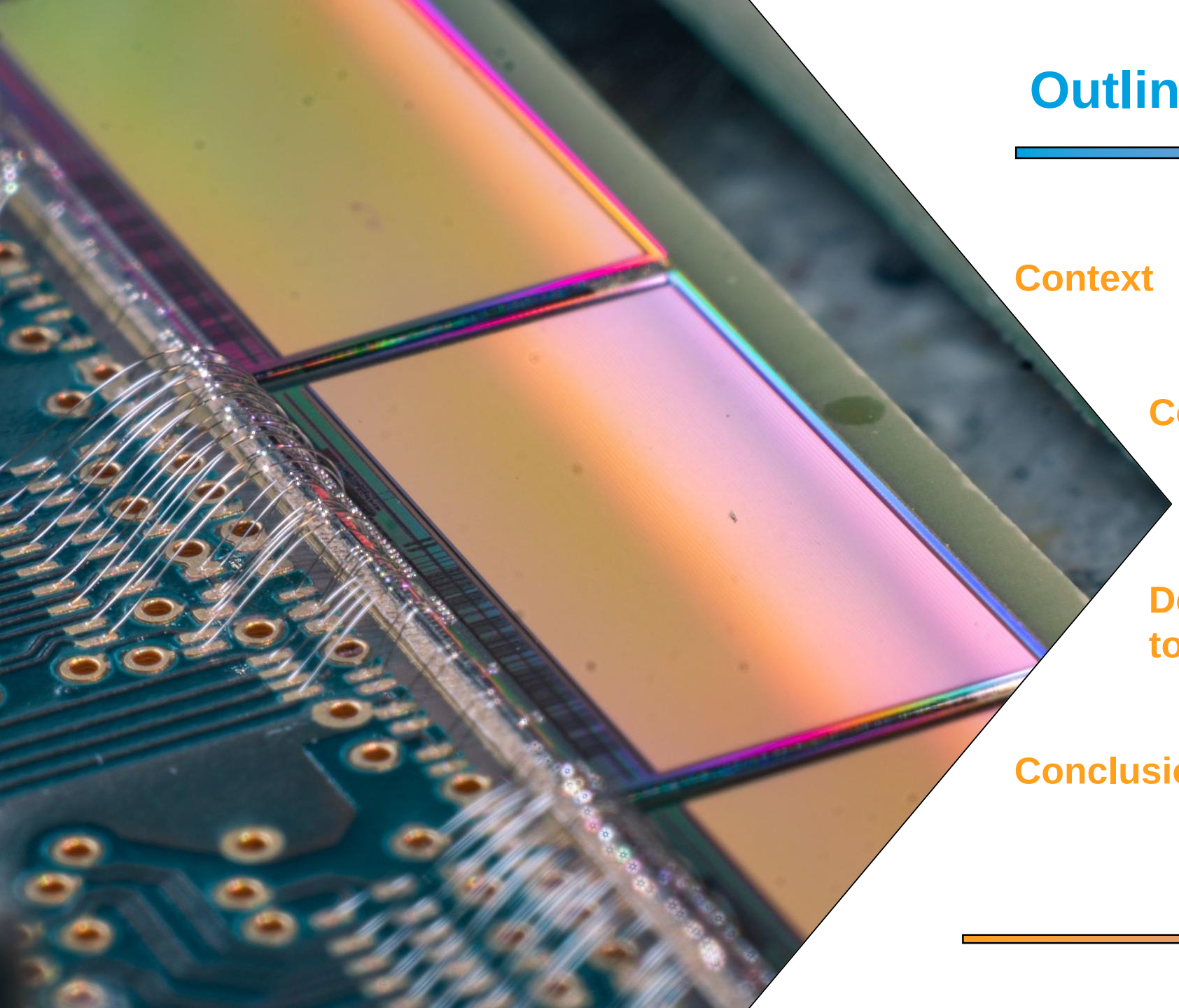
Exhaustive model building for the development of the next generation of CMOS pixel sensors

Elio Sacchetti (IPHC)

