

# **MACACO:** a Compton camera for *in-vivo* hadron therapy monitoring

**Rita Viegas**

University of Valencia

**Beams & Dreams** 07-06-2022

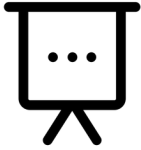


# Hello!



Image **R**econstruction,  
Instrumentation and  
**S**imulations for medical  
imaging applications (IRIS)





# Introduction

**Hadrontherapy**



# Introduction

## Hadrontherapy



Uncertainties

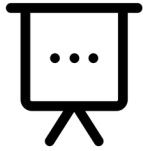


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## Hadrontherapy

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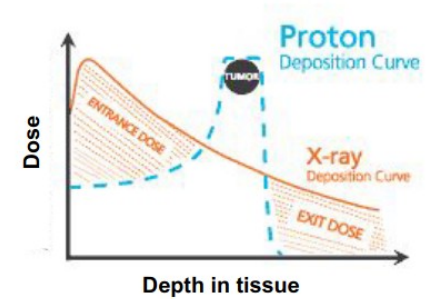
**In-vivo beam range verification**



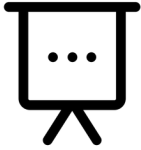
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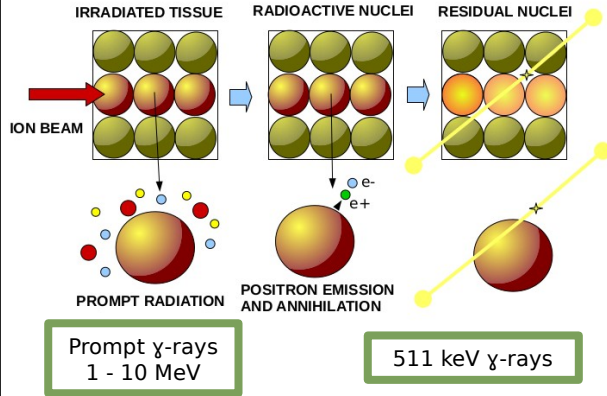


**In-vivo beam range verification**



Irradiation

Time



Long after therapy ( $\Delta T$  days - weeks)  
MRI

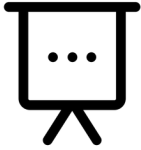
Long after treatment ( $\Delta T$  10 - 20 min)  
Offline PET

Post-treatment ( $\Delta T$  0 - 10 min)  
In-room PET

In-beam "delayed" ( $\Delta T$  ms - min)  
In-beam PET

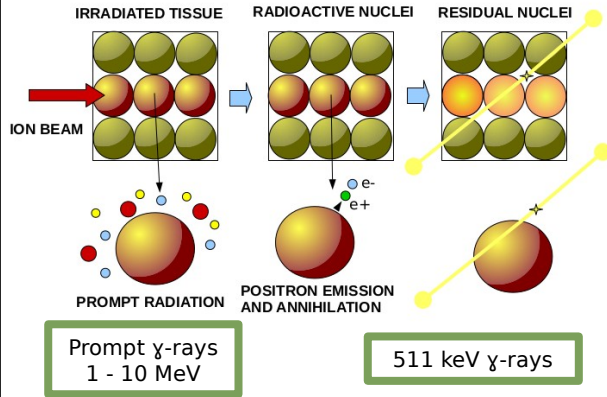
In-beam "real-time" ( $\Delta T < ms$ )  
Prompt-gamma, ionoacoustic, emitted particles

Adapted from Proton Therapy Physics (2nd edition),  
H. Paganetti



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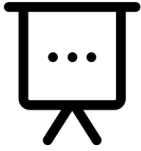
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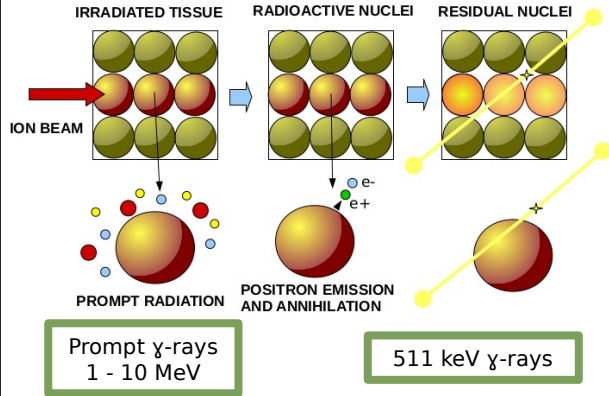
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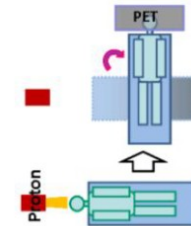
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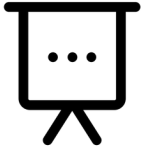
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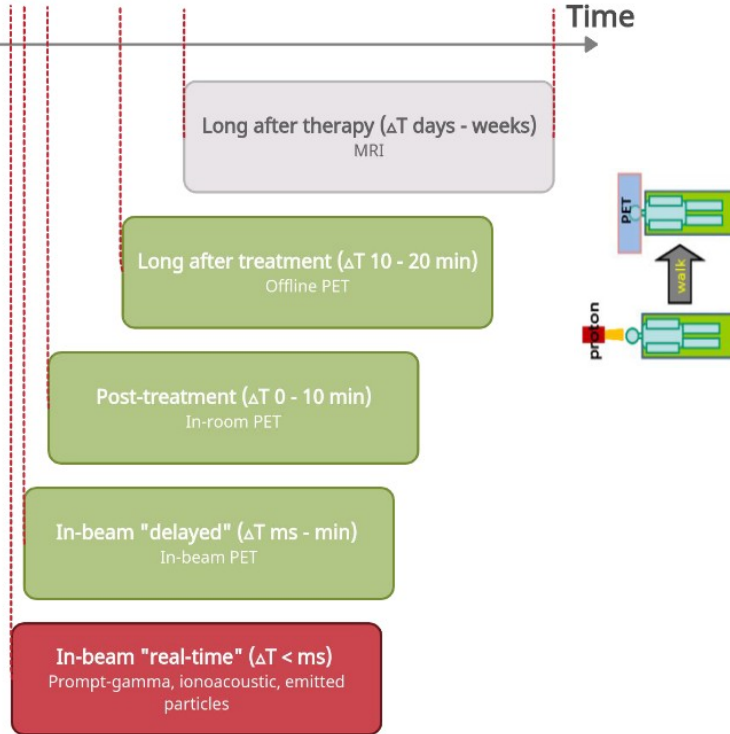
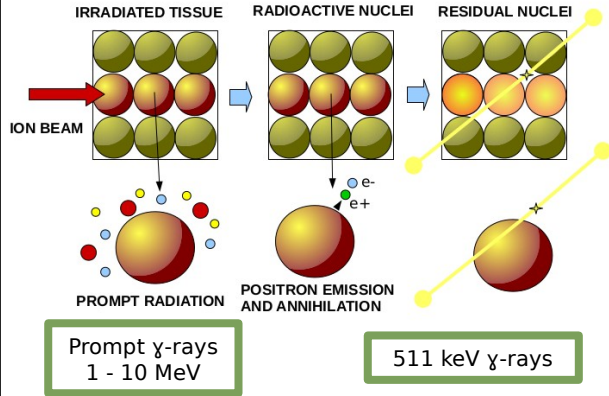


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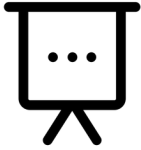


