Electric field simulation for Proto-0 TPC

2D and 3D model comparison
Influence of the absence of 1 wire

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08.04.2024

Introduction:

- The presentation consists of two parts. The first one is devoted to 2D/3D differences in simulations. I have tried to highlight the advantages and disadvantages of simulation in 3D, as well as possible tasks for which simulation in 3D geometry is necessary.

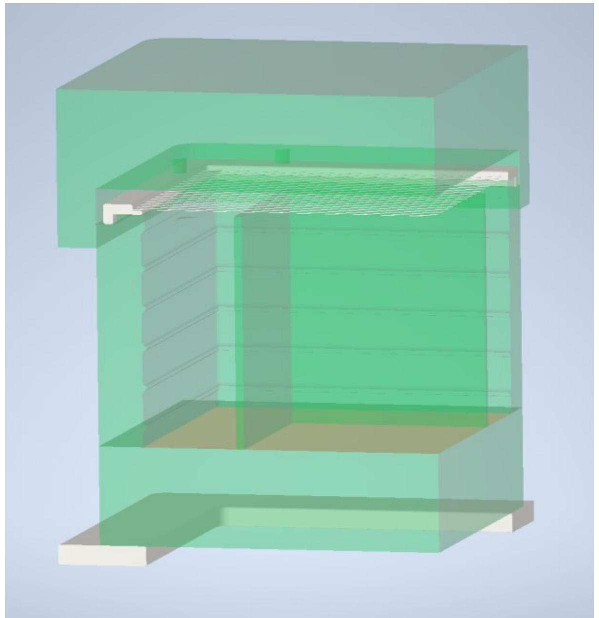
- The second part is devoted to simulation (in 2D) of the Proto-0 geometry considering the absence of 1 wire.

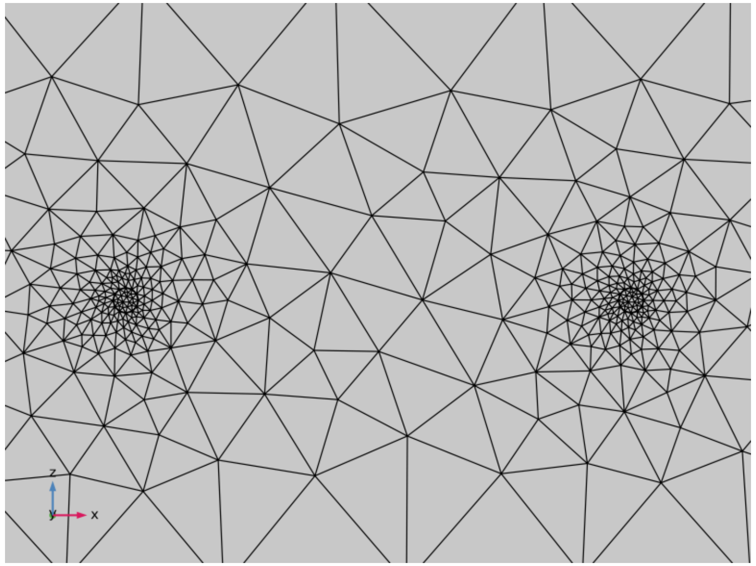
3D and 2D model comparison

The 2D modeling considers a cross-section of the detector geometry and assumes that it remains unchanged at infinite depth ("inside the screen"). As long as the geometry of the detector (and with it the field configuration) remains almost constant when this cross section is shifted along the direction perpendicular to that, the results of the 2D model correctly describe the real field configuration in the detector.

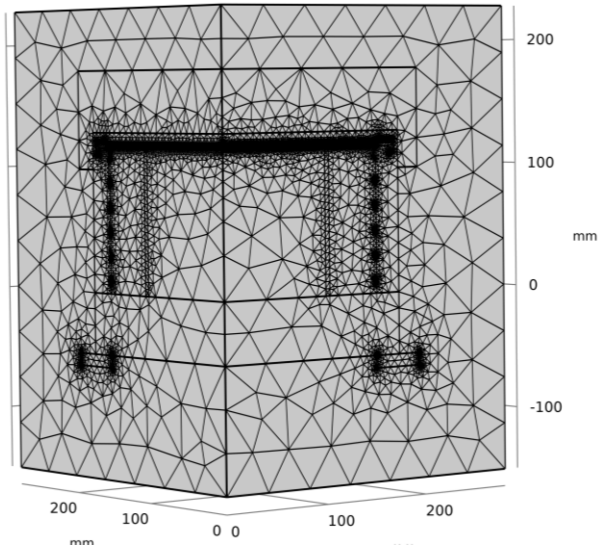
When using in a large enough detector (tens of centimeters) extraction grid of parallel wires, simulation of the electric field in 3D geometry is necessary only to:

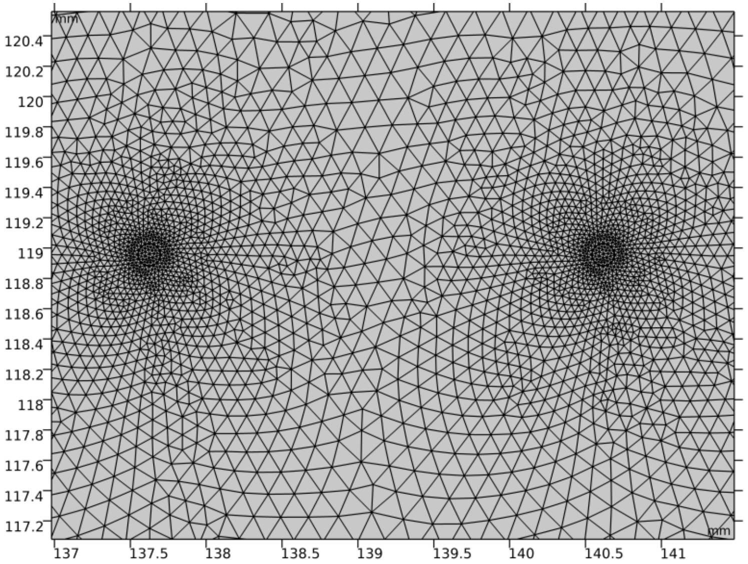
- determine the electric field in the corners of the detector;
- to evaluate the effect of asymmetry associated with the design of the wire frame and the attachment of wires to it (or any other small structural elements);
- to study the electric field between the TPC and the cryostat (if the distance between their walls is highly variable).





Computation mesh in 3D model





Computation mesh in 2D model

Old 2D model parameters, that used for 3D simulations

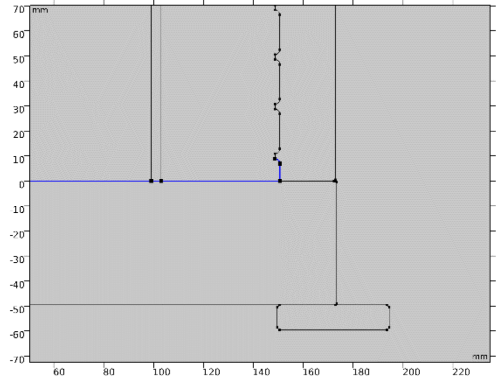
GAr thickness = 7 mm;
Wire to anode distance 10 mm;
Grid with 150 µm diameter wires,
with a pitch of 3 mm (from the STEP-file).

Height of the filed shaping rings 18 mm,
with 2 mm gap between them.

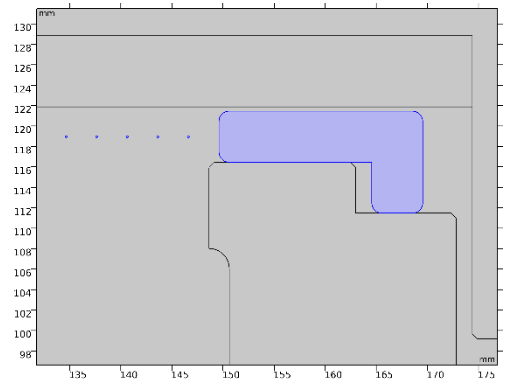
Target electric field in the GAr = 4200 V/cm;
Target electric field in drift area = 200 V/cm.

Anode and cryostat walls = 0 V;
Grid = –3987 V;
R1 = Grid – 150 V = –4137 V;
R1 – R2 = (R1 – Cathode)/5 = 400 V;
Cathode = Grid – 2150 V = –6137 V.

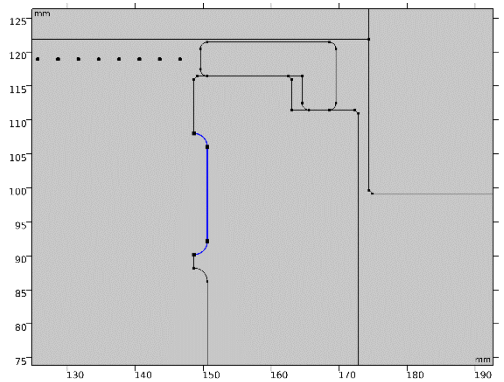
Acrylic dielectric constant: 2.6;
LAr dielectric constant : 1.5;
GAr dielectric constant : 1.0.



