The 3CaTS project: room temperature solid state CdZnTe detectors for BNCT-SPECT

Curso Intensivo "Terapia por Captura Neutronica en Boro. Aspectos Interdisciplinarios para la Concreción de una Radioterapia Selectiva" - Facultad de Ingeniería y Ciencia Exactas y Naturales, Universidad de Favaloro

Modulo :: Instrumentación y Detección - 05/05/2018

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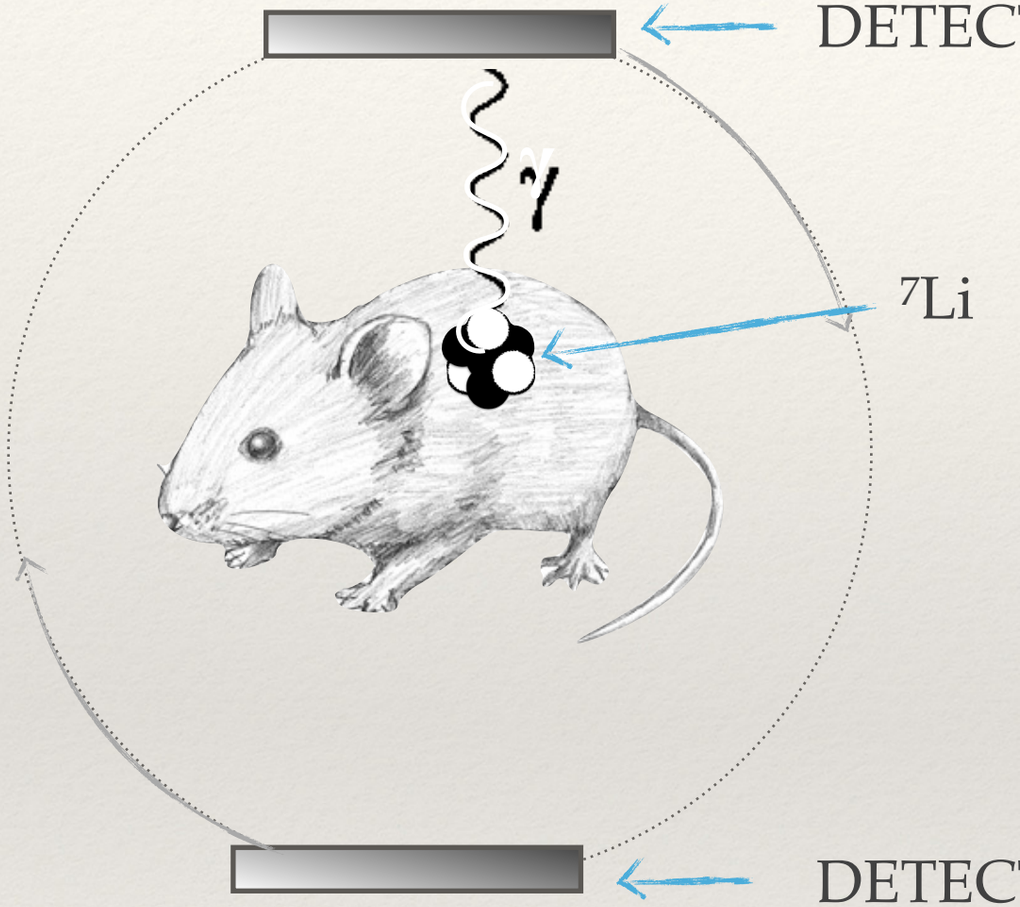
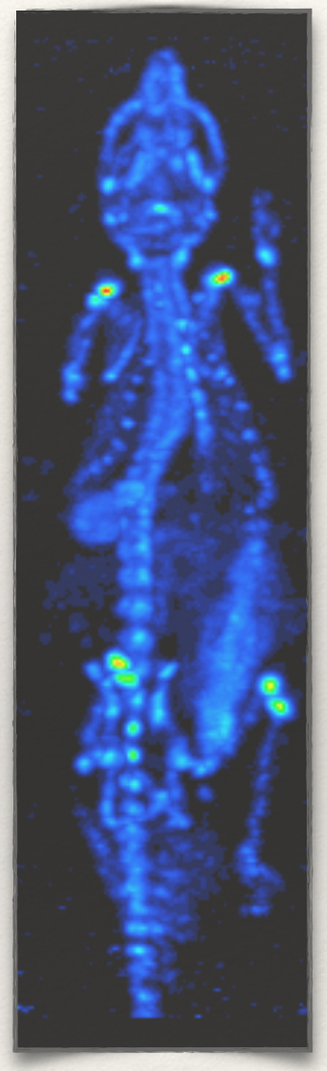
Boron imaging via SPECT



Live photon counting
proportional to ^{10}B
concentration
spatial distribution



https://commons.wikimedia.org/wiki/File:Mouse02-spect.gif#/media/File:Mouse02-spect.gif

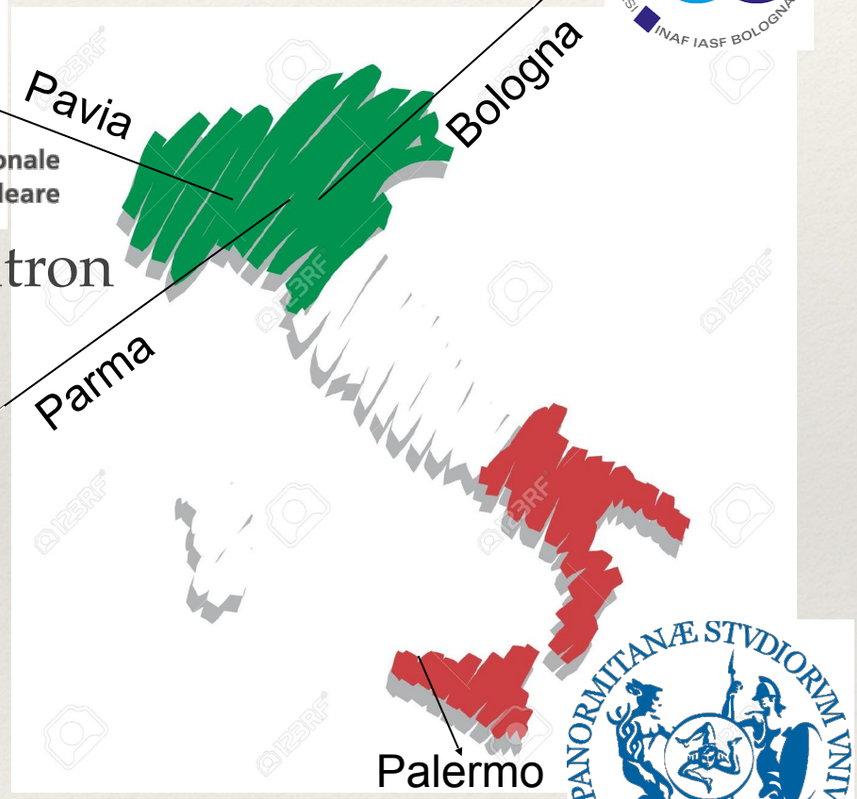
$$D \propto \int n_B \sigma \phi dV$$

3CaTS (3D Cadmium-Zinc-Telluride spectra-imager for X and gamma-ray applications) project

Astronomy and image reconstruction

Istituto Nazionale di Fisica Nucleare

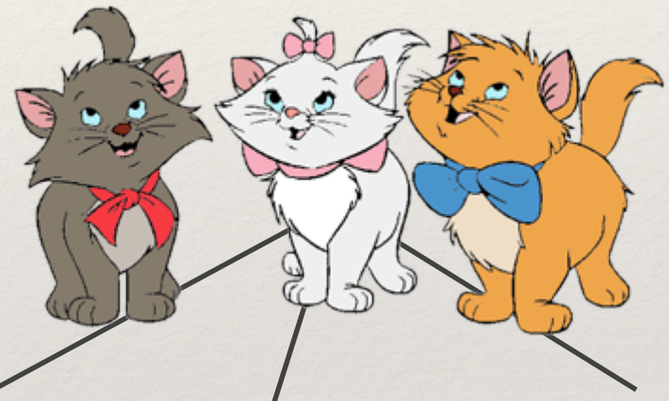
BNCT and neutron facility



Detector procurement & costumization

Customable, digital & fast electronics

Aims of the project:



SPECT-BNCT

fine spectroscopy for fundamental physics

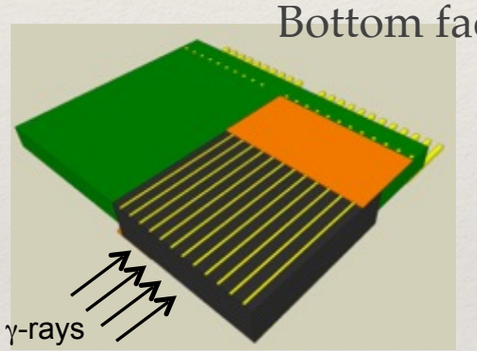
hard X and soft gamma rays astronomy

3CaTS (3D Cadmium-Zinc-Telluride spectra-imager for X and gamma-ray applications) project

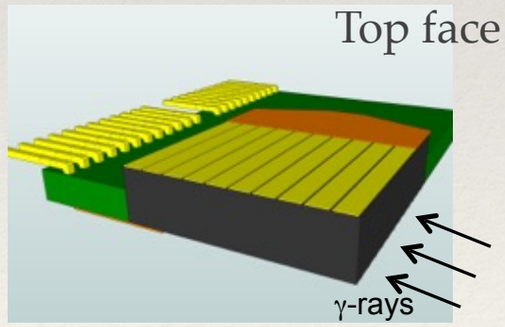
CZT single unit of detection:
20x20x5 mm^3,
planar transversal filed (PTF),
orthogonal strip electrodes +
DOI analysis for 3D sensitivity

