Report of the DESY Summer Student Programme 2015

Sparking Behaviour of GEMs and Setting Up An ALTRO

at the FLC-TPC group

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Abstract

This report is about my work during the DESY summer student programme 2015. The group I was working in, is working on a Time Projection Chamber for the International Large Detector at the International Linear Collider. Gas Electron Multipliers are planned to be used for the readout of its TPC. My task at DESY was to assemble a test chamber to test the sparking behaviour of GEMs. The assembly process is described in this report. Another part of the readout of the TPC is designed to be an ALTRO system. This was set up for small scale testing and the procedure is explained in detail. Finally, it was tried to measure a pulse with help of an ALTRO. How this was tried and why it is still ongoing is discussed.

1 Introduction

The DESY summer student programme 2015, which I was part of, went from the 21 July 2015 until the 10 September 2015. During this time, I was part of the FLC-TPC group, which is working on a Time Projection Chamber (TPC) for the International Linear Collider (ILC). The ILC is a major future collider project. It is supposed to be a linear collider, accelerating electrons and positrons to centre-of-mass energies of up to 500 GeV. High precision measurements of the standard model and hints towards physics beyond the standard model are aims of the ILC. One of its featured detectors, the International Large Detector (ILD), is planned to host a TPC for high precision momentum measurements. More details on the ILC, ILD and a TPC can be found in chapter 2. The TPC for the ILC is designed to use Gas Electron Multipliers (GEMs) for electron multiplication within the readout process and is partially developed at DESY. Another part of the readout system is planned to be an ALICE TPC Read Out (ALTRO), which is developed at Lund University.

A problem arising with GEMs are sparks. The sparking behaviour of GEMs had recently been tested in my group outside of a TPC environment. In particular, the electric field was missing. My task during the DESY summer student programme was to assemble a test chamber, in which the sparking behaviour of GEMs in an electric field environment could be tested. This is described in chapter 3.

A second task was to set up an ALTRO system. This was previously done by people from Lund University. In order to use an ALTRO for small testing purposes it was required to understand how to set up such a system. A detailed description of how to do so can be found in chapter 4. Furthermore, it was intended to measure the reaction of an ALTRO to a pulse, since this is required for simulations. Why this did not work out during the summer student programme is also described in chapter 4.

2 ILC, ILD and TPC

2.1 The International Linear Collider (ILC)

The ILC is a future linear collider. Electrons and positrons are supposed to be collided at the ILC at a centre-of-mass energy of $\sqrt{s} = 500\,\text{GeV}$. Circular colliders are not very effective for accelerating electrons and positrons to these high energies, due to high energy losses through synchrotron radiation, which scales with the inverse of the radius [1]. A sketch of the most recent layout of the ILC can be found in figure 1. The ILC will provide space for two detectors, which will not be able to be used simultaneously though. One of these detectors is the ILD, described in the next section. Goal of the ILC is to make high precision measurements of the standard model and to find physics beyond the standard model. It is argued that

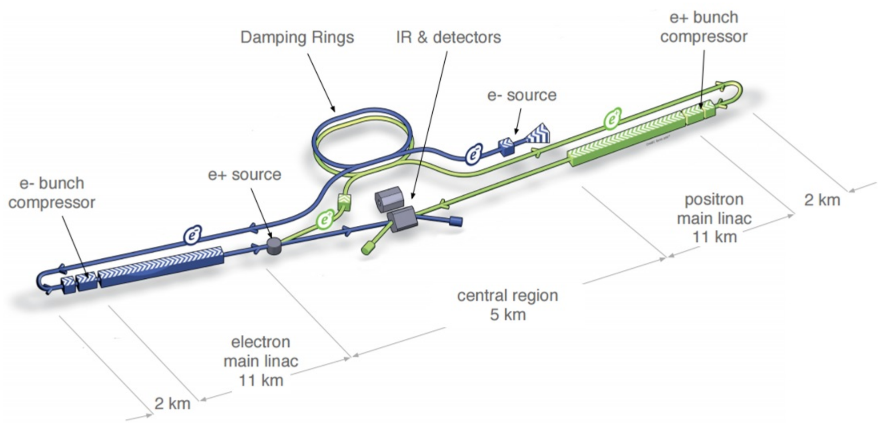


Figure 1: The most current layout of the ILC [2].

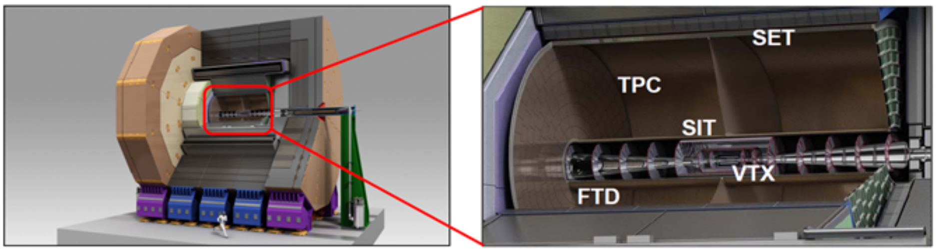


Figure 2: A sketch of the planned setup of the ILD and its tracking detectors [3].

both of these points should be possible with electrons and positrons at energies of 500 GeV, since they are thought to be elementary particles and collisions of these are far better understood than for protons, for example. It is often highlighted that the precision measurements are needed for the found Higgs like particle, for which it is not clear yet, whether it fulfils all properties predicted by the standard model.

2.2 The International Large Detector (ILD)

The ILD is a detector that is planned to be installed at the ILC. A sketch of it can be found in figure 2. The inner most part of the ILD is a vertex detector. It is followed by a Silicon Strip Detector (SIT) and a Time Projection Chamber (TPC). Silicon Sensors (SET) shall surround the TPC. In the end caps, we have the Forward Tracking Detector (FTD) and the End cap Tracking Detector (ETD). All of these detectors make up the tracking detectors to measure the momentum of a given particle. The tracking detectors are followed by the Electromagnetic Calorimeter (ECAL), the Hadronic Calorimeter (HCAL) and a muon chamber. ECAL and HCAL are used to measure the energy of the particles produced in the interaction. Combining momentum and energy measurements, the mass of a constituent can be calculated. The magnet for bending the tracks of charged particles and making momentum measurements is supposed to be located between the HCAL and muon chamber and its strength is planned to be 3.5 T [1].

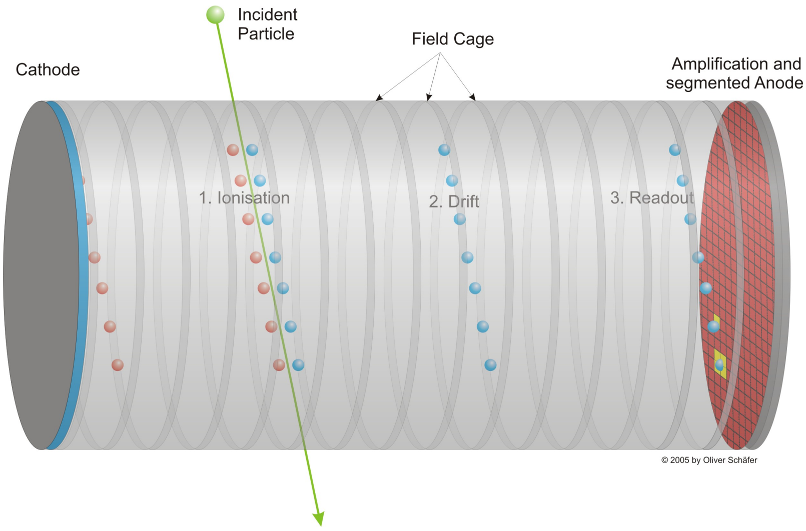


Figure 3: Working principle of a TPC. Courtesy of Oliver Schäfer.

2.3 A Time Projection Chamber (TPC)

A TPC is a type of tracking detector and is planned to be used at the ILD. The structure of a TPC is a gas filled cylinder with two end caps. The idea is that particles collide on the axis of the cylinder and produce charged particles moving away from the vertex. The charged particles ionise the gas inside of the TPC, producing ions and electrons. By applying an electric field to the end caps, the ions and electrons will move to one of the two sides of the end cap. For that reason, the electrons are called drift electrons. By installing readout instrumentation at the end caps, the projection of the track of the charged particles can be measured. By also measuring the time at which a hit was registered, one can calculate the third dimension of the tracks. Thus the name Time Projection Chamber. The third dimension calculation requires a certain number of registered points. In comparison to a silicon tracker, a TPC can measure more points of a track while having less resolution per point. A scheme of a TPC and its working principle can be found in figure 3.

2.3.1 The TPC at the ILD

The TPC planned to be used at the ILD shall consist of a cathode in the middle and an anode in each end cap. Its readout is designed to detect the drift electrons. Therefor, the number of incoming electrons is to be multiplied with Gas Electron Multipliers (GEMs), which are explained in the next chapter. The multiplied number of electrons is then measured on so-called pad planes, of which an image can be found in figure 4. These measure the charge as follows: An incoming electron has an electric field around it. This induces a current on some of the pads, which is usually going to be more than one. Finally, the electron is going to reach one pad and a negative current will occur on the other pads, since the net charge has to be zero there. Without the electron multiplication by the GEMs, the signal of the drift electrons would not be recognisable on pad planes. The signal of the pad planes is planned to be processed by an electronic system called ALTRO, which then sends it to a computer.

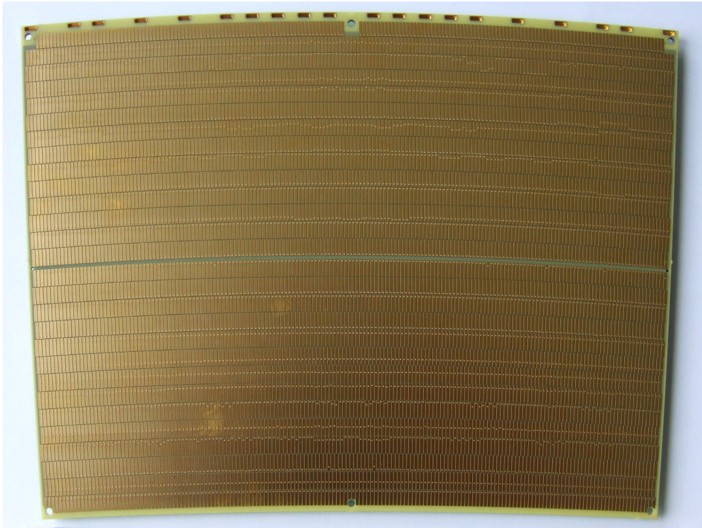


Figure 4: The pad planes for the readout of the TPC at the ILC.

3 Gas Electron Multipliers and their Sparks

The group I was working in during my summer student programme wants to use Gas Electron Multipliers (GEMs) to amplify the drift electrons inside the TPC of the ILD. A problem occurring with GEMs are sparks in them. My task was to assemble a test chamber for testing the sparking behaviour of GEMs in a TPC-like environment.

