Triple junction 'shed' electrostatic design and high voltage performance for the 200kV CEBAF gun upgrade
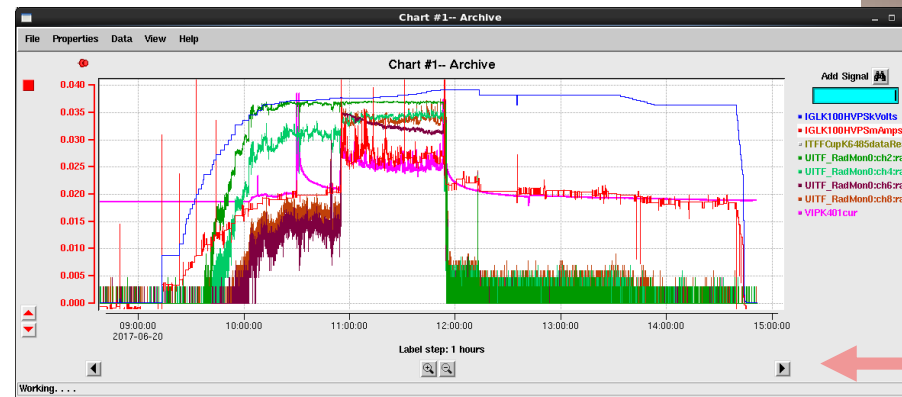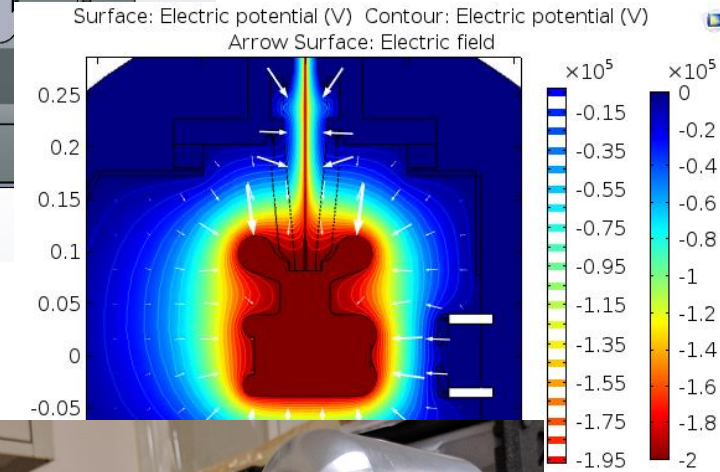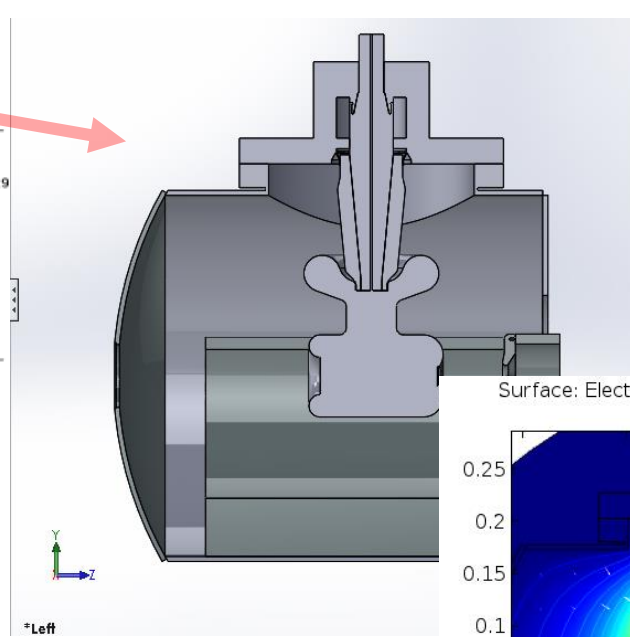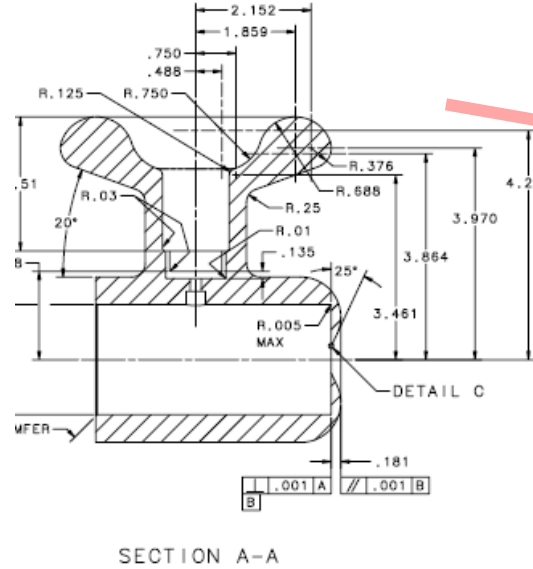
G. Palacios

gpala001@odu.edu
02/16/18

Summary

- COMSOL details on simulation
  - Materials
  - Electrostatics
  - Electric currents
  - Mesh
  - Study
  - Results
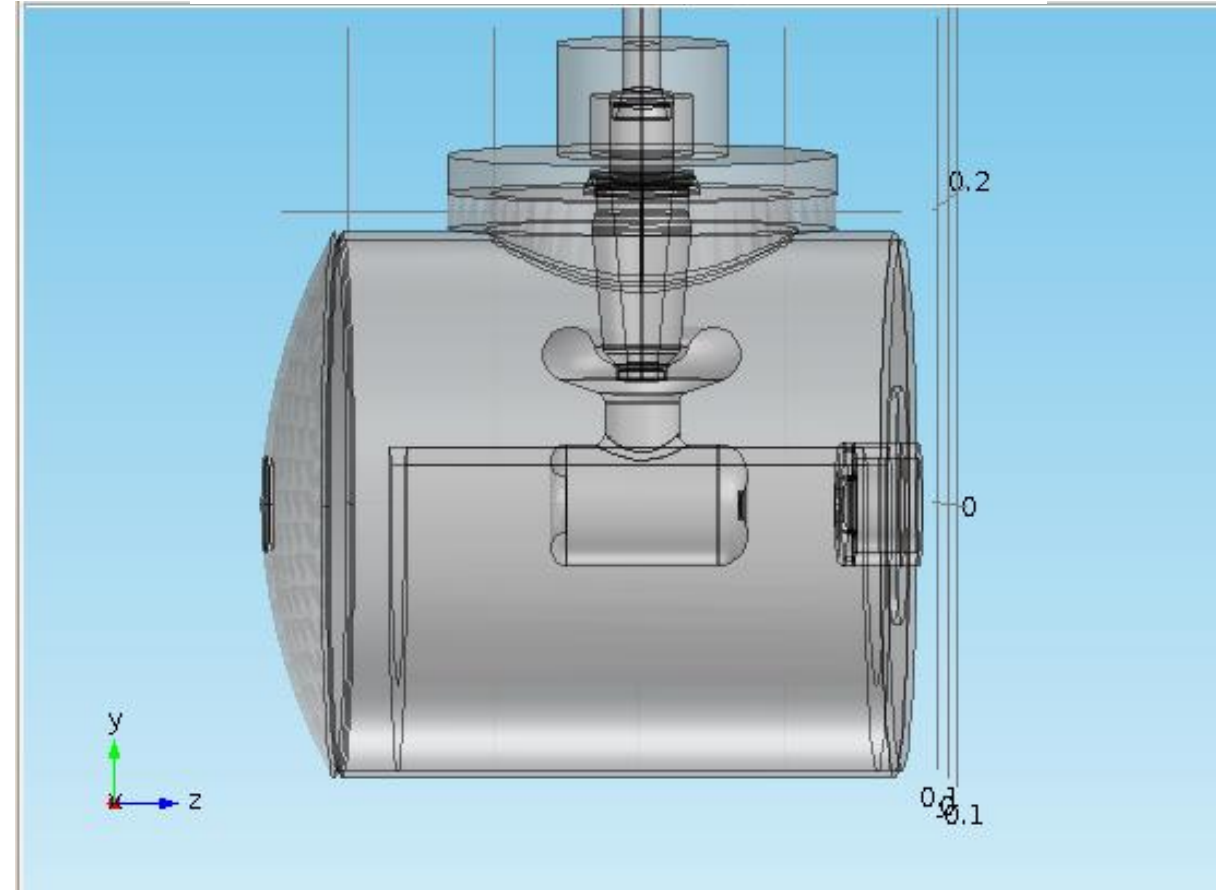 - Plots
- Future steps
- Extra slides

COMSOL materials:

- Stainless steel for all metal components with $\varepsilon_r=1$ and σ of 1.1E6 S/m
- Air for the vacuum surroundings.
- Alumina for the ceramic.
  - $\varepsilon_r=8.4$ and σ of 2E-12 S/m for the black.
  - $\varepsilon_r= 9.1$ and σ of 2E-14 S/m for the white.
- Rubber for the HV cable plug with $\varepsilon_r=2.37$ and σ of 1E-14 S/m .

COMSOL electric currents:

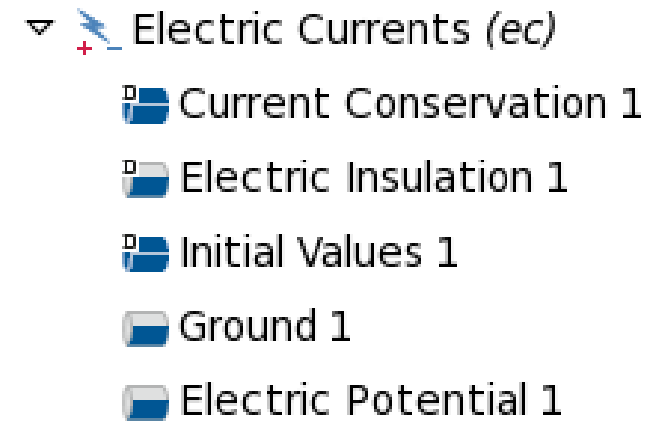- Current conservation in all domains.
- Electric insulation at the outer air boundary.
- Initial value (of potential) set to zero by default.
- Ground 1 at vacuum chamber, NEGs, anode, flanges.
- Electric potential at -200kV at the cathode, shed and HV cable.

▾ Equation

Equation form:

Study controlled

Show equation assuming:

Study 1, Stationary

$$\nabla \cdot \mathbf{J} = Q_j$$

$$\mathbf{J} = \sigma \mathbf{E} + \mathbf{J}_e$$

$$\mathbf{E} = -\nabla V$$
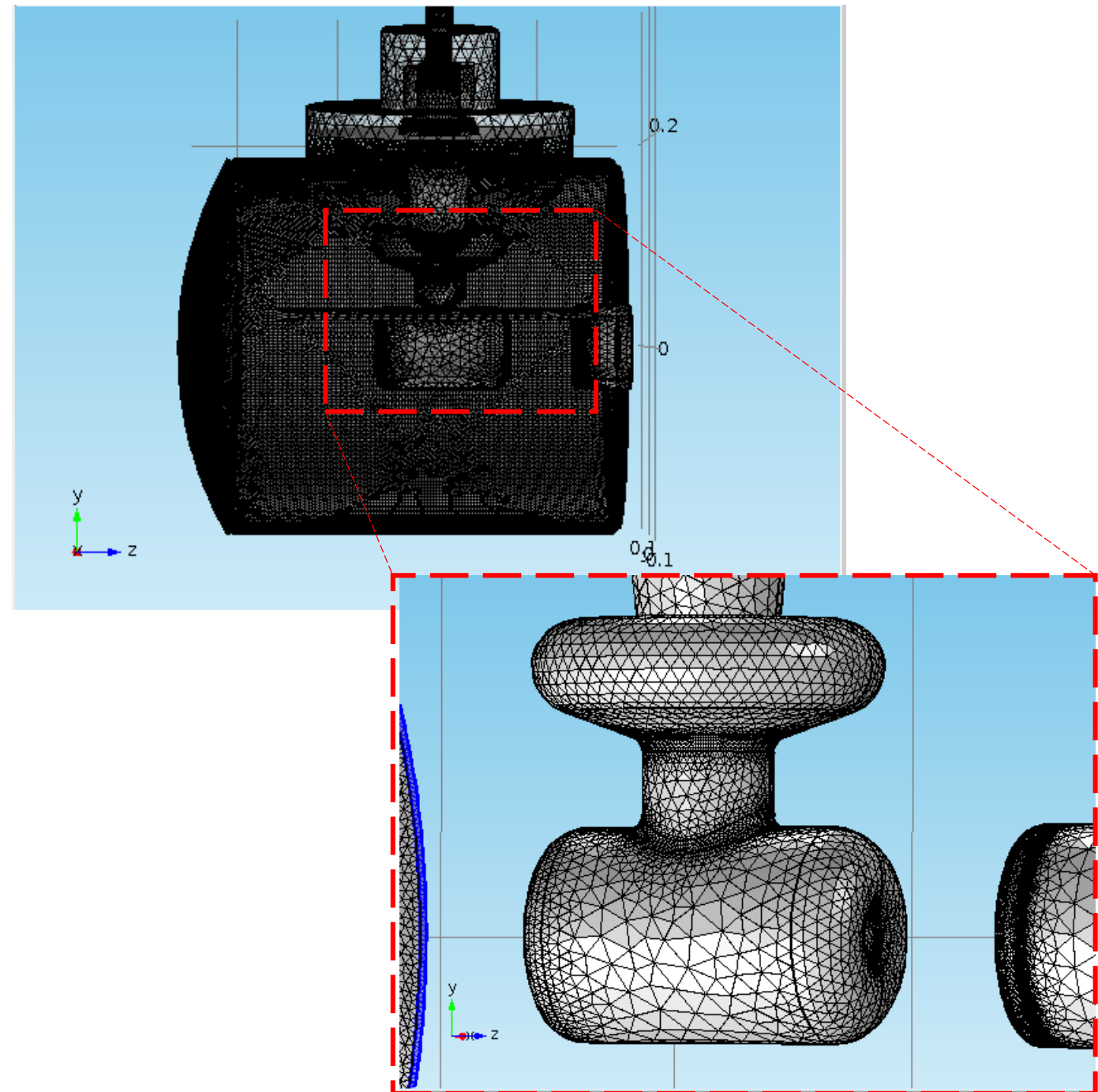
COMSOL mesh:

▽ ◭ Mesh 1
  ◿ Size
  ◭ Free Tetrahedral 1
  ◭ Free Tetrahedral 2
  ◭ Free Tetrahedral 3
  ◭ Free Tetrahedral 4

- An extra fine mesh was used to account for the smaller details.
- The mesh was separated into 4 pieces.

COMSOL study:

- The study solves for the electric field and potential including the effect of the conductivity of the materials using the currents module.

▽ ∿ Study 1
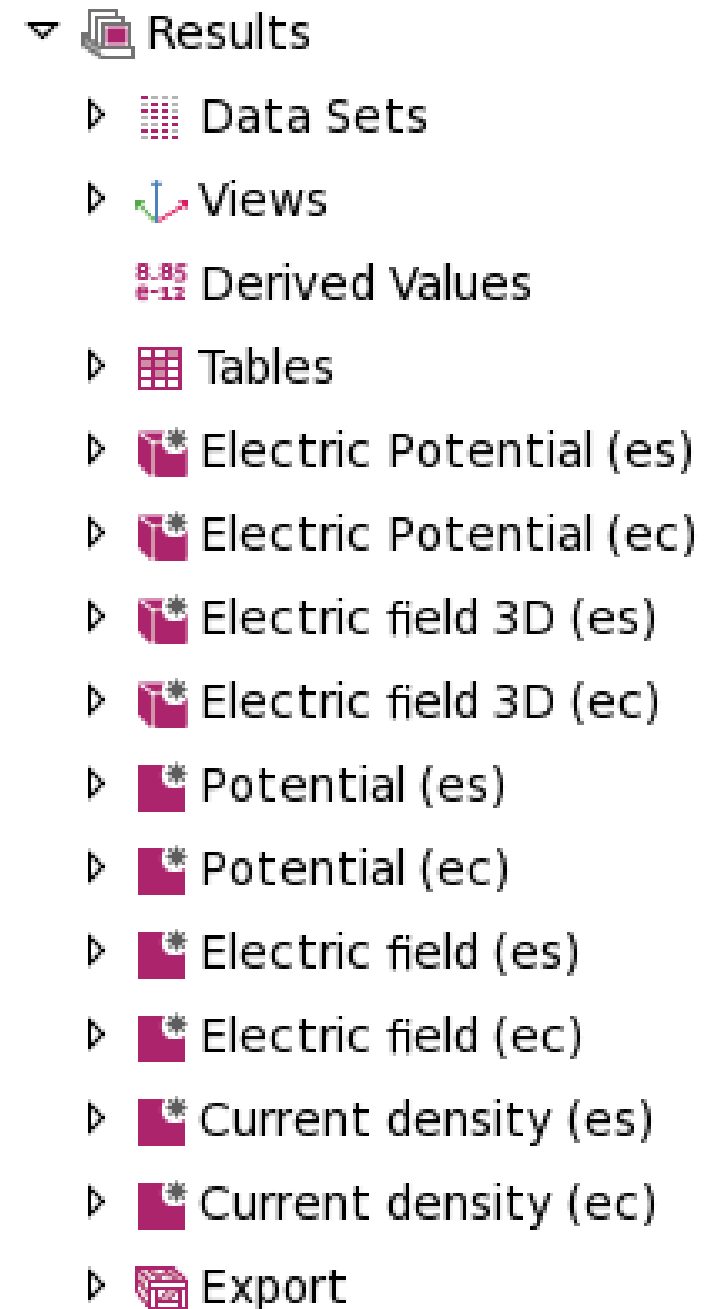
    ⊨ Step 1: Stationary

▽ ▥ Solver Configurations

▾ Physics and Variables Selection

☐ Modify physics tree and variables for study step

| Physics interface	Solve for
Electric Currents (ec)	✔

COMSOL results:

- Plotted the potential and electric fields.
- The results shown up next are comparisons between the white insulator without shed (representing the actual CEBAF gun) and the black insulator with shed (representing the improved version).

