Julius-Maximilians-
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A systematic numerical study on different Micromegas for HV stability

RD51 meeting September 2018

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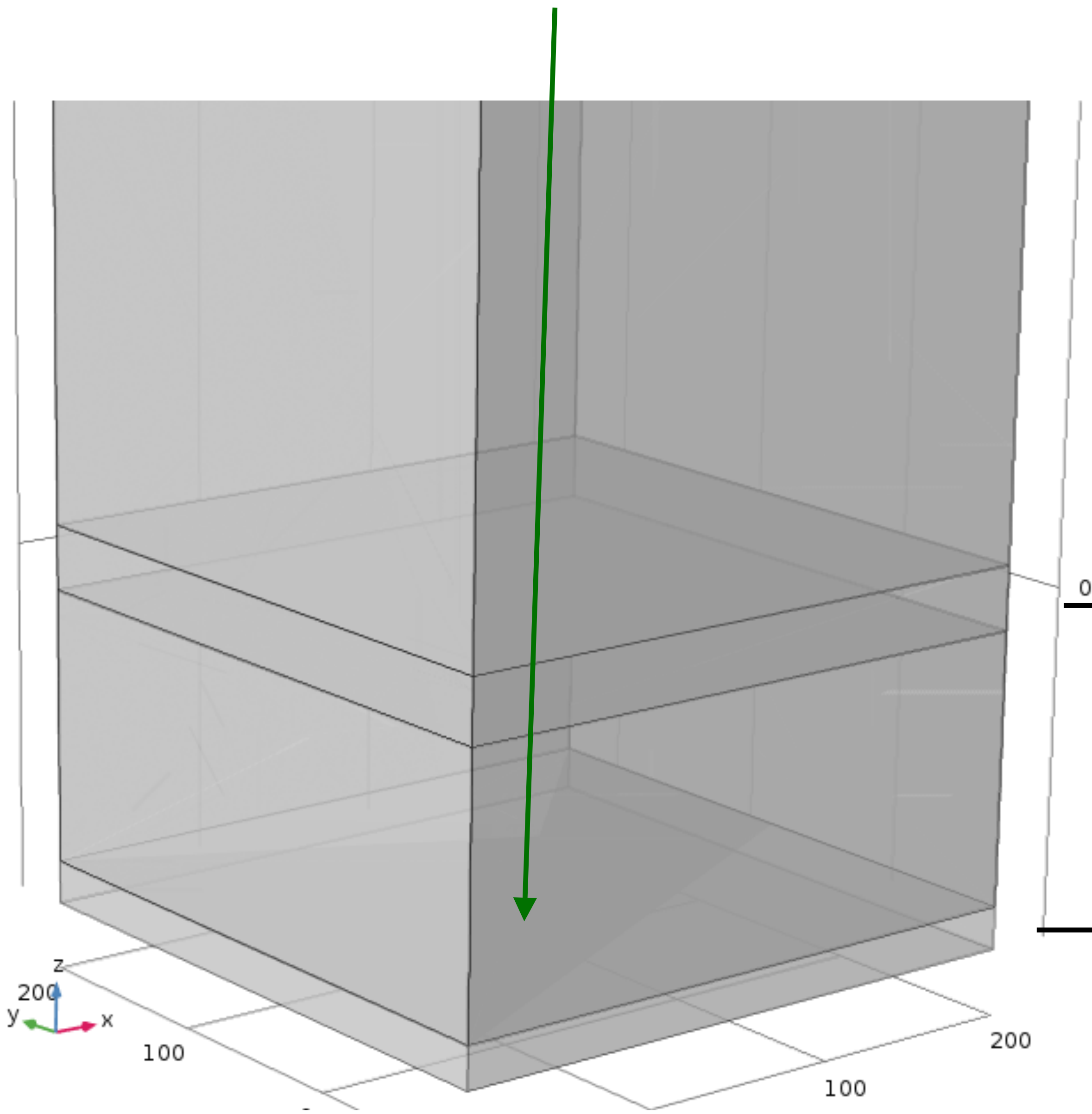
Motivation

- the average electric field in the amplification gap decides the Gain and other behaviour of the detector.
- however, there are small regions where the field is enormously high and influence the HV stability of the detector.
- these high field regions depend on the mesh geometry. A systematic study can give an indirect, still valid, indication for HV stability.
- solving basic sets of equations for streamer discharge (even in 2D) can give better insight.

I am using COMSOL multi physics, which relies on Finite Element Methods.

To me, this tool is also very helpful to realise complicated geometries and composite (multi physics) jobs.

Let's start with the parallel plates



copper drift at -600 V (not shown)

drift gap 1mm.

Argon is the fill gas here

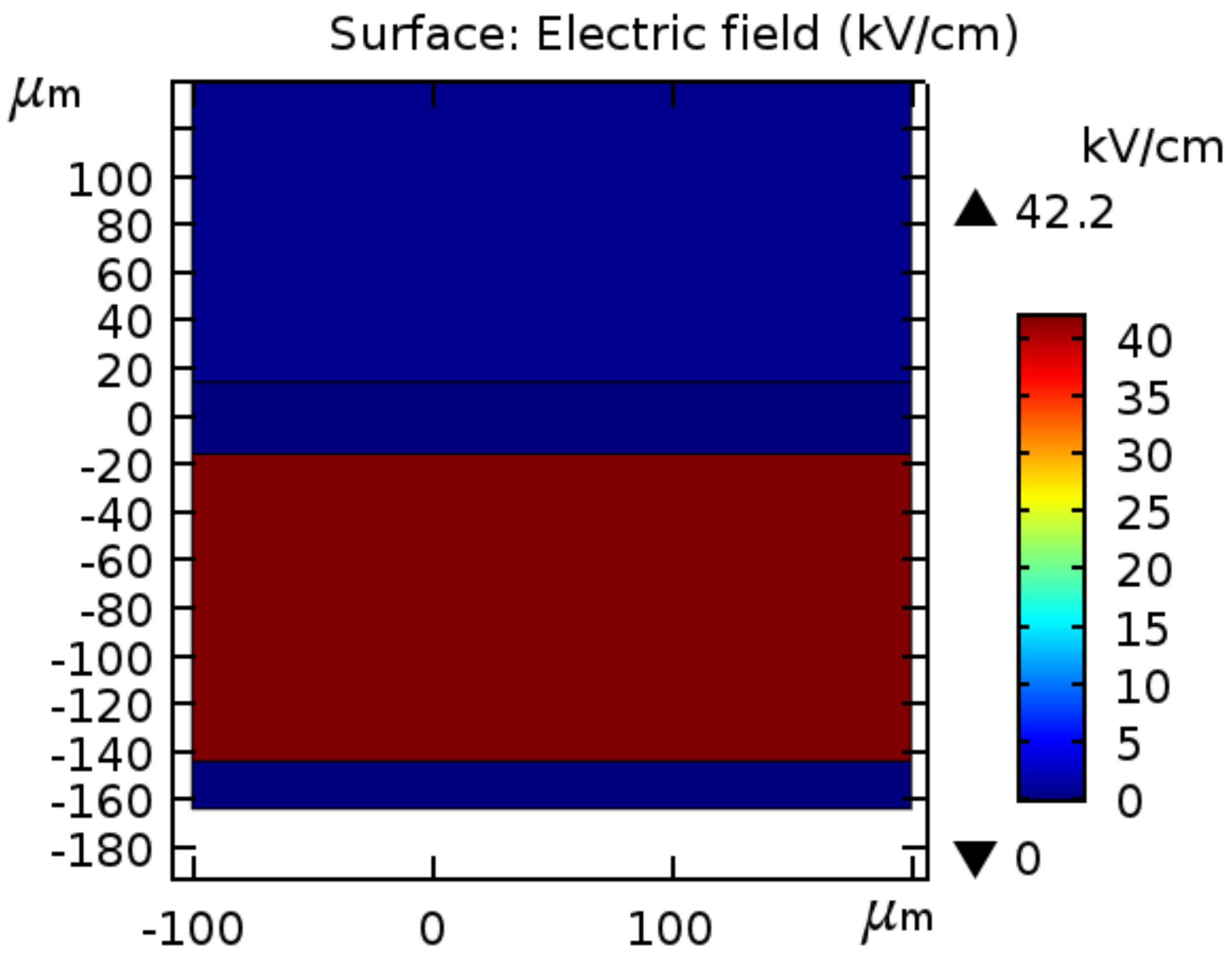
30 μm thick steel (AISI 4340) Mesh(m-plate) at -540 V

Amplification Gap 128 μm

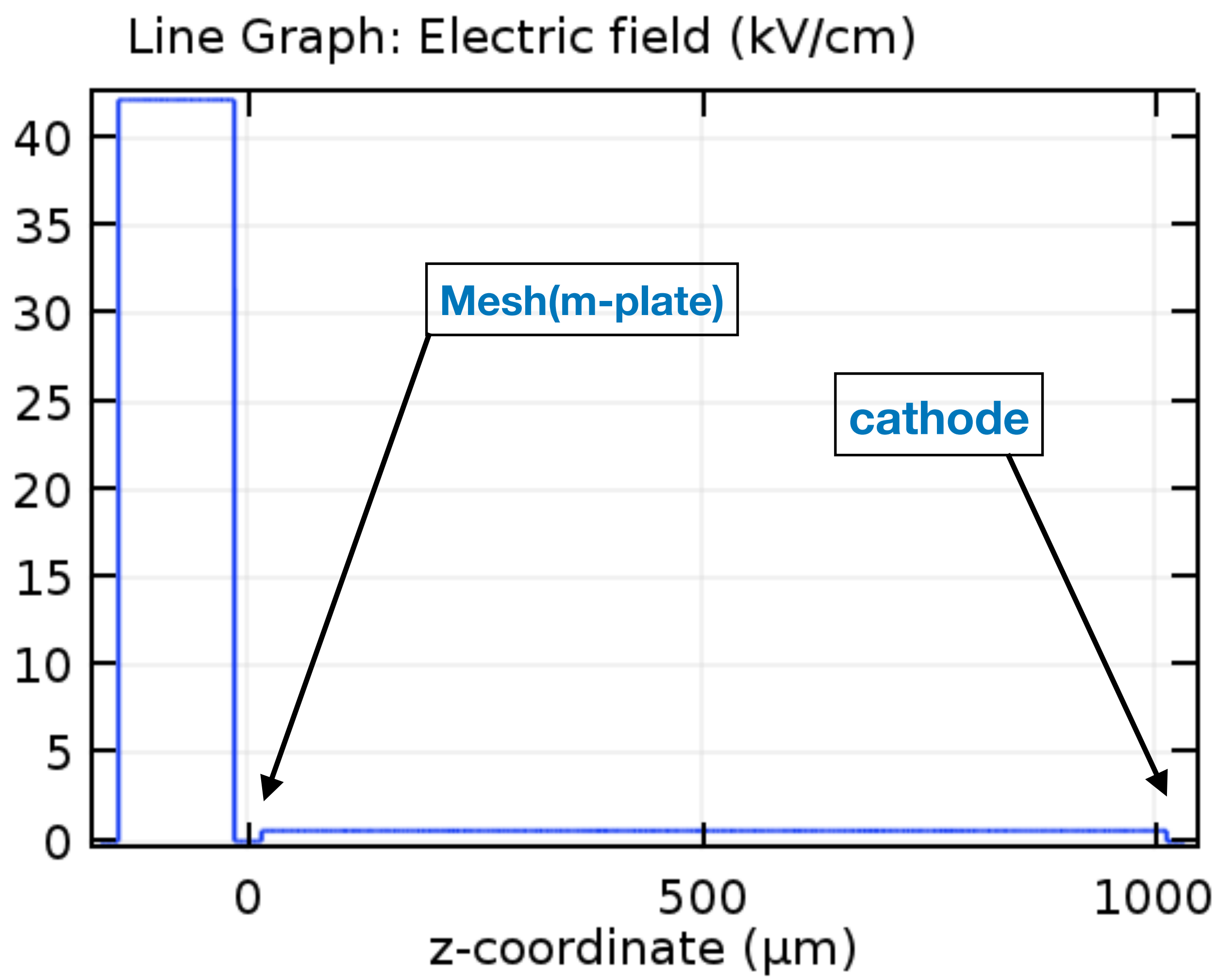
20 μm thick copper Anode at Ground potential

parallel plates

Electric field (on the YZ plane)

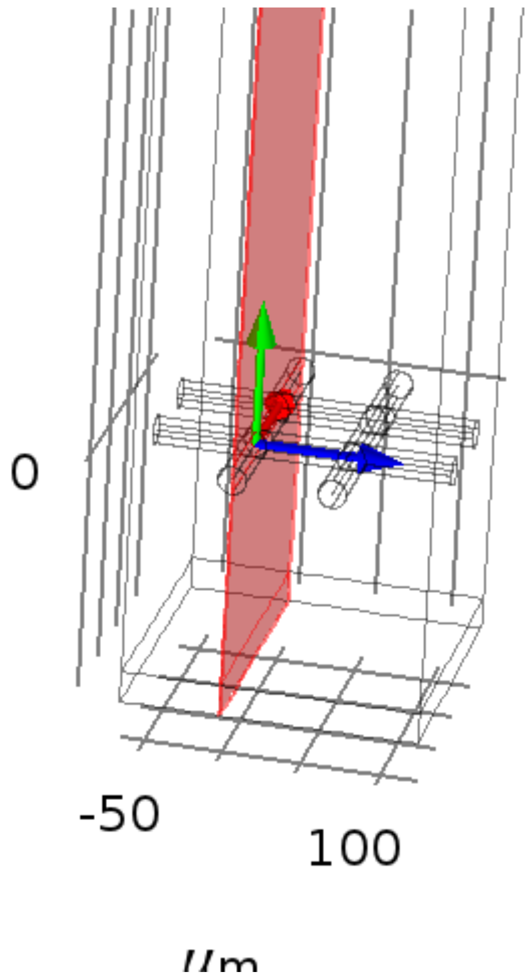


Along a line on the YZ plane, at X=Y= half pitch

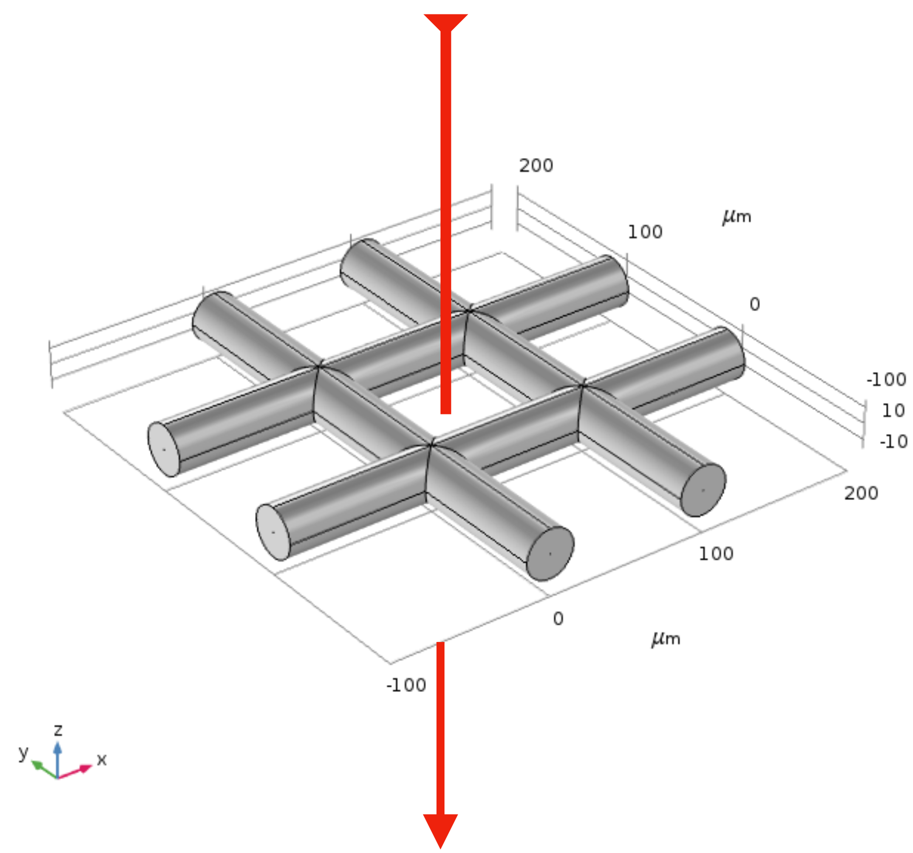


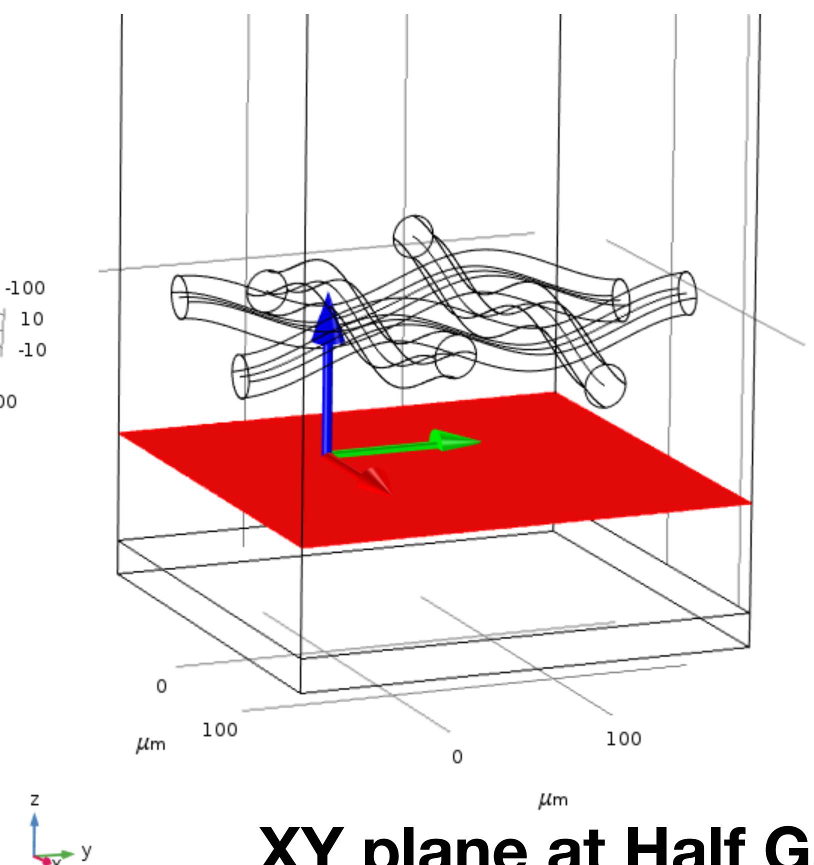
The electric field is like the exact solution ! It is uniform through out.

where the electric field is probed !



YZ-plane

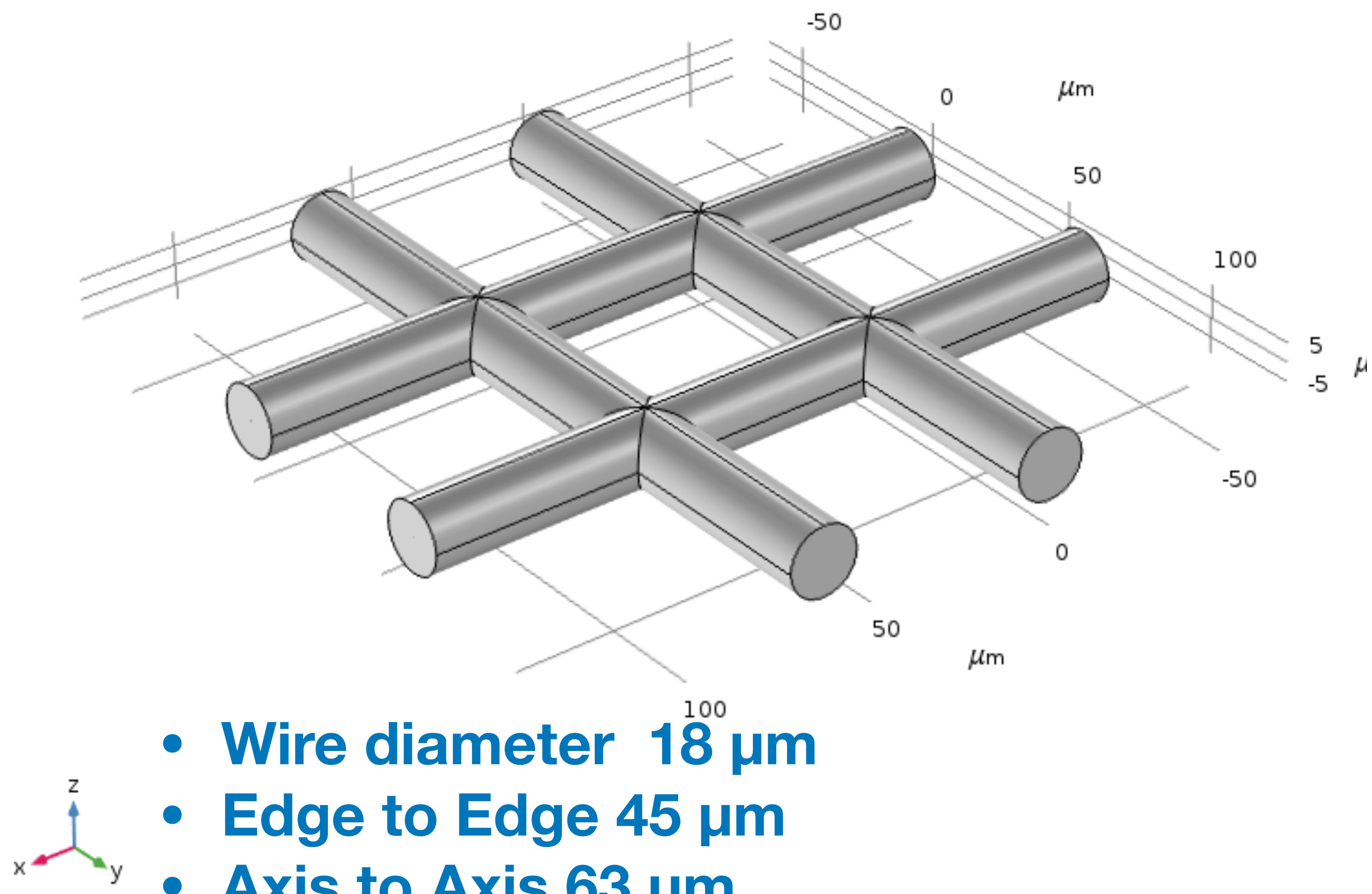




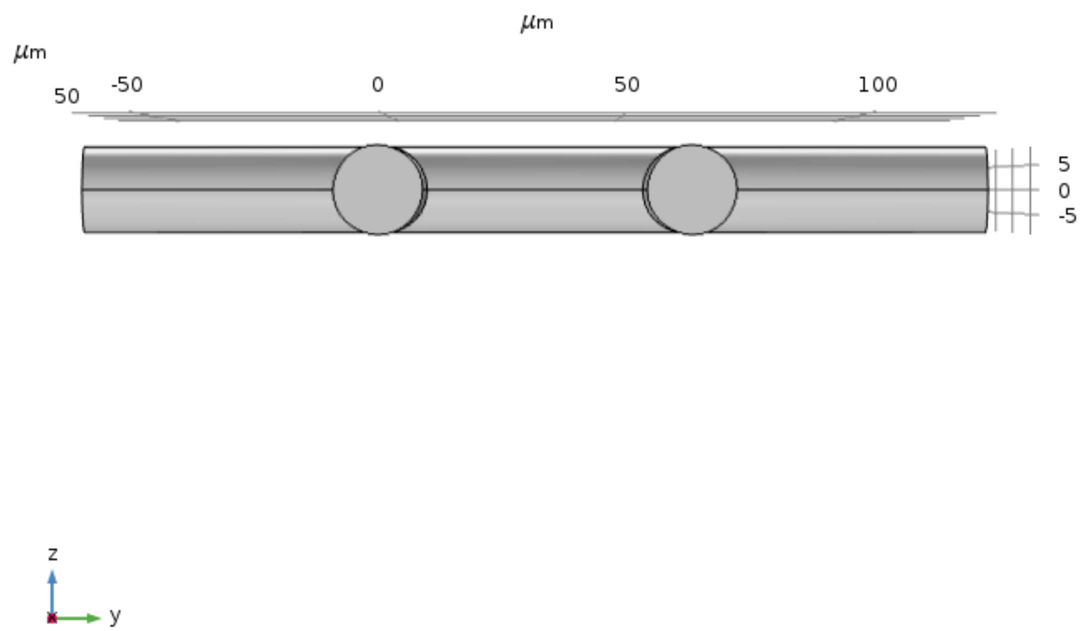
XY plane at Half Gap

Along Axis (for line graphs)

18/45 Calendared :



- Wire diameter 18 µm
- Edge to Edge 45 µm
- Axis to Axis 63 µm

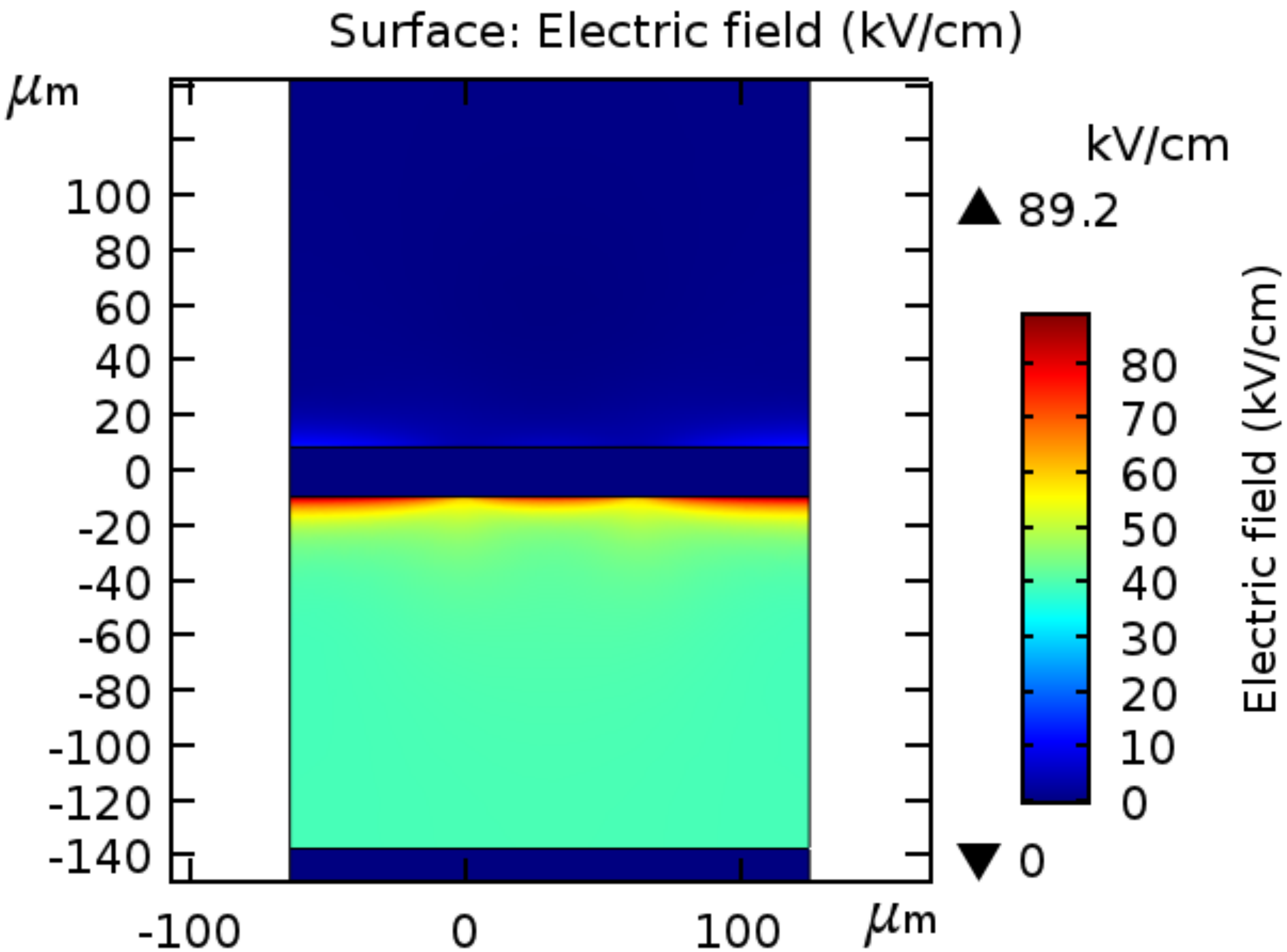


The wires are taken as inter-penetrating

the drift gap, amplification gap are the same

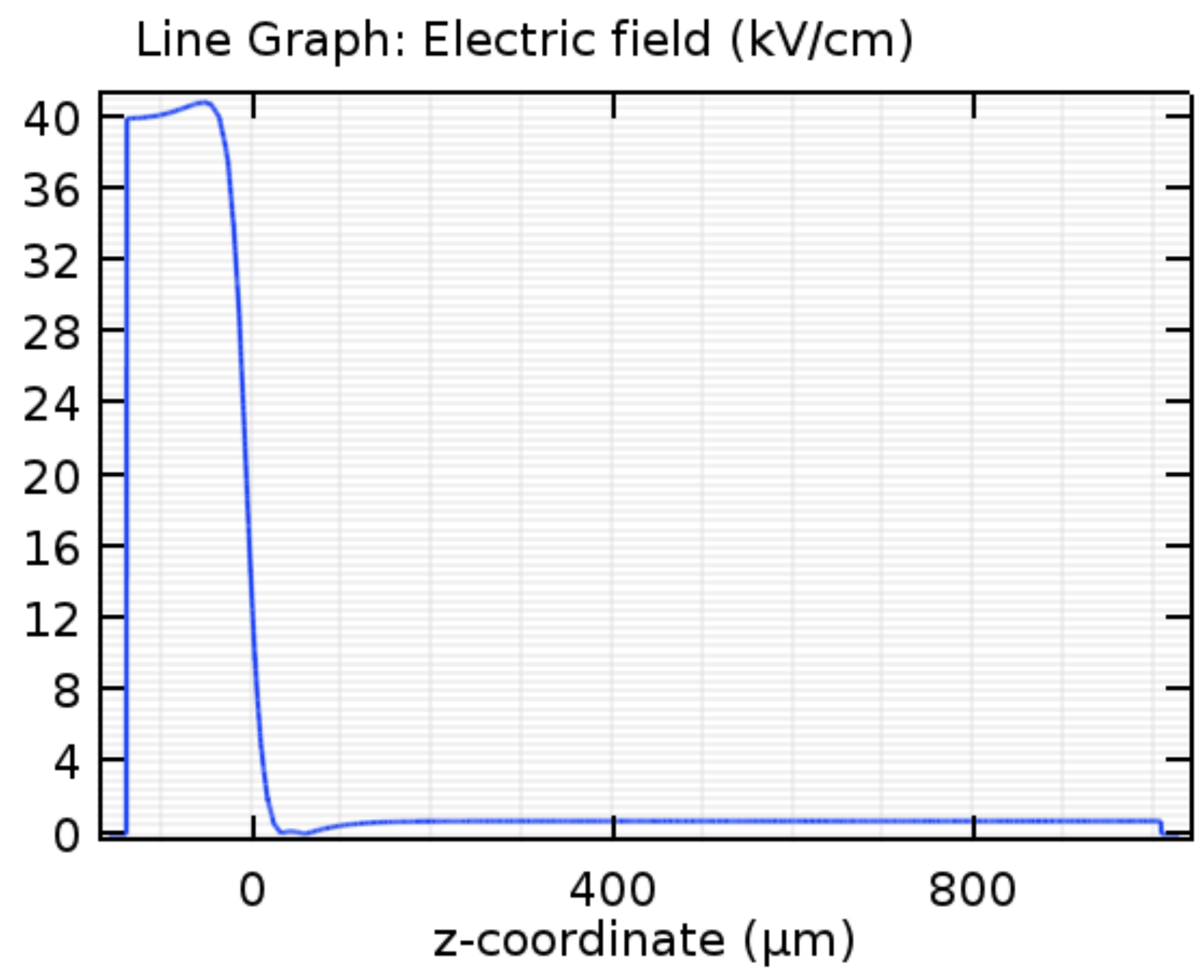
18/45 calendared

on the YZ plane, through a wire

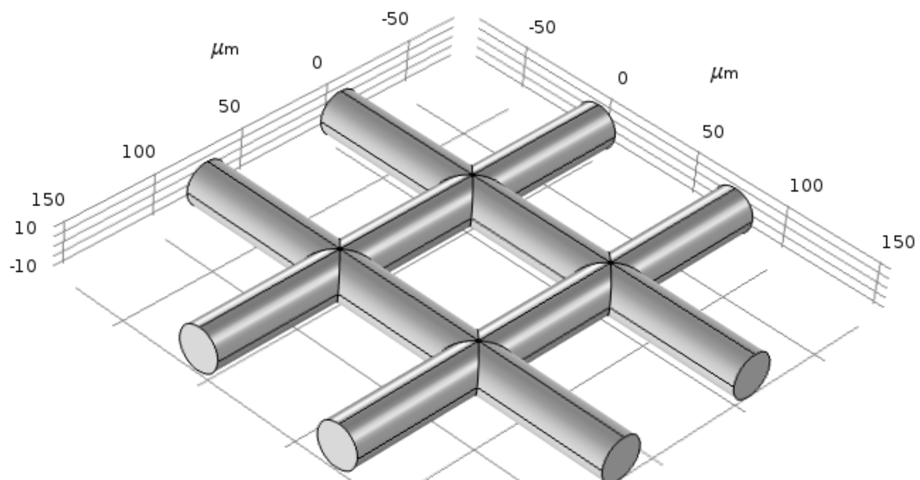


the maximum field is 89.2 kV/cm

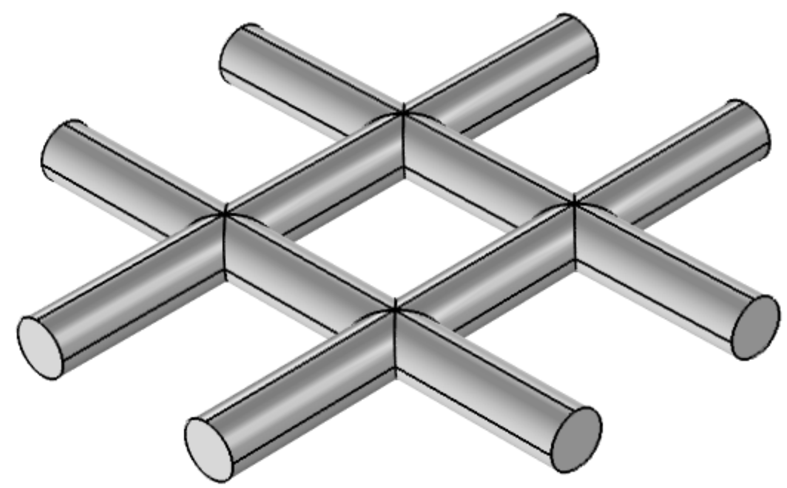
Along a line on the YZ plane, at X=Y= half pitch



