200kV gun COMSOL simulations Corrections

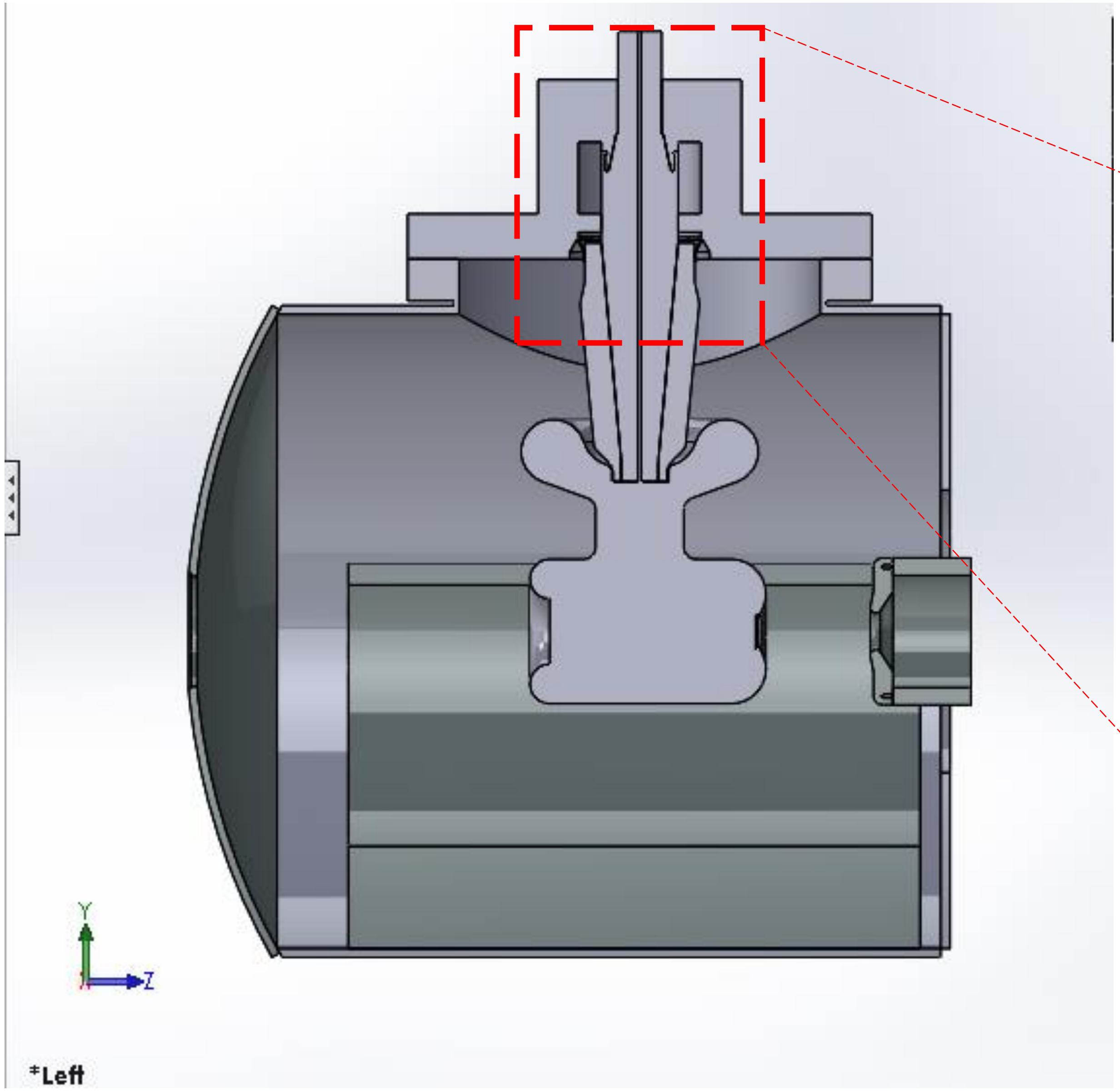
Gabriel Palacios

gpala001@odu.edu
06/14/18

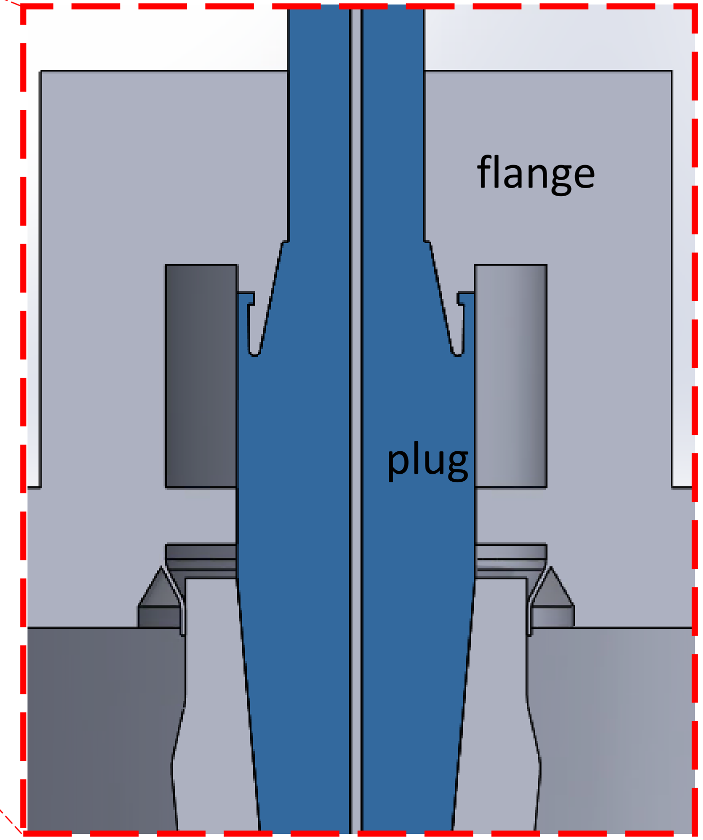
Summary

- Geometry used
- COMSOL details on simulation
  - Materials
  - Electrostatics
  - Electric currents (now with the method suggested by Fay)
  - Mesh
  - Study
  - Results
  - Plots
- Preliminary conclusions
- Future steps
- Extra slides

Solidworks model:



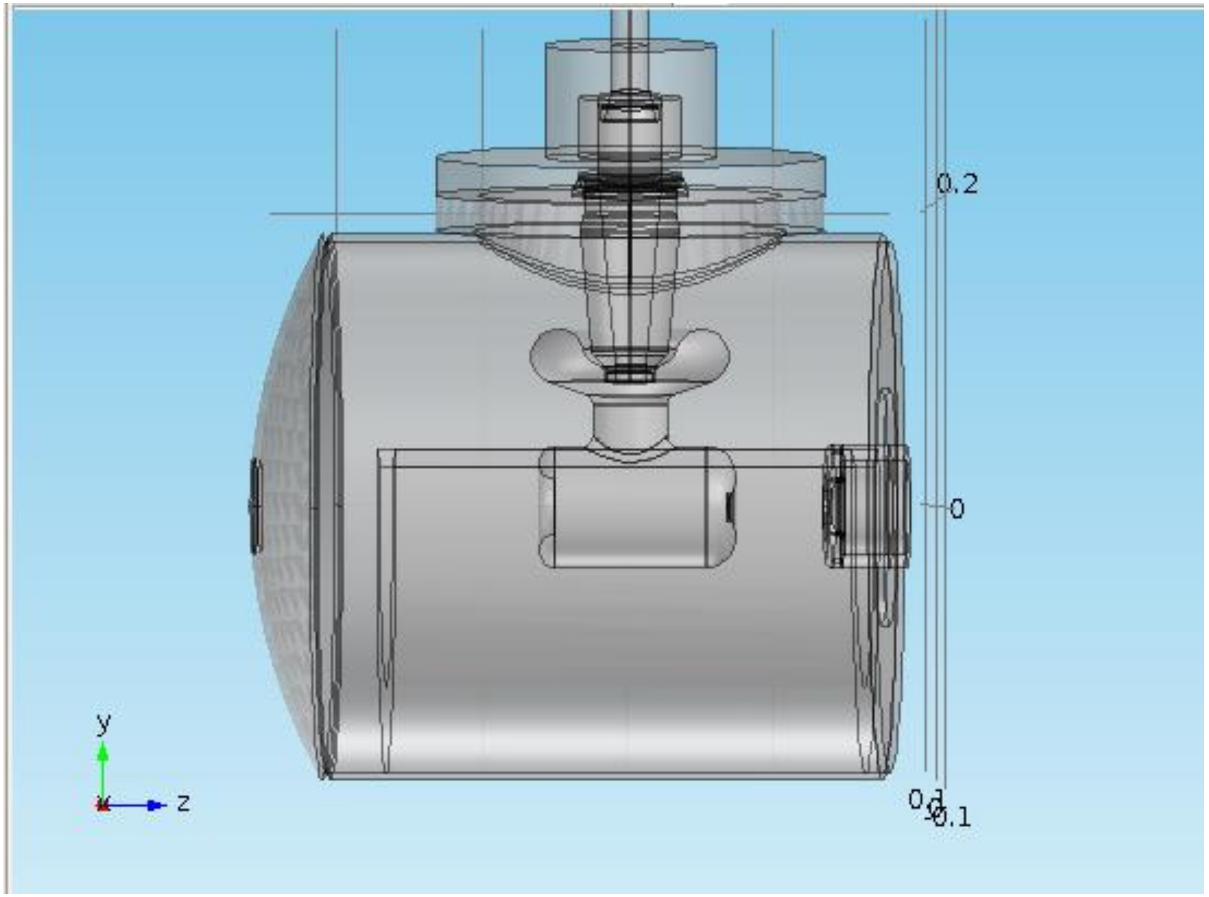
- In this simulation I used the latest model that includes shield, HV connection and black alumina insulator.
- I also used the model of the old CEBAF gun without shield and with white alumina insulator



COMSOL materials:

- Materials
  - High-strength alloy steel *(mat1)*
  - Air *(mat2)*
  - Alumina *(mat3)*
  - Rubber *(mat4)*

- Stainless steel for all metal components with Relative permittivity 1 and conductivity of 1.1E6 S/m
- **Vacuum surroundings Relative permittivity 1 and conductivity of 0 S/m.**
- Alumina for the ceramic.
  - **Relative permittivity 8.4 and conductivity of 2E-12 S/m for the black alumina.**
  - **Relative permittivity 9.1 and conductivity of 2E-14 S/m for the white alumina.**
- Rubber for the HV cable plug with Relative **permittivity 2.37 and conductivity of 1E-14 S/m.**



COMSOL electrostatics:

- Electrostatics *(es)*
  - Charge Conservation 1
  - Zero Charge 1
  - Initial Values 1
  - Ground 1
  - Electric Potential 1

- Charge conservation in all domains.
- Zero charge 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, shield and HV cable.

Equation

Equation form:

Study controlled

Show equation assuming:

Study 1, Stationary

$$\nabla \cdot \mathbf{D} = \rho_v$$

$$\mathbf{E} = -\nabla V$$

No conductivity!

COMSOL electric currents (stationary):

- Electric Currents *(ec)*
  - Current Conservation 1
  - Electric Insulation 1
  - Initial Values 1
  - Ground 1
  - Electric Potential 1

Equation

Equation form:

Study controlled

Show equation assuming:

Study 1, Stationary

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

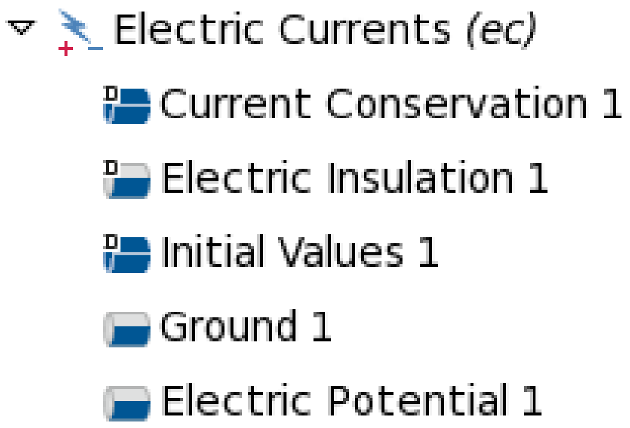
$$\mathbf{J} = \sigma \mathbf{E} + \mathbf{J}_e$$

$$\mathbf{E} = -\nabla V$$

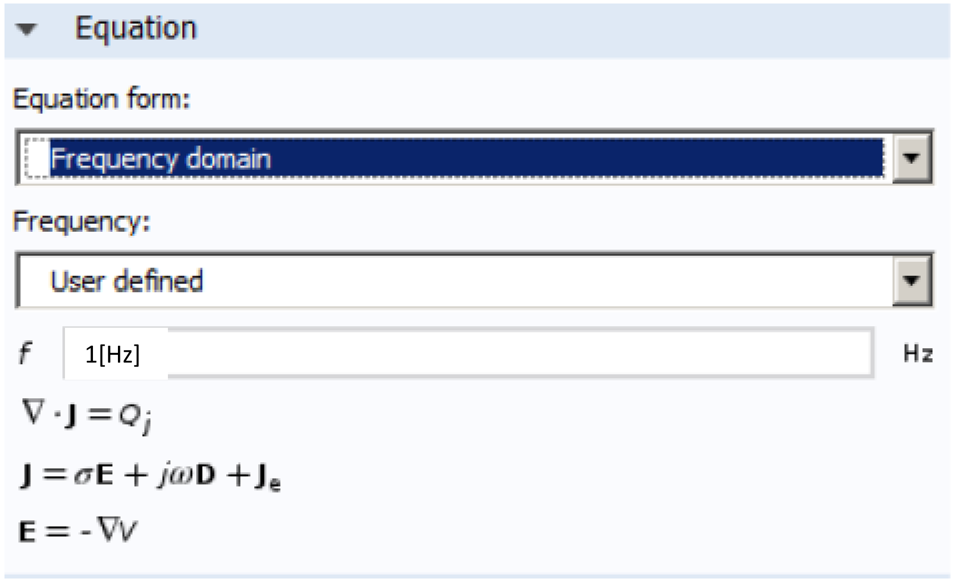
- Current conservation in all domains.
- Electric insulation at the outer air boundary.
- Initial value (of potential) set to zero by default.
- Ground 1 at vacuum chamber, NEGs, anode, flanges.
- Electric potential at -200kV at the cathode, shed and HV cable.

