Dual gamma-neutron imaging device GN-Vision: development of the first demonstrator and first field tests in BNCT

A. Sanchis-Moltó, J. Lerendegui-Marco, G. Cisterna, J. Hallam, S. Valladares, V. Babiano-Suárez, J. Balibrea-Correa, D. Calvo, C. Domingo-Pardo, G. de la Fuente, B. Gameiro, I. Ladarescu, P. Torres-Sánchez. C. Michelagnoli, M.Daugas

CSIC
Consejo Superior de Investigaciones Científicas
Universitat de València
CPAN Ingenio 2010
IFIC Institut de Física Corpuscular
Excelencia Severo Ochoa

Outline

- **Motivation**
- GN-Vision concept
- Neutron imaging prototype
- Current development of the first GN-Vision prototype
  - Compton imaging in GN-Vision
  - Neutron imaging using CLLBC crystal
- Perspectives
- Conclusions

Motivation: Hadron Therapy

· Protontherapy

Challenge:
Uncentainties in range of primary beam
Proton Range Verification

Possible solution:
Monitoring the spatial distribution of prompt gammas

scientific reports

Check for updates

OPEN **Towards machine learning aided real-time range imaging in proton therapy**

Jorge Lerendegui-Marco✉, Javier Balibrea-Correa, Víctor Babiano-Suárez, Ion Ladarescu & César Domingo-Pardo

https://doi.org/10.1038/s41598-022-06126-6

· Boron Neutron Capture Therapy (BNCT)

Imaging of the 478 keV gammas to spatially localize the dose distribution

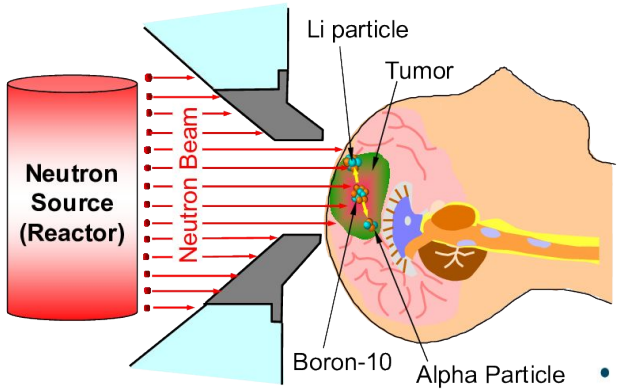
$$^{10}_{5}B + ^{1}_{0}n \rightarrow [^{11}_{5}B]^{*} \rightarrow {}^{4}_{2}He + {}^{7}_{3}Li + \gamma\,(0.48MeV) + 2.31\ MeV \quad (93.9\%)$$

$$^{10}_{5}B + ^{1}_{0}n \rightarrow [^{11}_{5}B]^{*} \rightarrow {}^{4}_{2}He + {}^{7}_{3}Li + 2.79\ MeV \quad (6.1\%)$$

$$(E_{^{4}_{2}He\,(\alpha)} = 1.47MeV,\ E_{^{7}_{3}Li} = 0.84MeV)$$

Significant fraction of secondary dose

NEUTRONS



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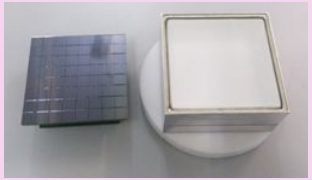
GN – Vision concept: comparison with i-TED

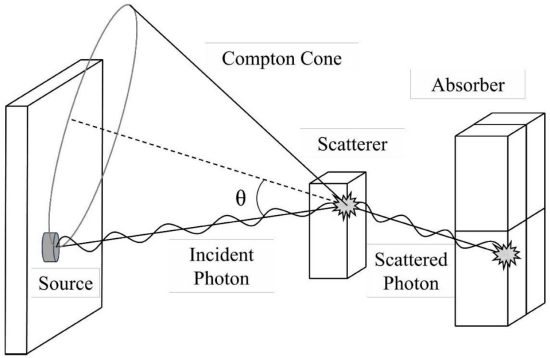
i-TED

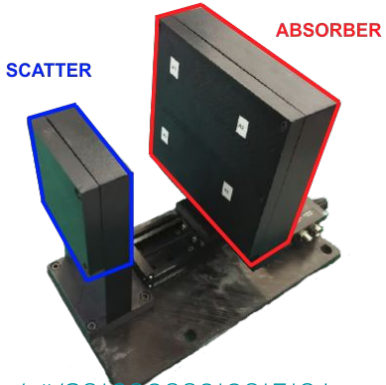
- **Gamma** imaging → Compton Technique
  - 2 detection planes with position sensitive detectors (monolithic LaCl3 crystals) coupled to SiPMs
    - Compton scatterer
    - Absorbers
- Compton technique
  - Superposition of reconstructed cones



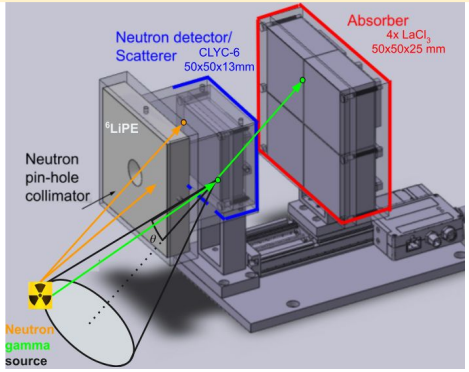
GN –Vision

- **Gamma** imaging → Compton Technique
- **Slow Neutron** imaging (E < 1keV) → Pinhole Cameras
  - ➢ Neutron Li6PE collimator
  - ➢ 2 detection planes with monolithic sensitive to position crystals
    - Neutron detector/ Compton scatterer
      - CLYC-6
      - CLLBC → Gamma/neutron discrimination, Good energy resolution
    - $LaCl_3$ Absorbers





https://www.sciencedirect.com/science/article/pii/S0168900219315104



https://doi.org/10.1140/epjti/s40485-024-00108-w

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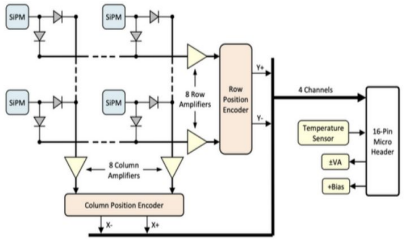
Development and validation of the neutron imaging module

Integration of neutron and gamma imaging in a single device

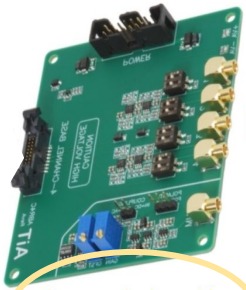
Experiment at ILL: neutron imaging prototype

