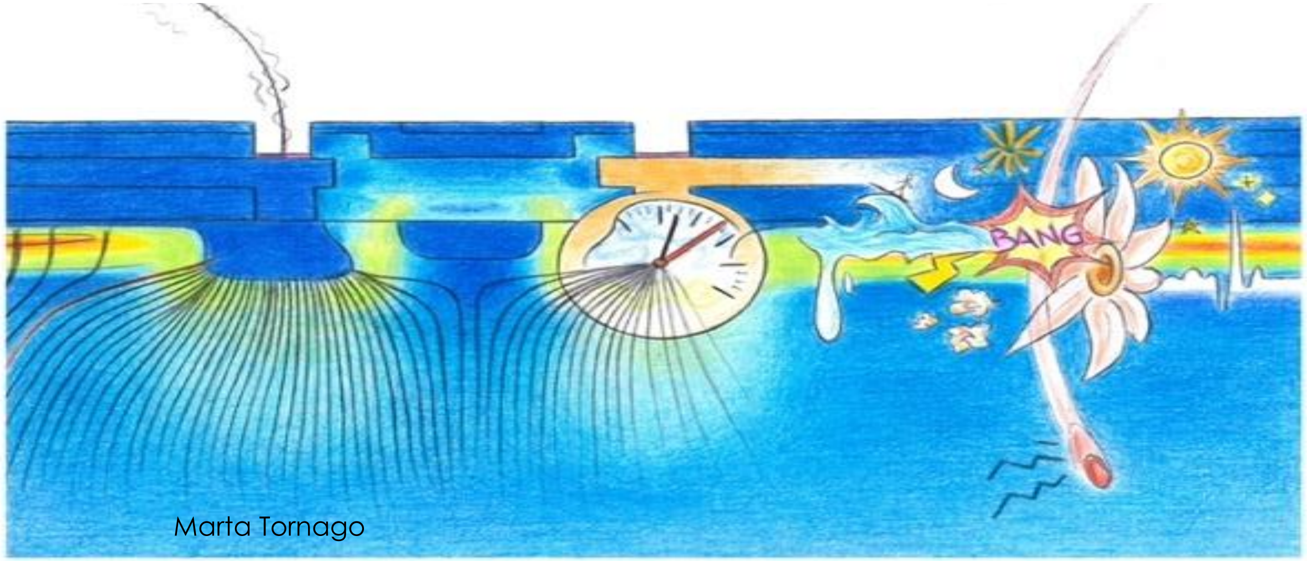
Topics in LGAD design

- **DC-RSD**
- **SEB-resistant (Single Event Burn-out) LGAD design**



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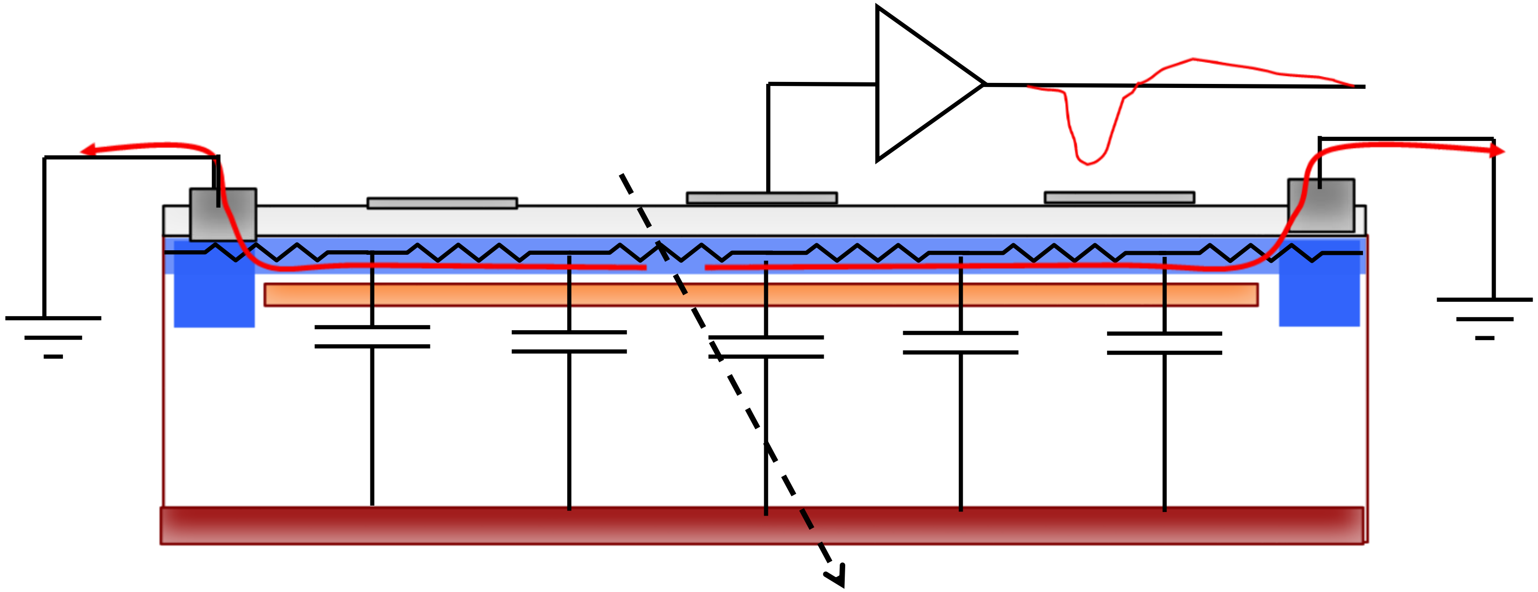
FBK, Univ. of Trento, UCSC

Part I: Resistive readout

In [1], the idea of resistive read-out has been introduced.

The realization exploited a resistive layer AC-coupled to the read-out pads



In this design, there is only 1 contact to the n++: the charges collected on the n++ flow to the edge of the sensor.

[1] TREDI 2015

https://indico.cern.ch/event/351695/contributions/828366/attachments/695875/955507/TREDI_Cartiglia.pdf

AC-RSD

AC-RSD have been proven to work quite well:

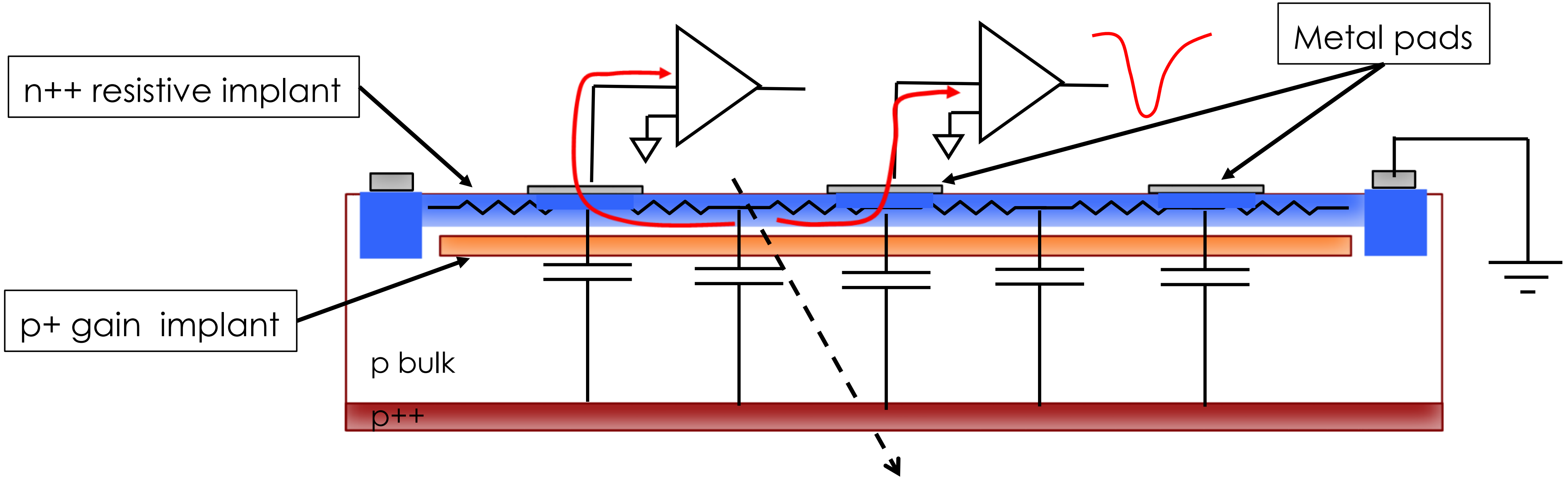
- Temporal resolution similar to the other "LGAD" designs
- Excellent position resolution using large pixels
- 100% fill factor

A few known problems with the AC-RSD design:

- The signal is bipolar, with a long tail (~ 100 ns)
- The number of pads seeing a signal depends upon the hit position: it might be 3,4, 5, 6
  - ➢ Studies to minimize these effects are on-going, see FBK RSD2 production
- Normally, 3 or 4 pads collect most of the signal but several more pads see "something"
- The leakage current is collected at the edge of the sensor
- Not yet proven that AC-RSD can made large, for example 10x10 cm^2

Design evolution: DC-RSD

What would be the consequences of a DC read-out in resistive read-out ?