Conductivity of vacuum approximated as 1E-40 [S/m]

COMSOL electric currents (frequency domain):



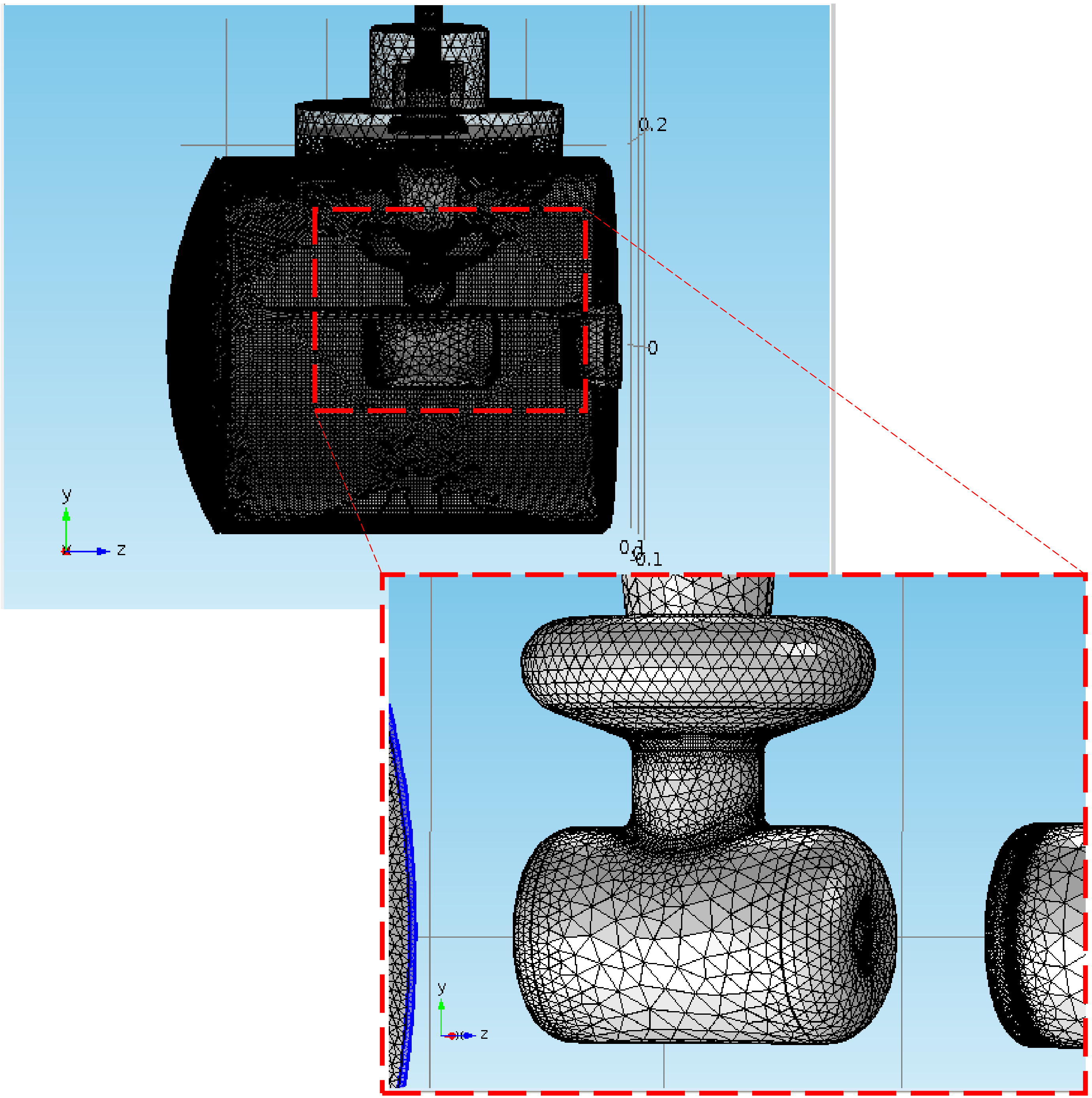
- Current conservation in all domains.
- Electric insulation at the outer air boundary.
- Initial value (of potential) set to zero by default.
- Ground 1 at vacuum chamber, NEGs, anode, flanges.
- Electric potential at -200kV at the cathode, shed and HV cable.
- Frequency set to 1 Hz



Conductivity of vacuum as it should be 0 [S/m]

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:

- I performed three different studies, one that solved for the electrostatics problem, one that solved the steady state and one that solved the frequency domain.

- Study 1
  - Step 1: Stationary
  - Solver Configurations

Physics and Variables Selection

☐ Modify physics tree and variables for study step

Physics interface	Solve for	Discretization
Electrostatics (es)	☑	Physics settings
Electric Currents (ec)	☐	Physics settings

- Study 2
  - Step 1: Frequency Domain
  - Solver Configurations
    - Solution 2

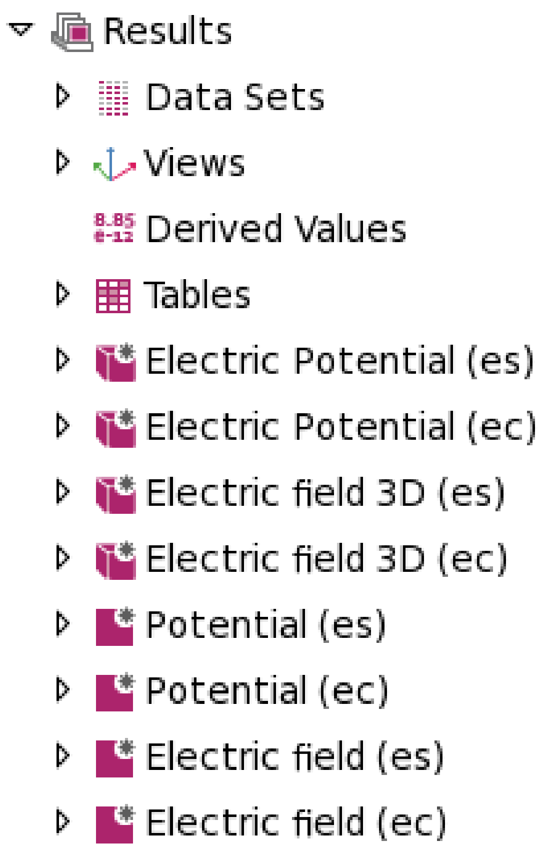
Physics and Variables Selection

☐ Modify physics tree and variables for study step

Physics interface	Solve for	Discretization
Electrostatics (es)	☐	Physics settings
Electric Currents (ec)	☑	Physics settings

COMSOL results:

- After the solver finished obtaining the solutions, I produced a group of plots that show the potential and electric field in different cases as a visual aid. Then using the data sets, I extracted the information from a line parallel to the ceramic insulator - rubber plug boundary and plotted the potential and electric fields.



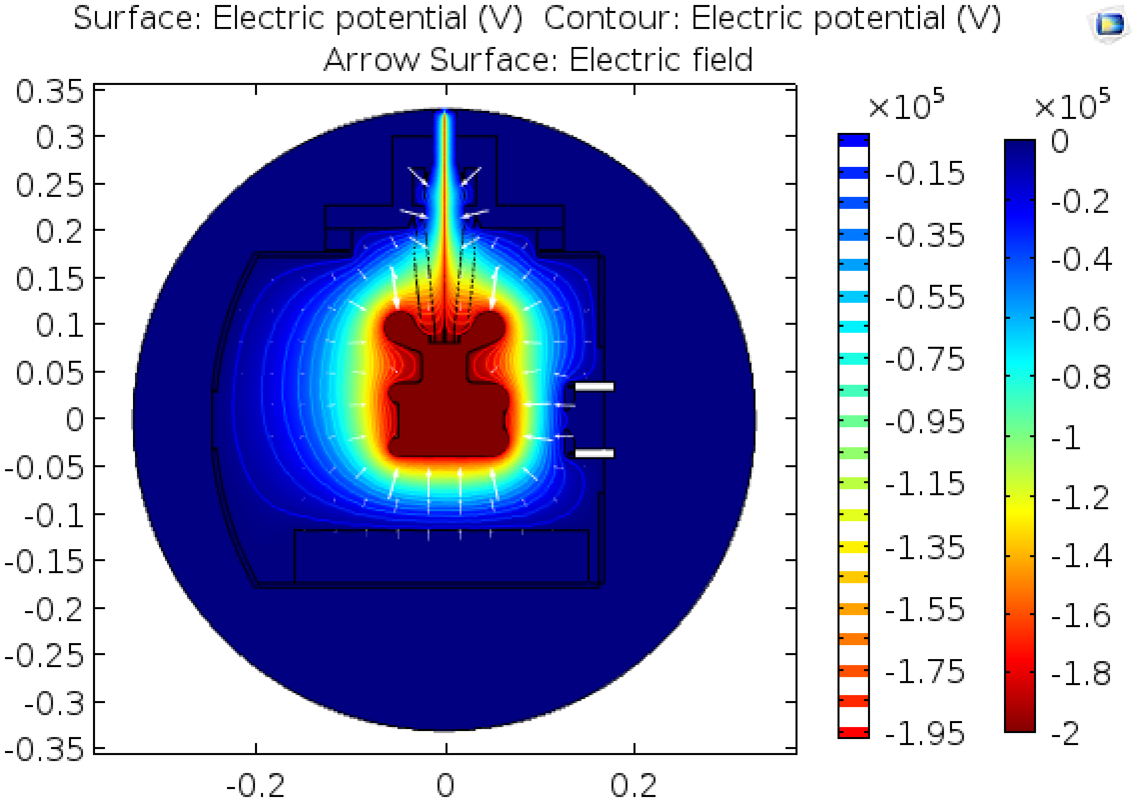
No conductivity vs Black insulator conductivity (solved properly with low frequency solver)

- Conductivity of black insulator as 2E-12 S/m

COMSOL Potential:

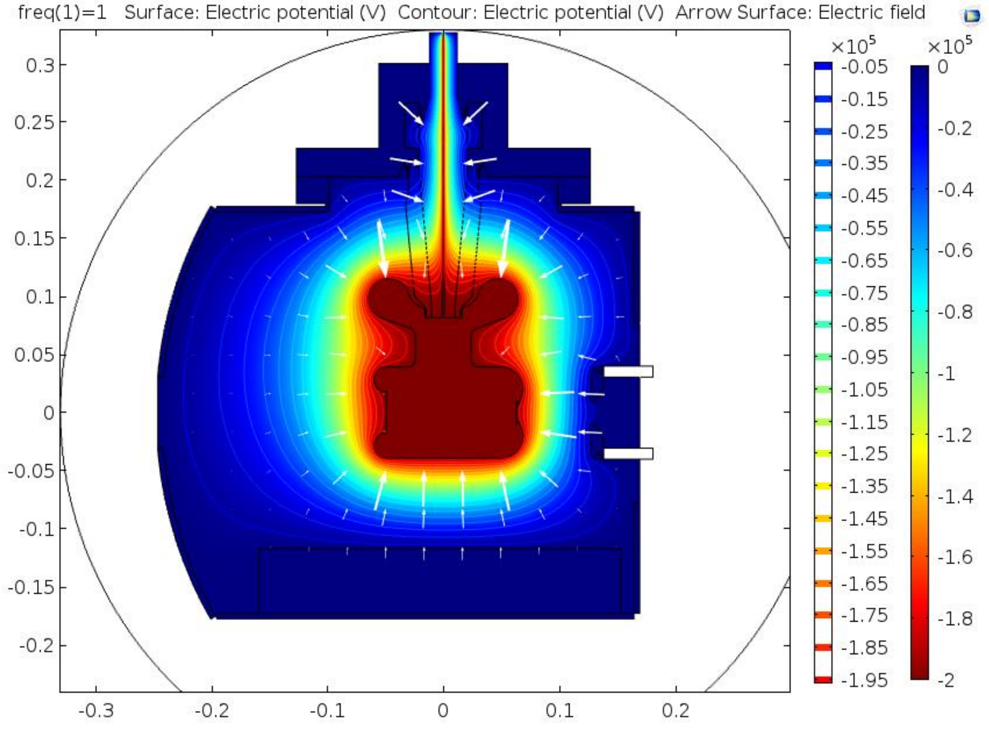
- This image shows the potential as color intensity (with equipotential lines). The white arrows size is proportional to the intensity of the electric field at the arrow tip. The axis are coordinates in meters.

