A GEM detector for thermal and fast neutron monitoring

A GEM (gas electron multiplier) is made of a thin (50 μm) kapton foil, a copper cladding on each side, perforated with a high surface density of holes, each one acting as an electron multiplication channel. Each hole has a bi-conical structure with external (internal) diameter of 70 μm (50 μm) and a pitch of 140 μm (fig. 1).

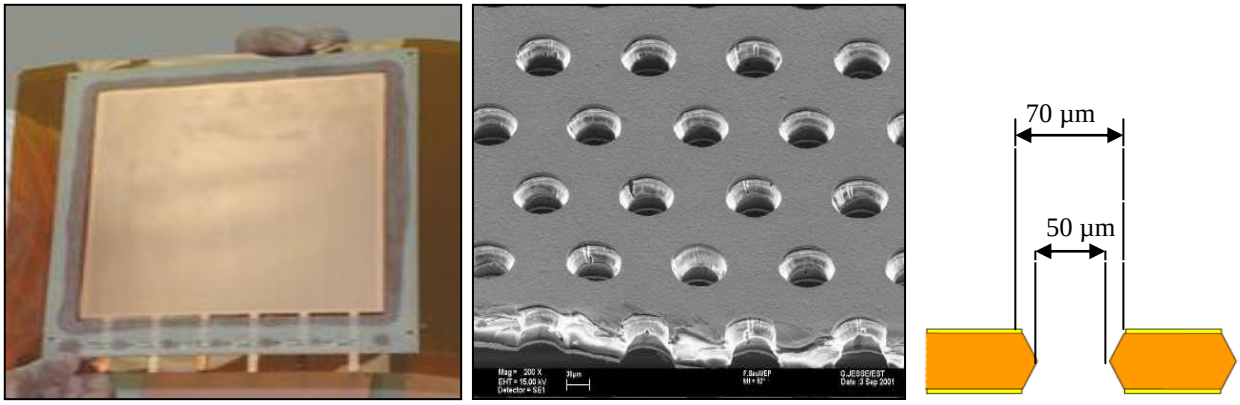


Figure 1: a 10 x 10 GEM foil (on the left), how a GEM appear to microscope (in the middle), GEM hole: shape and dimensions (on the right).

The bi-conical shape of the hole minimizes the effect of charging-up of the kapton inside the holes (with respect to the conical shape) and is a consequence of the double mask process used in standard photolitographic technologies. A GEM is the key element of a new generation of gas detectors: when a voltage difference of 350 to 500 kV is applied between the two copper claddings, an high electric field of 100 kV/cm is created inside the hole so that the electrons produced by ionization in the gas have e sufficient energy to generate an proportional charge multiplication.
To realize charge multiplication, the GEM detectors developed at LNF make use of three GEM foils in order to have three independent stages of multiplication. The layout of the detector provides three elements: a cathode, an anode and the three GEM foils sandwiched between the first two elements. Anode is segmented in pads and connected to the readout electronics, in order to collect the charge induced by the drifting electron cloud originating from the last GEM stage. Usually the two regions included between the cathode and the first GEM and between the third GEM and the anode are called drift zone and induction zone, while the two region between the three GEM (from the cathode) are called first and second transition zones (fig. 2).

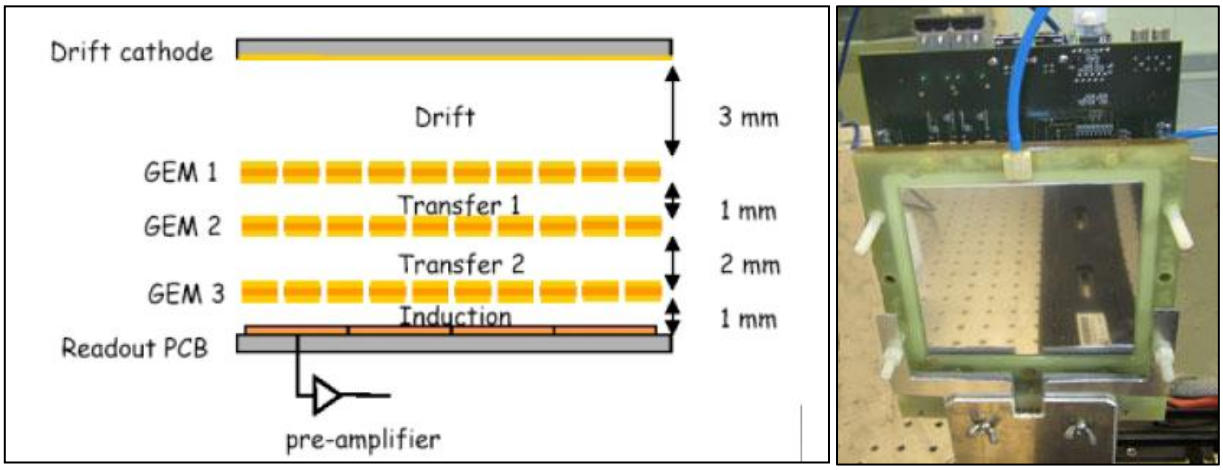


Figure 2: geometrical configuration scheme of a typical head-on GEM detector (on the left) and photo of aluminate mylar window GEM detector

Typically, for the so-called head-on detectors, the gaps of the successive four regions are 3, 1, 2, 1 mm, respectively and an electric field is applied in each gap. Usually anode is divided in 128 pads. Until now, pads used for neutron detection have dimension of 6x12, 8x8 and 3x6 mm².

