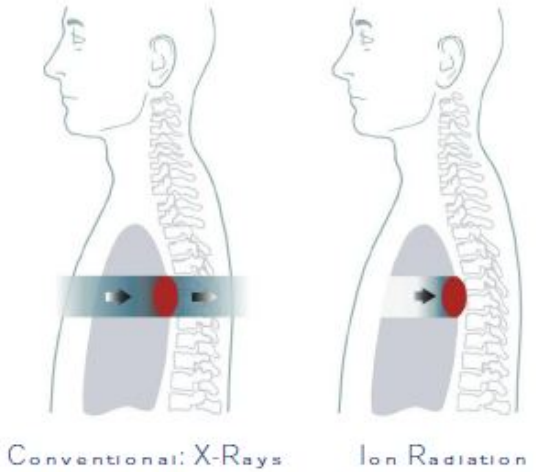
MACACO imaging system for hadron therapy treatment monitoring

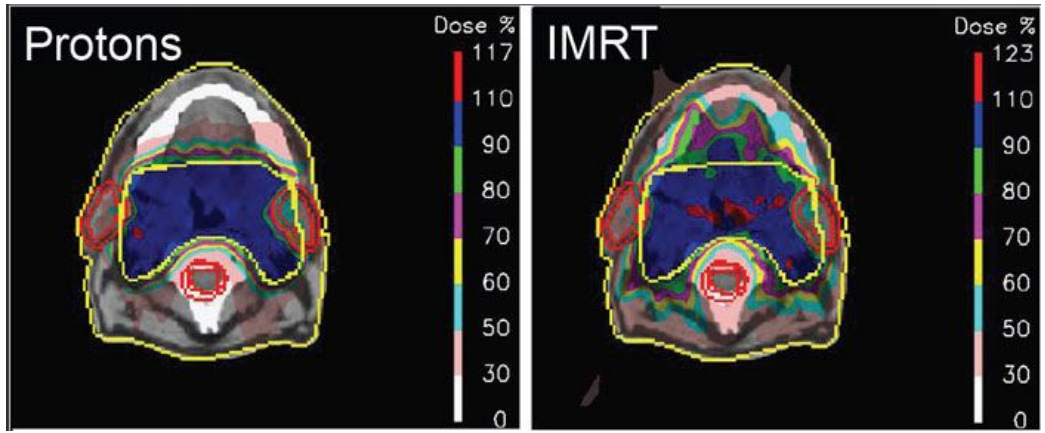
L. Barrientos, M. Borja-Lloret, J. V. Casaña, F. Hueso-González, J. Pérez Curbelo, A. Ros, J. Roser, C. Senra, R. Viegas and G. Llosá.

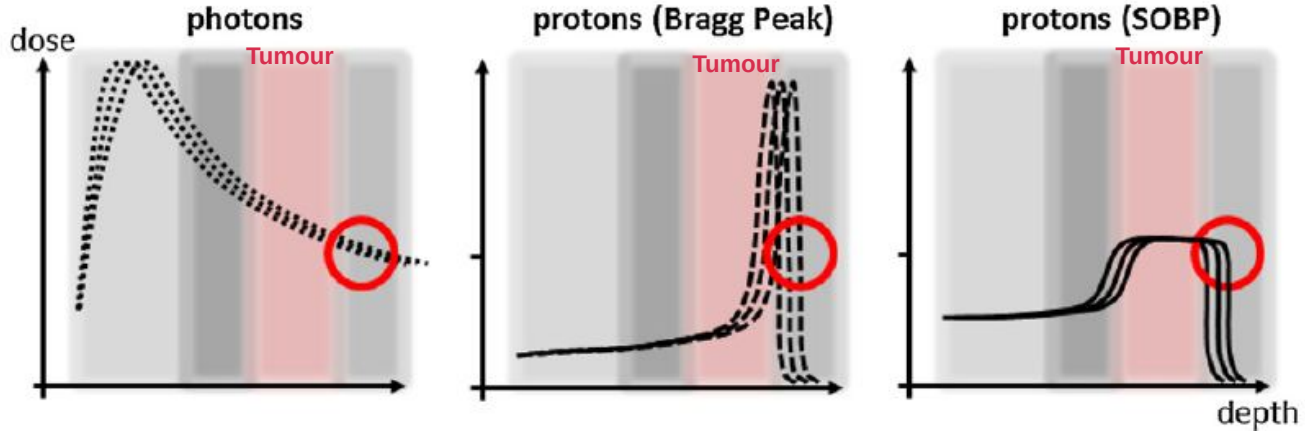
Instituto de Física Corpuscular IFIC (CSIC-UV)
http://ific.uv.es/iris

IGFAE workshop on technologies and applied research at the future Galician proton-therapy facility
9 -10 May 2023

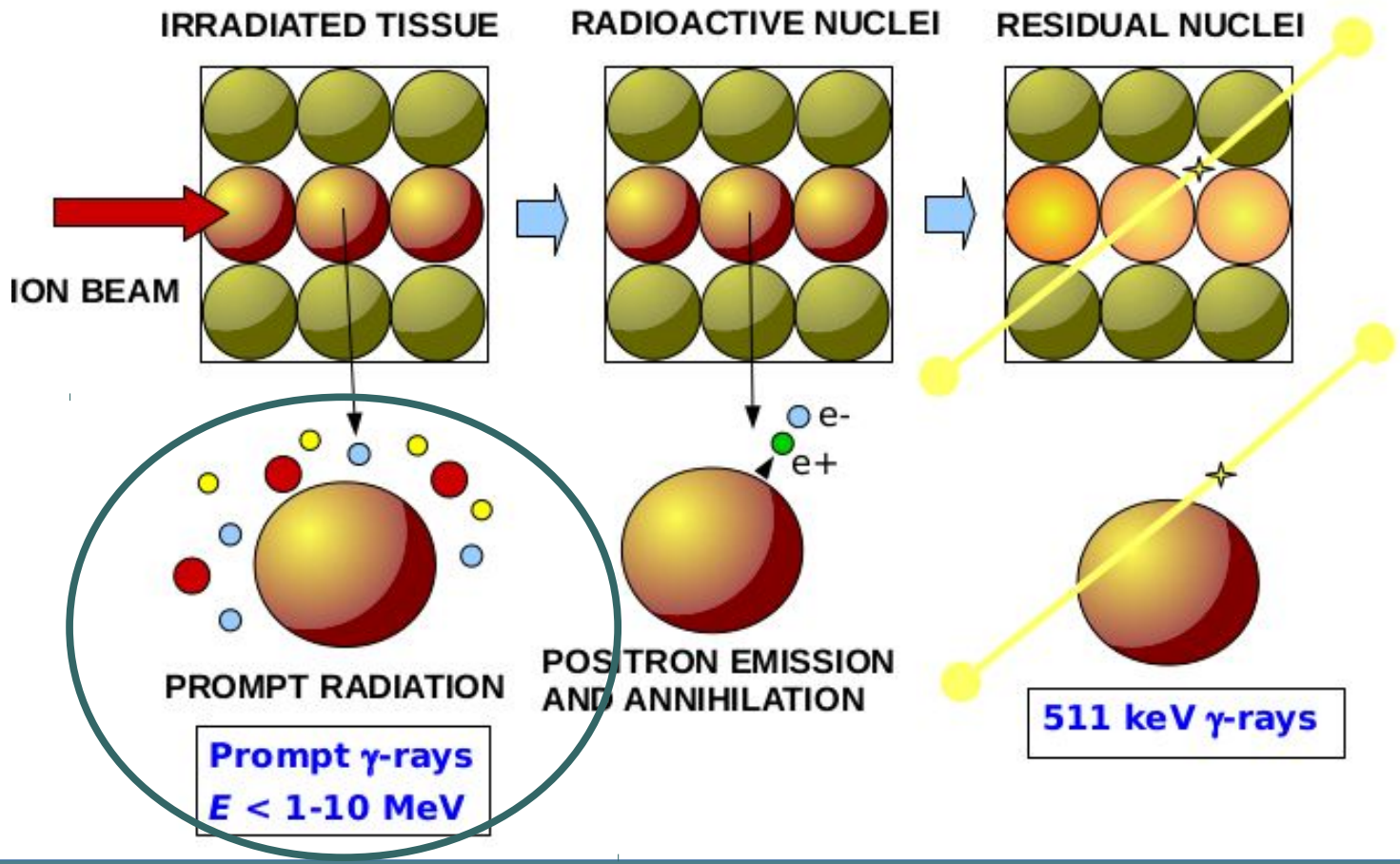
Hadron therapy treatment monitoring



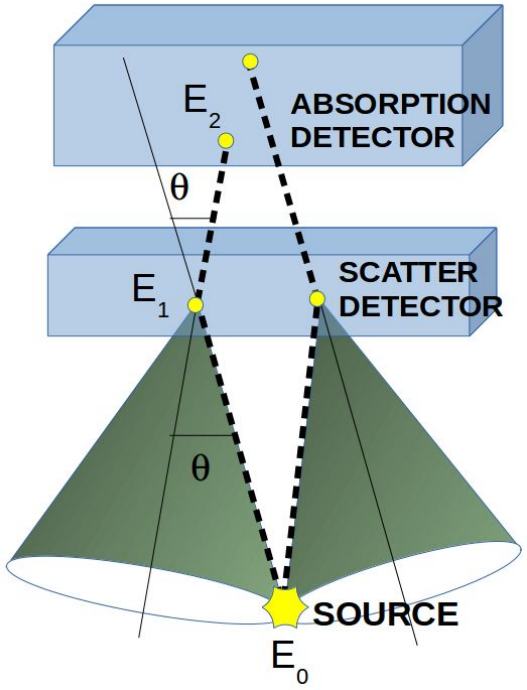




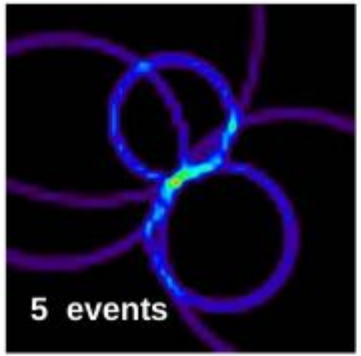
Hadron therapy treatment monitoring

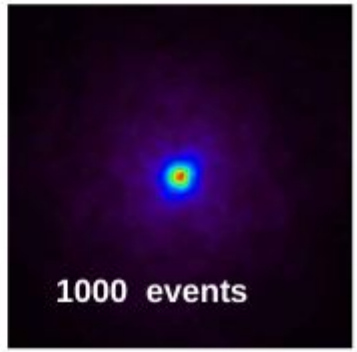


Compton camera



Backprojection





$$\cos\varphi = 1 - m_0 c^2 \left(\frac{1}{E_{\gamma'}} - \frac{1}{E_\gamma} \right)$$