Without solving for conductivity



With black alumina conductivity

conductivity of 2E-12 S/m

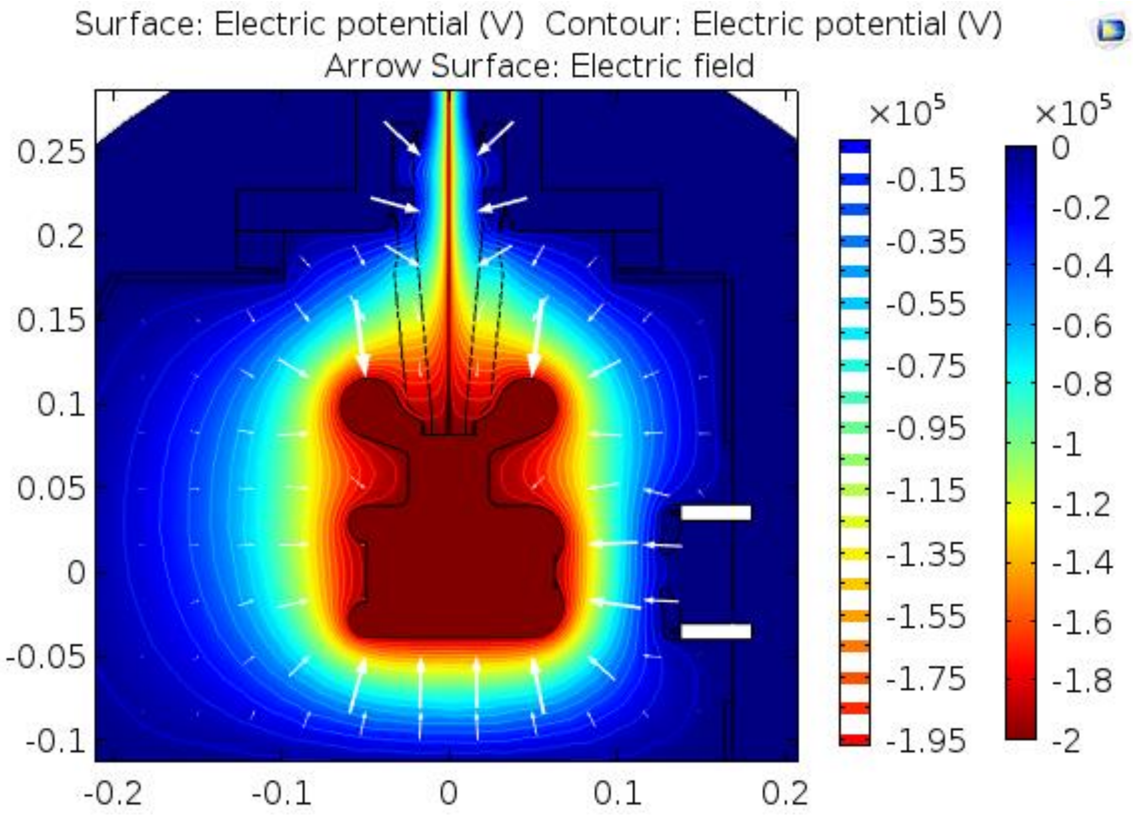


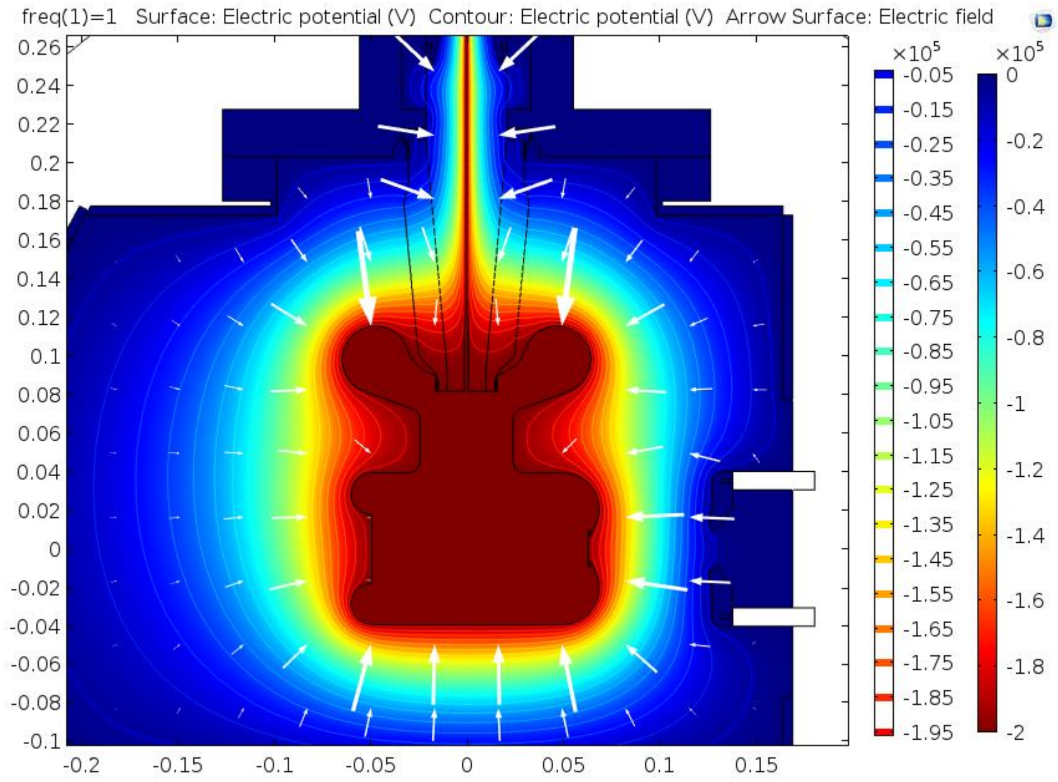
COMSOL Potential:

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

Without solving for conductivity

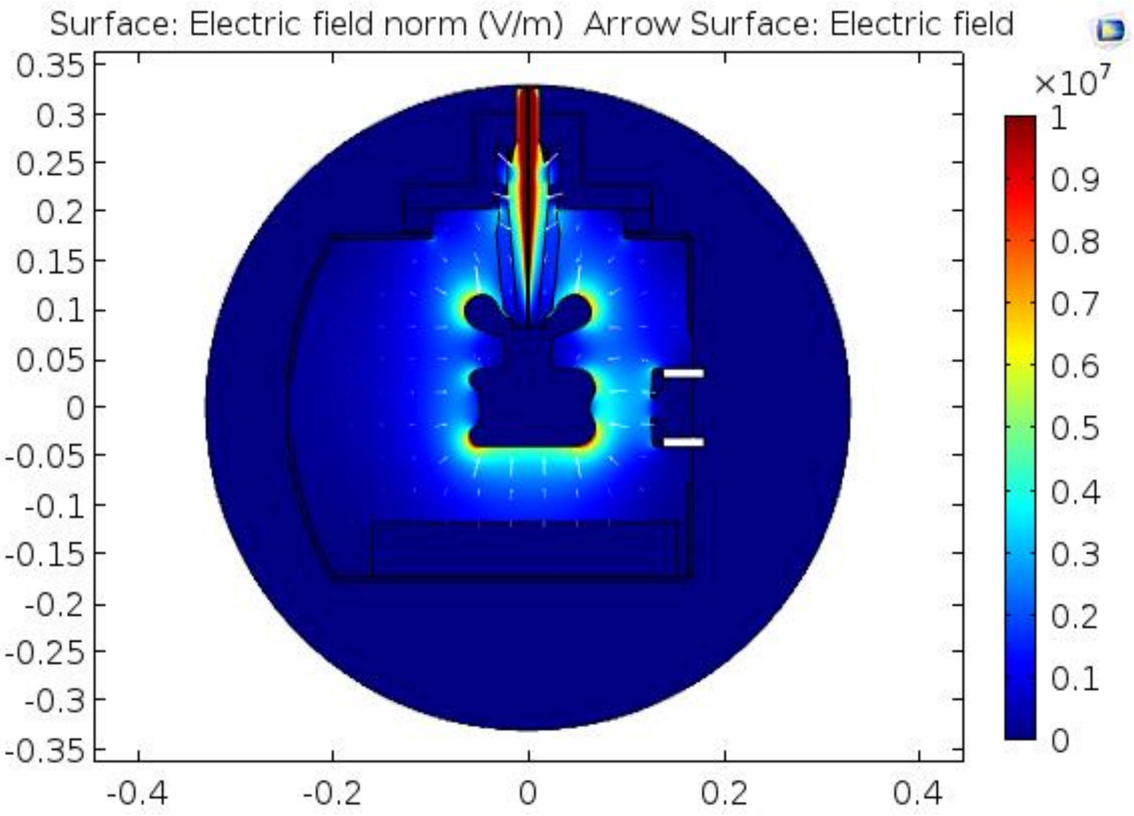




COMSOL Electric field Norm :

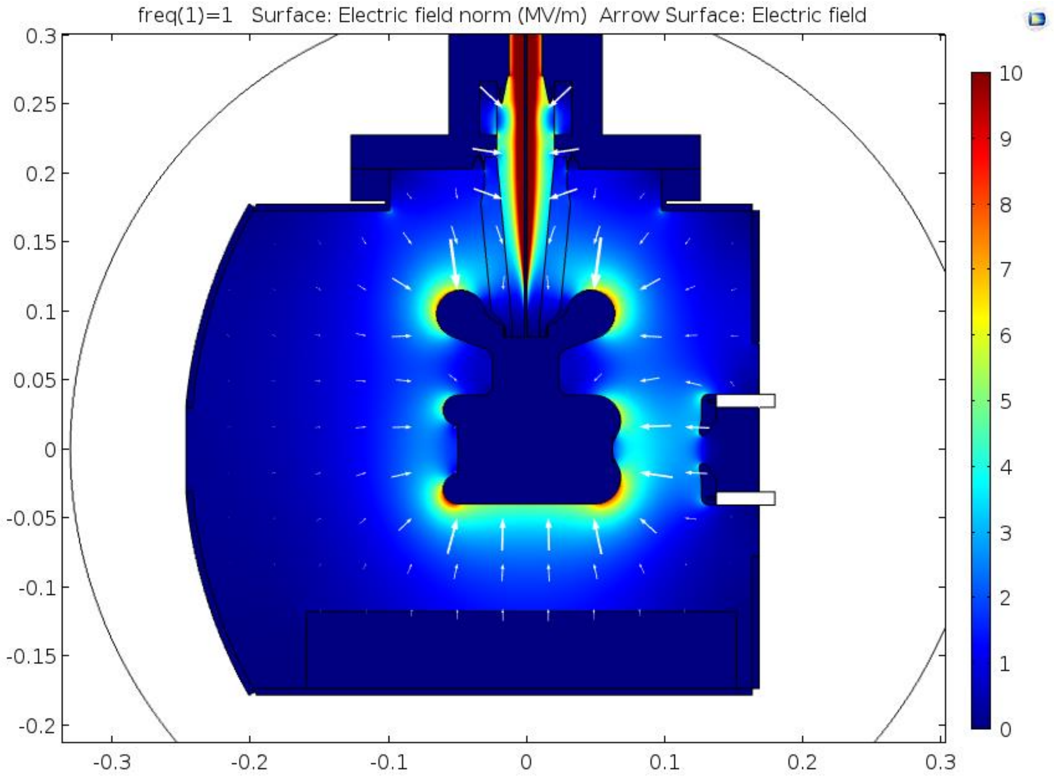
- This image shows the electric field norm |E| in MV/m as color intensity. The white arrows size is proportional to the intensity of the electric field at the arrow tip. The axis are coordinates in meters.