4 CZT stack prototype,
20x20x20 mm^3,
120 read-out channels

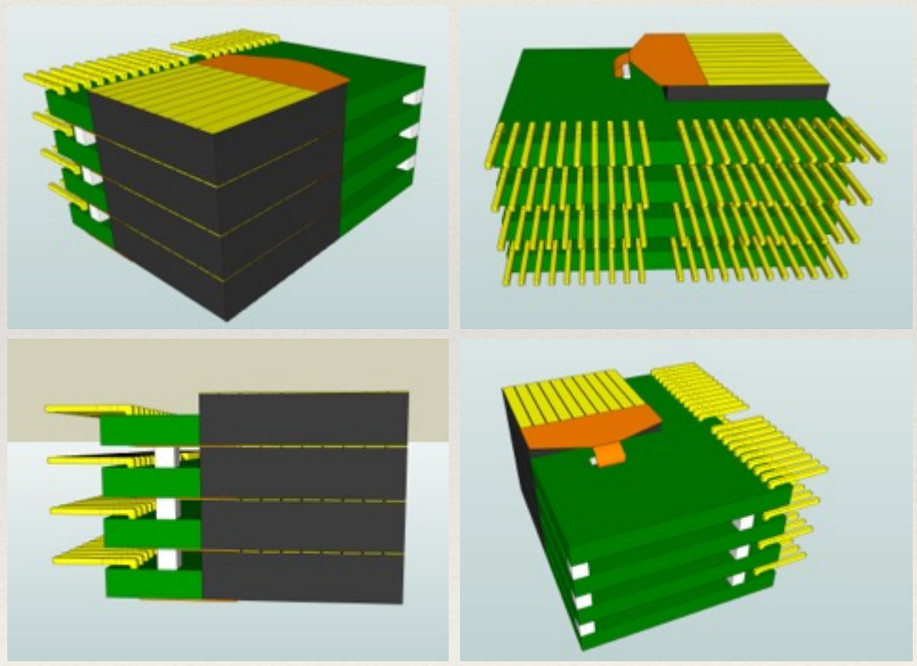
Bottom face(*)



Top face



x4

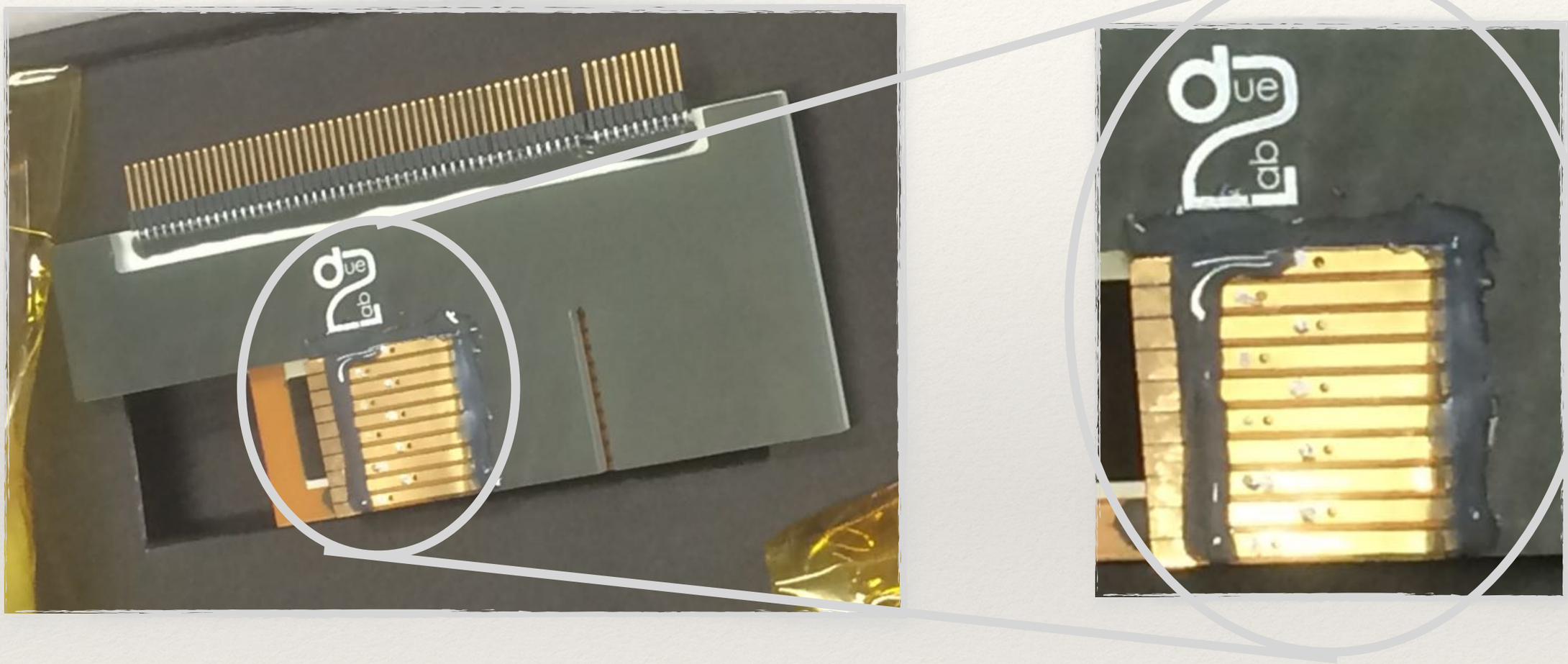


(*) drift stripes not
reported for clarity

3CaTS (3D Cadmium-Zinc-Telluride spectra-imager for X and gamma-ray applications) project

- Main goals of the project:
  - Highly segmented CZT spectrometer with **3D spatial resolution capabilities**
  - Energy range form **few tens of keV up to 700 keV**
  - **High efficiency, fine spectroscopy and imaging limiting** the **complexity** of detector design and realisation
- Expected performance:
  - Intrinsic geometrical **space resolution** of **1x5x2 mm³ improvable** by reconstruction methods down to 0.2x0.3 mm² in the plane directly exposed to the photon flux ($\Delta x \cdot \Delta y$) and 0.6 mm in depth (Δz)
  - **Detection efficiency** at **478 keV**: **13%** for photoelectrons, **52%** for Compton scattered events
  - **Energy resolution**: **<3%** at 500 keV without correction, **improvable** to **<1%** after corrections
  - Operating as scattering polarimeter above 100 keV (astrophysical applications)

3CaTS (3D Cadmium-Zinc-Telluride spectra-imager for X and gamma-ray applications) project



20 anode strips of pitch 1 mm
Cathode: 10 segments, pitch 2 mm

→ Voxel size: 1x2x5 mm^3

Room temperature solid state detectors

Material	Ge	Si	GaAs	CdTe	**CdZnTe**	HgI_2
Atomic number	32	14	31,33	48,52	**48,30,52**	80,53
Density (g/cm^3)	5.33	2.33	5.32	6.20	**5.78**	6.4
Band gap (eV)	0.67	1.12	1.43	1.44	**1.57**	2.13
Pair creation energy (eV)	2.96	3.62	4.2	4.43	**4.6**	4.2
Resistivity (Ωcm)	50	10^4	10^7	10^9	**10^{10}**	10^{13}
Electrons mobility (cm^2/V)	>1	>1	10^{-5}	10^{-3}	**10^{-3} - 10^{-2}**	10^{-4}
Holes mobility (cm^2/V)	>1	~1	10^{-6}	10^{-4}	**10^{-5}**	10^{-5}

