Resistive AC-Coupling: a new readout paradigm in 4D tracking with Ultra-Fast Silicon Detectors

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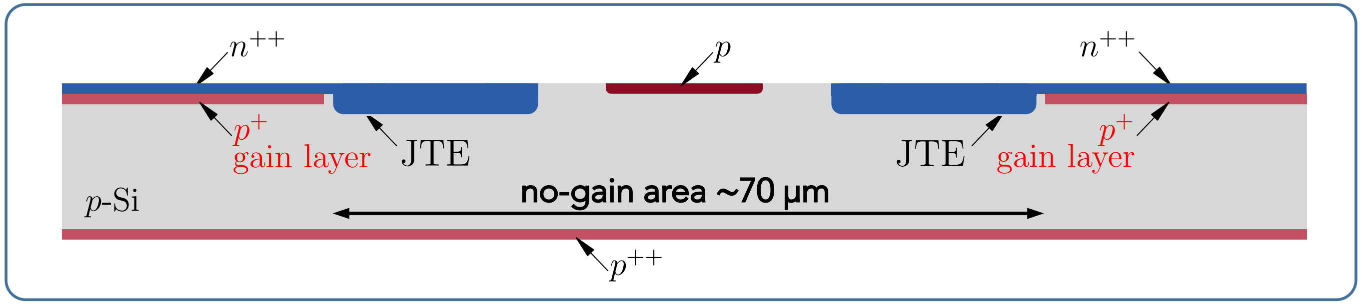
Motivations

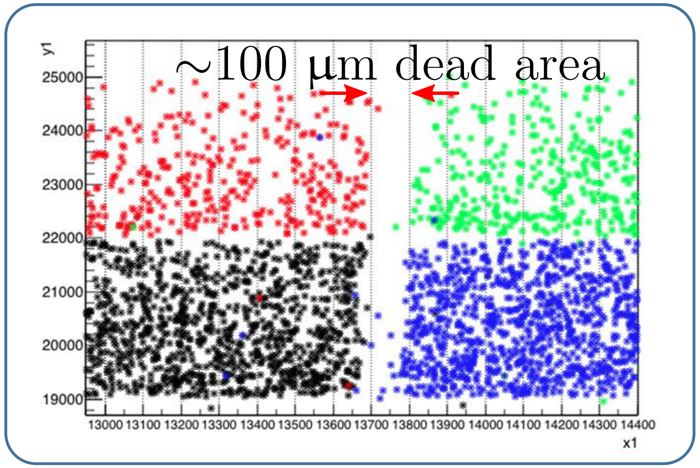
- In the current **UFSD** design, **isolation structures** between readout pads represent a **no-gain area** for the signal collection



present limit of no-gain area in the UFSD design 70-100 µm

- **Beam-test** results confirm the presence of a non-gain space between active regions:
    - **HPK**: 100 µm
    - **FBK**: 70 µm
    - **CNM**: 70 µm

pre-print on 2017 test-beam @ FNAL (H. Sadrozinski *et al.*)



