Radionuclide therapy assessment with MACACO III+

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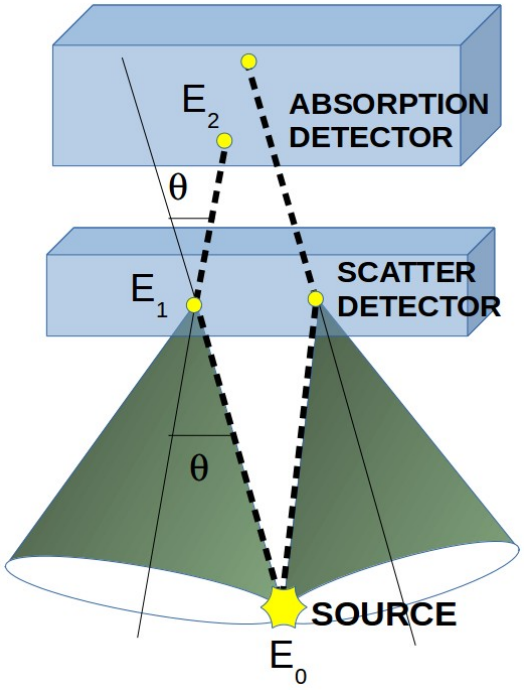
http://ific.uv.es/iris

XVI CPAN days. Madrid, 19-21 November 2024.

Outline

- MACACO Compton camera.
- Application to treatment verification in targeted radionuclide therapy.
- Conclusions

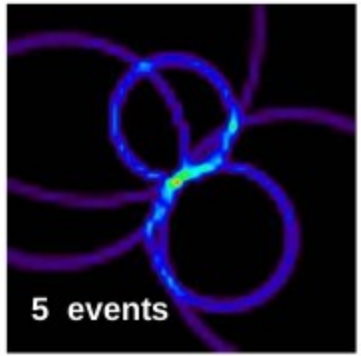
Compton camera

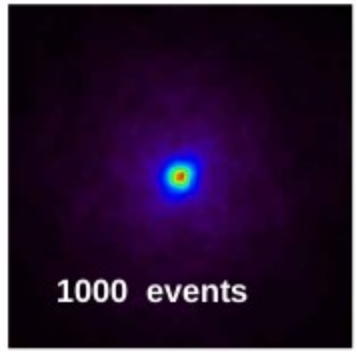


$$\cos\varphi = 1 - m_0c^2\left(\frac{1}{E_{\gamma'}} - \frac{1}{E_\gamma}\right)$$

$$E_\gamma = E_{e^-} + E_{\gamma'}$$

Backprojection



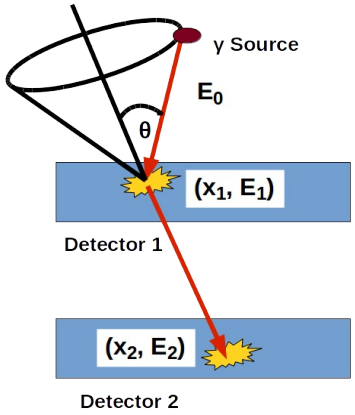


+ Image reconstruction

$$\lambda_j^{n+1} = \frac{\lambda_j^n}{s_j}\sum_{i=0}^{N}\frac{t_{ij}}{\sum_k t_{ik}\lambda_k^n}$$

List mode ML-EM

Compton camera



Scatterer + "absorber"
2 interactions

Problem if the photon energy is unknown/high (MeV)

$$cos(\theta) = 1 - m_0c^2(\frac{1}{E_0 - E_e} - \frac{1}{E_0})$$

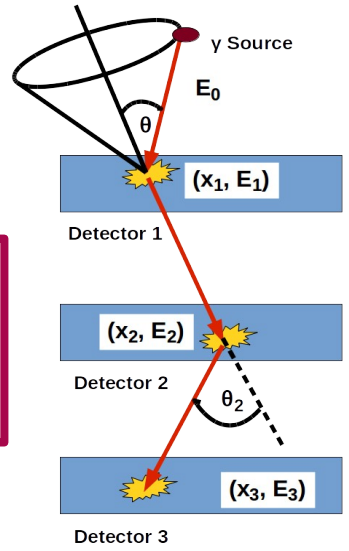
Multilayer
3 int. in 3 detectors

Energy determined

Lower efficiency

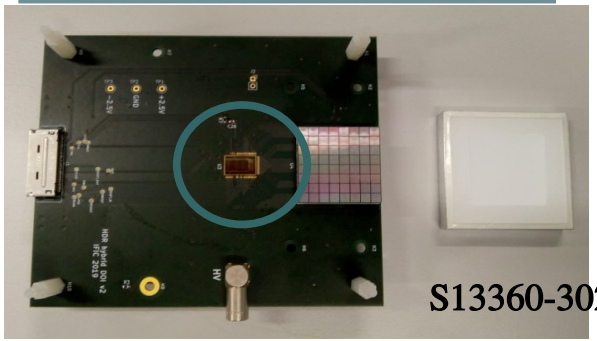
$$cos(\theta) = 1 - \frac{E_1 m_e c^2}{E_0(E_0 - E_1)}$$

$$E_0 = E_1 + \frac{1}{2}(E_2 + \sqrt{E_2^2 + 4\frac{E_2 m_e c^2}{1 - cos(\theta_2)}}$$

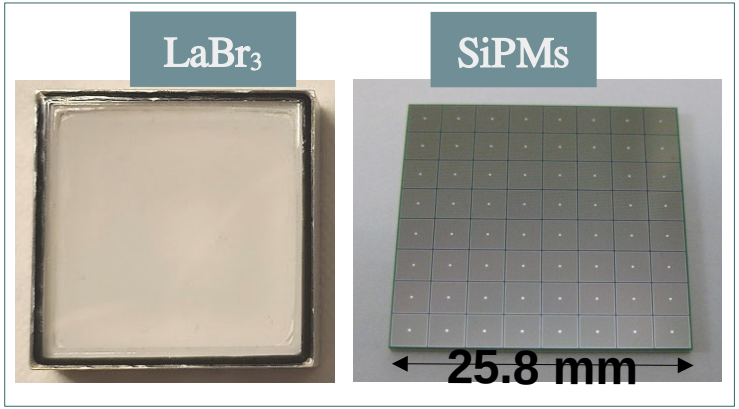


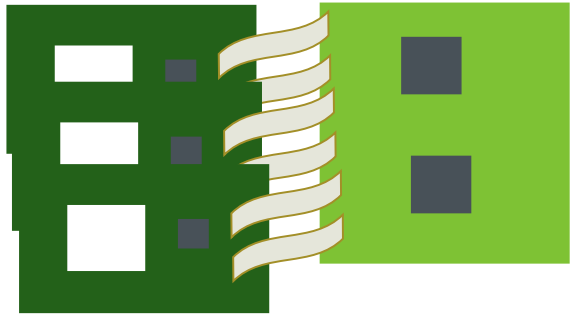
MACACO III

VATA64HDR16 from IDEAS

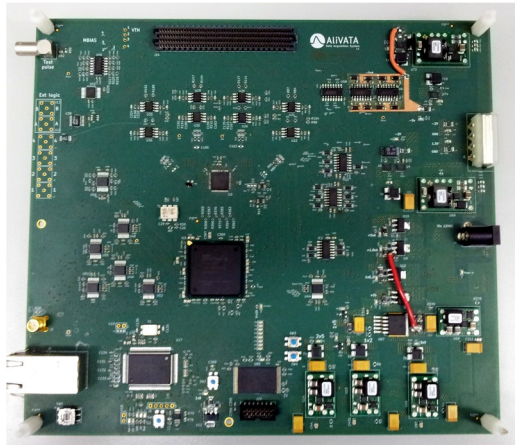


S13360-3025CS





AliVATA DAQ board



Developed by the group.
Commercialized by Alibava Systems S. L.

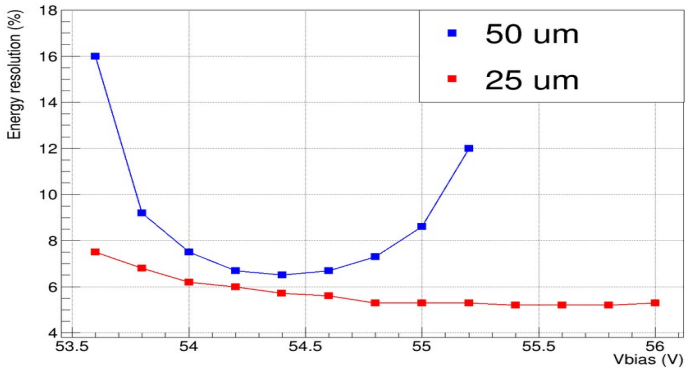
MACACO III characterization

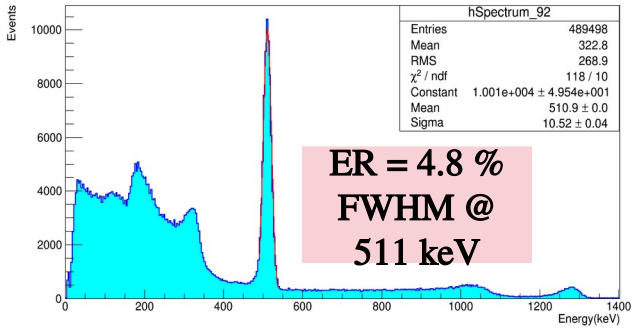
S13360-3025CS (25 µm)