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ADVANTAGES

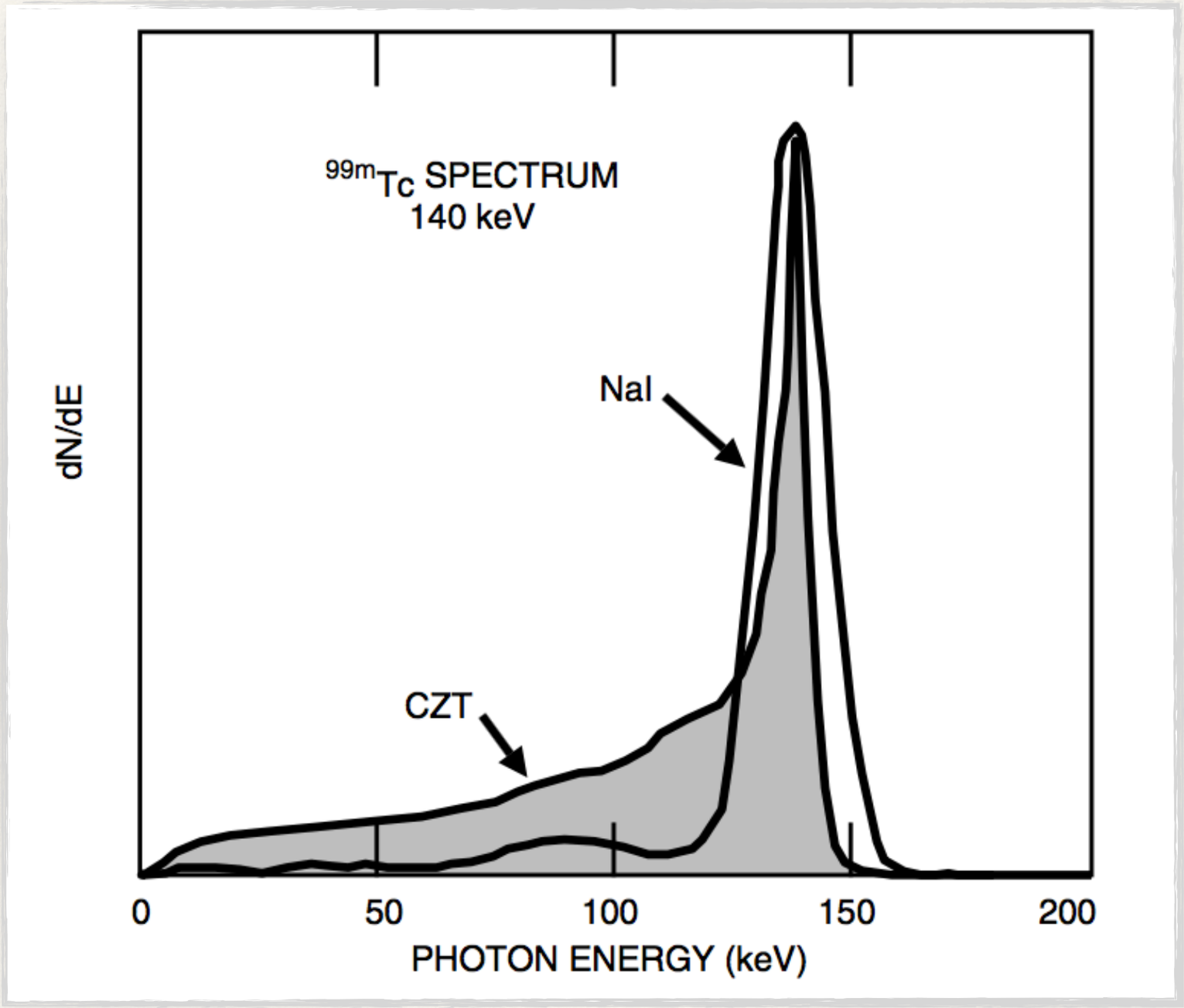
High Z = high detection efficiency even with small volumes

Wide band gap = leakage current < nA & room temperature operations

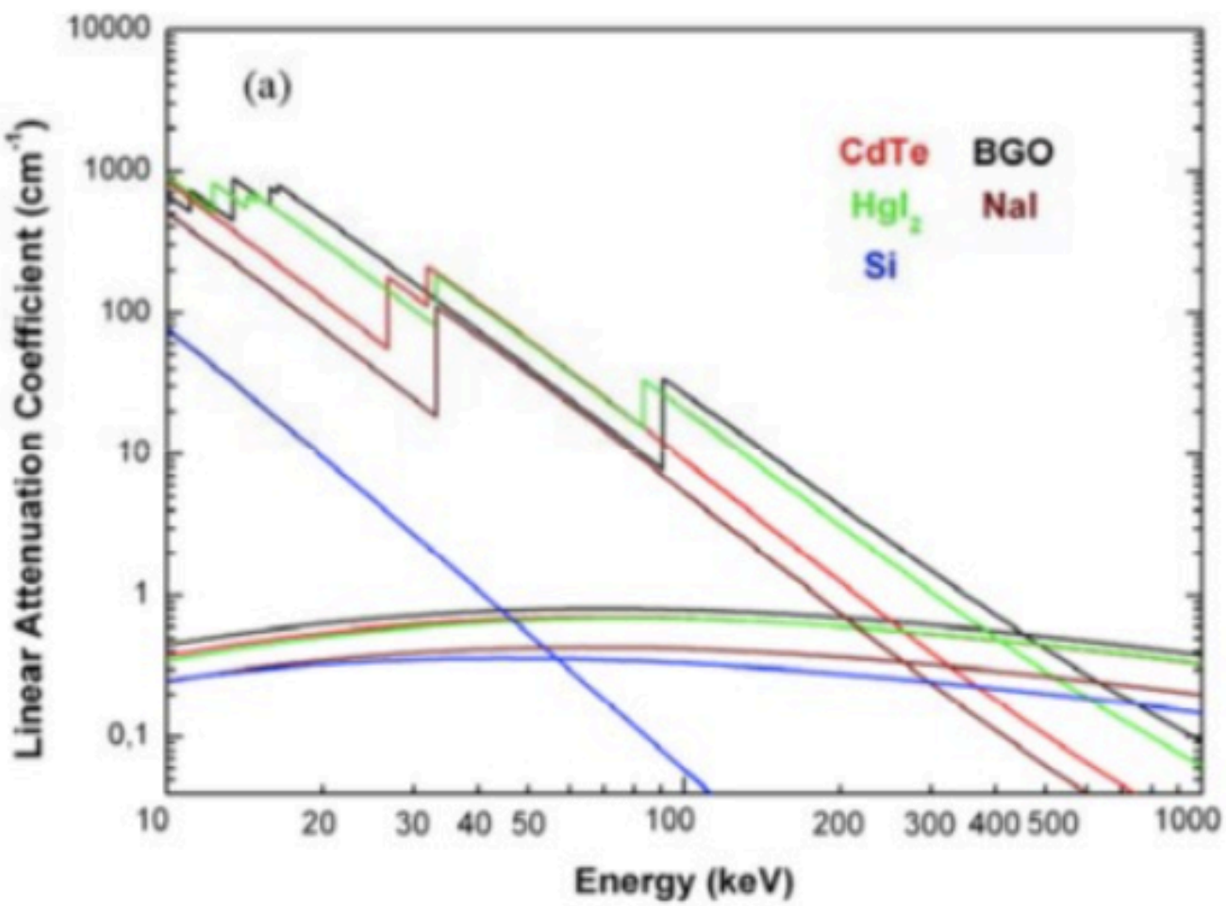
DISADVANTAGES

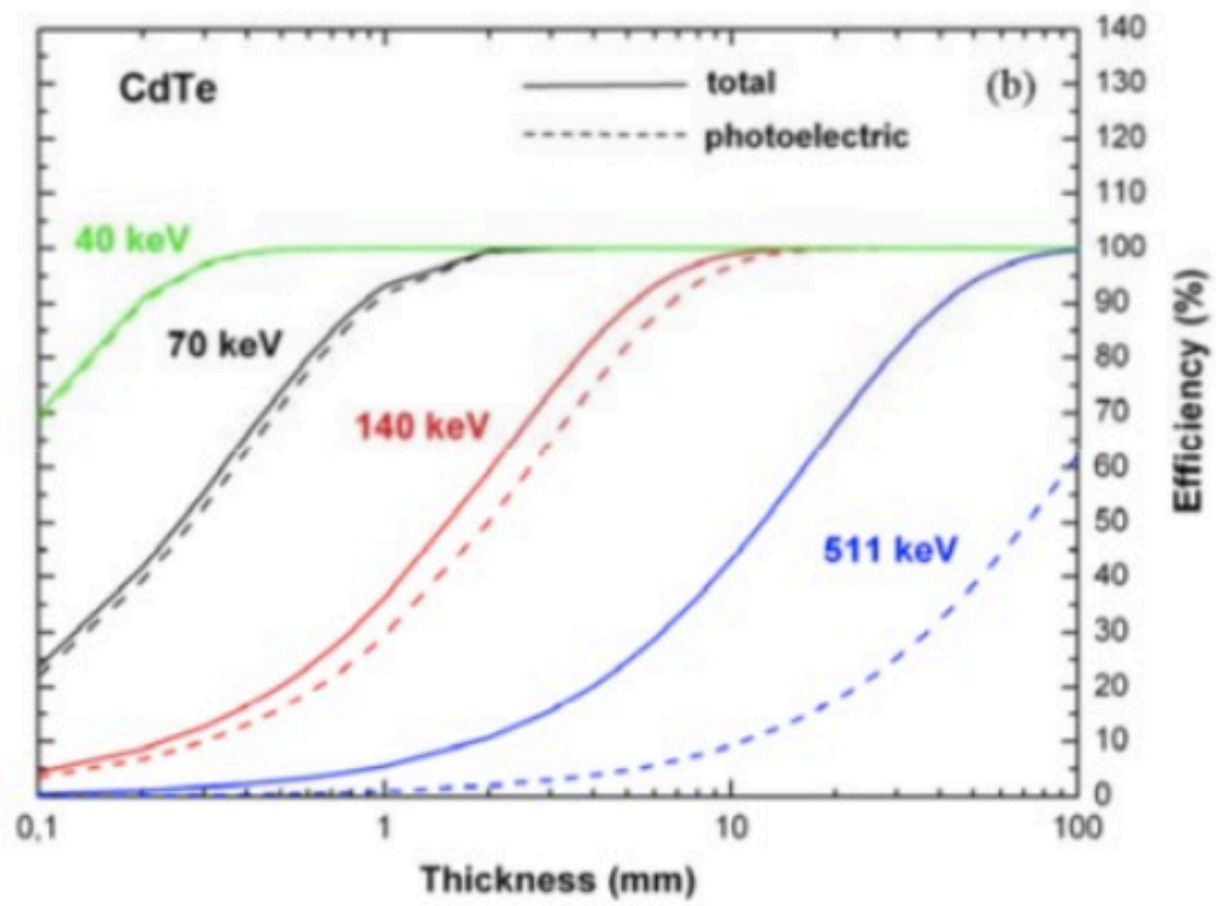
Charge carriers trapping = reduction of energy resolution & enhancement of detector performances breakdown at high counting rate