Before describing what I actually did, which problems arose and how they were solved, let me give a short introduction to GEMs, why they spark, why this matters and attempts to solve this.

3.1 The working principle and design of GEMs

A GEM is an electric device to multiply a certain number of electrons. The GEMs planned to be used for the ILD TPC can be found in figure A.1 and a under an electron microscope in figure A.2. The GEMs on these pictures have a thickness of 60 µm, consisting of a 50 µm kapton layer, coated by a 5 µm copper layer on both sides. The holes have double coned walls and at its maximum a diameter of 70 µm. They are separated by about 140 µm. The hole size and distance determines the spatial resolution of the multiplication of a GEM. GEMs are worked in a gas environment, the gas often being argon based and in this case the same as inside the TPC. A voltage difference is applied between the top and the bottom copper layer, creating large fields in the holes. Incoming electrons are then accelerated vastly, ionise the gas and the resulting electrons are then again accelerated in the direction of the incoming electron. Such, the incoming electron is multiplied. An illustration of this process can be found in figure A.3. The yellow lines stand for electron tracks, the red ones for ion tracks. The yellow line coming from the top represents the path of an incoming electron. It can nicely be seen how a single electron is multiplied. Also, the spatial variance of the produced electrons can nicely be seen. Visible in figure A.1 is a GEM with a ceramic frame attached to it. This is for stability reasons. Also, the four areas created thereby are referred to as four sectors and will be explained further down. The strips visible at the bottom of the GEM connect it to a power supply.

There are many aspects contributing towards the multiplication rate of a GEM. First of all, there is the thickness of a GEM. The thinner a GEM is, the less voltage difference is required to reach a large multiplication rate, since the field strength decreases with increasing distance. The kapton between the copper layers makes the electric field in the holes stronger than without, since kapton's dielectric constant is higher than the used gases. By choosing a small hole size, the multiplication rate is increased in comparison to larger one. The wall shape of a hole, e.g. a double cone, can also influence the multiplication rate of a GEM, as the wall of a GEM hole is charged which can change the property of the electric field inside the hole.

For a TPC application the thinness of a GEM is helpful, since it gives the possibility to make the readout small. If GEMs were a couple of centimetres thick for example, they would block parts of the detector.

3.2 GEMs and Sparks

A problem occurring with GEMs are sparks between the two copper layers in the holes of the GEMs. But how does a spark develop? If an electron is multiplied by a GEM, it leaves behind ions. The copper layers are charged. Should there now be many incoming electrons at once, then many ions are produced as well. If this number exceeds a certain limit, an ion channel becomes possible and electrons from one copper layer can move to the other one, creating a spark inside of the hole, discharging the GEM. If the surface area of the copper is big or the voltage difference large, the spark will consist of more electrons, since there is more charge available. It may happen that a chemical reaction takes place at the edge of the kapton, if a spark consist of a sufficiently high amount of electrons. This chemical reaction leads to a carbon bridge, which has a conductivity in the order of $10\,\mathrm{k}\Omega$. By these means, a permanent connection between the two sides of a GEM is created. That is to say the electric field strength of the GEM is a lot less than before, or, the GEM is broken.

To reduce the probability carbon bridges, one copper layer of a GEM is divided into four parts, called sectors. The other layer is left whole and called common layer (COM). Figure A.1 shows a GEM consisting of four sectors, divided by the ceramic frame. Unfortunately, carbon bridges occur still with divided GEMs. The reason therefor is not understood yet. Investigation is ongoing and I was part of this group during my summer student programme.

One approach was looking at multiple sparks. This describes a spark not only in one sector, but on several sectors within 20-200 ns. Therefor, a simulation of a spark occurring in a multi sector GEM was done. The result can be found in figure A.4. Visible here is the surface current after a spark happened in the top left sector. The scale is a rainbow scale from blue to red, where blue refers to the least and red to the largest current value. Since we are only interested in a qualitative description, no scale is given. It is visible that after the spark occurred a current wave develops that moves across the first sector where the spark emerged. Via the common layer this wave propagates to the other sectors, generating a current there as well. A current always means a redistribution of charge. In this case, it means that there will be areas where charge is piling up, namely where the current is zero. But piled charge makes a spark more likely. Actually, this does not hold for the initial sparking sector, as the first spark reduces the charge on it significantly. For the other sectors though, the spark probability rises. This simulation is currently the working hypothesis why multiple sparks are developed.

To prevent them, a low pass filter, which can be seen in figure 5 was installed to each channel of the GEM. The effect of these filters was tested by putting GEMs into an N_2-gas environment and applying high voltage differences between the sectors and the COM. This was done with and without low pass filters connected between

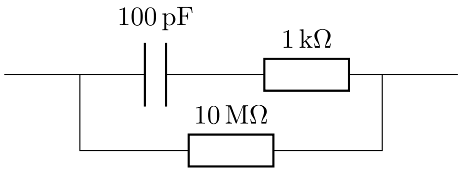


Figure 5: Circuit diagram of the low pass filter used. The left end is connected to the voltage supply, the right one to the GEM.

the GEM and the power supply. The voltage was increased step by step and the sparking behaviour analysed, detecting sparks optically with a camera. Additionally, an oscilloscope was connected, to be able to measure the oscillations predicted by the simulation presented in figure A.4. Increasing the voltage was stopped after a carbon bridge was formed. The GEMs used for these tests had at least one broken sector already. It turned out that the maximum voltage increased. It could be raised from 640 V to about 700 V with the low pass filters, whereby sparks appeared more frequently at 700 V before one sector broke. The oscillations on other sectors could be reduced, as can be seen in figure A.5. However, the testing environment was not very similar to the environment a GEM will have to endure inside a TPC. A major absence was the electric field inside a TPC.

3.3 A test chamber for sparking tests

My task during the summer student programme at DESY was to assemble a test chamber, in which the sparking behaviour of GEMs could be tested in more realistic environment. Realistic refers to its application inside a TPC. It meant adding an electric field. The test chamber itself was already existing and can be seen in figure A.6. It has an acrylic glass cover, which allows optic measurements. The GEMs have to be installed on a special module which is then installed to the chamber. This module can include a pad plane. and the one we used can be seen in figure A.7. It does not include a pad plane, but only holes for connections and pillars to mount things on top, such as GEMs. The idea is to install three GEMs on it at the end.

The electric field in the test chamber is either generated by the pad plane and a cathode, which is a copper frame with a copper net in the middle, or by a dummy electrode, realised with a copper plate, and the cathode. We used a copper plate. To smooth the electric field and its boundary effects, there are field strips and a copper rectangular with a opening for the module, called the anode. The position of cathode, anode and module can also be seen in figure A.6.

My job was to mount a GEM and the described copper plate onto the module and install it in the test chamber. Then, the chamber was to be connected to a gas and a power supply and gas tightness as well as correct operation of the electric components was to be checked.

Whenever using the pronoun "we", I am referring to Oleksiy Fedorchuk and myself, who carried out most of the lab work together.

3.3.1 High voltage connections and the electric field

We wanted to test the sparking behaviour of one GEM inside the test chamber. So, six electronic connections to the module were needed, four for the four sectors of the GEM, one for the COM and one for the copper plate. As we were going to use voltages up to 1500 V, everything had to be high voltage secure. We wanted to attach low pass filters to each channel of the GEM and wanted everything to be flexibly exchangeable. So, we decided to build a circuit board which would be connected with plugs and contain five low pass filters for the GEM (four sectors + COM) and one connection for the copper plate. It can be seen in figure A.8. The capacitors of the left and right outer two low pass filters have a voltage resistance of 2 kV and the one in the middle has a voltage resistance of 5 kV. Soldering the circuit board was a challenge, since we were using pre-used capacitors, whose legs were partially quite short and coated in solder and thus hard to connect to the conductor board. To compensate for the short legs, bare wire had to be used which was hard to install. Also, due to lack of knowledge, a quite low soldering temperature was used, which made things more complicated.

The circuit board, which I will call module board from now on, was screwed to the module and a metal box would be installed behind the module to the chamber, to provide high voltage connectors and security. The connectors of the metal box would thereby be connected to the module board.

Cables used to connect the metal box, the copper plate and the GEM with the circuit board were also prepared. Extra isolation of cables and plugs was provided by shrinking tube and a crimping tool had to be used to manufacture the plugs. Also, at the beginning, the cables from the metal box to the module board were made too short, making it impossible to connect these two. A picture of the metal box with all related cables and parts can be found in figure A.9.

In the next step, the components for the electric field were installed in the chamber (except for the copper plate). This consisted of the anode, 11 field strips and the cathode, which were stacked onto each other with two 2 mm plastic chimes between them. The field strips were additionally held together with a plastic bar. Voltage was provided by a circuit board, which consisted of 20 channels, connected in series, with a 1 MΩ resistor between them. The circuit board shall be called field board. The anode, field strips and cathode cables had cable shoes at their ends and were screwed to the field board one by one, without skipping a connector of the field board in between. Using two cables ending in feedthroughs of the chassis of the chamber, the field board could be connected to a power supply. A bracket connecting the field board to the bottom of the chamber was used to ground the chamber, by connecting it to a third wire ending in a connector in the chassis of the chamber. Anode, cathode, field formers and parts of the field board installed in the chamber can be seen in figure A.10.

The cathode was actually not installed at this point yet, since otherwise the module could not have been installed any more. The preparation of the test chamber was finished. Now, the GEM would be installed on the module.

3.3.2 Connecting a first GEM

The first GEM that we planned to connect to the module had two working sectors. The other two sectors were previously destroyed by carbon bridges. We soldered the cables that were going to be connected to the module board to the GEM. This was done for the copper plate by the electronic workshop, because it could not be soldered. We put all cables of the GEM and the copper plate through the holes of the module and installed the copper plate. Plastic nuts were then screwed to the pillars, to provide a distance between the copper plate and the GEM. When trying to put the GEM onto the pillars of the module, first problems arose. Due to cable stiffness, the GEM could not be put onto the pillars. Instead the cables had to be pulled through the holes while installing the GEM. This was not easy, as the connection to the GEM was fragile. When trying to mount the module in the chamber, it was noticed that little space between anode and module required the cables to the GEM to be connected tightly. At the same time it was noticed, that the point were the cables were connected to the GEM offered too much free metal, which could lead to a spark. So this had to be shortened, meaning that the cables and the GEM were disconnected again. While shortening these connections, some of them were vastly modified and some solder came onto the GEM. Luckily, it hit a broken sector. To reduce the shortcut probability of the copper plate and the GEM even more, a kapton tape stripe was stuck onto the copper plate. Next, the cables were tightened, which involved using two pairs of tweezers, one holding the fragile connection to the GEM, one tightening. Thereby, one connection to a sector on the GEM broke and had to be replaced by another one. All connections to the GEM were checked with a multimeter and the GEM fixed to the module with a nut. Then it was installed inside the chamber. The cathode was installed, the lid screwed to the chamber and all connections to the module board established.

