Contents

Chapter 1

Scanning the Parameters of the Design Simulation

1.1 Global section

1.1.1 Axy-symmetrical

Let's talk about the fact that I used 2D simulation which is then rotated to form a 3D simulation of cylindrical symmetry.

2D simulations are quicker than 3D simulation. According to some quick tests, the simulation of a given geometry is the same in 3D or 2D. So yeah, using that.

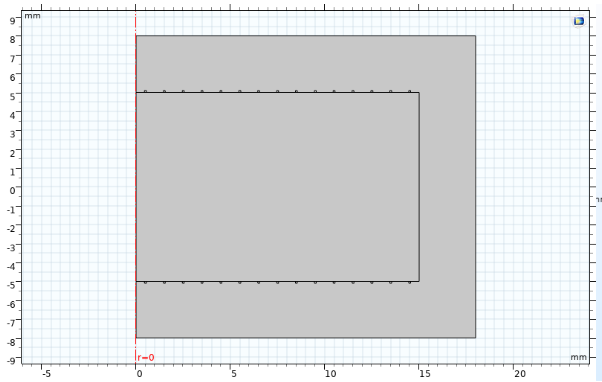
Maybe, search in the comsol manual and see how this is done in the equations. TO BE DONE.

1.1.2 Building the geometry

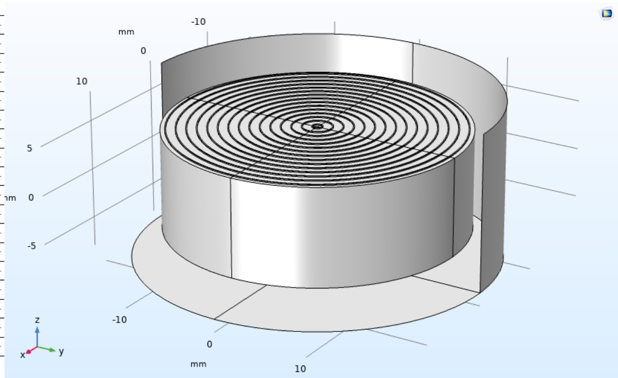
Assomptions used for the simulation (like perfect cylindrical symmetry) No simulation of the NTD, just test in 3D, no impact if put on electrode, but discussion and checking are necessary for that.

1.1.3 Meshing

Did I told you that comsol is a finte elements software ? no ? well, it is ! These finite elements are small section of the geometric space where the calculationb of the physics quantities are calculated discritely. These finite elements are defined by the meshing, which divide the space. However, there is a way to divide space more efficiently than others. Like attribuating large



(A) Simulation of the concentric grid planar in 2D-axisymmetry with COMSOL.



(B) Simulation of the concentric grid planar in 3D with COMSOL.

FIGURE 1.1: To illustrate the differences between 2D and 3D.

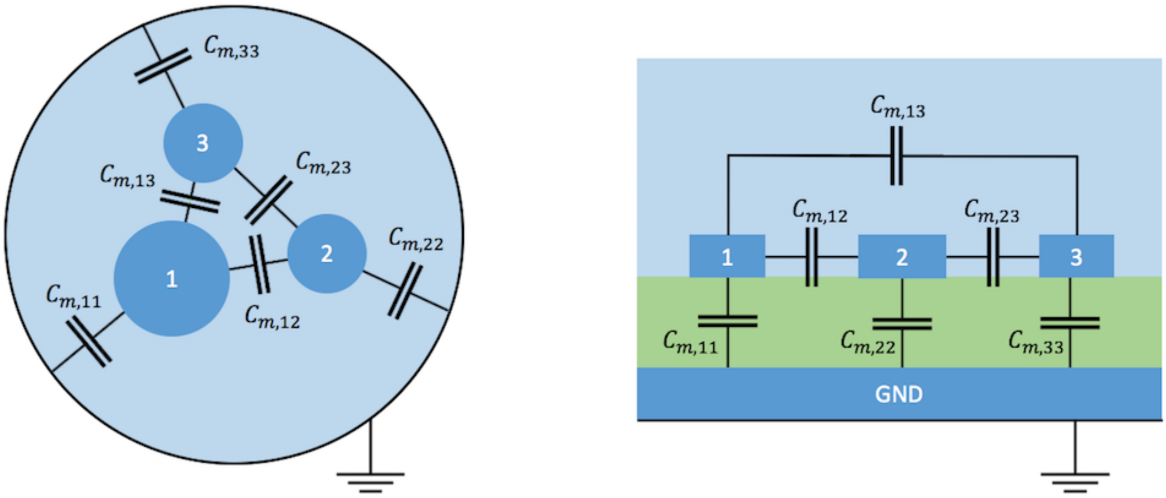


FIGURE 1.2: Scheme representing the capacitance between each electrodes in electric field simulation.

portion of space where the physical quantities are quite constant and small portions where they are prone to a lot of fluctuation. And guess what I did with this fabulous option ? yeah, I kept it on full automatic for physics. Guess I should dig a bit deeper to see what this is all about. Like, size a mesh simplex according to the smallest feature in the geometry and things like that. TO BE DONE.

1.1.4 Capacitance Calculation

Everybody know that the capacitance C links the voltage of an electrode V and Q the charges accumulated in this electrode:

$$C \times U = Q \tag{1.1}$$

This is quite basic, but no so evident when their is more than two electrodes with different electric potential in a system. That is why it is hopefully possible to generalized the notion of capacitance to more electrodes with the lumped matrix capacity or the Maxwell capacity matrix (consider whatever suits you, they mean the same).

