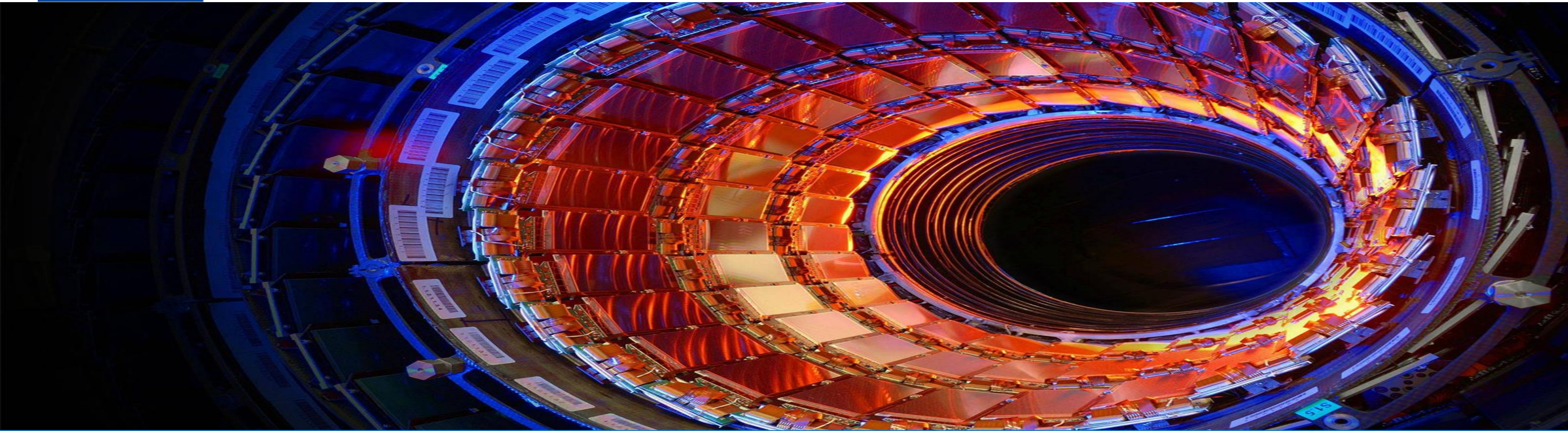


JRA8 - ASTRA

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

Johann Zmeskal, SMI

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

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

JRA8 - project objectives

ASTRA will develop a versatile advanced detector system, from sensors and read-out electronics, to DAQ and controls, namely compact large-area CdTe and CdZnTe 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

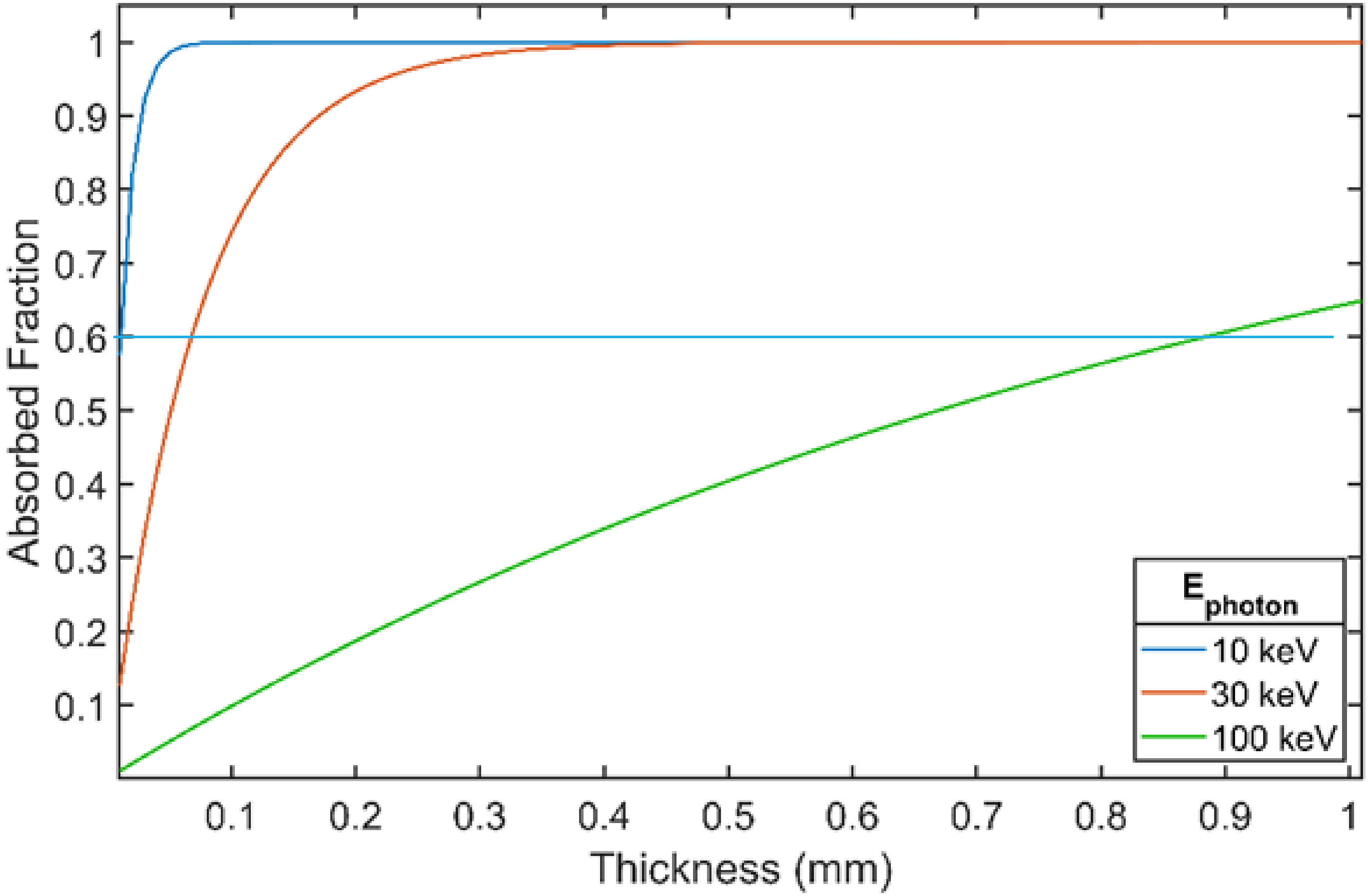
Task 2: High energy detection region - energy range: 50 – 1000 keV

JRA8 – detector simulation

CNR-IMEM has developed a simulation system using first principle calculations that allows to provide detector engineering parameters, which are mandatory to reach the desired performance.

