Garfield++ simulation of silicon sensors

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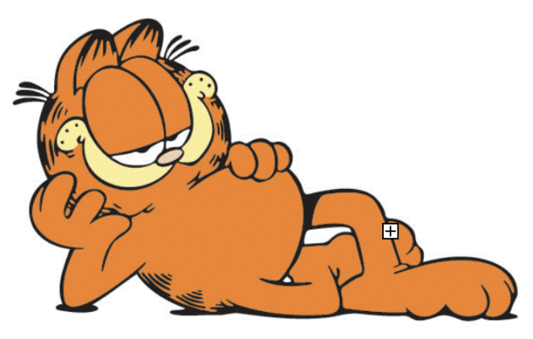
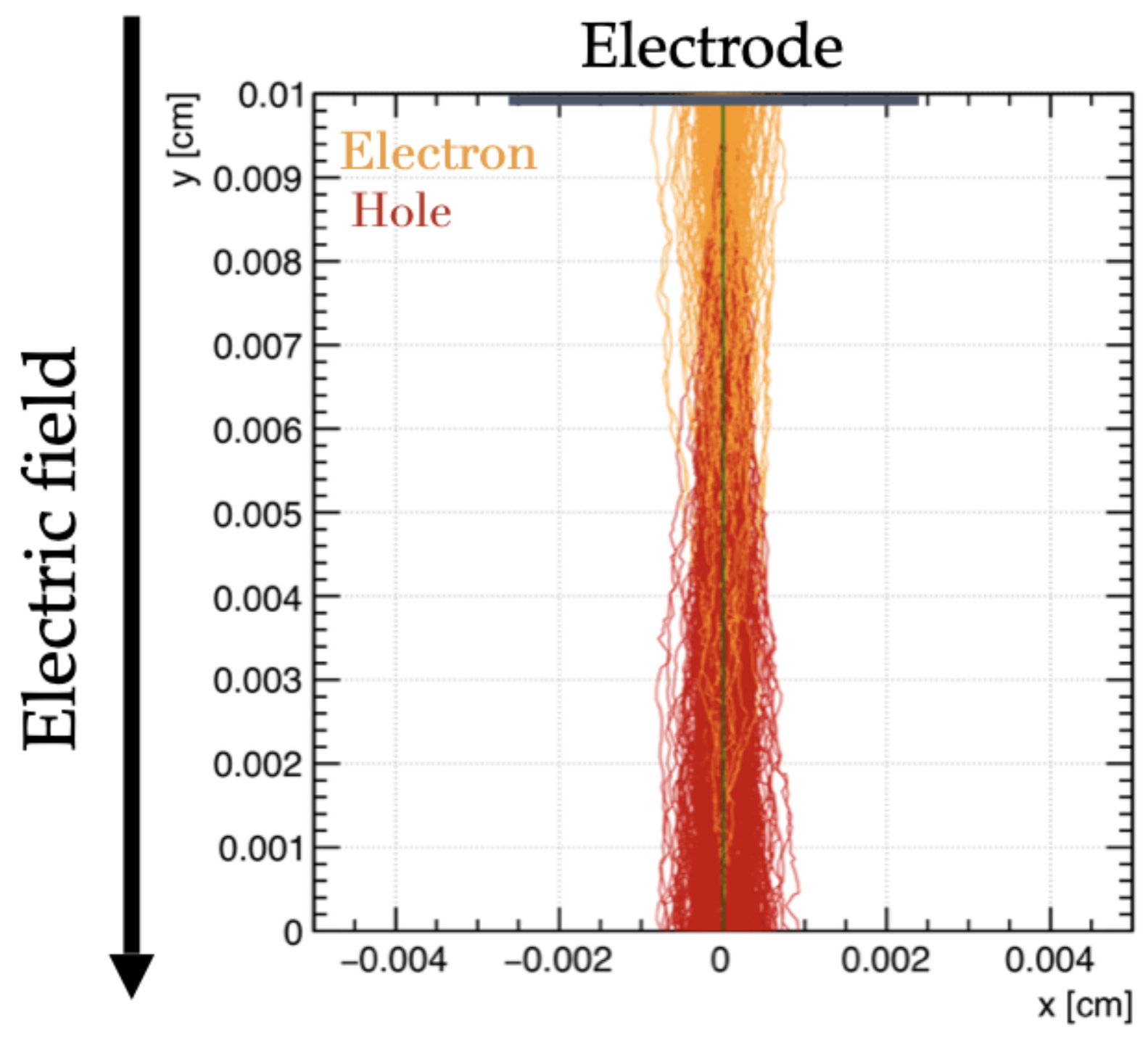


Introduction

In this study, we compare the TCAD simulation of a silicon sensor with an equivalent COMSOL simulation. Furthermore, we aim to understand to what extent the results can be approximated without using the doping profile and other complexities. We use Garfield++ to simulate signal induction and analyze the resulting signal shapes. Specifically, we focus on resistive silicon detectors (or AC-LGADs) for which TCAD and COMSOL simulations are already available. We aim to integrate the doping profile into the COMSOL simulation, export the data to Garfield++, and compare the signal shapes.

Silicon Sensors

Silicon sensors are used in high-energy physics experiments to detect particles by ionizing a sensitive medium. As particles pass through, it creates electron-hole pairs, which are then drifted by the electric field to produce a measurable macroscopic current.



Garfield++

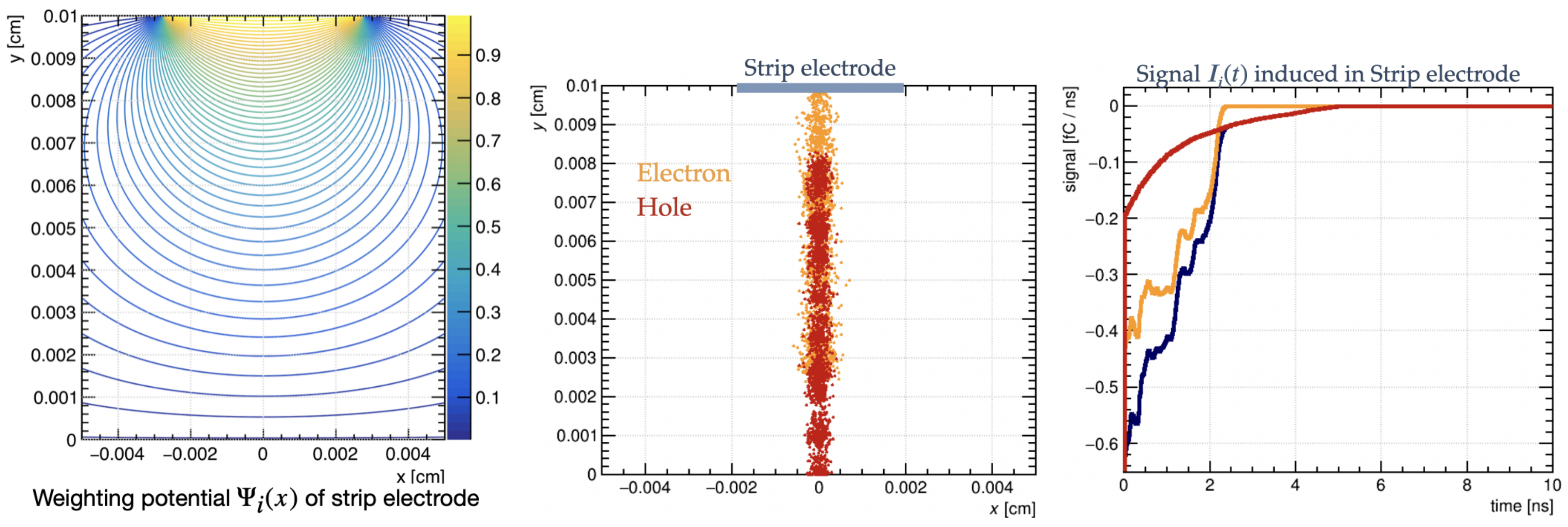
Garfield++ is an open-source Monte Carlo toolkit for detailed particle detector simulations, including ionization measurements in gases and semiconductors. It covers:Primary Ionization, Charge Transport, Signal Induction and Charge Amplification

Ramo-Shockley theorem

Ramo-Shockley Theorem:

Used to induce signals on readout electrodes through charge movement. Weighting potentials are calculated using analytical solutions or numerically via FEM solvers.

$$\mathrm{I}_i(t) = \frac{-q}{V_w} E_i(x_q(t)).\dot{x}_q(t) \qquad E_i(x) = -\nabla\Psi(x)$$



Weighting potential $\Psi_i(x)$ of strip electrode

Ramo-Shockley theorem extension for conducting media:

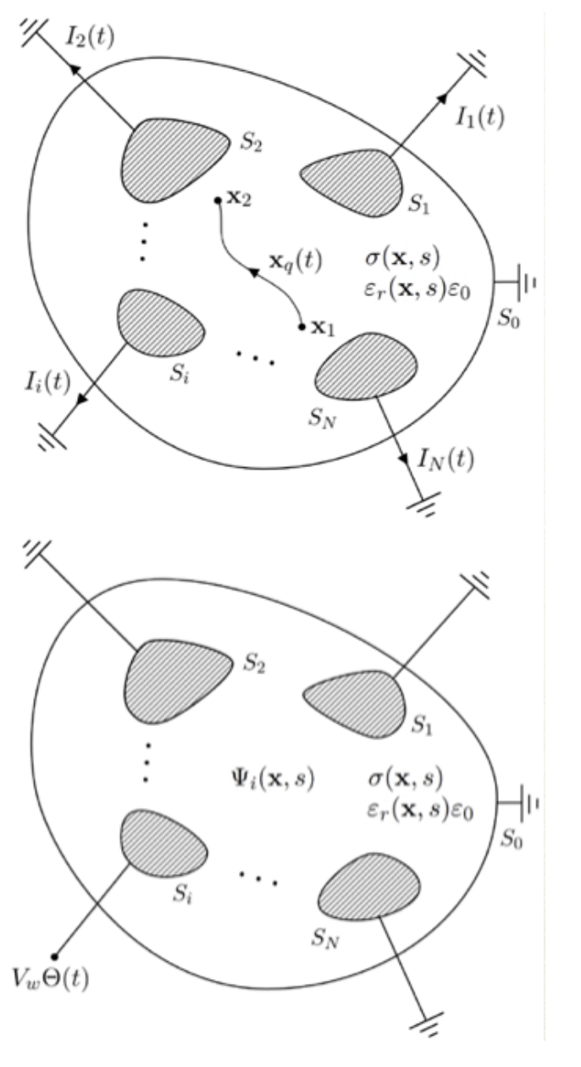
In detectors with resistive elements, the induced signal depends on both charge movement in the drift medium and the time-dependent response of resistive materials.

$$\mathrm{I}_i(t) = -\frac{q}{V_w}\int_0^t H_i[x_q(t'), t-t'].\dot{x}_q(t')dt' \qquad H_i(x,t) := -\nabla\frac{\partial\Psi_i(x,t)\Theta(t)}{\partial t}$$

The dynamic weighing potential $\Psi_i(x,t)$ can be calculated:

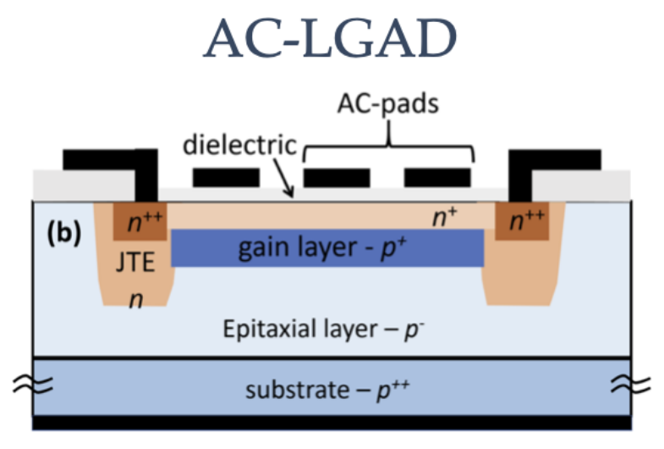
-Remove all the drifting charge. -Apply the biasing voltage V_b to obtain $\Psi_b(x)$. -Apply an additional voltage pulls $V_w\Theta(t)$ to the electrode at time t=0 , where $V_w \ll V_b$. The resulting potential is given by $\Psi(x,t) = \Psi_i(x,t) + \Psi_b(x)$. -Obtaining the weighting potential is thus: $\Psi_i(x,t) = \Psi(x,t) - \Psi_b(x)$

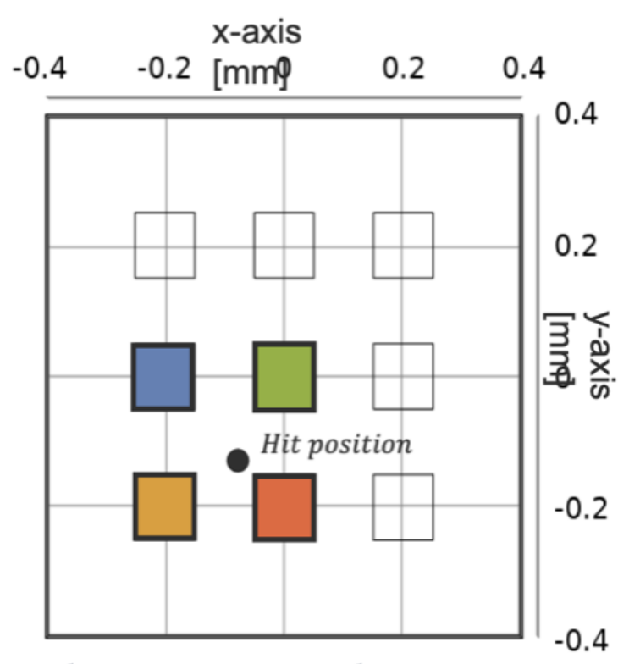
We can calculate time dependent weighting potential using COMSOL and TCAD.



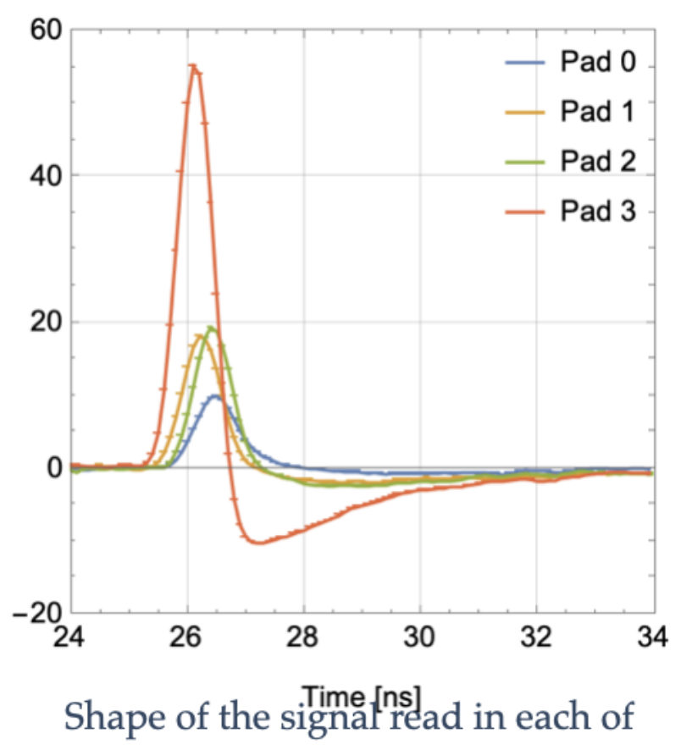
AC-LGAD's COMSOL Simulation

Given their excellent spatial and time resolution, AC-LGADs (or Resistive Silicon Detectors) feature an n+ resistive layer with a sheet resistance on the order of kΩ/□, separated from the readout electrodes by an insulating layer (SiO2).



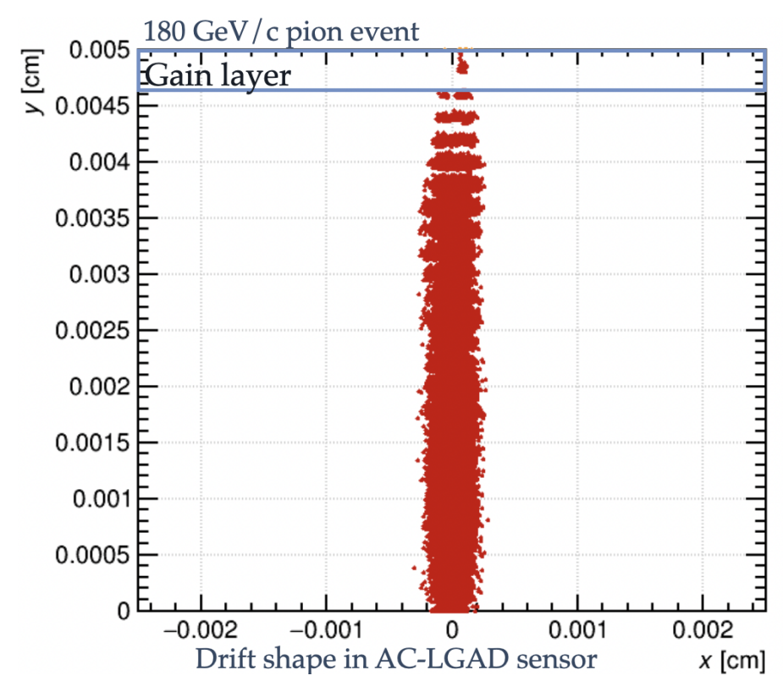


The careful design of the read-out electrode shape can be performed to optimize signal sharing.

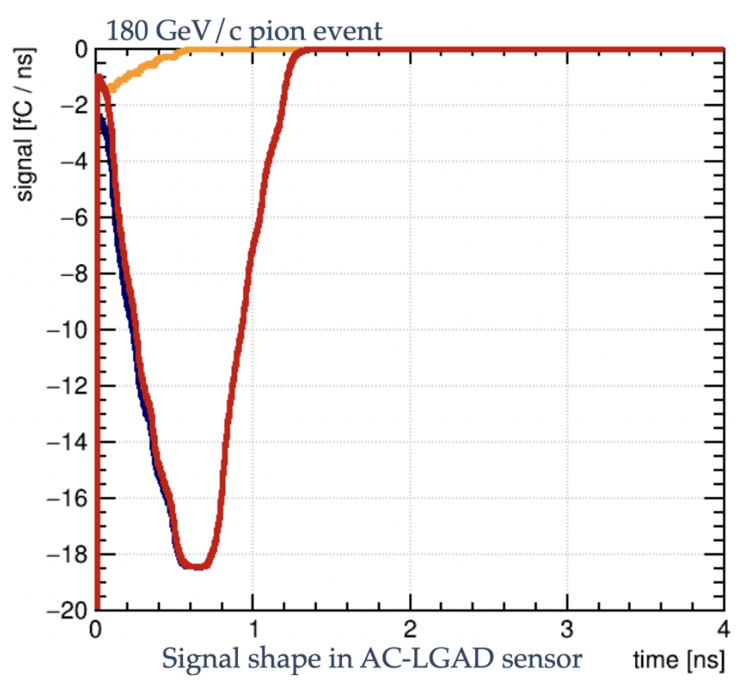


Shape of the signal read in each of the electrode

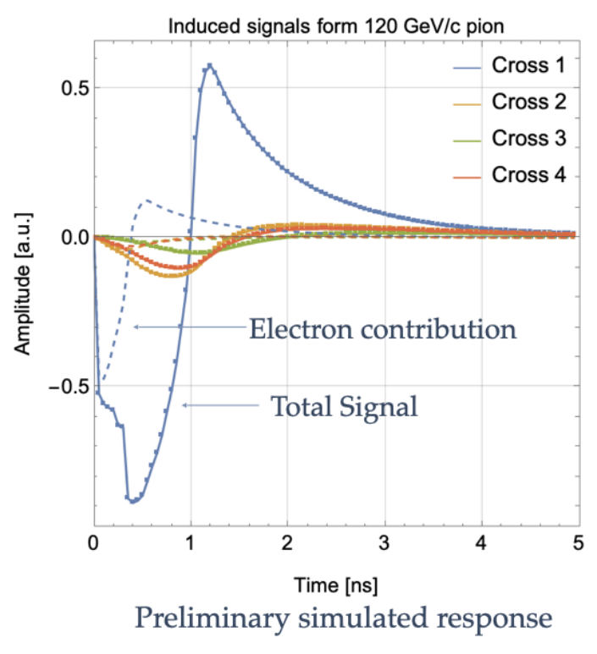
Using COMSOL, the weighting potential of cross-shaped electrodes in a Resistive Silicon Detector (RSD) was calculated. This is passed to Garfield++ for the Monte Carlo simulation.



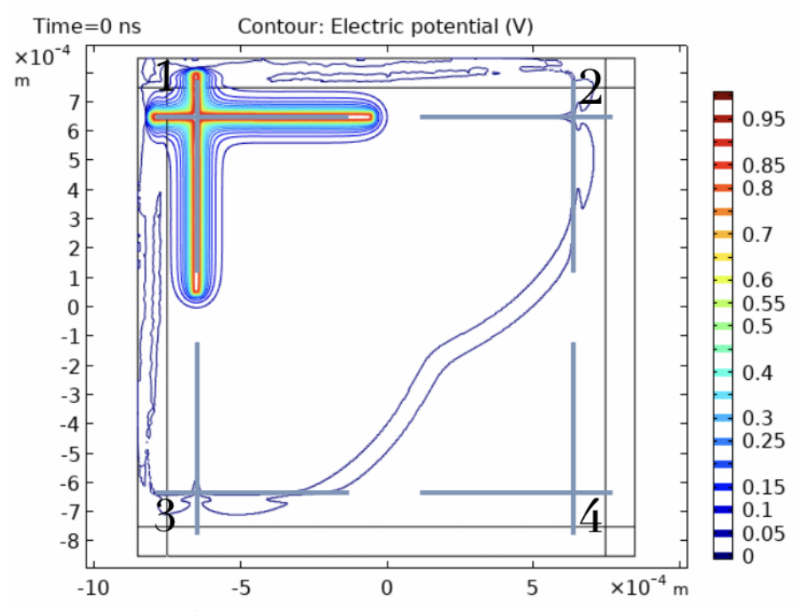
Drift shape in AC-LGAD sensor



Signal shape in AC-LGAD sensor



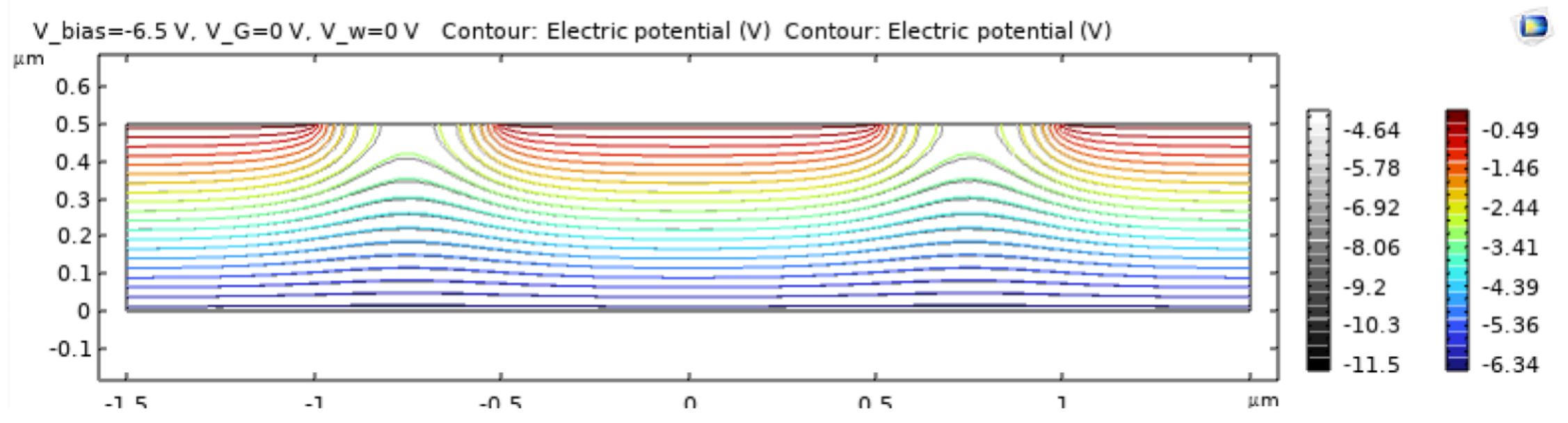
Preliminary simulated response



Weighting potential of AC-LGAD sensor

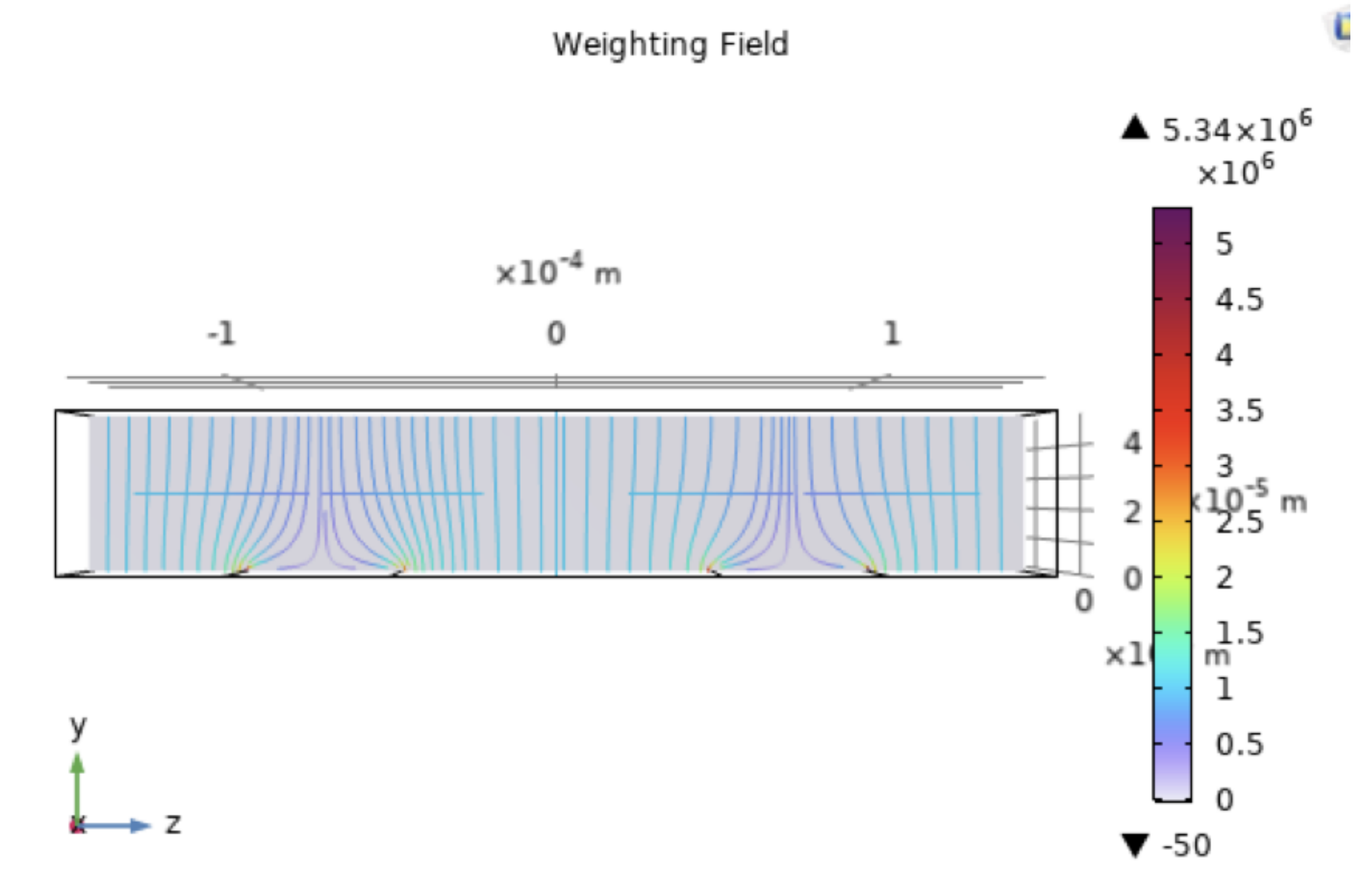
Sensor with doping profile

We simulated a simple 3D sensor with (grayscale contours) and without (coloured contours) doping.



_ Grey contour lines are without doping _ coloured contour lines are with doping

Weighting potential calculating for simulation without doping:



Conclusions and Future Work

Comparison of Signal Shapes:

- Simulations: TCAD simulation of AC-LGAD sensor, COMSOL simulation of AC-LGAD sensor (without doping)
- Objectives: Add doping profile to COMSOL model
- Analysis: Extract signal shapes using Garfield++, Compare signal shapes across three models

References

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