RD51 Mini-Week

DRD1 Preparation - Simulation of Resistive Detectors

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Overview

Detectors with resistive elements become increasingly more popular in our community to improve the performance and stability of our detectors.

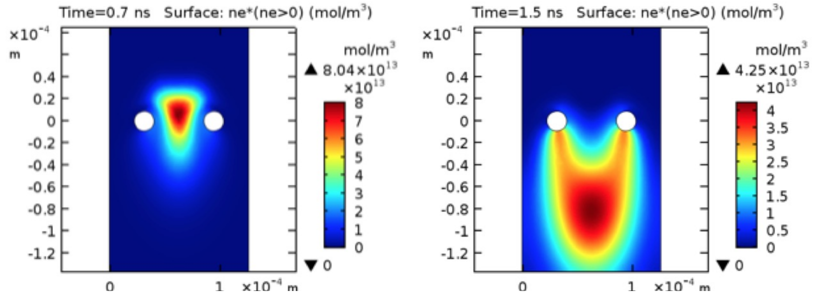
Signal formation:

- Importing 2D COMSOL solutions into Garfield++
- Inclusion of non-uniformities and defects in resistive electrodes
- General form of the Ramo-Shockley theorem

Quenching of sparks:

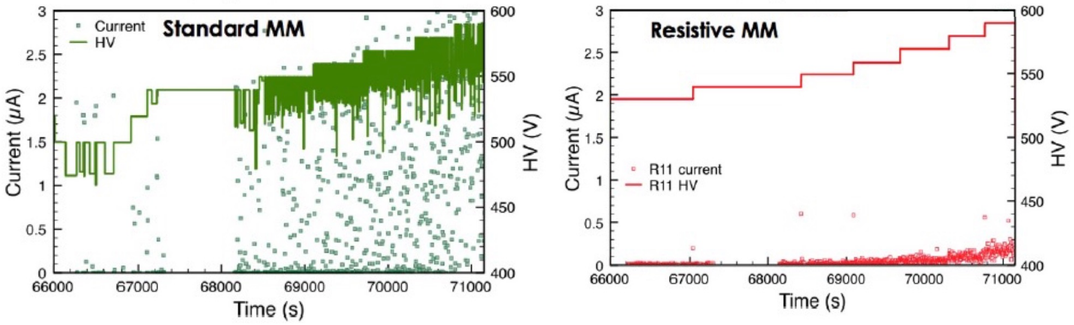
- Possible synergy with P. Gasik suggestions.

Simulation:



D. S. Bhattacharya et al., J. Phys. Conf. Ser. 1498 (2020) 012032

Measurments:



T. Alexopolous et al., NIM A 640 (2011) 110.

Ramo-Shockley theorem and its extensions

Currently we are not able to calculation signals in detectors where signal propagation times and radiation effects are not negligible, like transmission lines and antennas.

- Geometries including space-charge

  G. Cavalleri, E. Gatti et al., NIM 92 (1971), 137-140
- Signals on electrodes connected with impedance elements

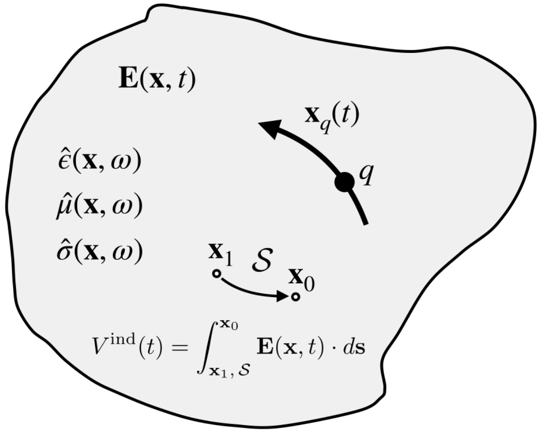
  E. Gatti, G. Padovini and V. Radeka, NIM 193 (1982) 651-653
- Permittivity and non-linear materials

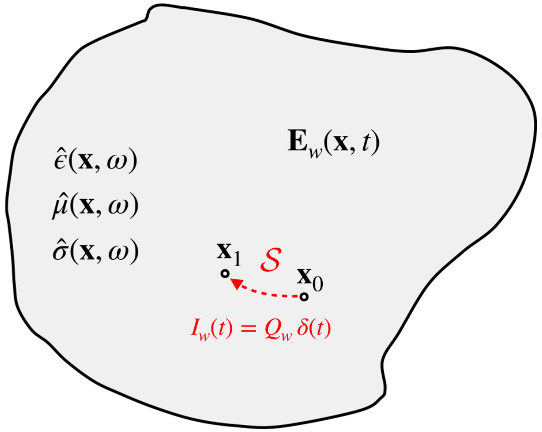
  L. A. Hamel, M. Julien, Proceedings of SPIE vol. 4507 (2001), 255-263
  L. A. Hamel, M. Julien, NIMA 597 (2008), 207-211
- Geometries that contain material of finite resistivity

  W. Riegler, NIMA 491 (2002), 258-217
  W. Riegler, NIMA 535 (2004), 287-293
  W. Riegler, NIMA 940 (2019) 453-461
- General Maxwell compliant form using Lorentz-reciprocity

  W. Riegler and P. Windischhofer, NIMA 980 (2020) 164471

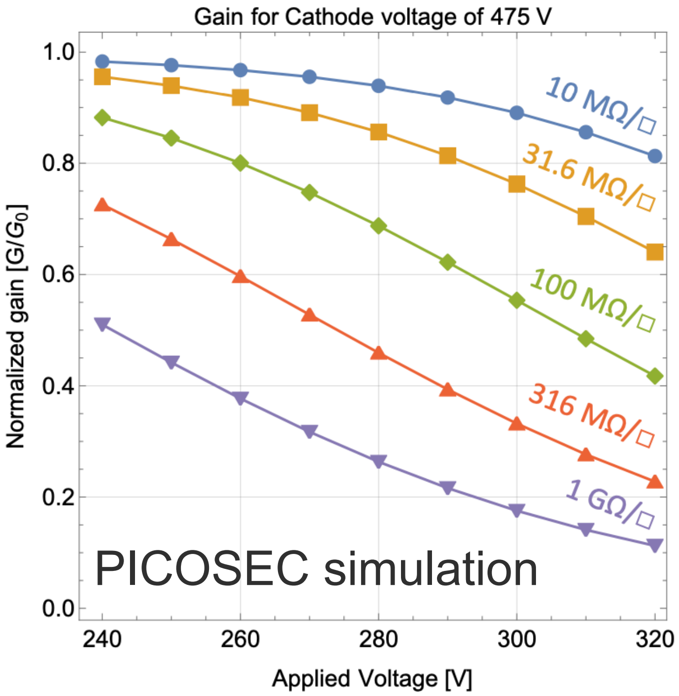
$$V^{\mathrm{ind}}(\omega) = \int_{\mathbf{x}_1,\mathcal{S}}^{\mathbf{x}_0} \mathbf{E}(\mathbf{x},\omega)d\mathbf{s} = -\frac{1}{I_w(\omega)}\int_V \mathbf{E}_w(\mathbf{x},\omega)\mathbf{J}^e(\mathbf{x},\omega)dV$$





Overview

Alongside these desirable effects, other “secondary” processes play a role in the performance of resistive detectors.



Rate capability studies:

- Already great progress in the form of equivalent circuits:
  Zhujun Fang et al., Nucl. Instrum. Meth. A 1032 (2022) 166615
- This could be extended using finite element solvers, the solution of which can be imported into Garfield++

Thermal or Johnson Noise:

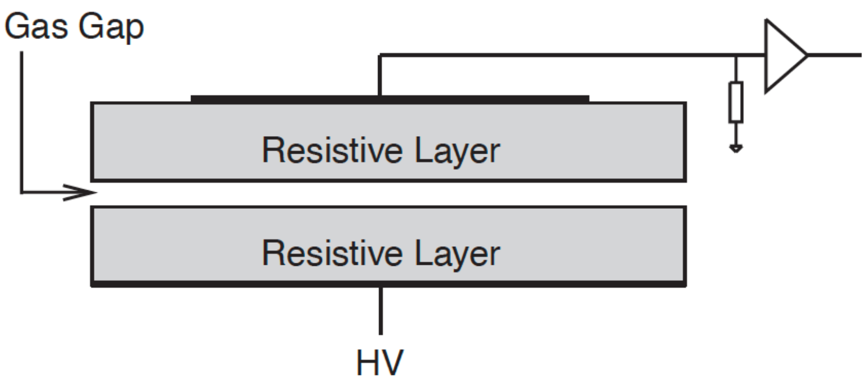
- Simulate noise contribution based on the power spectrum of of a detector with impedance Z(iω).

$$w_i(f) = 4k_B T \,\mathrm{Re}\left(\frac{1}{Z(i\omega)}\right)$$

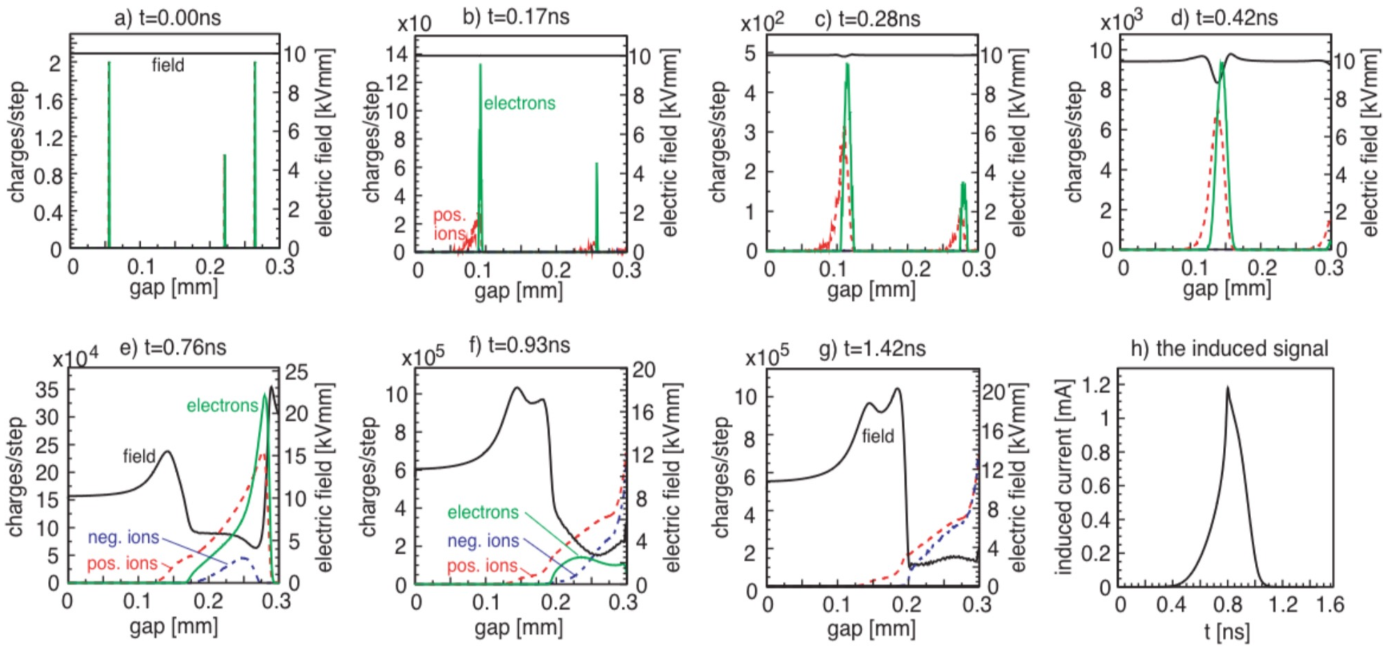
Space-charge effects and resistive elements

Resistive materials that collect electrons need time to spread and evacuate their charge from the collection area.

Locally this can result in the collapsing of the amplification field, limiting the growth of the avalanches of subsequent clusters.



Simulation work:

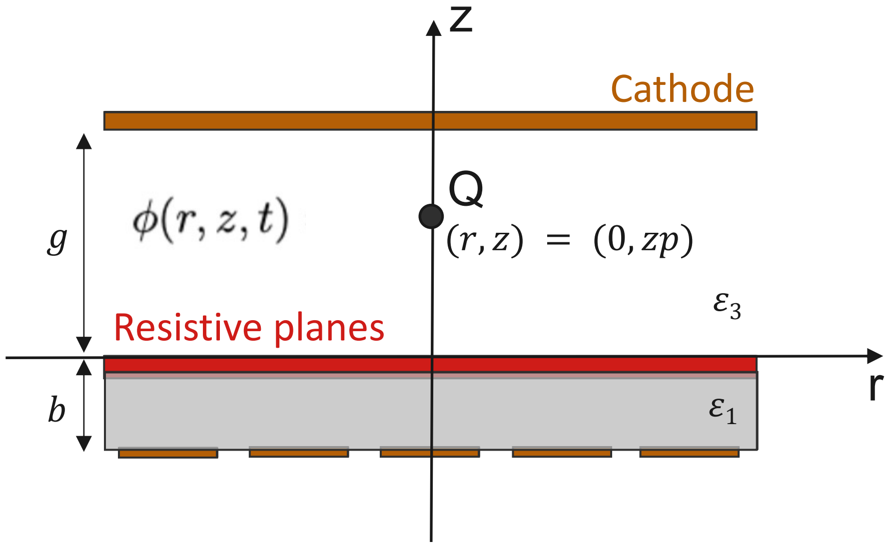


C. Lippmann and W. Riegler, Nucl. Instrum. Meth. A 517 (2004) 54–76

Space-charge effects and resistive elements

A way of implementing this is to include the analytical dynamic potential of the charge in a parallel plate type geometry.

$$\phi(r,z,t) = \frac{Q}{2\varepsilon_3\pi}\int_0^{\infty} dk\, J_0(kr) f(k,z,t)$$



For those who like equations

$$f(k,z,t) = \frac{e^{-k(b+z_<)}(1-\coth(gk))\sinh(k(g-z_>))\left(h_1 - h_2 e^{-\frac{t}{\tau(k)}}\right)}{D(k)}$$

$$D(k) = 2\varepsilon_3\left(\varepsilon_1\left(e^{2bk}+1\right)\left(e^{2gk}-1\right)+\varepsilon_3\left(e^{2bk}-1\right)\left(e^{2gk}+1\right)\right)$$

$$\tau(k) = \frac{R}{k}\left(\varepsilon_1\coth(bk)+\varepsilon_3\coth(gk)\right)$$

$$h_1 = \left(e^{k(b+g)} - e^{k(b+g+2z_<)}\right)\left((\varepsilon_1+\varepsilon_3)\left(e^{2k(b+g)}-1\right) - 2(\varepsilon_1-\varepsilon_3)e^{k(b+g)}\sinh(k(b-g))\right)$$

$$h_2 = 8\varepsilon_3\sinh(bk)\sinh(k(g-z_<))\exp\left(k\left(+2b+2g+z_<\right)\right)$$

Space-charge effects and resistive elements

This potential, which only needs to be evaluated once over all possible z positions, needs to integrated over the drifting particles.

The resulting field will then be a correntión factor to the applied static field inside the geometry.