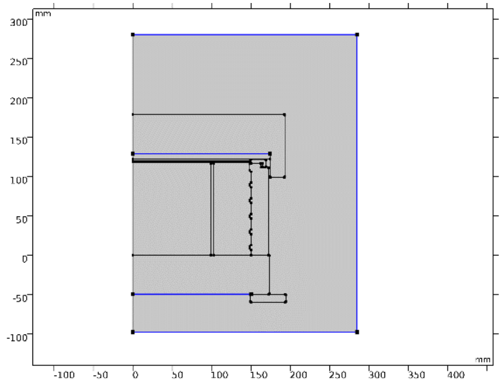
Cathode = –6137 V.

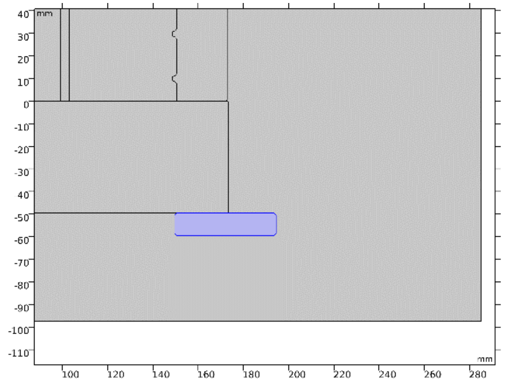


Grid = –3987 V;



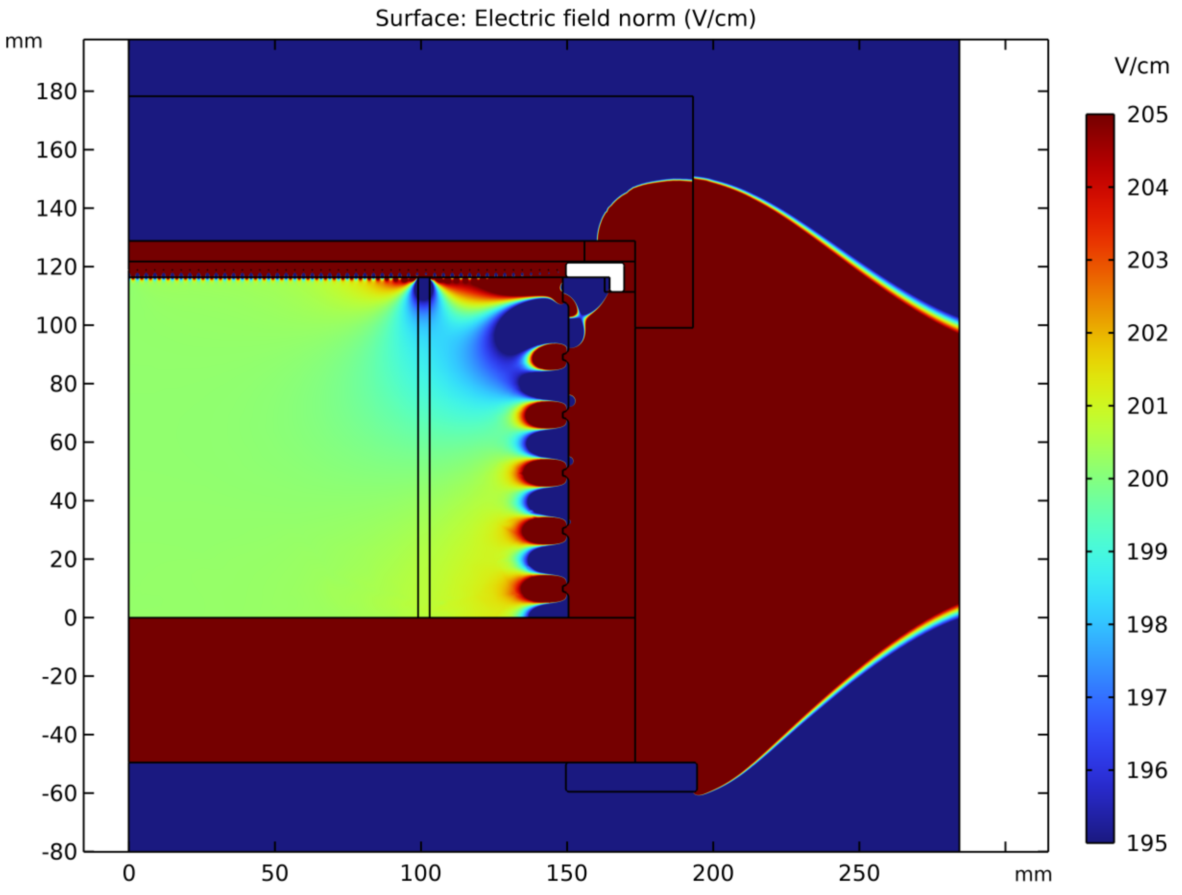
R1 = –4137 V;



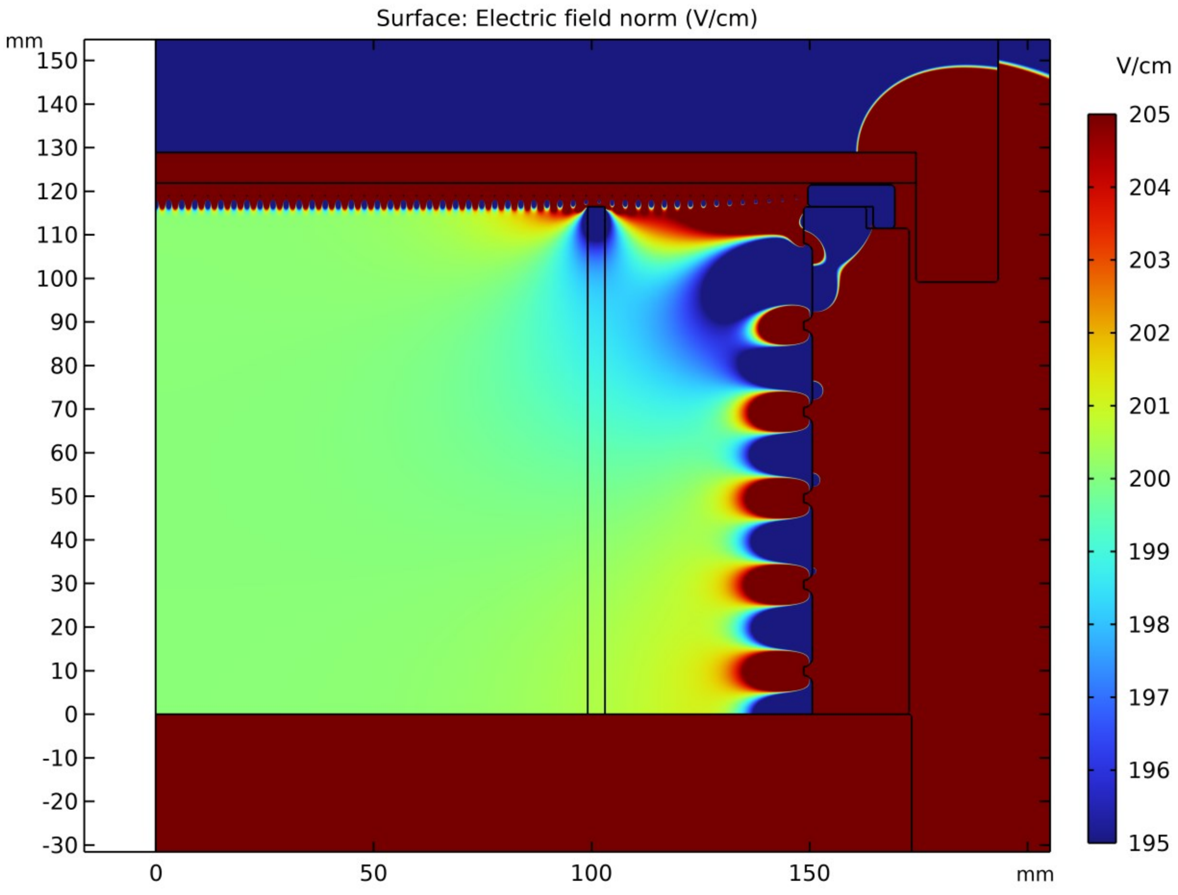


Anode, bottom face of cathode window and cryostat walls are grounded (0 V)

