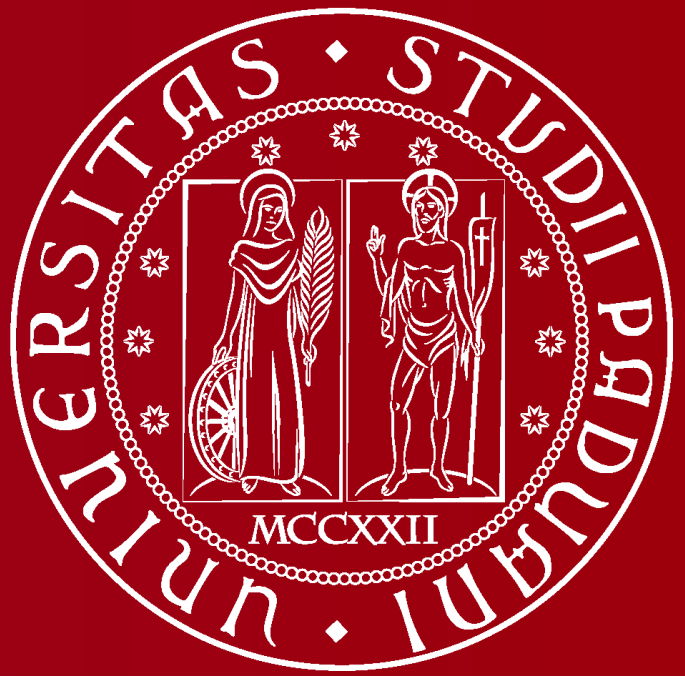




Low power FD-MAPS for charged particle tracking and photon imaging



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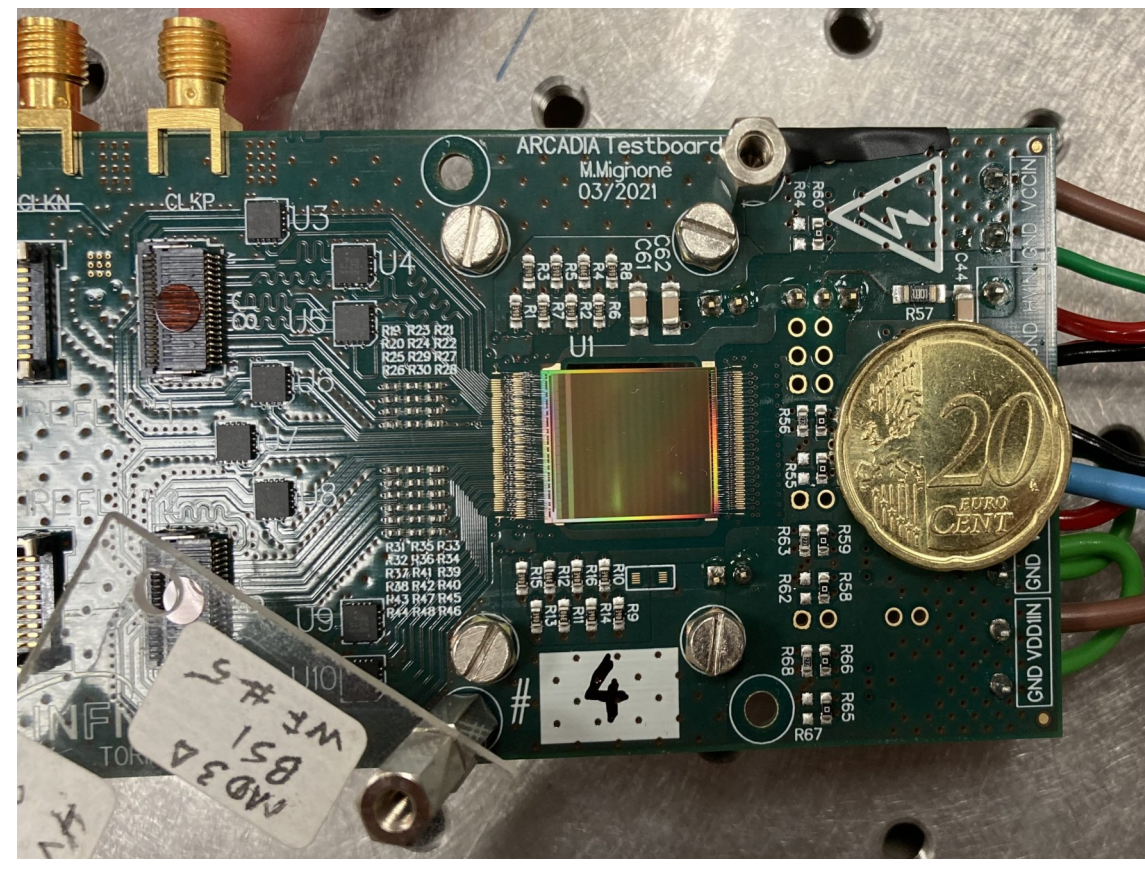
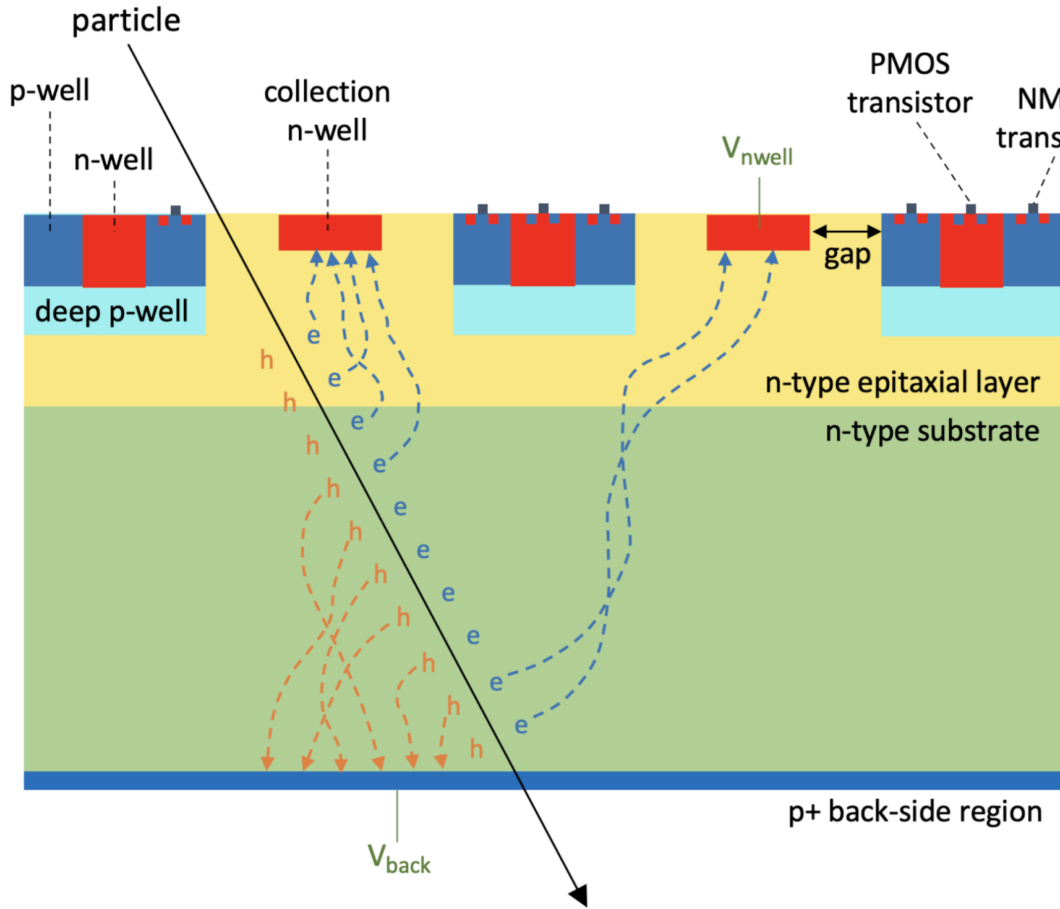
Sensor Characterization

ARCADIA (Advanced Readout CMOS Architecture with Depleted Integrated sensor Arrays) is a **Fully Depleted Monolithic Active Pixel Sensor (FD-MAPS)**, developed by an INFN collaboration using a customized **LFoundry 110 nm CIS process** on a **high-resistivity n-type substrate**.

Unlike standard epitaxial MAPS (e.g. ALPIDE), charge collection is exclusively by **drift**, ensuring: faster charge collection, higher detection efficiency, improved radiation hard-