Irradiation

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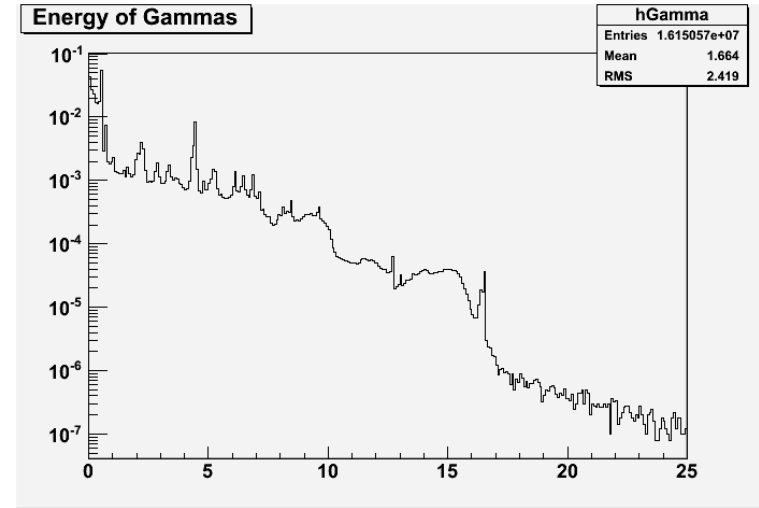
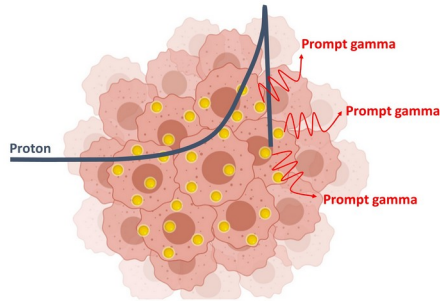


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## Prompt gammas

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



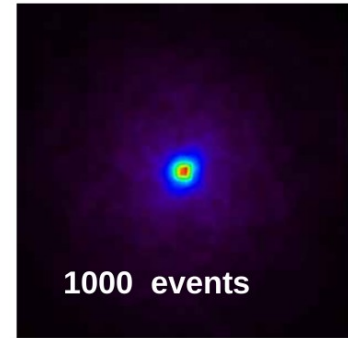
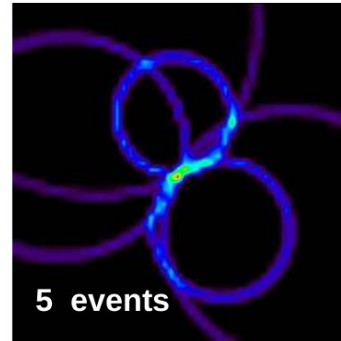
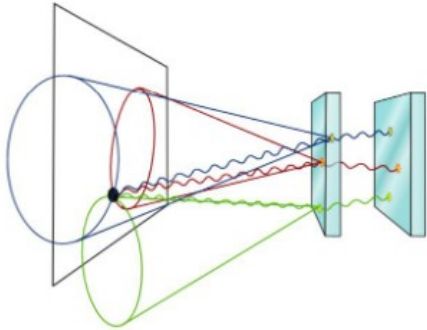
Krimmer et al.  
NIMA 2017



# Compton Imaging

¿? Origin of gamma rays

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



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



# MACACO @ IRIS group

Excellent  
ER (< 4 %)

Very good  
SR (~ 2 mm  
FWHM)

Very good  
TR (< 1 ns  
FWHM)



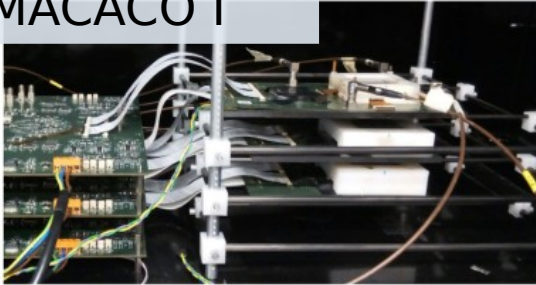
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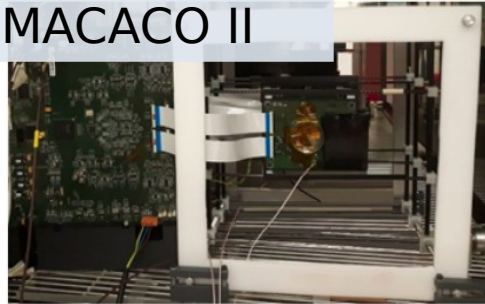
Very good  
TR ( $< 1\text{ ns}$   
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## MACACO I



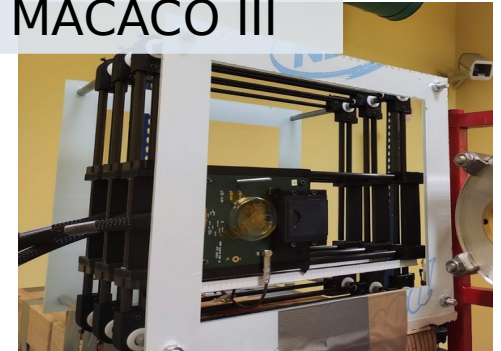
E. Muñoz et al.  
Phys. Med. Biol. (62)  
2017

## MACACO II



L. Barrientos et al.  
NIMA 2021

## MACACO III



L. Barrientos et al.  
In preparation



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MACACO III



ER ~ 5.2 % @ 511 keV

SR ~ 1.2 mm FWHM

TR 20 ns FWHM



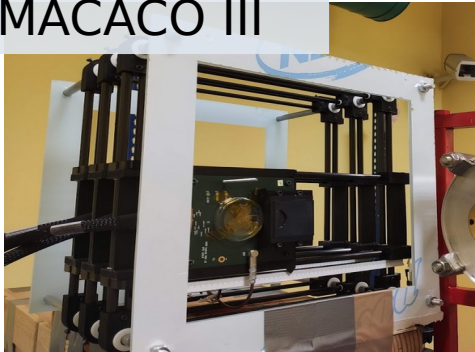
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ER  $\sim 5.2\%$  @ 511 keV

