

Modelling the electric field in High Voltage and iZIP Detectors for SuperCDMS collaboration

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Direct Dark Matter Detection + SuperCDMS

- Direct detection methods of WIMPs using Germanium and Silicon detectors operated at 15mK
- SuperCDMS is a cryogenic dark matter search experiment
- Measurements of crystal vibrations ("phonons") produced by particle interactions made using TES (Transition-Edge Sensor)

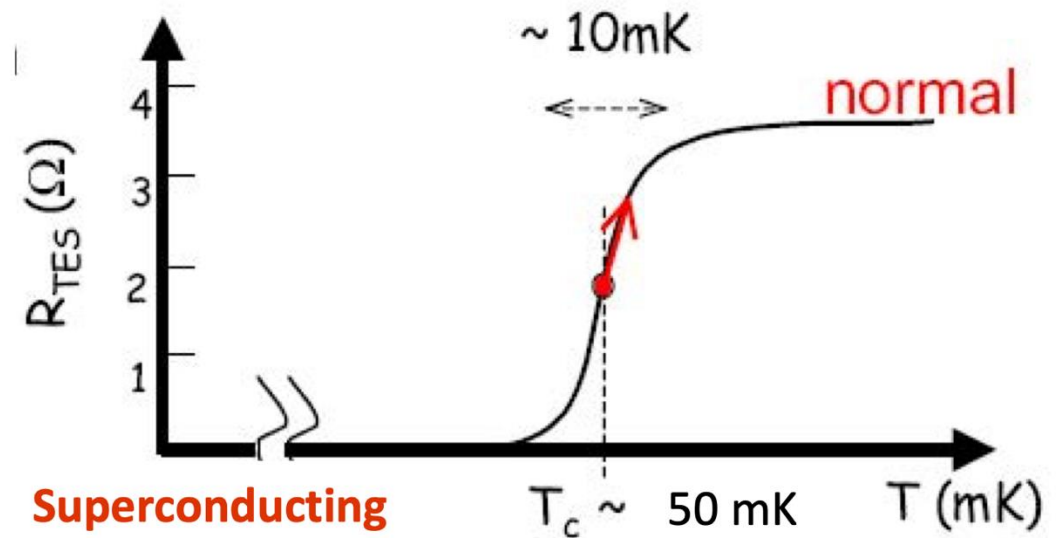


Figure 1: TES resistivity as a function of Temperature

Interactions in the detector

- Electron and nuclear recoils produce prompt phonons and e/h pairs
- Potential difference causes Neganov-Luke amplification for the phonon energy

$$E_t = E_r + (N_{eh} \cdot e \cdot V_b)$$

- E-Field configuration affects this amplification.

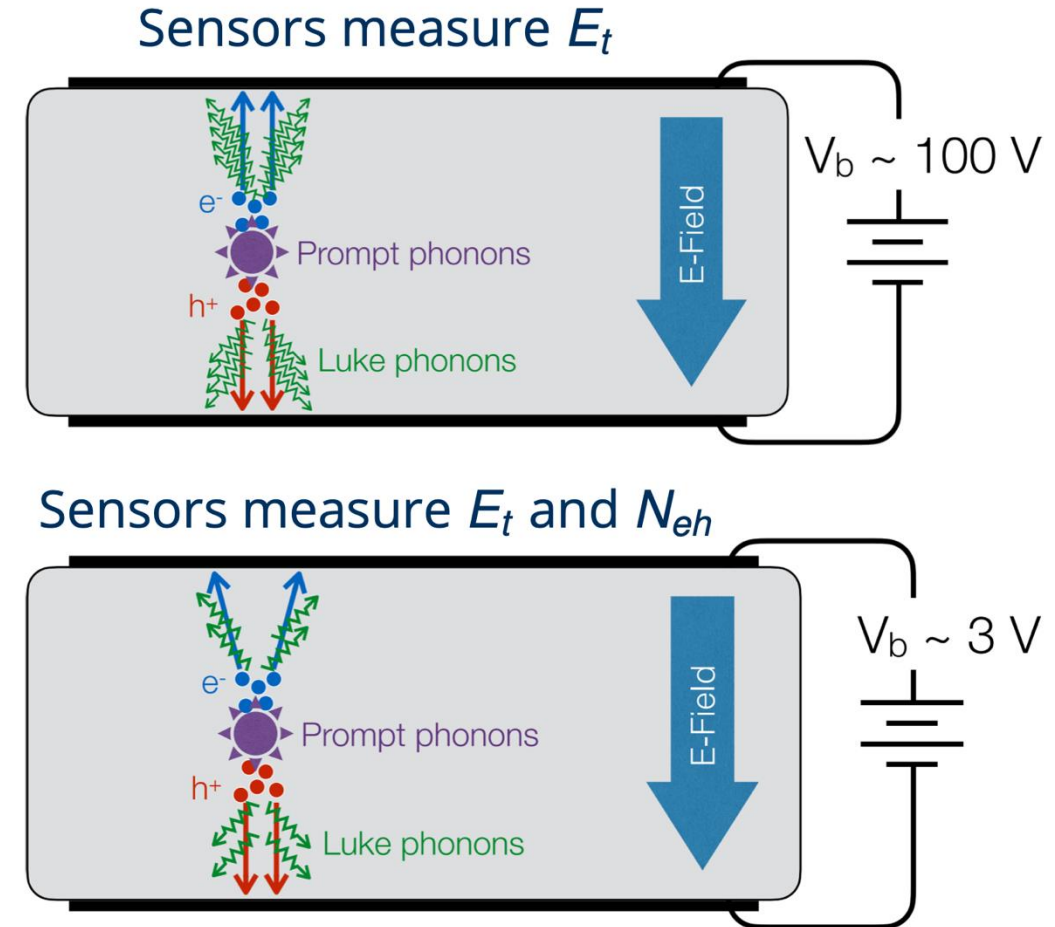


Figure 2: Luke phonon amplification due to electric field

TES Response in the Detector

- Phonons are absorbed by Aluminium fins
- Phonons can break cooper pairs
- Quasi particles diffuse into the TES
- The thermal energy increases the resistance of the TES, which we measure with sensitive electronics.

