MACACOp: a Compton Camera for hadron therapy treatment monitoring

Rita Viegas

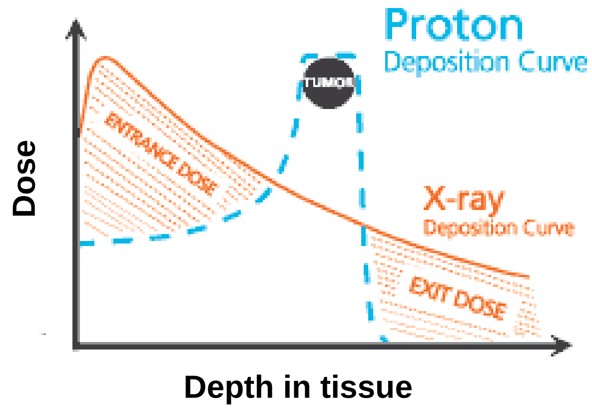
Instituto de Física Corspuscular IFIC (CSIC - U. Valencia), Spain

Introduction

Hadrontherapy

charged particles (protons or carbon ions) instead of photons

Uncertainties



Introduction

Hadrontherapy

charged particles (protons or carbon ions) instead of photons

Uncertainties

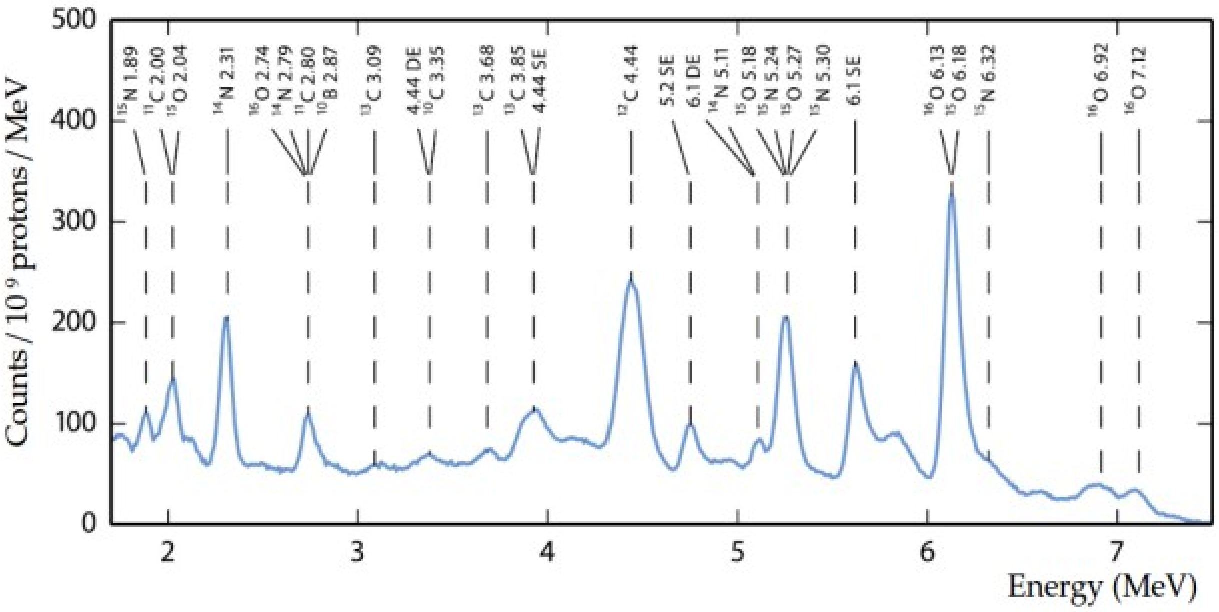
Large margins have to be applied

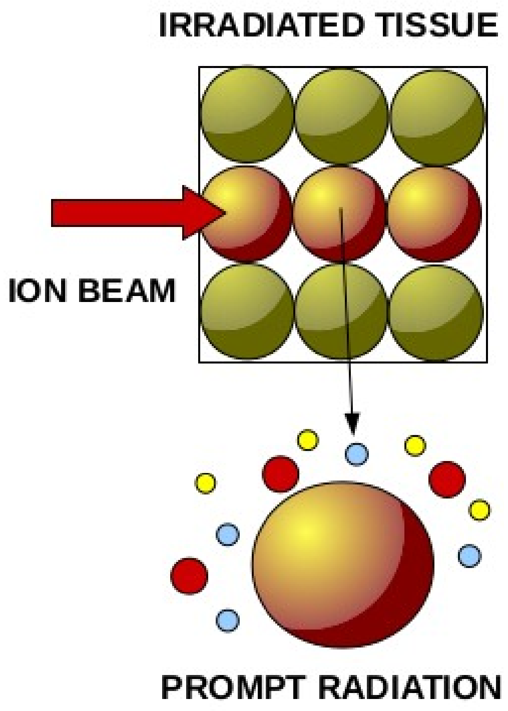
In-vivo beam range verification

Introduction

Prompt gammas

- MeV in a continuous energy spectrum
- Emitted within ns after irradiation
- Higher amount than positrons emitters



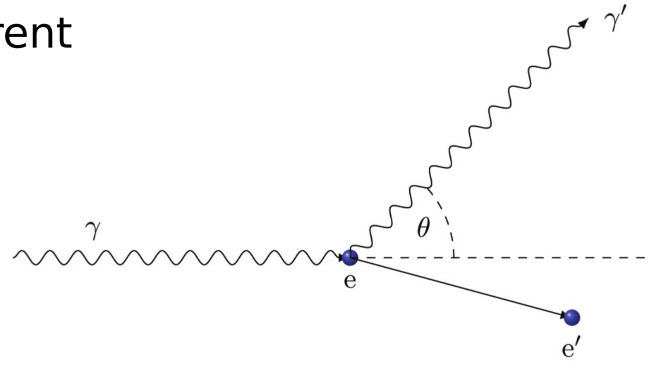


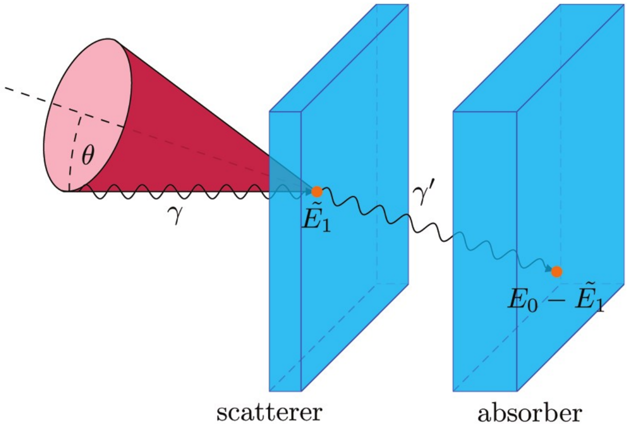
Prompt ɣ-rays
1 - 10 MeV

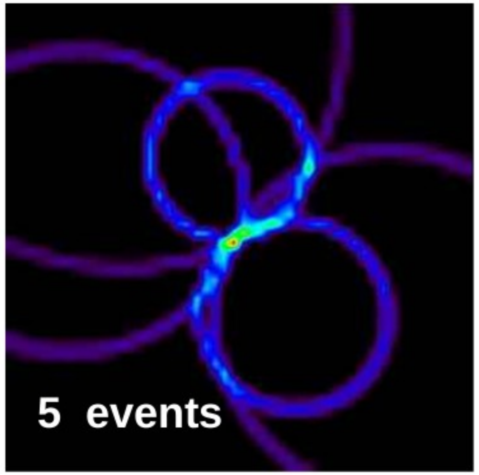
Compton Cameras

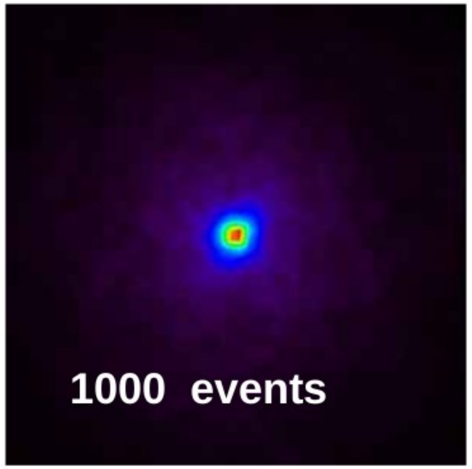
A Compton camera aims to determine the direction of incidence of a photon that undergoes incoherent scattering with an electron.

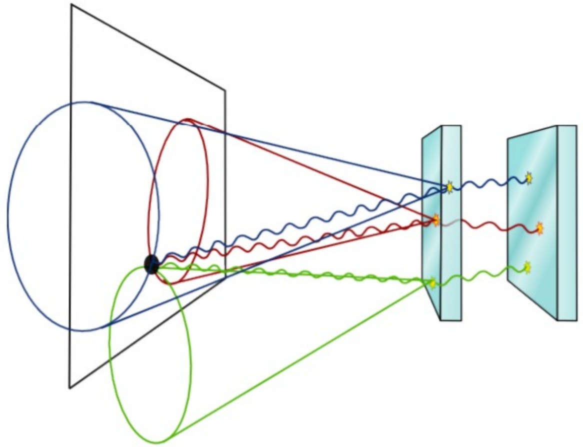
$$\boxed{cos(\theta) = 1 - m_0c^2\left(\frac{1}{E_0 - E_e} - \frac{1}{E_0}\right)}$$









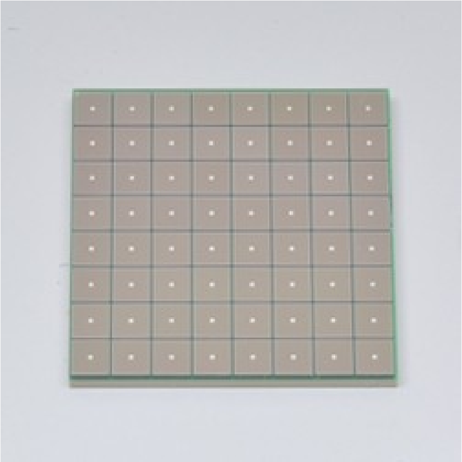


Compton camera @ IRIS

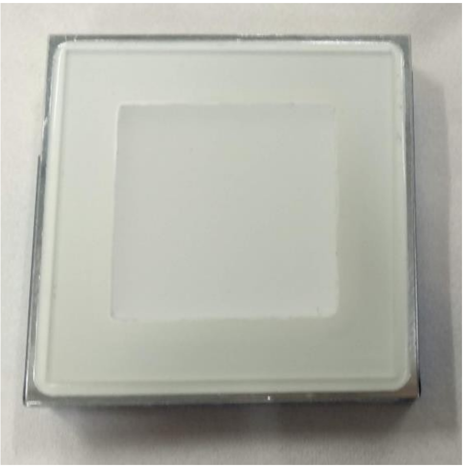
Requirements	Goals
Excellent ER	< 4 %
Very good SR	~ 2 mm FWHM
Very good TR	< 1 ns FWHM