GEM detectors for neutrons

Typically, GEM detectors working as neutron monitors have a planar geometry with a 10 x 10 cm² converter material window. Materials used as neutron converter are polyethylene for fast neutrons and boron 10 for thermal neutrons. In polyethylene neutrons produce protons and the window has suitable thickness (~500 µm) so that only protons produced in the forward direction reach the gas and ionize it. Beneath this layer, there is a thin (< 100 µm) aluminum foil which acts as a cathode. In using boron, instead, window is realized with an aluminum plate covered by thin layer of boron on the side facing the gas. A neutron interacting on boron layer produces ^{7}Li and α. Ionization is produced mainly by alpha particles; ^{7}Li particles have a minor probability to reach the gas because they are absorbed by boron itself.

How a GEM detector work

A charged particle or a photon that interact in the gas of the drift region produces a ionization clusters of positive ions and electrons. Due to the applied electric field, the cluster of positive ions drift towards the cathode, while the electron cluster drift towards the holes of the first GEM foil. Here charge is multiplied and while the amplified charge drift toward the second GEM foil a great percentage of positive ions produced in the holes is captured by the upper GEM electrode. So multiplication channel is quickly released and ready multiply new electron clusters. These is also a little percentage of multiplied electrons that is captured by the lower GEM electrode. A similar process occurs on the others GEM foils. In this manner electron charge is multiplied in three successive stages preventing discharges on each single GEM due to excessive storage of charge. Gain is proportional to the sum of the three GEM voltages. Beneath the third GEM, multiplied electron cluster induces a current pulse on a pad. Read-out electronics discriminate this signal and count it so that a digital information is visualized and stored (fig. 3).

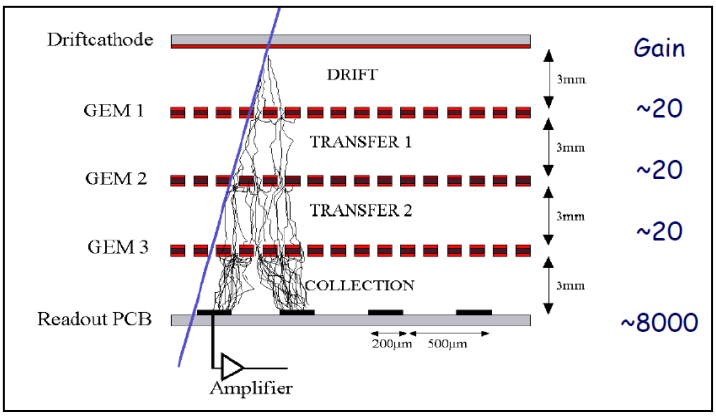


Figure 3: schematics of how a signal in produced when a particle interact in the drift region.

The detector used during tutorial has planar geometry as described before but it has an aluminate mylar window with no converter material. This detector is used for X and gamma rays detection. Also in this case, anode is divided in 128 pads, each one covering an area of 3 x 6 mm² so that the total active area is 5 x 5 cm².

Experimental material

1. Planar GEM detector;
2. HV GEM power supply: PC cable, HV cable, HV filter;
3. Read-out electronics: 8 CARIOCA chip boards, FPGA Mother Board (MB) + power supply & ethernet cable;
4. GAS: $ArCO_2$ (70/30) bottle, tubes, flowmeter;
5. ^{137}Cs source
6. PC interface for detector control and data acquisition system.

Experiment description

Tutorial experiment consists of an HV scan when detector is exposed to the ^{137}Cs source. HV is proportional to the gain so varying this parameter is possible to change current pulse height induced on pads. Fixed a certain threshold, an increasing number of pulses is counted when gain is increased. This kind of measurement shows an important feature of GEM detector: the ability to distinguish between different types of particles when they release different amounts of energy within the gas. For ^{137}Cs, this is not evident, because there is also a low energy X ray spectrum other than gamma at 661 keV (fig. 5).

