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XXXVI Cycle

# CMOS Radiation Sensors for Fast Timing Applications


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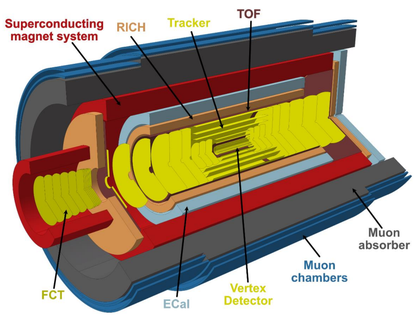
## Research context and motivation

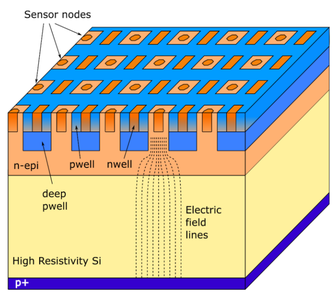
- **ALICE Experiment** is studying the properties of strongly interacting matter at **CERN**
- **ALICE 3** upgrade (2035): The new detector concept includes 2 new **Times of Flight (ToF)** layers for **PID**
  - Target : **20 ps** time resolution
- **Fully Depleted Monolithic Active Pixel Sensors** - FDMAPS
  - Sensor and readout electronics in the same silicon wafer
  - Full depletion of the substrate allows to collect the charge mainly by **drift**

Compared to hybrid silicon detectors:
- Strong reduction in the material budget and costs
- Cheaper and simpler assembly

Still, a 20 ps time resolution far from the present technologies




ALICE 3 Detector



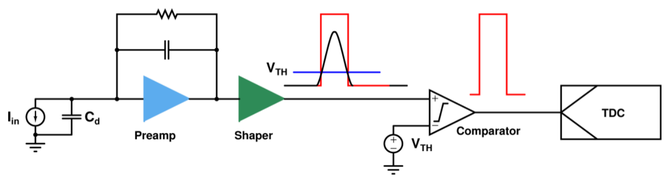

ARCADIA Sensors Scheme

**ARCADIA, INFN** project, as a first testbench :
- n-on-n sensor concept
- Deep p-well for CMOS electronics, 110 nm technology
- p+ boron doped backside layer, $V_{back}$ negative for starting full depletion

## Addressed research questions/problems

$$\sigma_t^2 = \sigma^2_{LandauNoise} + \sigma^2_{Distortion} + \sigma^2_{Jitter} + \sigma^2_{TimeWalk} + \sigma^2_{TDC} + \sigma^2_{ck}$$

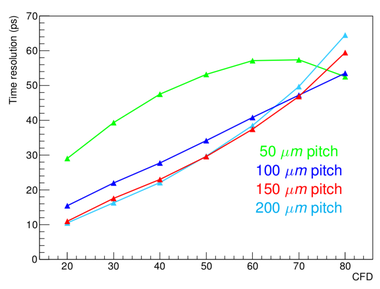
- ToF System key building blocks:
  - Sensor
  - Very front-end electronics
  - TDC, ck management system and readout electronics




- Up to now, the best time resolution achieved is > 100 ps
  The resolution limit is at the **sensor front-end interplay**

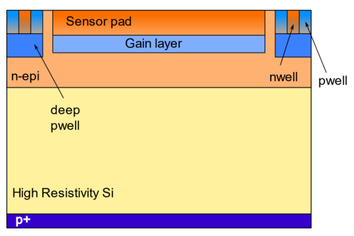
  **Sensor:**
  - Landau Noise – Fundamental limit
  - Distortion – Uniform and fast collection of the charge

  **Front-end:**
  - Jitter – Noise and GBW optimization
  - Time Walk – Correction techniques (ToT, Amplitude, CFD)




50 µm thick sensor resolution
C. Ferrero, G. Andrini

- ARCADIA pixel **sensor simulations** show:
  - Better time resolution for **l**arger pixel pitches (electrodes)
    **< 20 ps at a pixel pitch > 150 µm**
  - Thinner sensors show better results,
    but less charge collected - higher electronics jitter !




