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15 August 2001

Professor J. Armitage
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Dear Sir:

This report entitled "Report on the Refinements Made to an Existing Gas Electron Multiplier Detector Housed in a Time Projection Chamber" was prepared in conjunction with course 95.394*A for the Physics Department of Carleton University. This is my first work term report.

The Physics Department is currently testing and refining particle detectors for future use in linear collider experiments.

The OPAL group at Carleton University, is testing Gas Electron Multipliers housed in a Time Projection Chamber. This report is on the design and construction of several experimental components, such as testing apparatuses and Data Aquisition systems, and the refinement of software which simulates the detector.

This report has been prepared and written by me and has not received any previous academic credit at this or any other institution. I would like to thank Madhu Dixit, Philippe Gravelle, Dean Karlen, Vance Strickland, Ernie Neuheimer and Jean-Pierre Martin for their help during the work term.

Sincerely,

P. J. Elahi
Student #234956

CARLETON UNIVERSITY
Faculty of Science
Department of Physics

Report on the Refinements Made to an Existing Gas Electron Multiplier Detector Housed in a Time Projection Chamber

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Prepared by

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August 15th, 2001

ABSTRACT

This report focuses on the construction and refinement of a new Data Acquisition (DAQ) system, testing procedures, and apparatus setup for a Gas Electron Multiplier (GEM) particle detector housed in a Time Projection Chamber (TPC) for use in future linear collider experiments. The scope of this report is to outline the various pre-testing and simulation methods created and the subsequent creation of related apparatuses with relevant detector theory given accordingly. A java program, GEM Simulator, was modified to improve usability and certain aspects expanded to more accurately represent reality. The prototype detector is tested using naturally occurring cosmic rays as a ionizing radiation source. To utilize this source, an appropriate apparatus consisting of scintillation counters and lead shielding was constructed, giving due consideration to the DAQ system. Procedures designed to verify the integrity of components of the detector had to be outlined and implemented. Component testing was limited to outlining test procedures for GEM foils, and constructing the appropriate test chamber. The new DAQ software was tested and procedure for altering existing code was outlined. The DAQ hardware was revised and retested due to abnormal failures and compatibility issues with older existing hardware.

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1.0 INTRODUCTION

Particle detectors are a vital component in high-energy physics, allowing physicists to verify theory with experimental data. Due to the necessity of having such detectors operate for extended periods of time without maintenance and the exposure to constant ionizing radiation, be it from natural sources such as cosmic rays or in a particle collider, the detectors need to be robust and well-tested.

There is a large variety of detectors, ranging from bubble chambers to proportional detectors and Geiger counters. Geiger counters rely on the ability of incoming particles to ionize a gas which is in an electric field. The ions rapidly cascade resulting in a small but measurable current indicating the presence but not the energy or the trajectory of the particle. The need to measure these parameters has spurred research into Gas Electron Multipliers (GEMs) in Time Projection Chambers (TPCs) detectors. These detectors are capable of taking several thousand measurements a second, suited for the high particle counts in particle colliders.

Carleton University at 1125 Colonel By Drive is researching the use of a GEM based detector. In the Herzberg Building, a prototype TPC housing a GEM detector has been built and is undergoing refinement. As a research assistant, I was to aid the design process and make refinements to the detector and related apparatuses. A trial of a prototype utilizes the prototype detector itself, the experimental apparatus, a Data Acquisition (DAQ) system, and a simulator to verify theory. This report explains the basic detector theory in the 2nd chapter, the refinements made to an existing GEM simulator in the 3rd chapter, the procedures and apparatus used in component testing in the 4th chapter, the refinements made to the DAQ in the 5th chapter, and the construction of the experimental setup in the 6th chapter. The final chapter entails future improvements to the experimental setup.

2.0 CURRENT DETECTOR STATE

2.1 GEM Structure The double GEM detector consists of four sections: the drift gap consisting of 30 windows, the transfer gap, the induction gap, and the readout plane containing the pad arrays (see Fig. 1) enclosed in a TPC (see Fig. 2). The drift gap and transfer gap are separated by a thin GEM mesh. The transfer gap is approximately 3.5 mm across and is separated from the induction gap