INSERT MATRIX HERE

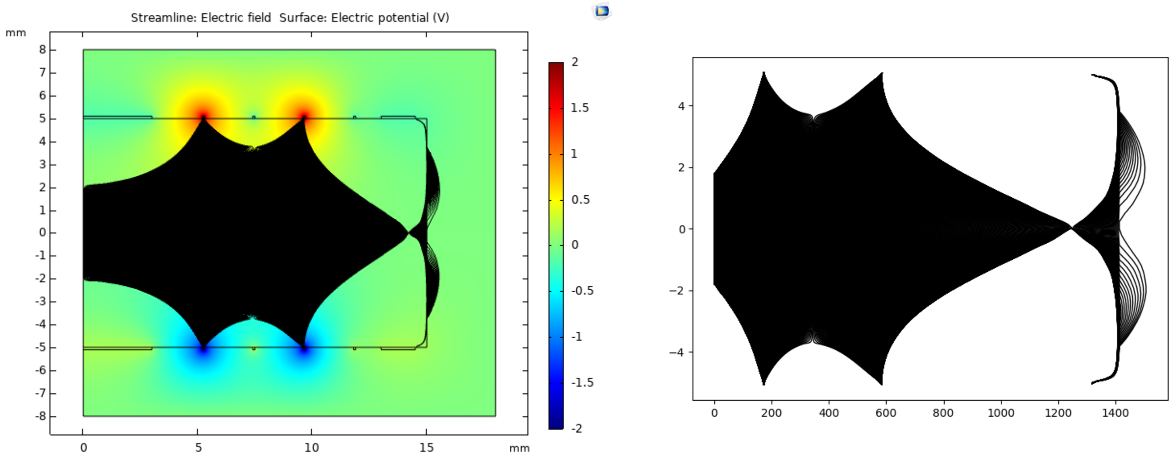
How does comsol calculate this lumped capacitance matrix ? Well, it considers the equation i just wrote before, and fixes all except one electrode to zero and sweep over the electrodes with 1V of potential. Just with that, the software is able to deduce all the terms of the matrix. Yeah, i should read more about that in the manual to see if this is done like that. But it is. yep. TO BE DONE.

CROSSTALK Yep, gotta talk about the link between the crosstalk on the ionization channels and the capacitance term between those electrodes. We can simply say for now that the higher the capacitance is and the higher the crosstalk will be. However, it should be very interesting to quantify the link between these two quantities. Linking the crosstalk matrix and the capacitance matrix, and be able to compare that experimentally.

ANALYSIS TO BE DONE

1.1.5 Estimation of the Theoretical Fiducial Volume

In this subsection, i explain how to estimate the fiducial volume. Draw streamlines crossing the z=0. Exporting to image png. Using graphical analysis with python and rescaling to take into



(A) Drawing streamlines in COMSOL

(B) for 4*4mm NTD

FIGURE 1.3: Illustration of the estimation of the fiducial volume.

account 2D-axisymmetry.

1.1.6 General region for the charge collection in a detector

WITH A SCHEME To illustrate the different region of the detector differing by the expected charge collection.

- collecting zone
- veto zone
- guard zone
- lost zone (streamlines exiting the crystal)
- in between all of them, either low electric field (bad for trapping and recombination) or unclear frontier (when thinking of the recoil as a charged firework).

1.2 Simulated Configurations

In this section, I will talk about the different configurations that were simulated. These configurations can differ according to the mass of the crystal, the number of electrodes, the position and geometry of the electrodes. Maybe, i should describe the configurations in a kind of general way: planar, grid, ID, FID, etc.. and put the exact simulation of each detectors in the annexes. I dont really know yet.

1.2.1 Planar Geometry

(Like REDN1 or RED80, with planar polarization, not much runs)

Full Planar

Maxwell Capacitance: 11.88×10^{-12}F

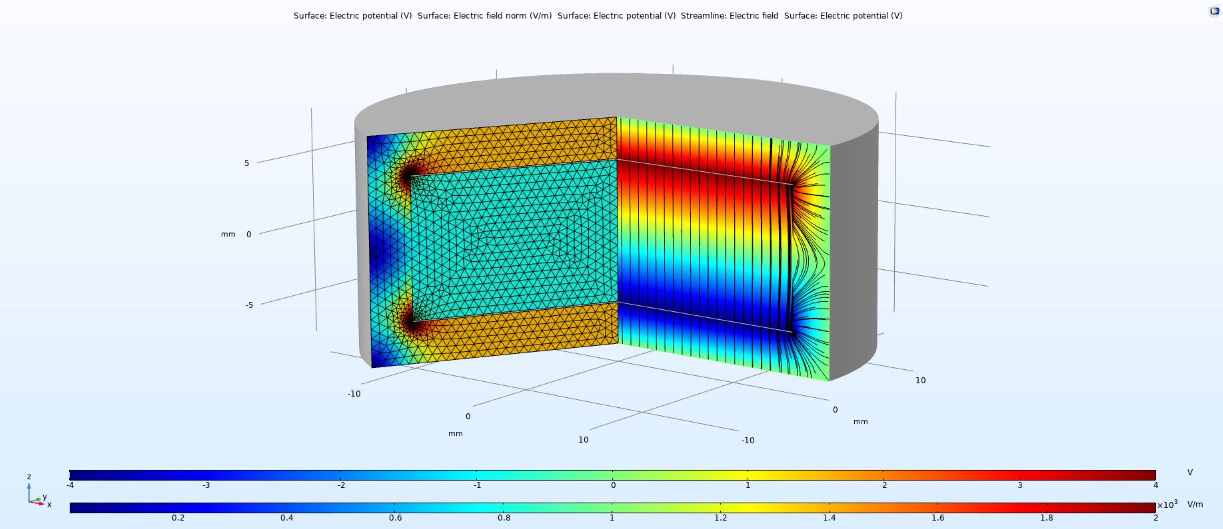


FIGURE 1.4: Scheme of the simulated full planar h10phi30 detector.