CNR-IMEM performed several simulations in order to identify the best detector shape and electrodes configuration for both energy configurations.

JRA 8 – Task 1, detector simulation



Low energy detection region

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

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

JRA 8 – Task 1, detector simulation

Material consideration, geometry

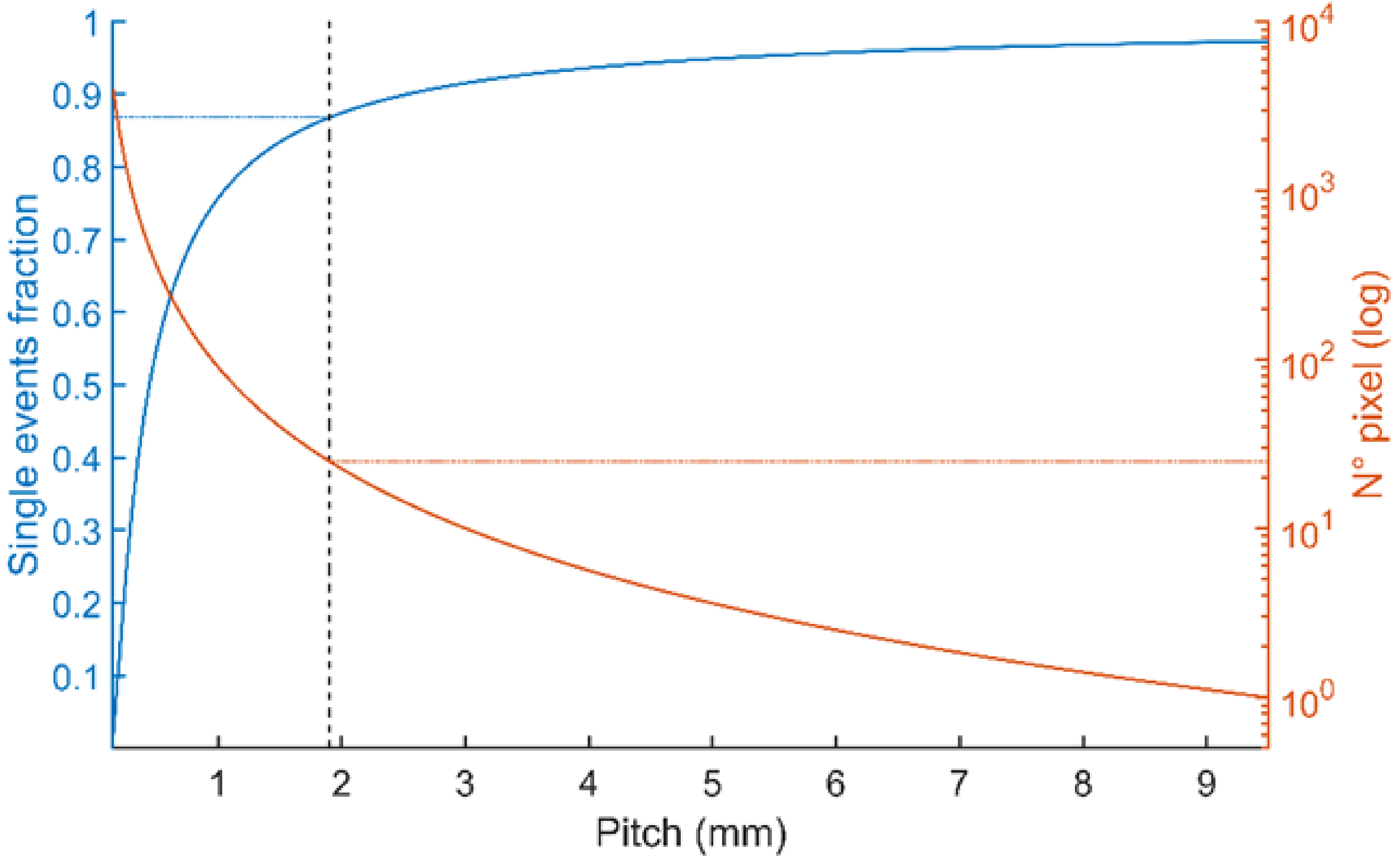
- For a proposed thickness of 1 mm, both CdTe and CZT guarantee good overall performances.
  - A detector thickness of 1 mm guarantees a full charge collection efficiency (CCE) for CdTe and CZT materials, due to high quality a single pixel detector may be an option, especially to evaluate material and contact performances
  - **4 pieces of CdTe with a single pixel anode are ordered**
- A pixelated structure would allow to adjust the gain of each pixel in order to compensate a possible inhomogeneity (*e.g.* different Te concentration or different contact quality), leading to an improved energy resolution.
- The ideal pixel dimension depends on several factors which also concerns the electronic read-out specifications, bonding step and charge sharing.

JRA 8 – Task 1, detector simulation

Pixelated anode:

Fraction of events which are not shared among pixels as a function of the pitch for a 25 keV beam (blue).

Number of pixels as a function of the pitch for a 1 cm^2 detector (red).



JRA 8 – Task 1, detector simulation

Pixel matrix design

Advantage

- The weighting potential is focused in a small region under the pixel ("*small pixel effect*").
- 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).