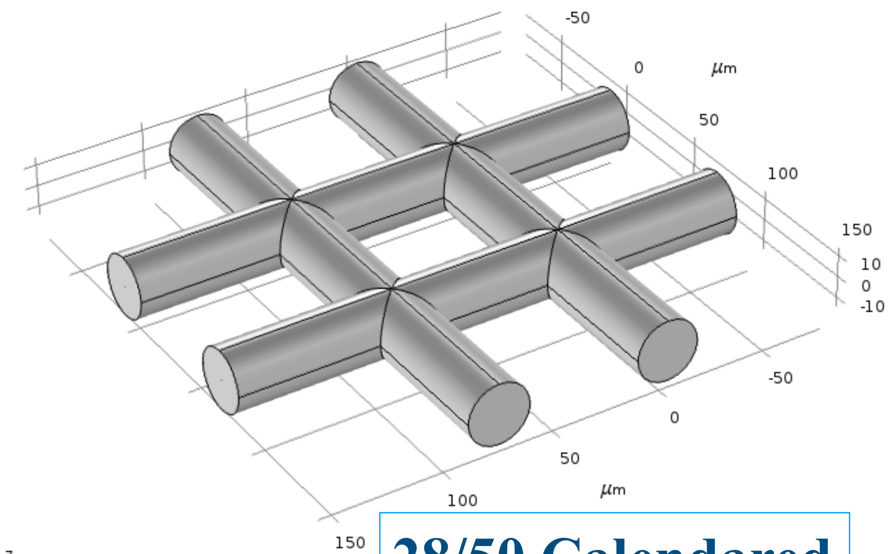
average field is ~ 40.5 kV/cm



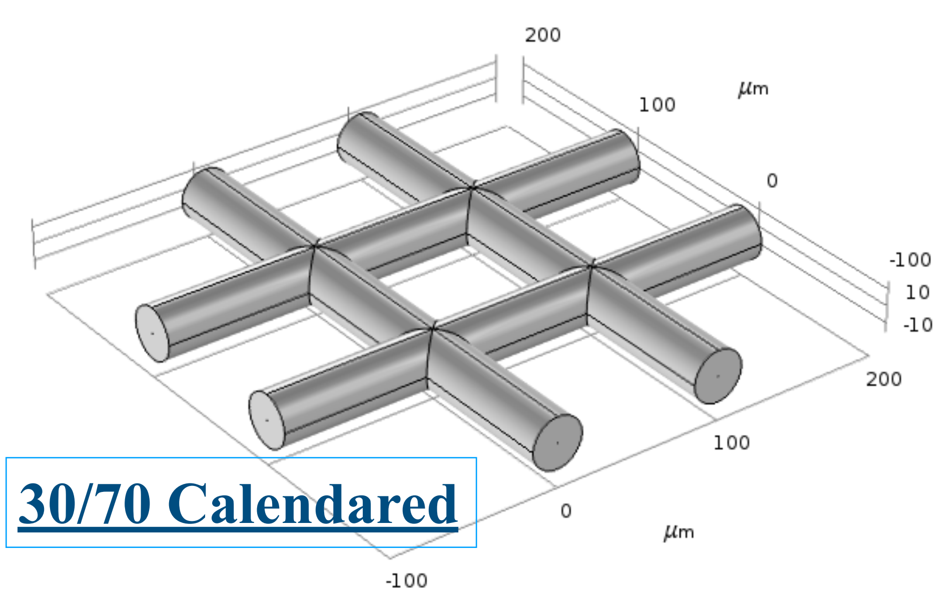
22/56 Calendared



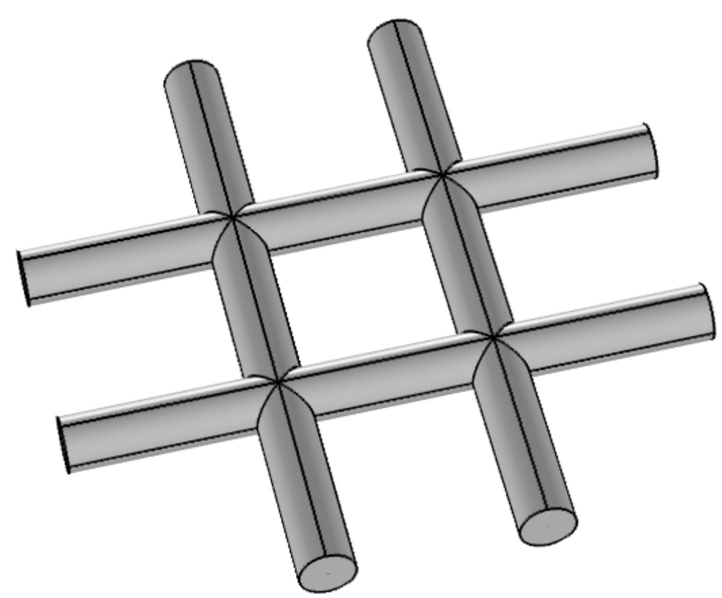
25/67 Calendared



28/50 Calendared



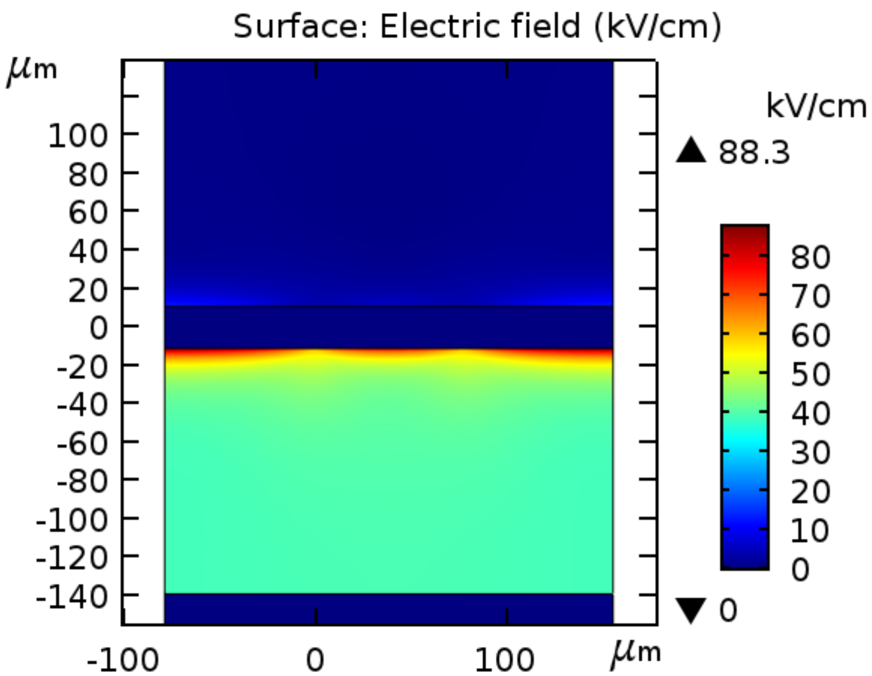
30/70 Calendared



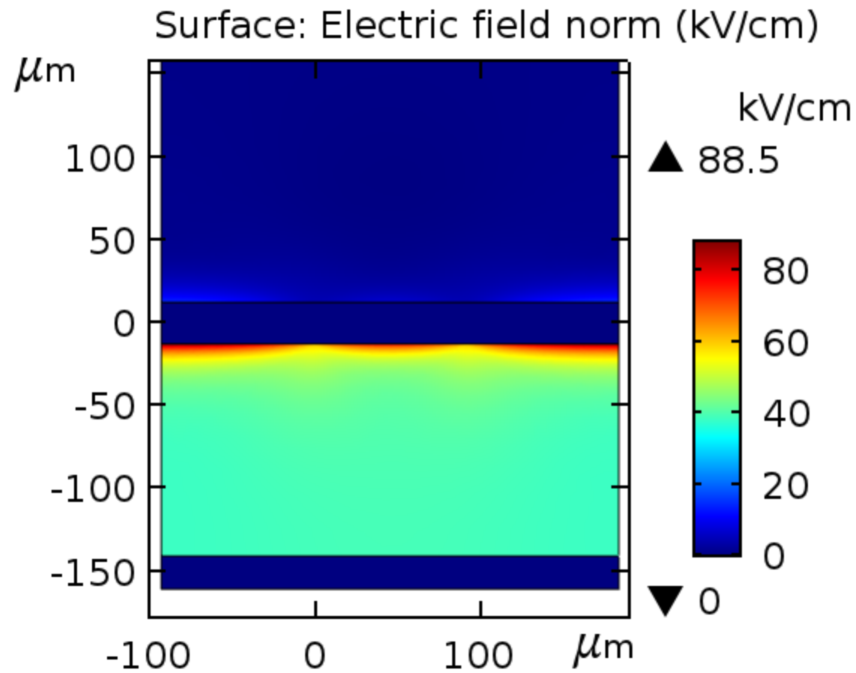
30/85 Calendared

the drift gap, and the amplification gap remains the same

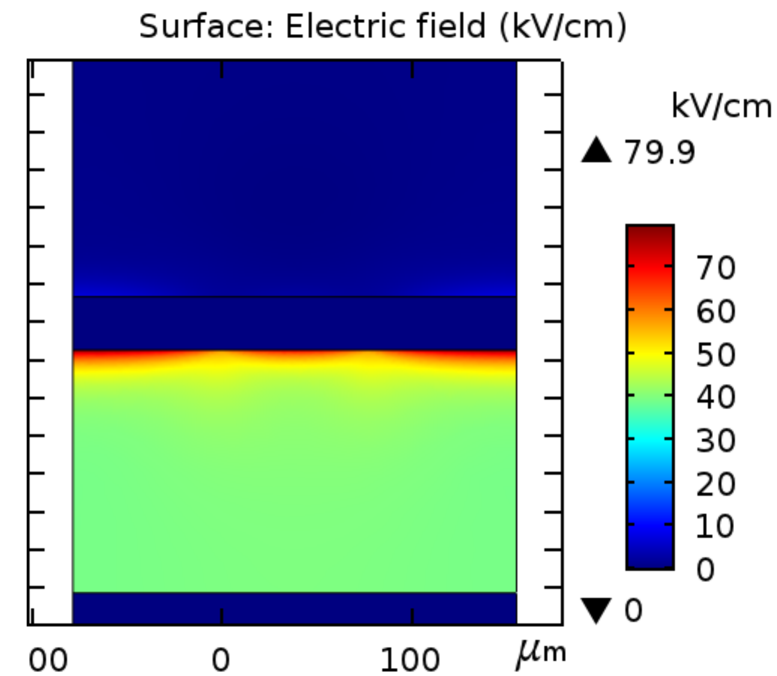
Calendared: on the YZ plane, through a wire



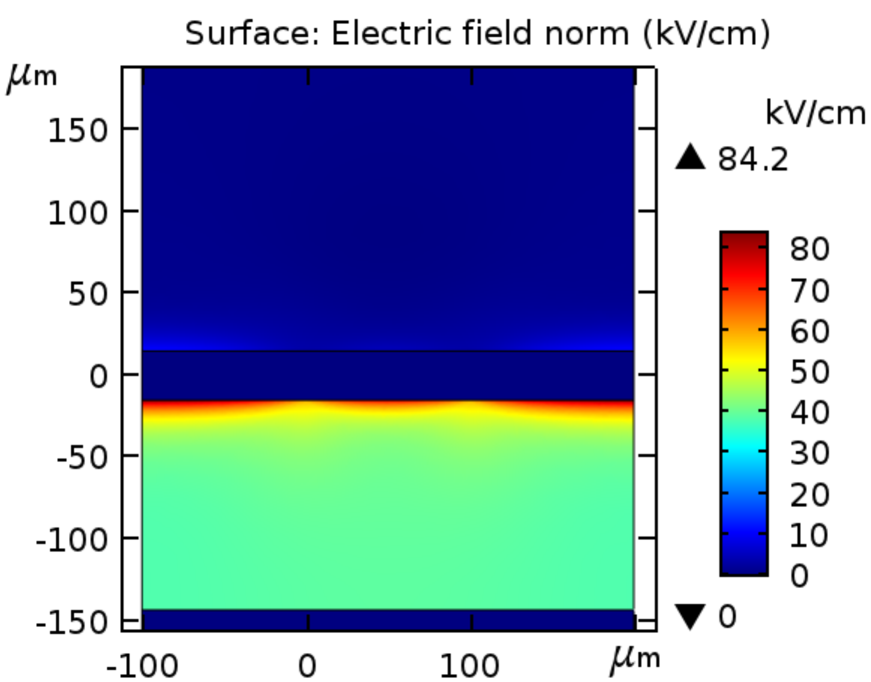
22/56 Calendared



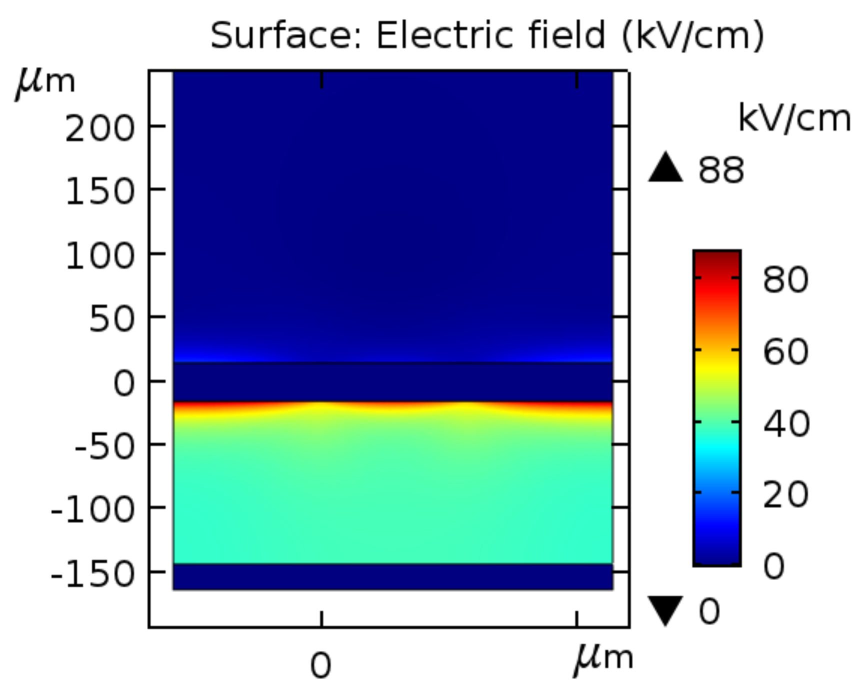
25/67 Calendared



28/50 Calendared



30/70 Calendared



30/85 Calendared

Maximum Fields (kV/cm):

- **18/45 => 89.20**
- **22/56 => 88.30**
- **25/67 => 88.50**
- **28/50 => 79.90**
- **30/70 => 84.20**
- **30/85 => 88.00**

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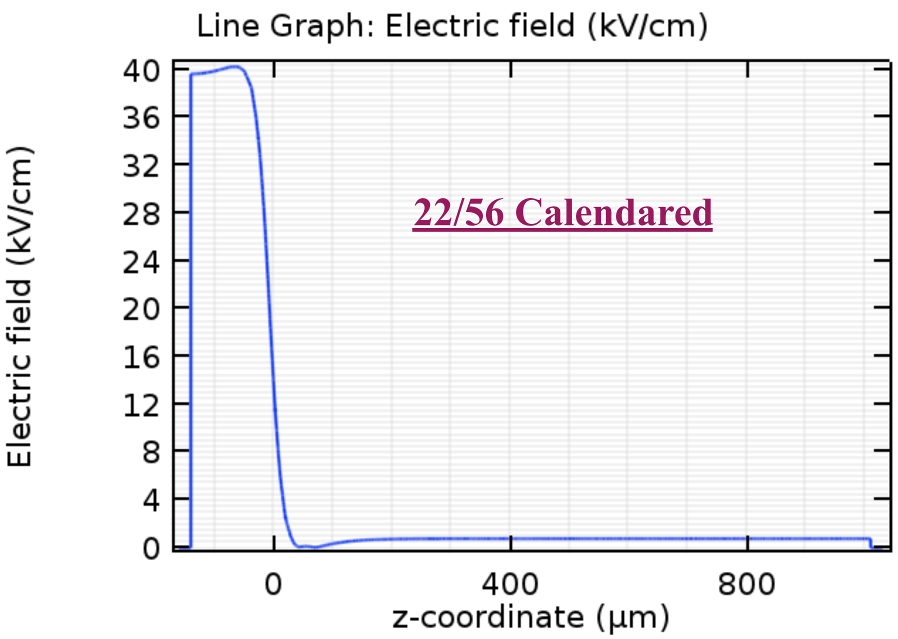
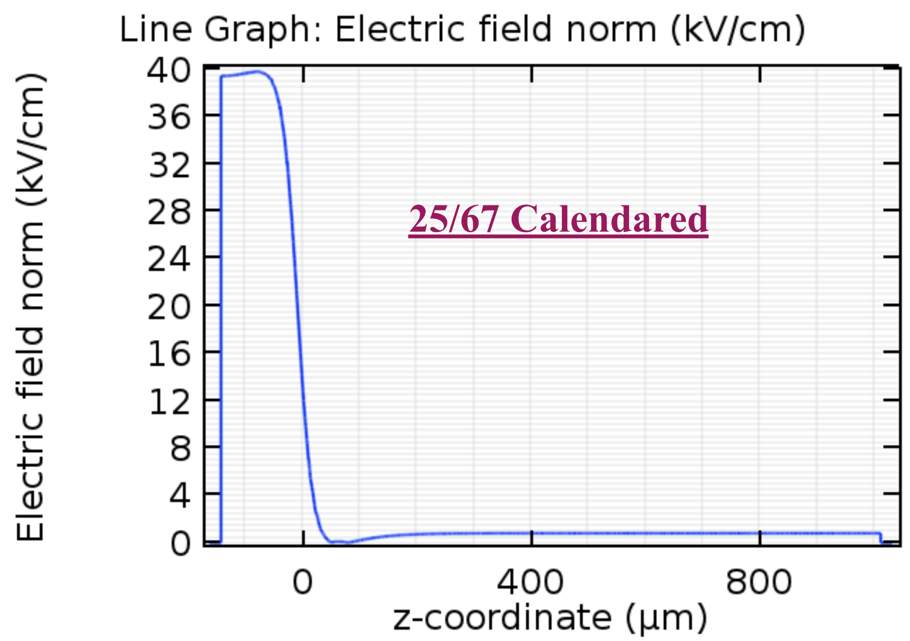
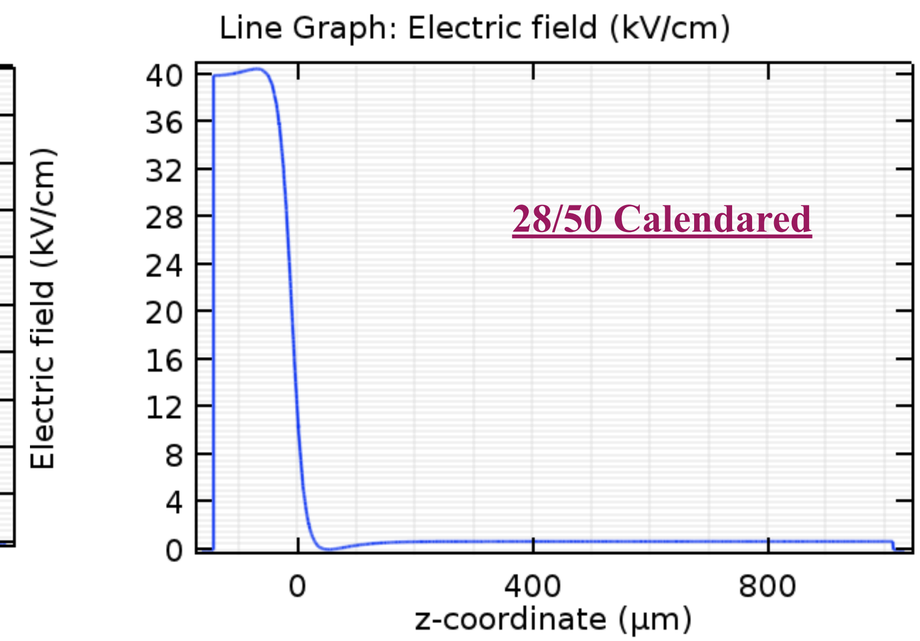
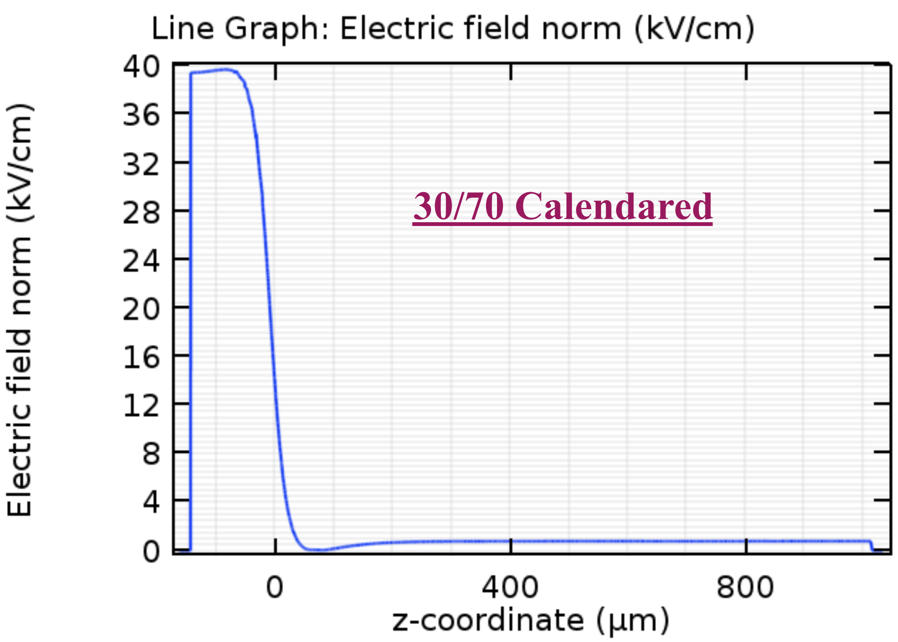
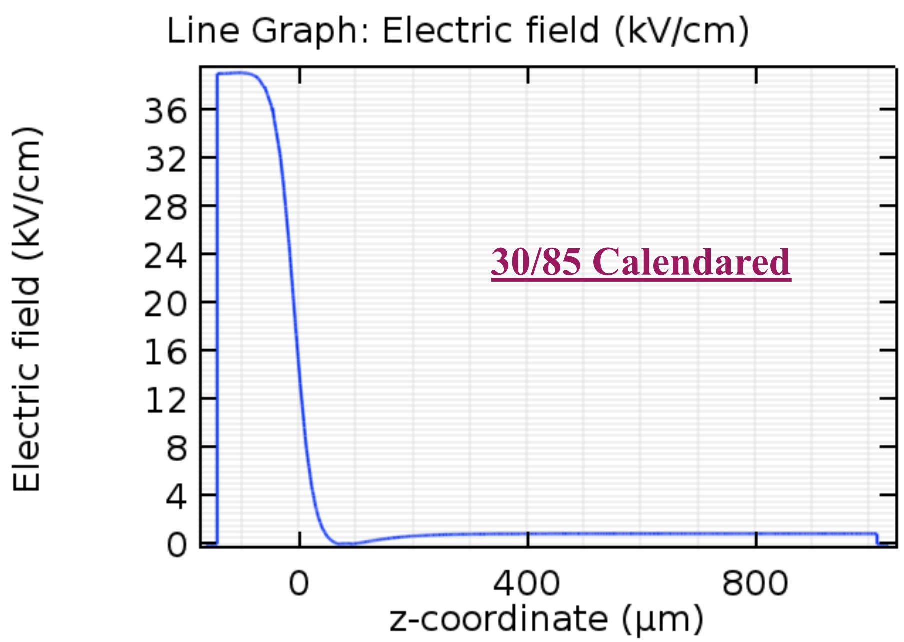
Calendared: Along a line on the YZ plane, at X=Y= half pitch









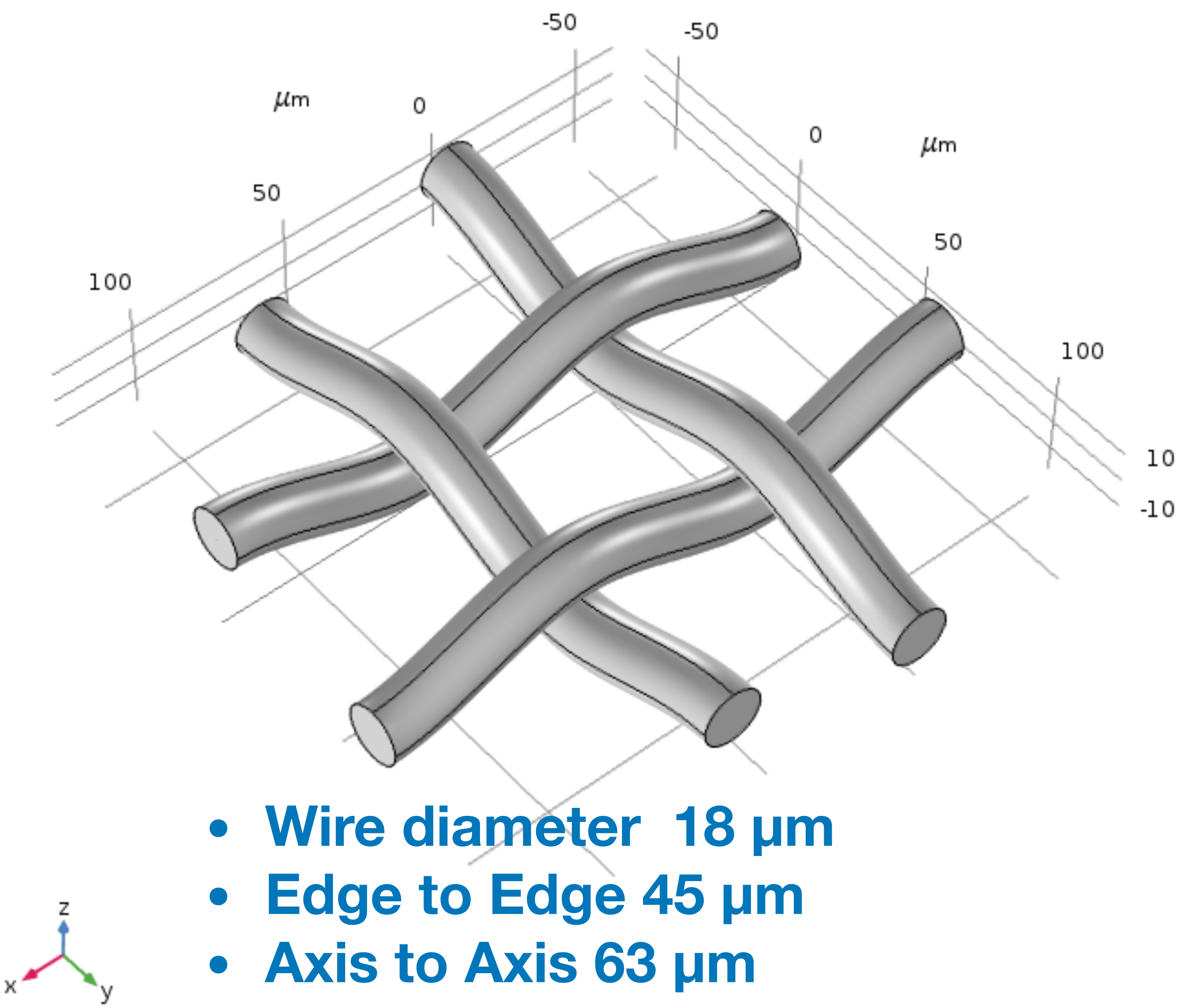


Average Fields (kV/cm):

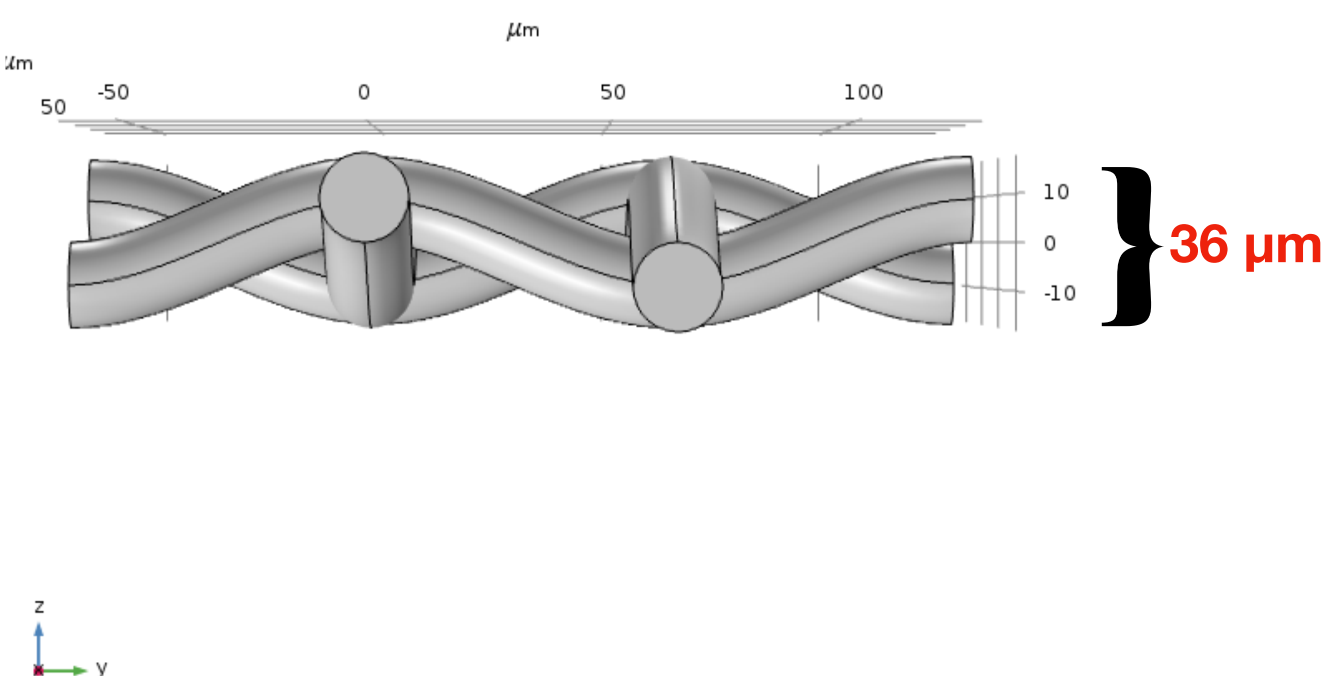
- 18/45 => ~40.50
- 22/56 => ~40.00
- 25/67 => ~40.00
- 28/50 => ~40.00
- 30/70 => ~40.00
- 30/85 => ~39.50

woven Mesh

18/45 Standard Woven :