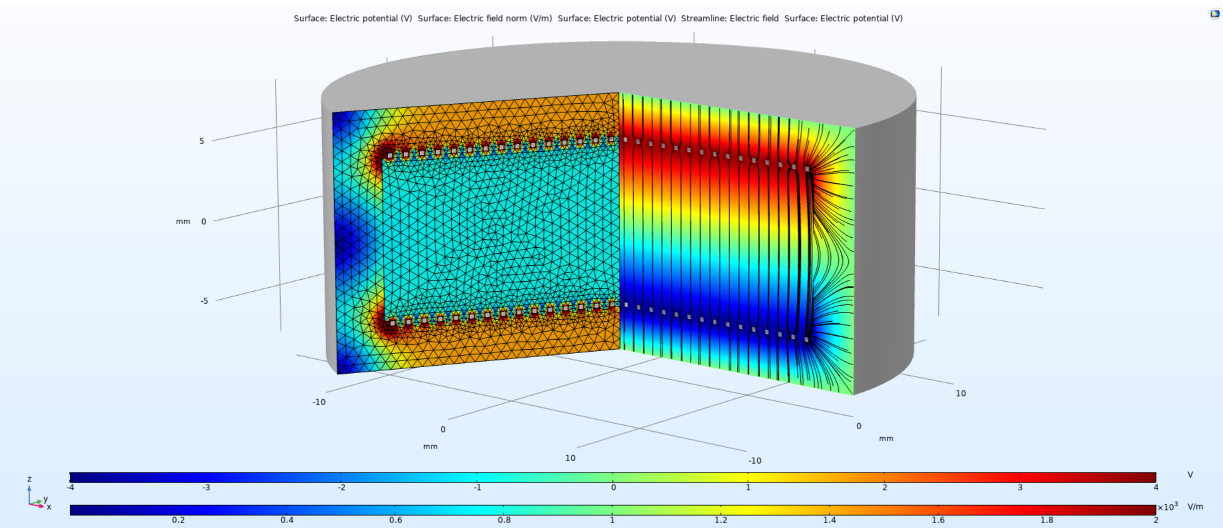


FIGURE 1.5: Scheme of the simulated concentric grid planar h10phi30 detector.

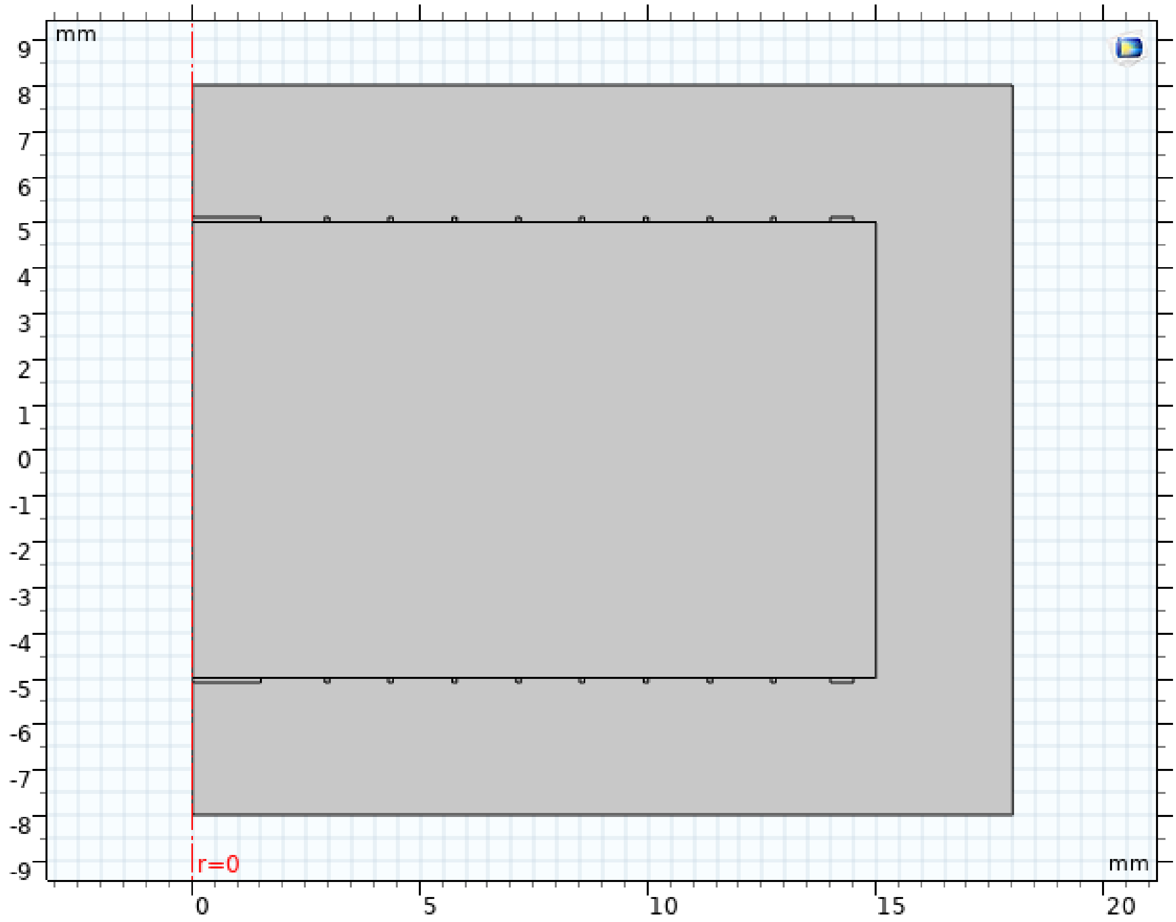


FIGURE 1.6: Scheme of the simulated interdigitized detector.

Concentric/Square Grid Planar

Maxwell Capacitance: 11.88×10^{-12}F

1.2.2 Planar with Guard

Like RED80, many runs.

1.2.3 Interdigitized

Like REDN1, many runs.

Lot of different variants here.

On the presented figure, the central pad is chosen to be polarized at veto potential and the NTD thermal sensor should be glued on it.

1.2.4 Fully Interdigitized

Like RED70 (no run, RIP)

Presenting the FID geometry, with veto zone, collect, zone and the faraday cages effect which means that the charge collection is *really* good.

FIGURE 1.7: Illustrating the veto zone and the collect zone thanks to the electric field shape induced by the FID electrodes.