CLYC-6 + SiPM + AiT Electronics

8x8 array SiPM



AIT AB4T-ARRAY64P
4-Channel Active Base



4- encoded position signals: X+,X-,Y+,Y-

PCB

CAEN DT5730
8 Channel 14 bit
500 MS/s Digitizer

AiT Electronics

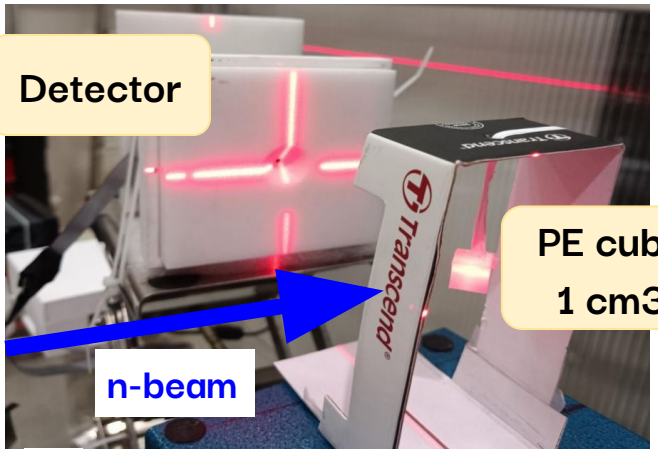
Experiment at Institut Laue-Langevin

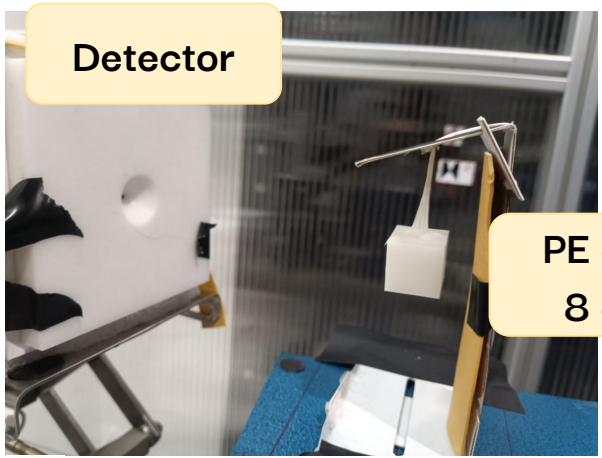
- Production of a collimated neutron beam at FIPPS experimental hall
- Neutron imaging using different targets/phantoms

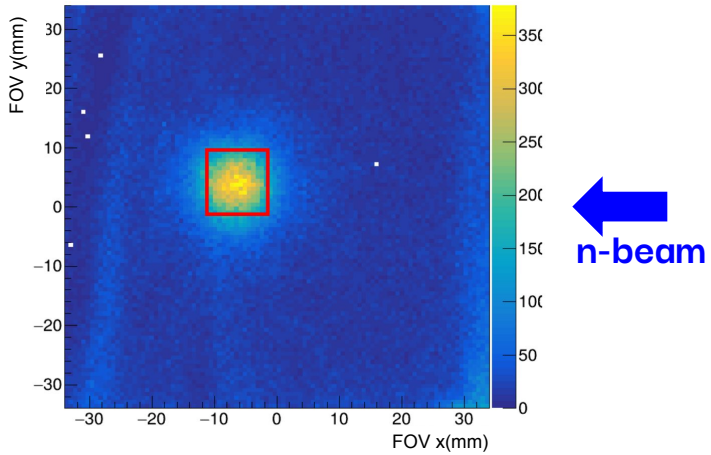
Experiment at ILL: neutron imaging prototype

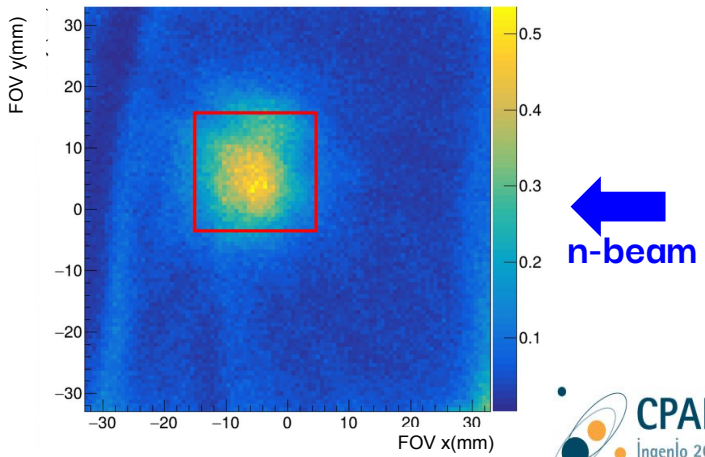
To validate the imaging capabilities of the device

First neutron images of the device





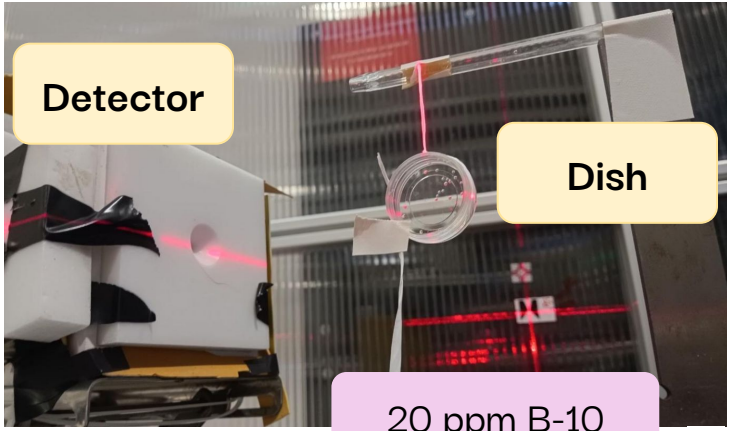




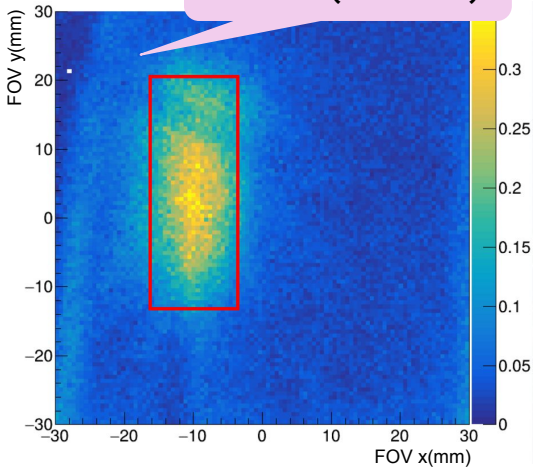
J. Lerendegui-Marco et al. Nucl. Phys. A 1079, 170594 (2025), doi: https://doi.org/10.1016/j.nima.2025.170594

Experiment at ILL: neutron imaging prototype

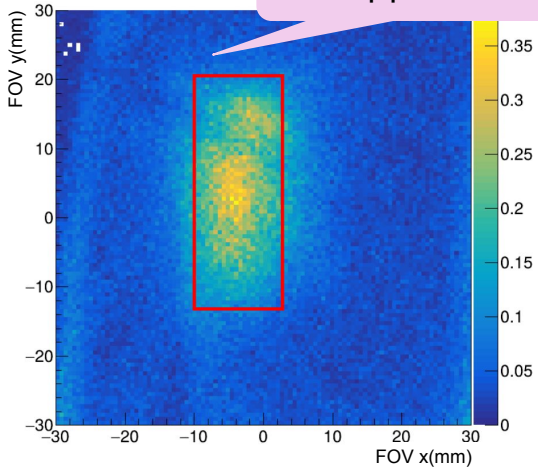
Exploring its potential applicability to BNCT



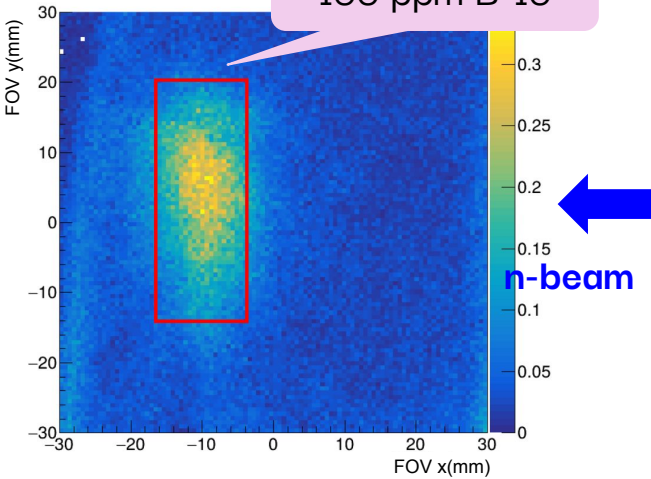
Water (no B-10)



20 ppm B-10



100 ppm B-10



Experiment at ILL: neutron imaging prototype

Exploring its potential applicability to BNCT

EPJ Web of Conferences **338**, 09013 (2025) https://doi.org/10.1051/epjconf/202533809013
ANIMMA 2025

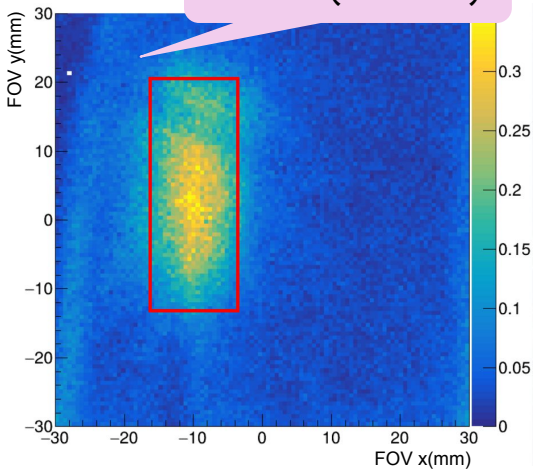
Experimental proof-of-concept and first field tests of the dual gamma-neutron imager GN-Vision

A. Sanchis-Moltó[1], J. Lerendegui-Marco[1,*], G. Cisterna[1], P. Álvarez-Rodríguez[1], J. Balibrea-Correa[1], V. Babiano-Suárez[1], J-M. Daugas[1], G. de la Fuente[1], B. Gameiro[1], I. Ladarescu[1], C. Méndez-Malagón[1], C. Michelagnoli[1], I. Porras[1], A. Navarro-Mocholi[1], M. Porras-Quesada[1], C. Ruiz-Ruiz[1], P. Torres-Sánchez[1], S. Valladarés[1] and C. Domingo-Pardo[1]

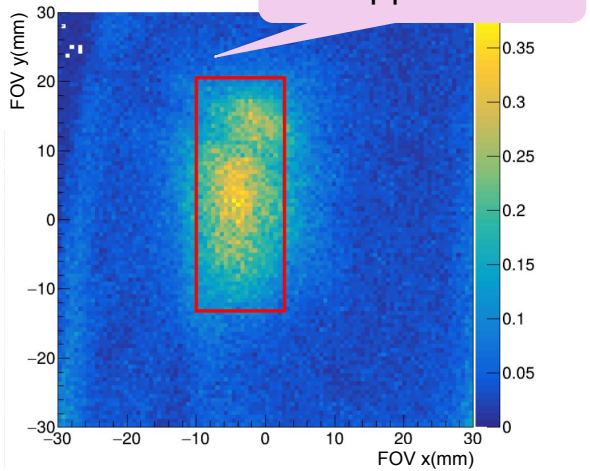
[1]Instituto de Física Corpuscular, CSIC-Universitat de València, Spain

https://www.epj-conferences.org/articles/epjconf/pdf/2025/23/epjconf_animma2025_09013.pdf

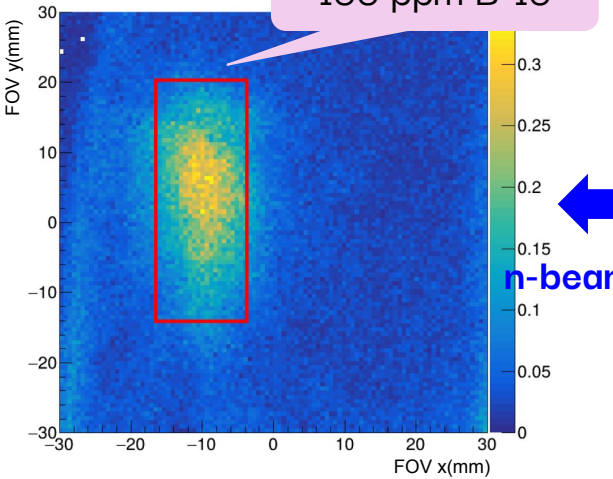
Water (no B-10)



20 ppm B-10



100 ppm B-10



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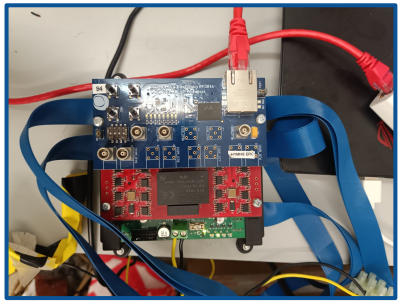
GN-Vision setup

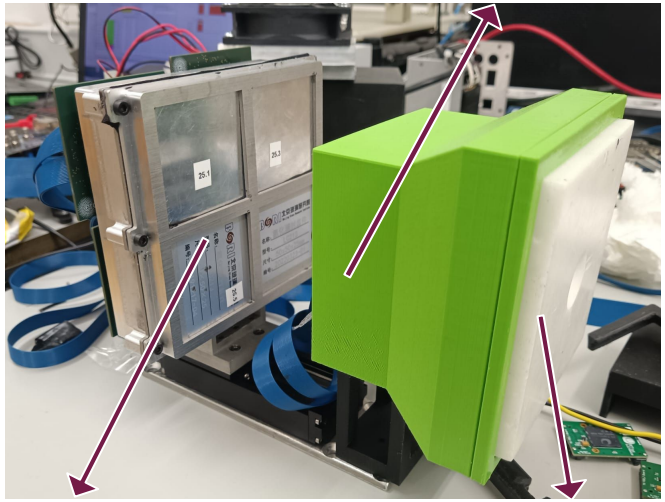
- Integration of CLYC-6 with PETSys not possible because of the poor light yield
- Introduction of CLLBC working with PETSys allows for
  - 64-channel readout → **Unlike with AiT!**
  - Integration of neutron and gamma imaging in a single device