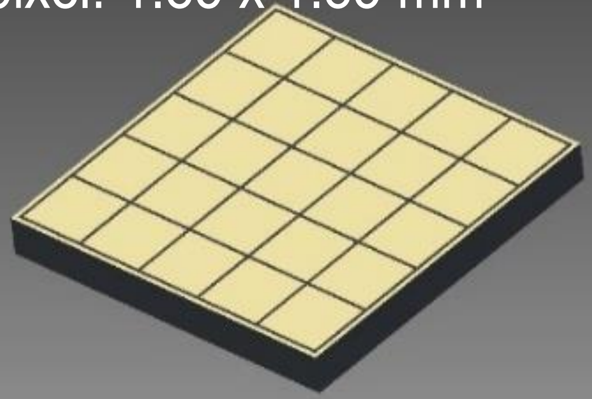
Disadvantage

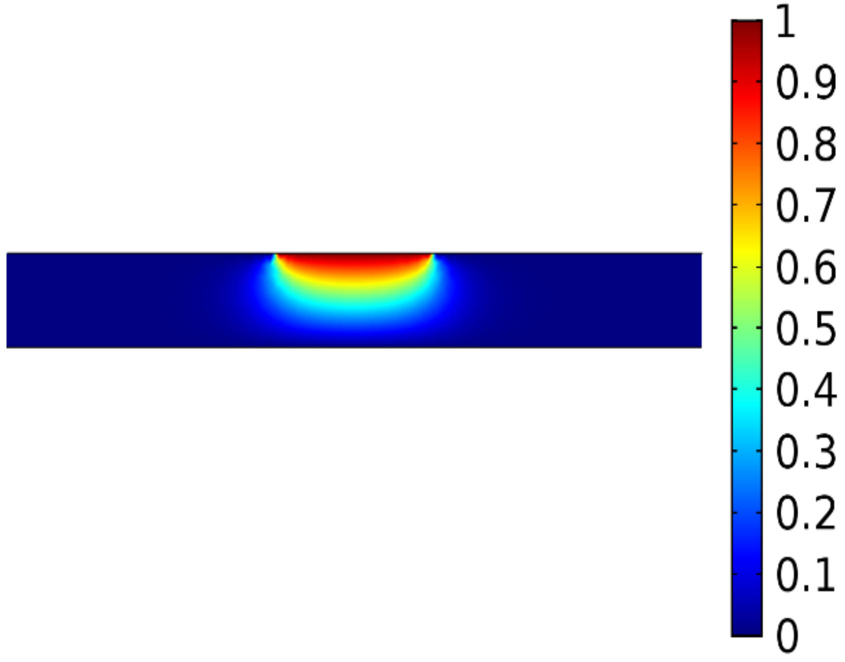
- A greater number of read-out channels is required.
- More events are shared among multiple pixels because of the finite dimension of the charge cloud, which results in an incomplete charge collection (charge sharing).
- Bonding can be an issue.

JRA 8 – Task 1, detector simulation

A possible detector design consists of a 5×5 matrix with a pitch of 1.9 mm (1850 μm pixel + 50 μm gap). The weighting potential (a full area cathode is assumed) for the central pixel is shown.

5 x 5 matrix
pitch: 1.90 mm
pixel: 1.85 x 1.85 mm^2





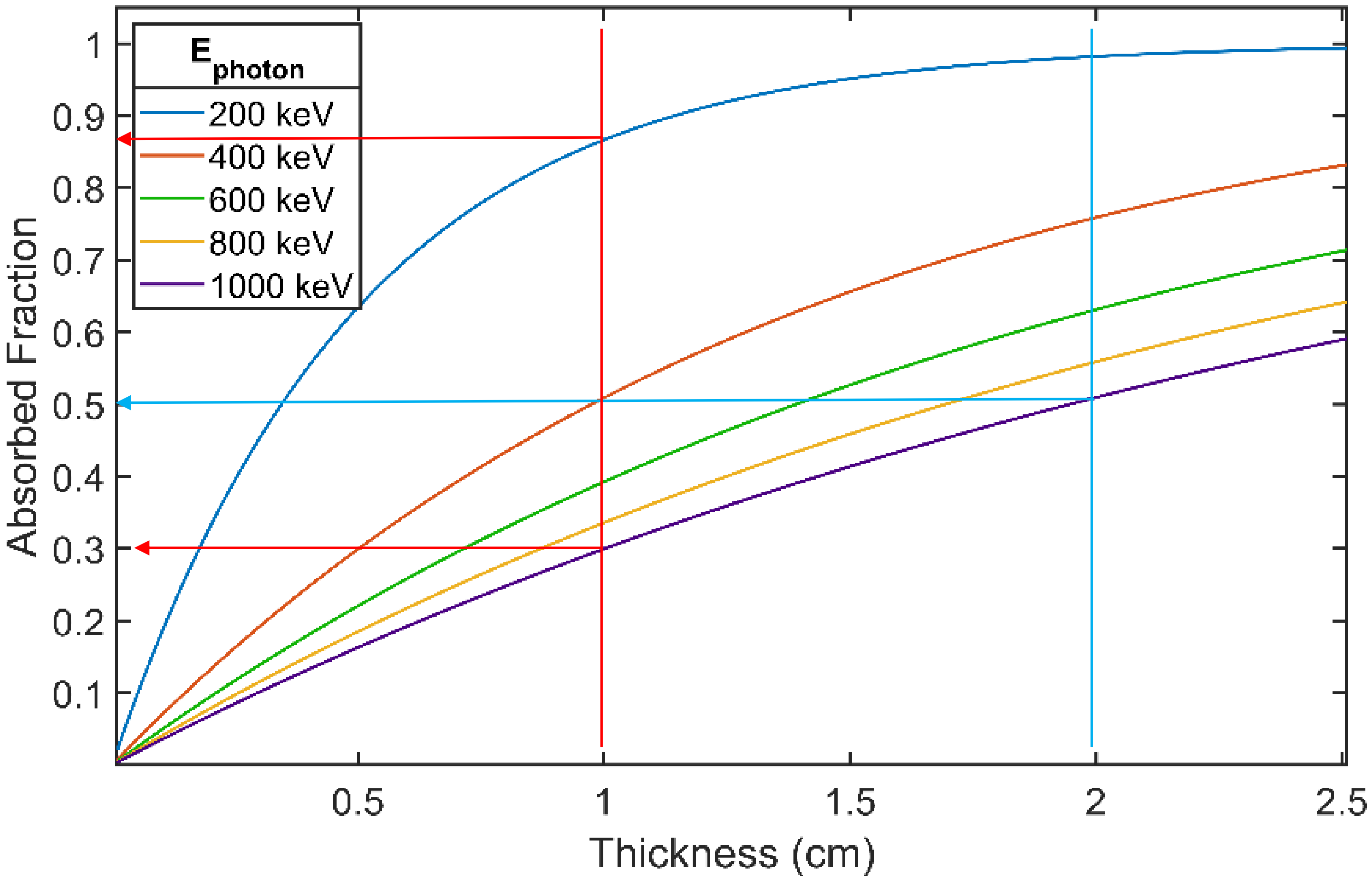
- **10 pieces of CZTs with an 8 x 8 matrix (same pixel size) are ordered**

JRA 8 – Task 2, detector simulation

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.



