CMS GEM INTERNAL NOTE

GE1/1 Quality Control : instructions

Michele Bianco*, Brian Dorney†, Jeremie A. Merlin‡
CERN
On behalf of the CMS GEM Collaboration

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In this document we will describe the quality controls for the GE1/1 production and we will present the detailed test procedures to ensure that all the detectors will be operational with the best performance.

*michele.bianco@cern.ch
†brian.dorney@cern.ch
‡jeremie.alexandre.merlin@cern.ch

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1 PREREQUISITES

The key to any mass detector production project is coordination and documentation. During your site's production process you will be confronted with a series of challenges. The most critical will be tracking the various stages of each detector/component and how you will maximize the use of your sites infrastructure/test stands for the benefit of the project.

In this section we describe the prerequisites for each site from a policy point of view. These fall in four areas:

1. site planning and management
2. a gas supply log
3. an individual's personal lab manual,
4. and the use of the centralized logbook on cmsonline.cern.ch.

These four areas are often overlooked. We have found that individuals new to lab work (students, postdocs transitioning from analysis, etc ...) generally overlook items 3 and 4 and require repeated reinforcement to build good "book-keeping habits." Such reinforcement only succeeds when the "boots-on-the-ground" leader is continually providing feedback and reminders to the institute's team assigned to detector production.

Additionally it has been our hard-learned experience that the "boots-on-the-ground" leadership often struggles with keeping the over-arching vision of the production site in mind when faced with the challenges of making a given test stand, detector, or component "work."

While we cannot give an a complete look at project management and laboratory policies- as people train their entire lives for these-we do our best to provide a set of "best practices" we expect everyone involved in the production to follow.

1.1 SITE PLANNING AND MANAGEMENT

We ask that the"boots-on-the-ground" leader of your site organize a weekly planning meeting similar to the run meetings held by the various CMS Operations teams. It is best if this is a stand-alone meeting only including those members of your team who will be involved in the production rather than as an after thought added to a pre-existing meeting. For this meeting you should talk about:

1. the status of each detector/detector-kit you presently have on site;
2. the goals/objectives that were met in the previous week;
3. outstanding goals/objectives from the previous week;
4. issues that have arisen during the production;
5. the goals/objectives for this week;
6. and filling out a task matrix for the daily activities of each member of your production team.

We generally have found that this order is the most helpful. This meeting will help you and your team set the daily direction; and helps your boots on the ground leader to have an over-arching view of your sites activities. Item number 6 above is particularly important as it gives the daily direction for the entire team. An example weekly task matrix of the CERN team is shown in table Tab. 1.1.

Name	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Brian	////////// //////////	ICHEP poster prep	QC procedure technical report	QC8 prep	QC8 running
Jeremie	QC5 analysis Short 2	QC5 analysis Short 2	904 test stand QC procedure	QC5 procedure technical report	QC5 procedure technical report
Marek	QC3 Short 1	QC3 Long 4	QC4 drift short 6	Fix leaks short 3	QC4 short 5

Table 1.1: Example of a weekly task-matrix for the CERN team developed at the end of a regular weekly planning meeting.

Of course the activities laid out in the task-matrix can change as the week develops however it serves remarkable well at organizing the team's activities.

Additionally your site should have a detector dashboard that allows you to track the current status of each detector/detector-kit presently on site. We have found the best layout for this dashboard is to list in tabular form detector serial number, current step/location, notes (e.g. completed steps or outstanding issues), and plan for future actions. This dashboard is immensely helpful when used in conjunction with the weekly planning meeting. It is the place where you can record item number 1 and allows you to at a glance determine what objectives/goals have been met, still outstanding, and need to be put into the queue (items 2 to 5). As detector/detector kits leave (arrive) from (at) your site you should remove (add) items from your detector dashboard to ensure it stays current.

The best way to combine the detector dashboard and the weekly planning meeting is to invest in a large white board that is centrally located in your lab, easily accessible, and highly visible. CERN has such a white board at the entrance to the GEM QC lab. We use this to store our detector dashboard and our weekly task matrix.

1.2 Gas Supply Log

During the production it is of critical importance to have an up-to-date understanding of the state of your gas infrastructure. Each member of your team should always know what gas they are using at a given test stand and how much of that gas is left. If you are using a central mixing system the importance of this is increased further as problems with a central system can have consequences at multiple test stands.

The key points any gas supply log should answer is:

1. your current gas inventory (e.g. X bottles of Ar, Y bottles of CO2, etc ...);
2. the gas pressure and draw in L/hr of your test stands' gas infrastructure at each stage (e.g. pressure on the bottle, pressure on the patch panel, pressure on the mixer input and output mixer pressure);
3. and how long the gas in your lines will last.

It should be obvious that item 1 is critical since if a site runs out of a required gas during the production that this could incur some lost time that has not been put into the project schedule (for example at CERN it can take several weeks for a gas order to be fulfilled).

Items 2 and 3 go hand-in-hand. Pressures recorded for item # 2 should help you to determine item # 3; and item # 3 should help you to understand how often you should check items that are required for 2. For example at moderate draw from multiple test stands at CERN we know that the gas in our lines between the bottles and the mixer will supply the lab for 56 hours or less. This calculation is done using the ideal gas law so it has some shortcomings. As a result at CERN we check the pressure on the bottles supplying our mixer every two days or less and the inlet pressures to our mixer, output pressure, and flow fractions daily before the start of each test using the mixer. This is all logged in a Google Doc that is configured to have a shareable link that anyone in the CERN team can access.

Fig. 1.1 shows an example gas log as used at CERN.

Each GE1/1 represents a significant time and monetary investment. Damaging or destroying a detector due to an improper gas mixture should be avoided at all costs. Maintaining and regularly updating a gas log as described is one policy that should be put in place to ensure this does not occur.

1.3 Personal Lab Notebook

It is standard practice of an experimentalist, regardless of field, to keep a personal lab notebook. This allows the individual to record important information that can include anything from instructions on how to operate a particular piece of equipment to details regarding an on-going measurement in one of your site's QC stations. This notebook should serve as your sounding board and should supplement the Centralized E-Log. However since your logbook is not accessible from anywhere in the world by the rest of the community it should never act as a replacement to the central E-Log post. As a rule-of-thumb, if it's important enough to write down in your personal lab notebook it is important enough to post to the central E-Log.

1.4 The Centralized E-Log

The centralized E-Log serves as a long-term, stable, logbook for the entire community accessible from anywhere in the world. If used correctly it will serve as an invaluable logbook that will stand the test of time and provide an excellent experimental record of the detector quality control during the production, and after installation. Additionally the E-Log allows collaborators across the globe to provide real-time troubleshooting assistance if a community member is struggling with a given measurement.

To access the central E-Log navigate to cmsonline.cern.ch. You will be prompted to login with your CERN credentials. Then click the "E-Log" link on the left side bar. Navigate to "Subsystems -> GEM -> Quality Control." From here you will see a list of E-Logs associated with each quality control step that are described in Tab. 1.2.

Quality Control	**E-Log**
QC2	Foil Leakage Current Testing
QC3	HV & Gas Leak Stand
QC4	HV & Gas Leak Stand
QC5	X-ray Station
QC8	Cosmic Stand

Table 1.2: Mapping of quality control steps to E-Log category for documenting QC measurements on cmsonline.cern.ch.

For historic reasons these E-Log books follow the test stand setup at CERN and thus QC3 and QC4 share a common E-Log called "HV & Gas Leak Stand."

The philosophy for using the E-Log is that the user should make entries that allow a reader who was not present during the experiment to recreate both the exact experimental conditions and the procedure/steps taken in an unambiguous way. To accomplish this goal the user should be concise and descriptive in their statements and include pertinent information that may or will be important later when analyzing the data, attempting to compare to measurements from other detectors, or repeat measurements of the same detector.

We are building a system to last 20 years and may outlive our own careers in high-energy physics. It is important to make good E-Log posts now so that we can give future CMS members a good log to refer to in the future.

To make an E-log entry navigate to the pertinent E-Log for the action you are performing (e.g. $QC5\_Eff\_Gain$ would go to "X-Ray Station"). If this is a new measurement make a post titled $<SiteName>:<Det.S/N>-Test\ type$. If you want to report another action use the title $<SiteName>:<Action/Problem/Solution>$. Example 1: a new $QC5\_Resp\_Uni$ measurement would go under "X-Ray station" titled $CERN: GE11-VII-L-CERN-0003\ Response\ uniformity$. Example 2: the installation of new drivers would be $CERN: Installing\ AmpTek\ X-Ray\ Drivers\ on\ X-Ray\ PC$. Use the appropriate CERN E-Log entry template for the correct format of the log. This keeps a standard Log entry for each site that will prove invaluable when referring Log entries across the community.

Do not wait until the end of a test/measurement to post an E-Log. Setup the correct E-Log template in the correct category and then submit the post, then start the test/measurement. For several hours after your initial post you will be able to edit the post and update it with new information. Fig. 1.2 shows where the Edit button can be found. This serves two purposes as it will prevent you from forgetting important details or occurrences during the measurement and it will prevent you from losing what you have written in the text dialog box of the E-Log entry i.e. pressing back/refresh in your browser or being flagged as inactive by cmsonline.cern.ch will cause you to lose anything you have put in the text dialog box that has not yet been submitted.

Additionally if new details come up later, say after a measurement, or you are no longer able to edit your original post you should reply to the original post to add new details to what has already been written. An example reply history for a given measurement can also be seen in Fig. 1.2. Additionally, you should not delete E-Log posts as this removes information from the project.

To refer to a specific E-Log post or reply history use the E-Log short link that is shown on the top of the post below the reply history, see Fig. 1.2.

In closing the E-Log is only as useful as the user makes it; if for a given E-Log entry a reader cannot recreate the experimental conditions and the steps taken your site manager and/or the GEM production manager will ask you to either 1) go back and add the required details to improve clarity to the E-Log, or 2) repeat the test from scratch with better logging skills. The second case would be the extreme case in which the analyzed data cannot be understood and the E-Log does not give enough details to understand the results.

Figure 1.1: Example gas supply log kept for the mixer used by the CERN group.

Instructions

1. Update the red "Mixer draw of X (L/hr)" values shown in cells D13 through D15
2. Update the red "Pressure of Manifold (mbar)" value shown in cell L17
2. Update the "Gas Bottle Pressure" table every 2 days
3. Update the "Gas Pressure at Patch Panel" table every day
4. Update the "Gas Pressure at Mixer" table every day
5. Change/order bottles as required based on information in "Gas Bottle Pressure" table

Line 4 Gas	Ar/CO2/CF4 (45/15/40)
Mixer draw of Ar (L/hr)	2.23
Mixer draw of CF4 (L/hr)	0.00
Mixer draw of CO2 (L/hr)	0.97
Time until Ar runs out (hrs)	1.71E+02
Time until CF4 runs out (hrs)	#DIV/0!
Time until CO2 runs out (hrs)	7.16E+02
Check gas at TIF mixer interval (hrs)	1.71E+02

Fraction of Ar	0.70
Fraction of CF4	0.00
Fraction of CO2	0.30
Pressure of Manifold (mbar)	27

Temperature (K)	298
Gas Constant (L bar) / (mol K)	8.314
Amount of Ar (mol)	2.89E-03
Amount of CF4 (mol)	5.18E-05
Amount of CO2 (mol)	2.29E-03
Draw of Ar (mol/hr)	1.69E-05
Draw of CF4 (mol/hr)	0.00E+00
Draw of CO2 (mol/hr)	3.20E-06

Out -> Distance from bottle to B186 wall
Inside -> Distance from B186 wall to TIF ceiling
TIF -> Distance from TIF ceiling to patch panel
Mixer -> Distance from patch panel to mixer box

Gas Bottle Pressure

Date	Time	Ar	CF4	CO2	N2	Line 4
(YYYY/MM/DD)	(HH:MM)	(bar)	(bar)	(bar)	(bar)	(bar)
2016/06/15	18:03	200	140	55	120	85
2016/06/17	13:45	200	135	65	115	85
2016/06/20	10:06	180	125	45	110	85
2016/06/23	13:45	180	150	45	115	90
2016/06/27	13:53	170	135	45	110	85
2016/06/30	13:41	165	140	60	115	80
2016/07/04	16:02	155	150	55	120	90
2016/07/05	10:10	142	137	50	110	85
2016/07/06	9:09	150	125	45	110	80
2016/07/11	11:34	135	145	59	115	87
2016/07/12	9:44	133	138	51	110	88

Gas Pressure at Patch Panel

Date	Time	Ar	CF4	CO2	N2	Line 4
(YYYY/MM/DD)	(HH:MM)	(bar)	(bar)	(bar)	(bar)	(bar)
2016/06/16	10:00	7	0	5.5	7	7
2017/06/17	13:32	7	0	5	7	7
2016/06/20	10:06	7	0	5	6.5	7
2016/06/21	9:13	7	0	5	6	7
2016/06/23	13:30	6.5	0	5	6.5	7
2016/06/24	11:03	6.5	0	5	6.5	7
2016/06/27	13:37	6.5	0	5	6.5	7
2016/06/28	9:43	6.5	0	5	6.5	7
2016/06/29	10:23	6.5	0	5	6.5	7
2016/06/30	13:44	6.5	0	5	6.5	7
2016/07/04	16:02	6.5	0	5	6.5	7.5

Gas Pressure at Mixer

Date	Time	Ar	CF4	CO2
(YYYY/MM/DD)	(HH:MM)	(bar)	(bar)	(bar)
2016/06/16	10:00	2	1.9	2.5
2017/06/17	13:32	2	1.9	2.5
2016/06/20	10:06	2	1.9	2.5
2016/06/21	9:13	2	1.9	2.5
2016/06/23	13:30	2	1.9	2.5
2016/06/24	11:03	2	1.9	2.6
2016/06/27	13:37	2	2	2.6
2016/06/28	9:43	2	2	2.6
2016/06/29	10:23	2	2	2.6
2016/06/30	13:44	2	2	2.5
2016/07/04	16:02	2	2	2.6

Physical Parameters of Manifold

	Out	Inside	TIF	Mixer
Pipe Length (m)	15.25	1.9	2.8	2.39
Inner Pipe Diameter (m)		0.008		0.006
Volume (L)		1.003		0.068

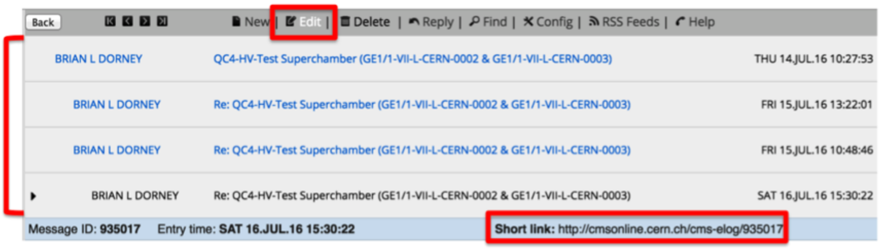


Figure 1.2: Example E-Log reply history for an ongoing measurement; notice the *Edit* button in the upper bar (red box) is still accessible since the last post was made recently. This E-log can be referred to it's short link in the lower right, also boxed in red.