▽ 🗔 Results
  ▷ ▦ Data Sets
  ▷ ⌊↲ Views
    8.85 Derived Values
    e-12
  ▷ ▦ Tables
  ▷ ▮* Electric Potential (es)
  ▷ ▮* Electric Potential (ec)
  ▷ ▮* Electric field 3D (es)
  ▷ ▮* Electric field 3D (ec)
  ▷ ▮* Potential (es)
  ▷ ▮* Potential (ec)
  ▷ ▮* Electric field (es)
  ▷ ▮* Electric field (ec)
  ▷ ▮* Current density (es)
  ▷ ▮* Current density (ec)
  ▷ 🗃 Export

COMSOL Electric field Norm at 4 points:

- The simulations show a lateral cross section. The electric field norm was obtained at three points around the cathode electrode and one near the triple point junction in both cases.
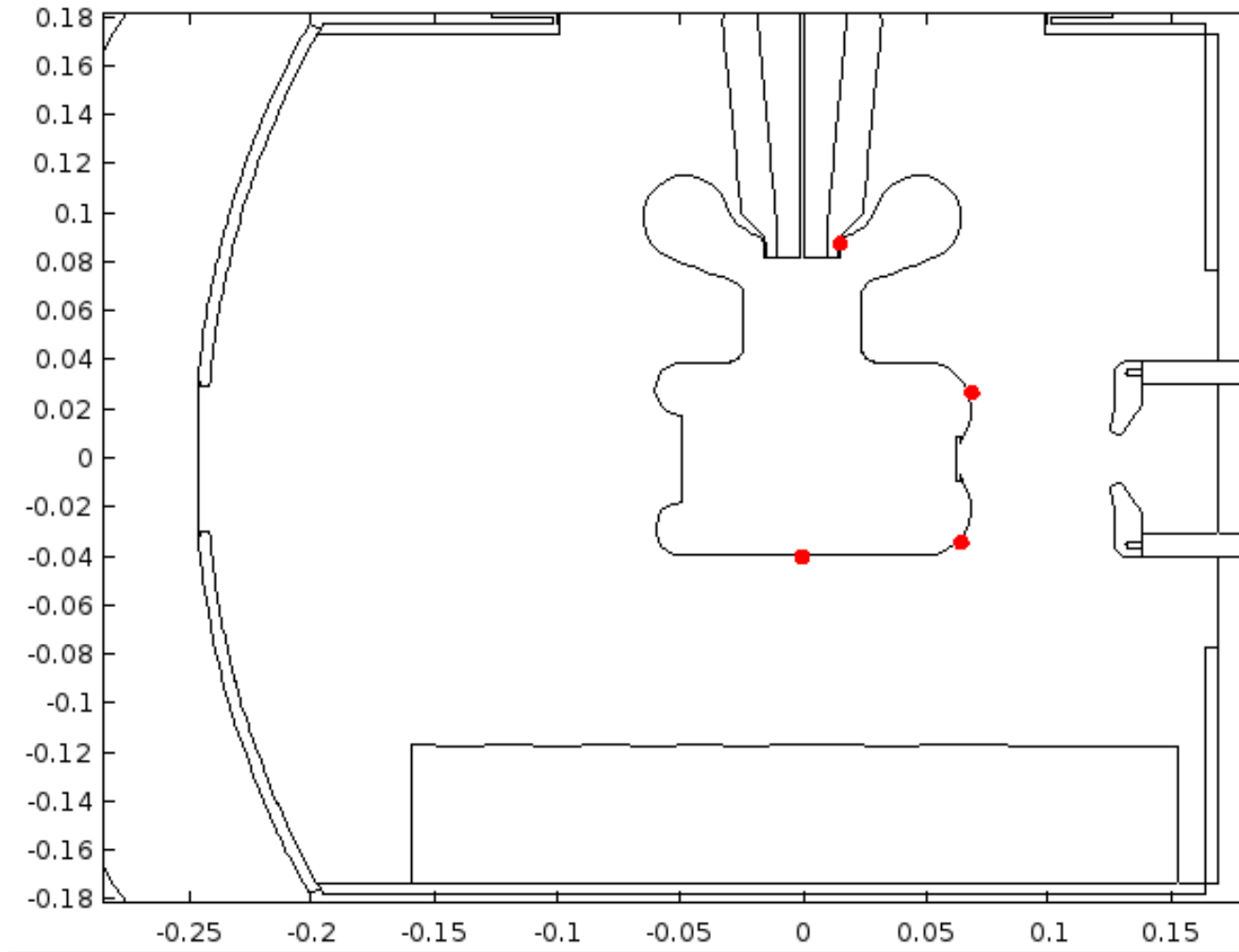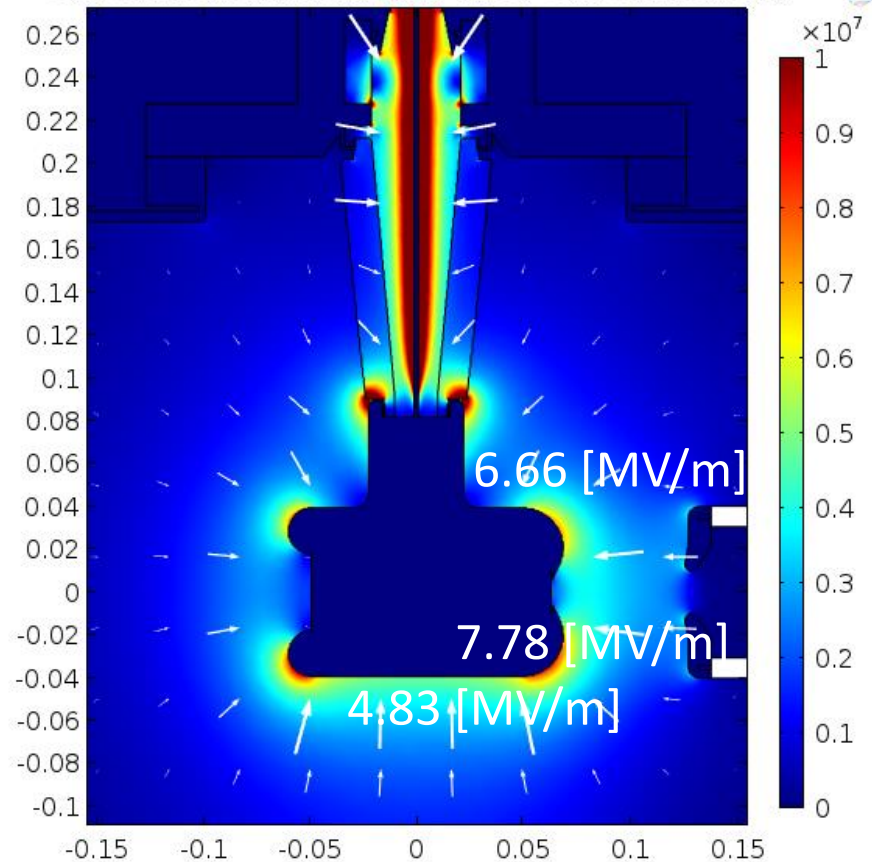
COMSOL Electric field Norm :

- For the lowest point the electric field norm remains around 4.8 MV/m. At the bottom right corner the difference is of less than 0.39% with both fields around 7.7 MV/m, while the top right corner the presence of the shed produced a value around ~14% smaller than the unprotected cathode.

White Conductivity of 2E-14 S/m

Black Conductivity of 2E-12 S/m
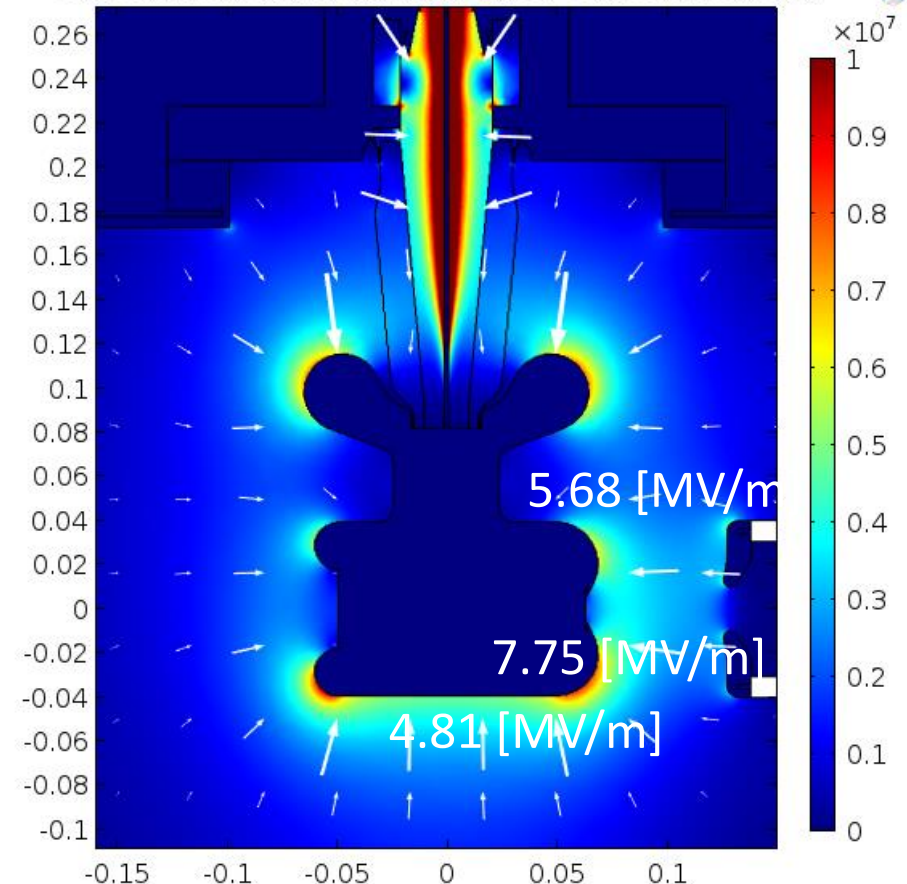
COMSOL Electric field Norm :

* For the triple-point joint the |E| field is around two orders of magnitude smaller for the protected cathode. The vertical component of the electric field, Ey, shows a reduction of around 99% for the protected cathode.

White Conductivity of 2E-14 S/m

|E|=146.9 [V/m]
Ey=-139 [V/m]

Black Conductivity of 2E-12 S/m

|E|=1.16 [V/m]
Ey=-1.14 [V/m]
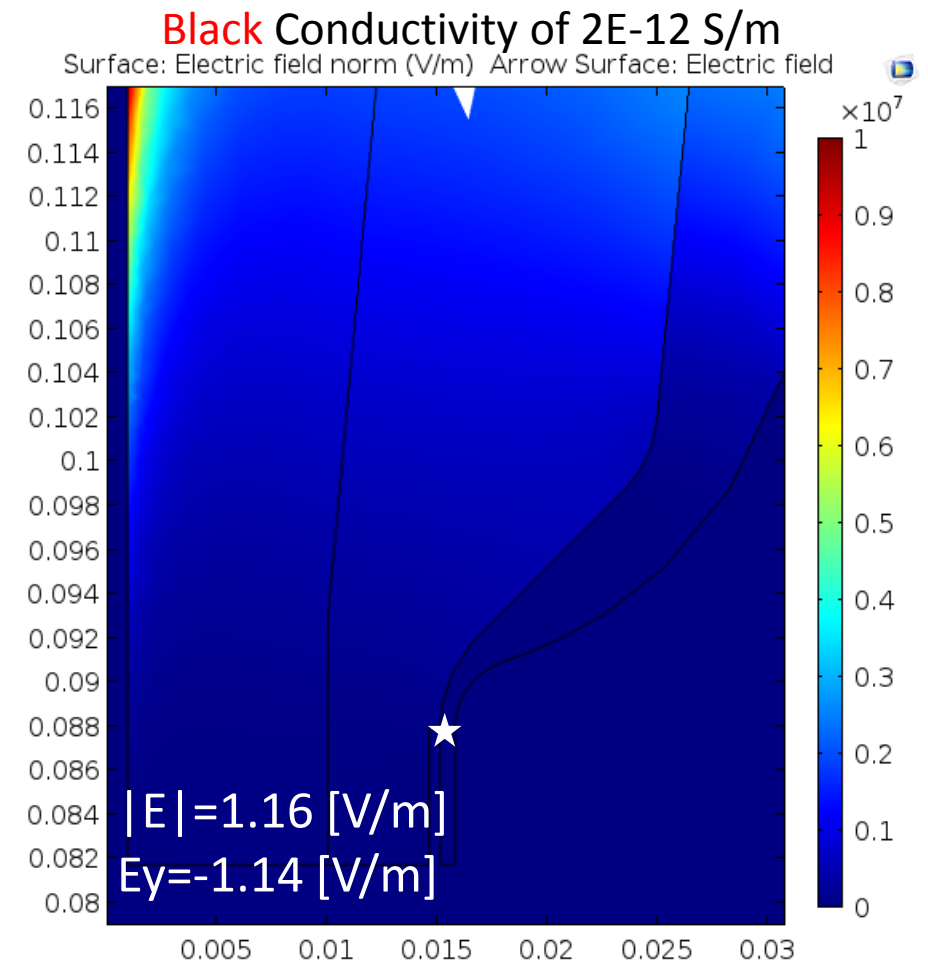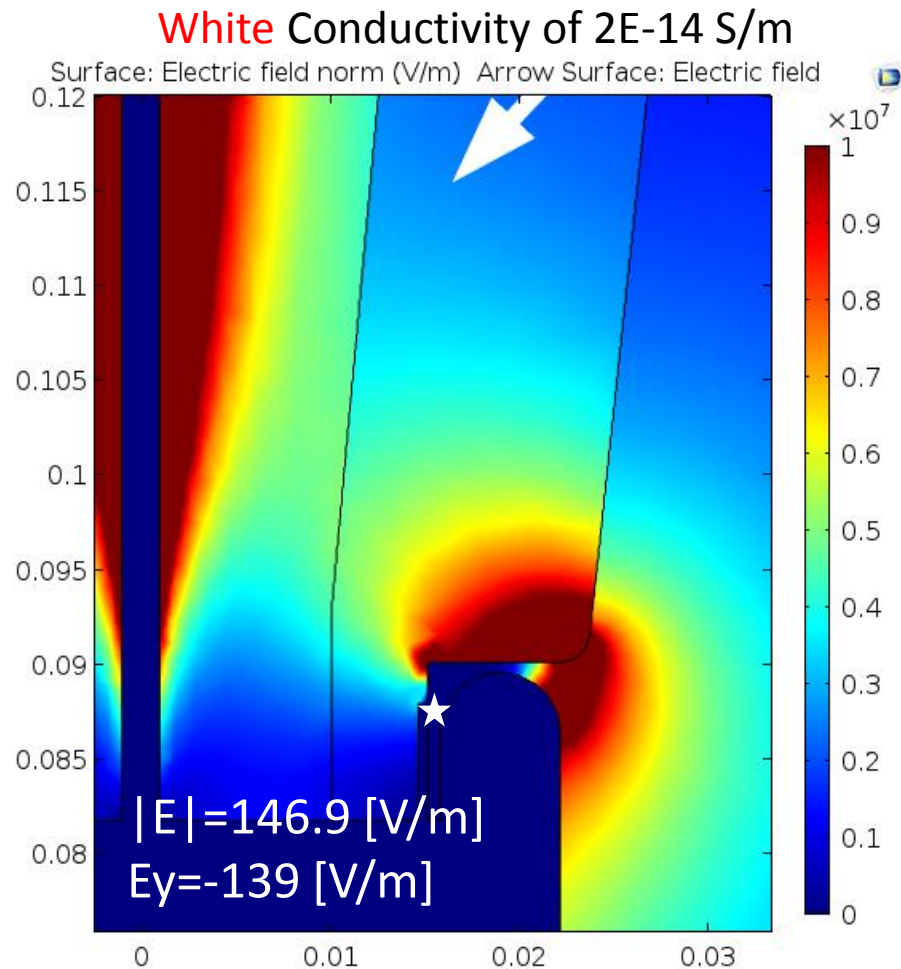
Rubber plug-insulator interface:

- The potential and electric field along the rubber plug – ceramic insulator interface was obtained (as shown in the image as a red dotted line), <u>plotted as a function of the height (y-coordinate)</u> and compared for between the white insulator without shed (representing the actual CEBAF gun) and the black insulator with shed (representing the improved version).
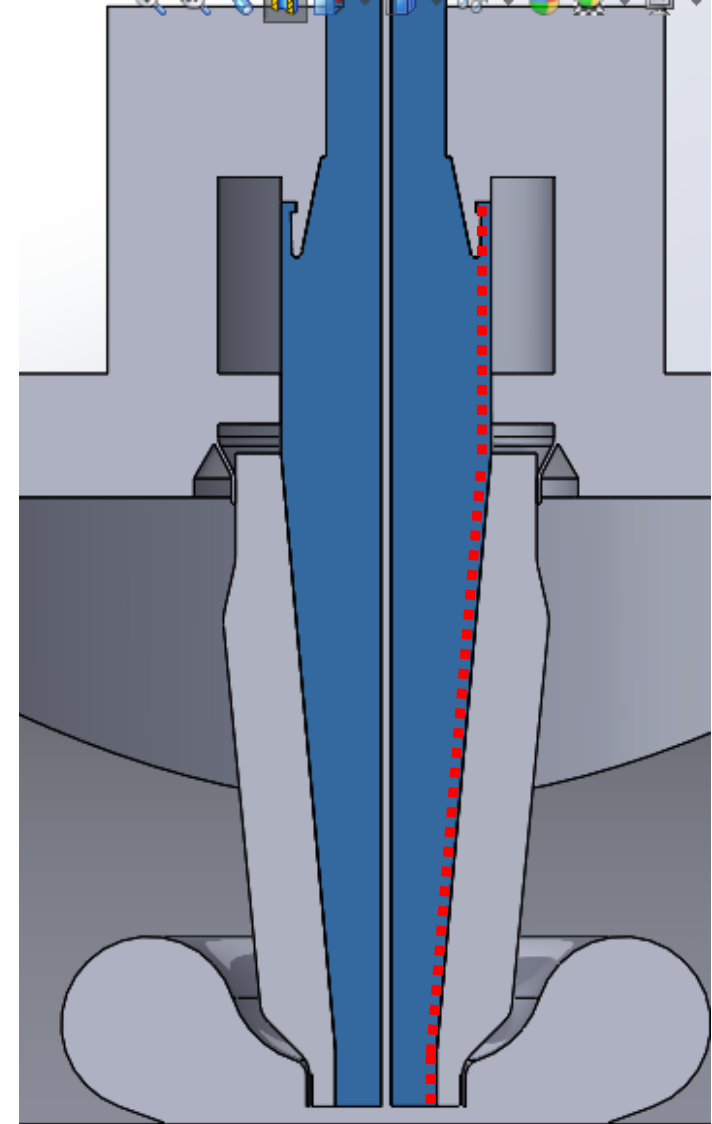
Potential:

The interpolated fields along the rubber plug-insulator interface shows the linearization effect related to the combined effects of the doping of the insulator material that allows for a bulk current and the presence of the shed. The black line represents the ideal case.
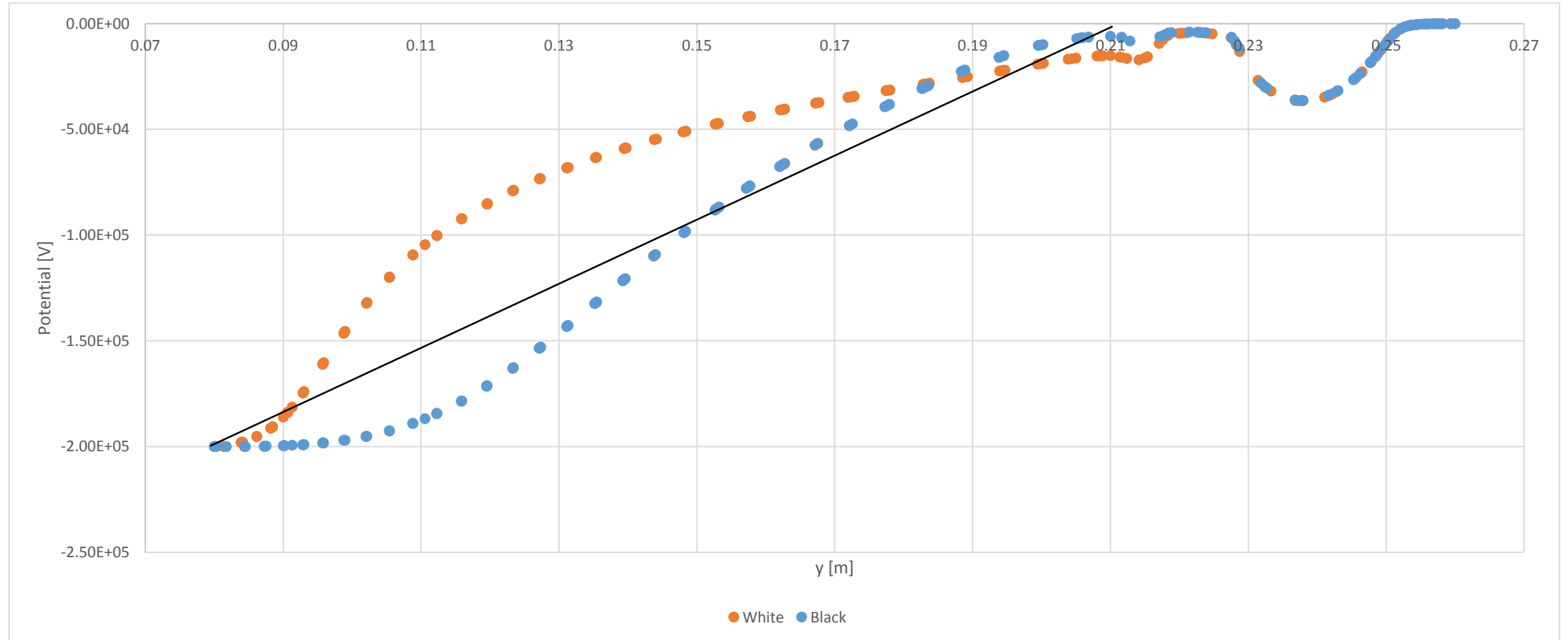
Potential along insulator:

The interpolated fields along the rubber plug-insulator interface shows the linearization effect related to the combined effects of the doping of the insulator material that allows for a bulk current and the presence of the shed. The black line represents the ideal case.
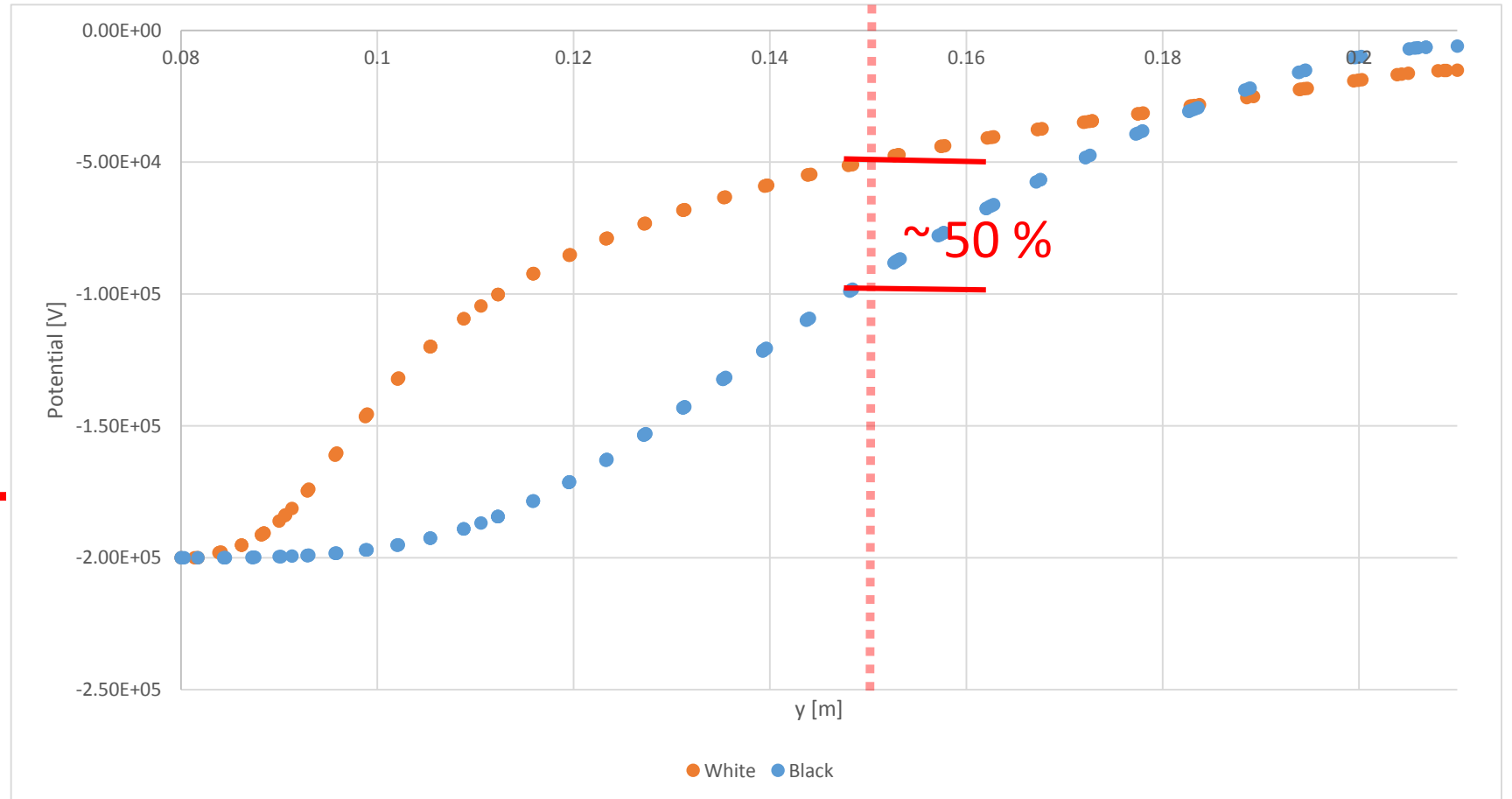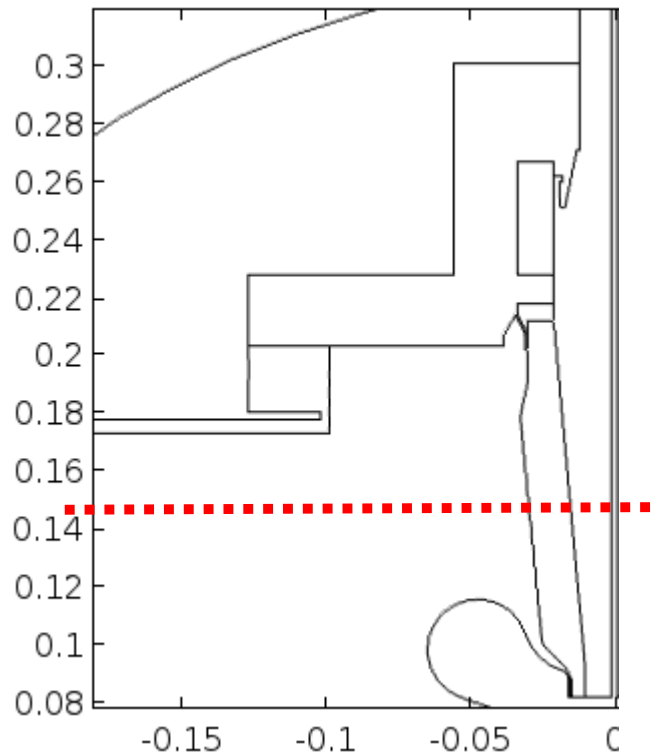
Electric field in the y-direction:

The simulation shows that the implementation of the shed near the triple-point junction decreases the magnitude of the field in ~92.9% bringing it closer to zero.
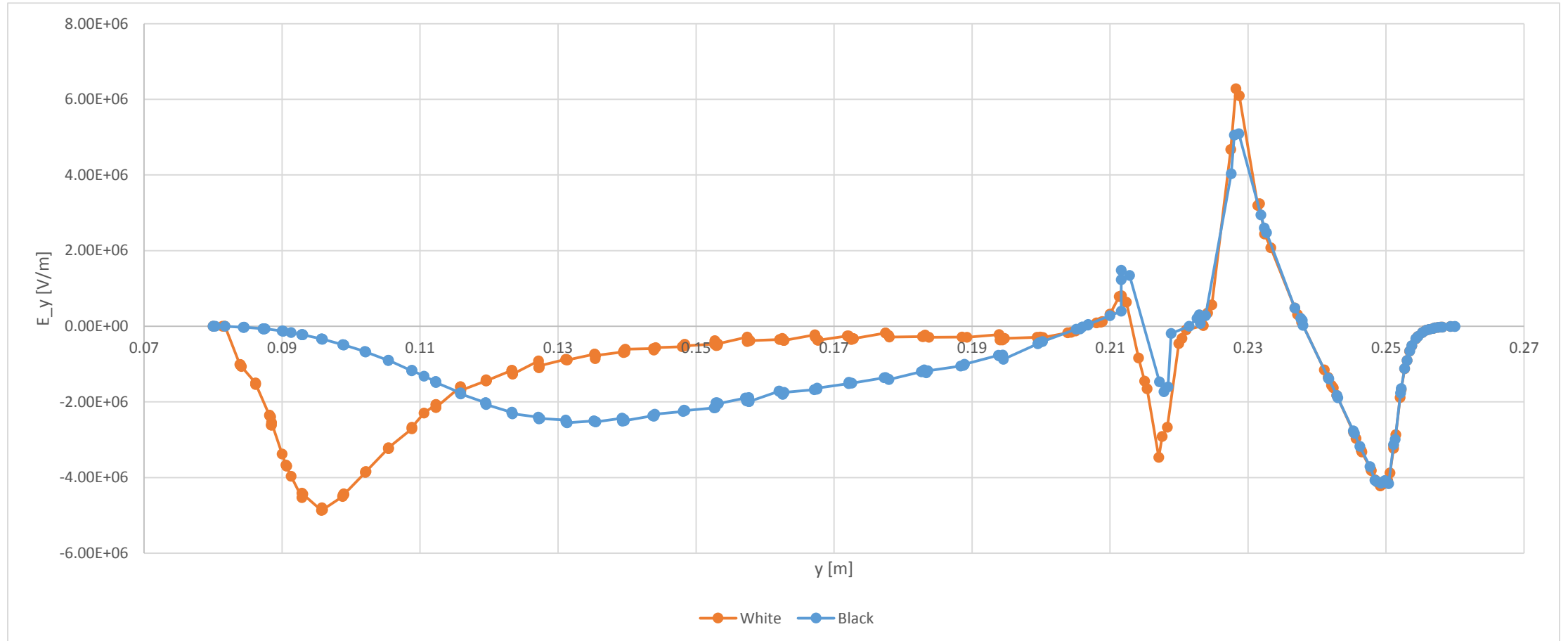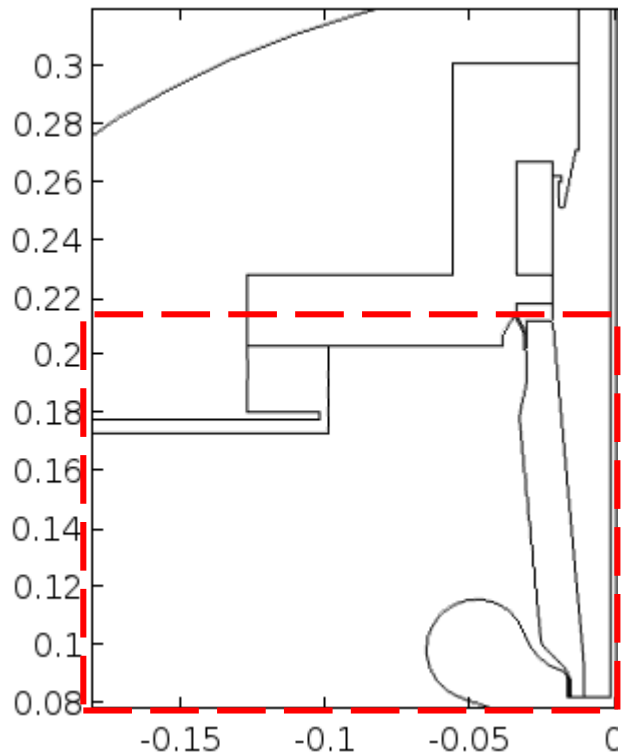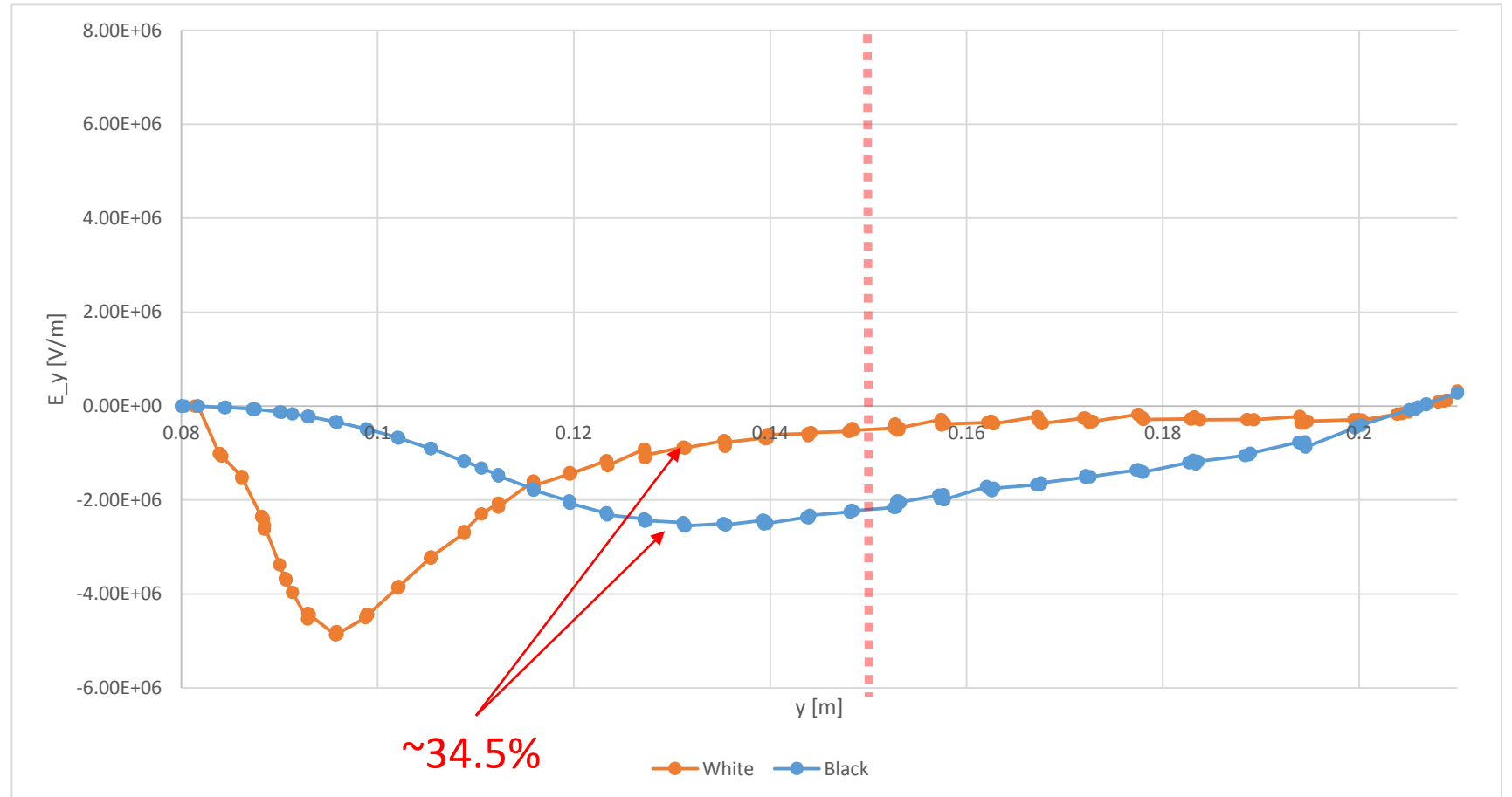
E_y near triple point:

The simulation shows that the implementation of the shed near the triple-point junction decreases the magnitude of the field in ~92.9% bringing it closer to zero.
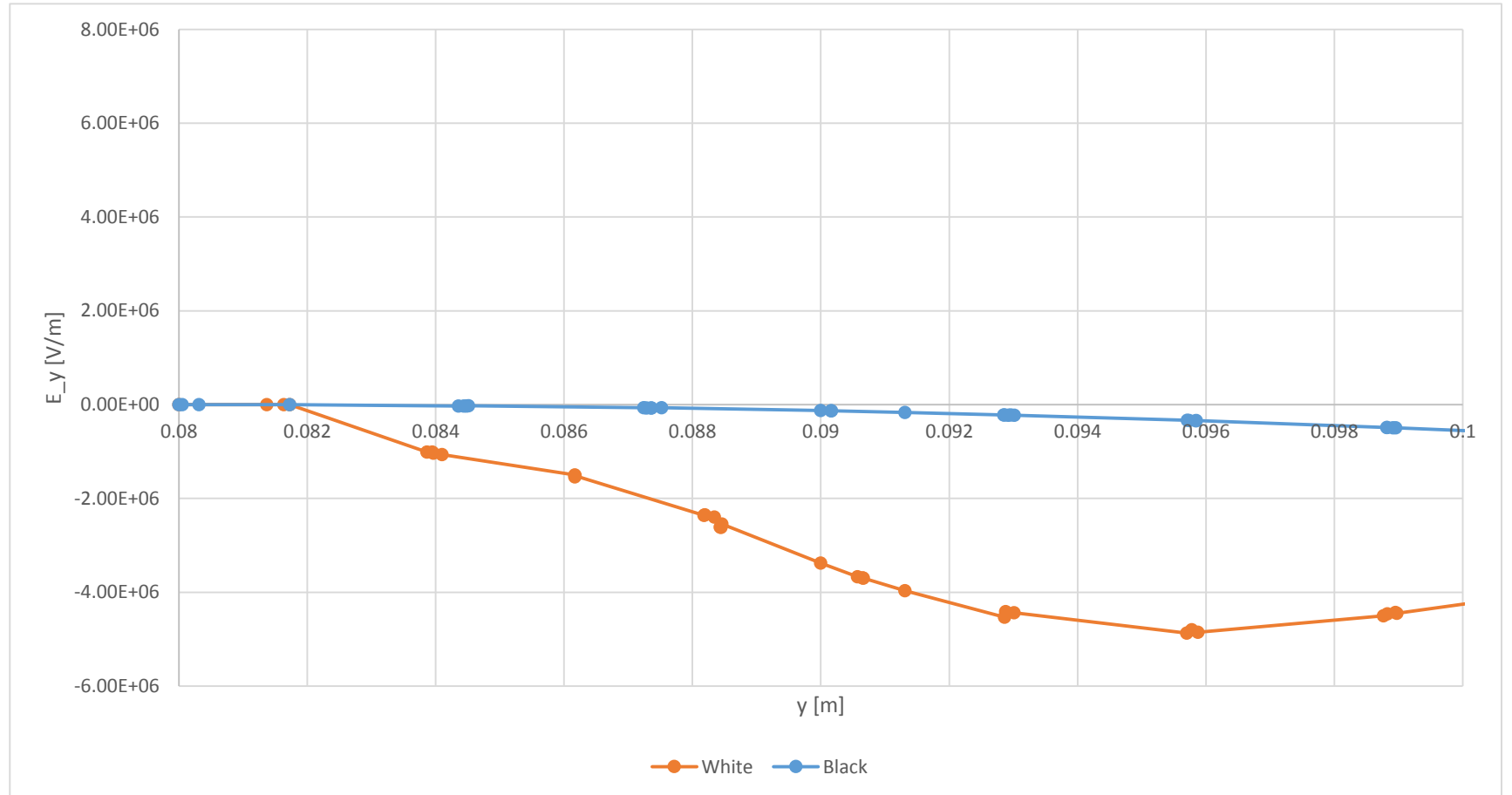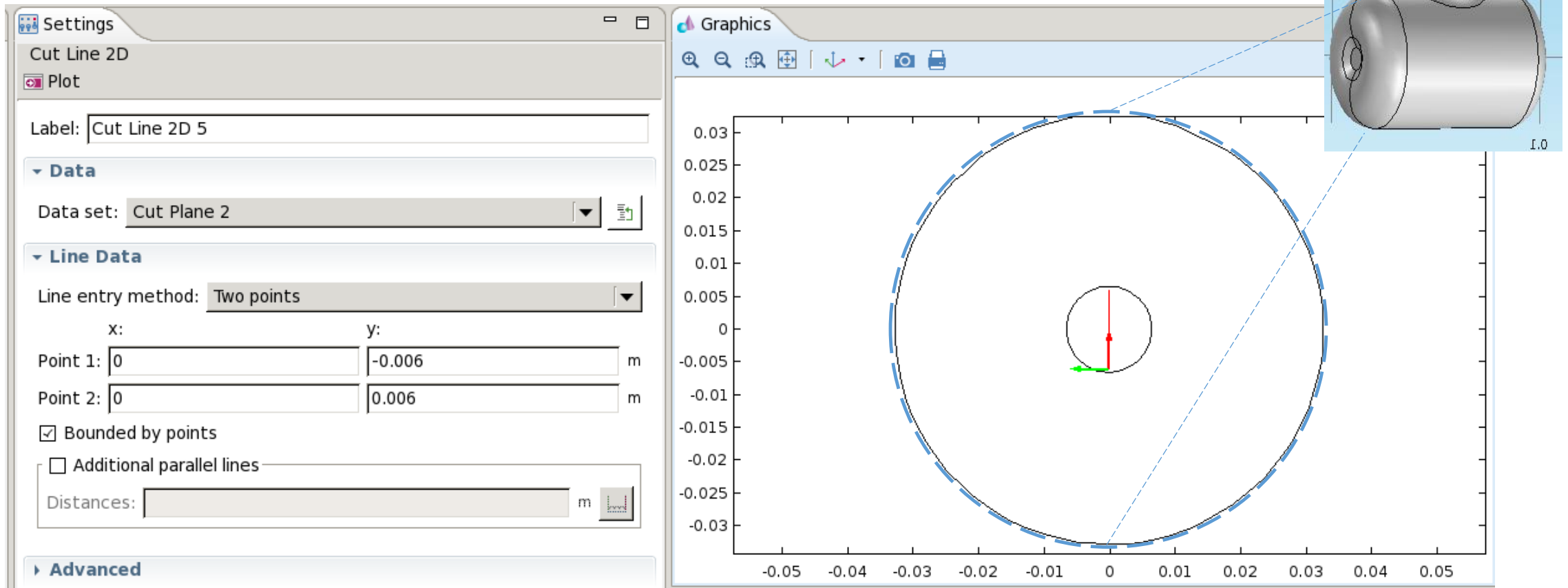
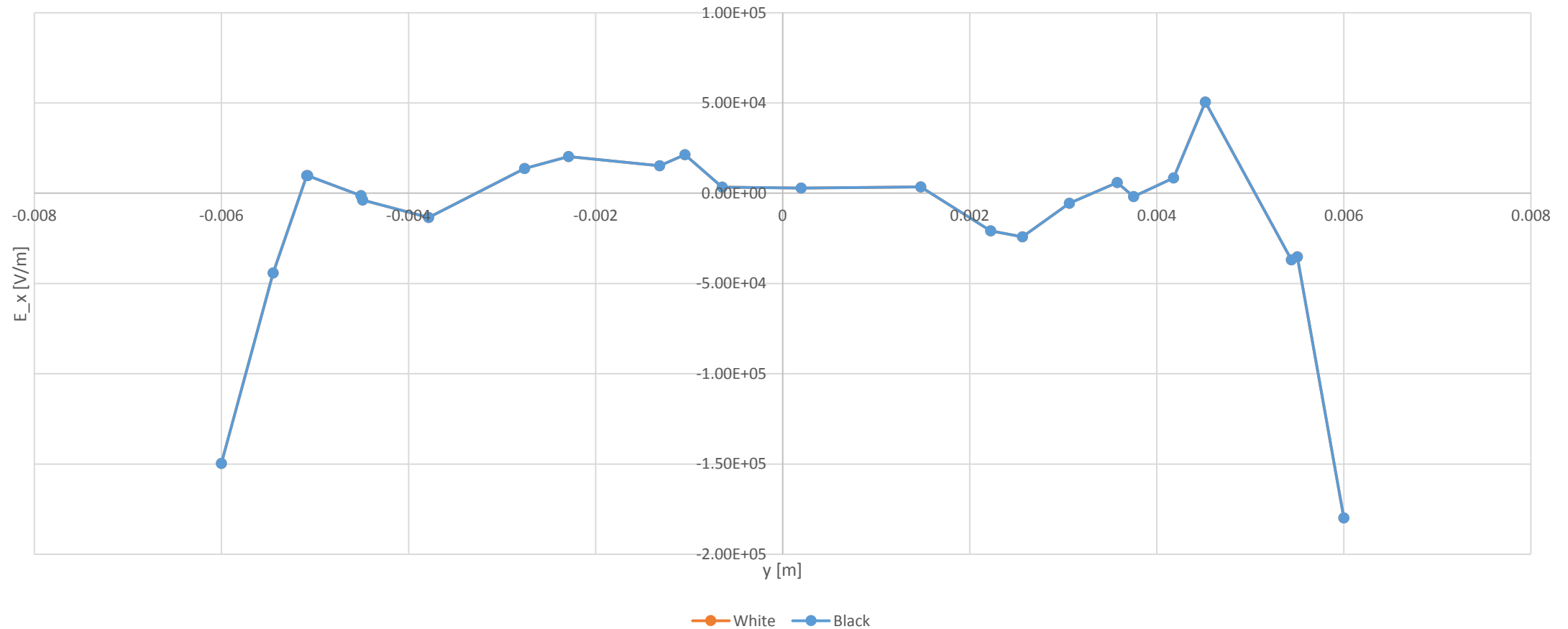# E_y field component along insulator:

The height is ~0.14m

Photocathode vertical line:

The data for the following plots was taken along a vertical line from -6mm to +6mm that passes through the center of the photocathode as shown in the red line
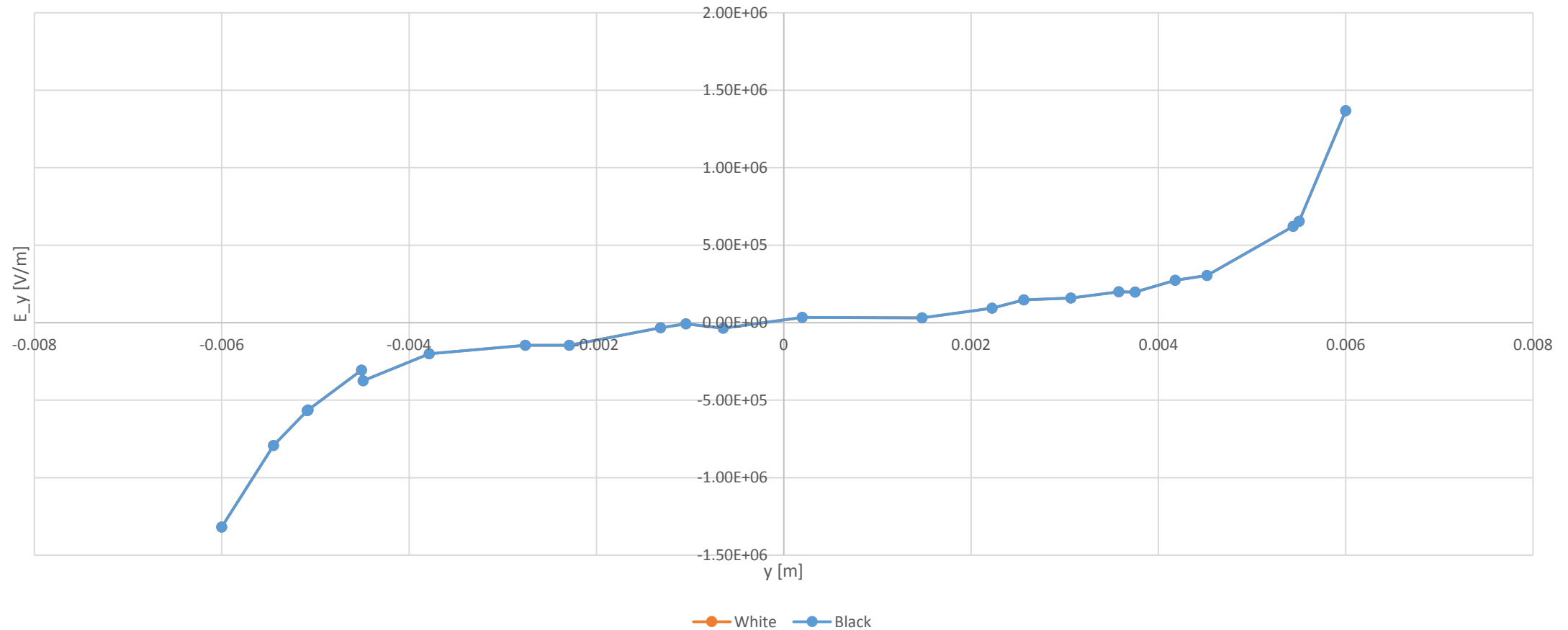
Photocathode vertical line:

- This image shows the electric field Ex component in V/m as a function of position on the y axis.

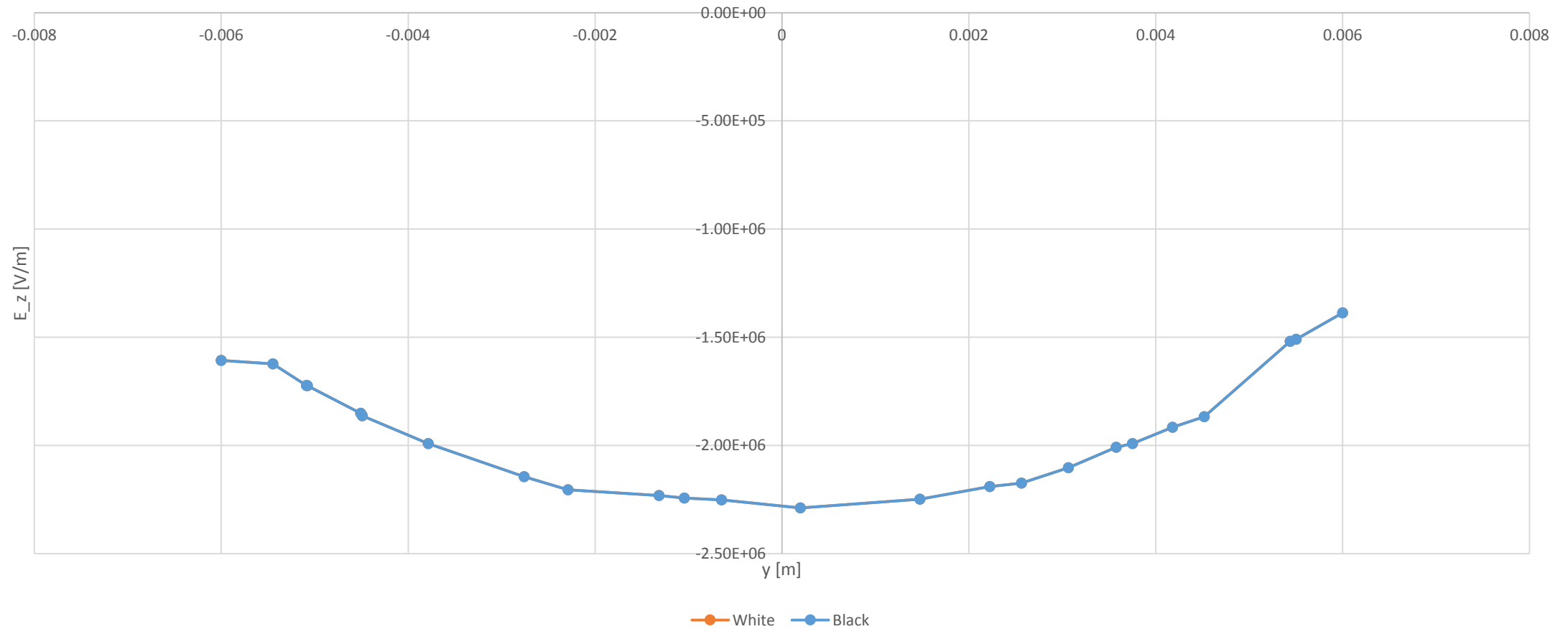Small asymmetry as we go up…

Photocathode vertical line:

- This image shows the electric field Ey component in V/m as a function of position on the y axis.