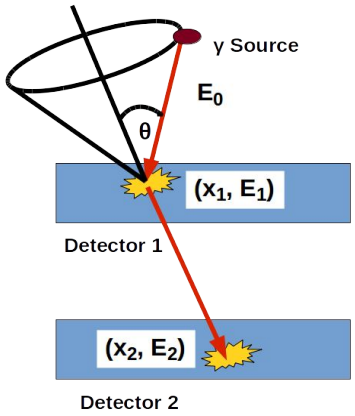
$$E_\gamma = E_{e^-} + E_{\gamma'}$$

+ 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

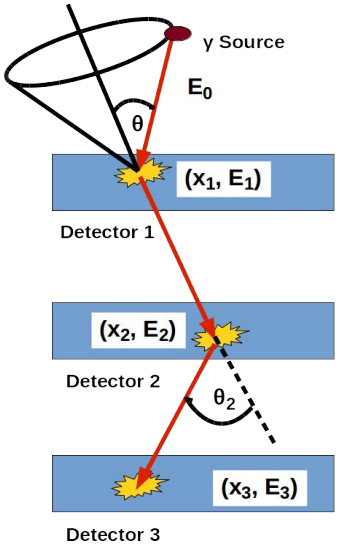
Compton camera configurations



Scatterer + "absorber"
2 interactions

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

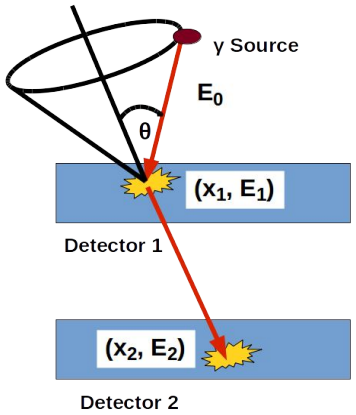
Multilayer
3 int. in 3 detectors



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

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

Compton camera configurations



Scatterer + "absorber"
2 interactions

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

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

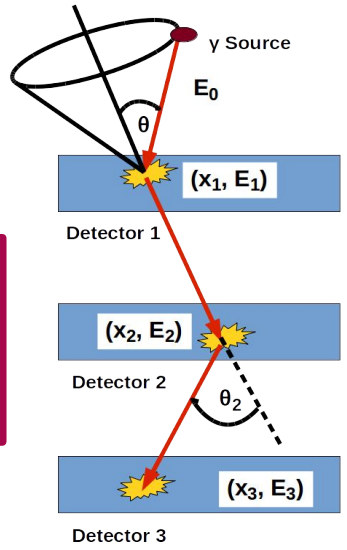
Multilayer
3 int. in 3 detectors

Energy determined

Lower efficiency

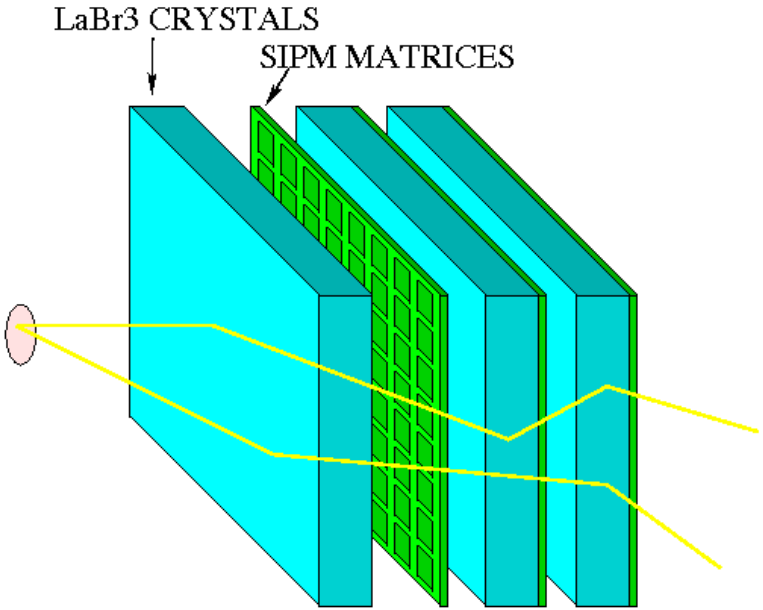
$$cos(\theta) = 1 - \frac{E_1 m_e c^2}{E_0(E_0 - E_1)}$$

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



MACACO

Medical Applications CompAct COmpton camera

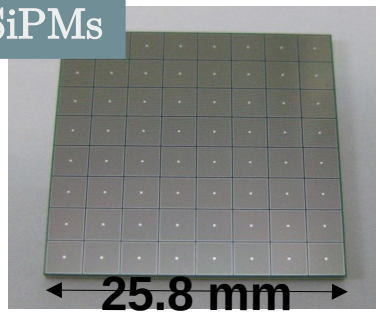


Fast response
3 planes + no absorption required

MACACO III

Detectors

$LaBr_3$

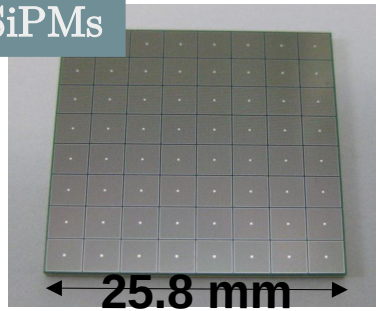


MACACO III

Detectors

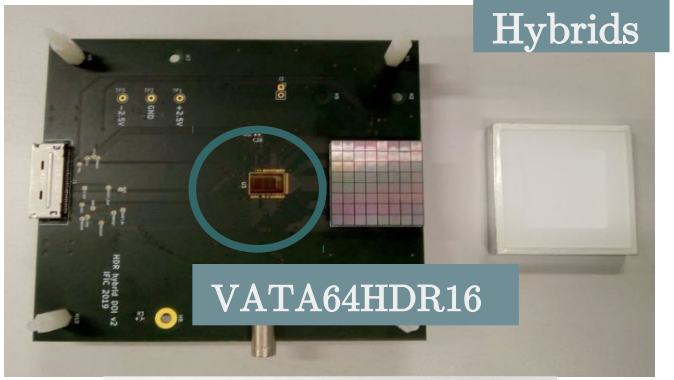
$LaBr_3$

SiPMs

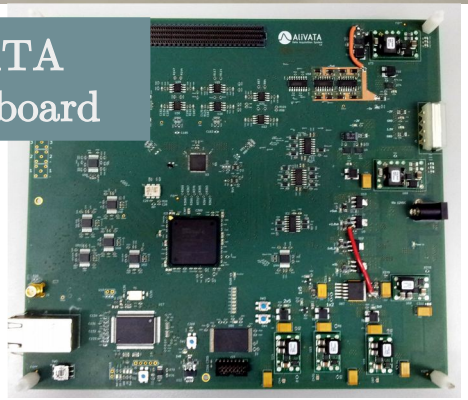


Readout

Hybrids



AliVATA DAQ board



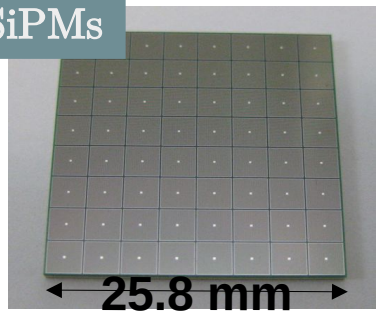
Commercialized by Alibava Systems S. L.

MACACO III

Detectors

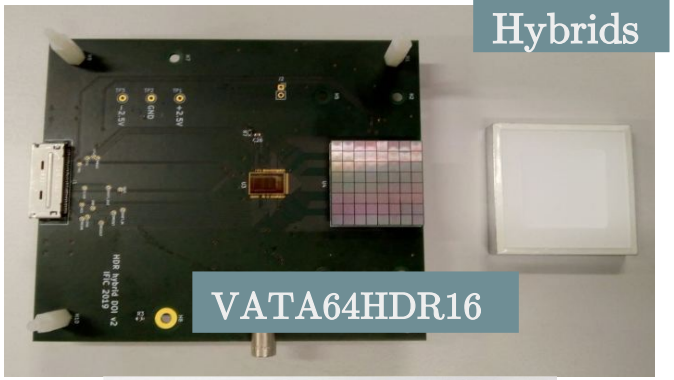
$LaBr_3$

SiPMs

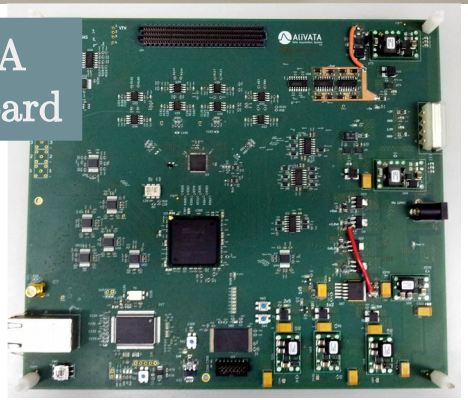


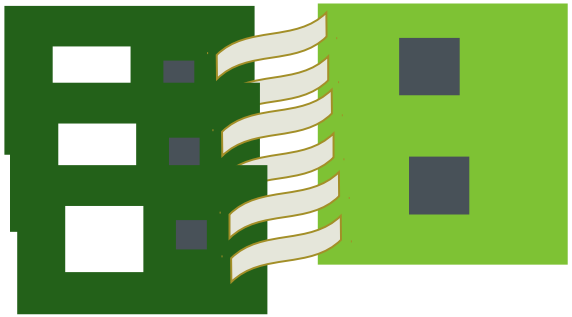
Readout

Hybrids



AliVATA
DAQ board





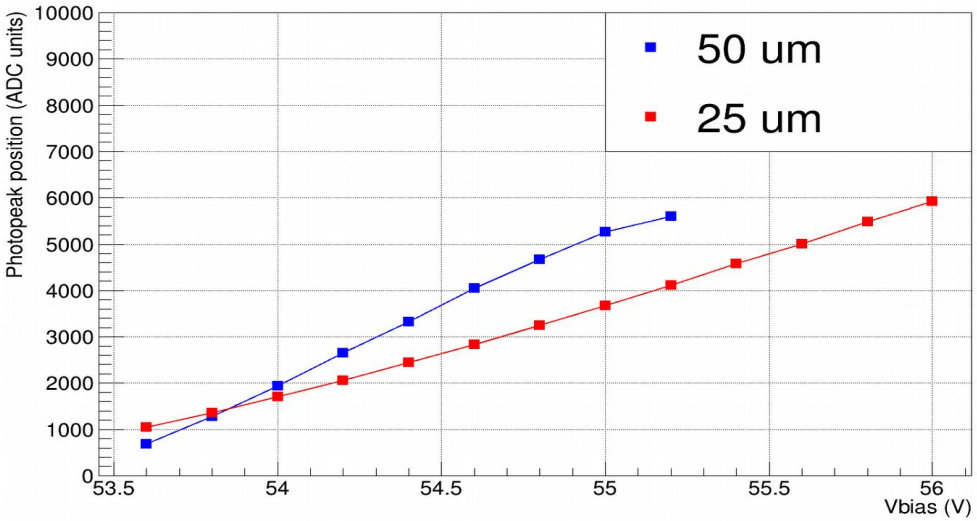
MACACO III

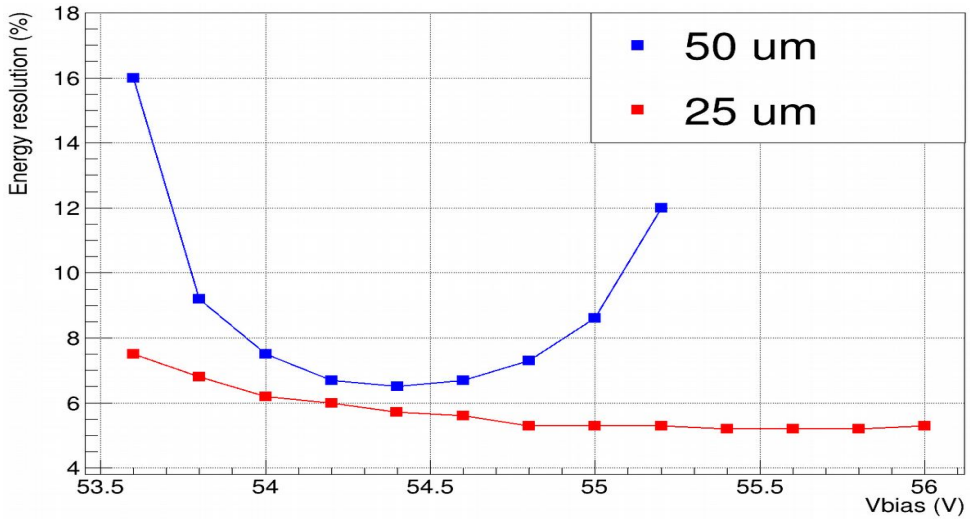
Photodectector selection

S13360-3025CS (25 µm)

vs

S13361-3050AE-08 (50 µm)