SR  $\sim 1.2$  mm FWHM

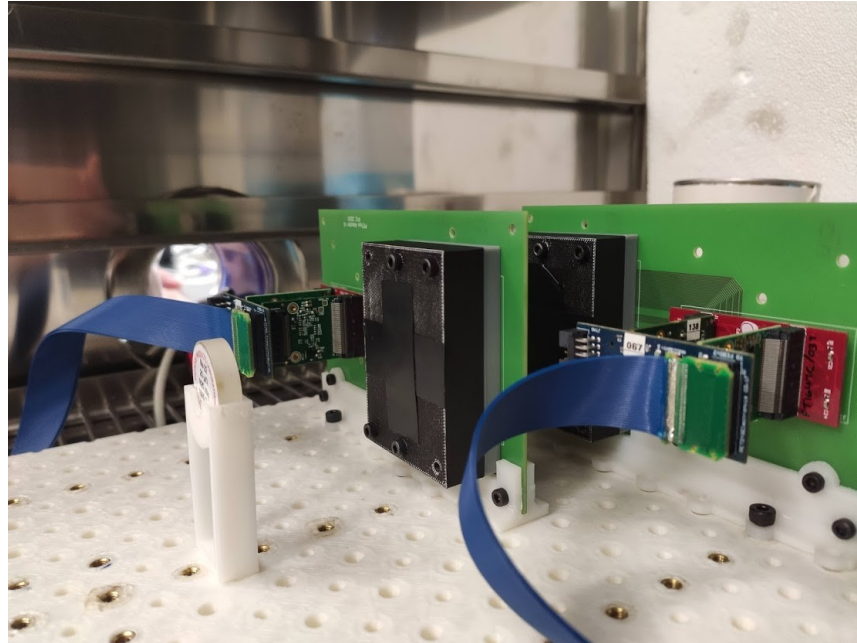
TR 20 ns FWHM







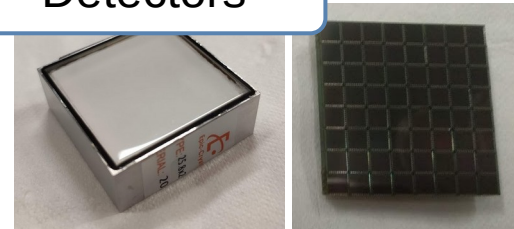
# MACACOp



TOFPET2 ASIC

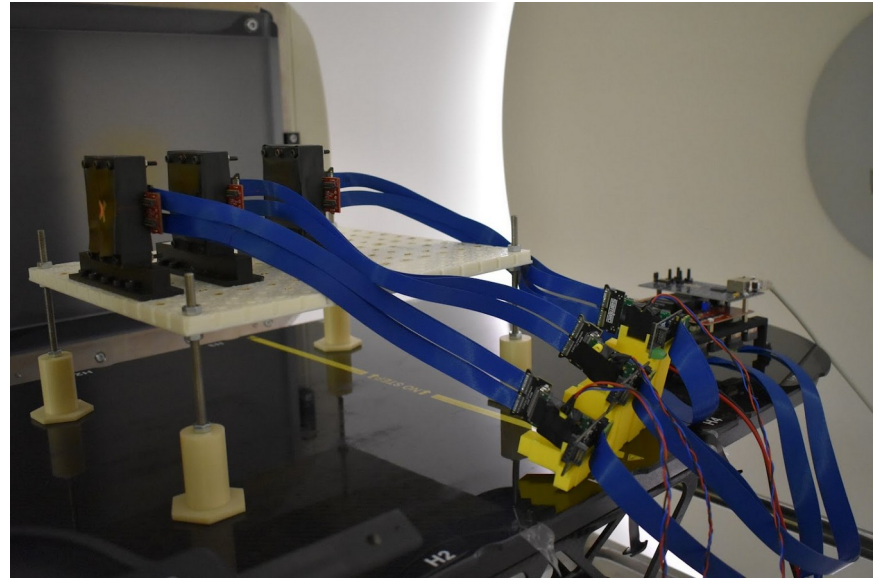
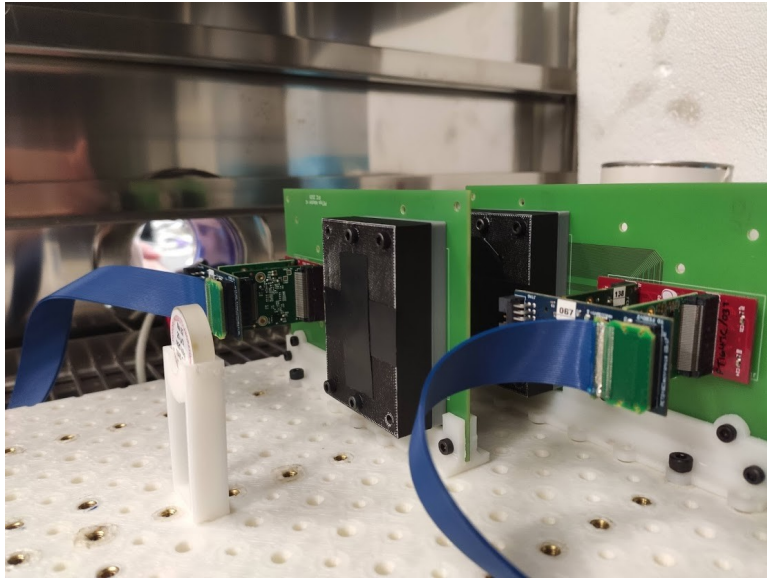


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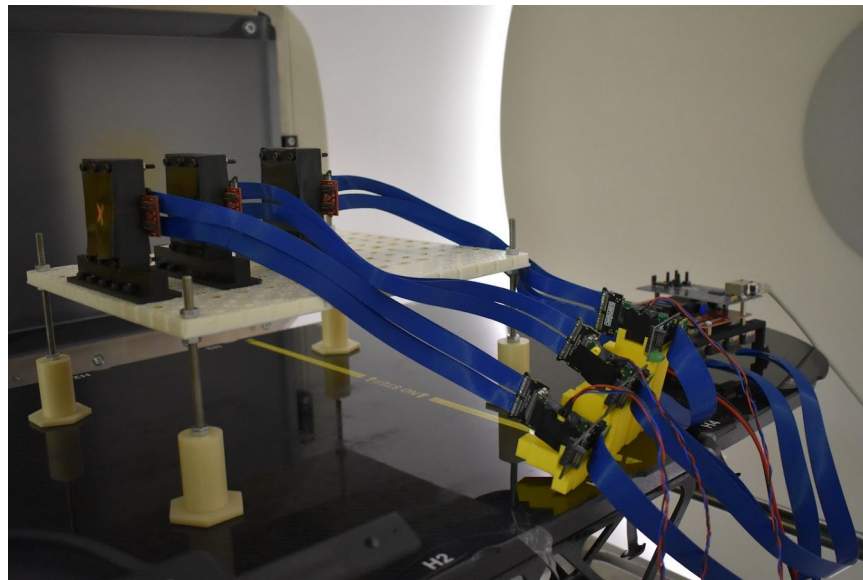
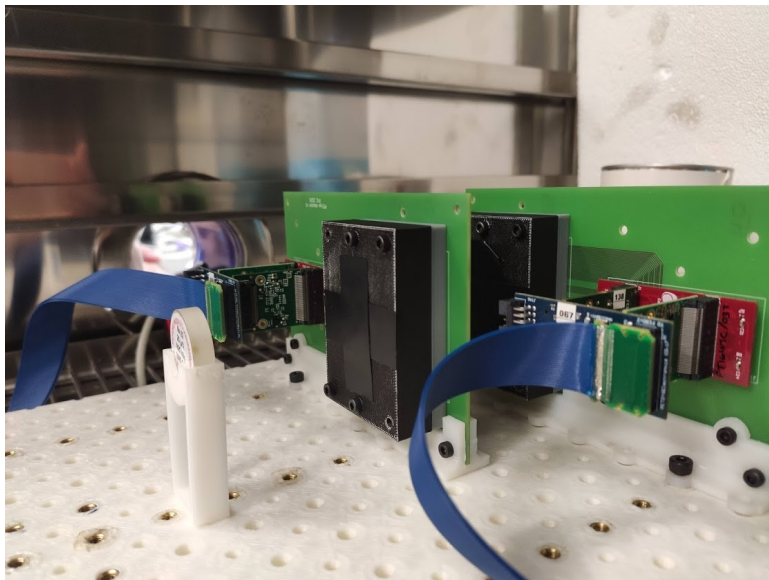