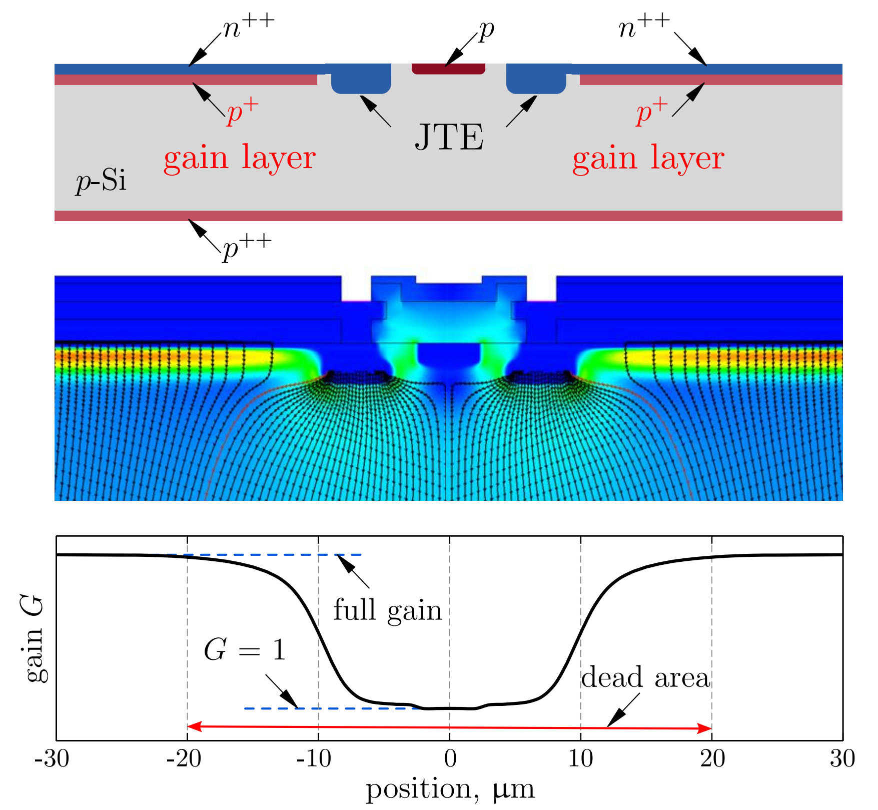
Motivations

- **TCAD simulations** performed on 50-μm UFSD show that, even with the **most aggressive design rules**, a **no-gain area of about 40 μm** is produced