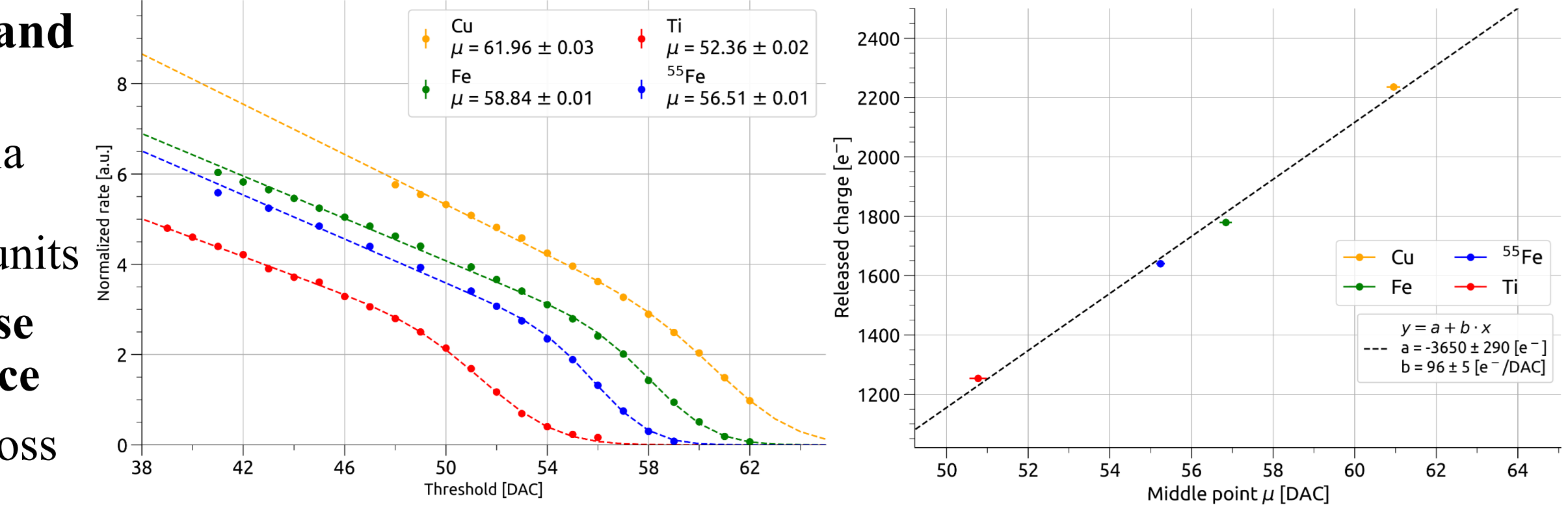
MD3 chip features:

- Matrix of **512x512 pixels** with **25 μm pitch**
- Active thickness of 50 / 100 / 200 μm
- 16 independent sections, each with a 100-320 MHz DDR serializer
- Back-side bias voltage to **fully deplete the sensor** (-90 V for 200 μm thickness)
- Low power consumption** for air-cooled operation (<30 mW/cm² in normal mode, <10 mW/cm² in space mode)
- Readout rate up to **100 MHz/cm²**
- Operations in **high-radiation environments**



Threshold uniformity and energy calibration:

- Threshold controlled via **VCASN**, expressed as (63-VCASN) in DAC units
- Evaluated with **test pulse injection** and **⁵⁵Fe source**
- Uniform response** across the matrix
- Injection-circuit artifacts absent with real radiation sources