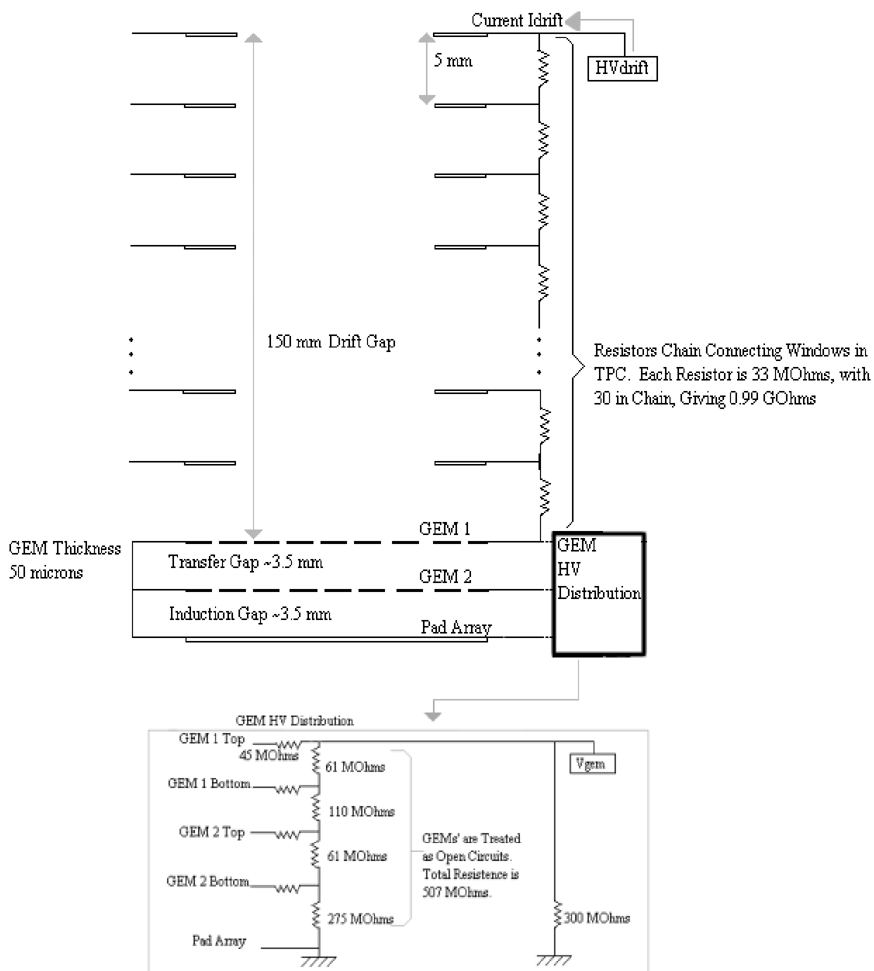

FIGURE 1: Internal GEM detector structure showing windows and resistor newtork

by another GEM foil. The cathode, anode and GEM foils are connected via a resistor network designed to distribute the high voltage potentials.

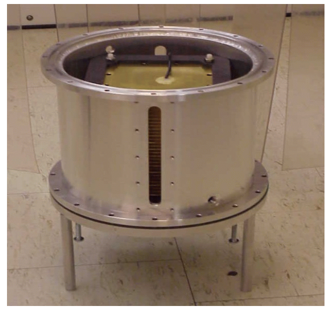

FIGURE 2: TPC containing GEM detector.

The drift gap is a region of gas where an applied voltage creates a nearly uniform electric field. The gas consists of two molecules; one that is readily ionized, such as Argon, and another which acts as a quencher, such as CO_2. The applied voltage across the 150 mm gap is a negative potential of 3-5 kV.

Each GEM foil is made up of an insulating layer of kapton, about 50 microns thick, with thin conducting layers of copper on either side, each about 5 microns in thickness. The three layers are perforated by hexagonal array of holes 50 microns in diameter with a pitch of 140 micron (see Fig. 3). The potential difference between the outer conductive layers causes the electric field

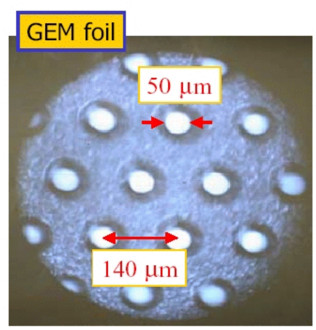

FIGURE 3: GEM foil.

to intensify dramatically within the holes. The shape and size of the holes is designed to minimize the divergence of the field, ensuring that the field vectors point in the same direction (see Fig. 4).

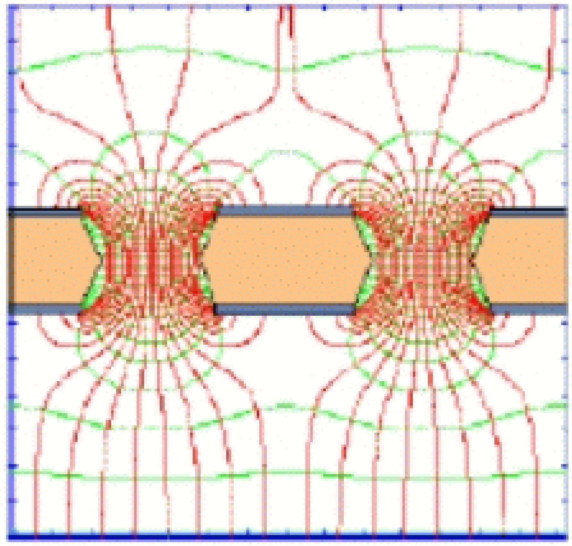

FIGURE 4: Electric field at GEM foil holes.

The readout plane is a printed circuit consisting of 32 pads arranged in a hexagonal pattern and another set of 32 arranged in an alternating grid pattern on copper clad G10, a common circuit board material (see Fig. 5). Each pad is connected to an individual channel in

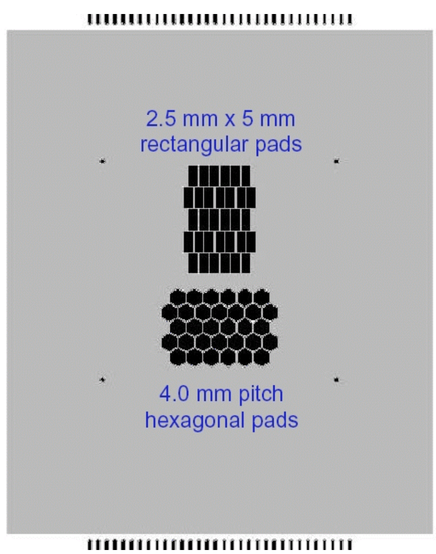

FIGURE 5: Readout plane s pad arrays.

the electronics. The readout plane is at ground potential, absorbing electrons, thus generating a signal that can be amplified and measured.

2.2 Electronics The electronics designed to amplify and measure the signal accumulated by the readout plane is under revision. New Flash Analog-Digital Converters (FADC) electronic cards have been purchased and thus this has required the construction of several electronic boards. Furthermore, problems with the FADC have required a great deal of human and electronic resources to correct. The current setup consists of Aleph pre-amplifiers connected to the readout plane.

2.3 Detector Theory The process of particle detection begins with ionizing radiation of some form, such as UV light or cosmic muons, which liberates the valence electron of an argon gas molecule within the drift gap. This electron is known as the primary electron. The induced electric field causes the electrons to acquire a drift velocity in the direction of the GEM foils. Thus, as ionizing radiation passes through the detector, positive ions are repelled from the readout plane and the released electrons are attracted to the readout plane at specific velocities. Given the initial time of entry of the ionizing radiation, such as using a scintillation counter to register its passing, one can calculate the distance traveled through the detector when the final signal is received from the readout plane.