Small asymmetry as we go up…
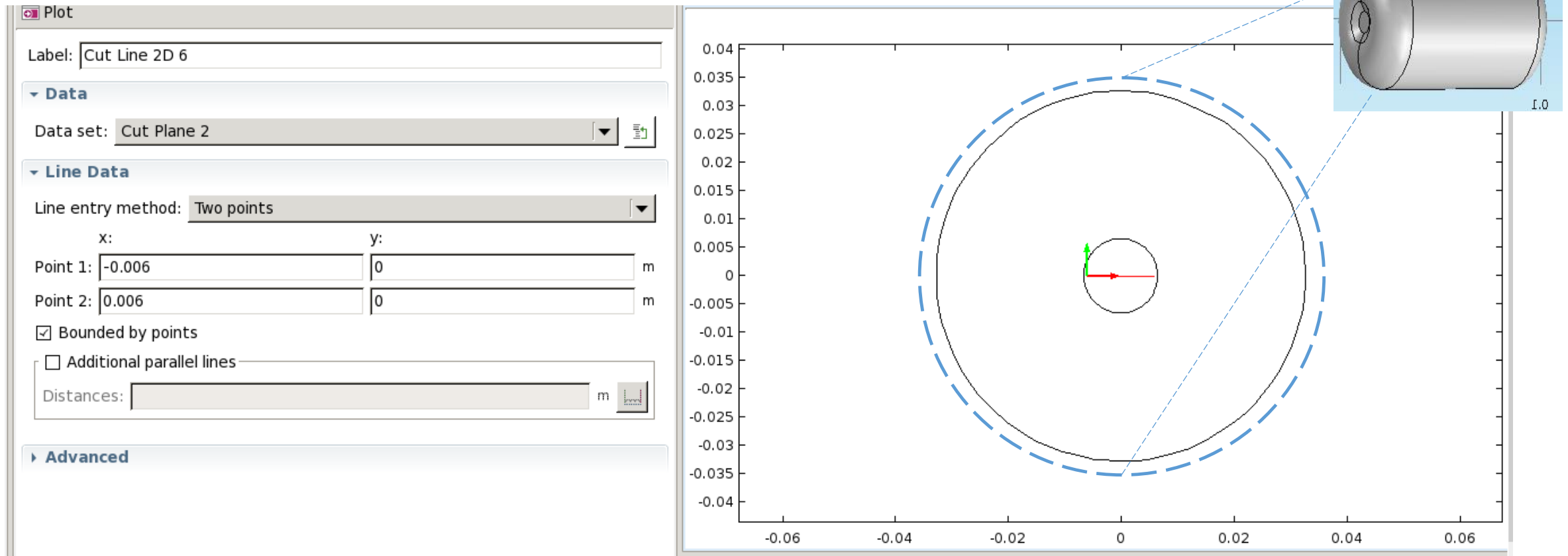
Photocathode vertical line:

- This image shows the electric field Ez component in V/m as a function of position on the y axis.
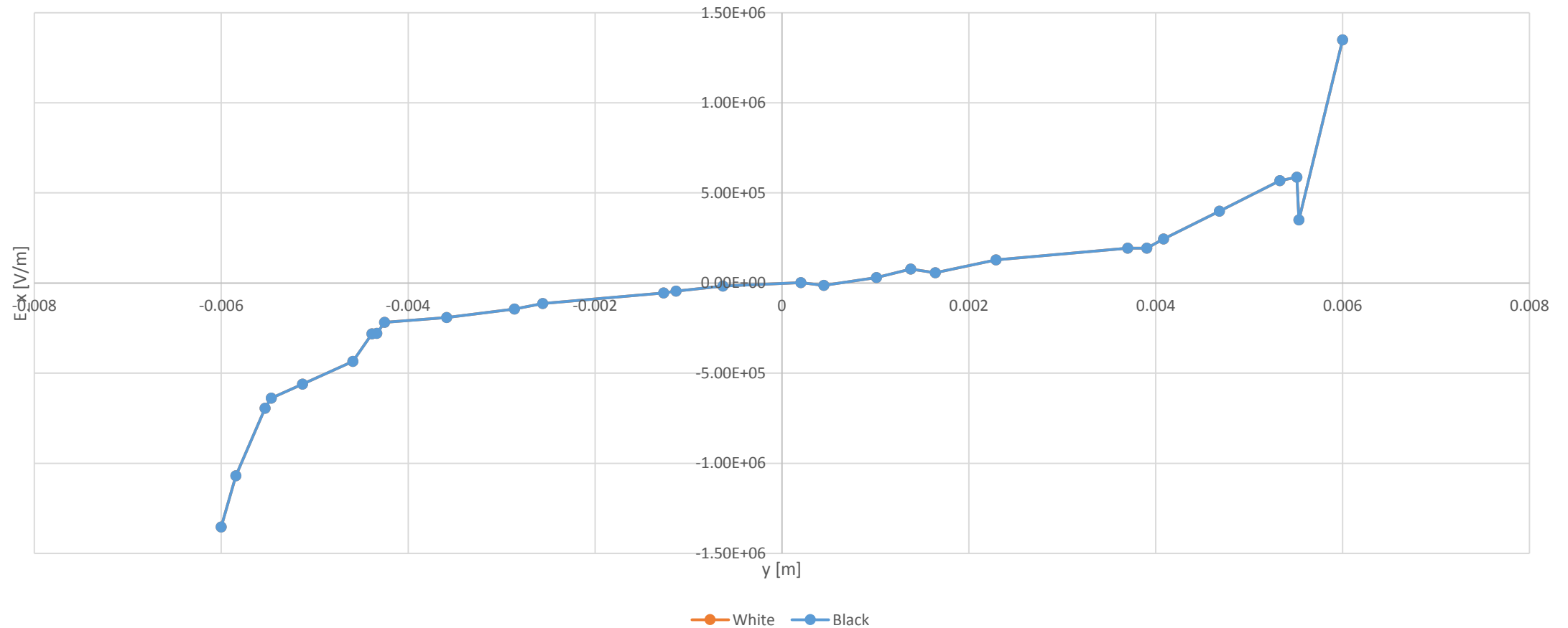

Small asymmetry as we go up...

Photocathode horizontal line:

The data for the following plots was taken along a horizontal line from -6mm to +6mm that passes through the center of the photocathode as shown in the red line
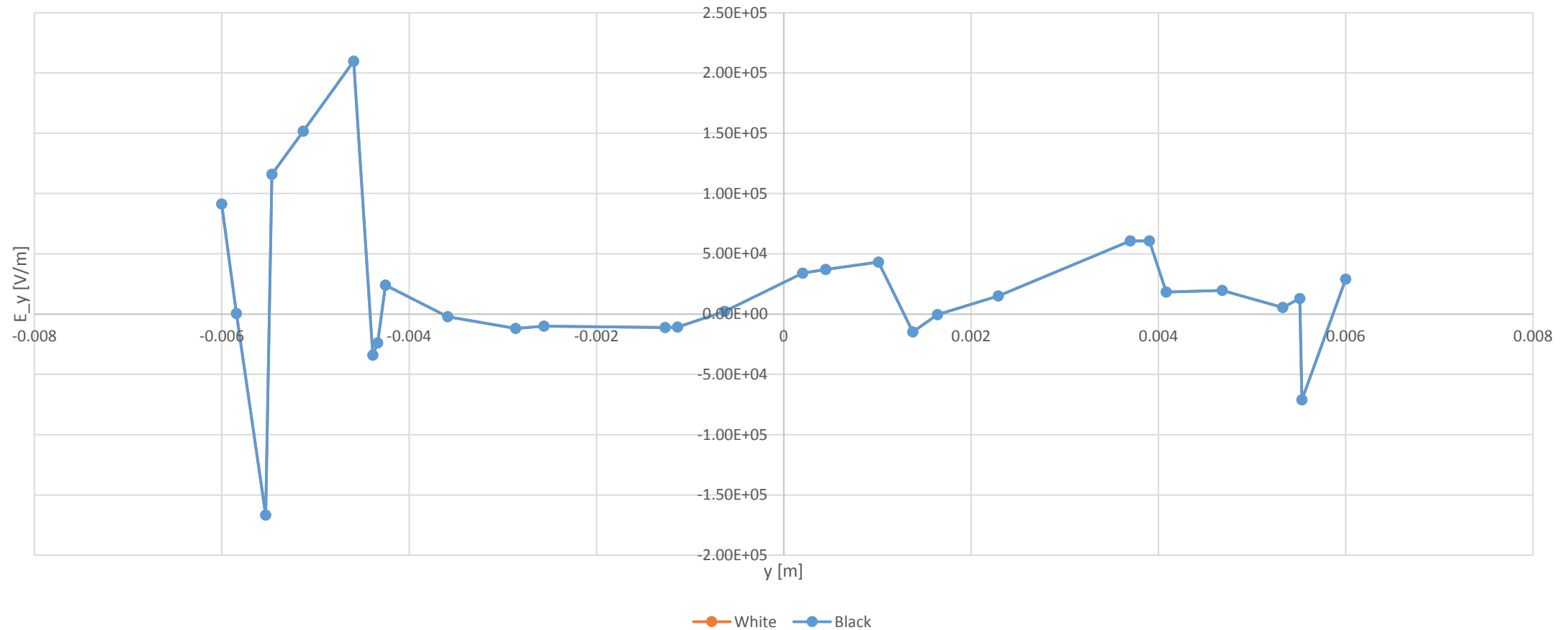
Photocathode horizontal line:

- This image shows the electric field Ex component in V/m as a function of position on the y axis.

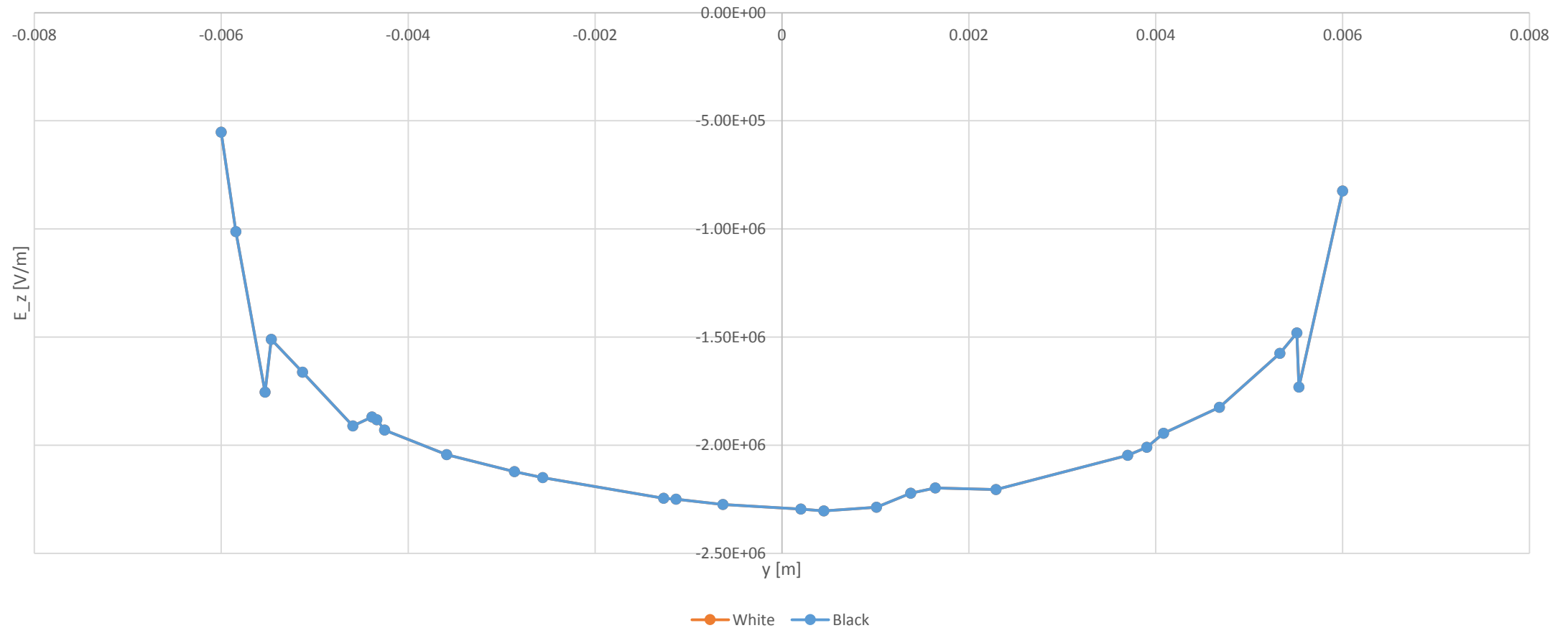Small asymmetry as we go up…

Photocathode horizontal line:

- This image shows the electric field Ey component in V/m as a function of position on the y axis.

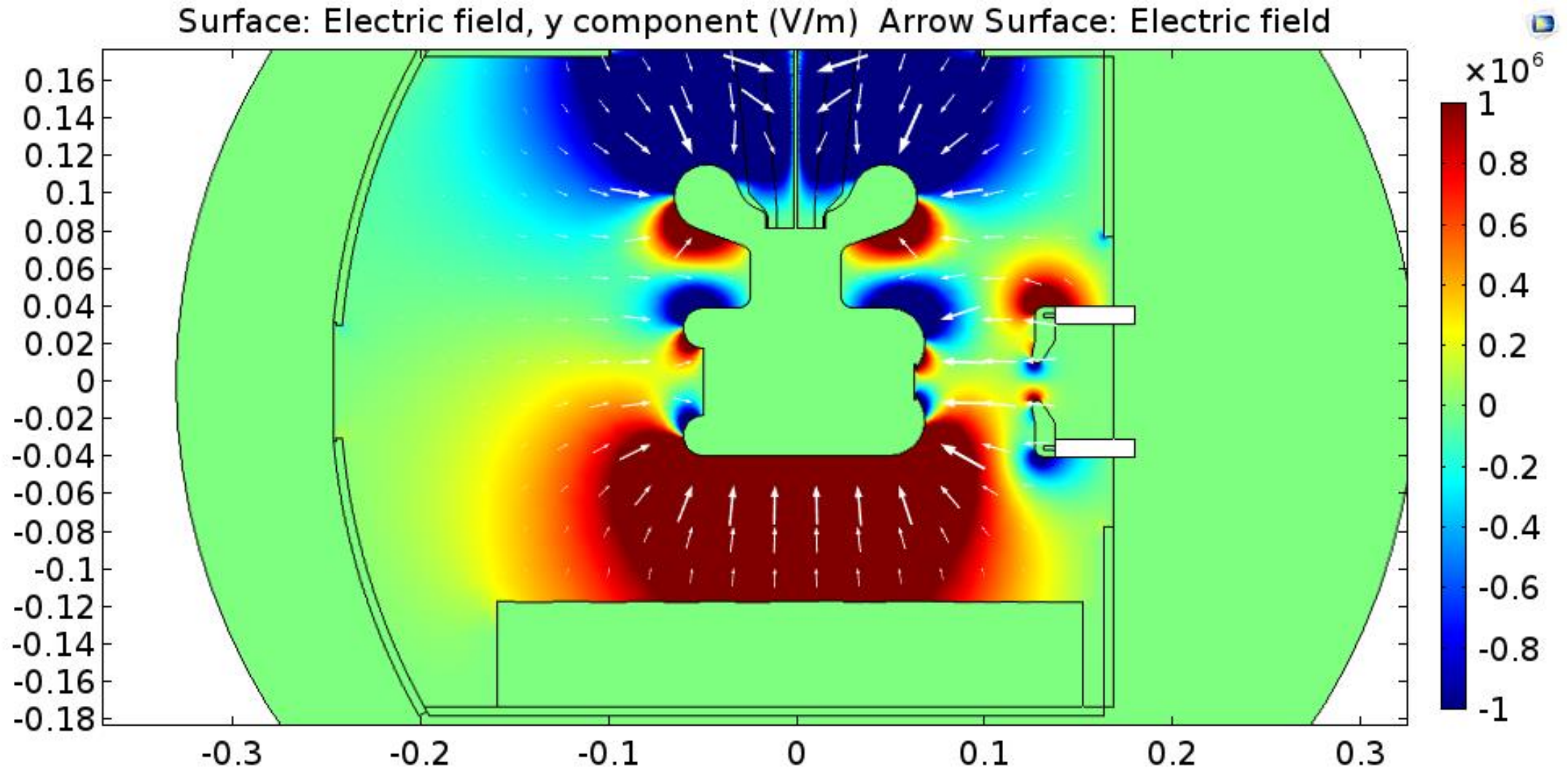Small asymmetry as we go up…

Photocathode horizontal line:

- This image shows the electric field Ez component in V/m as a function of position on the y axis.
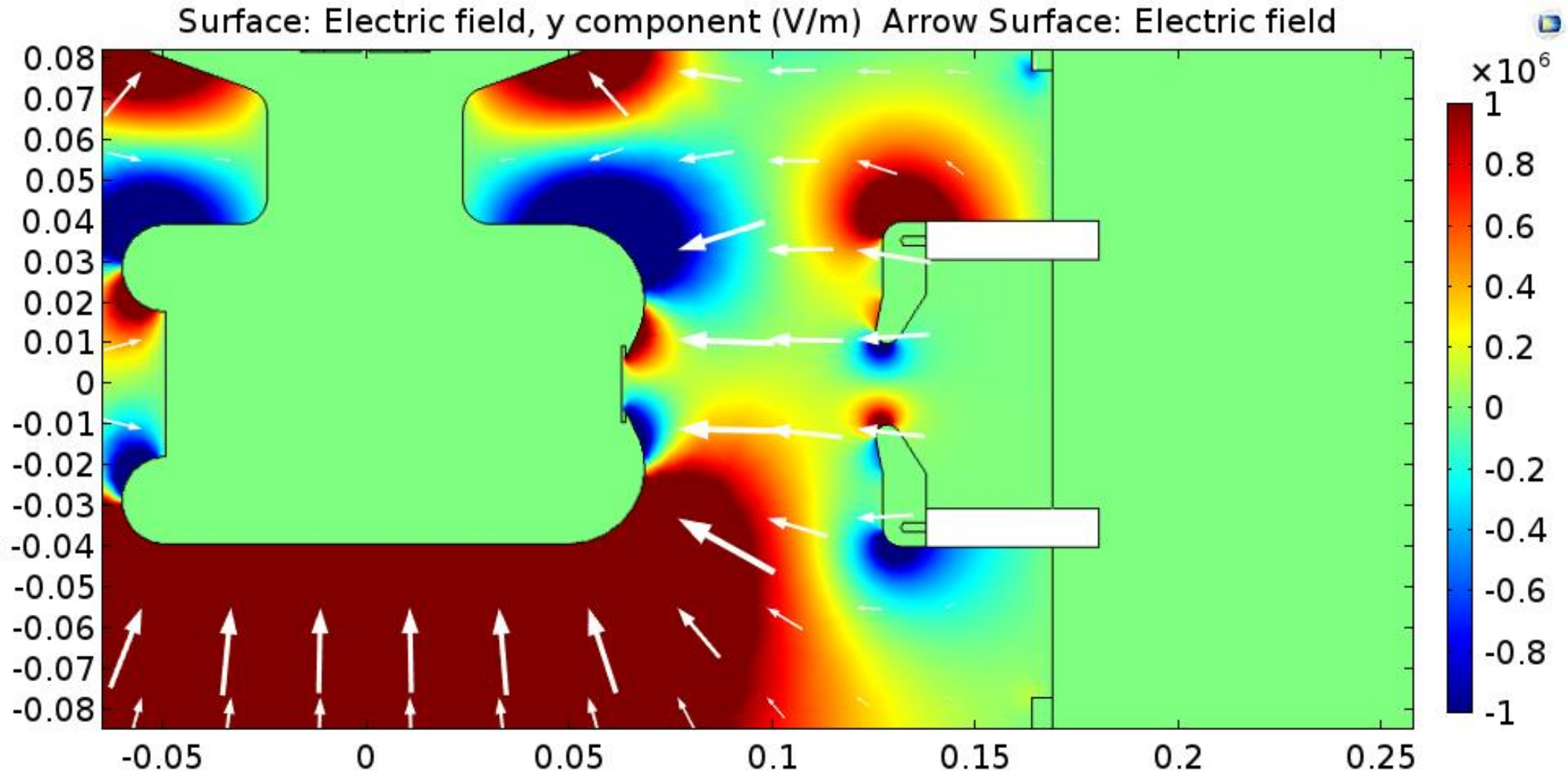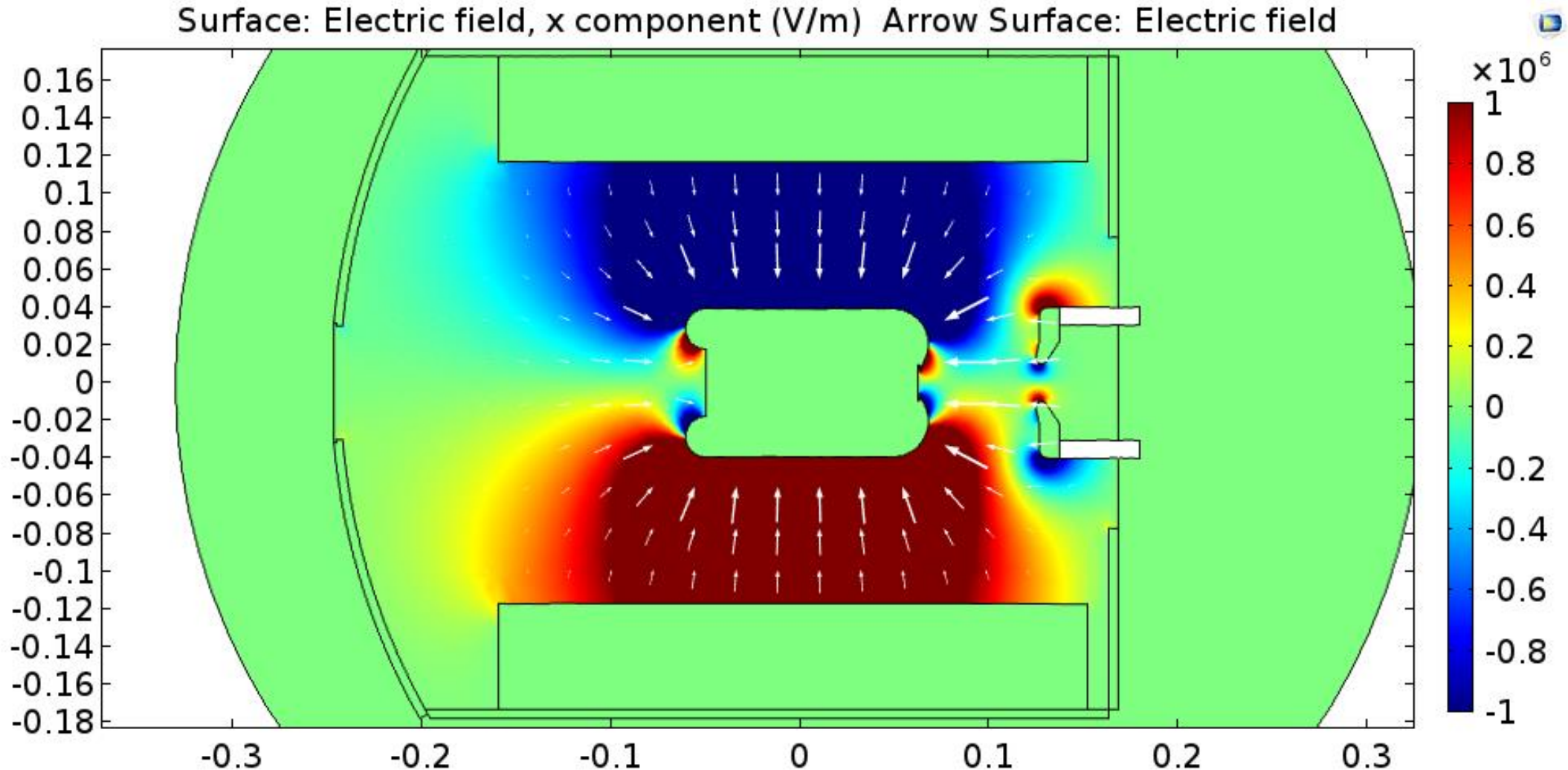

Small asymmetry as we go up…

Electric field- y component: side view

The image shows the y component of the electric field plotted as color intensity. The arrows are the components of the norm of E on the plane and they are proportional to the intensity.

Surface: Electric field, y component (V/m)   Arrow Surface: Electric field

Electric field- y component: side view

The image shows the y component of the electric field plotted as color intensity. The arrows are the components of the norm of E on the plane and they are proportional to the intensity.
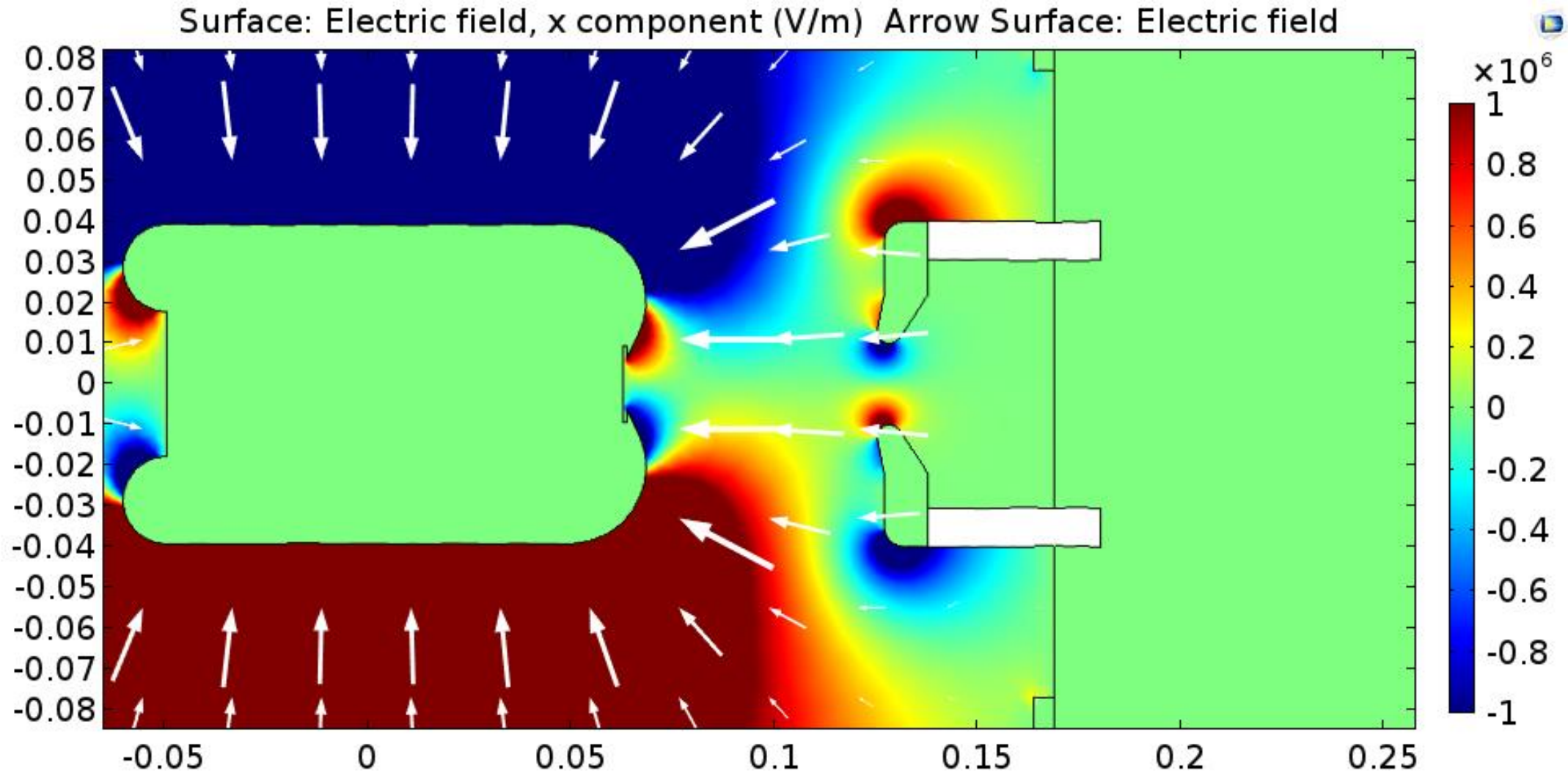

Surface: Electric field, y component (V/m) Arrow Surface: Electric field

Electric field- x component: top view

The image shows the x component of the electric field plotted as color intensity. The arrows are the components of the norm of E on the plane and they are proportional to the intensity.

Surface: Electric field, x component (V/m) Arrow Surface: Electric field

Electric field- x component: top view

The image shows the x component of the electric field plotted as color intensity. The arrows are the components of the norm of E on the plane and they are proportional to the intensity.

Surface: Electric field, x component (V/m) Arrow Surface: Electric field

Photocathode-anode line:

The data for the following plots was taken along a horizontal line from the center of the photocathode to the back of the chamber passing through the anode center as shown in the red line
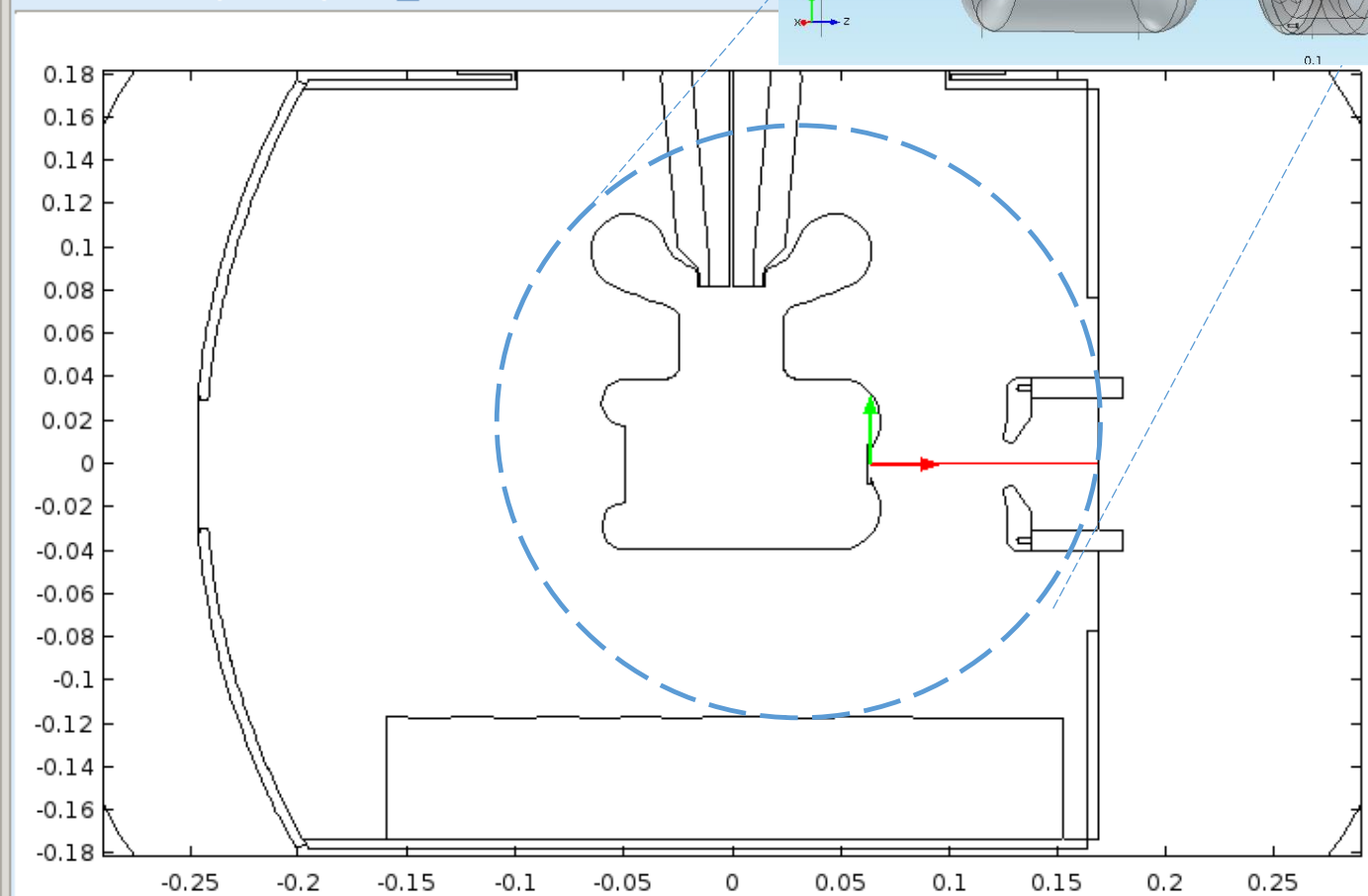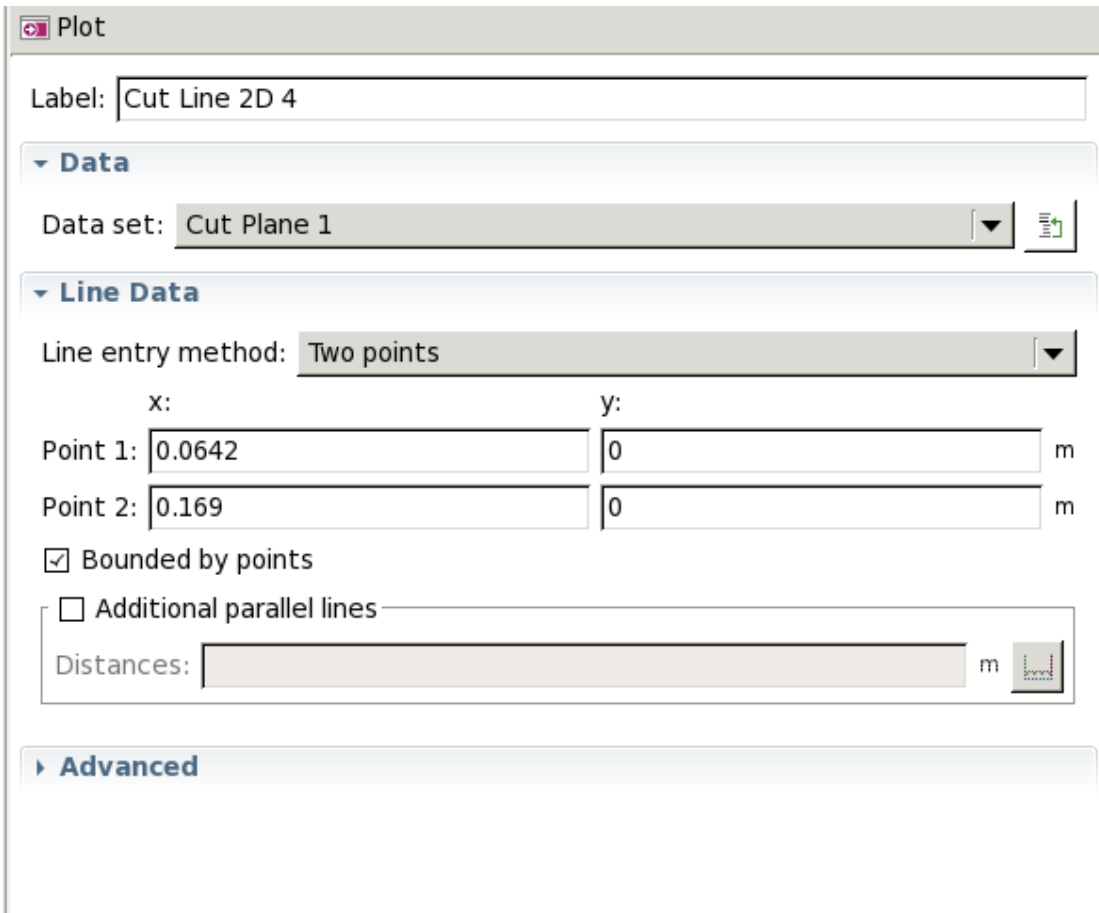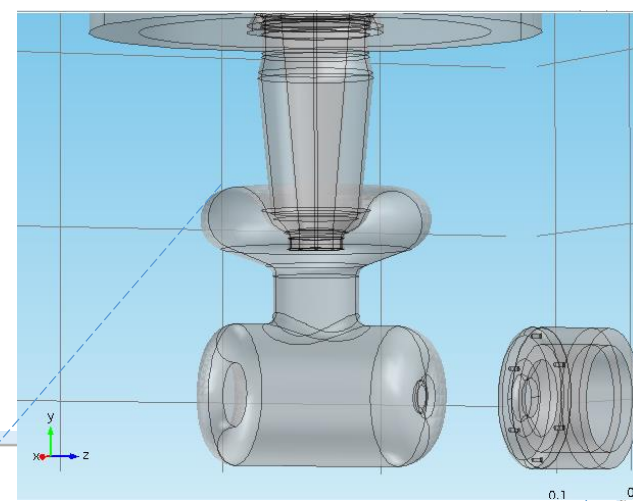
Photocathode-anode line :

