# Assembly of GEM Module for TPC Test Beam

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**Abstract**

The TPC subgroup of FLC at DESY have test beam time for the testing of their Time Projection Chamber. The new set of Gas Electron Multipliers (GEM) which were intended to be used would not arrive by this time do to manufacturing delays. Consequently old GEMs were needed to be repurposed and/or fixed. One fully working GEM modules was construction and two GEM module which had three broken sectors each were constructed. The broken sectors of each module were placed on the left and right hand side of the modules such that the broken sectors would lie outside the line of the test beam. The broken sectors were shortcutted to the common side of the GEM in order to keep the voltages on each GEM correct.

# Contents

# 1 Personal Statement

My project was initially planned to involve the measuring of the flatness and gain of a GEM Module during the assembly procedure. The TPC group which I was working in has test beam time in September. For this test beam the group requires three working GEMs. Due to an issue with the ordering/manufacturing of new GEMs my project's focus changed to constructing these three modules from old GEMs. As a result of this the main aim of the project had to be changed and the original gain and flatness measurements where not able to be made due to time constraints.
During the first week of my stay at DESY my supervisor was away at a conference so I spent the time learning ROOT and receiving the necessary safety training for the various locations at DESY I would need to be working at. The second week of my stay involved learning MARLINTPC software and familiarising myself with the techniques which will be used to measure flatness and also assembly of the GEMs.The former ended up not being needed as this element of the project was decided not to be completed due to time constraints. The third week of my stay in DESY is when my actual project started. Contained in this report is the details of the assembly and testing of GEM Modules for the TPC test beam.

# 2 Introduction

This work involved the construction, testing and fixing of Gas Electron Multiplier (GEM) Modules. These modules were needed for the test beam time of the 'Time Projection Chamber' (TPC) subgroup of the 'Forschung mit Lepton Collidern' (FLC) group at DESY. FLC works on the International Linear Collider (ILC) project. ILC is a proposed positron-electron linear collider which is currently planned to be built in Japan. The operating energies of the ILC are planed to range from 91 GeV to approximately 500 GeV. The FLC group is specifically looking at one of the detectors called International Large Detector (ILD) which will potentially be in the ILC. The TPC group is looking at making the time projection chamber which will go into the ILD.
The TPC group has test time on the DESY Test Beam in September where they will test their prototype TPC. For this test beam three GEM Modules where required. Due to manufacturing delays the GEMs which were to be used in this test beam would not arrive on time for the Test Beam so the modules which will be used need to be made out of old GEMs used in previous tests. The group had four already constructed GEM modules. This project involved the disassembly of these 'broken' GEM modules in order to use parts from them to make three working GEM Modules. The cleaning/fixing of the GEMs was also required in order to get enough GEMs for the construction of the modules. The newly assembled modules also needed to be tested under the conditions they will be during the Test Beam in order to make sure they were able to cope under such high voltages. This is done to minimise the chances of any breakages during the test beam. In order to achieve these conditions a test chamber was needed. An old test chamber was adapted for this purpose and two new test chambers were constructed.

# 3 Theory

## 3.1 Time Projection Chamber

A time projection chamber is the inner most detector of the proposed ILD. A TPC can be used to track a charged particle as it passes through the chamber. A TPC is a cylindrical tube with a cathode on one end and an anode on either end. See figure 1.