Compton camera @ IRIS

Requirements	Goals
Excellent ER	< 4 %
Very good SR	~ 2 mm FWHM
Very good TR	< 1 ns FWHM



Silicon Photomultipliers
Small
Light
Insensitive to magnetic fields
High gain
Excellent S/N

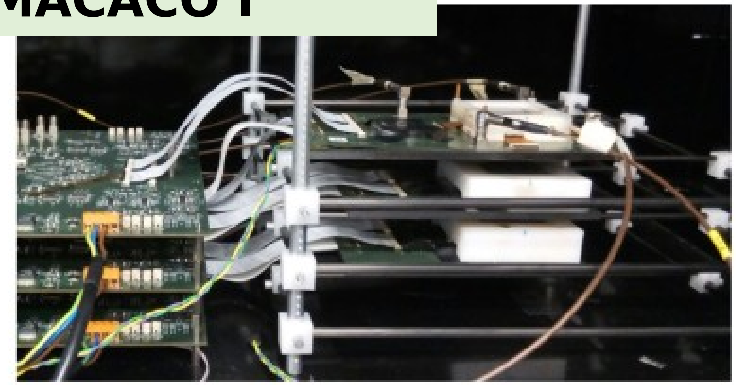


$LaBr_3$ monolithic scintillator crystal
Decay time - 17 ns
Light yield - 63000 ph/MeV
High ρ - 5.29 g/cm3
High Z_{eff} - 47
Excellent TR <300 ps
Excellent ER @ 662 keV ~ 3.8 %

Compton camera @ IRIS

Requirements	Goals
Excellent ER	< 4 %
Very good SR	~ 2 mm FWHM
Very good TR	< 1 ns FWHM

MACACO I



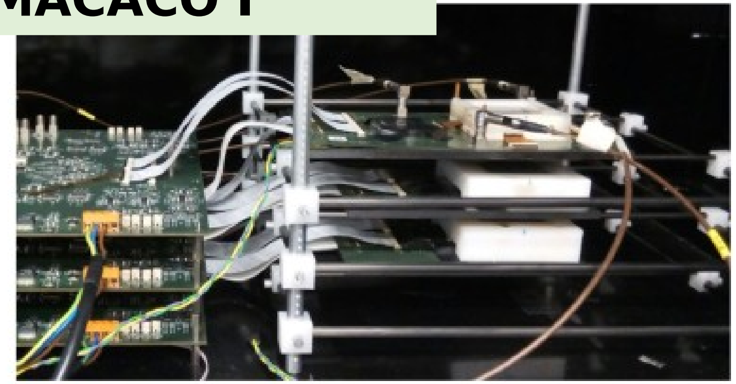
E. Muñoz et al.
Phys. Med. Biol. (62) 2017

ER ~ 8 % @ 511 keV
SR ~ 1.3 mm FWHM
TR 20 ns FWHM

Compton camera @ IRIS

Requirements	Goals
Excellent ER	< 4 %
Very good SR	~ 2 mm FWHM
Very good TR	< 1 ns FWHM

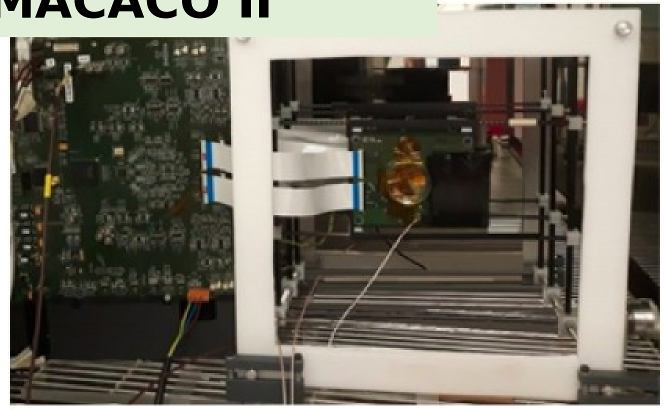
MACACO I



E. Muñoz et al.
Phys. Med. Biol. (62) 2017

ER ~ 8 % @ 511 keV
SR ~ 1.3 mm FWHM
TR 20 ns FWHM

MACACO II



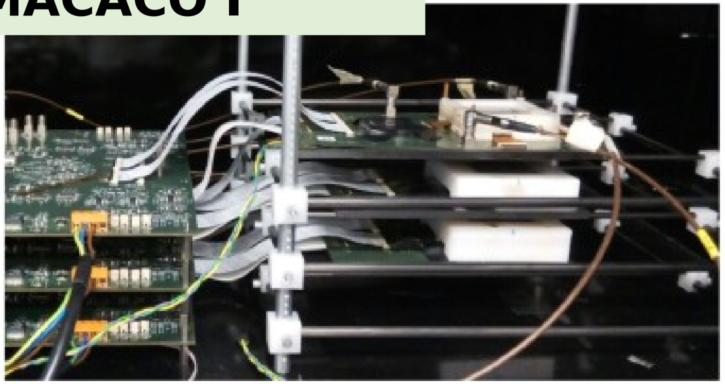
L. Barrientos et al.
NIMA 2021

ER ~ 5.6 % @ 511 keV
SR ~ 1.2 mm FWHM
TR 20 ns FWHM

Compton camera @ IRIS

Requirements	Goals
Excellent ER	< 4 %
Very good SR	~ 2 mm FWHM
Very good TR	< 1 ns FWHM

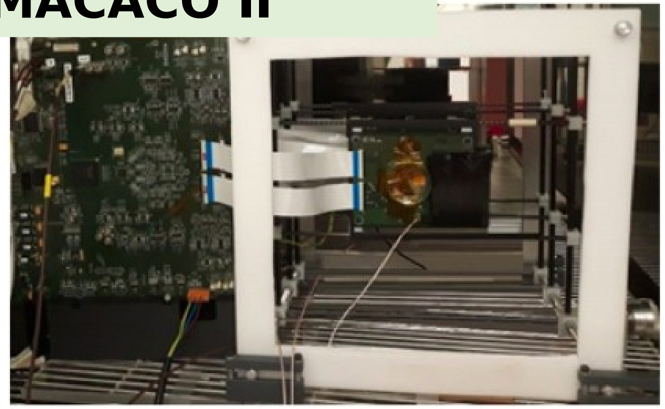
MACACO I



E. Muñoz et al.
Phys. Med. Biol. (62) 2017

ER ~ 8 % @ 511 keV
SR ~ 1.3 mm FWHM
TR 20 ns FWHM

MACACO II



L. Barrientos et al.
NIMA 2021

ER ~ 5.6 % @ 511 keV
SR ~ 1.2 mm FWHM
TR 20 ns FWHM

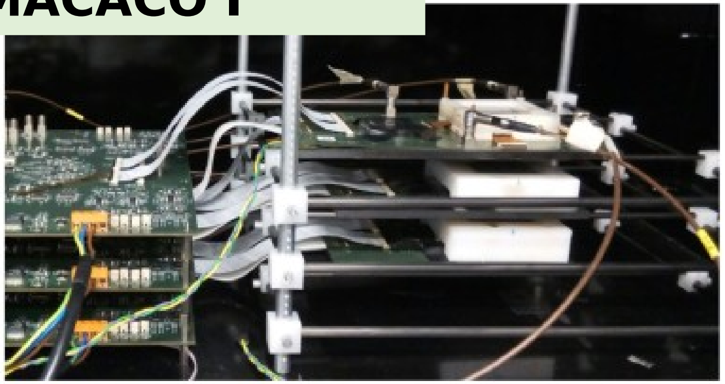
MACACO III

ER ~ 5.2 % @ 511 keV
SR ~ 1.2 mm FWHM
TR 20 ns FWHM

Compton camera @ IRIS

Requirements	Goals
Excellent ER	< 4 %
Very good SR	~ 2 mm FWHM
Very good TR	< 1 ns FWHM

