Energy response of MAPS designed at C4PI

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On behalf of the C4PI

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Outline

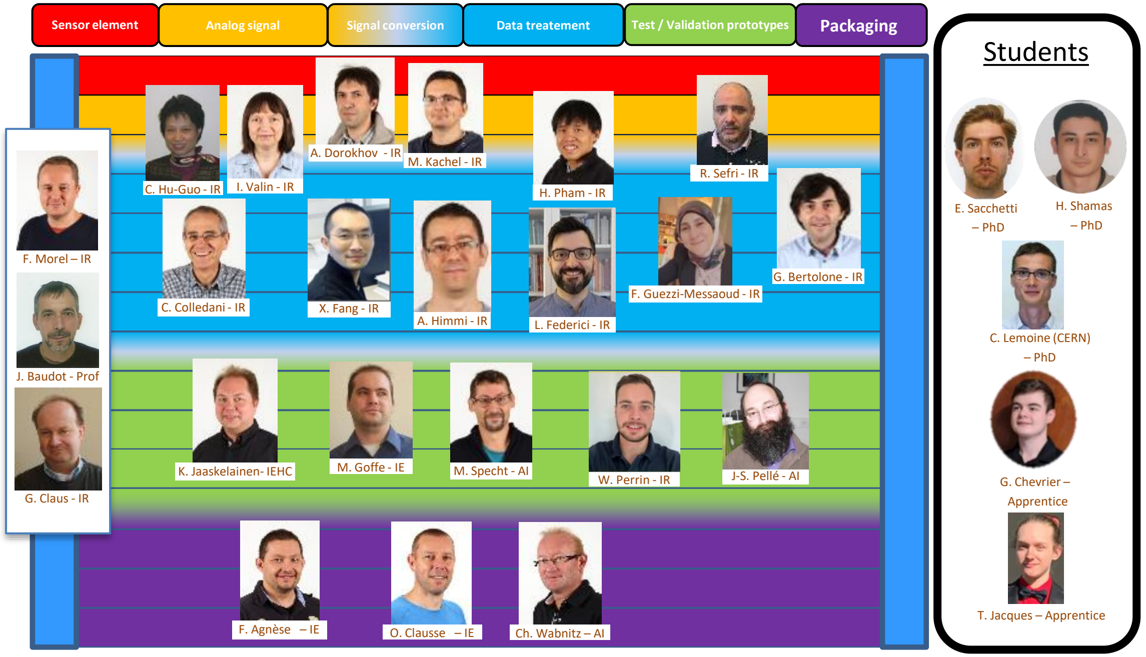
Energy measurement @ C4PI

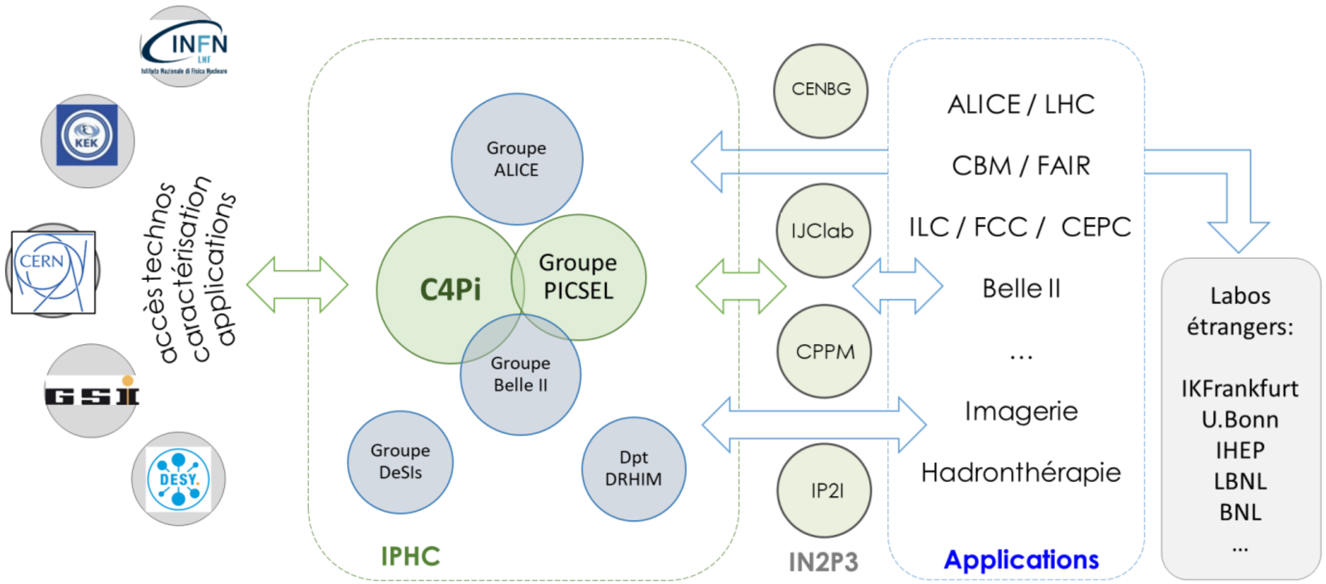
1. Main HEP applications

2. Spectroscopy

3. Ion identification

C4PI





<u>Our Goal</u>: Provide sensors for HEP applications