2 QC2 : GEM FOIL TESTING

The QC2 test aims to determine the quality of a GEM foil by measuring the maximum leakage current flowing on the surface of the GEM holes. It is therefore mandatory to perform the QC2 test before, during and after the assembly of the detector.

The QC2 procedure is divided in five steps in order to ensure the perfect functionality of the GEM foils:

- GEM foil preparation and cleaning.
- QC2 fast : GEM acceptance test I.
- QC2 long : GEM acceptance test II.
- QC2 fast post-assembly in clean room.
- QC2 fast in dry gas.

Each step has a specific procedure and output that will be described below.

2.1 GEM FOIL PREPARATION AND CLEANING

GEM foils are delivered from CERN to the construction sites in a sealed box, enclosed into anti-static paper and wrapped with bubbles foils to prevent any possible damage. To prevent contaminations that may compromise the GEM foils performance, all operations during which the foils are exposed directly to the air must be carried out in clean room certified at least class 1000. The box itself must be cleaned before the opening phase to avoid contamination. After opening, the inside of the box must be cleaned with a vacuum cleaner equipped with a HEPA filter to avoid the deposition of plastic dust on the GEM foils. The GEMs have to be extracted one at a time by at least two trained operators who have to keep the foils well tensioned to avoid the formation of folds. The operators should not wear gloves but carefully wash their hands before starting the manipulation.
In order to correctly test the foils and afterwards proceed with the chamber assembly, it is necessary to:

1. Fix the foil to its dedicated frame with tape as shown on Fig. 3.1. The support frame can be realized with FR4, aluminum or any other rigid, light and easily cleanable material.
2. Clean the foils with a dedicated anti-static and dust remover roll (see Fig. 2.2) in order to remove any possible dust particle deposited on the foils during the delivery and the fixation on the frame (e.g. "Particles Cleaning Roller" by Euro Cipel).

2.2 QC2 FAST : GEM ACCEPTANCE TEST I

The first step of the acceptance test consists of applying voltage to the GEM foil and measure the leakage current between the top and the bottom electrodes. The

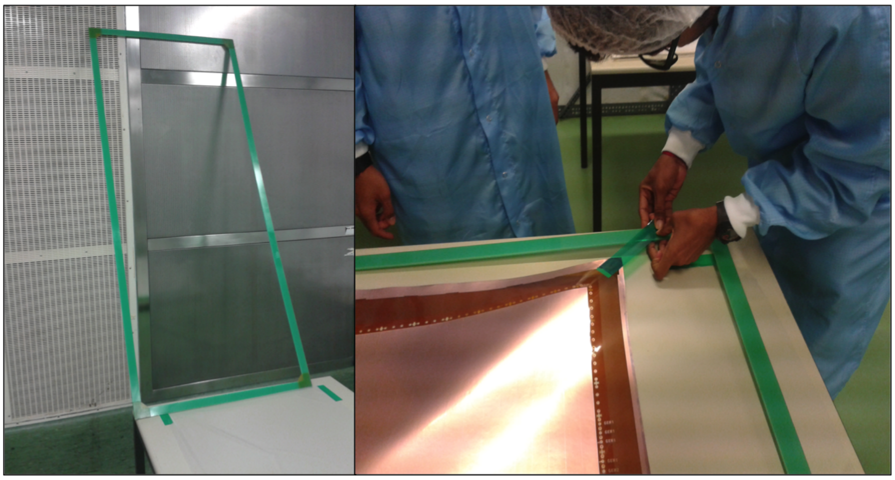


Figure 2.1: Preparation of the GEM foil and installation on the FR4 frame.

QC2 fast test is performed with a Multi Mega-ohmmeter (e.g. Insulation Tester MEGGER MIT485 by RECOM Electronic AG), also called Megger, connected to the GEM top and bottom HV pads (see Fig. 2.3). The connection between the Megger and the GEM electrodes is done using custom HV clips shown on Fig. 2.4.

Since the surface conductivity of the GEM foil depends on the relative humidity of the environment, a meteo-station with temperature and humidity sensors is setup near the QC2 test stand. In order to obtain comparable results, the relative humidity in the clean room must be equal or less than 40 %.

To perform the QC2 fast test, proceed as follows:

1. Place the foil and its frame in vertical position against a wall of the clean room (see Fig. 2.4).
2. Connect the Megger to the GEM HV pads with the custom clip (see Fig. 2.4).
3. Set the HV to 550 V on the Megger.
4. Measure the impedance of the foil and count the number of sparks after 30 s and then every minutes over a period of 10 minutes.
5. Report the time, the applied voltage, the impedance of the foil, the leakage current and the number of sparks in the summary table, as indicated in table Tab. 2.1.

The GEM foil is accepted if its impedance is above 10 GΩ and the spark rate lower than 2 Hz during the last two/three minutes of test. If the number of sparks exceeds this limit, the foil needs to be cleaned again with the anti-static roll. If the problem persists after several cleaning attempts, the foil has to be sent back to the production workshop and cleaned with DI water.

Note: the QC2 fast acceptance test must be performed at each step of the assembly of the GE1/1 detectors to identify possible damages on the GEM foils and to

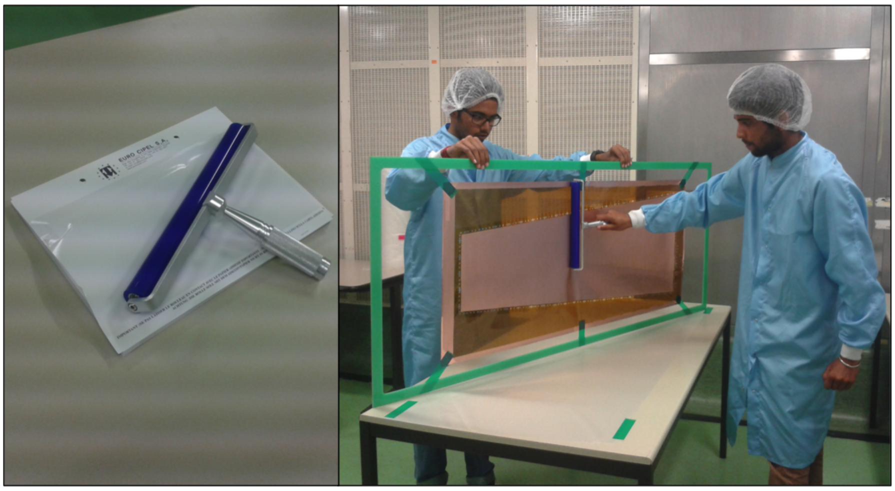


Figure 2.2: Cleaning of the GEM foil with an anti-static roll to remove the dust.

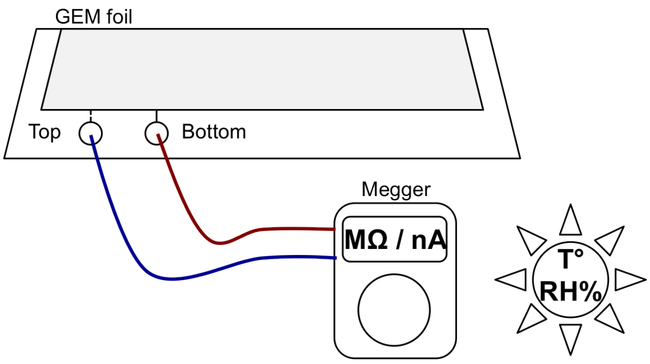


Figure 2.3: Schematic view of the QC2 fast test setup (acceptance test I).

remove the dust that could have been produced during the mounting of the internal frame.

2.3 QC2 long : GEM acceptance test II

The second step of the acceptance test consists of measuring the HV long-term stability of the GEM foils in a dry environment. The so-called QC2 long test is initially performed at CERN before the shipment of the foils to the production sites. It consists of monitoring the leakage current and the possible sparks when the GEM foil is subject to HV, typically up to 600 V during a period of 30 minutes - 1 hour .

As shown on Fig. 2.5, the foils under test are placed in a dedicated plexiglass box filled with pure nitrogen. The temperature and the humidity inside of the box are monitored using a professional Meteo-station and a dedicated software that

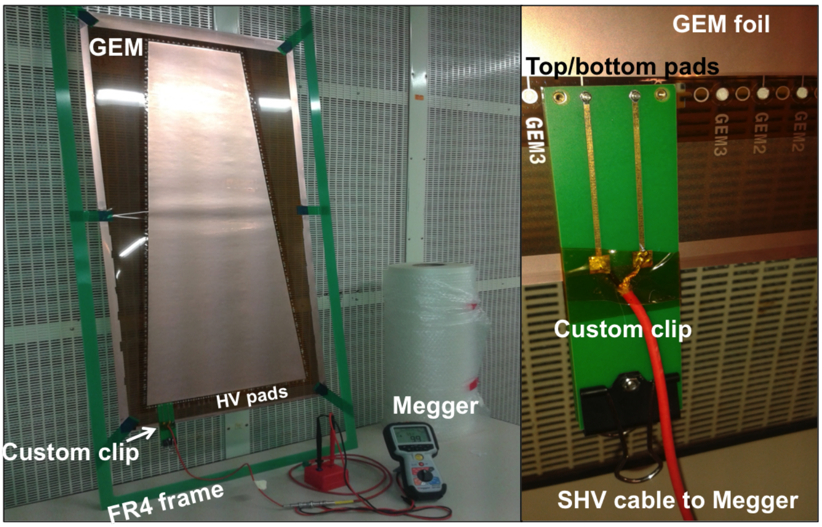


Figure 2.4: Picture of the QC2 fast test on a GEM foil (acceptance test I).

records the data every minutes over the entire test. The GEM foils are powered using a programmable HV power supply (e.g. CAEN R1471HETD) that has a current monitoring resolution lower than 1 nA. The control of the system and the data acquisition are possible via a custom made Labview interface available at https://twiki.cern.ch/twiki/bin/view/MPGD/GEMDetectorProduction.

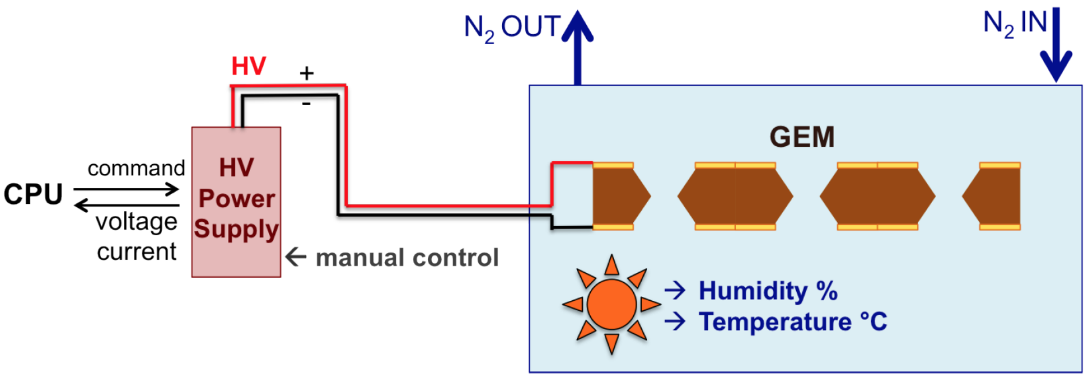


Figure 2.5: Schematic view of the QC2 long test setup (acceptance test II).

A picture of the QC2 long test setup at CERN is shown on Fig. 2.6

Time [min]	Voltage [V]	Impedance [G Ω]	Current [nA]	Sparks	Total sparks
0.5	550	3.11	176	6	6
1	550	3.73	147	3	9
2	550	5.9	93	1	10
3	550	7.6	72	0	10
4	550	8	68	1	11
5	550	8.5	64	1	12
6	550	9.2	59	1	13
7	550	9.6	57	0	13
8	550	10.5	52	0	13
9	550	10	55	0	13
10	550	11	50	0	13

Table 2.1: Typical QC2 fast summary table for an accepted GEN foil.

2.3.1 Preparation of the GEM foils

To prepare the QC2 long test, proceed as follows:

1. Clean the foils with the anti-static roll in order to remove the possible dust particles deposited on the foils during the previous operations.
2. Gently insert the foils into the HV box one at the time and keep note of the foils ID.
3. Fix the custom clips to the HV pads to each foil (see Fig. 2.4).
4. Start the Meteo-station, set the recording rate to one measurement per minute and insert it into the nitrogen box.
5. Use the Megger or a standard multimeter to check the connectivity between the custom clips and the SHV connectors outside of the nitrogen box.
6. Use the manual control of the power supply to apply 500 V across the GEM foils.
7. Set the nitrogen flow rate to 50 L/hr and let it flush until the relative humidity inside of the nitrogen box is equal or lower than 7 % (typically 48 hours). Maintain the HV on the GEM foils during the entire process.

2.3.2 Measurement of the leakage current

To perform the QC2 long test, proceed as follows:

1. Enable the remote control mode of the HV module as indicated in Fig. 2.7.
2. Connect "channel 0" of the power supply to the SHV connector that corresponds to the first GEM foil in the nitrogen box (the foils are tested separately, one after the other).

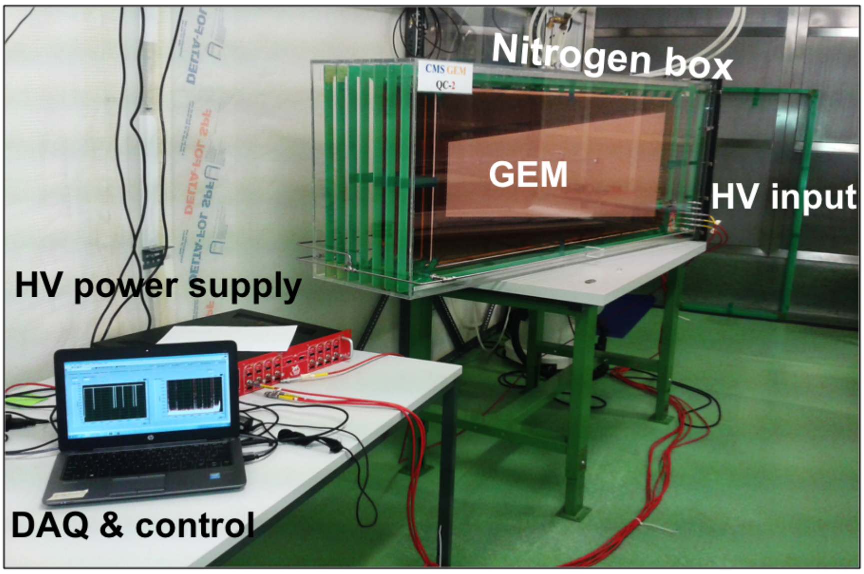


Figure 2.6: Picture of the QC2 long test setup at CERN.

3. Start Labview, open and run the virtual instrument QC2_Long.vi .
4. Enter the test information in the new popup window as shown on Fig. 2.8. Ignore the fields covered with a dark green layer. In the fiels *Notes*, indicate the relative humidity and the temperature inside of the box at the beginning of the test.
5. In the Labview front pannel, open the "Configuration" tab and click on the folder icon next to the field "Setting File To Load", as indicated on Fig. 2.9. Then select the configuration file "Config_Step_1" and click on the "Load Settings From File" button to load the configuration in Labview.
6. Indicate the absolute path the data directory in the field "Set Data Folder" (Fig. 2.9).
7. Click on the "Start Test" button to start the acquisition.

