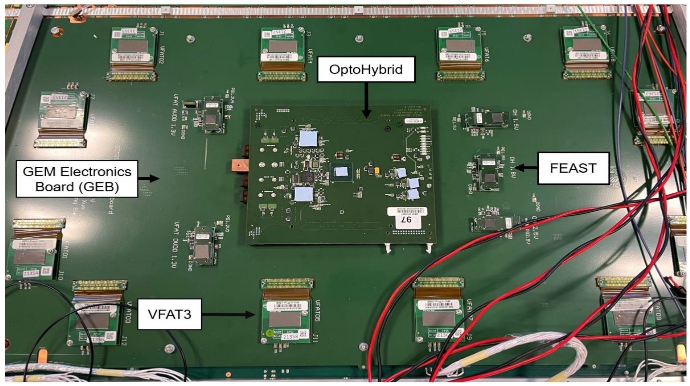

Figure 4: The GEM GE2/1 open chamber with all the front-end electronics.

The way everything works has to do with the fact that when the primary electrons, that are released by the crossing of the particle in the gas volume, reach the GEM holes, they will get accelerated in the intense electric field and acquire sufficient energy to produce an electron avalanche. After the amplification, the charge drifts towards the readout board where it induces an electrical signal. This is an analog signal and it is converted into a digital signal by the VFAT3 component. Then through the GEB, the digital signal is sent to the OptoHybrid that is connected to outputs of the trigger and the tracker paths. Using optical fibers, this signal is sent form the front-end to the back-end with a speed almost at the speed of light, so that the filtering of the events, the decision whether it is one of interest, can be done quickly.

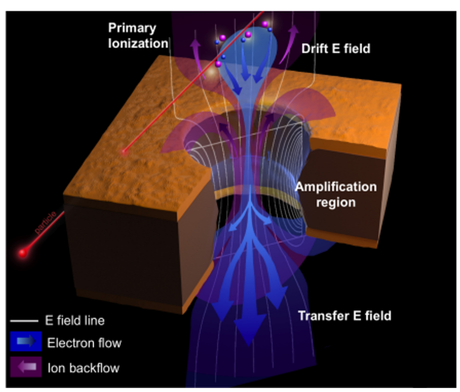

Figure 5: Cross section view of a GEM hole, with two layers of copper in the top and bottom and the polymer in the middle, showing the amplification of the primary electrons. Figure from [4].

In Figure 5 it can be seen that the electrons entering the GEM holes get accelerated in the presence of the intense electric field, provoking the ionization of the gas molecules and thus creating an avalanche.

2 Quality Control

The production of a GEM detector is based on the distribution of this process among several sites, such as production sites around the world and CERN. Before being installed and used in the CMS Experiment, the GE2/1 detectors are tested in eight quality control (QC) steps, where the main purpose of each step is to ensure the most optimal construction and operation of the detectors.
All the steps and their standard procedures are briefly presented below, as the main focus of this report are the two quality control steps, QC7 and QC8.

- **QC1:** Detailed visual inspection of the GEM foils and thorough measurements of their characteristics such as impedance, leakage current and discharge rate, and measurements of the frames. Testing of the readout board to make sure there are no damages before further steps.
- **QC2:** A potential difference ranging from 500V-600V is applied across the GEM foils to ensure that there are no defects or contaminants.
- **Chamber Assembly:** The preparation of the components such as the HV circuit, cleaning of the frames, mounting of the stretching structure and selection of the O-rings are done in the laboratory. Then the assembly that deals with fast tests of the foils, mounting of the GEM stack and closing of the chamber is done in the clean room.
- **QC3:** The chamber is tested under high pressures, 25mbar and the leak rate is monitored along with the flow rate. The pressure drop is measured in one hour and the results are fit to extract the time constant of the system.
- **QC4:** The first HV test of the chamber, where a voltage divider is connected to the top and bottom electrodes of each foil, so that each to each electrode, a constant proportion of HV is provided. The main purpose is to ensure that the chamber can maintain the HV continuously while it is flushed with CO_2, in order to have less discharges so that the HV can be pushed higher.
- **QC5:** The chamber is placed inside of the copper box with an X-ray gun to measure the gas gain and evaluate the response uniformity of the detector.
- **QC6:** The second HV test of the chamber, where a multichannel sytem that applies different voltages to each GEM foil is used. This can set the chamber HV stability much further.
- **QC7:** On-chamber front-end electronics testing of the connectivity, power, noise, and signal outputs in order to ensure the proper operation of the all the electronics.
- **QC8:** The GE2/1 single-layer detectors are coupled to form a GE2/1 superchamber that is placed on the cosmic ray stand. Using comic rays, measurements of the efficiency of each chamber are carefully done, where the targeted efficiency to get qualified for use in the CMS experiment must be above 95%.