- This image shows the electric field Ey component in V/m as a function of position on the z axis.
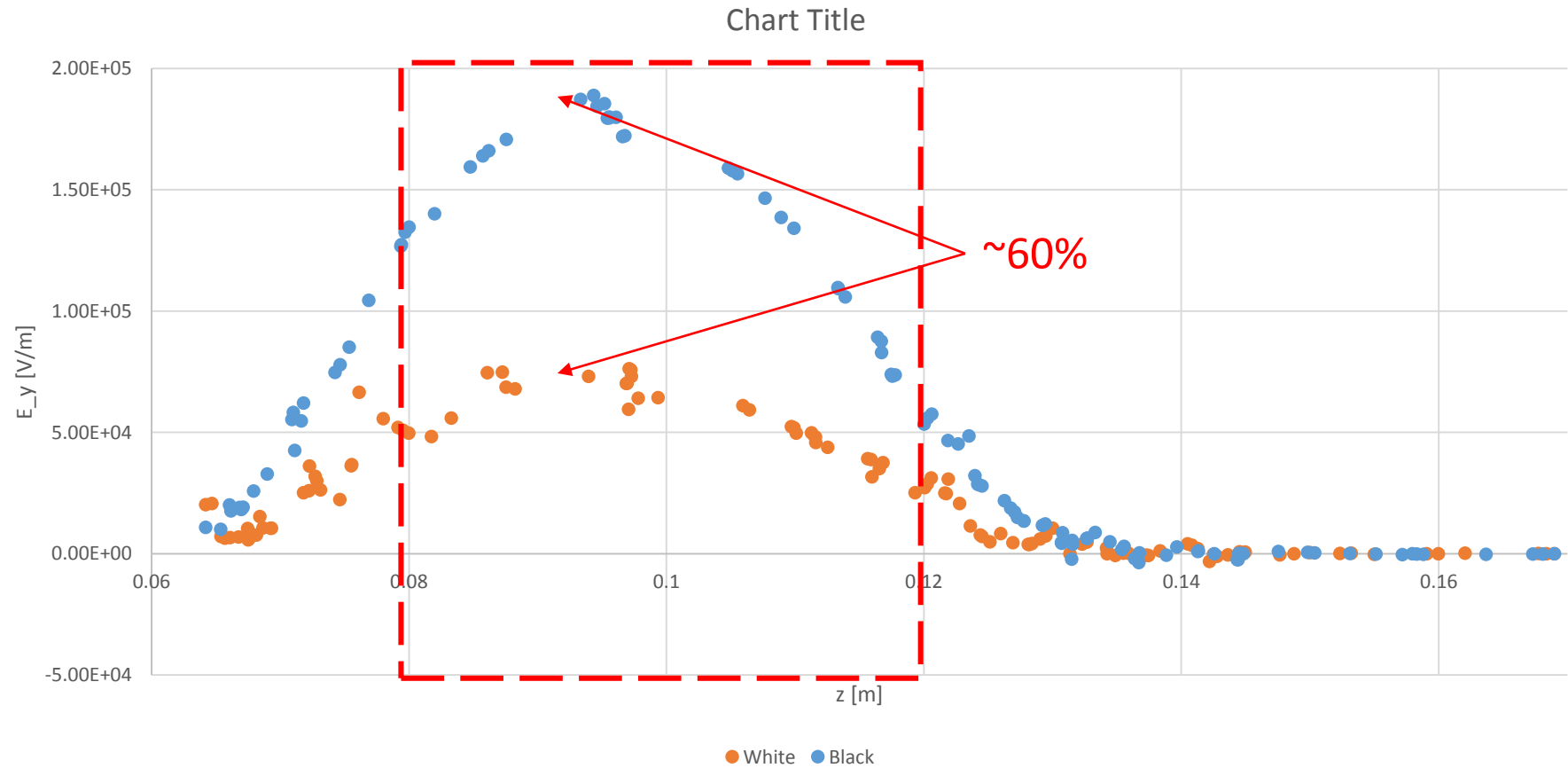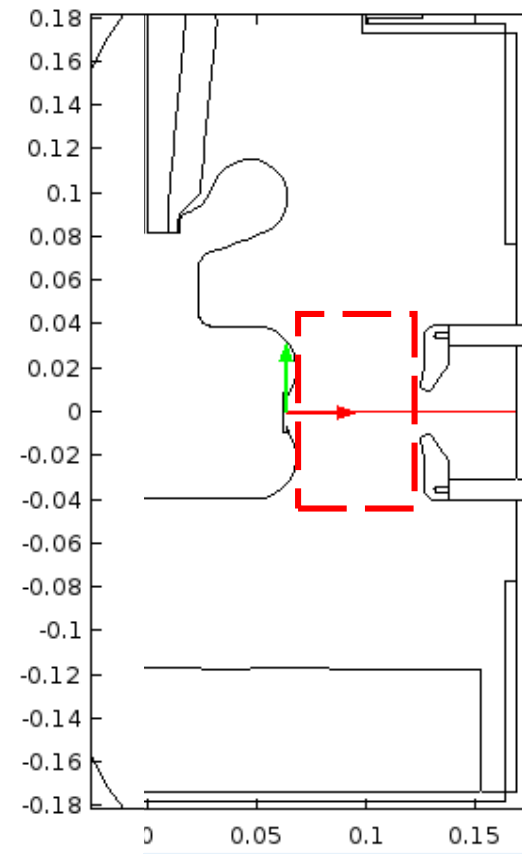
Future steps.

- Beam pipe field maps.
- 3D electrostatics maps.
- Explore the use of another shed near ground because of the existence of another triple point where the top flange meets the insulator.
- Charge accumulation?
- Beam dynamics?
- GTS?
  - Magnetic fields too!

Fin.

Additional slides

- COMSOL potential R30 vs R28
- Insulator fields
  - $|E|$
  - Ex
  - Ez
- COMSOL frame of reference
- Cathode anode
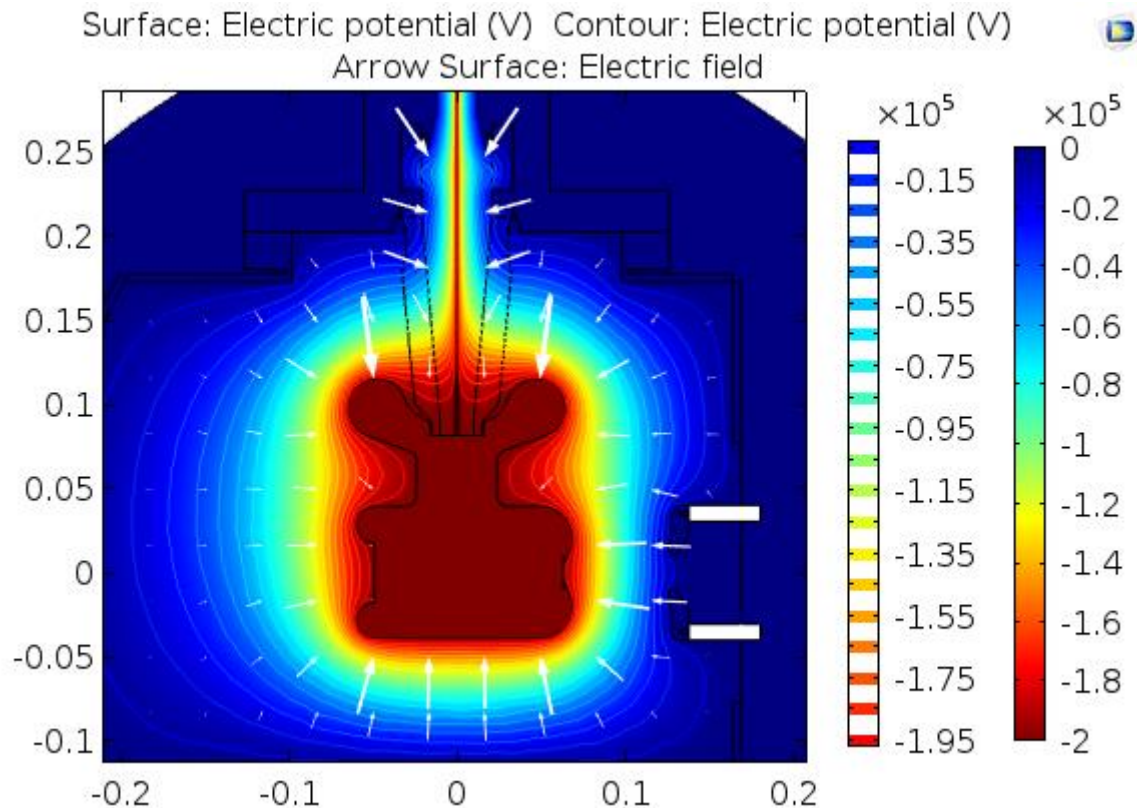 - Ex
  - Ez
- HV processing
  - Anode current
  - Vacuum
  - Green Geiger counter

COMSOL Potential:

- This image shows the potential as color intensity (with equipotential lines). The white arrows size is proportional to the intensity of the electric field at the arrow tip. The axis are coordinates in meters.
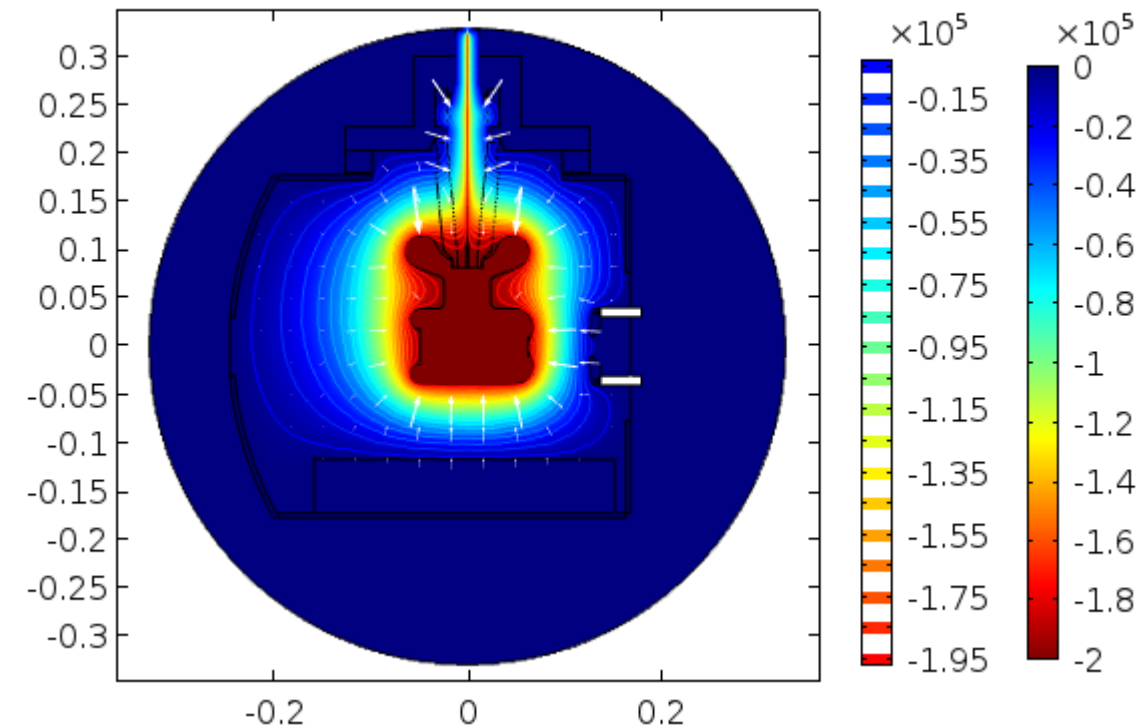
With white alumina conductivity
Conductivity of 2E-14 S/m

With black alumina conductivity
conductivity of 2E-12 S/m

COMSOL Potential:

- This image shows the potential as color intensity (with equipotential lines) closer to the cathode electrode. The white arrows size is proportional to the intensity of the electric field at the arrow tip. The axis are coordinates in meters.
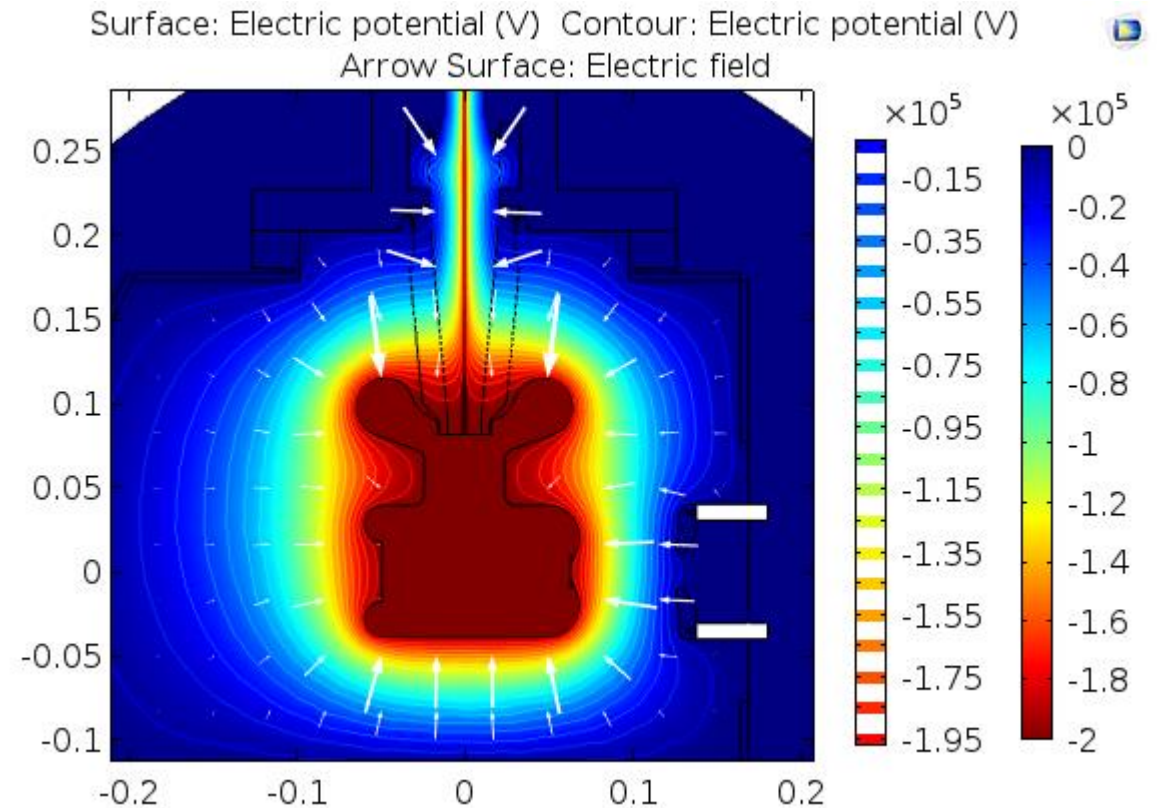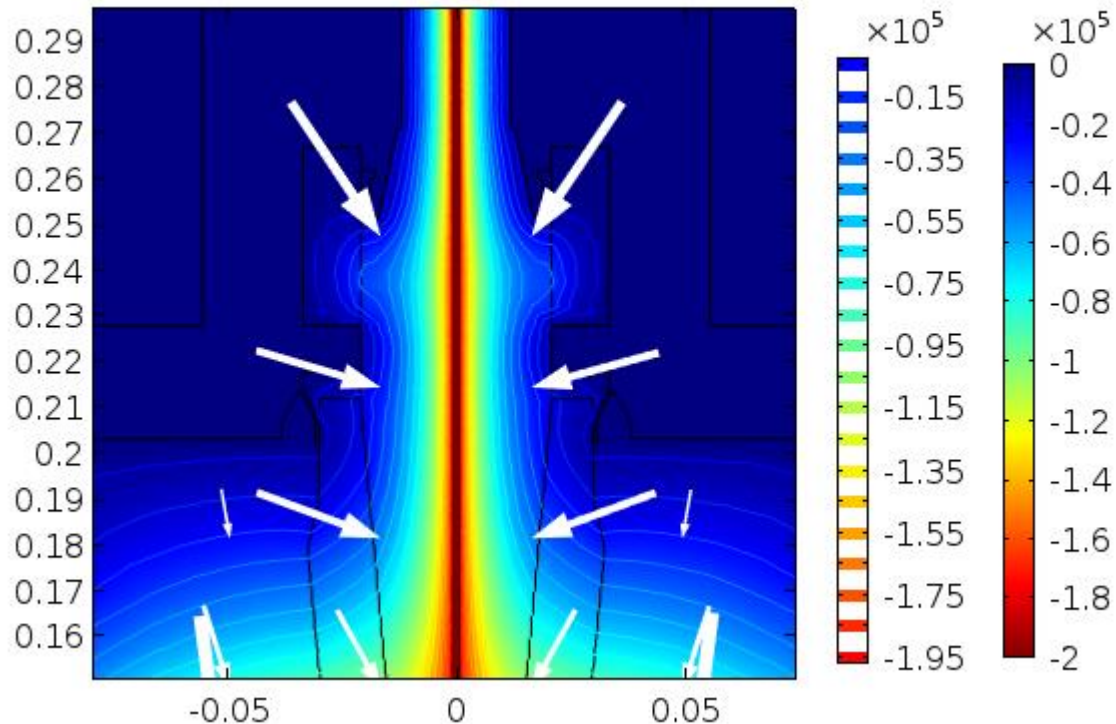

**With white alumina conductivity**
Conductivity of 2E-14 S/m

With black alumina conductivity
conductivity of 2E-12 S/m

COMSOL Potential:

- This image shows the potential as color intensity (with equipotential lines) closer to the upper flange. The white arrows size is proportional to the intensity of the electric field at the arrow tip. The axis are coordinates in meters.