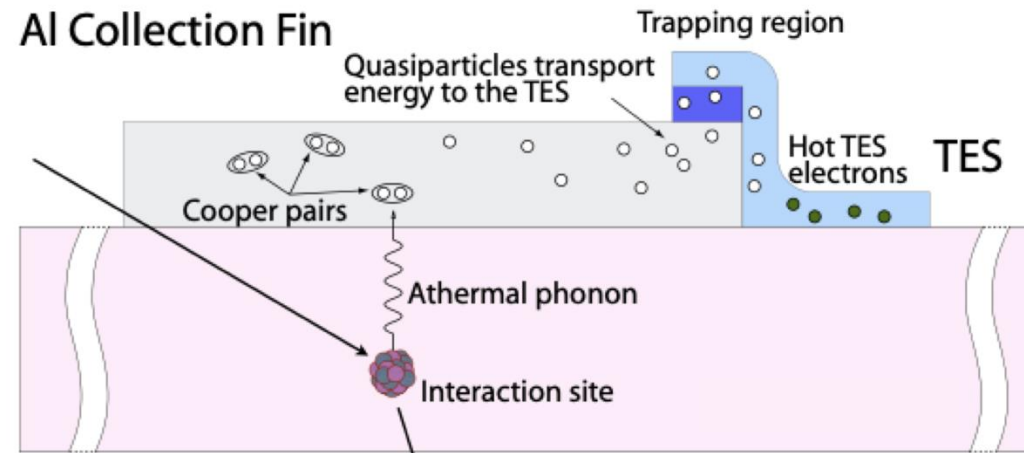


Figure 3: TES response to phonon absorption

HVeV Electric Field Modelling

Goal: To create a model of the TES sensor on the surface of detector and using the simulation to evaluate the effects of sensor design on detector performance

HVeV Detectors

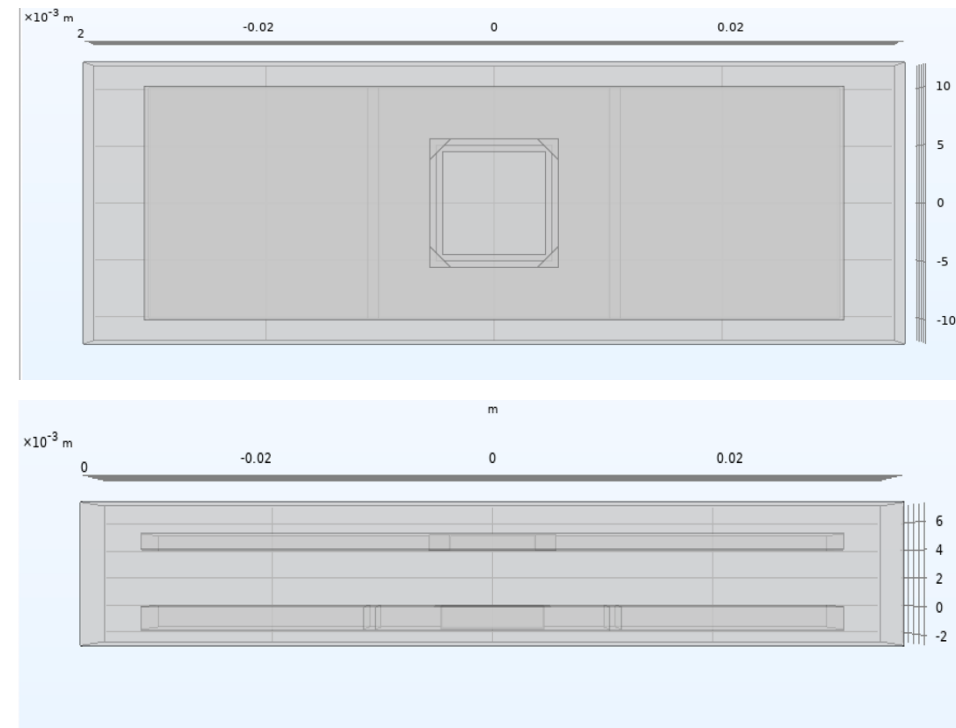
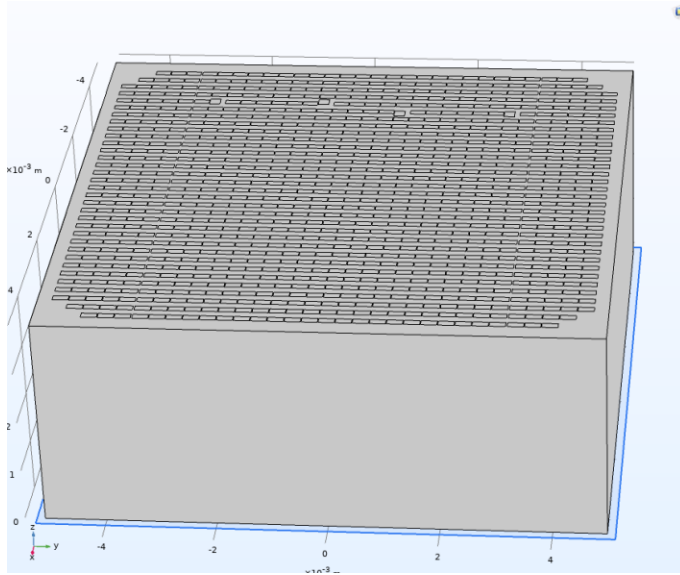


Figure 4: 10x10x4mm silicon crystal used with QET design (left) copper holder used in COMSOL models (right)

- 10mm x 10mm x 4mm silicon eV resolution gram size detector (NFC QET design as example)
- The model includes a realistic copper holder at ground potential

