Signal propagation and spark mitigation in resistive strips read-outs

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Outline

- **Gaseous detectors and simplified spark phenomena explanation. Study motivation**.

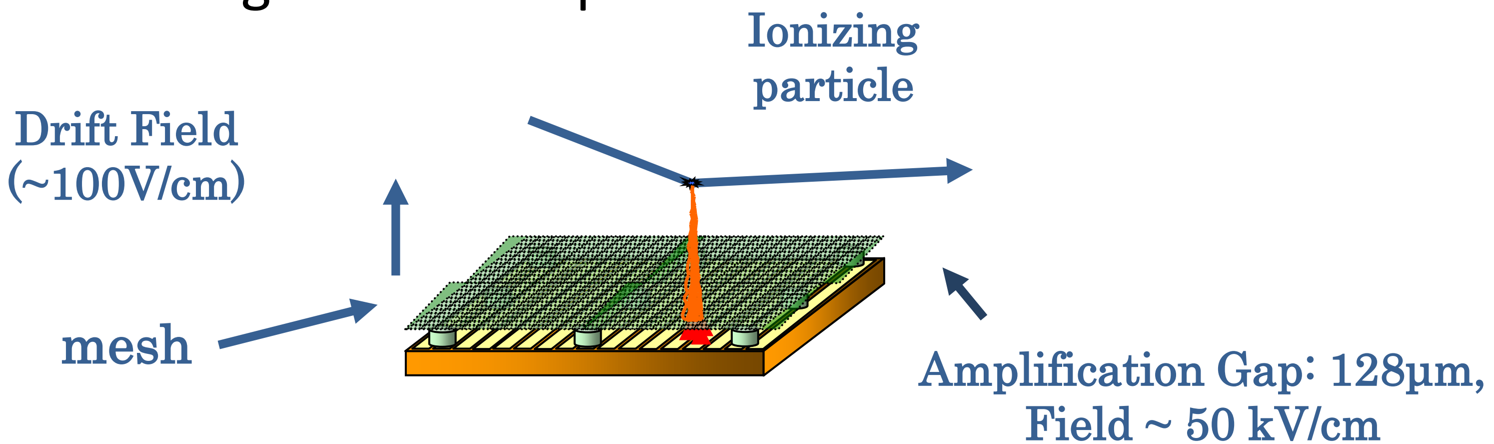
- Resistive strip model.

- Simulation results.

Micromegas detectors

Micromegas are gas based detectors.

Charges are produced at the drift volume (low intensity field) and driven to the amplification volume (high intensity field), where charges are multiplied.



Amplification field is obtained by using a mesh structure on top of insulating pillars of about 100 um height allowing to obtain gains of about 10^6.

Sparks and discharges in gaseous detectors

One of the main problems on gas based detectors comes from the appearance of sparks.

Sparks appear in the gaseous media when the charge density given by the Raether limit is reached, which is related with the probability to generate new secondary avalanches.

When the number of secondaries generated is higher than the number of primaries then the process is non-STOP.

The consequence is the discharge of the mesh and the drop of the voltage given by the power supply.

Three main disadvantages: gain limitation, deadtime increased due to the HV recovery time, detector reduced lifetime.

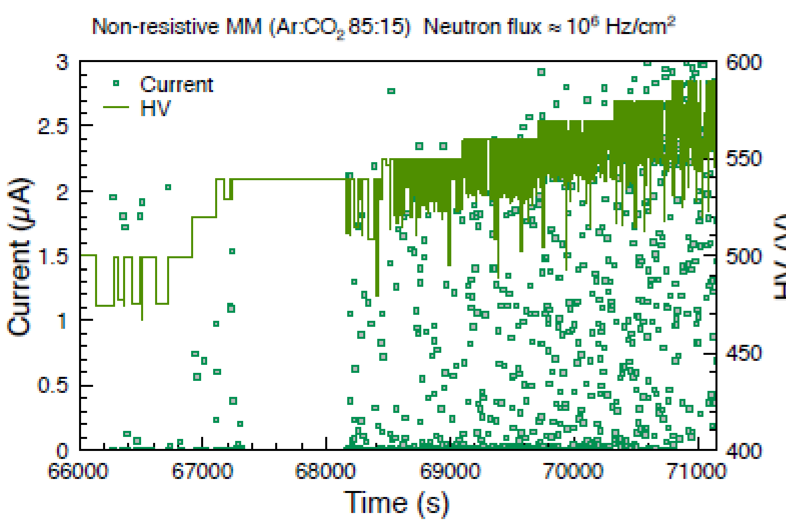
How sparks are quenched?

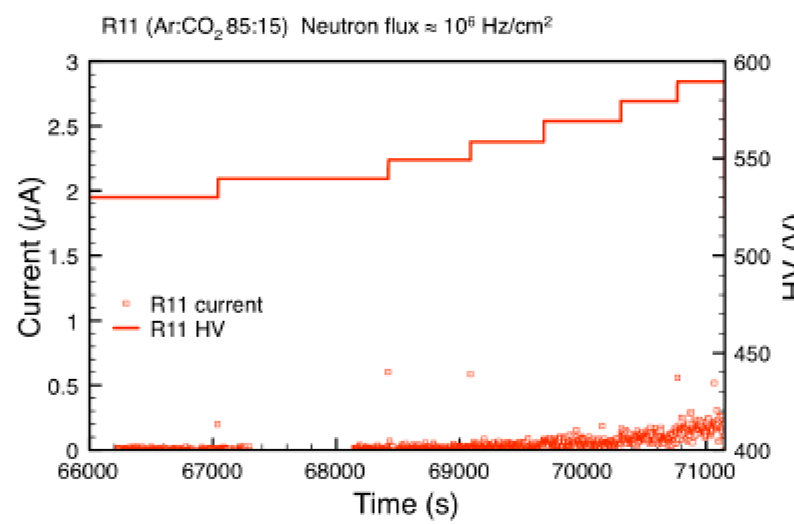
In order to reduce sparks resistive materials were introduced

<u>First spark-protected detectors made of Resistive Plate Chambers</u>

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

Recently this technique was also applied to Micromegas detectors by testing different resistive foils and strips topologies and proving good protection against sparks (development carried out within MAMMA collaboration for ATLAS muon chambers upgrades).

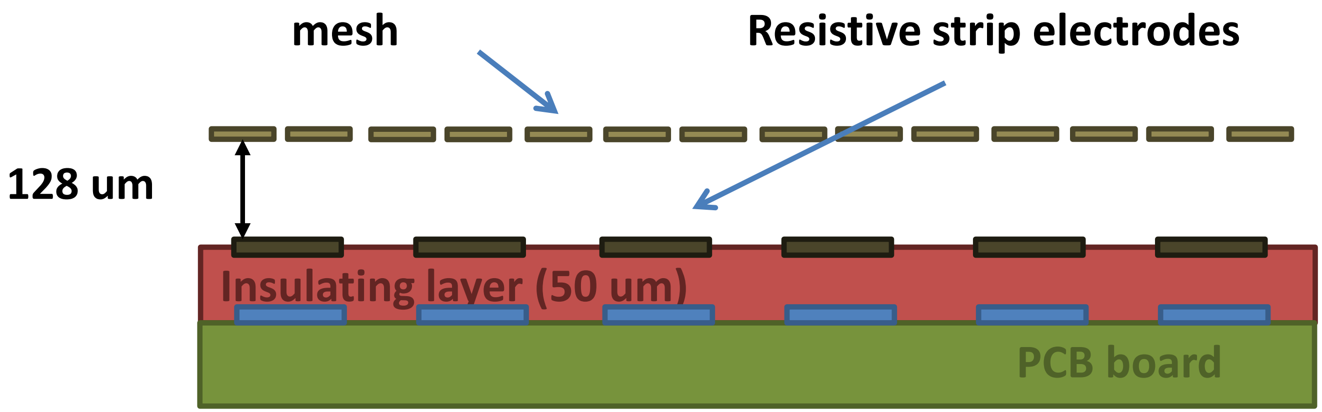




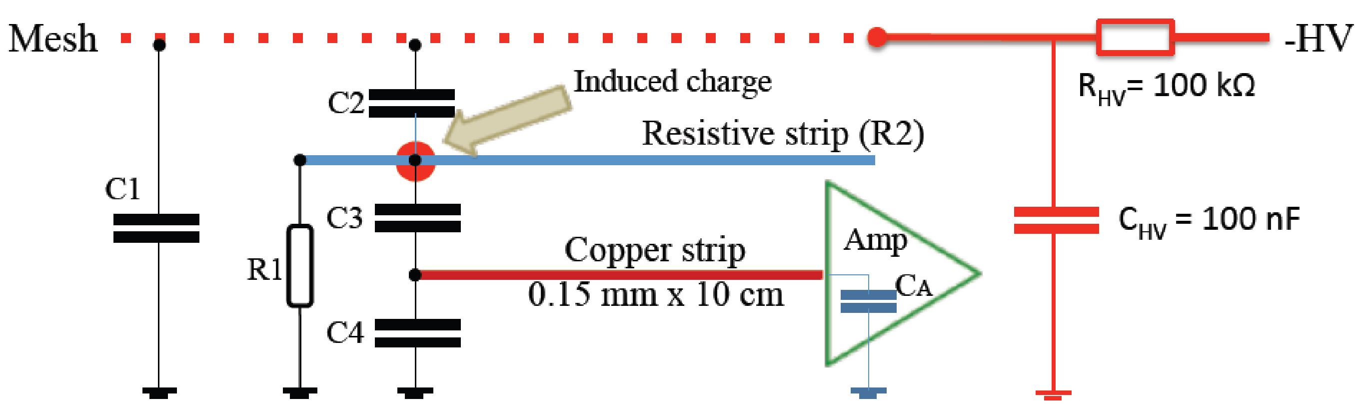
A spark-resistant bulk-micromegas chamber for high-rate aplications,
J. Wotschack, NIM A 640 (2011) 110-118

Resistive Micromegas and studies motivation

One of the topologies that better performance presented was the following



The same publication gives the equivalent electronic modeling



Work motivation

The present work is motivated by the better understanding of the resistive structure on the role of spark quenching and detector optimization, and effect of the resistive on the read-out signal.

<u>The work I will present</u> is inspired on the previous work of Dixit, where he obtains an analytical approach to the charge dispersion on a bi-dimensional resistive foil.

Simulating the charge dispersion phenomena in Micro Pattern Gas Detectors with a resistive anode, M.S. Dixit NIM A 566 (2006) 281-285

The main idea is to study the charge dispersion in the new topology given by the resistive strip read-out.

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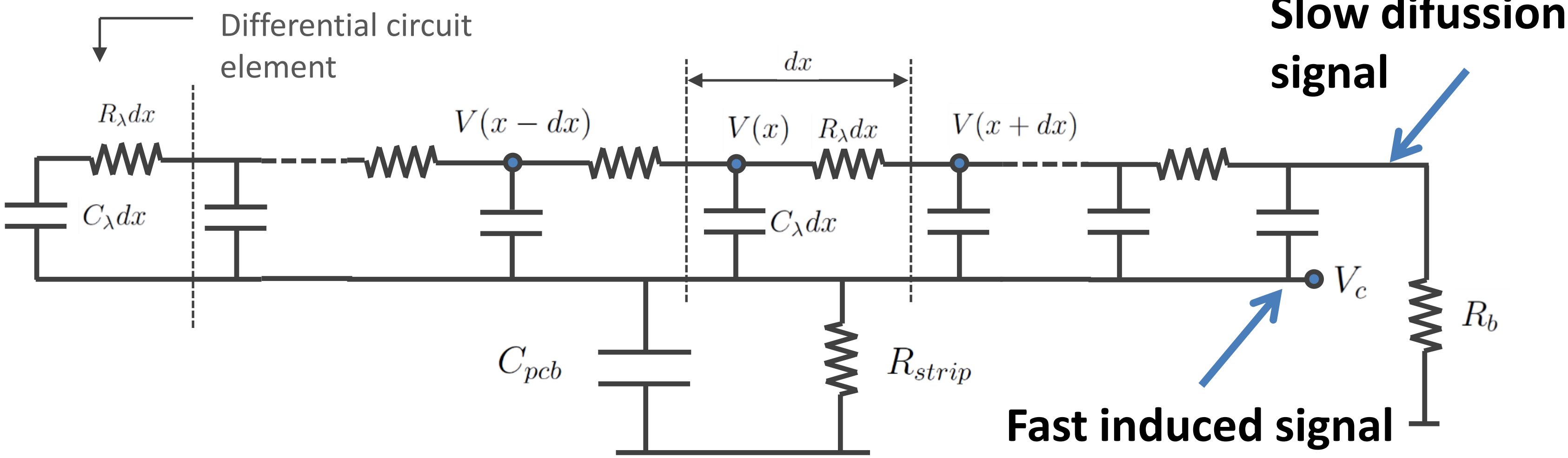
- Gaseous detectors and simplified spark phenomena explanation. Study motivation.
- **Resistive strip model.**
- Simulation results.

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

These equation are solved by spatial discretization (standard and very well known method)

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

Which leads to a set of coupled differential equations

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

Which after some transformations allow to solve a set of N undependent equations.

Diagonal matrix

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

Transformed potential

Code implementation

A particular solution to this problem could have been obtained with a circuit package solver, i.e. spice engine.
Few advantages on producing your own simulation 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.**
- **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.**

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- Gaseous detectors and simplified spark phenomena explanation. Study motivation.
- Resistive strip model.
- **Simulation results and prototypes for testing.**

Different simulation set-ups

Simulations at different boundary resistors values.

R_b = 250K, 2.5M, 5M, 10M

R_λ = 100k/mm C_λ = 0.2pF/mm

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

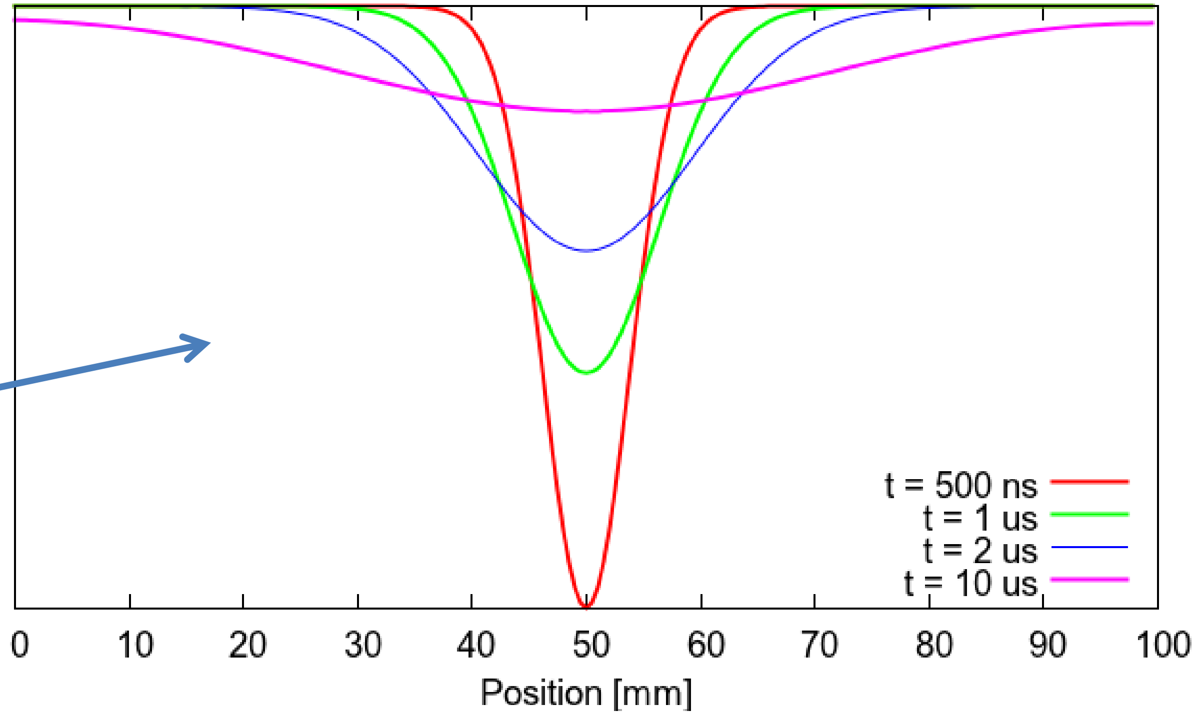
C_λ = 0.2pF/mm R_λ = 100 k/mm R_b = 5M

Cluster size simulations 100 um

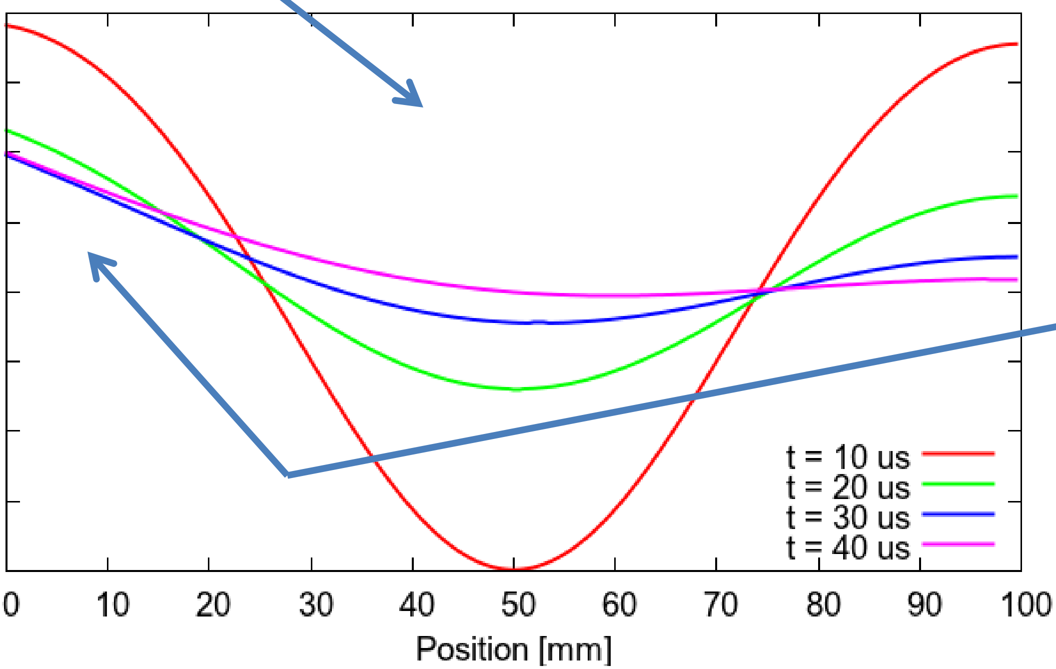
Contrary to fake intuition signal is not dependent **on transversal difussion**

Temporal charge evolution along the resisitive strip

First time steps



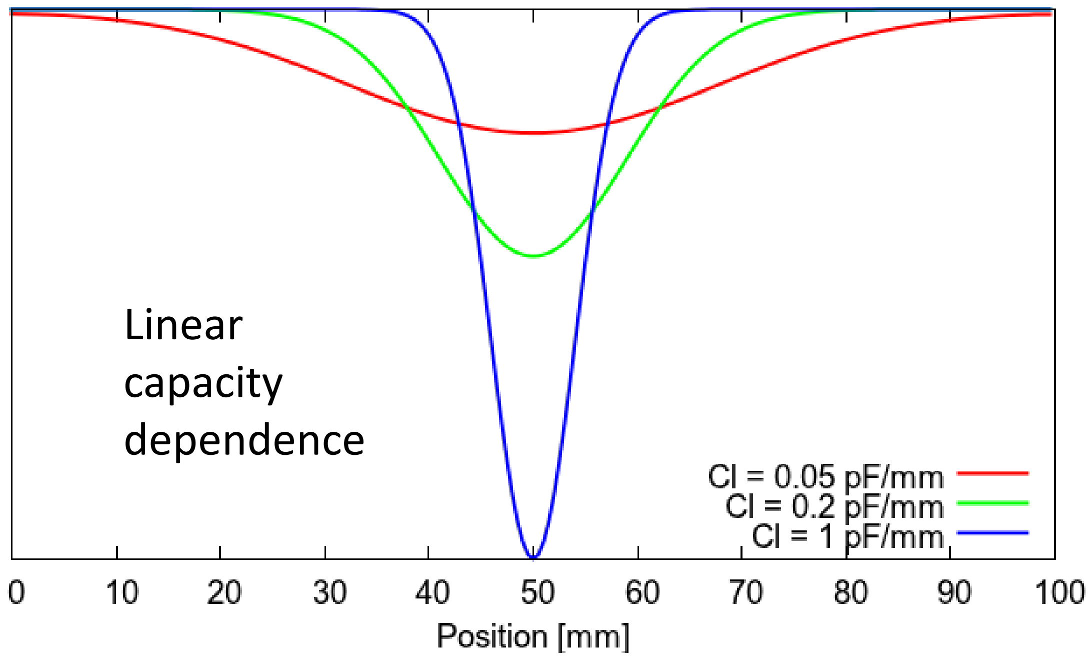
Last time steps

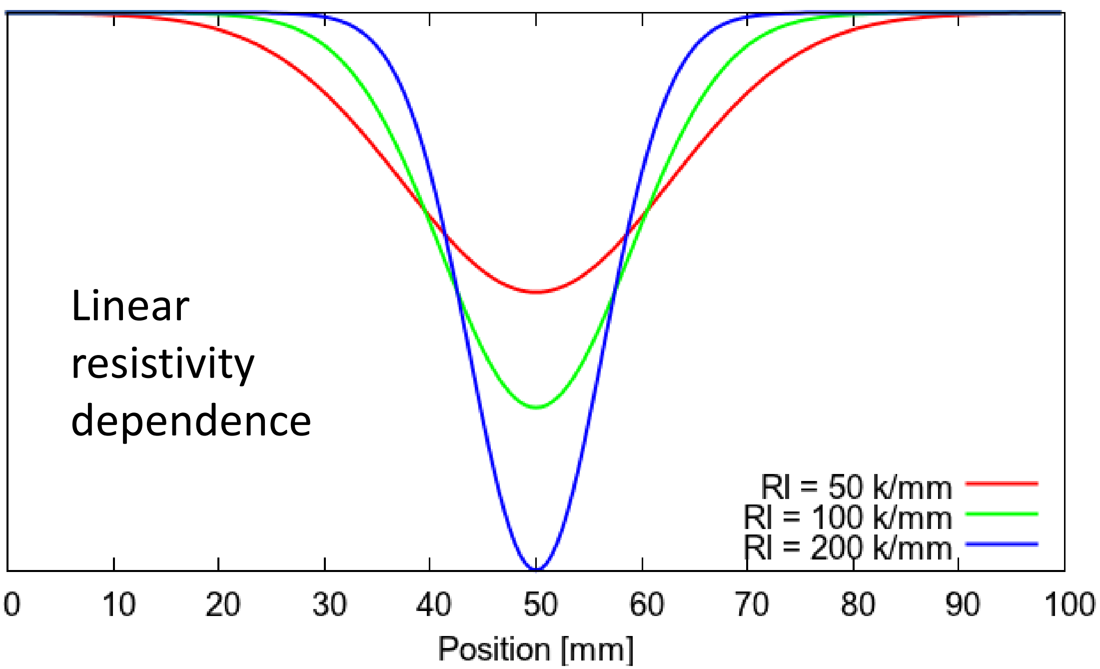


Charges drifting to ground

Charge diffusion at different resistivities and capacitances

After 1 us difussion





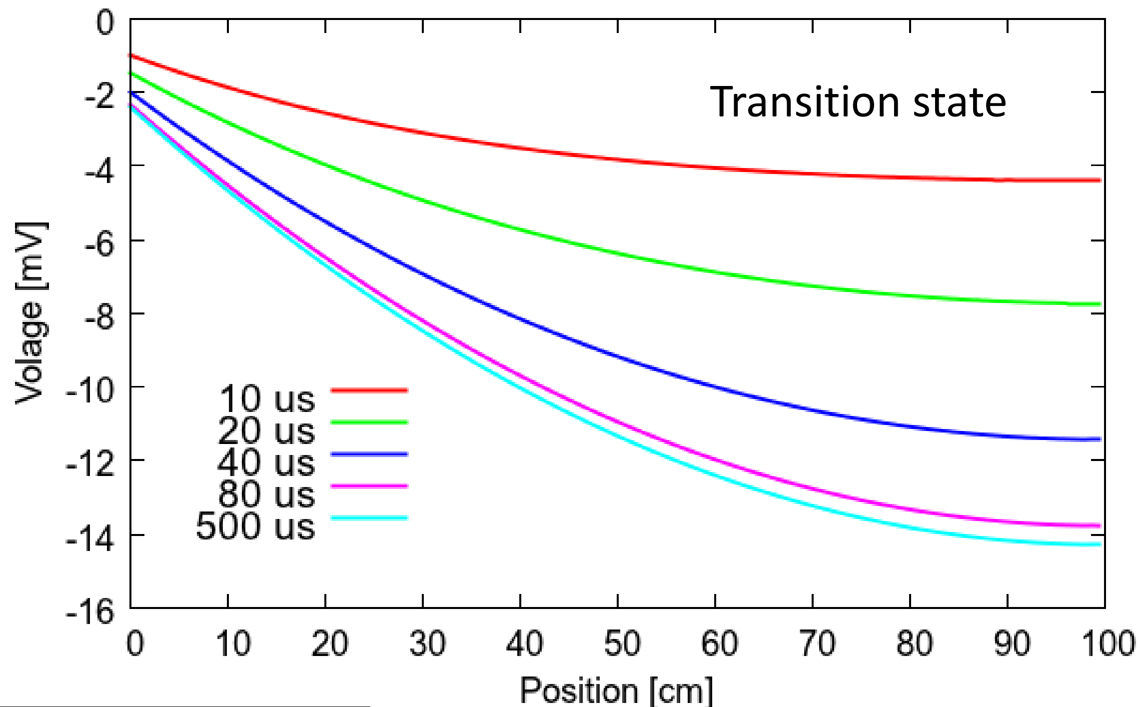
Higher capacitance and higher resistivity -> lower charge difussion

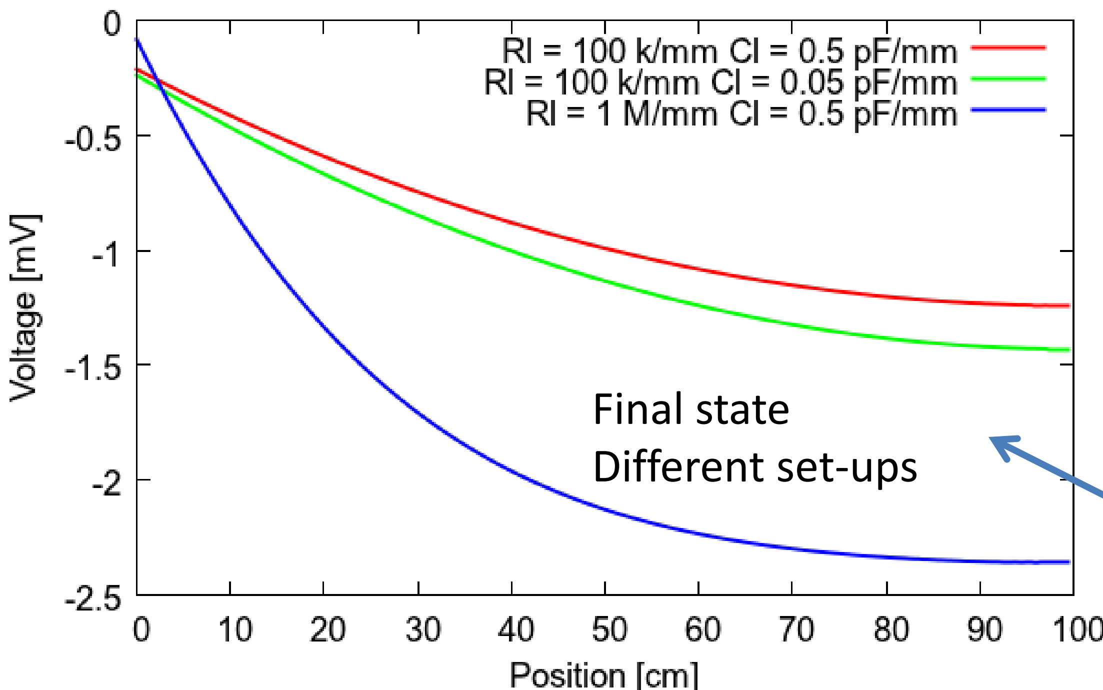
Simulating homogeneous charge current deposition

Rate = 100 kHz

Gain = 10000

Primary electrons = 300

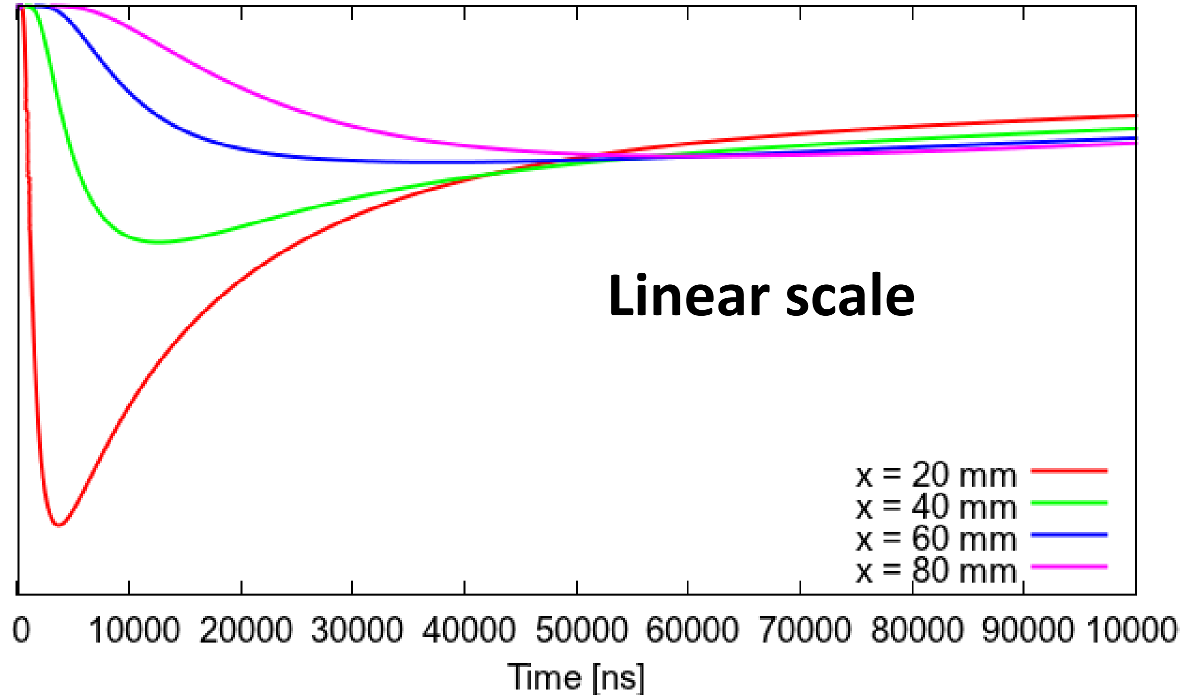


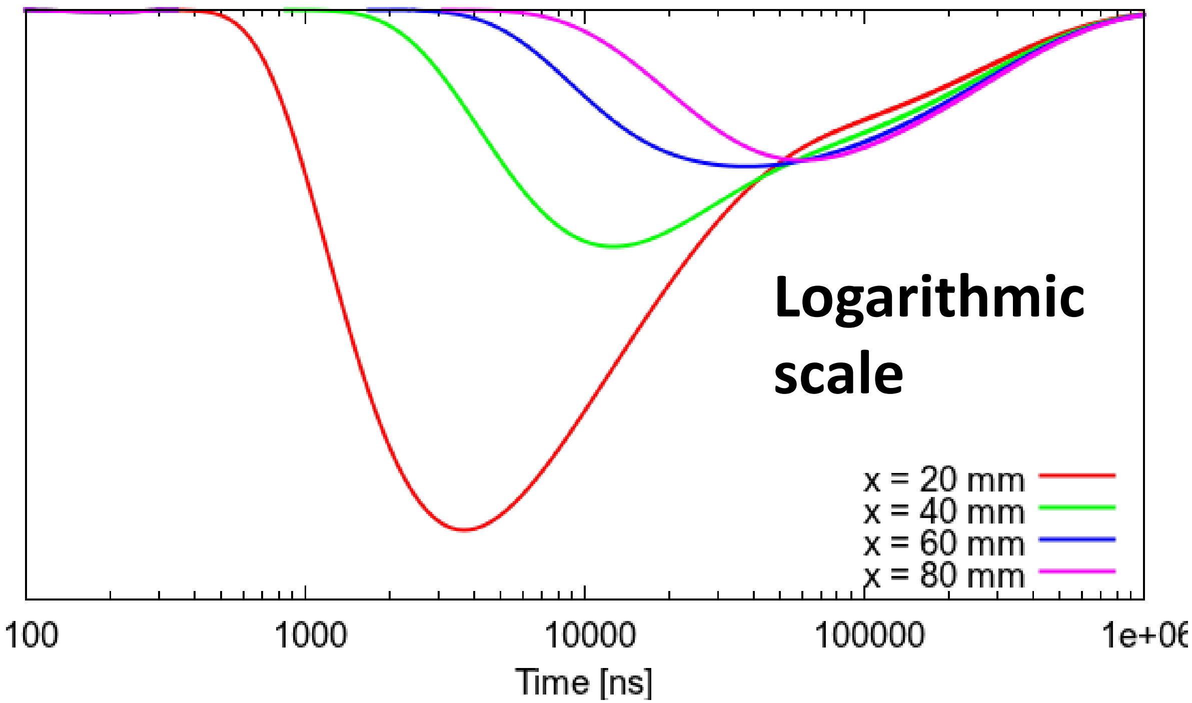


At the non-grounded strip end the tension reached is proportional to the rate.

Relation with resistivity and capacitance at the final state.

Current at the boundary resistor due to different event positions

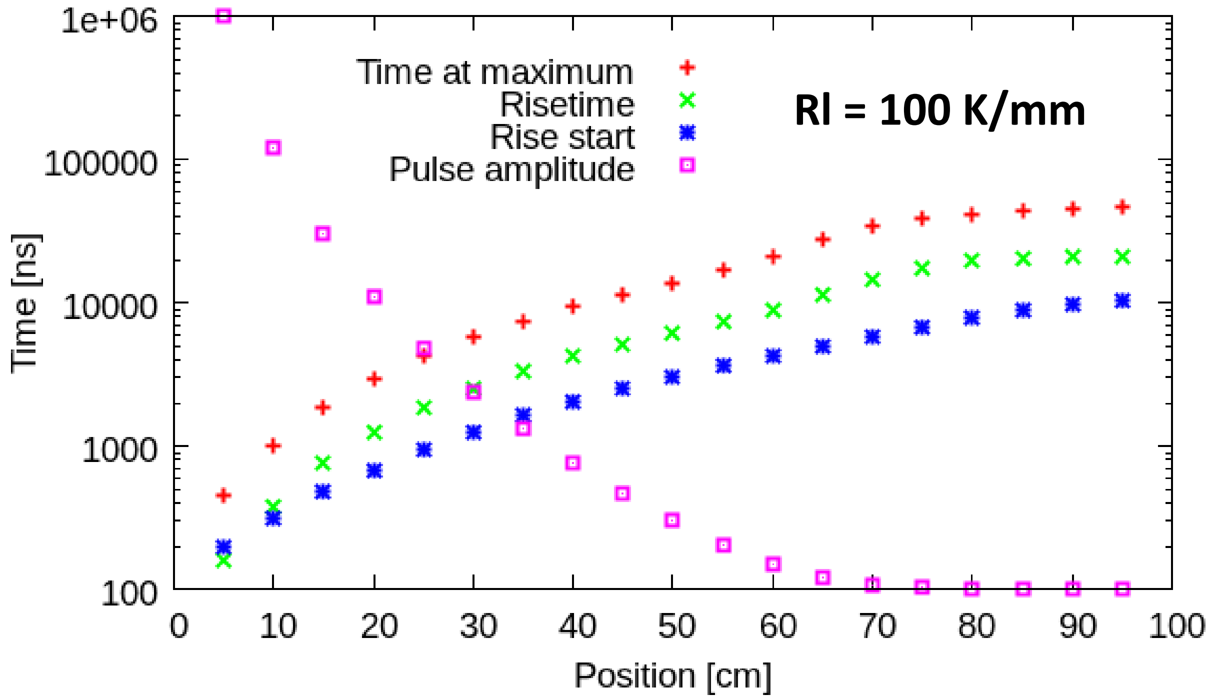


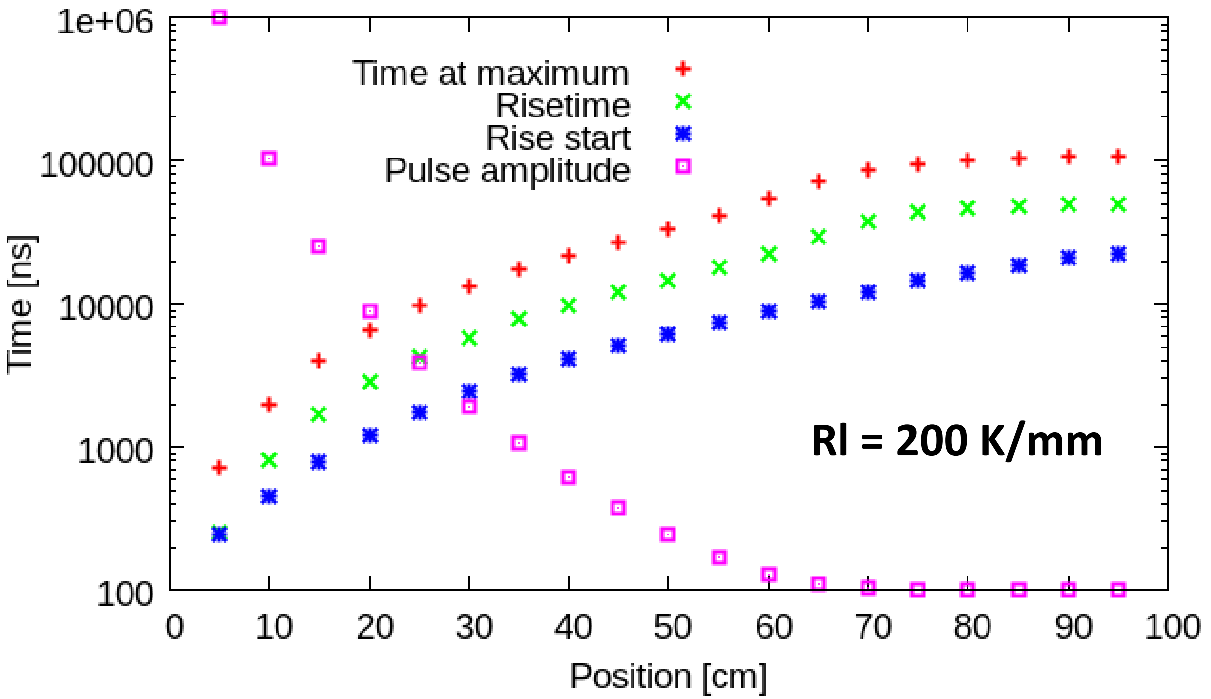


Gaussian current signal
At 200 ns and sigma 50 ns

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

Pulse properties are obtained for different hit positions.

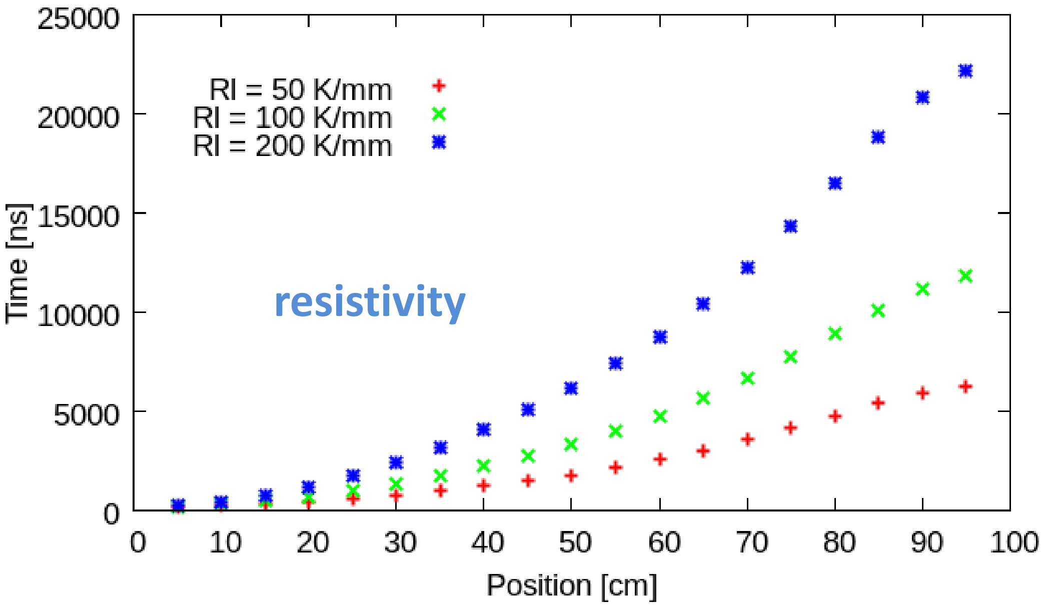


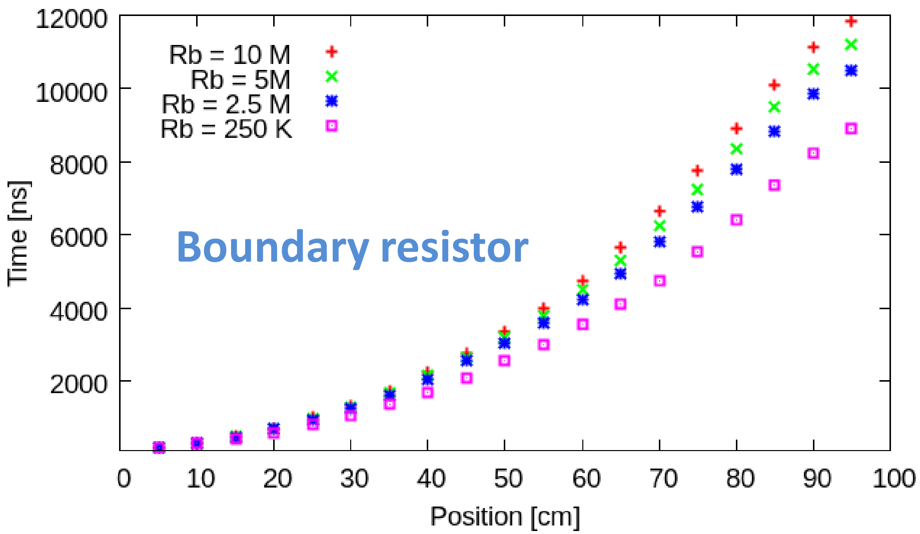


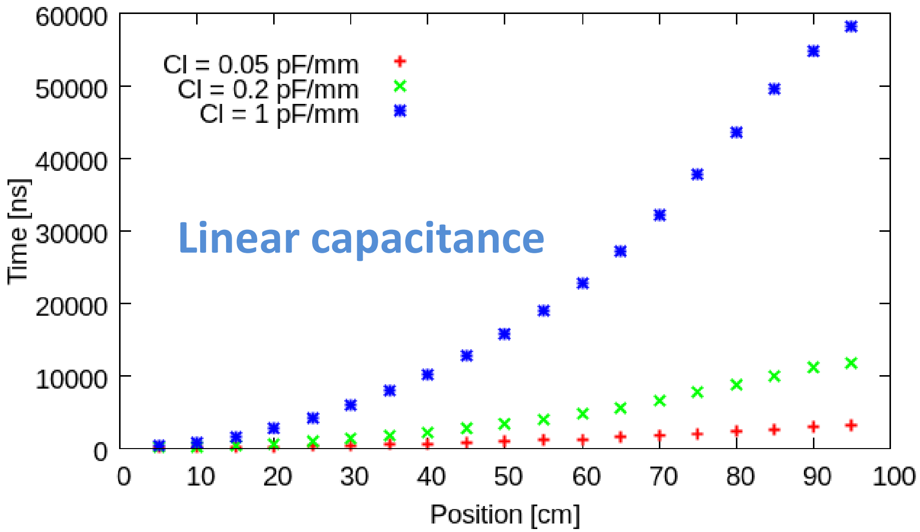
Typical signal times and amplitude

Cl = 0.2 pF/mm
Rb = 10 M

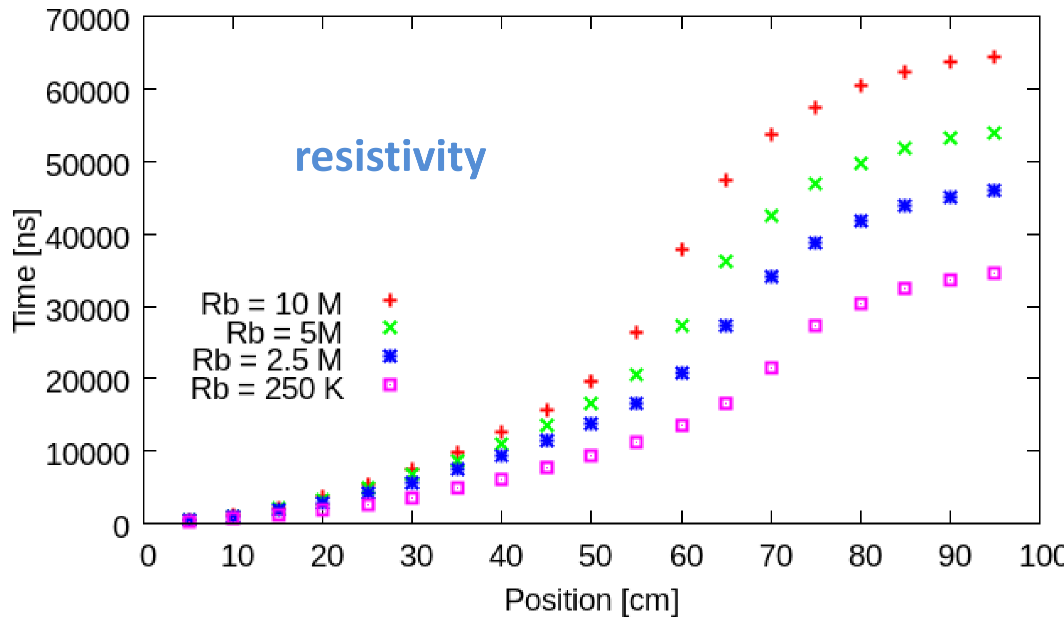
Risetime start delay for different resistivity and capacitance values.

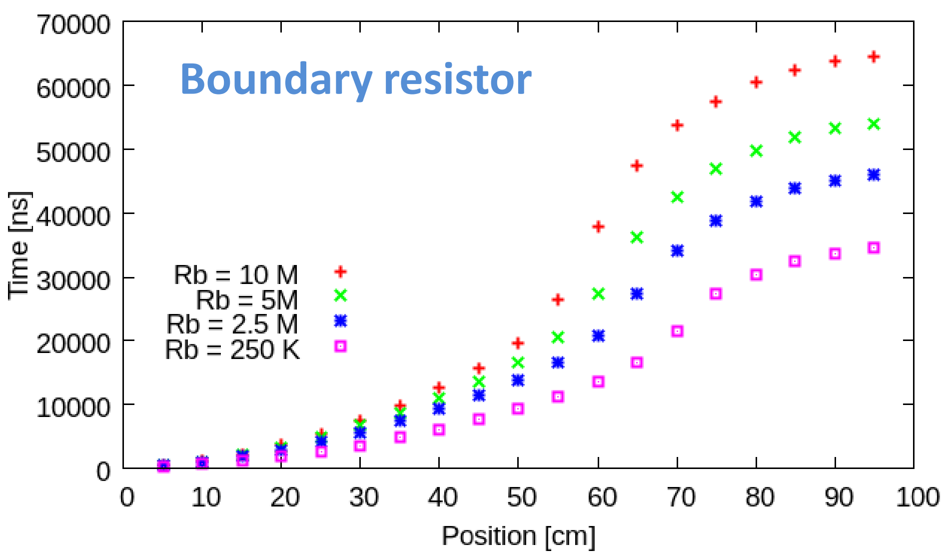


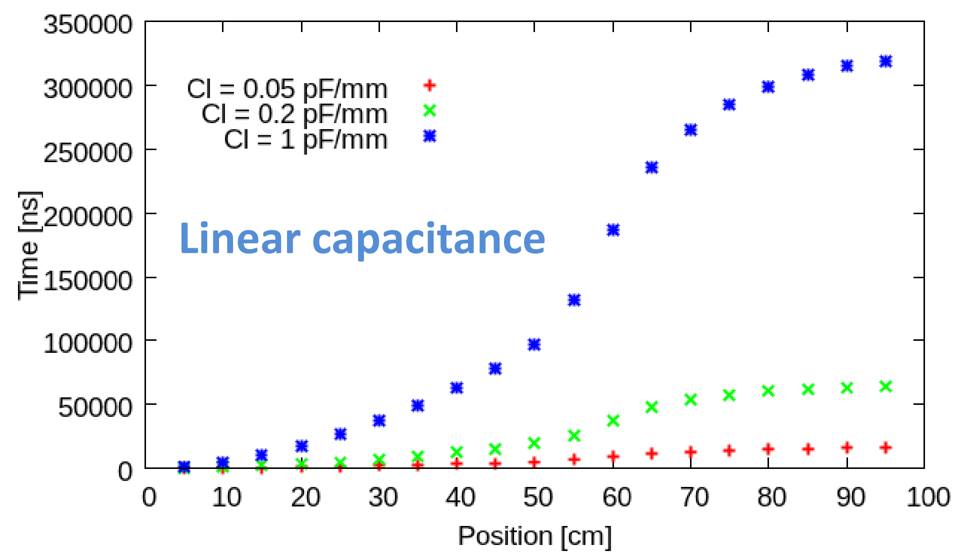




Maximum peak position delay for different parameter values



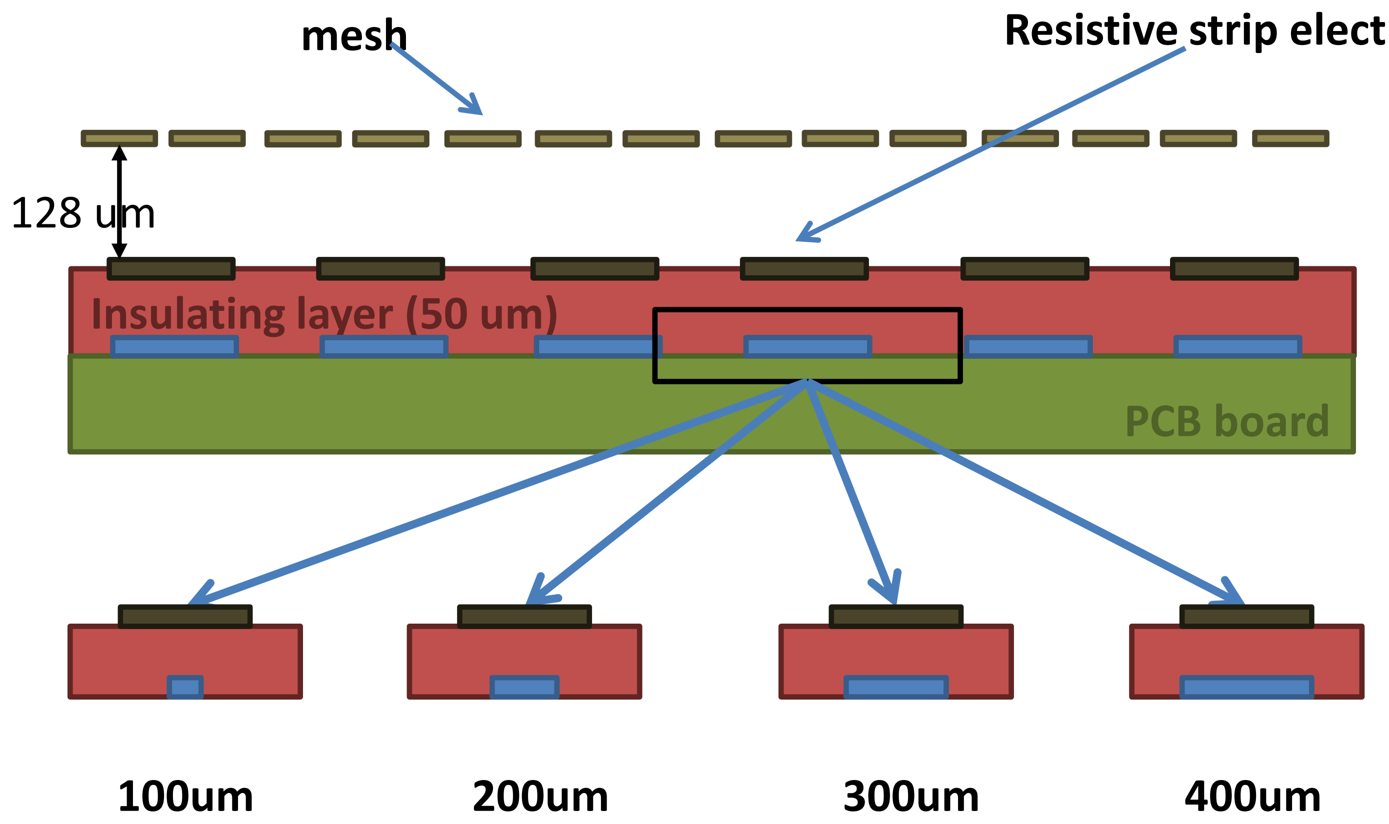




Resistive prototypes underconstruction

3 different prototypes are now under-production at CERN Micromegas Workshop, that include access to the resistive strip read-out.

These detectors include different strips widths and resistivities in order to test different strip resistivities, capacitances and boundary resistors values.



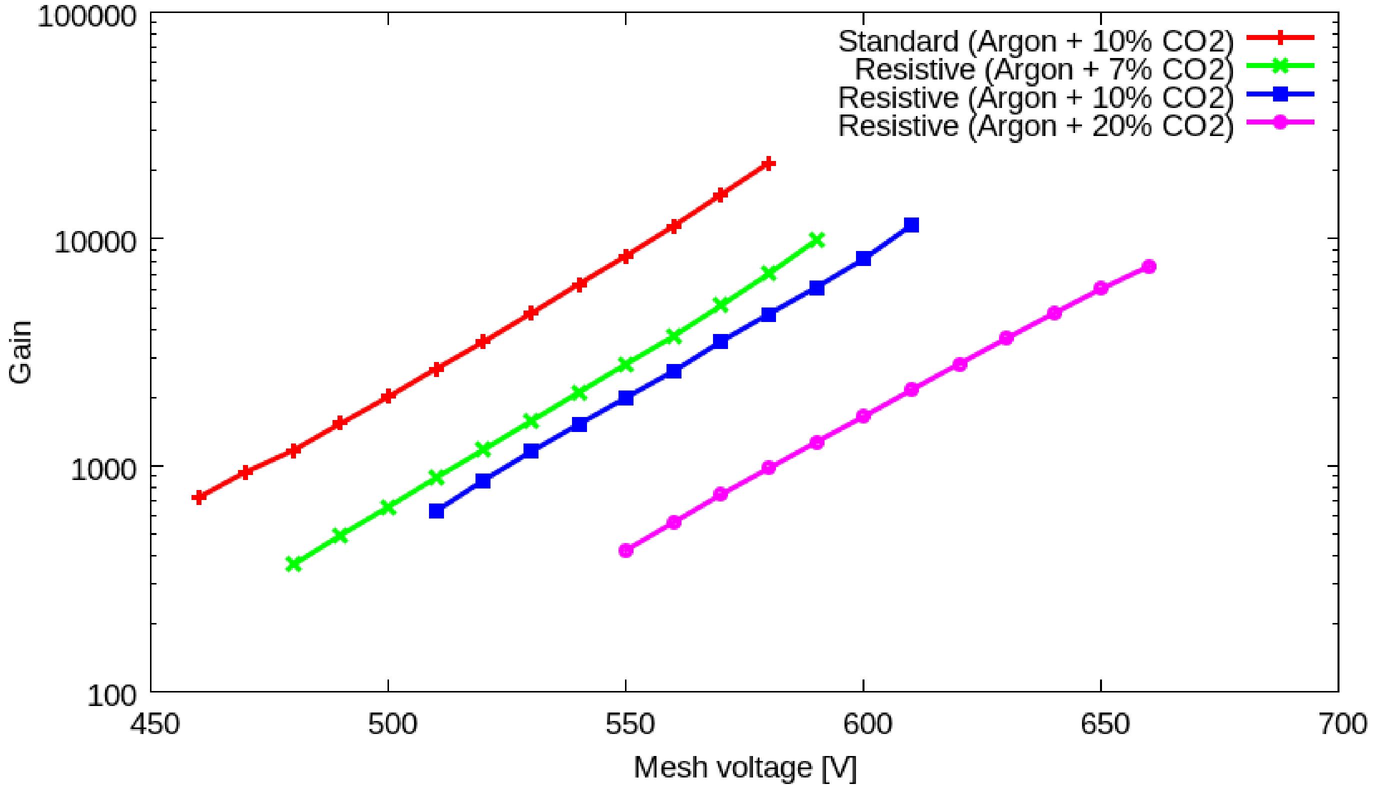
Conclusions

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 different positions could allow to increase our event position information for these kind of spark-protected detectors.

Backup slides

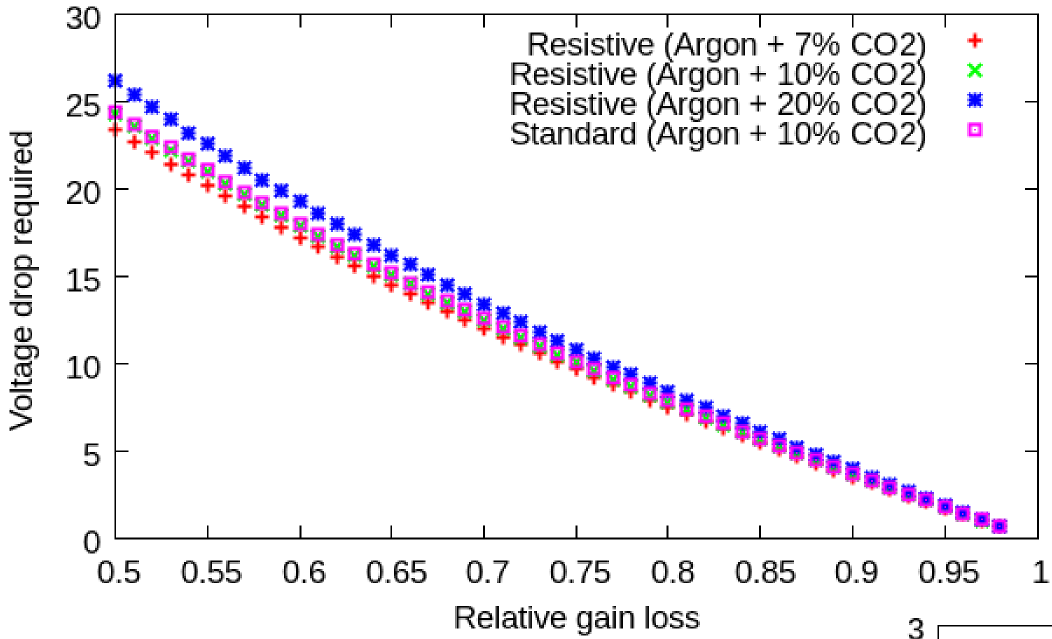
Gain curves for resistive strip detectors



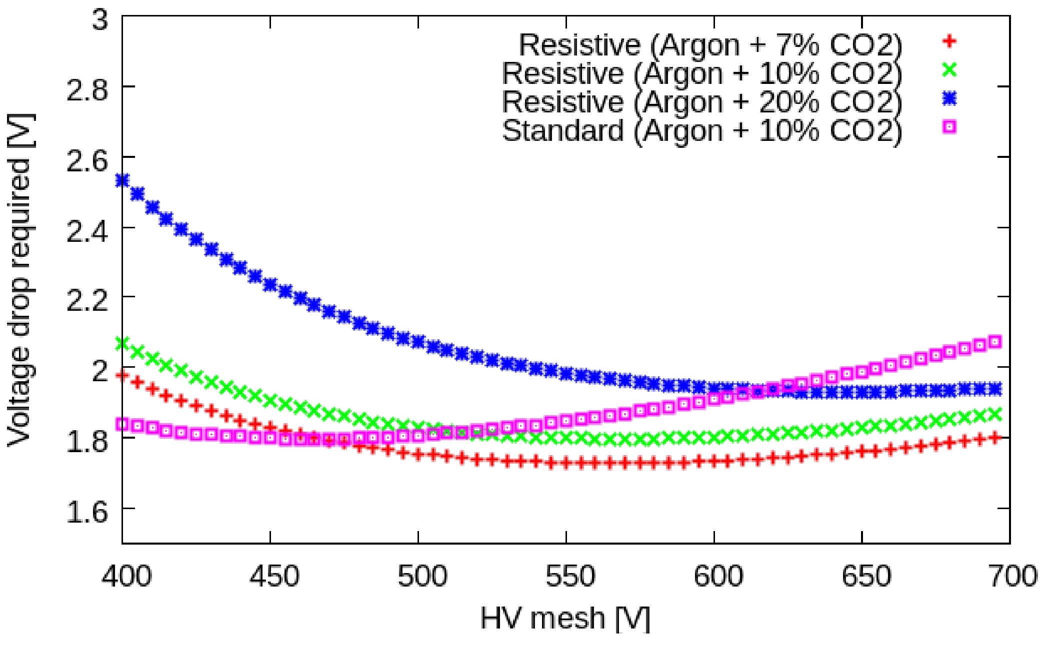
$$\log\left(\log\left(M\right)\right) = A - \frac{B}{V}$$

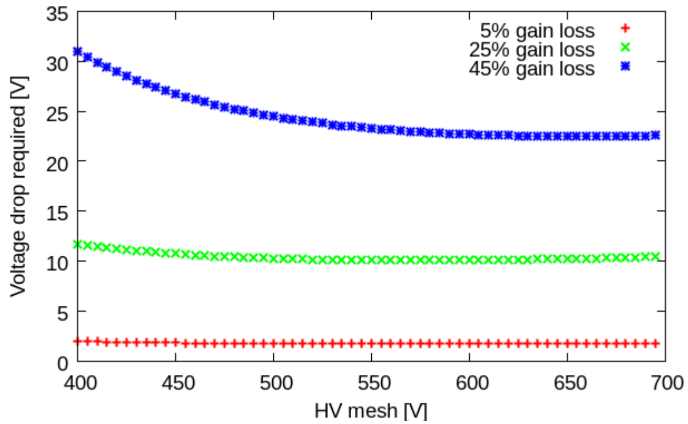
Technology	Gas Mixture	A	B
Standard	Argon + 10%CO2	3.88995 (0.65%)	927.598 (1.4%)
Resistive	Argon + 7%CO2	4.1251 (0.28%)	1128.05 (0.544%)
	Argon + 10%CO2	4.09194 (0.32%)	1135.18 (0.544%)
	Argon + 20%CO2	4.14518 (0.38%)	1287.48 (0.75%)

Voltage drop required for given gain loss



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



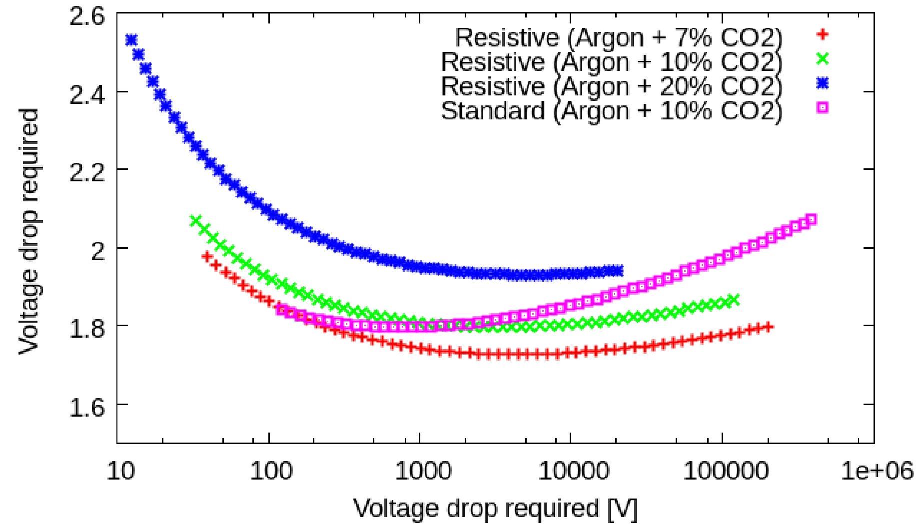


Resistive Argon + 10%CO2

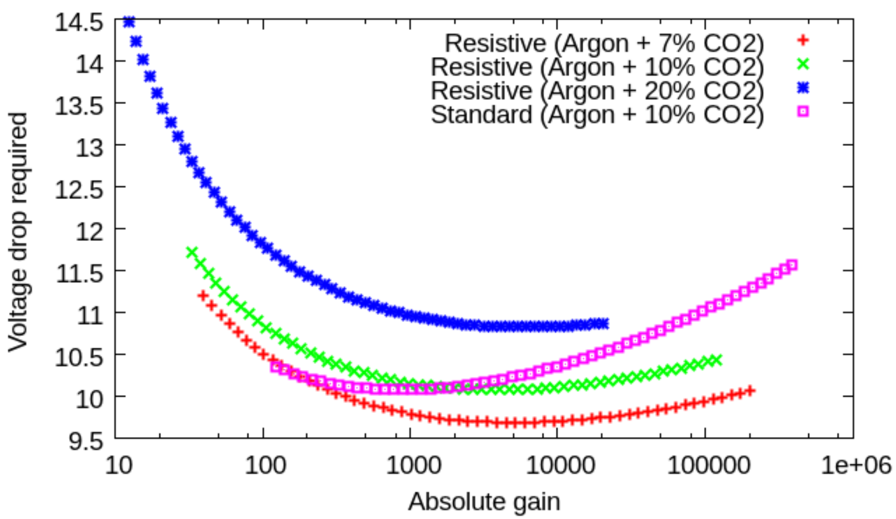
Nominal voltage 564.3V for 3000 gain

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

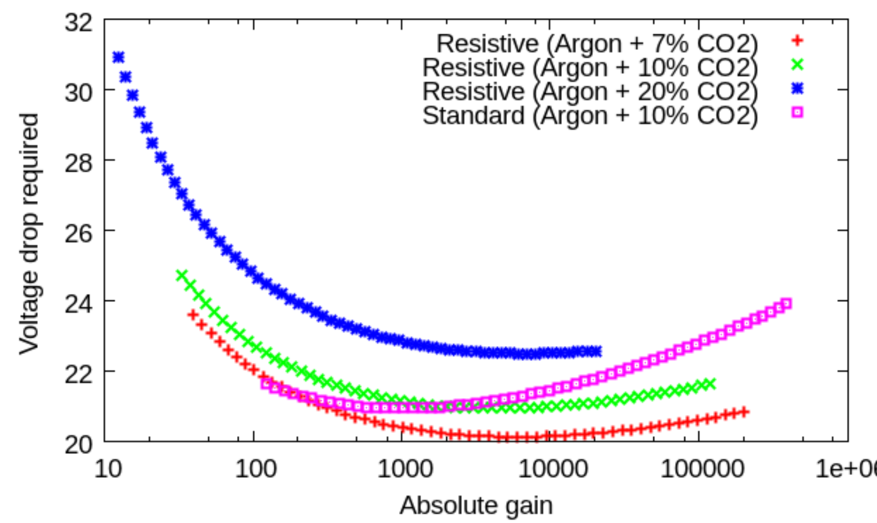
5% gain drop



25% gain drop



45% gain drop



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?

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

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.

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.

Semi-analytical solution

Diagonal matrix

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

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.