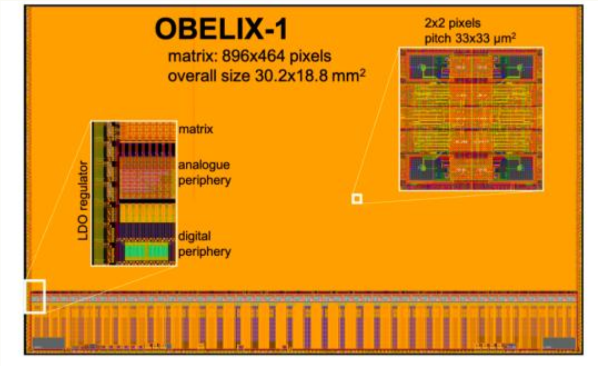
1. Energy measurement in HEP applications

Why sensors for trackers needs to measure energy

- Correct time walk
- Better spatial resolution

OBELIX-1

BELLE II VTX Upgrade

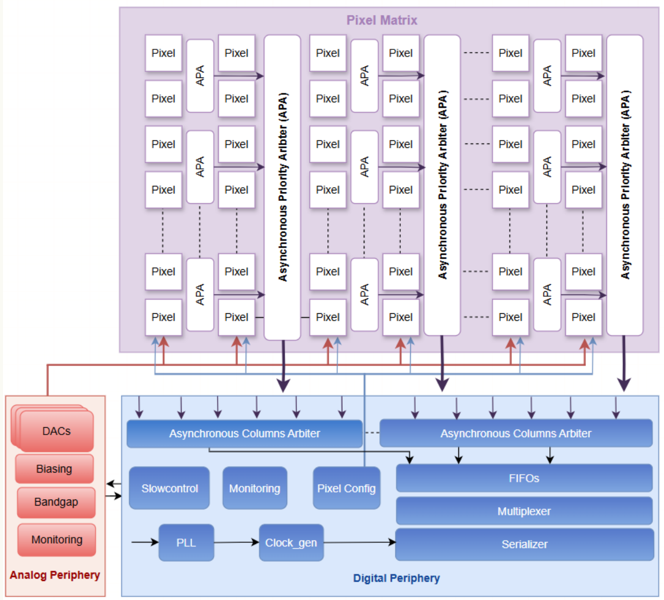


- BELLE II VTX collaboration
- 7-bit TOT in pixel
- Time-walk compatible with 25 ns 98% in-time efficiency