As the primary electron approaches the first GEM foil it is accelerated by the increase in the intensity of the electric field. The field is most intense at the holes, and as the electron is accelerated through the holes, it will collide with other Argon gas molecules, ionizing them as it passes. As Argon is ionized, it releases electrons capable of ionizing more Argon. A chain reaction occurs, called a Townsend avalanche (see Fig. 6). The number of secondary electrons released is called the gain. In the current setup the gain could be extraordinarily high without the CO_2 molecules to act as quenchers, absorbing some of the UV photons. With the mixture of gas used, the gain of each GEM is approximately 70, giving a total gain of 5000.

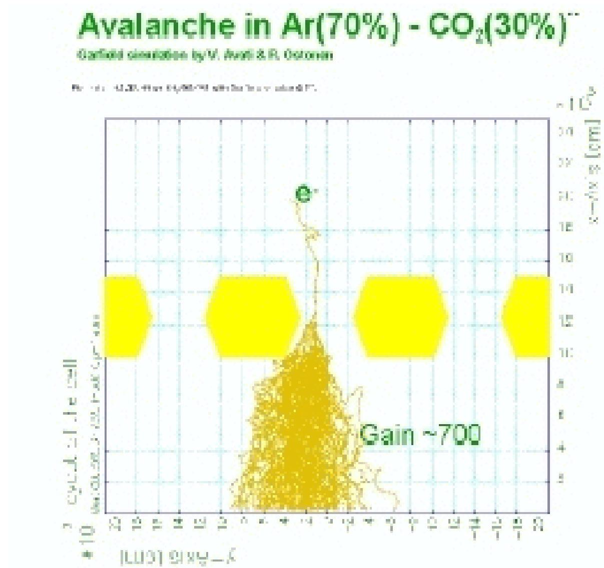

FIGURE 6:Model of Townsend avalanche.

The cloud of electrons emerges from the second GEM passing through the induction gap. As it approaches the readout plane, it causes electrons within the readout plane to be repelled, producing an induced charge signal within each readout pad with an amplitude inversely proportional to distance to the corresponding pad (see Fig. 7). The cloud of electrons is finally deposited on the readout plane.

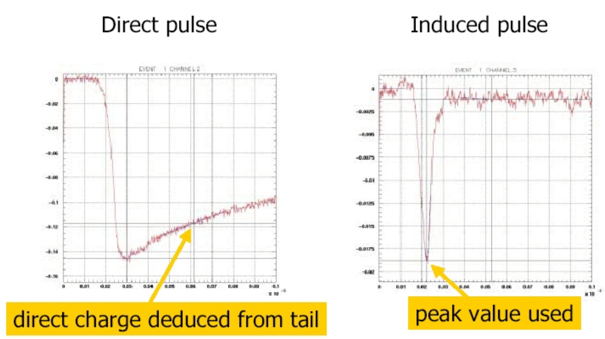

FIGURE 7: Pulse shapes as seen from oscilloscope.

The electron clouds which are absorbed by pads create large direct charge signal (see Fig. 7). This signal slowly rises back to zero over time given by the time constant of the amplifier. Pads which experience an induced pulse only return to zero charge immediately once the charge has been absorbed. A pad experiencing both is the most likely occurrence, resulting in a mixed pulse.

3.0 MODIFICATIONS TO GEM SIMULATOR

3.1 Object Serialization An existing GEM Simulator [Karlen, 2000] written in the Java language was modified as needed. To ensure modifications were compatible with existing code, a rough UML document was drawn up, showing Java objects, whether they were purely graphic or method based and their relationships with each other. This allowed modifications to be pre-tested by verifying if alterations to an object required a large number of alterations to others.

The first major modification to be made was to allow the program to save the general setup of the virtual GEM detector, disregarding all Graphical User Interface (GUI) components. The GEM detector consisted of several classes, both abstract and non-abstract, with the possibility of several instances of each class within a given virtual GEM detector. Object Serialization, Java s own method of saving objects was chosen [http://java.sun.com]. Test programs were written with complex object relations, implementing serialization. As they function, modifications were made to the simulator.

However, several problems were encountered. Initially, the save would not work, and open would simply reinitialize the virtual GEM detector to its default values. The relations of several key objects were modified so as to limit object interactions and remove unnecessary object relations.

Errors persisted; saving an object and reopening it would cause certain graphical components to become inactive. These problems were finally traced down to the Java swing library, which consists entirely of graphical components. The program had initially be written in such a manner that certain objects containing vital internal data had graphical components were necessarily being saved. It was found that Java s graphical library should not be serialized and that this ability was soon to be depreciated [http://java.sun.com]. The entire program s architecture required revision. The author, Dr. Karlen rewrote the general architecture and eliminated this problem.

3.2 Modifications to Virtual GEM Readout Plane Certain modifications were prompted by alterations made to the actual GEM detector. A new arrangement of pads on the readout plane had been constructed and a virtual representation need to be made. This arrangement consisted of rectangular grid pattern with the odd rows offset by a certain amount. To integrate this new layout, a detailed outline of how the program constructed and implemented such layouts was made. All layouts used in modelling the hole pattern in GEM foils and the readout plane s pads were sub-classed from the abstract TwoDimenLayout class, and were each accompanied by a graphical panel based class. Thus, two new classes were written, one based on existing panels accompanying the other two layouts, HexPack and Grid, the other written to properly model the geometric properties of the new layout.

Once this was completed, a thorough search of the program was made to find instances of layouts and the appropriate inclusions of the new layout were made. Testing commenced and several minor problems relating to initial design flaws of the layouts were found and the appropriate corrections were made, usually to the TwoDimenLayout superclass. All modifications were documented.

3.3 Creation of Graphical Readout Plane The simulator had several ways of displaying results from a virtual particle detection. For statistical analysis of the modelled signals, a graphical histogram capable of showing the accumulated charge from six different pads at any given time was written. However, this method of showing results was cumbersome, especially when a large array of pads was modelled. If the charge did not accumulate on the six pads watched by default, one would have to guess where the charge might have accumulated. Thus, the need to graphically represent the readout plane s pad array, indicating visually which pads accumulated charge and how much was accumulated.