# MACACOp



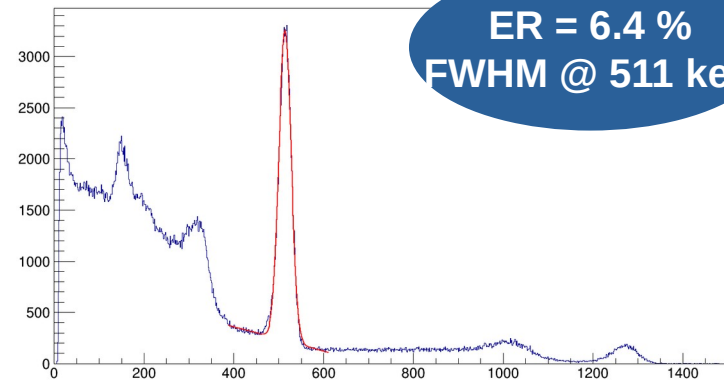
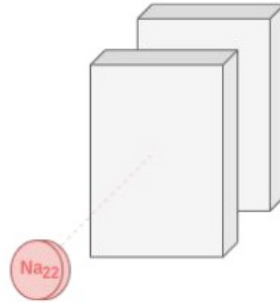
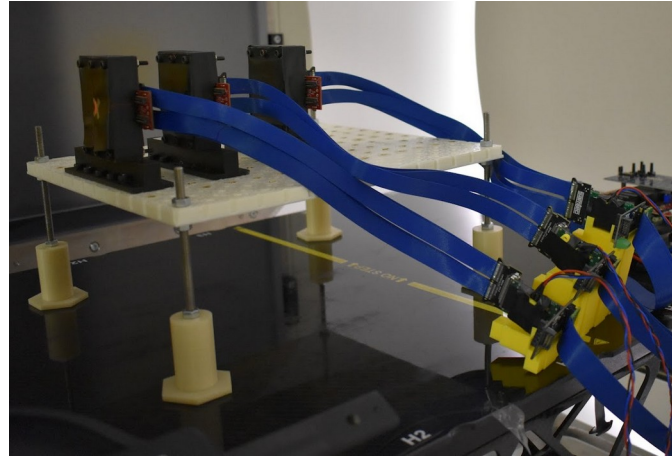


# MACACOp



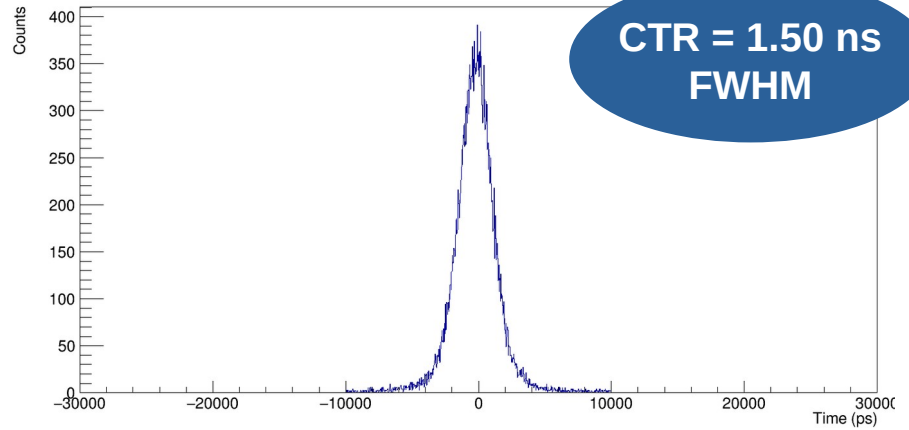
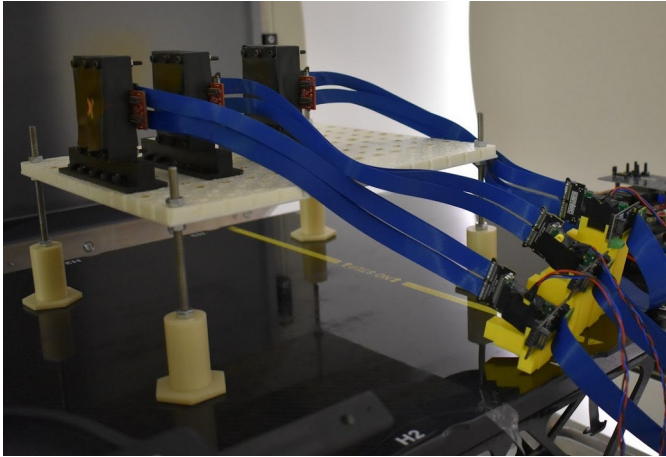
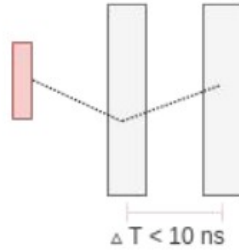


# MACACOp





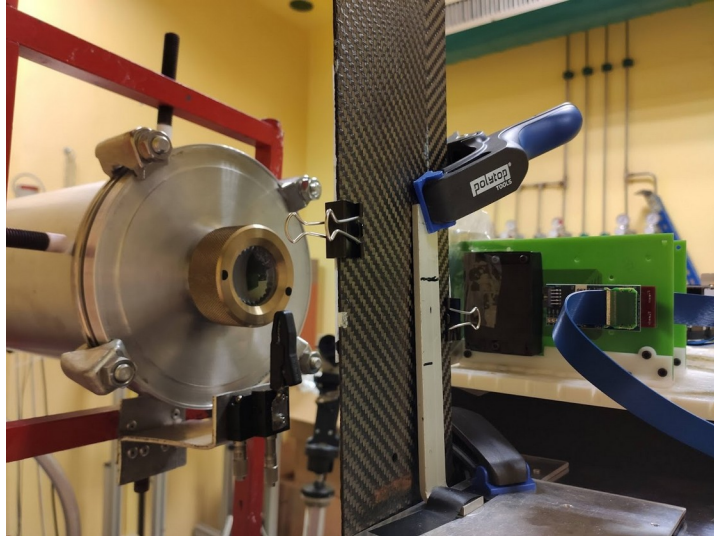
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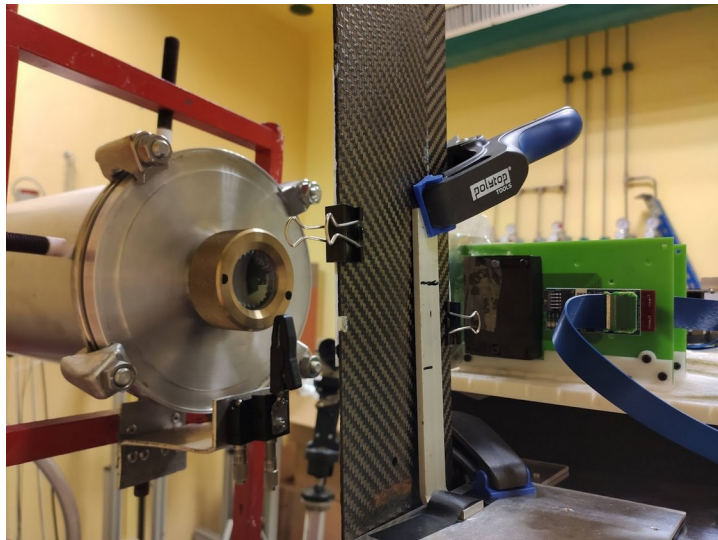