10.1016/j.nima.2023.168015

OCTOPUS

DRD3 collaboration



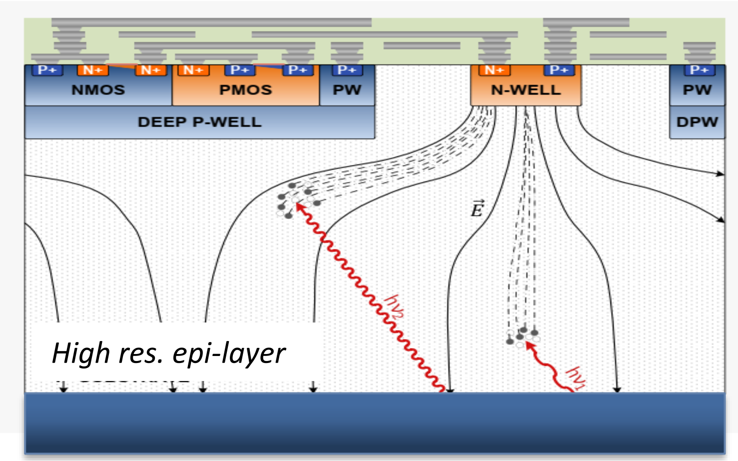
Aims to reach 3µm spatial resolution => TOT for time walk correction & cluster center calc.

2a. Spectroscopy – why?

MAPS can have excellent energy resolution

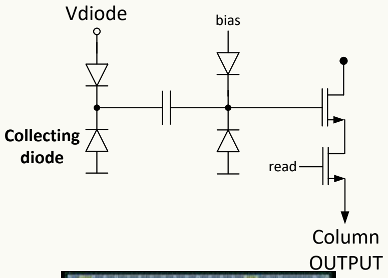
New MAPS technologies made it better:

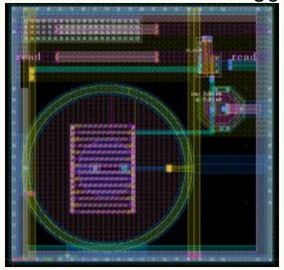
- Depletion => faster collection, smaller clusters, better rad hard
- Thicker epi-layer possible (50-100µm) => for collection efficiency

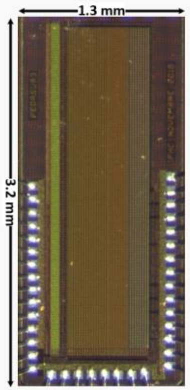


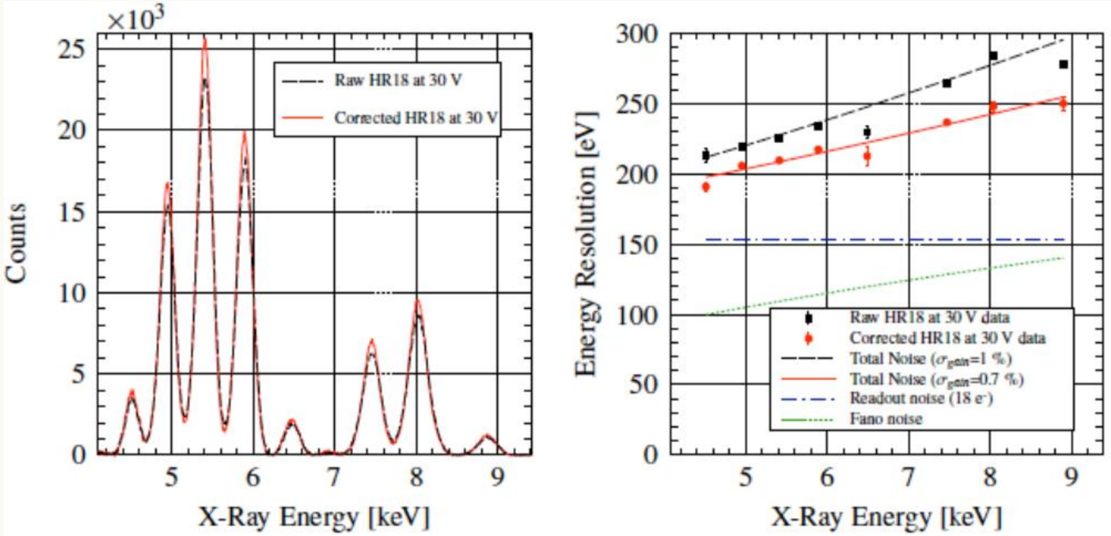
We have studied this with the PIPPER family sensors