Several designs were outlined, using previous knowledge of the architecture of layouts. Earlier experiences with the Layout code ruled out several designs due to the inordinate number of changes required. The design chosen required the creation of two new classes, both graphical in nature and modification to both TwoDimenLayout based classes, and Shape based classes.

One class called DrawArea acted as canvas, upon which graphical representations of the pads would be drawn. This object required that the shape objects which represent individual pads and layout objects representing the arrays knew how to draw themselves given a Graphic object, which acted as pen. This object would generate appropriate coordinates and pass them along with the draw command to the shapes and layouts objects. The DrawArea also stored the number of hits a pad received, allowing the colour of the pad to be altered accordingly.

The second class was to act as the GUI of the DrawArea class. It consisted of a window with various buttons and fields which allowed the user to draw, clear, and adjust the scale of the graphical representation. This moderator was then integrated with the rest of the program by placing the appropriate call commands within the general GEM GUI and connecting it to the virtual readout plane.

Testing consisted of refining the ability of visually representing the data, so as to make it apparent which pads accumulated charge and a general indication of its amount. The alterations made were documented thoroughly to avoid future problems.

4.0 GEM FOIL TEST CHAMBER

4.1 Design During previous runs of the GEM detector using an X-ray source it was noticed that the GEM foils would short circuit with too high a frequency given the detector s future use. This was attributed to the unclean methods of mounting GEM foils to insulating frames, the care in which they were handled and the environment in which they were handled. Several ideas were outlined to reduce the frequency of GEM foil short circuits: altering the cleanroom in which they were kept and mounted to reduce contamination from dust; altering the mounting methods so as to have solderless connections; and to test the GEM foils optically for flaws and under High Voltage (HV) for high resistence [Capeans et al, 2000]. The former ideas could be implemented immediately, however, to HV test the GEMs required a specialized test chamber.

Since GEMs should not be exposed to dust, the testing would have to be done in the cleanroom in which the GEMs were mounted. The testing would have to be done in a dry environment, thus a gas tight chamber in which nitrogen would be flowed was needed. This chamber also needed high voltage connections, an insulating cushion upon which the GEMs would rest and the insulator could not be made of a substance that retained humidity. Finally, the enclosure must have a window where one could visually inspect the GEMs for sparking.

After discussions with Dr. Dixit and Philippe Gravelle, a nitrogen tank would be placed outside the cleanroom with a gas line inside the room. This gas line would be split, one going to a lower pressure value for use in the test chamber and the other to be used for an air gun. An existing metallic chamber with the appropriate connections would be used, but required a transparent lid. Acrylic was chosen for the lid material. Insulators had to be found to be placed inside the test chamber and foam covered in a sealant with a plastic plate on top was decided upon. Once most of the design had been work out, full construction began.

4.2 Construction Gas lines inside the chamber had to be made first. Copper tubing of a proper width was used once cut to the appropriate length, with connections made using specialized swagelok tube fittings. A hole was made in the cleanroom plastic wall and tubing was fed through then filled with a silicon gel. The gas line was then connected to a T connector with one connection going to an on/off value and an air gun. The other was connected to a pressure value, which would allow the gun to be used with high pressure, while the line going to the test chamber could operate at lower pressures. The entire T connection was mounted to the cleanroom frame and tested for leaks. A major leak was found and traced to the air gun. The air gun was replaced with a different model and the system then tested successfully.

Alterations to the existing HV chamber were made next. A clear acrylic lid was manufactured by the Science Technology Centre (STC) of Carleton to be used as a window. Soldering a wire to the live line of the socket required several attempts to ensure a high degree of electrical and mechanical safety. For the ground connection, a special ground lug was used and a wire was soldered to it. Flat clips were chosen so as to make the best possible connection to the GEM foil s leads. The test chamber itself was grounded using a wire connected to one of the metallic clamps which was attached to the metallic frame of the cleanroom. The connections were tested by measuring their resistence. If they showed more than 1 Ohm resistence, they were redone.

Connections between the pressure value and the test chamber had to be made using flow controllers. Rubber tubing was attached to the pressure valve and connected to the inflow controller, which in turn was connected to the chamber. The outflow controller was only connected to the test chamber, as nitrogen out gassing posed no danger. Once the acrylic lid arrived, the entire setup was tested for gas leaks. Several were found and removed, though one remained, it was negligible.

A HV power supply was needed and due to space constraints an older, small NIM bin which could have a HV power supply inserted in it needed to be refurbished. The bin lacked a +6 and -6 volt source necessary to power the HV supply. The bin was opened, and available voltages were checked, with the voltages provided by several capacitors being used as a voltage source. After discussion with Ernie Neuheimer, voltage regulators were attached to these capacitors to provide the voltages. These end connections coming from these regulators were to be daisy chained to the appropriate pins in the NIM architecture. Given what was assumed to be the correct regulators, connections were made, however, when power was supplied, several diodes within the circuit blew. Initially the cause was unclear, and the newly made connections along with all the diodes were checked. All the blown diodes were connected to the negative regulator. The regulator was tested and found to be faulty. Once a different type of negative regulator which fit the specifications was used, the problem was eliminated. The connections were then daisy chained and the NIM bin was functional.

The NIM bin and HV power supply were brought into the cleanroom once properly cleaned and connected to the GEM test chamber. Two layers of foam with a plastic plate were used to electrically insulate the clips from metal test chamber.

Once an initial test was performed on a GEM foil, new design flaws were found. Given that a detector will contain two GEM foils, alterations were made to the HV connections so that two could be tested at the same time. The lack of space required a shelf to be built so the NIM bin and DMM s could rest easily at eye level. This required the positioning of the gas lines to be adjusted without causing any leaks to form. A sealed piece of foam replaced the previous layers, which might have been susceptible to uptake of water. With these minor changes made, the GEM testing area was complete (see Fig. 8).