3D and 2D model comparison



3D model

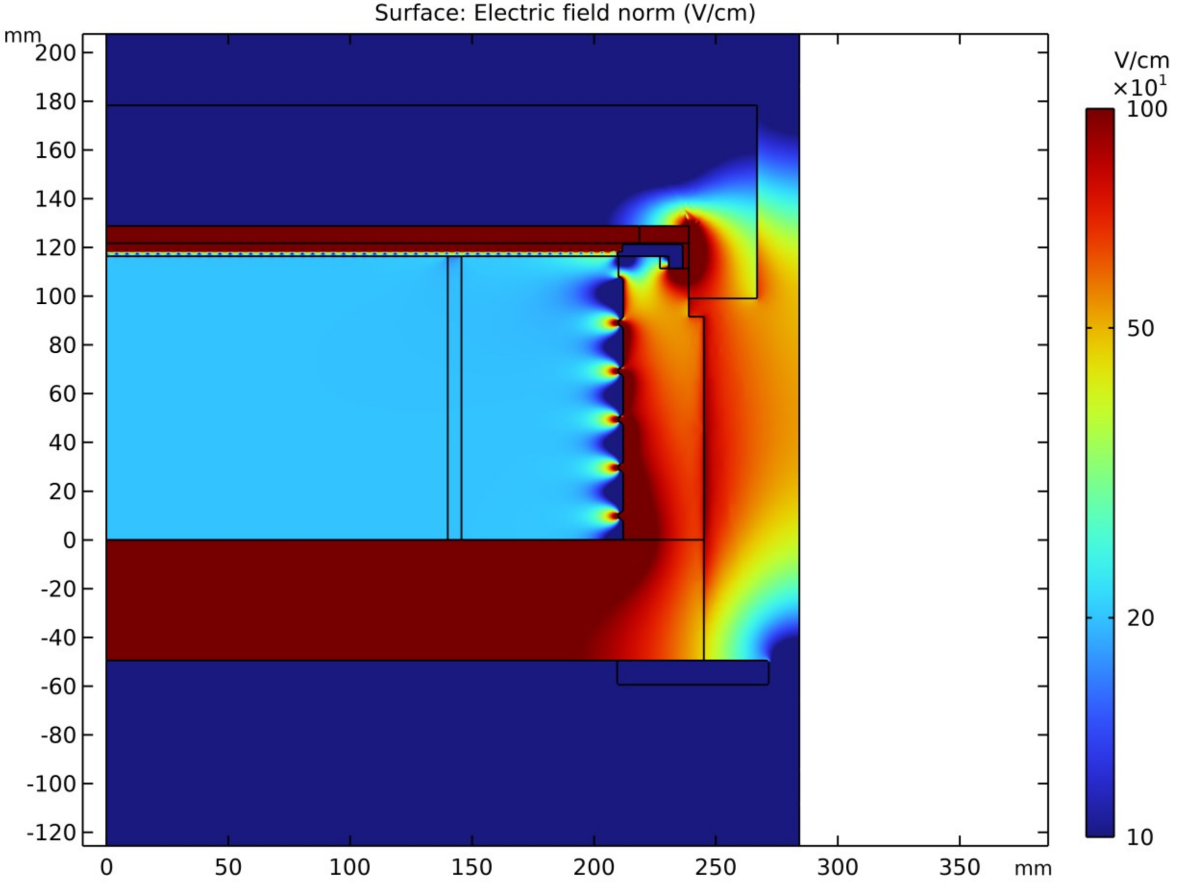


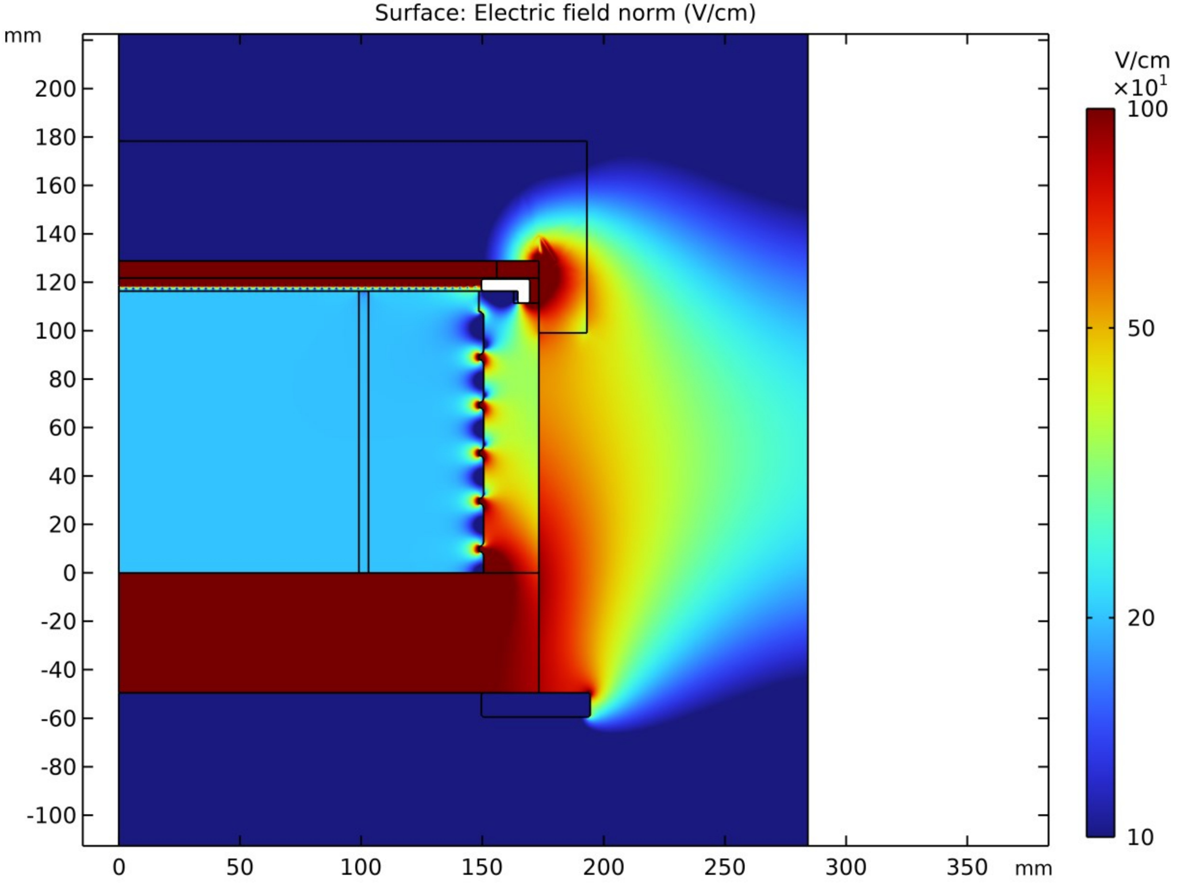
2D model

If we compare the results of 2D and 3D modeling in the same cross section, the results obtained are identical.

But, rebuilding the mesh and updating the results in a 2D model takes ~1 minute while in a 3D model it takes 3-4 hours (and requires >100 Gb of RAM).

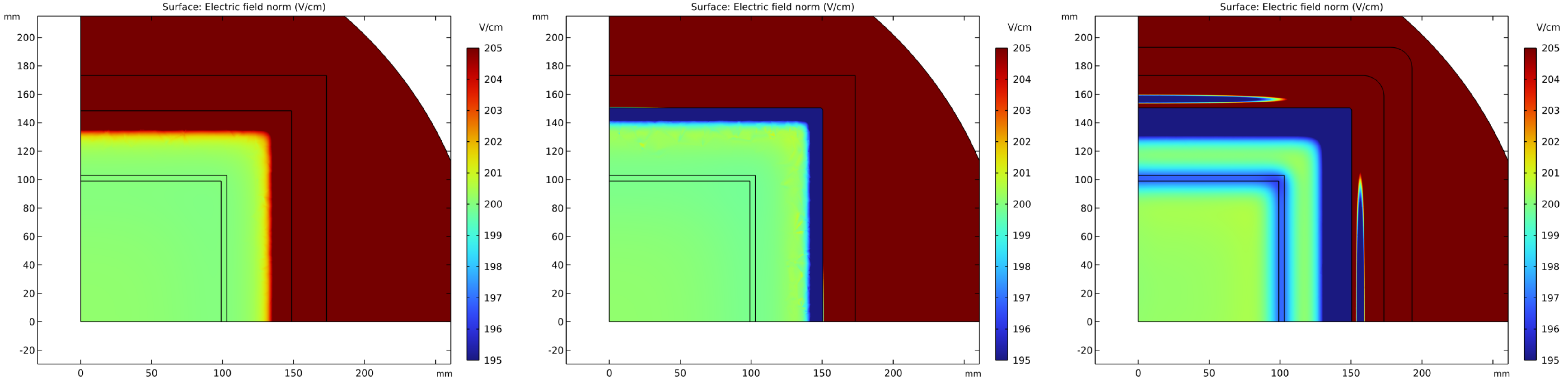
Outer field (3D model)





The results of 3D simulation provide more correct information about the electric field between the TPC and the cryostat