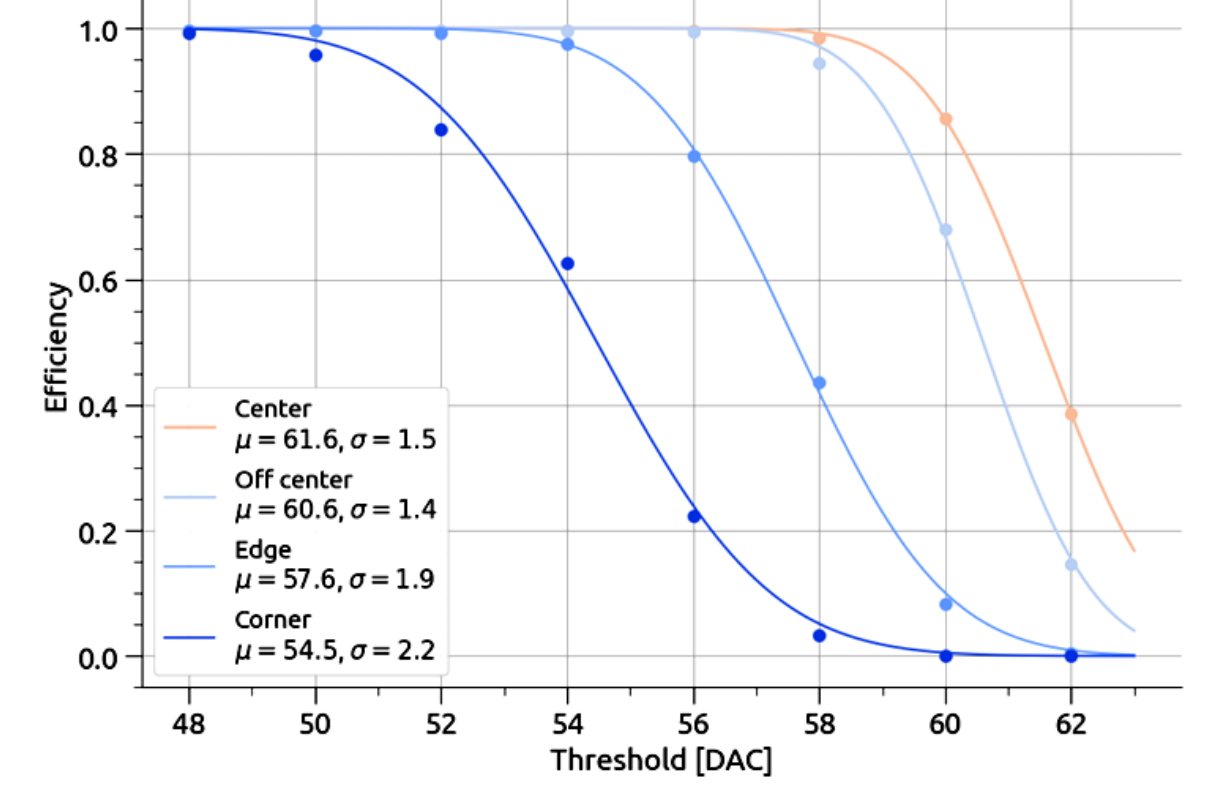


$$S(t) = S_0 \left[1 + \frac{C_s}{\sigma} (\mu - t) \right] \left[1 + \operatorname{erf} \left(\frac{(\mu - t)}{\sqrt{2} \sigma} \right) \right]$$

- Backside illumination shows $\sim 300 \text{ e}^-$ lower apparent threshold due to greater diffusion
- Energy calibration** combines fluorescence X-rays of Ti, Fe, Cu targets ($K\alpha_1$: 4.51, 6.40, 8.08 keV) with ⁵⁵Fe to convert DAC units to electrons
- Linear conversion**: $\sim 96 \text{ e}^-/\text{DAC}$

Charge collection efficiency:

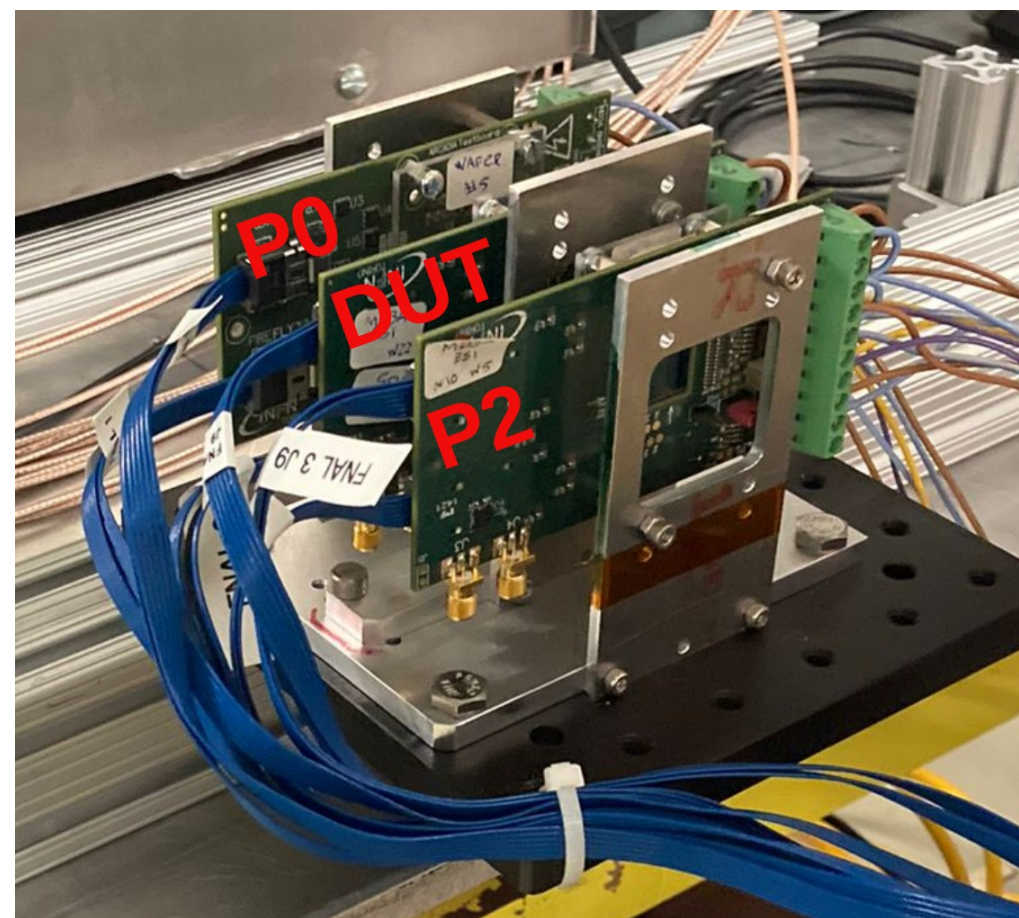
- IR laser scans** (1064 nm) characterize charge collection in a pixel region illuminated from the **backside**
- Full charge **collection efficiency** uniform across matrix
- Peak efficiency at pixel center; lower at edges due to charge sharing
- Noise: $\sim 30 \text{ e}^-$