2.1 QC7 of GE2/1

The chamber undergoes the QC7 step of quality control after it has successfully passed the HV test in QC6. At this stage, the front-end electronics are integrated and calibrated on the chamber that is connected to the low voltage. All the QC7 testings listed below are performed for individual modules and then for the full chambers on the QC7 stand:

1. Testing communication between front-end and back-end electronics.
2. Calibration of the electronics and identifying optimal working points for VFAT circuits.
3. Measurements of the intrinsic noise in the electronics.

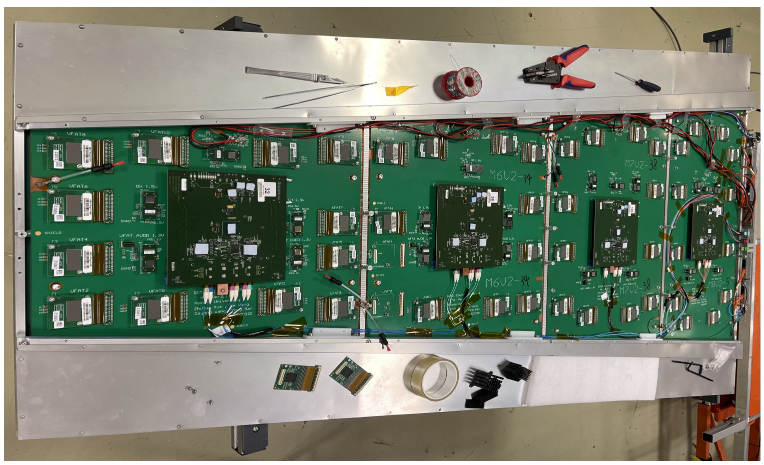

Figure 6: GEM GE2/1 on-chamber electronics for QC7 stand.

2.1.1 GEM Electronics Connectivity Test

The noise that is due to the electronics and the detector is called the intrinsic noise. While the QC7 step of quality control is ongoing, the intrinsic noise is monitored and it can be significant if there was an issue during electronics installation.
The channels are monitored by measuring the intrinsic noise by delivering an internal pulse. The internal pulse is used for the S-curves to inject charge and look at the response. The VFAT chips are equipped with an arming comparator that converts analog to digital signals by creating a square pulse when a signal exceeds the threshold

charge. The threshold charge value can be increased to discriminate data from electronic noise.

My work during QC7 focused on generating noise-scan plots in the tracking path, to look for problematic channels from the readout strips on GEB. The main aim is to validate the front-end electronics of the detector, to ensure the nominal operation by providing the lowest possible noise and the most reliable response from the readout. To do this, it is necessary to fix communication failures between the components and identify broken, disconnected and dead channels, as the threshold of the number of problematic channels per η-partition is at mostly two.
Errors that appear during the QC7 testings correspond to hardware issues, and the affected VFAT/s or OptoHybrid/s are replaced. Then QC7 continues with testing the analog and digital sides of the VFAT.

The python code below is used to generate noise-scan plots for all the readout strips. We