With white alumina conductivity
Conductivity of 2E-14 S/m

With black alumina conductivity
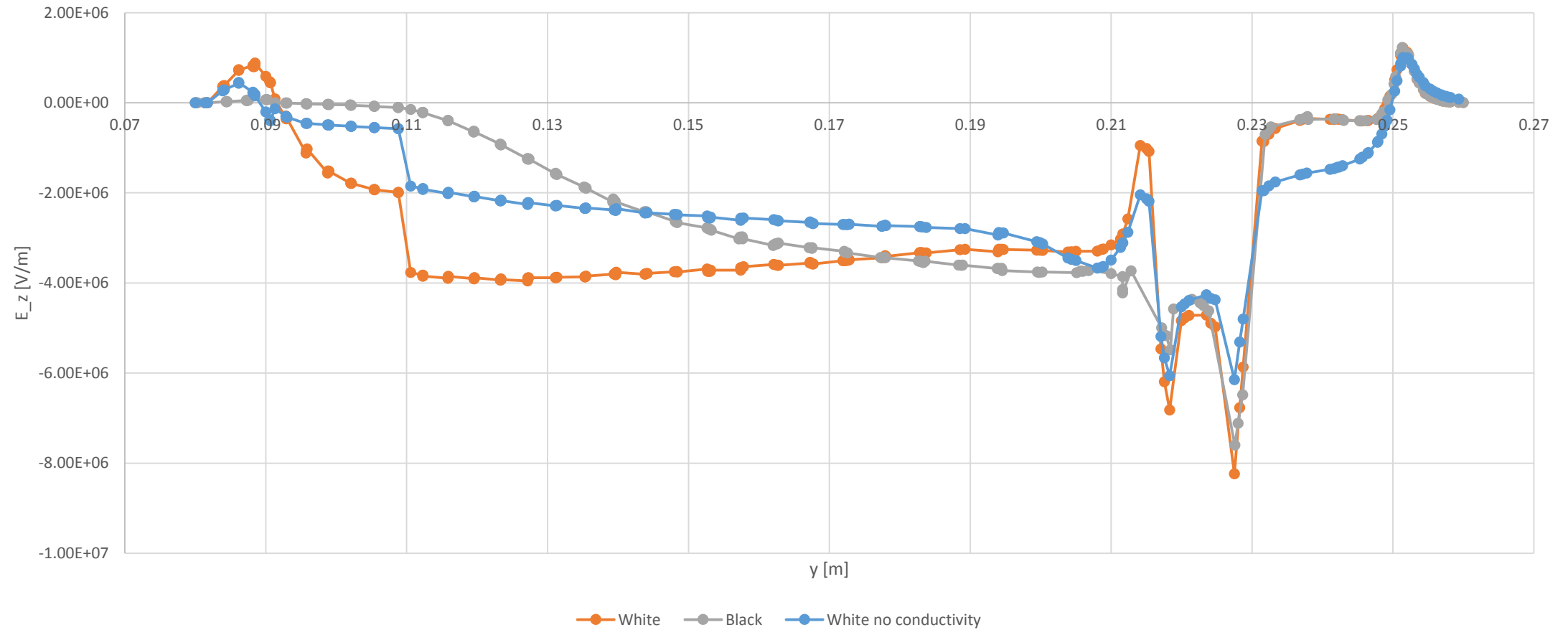conductivity of 2E-12 S/m
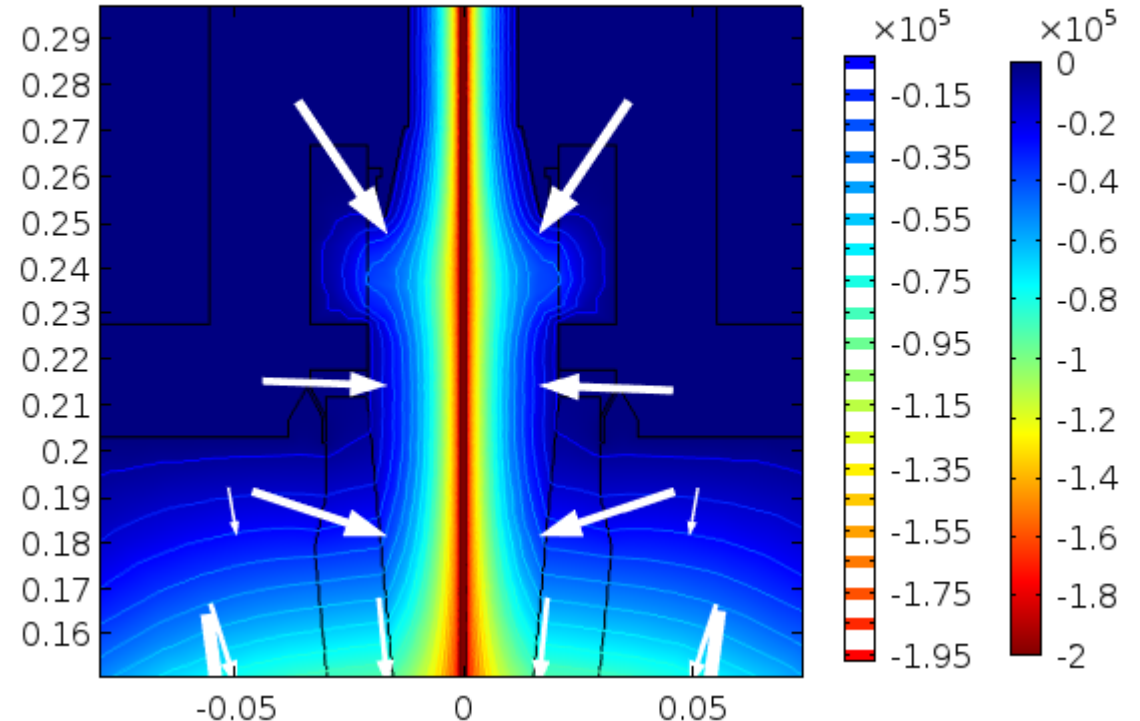
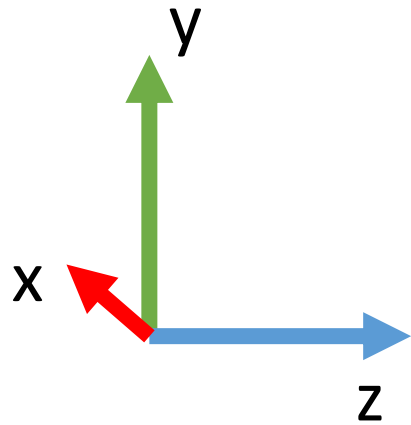# Electric field norm |E| insulator:
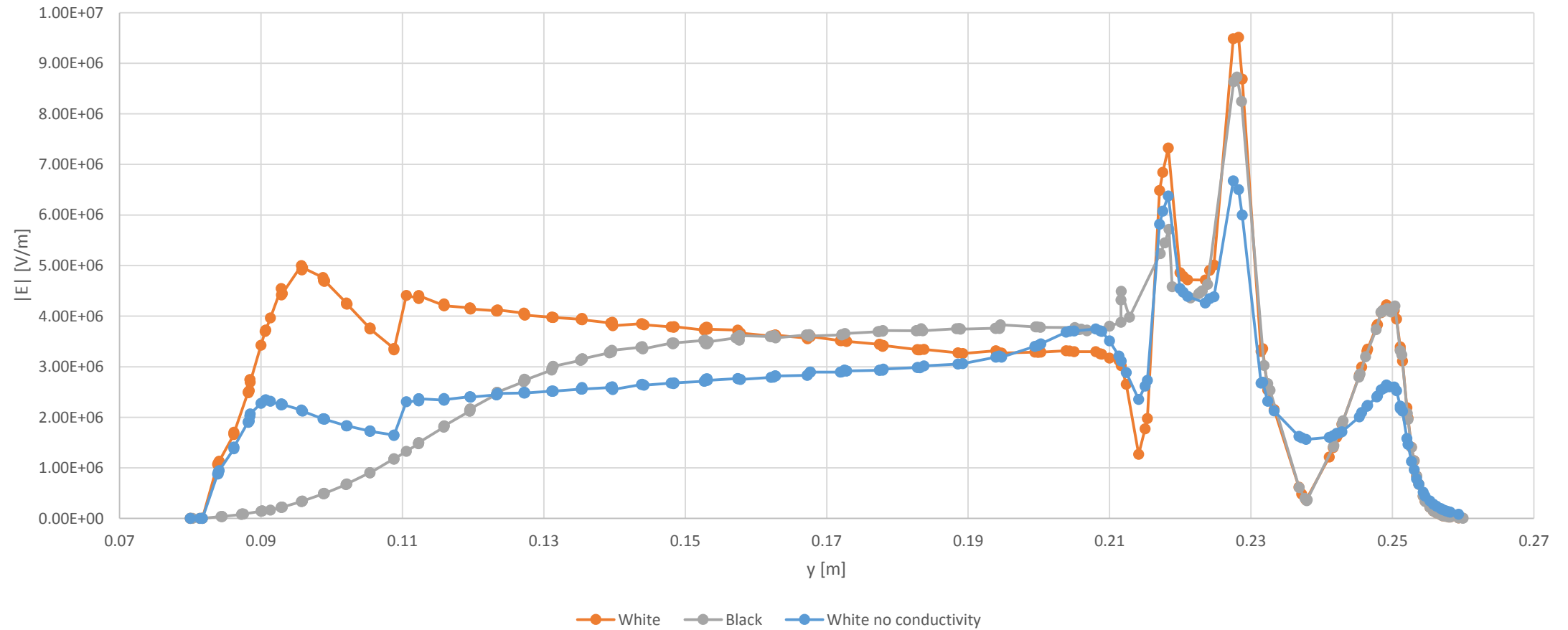
Parallel Electric field Ex insulator:
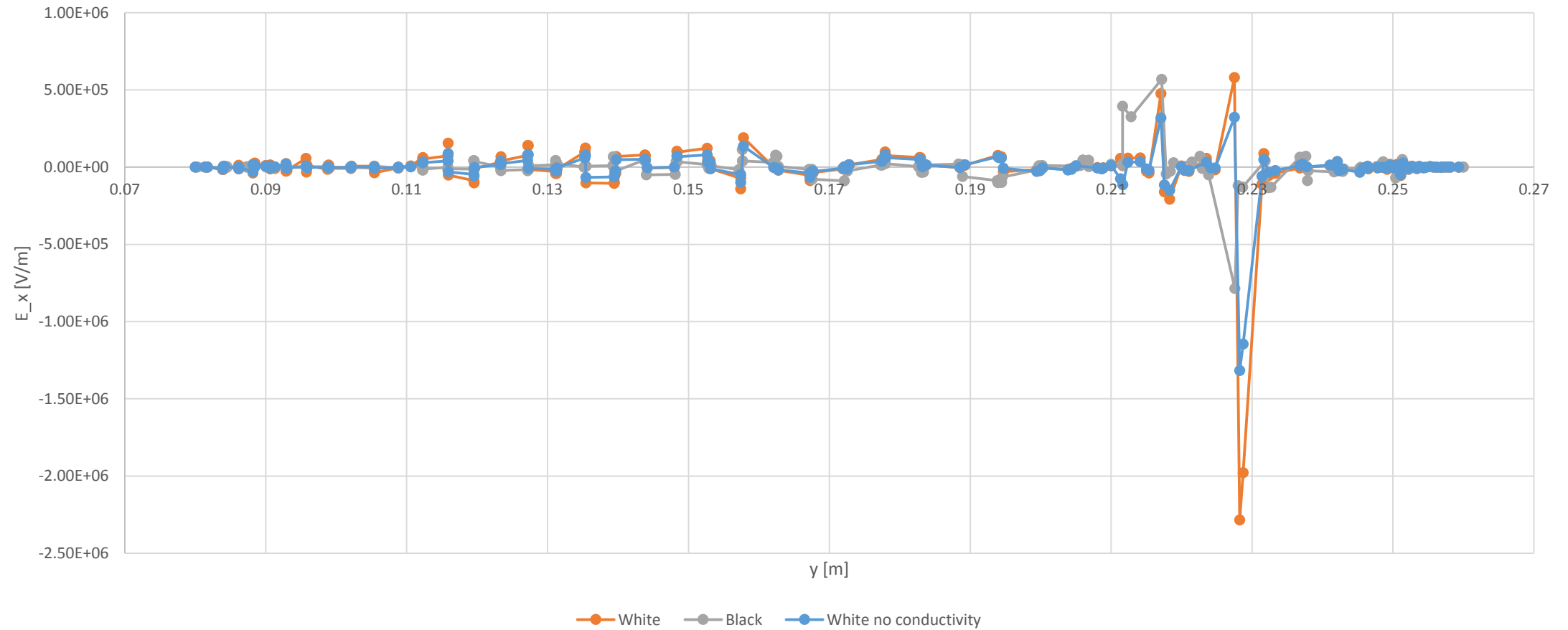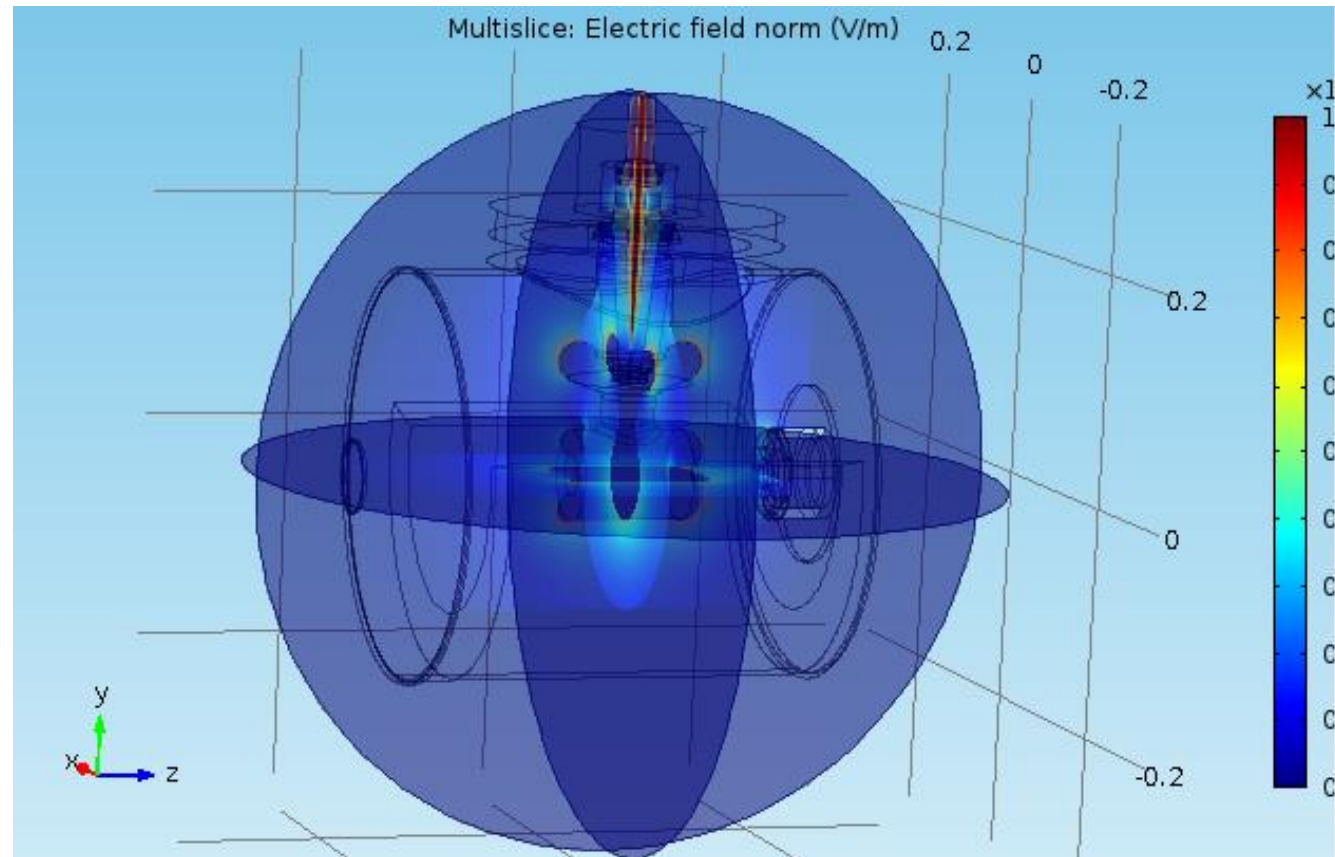
Parallel Electric field Ez insulator:
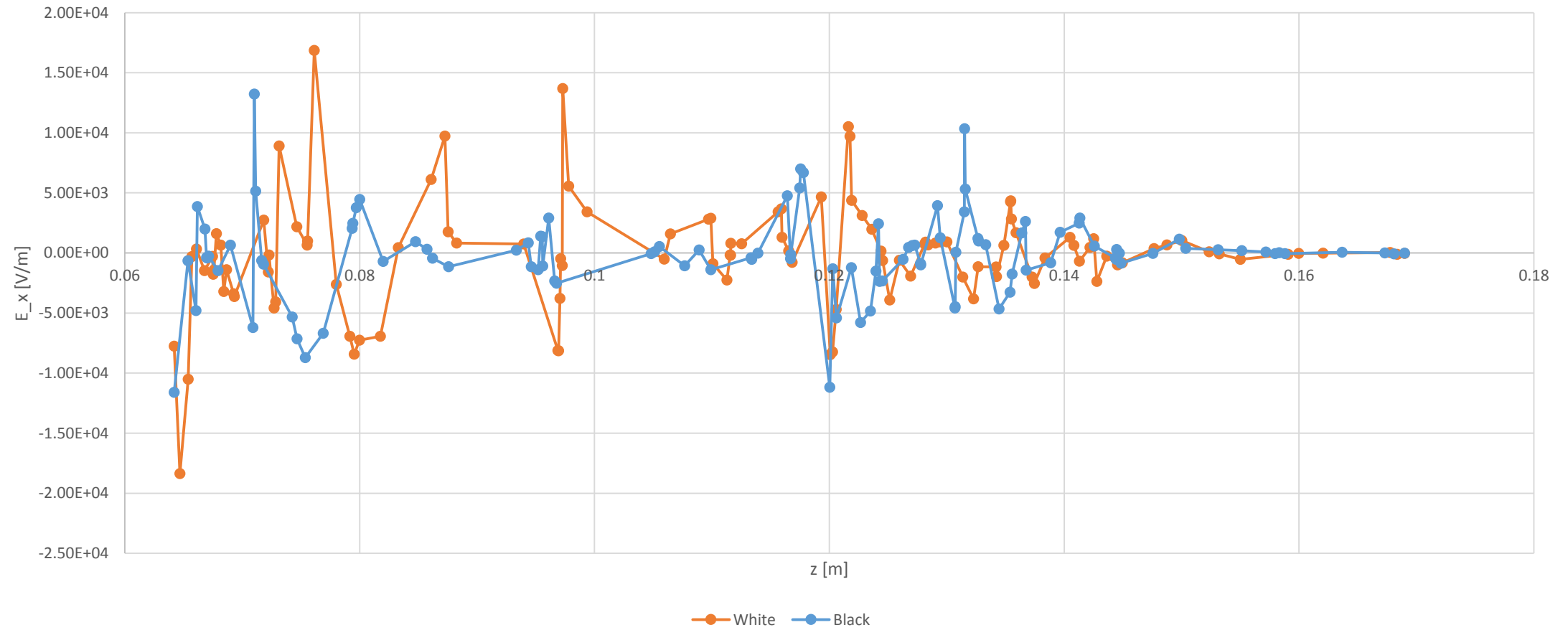
COMSOL frame of reference:

y

x

z

X goes into the page.

- This image shows the electric field norm |E| in MV/m as color intensity. The coordinate system is as shown for all plots and images the origin is at the center of the cathode electrode. (The anode is at the right)

Ex cathode-anode:

Ez cathode-anode: