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16-18 February 2021 - FBK, Trento

New multichannel modular detection system based on Silicon Drift Detectors

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UNIVERSITAS STUDIORUM UTINENSIS

RESEARCH DRIFT FOR SOFT X-RAYS redSOX

New multichannel modular detection system based on Silicon Drift Detectors

We present a detection system with high sensitivity and efficiency specially designed to exploit the potentials of X-ray absorption spectroscopy in fluorescence mode. It consists of 8 monolithic multipixel arrays, each with 8 (SDD) cells with a total area of 570 mm^2. Optimized to work in an energy range of 3-30 keV, this 64 channels integrated detection system includes ultra-low noise front-end electronics, dedicated acquisition system, digital filtering, temperature control and stabilization.
Room temperature characterization tests at Elettra Sincrotrone Trieste demonstrated very interesting results; they include an energy resolution at the Ka line of Mn (5.9 keV) below 170 eV FWHM. The system is now installed and operating at the XRF-XAFS beam-line of the SESAME Synchrotron light source in Jordan.

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ReDSoX (REsearch Drift for SOft X-rays) Collaboration

- Development of high energy resolution SDD for soft X-rays
- Evolution of SDD technology in collaboration with FBK CMM Trento
- Evolution of FE electronics in collaboration with PoliMI
- Development of large surface SDD for X-ray astrophysics
- Development of detection systems for Advanced Light Sources

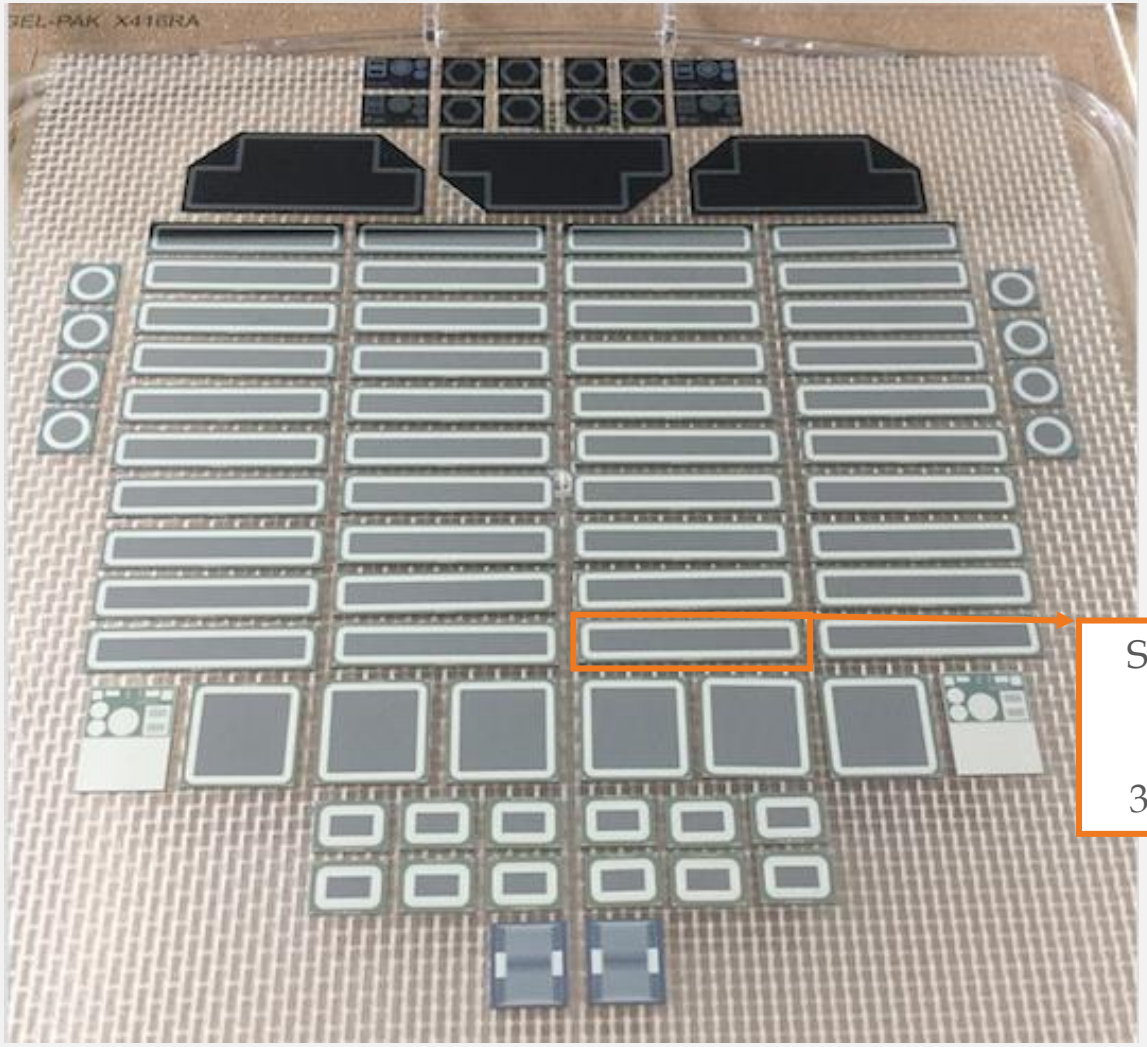
- External institutions involved: FBK-CMM (Trento), Elettra - Sincrotrone Trieste, IASF-BO, INAF-IAPS-ROMA, PoliMI, ICTP Trieste
- INFN groups: Trieste, TIFPA, Bologna, ROMA2, Milano, Pavia
- Principal Investigator: Andrea Vacchi

RESEARCH DRIFT FOR SOFT X-RAYS redSoX

Scientific and technological applications of SDD

- X-ray Astrophysics
- Gamma-ray Astrophysics
- Advanced Light Sources
- Biophysics
- Medicine
- Nanotechnology
- Materials science
- Industry
- Cultural heritage

SESAME Wafer - SDD

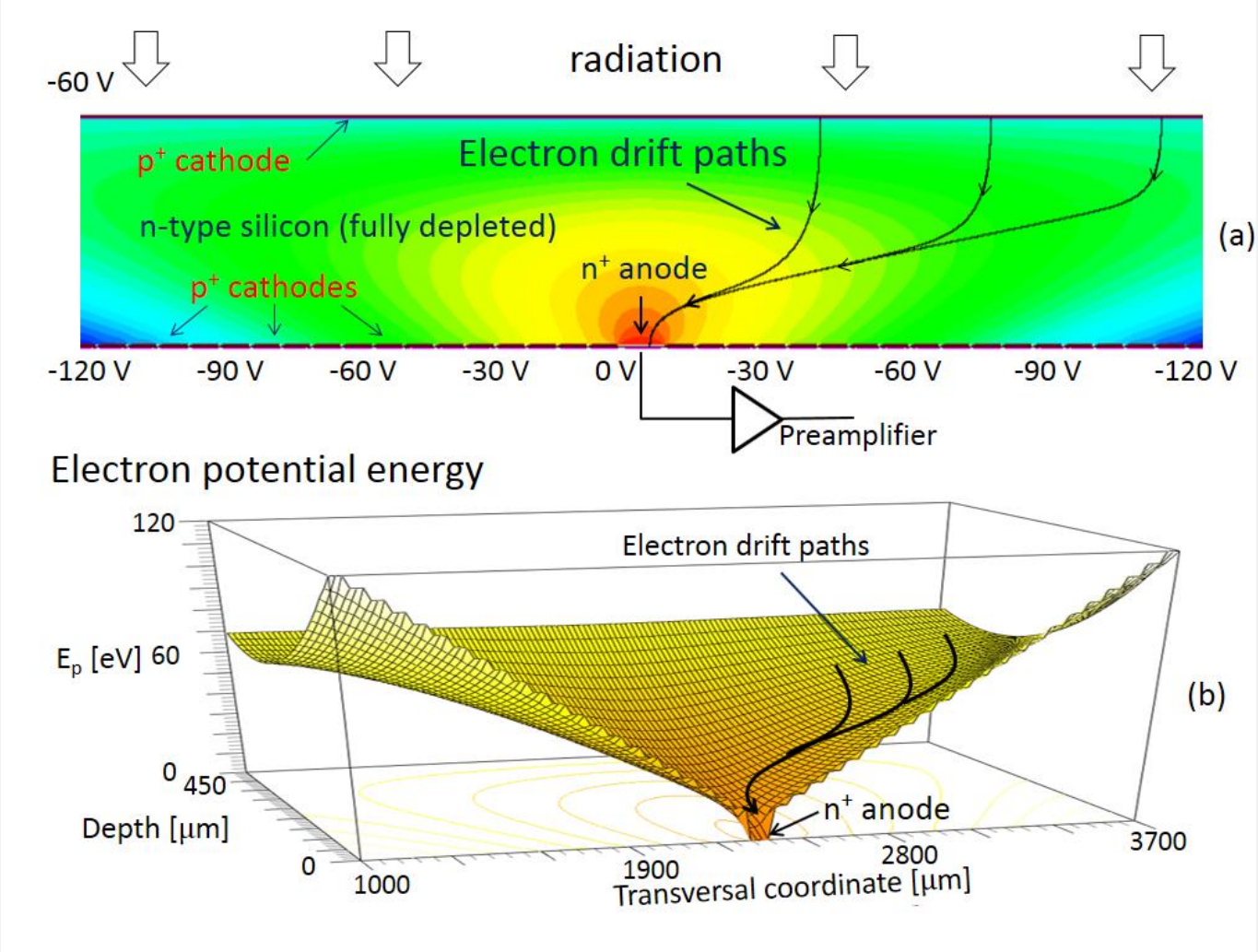


Ongoing developments: from prototypes to detectors

Improvement and detailed study to have:

- **Detector optimization**
- Excellent energy resolution performances at room temperatures
- Dedicated design of sensors and electronics for each application
- Reliability
- Repeatability

Section of SDD sensor and potential energy of the electrons



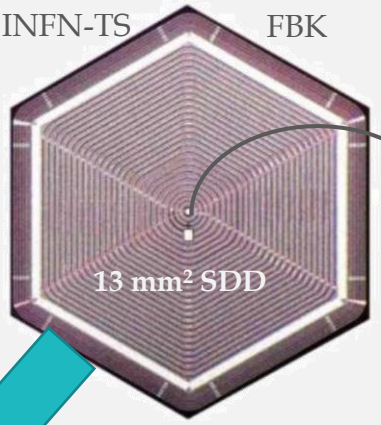
G. Bertuccio, et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 63, NO. 1, FEBRUARY 2016

SIRIO: Ultra Low Noise CMOS Charge Sensitive Preamplifier

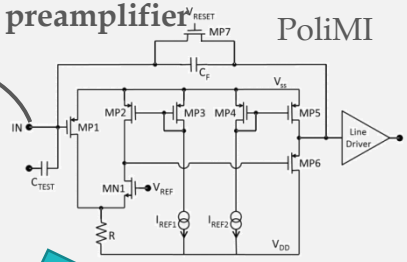
Very-low leakage current production process was developed at FBK

- Typical: < 150 pA/cm^2
- Minimum: 25 pA/cm^2

INFN-TS FBK

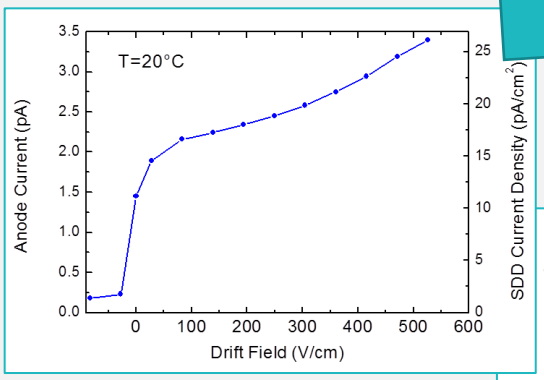


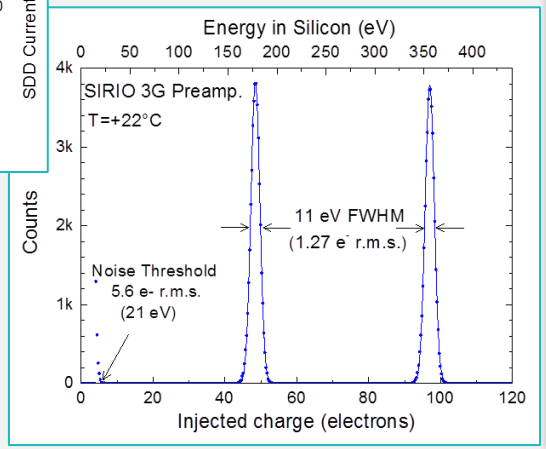
SIRIO preamplifier PoliMI

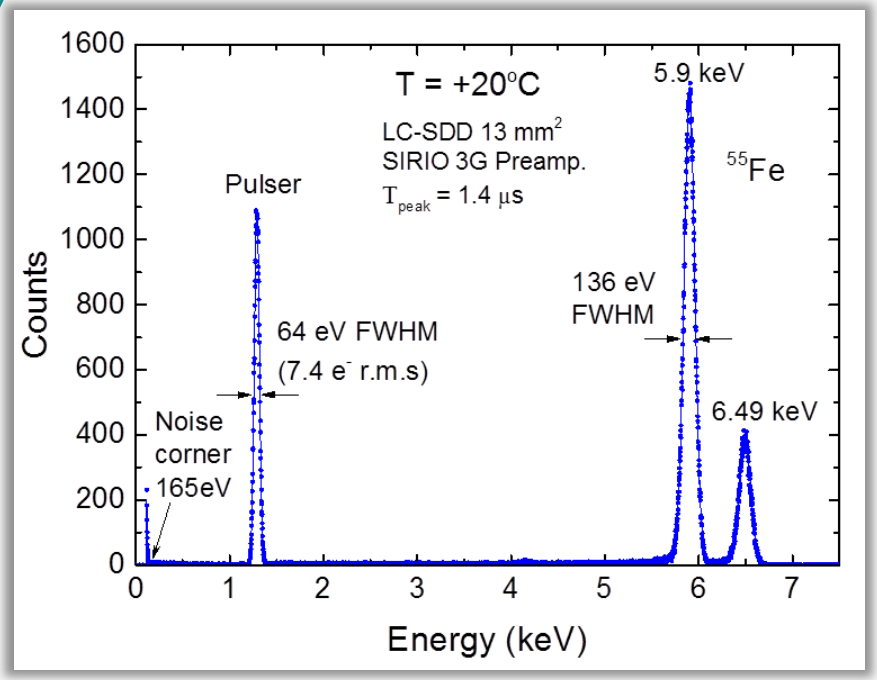


Low-power and very-low noise optimized preampl. in sub-micron technology

- Power: 10 mW including the output buffer
- ENC of 1.27 e$^-$ r.m.s. at 20 °C



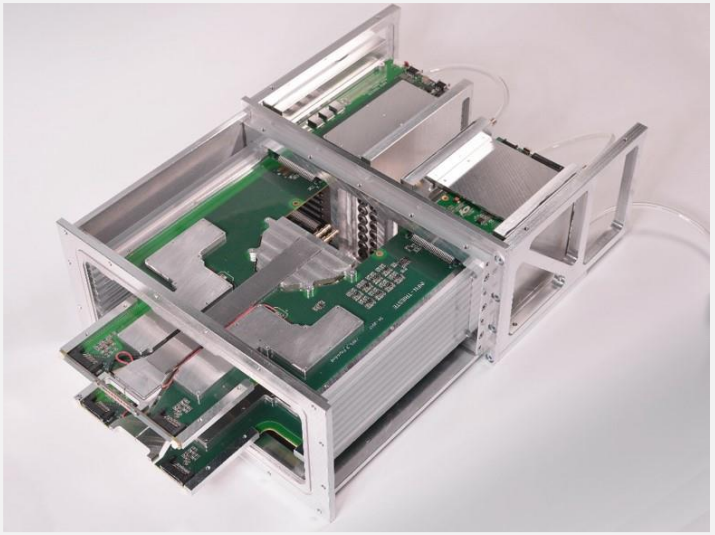


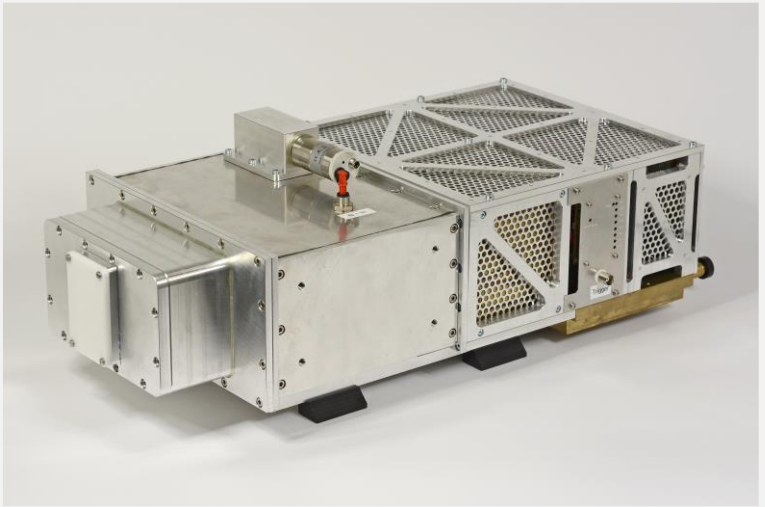


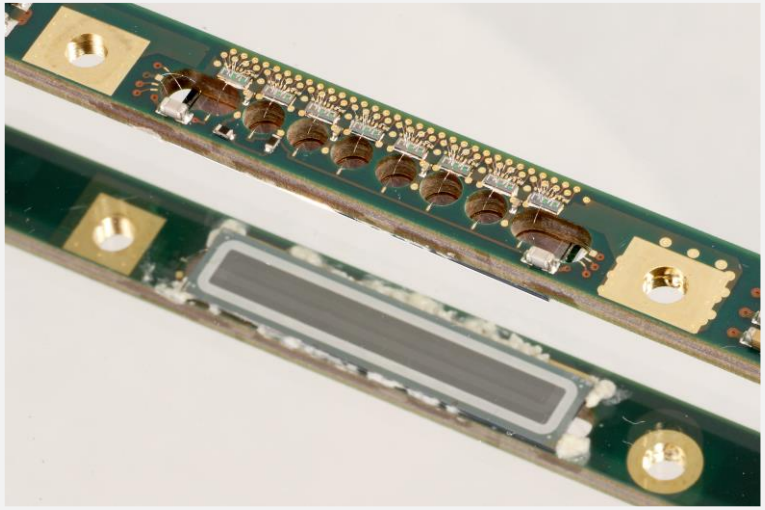
G. Bertuccio, et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 63, NO. 1, FEBRUARY 2016

64-channel XAFS-SESAME Detection System for XRF-XAFS Beamline of SESAME

XAFS-SESAME Detection System



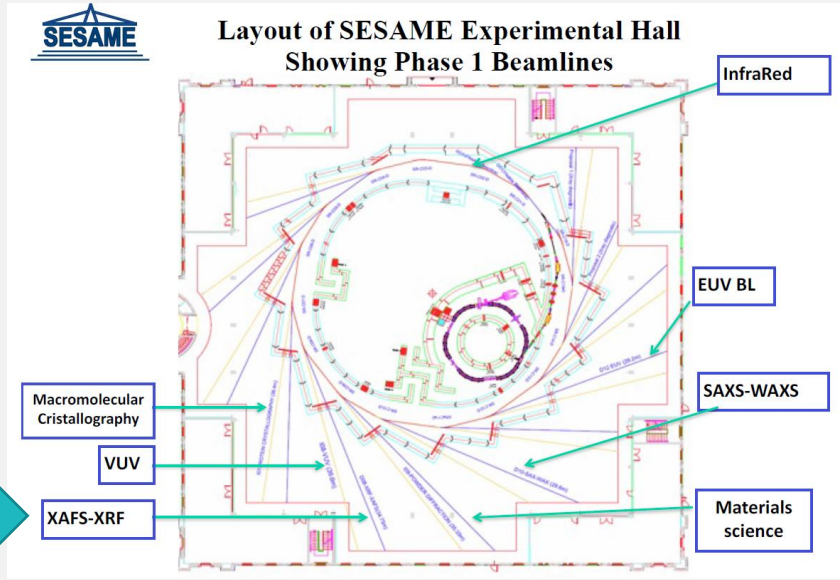




Synchrotron-Light for Experimental Science and Applications in the Middle East (Jordan)
http://www.sesame.org.jo/sesame_2018/

SESAME: Synchrotron-Light for Experimental Science and Applications in the Middle East (Jordan)

SESAME

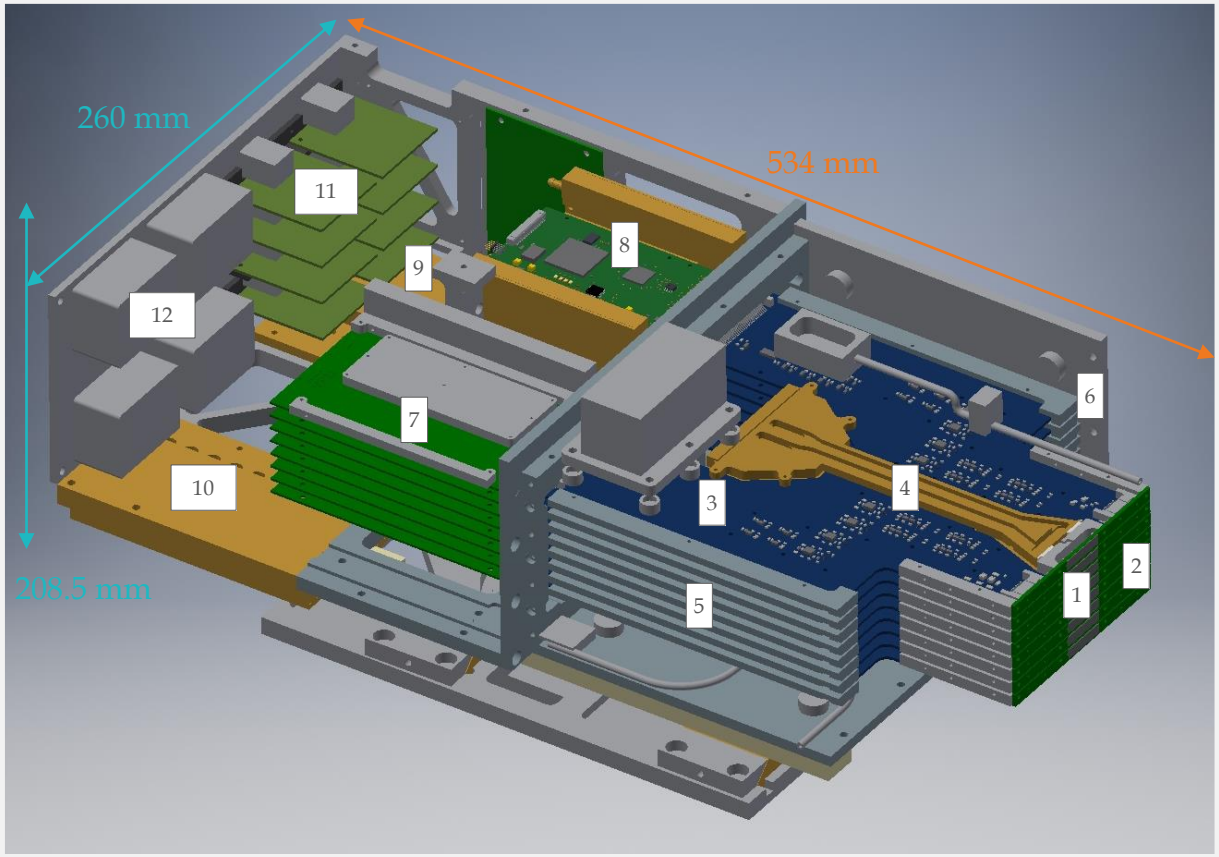


XAFS-XRF Beamline

XAFS-SESAME Detection System

Description

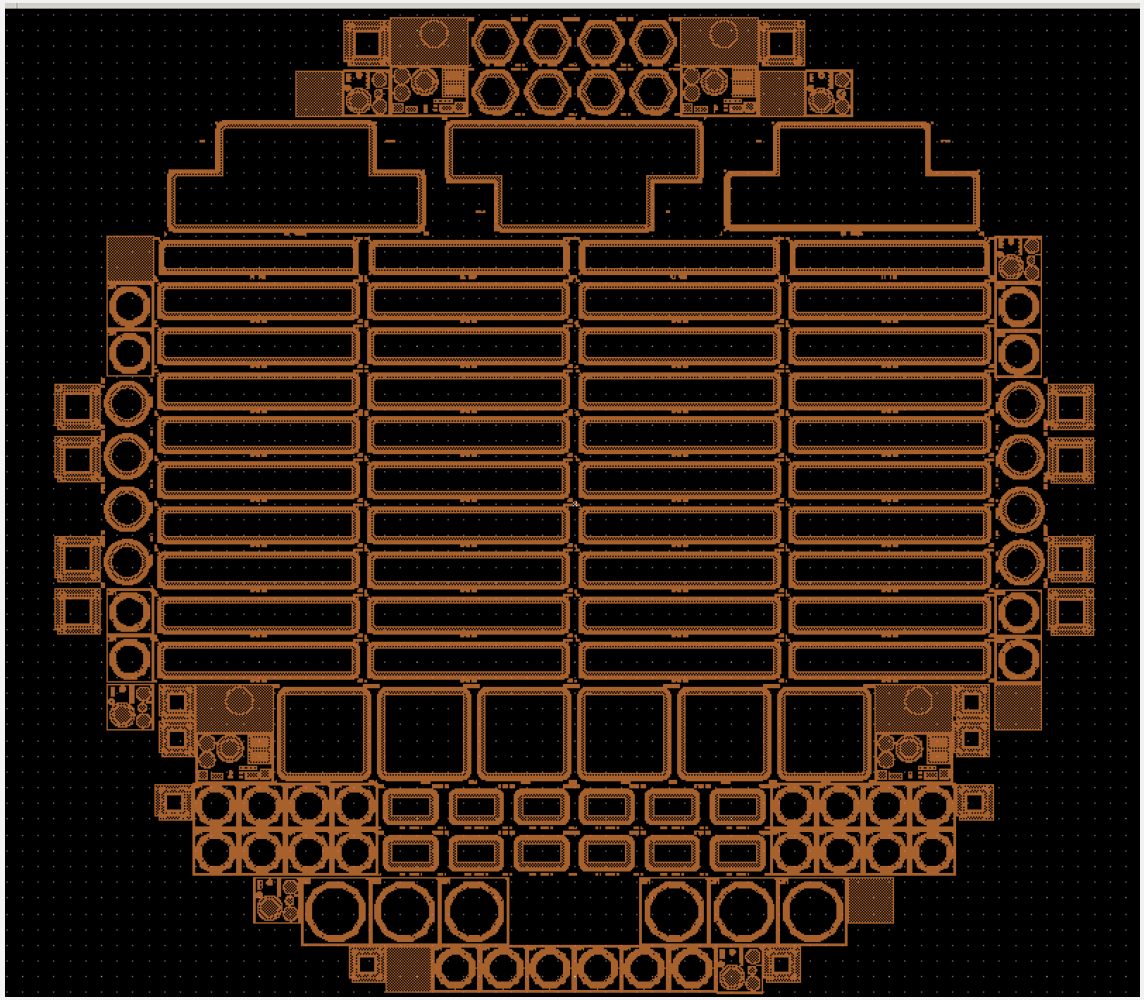
XAFS-SESAME 64-channels SDD Detection System



1. Sensors
2. Detector PCBs
3. Front-End PCBs
4. Brass profile with cooling liquid flowing inside
5. Insertion guides at flanks of detecting heads
6. Rails for eight detection heads
7. Power supply and filters PCBs
8. Back-End PCBs
9. Cooling distribution inlet
10. Cooling distribution outlet
11. Ethernet PCBs
12. Power supply connectors

A. Rachevski, et al., NIMA, 2019, 936: 719-721 & D. Cirrincione, Il nuovo cimento C 42.5 (2019): 1-8

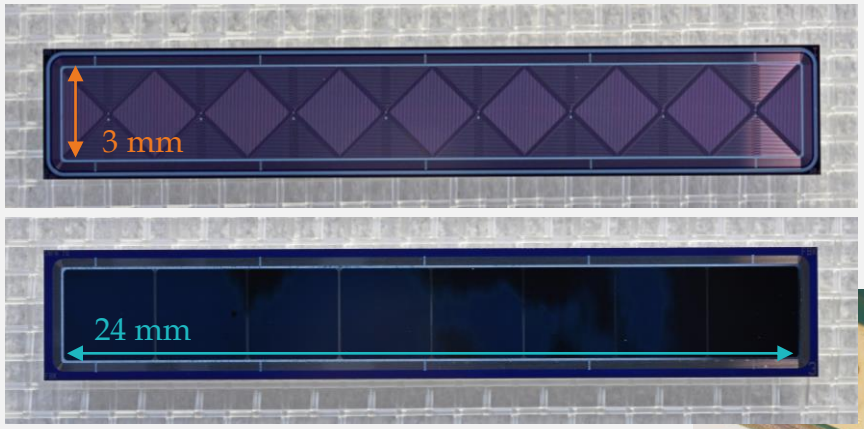
SESAME SDDs - 8 cells 3x3 mm^2

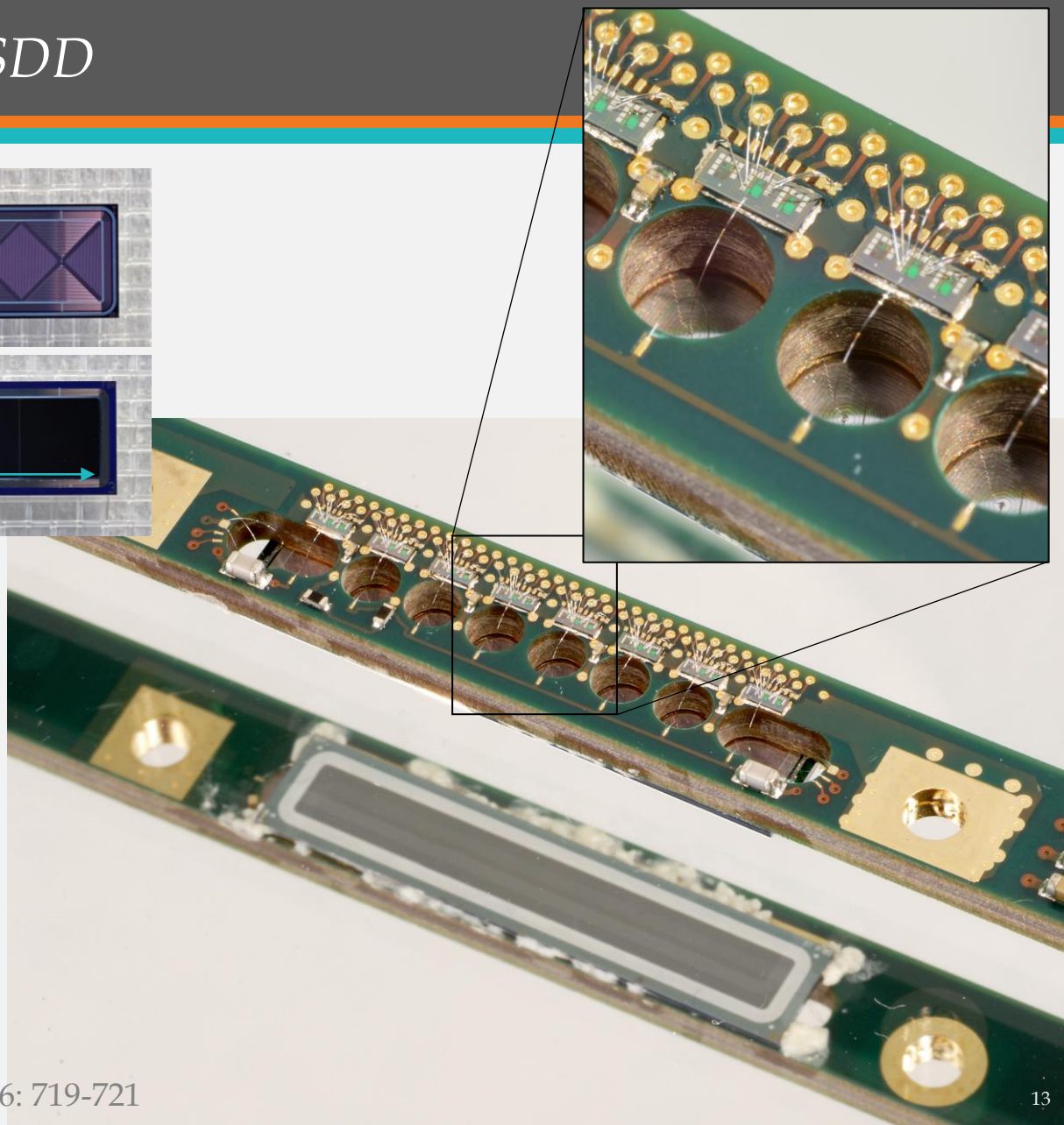


SDDs testing and selection

- Electrical characterization of sensors. Definition of the Bias voltage for the whole system.
- Selection of sensors with uniformity Bias characteristics.
- Sensor test with 18 needles Probe Card. Selection of the sensors with anode current less then 10 pA at 20 °C (111pA/cm^2).

Strip: 8 channels SDD



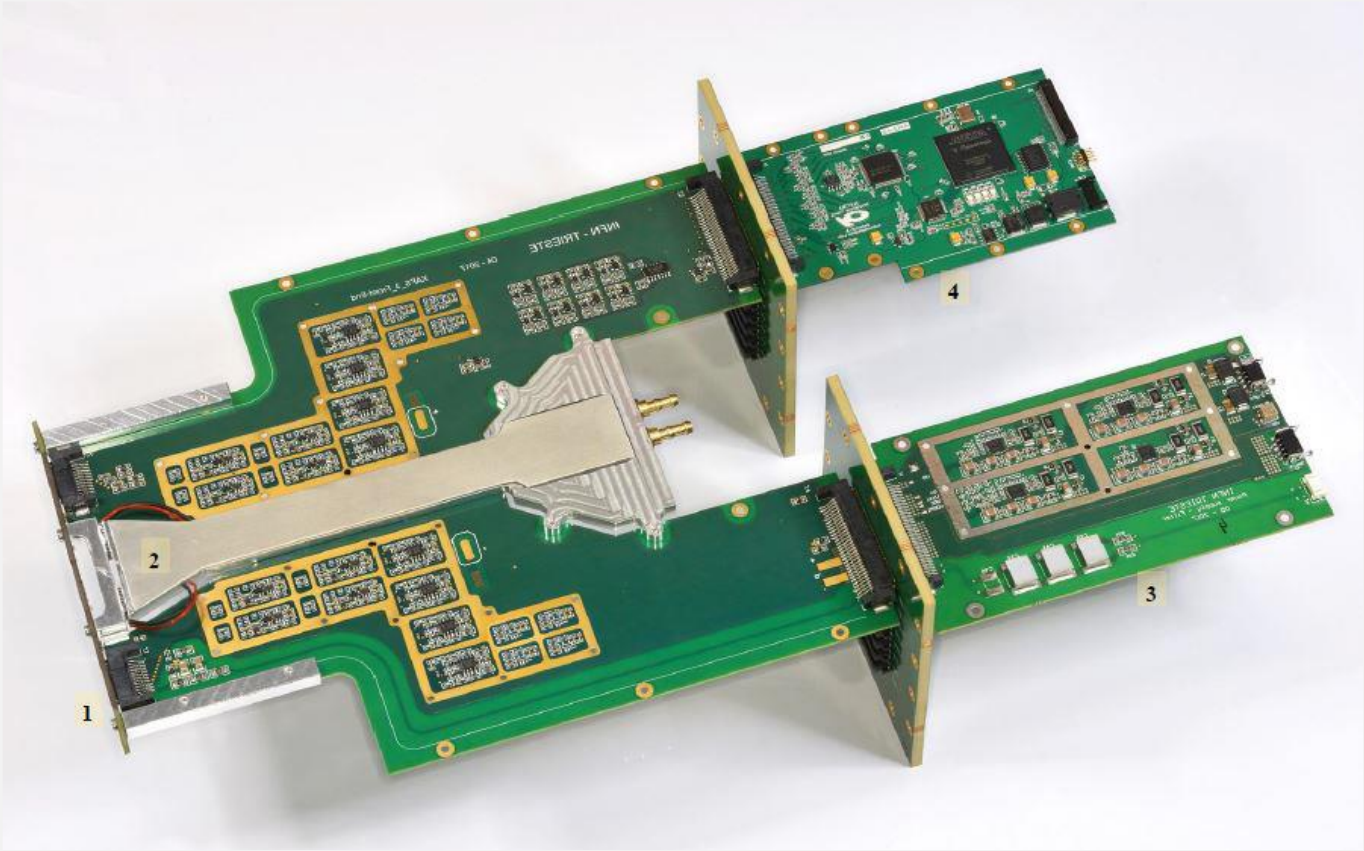


- Sensors: SDD (linear array comprising 8 square cells with a 3 x 3 mm^2 active area)
- Preamplifier: SIRIO (SFS3)
- Detector PCB

A. Rachevski, et al., NIMA, 2019, 936: 719-721

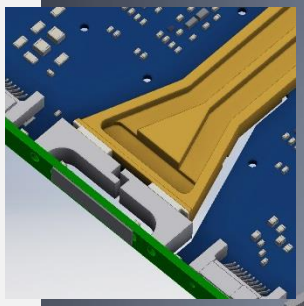
Plane

1. *Strip* (SDD+SIRIO+PCB detector)
2. Front-End PCB
3. Back-End PCB
4. Power supply and filters PCB
5. Interface connectors

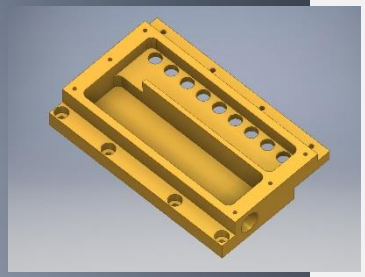


Temperature stabilization system

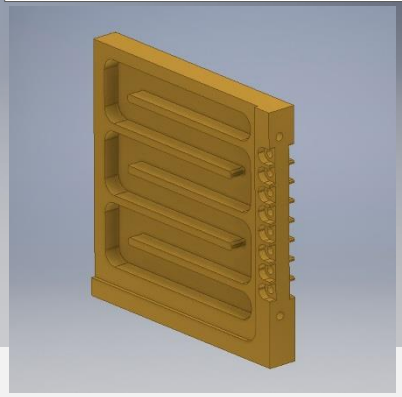
1 - Brass profile and peltier cells



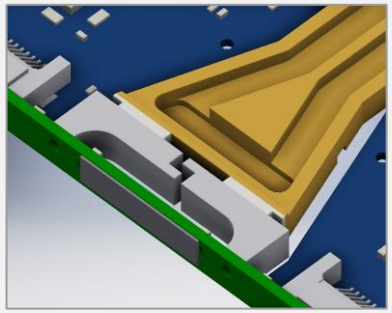
2 - Inlet and outlet of cooling distribution

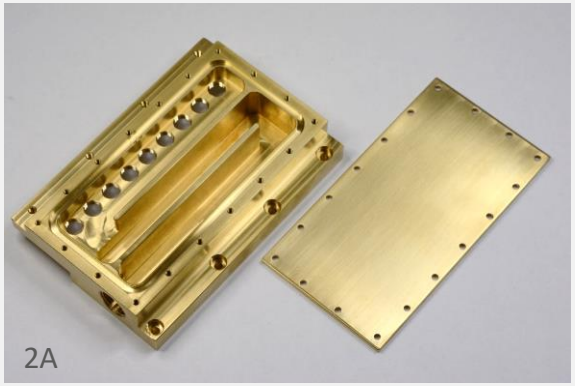


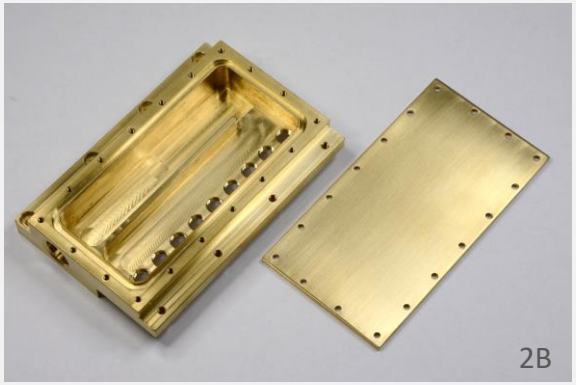
3 – Back-end exchangers

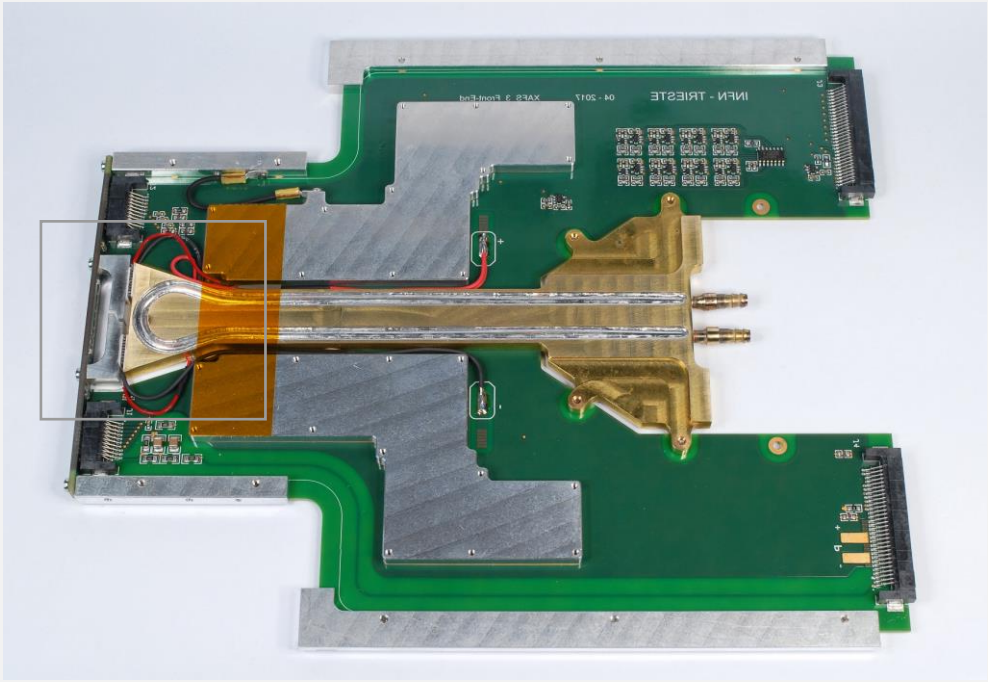


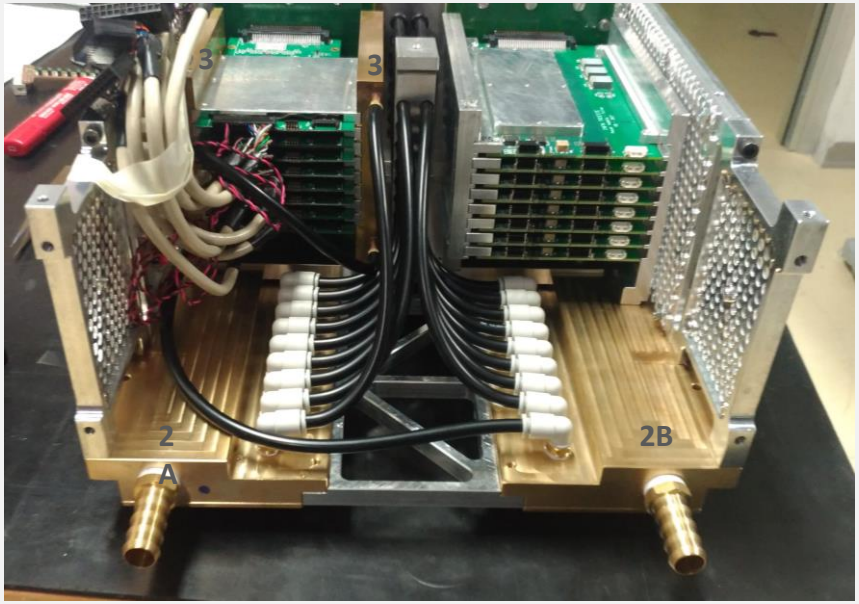
Temperature stabilization system



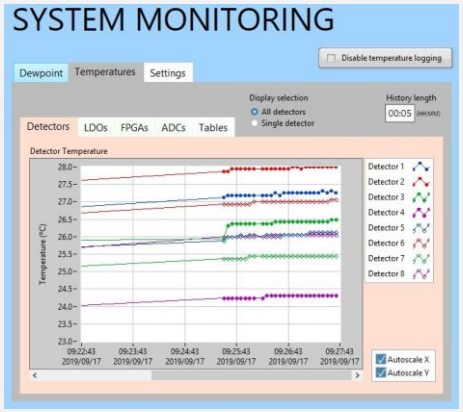


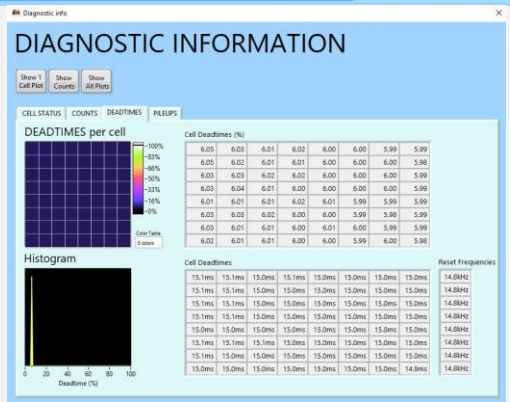


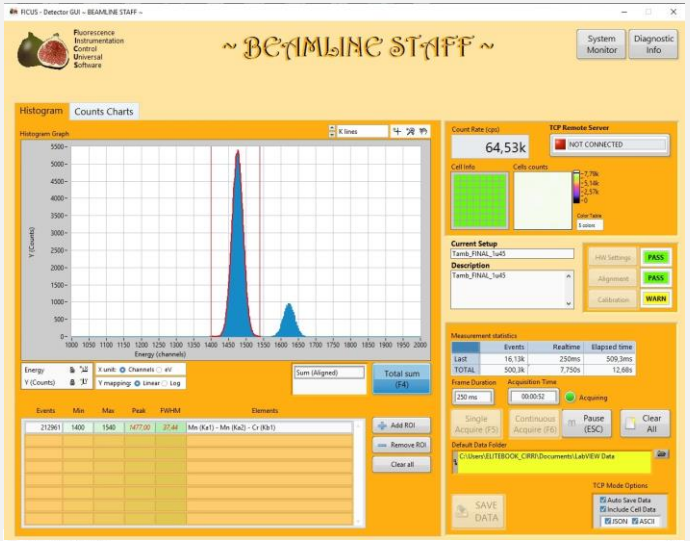


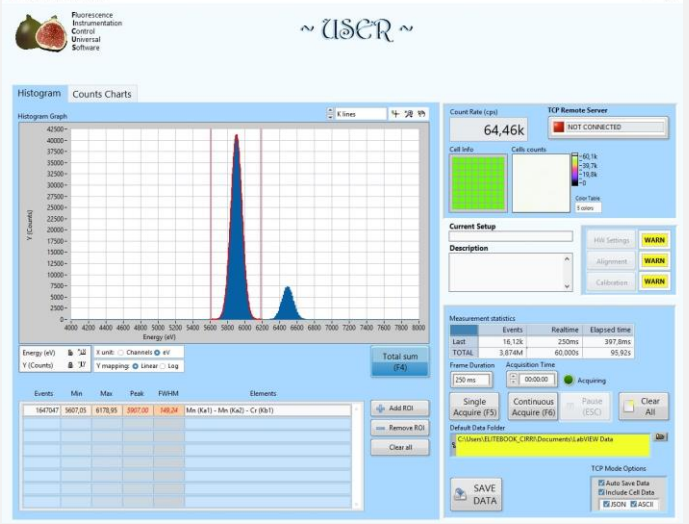


Dedicated Acquisition System: Fluorescence Instrumentation Control Universal Software (FICUS)







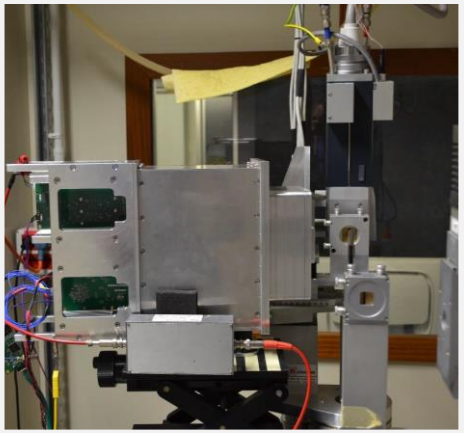


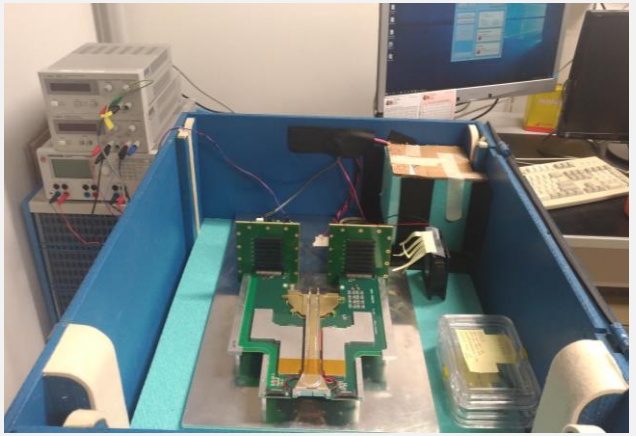
XAFS-SESAME Detection System

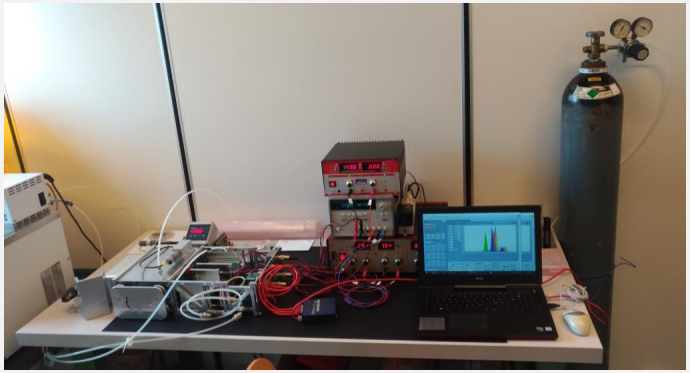
Characterization and results

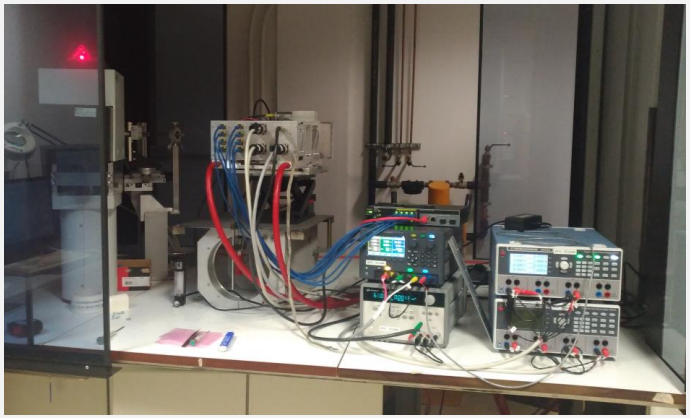
Tests with X-ray sources

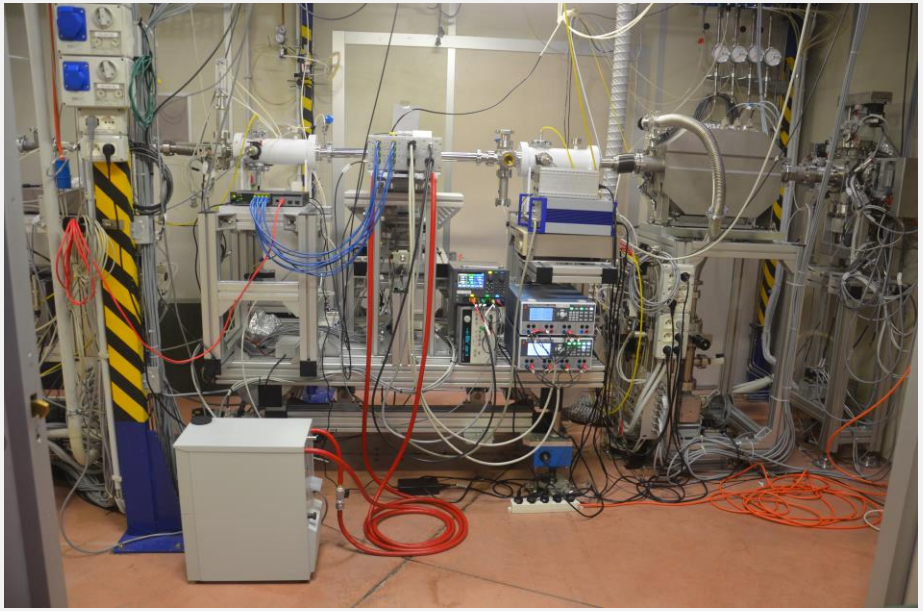
- ^{55}Fe
- Ag anode X-ray tube
- Cu rotating anode X-ray tube
- Synchrotron light



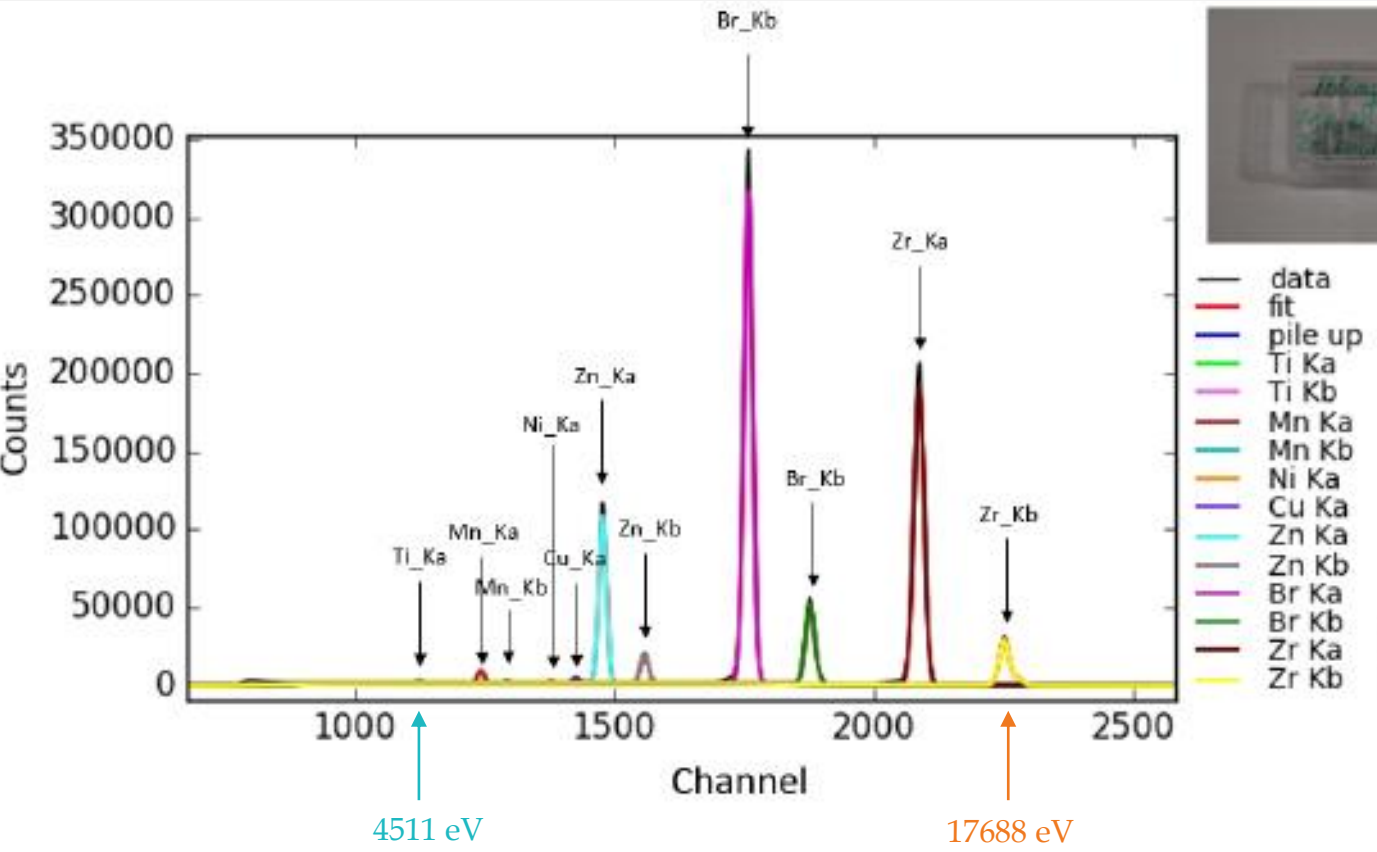




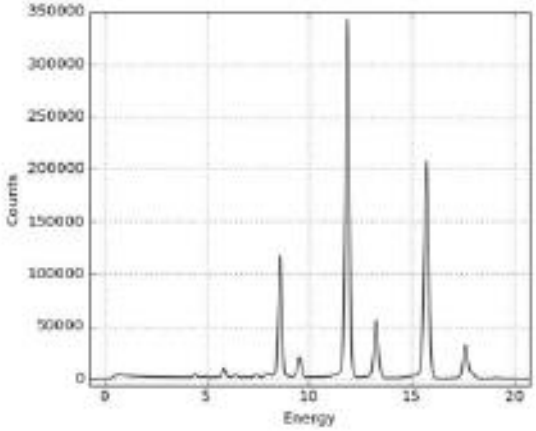




Calibration sample (Zr, K, Br, Zn, Mn, Ti)

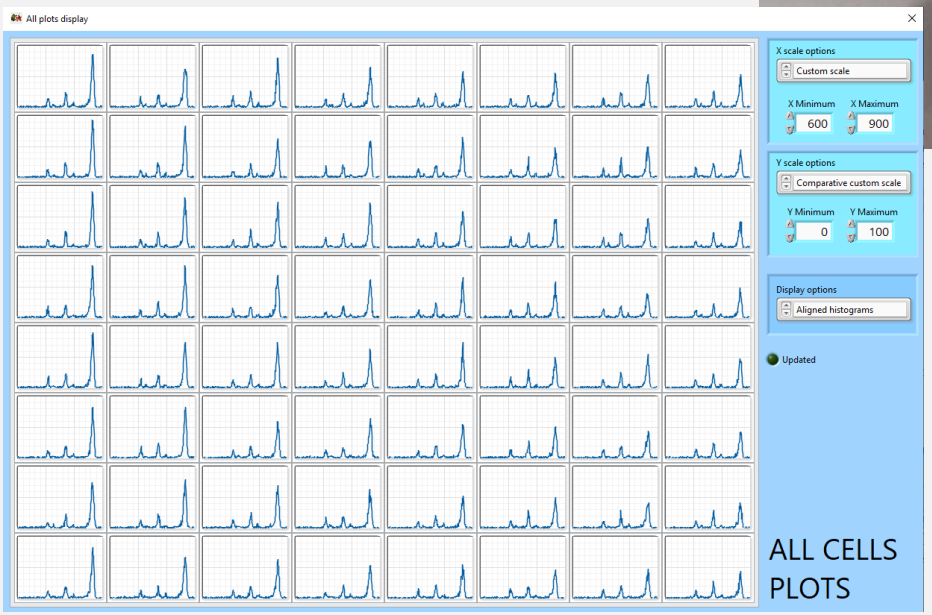


Kα Ti – 4511 eV
Kβ Ti – 4932 eV
Kα Mn – 5899 eV
Kβ Mn – 6490 eV
Kα Ni – 7478 eV
Kα Cu – 8048 eV
Kα Zn – 8639 eV
Kβ Zn – 9572 eV
Kα Br – 11924 eV
Kβ Br – 13291 eV
Kα Zr – 15775 eV
Kβ Zr – 17668 eV



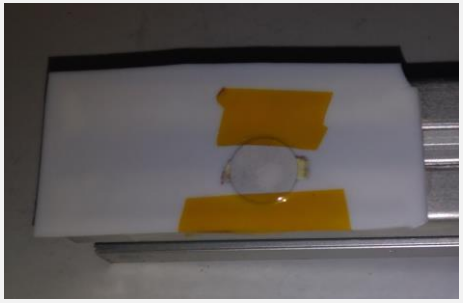
Complete XAFS-SESAME Detection System

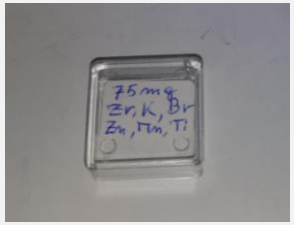
- 8 strips
- 64 channels
- 576 mm^2 active area



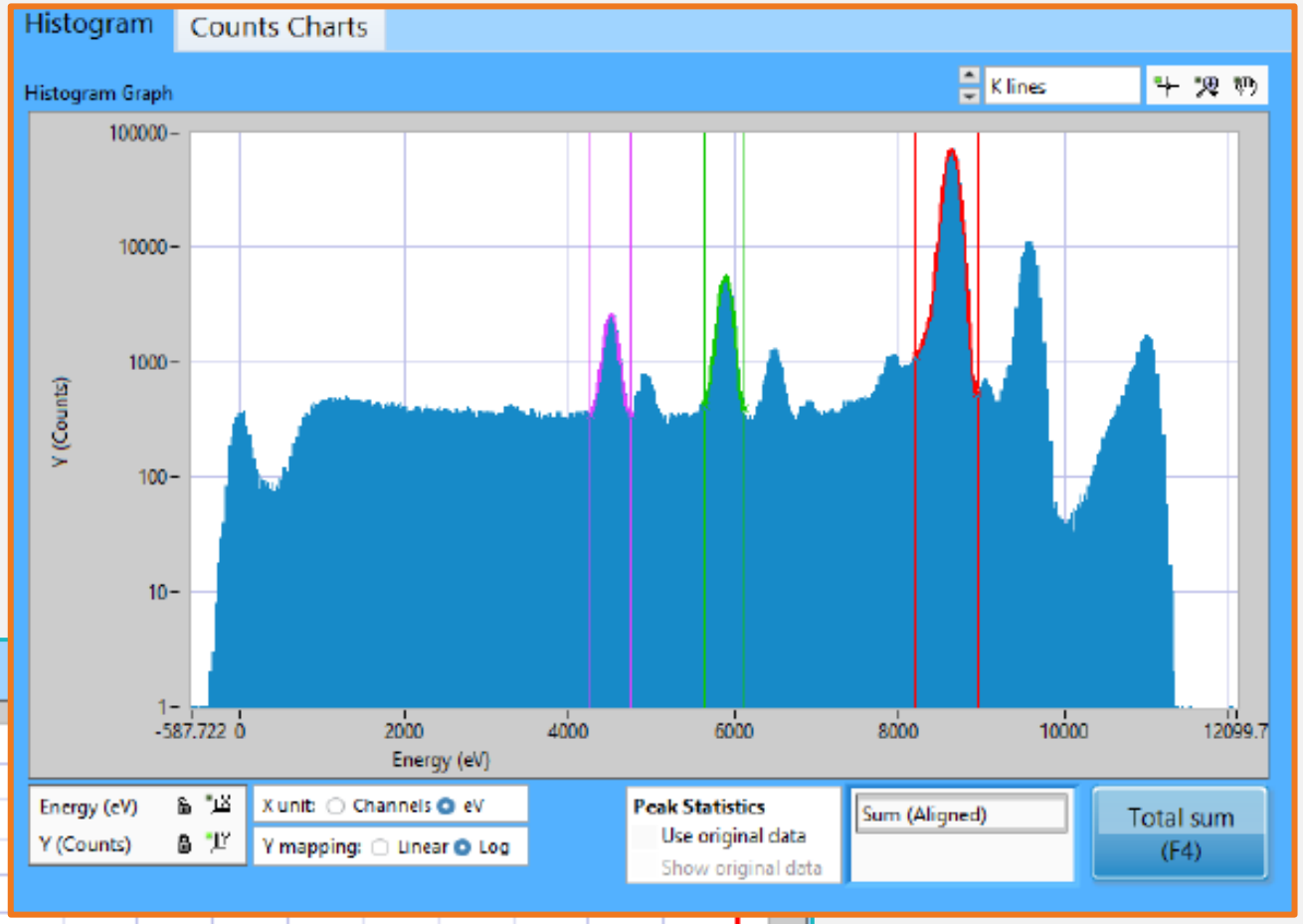
IP Address	Port	Status	Unique Part Identifier
192.168.1.1	10001	ENABLED	SDD_STRIP_012
192.168.2.2	10002	ENABLED	SDD_STRIP_020
192.168.3.3	10003	ENABLED	SDD_STRIP_016
192.168.4.4	10004	ENABLED	SDD_STRIP_014
192.168.5.5	10005	ENABLED	SDD_STRIP_015
192.168.6.6	10006	ENABLED	SDD_STRIP_021
192.168.7.7	10007	ENABLED	SDD_STRIP_022
192.168.8.8	10008	ENABLED	SDD_STRIP_018

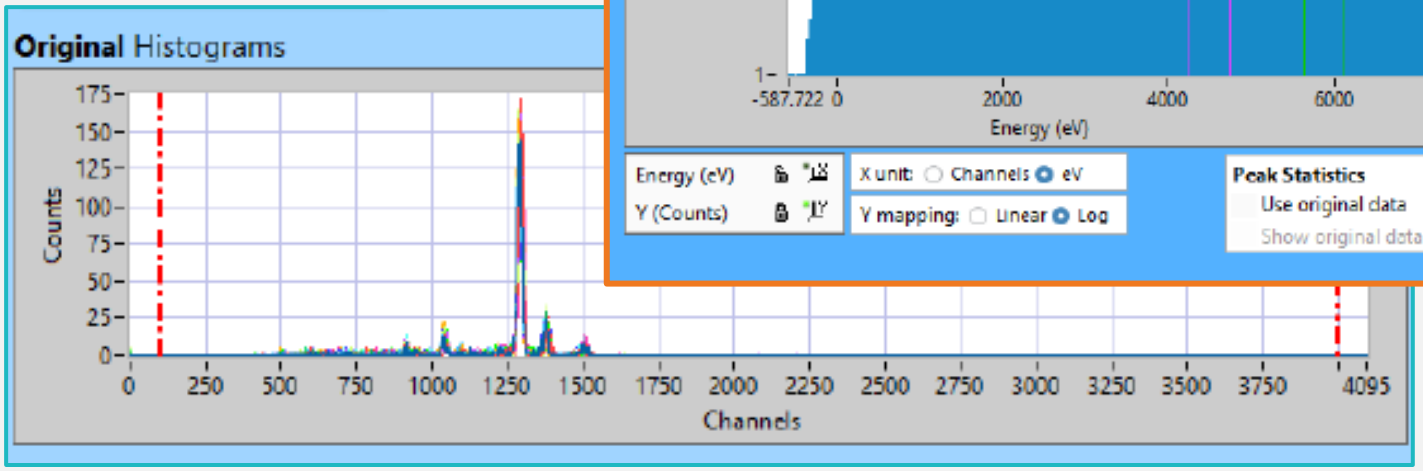
Sum of 64 channels – Calibration sample



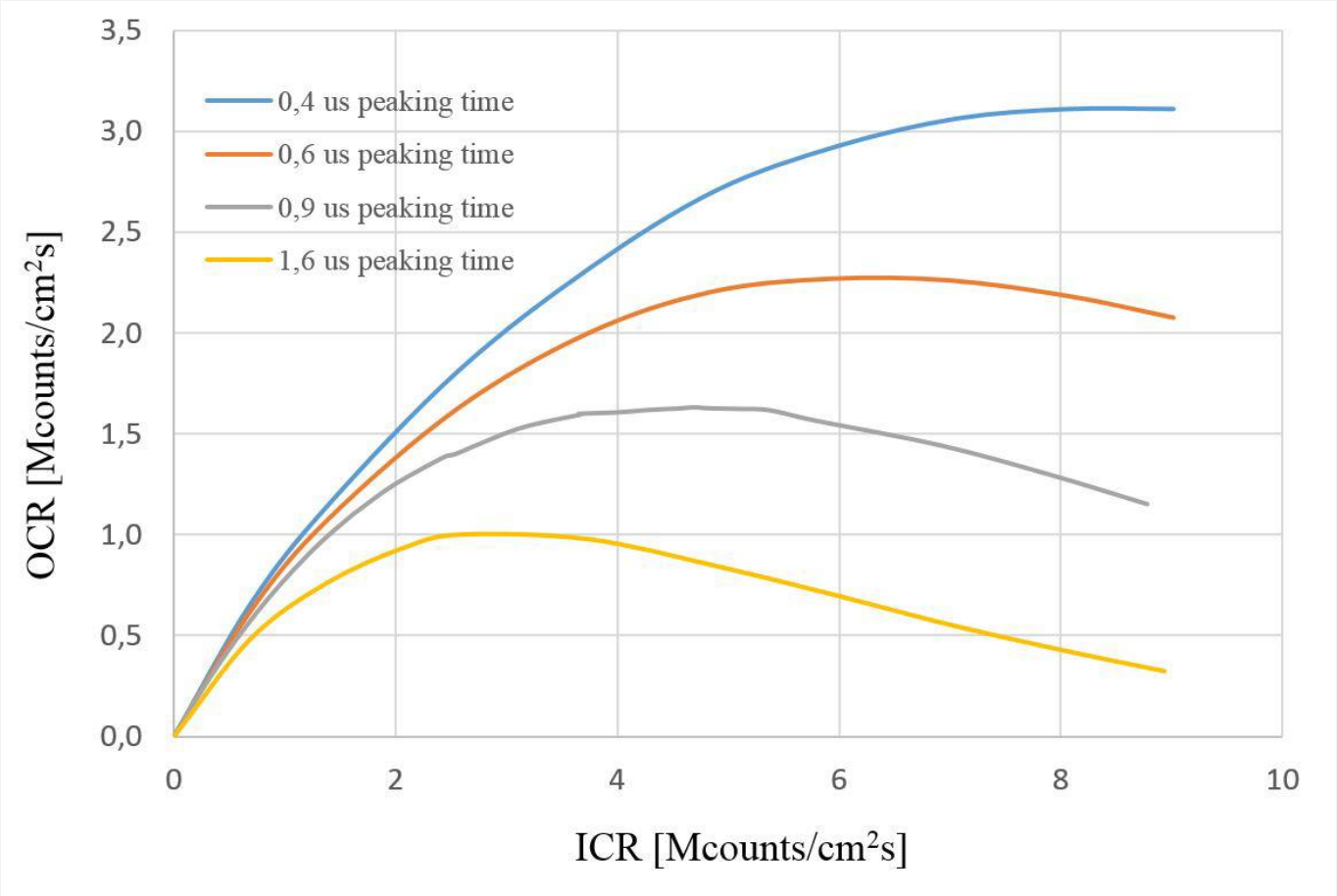


Calibration sample
(Zr, K, Br, Zn, Mn, Ti)





Output count-rate (OCR)



Output count-rate (OCR) versus input count-rate (ICR), obtained with different peaking times ranging from 0.4 to 1.6 µs. Test with 13 active cells to confirm the ability of the new system to work at high input count-rates (ICR) while maintaining low dead time and good energy resolution. This translates into an output count-rate (OCR) of **15.5 Mcount/s for the entire 64 elements detector**.

J. Bufon, et al., AIP Conference Proceedings. AIP Publishing LLC, 2019, p. 060061

System at different temperatures

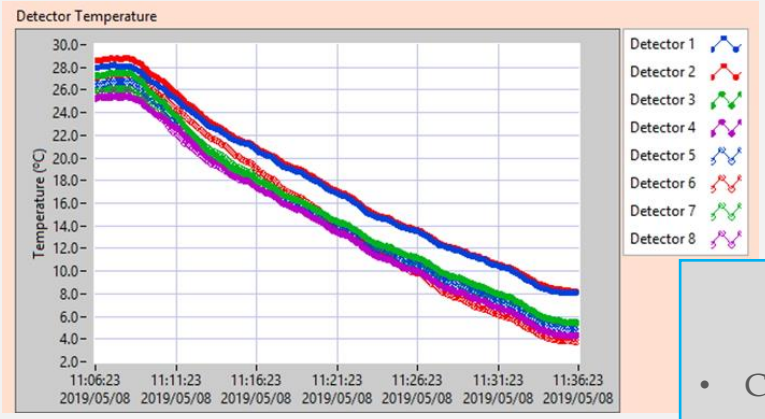
Mode select: Last value

Detector	LDO	FPGA	ADC
Detector 1	27.81 °C	43.56 °C	35.81 °C	32.06 °C
Detector 2	28.50 °C	43.12 °C	35.87 °C	33.06 °C
Detector 3	27.12 °C	40.50 °C	35.94 °C	32.75 °C
Detector 4	24.75 °C	44.81 °C	36.25 °C	32.87 °C
Detector 5	26.75 °C	42.81 °C	34.75 °C	32.50 °C
Detector 6	27.50 °C	43.25 °C	35.19 °C	31.69 °C
Detector 7	25.87 °C	42.25 °C	35.94 °C	32.06 °C
Detector 8	26.75 °C	42.94 °C	35.25 °C	33.25 °C

Tamb

- Chiller (18 °C)
- Nitrogen fluxing

With relative settings: filters, baselines, and thresholds for every channel



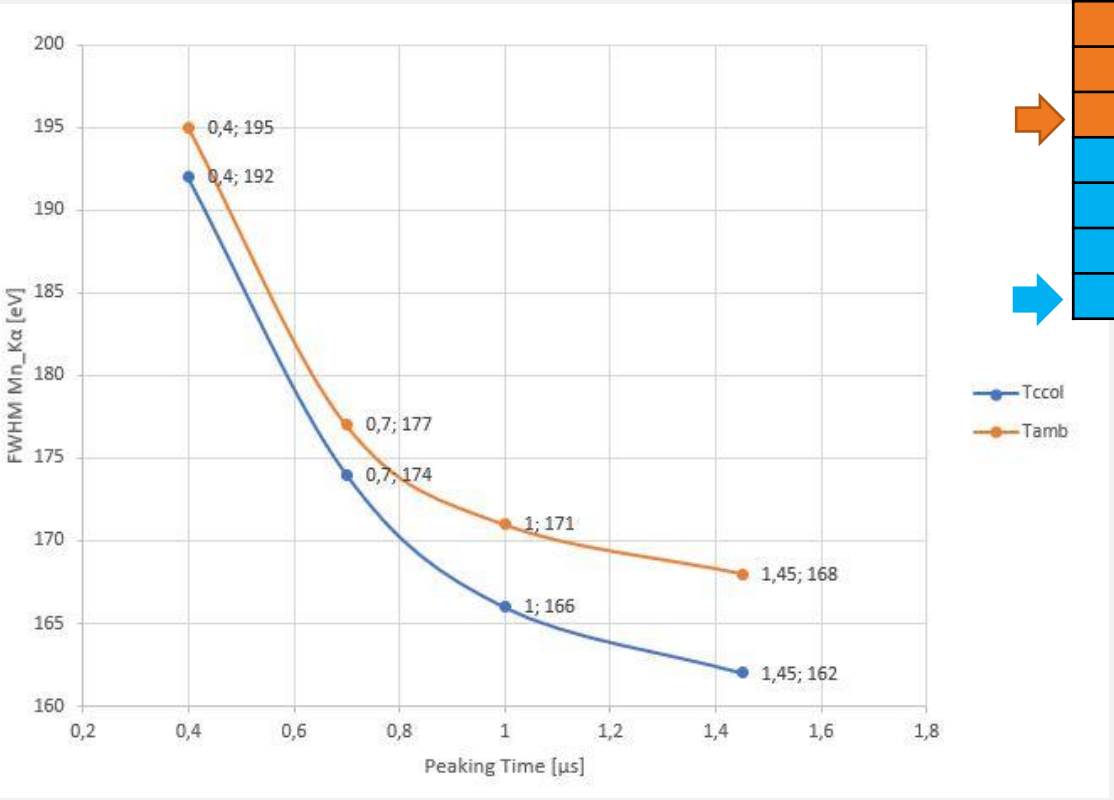
Tcool

- Chiller (18 °C)
- Nitrogen fluxing
- Peltier cells

Mode select: Last value

Detector	LDO	FPGA	ADC
Detector 1	7.75 °C	48.00 °C	38.25 °C	33.56 °C
Detector 2	8.37 °C	47.44 °C	38.31 °C	34.69 °C
Detector 3	5.31 °C	44.12 °C	38.12 °C	34.37 °C
Detector 4	3.37 °C	49.00 °C	38.50 °C	34.44 °C
Detector 5	4.94 °C	46.69 °C	36.87 °C	33.81 °C
Detector 6	4.50 °C	47.06 °C	37.75 °C	33.44 °C
Detector 7	5.69 °C	46.25 °C	38.50 °C	33.56 °C
Detector 8	6.56 °C	47.12 °C	37.87 °C	34.75 °C

Acquisitions with the complete detection system at different peaking time and temperature



Temperature	FWHM Mn kα [eV]	Peaking time [µs]	(P/B) RATIO
Tamb	195	0,4	26,5
Tamb	177	0,7	28,5
Tamb	171	1,0	28,0
Tamb	168	1,45	26,6
Tcool	192	0,4	28,7
Tcool	174	0,7	30,1
Tcool	166	1,0	30,9
Tcool	162	1,45	29,2

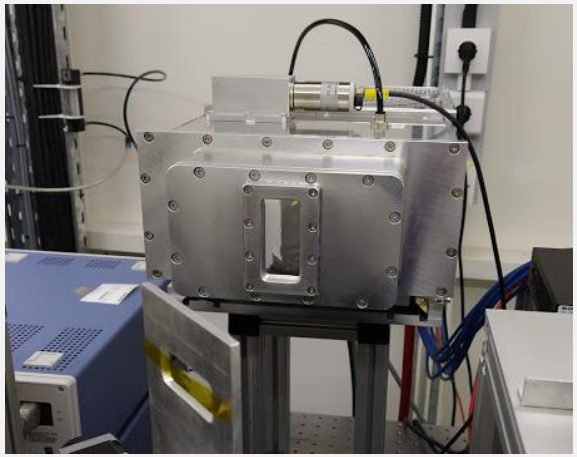
Mode select: Last value

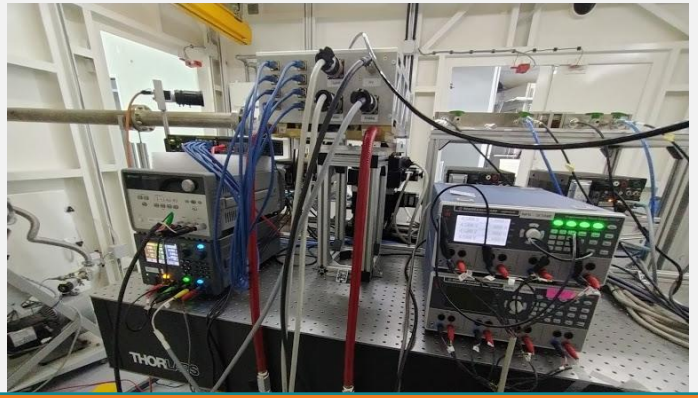
	Detector	LDO	FPGA	ADC
Detector 1	27.81 °C	43.56 °C	35.81 °C	32.06 °C
Detector 2	28.50 °C	43.12 °C	35.87 °C	33.06 °C
Detector 3	27.12 °C	40.50 °C	35.94 °C	32.75 °C
Detector 4	24.75 °C	44.81 °C	36.25 °C	32.87 °C
Detector 5	26.75 °C	42.81 °C	34.75 °C	32.50 °C
Detector 6	27.50 °C	43.25 °C	35.19 °C	31.69 °C
Detector 7	25.87 °C	42.25 °C	35.94 °C	32.06 °C
Detector 8	26.75 °C	42.94 °C	35.25 °C	33.25 °C

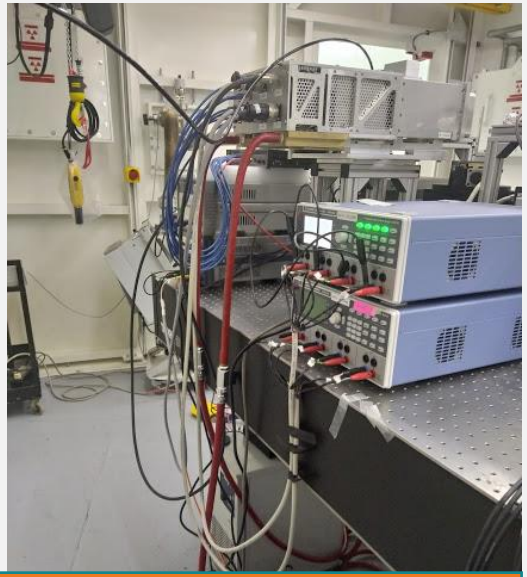
Mode select: Last value

	Detector	LDO	FPGA	ADC
Detector 1	7.75 °C	48.00 °C	38.25 °C	33.56 °C
Detector 2	8.37 °C	47.44 °C	38.31 °C	34.69 °C
Detector 3	5.31 °C	44.12 °C	38.12 °C	34.37 °C
Detector 4	3.37 °C	49.00 °C	38.50 °C	34.44 °C
Detector 5	4.94 °C	46.69 °C	36.87 °C	33.81 °C
Detector 6	4.50 °C	47.06 °C	37.75 °C	33.44 °C
Detector 7	5.69 °C	46.25 °C	38.50 °C	33.56 °C
Detector 8	6.56 °C	47.12 °C	37.87 °C	34.75 °C

XAFS – SESAME Detection System installed at SESAME



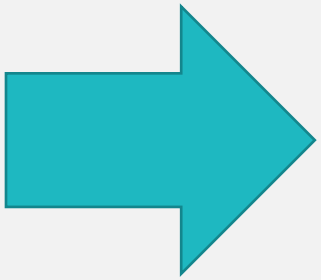




SESAME waiting commissioning because of COVID-19

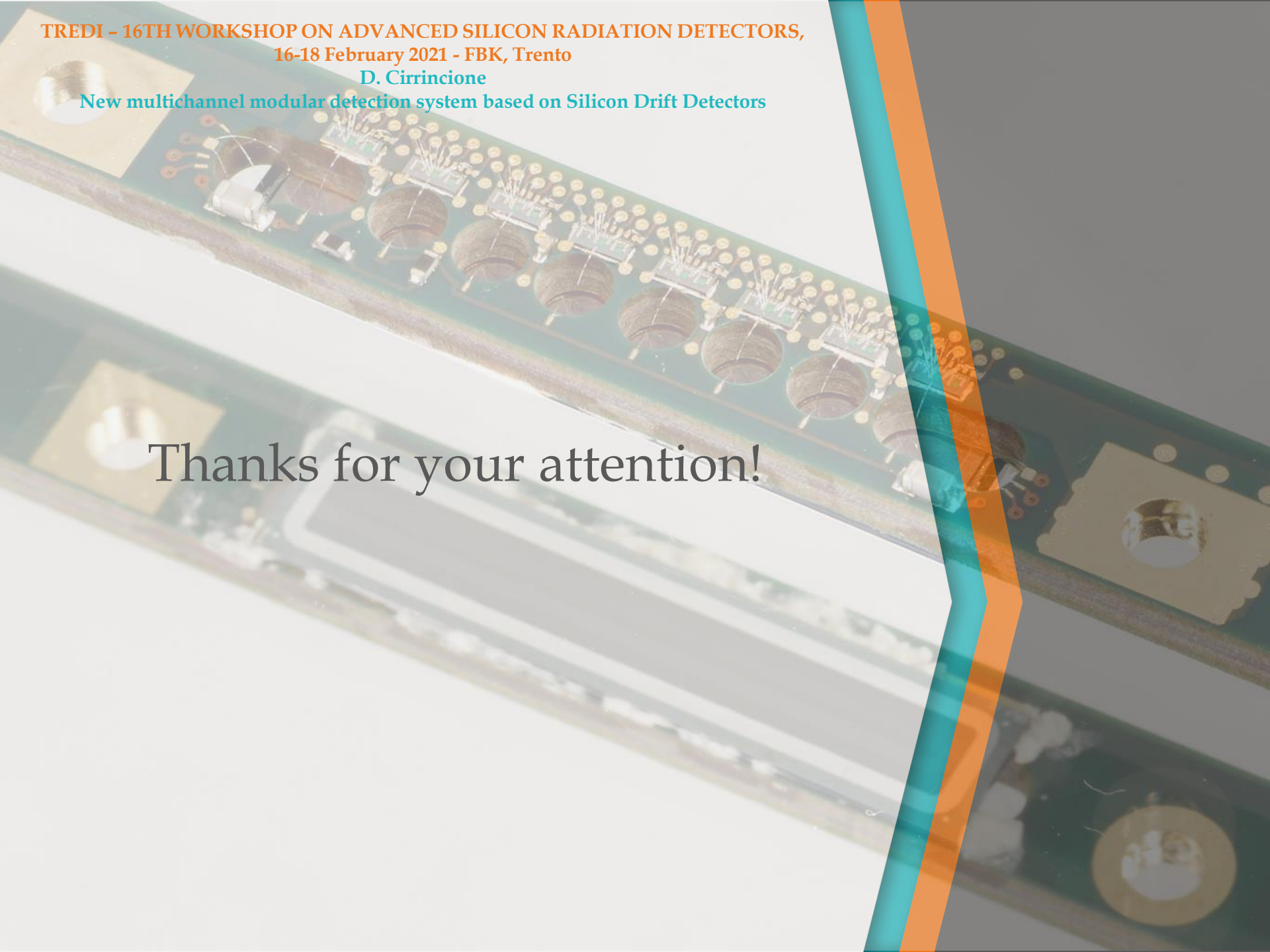
Conclusions

- SDDs have demonstrated very **good performances** and represent a very important **scientific and technological instrument**
- **Versatile dedicated design** of detection system
  - Very good energy resolution
  - Room temperature operability
  - Large area, in multipixel array
  - Low dead time
  - High count rate



Unique Detection System

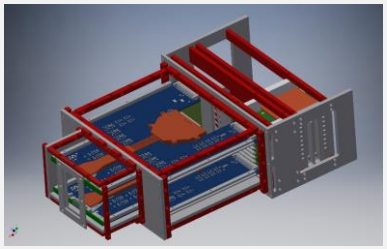
- Numerous **important applications** of the detection system:
  - Agricultural and food chain (pollutants and contaminants)
  - Biophysics
  - Materials science and industry
  - Cultural heritage



Thanks for your attention!

Backup slides

Evolution of the Detector System

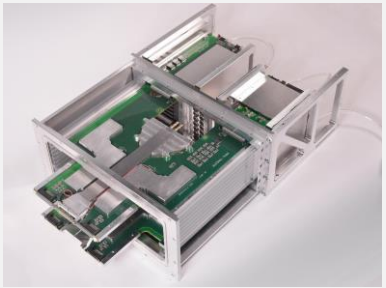


2016

Project and rendering

3D rudimentary rendering

2017

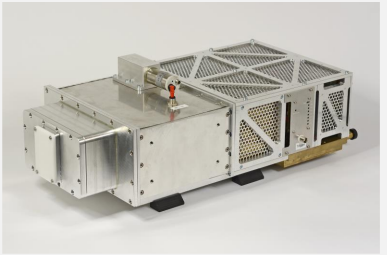


2018

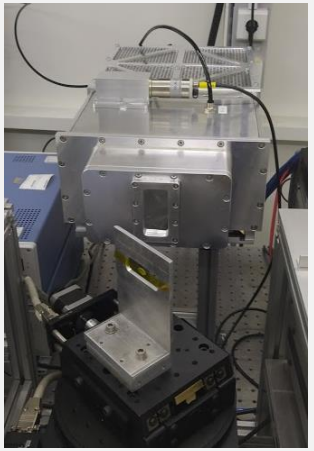
Structure with 16 channels

64 channels Detector System

Spring 2019



Autumn 2019



Complete XAFS-SESAME Detector System: Manuals and Datasheet

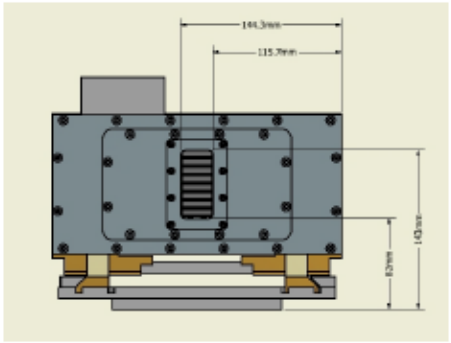


Figure 9: Front side of the detector system

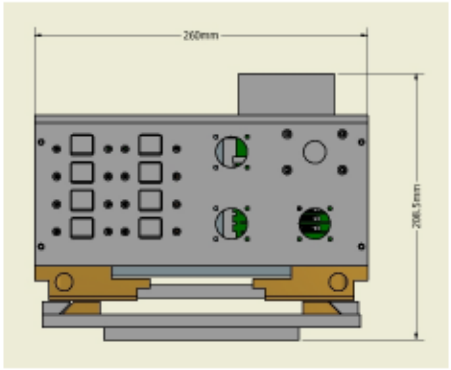


Figure 10: Back side of the detector system

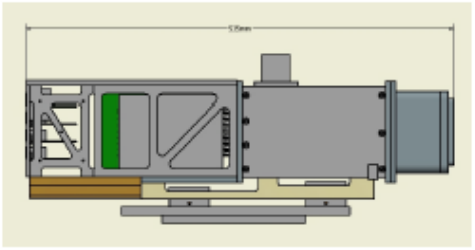


Figure 11: Right side of the detector system

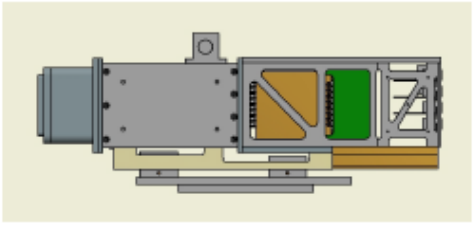


Figure 12: Left side of the detector system

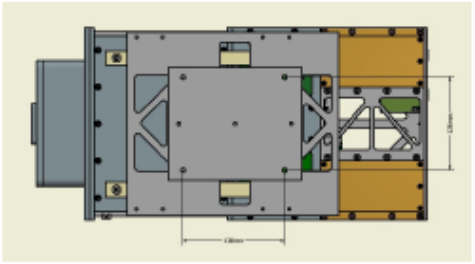


Figure 13: Down side of the detector system

FICUS software manual for the SESAME-XAFS Detector System

Contents

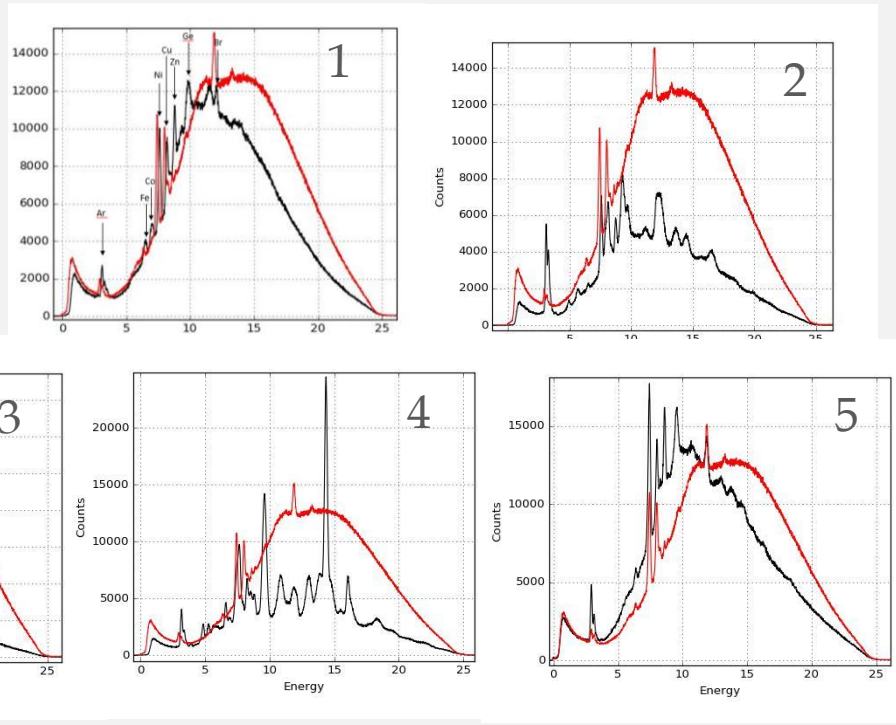
SESAME Detector System Datasheet

Contents

Test strip8 - Characterization of detector materials

Characterization of detector materials:

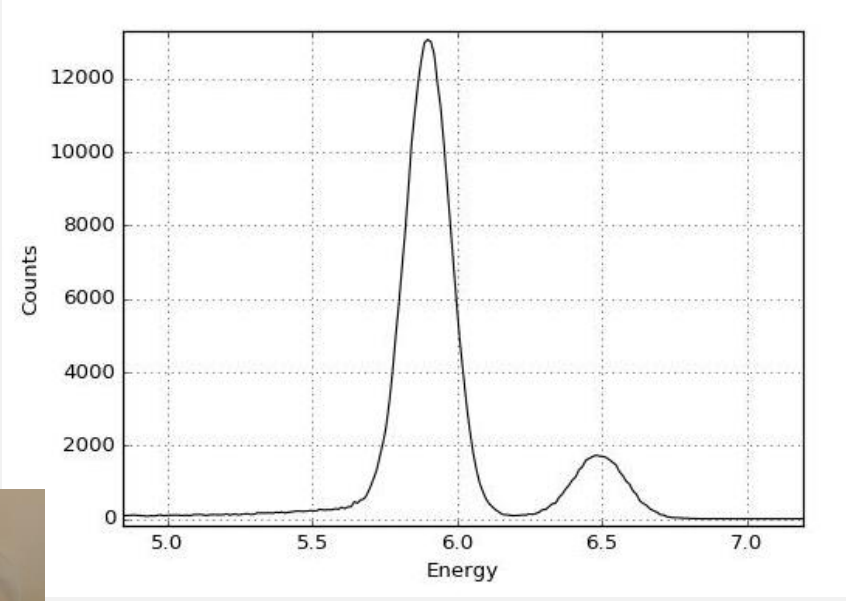
1. Glue of detector
2. Glue of ASIC
3. PCB e ASIC
4. Peltier cell
5. Glue of Peltier

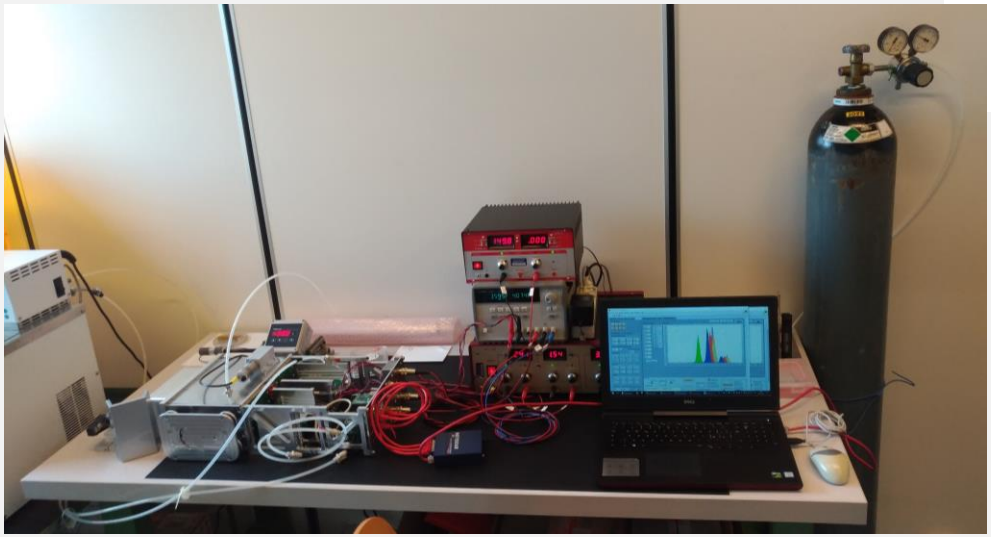


- **Scattering**: Argon, Potassium, Iron, Nickel, Copper, Bromine
- **Glue detector**: Chlorine, Argon, Potassium, Iron, Cobalt, Zinc, Gallium, Germanium, Bromo
- **Glue ASIC** Argon, Potassium, Iron, Cobalt, Nichel, Copper, Zinc, Gallium, Bromine
- **PCB+Detector**: Argon, Calcium, Iron, Nickel, Zinc, Bromine
- **Glue Peltier**: Argon, Calcium, Titanium, Chrome, Iron, Nickel, Copper, Gallioum, Arsenic, Bromine, Strontium
- **Glue Peltier**: Argon, Calcium, Iron, Nickel, Zinc, Arsenic, Bromine

Tests in INFN-Ts laboratory

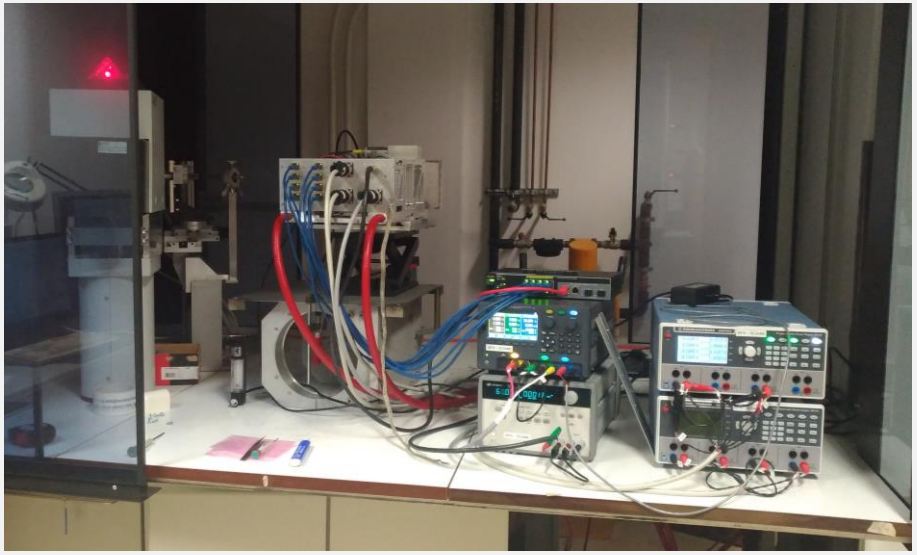
- Test and selection of the detectors
- Step by step detector assembly
- Test of every strip
- Strip selection

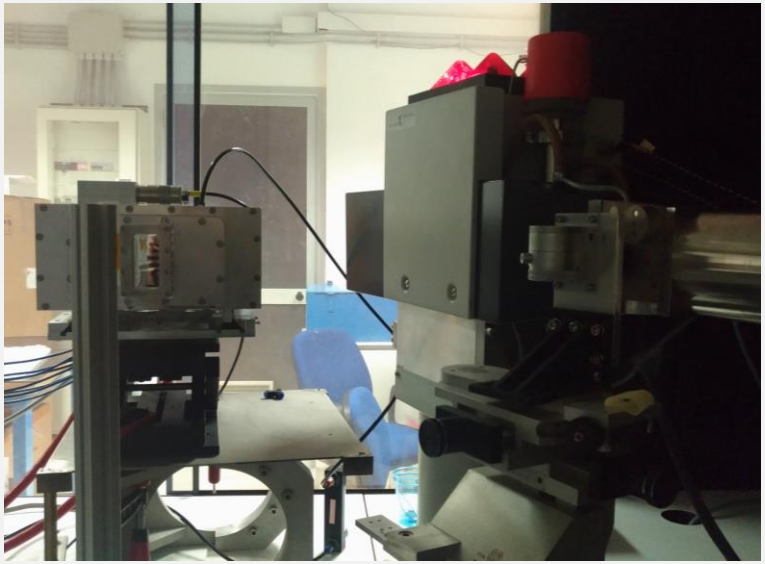


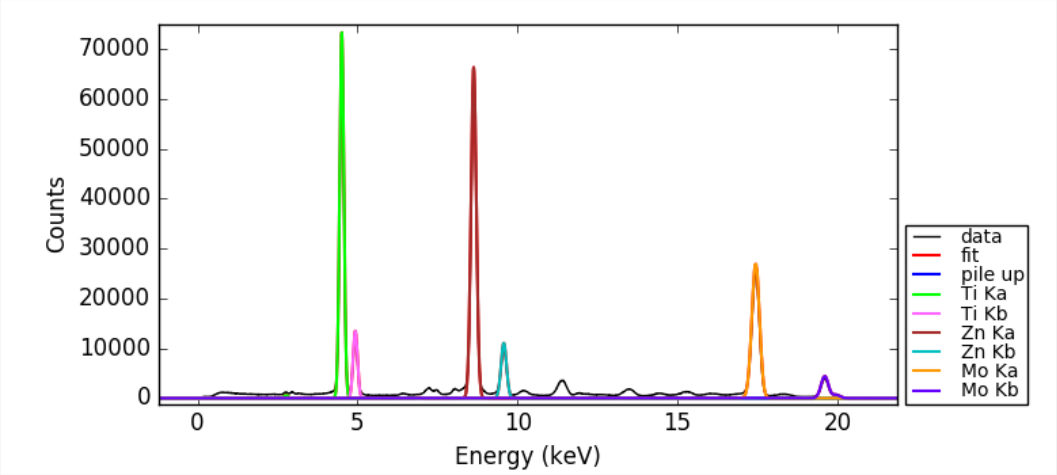


Acquisition with all the 8 channels of strip21 and ^{55}Fe source at room temperature.
The resolution is 170 eV at Mn k*a* line at room temperature with a peaking time of 0.9 µs.

Tests in X-ray optical laboratory (Elettra)



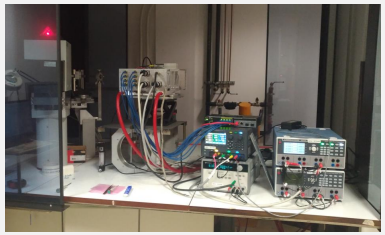


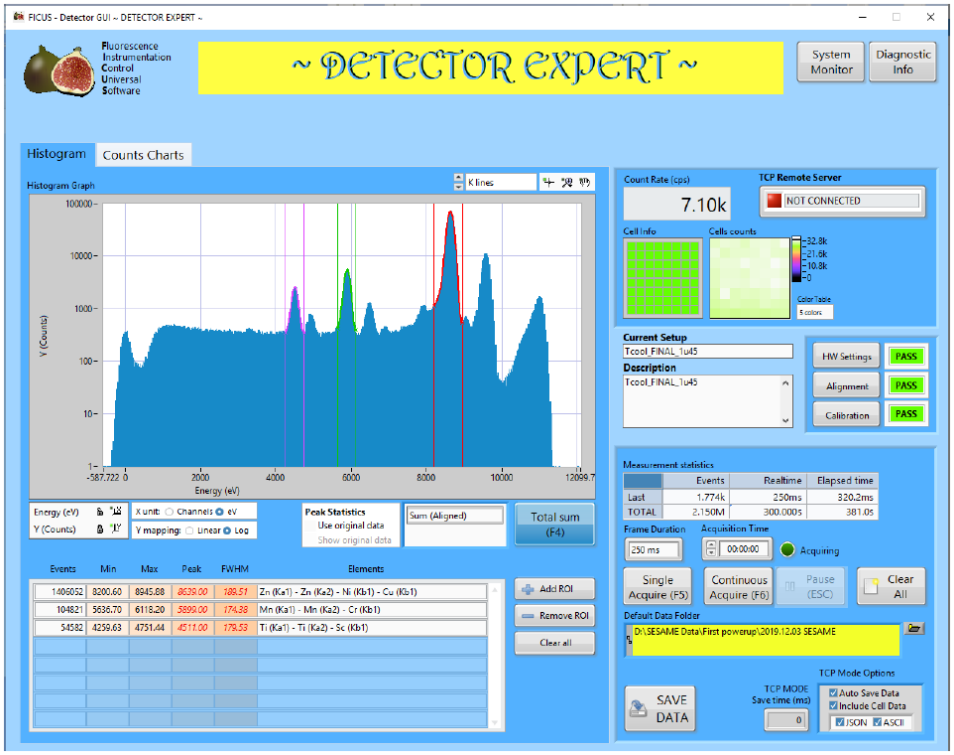


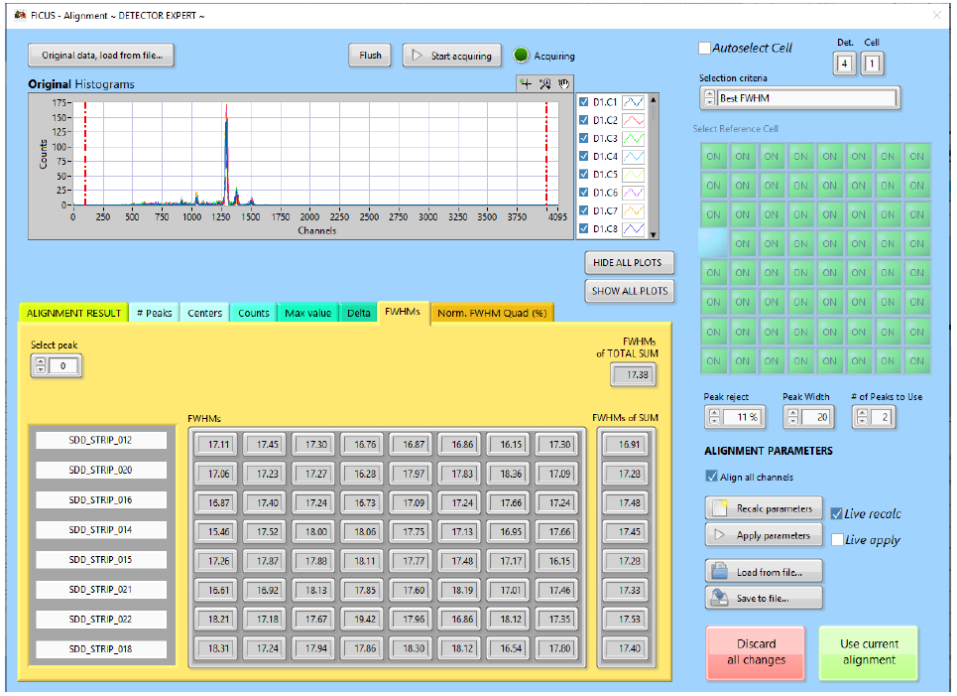
Analysis of the calibration sample (Ti, Zn, Mo), acquisition with strip8 at room temperature with a peaking time of 0.9 μs.

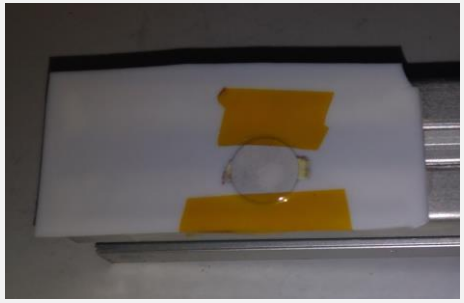
Line	Energy [eV]	FWHM [eV]
Ti Kα	4509	155
Ti Kβ	4932	159
Zn Kα	8639	193
Zn Kβ	9572	201
Mo Kα	17479	257
Mo Kβ	19607	270

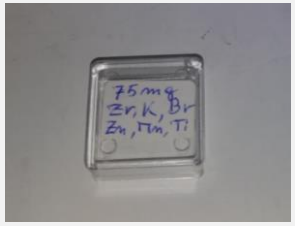
Sum of 64 channels – Calibration sample





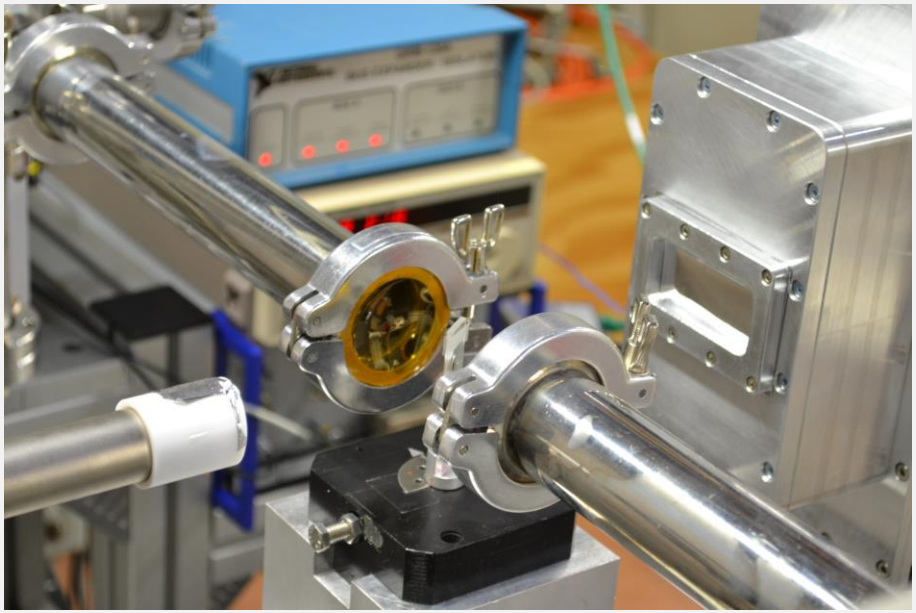






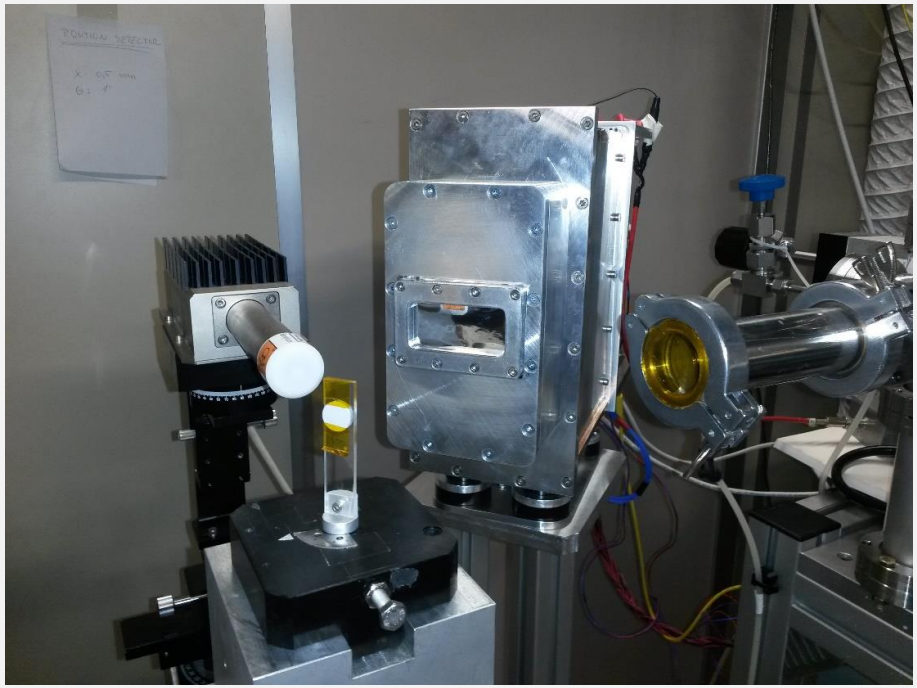
Calibration sample
(Zr, K, Br, Zn, Mn, Ti)

Position of detectors on beamline XAFS-ELETTRA

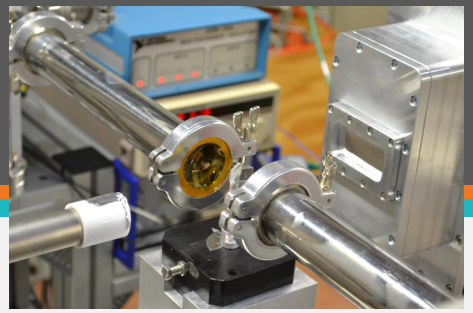


Detector in normal position

Detector in parasitic position



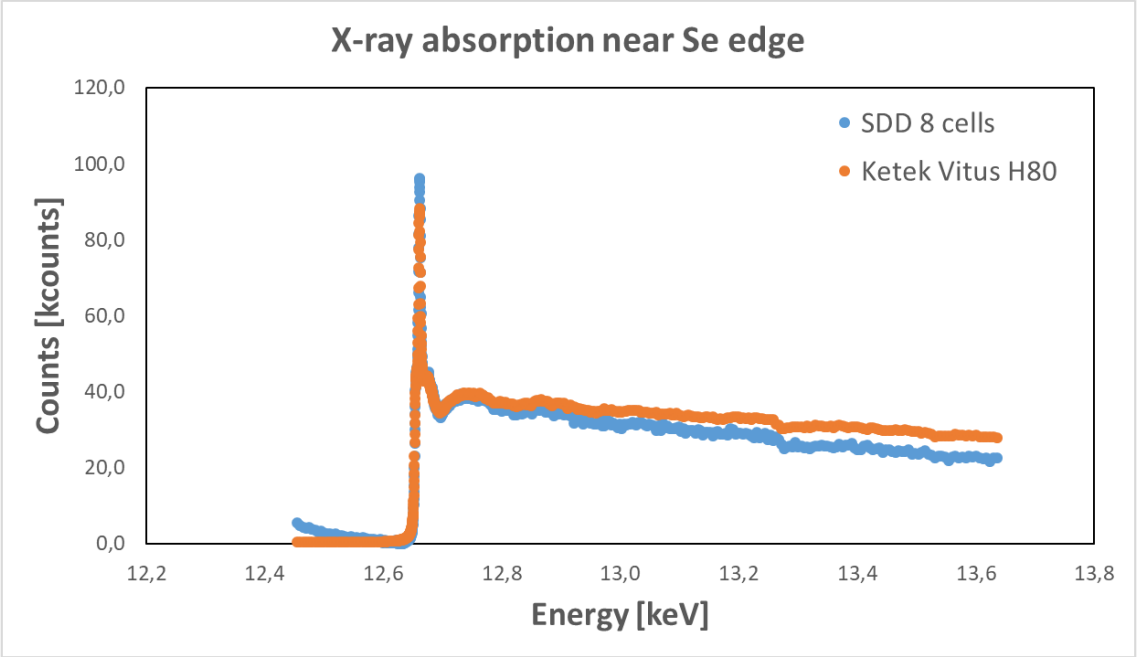
The current detector of the beamline



KETEK GmbH AXAS-M Silicon Drift Detector

It has a single 100 mm² SDD cell (80mm² of effective area with collimation) with an FWHM energy resolution of ~170 eV for the Mn *Ka* line at 5.89 keV for a peaking time of 1.32 μs at −70°. It reaches up to 50% of dead time with 1.3 × 105 counts s^{-1} of output.

XAFS spectrum normalized for the two detectors



This measurement was achieved thanks to the synchronization capabilities of our system. In this way we were able to measure at the same time with both our system and the Ketek one transparently and accordingly to the beamline control software