The voltages were connected. Connecting gas did not make any sense, since the holes in the module were open. Apparently, no sink had been installed to the field board and hence the correct voltages could not be applied and the electric field could not be tested. A sink is a connection of a circuit to the ground, which is needed, if two different voltages are wanted to be applied to different parts of the circuit. This is, because voltage supplies cannot take current backflow. A voltage difference of 640 V was put to the GEM and sparks were detected with a webcam. An overlay of all detected sparks can be seen in figure A.11. Making the setup gas-tight was the next step.

In future procedures, I would connect the cables to a GEM as the very last step, since mounting a GEM with cables attached to it was a challenge that could have been avoided. We did not want to remove the cables from the GEM, since we feared that this might break the connections, but in the end we would have destroyed a lot less by doing so.

3.3.3 Solving gas tightness

In order to make our system gas-tight, screws, shims and nuts were used. The screws filled the holes of the module and were conductor at the same time. Cables were connected to the screws with soldering eyelets. These eyelets were installed to the cables of the GEM, while the cables were connected to the GEM, which made things more complicated, due to the fragile connection again. While tightening the screws, which on one side had to happen while the cables were connected, a cable to the GEM tore at the GEM and consequently all cables were unsoldered. The cables to the GEM were stuck to the module with kapton tape, in order to avoid too long free parts. Also, the isolation kapton stripe on the copper plate was renewed. Then the copper plate and the GEM were mounted, the cables soldered to the GEM and tightened. All connections were checked with a multimeter and found to be working. A sink was attached to the anode by connecting a free connection of the field board next to the anode to the bracket of the field board. The cable therefor was produced by me and involved soldering shoes, which were harder to use than the soldering eyelets from before, because the cable was too thin. The module was installed in the chamber, everything closed and attached to the gas, which was N_2 in our case.

To measure the gas tightness of the chamber, the water content of the gas in the chamber was measured. First data showed a water content of about 2000 ppm. We connected the high voltage and tested whether all connections of the GEMs were correct. This can be done by putting a voltage onto certain sectors. If a sector is broken, then you will see the voltage on the COM rising with the broken sector. If it is not broken, only induction effects will be seen. It was then tried to ramp up the voltages to their testing values. In order to achieve an electric field of $240\,\frac{\text{V}}{\text{cm}}$ inside the chamber, which is the field inside a TPC, we had to apply a 2586 V to the cathode and 1050 V to the anode inside the chamber. The voltages given are always with respect to the ground voltage. A voltage of 1050 V was also applied to the broken sectors and the COM of the GEM, while the other sectors were set to 450 V. The voltage on the copper plane was set to 0 V. When trying to ramp up anode and cathode, we noticed that the outputting current of the ground was exceeding the maximum current of the power supply. This was limited to 1 mA. So, we slowly ramped up the voltages simultaneously, such that the current stayed small enough. We concluded that installing an additional resistor in the circuit boards of the electric field would be helpful.

We then examined why the water content was so high in our setup. Therefor, we shortcut the gas pump. The water content shown was still at about 2000 ppm. It turned out that this was due to a dirty mirror inside the water measuring device. After fixing this, the water content was still about 2000 ppm in the chamber. So, we checked for gas leakages with a gas leak detector, which worked by measuring heat capacities of gases. Please note that it is very important to wear gloves when working with a gas leak detector, since it also measures gas coming from skin. Also, wearing a mask is recommended, in order not to alter the gas streams. When testing for gas leaks, we found a great leak at the frame of the module at the back of the test chamber, which keeps the module attached to the chamber. We tried to reduce it, by screwing additional screws into the frame and module. This did not help. In the end, the cause for the leak was that an o-ring had been forgotten when screwing the frame, module and chamber together, but this was only noticed after a second GEM had been installed.

We concluded the chamber being ready for testing the sparking behaviour of GEMs. Our plan was to install a GEM with four working sectors next.

3.3.4 Installing a second GEM

In order to test the sparking behaviour in a realistic environment with a full functioning GEM, a pre-used GEM with four working sectors was installed. We opened the chamber, detached the module from the chamber and removed the GEM. Then we installed the GEM with four working sectors and soldered the connections. This went rather fast, since the cable connections were already existing and the GEM had good connection strips. An additional resistor was added to the anode sink by the field board, the module reinstalled and the chamber closed. Gas and voltages were connected. The voltage differences between the two sides of the GEM were 600 V. Apparently, after some time of testing one sector broke. The reasons are not known and still under investigation.

3.4 Summary

The goal was it to assemble and launch a test chamber, in which GEMs could be tested in a more TPC-realistic environment than before. This goal could be achieved. However, in a first proper test a GEM sector broke. The reason for this breakdown is not clear yet. As a summer student, I could gain great insight into experimental work and how many problems occur. Also, I learnt how important small details can be.

4 Setting up an ALTRO

The second task during my summer student programme at DESY was to set up an **AL**ICE **T**PC **R**ead**O**ut system, abbreviated ALTRO. An ALTRO was used in connection with the Large TPC Prototype at DESY before and was maintained then by collaborators from Lund University. In order to be able to use it for small scale testing, it was a task to set up a smaller lab version operable by the DESY group. In a second step the output of an ALTRO when inputting a pulse was supposed to be investigated. This is of relevance, since simulations run in the FLC-TPC group need this information.

The next subsection deals with the functionality of an ALTRO. Since building up a PCA16-ALTRO readout system, which is the precise description of the used system, needed a lot of effort, it shall be explained in detail in the next but one subsection how to set it up. Following that I will explain the attempted procedure of creating and measuring a pulse and arising difficulties.

4.1 Functionality of an ALTRO

ALTRO is the readout electronics used by the ALICE project at CERN. The system we used is called an ALTRO, because it uses a chip from the original ALICE TPC Read Out. It shall be explained how we are planning to use an ALTRO for a TPC. For details on a TPC please see section 2.3.

After the drift electrons have been multiplied by GEMs they are supposed to be read out. Therefor, they drift towards the pad plane, see figure 4, on which a current is induced in some pads. An ALTRO now integrates this current to measure the charge. The signal is then amplified and shaped. Before digitalisation the signal is offset to keep its negative part after digitalisation. This offset is called pedestal. The signal is digitalised, the pedestal is subtracted and it is checked, whether the measured signal is above a certain threshold. This is done in order not to save data without a signal and called zero-supression. In a final step the ALTRO passes the signal in form of some data to a computer.

An important note is that ALTRO only passes the positive part of an integrated current to a computer, because during zero-supression and pedestal subtraction the negative part is lost. If one imagines a single electron drifting towards a pad plane, then a charge will be induced not only on the pad from which it will eventually be absorbed, but also on surrounding ones, called neighbours. The current on these neighbours will change from positive to negative as soon as the electric field by the electron on the pad decreases. The net integrated current on the neighbours should be zero. On the pad it is absorbed by, this of course is not the case. ALTRO now integrates over certain time periods. There will be negative and positive charge measured on these pads. In total, the charge should be zero though. Since ALTRO only passes on the positive part of this charge, it will not only show a non zero net charge on the pad the electron was absorbed by, but also on its neighbours. The measured charge on the neighbouring pads is called a “fake” charge. Fake charge is a problem in the readout process, since it reduces the precision of the TPC.

A detailed and technical description of the functionality of the used PCA16-ALTRO can be found in [4].

4.2 Building up the system

In this section, a detailed description of how to set up an ALTRO and measure a signal is given. It describes what Oleksiy Fedorchuk and I had to do, in order to build up an ALTRO. Occurring problems will be pointed out.

4.2.1 Required parts

Before starting to put things together one should be aware of what is needed. First of all, the system consists of three general parts:

1. the actual readout cards,

2. the power supplying equipment for the cards,

3. the computers needed for processing the information from the ALTRO cards.

The readout cards consist of the following:

- a Front End Card (FEC), see image A.12, which integrates, amplifies, digitalises and processes the signal [4],
- a Readout Control Unit (RCU), see image A.13, that transfers the signal to a computer and executes the trigger [4],
- a pair of backplanes, divided into a left and a right pair, see image A.14, in order to connect FEC and RCU,
- a trigger box, see image A.15, converting the trigger signal and providing a clock.

Whether a used backplane is a left or a right one, should become clear from a stripe of tape on one side of the backplane containing one of the letters "L" or "R" corresponding to left and right. If the tape is missing, please check [5, p. 10] to find out whether the backplane used is a left or a right one.

Three power supplies are needed. All three of these should be low voltage supplies, i.e. up to about 10 V. Beware that the RCU and FEC may need currents of above 1 A, so make sure to have power supplies that can deliver a couple of Amperes in the low voltage area. The power supplies we used can be seen in figure A.16.

In order to read out the data from the RCU, two computers are needed. One computer actually processes the data, the other one is used to monitor. The two computers can be seen on image A.17. The tall computer is called ilcdaq and processes the data, the small one is called ilcmon and is the monitoring computer. To be able to use the computers, two power supply cables, three network cables, two computer mice, two Swedish (!) keyboards (or at least know the Swedish key assignment), two monitors with power supply cables, of which one needs to be connectable to a VGA port, one VGA cable, one VGA or DVI cable, one optical fibre cable and a special router with power supply are needed. The router mentioned can be found in figure A.18. Make sure to use this router or a similar one, in particular make sure that the used one is not "too intelligent". In our case for example, we were first using a router which was not only redistributing a signal, but also applying DHCP etc. This made a connection to the DESY network impossible. Also, make sure that the network cables are proper network cables and not e.g. IP-telephone ones.

Before proceeding it should be mentioned that the hard drives of the two used computers lundmon and lunddaq were backed up by two bit to bit copies, which are being taken care of by Oliver Schäfer.

4.2.2 Preparing the power supply

First of all the power supplies should be set up. Three power supplies are needed, one with 2.8 V at ≤ 1 A, one with 3.6 V at ≥ 1 A and finally one with 5.2 V at ≥ 1 A. Please note that we set up an ALTRO consisting of only one RCU and one FEC. Hence it may be that the required currents are higher or more power supplies are needed for larger setups. Finding out the correct voltages needed some time. The voltages that can be found in the instructions from former years, [5] and [6], were thereby increased by about 0.2 V to 0.5 V in agreement with the collaborators from Lund.

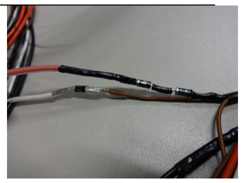
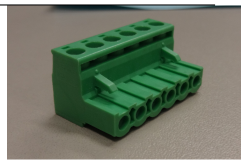
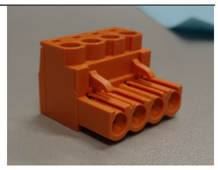
Part	Specification	Amount	Picture
Schottky diode	voltage dropping 0.3 V	3	
6-pole connector	MSTB 2.5/ 6-ST-5.08	2	
4-pole connector	BLZ 5.08/4 -1526660000	1	

Table 1: Specification of the parts used to connect the power supplies to RCU, FEC and trigger box.