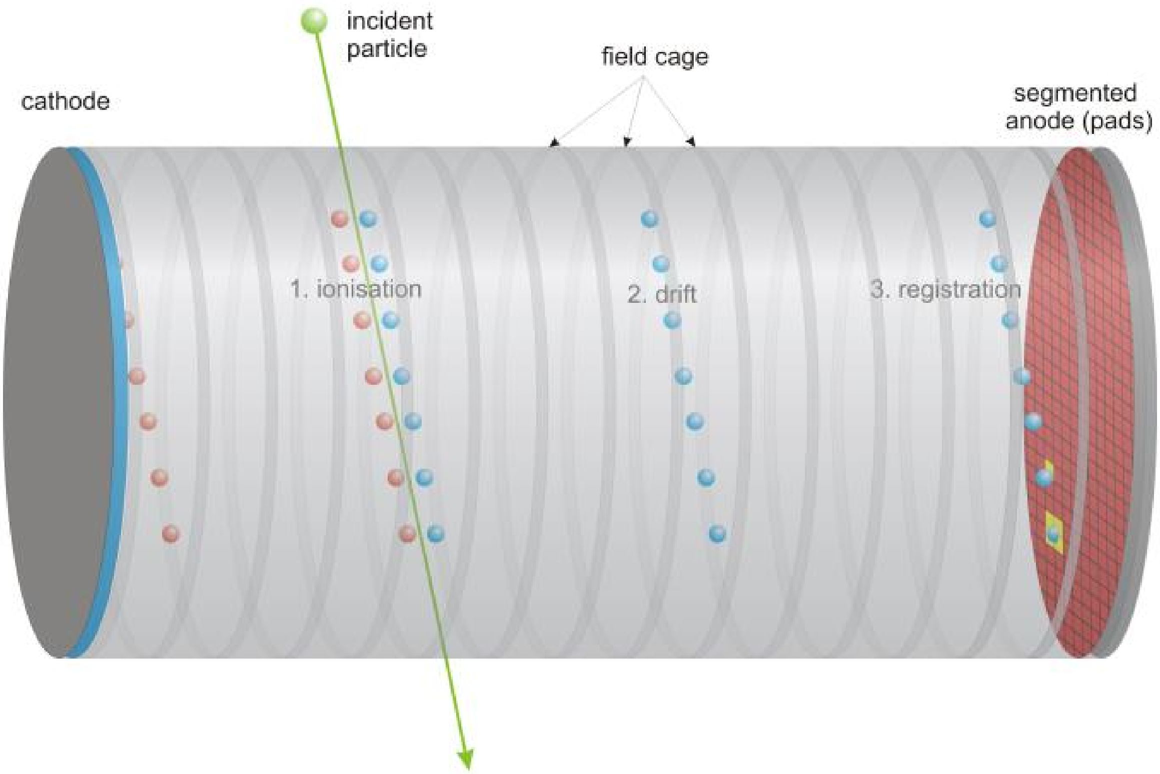


Figure 1: Shows a TPC. Ionisation near the in the middle occurs and then the electrons drift toward the anode where they are detected by pads. In the TPC which is being used in this project GEM Modules are placed in front of the pads in order perform gas amplification of electrons before being detected by the pad. [1]

The incident particle ionises gas in the chamber. The electrons released in the ionisation then drifts towards the anode. At the anode side of the TPC there is a detector which can be used to reconstruct the path of the particle. In the TPC used in this group Gas Electron Multiplier (GEM) Modules are used to preform the gas amplification stage. The detectors are located at the anode side of the GEM modules. This pad plane is were the detection of the electrons takes place.

## 3.2 Gas Electron Multiplier

A Gas Electron Multiplier is a device invented by Fabio Sauli in 1997. [2] It is a device which provides gas amplification of electrons when placed in the path of electrons in a drift chamber. A GEM consists of two thin sheets of metal (copper) separated by an insulator (sheet of Kapton foil). Each sheet has a hexagonal grid of holes etched into it. See figure 2

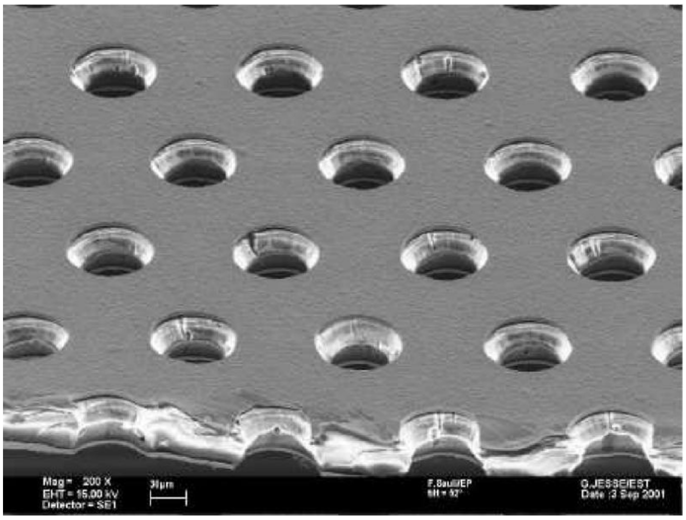


Figure 2: This shows a image of a GEM using an electron microscope. Image was produced by CERN GDD Group [3]

These holes provide the electric field required for gas amplification when the correct voltages are applied. Electrons from ionisation higher in the drift chamber pass through the GEM holes and gas amplification occurs. See figure 3.