- Wire diameter 18 µm
- Edge to Edge 45 µm
- Axis to Axis 63 µm

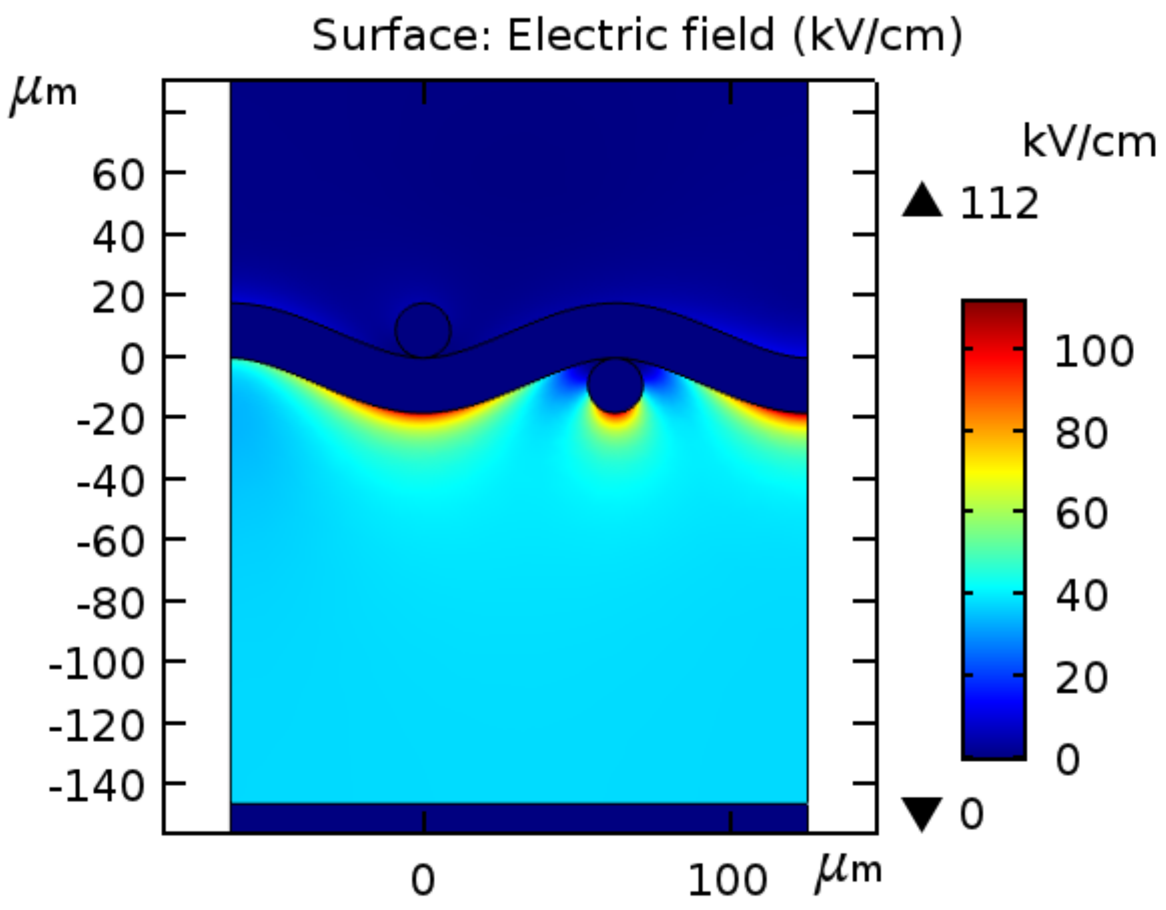


The wires have equal amplitudes

the drift gap, amplification gap are the same

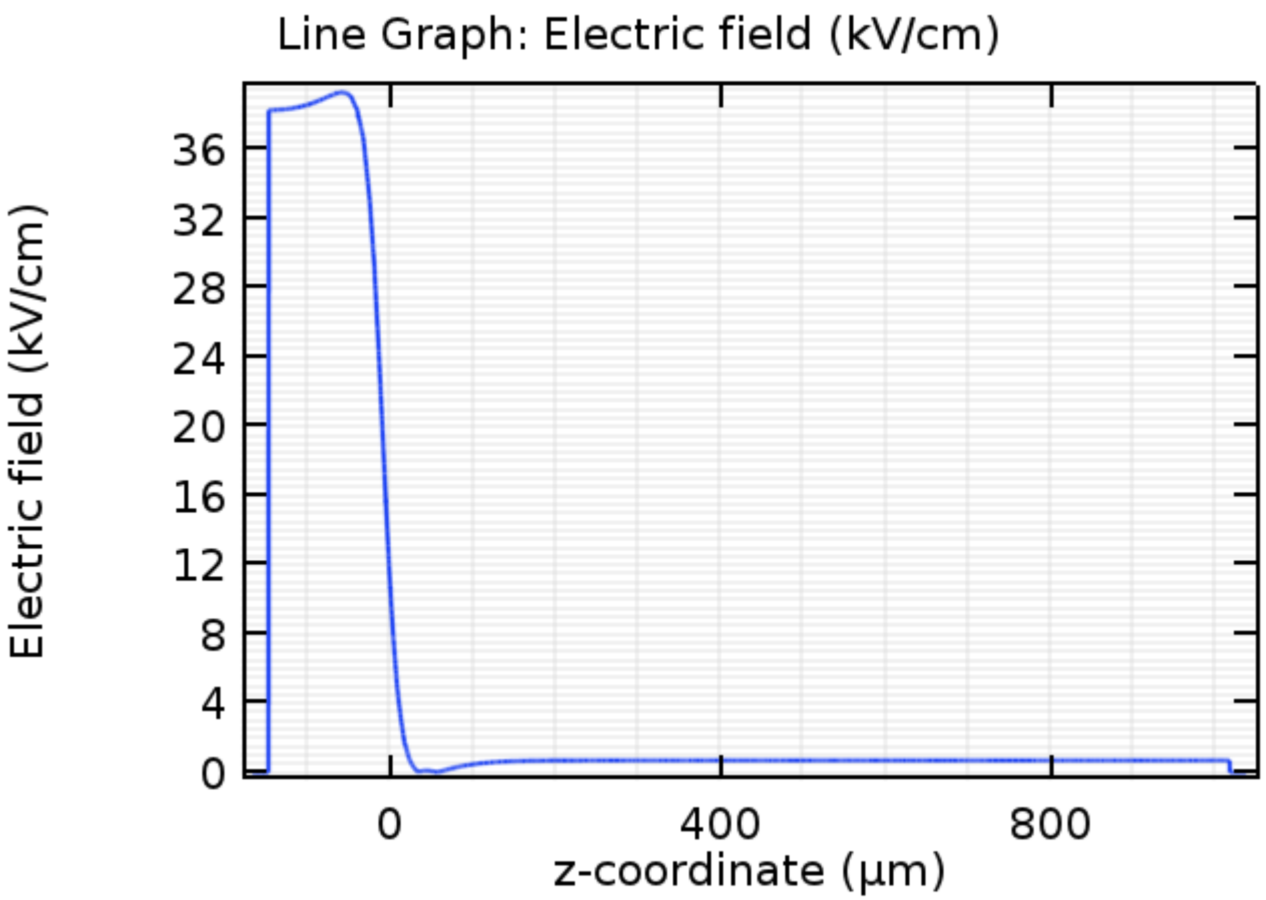
18/45 standard woven

on the YZ plane, through a wire

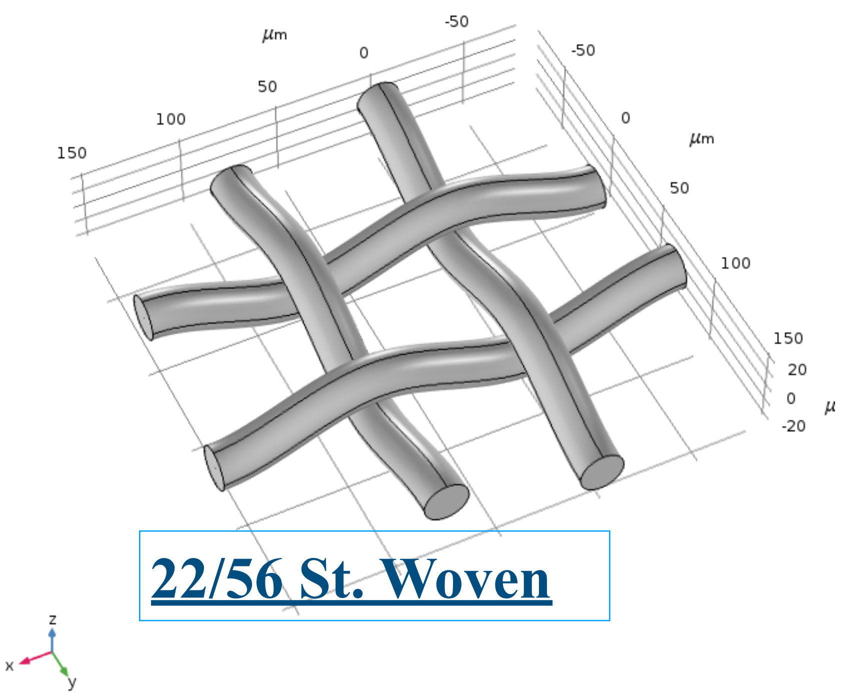


the maximum field is 112 kV/cm

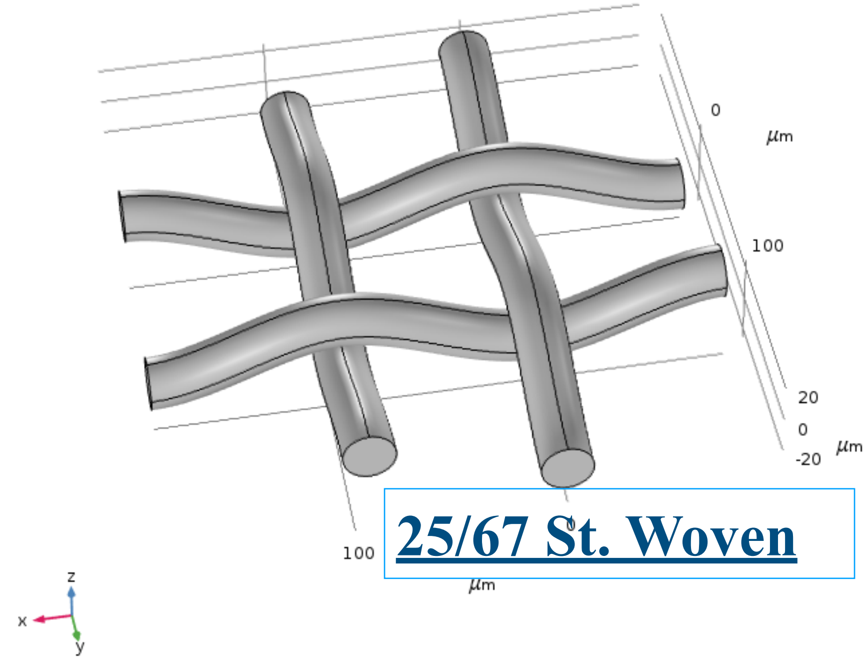
Along a line on the YZ plane, at X=Y= half pitch



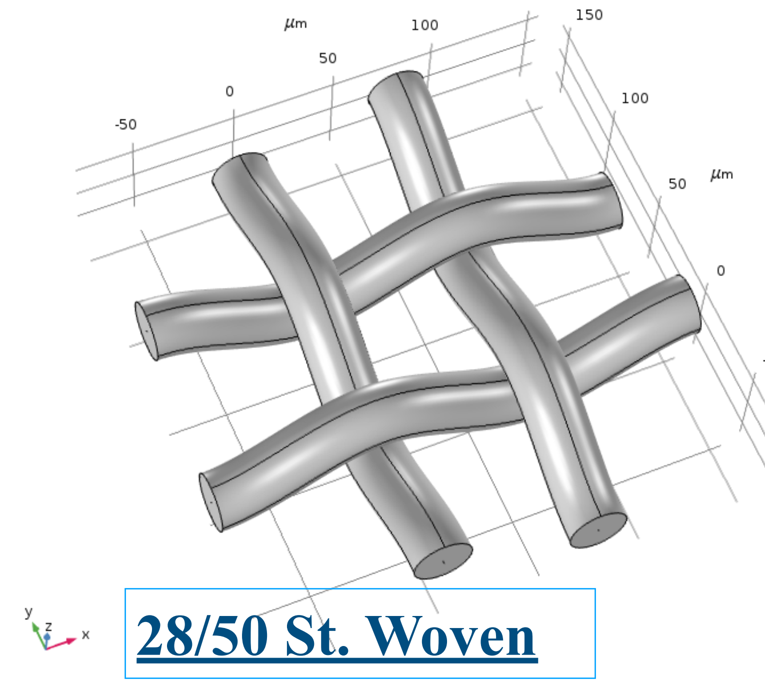
average field is ~38.75 kV/cm



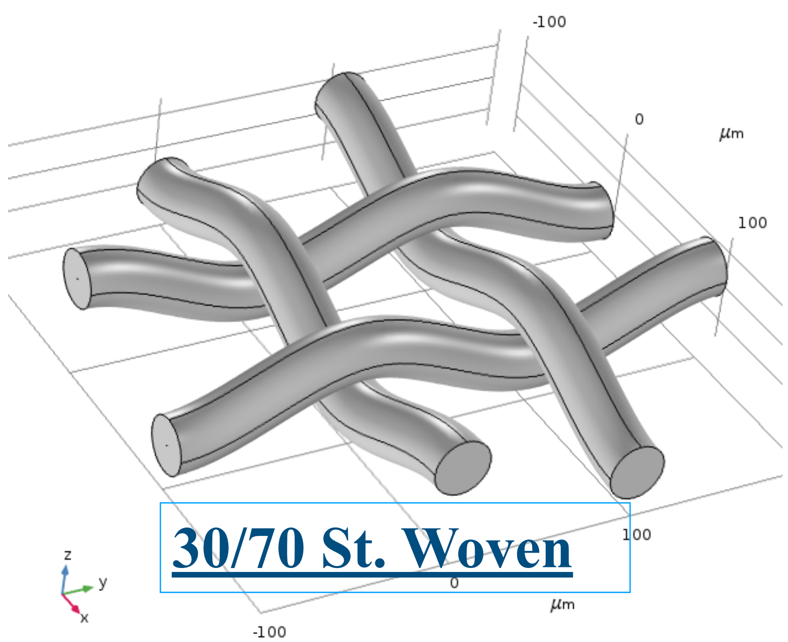
22/56 St. Woven



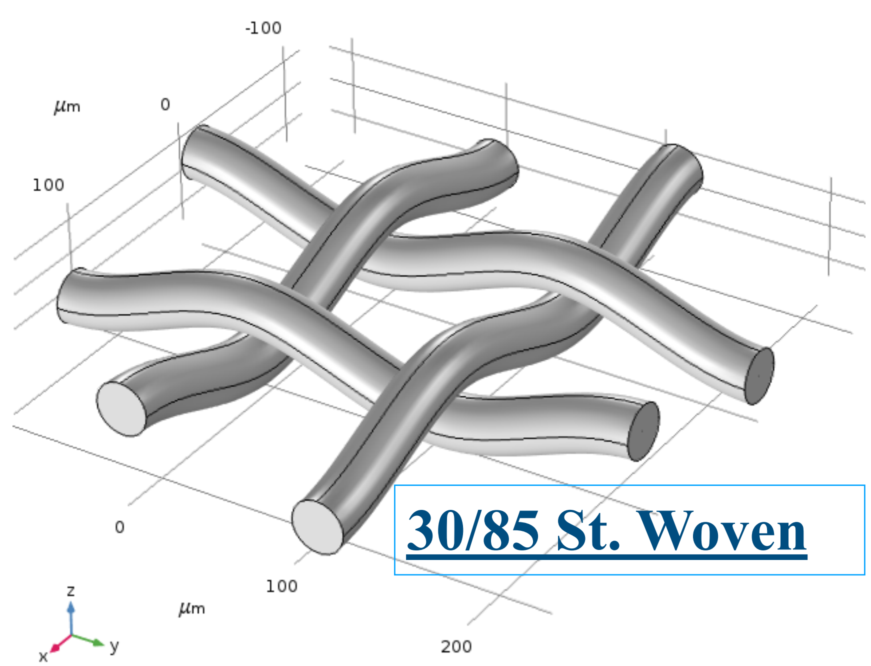
25/67 St. Woven



28/50 St. Woven



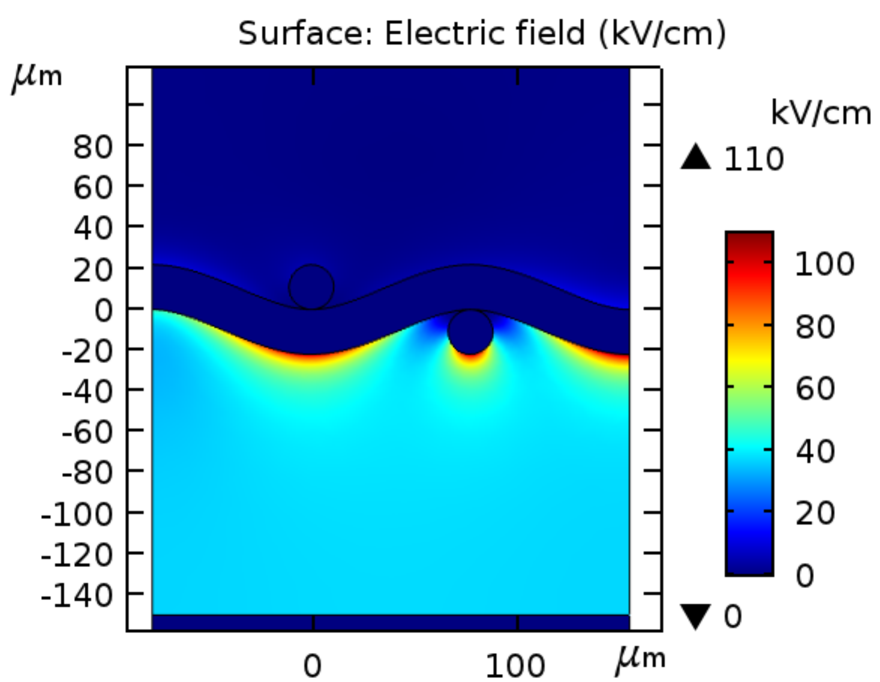
30/70 St. Woven



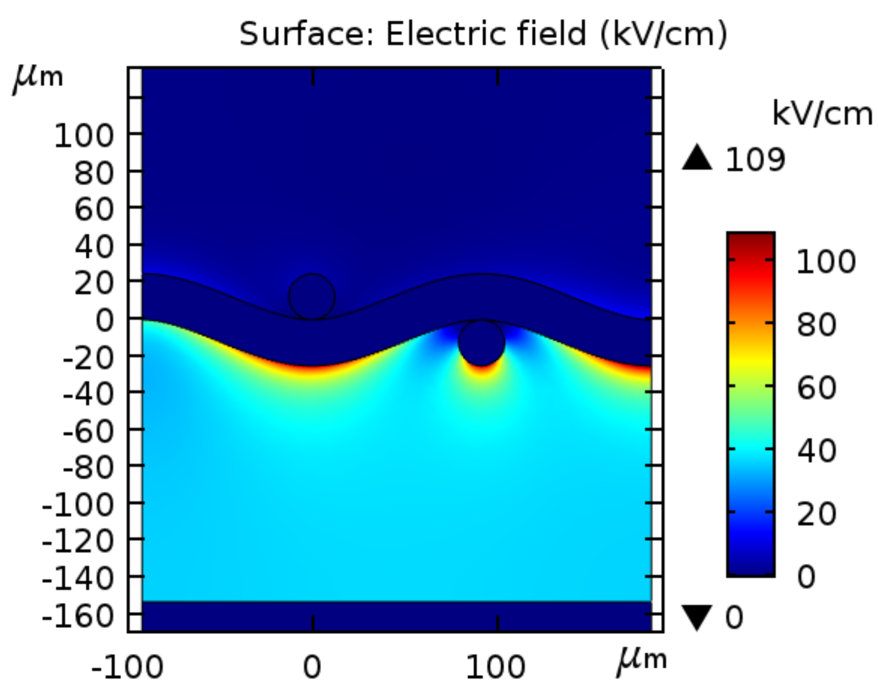
30/85 St. Woven

the drift gap, and the amplification gap remains the same

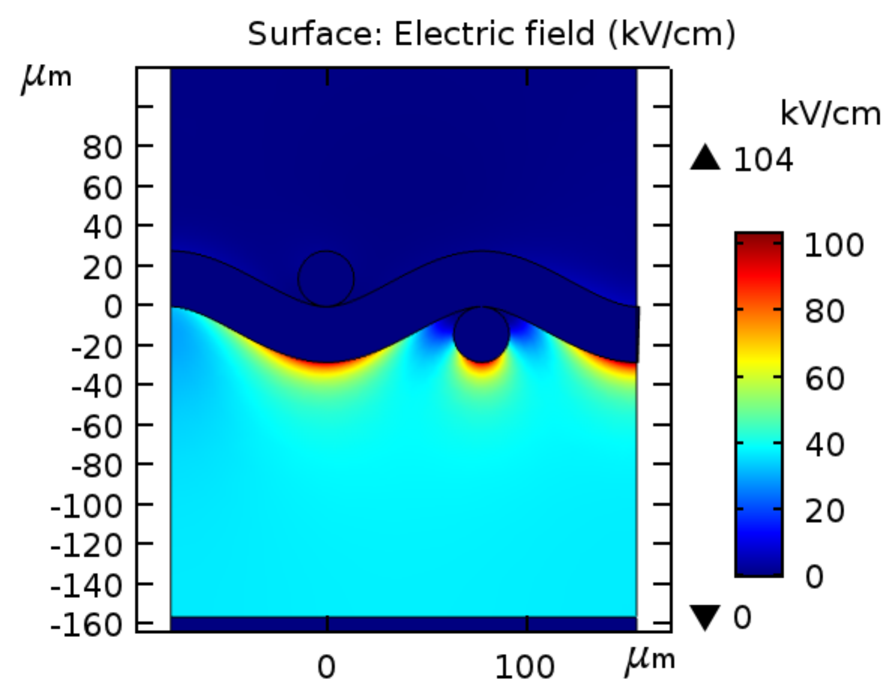
Standard woven: on the YZ plane, through a wire



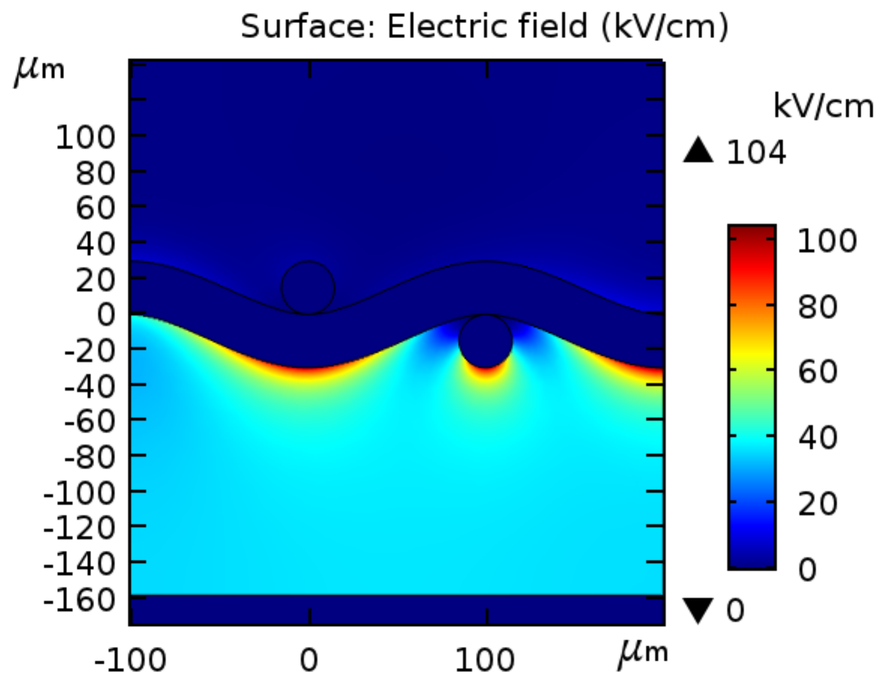
22/56 St. Woven



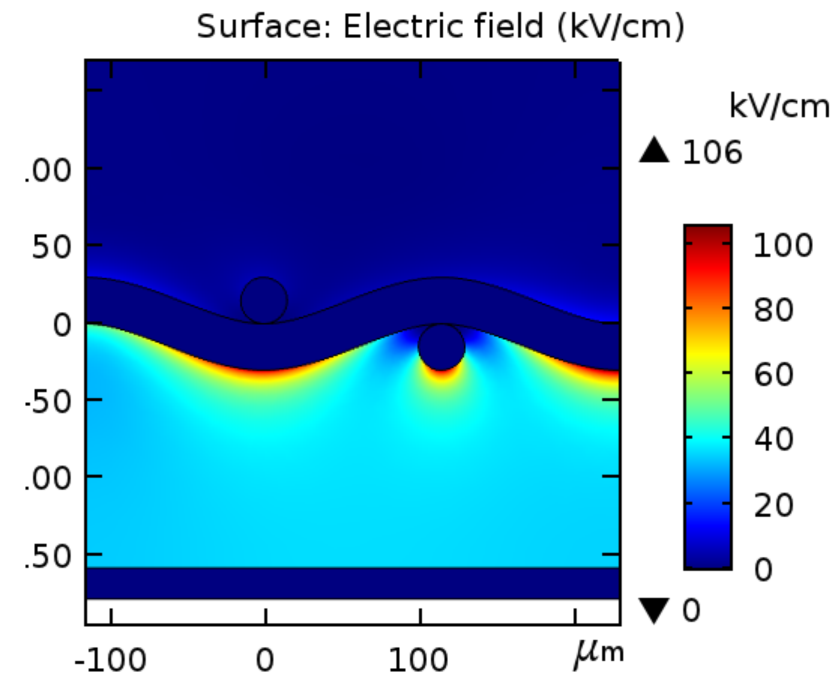
25/67 St. Woven



28/50 St. Woven



30/70 St. Woven

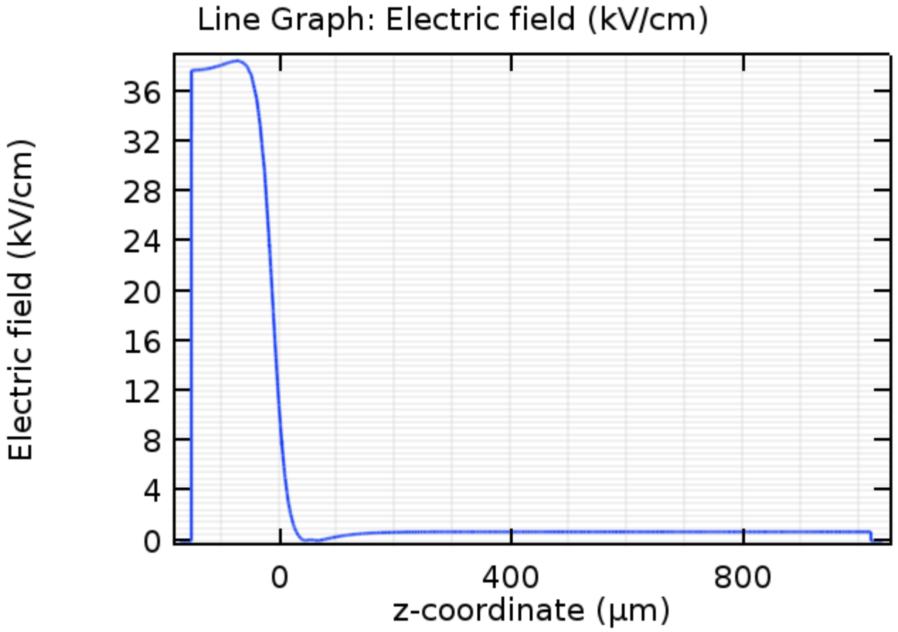


30/85 St. Woven

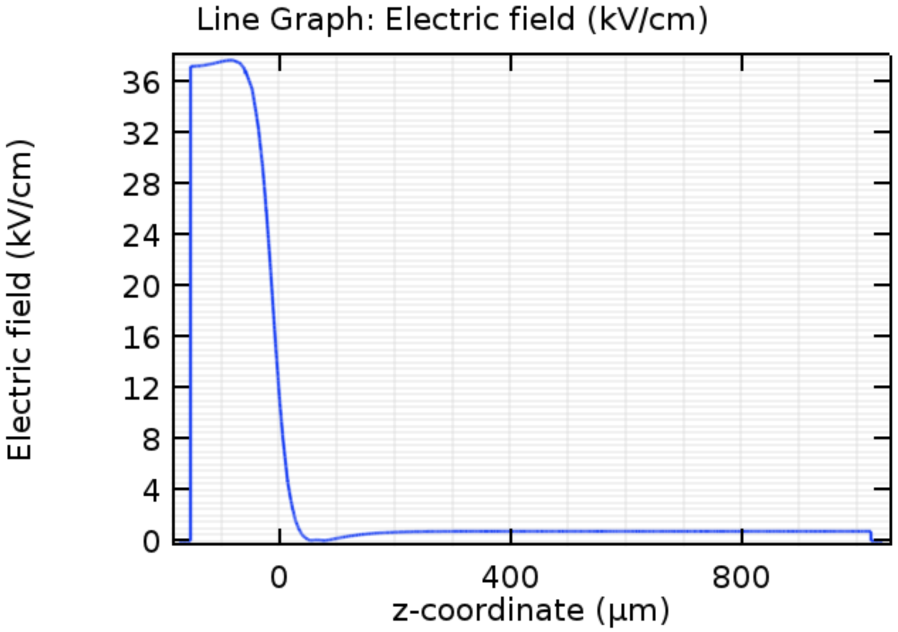
Maximum Fields (kV/cm):

- 18/45 => 112 kV/cm
- 22/56 => 110 kV/cm
- 25/67 => 109 kV/cm
- 28/50 => 104 kV/cm
- 30/70 => 104 kV/cm
- 30/85 => 106 kV/cm

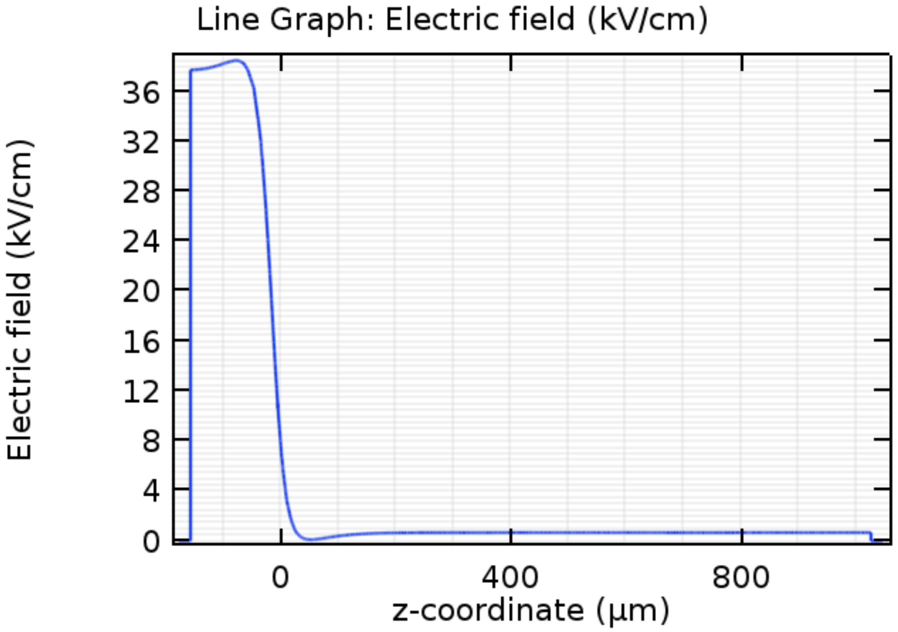
Standard woven: Along a line on the YZ plane, at X=Y= half pitch