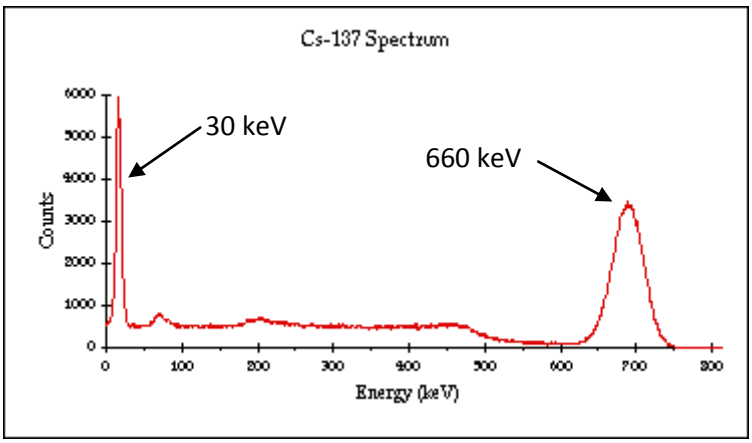


Figure 4: Energy spectrum of ^{137}Cs decay.

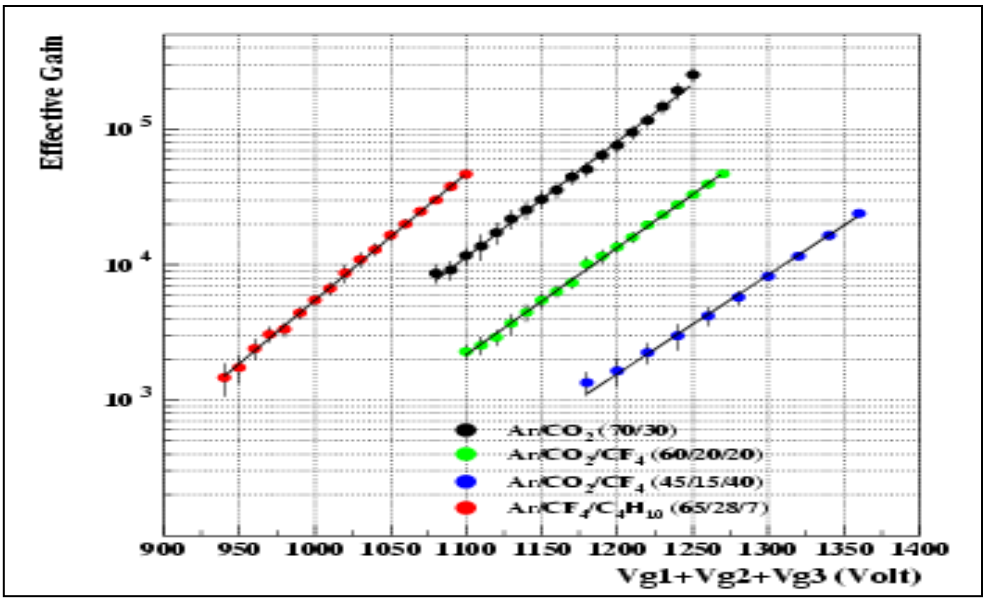
So, when gain is increased, a continuous increment of the total counts registered by the detector is expected.

Main steps to perform the experiment:

1. Mount read-out control electronics on the detector: CARIOCA cards and FPGA MB;
2. Using an ethernet cable, connect FPGA MB to the internet outlet;
3. Connect HV power supply module to the detector: HV filter and cable;
4. Connect HV power supply to PC CAN port;
5. Connect in and out gas tubes to the detector;
6. Switch on HV module and FPGA MB;
7. Run HV and FPGA Labview control softwares;
8. On the HV software panel, set the fields and then the GEM voltage VG1, VG2 and VG3 to values of 330, 320, 310 Volts in order to have a total HV of 960 Volts;
9. On the FPGA MB software panel, control values of the 16 threshold values and set threshold zero value in order to cancel electronic noise;
10. Place ^{137}Cs source near the detector window;
11. On the FPGA MB software panel, set the time gate width to 1000 ms and run the software;
12. Medium counts and sigma on ten samples are written in the FPGA MB software panel;
13. Rise applied HV in step of 20 Volts until 1100 Volts. For each step sign HV GEM voltages, medium counts and sigma filling a table like that below:

VG1	VG2	VG3	∑VGi	Medium Counts	Sigma Counts
330	320	310	960		

14. Plot a Medium Counts vs Gain. Gain can be obtained from the following gas calibration diagram.



15. In the best configuration set, get an image of the source by placing the ^{137}Cs in different position onto the GEM cathode.

Further measurements (if possible within the allocated time)

16. At fixed threshold and ∑VGi, measurement of the integrated counts over the whole set of pads with the ^{137}Cs source as a function of drift HV V_{drift} between 0.5 and 3.5 kV in step of 0.25 V.
17. At fixed threshold, measurement of the integrated counts over the whole set of pads with the ^{137}Cs source as a function of induction HV V_{ind} (between the last GEM and the pads) between 0.5 and 5 kV in steps of 0.5 kV.