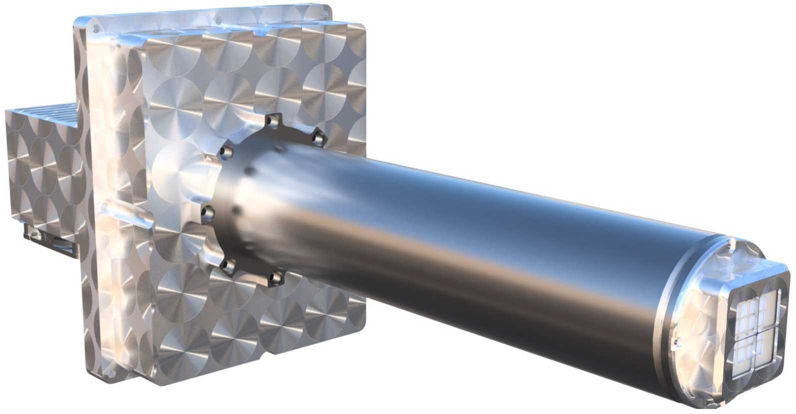
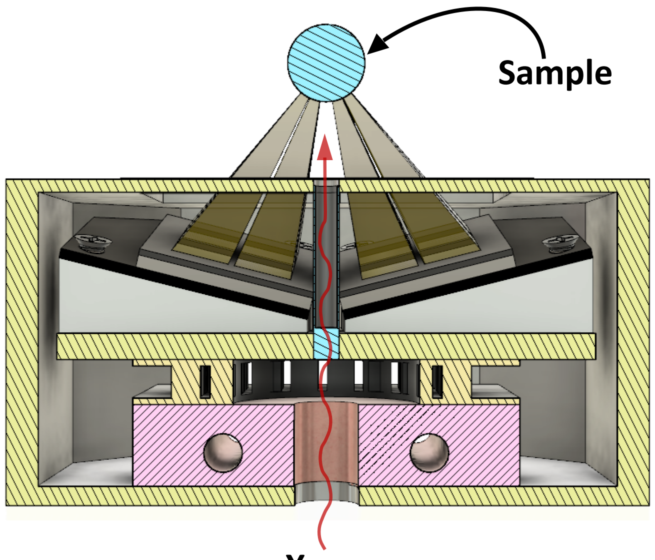




Silicon Drift Detectors and Related Electronics for Fundamental Physics and Synchrotron Applications

Giacomo Borghi *on behalf of* RadLab

Politecnico di Milano and INFN, Milano, Italy

2nd Workshop on Silicon Sensors, Berg – 13th of May 2025

The RadLab Team @ Politecnico di Milano

Part of the Electronic Engineering Department, among whose founders was Emilio Gatti.

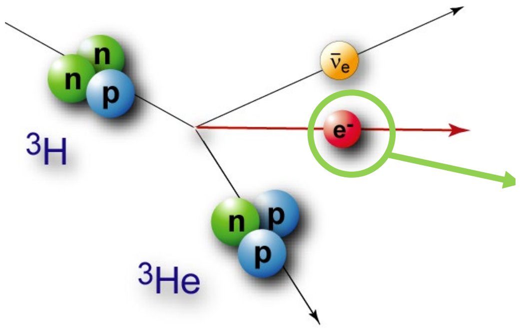
People:
- 3 staff.
- ~20 Ph.D. students and post-docs.
- ~20 M.Sc. thesis students/year.

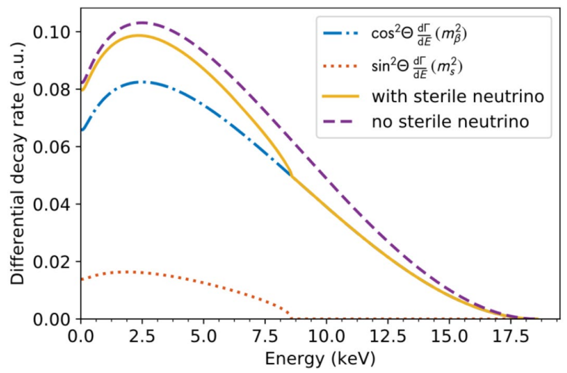
Focus:
- Design and production of low-noise read-out electronics.
- Development of radiation detection modules and instrumentation.

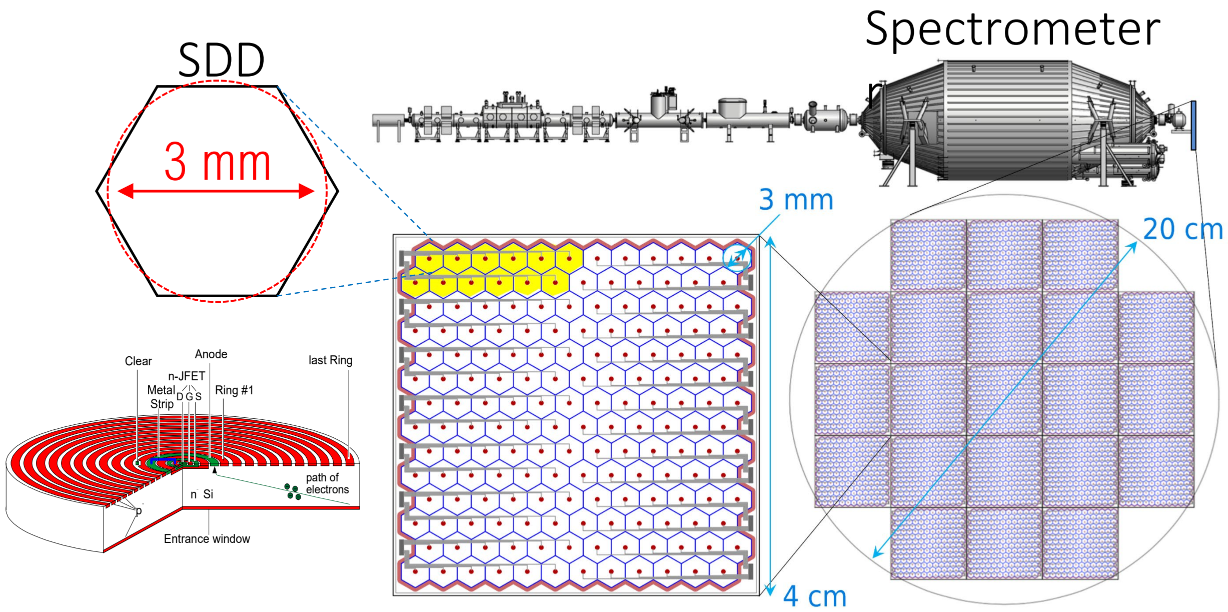
Main application fields:
- **X-ray detectors (SDDs) for x-ray spectroscopy.**
- Gamma-ray detectors for medical applications.

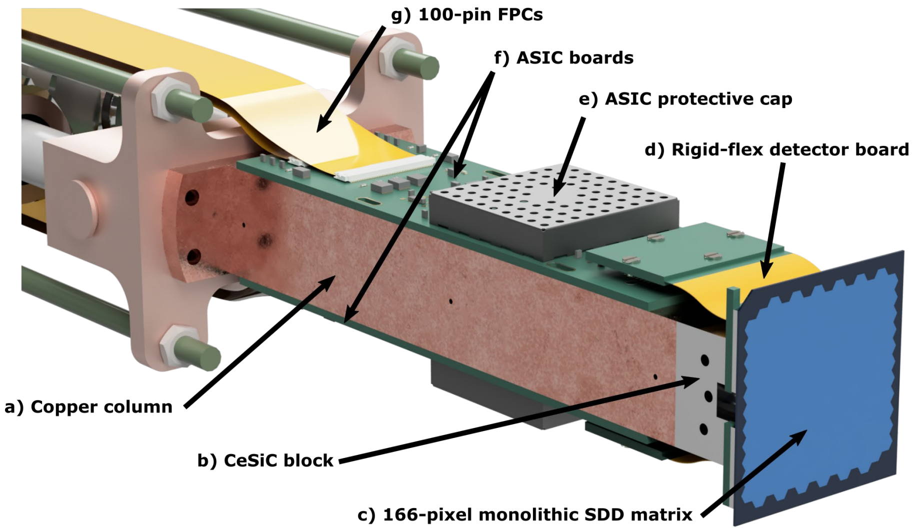
SDD Detection Modules and Readout Electronics for Fundamental Physics Experiments

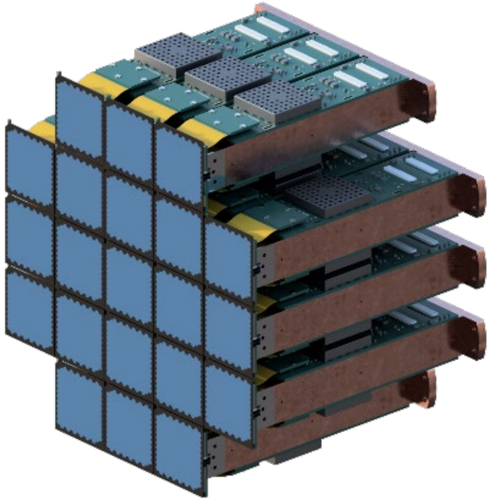
The TRISTAN Detector





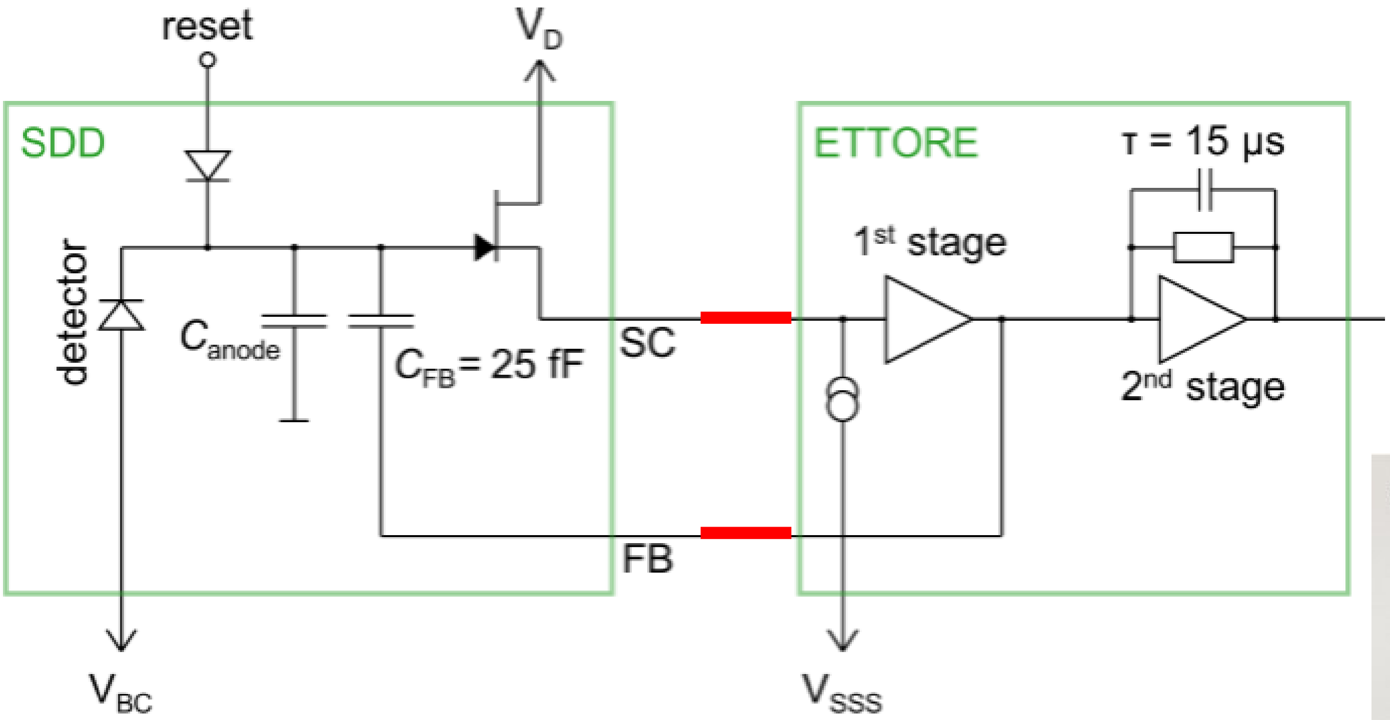


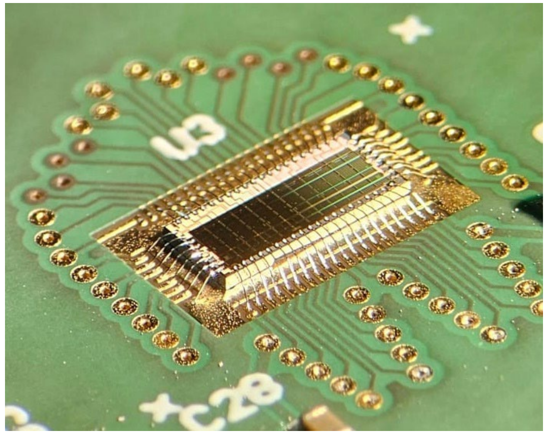


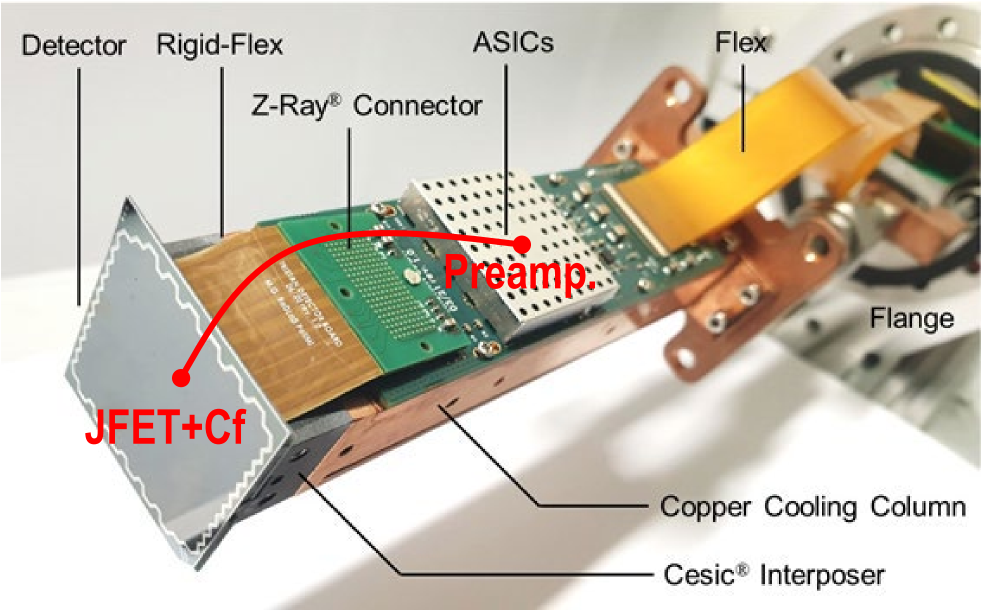


- 21 detection modules
- 166 mini-SDDs (3mm) in each array
- ~3500 total channels
- 100kcps per channel
- SDD with integrated JFET designed and produced at MPI HLL

Electronics Readout (in-vacuum)



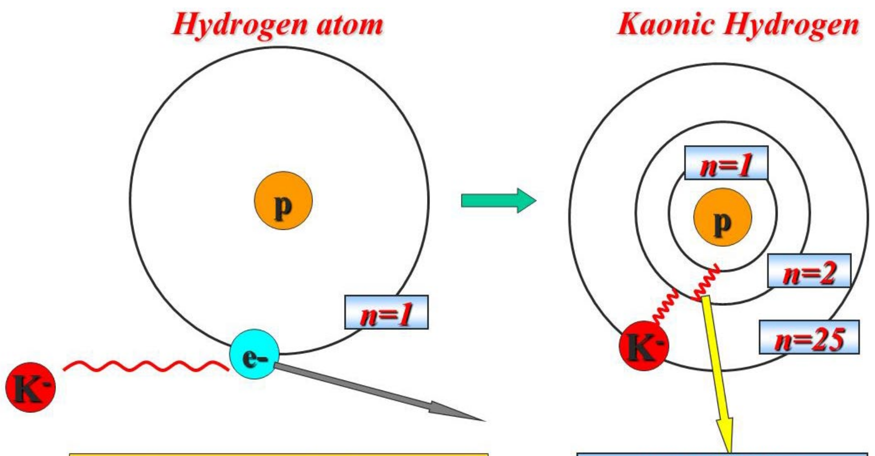




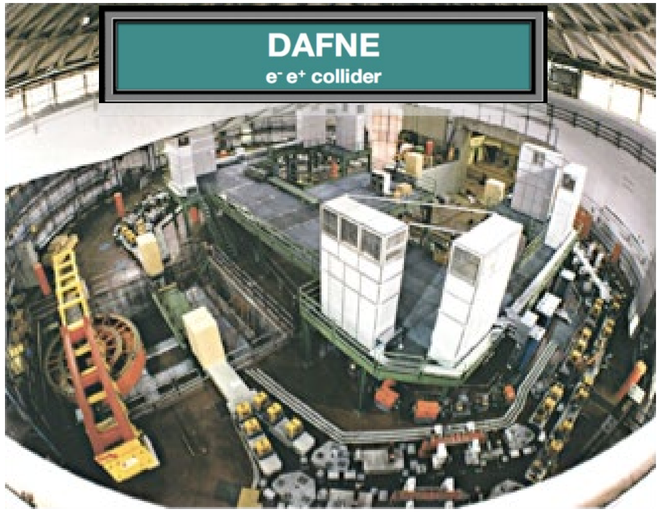
[1] M. Carminati et al. "The TRISTAN 166-pixel detector: Preliminary results with a planar setup" NIM:A 1049, 2023.

[2] D. Siegmann et al "Characterization measurements of the TRISTAN multi-pixel silicon drift detector" J. Phys. G: Nucl. Part. Phys. 51 , 2024.

The SIDDHARTA Experiment

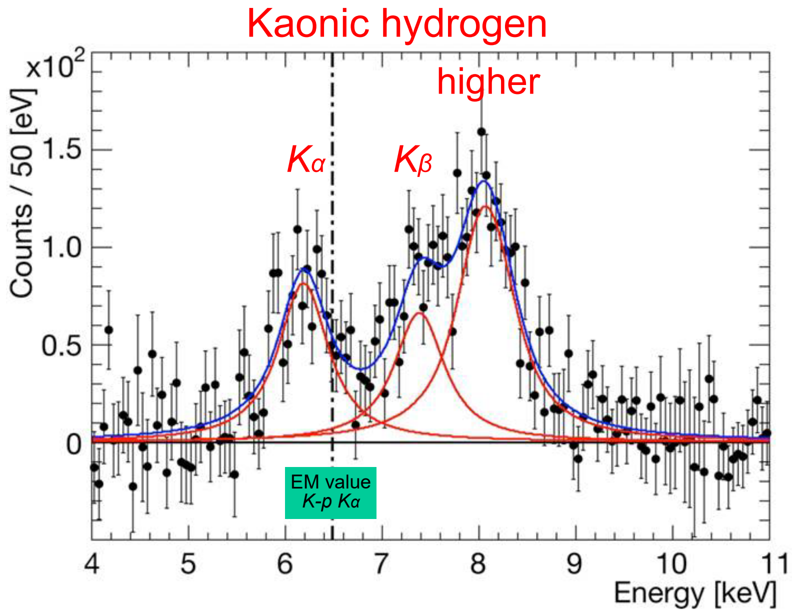


$$\varepsilon = \left| E^{measured}_{2p-1s} \right| - \left| E^{e.m.}_{2p-1s} \right|$$



Strong interaction studies al low energy through precise **X-ray spectroscopy** measurements of **Kaonic atoms transitions**

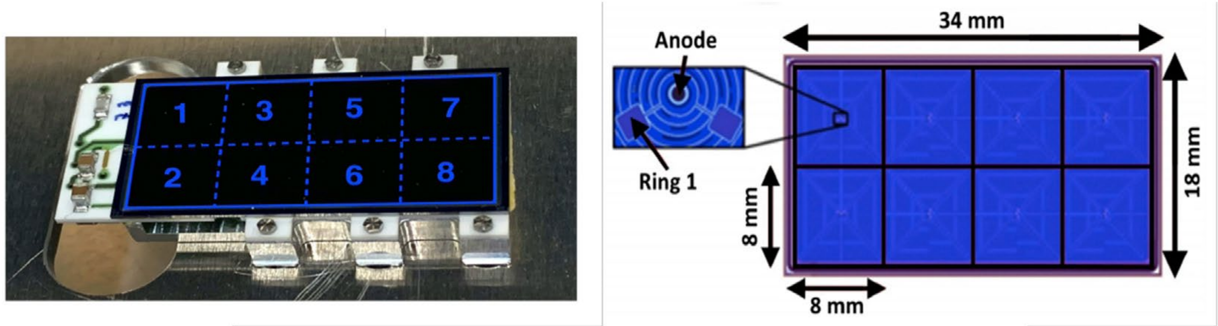
Main goal: Measurement of the strong-interaction-induced shift and width of the 1st state of kaonic deuterium

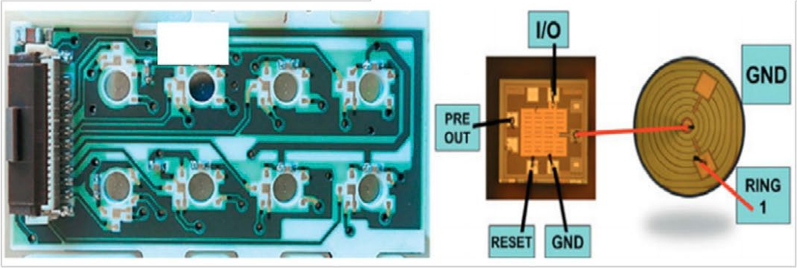


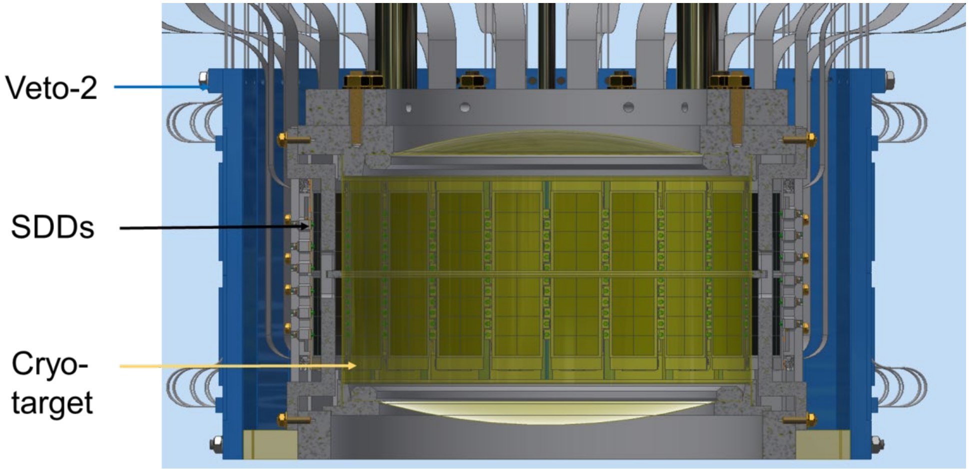
[1] C. Curceanu et al. "Kaonic atoms at the DAΦNE collider: a strangeness adventure" 2023 Front. Phys. 11:1240250 DOI:10.3389/fphy.2023.1240250

SIDDHARTA-2: The Experimental Apparatus

- **48** large-area monolithic **SDD arrays**:
  - 2 × 4 pixels, 8 mm pixel pitch (produced by FBK), 384 channels in total (**246 cm²**)
  - silicon thickness: 450 µm
- Readout **electronics** (developed by Polimi):
  - Front end: **CUBE** charge-sensitive amplifier (on the detection module)
  - Pulse processing: **SFERA ASIC** (analog pulse-processor)
- Resolution of SIDDHARTA-2 SDDs: **157eV @ 6.4 keV** (linearity below 2–3 eV)
- Measurement conditions: 100 °K - 10-5 mbar

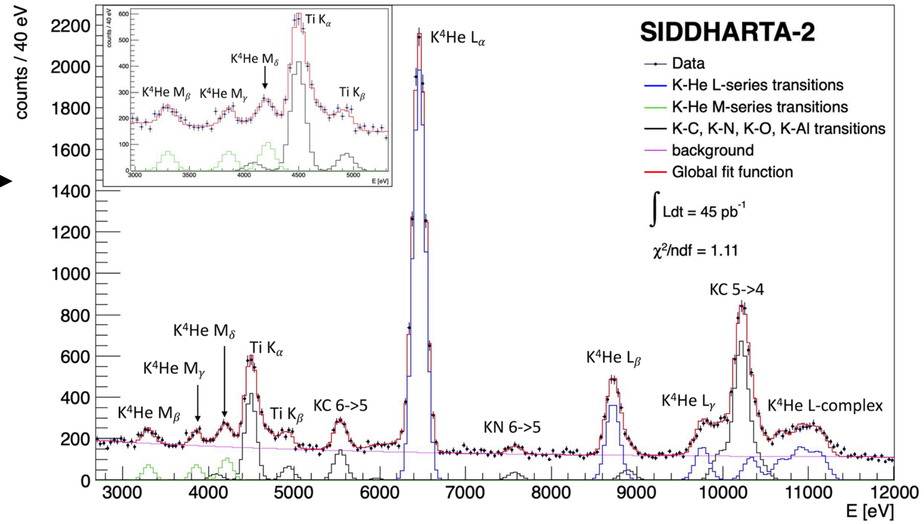


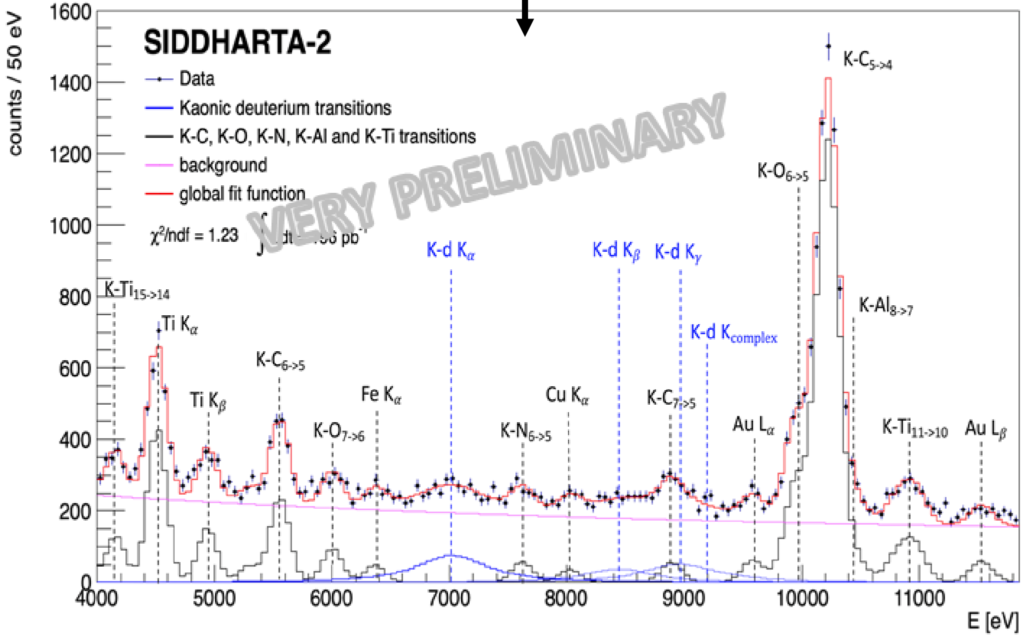


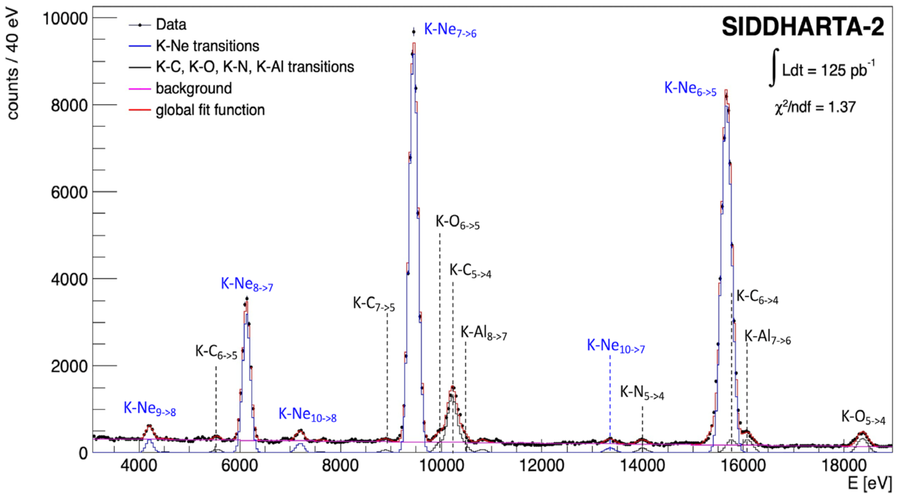


Recent Results with New Kaonic Atoms

- Characterization of the SIDDHARTA-2 Setup via the Kaonic Helium Measurement
- First Measurement of KHe M-lines
- First Measurement ever of kaonic Neon (record of precision < 1 eV)
- **First kaonic deuterium** measurement: preliminary!







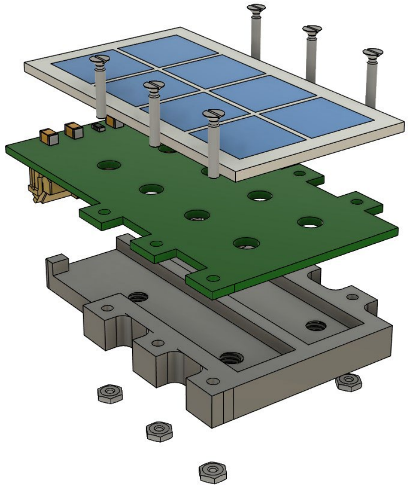
New 1-mm-Thick Detection Modules

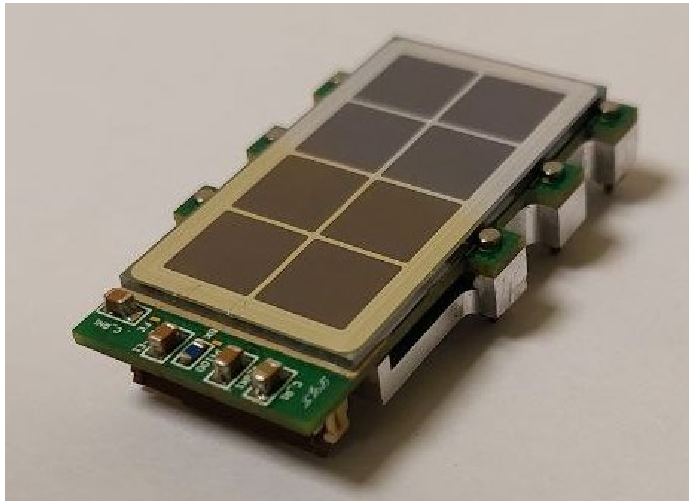
New single-SDD module for **higher X-ray energies**:
- **1-mm-thick SDD** to improve sensitivity to high-energies
- New focusing electrode to reduce charge sharing

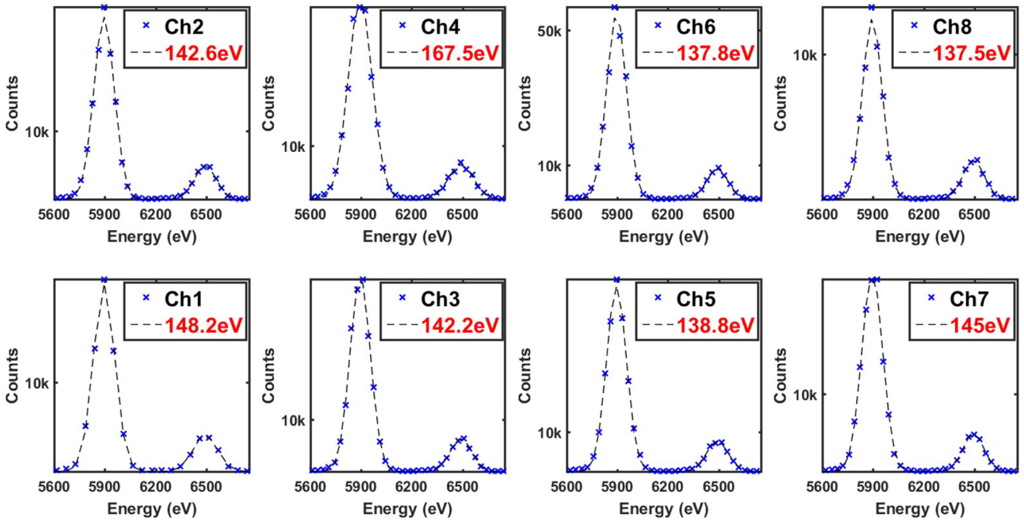
Characterization results:
- Good energy resolution: ~140 eV @ Mn-kα line, -30 °C

Next steps:
- **60 modules** based on 1-mm-thick SDD are currently **being assembled in FBK** for future experiment upgrade

L.G. Toscano et al. "Development of high-efficiency X-ray detectors based on 1 mm thick monolithic SDD arrays" 2024 JINST 19 P07039







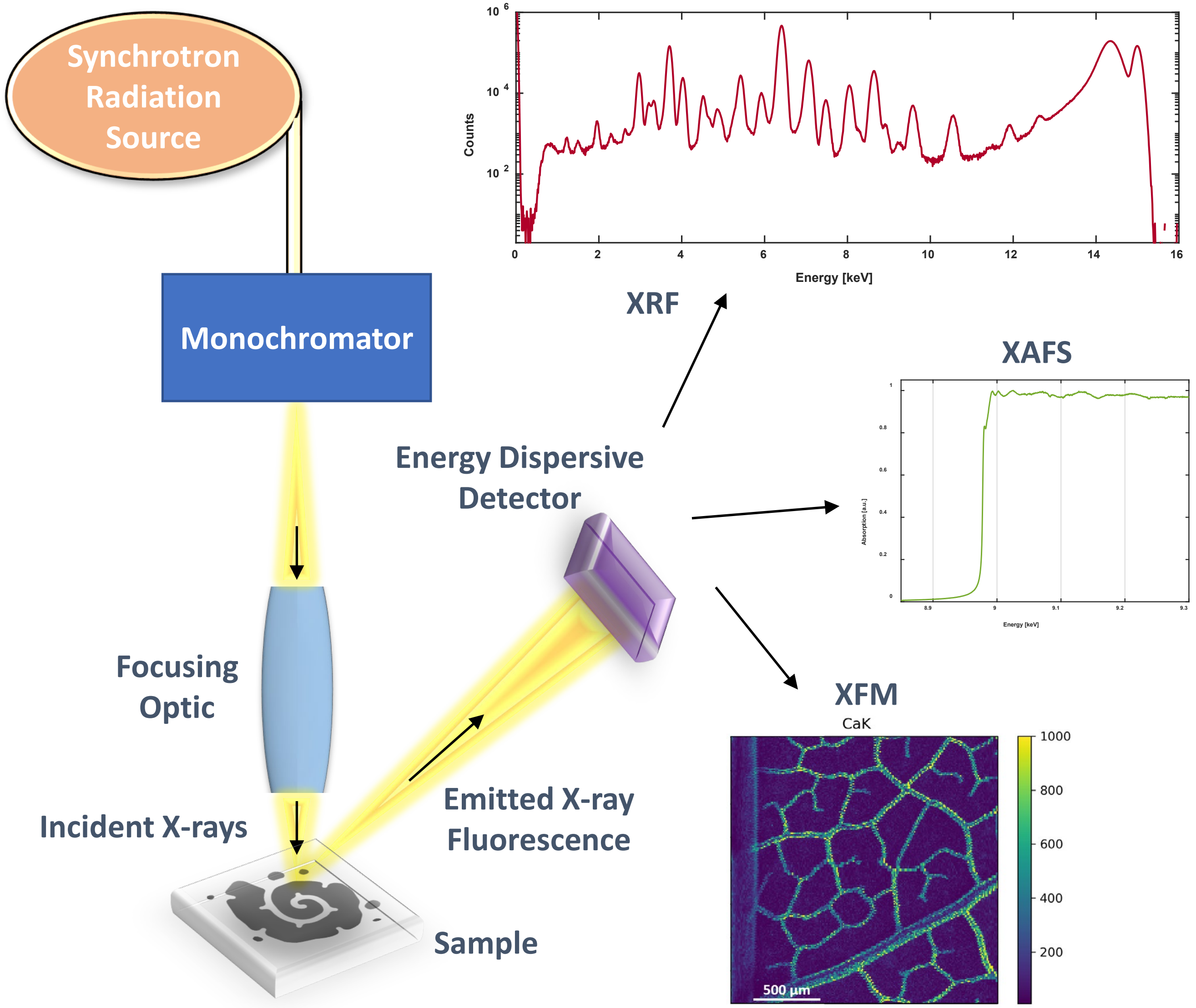
SDD Arrays for X-ray Spectrometers in Synchrotron applications

X-ray Spectrometers for Synchrotron Applications

Motivation:
Develop low-noise and versatile **instruments** 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



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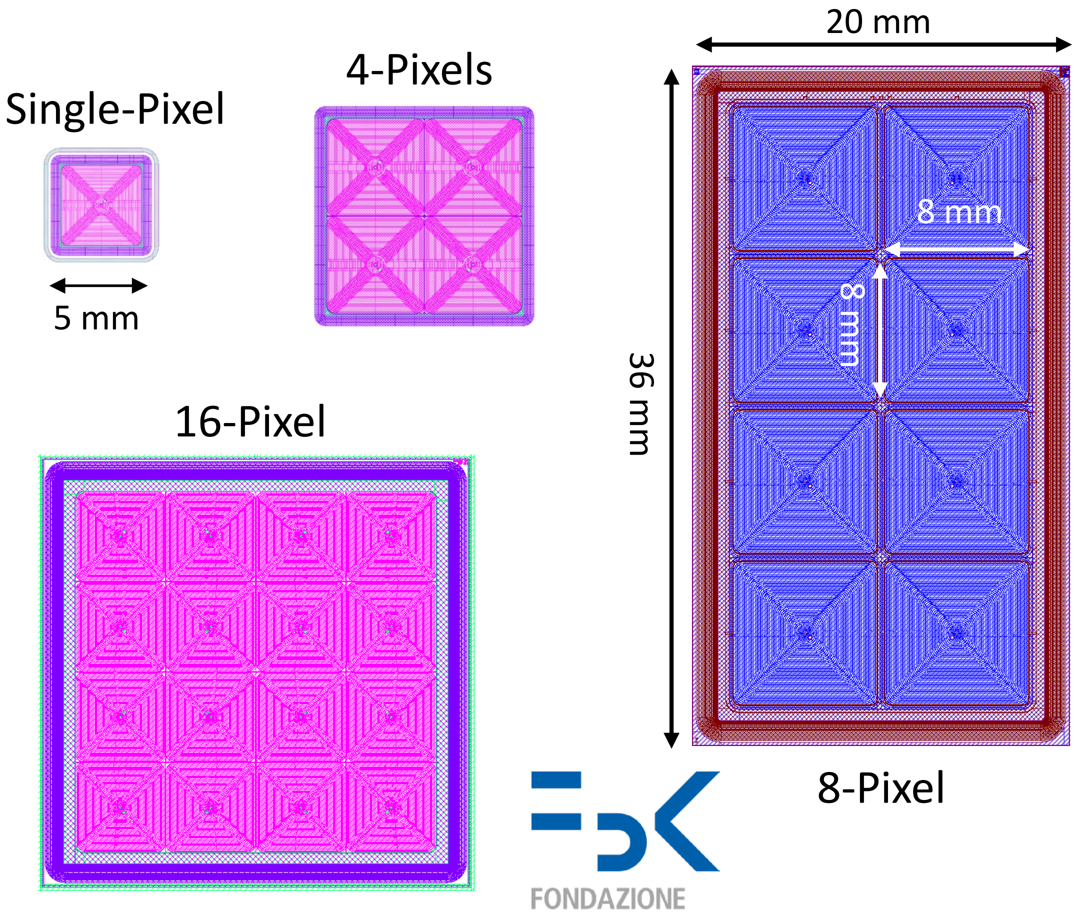
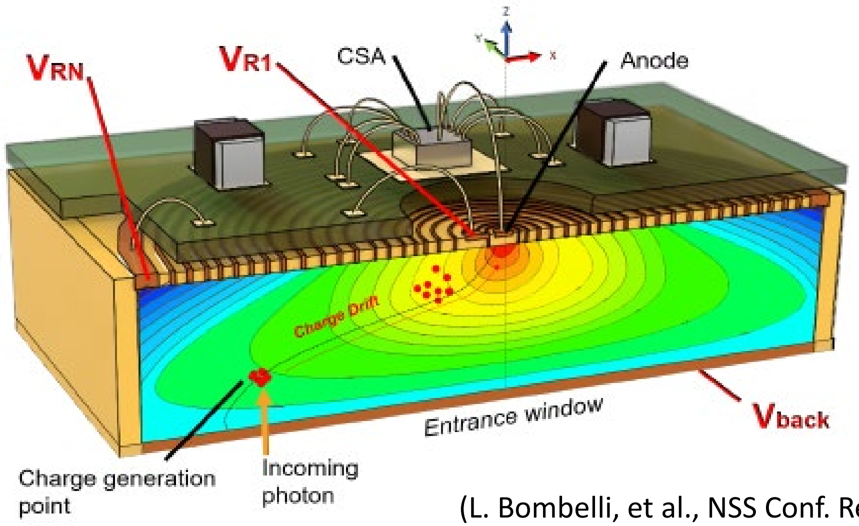
Key Components

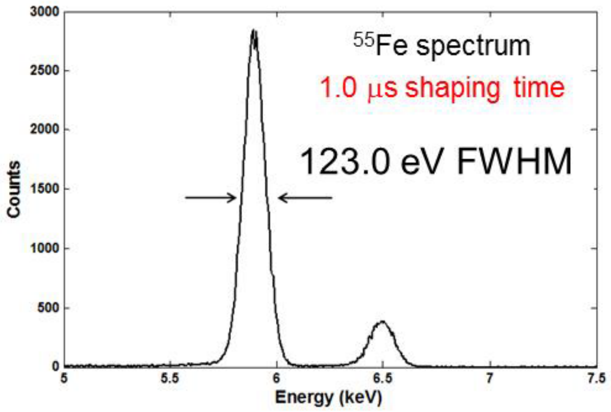
Silicon Drift Detectors

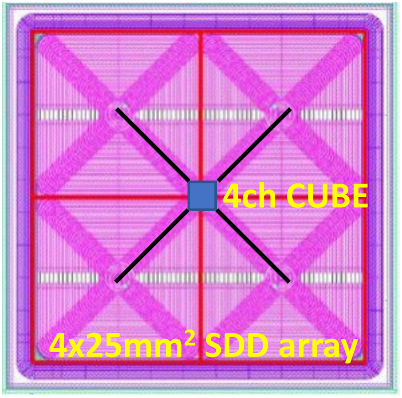


CUBE: CMOS Charge Sensitive Amplifier

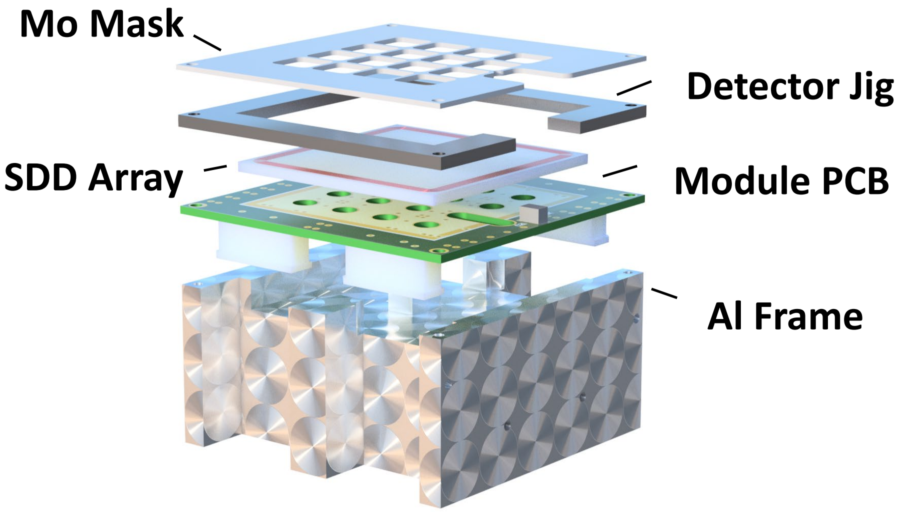


(L. Bombelli, et al., NSS Conf. Rec., 2011)



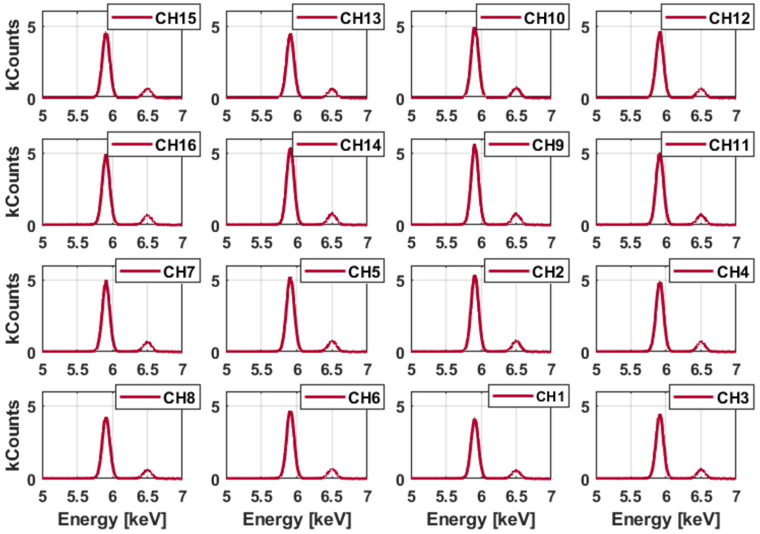


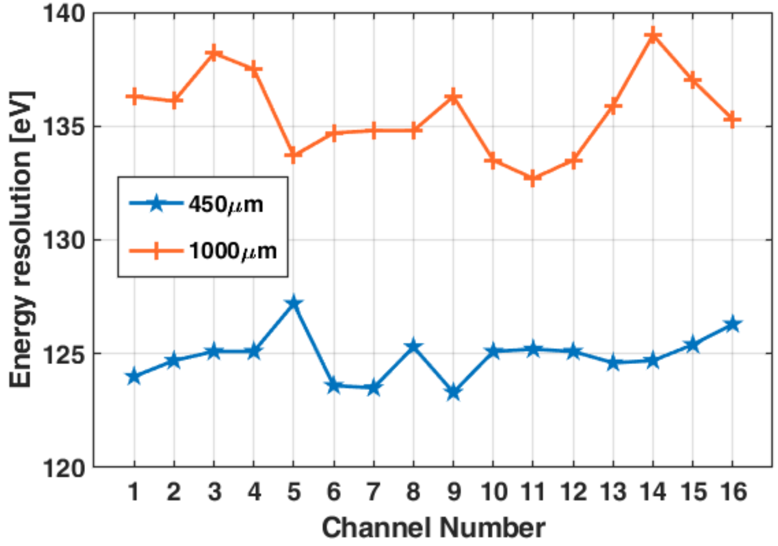
ARDESIA-16 Detection Module



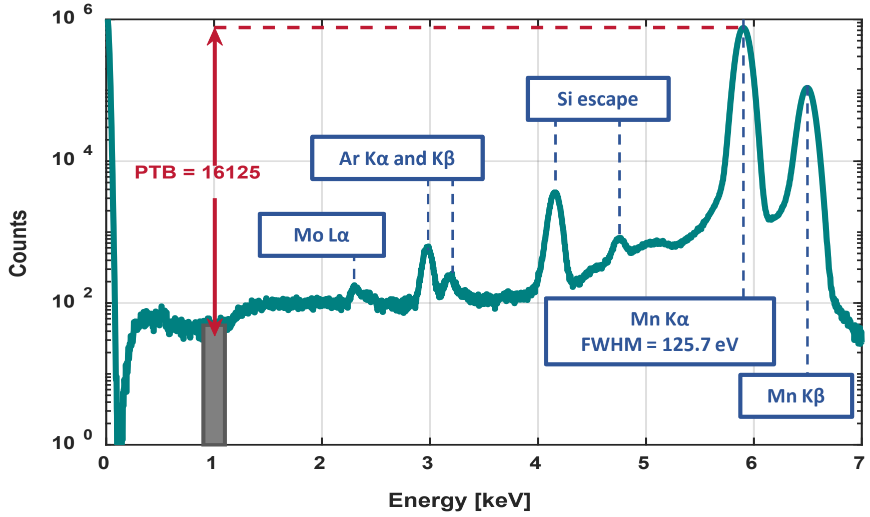
- **16-channel** monolithic **SDD** array: **5-mm pitch, thickness** 450 and **1000 µm**
- 500 µm thick **Molybdenum (or Zirconium) Mask** to prevent charge sharing phenomena
- Total collimated area is **324 mm²**
- Four custom-designed **4-channel CUBE Preamplifiers**
- Preamplifier and Detectors are glued to an **Alogen-free PCB**

Peaking Time = 3 µs





PTB > 15000 for each element



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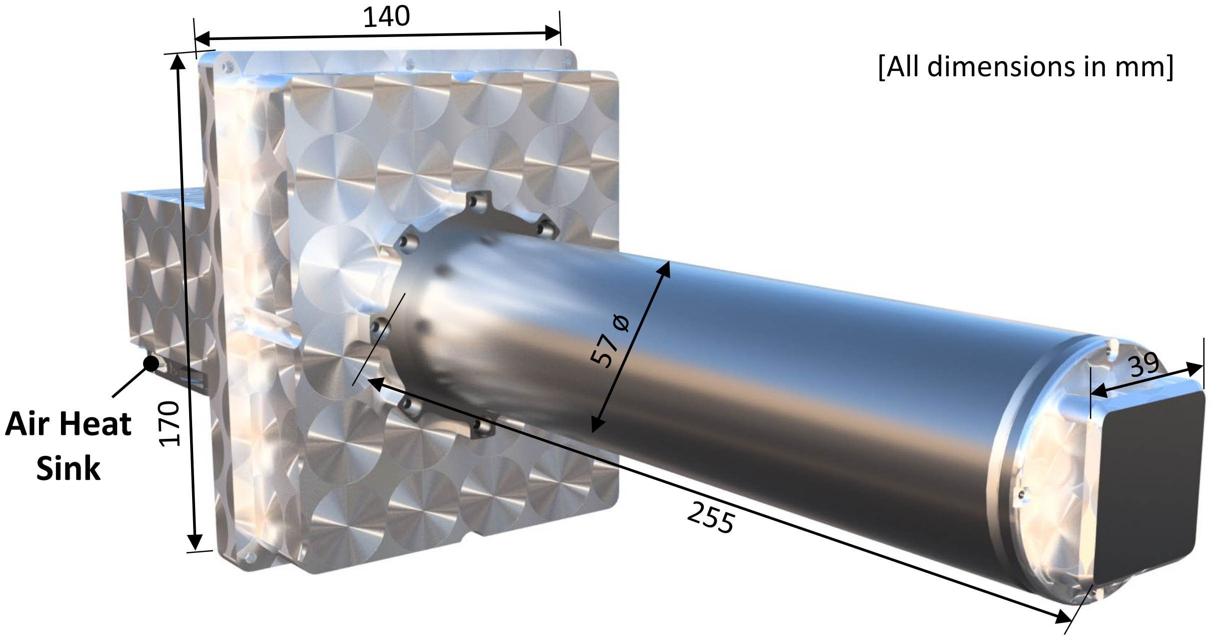
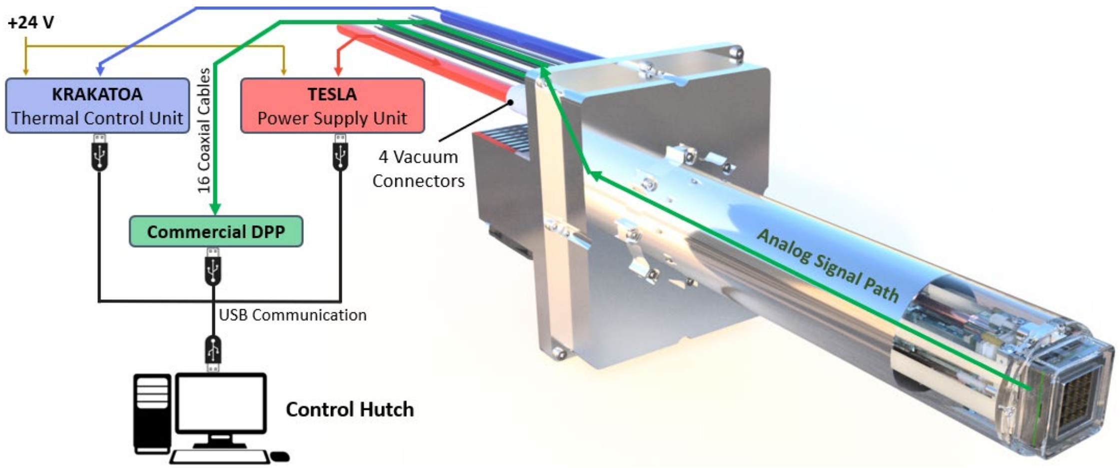
ARDESIA-16 Spectrometer



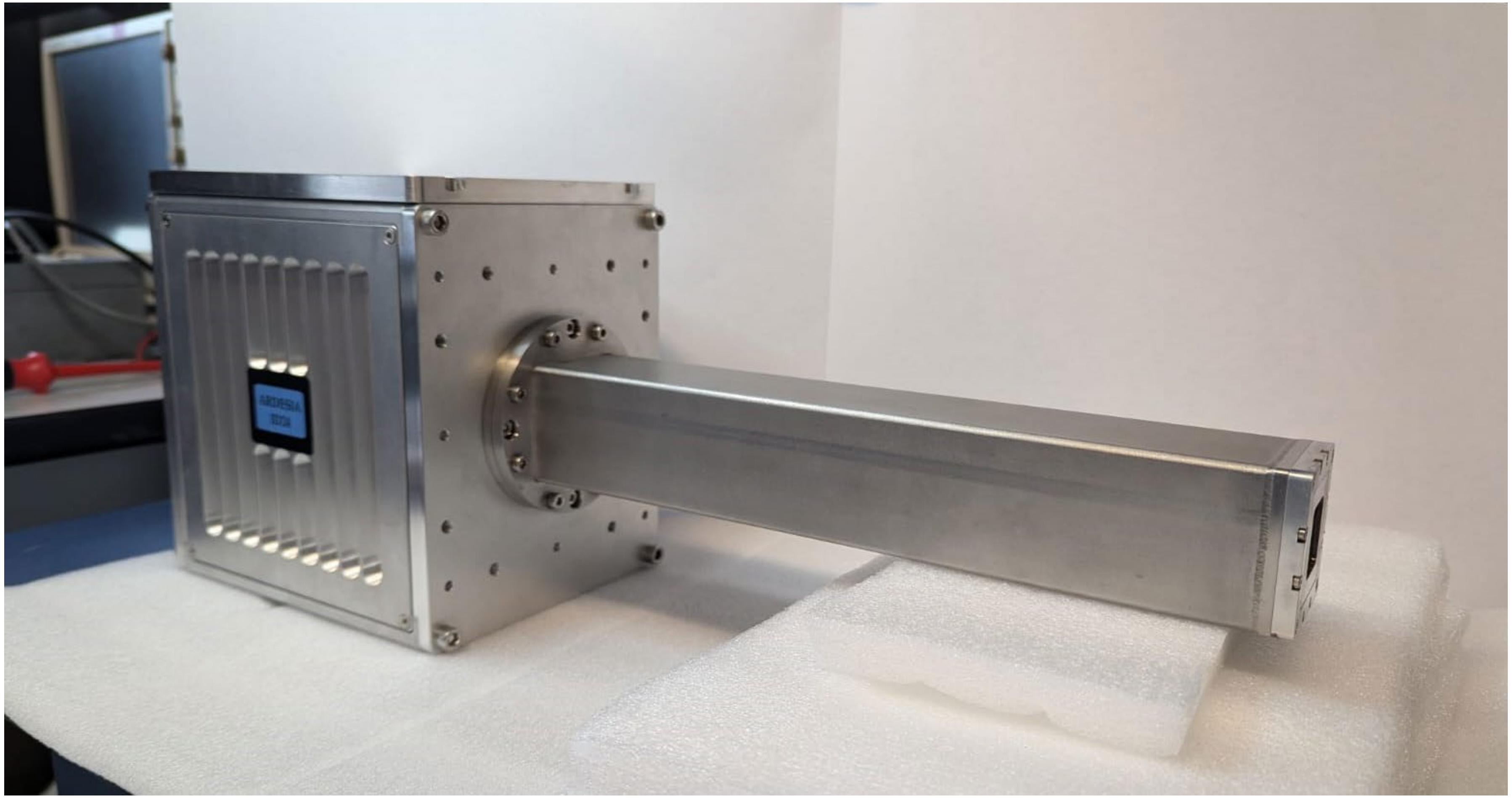
[All dimensions in mm]

- **Hosts the detection module**
- **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

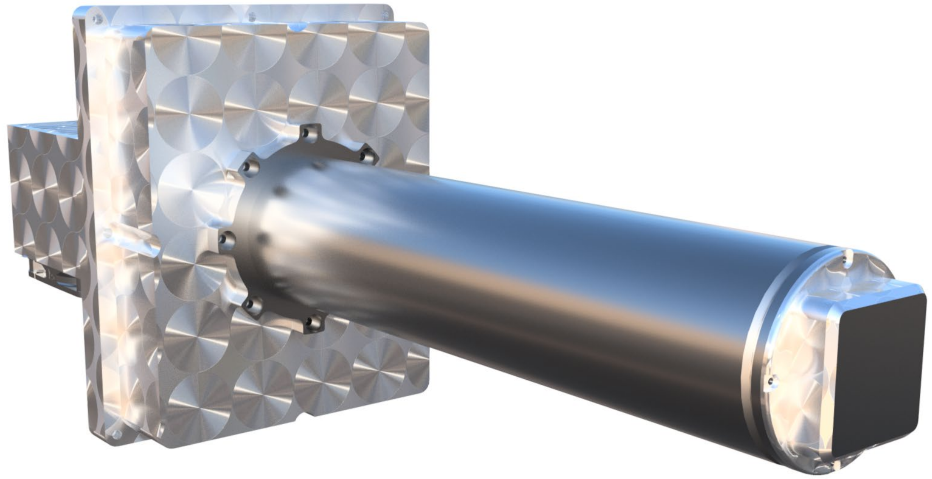


ARDESIA-16: New ESRF version



Feature: stand-alone vacuum by ion pump inside the instrument.

ARDESIA Spectrometers in Europe



ESRF

- *ID16A:* ARDESIA-16
- *ID24:* ARDESIA-16
- *LISA:* ARDESIA-4

DESY

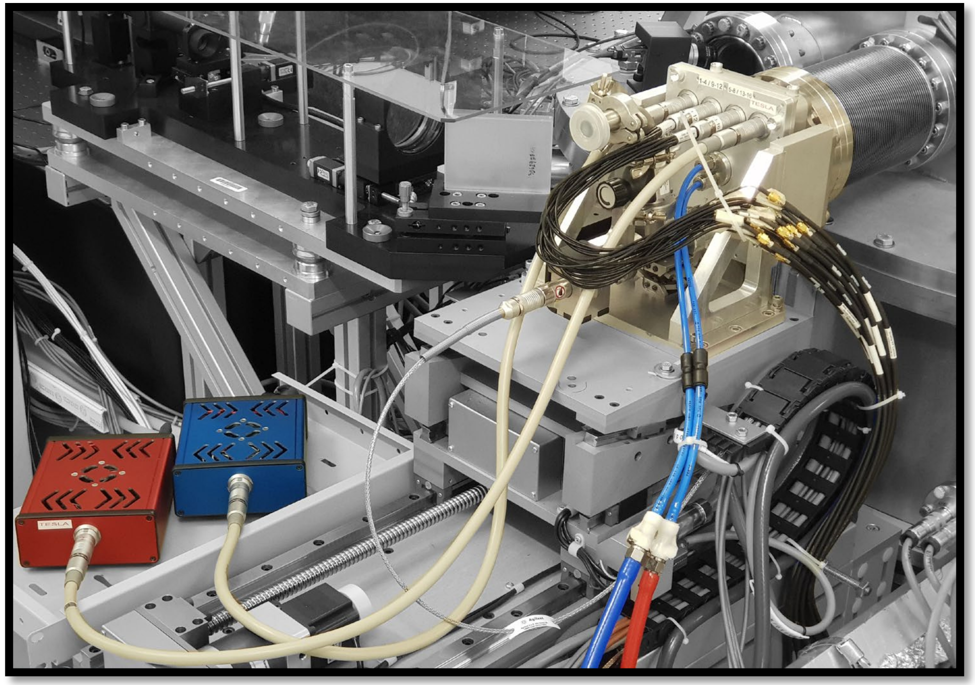
- *P06:* ARDESIA-16
- (*P06:* ASCANIO-16)

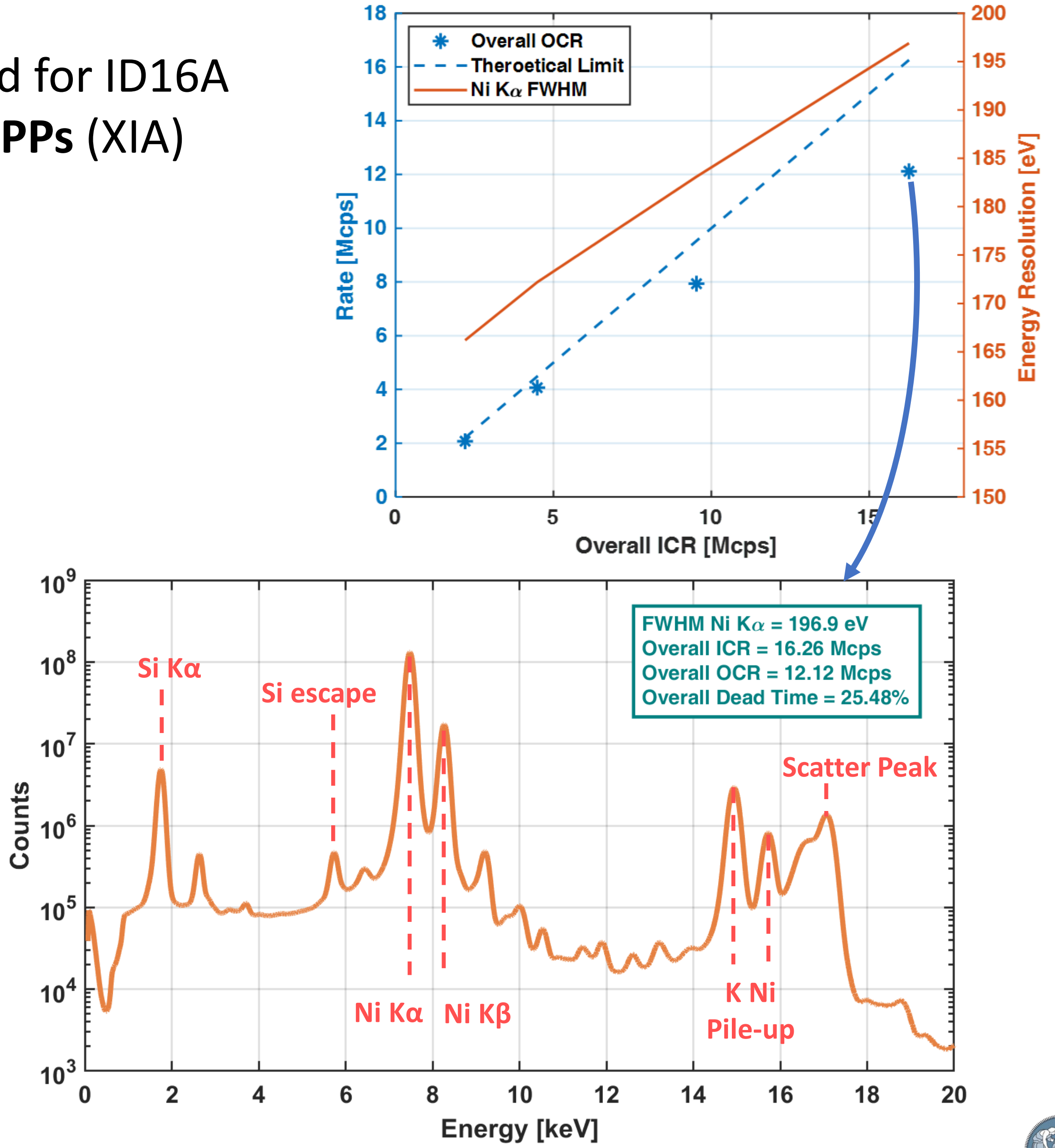
LNF

- *DAFNE LIGHT* ARDESIA-4

ESRF ID16A: Count-Rate and Energy Resolution

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



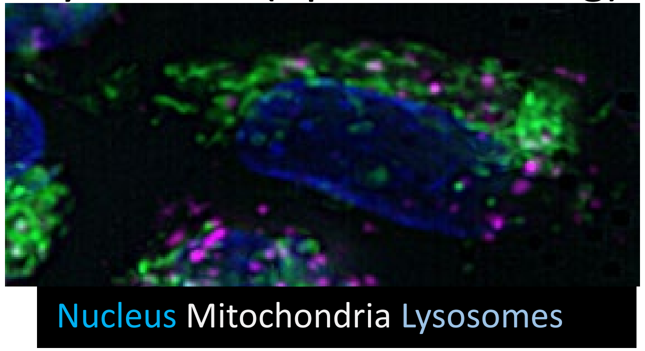


Sample: 10 nm thick square of **Nickel** on a Si-substrate (20 µm × 20 µm)

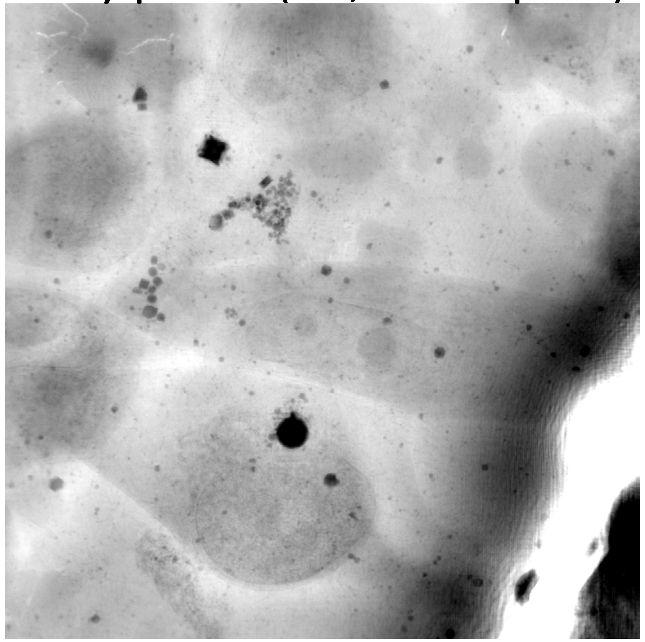
Energy of the Beam: 17 keV

ESRF ID16A: XFM on a Biological Sample

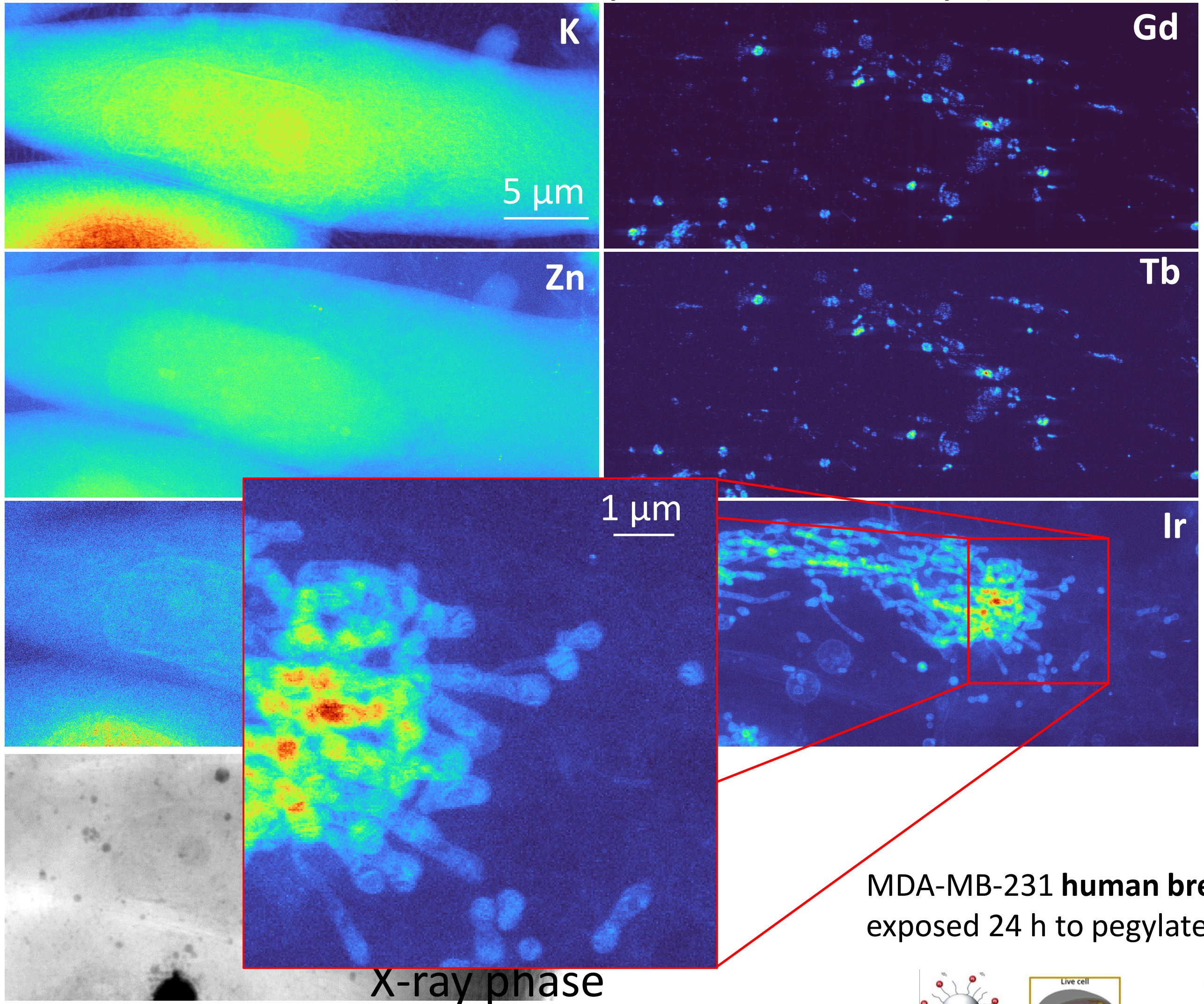
Cryo-CLEM (optical clearing)



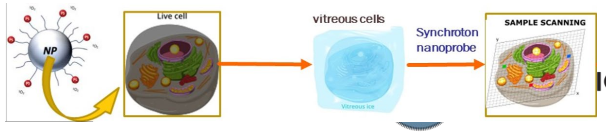
X-ray phase (2D, 25nm pixel)



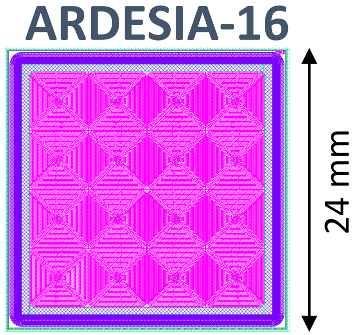
XRF (2D, 30nm pixel size, 50ms/pt)



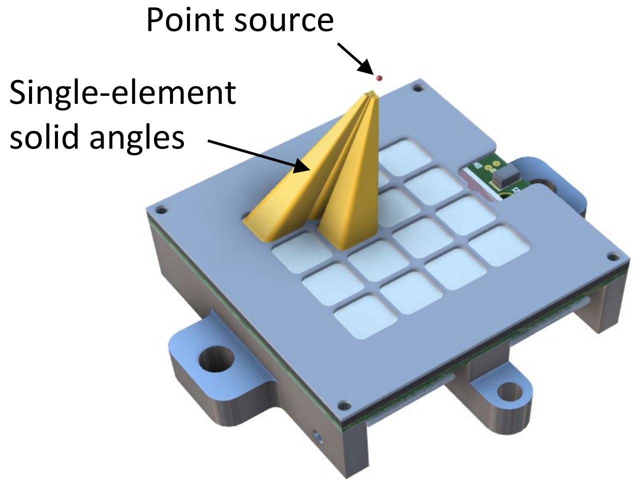
MDA-MB-231 **human breast cancer cells** exposed 24 h to pegylated **Gd/Tb nanohybrids**

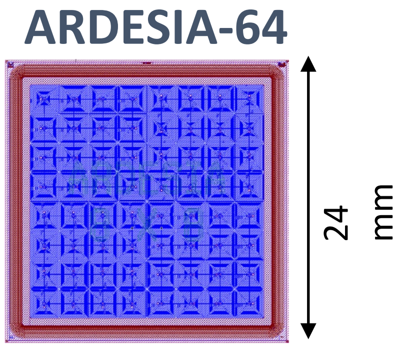


From ARDESIA-16 to ARDESIA-64…

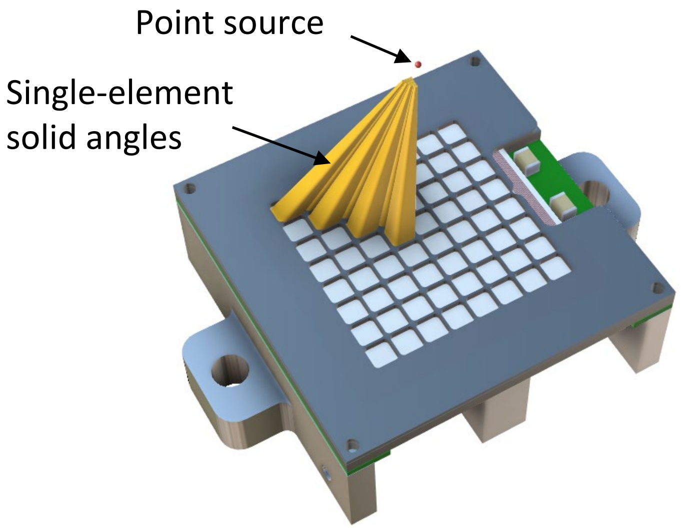


- 4 x 4 Matrix
- 5 mm Pixel Pitch

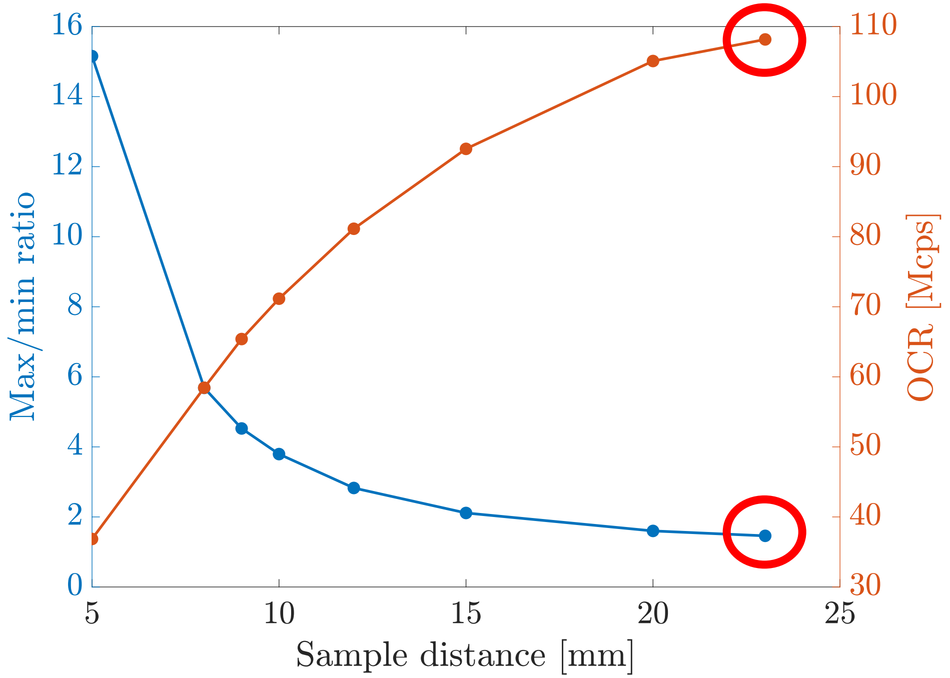




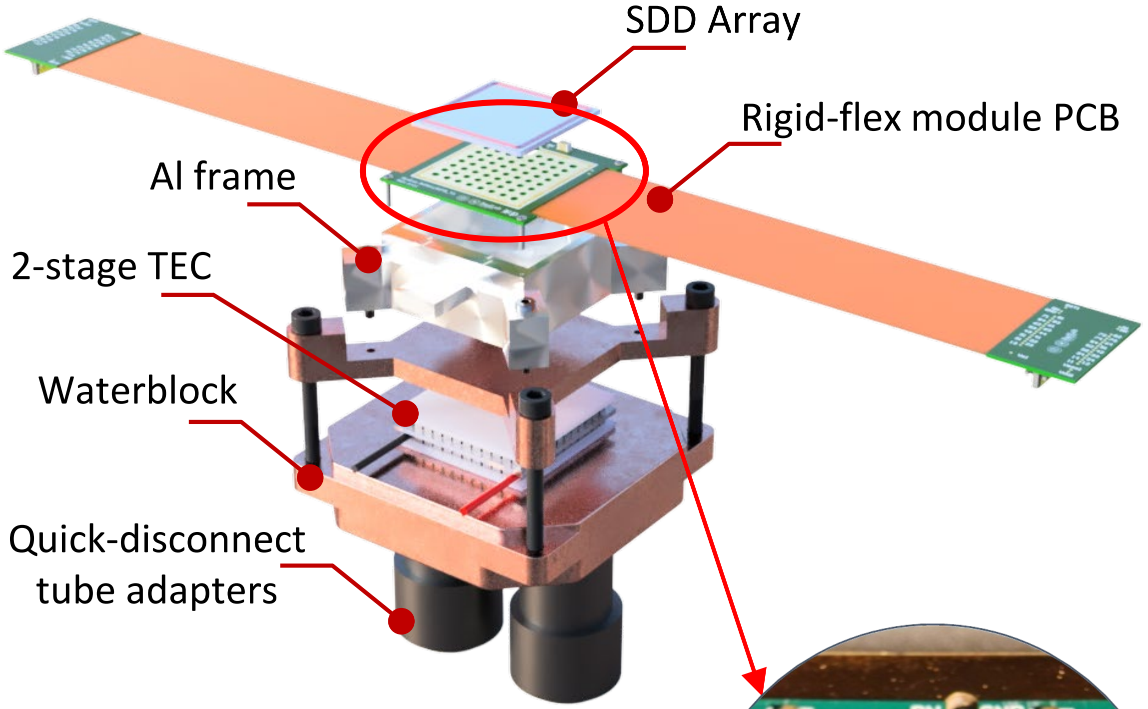
- 8 x 8 Matrix
- 2.5 mm Pixel Pitch



Sample distance	Total solid angle	16ch OCR @ 2 Mcps ICR	64ch OCR @ 2 Mcps ICR
10 mm	2.09 sr	20 Mcps	71 Mcps
15 mm	1.25 sr	25 Mcps	92 Mcps
23 mm	**0.63 sr**	**28 Mcps**	**108 Mcps**

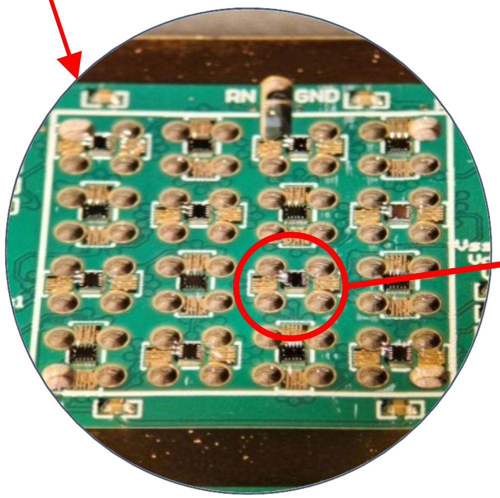


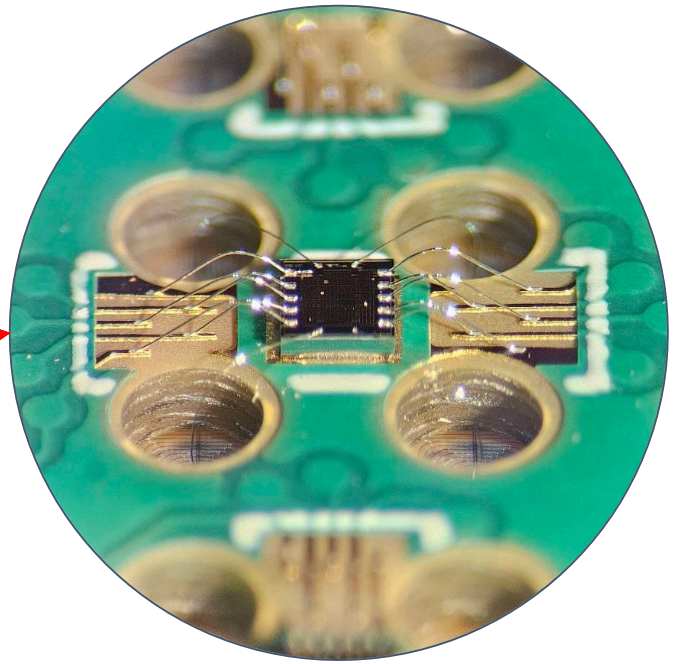
ARDESIA-64 Detection module



Detection module

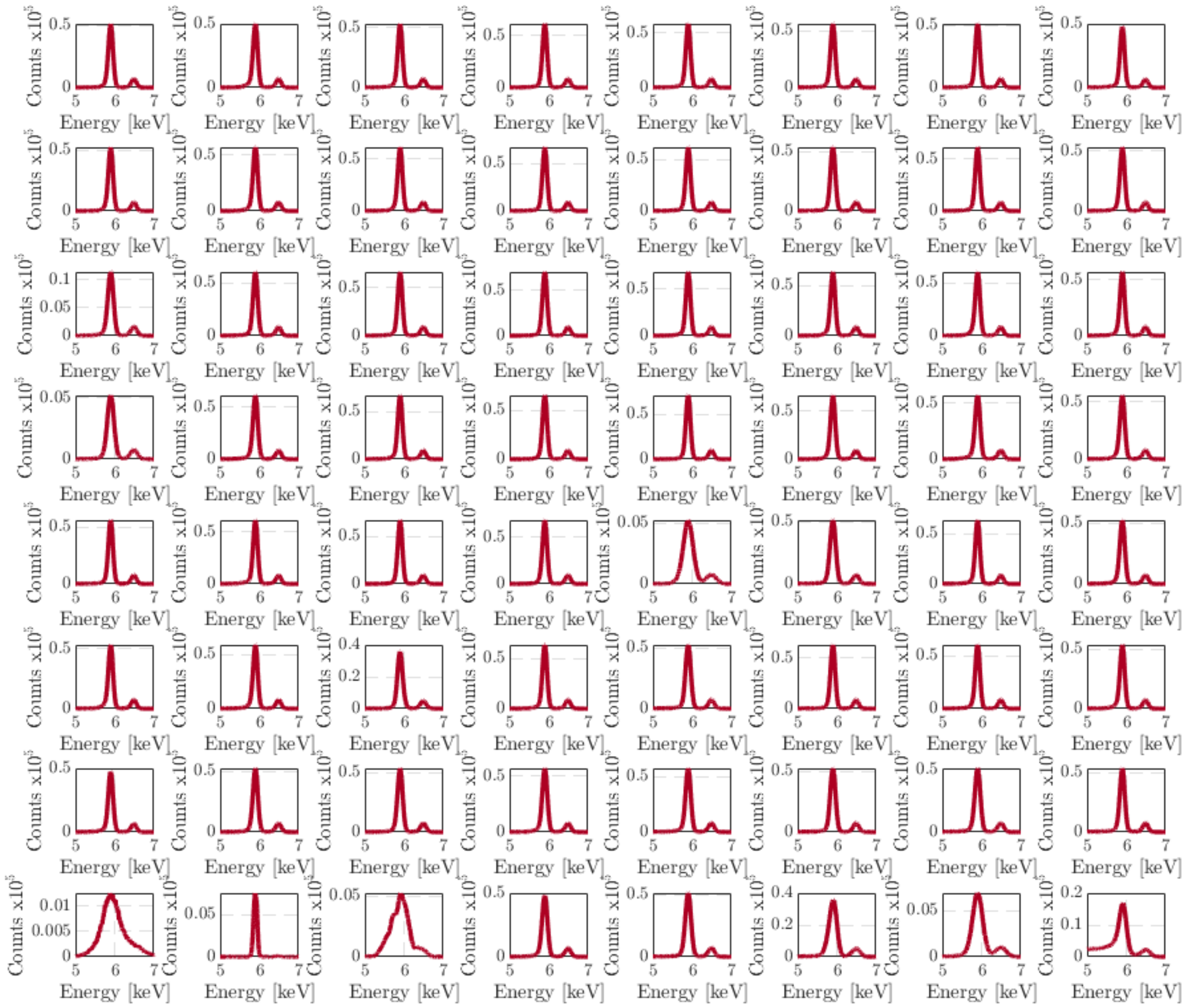
- **64-channel** monolithic **SDD** array (**1mm-thick**)
- **16** custom-designed **4-channel CUBE** preamplifiers
- Preamplifier and detectors are glued to a **high-density rigid-flex PCB**
- 2-stage TEC coupled to water cooling

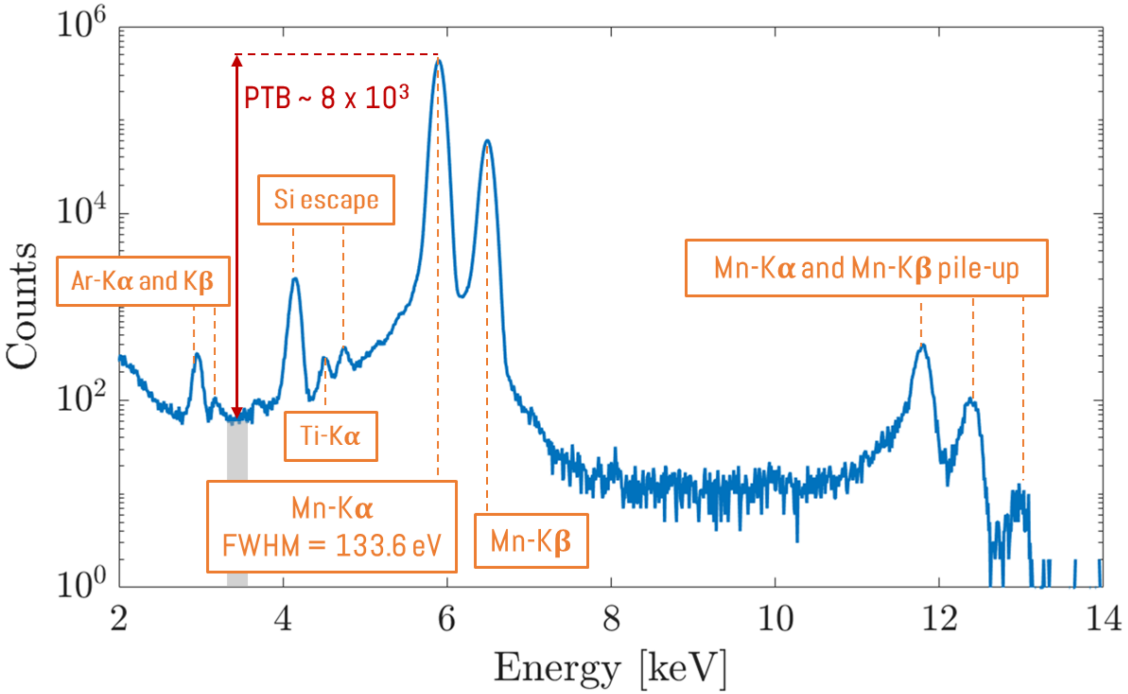




4ch CUBE ASIC

First Prototype: Preliminary Tests





Preliminary measurements:

- 1 mm thick SDD
- 59 working channels: 92% yield
- ^{55}Fe at low count rate: ~15 kcps
- Detector Temperature = -30 °C
- Peaking time: 1 µs

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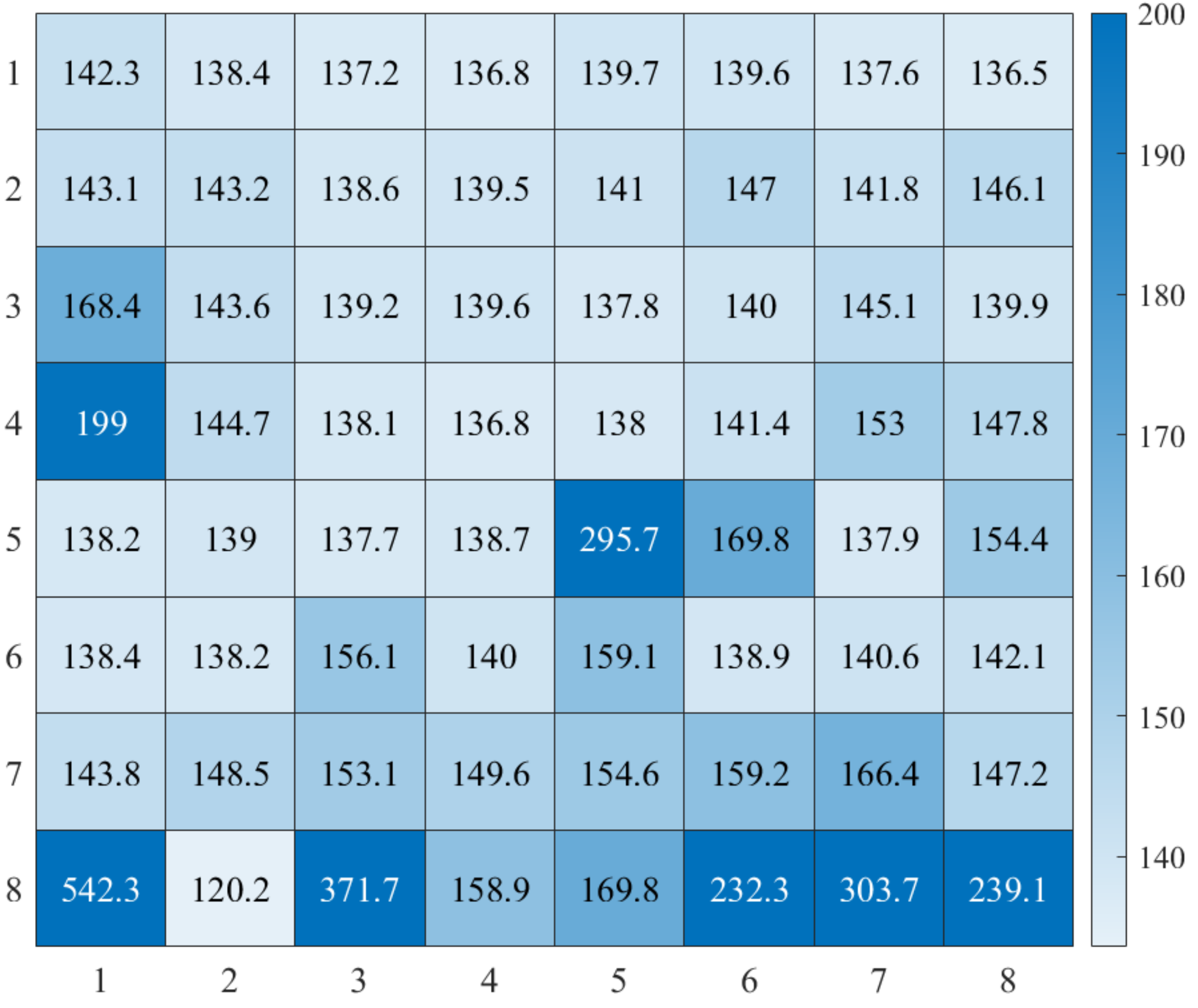
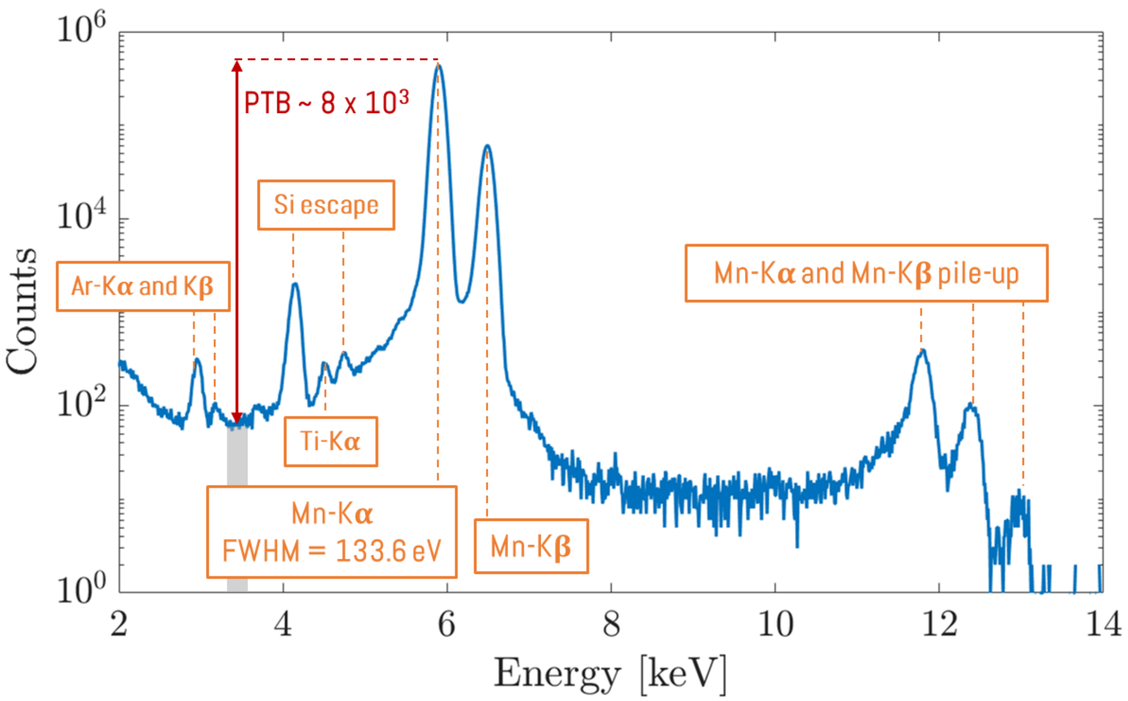
First Prototype: Preliminary Tests





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- 59 working channels: 92% yield
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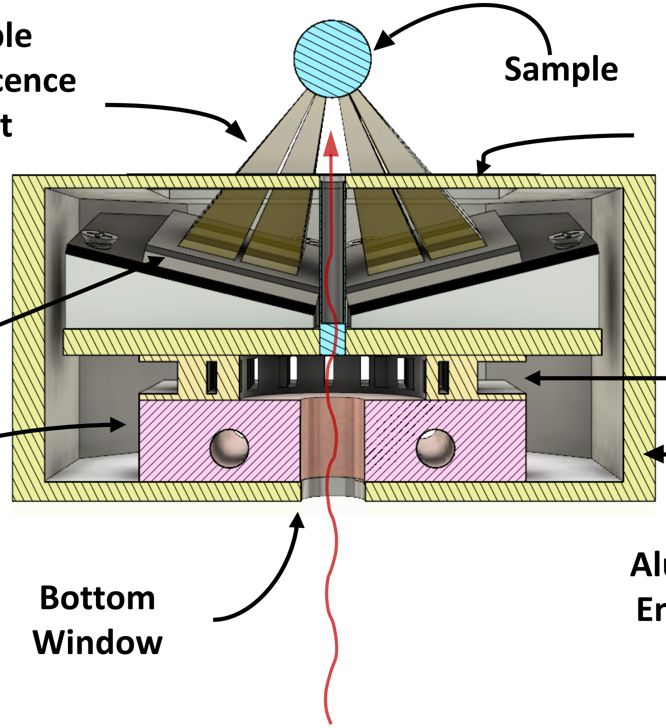
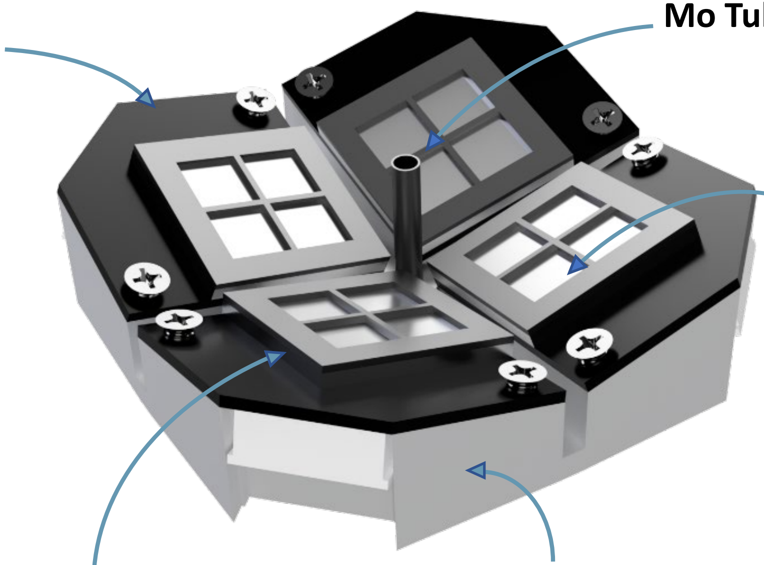
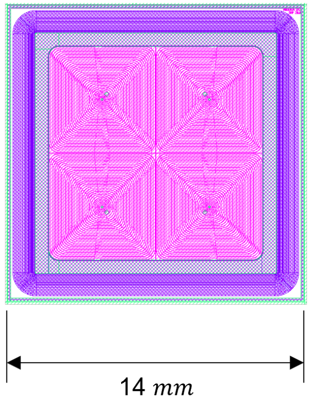
The ASCANIO Detector

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



Backscattering geometry* with tilted SDDs

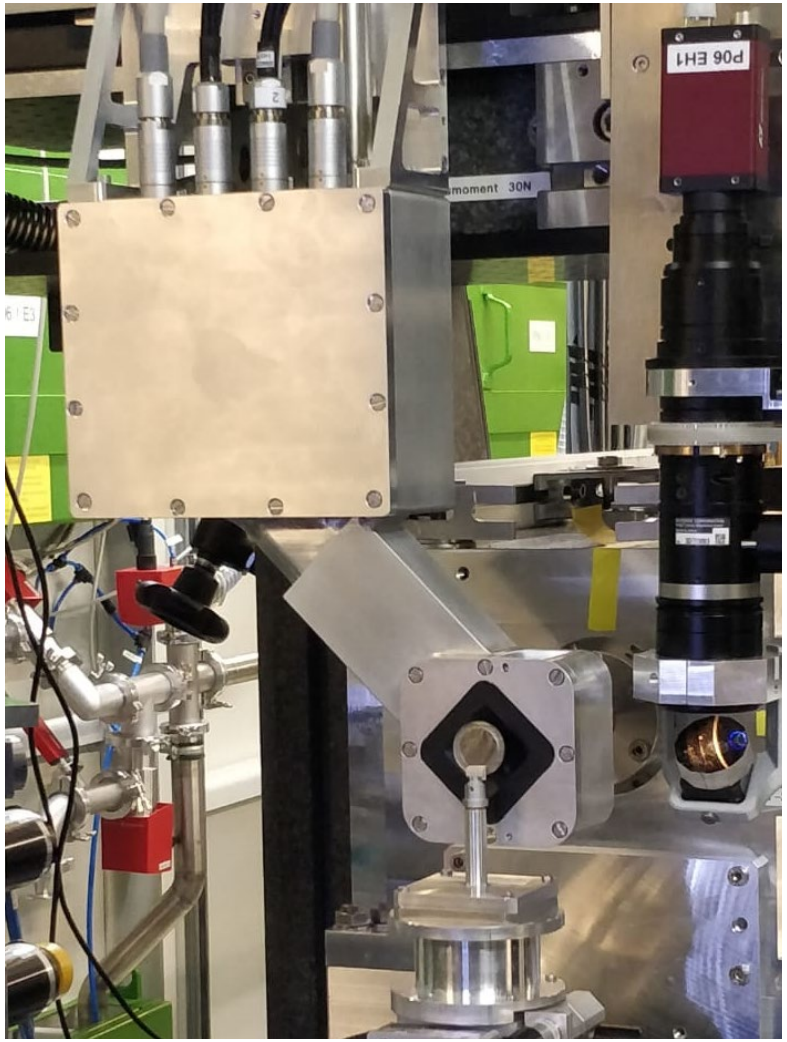




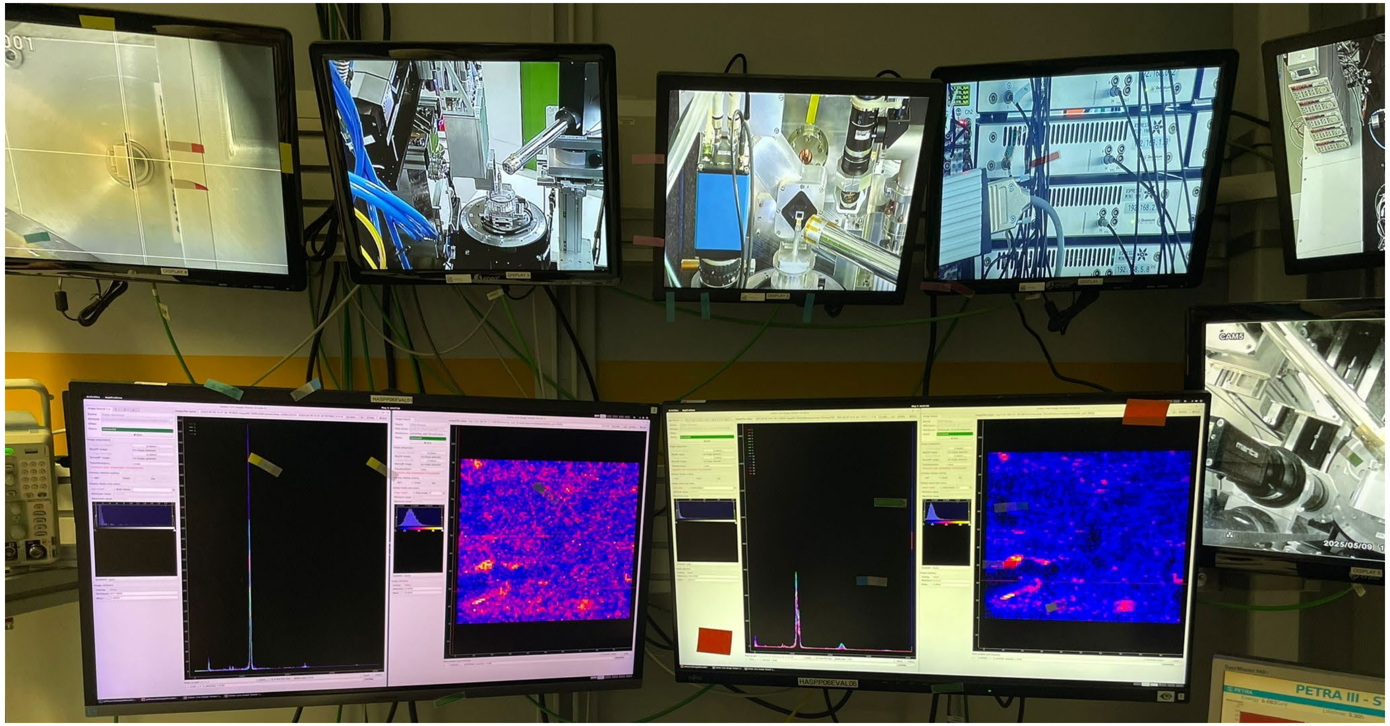
- **5 mm** side for each pixel
- Thicknesses: 450 µm - **1 mm**
- Active area = 100 mm^2
- FBK – Trento, Italy

[*] 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

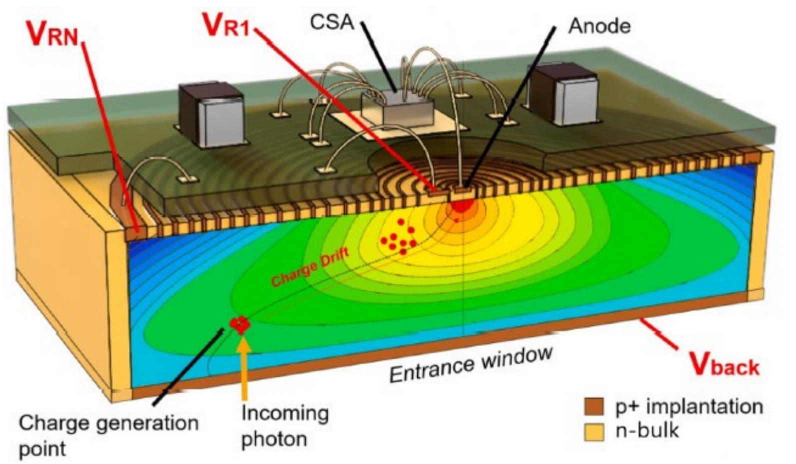
Detector Installed @ PETRA III P06

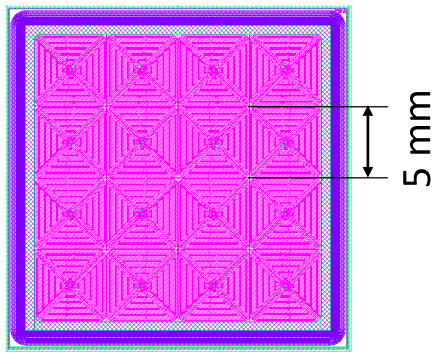


- **ASCANIO** detector installed last week **@ PETRA III P06**
- Instrument immediately operational
- Comparison with current system (Vortex 4ch) showed a significant **improvement in statistics** during **XFM measurements**

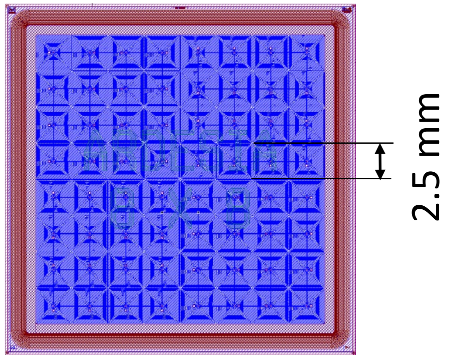


Charge Sharing in Monolithic Arrays of SDDs

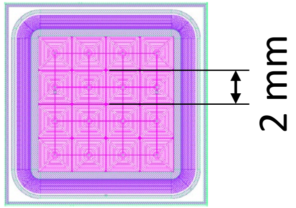




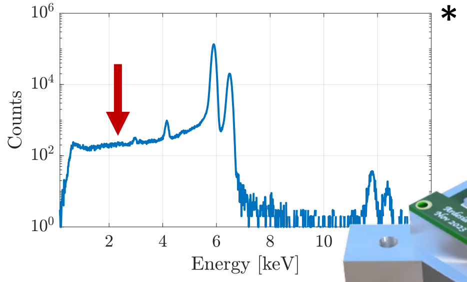
Total active area: **400 mm²**

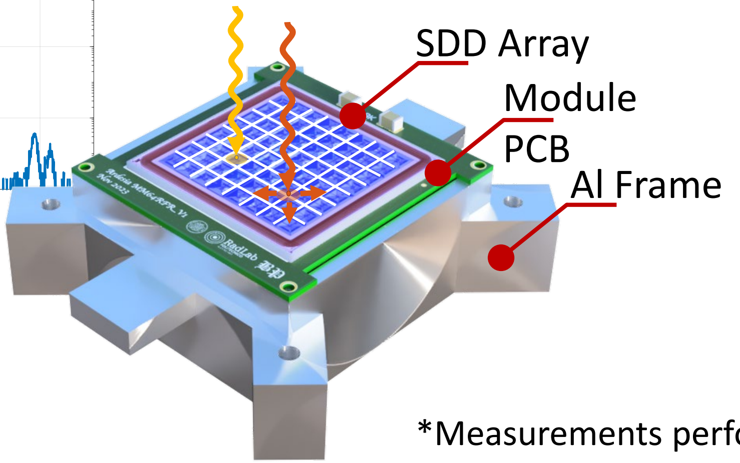


Total active area: **400 mm²**



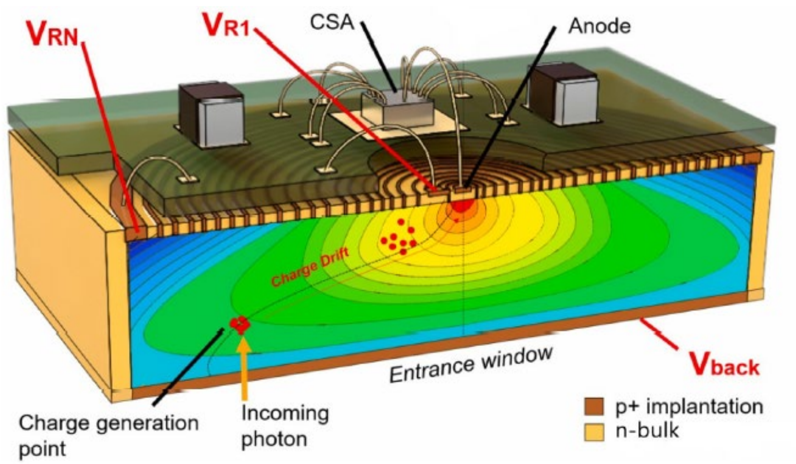
Total active area: **64 mm²**

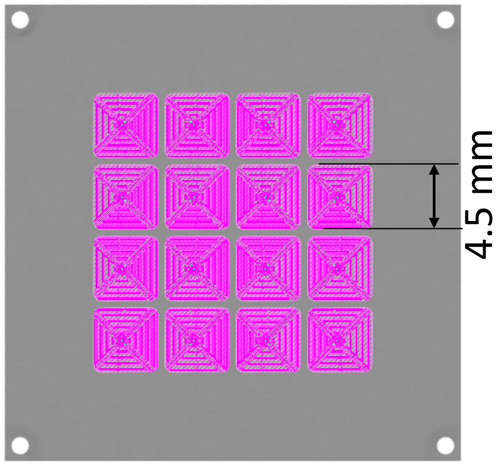




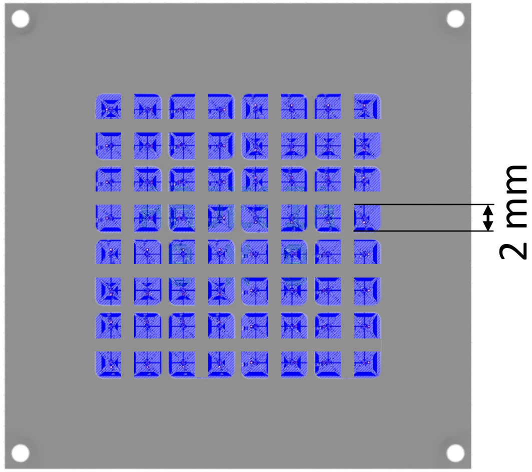
*Measurements performed with 16-channel module

Charge Sharing in Monolithic Arrays of SDDs

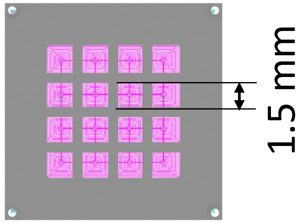




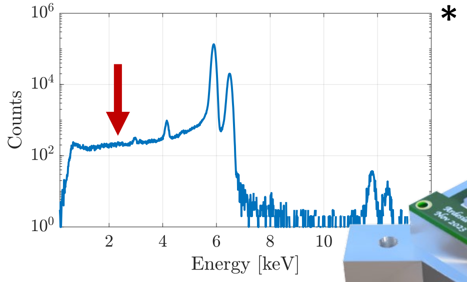
Total active area: **400 mm²**
Coll. active area: **324 mm²**
20% active area loss

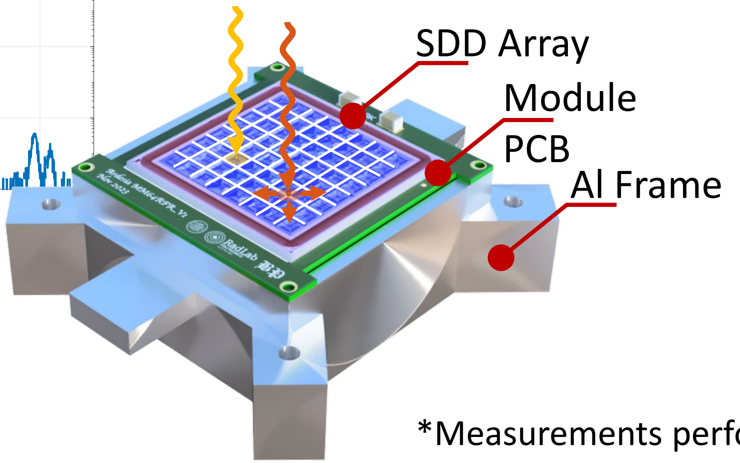


Total active area: **400 mm²**
Coll. active area: **144 mm²**
64% active area loss

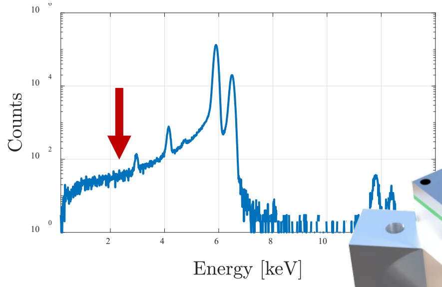


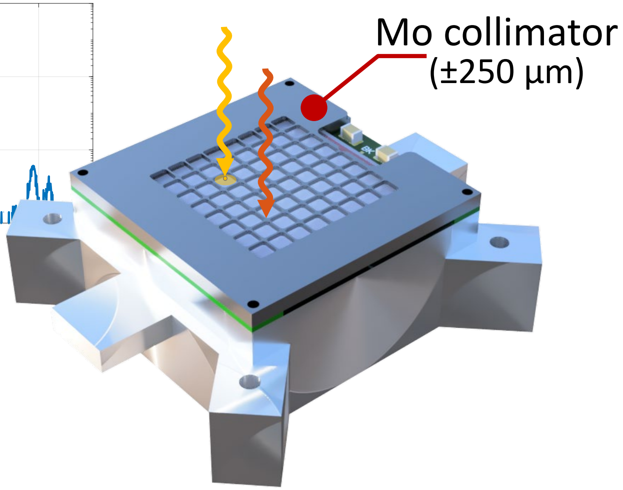
Total active area: **64 mm²**
Coll. active area: **36 mm²**
45% active area loss





*Measurements performed with 16-channel module

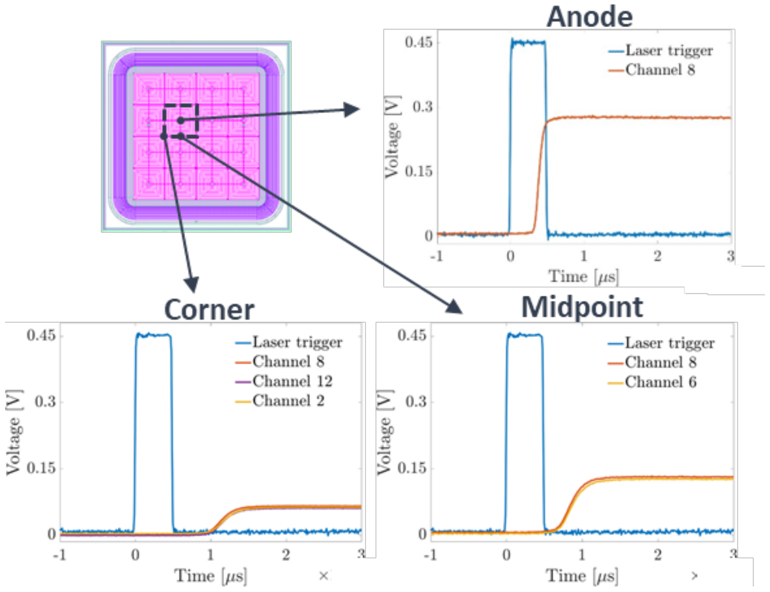


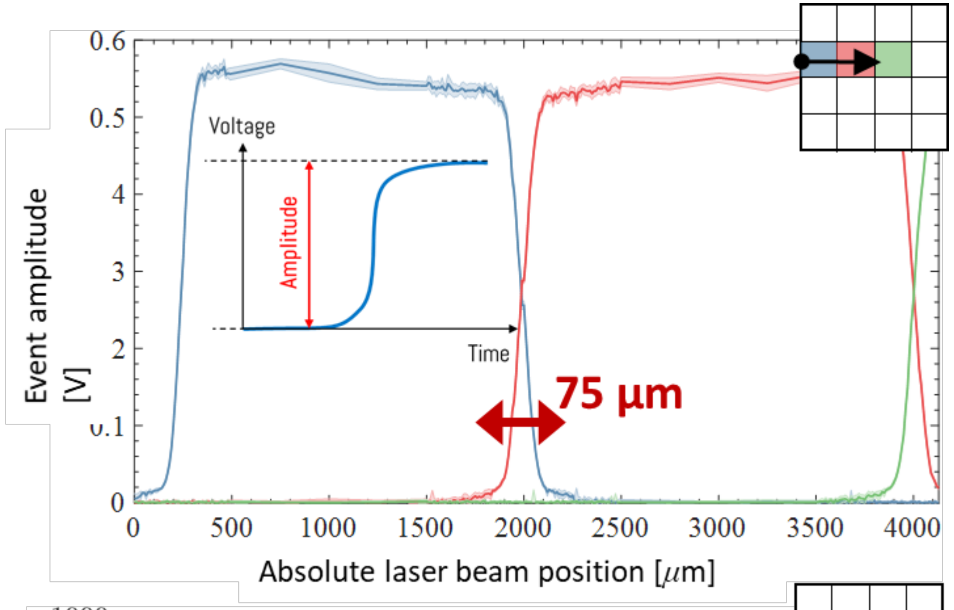


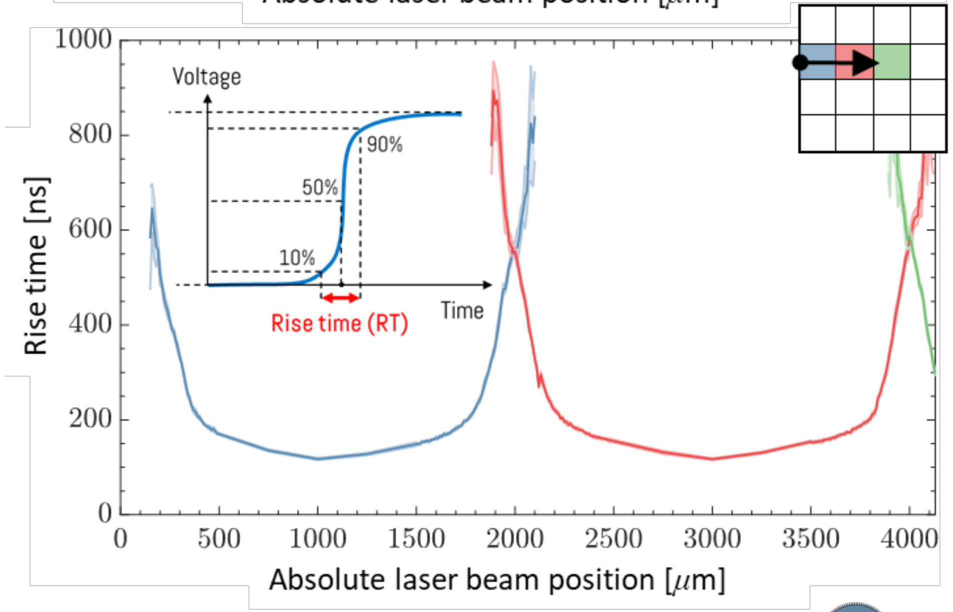
Charge Sharing Region: Amplitude vs. Rise Time

Characterization of SDD array response:

- Scan using a micro-focused **laser**
- Acquisition of the **anode signals** using **oscilloscope**
- The charge sharing **(CS) region** shows a **decrease** in **signal amplitude** and **increase** in **rise time**
- Extension is **75 µm** on each side of the **pixel edge**
- ~14% of the total pixel area



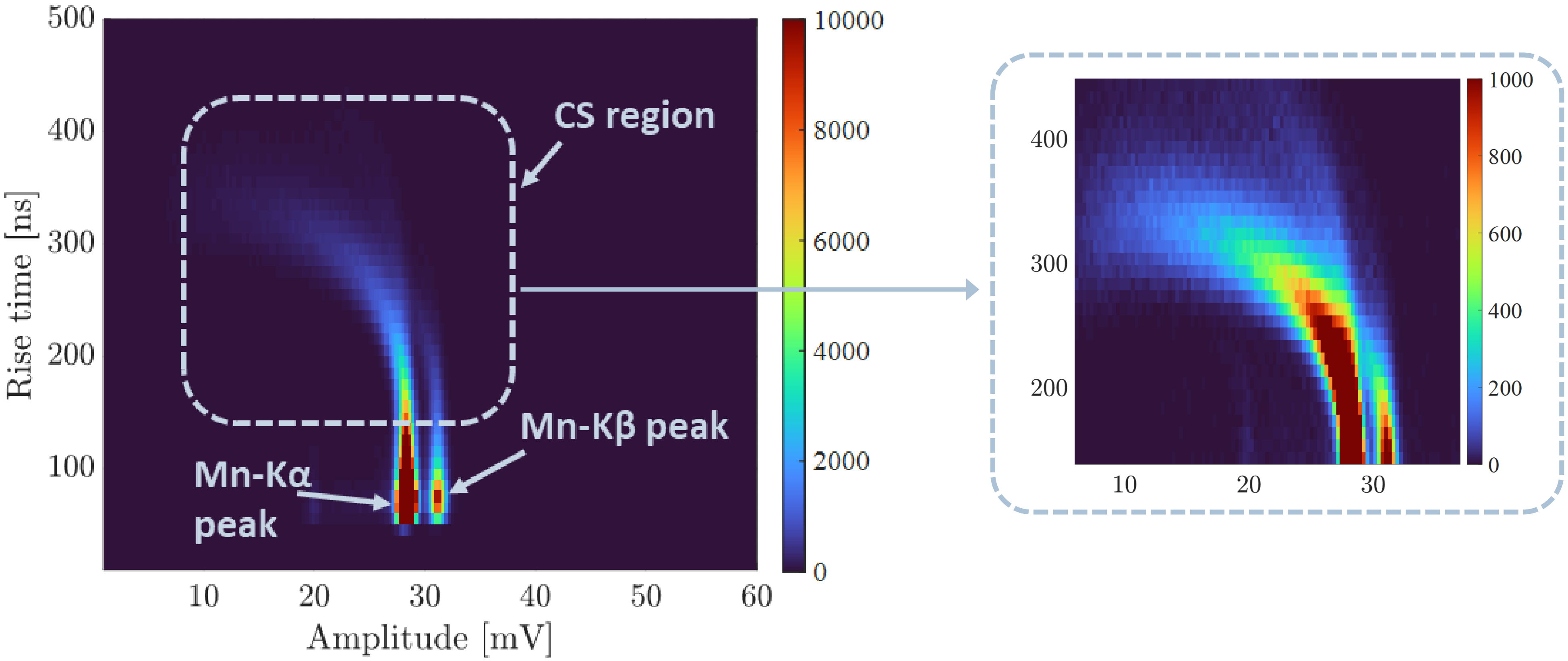




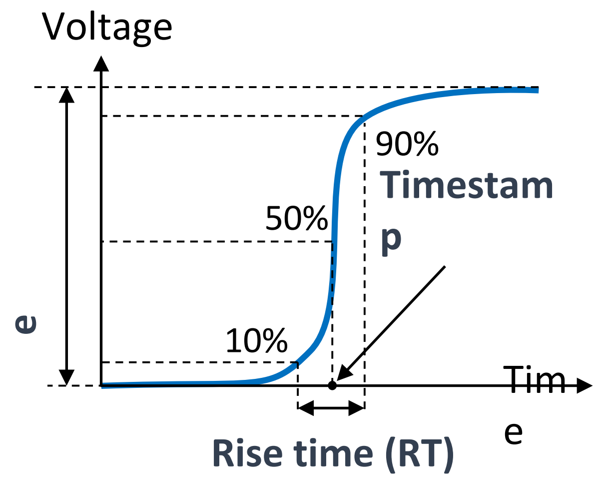
Charge Sharing Region: Amplitude vs. Rise Time

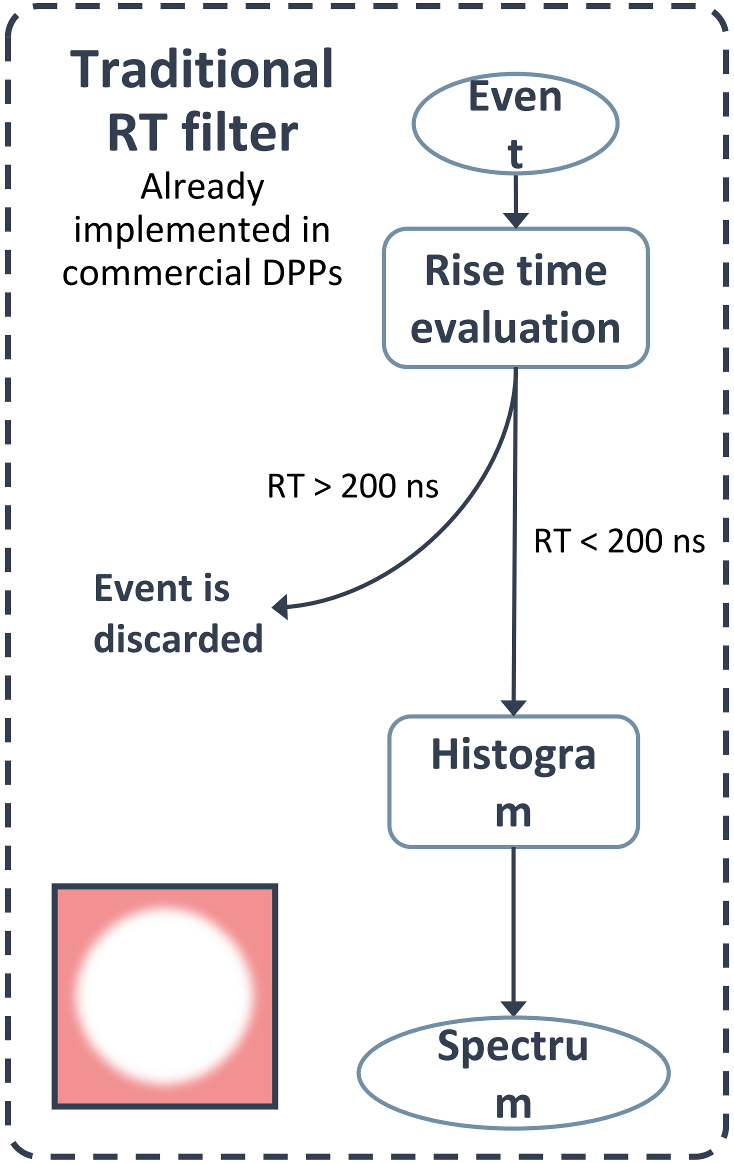
Characterization of SDD array response:

- Flood irradiation using uncollimated **^{55}Fe source**
- Acquisition of the **anode signals** using **oscilloscope**
- Similar correlation between amplitude and rise time found in CS events



Charge Sharing Reconstruction Algorithm





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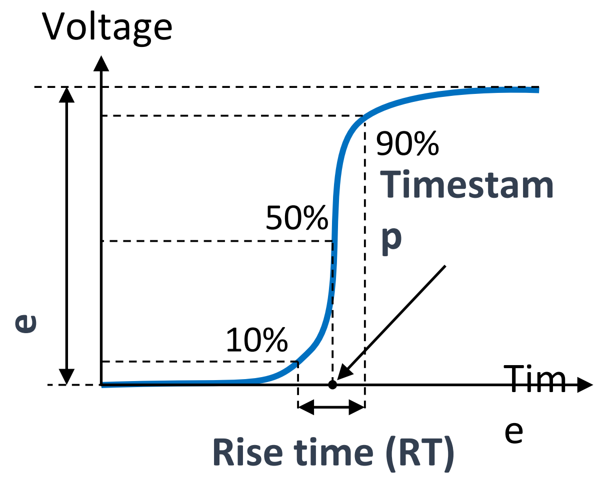
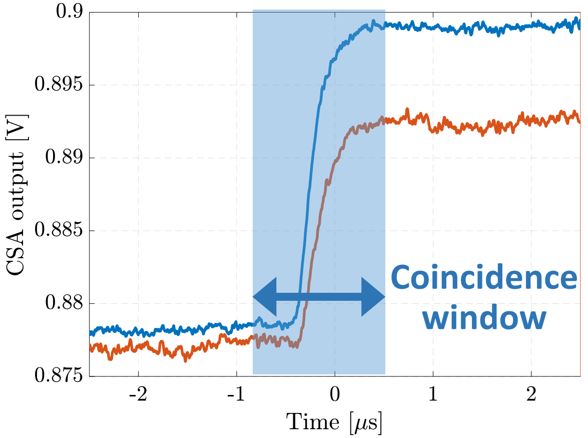
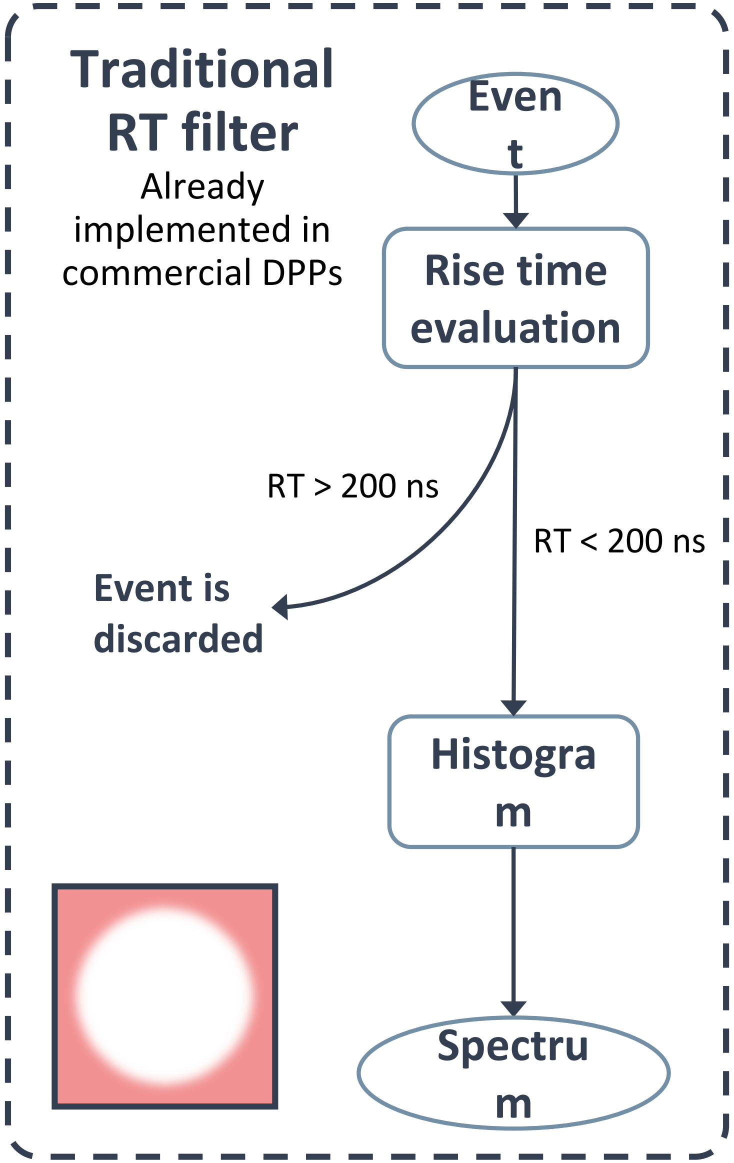
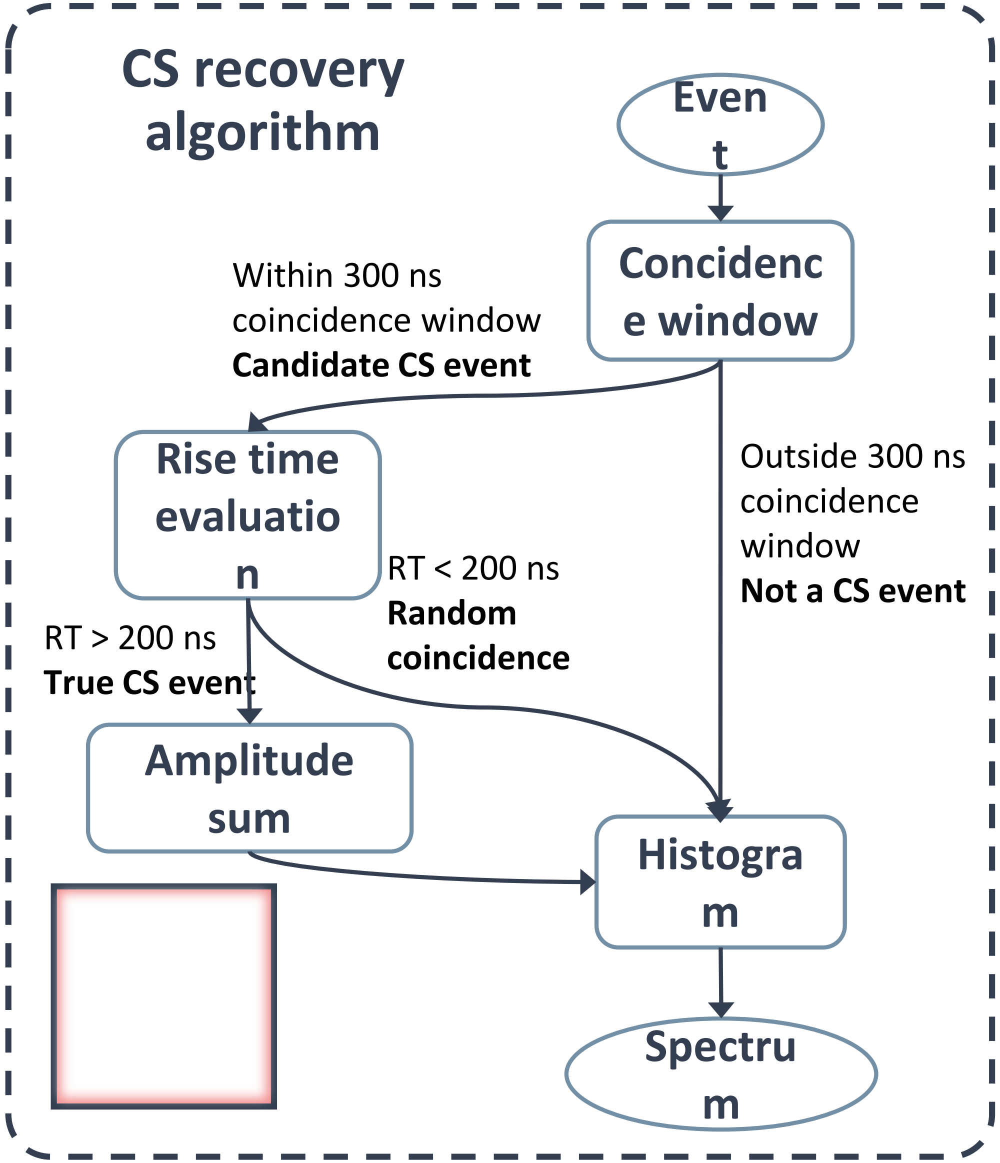
Charge Sharing Reconstruction Algorithm

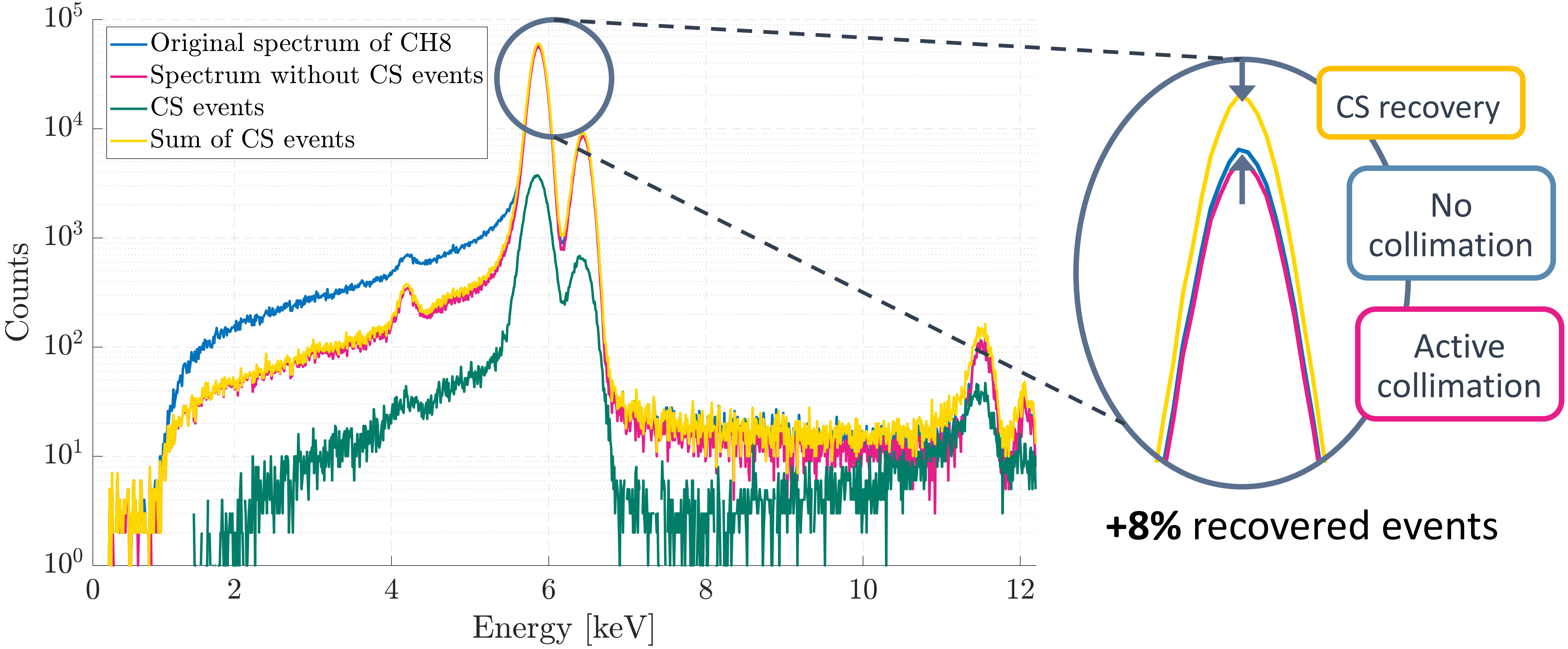








Active Collimation vs. CS Events Recovery



+8% recovered events

*300 ns coincidence window, 200 ns RT filter

Conclusions

- POLIMI is developing **multi-element X-ray spectrometers** based on monolithic arrays of SDDs, including the full electronic readout chain.
- One application is in fundamental physics experiments for x-ray/e^- precision spectroscopy, covering very large areas.
- Another applications is in synchrotron beamlines for high-count-rate measurements:
  - **ARDESIA-16** is ready to be used in different configurations.
  - **ASCANIO** spectrometer has been installed at DESY within 2025.
  - **ARDESIA-64** is currently being developed.
- **Active collimation** and **multi-channel electronics** are under study.
- POLIMI is available to develop/adapt spectrometer designs according to **specific experiment requests**.

Thank you for your attention!

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