Topology	Capacitance $[pF]$	Fiducial $[\%]$	Surface Tagging	Charge Collection	Other characteristics
Full Planar	≈ 10	≈ 90	No	Side:No	HO on Al?
Grid Planar	≈ 10	≈ 80	No	Side:No	Collect near Al?
ID	8 to 25	45 to 55	Yes*	Center/Side: ???	–
FID	> 25 to ≈ 100	50 to 80	Yes	Very Good	–

TABLE 1.1: Sum-up of the performance and specificity of each electrode topology.

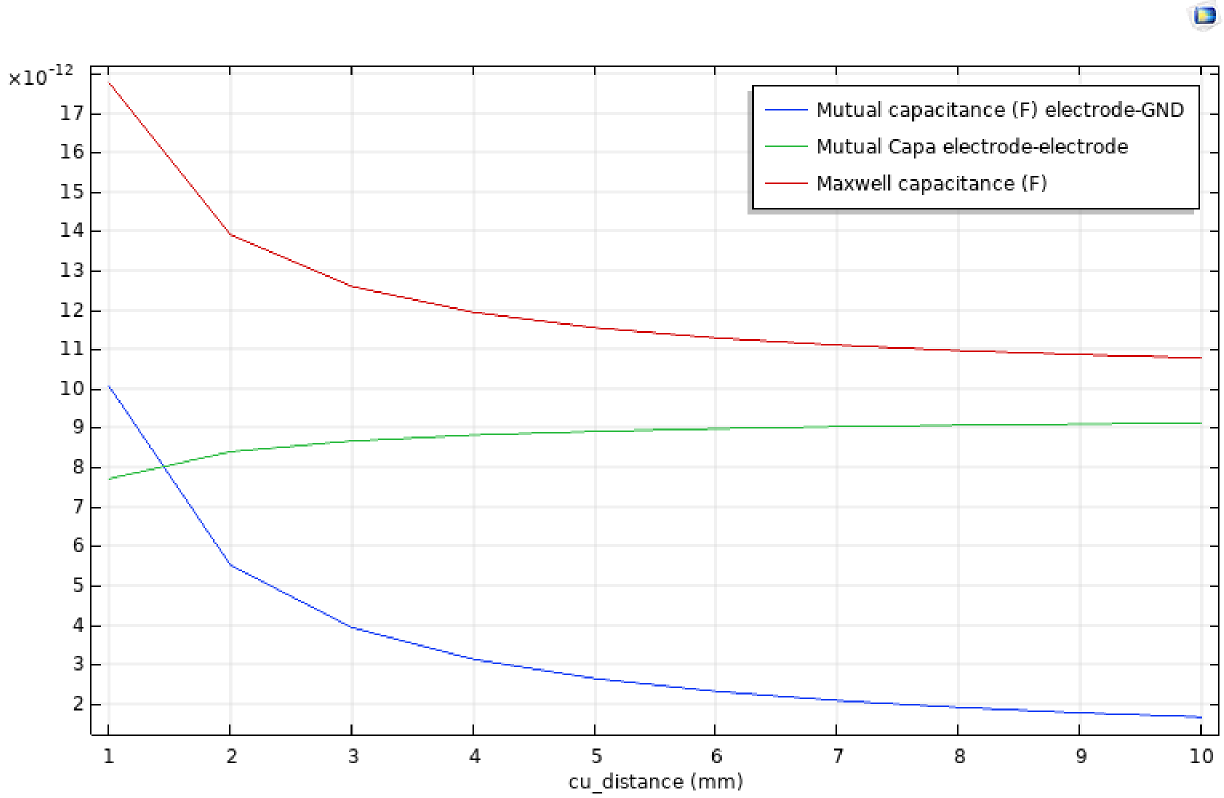


FIGURE 1.8: Graph of the capacitance terms in function of the distance between the Ge crystal and the copper chassis (concentric grid planar h10phi30 detector).

1.2.5 Comparing the different topologies

1.3 Influence of parameters

For each parameter, we want to study their impact on the performances of the detector. The fiducial volume, the electric field shape, the electric field norm and the capacitance.

The fiducial volume is a number. The electric field shape/norm is one or two graphs. The capacitance is a matrix (non-diagonal term are useful to estimate the coupling between each electrodes)

1.3.1 Capacitance with chassis distance

All topologies

The capacitance term between the electrodes and the ground decreases with the distance of the copper chassis. As expected by the capacitance formula of a plan capacitor. The capacitance term capa-capa tends to the expected value for a plan capacitor in empty space.

1.3.2 Capacitance with electrode spacing

All topologies except full planar

The electrode spacing directly fixes the number of concentric circle on a plan face of the germanium crystal. As a result the curves show a saw-shaped profile corresponding to the discrete number of electrodes. Anyway, the global trend is that with a high spacing, there is less electrodes and less capacitance.

