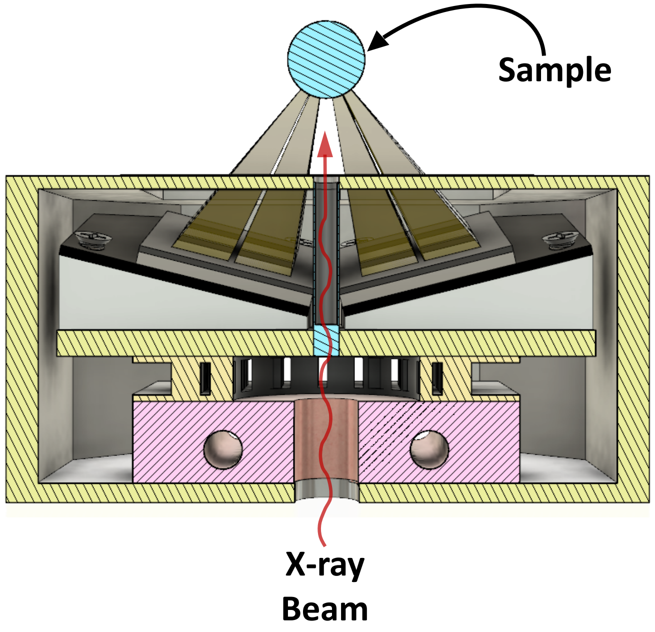
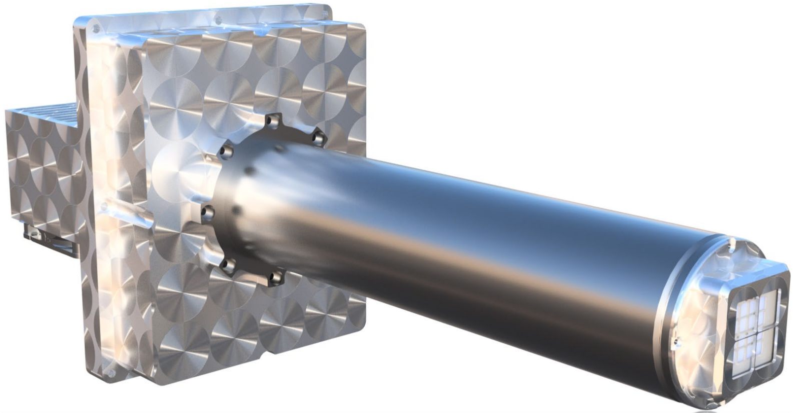




High-Rate X-ray Spectrometers based on Monolithic SDDs Arrays

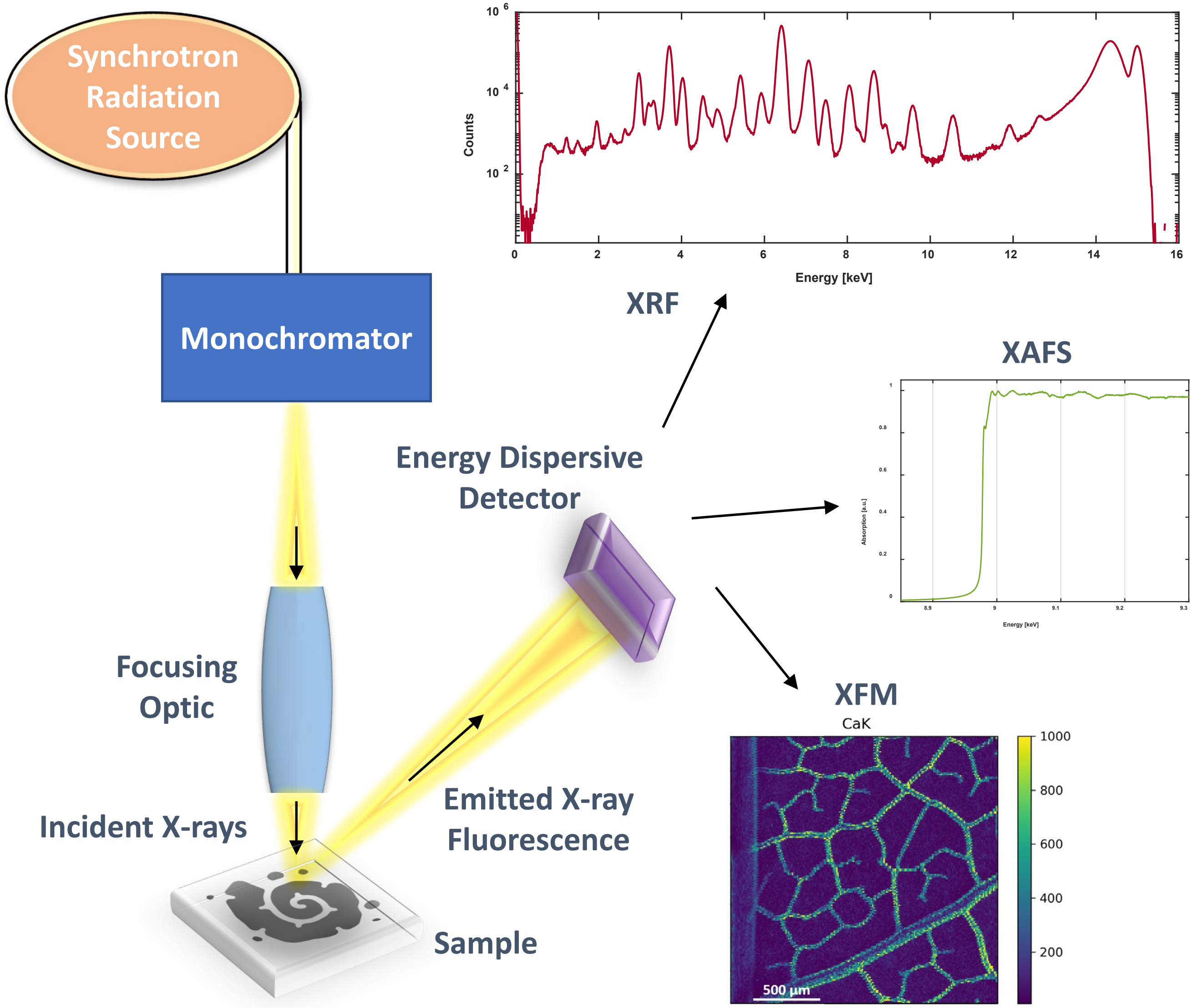
Giacomo Ticchi on behalf of RadLab Group

XDEP at SOLEIL Synchrotron – 6th Febraury 2024

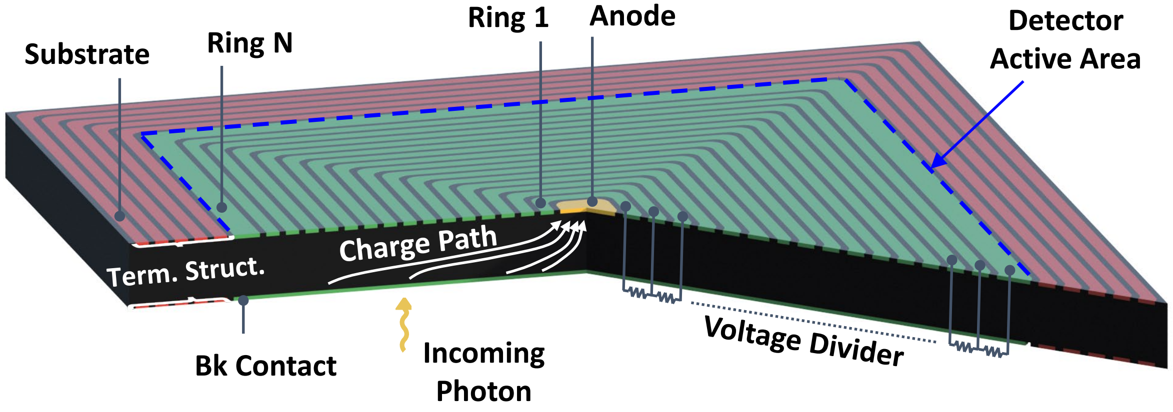
X-ray Spectrometers for Synchrotron Applications

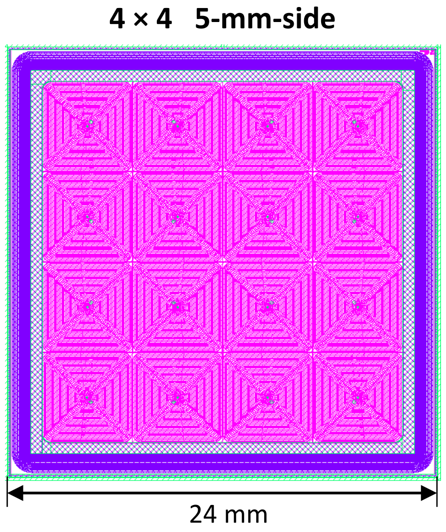
Motivation :
Develop a low-noise and versatile detector based on monolithic arrays of **Silicon Drift Detectors** for high-rate synchrotron applications (mainly XRF, XAFS, and XFM)

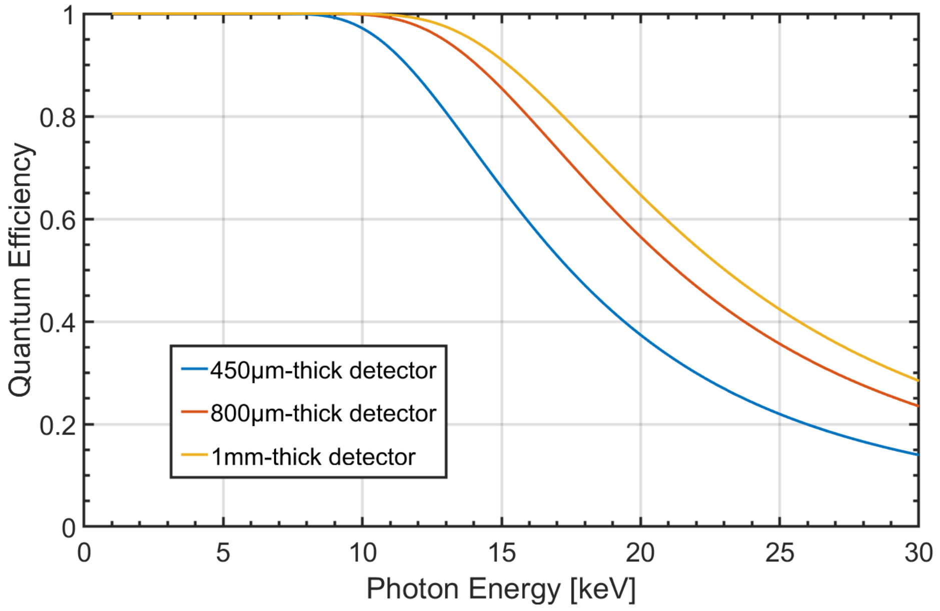
- **Detector requirements:**
- X-ray energy range: **0.2 keV – 20 keV** (Si detection region)
- **Best resolution (~125 eV** of FHWM Mn-Kα**)** at optimum shaping time and low rate, **good resolution** (≤ **200 eV**) at short shaping time and **high throughput (> 1 Mcps/ch.)**
- **Modular and scalable** design, to easily increase sensitive area and adapt with different experiment configurations



ARDESIA-16: Monolithic SDD Matrix

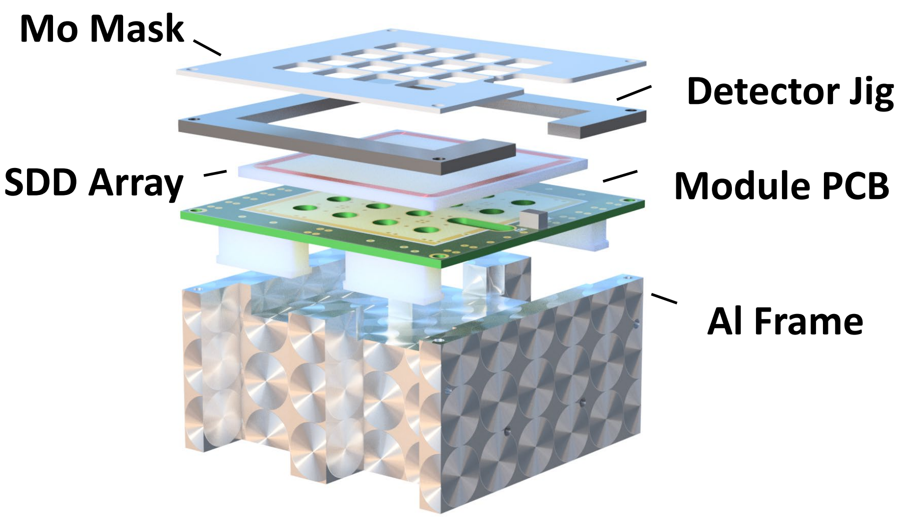






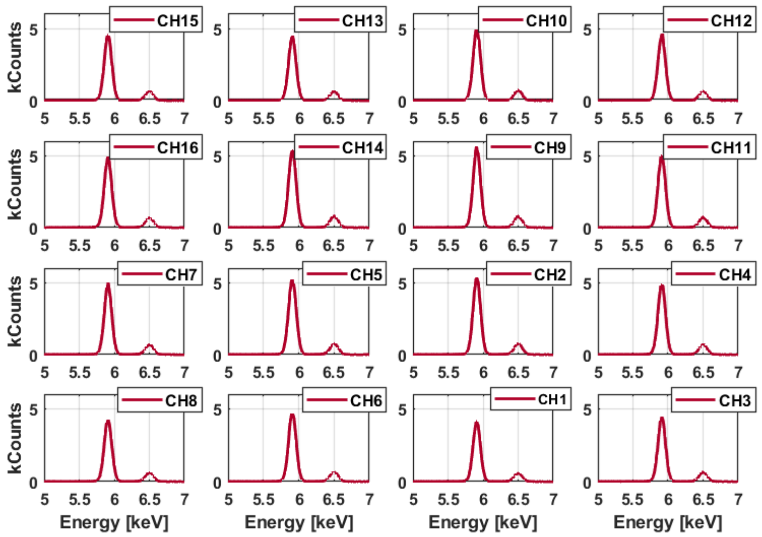
- ❑ **16-channel** detection system
- ❑ Thicker substrate (**450 µm**, **800 µm and 1000 µm**) to extend energy detection range, with expected ρ ≥ 10 kΩ·cm
- ❑ **5 mm side** for detector element

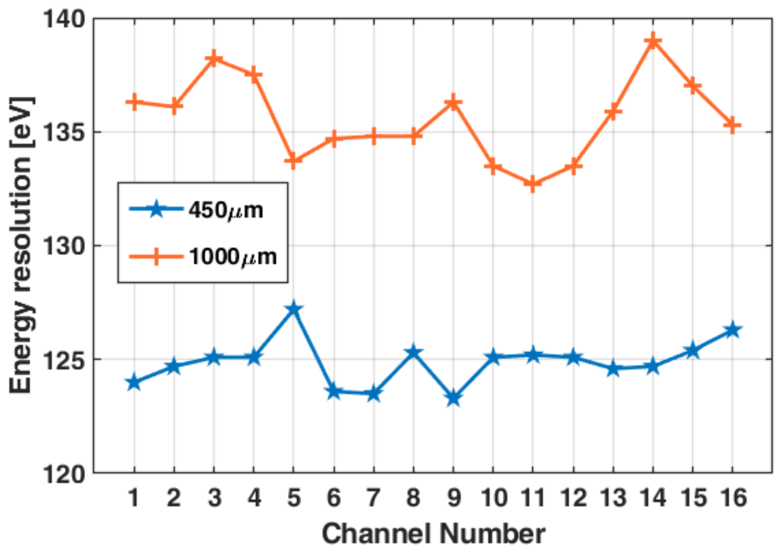
ARDESIA-16: Detection Module



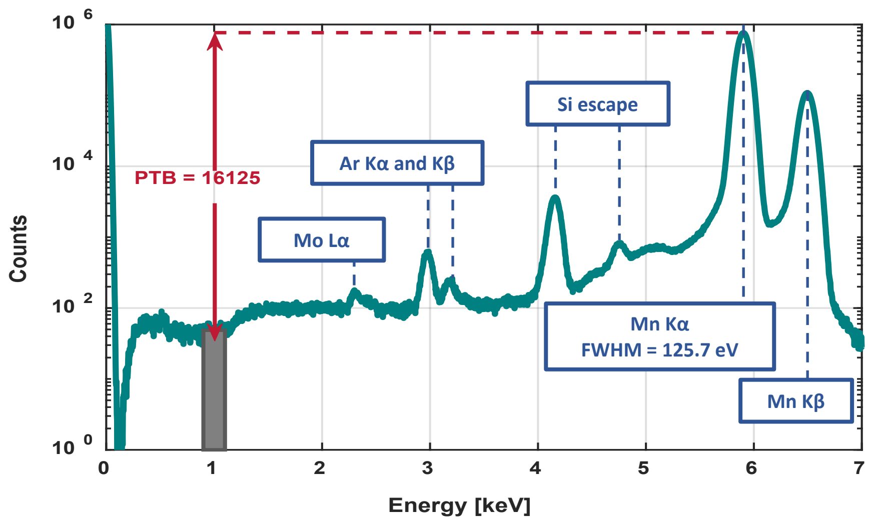
- 500 μm thick **Molybdenum Mask (or Zirconium)** to prevent charge sharing phenomena
- Total collimated area is **324 mm²**
- Hosting the **16 channel Monolithic SDD array** with all thicknesses
- Four custom-designed 4-channel **CUBE Preamplifiers**
- Preamplifier and Detectors are glued to an **Alogen-free PCB**
- Aluminum frame to anchor PCB and Mask

Peaking Time = 3 μs

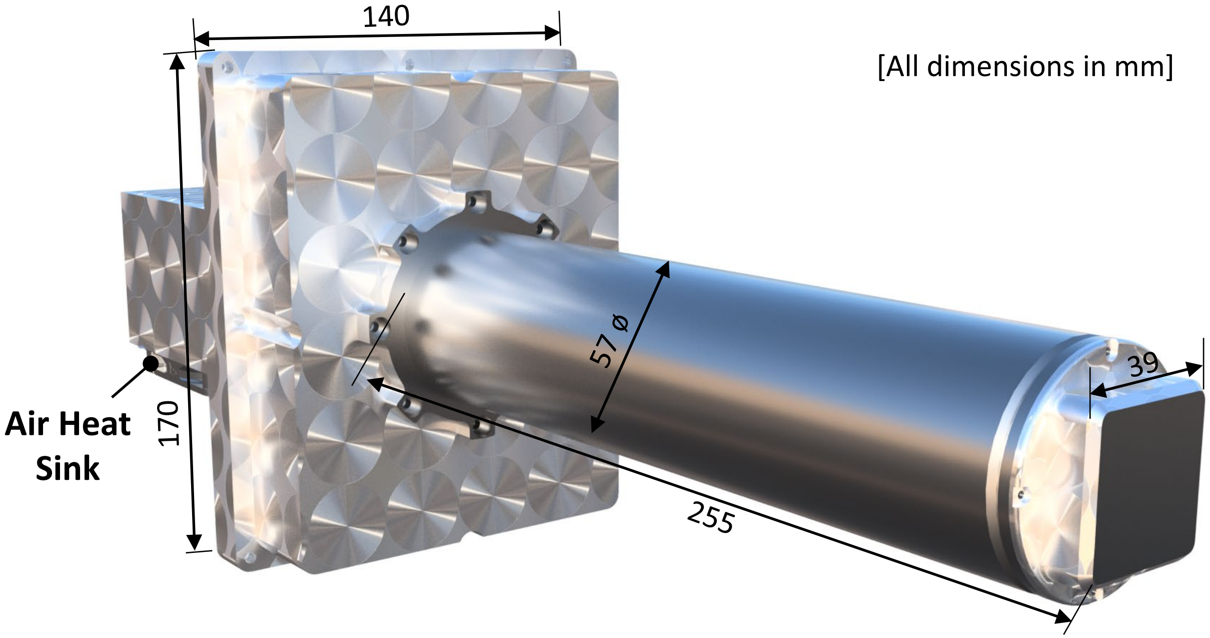




PTB > 15000 for each element



ARDESIA-16 Spectrometer

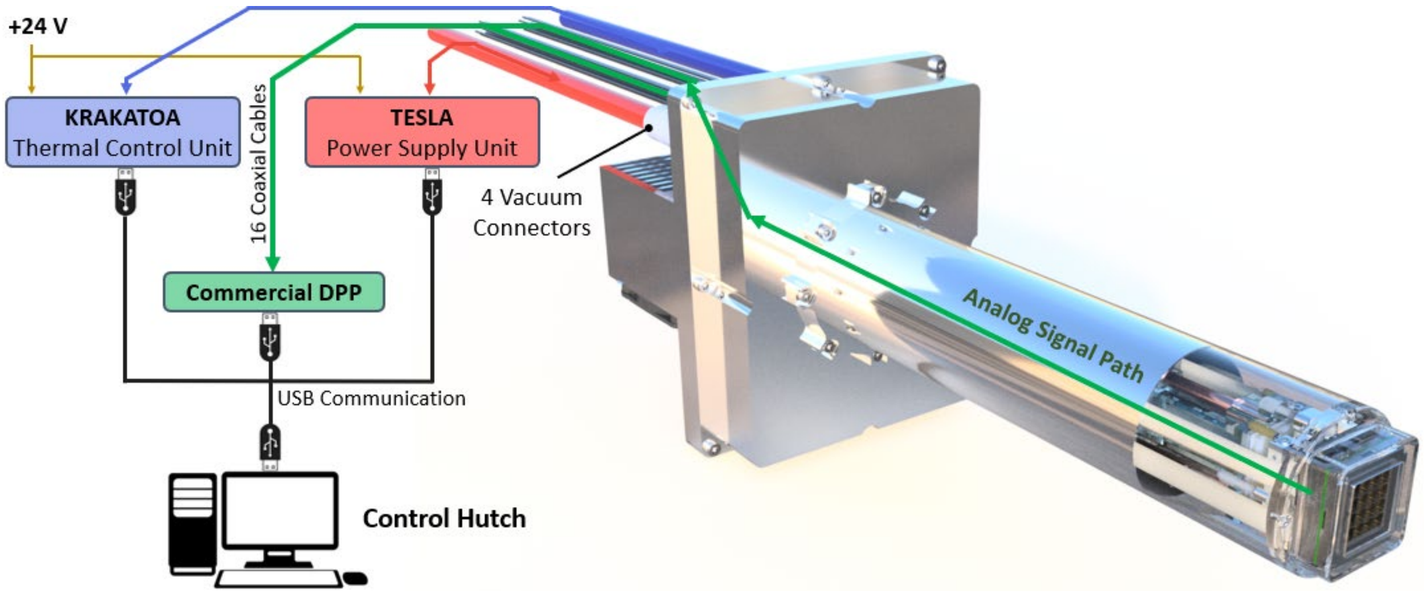


[All dimensions in mm]

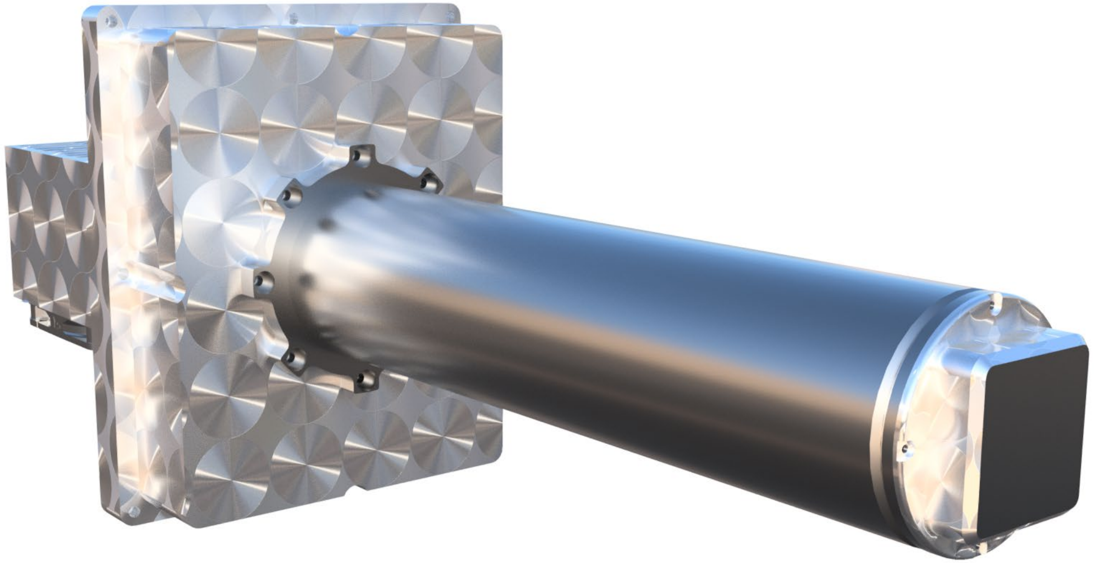
ion
le

- **Host the Detection Module** for every detector thickness
- **TEC Cooling** with a PI controller to keep the Detector temperature stable
- **≈ 0.45 sr Maximum Solid Angle at sample distance of 20 mm**
- **Window material:** Be or Polymer

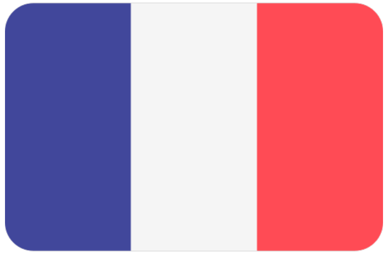
- **Two external units** for bias and cooling control
- **16 Coaxial cables** to be connected to an external DPP
- **USB connection** to a PC
- **Dedicated GUI** to monitor and control the spectrometer



ARDESIA Spectrometer in Europe



ESRF



- *ID16A* ARDESIA-16
- *BM8* ARDESIA-4

DESY

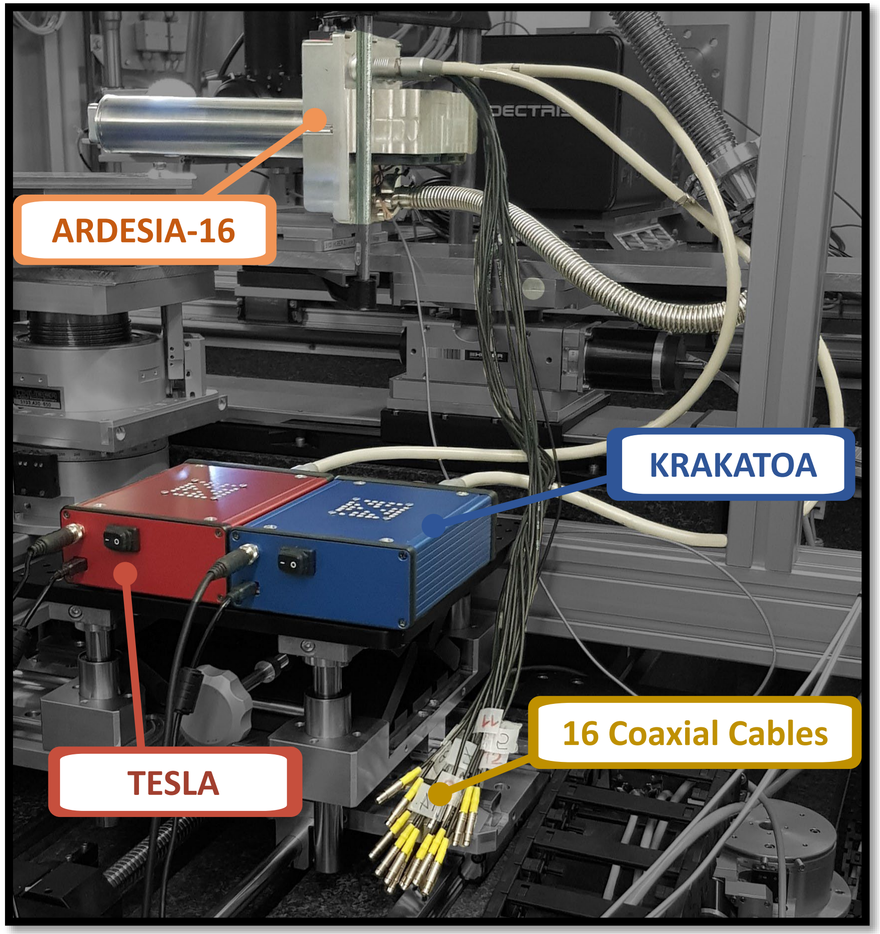
- *P06* ARDESIA-16

LNF

- *DAFNE LIGHT* ARDESIA-4

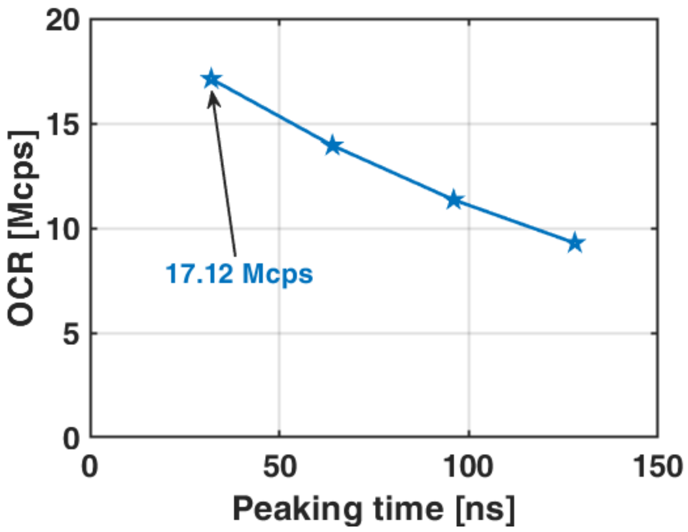
PETRA III P06: High Count-Rate and XFM

ARDESIA-16 at P06 Beamline (PETRA, DESY, Hamburg)



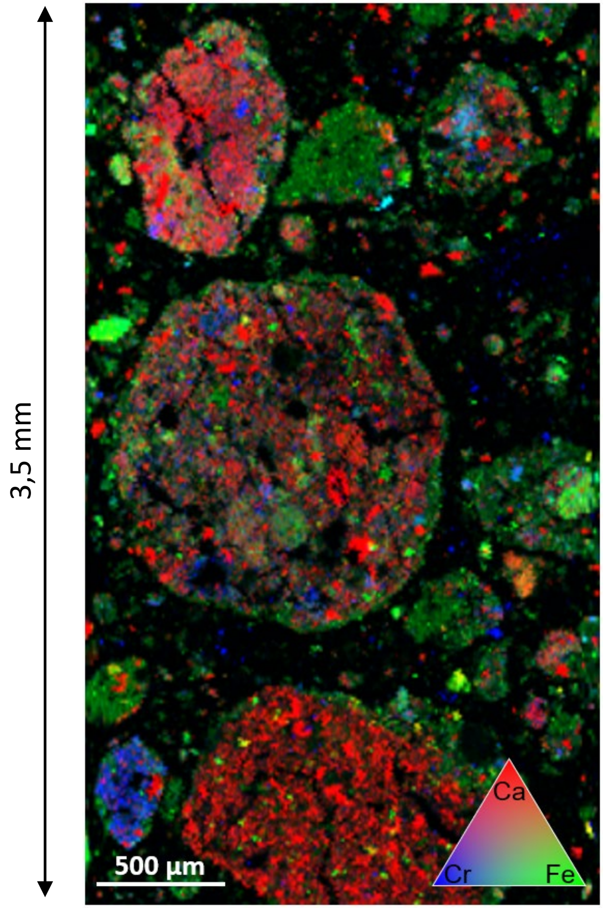
High Count Rate Measurements by sweeping the synchrotron beam intensity

- ❑ **Pure Manganese Sample**
- ❑ Beam Energy = 15 keV
- ❑ Meas. time = 60 s
- ❑ Detector T = −35 °C
- ❑ **DANTE DPP** (XGLab)
- ❑ Peaking Time = 32 − 128 ns
- ❑ Flattop = 128 ns



XFM of a Soil

- ❑ Dwell time 10 ms
- ❑ 350 × 200 pixels
- ❑ **Xpress3 DPP** (Quantum Det.)

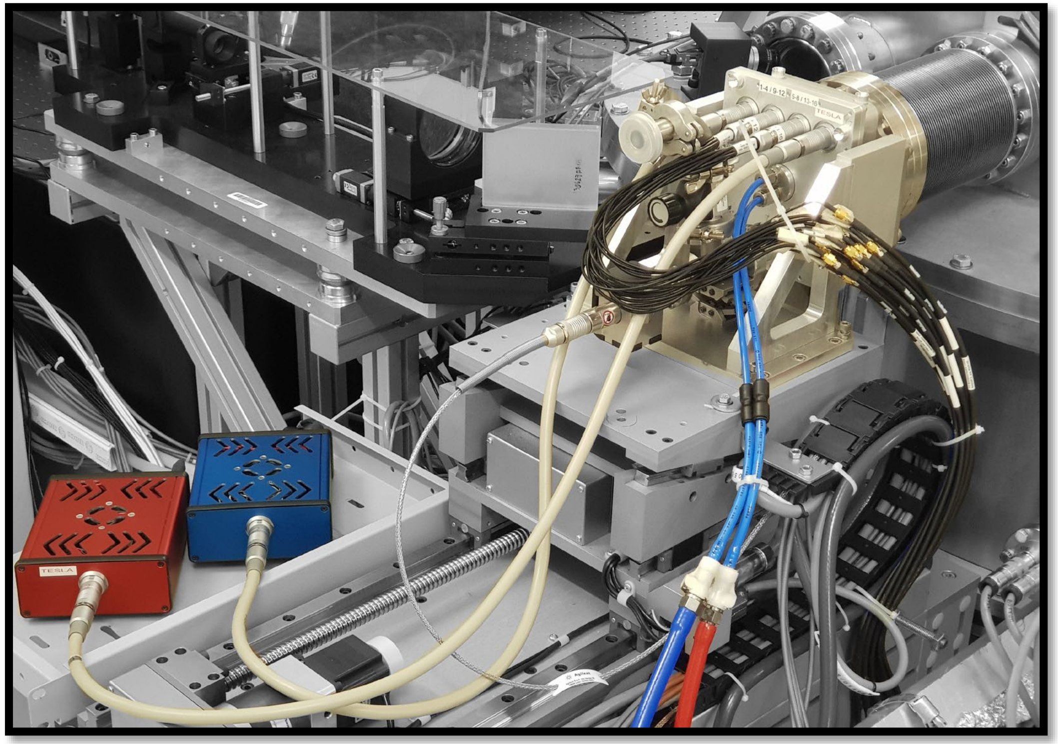


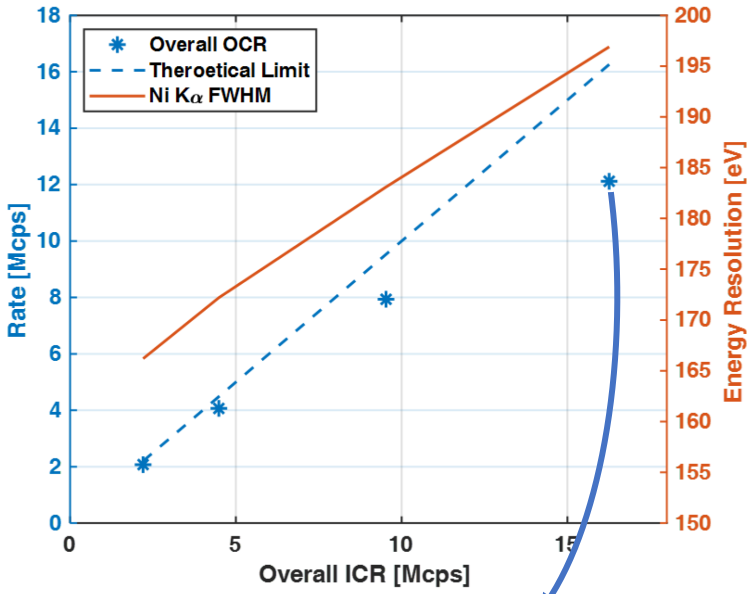
RGB image of the Cr contamination in soil.

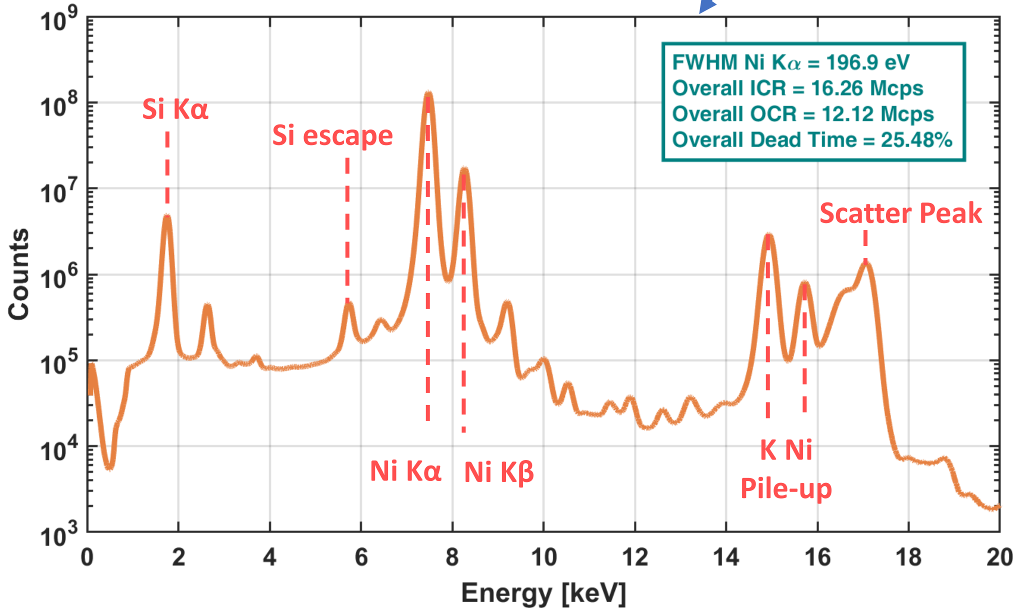
Utica, G., et al. "ARDESIA-16: … " *Journal of Instrumentation* 16.07 (2021): P07057.

ESRF ID16A: Count-Rate and Energy Resolution

Second version of ARDESIA-16 custom designed for ID16A (ESRF, Grenoble) to be coupled with two **FalconX8 DPPs** (XIA)

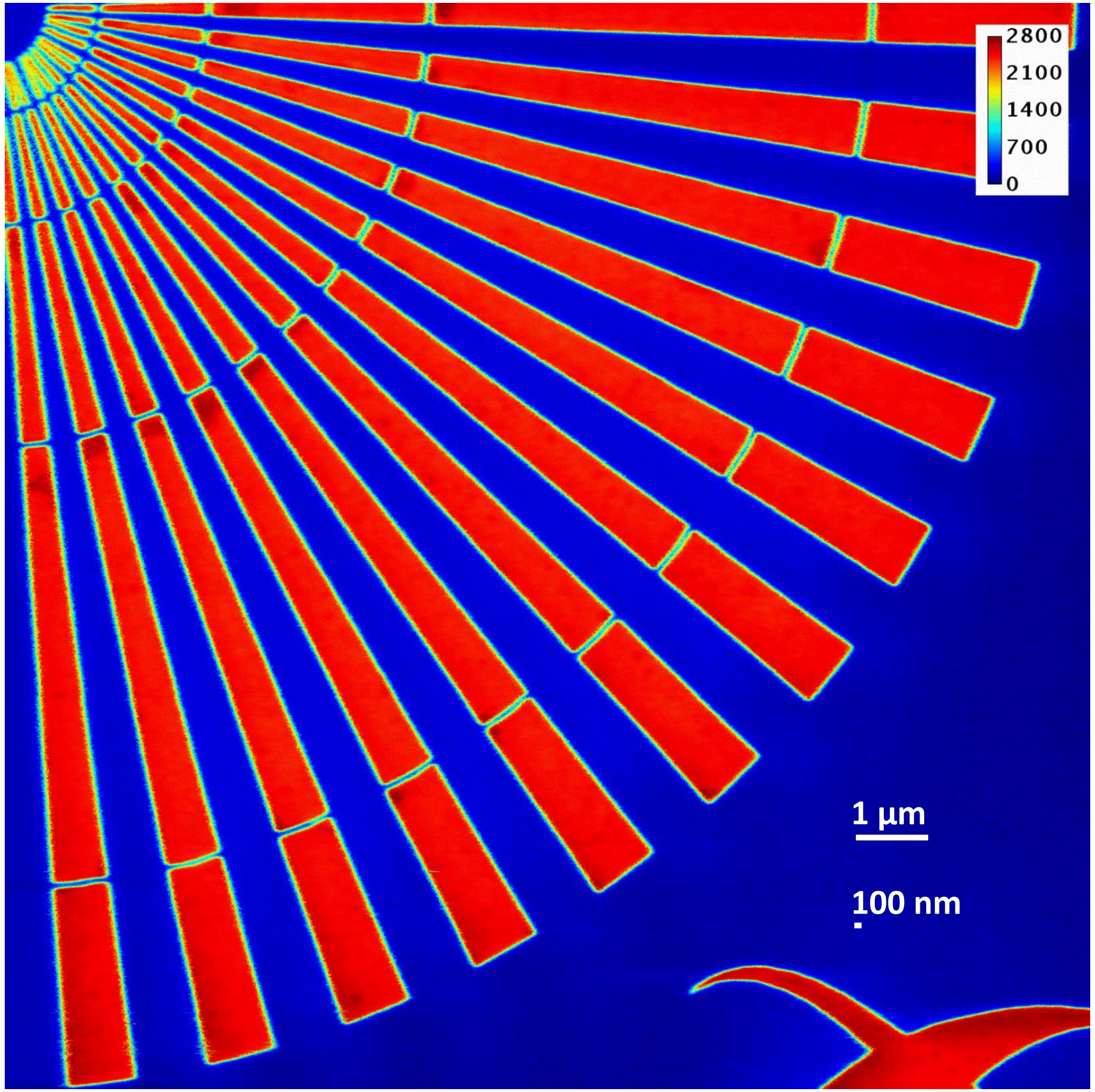






Sample: 10 nm thick square of **Nickel** with an area equal to 20 µm × 20 µm on a Si-substrate
Energy of the Beam: 17 keV

ESRF ID16A: Gold Siemens Star

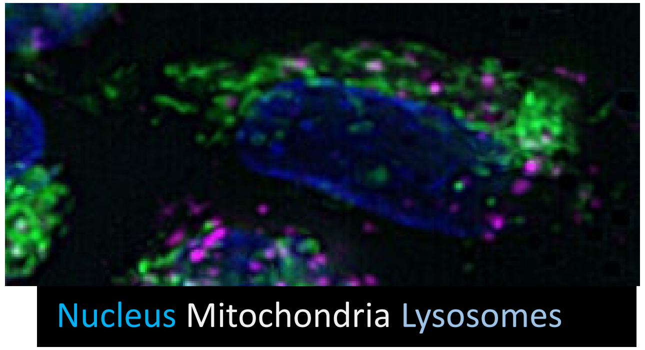


Au areal mass density (ng/mm^2)
Beam Energy: 33.5 keV
Step Size: 10 nm
Dwell Time: 15 ms
Image Size: 1500 x 1501 pixels

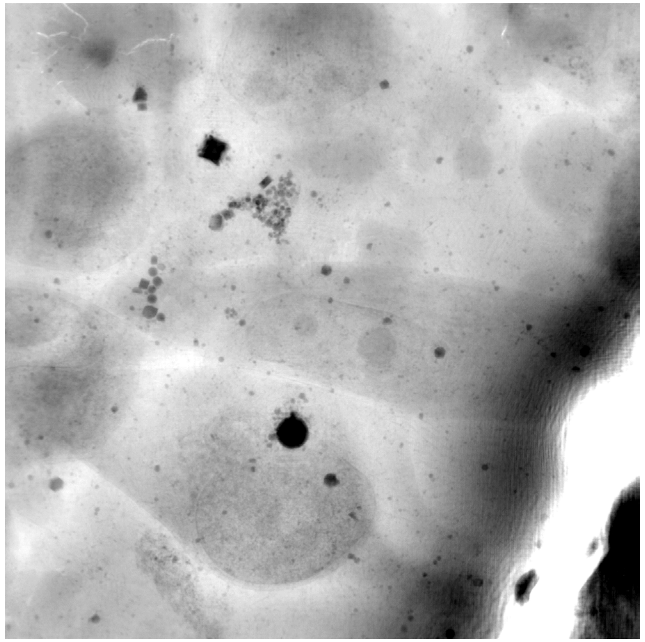
ID16A Nano-Imaging beamline
High-Definition nano-XRF
Not achievable before, thanks to the combination of Ardesia-16 and FalconX8

ESRF ID16A: Biological Sample

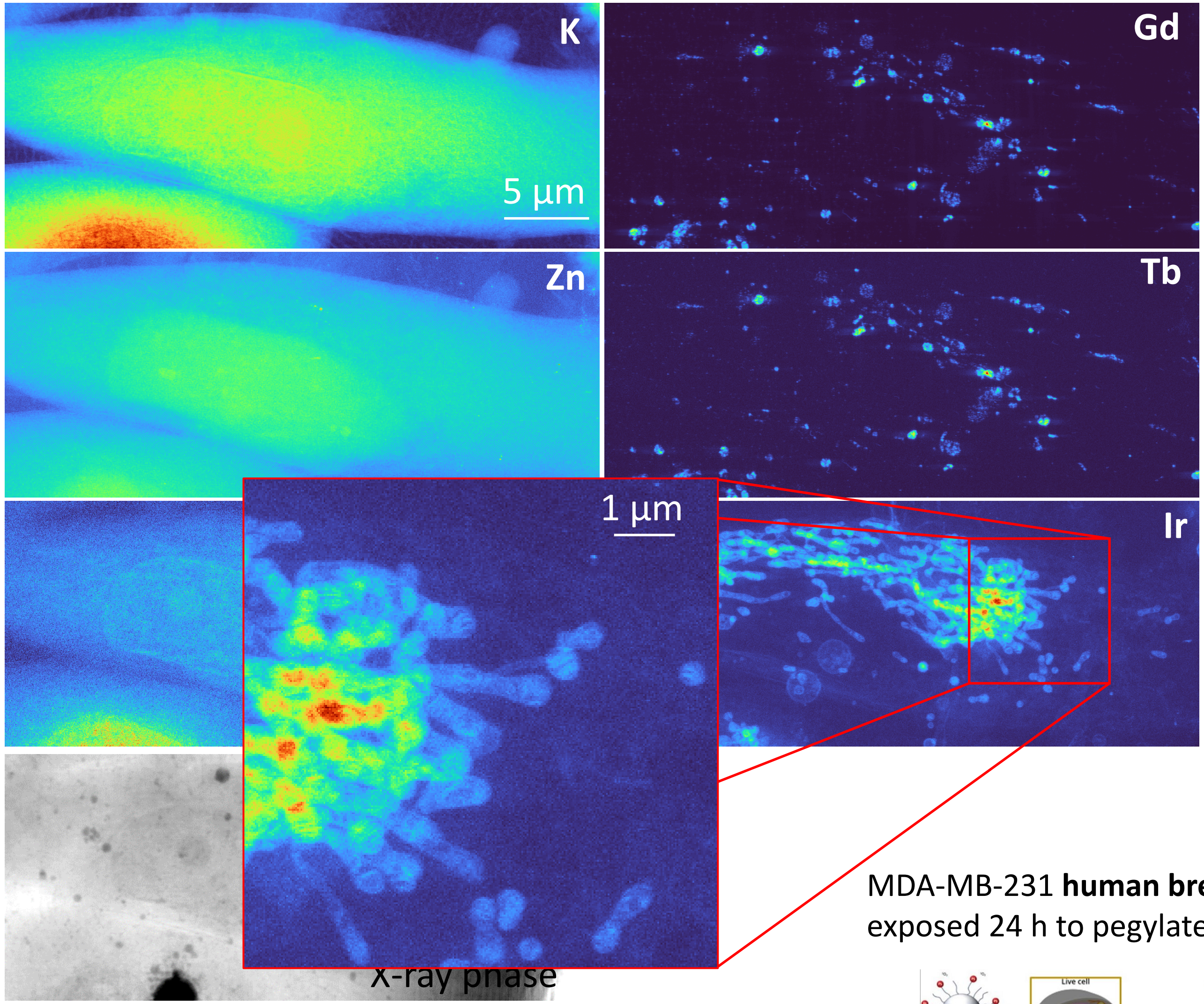
Cryo-CLEM (optical clearing)



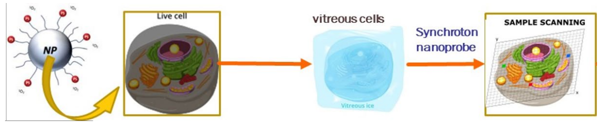
X-ray phase (2D, 25nm pixel)



XRF (2D, 30nm pixel size, 50ms/pt)

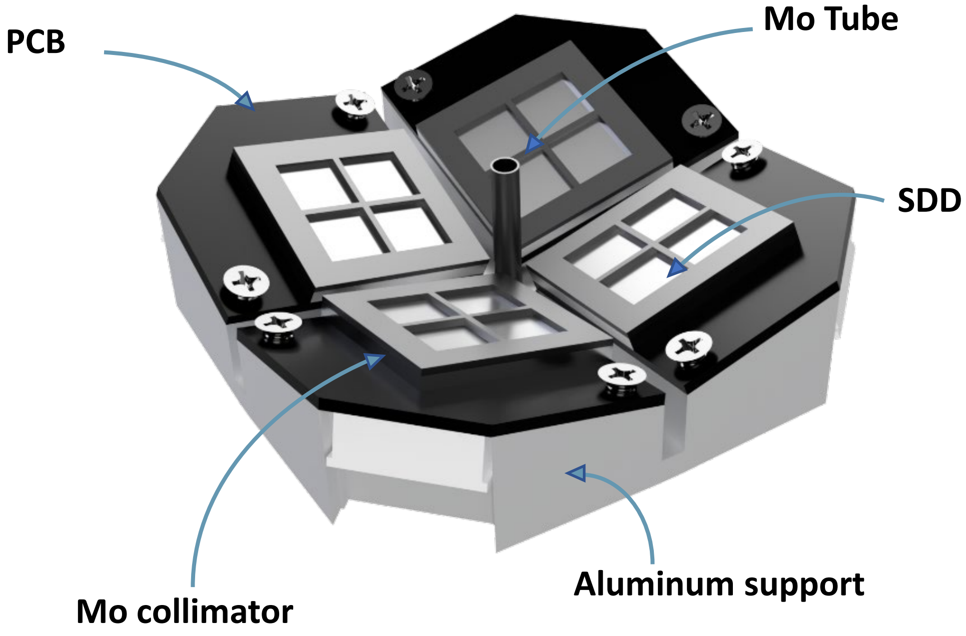


MDA-MB-231 **human breast cancer cells** exposed 24 h to pegylated **Gd/Tb nanohybrids**



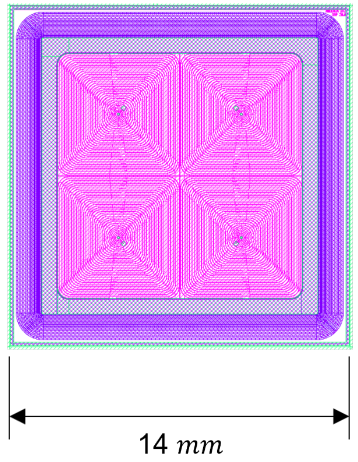
Current Development: ASCANIO

Designed for X-ray fluorescence microscopy (**XFM**) imaging in synchrotron beamlines



Backscattering geometry* with tilted SDDs

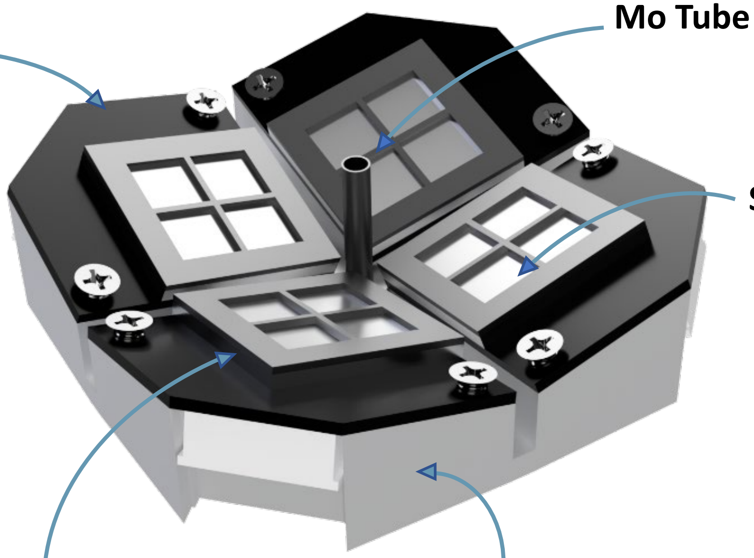
4 channels monolithic array

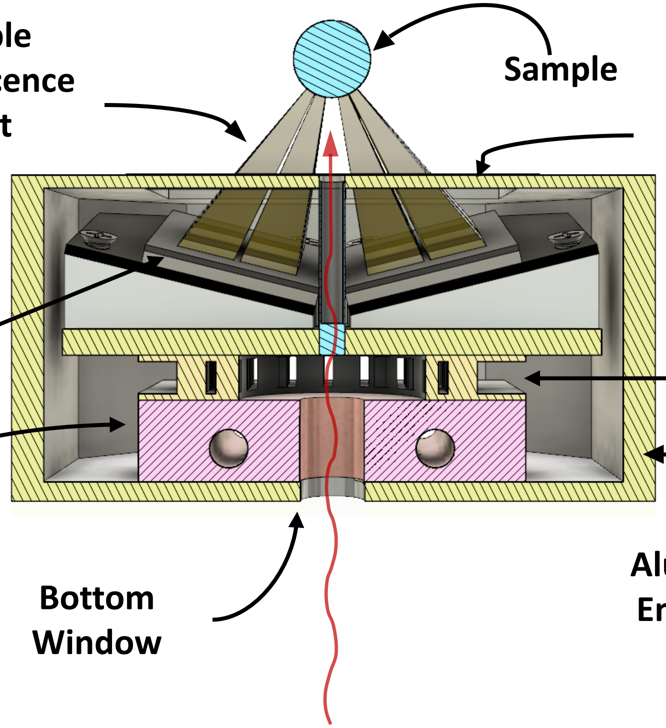


- **5 mm** side for each pixel
- Thicknesses: **450 µm - 800 µm - 1 mm**

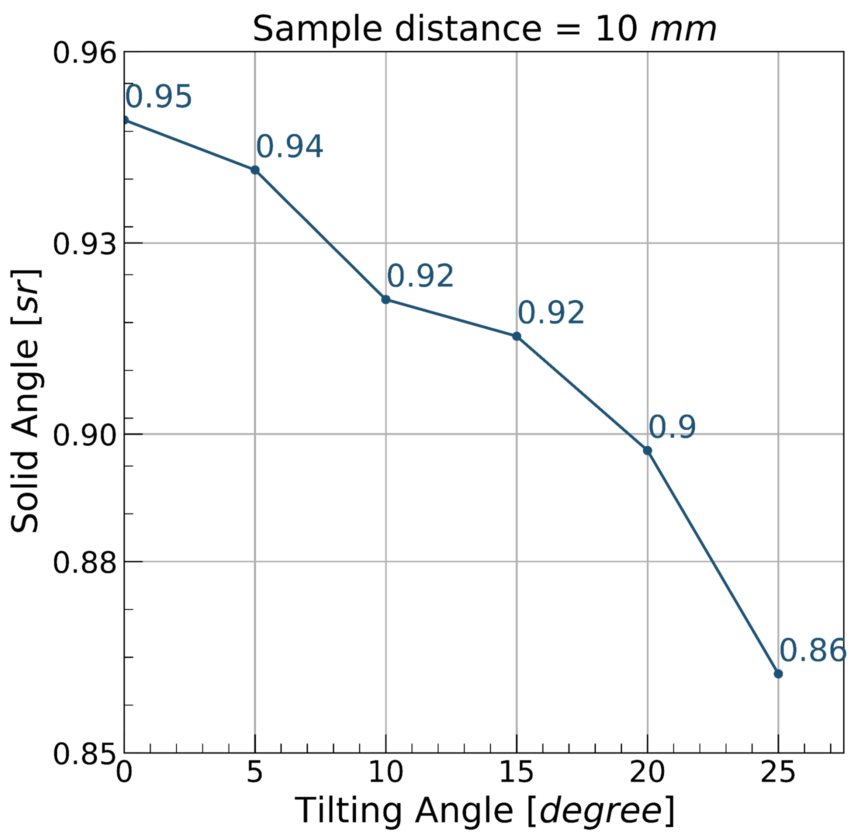
[*] D. P. Siddons, et al. Maia X-ray Microprobe Detector Array System. 22nd International Congress on X-Ray Optics and Microanalysis. Journal of Physics: Conference Series **499** (2014) 012001, doi:10.1088/1742-6596/499/1/012001

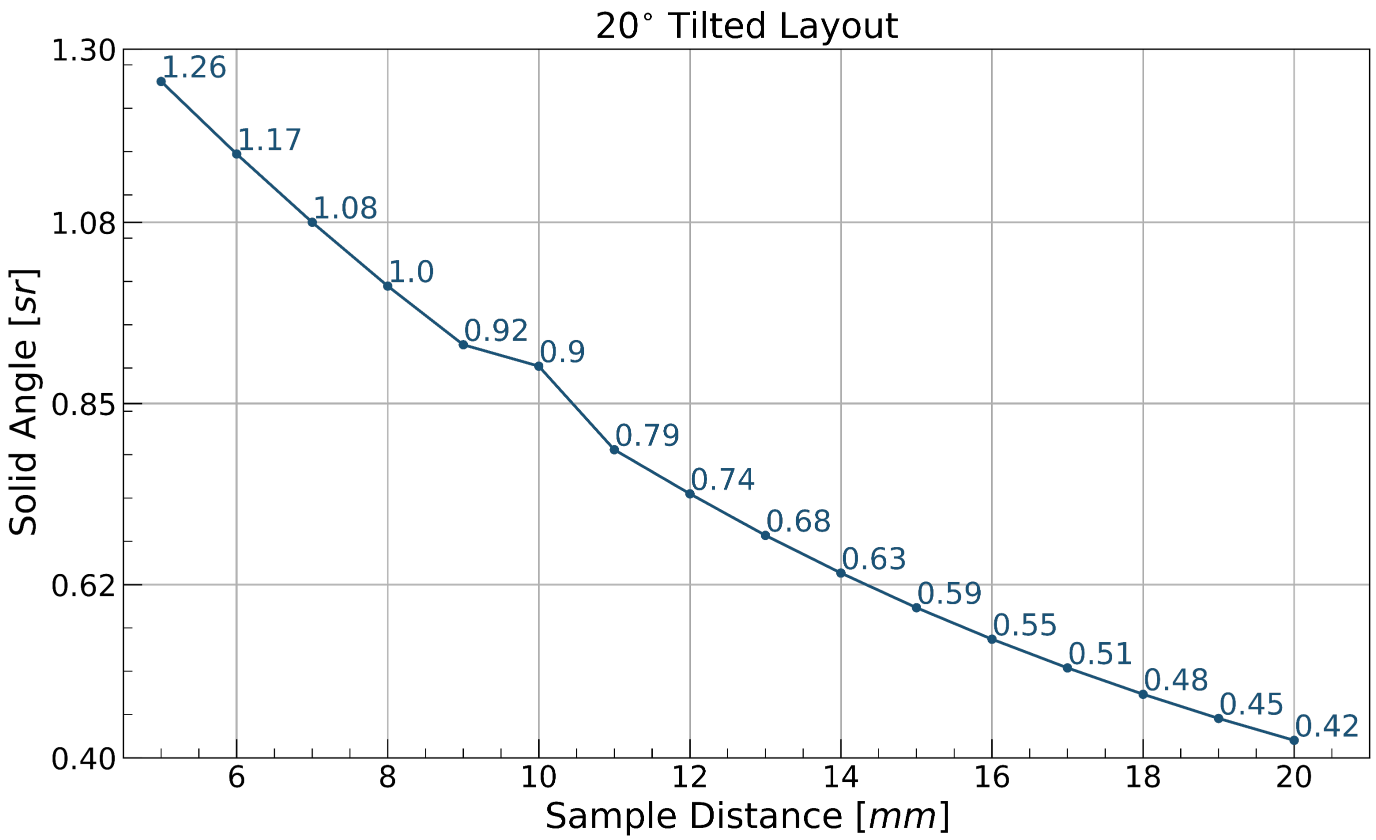
Current Development: ASCANIO

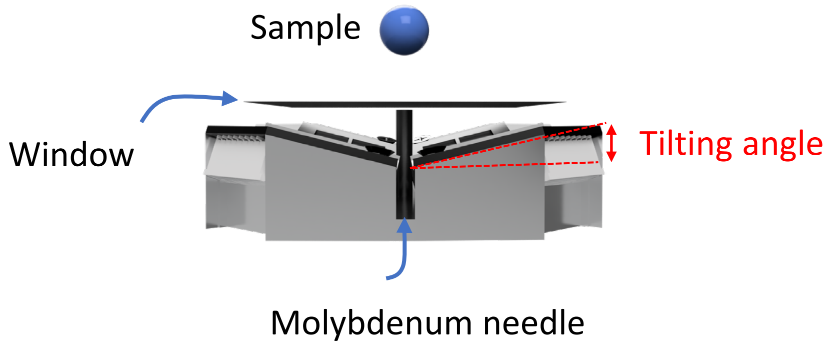




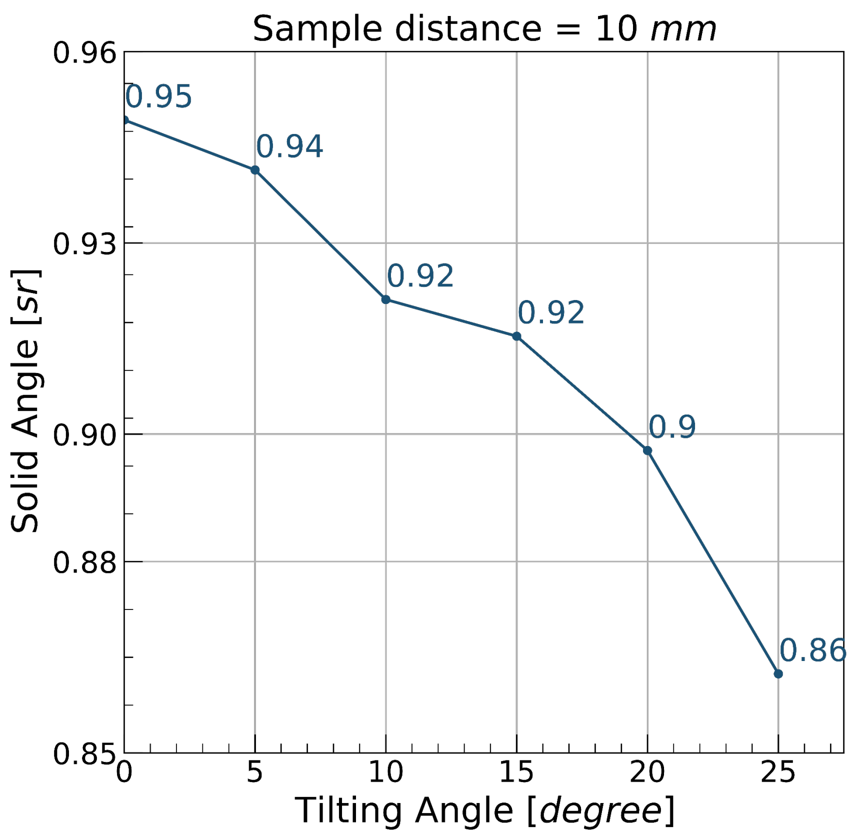
Solid Angle Analysis

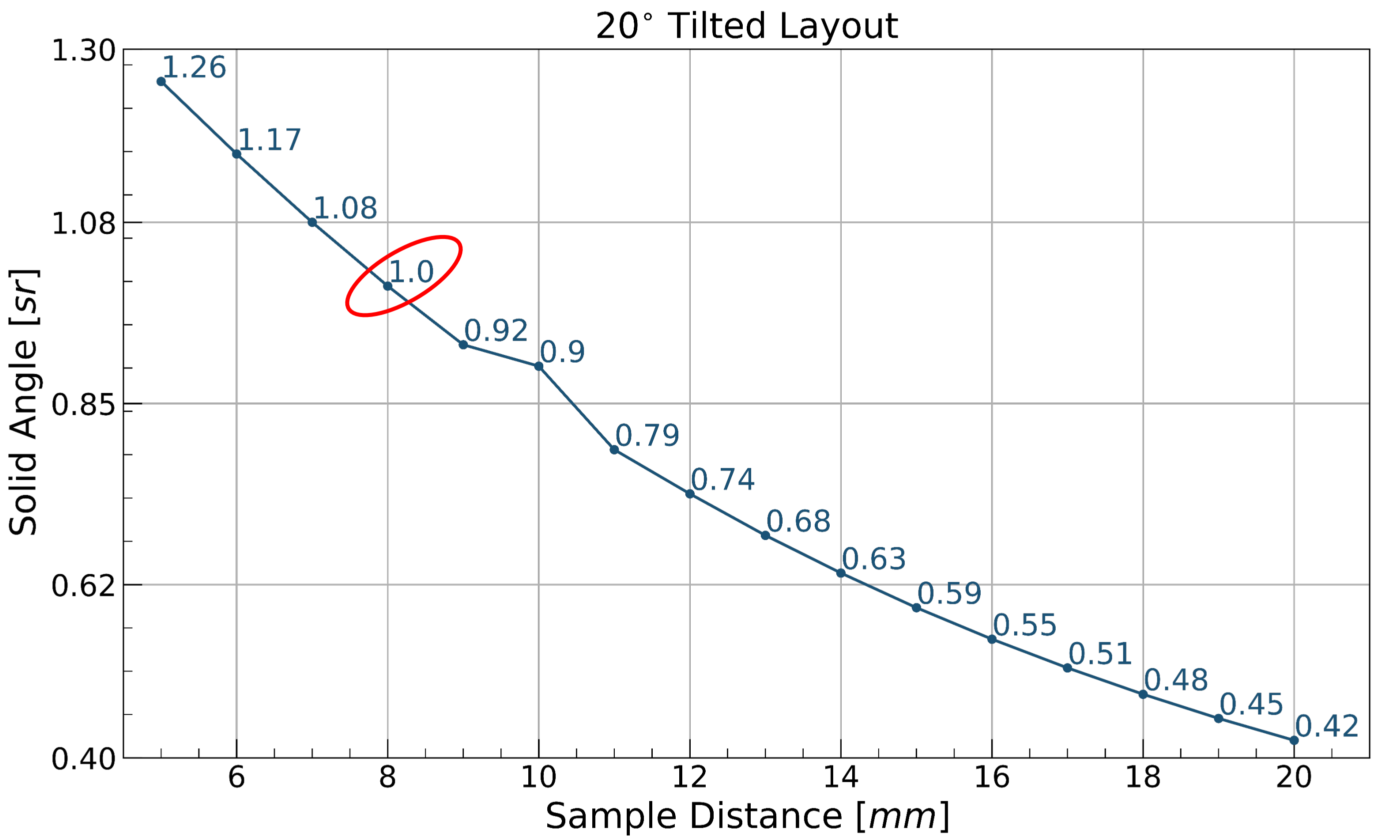


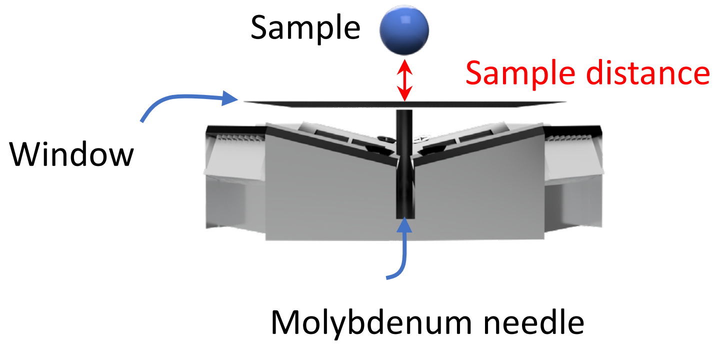




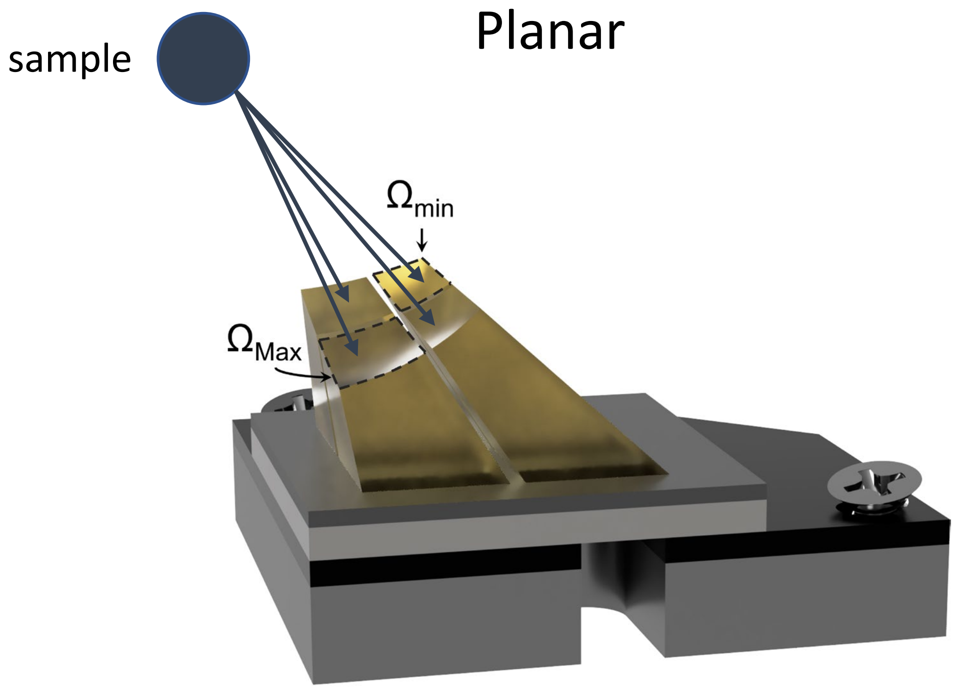
Solid Angle Analysis



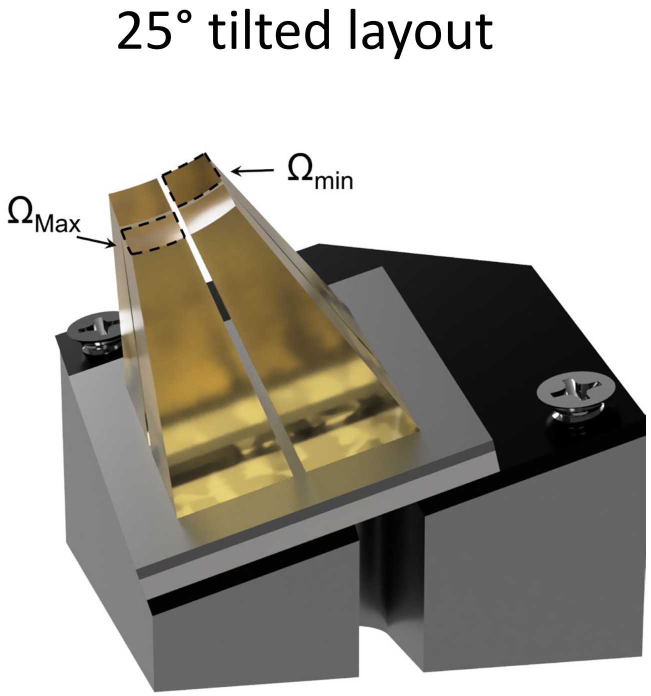




Advantage of a Tilted Layout



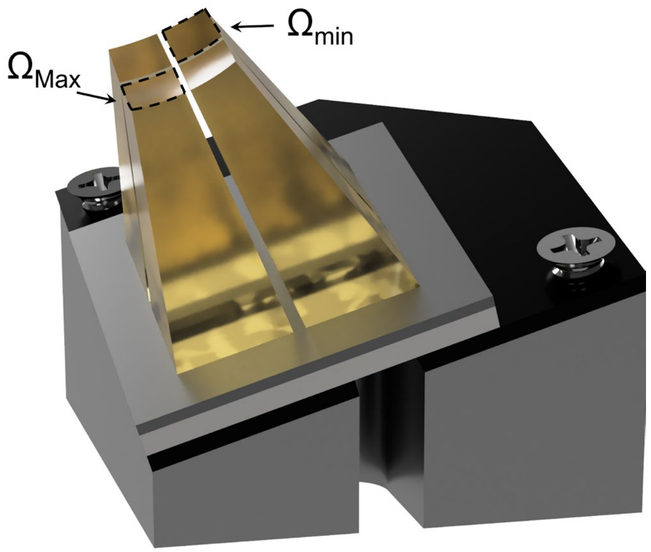
Ω_{min} = 43% Ω_{max}



Ω_{min} = 90% Ω_{max}

Advantage of a Tilted Layout

25° tilted layout

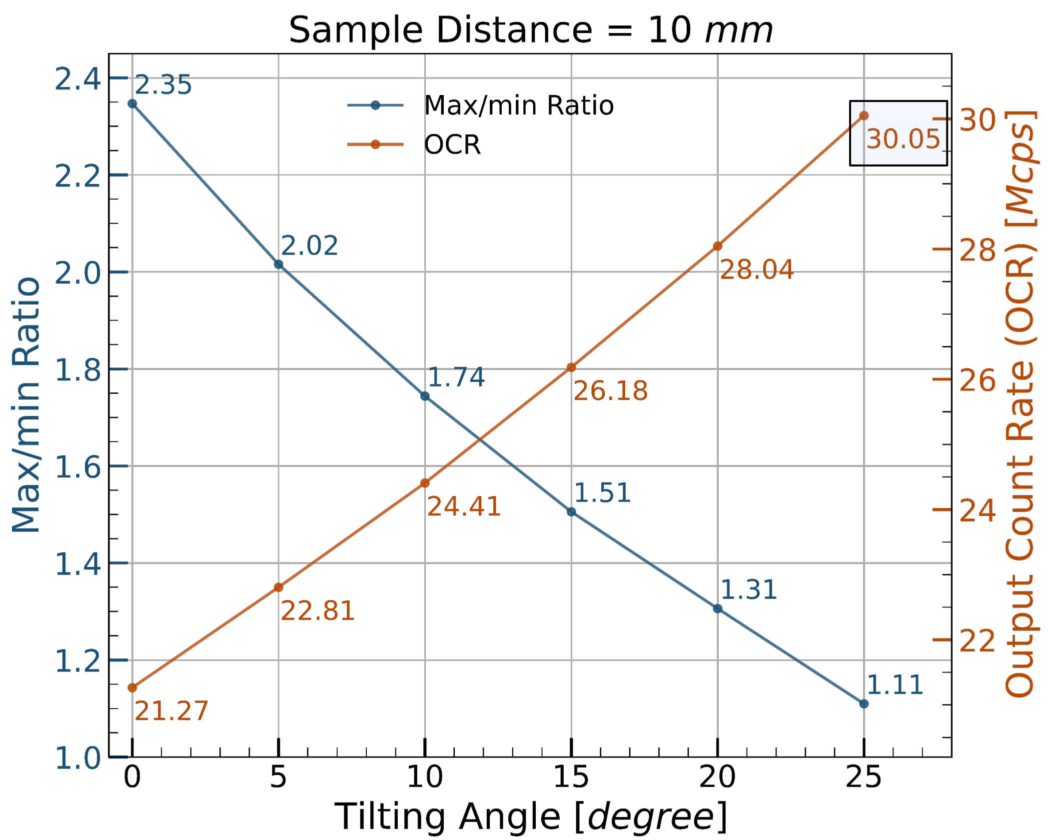


Uniform fluorescence light distribution among channels

$$Max/min = \frac{\Omega max}{\Omega min} \rightarrow 1$$

Ω_{min} = 90% Ω_{max}

Output Count-Rate

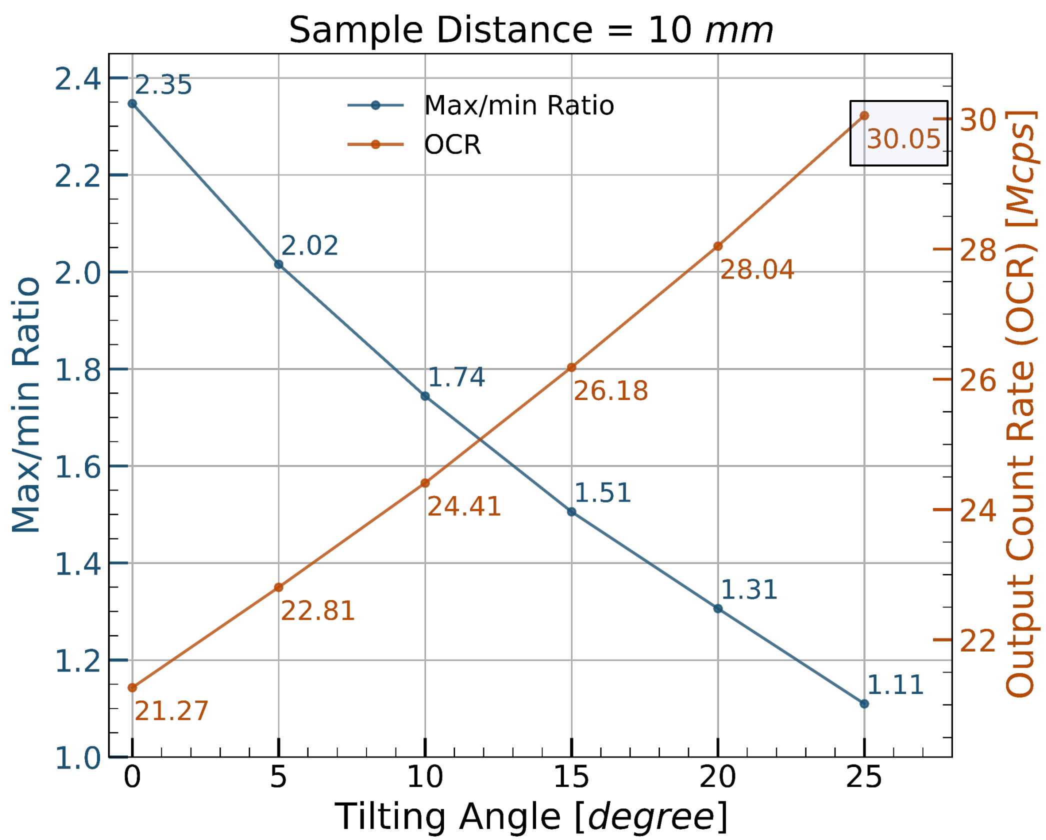


$$Max/min = \frac{\Omega max}{\Omega min}$$

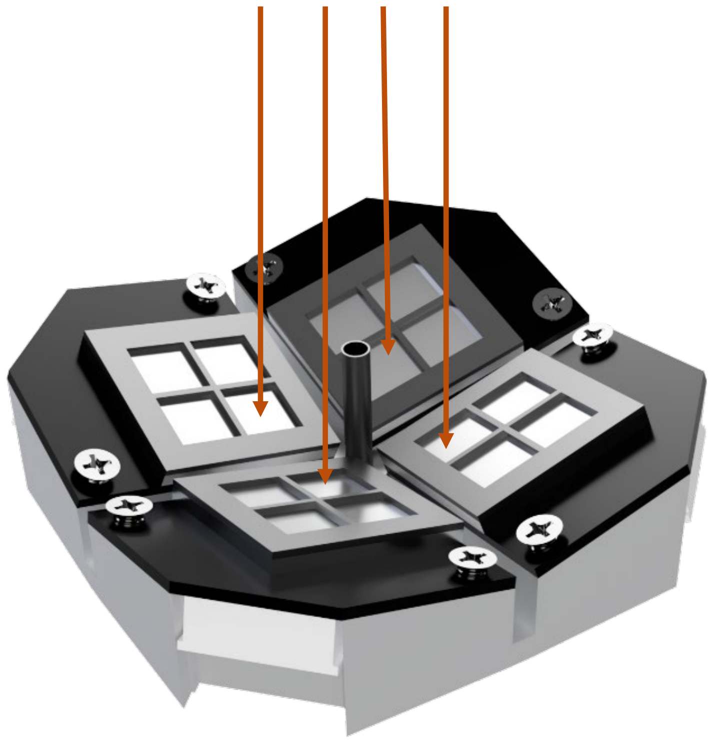
$$OCR = \varphi_{max} \sum_{i=1}^{16} \frac{\Omega_i}{\Omega_{max}} \ [\mathrm{Mcps}]$$

[*] Scoullar P A, McLean C C and Evans R J 2011 Real time pulse pile-up recovery in a high throughput digital pulse processor AIP Conference Proceedings vol 1412 (American Institute of Physics) pp 270–277.

Output Count-Rate

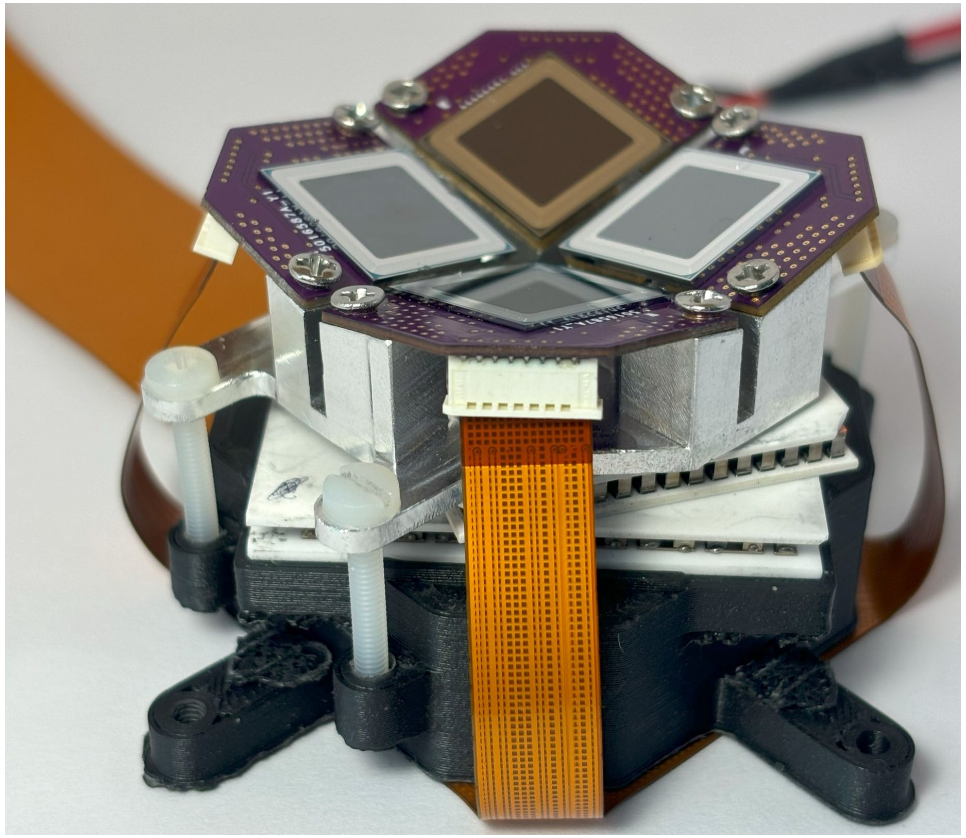


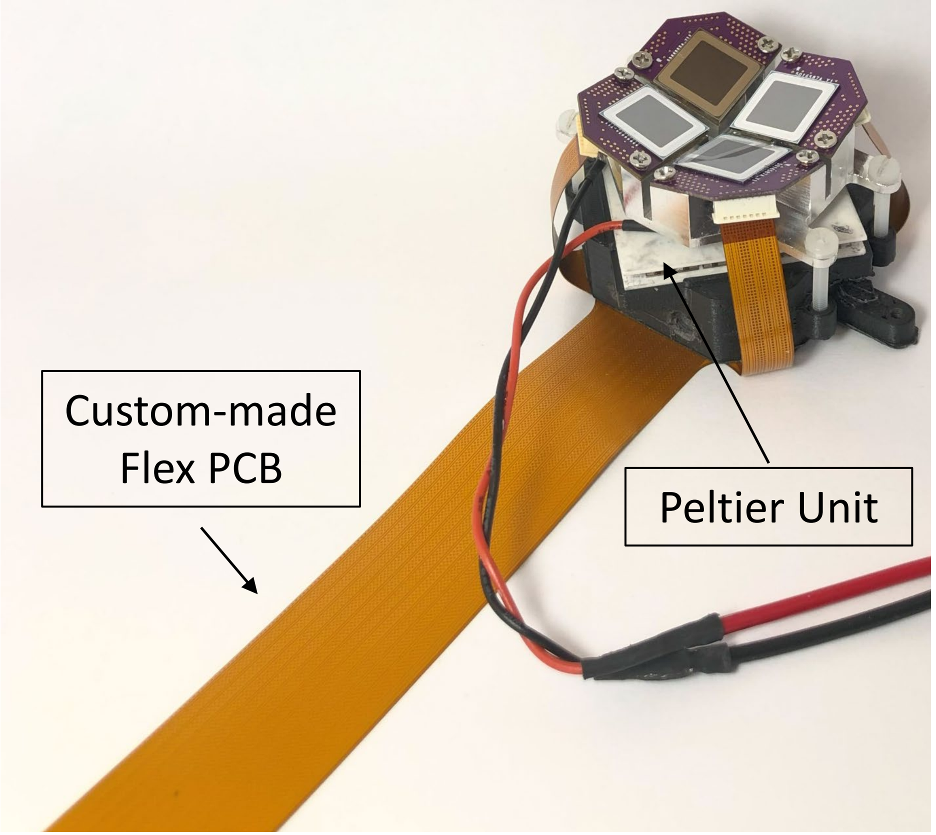
Assumption: largest solid angle channels operate at 2 Mcps*



[*] Scoullar P A, McLean C C and Evans R J 2011 Real time pulse pile-up recovery in a high throughput digital pulse processor AIP Conference Proceedings vol 1412 (American Institute of Physics) pp 270–277.

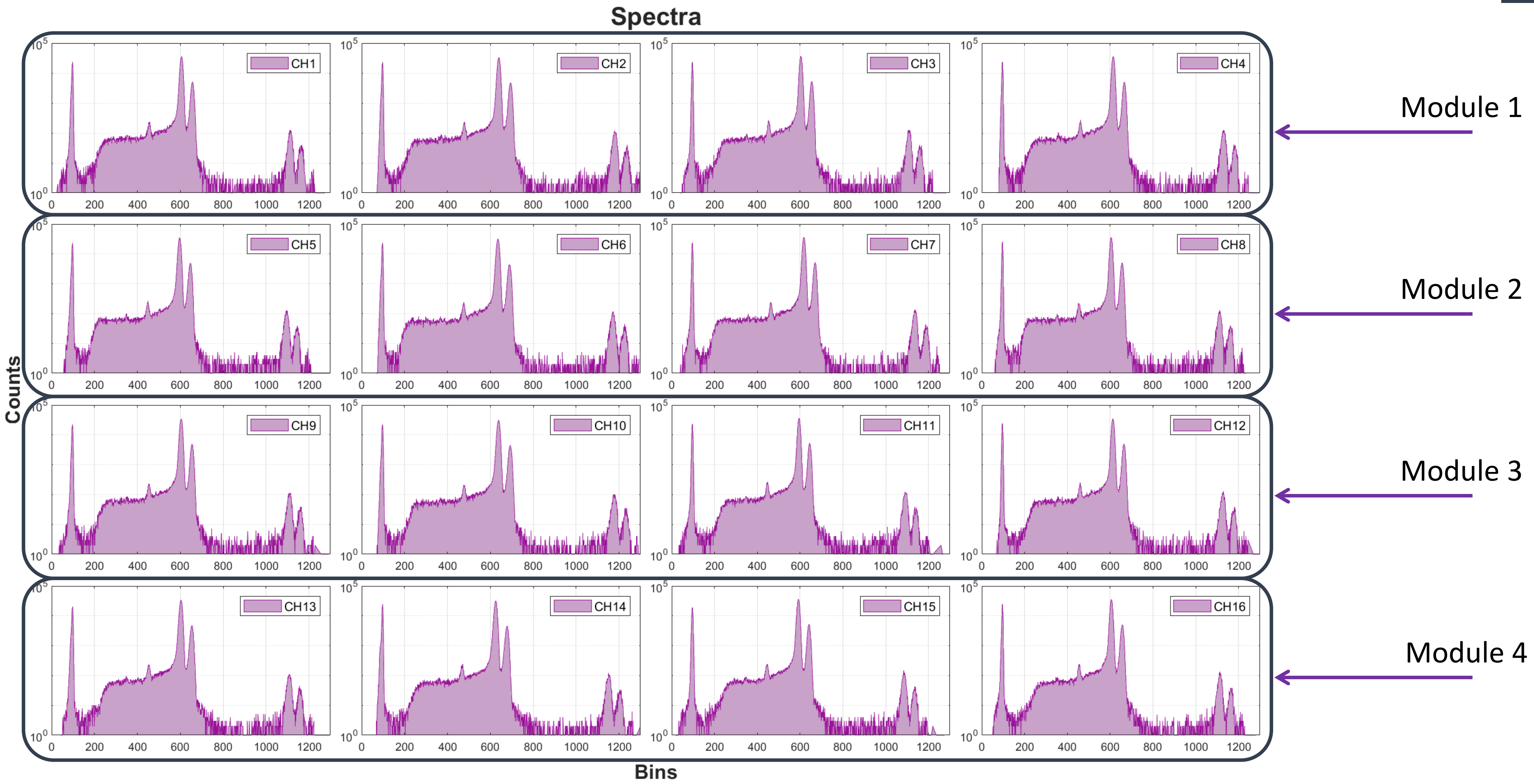
First Detection Module Prototype



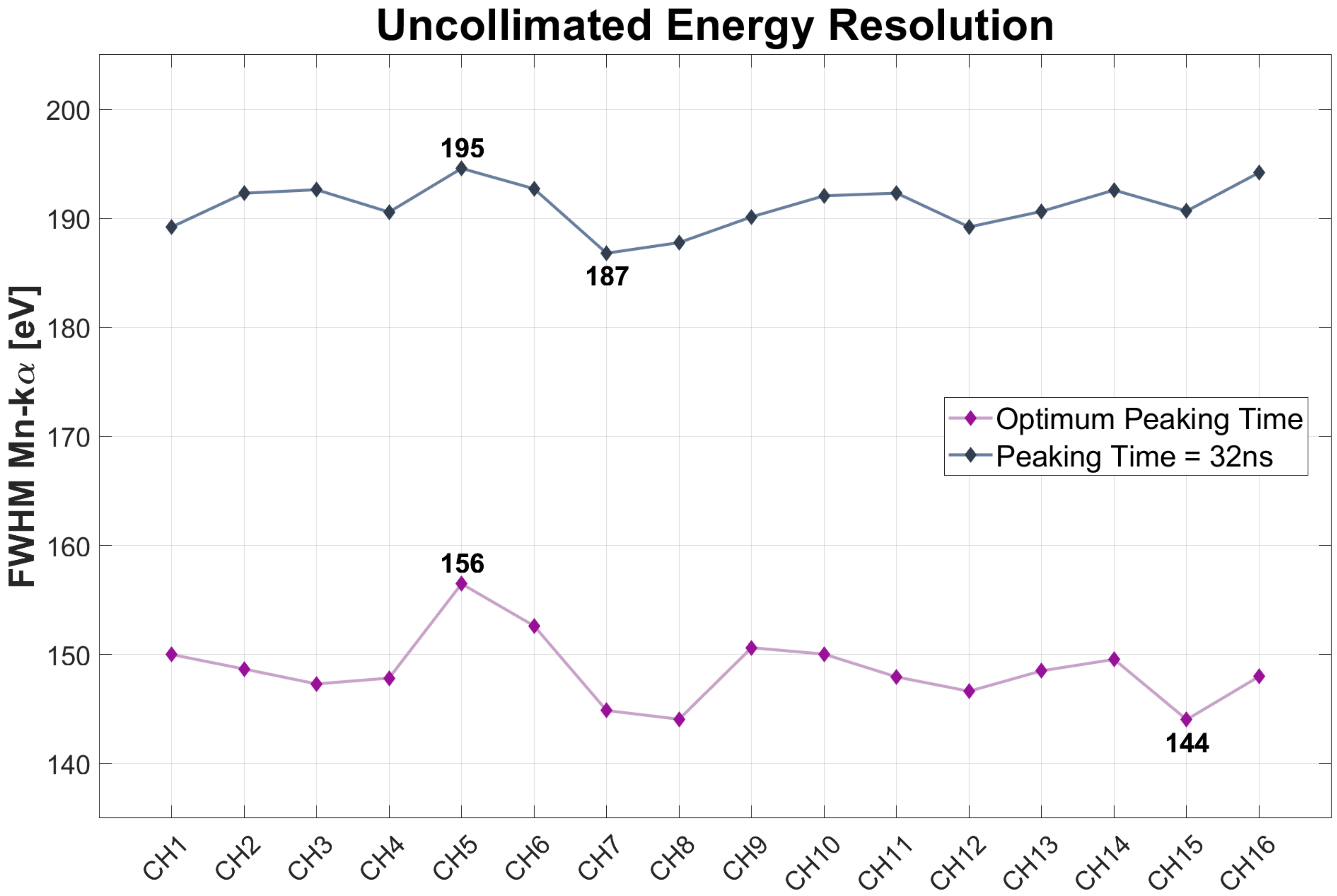


- 800 µm Thickness
- Individually Tested
- Uncollimated

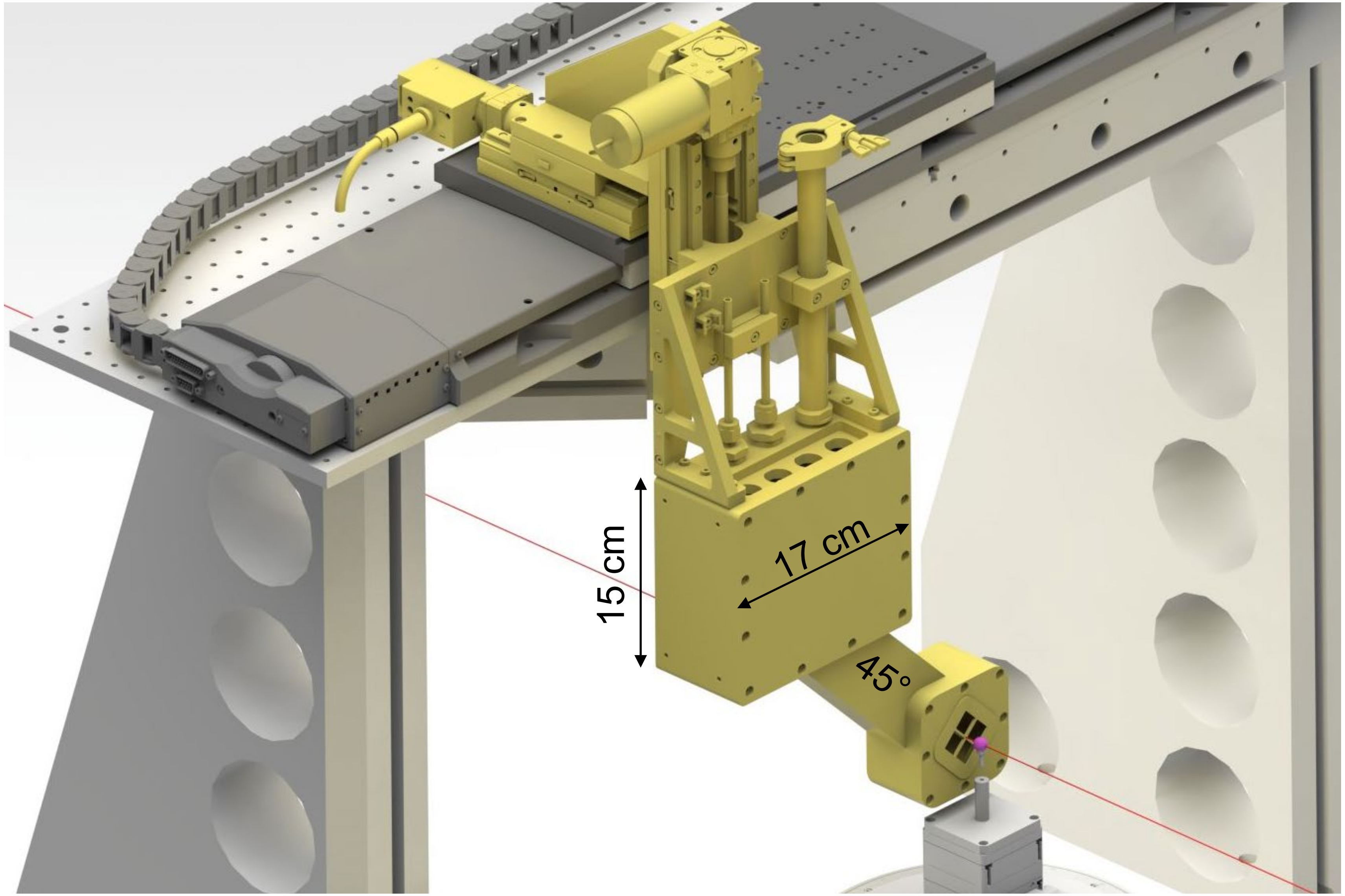
Spectroscopy with ^{55}Fe Source



Spectroscopy Performance: ^{55}Fe Source



Rendered Implementation: PETRA III P06



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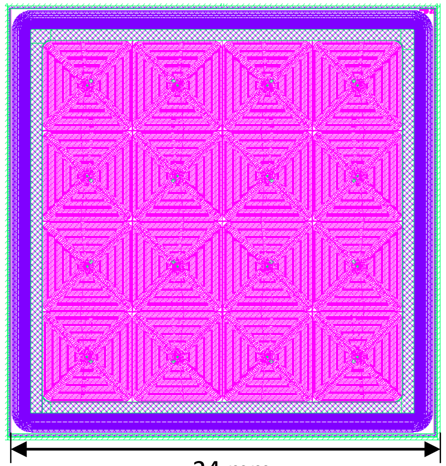
RadLab POLITECNICO MILANO 1863

Future Developments

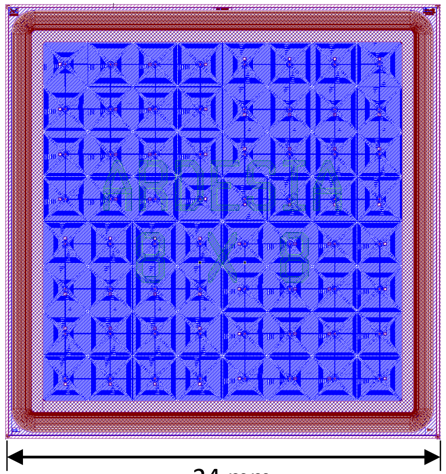
Towards ARDESIA-64

ARDESIA-16



- 4 x 4 Matrix
- 5 mm Pixel Pitch

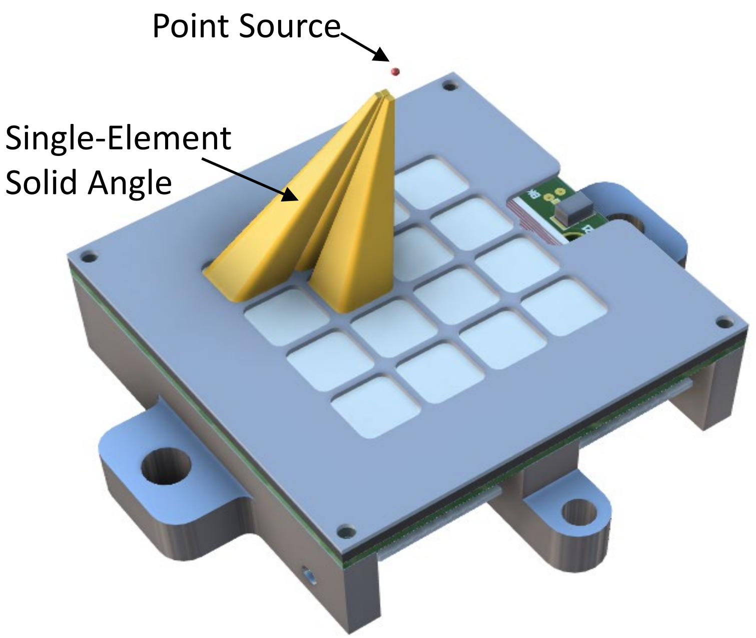
ARDESIA-64



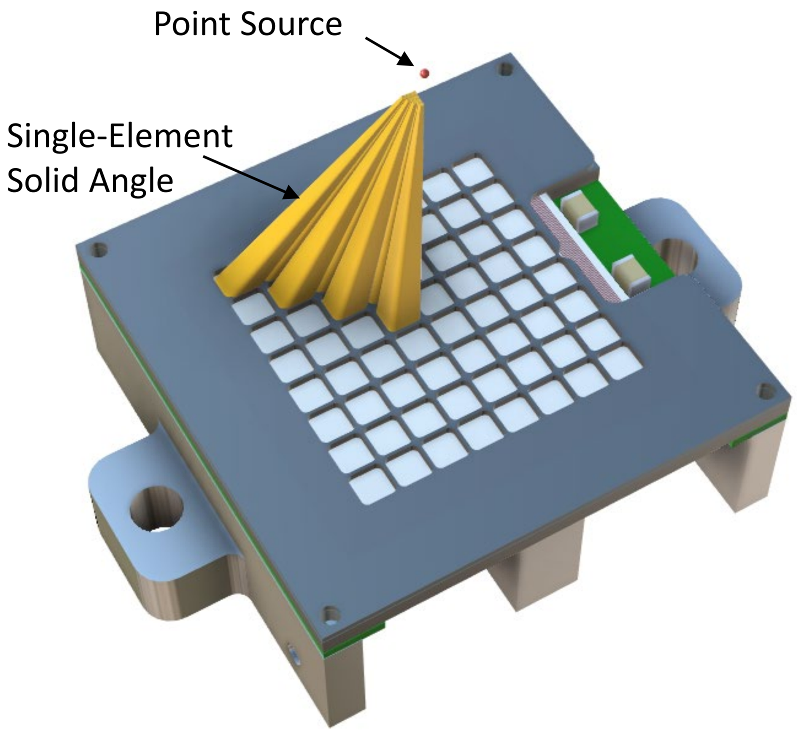
- 8 x 8 Matrix
- **2.5 mm** Pixel Pitch
- 1 mm Thick
- Characterisation stage

FONDAZIONE BRUNO KESSLER

Towards ARDESIA-64



ARDESIA-16



ARDESIA-64

Output Count-Rate up to 20 Mcps

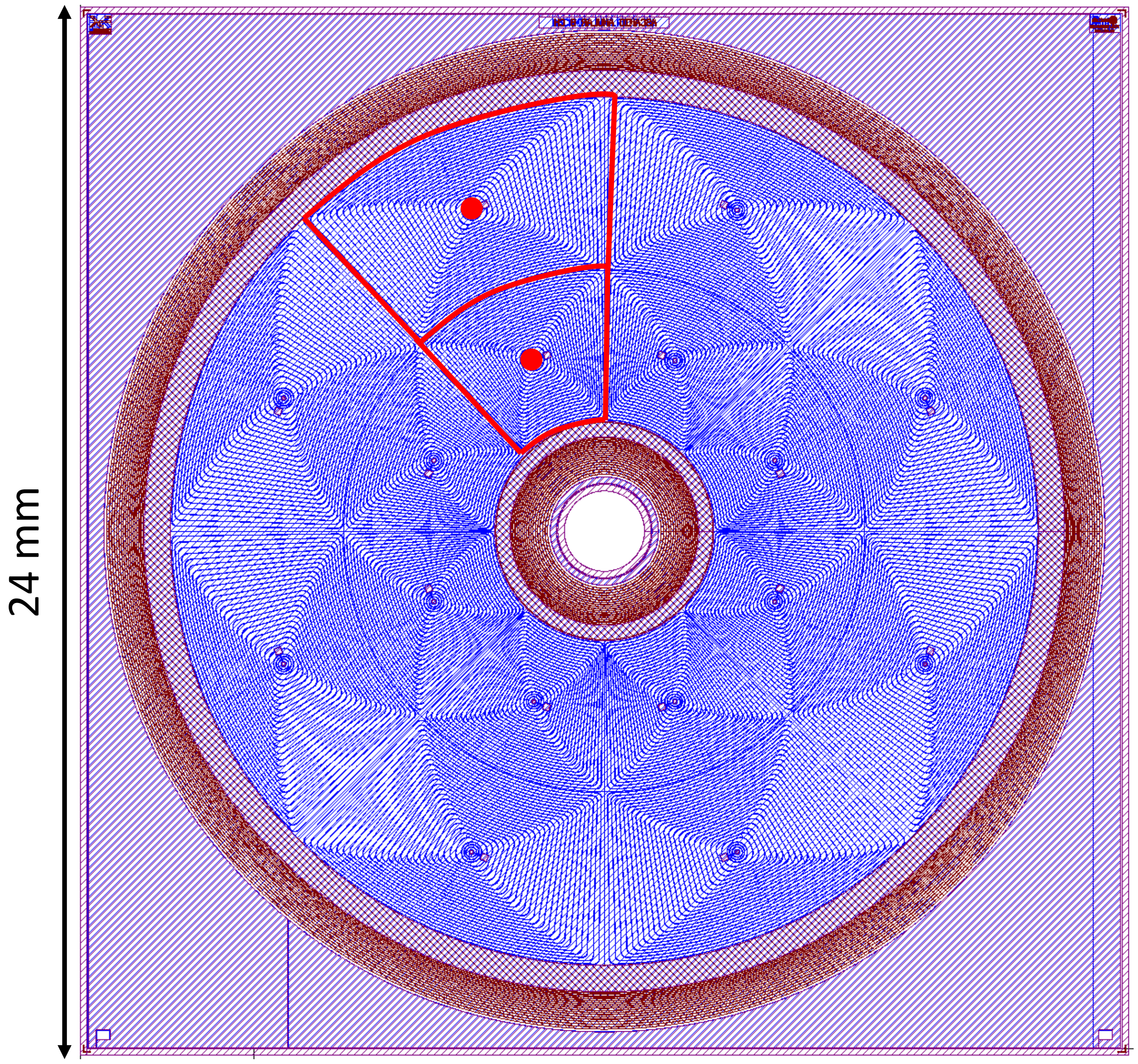
Output Count-Rate > **70 Mcps**

Enhanced Backscattering Geometry

Monolithic ASCANIO

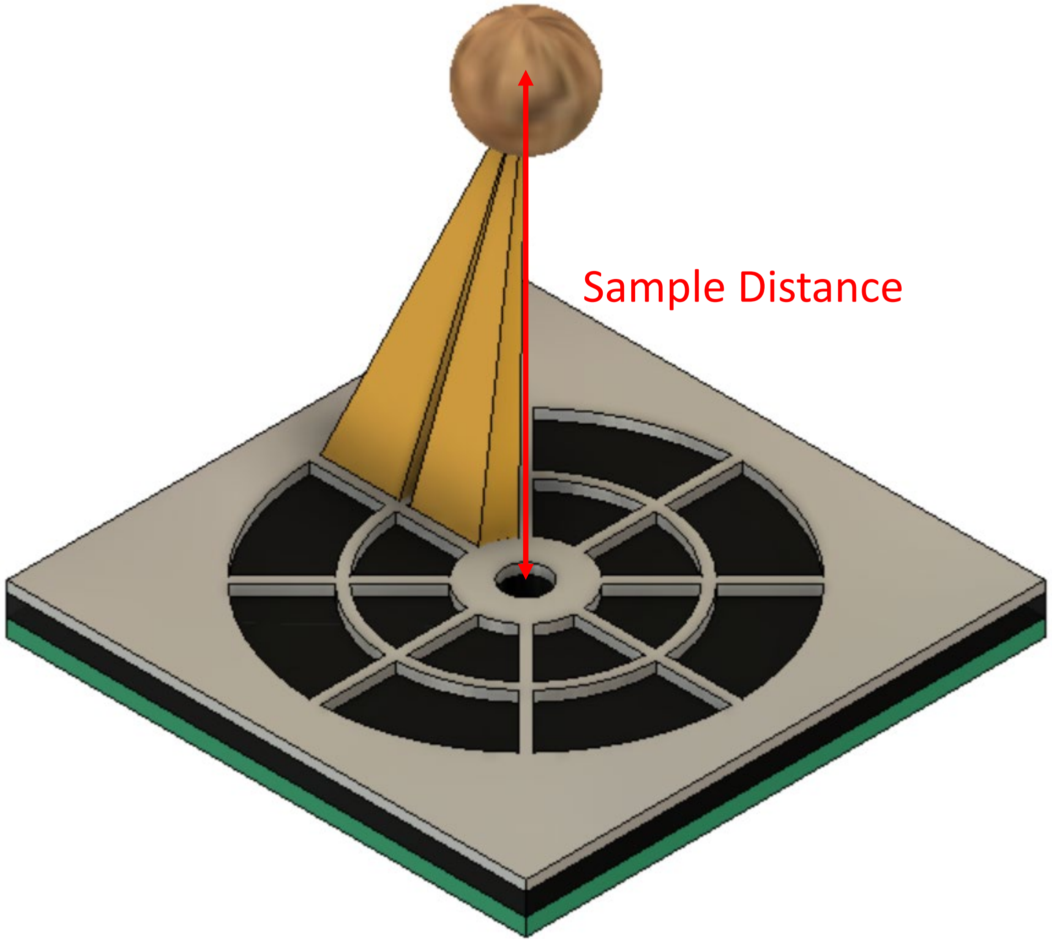
- 16-Channel
- 1 mm Thick
- Pixel with Trapezoidal-like Shape
- 2 mm Hole Diameter in the Middle
- Inner Pixels: 11.7 mm^2
- Outer Pixels: 25.1 mm^2
- Characterisation stage

FONDAZIONE BRUNO KESSLER



Enhanced Backscattering Geometry

Sample Distance [mm]	Solid Angle [sr]	Max/Min Ratio
4	2.42	1.50
5	2.27	1.22
6	2.09	1.03
7	1.89	1.12
8	1.69	1.25
9	1.52	1.38
10	1.36	1.49
11	1.22	1.59
12	1.10	1.68



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Thank you for your kind attention!

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DIPARTIMENTO DI ELETTRONICA
INFORMAZIONE E BIOINGEGNERIA

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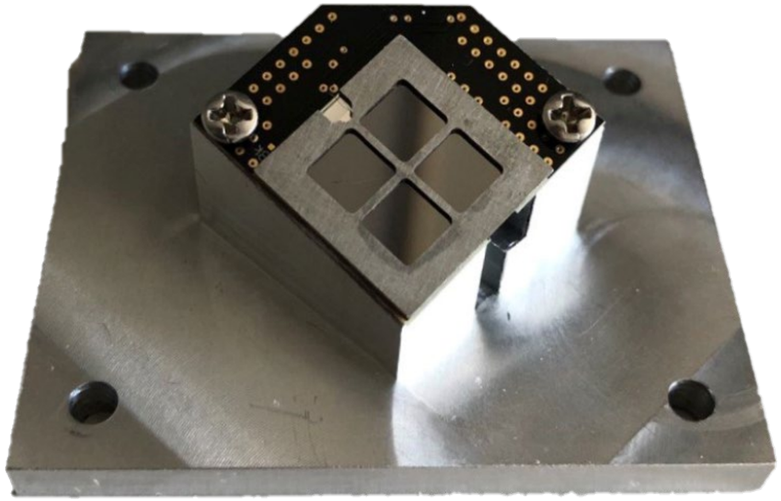
First Detector Unit Prototype

- 450 µm thick SDD
- 0.5 mm thick Mo collimator directly glued on the SDD



- Uncollimated active area = 100 mm^2
- Collimated active area = 81 mm^2
- Total ASCANIO collimated active area = **324 mm^2**

PTB > 10^4