DMLab Meeting IV

17 - 18 October 2024 LPNHE - Paris



Outline

Context

Context - TIIMM sensor

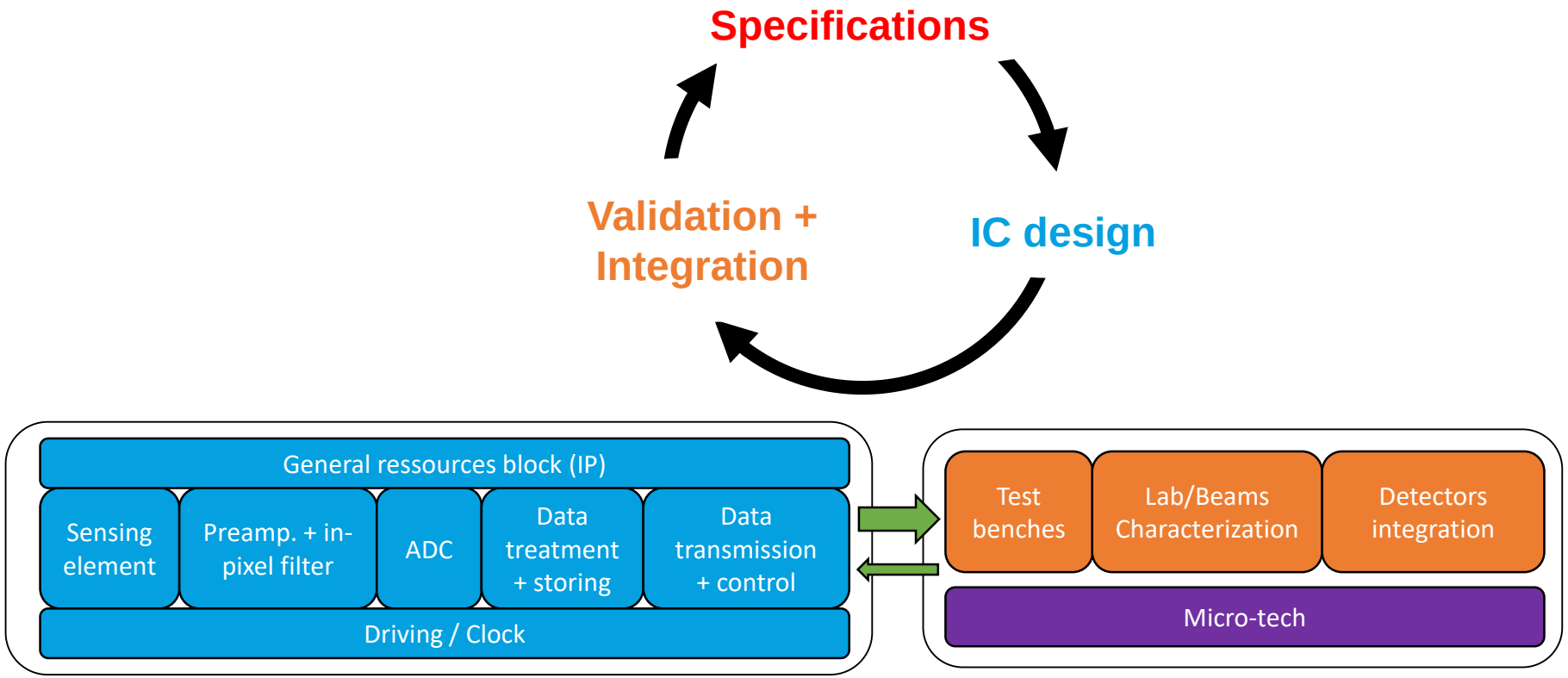
Developing an integrated physics to electronics simulation flow

Conclusion

Context

C4Pi* platform: ~ 20 engineers + students

CMOS MAPS* sensors development for HEP experiments and spin-off applications



*MAPS : « Monolithic Active Pixel Sensor »
*C4Pi : « Centre de Compétences de Capteurs CMOS à Pixels Intégrés »

Context

Necessity to reach unprecedented performances:

- **Spatial** resolution (Pixel size / Charge sharing)
- **Temporal** resolution (Rise time / Readout speed)
- **Energy** resolution (Time-over-Threshold / ADC)

Next presentation after coffee break!
"New results with 65nm CMOS sensors", Ziad El Bitar

