The Performance of Gaseous Electron Multiplier Preamplifiers (GEM) as a Neutron Sensitive Detector

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Abstract

I propose to construct and measure the performance of a fission chamber instrumented with preamplifiers known as a Gas Electron Multiplier (GEM). This fission chamber is a chamber filled with a 90/10 Ar/ CO_2 gas mixture enclosing U-233 as a neutron sensitive material. A neutron of sufficient energy has the potential to interact with the fissionable material, producing heavy ions known as fission fragments. The fission fragments within 5 microns of the target's surface may escape and ionize the gas in the chamber. Electrons,freed from ionization, will be driven by an electric field toward the GEM preamplifiers to produce secondary electrons. After multiplication by GEM preamplifiers, most of the electrons will end up to a charge collector to provide a pulse to the DAQ-system.

The Gas Electron Multiplier (GEM), invented by Fabio Sauli in 1997.[?,?,?,?] The GEM preamplifier is a 50 micron sheet of kapton that is coated on each side with 5 microns of copper. The copper clad kapton is perforated with 50-100 micron diameter holes separated by 100-200 micron in a staggered array . The GEM detector has been designed, developed and used for detection in CERN since 1997. Fabio Sauli invented the GEM preamplifier in 1997[?,?,?,?] and Gandi and De Oliveira designed it. The design was on 50,5 um kipton copper clad cards, which had holes of 70 um in diameter in a an equilateral triangular pattern with a 140 um pitch distance.

It is worth mentioning the thick gaseous electron multiplier (THGEM) preamplifier design, the macroscopic version of GEM, which represents the next generation of GEM preamplifiers. THGEM preamplifier uses a perforated fiberglass board (PC board) clad with a conducting material. A thick fiberglass sheet, that may have up to 10mm thickness, is perforated with holes with a diameter of 2 mm.

Motivation

Fast neutron detectors have many applications in different disciplines of nuclear technology. For instance, fast neutron detectors are used in Homeland security applications, such as neutron imaging for large cargo containers; high penetrating neutrons are desirable when efficient fast neutron detectors are available. They are also used for real time measurements of fast neutron beam flux, which is used in nuclear reactors such as the Advanced Test Reactor (ATR). The goal of this research is to economically build and test the performance gaseous electron multipliers preamplifiers, as they are installed in detector's chamber that has a coated layer of fissionable material such as U-233.

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Chapter 1

Detector Description and Operation

1.1 GEM preamplifiers

The GEM preamplifier described previously was used to increase the signal amplitude of the ionization chamber. Primary electrons are liberated by an ionizing particle intersecting an ionization chamber that has a 90/10 Ar/CO2 gas; the cathode's electric field accelerates the electrons towards the GEM preamplifier. As described in section 2.7, a single GEM preamplifier can increase the number of liberated electrons by three orders of magnitude via secondary ionization.[?,?,?,?,?,?,?,?,?,?,?,?] Using three preamplifiers will increase the signal amplitude, making it measurable. A high voltage divider circuit is used to establish the electric fields for each preamplifier, using a single power supply channel; secondary electrons are guided towards a segmented charge collector.

1.2 Detector Structure

The triple GEM detector is composed of three GEM preamplifiers, a cathode and an anode. A GEM preamplifier is a 50 micron thick kapton foil clad on both sides with 5 microns of copper. A staggered pattern of 50 micron diameter holes, equally spaced by distances comparable to the hole diameter, is chemically etched into the copper clad foil of a 140 um pitch distance over an area of 10x10cm.[?,?,?,?] The detector contains three GEM preamplifiers mounted on square plastic frames separated by a vertical distance of 2.8 mm and placed parallel to the cathode as shown in the figure below.