CLLBC crystal

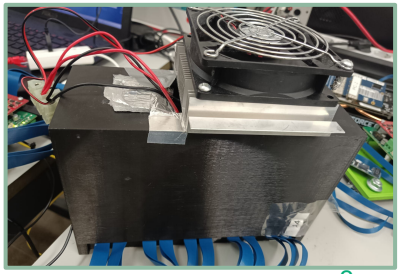
CLLBC crystal + SiPM



PETSys e.kit -> PETSys TOFPET2 ASIC



4 $LaCl_3$ crystals (absorbers) + SiPMs



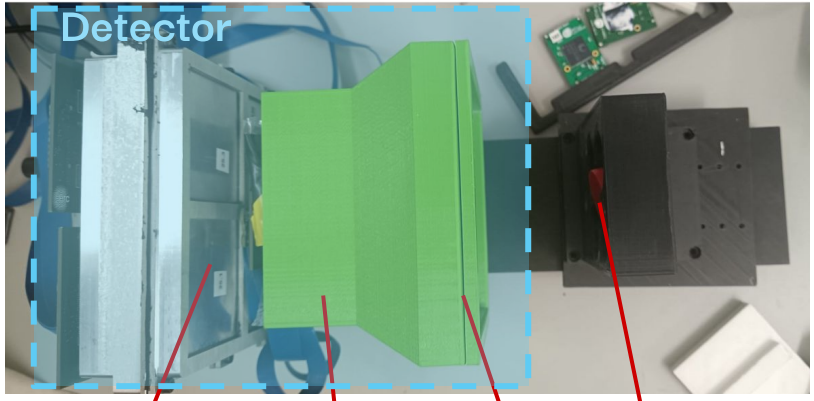
Air cooling (T: 30-32°C)

^{6}Li PE pinhole collimator

DAQ and processing

Compton imaging in GN-Vision: first tests

Experimental setup: top view



4 $LaCl_3$ crystals (absorbers)

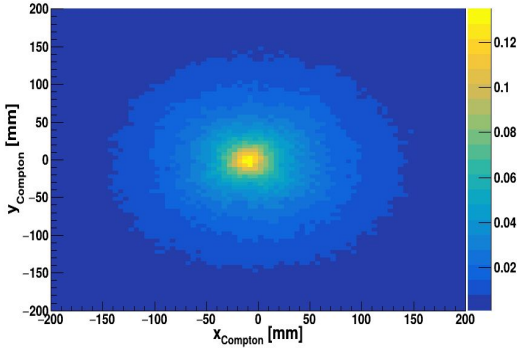
CLLBC (scatterer) + SiPM

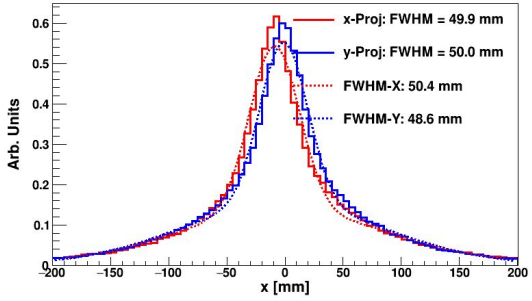
^{6}Li PE pinhole collimator

Na-22 source

Image reconstruction 1.27 MeV peak

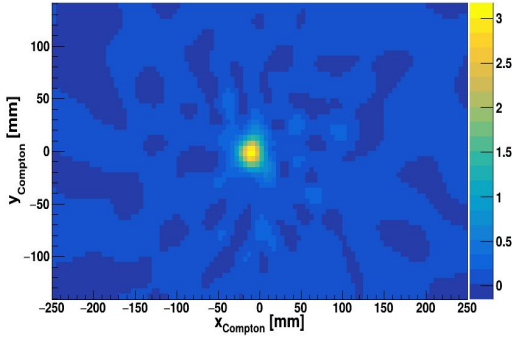
Back-projection

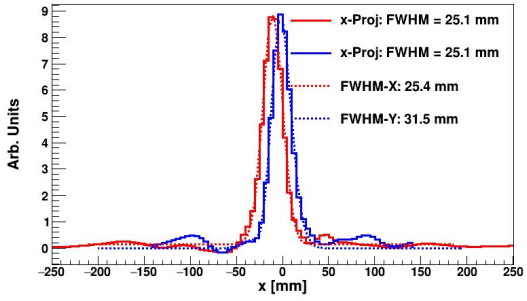




Wilderman, S. J., et al. IEEE Trans. Nuclear Sci. 45, 957-962. https://doi.org/10.1109/23.682685

Analytical algorithm





Tomitani, T. et al Phys. Med. Biol. 47, 2129-2145. https://doi.org/10.1088/0031-9155/47/12/309

Compton imaging in GN-Vision: first tests

We reproduce the results previously obtained for Compton imaging using i-TED

i-TED: Compton Imaging and Machine-Learning Techniques for Enhanced Sensitivity Neutron Capture Time-of-flight Measurements

J. Lerendegui-Marco, V. Babiano-Suárez, J. Balibrea-Correa, L. Caballero, D. Calvo, C. Domingo-Pardo, I. Ladarescu

10.1109/NSS/MIC44867.2021.9875461

Eur. Phys. J. A (2021) 57:197
https://doi.org/10.1140/epja/s10050-021-00507-7

THE EUROPEAN PHYSICAL JOURNAL A

Special Article - New Tools and Techniques

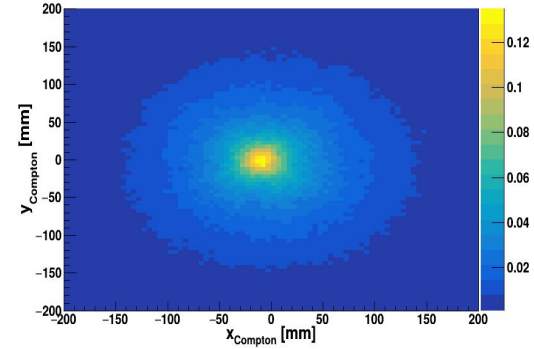
Imaging neutron capture cross sections: i-TED proof-of-concept and future prospects based on Machine-Learning techniques

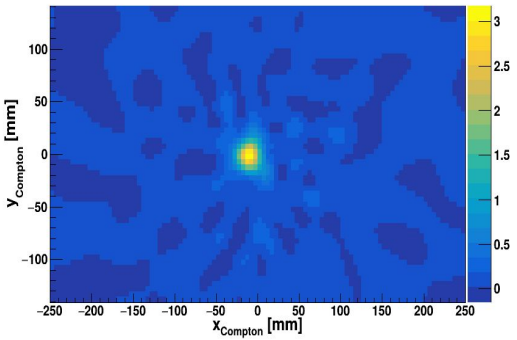
https://doi.org/10.1140/epja/s10050-021-00507-7

