The 3CaTS project for BNCT-SPECT in Pavia: overview and ongoing activities

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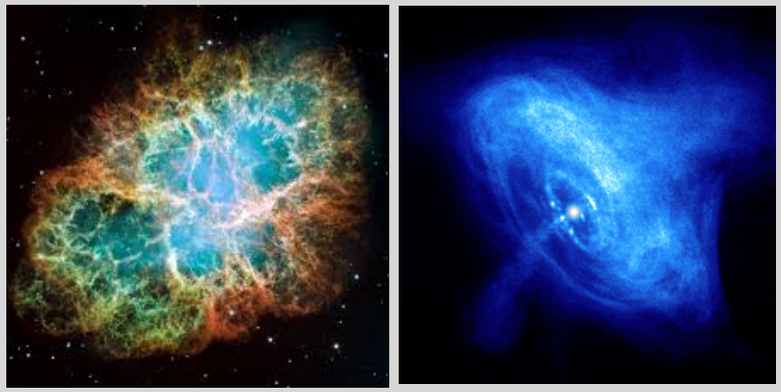
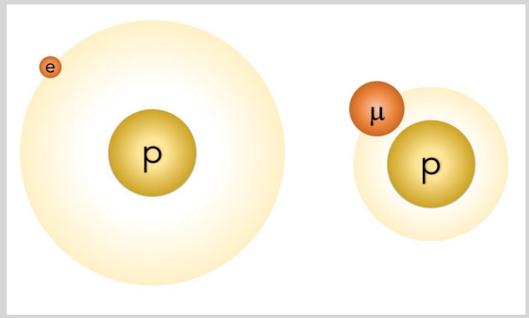
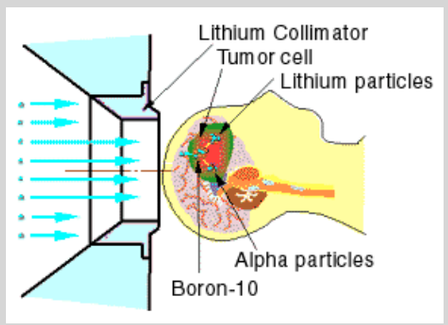


(1) hard-X and soft γ-rays **astrophysics**



(2) fine spectroscopy for **fundamental physics**



(3) medical application for **SPECT-BNCT**

INFN Call n° 18203/2016
National call to fund n. 6 projects to promote young researchers

INFN Istituto Nazionale di Fisica Nucleare

3 CaTS

3D Cadmium-Zinc-Tellurium spectro-imager for X and gamma-ray applications

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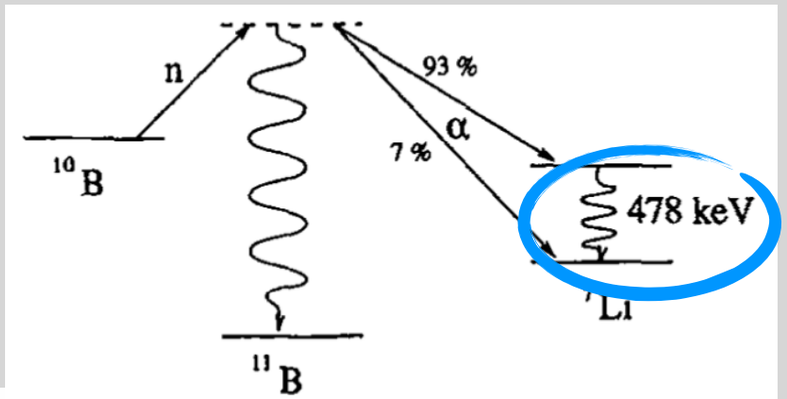
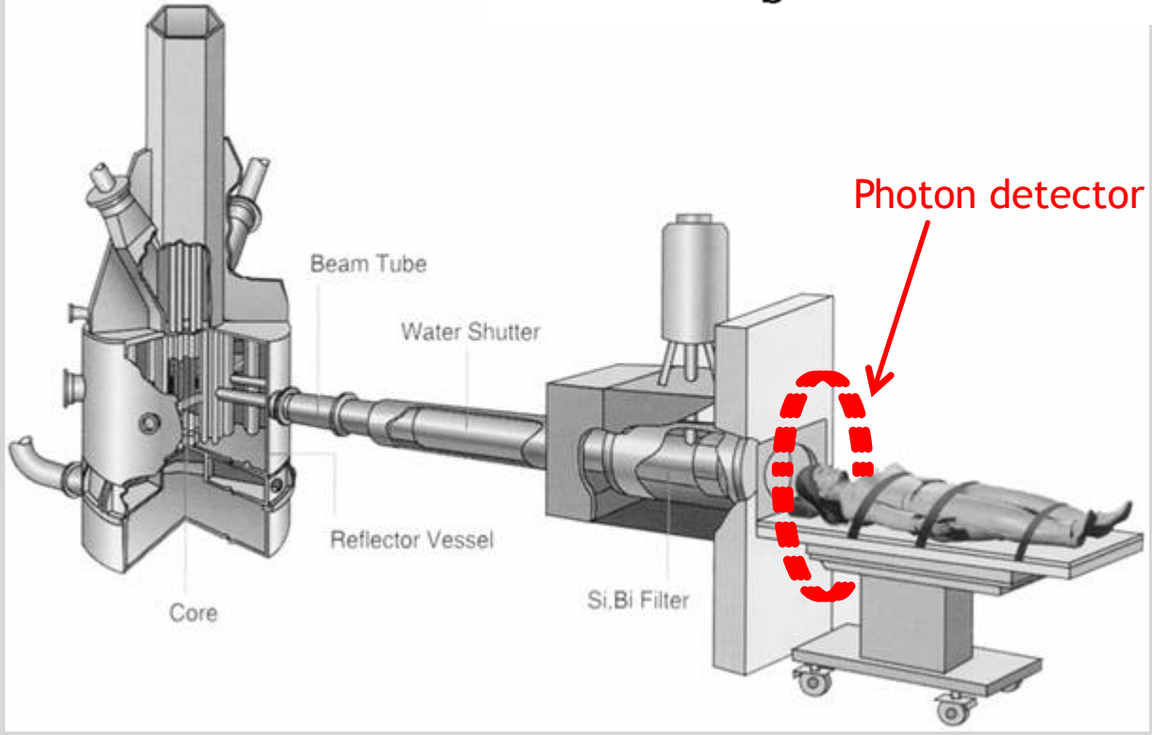
in vivo BNCT dosimetry by single photon detection

$$dD(x,y,z) \approx \boxed{n_{B10}(x,y,z) \cdot \Phi(x,y,z)}\ dV \approx \mathbf{dI_{\gamma}(x,y,z)}$$





BNCT group in Pavia currently involved in small animal (rats, mice) tumour models irradiation at the thermal neutron facility of Pavia University TRIGA Mark II reactor

REQUIREMENTS for **SPECT-BNCT**

- high spatial resolution (≤ 5 mm)
- good detection efficiency @ 478 keV
- compact and portable system
- high performance even in presence of mixed (n+g) fields

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Why CZT?

- Compact
- High energy resolution
- Works at room temperature

Table 1. Physical properties of the principal compound semiconductors at T = 25 °C.

Material	Si	Ge	GaAs	CdTe	$Cd_{0.9}Zn_{0.1}Te$	HgI_2	TlBr
Crystal structure	Cubic	Cubic	Cubic (ZB)	Cubic (ZB)	Cubic (ZB)	Tetragonal	Cubic (CsCl)
Growth method*	C	C	CVD	THM	HPB, THM	VAM	BM
Atomic number	14	32	31, 33	48, 52	48, 30, 52	80, 53	81, 35
Density (g/cm^3)	2.33	5.33	5.32	6.20	5.78	6.4	7.56
Band gap (eV)	1.12	0.67	1.43	1.44	1.57	2.13	2.68
Pair creation energy (eV)	3.62	2.96	4.2	4.43	4.6	4.2	6.5
Resistivity (Ω cm)	10^4	50	10^7	10^9	10^{10}	10^{13}	10^{12}
$\mu_e\tau_e$ (cm^2/V)	> 1	> 1	10^{-5}	10^{-3}	10^{-3} - 10^{-2}	10^{-4}	10^{-5}
$\mu_h\tau_h$ (cm^2/V)	~ 1	> 1	10^{-6}	10^{-4}	10^{-5}	10^{-5}	10^{-6}

* The more common growth methods: C = Czochralski, CVD = chemical vapor deposition, THM = traveler heater method, BM = Bridgman method, HPB = high-pressure Bridgman and VAM = vertical ampoule method

High Z → high detection efficiency even with small width at high energies
Wide band gap → leakage currents < nA, room temperature operation
Trapping → degradation of energy resolution and performance breakdown at high rates

S.Del Sordo et al., Sensors 2009 9, 3491-3526
A.Owens et al., NIMA 2004 531 18-37
D.S. McGregor et al., NIMA 1997 395 101-124

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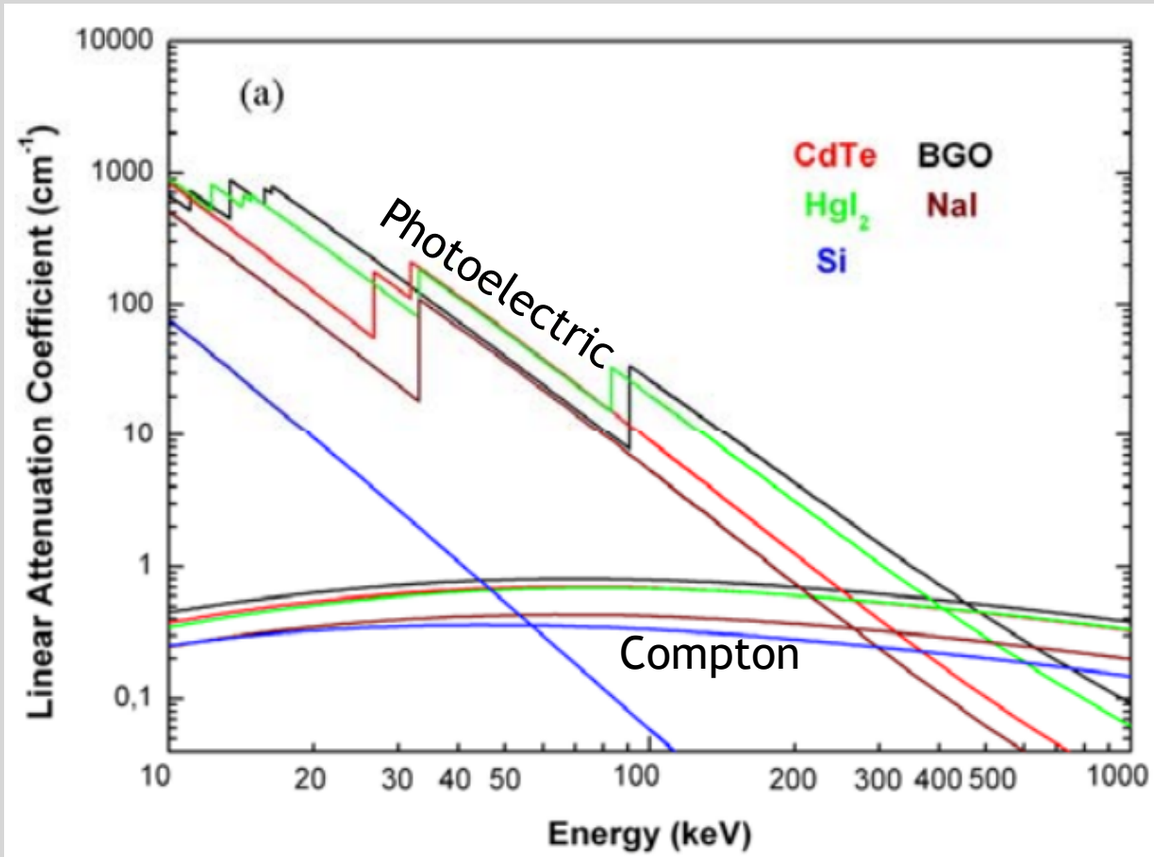