M. Da Rocha Rolo et al. (2025), ARCADIA fully depleted CMOS MAPS development with LFoundry 110 nm CIS, Front. Sens., DOI: 10.3389/fsens.2025.1603755
C. Pantouvakis et al. (2026), Pixel response characterization of the ARCADIA fully depleted MAPS, JINST, DOI: 10.1088/1748-0221/21/04/P04003

Particle Tracking Performance

Measurements performed at the **Fermilab Test Beam Facility (FTBF)** with a **120 GeV proton beam**, considering MIP signal in 200 μm Si $\approx 16\,000 \text{ e}^-$. The telescope comprises **three 200 μm -thick MD3 planes**:

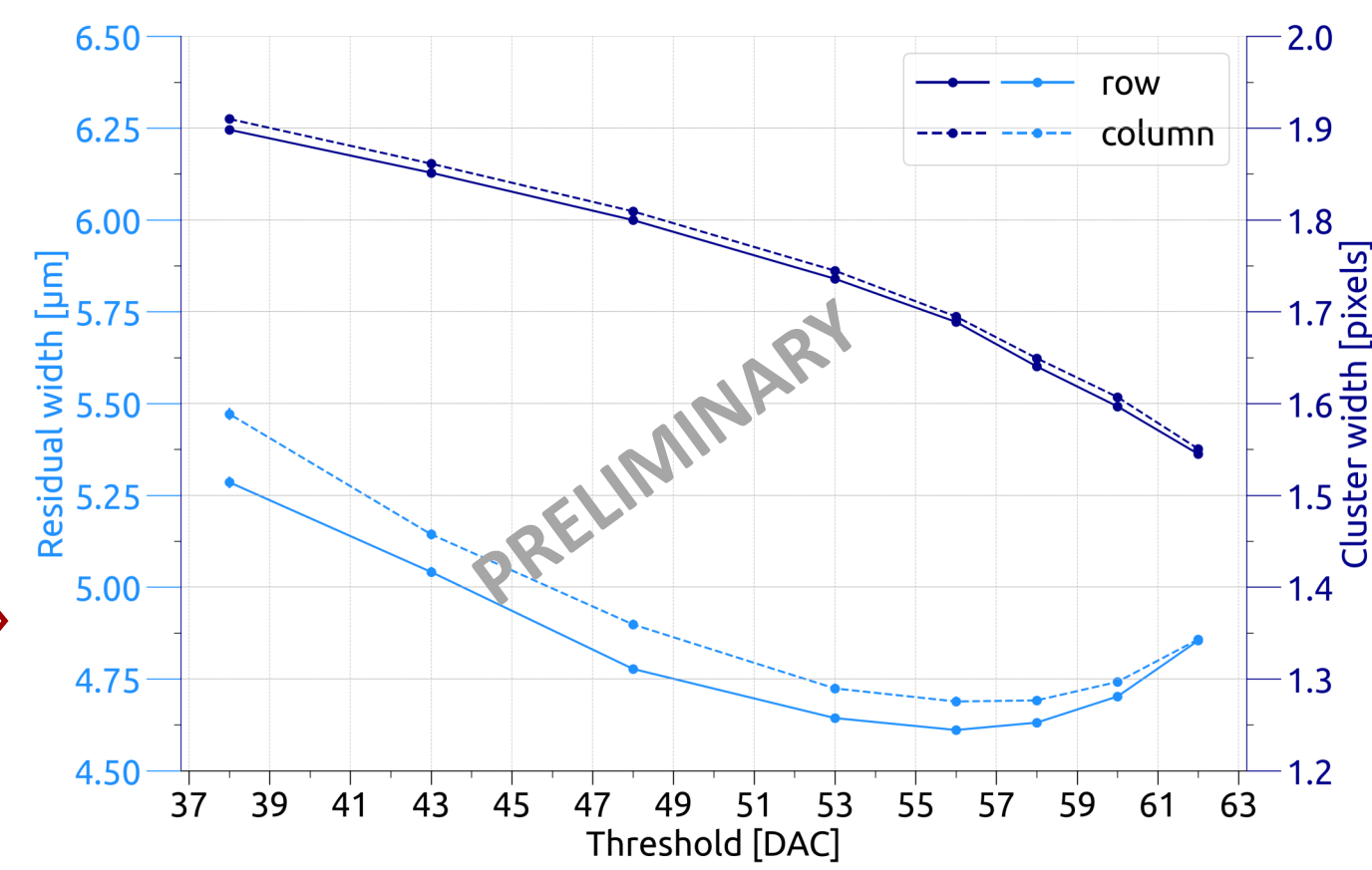


- Plane 0 (P0)**: tracking, at $z_0 = -33.8 \text{ mm}$
- DUT**: device under test, at $z = 0 \text{ mm}$
- Plane 2 (P2)**: tracking, at $z_2 = +29.4 \text{ mm}$

Track reconstruction:

With 200 μm active thickness, **charge sharing dominates** even at the highest threshold setting:

- At **highest threshold**: only 25% single-pixel clusters; multiplicity 2 dominant
- At **lowest threshold**: most frequent multiplicity = 4 pixels
- Average cluster width **always > 1.5 pixels** across entire threshold range



Large charge sharing
↓
Residual width
always **below** binary
resolution of 7.2 μm

Tracking resolution:

With three identical planes, the DUT resolution is directly proportional to the intrinsic sensor resolution and the **tracks** are reconstructed as **straight lines** connecting two points on the tracking planes.

