4DShare

CSN5 experiment: 4DShare

- Long title:

DC-resistive readout in silicon sensors with internal gain: signal sharing for future 4D tracking

- Coordinator: Roberta Arcidiacono

- Units: INFN Torino, INFN Perugia, TIFPA .

- Research field: PE2_3

- Duration: 3 years

Project Goals

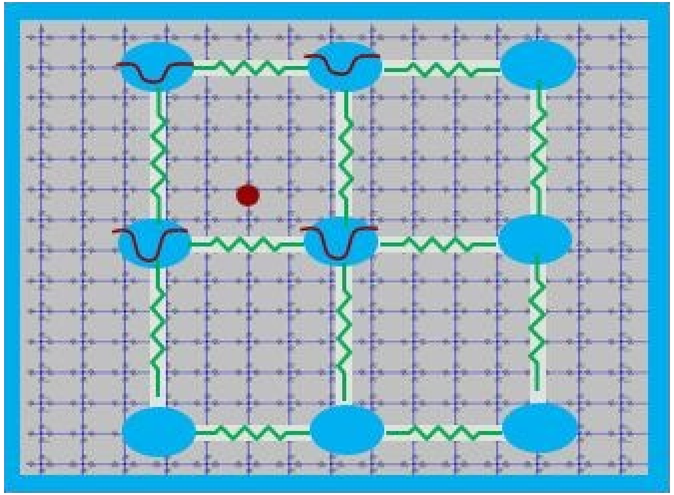
This project aims at evolving the RSD design to **overcome the limits**

e.g., long tail-bipolar signals, baseline fluctuation,

while **maintaining** their stronger **advantages**

e.g., signal spreading, 100% fill factor.

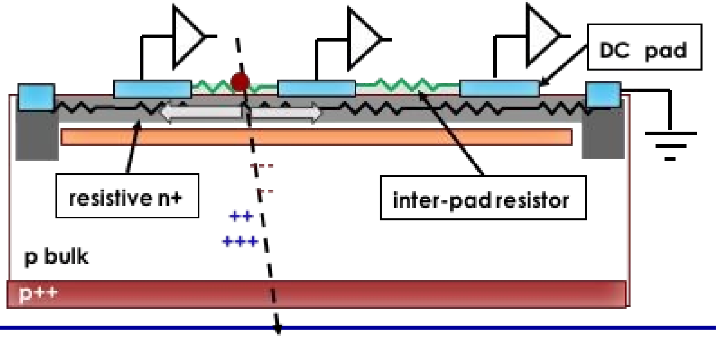
Key point: controlled signal sharing in a predetermined number of pads



Technical innovation: the sensor is a thin LGAD with a **resistive DC-coupled read-out** (DC-coupled Resistive Silicon Detector, **DC-RSD**). Signals are **DC-coupled, unipolar and contained within a grid of resistors.**

Main goals:

1. Define the design using analytic modeling, TCAD and SPICE.
2. Develop the process flow to manufacture DC-RSD.
3. Obtain the proof of concept with a first prototype run of DC-RSD.
4. Optimize the design in a second prototype run.



Milestones

WP1
- **Definition of the DC-RSD design parameters for the first production (5/23) → 90%**
- **Identification of the most radiation-hard structures (6/23) → 60%**
- Definition of the DC-RSD design parameters for the second production (Q3/24)

WP2
- **DC-RSD wafer layout and split tables for first production (6/23) → 90%**
- **Delivery of 4DShare sensors run 1 and their electrical measurements (12/23)**
- DC-RSD wafer layout and split tables for second production (Q4/24)
- Delivery of 4DShare sensors run 2 and their electrical measurements (Q2/25)

WP3
- **Provide dataset (on AC-LGAD) for tuning of simulation (5/23) → 100%**
- Determination of the best doping splits of the DC-RSD productions (Q3/24)
- Evaluation of the radiation hardness of DC-RSD sensors run 1 and run 2 (Q4/25)