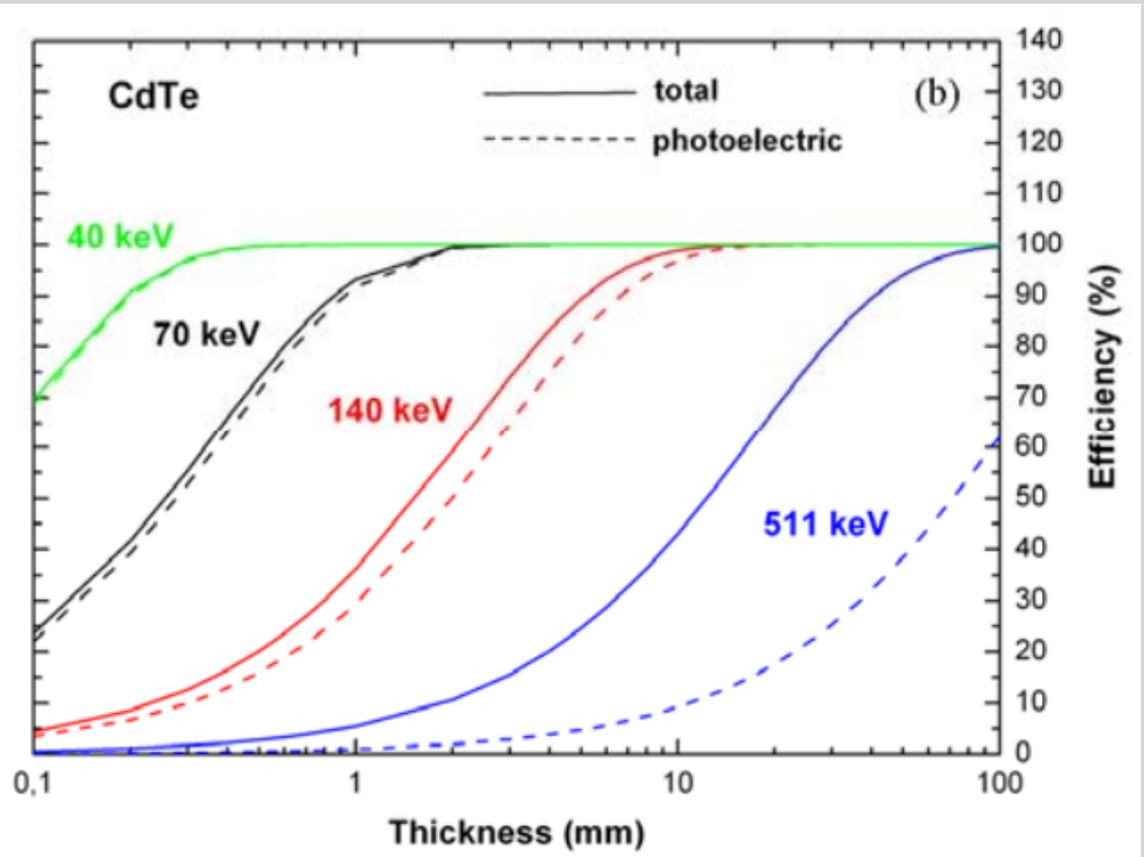

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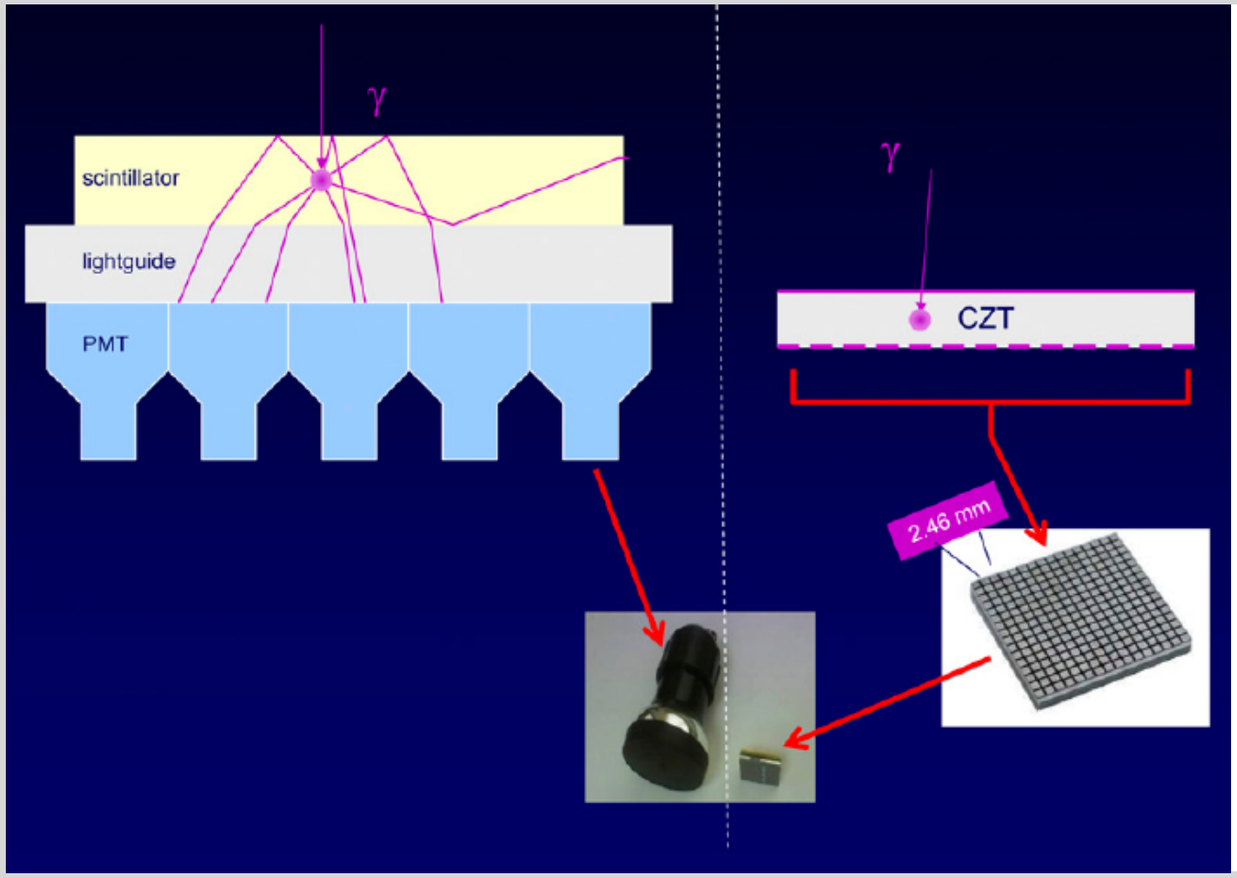

