Technische Universität München
Fakultät für Physik

Abschlussarbeit im Bachelorstudiengang Physik

Development of a new concept for the HV supply for the ALICE GEM-based TPC

Entwicklung eines neuen Konzepts für die Hochspannungsversorgung der auf GEM basierenden ALICE TPC

Christoph Bilko

September 2nd, 2013

Erstgutachter (Themensteller): Prof. Laura Fabbietti
Zweitgutachter: Prof. Lothar Oberauer

Contents

Introduction

The ALICE (A Large Ion Collider Experiment) is a particle physics experiment located at the Large Hadron Collider at CERN (Conseil Européen pur la Recherche Nucléaire) near Geneva. It is a heavy-ion detector to study Pb-Pb collisions at a center-of-mass energy of 5.5 TeV per nucleon pair [1]. Aim of the ALICE is to produce and measure a quark-gluon-plasma, how it is supposed to be right after the Big Bang. This occurs during high energetic collision between two Pb cores. To measure the result of the Pb collisions, the ALICE is built around the collision points. It consists of many different detectors, each one to measure different types of particles.

The Time Projections Chamber (TPC) is a particle detector made to trace charged particles. Original, it consists of Multi Wire Proportional Chambers (MWPC) for the electron amplification necessary for the readout. But after the upgrade after the second Long Shutdown (LH2) of the LHC it doesn't achieves its requirements. After the LH2 the ALICE TPC will be upgraded with the GEM (Gas Electron Multiplier) based technology, which were invented by Fabio Sauli in 1997.

The Inner Read Out Chamber (IROC) consists of a triple stack of GEM-Foils for the use of electron amplification. A prototype of this IROC were build in Garching and tested at the MLL. Before mounting the triple GEM stack to the IROC the foils have to run through quality test, to assure their functionality.

This thesis will explain the quality test, their improvement and the production of a power supply for the MLL-Beamtime for the IROC.

Chapter 1

The GEM based TPC

The principles of a Gas Electron Multiplier (GEM) based Time Projection Chamber (TPC) are based on the direct collection by GEM detectors of ionized electrons from the inner gas medium produced by charged particles traversing the detector gas volume [2].
The ALICE TPC is the main particle tracking device in ALICE. Charged particles crossing the gas of the TPC ionize the gas atoms along their path, liberating electrons that drift towards the end plates of the detector. An avalanche effect inducted by the MWPC, or now the GEMs, amplifies the signals for acquisition, since the primary electrons from the ionization of the gas particles carry a too small charge for a good detection. With a active volume of 88 m^3 and a total lenght of 5 m [1] the ALICE TPC is the largest detector of this type in the world. Its readout chamber are arranged in 18 sectors each covering 20° in azimuthal angle [1]. These chambers are subdivided into inner (IROC - Inner Read Out Chamber) and outer (OROC - Outer Read Out Chamber) chambers, thus accounting to 72units [14].

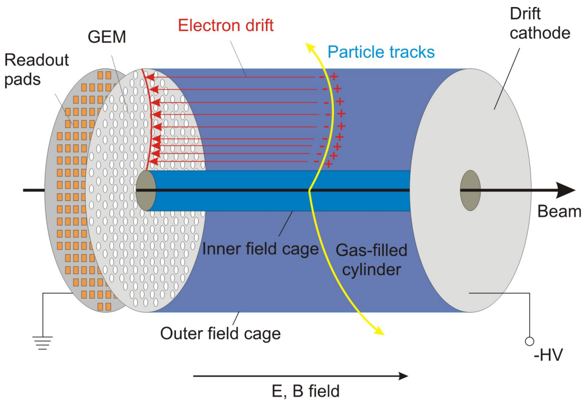

Figure 1.1: GEM based TPC "PANDA"[2]

1.1 The principles of a TPC

A TPC [3] is used in particle physics for 3D tracking (Fig. 1.2) of charged particles in a gas volume and consist of a gas-filled, typically cylindrical, detection volume in an electric field with a position-sensitive electron collection system [4]. An electric field along the cylinder axis separates positive gas ions from electrons created by ionizing particles traversing the gas volume. Primary electrons drift towards the readout anode (Fig. 1.1 "Readout pads"). There avalanche amplification occurs typically in Multi-Wire Proportional Chamber (MWPC) or, as mentioned, in Gas Electron Multipliers (GEM). The induced signals being detected by an arrangement of pad electrodes measuring the projection of the track onto the end plane [2]. Gas mixtures used in a TPC usually consists of 90% of a noble gas (e.g. Ne, Ar, Xe) and 10% of a quencher gas (e.g. CO_2, CF_4) [5]. For a better signal it is necessary to have a highly homogeneous electric field inside the TPC which is realized by a field cage consisting of a series of field strips surrounding the cylindrical volume. Further the transverse diffusion is reduced by a strong magnetic field parallel to the drift direction.

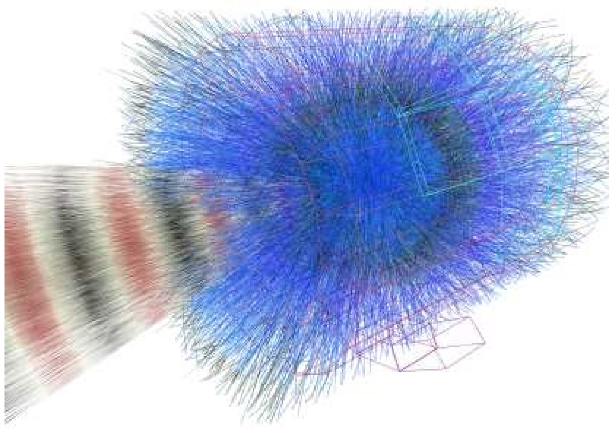

Figure 1.2: Tracks of subatomic particles taken with the ALICE TPC [6]

1.2 The principles of a GEM

The signals of electrons created by ionized particles in the gas volume of the TPC are insufficient for a readable signal on the anode readout pads. Electron avalanche amplification is conducted for a better read out. The Gas Electron Multiplier, invented by Fabio Sauli in 1997, is a possibility for electron amplification [7]. GEM-Foils are constructed of 50 μm thick Kapton foils with 5 μm copper clad on both sides. A photolithography and acid etching process forms holes with an inner diameter of 50 μm and outer outer diameter of 70 μm (Fig. 1.3) in a dense structure with a hole pitch of around 140 μm.

For electron amplification a potential difference of 200 V - 400 V is applied between top and bottom side of the GEM to create an electric field. The field lines focus in the double conical holes (Fig. 1.3 (right)) [8]. This electric field can reach a value up to 50 kV/cm [2]. In this strong field electrons get accelerated and ionize other gas atoms. The electrons may be extracted on the bottom side of the foil and transferred to the next amplification stage or the readout plane. The ions created due to the amplification are following the electric field lines in the opposite direction and can either recombine on the cathode of the foil or flow back into the drift volume of the detector. The field created between two GEM-Foils is called the transfer field and the field between the last GEM-Foil and the anode is called the induction field. A example for using GEM technologies for amplification is the COMPASS (COmmon Muon and Proton Apparatus for Structure and Spectroscopy) at CERN [10].

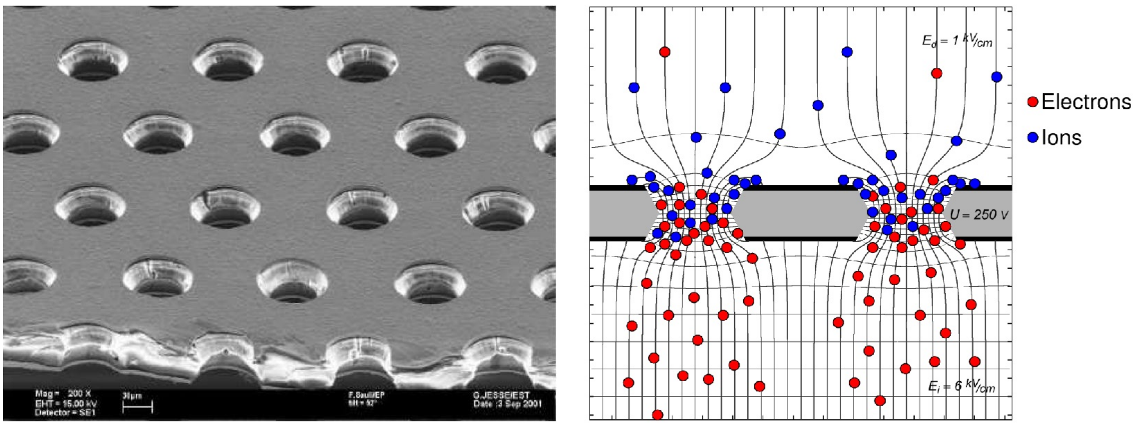

Figure 1.3: Surface of a typical GEM foil [11] (left) and Electric field in a GEM hole [12]

1.3 The IROC-GEM Foils

The GEM-Foils for the ALICE GEM TPC and accordingly for the IROC prototype are manufactured in CERN in a single-mask process [13]. The foils got a trapezoidal shape with the dimensions 292 mm for the top side, 467 mm for the bottom side and a hight of 497 mm (Fig. 1.4) which fits to the dimensions of the IROC alubody. The top side of the foil is divided in 18 sectors with an area ∼100 cm^2 each (Fig. 1.4). This is necessary to keep the total charge during a discharge low to prevent damages on the foil.
For later simulations it is interesting to calculate the capacitance of a sector. With the area of a sector around 100 cm^2, the hole pitch of 140 μm and a hole diameter of 70 μm it calculates an overall real estimated area of A = 80 cm^2. With a relative permittivity of k = 3.9 for Kapton [20] and the thickness of d = 50 μm the capacitance is:

$$C = \frac{k\varepsilon_0 A}{d} = 5.5nF$$

For later simulations the value C = 5 nF is absolutely sufficient.

