

4th DRD3 Week on Solid State Detectors

Garfield++: New Features and Ongoing Development

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On behalf of all Garfield++ developers

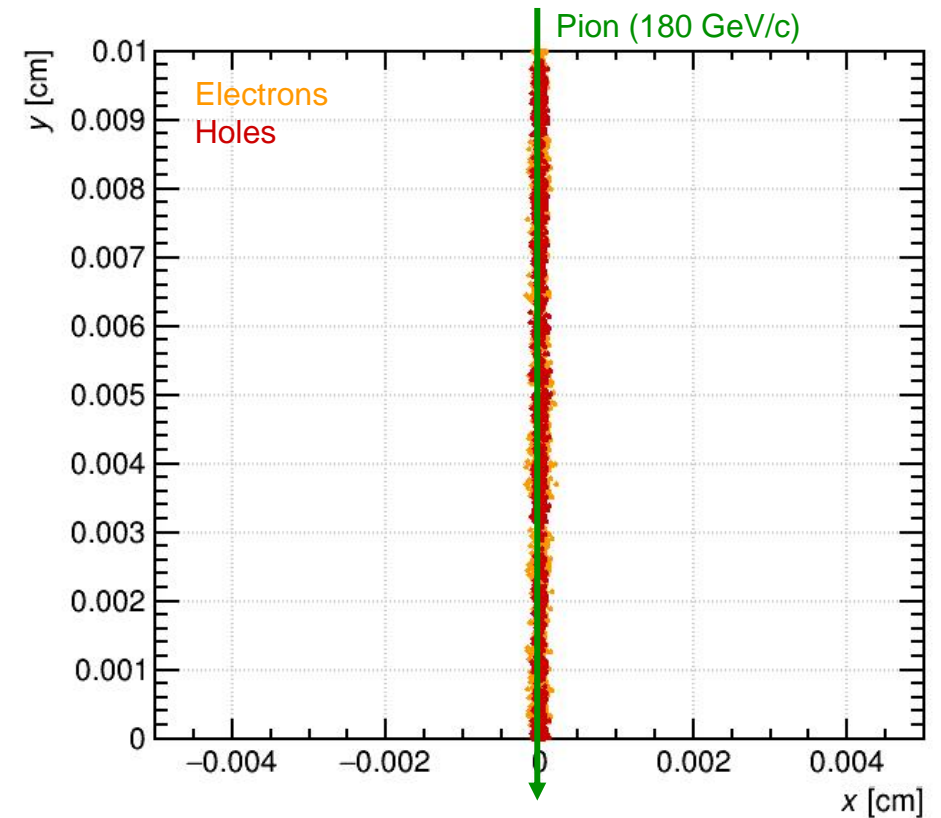
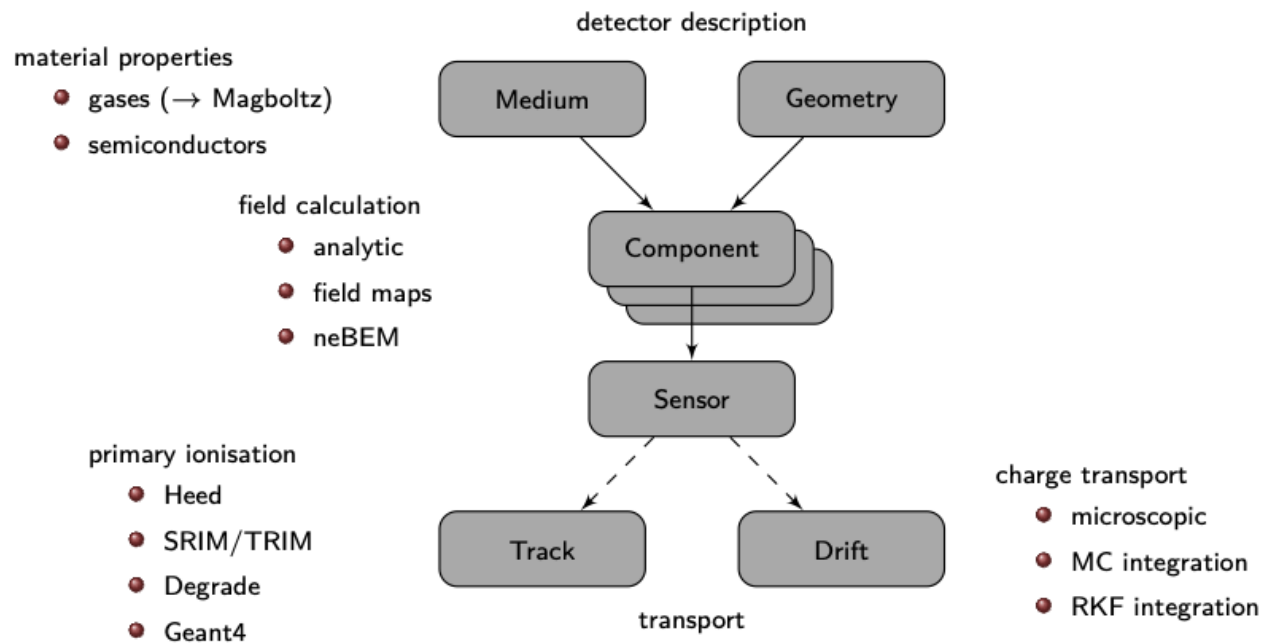
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November 12th, 2025