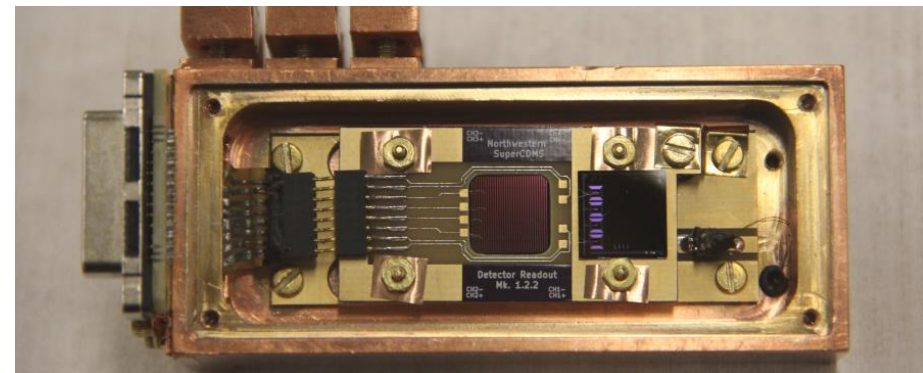


Figure 5: SuperCDMS HVeV Detector with Copper holder

COMSOL Results

- COMSOL creates a model of the electric potential across the detector
- With two biased electrodes we expect a model similar to a capacitor with linear potential in the bulk
- The model shows a slight field distortion along the sides of the crystal (<10% effect)
- The model sets the basis of particle transport simulation and phonon creation in the detector

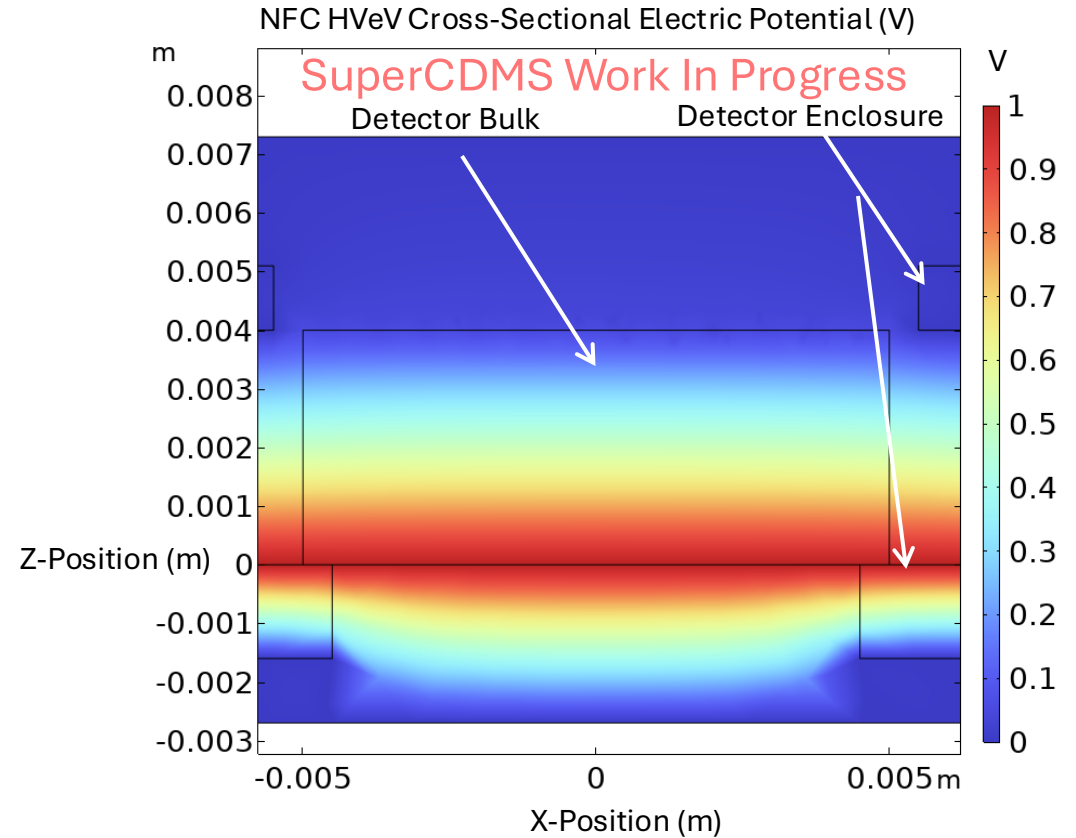


Figure 6: Electric potential simulation result of HVeV detector

Effect of Aluminum on Surface Potential

- The simulation shows the potential difference of the biased electrodes (QETs) on the surface of the silicon crystal
- QETs are grounded however the silicon in between and sidewalls deviate from 0
- The detailed potential map can be used within Detector Monte Carlo simulation to find the energy collection of the detector