Room temperature solid state detectors



Room temperature solid state detectors

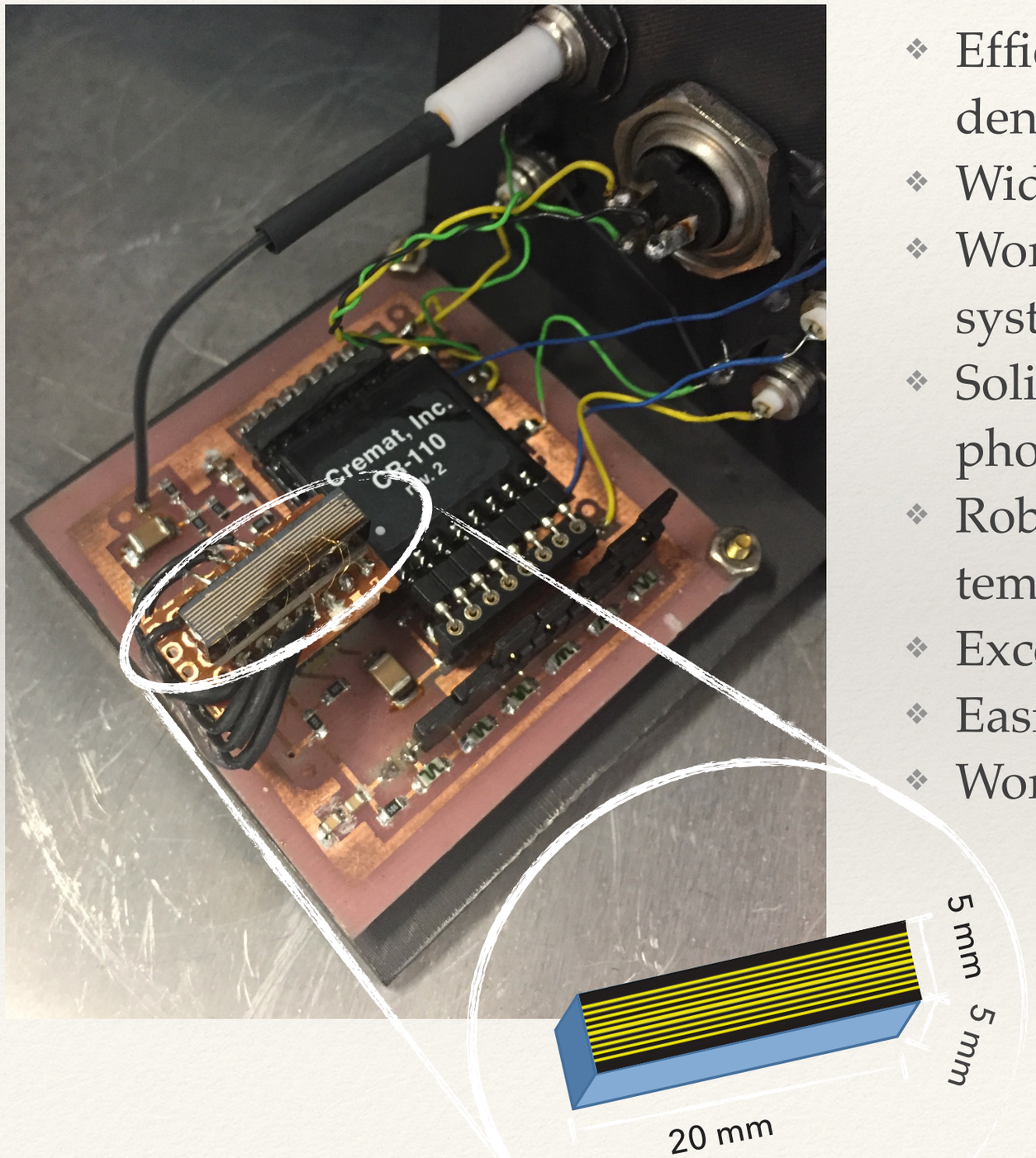




Important contribution of Compton effect @ 478 keV

3D spacial detection: Compton Camera?!

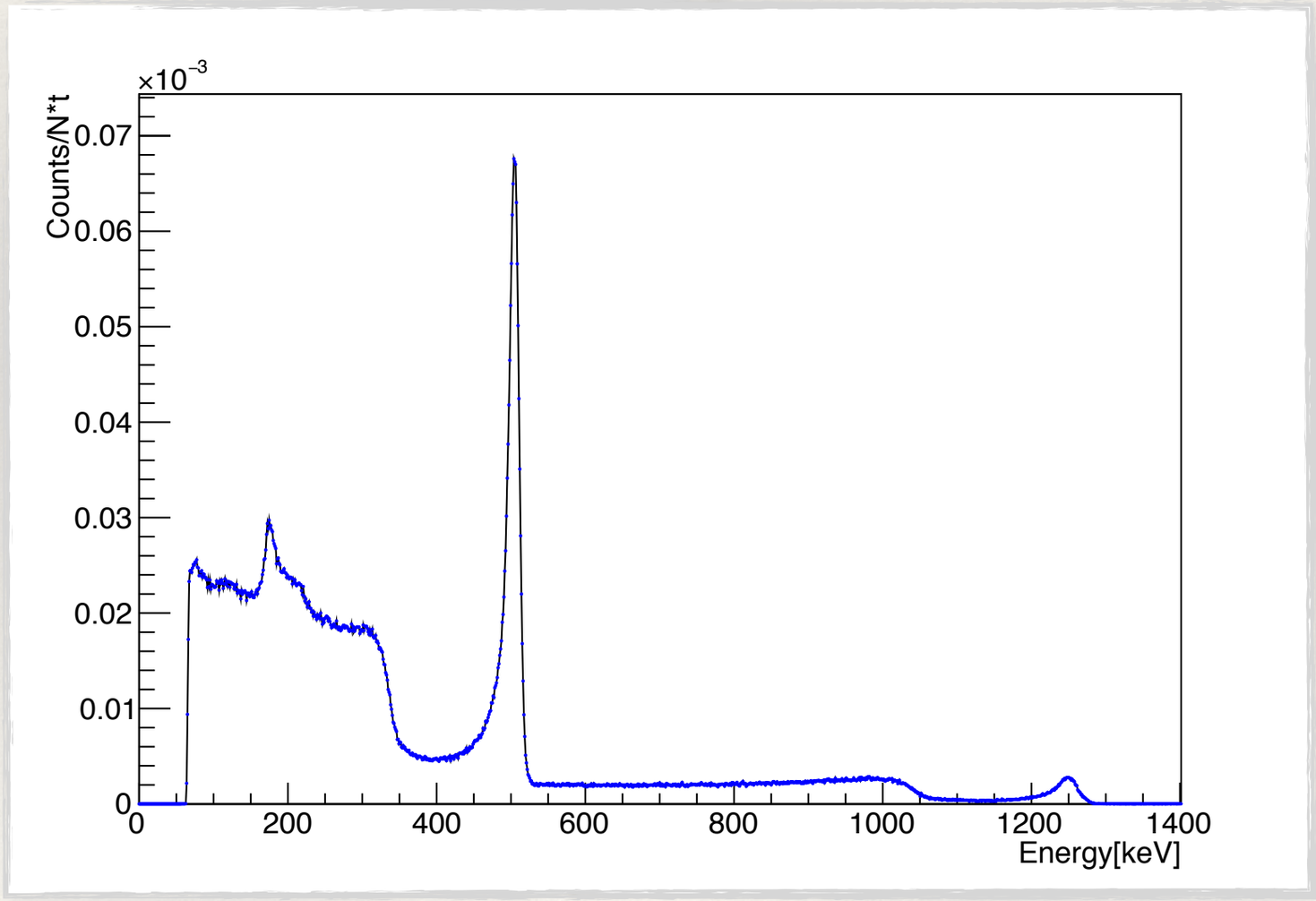
Why CZT detector?



- Efficient yet compact due to their high density
- Wide photon energy range
- Works at room temperature (no cooling system)
- Solid state: do not require fragile photomultiplier tubes
- Robust and able to withstand rapid temperature changes
- Excellent energy resolution
- Easily enabled imaging capabilities
- Works in a magnetic field