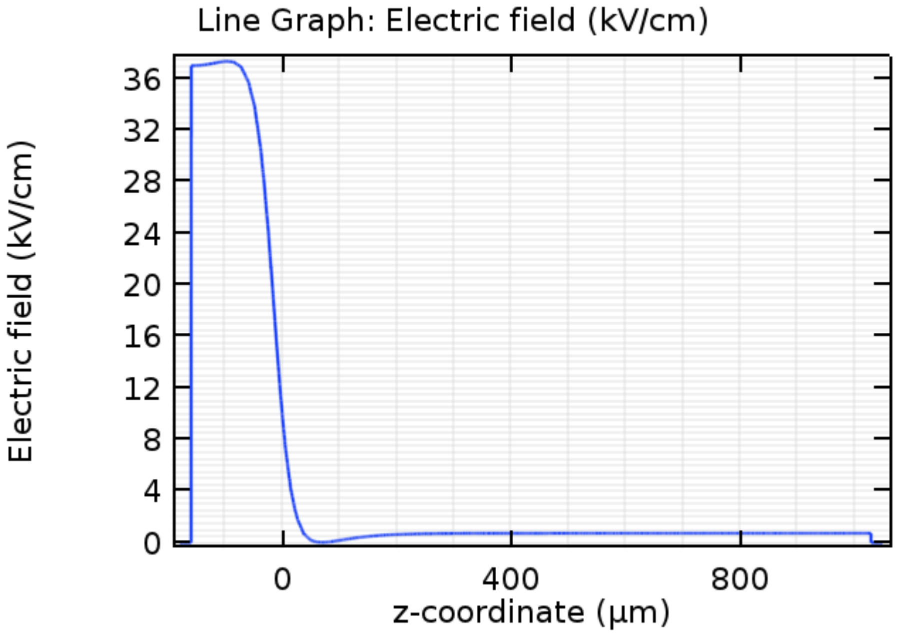
22/56 St. Woven



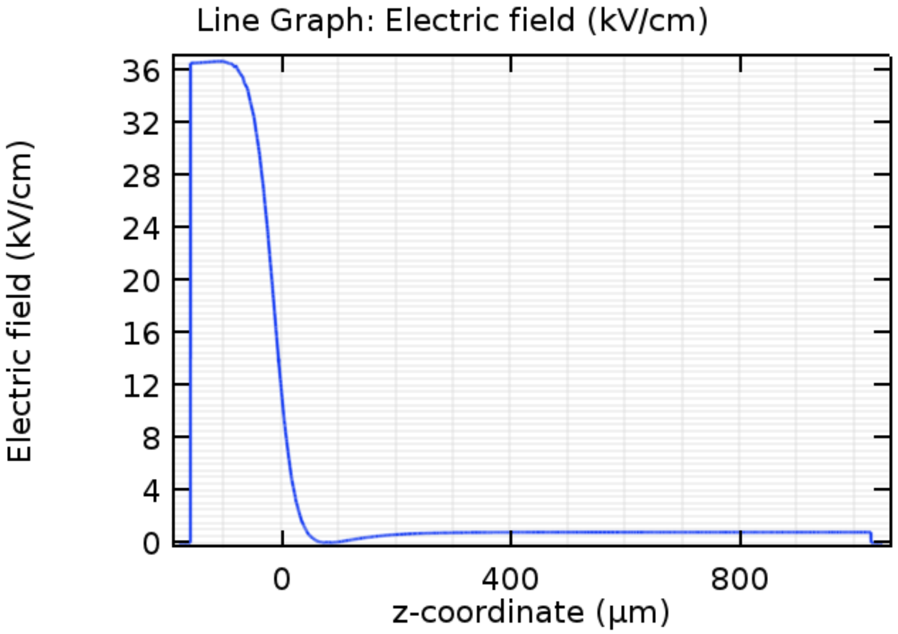
25/67 St. Woven



28/50 St. Woven



30/70 St. Woven

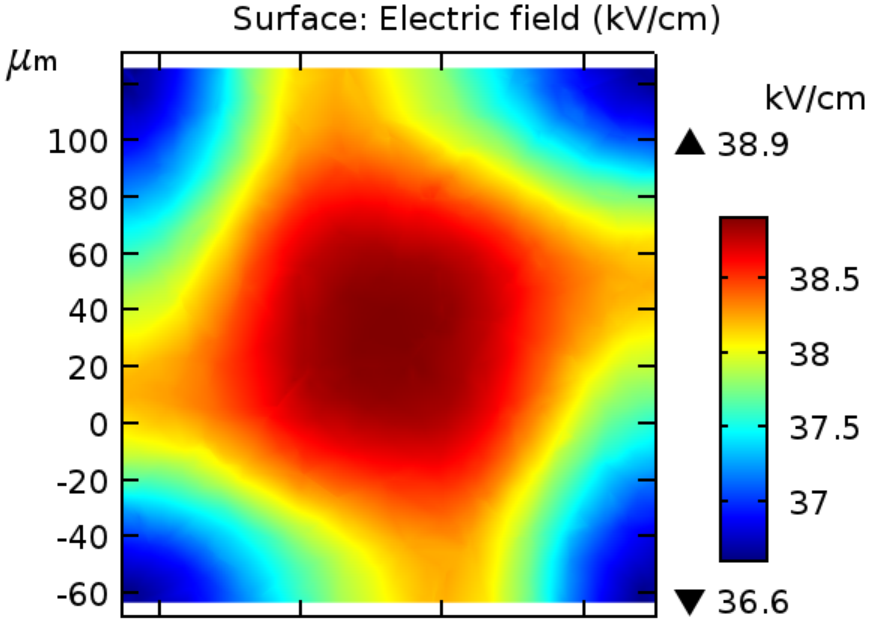


30/85 St. Woven

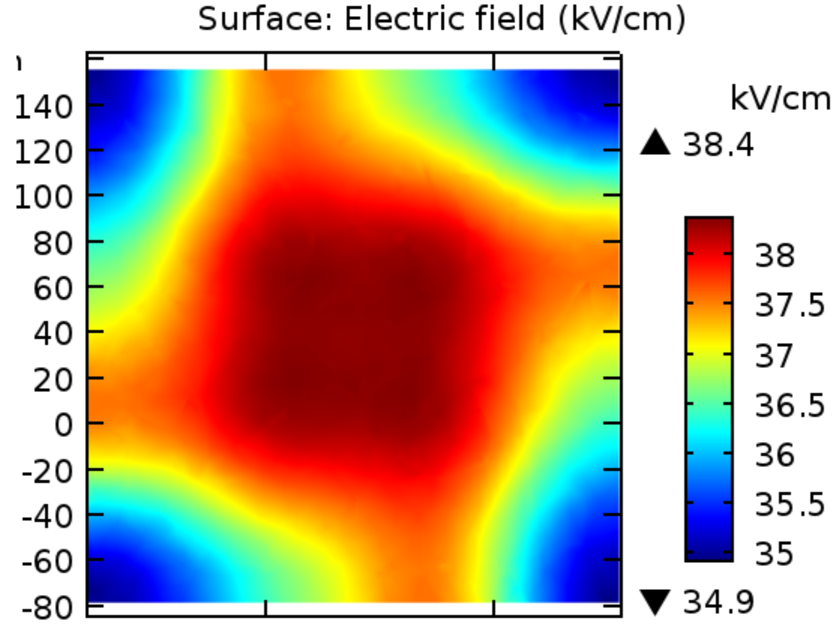
Average Fields (kV/cm):

- 18/45 => ~38.75
- 22/56 => ~38.00
- 25/67 => ~37.50
- 28/50 => ~38.25
- 30/70 => ~37.25
- 30/85 => ~36.50

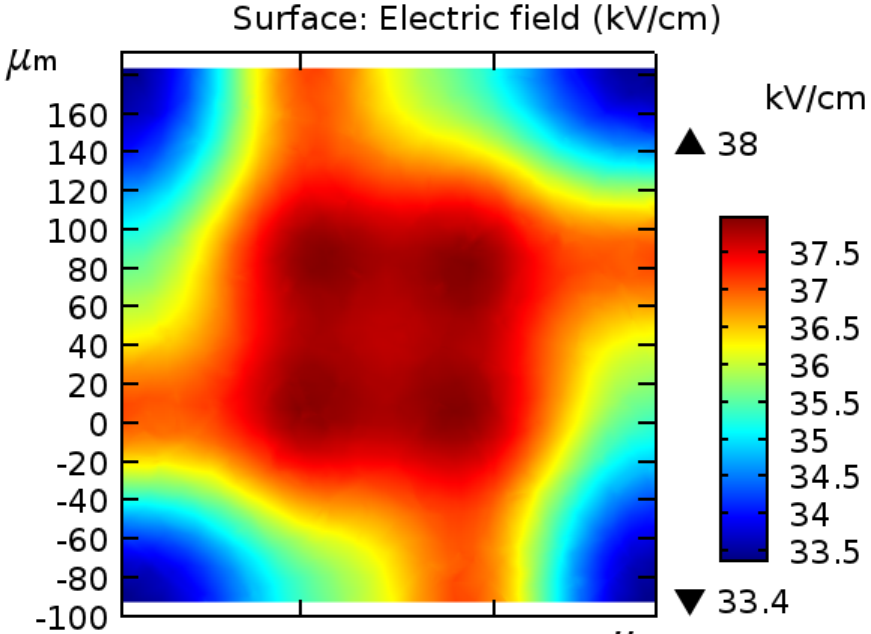
Standard Woven: The surface plot of field on XY plane at Z = 'half amplification gap'



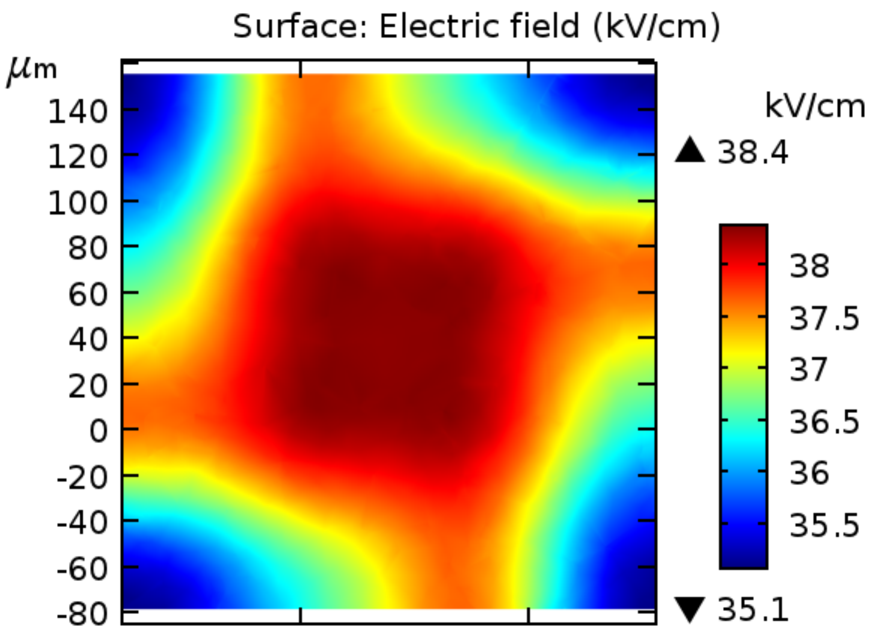
18/45 standard woven;
Ave = 38.0614 kV/cm



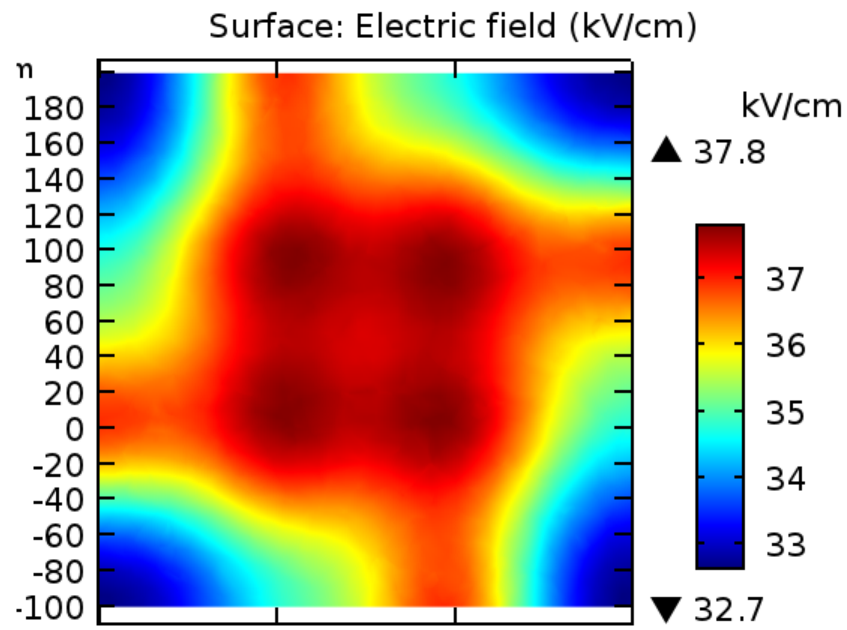
22/56 standard woven:
Ave =37.1996 kV/cm



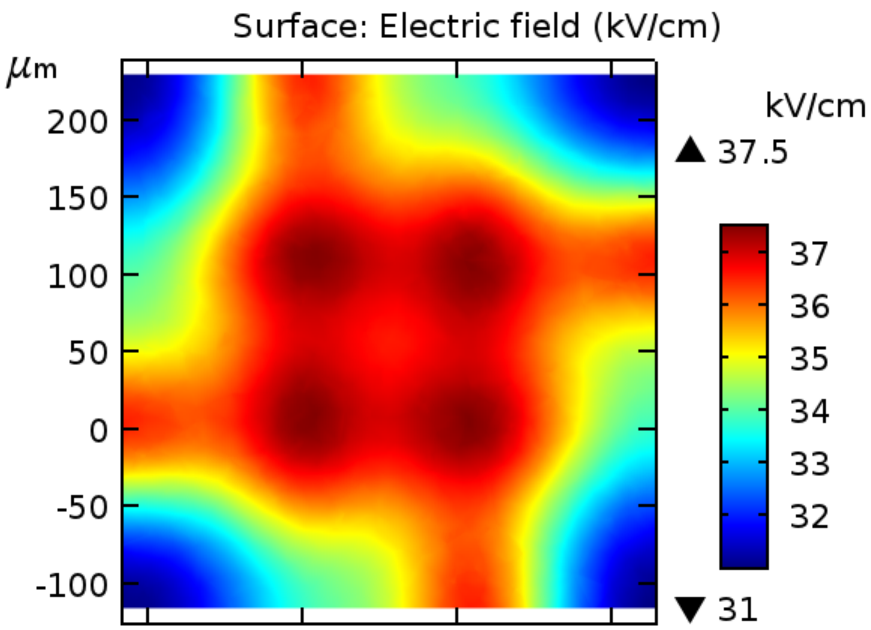
25/67 standard woven:
Ave=36.4289 kV/cm



28/50 standard woven:
Ave= 38.25 kV/cm



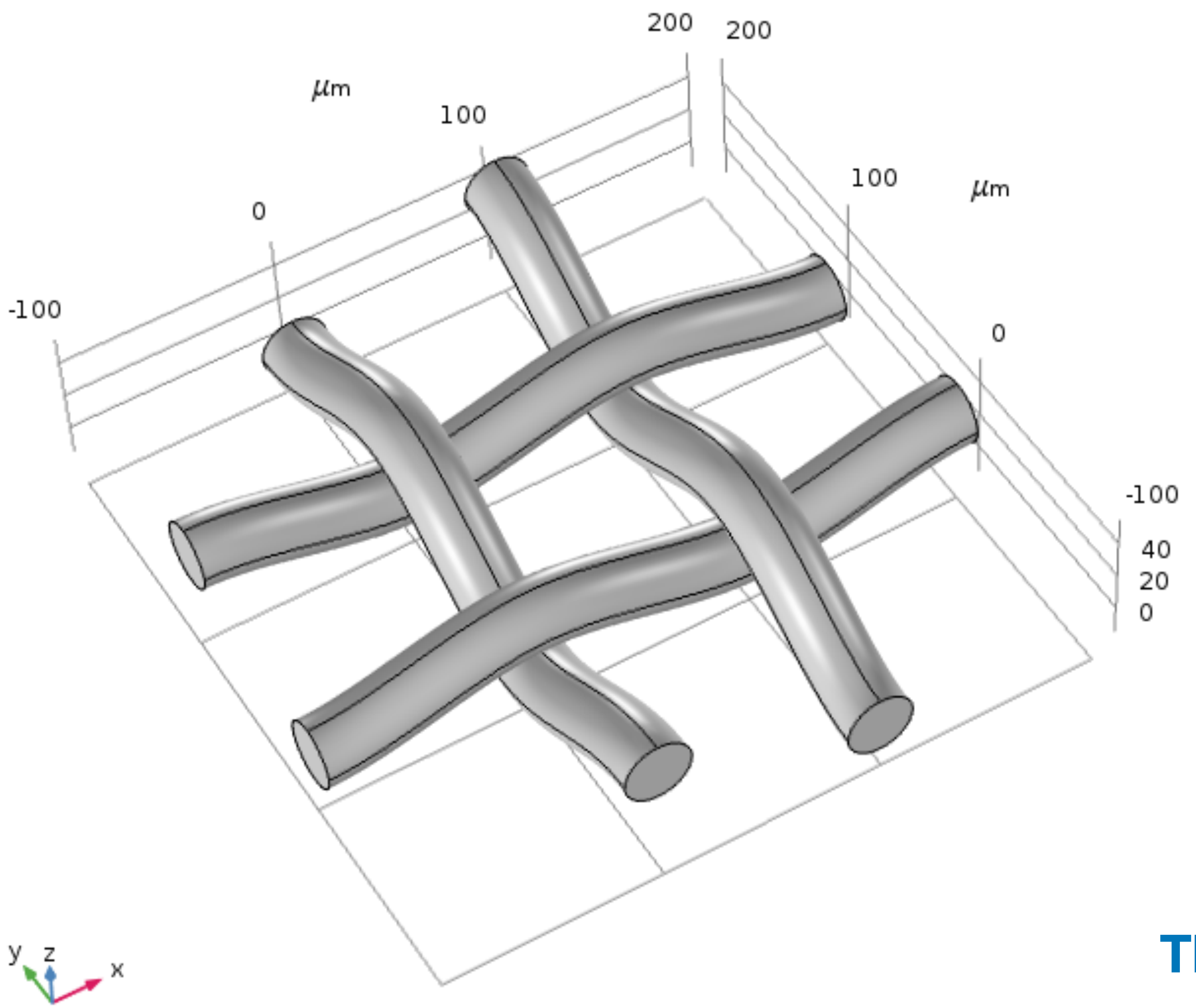
30/70 standard woven:
Ave=36.0197 kV/cm

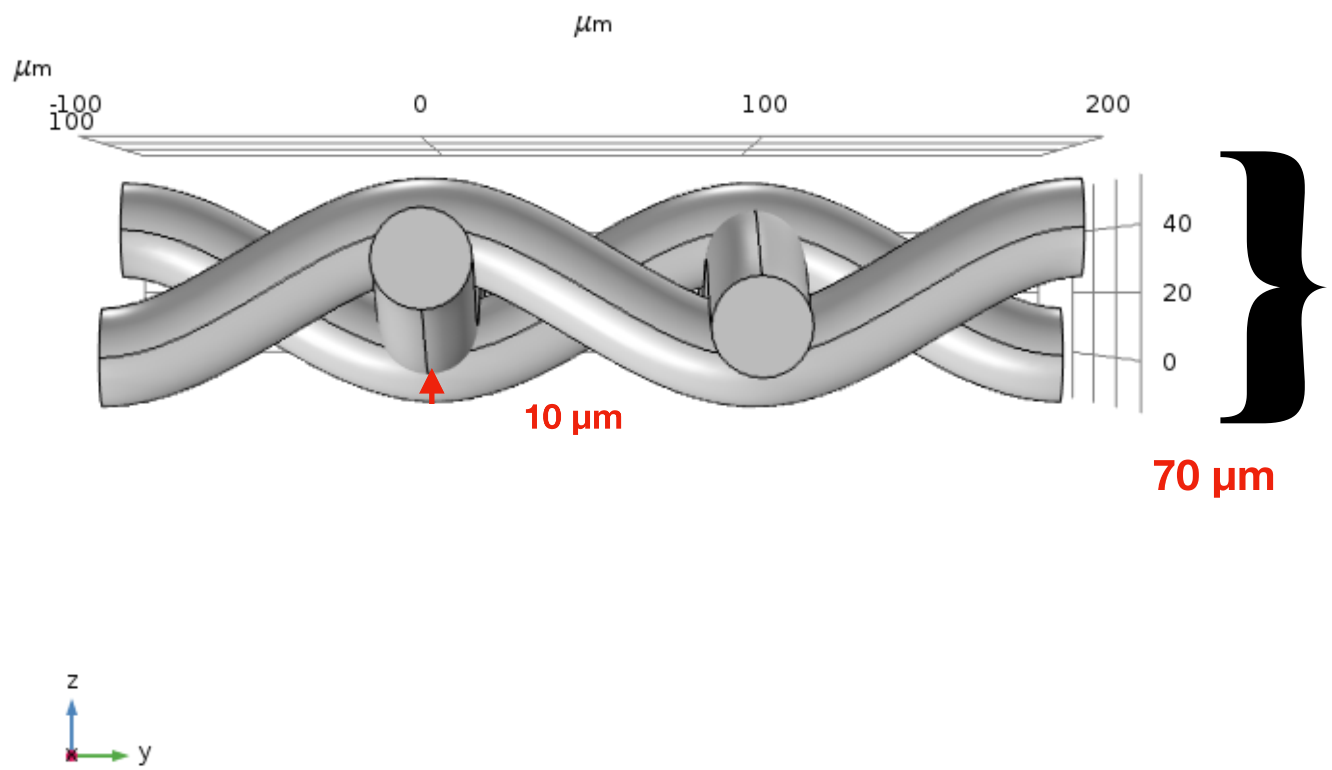


30/85 standard woven:
Ave= 35.2346 kV/cm

If the mesh weaving is not symmetric

30/70 special woven





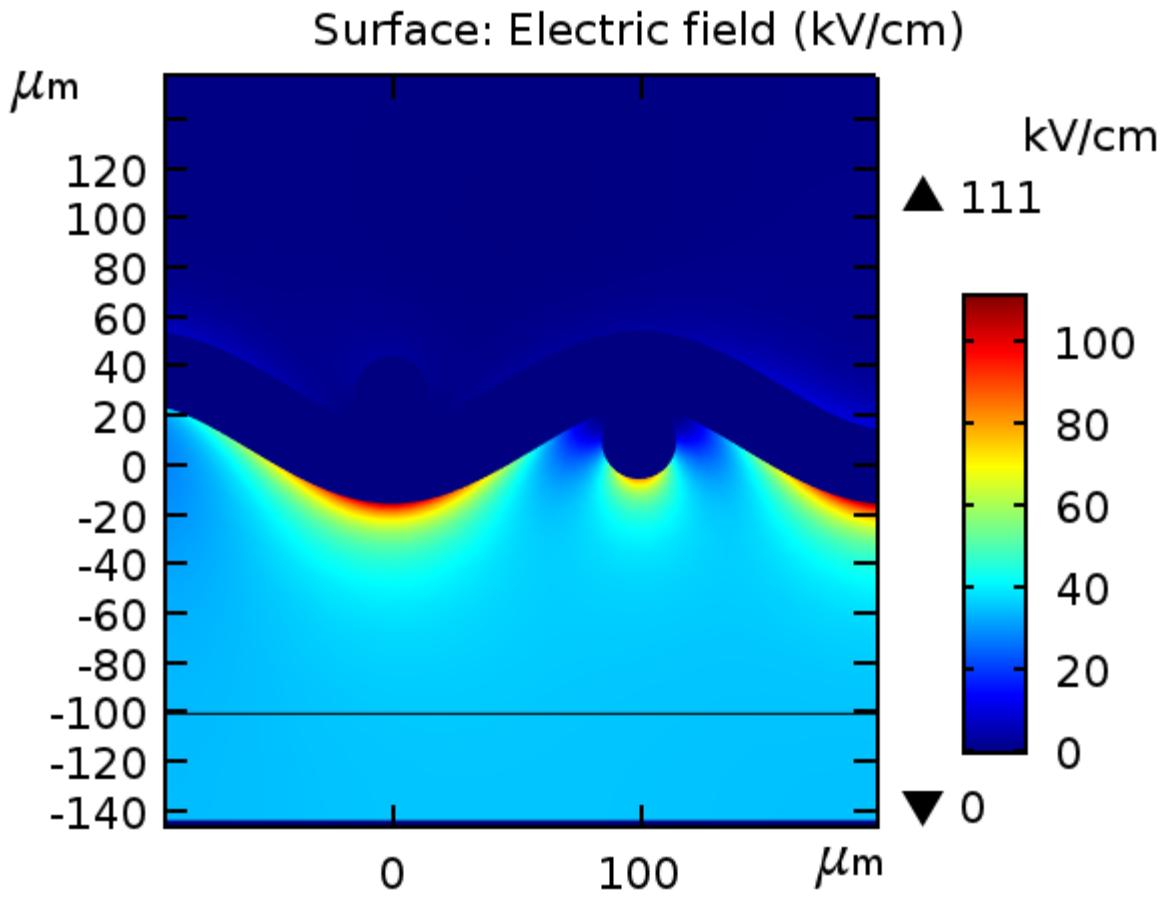
- Wire diameter 30 μm
- Edge to Edge 70 μm
- Axis to Axis 100 μm

The weaving amplitudes are different by 10 μm

rest of the geometry is same as the last one

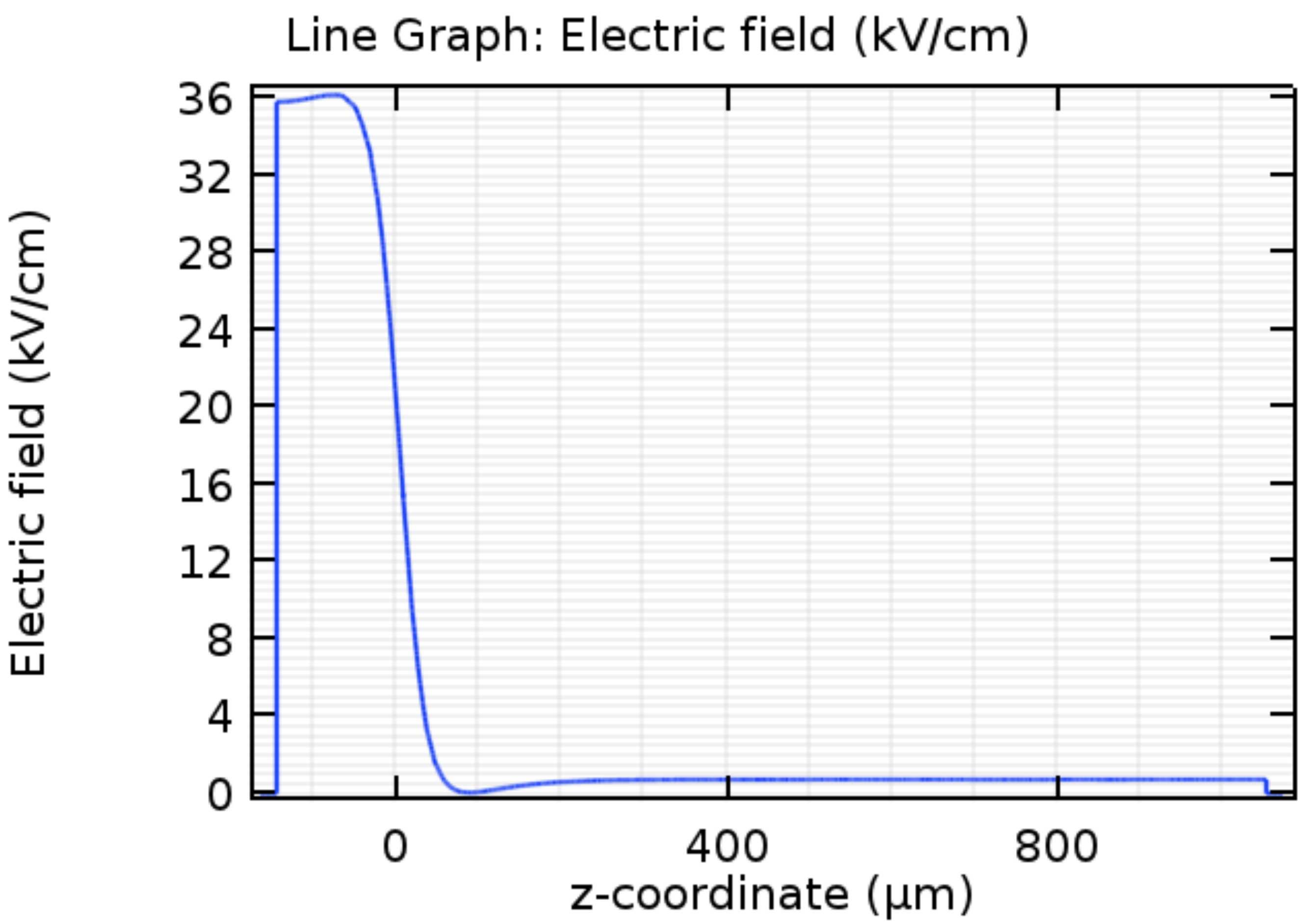
30/70 special woven

on the YZ plane, through a wire



The maximum field (111) is ~ 6.7 % higher than standard woven

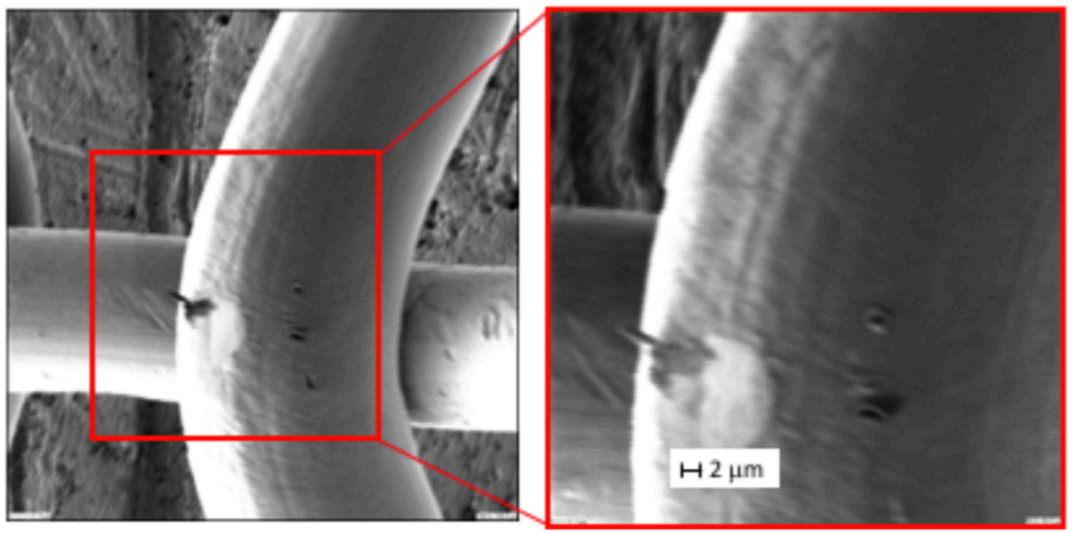
Along a line on the YZ plane, at X=Y= half pitch

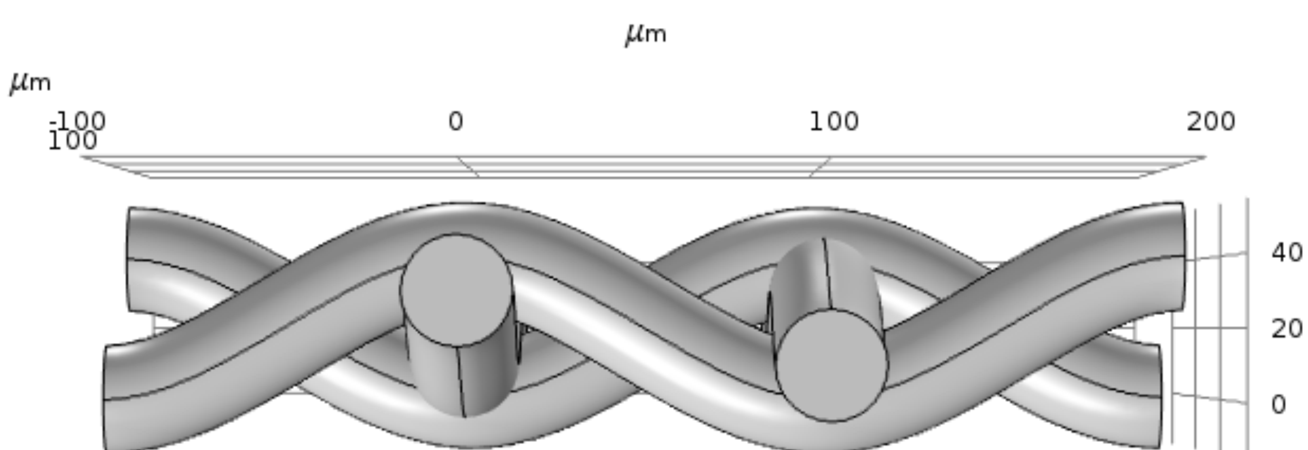


average field is ~36 kV/cm, as in standard

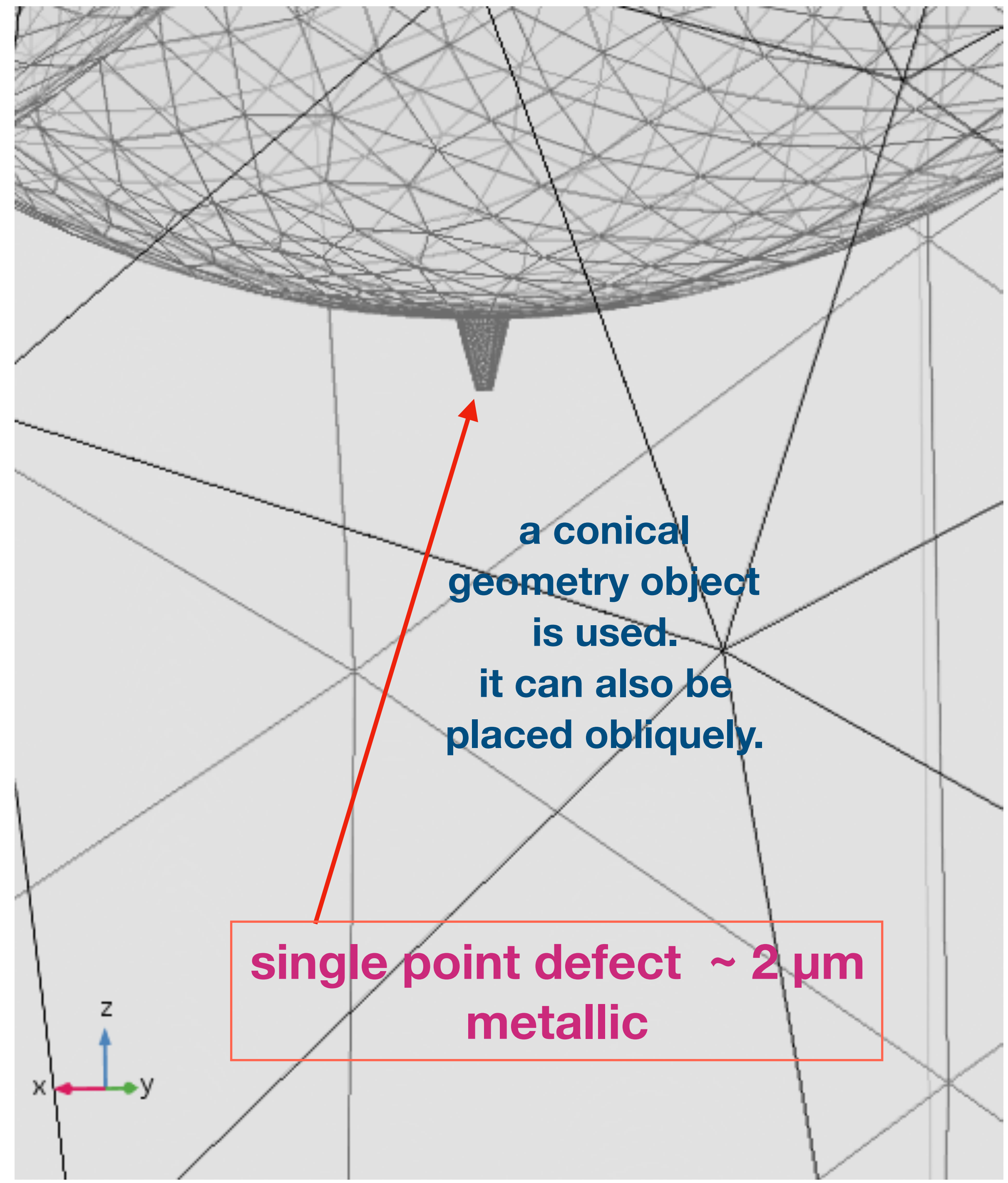
a special-CASE

The special Weaving, with a single point defect :

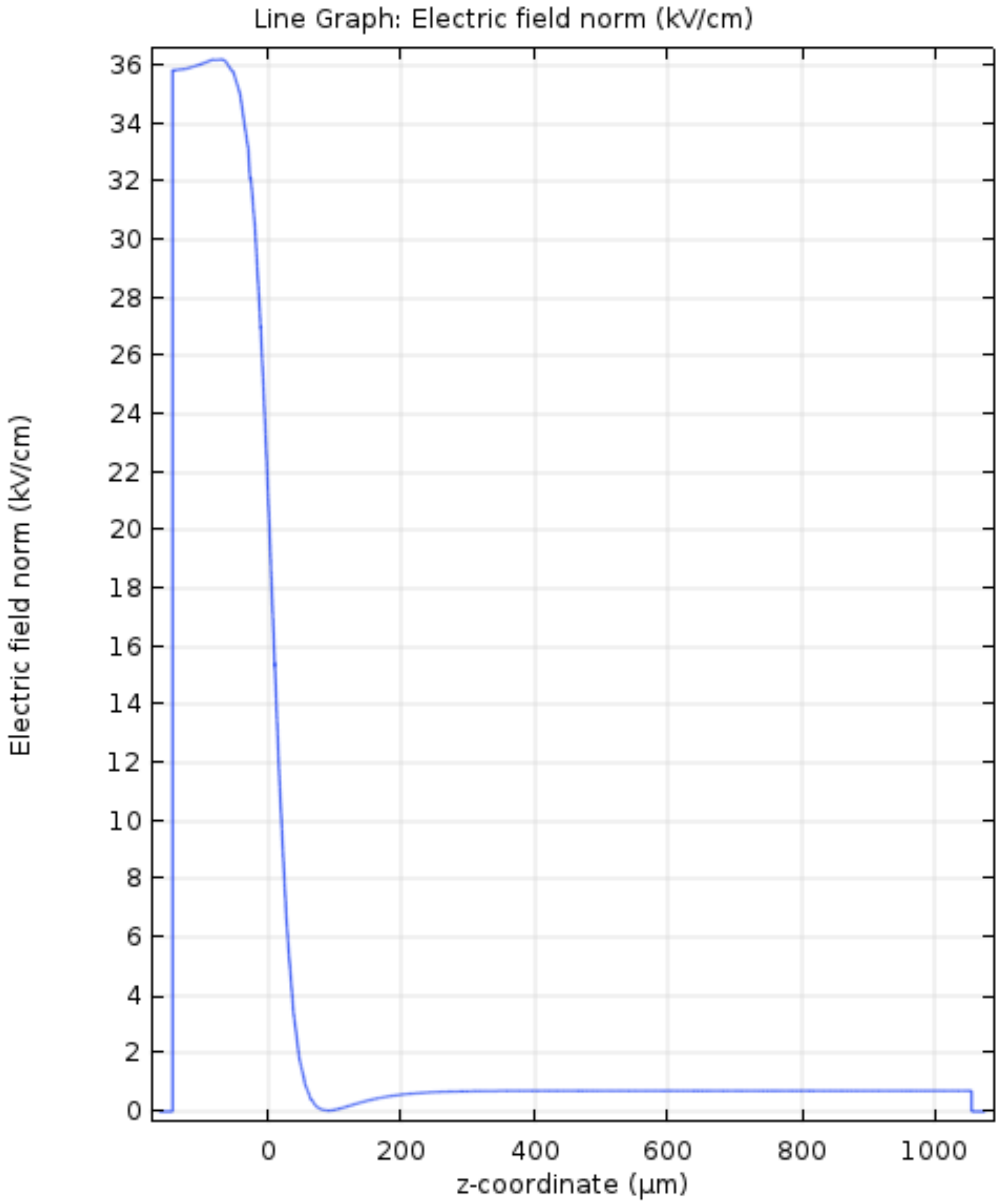




- Wire diameter 30 µm
- Edge to Edge 70 µm
- Axis to Axis 100 µm

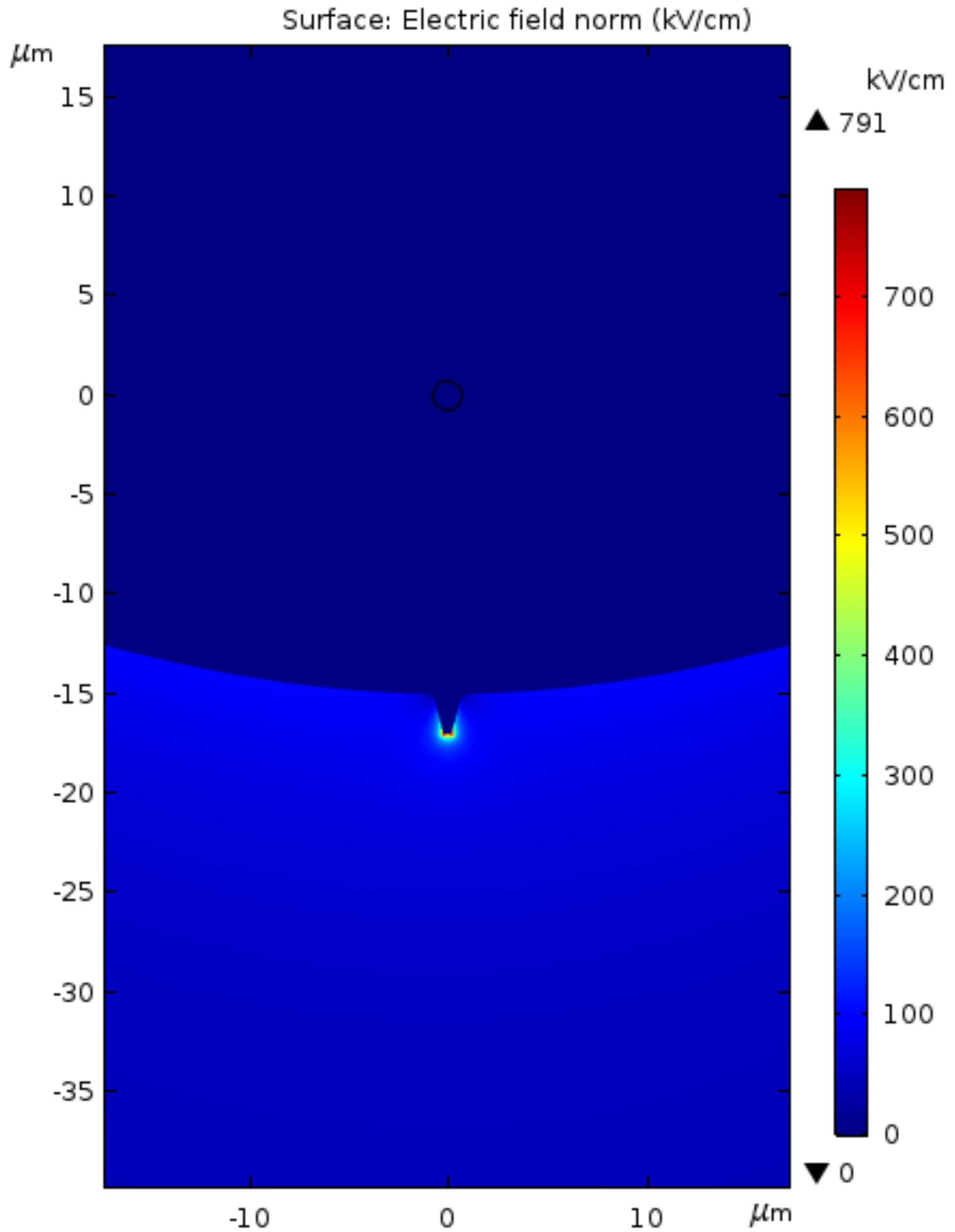


The field through the centre of the hole



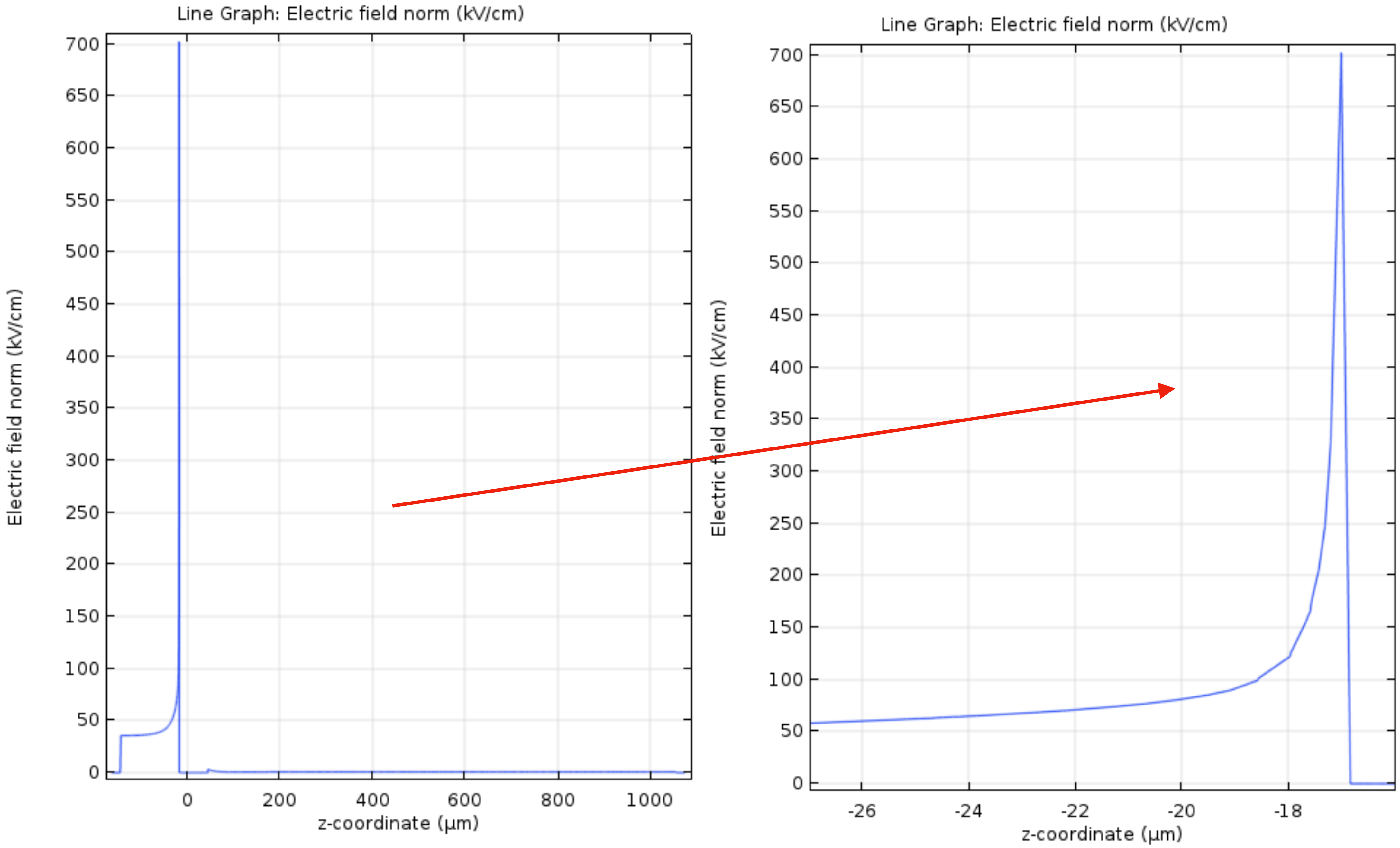
this remains as before

The field contour (on the YZ plane, at X=0)



A very high field is localised around the defect

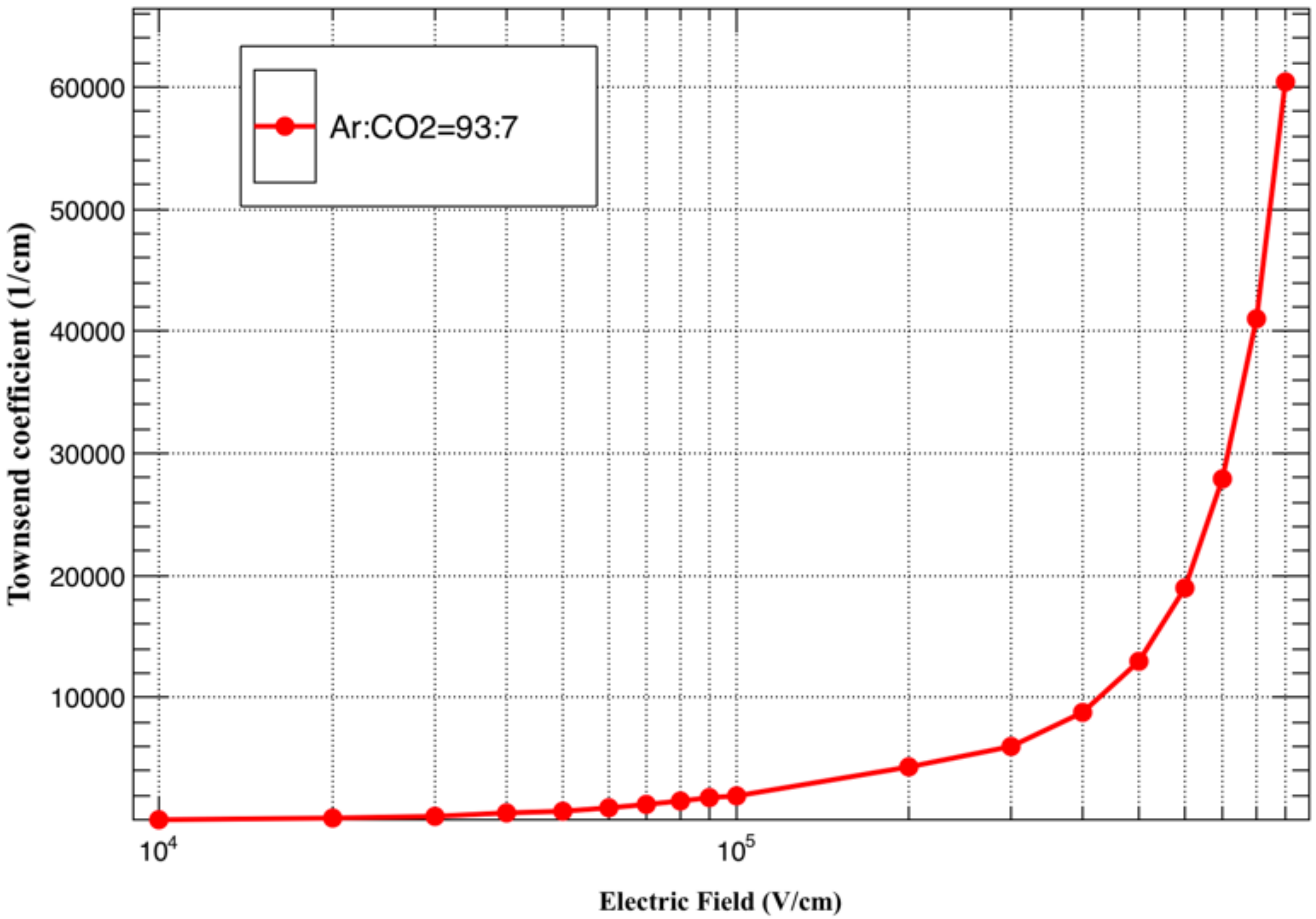
The change in field along a line, going through the defect (YZ plane, X=50)



the field is changing within a few µm

The effect is highly localised

a quick calculation in Magbolz



Field beyond 100 kV/cm is quite high

at 300 kV/cm, the inverse Townsend is almost 1 μm.

at 700 kV/cm, the inverse Townsend is ~0.35 μm.

Summary tables

Calendared Mesh

geometry (µm)	Maximum (kV/cm)	Average (kV/cm)	m.q.f. = (ave/max)%
18/45	89.20	~40.5 (max gain)	45.40
22/56	88.30	~40	45.30
25/67	88.50	40.00	45.19
*28/50	79.9 (min)	~40	50.06
30/70	84.2	~40	47.50
30/70 special	NA	NA	NA
30/85	88.00	39.50 (min gain)	44.88

Woven (standard) Mesh

geometry (µm)	Maximum (kV/cm)	Average (kV/cm)	m.q.f. = (ave/max)%
18/45	112	~38.75	34.59
22/56	110	~38	34.54
25/67	109	~37.5	34.40
28/50	104	~38.25	36.77
30/70	104	~37.25	35.81
*30/70 special woven	112	~ 36 (min gain)	32.14
30/85	106	~36.5	34.43

Discharge in different geometries

A simplistic approach to Streamer discharge

electron flow density

drift velocity

$$\frac{\partial n_e}{\partial t} + \nabla \cdot \left[n_e(\mu_e \cdot E) - D_e \cdot \nabla n_e \right] = R_e$$

electron diffusion

rate of electron creation

$$R_e = \sum x_j \alpha_j N_n |\Gamma_e|$$

$$\Gamma_e = \left[n_e(\mu_e \cdot E) - D_e \cdot \nabla n_e \right]$$

= electron flux

α_j = Townsend coefficient

x_j = mole fraction of the target species for reaction j

$\mathcal{N}_n$ = Total neutral number density

For heavy species :

$$\rho \frac{\partial w_k}{\partial t} + \rho(u \cdot \nabla) w_k = \nabla \cdot J_k + R_k$$

for Field :

$$-\nabla^2 V = \frac{\rho}{\epsilon_0 \epsilon_r}$$

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Different Species

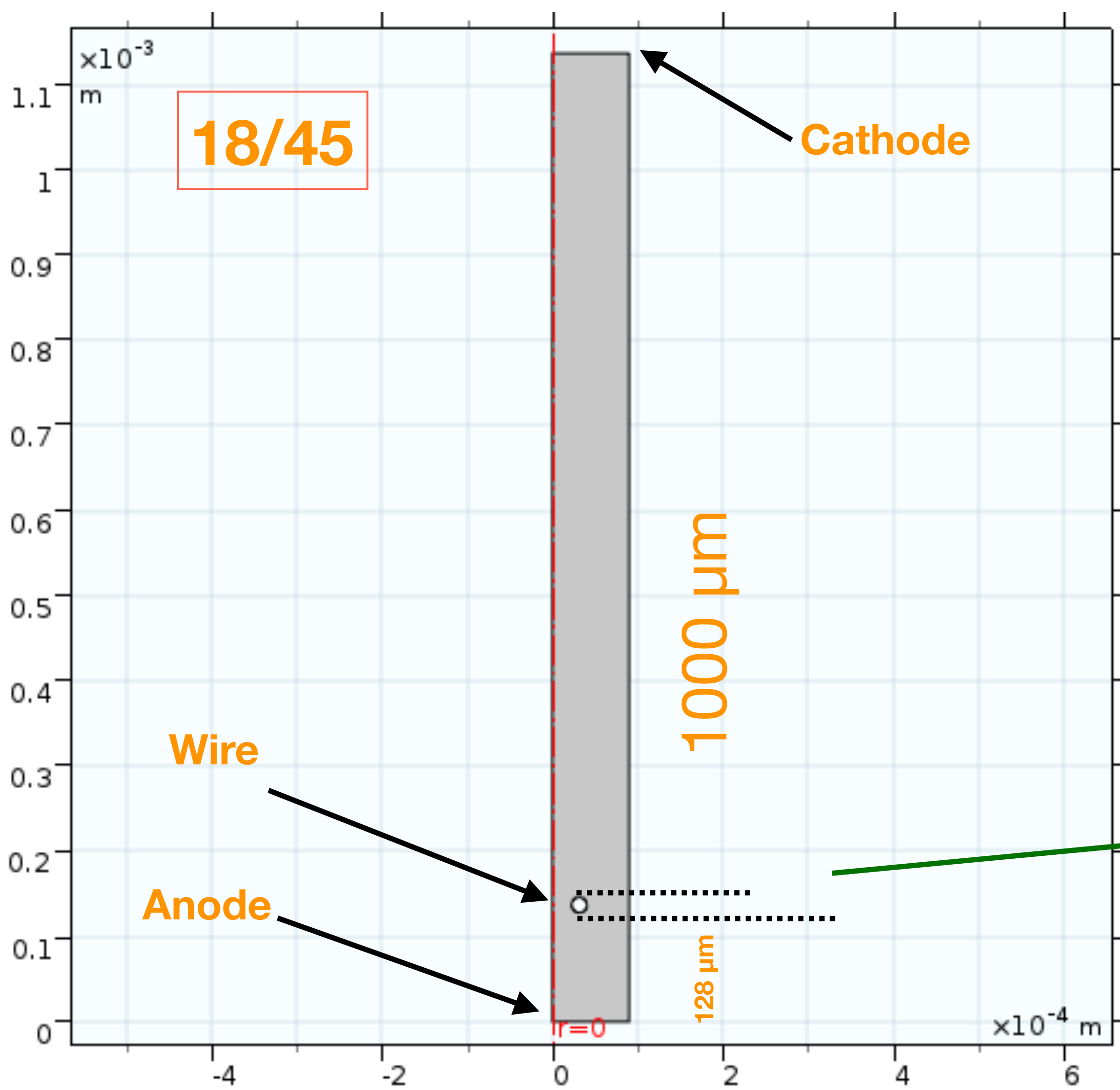
e- => electron
Ar => Neutral Argon
Ars => Metastable Argon
Ar+ => Singly Positive Argon Ion

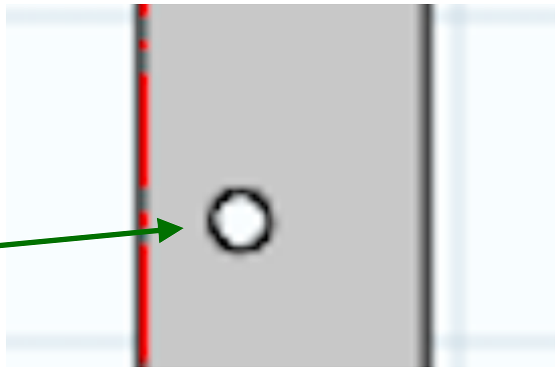
The reactions:

	Reactions	Types	energy (eV)
1	e+Ar => e+Ar	Elastic	0
2	e+Ar => e+Ars	Excitation	11.5
3	e+Ars => e+Ar	Superelastic	-11.5
4	e+Ar => 2e+Ar+	Ionization	15.8
5	e+Ars => 2e+Ar+	Ionization	4.25
6	Ars+Ars => e+Ar+Ar+	Penning Ionization	X
7	Ars+Ar => Ar+Ar	Metastable quenching	X

Before you ask …….. it is a simplified geometry !

the 2D axis symmetric Geometry

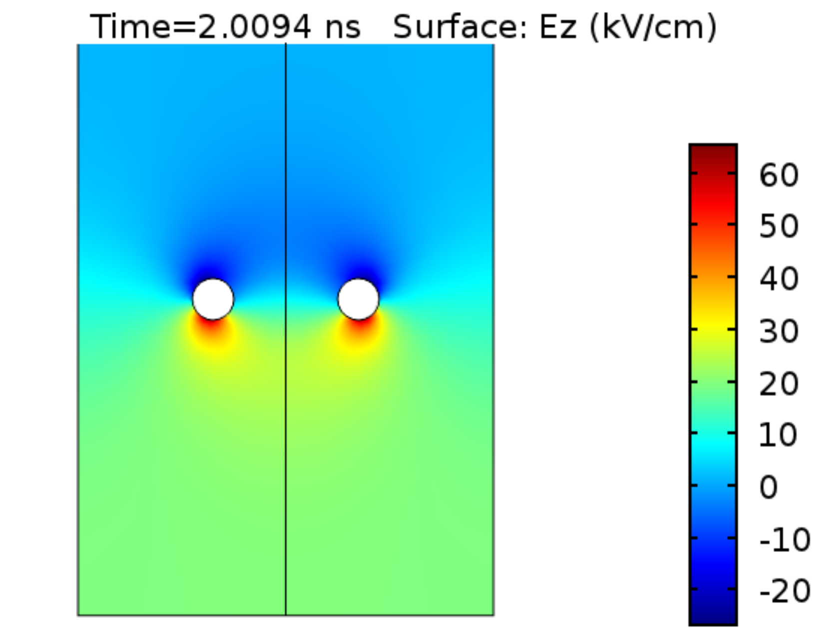


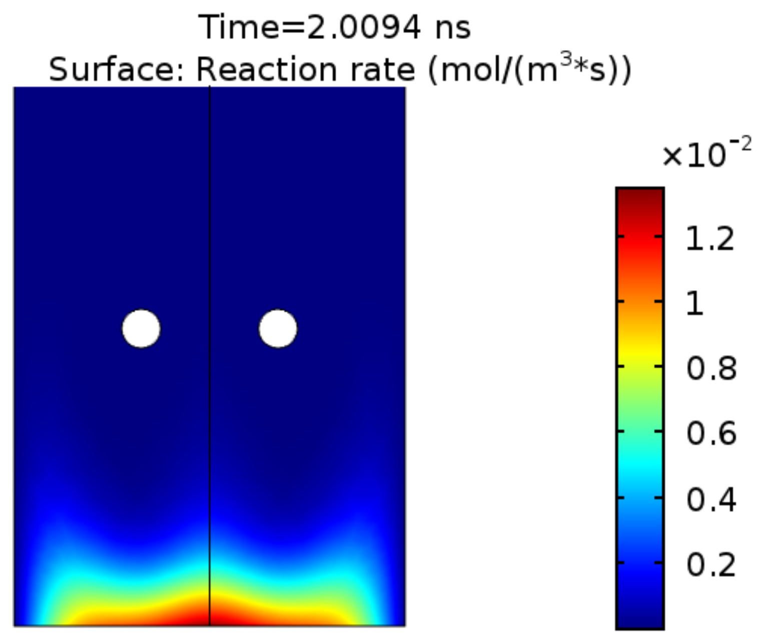


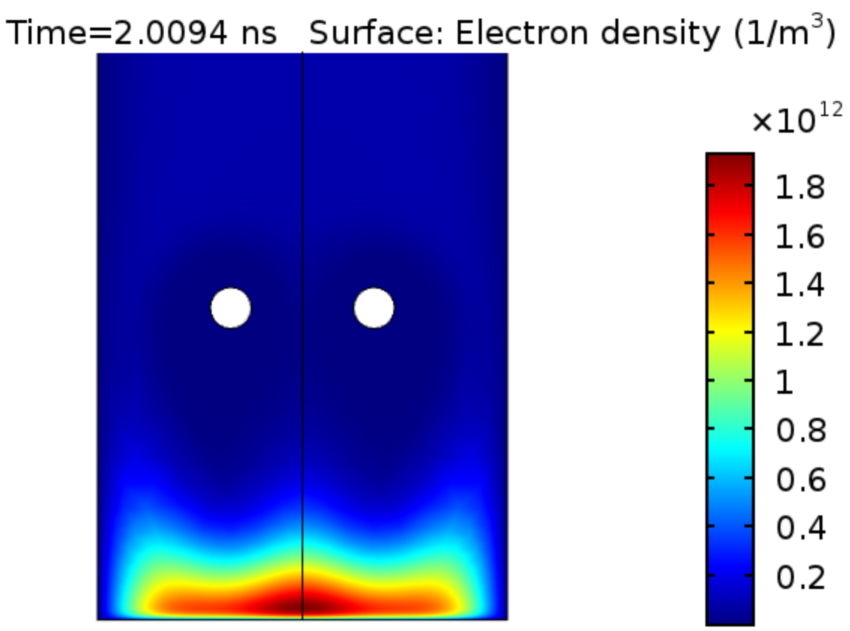
boundary (and other) conditions

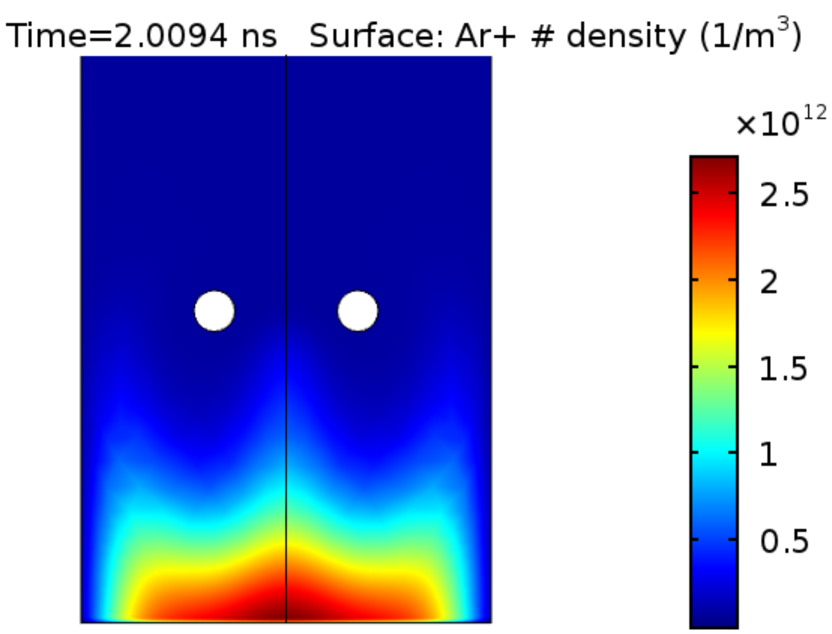
- Cathode => - 410 V
- Mesh => - 350 V
- Anode => ground potential
- Gas = pure Argon
- secondary emission occurs when 'Ar+' reaches Mesh/ Cathode
- Ar* de-excites on the walls
- initial electron present= ~2.
- pressure = 1 atm.

