Numerical simulations on single mask GEM detectors

The Gas Electron Multiplier (GEM) is a gas detector invented in 1997 in the Gas Detector Development group at CERN by the physicist Fabio Sauli.
The detector consists of a kapton layer, usually 50µm in thickness, clad with a 5µm copper layer on each side. A photolithographic process, followed by acid etching, creates holes 70µm in diameter through the detector. Since the etching process proceeds from both sides of the detector, the holes assume a double-conical shape. The holes are arranged in an hexagonally-packed structure which allows to reach a surface density of about 60mm^{-1}. Figure 1 shows a picture of a standard GEM foil taken with a scanning electron microscope.
The primary ionization electrons produced in the drift gap migrate toward the GEM, where they are eventually focused into the holes by the electric field. The voltage across the GEM, usually of the order of 400 - 500V, generates an electric field that reaches several tens kV/cm inside the holes. In such field, the primary electrons start to multiply, creating avalanches. The secondary electrons that are eventually extracted are driven to the anode by the induction field.

Figure 1: scanning electron microscope 3D view of a standard GEM foil. The magnification factor is 200x

Figure 2: electron microscope view of a single mask GEM foil. The magnification factor is 500x

The described manufacturing procedure is not suitable for the production of large area detectors, due to difficulties in the alignment of the two photolithographic masks. The most promising technology in this sense is the single mask technique, in which the polyamide is etched from one side only. This leads to conical holes, as shown in figure 2.
In this framework, numerical simulations can be helpful to gain knowledge on some detector properties, such as the electrical field shape, the electron transparency, the avalanche shape and the charging-up properties. The simulations are performed using the ANSYS® and Garfield software packages.

♦ ANSYS® is used to:
1) define the detector geometry;
2) specify the material properties;
3) fix the electrodes voltages;
4) set the boundary conditions;
5) find the fieldmap using a finite elements analysis method

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♦ Garfield is used to:
1) read the ANSYS® fieldmap;
2) define the gas properties;
3) simulate the behavior of electrons in the detector

Step 1: generating the fieldmaps with ANSYS®

To study the detector properties as a function of the holes geometry, several fieldmaps have been generated. The holes diameter on the surface of one GEM electrode is fixed to 55µm, while the diameter on the other GEM electrode varies from 95µm to 55µm in different fieldmaps.
In order to speed up the simulations, only the elementary cell marked with red color in figure 3 is taken into account. The imposition of symmetrical boundary conditions on all the lateral surfaces of the elementary cell allows to get an infinite fieldmap with simple x and y reflections.

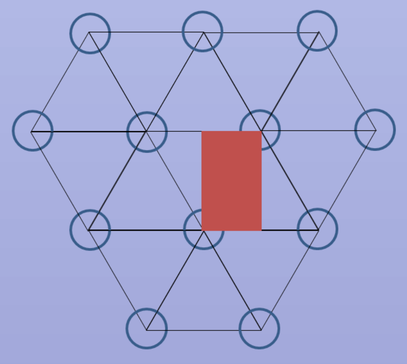

Figure 3: schematic view of a GEM detector. The red rectangle marks the elementary cell

♦ kapton thickness = 50µm
♦ copper thickness = 5µm
♦ drift gap thickness = 770µm
♦ induction gap thickness = 770µm
♦ holes pitch = 140µm
♦ holes smaller diameter = 55µm
♦ holes larger diameter = 95µm → 55µm
♦ drift field = 3kV/cm
♦ GEM voltage = 400V
♦ induction field = 3kV/cm

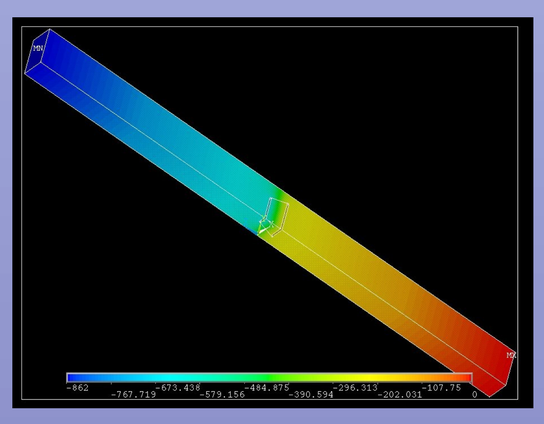

Figure 4: electrical potential in Volts in the elementary cell. The hole diameter is 95µm on the GEM top and 55µm on the bottom