- Prototype chip 32x128 pixels
- Analog outputs
- Pixel size 22 x 22 µm^2
- **Small** (4µm) **circular diode**
- **AC coupled** collecting diode
- Produced on two substrates:
  - Epitaxial layer 18 µm
  - High resistivity substrate









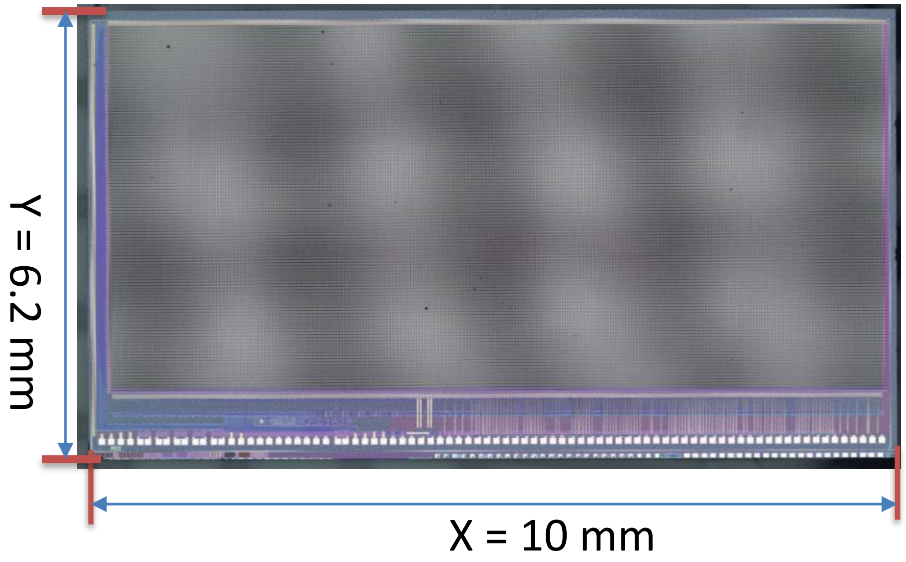
PhD thesis of Julian Heymes

How to get below 200 eV?

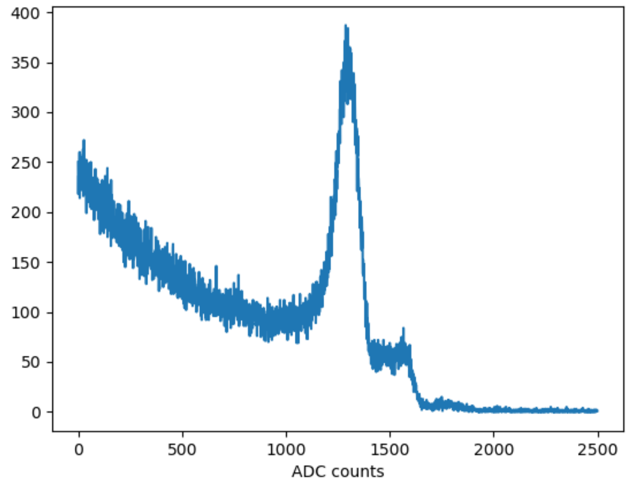
2b. Spectroscopy – application circuit

Monolithic Imager 1 :

- DC coupled pixels with diode reset
- Back biasing (TJ modified process)
- Pixel size 20x20 µm
- Matrix of 256x512 pixels
- Rolling/global shutter operation
- Programmable analog readout