After the first step is finished, the program will automatically save the data files in the data directory and stop. To perform the second and the first steps of the QC2 long test, repeat steps 3 to 7. At step 5, when loading the configuration into Labview, select the appropriate file ("Config_Step_2" or "Config_Step_3").
After the three steps are successfully performed, connect "channel 0" of the power supply to the SHV connector that corresponds to the next foil you want to test and repeat the procedure from step 3 to 7.

2.4 QC2 fast post-assembly in clean room

After the GE1/1 detector is assembled, it is mandatory to repeat the QC2 fast test in the clean room. As for the QC2 fast acceptance test, this test is carried out

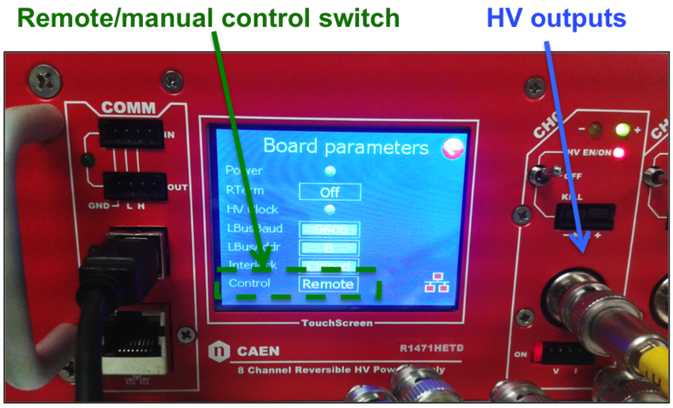


Figure 2.7: Picture of the CAEN R1471HETD front pannel.

using a Multi Mega-ohmmeter (Megger). The voltage has to be applied on the pads of the HV distribution present on the Drift PCB (Fig. 2.10). Since this test is performed in air, it is necessary to measure the ambient temperature and the relative humidity in the vicinity of the detector.

To perform the QC2 fast test on a GE1/1 detector, proceed as follows:

1. Set the detector in vertical position.
2. Connect the Panasonic-to-LEMO adapters with the 0 Ω terminations to all the readout sectors, as shown on Fig. 2.11.
3. Connect the Megger to the appropriate GEM HV pads by putting the negative pin on the top electrode and the positive pin on the bottom electrode. Example 1: to test GEM 1 connect the negative pin of the Megger to the GEM 1 top pad and the positive pin to the GEM 1 bottom pad. Example 2: to test the transfer gap 2 connect the negative pin to the GEM 2 bottom pad and the positive pin to the GEM 3 top.
4. Set the HV to 550 V on the Megger.
5. Measure the impedance and count the number of sparks after 30 s and then every minute over a period of 10 minutes.

The detector is accepted if the impedance of all GEM foils is above 10 GΩ after few minutes and no sparks can be observed after 10 minutes. Similarly, the impedance of the gaps must reach 100 GΩ or more after only few minutes, with no sparks.

If the impedance of the induction gap is lower than 100 GΩ, or if you experience several discharges at 550 V, there might be a short circuit of a weak point caused by the bending of the readout PCB toward the third GEM foil. In this case you can localize the problem by proceeding as follows:

1. Remove all the 0 Ω terminations from the Panasonic-to-LEMO adapters.

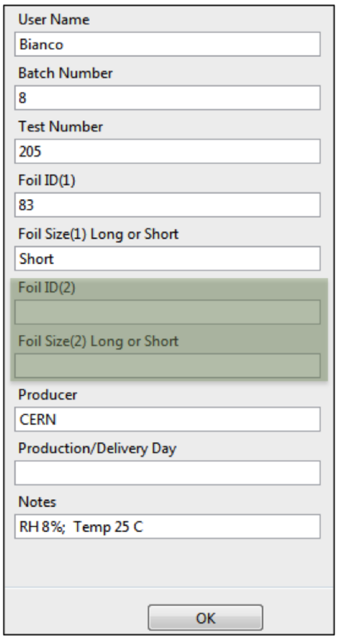


Figure 2.8: QC2 Labview interface information window.

2. Connect the Megger's negative pin on the HV pad corresponding to GEM 3 bottom.
3. Connect the Megger's positive pin on the signal pad of the Panasonic-to-LEMO adapter on the readout sector iη=1, iϕ=1 (Fig. 2.12).
4. Set the HV to 550 V on the Megger.
5. Measure the impedance after one minute and count the number of sparks over a period of 1-2 minutes.
6. Repeat this procedure for all the 24 readout sectors.

After a GE1/1 detector passes this test, it can leave the clean room and mounted on the QC3 test stand to start the gas tightness measurement. Chambers that does not pass this step should not be moved out of the clean room but immediately re-opened for further investigations. If the problem is identified and fixed, the QC2 fast test must be performed again before the chamber can move to the next QC step.

2.5 QC2 FAST IN DRY GAS

The QC2 fast test in dry gas must be done just before mounting the HV circuit on the detector. Moreover, it is usually the first step of every investigations or repairing protocols that start after a chamber showed a suspicious behavior (e.g. sparking at high gain, instability, high-rate spurious signal ...).

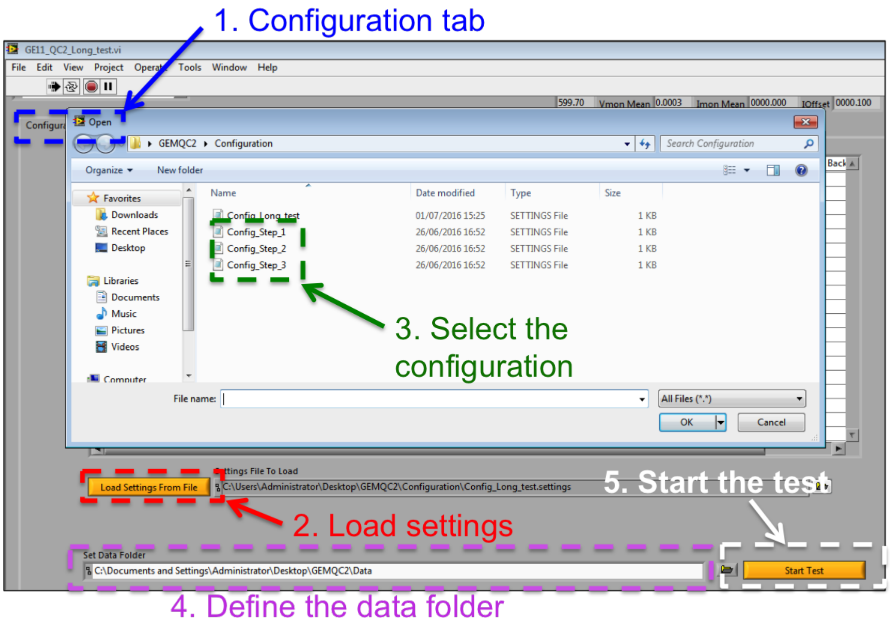


Figure 2.9: QC2 Labview configuration pannel.

To perform QC2 fast in dry gas, the GE1/1 detector must be flushed for at least 5 hours with pure CO_2 at a gas flow rate of 2.5 L/h [1]. The CO_2 gas is useful to dry out the GEM foils, to prevent electron amplification and therefore to avoid the possible propagation of discharges.

After the detector is flushed, proceed exactly as for QC2 fast in a clean room 2.4. However, the acceptance criteria are different in dry gas: the impedance of the GEM foils should be above 20 GΩ after one minute with no repetitive discharges. Few discharges may occur after few seconds due to the deposition of dust on the GEM foils. After the dust particles are blown away, the GEM should be completely quite. Similarly, the impedance of the detector's gaps should be above 100 GΩ after few seconds, with no discharges.

[1] See the next sections about QC3 3 and QC4 4 for a detailed description of the gas system.

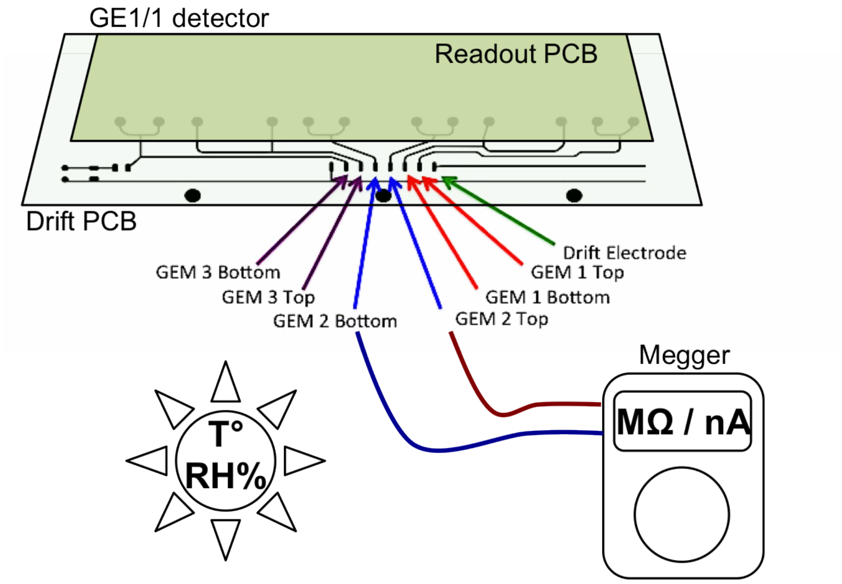


Figure 2.10: Schematic view of the QC2 fast test on a GE1/1 detector.

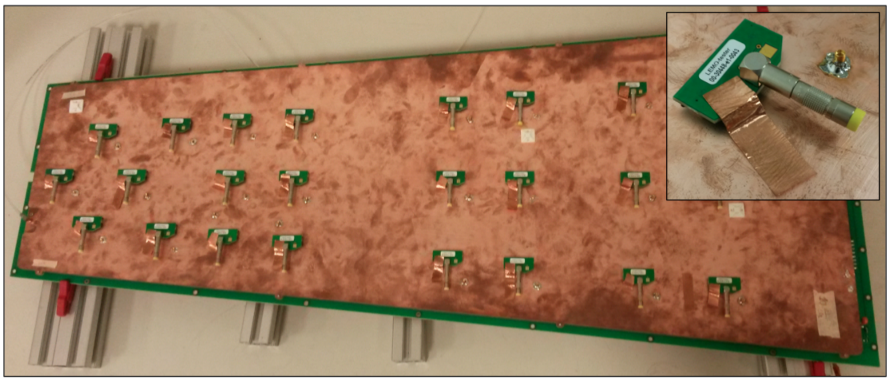


Figure 2.11: QC2 overview of the detector with the grounding plate and the 0 ohm terminations.

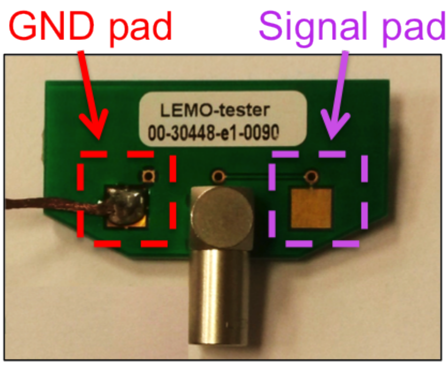


Figure 2.12: QC2 picture of the Panasonic-to-LEMO adapter.

3 QC3: GAS LEAK TEST

The QC3 gas leak test aims to identify the gas leak rate of a GE1/1 detector by monitoring the drop of the internal over-pressure as a function of the time.

3.1 DESCRIPTION OF THE SETUP

A schematic overview of the QC3 gas circuit is shown in Fig. 3.1 (top). The gas input is connected to a CO_2 gas bottle equipped with a 2-stage pressure regulator with the output pressure being set to a maximum of few hundred millibars. The input flow meter, together with its manual valve, allows controlling the gas flow rate at the entrance of the detector while the output flow-meter helps to monitor the output flow and therefore to identify large leaks. The input and output valves are used to isolate the detector from the rest of the gas system during the gas leak test. The calibration of the gas system itself is done before connecting the detector, as indicated in Fig. 3.1 (bottom)

A pressure indicator is connected between the input and the output valves in order to monitor the over-pressure inside of the system only or of the detector+system. Additional atmospheric pressure and ambient temperature sensors are located nearby the test stand. All the sensors are then connected to a microcontroller (e.g. ARDUINO Mega 2560) that is responsible for the data acquisition and slow control.

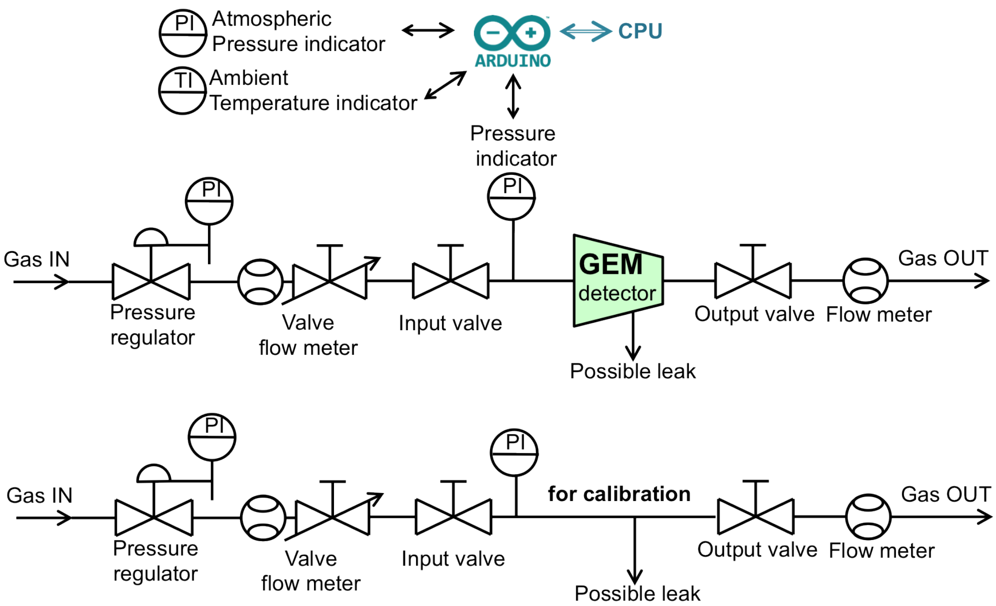


Figure 3.1: Schematic overview of the QC3 gas system for the gas leak test of GE1/1 detectors (top) and for calibration (bottom).

Even though the GE1/1 detectors are not supposed to operate when installed on the QC3 test stand, the entire gas system (stainless steel pipes and components) must be kept clean and free from any materials that could possibly contaminate the detectors.

3.2 Procedure

The QC3 gas leak test is divided into two steps: the calibration of the system; the leak measurement of the detector+system.

To perform the calibration of the gas system only, proceed as follows:

1. Connect together the input and the output lines the gas system as indicated on Fig. 3.1 (bottom). Instructions on how to correctly seal gas connectors can be found in the Swagelok Installer's Pocket Guide.
2. Open the input and the output valves of the gas system.
3. Adjust the manual valve of the input flow-meter to allow the CO_2 to flow through the system. Set the input gas flow rate to 5 L/hr. The output flow rate should be immediately visible on the output flow-meter.
4. Start the Excel macro named *QC3_Data_Logger_V2.xlsm*. A new window will appear with a warning message about ActiveX controls. Then press *OK*.
5. Enter you name in the new window (Fig. 3.2). Then press *OK*.