JRA 8 – Task 2, detector simulation

Material considerations

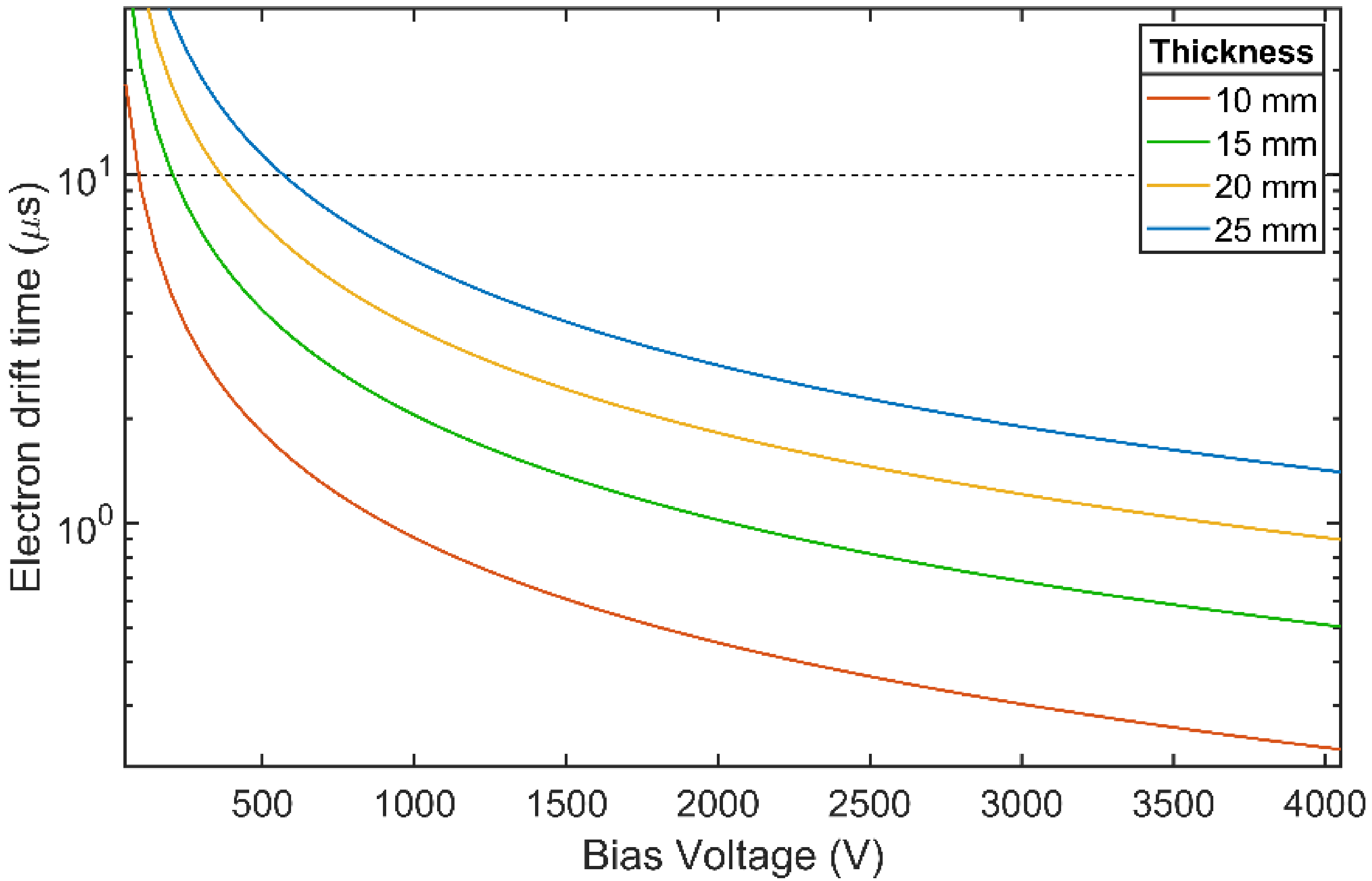
- For high energy detection CdTe cannot be an option since the polarization effect increases with the thickness and therefore we will use CZT.
- From our experience, CZT from Redlen Technologies is one of the best materials to realize thick detector (>10 mm).
- The electron mobility and lifetime product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

➢ The choice of the thickness has several consequences on the signal induction.
  - 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.

JRA 8 – Task 2, detector simulation

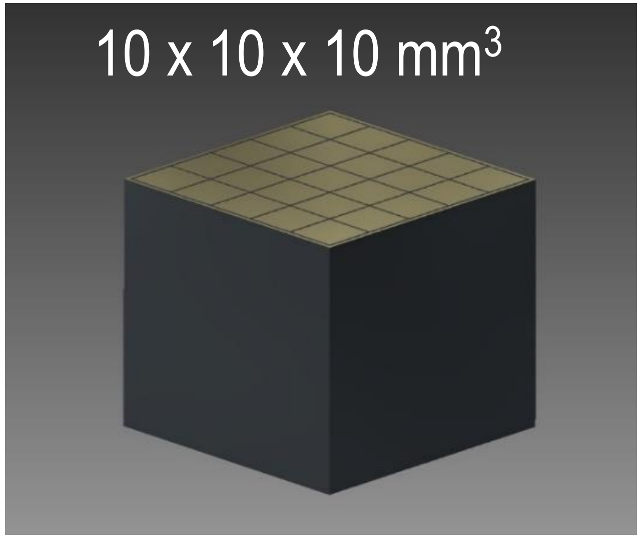
Electron drift time as a function of the applied bias voltage for CZT crystal of different thickness.