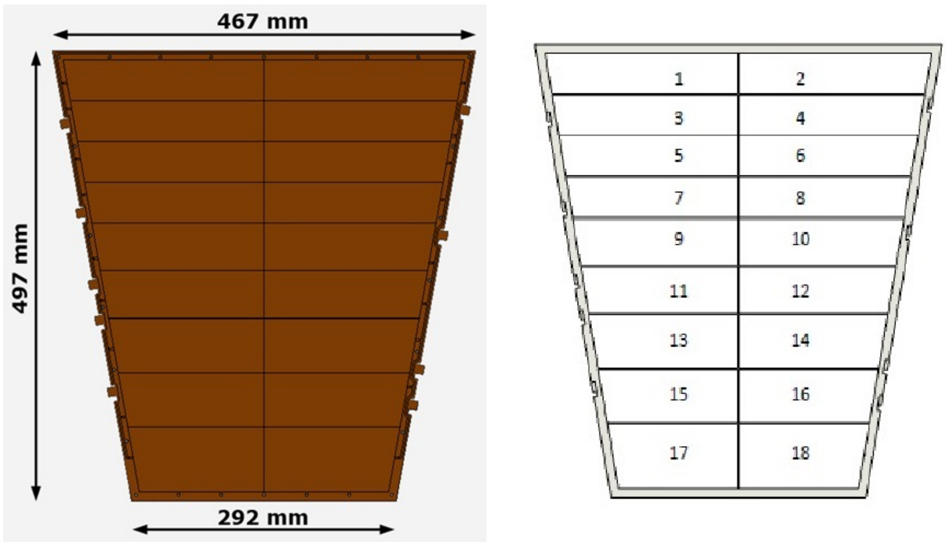

Figure 1.4: GEM-Foil layout for the IROC prototype

1.4 The GEM-IROC prototype

The Inner Read Out Chamber (IROC) prototype consists of a triple GEM-Foil stack, a padplane attached to a alubody and a aluminium Testbox. The GEM-Foils are glued on 2 mm thick fibergalss (G10) frames. The frames supply a 400 μm thick spacer grid to prevent the foils from touching each other due to attraction from electrostatic forces. Before gluing, the frames are polished with fine sand-paper, cleaned in an ultrasonic bath and finally dried in the oven at 60°C for at least 8 hours [14]. After an additional HV-Test (for more information see chapter 2) the framed foils are mounted in a triple stack on the alubody on the padplane (Fig. 1.5) and connected to it. The IROC is than transfered into an aluminium test box with a field cage (Fig. 1.5) with a drift field of 360 V/cm. The box has cut-outs with aluminized Mylar windows (50 μm) providing acces for radioactive sources or beams from two sides of the box and from the bottom side [14].

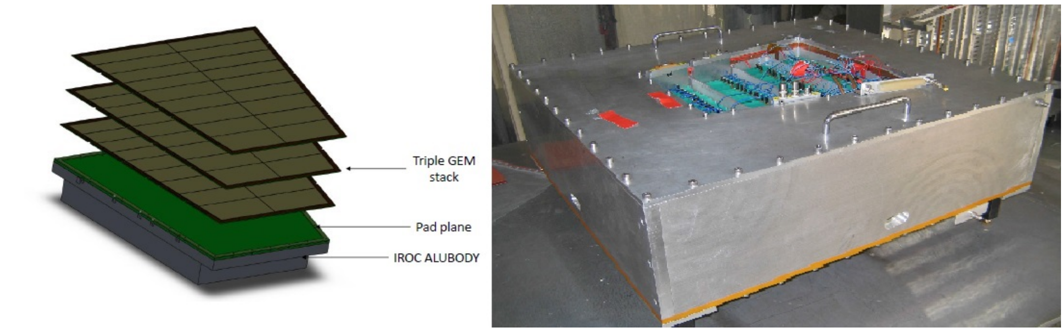

Figure 1.5: Triple GEM stack on pad plane and alubody (left) and aluminum Testbox (right)

Chapter 2

Quality Assurance of the GEM foils

The Quality Assurance (QA) of the GEM foils is for validating the foils for their final mount. It is separated in two different tests: the optical check and the high voltage test. Both tests are necessary to ensure the foils to work as expected or to detect defects. They are realized in a cleanroom to ensure a high level of purity to prevent contaminants (e.g. dust) which could affect measurements, unexpected behavior and/or increase the probability of discharges.

2.1 Optical Check

The optical check is a QA step limited to the optical search for defects and/or construction faults on the surface of the GEM foils. Also it is necessary to ensure homogeneous hole sizes. Frequent types of this defects are big size hole defects (Fig. 2.1a), overetched copper on the foil surface (Fig. 2.1b), missing holes (Fig. 2.1c) due to production faults and different hole diameter sizes (Fig. 2.1d) which differ from the default sizes. The physical defects on the copper and/or the kapton layer may increase the probability of electrical discharges and may create short circuits between the top and the bottom sides of the GEM foils. Whereas the different hole sizes and missing holes may decrease the efficiency of the foils and may corrupt the gain.

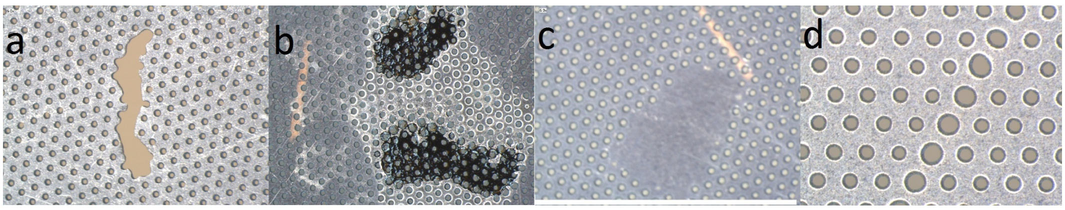

Figure 2.1: Different defects: a) big size scratch; b) overetched copper; c) missing holes; d) inhomogeneous hole sizes

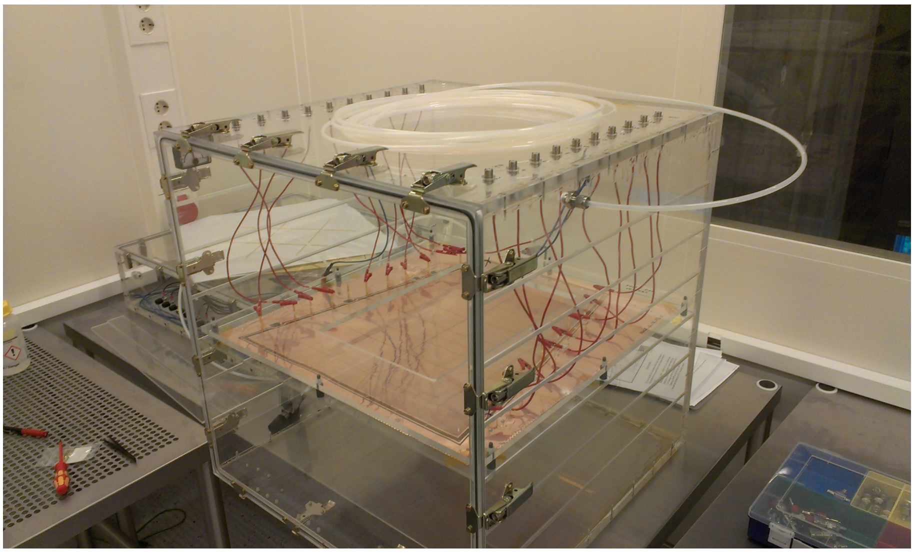

Figure 2.2: The used HV-Test Box in the Cleanroom

2.2 High Voltage Test

The High Voltage Test (HV-Test) is as test which is executed for all 18 sectors of a GEM-Foil in particular to ensure proper functionality of the foils. Before applying the foils to a high voltage source they are arranged in a test box (Fig. 2.2) flashed constantly with nitrogen to ensure a dry-gas environment which also prevents additional dust particle to enter which could increase the probability of discharges and to decrease the oxidation of the copper due to discharges.

The GEM-Foil sectors are further protected through an protective resistor, which is connected in series with the high voltage source (see circuit scheme in Fig. 2.3). During the HV-Test the tested top side sector is ramped up at specific voltage steps up to 550 V with the surrounding sectors and the bottom side being grounded for a better. At each voltage step the leakage current is measured, which shouldn't exceed 1 nA. This behavior would indicate a short circuit between top and bottom side of the sector. Typically the currents are within the range of 0.1 nA to 0.3 nA for the voltage steps. Ramped around a defined limit of 550 V it is mostly common that the sector begins to spark. The spark is the consequence of a discharge between the top and the bottom side of the GEM-Foil sector. If the sector did not spark for three minutes and has nominal values for the leakage current, it is classified to have passed the voltage test. In case it already sparks earlier than 550 V it indicates an unstable sector.

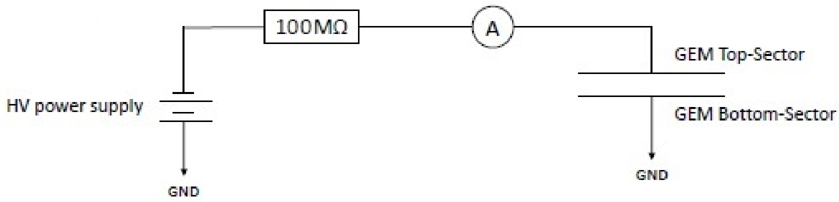

Figure 2.3: Powering scheme of the HV-Test [14]

2.3 Automation of the HV-Test

The HV-Test at is current execution is not made for long time measurements, which could give more information about a GEM-Foil. For planed 24 hour test for sectors of the foils, it is needed to establish an automatically procedure for controlling the high voltage supply and continuous data acquisition. For this purpose a Keithley 6517B Electrometer was connected to a PC and the HV-Testbox to establish the possibility of a remote control of the HV-Test and a automatically data acquisition. This part will mainly consist of how to connect the high voltage source and the ampere-meter to the HV-Test Box and how to connect this to a PC for additional Data Acquisition (DAQ) with special programed software.

2.3.1 The Keithley 6517B Electrometer

The Keithley 6517B Electrometer (Fig. 2.4) is a mulit-measurement and high voltage supply device with the following capabilities of measuring and measure ranges [15]:

Unit	Range minimum	Range maximum
Current	1 fA	20 mA
Voltage	10 μV	200 V
Resistance	50 Ω	10^{16} Ω
Charge	1 fC	20 μA

It got a very precise range for current measurements and is therefore suitable for measuring the leakage current of the HV-Test. Further it provides a power supply of 1 W with 100 V and 10 mA or 1000 V and 1mA. If the current exceeds the limited current the 6517B have a build in hardware short circuit protection which automatically ramps down the voltage to correlate the current [16].

Figure 2.4: Front side (left) and back side (right) of the Keithley 6517B Electrometer [15]

2.3.1.1 Connection to the HV-Testbox

The Keithley 6517B has two possible connection methods (Fig. **??**). The High-resistance meter connection (HRMC) and the voltage source output connection (VSOC).