L. Pancheri

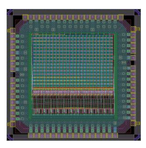
- An additional **Low Gain** layer implant can **increase** the **SNR**
  - A p doped gain layer can be added under the n electrode with minimal modification to the process
    Drawback:
  - sensor top biased at HV ( 40 V)
    Capacitive coupling with the 1.2 V CMOS electronics

## Novel contributions

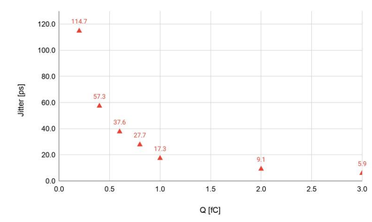
- This work is focused on the design of Fully Depleted CMOS sensors for fast timing applications in particle physics experiments
  - ARCADIA process FDMAPS prototype has been produced
  - A second different prototype implements a gain layer
- MAPS optimized for ps time resolution applications do not exist yet
- 20 ps resolution CMOS sensors will comply with the requirements dictated by ALICE 3 with the advantage of a strong reduction in the material budget and costs compared to hybrid solutions

## Adopted methodologies

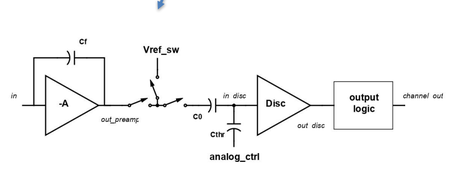
- 2 Prototypes have been designed and simulated with CAD simulation tools:



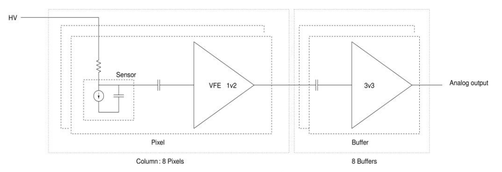
- HERMES
  - 2 x 2 $mm^2$
  - 50 µm pitch pixels
  - Preamplifier + Discriminator (ToT)
  - **$\sigma_{t\text{-}sensor}$ = 30/40** ps , **$\sigma_{t\text{-}fe}$ = 80** ps
  - **Silicon now available**



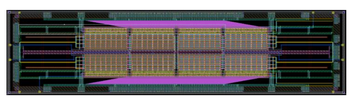

Jitter vs Q collected

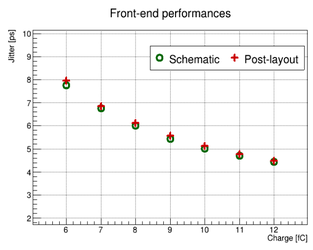



Channels block schemes




- Monolithic CMOS Avalanche Detector prototype
  - 16.4 x 4.4
  - Sensor gain between 10 and 20
  - 250 x 100 $\mu m^2$ pixels
  - Preamplifier, analog output
  - **$\sigma_{t\text{-}sensor}$ = 20** ps , **$\sigma_{jitter}$ < 10** ps
  - **Silicon available in December 2022**

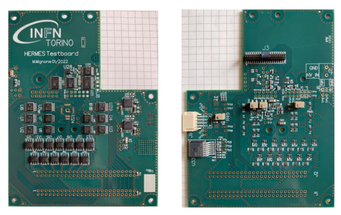





Jitter vs Q collected

## Future work

- HERMES is ready to be tested
  - Testboard produced at INFN
- The prototype with gain will be available in December 2022
  - Ongoing activities for the production of the testboard
- 2023 Test Campaign is ready to start



HERMES PCB – M. Mignone

## Submitted and published works


- S.Durando, "Ultra-Low Power Discrete-Time Readout for CMOS Radiation Sensors", Virtual IEEE Nuclear science symposium and medical imaging conference, Tokyo, 2021
- F.Carnesecchi et al., "Direct detection of charged particles with SiPMs", IOP Journal of Instrumentation, vol. 17, no. 06, 2022, pp. P06007
- F.Carnesecchi et al., "Beam test results of 25 µm and 35 µm thick FBK UFSD", Arxiv, 2022


## List of attended classes

- 01TSGKG, The Monte Carlo Method, 29/10/2021, 40

External Courses :
- Barcelona Technoweek, 19/4/2021, 34
- Integrated Circuits for Detector Signal Processing and Radiation Hardened Design, 16/10/2021, 5
- XXX Giornate di Studio sui Rivelatori, 13/6/2022, 35.07
- Low Power Analog IC Design - Mead Education, 29/8/2022, 30

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