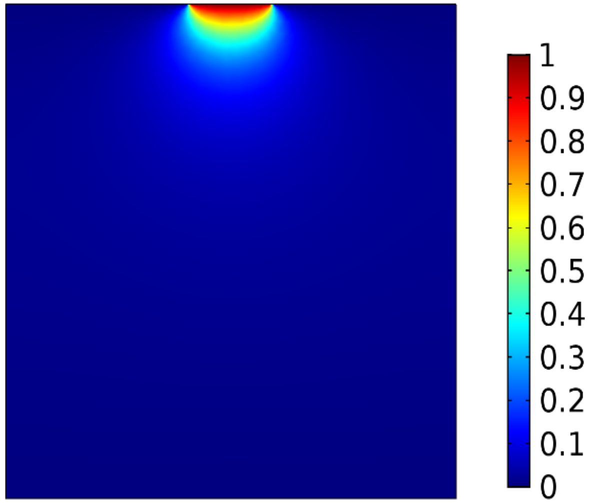
The dashed line represents the electron lifetime in CZT.



JRA 8 – Task 2, detector simulation

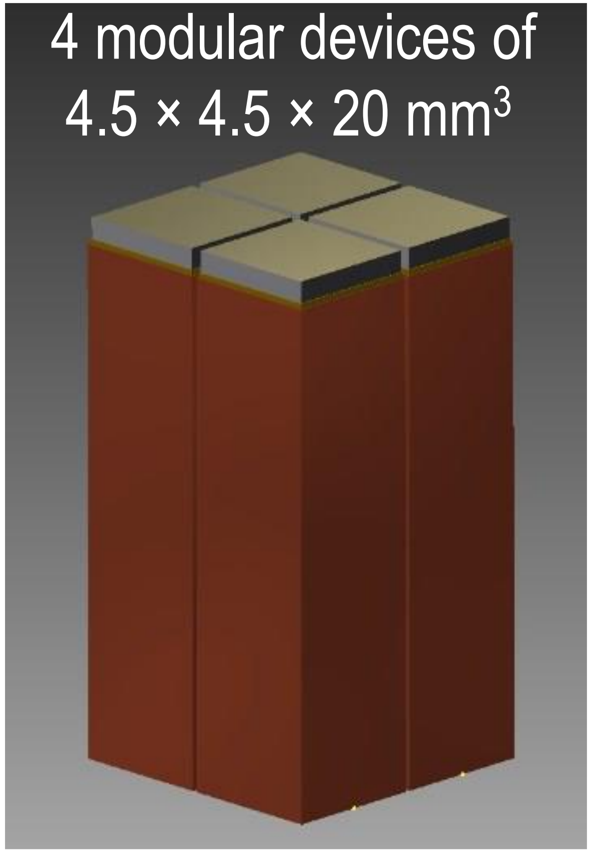
The same geometry as for the low energy detector could be used. The weighting potential of the pixels is sufficiently focused in a small region under the pixel for max.10 mm thick detectors. Disadvantage: for thick detectors the charge clouds have more time to spread because of diffusion and Coulomb repulsion. Therefore the charge sharing effect will increase.

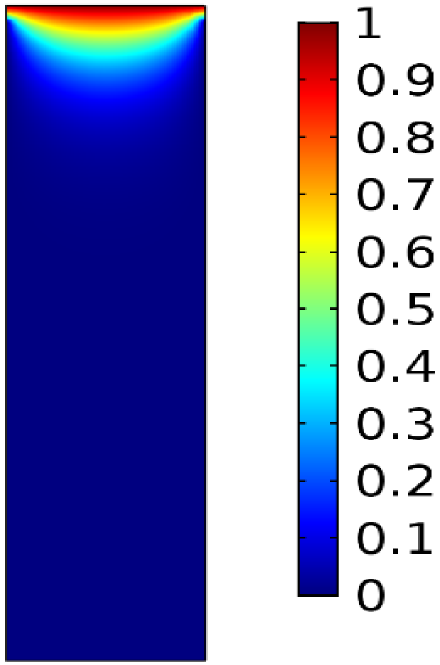




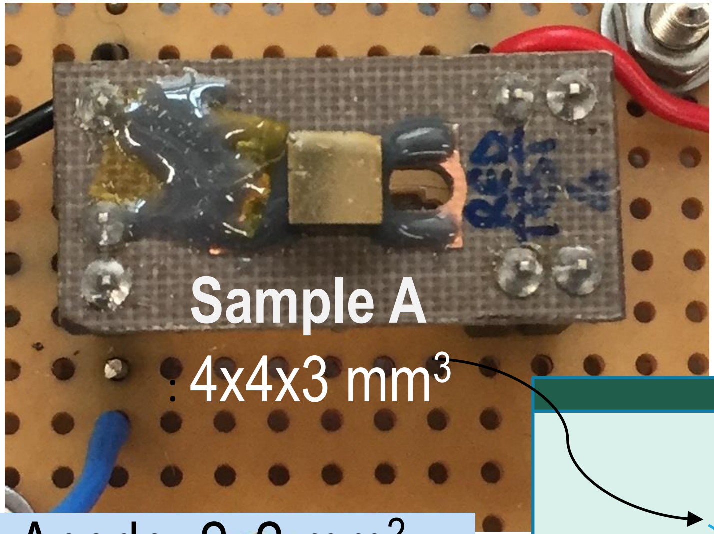
JRA 8 – Task 2, detector simulation

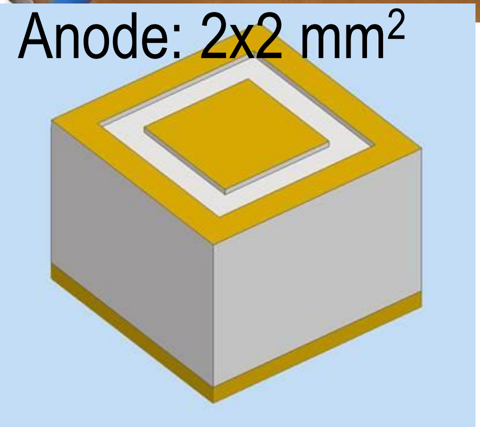
Frisch-grid configuration
Due to the presence of non-collecting contacts on the lateral surfaces of the crystal, the weighting potential is focused in a small region under the collecting electrode.
The Frisch grid detector has only one collecting electrode, charge sharing is avoided in this type of geometry. thickness.