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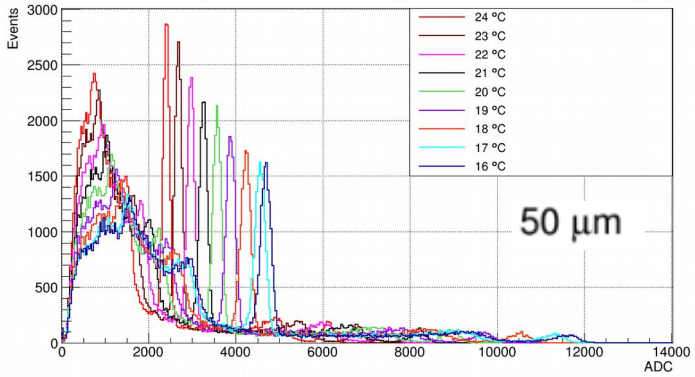
Photodectector selection



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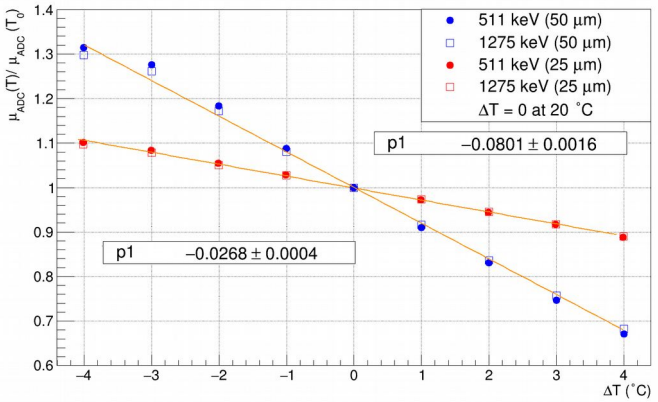
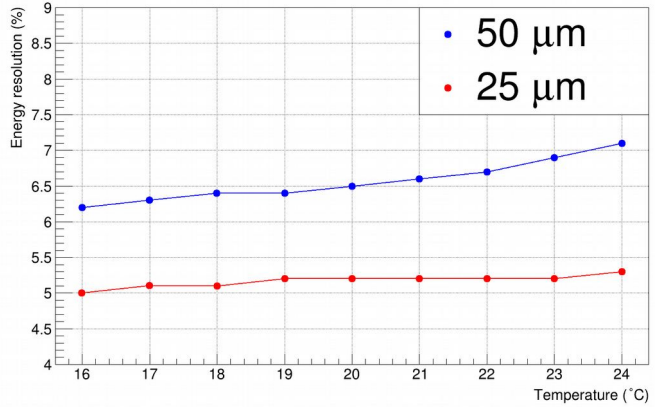
S13360-3025CS (25 µm)

vs

S13361-3050AE-08 (50 µm)





MACACO III

Photodectector selection

S13360-3025CS (25 µm)

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S13361-3050AE-08 (50 µm)

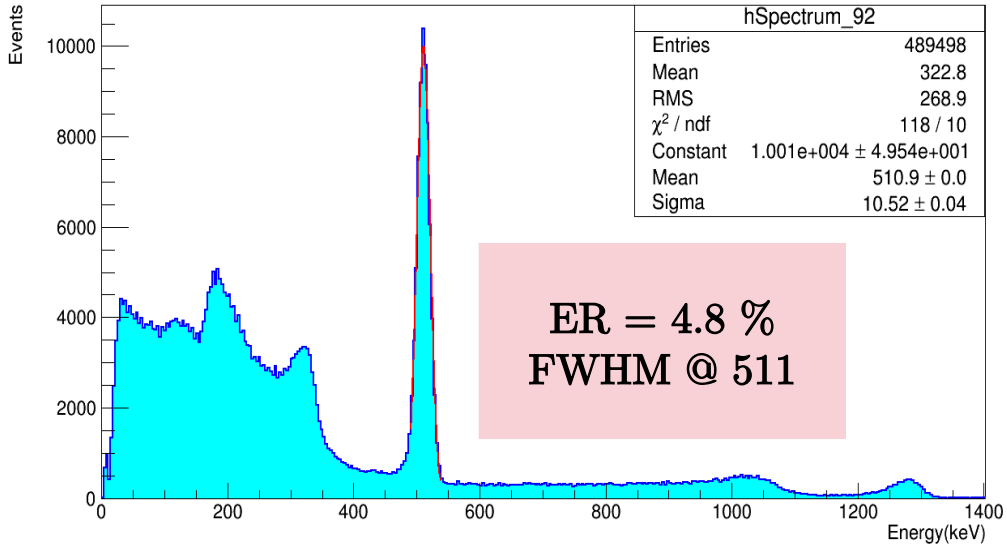

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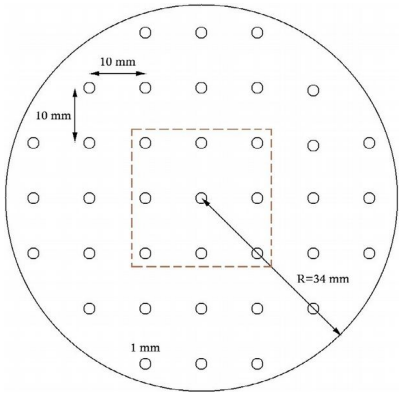
Image reconstruction

Sensitivity model for 2- and 3- interacion events



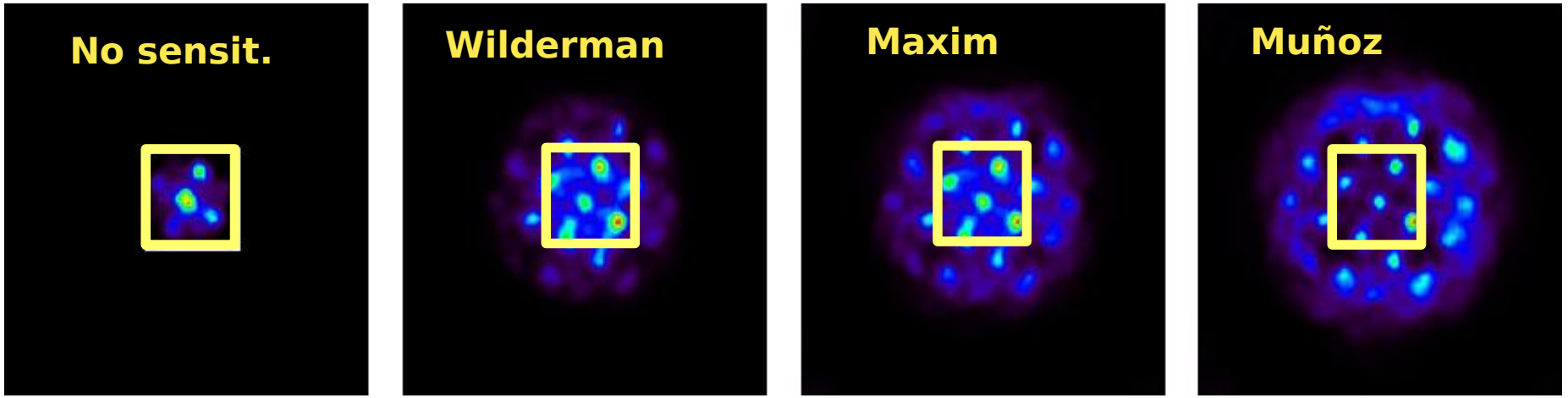


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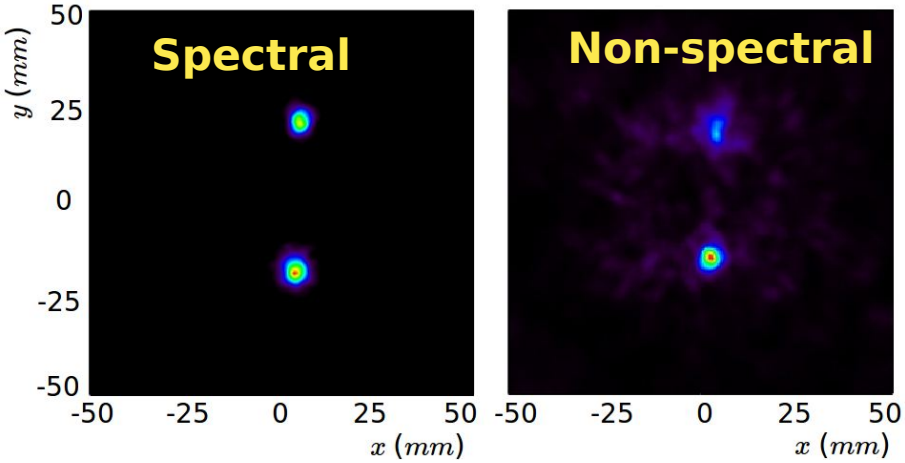
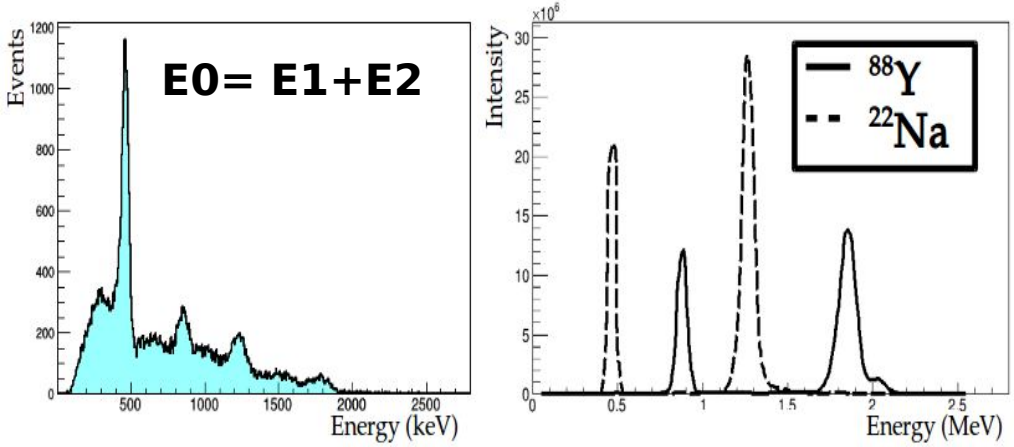
Image reconstruction

Spectral code: position and energy distributions

Simultaneous reconstruction of Y-88 + Na-22





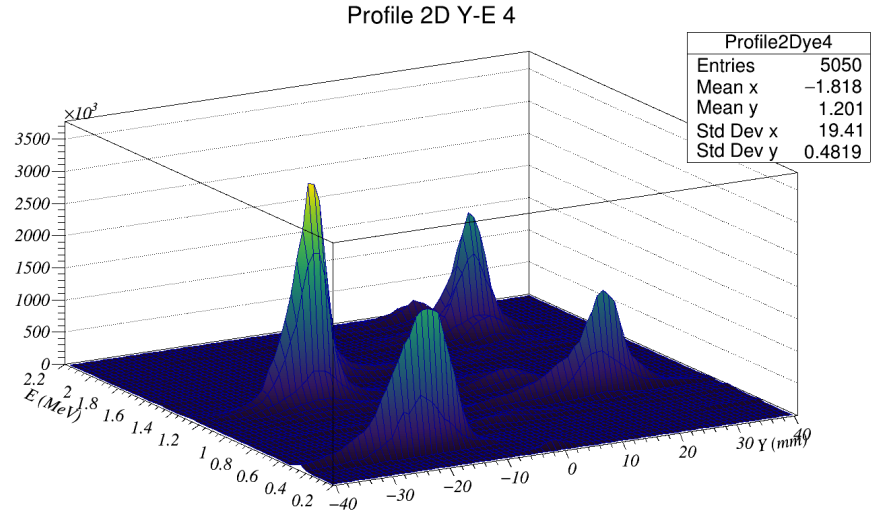


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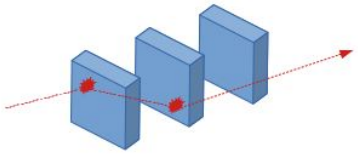
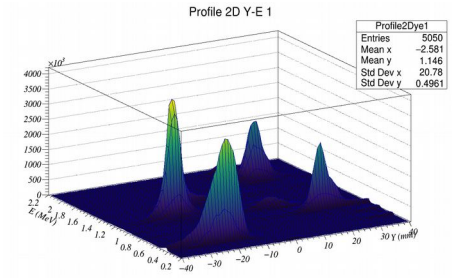
Image reconstruction

