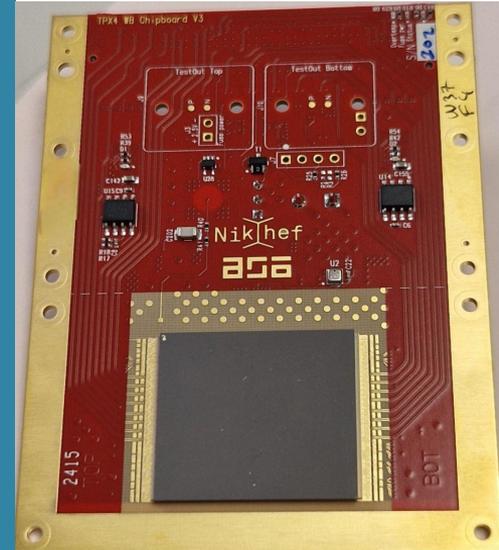


First characterization of a GaAs-based Timepix4 detector assembly for X-ray imaging applications

26th International Workshop on Radiation Imaging Detectors



S. Velardita*, N. Biesuz, R. Bolzonella, P. Cardarelli, V. Cavallini, L. Cimmino, A. Feruglio, M. Fiorini, R. Longo, V. Mazzini, V. Rosso and A. Taibi

*INFN Ferrara

Hybrid pixel detectors



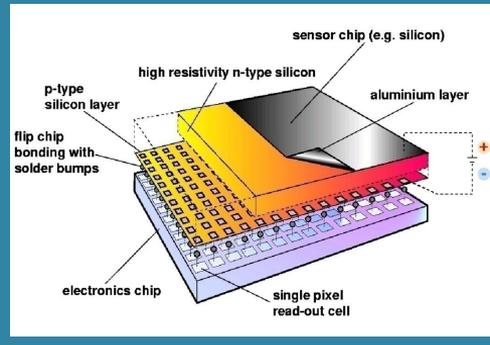
Medipix* Collaboration (based at CERN) develops **hybrid pixel detectors** for particle tracking and X-ray imaging.

INFN is an official member of the Medipix4 Collaboration since **November 2020** (Medipix4 and Timepix4 ASICs)

Advantages of hybrid approach:

- **Standard CMOS** can be used (follow industry)
- **Sensor material** can be changed (Si, GaAs, CdTe..)

Developed two chips: Medipix4 and **Timepix4**



*<https://medipix.web.cern.ch/>

Timepix4 readout

Two different readout modes:

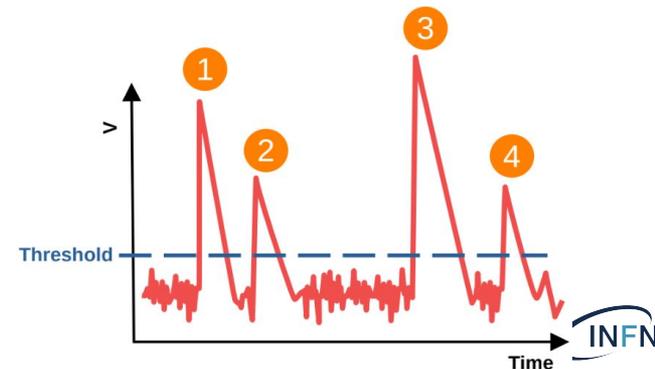
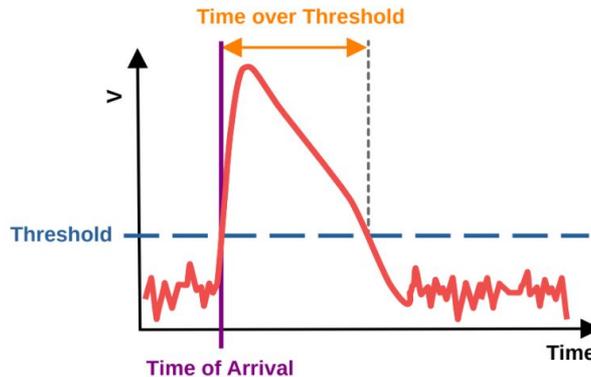
Data-driven

- Event-based readout, sending only relevant data (particle hits)
- Zero-suppressed continuous acquisition, up to 10.8 kHz/pixel
- Time-of-Arrival, sub-ns time binning <200 ps
- Time-over-Threshold 11-bit dynamic range with $\sim 200 e^-_{\text{rms}}$ resolution

Frame-based

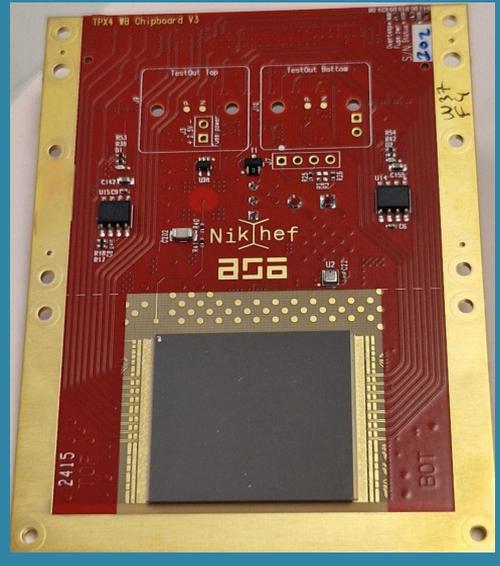
- Full frame readout with continuous read-write (CRW)
- No zero-suppression (no pixel address sent)
- Frame rate limited by bandwidth, e.g. 44.6 kfps @ 163.84 Gbps (16 bit)
- 8-bits or 16-bit counter depth up to 5×10^9 hits/mm²/s

Ferrara fully developed a data acquisition system based on FPGA and its software ([DATAPIX4, 10.1016/j.cpc.2025.109658](https://doi.org/10.1016/j.cpc.2025.109658))

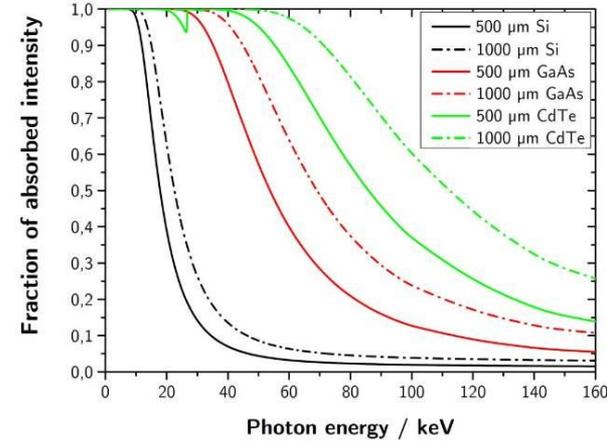


GaAs properties

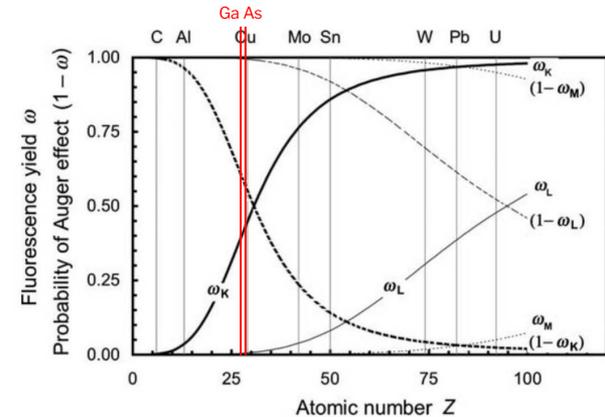
- GaAs detector (500 μm) efficiently **absorbs ($\sim 70\%$)** $E_{\text{X-rays}} < 50 \text{ keV}$
- Higher absorption efficiency than Si detectors for $E_{\text{X-rays}} > 20 \text{ keV}$
- Lower **fluorescence yield ($\sim 50\%$)** compared to higher Z semiconductors
- Balanced fluorescence and Auger electron emission enhance imaging contrast
- Superior performance for X-ray imaging applications for the range **20–50 keV**



10.1109/TMI.2014.2317314



10.1007/3-540-29471-6



Experimental setup Frame-Based

- 500 μm GaAs Timepix4 Assembly (**Advafab**)

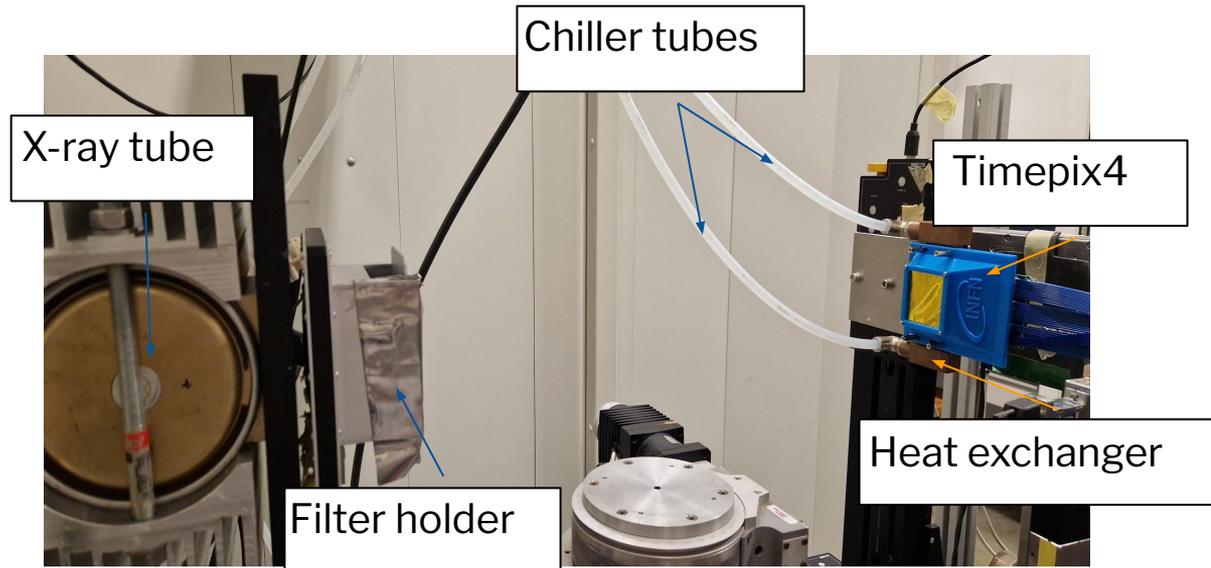


Poster: “*Chromium compensated gallium arsenide sensor evaluation using photon counting readout electronics*”, Dr. J. Kalliopuska et al. (07/07/2025)

Oral: “*Evaluation of detector-grade GaAs via alpha and X-ray spectrometry*”, Dr D. Nalyvaiko et al. (08/07/2025, 11:40)

Experimental setup Frame-Based

- 500 μm GaAs Timepix4 Assembly (**Advafab**)
- $V_{\text{bias}} = -350 \text{ V}$
- Readout SPIDR4
- Cooling System: chiller + copper heat exchanger (15°C)
- FB settings: 16bit, frame duration 0.01s
- Mammography X-Ray Tube

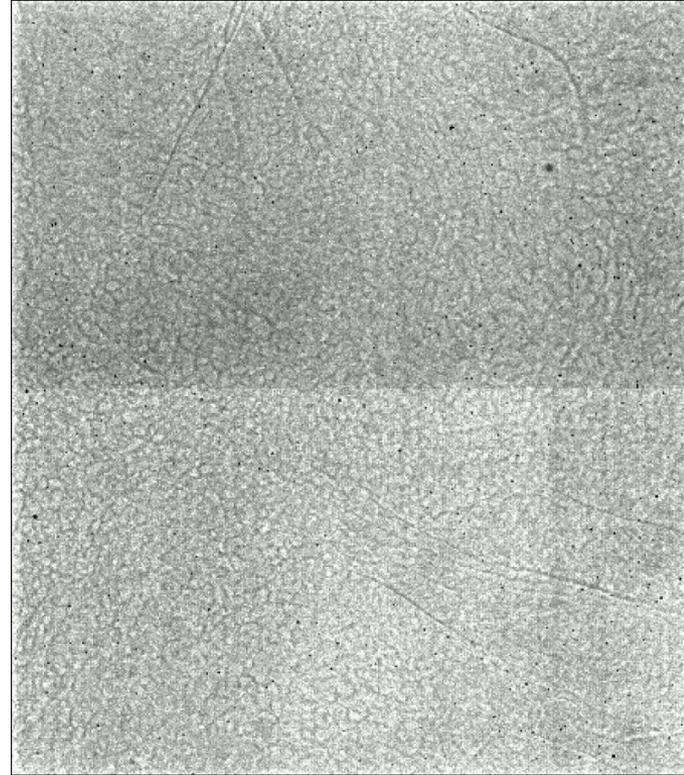


Flat-field stability: Method

- Flat stability test conducted over a continuous **3-hour** period
- 22 Flats acquired every 10 min under identical conditions
- Each flat acquisition had an exposure time of **1s**
- Method helps identify temporal drifts or fluctuations in **detector performance over time**

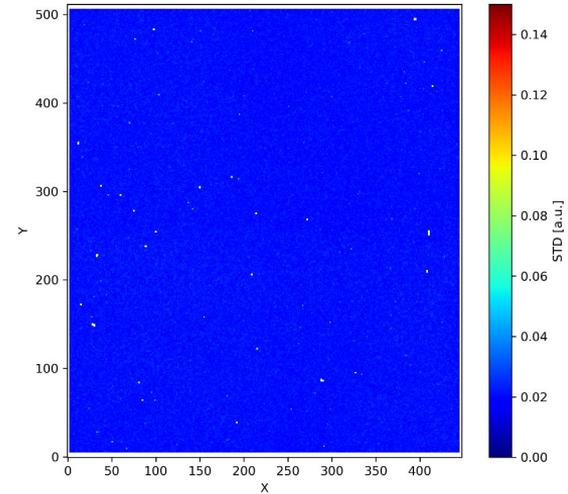
The acquisition settings are:

- Tube Voltage→35 kVp
- Tube Current→20 mA
- Beam Filter→2 mm Al
- Acquisition time→1s
- Threshold→17.64 keV

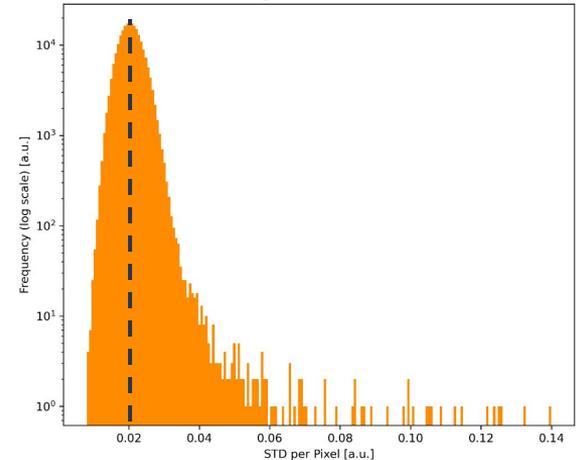


Flat-field stability: Single pixel standard deviation

- Analyzed standard deviation (**STD**) **variation** for individual pixels over time
- Tracked each pixel across all **flat-field acquisitions**
- Observed STD aligns with **expected statistical variation** from a single flat

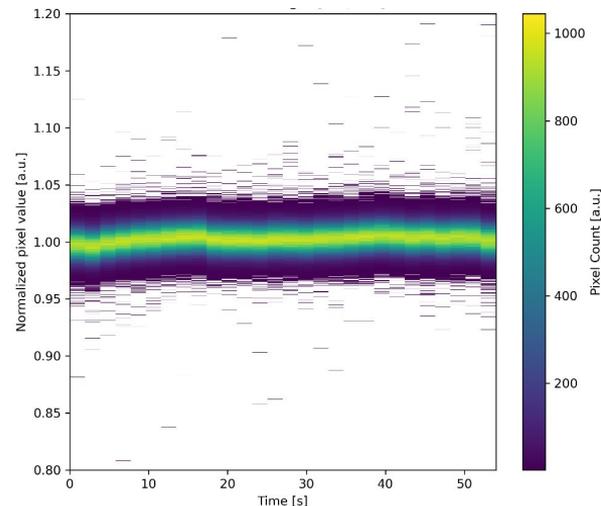
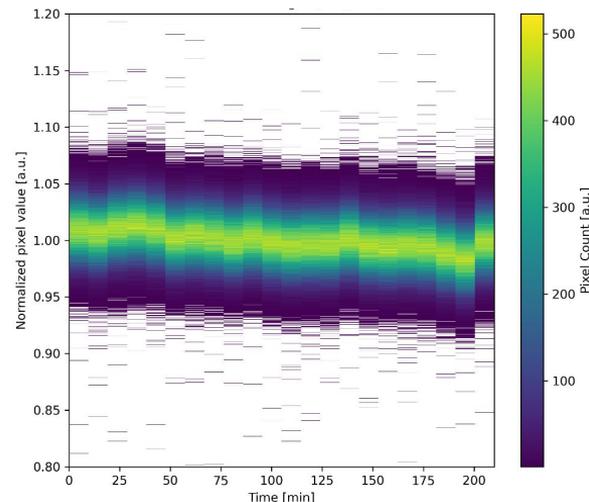


Single frame STD



Flat-field stability: Trend Analysis

- Assessed temporal stability by normalizing each pixel to its mean over all flats
- **98%** of pixels remained **within $\pm 5\%$** variation around 1
- Repeated analysis on a 1-minute acquisition (2s flats) confirmed similar stability
- Observed **stable pixel response** and consistent sensor polarization throughout

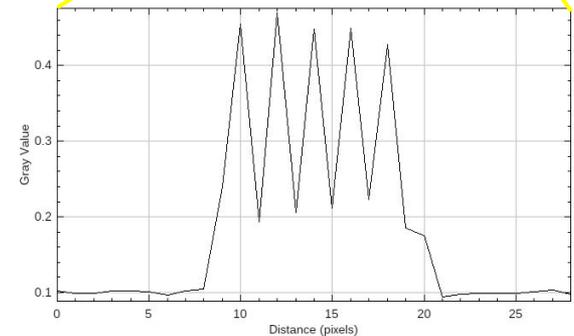
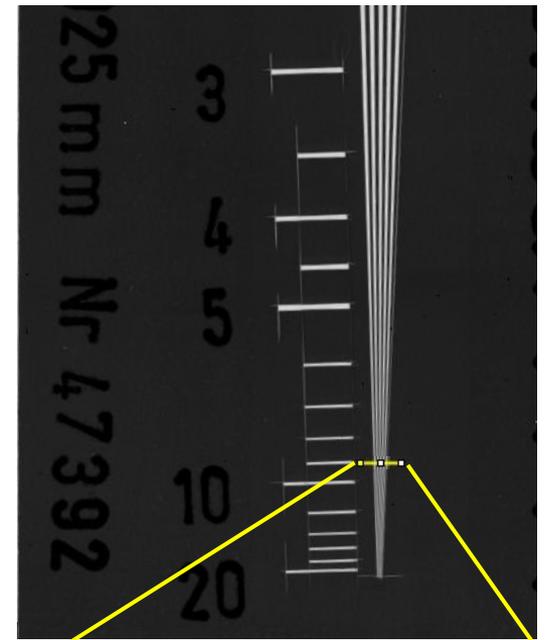


Spatial resolution: Star pattern

- Star pattern offers a clear visual representation of resolution limits
- Lines remained resolvable up to the Nyquist frequency (9.1 mm^{-1})

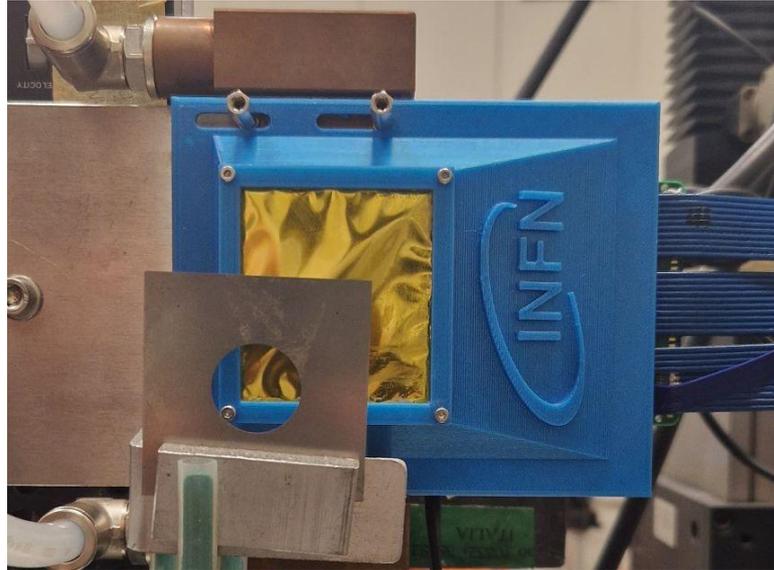
The acquisition settings are:

- Tube Voltage \rightarrow 25 kVp
- Tube Current \rightarrow 20mA
- Beam Filter \rightarrow 2 mm Al
- Acquisition time \rightarrow 2s
- Threshold \rightarrow 3.36 keV



Spatial resolution: Slanted edge

- Used **3.2° tilted edge** to capture sub-pixel sampling in one acquisition
- Built **Edge Spread Function (ESF)** by aggregating data along the slant
- Computed **Line Spread Function (LSF)** from ESF and fit with Gaussian
- Extracted spatial resolution from **FWHM** of the LSF fit



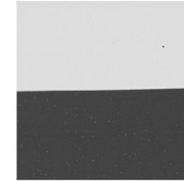
Spatial resolution: LSF vs Energy

- Acquired slanted edge data at **15 keV** and **25 keV** X-ray energies
- Spatial resolution dropped from **62 μm** to **70 μm** at higher energy
- Degradation caused by increased **charge sharing**

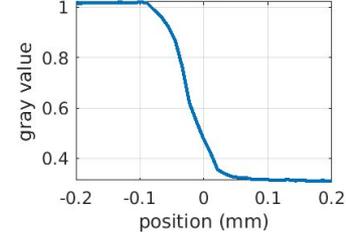
Acquisition parameters:

- Tube Voltage \rightarrow 20 && 40 kVp
- Tube Current \rightarrow 90 && 60 mA
- Beam Filter \rightarrow 1.08 Al && 2.02 Al
- Acquisition time \rightarrow 3 s
- Threshold \rightarrow 3.36 keV

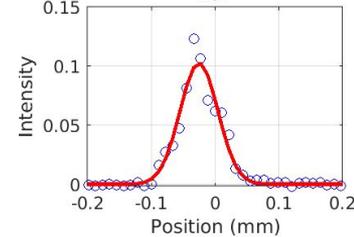
Slanted edge



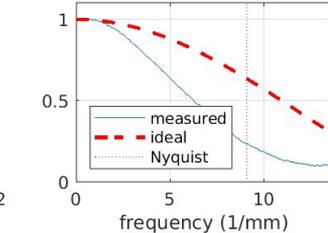
ESF



LSF



MTF [$@50\% = 6.26 \text{ lp/mm}$]

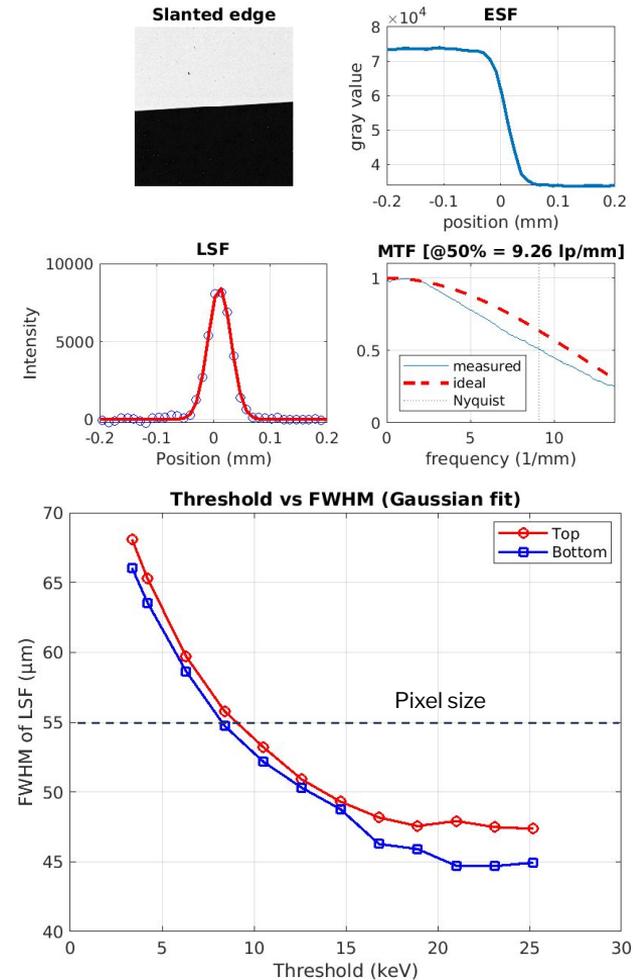


Spatial resolution: LSF vs Threshold

- Spatial resolution improves with **higher acquisition thresholds**
- Elevated thresholds reduce **charge sharing**, sharpening edges

Acquisition parameters:

- Tube Voltage→49 kVp
- Tube Current→40 mA
- Beam Filter→1.55 Al + 0.02Cu
- Acquisition time→3 s
- Threshold→[1000e-, 6000e-]



Radiography: Frame-based

Acquisition Parameters

- **Tube Settings:** 25 kVp, 60 mA
- **Acquisition:**
 - 1s **test object**
 - 1s **Flat-field**
- **Hit Rate:** 15,000 hits/pixel/s
- **Timepix4 Settings:**
 - **Bias Voltage** → -350 V
 - **Threshold** → 3.36 keV

Fishing line



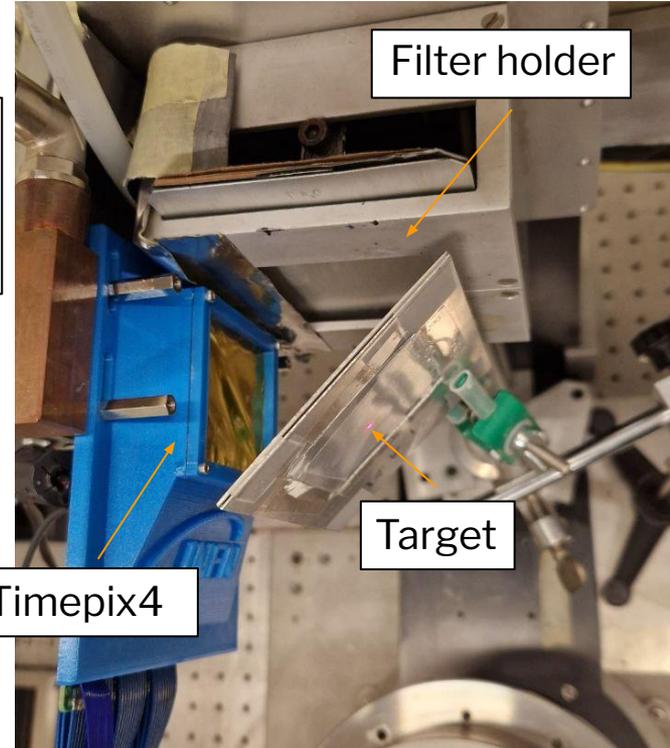
What is it?

Hint: We are an italian research
group

Experimental setup Data-Driven

Fluorescence setup for **energy calibration**:

Poster: "*Timepix4 Based Detection System with 1 mm CdTe Sensor: Calibration and Preliminary Spectral Imaging Application*", A. Feruglio et al. (07/07/2025)



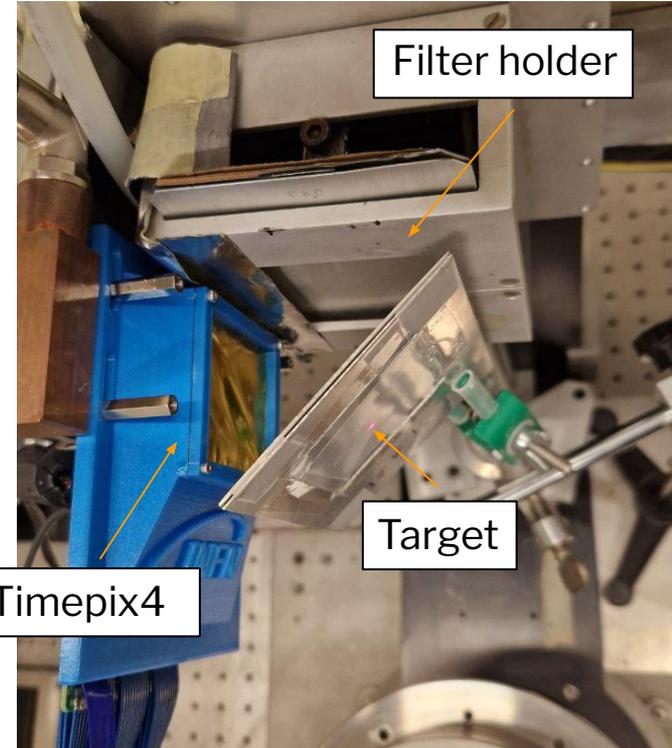
Experimental setup Data-Driven

Fluorescence setup for **energy calibration**:

- 500 μm GaAs Timepix4 Assembly
- Acquisition software DataPix4
- Read-out SPIDR4
- Cooling System
- Mammography X-Ray Tube
- Target holder

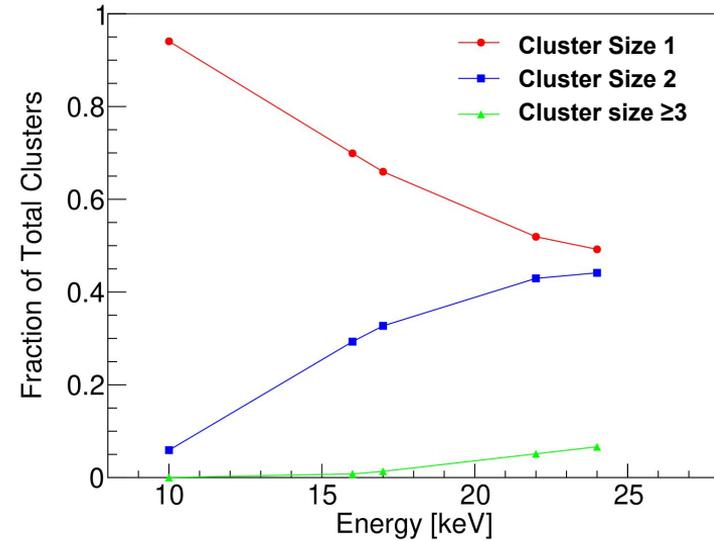
Target materials:

Material	$K\alpha_1$ [keV]
Ge	9.89
Zr	15.77
Mo	17.43
Ag	22.16
In	24.21



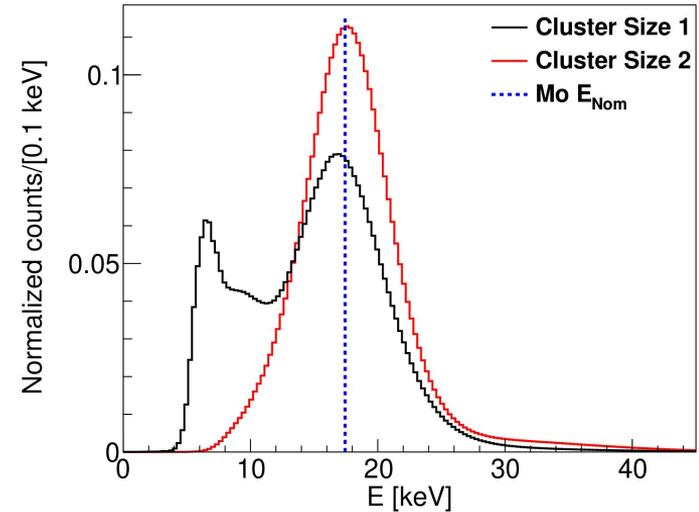
Cluster formation

- **Small clusters dominate** in the **10–25 keV** energy range
- **Single-pixel events** decrease as energy increases
- Higher energies produce **larger charge clusters**



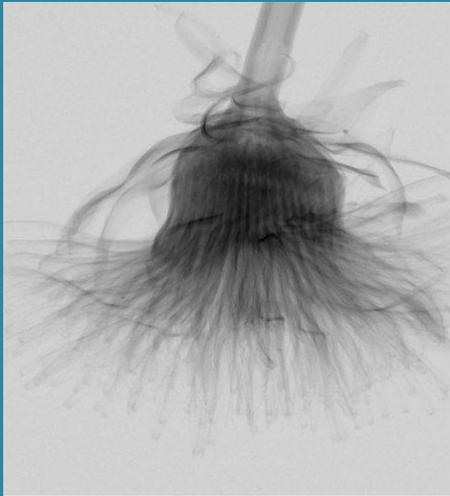
Charge-loss

- **Single-pixel clusters** may originate from larger clusters with **sub-threshold neighbors**
- This effect diminishes when considering **cluster size 2** events



Preliminary calibration

Summary and Outlook



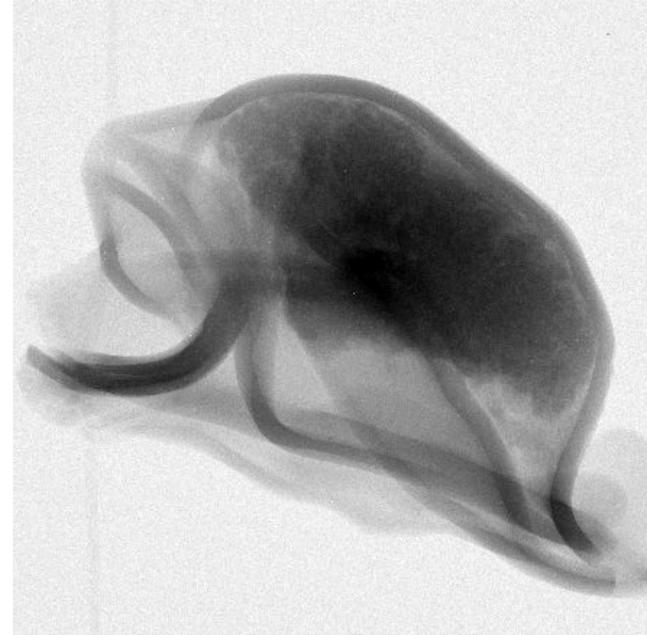
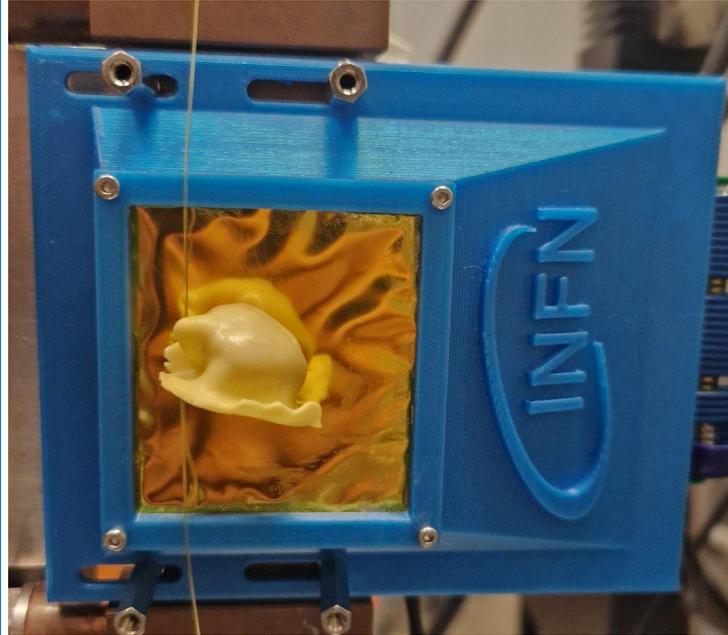
Summary

- Demonstrated good **flat-field stability** over 3-h and during continuous 1-min acquisitions
- Achieved high **spatial resolution**, validated through multiple evaluation techniques
- Obtained clear and detailed **radiographic images**
- Conducted preliminary Data-Driven analysis of **cluster formation** dynamics

Outlook

- Further investigations planned on charge loss mechanisms and spectral response
- **Synchrotron beamtime** approved at **SOLEIL** for advanced characterization
- **First in-lab μ CT** experiment scheduled with current setup in July

Radiography- Cappelletti



Thank you for your attention!

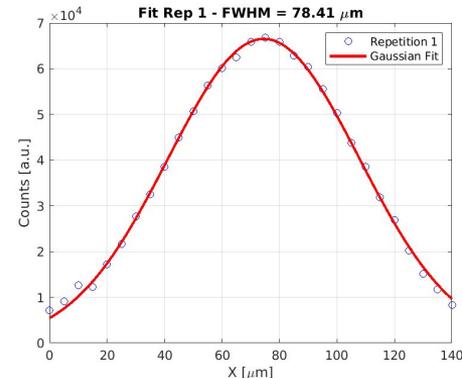
SPARE SLIDES

Spatial resolution: Scanning edge

- Conducted scanning edge study with edge aligned $\sim 1^\circ$ to pixel rows [[10.1088/1748-0221/20/02/C02047](#)]
- Edge incrementally shifted to transition pixels from fully illuminated to dark
- Extracted Edge Spread Function (ESF) per pixel across positions
- Derived Line Spread Function (LSF) from ESF and fitted with a Gaussian to determine spatial resolution (FWHM)
- Method requires high sampling: 22 acquisitions to cover 2 pixels with $5 \mu\text{m}$ steps

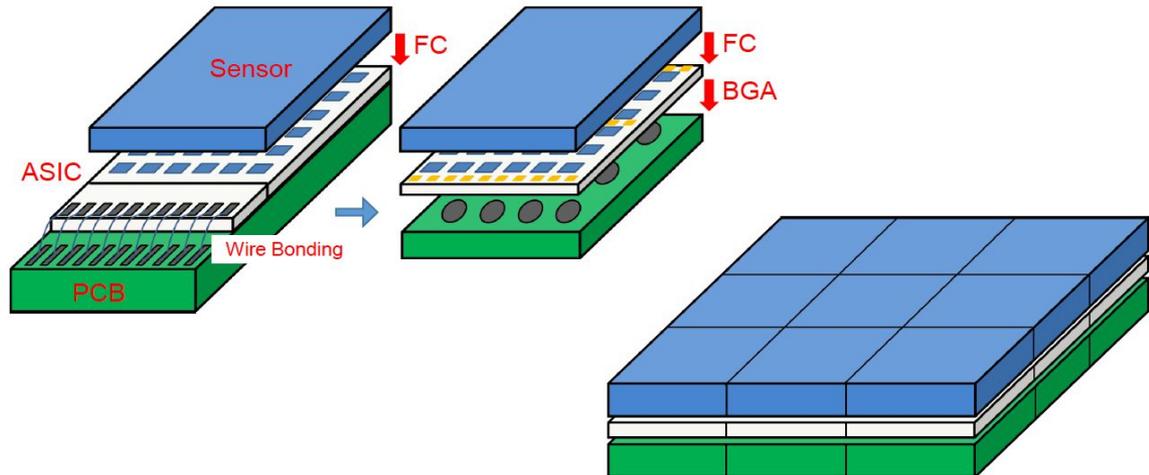
The acquisition settings are:

- Tube Voltage $\rightarrow 40 \text{ kVp}$
- Tube Current $\rightarrow 60 \text{ mA}$
- Beam Filter $\rightarrow 2 \text{ mm Al}$
- Acquisition time $\rightarrow 1 \text{ s}$
- Threshold $\rightarrow 3.36 \text{ keV}$



Scalable large-area detector

- Construction of **large-area detectors** by tiling smaller modules
- Prepared for **Through Silicon Vias technology**
 - Periphery integrated inside the pixel matrix
- Removes side periphery for **4-side buttable** seamless tiling



Energy calibration pixel-by-pixel

