Compact gamma camera: from design to prototype

João Marcos on the behalf of
Gamma camera group

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

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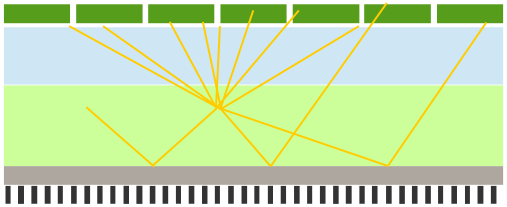
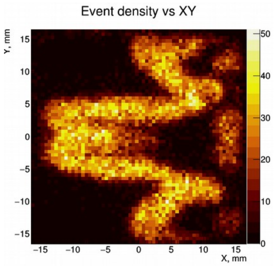




Jornadas do LIP

Braga, 14-16 February 2020

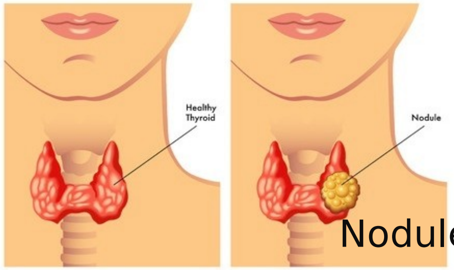
Motivation

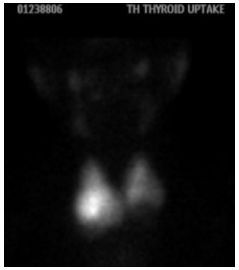
Design, construction and optimization of compact gamma cameras for clinical and pre-clinical applications

Clinical Functional imaging

1. Thyroid

Heathy Thyroid

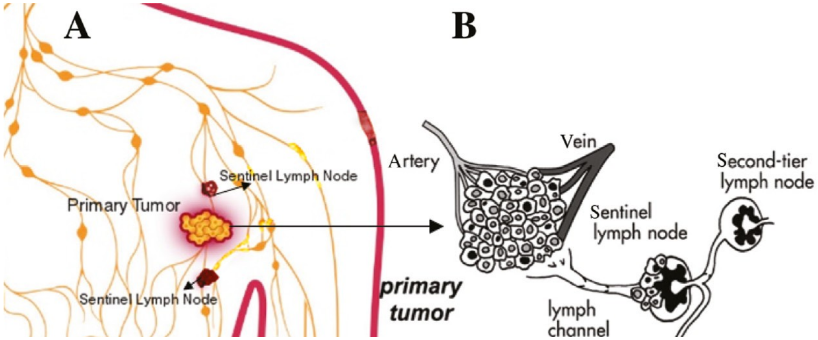




Thyroid scintigraphy with 99mTc showed a nodule of the left lower pole

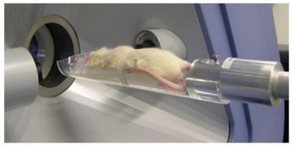
2. Sentinel lymph node biospy

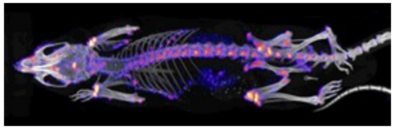
SLN biopsy needs **real-time imaging**



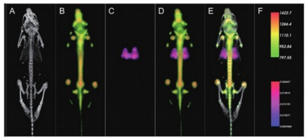
DOI: https://doi.org/10.1515/bmt-2016-0164

Pre-clinical imaging





From University of Ottawa Heart Institute gallery



Multimodal imaging

Camera design

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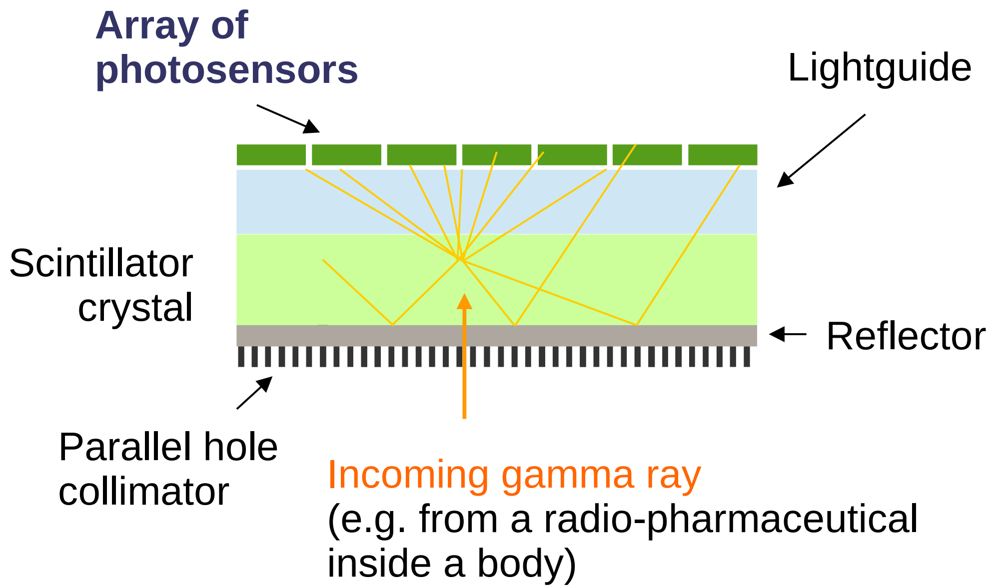
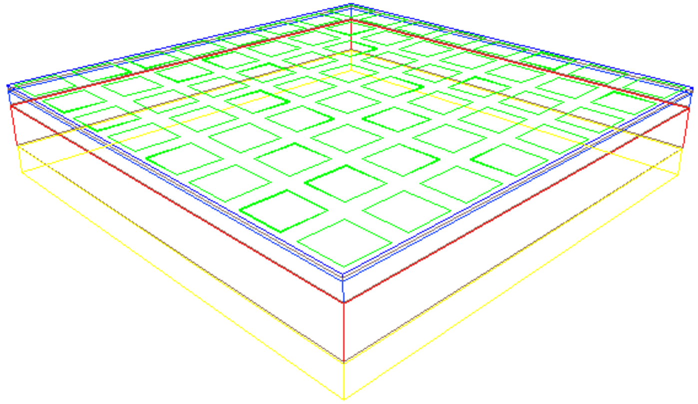
→ **Objective is to optimize camera parameters**:

- crystal thickness: efficiency *vs* spatial resolution
- crystal side finishing: light collection *vs* field of view
- lightguide thickness: resolution *vs* distortions

→ **Done by means of ANTS2 simulations**

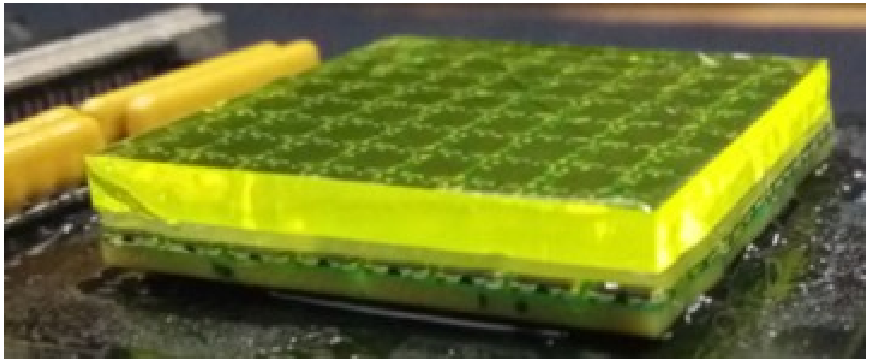
Validation by comparing with experimental data: good agreement in the end