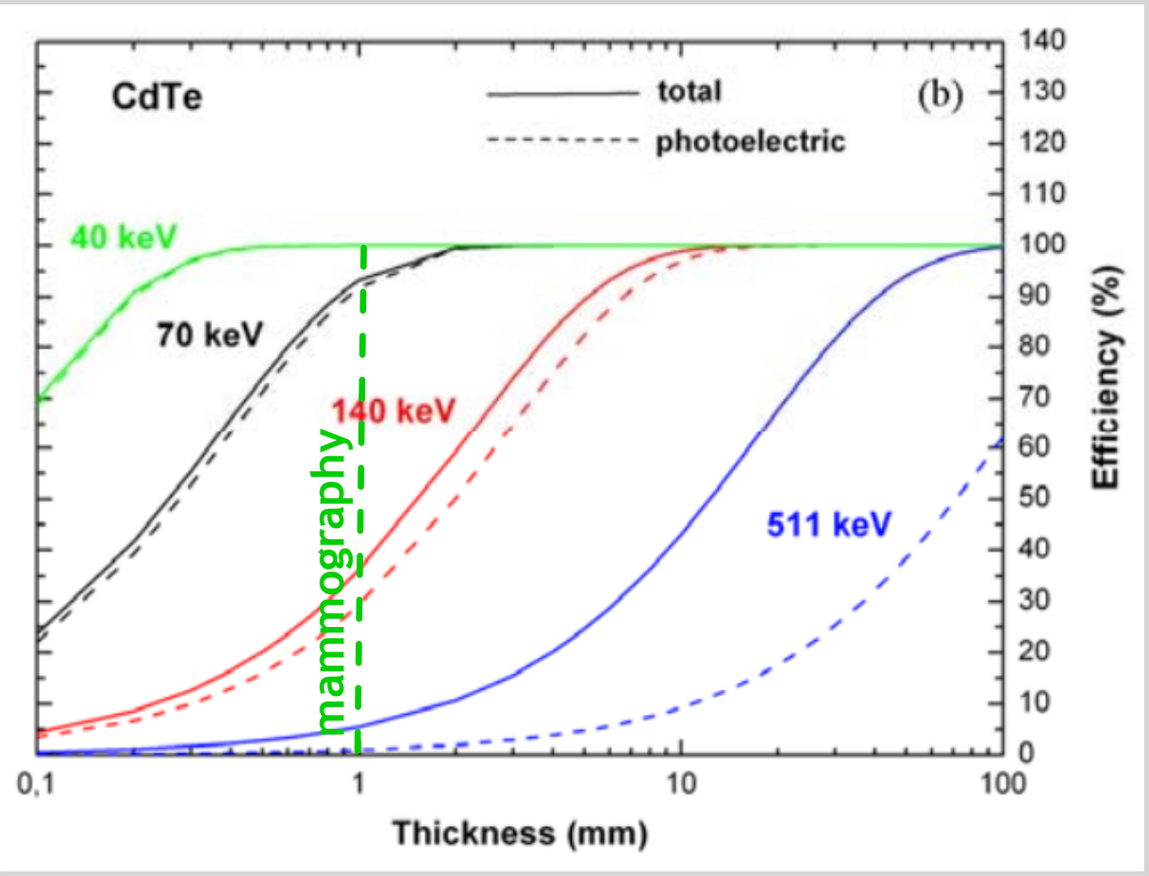

taken from E.V.Garcia et al., J Nucl Med 2011, 52 210-217

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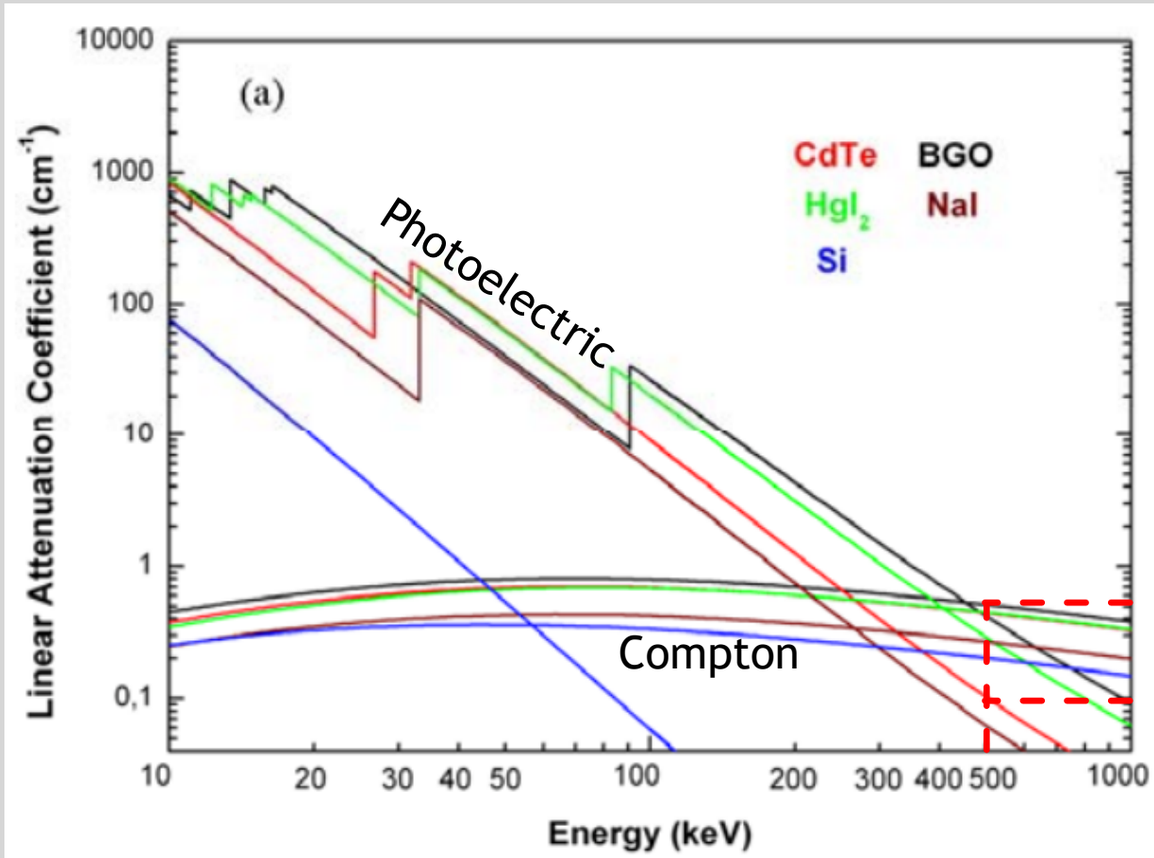

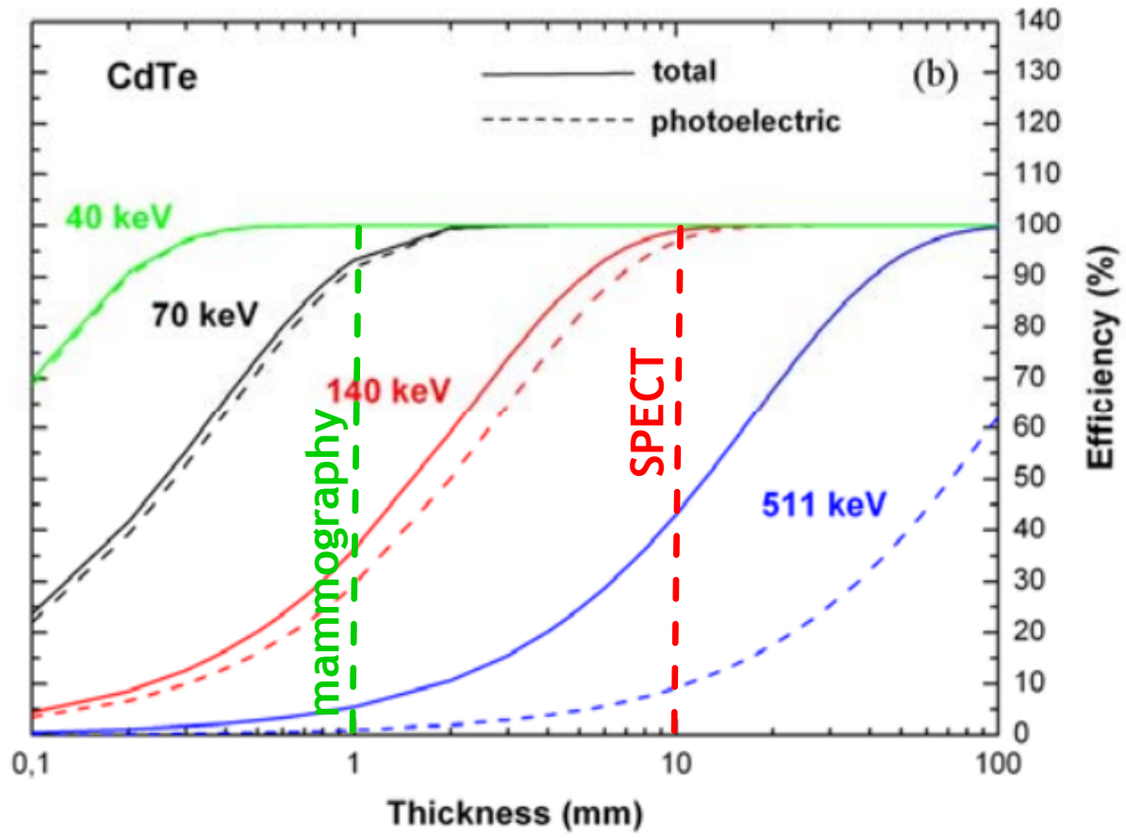

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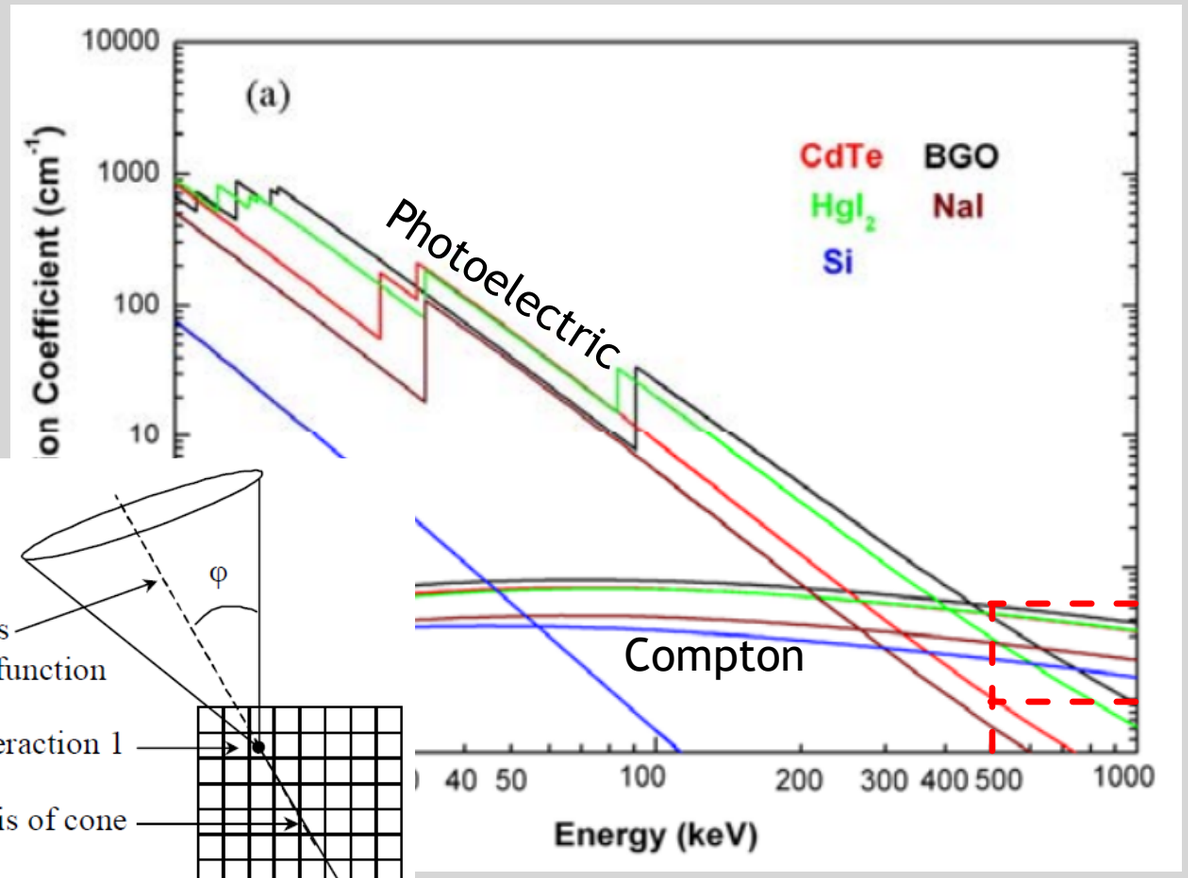
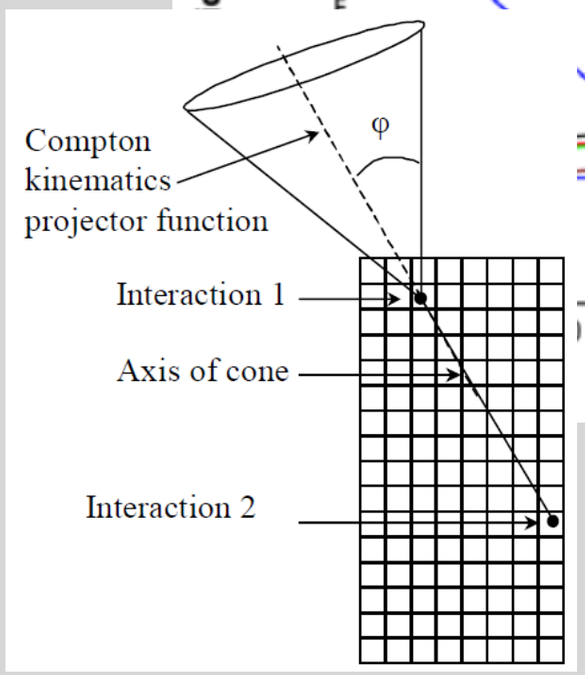




COMPACT COMPTON CAMERA

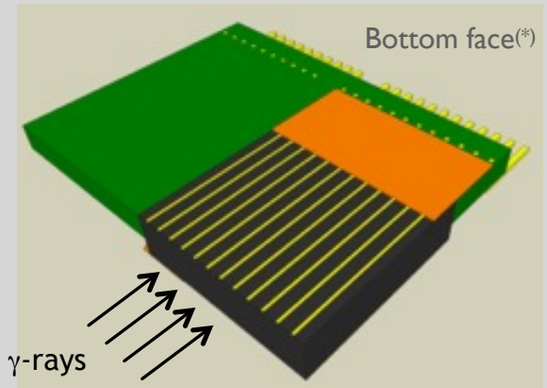
single stage Compton imager exploiting 3D position sensing CZT

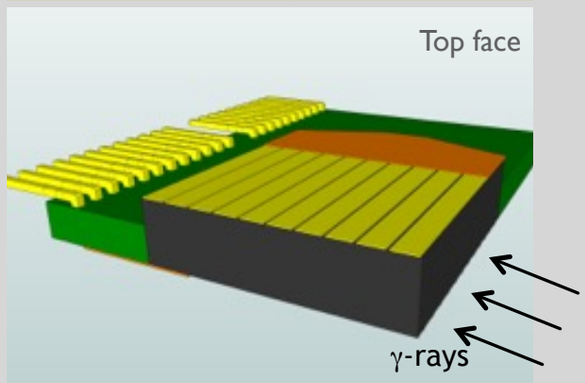
- Energy range of SPECT-BNCT peaked around 500 keV: Compton interaction probability in CZT 4 times > that photoelectric effect
- Development of an image reconstruction software based on Compton imaging thanks to the 3D detecting capabilities of CZT (co-registration of interaction position and deposited energy *per hit*)
- improvement of detection efficiency and reduction of noise

Why CZT?

