Innovative pixel sensors for timing applications

Chiara Ferrero

Supervisor: Prof. Angelo Rivetti

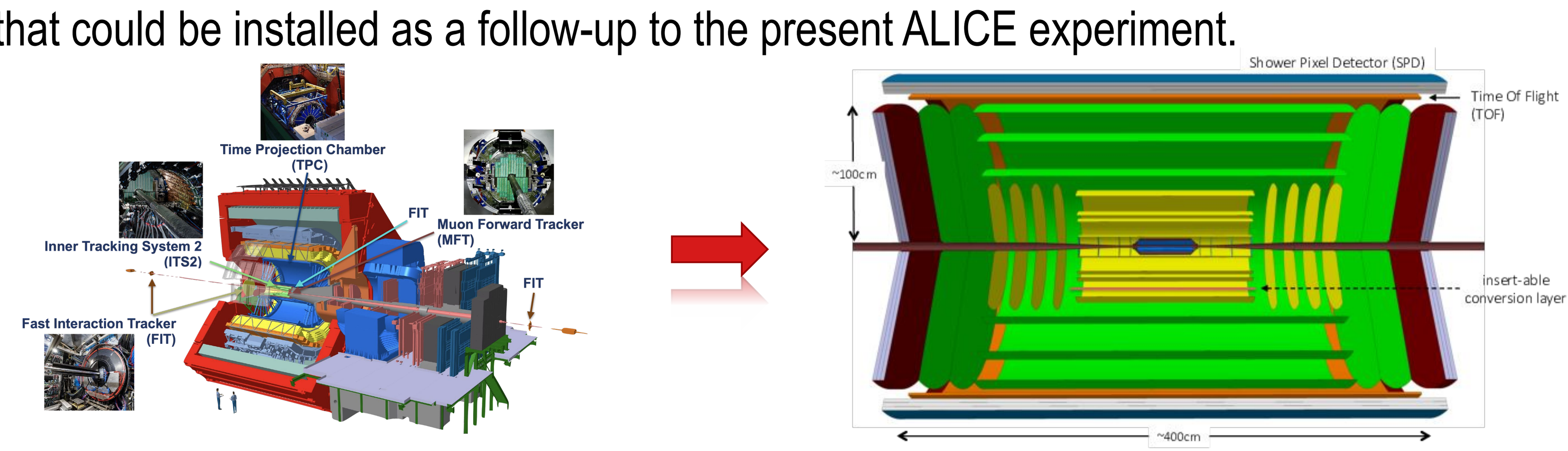
ScuDo – Scuola di Dottorato – Doctoral School

WHAT YOU ARE, TAKES YOU FAR

XXXVII Cycle

Research context and motivation

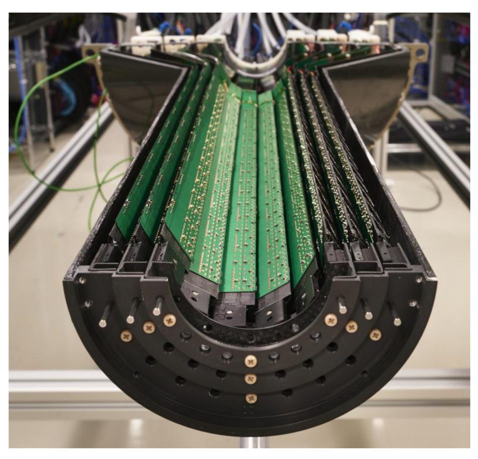
- **M**onolithic **A**ctive **P**ixel **S**ensors (MAPS) will continue to be largely employed in the future upgrades of particle physics experiments like ALICE (**A** **L**arge **I**on **C**ollider **E**xperiment), at the CERN LHC and in particular in ALICE 3: a proposal for the next-generation detector that could be installed as a follow-up to the present ALICE experiment.



▶ **ALICE 3 TOF** detector: dedicated to **T**ime **O**f **F**light measurements. The possible choice of MAPS, with CMOS technology, resides also in its excellent timing resolution capabilities: the goal of a timing resolution of 20 ps, which has never been reached before, will provide accurate particle identification information.