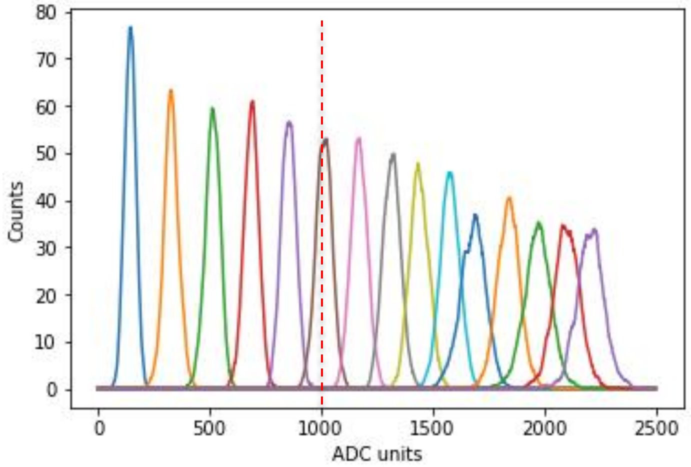


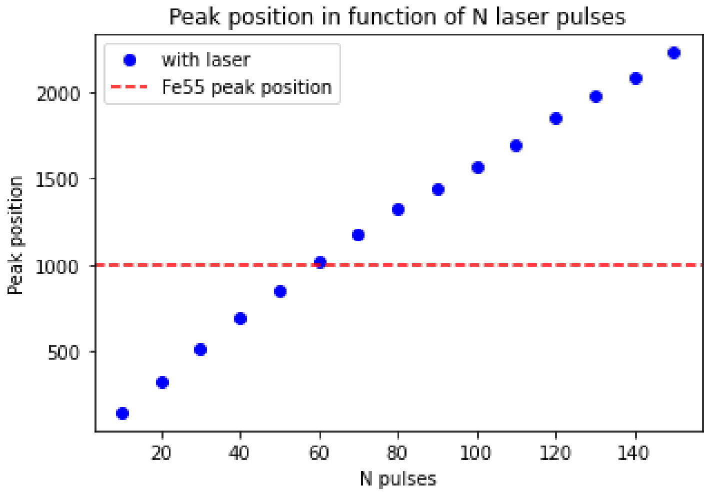
Energy resolution



- Front side illumination @ room T
- No correction
- Energy resolution ~ 350 eV

Dynamics (NIR laser)



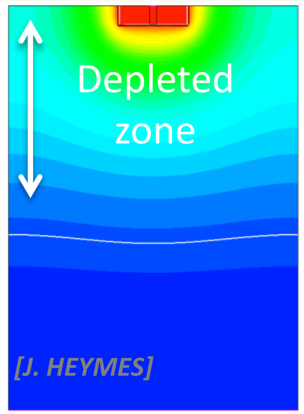


2c. Spectroscopy – How to make it better

- Enable low E (<1keV) particles measurement
- Higher Quantum efficiency => Full depletion
  - Mix of modified process, thick epi (or Czochralski substrate) and **back side processing**
- Better energy resolution
  - In-pixel gain => APIX project @ C4PI
- High frame rate
  - ADC on chip => 12bit column ADC developed with collaboration between LPSC, APC& IPHC

