Simulation of Charged Particle in a TGC Detector

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As the new LHC (the sLHC) approaches, we need to be prepared with our best tools to deal with it, in order to get the results quicker and more precise. As part of the new detector creation, we made its simulation[1], and that will give us the opportunity to change parameters without building a whole new detector each and every time. Also, the simulator, COMSOL Multiphysics, is able to calculate a few helpful details, which will be shown in this article.

The current LHC (Large Hadron Collider) had produced proton-proton collisions at a centre of mass energy of 8[TeV] and luminosity of up to $10^{34}\left[\frac{1}{(\text{cm})^2\cdot\text{sec}}\right]$, while in the next year, 2014, it is supposed to reach even 14[TeV], and in the year 2018, the sLHC (super LHC), is supposed to multiply its luminosity by 10.

The detector is a Muon Detector type, which means it is located at the end of the detector (with regards to the collision beam), and most probably will give only the muon's signals, because the heavier charged particles will most probably interact or decay before reaching this detector, and the neutral particles won't leave a signal (the electron will probably remain at the electromagnetic detectors).

The detector is composed of several parts (see Fig. 1a and 1b); insulator (FR4), strips (copper), plates / cathodes (carbon – graphite), wires / anodes (tungsten covered with a negligible layer of gold), pads (copper), and gas mixture (55% CO_2 and 45% of n-pentane).

The detecting method: a charged particle enters the detector with very high momentum (assumed to be at the speed of light), and tears away the electrons from their CO_2 molecules. After that (assuming it was a muon) it continues with its course and vanishes from the detector. Meanwhile, the wires are held in a voltage of 3000[V] while the carbon plates are held as a ground, 0[V], which creates an electric potential

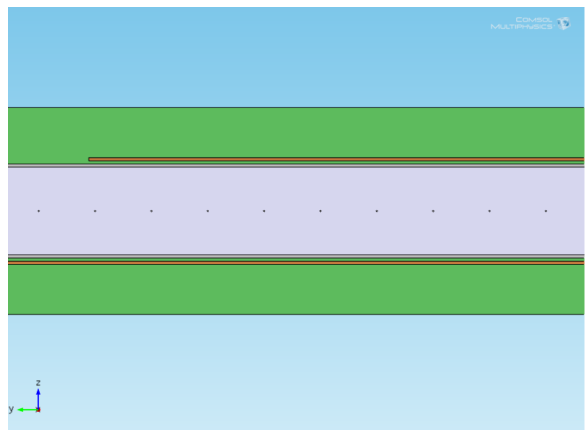

FIG. 1a. Detector's layers from top to bottom (zy plate view): pads surrounded by FR4, carbon plate (layer), wires surrounded by gas mixture, carbon plate (layer), strips surrounded by FR4 (3 layers).

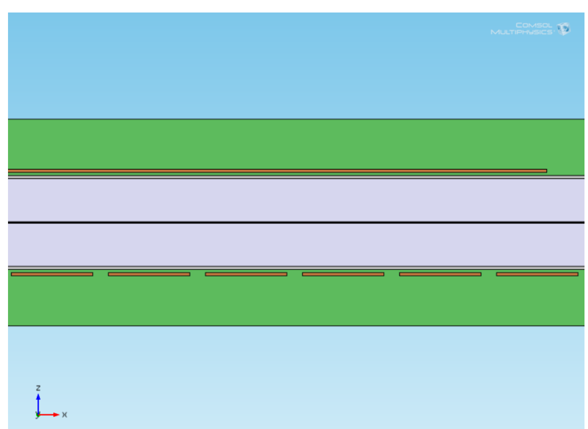

FIG. 1b. Detector's layers from top to bottom (zx plate view): pads surrounded by FR4, carbon plate (layer), wires surrounded by gas mixture (3 layers), carbon plate (layer), strips surrounded by FR4.