Figure 2.5: VSOC connection (left) and HRMC connection (right) [16]

The VSOC is plugged for using the 6517B only as a voltage supply. For using the internal ampere meter of the device it is recommended to use the HRMC. To use the HRMC it assumes that the voltage source LO plug is internally connected to the ampere meter. This can be done by changing the configuration of the device. The independent configuration (Fig. 2.6 (left)) is the default configuration of 6517B. This setting is mainly for using the 6517B as a voltage source, as mentioned.
The second configuration is the force voltage measure current (FVMI) configuration (Fig. 2.6 (right)). This configuration is used for resistance and current measurements. It is possible to switch between this two modes by using the Standard Commands for Programmable Instruments (SCPI):

:SOURce:VOLTage:MCONnect ON/OFF
It is also possible to measure current with the 6517B in the independent config-

urations by bypassing the internal switch with a three plug cable. For current measurements in the Independent Configuration a cable was constructed especially for the 6517B (Fig. 2.7).

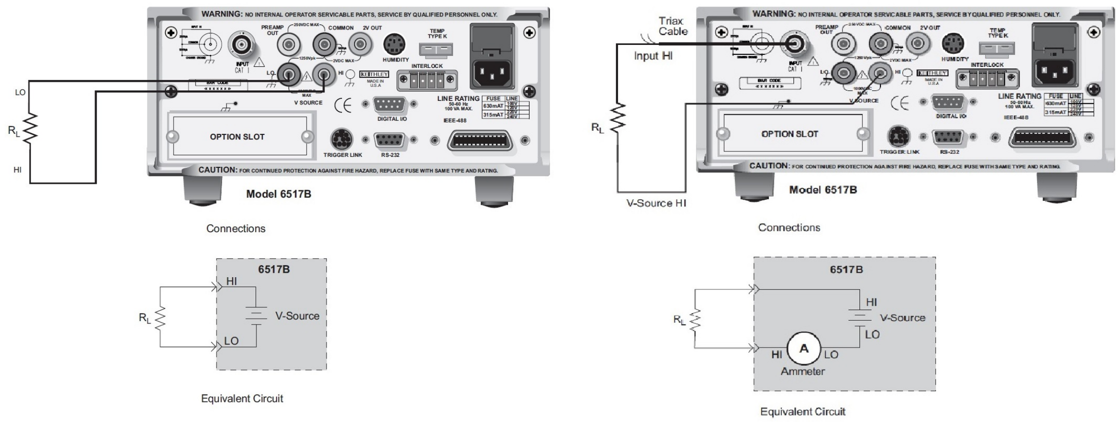

Figure 2.6: Independent configuration (left) and FVMI configuration (right) [16]

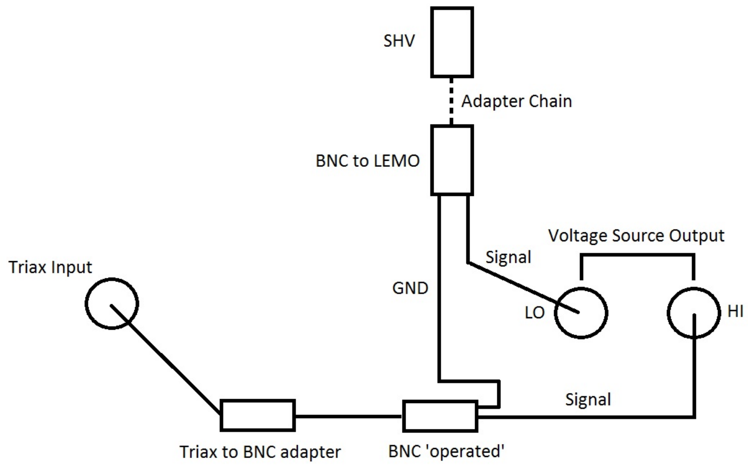

Figure 2.7: Cable circuit to connect for current measurements with the Keithley 6517B (right) [17]

2.3.1.2 Connection to a Computer

To connect the Keithley properly with a PC a communicator between the device and the computer is needed. The Agilent E5810A LAN/GPIB Gateway (Fig. 2.8 (left)) is a device for transmitting data and commands from GPIB devices to computers via LAN and vice versa. The E5810A get a TCP/IP address assigned through DHCP (default: 169.254.44.22) and attributes every connected device a GPIB port number (default for 6517B: 27). Through this TCP/IP and GPIB port combination, the device can be located and it is possible to communicate with it. If connected it is possible to call up an intern operator interface (Fig. 2.8 (right)) with a common web-browser just by going for the TCP/IP address, to configure the E5810A
Needed cables for this connection are a GPIB cable to connect the 6517B and the E5810A and standard LAN patch cable for network connection or a LAN crossover cable for direct connection between the E5810A and a computer.

Figure 2.8: Agilent E5810A LAN/GPIB Gateway [18] and intern user interface(right)

2.3.2 Remote Control and Acquisition

The remote control and DAQ is established with LabVIEW. LabVIEW is a system-design platform and development environment for a visual programming language from National Instruments [21]. The programming language used in LabVIEW is a dataflow programming language. Execution is determined by the structure of a graphical block diagram.
The LabVIEW programs are called VI (Virtual Instrument). Each VI can consist of multiple smaller VIs, which are called subVIs. Using such subVIs facilitate the programing process and are a common instrument for bigger VIs.
Following it is described how the program works in its program language (for further development), how to use the program itself for DAQ and analyzes of the acquiered data.

2.3.2.1 Important Commands with explanation

The Keithley 6517B is controllable with commands. Most of them are SCPI but it also have its own specific commands for advanced controlling and calculation. Here is a list of the used commands in the LabVIEW program with explanation of their function for the 6517B:

SCPI Command	
*RST	Restart the Keithley 6517B and set default settings
SYST:ZCH OFF	Turns off the Zero Check. This is necessary to start measurements.
SYST:ZCOR ON	Turn on the Zero Correct. Increases precision for low current measurements.
SOUR:VOLT:RANG 1000	Set the voltage source range to 1000 V. Necessary since the default settings range is at 100 V.
MEAS:CURR?	Measures current and set the measuring mode to ampere mode
SOUR:VOLT X	Sets volt output value to X
read?	Reads value (depends on which measuring mode is switched on)

2.3.2.2 The LabVIEW Program

The program created for the automation of the Keithley 6517B is mainly divided in 4 main processes:

1. Setting up the 6517B to be ready for measurements
2. Ramping the voltage to set voltage
3. Measuring the current at fixed voltage
4. Ramping the voltage down and reset the 6517B

By executing steps "2" and "3" once, voltage is ramped to a certain level and the current is measured for a given amount of time. For more than one voltage value (e.g. from 0 V to 100 V and than from 100 V to 200 V etc.) these two steps have to be added up again in the program queue. In the current version of the program, up to 6 adjustable voltage steps may be used.

It's worth to be mentioned, that there are two possibilities for step "2": either with a permanent current measurement or a mode where current measurement is disclaimed while the voltage ramps up.
The reason to separate the current measurement while ramping the voltage is that while ramping up the 6517B it has to receive the commands for the next voltage step (e.g. SOUR:VOLT 1; SOUR:VOLT 2,... etc.) in the determined ramping speed. Adding a parallel command for a current readout "read?" would cause an error in the information queue. Therefore these two commands, for setting the voltage and reading the current, have to be executed successive. This determines the ramping speed by the readout speed which is much slower, because this is an input-output procedure whereas setting the voltage is just an input procedure by telling the 6517B to go to a voltage level.

Such a read and ramp command combination may cause a maximum ramping speed of 1 V/s for which reason it is just recommended for long time measurements.

The single steps will be explained in detail for a better understanding of the program:

Step 1: The Set up

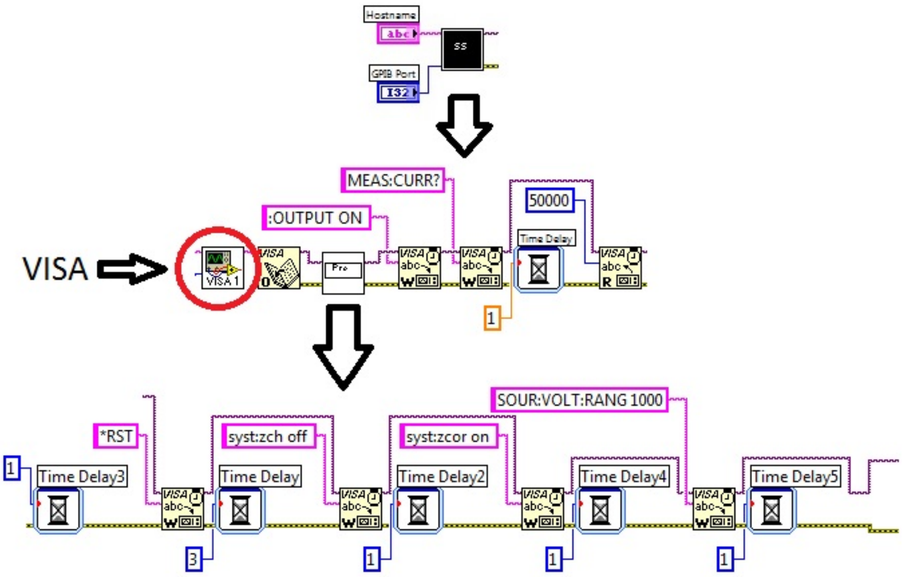

Figure 2.9: subVI of Step 1, red circle: VISA subVI

The "Set Start" subVI 2.9 mainly consists of commands for configuring the Keithley 6517B. It starts with reading the "Hostname" and the "GPIB Port" given by the user to address the 6517B. The VISA subVI (Fig. 2.9 converts this information into a readable value for the remaining VI. Then, the following steps are executed:

1. Reseting the device first. Necessary to prevent using the configurations of previous users.
2. Turn off the Zero Check. During the Zero Check mode the device can not acquire data.
3. Turn on the Zero Correct. Zero correct is for achieving optimum accuracy for low current measurements [16]
4. Set the voltage range to 1000 V to be able to ramp up to higher values.
5. Turning the output on.
6. Switch the device to an ampere meter to measure current. Default the 6517B is set as a voltmeter.