Spatial resolution is decoupled from telescope contribution via geometrical calculation:

$$x_{DUT} = \frac{x_0 z_2 - x_2 z_0}{z_2 - z_0} \Rightarrow \sigma_{det,x} = \frac{\sigma_{residual,x}^2}{\sqrt{1.502}}$$
$$\sigma_{tel,x}^2 = \frac{z_2^2 + z_0^2}{(z_2 - z_0)^2} \cdot \sigma_{det,x}^2 \Rightarrow \sigma_{residual,x}^2 = \sigma_{det,x}^2 + \sigma_{tel,x}^2$$

Threshold value of 56 DAC ($\sim 1700 \text{ e}^-$):

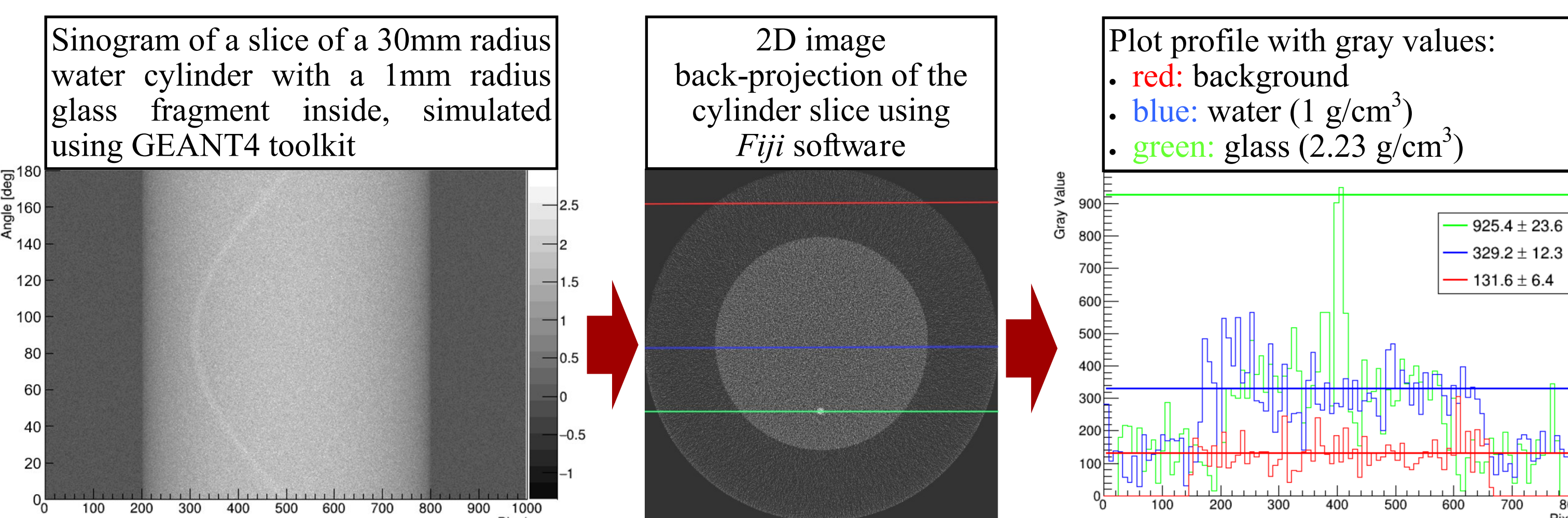
- Mean residual width of 4.65 μm
- Spatial resolution of 3.8 μm

Medical and Industrial Application

Photon Counting Computed Tomography is the emerging technology in both medical and industrial fields. **CT scanners** are used as **automatic non-contact inspection systems** for both human body and initial/final product stages of industrial production lines.

Key requirements are mainly two: **short scan and image reconstruction times** and **high signal to noise ratio**.