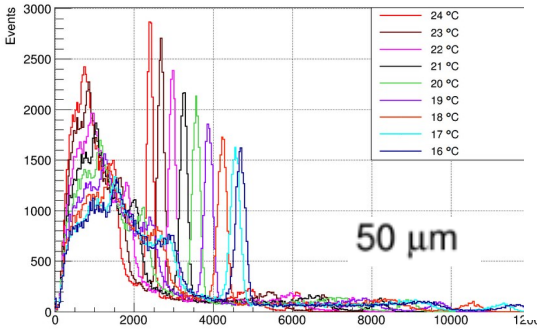
vs

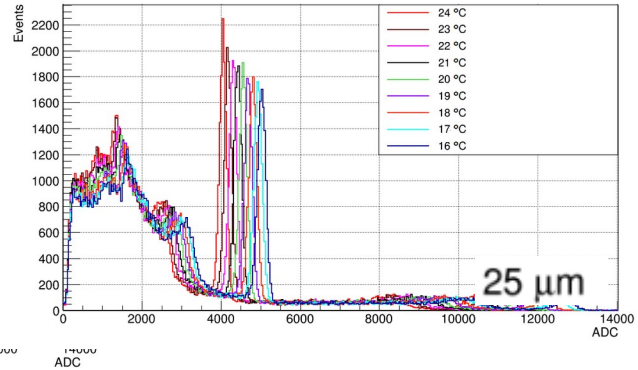
S13361-3050AE-08 (50 µm)

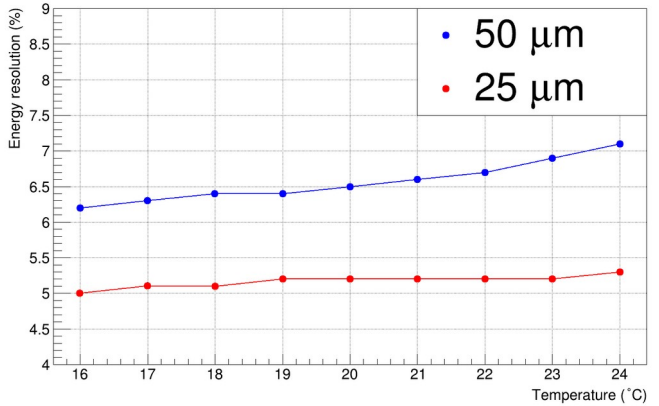
Specific SiPM design - Now commercial product









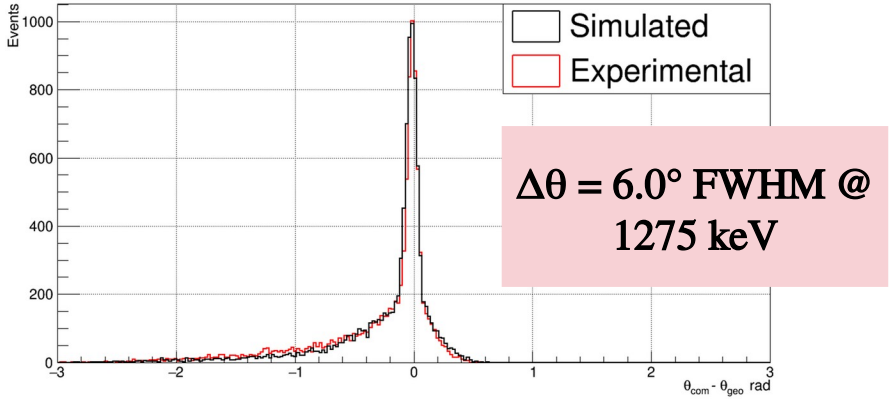


L. Barrientos et al. Rad. Phys. Chem. 2023

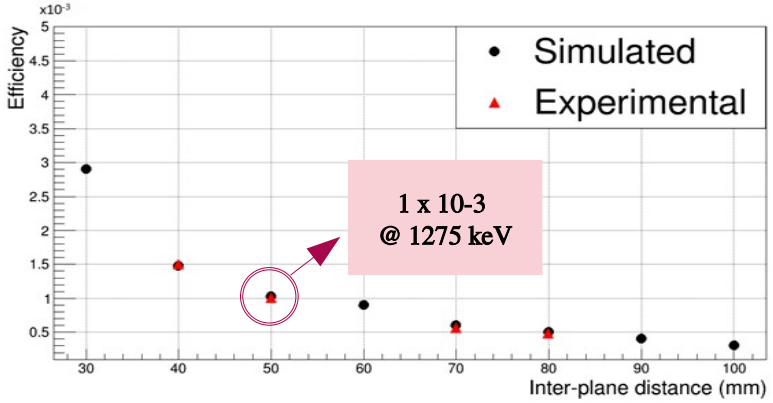
GATE simulations

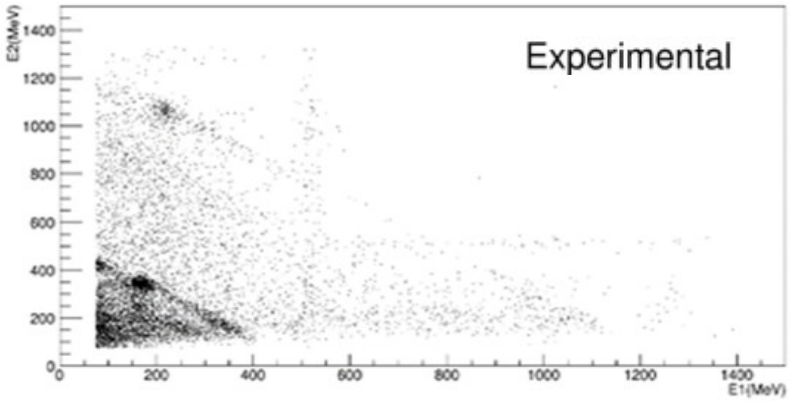
Comparison with MACACO III

Excellent agreement between experimental results and GATE v8.2 simulations.



$\Delta\theta = 6.0°$ FWHM @ 1275 keV





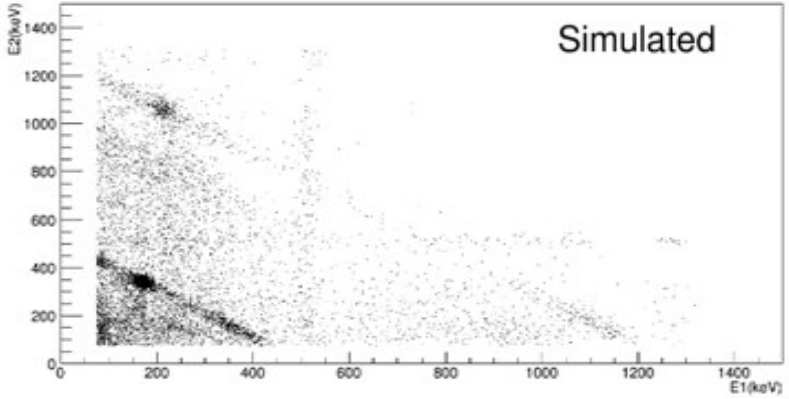
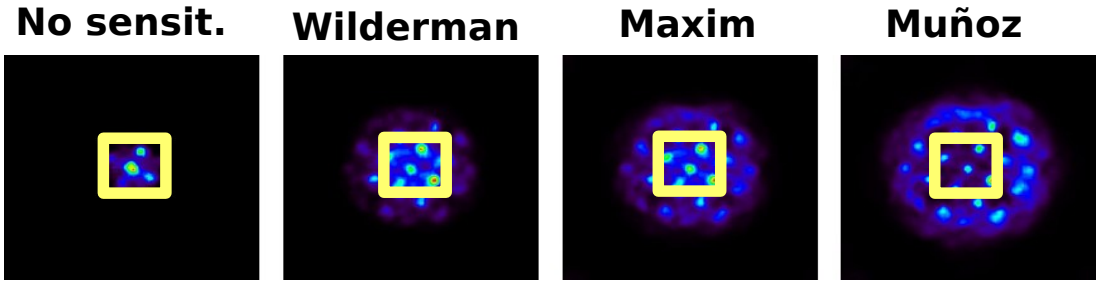
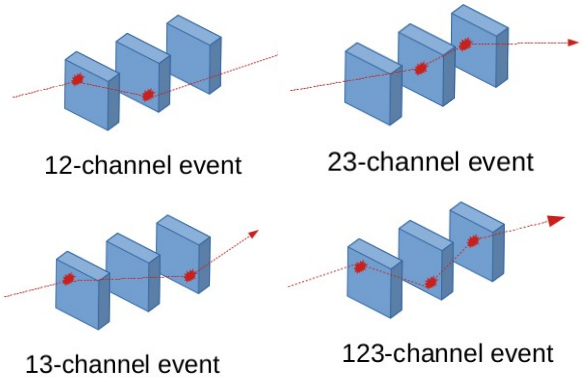