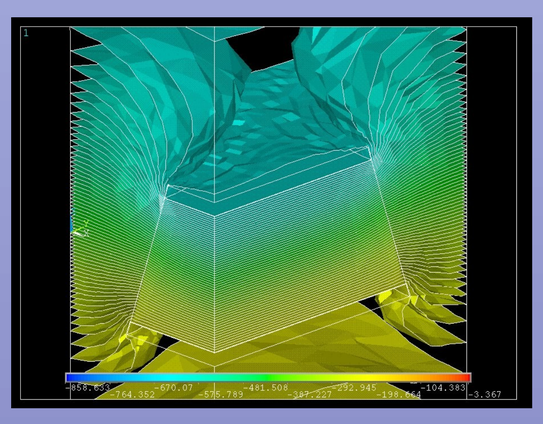

Figure 5: detail of the central part of figure 4, around the GEM foil. The equipotential plans are shown

Step 2: simulating the detector with Garfield

The ANSYS® fieldmap is loaded into Garfield and mirrored in x and y to obtain the whole detector. Figure 6 shows detector cross-sections along the hole axis for different geometries. The equipotential lines are drawn in green, while the yellow lines represent electron drift lines as they would appear if there was no thermal diffusion.

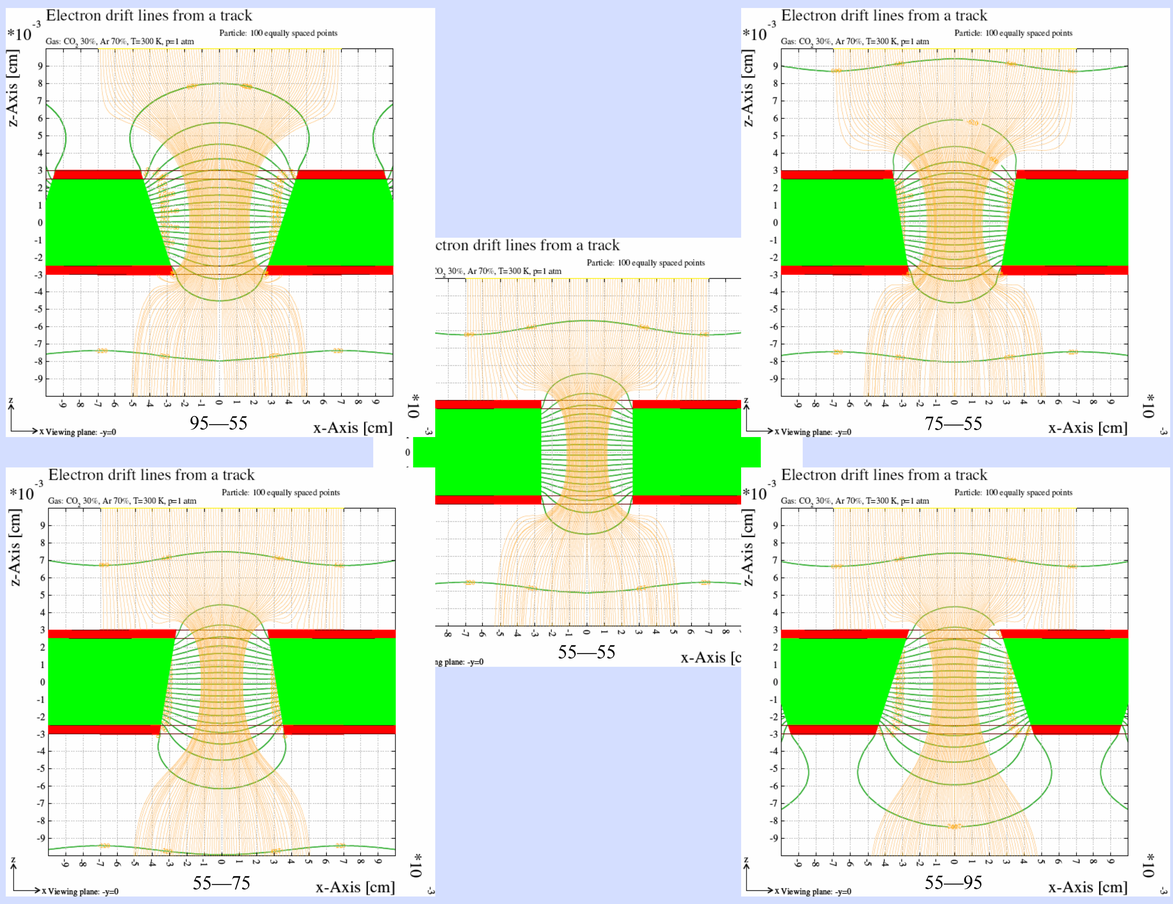

Figure 6: GEM cross-sections for different hole geometries. The labels indicate the hole diameter in micrometers on the top surface of the upper GEM electrode and on the bottom surface of the lower GEM electrode