- Compact
- High energy resolution
- Works at room temperature

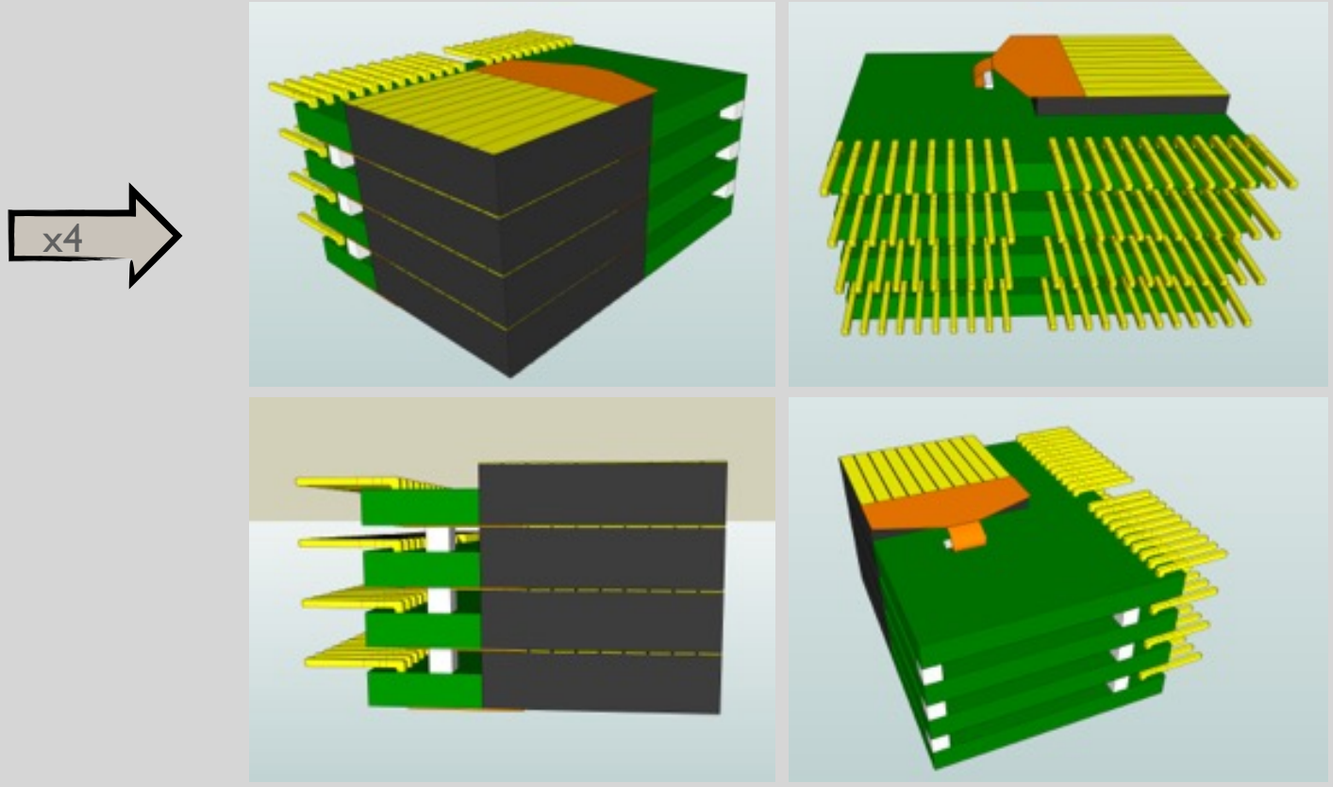
CZT single unit: **20x20x5 mm³**,
planar transversal field (PTF),
orthogonal drift strip electrodes

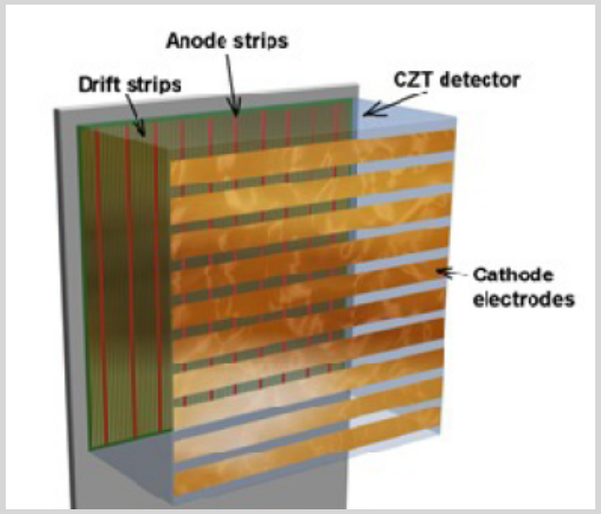




(*) drift strips not reported

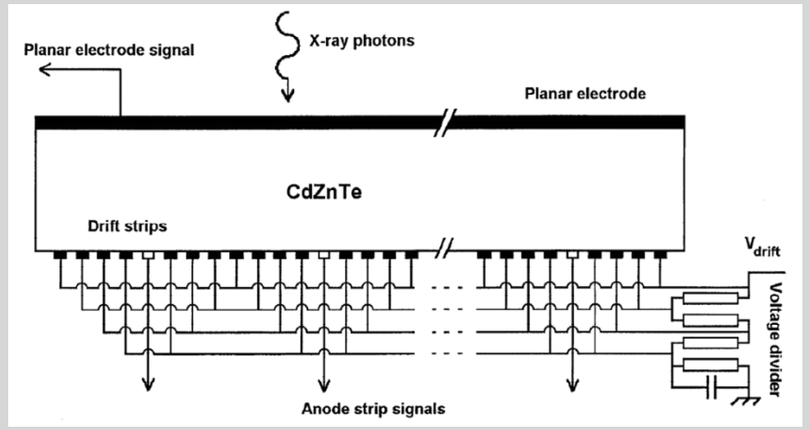
3D-CZT prototype, 20x20x20 mm³





Electrodes pattern: DRIFT STRIP detector.

- a virtual "pixel" is generated in the overlapping area of two cross orthogonal strips;
- position determination achievable (2D sensing + DOI technique);
- good spatial resolution obtainable with small width strips;
- partial recovery of low energy tailing.



CZT single unit: **20x20x5 mm³**,
planar transversal field (PTF),
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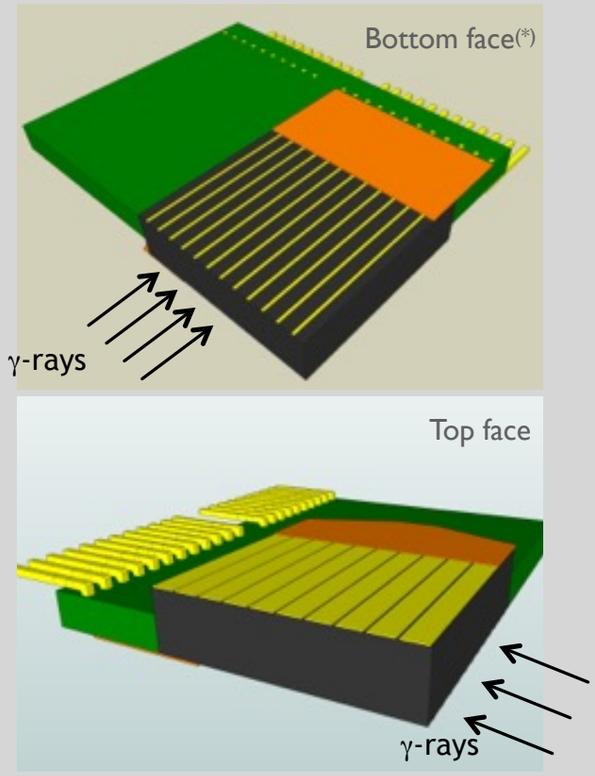
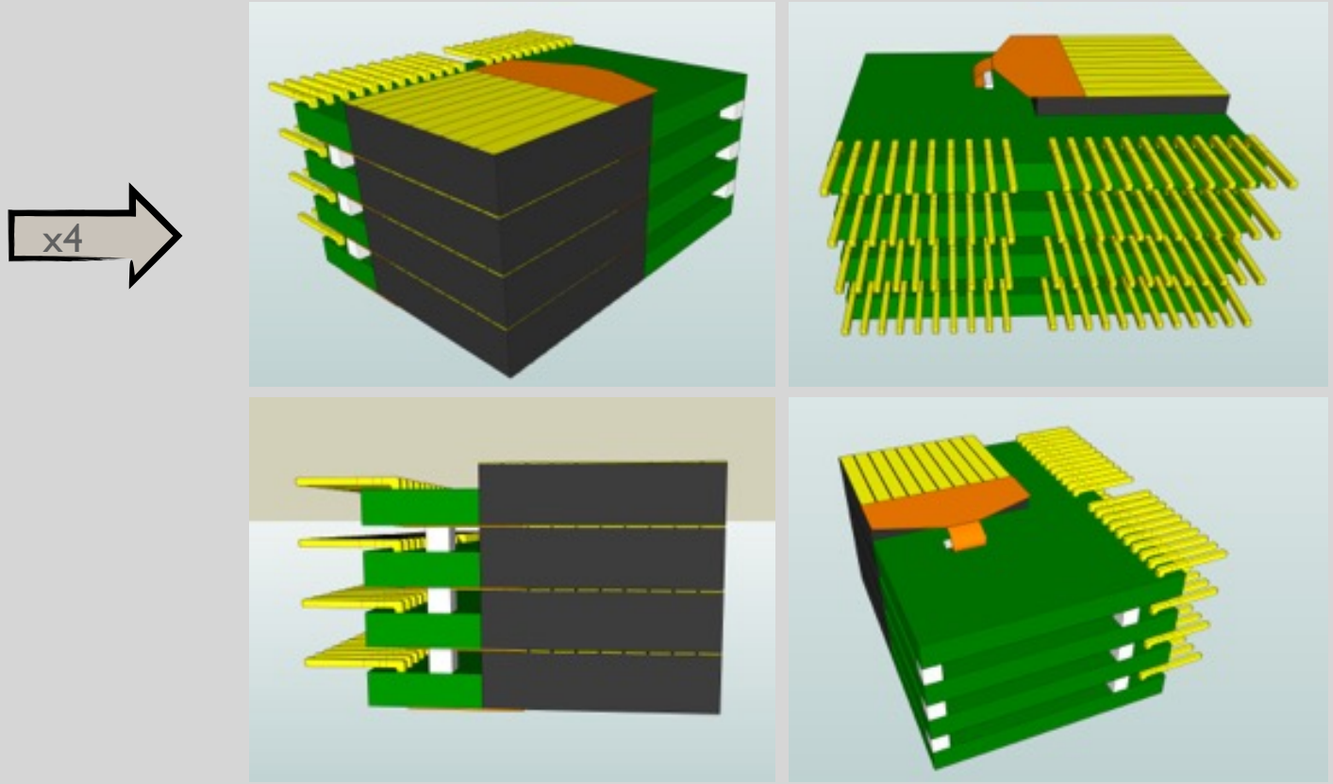
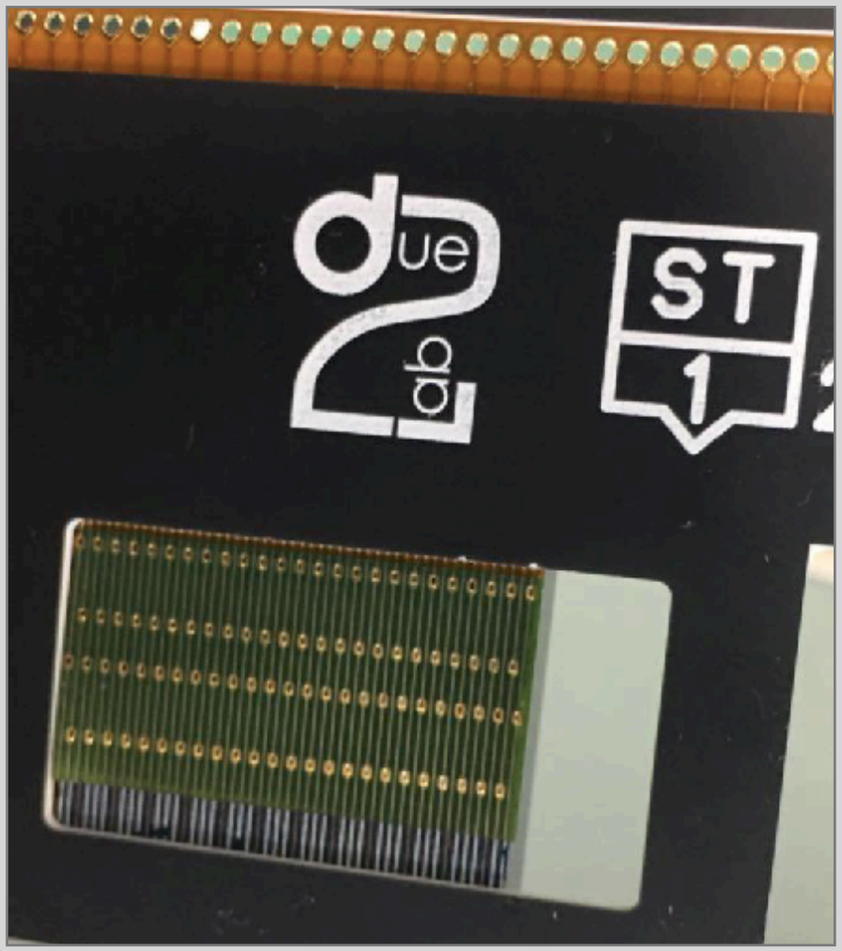