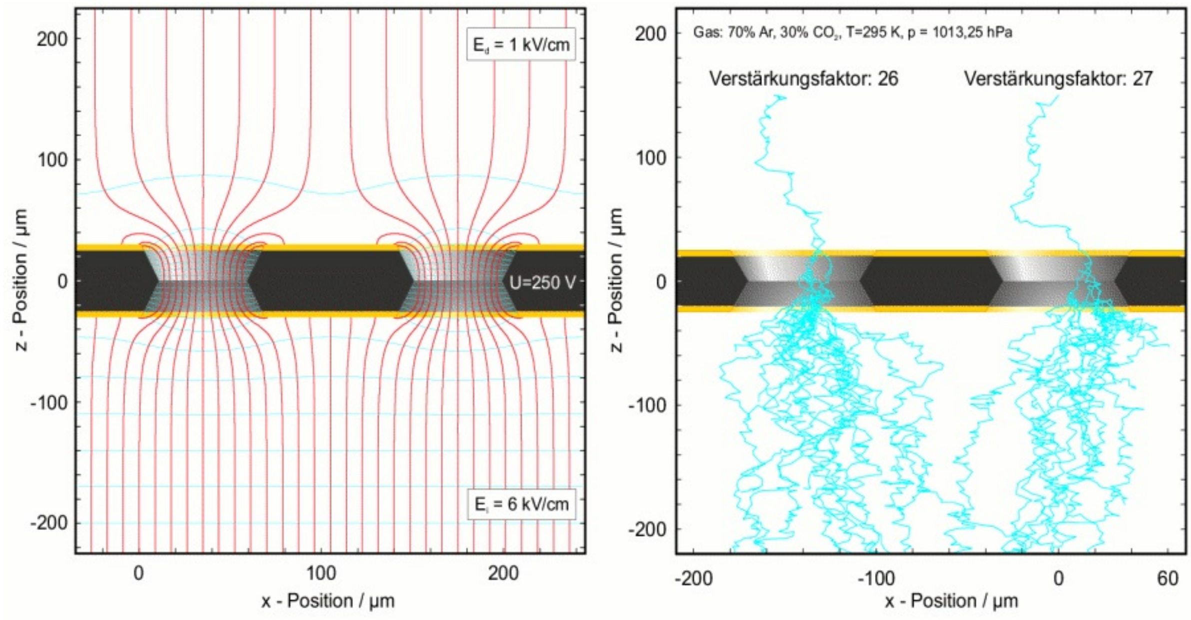


Figure 3: Here is a side profile diagram of the GEM. The geometry of the holes and the potential difference between the copper layers creates a large electric field which is required to cause gas amplification. The left hand image shows the electric field in the holes. The right hand image shows one electron entering a hole and then the cascade of many electrons (gas amplification). Group [3]

This allows the trace of an electron passing through the drift chamber to be measured as the strength of the signal is strong enough to be detected by the readout electronics. The GEMs used here are separated into four sectors as seen in figure 4. Each sector has a commonly connected cathode side and then four electrically isolated sections on the anode side. The reason for this separation is to limit the energies of any discharges which may break the GEMs. As an additional side effect by splitting the GEMs into sectors the use of broken GEMs is still a possibility if one does not need the complete area of the GEM. This will be discussed later in section 4.4.

GEMs are considered to be broken if there is some sort of electrical connection between the anode and the cathode side of the GEM. This can be caused by either a direct metal contact, a piece of dirt or dust or carbon wiring created by burned substances in the holes of the GEMs. Some of these broken GEMs were able to be fixed whereas others where damaged beyond repair.

