

First Radionuclide Imaging Tests with MACACOIII+ Compton camera

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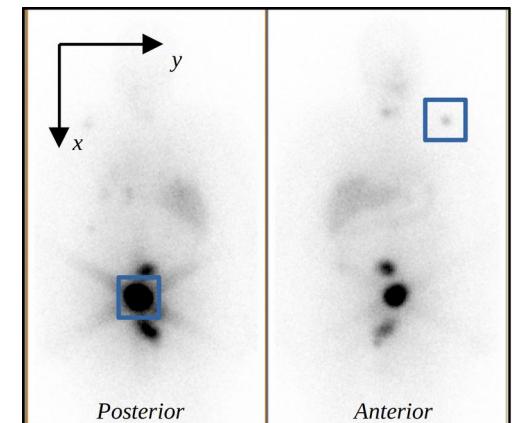
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² Université de Lyon; CREATIS; CNRS UMR5220; Inserm U1294; INSA-Lyon; Université Lyon 1, Léon Bérard cancer center, Lyon, France.

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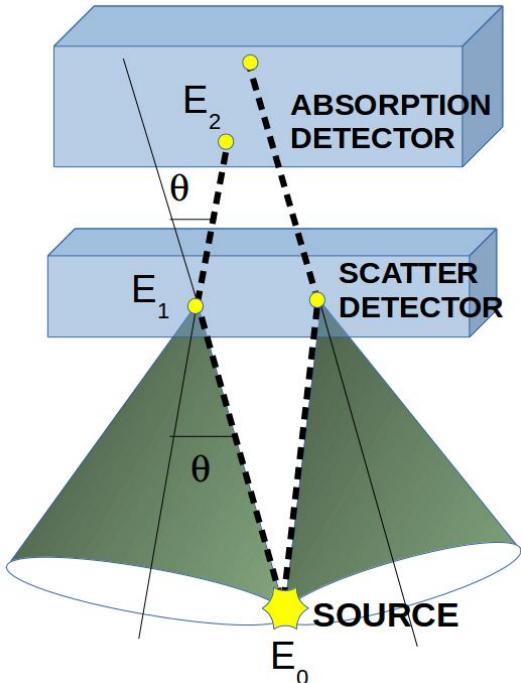
Imaging in radiopharmaceutical therapy

- The interest on radiopharmaceutical therapy is rapidly increasing.
- Imaging can be used to visualize the distribution of radionuclides 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 complement gamma cameras in this task.
 - Higher efficiency.
 - Better performance at high energies.
 - Better suited for multi-gamma imaging.

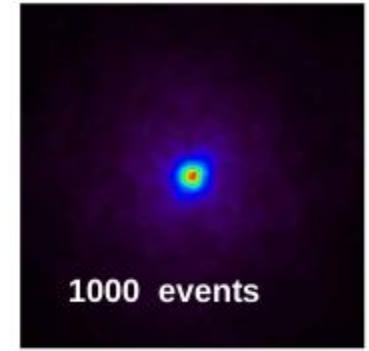
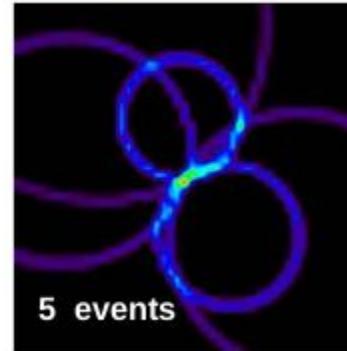


Gamma camera images of a patient treated with ^{131}I -NaI

Compton camera



Backprojection:



+ Image reconstruction

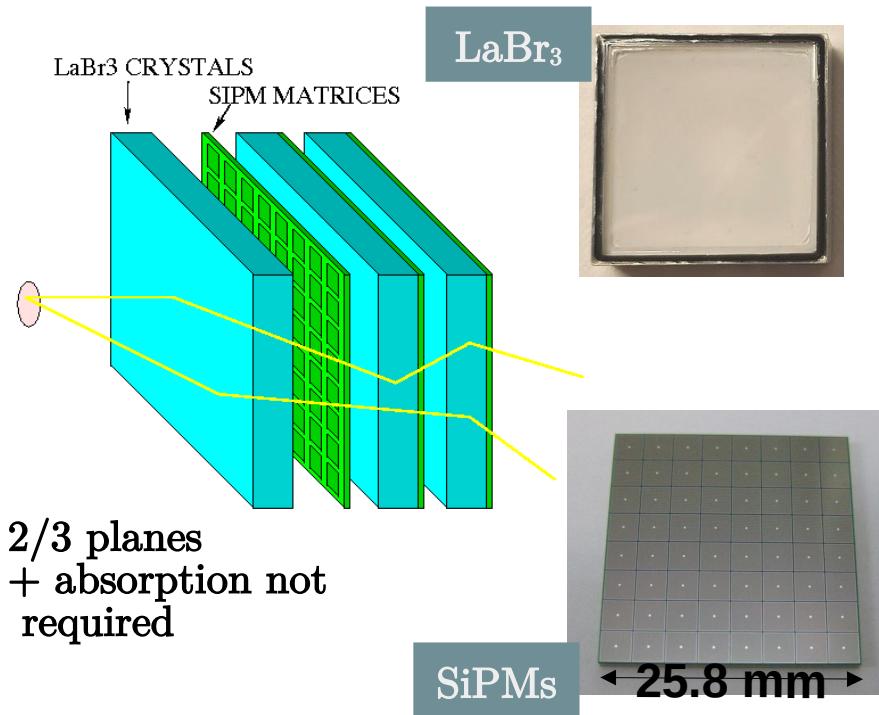
List mode ML-EM

$$\begin{aligned}\cos \varphi &= 1 - m_0 c^2 \left(\frac{1}{E_{\gamma'}} - \frac{1}{E_\gamma} \right) \\ E_\gamma &= E_{e^-} + E_{\gamma'}\end{aligned}$$