Compact camera prototypes

GAGG prototype

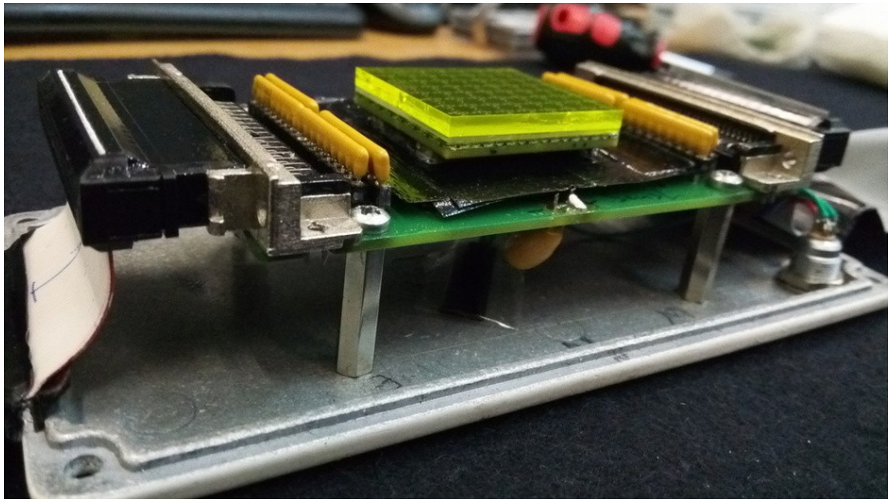


LYSO prototype

- LYSO has better efficiency and intrinsic resolution, however it is radioactive and has too much of intrinsic background for imaging of weaker sources (as in SLN surgery)

- GAGG, with much lower radioactive background, is more sutable in this case

Camera perspective - reflector removed



Collimator models in ANTS2

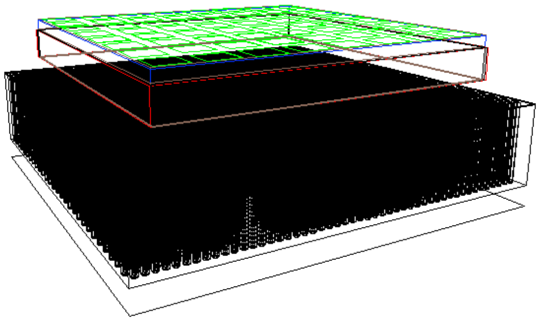
Target parameters

Minimal requirements for SLN imaging also suitable for thyroid:

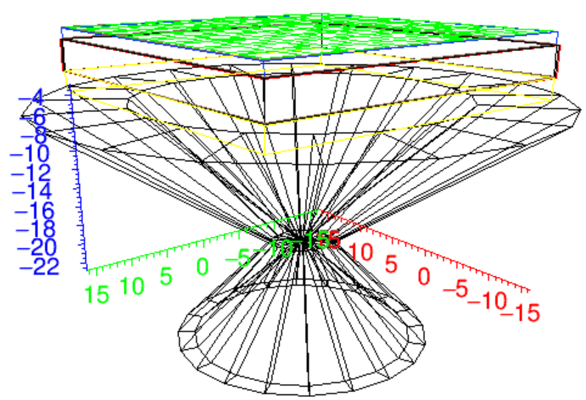
Spatial resolution: < 0.5 cm at 5 cm

Efficiency: **>** 0.0001 (100 cps/Mbq)

Parallel-hole collimator

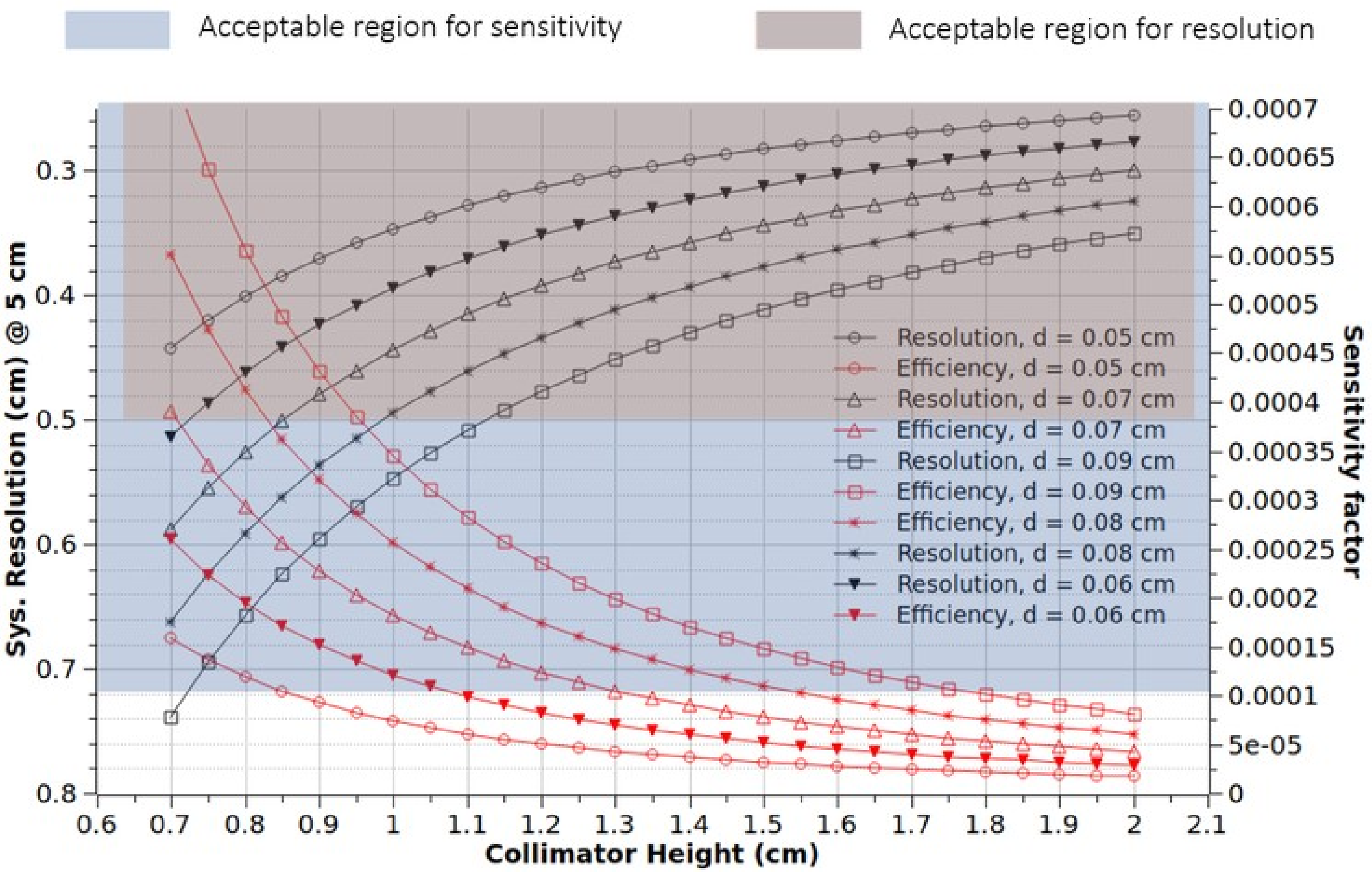


Pinhole collimator (magnification factor = 2)