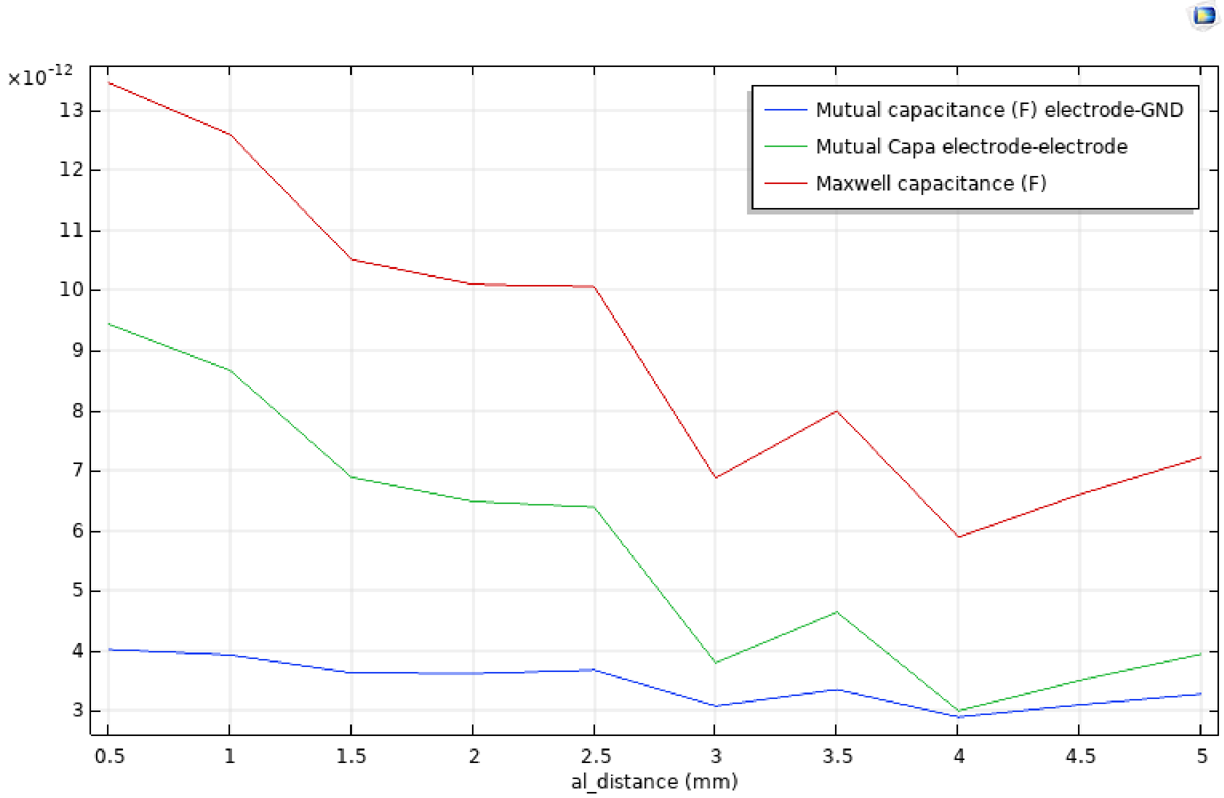


FIGURE 1.9: Graph of the capacitance terms in function of the electrode spacing (concentric grid planar h10phi30 detector).

This tells us that we want to reduce the surface of electrode on the crystal in order to decrease the capacitance. However, a lower surface of electrodes comes with a worse charge collection eventually. So trade-off time.

I could also mention the projection for the fid32 and fid38 that were simulated with different electrode spacing.

1.3.3 Capacitance with the electrode width

All topologies except full planar

As expected, increasing the width of electrodes also increases the surface of the electrodes and the capacitance of the detector. Some configurations are more affected than others: planar detector less affected than the interleaved electrode configurations.

1.3.4 Potential of the veto/guard electrodes

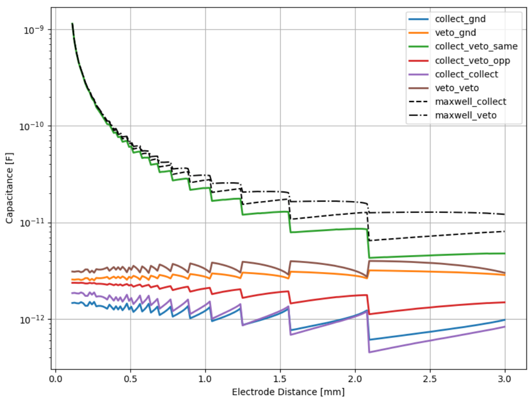
Planar with guard, ID and FID

When considering geometry with veto or guards electrodes, the potential of these electrodes in respect to the main collecting electrodes is a parameter. Changing this parameter has an impact on the shape of the streamline of the electric field in the detector.

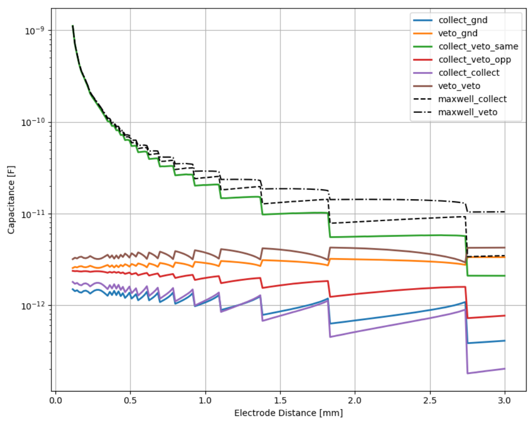
1.3.5 Symmetry of the polarization

All topologies

Checking that a symmetric polarization is better than asymmetric, and showing some numbers/graphs to justify that (±1V is better than 0,2V)



(A) for 2*2mm NTD



(B) for 4*4mm NTD

FIGURE 1.10: Graph of the capacitance terms in function of the electrode spacing (interdigitized).

Lateral $[mm]$	Lateral Elec. Veto/Collect	Plan $[mm]$	Plan Elec. Veto/Collect	$\%_{fiducial}$	$C_{veto}[pF]$	$C_{collect}[pF]$	Comments
1.6	3 / 3	1.4	4c / 3	63	21.5	18.8	OK
			3 / 4c	66	20.4	18.4	Collect
			4o / 4c	66	22.9	20.1	Special
		1.7	3c / 3	66	19.3	17.3	Collect
			3c / 4o	64	21.8	19.1	Special
			3 / 3c	62	20.4	17.8	OK
		2.1	3c / 2	61	19.3	16.7	OK
			2 / 3c	64	18.2	16.2	Collect
			3o / 3c	62	20.7	18.0	Special
2.0	3 / 2	1.4	4c / 3	57	18.6	15.1	Veto
			4c / 4o	61	20.4	17.6	Special
			3 / 4c	61	19.1	16.3	OK
		1.7	3c / 3	60	18.0	15.3	OK
			3 / 3c	57	17.5	14.0	Veto
			3 / 4co	60	19.4	16.6	Special
		2.1	3c / 2	56	16.4	12.9	Veto
			3c / 3o	59	18.2	15.5	Special
			2 / 3c	58	17.0	14.1	OK