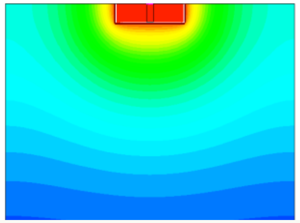
Sensor post processing

collecting diode



- **Thinning**
- **Ion implant**
- **Laser annealing**

collecting diode



p+ layer

PULSION® process

✓ Done for Monolithic Imager

❑ Tests are under way…

3a. Ion identification – “historical” example

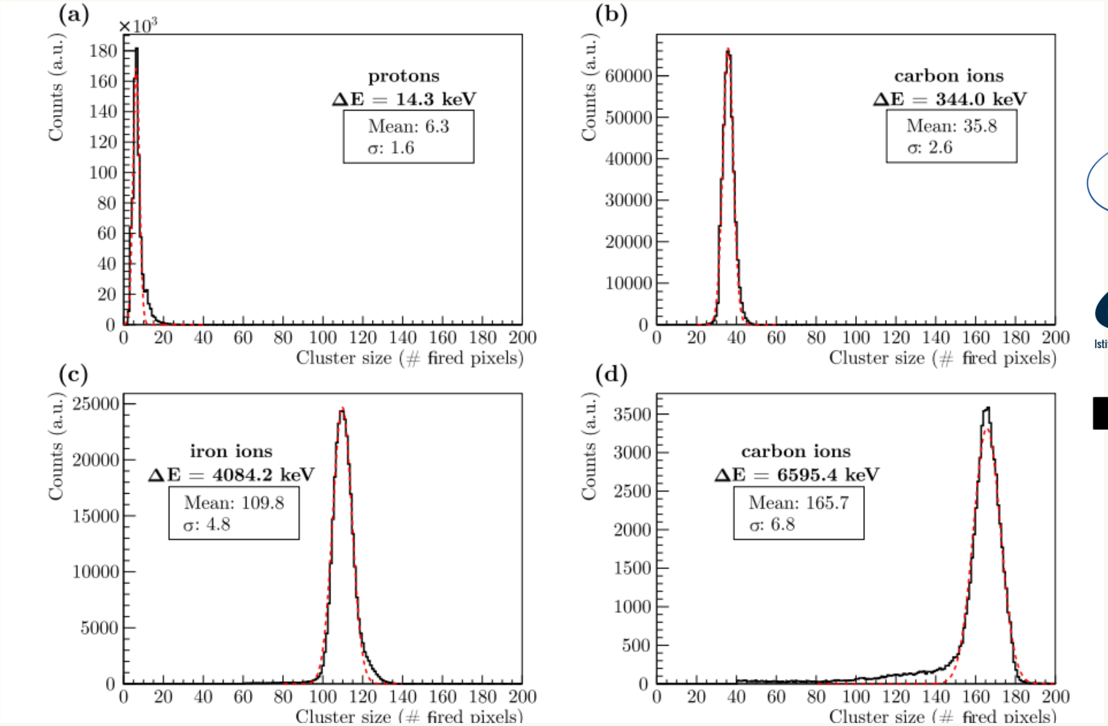
MAPS can be useful for Ion identification => Gaussian like distribution unlike the high energy particles – Landau

Mimosa28 (Ultimate)

- Matrix: 928 x 960
- Pixel pitch: 20.7 µm
- AMS 0.35 high-res process
- Readout time= 185.6 µs
- Rolling Shutter readout

PXL, STAR experiment at BNL

First vertex detector at a collider experiment based on MAPS



C.-A. Reidel et al, “Response of the Mimosa-28 pixel sensor to a wide range of ion species and energies “ NIMA, vol. 1017 (2021) 165807 - https://doi.org/10.1016/j.nima.2021.165807

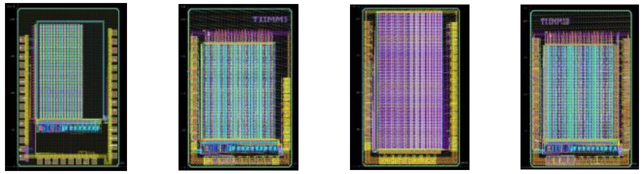
Indirect energy measurement via cluster size

3b. Ion identification – TIIMM project

TIIMM target = **Precision tracking** $\sigma_{pos.} \leq 10\ \mu m$ + **Low material budget** << % X_0 + **Energy loss measurement** $1\text{-}10^3$ MIPs

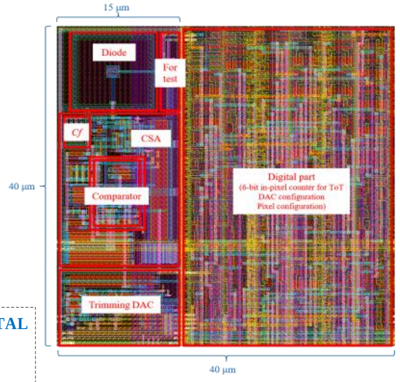
Tracking | **Identification**

Family of TIIMM sensors was designed (2020-2023)

