Development of CZT detector systems for a broad energy range 10 - 1000 keV for hadron physics

Johann Zmeskal

LNF - SYMPOSIUM

High precision measurements of kaonic atoms

Laboratori Nazionali di Frascati

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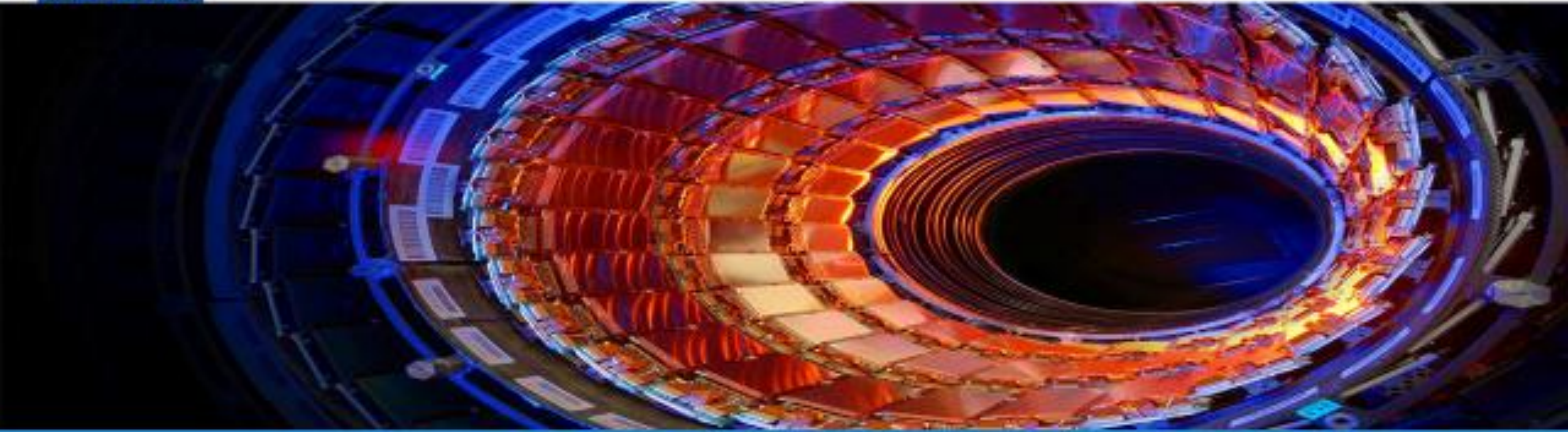

JRA8 - ASTRA
Advanced ultra-fast solid STate detectors for high precision RAdiation spectroscopy

Johann Zmeskal, SMI

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JRA8 - project members

Beneficiary number	Organization legal name (in italics the Research Units)	Short name
2	Oesterreichische Akademie der Wissenschaften	OEAW
26	Sveuciliste u Zagrebu	UNIZG
28	Consiglio Nazionale delle Ricerche	CNR
30	Istituto Nazionale di Fisica Nucleare	INFN
31	Politecnico di Milano	POLIMI
38	Uniwersytet Jagiellonski	UJ

Why Cadmium Zinc Telluride (CZT)

Cadmium Zinc Telluride (CZT) is a very promising semiconductor materials for X-ray and gamma ray detection.

- The high atomic numbers of the materials ($Z_{Cd/Zn/Te}$=48, (30), 52) provide a high quantum efficiency in comparison with Si (Z=14).
- The larger band-gap energy Eg~1.5 eV allows the operation of the detector at room temperature (compared to Si Eg~1.1 eV, Ge Eg~0.7)

CZT energy range up to 50 keV	resolution 500 eV (FWHM) @ 20 keV
CZT energy range 0.05 – 1 MeV	resolution 1 keV (FWHM) @ 200 keV

➢ energy resolution is slight worse than achieved with HPGe, BUT better timing and high rate capability

CZT detectors - expected results

Compact modular room temperature detector systems optimized for two energy ranges with excellent energy resolution; FWHM about 3% at 60 keV and about 1% at 662 keV.

Strangeness precision frontier at DAΦNE (LNF-INFN):

- Determination of the charged kaon mass (K^-).
- Understanding the antikaon-nucleon interaction

Medical applications:

- Compton camera, PET (UY)
- Non-invasive input function measurement for positron emission tomography (SMI)
- Boron Neutron Capture Therapy (CNR-IMEM)

Physics motivation

LNF Workshop: Fundamental Physics at the Strangeness Frontier (Feb. 2021)

KAonic **HEL**ium 2p → 1s transition

The first measurement of the $K^{3,4}He(2p \rightarrow 1s)$ transitions will allow to extract the isospin dependent scattering length in a system with more than two nucleon, to put stronger constraints on the theoretical models describing the kaon nucleon interaction.

LIght **K**aomic **A**toms **M**easurements

Hints on the nature of the Λ(1405) can be, instead, obtained from the upper level transitions of light kaonic atoms like Li, Be and B

