Resistive strips signal propagation studies and spark mitigation

Javier Galan

For the 8th RD51 Collaboration meeting
2-3 September Kobe – Japan 2011

Outline

- **A simplified spark phenomena explanation. Study motivation**.
- Resistive strip model.
- Simulation results.

How sparks are triggered/quenched?

After the Raether limit is reached at electron densities of ~10^8 e^- (per avalanche volume) an spark is started (streamer) and it will probably develop into a real spark process (or uncontrolled discharge). In the limit, a streamer can develop to spark with certain probability.

Even if the spark/streamer development requires a complex treatment (many reviews, and literature about the field are around**), the idea of spark generation can be easily understood in terms of Townsend continuity relations*.

***Transient Analysis of the Townsend Discharge, P. Auer, Phys. Rev. 111, 671–682 (1958)**
**** Electron avalanches and breakdown in gases, H. Raether, 1964**

How sparks are triggered/quenched?

<u>The key are the secondaries coming from the avalanche</u>, UV photons and ions, which generate secondary avalanches.

From a conceptual point of view **<u>each avalanche has an implicit probability to produce a number of secondaries</u>** which must be **<u>related with the electron density</u>** (Raether limit). If the number of secondaries generated by the avalanche (if any) is higher than the primaries it is "obvious" that the secondaries will grow exponentially with the subsequent avalanches, and a channel will finally be created, with no-end till there is no more charge available.

From this point of view, **<u>once the secondaries have exceeded the population of primaries</u>**, the process seems to be non-STOP.

A spark is not a short circuit (spark is stopped when gain is not enough to clonate secondaries) neither conductive media (in a conductor there is no spontaneous charge creation).

How sparks are triggered/quenched?

The key are the secondaries, UV photons and ions.

From a conceptual point of view **each avalanche has an implicit probability to produce a number of secondaries** which must be **related with the electron density** (Raether limit). If the number of secondaries generated by the avalanche (if any) is higher than the primaries it is "obvious" that the secondaries will grow exponentially with the subsequent avalanches, and a channel will finally be created, with no-end till there is no more charge available.

From this point of view, **once the secondaries have exceeded the population of primaries**, the process seems to be non-STOP.

The only way is to reduce the gain and thus, the amplification field.

How sparks are quenched?

Standard Readout

The charges created at the gas volume are quickly driven to ground through a low impedance connection. **The field is not lost until the power supply cannot provide additional charges to the mesh**. And thus, **the field is lost at the full detector area**.

Resistive Readout

The electrons created at the amplification gap drop in the resistive foil, or strips. The typical charge diffusion time **(in the order of a few us)** in the resistive material allows to **locally reduce the amplification field** during the streamer formation and maintain the amplification field reduction during the time necessary for the charges to leave the gas volume.

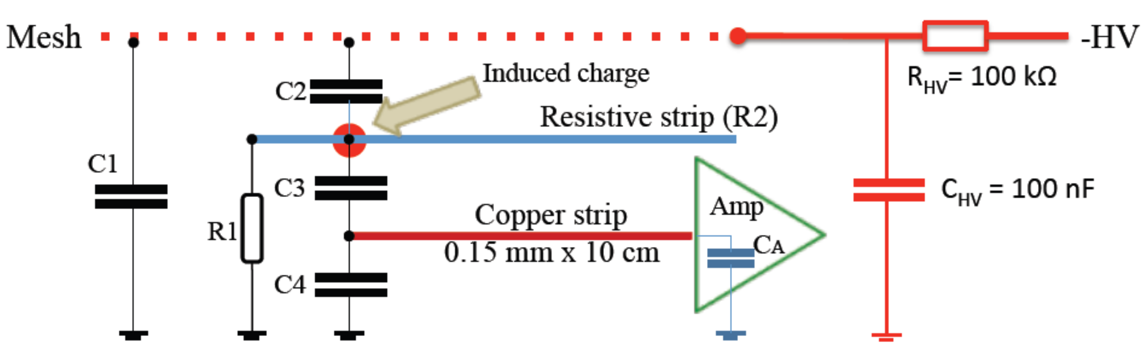
First spark-protected detectors made of Resistive Plate Chambers

A spark-protected high-rate detector, P. Fonte, NIM A 431 (1999) 154-159

Resistive Micromegas and studies motivation

Recently this technique was applied also to Micromegas detectors.

A spark-resistant bulk-micromegas chamber for high-rate aplications, J. Wotschack, NIM A 640 (2011) 110-118



Recently, there weas a lot of progress on different prototype topologies and materials, **shown in J. Wotschack contribution to MPGD 2011 conference**

<u>**The work I will present**</u> is inspired on the previous work of Dixit, **Simulating the charge dispersion phenomena in Micro Pattern Gas Detectors with a resistive anode, M.S. Dixit NIM A 566 (2006) 281-285** where he obtains an analytical approach to the charge dispersion on a bi-dimensional resistive foil.

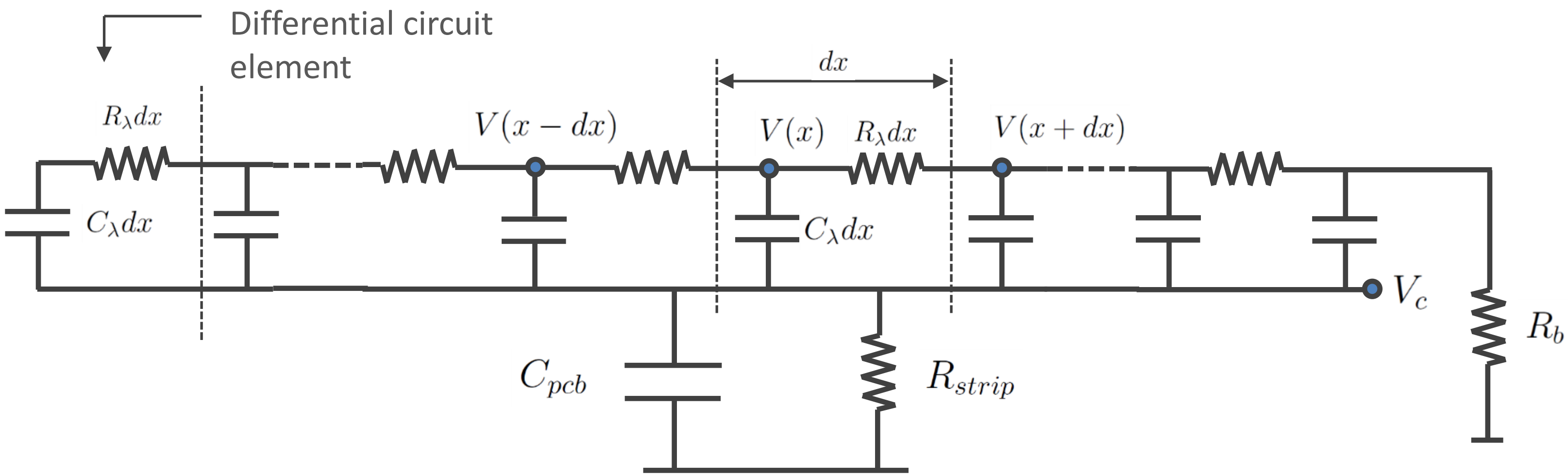
The main idea is to study the charge dispersion in the new topology given by the resistive strip read-out, detector type already tested at SPS beam, **shown by J. Manjares at MPGD 2011**.

Outline

- A simplified spark phenomena explanation. Study motivation.
- **Resistive strip model.**
- Simulation results.

Resistive Strip model.

The most simplified model of a resistive strip is obtained by replacing the strip by a transmission line.



The propagation of the signal generated by a charge deposited at the resistive strip surface is described by the following expression.

$$\frac{\partial^2 V(x,t)}{\partial x^2} = C_\lambda R_\lambda \frac{\partial \left(V(x,t) - V_c(t)\right)}{\partial t} + R_\lambda \frac{\partial \rho(x,t)}{\partial t}$$

Which is moreover bounded by the electronic read-out connection

$$\frac{dV_c(t)}{dt} = \frac{C_\lambda}{C_{pcb} + x_L C_\lambda} \int_0^{x_L} \frac{\partial V(x,t)}{\partial t} dx - \frac{V_c(t)}{(x_L C_\lambda + C_{pcb}) R_{strip}}$$

Semi-analytical solution

In order to solve the signal propagation, the strip is discretized in N finite elements, then we must solve a system of N+1 coupled partial differential equations

$$\frac{dV_j}{dt} = \frac{1}{\tau_\lambda \delta x^2}\left(V_{j+1} - 2V_j + V_{j-1}\right) + \frac{dV_c}{dt} - \frac{1}{C_\lambda}\frac{d\rho_j}{dt}$$

which acquires the following matricial notation

$$\frac{d}{dt}\begin{bmatrix} v_1 \\ \vdots \\ v_n \end{bmatrix} = \frac{1}{\tau_\lambda \delta x^2}\begin{bmatrix} -2 & 1 & & & 0 \\ 1 & -2 & 1 & & \\ & \ddots & \ddots & \ddots & \\ & & 1 & -2 & 1 \\ 0 & & & 1 & -1 \end{bmatrix}\begin{bmatrix} v_1 \\ \vdots \\ v_n \end{bmatrix} + \frac{1}{\tau_\lambda \delta x^2}\begin{bmatrix} v_o \\ 0 \\ \vdots \\ 0 \end{bmatrix} - \frac{1}{C_\lambda}\frac{d}{dt}\begin{bmatrix} \rho_1 \\ \vdots \\ \rho_n \end{bmatrix} + \frac{dV_c}{dt}\begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix}$$

The potential at each point must be solved simultaneously, in order to decouple the equation system some algebra is applied and the calculation is done over the transformed potential.

Diagonal matrix

$$\frac{d\mathbf{u}}{dt} = \frac{1}{\tau_\lambda \delta x^2}\Lambda \mathbf{u} + \frac{1}{\tau_\lambda \delta x^2}\mathcal{X}\mathbf{v_o} - \frac{1}{C_\lambda}\mathcal{X}\frac{d\boldsymbol{\rho}}{dt} - \frac{\xi V_c}{C_\lambda R_{strip}}\mathcal{X}\,\mathbf{b}$$

Transformed potential

Semi-analytical solution

Diagonal matrix

$$\frac{d\mathrm{u}}{dt} = \frac{1}{\tau_\lambda \delta x^2}\Lambda \mathrm{u} + \frac{1}{\tau_\lambda \delta x^2}\mathcal{X}\mathrm{v_o} - \frac{1}{C_\lambda}\mathcal{X}\frac{d\rho}{dt} - \frac{\xi V_c}{C_\lambda R_{strip}}\mathcal{X}\,\mathrm{b}$$

Transformed potential

Independent potential terms

We have now a set of **N+1 undependent and linear differential equations** which can be solved independently by applying a **Runge-Kutta method**.

The **transformed potential is solved** for each time step iteration, and **the real potential and V_c are obtained** by applying the inverse transformation and the boundary expression.

The description of **detailed calculations will be provided** at PSD9 conference proceedings.

The calculation is **implemented in a simple C code** where all the initial parameters can be defined in command line. **The code will be available** for download together with these slides at the indico website.

Software implementation

A particular solution to this problem could have been obtained with a circuit package solver, i.e. spice engine.
Personally, I believe there are some few advantages on producing your own calculation in C code ... once the method is well established it gives much more flexibility

- **Almost every person dedicated to simulation in physics is familiar with C code and knows about its unlimited possibilities.**
- **In general, premade software entails some limitations because it was conceived for a specific set of problems.**
- **Future additions to the simulation, different current shapes, resistivity and capacitive inhomogeneity's can be easily inserted.**
- **Easier connection to future or existing simulation software.**
- **Easy to prepare jobs for the CERN lxbatch services.**
- **The only limit is set by maths and imagination.**

Outline

- A simplified spark phenomena explanation. Study motivation.

- Resistive strip model.

- **Simulation results.**

Different simulation set-ups

Simulations at different boundary resistors values.

R_λ = 100k/mm C_λ = 0.2pF/mm R_b = 250K, 2.5M, 5M, 10M

Simulations at different strip resistivities R_λ = 50,100,200 k/mm

R_b = 10M C_λ = 0.2pF/mm

Simulations at different strip capacitances C_λ = 0.05, 0.2, 1 pF/mm

R_b = 10M R_λ = 100 k/mm

Simulations at different signal positions Δx = 0.5 mm

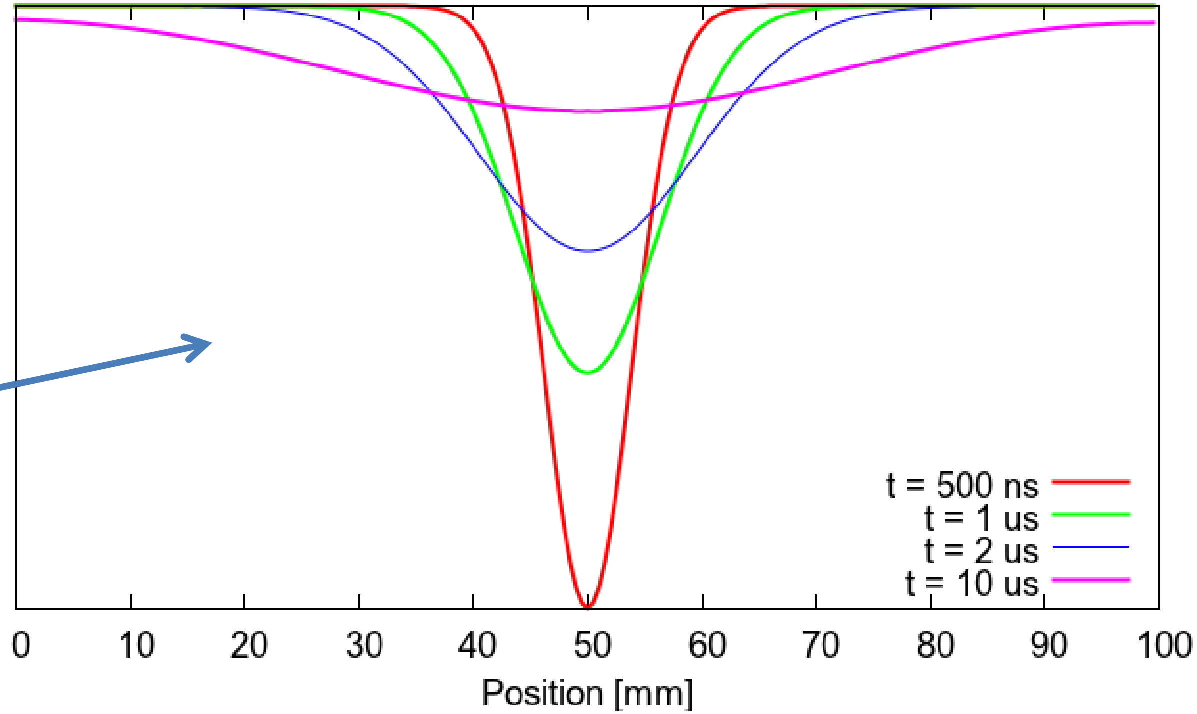
C_λ = 0.2pF/mm R_λ = 100 k/mm R_b = 5M

Cluster size simulations 100 um

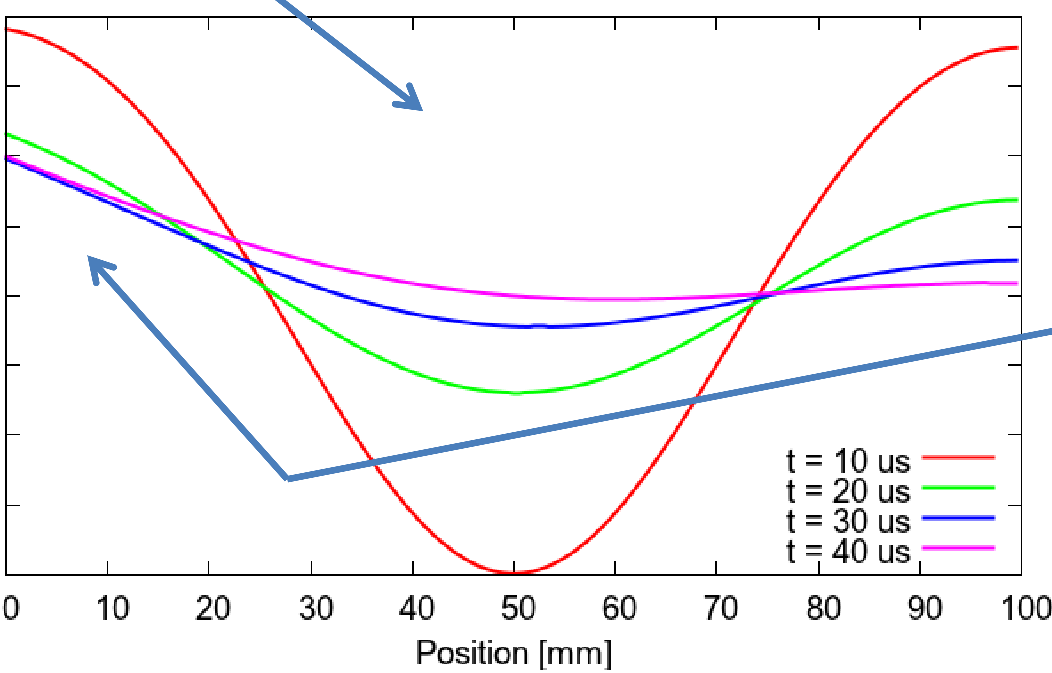
Contrary to fake intuition signal is not dependent **on transversal difussion**

Temporal charge evolution along the strip

First time steps



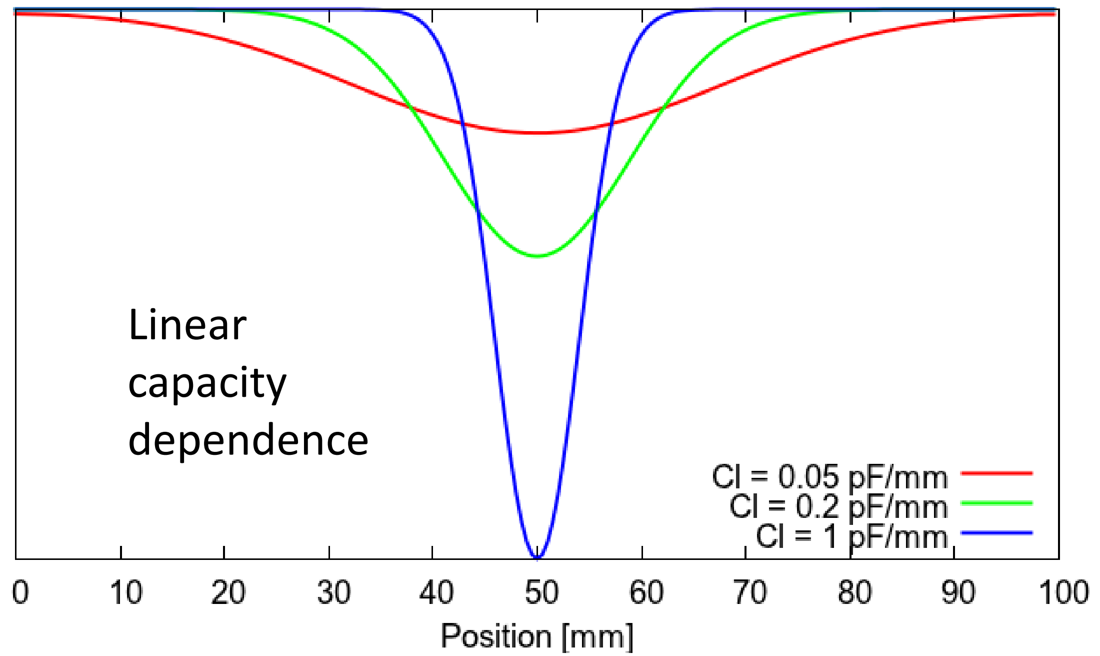
Last time steps

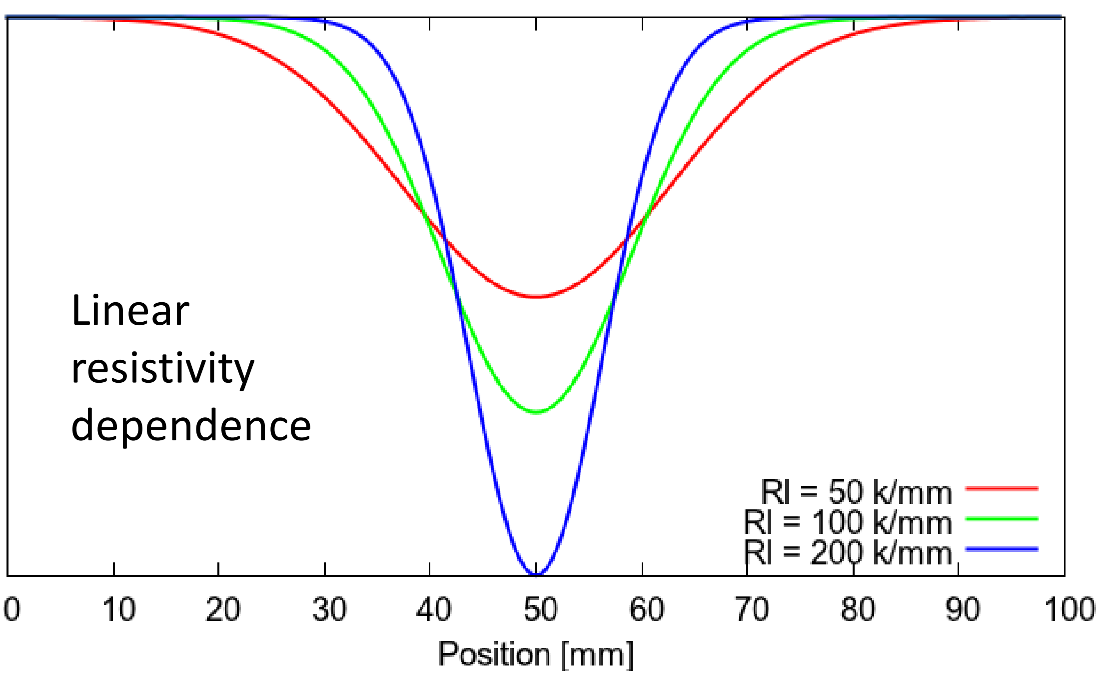


Charges drifting to ground

Charge diffusion at different resistivities and capacitances

After 1 us difussion

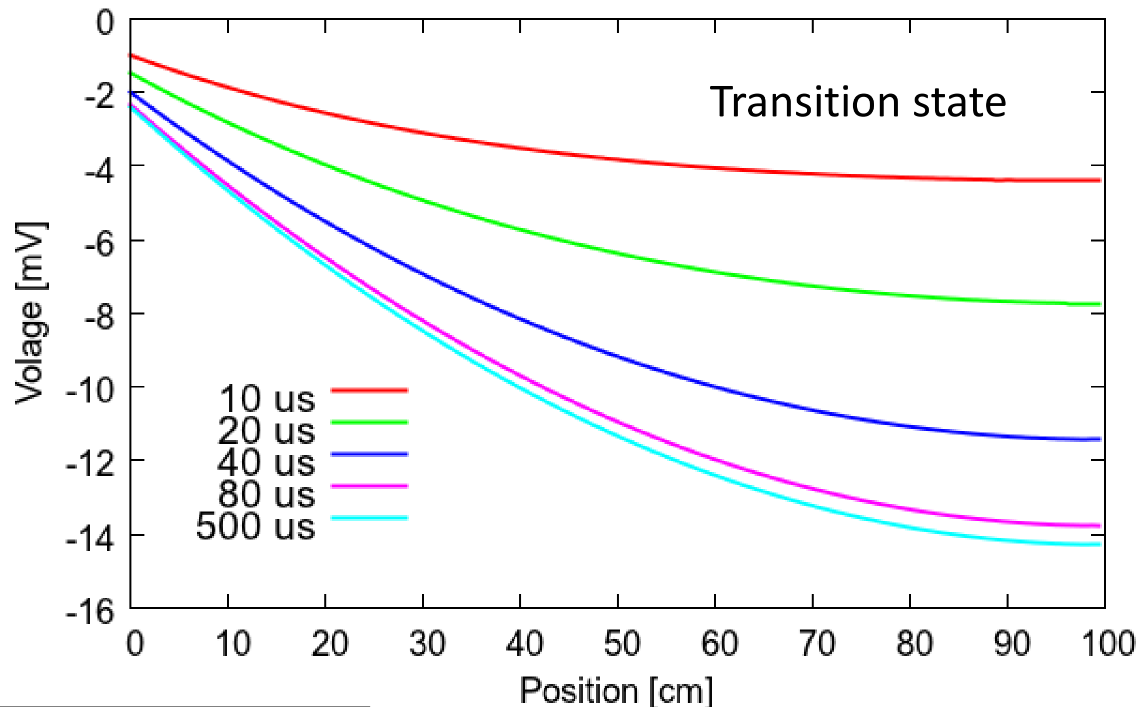


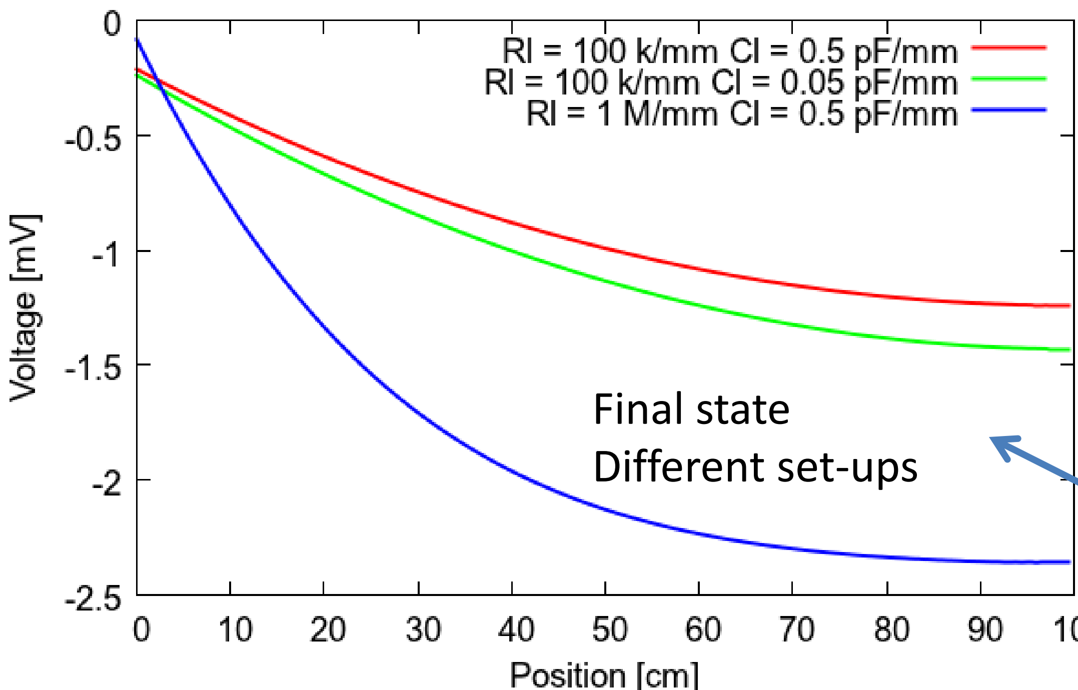


Higher capacitance and higher resistivity -> lower charge difussion

Simulating homogeneous charge current deposition

Rate = 100 kHz
Gain = 10000
Primary electrons = 300

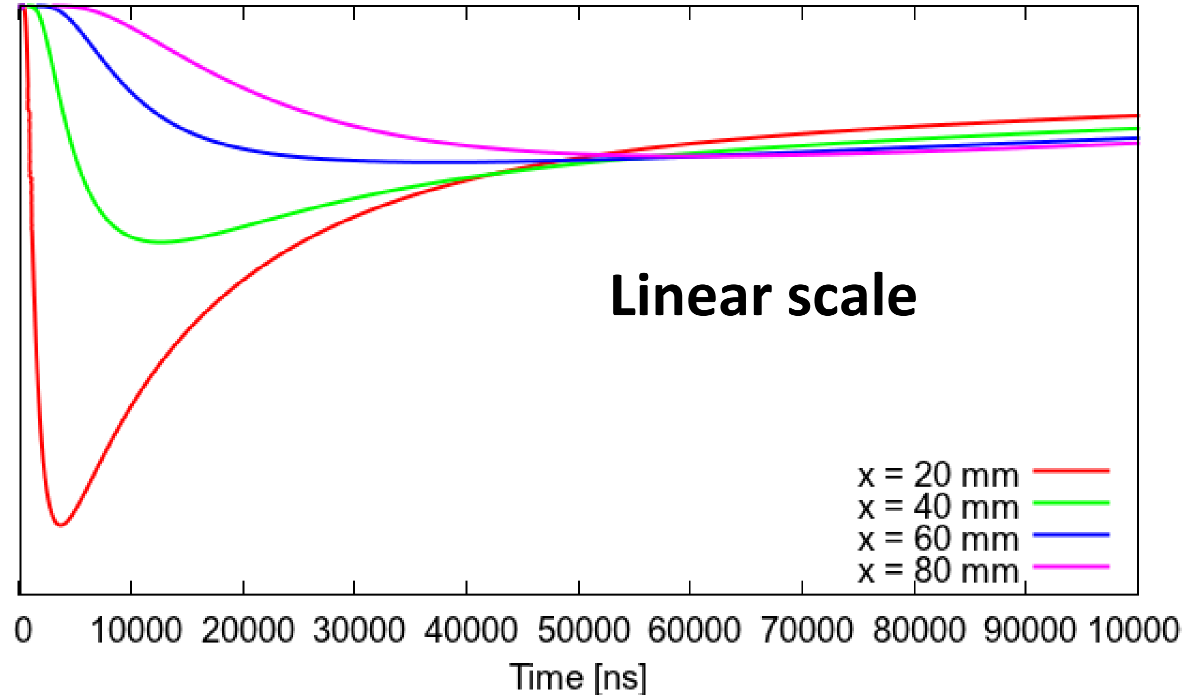


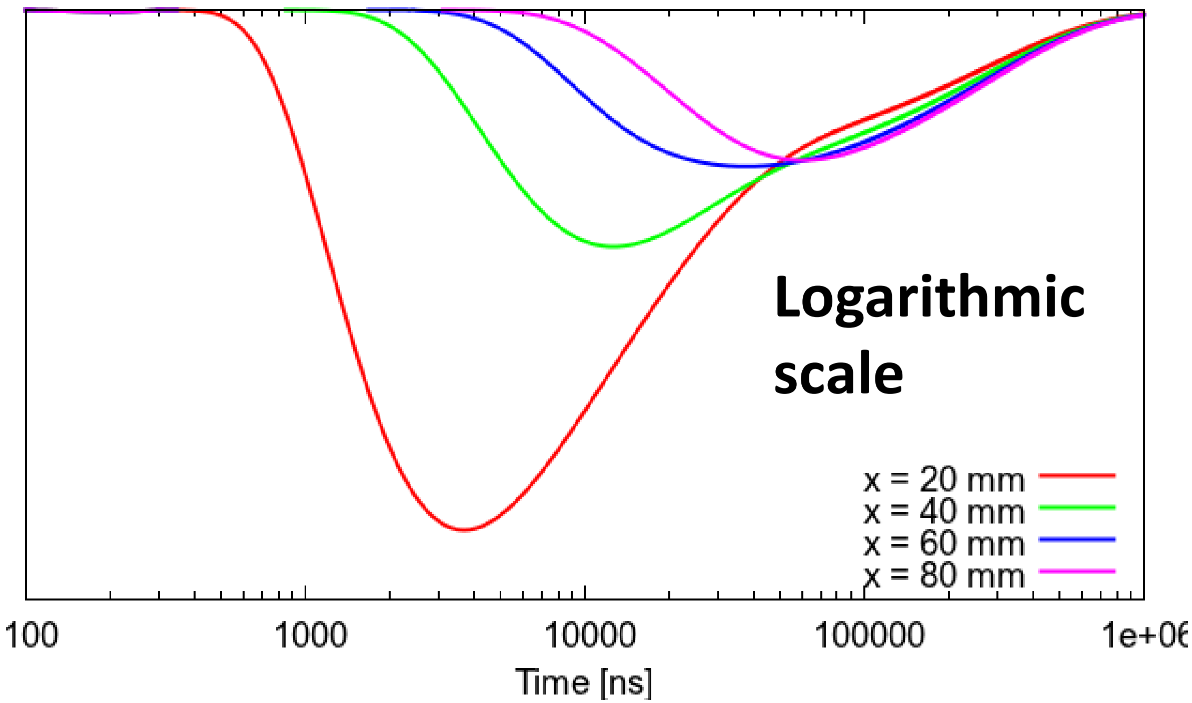


At the non-grounded strip end the tension reached is proportional to the rate.

Relation with resistivity and capacitance at the final state.

Current at the boundary resistor due for different event positions

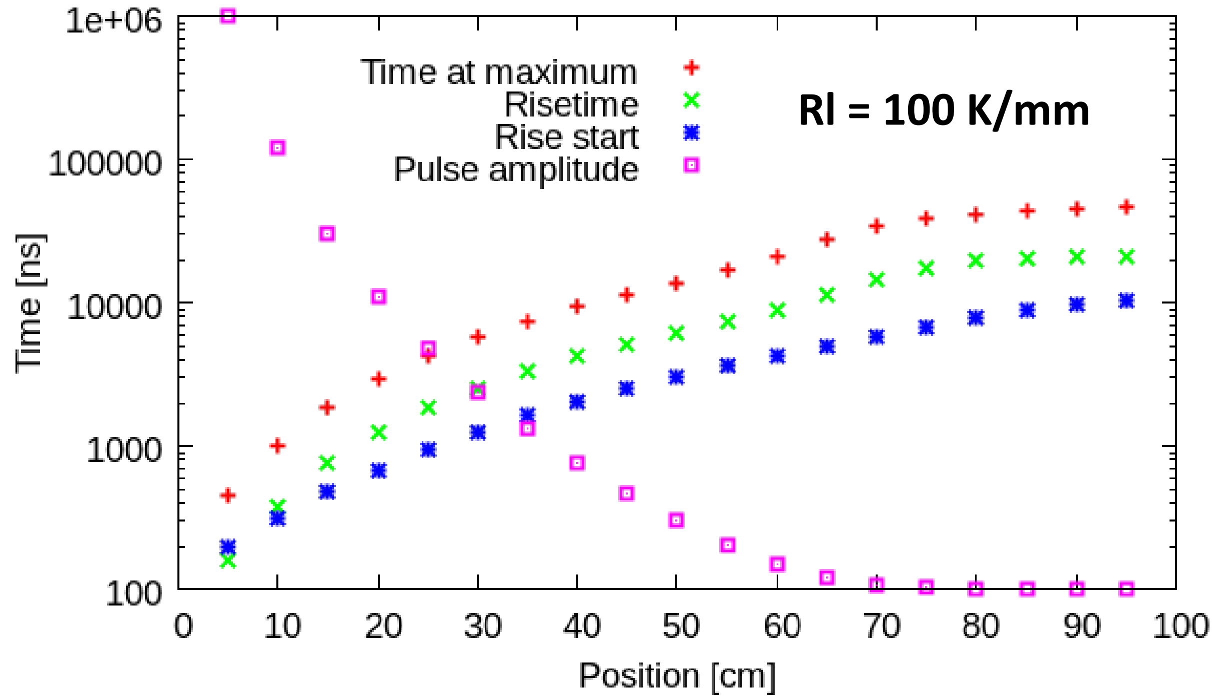


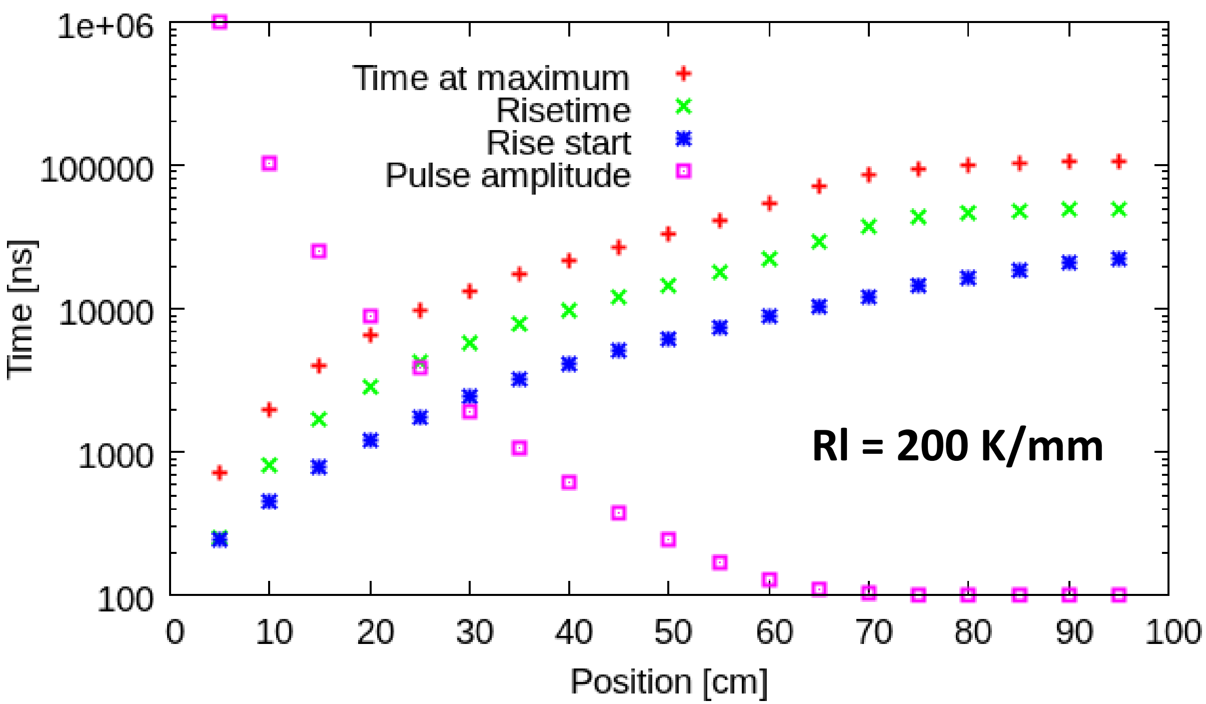


Gaussian current signal
At 200 ns and sigma 50 ns

Rl = 100 k/mm
Cl = 0.2 pF/mm
Rb = 5M

Pulse properties are obtained for different hit positions.

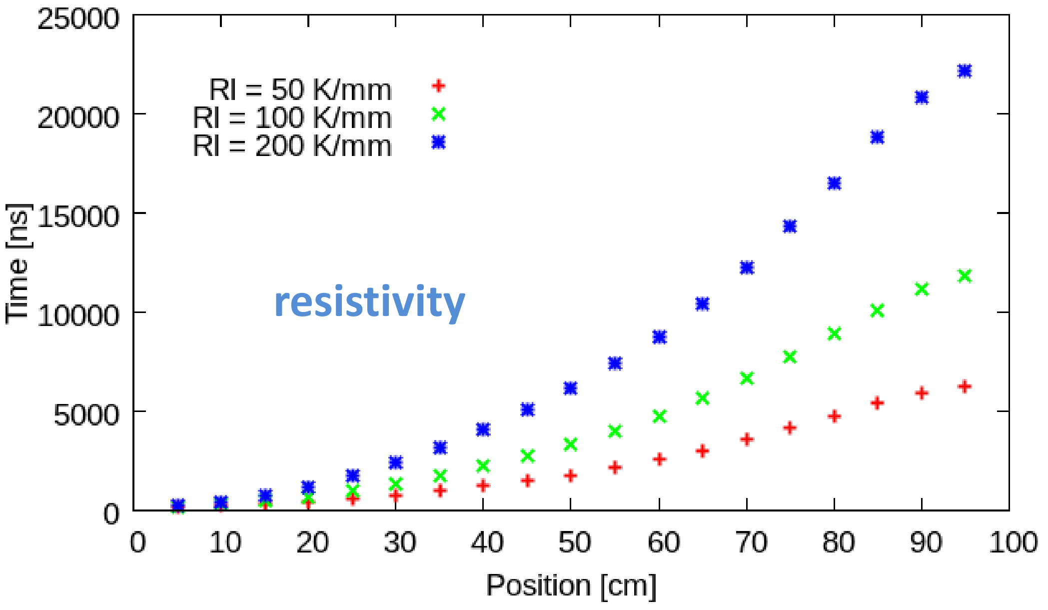


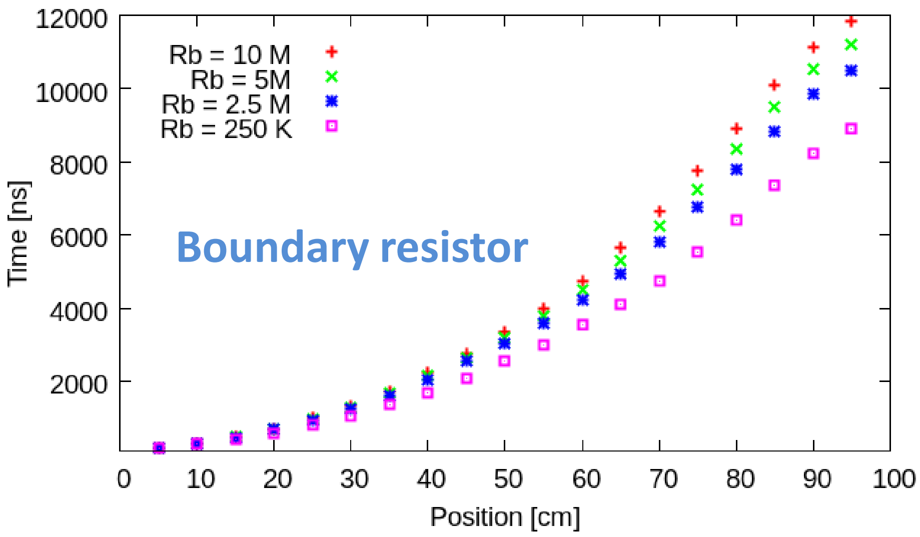


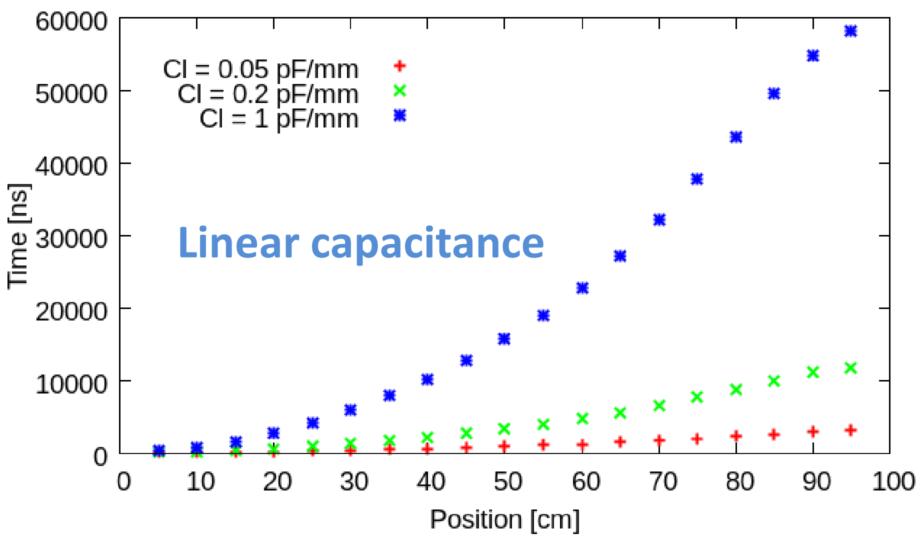
Typical signal times and amplitude

Cl = 0.2 pF/mm
Rb = 10 M

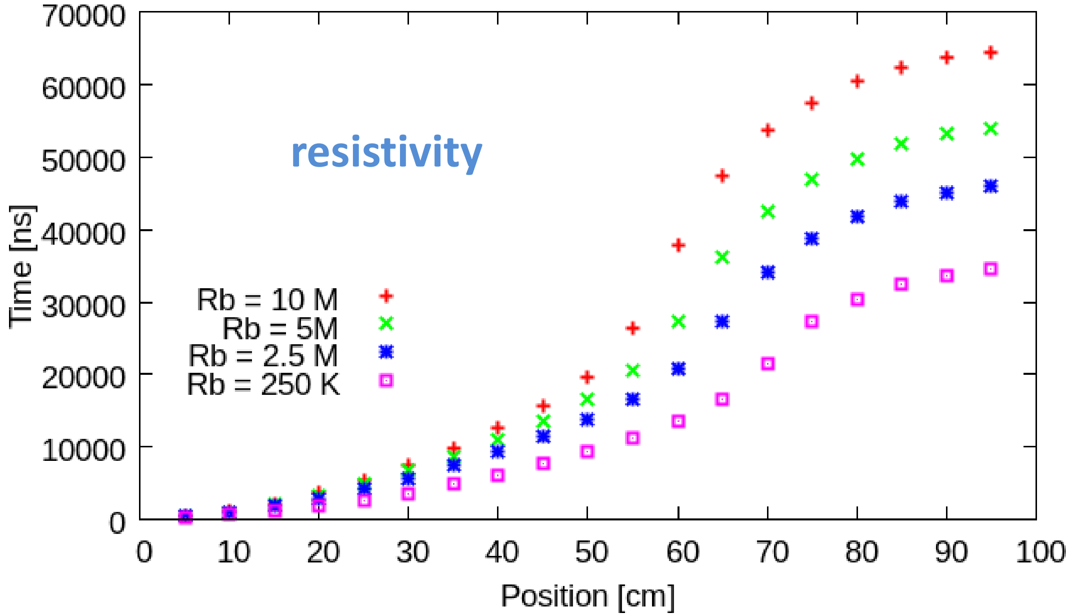
Risetime start delay for different resistivity and capacitance values.

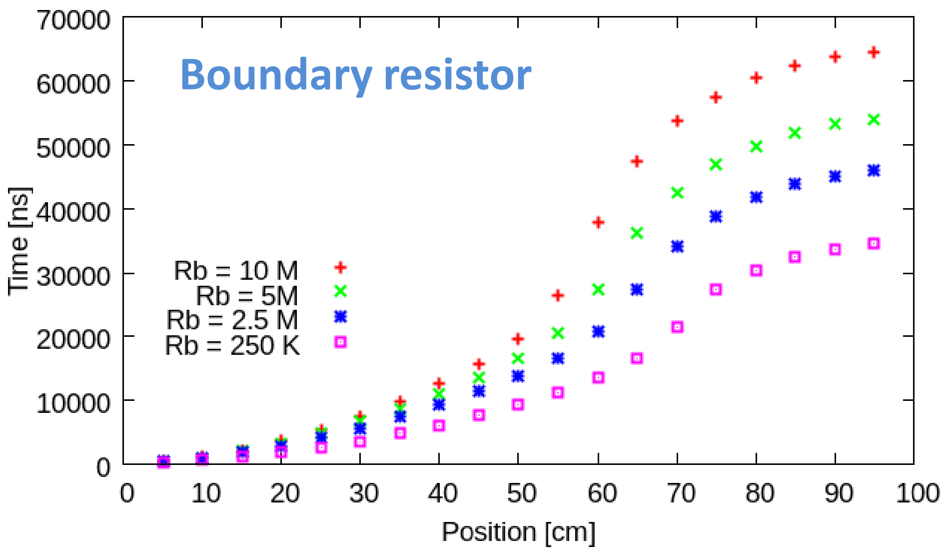


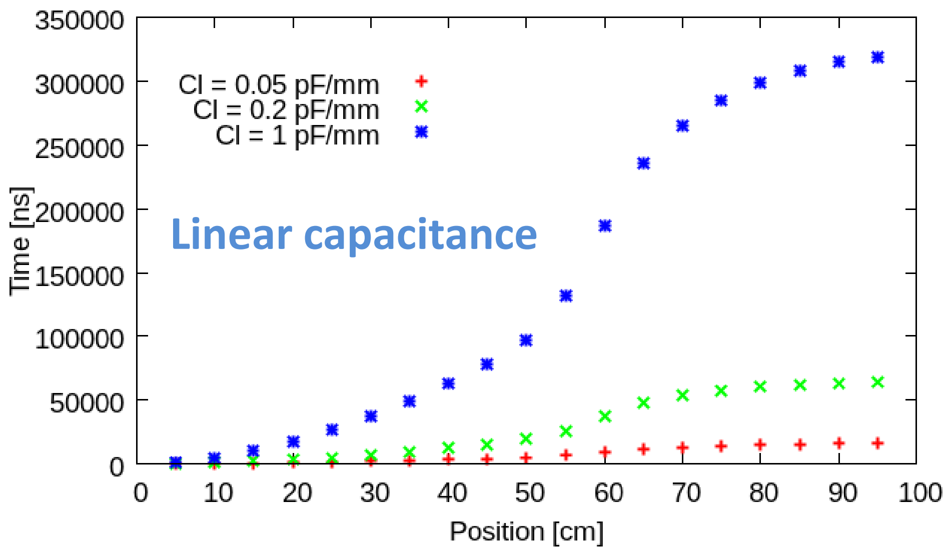




Maximum peak position delay for different parameter values







Summary and conclusions

A simple model allows us to learn about

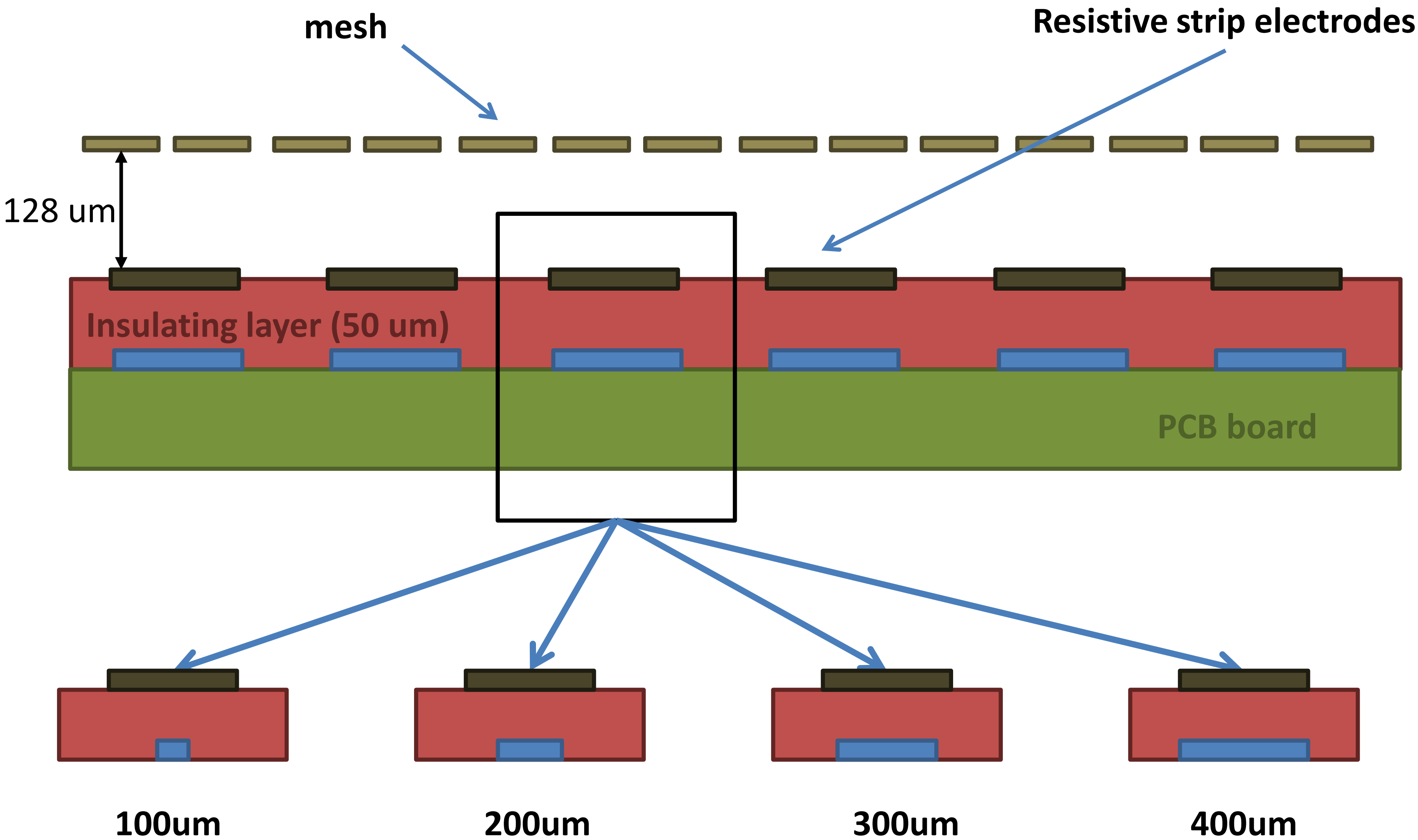
- read-out signal dependency (or not) with different parameters.
- Charge diffusion through the resistive strip, time required to evacuate charge, effect on detector **gain at different rates/currents**?
- Temporal signal properties (risetime, time delays, etc) for differennt positions could allow to increase our event position information .

Model has to be validated. Detector prototypes now under construction. Model could be extended to a more realistic detector (i.e. 2D read-out).

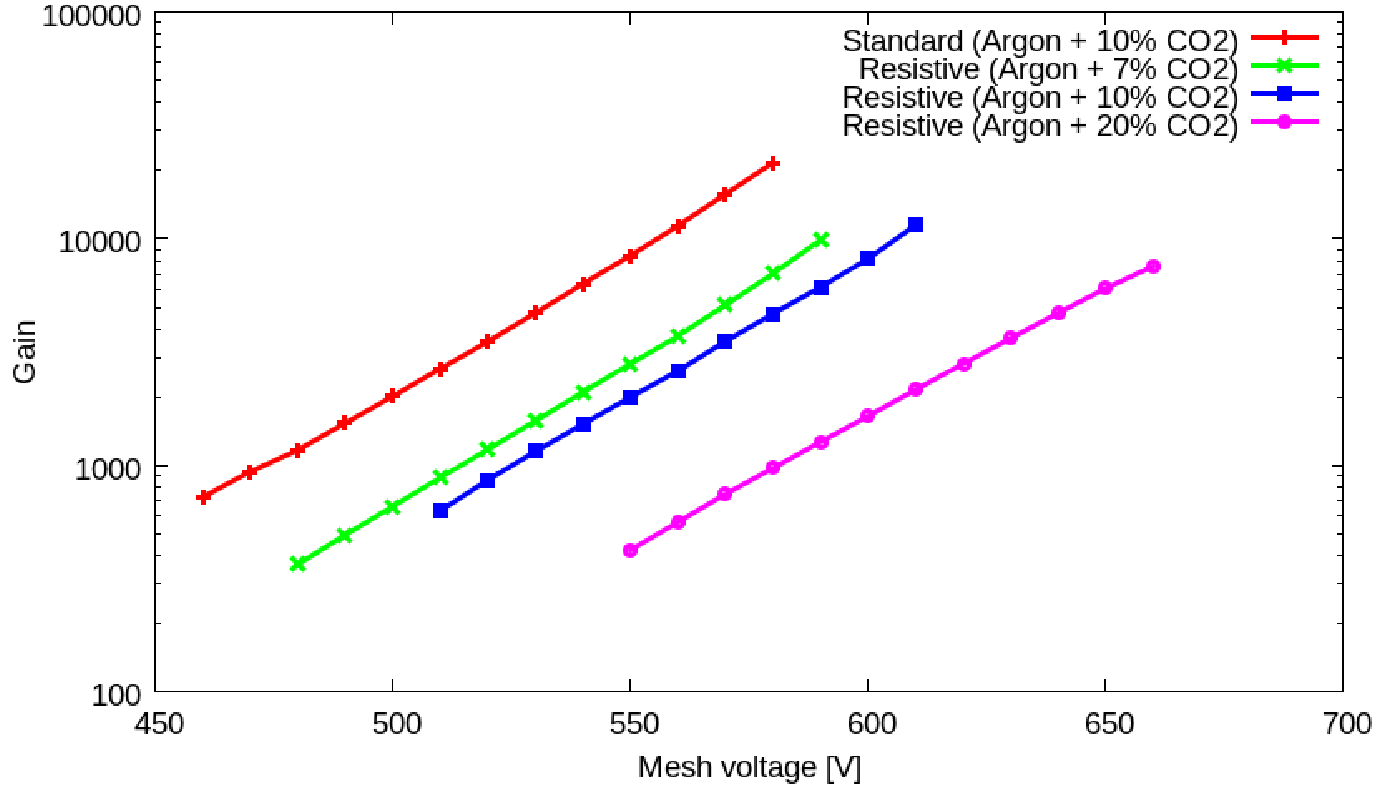
Backup slides

Prototype

<u>Resistive strips</u> width is kept constant (Constant resistivity).



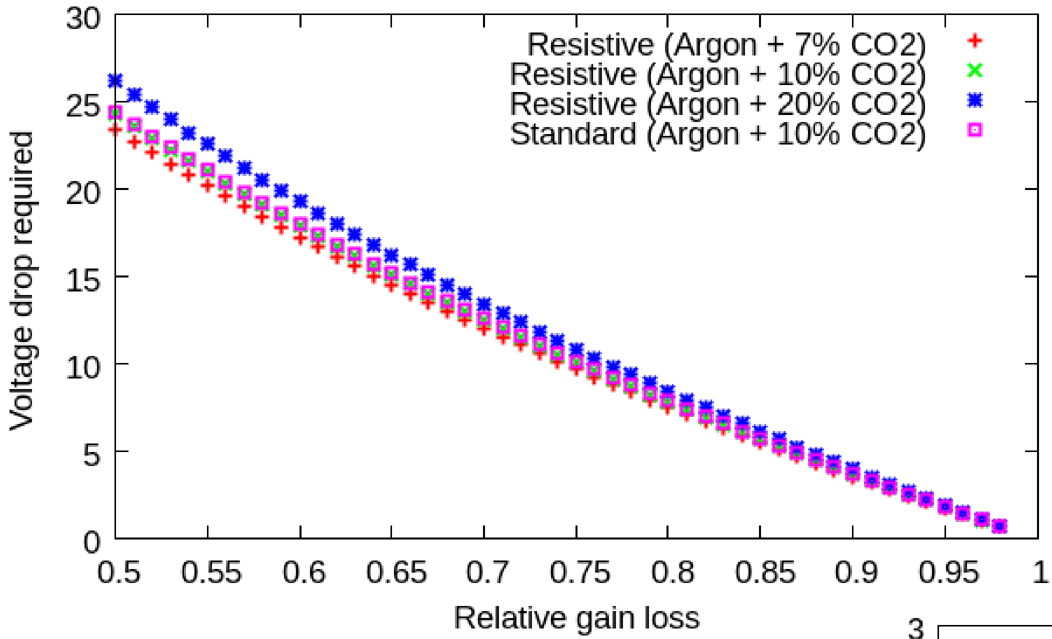
Gain curves for resistive strip detectors



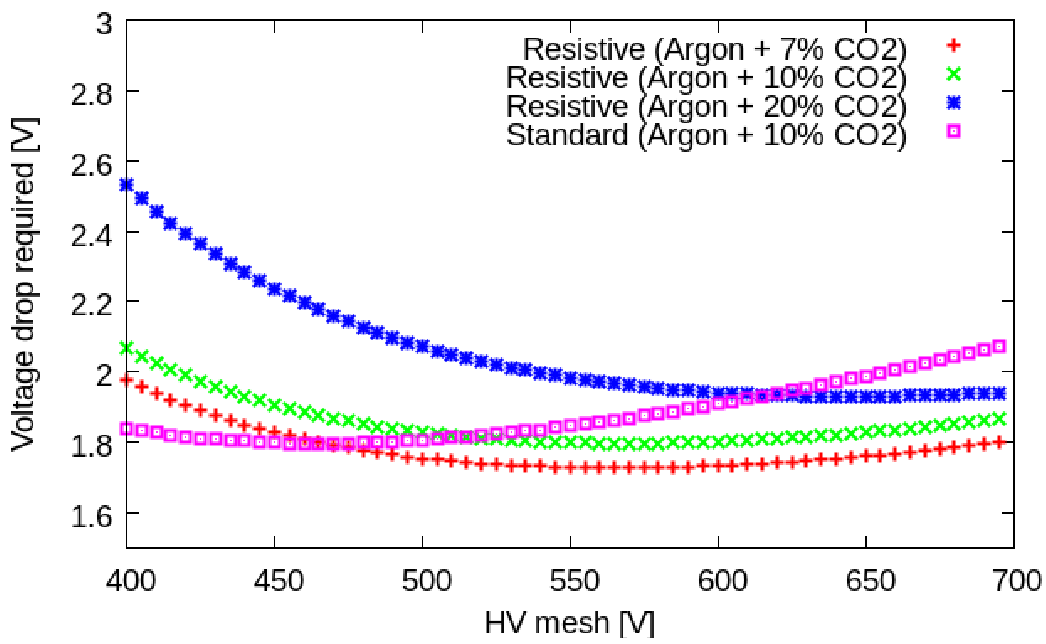
$$\log\left(\log\left(M\right)\right) = A - \frac{B}{V}$$

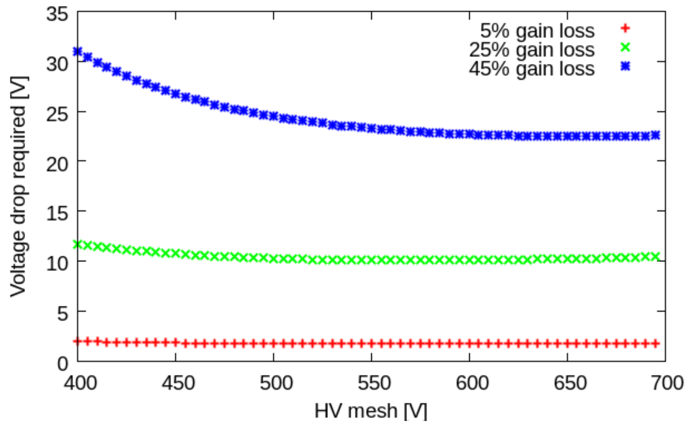
Technology	Gas Mixture	A	B
Standard	Argon + 10%CO2	3.88995 (0.65%)	927.598 (1.4%)
Resistive	Argon + 7%CO2	4.1251 (0.28%)	1128.05 (0.544%)
	Argon + 10%CO2	4.09194 (0.32%)	1135.18 (0.544%)
	Argon + 20%CO2	4.14518 (0.38%)	1287.48 (0.75%)

Voltage drop required for given gain loss



$$\Delta V = V_o \left\{ 1 - V_o \left[V_o \left[\frac{1}{B} \frac{\log(M)}{\log(\gamma M)} \right] + 1 \right]^{-1} \right\}$$



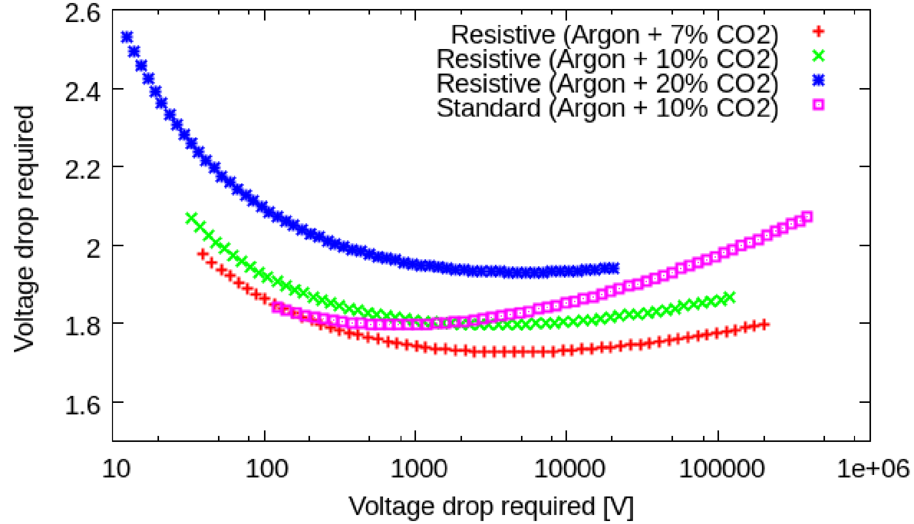


Resistive Argon + 10%CO2

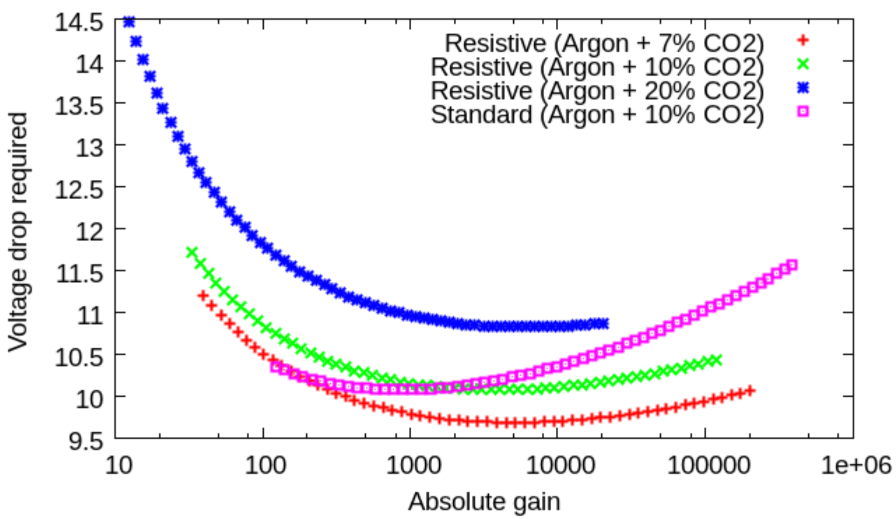
Nominal voltage 564.3V for 3000 gain

$$\Delta V = V_o \left\{ 1 - V_o \left[V_o \left[\frac{1}{B} \frac{\log(M)}{\log(\gamma M)} \right] + 1 \right]^{-1} \right\}$$

5% gain drop



25% gain drop



45% gain drop