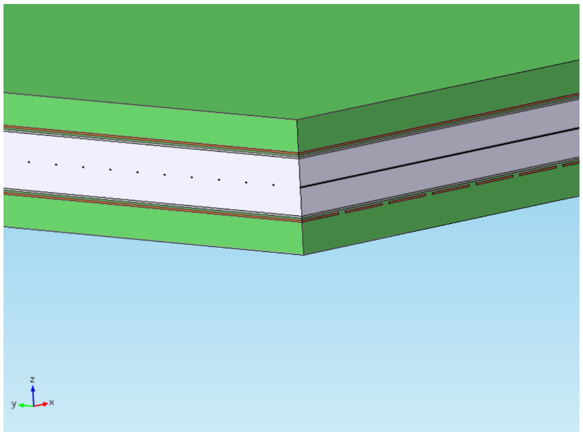

FIG. 1c. Detector's layers from top to bottom (edge cuts view): pads surrounded by FR4 (3 layers), carbon plate (layer), wires surrounded by gas mixture, carbon plate (layer), strips surrounded by FR4.

(see Fig. 2a and 2b) and an electric field (see Fig. 3a and 3b) in the medium between those wires and plates, which pulls the negatively charged particles (electrons in this case) to the wires (the positively charged particles are assumed to remain at their places, because of their large mass and low velocity compared to the relaxation time), while we assume all the charged particles do not interact with each other or change the field around them (which is not exact if we consider large avalanches, but we don't).

The wires are divided into groups of 5 close wires each, which makes the detecting easier, considering receiving all the data from the wires takes a lot of time due to their very large amount, and with the enormous amount of events per time unit a selection is needed in order to get the relevant results. When the process occurs the wires are collecting charge and since they are located near an electric circuit, it acts like a capacitor and creates induced current in that circuit that makes an electric reading of a particle. That reading brings us information about the 1st axis of the location (5 wires out of several hundreds). The rest of the information (the 2nd axis) comes from the strips, which are crossed to the wires (see Fig. 1c),

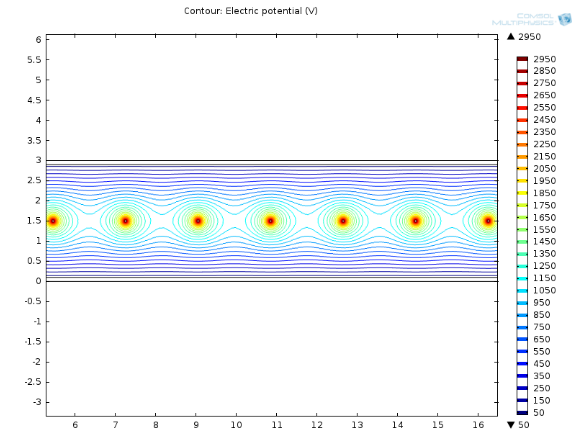

FIG. 2a. The electric potential between the carbon plates with no charge distribution in the medium (contour lines view).

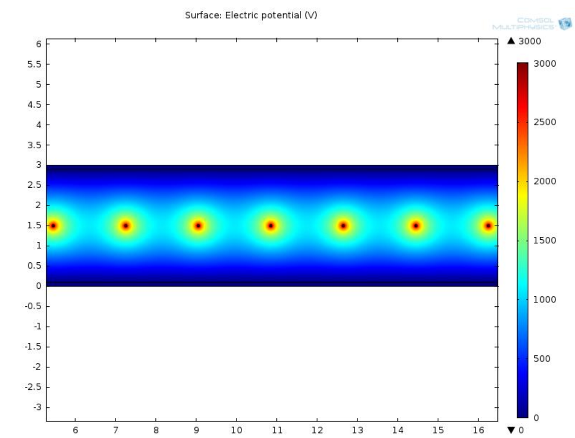

FIG. 2b. The electric potential between the carbon plates with no charge distribution in the medium (continuous domains view).

and get their charge from induced charge of the electrons from the CO_2, by the charge reflection created by the ground plate.

In the new version of the detector, designed for the sLHC, there are also pads, which responds the same way as the strips, but covering much larger area (8.7x8.7[(cm)^2] instead of 3.2[mm] width for strip), and by that, making the selection process more efficient. The first readings are the ones from the pads, then we can cover several big areas in a short time and can observe which one is that of our interest. Immediately after, we check only the wires and the strips of that pad's covered area and read the

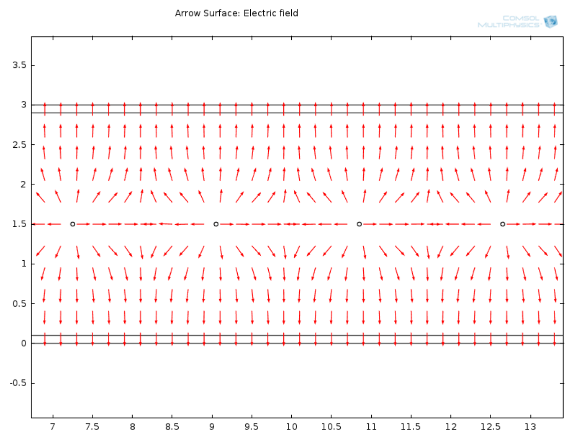

FIG. 3a. The electric field between the carbon plates with no charge distribution in the medium (normalized arrows – shows only direction of the field, which actually is also the positively charged particles motion's direction).