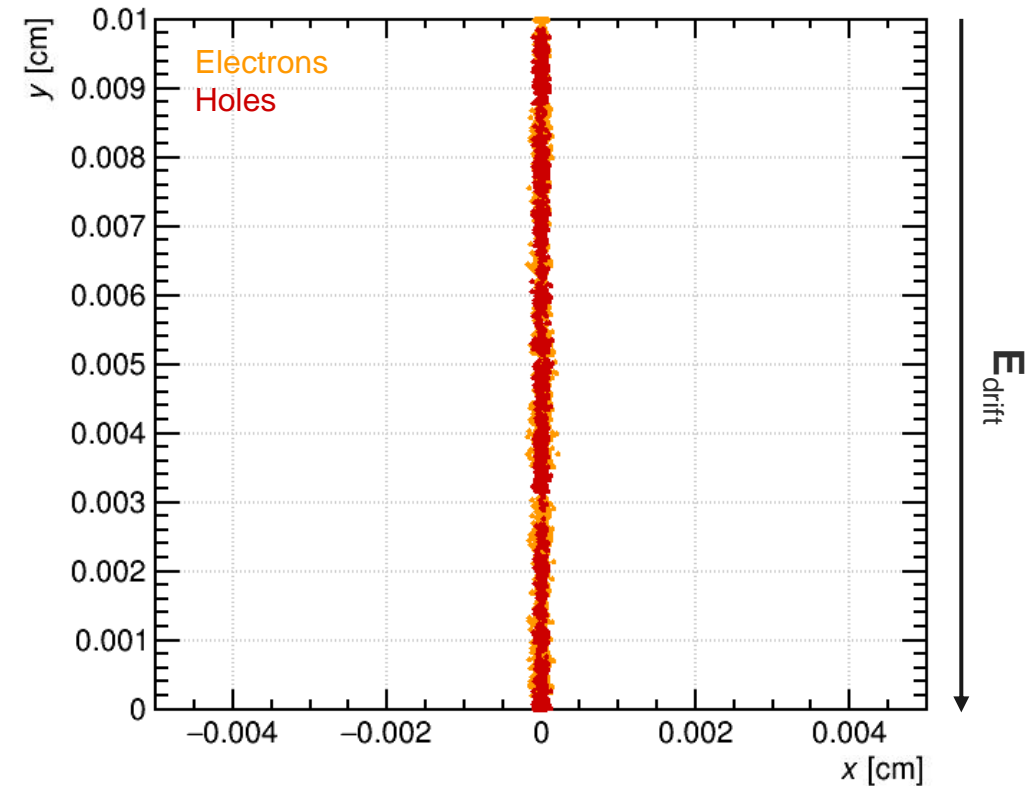
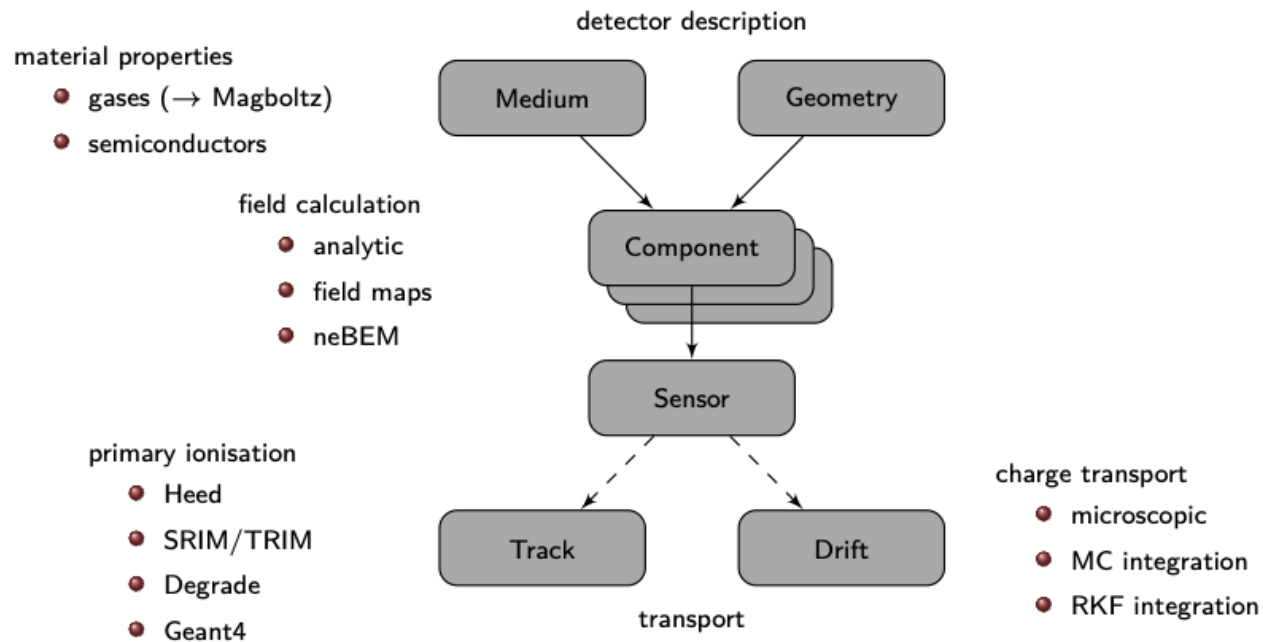
Introduction

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Introduction

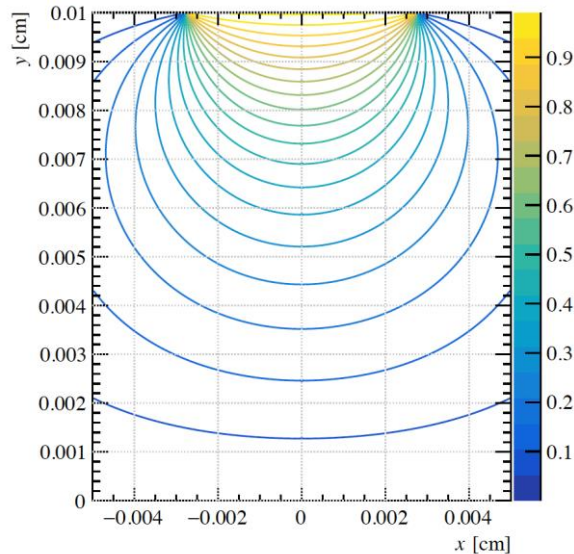
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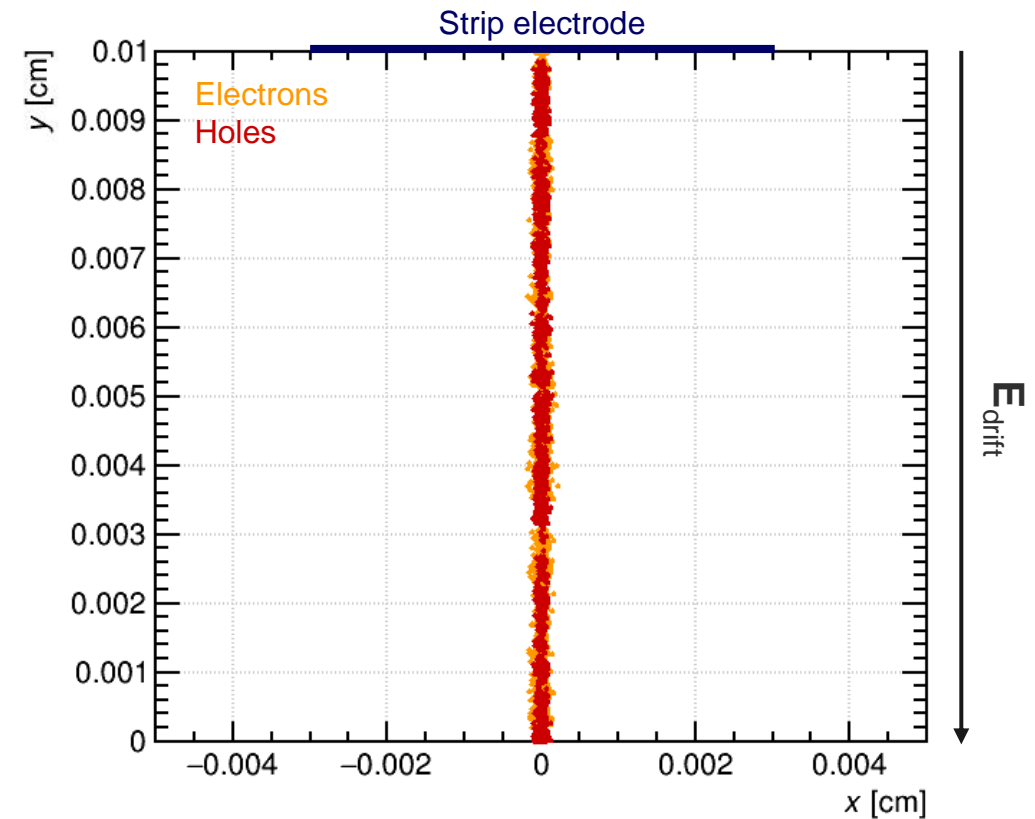
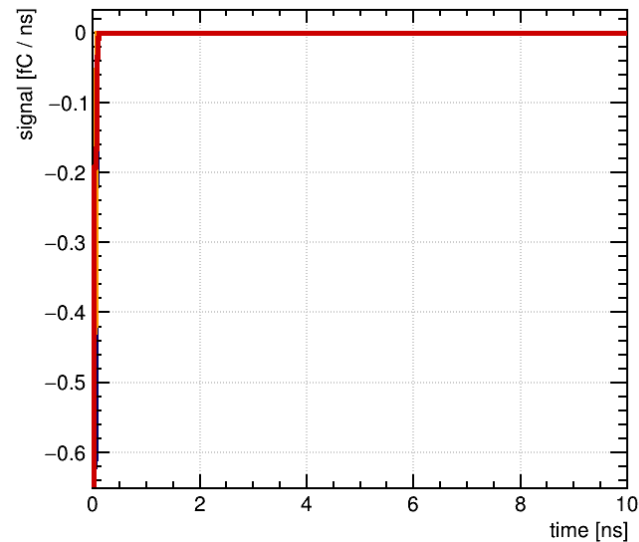
Introduction

The Ramo-Shockley theorem is used to induce signals on readout electrodes by charge movement. Weighting potentials are calculated using built-in analytical solutions or numerically via FEM solvers.