Characterisation of 1D CZT prototype

Source	Peak (keV)	FWHM (keV)	R
22 Sodium	511	15.43	2,99%
	1275	26.66	2,09%



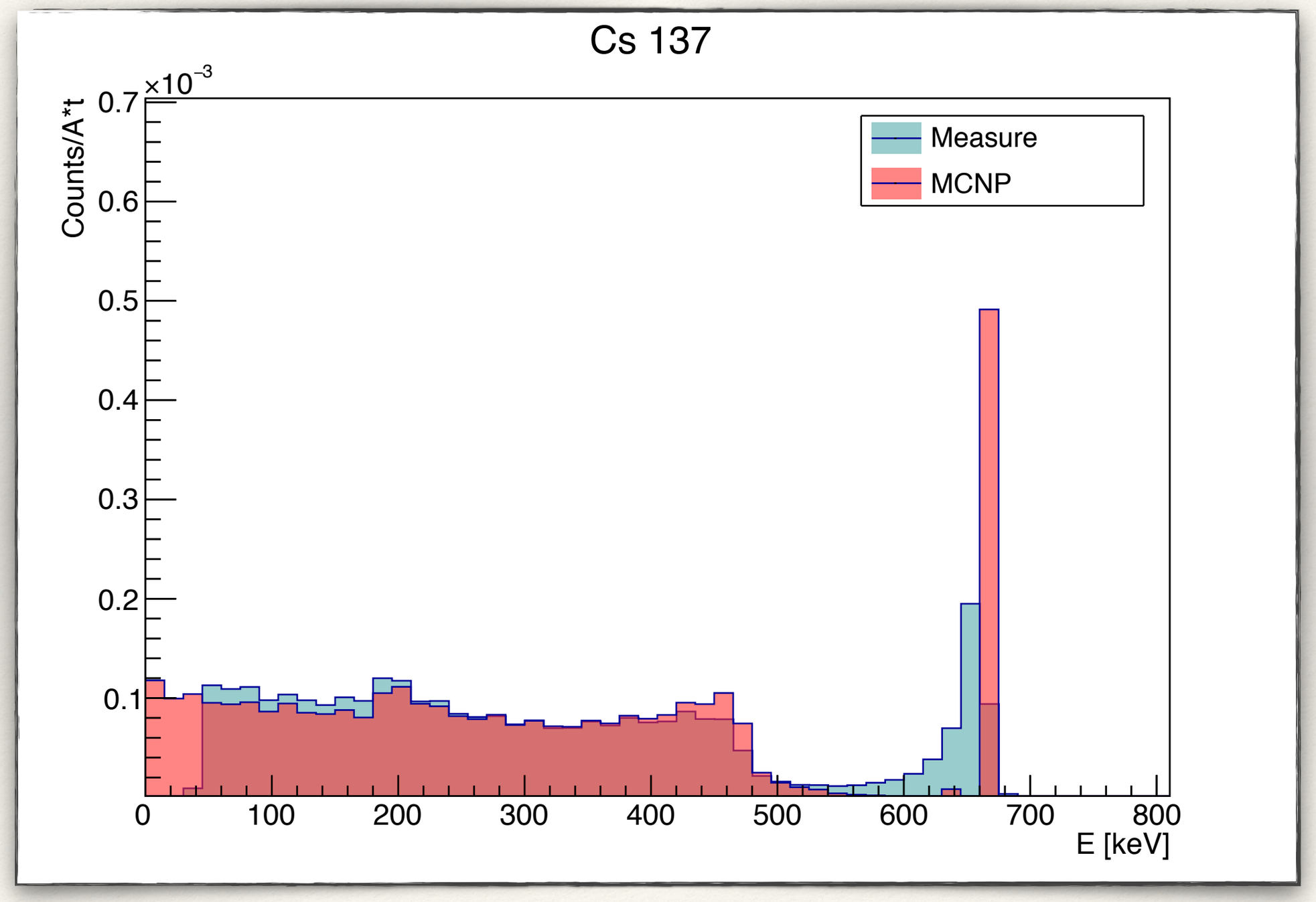
From S.Fatemi, PhD thesis

Characterization of 1D CZT prototype

Source	Energy (keV)	FWHM (keV)	Resolution (%)
Ba133	276	8.2	2.97
	302.8	7.7	2.53
	356	10.0	2.81
Na22	511	15.4	2.99
	1274	26.7	2.09
Cs137	661.6	18.6	2.81
Co60	1173	19.3	1.64
	1332.5	23.7	1.78

From S.Fatemi, PhD thesis

Characterization of 1D CZT prototype



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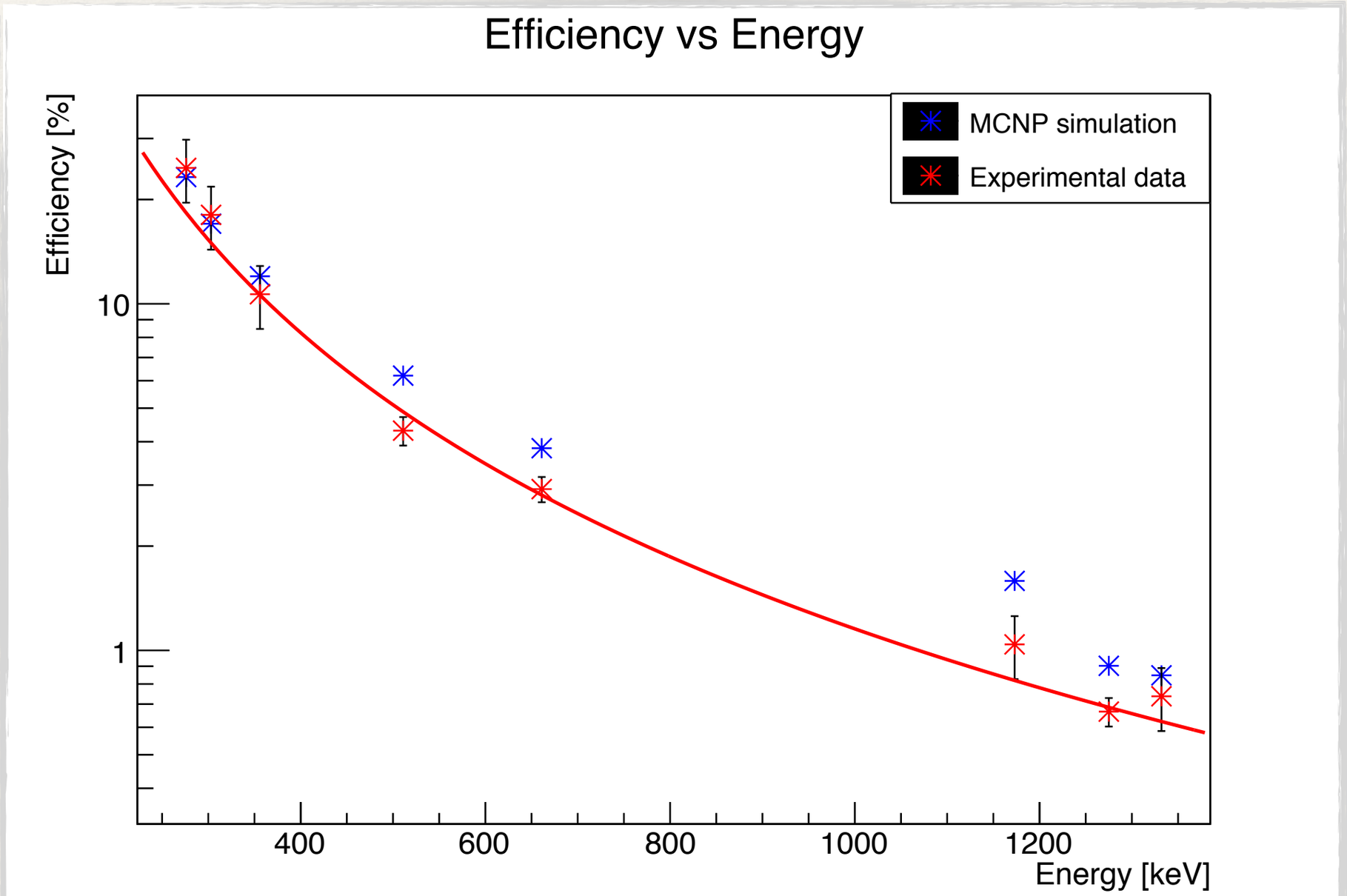
Characterization of 1D CZT prototype