WP4
- **Have an analytic reconstruction code package which provides the best position and time resolutions for several existing AC-LGADs sensors (3x3 or 4x4) (Q4/23)**
- Provide the position and time resolutions for the different DC-RSDs types (using 3x3 or 4x4 matrices) (Q4/24)

Publications & Conferences

- **Pubblications:**
  - T. Croci et al., “A two-prong Approach to the Simulation of DC-RSD: TCAD and Spice”,
    to be submitted in Transaction on Nuclear Science.
  - T. Croci et al., “ Development and test of innovative Low-Gain Avalanche Diodes for particle tracking in 4 dimensions”,
    NIM A, 1047 (2023) 167815.
  - F. Moscatelli et al., “TCAD simulations of innovative Low-Gain Avalanche Diodes for particle detector design and optimization”,
    to be submitted in JPS Conference Proceedings.

- **Presentations at Conferences**
  - F. Moscatelli et al., “TCAD simulations of innovative Low-Gain Avalanche Diodes for particle detector design and optimization”
    at VERTEX 2022 (**invited oral**).
  - A. Fondacci et al., “ TCAD simulations of DC-RSD LGAD devices ”
    at FAST 2023 (**oral**).
  - T. Croci et al.,“A two-prong Approach to the Simulation of DC-RSD: TCAD and Spice”
    at IEEE NSS MIC RTSD 2022 (**oral**)
  - T. Croci et al., “Development and test of innovative Low-Gain Avalanche Diodes for particle tracking in 4 dimensions”
    at Pisa Meeting 2022 (**poster**).

Financial requests

Team (fraction of FTE):

INFN - Sezione di Torino (1 FTE):

- *R. Arcidiacono* 0.3
- N. Cartiglia 0.2
- M. Ferrero 0.2
- V. Monaco 0.3

INFN - Sezione di Perugia (1 FTE) :

- *A. Morozzi* 0.5
- D. Passeri 0.3
- F. Moscatelli 0.2

TIPFA (1 FTE) :

- *M. Centis Vignali* 0.4
- M. Boscardin 0.1
- G. Pepponi 0.1
- S. Ronchin 0.1
- O. Hammad Ali 0.3

Richieste Finanziarie:

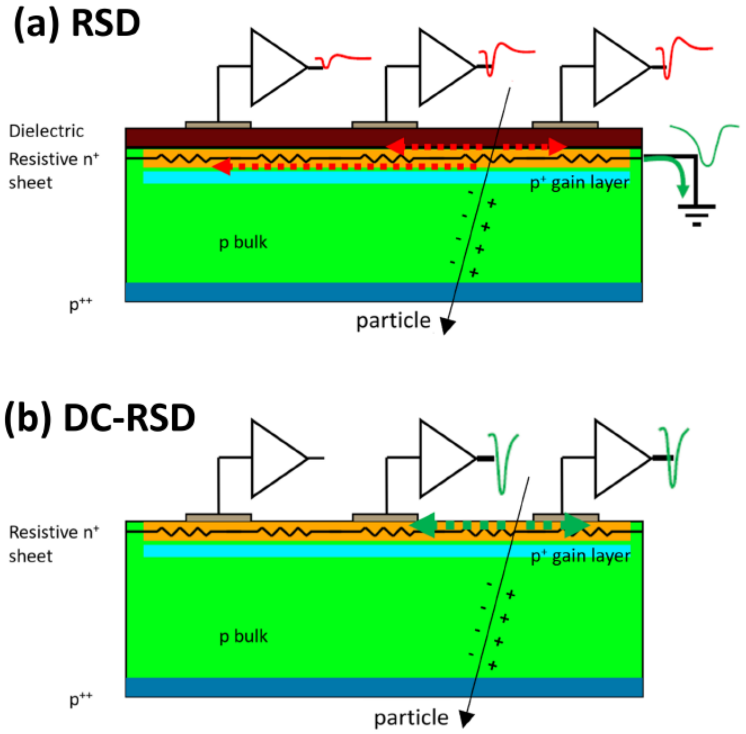
PERUGIA - Group

	2023	k€	2024	k€	2025	k€
Travels	Collaboration meetings	1.0	Collaboration meetings	1.0	Collaboration meetings	1.0
Software packages and licenses	Synopsys Advanced TCAD	2.0	Synopsys Advanced TCAD	3.0	Synopsys Advanced TCAD	3
Hardware	Workstation	5.0	-	-	-	-
Consumables	Laboratory consumables	1.5	Laboratory consumables	1.5	Laboratory consumables	1.5
TOT	**-**	**9.5**	**-**	**3.8**	**-**	**3.8**

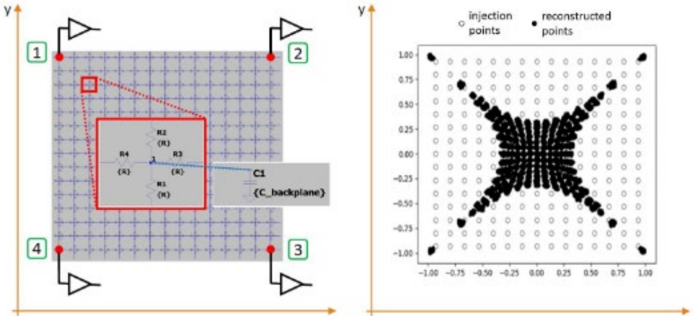
4DShare is in synergy with CMS

A new RSD design: DC-coupled RSD (DC-RSD)

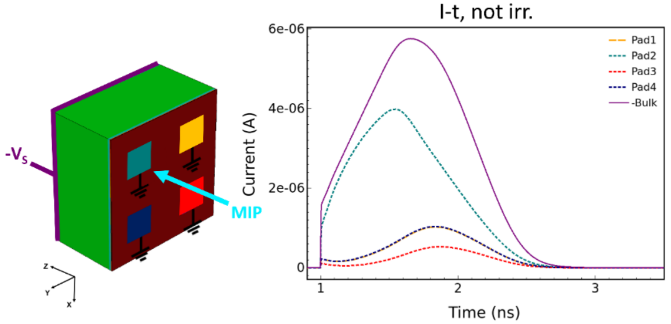
- The sensor is a thin **LGAD** with resistive DC-coupled read-out.
- Emerging technology for spatial and timing detection (4D-tracking).
- Continuous n^{+}-resistive electrode and a continuous p^{+}-gain layer, thus avoiding segmentation that affects the fill factor.
- The simulation of DC-RSD presents several unique challenges linked to the complex nature of its design and to the large pixel size.
- Mixed-model approach to the DC-RSD simulation, which combines TCAD and Spice (circuit and device).



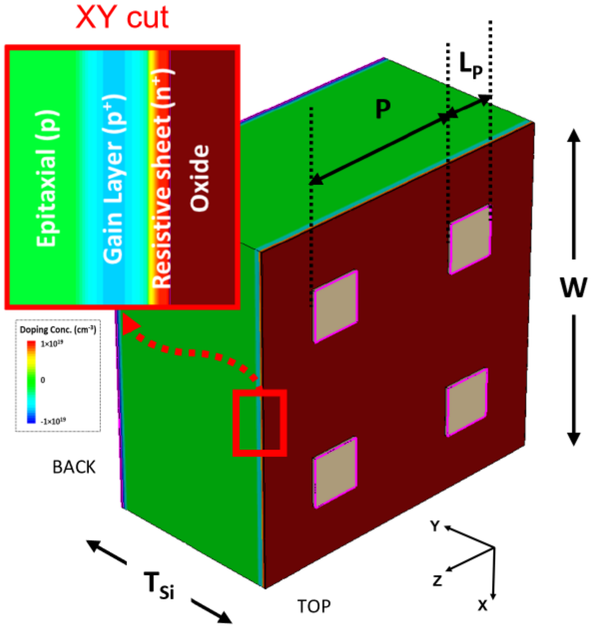
DC-RSD simulation: a mixed-mode approach



Simulations of the output waveforms in **Spice environment**, accounting for an equivalent lumped-element electrical model (left), by injecting a test input signal → **reconstruction of the particle impact position** (right) with very short simulation times [1].
→ Proof of principle.



Full 3D TCAD simulation to characterize the device behavior in terms of response after the passage of a charged particle, e.g. a minimum ionizing heavy ion => the key features of the RSD' design, i.e. **excellent timing** and **spatial resolutions** (few tens of ps and µm), are maintained with the new paradigm of DC-RSDs.

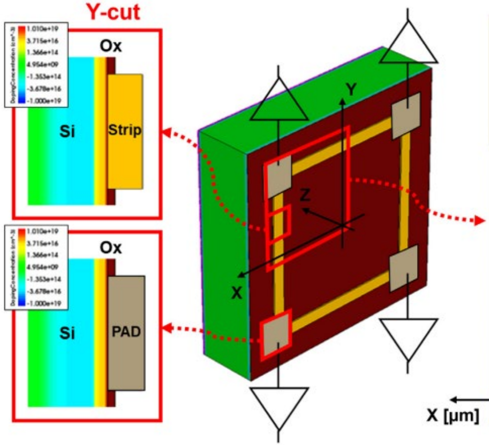


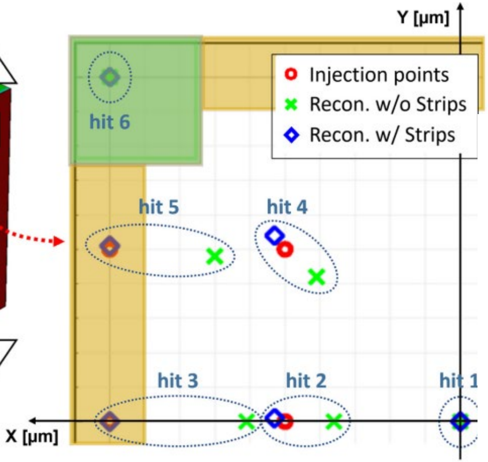
TCAD model of a 50 µm-pitch four-pad DC-RSD device in 3D domain.

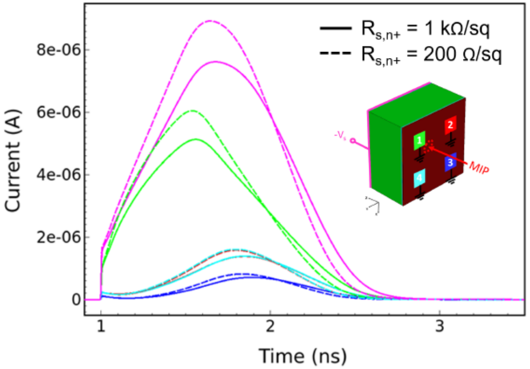
[1] L. Menzio et al., "DC-coupled resistive silicon detectors for 4D tracking", NIM A, 1041 (2022) 167374.

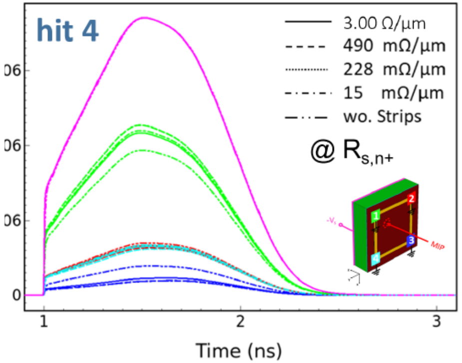
TCAD simulations of DC-RSD

- The accuracy of the position reconstruction increase by considering **strip-connected pads in the DC-RSD design**
- By varying the shape of the n^+-resistive sheet implant (i.e., the thickness and the doping concentration), we have explored the impact of different values of the sheet resistance (R_{s,n^+}) on the DC and TV behaviour of the sensor.
- Study of the impact of different values of the strip resistance on the TV behaviour of the device and on the reconstruction of the particle impact positions.