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

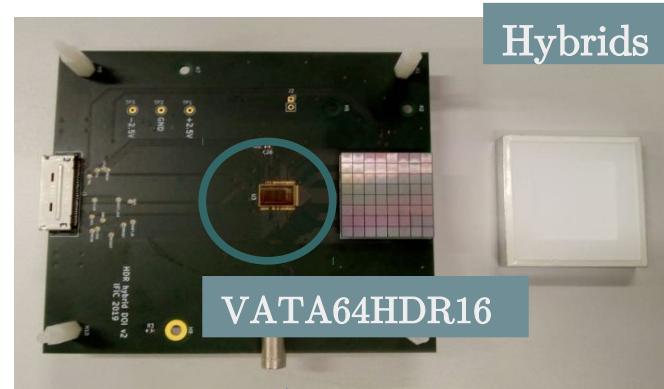
MACACO III (Medical Applications CompAct COmpton camera)

Detectors

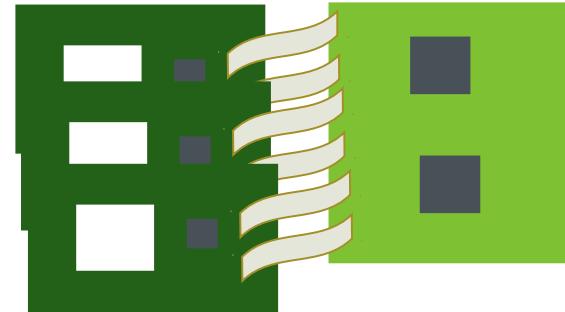


2/3 planes
+ absorption not
required

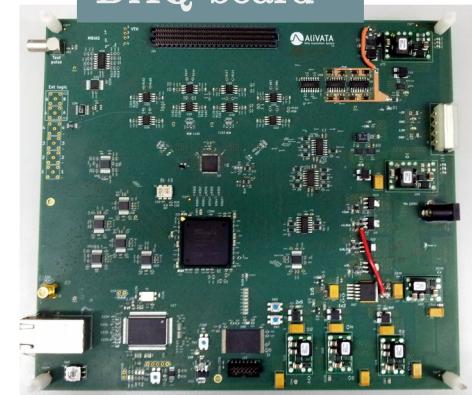
Readout



Hybrids



AliVATA DAQ board



Commercialized
by Alibava
Systems S. L.

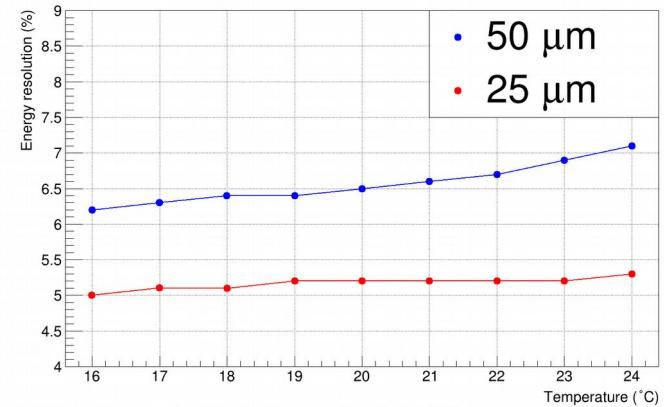
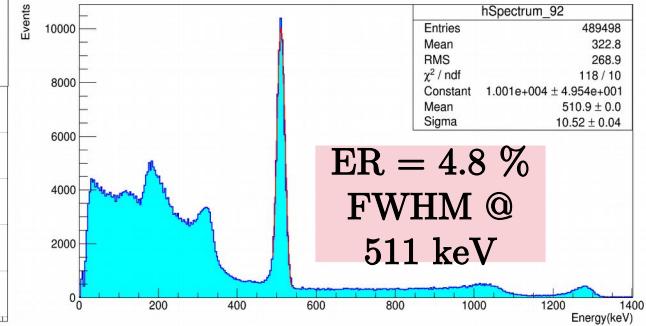
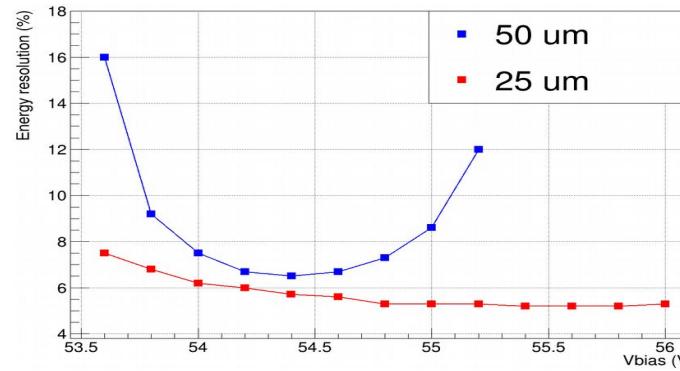
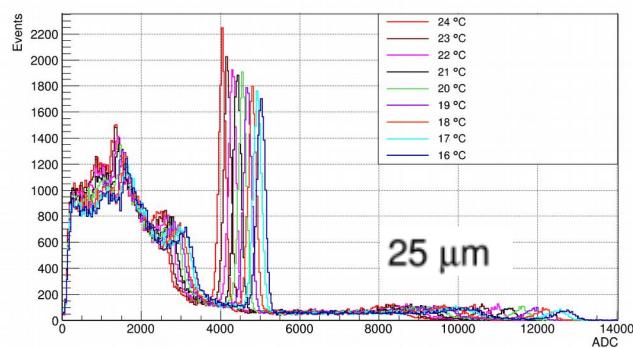
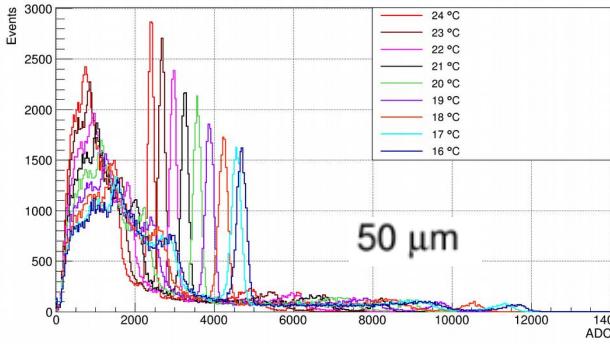
MACACO III detectors

S13360-3025CS (25 μm)

VS

S13361-3050AE-08 (50 μm)

Now commercial product

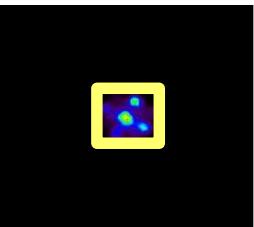


L. Barrientos et al. Rad. Phys. Chem. 2023

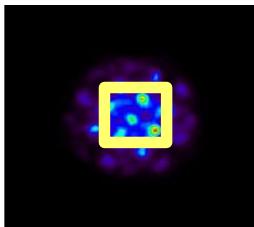
Image reconstruction: list-mode MLEM

Sensitivity model for 2- and 3- interaction events

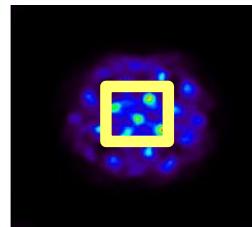
No sensit.