---

```
import os
import glob
import gc
import pandas as pd
import matplotlib as mpl
import matplotlib.pyplot as plt
import mplhep
import numpy as np
import seaborn as sns
from matplotlib.ticker import MaxNLocator
from scipy.stats import iqr
from scipy.stats import norm
plt.style.use(mplhep.style.CMS)

with open('filenames.txt') as f:
filenames = f.read().splitlines()

scurvefiles = []
for fname in filenames:
longname =
'/eos/user/q/qc7shift/www/results/'+fname+'/results/'
for oh in range(4):
list_of_files = glob.glob(longname+'*oh%i_noise.csv'%oh)
latest_file = max(list_of_files, key=os.path.getctime)
```

```
print(latest_file)
scurvefiles.append(latest_file)

dfs = []
for i in range(len(scurvefiles)):
scurvefile = scurvefiles[i]
number = int(scurvefile[52:55])
ohnumber = int(scurvefile[87:88])
df = pd.read_csv(scurvefile)
df['chambernumber'] = number
df['oh'] = ohnumber
dfs.append(df)
df = pd.concat(dfs)
df['iqrval']=np.nan

for chambernumber in df["chambernumber"].unique():
for oh in range(4):
for vfat in range(12):
sel = df["chambernumber"] == chambernumber
sel &= df["oh"] == oh
sel &= df['vfat'] == vfat
df.loc[sel,"medianval"] = df[sel]["sigma"].median()
df.loc[sel,"iqrval"] = iqr(df[sel]["sigma"])
df["pull"] = (df["sigma"]-df["medianval"])/df["iqrval"]
df

sel = df["pull"]>-10
df_sel = df[sel]
plt.hist(df_sel["pull"], bins=100, alpha=0.5, density=True,
ec='black',label='Pull Distribution')
plt.xlabel('p')
plt.ylabel('Density')
plt.legend()
plt.yscale("log")
```

output:

```
sel = df["sigma"]>-1
df_sel = df[sel]
plt.plot(df_sel["iqrval"],df_sel["sigma"]/df_sel["medianval"],".")
```

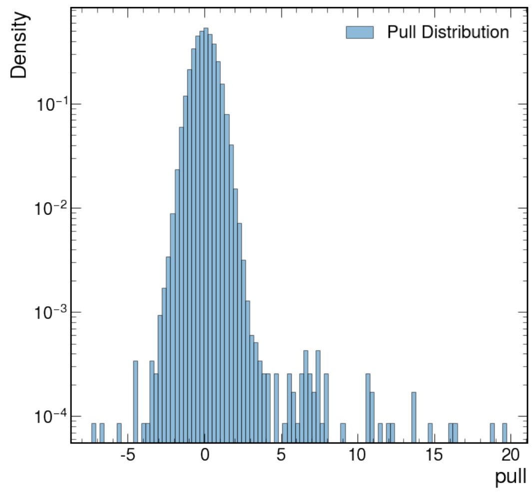

Figure 7: We generate a "Pull Distribution" plot, that ideally has a standard Gaussian distribution shape, in order to visually understand the distribution of our data and especially look out for outliers.

output:

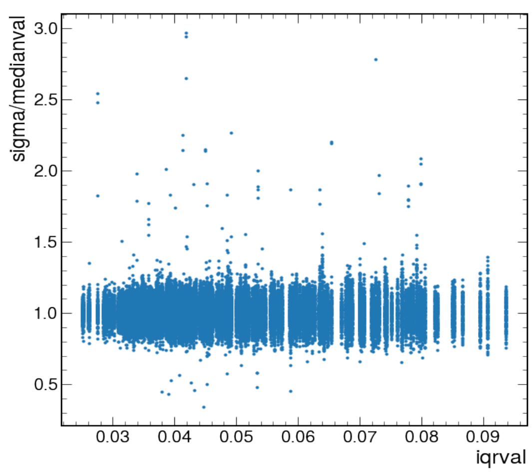

Figure 8: We generate a scattered plot in order to see the trend in our data points and put the threshold for the next noise distribution plot.

```
sel = df["sigma"]>-1
df_sel = df[sel]
plt.hist(df_sel["sigma"]/df_sel["medianval"], bins=100,
alpha=0.5, density=True, ec='black',label='Pull
Distribution')
plt.xlabel('p')
plt.ylabel('Density')
plt.legend()
plt.yscale("log")
```

output:

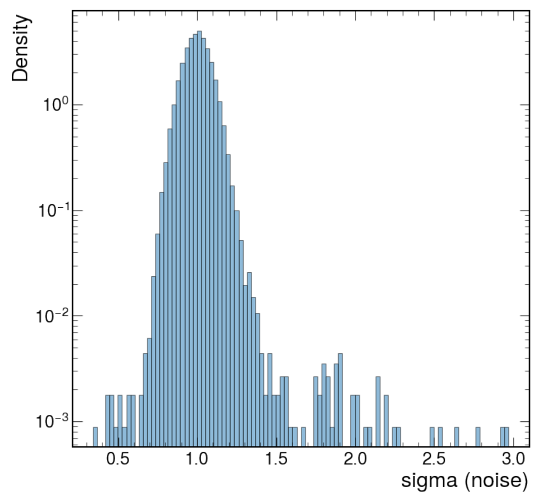

Figure 9: We generate another histogram to see the noise distribution of our data, so that we can set the threshold values for outliers in the noise plots.

```
plt.plot(df["pull"],df["sigma"],".")
plt.xlabel('pull')
plt.ylabel('sigma (Noise)')
```