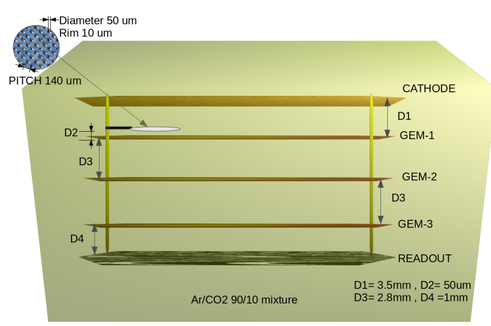


Fig.1 shows the original GEM detector design.

The cathode is a square copper plate that is 10x10cm and is 3.5 mm away from the top of the first GEM card. This cathode design is capable to hold potential voltage of 5 kV (in the air) between the top and bottom side without any discharge. The charge collector (readout anode) is constructed of 50-80 micron wide strips that are insulated to determine the location of the collected electrons, and are arranged to allow equal charge sharing on the upper (x coordinate) and lower (y coordinate) charge collector layers.[?,?,?,?]

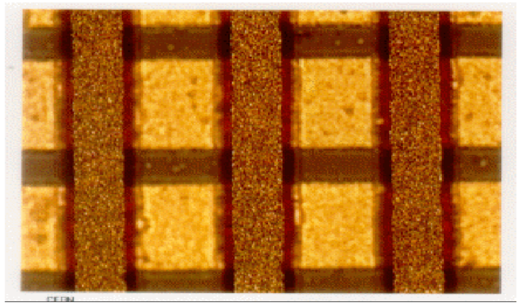
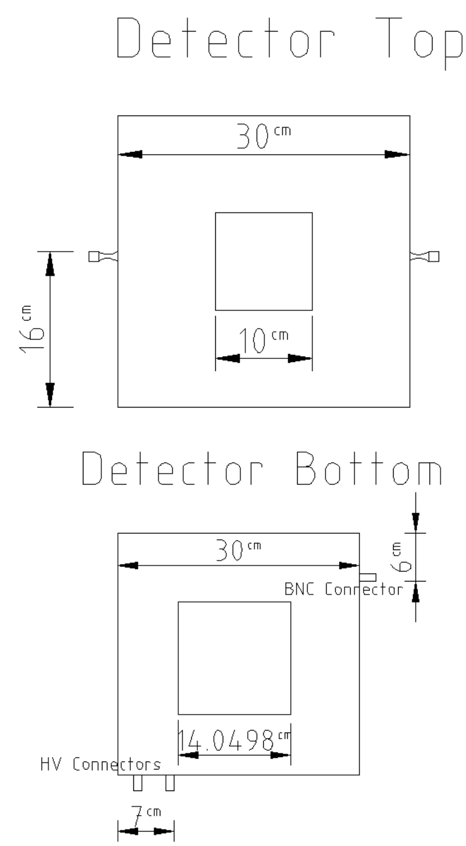
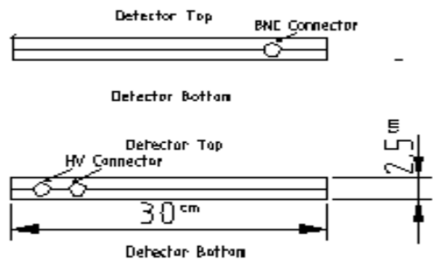


Fig. shows the charge collector dimensions and arrangement.

All the above components exist in a sealed chamber that consists of two ertalyte plastic sheets; they are bolted together by a number of M3 plastic screws located around the detector window to form a well enclosed cavity. Also, the chamber has a 13x13cm kapton window to reduce the energy loss of incident particles entering the chamber. The figures below show top, bottom, and side views of the detector's chamber design.