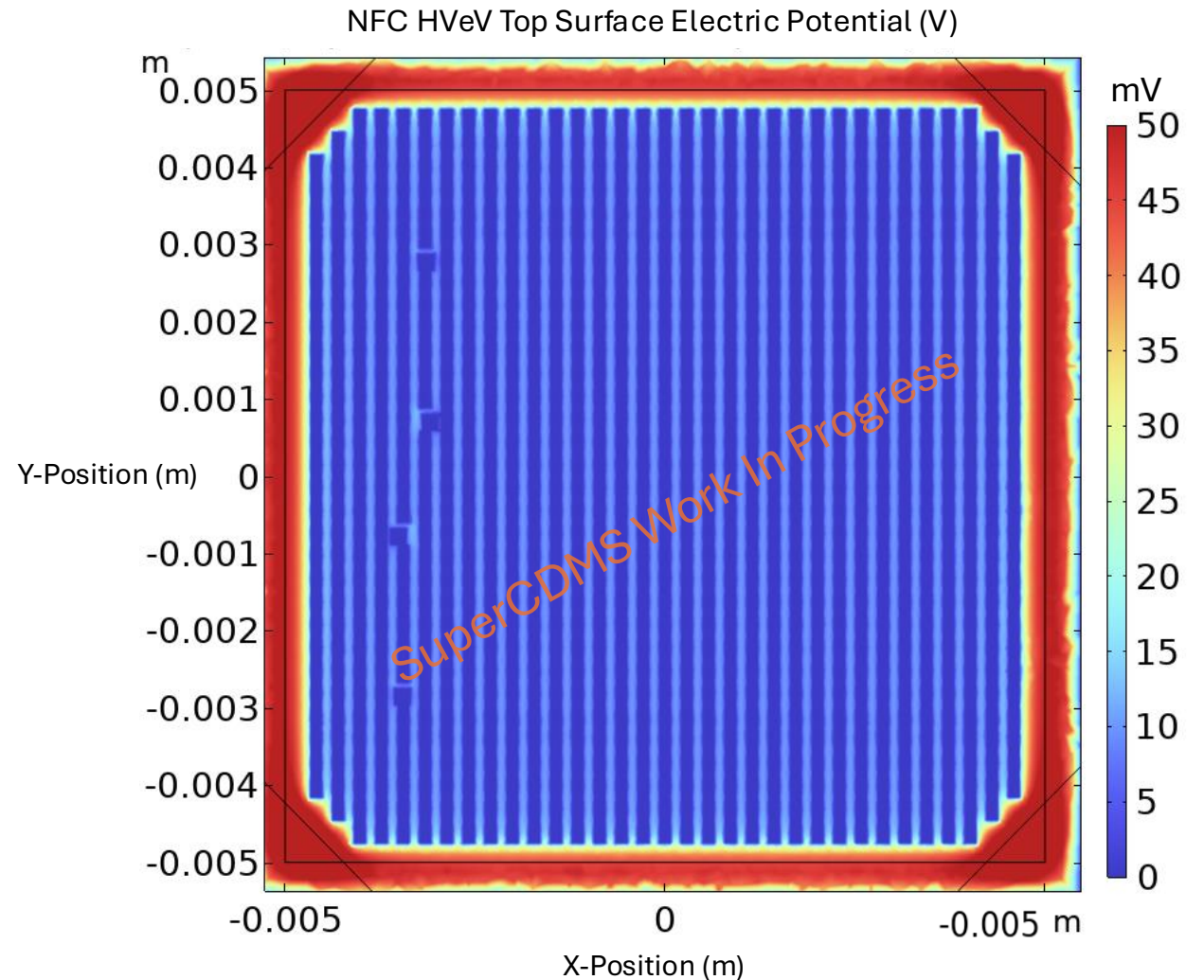


Figure 7: Electric potential on TES surface of Detector 8

HVeV NFC Detector Results

- Electric potential files are used within G4DMC simulations to track particle transport within the crystal and can be used to simulate phonon collection.
- The tail shows the impact of the QET design on phonon collection as collection slightly away from the QETs results in a lower NTL gain.

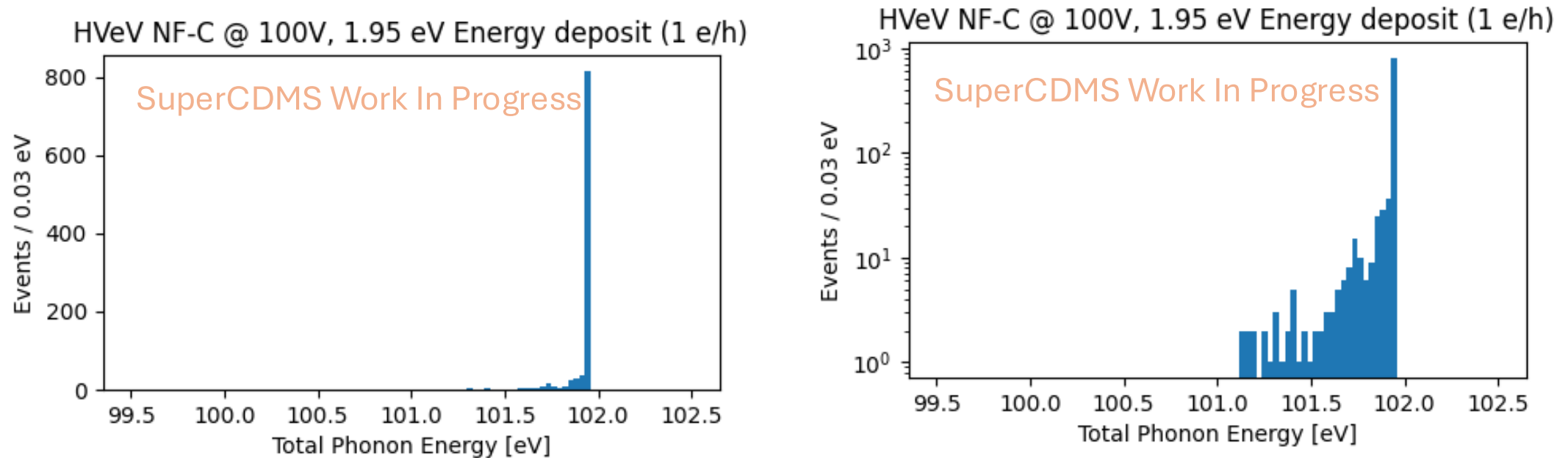


Figure 8: Phonon collection result from 1000 events at 1.95eV energy depositions at the center of the HVeV NFC detector on a linear (left) and log (right) scale.

HVeV Modelling Outcome

- Previous models for a single QET type of HVeV detectors existed, so we aimed to recreate those results
- Expand that model to different QET designs (e.g. NFF and NFE)
- Evaluate how the QET density on the surface affect energy collection within G4DMC simulation framework.

Kilogram scale SuperCDMS iZIP/HV electric field modeling

Goal: To create a model of the TES/FET sensor on the surface of detector and using the simulation to evaluate the effect of sensor design and detector tower and performance