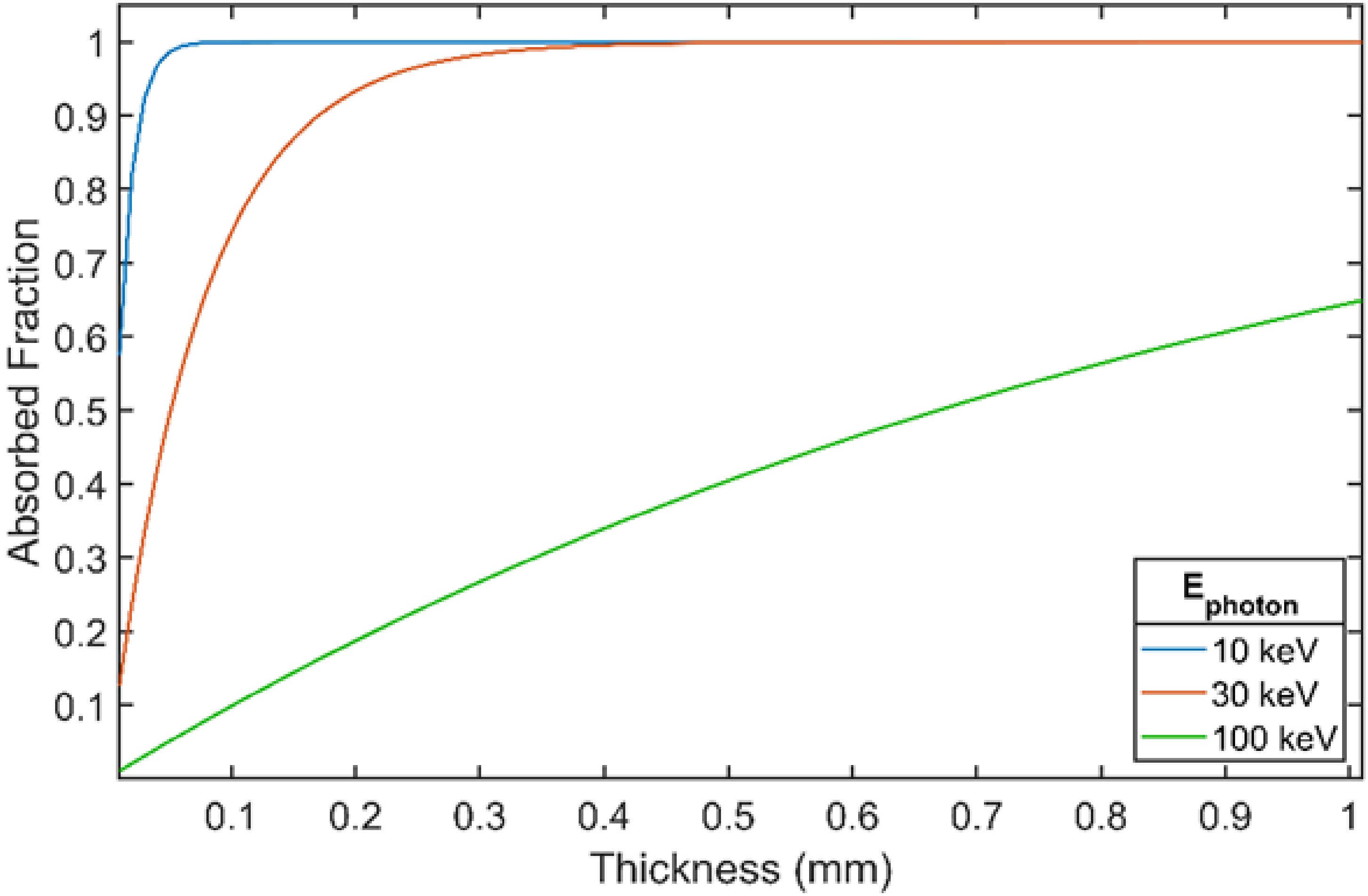
- with energies laying between 10 and 100 keV

ASTRA - project objectives

ASTRA will develop a versatile advanced detector system, from sensors and read-out electronics, to DAQ and controls, namely compact large-area CZT detectors to perform high precision photon energy measurements from 10-100 keV and up the MeV range, respectively.

- **Task 1:** Low energy detection region - energy range: 10 – 100 keV
- **Task 2:** High energy detection region - energy range: 50 – 1000 keV

Task1 – low energy detector



Low energy detection region

Fraction of absorbed radiation as a function of the CZT thickness for different photon energies.

- for 1 mm thick CZT
  efficiency at 30 keV ~100%;
  at 100 keV ~ 65%

Task1 – low energy detector

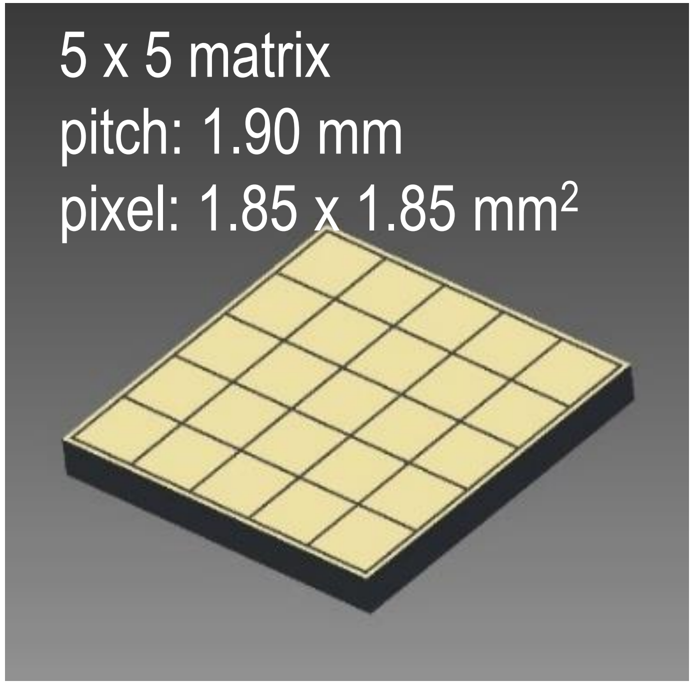
Pixel matrix design

Advantage

- The weighting potential is focused in a small region under the pixel.
- Possible effects due to crystal inhomogeneity can be corrected electronically.
- For a given flux, the number of events/channel is reduced (pileup effect is less probable).

Disadvantage

- A greater number of read-out channels is required.
- More events are shared among multiple pixels