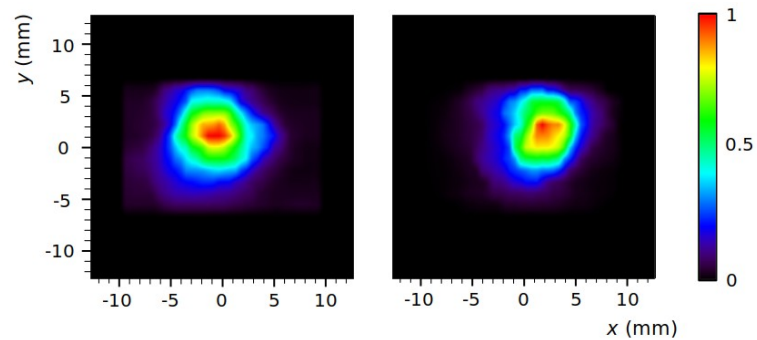
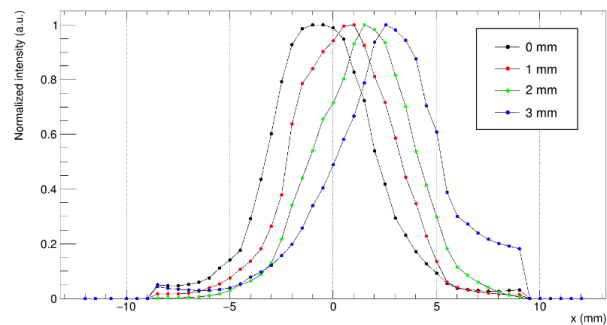
# Tests @ CNA (Sevilla)



L. Barrientos et al.  
In preparation

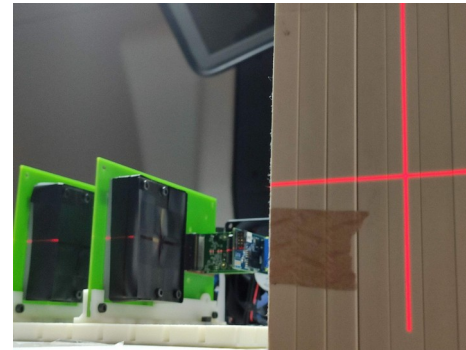
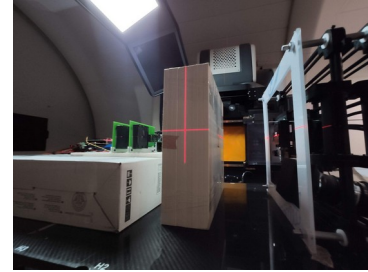


R. Viegas et al.  
Radiat. Phys. Chem (2022)  
Accepted for publication to





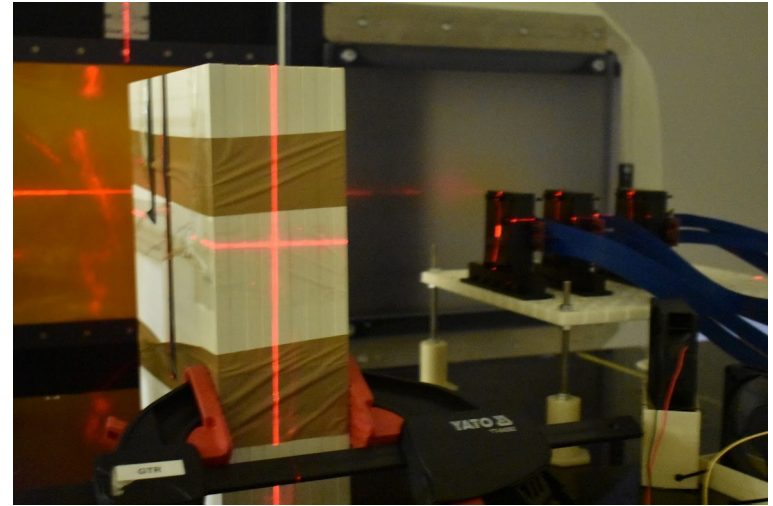
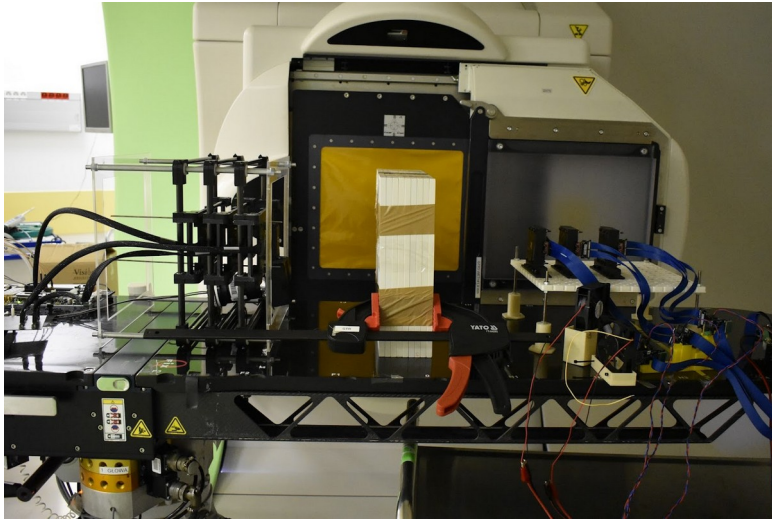
# Tests @ Quirón Salud (Madrid)







# Tests @ CCB - IFJ PAN (Krakow)



# 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. 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. Ozoemelum, 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,

Phys. Med. Biol. 65 (2020) 145005.