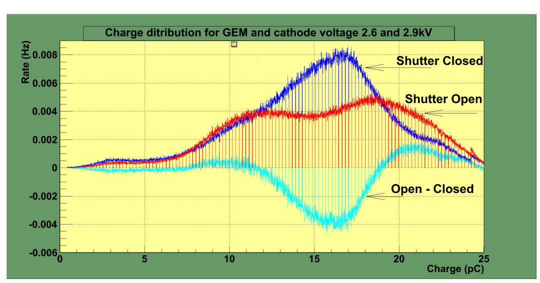




1.3 Modifying the GEM detector as neutron sensitive detector

The GEMs original design was modified to convert it to a neutron-sensitive detector. As mentioned previously in Section 2.2.1, fissionable material, inserted inside the chamber, has been used to directly detect neutrons. The cathode design has a 3 cm diameter coating of U-233 with a 30-40 um thickness. The kapton window height was increased 2.5 mm to accommodate an increase in the distance of the cathode to 8 mm from the top of the first of GEM card (instead of 3.5 mm in the original design). An FR4 shutter which had enough area to cover the fissionable material was attached in the space between the cathode and the first GEM card. The shutter could be opened or closed from outside the chamber.

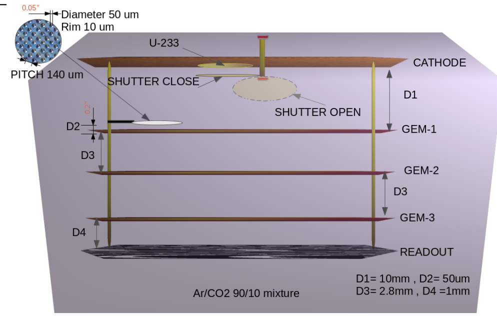
The shutter has the ability to stop the fission fragments that are emitted from U-233 coating. Having the U-233 as a source for alpha particles, the QDC charge spectrum showed a difference in case the shutter was open and when it was close, such a test proved the ability of the FR4 shutter to stop (or partially stop) the emitted alpha particles from U-233 coating. The figure below shows the charge spectra in case of shutter open and closed as the detector's operating voltage is 2.6 kV and 2.9 kV for GEM and cathode successively.



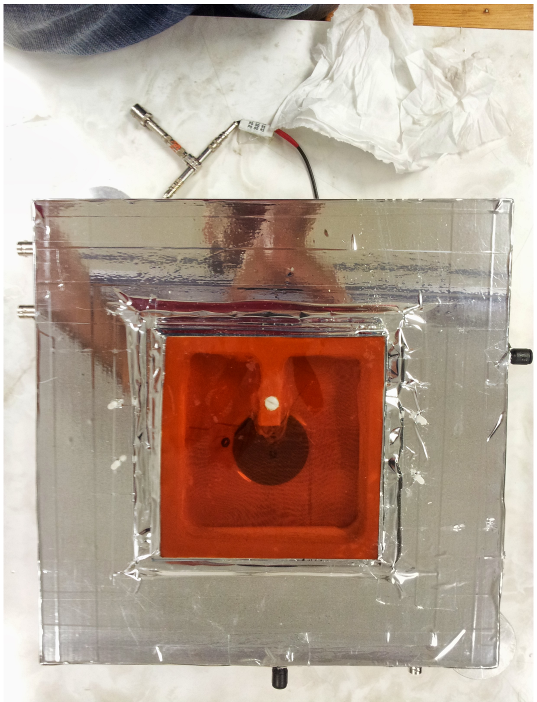
charge collected as the voltage is 2.60 2.90 kV for GEM and cathode successively

Since the fission fragments are heavier ions than the alpha particles, and after the fission event they have kinetic energy to move a distance measured in micrometers in gas, an FR4 closed shutter should stop them, which is important, in order to distinguish the fission fragments' signal from the other particles' signals in a heavy radiation environment that the detector survives in an operating accelerator or reactor hall.

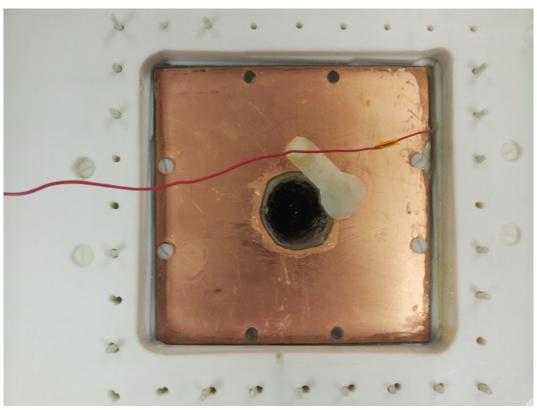
The figures below show the modified components of the detector.