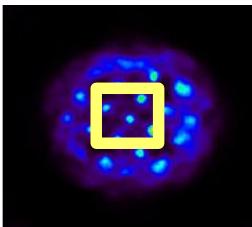
Wilderman



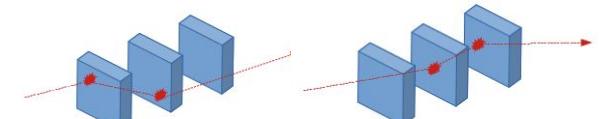
Maxim



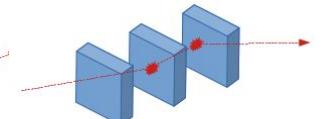
Muñoz



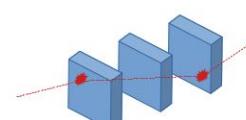
Joint reconstruction of all channels



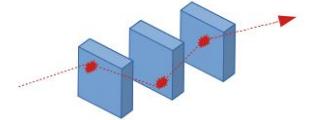
12-channel event



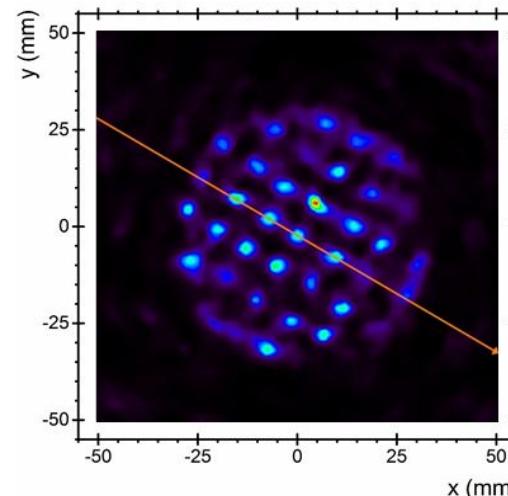
23-channel event



13-channel event



123-channel event



E. Muñoz et al. Phys. Med. Biol. 2018



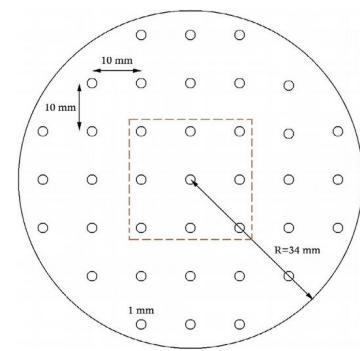
E. Muñoz et al. Phys. Med. Biol. 2020



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



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



Array of 37 Na-22 point-like sources

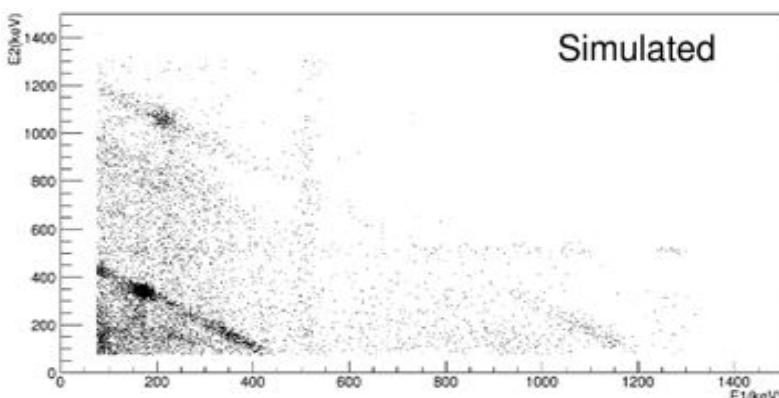
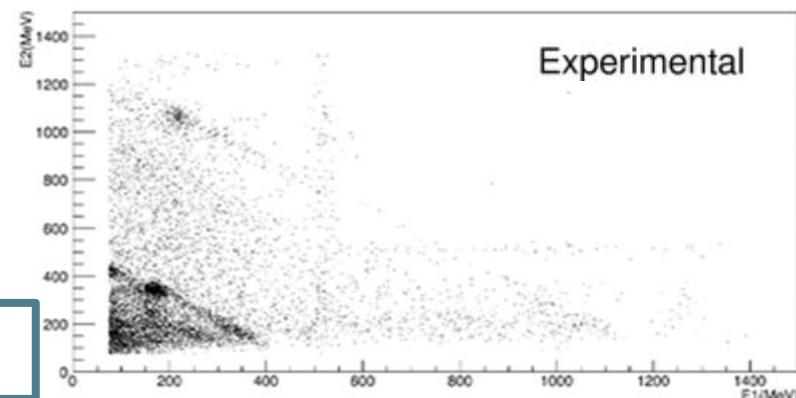
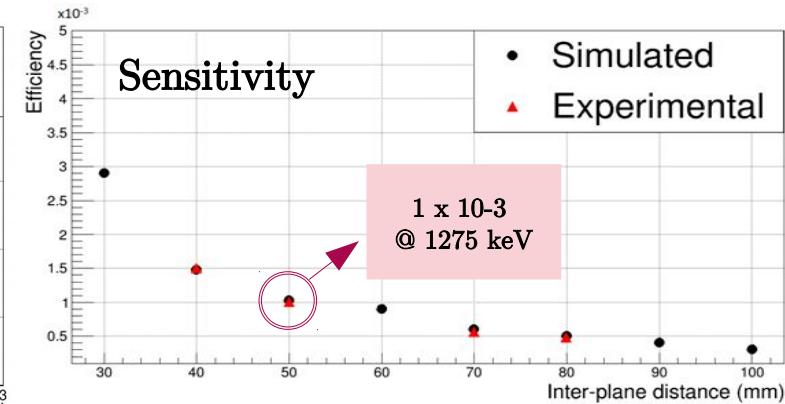
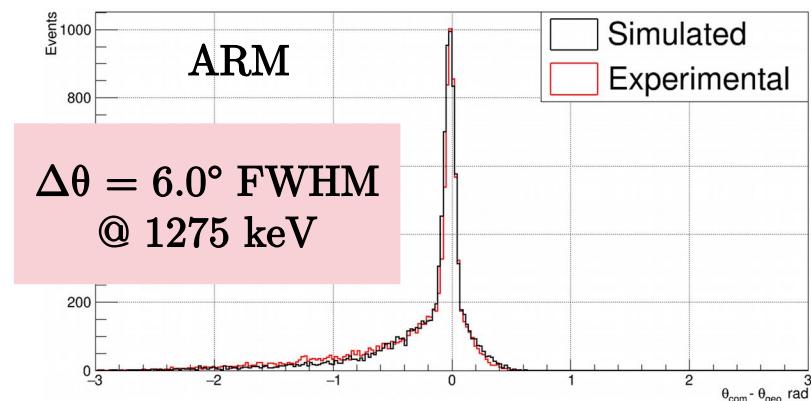
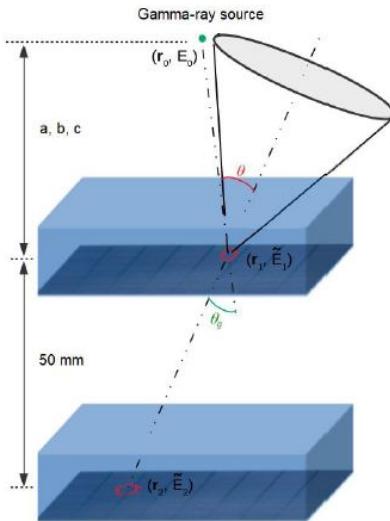
Simulations validation



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

Angular resolution

$$\text{ARM} = \theta_c - \theta_g$$



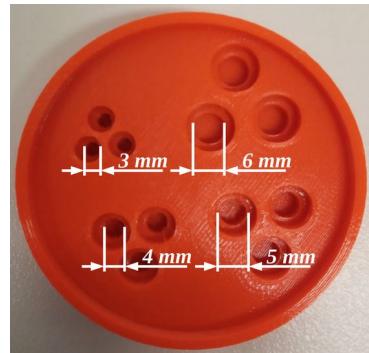
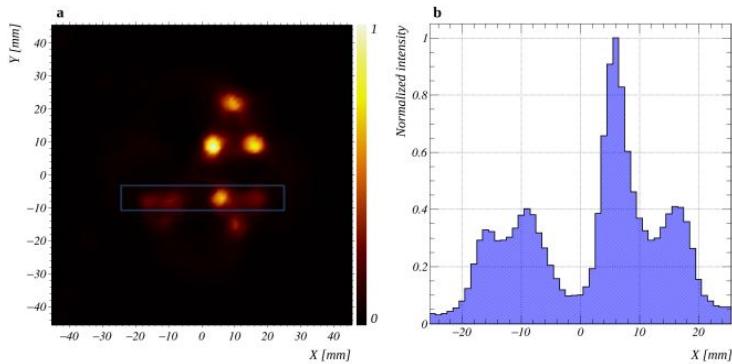
L. Barrientos et al.
Rad. Phys. Chem. 2023

Tests in La Fe hospital (Valencia)

3D printed Derenzo-like phantom

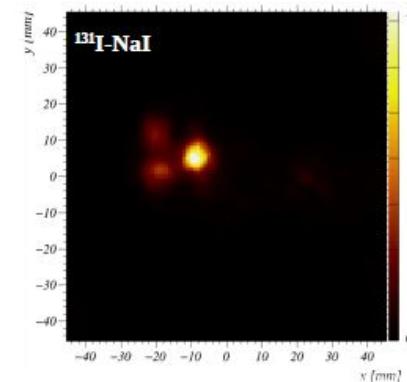
^{18}F -FDG (511 keV)

Compton camera

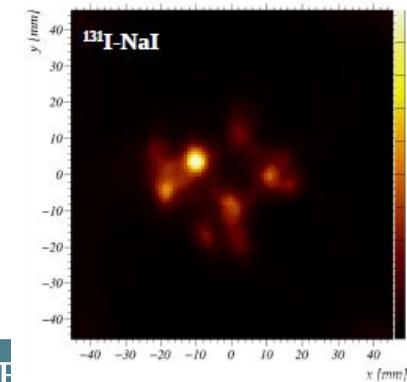


^{131}I -NaI (364 keV)

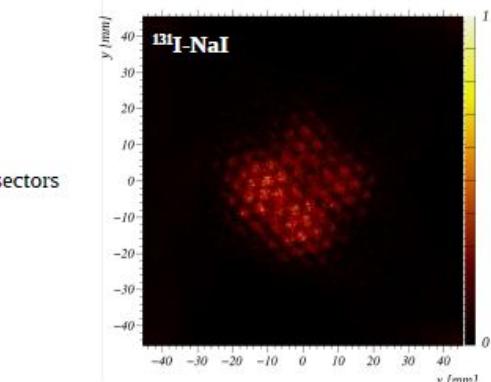
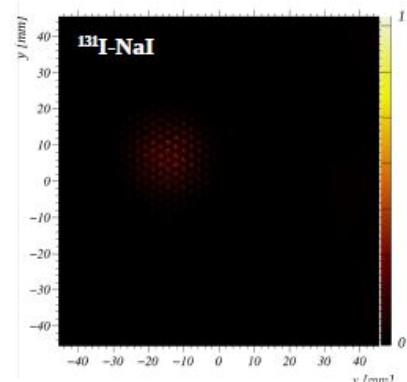
Compton camera



One sector



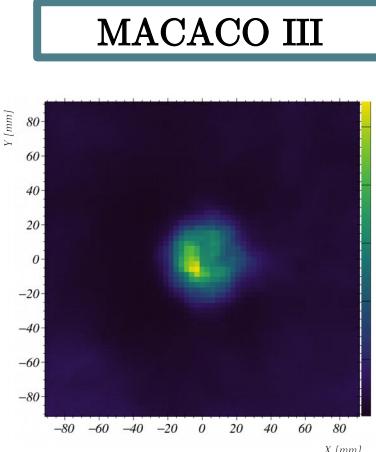
All sectors



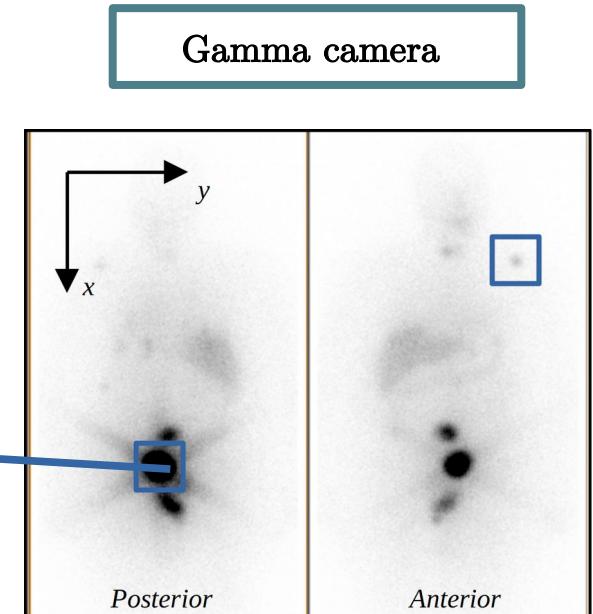
In collaboration with Irene Torres-Espallardo, José Manuel Calatayud, Pilar Bello and Stefan Prado from La Fe.

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.

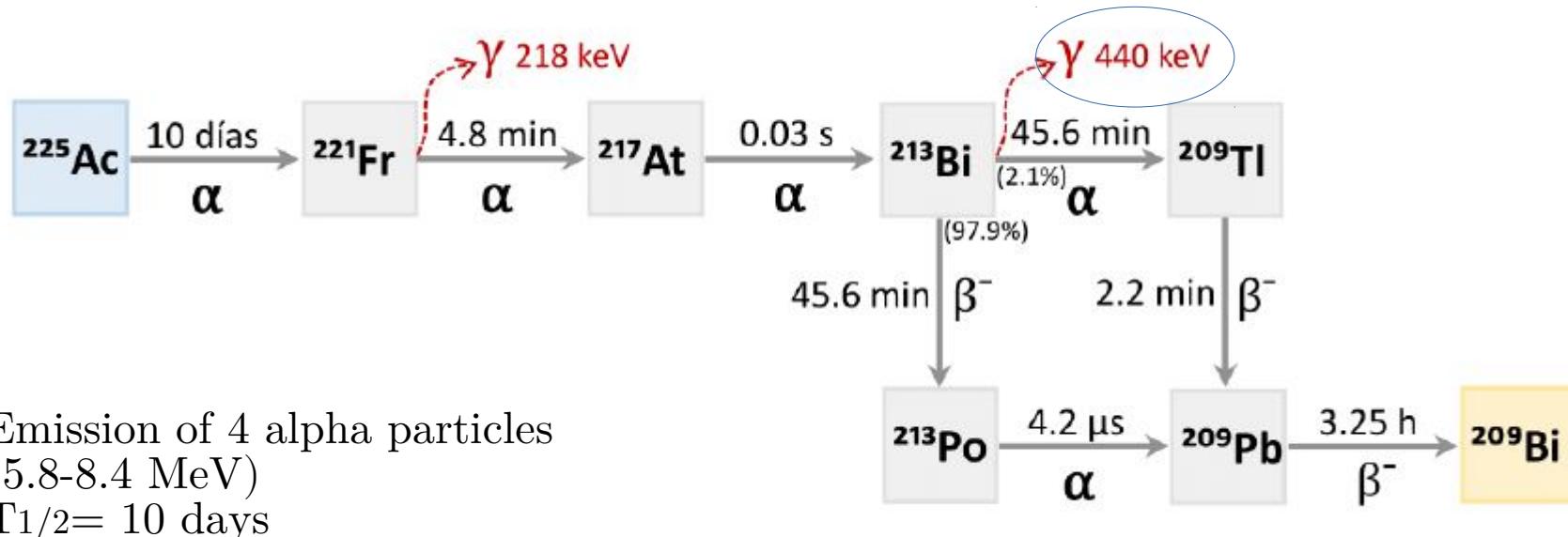


Sacrum lesion



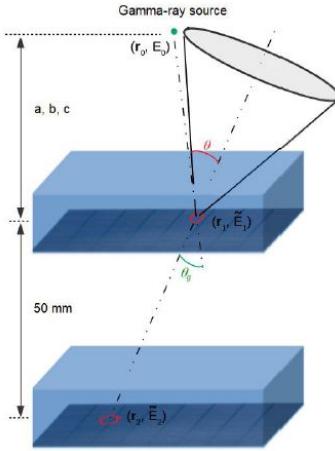
J. Roser et al. In preparation.

Ac-225



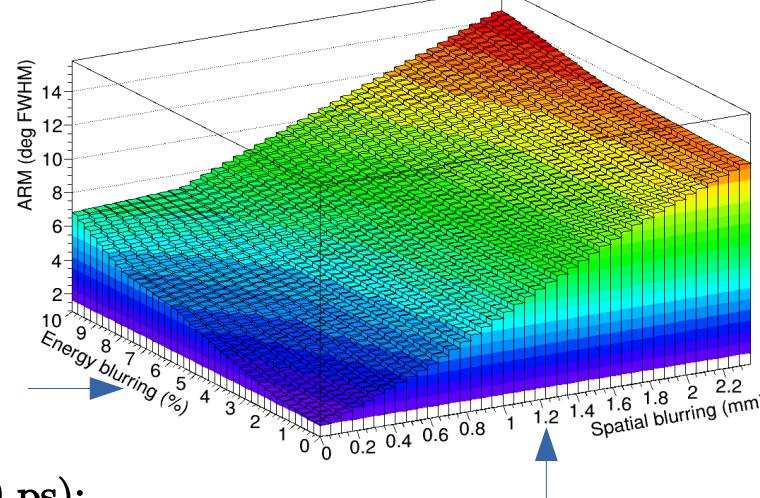
- Emission of 4 alpha particles (5.8-8.4 MeV)
- $T_{1/2} = 10$ days

Performance estimation with GATE simulations



Angular resolution @440 keV

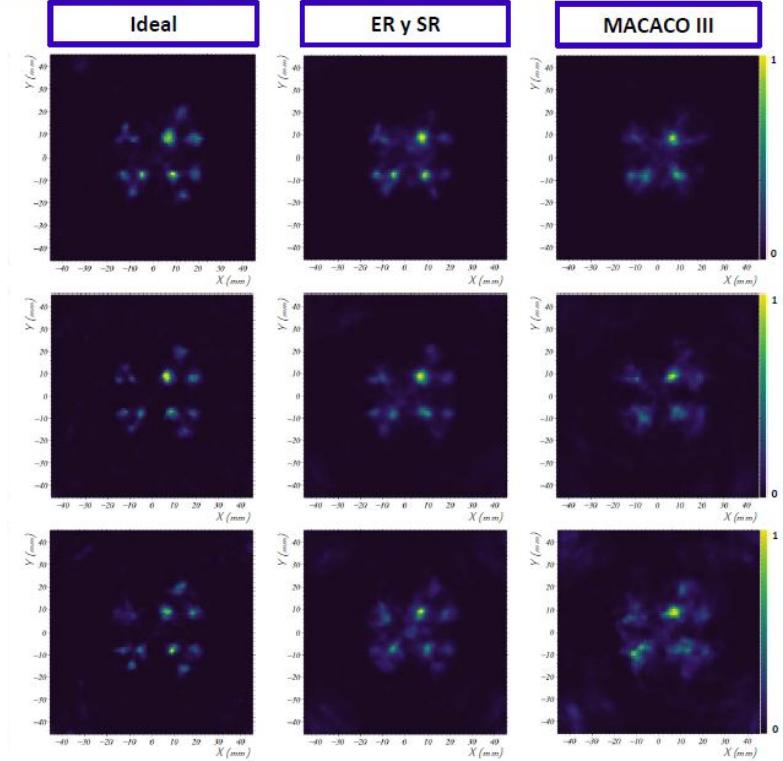
$$\text{ARM} = \theta_{\text{Compton}} - \theta_{\text{geometrical}}$$



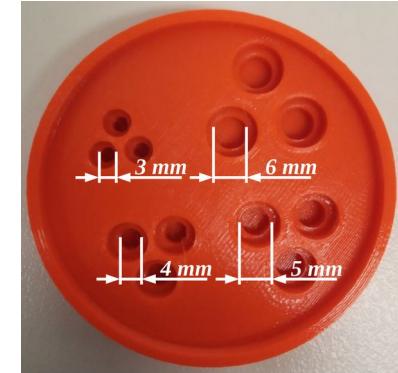
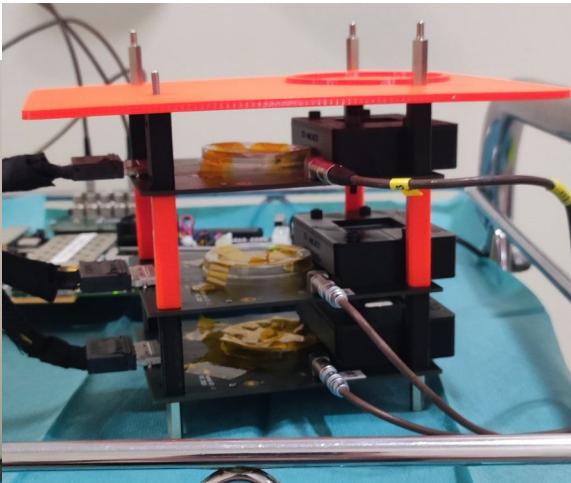
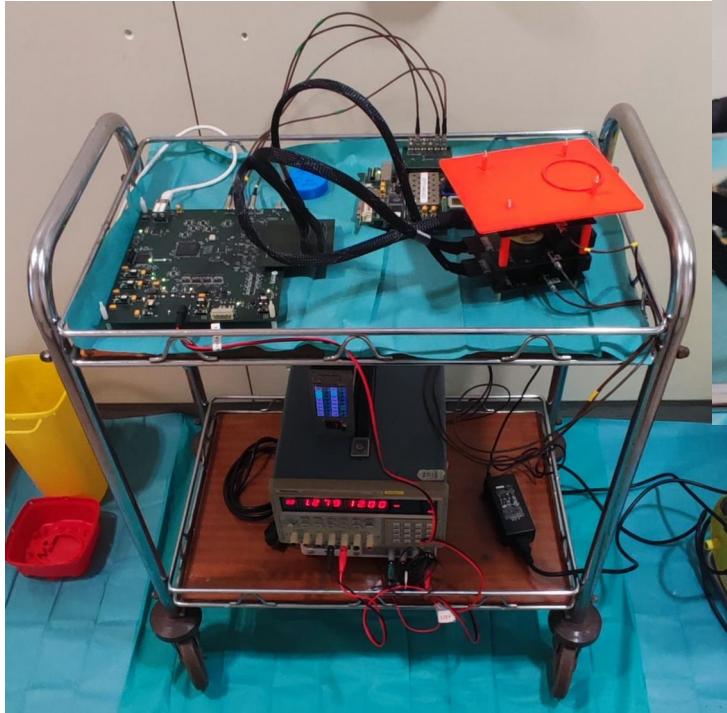
Fast timing (< 200 ps):

- Background reduction
- Determination of interaction sequence.

Ac-225 Simulations with MACACO III

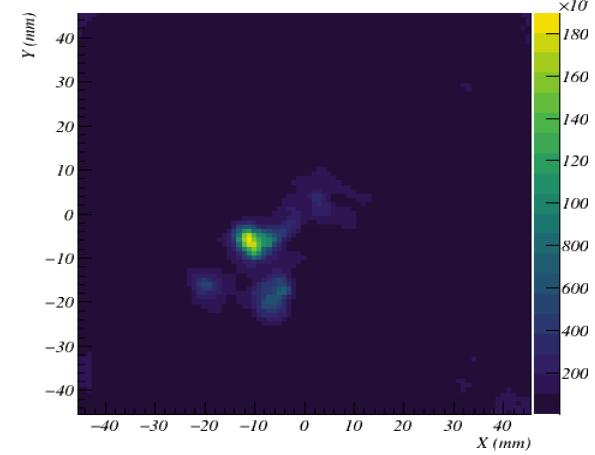


Ac-225 Measurements at Léon Bérard hospital (Lyon)



6 mm diameter
rods reconstructed

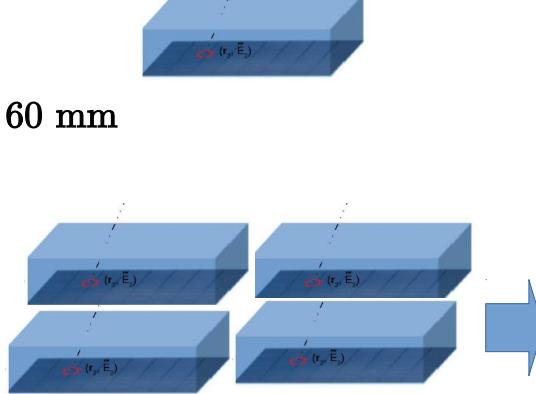
70 kBq /rod



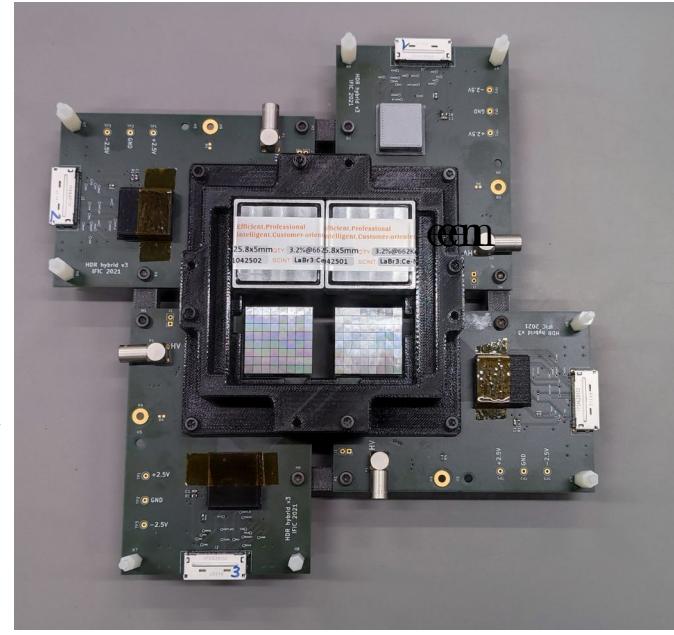
In collaboration with Ane Etxeberria, David Sarrut, Jean Noël Badel
from Creatis and Léon Bérard hospital (Lyon).