In the open-top configuration the field lines are very effective in focusing the electrons into the hole, but the extraction efficiency isn't so good. In the cylindrical and open-bottom configurations, on the other hand, many electrons are lost on the top copper foil, but the extraction efficiency is better.
In order to estimate the electron transparency as a function of the hole geometry in a more accurate way, it is necessary to implement a Monte Carlo simulation in which:
♦ the x and y starting coordinates of the electrons are generated randomly inside the elementary cell marked with red color in figure 7;
♦ the electrons are generated in a zone where the drift field is uniform;
♦ the thermal diffusion is taken into account.
The simulation therefore proceeds through the following steps:
0) define the simulation volume as the black rectangle in figure 7. The z coordinate ranges from –70µm below the GEM to +170µm above the GEM;
1) generate an electron with random x_{start} and y_{start} coordinates within the elementary cell marked with red color in figure 7. Use z_{start} = 70µm above the GEM;
2) assign a small E_{start} = 0.1eV to the electron, with random direction of **p**;
3) drift the electron using a microscopic technique which step is the free path with its natural distribution. At each step a collision with a gas molecule is simulated;
4) repeat step 3 until the electron ends up on a solid or it exits the simulation volume, then record its status and its final coordinates. 5 scenarios are possible: the electron hits the top electrode, the kapton or the bottom electrode, the electron reaches the bottom of the simulation volume or it attaches to a gas molecule;
5) repeat steps 1 - 4 for 1000 electrons.

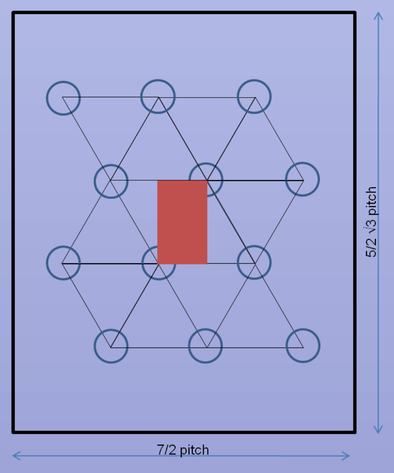

Figure 7: elementary cell and simulation volume

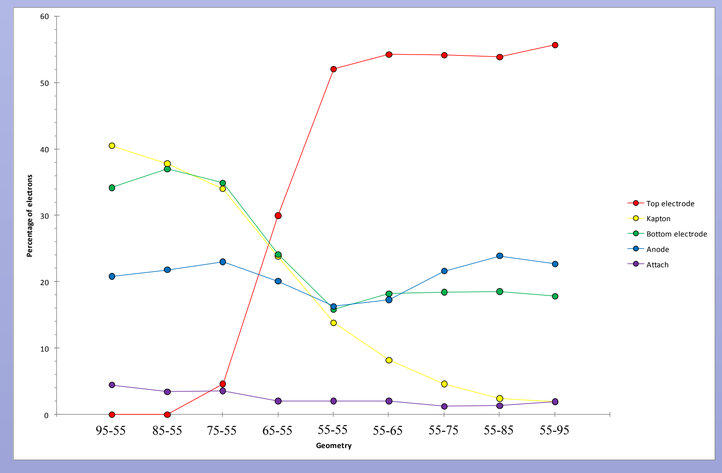

Figure 8: electrons final position as a function of the hole geometry

According to the simulation, in the open top geometry only few electrons end up on the upper electrode, while many of them reach the kapton and the bottom electrode. Going to cylindrical and open bottom geometries, more and more electrons are stopped by the upper copper foil. The number of electrons that finish on the kapton smoothly decreases, while the number of electrons captured by the lower copper foil decreases and reaches a plateau. The overall transparency is about 20% and does not strongly depend on the geometry.