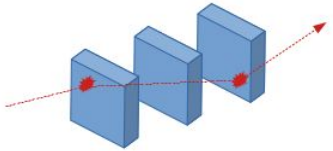
Joint reconstruction of 2- and 3-interaction events

Y-88 + Na-22

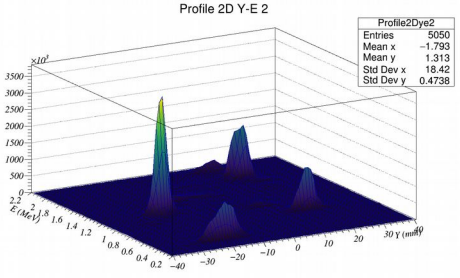


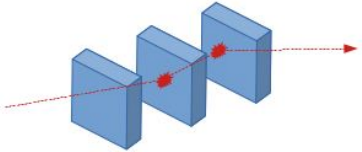
12-channel event



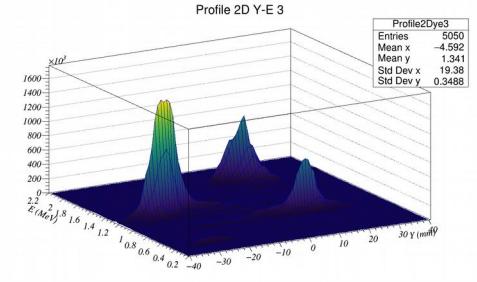


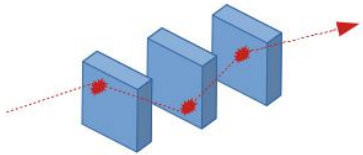
13-channel event



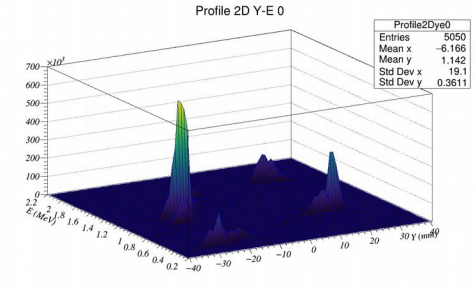


23-channel event

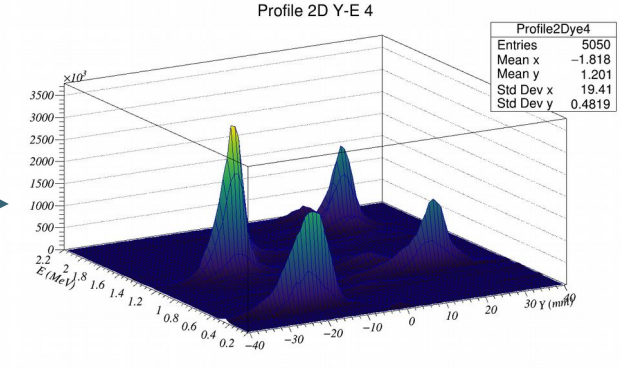




123-channel event



Joint Reconstruction



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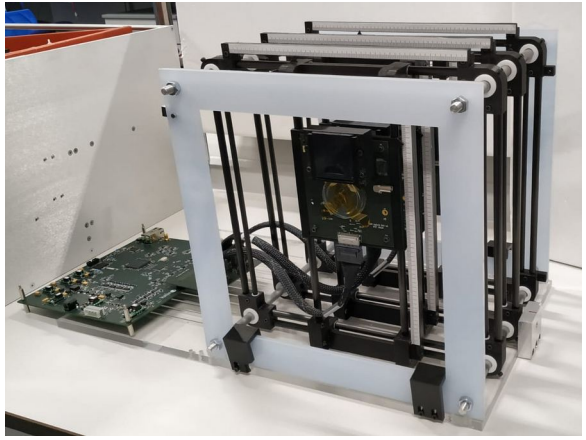
Experimental Setup



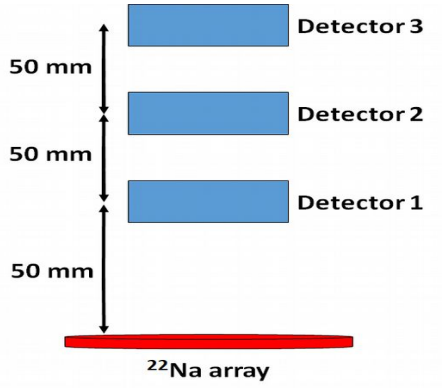
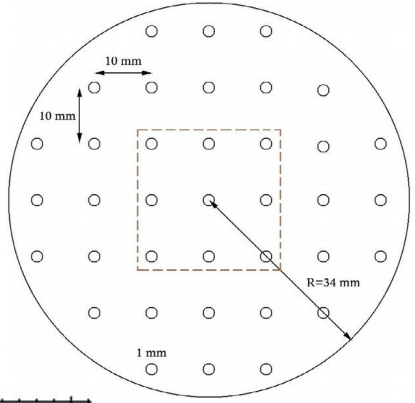


Image reconstruction



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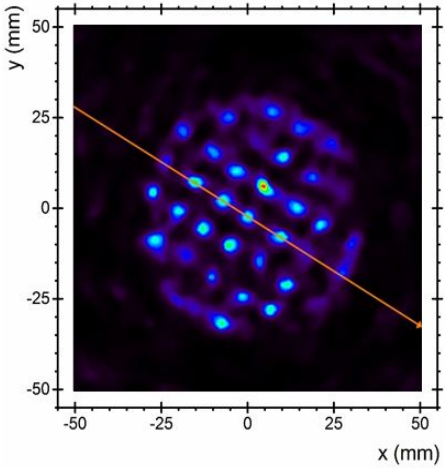
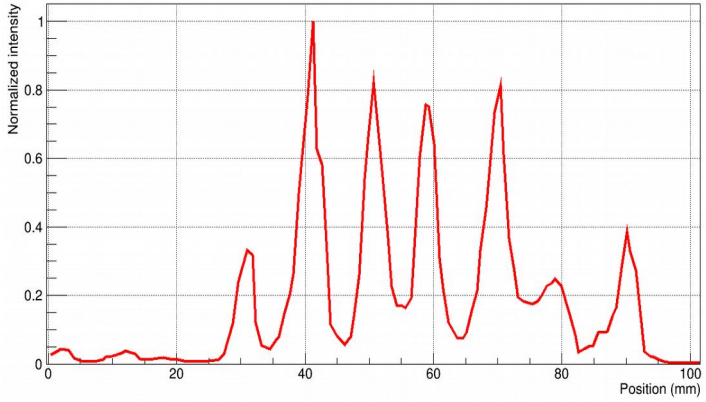
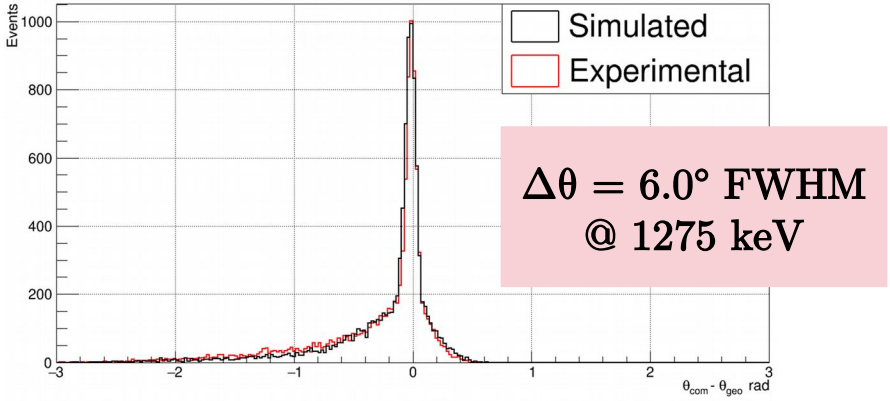