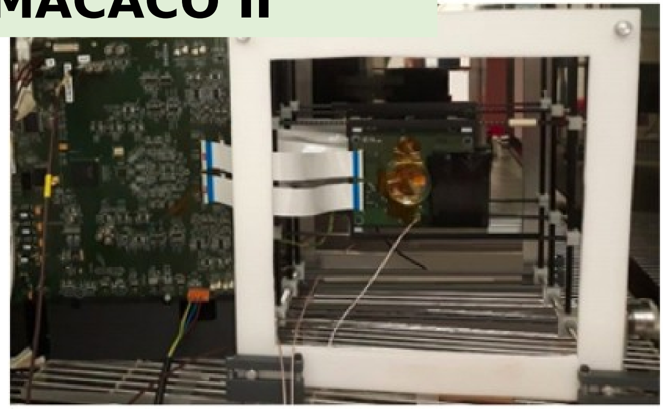
MACACO I



E. Muñoz et al.
Phys. Med. Biol. (62) 2017

ER ~ 8 % @ 511 keV
SR ~ 1.3 mm FWHM
TR 20 ns FWHM

MACACO II



L. Barrientos et al.
NIMA 2021

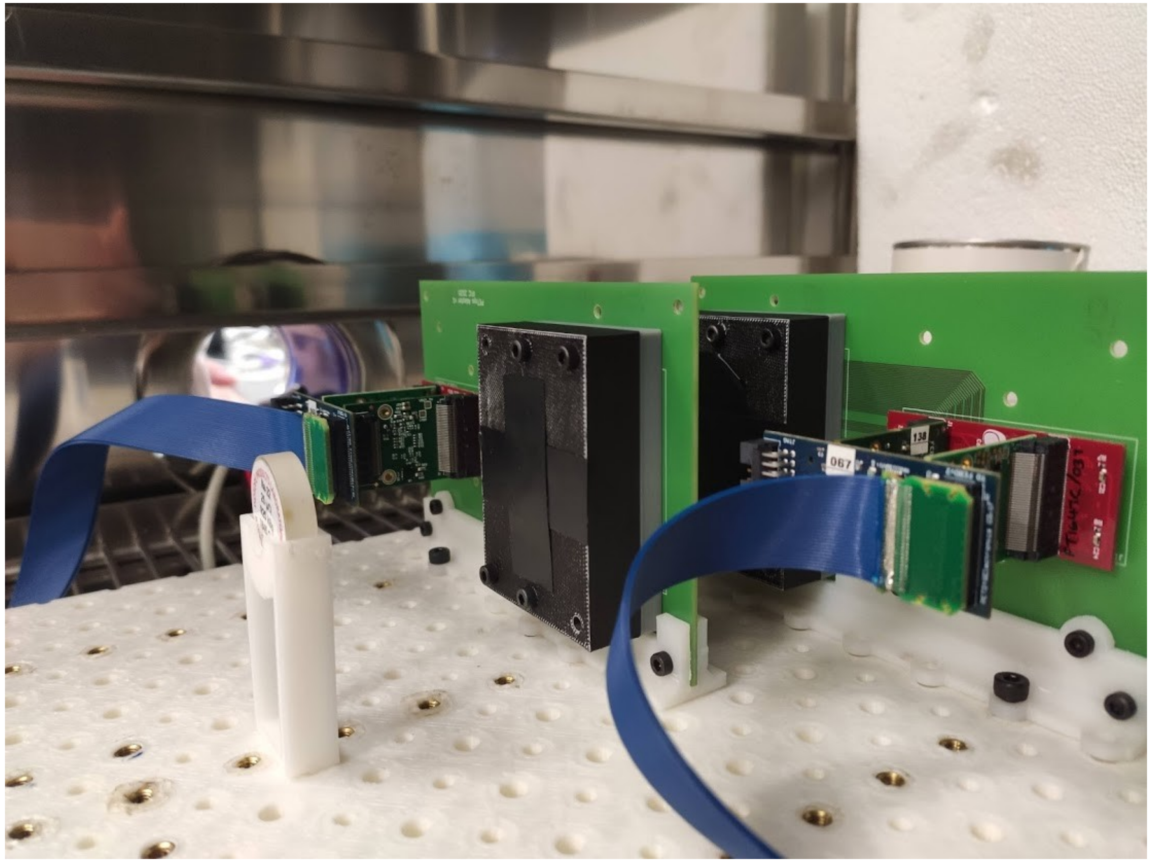
ER ~ 5.6 % @ 511 keV
SR ~ 1.2 mm FWHM
TR 20 ns FWHM

MACACO III

ER ~ 5.2 % @ 511 keV
SR ~ 1.2 mm FWHM
TR 20 ns FWHM

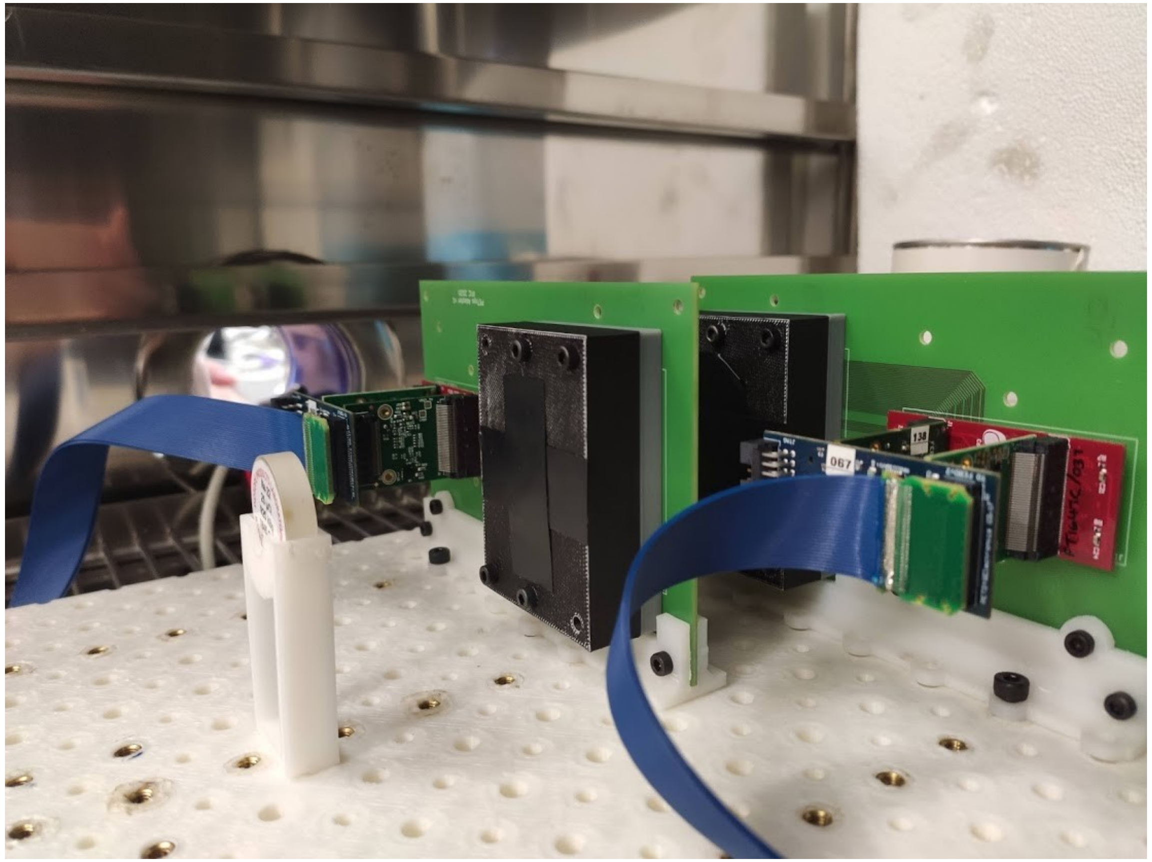
Compton camera @ IRIS

MACACOp



Compton camera @ IRIS

MACACOp

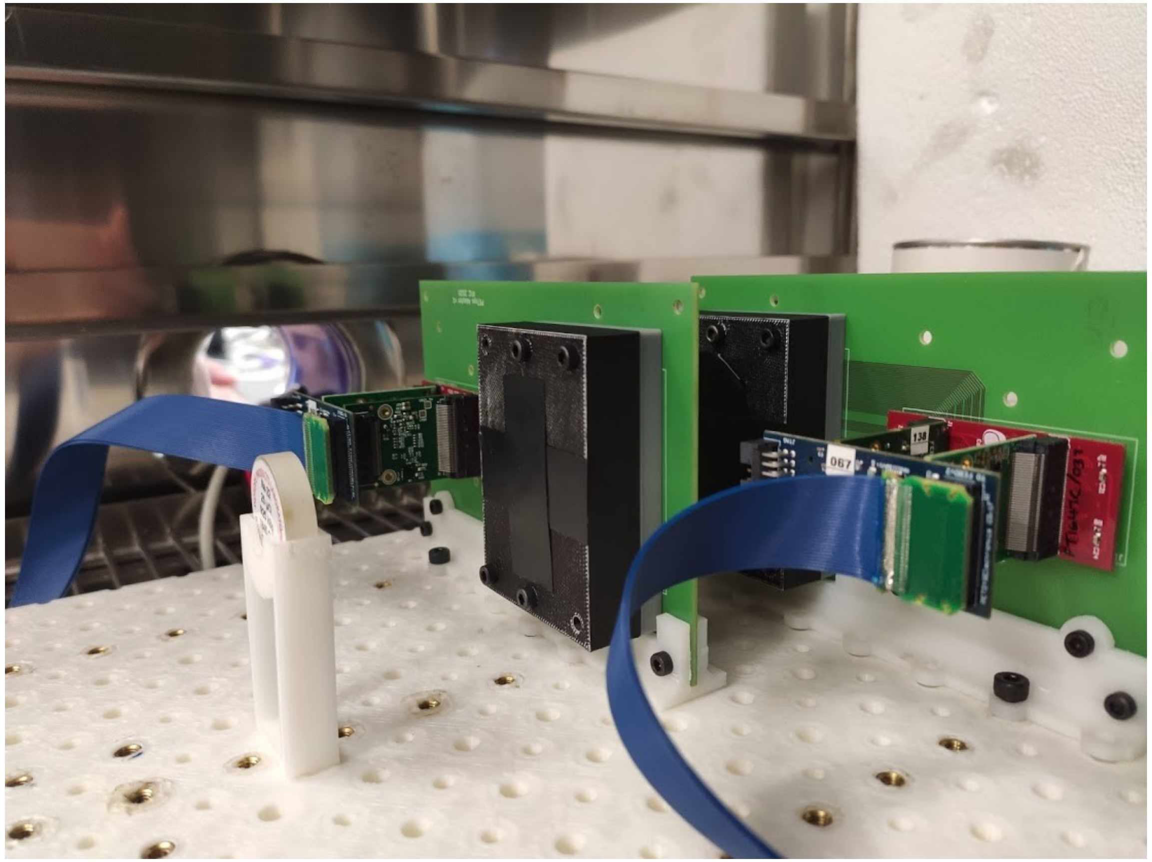


Readout electronics

TOFPET2 ASIC

Compton camera @ IRIS

MACACOp

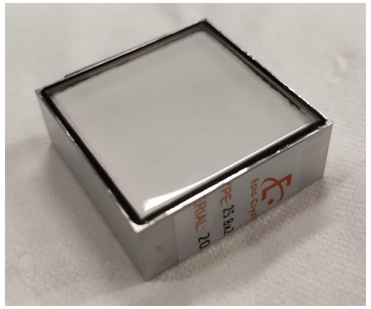


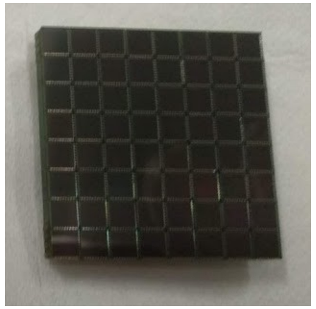
Readout electronics

TOFPET2 ASIC

Detectors

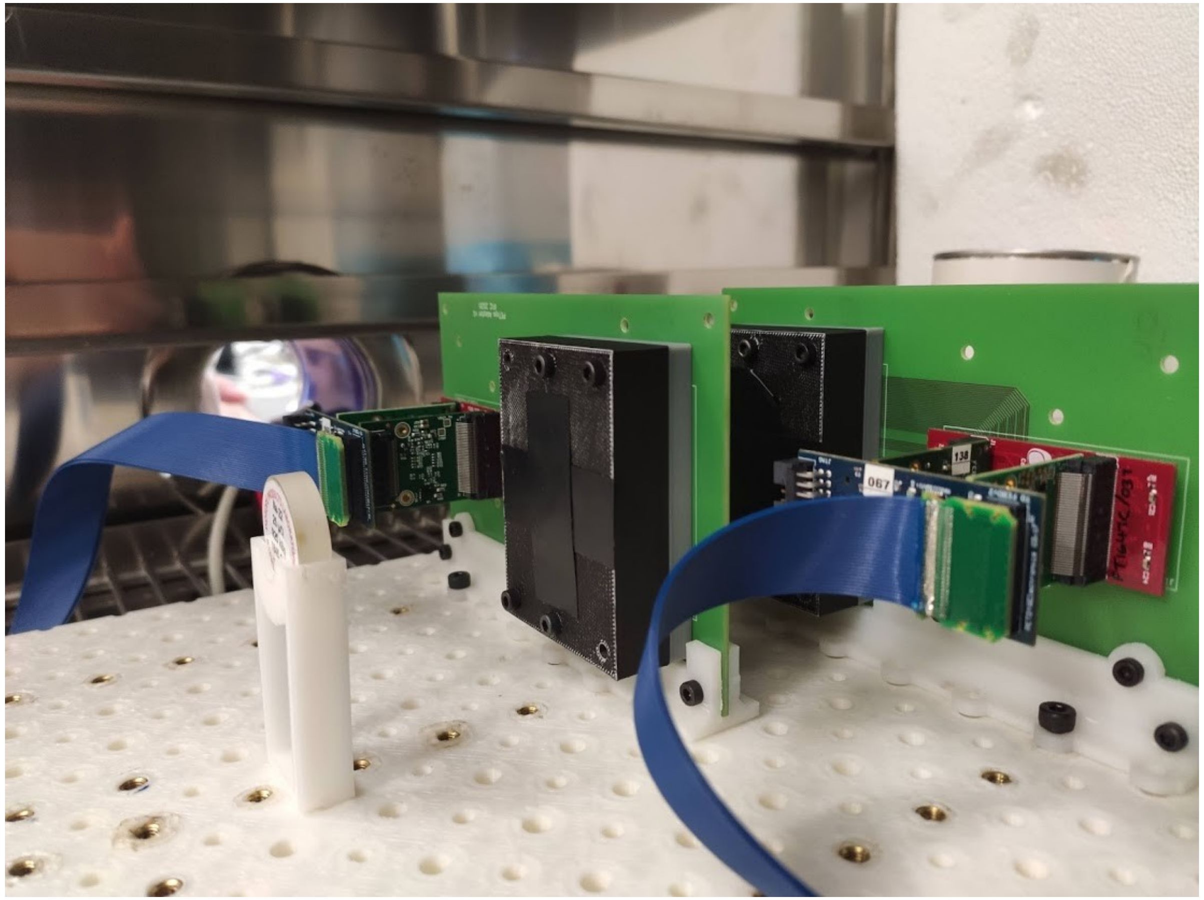
Two identical phototedector layers
SiPM array with 64 elements from Ketek
$LaBr_3$ monolithic scintillator crystals

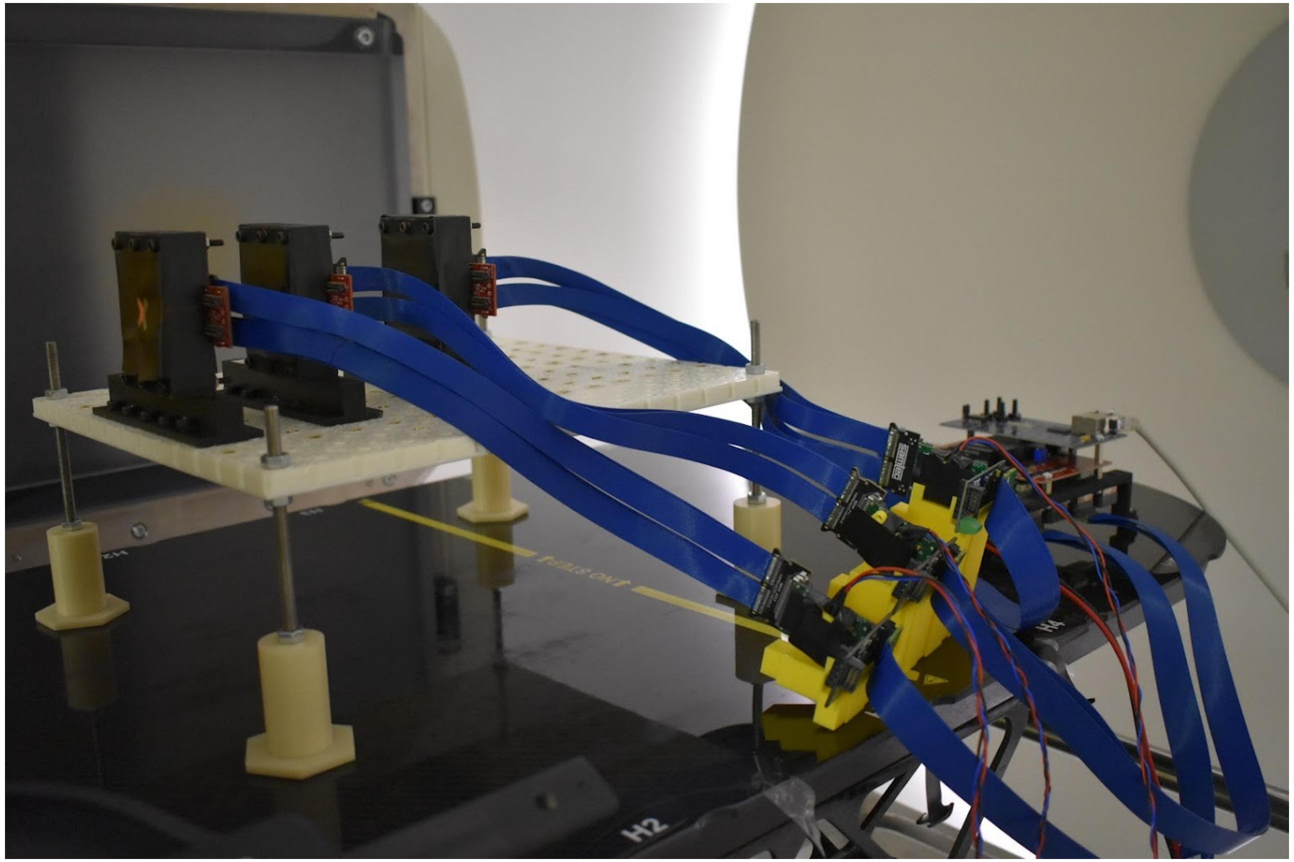




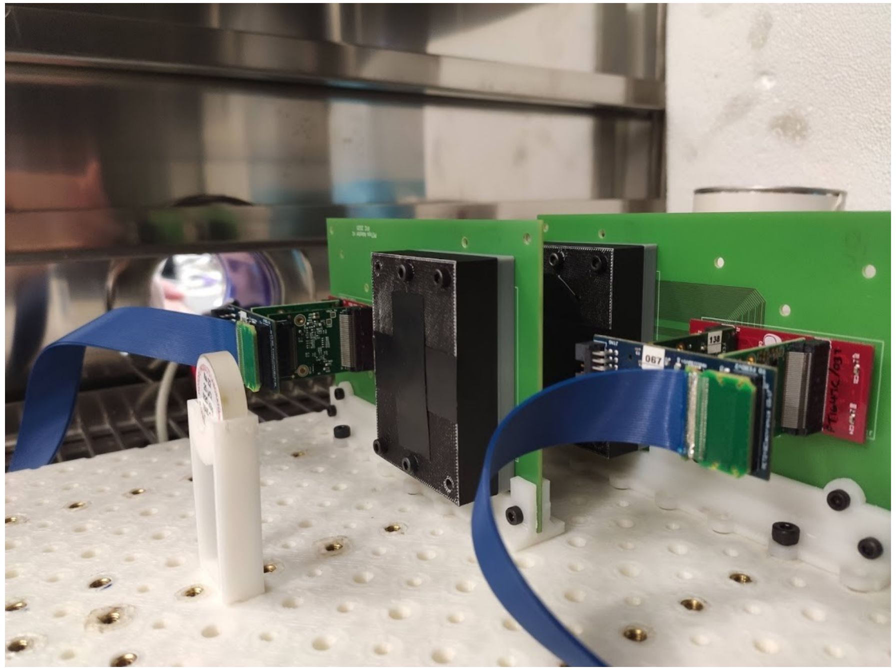
Compton camera @ IRIS

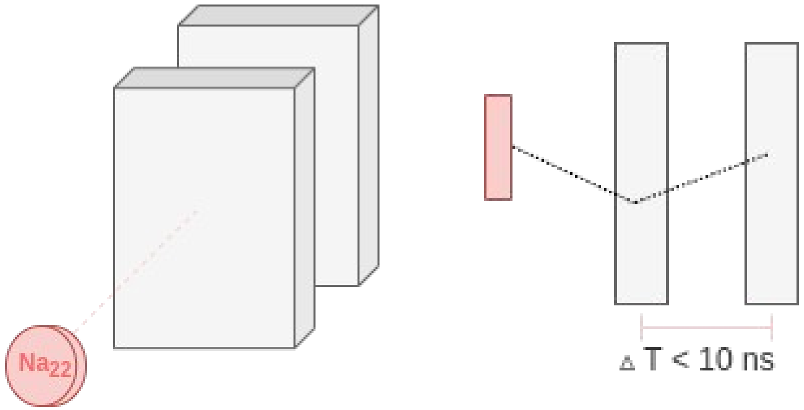
MACACOp

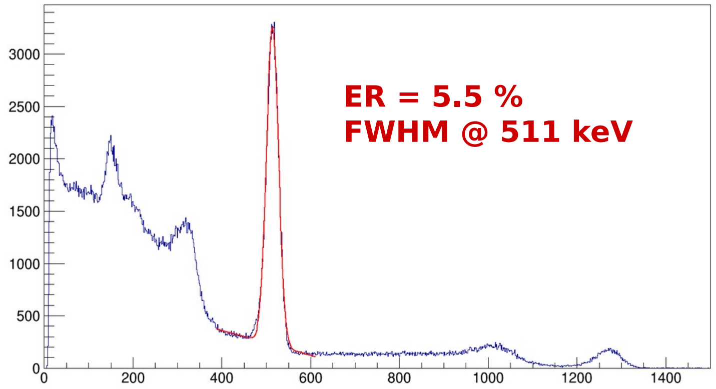


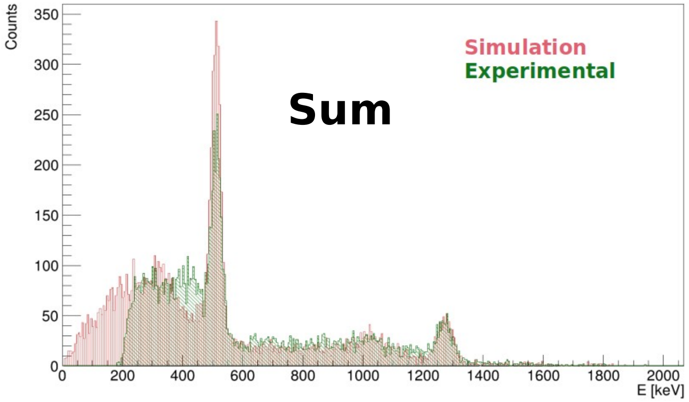


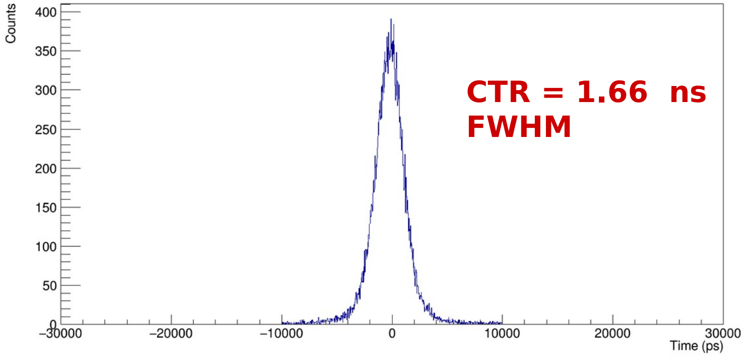
MACACOp @ IRIS



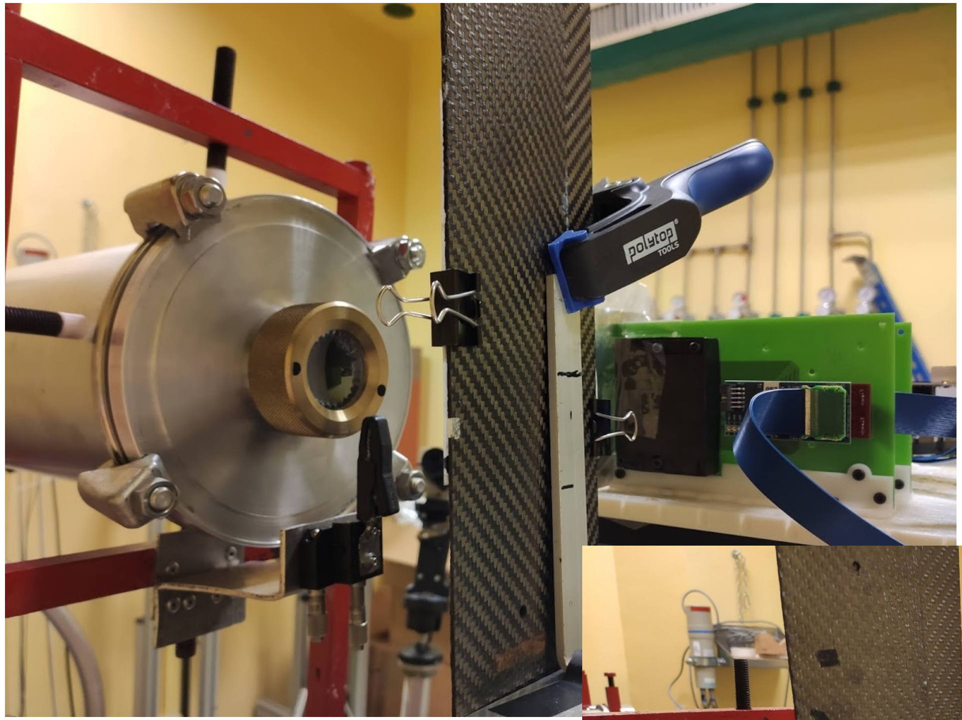


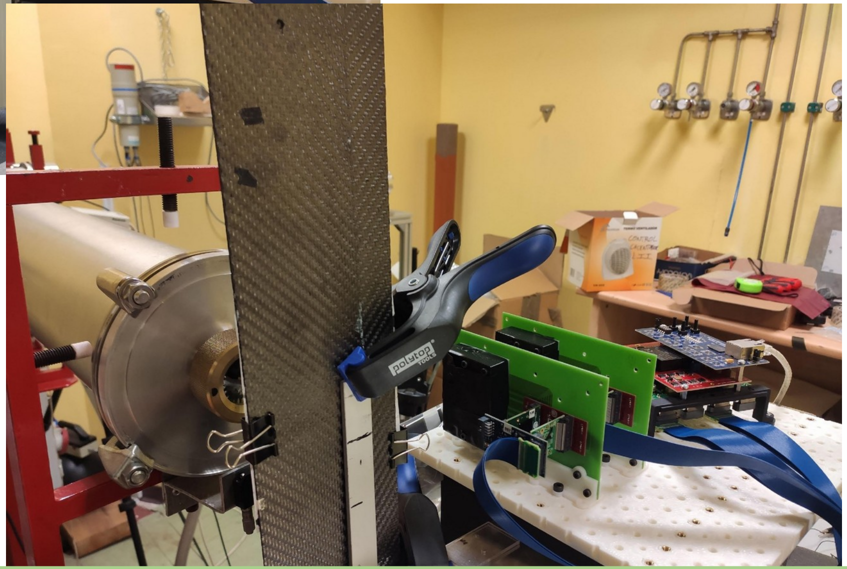


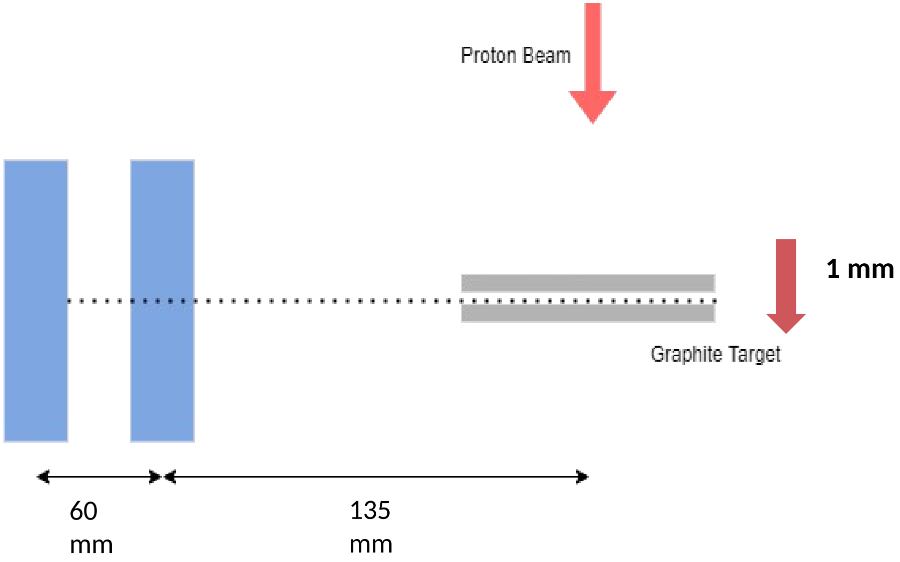




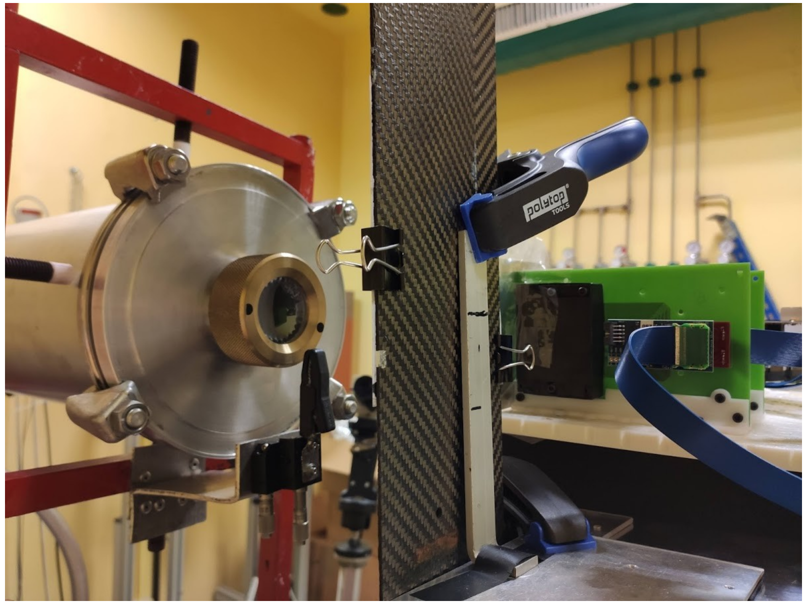
Tests at CNA, Sevilla

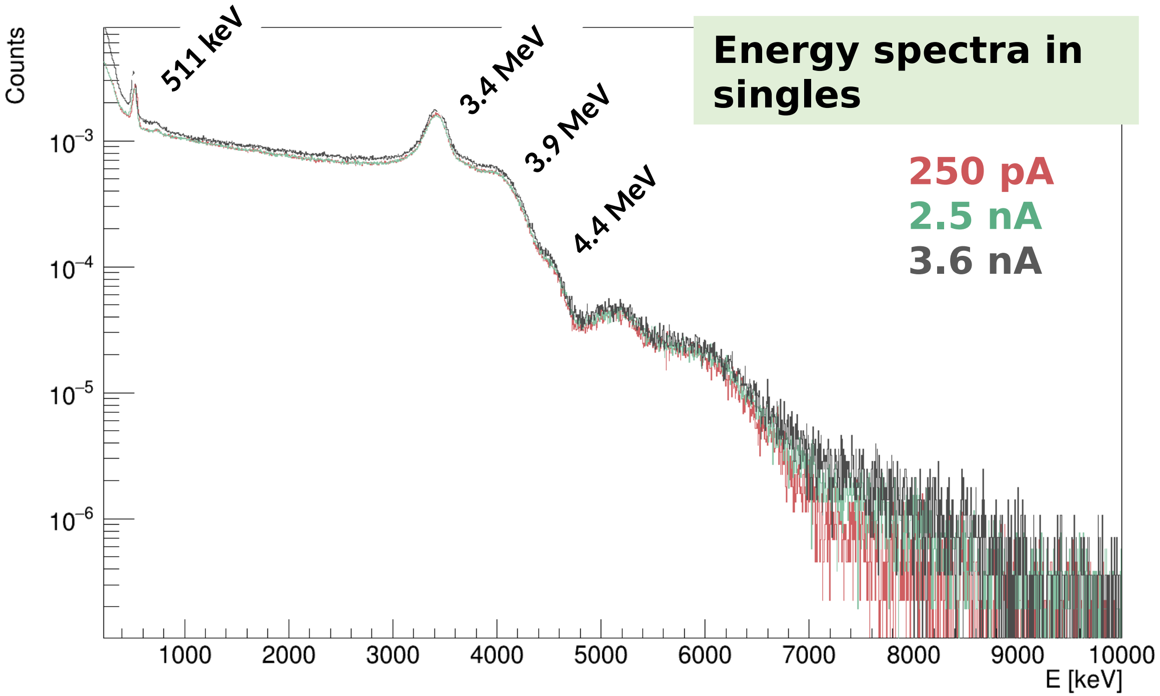






Tests at CNA, Sevilla

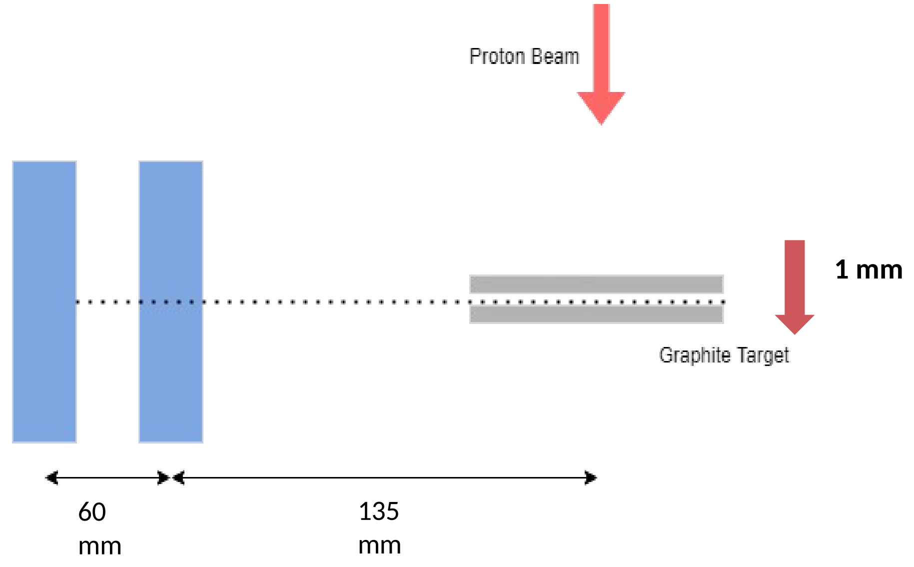


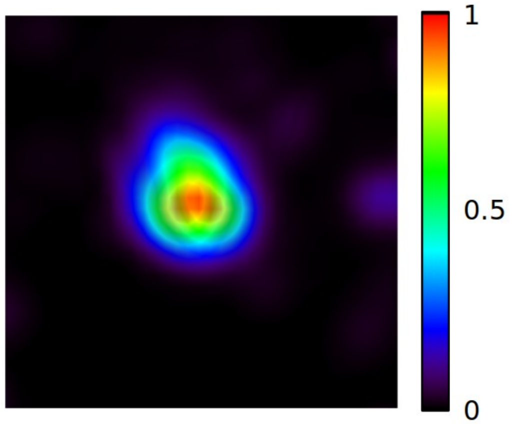


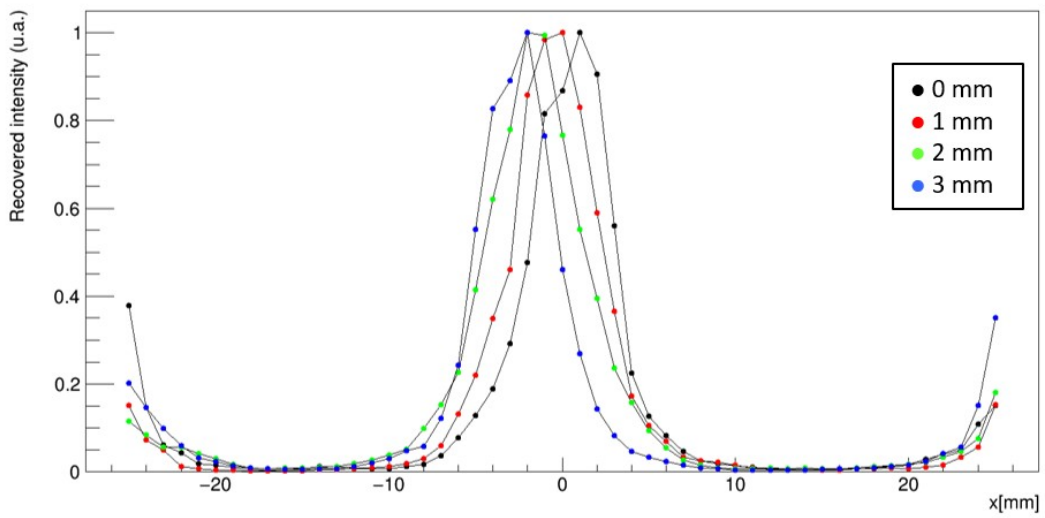
Energy spectra in singles

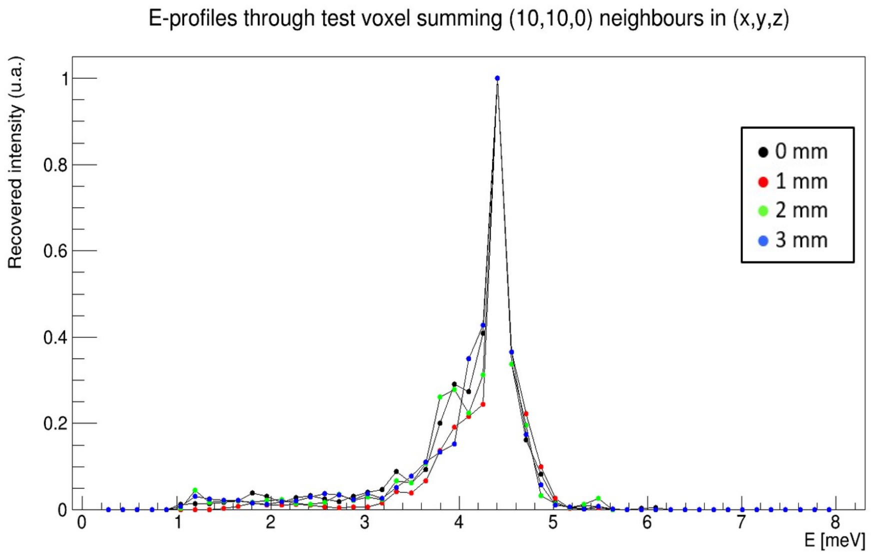
250 pA
2.5 nA
3.6 nA

Tests at CNA, Sevilla

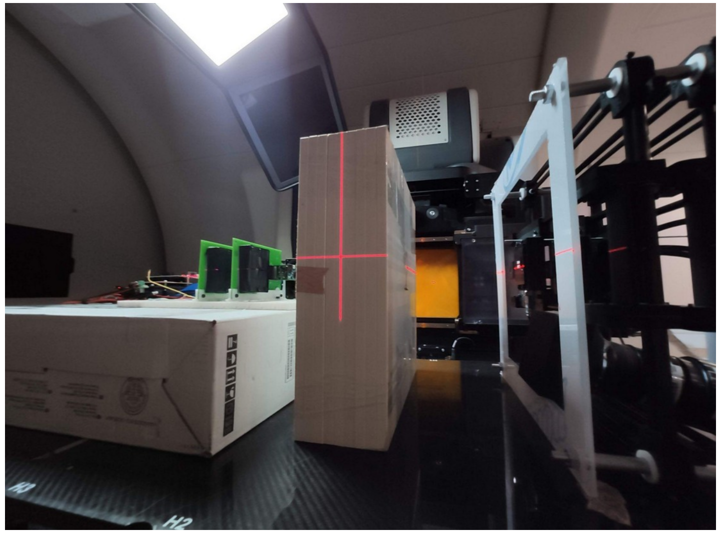


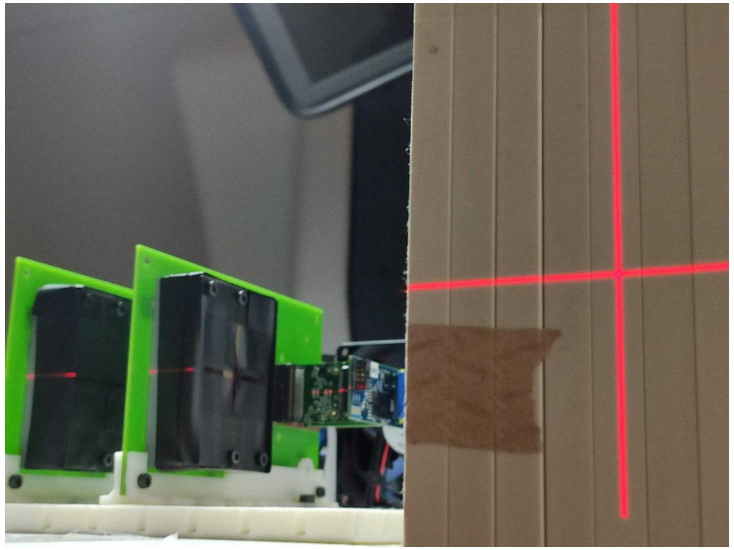




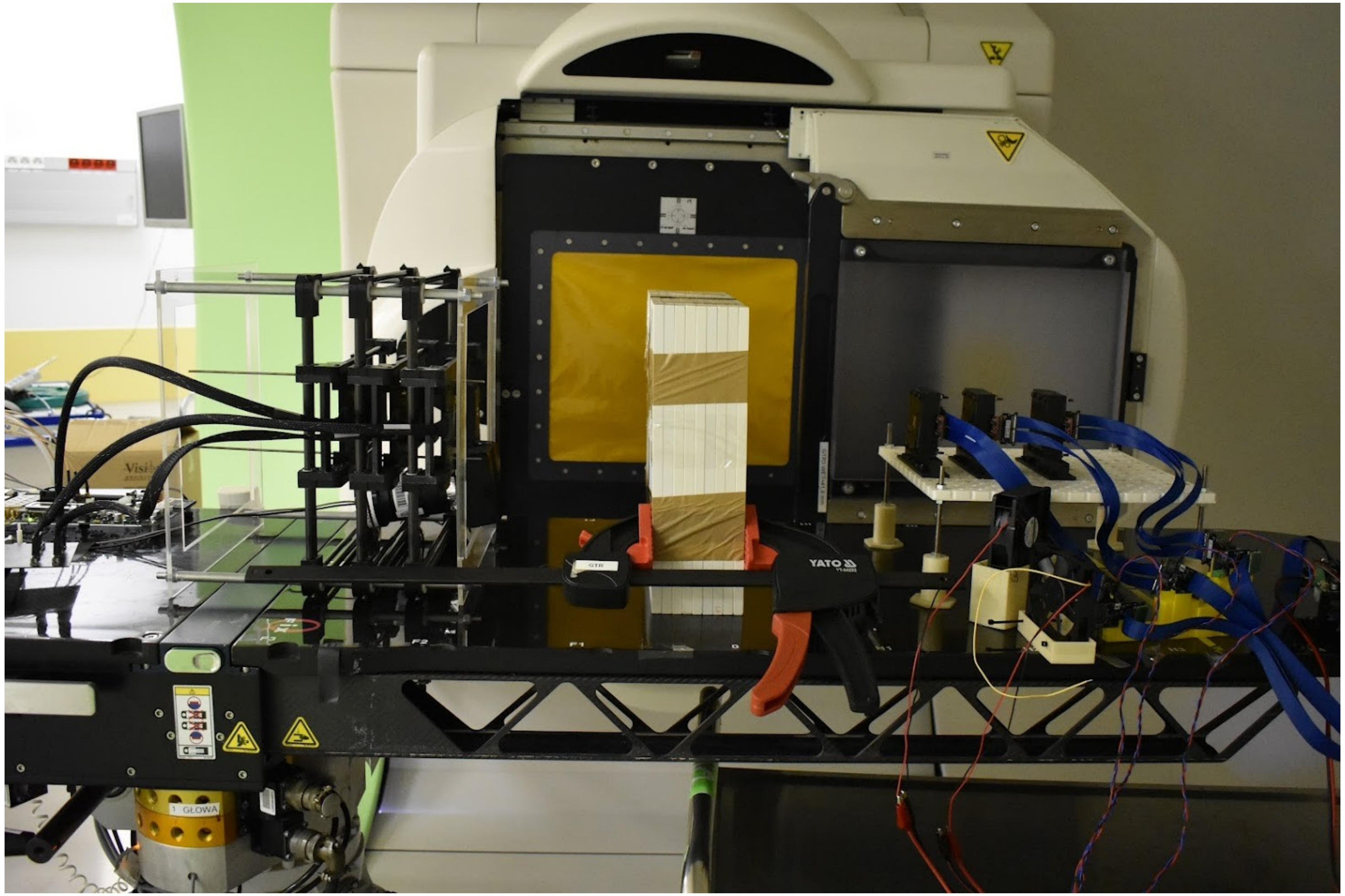


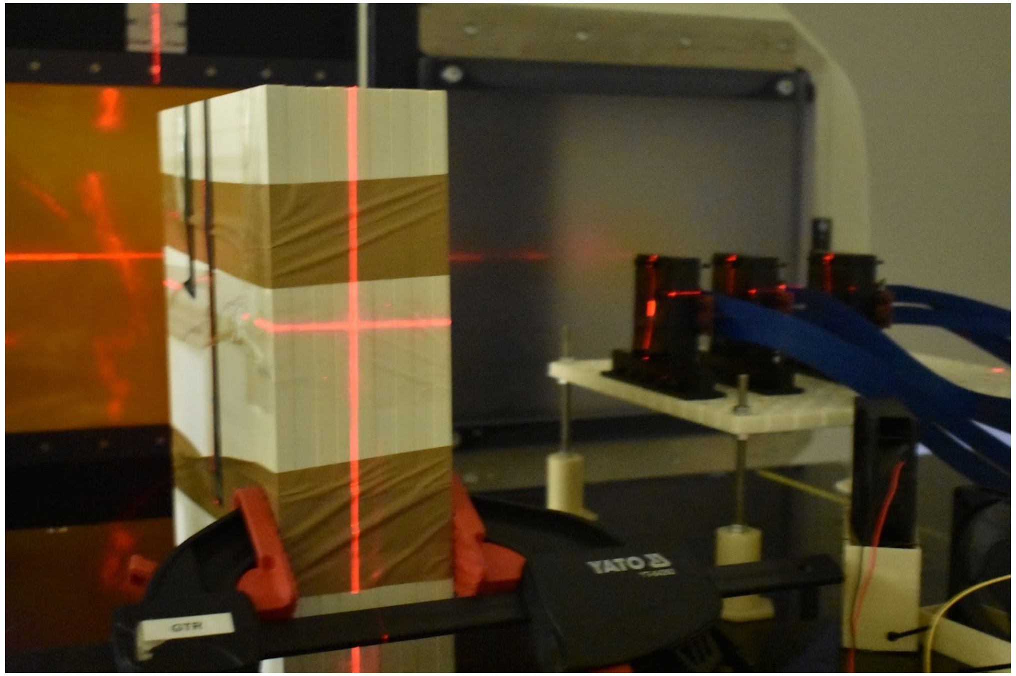
Tests at Quirón Salud, Madrid



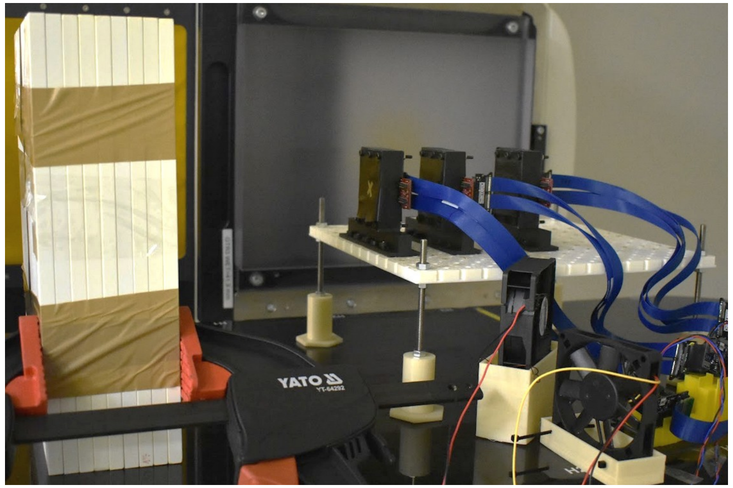


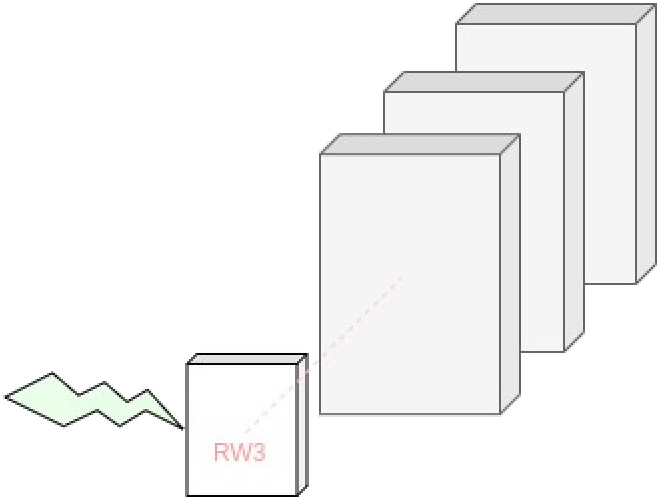
Tests at CCB (IFJ PAN), Krakow, Poland

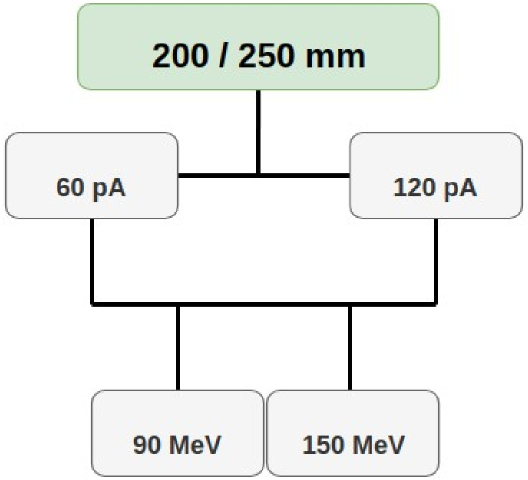




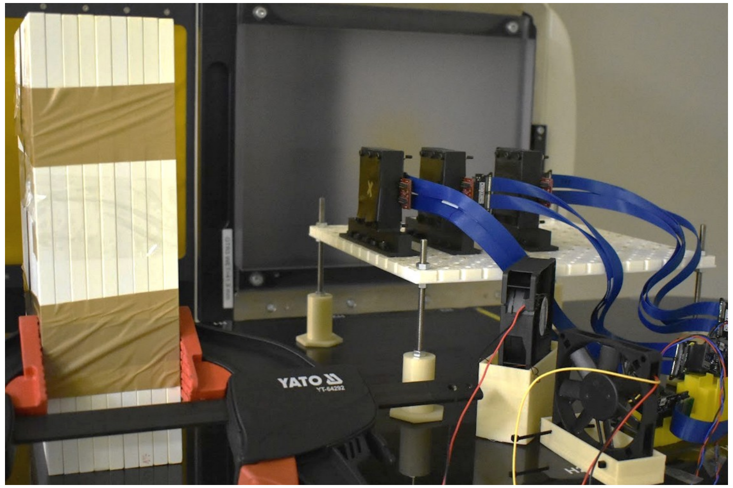
Tests at CCB (IFJ PAN), Krakow, Poland

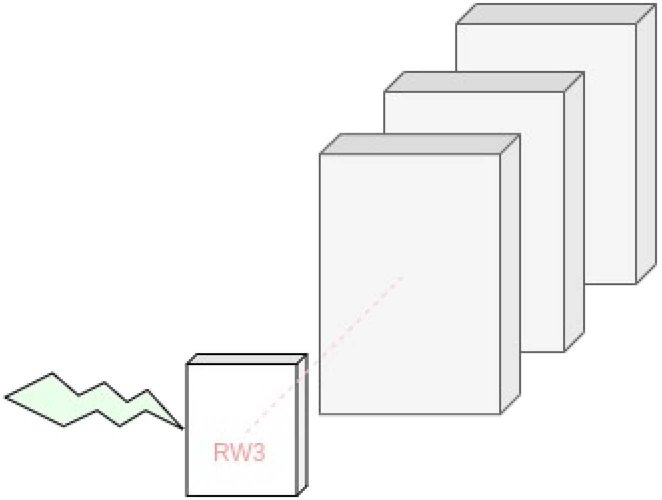


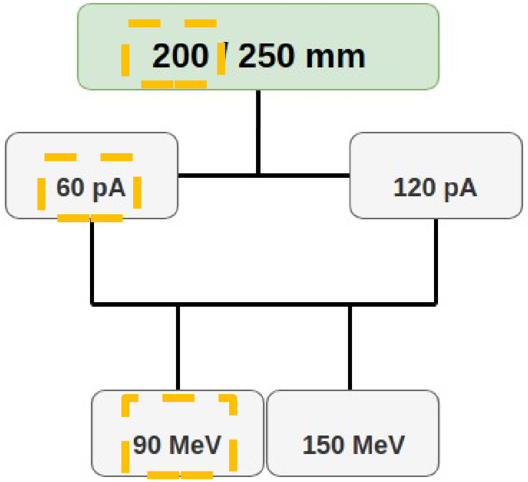


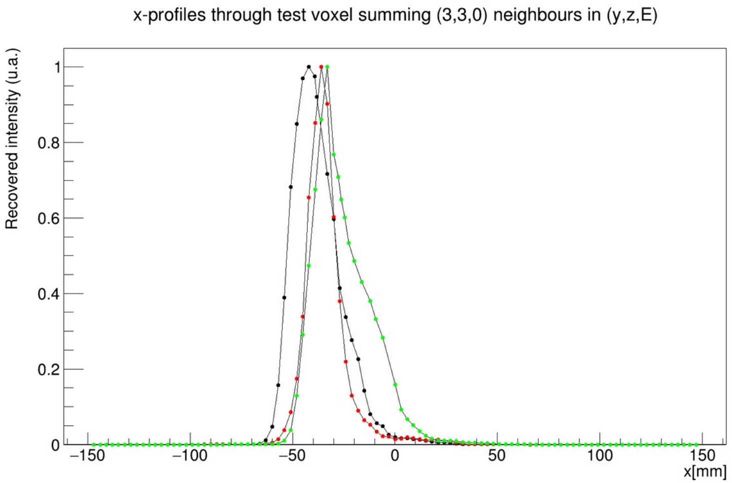


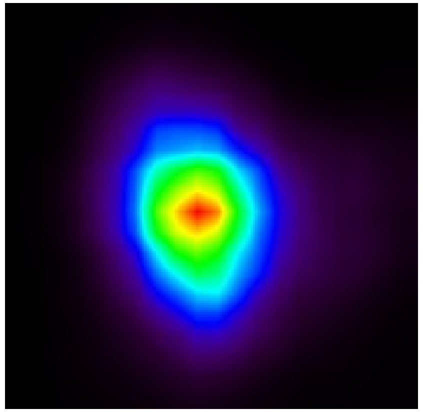
Tests at CCB (IFJ PAN), Krakow, Poland











Latest Publications

Performance evaluation of MACACO II Compton camera
L. Barrientos, M. Borja-Lloret, A. Etxebeste, E. Muñoz, J. F. Oliver, A. Ros, J. Roser, C. Senra, R. Viegas and G. Llosá.
Nuclear Inst. and Methods in Physics Research, A. vol 1014 (2021) 165702.

Proton range verification with MACACO II Compton camera enhanced by a neural network for event selection
E. Muñoz, A. Ros, M. Borja-Lloret, J. Barrio, P. Dendooven, J. F. Oliver, I. Ozoemelam, J. Roser and G. Llosá.
Sci Rep 11, 9325 (2021).

MACACO II test-beam with high energy photons
A. Ros Garcia, J. Barrio, A. Etxebeste, J. Garcia-Lopez, M.C. Jimenez-Ramos, C. Lacasta, E. Muñoz, J.F. Oliver, J. Roser, G. Llosa
Phys. Med. Biol. 65 (2020) 245027.