iZIP7 Detector Housing

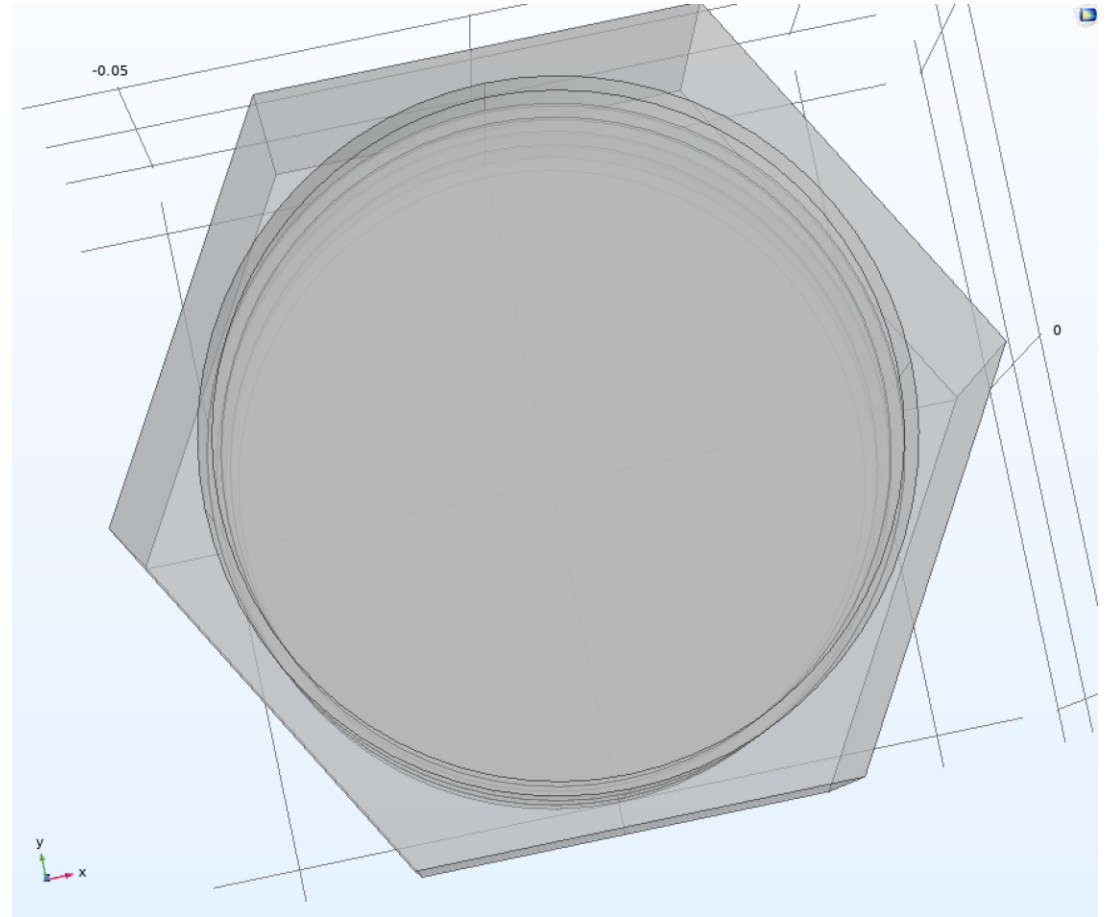
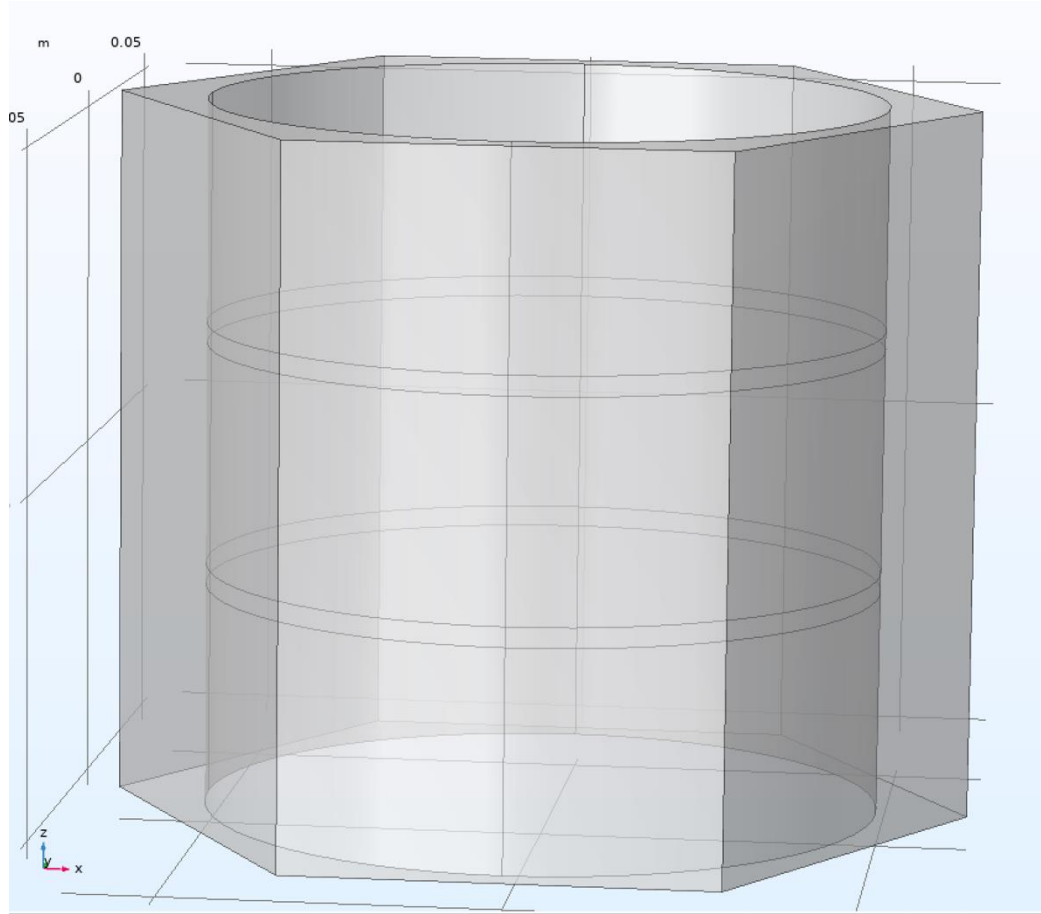
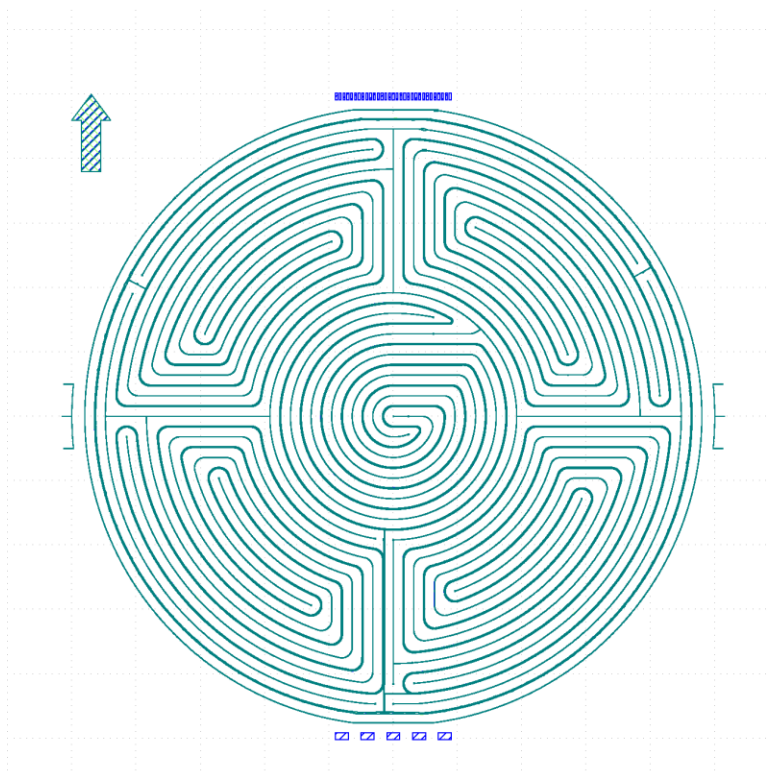