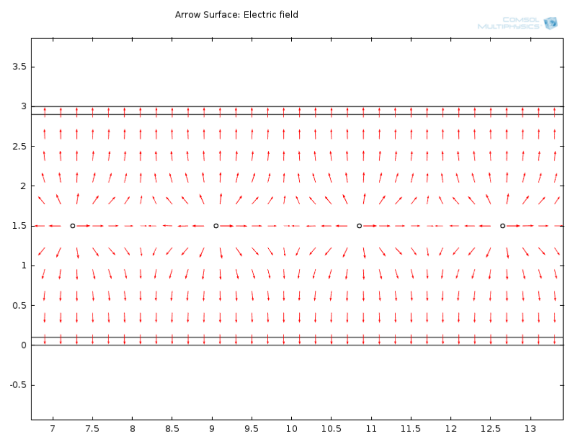

FIG. 3b. The electric field between the carbon plates with no charge distribution in the medium (logarithmic arrows – shows direction and the relative field's size at each point).

exact reading location, and thus we record the exact location of the particle in a very fast and efficient way, and save a lot of time of unnecessary readings.

The charged particle gets inside the gas medium, there it excites the CO_2's electrons (about 11 times according to experiments[2], 42±8 per cm) and those electrons, on their way to the wires (see Fig. 4), excite more electrons from the CO_2. The n-pentane gas is located in this medium in order to balance[3] the amount of free electrons released in this medium and is absorbing some free electrons, so the

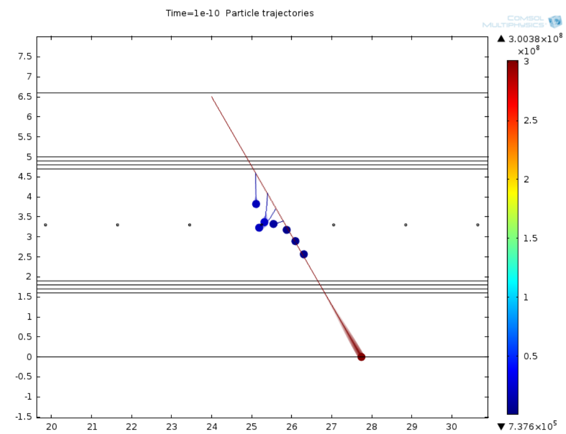

FIG. 4. The red particle is the muon, which crossed the gas medium, while the rest of the particles (the blues) are the electrons emitted from the ionized CO_2 gas.

charge on the wires won't be too high, so that the system can reach its stationary relaxed state faster and be prepared to the very close next particle entrance and excitations. Unfortunately, the simulation program is not willing to use a gas mixture so easily, so we only used a pure CO_2 gas (which gives different results)[4], with no n-pentane (see also discussion for future calculations at the end of the article) and without any avalanches (because of the complexity of the calculations and its duration of receiving results).

When electrons are released in the medium, in this simulation they are released at zero velocity (which is not accurate), they are attracted to the wires, because of the electric field mentioned earlier (see Eq. 1-3), but since the electric field is changing according to the position in the medium, so does the electric force operating on the electrons, and therefore their acceleration is time dependent. It is still predictable that the closer the electron's release to the wire, the faster it will reach it, so we checked that theory (the original full theory including the gas mixtures, the avalanches, and non-zero initial velocity gives some other results[3]) and get the results at Fig. 5a and 5b;

X \ Y	0.15[mm]	0.5[mm]	0.9[mm]	1.3[mm]
10[mm]	0.38[nsec]	0.33[nsec]	0.26[nsec]	0.20[nsec]
10.2[mm]	0.13[nsec]	0.12[nsec]	0.12[nsec]	0.10[nsec]
10.5[mm]	0.12[nsec]	0.11[nsec]	0.09[nsec]	0.05[nsec]
10.8[mm]	0.12[nsec]	0.10[nsec]	0.07[nsec]	0.02[nsec]

FIG. 5a. The time given here is measured since the start of the electrons' motion until the closest point to the 1st wire. The red time, indicates electrons which are doing 2 motion lines before getting into the wire.