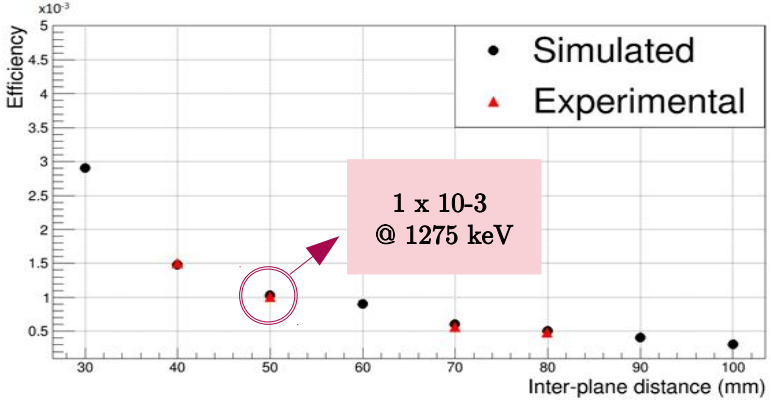


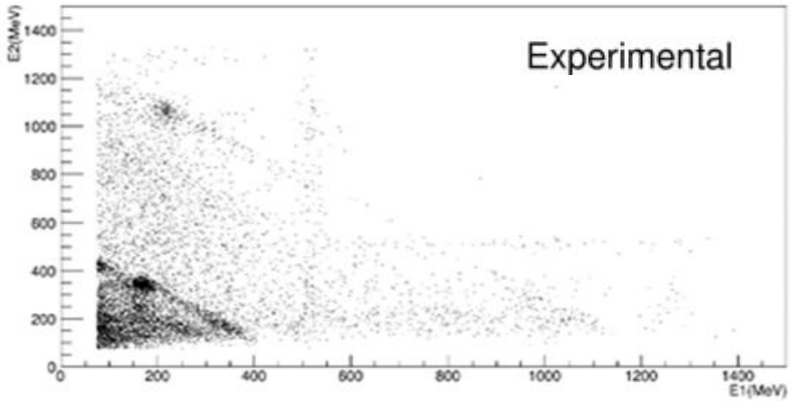
MACACO III

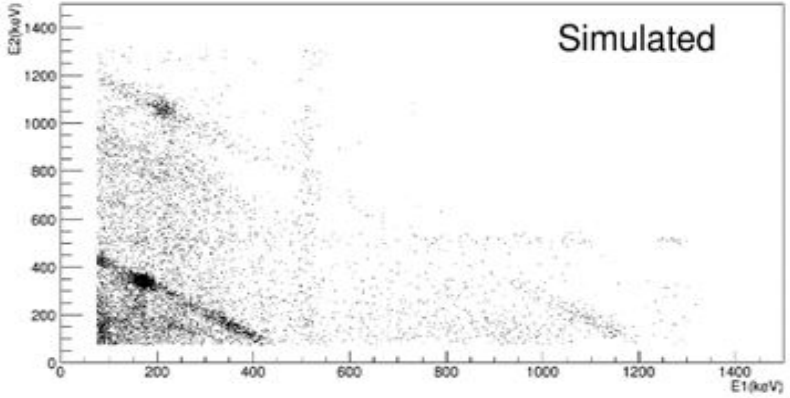
System characterization



$\Delta\theta = 6.0°$ FWHM
@ 1275 keV



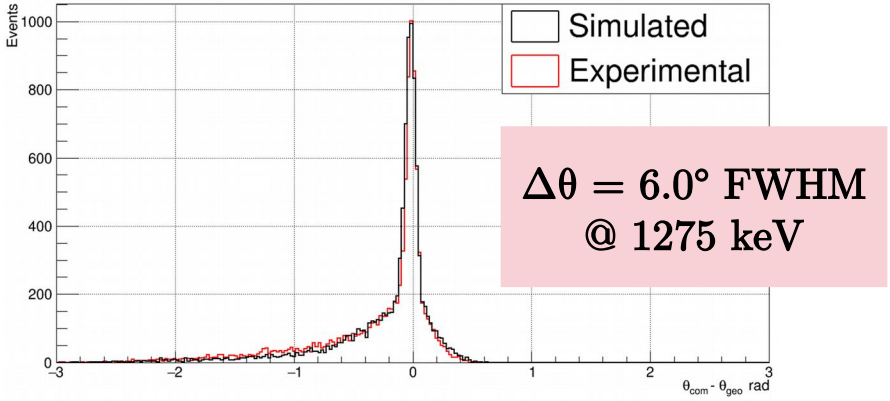




MACACO III

System characterization

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



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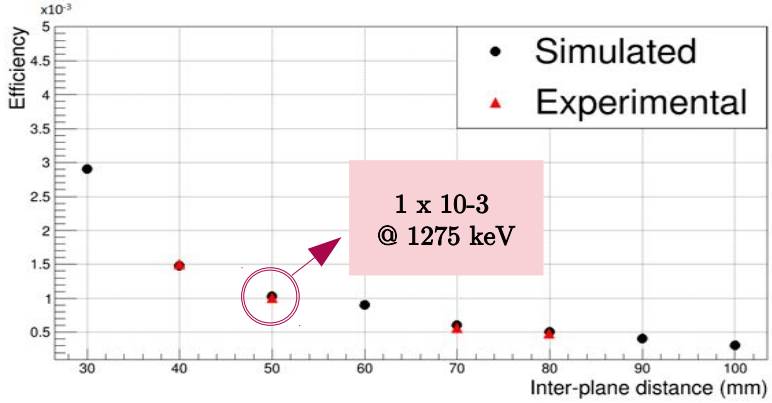
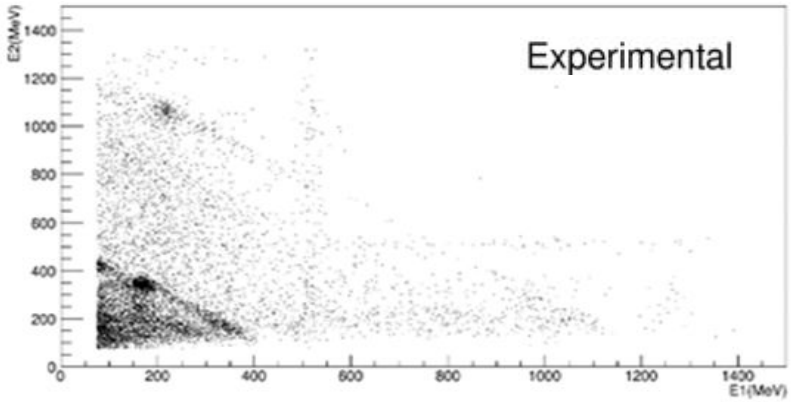
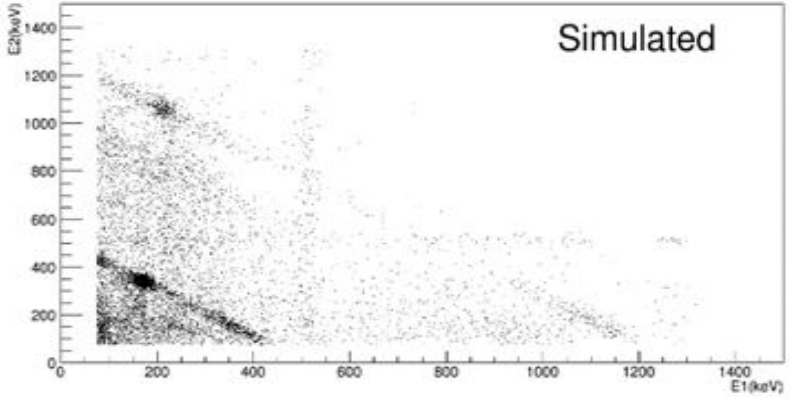
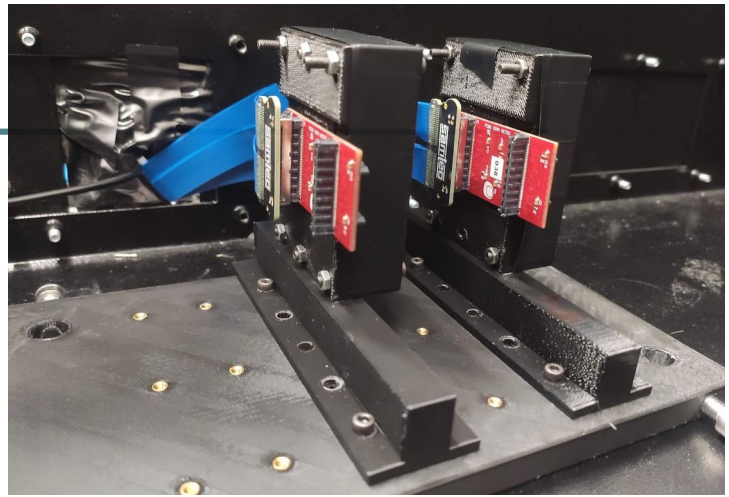


1 x 10-3
@ 1275 keV

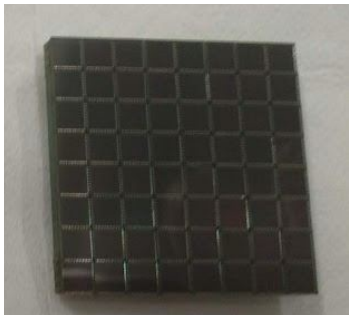






Experimental setup

monolithic **$LaBr_3$:Ce**



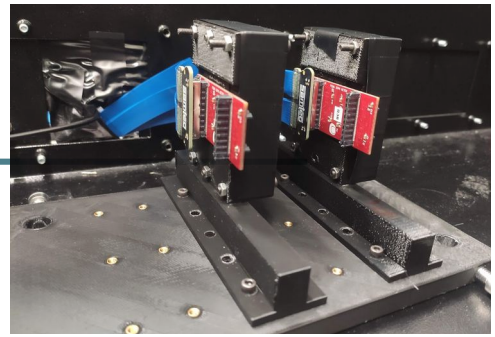
8 x 8 SiPM array

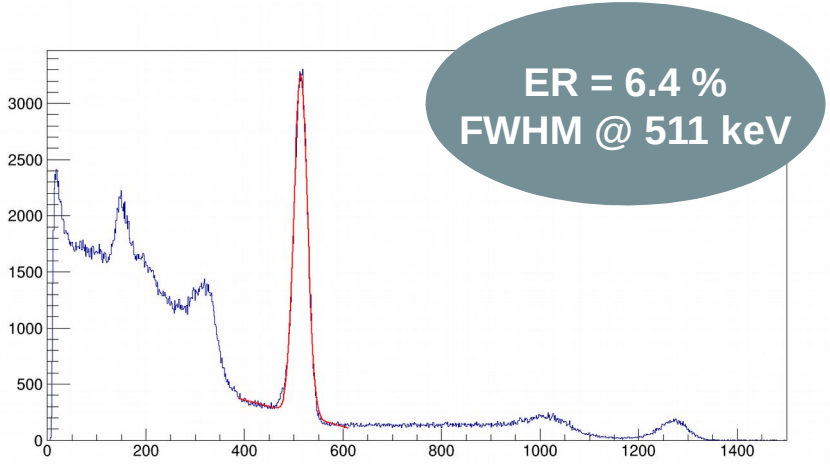
PA3325-WB-0808

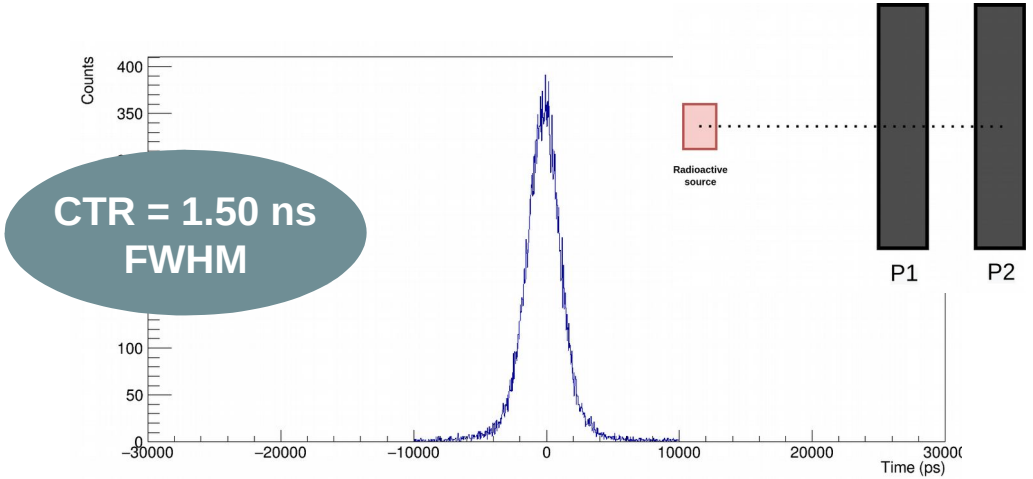
TOFPET2 ASIC

- Q 30 ps binning
- Q Broad dynamic range (up to 1500 pC)

Results







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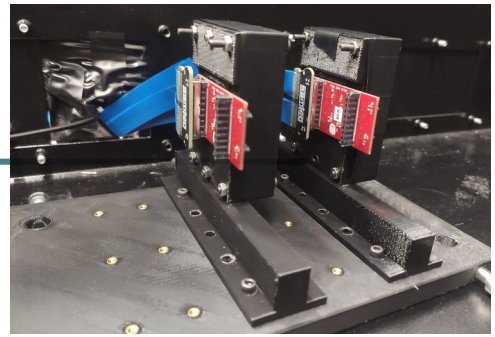
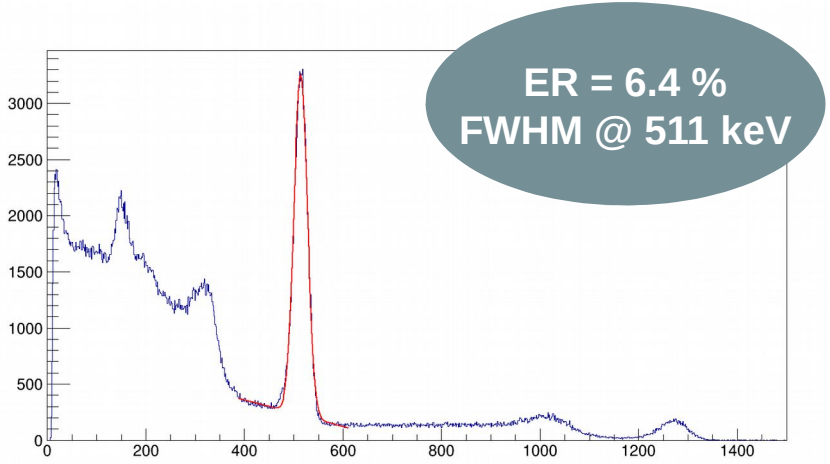
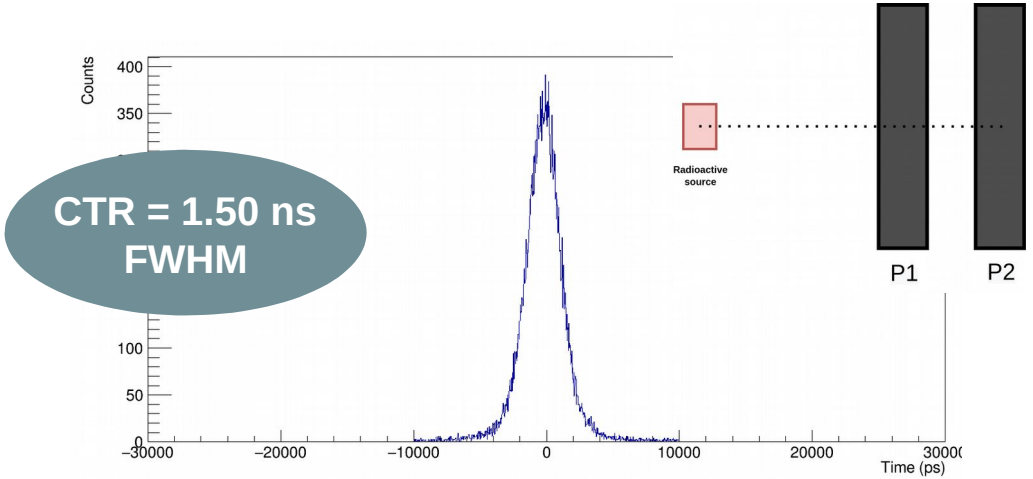
Alternative CC