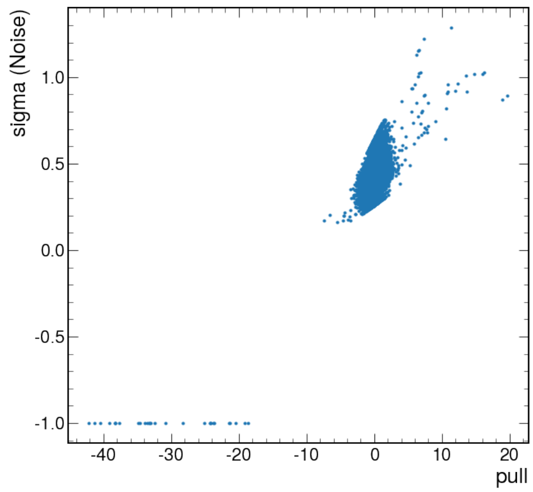

Figure 10: This generated scattered plot helps in understanding the distribution of the noise with respect to the pull values.

```
df_stripmap = pd.read_csv('ge21_mapping.csv')
df1 = pd.merge(df, df_stripmap, how="inner",
left_on=["vfat","ch"], right_on=["vfatId","vfatCh"])
for chambernumber in range(1,8):
sel = df1["chambernumber"] == chambernumber
df2 = df1[sel]
for oh in df1.oh.unique():
sel = df2["oh"] == oh
df3 = df2[sel]
for eta in range(1,5):
sel = df3["iEta"] == eta
df_full = df3[sel]
plt.figure()
plt.xlim(0,380)
sel1 =
(df_full["sigma"]-df_full["medianval"])<-2.5*df_full["iqrval"]
sel2 =
(df_full["sigma"]-df_full["medianval"])>2.5*df_full["iqrval"]
sel3 =
(df_full["sigma"]-df_full["medianval"])<2.5*df_full["iqrval"]
sel3 &=
```

```
(df_full["sigma"]-df_full["medianval"])>-2.5*df_full["iqrval"]
plt.plot(df_full[sel3]["strip"], df_full[sel3]["sigma"],
's', color="blue")
plt.plot(df_full[sel2]["strip"], df_full[sel2]["sigma"],
's', color="red")
plt.plot(df_full[sel1]["strip"], df_full[sel1]["sigma"],
's', color="red")
plt.bar(df_full[sel2]["strip"], df_full[sel2]["sigma"],
width=1, color="red", alpha=0.1)
plt.bar(df_full[sel1]["strip"], df_full[sel1]["sigma"],
width=1, color="red", alpha=0.1)
plt.xlabel("Strip Number", fontsize=24)
plt.ylabel("Noise [fC]", fontsize=24)
plt.title("Chamber %i, OH %i, Eta %i"
%(chambernumber,oh,eta), fontsize=24)
plt.xticks(fontsize=24)
plt.yticks(fontsize=24)
plt.tight_layout()
```

The output of the last code block generates the noise plots for the seven chambers, and for each η-parition and OptoHybrid from the noise scan test of QC7. Noise is in Equivalent Noise Charge (ENC), therefore the units [fC], while the strip number corresponds to the 384 strips from the readout board. The threshold value, that is around 0.4fC-0.5fC, is translated into charge units to allow for a comparison with the expected detector signal charge.