device sketch

field simulation

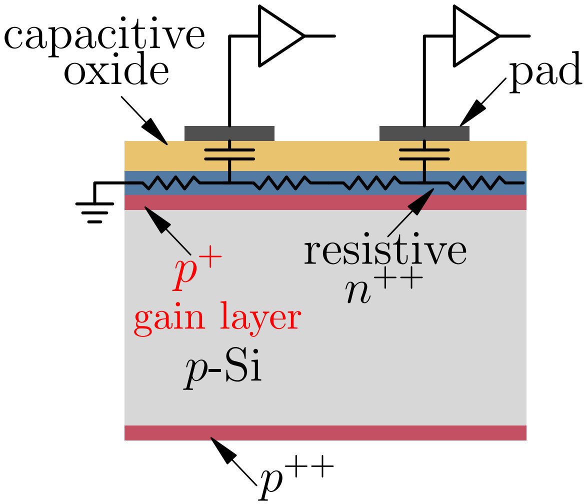
gain simulation



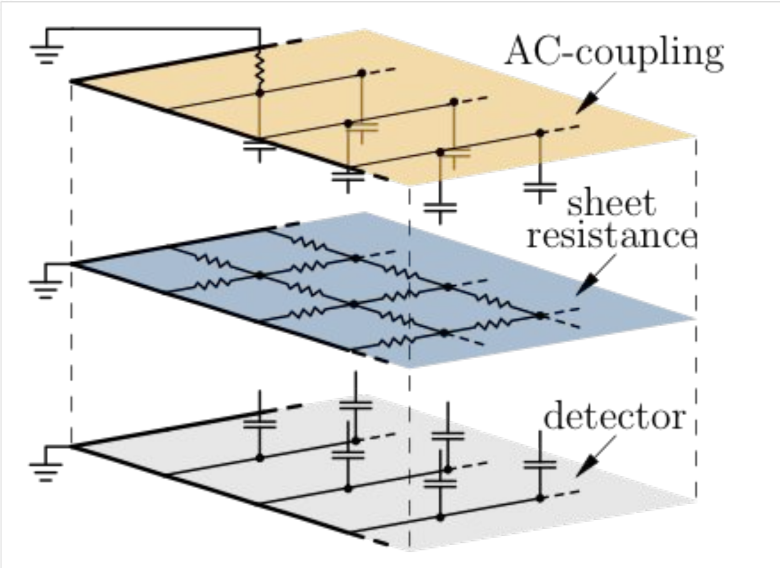
physical limit
30-40 μm

The RSD paradigm

Resistive AC-Coupled Silicon Detectors – RSD



device-level sketch

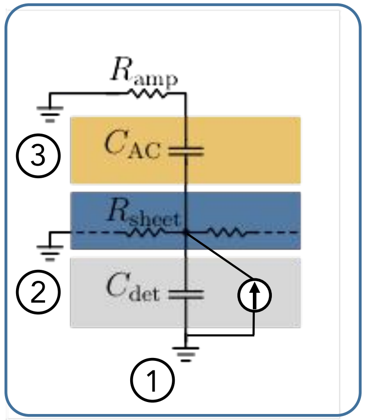


circuital model

The RSD paradigm

Design Goals:

- Realize a readout with the **lowest impedance path**
- The **readout characteristic time** is short enough for the signal to be seen, and long enough to minimize pile-up



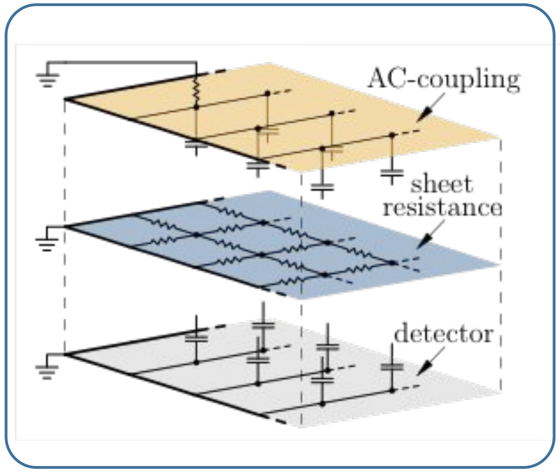
1) **Detector bulk:**
   Small detector capacitance C_{det} (units of pF) then
   ⇒ **High** signal **impedance**

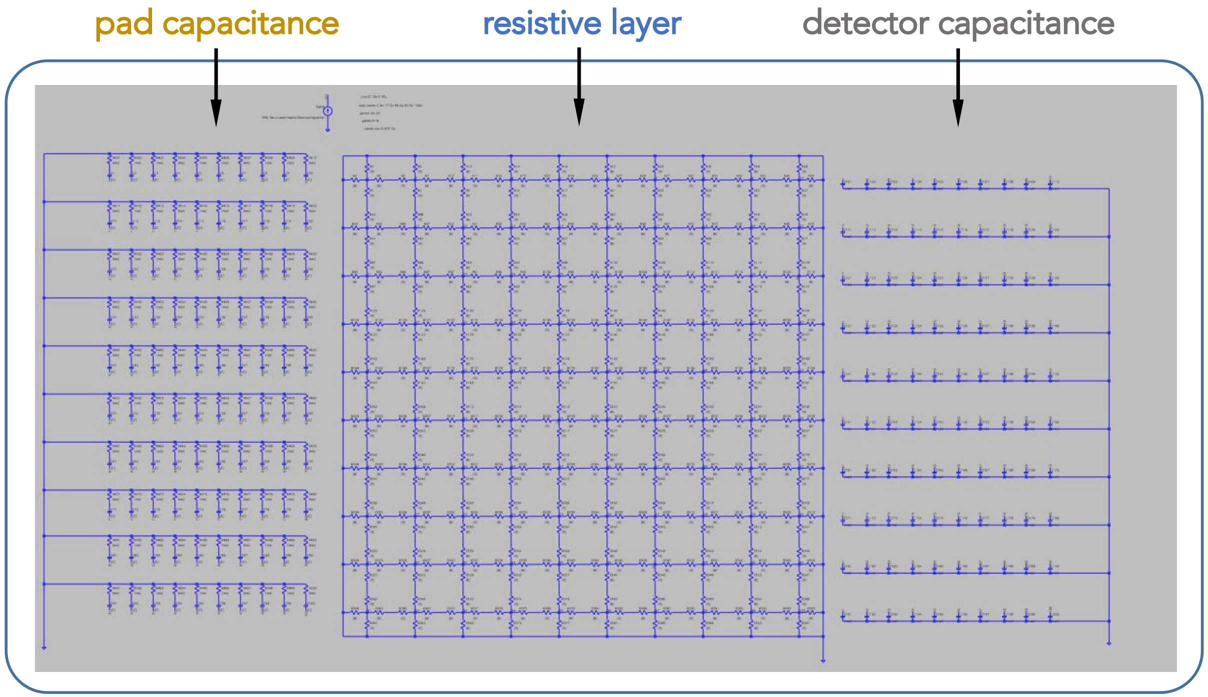
2) **Resistive layer:**
   Resistivity in the n^{++} **layer** will be accurately chosen
   ⇒ Example 1: R_{sheet} **= 1 kΩ** (i.e. discharging time t **~100 ns**)
   ⇒ Example 2: R_{sheet} **= 60 Ω** in AC-LGAD by CNM