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 Uncertainties



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⚠ Uncertainties

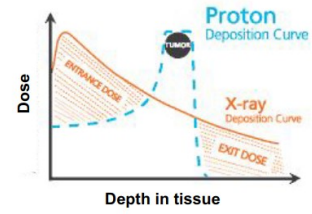
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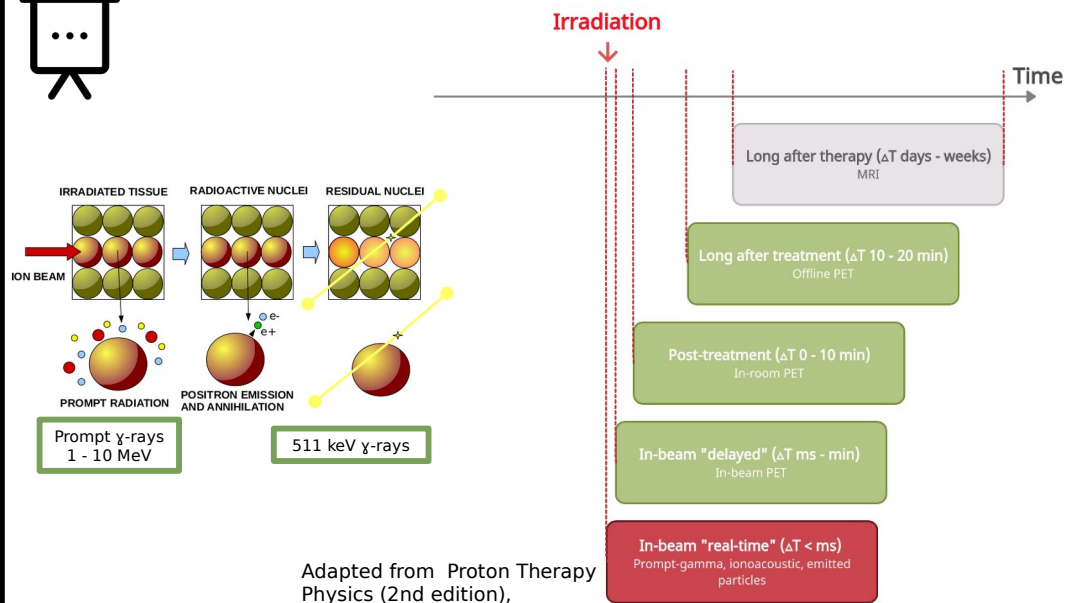
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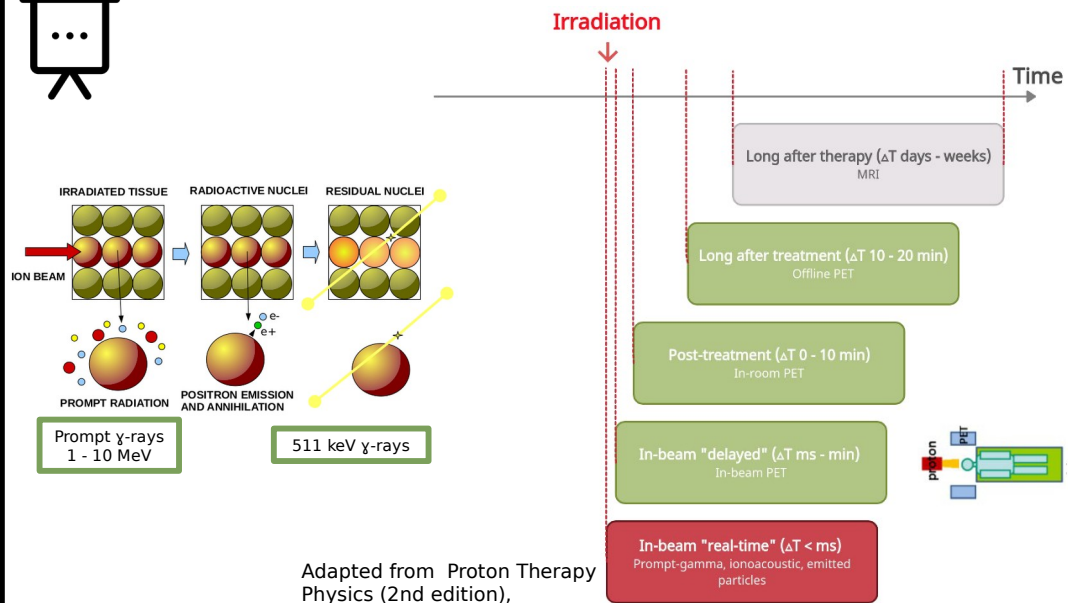


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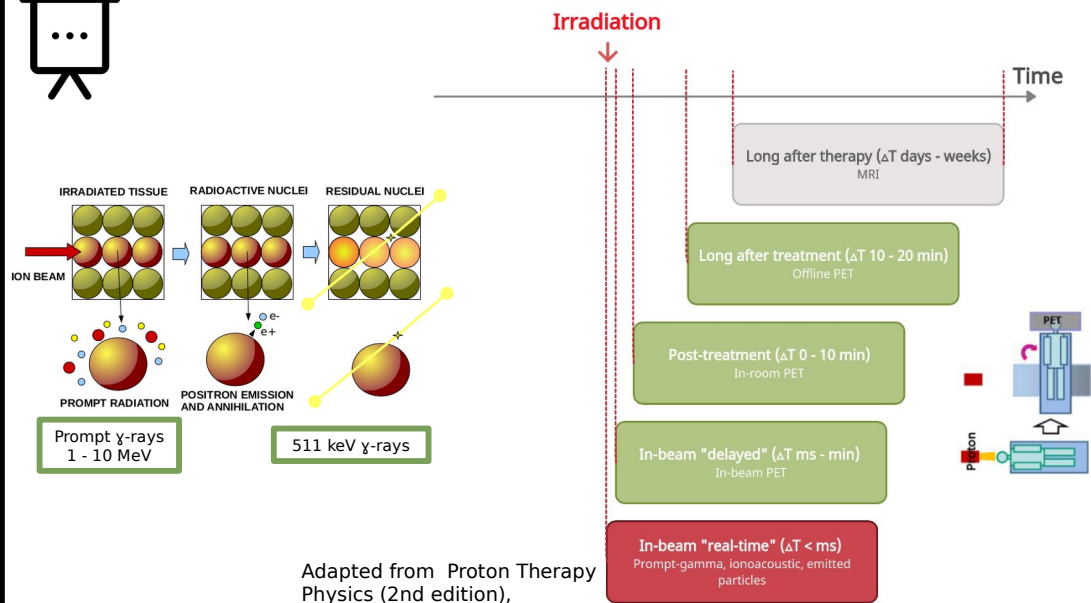




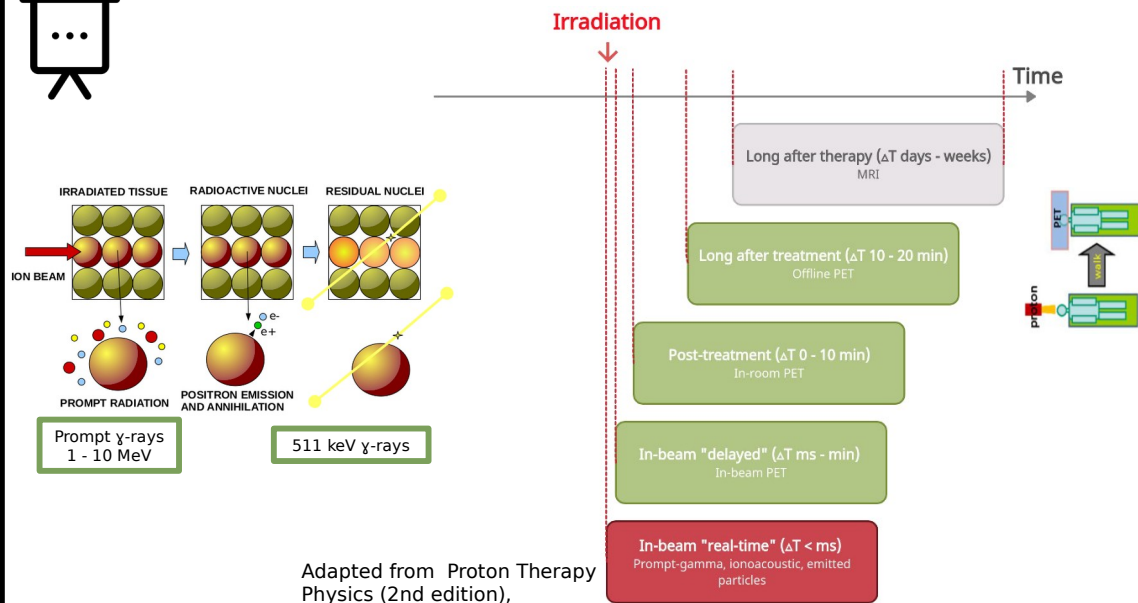
Adapted from Proton Therapy  
Physics (2nd edition),  
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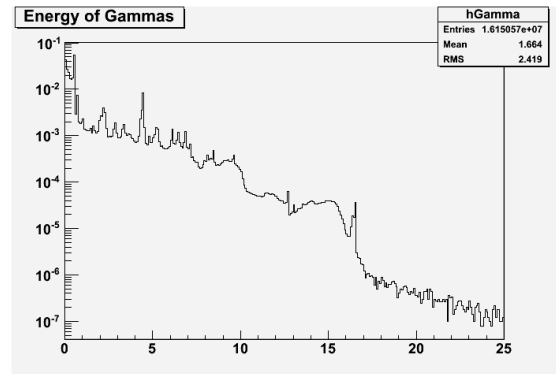
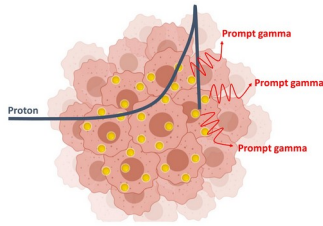