Results







Better time resolution, readout speed and dynamic range

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In-beam experiments

Tests with previous prototypes

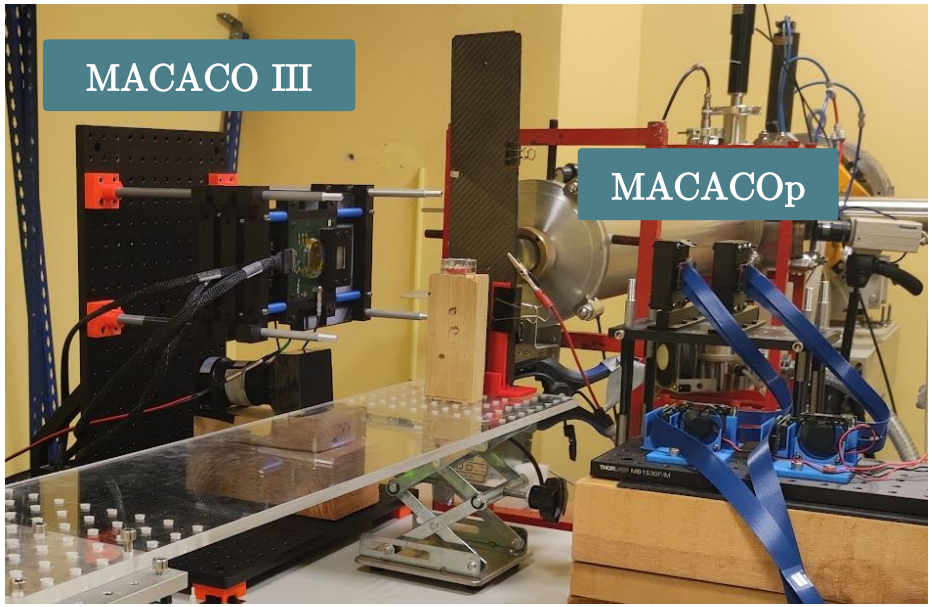
Center	Radiation	Publication
CNA, Sevilla	18 MeV Protons → photons	A. Ros et al. Phys. Med. Biol. 2020
KVI-CART, Groningen	150 MeV protons	P. Solevi et al, Phys. Med. Biol. 2016 E. Muñoz et al. Sci Rep 2021.
HZDR Dresden	4.4 MeV photons	E. Muñoz et al. JINST 2018

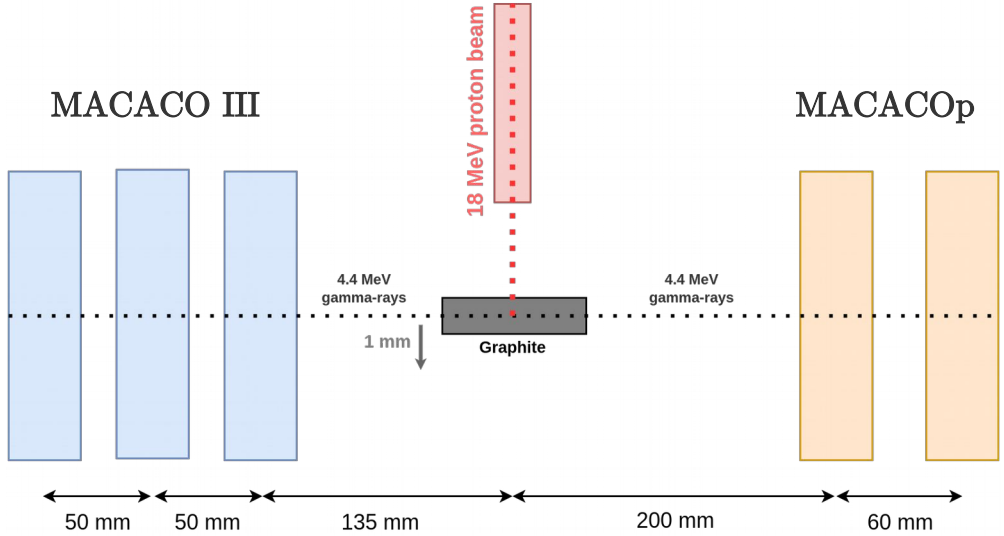
In-beam experiments

Tests at CNA and proton therapy centres

Center	Accelerator	Target	Energy (MeV)
CNA	Cyclotron	Graphite	18
CCB	Cyclotron (Proteus C-235)	RW3	88.38 – 91.62
QuirónSalud	Synchrocyclotron (S2C2)	RW3	70-90
MedAustron	Synchrotron-based particle accelerator	ARDOS	99.6

In-beam experiments CNA (Sevilla, Spain)

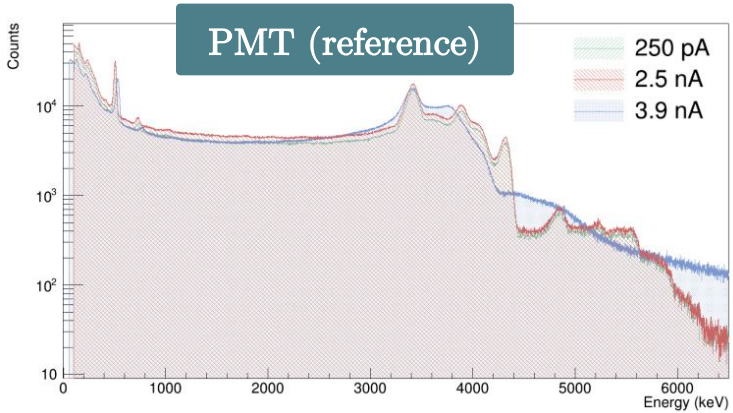


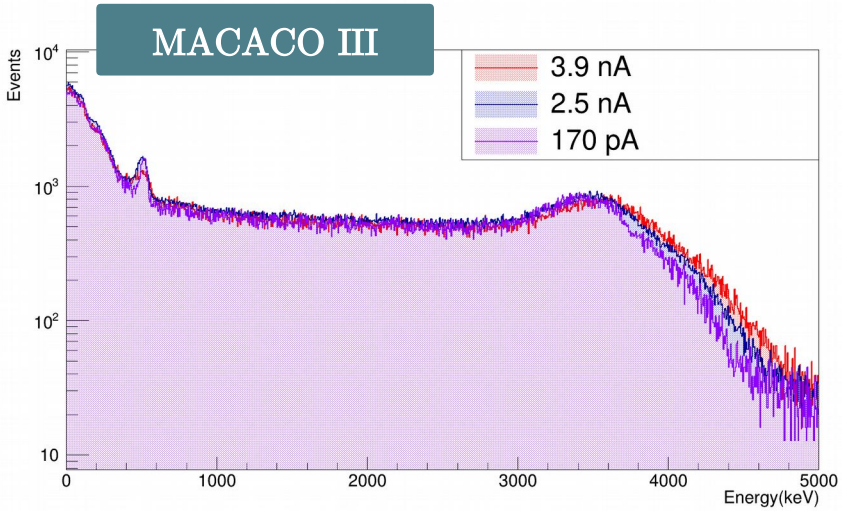


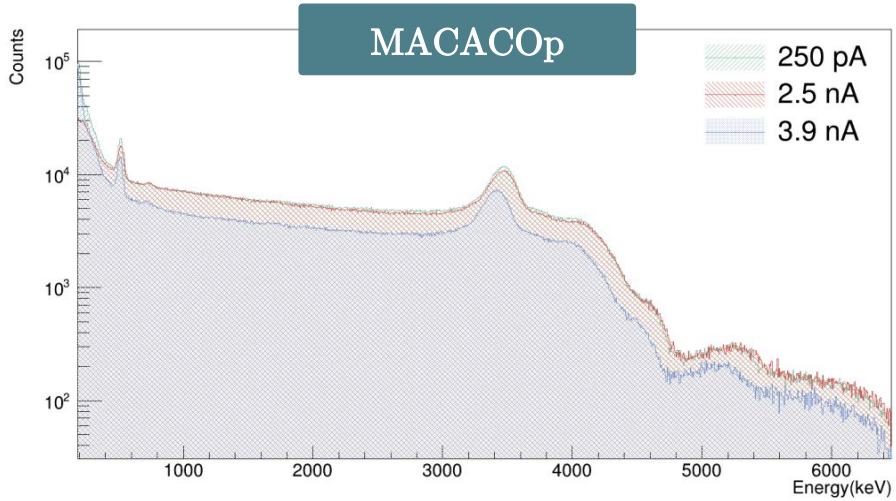
PMT + LaBr3

$51.2 \times 51.2 \times 10 \times \text{mm}^3$

In-beam experiments CNA (Sevilla, Spain)



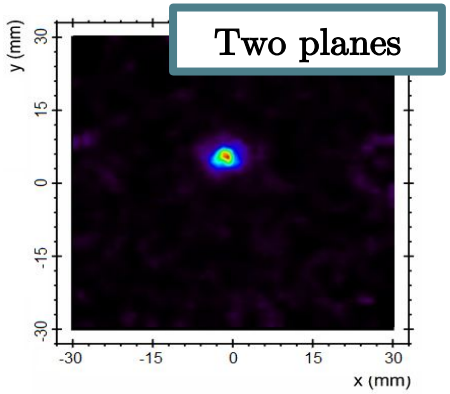


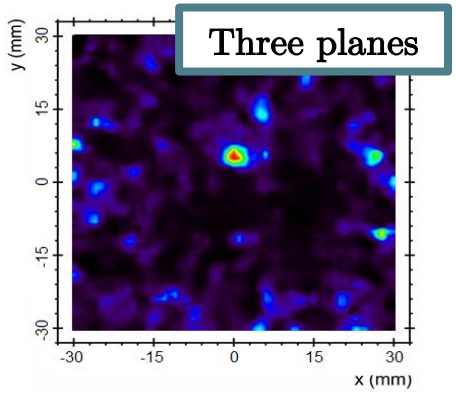


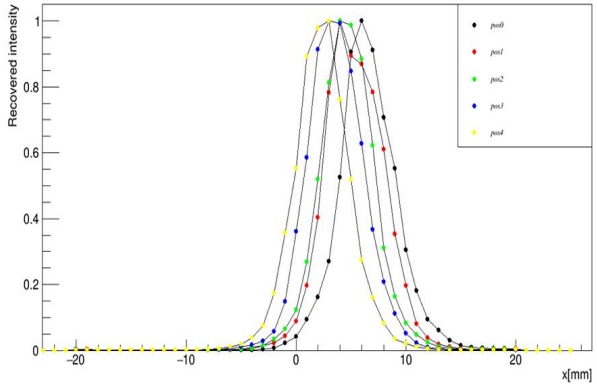
In-beam experiments CNA (Sevilla, Spain)