Image reconstruction: list-mode MLEM

Sensitivity model for 2- and 3- interacion events



Joint reconstruction of all channels

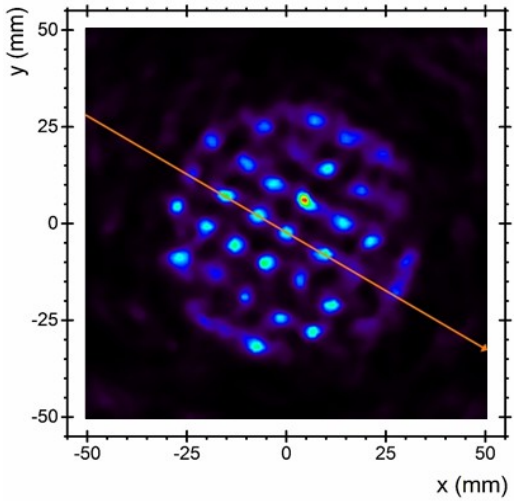


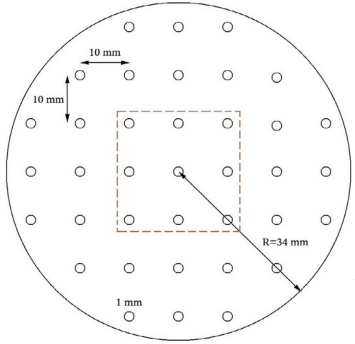
E. Muñoz et al. Phys. Med. Biol. 2018

E. Muñoz et al. Phys. Med. Biol. 2020

J. Roser et al. Phys. Med. Biol. 2020

J. Roser et al. Phys. Med. Biol. 2022





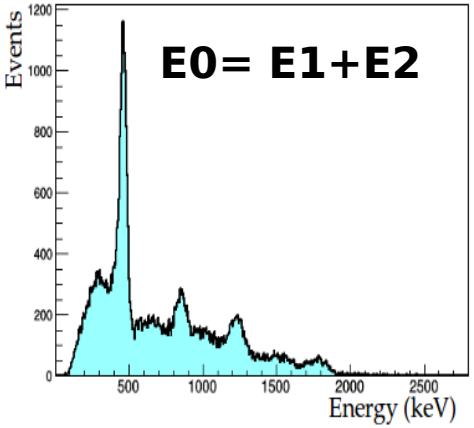
Array of 37 Na-22 point-like sources

Image reconstruction: spectral code

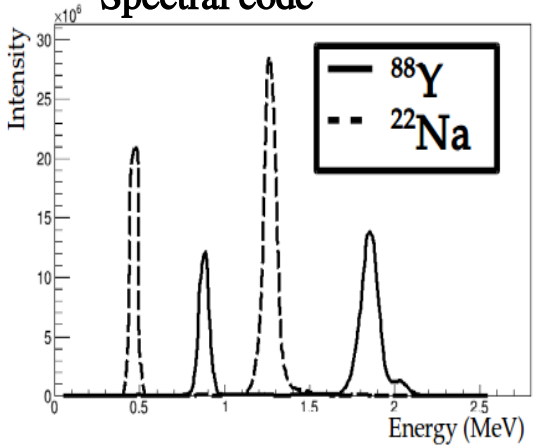
Reconstruction of position and energy distributions

Simultaneous reconstruction of
Y-88 (898, 1836 keV) + Na-22 (511, 1275 keV)

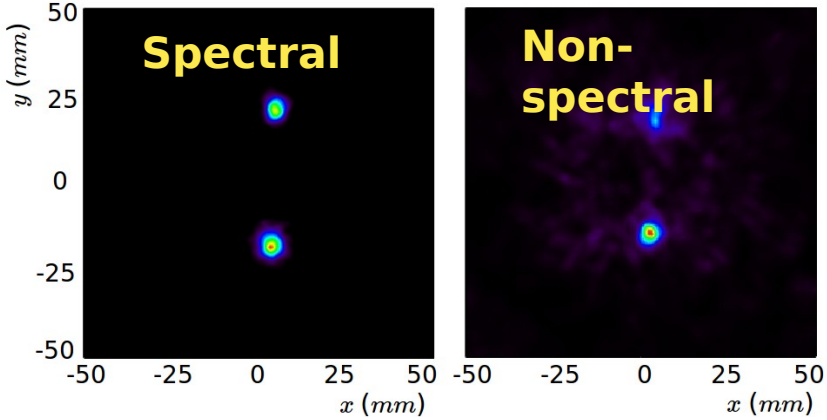
Sum spectrum

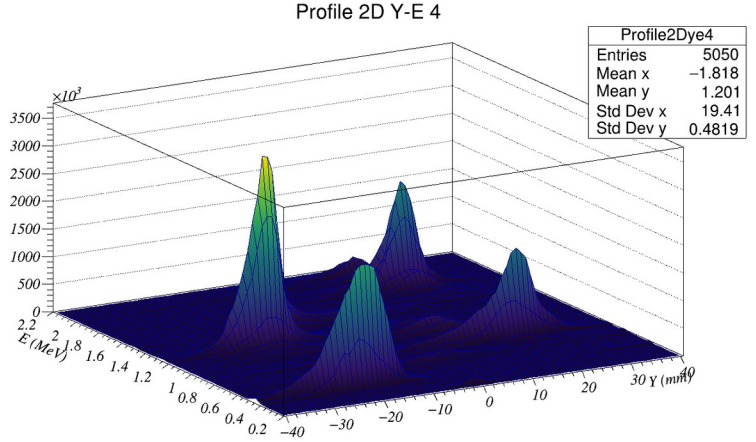


Spectral code



E. Muñoz et al. Phys. Med. Biol. 2020





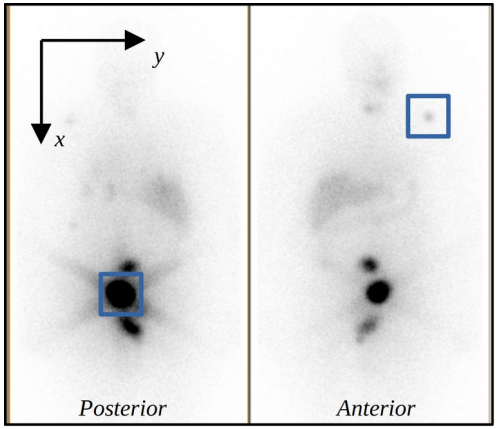
Radionuclide imaging

- Imaging can be used to visualize their distribution in the body and carry out dosimetry employing secondary gamma radiation.

- More challenging than diagnostic imaging since photon energies and activities are not optimized for gamma cameras, in particular for alpha emitters.

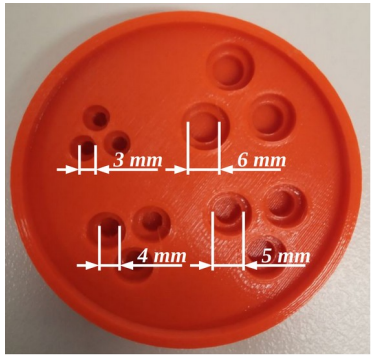
- Compton cameras can be advantageous in this field.

Gamma camera images of a patient treated with ^{131}I-NaI



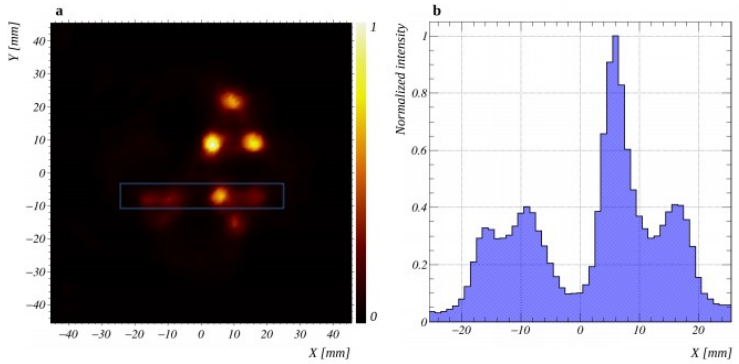
Initial tests in La Fe hospital (Valencia)

3D printed Derenzo-like phantom



^{18}F-FDG (511 keV)