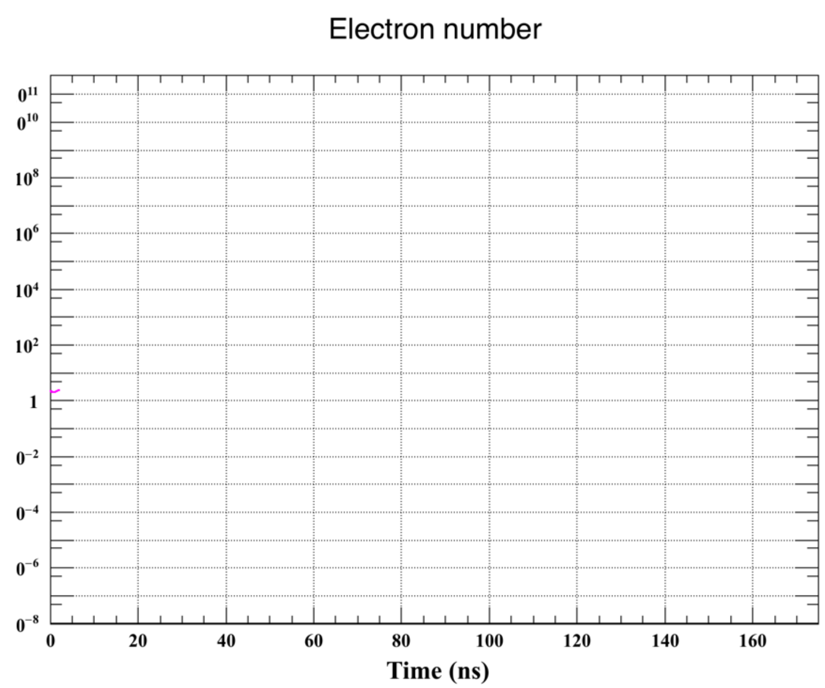
discharge in 18/45 geometry

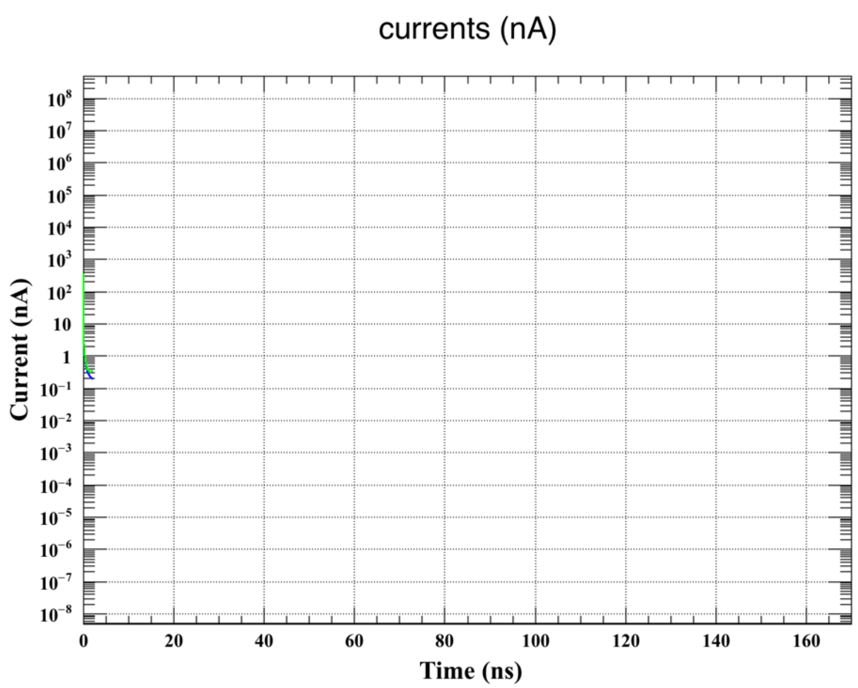




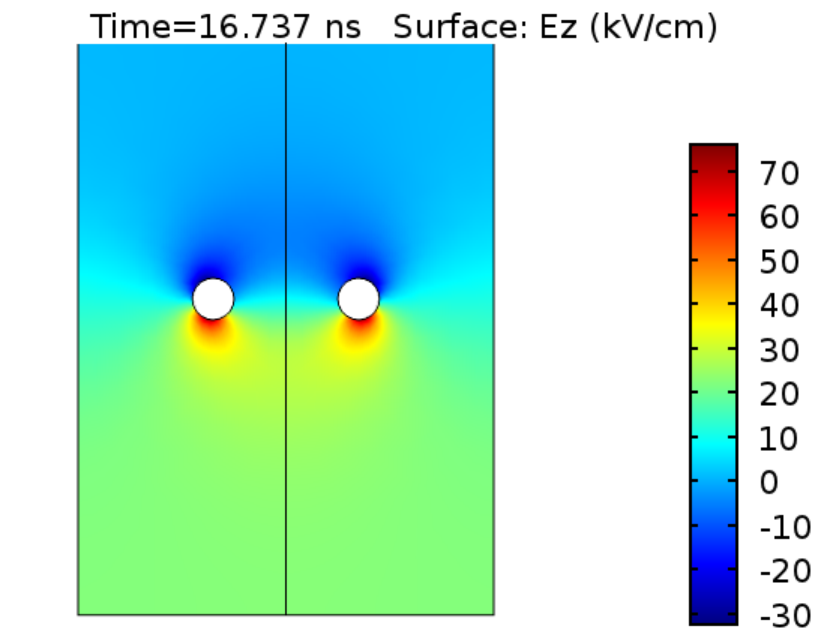


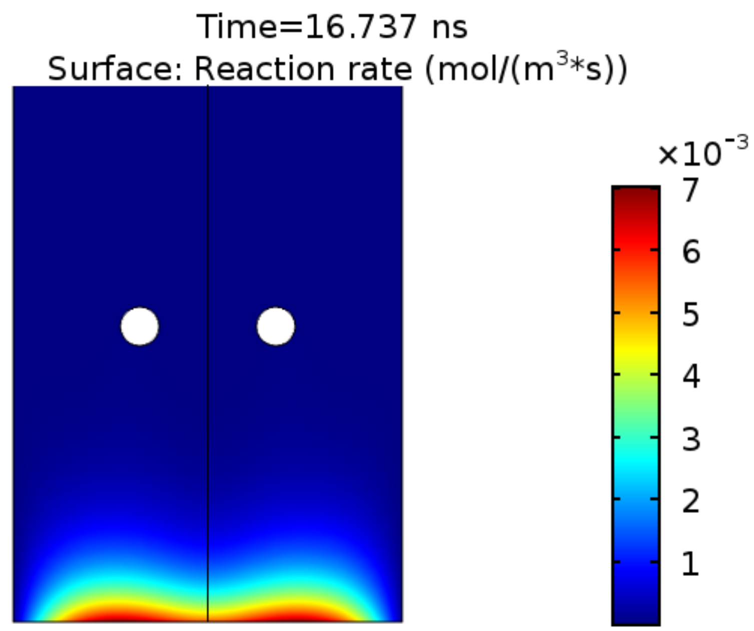


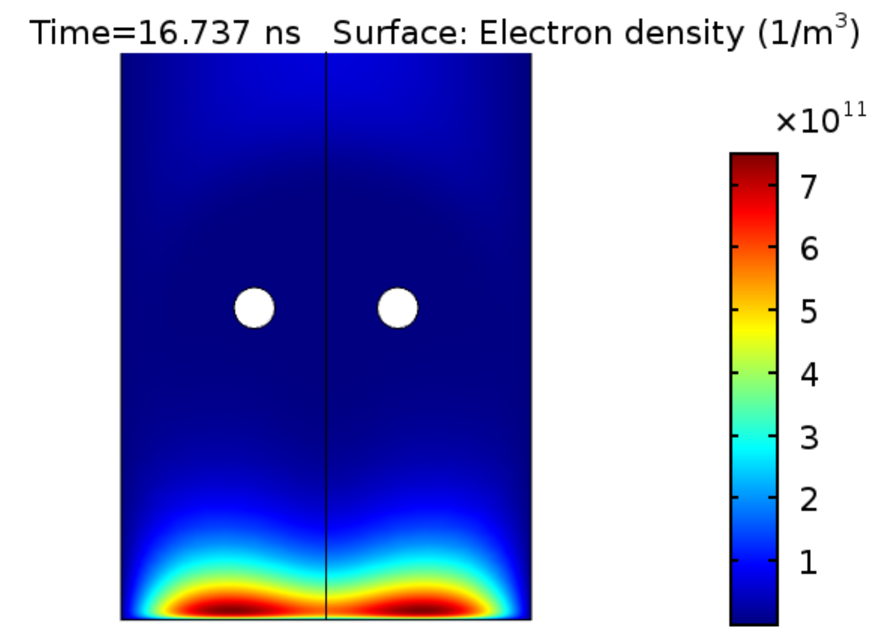


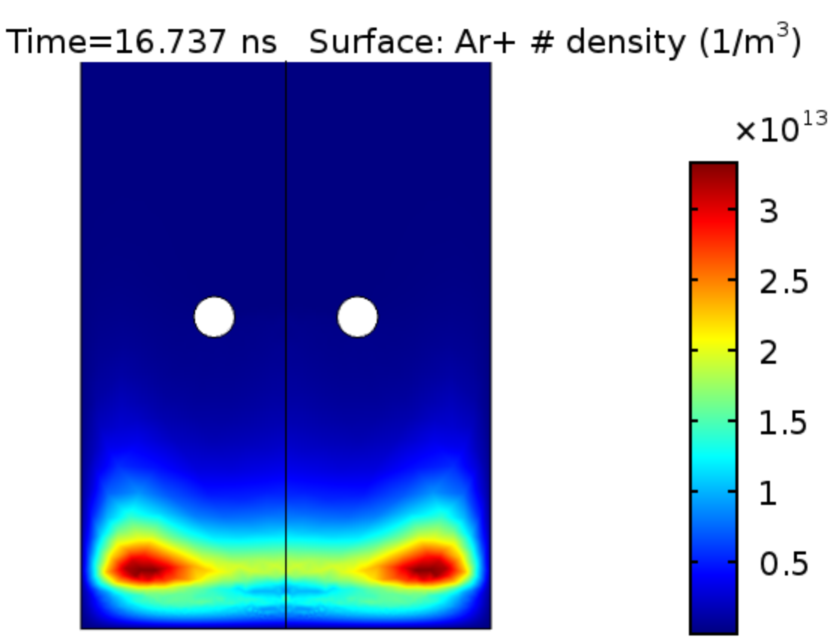


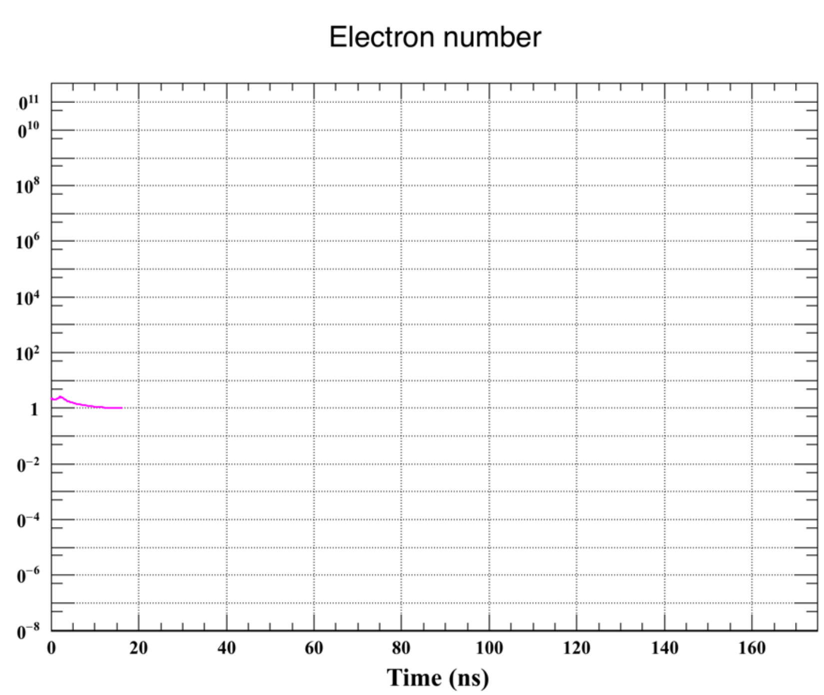
discharge in 18/45 geometry

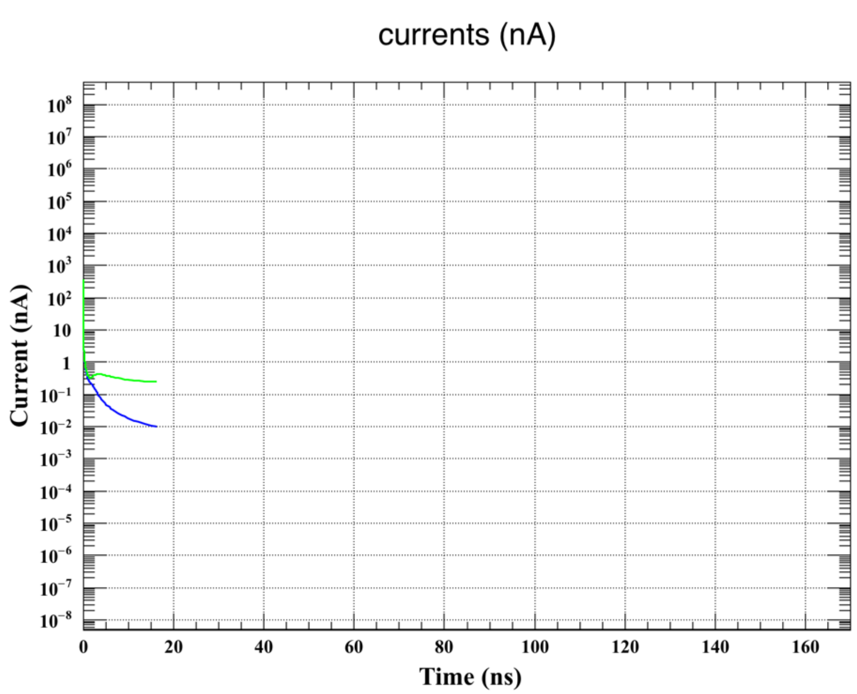












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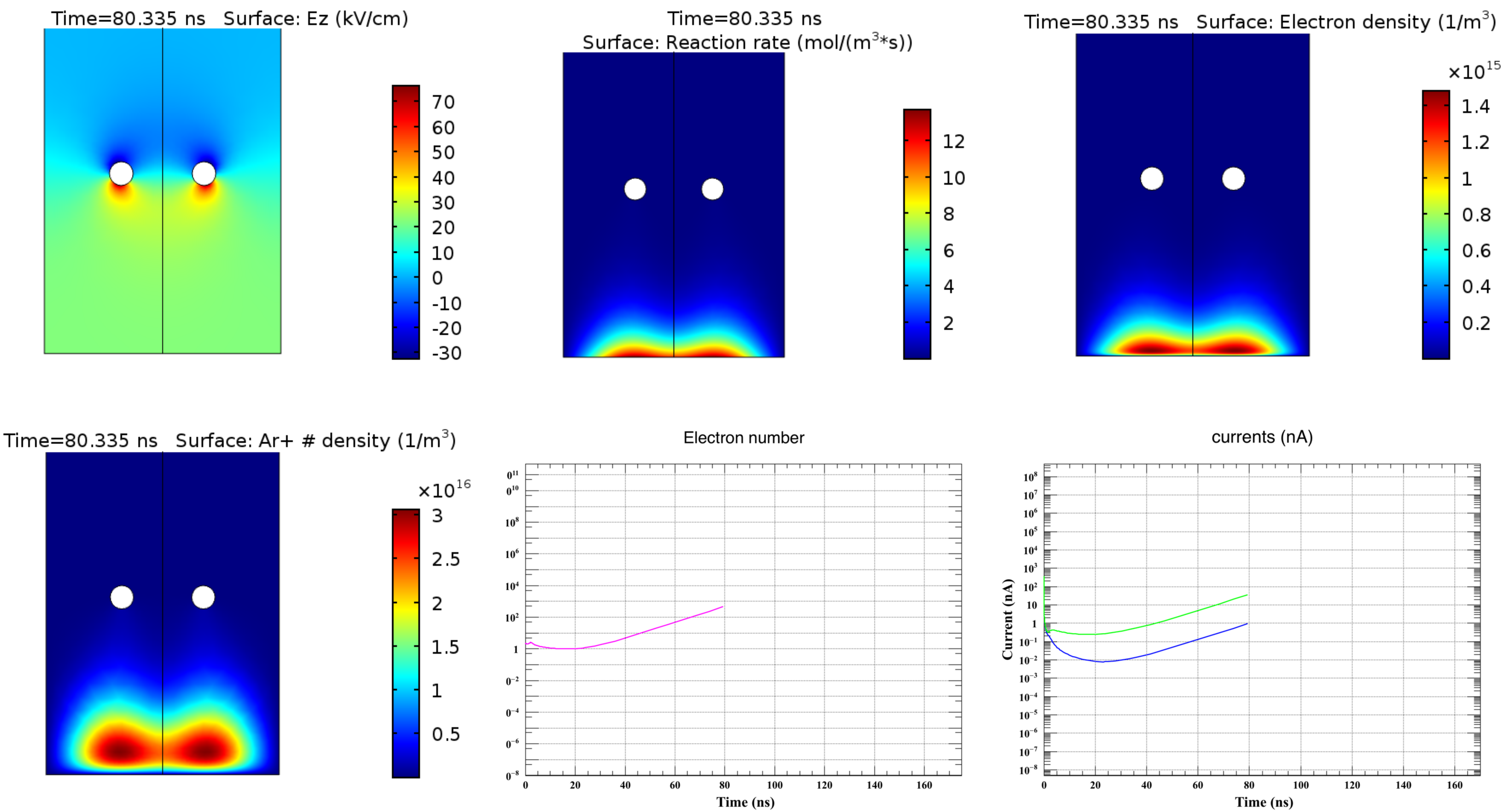
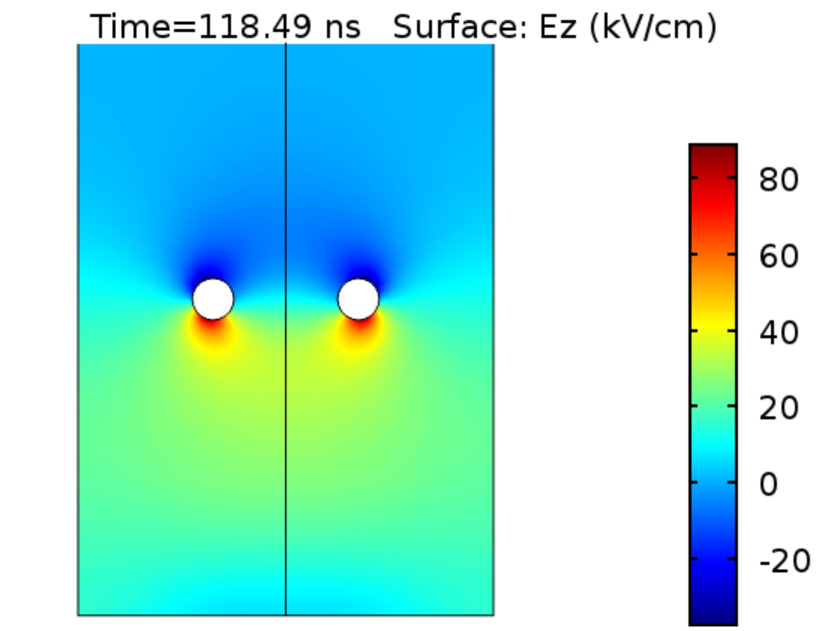
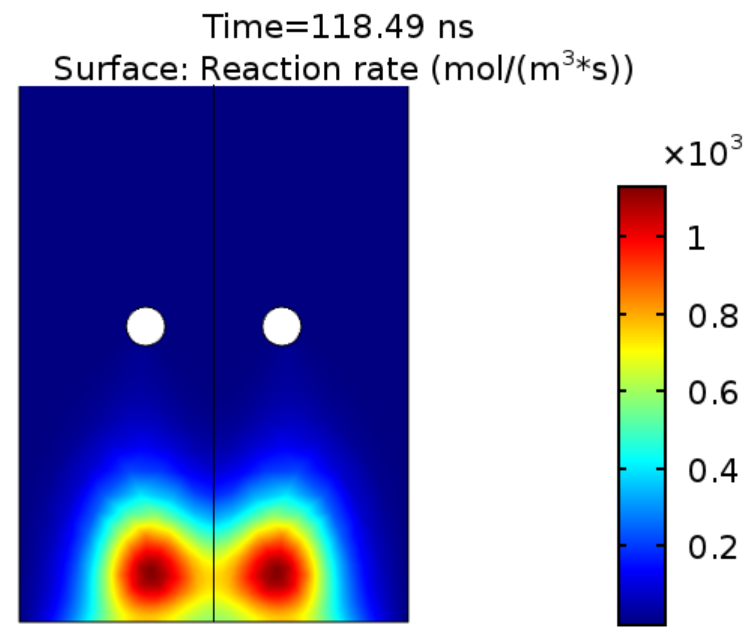
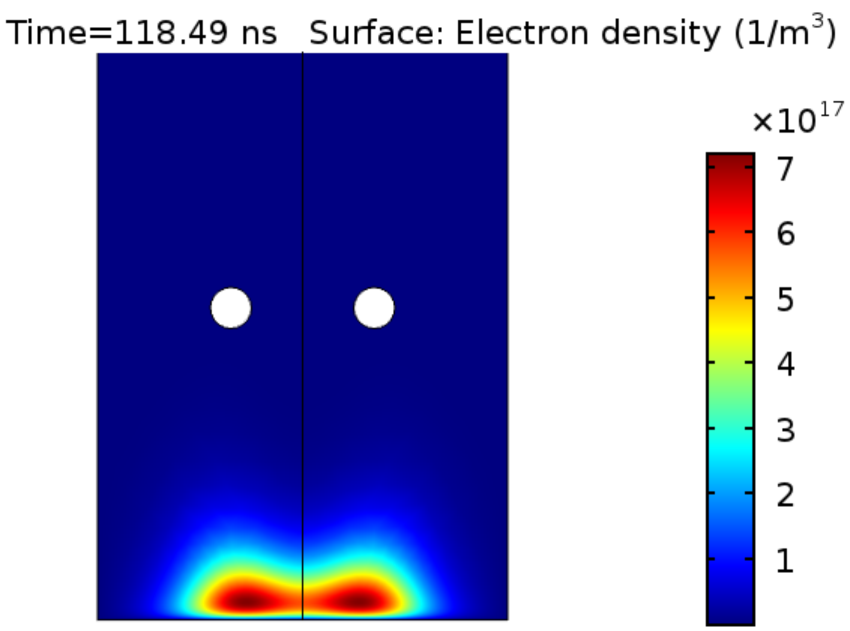
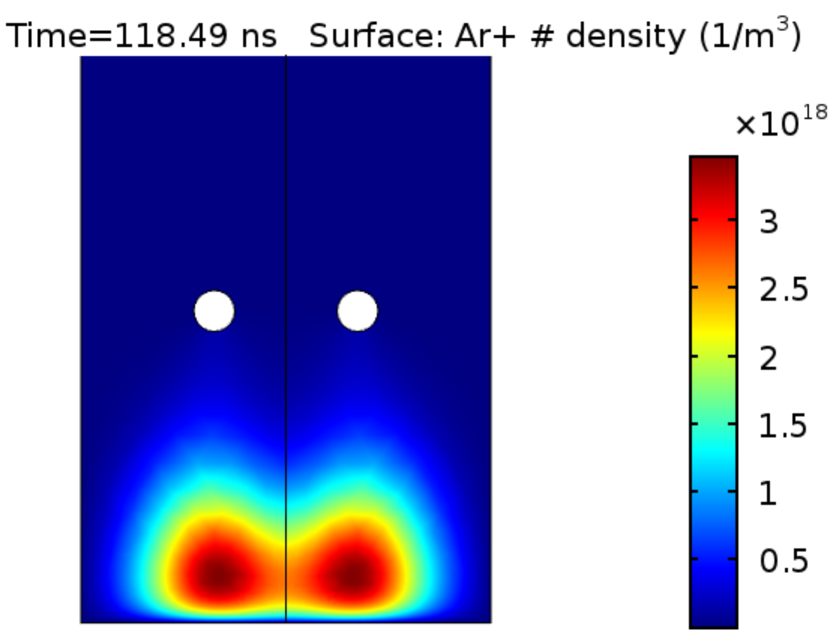