Without solving for conductivity



With black alumina conductivity

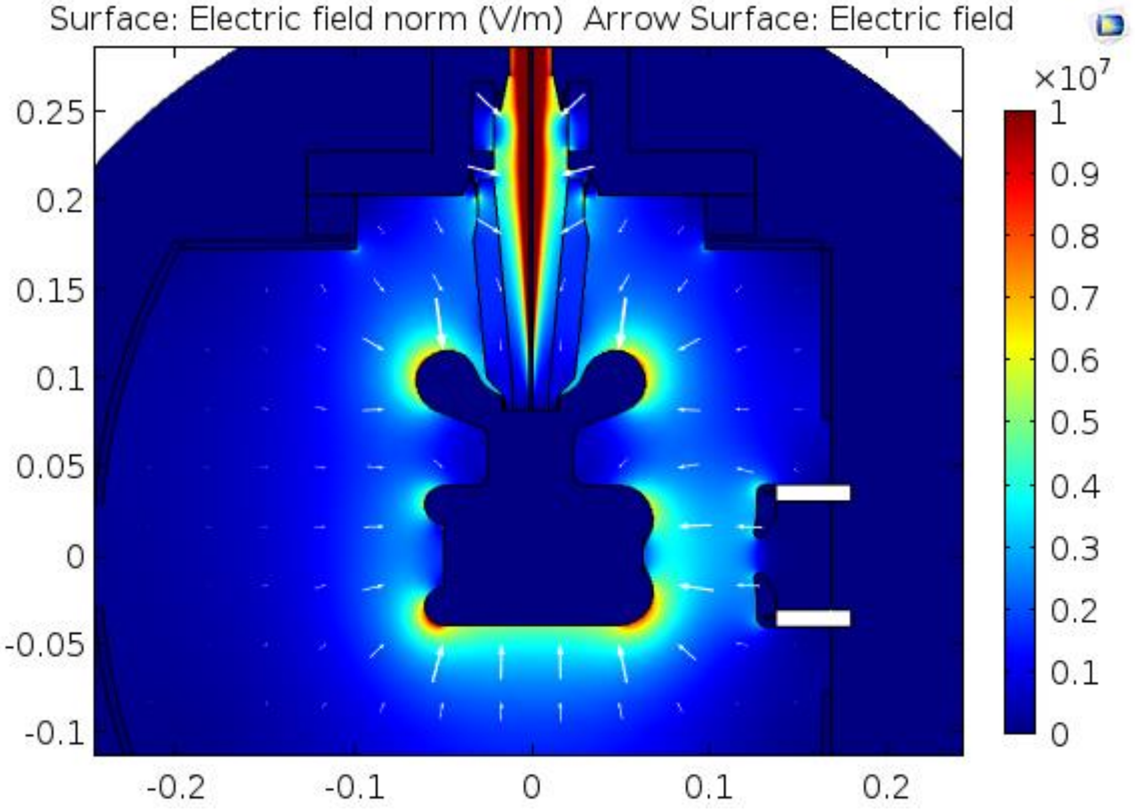
conductivity of 2E-12 S/m



COMSOL Electric field Norm :

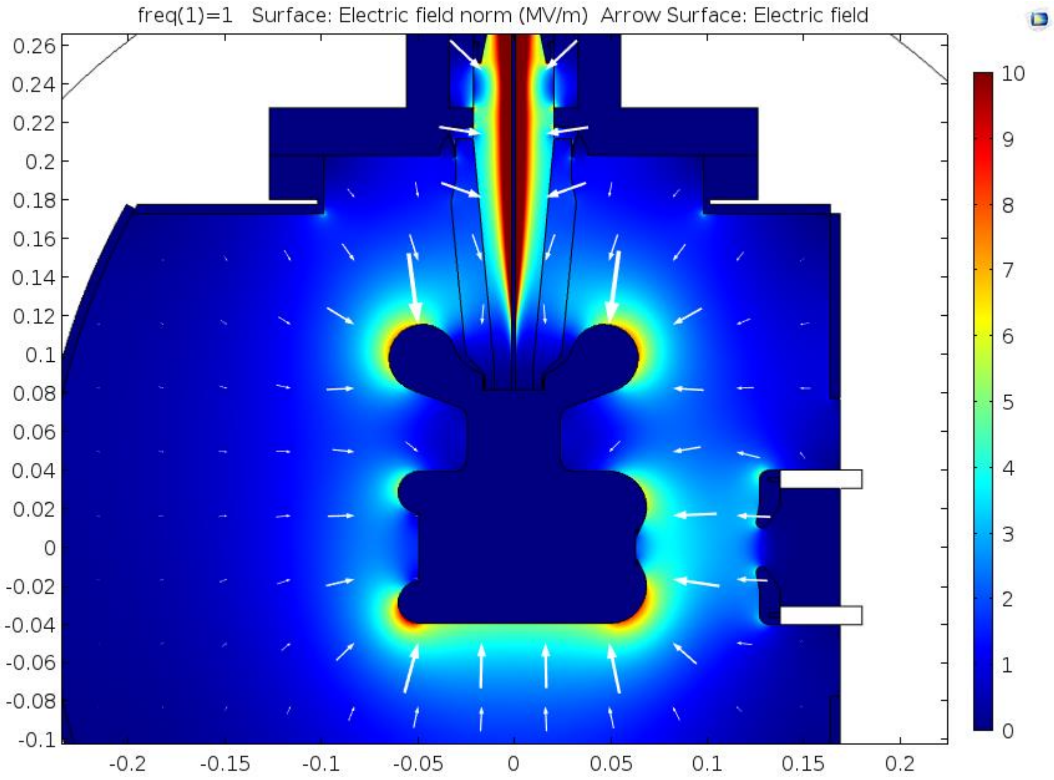
- This image shows the electric field norm |E| in MV/m as color intensity. The white arrows size is proportional to the intensity of the electric field at the arrow tip. The axis are coordinates in meters.

Without solving for conductivity



With black alumina conductivity

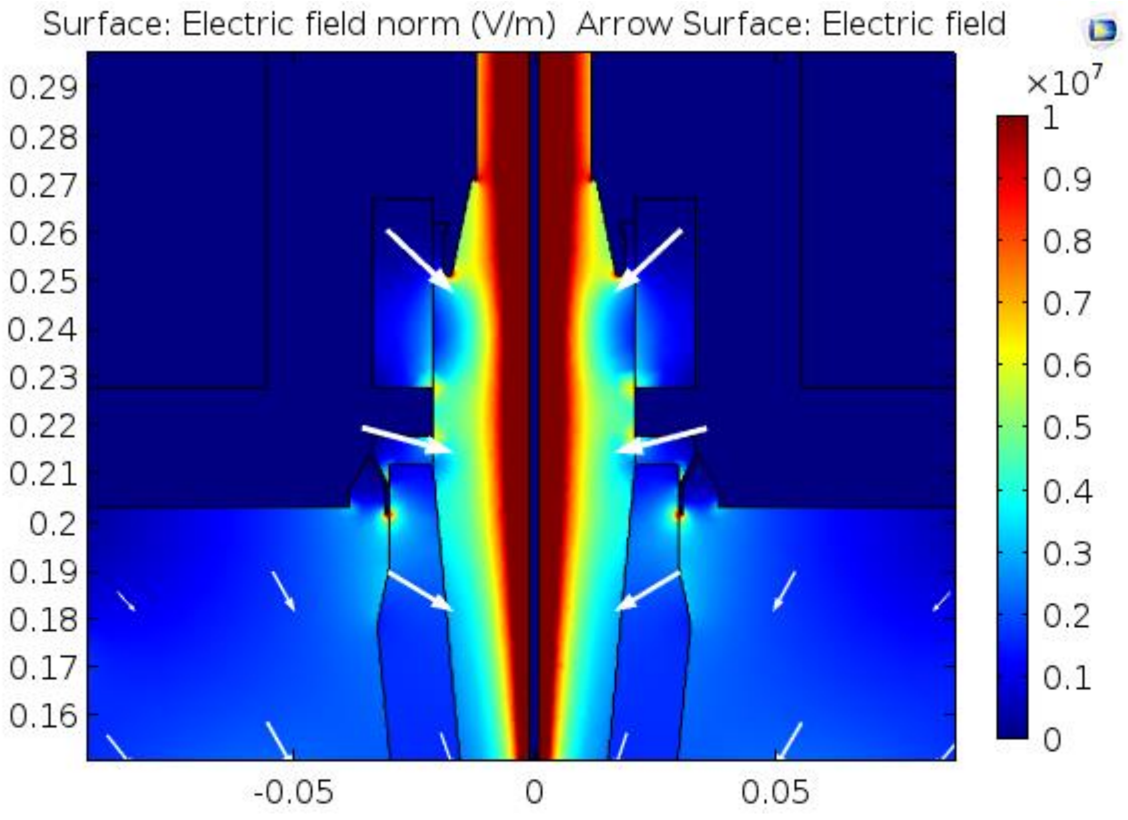
conductivity of 2E-12 S/m



COMSOL Electric field Norm :

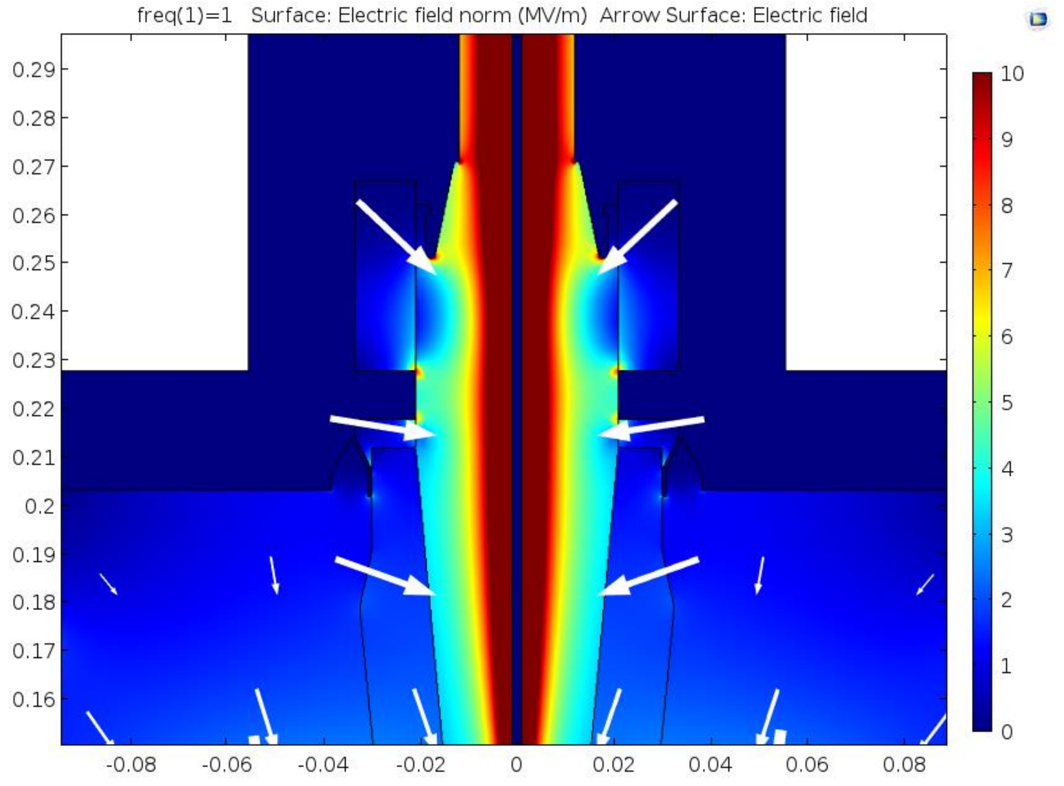
- This image shows the electric field norm |E| in MV/m as color intensity closer to the upper flange. The white arrows size is proportional to the intensity of the electric field at the arrow tip. The axis are coordinates in meters.

Without solving for conductivity



With black alumina conductivity

conductivity of 2E-12 S/m



White insulator vs Black insulator (Solved with low frequency solver)

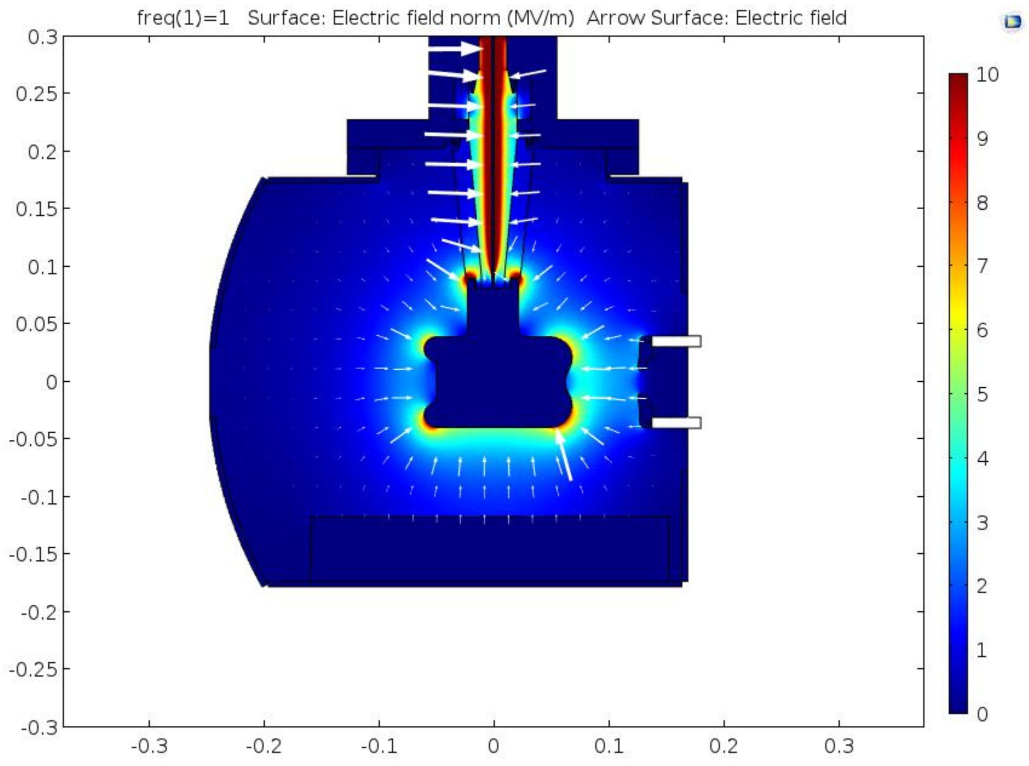
- White alumina conductivity of 2E-14 S/m
- Black alumina conductivity of 2E-12 S/m

COMSOL Electric field Norm :

- This image shows the electric field norm |E| in MV/m as color intensity. The white arrows size is proportional to the intensity of the electric field at the arrow tip. The axis are coordinates in meters.