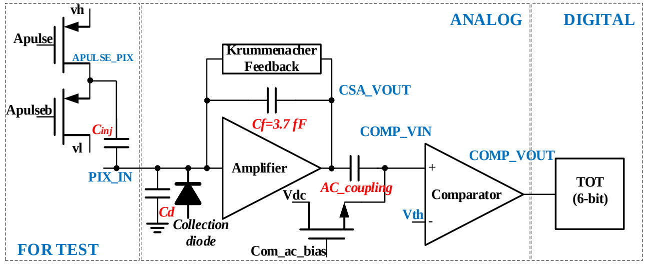


Goal: Linearity up to 800 ke^-

- Krummenacher feedback
- AC coupled comparator
- 6-bit TOT
- ~40x40 µm pixel

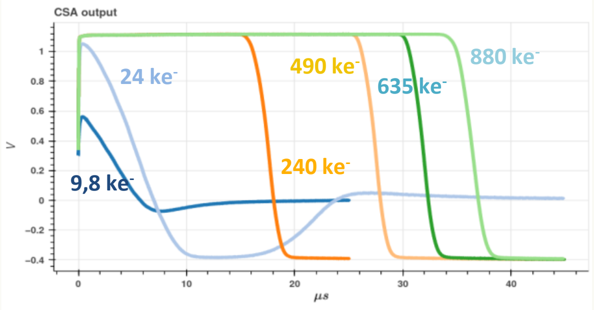


Pixel layout

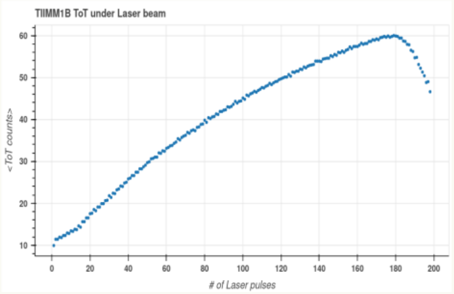


Pixel schematics

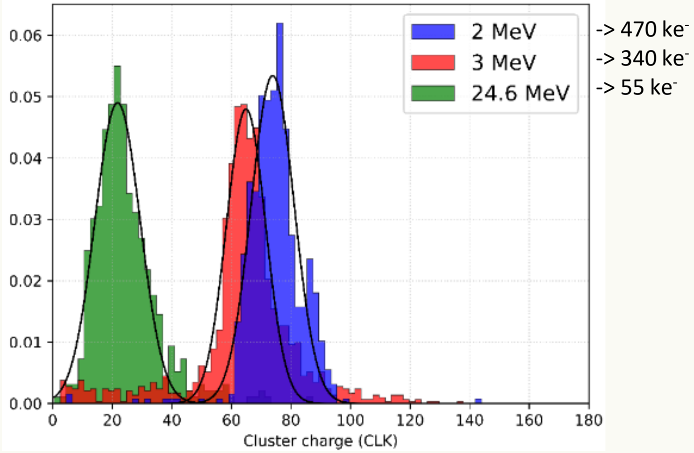
CSA output



Output linearity with laser



Proton measurements at AIFIRA (Bordeaux) and CYRCE (Strasbourg)



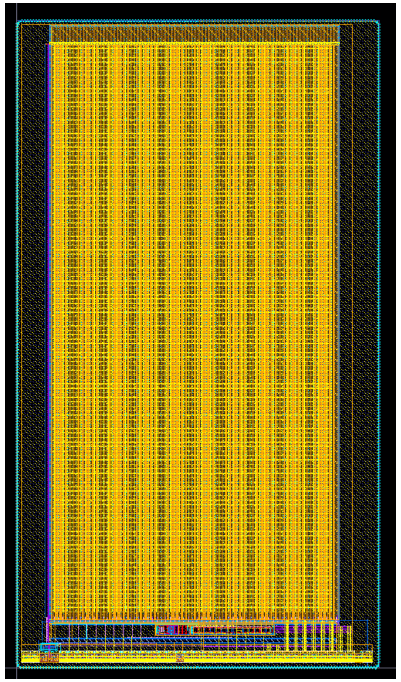
Promising results but can we do more than 6bit TOT ??