The voltage supplies have to be connected to the RCU, FEC and trigger box. Therefor, special plugs and three Schottky diodes are needed. For technical details of these parts, please refer to table 1. How to connect these parts correctly to the power supplies can be seen in figure 6. It is strongly recommended to use the same cable colours as in figure 6, whereby the blue colour cables were replaced by white ones in our setup. The connector orientation in figure 6 is such that the clips of the connectors are facing upwards and the finished plugs can be seen in figure A.19. We did not connect separate cables to the power supply as figure 6 may be read, but instead soldered the cables to each other. The result can be seen in figure A.20.

4.2.3 Installation of the different components

The next step is to connect the computers correctly. Connect the computers to the power, connect keyboards and mice, connect lundmon via VGA to one of the monitors (it has only VGA), connect lunddaq to a monitor, connect the switch to the power and via one network cable to the DESY network.

lunddaq and lundmon have more than one network card. It is important to connect the computers to the switch via the right port in order to have a connection to the DESY network immediately. Put a network cable in the bottom port of lundmon and in the second port of lunddaq and then connect both cables to the router. Attach the optical fibre cable to one of the optical ports on the back of the lunddaq computer. It does not matter which one is used. Turn on the computers. Passwords for both computers can be requested from Ralf Diener. The computers should be prepared. Check that lundmon and lunddaq are properly connected to the DESY network and check by typing `ssh flctpc-lunddaq` into a terminal on lundmon that they are connected to each other. Should either not be the case, inspect the network cables and the router used and make sure that they fulfil the requirements specified above.

The next step is to connect the different cards to each other and to the computer. Also, the trigger has to be connected. It is presumed that the user wants to, as we did, connect only a few/one card. First of all, one takes the RCU. This is connected to the computer lunddaq via the optical fibre cable. Next in turn is the trigger box.

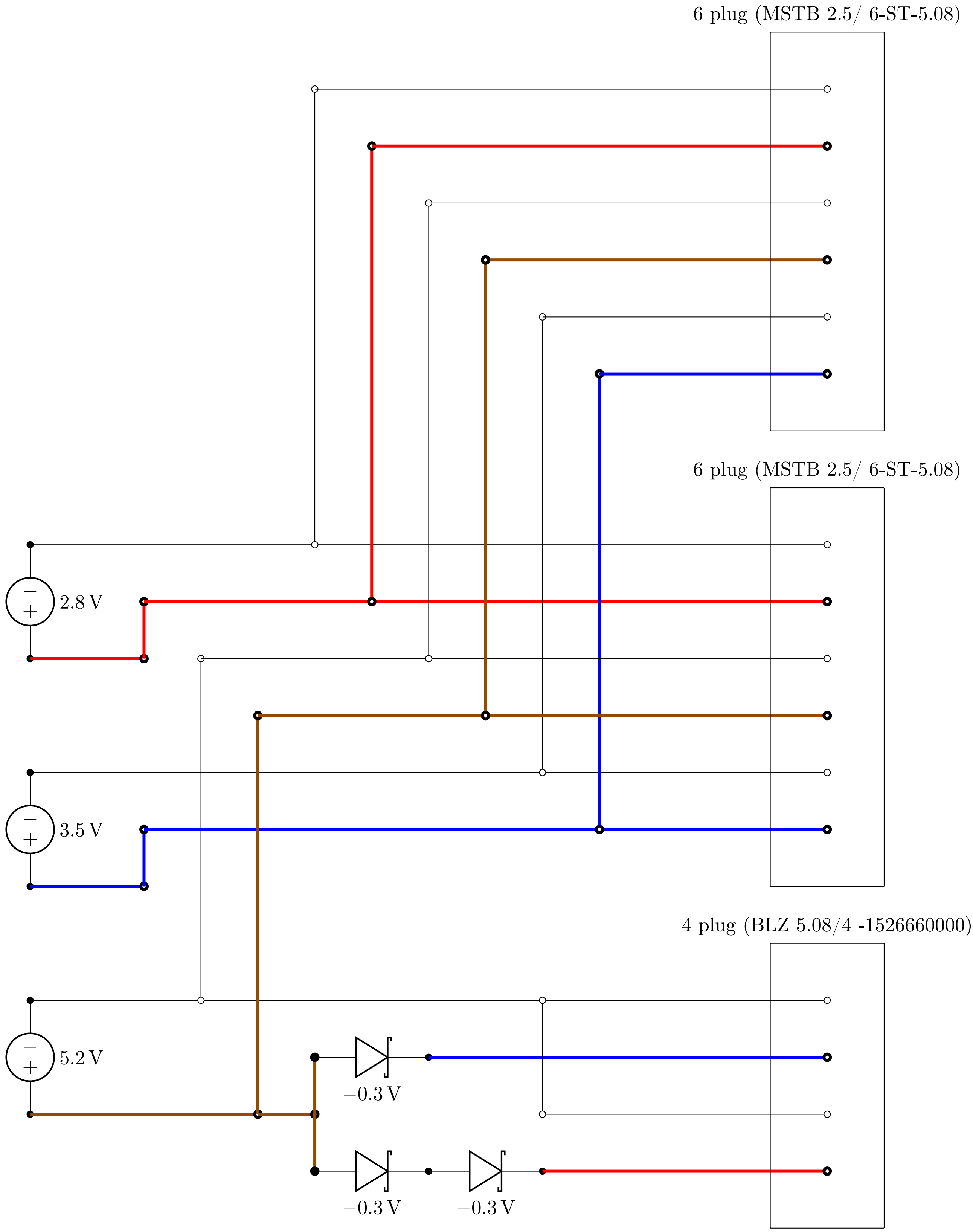


Figure 6: The power supplies and cables used by us. The colours of the connections here correspond to the colours used by us, except for blue having to be replaced by white. The orientation of the plugs is such that the clips of the plugs are facing upwards.

It has four sides. On one side there is a green connector, which is its power supply socket. If one makes this connector point towards oneself, then the clock output is opposite, the TriggerIn is on the left and the TriggerOut is on the right. The trigger box creates the clock for the RCU. A signal connected to a TriggerIn port will be output on the port directly opposite to the input port, but not on others! Connect the trigger signal to the TriggerIn port. Note that this has to be a TTL signal. Connect a Lemo cable to the opposite TriggerOut and connect this to the RCU, where in our case there was already such a cable connected saying “Trigger” on it. Should this not be the case, turn the RCU, such that the plugs are facing towards yourself and the power plug (an orange connector) is facing upwards. Then connect the Lemo cable from the TriggerOut to the right Lemo connector on the RCU. Take another Lemo cable and connect an arbitrary Clock output of the trigger box to the left Lemo connector on the RCU. Again, in our case, such a connection was already established and the cable had a tag saying “Clock” on it.

Next, the backplanes are attached to the RCU. There are two different versions of these called left and right backplanes. Turn the RCU around, such that the power connector is facing downwards. Place the RCU such that the Lemo cables attached to it are exiting on the left side. They might have to be detached before turning the RCU. Left backplanes are now connected to the left visible connectors, right backplanes to the right visible ones. Lay the side of the backplane with one connector on it on top of the connector of the RCU. Since there are two types of backplanes, a big and a small one, make sure that they are lying on the corresponding connector. Also, a left backplane should lie such that its long side is showing to the left, and a right backplane such that its long side is showing to the right. Attach both backplanes, by pushing them smoothly into the plug. A pair of left backplanes being connected can be seen in figure A.21 through figure A.22.

In the following step, the FEC is installed on the backplanes. Therefor, the FEC is put vertically on the backplanes, such that the wide connector of the FEC is facing the wide backplane connector and the same holds for the short connectors. Verify that the little handles on the connectors of the FEC are in up position in order not to block a connection. Firmly press the FEC onto the backplanes and push the handles down. The cards are connected to each other now. An image of this can be seen in figure A.23

Next one can connect a signal to the FEC via the small connectors on the top of the FEC, e.g. with a kapton cable. Also, if using many FECs, one might want to connect some temperature sensors to the FECs. Because we only used one FEC and no temperature sensor was used, this will not be explained.

Before connecting the power supply cables to the cards and the trigger, please check all voltages and make sure that the resistance currents are not set too high. Finally, turn off the power supplies before connecting. Connect the power supply cables to the parts, the 4-pole connector to the RCU, one 6-pole connector to the FEC and one 6-pole connector to the trigger. Then turn on the power for RCU, FEC and trigger. Some lights on the RCU should light up. One of them should turn green, as soon as the RCU is connected to the computer.

The hardware set up of an ALTRO is now finished.

4.2.4 The software

In this section, a brief overview over the software shall be given. For more details, please see to [6].

To start a readout with an ALTRO, log in to lundmon and open a terminal. Enter the command “localdaq”. This will connect lundmon to lunddaq and then start a software with a GUI. Should there be a problem in the software and all the buttons on the left are light blue, a file on lunddaq will have to be deleted. First though, close the GUI, kill all on going terminal processes with ctrl+C and close all terminal windows. Log in to lunddaq and delete the file `ilcserver.pid` in `misc` ▸ `ilcdaq` ▸ `log-v4.7`. Make sure that version 4.7 is still the version used. When we were using the software, we were reading the instructions [6]. In this manual, the used version is version 4.6, resulting in there never being a file called `ilcserver.pid` in the folder we were looking at. Only when checking the symlink that was applied to "localdaq", we found out that we were using a more recent version. It will be necessary to delete `ilcserver.pid` every time "localdaq" is not exited properly by closing the GUI window and killing all terminal processes with ctrl+C.

As soon as the GUI is up and running and the buttons on the left are green or red, one of the RCUs at the top should be coloured red. This means that it has been detected by the software. If this is not the case, click DROCs ≫ Find DROCs and then RCUs ≫ Find RCUs in the menu. Select the backplane slots FECs are connected to, by clicking FECs ≫ RCU being used in the menu. Save the choice done and click "PowOn". All FECs connected should go green in the RCU control bars. Then set the PCA16 settings (PCA16 is the integrator, amplifier and shaper used for this readout system [4]) and click "PcaLoad". Finally click "StartDAQ".

The system is now ready for measurements. Via the bottom options of the GUI it can be specified, what is supposed to be measured. Options are for example a pedestal run, a physics run, activate zero-suppression, whether data shall be logged etc. Start the measuring process with "Start Run". While measuring, the measured data can be viewed, by typing "startmon" into a terminal of lundmon. Then a window appears, from which the measured data can be seen. How to use this window can be found in [6].

