Fast simulation of the Silicon Pad Detector

JaeYoon CHO
INHA University

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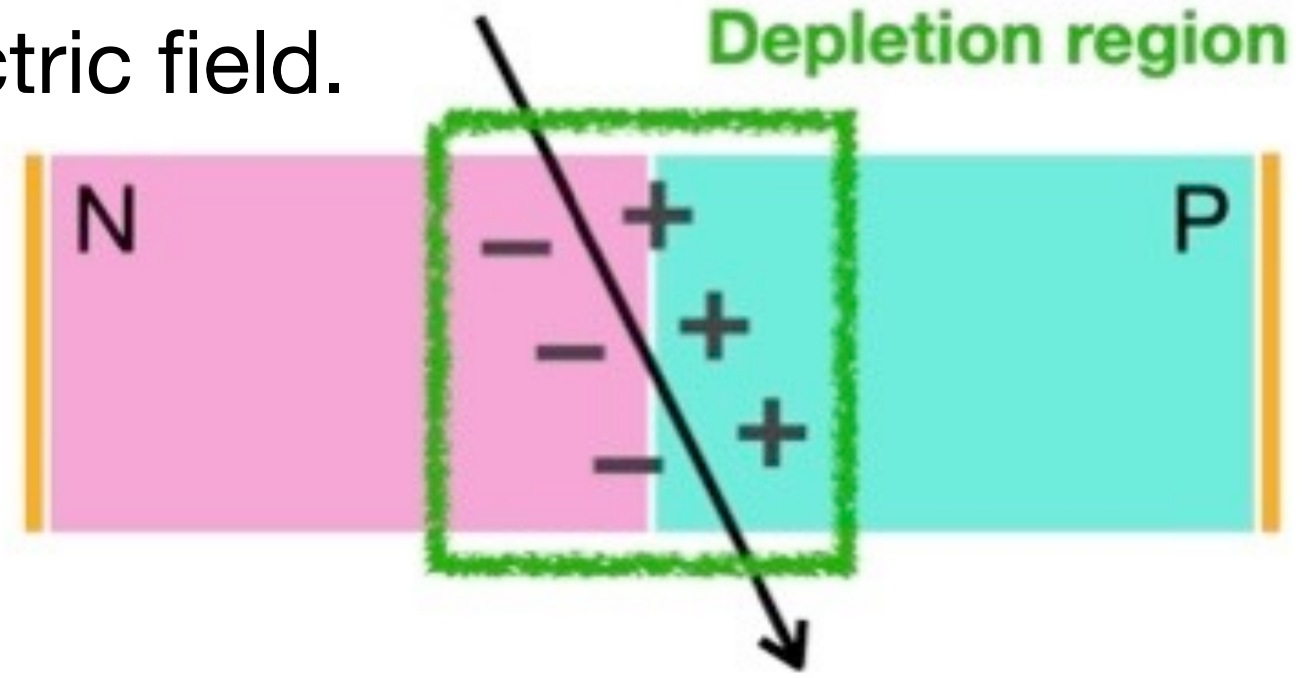
Introduction

Silicon Detector

- Because of its superior energy resolution and good response time, Silicon detector is widely used in nuclear physics experiments.
- The region where any free charge carrier (electrons and holes) rarely exists is called the **depletion region**.
- When the charged particles pass through the depletion region, they lose their energy by creating electron-hole pairs along the trajectory.
- Created electrons and holes are drifted to the electrodes because of the external electric field.
- To increase the depletion region, a reverse-bias voltage is applied to the device.

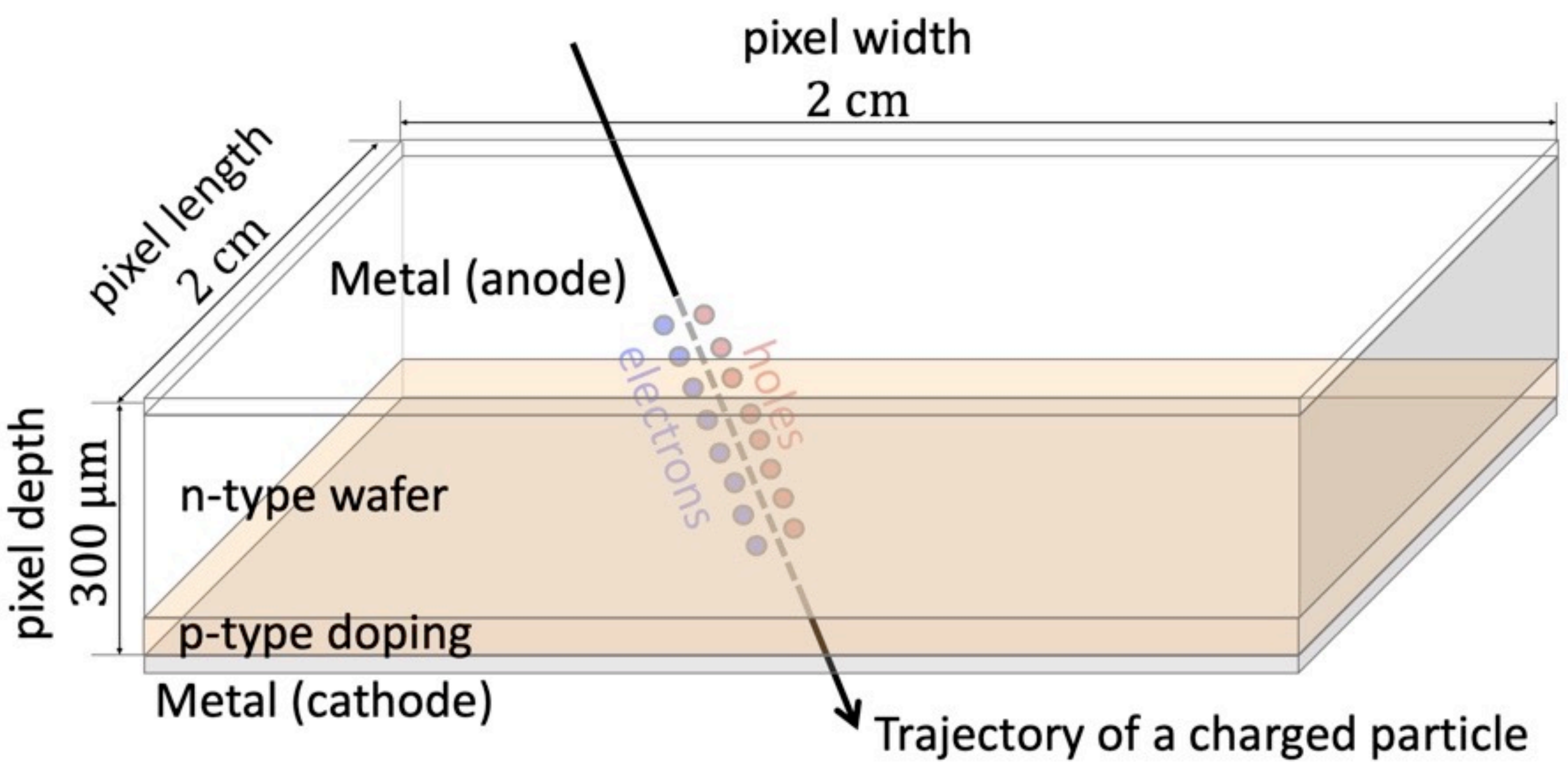


Detector Simulation

- We introduce an **open-source**-silicon-detector simulator named "***Fast Silicon Simulation***".
- Calculated results by "*Fast Silicon Simulation*" is compared with the results by a commercial simulation.

Simulation Setup

- We construct a 2cmx2cmx300μm volume of device composed of lightly doped n-type bulk and heavily doped p-type pad.
- To simplify electron-hole-pair generation process, we consider the MIP(Minimum Ionizing Particles).



Input parameter		
Size(width×length×depth)	2cm×2cm×300μm	
Reverse bias voltage	140V(fully depleted)	
Operation temperature	300K	
Doping density	n-type	$1.9 \times 10^{18}\ m^{-3}$
	p-type	$10^{21}\ m^{-3}$
Mobility	Electron	$0.135\ m^2V^{-1}s^{-1}$
	Hole	$0.048\ m^2V^{-1}s^{-1}$

Incident beam and its energy loss	
Density	$75 \mu m^{-1}$(MIP)
Angle of incidence	0 degree(vertically incidence)
Position	(0,0,0)→(0,0,300)

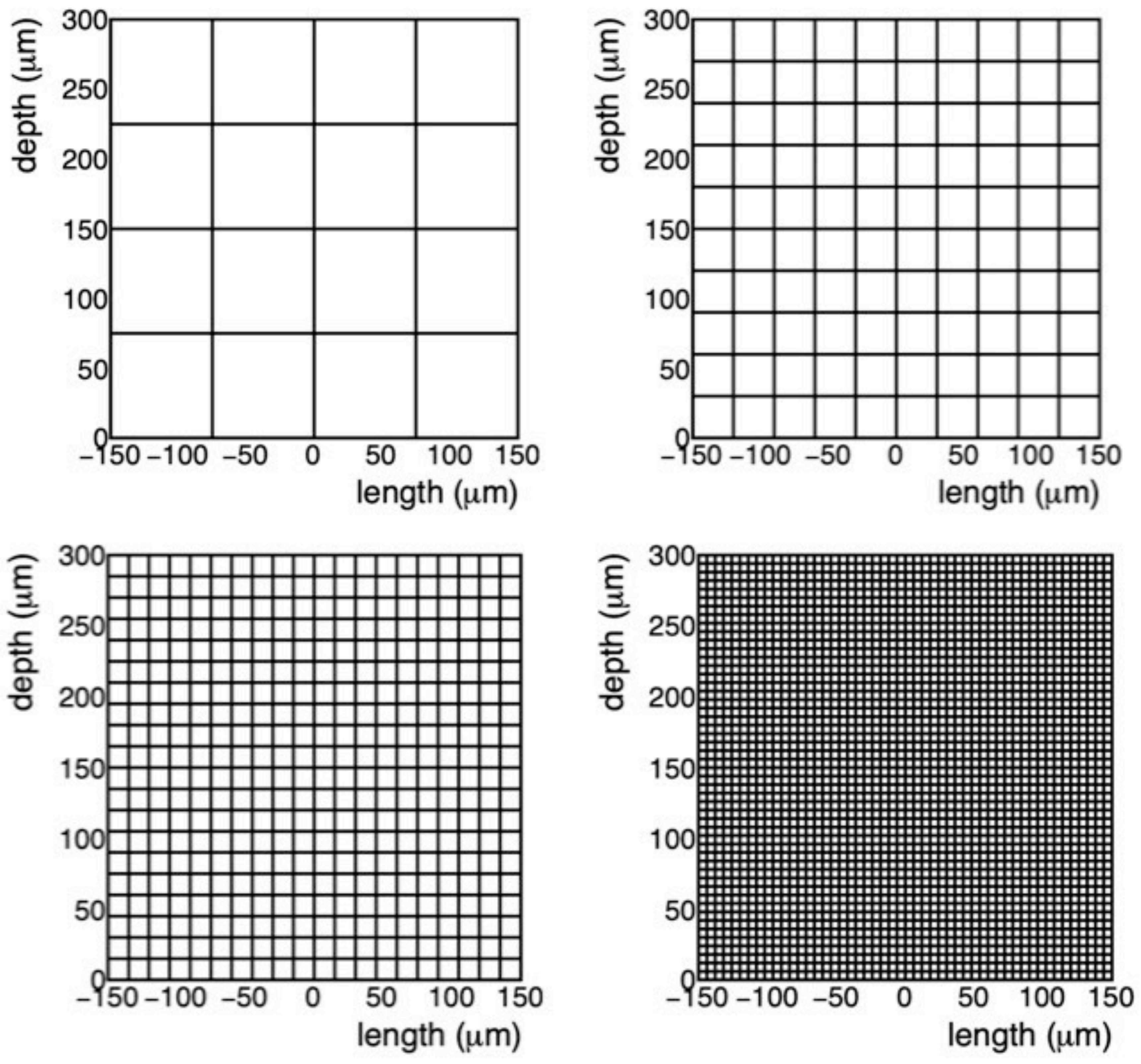
Calculation

Electric potential $\nabla^2 \phi = -\frac{\rho}{\epsilon}$

where ϕ : electric potential, ρ : volume density, ϵ : permittivity of the material

In this study, electric potential is calculated by the *Multi-grid method*.

Multi-grid method



- Apply the iteration method to wider lattices as an initial condition.
- By interpolating with the values of the surrounding lattice components, the denser lattices are created.
- For each step, the iteration method is repeated until the potential values at the lattices do not change by less than 0.01%.
- By filling the inside of the grid with the average value, calculation time can be reduced.

Calculation

When the potential is calculated, other quantities are calculated by following the equations below.

Electric field $\vec{E} = -\nabla\phi$

Induced current for electron $\vec{J_e} = e\rho_e\mu_e\vec{E} + eD_e\nabla n_e$

And hole $\vec{J_h} = e\rho_h\mu_h\vec{E} - eD_h\nabla n_h$

where $\vec{J_e}(\vec{J_h})$: current density of electron(hole), $\rho_e(\rho_h)$: volume charge density of electron(hole), e : elementary charge, $n_e(n_h)$: electron(hole) density, Einstein's relation $D_e = -k_BT\mu_e/e$ $(D_h = k_BT\mu_h/e)$

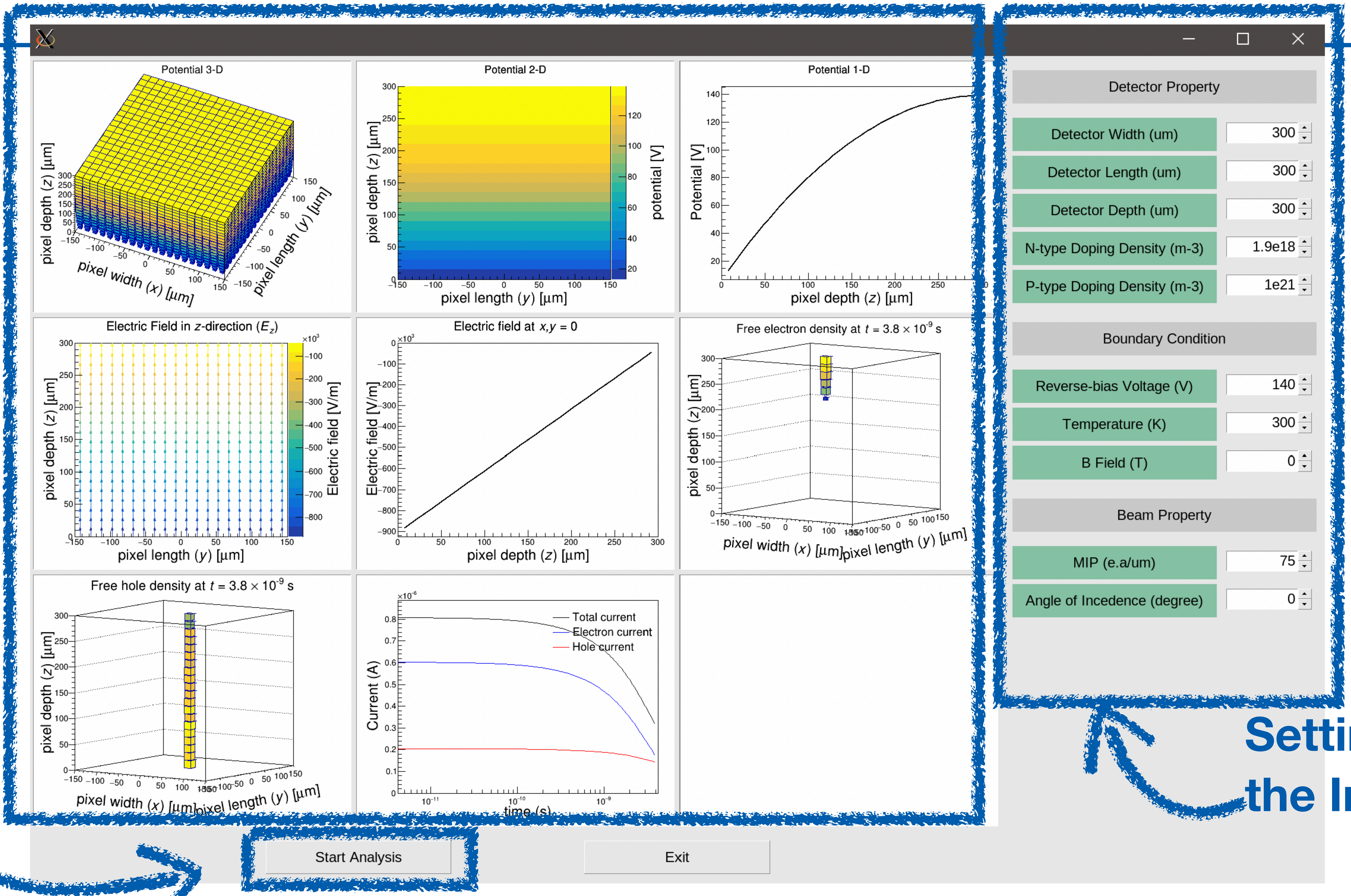
Mobility

$$\mu_e(E) = \mu_{0,e}\left(\frac{1}{1+\left(\frac{\mu_{0,e}E}{v_{sat,e}}\right)^2}\right)^{1/2} \qquad \mu_h(E) = \mu_{0,e}\frac{1}{1+\frac{\mu_{0,h}E}{v_{sat,h}}}$$

Where $\mu_{0,e}(\mu_{0,h})$: mobility for electron(hole), $v_{sat,e}(v_{sat,h})$: saturation velocity of electron(hole)

Results

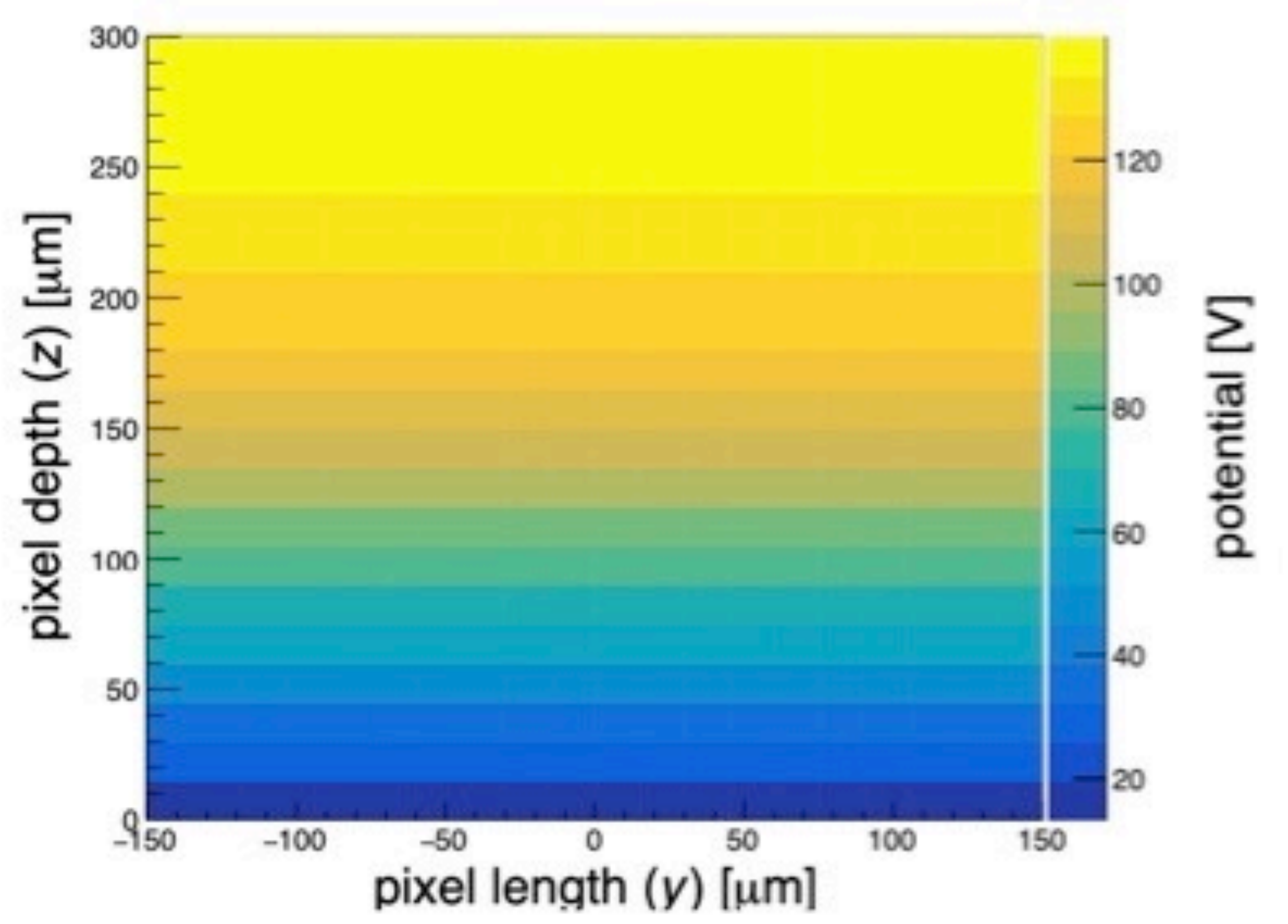
Result panel

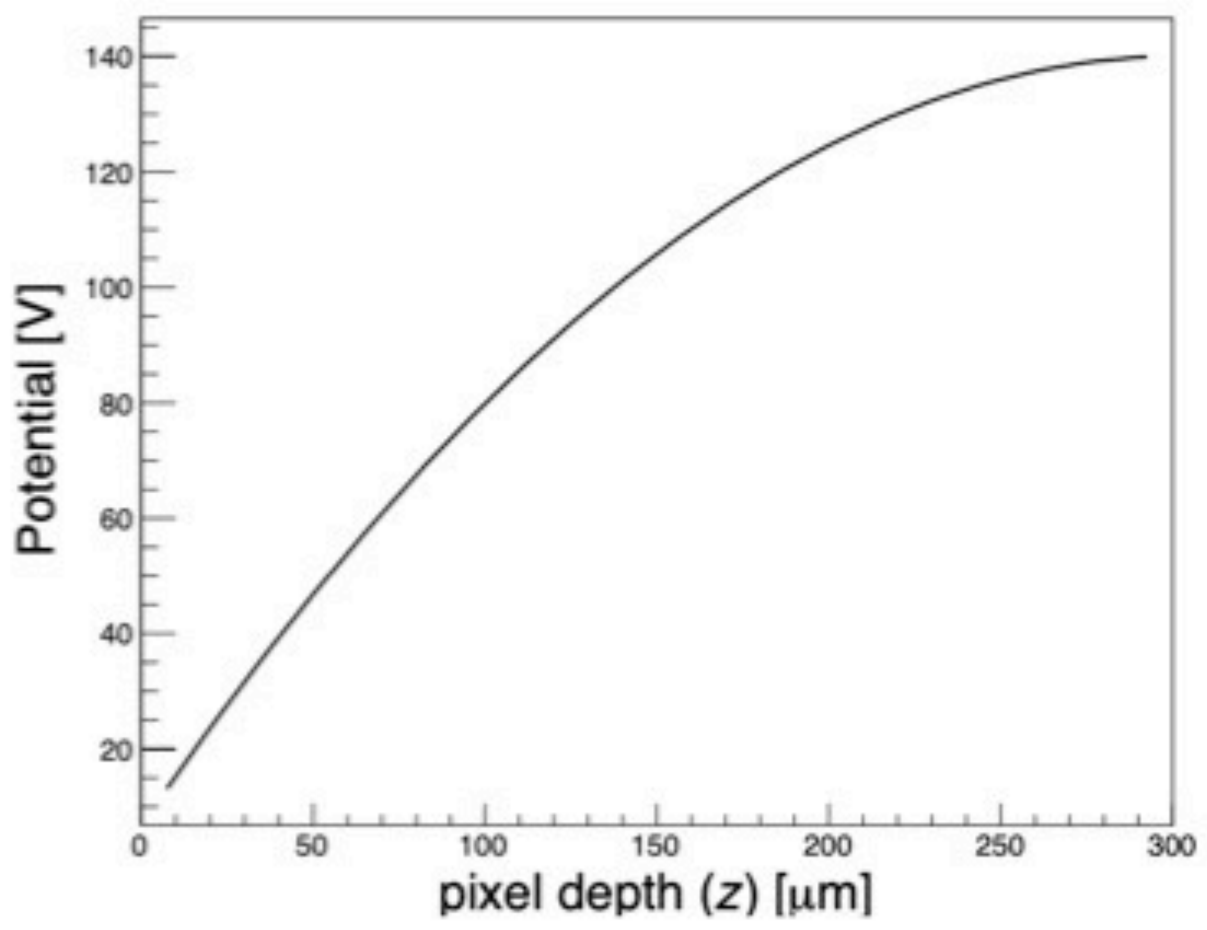


Setting the Input Parameter

Analysis Start!

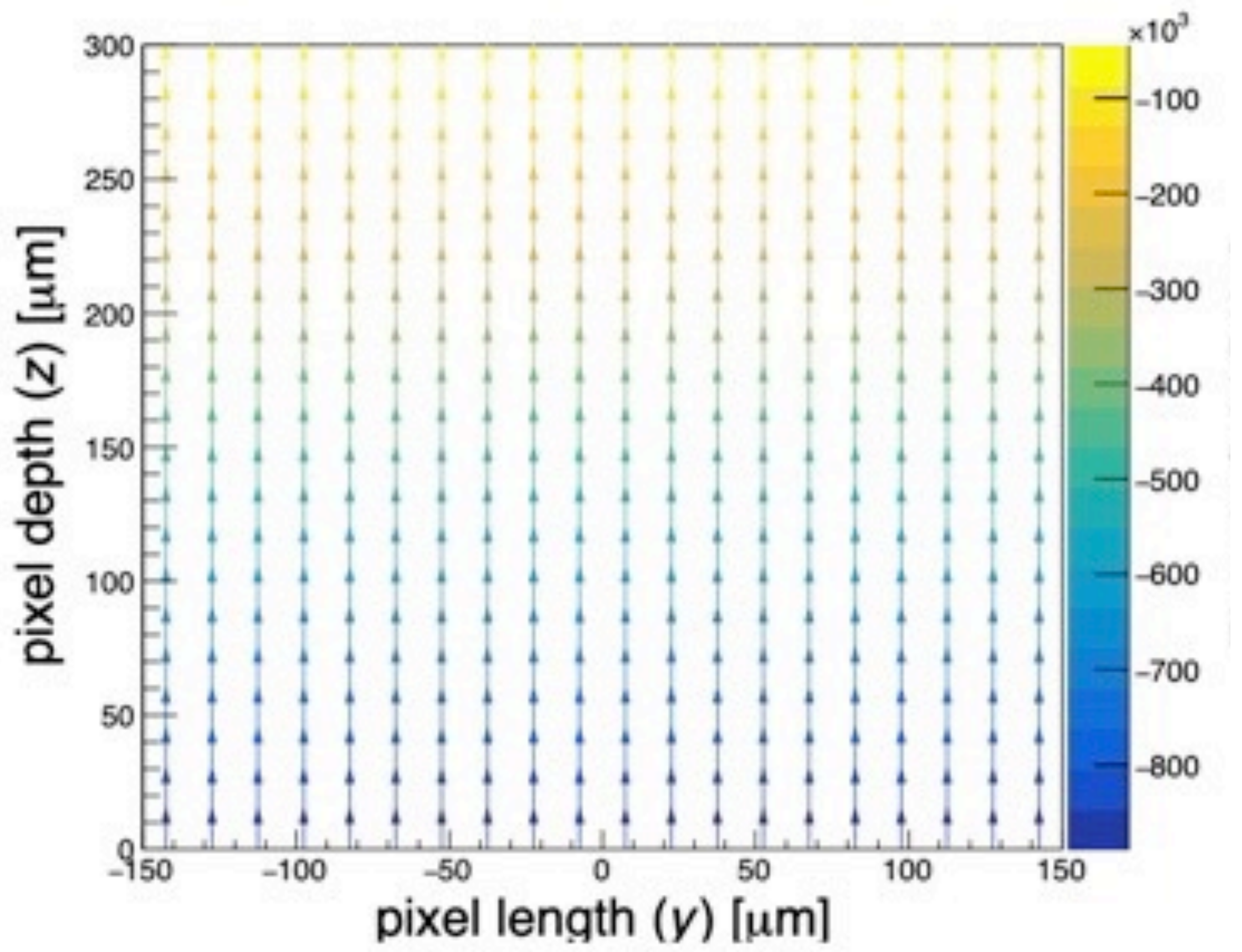
Results

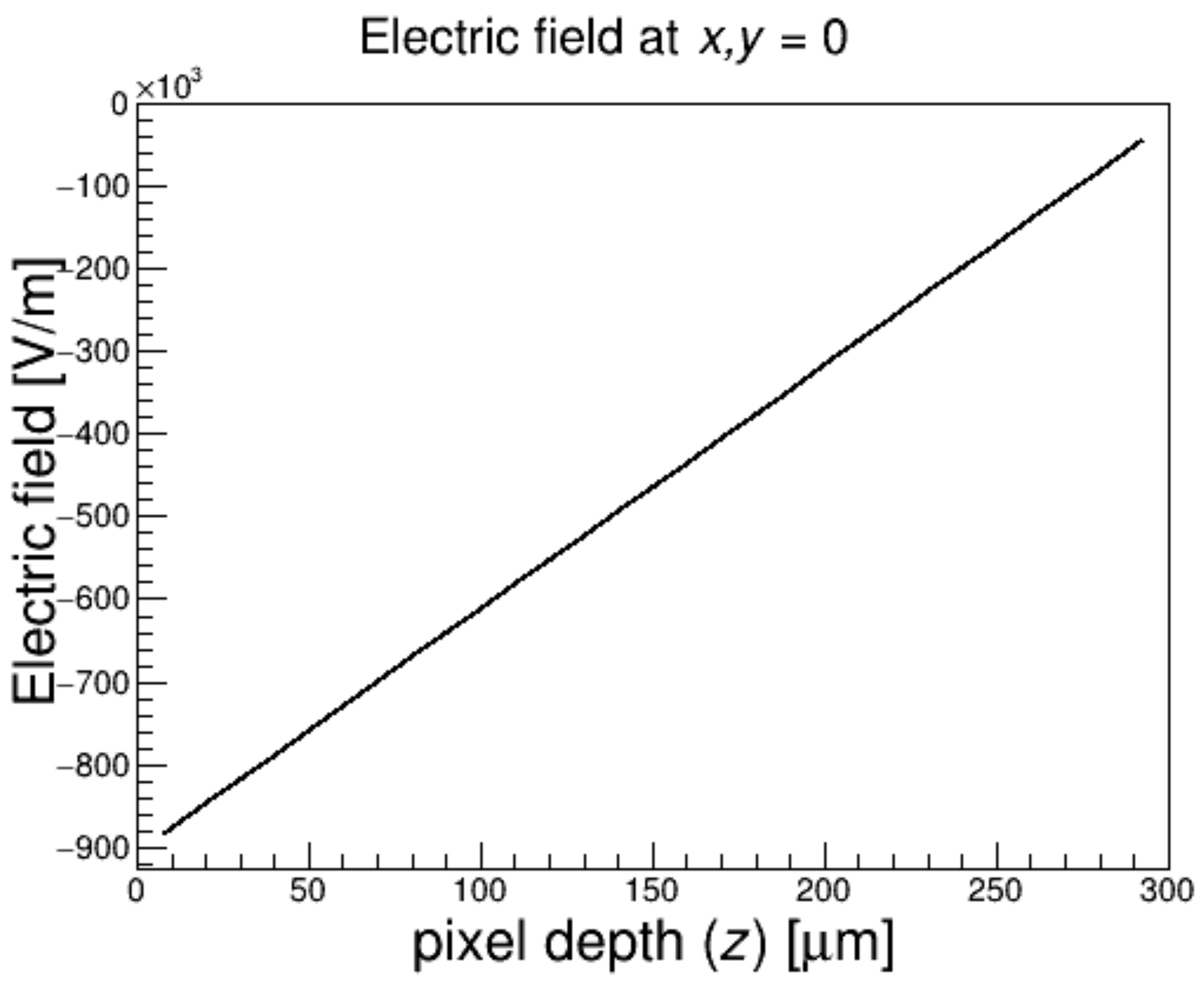




Potential

- The potential projected in yz-plane at $x = 0$
- The potential distribution along the depth direction of the device in the depleted p-n junction follows the second-order polynomial.





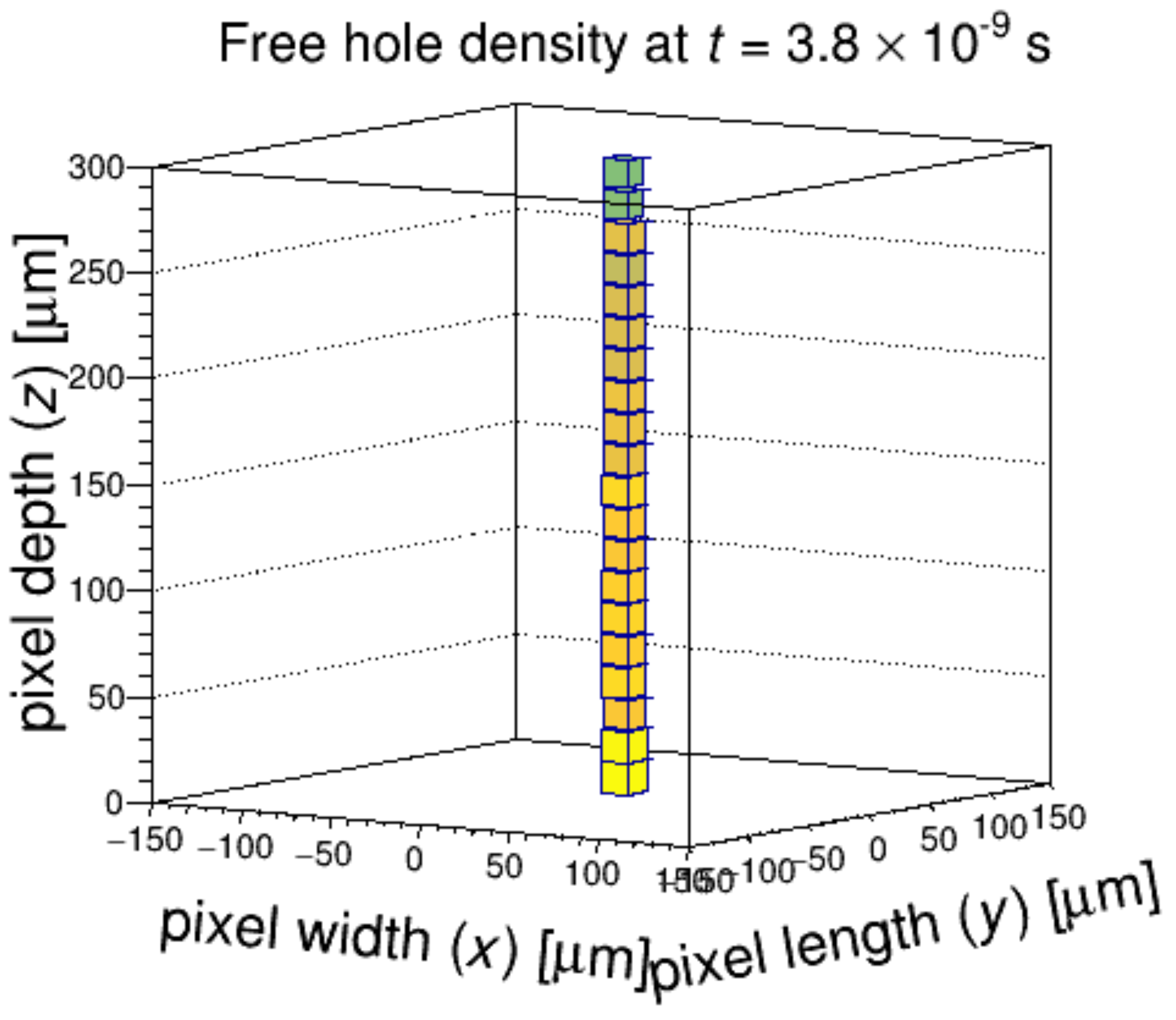
Electric field

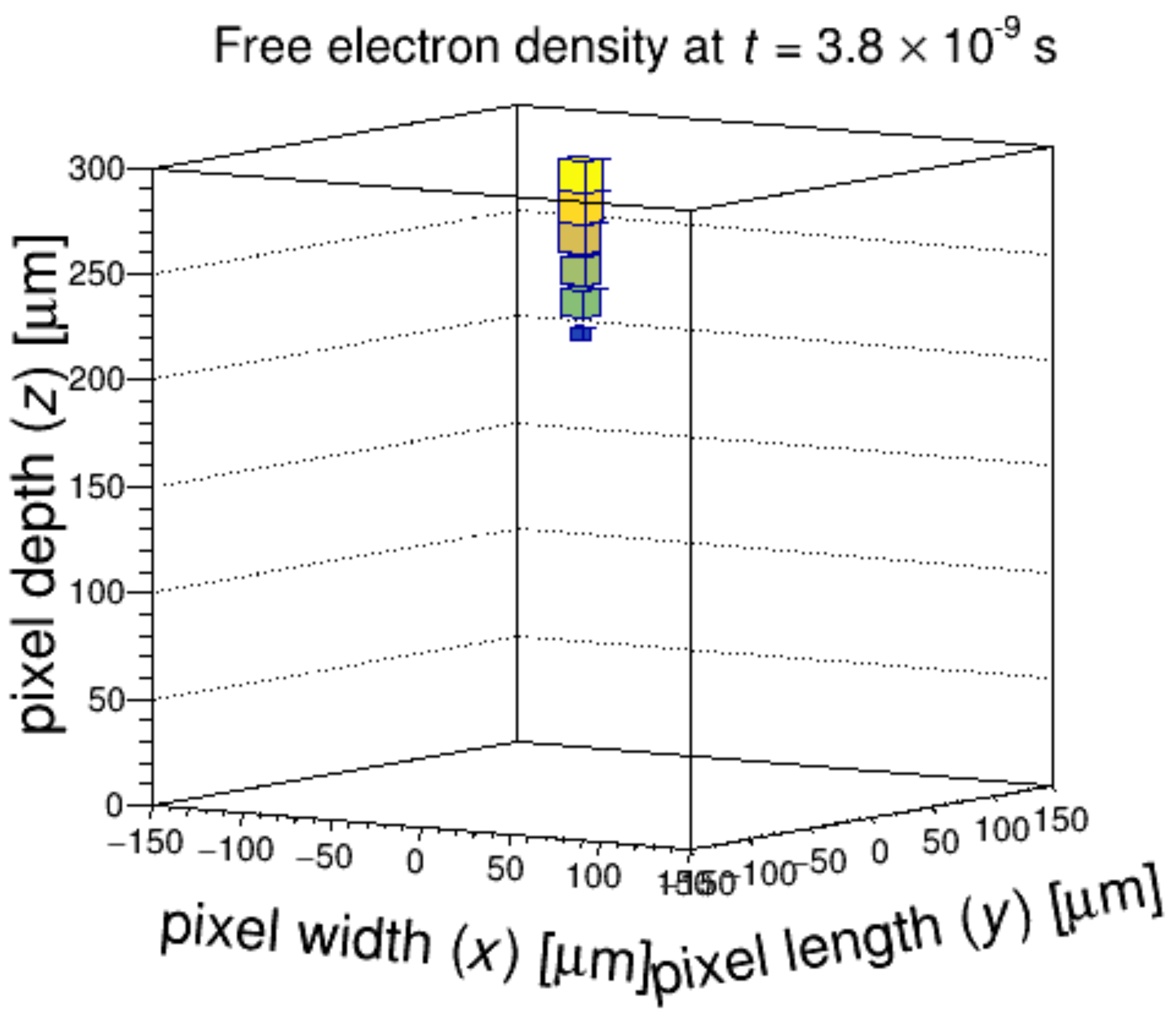
- The direction and magnitude of the electric field along the depth axis.
- The electric field varies linearly from top to bottom of the device due to its uniform doping density.

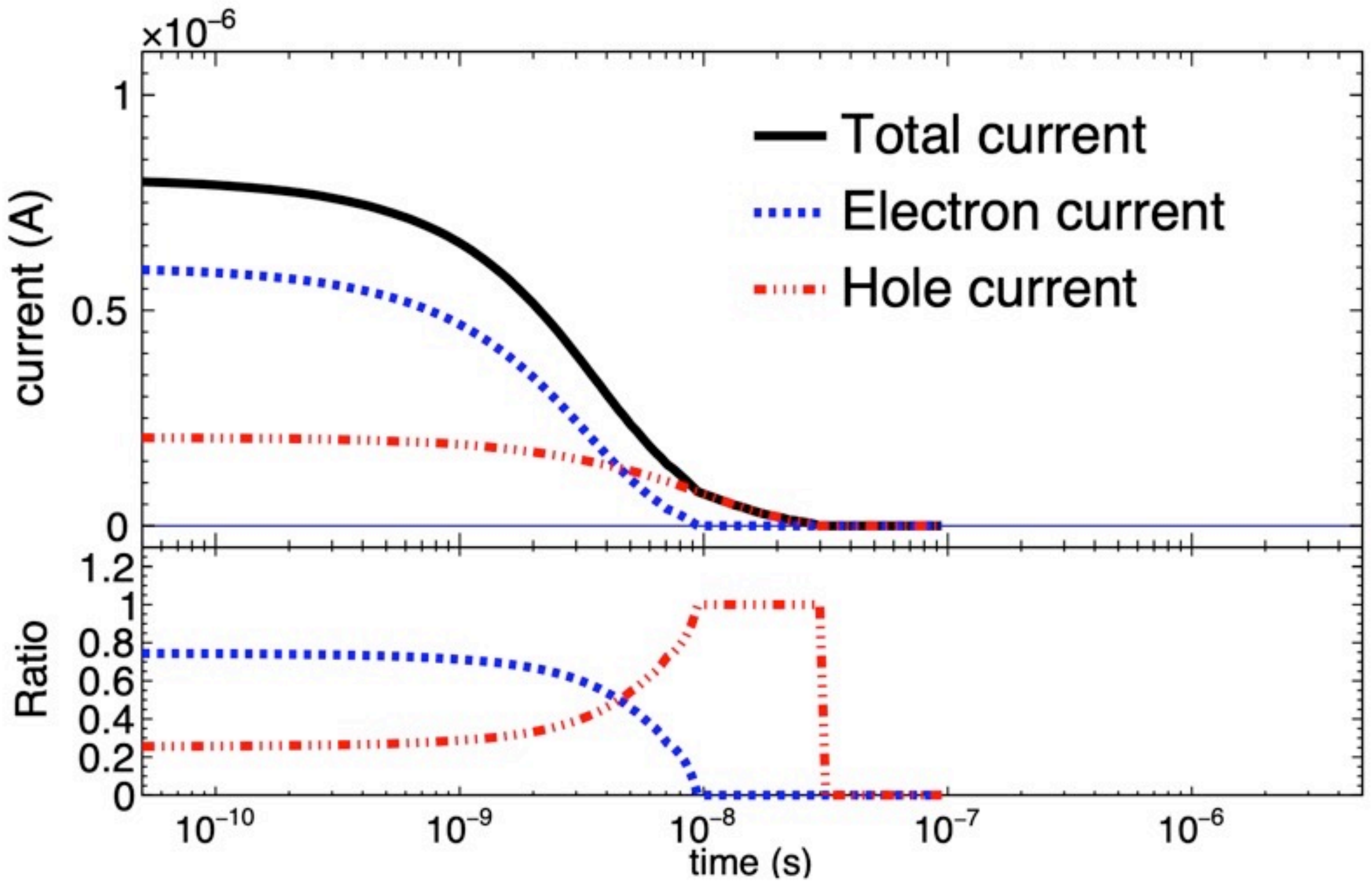
Results

Induced current

- The number of generated electron-hole pairs is set by 75 per μm in the silicon volume.
- Holes move slower than electrons in the device. The hole current is lower and falls later than the electron current.
- Also, electrons are collected quickly to the anode than holes.



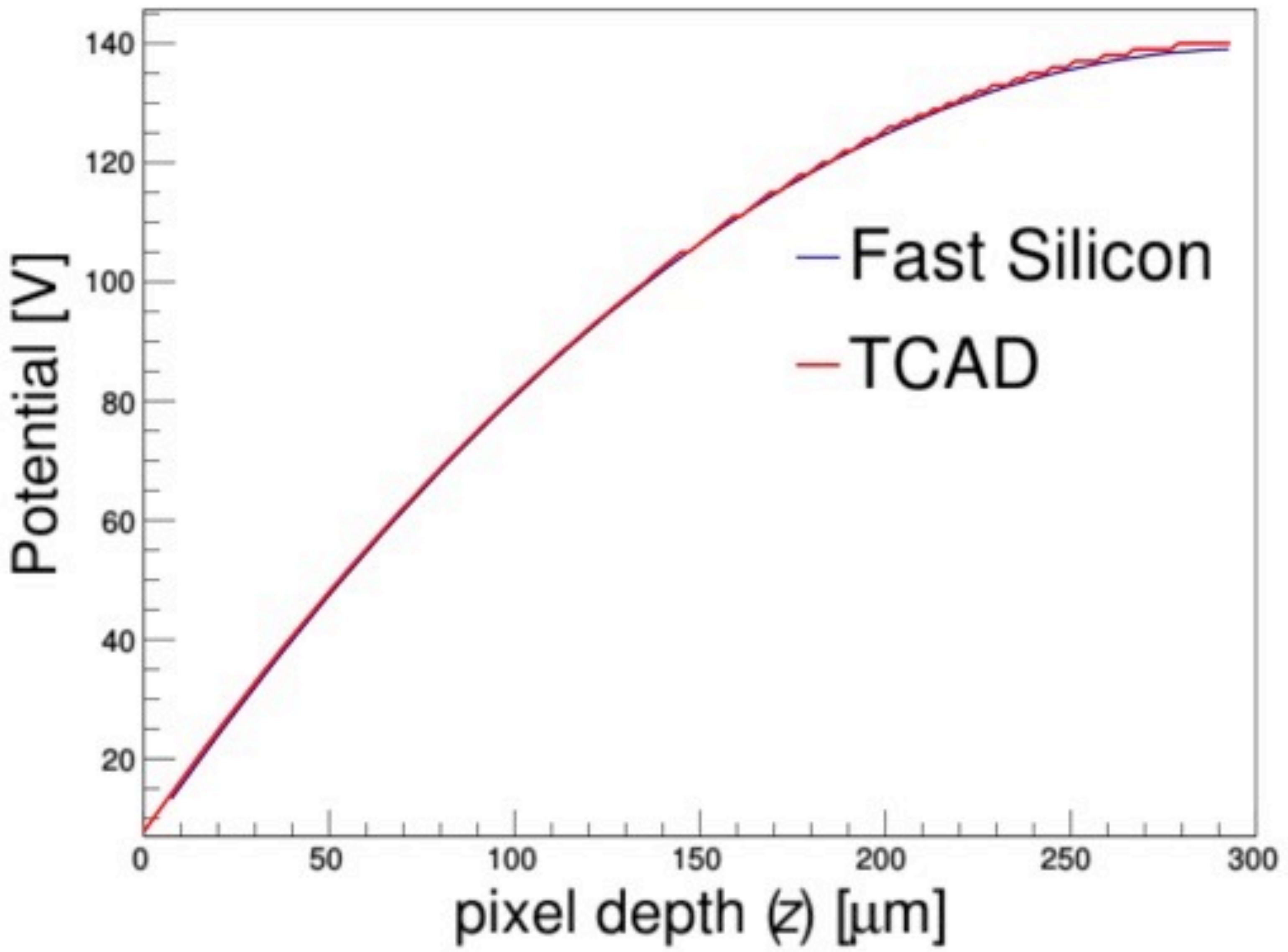


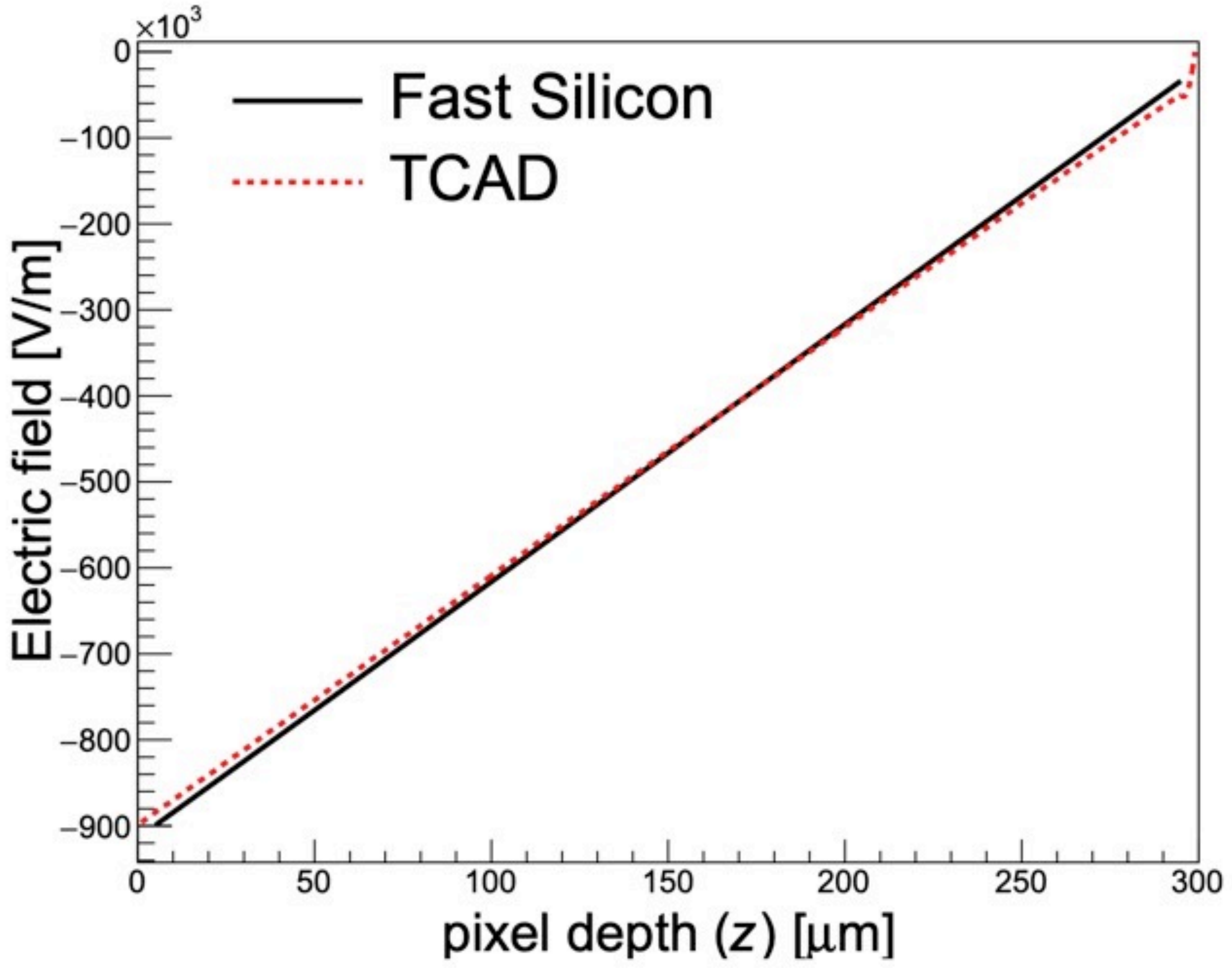


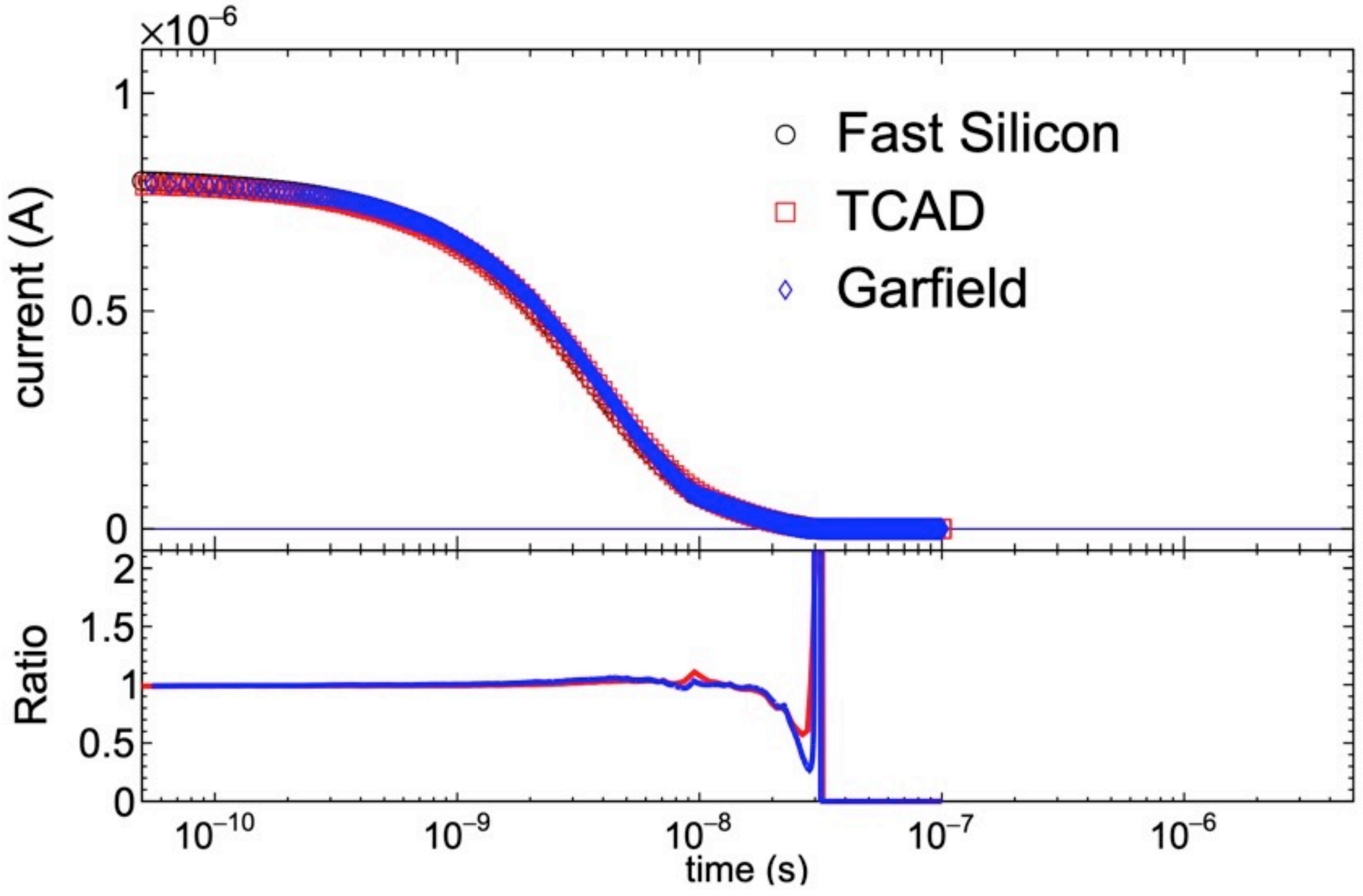
Results

Comparison with other simulation

- Silvaco TCAD (**T**echnology **C**omputer-**A**ided **D**esign) is a commercial semiconductor device simulator.
- Garfield++ is a simulation toolkit for particle detectors based on ionization measurement in gases or semiconductors.
- Electric field, potential, and induced currents in the Fast Silicon Simulation are consistent with the results from TCAD and Garfield++.







Conclusion & Summary

- We introduce a new **open-source**-silicon-detector simulator named "***Fast Silicon Simulation***".
- To calculate the potential and electric field, the multi-grid method and iterative method are used.
- Results by *Fast Silicon Simulation* are consistent to the results by TCAD simulation qualitatively and quantitatively.
- *Fast Silicon Simulation* is **100 times faster** than TCAD simulation.
- This simulation method can be used to study the optimized design and physical properties of the silicon detector.