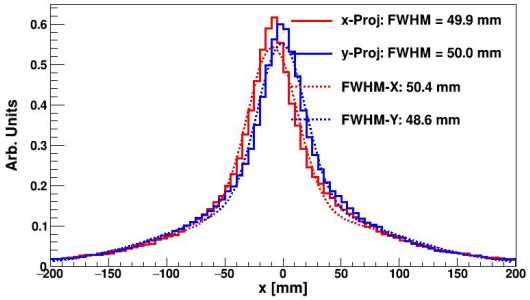
Image reconstruction

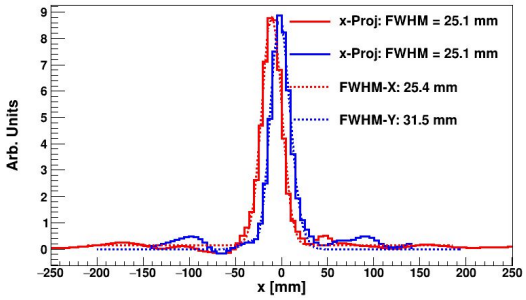
Back-projection

Analytic algorithm







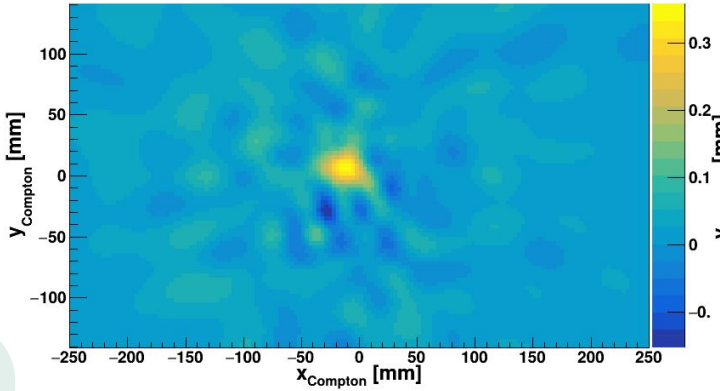


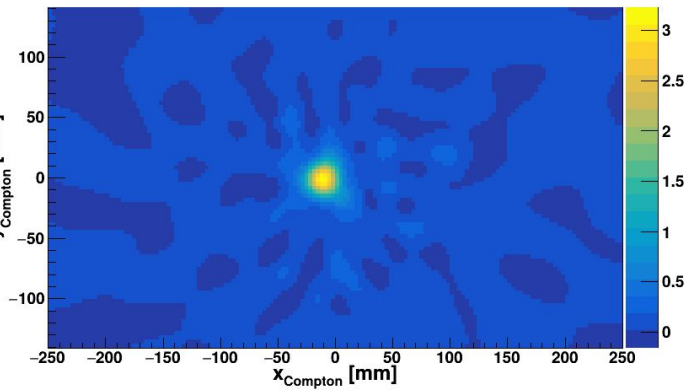
Compton imaging in GN-Vision: first tests

Different energies

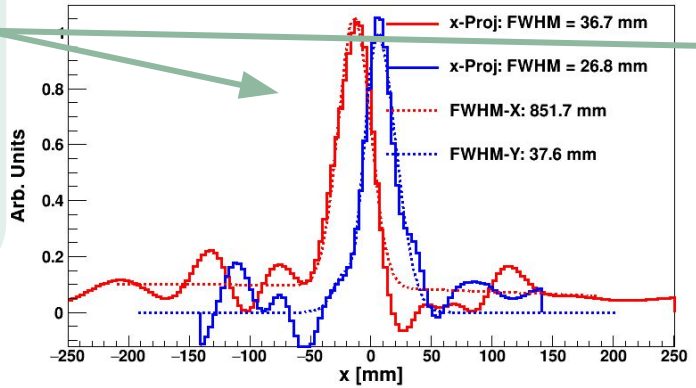
511 keV

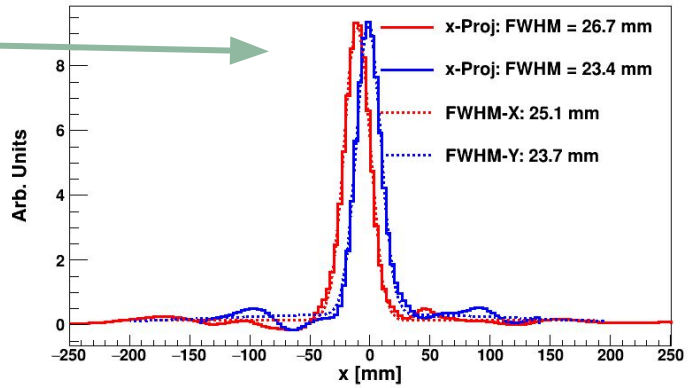
1278 keV





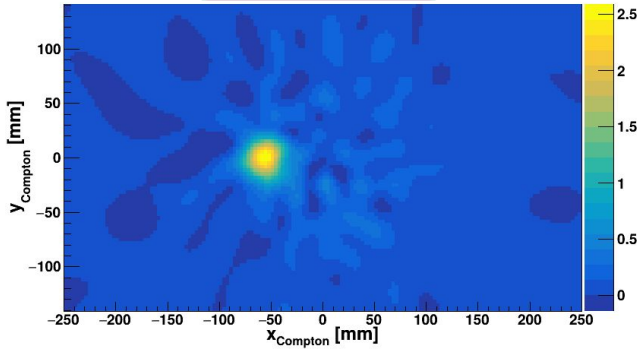
Worsening of the resolution at 511 keV expected due to the much worse E-resolution at low deposited energies

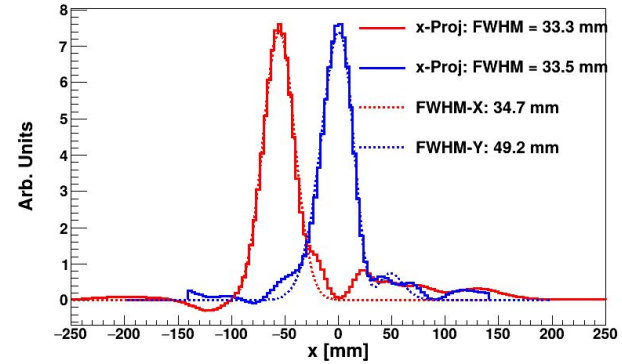




Different source positions E = 1.27 MeV

-50 mm



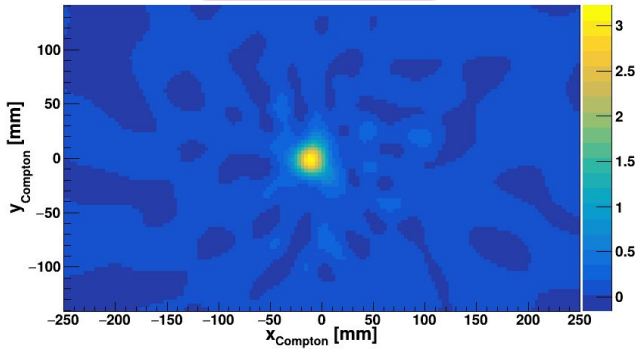


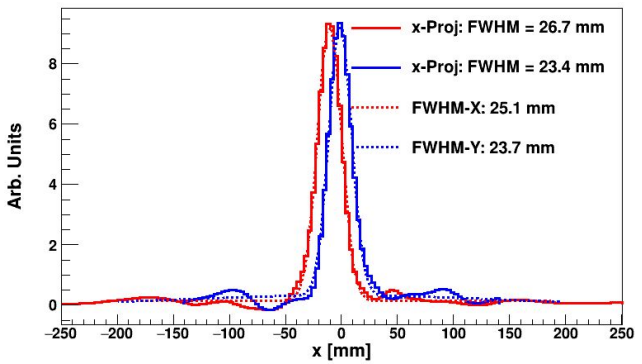
Fit x (mm) = -55.6

-44.9 mm

dev = 10.2%

center



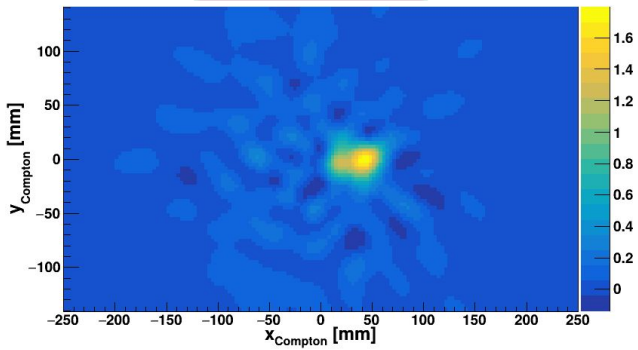


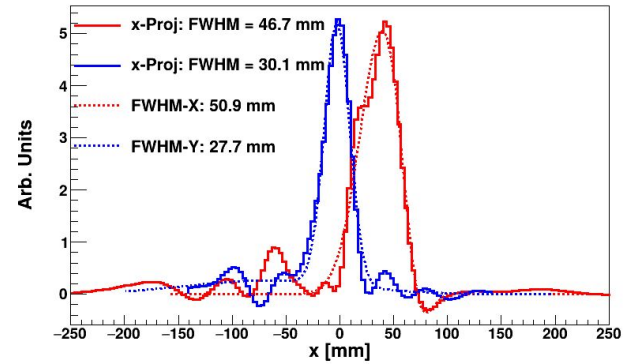
Fit x (mm) = -10.7

+51.4 mm

dev = 2.9%

+50 mm

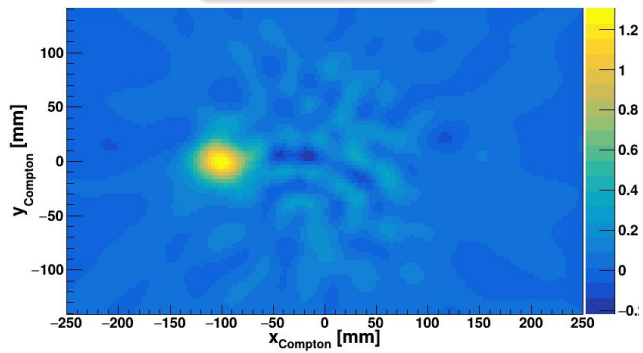


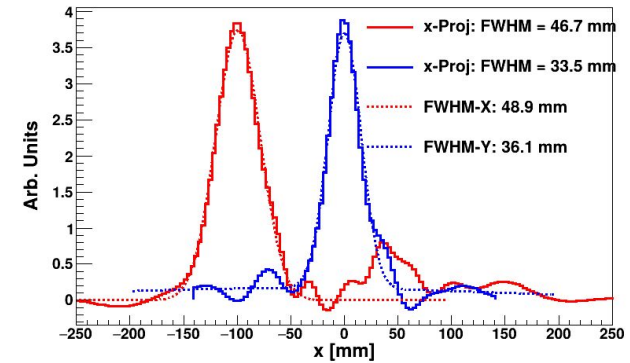


Fit x (mm) = +40.8

Different source positions E = 1.27 MeV

-100 mm



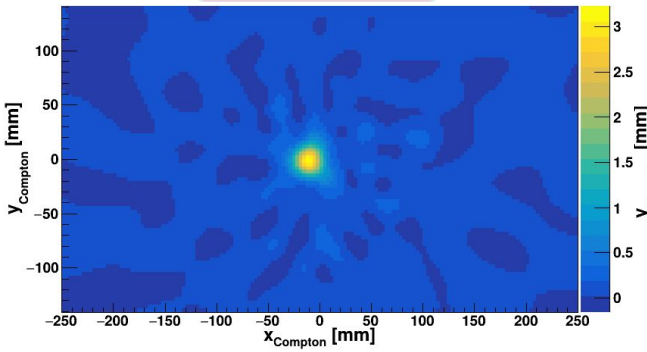


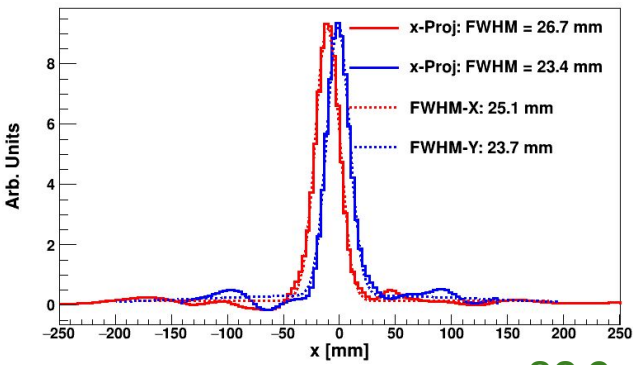
Fit x (mm) = -99.3

-88.6

dev = 11.4%

center



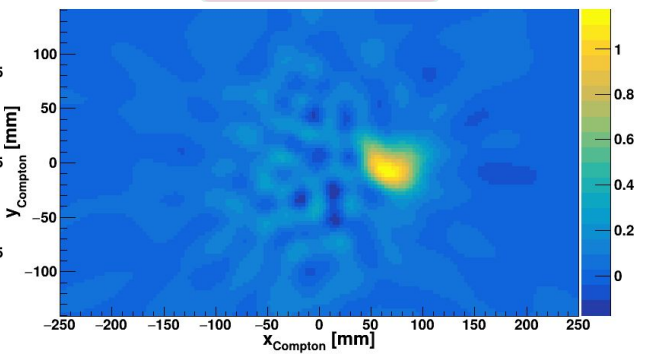


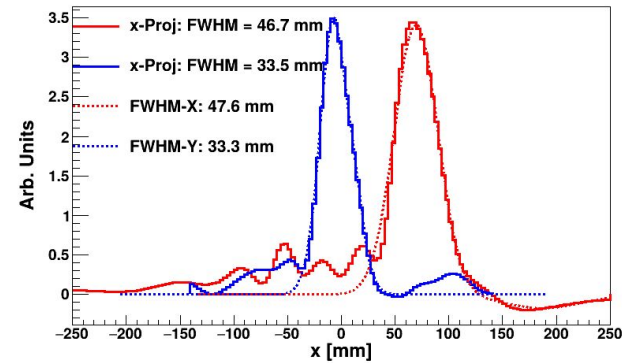
Fit x (mm) = -10.7

80.2 mm

dev = 19.8%

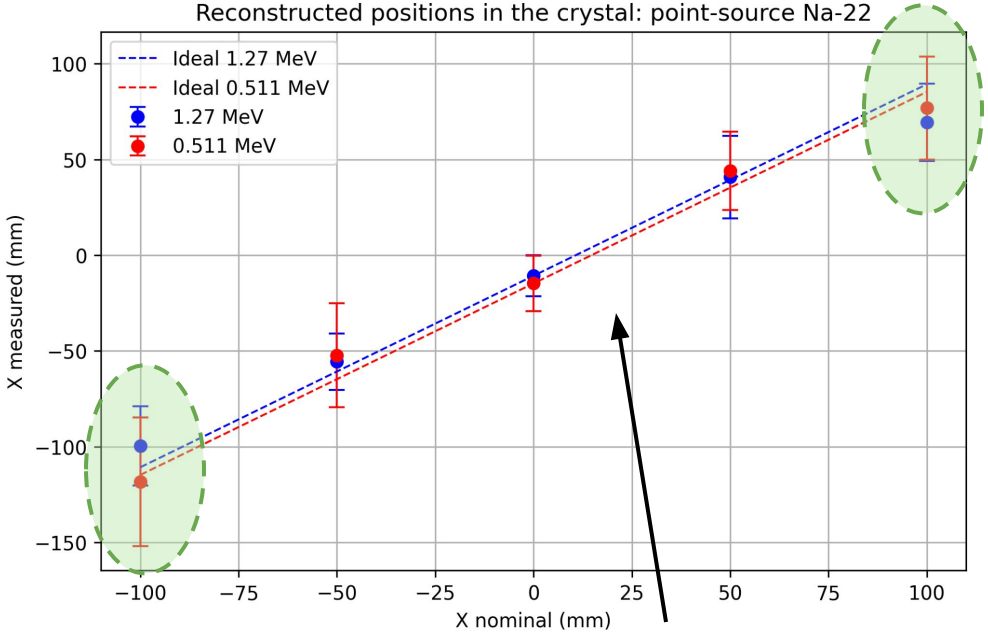
+100 mm





Fit x (mm) = +69.5

Compton imaging in GN-Vision: first tests