X \ Y	0.15[mm]	0.5[mm]	0.9[mm]	1.3[mm]
10[mm]	1.569[mm]	1.281[mm]	1.000[mm]	0.825[mm]
10.2[mm]	1.477[mm]	1.166[mm]	0.849[mm]	0.632[mm]
10.5[mm]	1.383[mm]	1.044[mm]	0.671[mm]	0.361[mm]
10.8[mm]	1.350[mm]	1.000[mm]	0.600[mm]	0.200[mm]

FIG. 5b. The distance of the electrons from the 1st wire, according to their position.

the position of the observed 1st wire is given at (x, y) = (10.8[mm], 1.5[mm]), while the 2nd to the left is at (x, y) = (9[mm], 1.5[mm]). We also added here the snapshots from the simulation of these measurements for better understanding of the process (see Fig. 6a - 6d), but in this simulation the electrons do not stop moving, even if they going through the

$$\vec{F} = m\vec{a}$$

EQ. 1. Newton's second law of motion[6] (F is the force influencing the particle, m is the particle's mass, and a is its acceleration).

$$\vec{F} = q\left(\vec{E} + \vec{v} \times \vec{B}\right) = q\vec{E}$$

EQ. 2. Lorentz force[7] (while we neglect the magnetic influence, B→0), q is the particle's charge, and E is the electric field.

$$\vec{F} = m_e\vec{a} = -e\vec{E} \to \vec{a} = \frac{d^2\vec{x}}{dt^2} = -\frac{e}{m_e}\vec{E} = -\left|\frac{e}{m_e}\right|\vec{E}$$

EQ. 3. The electron's case (m_e is the mass and -e is the charge). x is the location of the particle (electron at this case), while here is given its 2nd time derivative. As we can see the electron will move to the opposite direction of the electric field (the negative coefficient of the electric field).

wire itself.

As we can see from the results, the time scales at this experiment are much shorter than the expected results, which predict[5] a scale of 25 ns for collecting signals from 99% of the particles, while in our case even 1[ns] will be a long time term. These differences may come out from the initial details we mentioned earlier (gas mixture, initial speed, absorption and avalanches), but the main idea of the movement remain the same, the closer to the wire and the farther from the half-way to the next wire the shorter time the electron will reach the wire.

There is an option to do this simulation in a more advanced form of this simulation program (4.3b for

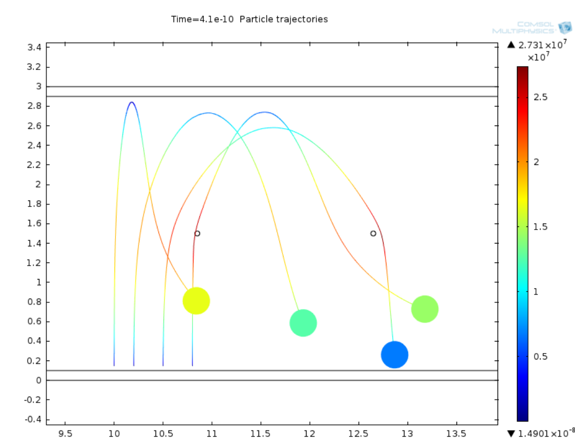

FIG. 6a. The electrons' motion from 0.15[mm] at y axis.

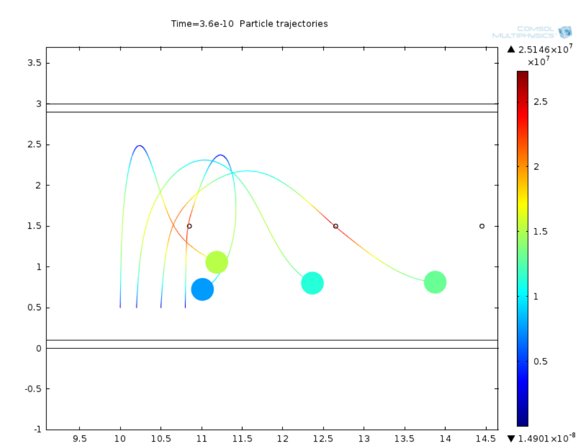

FIG. 6b. The electrons' motion from 0.5[mm] at y axis.