Collimators design

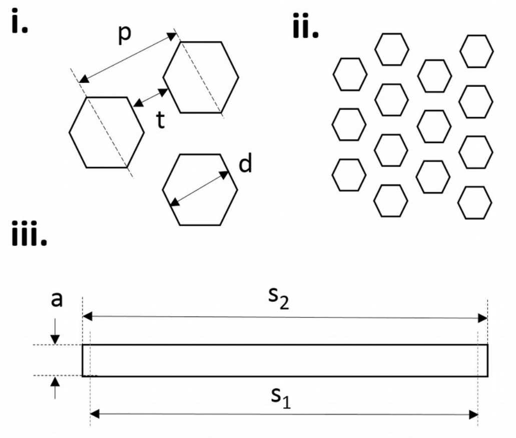
Parallel-hole collimator trade-of curves



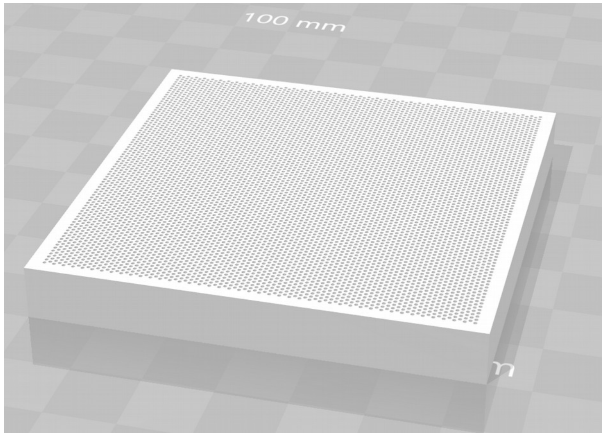
Optimized parameters: d = 0.05 cm, septa t = 0.03 cm, height = 0.8 cm

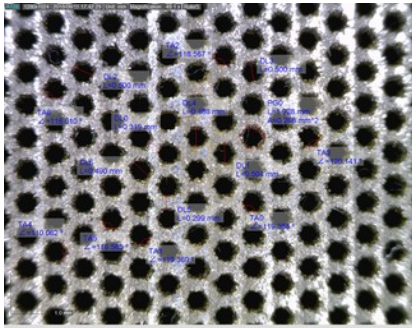
Collimators prototypes

Parallel-holes collimator (hexagones 0.5 mm “diameter)



Made of tungsten using Selective laser melting





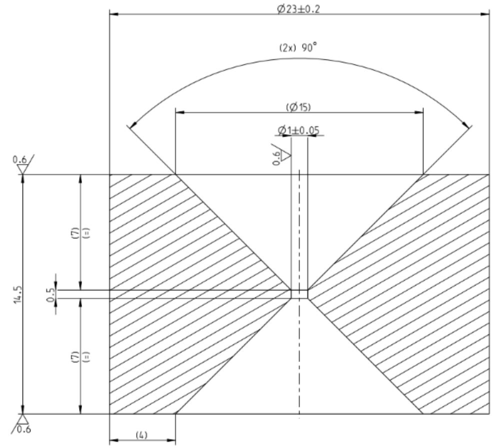
- **Specification** by João Marcos
- **Designed** by Eng. Rui Alves (LIP mechanical workshop)
- **Manufactured** by M&I Materials

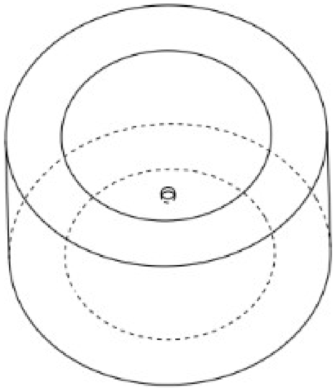
Collimators prototypes

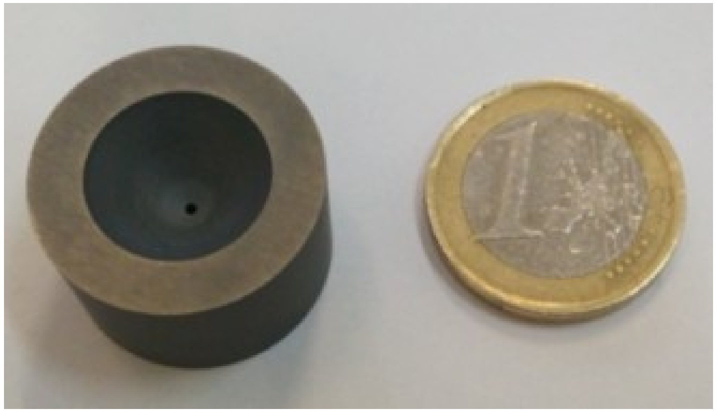
Pinhole collimator (1 mm hole, 0.5 mm channel edge height)

Made of Tungsten alloy (95.5% W, 4.5% Co)

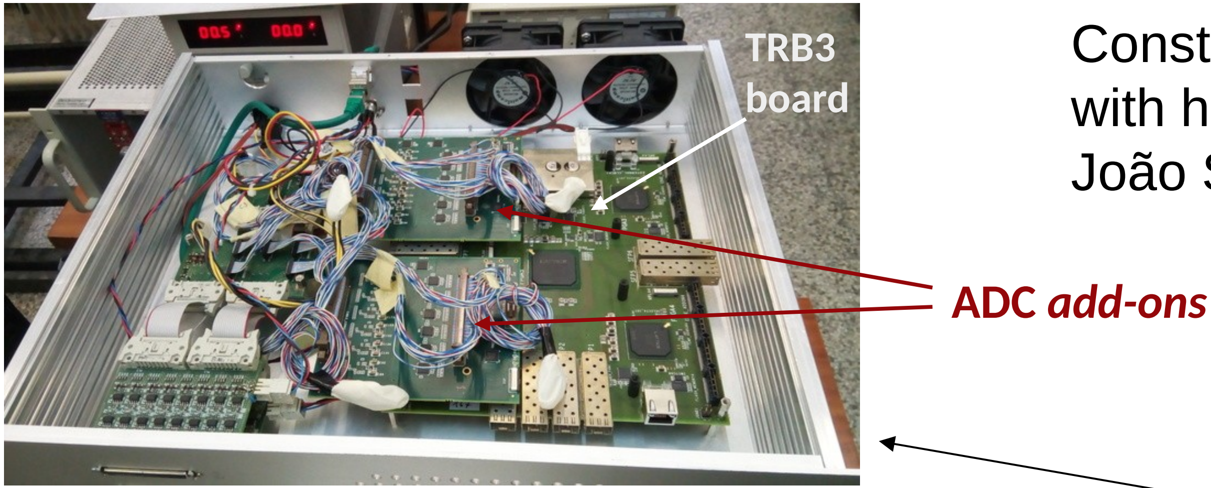
- **Specification** by João Marcos
- **Designed** by DURIT (Albergaria-a-Velha)
- **Manufactured** by DURIT