In this design, the charges collected on the n++ flow to the electronics as in standard sensors

The read-out pads are embedded into a resistive n++ sheet that assures pad isolation

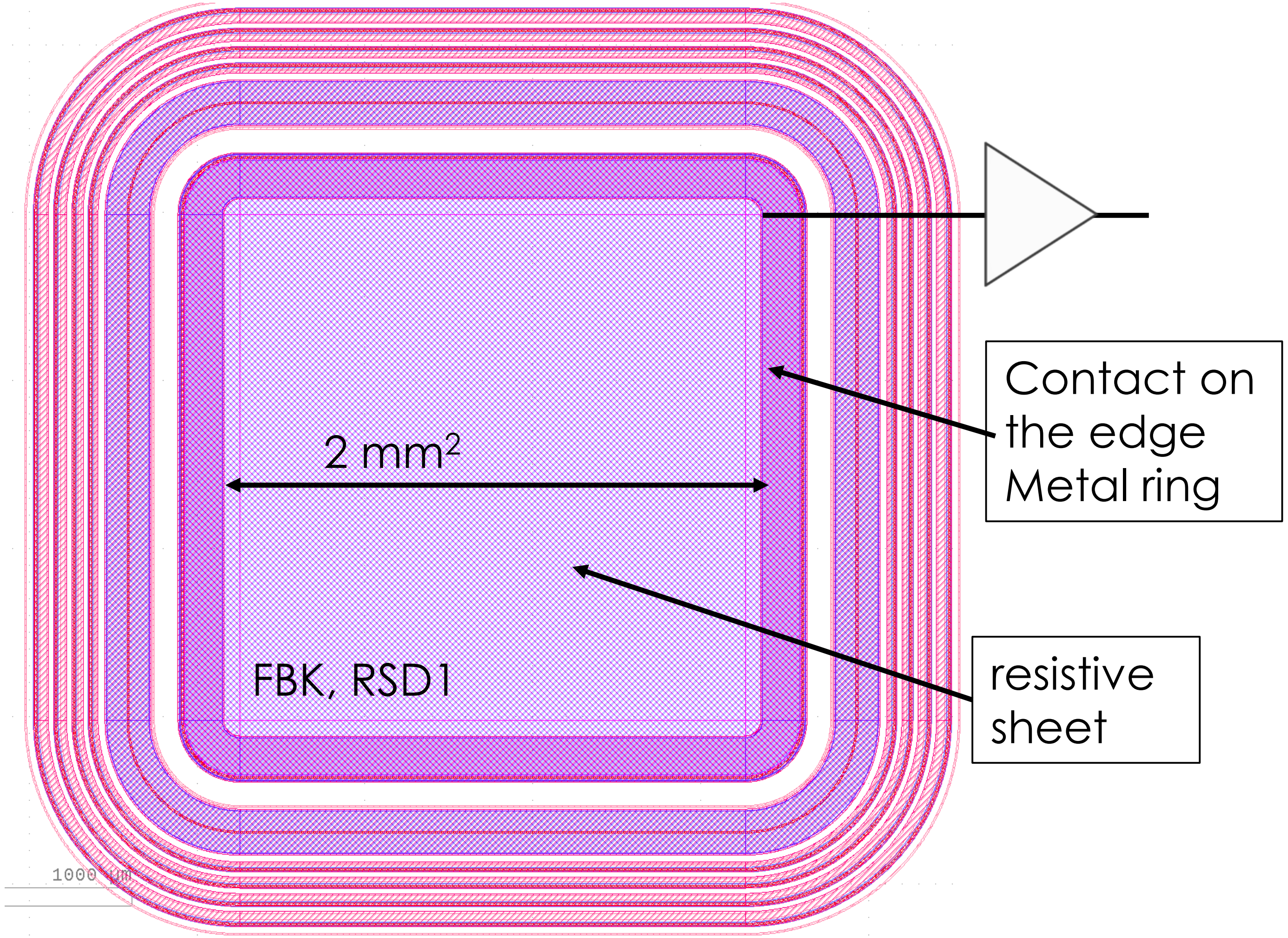
- Signal propagation on the n++ ?
- Signal sharing?

Signal propagation on a resistive sheet

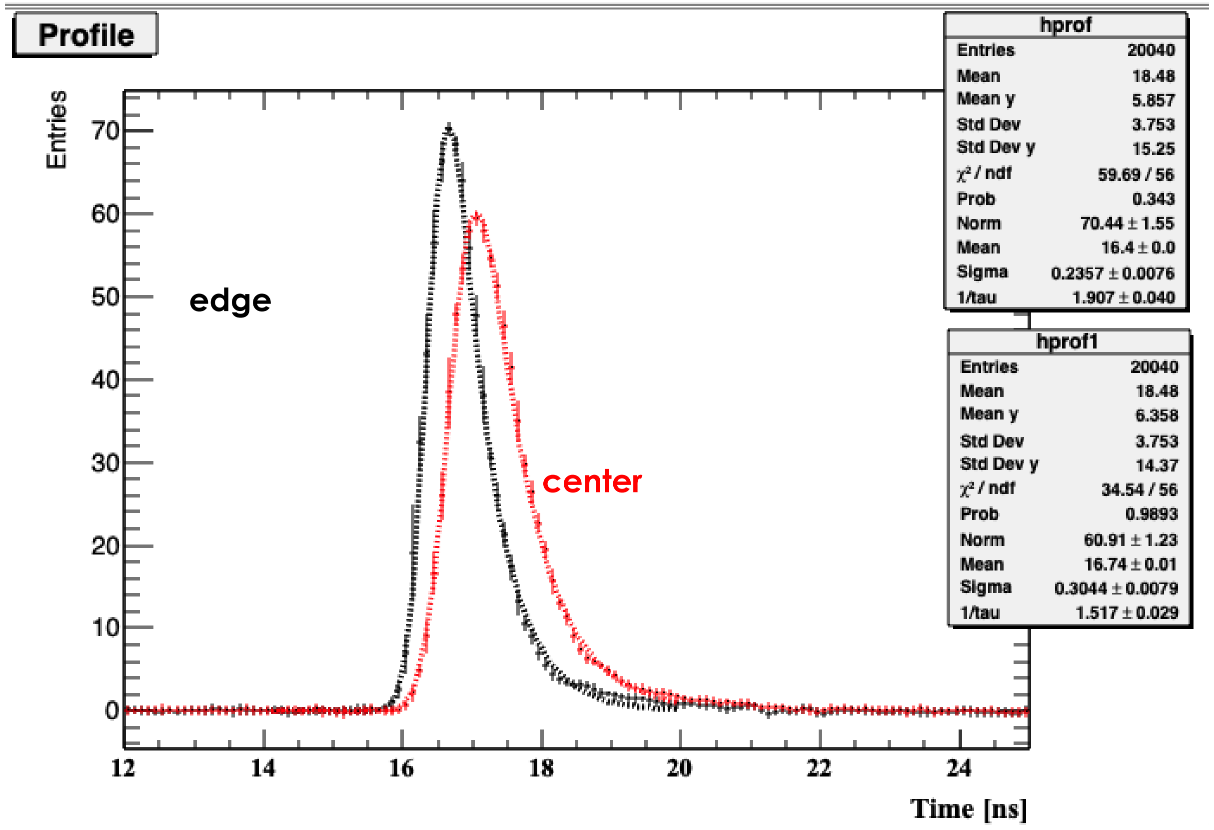
The first step is to understand how a signal spreads on a resistive sheet
==> manufacture a resistive sheet and study signal propagation

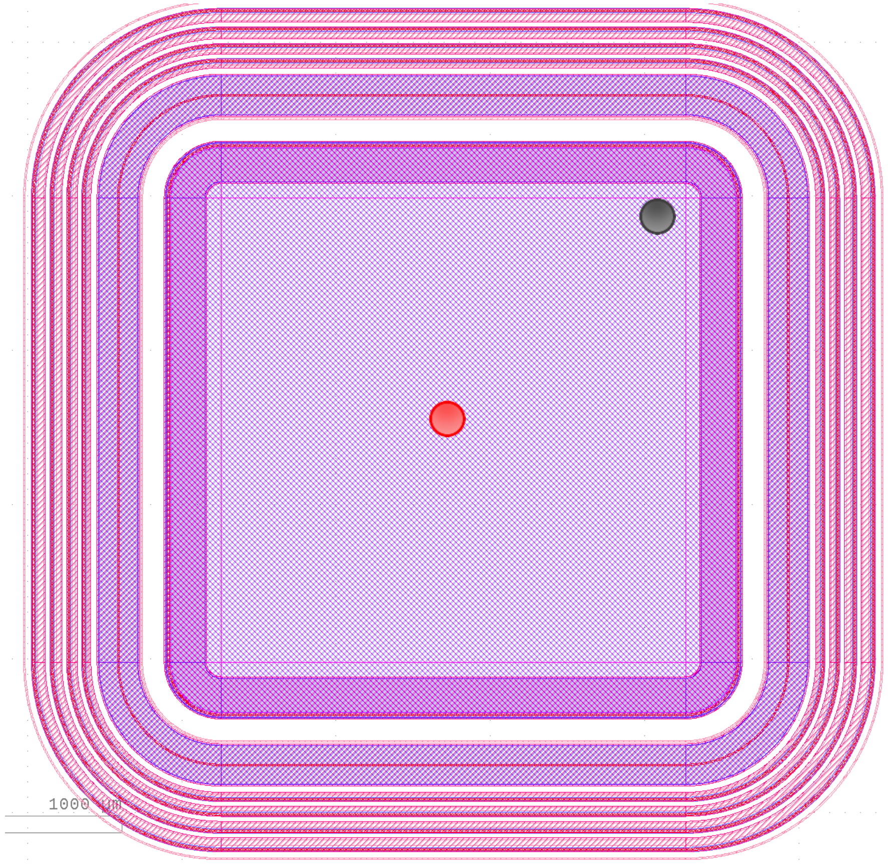
In RSD1 production we have:

- single pads: 2x2 mm^2 resistive sheet
- Contact at the periphery to read-out of the n++
- Various doping levels of the resistive sheet



Signal shape of hits near the edge or in the center

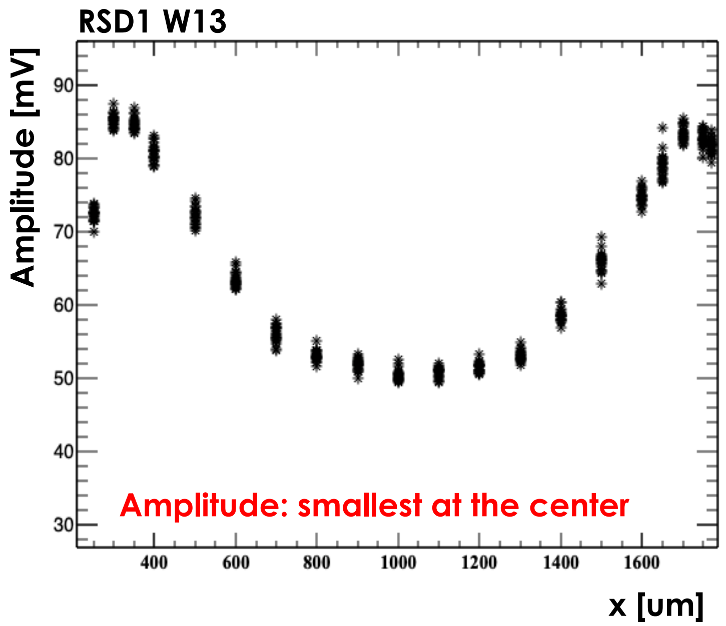


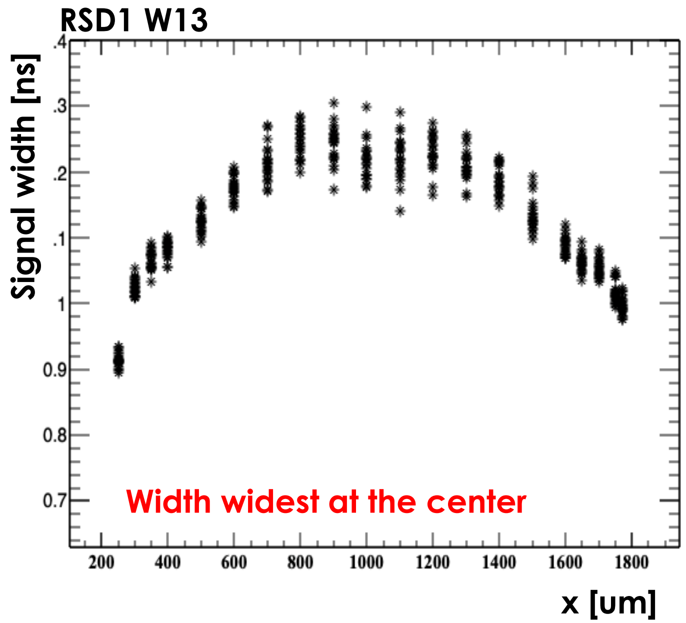


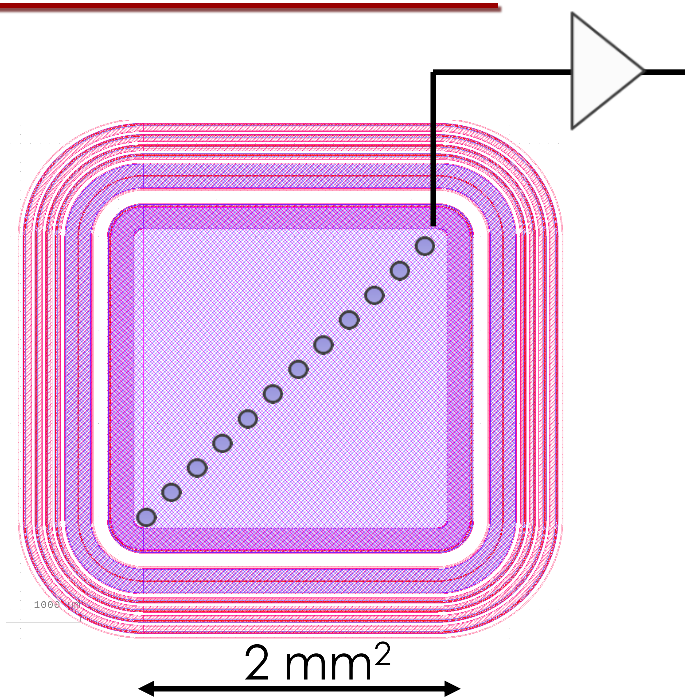
Even after a sizable distance, ~ 1 mm, the rising edge is still quite sharp

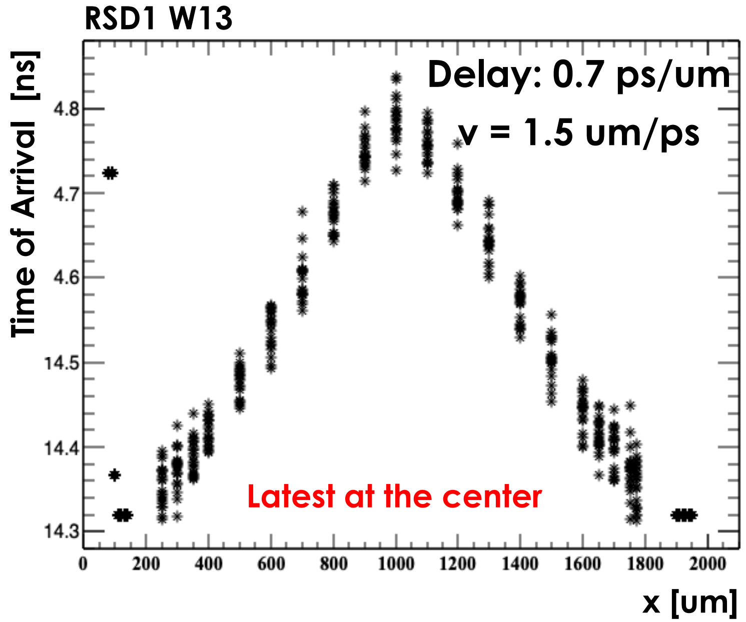
The signal shape is that of an exponetially modified gaussian

Shooting along the diagonal and reading out the signal at the edge









At lower sheet resistivity:

lower attenuation,

faster propagation

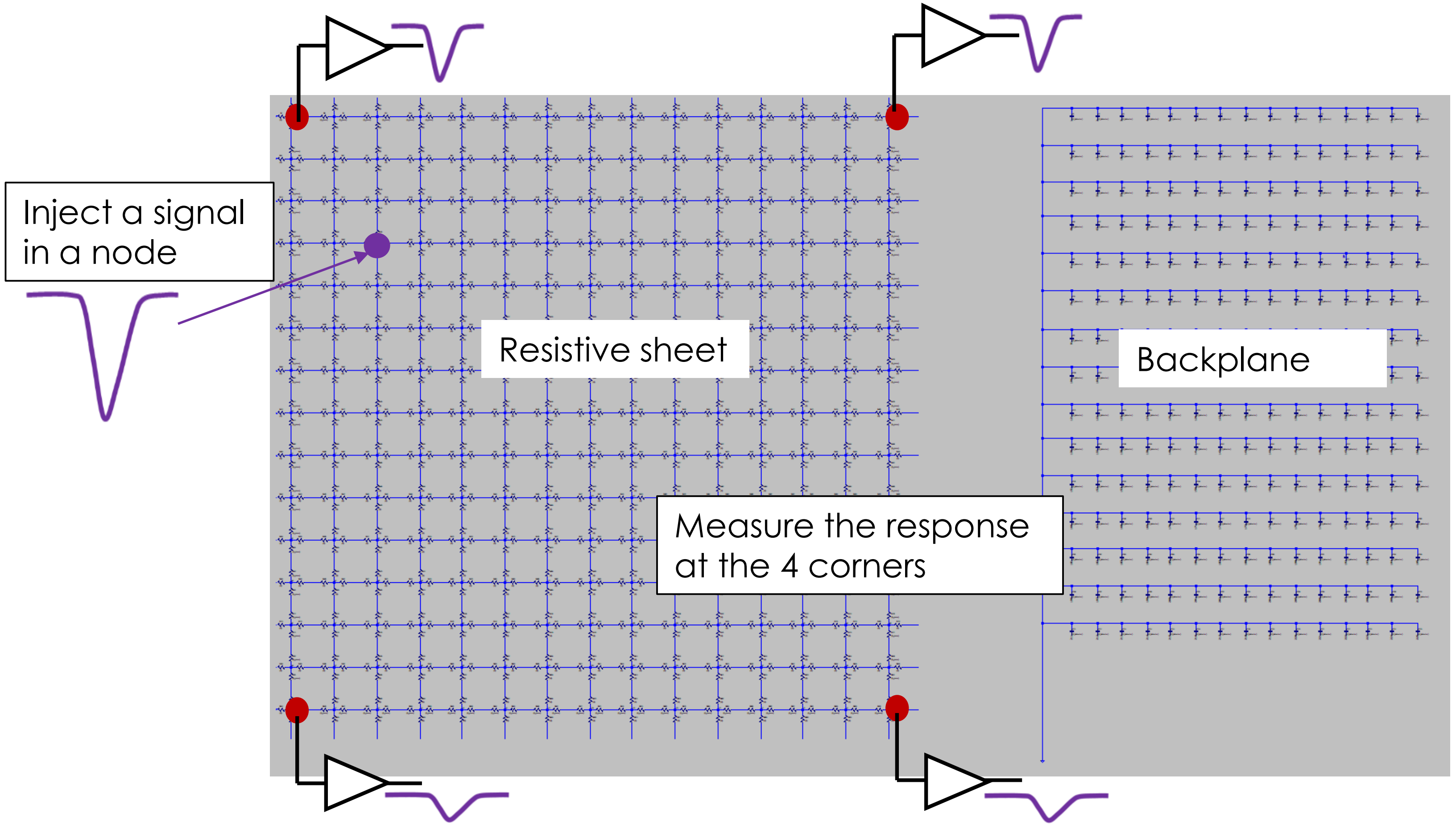
Summary:

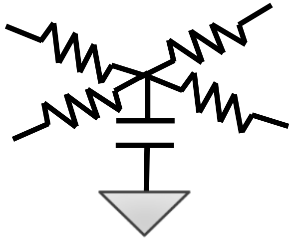
Propagation does not ruin the signal shape,

the shape changes as expected: it becomes shorter and wider with distance

DC-LGAD LTSpice simulation

The resistive sheet is simulated with a grid of resistors.
The bulk as capacitors attached to each node [2].





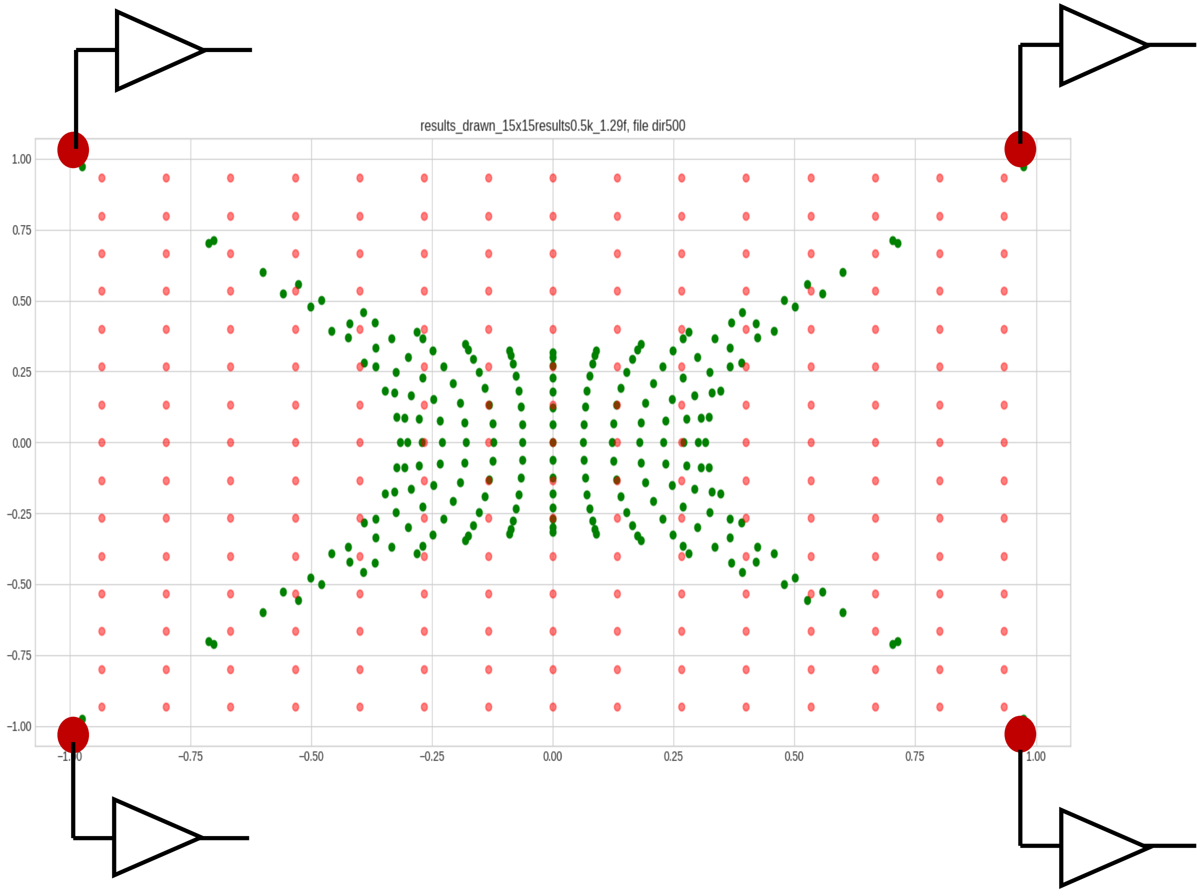
[2] For additional details on this study, ask the author, luca.menzio@to.infn.it, more details soon

Position reconstruction using charge imbalance

Simplest alghoritms for position reconstruction:

$$x_i = \frac{Q_{top\ right} + Q_{bottom\ right} - Q_{top\ left} - Q_{bottom\ left}}{Q_{tot}}$$

$$y_i = \frac{Q_{top\ right} + Q_{top\ left} - Q_{bottom\ left} - Q_{bottom\ right}}{Q_{tot}}$$



Shoot in a grid of points, and see where the position is reconstructed:

Red: points where the signals are injected

Green: reconstructed points

Very large distortion.
This is a known problem in resistive read-out (for example, in grid of SiPM)

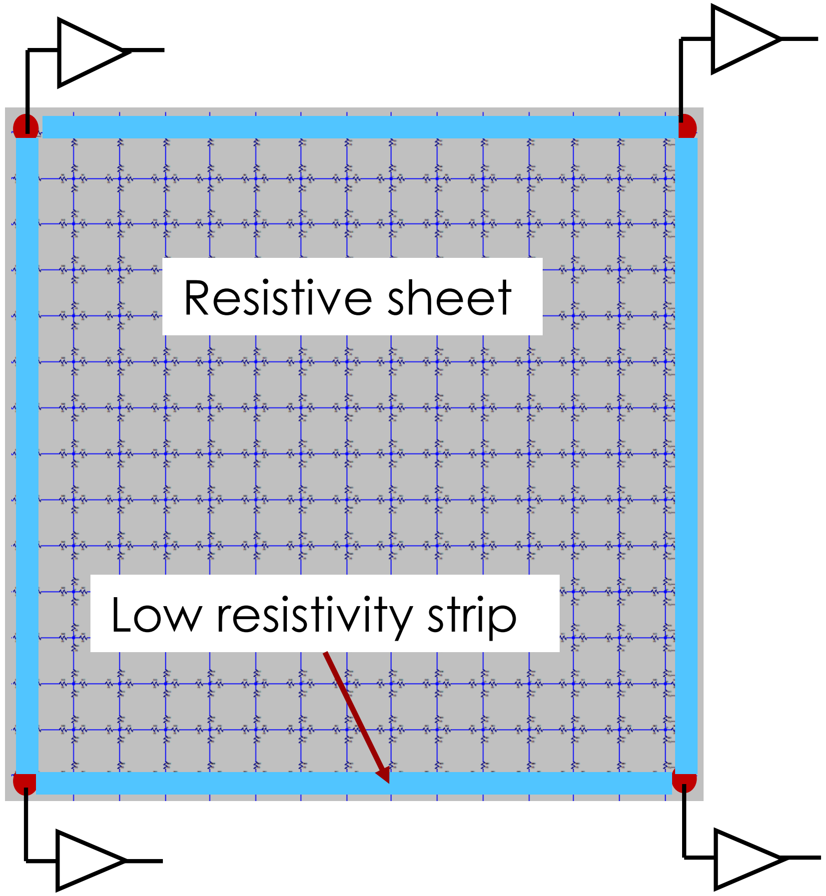
Often corrected using homography [3]

[3] Su-Jin Jeon et al, “Position error Correction Using Homography in discretized positioning circuit…”, IEEE Vol 64 No.2 feb 2017

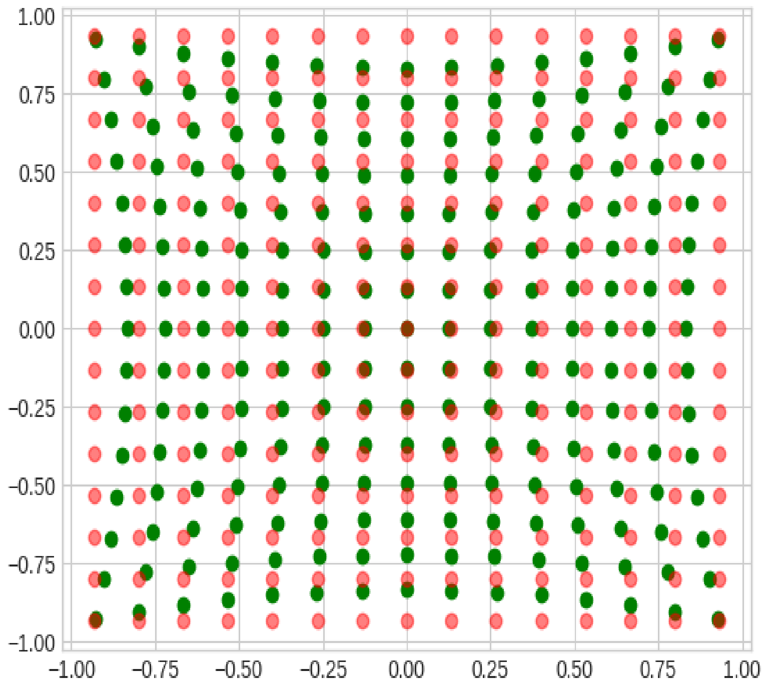
Mitigation: add low resistivity strips between read-out points

There is a hardware solution [4][5] to this distortion: add a low-resistivity strip between each pair of points

Important benefit: in this design, **the signal is contained in a square**, firing always the 4 corners.



$R_{strip} \sim (0.01 - 0.1)*R_{sheet}$



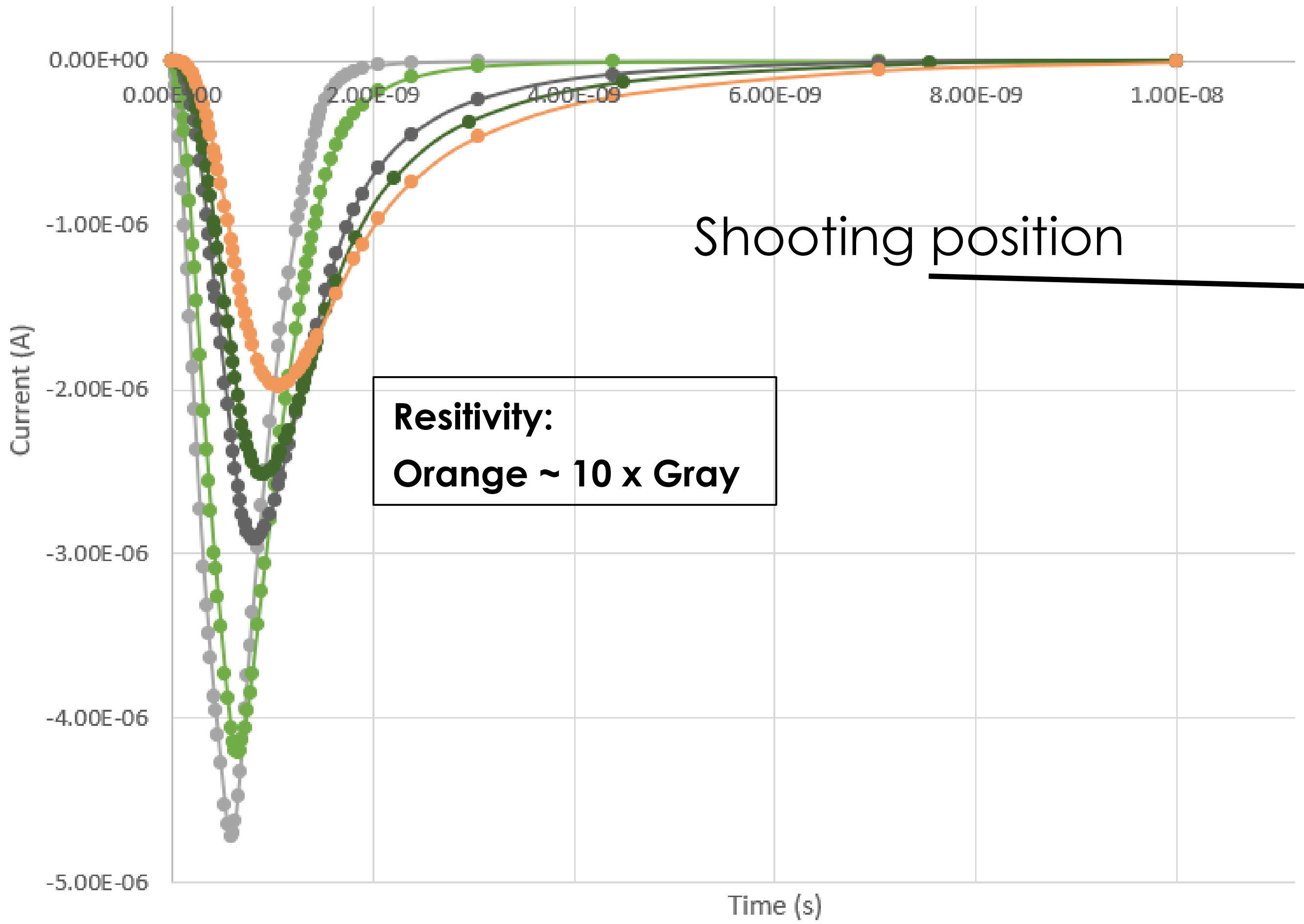
Red: points where the signals are injected

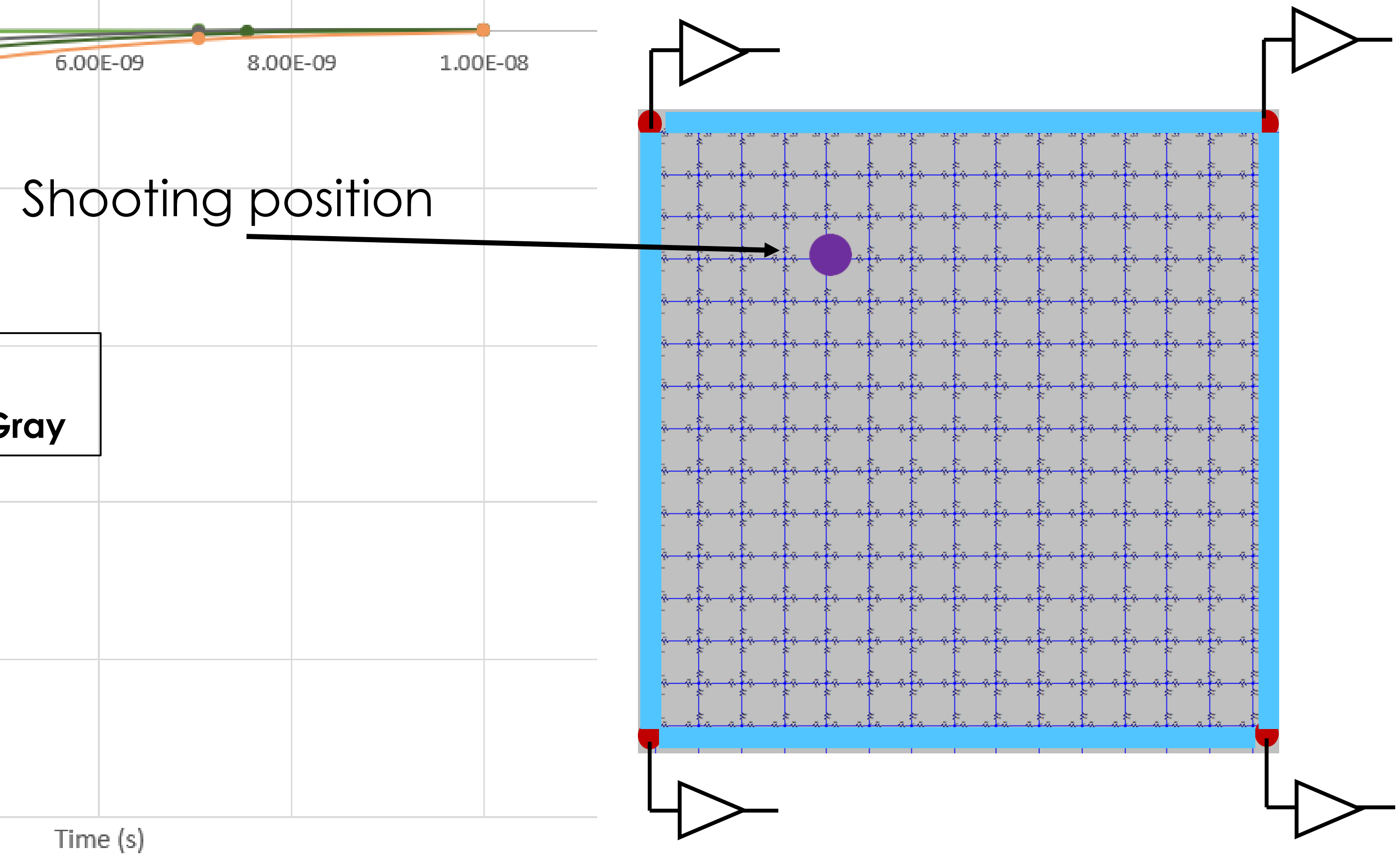
Green reconstructed points

[4] H. Wagner et al, *On the dynamic two-dimensional charge diffusion of the interpolating readout structure employed in the MicroCAT detector*, NIM A 482 (2002) 334–346.

[5] Many thanks to W. Riegler for pointing-out this paper to us

Signal shape vs sheet resistivity





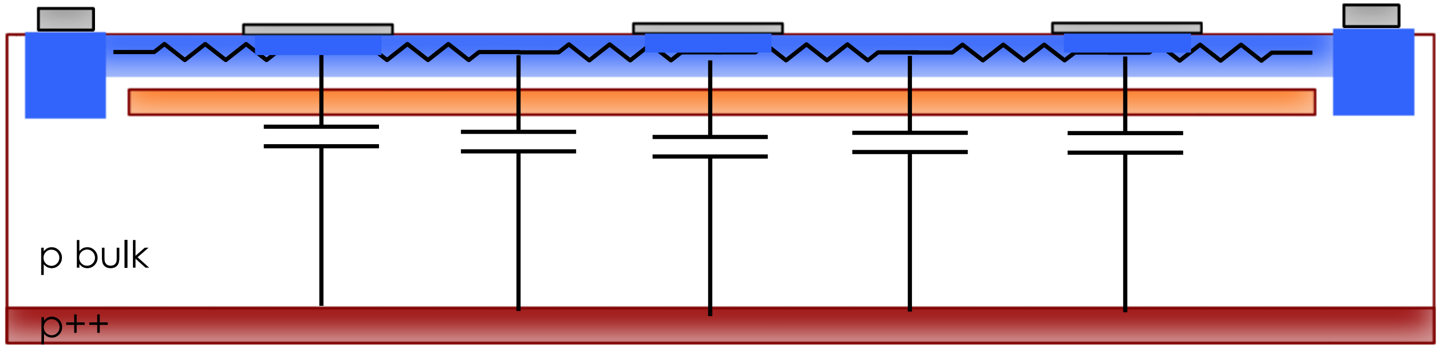
As the n++ resistivity increases, the simulation predicts shorter and wider signals

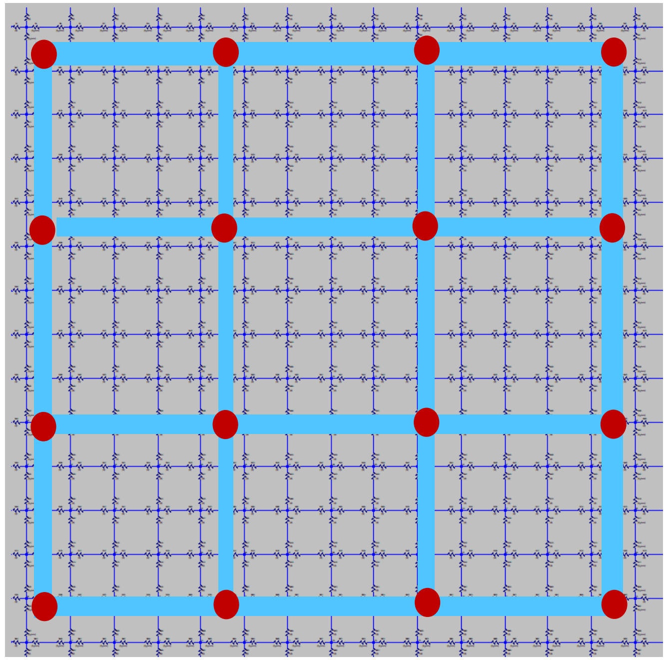
N. Cartiglia, INFN Torino, RD50, Valencia

Wrap-up DC-RSD

DC-RSD:

- Use DC read-out on a resistive sheet
- Link the read-out pads with a lower resistivity strip





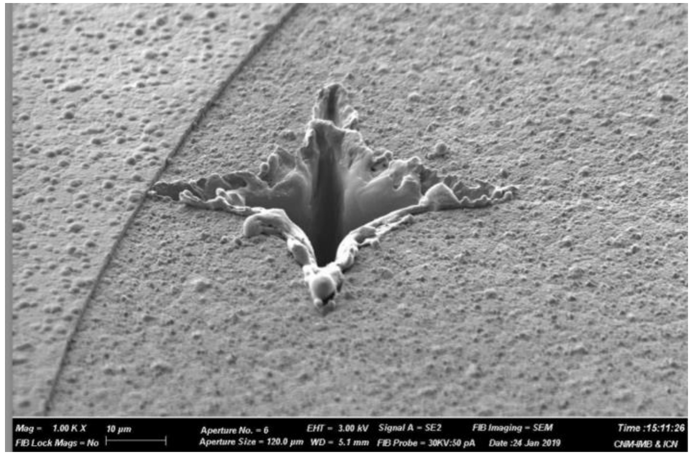
Benefits:

- Fast signal
- Large pixels (200-300 um): still sharp rising edge even after a propagation of 1 mm.
- Excellent position resolution
- DC connection to the read-out
- Well-defined sharing among 4 pads

Futures:

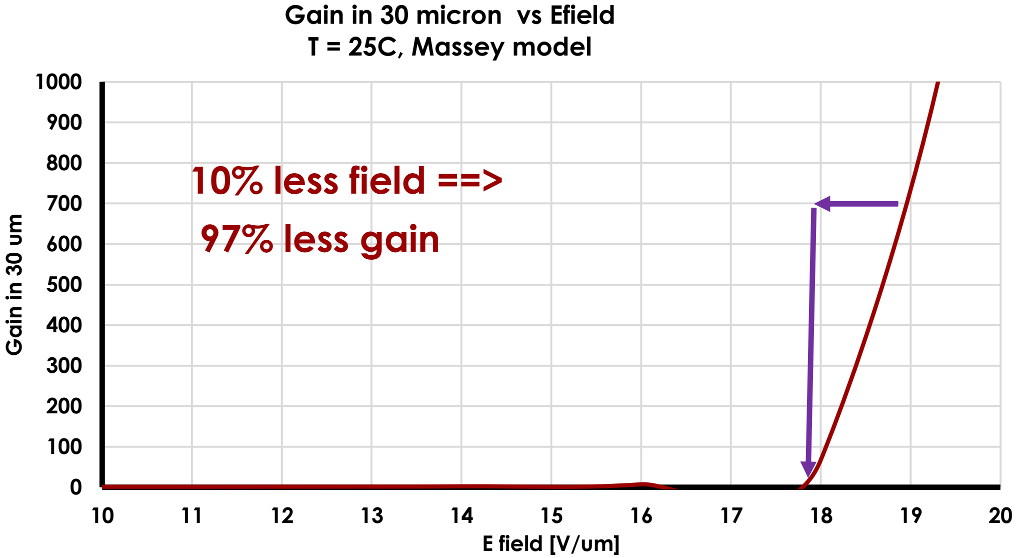
- Simulation studies on-going
- Detailed presentation soon (VCI, TREDI…)
- FBK production in 2022

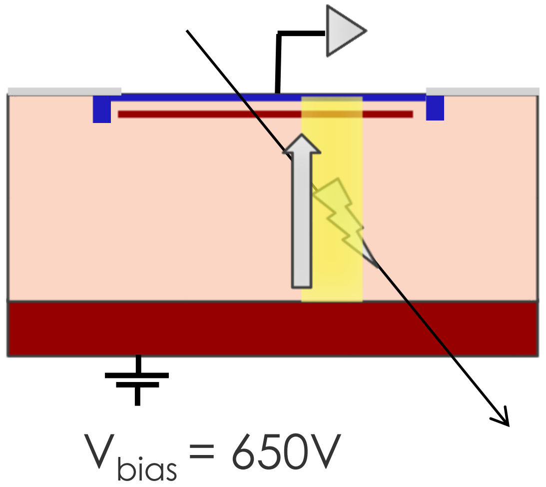
Part II: SEB-resistant LGAD design



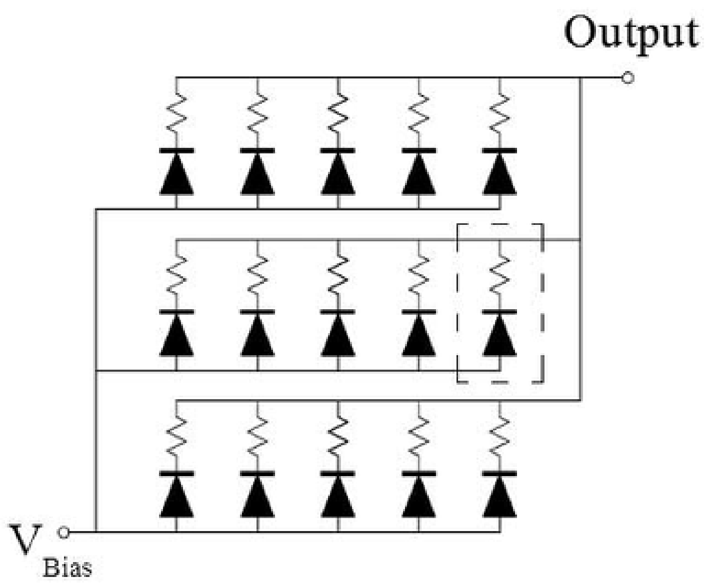
- **50 μm thick LGAD** sensors exposed to 120 GeV/c protons, when biased at 625V or higher (**12.5V/μm**) , break down permanently.
- **45 μm thick LGAD** broke down at 550V (**12.2V/μm)**
- 50 μm thick LGAD sensors, biased at 575V or less (**11.5V/μm**), did not break.
- **55 μm thick LGAD** survived many hours at 600V (**10.9V/μm**).

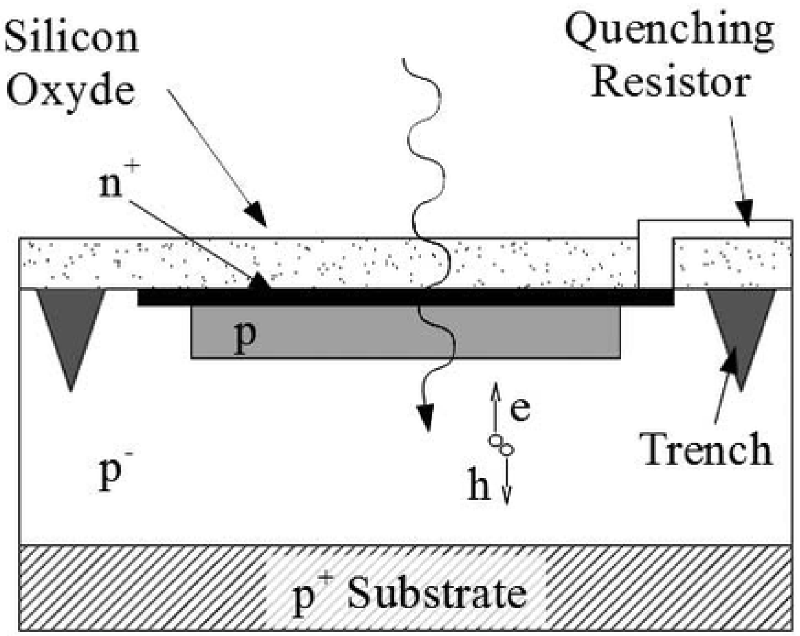
Threshold effect: SEBs happen quickly if the Electric field is high enough





SiPM: aide mémoire

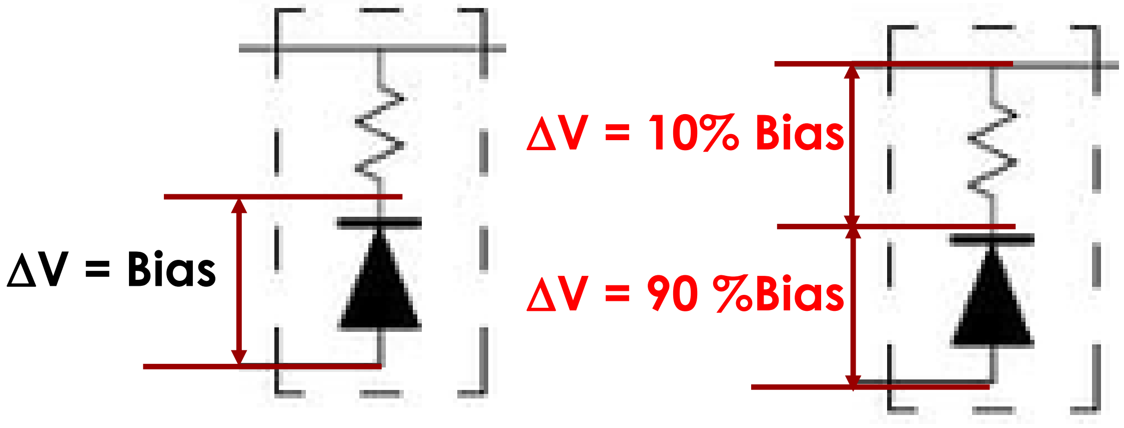




SiPM: one single bias, working in avalanche mode

SiPMs do not burnout. Why?

1) A SiPM goes into avalanche
2) A large current flows
3) A fraction of ΔV shifts from the capacitor to the resistor, **ΔV = Vbias-V_{BD}**
4) The voltage on the silicon bulk drops,
5) The avalanche is quenched
6) The capacitor does not discharge, ΔV is preserved



No signal

Signal

SEB-resistant LGAD design

Can we add a quenching resistor in LGAD?

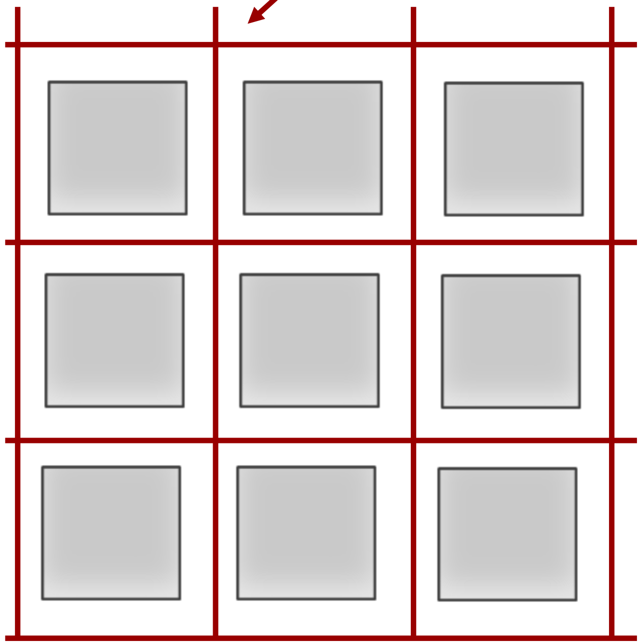
What are the consequences?

- **Where do we connect the resistors to ground?**
- **Do we spoil the signal shape?**
- **Do we increase dramatically the fill factor?**
- **How do we do this study?**

LGAD matrix with grid guard-ring

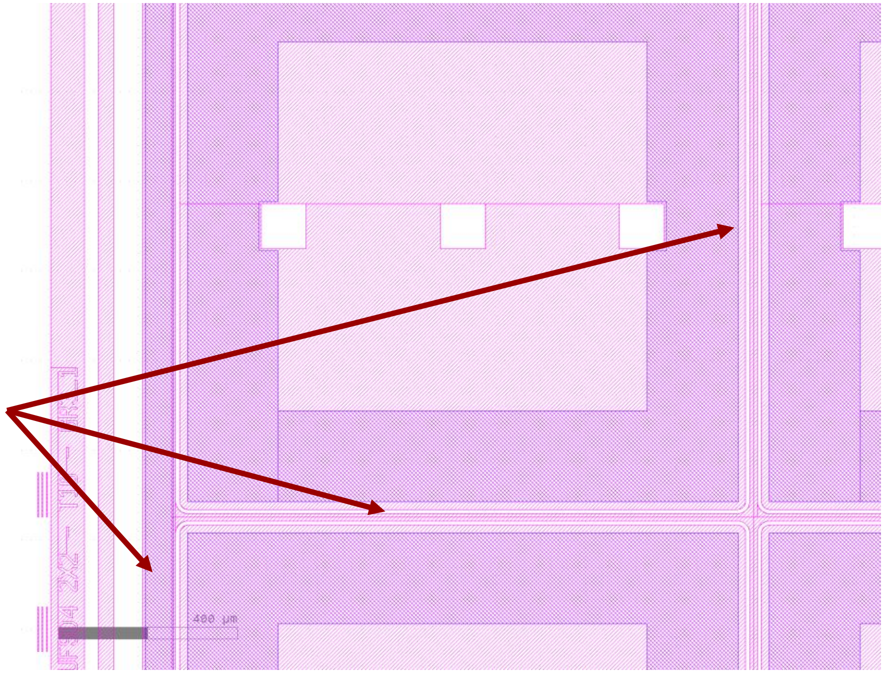
Independently from the SEB issue, FBK has developed LGAD matrices with a grid guard-ring, i.e., there is a ground grid among the pads (the so-called FBK UFSD Type10)

Grid guard ring



No-gain region ~ 70 um

Grid guard ring



We have a design where each pad has a near-by ground. Can we use it?

LGAD: aide mémoire

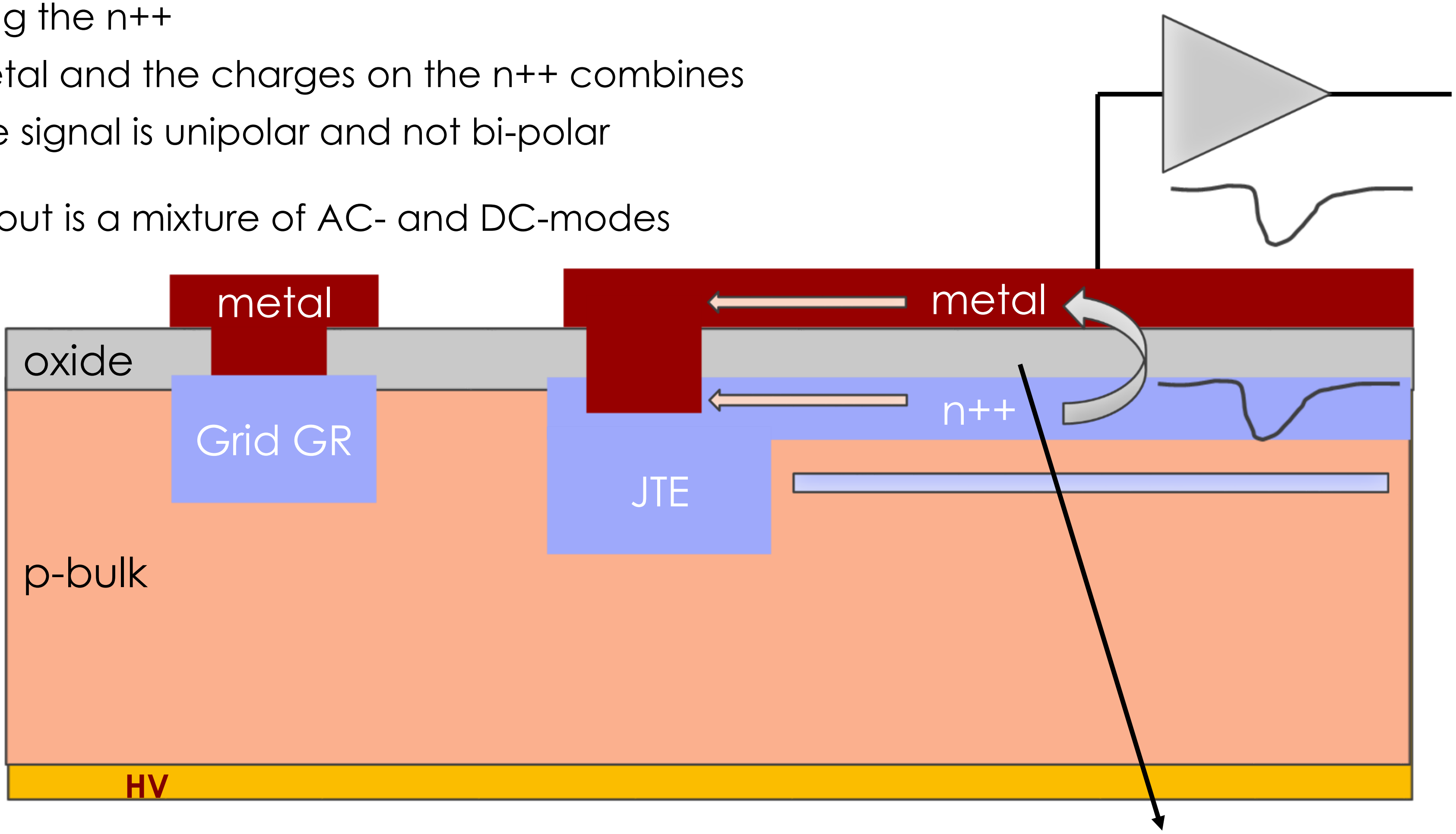
Signal formation:

- The signal is formed on the n++
- It is AC-coupled to the metal

  ==> that is why the timing is not "position dependent" as it is in "not metallized" LGADs.
- Charges travels along the n++
- The signal on the metal and the charges on the n++ combines

  ==> that is why the signal is unipolar and not bi-polar

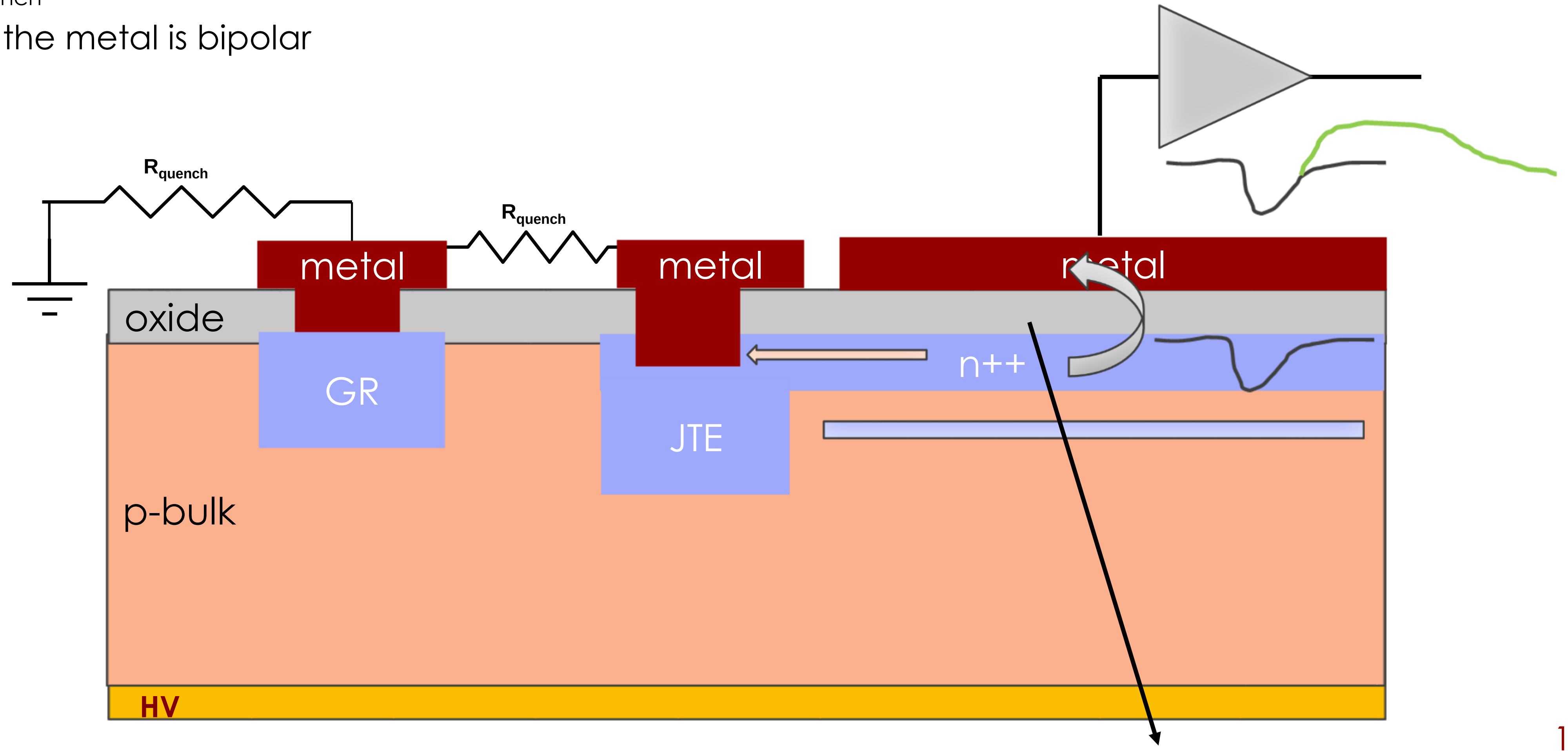
Oddly, the LGAD read-out is a mixture of AC- and DC-modes



LGAD with quench resistor

Let's imagine a new design:

- The signal is formed on the n++ and it is AC-coupled to the metal
- Charges travels along the n++
- Goes via R_{quench}
- The signal on the metal is bipolar



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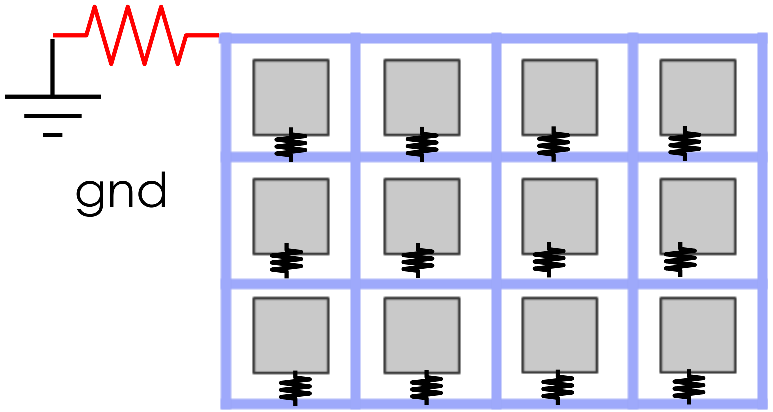
Note: every diode needs to have a resistor

Beam-tests demonstrated that not only the pads but also the guardrings are suffering from SEB

Restistors need to be placed in:

1) Pads to grid guard-ring
   (necessary for AC read-out and pad isolation)
2) Grid guard-ring to gnd
3) Your ideas here….



R_{quench} needs to:

- Limit the current in case of a quench
- Be high resistive to limit the signal loss
- Small enough for a fast recovery τ = RC
- Generate enough ΔV to quench the avalanche

Position of R_{quench} : the closer to the diode, the smaller the amount of charge flowing $Q = \Delta V^* C_{total}$

Example:

- R_{quench} = 100 kOhm
- ΔV = Vbias – Vbreakdown ~ 100V
- Max current = 100V/ 100 kOhm ~ 1 mA

Performances:

- Signal loss minimal ~ 50 Ohm/100 kOhm
- RC = 100kOhm*5 pF = 500 ns

Wrap-up SEB-resistant LGAD design

Can we add a quenching resistor in LGAD?

What are the consequences?

- **Where do we connect the resistors to ground?**
  - To the grid guard-ring and at the periphery of the grid
- **Do we spoil the signal shape?**
  - The fast part won't change, it will not affect the timing performance
- **Do we increase dramatically the fill factor?**
  - Probably it won't change with respect of UFSD Type10 (~ 70 micron no-gain distance)
- **How do we do this study?**
  - FBK will propose an RD50 project in the near future

Acknowledgements

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- RD50, CERN
- MIUR, Dipartimenti di Eccellenza (ex L. 232/2016, art. 1, cc. 314, 337)
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- Ministero della Ricerca, Italia, FARE, R165xr8frt_fare
- INFN CSN5