3c. Ion identification – Next steps

IMPACT sensor

- Analog front end => TIIMM1B
    - Large linearity
- Digital => TOT measurement:
    - **12bit per pixel**
    - Single hit/Accumulation counting
    - Synchronous readout
- Design for Test (masking/pulsing)
- Matrix:
    - Pixels of 50x50μm^2
    - 128x64 pixels
    - Active area = 6.4 x 3.2 mm2
- 8 digital outputs @ 50MHz

  => 4k frame rate



Submission under way

Next steps

- Verify the sensor functionality
- Build a multi-sensor detector

Next version goals

- Asynchronous readout
- High speed serializers
- Bigger area (few cm^2)

Summary & future steps in Energy measurement

- Main branch of the C4PI (HEP applications)
    - OBELIX
    - OCTOPUS
    -
- Application branch of the C4PI (Spectroscopy, Ion identification)
    - Low energy X-ray / electron tests
    - In-pixel gain development
    - ADC development
    - TOT sensors development for Ion identification (IMPACT and more)

Thank you for your attention

Back-up: some generic informations

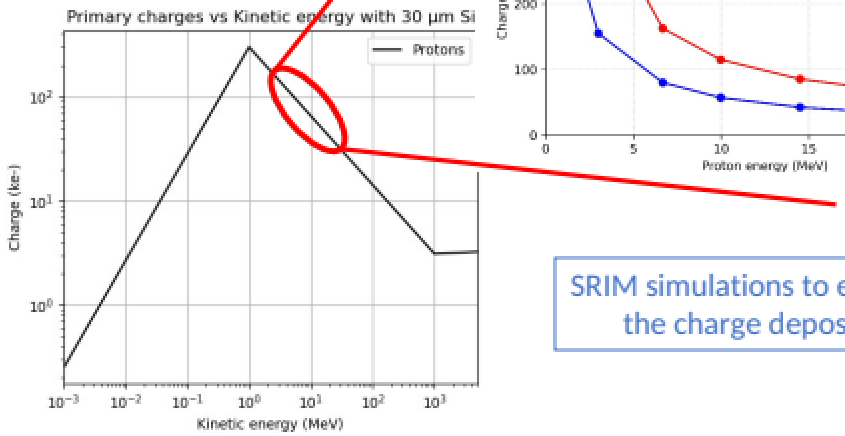
Sensor tested: TIIMM 1B (uniform N layer + extra deep P)

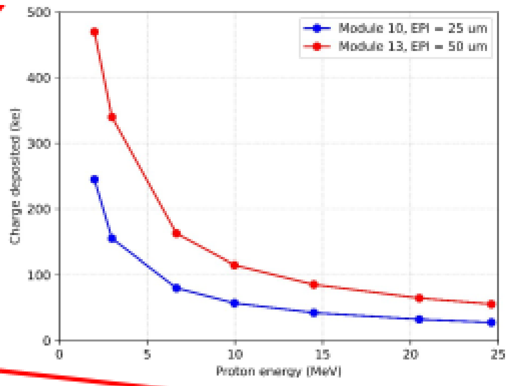
- Module n°10: 25 um EPI
- Module n°13: 50 um EPI

6 bits ToT + prescaler (CLK cycle period multiplier)

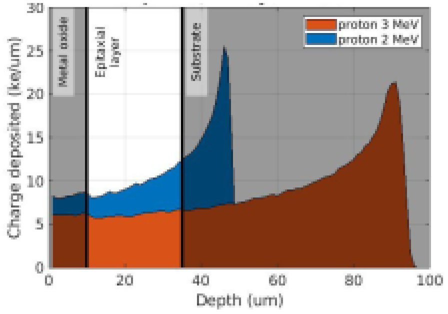
2 measurements campaigns with proton beams :

- AIFIRA (LP2iB, Bordeaux) 04.2024
  2 MeV, 3 MeV
- CYRCE (IPHC, Strasbourg) 02.2025
  5 MeV, 10 MeV, 15MeV, 20 MeV

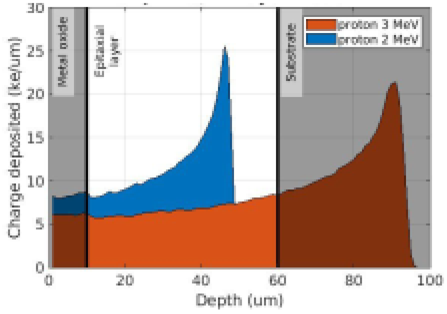




SRIM simulations to estimate the charge deposited



EPI 25 um



EPI 50 um