…. will be used on future experiments searching for dark matter

→ **ALICE – ITS3 (2027)**

→ **CBM (2028)**

→ **Belle II (2032)**

→ **FCC ee (2045) ?**

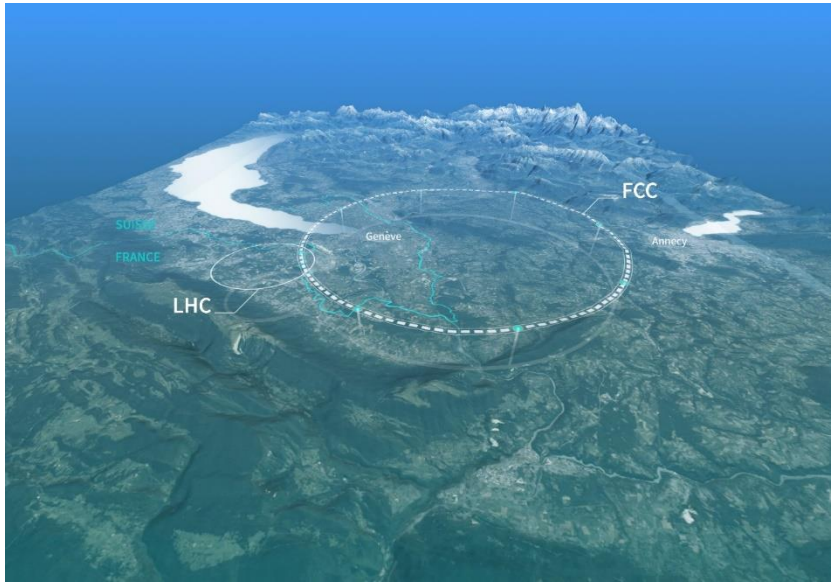
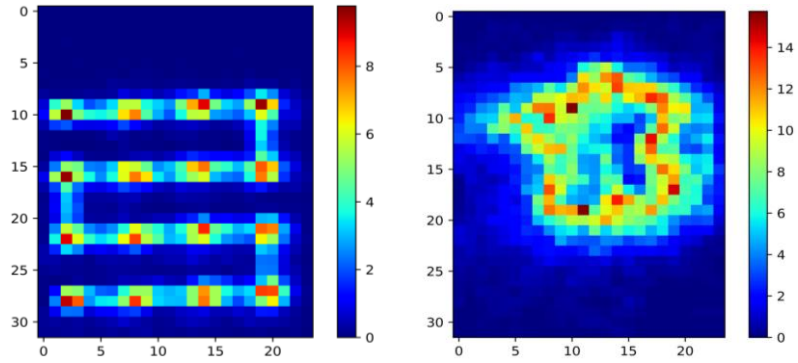


Schéma montrant l'emplacement proposé pour le Futur collisionneur circulaire. (Image : CERN)

Context – TIIMM sensor

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

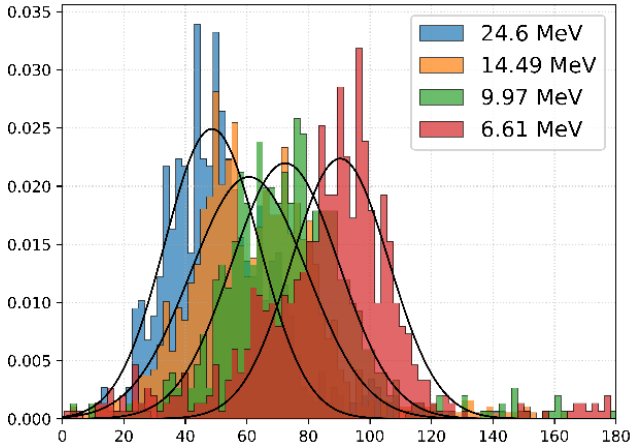


Proof of concept @AIFIRA (LP2iB) in April 2024

Large dynamics (700 ke-) at the limits of analog front-end -> need for careful simulation