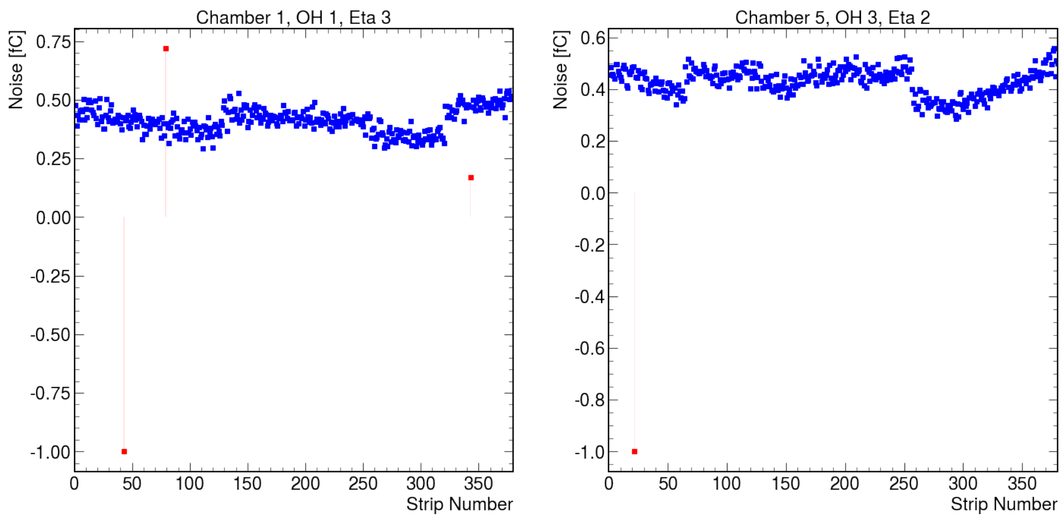

Figure 11: In these plots, anything above is noise due to a short between two channels or a channel and the ground; anything below is a disconnected channel, and dead channels that give no response are put by default at -1fC, just like it is shown in the plot on the left. The plot on the right shows only one dead channel.

There are some cases like the following ones, where:

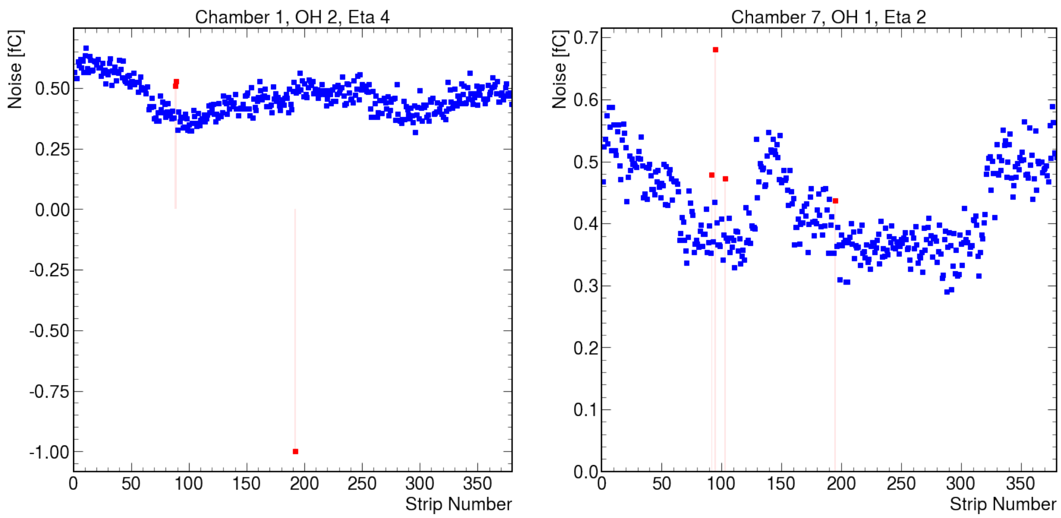

Figure 12: In the plot on the left there is one dead channel, and two channels in the threshold value around 0.5fC that are flagged as outliers by the algorithm. Similarly, in the plot on the right, there is a noisy channel above the threshold value, but three channels around 0.5fC that are also flagged as outliers. In these cases it is up to us to decide whether it is a noisy channel or not.

This quality control step as well as others is being validated, and accepted chambers have been accepted to be used at P5 for real data-taking.

2.2 QC8 of GE2/1

The final step of the quality control tests is QC8, that assesses the detectors as a whole. The GEM cosmic ray stand is where all the validation measurements are done for GE2/1 and it utilizes the cosmic ray muons as minimum ionizing particle source.

Figure 13: GEM detectors QC8 cosmic ray stand.