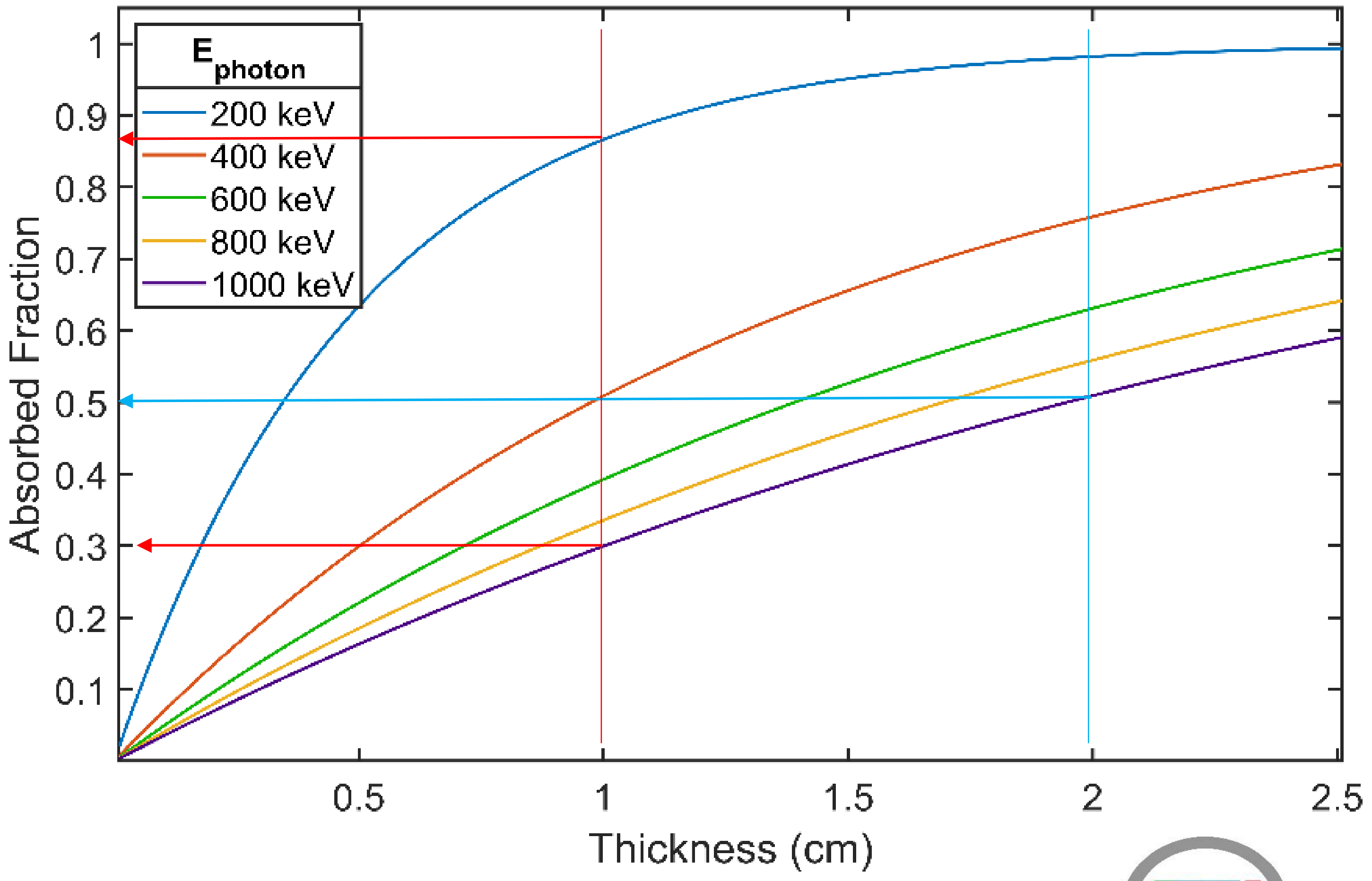
A possible detector design consists of a 5×5 matrix with a pitch of 1.9 mm (1850 μm pixel + 50 μm gap).

Task2 – high energy detector

For the high energy detector a complete absorption is not feasible.

The absorbed fraction as a function of the crystal thickness is shown in the figure for photons of different energies.

- ➢ 25 mm can be considered the maximum possible thickness since it represents the state-of-the-art for this class of detector.



Task2 – high energy detector

Material considerations

- For high energy detection CdTe cannot be an option since the polarization effect increases with the thickness and therefore we use CZT.
- From our experience, CZT from Redlen Technologies is one of the best materials to realize thick detector (>10 mm).
- The electron mobility and lifetime product ($\mu_e \tau_e$) allows a good CCE up to 25 mm.

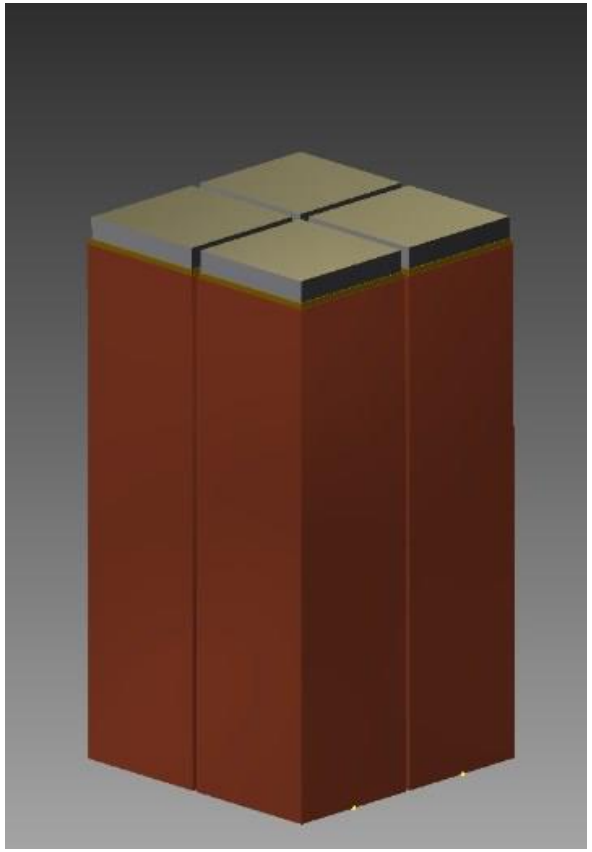
➢ The choice of the thickness has several consequences on the signal:
  - A strong electric field is required for collecting all electrons.
  - In case of multi-electrodes detector charge sharing effect will increase.
    ➢ Solution: Frisch grid detector has no charge sharing regardless the CZT thickness.

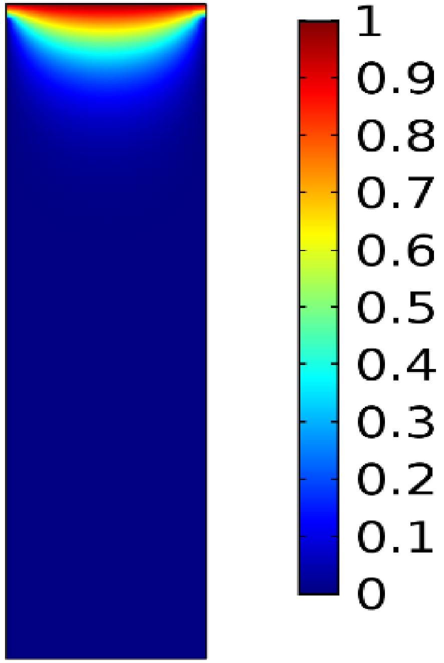
Task2 – high energy detector

Frisch-grid configuration

Due to the presence of non-collecting contacts on the lateral surfaces of the crystal, the weighting potential is focused in a small region under the collecting electrode.