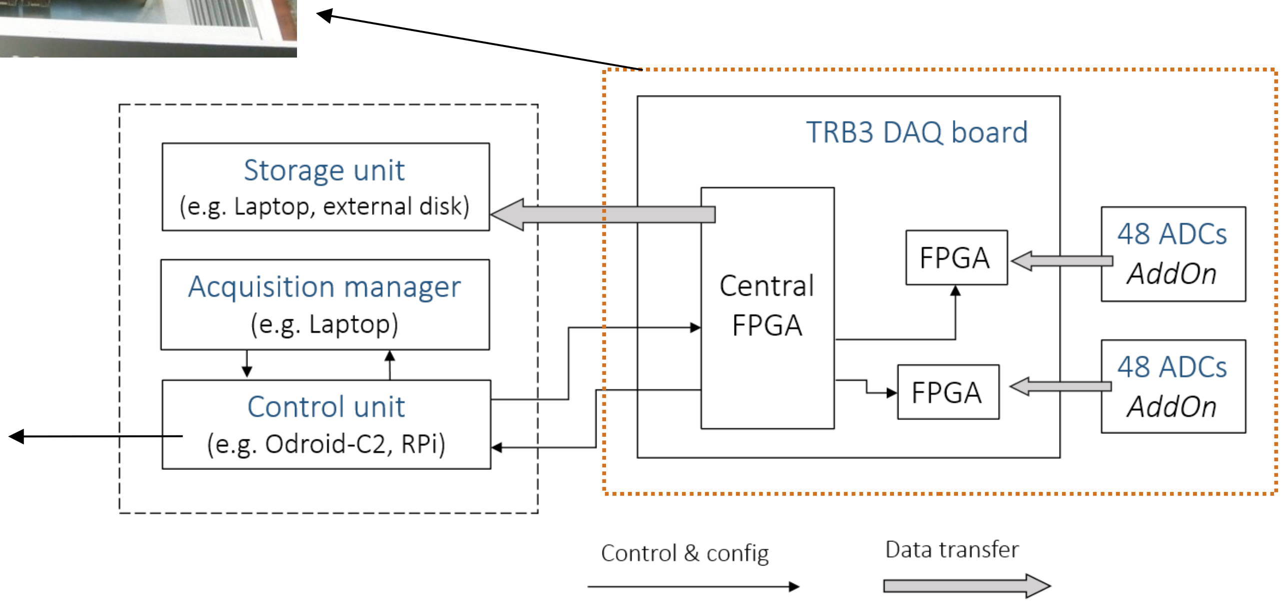


TRB3 (GSI) based readout for 64 channels



Constructed and programmed with help of Alberto Blanco and João Saraiva (LIP Coimbra)

Odroid-C2 mini-computer:



Readout and acquisition system

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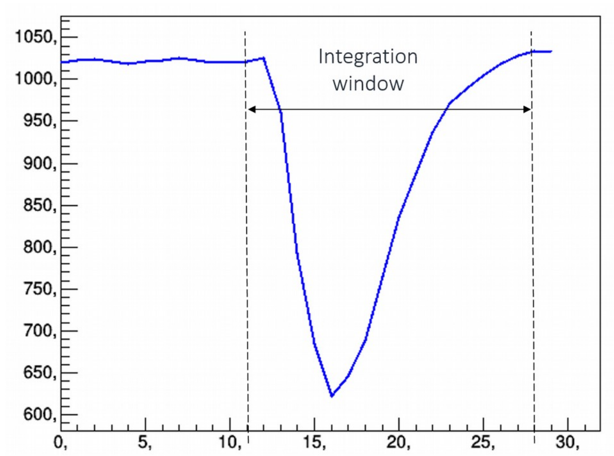
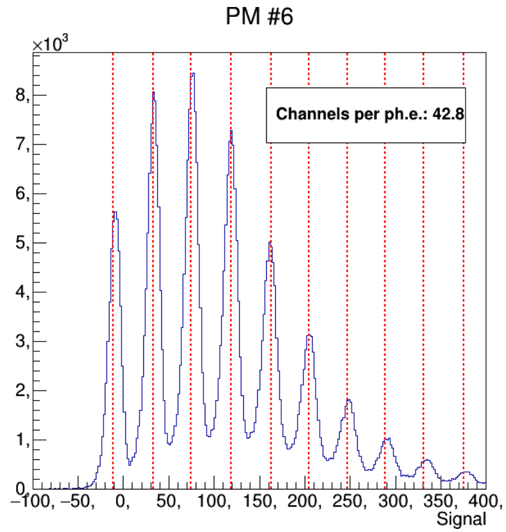
Signal waveform



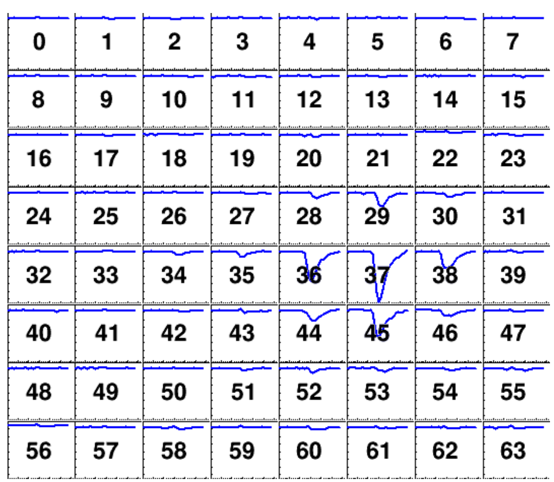


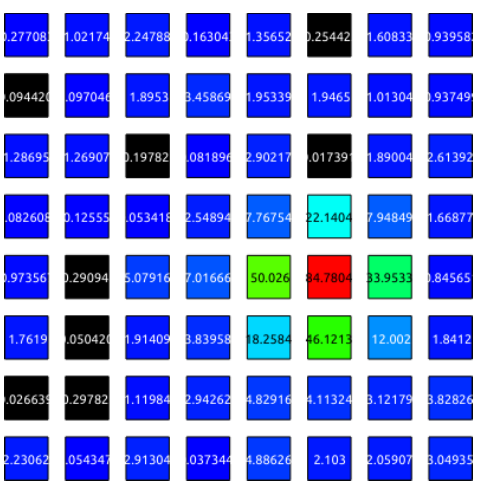
ADC channels per photoelectron

Conversion of the waveform integral into number of photoelectrons

Example of a scintillation events

64 SiPM Signal waveform





Number of photoelectrons

Real-time acquisition workflow

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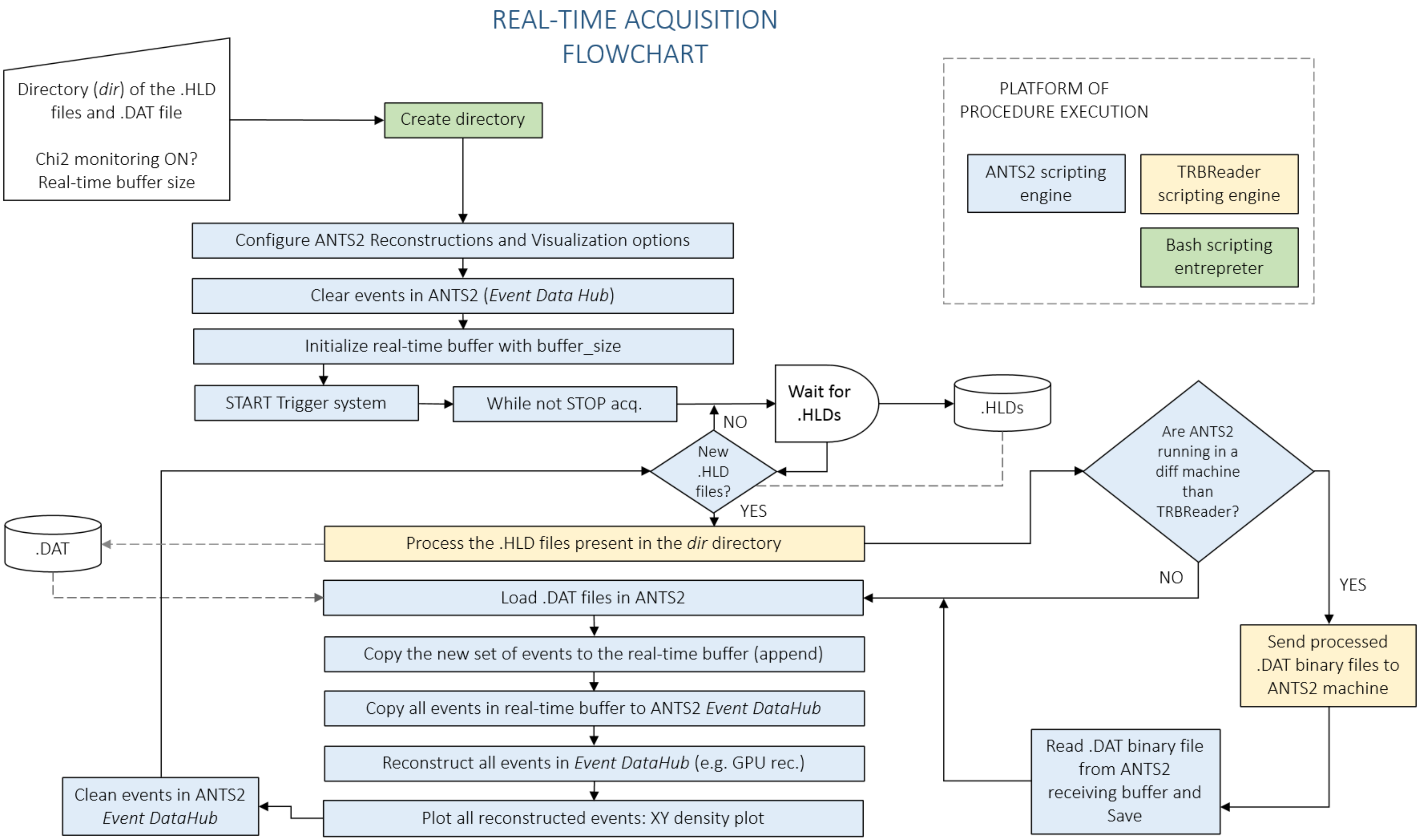

Real-time imaging

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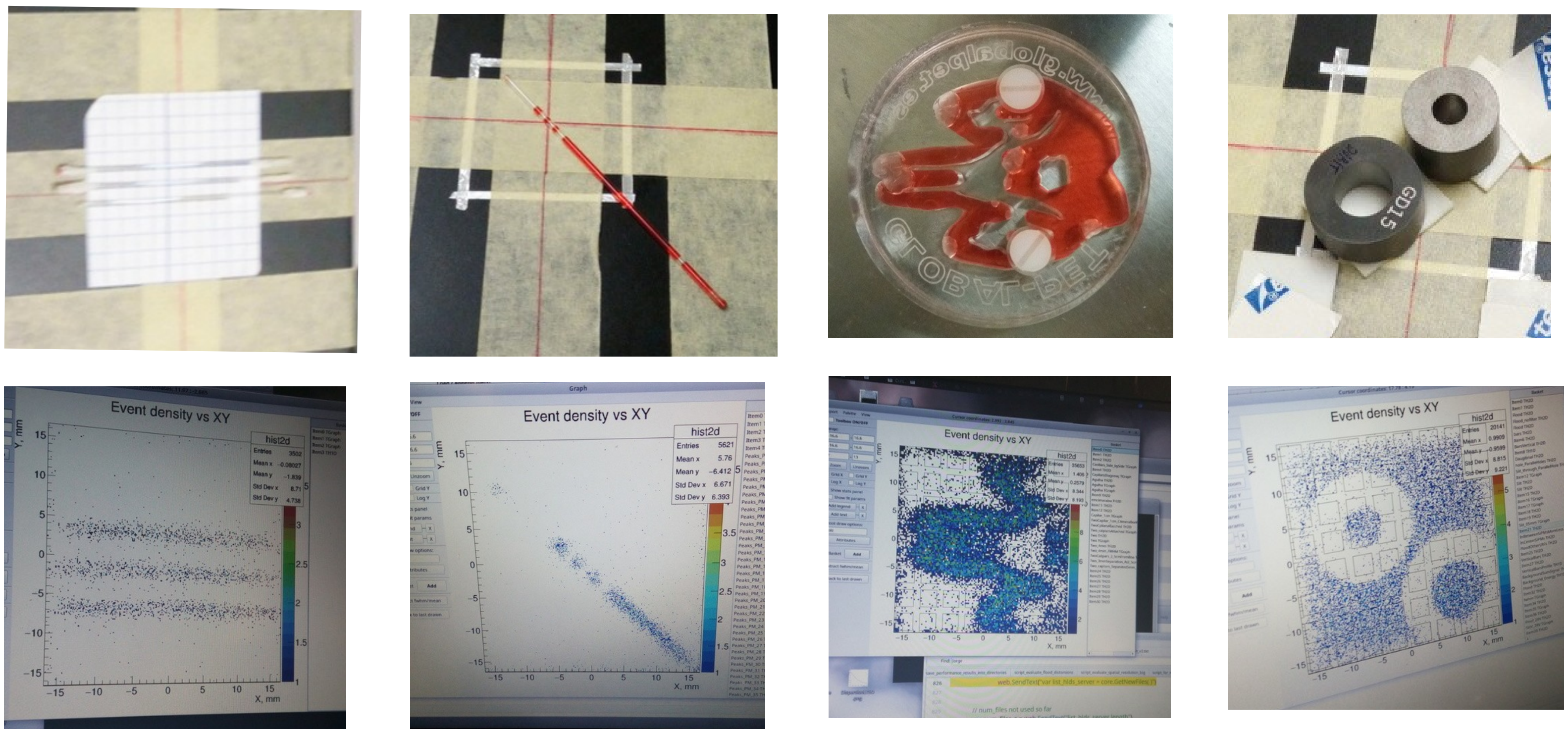
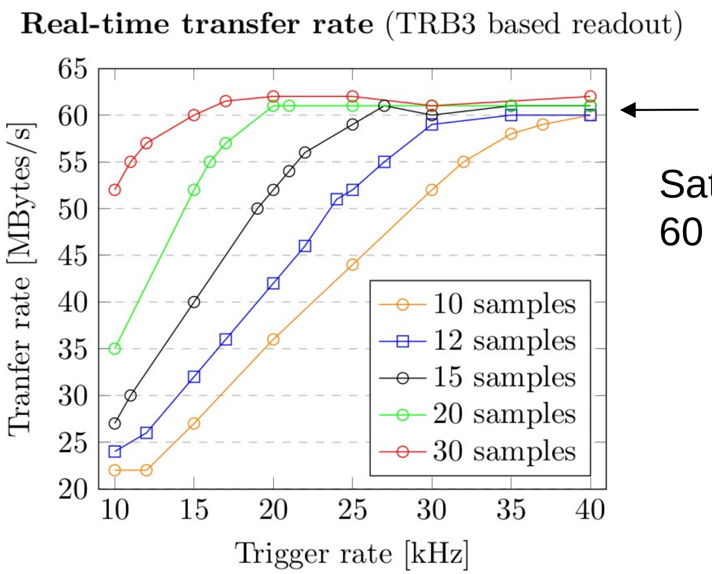
Snapshots of **ANTS2** reconstruction and visualization in real-time



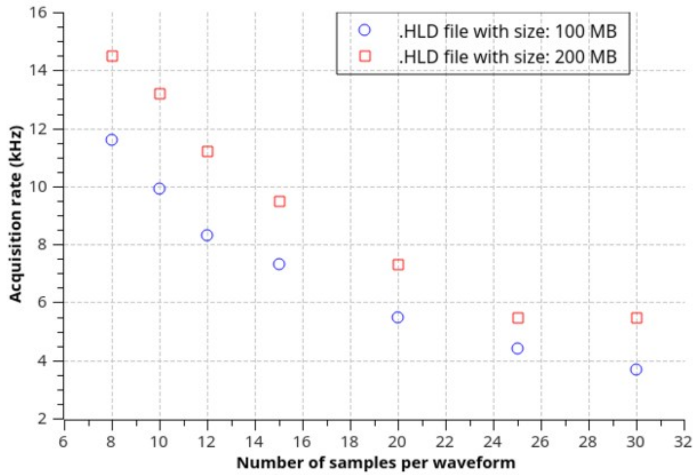
DAQ performance

Transfer rate

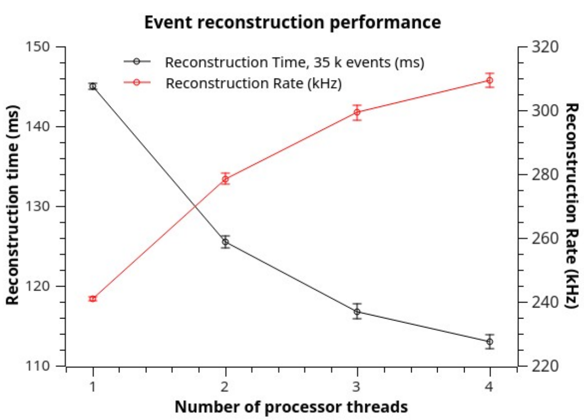


Saturation at 60 MBytes/s

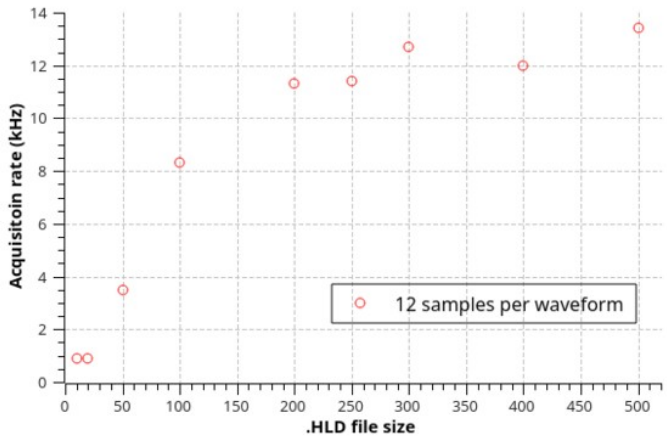
Acquisition rate *vs* # of waveform samples



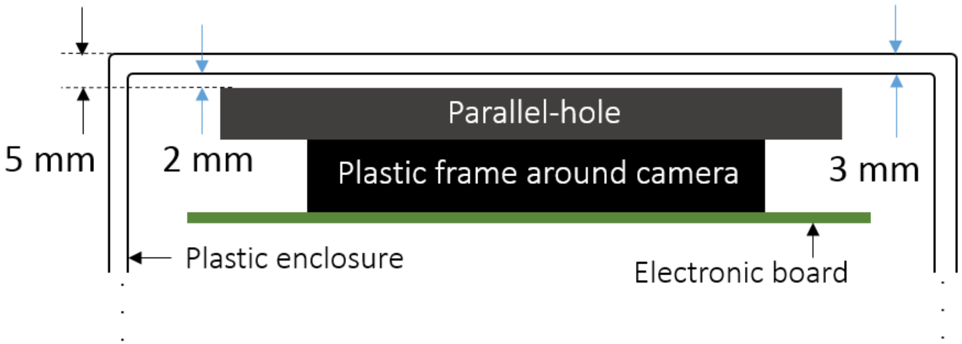
Reconstruction time vs # of used processor threads

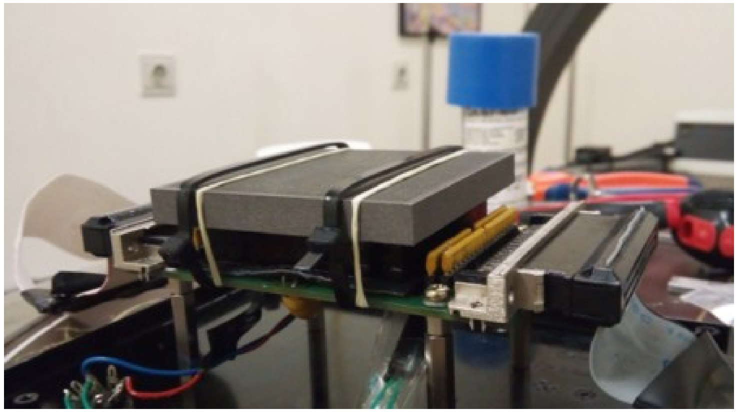


Acquisition rate *vs* size of data files (.HLD files)



Prototypes characterization

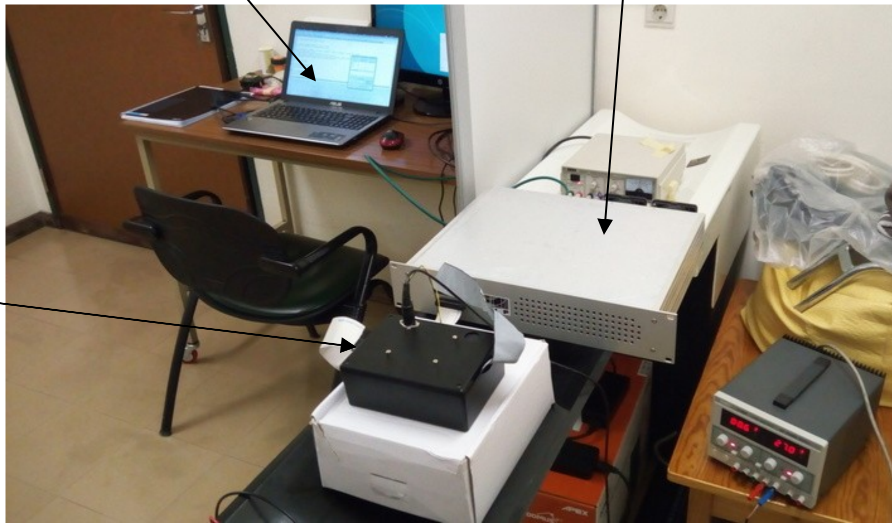




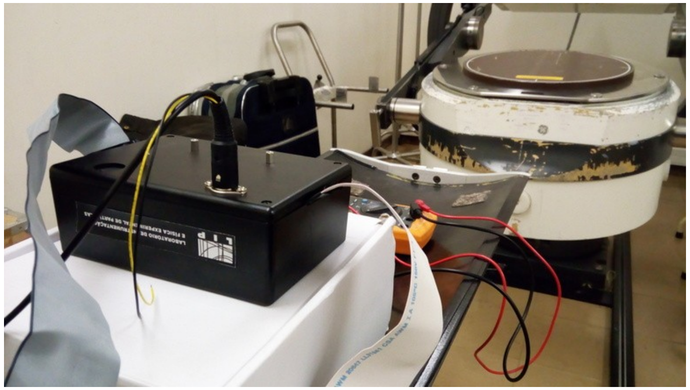
Performed at **University Hospital of Coimbra** in collaboration with Eng. Jorge Isidoro, Eng. Paulo C. Gil, Drª Gracinda Costa and Dr. Rodolfo Silva

Control and storage (PC + mini-PC)

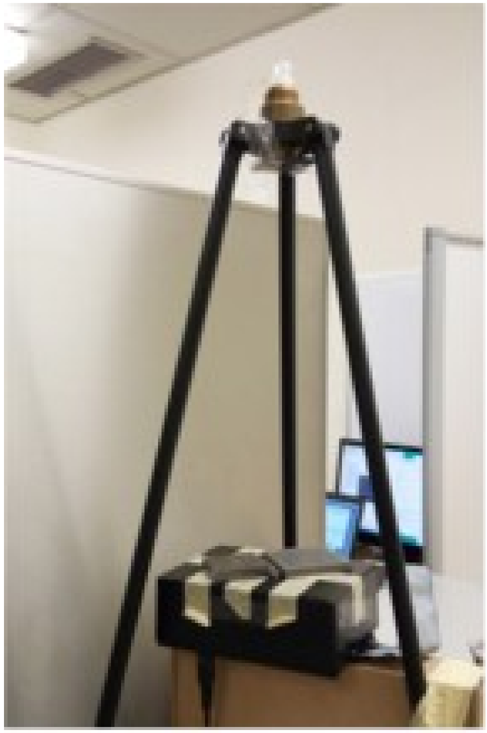
Readout system box

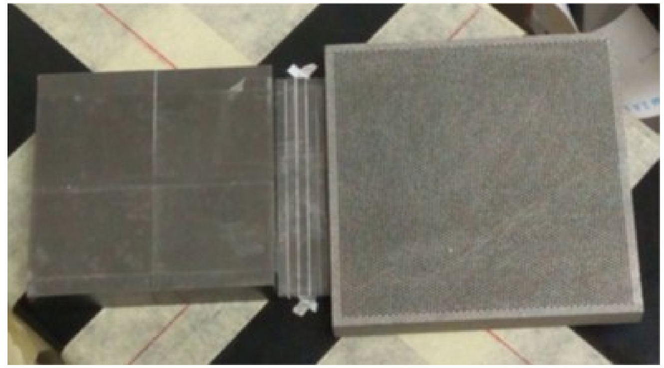


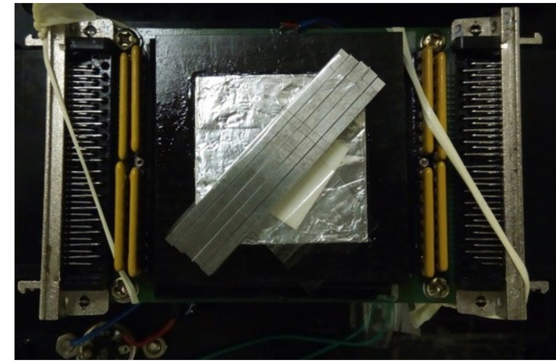
Compact gamma camera

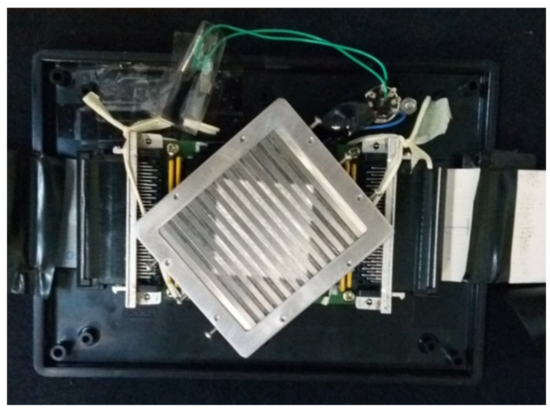


Masks and phantoms





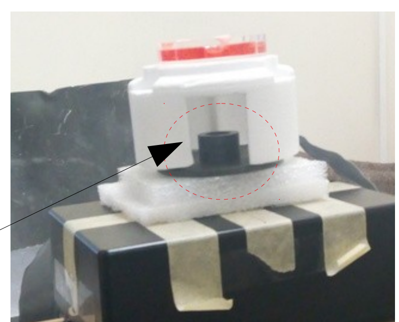


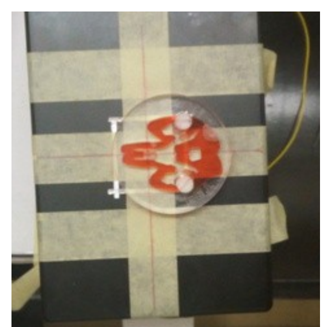


Capillary tube

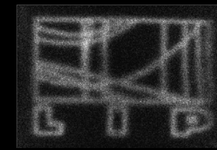
“Brain slice”

Pinhole collimator





Intrinsic assessment



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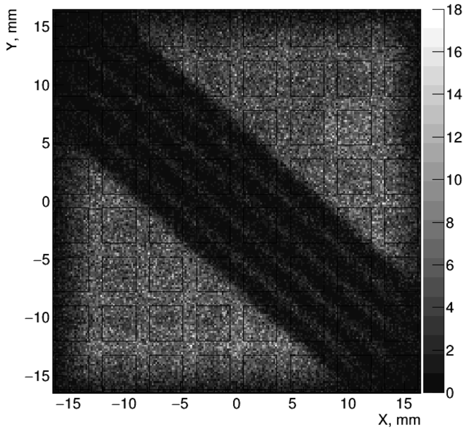
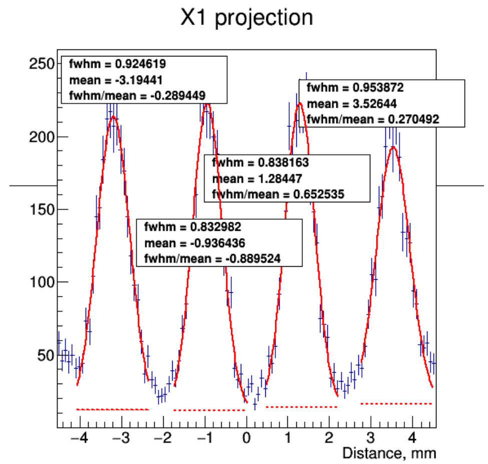
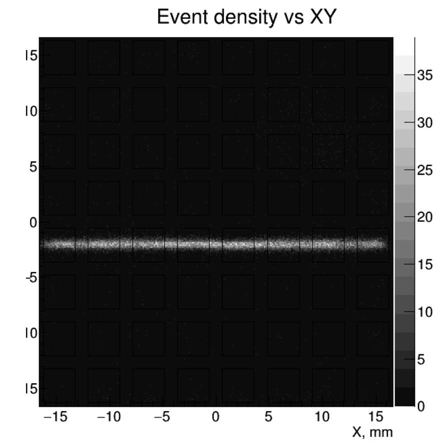
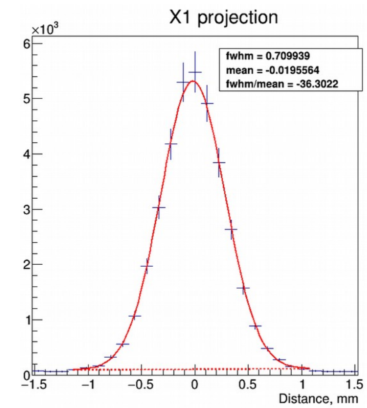
Spatial resolution