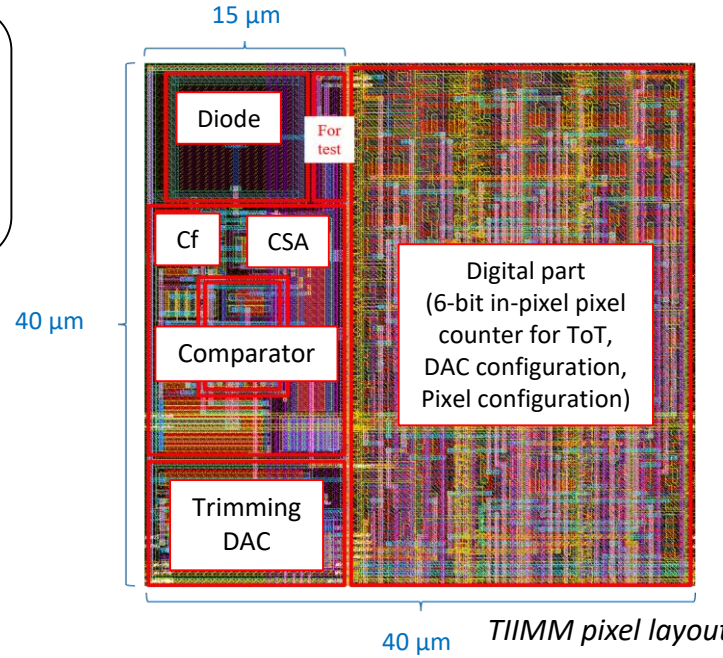
TIIMM -> 6 bits ToT
TIIX (evolution of TIIMM) -> 10 bits ToT but splitted for compactness reason, 6 bits in the matrix and 4 bits in the periphery

Preliminary results



Cluster charge (CLK edges)

Resolution (position & energy) depends on interplay between pixel front-end and matrix read-out.



TIIMM pixel layout

Developing a physics → electronics integrated simulation flow

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

Several tools/framework/software already exist for specific simulations but nothing unified

→ **A fluid workflow is mandatory**

Part of ECFA DRD7 collaboration

- Work Package 7 “Intelligence on-Detector”
  - Project c “Virtual Electronic System Prototyping”
    - Topic #1 → Signal generation in detector elements
    - Topic #2 → Digitization and signal processing
    - Topic #3 → Data readout architecture

Developing a physics → electronics integrated simulation flow

From the particle interaction with the sensor...

Simulation flow

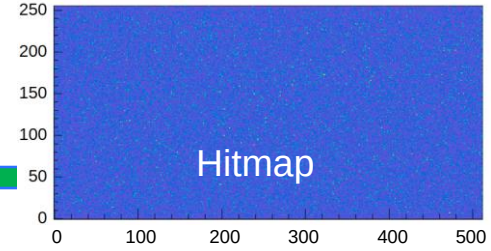
… to the chip digital output

Sentaurus TCAD SYNOPSYS

Sensing element design

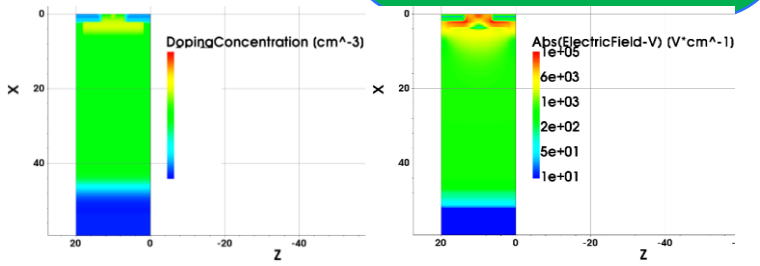
ap² allpix squared

Charge deposition + collection (+ digitization)