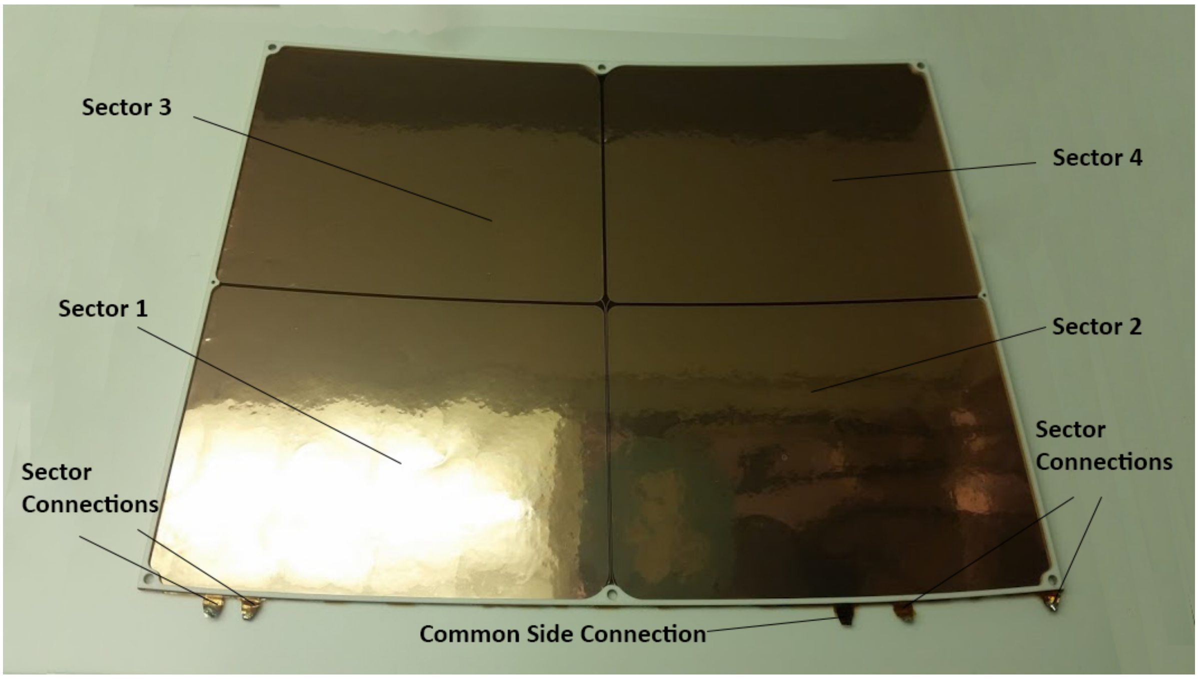


Figure 4: One of the GEM modules used in the project. This is shown with the common side facing downward with the four sectors visible(arbitrarily labelled 1-4). The 5 contact strips at the bottom of the image are used to connect the voltages to the GEM.

## 3.3 GEM Module

In order to increase the gas amplification of the experimental set up three GEMs in a stack are intended to be used. By doing this each GEM provides a gas amplification stage. An electron is intended to be amplified in the first GEM and then second GEM further amplifies the electrons coming from the first amplification and so on in the third. Further GEMs could be used to increase amplification further but in this case three were chosen to effectively provides three times the amplification of a single GEM.
A GEM Module thus contains three GEMs stacked on top of one another and separated by ceramic frames. At the bottom of the stack there is a readout pad plane which detects the electrons at the end of the amplification which is then encased in a back frame which contains the readout plugs and the voltage cables to place the GEMs at the various voltages required.
Each layer of the GEM Module can be placed at varying voltages. The Electrons in the modules drift from the cathode side to the anode side due to the potential difference placed across the module. See 5

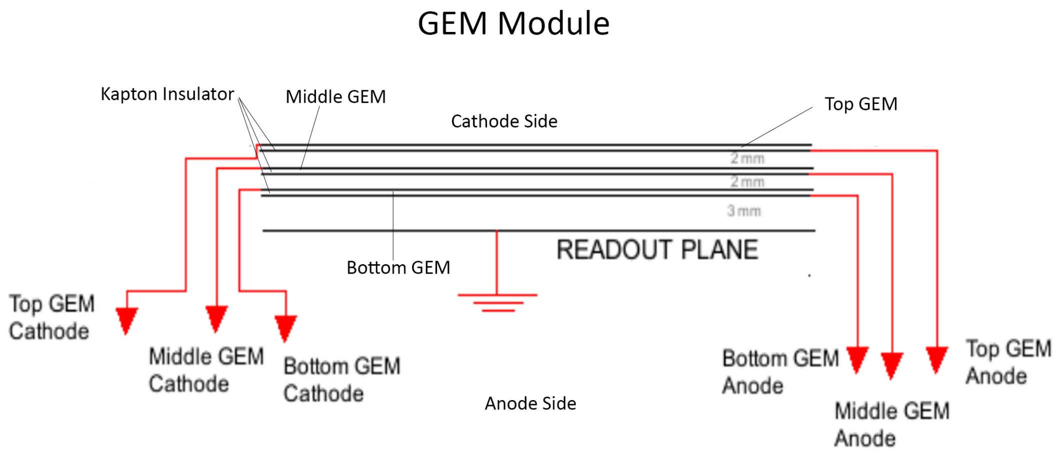


Figure 5: Shows a diagram of a GEM Module. Red lines show the connection to power supply which are used to place the GEM module at the various voltages required.

These modules can then be placed into the TPC at the anode side and are used to track a particle as it passes through the TPC.

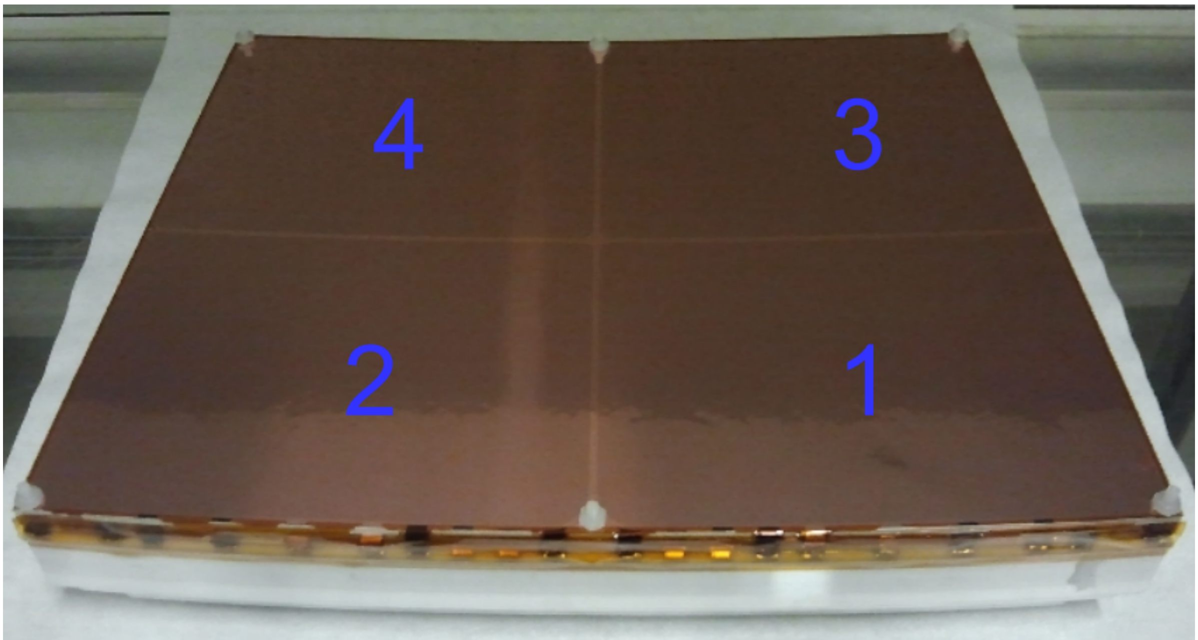


Figure 6: Shows a GEM Module which is assembled. There is three GEMs in this stack with the connection strips showing at the front. Note: This time the GEMs are facing with the common side on top so numbering of sectors has been flipped from figure 4.

# 4 GEM Module Assembly

## 4.1 Preparation

Before any testing could occur appropriate test chambers where necessary in order to test the GEMs and the GEM Modules in experimental conditions. A pre-existing test chamber was slightly modified for this purpose. A diagram of the test chamber used can be seen in figure 7

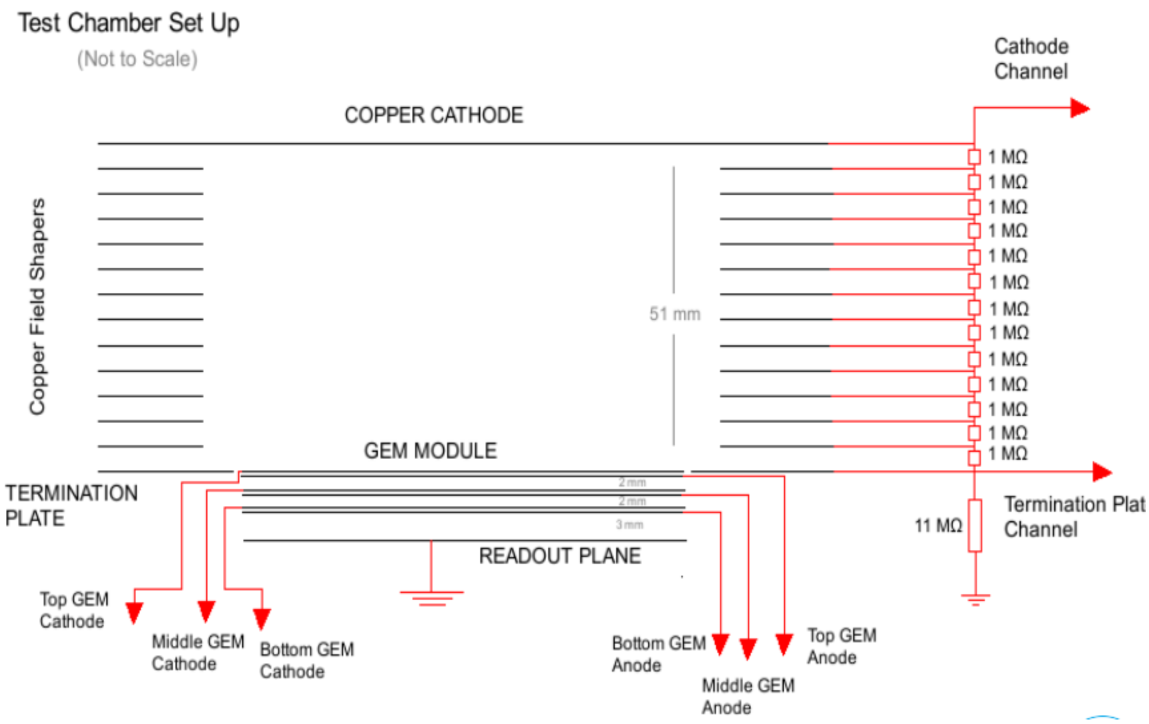


Figure 7: The test chamber simulates the conditions in a TPC. This test chamber has only one GEM Module location whereas the real TPC has a number placed in a grid structure across the anode side.

This chamber allowed the GEM layers of the module to be placed at required voltages and in a chamber with similar electric fields as the real TPC.
Two more test chambers where also prepared which could test individual GEMs. Figure 8 shows a diagram of the two test chambers. Using these two test chambers it was possible to test all the GEMs and also the modules. A nitrogen source and a T2K amplification gas (95% argon, 3% tetraflurometthane and 2% isobutane) could be placed in the test chambers for tests in either gas. All chambers where cleaned with isopropanol and compressed nitrogen before any GEM was placed inside. This was done as the GEMs are very susceptible to damage from dust particles.

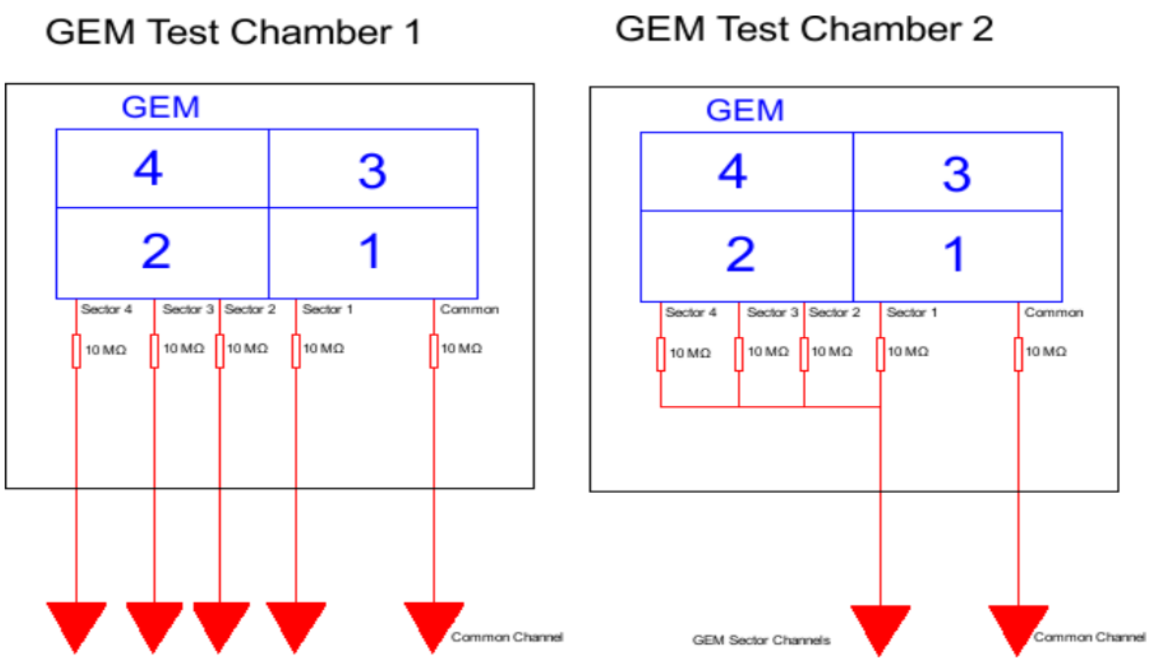


Figure 8: Shows a diagram of the two test chambers used in the testing of the GEMs. The test chamber on the left can be used to test all sectors in isolation and the right hand side can be used to test all the sections together.

## 4.2 Testing of GEMs

The GEMs used for this assembly where re-purposed from previous tests. Available for re-purposing were four GEM modules. Thus twelve GEMs were available for the construction of the three GEM modules. Nine GEMs where needed to be working in total. Due to the connection strips on the GEMs only being able to go into specific connection ports in the back frame and due to the ceramic frames structure a top GEM from the previous experiment could only be a top GEM in the new module and likewise for middle and bottom GEMs. Thus in total three top, middle and bottom GEMs were needed for the assembly of the new GEMs.
Initially GEMs where tested directly to see which had any broken sectors. This was done with a multimeter for low resistance connections and a power source for higher resistance connections. Connections with resistances $\ll 1M\Omega$ were deemed 'unfixable'. Connections with $\gtrsim 1M\Omega$ were deemed fixable and procedures would be followed in order to make them work again.
After a GEM was tested to have no broken sectors voltages were applied up to 560V to see if they would not break. From $\sim 500V$ and higher discharges occurred between cathode and anode side of the GEMs. These eventually died away after dust was 'burned' away. The voltages across the GEMs were slowly raised until until stable at 560V. This procedure is referred to as training the GEM. Once training of a GEM had occurred it was considered ready for assembly into a stack. Once assembled the modules were left

at 250V in T2K and left for a day or two. This was in order to test the tolerance of the modules. After this occurred they were then placed at operational voltages which had the anode side of the bottom GEM at 900V and the cathode side of the top GEM at 2250V. The potential difference between the cathode and anode side of the GEMs was 250V and the potential difference between GEMs was 300V. These voltages were dependant on the spacing in the module and also the gas used. These voltages are only applicable for T2K gas. The modules were again left at these voltages for about a day. Once a module had been through all these tests it was deemed ready for the test beam.