Electric field in drift volume (cross sections x-y), 3D model



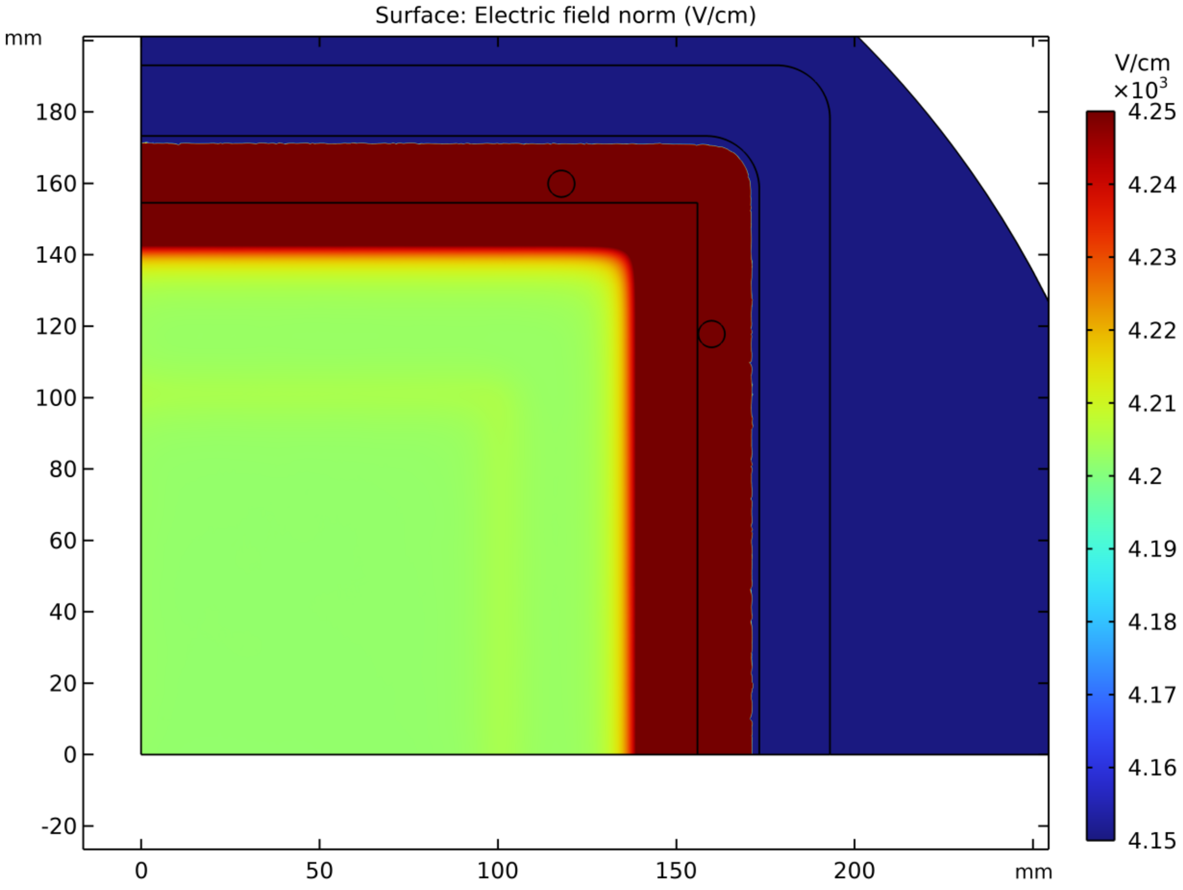
50 mm from the cathode

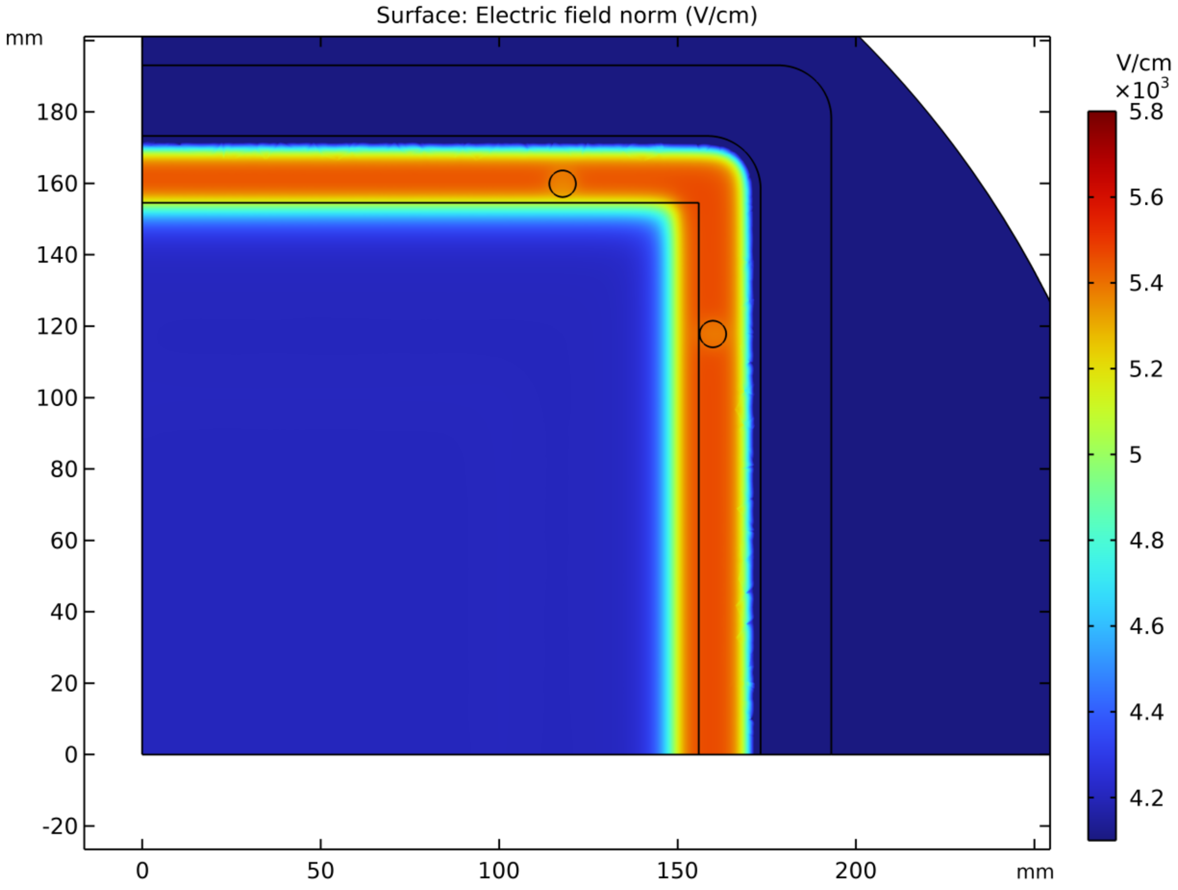
55 mm from the cathode

105 mm from the cathode

Allow you to look at the electric field in a horizontal section at different heights

Electric field in the gas pocket (cross sections x-y) , 3D model





And take into account the effect of wireframe asymmetry on the electric field in the gas pocket

But to carry out such simulations for many different configurations will be difficult both in terms of the required computing power and the probability of error due to the complexity of the geometry of the model and its preparation for simulation.

Update 2D model

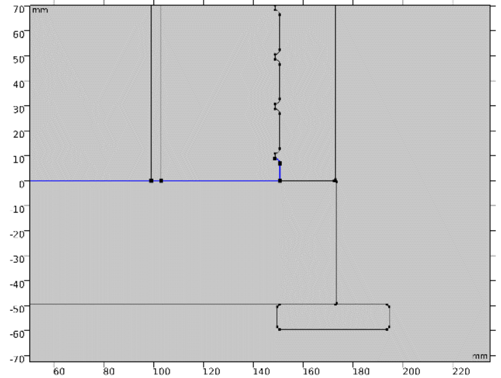
GAr thickness = 7 mm;
Wire to anode distance 10 mm;
Grid with **200** µm diameter wires,
with a pitch of 3 mm (from the STEP-file).

Height of the filed shaping rings 18 mm,
with 2 mm gap between them.

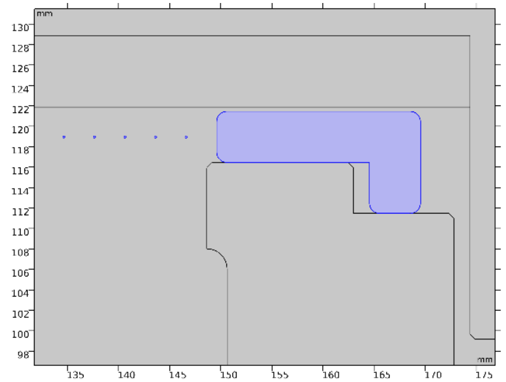
Anode and cryostat walls = 0 V;
Grid = **-5100 V** (current values suggested by Marco Rescigno for DarkSide-20k);
R1 = Grid – 150 V = **-5250 V;**
Cathode = Grid – 2150 V = **-7225 V.**

Electric field in the GAr = **5417 V/cm;**
Electric field in the drift area = 200 V/cm.

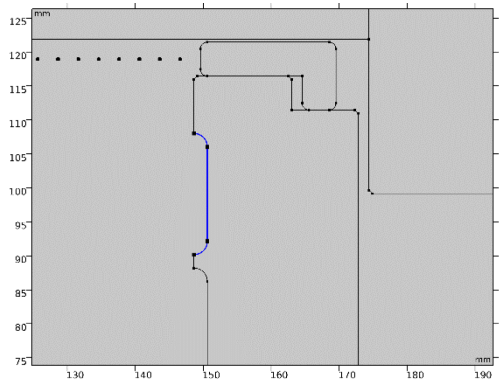
Acrylic dielectric constant: 2.6;
LAr dielectric constant : 1.5;
GAr dielectric constant : 1.0.



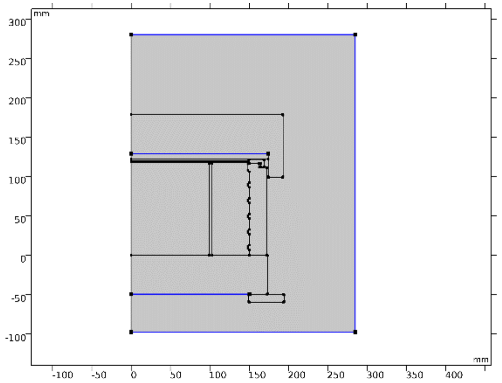
Cathode = –7225 V.