Digitization + signal processing

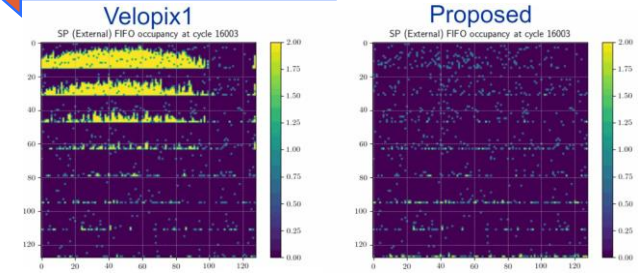
cadence



Doping concentration and electric field maps

Readout architecture sizing

PixESL



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

Done

To be done…

Developing a physics → electronics integrated simulation flow

From the particle interaction with the sensor…

Simulation flow

… to the chip digital output

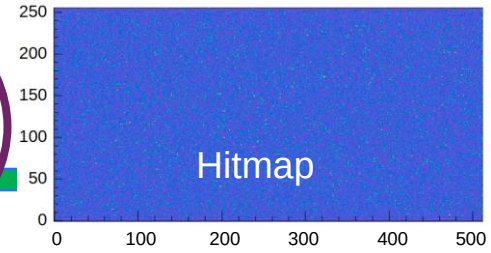
Topic #1

Sentaurus TCAD SYNOPSYS

Sensing element design

ap² allpix squared

Charge deposition + collection (+ digitization)



Topic #2

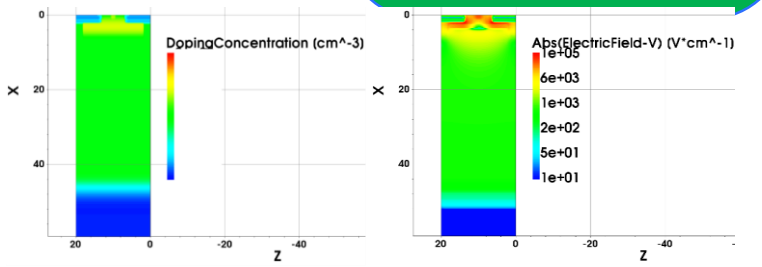
Digitization + signal processing

cadence

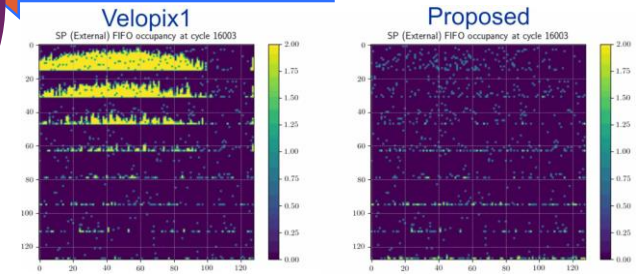
Topic #3

Readout architecture sizing

PixESL



Doping concentration and electric field maps



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

Topic #1 → Signal generation in detector elements
Topic #2 → Digitization and signal processing
Topic #3 → Data readout architecture

Done

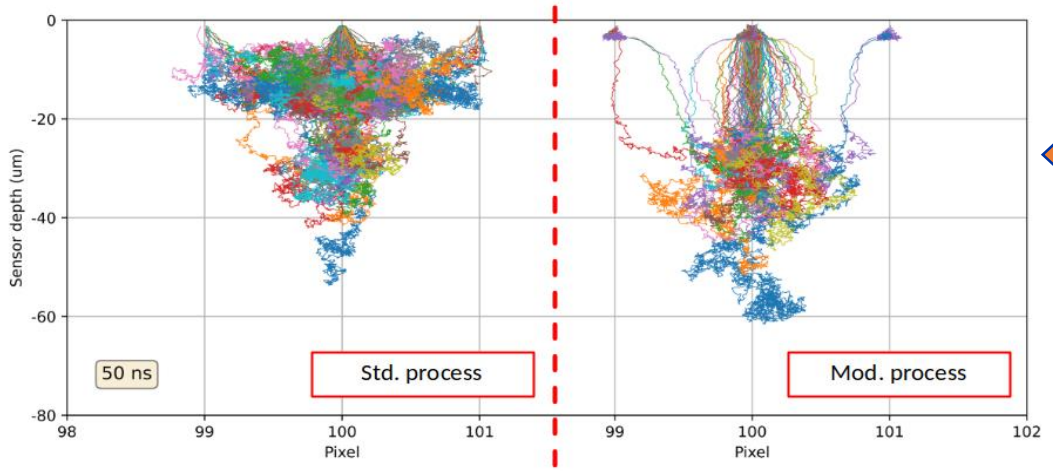
To be done…

Topic #1: Signal generation in detector elements

Allpix² flow

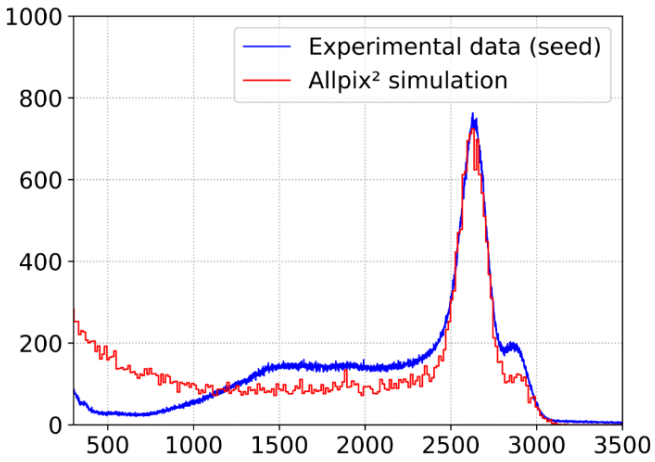
S. Spannagel et al., "Allpix²: A modular simulation framework for silicon detectors", Nucl. Instr. Meth. A 901 (2018) 164 – 172, doi:10.1016/j.nima.2018.06.020, arXiv:1806.05813

Impinging particle generation → Charges deposition in the detector → Charges propagation → Charges collection → Digitization



Charge propagation study :
Comparison between standard and modified CMOS imaging processes

Fe55 spectrum

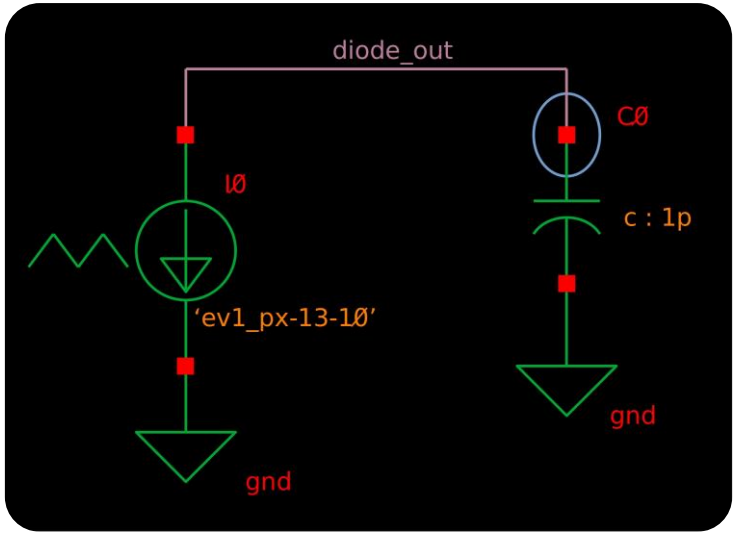


Monolithic Imager 1 sensor used here for experimental results

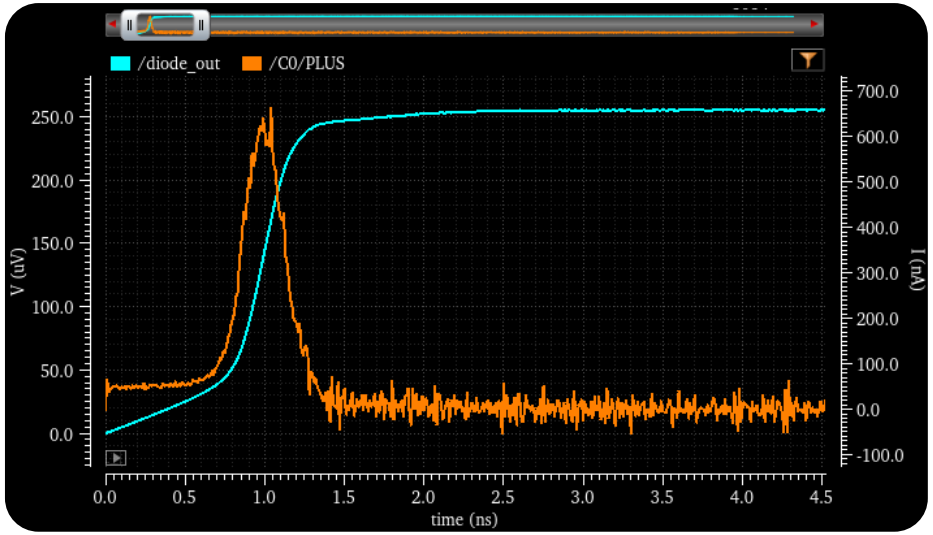
Topic #2: Digitization and Signal Processing