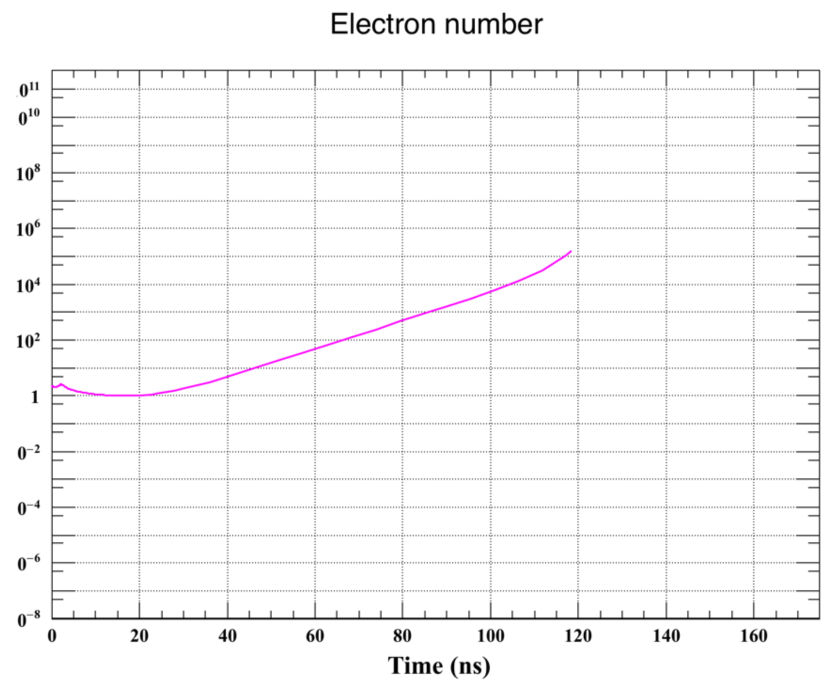
discharge in 18/45 geometry

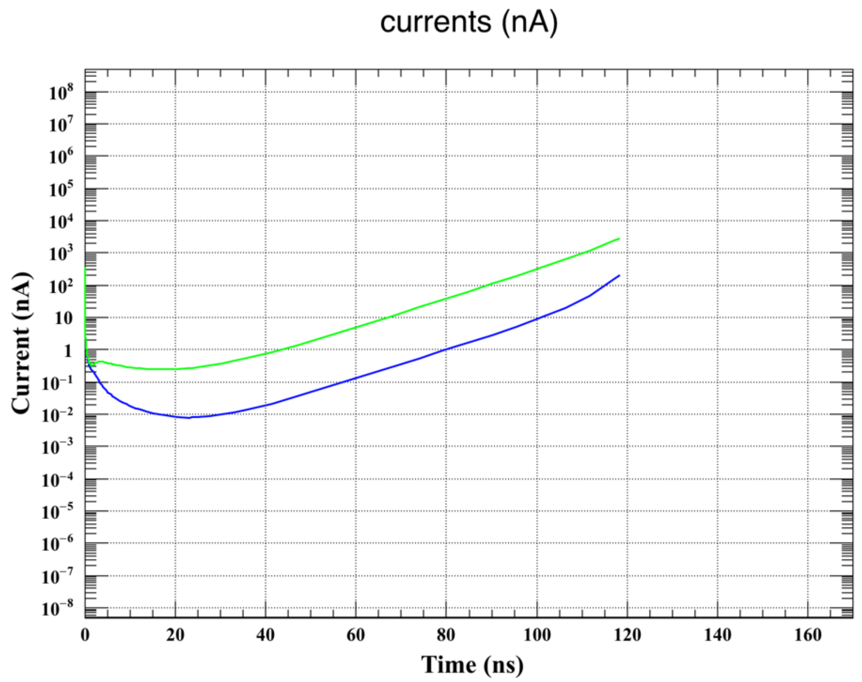




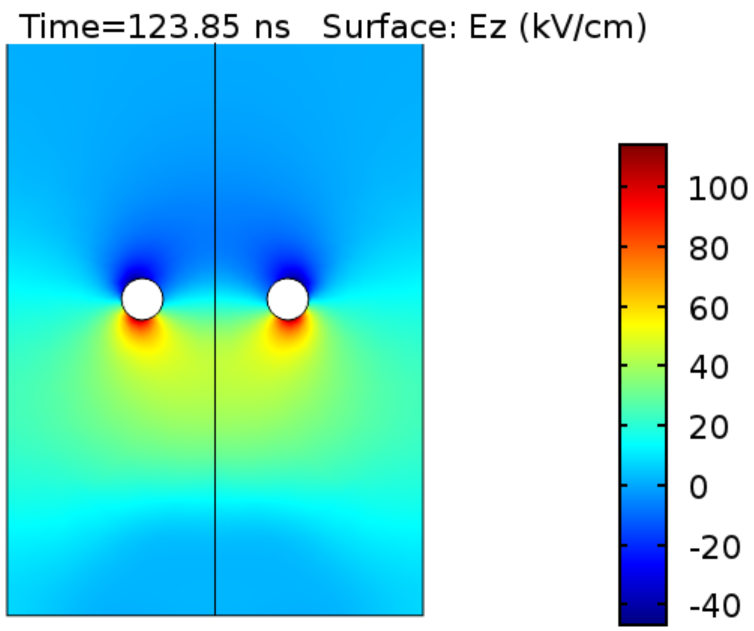


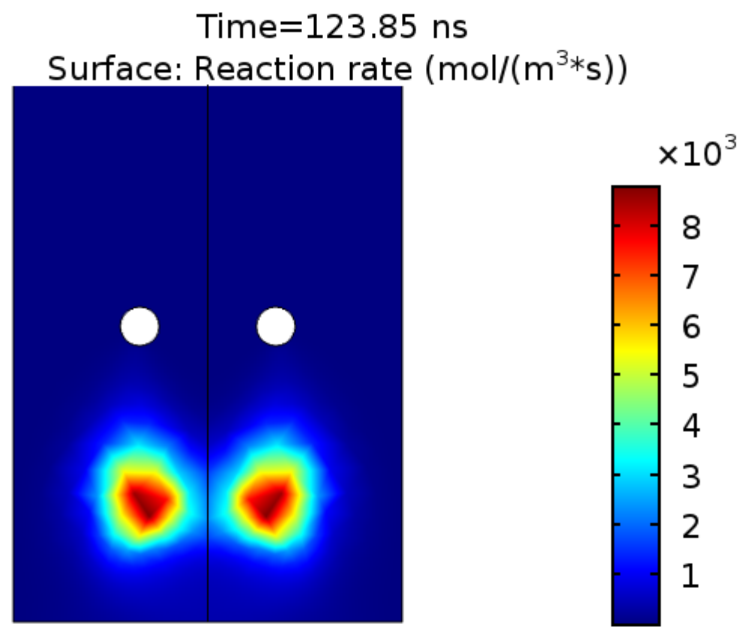


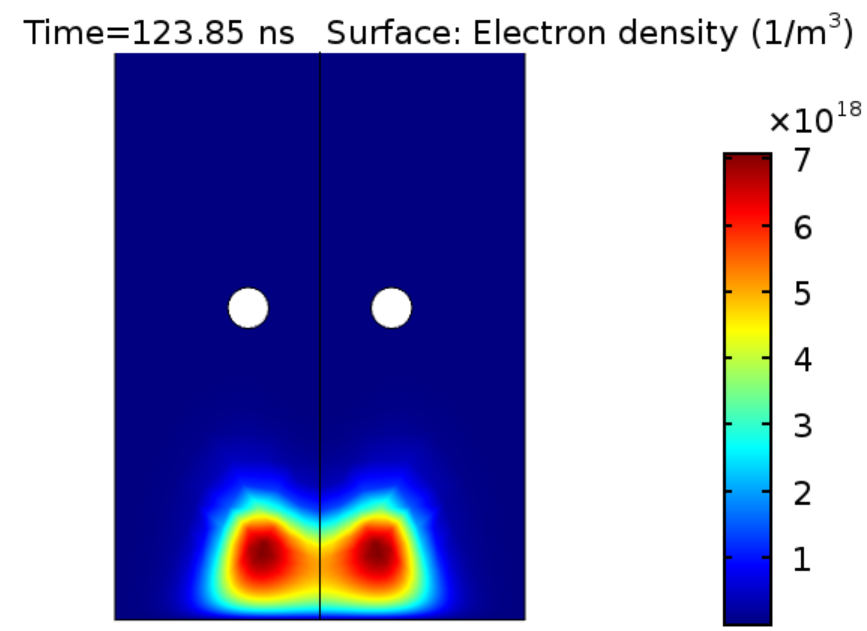


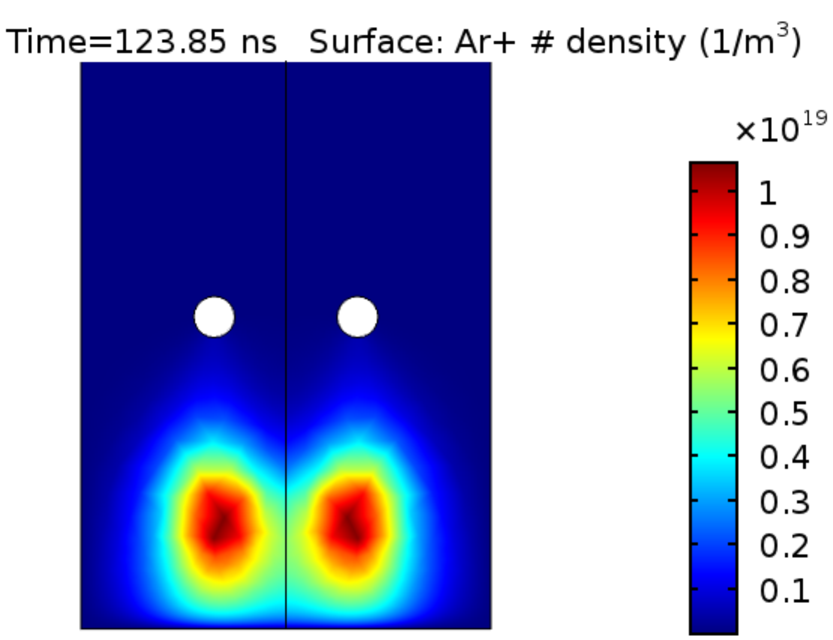


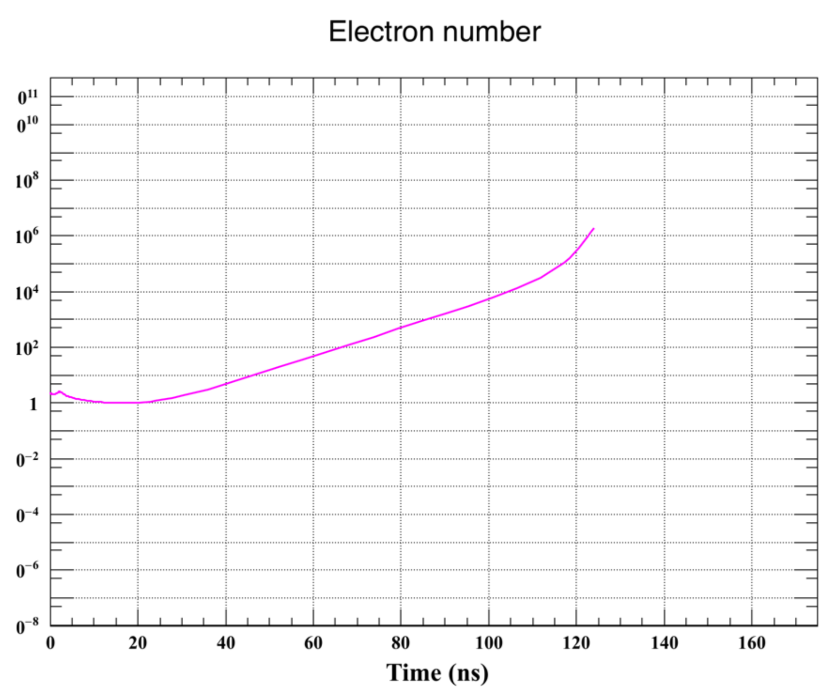
discharge in 18/45 geometry

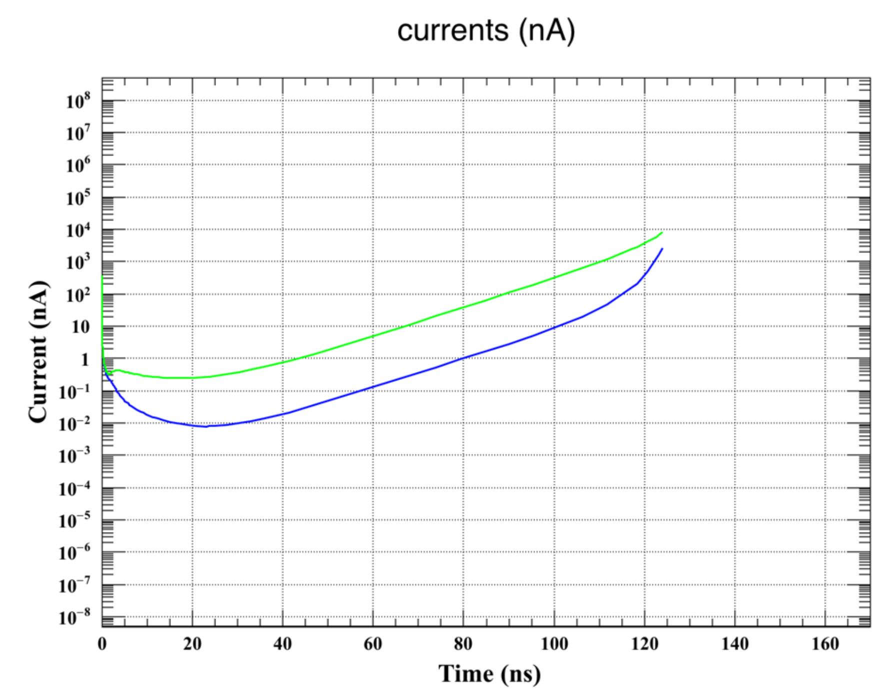




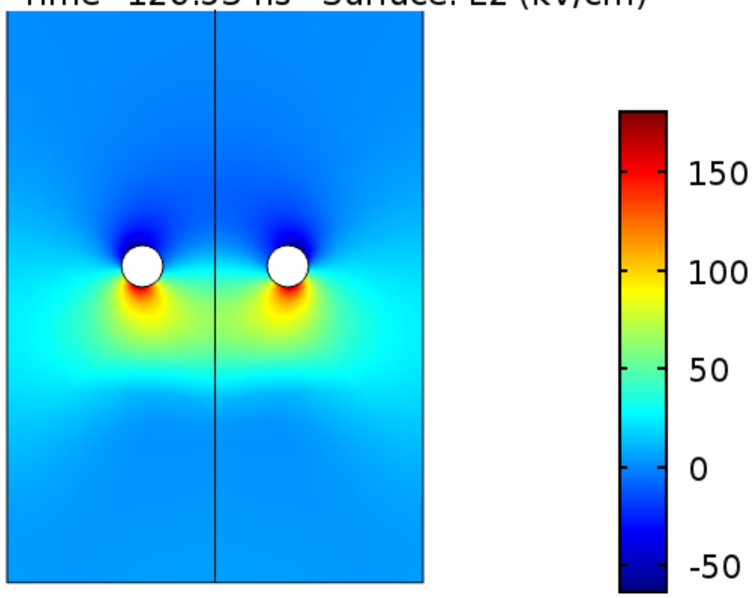


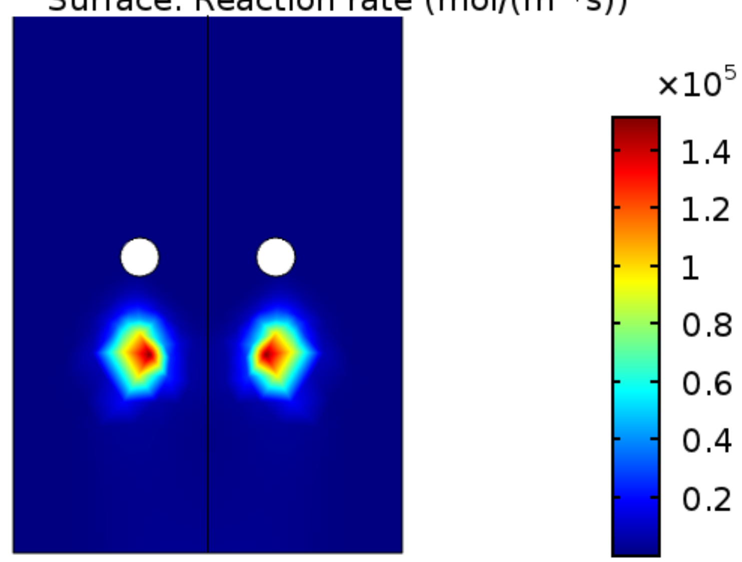


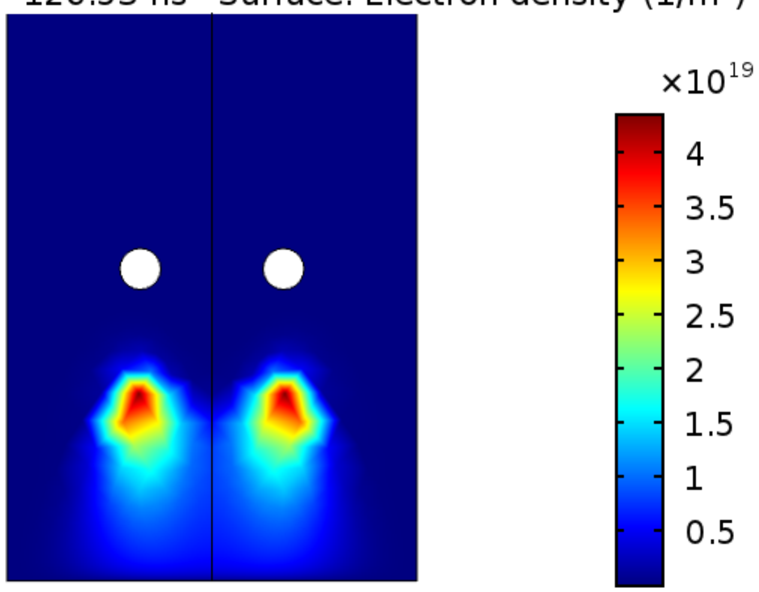


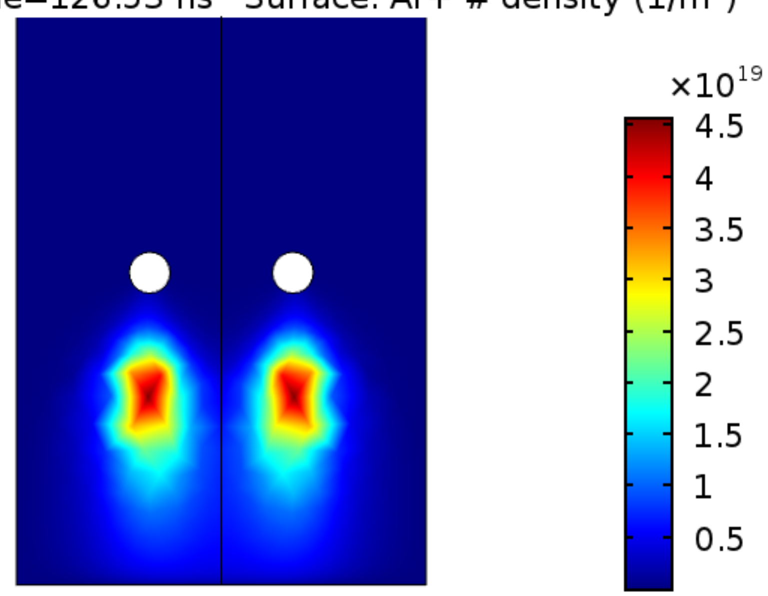


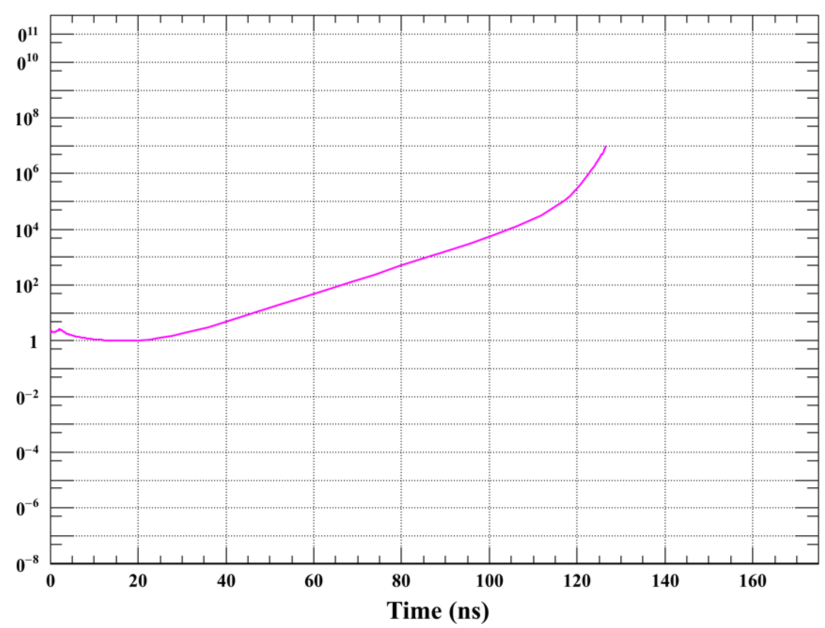
discharge in 18/45 geometry

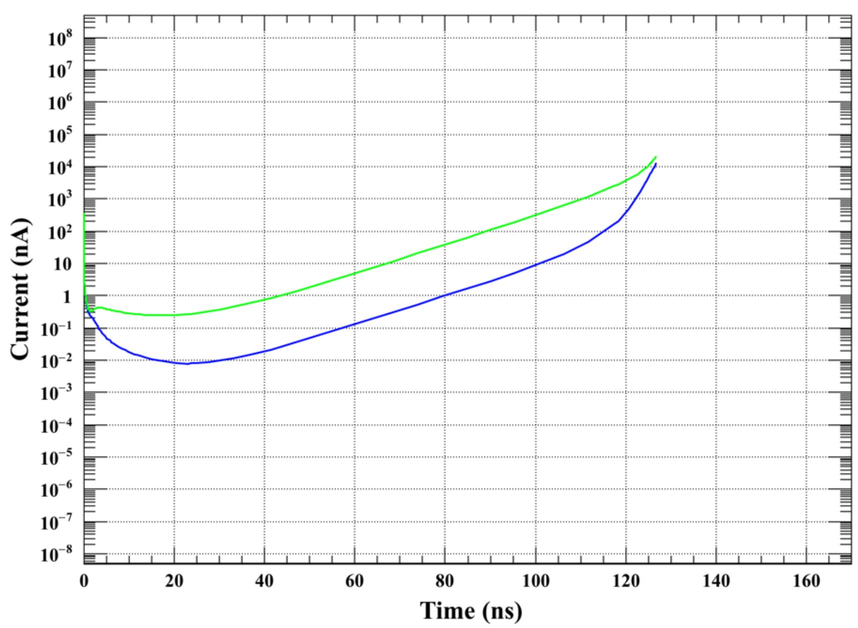




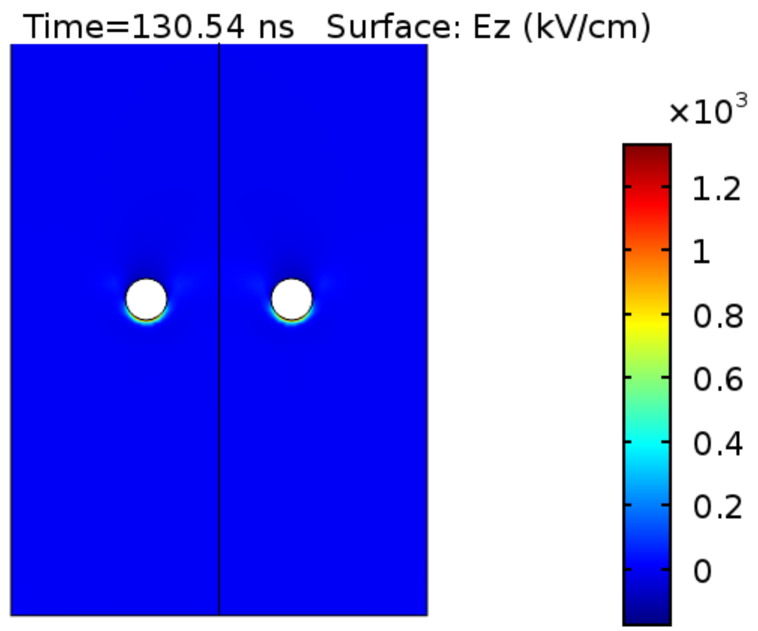


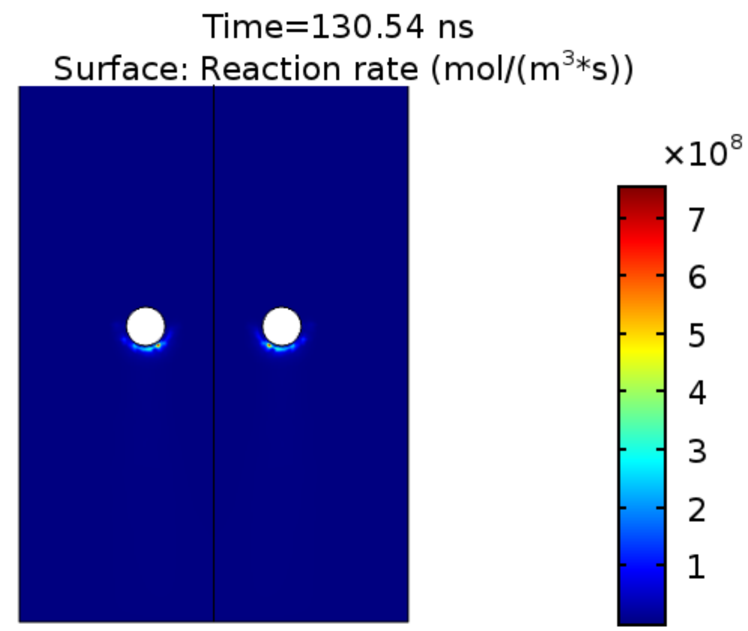


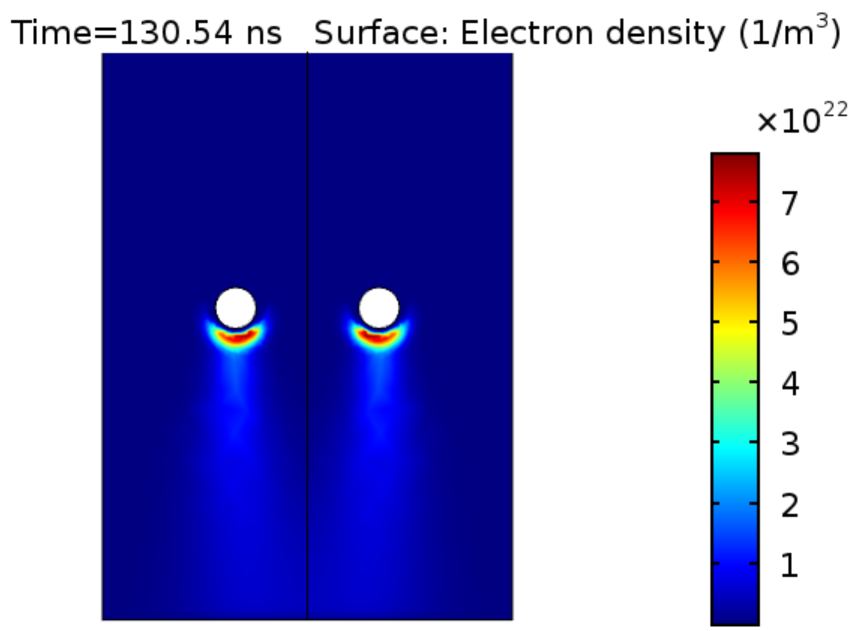


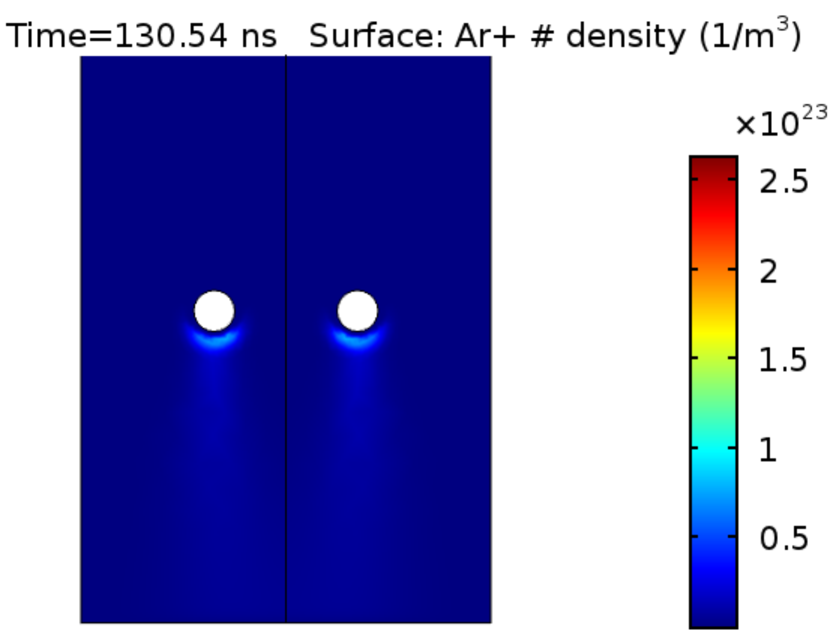


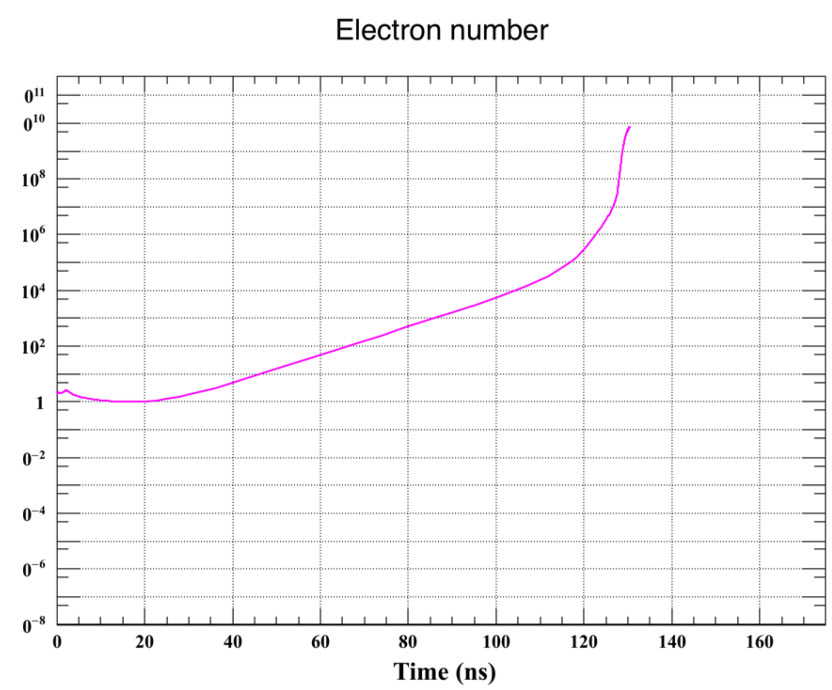
discharge in 18/45 geometry

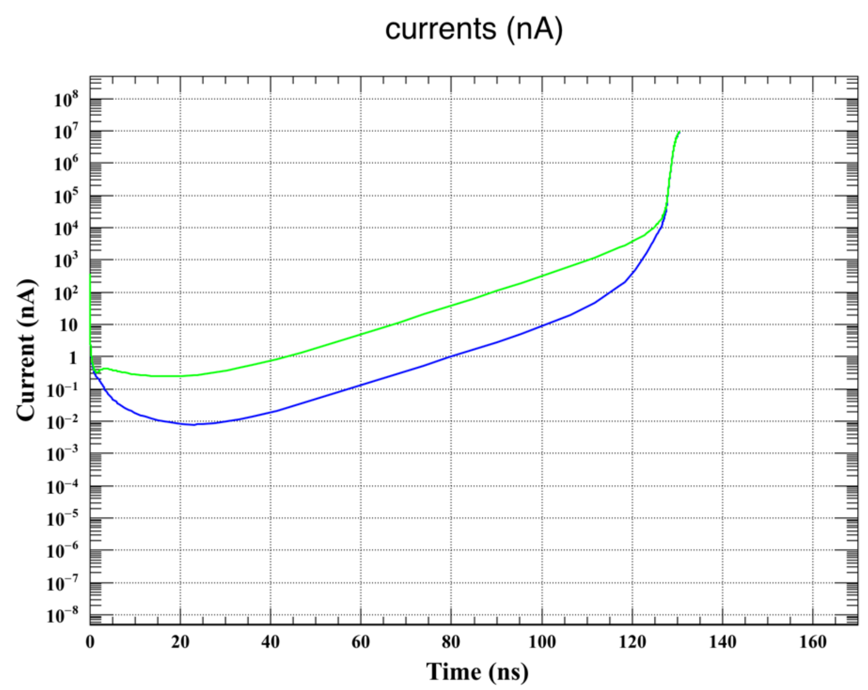




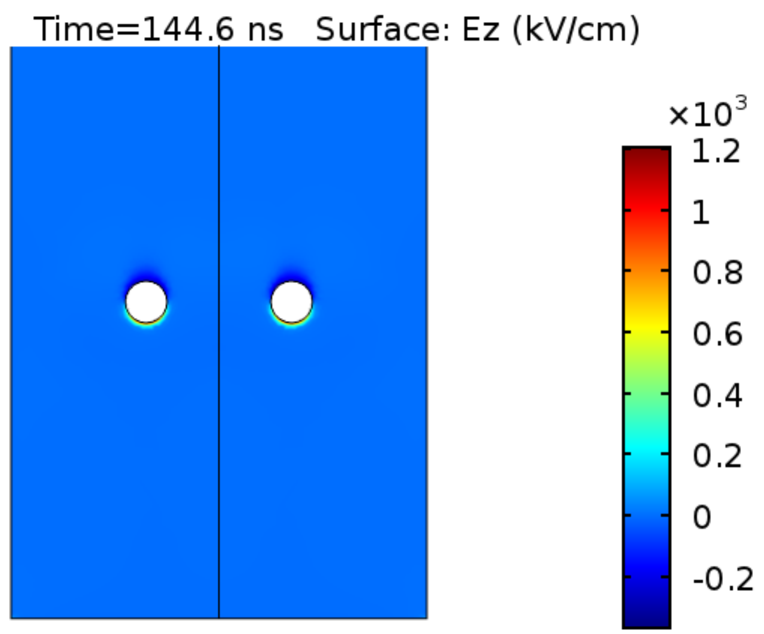


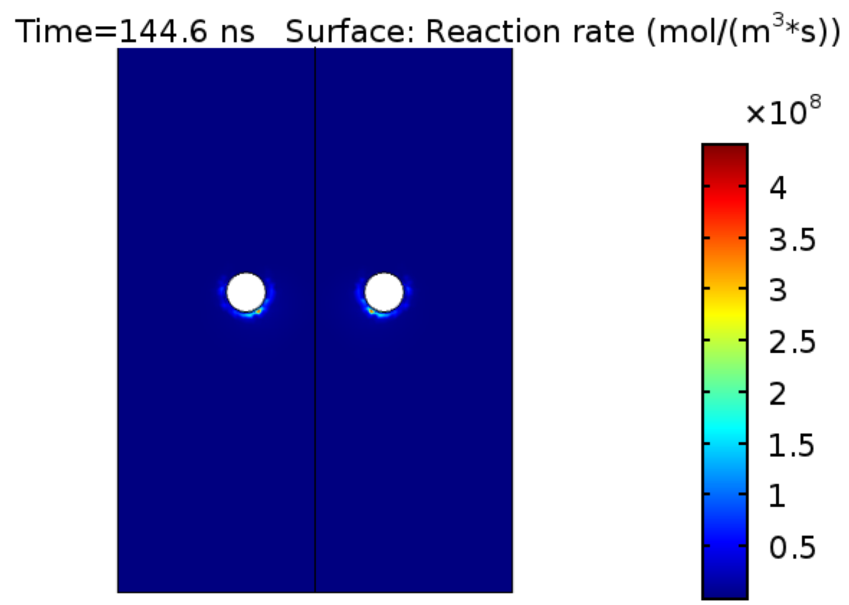


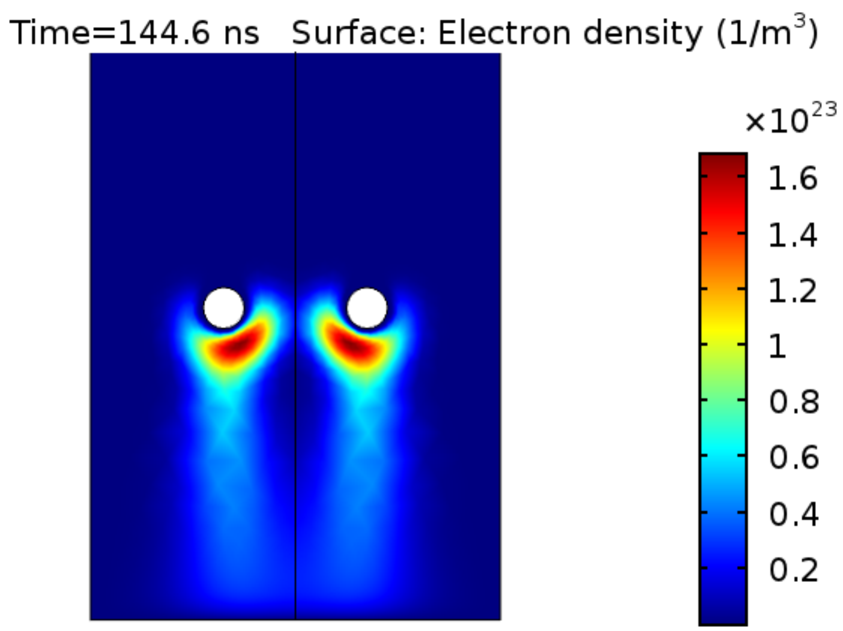


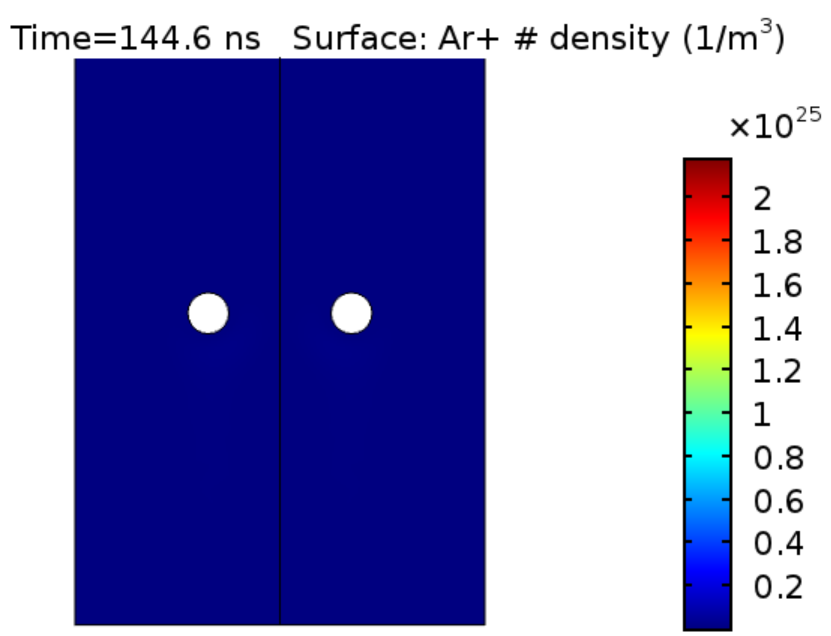


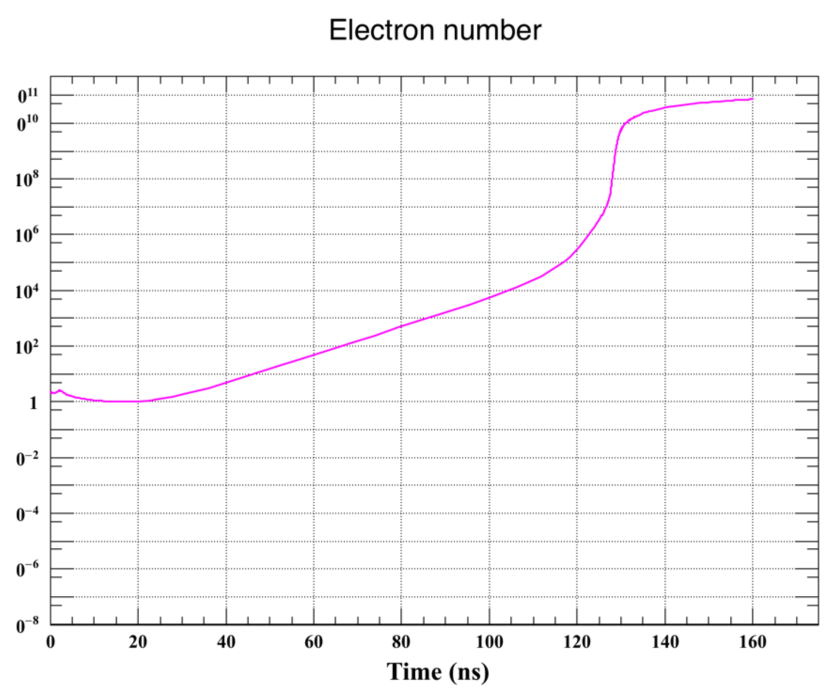
discharge in 18/45 geometry

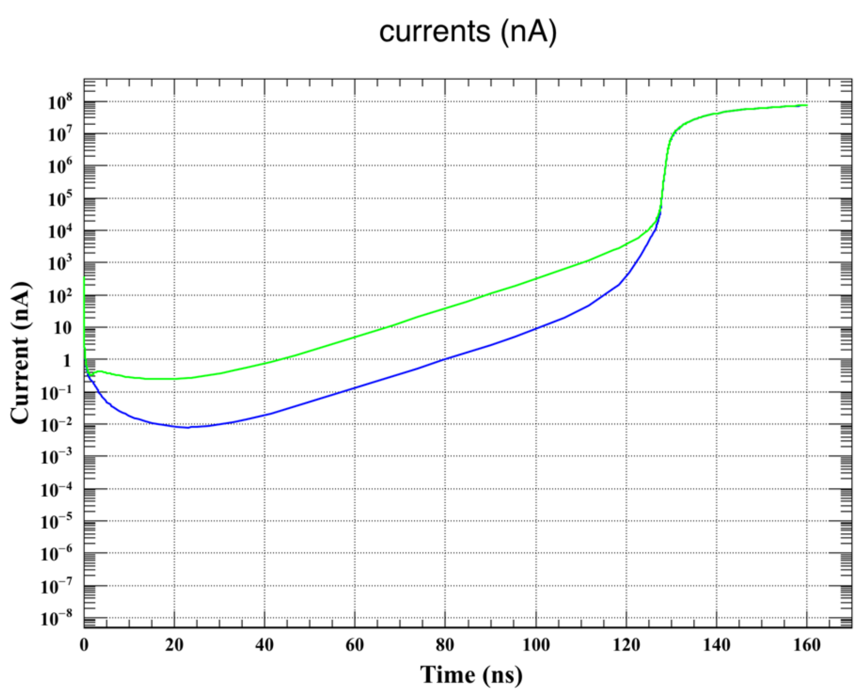




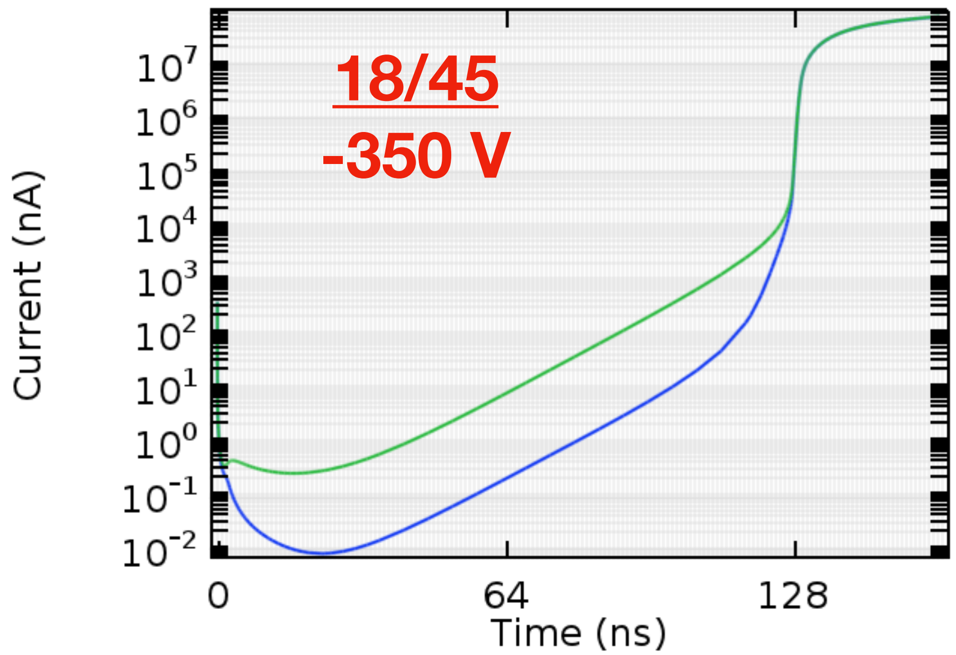


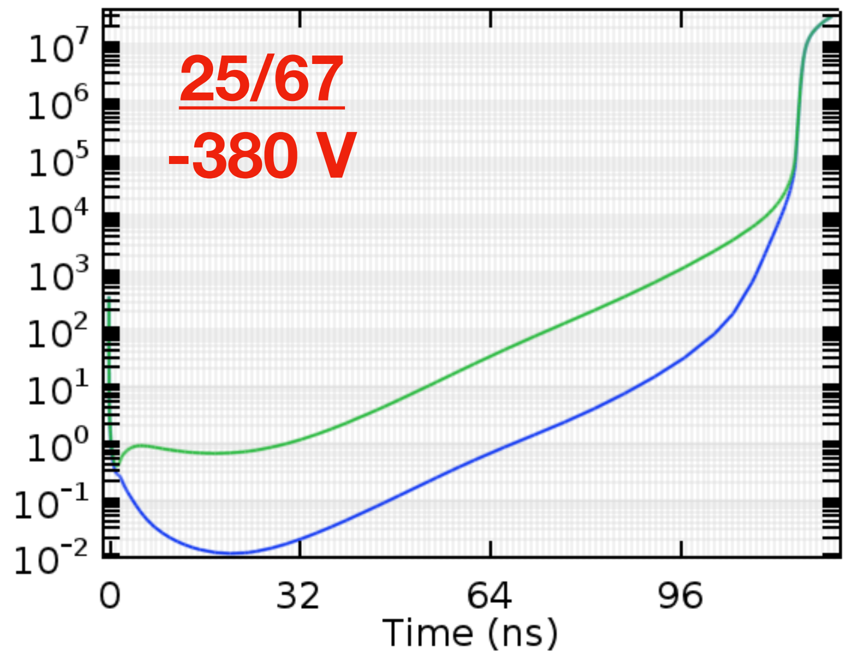


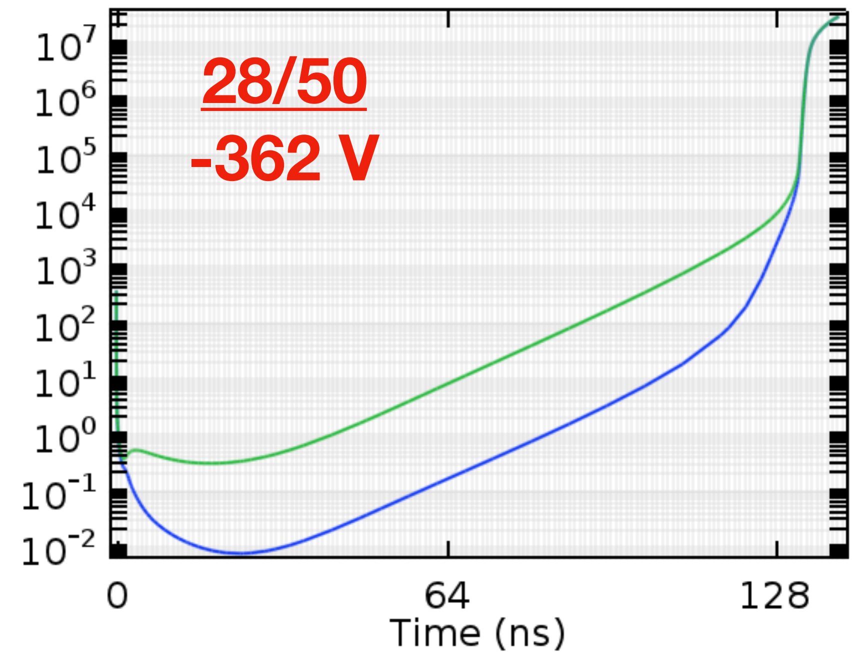


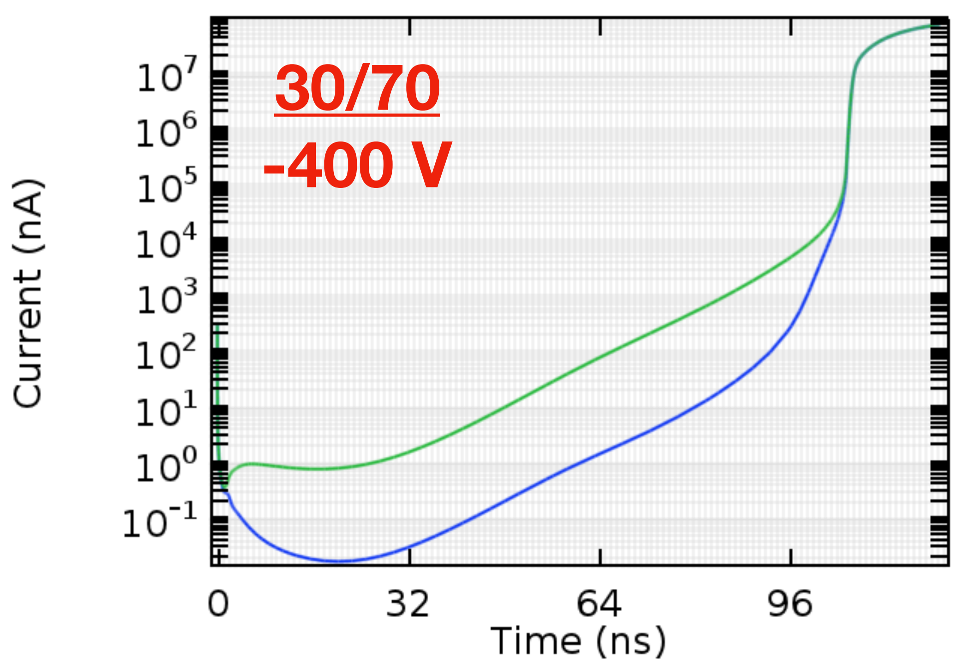


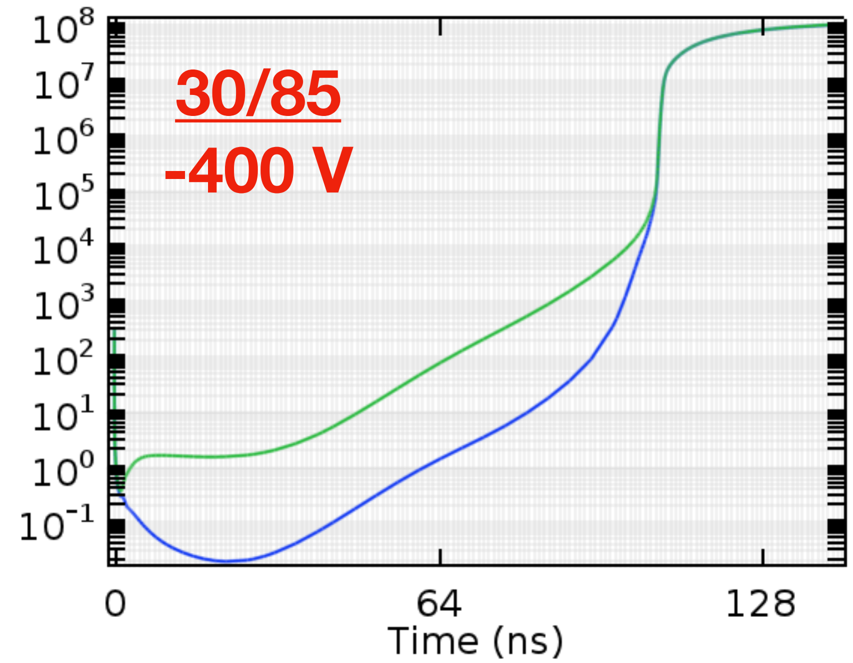
growth of streamer in different geometries









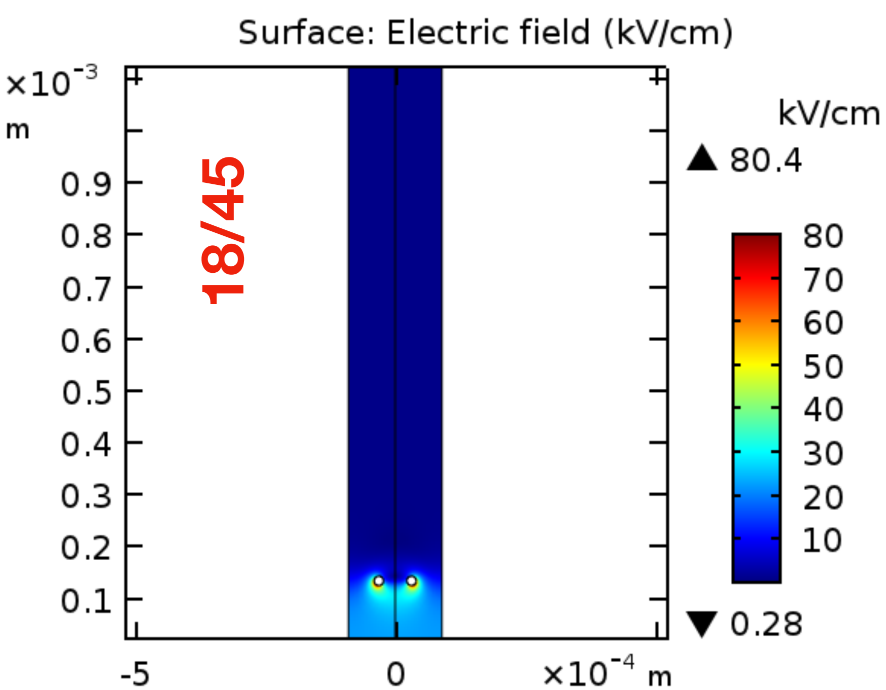


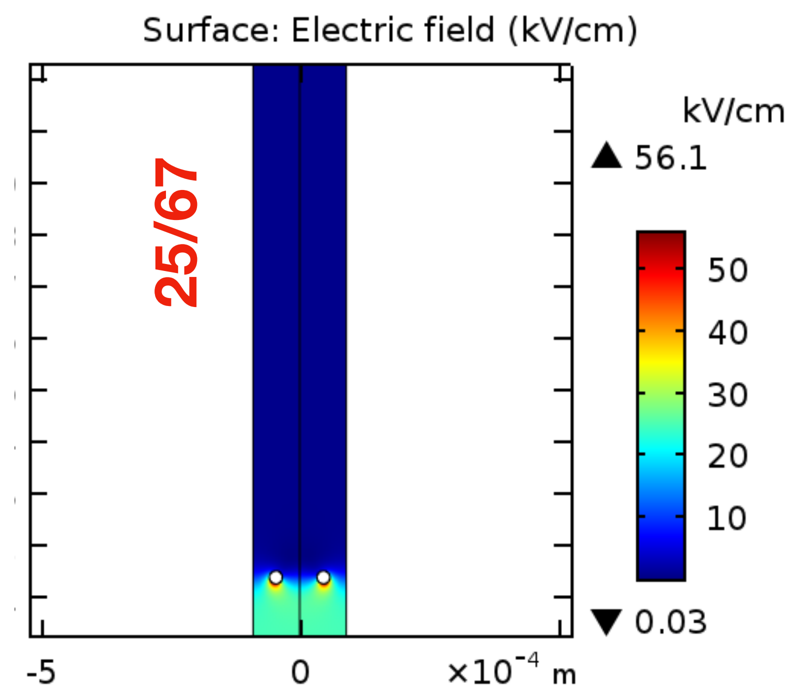
30/70 : 1000 nA -> 99 ns
(#10^6 -> 100 ns)

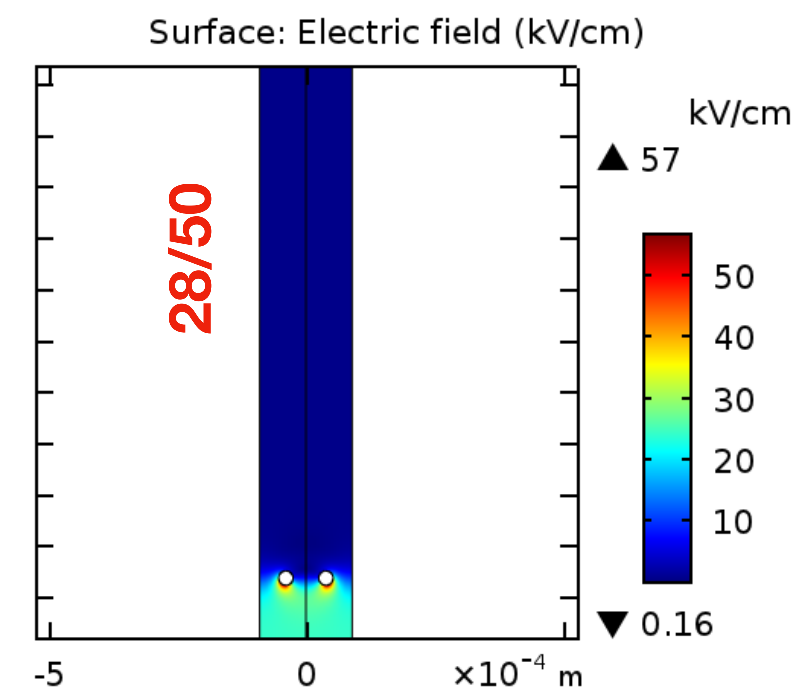
30/85 : 1000 nA -> 100.5 ns
(#10^6 -> 101.5 ns)

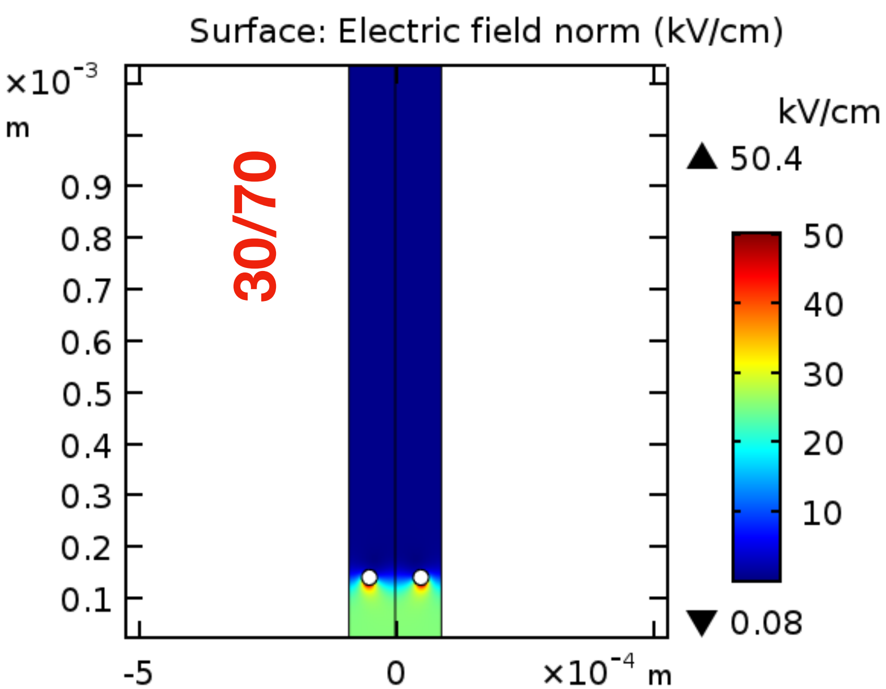
How is the field in 2D (from electric field Solver) ?

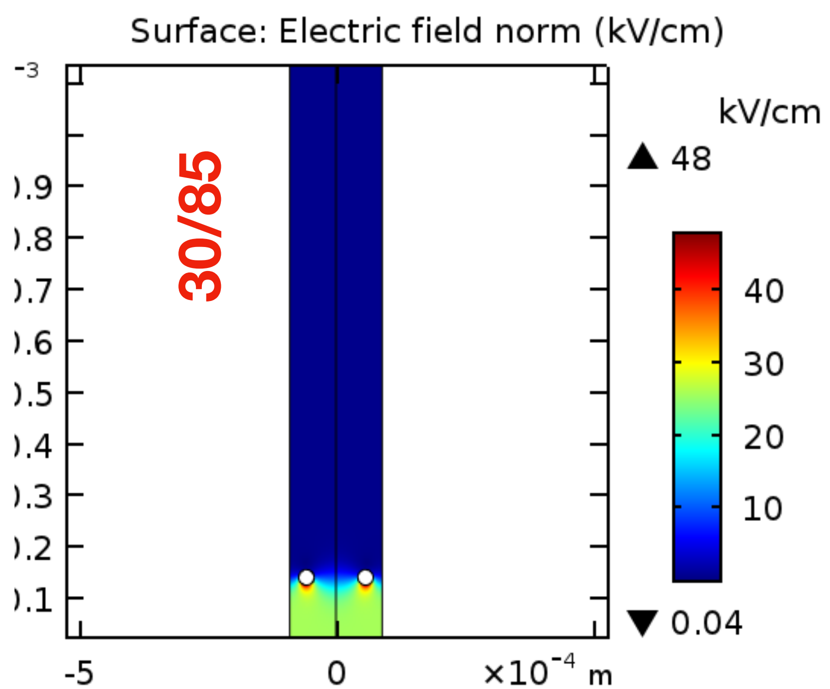
the meshes are at -350 V











Geometry	Max Field