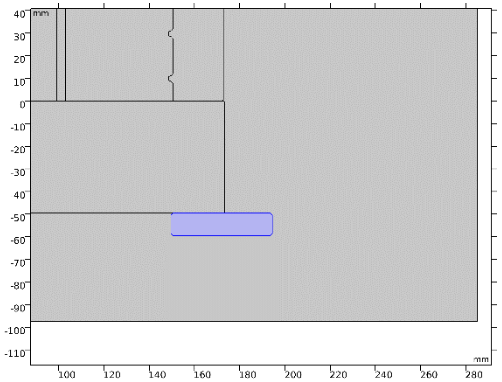


Grid = –5100 V;



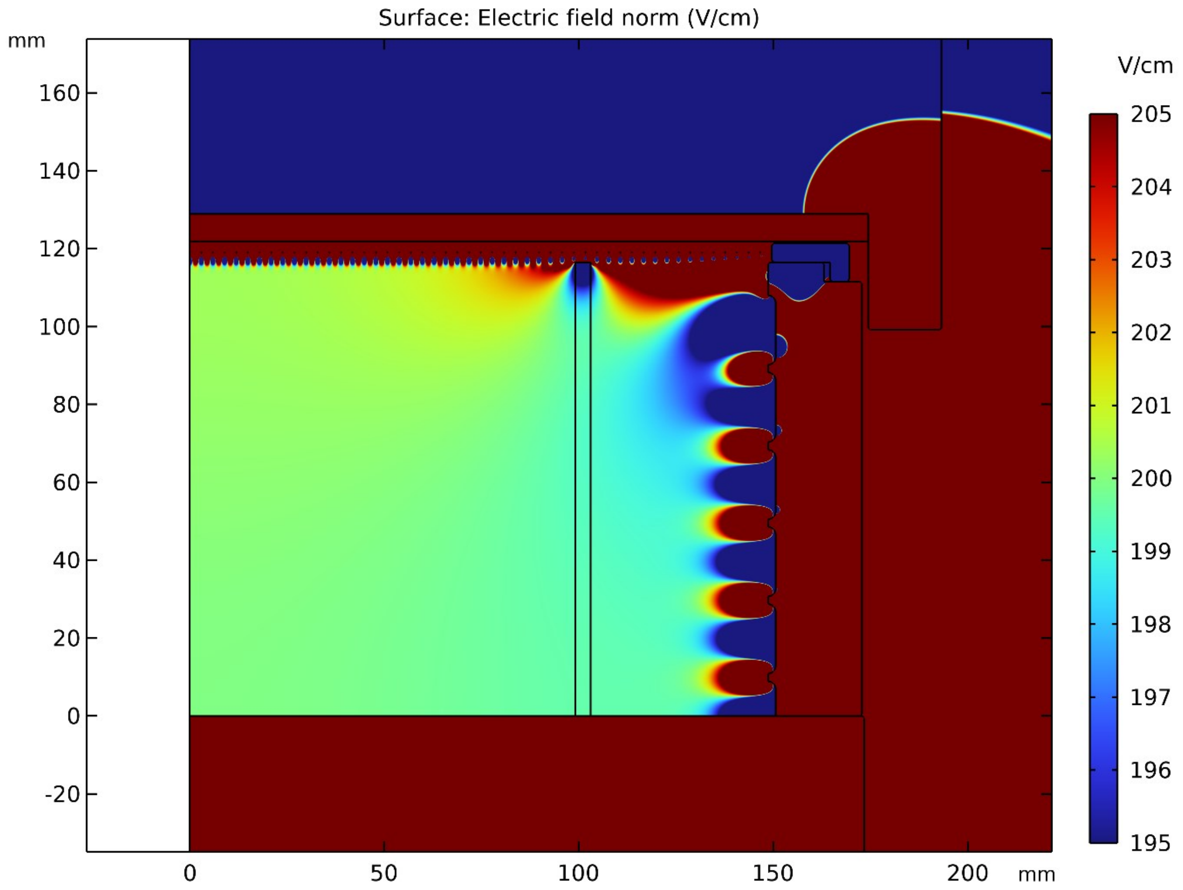
R1 = –5250 V;

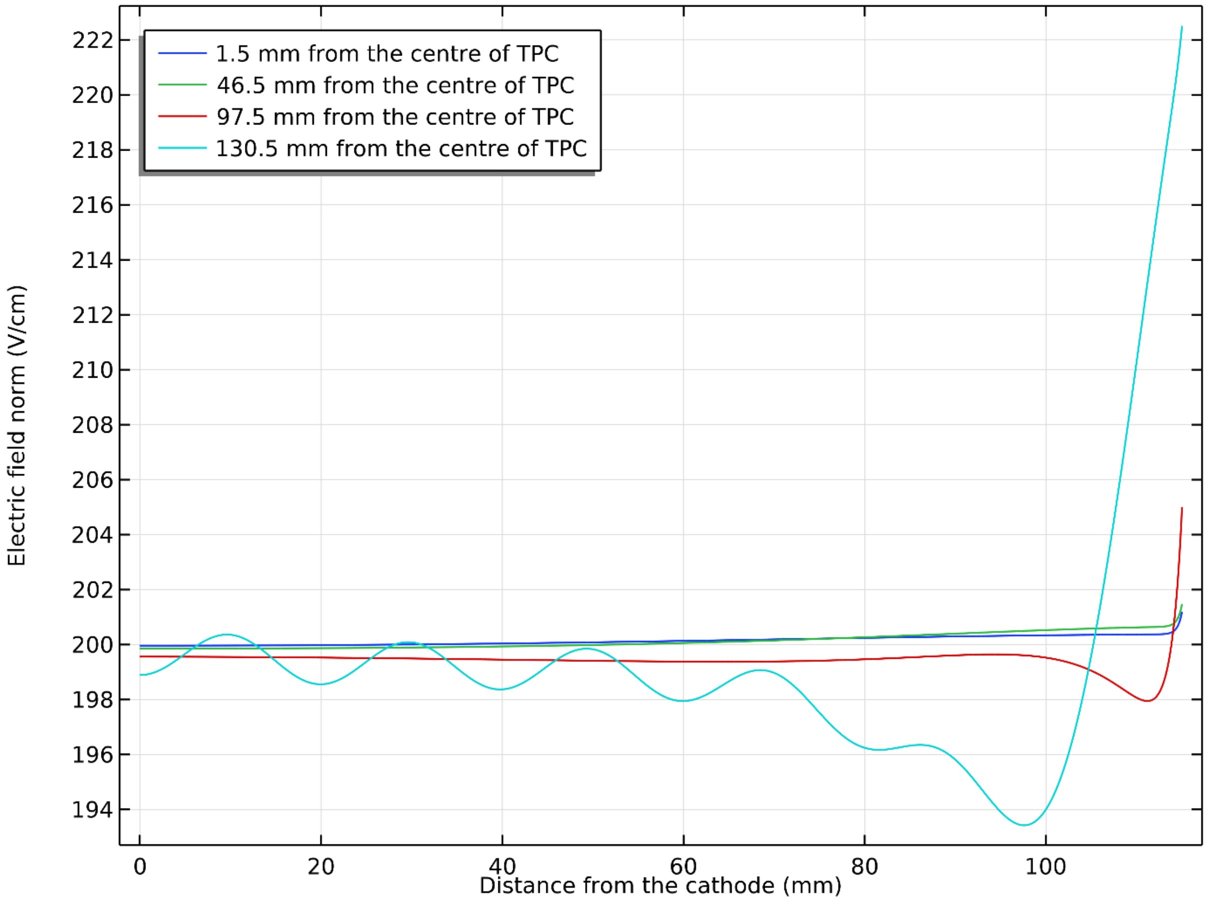




Anode, bottom face of cathode window and cryostat walls are grounded (0 V)