The Frisch grid detector has only one collecting electrode, charge sharing is avoided in this type of geometry.



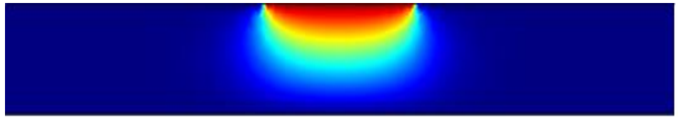


First low energy detector prototype

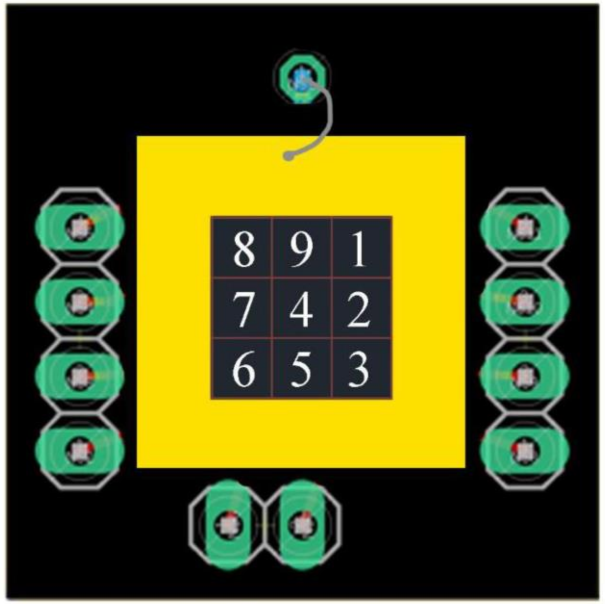
First low energy detector prototype
consisting of a 3×3 matrix with a pitch of 1.9 mm (1850 μm pixel + 50 μm gap), thickness 1.5 mm

Advantage

- The weighting potential is focused in a small region under the pixel.



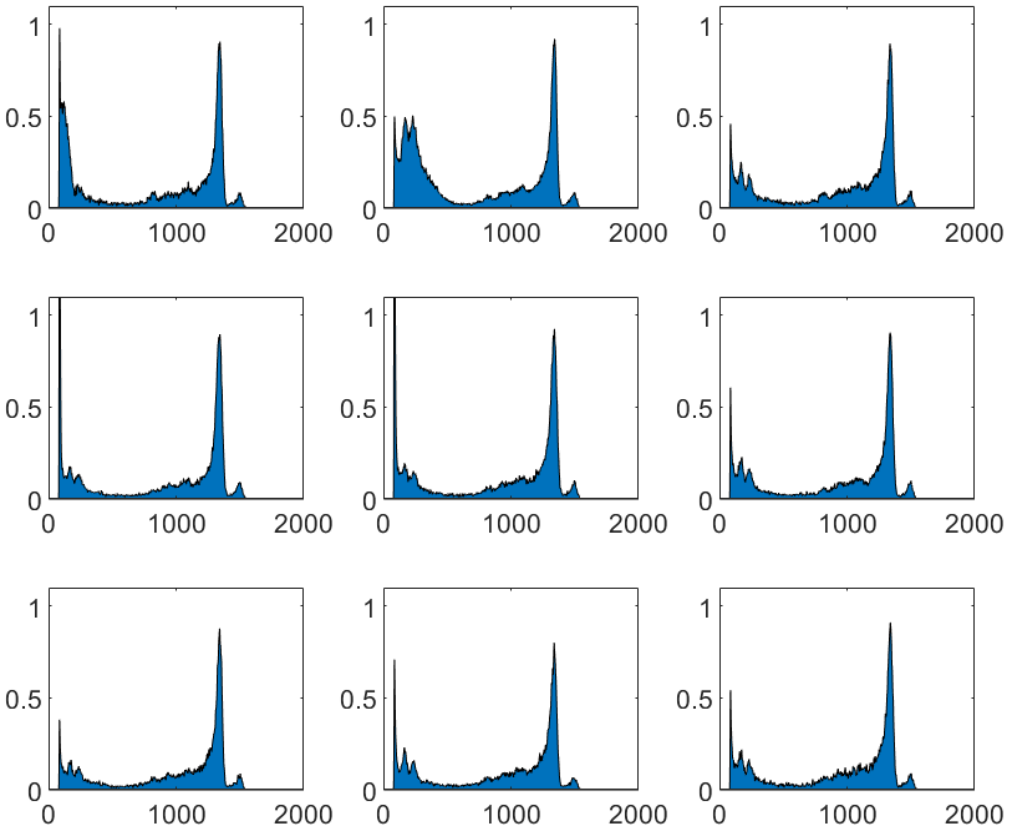
- Possible effects due to crystal inhomogeneity can be corrected with dedicated electronics.

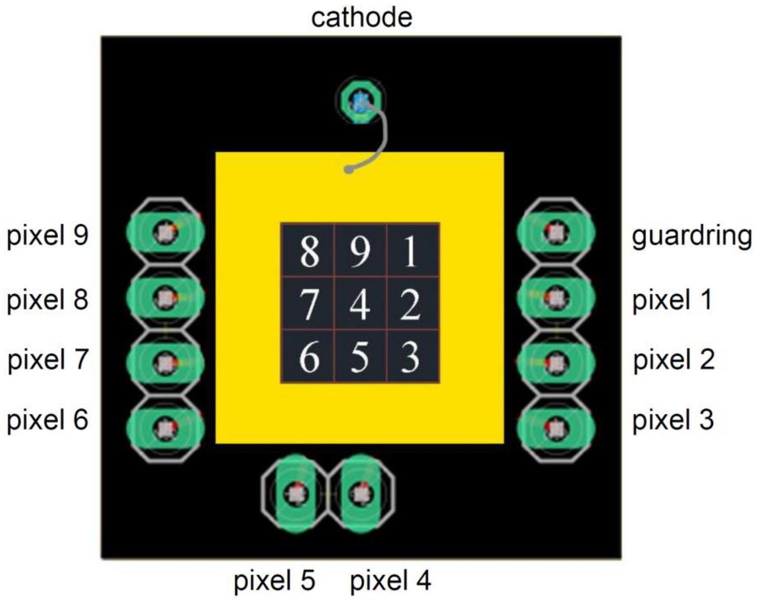


First low energy detector prototype

Spectroscopic performance, with Co57:

of a 3x3 matrix with pixel sizes of 1.85x1.85 mm^2 and a thickness of 1.25 mm





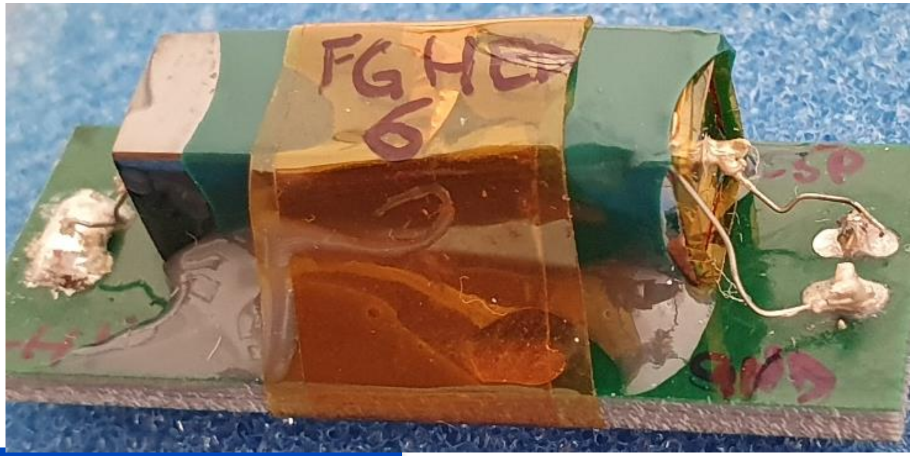
FWHM at 122 keV with Co57

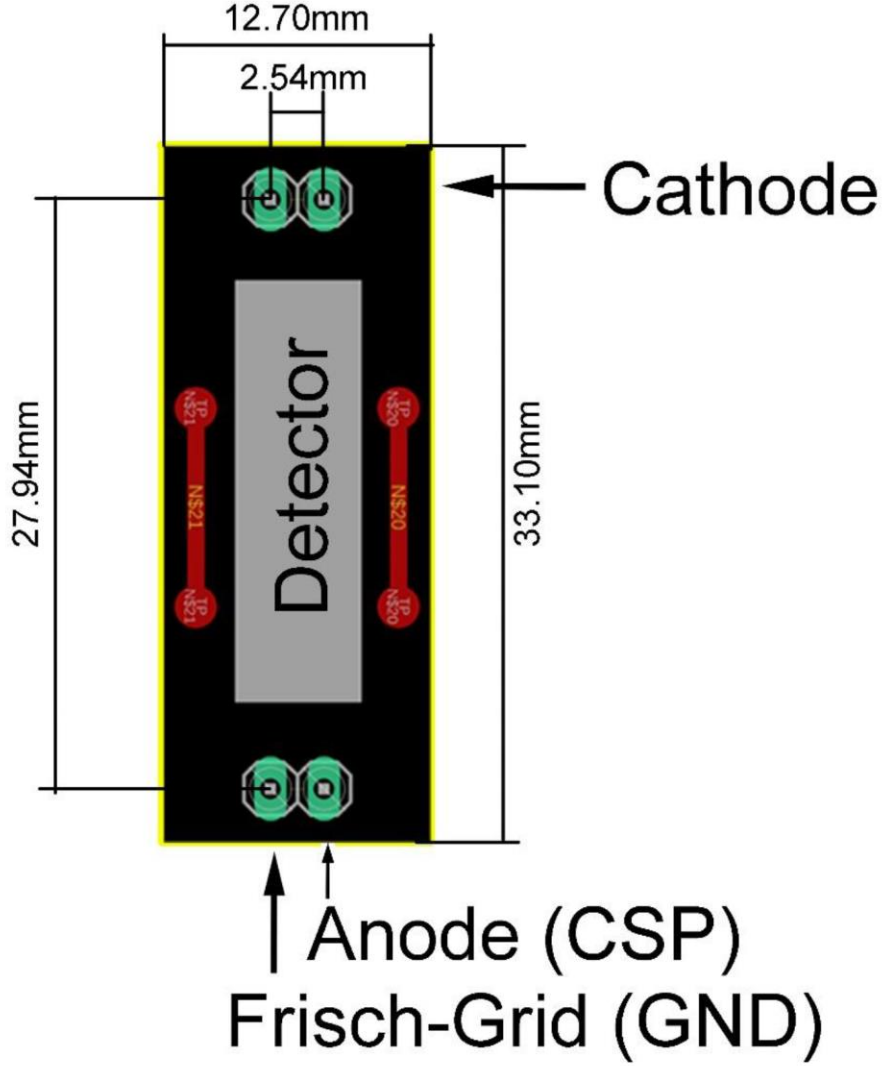
3.6%	3.8%	4.3%
4.2%	4.4%	3.8%
3.6%	4.5%	3.6%

First high energy detector prototype

Fabrication:

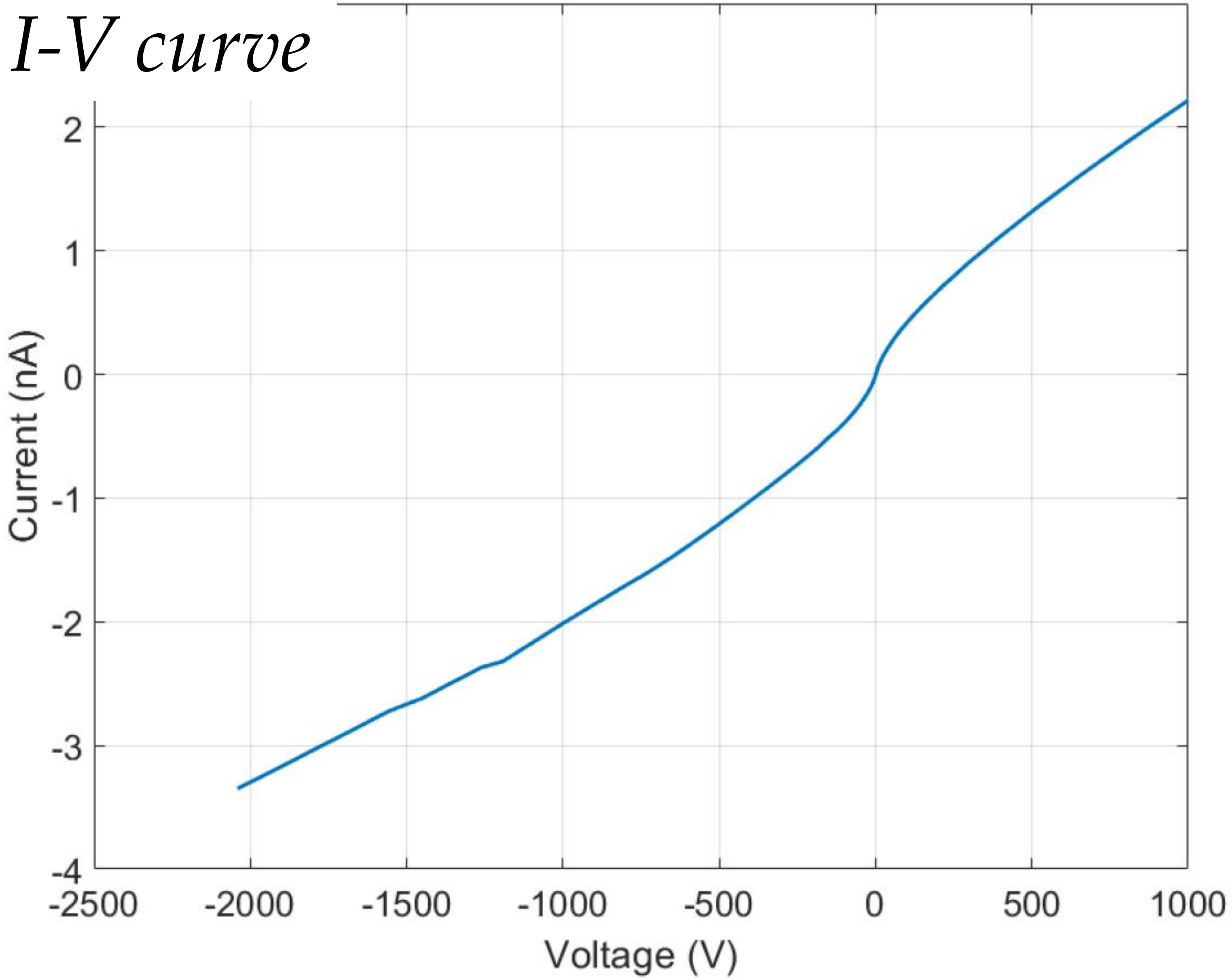
- A 19.4x19.4x6 mm^3 Redlen crystal was cut in dimensions of **6x6x19.4 mm^3**
- Lateral surfaces of sample were covered with Kapton foils and, at the anode side, a 5mm Cu tape was coiled around the samples (Frisch-grid).
- The CZT was bonded on a dedicated Diclad PCB



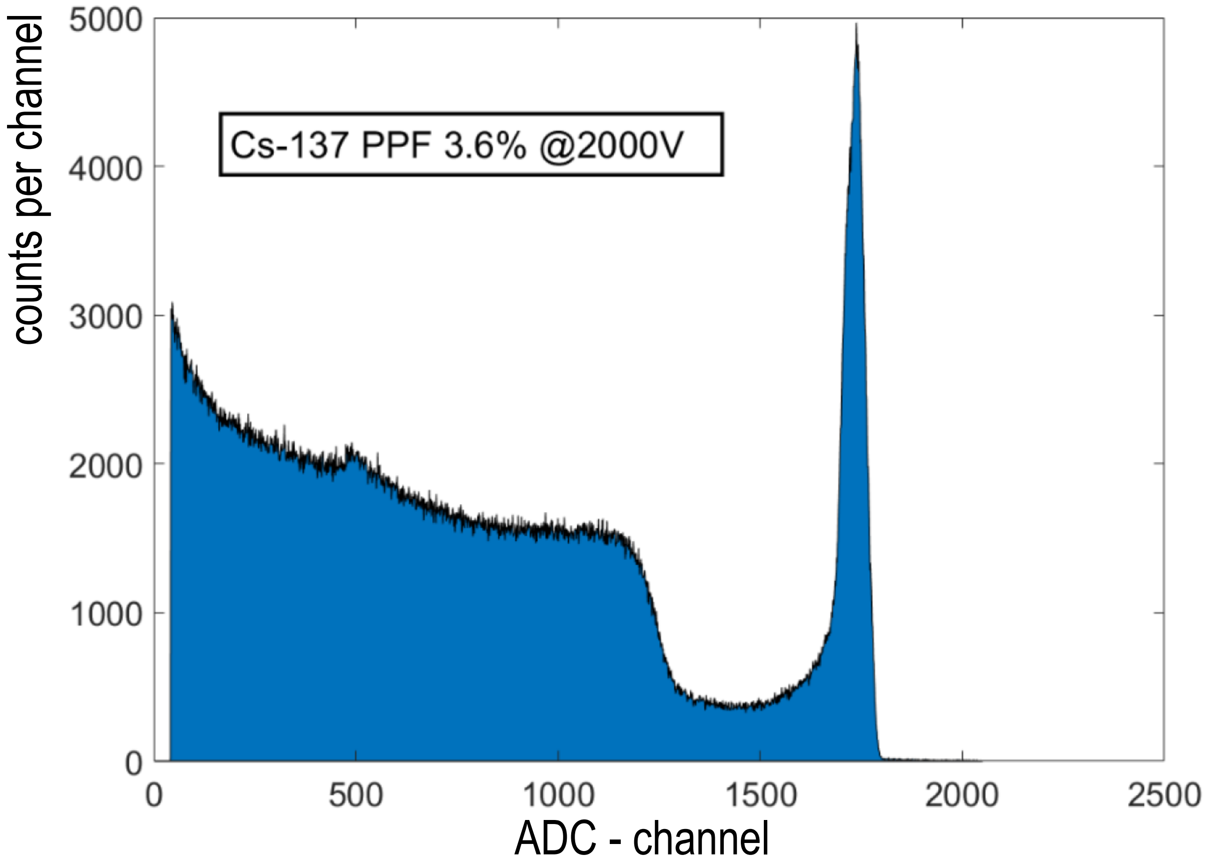


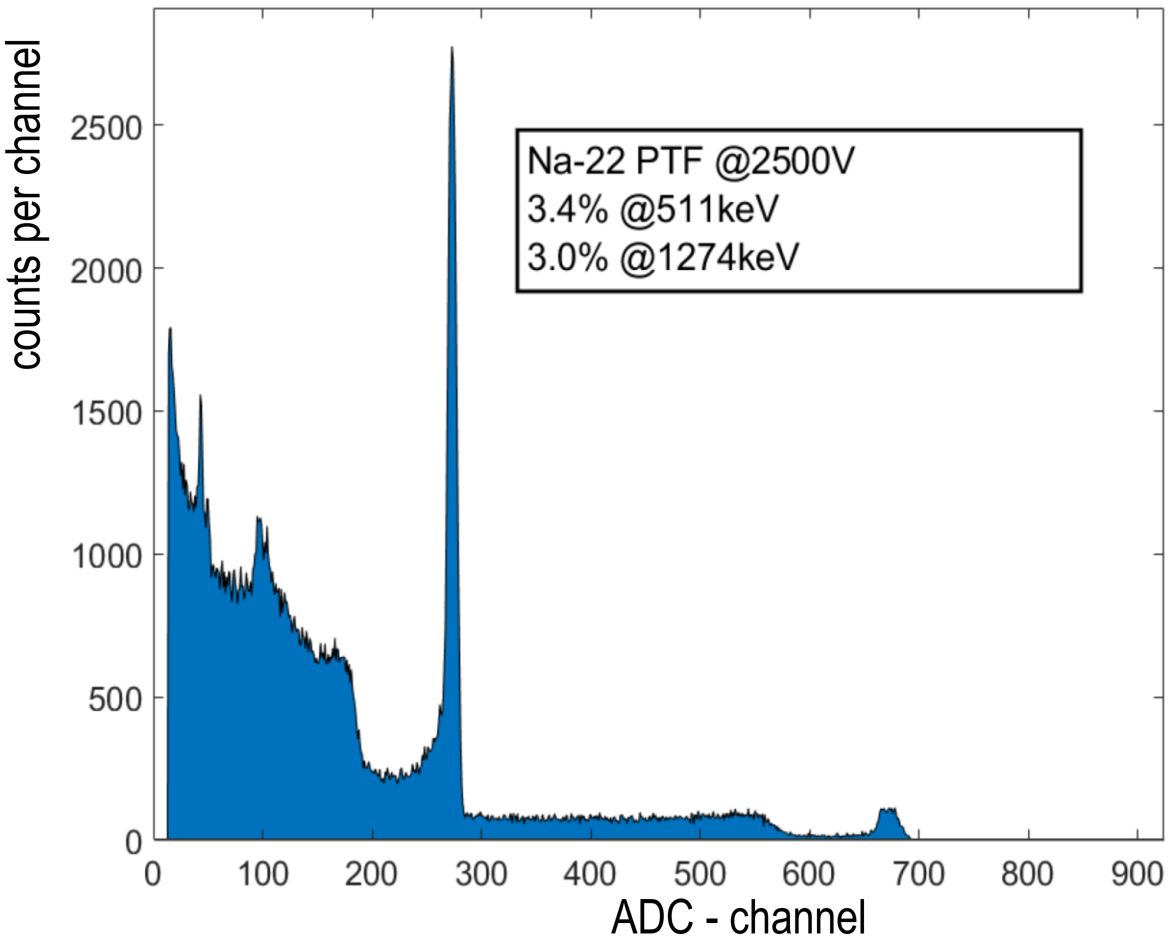
High energy detector I-V curve

The very low leakage current is remarkable: about 3.2nA at - 2000V



High energy detector spectroscopy





Summary

First low and high energy **CZT** prototypes were successful tested at SMI, CNR and LNF

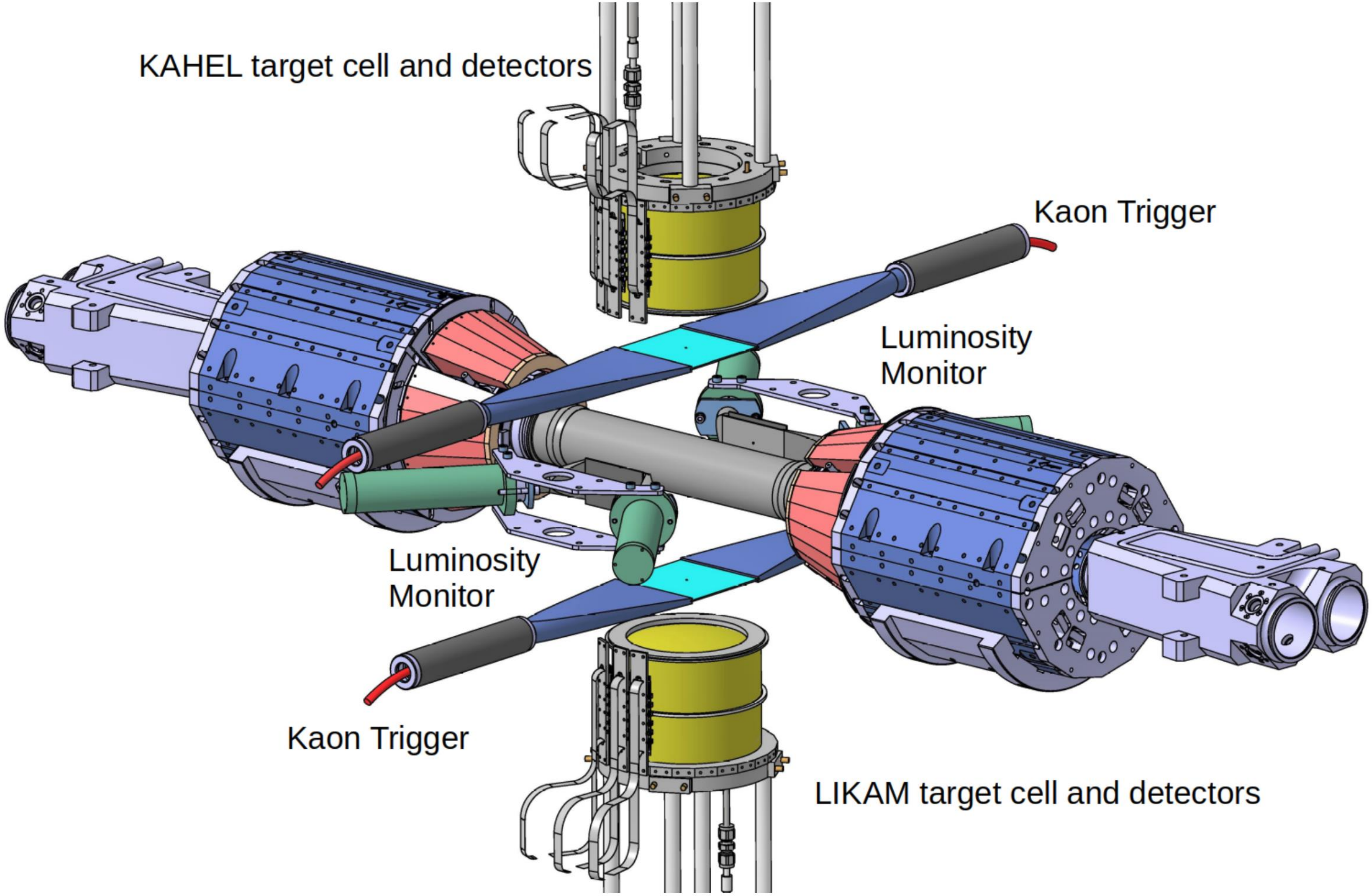
- Master thesis at SMI ("Characterization of CdZnTe Detectors") finished
- new Master thesis started at Sept. 2021