(*) drift strips not reported

3D-CZT prototype, 20x20x20 mm³

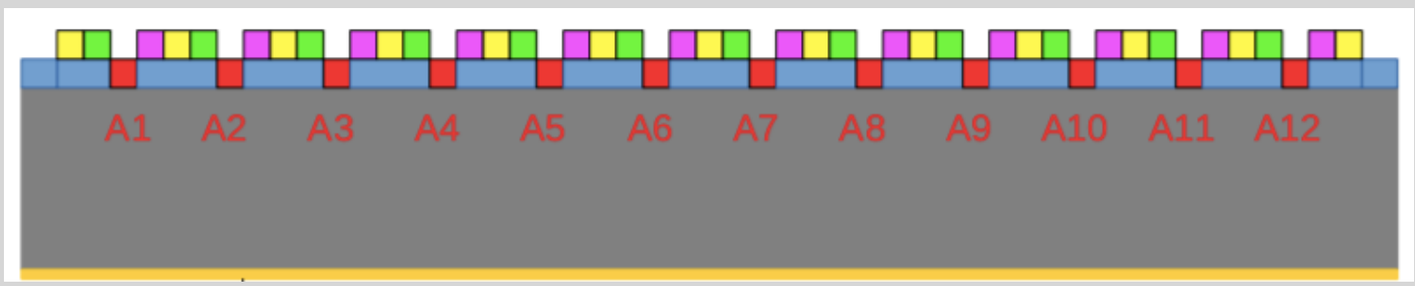


3D-CZT prototype for BNCT-SPECT applications



Anode side: 12 drift strip cells

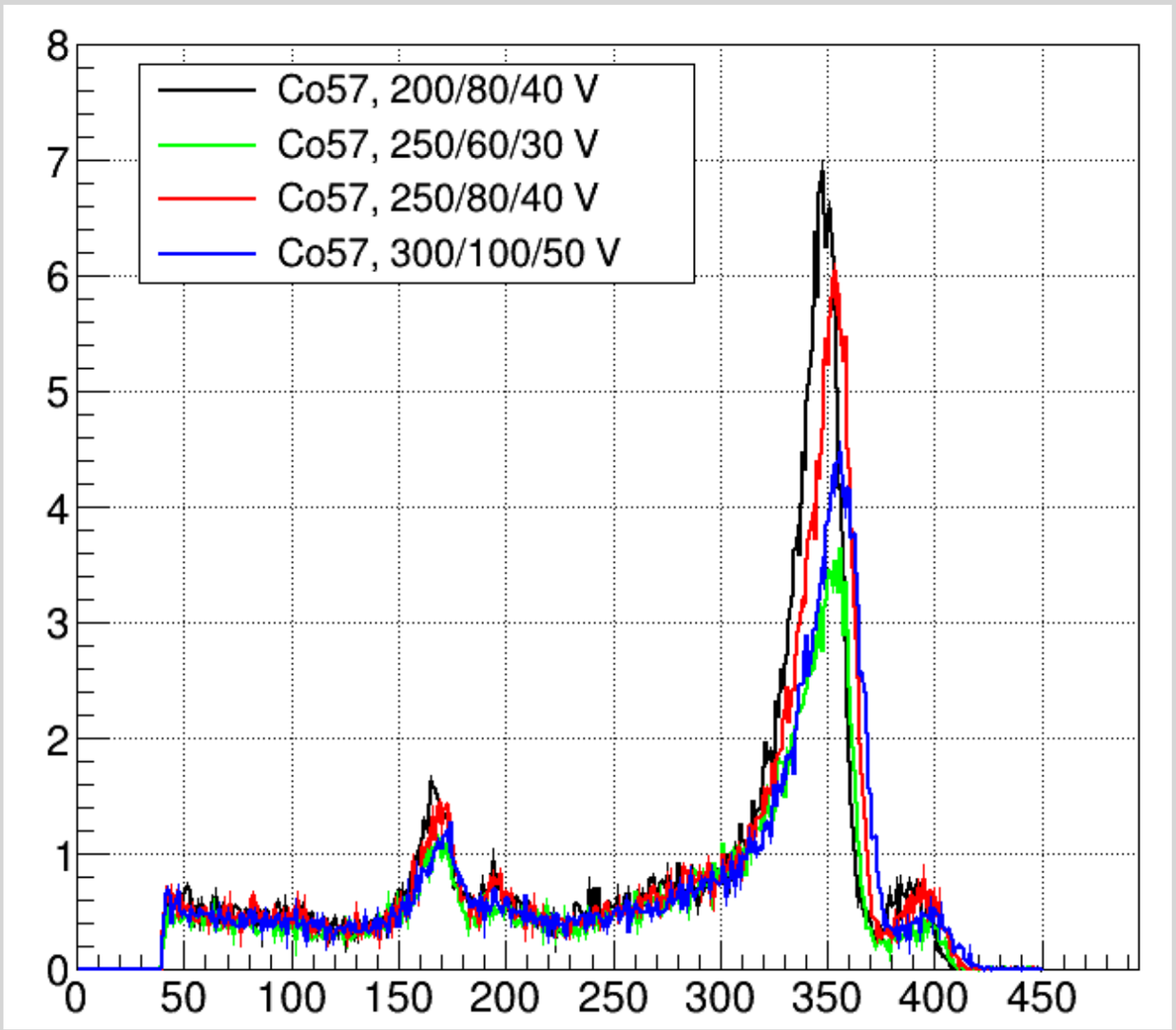
Cathode side: 10 segments

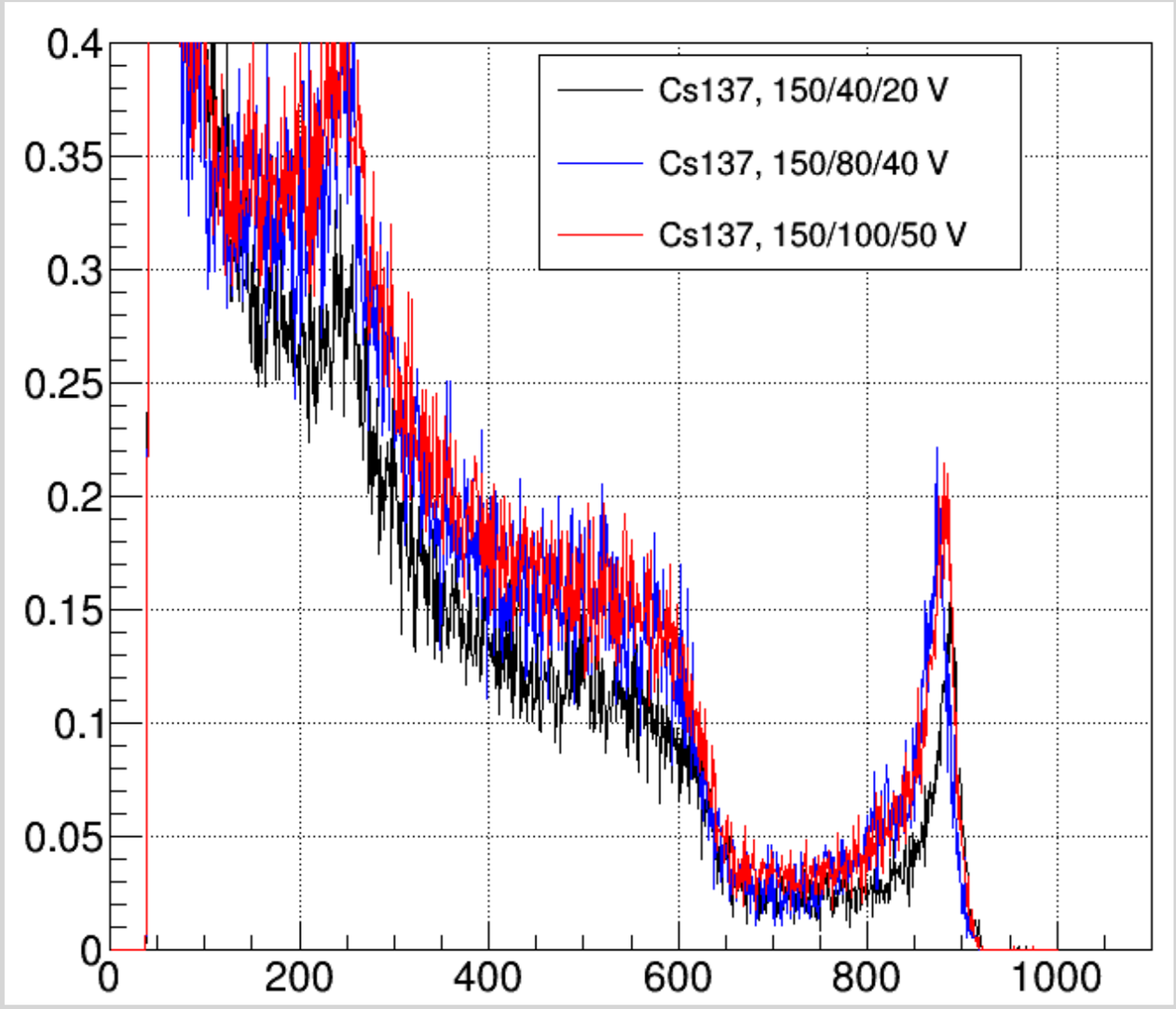


Scheme of electrodes pattern on anode side: 12 strip cells (1.6 mm pitch), each made by a central anode (A) + two lateral stripes per side (yellow + green, pink + yellow)