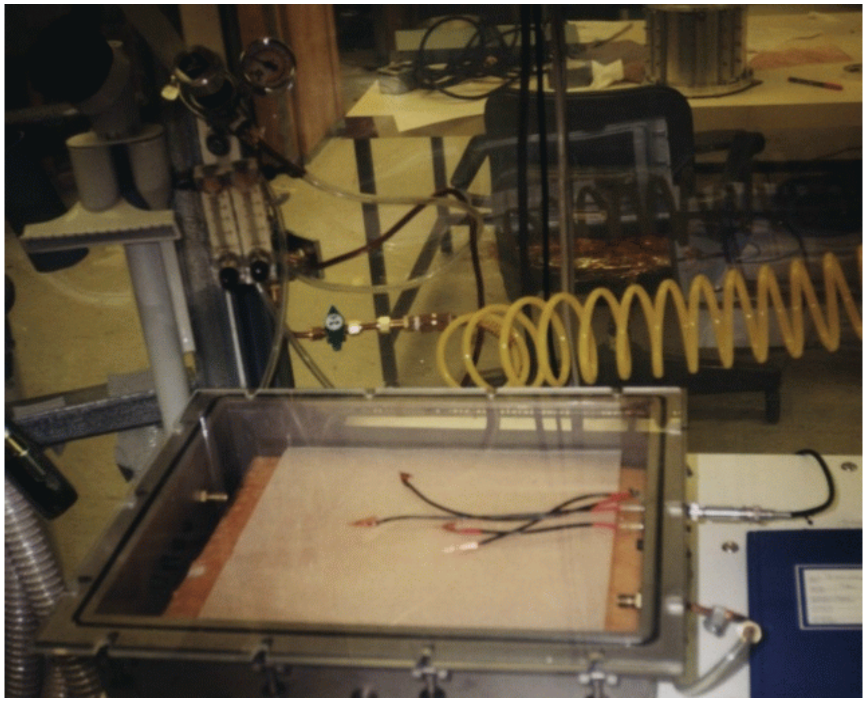

FIGURE 8 : HV GEM Testing area showing metallic container with HV connections, and gas flow apparatus in the upper left corner.

<u>4.3 HV GEM Testing</u> Testing GEMs required that they be insulated from the surrounding environment. To ensure that nothing interfered with testing of the electrical properties of GEM s, previously mounted GEMs were first cleaned with the nitrogen gun inside the cleanroom. This removed any dirt, which would have ruined the GEM foil electrically. Next the GEM foil was placed carefully on the insulating foam within the test chamber. The clips were attached to the appropriate leads, and the connections checked for low resistence between a clip and the related GEM lead. If it was approximately zero, the test chamber was closed and made gas tight. Otherwise the copper tape used to make GEM leads was redone. The pressure value and the inflow controller were adjusted to have nitrogen flow rates at approximately 0.3 litres per minute [Capeans et al, 200]. The GEM was left for approximately 1½ hours. This flow ensured that most of the moisture was removed from the testing environment, which would otherwise reduce the electrical resistence of the GEM foil.

After letting the GEM sit, the HV connections were made to the outside and the voltage was slowly applied to the GEM foil. Two DMM s were used, one to monitor the voltage and another to measure the current being provided by the power supply. The voltage was slowly increased in steps of 50 V up to 400 V, after which steps of 20 V were used up to a maximum of 500 V. The current was constantly checked. If current greater than 50 nA was measured, the foil failed the HV test [Capeans et al, 2000]. Once at 500 V, the GEM was left at that voltage and checked visually for sparking. If the current measured at that voltage coincided with a resistence of greater than 100 GOhms, the foil passed the HV test [Capeans et al, 2000].

Two faulty GEMs were tested to ensure that the test was valid. The GEM failed as predicted. Both had currents corresponding to resistance of 10 MOhms. Furthermore, the current could be seen increasing as one increased the voltage, then it decreased back towards a specific value as one stopped increasing the voltage. To verify that this capacitive element was from the GEM foils, the voltage was increased on clips with nothing attached. As expected, the capacitive element decreased greatly implying the cable had a negligible capacitive component. Thus, the capacitance seen was due to the GEM foil, meaning the connections were solid. These tests proved that the method of testing GEM foils was valid.

5.0 DAQ

5.1 Hardware Problems and Resolution A new DAQ was constructed for the TPC. This consisted of a linux machine acting as both analyser and store of initial data. This linux machine was then connected to a VME electronic crate via an electronic PCIADA card with a SCSI connection. The SCSI cable would connect the PCIADA card to a VMEMM interface card which would act as the master for the VME electronic crate. Placed among the slots of the crate would be 8 FADC cards constructed by Dr. Jean-Pierre Martin of the University of Montréal. These cards would be connected to the pre-amplifiers which in turn would be connected to the readout pads of the TPC to gather data.

The major problem was the inability of the VMEMM card to talk to the PCIADA card. Using a simple program written by Dr. Martin called tflash, the card was unable to establish a connection, and would continually freeze the computer. It was initially thought the cable was responsible, thus it was replaced with another but the problem remained. Both the PCIADA card and the VMEMM interface card were sent back to the manufacturer, WIENER, for tests, and they passed. Considering the drivers had to be rewritten, it was thought that linux itself might be the problem. A Windows98 machine was brought in, the card placed in it, and a standard program, pvmon.exe, was run. The connection was found to be sporadic, failing often. Usually it just connected on the power up cycle of the machine or the VME crate. The crate was checked to verify that its J1 upper bus connection had the proper voltages. One voltage, a +5 sources, was found to be sporadic. The crate, also coming from WIENER, was sent back to be replaced by another VME crate with not only the J1 upper bus, but the J2 lower bus. The new crate had the proper voltages, but the connection still failed.

Concurrently, lengthy email discussions were occurring between Dr. Dixit, Dr. Martin, Dr. Pierre Amuadruz, and myself. It was decided that Dr. Martin would setup a working system at the University of Montréal. Once a system was setup, Dr. Karlen and I went to Montréal with the system from Carleton University. The working system allowed us to swap components individually to see whether they caused Dr. Martin s system to fail. After several false leads, it was eventually tracked down to the PCIADA card. It would connect if cool, but after approximately 15-20 minutes in an active computer, the connection would fail. A coolant was sprayed onto the card, and it would work momentarily, proving the card was overheating. This was repeated several times just to confirm where the problem lay, as the card had passed tests at WIENER. The card was sent back for a replacement.

5.2 Compatibility Issues An issue that was being resolved concurrently with the VME problems was a compatibility issue. The readout pads are designed to go through an Aleph pre-amplifier. This pre-amplifier provided access to 16 channels on a 40 pin connector, however, each FADC could only receive 4 channels on a 26 pin connector. Thus, a patch board had to be made which could accept two 40 pin connections and split it into eight 26 pin connections, while provided the pre-amplifiers with the appropriate voltage supplies [Anon., 1987].

Several schematics were searched and simple diagram using a Computer Aided Design (CAD) program was created (see Fig. 9) to illustrate the required connections. After several discussions with Ernie Neuheimer, a layout on the patch board was decided upon. The design limited noise, and reduced the number of connections that had to be made. The card would connect to the VME lower bus. The power supply for both Aleph connections would be provided by configuring the lower VME bus on the VME crate in order to provide the necessary voltages. When the crate was sent back to be replaced, this requirement was passed to WIENER, and a lower bus was added. Precise soldering was needed to minimize the amount of crosstalk between connections. It was completed and required testing.

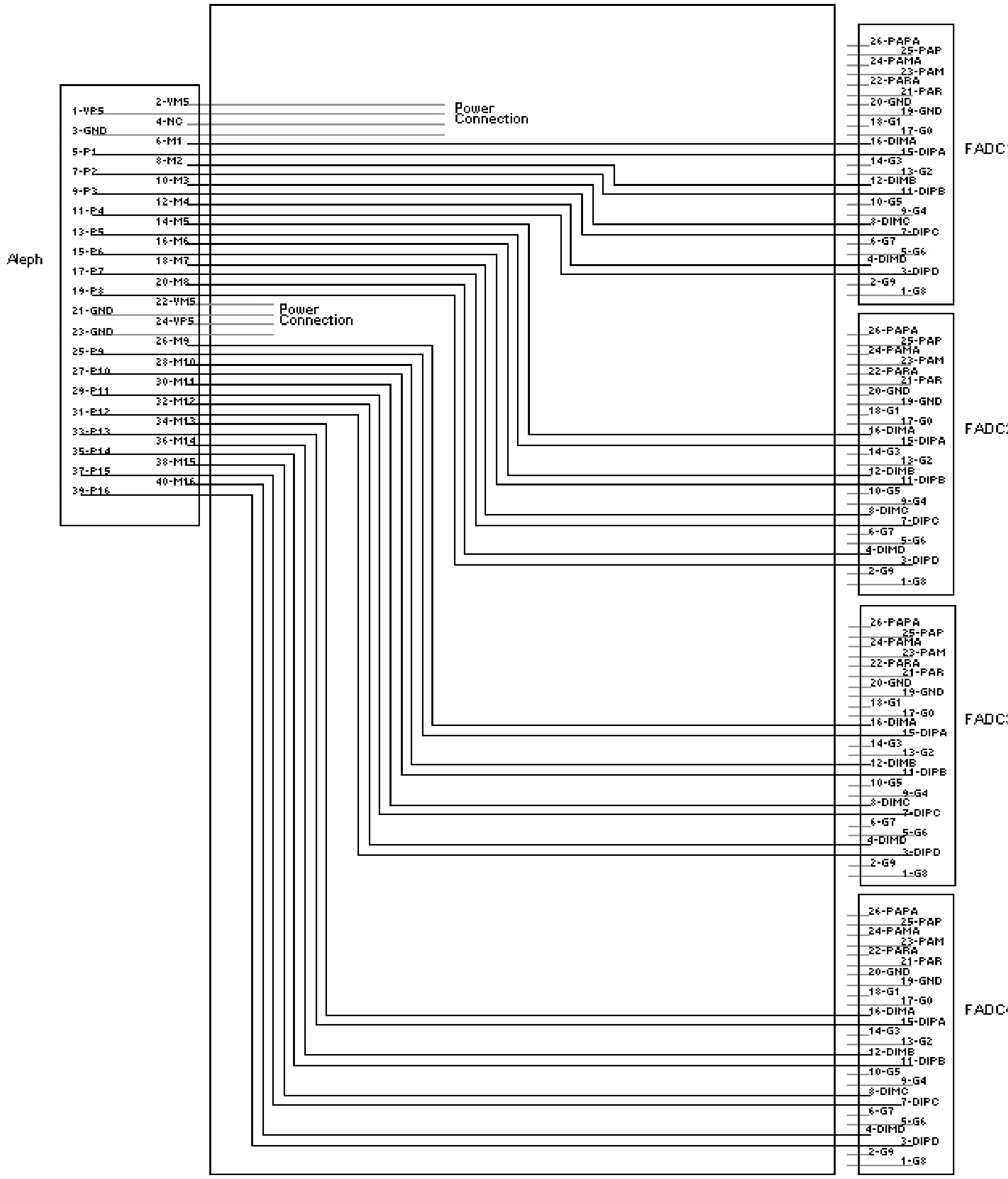

FIGURE 9: CAD diagram of patch board connecting 40 pin Aleph to 26 pin FADC s.

<u>5.3 Software</u> Along with the new hardware, new software was being used. MIDAS was being used as a DAQ. MIDAS is a software which consists of an Online DataBase (ODB) from which one can access frontend or hardware accessing code, pass data to an analyser or store it using a mlogger executable. MIDAS uses C or Fortran and is designed to run under multiple operating systems on multiple computers.