3) **AC coupling + amplifier input impedance:**
   Since we expect C_{AC} ~ 100 pF then
   ⇒ **Low** signal **impedance**

RSD preliminary simulations

The **equivalent circuit** is modeled with **Spice**





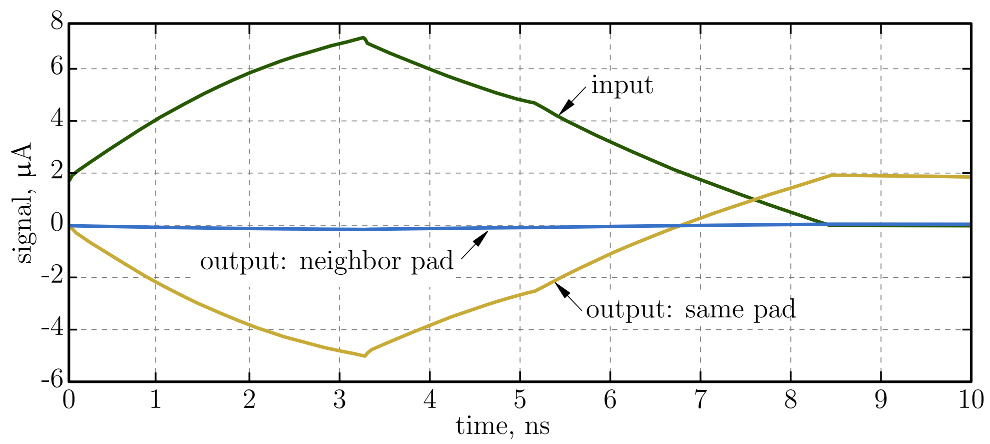
How large should the AC pad be so that the **signal is similar to the input current**, still having a **large coupling capacitance**?

RSD preliminary simulations

Cross-talk between pads

Simulation parameters:

Pad size: **500 x 500 μm^2**
Oxide/passivation thickness: **250 nm**
Pad capacitance: **C_{AC} = 48.5 pF**
Sheet resistance: **R_{sheet} = 1 kΩ**
Detector capacitance: **C_{det} = 0.3 pF**
Output resistance: **R_{amp} = 50 Ω**



simulations performed by M. Ferrero

- By choosing the optimal circuital parameters, **each read-out pad is almost insensitive to next-neighbor nodes**
- Thanks to the **high sheet resistance R_{sheet}**, the pre-amp stage sees only a **small volume** of the detector, so that the noise due to leakage contribution is similar of that of standard UFSD

RSD preliminary simulations

Sheet resistance homogeneity

Simulation parameters:

Pad size: **500 x 500 μm^2**
Oxide/passivation thickness: **250 nm**
Pad capacitance: C_{AC} **= 48.5 pF**
Sheet resistance: R_{sheet} **= 1 kΩ**
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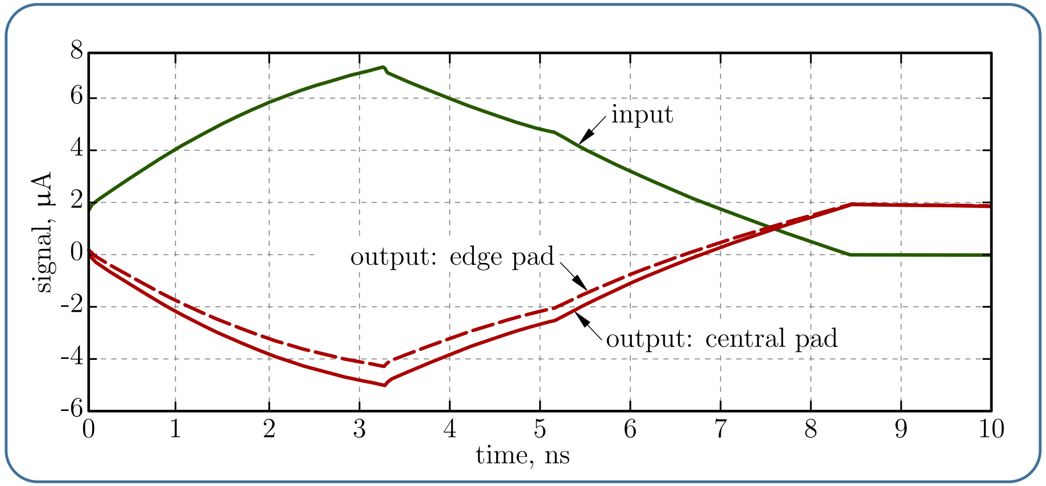
Output resistance: R_{amp} **= 50 Ω**



simulations performed by M. Ferrero

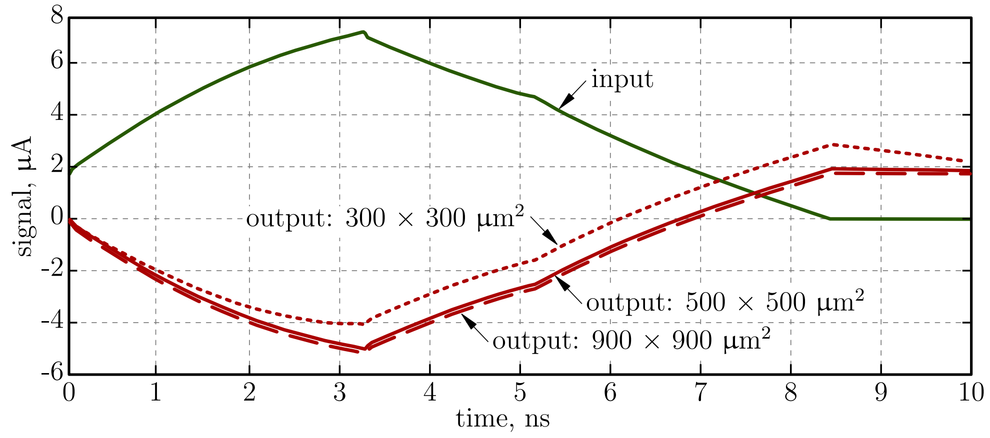
► The **difference** in terms of **signal peak** is about **0.4 μA**

RSD preliminary simulations

Pad size

Simulation parameters:

Pad size: 300 - 500 - 900 μm
Oxide/passivation thickness: **250 nm**
Pad capacitance: C_{AC} **= 48.5 pF**
Sheet resistance: R_{sheet} **= 1 kΩ**
Detector capacitance: C_{det} **= 0.3 pF**
Output resistance: R_{amp} **= 50 Ω**



simulations performed by M. Ferrero

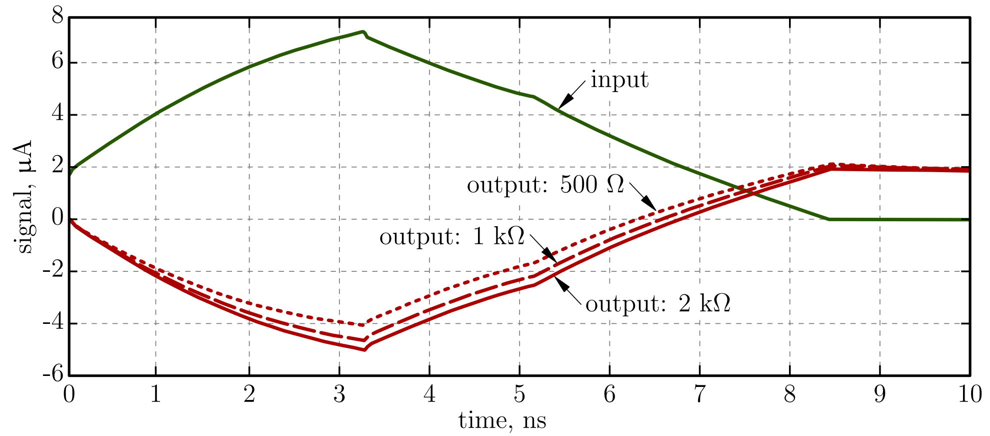
- The output **signal is larger when pad area increases**

RSD preliminary simulations

n^{++} resistivity

Simulation parameters:

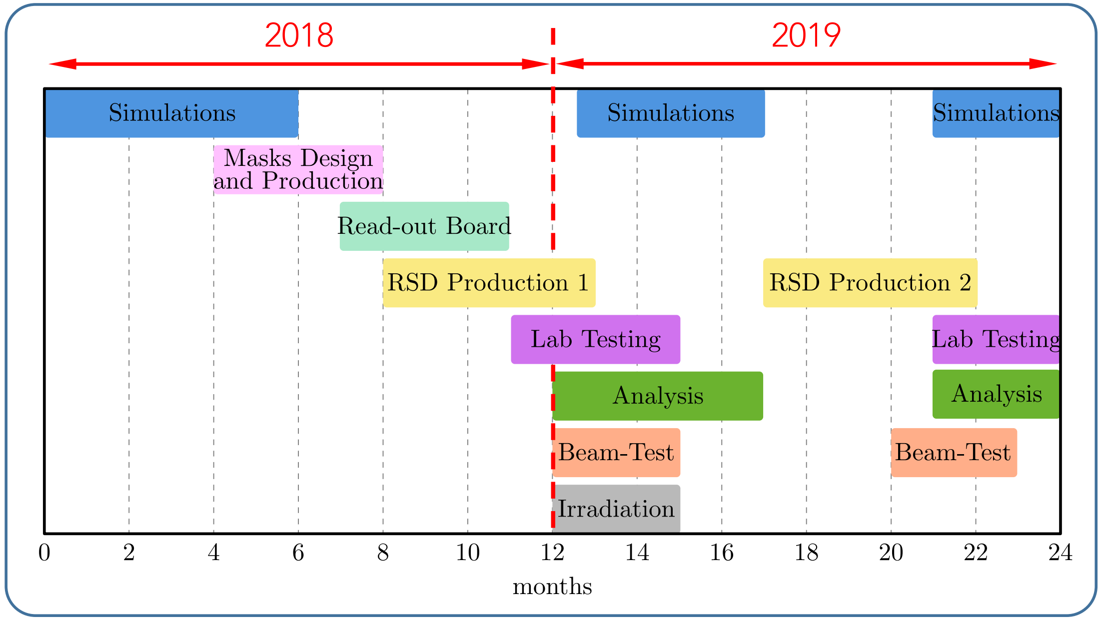
Pad size: **500 x 500 μm²**
Oxide/passivation thickness: **250 nm**
Pad capacitance: C_{AC} **= 48.5 pF**
Sheet resistance: R_{sheet} **= 0.5 - 1 - 2 kΩ**
Detector capacitance: C_{det} **= 0.3 pF**
Output resistance: R_{amp} **= 50 Ω**



simulations performed by M. Ferrero

► In UFSD the n^{++} **layer** is generally doped by **As with** $N_{peak} \sim 10^{19}$ **cm⁻³** and depth approximately **1 μm**. Sheet resistance between **0.1 Ω** and some **units of kΩ** can be achieved while maintaining a doping high enough to obtain a working UFSD

The project planning



- Involved Institutes: **INFN-Torino** & **FBK**

- Working packages:

WP1: Spice and TCAD **simulations**

WP2: design and production of **lithographic masks**

WP3: RSD productions

WP4: readout **board production** and laboratory **testing** of sensors

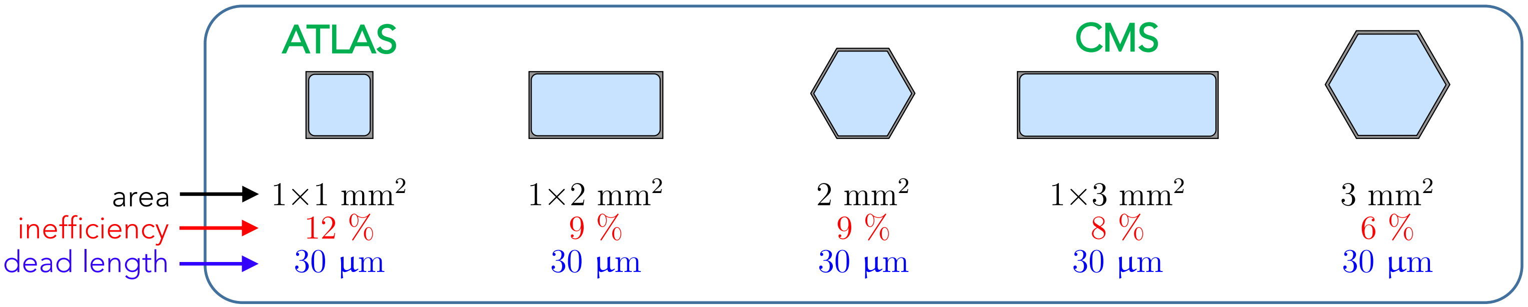
WP5: beam tests at CERN North Area

WP6: irradiation

- Total cost: **~100 kE** (funded by INFN)

Conclusions

- The **RSD project** – already approved by INFN – wants to circumvent the issues related to low fill-factors, by completely **eliminating the no-gain** area between adjacent pads
- The most important **application fields of RSD devices** could be the **high-rate**, **radiation-intense** and **high-pile-up environments** (high-energy physics), but also in other areas of applied physics as in **therapeutic beam monitoring**, where the UFSD technology is currently under consideration (see Anna Vignati's talk)



- **Collaboration** with other research groups working on **AC-LGADs** is highly welcome!

see you in **next Trento Workshop** with **updates about the RSD project!**

Acknowledgments

RSD is a project supported by the "**Gruppo 5**" of the **Italian National Institute for Nuclear Physics (INFN)**

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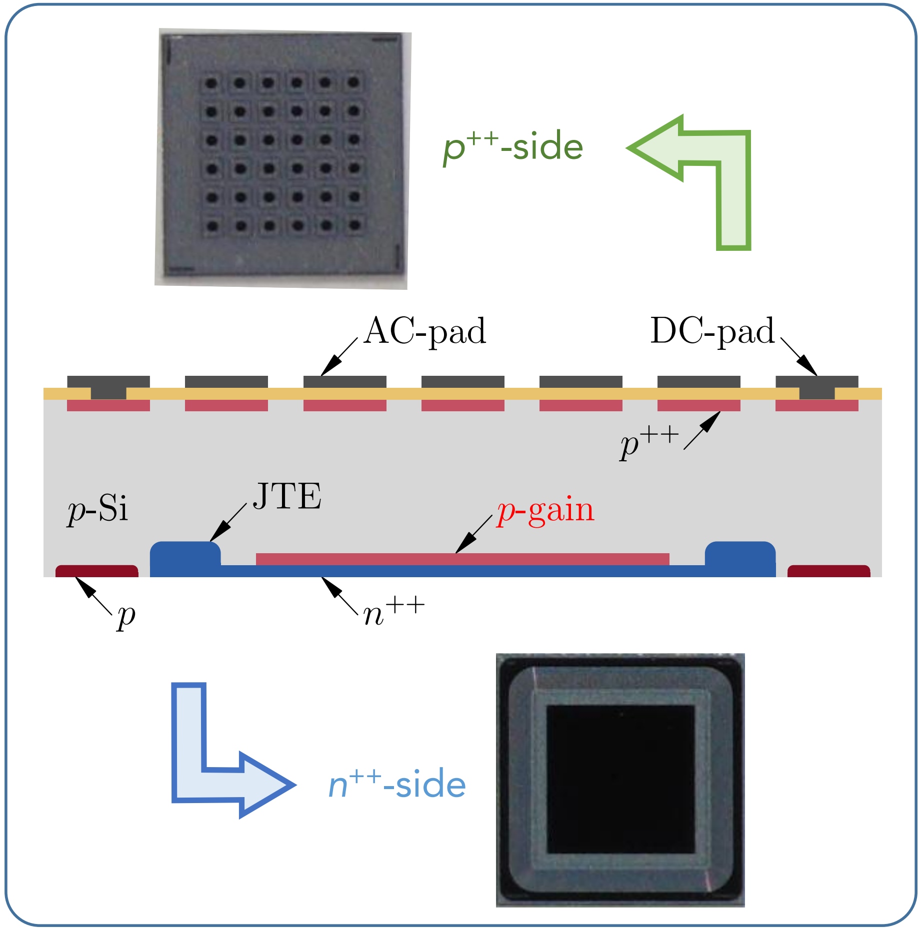
L. Pancheri, G. F. Dalla Betta (Trento University)

Thank you for your attention!

Backup

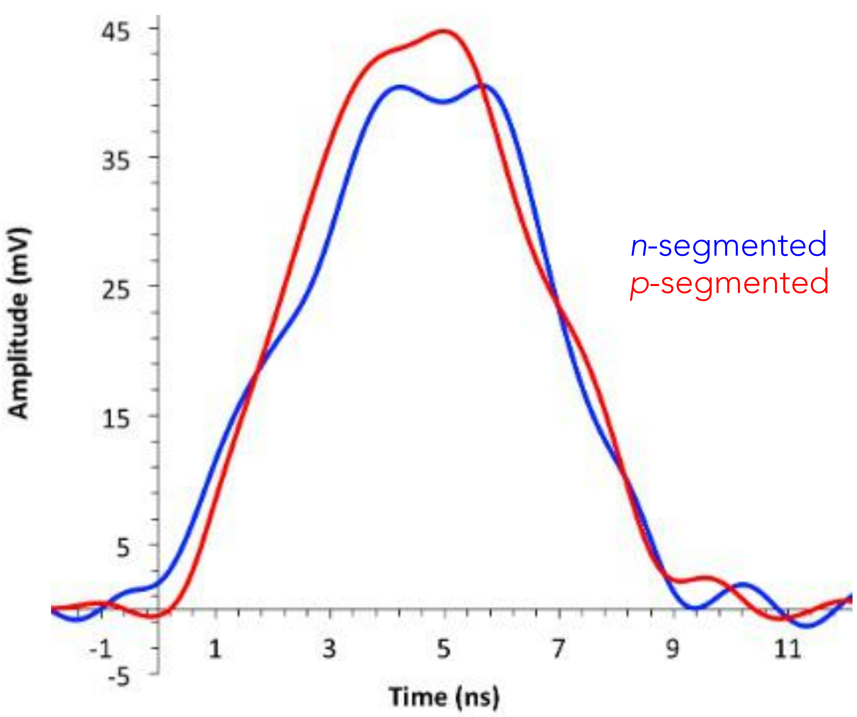
p-segmented UFSD1



Besides *n*-segmentation, the first UFSD production at FBK (300 μm) also accounted for ***p*-side segmentation**.

p-segmented UFSD1

DC-measurements



Besides *n*-segmentation, the first UFSD production at FBK (300 μm) also accounted for ***p*-side segmentation**.

- **No relevant differences between the two signals** (pad size ≫ thickness)
- *n*- and *p*-segmented sensors have the **same weighting field**
- *n*- and *p*-segmented signals have the **same width** (~9 ns);