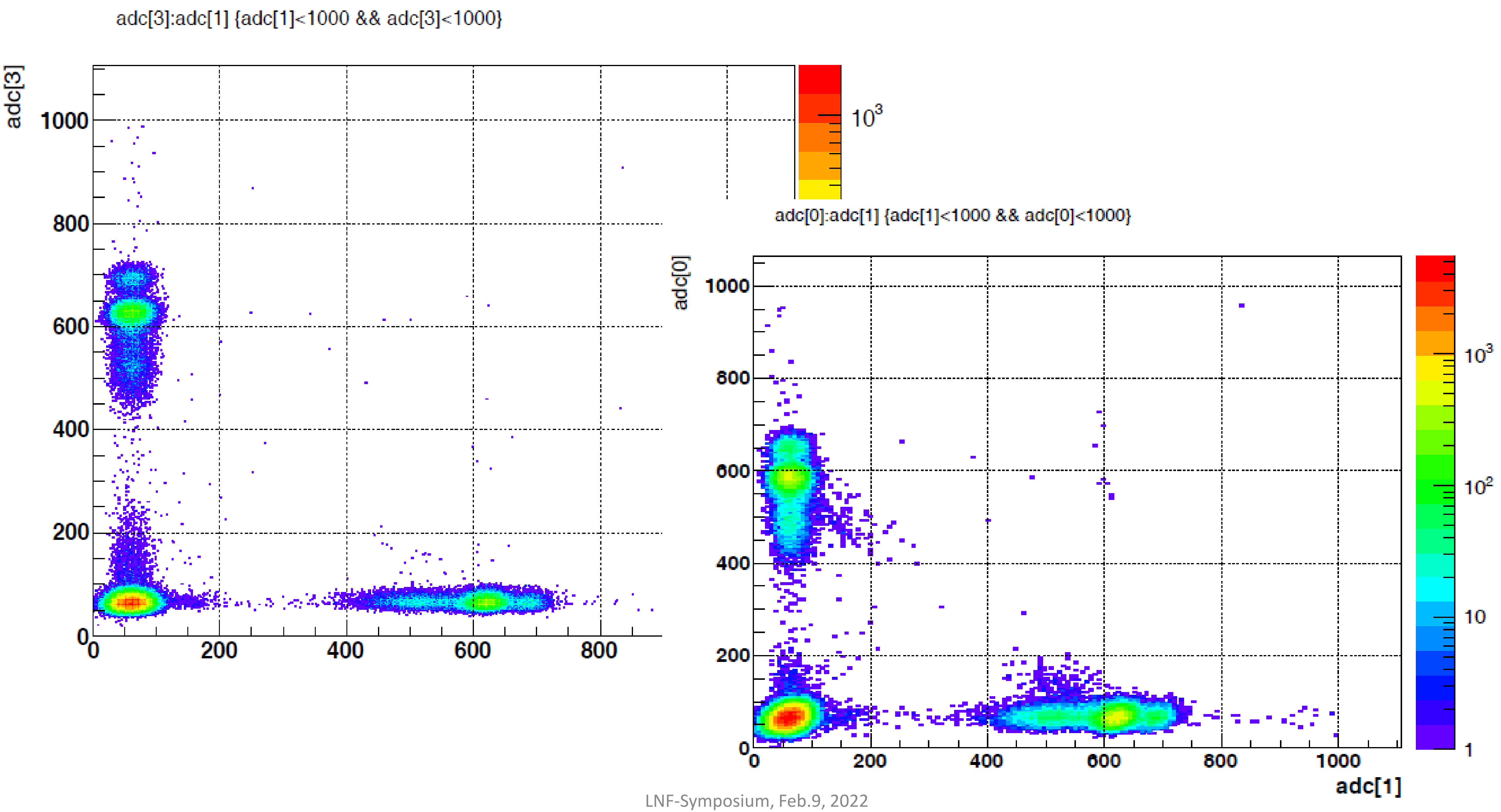
Readout electronic and DAQ

- further optimisation on preamplifier and DAQ are ongoing, by POLIMI and UZ
  - PhD thesis at POLIMI

First tests with beam (parasitic to SIDDHARTA-2) for low and high energy prototypes are under preparation!

Thanks


KAHEL target cell and detectors
Kaon Trigger
Luminosity
Monitor
Luminosity
Monitor
Kaon Trigger
LIKAM target cell and detectors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