Inject Allpix² simulation output in the CADENCE framework

First attempt with a single event on a single pixel



Current pulse in .txt format (time + current)



Current pulse extracted from Allpix² simulation
Storage capacitance voltage

Topic #2: Digitization and Signal Processing

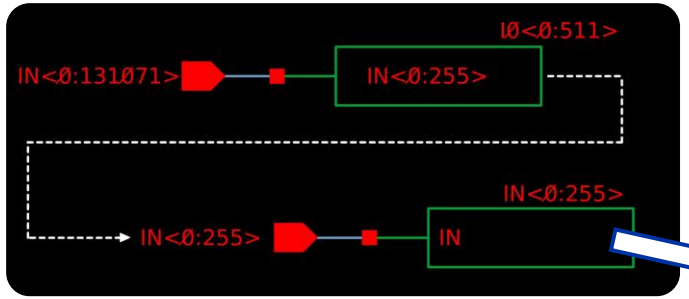
Inject Allpix² simulation output in the CADENCE framework

In the next weeks: Automatizing the flow

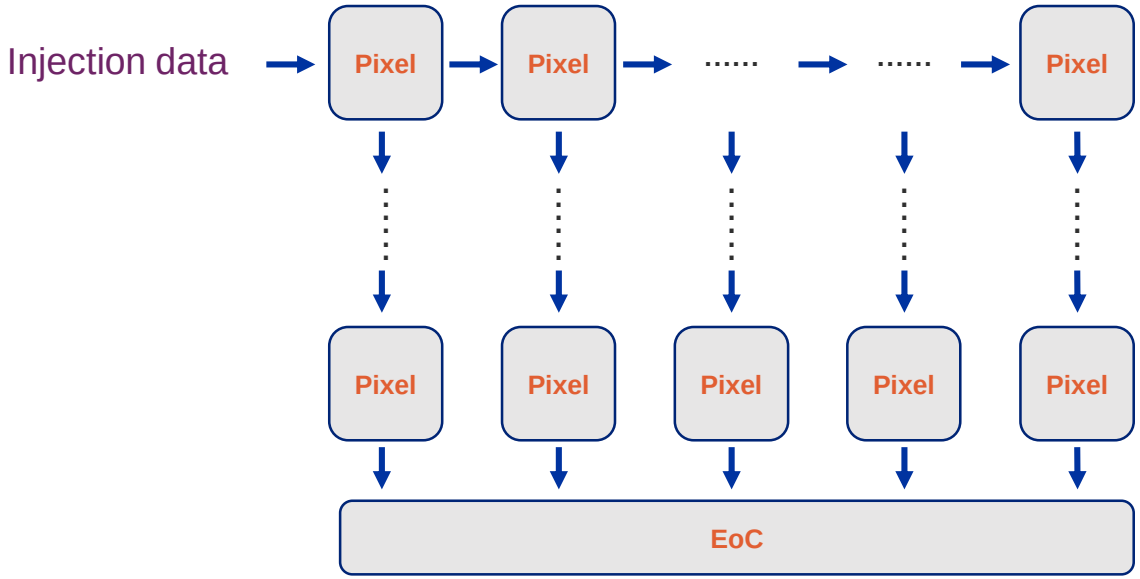
.root Allpix² file

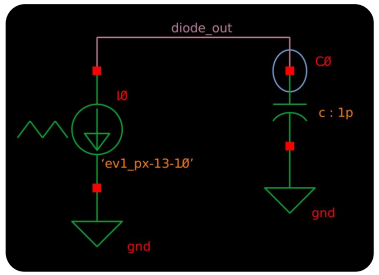
for each event…

Pixel address + ToA + I(t), current pulse



for example here with a 512x256 pixels matrix





Conclusion

A new tool to boost prototyping of MAPS with extreme performance is being developed

Those MAPS sensors will be used on experiments searching for dark matter

A 2-weeks visit @DESY is scheduled in Nov. 2024 to work with the Allpix² developers

Funded by DMLab

Thank you
for your attention !

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