$$\epsilon_i = 3.2 \cdot 10^6 \cdot E^{-2.14}$$

From S.Fatemi, PhD thesis

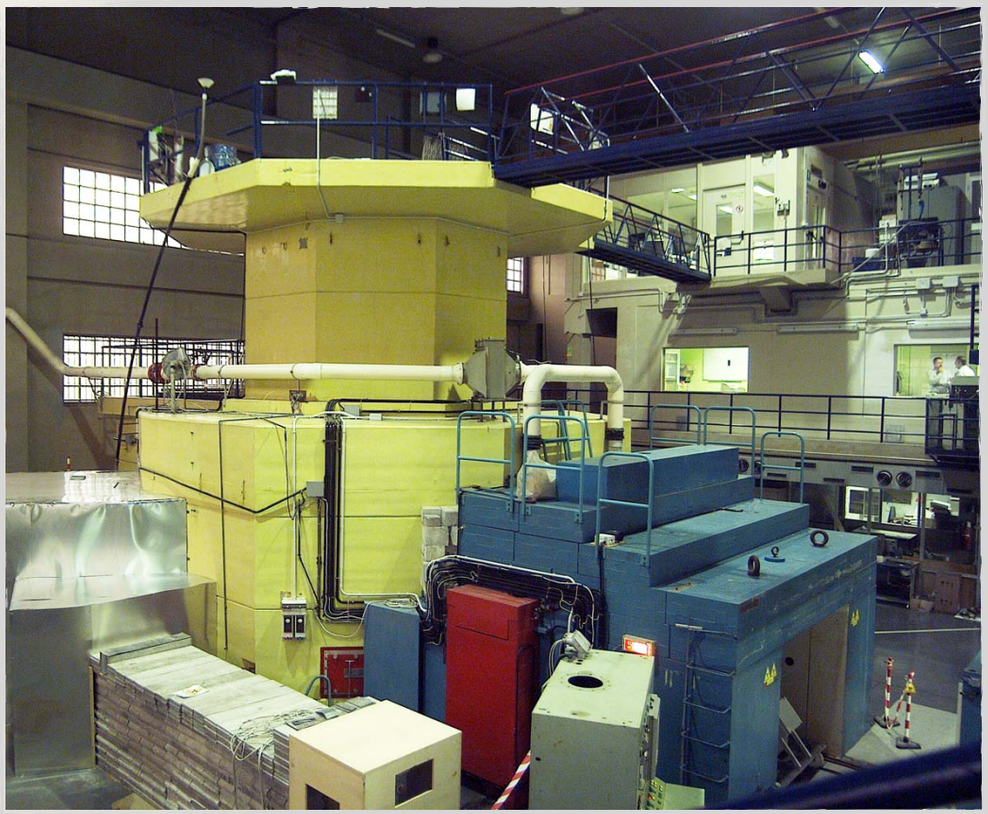
Characterization of 1D CZT prototype

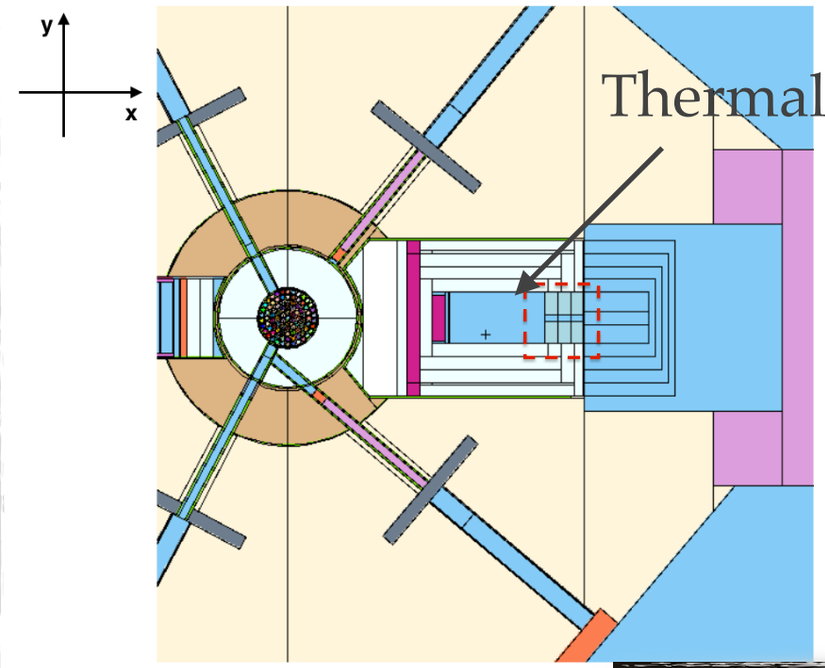
Source	Energy (keV)	En. Resolution (%)	Uncertainty
Ba133	276	24.7	5.1
	302.8	18.1	3.7
	356	10.7	2.2
Na22	511	4.3	0.4
Cs137	661.6	2.9	0.2
Co60	1173	1.0	0.2
Na22	1274.5	0.7	0.1
Co60	1332.5	0.7	0.2

Efficiency @ 478 keV : 6.08%

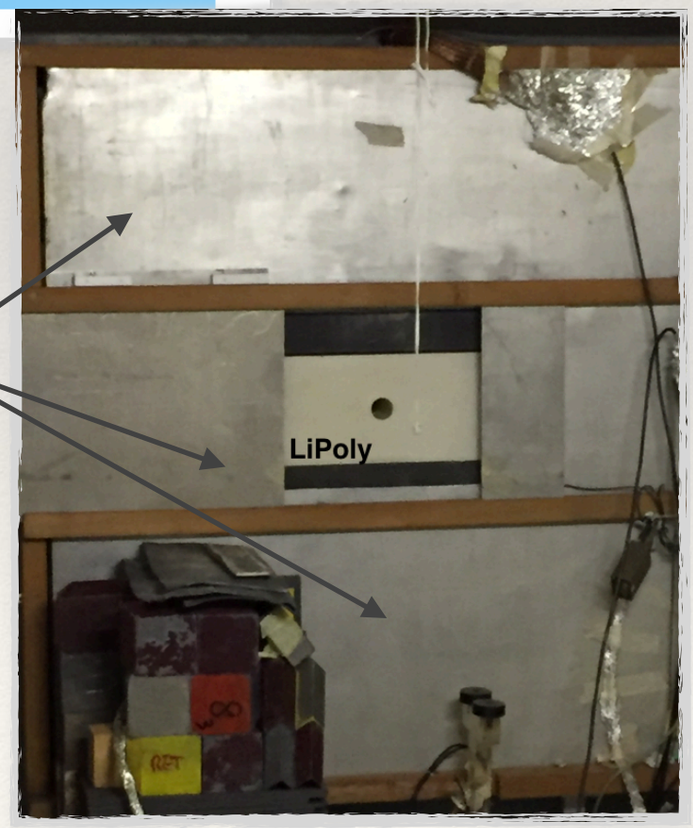
From S.Fatemi, PhD thesis

Preliminary measurements at Pavia TRIGA reactor





^{10}B enriched Boral shield



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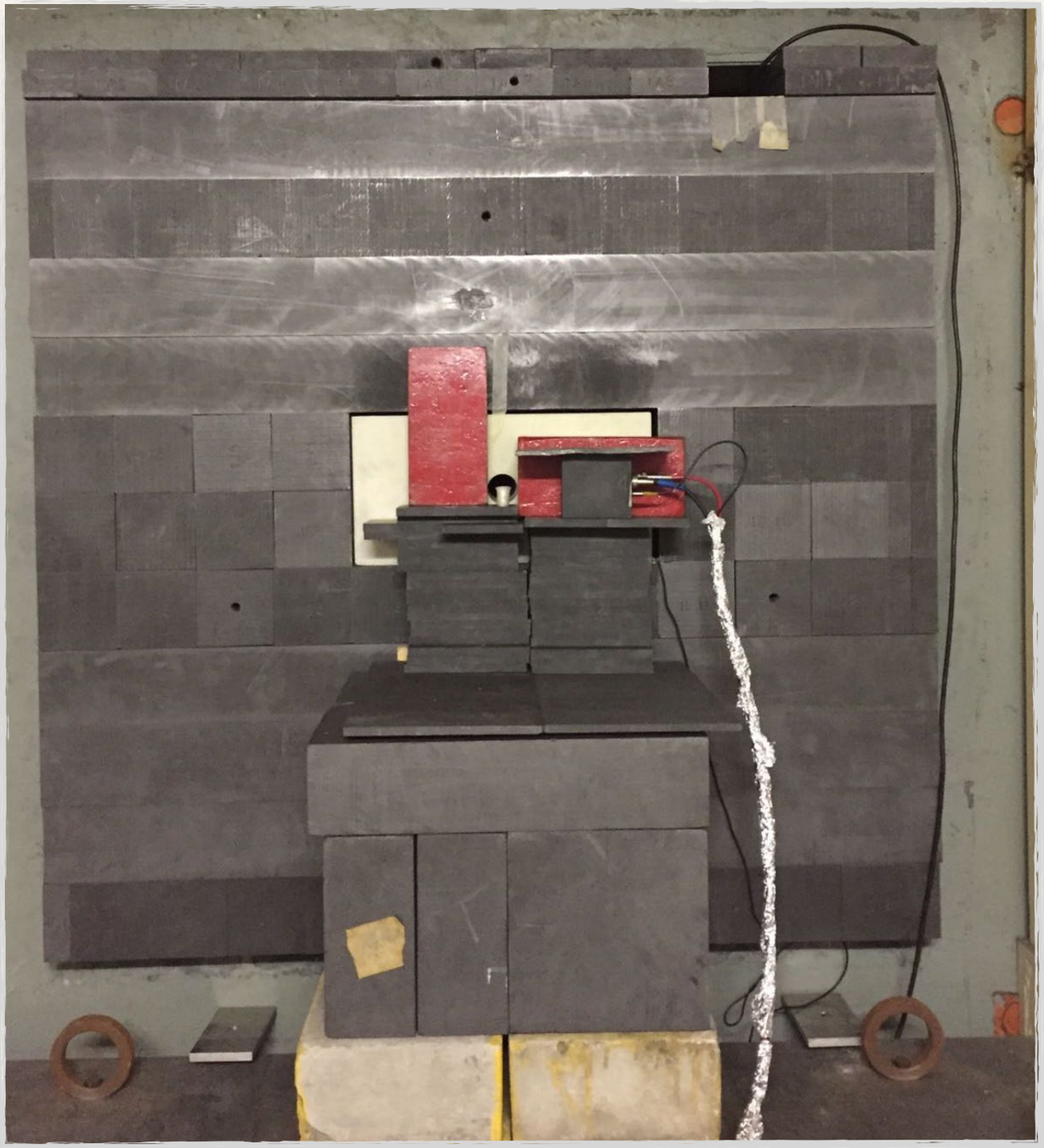
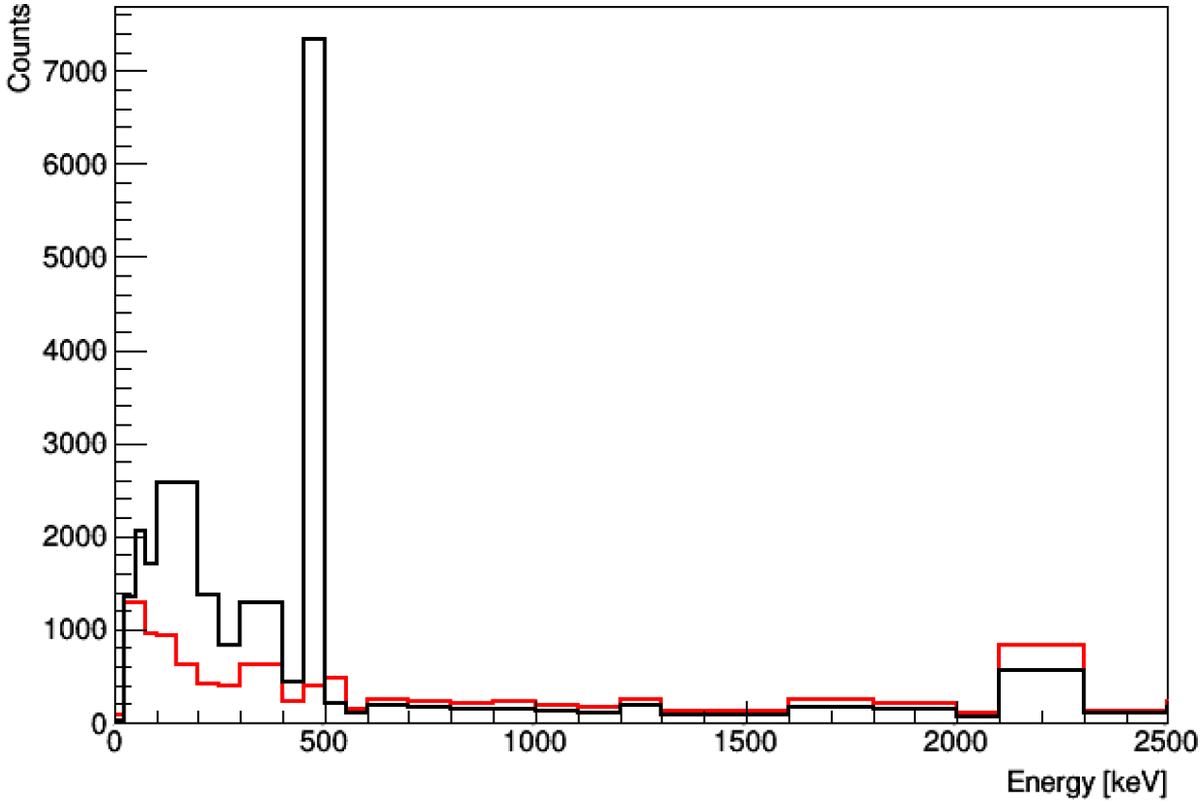
Preliminary measurements at Pavia TRIGA reactor