When shutting down, type "stopmon" in a terminal window of lundmon, click "Stop Run" in the GUI, click "Stop DAQ" and then "PowOff". Close the GUI and kill all ongoing terminal processes that the GUI opened with ctrl+C. Close all terminal windows.

4.2.5 The ALTRO we set up

An ALTRO was set up as described throughout the last section. At the end we measured some pedestals to show that our system was working. The pedestal in this case is the measured output in case of no input signal. The trigger we used therefor will be described in section 4.3.1. Thus, concluding, an ALTRO system was set up and is working.

4.3 Pulse Generation

4.3.1 Set-up

After having set up and getting an ALTRO system to work, our next task was to measure a pulse from a pulse generator with the ALTRO. Therefor, we needed a pulse generator. The one used can be seen in figure A.24. This pulse generator contained several features. First of all, it could be chosen how the pulse generation should be triggered. This means, when a pulse shall be created. It could be chosen between external trigger, gate, external width and normal. We only used the features external trigger and normal. In normal trigger mode, a pulse period could be chosen at the pulse generator being between 4 ns and 1 ms. Switching to external trigger mode, one could either trigger the pulse generator manually, by pressing a button, or use an external input, whereby polarity and input signal strength had to be specified. In general, a pulse delay time from 2 ns to 0.5 ms could be specified on the pulse generator, the pulse width could be adjusted from 2 ns to 0.5 ms, the strength of the signal could be changed from 0.4 V to 5 V, an offset could be applied to this voltage and one could choose the polarity of the output signal. Additionally, the slopes of the pulses could be modified.

To test the ALTRO electronics during a pedestal run, see above, we connected the pulse generator to the TriggerIn of the trigger box and manually input pulses by pressing the button on the pulse generator. The pulse width was set to a maximum and the amplitude to 2 V and 4 V, since we needed a TTL signal. Before connecting the pulse generator to the trigger box, we checked the signal for correctness with an oscilloscope. When checking the pulse periods that could be chosen, we noticed that if we wanted to measure a pulse with the ALTRO, then the pulse generator would in any case generate a new pulse before the previous pulse had been read out. The pulse generator was "too fast" for the ALTRO. While an ALTRO is ready to read a new signal about every 5 ms, the slowest pulse period was 1 ms. Also, we could not use the output signal as trigger and signal of the ALTRO at the same time, since a delay between signal and trigger was needed. So, an external trigger for the pulse generator and the ALTRO was necessary.

Before explaining how we installed the external trigger, let me mention another problem, that occurred with the pulse generator. At the pad plane inside the TPC, about 2000 electrons are expected to arrive per pad after multiplication. Also, an ALTRO measures charge and not voltages. Since the pulse generator gives voltage pulses, these have to be converted to charge via a capacitor. Since there are usually about 2000 electrons arriving, we wanted to induce a signal in the same range. Using the minimum voltage of our pulse generator being 0.4 V, we got for the capacitance via

$$Q = C \cdot U = 2000 \cdot 1.602 * 10^{-19}\,\mathrm{C} \simeq 3 \cdot 10^{-16}\,\mathrm{C} \Rightarrow C = 7.5 \cdot 10^{-16}\,\mathrm{F} = 0.75\,\mathrm{fF}.$$

Since we did not have any capacitors of this capacitance, we needed to change the calculation: Given $C = 2.5\,\mathrm{pF}$, we got $U \simeq 10^{-4}\,\mathrm{V}$ or 0.1 mV. Since the pulse generator creates a signal with minimum voltage 0.4 V, we would have to use resistors before connecting it to an ALTRO. Also, the pulse generator created cleaner pulses at 1 V than at 0.4 V. How we proceeded with the signal of the pulse generator, will be discussed in section 4.3.3.

4.3.2 The external trigger

As an external trigger, a Nuclear Instrumentation Standard (NIM) size dual gate generator was used. The dual gate generator consisted of two gates. Each gate generator could create a NIM signal of a certain, adjustable length. It could be initiated either by a button or by a starting signal to a start input. As soon as the signal was over, a stop signal was sent to a stop output. Combining the start and stop signals of the two gate, a pulse generator could be created. The available periodic times fitted our requirements. To connect this NIM module, a special rack and its power supply were needed. Installing the power supply to the rack took some time and in the end it was figured out that it had to be pushed in, until it was not possible anymore and then tightened by the screws at the front of the power supply. The dual gate generator installed in the rack can be seen in figure A.24.

A special feature of the dual gate generator we used was that it also provided a TTL output. This meant that we could use the dual gate generator as an input trigger for the ALTRO trigger box as well.

We checked all outputs of the external trigger with an oscilloscope before connecting them to the pulse generator and the trigger box. When checking the signal of the TTL output with a long cable, we noticed that this gave induction and hence disturbed the signal. So, we reduced the cable length. We also had disturbed signals when connecting a voltage divider. Thus, we did not do so, but could not monitor the signal while applying it.

The dual gate generator was connected to the ALTRO trigger box and again pedestals were measured. Also, the dual gate generator was used as external trigger for the pulse generator. The monitored signal with the oscilloscope showed the expected result, but still the amplitude was too high.

4.3.3 Reducing the signal and noise

As mentioned above, the output of the pulse generator had a too large amplitude. At the same time, the question how to connect the ALTRO to our input signal arose. I soldered two cables to a plug fitting to the ALTRO input plug, whereby one cable was for the ground and one for the signal. The result can be seen in figure A.26. It was not needed though, since Oliver Schäfer kindly gave us a device which contained resistors and capacitors and could directly be connected to the ALTRO. The circuit diagram of this device, which I will further call the charge box, can be found in figure A.25. An image of the charge box can be found in figure A.27.

The charge box was connected to the pulse generator via an extra resistor. This was needed, as the charge box did not provide a small enough charge for our purposes. This can be seen, as via $Q = C{\cdot}U$, where $C = 1\,\mathrm{pF}$ and $Q \simeq 3{\cdot}10^{-16}\,\mathrm{C}$, we get $U = \frac{1}{3} \cdot 10^{-4}\,\mathrm{V}$, which should be the voltage at resistor `R4`. The pulse generator generated pulses with an amplitude of $U_0 = 1\,\mathrm{V}$. The voltage at `R4` is, when applying another resistor R, calculated via (`R1` is for preventing cable reflections)

$$U = U_0 \frac{R_4}{R_2 + R_4 + R} \Rightarrow R = R_4 \frac{U_0}{U} - (R_2 + R_4) \simeq 8 \cdot 10^4 \Omega = 80\,\mathrm{k}\Omega.$$

So a resistor of $R = 80\,\mathrm{k}\Omega$ was needed. We used a slightly larger resistor of $90\,\mathrm{k}\Omega$. We tried to measure the voltage at the resistors and the capacitors of the charge box with an oscilloscope. Also, we connected a cable to the charge box that would usually be connected to ALTRO and measured the voltage there. Except for noise, nothing was measured. A sine curve of 1 V amplitude was seen, its frequency being very different from the trigger though. It could be removed by covering the charge box by its metal cover and measuring at the plug of the cable, which could be put through a little slit in the box. Thus, the sine curve was disturbance from the environment. Yet, a signal from the pulse generator was not measured. So, we removed the $90\,\mathrm{k}\Omega$ resistor and measured at the cable at the slit again. The visible image can be seen in figure A.28. As it becomes obvious there, the noise is in the same range as the signal. Hence, when reducing the signal by the $90\,\mathrm{k}\Omega$ resistor, it seems reasonable to measure only noise. To prevent this, first analysis of noise sources should be done and it should then be tried to reduce these.

Unfortunately, this could not be done, due to a lack of time. A signal was not tried to be measured with the ALTRO, since the input was not clear. However, investigation is ongoing.

4.4 Summary

An ALTRO system could be set up and is currently working. A pulse generator including external trigger and charge box was also built up. Yet, as the output signal of the pulse generator system was unclear, only pedestals were measured with the ALTRO.

5 Conclusion and Summary

The test chamber for testing the sparking behaviour in more realistic TPC environment could be set up and is running. Gas tightness of the module could be achieved by screws and gas leaks were related to a missing o-ring. A broken sector in a first tested GEM needs to be investigated further.

An ALTRO system is also up and running. Despite difficulties of required parts and installation at the beginning, the goal could be reached. Due to high noise measured with an oscilloscope, the outcome of a pulse was not measured with the ALTRO system. This requires studying the sources of noise and their reduction and could not be carried out during the summer student programme, but is ongoing.

Concluding, I learnt a lot about experimental particle physics during my time at DESY. It became clear to me how much effort and patience is required. Special thanks to Oleksiy Fedorchuk and Annika Vauth for being my supervisors and helping me so much. Also, many thanks to Ralf Diener and Oliver Schäfer for many fruitful conversations and tips. Finally I would like to thank our group leader Ties Behnke for taking me as a summer student and for his help regarding organisational matters.

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[6] L. Jönsson and U. Mjörnmark. *Instructions for testbeam september 2012 (for daq version 4.6)*, 2012. URL `http://www.hep.lu.se/eudet/daq/doc/instructions-201209.pdf`.

A Appendix

A.1 Pictures of GEMs and the test chamber

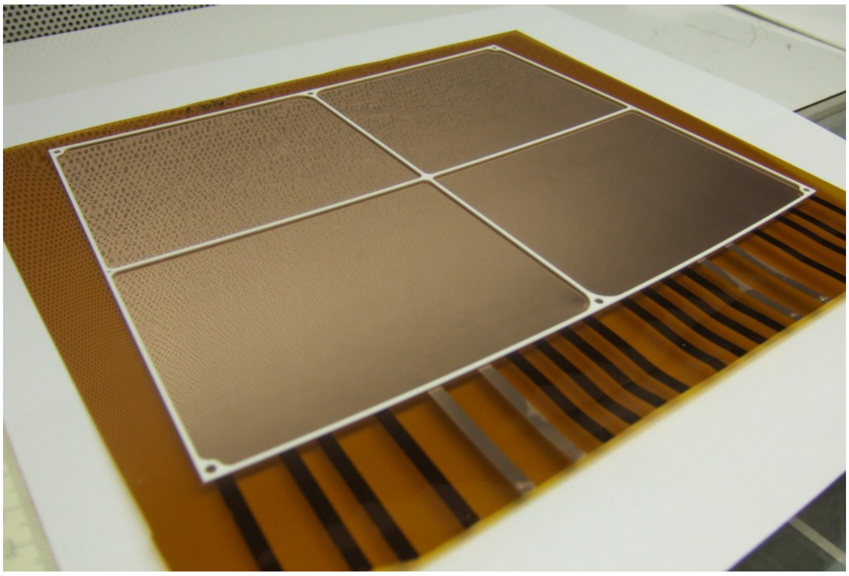


Figure A.1: Picture of a GEM similar to the ones that were used. The strips at the bottom are the connections to a voltage supply. There are four connections for every sector and the COM.