TABLE 1.2: Projection of the FID32 design performance with multiple variants (collect at $\pm$4V, veto at $\mp$1.5V)

Lateral $[mm]$	Lateral Elec. Veto/Collect	Plan $[mm]$	Plan Elec. Veto/Collect	$\%_{fiducial}$	$C_{veto}[pF]$	$C_{collect}[pF]$	Comments
1.1	2 / 2	1.3	6c / 5	71	34.8	30.5	OK
			5 / 6c	75	33.2	30.4	Collect
			6o / 6c	73	36.8	32.6	Special
		1.5	5c / 5	74	31.7	28.8	Collect
			6c / 5	72	35.6	31.4	Special
			5o / 5c	71	33.5	29.2	OK
		1.6	5c / 4	70	31.1	26.8	OK
			4 / 5c	74	29.5	26.8	Collect
			5o / 5c	72	33.2	29.0	Special
		1.8	4c / 4	74	27.6	25.1	Collect
			5co / 4	71	31.3	27.3	Special
			4 / 4c	68	29.3	25.0	OK
		2.1	4c / 3	67	27.6	23.5	OK
			3 / 4c	72	26.1	23.5	Collect
			4o / 4c	69	29.8	25.6	Special
1.6	2 / 1	1.3	6c / 5	64	30.0	24.3	Veto
			6c / 6o	68	32.4	28.2	Special
			5 / 6c	70	30.3	26.1	OK
		1.5	5c / 5	69	28.9	24.9	OK
			5 / 5c	65	28.4	22.8	Veto
			5 / 6co	67	31.3	26.9	Special
		1.6	5c / 4	62	26.4	20.5	Veto
			5c / 5o	66	28.7	24.5	Special
			4 / 5c	68	26.6	22.4	OK
		1.8	4c / 4	67	24.7	20.6	OK
			4 / 4c	60	24.7	18.7	Veto
			4 / 5co	64	27.0	22.6	Special
		2.1	4c / 3	59	23.1	17.1	Veto
			4c / 4o	63	25.3	21.1	Special
			3 / 4c	66	23.2	19.0	OK
2.4	1 / 1	1.3	6c / 5	68	26.1	22.5	OK
			5 / 6c	73	24.2	22.6	Collect
			6o / 6c	70	28.0	24.6	Special
		1.5	5c / 5	72	22.7	21.1	Collect
			6co / 5	69	26.8	23.4	Special
			5 / 5c	67	24.8	21.1	OK
		1.6	5c / 4	66	22.4	18.8	OK
			4 / 5c	72	20.5	19.0	Collect
			5o / 5c	68	24.3	20.9	Special
		1.8	4c / 4	72	18.6	17.3	Collect
			5co / 4	68	22.4	19.1	Special
			4 / 4c	64	20.6	17.0	OK
		2.1	4c / 3	63	19.0	15.5	OK
			3 / 4c	70	17.0	15.6	Collect
			4o / 4c	66	20.8	17.5	Special

TABLE 1.3: Projection of the FID38 design performance with multiple variants. (collect at $\pm$4V, veto at $\mp$1.5V)

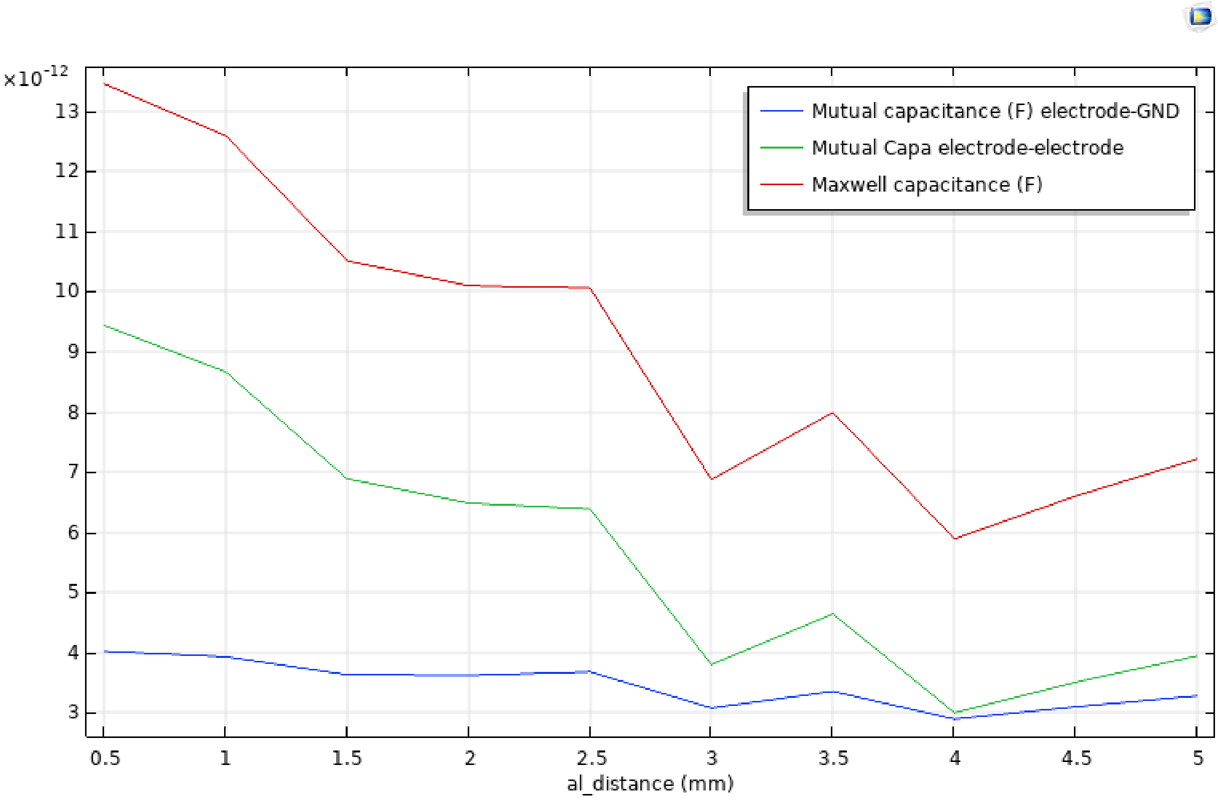
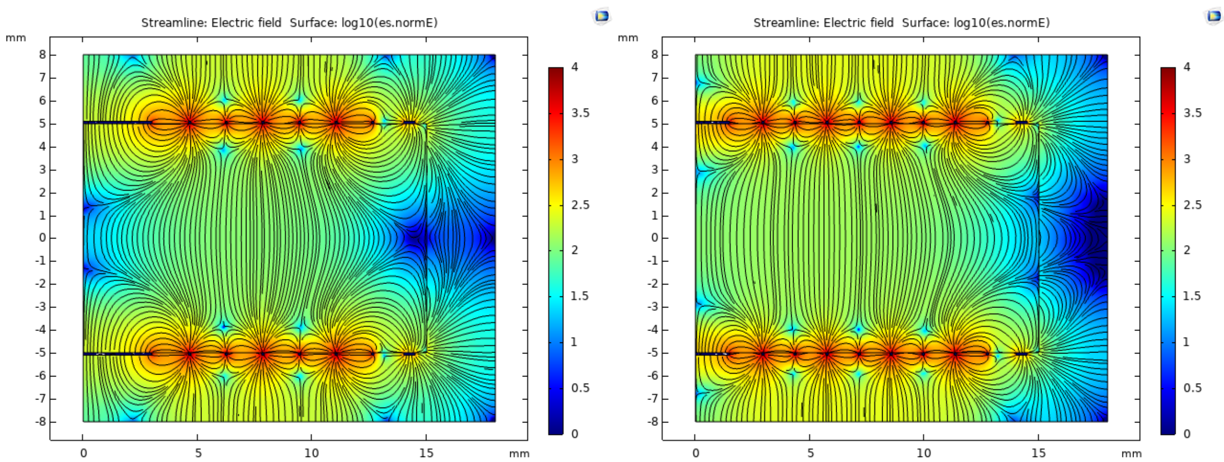