Photon flux on beam port plane:

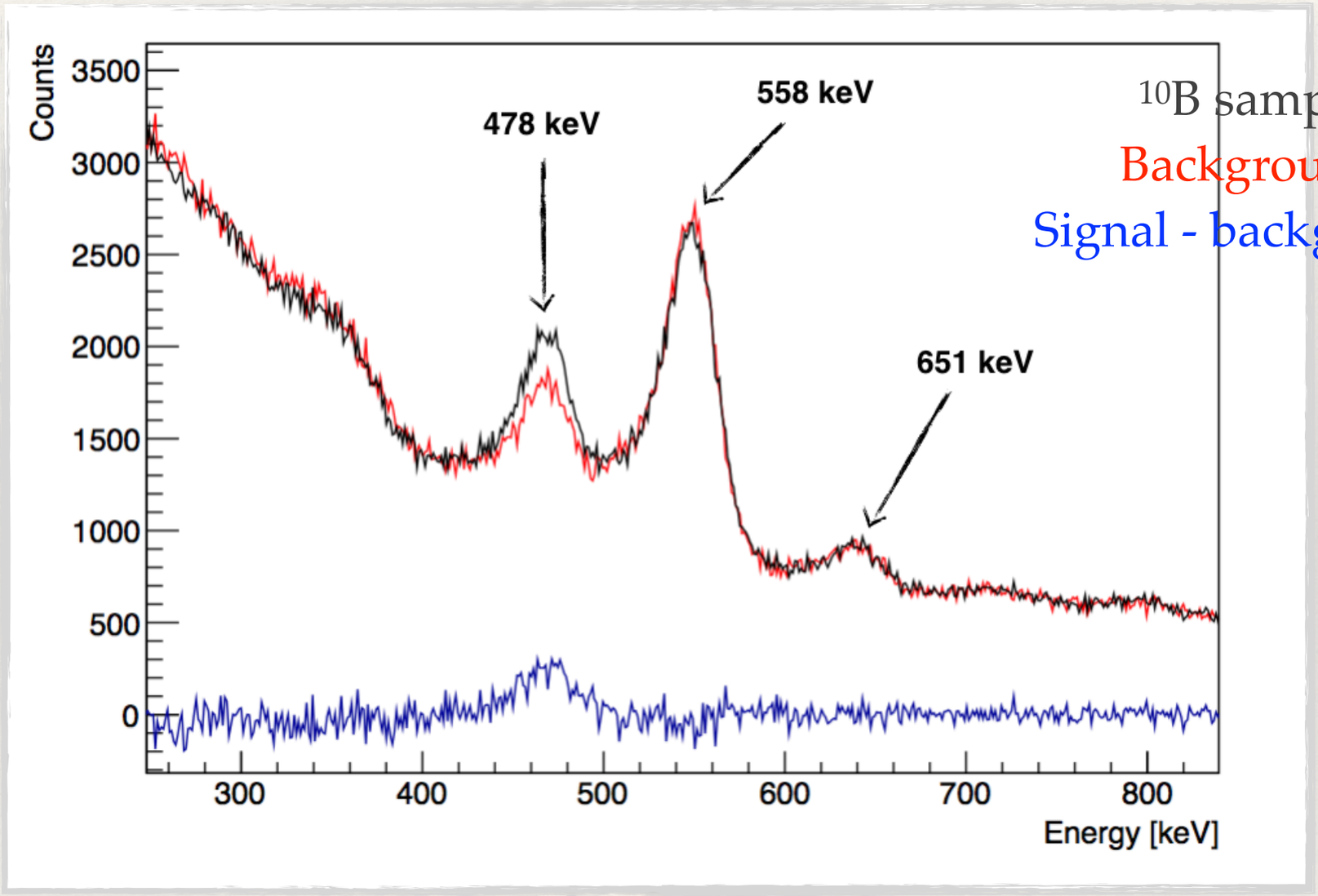
with Boral Shield

and

without Boral Shield

From S.Fatemi, PhD thesis

Preliminary measurements at Pavia TRIGA reactor



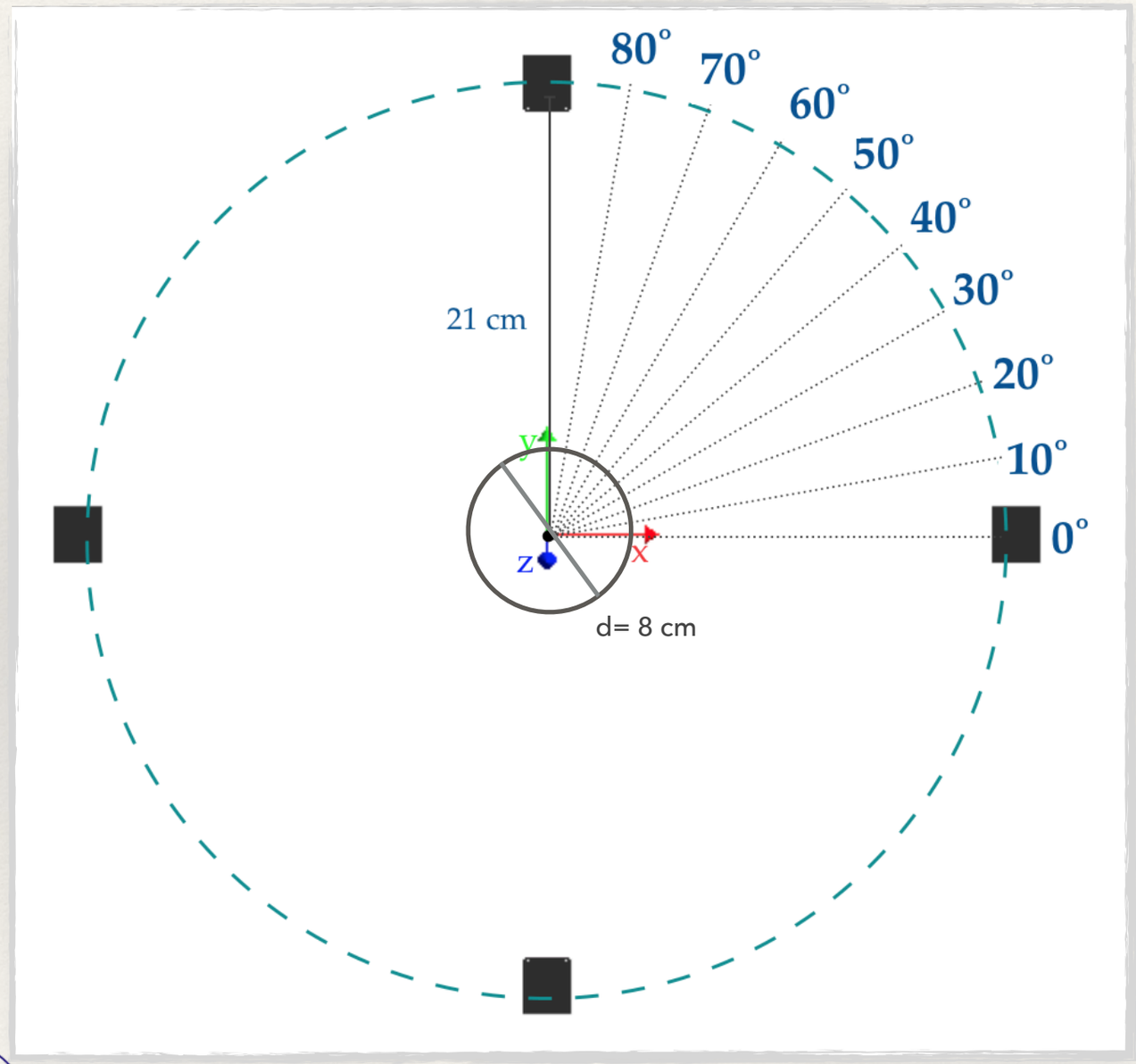
^{10}B sample

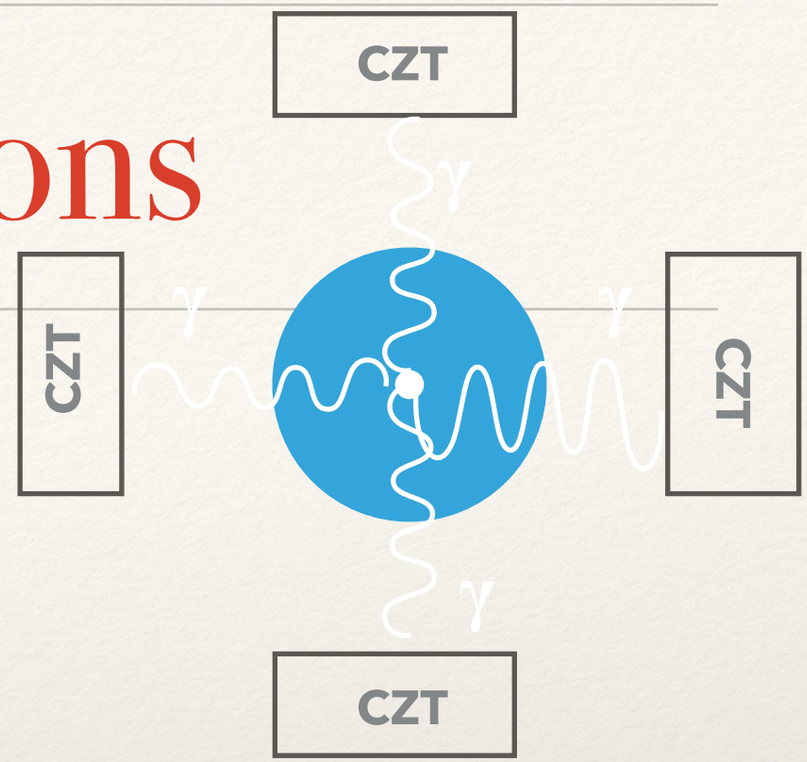
Background

Signal - background

From S.Fatemi, PhD thesis

SPECT imaging simulations





Geant4 code + Python FBP free routines

Four 20x20x20 mm^3 CZT detectors, each with 80 pixels