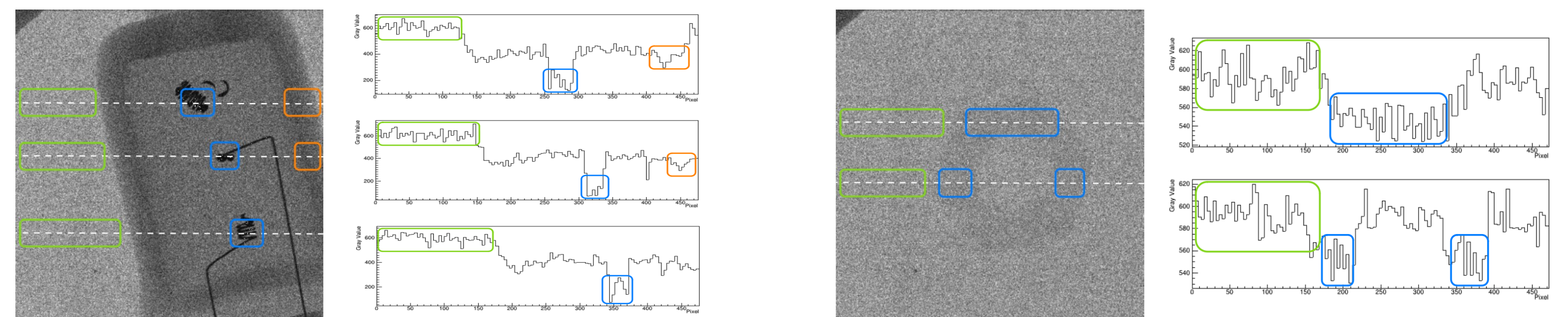
ARCADIA sensor represents a great candidate to develop a **competitive marketable silicon detector for CT applications**.



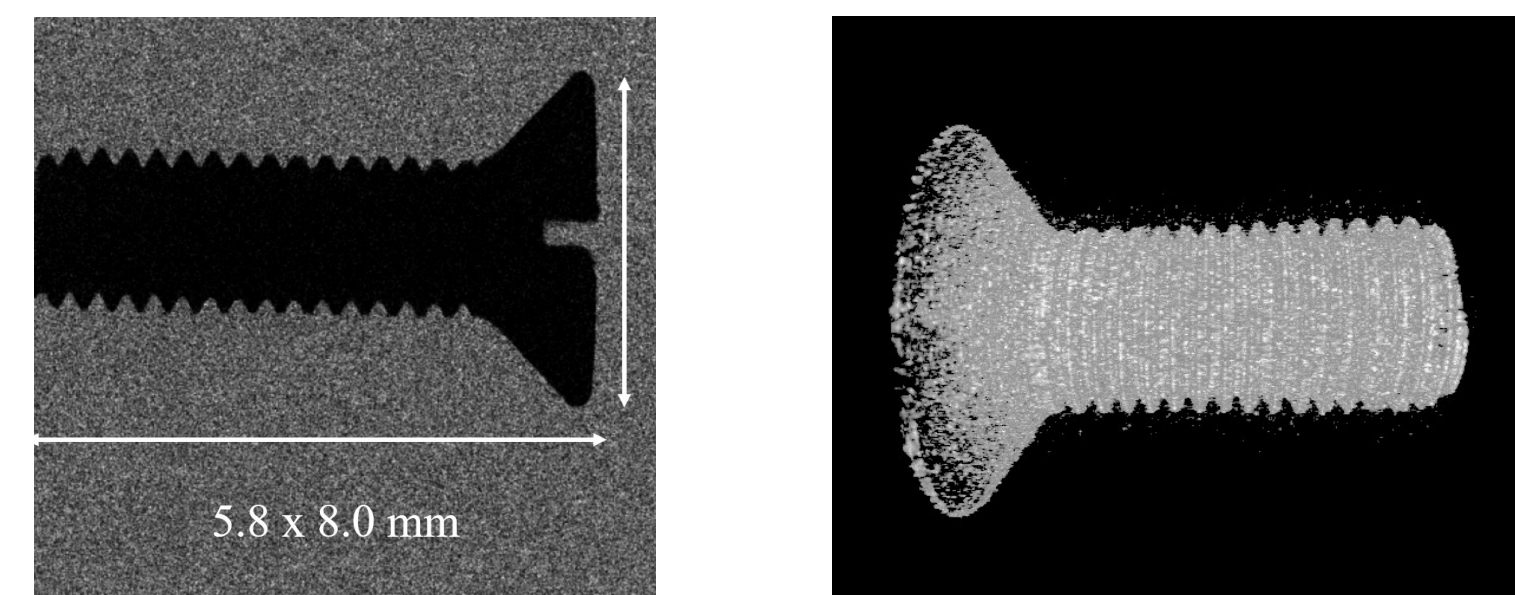
C. Bonini (2025), X-ray monolithic detectors for industrial CT scanning, Doctoral thesis, Università degli Studi di Padova, Dipartimento di Fisica e Astronomia "G. Galilei"

Test with MD3 chip under an X-ray tube of 40kV:

- Radiography of various small objects with the X-ray tube → High density materials are perfectly visible, while plastic materials can be spotted only after offline contrast enhancement



- Complete CT of a iron screw: projections are acquired rotating the sample of 1.8° from 0° to 180° using a stepper motor. The acquisition time is set to achieve a number of events per frame comparable to an industrial scanner