Figure 9: COMSOL model of iZIP7 detector tower, with three detectors in a hexagonal copper enclosure

iZIP7 TES/FET Design

Complete design of alternating phonon and charge sensors on surface of the detector



Zoomed in on the fine details of charge and phonon sensors

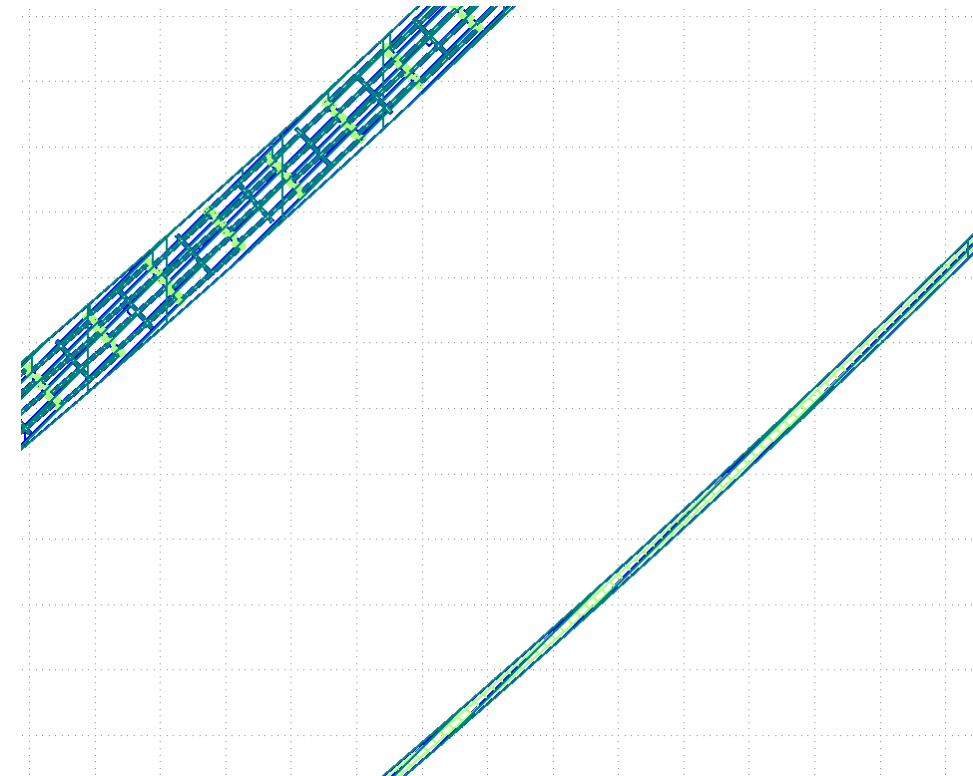


Figure 10: Complete iZIP7 charge and phonon sensor layout (left) with zoomed in details (right)

Simplified iZIP Sensor Design

- Efficient modelling required design simplification
- Simplified layout with rectangles creating the outline
- Phonon and charge sensor form thicker and thinner lines respectively