The last switch does not affect the input operation for changing the voltage of the 6517B, neither does the input command "SOUR:VOLT" change the readout back to voltmeter. It just indicates what is going to be measured. The command

"MEAS:CURR?" explicitly asks the device for the ampere value whereas the command "read?" just reads the value the device is currently reading. Setting the device to an ampere measure mode and using "read?" as a data acquisition command makes the measurements faster, since the "MEAS:CURR?" command checks if the mode is on ampere meter, every time. The time delays in between were build in due to experience shows that the 6517B can not attend to some commands fast enough before the next command is send. A new command while the last command is not executed may cause an error or even skipping the command at all.

Step 2: Ramping mode

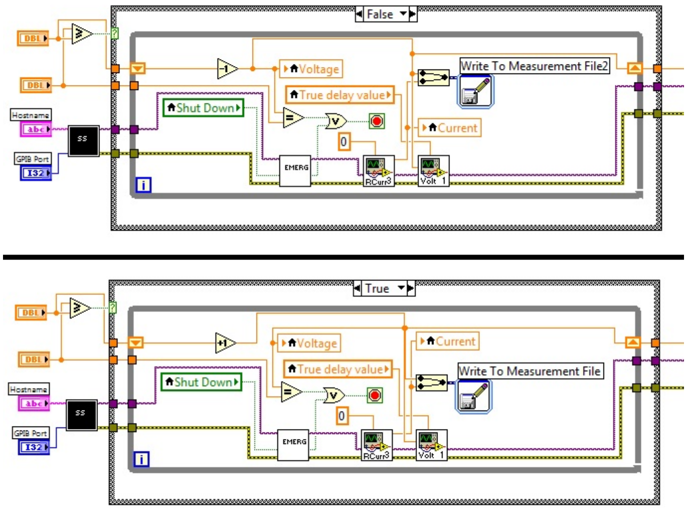

Figure 2.10: Ramp part of the VI.

The second step is for ramping the voltage source of the 6517B to the configured value. To choose the polarity of the applied voltage a "True/False" option was build in. Before starting the ramp, two values are compared, the "pre-value", which gives the previously value (for the first ramp this value is "0") and the "go-to-value", which is set by the user. Depending on this comparison the condition is set true or false. The only difference between this two conditions is that one increases the value and the other decreases it in a loop as long as the favored value is not reached.
In addition a subVI was included for instant shut down of the program and the device. This subVI sends a signal to the device to set the voltage value to "0" and stops the program.

Step 3: Current measurements

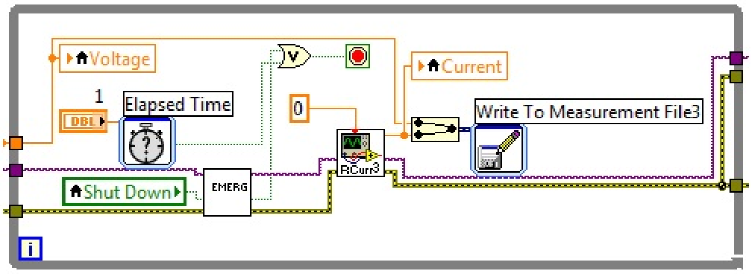

Figure 2.11: Step 3

After a constant voltage is reached the measurement loop start acquiring current values from the 6517B. With the "RCurr[3]"subVI the information from the readout can be converted into readable current measurement values for a proper DAQ. This loop reiterates until a set time has passed (Fig.2.10) or the "STOP"condition was initiated.

Step 4: Ramping down and reset

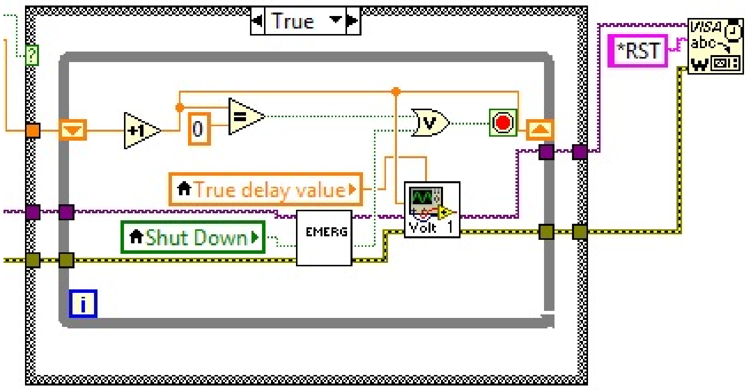

Figure 2.12: Step 4

The last step of the program is a voltage ramp to zero. After zero voltage are reached the loop stops and the "reset" command is send to the device. The DAQ is now over.

2.3.2.3 Functionality and Layout of the Program

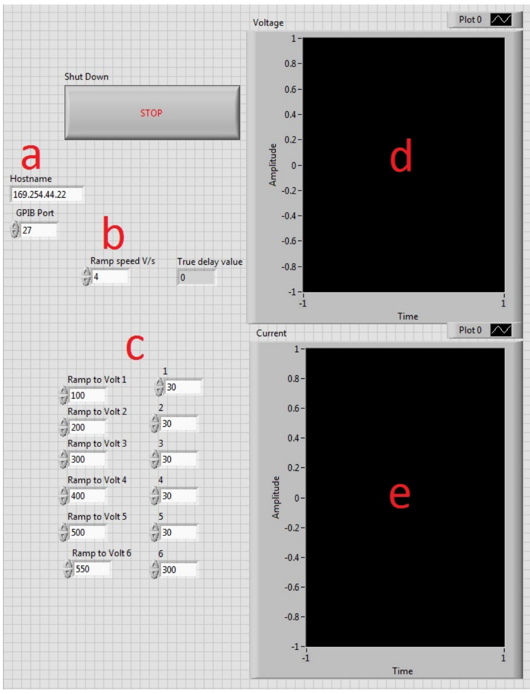

Figure 2.13: User interface of the remote control and DAQ

Before operating with the LabVIEW program it must be clear that the connection between the Keithley 6517B and the computer is established (e. g. by testing the connection with entering the IP to a web-browser and receiving the Agilent user interface (Fig. **??**). There is also the possibility to find the GPIB port number for the 6517B).
The needed IP address is on the front panel of the E5810A and the GPIB port number is available on the intern user interface of the E5810A. This must be tipped correctly into the "ADDRESS"field (Fig. 2.13a). The ramp speed (Fig. 2.13b) sets the delay time for the command to increase/decrease the voltage in the program. The left column (Fig. 2.13c) sets the voltage steps and the right column the measurement time at this step. The voltage will stay at the set voltage for the measurement time. The two displays shows the voltage (Fig. 2.13d) and the current (Fig. 2.13e) during the measurement.

All measurements are saved individual for each step at the directory: C:\Users\Christoph Bilko\Desktop\Measurements\Everything.lvm

The directory can be changed at any time rewriting the path in the software.
During a whole measurement sequenze the LabVIEW programm creates 12 ".lvm"files with different file names by the order they were taken (e.g.: Everything.lvm, Everything1.lvm,..., Everything11.lvm etc.) The "STOP"button will stop the hole measurement and ramp down the voltage to zero, immediately. The already measured values are saved in the files.

2.3.2.4 HV test of the GEM foil.

The hole setup were used for a HV-Test in the cleanroom with the framed GEM-Foil "ALICE GEM 12 11 01". Each sector where tested with "normal settings"and sector 9 was measured with "longtime settings". The normal measurements where realized with voltage ramping without current measurements due to this mode is much faster. The values for the settings were:

Voltage Steps in V	Normal meas. time in s	Longtime meas. time in s
100	30	60
200	30	60
300	30	60
400	30	60
500	30	60
550	300	1800

The longtime measurement shows the best data, since it was also realized with the "measuring while ramping"VI. During the longtime HV-Test of sector 9 two visible discharges occurred at 550 V on the sector which where also visible recorded on the data (Fig. 2.14).

Figure 2.14: Current of longtime measurements with two visible discharges

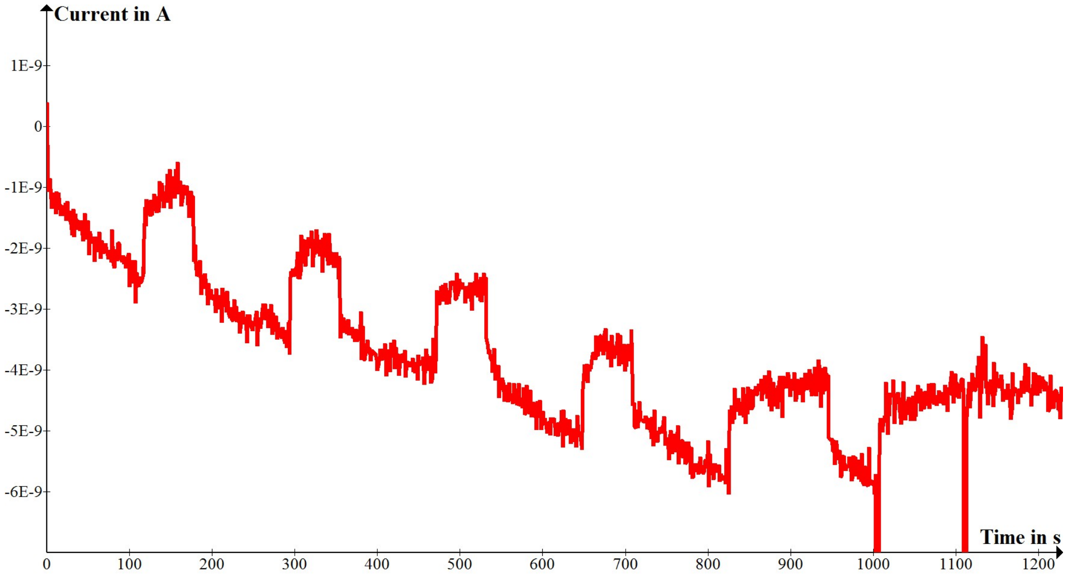

Figure 2.15: Close up of current of longtime measurements

The close up of the current (Fig. 2.15 during the ramp shows us the increasing current due to the rising voltage.