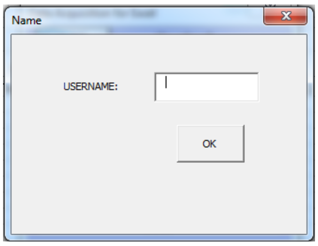


Figure 3.2: QC3 username window.

6. Enter the ID of the detector under test in the new window (Fig. 3.3) and add "*_Calibration*" to indicate that it is a calibration run, for example: *GE11 – VII – L – CERN – 0001_Calibration*. Then press *OK*

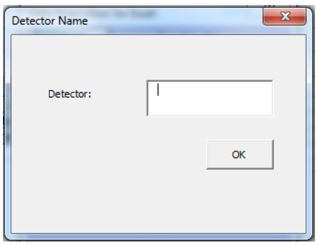


Figure 3.3: QC3 detector ID window.

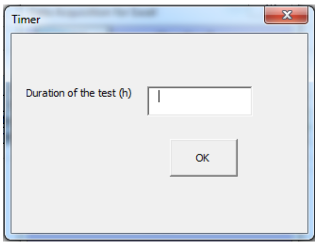


Figure 3.4: QC3 test duration window.

7. Enter one hour as the duration of the test (hours) (Fig. 3.4). Then press *OK*.
8. The DAQ window will appear as well as the Excel sheet that will contain the data (Fig. 3.5). At this point the system is ready to start the acquisition.

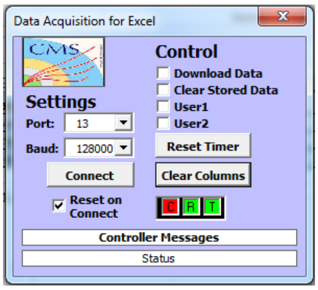


Figure 3.5: QC3 data acquisition window.

9. You need to set to correct over-pressure in the system before starting the recording of the data. To do so, close the output valve of the gas system. You will see that the pressure inside the system is ramping up. As soon as the over-pressure reaches 25 mbar, close the input valve. Then close the valve of the input flow meter.
10. Start the recording of the data by pressing the *Connect* button on the DAQ window (Fig. 3.5). After this step the Excel sheet will be updated every minutes with the new data from the different pressure and temperature sensors. Do not operate the computer while the test is running under the penalty of loosing the connection between the micro-controller and the Excel file.
11. Leave the system running for one hour as you defined at the beginning in Fig. 3.4. The Excel macro will automatically stop at the end of the test.
12. After the test is finished, the Excel files containing the data must be renamed following the template $GE11-VII-X-SITE-ZZZZ\_QC3\_Calibration\_YYYYMMDD.xlsm$ where X stands for S (short) or L (long), $SITE$ the official name of your production site, $ZZZZ$ the detector serial number, $YYYY$ the year, MM the month and DD the day. For example: $GE11-VII-L-CERN-0001\_QC3\_Calibration\_20160712.xlsm$

The pressure drop in the gas system should not exceed 1 mbar per hour. If the system passes this step you can proceed to the test with the GE1/1 detector.

To perform the QC3 test of the detector+system, proceed as follows:

1. Connect the detector's gas inlet and outlet to the gas system as indicated on Fig. 3.1.
2. Open the output and the input valves of the gas system.
3. Adjust the manual valve of the input flow-meter to allow the CO_2 to flow through the detector. Set the input gas flow rate to 5 L/hr and leave the detector flushing for at least 30 minutes. The output flow rate should be already visible on the output flow-meter after few minutes of flushing.
4. Start the Excel macro named $QC3\_Data\_Logger\_V2.xlsm$. A new window will appear with a warning message about ActiveX controls. Then press OK.
5. Enter you name in the new window (Fig. 3.2). Then press OK.
6. Enter the ID of the detector under test in the new window (Fig. 3.3), for example: $GE11-VII-L-CERN-0001$. Then press OK
7. Enter one hour as the duration of the test (Fig. 3.4). Then press OK.
8. The DAQ window will appear as well as the Excel sheet that will contain the data (Fig. 3.5). At this point the system is ready to start the acquisition.
9. You need to set to correct over-pressure in the detector before starting the recording of the data. To do so, close the output valve of the gas system. You will see that the pressure inside the detector is ramping up. As soon as the over-pressure reaches 25 mbar, close the input valve to isolate the detector. Then close the valve of the input flow meter. Attention: the GE1/1 detectors cannot sustain over-pressure higher than 40-50 mbar. Make sure you can control the gas system before closing the output valve.
10. Start the recording of the data by pressing the $Connect$ button on the DAQ window (Fig. 3.5). After this step the Excel sheet will be updated every minutes with the new data from the different pressure and temperature sensors. Do not operate the computer while the test is running under the penalty of loosing the connection between the micro-controller and the Excel file.
11. Leave the system running for the the duration you defined at the beginning in Fig. 3.4. The Excel macro will automatically stop at the end of the test.
12. After the test is finished, the Excel files containing the data must be renamed following the template $GE11-VII-X-SITE-ZZZZ\_QC3\_YYYYMMDD.xlsm$ where X stands for S (short) or L (long), $SITE$ the official name of your production site, $ZZZZ$ the detector serial number, $YYYY$ the year, MM the month and DD the day. For example: $GE11-VII-L-CERN-0001\_QC3\_20160712.xlsm$

3.3 Typical results

Typical results from the QC3 test stand can be seen in Fig. 3.6.

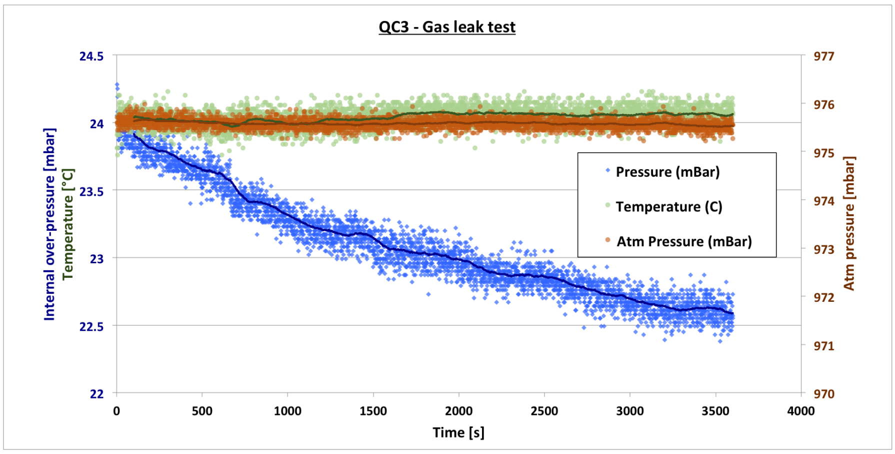


Figure 3.6: QC3 typical result with GE1/1-VII-L-CERN-0002.

4 QC4: HV TEST

The QC4 test aims to determine the V vs. I curve of a GE1/1 detector and identify possible malfunctions, defects in the HV circuit and spurious signals.

4.1 DESCRIPTION OF THE SETUP

The chamber is connected to the QC3 gas system (Fig. 3.1) and flushed with pure CO_2. The negative HV (VSET) is provided by a programmable HV power supply (e.g. CAEN N1470) that allows the user to control the current limit (ISET), the steps to ramp up and down the voltage, the maximum voltage, and the trip time. This power supply must be able to deliver a current up to 1 mA with a monitoring resolution lower than 1 μA in order to identify possible leaks, sparks, or unusual current fluctuations.

The QC4 data acquisition setup for spurious signal measurements is shown on Fig. 4.1. The readout of the detector is done using a charge sensitive pre-amplifier (e.g. CAEN A422A) connected to the bottom electrode of the third GEM foil. This connection is made through a decoupling RC circuit already present on the detector's PCB. The output of the pre-amplifier is then sent to an amplifier+shaper unit (e.g. ORTEC 474) and then to a discriminator (e.g. Lecroy 623A). The resulting digital pulses go through a dual timer and then to a scaler unit for the rate measurement.

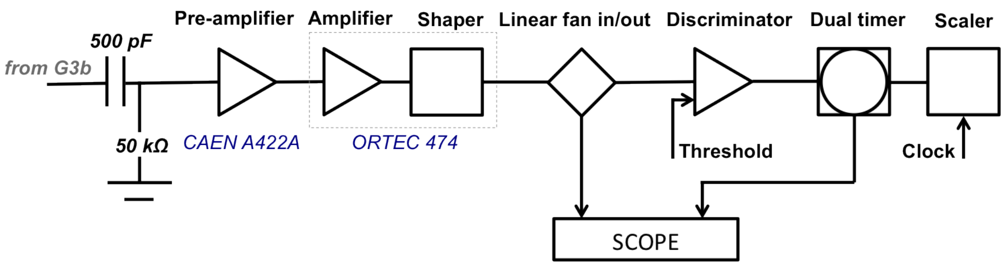


Figure 4.1: QC4 data acquisition setup.

4.2 PROCEDURE

To perform the QC4 test, proceed as follows :

1. Connect the GE1/1 detector to the gas system with pure CO_2, set the gas flow rate to 2.5 L/hr and let it flush for at least 5 hours.
2. Fix the grounding plate onto the readout board as shown on Fig. 4.2.
3. Connect the Panasonic-to-LEMO adapters with the 50 Ω terminations to all the readout sectors. Connect the ground pad of the PCBs to the grounding plate with copper tape, as shown on Fig. 4.2.

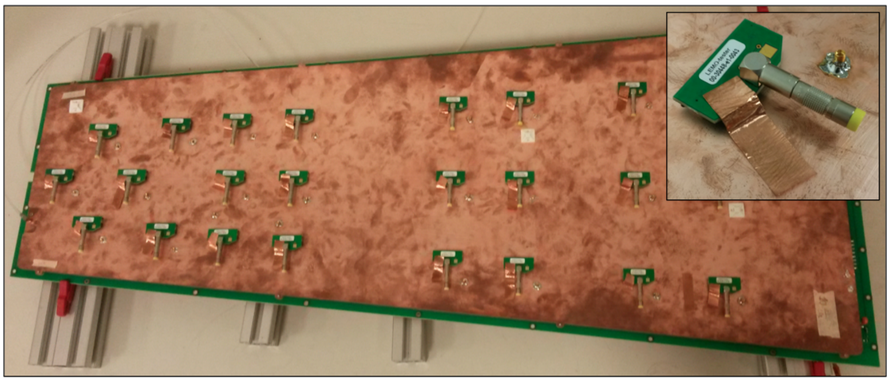


Figure 4.2: QC4 overview of the detector with the grounding plate and the 50 ohm terminations.

4. Solder the input wire of the pre-amplifier to the dedicated pad on the drift PCB, as shown on Fig. 4.3.

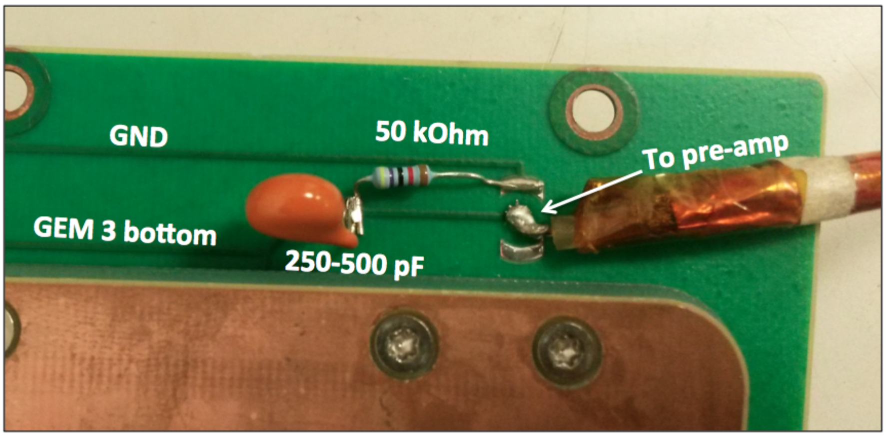


Figure 4.3: QC4 close view of the sample point on the drift PCB.

5. Connect the HV voltage cable to the SHV connector on the detector. In some cases it can be useful to insert a HV low-pass filter to cut the high frequency noise from the power supply. If so, the additional resistance introduced in the system should be mentioned in the log file and in the result file. Set the power supply settings as follows: $Ramp\ up = 50V/s$; $Ramp\ down = 250V/s$; $Max\ voltage = 5050V$; $Trip\ time = 0s$, $Trip\ action = KILL$.
6. Set the amplifier settings to $Coarse\ gain = 4$, $Fine\ gain = 4.5$, $Integrate = 500ns$ and $Differential = 500ns$.
7. Use copper ribbons to ground the detector, the pre-amplifier, and the HV filter. In this configuration the maximum noise level should be lower than

100 mV.

8. Set the discriminator threshold to -140 mV.

9. Set the scaler clock to 60 s.

10. Open the template file $GE11-VII-X-SITE-ZZZZ\_QC4\_YYYYMMDD.xlsx$. Rename the file with the appropriate name where X stands for S (short) or L (long), $SITE$ the official name of your production site, $ZZZZ$ the detector serial number, $YYYY$ the year, MM the month and DD the day. For example: $GE11-VII-L-CERN-0001\_QC4\_20160713.xlsm$

11. Use a multimeter to measure the total resistance of the HV circuit (including the divider and all the HV filters, if used) and report this value in the appropriate field of the the configuration table. The total resistance is used to calculate the expected current in the divider for every HV points. Then, indicate in the appropriate fields the model and the settings of the electronics modules you are using. At this point the setup is ready and the measurement can start.

12. To start the measurement set the current limit $ISET$ of the power supply according to the target value indicated in the template file, adding 5 μA. For example, if the Excel file were to indicate 700 μA, you should define ISET as 705 μA. Then set the corresponding voltage VSET as indicated in the Excel file and confirm.

13. When the detector is stable (after few seconds), fill the template file with the actual voltage $VMON$ and the current $IMON$ provided by the power supply. Start the clock of the scaler unit and after 60 s, report the total number of counts into the template file.

14. While the previous step is ongoing, look at the oscilloscope to identify possible spurious signals, unusual or repetitive signals in the chamber. Use the threshold of the device to scan both negative and positive regions.

15. In order to bring the detector to a new HV point, first set the current limit $ISET$ according to the value indicated in the template file, adding 5 μA. Then change the voltage $VSET$, and confirm.

16. Repeat the steps 12 to 15 until you reach 4900 V on the detector (maximum allowed voltage). Go by steps of 200 V from 0 to 3000 V then by steps of 100 V from 3000 V to 4900 V.

4.3 Typical Results

Typical results from the QC4 test stand can be seen on Fig. 4.4.