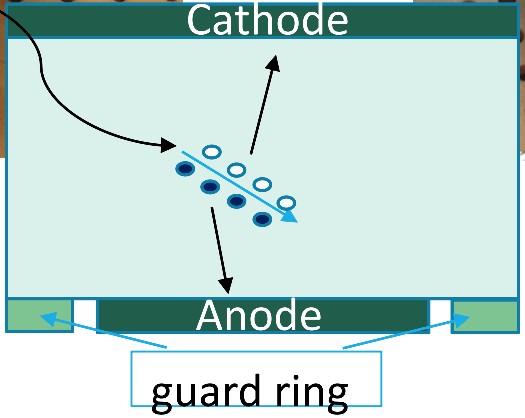


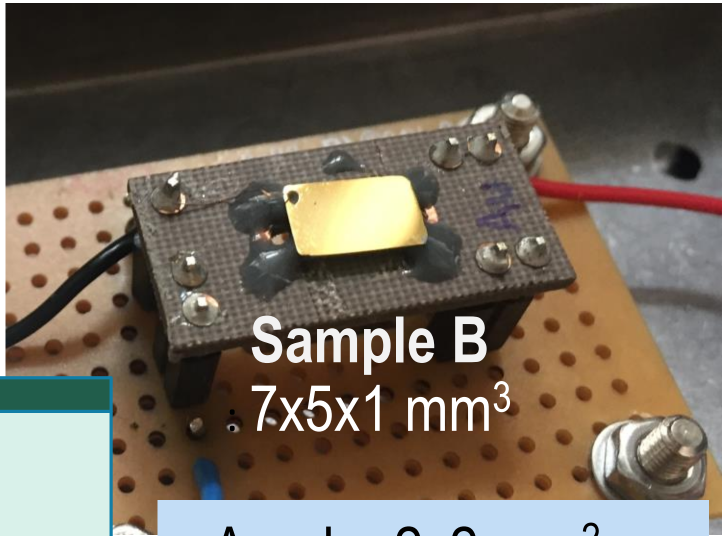


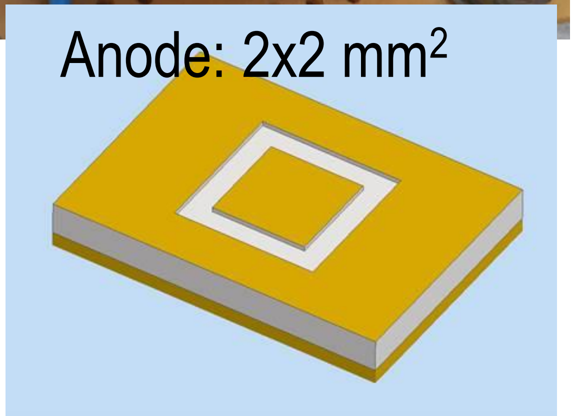
JRA 8 – prototype testing

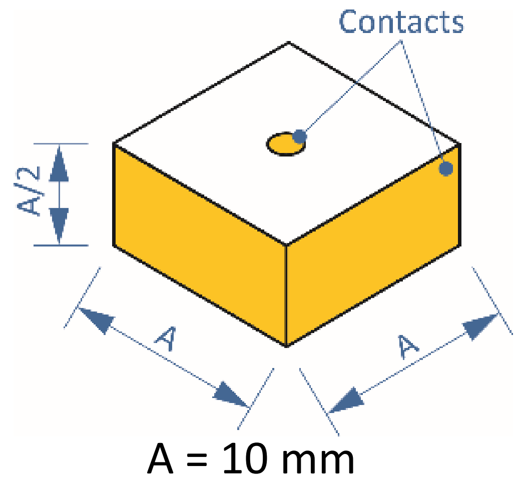




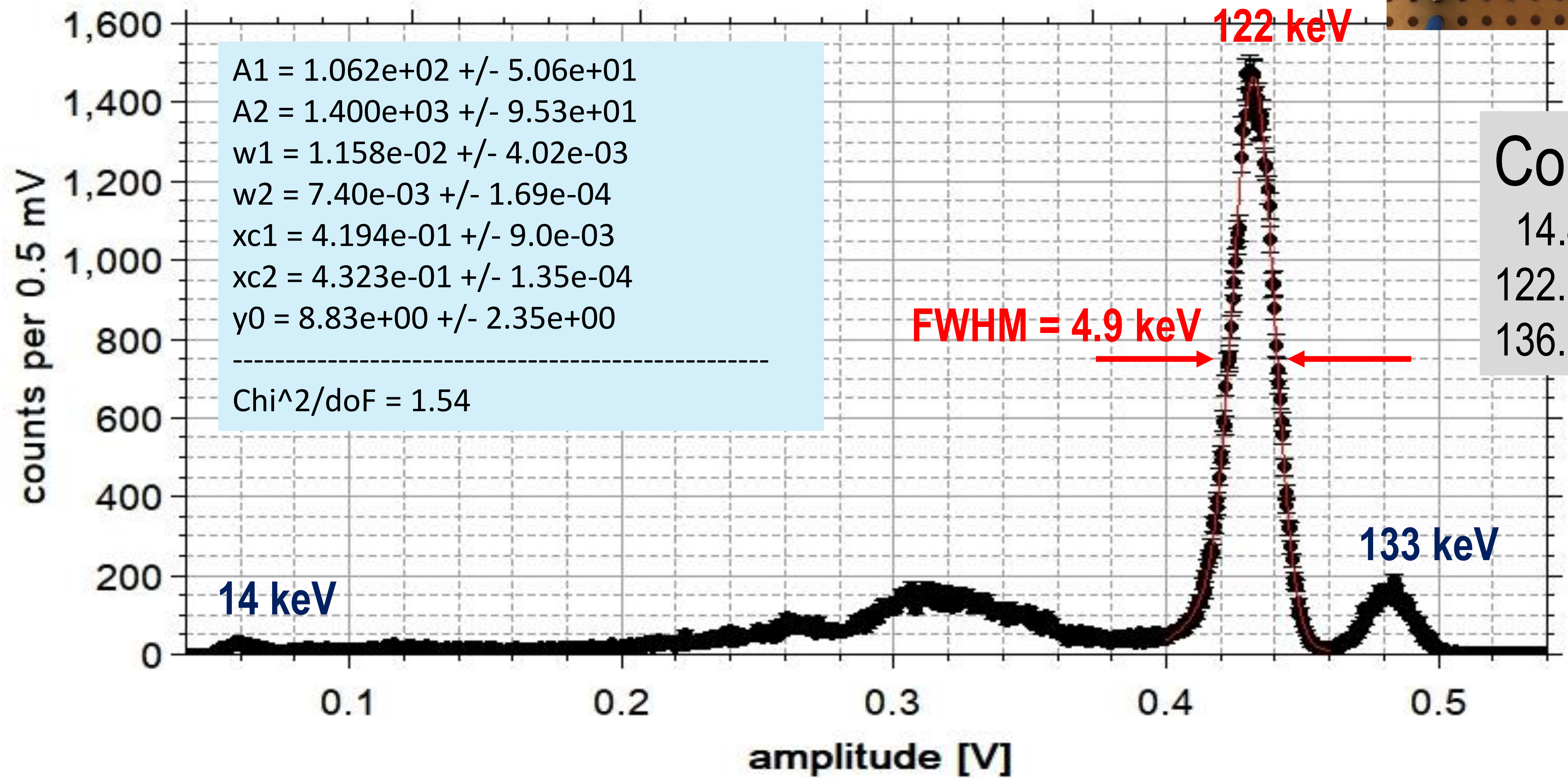




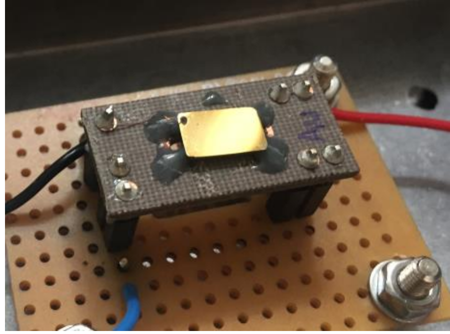




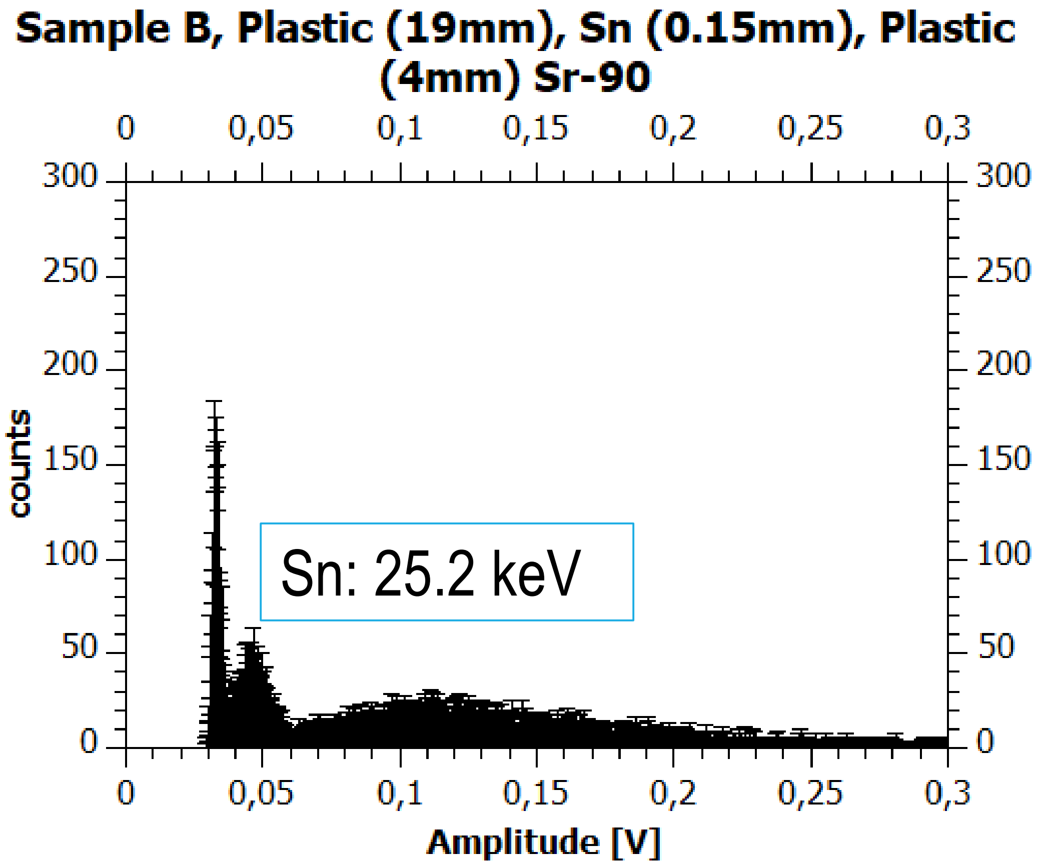
Sample A – Co57 bias: 1000 V



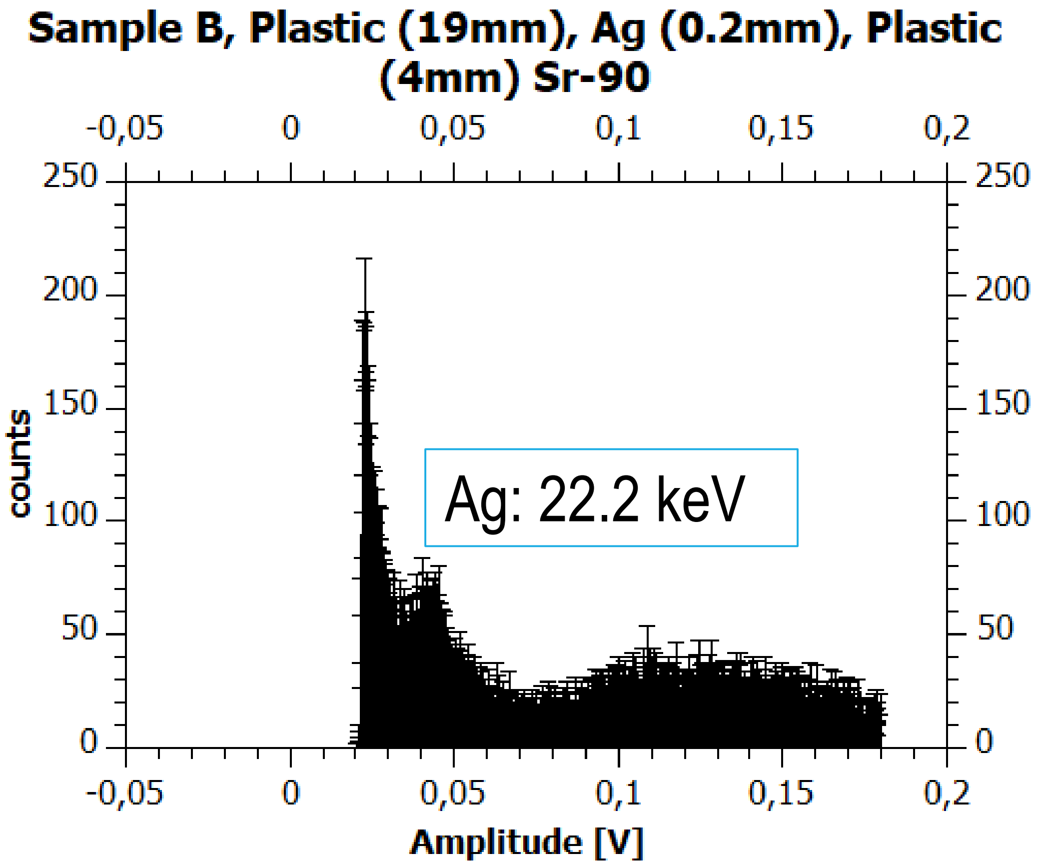
Co57
14.4 keV
122.0 keV
136.5 keV



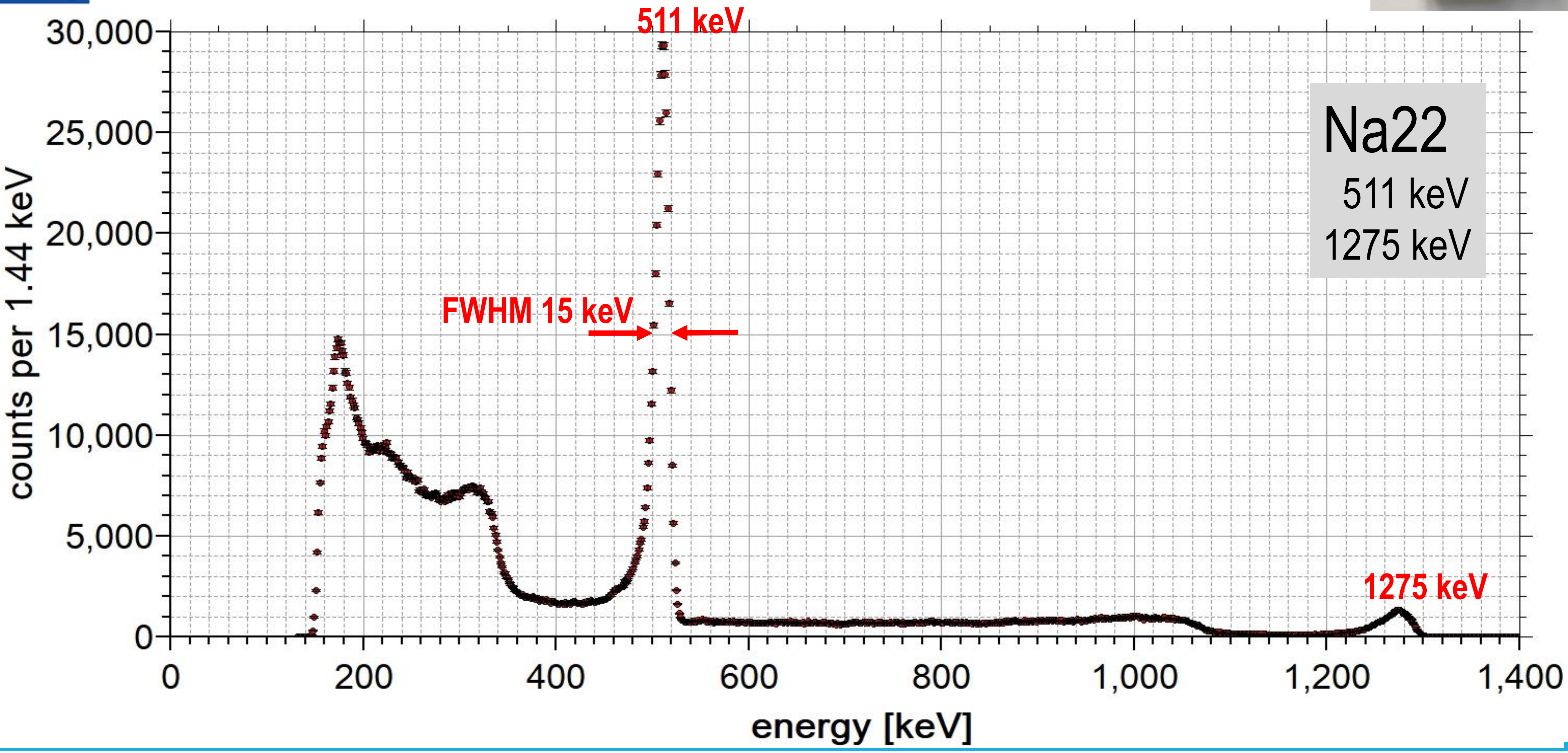
Sample B – foil-stack activated Sr90



foil stack activated with Sr90



CZT-500 – Na22 bias: 600 V



Milestone

Milestone number	Milestone name	Lead beneficiary	Delivery month from Annex I	Delivered (yes/no)	Comments
MS56	CdTe crystal characterized	2 - OEAW	8	yes	report
MS58	CdZnTe crystal characterized	2 - OEAW	8	yes	report

Summary

Simulation performed by CNR-IMEM to obtain best detector performances

- using their results new CdTe and CZT crystals are purchased

First **CZT** prototypes tested at SMI and LNF

- Master thesis at SMI ("Characterization of CdZnTe Detectors")

CdTe prototypes are under test at CNR-IME

Readout electronic and DAQ

- further optimisation on preamplifier and DAQ are ongoing, by POLIMI, UZ and UJ

Test setup for cooling CZT crystals as well as part of the preamplifier electronics to 120 K is under preparation at SMI

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, determination of the kaon-nucleus potential.

Medical applications:

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