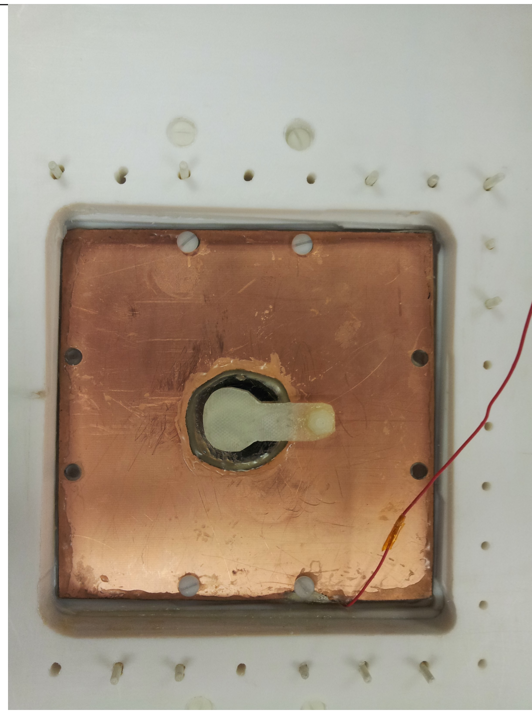
Adding modifications to GEM design.



Modifying the cavity size by the increasing the height of kapton window.



Detector's shutter is open.



Detector's shutter is close.

1.4 High voltage divider circuit

A high voltage divider circuit is used to proportionally apply voltages on both sides of each GEM preamplifier, as depending on the resistors used in the circuit, so the first GEM preamplifier encounters is set to have the highest voltage different between the sides, that is created by the higher voltage values after the detector's cathode.

The GEM preamplifiers are connected to the high voltage divider circuit to specify the electron multiplication and to support (manage) the electron transfer to the charge collector. As mentioned previously, the applied voltage on GEM cards determines all the detector's properties, such as the order of electron multiplication, and the electron collection by the readout plate. A high voltage divider circuit was designed for these purposes as shown in the figure below:[?,?,?]

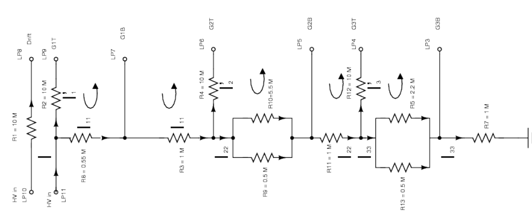


Figure shows the HV-divider circuit.

The table shows the measurements of voltage between the sides of the GEM electrodes, and voltage between each side and the ground that are provided by the HV-voltage divider circuit shown above.

$V_{source} \pm 1$	2550	2600	2650	2700	2750	2800
$V_{G1T} \pm 1$	2579	2630	2680	2731	2781	2832
$V_{G1B} \pm 1$	2259	2303	2348	2393	2373	2482
$\Delta V_1 \pm 1$	304	310	316	322	328	332
$V_{G2T} \pm 1$	1671	1704	1737	1770	1803	1836
$V_{G2B} \pm 1$	1394	1421	1449	1476	1503	1530
$_2 \pm 1$	279	285	290	296	302	307
$V_{G3T} \pm 1$	818	834	850	866	882	898
$V_{G3B} \pm 1$	570	581	592	603	614	625
$\Delta V_3 \pm 1$	245	250	255	260	264	269

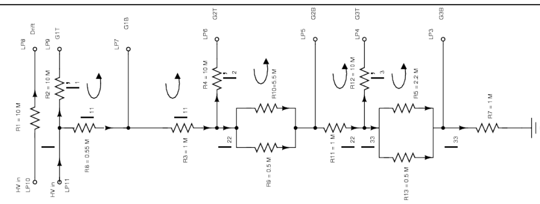
Table 1.1:

The circuit also provides a trigger signal through a high pass filter connected to the third GEM electrode. One of the ways to get the detector signal is by a high pass filter that is in contact with the bottom side of the third GEM card; a positive signal is detected by the oscilloscope, since all the electrons are leaving the last GEM electrode toward the charge collector. The job of the high pass filter is to block all the low signal frequencies to provide a signal that can clearly be detected by a 50 ohm terminated oscilloscope.