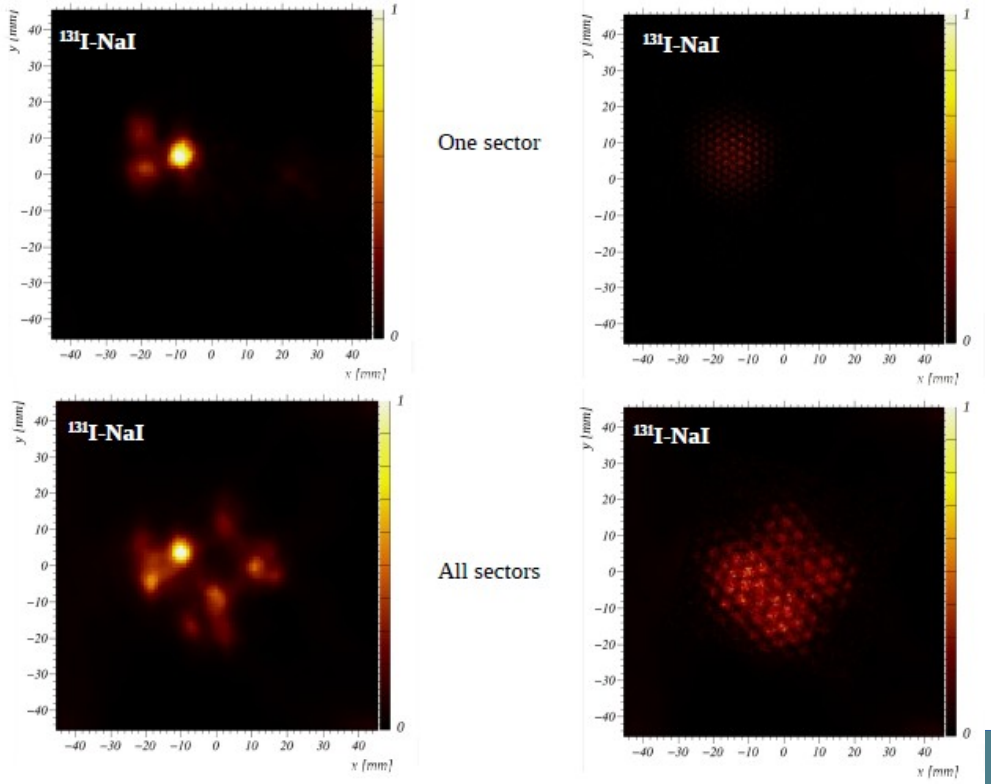
Compton camera



^{131}I-NaI (364 keV)

Compton camera

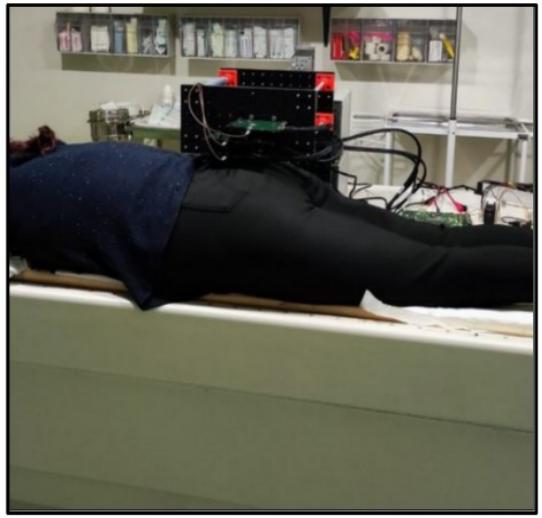
Gamma camera
Bright View XCT (Philips)



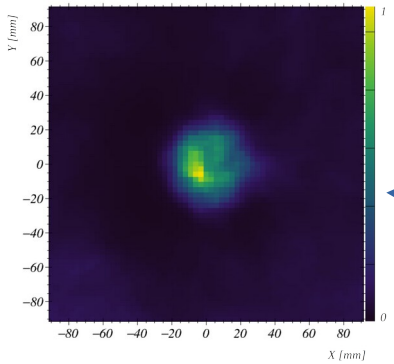
In collaboration with Irene Torres-Espallardo, José Manuel Calatayud, Pilar Bello and Stefan Prado from La Fe hospital.

Initial tests in La Fe hospital (Valencia)

- Metastatic lesions from patients treated with ^{131}I-NaI after thyroid gland resection
- Initial activity (total): 150 mCi
- MACACO III @ ~70 mm.

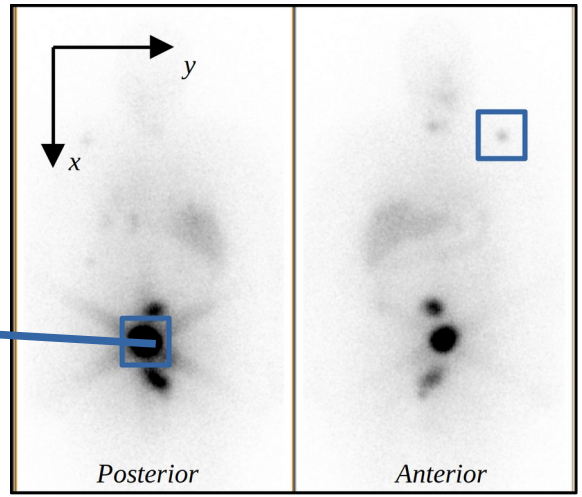


MACACO III



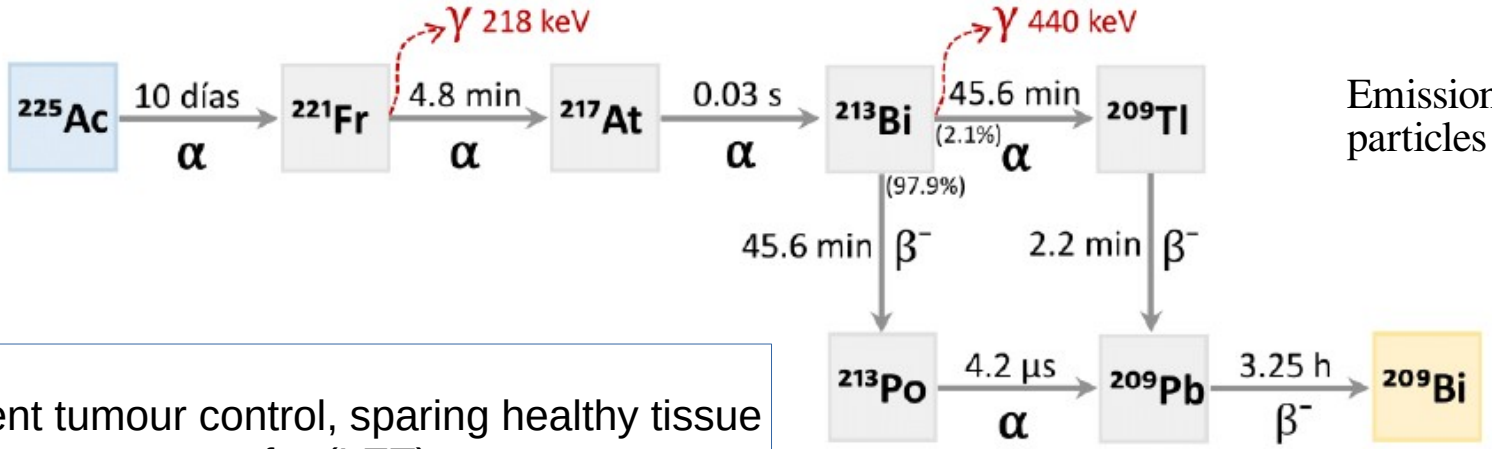
Sacrum lesion

Gamma camera



J. Roser et al. Sumbitted to EJMP.

Ac-225 Measurements at Léon Bérard hospital (Lyon)



Emission of 4 alpha particles (5.8-8.4 MeV)

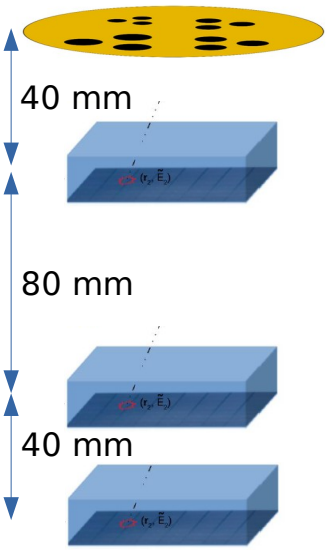
TAT: Efficient tumour control, sparing healthy tissue
- high linear energy transfer (LET)
- short range (<100 µm, a few cell diameters)

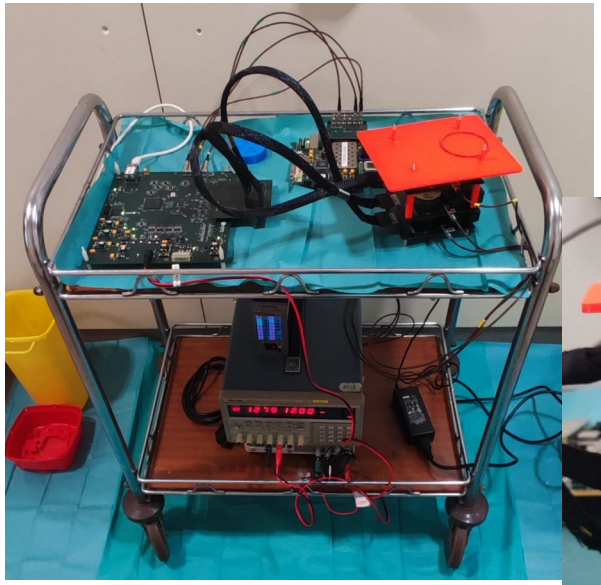
^{225}Ac: Promising alpha-emitter
- high net alpha yield
- high alpha energies
- 10 day half-life

	[^{177}Lu]Lu-PSMA-I&T	[^{225}Ac]Ac-PSMA-I&T
Therapeutic Activity	7.4 GBq	8 MBq
Photon yield	208 keV (10%) 113 keV (6%)	218 keV (11%) 440 keV (26%)

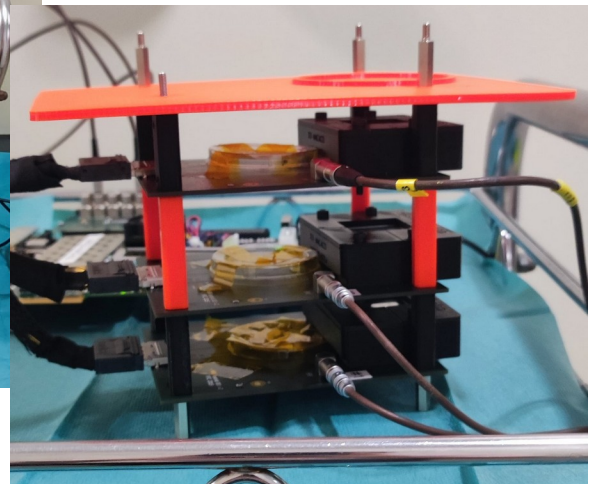
^{225}Ac - Low activities and high photon energies

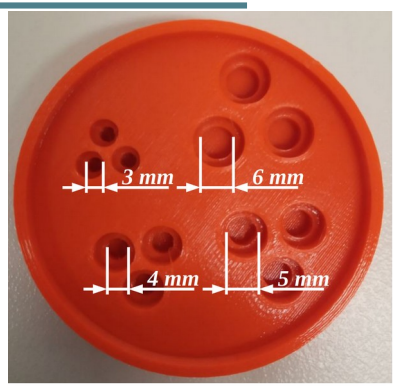
Ac-225 Measurements at Léon Bérard hospital (Lyon)

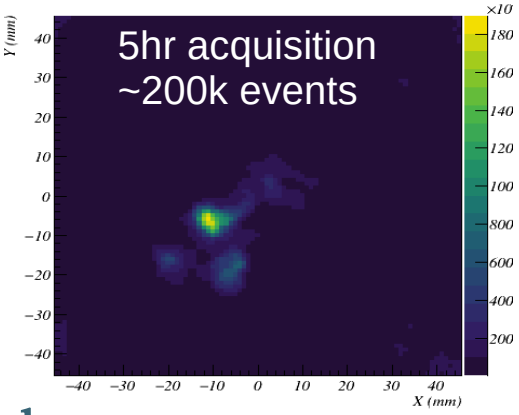




MACACO III







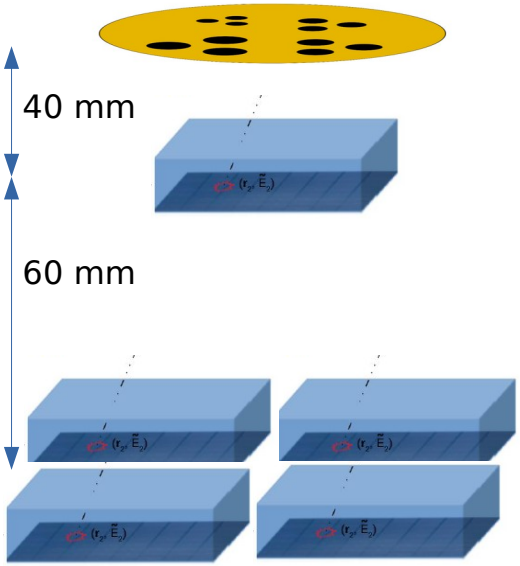
In collaboration with Ane Etxebeste, David Sarrut, Jean Noël Badel from Creatis and Léon Bérard hospital (Lyon).

6 mm diameter rods reconstructed

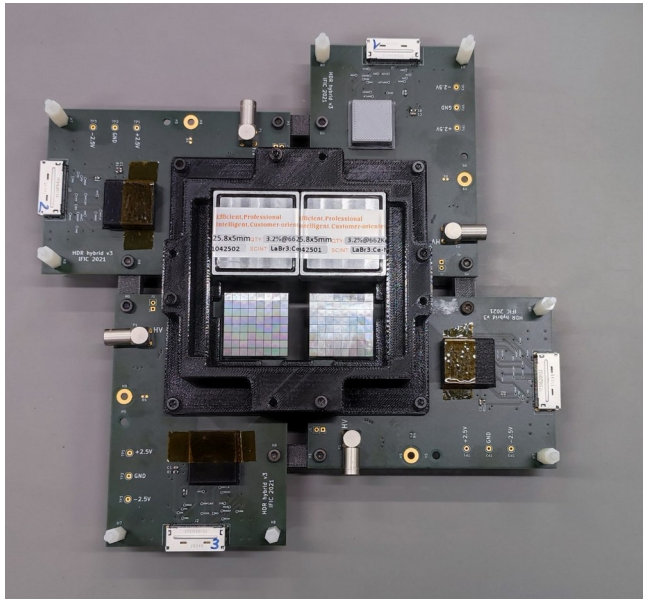
70 kBq /rod

Sensitivity enhancement

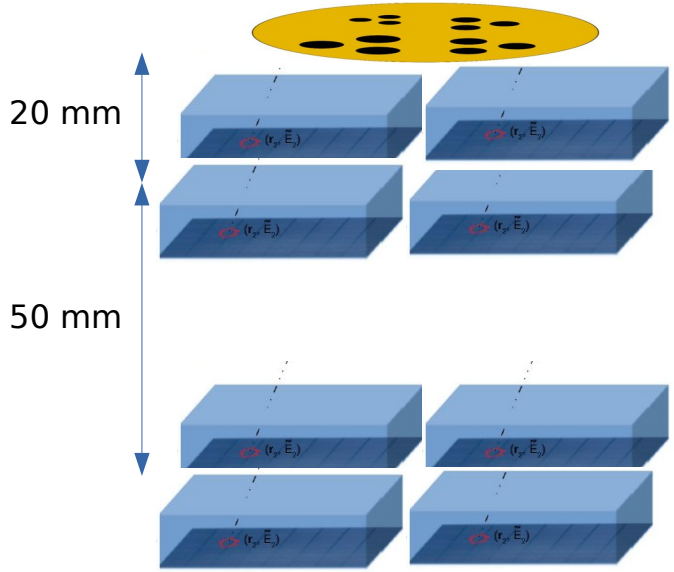
MACACO III+



Working prototype



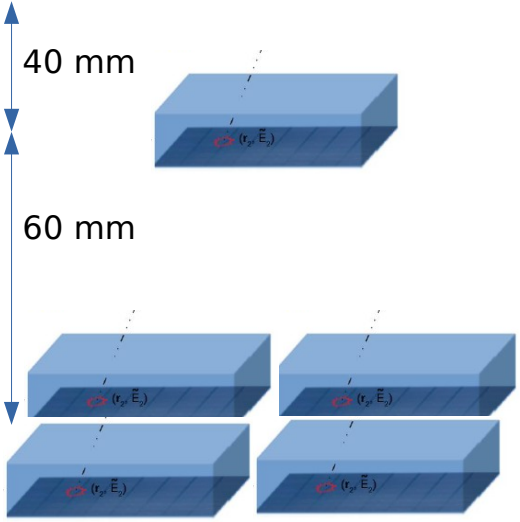
MACACO IV



Under development

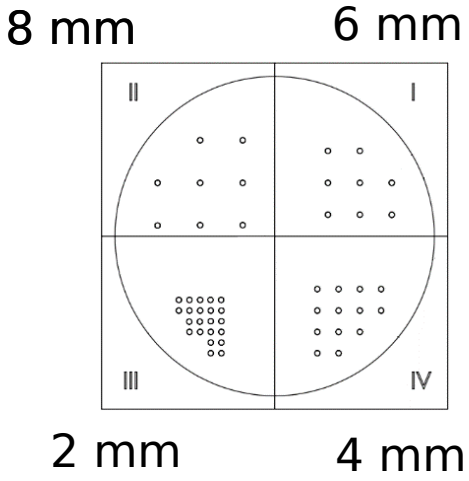
Sensitivity enhancement

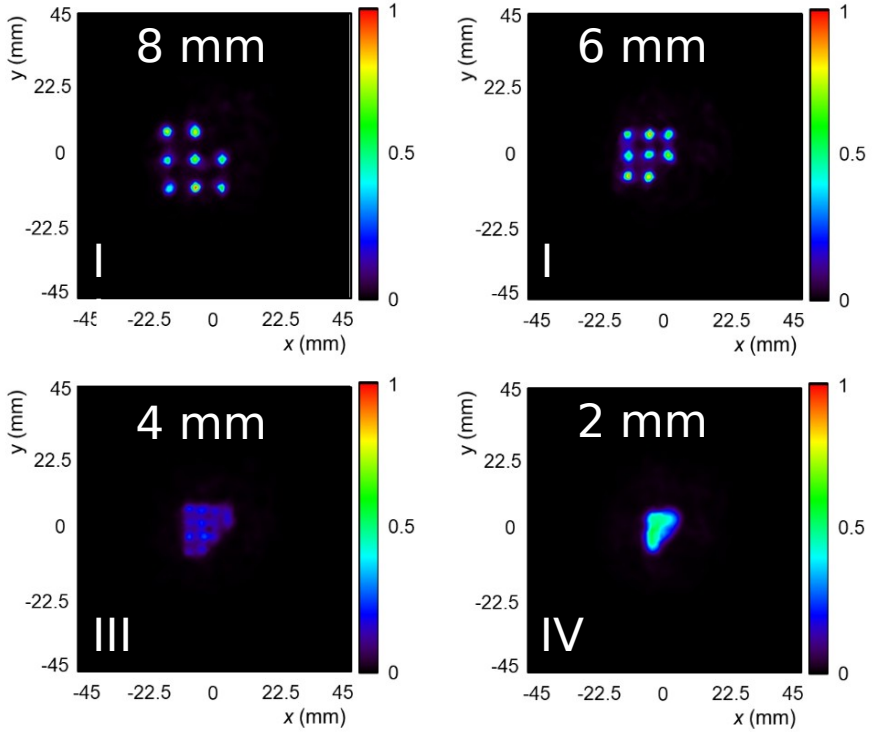
MACACO III+



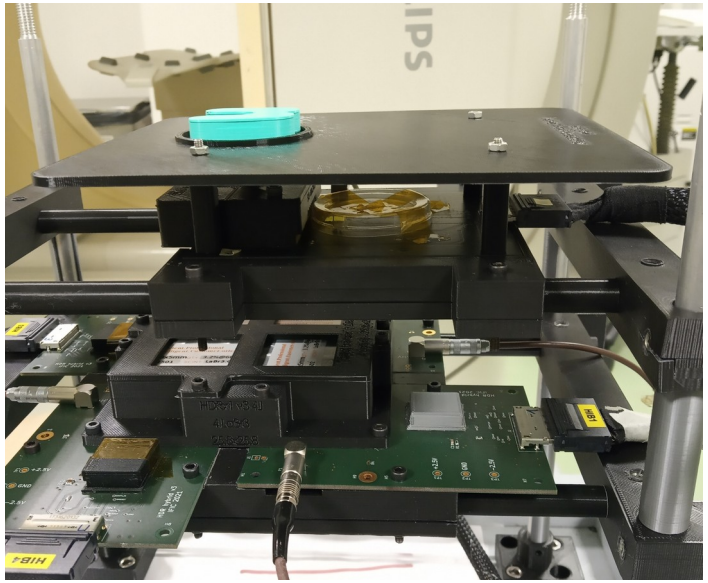
Working prototype

Array composed of four sectors with ^{22}Na point-like sources at different distaces

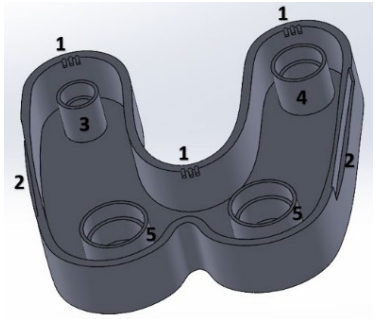




Measurements with ^{131}I with MACACO III+



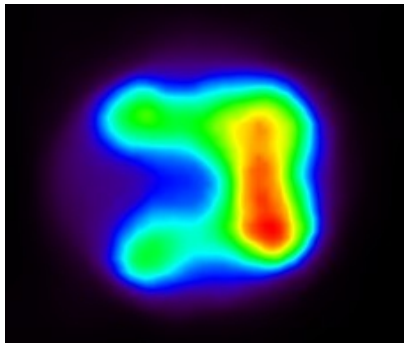
3D printed thyroid-shaped phantom filled with ^{131}I-MIBG

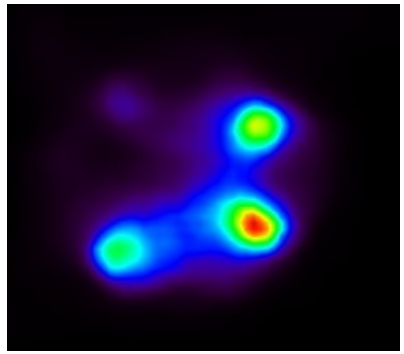


Background: ~3 ml
Rods:
3: 0.021 ml
4: 0.047 ml
5: 0.084 ml

In collaboration with Irene Torres-Espallardo et al from La Fe hospital.

Compton camera images

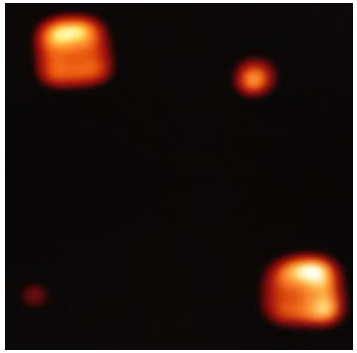




‘Uniform’ filling
~ 0.5 MB/ml

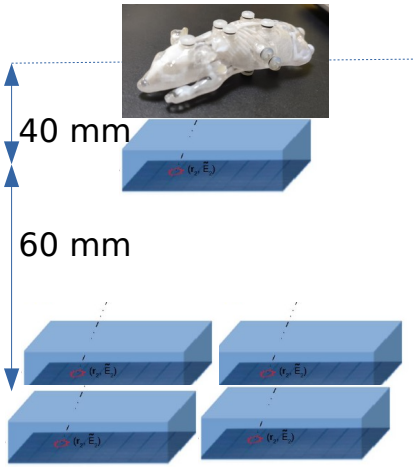
Background + hot rods at 10:1 activity concentration (0.1 : 0.01 MBq/ml)

Gamma camera images



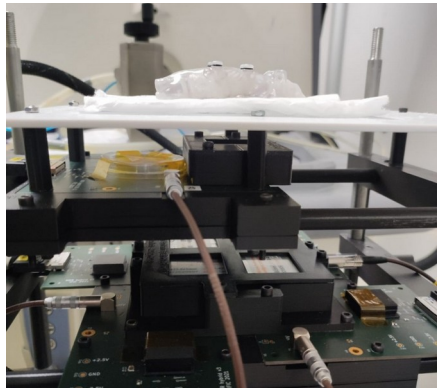
CT images

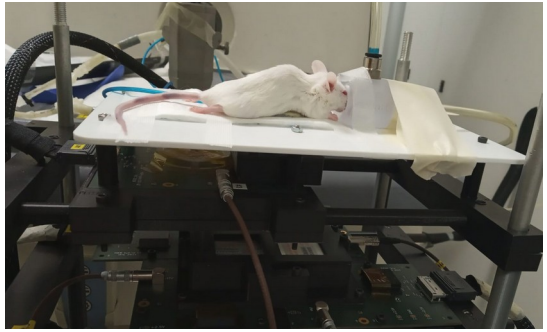
Measurements with ^{131}I with MACACO III+



In collaboration with Jordi Llop, Unai Cossío, Irati Aiestaran from CIC biomaGUNE.

^{131}I (364 keV)

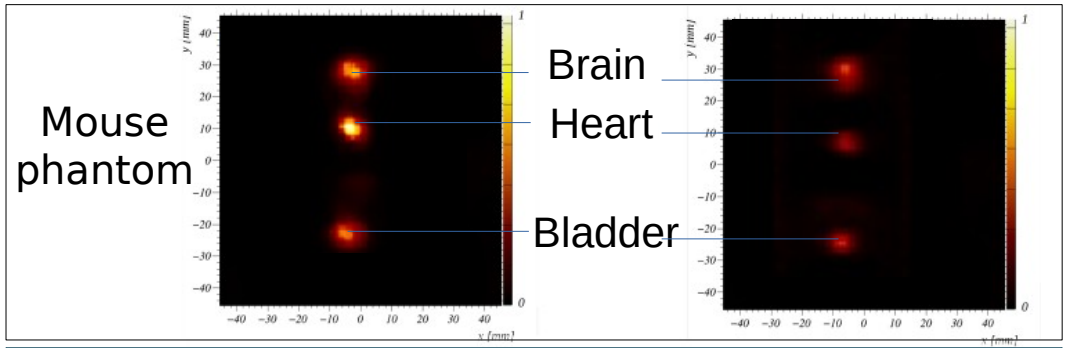


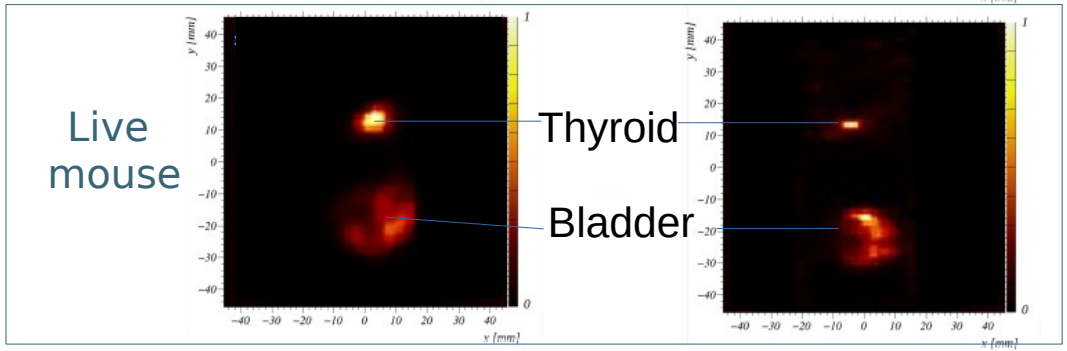


MACACO III+

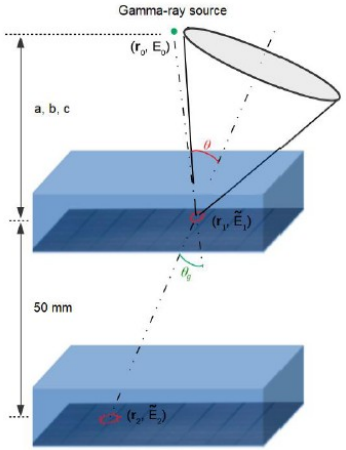
MACACO III+
30 min

γ-CUBE SPECT MOLECUBES
2 hrs





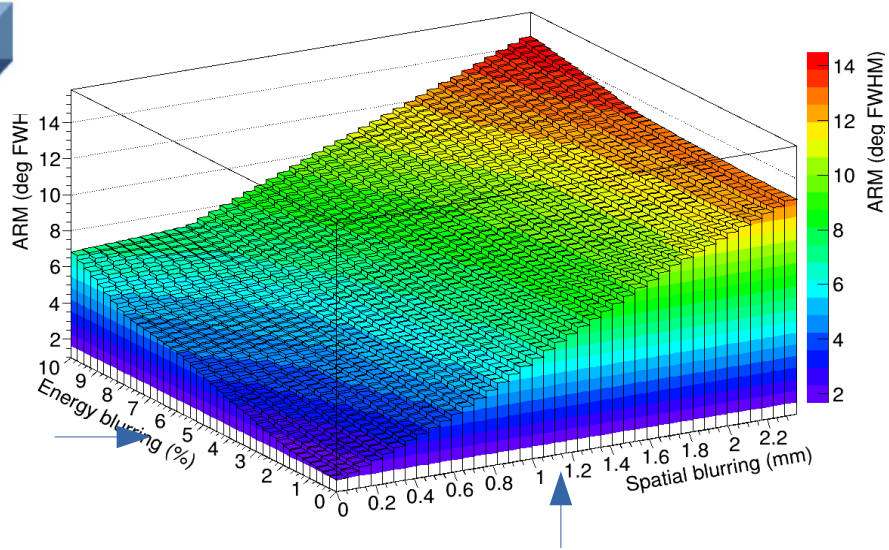
Performance estimation with GATE simulations



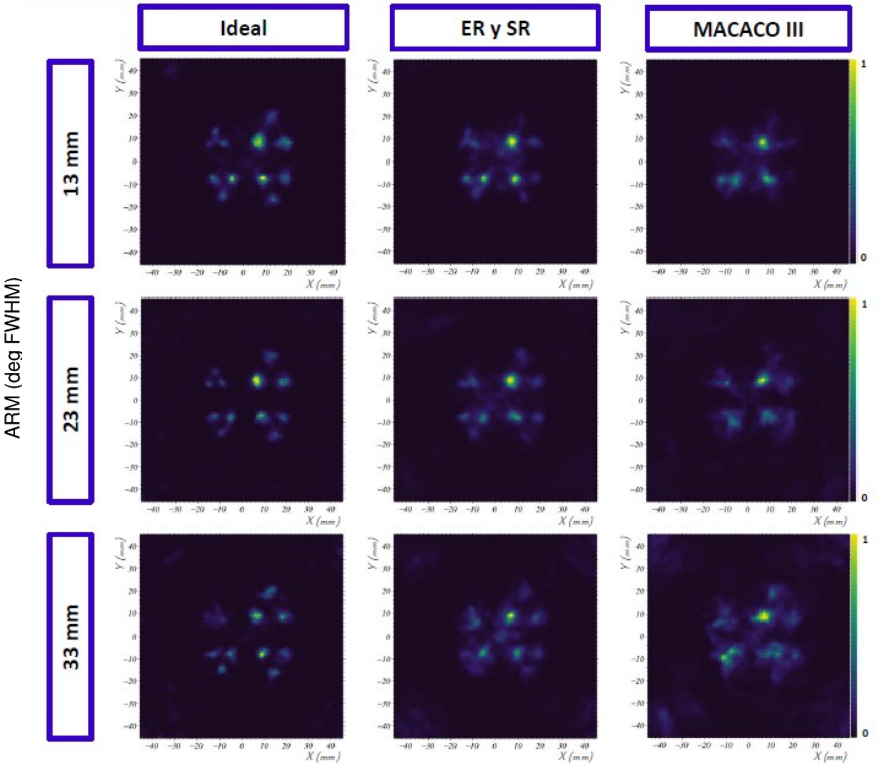
ARM = θc - θg

$$cos(\theta) = 1 - m_0c^2(\frac{1}{E_0 - E_e} - \frac{1}{E_0})$$

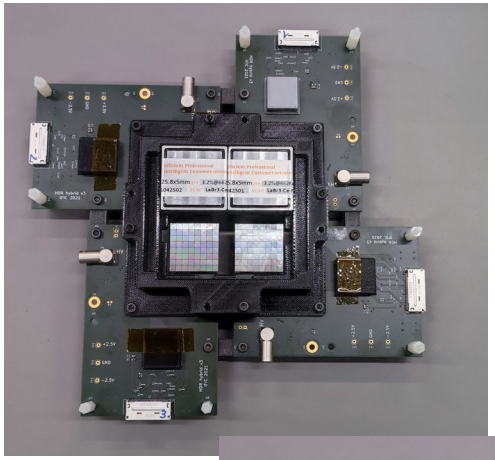
Angular resolution @440 keV

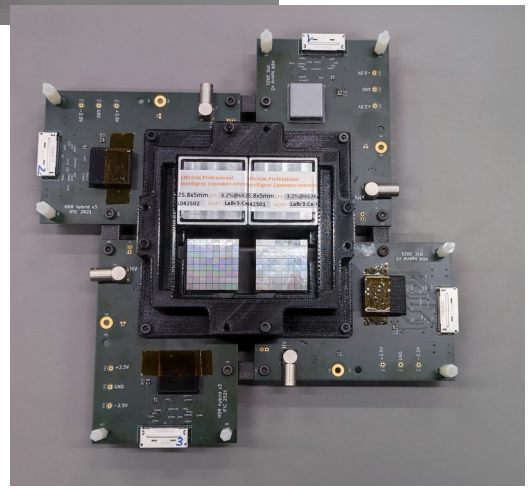


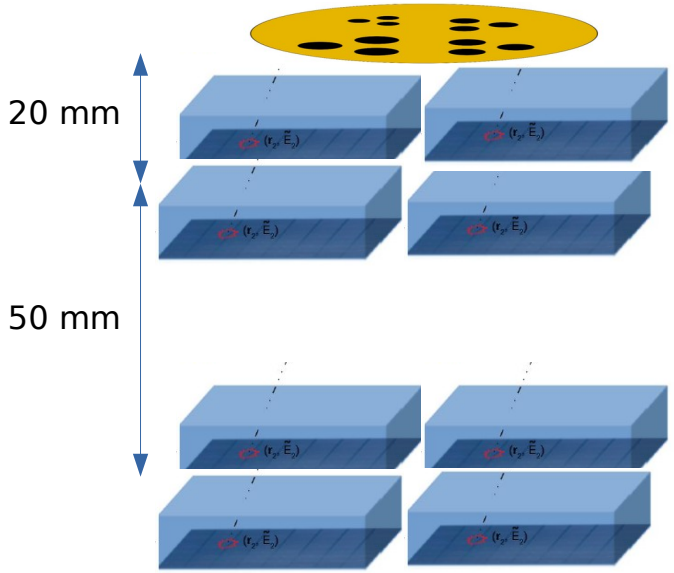
Ac-225 Simulations with MACACO III+



MACACO IV

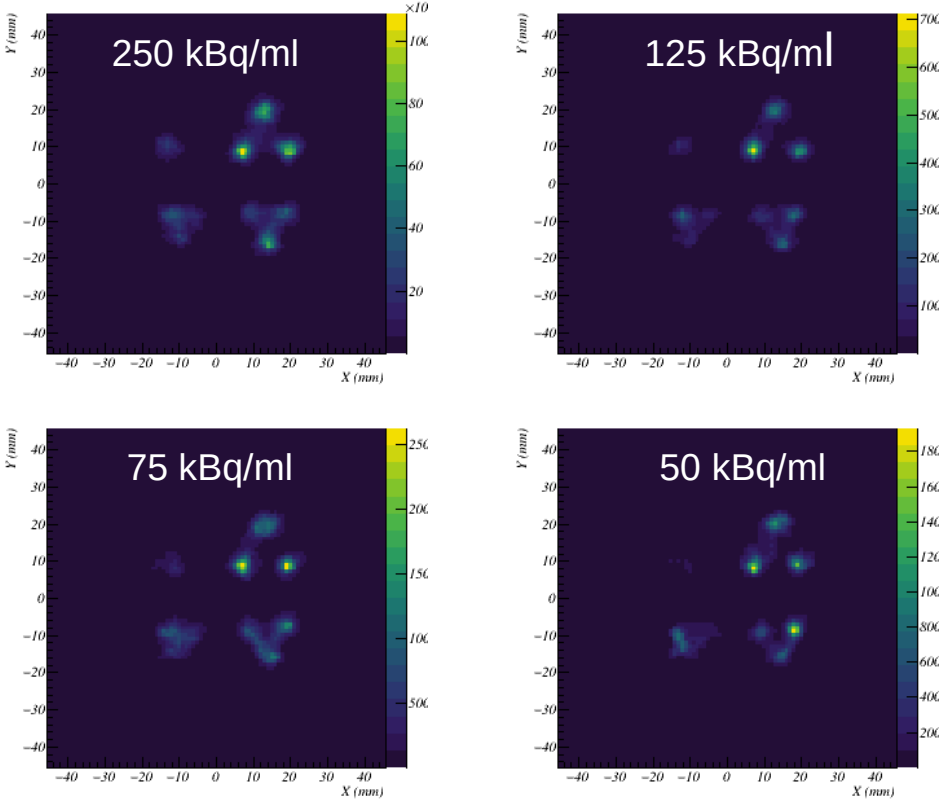






^{225}Ac simulations with MACACO IV geometry

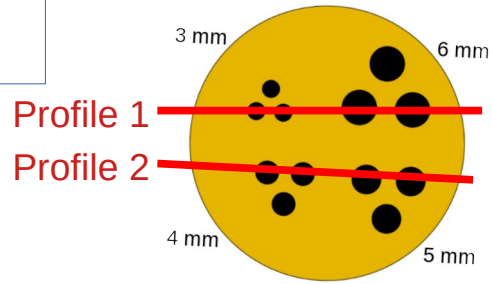
440 keV (^{213}Bi)

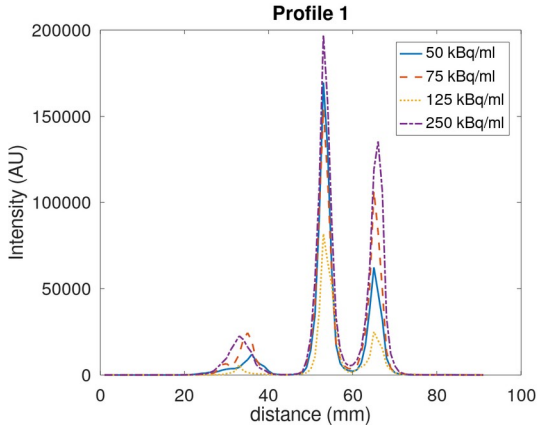


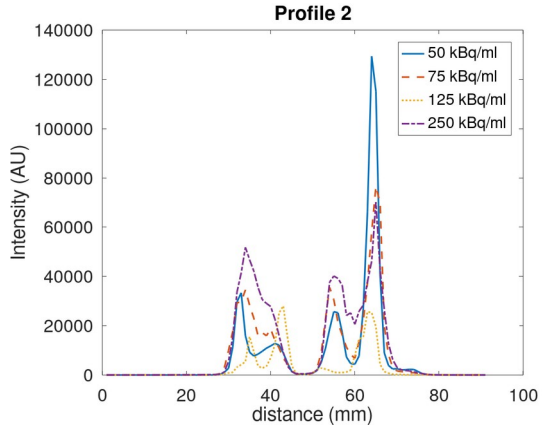
Detector:
1 mm FWHM spatial resolution
3.5% @ 511 keV FWHM
Ideal timing

20 min acquisition

50 iterations of ML-EM

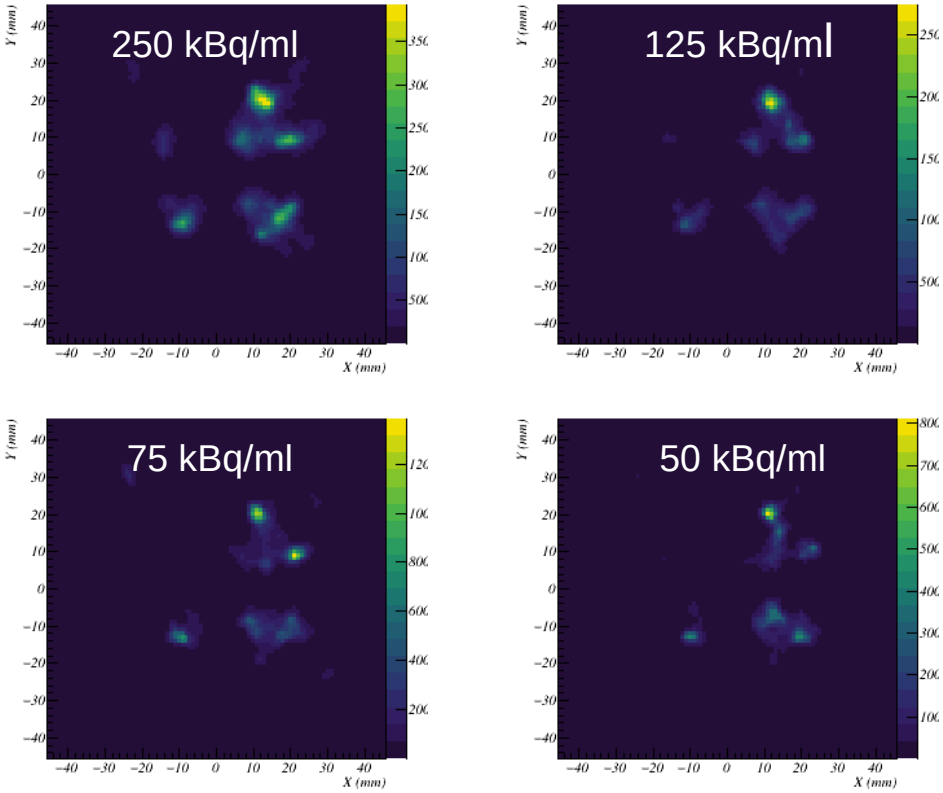






^{225}Ac simulations with MACACO IV geometry

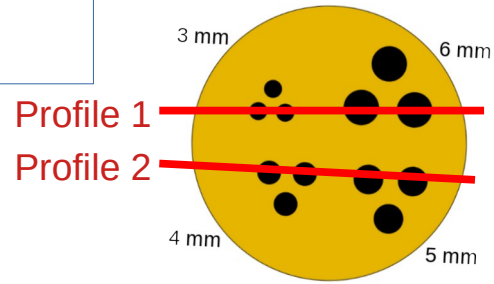
218 keV (^{221}Fr)

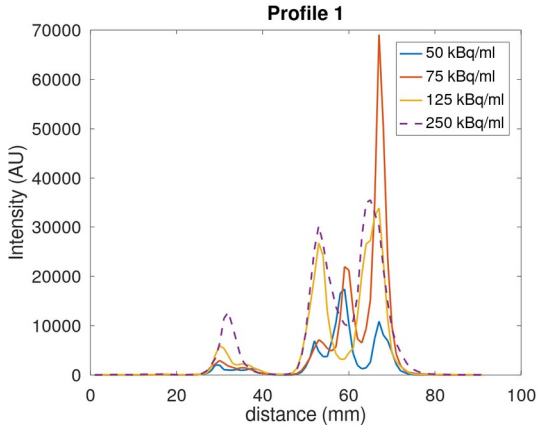


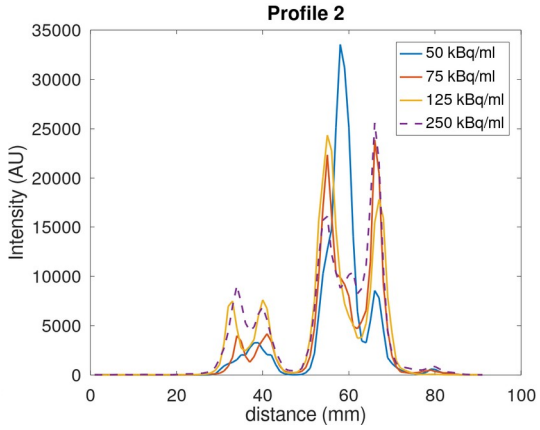
Detector:
1 mm FWHM spatial resolution
3.5% @ 511 keV FWHM
Ideal timing

20 min acquisition

50 iterations of ML-EM







Conclusions

- The IRIS group has developed Compton cameras suitable for photon imaging in the range of 300 keV – 7 MeV.
- Initial results for RT are very promising.
- Detector improvements are possible and can lead to better system performance in both fields.

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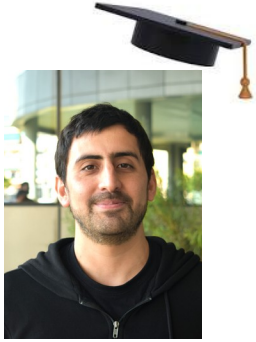

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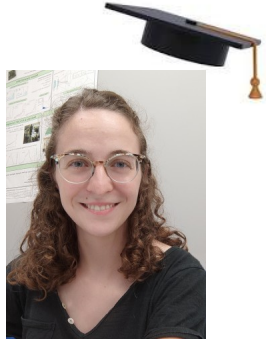

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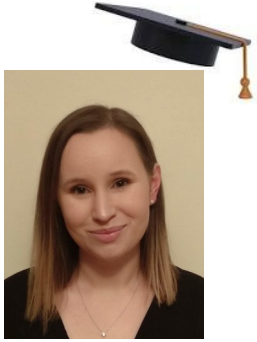

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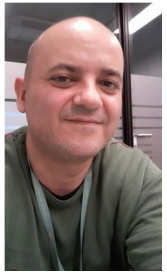
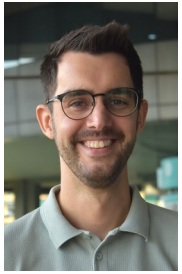


C. Senra



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Thank you

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