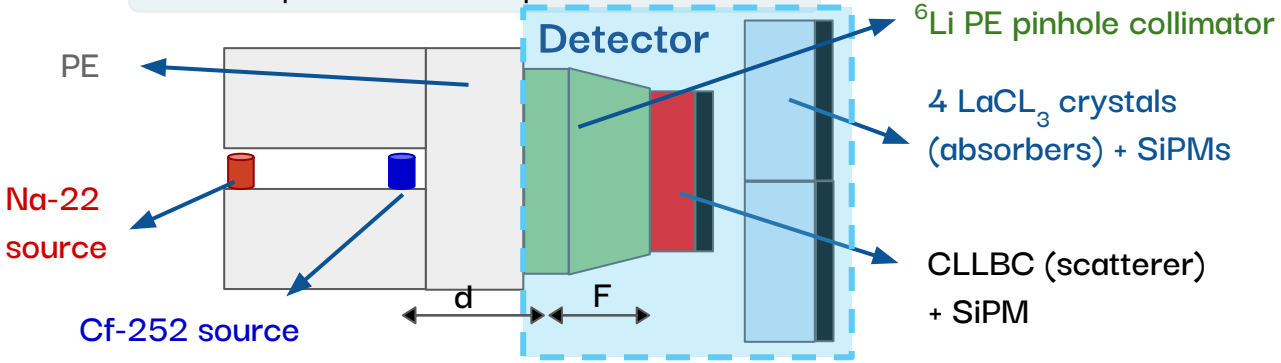


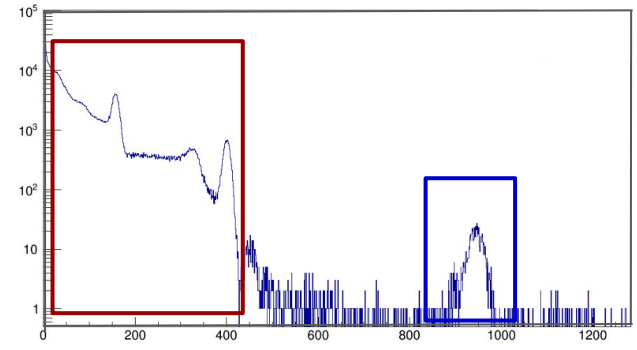
Ideal curves drawn assuming systematic errors in the center position

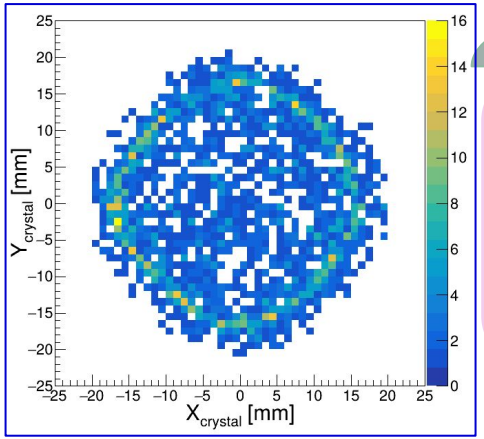
- Worse imaging resolution using 511 keV peak (due to lower deposited energies)
- **Compression effect towards the edges of the field-of-view**
- First reconstructed Compton images in the dual neutron-gamma imaging detector

Neutron imaging in GN-Vision: first tests

Experimental setup: side view





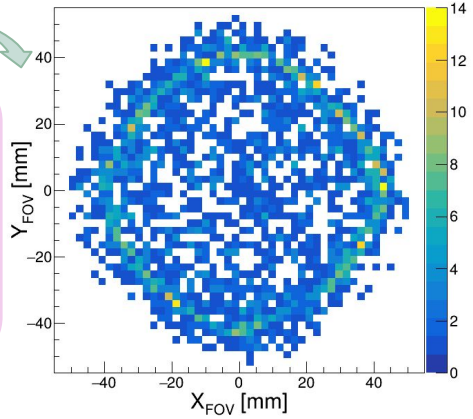


Reconstructed positions in the crystal

Pinhole imaging technique:

- scaling
- inversion

s = -d/F



Reconstructed image

- Motivation
- GN-Vision concept
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- Current development of the first GN-Vision prototype
  - Compton imaging in GN-Vision
  - Neutron imaging using CLLBC crystal