Update 2D model



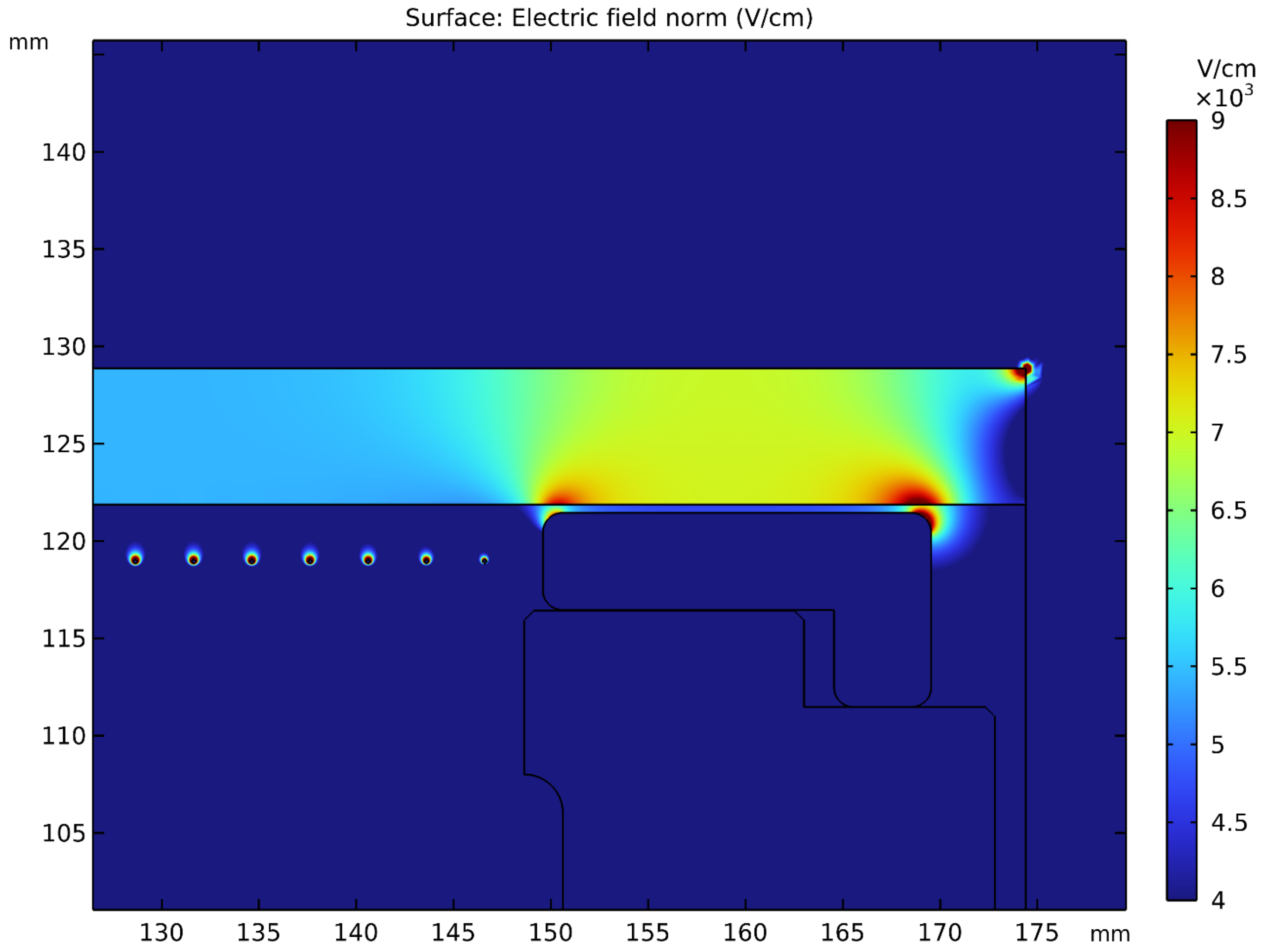


Change the wire diameter from 150 to 200 µm and set the target grid potential equal to -5100 V.

GAr thickness = 7 mm;
Wire to anode distance 10 mm;
Grid with 200 µm diameter wires;
Anode and cryostat walls = **0 V;**
Grid = **-5100 V;**
R1 = Grid – 150 V = **-5250 V;**
Cathode = Grid – 2150 V = **-7225 V.**
Electric field in the GAr = **5417 V/cm;**
Electric field in the drift area = **200 V/cm.**

Update 2D model

(Electric field near the wire frame)

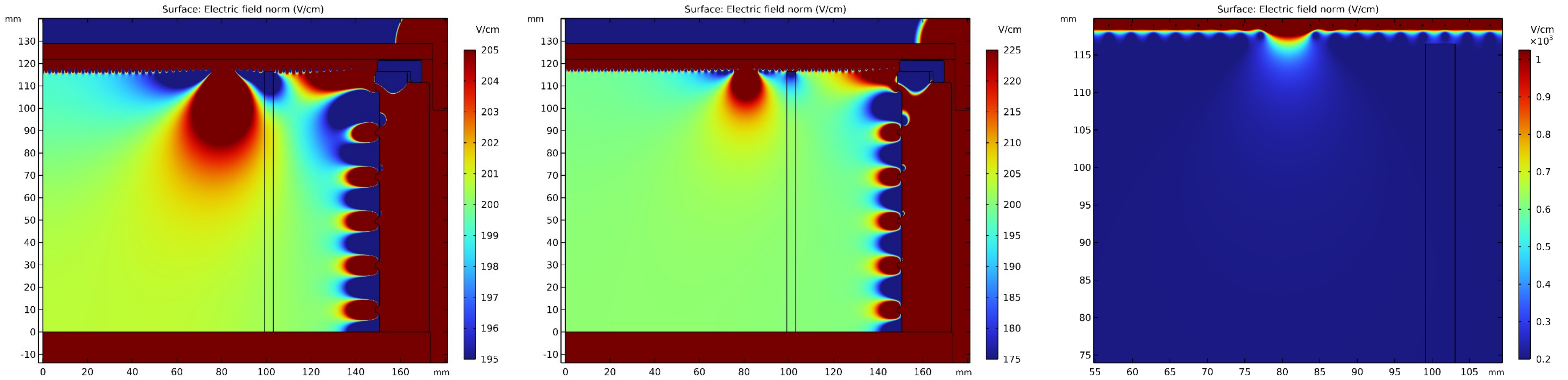


In general, the field strength above the wireframe remains within reasonable limits except for the uncertain situation at the anode edge (Clevios edge)

GAr thickness = 7 mm;
Wire to anode distance 10 mm;
Grid with 200 μm diameter wires;
Anode and cryostat walls = **0 V;**
Grid = **-5100 V;**
R1 = Grid – 150 V = **-5250 V;**
Cathode = Grid – 2150 V = **-7225 V.**
Electric field in the GAr = **5417 V/cm;**
Electric field in the drift area = **200 V/cm.**

Update 2D model

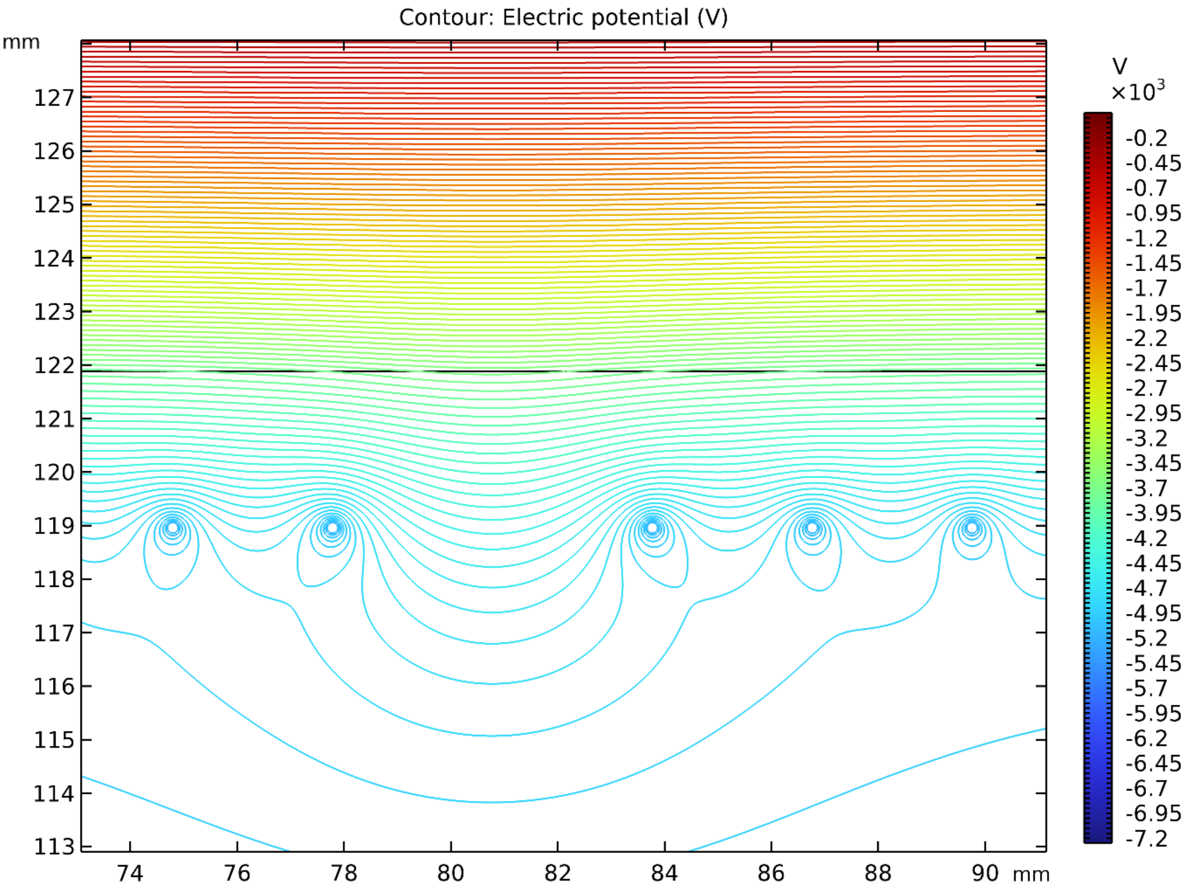
(without one wire)

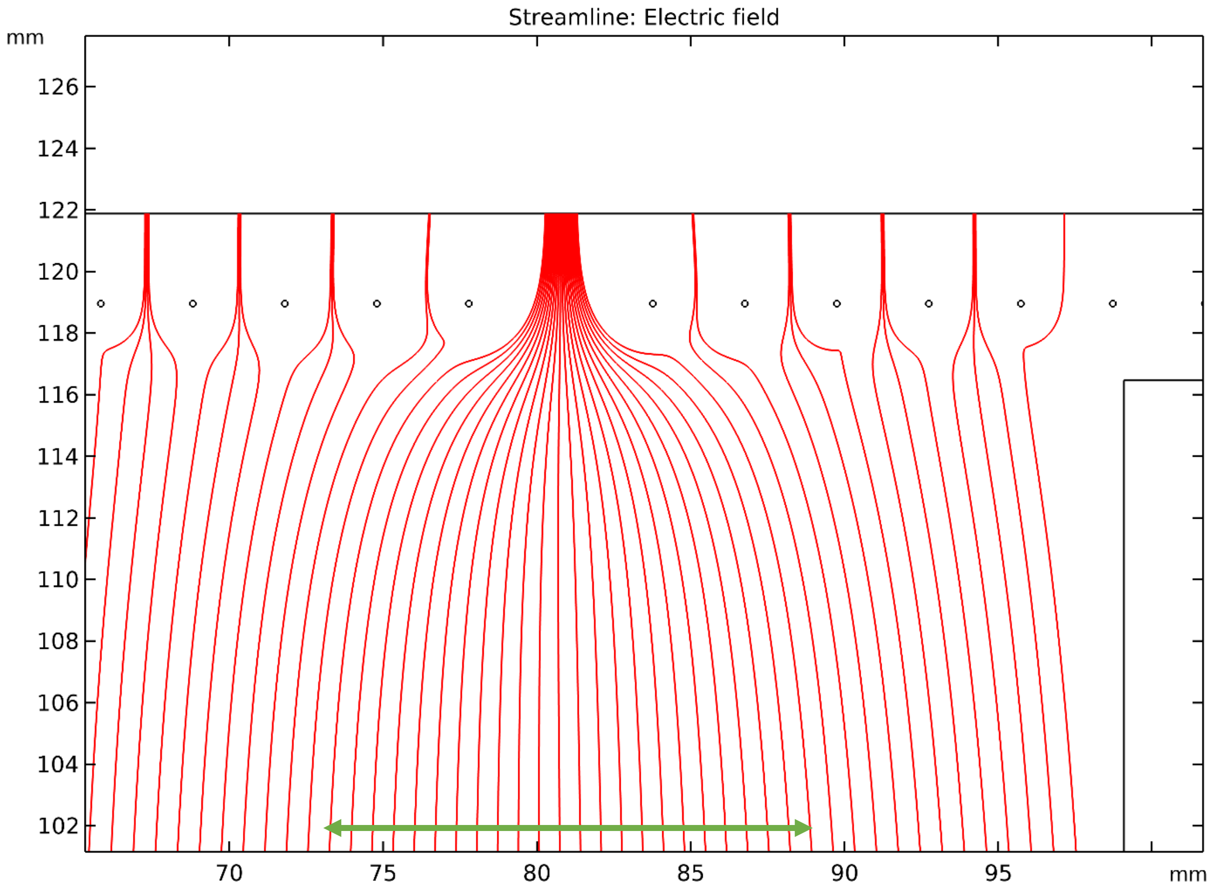


The absence of one wire leads to quite strong field nonuniformity.

A strongly nonlinear field gradient is formed under the missing wire. At a distance of ~1 cm, the field varies from ~220 V/cm to ~1000 V/cm. Under normal conditions, such a transition region is within ~2-2.5 mm from the grid wires. And another cm for the change from 205 to 220 V/cm.

Update 2D model
(without one wire)





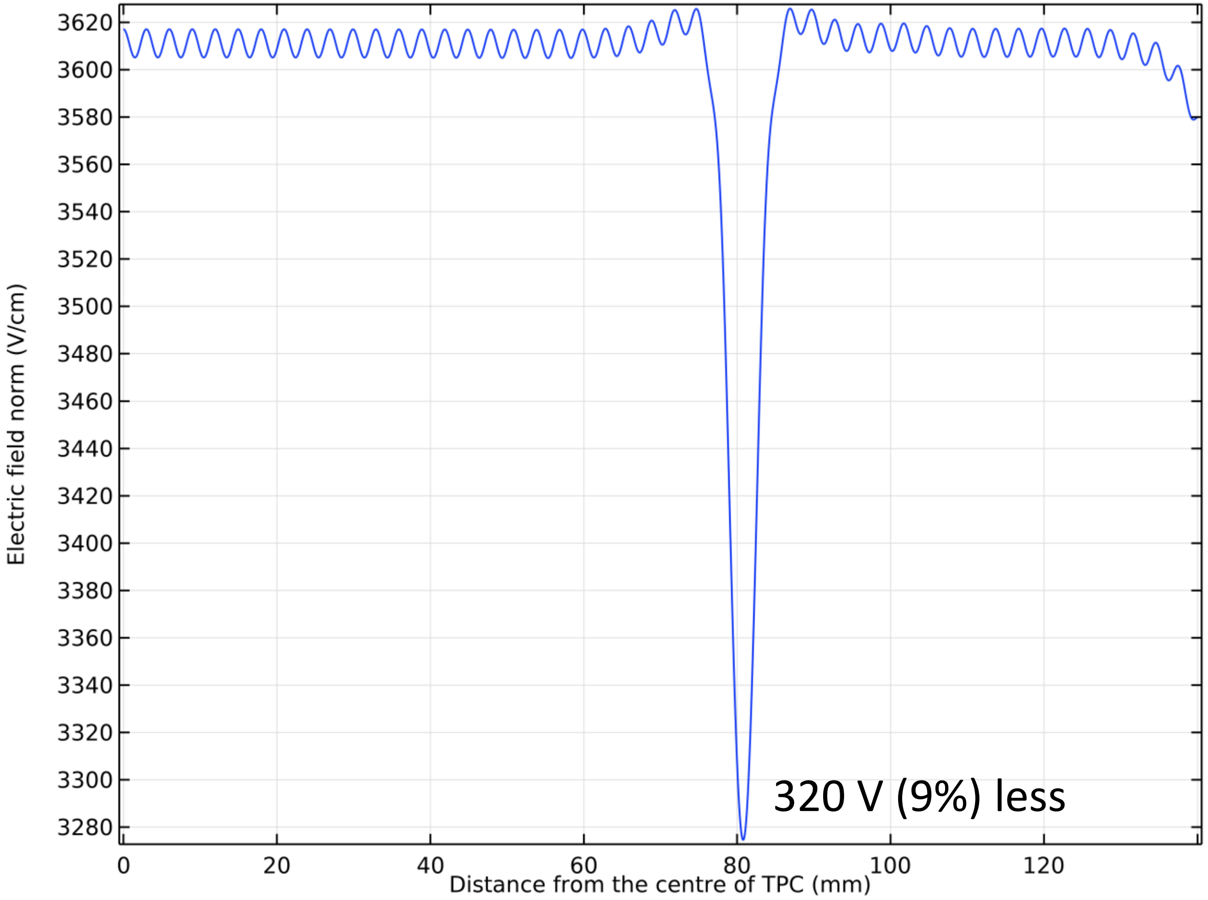
Since the usual "effective potential" remains under the other wires of the grid, the field leakage in the formed gap turns out to be much larger!

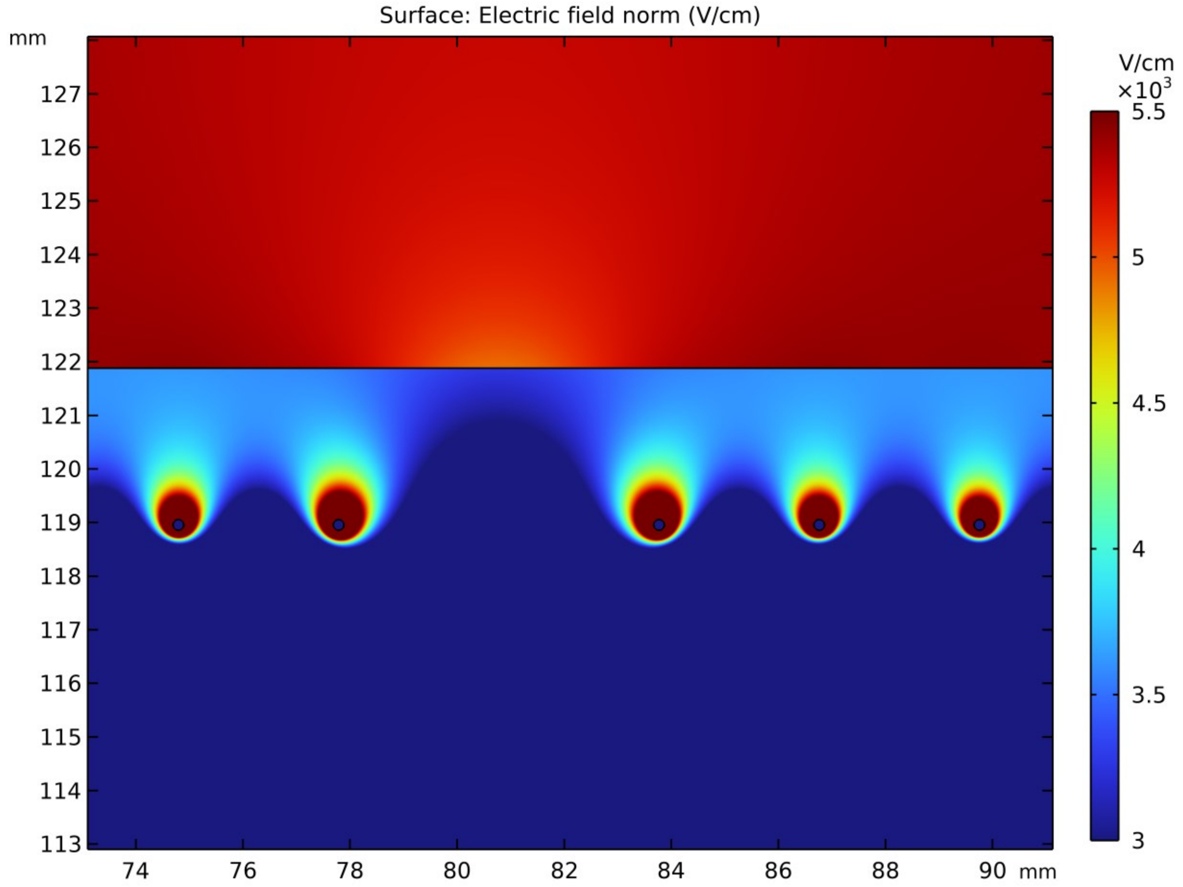
Electrons from a 15-20 mm thick layer will be focused into the resulting gap, whereas normally the tissue layer corresponds to the grid pitch (3 mm)

Update 2D model

(without one wire)

Extraction field

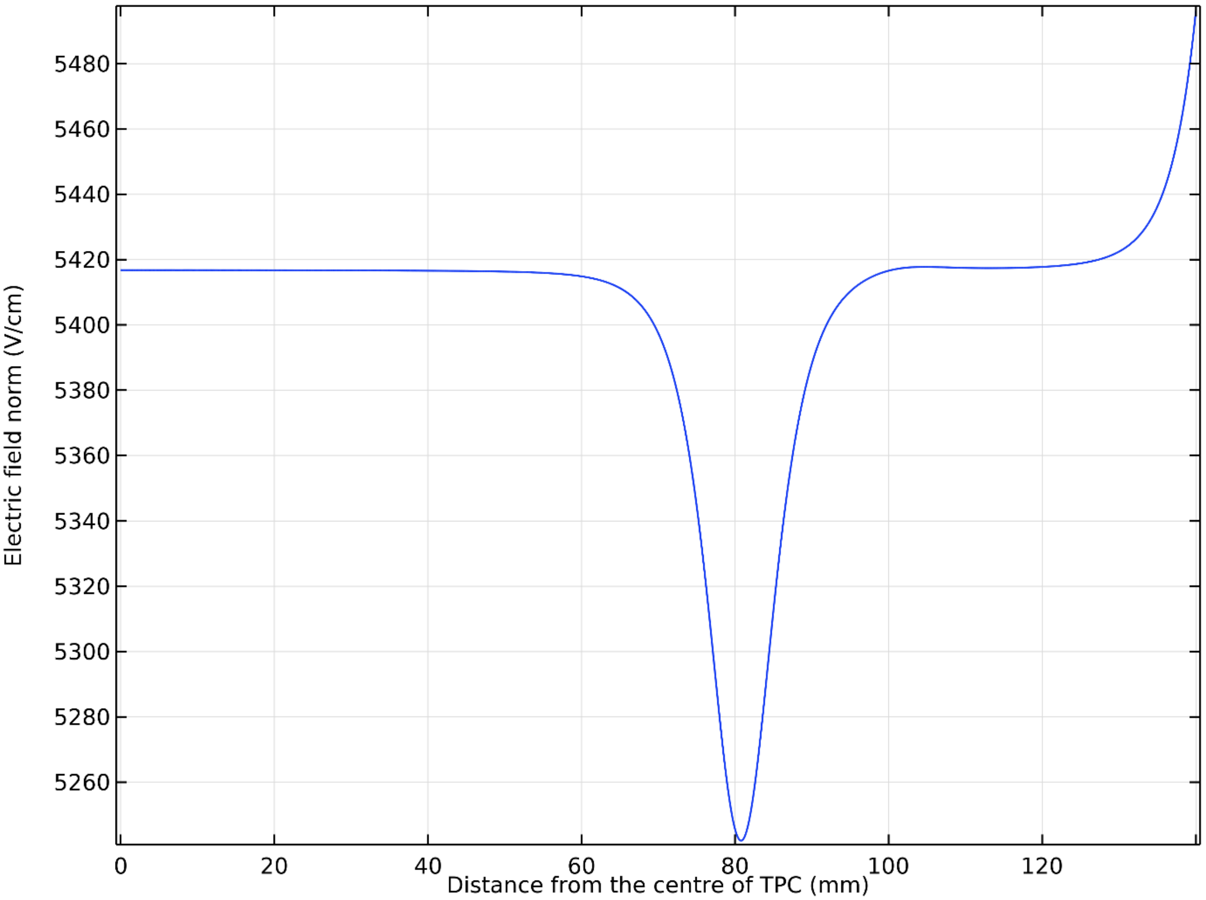




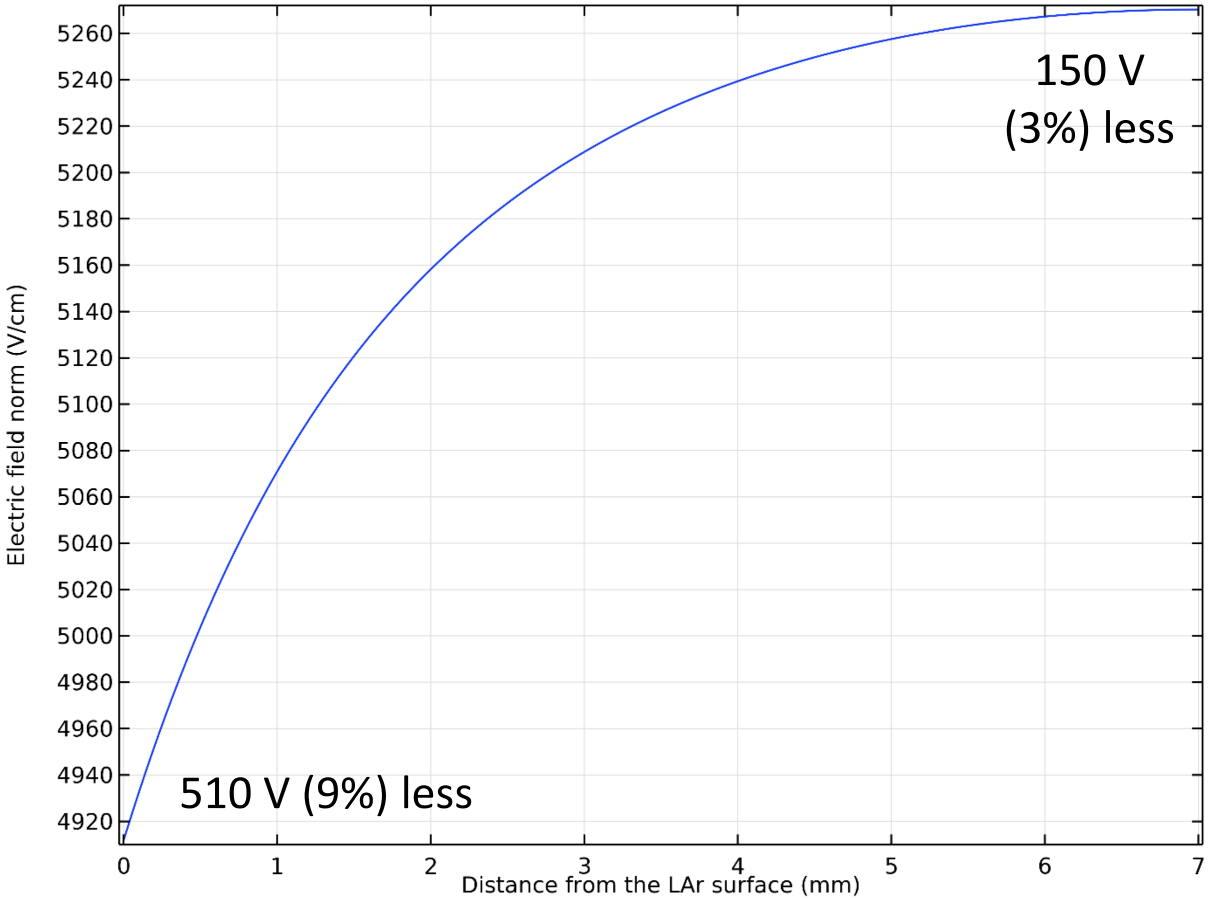
And for all these electrons the extraction field will be 320 V (9%) less.

Update 2D model
(without one wire)

Electric field in GAr



Electric field in Gar
(above the missing wire)



Moreover, above the missing wire, the electric field in the gas pocket will also be nonuniform

Conclusions:

- The absence of one wire will lead to significant nonuniformity of the drift field and the field in the gas pocket at the resulting gap in the grid;
- This field nonuniformity will lead to the fact that electrons from a wide layer (15-20 mm) will be focused into the resulting gap, thus the field nonuniformity will affect the operation of 7.5-10% of the sensitive volume of the detector (the area limited by the reflector);
- Above the missing wire in the gas pocket, the electric field is non-uniform and less by an amount of 9 to 3%;