## 4.3 Fixing GEMs

As all the required GEMs for the assemble of the modules were not present some of the GEMs had to be repaired. A GEM was repaired in a number of ways. First by leaving the GEM at a high voltage for a few days the connection was hoped to be burned away. Failing this the GEMs would be cleaned manually to try and remove the connection by force. This was either done by blowing the GEMs with a nitrogen gun, bathing it in isopropanol or rubbing it with clean room cloth. The final methods to fix a sector was to pass a high current through a current directly bypassing the resistors normally used. This method is the least favourable as chance of damaging the GEM further is mostly likely with this method.

## 4.4 Shortcutting

In the actual test beam only one side of each GEM would be needed to be working fully. As a result if a GEM had broken sectors only on one side these sectors could be shortcutted to the common in a worse case scenario. effectively this reduces the effective size of the GEM. By shortcutting a sector to the common side one creates undesirable field distortions in the TPC however this is favourable to not having a working gem. The shortcutted sectors are then placed outside the test beam line see figure 10. Shorcutting was achieved by running an insulated wire from the connection strip of the sector directly to the common side of the GEM.

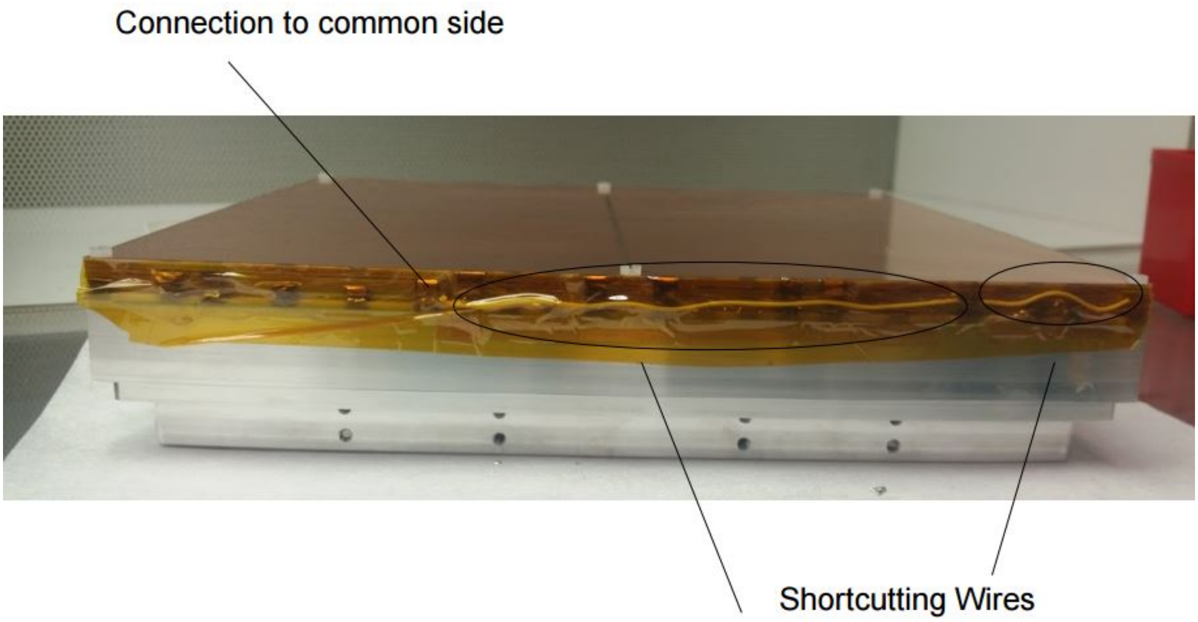


Figure 9: Shows how a sector was shortcutted. See yellow wire connecting two right hand side connections to the common side connector in the middle

The sections which can be shortcutted are either 1 and 3 or 2 and 4. By doing this one side or part of one side of the GEM does not work however the other half is fully operational so can be used in the test beam.