The average leakage current for the stable voltage, without taking the discharges into account, are:

Voltage Steps in V	Current in 10^{-9} A
100	1.19
200	2.17
300	2.74
400	3.80
500	4.40
550	3.64

Out of the data it is possible to see that the current is increasing with higher voltages and stabilizes within long enough time terms.
With the last values for U = 550 V and I = 3.64 $\cdot 10^{-9}$ A For simulations we can assume that the equal parallel capacitance of the GEM sector is calculated

$$R = \frac{U}{I} = \frac{550V}{3.64^{-9}A} = 1.5 \cdot 10^{11}\Omega$$

Chapter 3

The Experiment at MLL

The experiment at the Mayer-Leibniz Laboratorium (MLL) in Garching was conducted with a Tandem Van-de-Graaf accelerator [22].
A stripper foil in the middle of the accelerator removes some of the outer electrons of the accelerated ion. This changes the polarity of the ion, such that it can be re-accelerated in the second part of the Tandem accelerator. The maximum terminal voltage of the Tandem is 12.5 MV. For protons this is a maximal kinetic energy of $2 \cdot 12.5$ MeV = 25 MeV. Due to beam stability, the minimal beam energy is limited to around 10 MeV. The maximal proton beam current can reach up to 1 μA (1 x 10^{12} Hz).
In the experimental hall, where the experiment was set up (Hall II), the maximal beam current is limited to 10 nA (1 x 10^{10} Hz) due to radiation protection purposes.
For the purposes of this experiment, the ability to distinguish between beam correlated discharges and uncorrelated discharges is crucial. In order to get a clear separation between these two cases a chopped beam was chosen. In general, the chopping of the beam is only limited by the beam stability.
A stable operation can be achieved with pulses longer than 100 ns and a repetition rate between 250 Hz and 10 MHz [14].

3.1 The High Voltage Supply

The detector was powered using an ISEG EHS 8060n 8-channel 6kV high voltage module for the three GEM foils and the last strip volltage of the field cage, and by an ISEG HPn300 30 kV module for the cathode voltage [19]. The systems are full capable of precision current measurements of a resolution of 1 nA, adjustable voltage ramp speed and remote control. The triple GEM stack inside the IROC need 6 different voltage supply (always two for one GEM's top and bottom side) to support the needed voltage differences. The powering scheme is separated in two main types: 'Standard' and 'IBF' (Ion Back Flow).

The 'Standard' settings are usually used in triple GEM structures, whereas the 'IBF' is a configuration for minimizing ion back flow in the detector. These types are special defined and where used in special percentage value methods.

Trans 1 in V/cm	3730
Trans 2 in V/cm	3730
Ind in V/cm	3730
GEM 1 in V	400
GEM 2 in V	365
GEM 3 in V	320

IBF Trans 1 in V/cm	3800
IBF Trans 2 in V/cm	200 or 400
IBF Ind in V/cm	3800
Gem 1 in V	225
Gem 2 in V	235
Gem 3 in V	285

Following the voltage modulations for both settings:

Powering spot	Standard 69	IBF 100 T2=200	IBF 100 T2=400
GEM 1 Top	2293 V	2305 V	2345 V
GEM 1 Bottom	2017 V	2080 V	2120 V
GEM 2 Top	1502 V	1320 V	1360 V
GEM 2 Bottom	1250 V	1085 V	1125 V
GEM 3 Top	736 V	1045 V	1045 V
GEM 3 Bottom	515 V	760 V	760 V

Powering spot	IBF 103, T2=200	IBF 103, T2=400
GEM 1 Top	2327 V	2367 V
GEM 1 Bottom	2096 V	2136 V
GEM 2 Top	1336 V	1376 V
GEM 2 Bottom	1094 V	1134 V
GEM 3 Top	1054 V	1054 V
GEM 3 Bottom	760 V	760 V

The numbers behind the modulation types define the percentage value of the common modulation (e.g. "Standard 69"means "69 % of the Standard common value") For the MLL beatmtime a new powering scheme was used to get rid of problems with the former powering scheme.

NOTE: For the following simulations the in section 1.3 and 1.4 calculated capacitance of 5 nF for a GEM-Foil sector (top and bottom side), capacitance of 45 nF for GEM stack created capacitance and a calculated resistance from the leakage currant of a sector from the measurements in section 2.3.2.4 of 1.0 exp-11 Ω for the GEM-Foil sectors will be used.

3.1.1 The former used 6 Indipendent Channel HV-Supply

The former used 6 Independent Channel HV powering scheme (Fig. 3.1) were used for earlier tests of another IROC prototype. The GEM-Foils in the triple stack were individual powered by different channels of the ISEG EHS 8060n. Additional to the connection to the foils, the power supply is also connected to grounding resistors with the values 5 MΩ for the top side and 10 MΩ for the bottom side of GEM 1 and GEM 2. GEM 3 got 3.3 MΩ for top and bottom side.

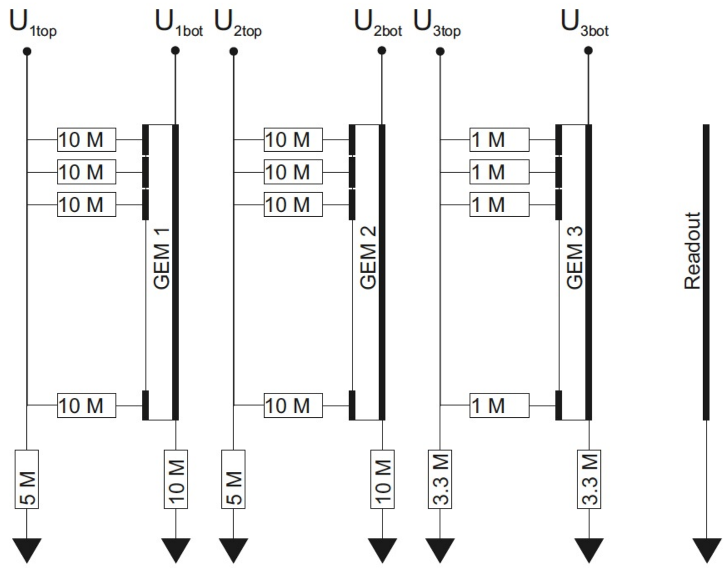

Figure 3.1: Powering scheme of the 6 indi channel

The following simulations were made with the Standard 69The behavior of the 6 Independent Channel is shown in the Figures Fig. 3.2, Fig. B.1 and Fig. B.2 for discharges at the sectors.

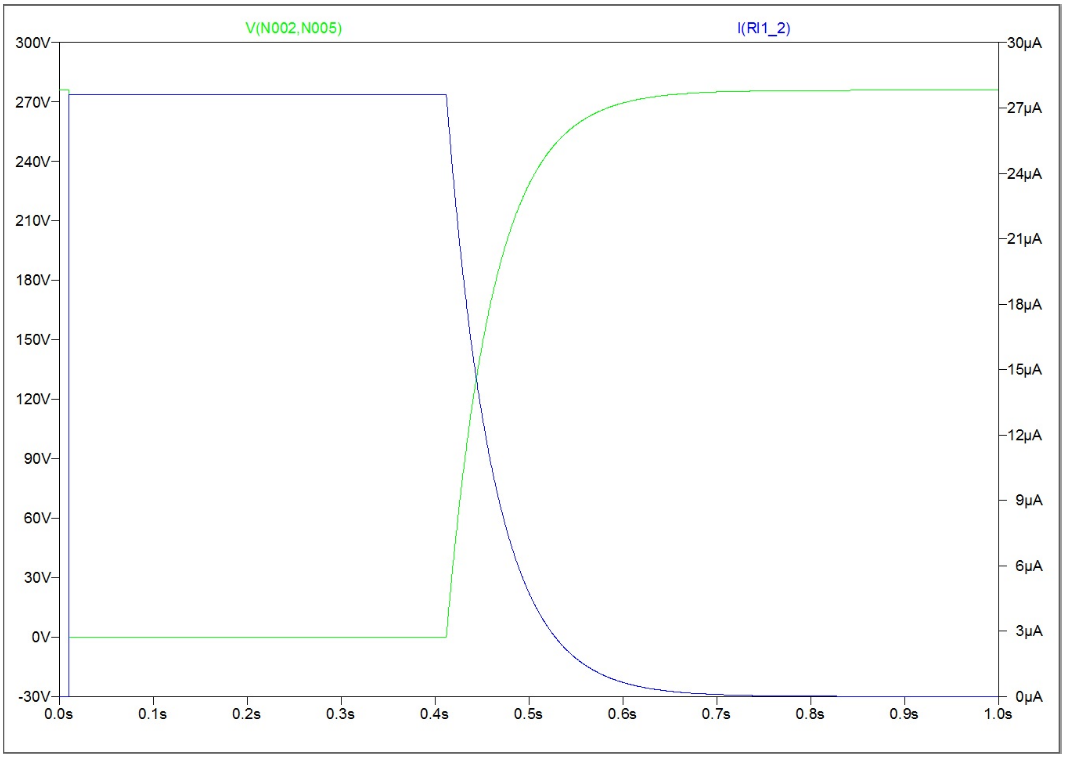

Figure 3.2: Voltage difference and current for a discharge in a 6 independent channel powered tripple GEM stack in one sector in GEM 1

The voltage and current behavior in Fig. B.2 is different to the other two. The cause of this is the loading resistor difference. For GEM 1 and GEM 2 the value is 10 MΩ and for GEM 3 1 MΩ
As it is possible to see in Fig. B.3, the voltage difference only drops for the discharging sector. The other voltages stay constant.

3.1.2 The new concept of a HV-Divider as HV-Supply

A new concept for the power supply for the IROC is High Voltage Divider (HVD). Instead of 6 independent voltage sources for the GEM stack of the IROC it uses one which is divided by the resistors in the resistor chain to get the wanted voltage values and voltage differences between top and bottom side of the GEM-Foil. Also this power scheme disclaim the use of grounding resistors.

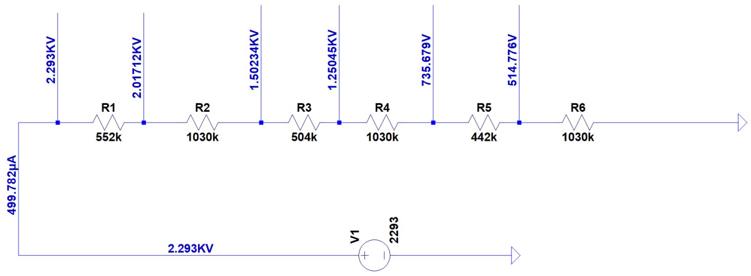

Figure 3.3: Circuit scheme of the HVD for a Standard 69% setup

3.1.2.1 Construction of the Device

The HVD (Fig. 3.4) was included to get rid of problems with the SIXCHAN power supply. It consist of over all 7 SHV plugs, 6 individual and exchangeable resistors (Fig. 3.4) and a circuit board (Fig. 3.3). The resistors are in series and supply the attached SHV plugs with a specific voltage, determined by the resistor chain. To assure a higher flexibility and efficiency at minimum cost, every single resistor is exchangeable. Each resistor consist of a resistor chain of up to 4 different resistors in series. The reason is, that the individual needed resistors are not available on the market for this exact value (e.g. 552 kohm = (500 + 50 + 2) kohm).
Overall a current of 1 mA should not be exceeded. Therefore the needed resistor chain was always calculated to assure a maximum current around 0.5 mA. This way 16 different resistors were produced.
The resistor equivalents for the voltage ensemble in table (tabel above) are:

Powering spot	Standard 69	IBF 100 T2=200	IBF 100 T2=400
R1 in kΩ	552	450	450
R2 in kΩ	1030	1520	1520
R3 in kΩ	504	470	470
R4 in kΩ	1030	80	160
R5 in kΩ	442	570	570
R6 in kΩ	1030	1520	1520

Powering spot	IBF 103, T2=200	IBF 103, T2=400
R1 in kΩ	464	464
R2 in kΩ	1520	1520
R3 in kΩ	484	484
R4 in kΩ	80	160
R5 in kΩ	587	587
R6 in kΩ	1520	1520

3.1.2.2 Simulations

The Simulations for the HVD were executed with the same parameters like the simulations of the 6 independent channel powering scheme. Please see appendix for more information.

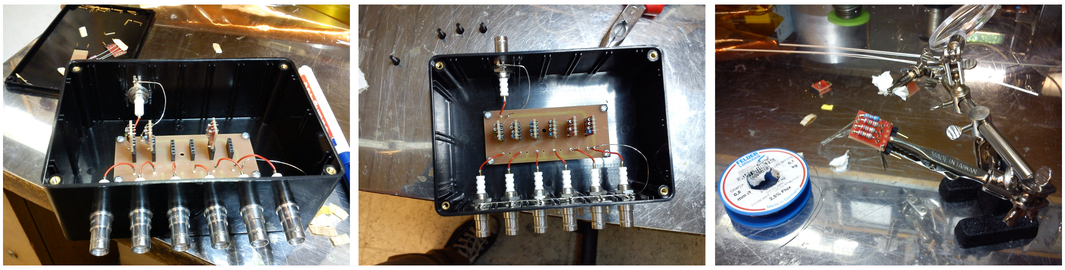

Figure 3.4: High Voltage Divider (HVD), open

3.1.3 Comparison

Resulting of the above discussed two different types of HV-supply they got different advantages and disadvantages. The first great difference is the change of the voltages during a discharge in the foil. The 6 independent Channel power supply provides a constant voltage to the rest of the GEM sides whereas the whole voltage in the HVD during a discharge. Advantages of the HVD are that there are no grounding resistors needed. Also there can't accrue a time delay between the channels during a trip of the voltage source.

Chapter 4

Conclusion

4.1 Summary

Concerning the automation of the HV-Test the software works within it needs. It was necessary to record the current over time to get a average value of the leakage current. Further the discharges where all recorded accurate. However the real maximum discharge current is not validated to be the value in the measurements. But the conditions of a previous manual executed HV-Test are now totally automated and ready for longtime measurements for several hours.

4.2 Outlook

For the future what can be done is a Improvement of the LabVIEW software. The program is working well but it is not completed yet. A better current over time resolution would be needed and the measuring of the current while ramping the voltage need to be improved to assure a higher ramping speed without resigning the current measurements. Also it would be better to let the user decide the amount of voltage steps. The 6 voltage steps in the current version are fixed. For more or less steps it is still necessary to rewrite the hole software.

Appendix A

DAQ for the GEM-Foil

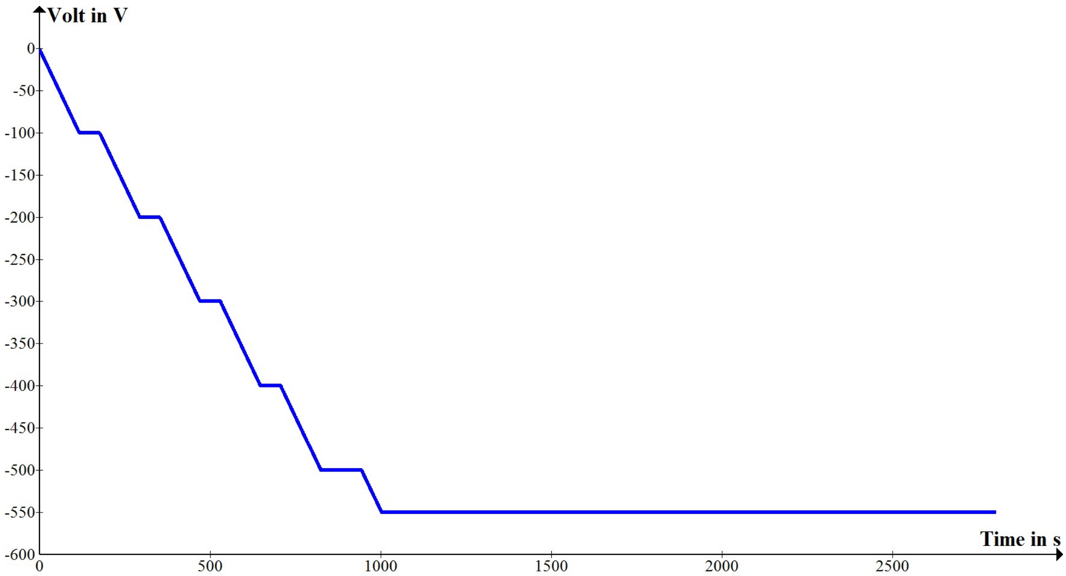

Figure A.1: Voltage of longtime measurements

Appendix B

Additional Simulations for the 6 independent channals and the HVD

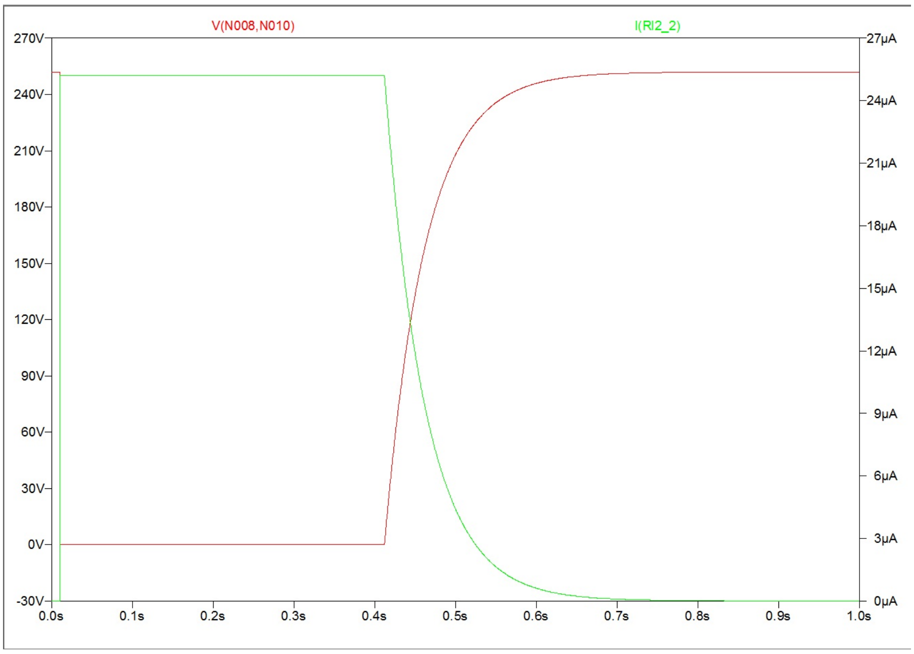

Figure B.1: Voltage difference and current for a discharge in a 6 independent channel powered triple GEM stack in one sector in GEM 2

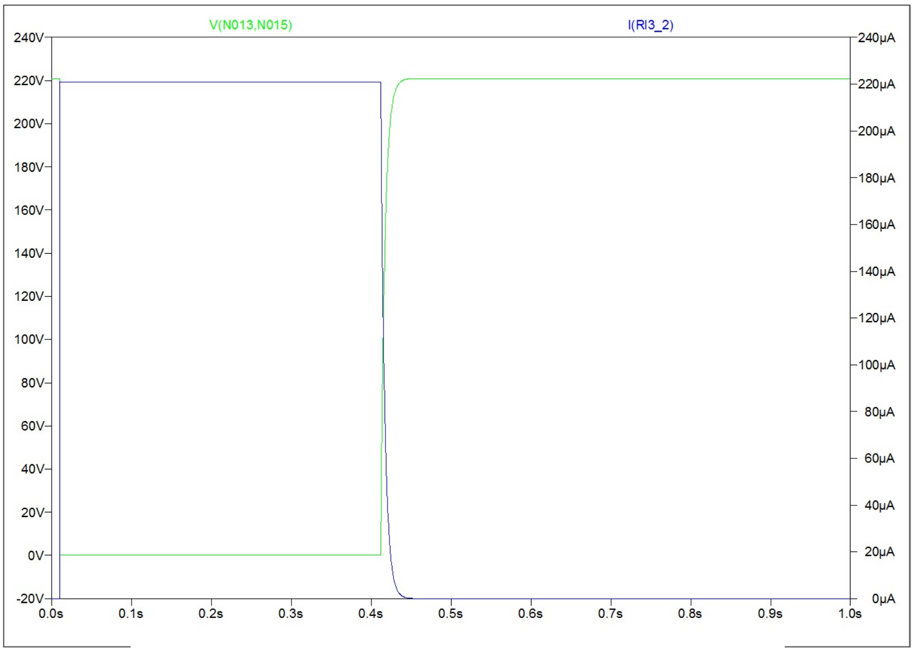

Figure B.2: Voltage difference and current for a discharge in a 6 independent channel powered triple GEM stack in one sector in GEM 3

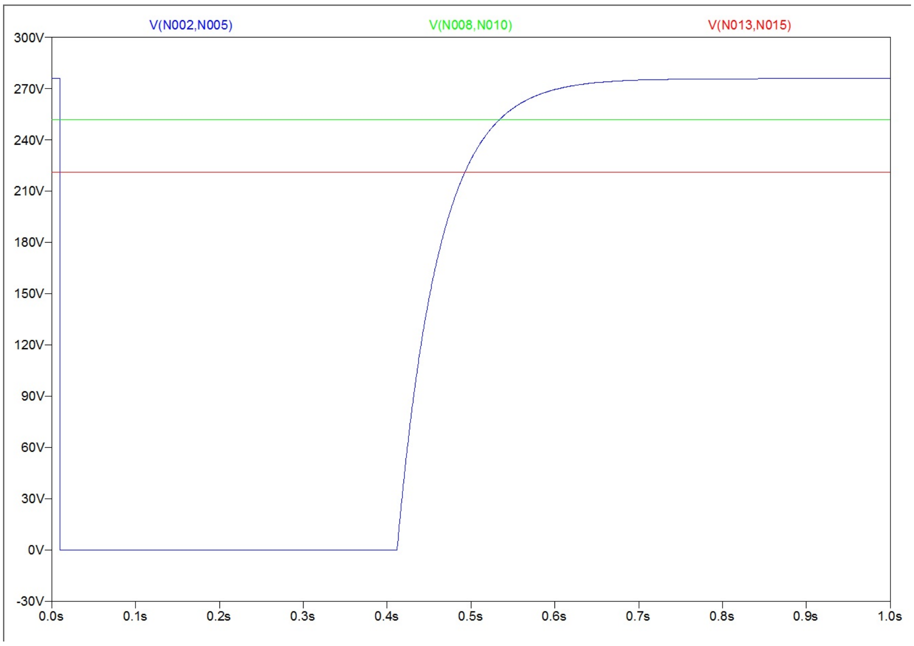

Figure B.3: Voltage differences for a discharge in GEM 1 in a 6 independent channel powered triple GEM stack of all GEMs

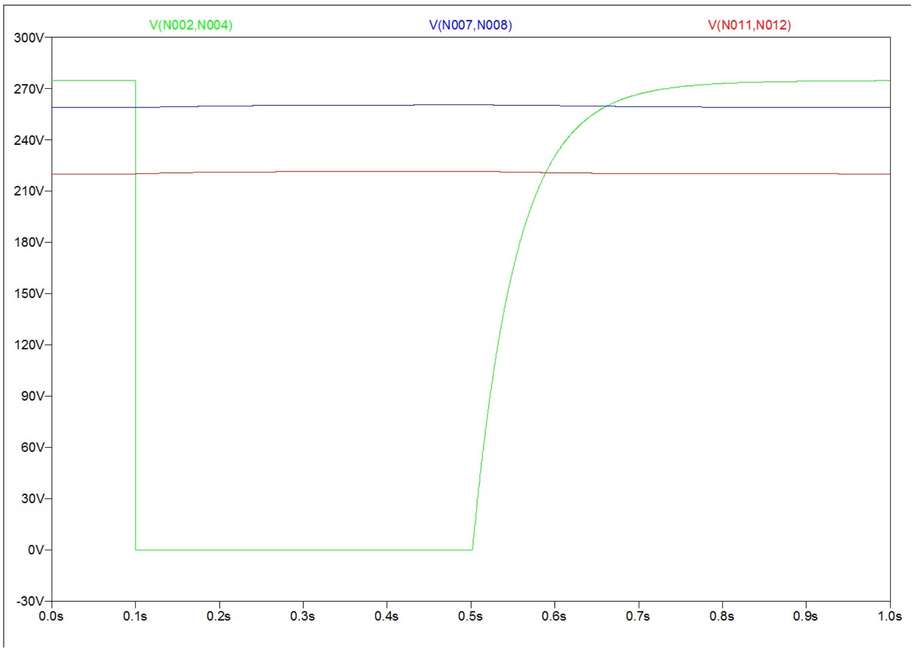

Figure B.4: Voltage differences for a discharge in GEM 1 in a HVD powered triple GEM stack of all GEMs

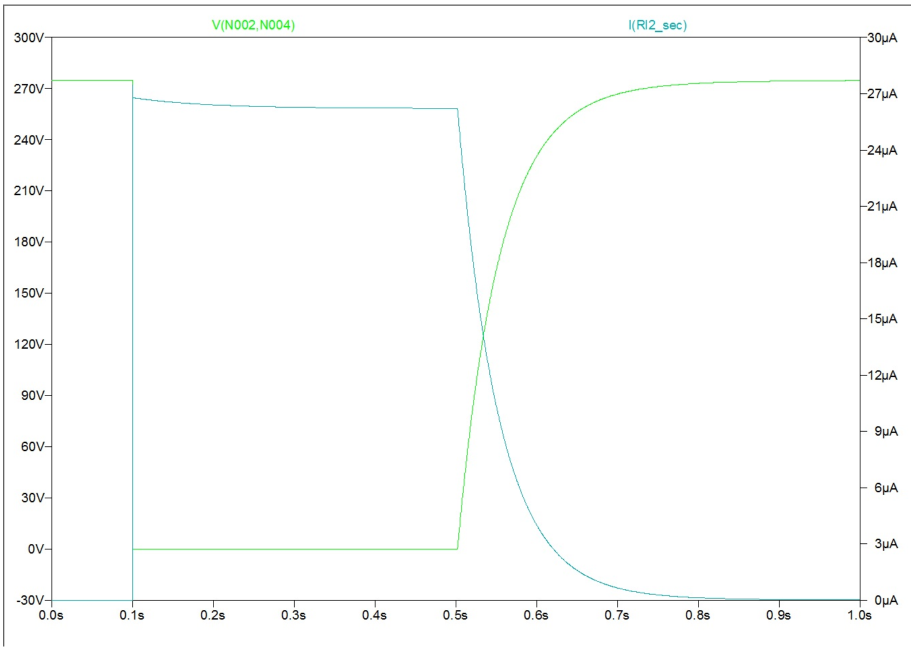

Figure B.5: Voltage difference and current for a discharge in a HVD powered triple GEM stack in one sector in GEM 1

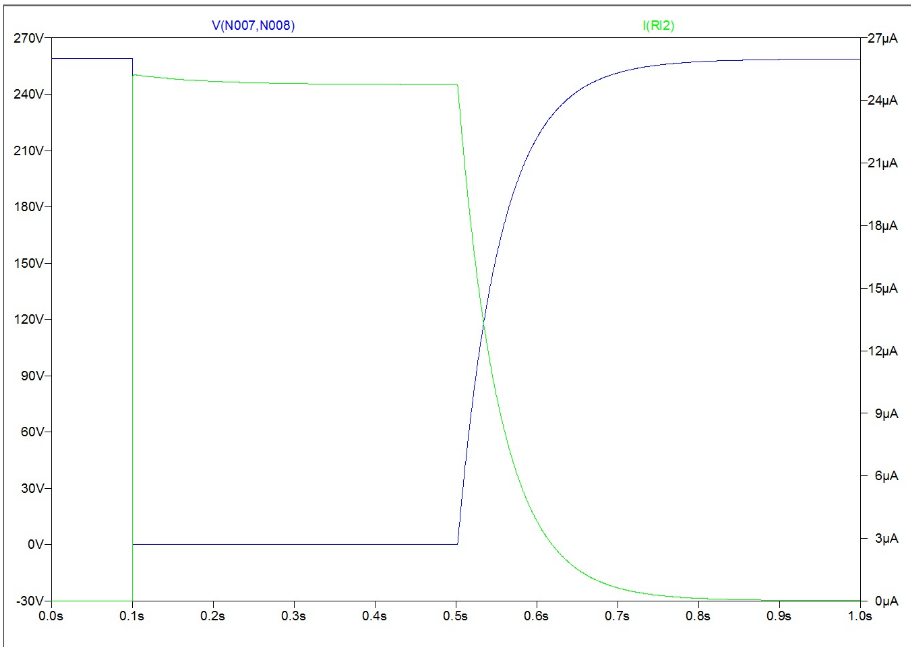

Figure B.6: Voltage difference and current for a discharge in a HVD powered triple GEM stack in one sector in GEM 2

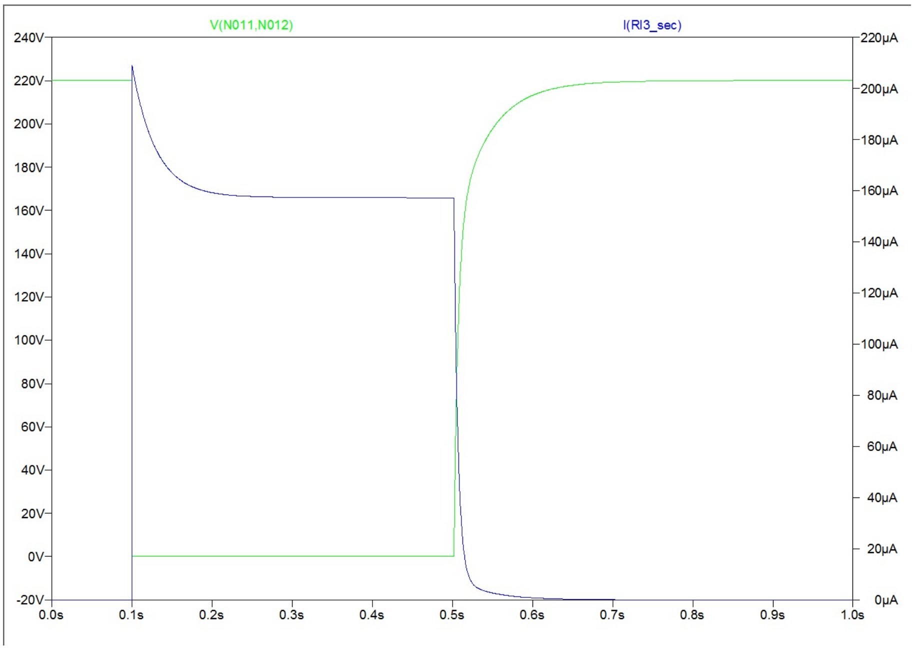

Figure B.7: Voltage difference and current for a discharge in a HVD powered triple GEM stack in one sector in GEM 3