▶ **ITS3**: all silicon detector consisting of 3 truly cylindrical layers based on curved wafer-scale ultra-thin MAPS.

- Technology: **65 nm** CIS of Tower & Partners Semiconductor
- 300 mm wafer-scale chips, fabricated using stitching
- thinned down to 20-40 µm → flexible



- Benefits:
  - extremely low material budget: 0.02-0.04% X_0
  - homogeneous material distribution

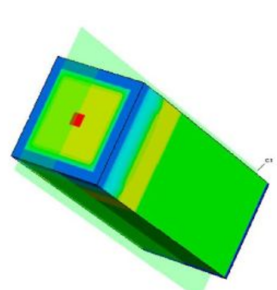
https://doi.org/10.1016/j.nima.2022.166875

Addressed research questions/problems

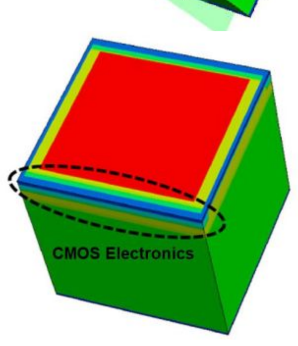
- Different technologies could represent the final choice for the ALICE 3 timing layer, based on their timing performance: LGAD, SPAD or MAPS.
  Timing resolution with silicon sensors:

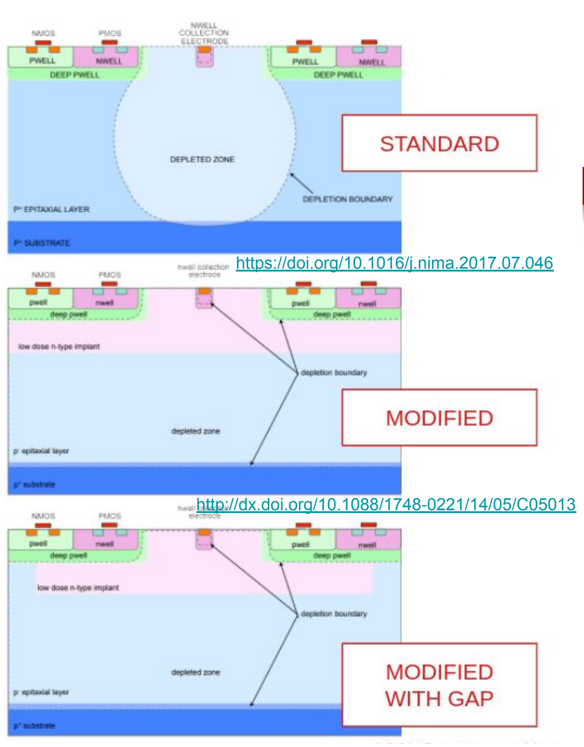
$$\sigma_t^2 = \sigma^2_{Time\ Walk} + \sigma^2_{Landau\ Noise} + \sigma^2_{Distortion} + \sigma^2_{Jitter} + \sigma^2_{TDC}$$

▶ Double sided fully depleted MAPS by Arcadia: **110 nm CMOS techonology**



- **10 µm pixel pitch with small collection electrode:** low capacitance (<1fF) but non-uniform electric field → timing resolution ~ 100 ps
- **pixels with large collection electrode (50, 100, 150, 200 µm pitch)**: high capacitance (30-35 fF) but uniform electric field in most of the area
- Maximum applicable bias voltage limited by punch-through current (power consumption increases exponentially above a certain threshold)





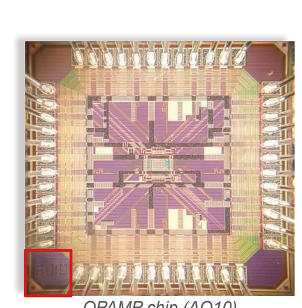
https://doi.org/10.1016/j.nima.2017.07.046

http://dx.doi.org/10.1088/1748-0221/14/05/C05013

▶ Single sided MAPS by TPSCo for ITS3: **65 nm CMOS IS**
Different process modifications with small collection electrode:

- standard
- modified (B)
- modified with gap (P)

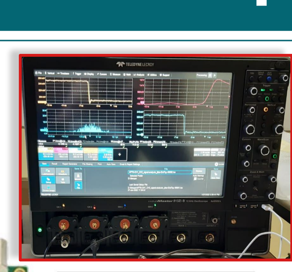
P type aims to increase the lateral electric field and to speed up the charge collection process.