FIGURE 1.11: Graph of the capacitance terms in function of the electrode width (concentric grid planar h10phi30 detector).



(A) ratio veto/collect: 0.21

(B) ratio veto/collect: 0.13

FIGURE 1.12: Illustration of the estimation of the fiducial volume.

Stream	Polar. ABCD	# Total	% B+D	% B+D expanded	% B+A	% C+D	% A+C
tk15l005	-0.4 1 0.4 -1	1534	33	55	18	9	0
tk16l000	-0.4 1 0.4 -1	2615	23	52	20	7	0
tk18l000	-0.2 0.5 0.2 -0.5	394	26	52	15	13	0
tk18l001	0.4 -1 -0.4 1	861	35	51	12	18	0
tk19l000	-0.1 0.25 0.1 -0.25	394	19	49	22	8	0
tk19l001	-0.05 0.125 0.05 -0.125	597	0	23	8	10	0
tk20l000	-0.8 2 0.8 -2	285	41	64	10	12	0
tk20l003	-0.6 1 0.6 -1	657	2	11	26	12	14
tk25l000	-0.8 2 0.8 -2	373	42	56	15	12	0
tk26l000	-1.0 2 1.0 -2	550	31	44	17	13	0
tk26l001	-0.6 2 0.6 -2	459	44	71	5	6	0
tk27l001	-0.4 2 0.4 -2	217	54	76	6	5	0
tk27l002	-1.4 2 1.4 -2	654	2	12	23	14	8

TABLE 1.4: Estimation of the experimental fiducial volume for REDN1.

1.3.6 Central hole/pad for NTD

All topologies

Impact of a hole/pad for the NTD. Important for electric field shape. Should be decided by the experimental heat-only rate.

1.3.7 Corner of the crystal

All topologies

No electrodes or electrodes on/near the corner. Impact of the charge collection, "dead" volume in the corner.

1.3.8 Equatorial distance

Planar extreme, Planar with guard, FID

Equatorial length, discussion on charge collection/trapping/tagging on this equatorial volume.

1.4 Experiment with REDN1

In this section, experiment with the ionization channel of REDN1, and analysis and results and comparison with expected performances. This is based on the run61.