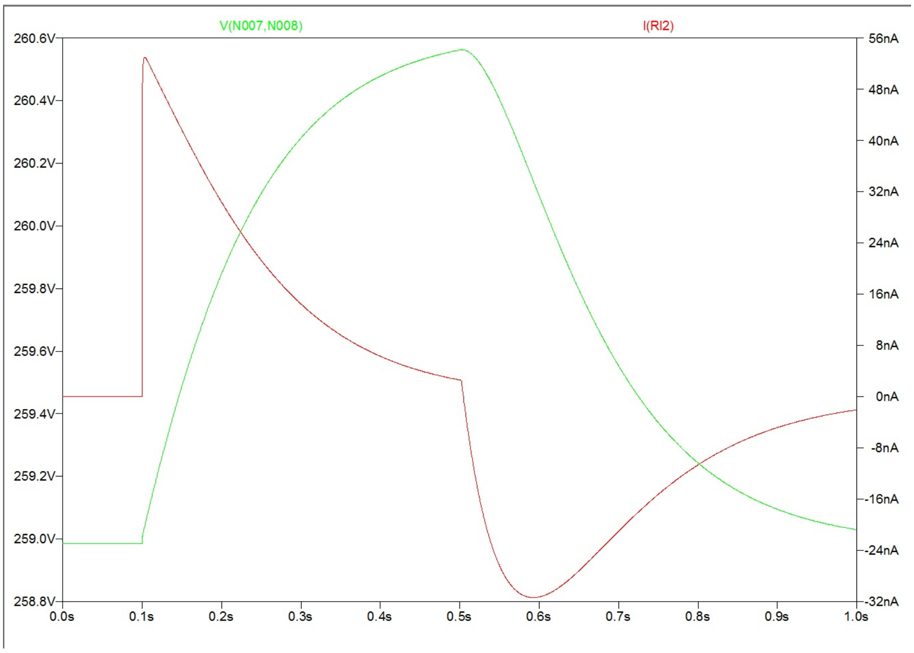

Figure B.8: Voltage difference and current for GEM 2 for a discharge in a HVD powered triple GEM stack in one sector in GEM 1

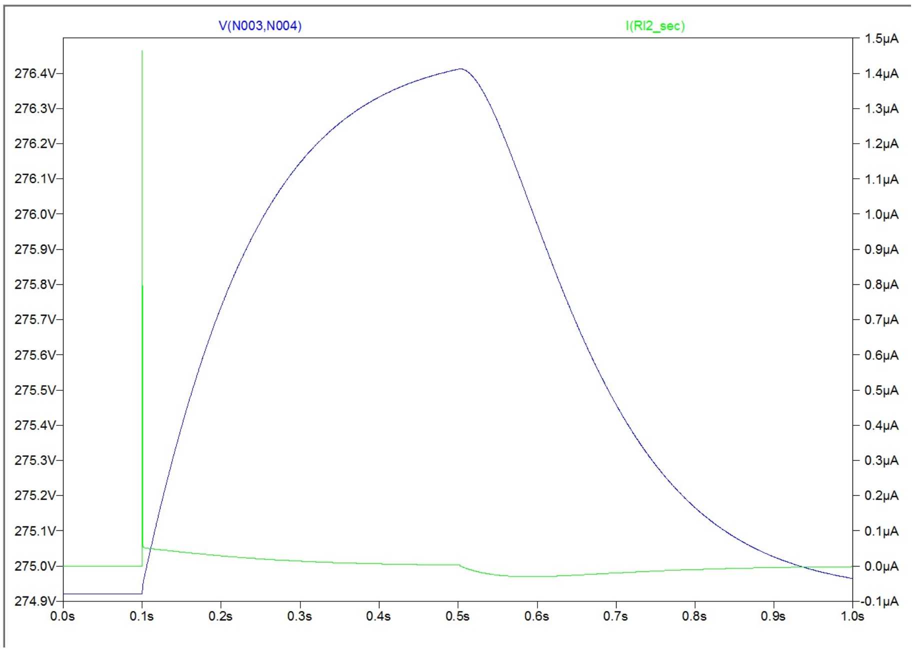

Figure B.9: Voltage difference and current for GEM 1 for a discharge in a HVD powered triple GEM stack in one sector in GEM 2

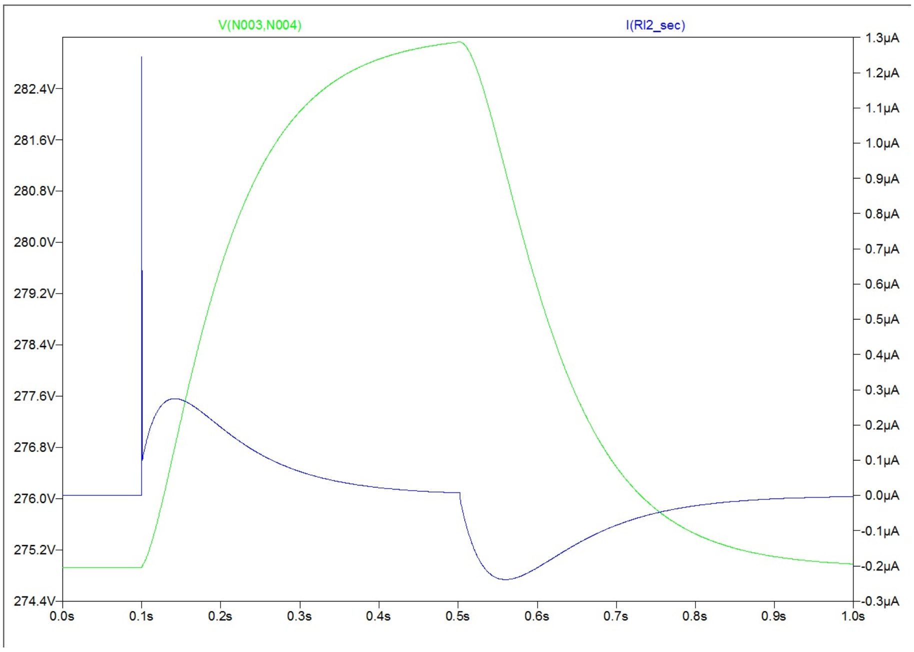

Figure B.10: Voltage difference and current for GEM 1 for a discharge in a HVD powered triple GEM stack in one sector in GEM 3

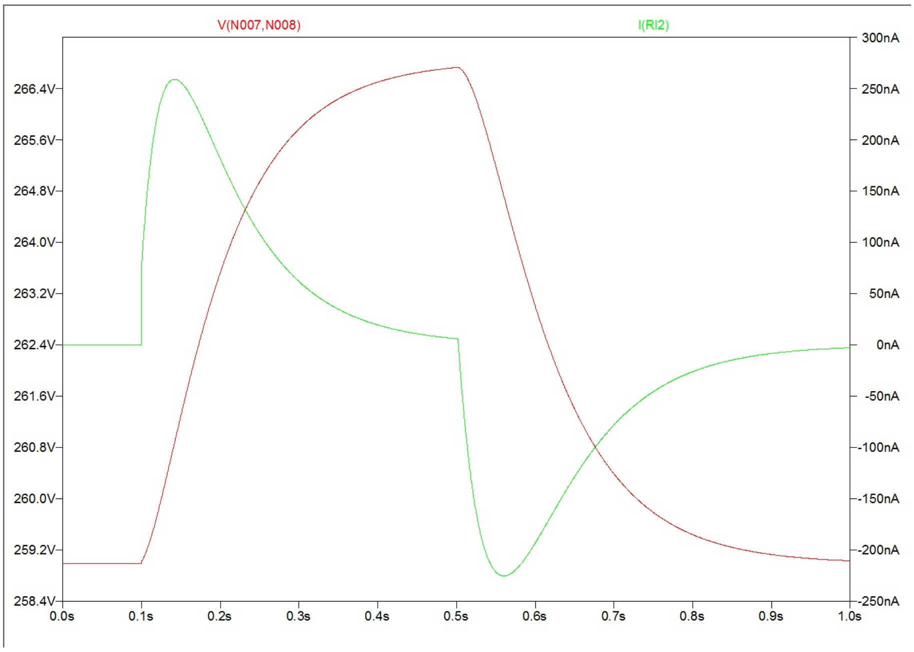

Figure B.11: Voltage difference and current for GEM 2 for a discharge in a HVD powered triple GEM stack in one sector in GEM 3

Bibliography

[1] ALICE Collaboration, *Nucl. Instr. and Meth. A 622, 316*. 2010.

[2] GEM-TPC Collaboration, *Technical Design Study for the PANDA Time Projection Chamber*. June 29, 2012.

[3] D. R. Nygren and J. N. Marx, *Phys. Today 31N10*. 1978.

[4] Collaborations, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*. 2006-2008.

[5] W. R. Leo, *Techniques for Nuclear and Particle Physics Experiments*. Springer, Second Edtion (2009).

[6] ALICE Time Projection Chamber, *picture from the official website*. `http://aliceinfo.cern.ch/TPC/`.

[7] European Organisation for Nuclear Research, *Official Website*. `http://gdd.web.cern.ch/GDD/`.

[8] F. Sauli et al., *Nuclear Instruments and Methods A560*. 269, 2006.

[9] F.V.Boehmer, *Nuclear Instruments and Methods A 719*. 101, 2013.

[10] COMPASS, *Official Website*. `http://wwwcompass.cern.ch/`.

[11] GAS DETECTORS DEVELOPMENT GROUP , *Surface of a typical GEM foil*. `http://www-flc.desy.de/tpc/basicsgem.php`.

[12] GAS DETECTORS DEVELOPMENT GROUP, *Electric fields in a GEM hole*. `http://www-flc.desy.de/tpc/basicsgem.php`.

[13] S. Duarte Pinto et al., *Journal of Instrumentation 4*. P12009,2009. *arXiv:0909.5039*

[14] A. Mathis, *Test of an IROC GEM prototype with low energy protons*. ,2013.

[15] Keithley, *Model 6517B, Data Sheet*. `http://www.keithley.com/products/dcac/voltagesource/application/?mn=6517B`.

[16] Keithley, *Model 6517B, Reference Manual*. June, 2009. `http://www.keithley.com/products/dcac/voltagesource/application/?mn=6517B`.

[17] M. Ball, *Personal discussion and creator of the cable layout*.

[18] Agilent, *Agilent E5810A, User's Guide*. http://cp.literature.agilent.com/litweb/pdf/E5810-90001.pdf.

[19] B. Ketzer, P. Gasik, F. Boehmer, M. Berger, *Operation of the ALICE GEM IROC*. May 1, 2013.

[20] RFcafe.com, *Dielectric Constant, Strength and Loss Tangent*. June, 2009. http://www.rfcafe.com/references/electrical/dielectric-constants-strengths.htm.

[21] National Instruments, *Company*. http://www.ni.com/labview.

[22] Maier-Leibnitz-Laboratorium, http://www.bl.physik.uni-muenchen.de/.