Space charge effects in simulations of large avalanche dynamics

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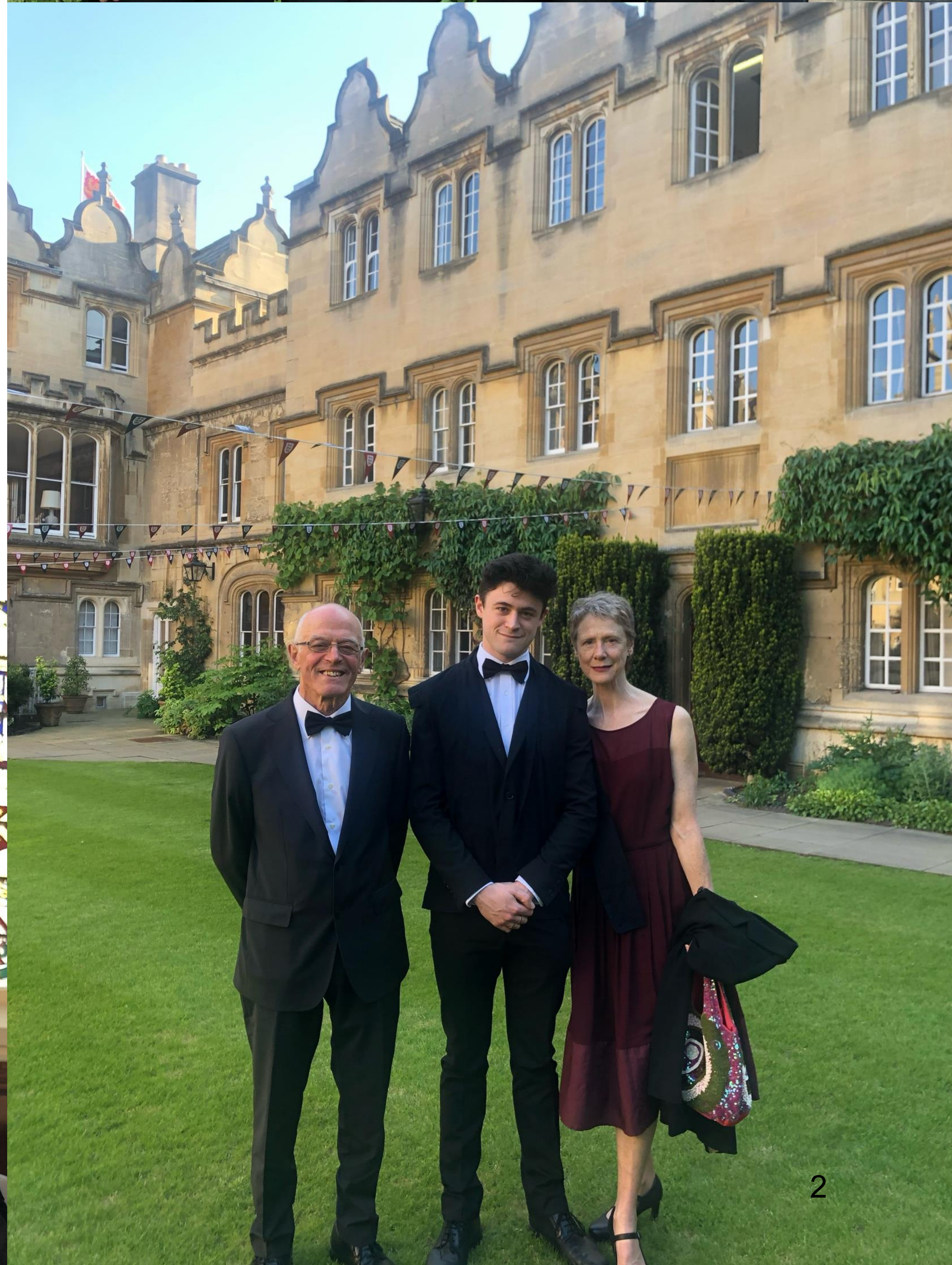
Introduction & experience

- Physics student at Oriel College, Oxford
- Starting Master's course this year
- Worked with the MIGDAL collaboration (STFC, RAL) last summer, simulating their double GEM system in Garfield++

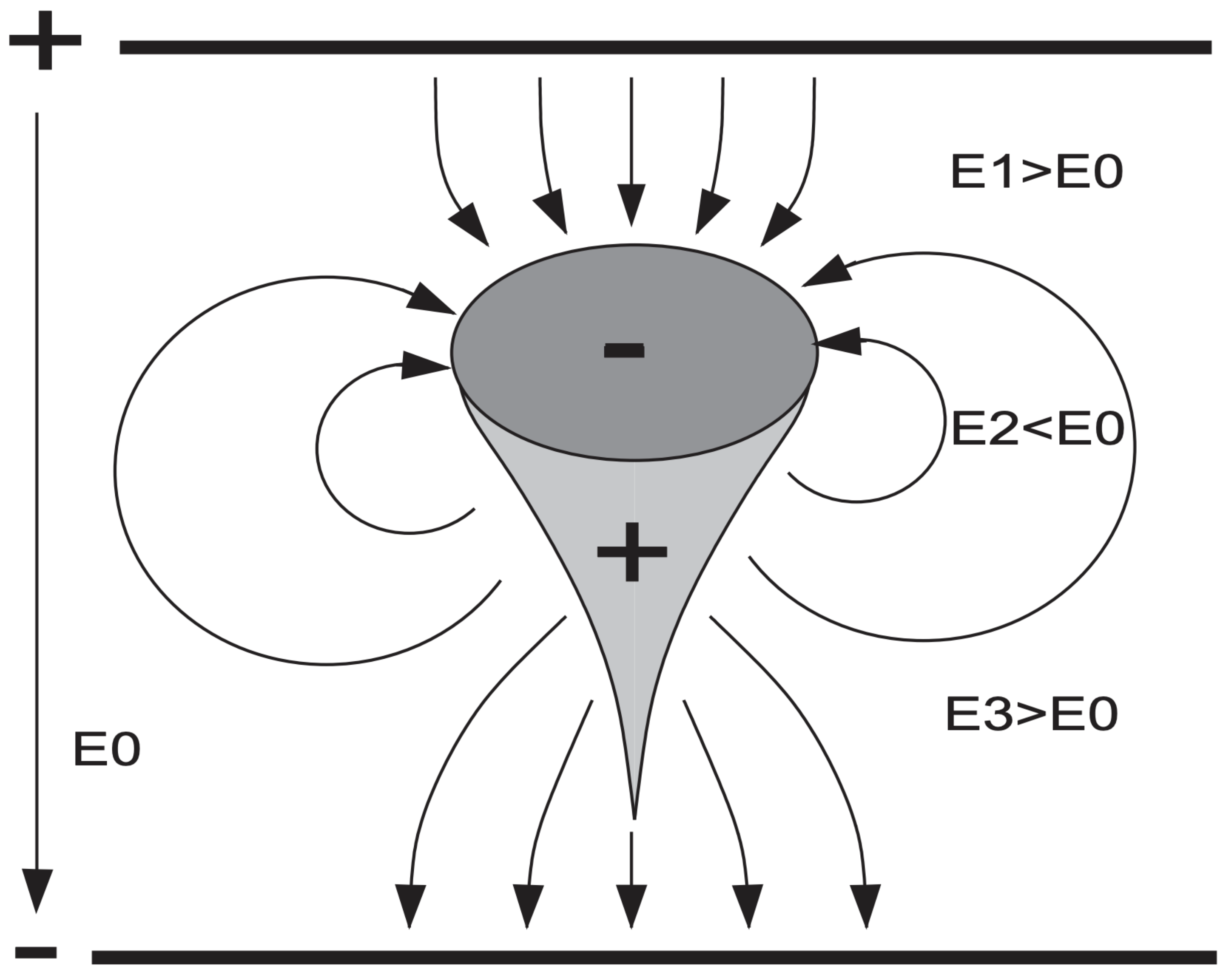


Project overview

- Add the space charge effect to Garfield++ microscopic simulations
- Investigate the accuracy and efficiency of the following approaches:
    - Axisymmetric rings of charge
    - Point charges
- Compare the accuracy of the free-space approximation against a parallel plate boundary condition

The space charge effect

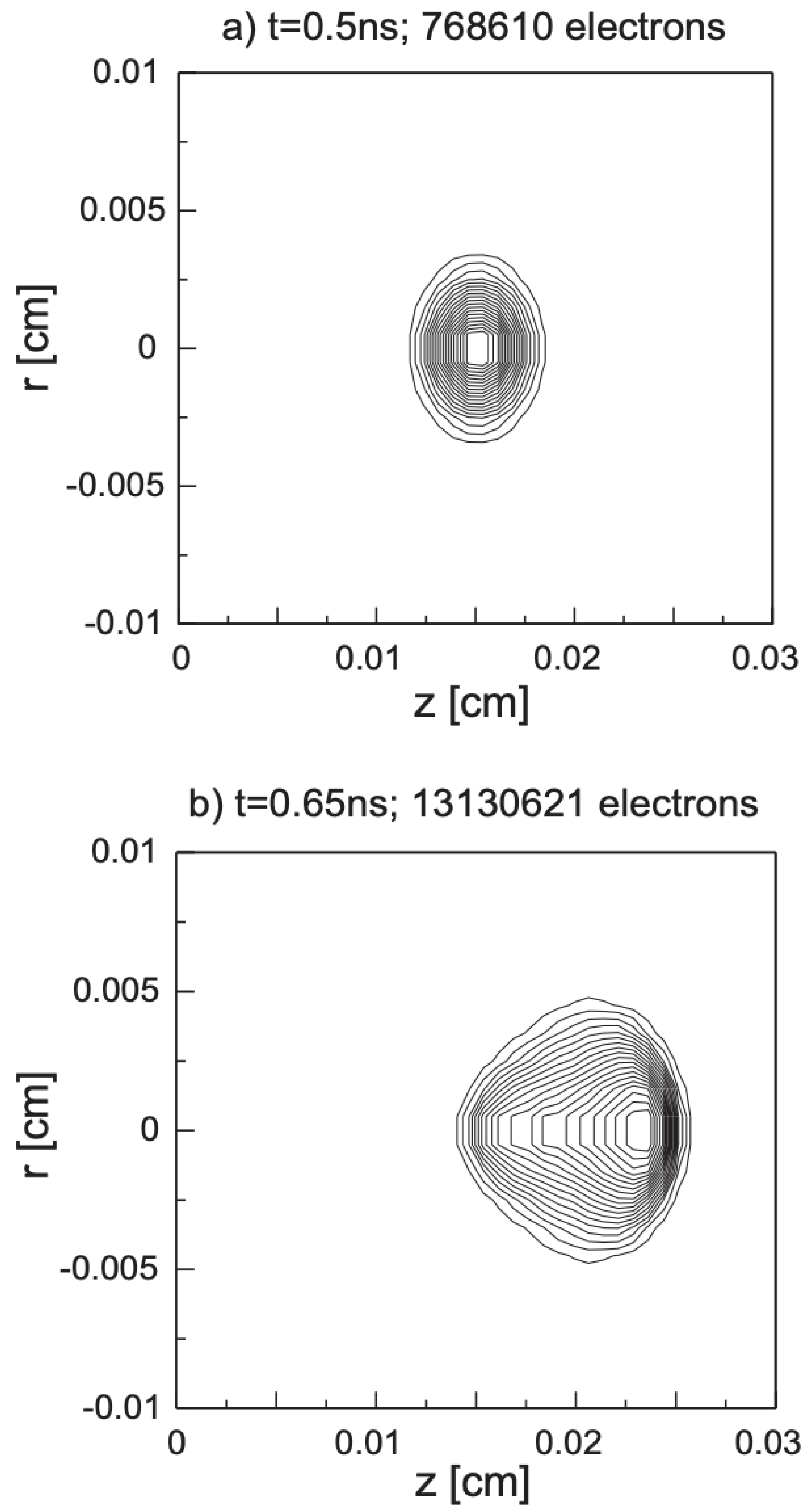
- During high-gain avalanches, non-negligible fields may arise from the charge distribution
- These charges may modify the background applied field
- This modifies the gas parameters



C. Lippmann, W. Riegler / Nuclear Instruments and Methods in Physics Research A 517 (2004) 54–76

Space charge in Garfield++

- The class `AvalancheGridSpaceCharge` allows for the simulation of the space-charge effect for transporting electrons along a grid
- The free-space axisymmetric approximation is used
- This is a dynamical approach, where the field due to the charges is recalculated at every timestep
- We would like to implement a similar dynamical approach using the microscopic transport of `AvalancheMicroscopic`



Charge distribution in the axisymmetric approximation for an RPC (C. Lippmann, W. Riegler / Nuclear Instruments and Methods in Physics Research A 517 (2004) 54–76)

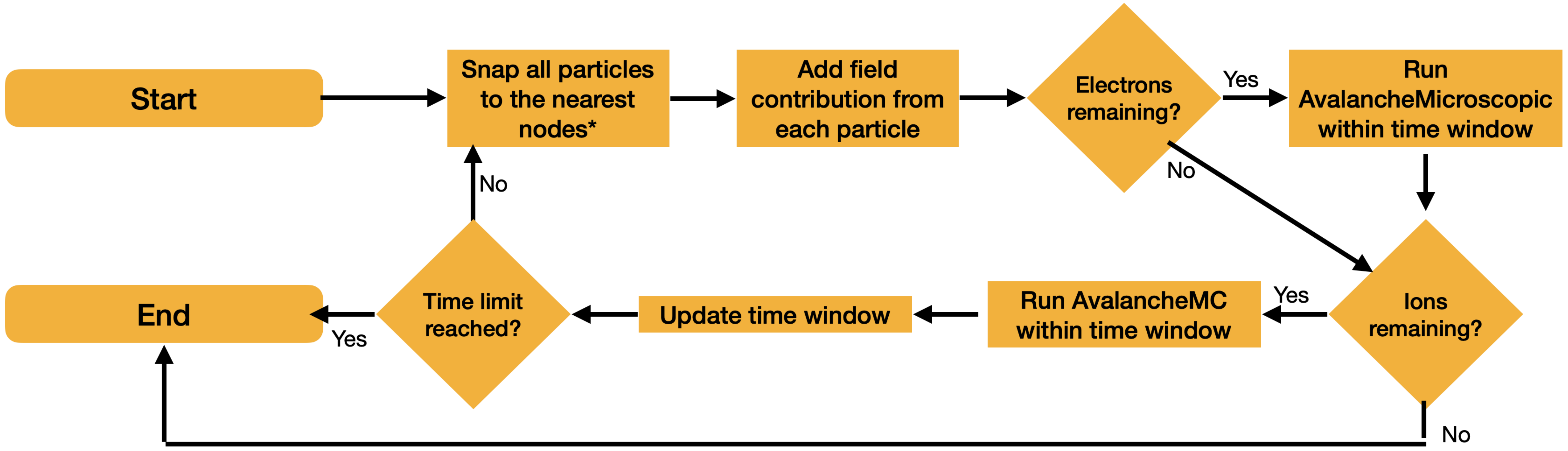
Initial grid-based approach

- Particles were snapped to grid nodes and the field calculated on the nodes
- The field was then interpolated between nodes when requested at an arbitrary point by `AvalancheMicroscopic`

- The grid is 2D (r, z)
- The avalanche propagates downwards along y

Structure of the simulation

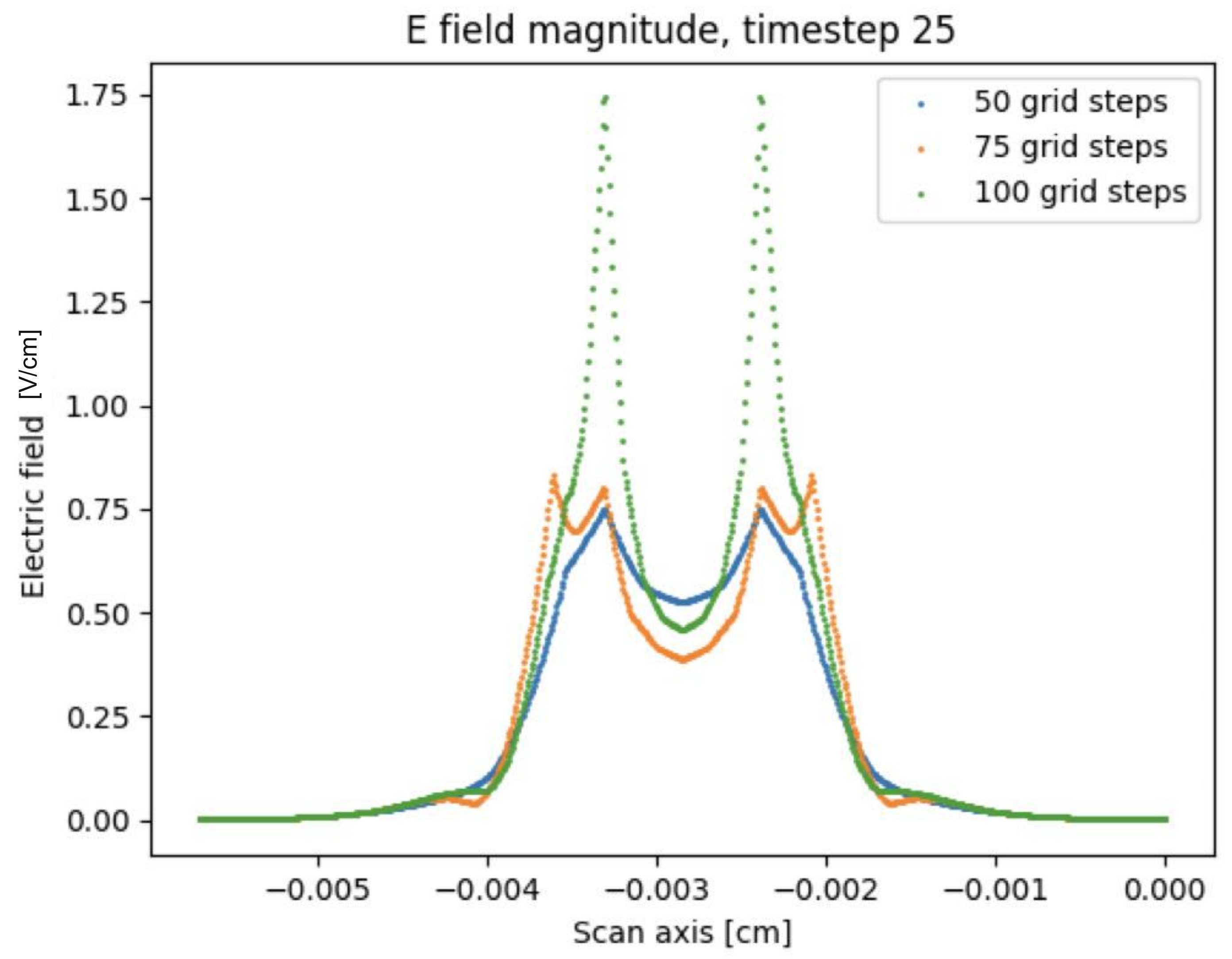
- Code was added to `AvalancheGridSpaceCharge`:
  - To interpolate between the nodes
  - To send the field to `Sensor`, where it is requested by `AvalancheMicroscopic`
  - To make the rings move with the mean position of the avalanche
- A main program was created to set up the simulation and alternately simulate the electrons and ions during a small time window