3D-CZT prototype for BNCT-SPECT applications: preliminary characterisations

Bias voltage

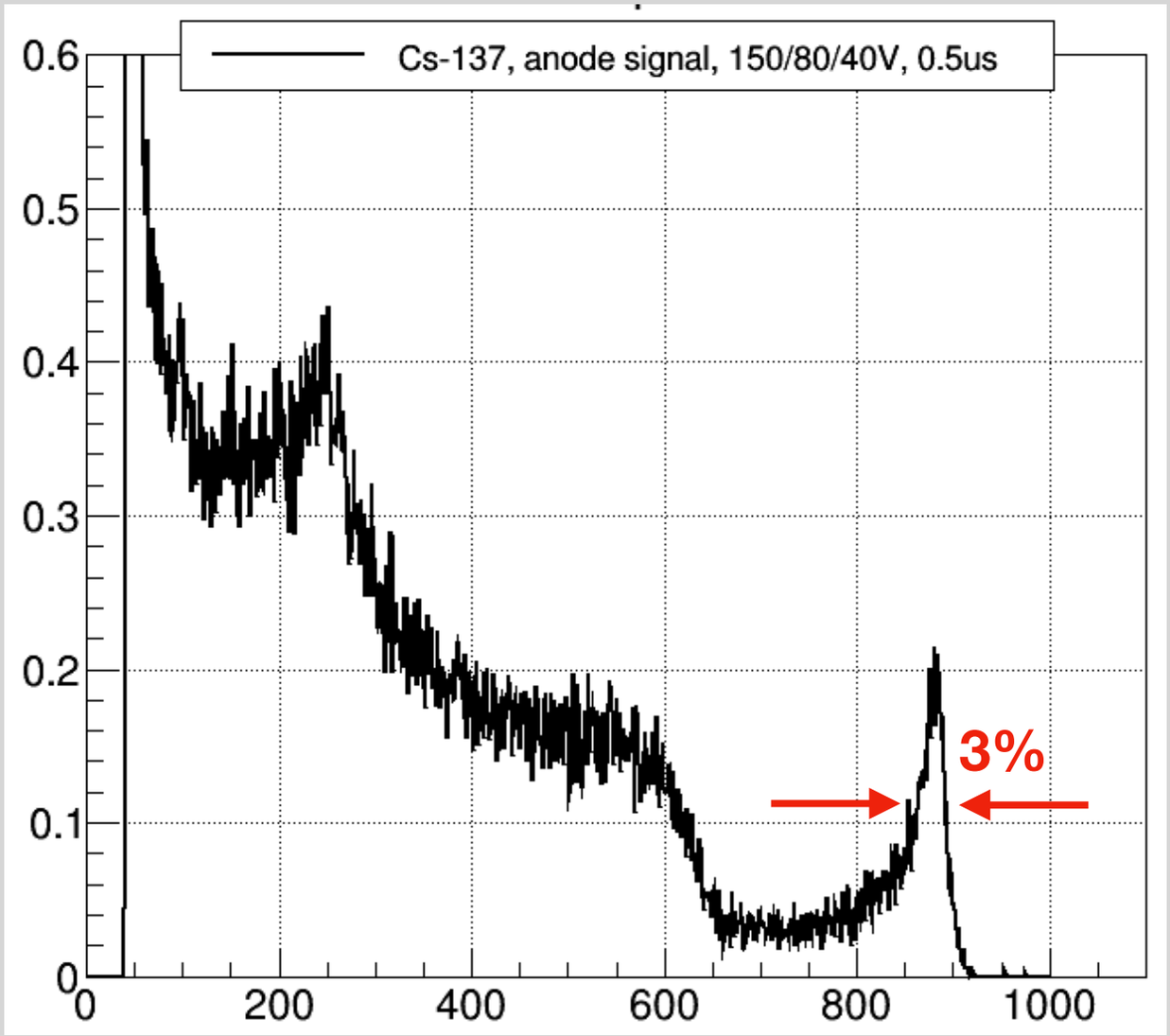




^{57}Co and ^{137}Cs photo peaks as function of drift strip voltages; shaping time 0.5 μm

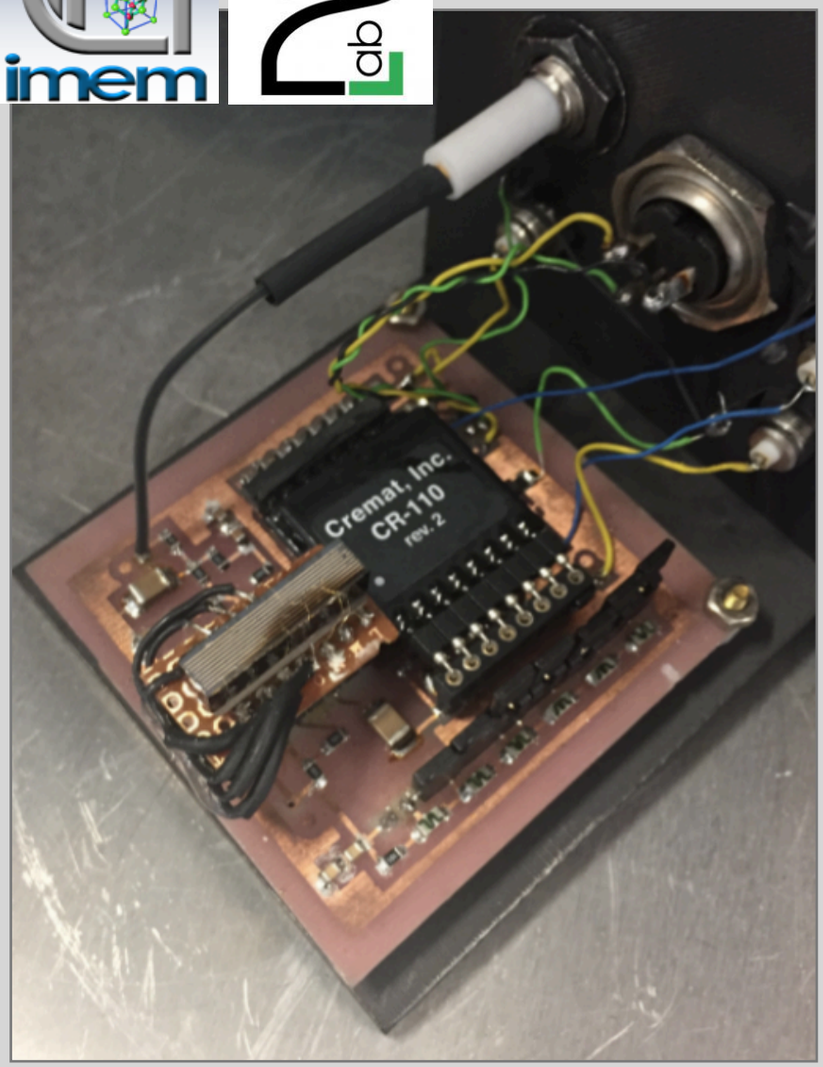
3D-CZT prototype for BNCT-SPECT applications: preliminary characterisations

Preliminary energy resolutions



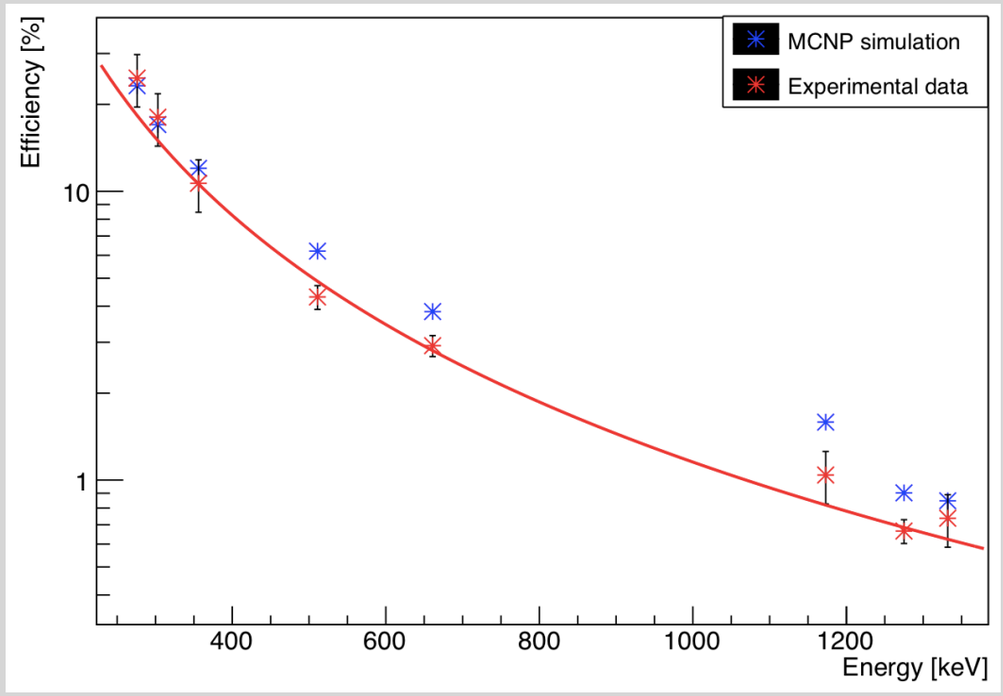
^{137}Cs spectrum of anode signals

Preliminary characterisation of 1D-CZT detector



20x5x5 mm³, single cathode,
1 read-out anode + (4+4) drift strip

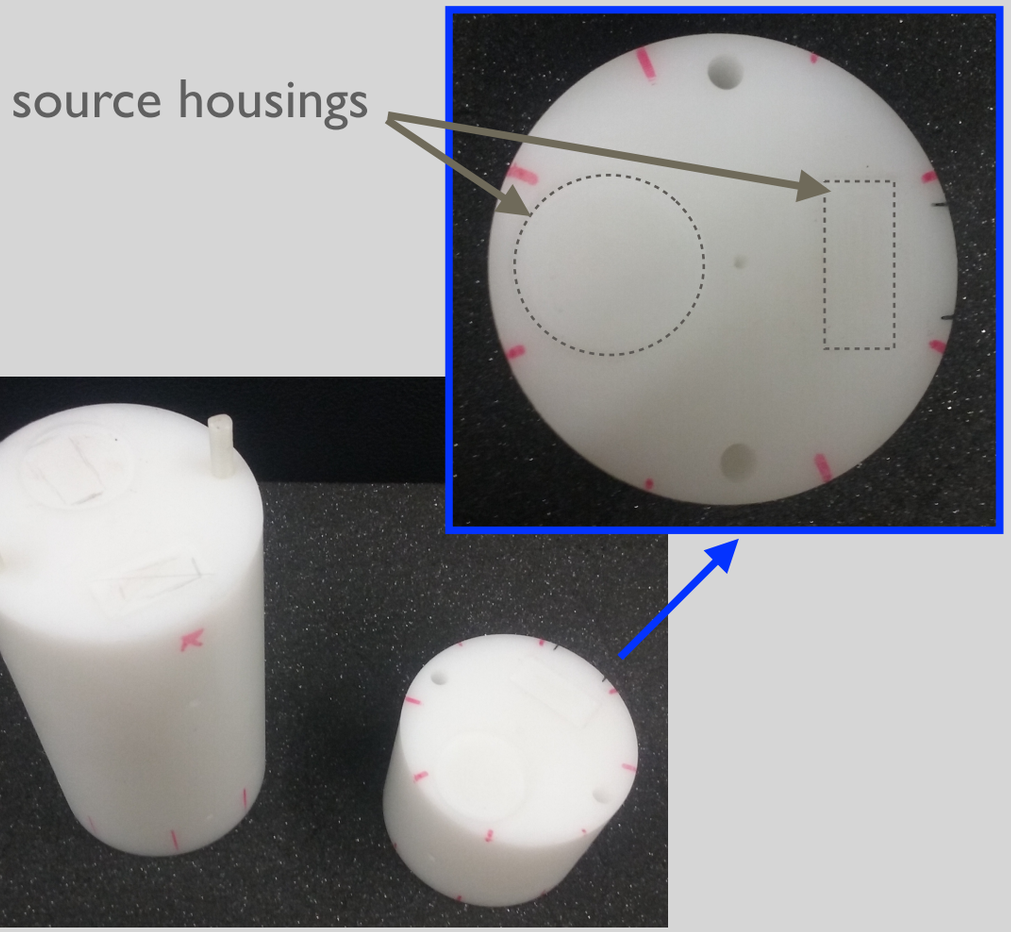
S.Fatemi et al., Preliminary characterisation of a CdZnTe photon detector for BNCT-SPECT, NIM-A 903 (2018) 134-139