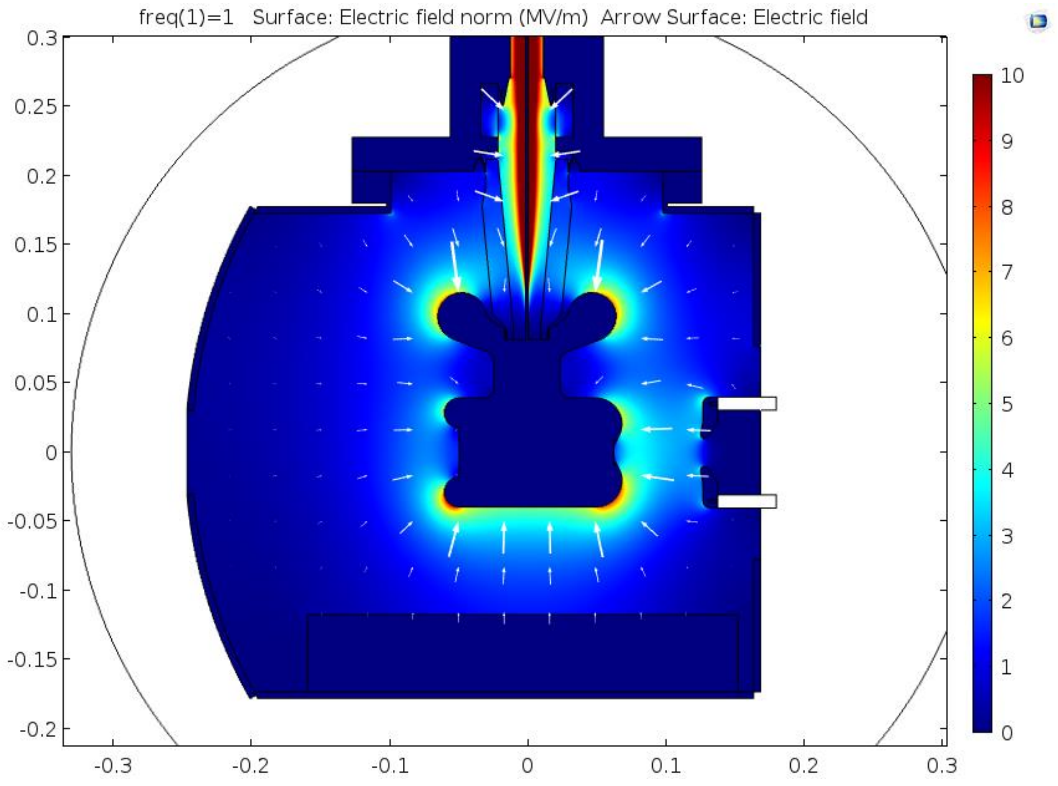
With white alumina conductivity and no shield

Conductivity of 2E-14 S/m



With black alumina conductivity

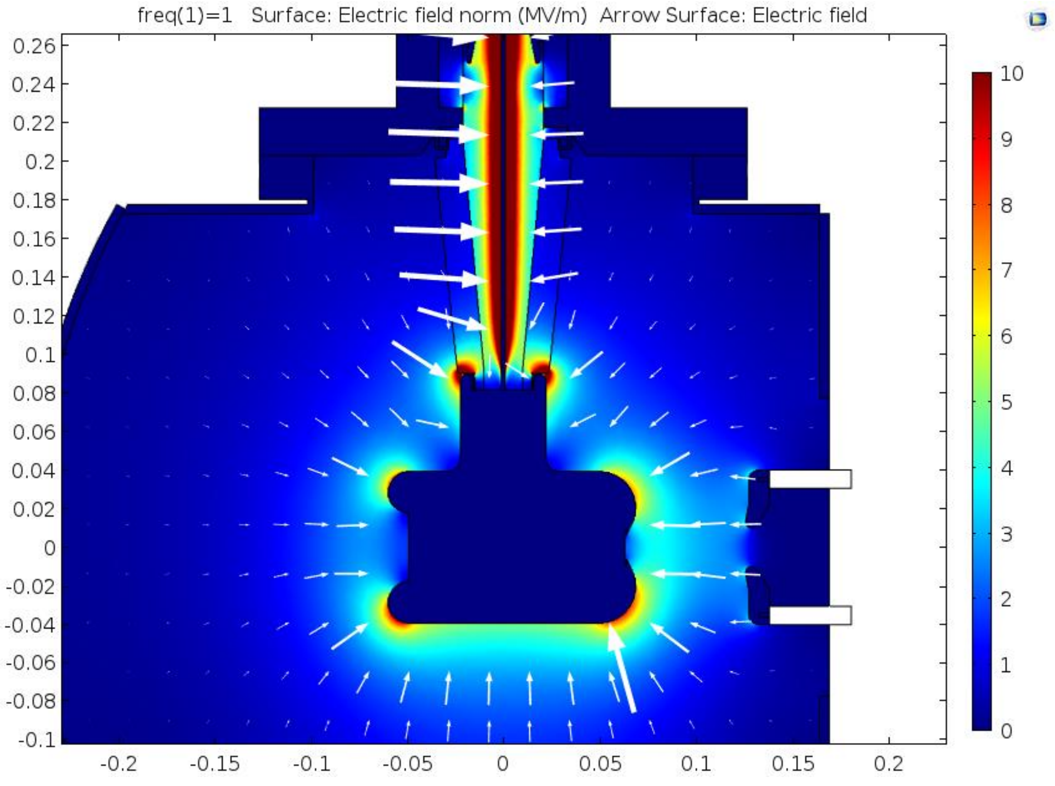
conductivity of 2E-12 S/m



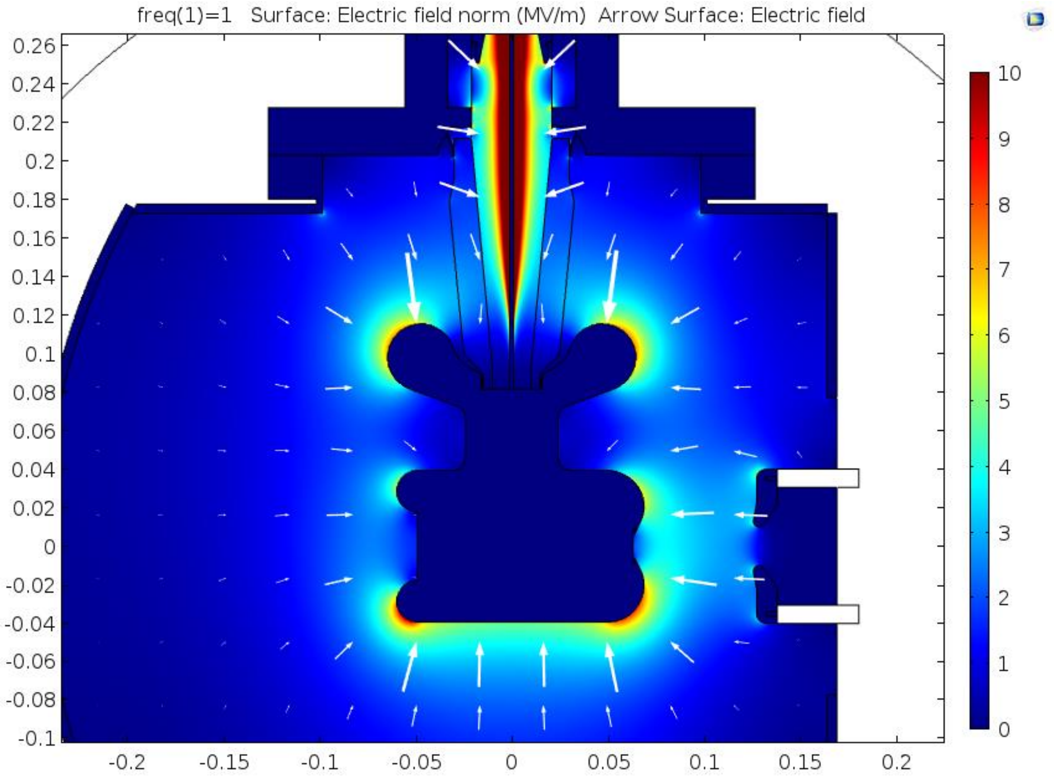
COMSOL Electric field Norm :

- This image shows the electric field norm |E| in MV/m as color intensity. 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 and no shield
Conductivity of 2E-14 S/m



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

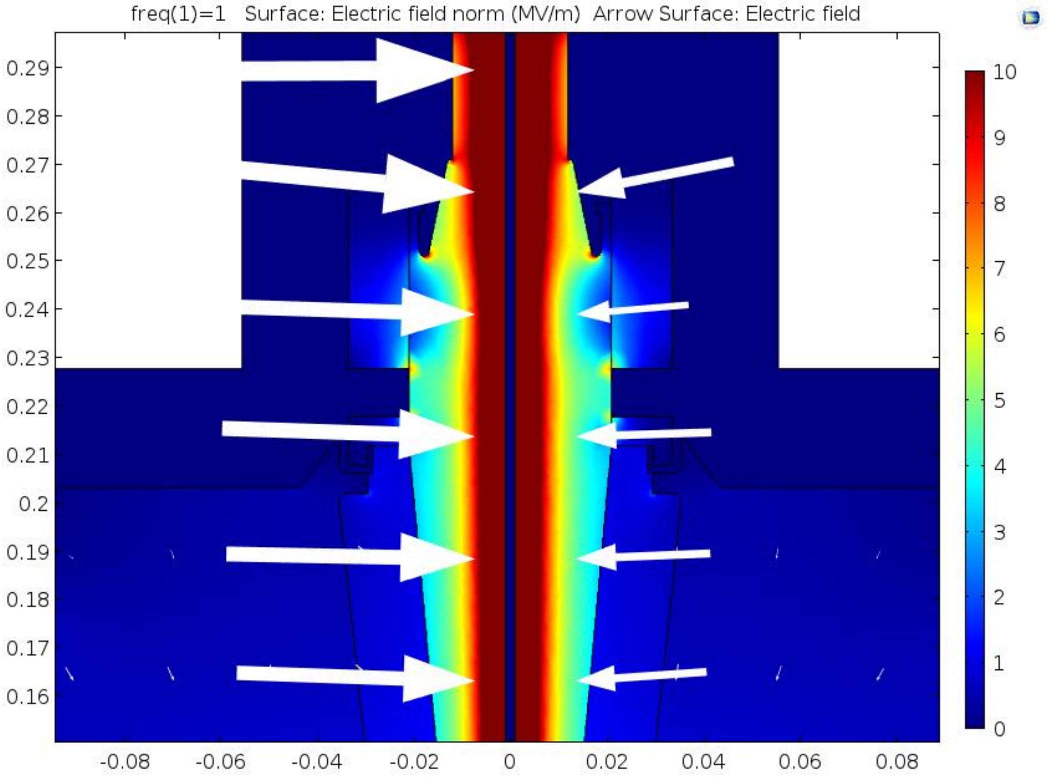


COMSOL Electric field Norm :

- This image shows the electric field norm |E| in MV/m as color intensity 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.