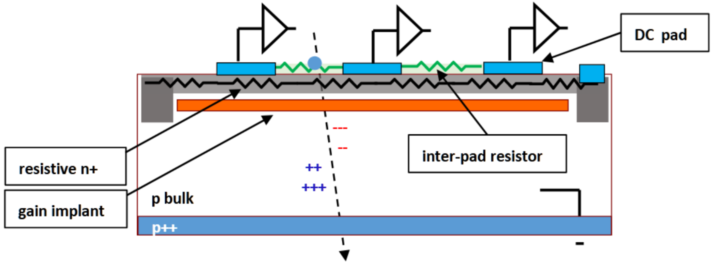






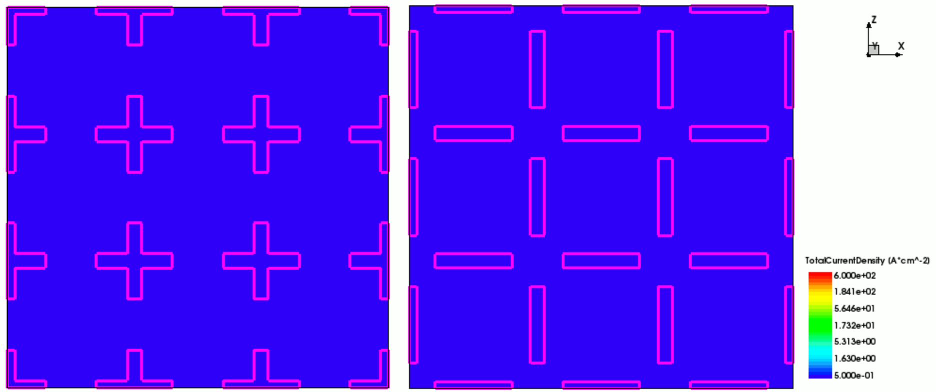
DC-RSD with resistors

- By accounting for resistors between the readout electrodes in the DC-RSD design the resolution of the sensors improves).



Signal confinement

- Investigation of different pad geometries aiming at the confinement of the signal within its generating cell.
- Account for the radiation damage effects.



Backup

Introduction

Sensors for 4D tracking:

- many years of R&D on thin LGAD technology, delivered sensors (pixel size O(1 mm^2)) with 30 ps time resolution (**UFSD project GR5 - 2015**): large inter-pad region not suitable for small pixel size!
- recent developments to decrease inter-pad region (keeping the excellent time resolution of thin LGAD)
  - **Trench-Isolated LGADs**: have inter-pad areas of few microns. Very promising technology for small pixelated devices (single pixel read-out) (**RD50 project @FBK**)
  - **Resistive AC-LGADs (RSDs)**: have a 100% fill factor and signal sharing among pads and improved position resolution (**RSD Grant Giovani GR5 - 2018**)

metal pad size - pitch	50 -100	100-200	150 - 300	200-500
Sigma_x (microns)	**4**	**5.5**	**5.9**	**15**

=> RSD1 production (2019) demonstrated the soundness of the idea. RSD2 production (2021) optimized the design and improved performances.

drawbacks: 1) position-dependent number of read-out pads involved -> non-uniform response
2) design not easily scalable to large area sensors

Methodology

Methodology to reach the goals of the project

1. Define the design using analytic modeling, TCAD and SPICE
    - tune the simulation (TCAD, SPICE) using results from existing RSD sensors (AC-coupled)
    - use the simulation tools to identify the production parameters (ranges)
2. Develop the process flow to manufacture DC-RSD
    - do engineering runs to develop the technical skills needed for DC-RSD (Ti-TiN resistor, metal implantation on shallow resistive layer)
3. Obtain the proof of concept with a first prototype run of DC-RSD
    - design and produce a first DC-RSD prototype run
    - perform full characterization of the production, with static and dynamic measurements in the laboratory, and at least one beam test
4. Optimize the design in a second prototype run
    - improve the simulation using the results from DC-RSD1
    - design, manufacture, and test DC-RSD2