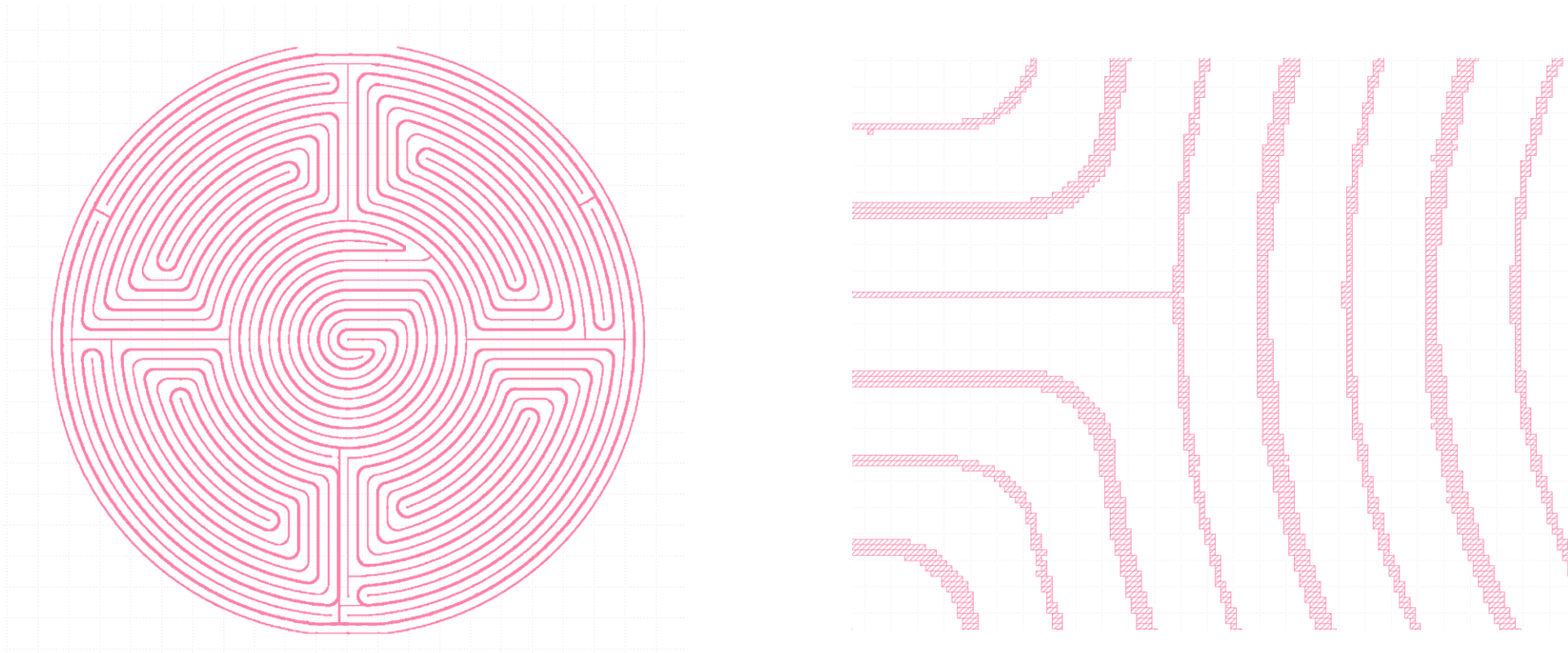


Figure 11: Simplified iZIP7 charge and phonon sensor layout (left) with zoomed in details (right) used for COMSOL simulations

iZIP7 Detector Model

- Example of iZIP7 detector in COMSOL with sensor design.
- The central detector was used for Detector Monte Carlo simulations
- Top and bottom detectors modeled with simplified electrode planes to reduce computing time.

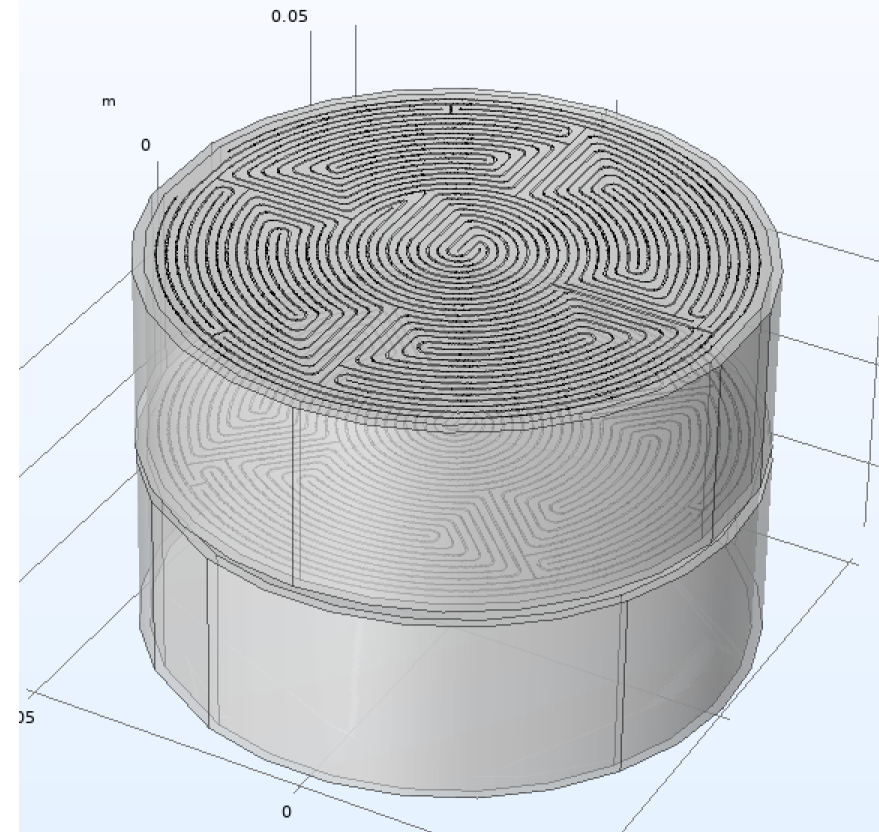


Figure 12: COMSOL model of iZIP7 detector tower with sensor design (top detector is omitted)

iZIP7 Detector COMSOL Model

- Result of COMOSL simulation of iZIP7 Detector with sensor design
- Alternating potentials on respective detectors in stack
- Middle detector has the area of interest for G4DMC simulation