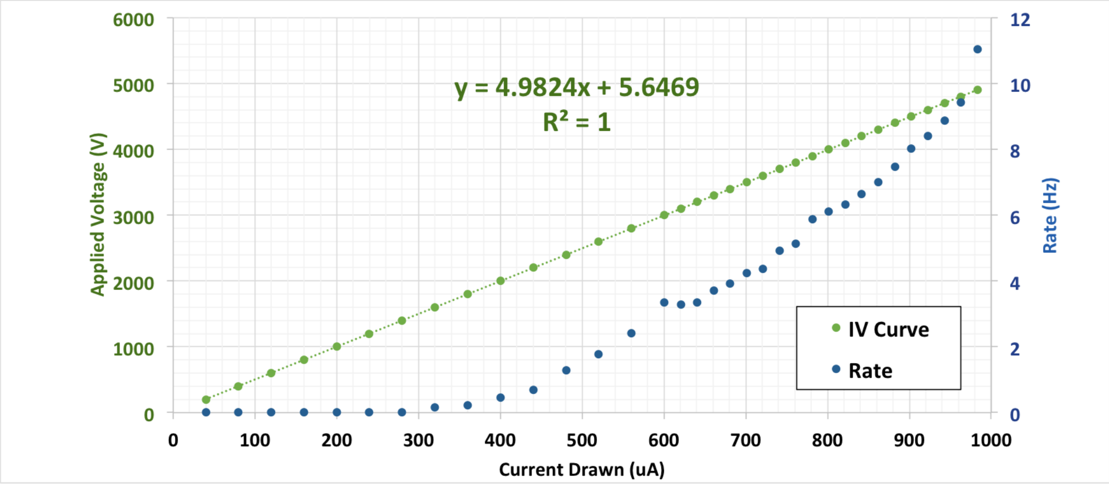


Figure 4.4: QC4 typical results with GE1/1-VII-L-CERN-0001.

5 QC5: GAIN CALIBRATION

The QC5 gain calibration is split into two steps: the measurement of the effective gain as a function of the voltage applied on the divider; and the measurement of the response uniformity of the detector. Both tests are done in a specific radiation box containing an AMPTEK miniX X-ray source with a silver target.

5.1 QC5: PREPARATION AND INSTALLATION OF THE CHAMBER.

The first step consists of preparing the detector before its installation on the QC5 test stand. To do so:

1. Set up the detector on a table (in horizontal position).
2. Fix the grounding plate onto the readout board and solder a ground cable from the ground pin of the divider to the top of the grounding plate (see Fig. 5.1). This cable should not be in contact or too close to the GEM 3 bottom pad, under the penalty of triggering discharges.

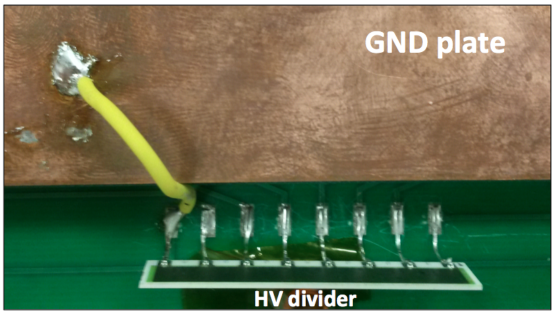


Figure 5.1: Close view of the ground wire connecting the divider and the grounding plate.

3. Connect the APV25 chips to the detector, following the map given in Fig. 5.2. Make sure the orientation of each APV is identical to the one indicated on the map.
4. Connect the ground wire of each APV to the ground plugs already placed on the grounding plate (see Fig. 5.3).
5. Carefully place the detector inside of the X-ray station: the orientation of the detector should have the short base of the trapezoid closest to the floor, with the readout PCB facing away from the X-Ray generator, as shown in Fig. 5.4.
6. Connect the detector's inlet (short base) and outlet (wide base) to the gas system and flush the chamber with the gas mixture $Ar/C0_2$ (70 : 30). Set the gas flow rate to 2.5 L/hr and let it flush for at least 5 hours.

While the detector is flushing, you can start preparing the grounding by placing three copper ribbons along the iϕ sectors of the detector. Make sure that non

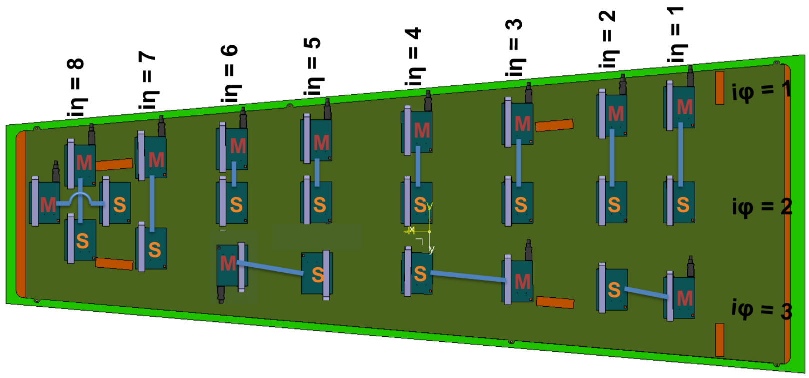


Figure 5.2: QC5 readout sectorization and APV mapping. The dark grey boxes represent the HDMI connectors on the output of the master APVs. This mapping is valid for both long and short detectors.

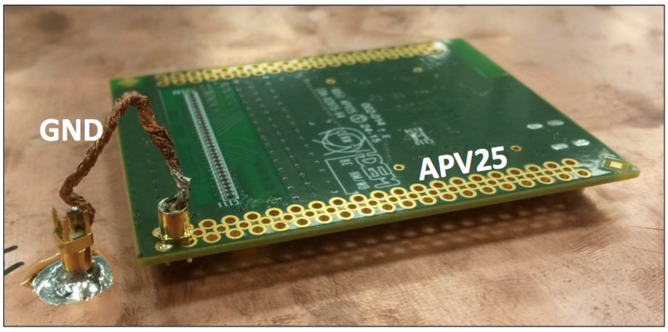


Figure 5.3: Close view of an APV plugged on the detector.

of the grounding cables are touching the HV circuit or an active part of an APV hybrid. Then connect the ground of each APV to the closest copper ribbon, as indicated on Fig. 5.5.

At this point the detector is ready for the the QC5 effective gain measurement.

5.2 QC5: EFFECTIVE GAIN MEASUREMENT

The measurement of the effective gain consists of comparing the primary current induced in the drift gap by the X-ray source with the output current after amplification. It includes the amplification factor in the GEM holes as well as the electron transparency of the GEM foils. The measurement of the effective gain is always performed on sector (iη,iϕ)=(4,2) (see Fig. 5.2).

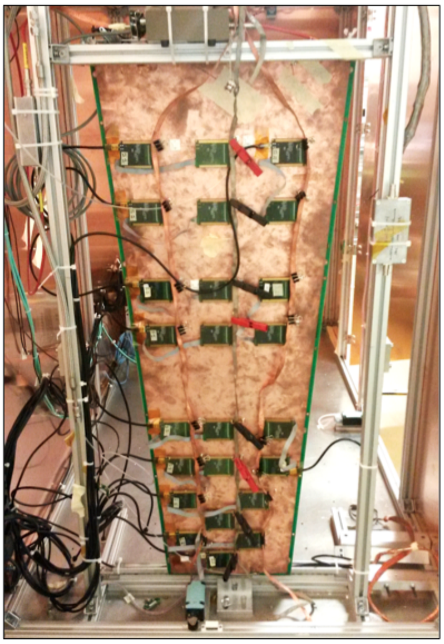


Figure 5.4: Picture of the GE1/1 chamber inside of the X-ray station.

5.2.1 DESCRIPTION OF THE SETUP

The detector is powered using a programmable HV power supply (e.g. CAEN N1470) that allows the user to control the current limit (ISET), the steps to ramp up and down the voltage, the maximum voltage, and the trip time. This power supply must be able to deliver a current up to 1 mA with a monitoring resolution lower than 1 μA in order to identify possible leaks, sparks, or unusual current fluctuations.

The data acquisition setup is shown on Fig. 5.6. The readout of the detector is done using a charge sensitive pre-amplifier (e.g. ORTEC 142PC) connected to the sector (iη,iϕ)=(4,2). The output of the pre-amplifier is then sent to an amplifier+shaper unit (e.g. ORTEC 474) and then to a discriminator (e.g. Lecroy 623A). The resulting digital pulses directly go to a scaler unit for the interaction rate measurement. This value, multiplied by the number of primary electrons per photon and by the elementary charge, gives the primary current induced in the drift gap by the X-ray source. The measurement of the output current is simply measured by connecting a pico-ammeter (e.g. Keithley 6487) to the same readout sector.

To finalize the connections for the QC5 effective gain measurement, proceed as follows:

1. Connect the Panasonic-to-LEMO adapter with a 50 kΩ resistance to ground to the readout sector (iη,iϕ)=(4,2). Then use a clamp to attach the ground

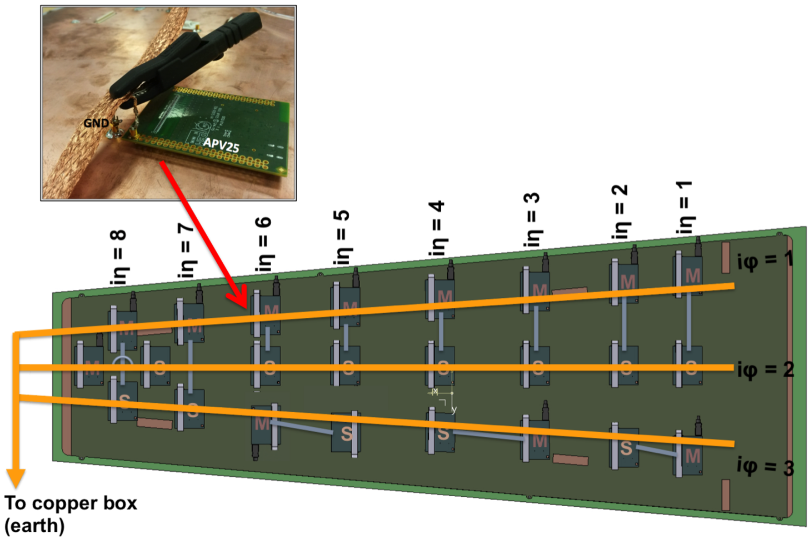


Figure 5.5: QC5 Schematic view of the optimum grounding for QC5. The orange line represents copper ribbon.

of the PCB to the main copper ribbon, as indicated in Fig. 5.7. The LEMO output of this PCB is then connected to the input of the pre-amplifier.

2. Use additional copper ribbons to ground the detector's drift PCB, the SHV connector, the pre-amplifier and the HV filter. In this configuration the maximum noise level should be of the order of 50-70 mV.

5.2.2 Procedure

TO minimize the noise in the detector, the SRS system and thus the APV chips must be kept OFF during the effective gain measurement.//
To perform the QC5 effective gain measurement, proceed as follows:

1. Connect the HV voltage cable to the SHV connector on the detector. Set the power supply settings as follows: $Ramp\ up = 50V/s$; $Ramp\ down = 250V/s$; $Max\ voltage = 4000V$; $Trip\ time = 0s$, $Trip\ action = KILL$.
2. Set the amplifier settings to $Coarse\ gain = 4$, $Fine\ gain = 4.5$, $Integrate = 100ns$ and $Differential = 100ns$.
3. Set the discriminator threshold to -100 mV.
4. Set the scaler clock to 60 s.
5. Open the miniX control software (Fig. 5.8), click on "Start Amptek MiniX" to enable the communication with the X-ray source. Set the HV value of the X-ray tube to 40 kV and the current to 5 μA, then click on "Set High Voltage and Current" to apply the new values. Do not turn the X-ray source ON at

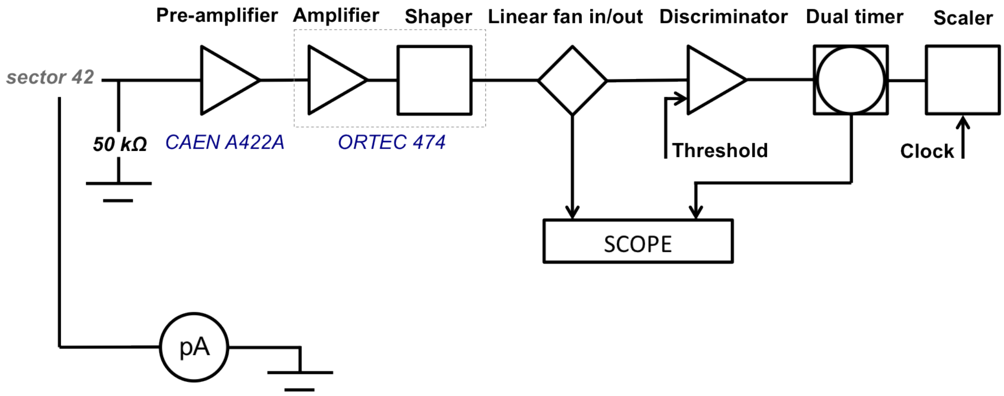


Figure 5.6: QC5 effective gain data acquisition setup.

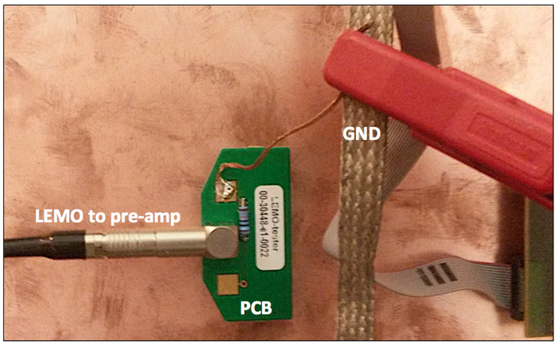


Figure 5.7: Close view of the Panasonic-to-LEMO adapter for the rate measurement.

this step. More information about the Amptek miniX control software can be found on the Amptek website.

6. Open the template file $GE11-VII-X-SITE-ZZZZ\_QC5\_YYYYMMDD.xlsx$. Rename the Excel file with the appropriate name where X stands for S (short) or L (long), $SITE$ the official name of your production site, $ZZZZ$ the detector serial number, $YYYY$ the year, MM the month and DD the day. For example: $GE11-VII-L-CERN-0001\_QC5\_20160713.xlsm$

7. In the first sheet called "Raw Data Summary," indicate in the appropriate fields the model and the settings of the electronics modules you are using and the configuration in which the measurement will be done.

8. Open the LabView control software of the pico-ammeter Keithley 6487 named "Keithley6487-Readout.vi".

9. On the software front panel (Fig. 5.9), set the "millisecond to wait" to 10, "Numeric" to 1, "Resolution (absolute)" to 10^{-13} and "nplc" to 6. Then set the "GPIB address" to $GPIB0::XX::INSTR$, where XX is the actual address of you pico-ammeter. More information can be found in the Keithley 6487

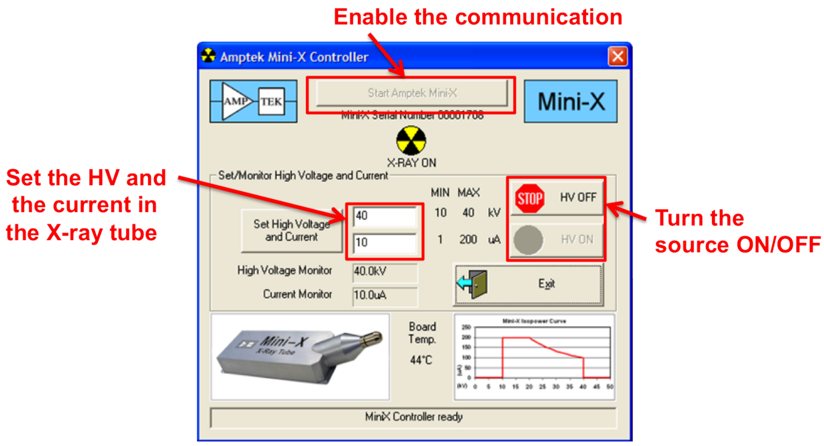


Figure 5.8: QC5 Amptek miniX control software.

manual.