To learn how to operate it, a sample experiment which came along with MIDAS was studied and altered. Several virtual data gather devices were created, with event triggers contained within a frontend code written in C. The data gathered from the virtual devices and stored in a MIDAS data type called Banks by the frontend if the mlogger executable was active. Along with this an analyser was written accompanied by several modules, which are considered calculated Banks. Using the odbedit interface as well as a daemon program, this sample experiment was run, testing its ability to read, write, alter, analysis data.

Several errors were encountered: certain types of data was not being accessed; certain banks were not being stored or processed; some banks appeared to contain invalid data. Dr. Stefan Rift, one of the authors of MIDAS was contacted to help solve the problems. It was found that certain errors were due to C interpretation of output statements written for C++, as well as certain values in the ODB structure not having been initialized [Rift, 2001]. All the errors and solutions were documented to produce a simple help document containing the proper method of creating an experiment.

6.0 EXPERIMENTAL SETUP

<u>6.1 Design</u> To test the GEM detector, an appropriate setup had to be constructed. For useful results, additional detectors had to be used along side the GEM detector, providing initial trigger that a particle had been detected. This would allow one to not only use the GEM detector s readout plane to track the particle in two dimensions but use the drift velocity of electrons in detector s gas to generate its position in the third dimension given the time delay between the two types of detectors. Measurements of the TPC housing the GEM detector and the position of the readout pads within the TPC were made. A schematic was drawn (see Fig. 10) and scale print outs were made for Dr. Mes

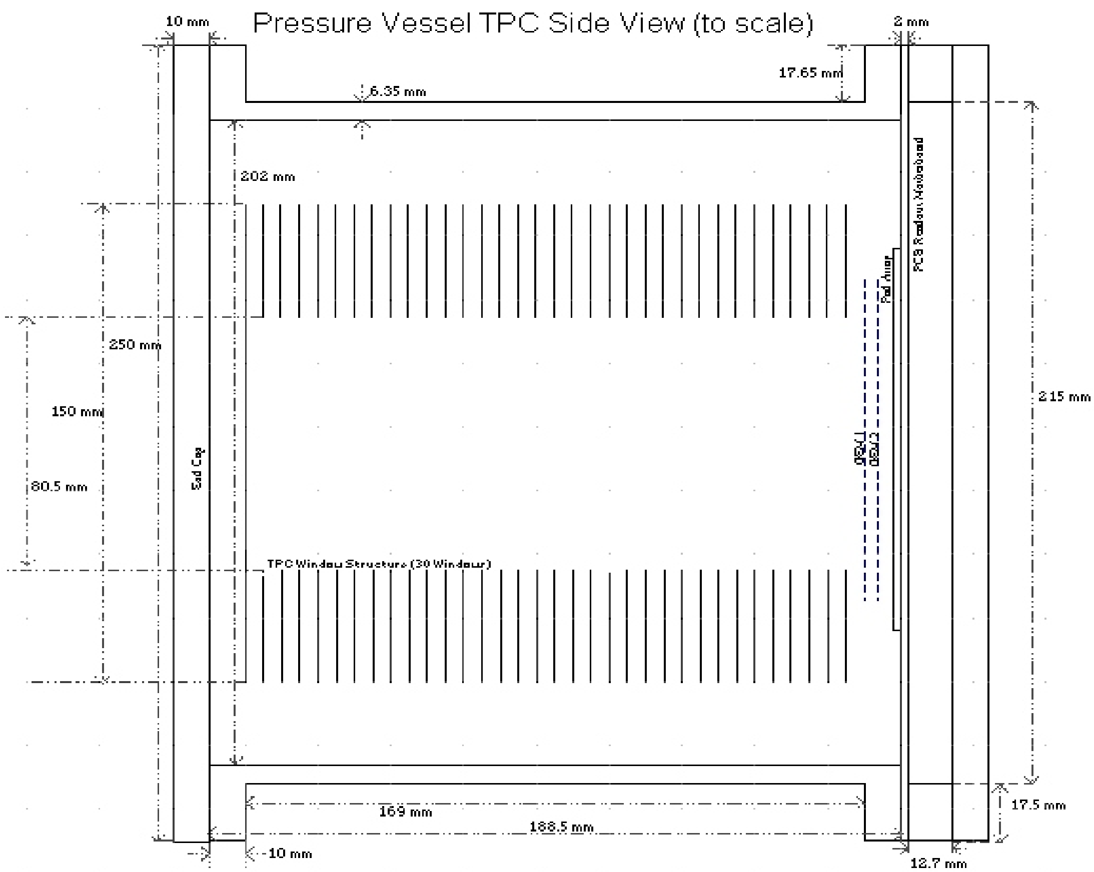

FIGURE 10: CAD diagram of TPC, initially drawn to scale.

who used these diagrams to select the appropriate additional detectors. This consisted of three scintillation counters attached to photo-multiplier tubes, two of the same size and a third smaller than the other two.

Scintillating materials are those which emit photons of light when struck by ionizing radiation. When coupled with a photomultiplier tube, it can be used as a detection device.

Calculations were then made to decide the best positioning of the counters in relation to the TPC. The optimum setup placed the smaller counter above the TPC, with the other two below it. The diagram was also used to find the desired overlap of the counters which all had active areas larger than the active area of the TPC. Calculations also indicated that to filter out unwanted events, approximately 10 cm of lead was needed somewhere between the counters with all three triggering at the same time for an event to be recorded. The CAD diagrams were useful in determining the area that needed to be under detection for proper filtering. This was to be placed on a metal table with the scintillation counters coming from alternate directions with the TPC in between (see Fig.10).

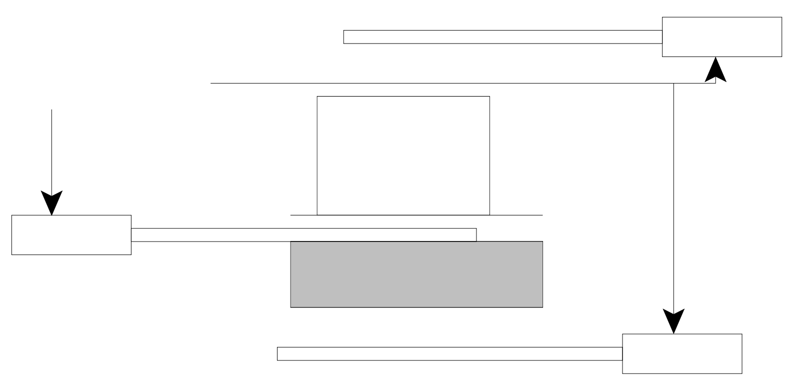

FIGURE 11: Experimental Layout with TPC and 3 scintillation counters.