18 MeV
I = 2.5 nA

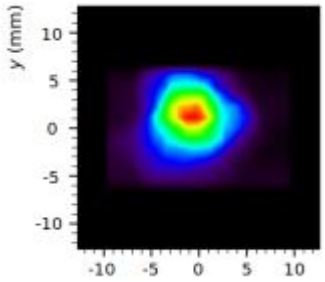
MACACO III



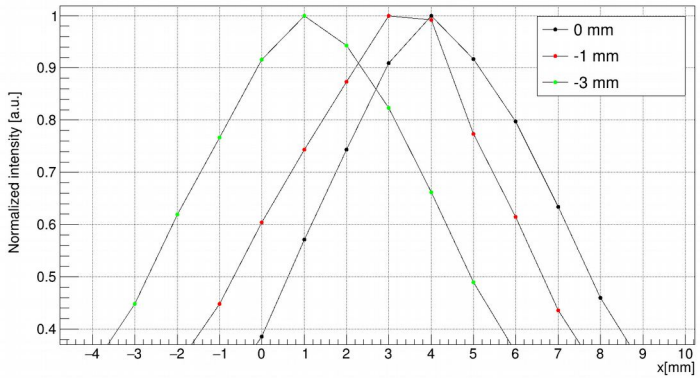




MACACOp



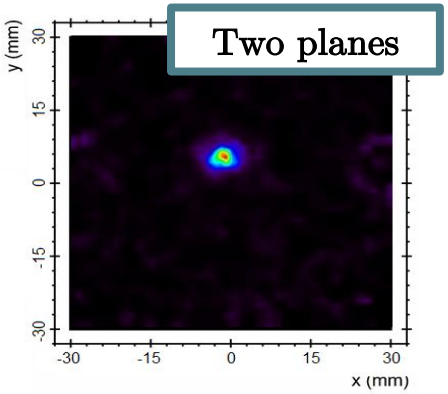
Target Separation (± 0.7 mm)		
Expected	**Max**	**R80 after Max**
1 mm	1	1.1
2 mm	2	1.7
3 mm	3	2.8

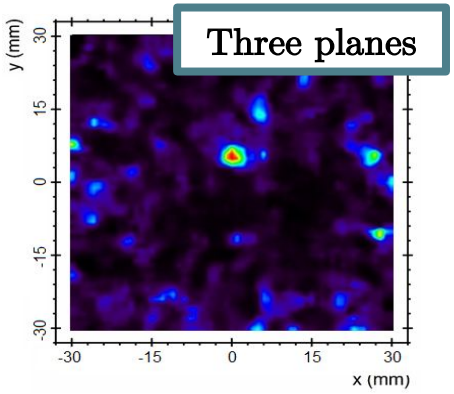


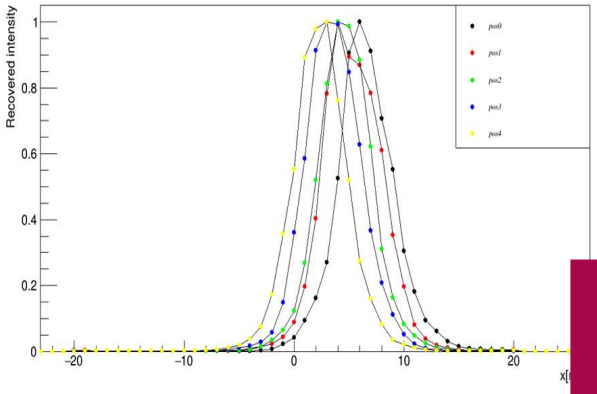
In-beam experiments CNA (Sevilla, Spain)

18 MeV
I = 2.5 nA

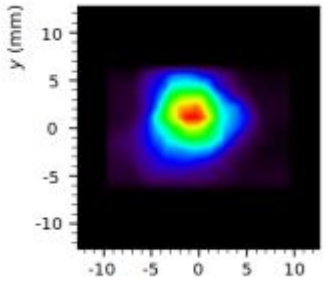
MACACO III







MACACOp



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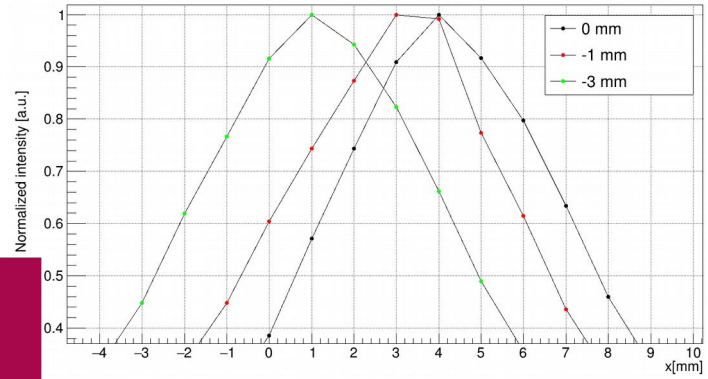
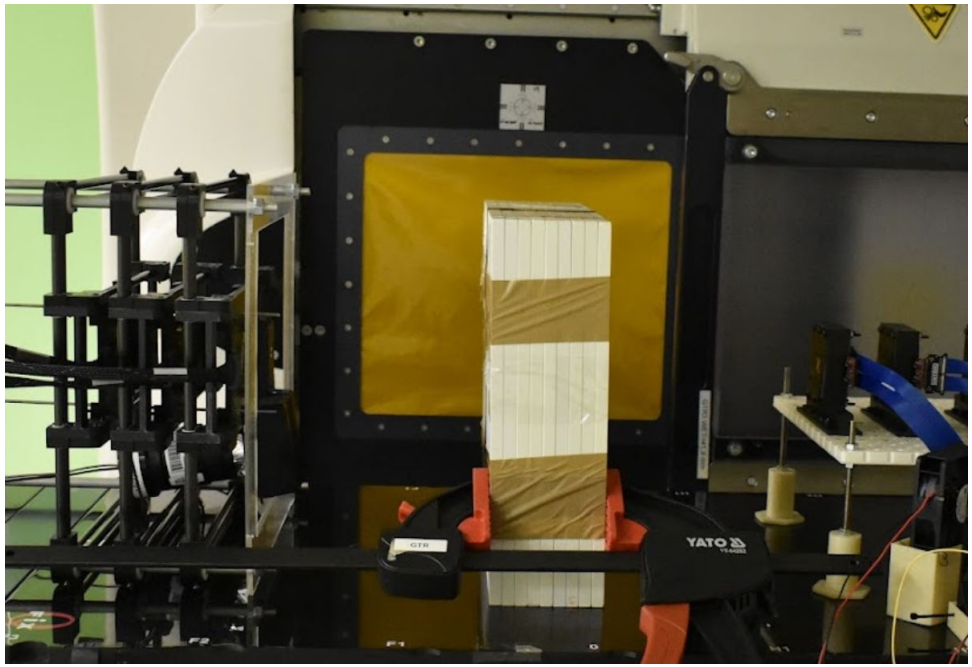
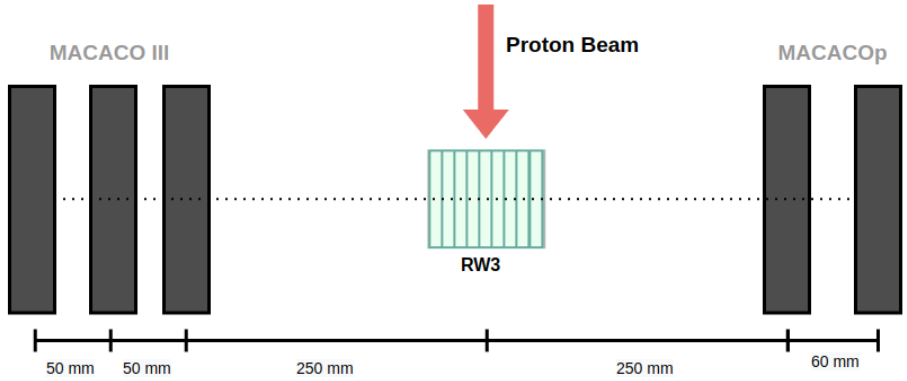
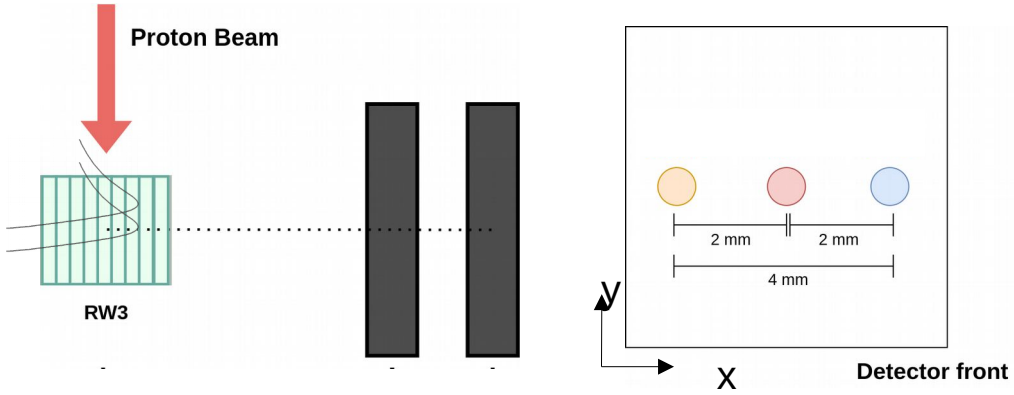


1 mm steps detected with both systems

In-beam experiments CCB (Krakow, Poland)



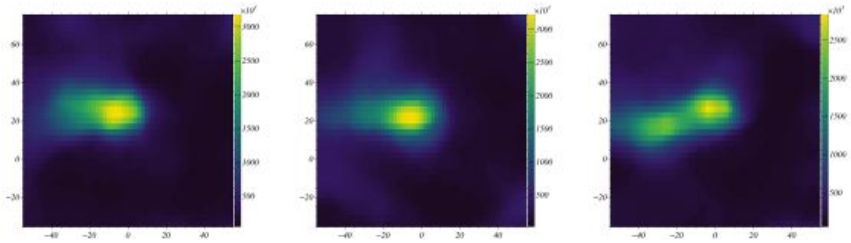




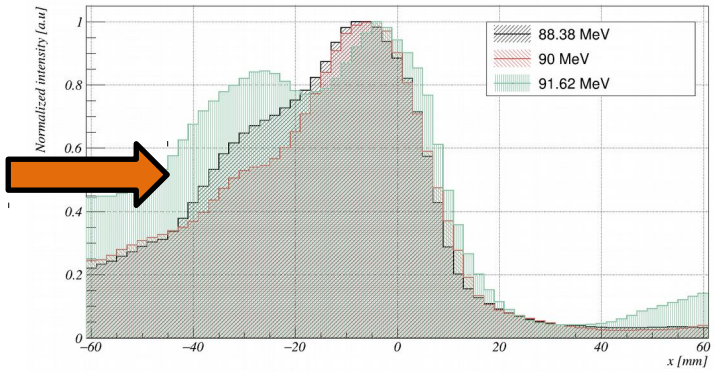
In-beam experiments CCB (Krakow, Poland)

90 MeV
I = 90 pA

MACACO III



88.38 MeV 90 MeV 91.62 MeV



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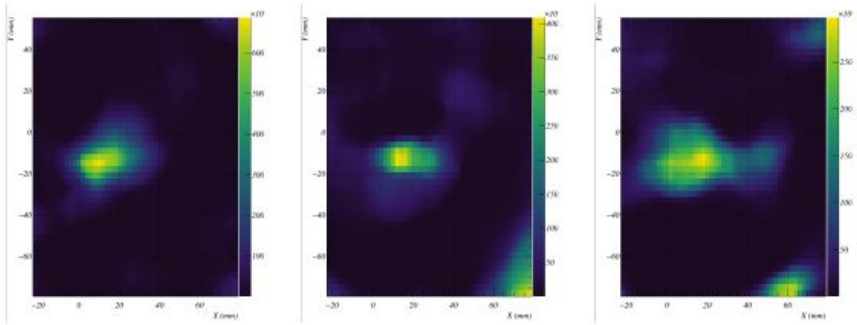
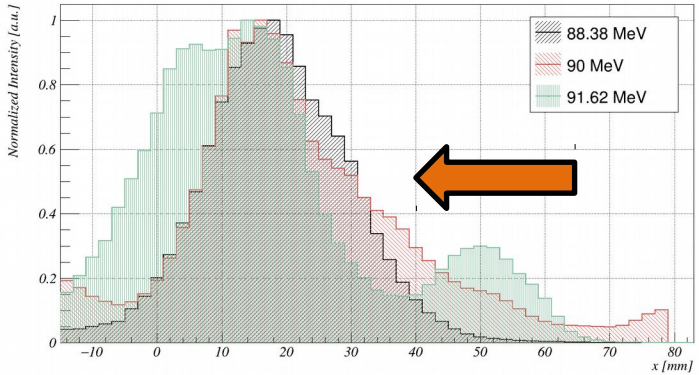