Image reconstruction for a multi-layer Compton Telescope: an analytical model for three interaction events
J. Roser, E. Muñoz, L. Barrientos, J. Barrio, J. Bernabéu, M. Borja-Lloret, A. Etxebeste, G. Llosá, A. Ros, R. Viegas, J. F. Oliver
Phys. Med. Biol. 65 (2020) 145005.

A spectral reconstruction algorithm for two-plane Compton cameras
E. Muñoz, L. Barrientos, J. Bernabéu, M. Borja-Lloret, G. Llosá, A. Ros, J. Roser and J. F. Oliver.
Phys. Med. Biol. 65 (2020) 025011

Study and comparison of different sensitivity models for a Compton Telescope
E. Muñoz, J. Barrio, J. Bernabéu, A. Etxebeste, C. Lacasta, G. Llosá, A., J. Roser and J. F. Oliver.
Phys. Med. Biol. 63 (2018) 13.

Thank you for your attention 😃

Backup slides

Compton Imaging

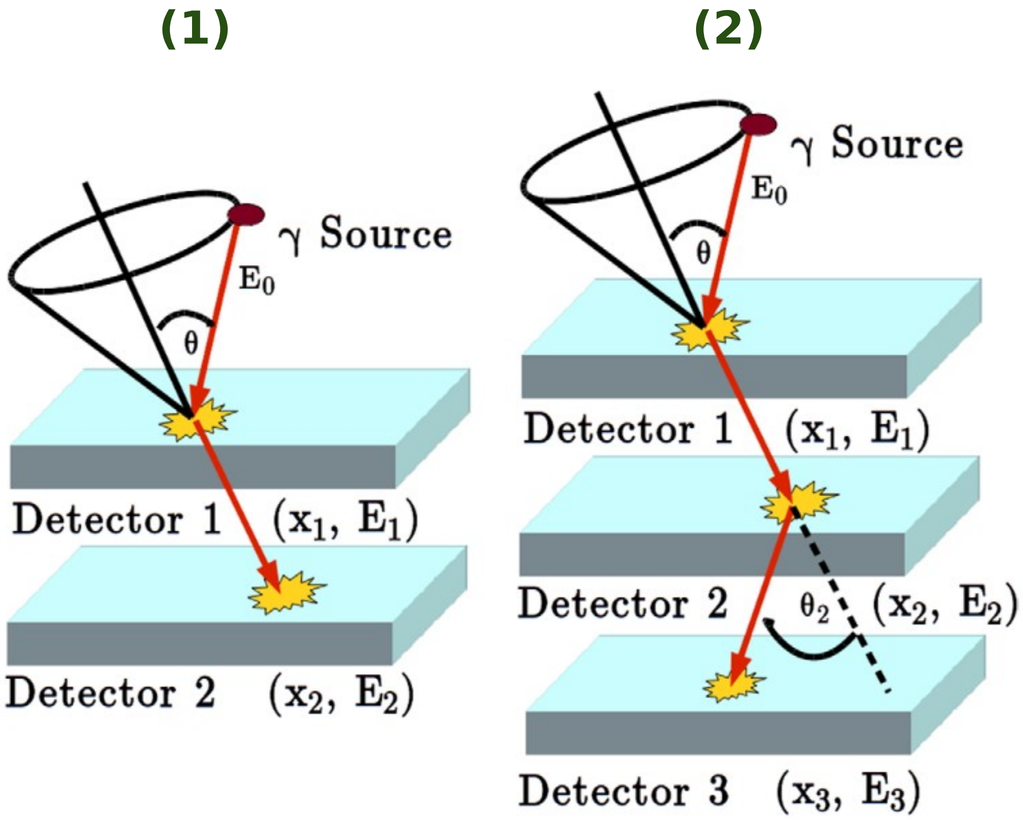
(1)2 Detector planes

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

(2) 3 Detector planes

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

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



E. Muñoz et al.
Phys. Med. Biol. (62) 2017

G. Llosá.
Nucl. Instrum. Methods Phys. Res. A 2018

Spectral Reconstruction for 2-plane CCs

The use of Compton imaging systems as monitors requires the **correct reconstruction of the distribution of prompt gamma productions** during patient irradiation.

In order to extract the maximum information from all the measurable events, we implemented a **spectral reconstruction method that assigns to all events a probability of being either partial or total energy depositions.**

The main concept behind its development is the **possibility to associate partial depositions of energy in the second interaction with a probability for a range of plausible incident gamma energies**, which in turn yield a set of CoRs with their corresponding aperture angles. In order to do so, the SM is divided into the three possible interactions that can produce a detection in the second detector plane: photoelectric absorption, a second Compton scattering or an e − e + pair production. Since the reconstruction is performed on a four dimensional FoV, during the iterative algorithm those voxels that contain both the spatial position and the spectral emission of the source are obtained.

E. Muñoz et al.
Phys. Med. Biol. (65) 2020