Thus, with the requirements outlined, Dr. Dixit, Vance Strickland, Philippe Gravelle and I discussed possible setups to support the experimental setup. A major constraint were the fact that the scintillating material of the counters were of such a length that they could not support themselves. Thus, special care was placed on the counters. Another was the amount of lead required to filter out unnecessary events, which had a mass of approximately 115 kg spread over 30x27 cm^2.

A material called dexion was used to create the supporting struts. Dexion is a metallic, L-shaped material with evenly spaced screw holes which can be easily cut. One counter would be placed on the table with foam supporting the counter. Around this, simple metallic blocks would be placed parallel to it. These blocks would have a height slightly greater than the height of the counter, and an aluminum sheet approximately ½ inch thick would be placed on top of the blocks to support the lead bricks. The strut material would surround the counter, leaving enough room for the counter to be moved lengthwise. Three vertical struts on each side would hold the platform upon which the TPC would rest. The second counter would rest directly on the lead bricks. Its photomultiplier tube supported by another strut material. This would be under the TPC. The third scintillation counter would be attached firmly to a wooden plank with the scintillating material attached by several plastic clamps. This would hang from a railing, thus completing the experimental setup.

6.2 Construction Measurements were made and the appropriate lengths of dexion were marked for cutting at a later date. Bolts, nuts and washers were purchased. Two metallic blocks to be used to support the lead were found, cut, and cleaned with acetone. A thick aluminum plate was found and tested to measure the amount it flexed under approximately 100 kg of weight. Due to the difference in height of the counter and the metal blocks, it could not bend more than 1 cm, otherwise some weight would compress the fragile scintillating material. The plate did not flex more than 5 mm thus it was acceptable. Lead bricks which were shaped so as to have no linear gaps were chosen. The dexion was then cut and cleaned.

Three vertical struts were on each side, two closer together as this is where the TPC would be placed. Then dexion was placed across these two vertical struts lengthwise on each side to allow another aluminum plate to be placed on top. The TPC would rest on this plate. Care had to be taken to provide enough height between the lead bricks resting below and this aluminum plate, so the second scintillation with a thickness of approximately 2 cm could easily slide under it.

Once the general skeleton surrounding the bottom scintillation was constructed, attention was turned to creating the railings that would span the upper portion and were to hold the inverted scintillation. The railings used a long piece of dexion with three smaller pieces of dexion attached to it, which were in turn mounted to the skeletal frame. Care was again taken to provide enough space vertically between the hanging scintillation and the top of the TPC, and that the railings provided enough of a ledge to support the wooden plank to which this scintillation counter was attached.

A small support stand was constructed for the second scintillation. This required holes in rectangular pattern to be drilled in the metallic table with matching threads to the threaded rods used. The threaded rods were placed, with dexion placed across their widths. These two dexion beams would support an aluminum plate between them to support the photomultiplier tube of second scintillation counter.

Once the setup was complete, crossbars were added for stability and the base was permanently attached to the table. Once completed, the counters were placed (see Fig. 11) and the table was vibrated mildly to see if there were any structural weaknesses. There were none. The completed setup allowed the first counter and third counter freedom of movement in only the lengthwise direction. The TPC and second counter, however, could be moved in all three dimensions.

FIGURE 11: Experimental Setup with three scintillation counters.

7.0 CONCLUSIONS

The work on GEM detectors as another method of tracking particles precisely is on going. The current TPC prototype detector still has many unresolved issues, though several problems have been resolved. To understand the results, the simulator is in constant state of flux. The problems with the GEM s and the DAQ have been partially solved, and a new experimental setup built.

The GEM simulator written by Dr. Karlen had to be updated to include several different layouts used in the readout pad. Due to poor readability of the simulators results, a graphical display had to be written, taking into account possible future revisions and the current simulator state. To improve the usability of the program, it had to be able to save the virtual detector setup. This required a major revision in the program s architecture. The simulator is still undergoing revision to include other possible layouts and the creation of a graphical editor, so the user can construct very specific readout pad layouts.

The construction of a GEM foil test chamber and the use of previously validated testing procedure is likely to improve the durability of the GEM detector. High voltage failures are a serious threat, and other steps will be taken in the future to minimize it. The TPC will be shaped and dielectrics placed to ensure the uniformity of the generated electric field. Electrical grounds will also be isolated, so as to reduce the possibility of sparking on components other than the GEM foils.

Several major issues involving the DAQ have been resolved. With a great deal of time and effort, the communication problem was tracked to a faulty PCIADA card. (Not resolved yet, haven t got the card). A patch board was created to resolve compatibility issues between the FADC connectors and the older Aleph pre-amps. The system has yet to be tested in full with the current linux machine. Once tested, there will likely be issues regarding linux drivers, as earlier tests suggested that this could be another issue for the communications error.

The current experimental setup involving three scintillation counters and the TPC has yet to be tested due to problems with the DAQ. It is structurally sound and as the table to which it is attached is on wheels, it can be moved easily. It is also adjustable though built in accordance with the geometrical requirements given by theory, the geometry could be changed.

There are several foreseeable changes to be made. One is the possibility of integrating the GEM simulator with the MIDAS DAQ, using the Java Native Interface. This would allow the Simulator to access both experimental data and theoretical results and compare them. Another change would be the addition of another eight FADC s. This would require another patch board and possibly require that some sort of shielding be built to isolate cards from one another to reduce noise. Eventually, a larger model would be constructed and would require a new experimental setup and testing area.

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