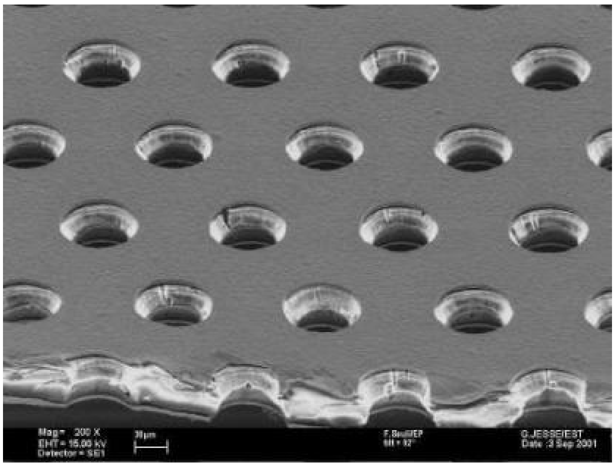


Figure A.2: An electron microscope picture of a used GEM. The kapton can be seen in white at the front of the picture in between the light grey copper layers. The double coned walls of the holes can be seen as well.

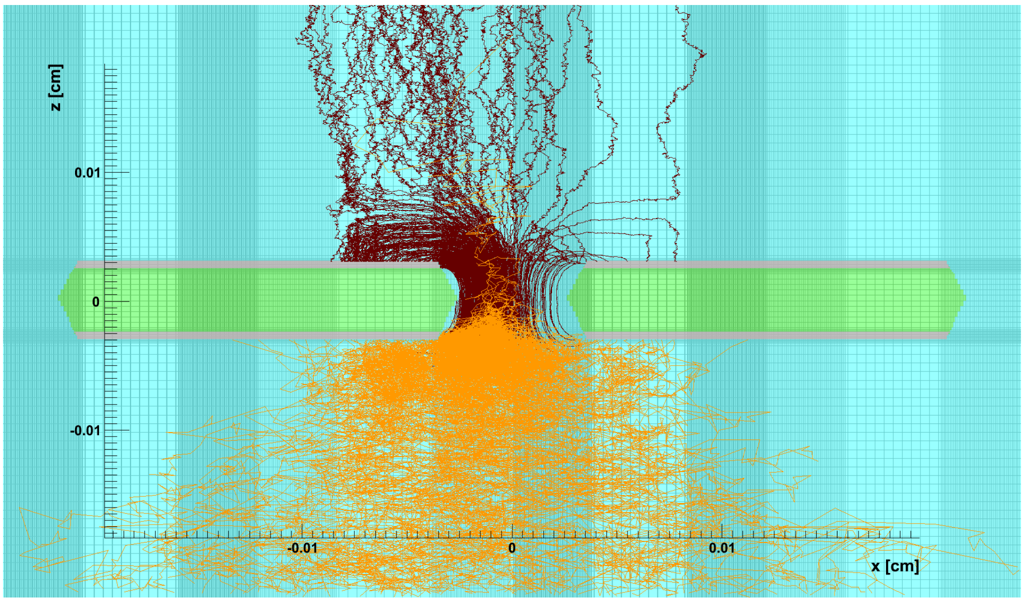


Figure A.3: Process how a single electron coming from the top is multiplied. The yellow lines show the tracks of electrons, the red ones the tracks of ions. Courtesy of Klaus Zenker.

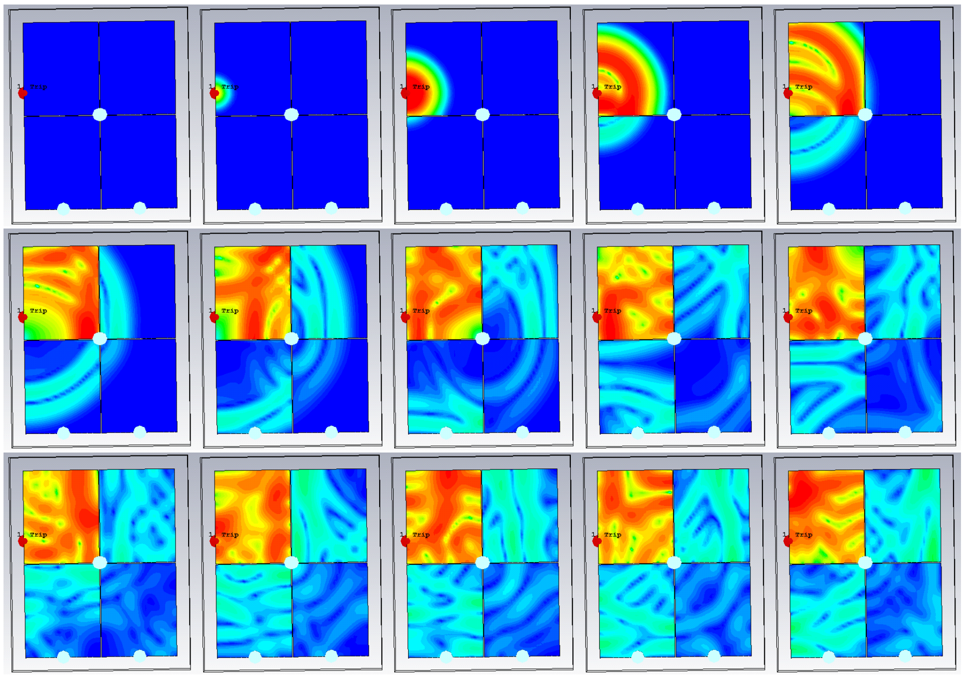
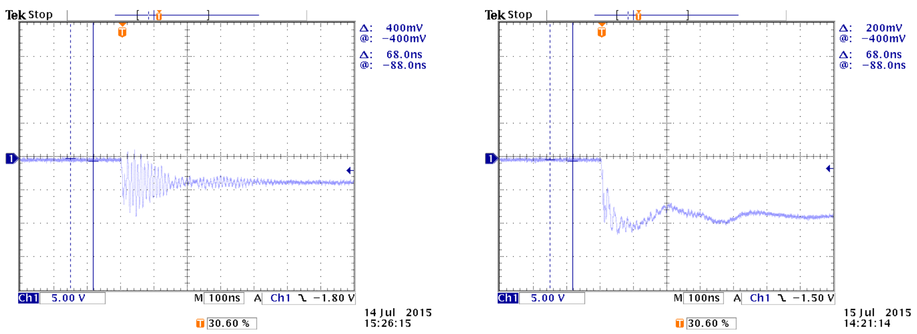


Figure A.4: Simulation of currents on the surface of a four sector GEM. It assumes a spark, called “trip” here, emerging at the red spot. The picture order is from top left to bottom right. The scale used here is a rainbow scale from blue to red, where blue indicates the least and red the most current. The scale is not quantified, since this picture is used for qualitative understanding in this report. The last picture is 1.4 ns after the spark. It can be seen, how current waves propagate over the sectors. Courtesy of Oleksiy Fedorchuk.



(a) (b)

Figure A.5: Showing the oscillation reduction on neighbouring sectors. On the left one sees a GEM connected without any low pass filters, on the right with a low pass filter attached to every connection. The voltage drop of the left and right picture is not the same, as the voltage differences at the GEM were different. Courtesy of Oleksiy Fedorchuk.

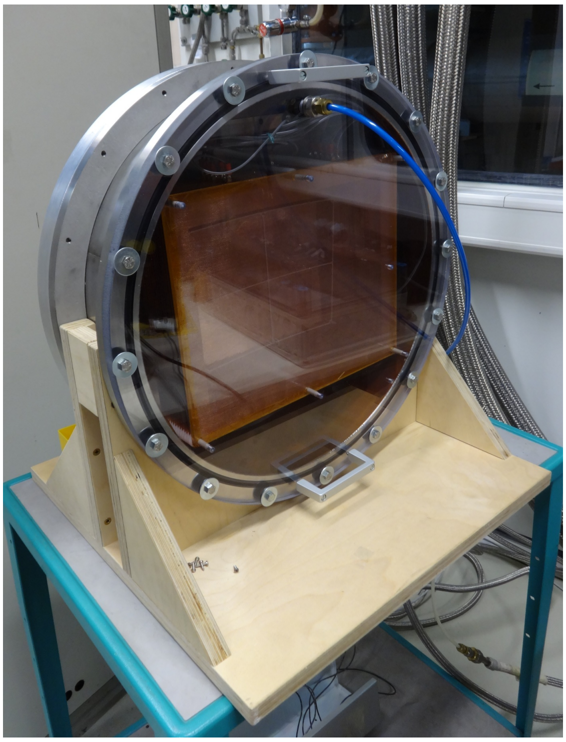


Figure A.6: The pre-existing test chamber. The acrylic glass lid allows optical measurements. In the middle of the picture the second connected GEM with four working sectors can be seen. The copper frame around the GEM is the anode and the copper frame at the top is the cathode.

(a) (b)

Figure A.7: The module used by us from the back and from the front. Courtesy of Oleksiy Fedorchuk.

Figure A.8: The module board installed on the module. Visible are also the screws that made the module gas tight. The big capacitor in the middle had 5 kV voltage resistance and was planned to be used for the COM. All others had 2 kV voltage resistance. On the right one can see the connection to the copper plate. Courtesy of Oleksiy Fedorchuk.

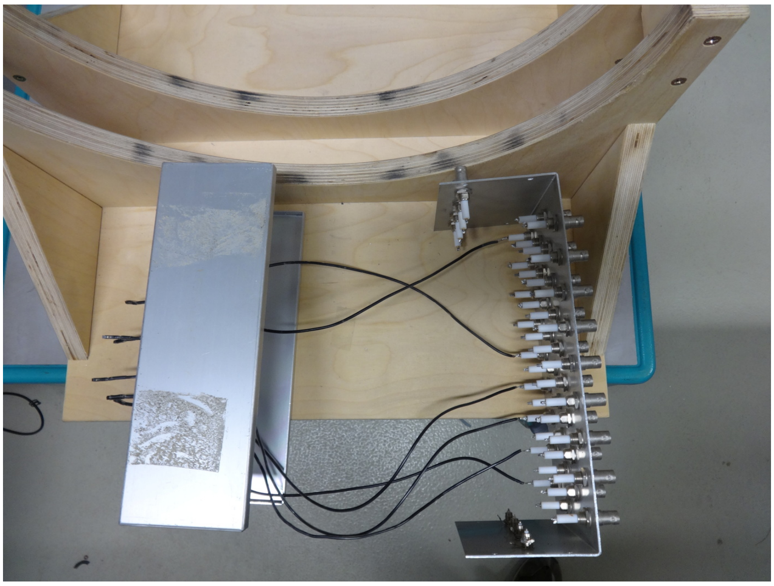


Figure A.9: The metal box, used to connect the voltage supply to the module board with all parts and cables. Also, the metal box was used to prevent the module board from being touchable, while voltage was applied.