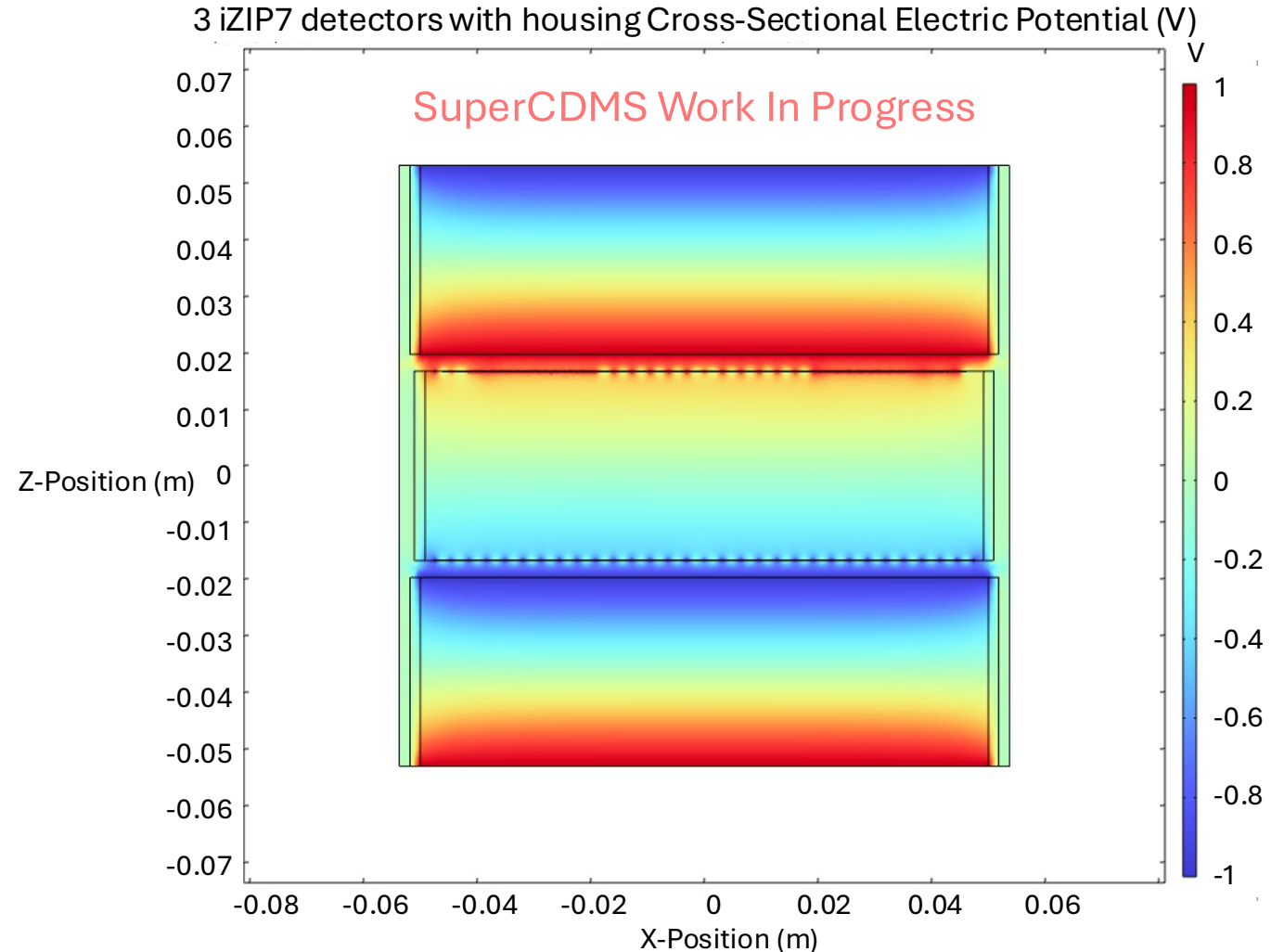


Figure 13: Example output of COMSOL simulation for iZIP7 detector in a copper enclosure

iZIP7 Detector COMSOL Model

- Result of COMSOL simulation with the surface of the detector.
- Phonon and charge channels separated into inner and outer phonon channels and a single charge channel
- Channels biased individually with a single channel set to +1V, all others grounded, repeated for each channel on top and bottom

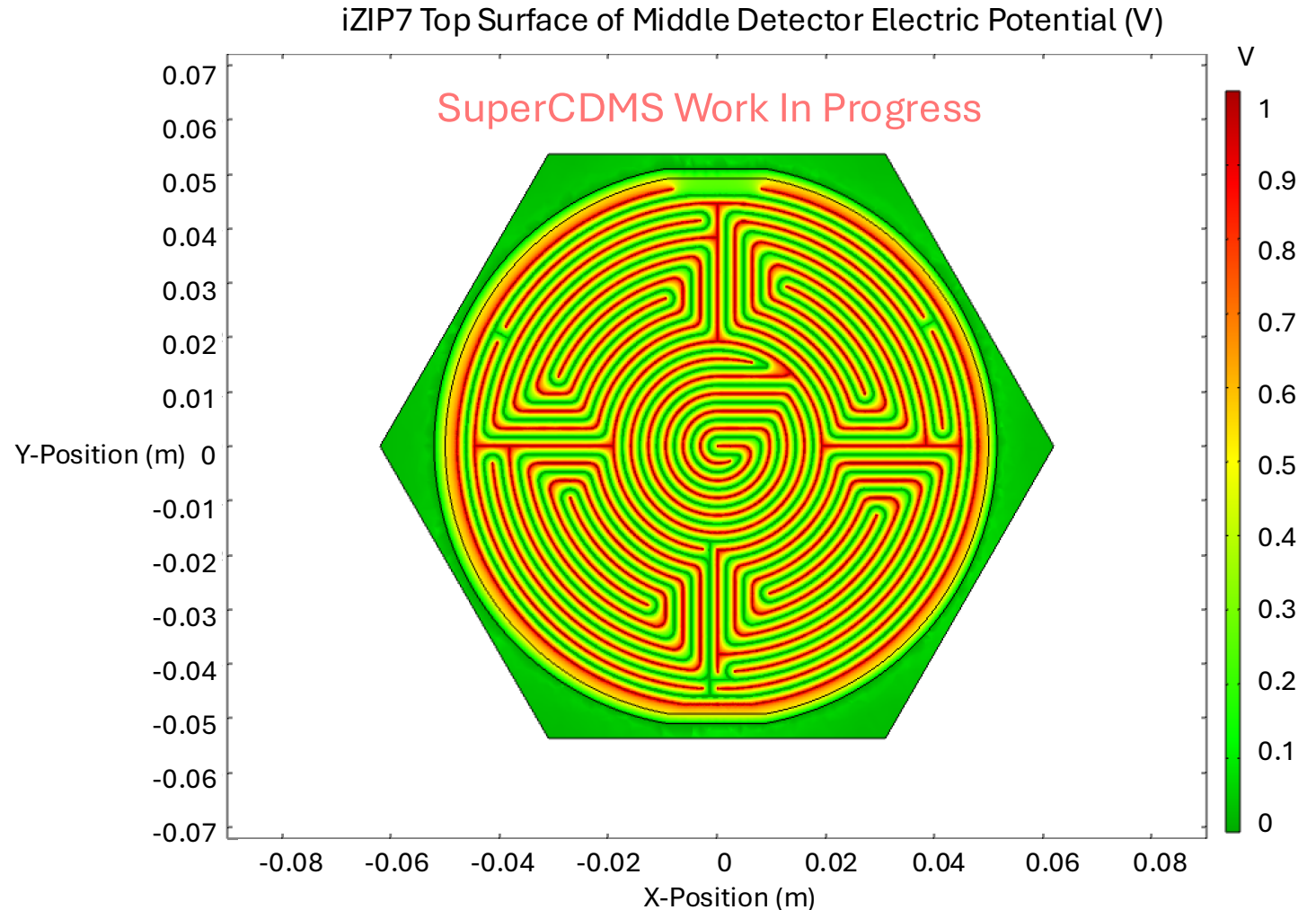


Figure 14: Example output of COMSOL simulation for top view of iZIP7 detector in a copper enclosure

Project Outcome

- A viable electric potential model for HV and iZIP7 detectors with incorporated sensor design to be used for particle transport simulations.
- Reproducible and effective method to increase computation efficiency for TES and FET incorporation in COMSOL simulations.
- Quantifying the impact of detector housing and a tower of detectors and the electric potential within the bulk.