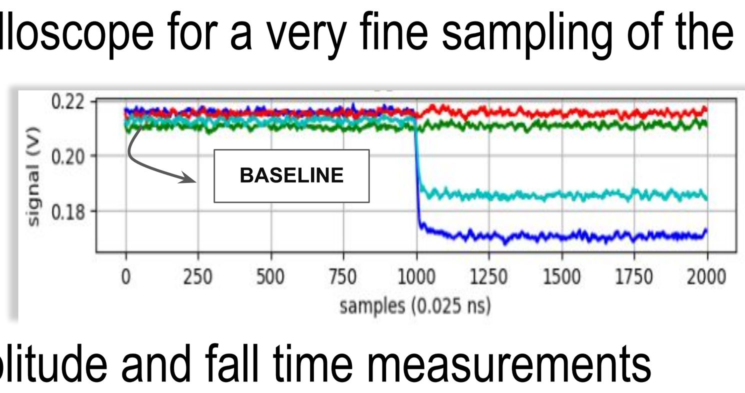


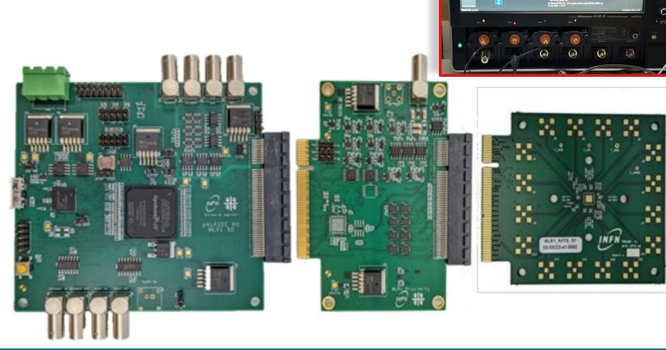
OPAMP chip (AO10)

Experimental setup for ^{55}Fe tests on 65 nm chip

- DAQ board based test system + intermediate proximity board
- Oscilloscope for a very fine sampling of the waveform (4x40 GS/s)







- Amplitude and fall time measurements

Submitted and published works

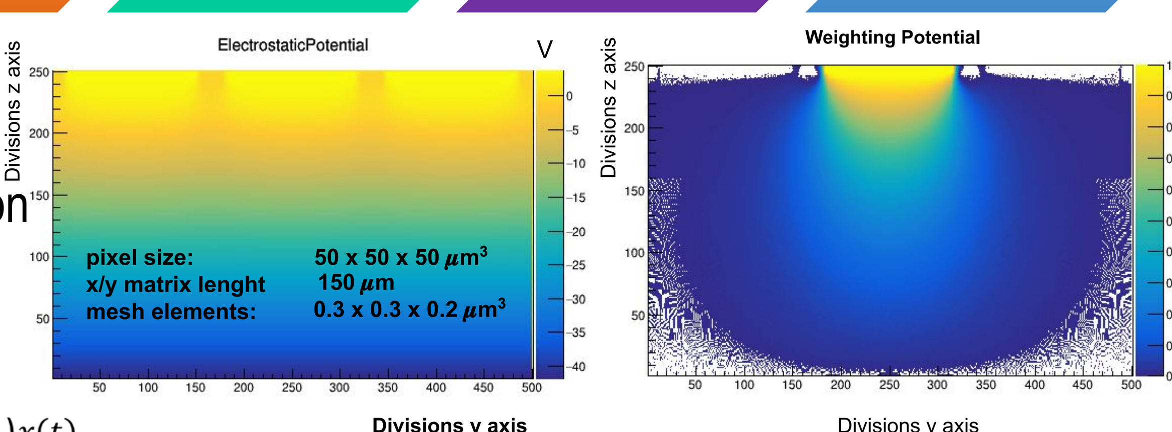
Adopted methodologies for the simulations