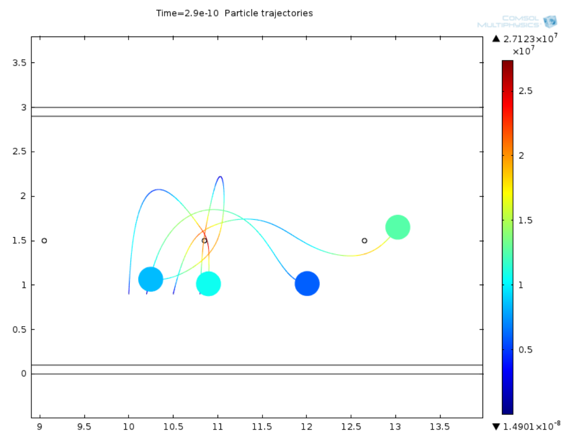

FIG. 6c. The electrons' motion from 0.9[mm] at y axis.

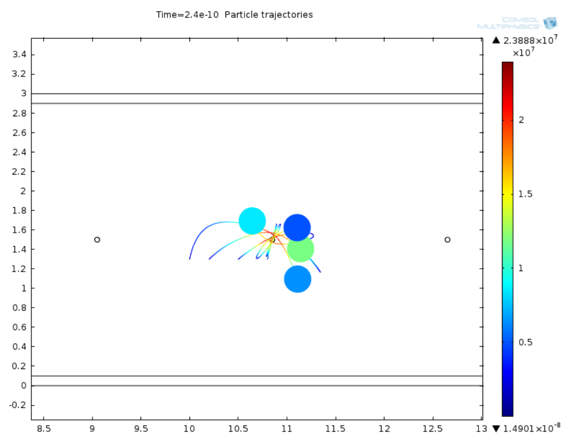

FIG. 6d. The electrons' motion from 1.3[mm] at y axis.

now), and it might appear in the next simulation article. Also there is an option to do so with longer results duration, or with getting other results of the same action, which we did not discuss here. As for the gas mixture problem, I suggested a solution by dividing the medium into small (infinite) sections with different gases in the appropriate relations (in this case for example, 55 cubes out of 100 will be CO_2, while the rest 45 will be n-pentane), but this type of calculation might drastically increase the calculation duration.

Thanks are given to Prof. Y. Rozen, Eng, N.Z. Lupu, for their help and explanations, and to the technical support in Israel, D. Gefen, and abroad, L. Andersson, and extra thanks to H. Oudean.

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[1]All the simulation pictures given at this article are made by the simulation program COMSOL Multiphysics Version 4.3a.

[2]D. Lazic, N. Lupu, A. Mincer, Y. Rozen, S. Tarem, A. Breskin, R. Chechik, D. Lellouch, G. Malamud, G. Mikenberg, K. Nagai, A. Pansky, M. Shoa, in *Drift velocity in n-pentane mixtures and its influence on timing properties of thin gap chambers* (Nuclear Instruments and Methods in Physics Research A 410 (1998) 159-165), p.5.

[3]A.I. Mincer, S. Dado, J.J. Goldberg, Y. Gernitzky, D. Lazic, N.Z. Lupu, S. Robins, Y. Rozen, S. Tarem, in *Charge production in thin gap multi-wire chambers* (Nuclear Instruments and Methods in Physics Research A 439 (2000) 147-157), p. 2.

[4]A.I. Mincer, S. Dado, J.J. Goldberg, Y. Gernitzky, D. Lazic, N.Z. Lupu, S. Robins, Y. Rozen, S. Tarem, in *Charge production in thin gap multi-wire chambers* (Nuclear Instruments and Methods in Physics Research A 439 (2000) 147-157), p. 10.

[5]A.I. Mincer, S. Dado, J.J. Goldberg, Y. Gernitzky, D. Lazic, N.Z. Lupu, S. Robins, Y. Rozen, S. Tarem, in *Charge production in thin gap multi-wire chambers* (Nuclear Instruments and Methods in Physics Research A 439 (2000) 147-157), p. 4.

[6]http://en.wikipedia.org/wiki/Newton's_laws_of_motion#Newton.27s_second_law.

[7]http://en.wikipedia.org/wiki/Lorentz_force.