Figure A.10: The cathode, anode, field formers and a GEM are visible. At the top, one can also see parts of the field board.

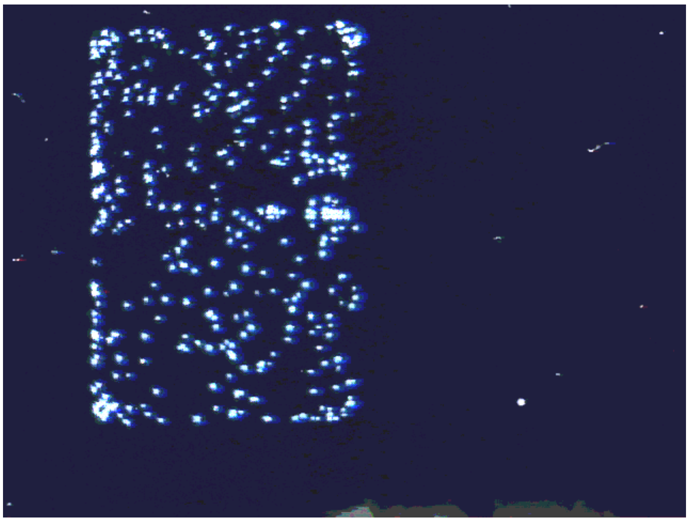


Figure A.11: Picture of overlays of sparks that were optically detected on a two sector GEM at 630 V in air. Courtesy of Oleksiy Fedorchuk.

A.2 Pictures of parts of an ALTRO

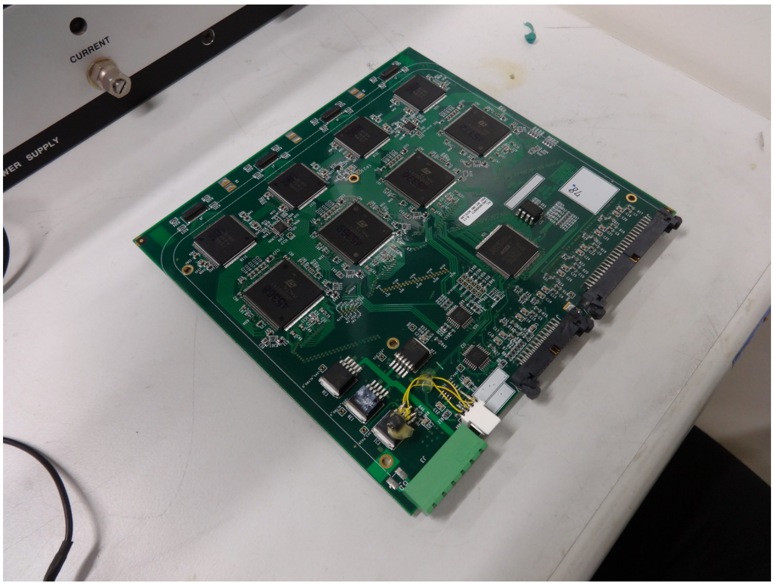


Figure A.12: The Front End Card (FEC).

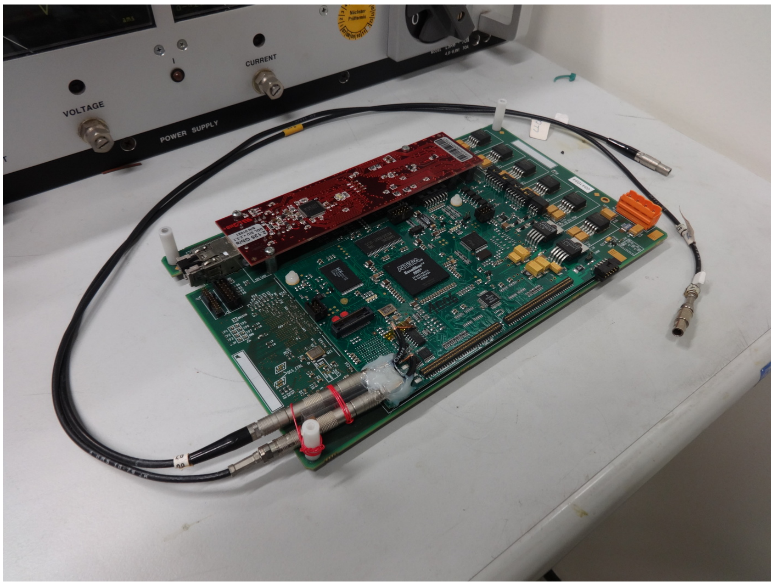


Figure A.13: The Readout Control Unit (RCU).

Figure A.14: A left pair of backplanes.

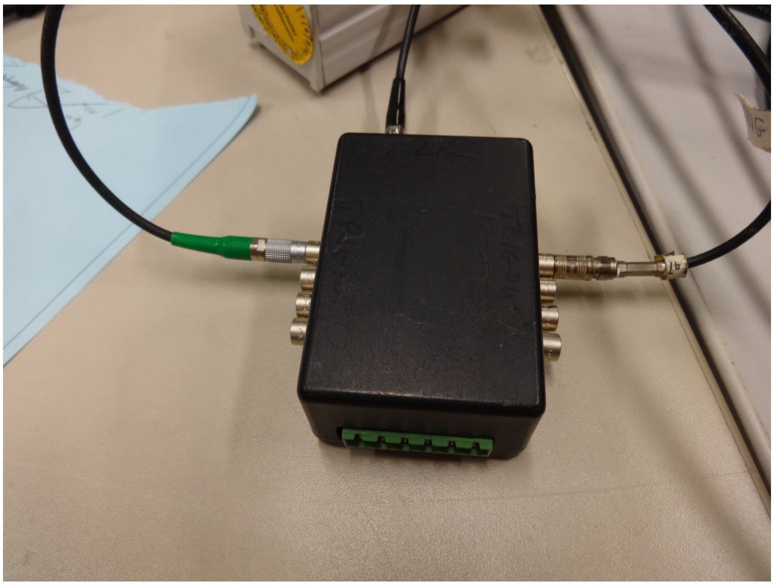


Figure A.15: A trigger box.

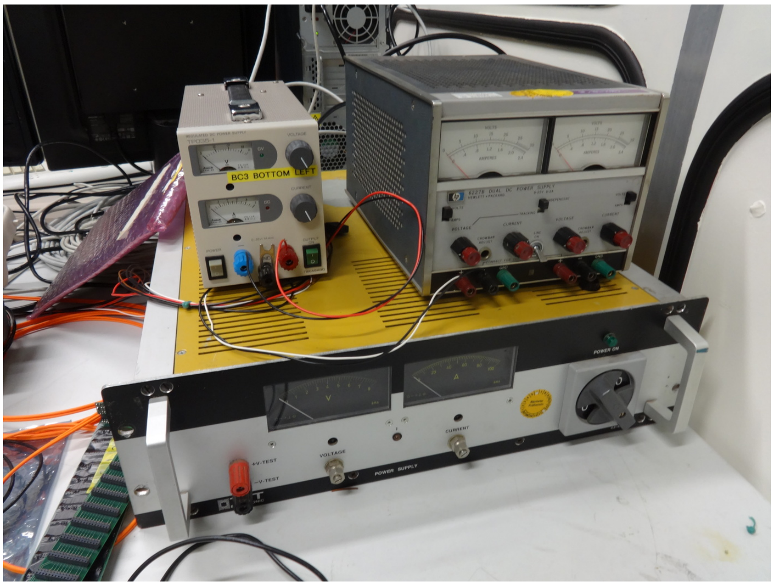
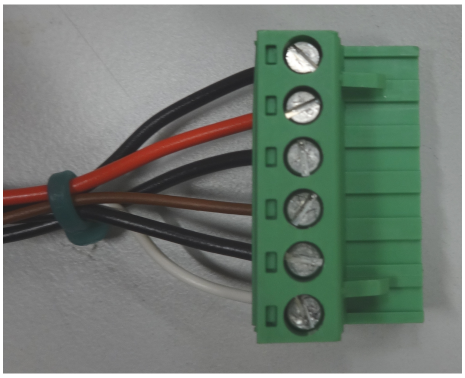


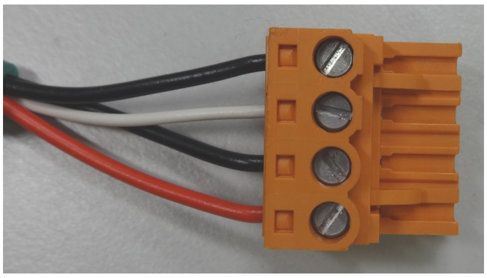
Figure A.16: The power supplies used to power the ALTRO in our setup.

Figure A.17: The two computers needed for an ALTRO. The one on the left is lundmon, the one on the right is lunddaq.

Figure A.18: The router we used for connecting the ALTRO computers with the DESY network.



(a)



(b)

Figure A.19: Power supply plugs with cables connected used in our setup. Please note the colours of the cables.

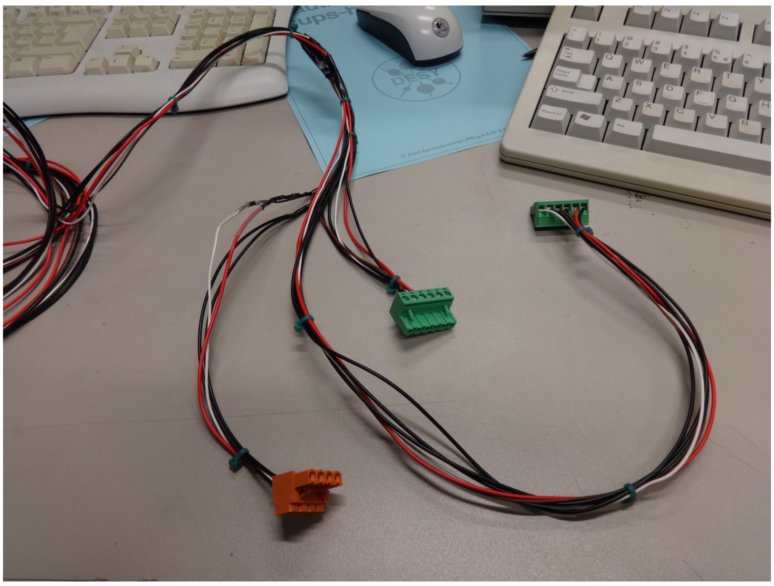


Figure A.20: The cables and plugs used by us in a post manufactured stage. The left end not visible in the picture was connected to the power supplies.