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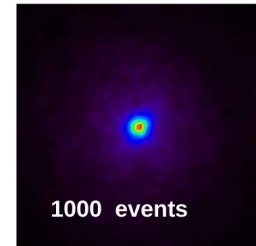
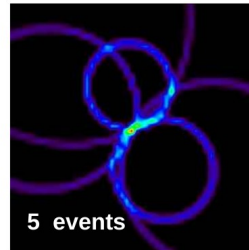
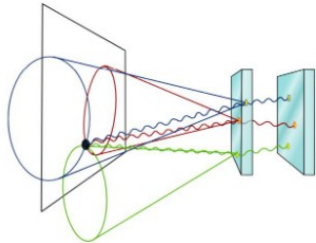
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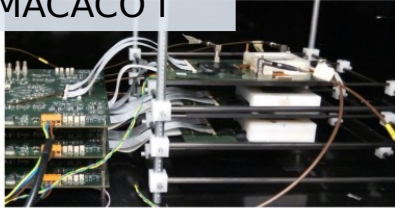
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L. Barrientos et al.  
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MACACO III



ER ~ 5.2 % @ 511 keV

SR ~ 1.2 mm FWHM

TR 20 ns FWHM



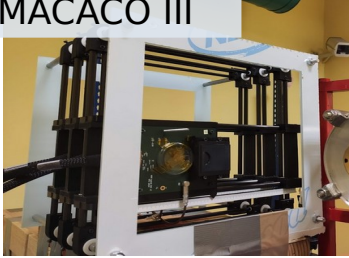
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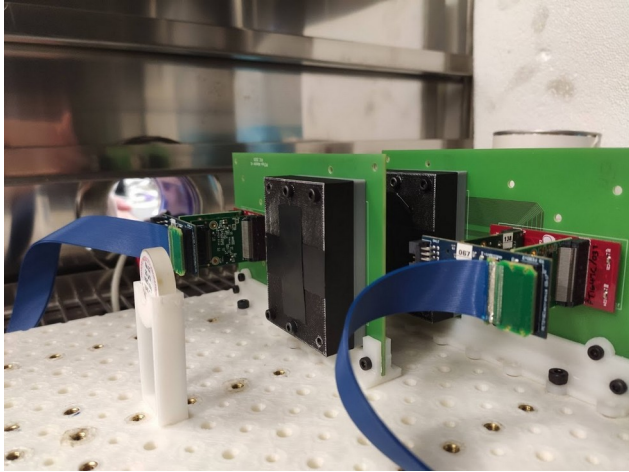
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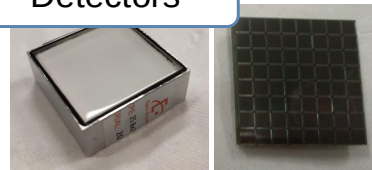
# MACACOP



TOFPET2 ASIC

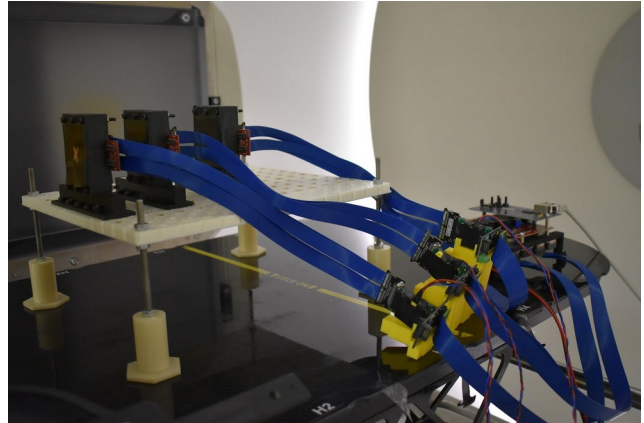
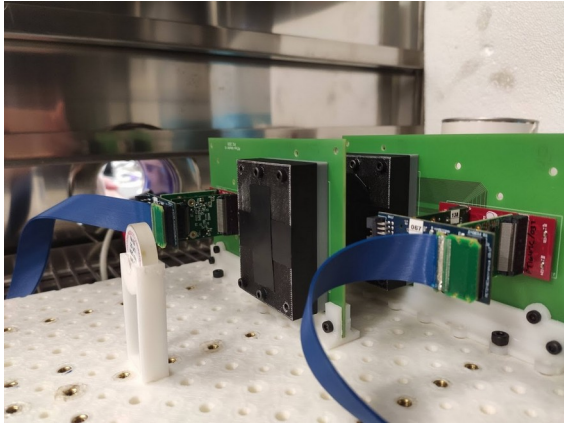


Detectors



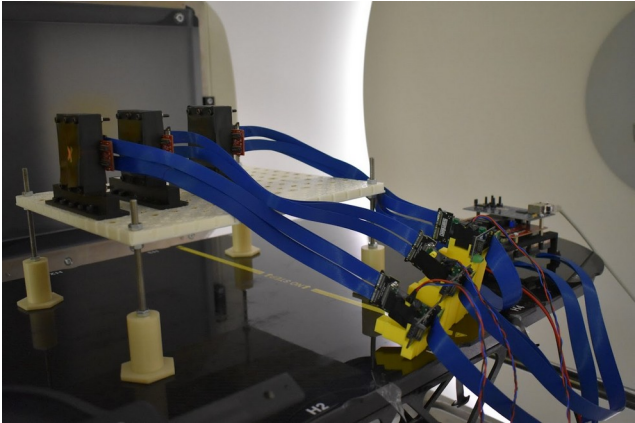
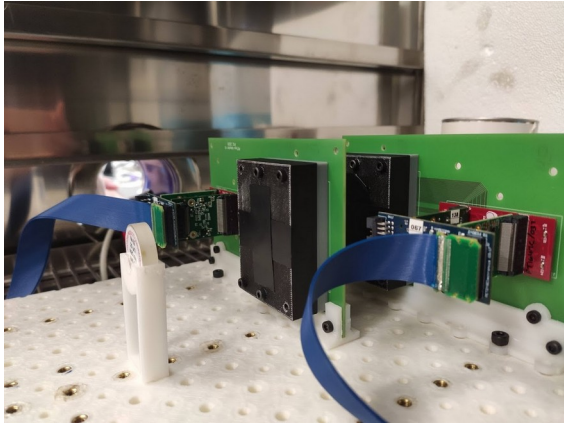


# MACACOp



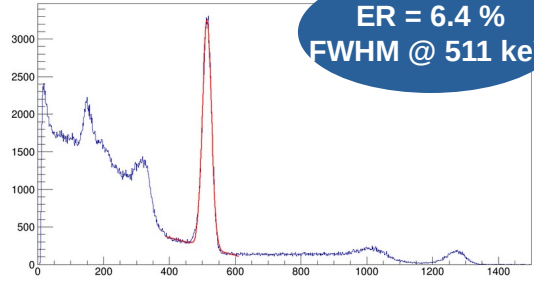
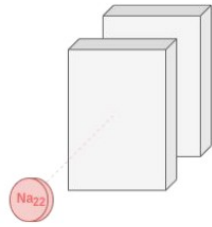
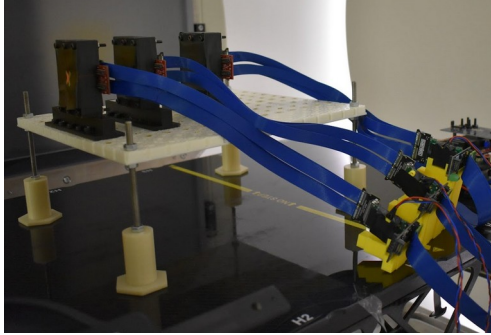