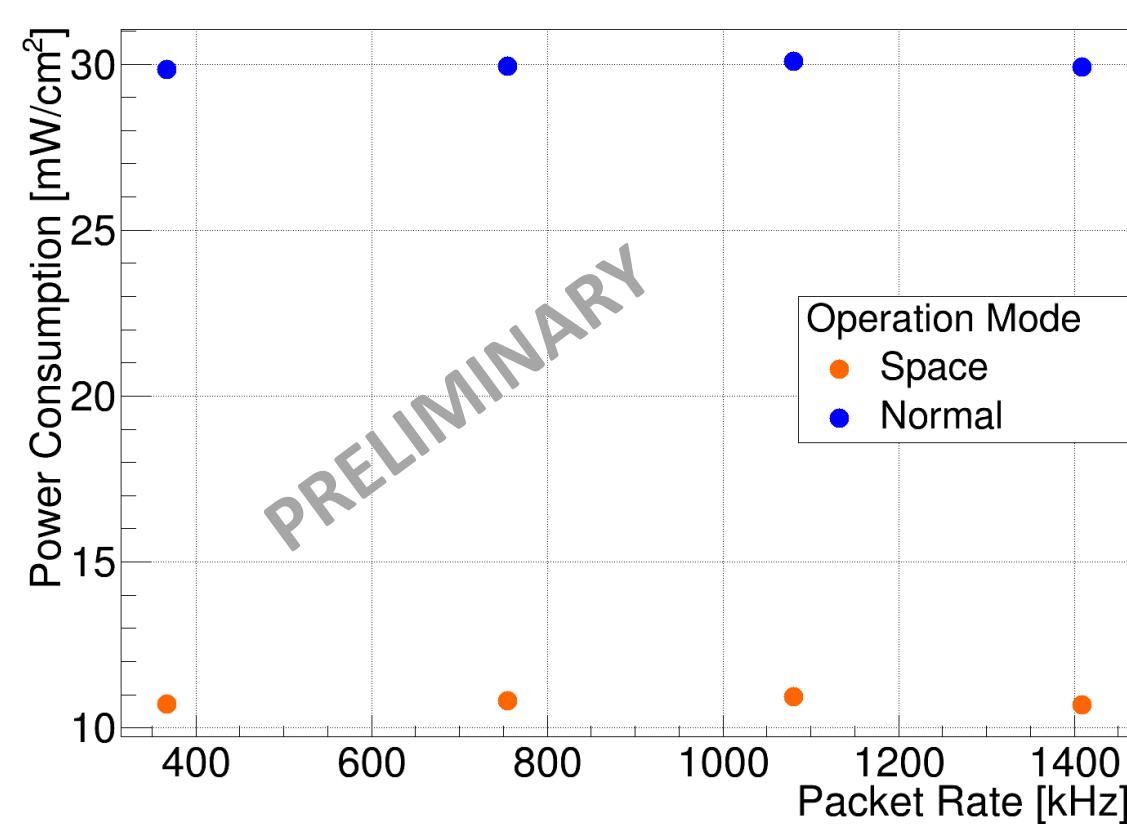
Threads of the screw well reproduced

Indentation of the slot screw drive appears as a slight recess along the edges of the head

Space Application

ARCADIA is a strong candidate for **space-borne pixel detector** applications, particularly on board **nanosatellites** and **CubeSats**:

- 16 independent sections**, parallel readout and independent parameter tuning
- Single serializer option for **ultra-low-power space mode**
- In **space mode**, power consumption calculated to be about 10 mW/cm²
- Backside bias voltage application, **fast charge collection** and only digital output signal for **high radiation tolerance**



Satellites are continuously exposed to several radiation sources that can damage semiconductor devices

A **Single Event Upset (SEU)** occurs when a single energetic particle deposits sufficient charge in a sensitive volume to cause a **bit-flip** in digital logic

Irradiate ARCADIA chip with ions of different Linear Energy Transfer (LET) to evaluate the **SEU cross-section** (σ_{SEU}).

Knowledge of the σ_{SEU} versus **LET** curve allows prediction of the in-orbit SEU rate for any orbit and shielding configuration.

ARCADIA digital logic sensitivity:

- Sensitive volume buried below **tens of μm of SiO₂** and metallization
- Sensitive depth of **few μm** (CMOS digital layer)
- Two pixel-level configurable latches: **Mask** and **Inj** (not triplicated)
- Both 0→1 and 1→0 transitions studied (distinct SEU cross-sections)

WORK IN PROGRESS

- Irradiate ARCADIA with ions of different LET at **LNL SIRAD beamline** (Tandem accelerator)
- Tune LET via device **tilt angle**: $\text{LET}_\theta = \text{LET}_0 / \cos\theta$
- Validation with **high-LET ALPI beam** (Au, Pb, Xe) for saturation confirmation