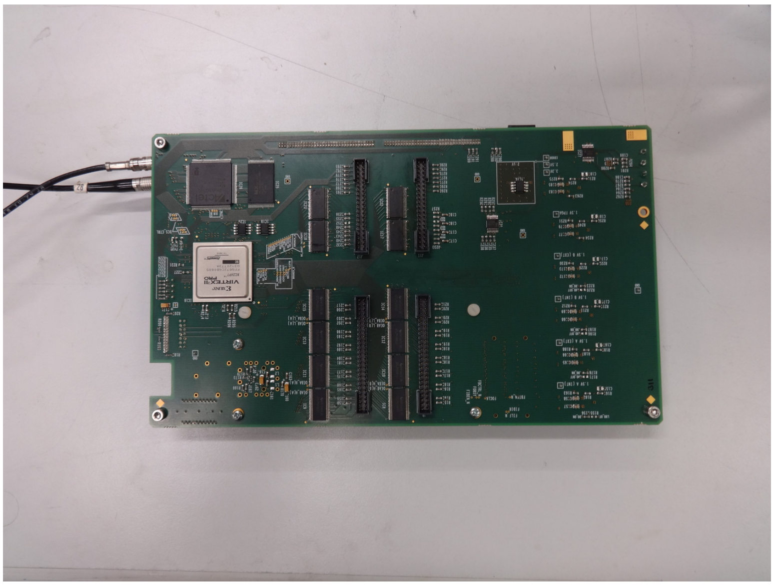


Figure A.21: The backside of an RCU.

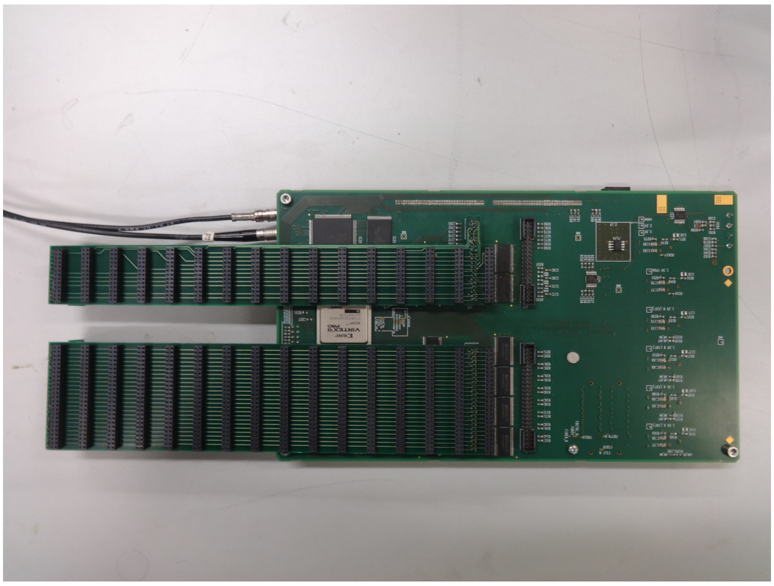


Figure A.22: A pair of left backplanes connected to an RCU.

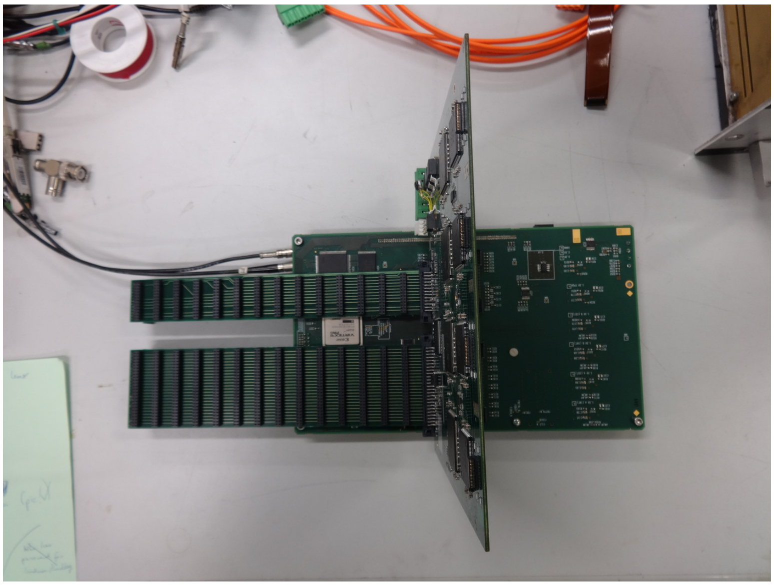


Figure A.23: A FEC connected to an RCU via a pair of left backplanes.

Figure A.24: In the top the pulse generator we used to create a pulse can be seen. Visible at the bottom is the dual gate used by us as trigger for trigger box and pulse generator. Also, one can see the NIM rack and power supply used.

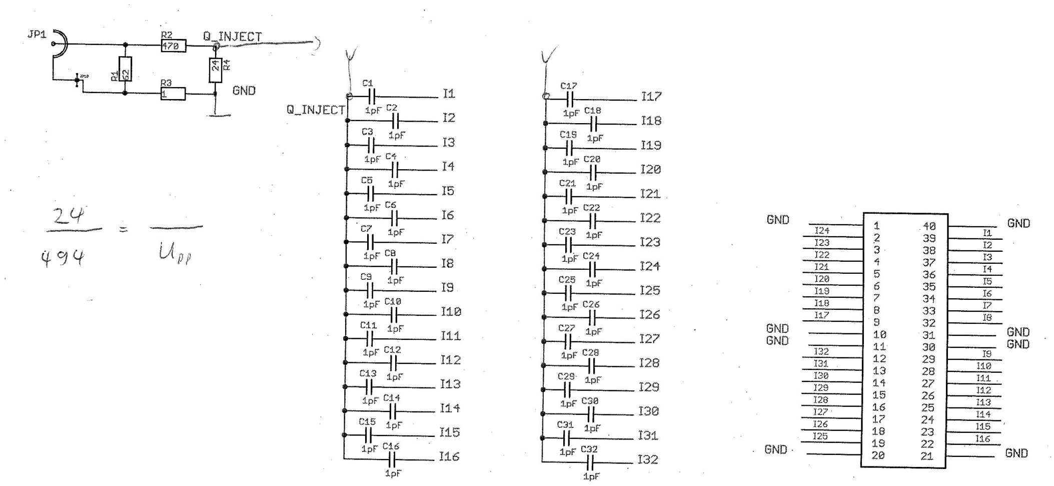


Figure A.25: Circuit diagramm of the charge box. Resistor `R1` is supposed to prevent electric reflections. Courtesy of Oliver Schäfer.

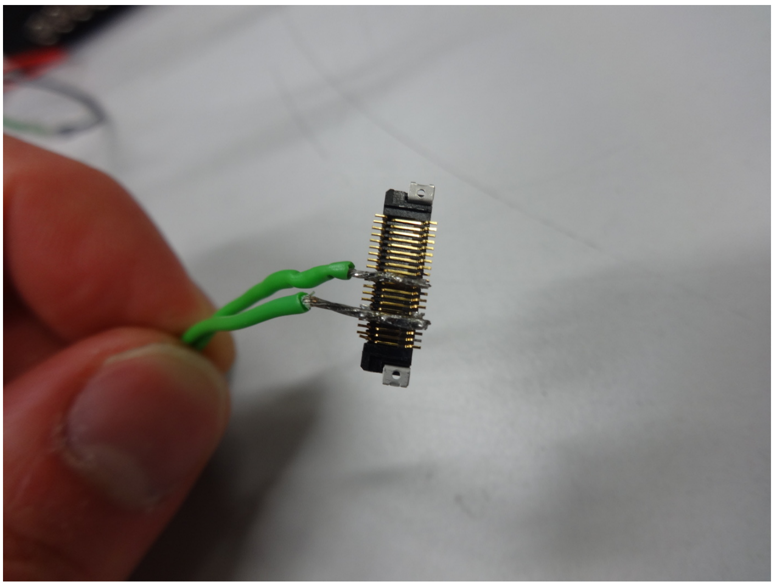


Figure A.26: A plug with two cables manufactored by me, in order to connect the pulse generator with the ALTRO system. It was not used in the end.

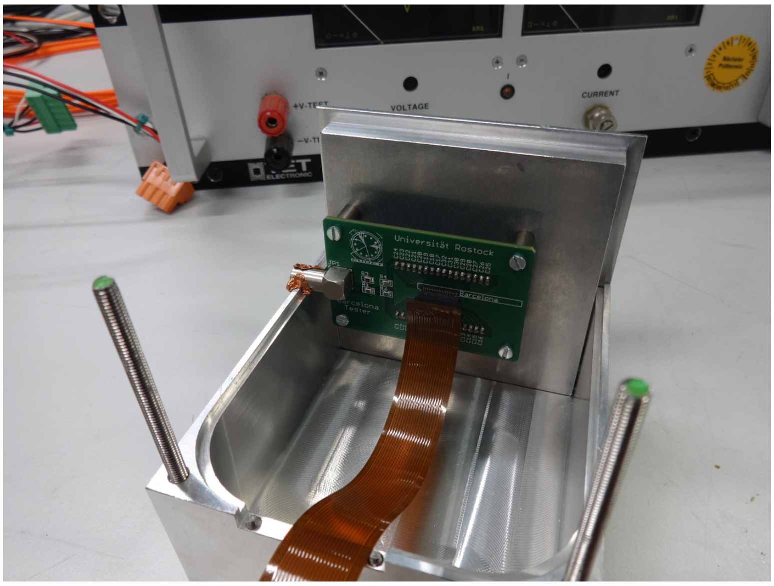


Figure A.27: Charge box we used. On the left one sees the connection to the voltage supply, in the middle the connector with a kapton cable connected to it, which is supposed to be attached to an ALTRO.

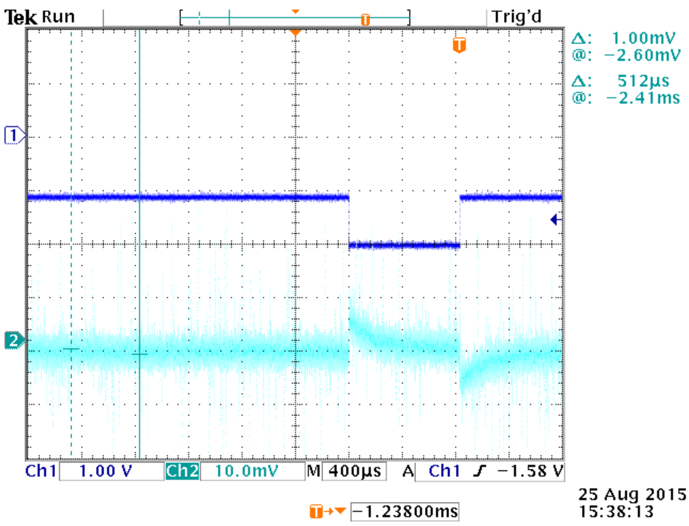


Figure A.28: The dark blue line is the inverted output signal of the pulse generator, the light blue is the signal measured at the charge box, without an additional resistor, with an oscilloscope. As can be seen, the noise is in the same range as the signal.