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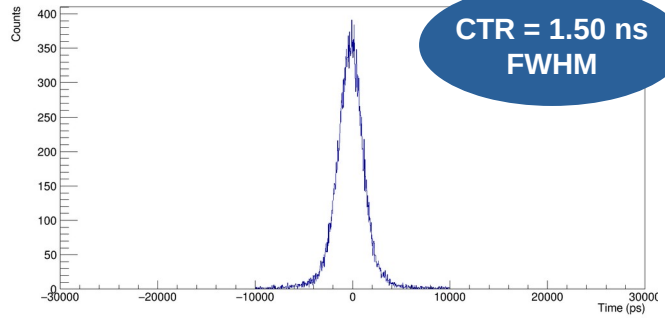
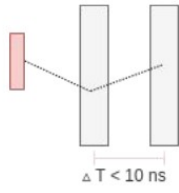
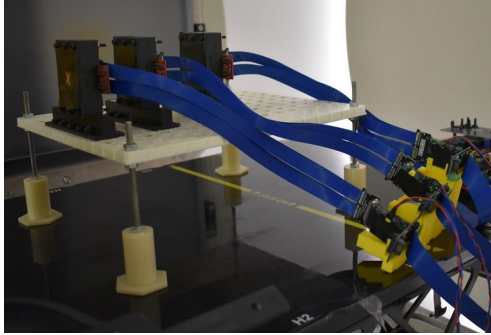


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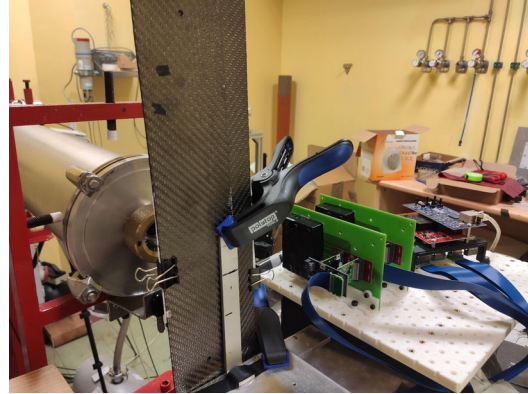
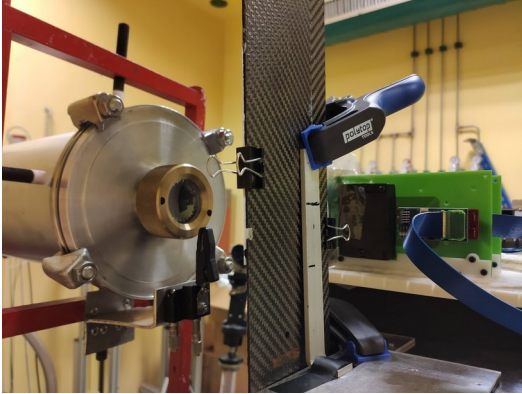


# MACACOP



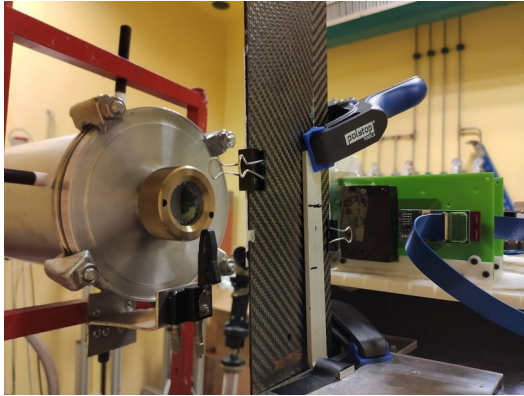


## Tests @ CNA (Sevilla)

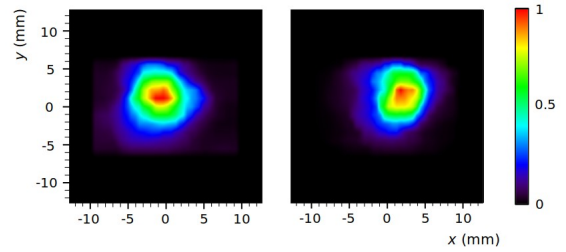
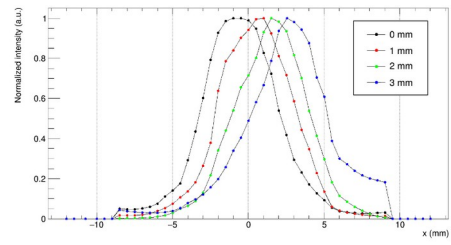


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In preparation



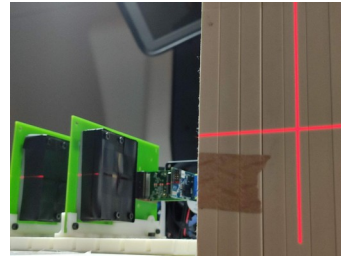
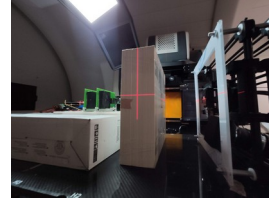


R. Viegas et al.  
Radiat. Phys. Chem (2022)  
Accepted for publication to



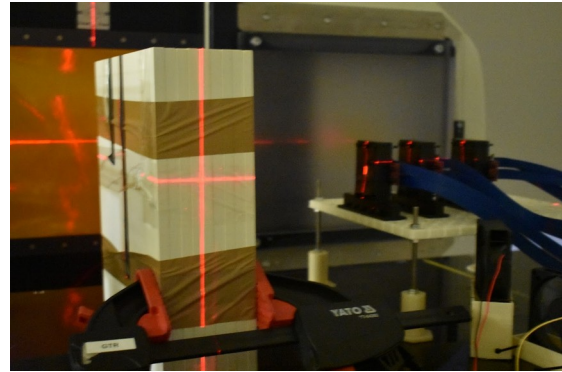
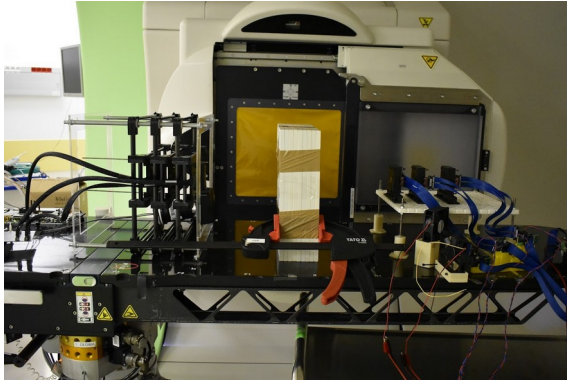


## Tests @ Quirón Salud (Madrid)





## Tests @ CCB - IFJ PAN (Krakow)



### **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. 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. Ozoemelum, 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,<sup>26</sup>

Phys. Med. Biol. 65 (2020) 145005.