One of the most important parameters of detectors is the detection efficiency, which is defined as the fraction of the detected particles out of the ones that cross the active area. Therefore the numerator of the chambers depends on some factors such as the number of primary and secondary electrons produced in the ionization, the chamber gas gain, the time width of the signals induced on the readout strips compared to the electronics integration time, the number of strips involved in the avalanche, the signal amplification and integration in the VFAT, and the readout channel thresholds.
The evaluation of the detector's performance in QC8 goes through careful and detailed testings as mentioned below:

1. Checking the functionality of the components of the chambers and their integration.

2. Monitoring the mid-term stability of the chamber foils and the on-chamber electronics.

3. The study of the tracking capabilities of the chambers.

4. Measuring efficiency with cosmic ray muons.

5. Verification of compliance to the requirements.

2.2.1 HV Training of GE2/1 chambers

In QC8 I was part of the (high voltage) HV Training in the Detector Control System (DCS).
The DCS of the GEM cosmic ray stand makes it possible to control and monitor the (low voltage) LV and the HV hardware that power the chambers and the scintillator PMTs, and it is able to check the environmental parameters and the status of the gas mixer. In addition, it is programmed to react preserving the integrity of the detectors and re-establishing the correct conditions for smooth operations in case of unusual situations, while sending notifications and alarms.
One of the main features of DCS is that it provides the option to set the HV working point of the chambers through an equivalent divider current. It then calculates and provides the voltages to the seven electrodes of the chambers just like the resistive high-voltage divider in the gas gain would do.
Another feature that eases the HV training procedure complements the previous one with the option to rescale the voltage of each of the electrodes by a percentage of the nominal one. It makes possible to set the global working point through an equivalent divider current value, and to keep the induction gap off.
In principal, the GEM foils electrodes have to be turned on in steps, in order to carefully eliminate any pollutants that may have entered into the chambers.

My work focused on adding some necessary tools to the existing code that already changes the equivalent divider current of the detector. The first one was to make a python nested dictionary using the two mainframes and the GE2/1 mapping of the HV channels in the QC8 stand. The dictionary is needed to be able to specify the chamber and the module of interest, while using board and layer for powering. The other tools are about adding an option that allows changing the equivalent divider current of the detector while keeping the induction gap off. And the next one was to add an option that can set the voltage to a single electrode and not to the entire chamber; the python classes created for these will be featured in the source code of the powering.