1. **TCAD** (**T**echnology **C**omputer-**A**ided **D**esign) VPN Service, Politecnico di Torino
   Numerical simulation tool for sensor modeling:
   → describes carriers motion and electromagnetic fields
   → very demanding on computing time

   Synopsys Sentaurus TCAD

2. **Allpix^2 :** a modular Monte Carlo simulation tool

- Electric field map imported from TCAD
- Geant4 for energy deposition
- Weighting potential $\psi_n(x)$ computation

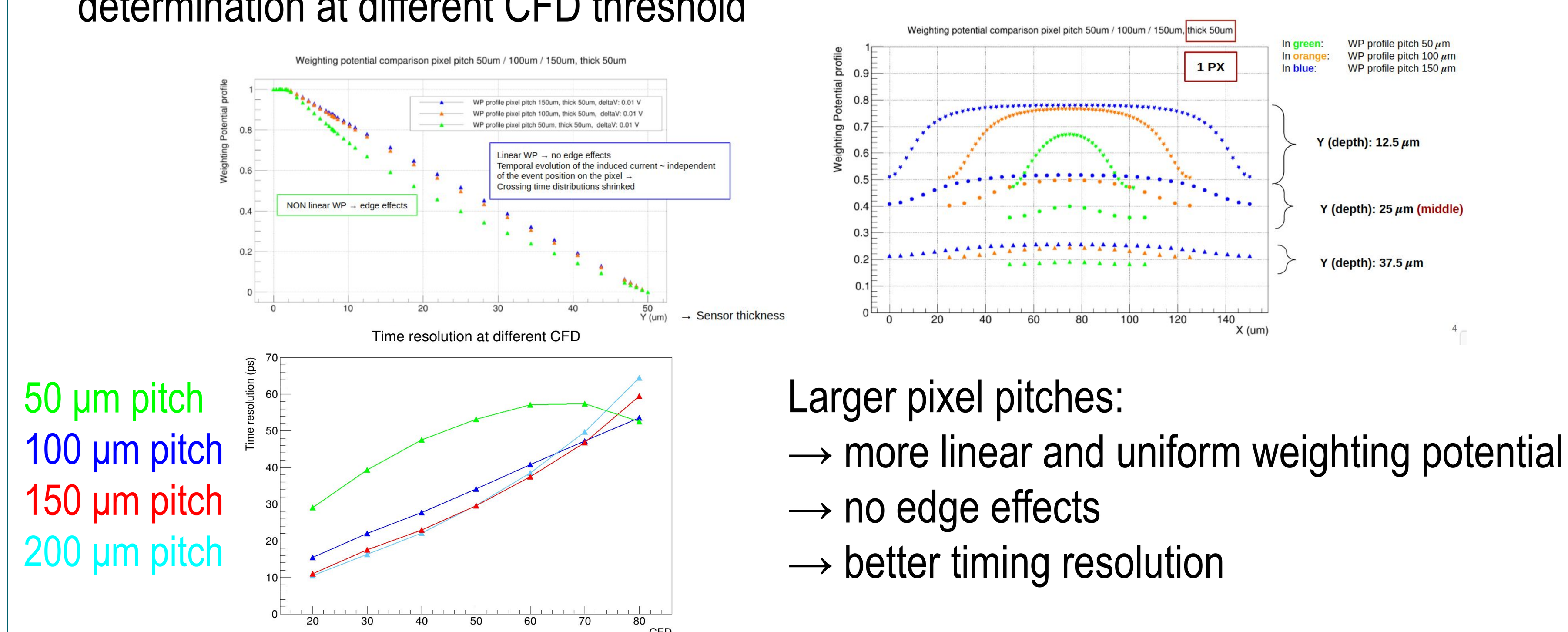


$$Q_n = \int_{t_0}^{t_1} dt\, I_n^{ind}(t) = -\frac{q}{V_w}\int_{t_0}^{t_1} dt\, \boldsymbol{E}_n(\boldsymbol{x}(t))\boldsymbol{x}(t) = \frac{q}{V_w}[\psi_n(\mathbf{x}_1) - \psi_n(\mathbf{x}_0)]$$

→ Allpix^2 simulations of the timing layers' performances for the ALICE 3 detector