18/45	80.4 kV/cm
28/50	56.1 kV/cm
25/67	57 kV/cm
30/70	50.4 kV/cm
30/85	48 kV/cm

Summary of discharge study

Geometry	Max Field	Breakdown Voltage
18/45	80.4 kV/cm	-350 V
28/50	56.1 kV/cm	-362 V
25/67	57 kV/cm	-380 V
30/70	50.4 kV/cm	- 400 V
30/85	48 kV/cm	- 400 V

Conclusions:

- electric field uniformity for different MicroMesh structures are studied.
- the occurrence of maximum and average electric fields are investigated.
- calendared structures are better than woven structures in terms of maximum and average field.
- a comparison among different meshes for field has been presented.

- Occurrence and propagation of streamer have been studied in 2D geometry.
- Break down in different geometries have been compared.
- The comparison suggest a strong correlation with Maximum Electric Field.

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Sincere Thanks to Raimund Ströhmer
and Mauro Lodice

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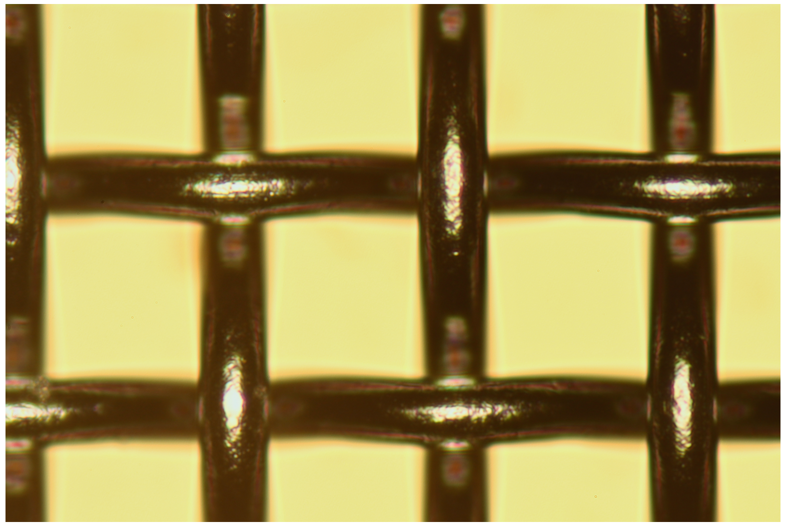
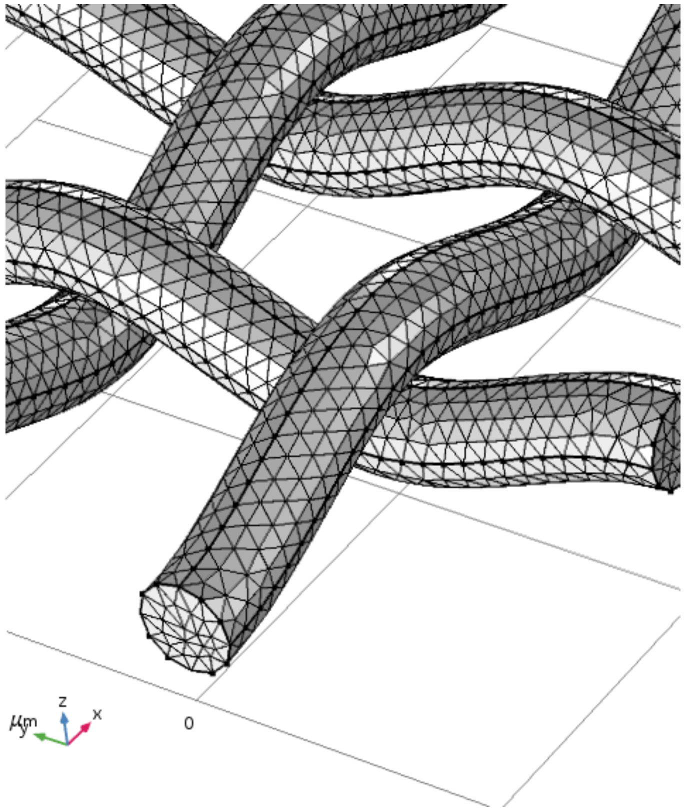
Thank you !



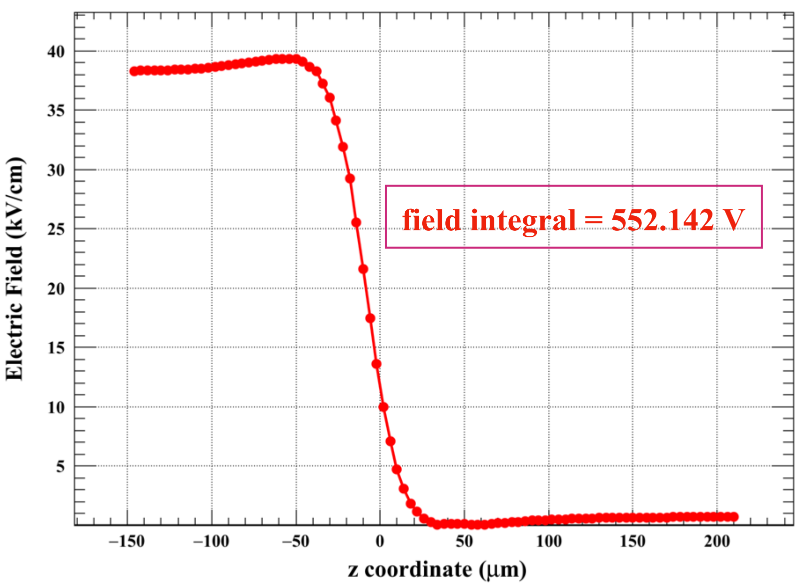


questions / comments / suggestions

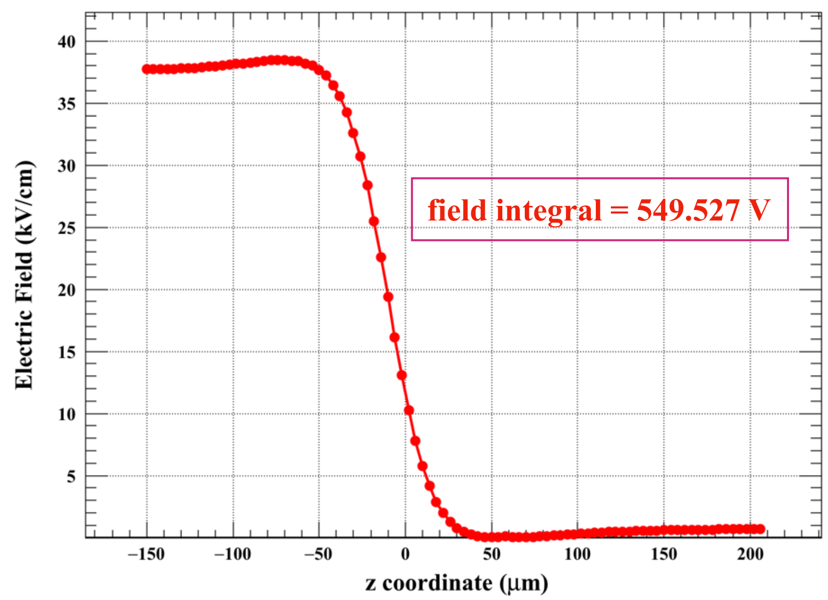
BackUp

Line Integral of the field through the hole

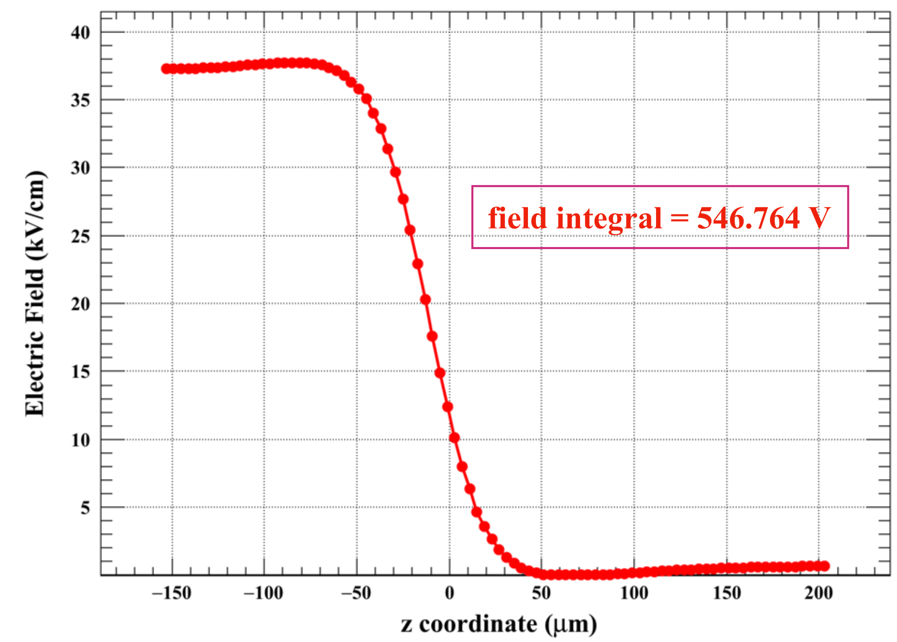
resultant field in 18/45 StWoven



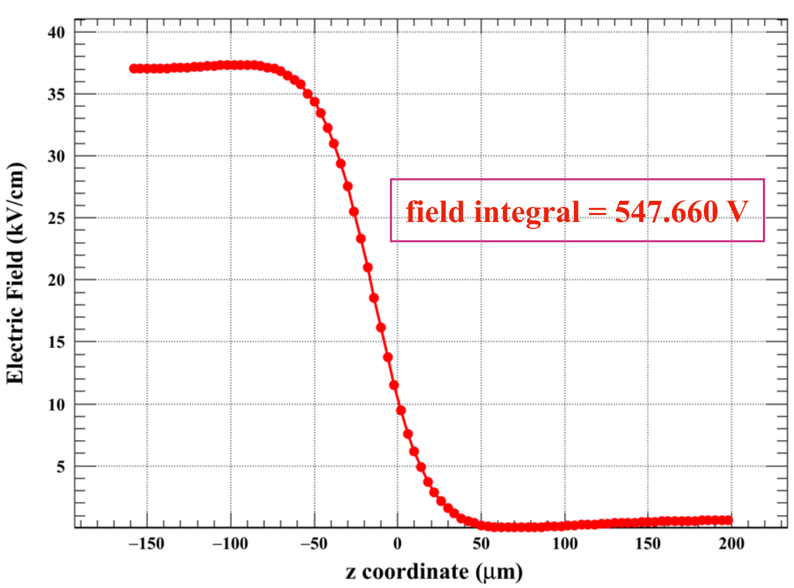
resultant field in 22/56 StWoven



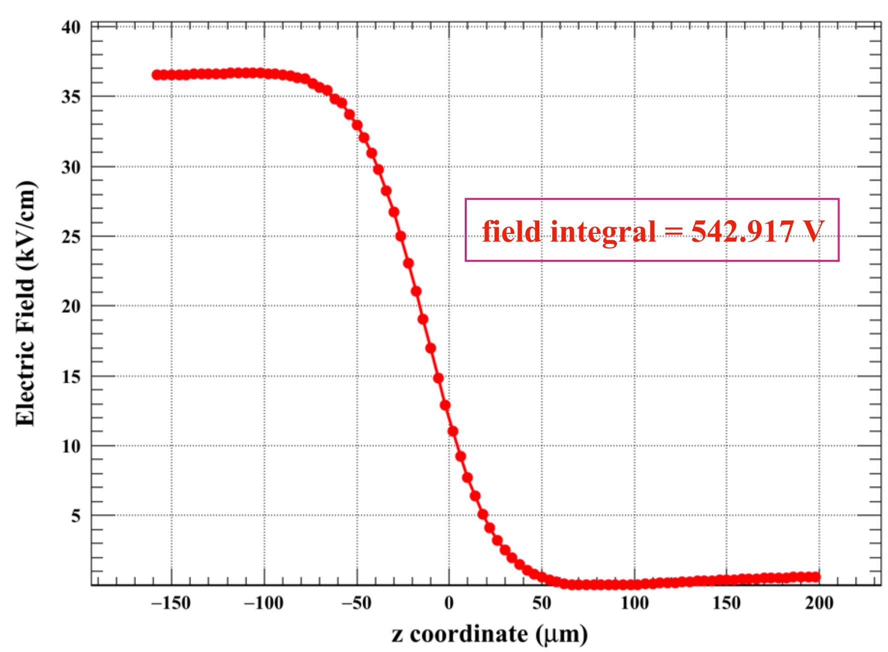
resultant field in 25/67 StWoven



resultant field in 30/70 StWoven

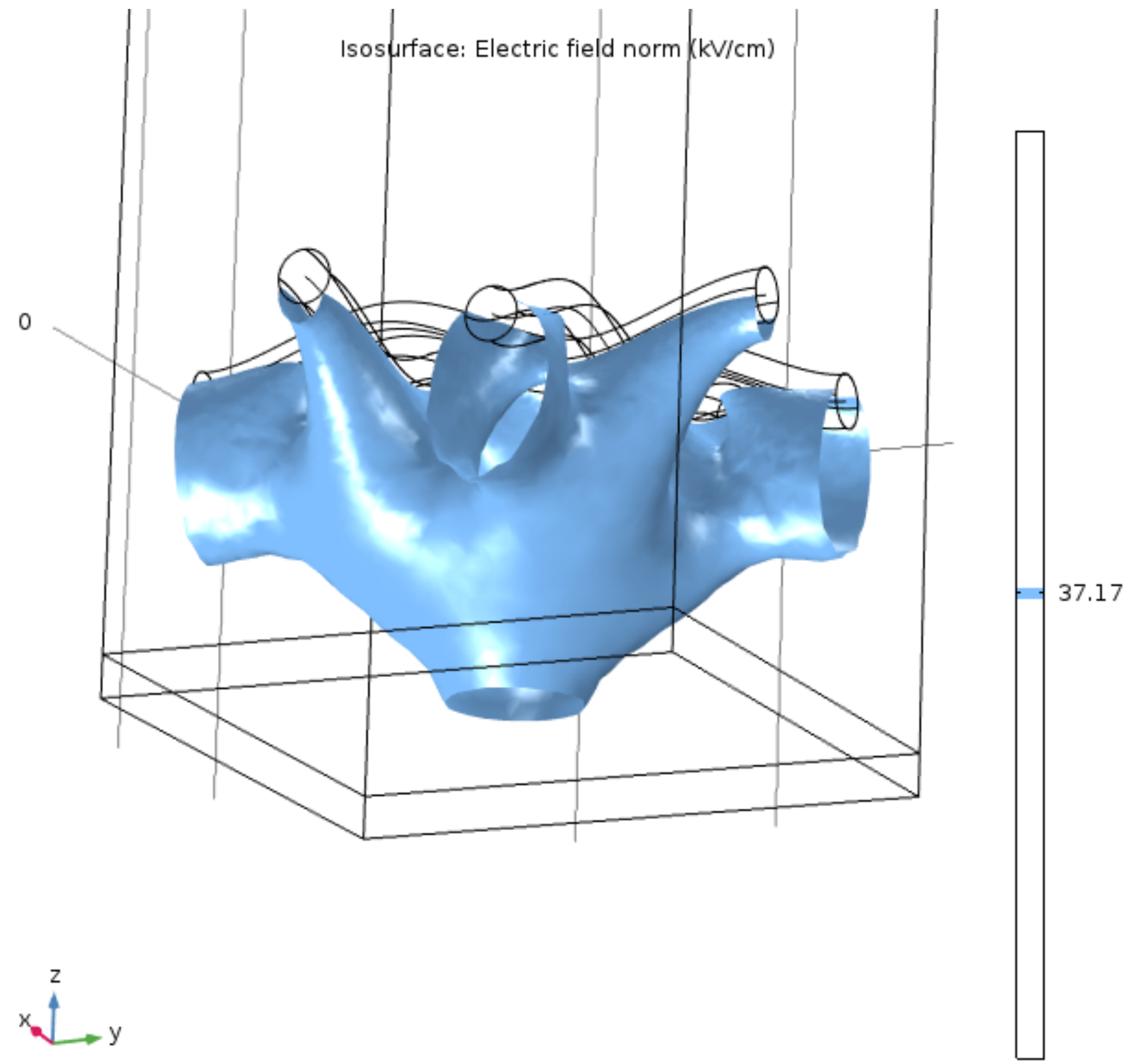


resultant field in 30/85 StWoven



- **The line integral of field is done up to 356 μm above the anode through the hole, in 4 μm interval, for all the cases. This means that the distance between the upper limit and the upper point(surface) of the mesh is slightly different for different cases.**

example of field funnelling
in 25-67 St Woven
at the average field level



discharge in 18/45 geometry (~ 432 ps)