The python code below is written for a channel in the QC8 HV board that is not connected to any chamber.

```
#Chamber-Module to Board-Layer mapping
mapping_dictionary = {
"Chamber1":{
"M4":{"Mainframe1":"HV904COSMIC", "Board_no":0,
"Layer_no":0},
"M3":{"Mainframe1":"HV904COSMIC", "Board_no":0,
"Layer_no":1},
"M2":{"Mainframe1":"HV904COSMIC", "Board_no":1,
"Layer_no":0},
"M1":{"Mainframe1":"HV904COSMIC", "Board_no":1,
"Layer_no":1}
},
"Chamber2":{
"M4":{"Mainframe1":"HV904COSMIC", "Board_no":2,
"Layer_no":0},
"M3":{"Mainframe1":"HV904COSMIC", "Board_no":2,
"Layer_no":1},
"M2":{"Mainframe1":"HV904COSMIC", "Board_no":3,
"Layer_no":0},
"M1":{"Mainframe1":"HV904COSMIC", "Board_no":3,
"Layer_no":1}
},
"Chamber3":{
"M4":{"Mainframe2":"HV904COSMIC", "Board_no":4,
"Layer_no":0},
"M3":{"Mainframe2":"HV904COSMIC", "Board_no":4,
"Layer_no":1},
"M2":{"Mainframe2":"HV904COSMIC", "Board_no":5,
"Layer_no":0},
"M1":{"Mainframe2":"HV904COSMIC", "Board_no":5,
"Layer_no":1}
},
"Chamber4":{
"M4":{"Mainframe2":"GE21HVCosmic", "Board_no":0,
"Layer_no":0},
"M3":{"Mainframe2":"GE21HVCosmic", "Board_no":0,
"Layer_no":1},
"M2":{"Mainframe2":"GE21HVCosmic", "Board_no":1,
```

```
"Layer_no":0},
"M1":{"Mainframe2":"GE21HVCosmic", "Board_no":1,
"Layer_no":1}
},
"Chamber5":{
"M4":{"Mainframe2":"GE21HVCosmic", "Board_no":2,
"Layer_no":0},
"M3":{"Mainframe2":"GE21HVCosmic", "Board_no":2,
"Layer_no":1},
"M2":{"Mainframe2":"GE21HVCosmic", "Board_no":3,
"Layer_no":0},
"M1":{"Mainframe2":"GE21HVCosmic", "Board_no":3,
"Layer_no":1}
},
"Chamber6":{
"M4":{"Mainframe2":"GE21HVCosmic", "Board_no":4,
"Layer_no":0},
"M3":{"Mainframe2":"GE21HVCosmic", "Board_no":4,
"Layer_no":1},
"M2":{"Mainframe2":"GE21HVCosmic", "Board_no":5,
"Layer_no":0},
"M1":{"Mainframe2":"GE21HVCosmic", "Board_no":5,
"Layer_no":1}
},
"Chamber7":{
"M4":{"Mainframe2":"GE21HVCosmic", "Board_no":6,
"Layer_no":6},
"M3":{"Mainframe2":"GE21HVCosmic", "Board_no":6,
"Layer_no":1},
"M2":{"Mainframe2":"GE21HVCosmic", "Board_no":7,
"Layer_no":0},
"M1":{"Mainframe2":"GE21HVCosmic", "Board_no":7,
"Layer_no":1}
},
}
```

```
#Setting the equivalent divider current to all the
electrodes with the induction gap off
```

```
def set_divider_current_induction_off(self,
divider_current):
for electrode in self.ELECTRODES:
if electrode != "DRIFT":
vset = self.calculate_voltage(divider_current, electrode)
calculate_current = vset /
self.DIVIDER_RESISTORS[self.ELECTRODES.index(electrode)]
self.set_current(calculate_current, electrode)
self.set_voltage("DRIFT", 0)

detector = Detector(host="host_name", board="board_number",
layer="layer_number")  #choose the host, board and layer of
the chamber
divider_current_value = 20  #set the value
detector.set_divider_current_induction_off(divider_current_value)
```

```
#Setting the voltage to a single electrode and switching it
on

def set_voltage_single_electrode(self, electrode, voltage):
for electrode in self.ELECTRODES:
self.set_voltage(electrode, 0)

self.set_voltage(electrode, voltage)

if switch_on:
self.set_voltage(electrode, voltage)
else:
self.set_voltage(electrode, 0)

detector = Detector(host="host_name", board="board_number",
layer="layer_number")  #choose the host, board and layer of
the chamber
target_electrode = "G3TOP"  #choose the electrode for
powering
voltage_value = 400  #set the value switch_on = True
detector.set_voltage_single_electrode(target_electrode,
voltage_value, switch_on)
```

List of Figures

References

[1] Merlin, J. A. *Study of long-term sustained operation of gaseous detectors for the high rate environment in CMS* (CERN-THESIS-2016-041) (2016) [PhD, Strasbourg University. CERN SPS; LHC, CMS]. Retrieved from CERN CDS: https://cds.cern.ch/record/2155685?ln=en

[2] Regnery, B. *The BEST Thesis: The Boosted Event Shape Tagger, A Search for Vector-like Quarks, and A Real GEM in CMS* (CERN-THESIS-2023-040) (2023) [PhD, University of California, Davis. CERN LHC, CMS]. Retrieved from CERN CDS: https://cds.cern.ch/record/2857021

[3] Mocellin, G. *Performance of the GE1/1 detectors for the upgrade of the CMS muon forward system* (CERN-THESIS-2021-327 ; 10.18154/RWTH-2021-07066) (2021) [Doctorate, RWTH Aachen University. CERN LHC, CMS]. Retrieved from CERN CDS: https://cds.cern.ch/record/2809098?ln=en

[4] Merlin, J. A. *Introduction to the GEM technology* (2022) [PhD, Strasbourg University. CERN SPS; LHC, CMS]. Retrieved from: https://cds.cern.ch/record/2155685?ln=en

[5] H. Keller, T. Hebbeker, K. Hoepfner, G. Mocellin and S. Zaleski *Influence of hole geometry on gas gain in GEM detectors* (2020) [Journal of Instrumentation, International Conference on Instrumentation for Colliding Beam Physics Novosibirsk, Russia]. Retrieved from https://iopscience.iop.org/article/10.1088/1748-0221/15/06/C06004/pdf