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

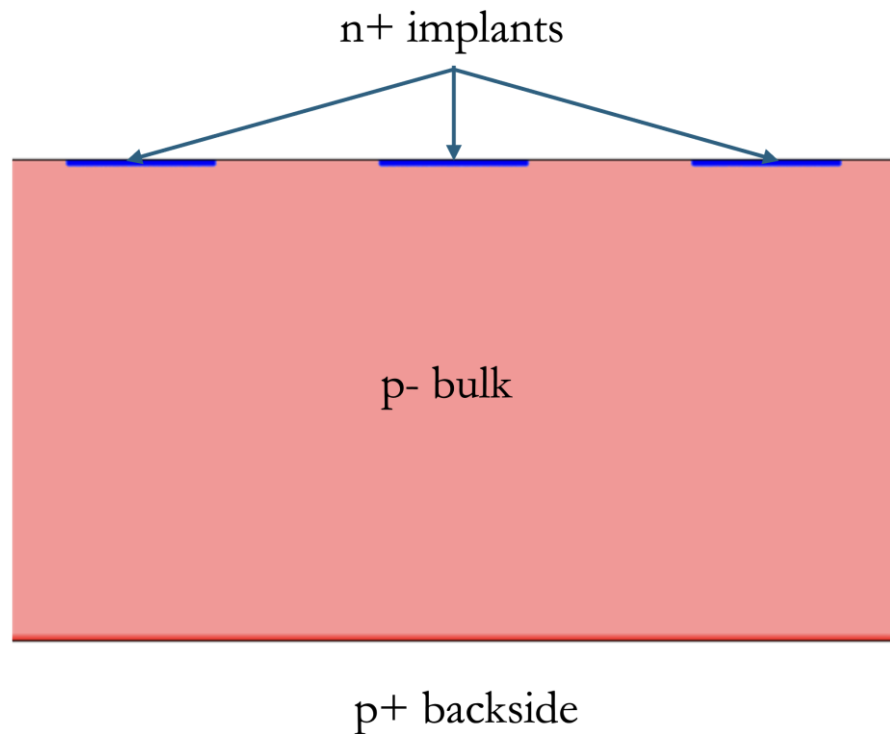


Signal $I_i(t)$ induced on strip electrode



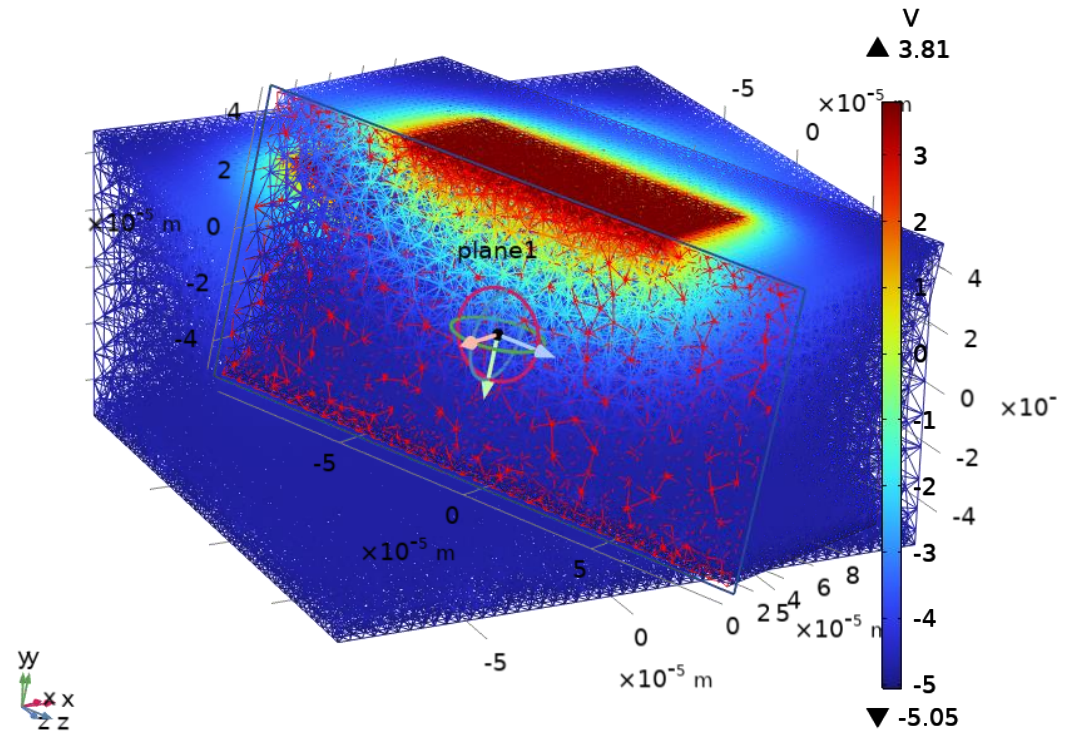
Interfacing COMSOL with Garfield++ for Silicon

Similar to the silicon example in Garfield++, a 3D p-n junction of a silicon photodiode was defined along the y-direction in COMSOL Multiphysics.

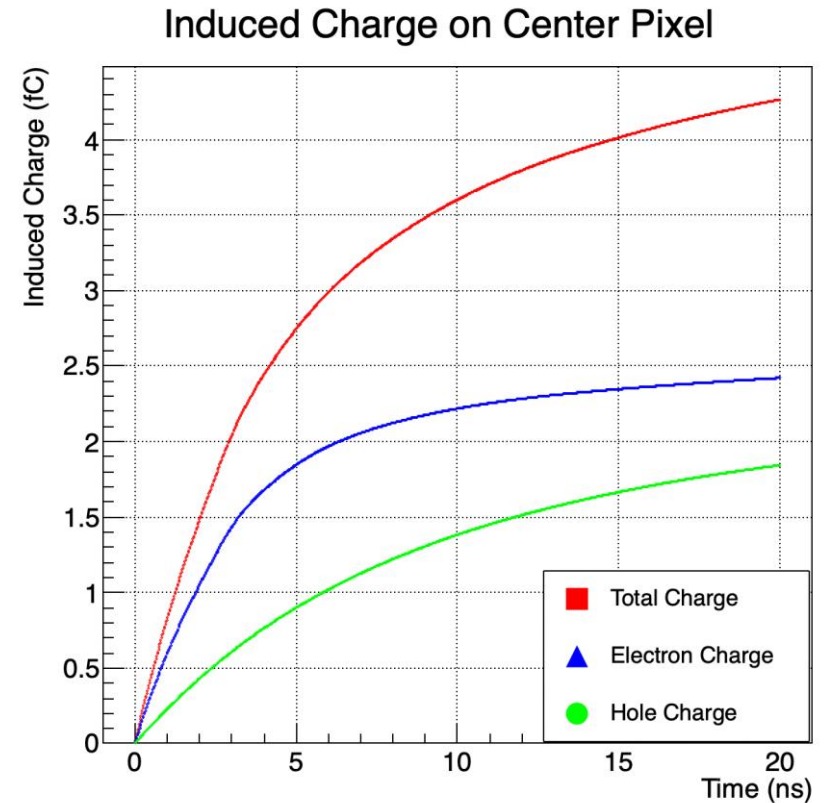
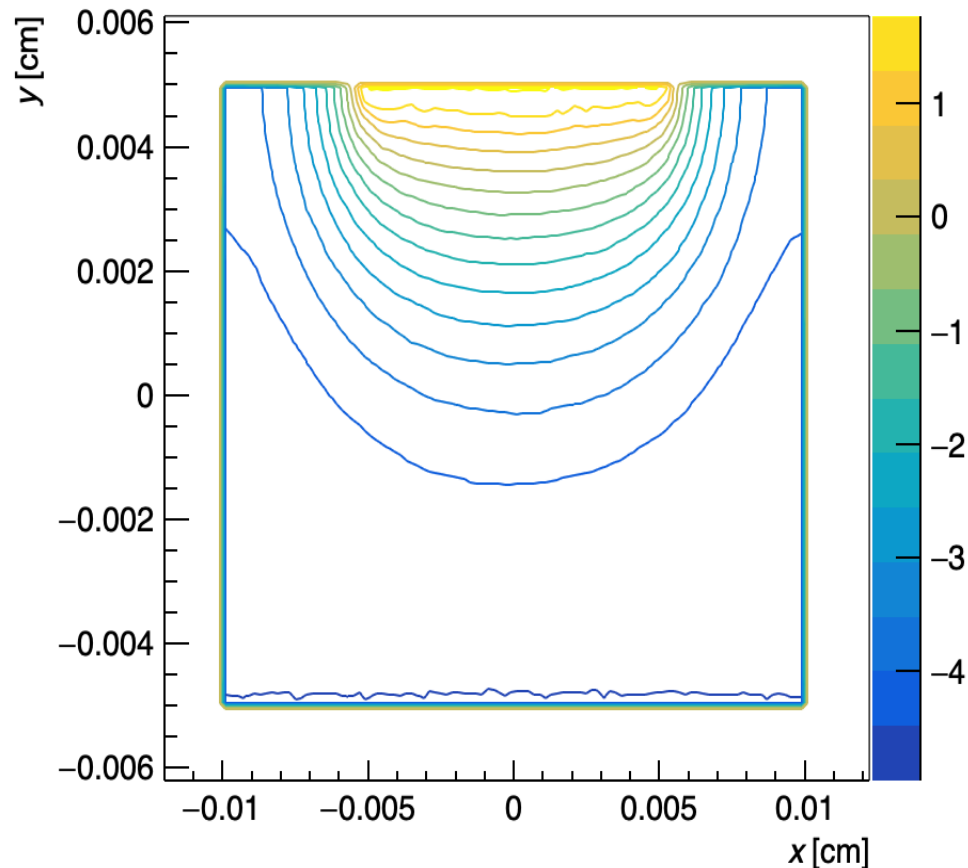


Vrev(17)=8 V

Volume: Electric potential (V)



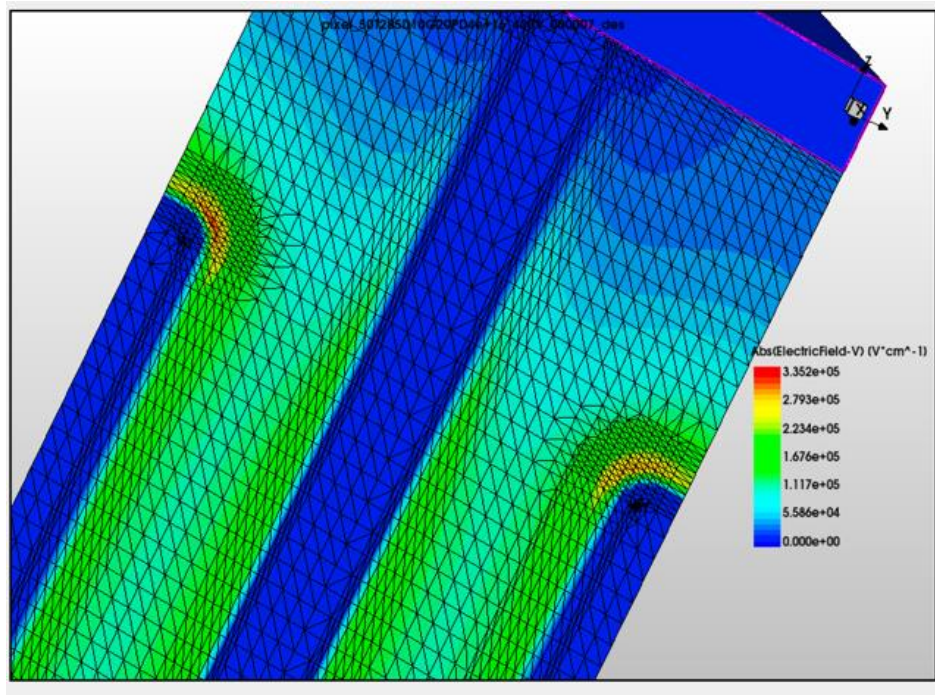
The electric potential map and mesh information can be exported as .txt files and later imported into Garfield++. The same procedure applies to the weighting potential, which is used in the signal induction calculation during charge-carrier drift.



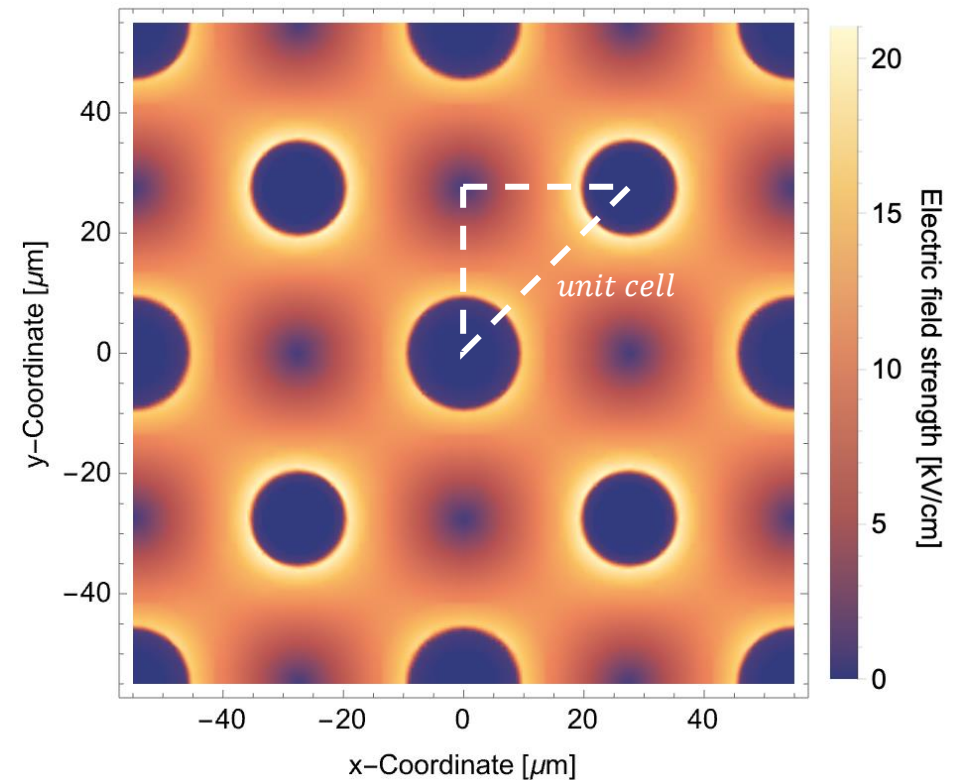
Symmetry Conditions for 3D Sensors

To reduce the simulated cell size in TCAD for 3D sensors, a triangular symmetry was implemented to replicate the electric field map across the full active area. This approach is now being used to optimize the design for the VELO Upgrade II.

TCAD electric field simulations



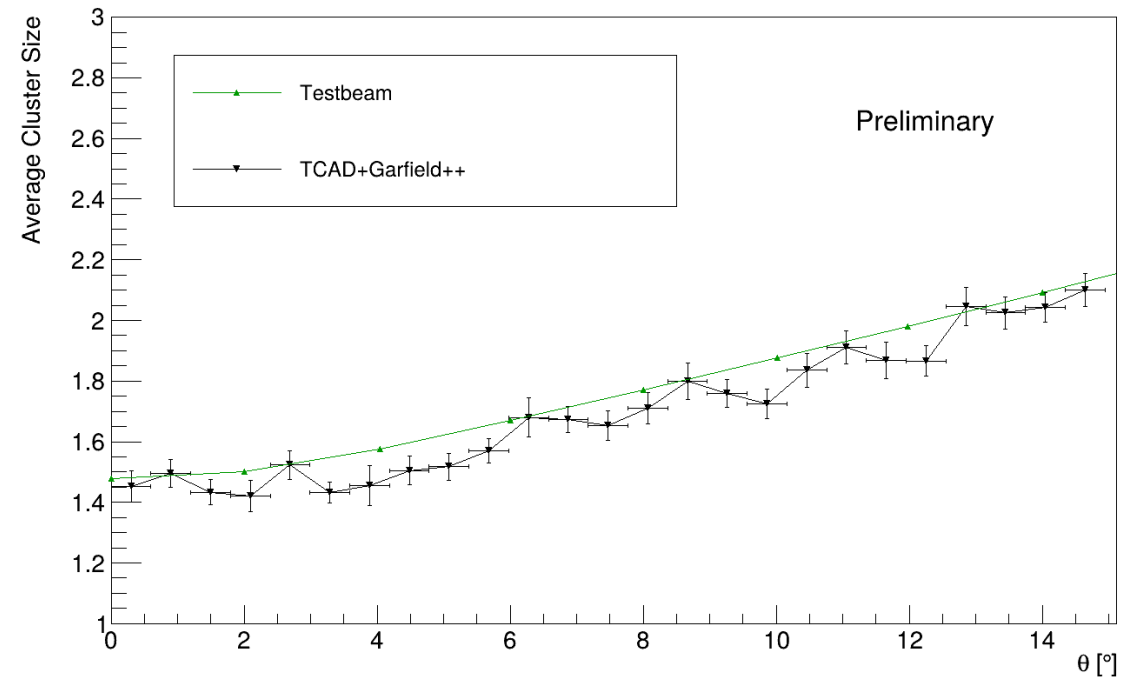
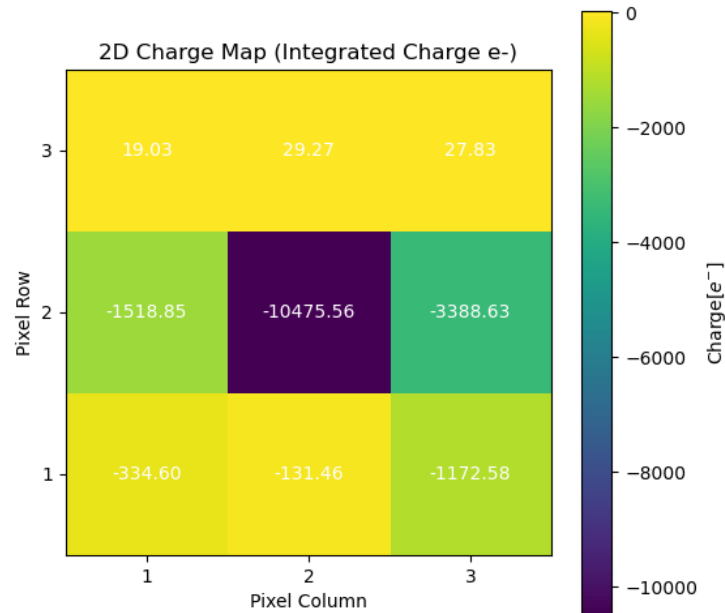
Garfield++ electric field repetition



Charge Sharing in Planar Pixel Sensors

Prototype planar n-on-p pixel sensors for the VELO Upgrade I (55 μm pixel pitch). Comparison of average cluster size versus incidence angle between TCAD + Garfield++ simulations and Timepix3 test-beam data.

The next step is to incorporate radiation damage effects by using the trap-occupation probability from TCAD.

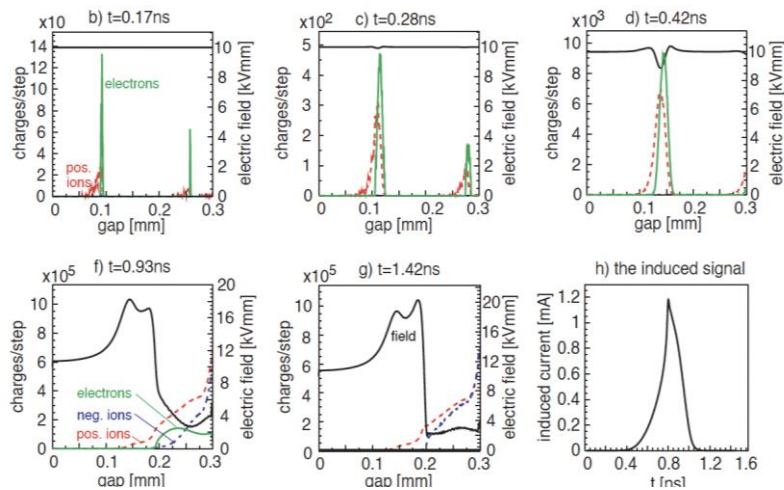


Space-charge Calculations Methods Under Development in DRD1

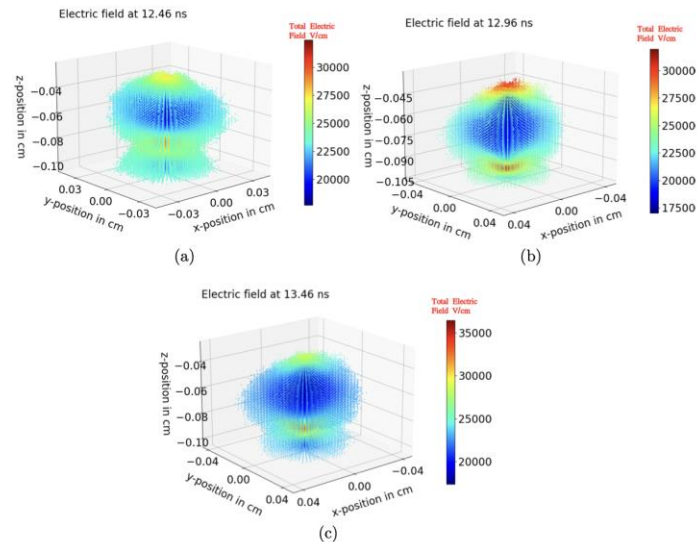
For the simulation of gaseous detectors, different approaches are being developed for the include the interplay between avalanche development and space-charge field modifications. Two distinct approaches are under development in Garfield++:



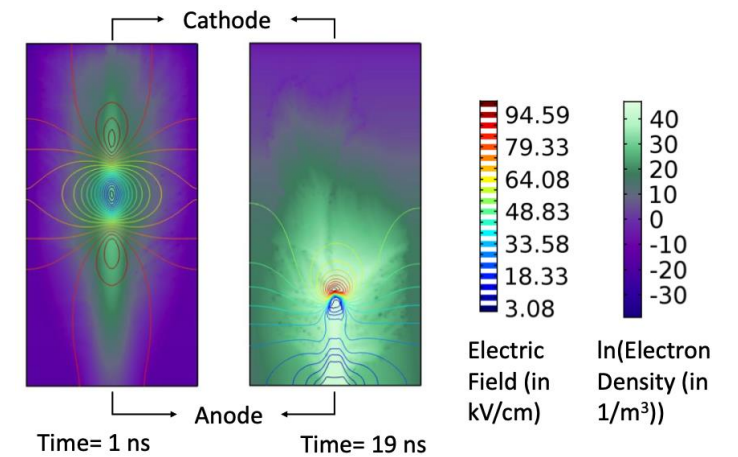
Field recalculation using charged rings



Field recalculation using numerical Poisson solvers



Field recalculation using hydrodynamic approx.



Space-charge Calculations using Charged Rings

Assuming a cylindrical symmetrical system and a linear material, the distribution of point charges are binning into a set of line charge rings confined in a parallel plate configuration

The electric field of each free-space ring $E_{i,ring}(\mathbf{x})$ is added to the background field: $E(\mathbf{x}) = E_b + \sum_{i=1}^N E_{i,ring}(\mathbf{x})$

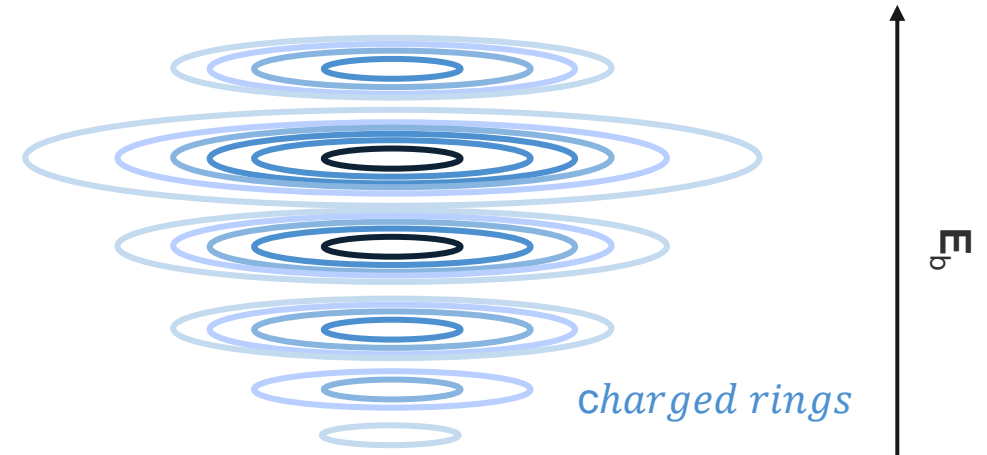
$$E_r(r, z, r', z') \approx \frac{Q}{4\pi^2\epsilon} \frac{1}{ra^2b} \times \left[c^2 E\left(\frac{-4rr'}{b^2}\right) + a^2 K\left(\frac{-4rr'}{b^2}\right) \right]$$

elliptical integral of 1st kind

$$E_\phi(r, z, r', z') = 0$$

elliptical integral of 2nd kind

$$E_z(r, z, r', z') \approx \frac{Q}{2\pi^2\epsilon} \frac{(z - z')}{a^2b} E\left(\frac{-4rr'}{b^2}\right)$$



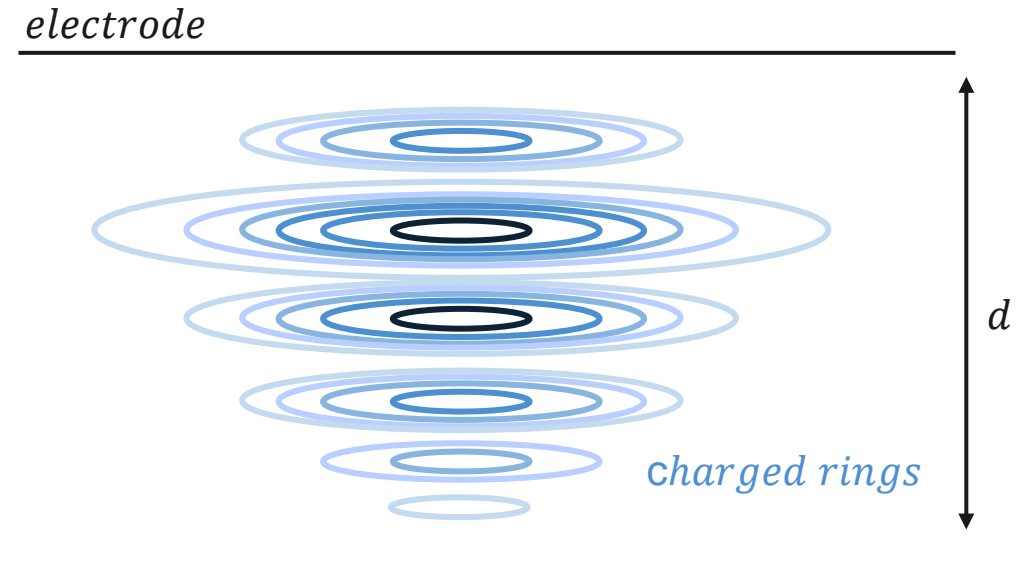
Space-charge Calculations using Charged Rings

When introducing the two parallel electrodes, each ring will have an infinite number of mirror rings. These boundary conditions especially affects the electric fields close to the electrodes (where the gain layer is).

For every ring between the Dirichlet boundaries, a set of $4L + 1$ mirror rings and a correction factor are used:

$$\begin{aligned}
 E_{D,r}(r, z, r', z') = & E_r(r, z, r', z') - E_r(r, z, r', -z') \\
 & + \sum_{l=1}^L E_r(r, z, r', z' - 2ld) + E_r(r, z, r', z' + 2ld) \\
 & - E_r(r, z, r', -z' - 2ld) - E_r(r, z, r', -z' + 2ld) \\
 & - \frac{Q}{\pi\epsilon} \int_0^\infty dk k J_1(kr) J_0(kr') f_r(k, L, z, z')
 \end{aligned}$$

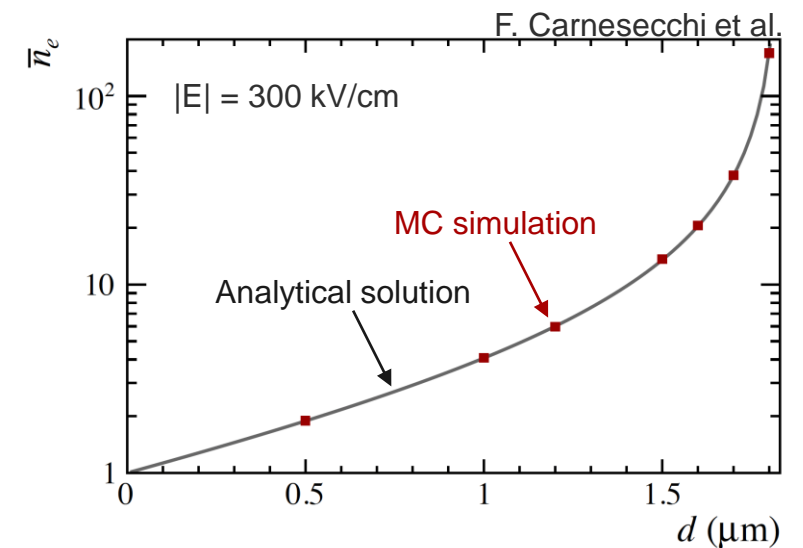
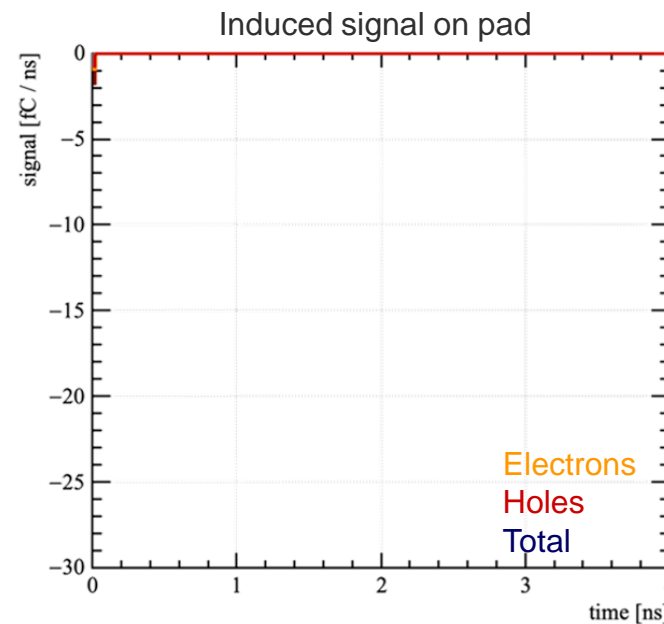
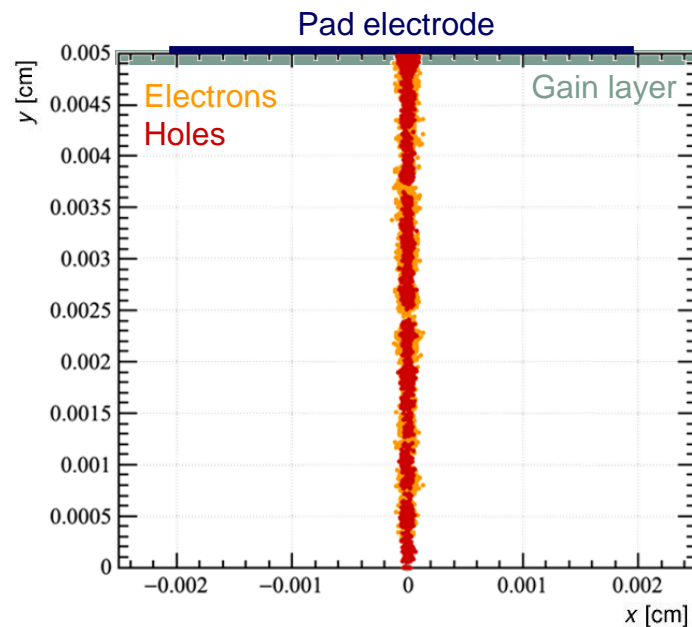
↑
Bessel function
↑
function capturing
z and z' dependency



Charge amplification in LGAD

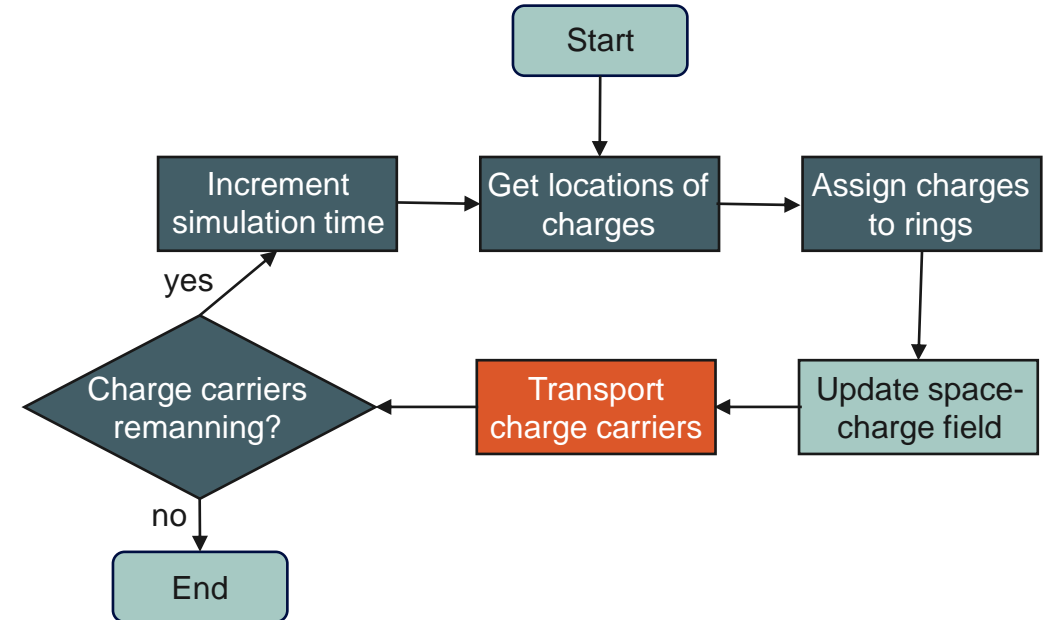
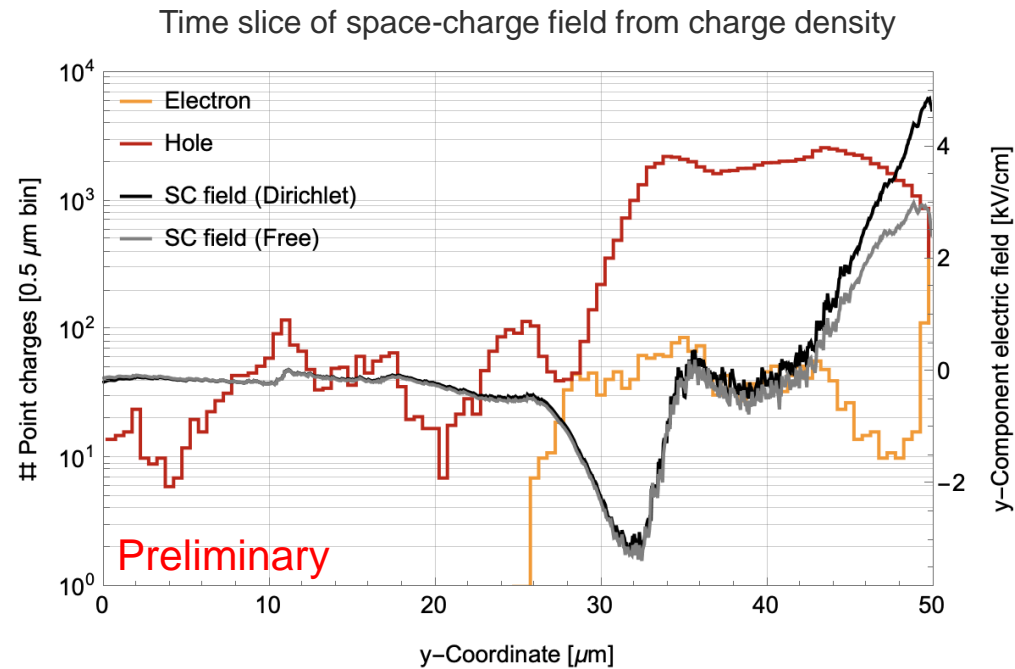
To simulate the development of an avalanche in high-field regions inside the sensor, such as a highly doped p+-type layer in an LGAD, one can:

- Use the Van Overstraeten - de Man model (for impact ionisation coefficient in silicon)
- Import a map of transport data from TCAD
- Import carrier lifetime data from TCAD



Space-charge Calculations using Charged Rings

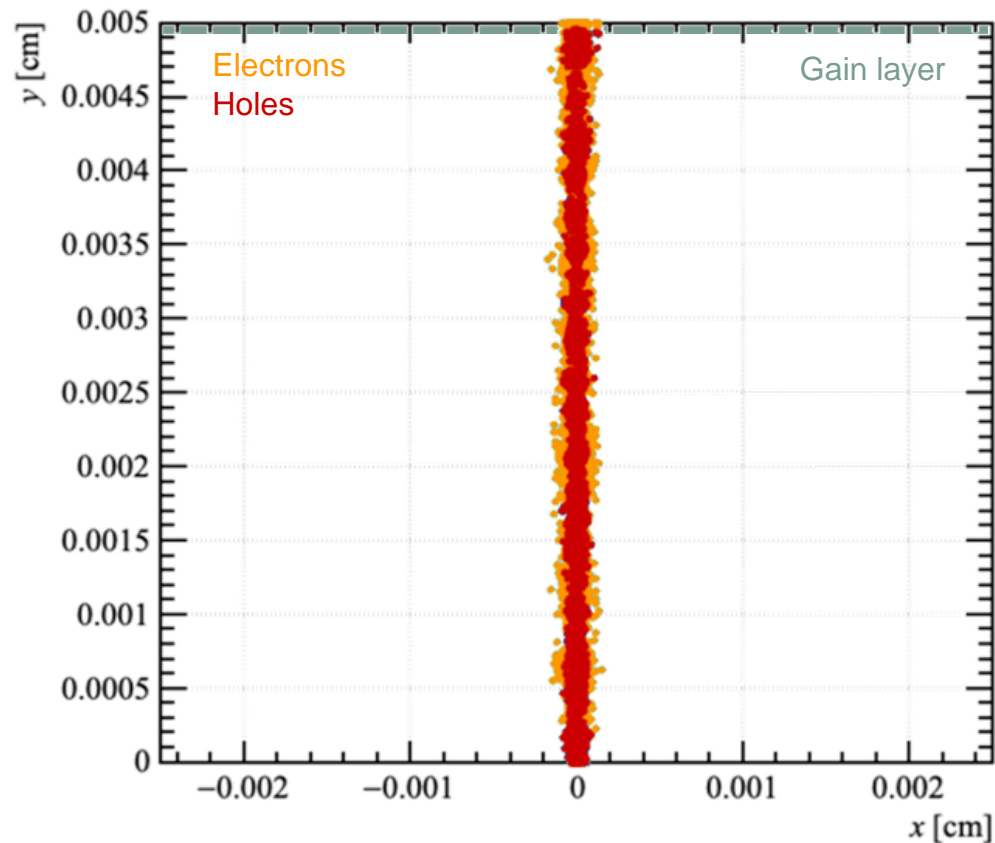
The simulation is divided into multiple time slices, at the end of which the space-charge field is updated for the next slice. A significant difference in the electric field within the LGAD gain layer is observed when Dirichlet boundary conditions are neglected.



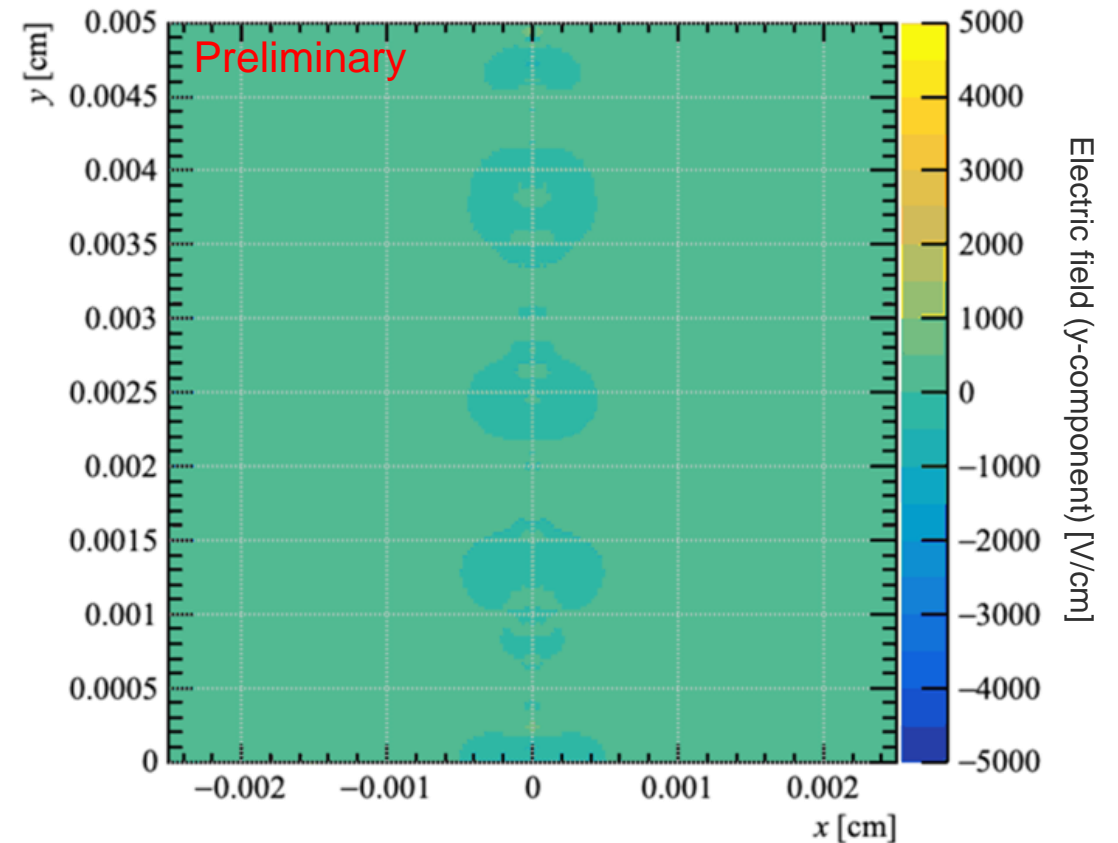
Space-charge Calculations using Charged Rings

Still some work to do ... In addition, a comparison with a TCAD transient simulation should be made to check if neglecting the influence of the sensor currents is significant.

Charge carrier positions



Space-charge field



Summary

Garfield++ is an object-oriented toolkit for detailed simulations of particle detectors, based on ionization measurements in gases and semiconductors.

What's New in 2025?

- **COMSOL Interface for Solid-State Field Maps** — The COMSOL Multiphysics interface has been extended to support the import of both electric and weighting field maps for solid-state sensors.
- **Triangular Symmetry** — A triangular unit cell (e.g., for 3D sensors) can now be imported and replicated across the full active area.

Under Development in 2025

- **Space-Charge Field Modifications** — Ongoing work aims to include first-order feedback from charge-carrier transport and amplification on the local electric field configuration.

Thank you for your attention!