## 4.5 Assembly

The final assembly of the module was done by stacking bottom, middle and top GEM on top of the pad plane and secured in place with plastic screws. Copper connection strips were then run and soldered into the pad base frame where then appropriate voltages could be placed.
After testing and attempted fixing of the GEMs it was possible to fully assemble one working module where all sections of the GEMs were operational. One of the GEM modules had three sectors on the left side of the module shortcutted and one of the GEMs modules had sectors on the right side of the module shortcutted. Figure 10 shows how the locations of the modules can be placed in the actual test beam such that no broken sectors are in the test beam line.

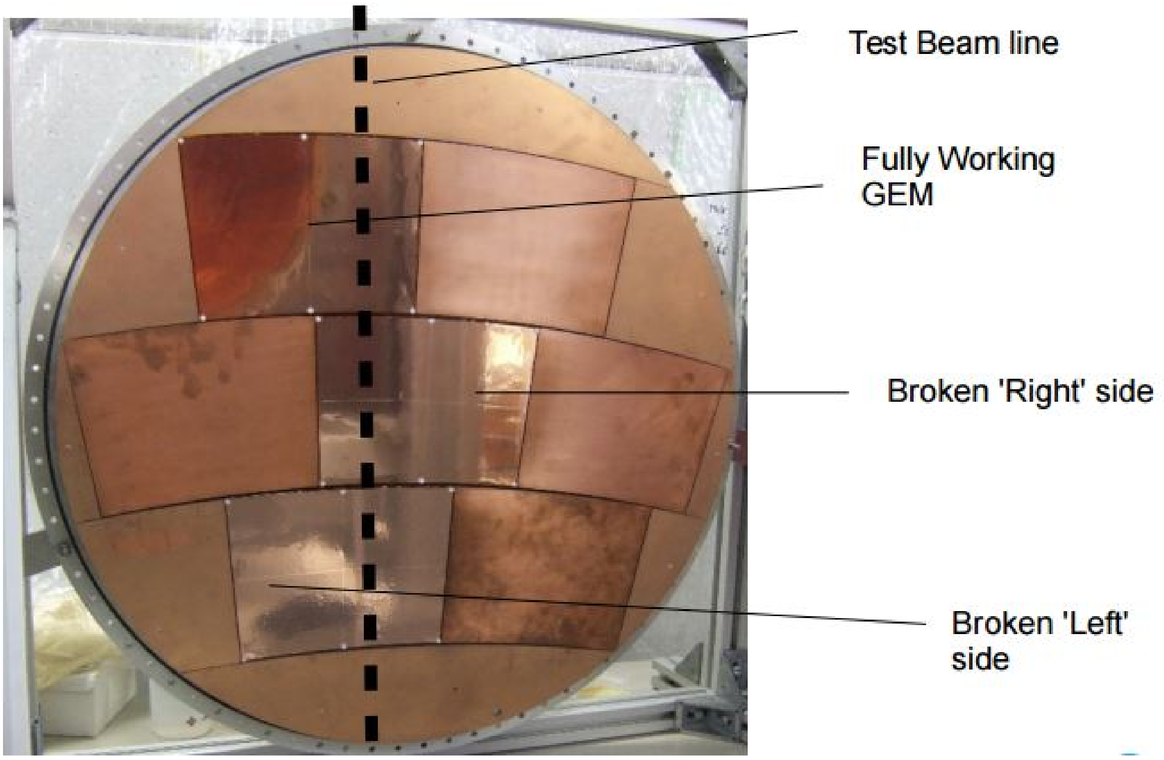


Figure 10: Shows a potential final configuration of the anode side of the TPC in the test beam. The three shinier surfaces are the GEMs and labelled is the path of the test beam. The two GEM modules with broken sectors can be seen lying outside the line of the beam.

The module which has sectors shorcutted on the 'left' (sectors 2 and 4) has both bottom and middle GEMs with shortcutted sectors. The Module which has sectors shorcutted on the 'right' (sectors 1 and 3) has sectors in all three GEMs shortcutted.

# 5 Conclusion

By the end of the project two of the GEM modules were working fully and had been tested in both nitrogen and T2K gas. The final module has been constructed but has not been tested fully in nitrogen or in T2K. This final module was unable to be tested due to time constraints but will be able to be tested by the test beam time in September.

# 6 Acknowledgements

I would like to thank my supervisor Paul Malek for helping me throughout this project. I would also like to thank the TPC group and the FLC group for their help in this project and for making working conditions enjoyable and rewarding. I would also like to thank DESY as a whole for giving me the opportunity to do this work.

## References

[1] LC TPC. Working Principle of a TPC, Available at www.lctpc.org/e8/e57671.

[2] Fabio Sauli. GEM: A new concept for electron amplification in gas detectors. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 386(2-3):531–534, 1997.

[3] LC TPC. Gas Electron Multipliers available at https://www.lctpc.org/e8/e46/e47/.