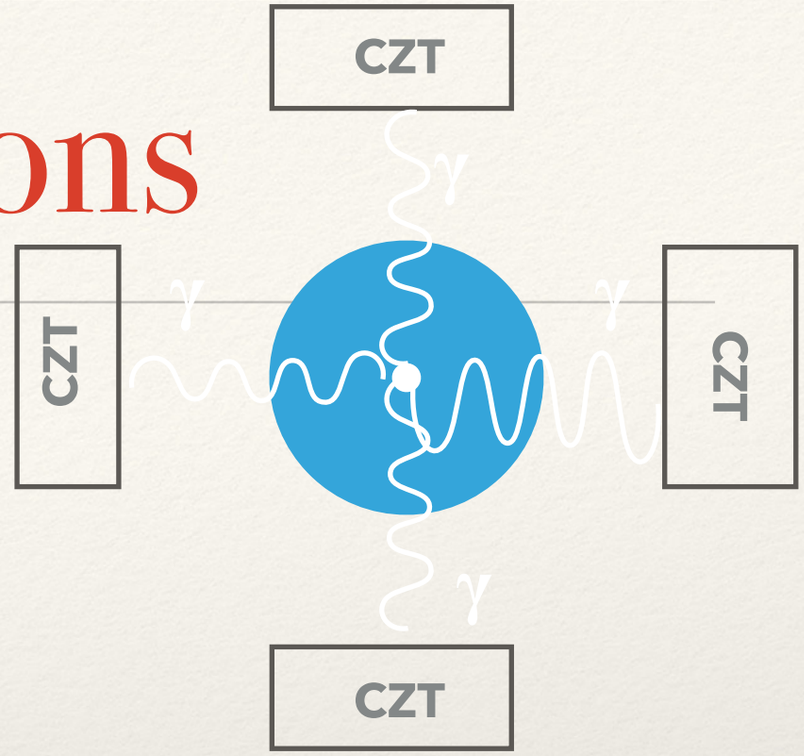
21 cm distance from source to detectors

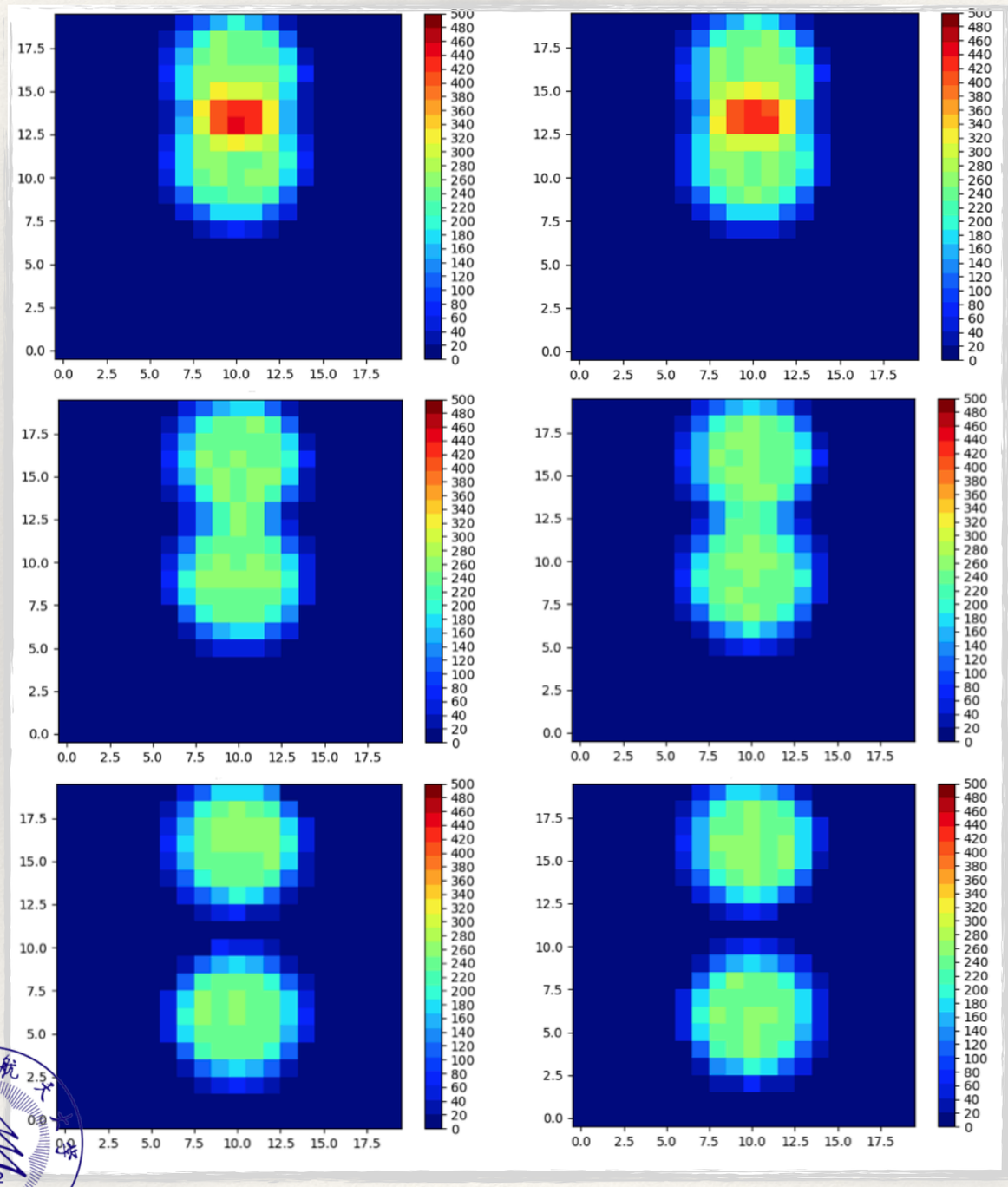
From 0 to 360 degrees with 10 degrees steps

Collaboration with Nanjing University of Aeronautics an Astronautics, Nanjing, China

From S.Fatemi, PhD thesis

SPECT imaging simulations





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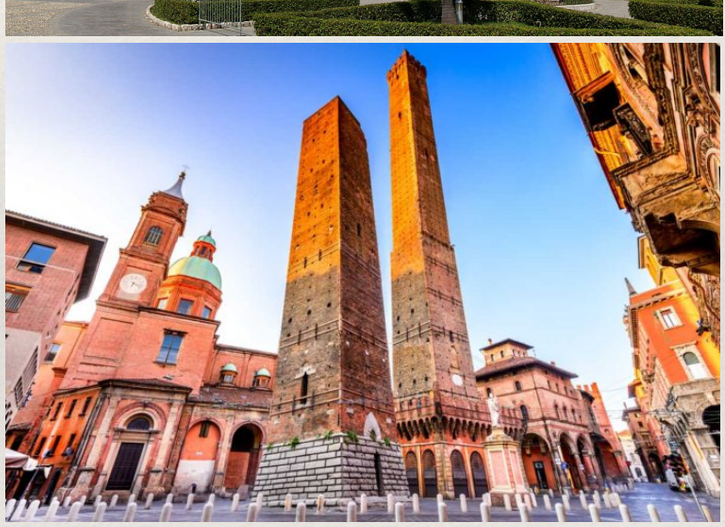

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… and thank you for your attention!