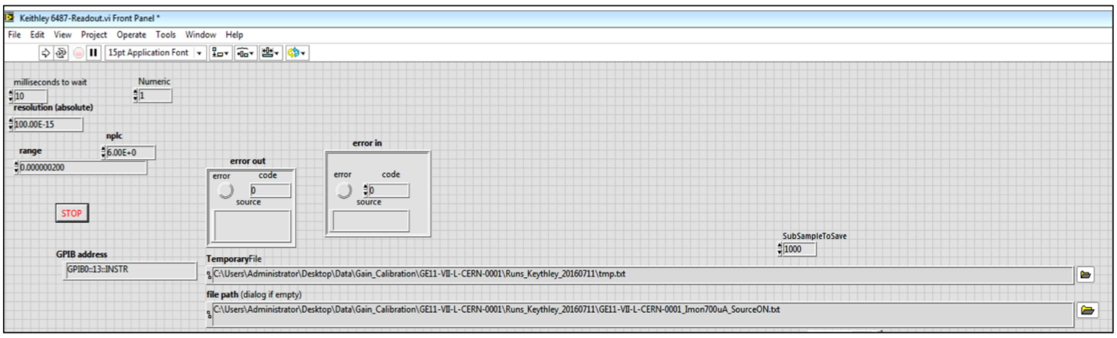


Figure 5.9: QC5 Keithley 6487 control software (front panel).

10. In the "Temporary File" field, set the absolute path to the text file that will contain all the data of the test. You may have to create an empty text file beforehand that can be renamed as "tmp.txt". In the "filepath" field, set te absolute path of the data file that will contain the current values for a given operating point. The name of this file should follow the template $GE11 - VII - X - SITE - ZZZZ\_ImonYYYuA\_SourceUUU.txt$ where X stands for S (short) or L (long), $SITE$ the official name of your production site, $ZZZZ$ the detector serial number, YYY the value of the current through the divider and UUU the status of the source (ON or OFF). For example: $GE11 - VII - L - CERN - 0001\_Imon700uA\_SourceON.txt$. At this point the setup is ready and the measurement can start.

Note: as indicated in the Excel file, the effective gain is measured for HV$_{drift}$ points between 2585 V and 3290 V, i.e. equivalent currents in the divider between

550 μA and 700 μA. The measurement starts from the maximum operating point (700 μA) to the lowest point (550 μA), by steps of 10 μA.

1. Slowly ramp up the voltage on the divider to reach the equivalent current of 700 μA. For each HV step, set the current limit ISET to the target value plus 5 μA, for example 705 μA if the target value is 700 μA. Then use the expected voltage value VMON indicated in the Excel file (Fig. 5.10) as VSET on the power supply. If necessary, adjust VSET to match the monitored current IMON with the current value you want to reach. In the Excel file, replace the expected VMON value by the real VMON after the adjustment, and indicate the real IMON.

	Single Chan HV Supply														
	Divider			Environment		For Measuring Rate				For Measuring Current				MCA	
	Vmon	Imon	Time	Pressure	Temp	Source Off		Source On		Source Off		Source On		Run #	Pk Pos
						Counts	Err	Counts	Err	Current	Err	Current	Err		
	(V)	(uA)	(HH:MM)	(hPa)	(Deg C)	(N)	(N)	(N)	(N)	(A)	(A)	(A)	(A)	(N)	(ADC Chan)
Ar/CO2:70/30 Range	3975.31	710					0		0						
	3919.32	700					0		0						
	3863.33	690					0		0						
	3807.339	680					0		0						
	3751.349	670					0		0						
	3695.359	660					0		0						
	3639.368	650					0		0						
	3583.378	640					0		0						
	3527.388	630					0		0						
	3471.398	620					0		0						
	3415.407	610					0		0						
	3359.417	600					0		0						
	3303.427	590					0		0						
	3247.436	580					0		0						
	3191.446	570					0		0						
	3135.456	560					0		0						
	3079.466	550					0		0						

Figure 5.10: QC5 template file : HV set point.

2. After few seconds of stabilization, load the clock of the scaler to start counting the events. At this step the X-ray source is still OFF.
3. After 60 s, report the number of counts in the appropriate field in the Excel file, as indicated on Fig. 5.11. The associated error will be automatically calculated.

	Single Chan HV Supply														
	Divider			Environment		For Measuring Rate				For Measuring Current				MCA	
	Vmon	Imon	Time	Pressure	Temp	Source Off		Source On		Source Off		Source On		Run #	Pk Pos
						Counts	Err	Counts	Err	Current	Err	Current	Err		
	(V)	(uA)	(HH:MM)	(hPa)	(Deg C)	(N)	(N)	(N)	(N)	(A)	(A)	(A)	(A)	(N)	(ADC Chan)
Ar/CO2:70/30 Range	3975.31	710	14:00	967	24.2	102	10.099505	558078	747.04618						
	3919.32	700					0		0						
	3863.33	690					0		0						
	3807.339	680					0		0						
	3751.349	670					0		0						
	3695.359	660					0		0						
	3639.368	650					0		0						
	3583.378	640					0		0						
	3527.388	630					0		0						
	3471.398	620					0		0						
	3415.407	610					0		0						
	3359.417	600					0		0						
	3303.427	590					0		0						
	3247.436	580					0		0						
	3191.446	570					0		0						
	3135.456	560					0		0						
	3079.466	550					0		0						

Figure 5.11: QC5 template file : rate measurement.

4. Turn the X-ray source ON and repeat the counts measurement in the same conditions. Report the result in the Excel file.
5. Turn the source OFF.

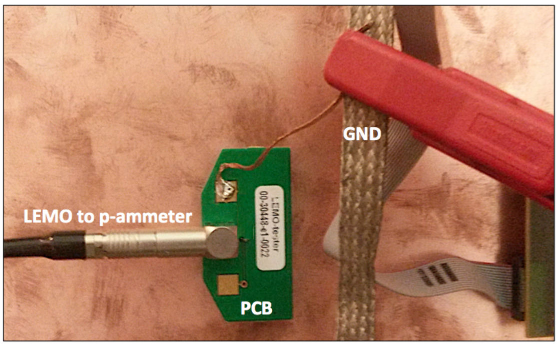


Figure 5.12: Close view of the Panasonic-to-LEMO adapter for the rate measurement.

6. Check the name of the data file on the Keithley control software (Fig. 5.9) and make sure it corresponds to the actual configuration of the setup (current in the divider and status of the source).
7. Start the acquisition in Labview by clicking on the white arrow on the top left of the front panel. After few seconds the data will be displayed in a waveform graph, as shown on Fig. 5.13. At this step the X-ray source is still OFF.

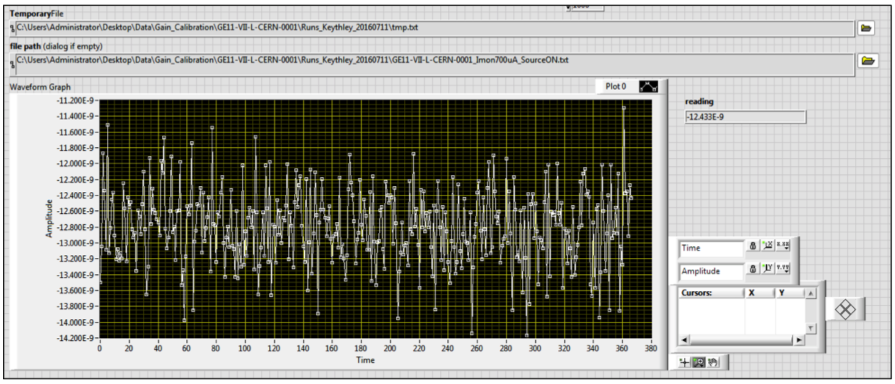


Figure 5.13: QC5 Keithley 6487 control software (front panel).

8. When the number of measurement points is larger than 200, stop the acquisition by clicking on the "stop" button shown on Fig. 5.9. The output file with the data will be automatically saved in the folder that you specified previously. Then copy the content of this file into the Excel file, in the dedicated tab named with the value of the equivalent current for this operating point, for example "700uA" (see Fig. 5.14). The average value and the error will be

automatically calculated and written in the tab "Raw Data Summary" (see Fig. 5.14).

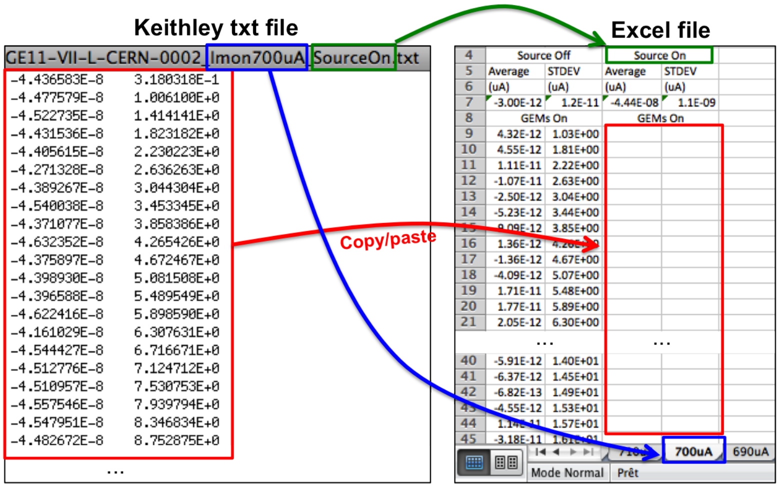
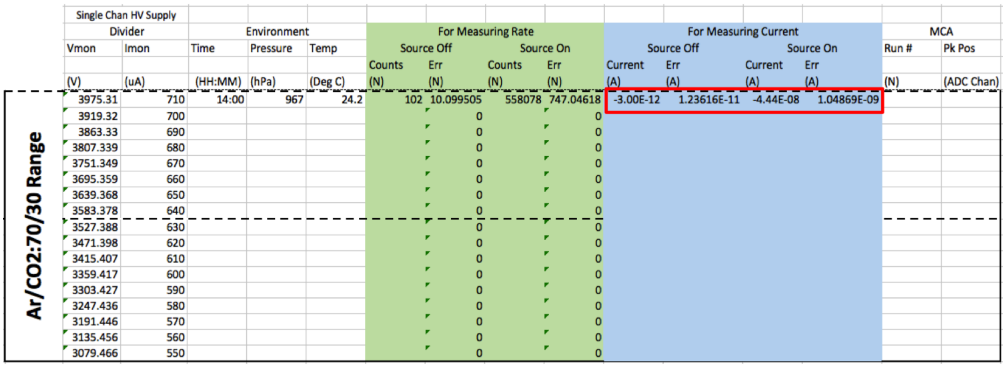


Figure 5.14: QC5 copying the data from the Keithley text file to the excel file.



Single Chan HV Supply														
Divider		Environment			For Measuring Rate				For Measuring Current				MCA	
Vmon	Imon	Time	Pressure	Temp	Source Off		Source On		Source Off		Source On		Run #	Pk Pos
					Counts	Err	Counts	Err	Current	Err	Current	Err		
(V)	(uA)	(HH:MM)	(hPa)	(Deg C)	(N)	(N)	(N)	(N)	(A)	(A)	(A)	(A)	(N)	(ADC Chan)
3975.31	710	14:00	967	24.2	102	10.099505	558078	747.04618	-3.00E-12	1.23616E-11	-4.44E-08	1.04869E-09		
3919.32	700					0		0						
3863.33	690					0		0						
3807.339	680					0		0						
3751.349	670					0		0						
3695.359	660					0		0						
3639.368	650					0		0						
3583.378	640					0		0						
3527.388	630					0		0						
3471.398	620					0		0						
3415.407	610					0		0						
3359.417	600					0		0						
3303.427	590					0		0						
3247.436	580					0		0						
3191.446	570					0		0						
3135.456	560					0		0						
3079.466	550					0		0						

Figure 5.15: QC5 template file : output current measurement.

9. Turn the X-ray source ON and repeat the Keithley measurement in the same conditions. Copy the content of the new file into the Excel file following the previous instruction.
10. Turn the X-ray OFF.
11. Repeat steps 1 through 11 for operating points 690 μA down to 550 μA point in steps of 10 μA as shown in the Excel file.

5.2.3 TYPICAL RESULTS

Typical results of the QC5 effective gain measurement are shown on Fig. 5.16.

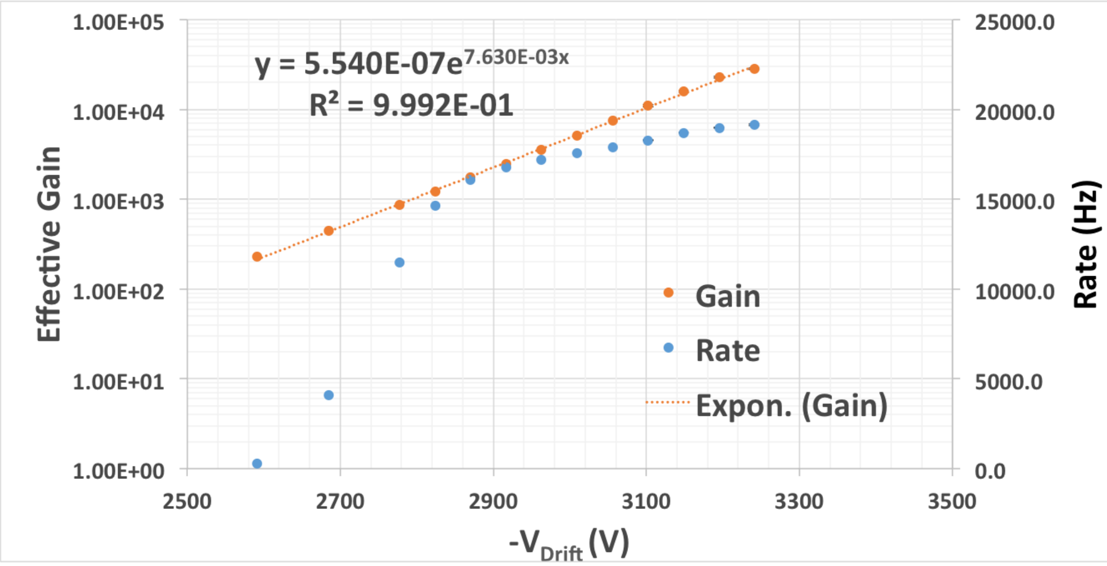


Figure 5.16: QC5 Typical results of the effective gain measurement with GE11-VII-L-CERN-0001.

5.3 QC5: Response uniformity

The QC5 response uniformity test consists of measuring the pulse hight distribution all over the active surface of a GE1/1 detectors.

5.3.1 Description of the setup

The QC5 response uniformity test takes place on the same test stand as the QC5 effective gain described in section 5.2. The detector is powered using a programmable HV power supply (e.g. CAEN N1470) that allows the user to control the current limit (ISET), the steps to ramp up and down the voltage, the maximum voltage, and the trip time. This power supply must be able to deliver a current up to 1 mA with a monitoring resolution lower than 1 μA in order to identify possible leaks, sparks, or unusual current fluctuations.

The detector is flushed with the gas mixture Ar/CO_2 (70:30) at least for 5 hours at 2.5 L/hr.

The readout electronics is based on the Scalable Readout System (SRS) designed by the RD51 collaboration. It consists of APV25 Front-End ASICs with 128 readout channels connected to the readout board of the detector (Fig. 5.17). Each channel contains a pre-amplifier and a shaper working at a frequency of 40 MHz. The analog information of the pulses is sent to an ADC card via HDMI cables, itself connected to the Front End Card (FEC) responsible for the communication with the external devices and the control of the chips.

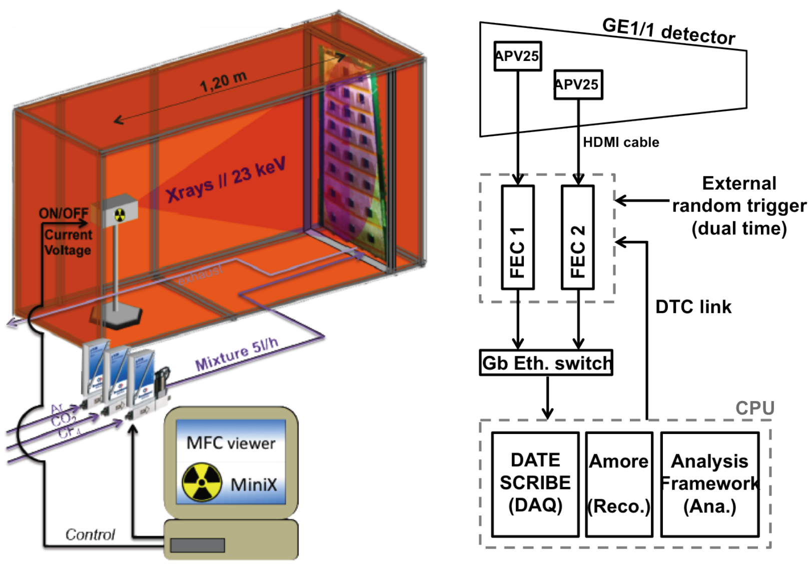


Figure 5.17: Schematic overview of the QC5 test setup.

The data acquisition is done using the Alice DAQ software named DATE. The configuration of the SRS registers is possible through the web interface SCRIBE designed by S. Colafranceschi[2] of FIT. The event reconstruction performed by amoreSRS (adapted from AMORE) with the final analysis handled by the CMS GEM analysis framework.

5.3.2 Preparation of the detector

After the QC5 effective gain test, the detector should be in position in the X-ray station, filled with the gas mixture $Ar/C0_2$ (70:30) and already grounded and equipped with the APV25 chips (Fig. 5.4). The preparation of the detector for the QC5 response uniformity test simply consists of connecting the APV hybrids to the FEC cards with HDMI cables. To do so:

1. Makes sure the SRS system is OFF before starting the intervention on the APV chips. Never plug/unplug the HDMI cable from the hybrid while the chip is powered.
2. Gently connect the HDMI cable labeled "11/12" to the master APV on the readout sector $(i\eta, i\phi)=(1,1)$ (associated to the slave APV in $(i\eta, i\phi)=(1,2)$).
3. Secure the HDMI connection by putting kapton tape or a cable tie near the APV connector, as shown on Fig. 5.18. Make sure you are not applying too much stress on the cable itself, under the penalty of breaking the HDMI connector on the hybrid.

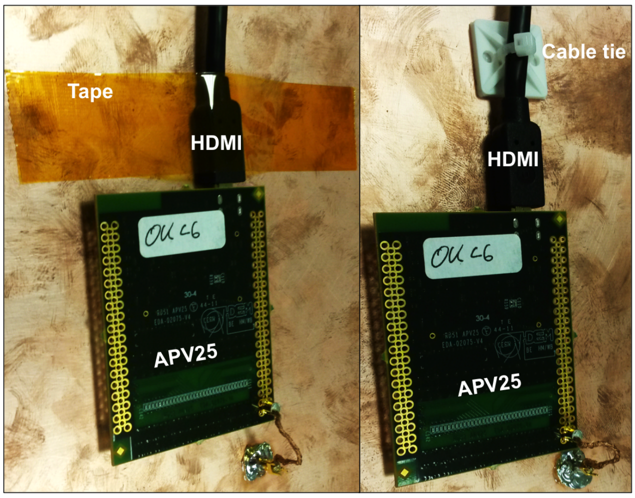


Figure 5.18: QC5 picture of the HDMI cable connected to its APV25 hybrid.

4. Repeat steps 2 and 3 for all the readout sectors.

[2] Stefano.Colafranceschi@cern.ch

Additionally, make sure the X-ray gun is facing the middle of the sector $(i\eta,i\phi)=(4,2)$, with no cap, no collimator, and no filter. At this step the detector is ready for the measurement.

5.3.3 Preparation of the DAQ system

The first step of the DAQ preparation consists of several steps:

1. Create, if not already existing, a new directory where to save the raw data and the root files after the event reconstruction in amoreSRS. By convention, the name of this directory should follow the template $GE11-VII-X-SITE-ZZZZ$, where X stands for S (short) or L (long), $SITE$ the official name of your production site and $ZZZZ$ the detector serial number, for example: $GE11-VII-L-CERN-0001$.
2. Then, start the DATE software by executing the command $DATE$ in a new terminal. After few seconds, two windows will appear. In the infoBrowser window, disable the online mode by clicking on the green ONLINE button, then change the "$devel$" status to "any" and enable the online mode, as indicated in Fig. 5.19.

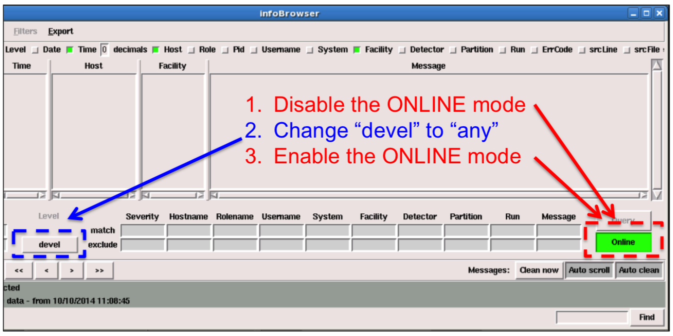


Figure 5.19: QC5 DATE info browser window.

In the test control window, activate the local control of DATE by clicking on the open locker (Fig. 5.20).

3. Turn ON the SRS crate.
4. Open a new terminal and send a ping request to the FECs with the command line "ping 10.0.0.2" (FEC 1) and "ping 10.0.1.2" (FEC 2). If the FEC are correctly communicating with your computer, you should receive return messages as shown in Fig. 5.21.
5. Open a new webpage and connect to SCRIBE (e.g. localhost/srs_v3.php).
6. In the General control panel (see Fig. 5.22), set the number of FEC to 2 and indicate their IP addresses (by default 10.0.0.2 for FEC 1 and 10.0.1.2 for FEC 2). Leave all the other parameters with the default values. Apply the new configuration and then start the initialization of the SRS system.

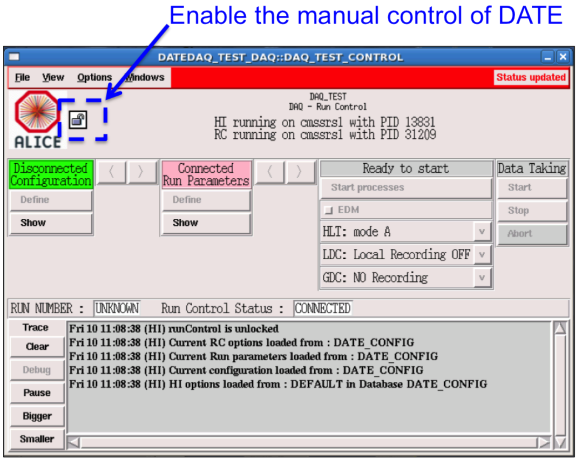


Figure 5.20: QC5 DATE test control window.

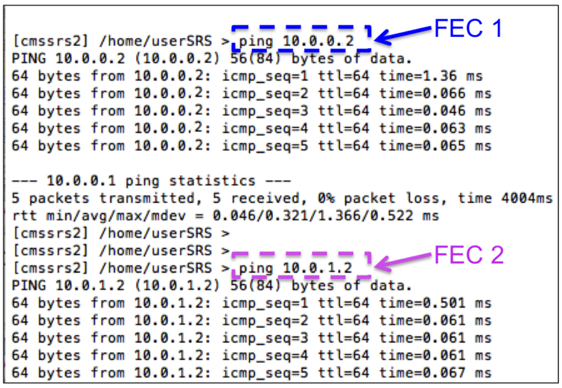


Figure 5.21: QC5 terminal output after a ping request.

7. Finally, to setup the trigger system, use a two stages dual timer (e.g. CAEN N93B). On the first stage, set the width of the output signal to 1 μs. Connect the *End Marker* output of the first stage to the input of the second stage. Set the width of the output signal of the second stage to 1 μs and connect the *End Marker* output of the second stage to the input of the first stage. Send the ouput of the first stage to a logic fan in/fan out module and then to the trigger input of the two FECs. Press the *Start* button of the dual timer to start the loop and generate the trigger signals. Adjust the width of the second stage to obtain a trigger rate of the order of 700 Hz.

5.3.4 Uniformity test

Before starting the response uniformity measurement you need to define the appropriate operating point of the detector. To do so, use the results obtained

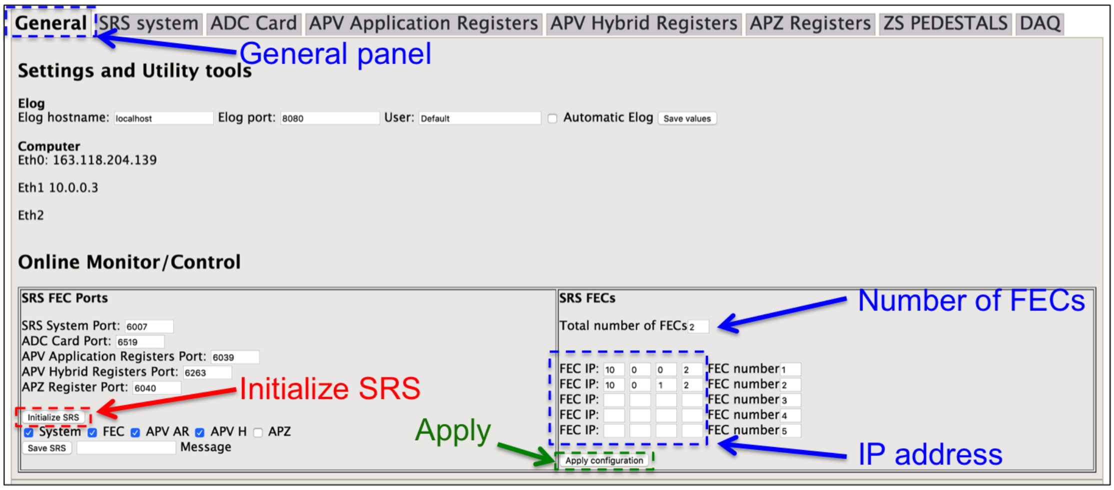


Figure 5.22: QC5 SCRIBE general panel.

with the effective gain measurement: fit the gain vs. divider current curve with an exponential function. Then use the resulting formula to define what divider current exactly corresponds to a gain of 600 (usually between 580 μA and 600 μA).

To perform the response uniformity test, proceed as follows:

1. Slowly ramp up the HV on the detector to reach the operating point corresponding to a gain of 600. .
2. Slowly ramp up the voltage on the divider to reach the divider current equivalent to an effective gain of 600. For each HV step, set the current limit ISET to the target value plus 5 μA, for example 305 μA if the target value is 300 μA.
3. Open the DAQ window in SCRIBE. Set the absolute path to the raw data folder the dedicated field, then apply the changes. Click on the "$ZS\ configuration$" button to start the configuration of the Zero-Suppression as indicated in Fig. 5.23. Note that this step must be done every time the electronics is power cycled or if the operating point is changed.

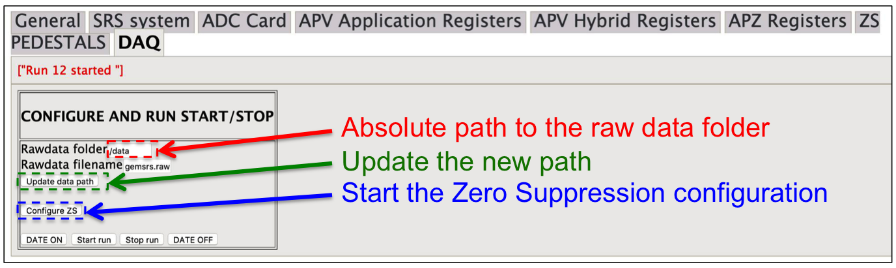


Figure 5.23: QC5 SCRIBE DAQ panel.

4. Open the APV Application Register window in SCRIBE (Fig. 5.24) and select FEC 1. In the "value to write" field, set the value 0x4 in the register with the address 0, then click on "*Write value*". Repeat this step for all the registers with the appropriate values indicated in Fig. 5.24. Then repeat the same procedure for FEC 2.

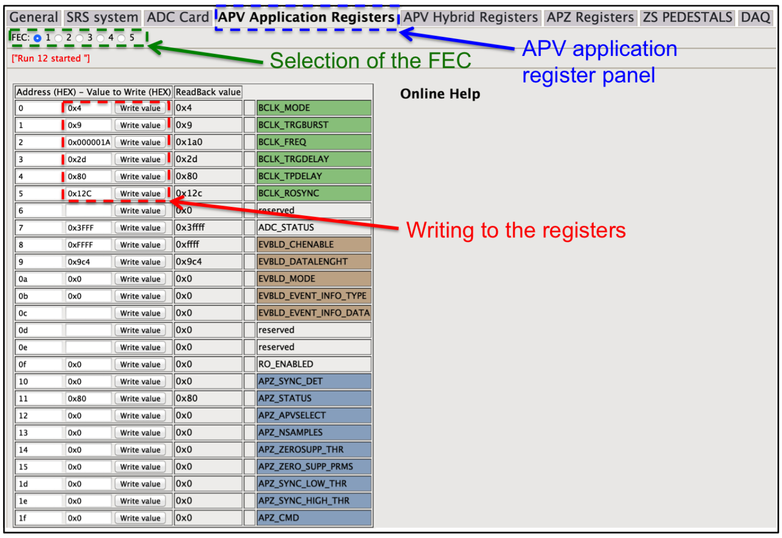


Figure 5.24: QC5 SCRIBE APV Application Register panel.