1.5 Detector operation

GEM detector operation determines the signal for the detector and its multiplication which is limited to a maximum voltage. GEM based detectors may contain one or more than one preamplifier. Operating a GEM detector mainly depends on the detector structure, The applied voltage on preamplifier's sides determines the its multiplication, so the multiplication increases by increasing the voltage. However, there is a limit for the applied voltage on each preamplifier to avoid the discharge, which may damage the GEM cards. The detector should have an appropriate number of GEM preamplifiers to avoid increasing the voltage to the discharge limit if the particle signal demands higher multiplication. Accordingly, GEM based detectors have many applications, and each one demands a specific area, shape, and number of cards which GEM preamplifier can provide. In our case, the detector's structure is based on triple GEM preamplifiers, which allows the maximum voltage to reach to 350 V on each preamplifier. The electron multiplication vs the applied voltage is shown in the figure below.

CAEN N470, a four channel digital power supply, allows an increase in the voltage between the sides of the first GEM preamplifier to reach up to 350 V; the voltage gradually decreases to be the least on the sides of the third GEM preamplifier to reach 265V. Usaully, two HV-channels is used, one provides a voltage up to 2.8 kV for the GEM preamplfiers, and the other is responsible for controlling the voltage on the cathode. When the cathode voltage is 3.1 kV and 2.8 kV on the preamplifiers, it creates a drift voltage of 300V in the drift area as shown in the table in the previous section.



The power supply is connected to a discharge protection circuit. CAEN N470 has a signal Lemo 00 input to activate a kill option automatically when a discharge signal occurs through the detector operation. The kill input is connected to the detector charge collector output, so if a discharge happens and its signal wider than 15 us, kill option state turns true to trip all the power supply channels.

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1.5.1 Detector operation purposes

Detector operation is usually for counting or for imaging purposes. As mentioned previously, the detector is equipped by a high-pass filter that is connected to the bottom of the last GEM preamplifier, and a wire-segmented charge collector. When the detector is used for counting, the electronics setup receives either a positive pulse from the high-pass filter, or a negative pulse from the charge collector. Both possibilities only help in counting the events that are created by the incident particles. In counting mode, collecting data by the DAQ is performed by the Nimbin traditional electronics' modules, as will be shown in the coming section. Operating the detector for imaging, or measuring the electron intensity on each pixel on the wire-segmented charge collector requires VME based electronics. There are different VME modules that are used for this purpose such QDC(CAEN V792), and CAEN V1495 (multipurpose programmable module). They are usually supported by circuit boards that have (VFAT) circuit boards and connectors, gum sticks, and an I2C controller that manage the separate signal transfer from each pixel on the wire segmented charge collector to CPU.

1.5.2 Data Acquisition circuit (DAQ)

There are two methods to collect the electrons after electron multiplication. As mentioned previously, electron multiplication provides enough charge to magnify the incident particle ionization in the detectors drift area. The charge collector will collect all the electrons as negative pulses to send them to the DAQ circuit. Or the high-pass filter will collect the charge that leaves the last GEM preamplifier as positive pulses, then it will send them to the CPU unit through the circuit pictured below:

The circuit contains a number of Nimbin modules and CAEN V792 QDC as a VME module. The circuit will provide the CPU unit with digital pulses through the VME bus. The CPU unit has a CODA 2.6.1 software package that is responsible for storing the data in a file; a script uses the file as input to generate an n-tuple root file, so a root package can view and manipulate the data for the collected charge spectrum.

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