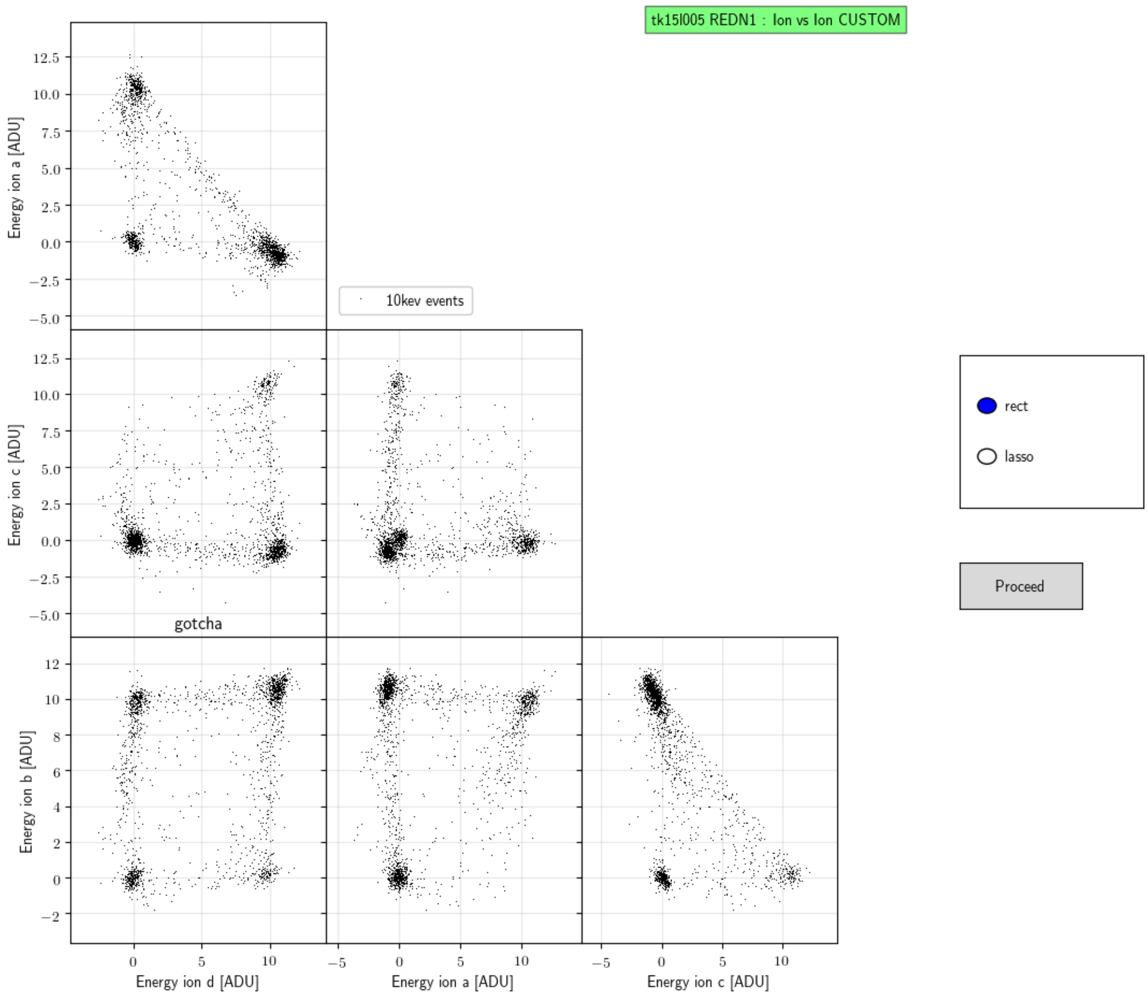


FIGURE 1.13: For each fiducial events of the run tk15l005, comparing the reconstructed ionization energy for each electrodes.

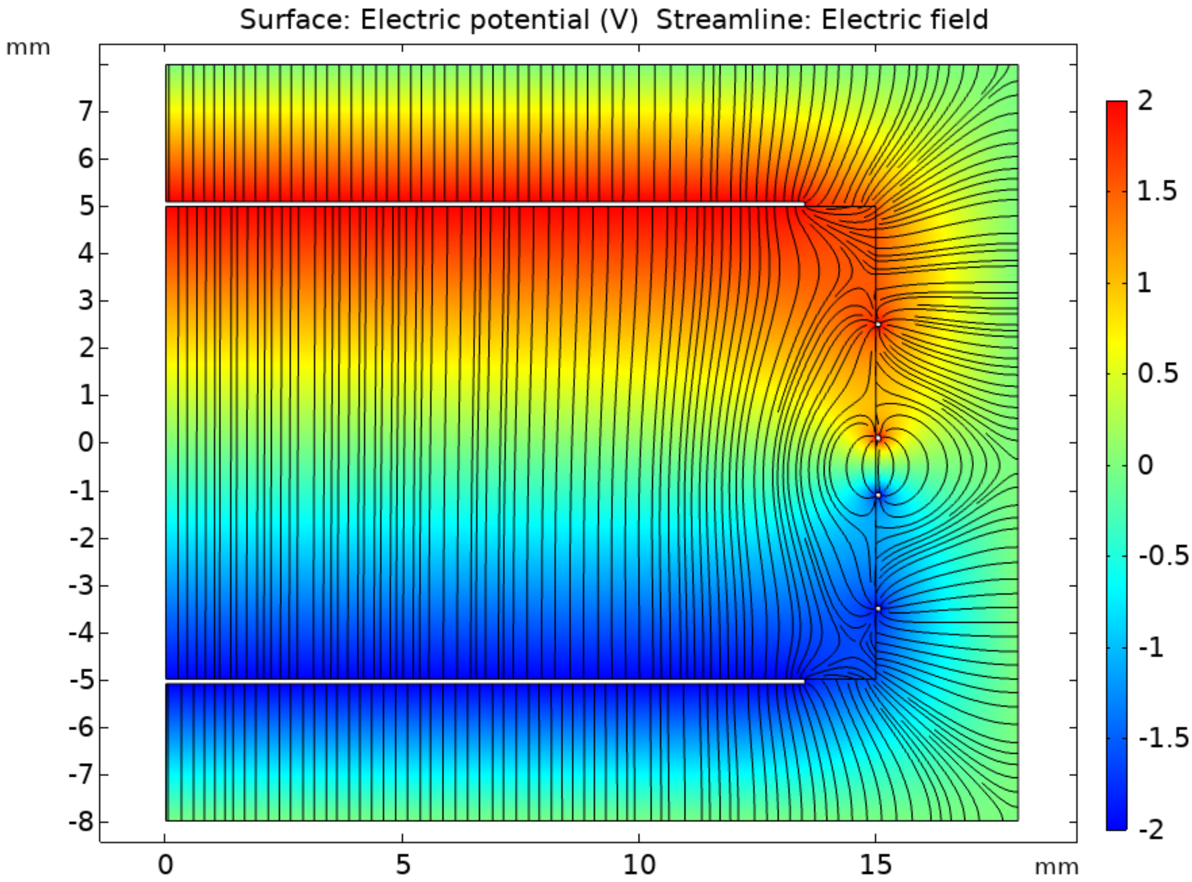


FIGURE 1.14: Streamlines of the electric field in RED80.

1.4.1 Experimental fiducial volume

1.4.2 Experimental Charge collection

1.4.3 Experimental sensitivity and crosstalk

1.5 Experiment with RED80

1.5.1 Experimental fiducial volume

1.5.2 Experimental Charge collection

1.5.3 Experimental sensitivity and crosstalk

1.6 Appendix: Catalog of Detectors fields lines