5. In the DATE test control window, select the available arrow to the right to enable the run parameterization (see Fig. 5.25). Click on Define, then LDC to open the run parameter window.

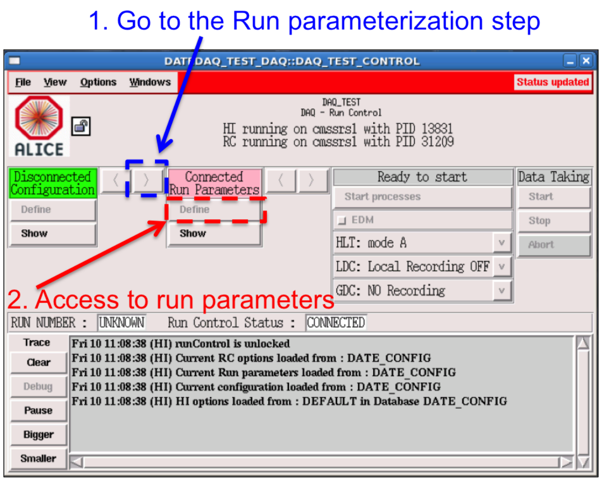


Figure 5.25: QC5 test control window.

In the run parameter window (see Fig. 5.26), fill the "*Max. number of sub–events*" field with the number of events you want to acquire per run (typically 500 000). In the "*Local Recording device*" field, set the absolute path to the raw file named "cmssrs.raw" in the raw data directory. This file will be automatically renamed by SCRIBE after the end of a run. For example "/data/GE11-VII-L-CERN-0001/cmssrs.raw". Make sure the filepath in DATE matches with the filepath indicated in SCRIBE. Click on "*Apply tagged values to selected items*", close the window, click "*OK*" then "*YES*" to approve the changes.

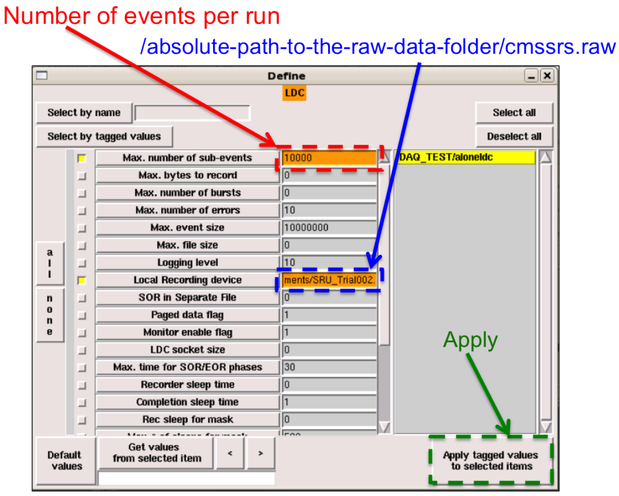


Figure 5.26: QC5 DATE run parameters window.

6. In the DATE test control window, select the available arrow to the right to enable the "*Ready to start*" panel (see Fig. 5.27). Switch the local recording of the LDC to ON. If the recording is set to OFF, the data will not be written on the disk and therefore lost forever. Then clock on "*Start processes*". After few seconds, the DATE info browser window (Fig. 5.19) will display the message "*Equipment ready*".
7. In the DATE test control window, select the available arrow to the right to enable the "*Data to Taking*" panel (see Fig. 5.28). Clock on "*Start*" to start the run.
8. Power ON the X-ray gun with the parameters 40 kV and 100 μA.
9. Open the SCRIBE "*DAQ*" window and click on "*Start run*" to enable the trigger, as indicated in Fig. 5.29.
10. After the trigger was enable in SCRIBE, you should see the trigger rate around 700 Hz in the DATE LDC status window (Fig. 5.30). Similarly, the number of recorded events is increasing while the acquisition in ongoing.
11. When the total number of required events is reached, the acquisition will stop automatically. After several seconds, SCRIBE will rename the raw file

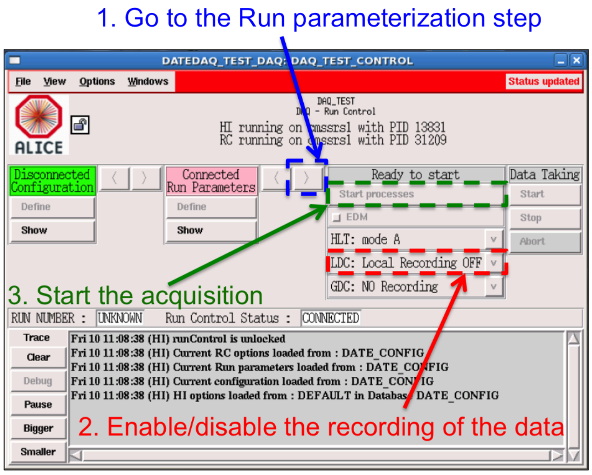


Figure 5.27: QC5 DATE test control window.

from $cmssrs.raw$ to $gemfitYYY.raw$, with YYY the run number.

12. Power OFF the X-ray gun.
13. Open a terminal and go to the raw data directory you defined previously. Rename the file $gemfitYYY.raw$ to $GE11-VII-X-SITE-ZZZZ\_RunYYY\_Xray40kV100uA\_WWEvt.raw$, where X stands for S (short) or L (long), $SITE$ the official name of your production site, $ZZZZ$ the detector serial number, YYY the run number and WW the number of events collected. For example: $GE11-VII-L-CERN-0001\_Run001\_Xray40kv100uA\_500kEvt.raw$. Note that the run number YYY should be unique and increasing across all tests of a detector. In case the QC response uniformity of a particular detector must be repeated, the first run of the new measurement must follow the number of the last run of the previous measurement.
14. Repeat steps 5 through 12 to take more runs until the total number of recorded events reaches 10 million.

Note 1: in the case of fatal error in DATE (e.g. no more space on your hard disk, hardware issues, trigger issues ...). You may have to stop the X-ray gun, quit DATE (close all the windows) and power cycle the SRS system. Then, to restart the system and take new runs, repeat step 2 though 12.

Note 2: in the case the trigger rate drops down to zero for no hardware reasons, you may have to stop the run manually. To do so :

1. Power OFF the X-ray gun.
2. Open the SCRIBE "DAQ" window and click on "$Stop\ run$" to disable the trigger (Fig. 5.29).

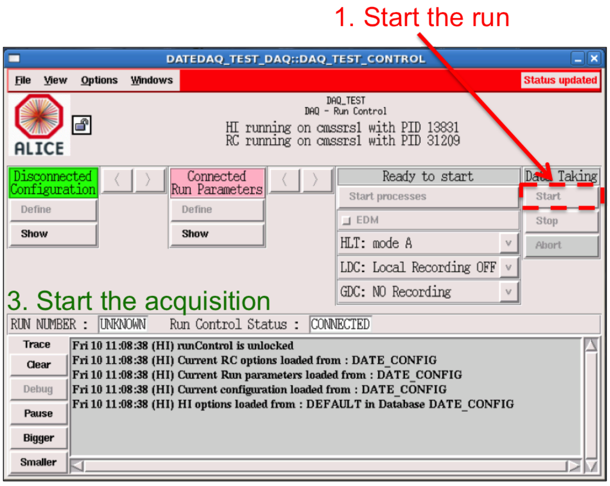


Figure 5.28: QC5 test control window.

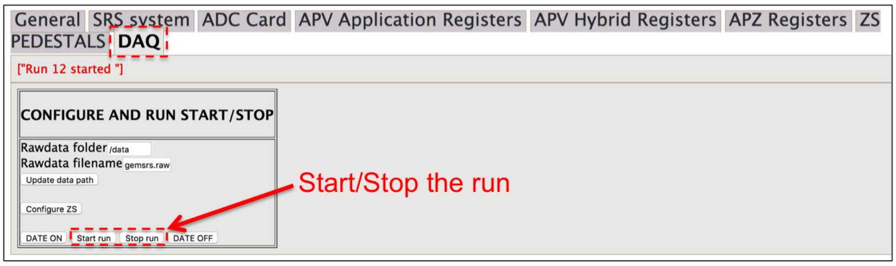


Figure 5.29: QC5 SCRIBE DAQ panel.

3. In the DATE test control window, select the available arrow to the right to enable the "*Data to Taking*" panel (see Fig. 5.28). Clock on "*Stop*" to stop the run.
4. In the SCRIBE "*DAQ*" window and click on "*DATE OFF*" (Fig. 5.29).
5. To start a new run, repeat the previous procedure 5.3.4 from steps 4 to 12.

5.3.5 Analysis

The analysis of th QC5 response uniformity test is divided in two steps:

1. the decoding and the reconstruction of the events with the analysis tool amoreSRS;
2. the data extraction and the fit of the pulse-height spectra using the CMS GEM analysis framework.

To perform the event reconstruction with amoreSRS, proceed as follows:

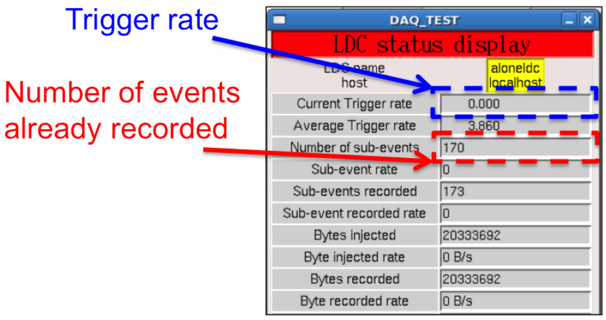


Figure 5.30: QC5 DATE LDC status panel.

1. Open a new terminal and type *Amore* to access the main directory of the reconstruction tool.
2. Edit the configuration file *amore.cfg* in the sub-directory *configFileDir*. For example : > *gedit configFildDir*/*amore.cfg* &.
3. In the *amore.cfg* file, set the first parameters as follows: *CYCLEWAIT* 2; *STARTEVENTNUMBER* 0; *EVENTFREQUENCYNUMBER* 1. The result is shown on Fig. 5.31.

```
#=====================================================================
########## SOME PARAMETERS TO DEAL WITH amoreSRS run

### How long amoreSRS wait (in second) between 2 monitoring cycles
CYCLEWAIT 2
### Start analysis at Event number STARTEVENTNUMBER
STARTEVENTNUMBER  0
### analyse only events with EvtNb module EVENTFREQUENCYNUMBER == 0
EVENTFREQUENCYNUMBER 1
#=====================================================================
```

Figure 5.31: QC5 amoreSRS configuration file (1).

4. In the section *CLUSTIZATION PARAMETERS*, set *ZEROSUPCUT* to 10, *MINCLUSTSIZE* to 1, *MAXCLUSTSIZE* to 20 and *MAXCLUSTMULTY* to 20. Then, set the *CLUSTER_ADCS* parameter to "totalADCs", as indicated on Fig. 5.32.
5. In the next section, set the *HIT_ADCS* parameter to "signalPeak", as shown on Fig. 5.33. Then set *ROOTDATATYPE* to "HITS_AND_CLUSTER" to allow both hit and cluster reconstructions. Leave the other options commented.
6. In the last section, indicate what mapping file should be used by amoreSRS (for long or short chambers) and leave the other option commented (Fig. 5.34). Indicate at the *RUNNAME* line the absolute path to the raw data folder and the name of the output file that will be created by amoreSRS. Make sure you don't use any extension after this name. The extension "_dataTree.root" will be automatically added by the program itself. Finally, set the *RUNTYPE* to "ROOTFILE" and leave the other options commented.

```
######## CLUSTERIZATION PARAMETERS

ZEROSUPCUT   10
MINCLUSTSIZE 1
MAXCLUSTSIZE 20
MAXCLUSTMULT 20
#==========================================================================================

#==========================================================================================
### CLUSTER_ADCS   keyword for the ADC information at the cluster level (collection of hits) used during the analysis
### maximumADCs == ADC of the strip/hit with the maximum charge in the cluster
### totalADCs == sum of the ADCs of all the strips/hits in the cluster
CLUSTER_ADCS  totalADCs
#==========================================================================================
```

Figure 5.32: QC5 amoreSRS configuration file (2).

```
#==========================================================================================
### HIT_ADCS: keyword for the ADC information at the hit level (individual strip) used during the analysis
### IntegratedADCs == sum of the ADC all the time sample (bin/slice) of the apv signal of the strip (hit)
### SignalPeak == only the time sample (bin/slice) with the highest ADC is used for the analysis
HIT_ADCS signalPeak
#==========================================================================================
#==========================================================================================
### ROOTDATATYPE: keyword for the type of data in the output root tree file
### HITS_ONLY: root tree contains only hit information: strip No, ADCs, time bin of the peak ...
### CLUSTER_ONLY: root tree contains only cluster information: hit position, cluster ADCs, time bin ...
### TRACKING_ONLY: root outup dedicated to tracking (still in progress ...) TRACKING runtype
### OTHER (or nothing) output both cluster and hit information

#ROOTDATATYPE  HITS_ONLY
#ROOTDATATYPE  CLUSTERS_ONLY
ROOTDATATYPE HITS_AND_CLUSTERS
```

Figure 5.33: QC5 amoreSRS configuration file (3).

7. Save the changes and close the configuration file.

To start the reconstruction with amoreSRS, type in the terminal : $> amoreAgent\ -a\ SRS01\ -s\ /path-to-data-file/data-file.raw\ -e\ XXX\ -c\ YYY$, where XXX stands for the number of events per cycle and YYY the total number of cycles of analysis. The product of XXX by YYY should be equal to the total number of events in the data file. For example: $> amoreAgent\ -a\ SRS01\ -s\ /data/GE11-VII-L-CERN-0001/Run045.raw\ -e\ 10000\ -c\ 10$.

The second step of the analysis consists of processing the root file provided by amoreSRS with the CMS GEM framework. Detailed instruction on how to install and how to use this framework are available in the README available on https://github.com/bdorney/CMS_GEM_Analysis_Framework/tree/release_v1.1.

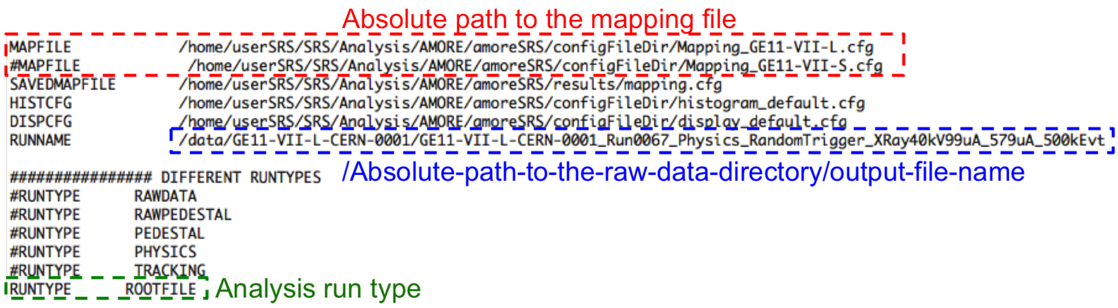


Figure 5.34: QC5 amoreSRS configuration file (4).

5.3.6 Typical results

Coming soon ...