Monolithic CMOS pixel sensors for low energy X-rays

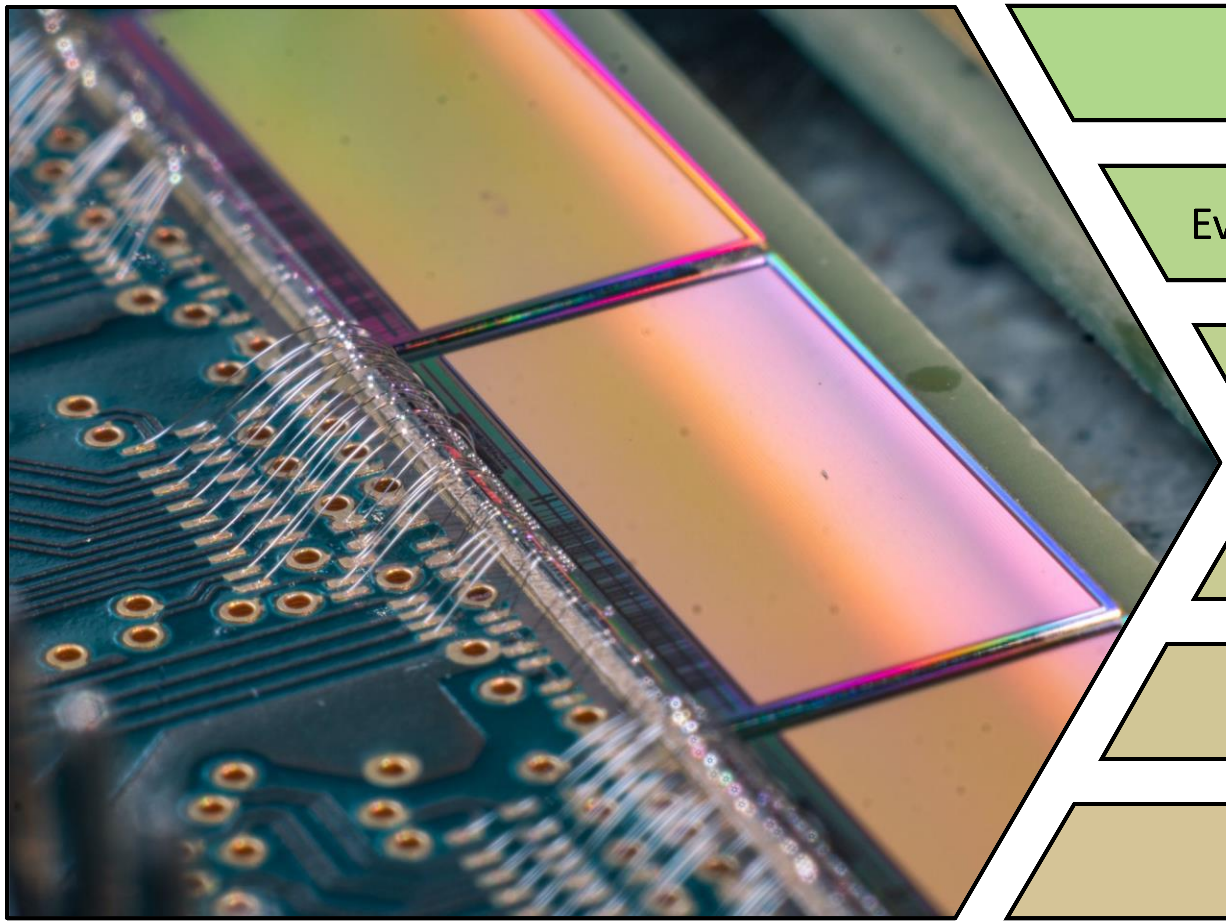
Elio Sacchetti

on behalf of C4Pi group

3 - 4 June 2024

LPSC - Grenoble

Outline



The C4Pi platform at IPHC

C4Pi platform: "Centre de Compétences de Capteurs CMOS à Pixels Intégrés"
~ 20 engineers + technicians
CMOS MAPS sensors development:

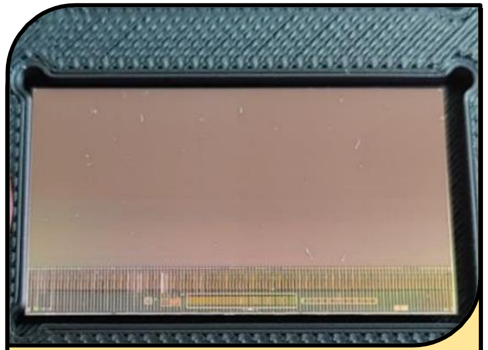
Specifications + Design + Validation + Tests + Integration

Sensor : MIMOSA 26
Beam telescope applications

2008

Sensor : MIMOSA 28
STAR exp. @BNL

2010

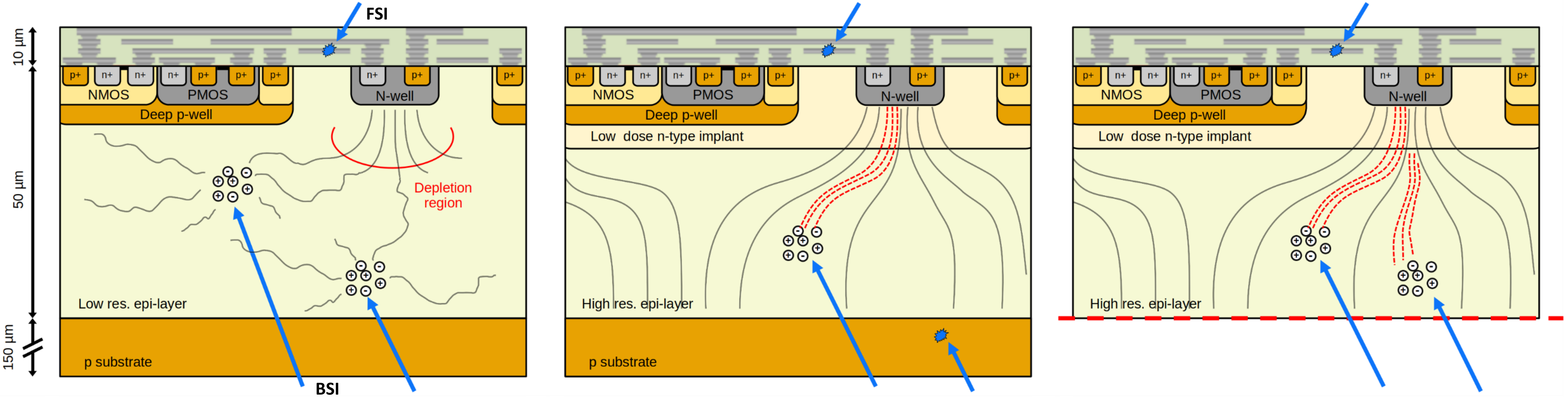


Sensor : MIMOSIS 1
CBM exp. @FAIR/GSI

2023

Features developed for particle physics projects => Transfer to spin-off applications

Evolution of CPS: how to detect low energy X-ray ?



Standard process - low res. epitaxial layer

Simple readout architecture (3T)

Small depletion volume
Charge collection mainly by diffusion

Modified process - high res. epitaxial layer + n-type implant

High res. : whole epi. layer depleted
N-type implant: depletion for low voltage
Better radiation tolerance

Thick substrate for low energy X-ray

Modified process + backside processing

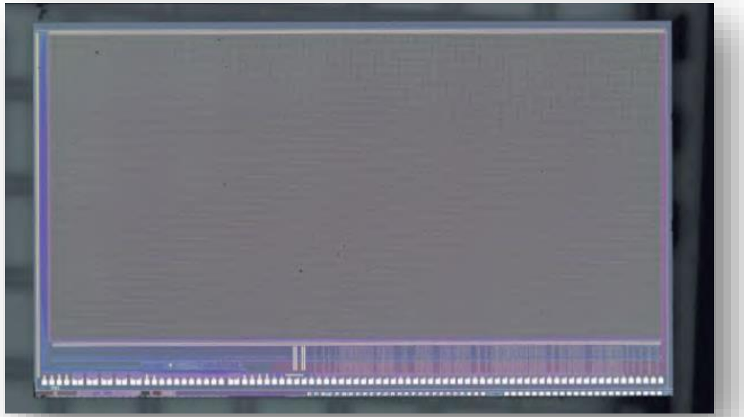
Thinning + ion implantation + laser annealing

Thin entrance window

W. Snoeys et al "A process modification for CMOS MAPS …" NIM A, vol 871 (2017)

A sensor for low energy X-ray detection : “Monolithic Imager 1”

Specifications



- 256 x 512 pixels
- Pixel pitch: 20 µm
- Total area: 10.5 x 6.2 mm²
- Rolling or global shutter operation
- Analog readout with programmable MUX (32/16/8/4)

[1 - 10] keV X-ray detection, designed for spectroscopic applications

Operation mode:

- High frame rate (max. 40 kHz)→ energy resolution on each impinging photon
- Low frame rate (min. 1 kHz) → integration over several photons/pixels (each pixel dynamics is important !)

Next version:

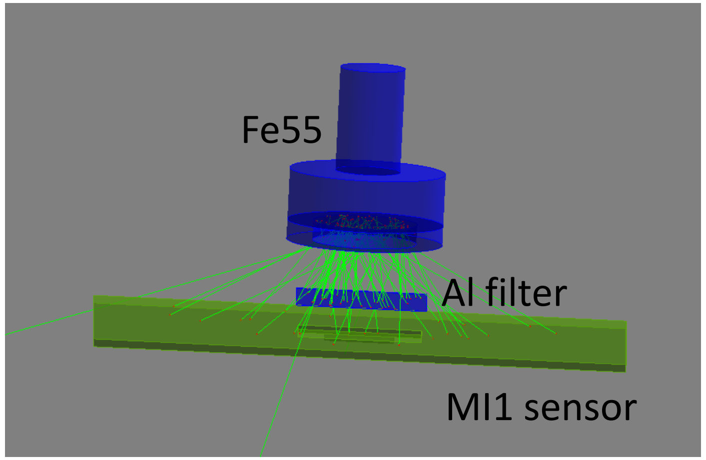
Higher dynamics (actual dynamics : 15 ke)
+ will integrate a 12 bits ADC (IPHC + LPSC + APC development)

Signal resolution
-
Spectroscopy

Signal dynamics
-
Particle counting

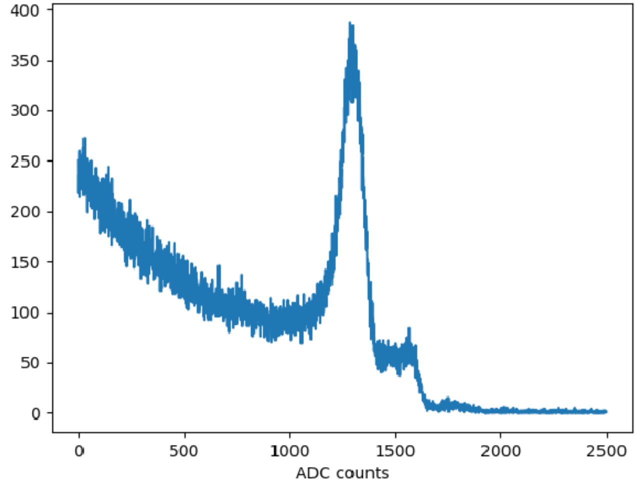
A sensor for low energy X-ray detection : “Monolithic Imager 1”

Characterisation



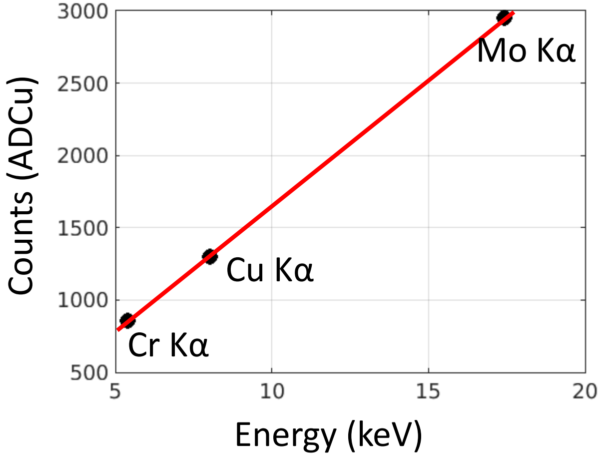
Characterisation setup with Fe55 sealed source

Measurements with ^{55}Fe



Energy resolution ~ 180 eV @Mn(Kα) (room temperature)

Linearity

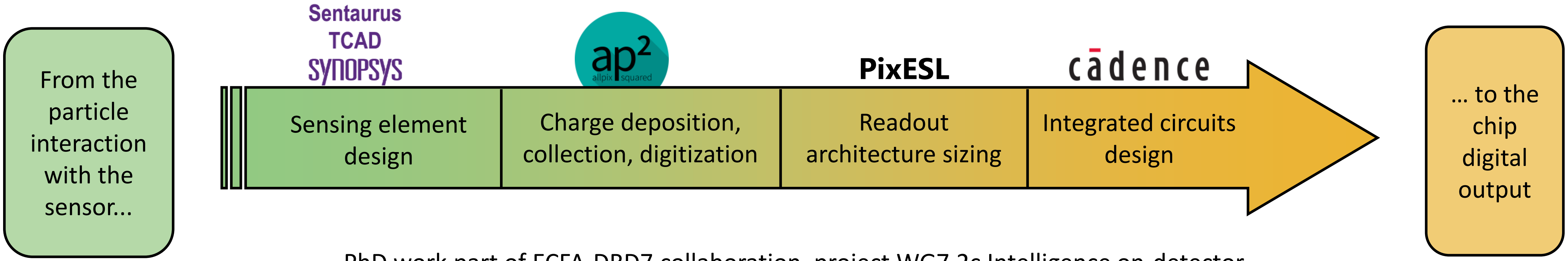


Measurements with X-ray generator

- Measurements performed **in air** (FSI)
- Measurements with soft X-ray (< 2 keV) **in vacuum**, soon @SOLEIL (BSI !)

Developing a physics-electronics integrated simulation based on MI-1

Exhaustive model building for the development of the new generation of CMOS pixel sensors



PhD work part of ECFA-DRD7 collaboration, project WG7.2c Intelligence on-detector
“Virtual electronic system prototyping” (CERN)

Why do we need such a framework?

Detector with enhanced performances (always more “aggressive”)

→ Requires accurate simulation on the following aspects:

Charge collection, signal digitization, readout architecture, data flow

→ A fluid workflow is mandatory

Developing a physics-electronics integrated simulation based on MI-1

From the particle interaction with the sensor...

Sentaurus TCAD SYNOPSYS

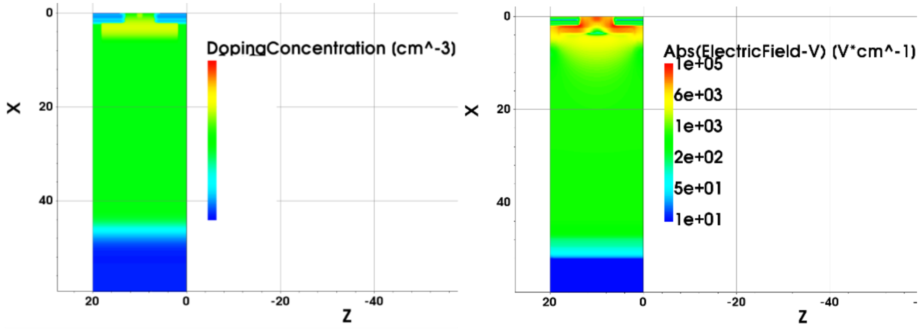
ap² allpix squared

PixESL

cādence

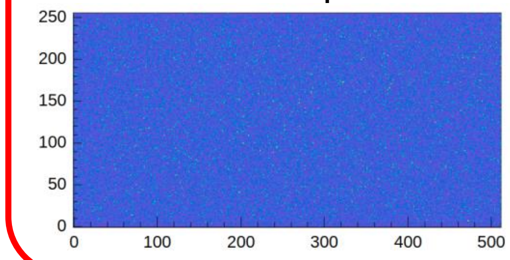
Sensing element design → Charge deposition, collection, digitization → Readout architecture sizing → Integrated circuits design