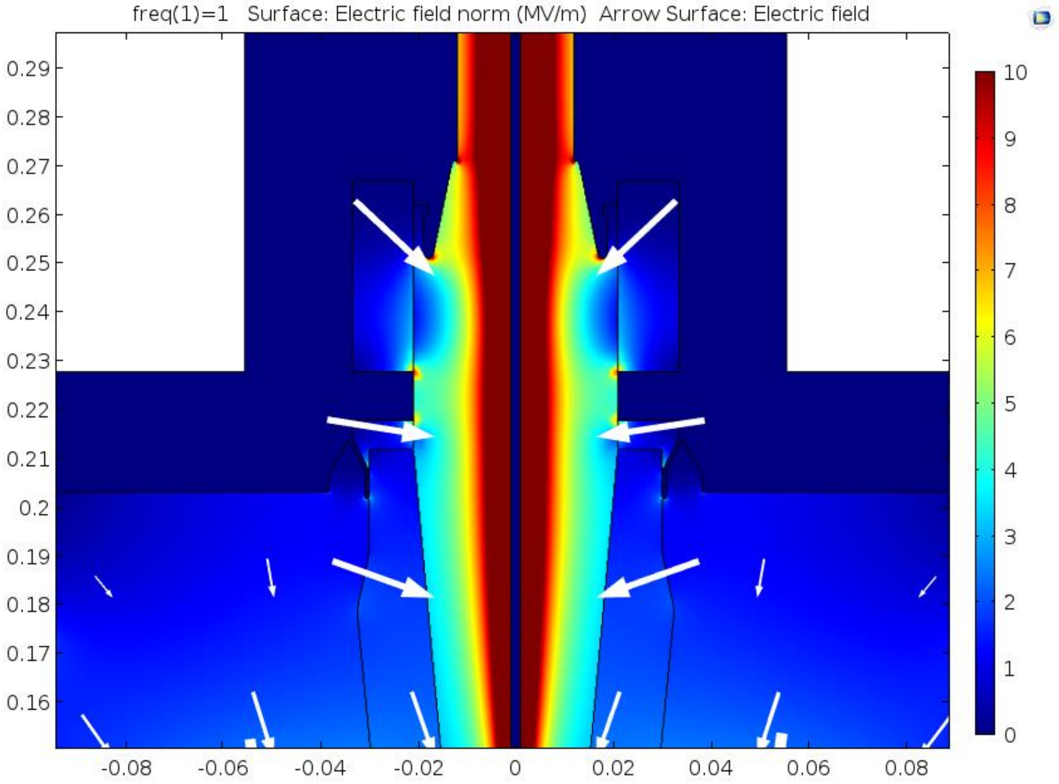
With white alumina conductivity and no shield

Conductivity of 2E-14 S/m



With black alumina conductivity

conductivity of 2E-12 S/m

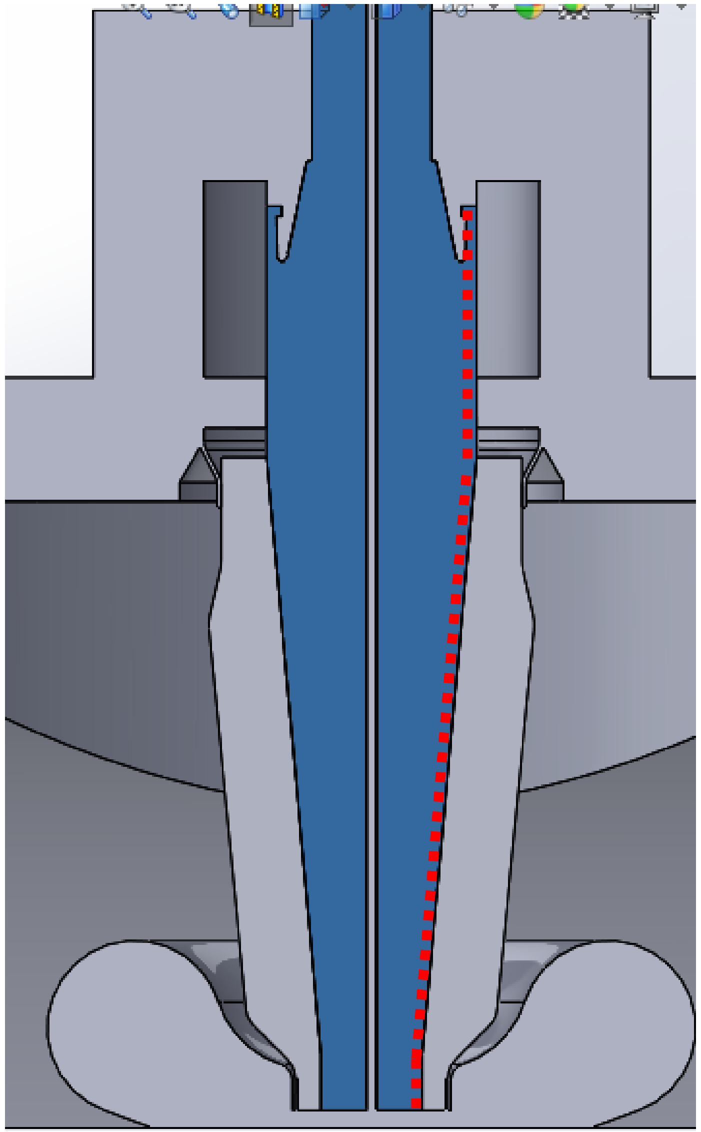


Now, to check the numbers of the paper…

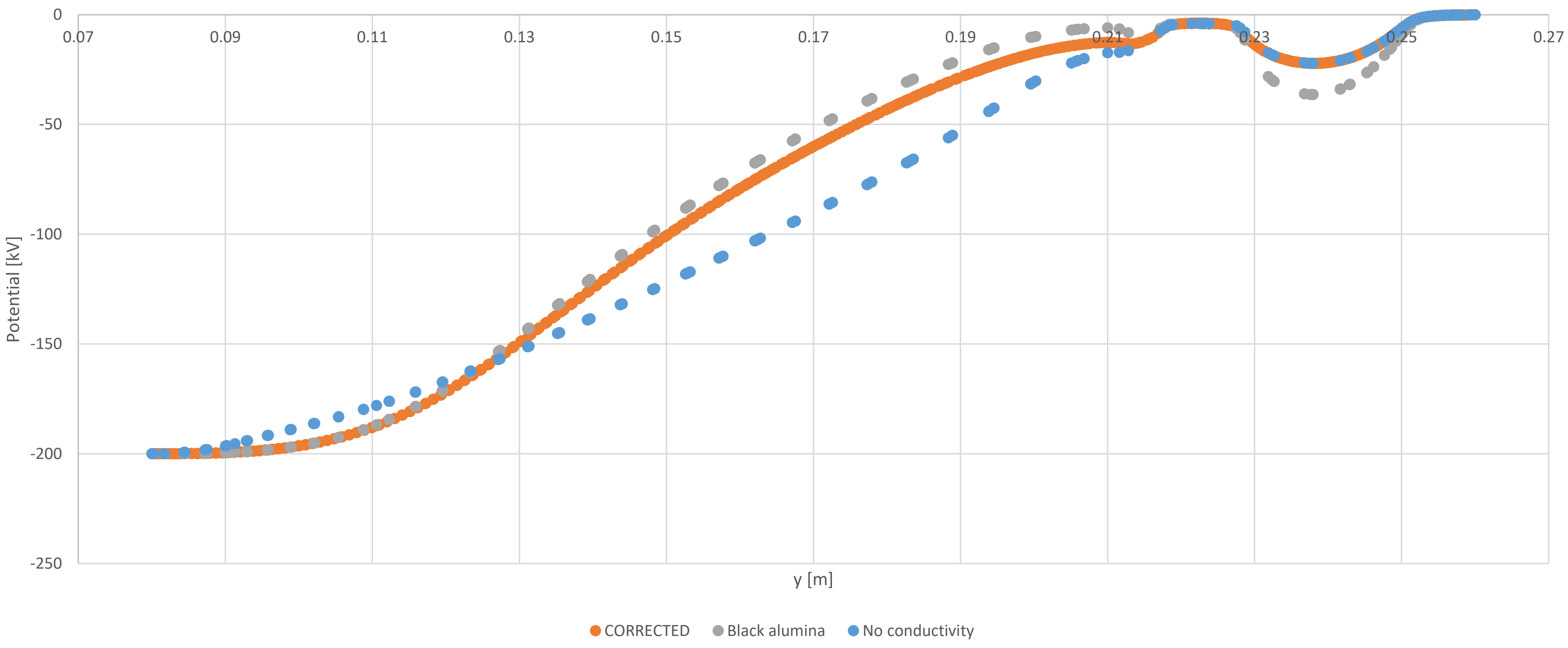
- In the plots the CORRECTED data set represents the values for the simulation obtained using Fay’s suggestion (low freq solver).
- The black insulator data set represents the values for the simulation obtained using Gabriel’s trick (steady state solver and vacuum conductivity as 1E-40 [S/m]).
- The no conductivity data set represents the values for the simulation obtained using the solver that <u>does not solve for conductivity</u> (electrostatics solver).

Potential and electric field:

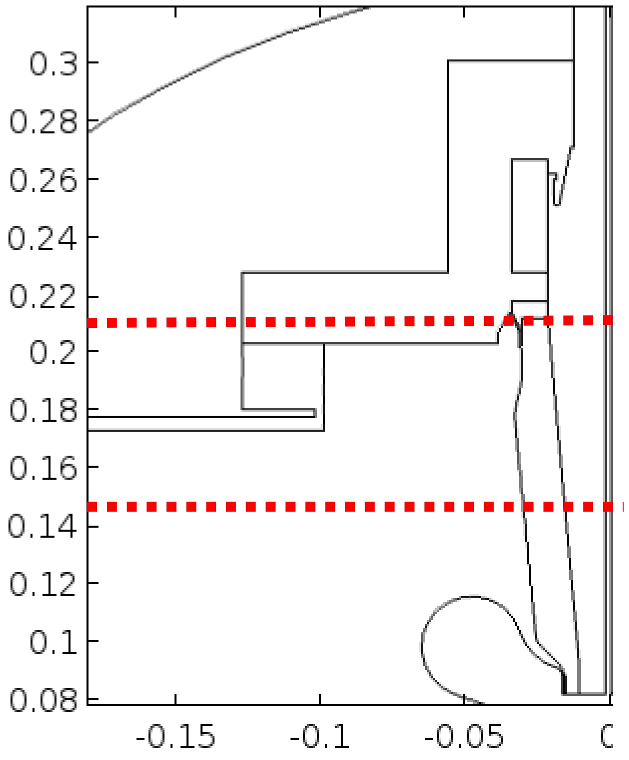
- Then the information about the potential and electric field along the rubber plug – ceramic insulator interface was obtained (as shown in the red dotted line), plotted as a function of the height (y-coordinate) and compared for three cases:
  - Without solving for the conductivity.
  - Solving for black alumina conductivity **using the steady state solver with vacuum conductivity approximated as 1E-40 [S/m]**.
  - Solving for black alumina conductivity using the **low frequency solver with vacuum conductivity exactly 0 [S/m]**.

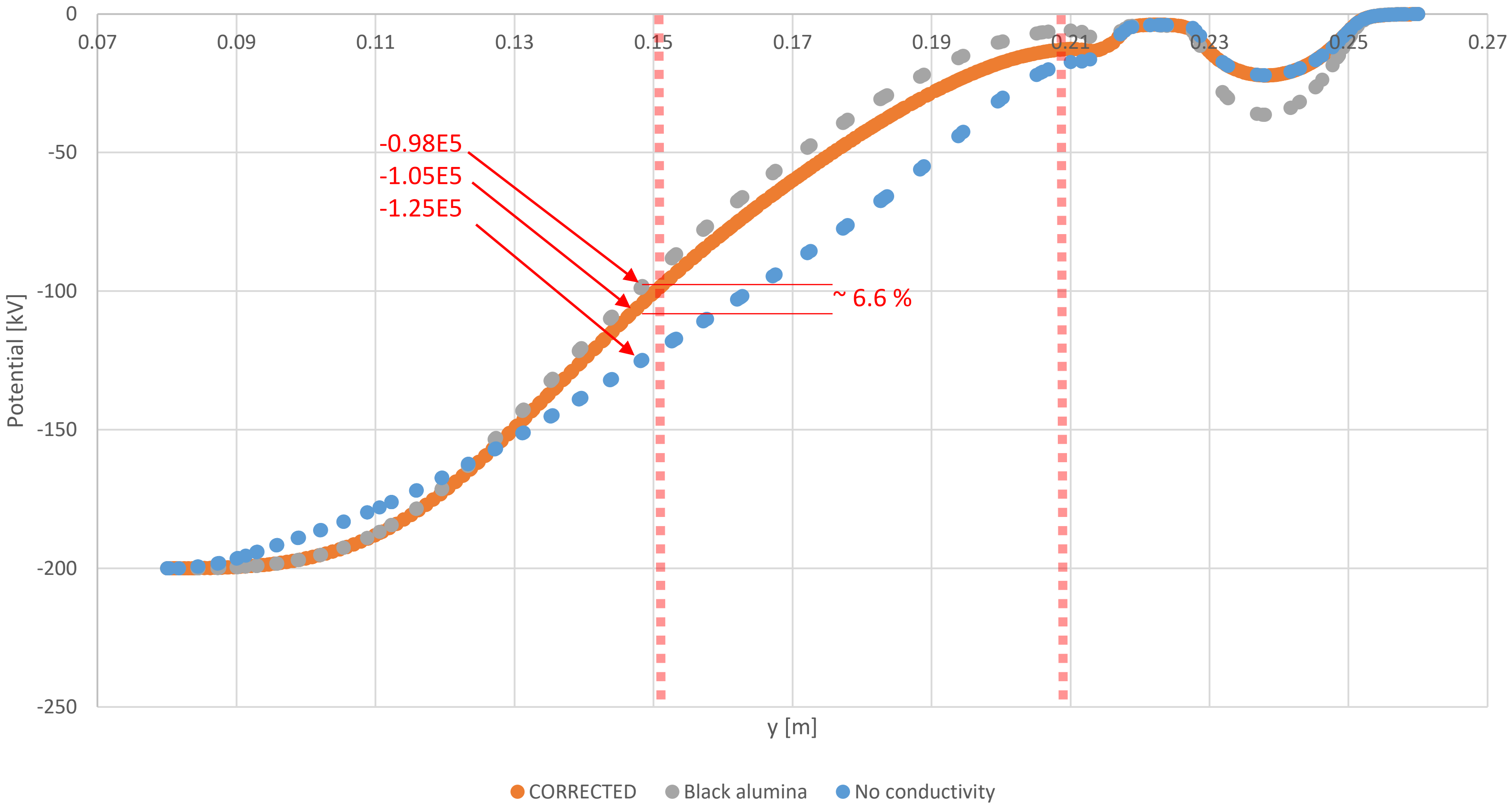


Potential along insulator inner surface:



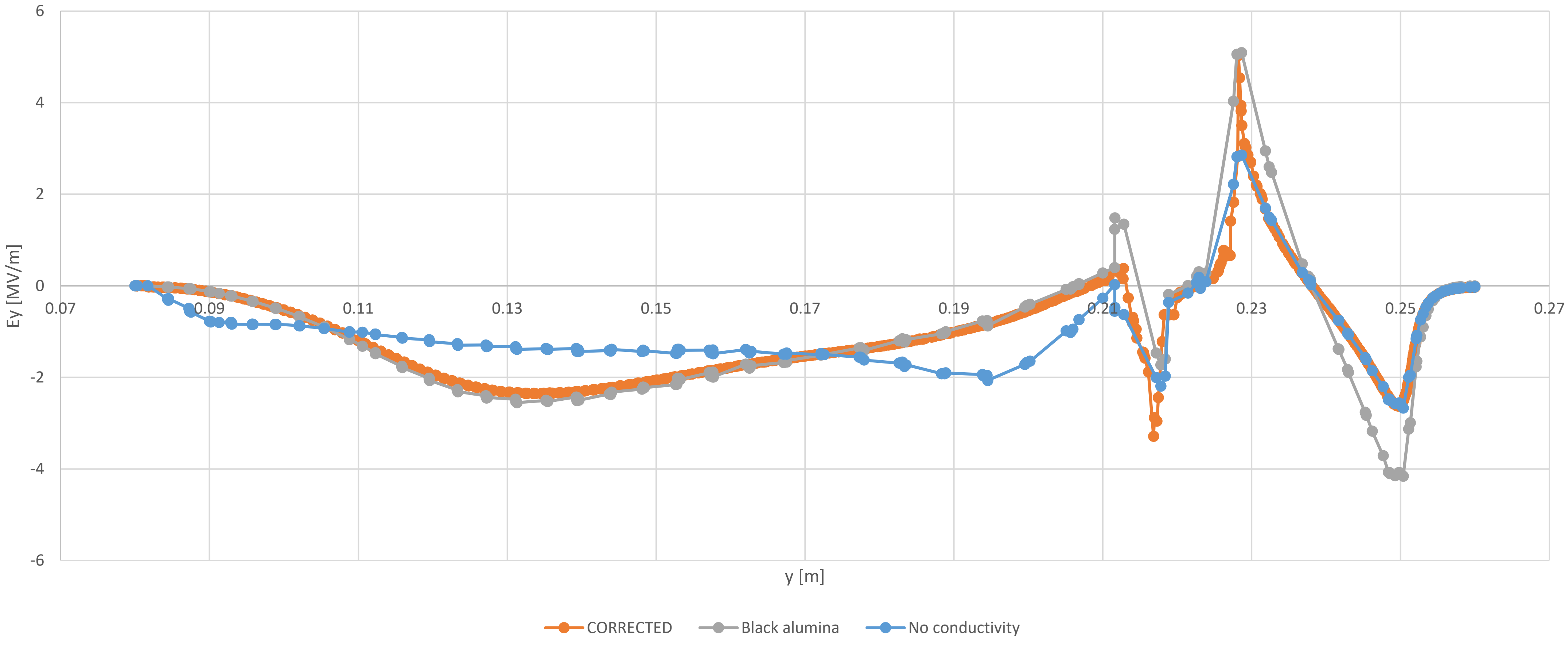
Potential near the middle of insulator surface:





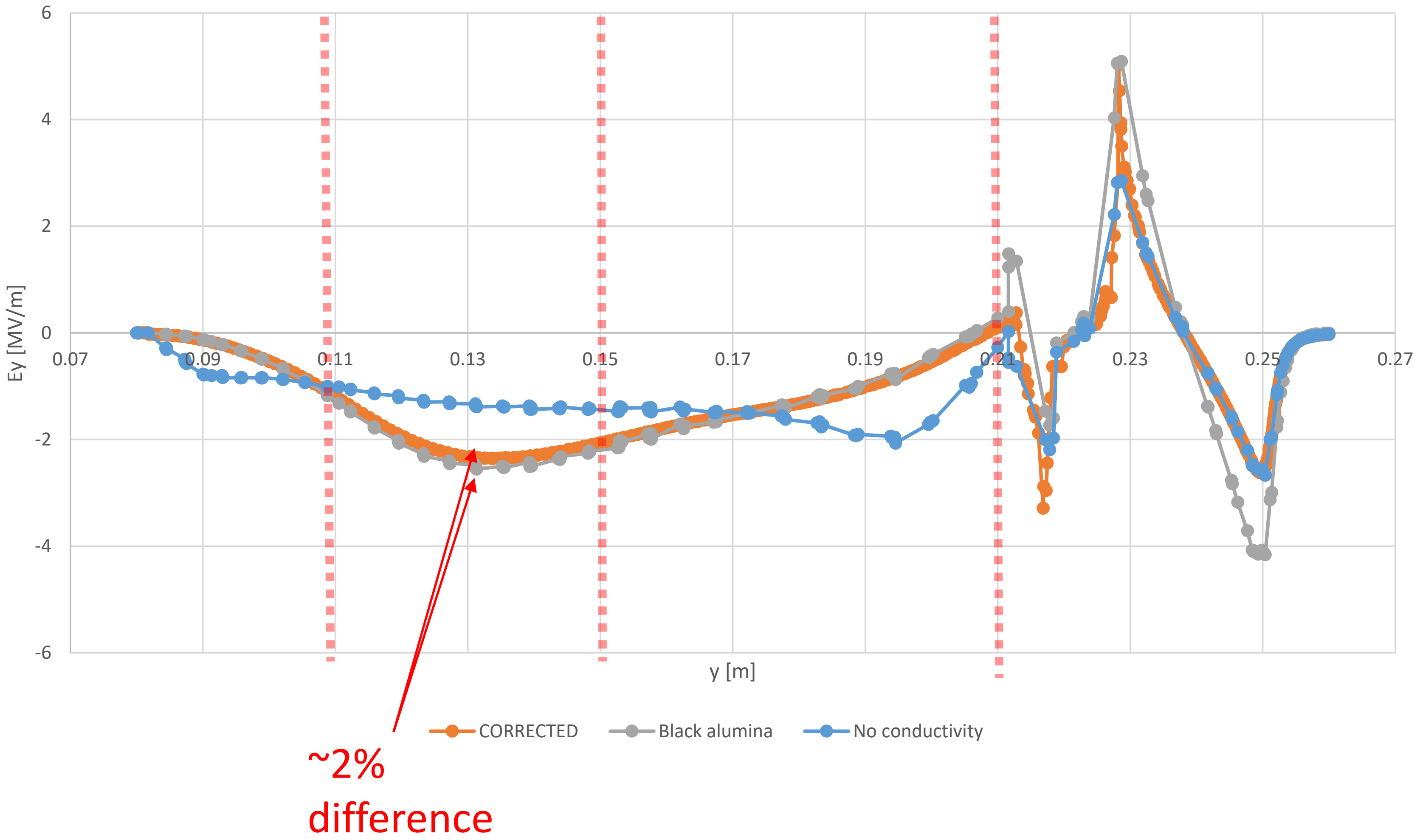
The height is ~0.14m

Potential gradient (Ey) along insulator surface:

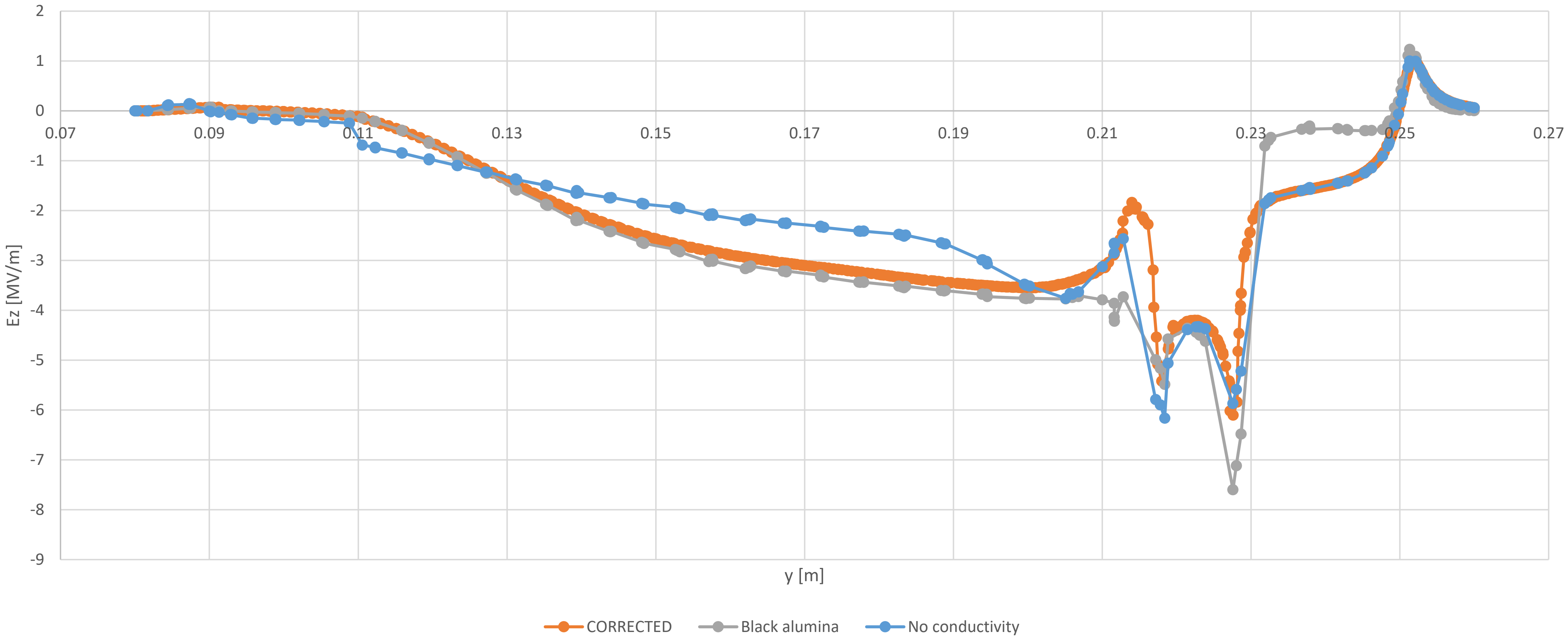


Potential gradient (Ey) along insulator surface:

The height is ~0.14m

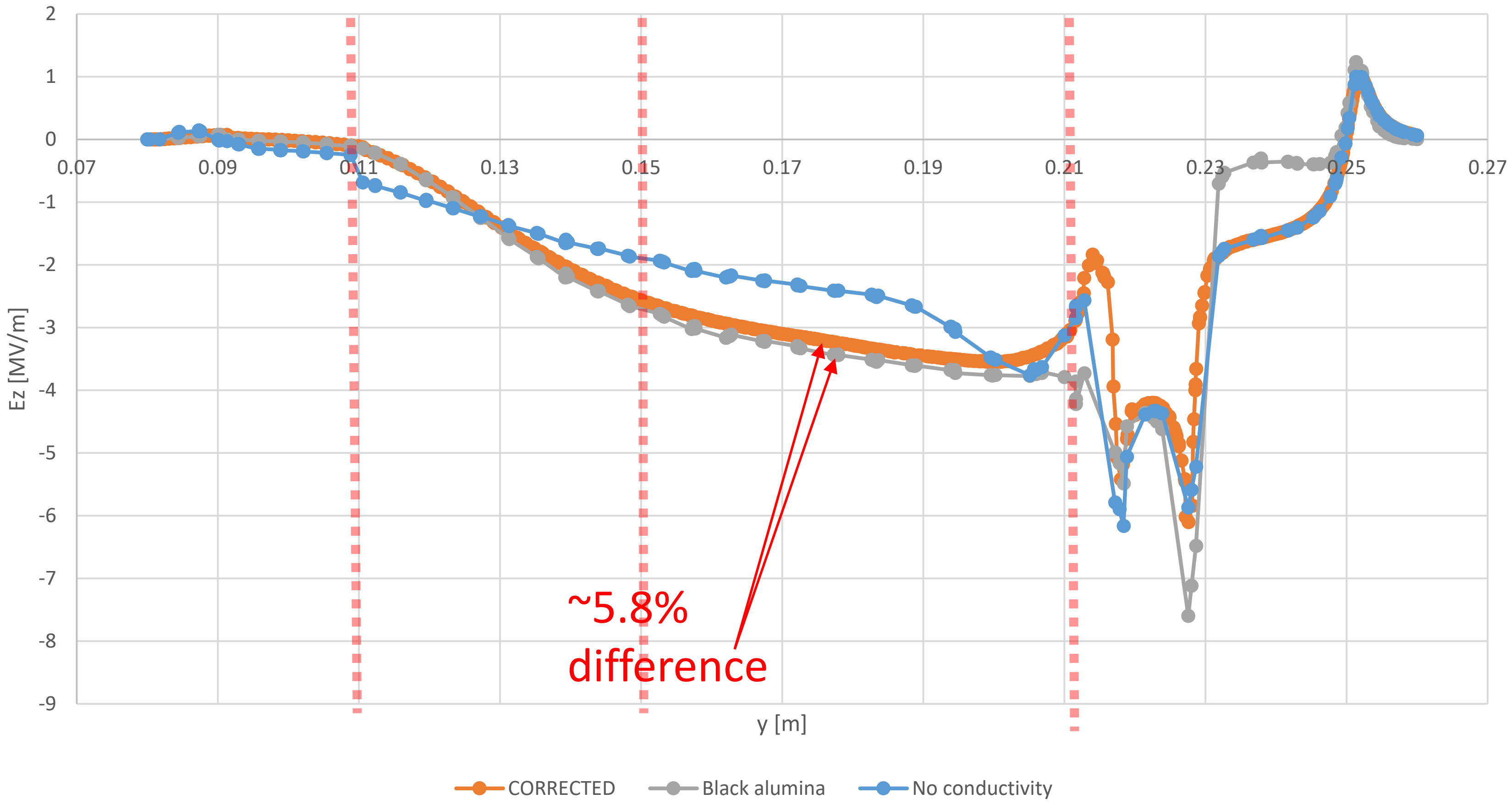


Potential gradient (Ez) along insulator surface:

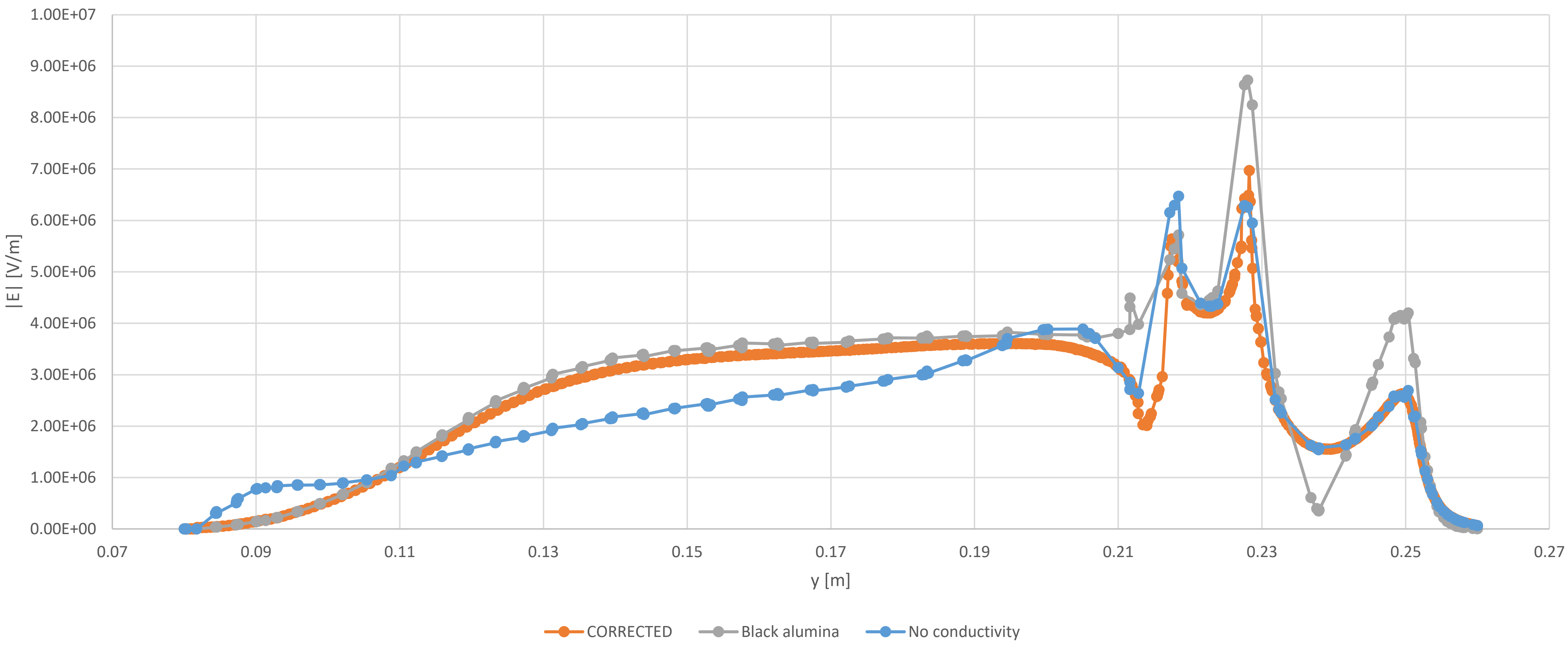


Potential gradient (Ez) along insulator surface:

The height is ~0.14m

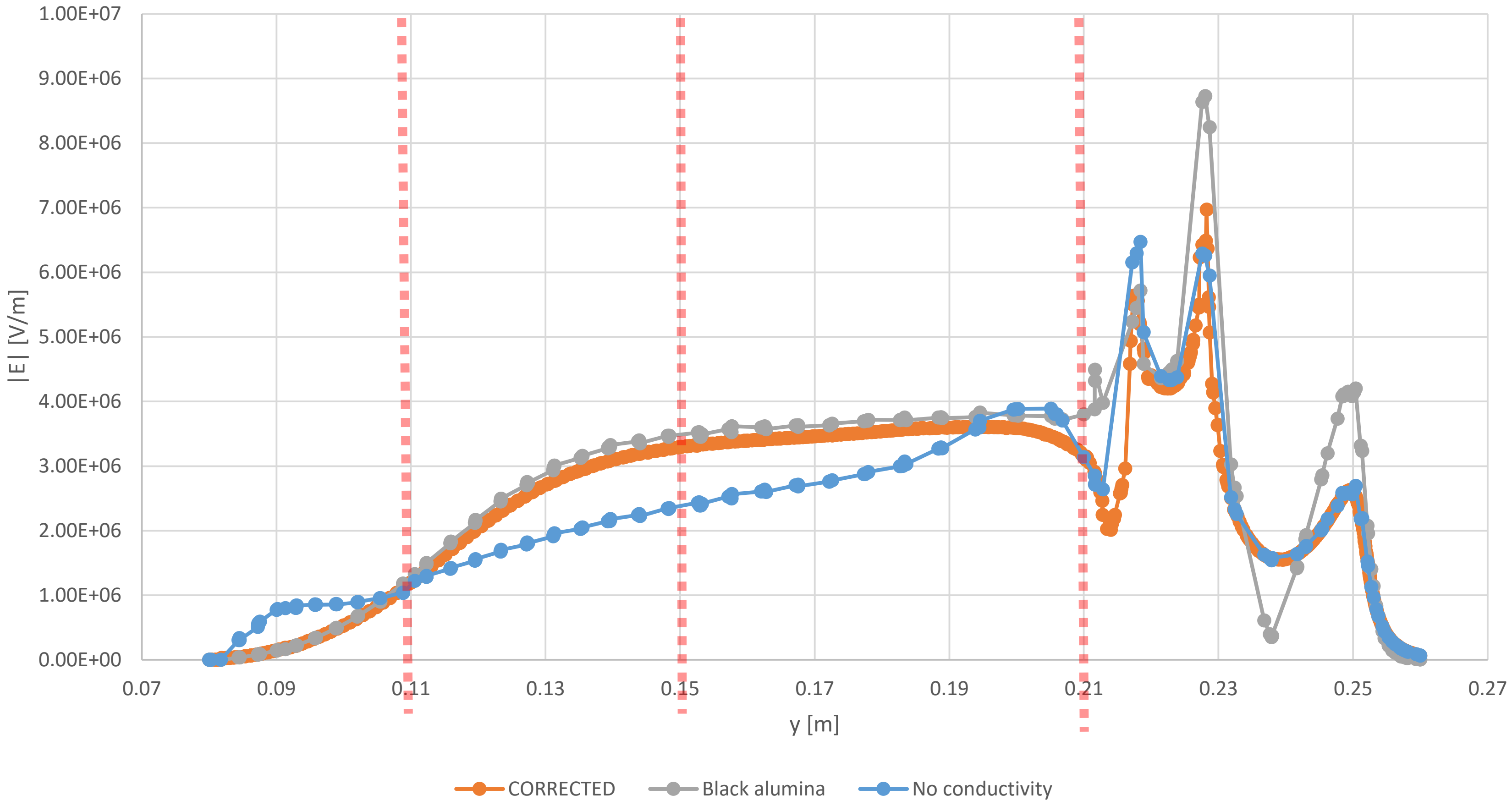


Electric field norm |E|:



|E| field along insulator:

The height is ~0.14m



Preliminary conclusions

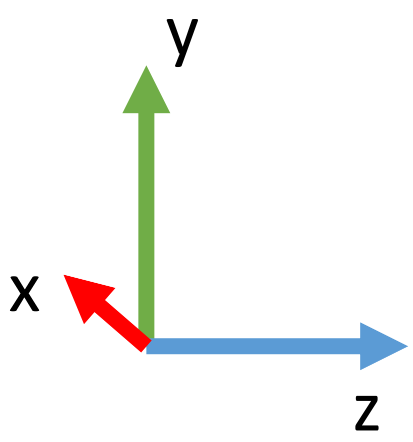
- The method that Fay uses in CST Microwave Studio (low frequency solver) was implemented in COMSOL. The produced results are *fairly* similar to the previously obtained with the steady state solver (and approximating the conductivity of vacuum as 1E-40 [S/m]).
- This implies that the results obtained for our paper just need a minor modification (if any).
- Phew!

Next steps.

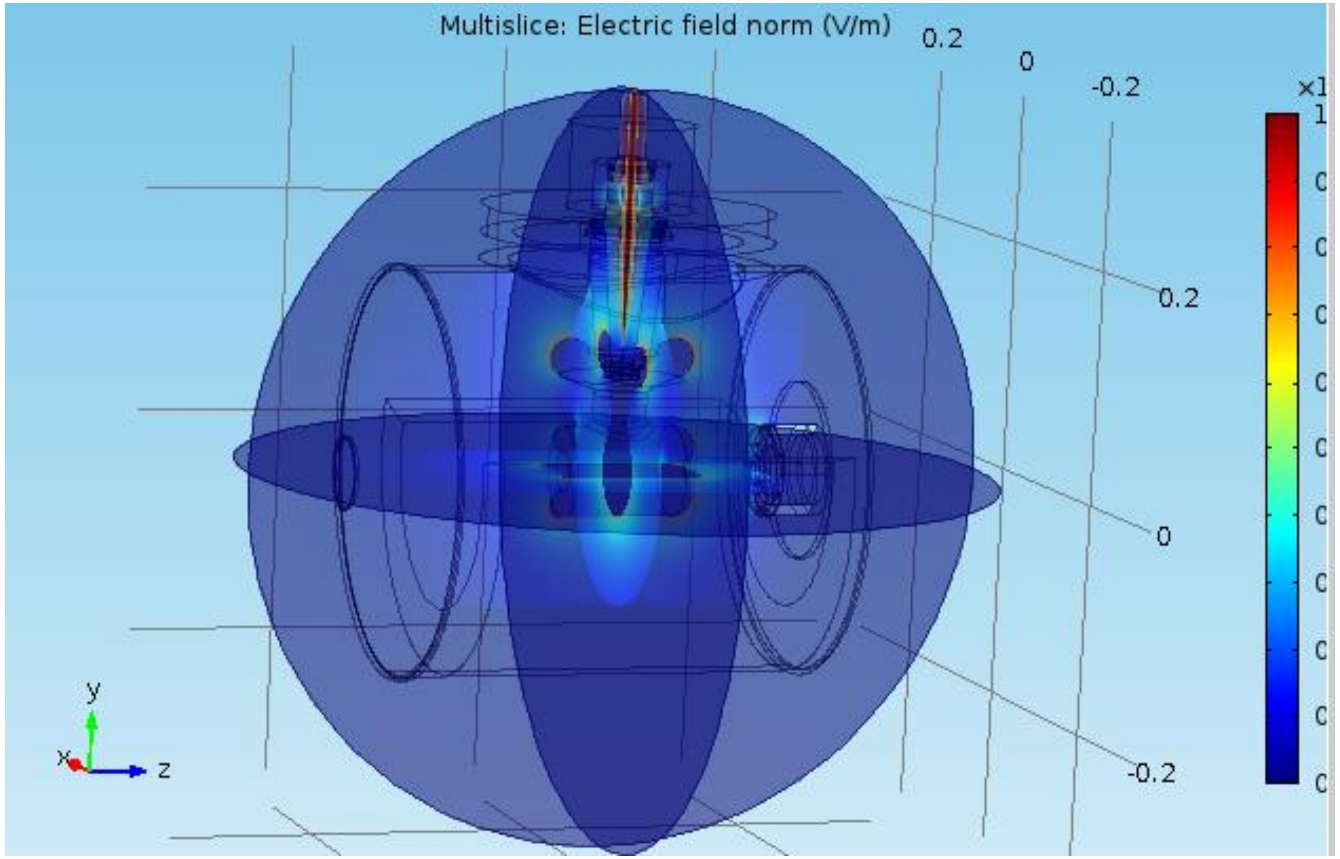
- Correct the data in the plots for the paper.
- Correct the figures too.

Fin.

COMSOL frame of reference:



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)

Potential gradient (Ex) along insulator surface: