First results and developments of the multi-cell SDD for Elettra and SESAME XAFS beam lines

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on the behalf of the INFN
R&D project RedSox collaboration and
Elettra Synchrotron Trieste

RESEARCH DRIFT FOR SOFT X-RAYS

26-30 September 2016, Padova, Italy

Outline

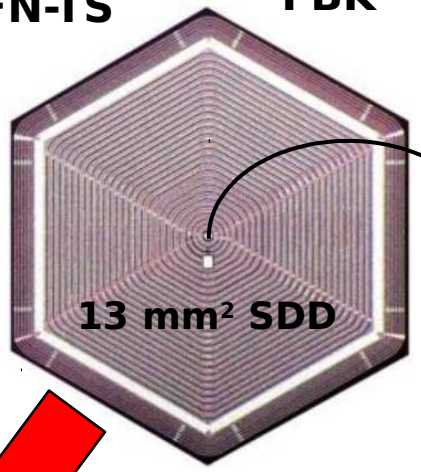
- Starting point: state-of-the-art technology (SDD and SIRIO preamplifier)
- Our goals: New detectors for the XAFS beamlines at Elettra (Trieste – Italy) and SESAME (Amman – Jordan) synchrotrons
- Beamline tests with two detector prototypes
- Towards the final detector deign

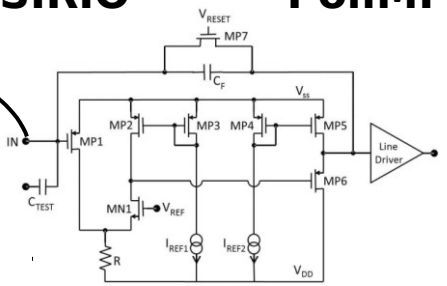
Starting point: state-of-the-art technology

Very-low leakage current production process was developed at FBK

Typical: < 150 pA/cm²

Minimum: 25 pA/cm²

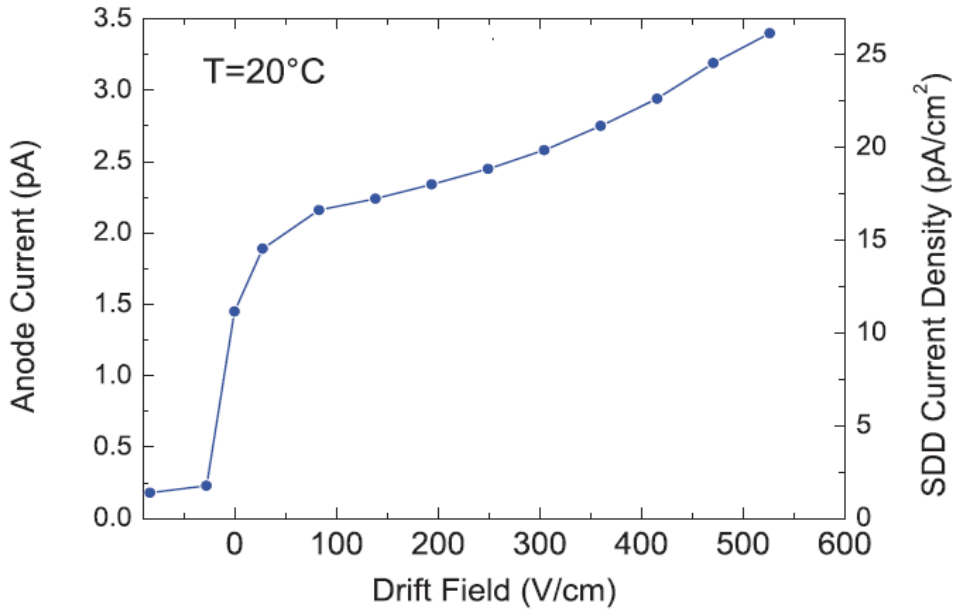


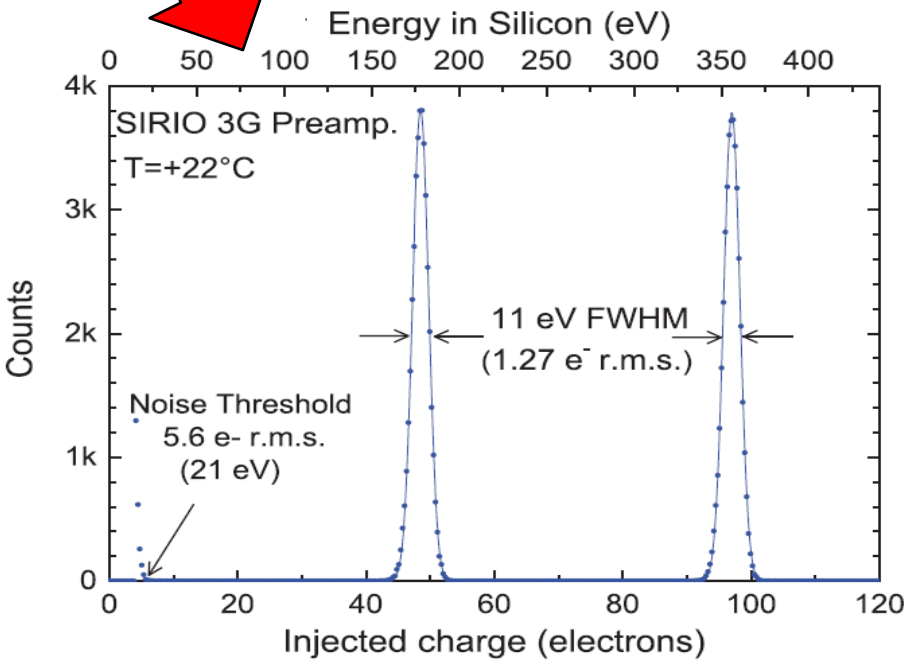


Low-power and very-low noise optimized preampl. in sub-micron technology

Power: 10 mW including the output buffer

ENC of 1.27 e⁻ r.m.s. at20 °C



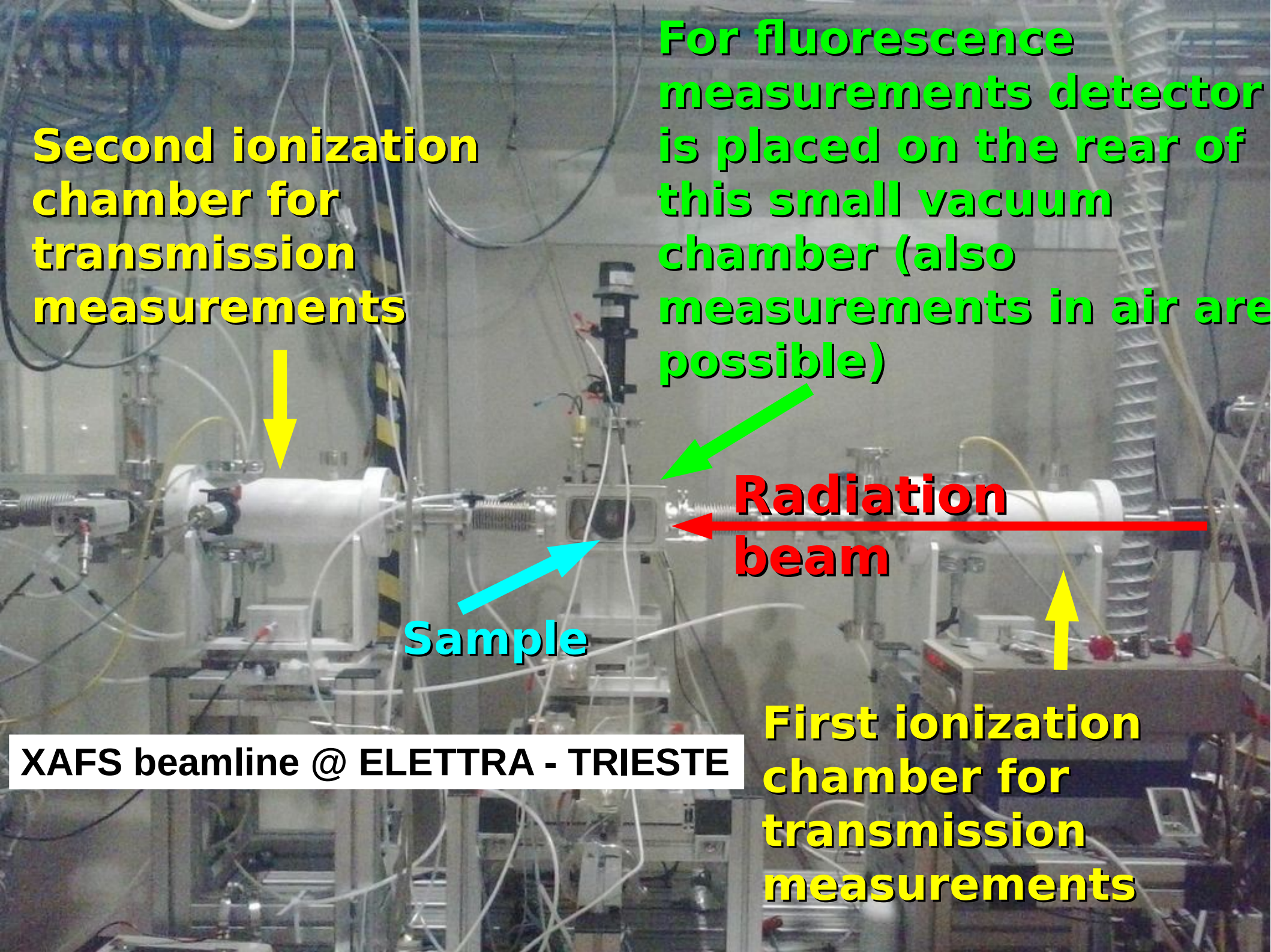


G. Bertuccio, et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 63, NO. 1, FEBRUARY 2016

The new detectors for XAFS beamlines at...

ELETTRA
Trieste - Italy

SESAME
Amman - Jordan


Second ionization chamber for transmission measurements
For fluorescence measurements detector is placed on the rear of this small vacuum chamber (also measurements in air are possible)
Radiation beam
Sample
First ionization chamber for transmission measurements
XAFS beamline @ ELETTRA - TRIESTE

The new detector prototype for XAFS at Elettra

Current detector at XAFS Elettra:

- Monolithic 80mm^2 SDD
- FWHM 170 eV at 6 keV with 1.32µs of peaking time and -70°C Peltir cooling
- Up to 50% dead time with 130 kcounts/s of output
- Typical XAFS measurement cycle duration is 6 hours

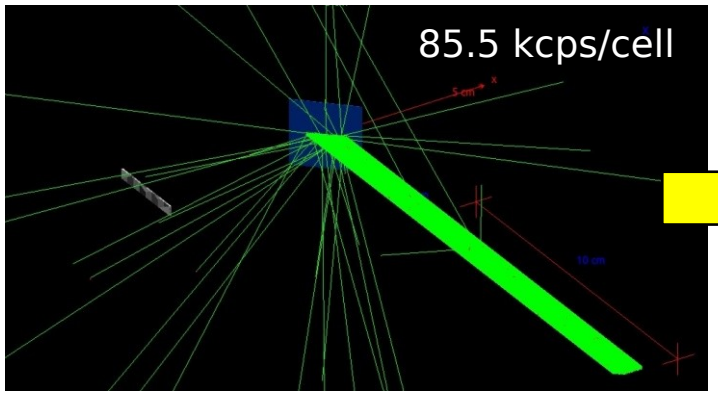
Goals:

- High count rate with low dead time and pile up
    - Larger collecting area (more counts)
    - Segmented SDD sensor (less dead time and pile up, at least ~50kcounts s^{-1} each SDD cell)
    - Fast shaping time (~1 µs or less)
- Energy resolution 150 eV at 6 keV at 0°C

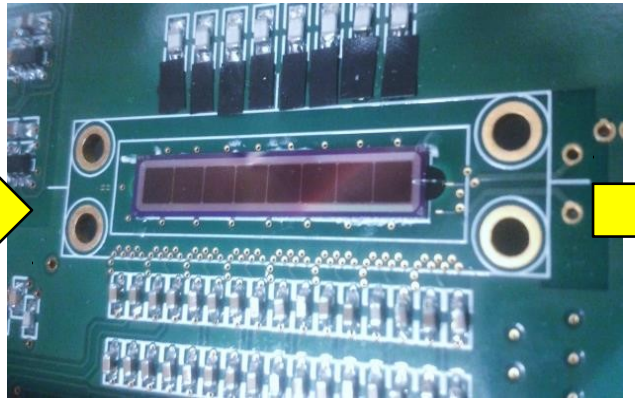
Therefore:

- Modular detector custom designed for the beamline
- 8 arrays of 8 SDD cells 3x3 mm^2 each (8*8*9 mm^2 = 576 mm^2)
- Fast analog pre-shaping in the FEE (few hundred nanosecond of peaking time),FIR digital filtering in the BEE (prototype 2 strategy)

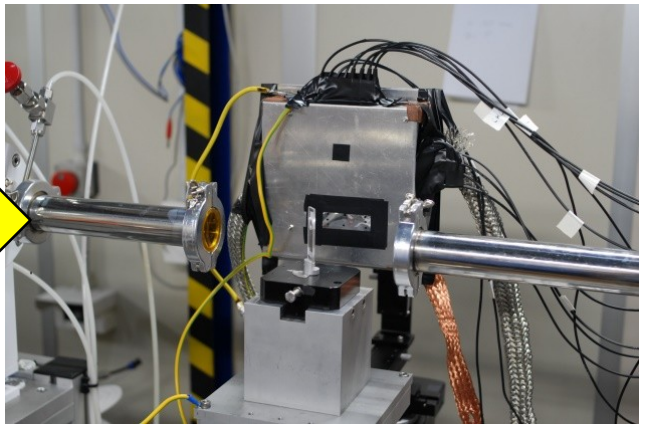
Beamline tests – prototype 1



GEANT4 simulation



Prototype 1



Beamline test in September 2015

- Detector operated near room temperature

-FEE output is the preamplifier integration ramp passed through an anti-aliasing filter, digital filtering not yet optimized

- Mn (K_α at 5.89 keV, K_β at 6.49 keV) and Zr (K_α at 15.75 keV , K_β at 17.67 keV)

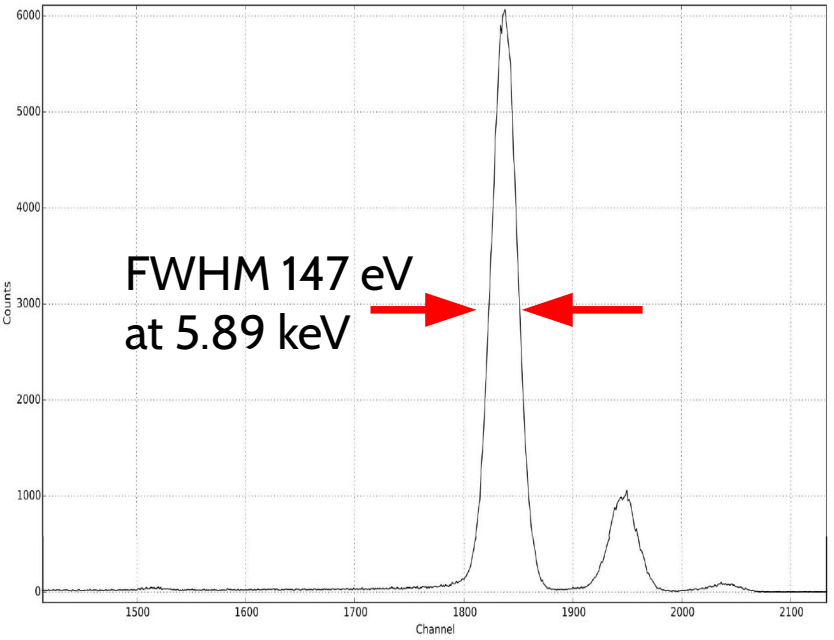
Achieved result:

- up to 10^5 kcounts/s/cell (Mn) , pile-up : 18%
  (9% for a count rate of 50 kcounts/s/cell)

Beamline test
13-14 September 2016

Beamline tests – prototype 2

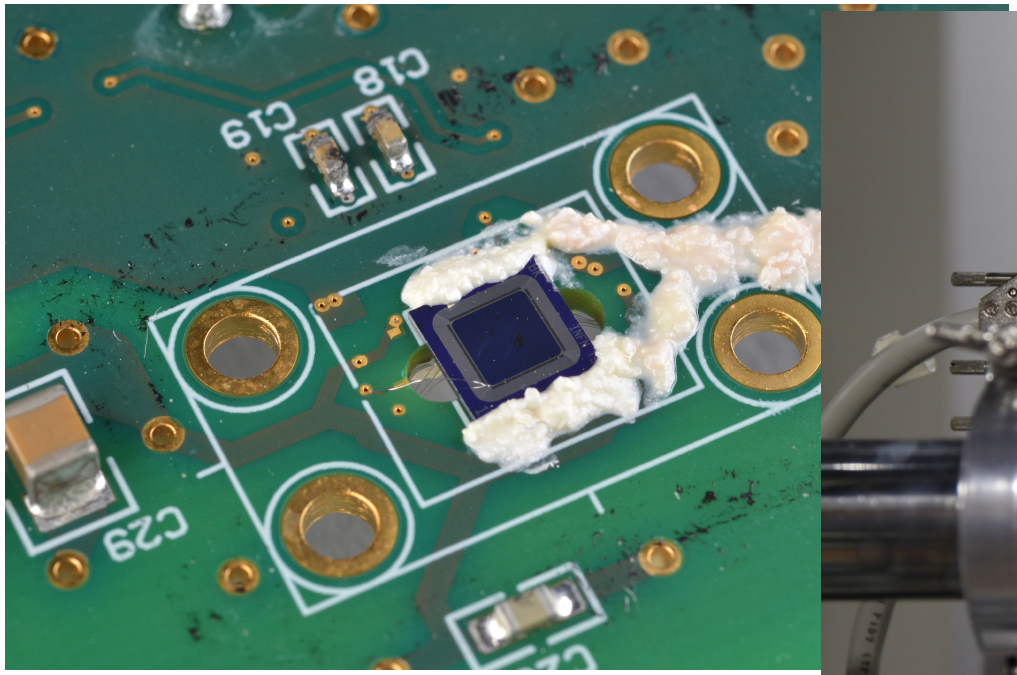
PRELIMINARY

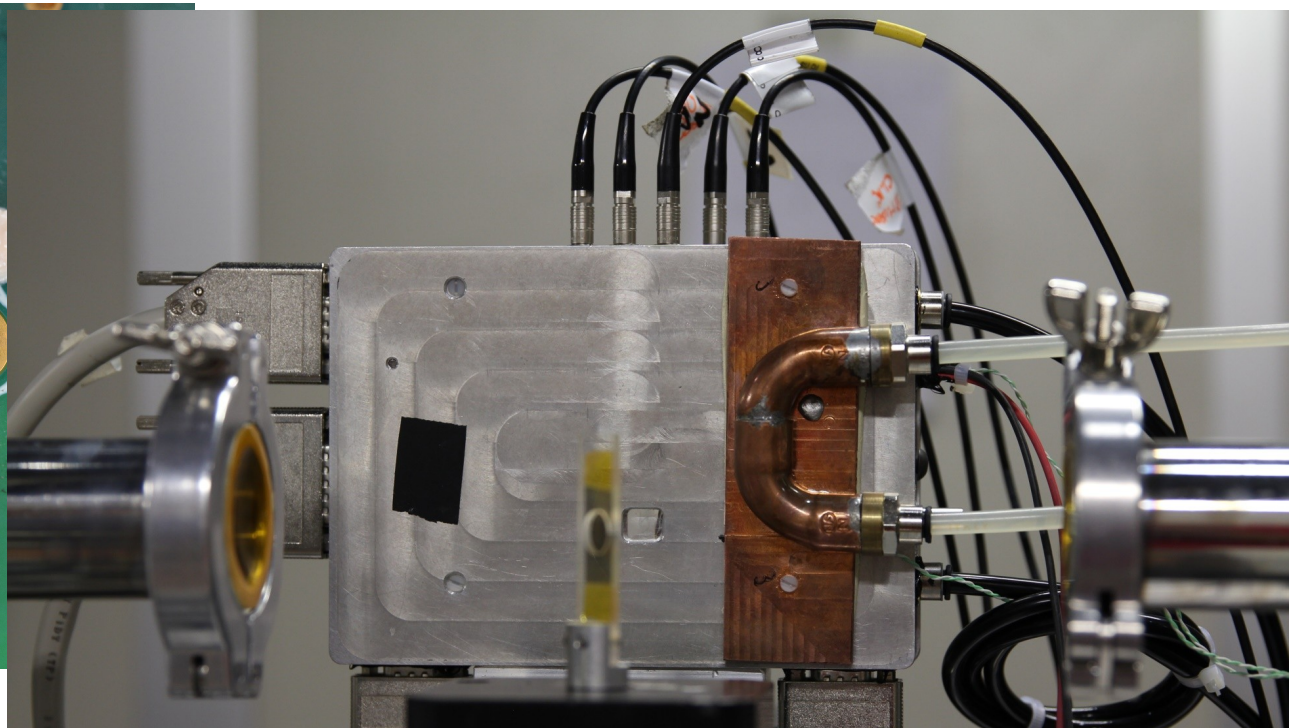


Detector operated at about 6°C (I_leak=5pA)
-Not yet collimation, energy resolution improvement

-Best energy resolution at 2.93 kcounts/s
FWHM 147 eV (t_peak=1µs)
Pile-up events negligible

- Higher count rate verified about 280 kcounts/s
FWHM 162 eV (t_peak=1µs, not yet pile up rejection)
Pile-up events 34%





Towards the final detector deign: the detector head

Improved detector layout:

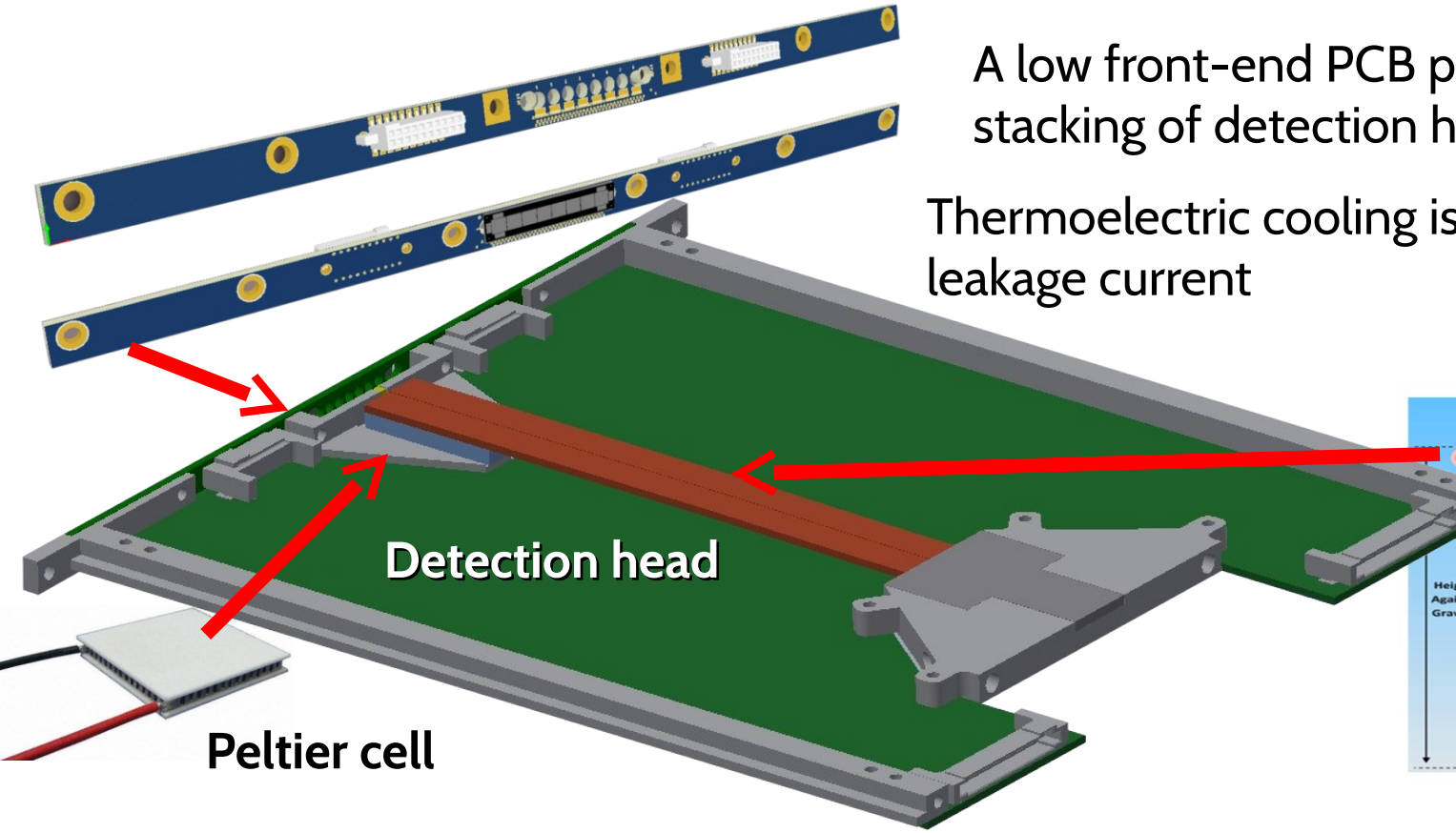
- better defined sensitive area
- on-board thermistors for temperature control

Tungsten collimator to minimize "split" events

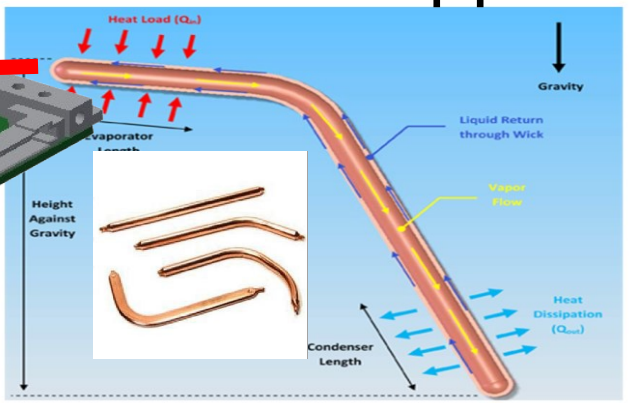
New SIRIO preamplifier prototypes optimized for SESAME now under test at Politecnico di Milano

- A low front-end PCB profile allows for compact stacking of detection heads

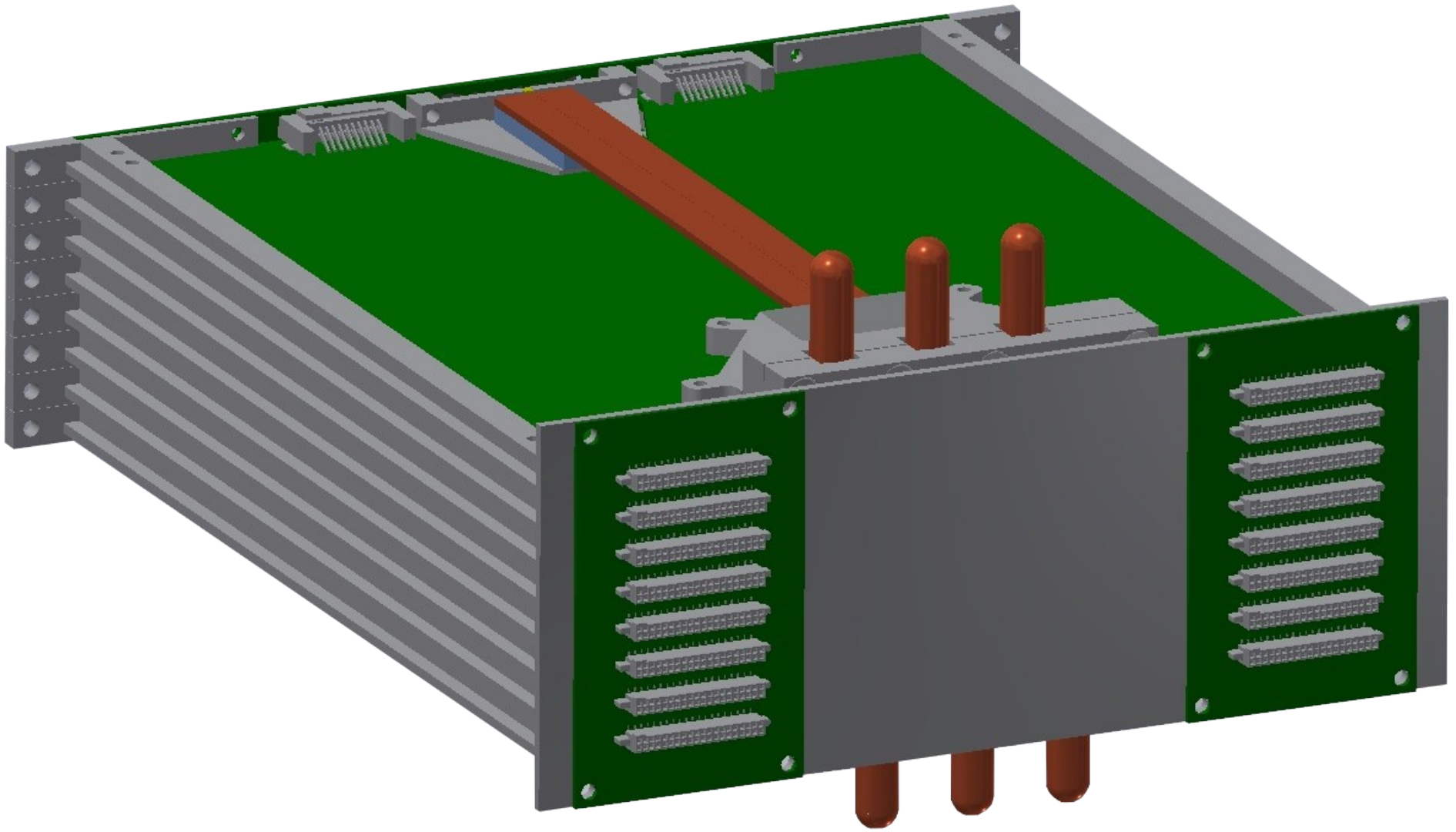
Thermoelectric cooling is employed to reduce the leakage current



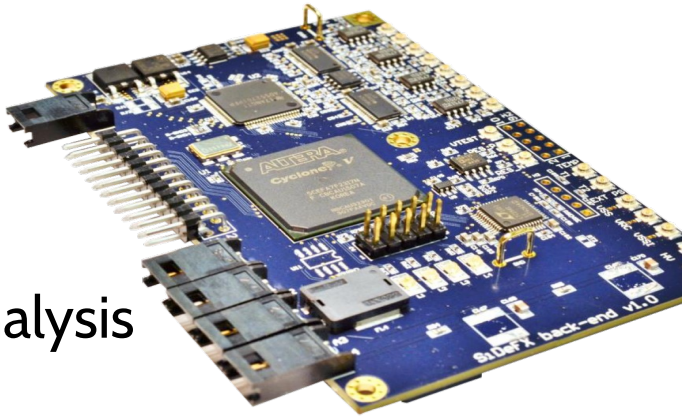
Heat pipes



Towards the final detector deign: the detector head stack



Towards the final detector deign: the detector backend electronics



- Its purposes are
  - the configuration of the instrument
  - the digitization and elaboration of the analog signals
  - the acquisition of histograms or raw data for system analysis
  - the communication with the controlling computer

- It features an 8 channel, 40 MSPS, 12 bit ADC. Depending on the conditioning circuit bandwidth it can allow for shaper rise times as fast as 250 ns

- Noise filtering is accomplished by means of a low-power, high-performance ALTERA Cyclone 5 FPGA, which implements also the data buffers and the configuration and control logic

- It features an Ethernet port (possibly in a separated board) for network communication with a host computer

Conclusions

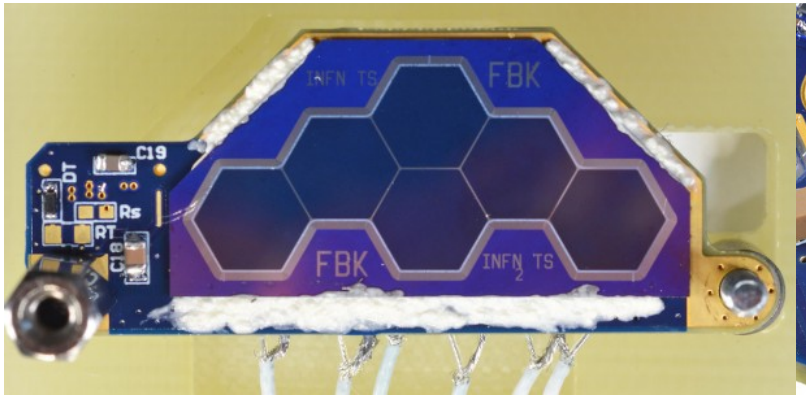
The SESAME XAFS fluorescence detector under development is a state-of-the-art instrument:

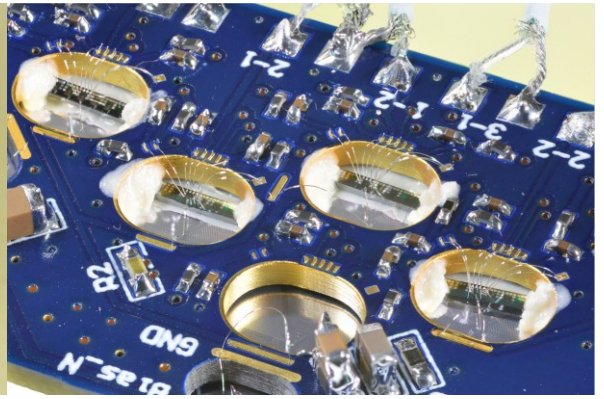
- it will sustain a rate of at least 50 kcps/cell (≈ 560 kcps/cm^2)
- It will have a total sensitive area of 576 mm^2 allowing for a total rate of at least 3.2 Mcps
- It will have an energy resolution < 150 eV FWHM at 5.9 keV, 0 °C with a peaking time ≤ 1 µs

The detector concept is being tested and optimized by way of two parallel developments for Elettra Sincrotrone Trieste (XAFS and TwinMic beamlines) with good results

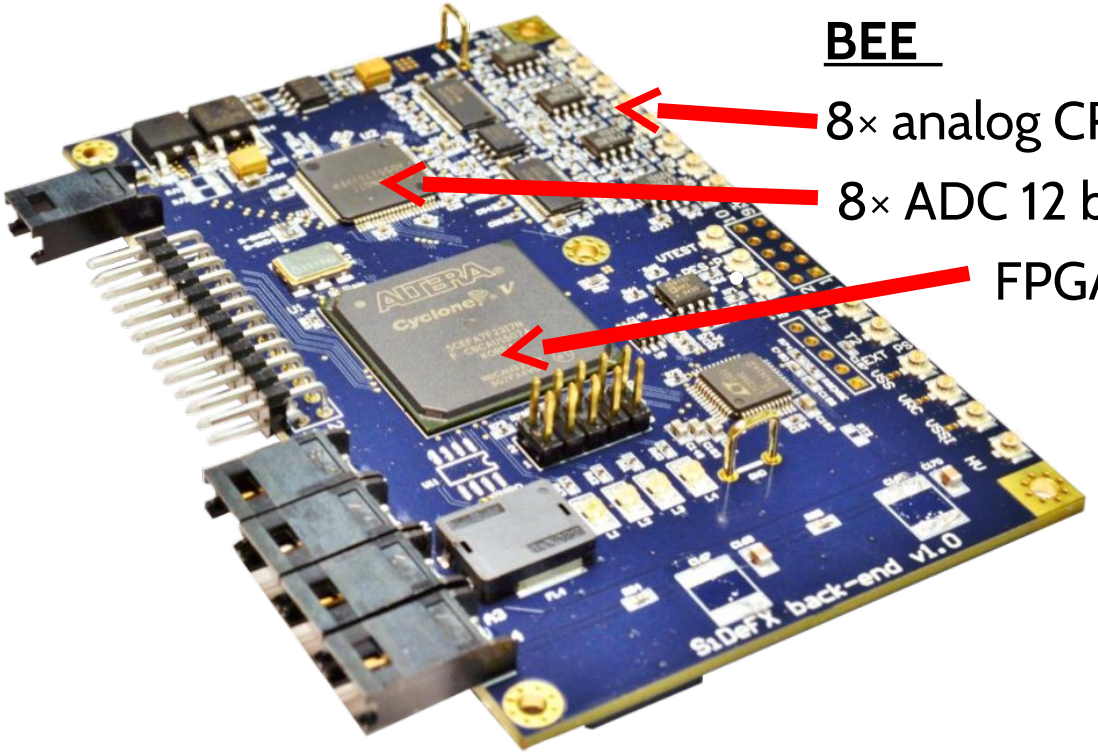
The timeframe set for this project forced us to consider conservative solutions, nonetheless further optimizations and improvements of such detector are possible and will be pursued in future developments

Parallel development of a new detector for TwinMic beamline at Elettra (similar detector concept)





6 hexagonal pixels (total area of 182 cm^2) read out by SIRIO preamplifiers

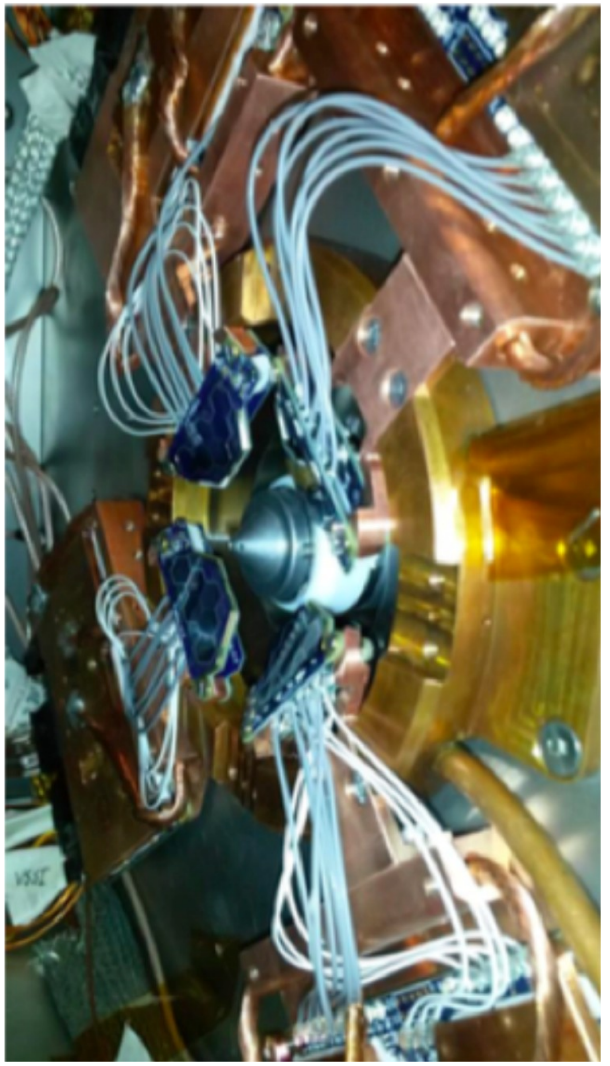


BEE

8× analog CR-RC^2 filters

8× ADC 12 bit 40 MSPS

FPGA Cyclone 5

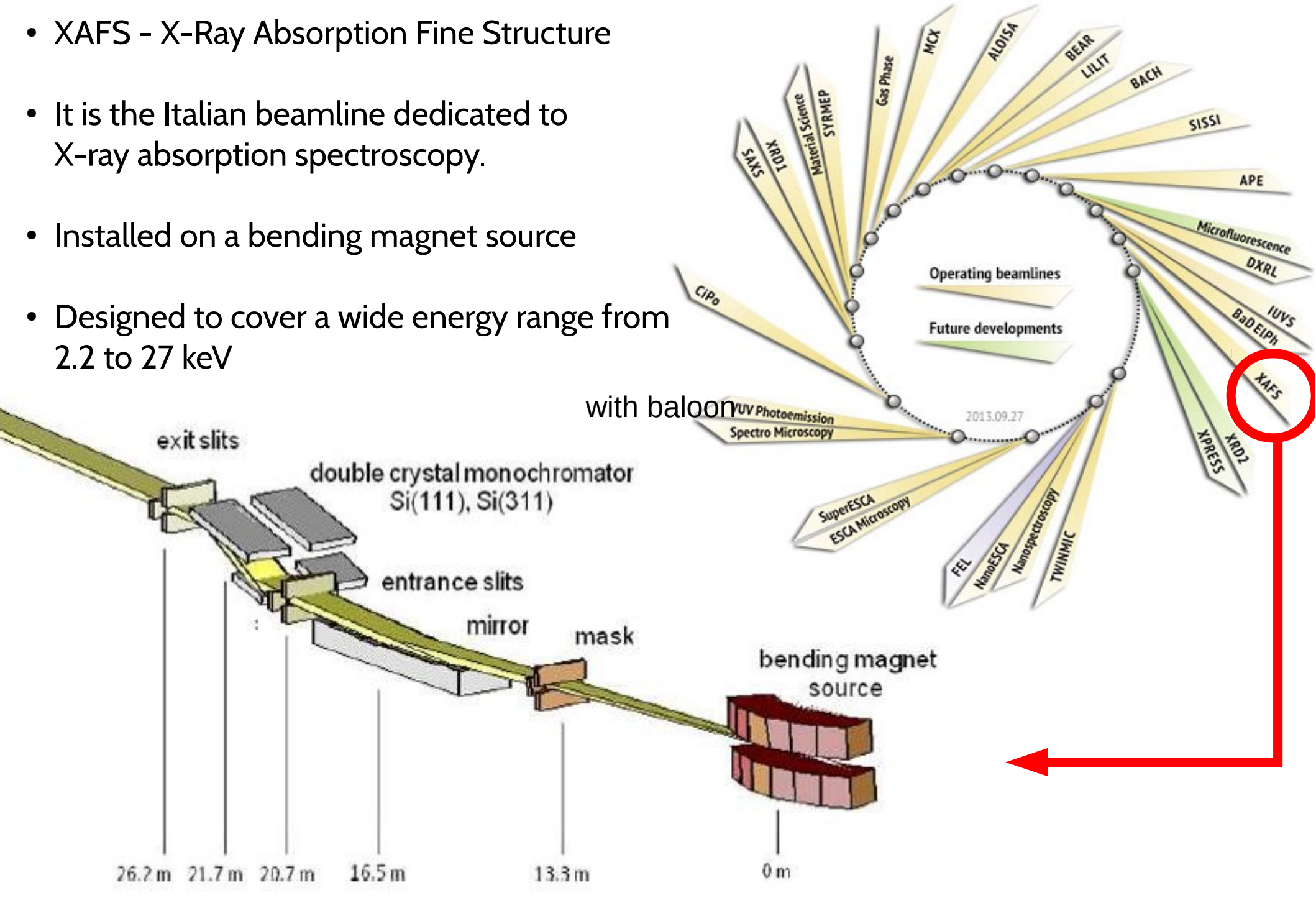


Four detectors mounted in the experimental chamber in vacuum

The XAFS beamline

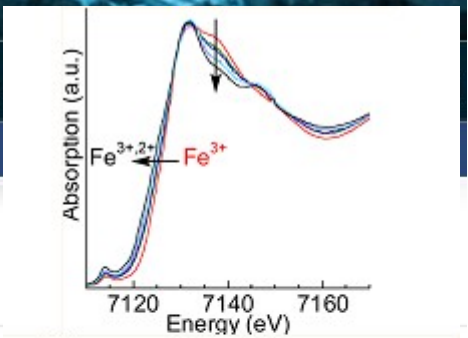
- XAFS - X-Ray Absorption Fine Structure
- It is the Italian beamline dedicated to X-ray absorption spectroscopy.
- Installed on a bending magnet source
- Designed to cover a wide energy range from 2.2 to 27 keV

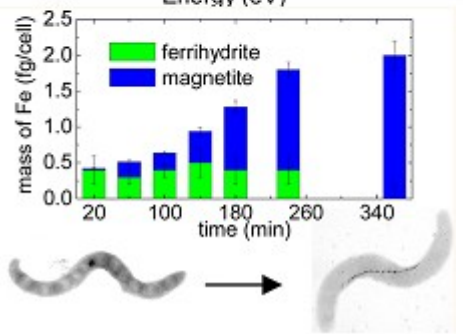
with baloon



The XAFS beamline

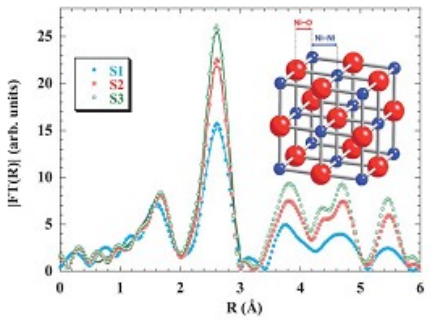
Elettra Sincrotrone Trieste | Elettra and FERMI lightsources

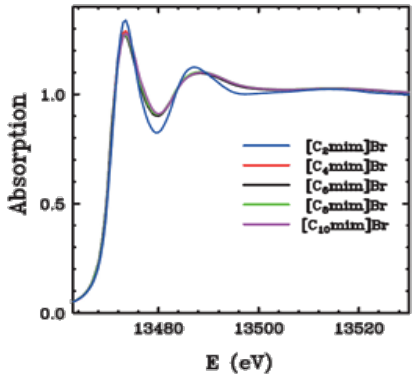




Highlights

- Copper complexes as potential bioinorganic target-specific drugs
- Structural Characterization of Ionic Liquids by X-Ray Absorption Spectroscopy
- Local structure of $LiCoO_2$ nanoparticles studied by Co K-edge x-ray absorption spectroscopy
- Exploring the Effect of Co Doping in Fine Maghemite Nanoparticles NEW
- Structural characterization of electrodeposited copper hexacyanoferrate films by using a spectroscopic multi-technique approach NEW
- Interplay between microstructure and magnetism in NiO nanoparticles: breakdown of the antiferromagnetic order NEW





The XAFS beamline

Measurement procedure

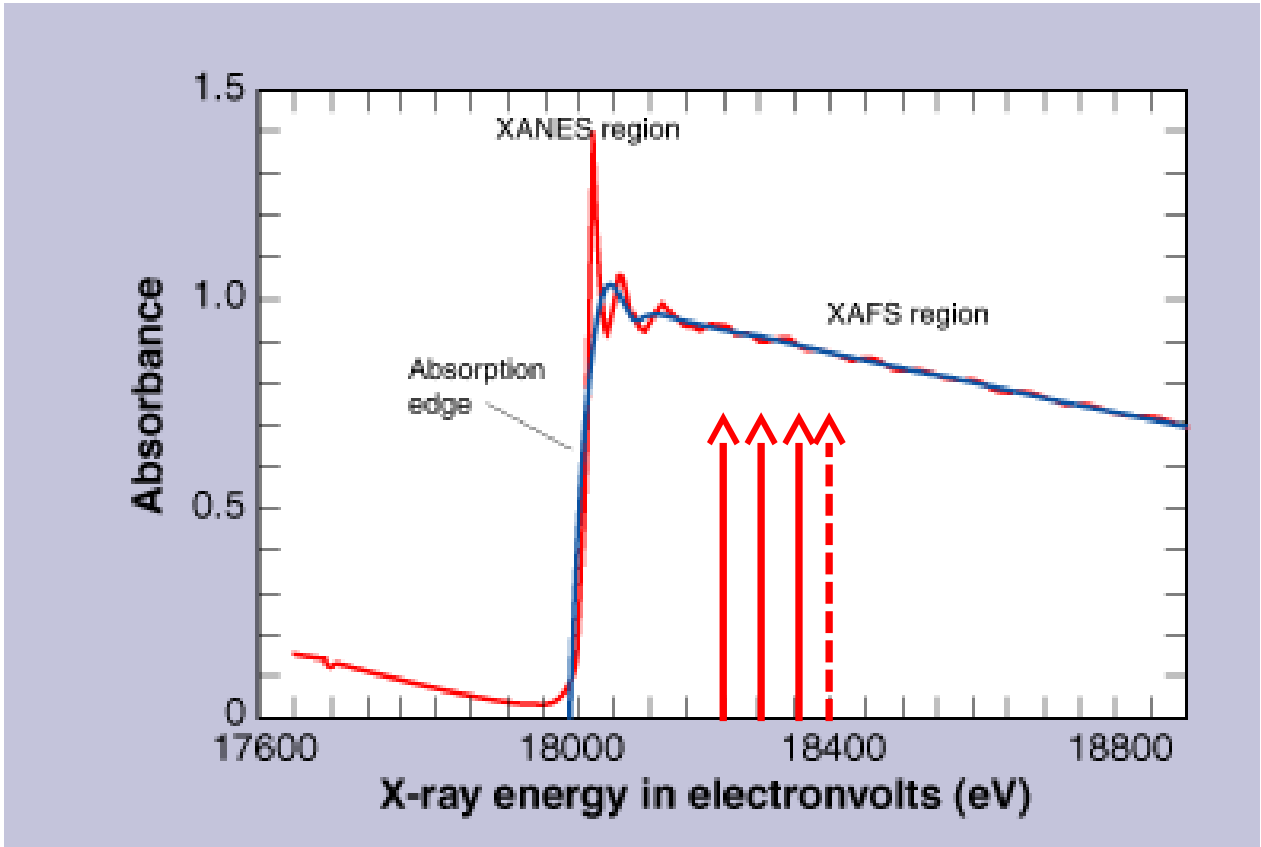
Energy scan by operating on the monochromator (about $\Delta E/E=10^{-4}$)

Measurement of fluorescence on the target to derive the behavior of the absorption coefficient at different energies

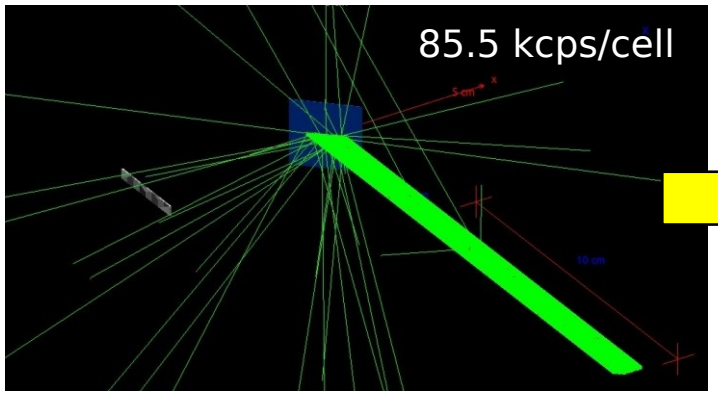
A measurement cycle comprises 1000-2000 points [energy range up to 1-2 keV]

At present 5-10 s are needed for each point (each energy)

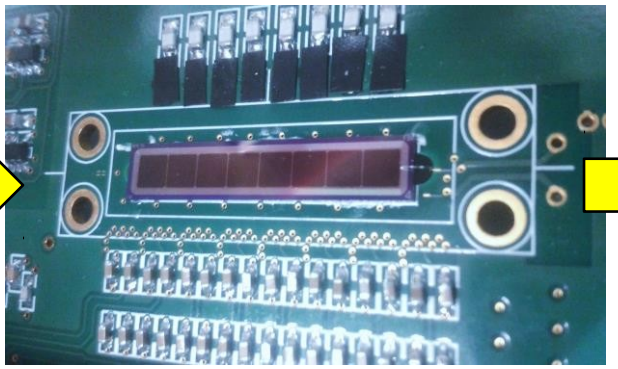
Therefore, up to $2x10^4$ s (about 5 h 30m)



Beamline tests – prototype 1



GEANT4 simulation



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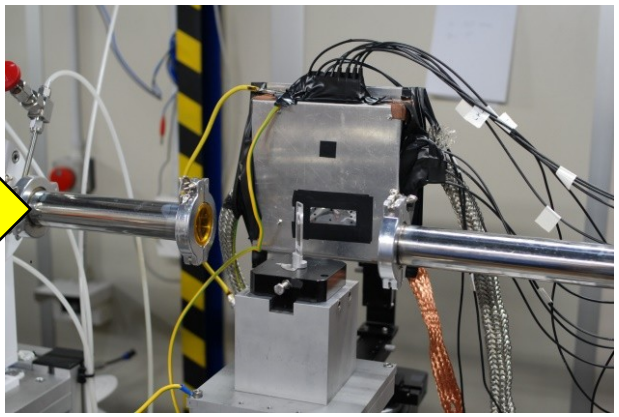

Beamline test in September 2015

Prototype detector 1:

- analogue signals from the 8 preamplifiers are sampled by a 40 MSPS,12 bit, 8-channel ADC
- digital data is transmitted to a PC and saved to disk
- LabVIEW acquisition software (filtering not yet optimized)

Beam test condition:

- detector operated near room temperature
- Measurement conditions: laminated samples of Mn (K_α @ 5.89 keV, K_β @ 6.49 keV) and Zr (K_α @ 15.75 keV , K_β @ 17.67 keV)
- Pileup events: 18% for t_{Reset} = 1 µs (9% for a count rate of 50 kcps/cell)