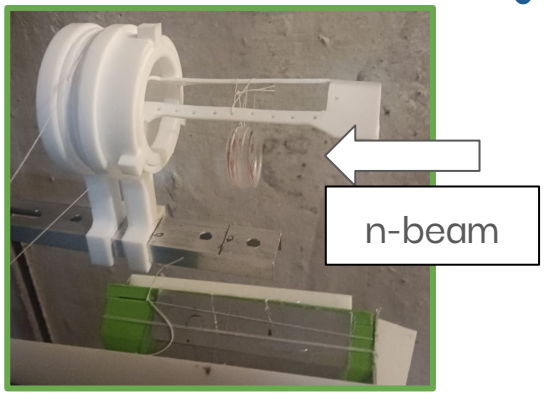
- **Perspectives**
- Conclusions

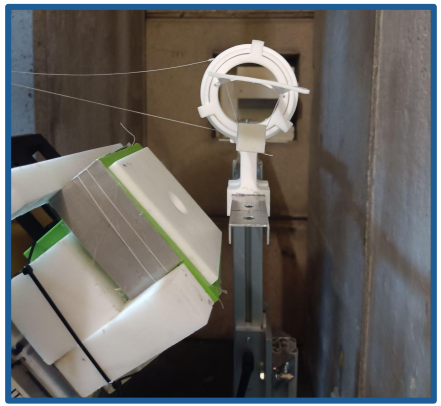
First dual neutron-gamma imaging experiment

Experiment in LENA-Pavia (experimental TRIGA reactor): First dual neutron-gamma imaging experiment

Measurements:

- Small PE cube (2x2x1 cm^3)

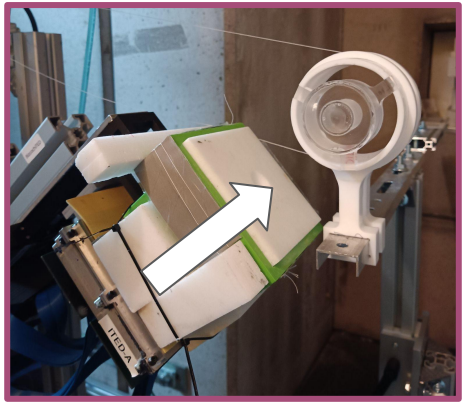




Water dish

- 0 ppm ^{10}B
- 500 ppm ^{10}B

- Derenzos
  - 70 ppm ^{10}B
  - 70 ppm ^{10}B + 500 mg Boric Acid



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- Motivation
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Conclusions

- GN-Vision is a compact device capable of imaging neutrons and gamma-rays simultaneously
- Very suitable for medical applications: Proton Therapy and BNCT
- Designed prototype for neutron imaging using CLYC-6 crystal as neutron absorber/Compton scatterer with AiT Electronics
- Dual gamma-neutron imaging capabilities of the CLLBC+PETsys prototype
  - Compton imaging in GN-Vision reproduces the results previously for i-TED
- First proof-of-concept of neutron-gamma imaging experiment in Pavia

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Thank you very much for your attention!

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CSIC Consejo Superior de Investigaciones Científicas

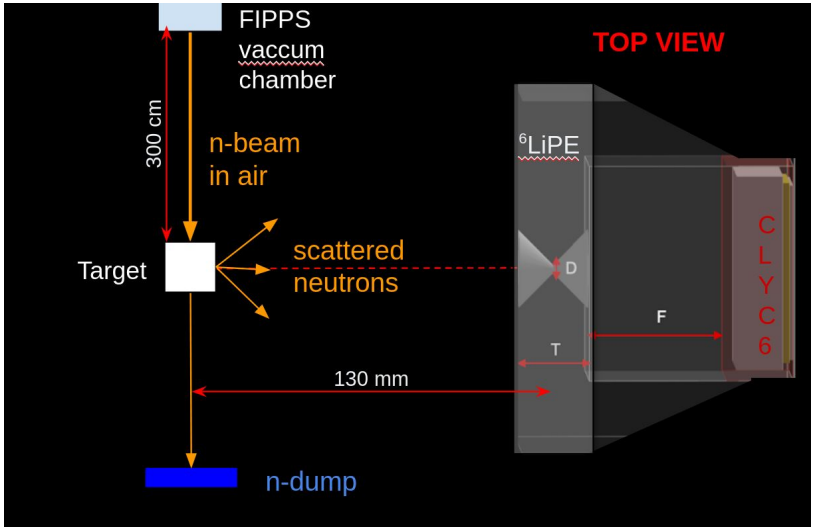
Universitat de València

IFIC Institut de Física Corpuscular

Excelencia Severo Ochoa

Additional Slides

Experimental Setup ILL



Neutron-gamma discrimination using CLYC-6

Pulse-shape discrimination

Neutrons

$^{6}Li(n,\alpha)^{3}H$ reaction

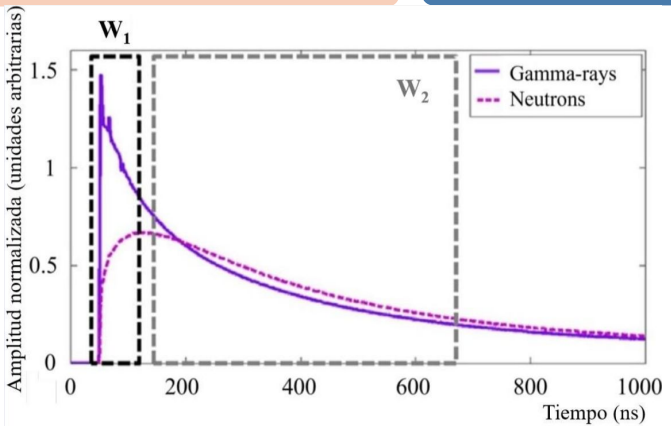
- Alpha particles
- Protons

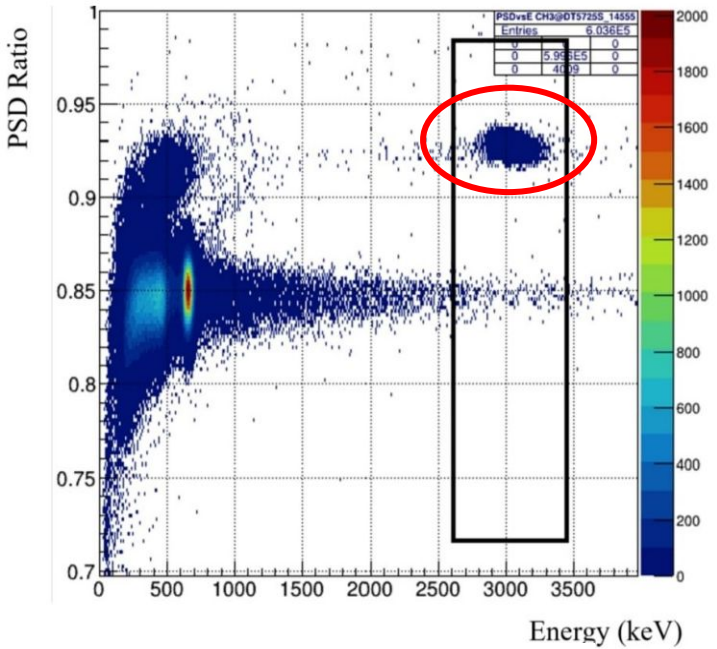
Broader and lower pulses

Gamma rays

Electrons

Thinner and higher





$$PSD\ Ratio = \frac{W_2}{W_1 + W_2}$$

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Experimental Setup ILL

Spatial linearity and resolution

Spatial resolution ~ 5 mm

Imaging neutrons with a position-sensitive monolithic CLYC detector

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