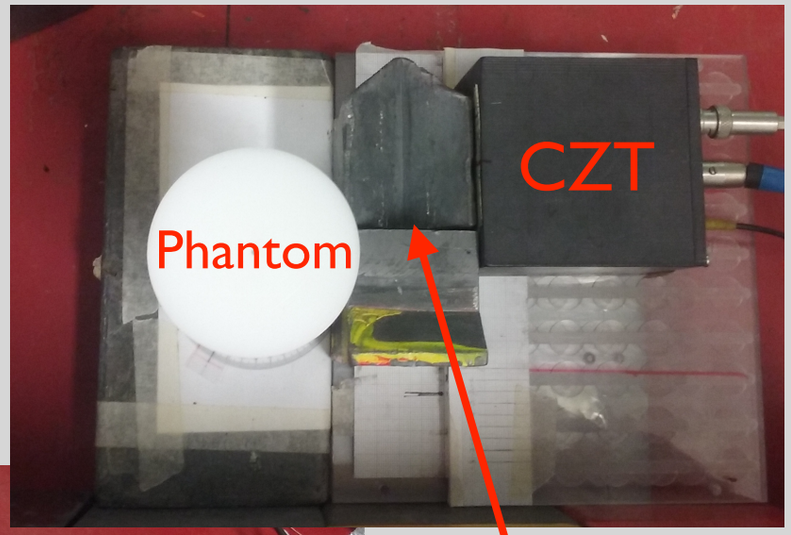


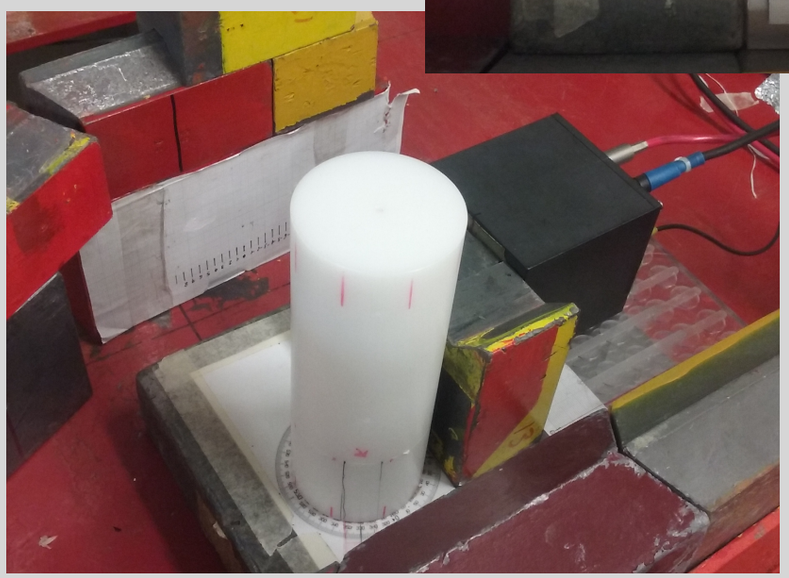
Isotope	Energy (keV)	En. resolution
Ba133	276	2.97
	303	2.53
	356	**2.81**
Cs137	**662**	**2.81**
Na22	**511**	**2.99**
	1275	2.09
Co60	1173	1.64
	1332	1.78

Preliminary studies of image reconstruction: experimental set-up

- Experiments carried out at Pavia University Applied Nuclear Energy Laboratory (L.E.N.A.)
- Polyethilene phantom simulating a small animal and equipped with internal housings to keep point-sources as well as neutron activated wires used to simulate the 478 keV γ ray emitting tumour



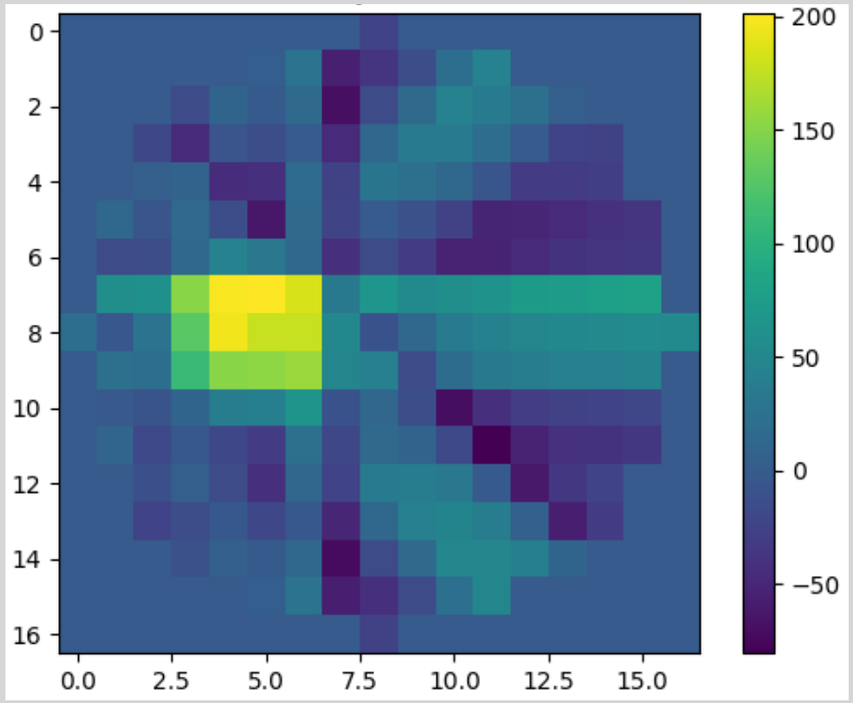




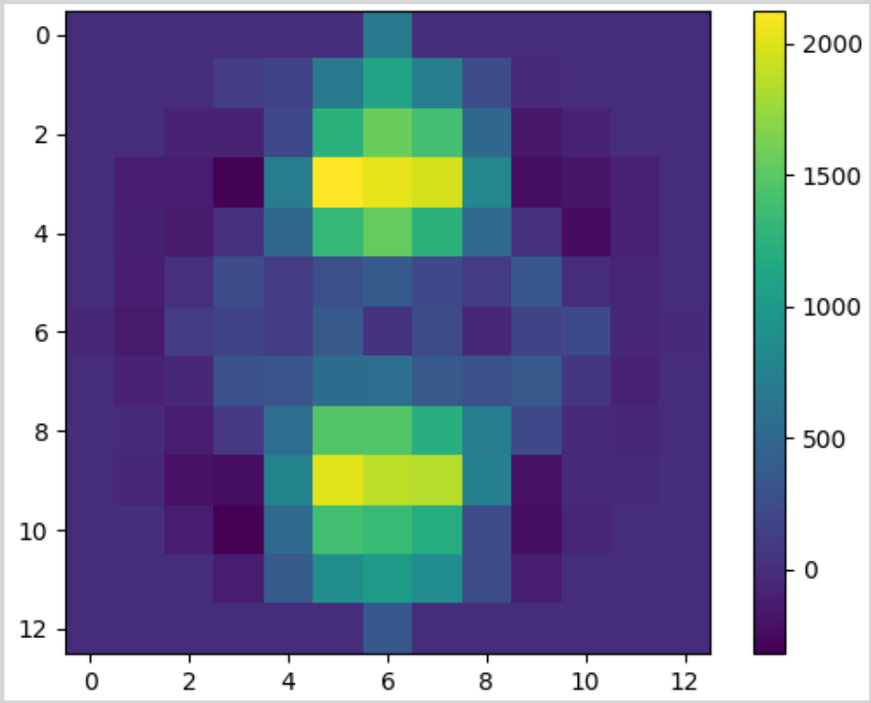
Preliminary studies of image reconstruction: experimental results

Experimental tomography tests using:

- small animal phantom (polyethilene, approx. 6 cm diameter)
- neutron activated small detectors (Au wires)
- 5x5x20 mm^3 1D-CZT detector



single Au activated wires (approx. 1 cm long), Pb collimator (approx. **13 mm diameter**), **45° rotation/projection**



couple of Au activated wires (approx. 1 cm long, each), Pb collimator (approx. **13 mm diameter**), **5° rotation/ projection**

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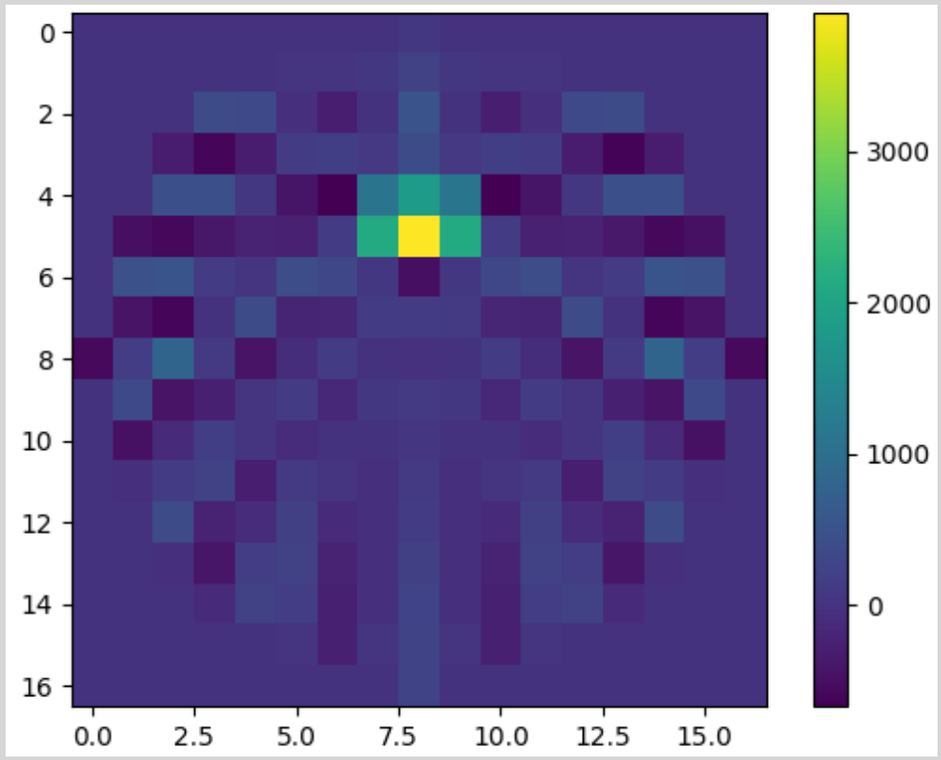
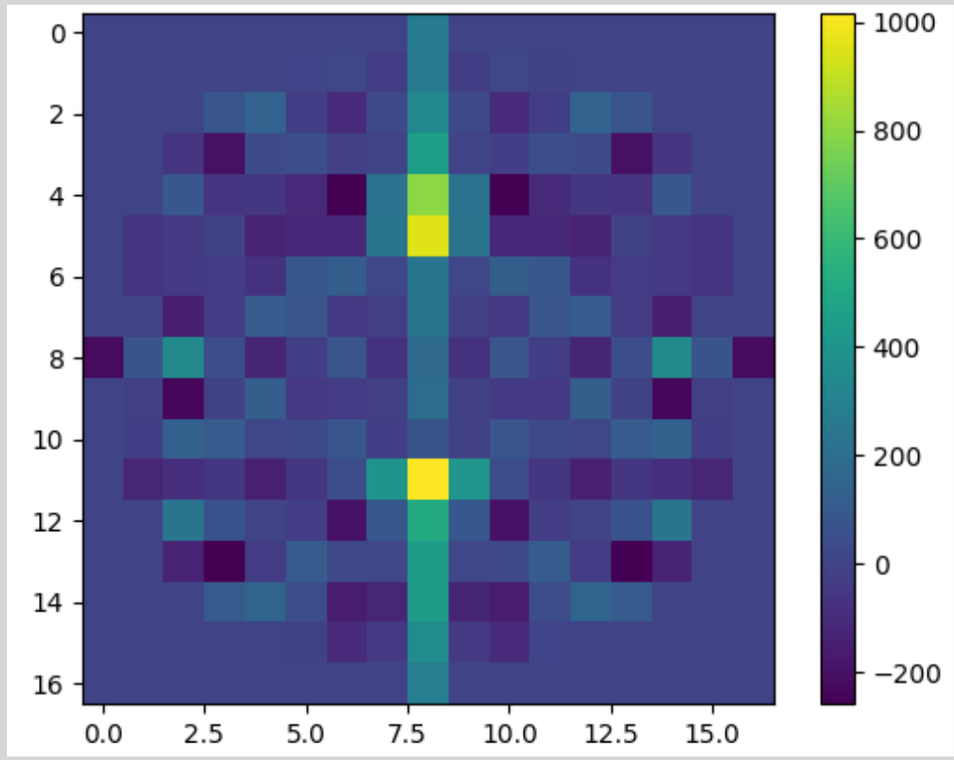
Preliminary studies of image reconstruction: experimental results

Experimental tomography tests using:

- small animal phantom (polyethilene, approx. 6 cm diameter)
- neutron activated small detectors (Au wires)
- 5x5x20 mm^3 1D-CZT detector



single Au activated wires (approx. 1 cm long), Pb collimator (**3 mm diameter**), **20° rotation/projection**



couple of Au activated wires (approx. 1 cm long, each), Pb collimator (**3 mm diameter**), **20° rotation/ projection**

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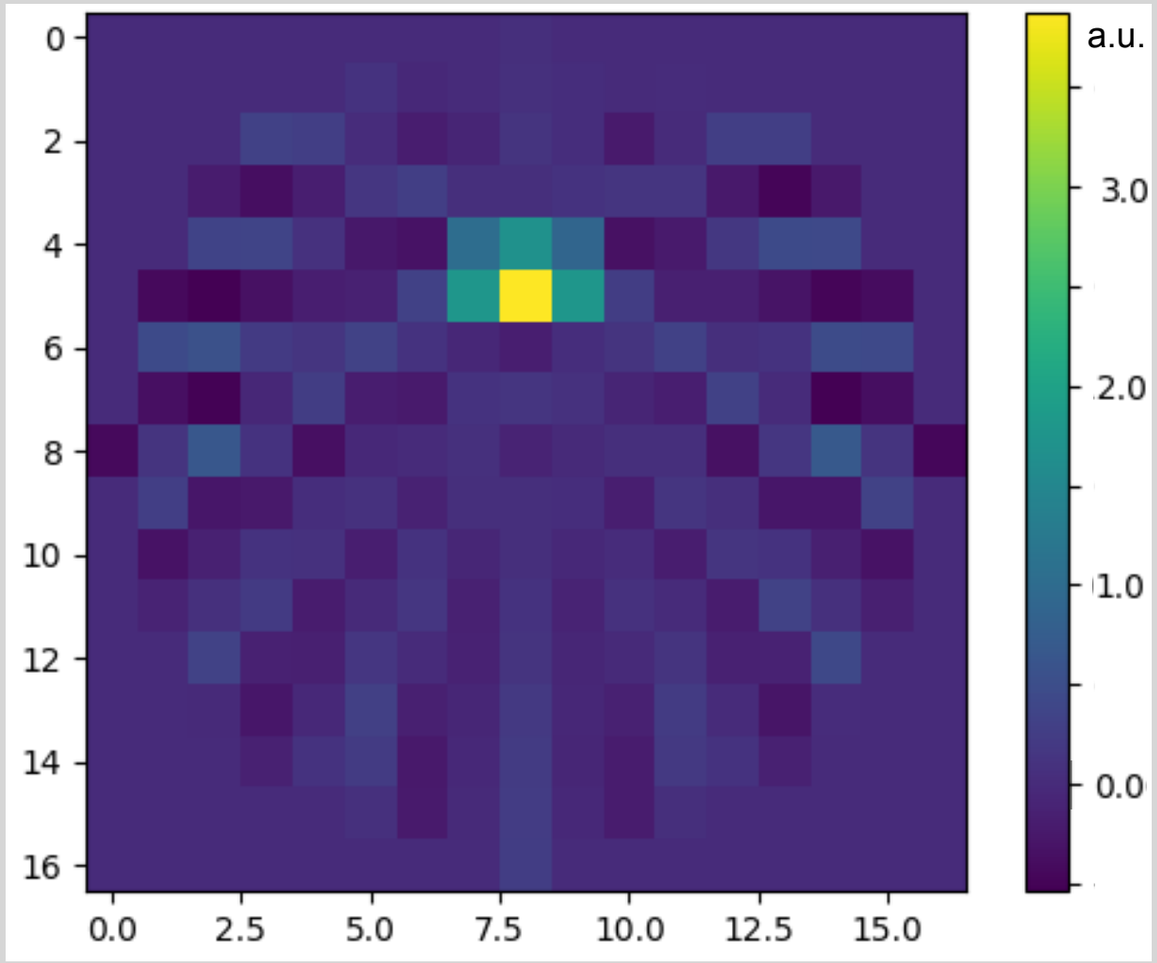
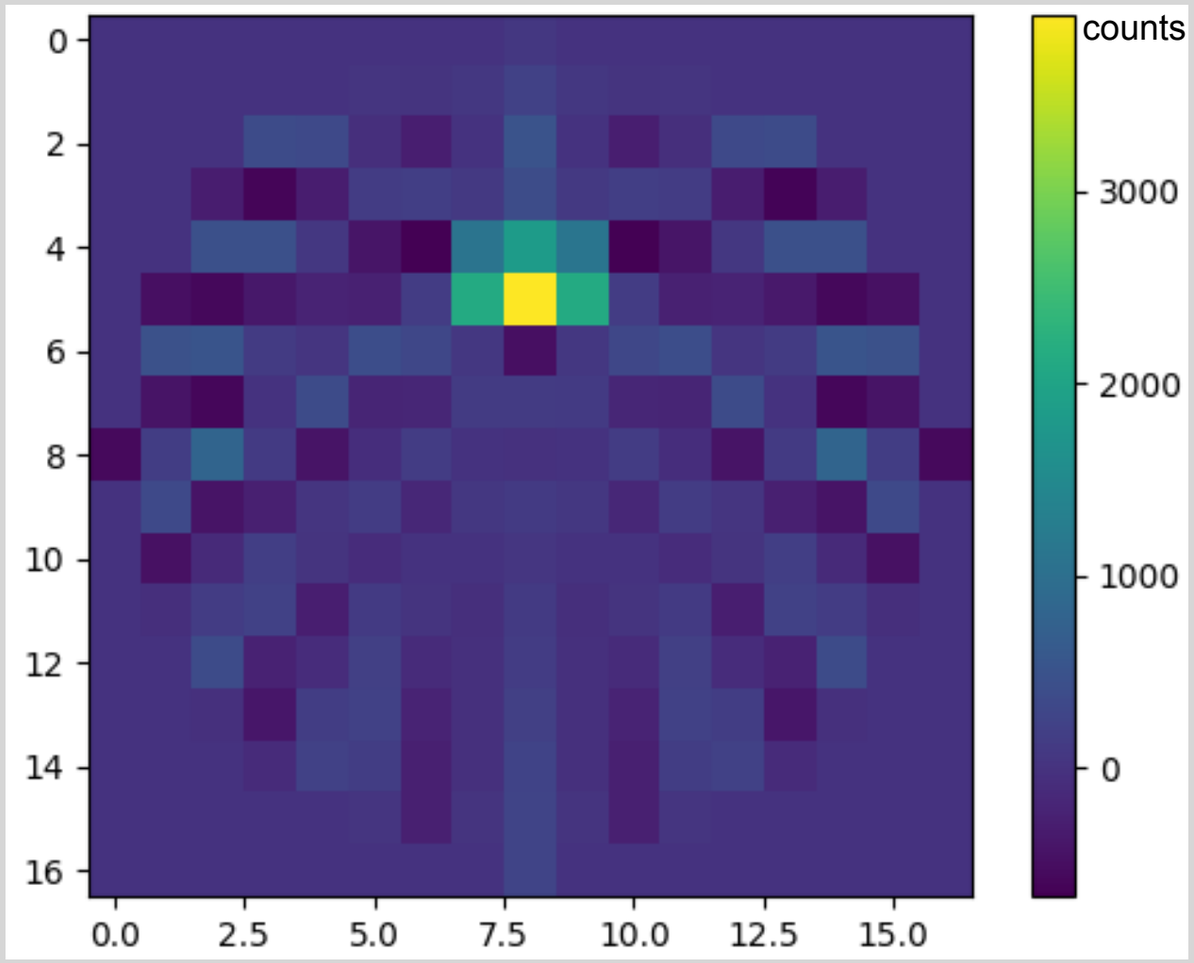
Preliminary studies of image reconstruction: MCNP simulated results

Simulated tomography tests using:

- single Au-wire inside polyethylene phantom (M.C. validation)

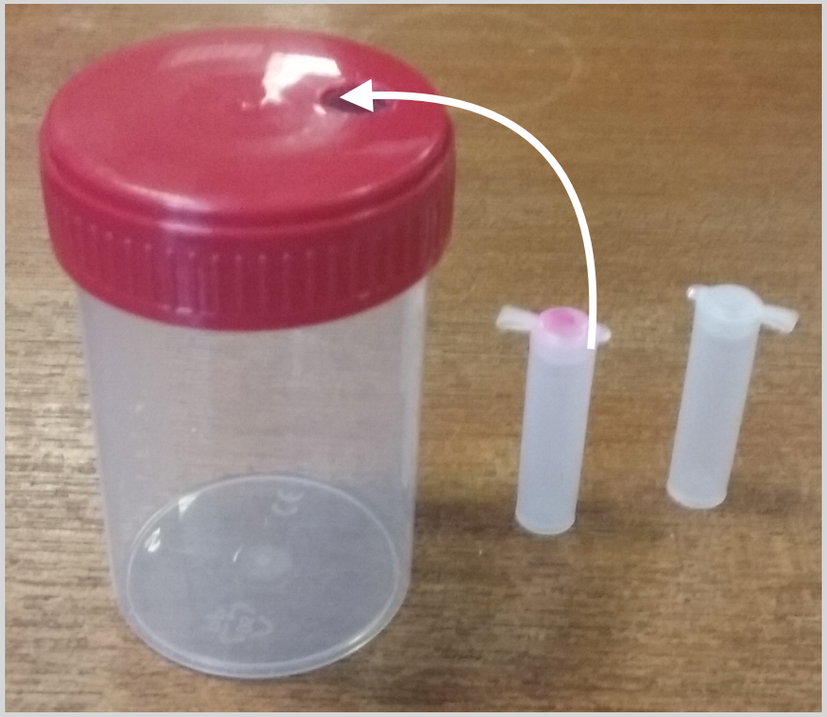




Preliminary studies of image reconstruction

Tomography tests using:

- Point sources (Na22, Cs137 -> dual isotope imaging)
- F18 "localised" and distributed solutions (~ BNCT situation with signal+noise at same energy)



Other on-going studies:

S.Fatemi: *Response of a CZT detector to the (n+g) radiation field of an accelerator based BNCT facility*

C.H.Gong: *Preliminary study of a single 3D position-sensitive CZT detector used for Compton camera*

Thanks for your attention…