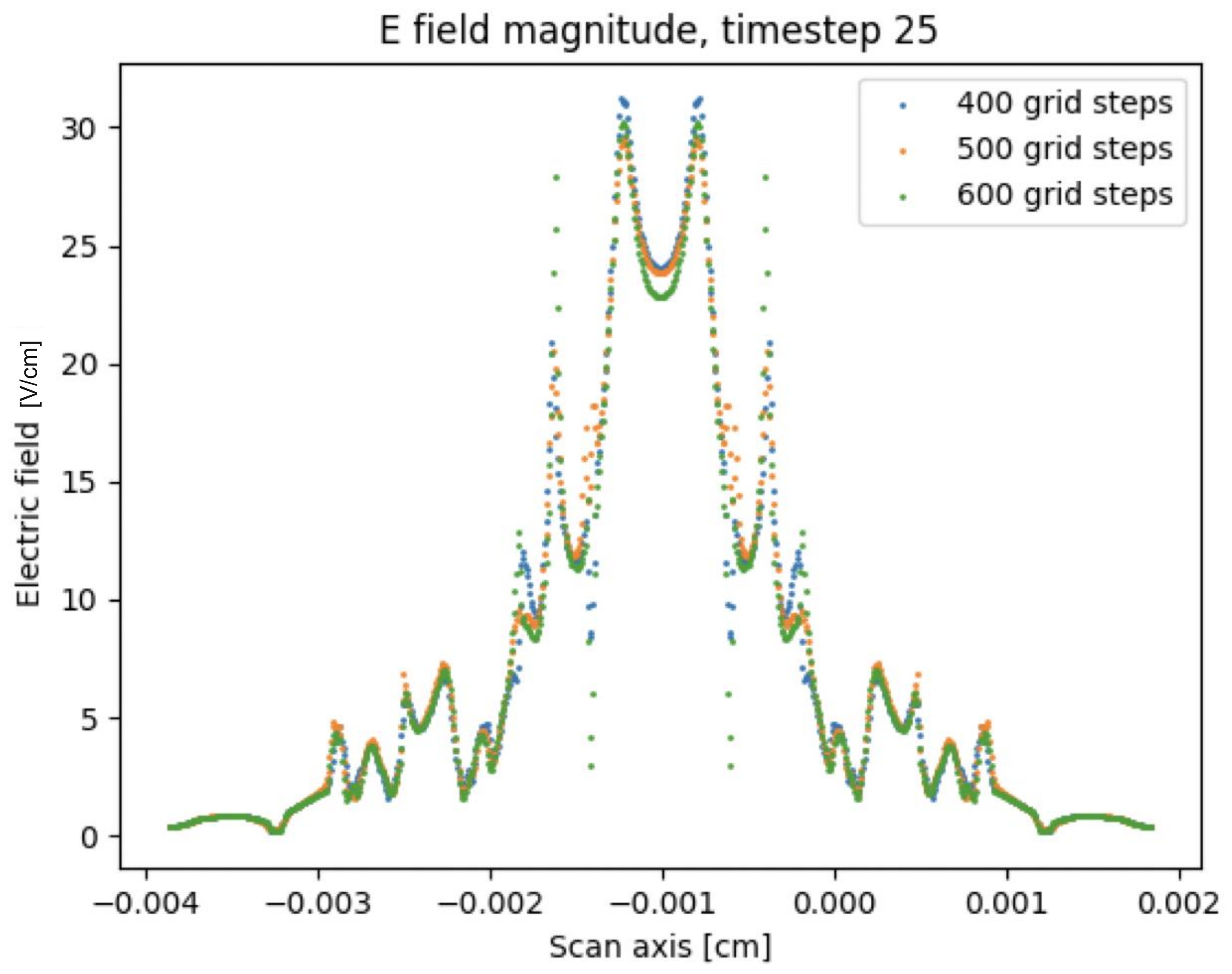


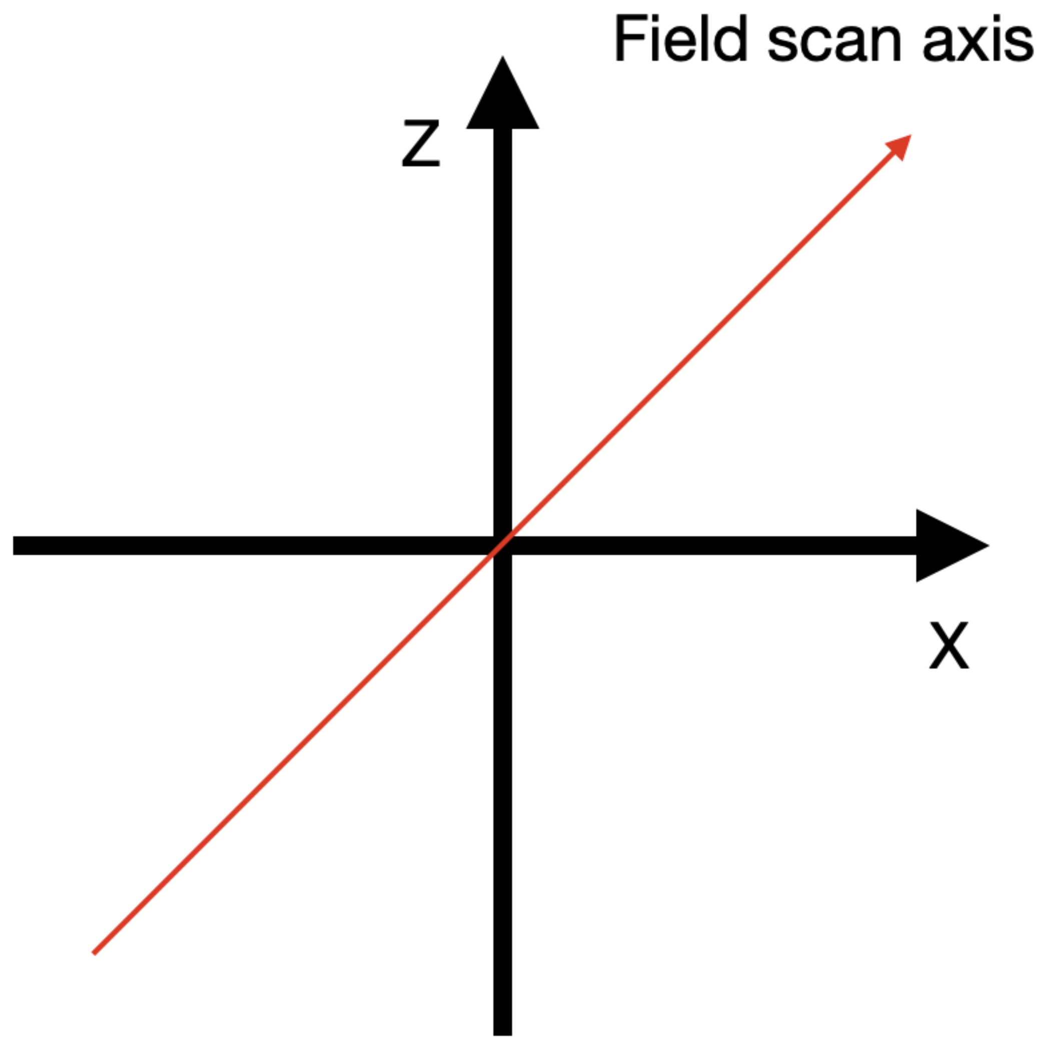
* the particles do not move in physical space - only on the grid, in order to calculate the field

Issues with a grid-based field

- The effect of grid spacing on the field was investigated
- It was found that the field strongly changes with grid spacing
- Divergences are sampled by finer grids but interpolated away for coarse grids
- For $\gtrsim$ 300 nodes in r and z, the fields begin to converge, but disagreement remains in regions of divergence

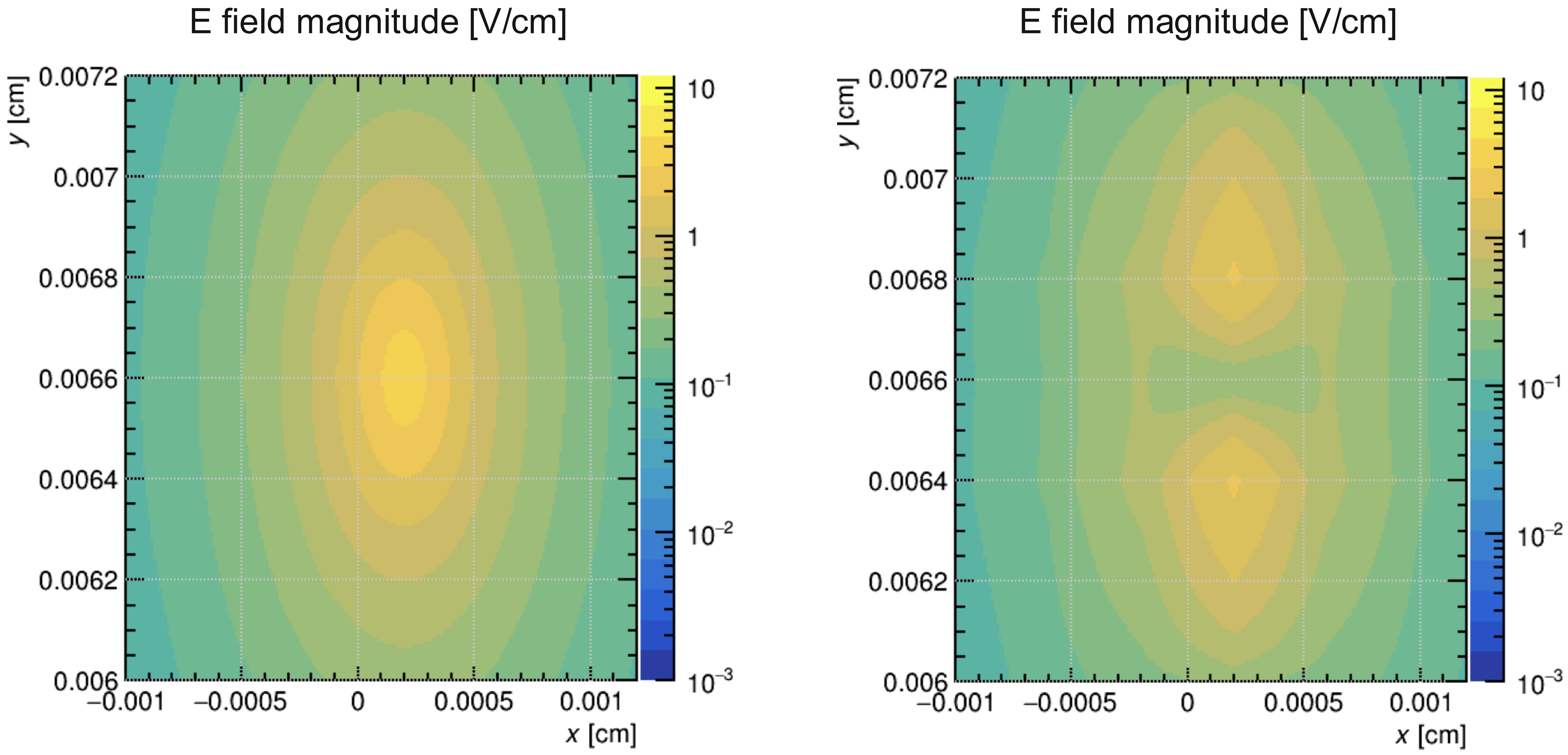






Issues with a grid-based field

- A splitting of the field was noticed
- The snapping to the grid was ruled out

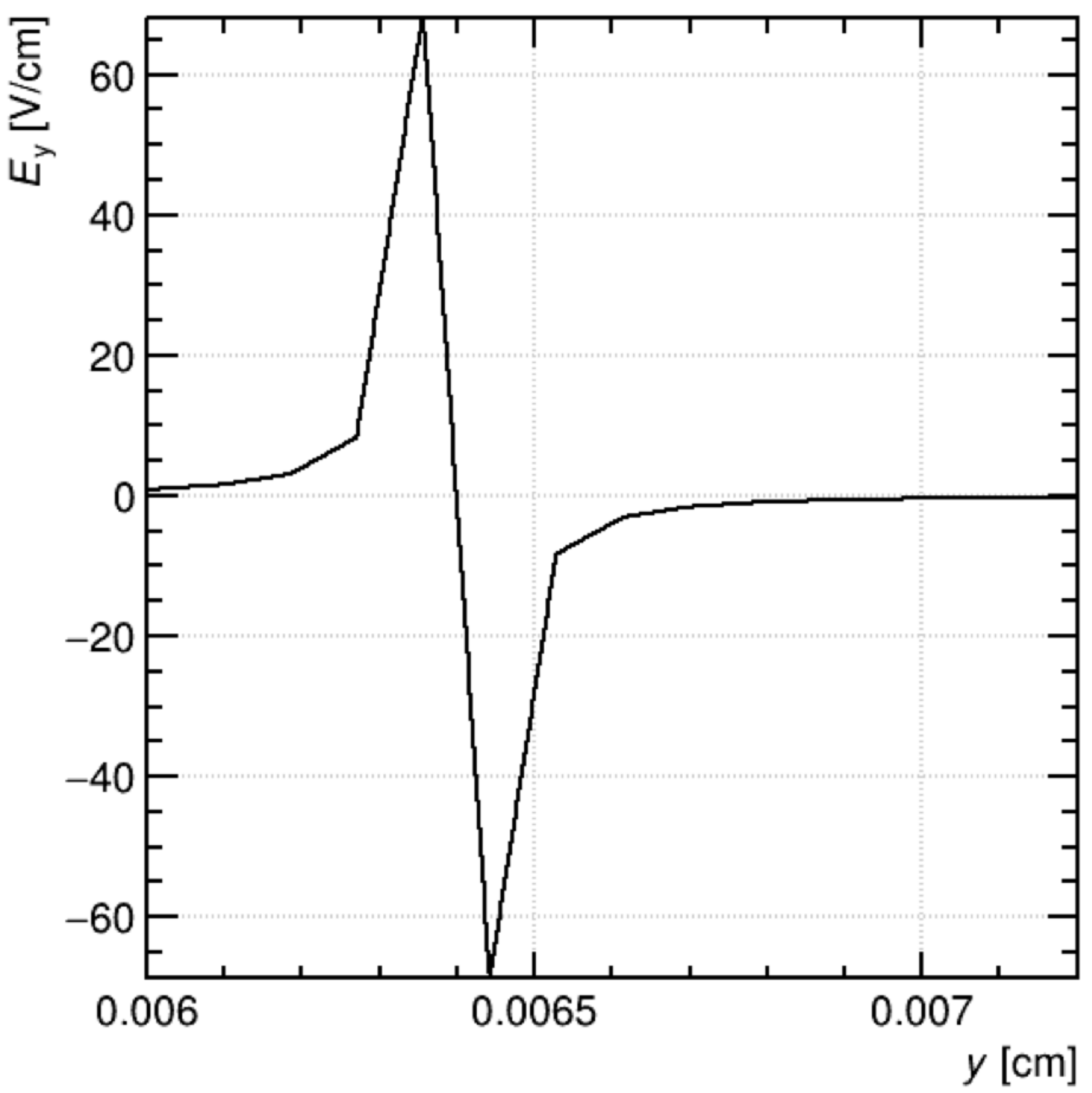


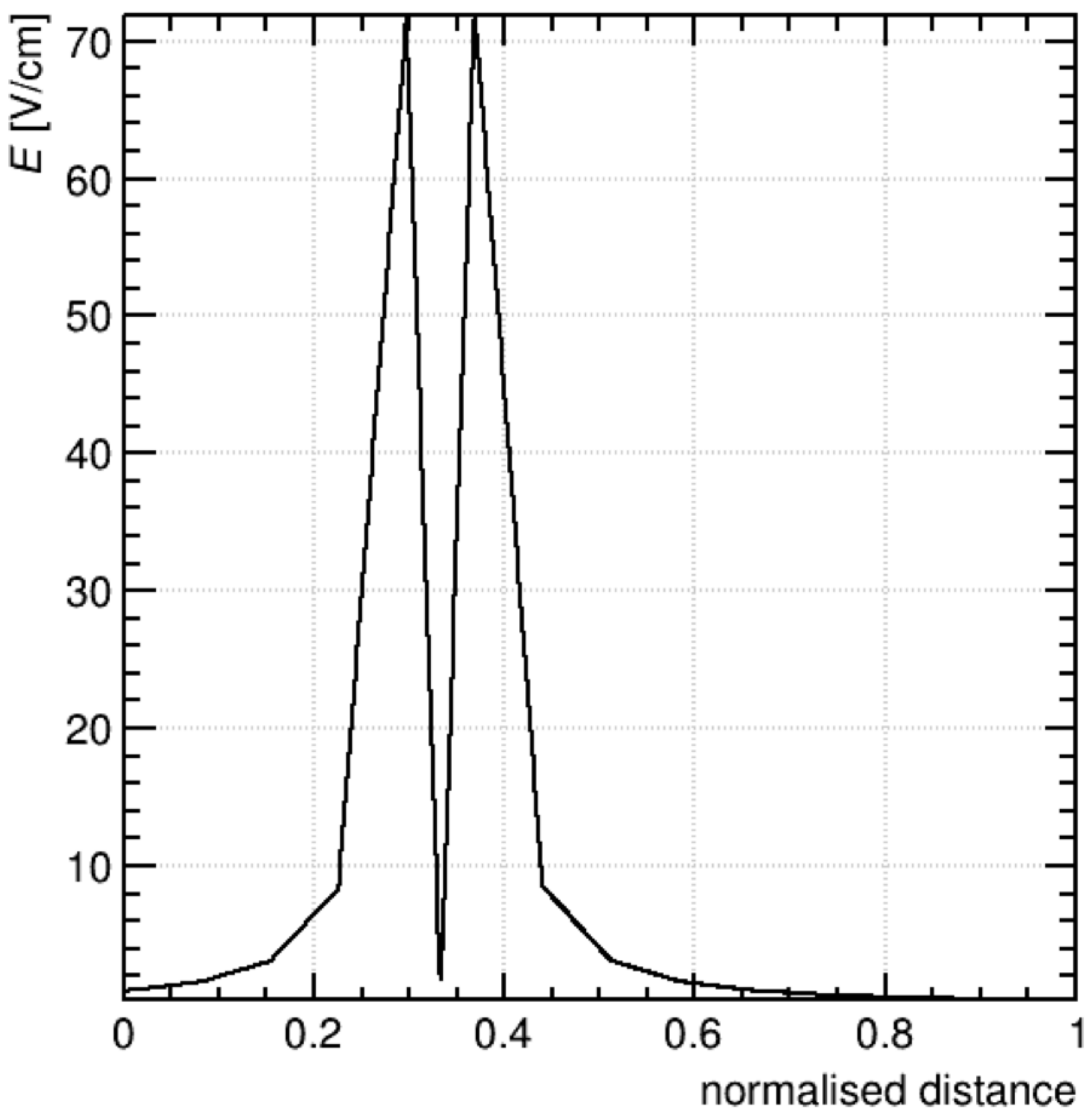
Left: field before interpolation
Right: field after interpolation

These plots were produced after snapping was removed; hence the field is centred in the same place

Issues with a grid-based field

- The splitting was found to be a result of the interpolation connecting positive and negative samples of the field components around a divergence
- These interpolated field components were used to calculate the magnitude
- This resulted in spiking of the magnitude
- To avoid this, and the dependence of the field on the grid spacing, the grid was abandoned





The grid-free approach

- Code was refactored into a new class, `ComponentChargedRing`
- Particles are no longer snapped to the grid, and the field is recalculated every time it is requested
- This implementation is simpler, more readable and separated from the intended use case (grid-based transport) of `AvalancheGridSpaceCharge`
- The grid-free approach comes with a computation time cost, but is still manageable with parallel computing

Space charge on

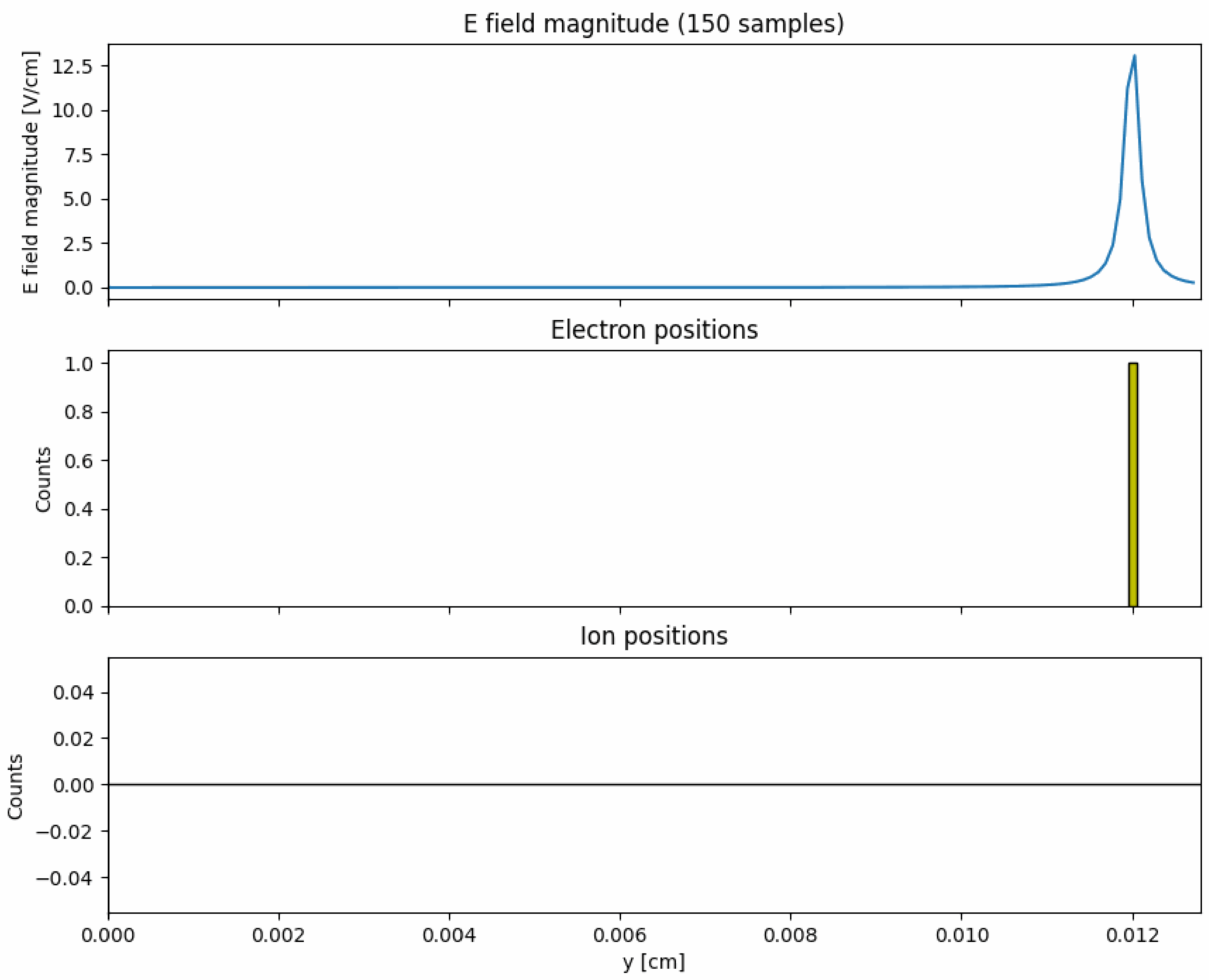
Gain	Time
23447	45 min
3040	2.5 min
1291	53 sec
383	9 sec

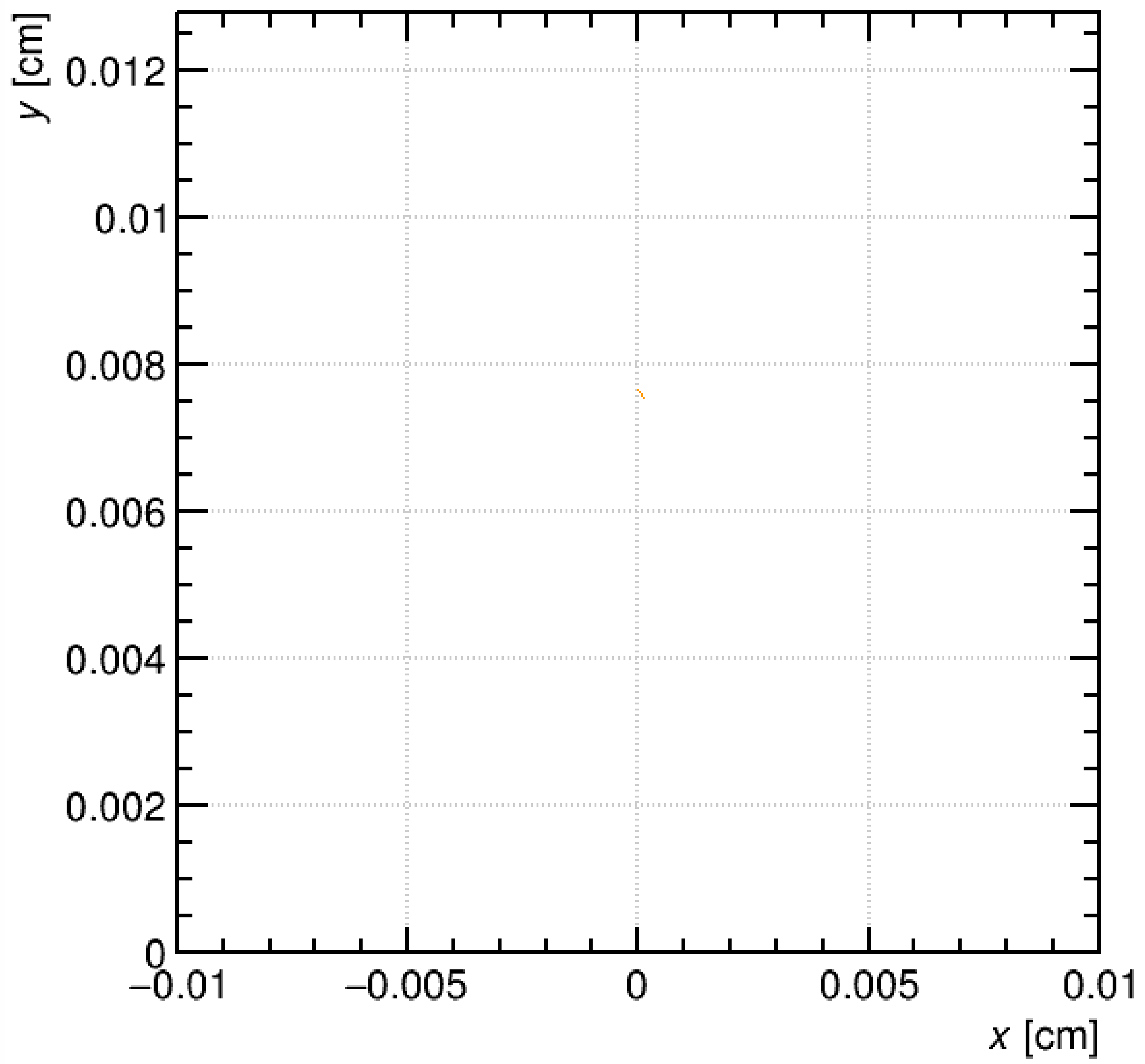
Space charge off

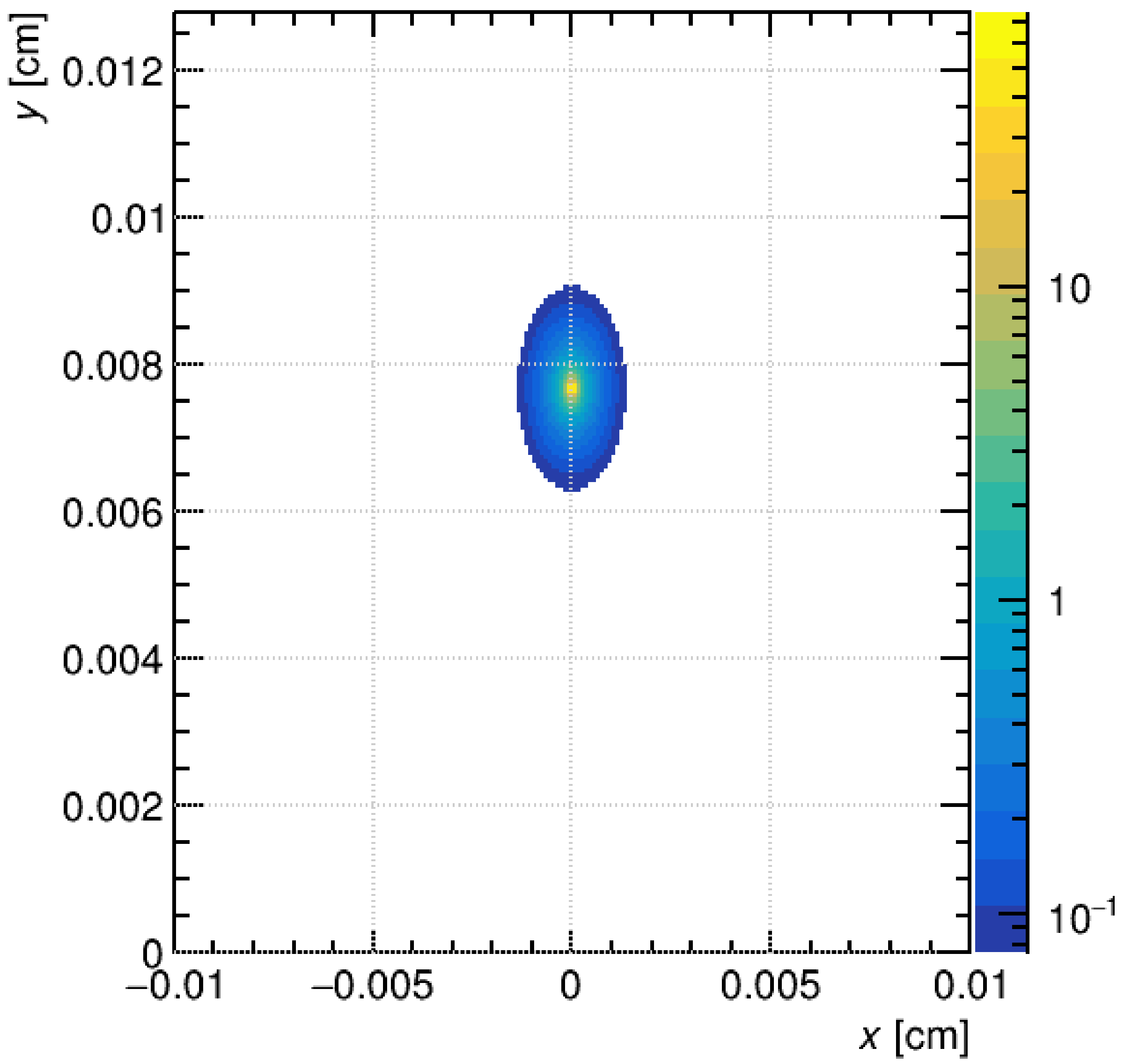
Gain	Time
11833	15 sec
2312	4 sec

Timestep: 0.05 ns

Visualising the space charge field





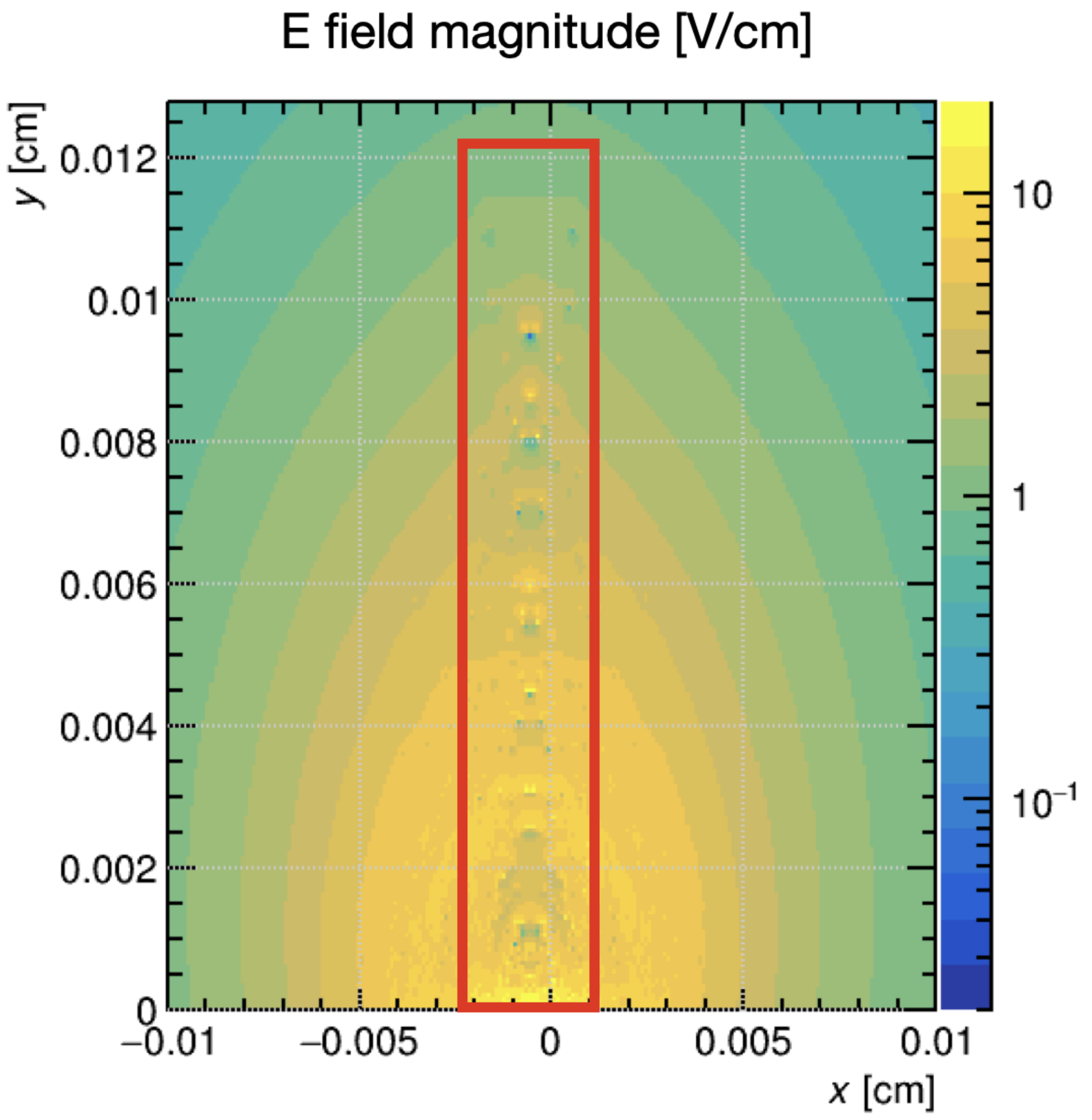


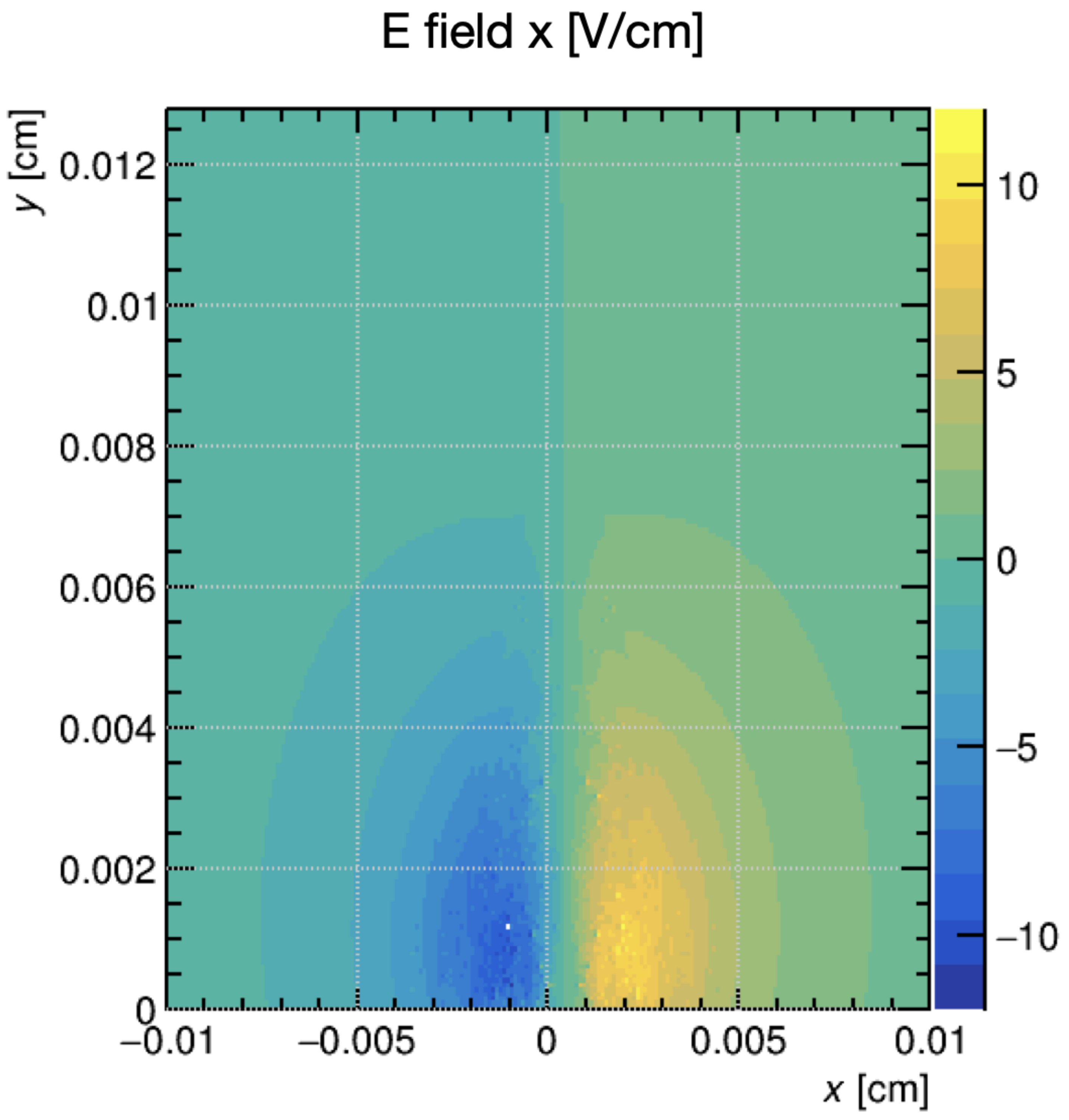
Gain: 12637

GIFs viewable at
https://github.com/tomszwarcer/spacecharge-sim

Visualising the field

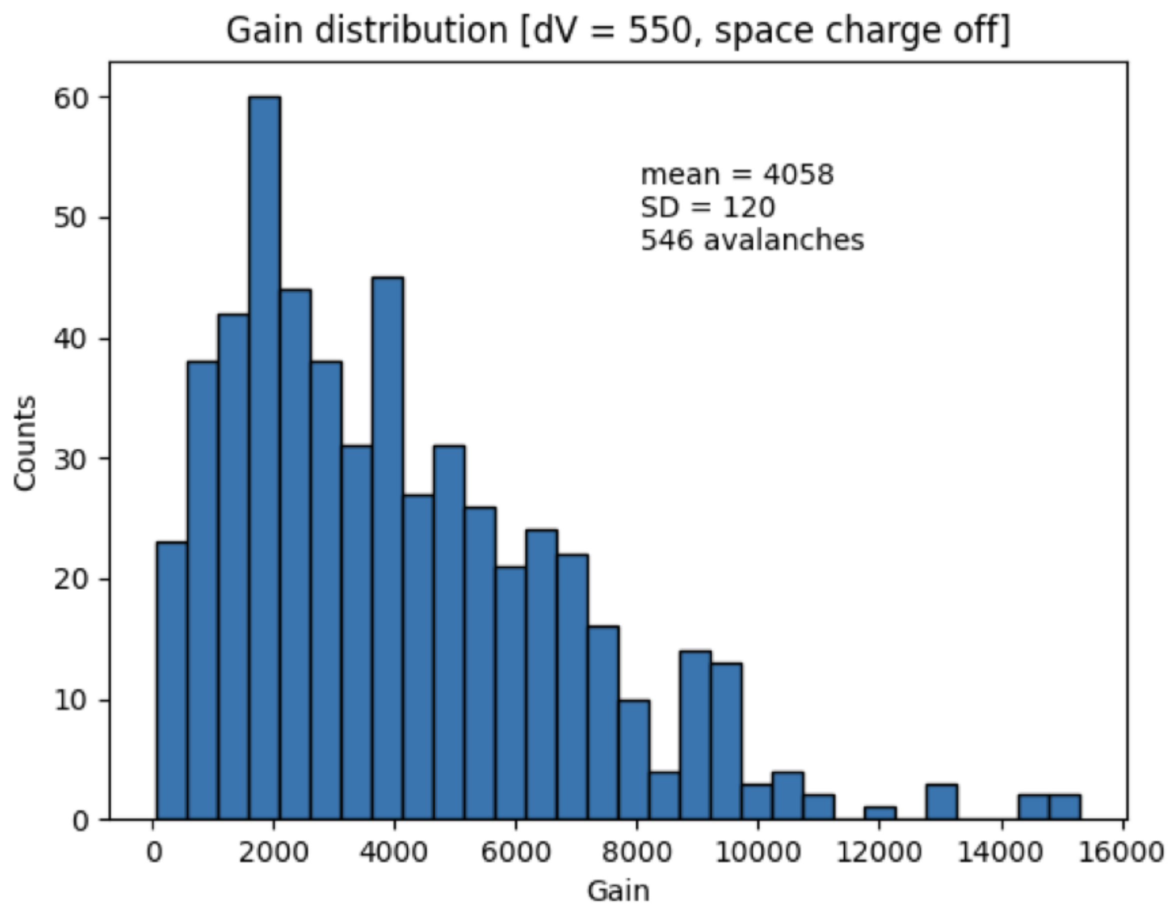
- We see a central dip in the field
- This is due to the polarity of the x, z components of the field changing over the central region

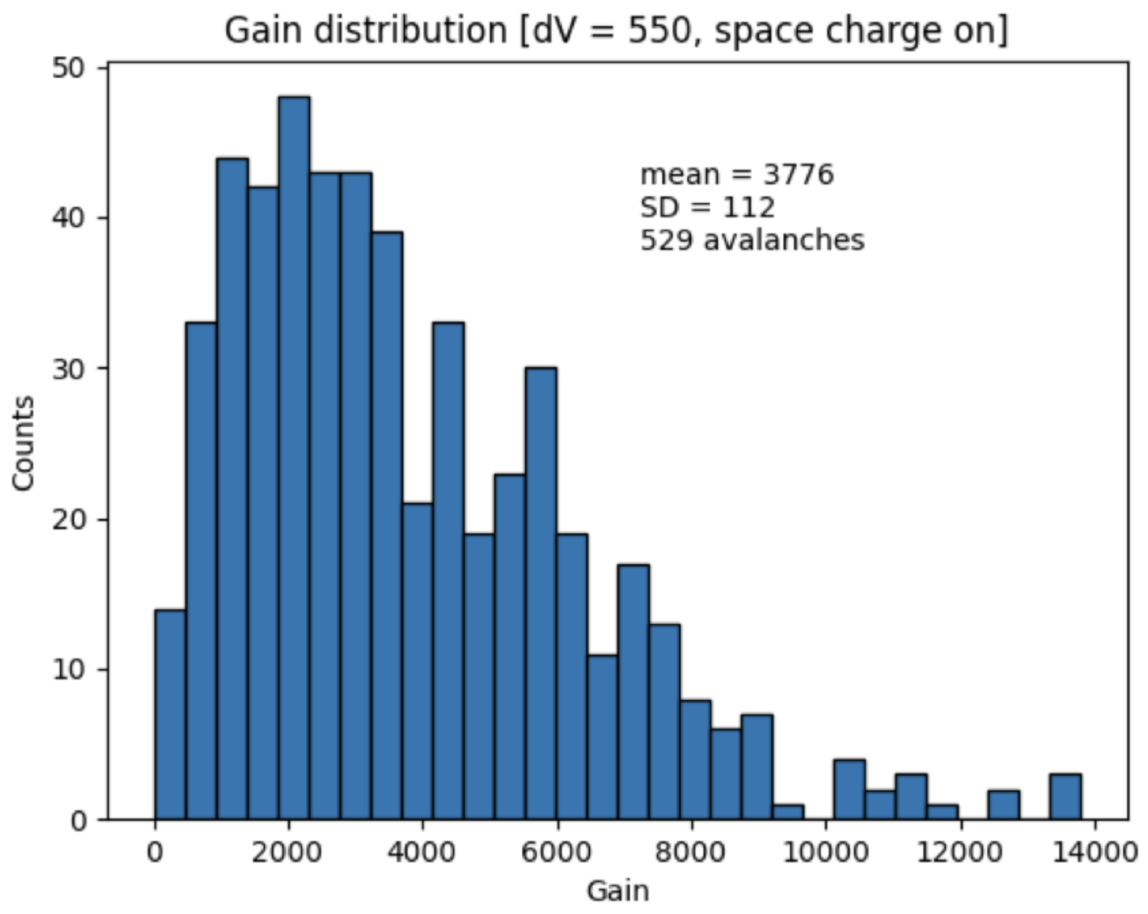


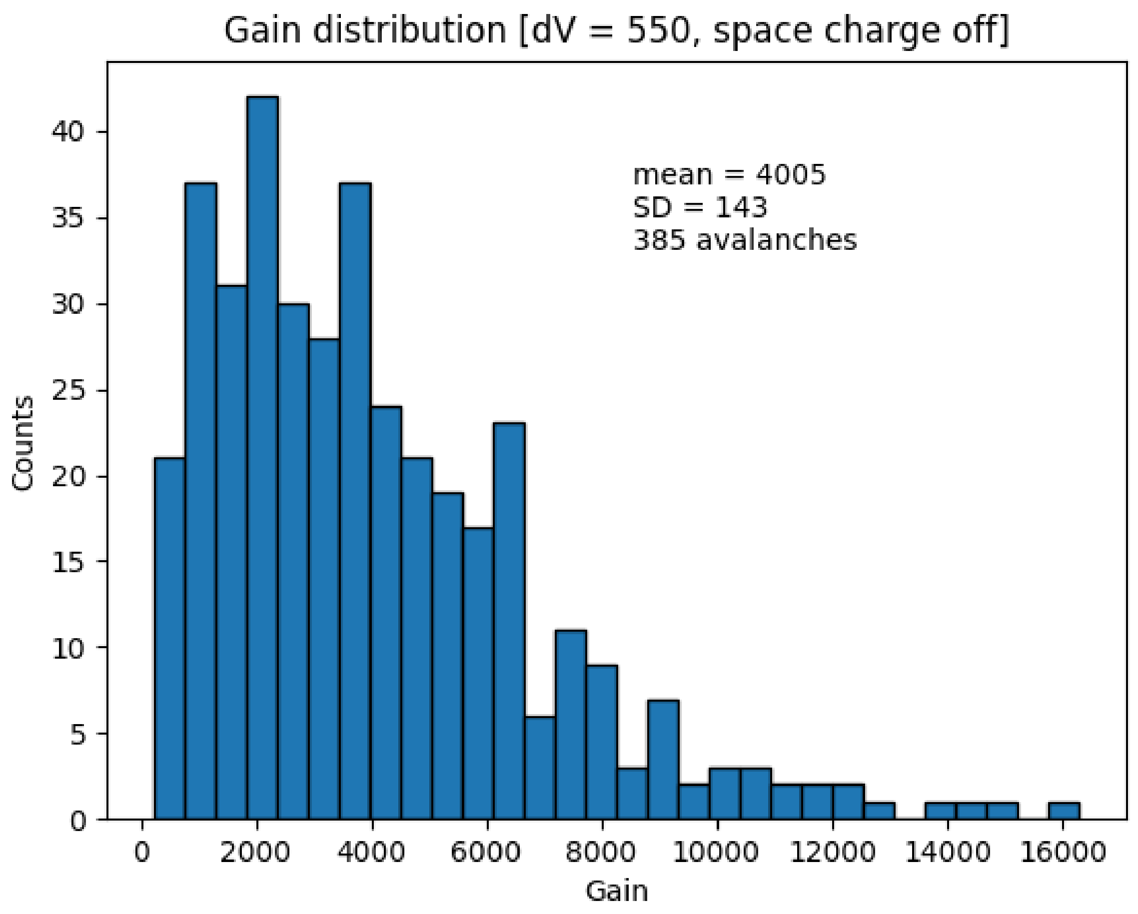


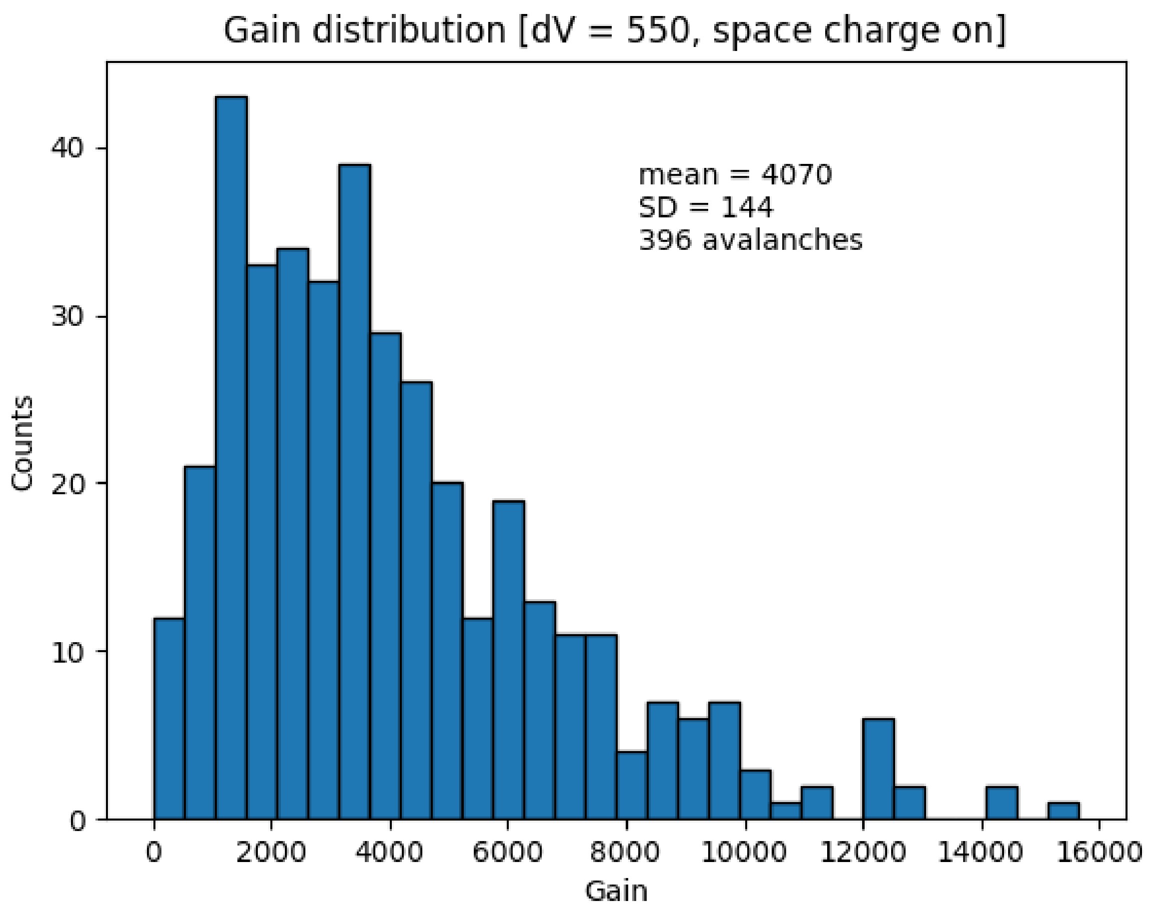
Gain spectra

- Initial gain spectra show a lower gain for space charge enabled (dt = 0.05 ns) but no difference for dt = 0.025 ns









dt = 0.05 ns

dt = 0.025 ns