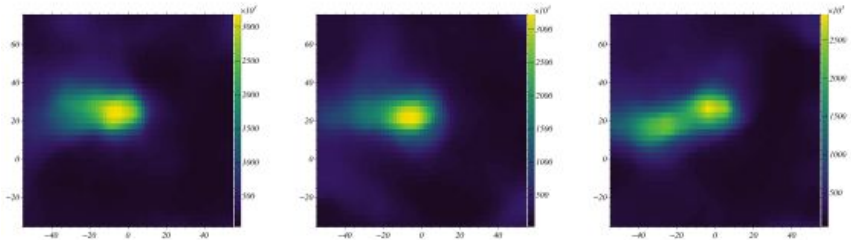
88.38 MeV 90 MeV 91.62 MeV



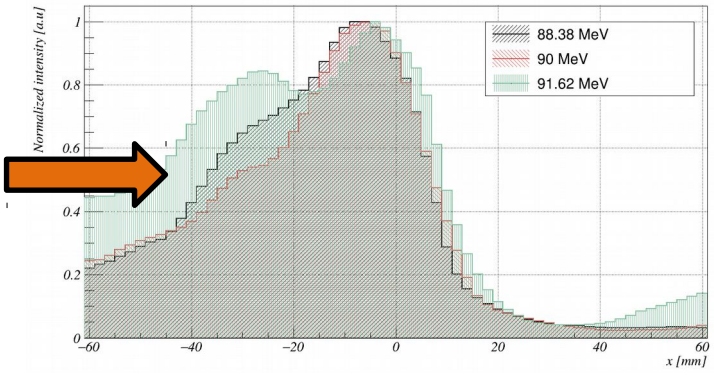
In-beam experiments CCB (Krakow, Poland)

90 MeV
I = 90 pA

MACACO III



88.38 MeV | 90 MeV | 91.62 MeV



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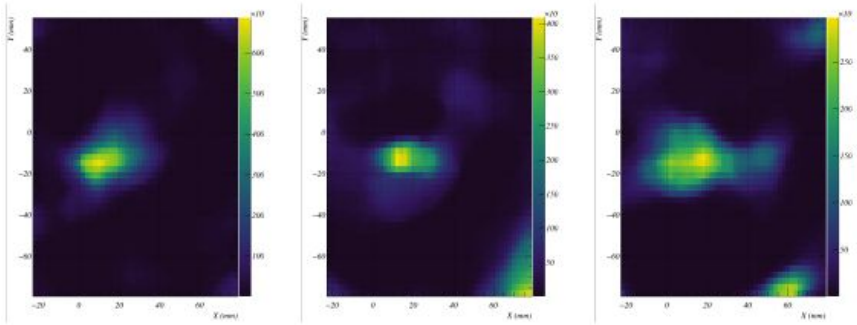
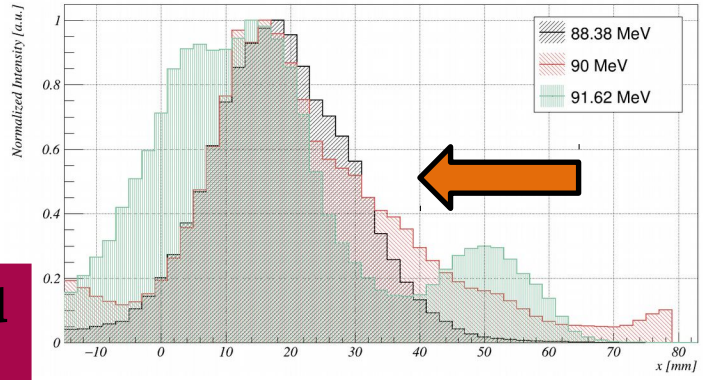


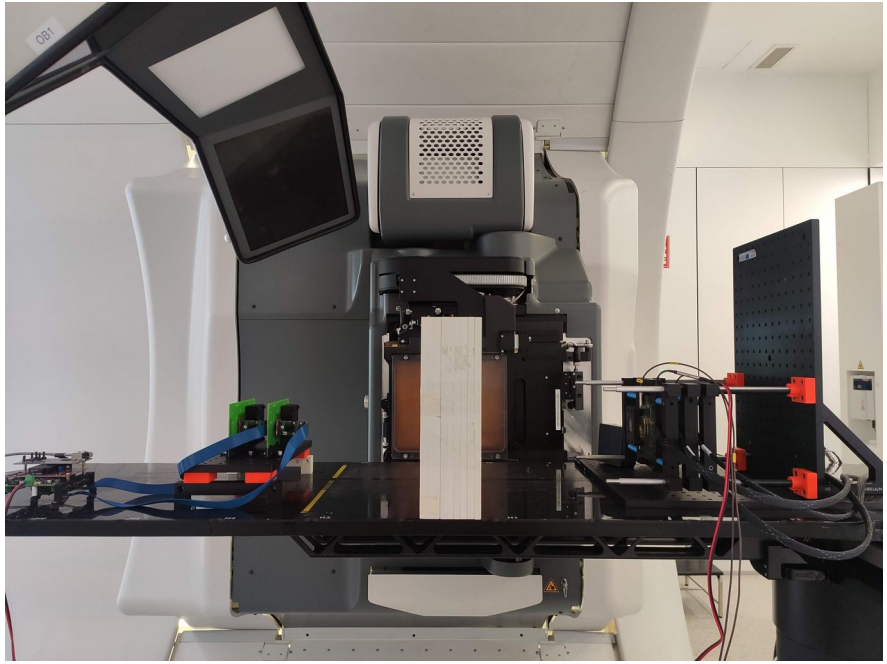
88.38 MeV | 90 MeV | 91.62 MeV



2 mm steps detected with both systems

In-beam experiments Quirónsalud (Madrid, Spain)

70 – 90 MeV



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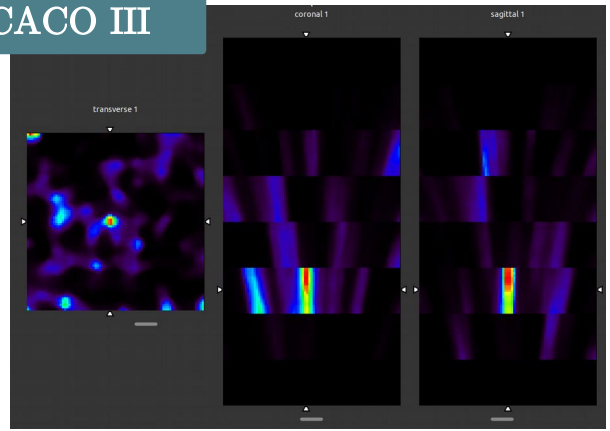

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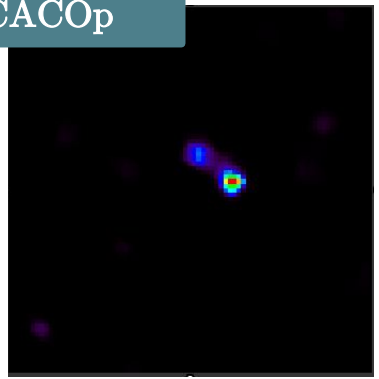
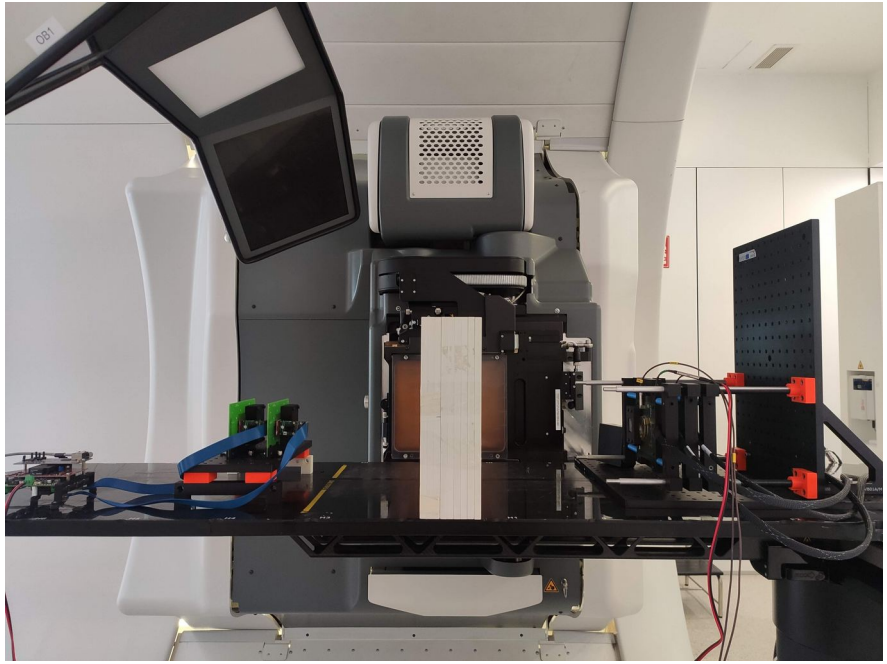


In-beam experiments Quirónsalud (Madrid, Spain)

70 – 90 MeV



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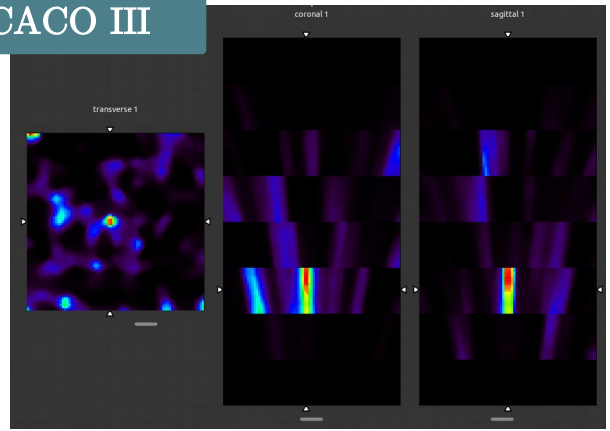

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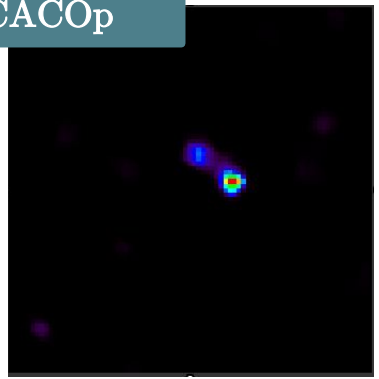


Data analysis ongoing

Conclusions

- The IRIS group is working in hadron therapy applications for almost fifteen years.
- We are developing a Compton camera for treatment monitoring.
- Results so far are encouraging.
- Beam tests are essential in the development.
- Experimental beams allow to test more extensively the system, with lower time and space constraints.

G. Llosá

A. Ros

F. Hueso-Glez

K. Brzezinski

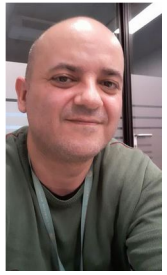
J. Roser

L. Barrientos

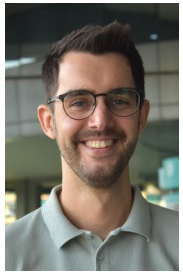
M. Borja-Lloret

R. Viegas

J. Pérez Curbelo



C. Senra



J. V. Casaña

http://ific.uv.es/iris

Acknowledgements

This work was supported in part by:

- Ministerio de Ciencia e Innovación (PID2019-110657RB-I00, PDC2021-121839-I00).
- Generalitat Valenciana. Agencia Valenciana Innovación (INNVA1/2021/37).

Group members are supported by GVA Excellence programmes, UVEG Atracció de Talent, GVA Grisolía and FPU contracts.

Thank you

Gabriela.llosa@ific.uv.es

http://ific.uv.es/iris