... to the chip digital output

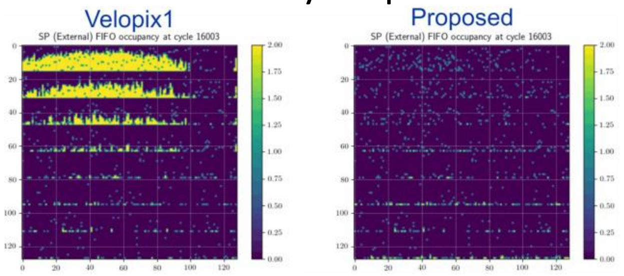


Doping concentration and electric field maps

Hitmap



Latency map



From "PixESL: A virtual Electronic System Level prototyping framework", Jashandeep Dhaliwal, 25/09/2023, p.5

Developing a physics-electronics integrated simulation based on MI-1

From the particle interaction with the sensor...

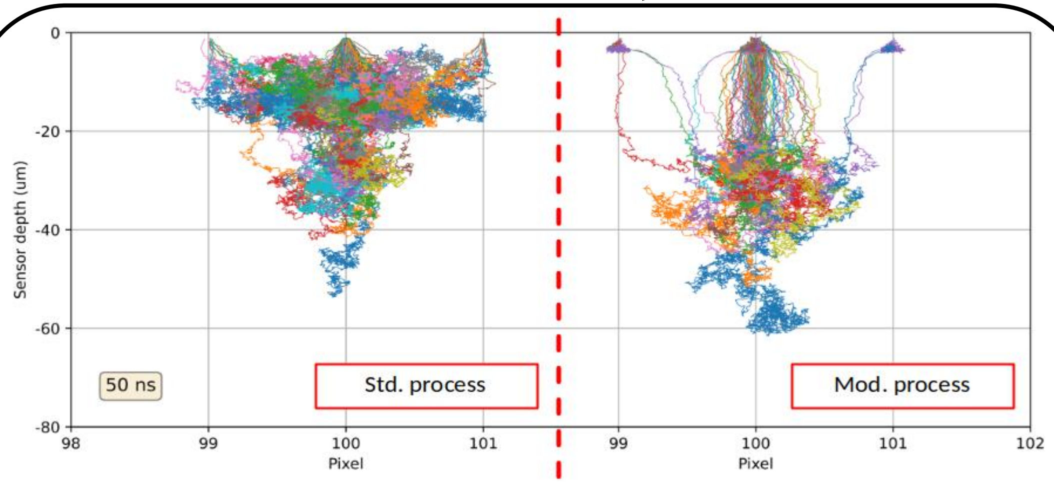
Sentaurus TCAD SYNOPSYS — Sensing element design

ap² allpix squared — Charge deposition, collection, digitization

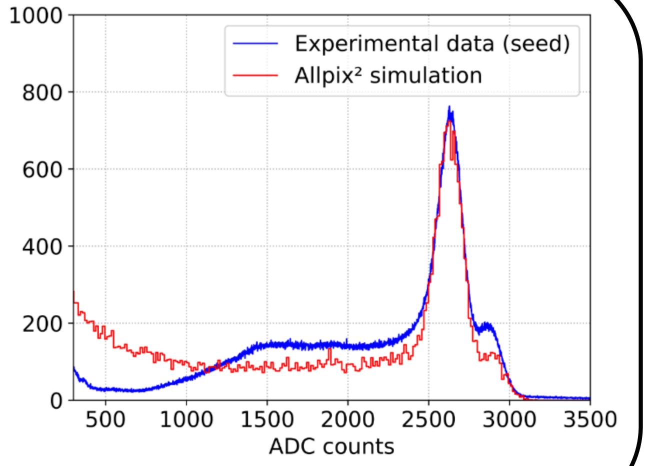
PixESL — Readout architecture sizing

cadence — Integrated circuits design

... to the chip digital output



Charge collection comparison between std. and mod. process



Fe55 spectrum

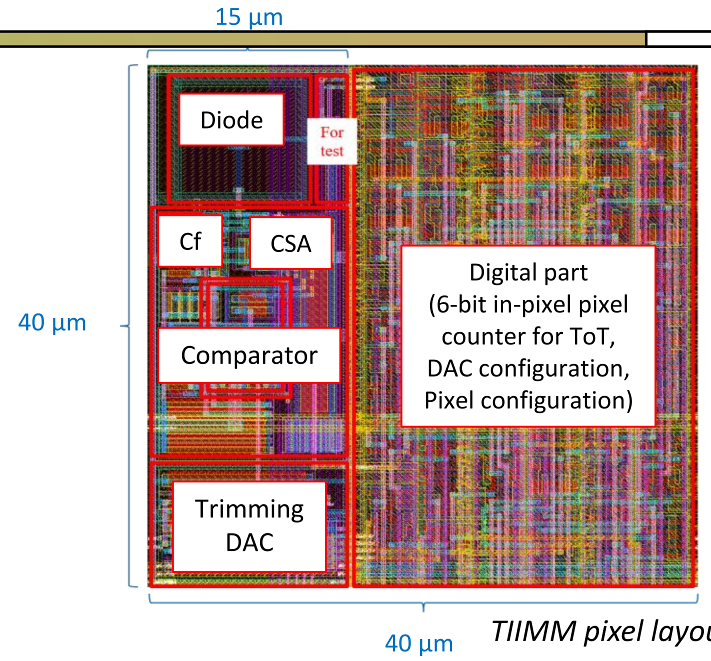
Technology transfer: "TIIMM" sensor

- TIIMM: Tracking and Ions Identifications with Minimal Material budget
- European funding: H2020-INFRAIA / STRONG-2020
- **Designed for position and energy measurement**

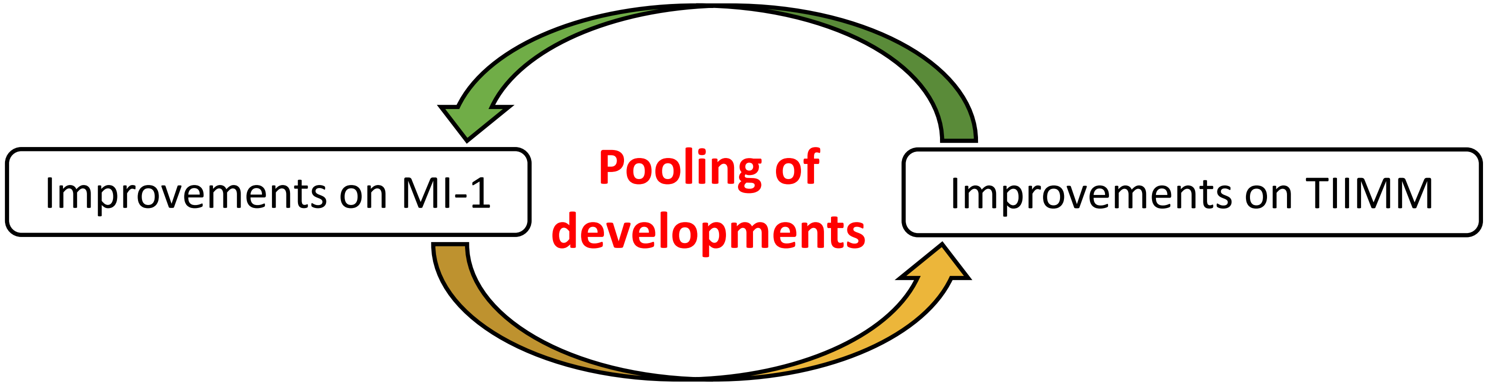
Maximum linear range of ToT:

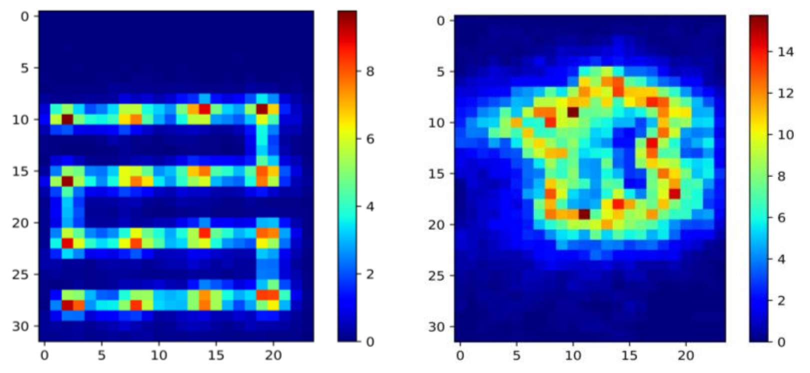
- TIIMM0 : 110ke-
- TIIMM1 : 250ke-
- TIIMM1B : up to 700 ke- (current maxi. of MI-1: 15 ke-)

Digitizing already integrated (6 bits ToT) => useful for signal dynamics



TIIMM pixel layout





Proof of concept @AIFIRA (LP2iB) in April 2024

Conclusion

R&D to develop MAPS to fit an application (HEP experiments or spin-off applications)

Processes mastered to optimize low energy X-ray detection

MI1 used as reference for the development of an exhaustive simulation chain

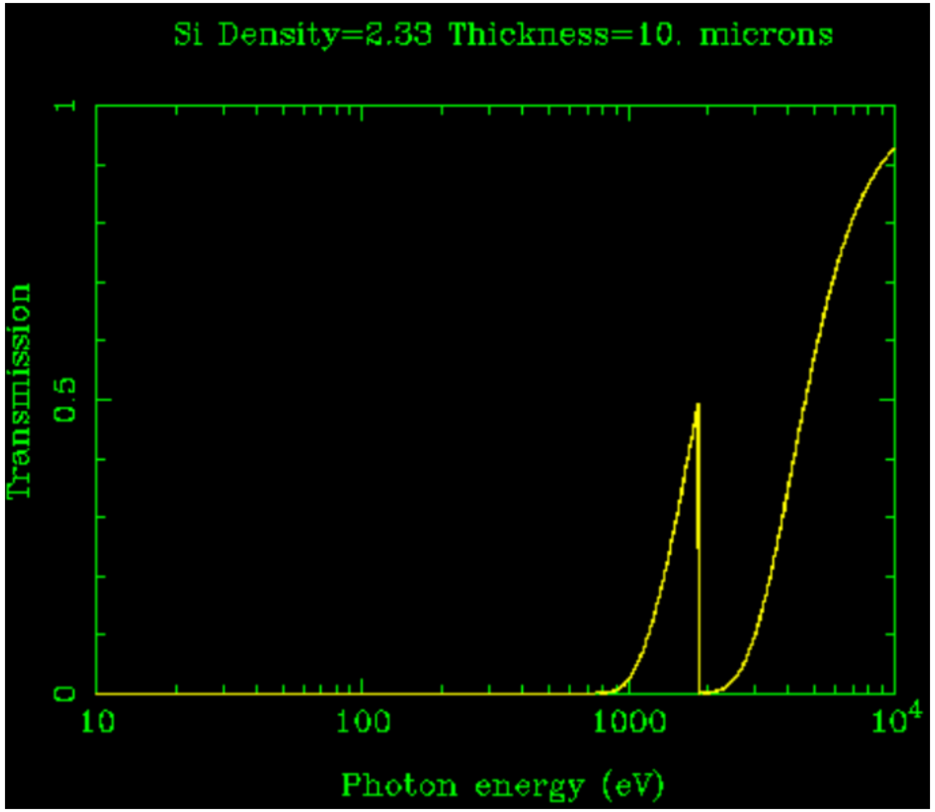
High versatility on the sensors characteristics - Transfer of technology

Thank you
for your attention !

3 - 4 June 2024

LPSC - Grenoble

Back-up



Transmission of 10 µm silicon (for the FSI)