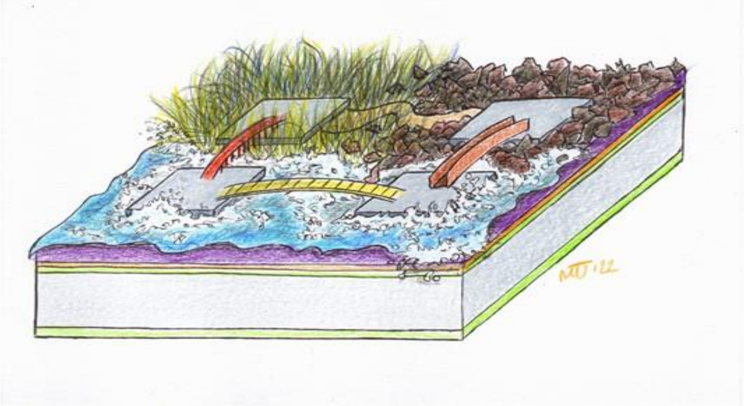
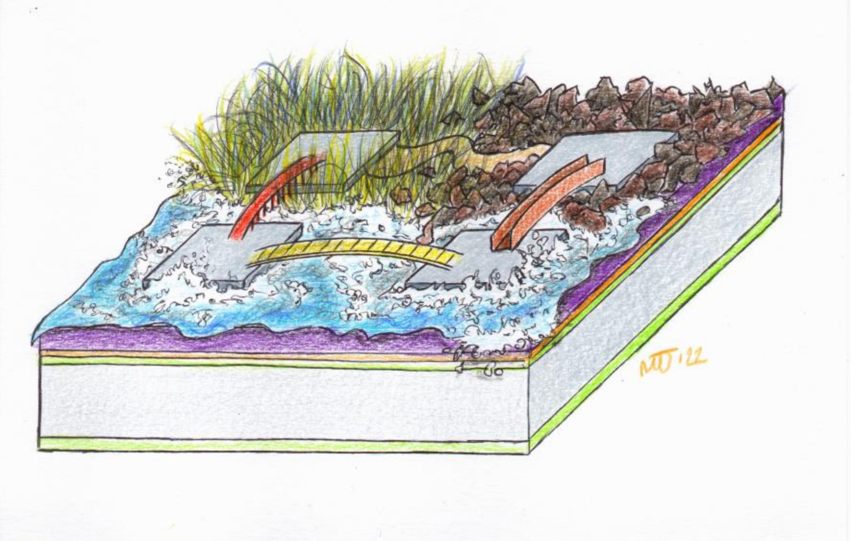


DC-coupled resistive silicon detectors for 4-D tracking

17TH "TRENTO" WORKSHOP ON ADVANCED SILICON RADIATION DETECTORS

L. Menzio, R. Arcidiacono, G. Borghi, M. Boscardin, N. Cartiglia, M. Centis Vignali, F. Ficorella, O. Hammad Ali, G. Gioachin, M. Mandurrino, M. Ferrero, R. Mulargia, T. Croci, G. Paternoster, F. Siviero, V. Sola, M. Tornago



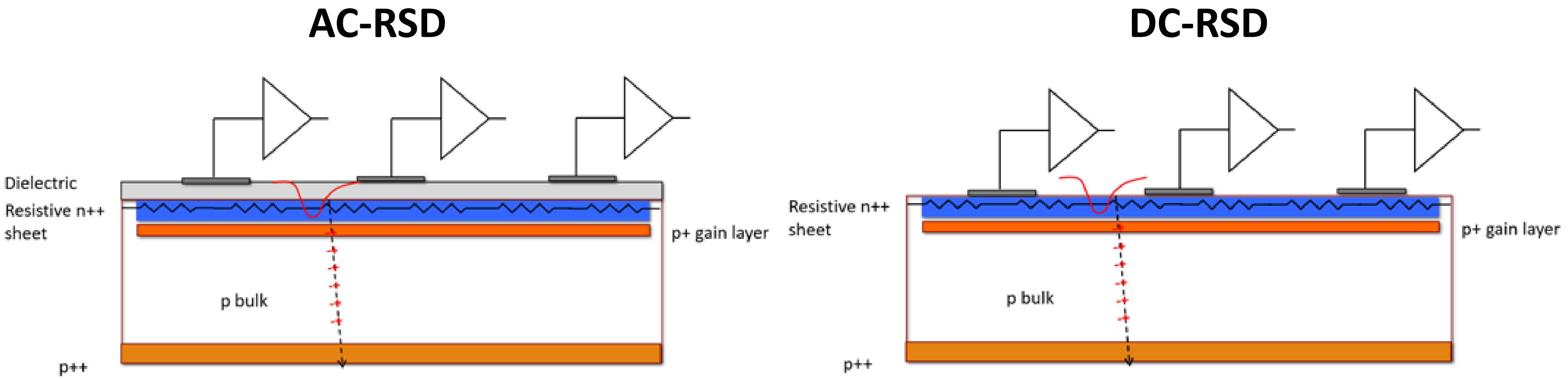
From AC- to DC-Resistive Silicon Detectors (DC-RSD)

Resistive read-out in silicon sensors has been introduced using an AC coupling to the electronics (AC-RSD or AC-LGAD, [i], see N. Cartiglia talk)

In this talk we introduce **DC-coupled RSD**, DC-RSD.

This evolution wants to *improve several aspects* present *in AC-RSD*:

- the **baseline fluctuation** due to the collection of the leakage current only at the edge of the sensor
- the spread of the signal over a **position-dependent number** of read-out pads
- the fact that the **signal is bipolar with a long tail**



All of these issues would be solved in an DC-RSD design, while maintaining the advantages of signal spreading and 100 % fill factor proper to AC-RSD

Given the direct contact of the electrodes to the bulk, DC-RSD could be very large (some cm, segmented in sub-regions)

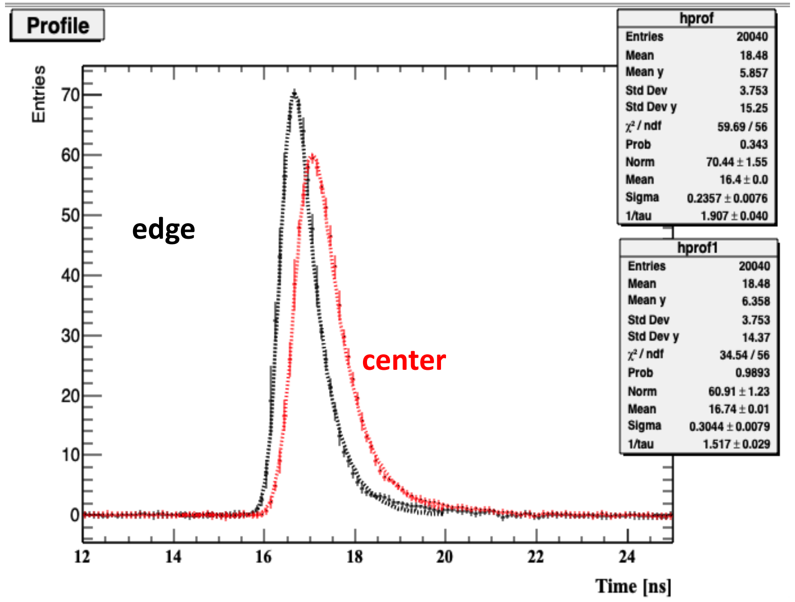
Signal Propagation on a Resistive Surface

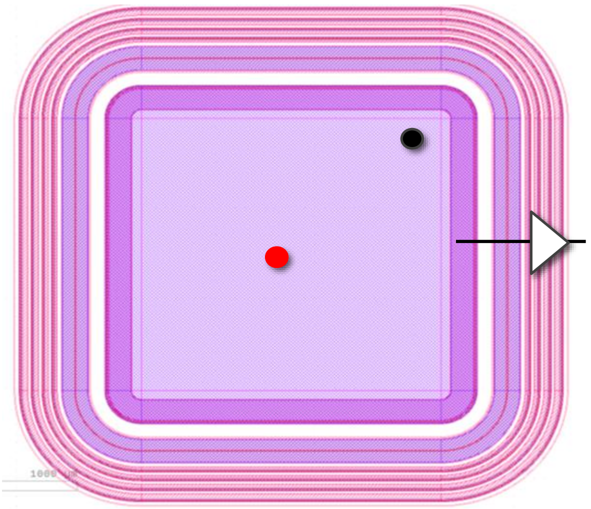
Pre-requisite: study the signal propagation on a silicon resistive surface

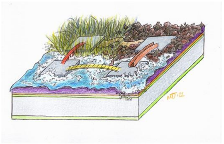
- Large structures (2 mm^2 resistive sheet from RSD1 production)
- Contact at the periphery to read-out the n++

- The shape changes with propagation: smaller and longer with distance

Large DC-RSD are feasible







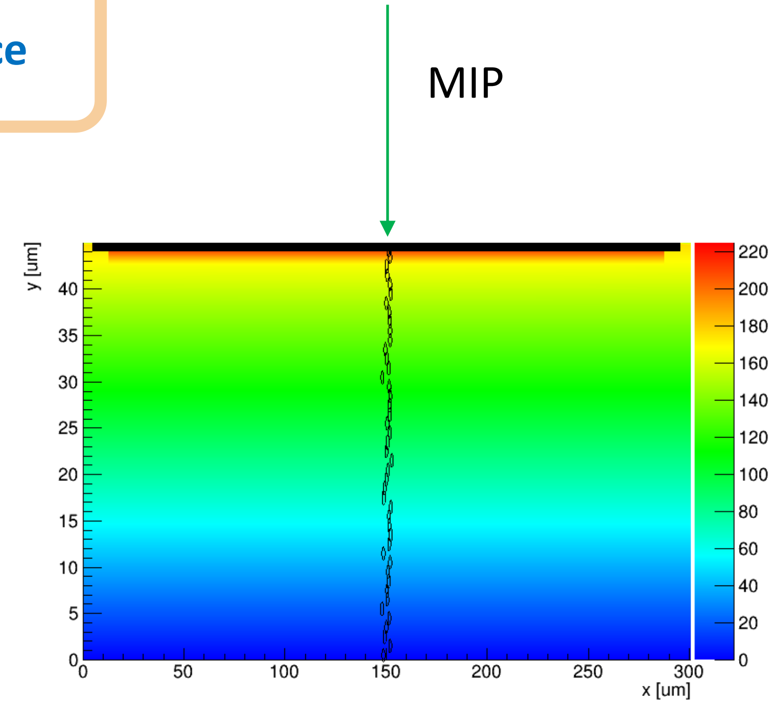
Simulations

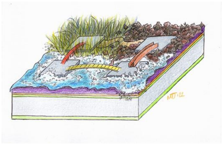
The simulation is based on a two-step procedure.

Weightfield2 RSD + **LTSpice**

- The passage of a MIP perpendicular to the sensor surface is simulated in Weightfield2 [*ii*], employing a well know sensor geometry (50 µm thick from UFSD3.2 W13 [*iii*]) with a single large pad.

- The electrical signal generated is registered and employed in the next step.





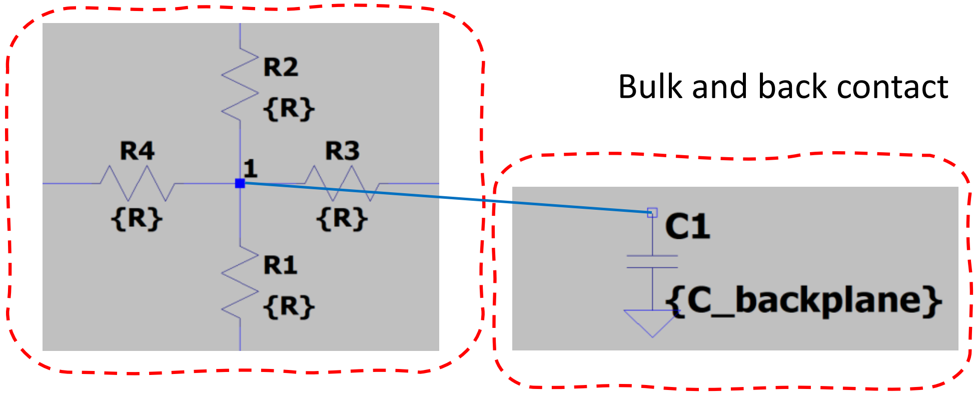
Simulations

The simulation is based on a two-step procedure.

Weightfield2 RSD + **LTSpice**

The DC RSD sensor has been simulated employing LTSpice, a schematics simulator.

Bulk and back contact



Connected with other blocks simulates the resistive sheet (n+)

- The fundamental block is a **node connected to**
  - **4 resistors –** ***resistive sheet***
  - **capacitor – sensor backplane**
- Multiple blocks connected to one another compose the sensor

Very short simulation times

Simulations Layout

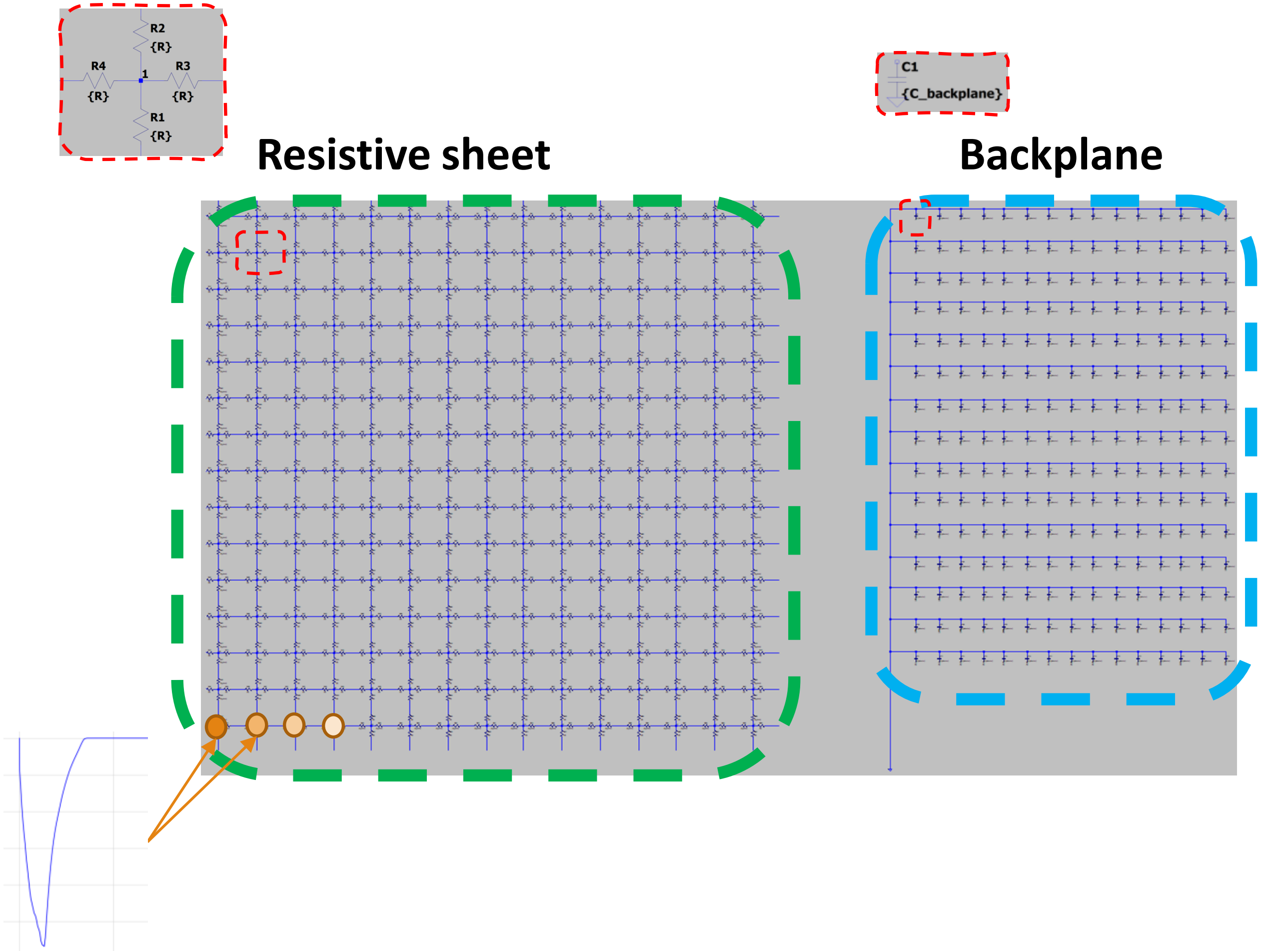
Values of each resistance and capacitance are tuned to match the experimental data.

The **signal** generated with Weigthfield **is injected in each node**

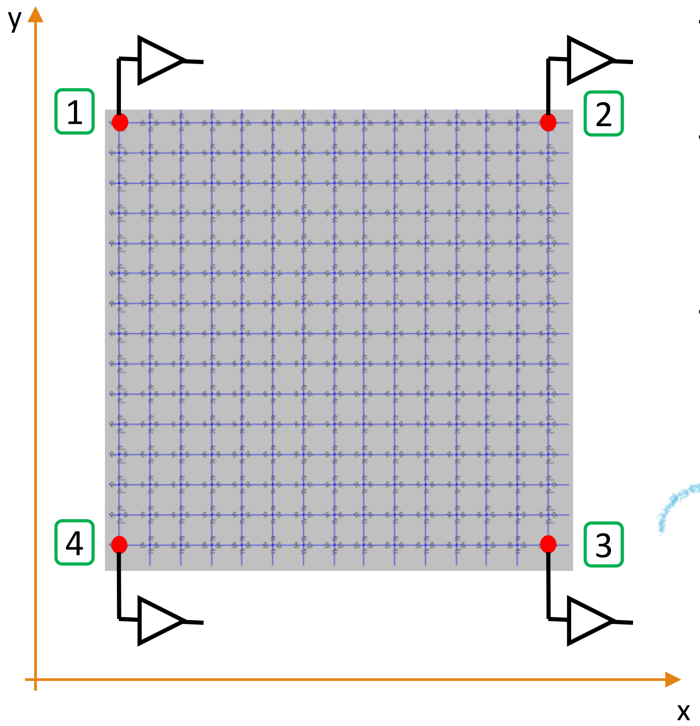
– one signal injection = one simulation

NB the capacitance value sets the geometrical scale, it is the only variable correlated to how large the structure is.

Unless otherwise specified, all results of this contribution refer to a 15x15 nodes geometry representing a 340 x 340 μm^2 sensor.



Signal Pick-up and Position Reconstruction

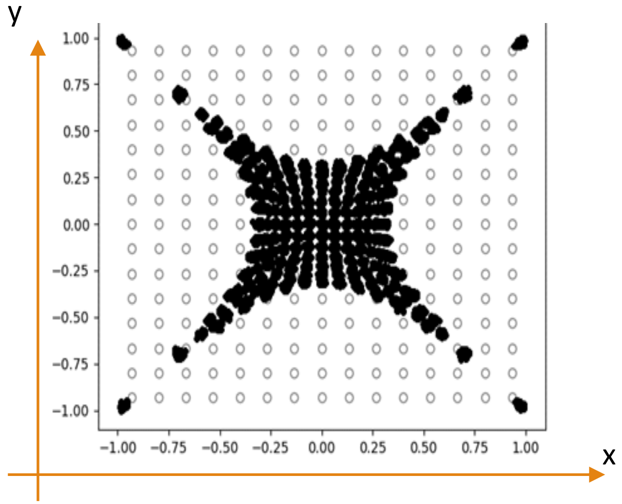


The injected current spreads over the resistive sheet and it is collected at the 4 corners via 50 Ω resistors, which mimic the read-out amplifiers.
This current is amplified with a trans-impedance of 4700 Ω and a noise with 2 mV RMS is added (both values are typical of our lab measurements) .

The **position** is then **reconstructed using the charge Q imbalance**

$$x_i = \frac{Q_2 + Q_3 - Q_1 - Q_4}{Q_{tot}}$$

$$y_i = \frac{Q_1 + Q_2 - Q_3 - Q_4}{Q_{tot}}$$



Empty circles injection points

Filled circles reconstructed points

Such distortion in the reconstruction is typical of resistive devices and present in literature ([*iv*]).

Reducing the distortion…

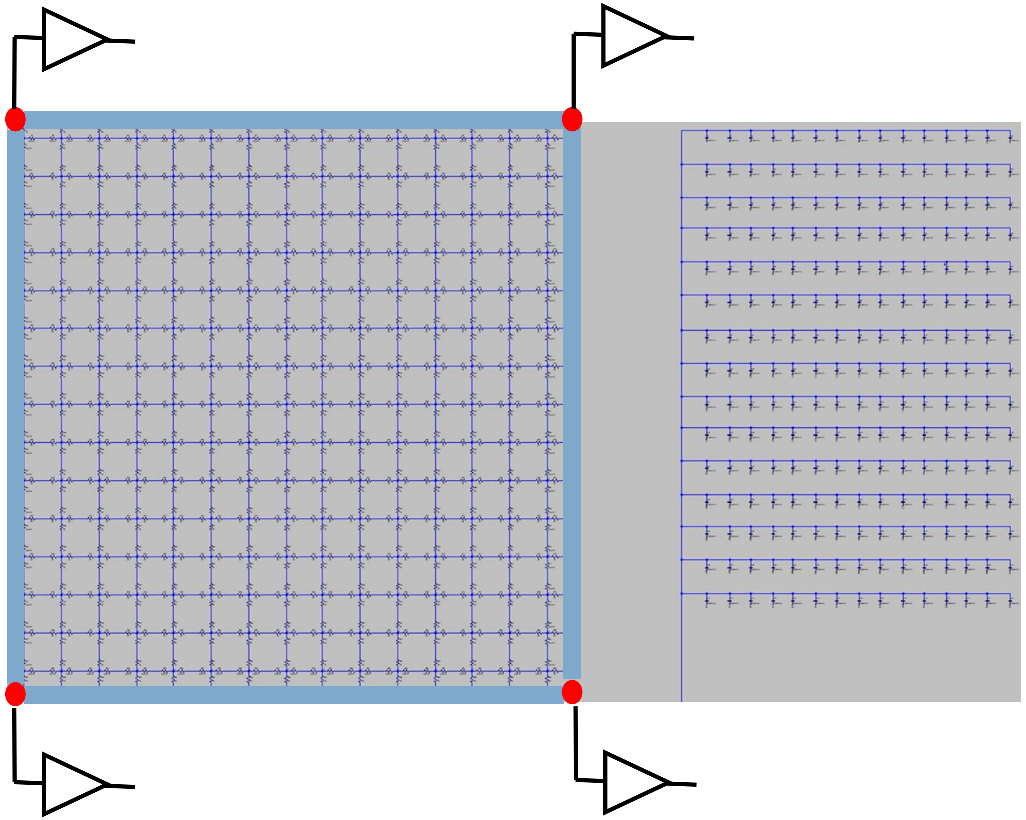
The results on the previous slide show that the reconstructed points tend to cluster in the centre

⬇

This **distortion** can be strongly **reduced by adding resistive strips connecting the electrodes**

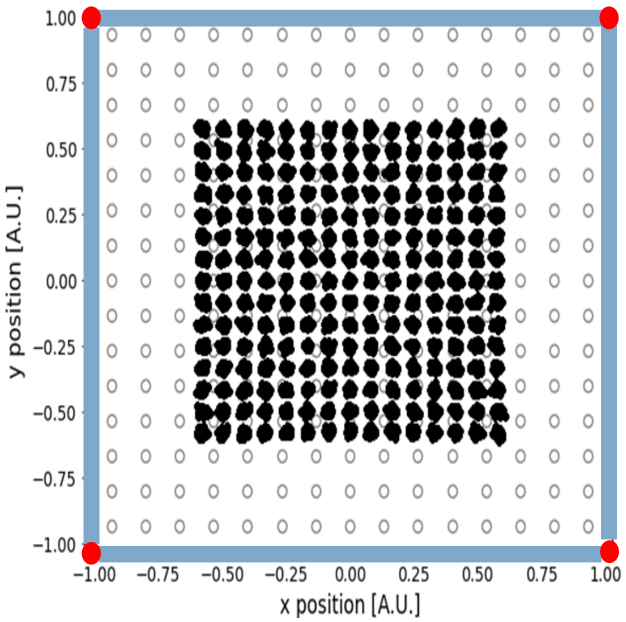
Note: the resistivity of the strips should ensure isolation among the read-out amplifiers

→ it should be at least x20 the electronics input impedance

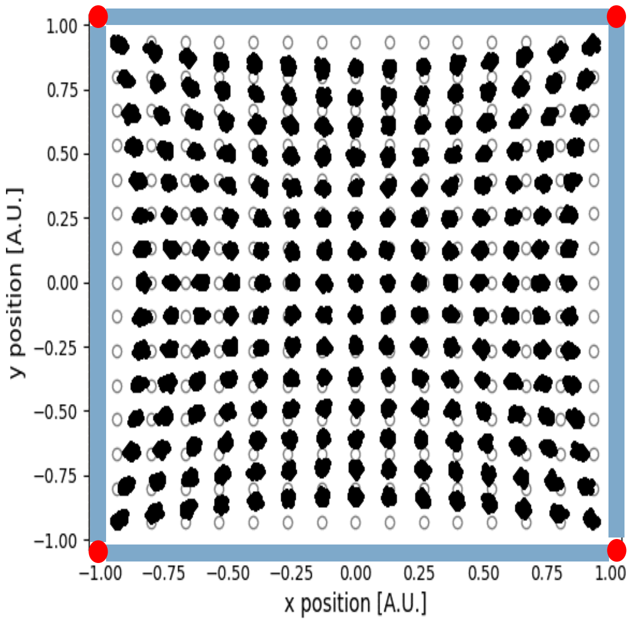


Impact of different strip resistivity

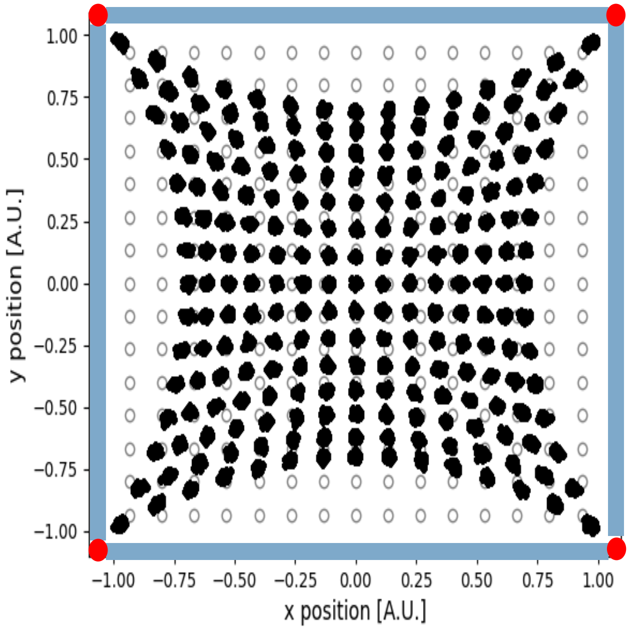
0.25 Ω/um



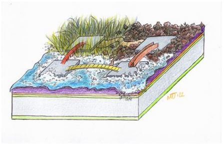
2.5 Ω/um



9 Ω/um



Empty circles: injection points **Filled Circles:** reconstructed points



Reconstruction parameters

In order to choose the best combination of sheet and strip resistivity, two parameters were defined.

- **Mean distance from the injection points, *d***

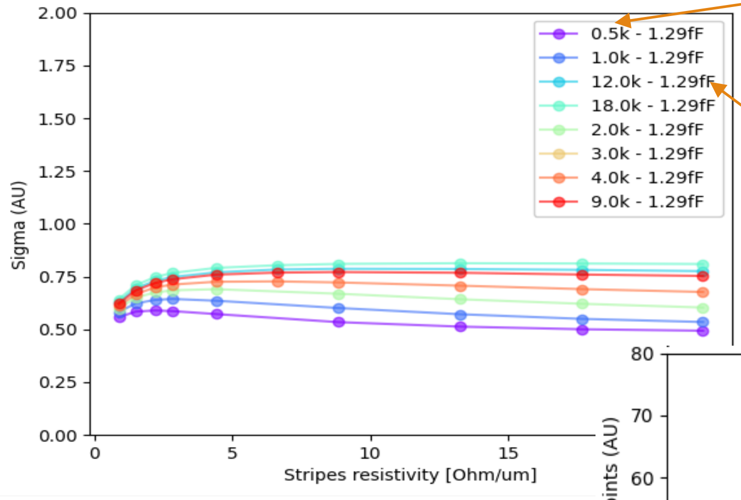
$$d_i = \frac{\sum_{n=0}^{N} |\vec{x}_r^{\,n,i} - \vec{x}_o^{\,i}|}{N}, \quad d = \frac{\sum d_i}{N_{nodes}}$$

where *i* is the node index, $\vec{x}_r^{\,n,i}$ the reconstructed position and $\vec{x}_o^{\,i}$ the injection one, N is the number of trials per point, N_{nodes} is the total number of nodes.

- **Mean reconstructed position dispersion *σ***

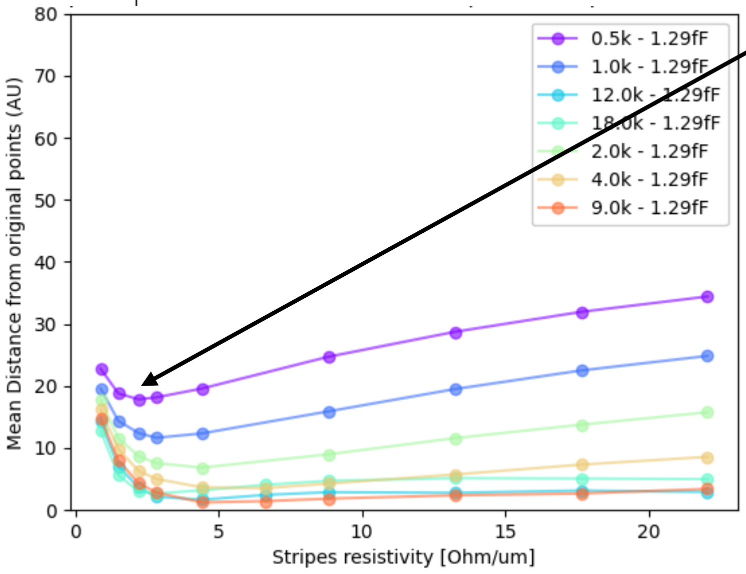
$$\vec{x}_{avg}^{\,i} = \frac{\sum \vec{x}_r^{\,n,i}}{N}, \qquad \sigma = \frac{1}{N_{nodes}} \sum_i \frac{\sum_{n=0}^{N} \left|\vec{x}_r^{\,n,i} - \vec{x}_{avg}^{\,i}\right|}{N}$$

Optimization of the strip resistivity



Sheet resistivity in kΩ/sq

Backplane capacitance
1.29 fF ⟷ 340 µm-wide sensor

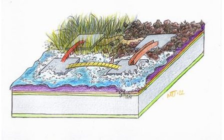


We explored many combinations of sheet and strip resistivity, and sensor dimensions (backplane capacitance).

- The mean dispersion ***σ*** is practically constant.
- Minimum ***d*** localized around R_{strip} = 3 Ω/um
- Best sheet resistivities are the highest.

! Each point on the graphs correspond to 225 independent single signal injections (simulations)

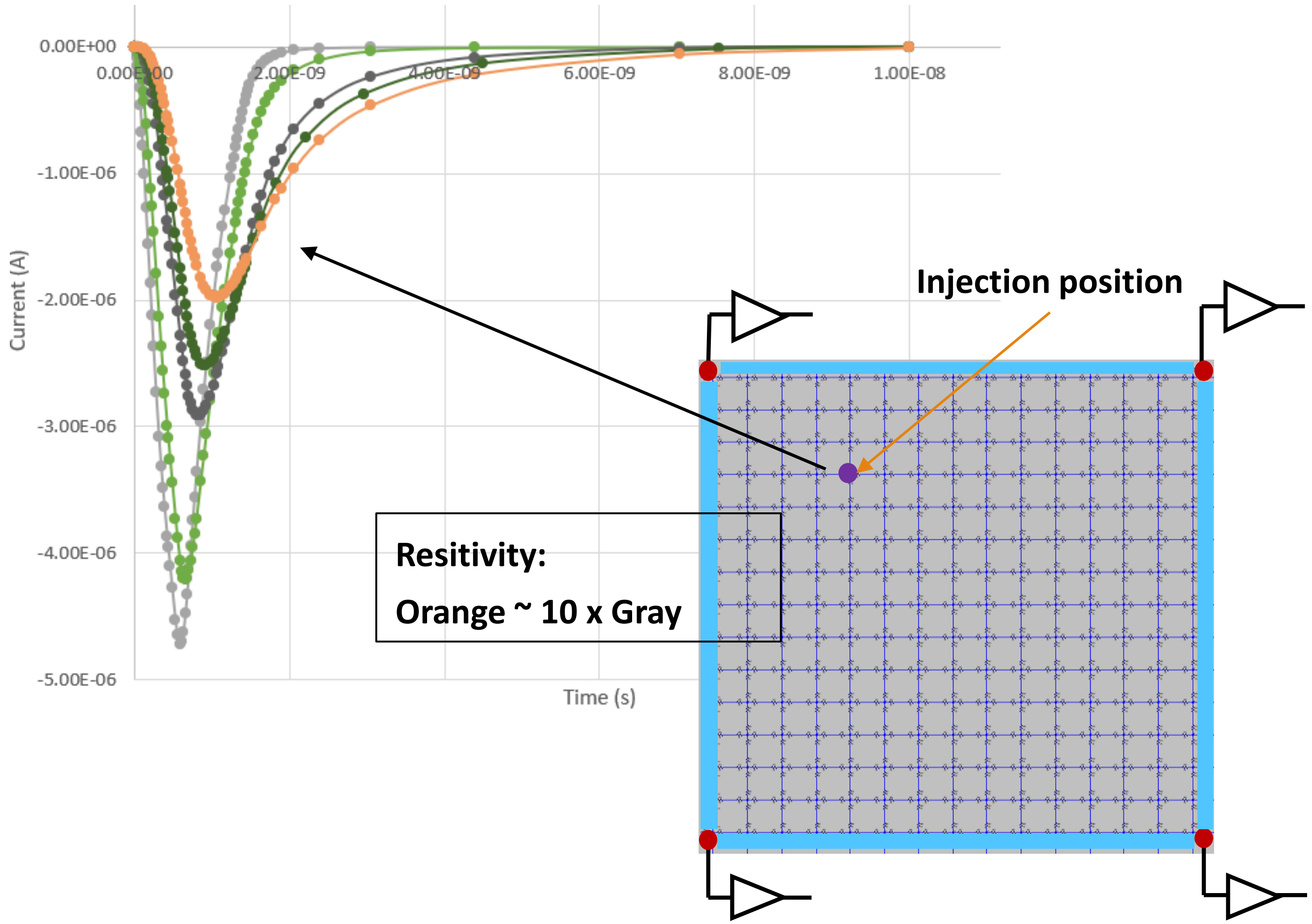
- Strips resistivity 3 Ω/um (800 Ω from pad to pad)
- Sheet resistivity as high as possible

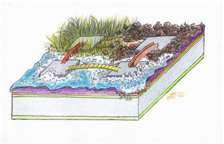


Sheet resistivity and signal shape

Shape of the signal picked up at the 4 corners of the sensor varies with the sheet resistivity

For higher sheet resistivities, the signal becomes smaller and longer, worsening the timing capabilities.





Sheet resistivity and signal shape

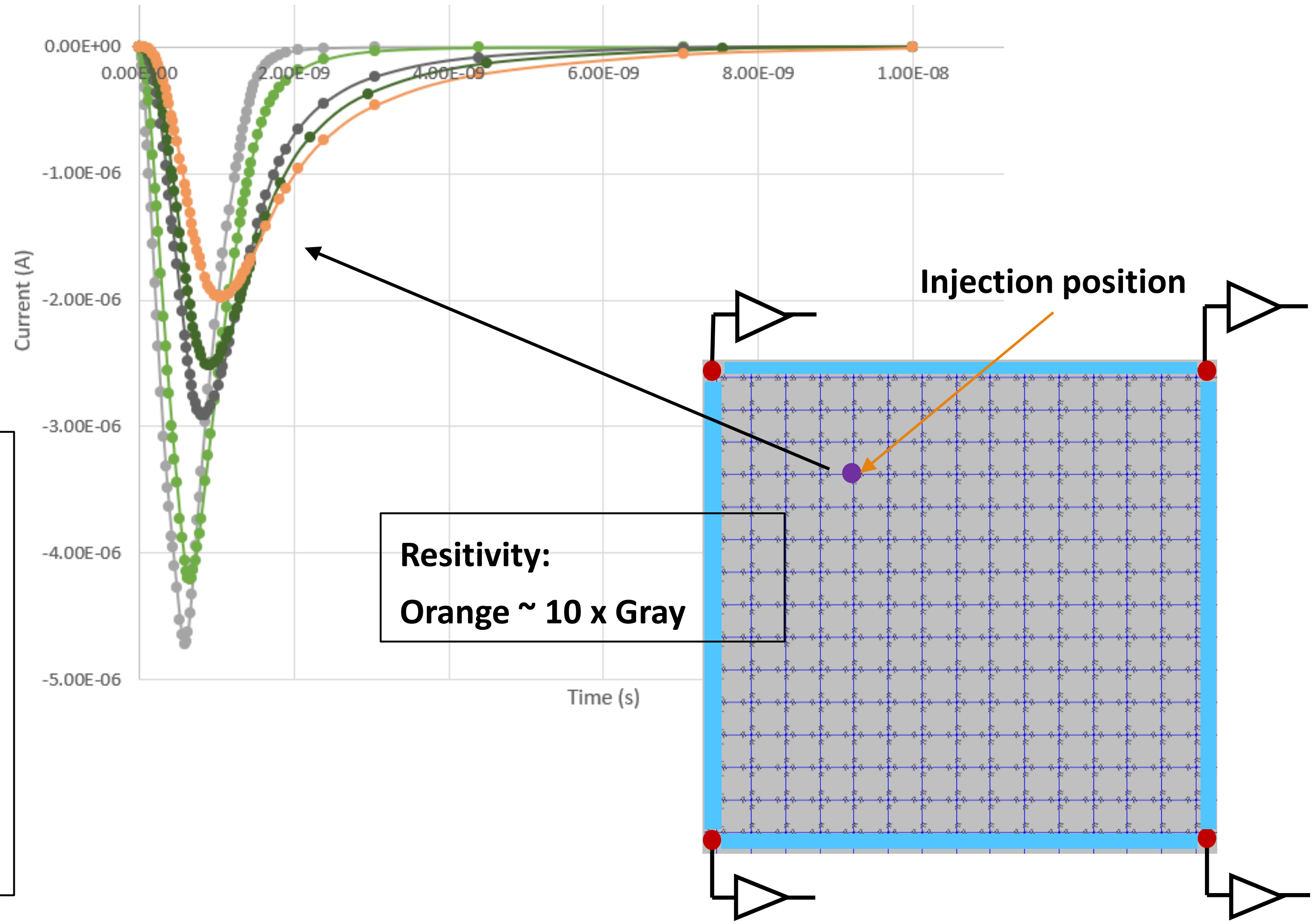
Shape of the signal picked up at the 4 corners of the sensor varies with the sheet resistivity

For higher sheet resistivities, the signal becomes smaller and longer, worsening the timing capabilities.

Combining the two effects, we opted for:

- **A sheet resistivity of about 1-3 kΩ/square**
- **A strip resistivity of about 3 Ω/um**

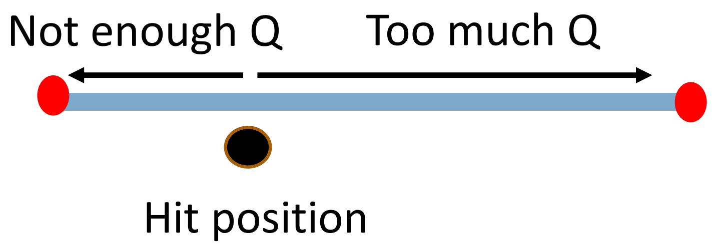
These values ensure a sharp signal, even after propagation, and a low distortion



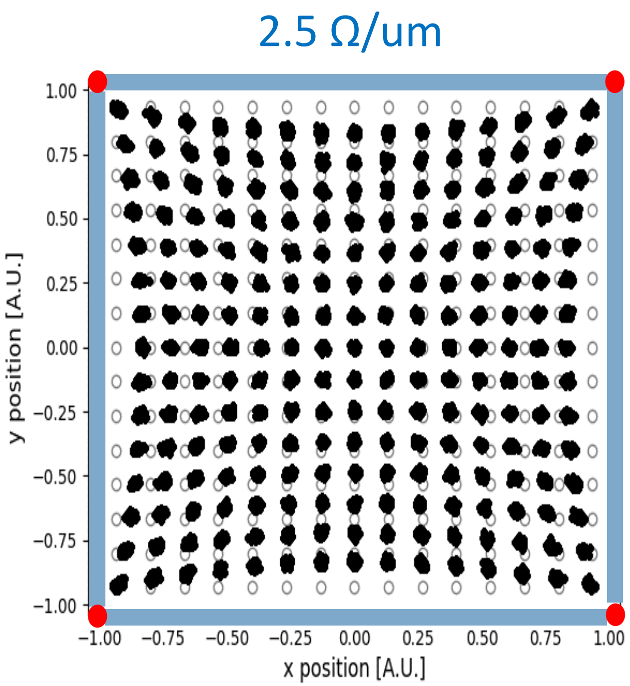
Fine tuning the reconstruction

Even with optimal strips resistivity between pads, the reconstructed positions are still systematically shifted with respect to the true positions, clustering toward the centre of the sensor

→ too much charge is reaching the side further away from the hit



Solution: variable strip resistivity

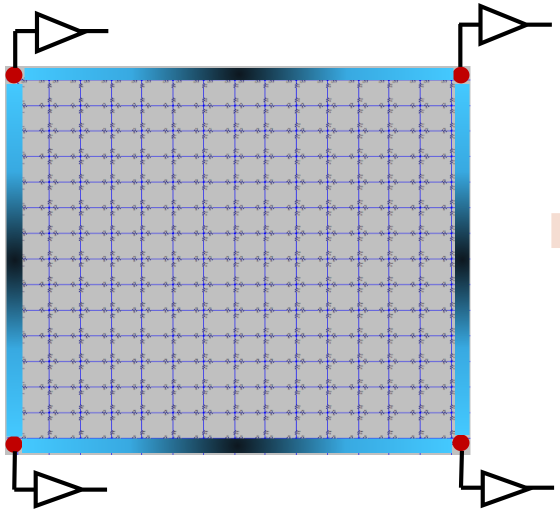


New Concept: Variable strip resistivity

→ Modulate the strip resistivity spatially

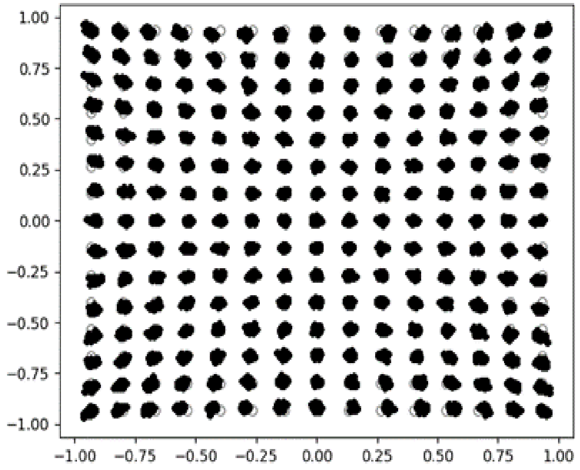
- Reconstructed points are almost aligned with the injection points
- No changes in the other parameters

Caveat: being the resistivity values very small, the amplifier impedance value starts to play a significant role.

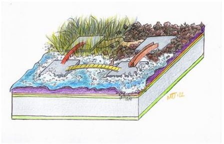


Empty circles injection points

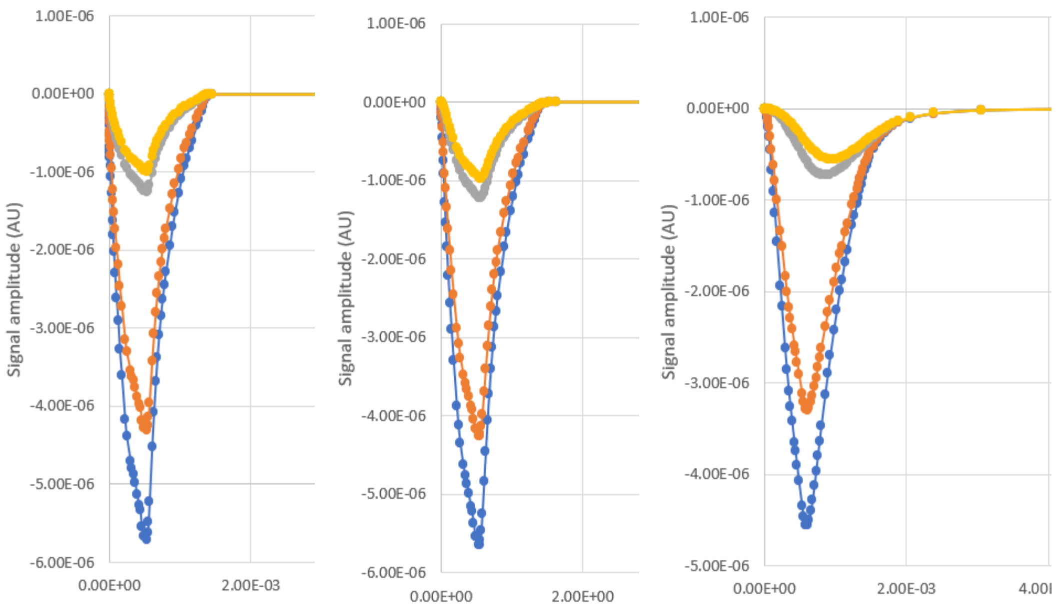
Filled circles reconstructed points



The cluster of reconstructed points are due to the noise



Different Sizes



133 µm 340 µm 1020 µm

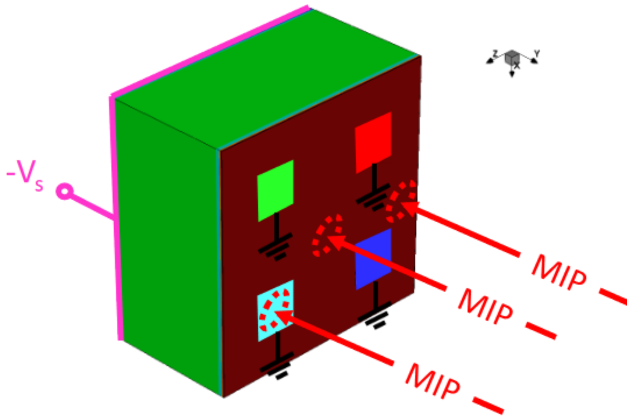
By changing the backplane capacitance values we explored signal propagation in sensors of different sizes.

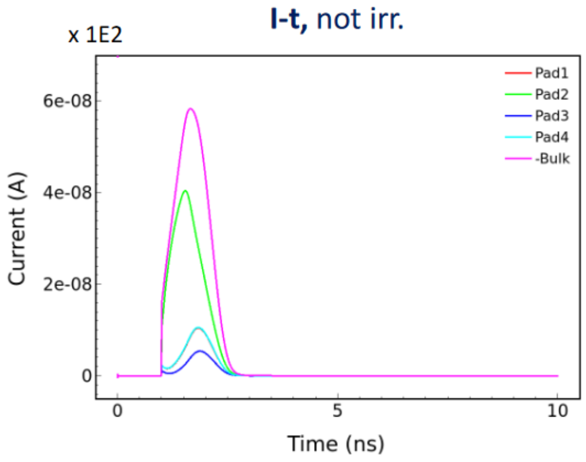
The signal maintains a sharp rising edge even for rather large pitch (~ 1 mm).

We foresee the possibility of having a sensor design yielding at excellent time (30-40 ps) and space (20-30 micron) resolutions with very large pitch (500-1000 microns).

Ongoing: TCAD Simulations

The results of this work are being used to simulate the complete sensor using TCAD.





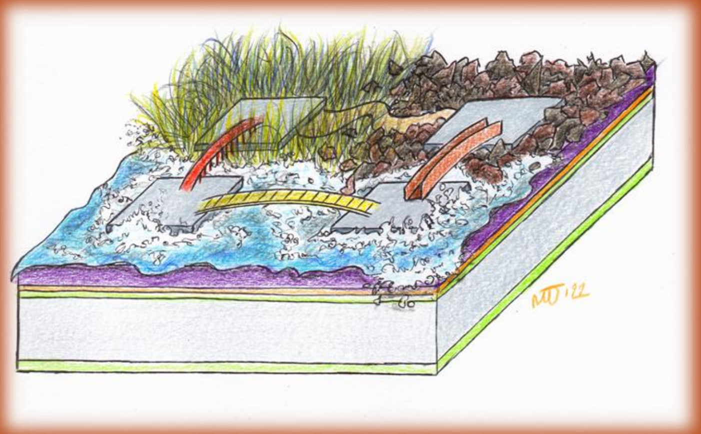
The Perugia group is simulating the passage of MIPs in a limited number of positions through a 3D DC-RSD.

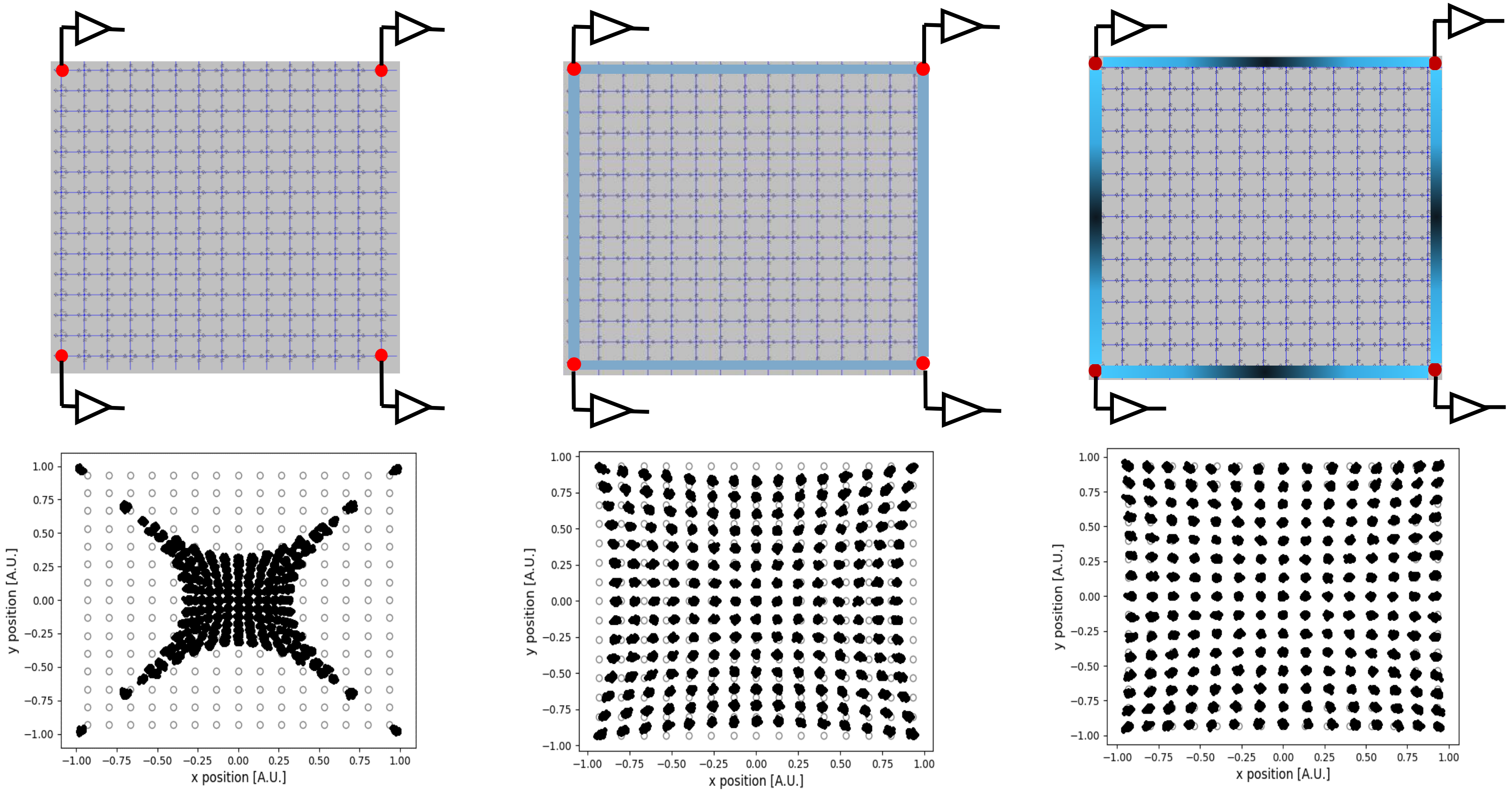
More on this soon – stay tuned!

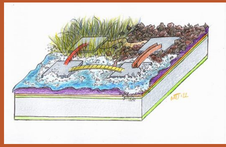
The TCAD results will provide all the necessary info for the FBK production foreseen for this Spring.

Conclusions

- **DC-RSD** are an **evolution** of silicon sensors with **resisistive read-out**.
- The introduction of *resistive strips* between the electrodes *reduces the position reconstruction distortion.*
- Strips with *variable resistance almost eliminate the distortion*.
- **Expected excellent time (30-40 ps) and space (20-30 micron) resolutions with very large pitch (0.5-1 mm)**
- **The first DC-RSD production is planned for this Summer**







Aknoledgements

- RD50 collaboration
- INFN - Gruppo V, RSD projects
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- Dipartimenti di Eccellenza, Univ. of Torino (ex L. 232/2016, art. 1, cc. 314, 337)
- Ministero della Ricerca, Italia , PRIN 2017, progetto 2017L2XKTJ – 4DinSiDe
- Ministero della Ricerca, Italia, FARE,   R165xr8frt_fare

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i. M. Tornago et al., *Resistive AC-Coupled Silicon Detectors: Principles of operation and first results from a combined analysis of beam test and laser data*, 2020 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC).
F. Siviero et al., *First application of machine learning algorithms to the position reconstruction in Resistive Silicon Detectors*, JINST, (2021).

ii. http://personalpages.to.infn.it/~cartigli/Weightfield2/

iii. F. Siviero et al, *Optimization of the Gain Layer Design of Ultra-Fast Silicon Detectors*, Preprint submitted to NIM Section A, (2021).

iv. On the dynamic two-dimensional charge diffusion of the interpolating readout structure employed in the MicroCAT detector, Wagner et al., NIM A, (2002).