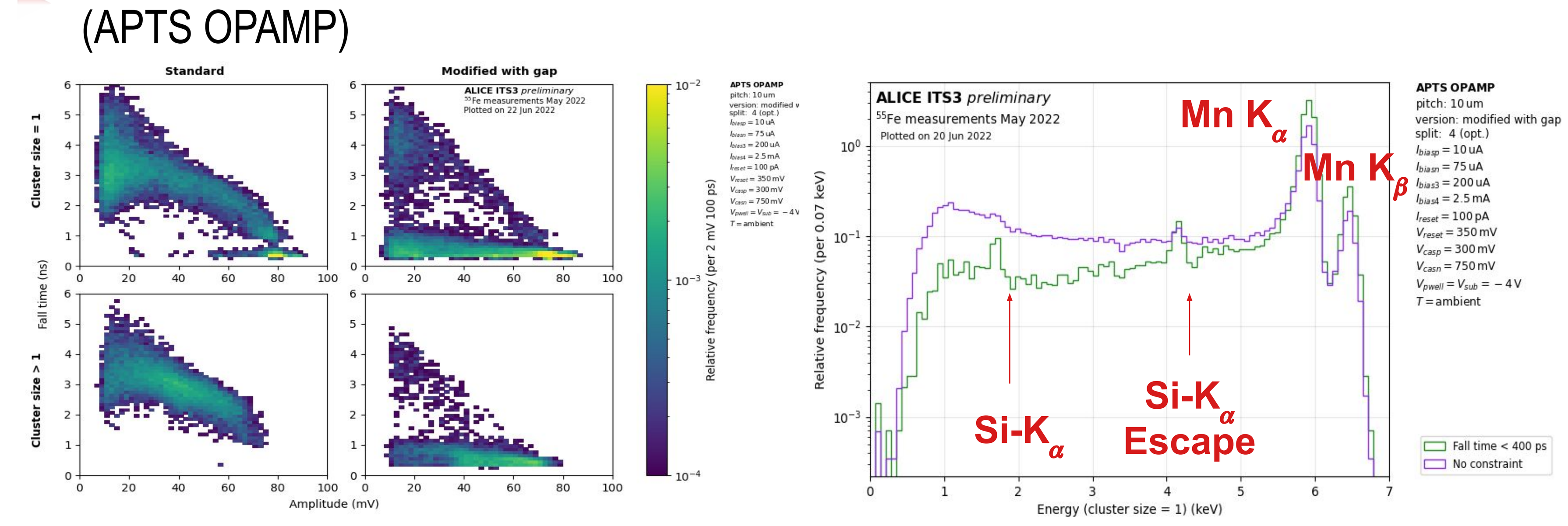
Novel contributions

▶ **Simulations** with TCAD + Allpix^2 of pixels with large collection electrode, thickness 25, 35 and 50 µm and different pitches → weighting potential investigation and timing resolution determination at different CFD threshold



Larger pixel pitches:
→ more linear and uniform weighting potential
→ no edge effects
→ better timing resolution

▶ **^{55}Fe tests** on 65 nm technology Analogue Pixel Test Structure with operational amplifier (APTS OPAMP)



Future work

- Simulation of the cluster size distribution for the Arcadia Main Demonstrator sensor
- MC simulations of MAPS with additional gain layer and timing performance investigation
- Further test beams for the 65 nm technology evaluation

List of attended classes

- 01TSGKG – The Monte Carlo Method (date: 6/5/2022, credits: 40)
- 01QORRV – Writing Scientific Papers in English (date: 16/06/2022, credits: 20)
- 01DMLKG - Introduzione alla microscopia ottica - Scienza e Tecnologia (didattica di eccellenza vp) (date: 24/3/2022, credits: 33.33)
- 02LWHRV– Communication (date: 14/1/2022, credits: 6.67)
- 08IXTRV – Project management (date: 5/1/2022, credits: 6.67)
- 01RISRV – Public speaking (date: 23/12/2021, credits: 6.67)
- 01SYBRV – Research integrity (date: 29/1/2022, credits: 6.67)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (date: 7/1/2022, credits: 6.67)

PhD program in
Electrical, Electronics and Communications Engineering