MACACO III+

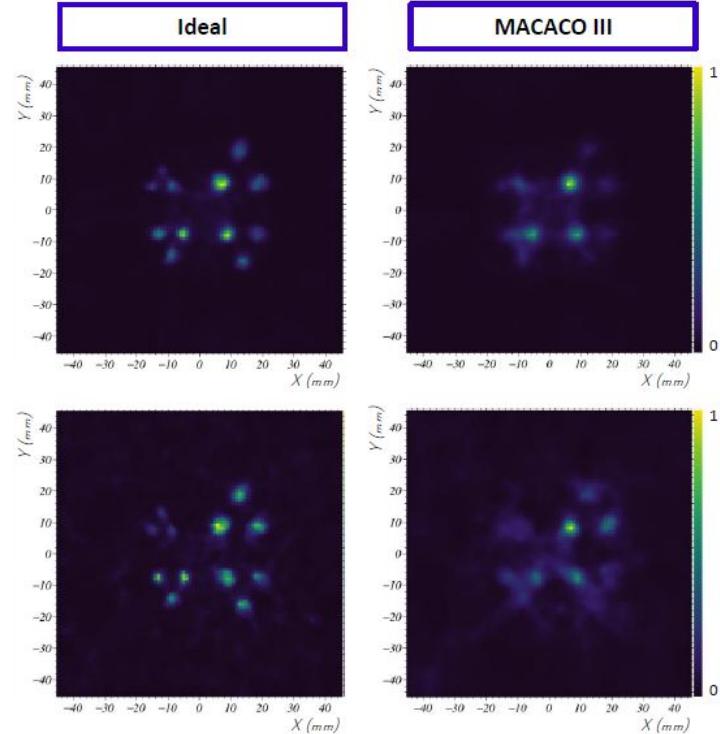
MACACO III+



4x larger 2nd plane
to increase sensitivity



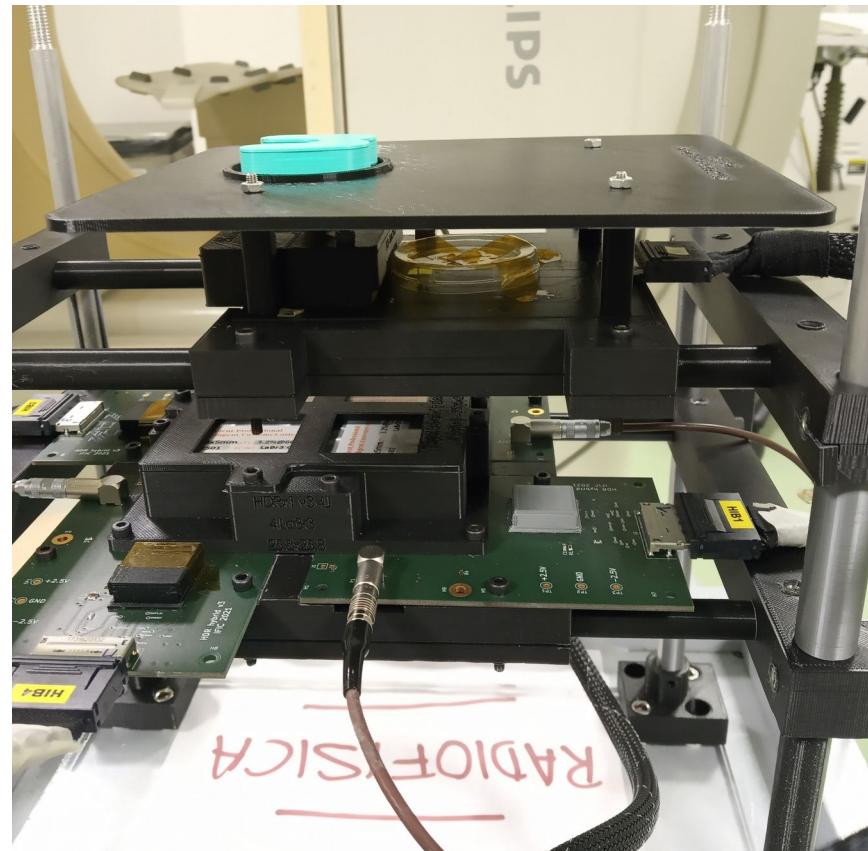
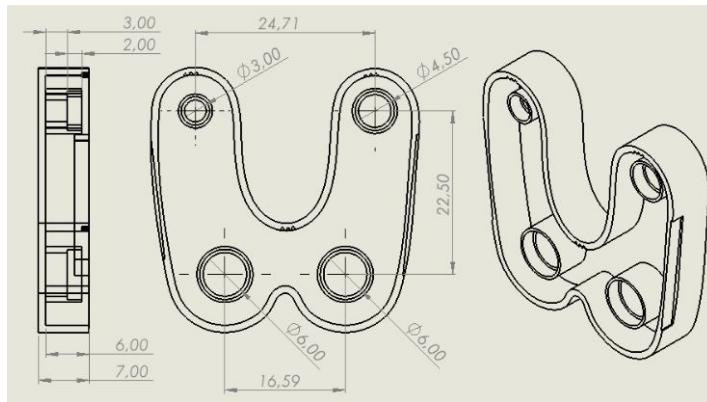
Ac-225 Simulations with MACACO III+



Further Ac-225 measurements foreseen with MACACO III+

Measurements with ^{131}I with MACACO III+

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



Measurements with ^{131}I with MACACO III+



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

Background: ~3 ml

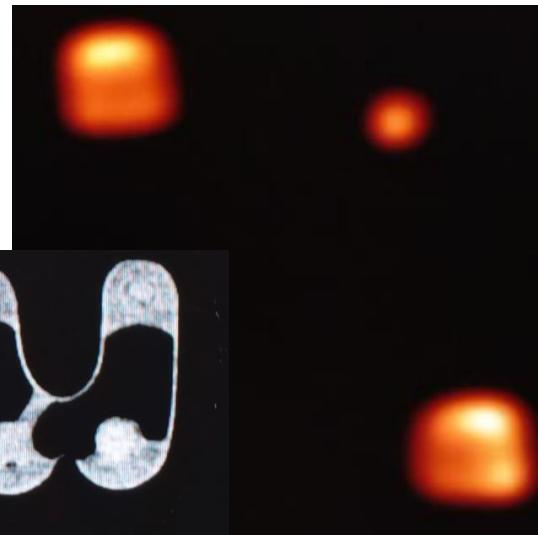
Rods:

3: 0.021 ml

4: 0.047 ml

5: 0.084 ml

Gamma camera images

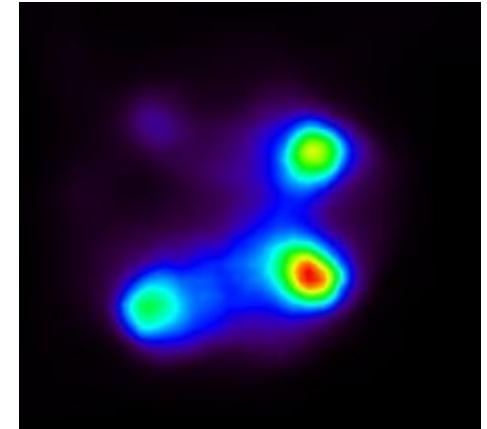
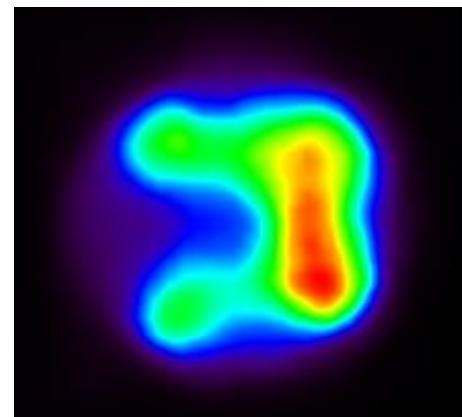


CT images



Compton camera images

PRELIMINARY



'Uniform' filling.
~ 0.5 MB/ml

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

Conclusions

- The IRIS group has developed a Compton camera suitable for photon imaging in the range of 300 keV – 7 MeV.
- Initial results in collaboration with La Fe hospital in Valencia and Léon Bérard hospital in Lyon are very encouraging.
- Detector improvements are possible and can lead to better system performance.
- Further system performance improvements and test in clinical sites are ongoing.

Compton cameras show potential for this application



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Fourth MODE Workshop on Differentiable Programming for Experimental Design

23-25 Sept 2024
23-25 September 2024
Valencia

The workshop aims at bringing together computer scientists and physicists from the HEP, astro-HEP, nuclear, and neutrino physics communities to develop optimized solutions to detector design and experimental measurements

Sessions

- Nuclear applications
- Muography applications
- Particle Physics applications
- Medical physics applications
- Astroparticle physics applications
- Computer Science developments

Keynote Speakers



Danilo Rezende
(DeepMind)



Andrea Walther
(Humboldt Universität zu Berlin)



Riccardo Zecchina
(Università Bocconi)

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https://indico.cern.ch/e/MODE_WORKSHOP2024



AI for detector / experiment design

Abstract submission deadline
November 14, 2024

Notification of acceptance
January 13, 2025

Registration opening
January 16, 2025

ANIMMA VALENCIA SPAIN

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Instrumentation

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Thank you

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