GAGG prototype: **0.9 mm FWHM** | LYSO prototype: **0.72 mm FWHM**

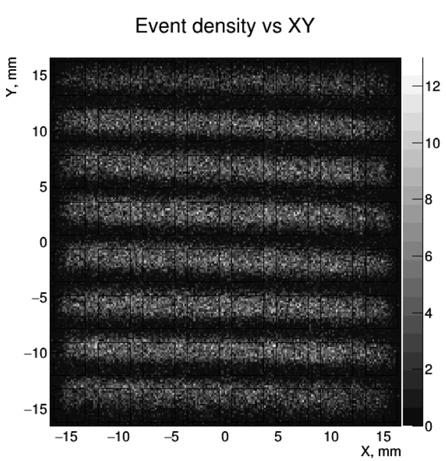


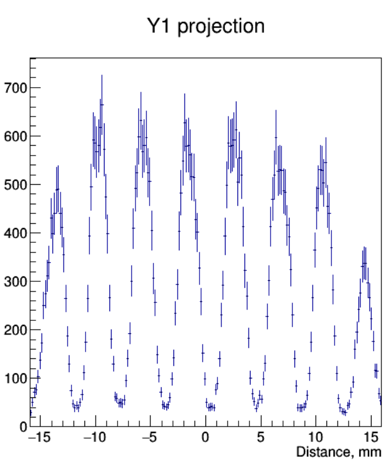


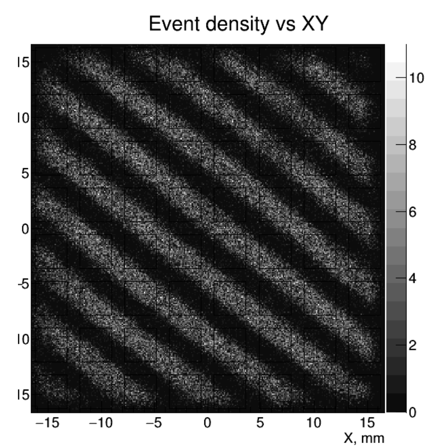


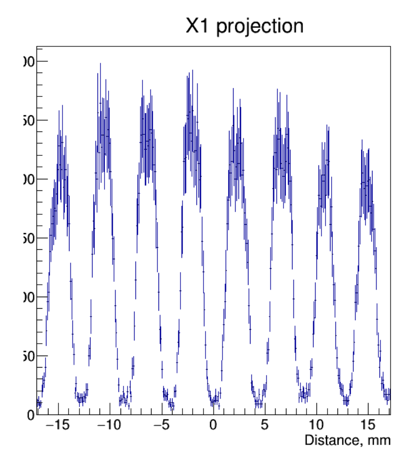


Linearity

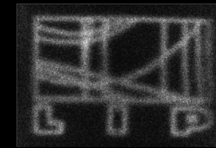








Extrinsic spatial resolution



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Parallel-hole collimator

^{99m}Tc source solution inside a capillary tube

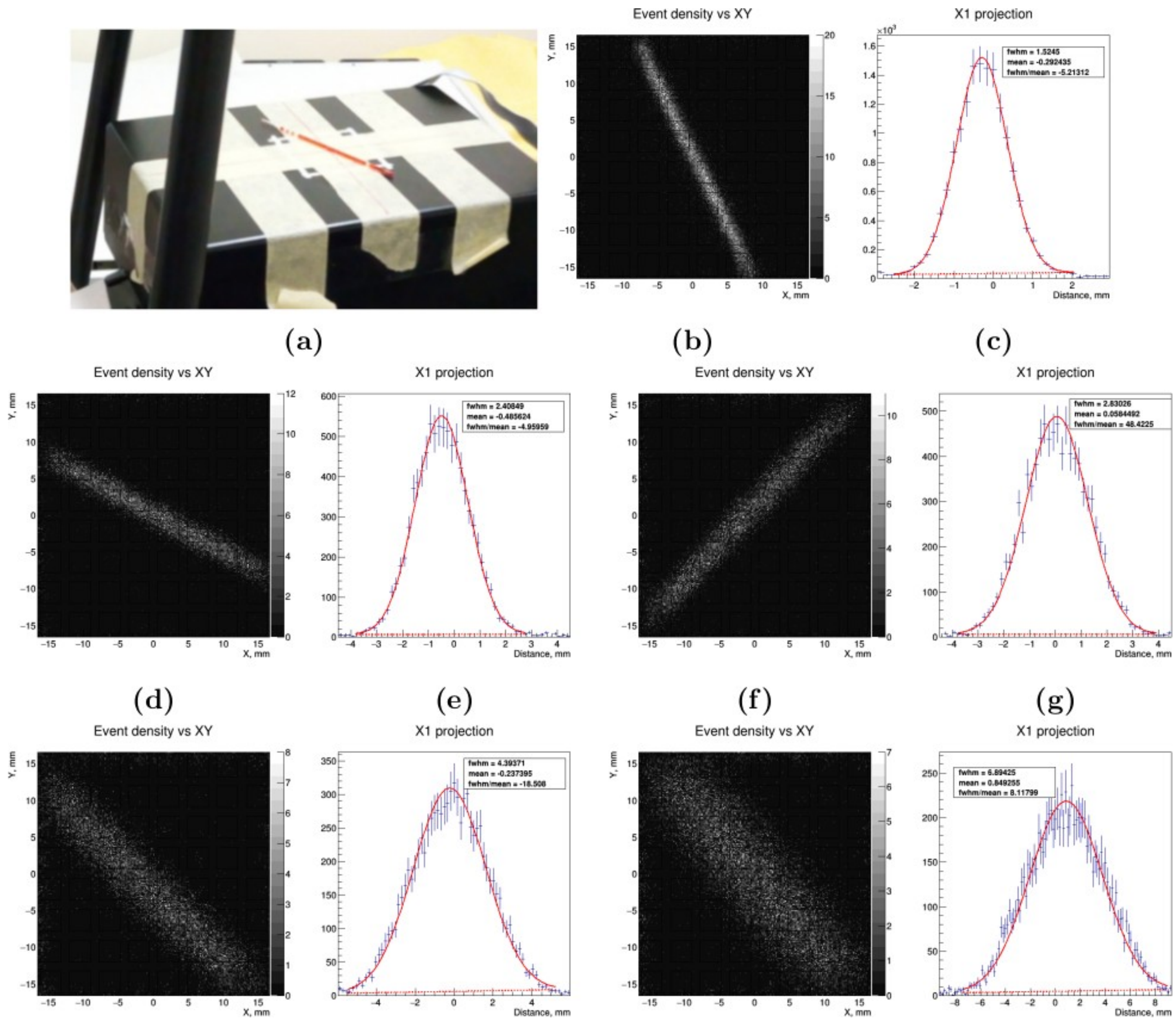
Measured (FWHM):

1.5 mm at 5.8 mm

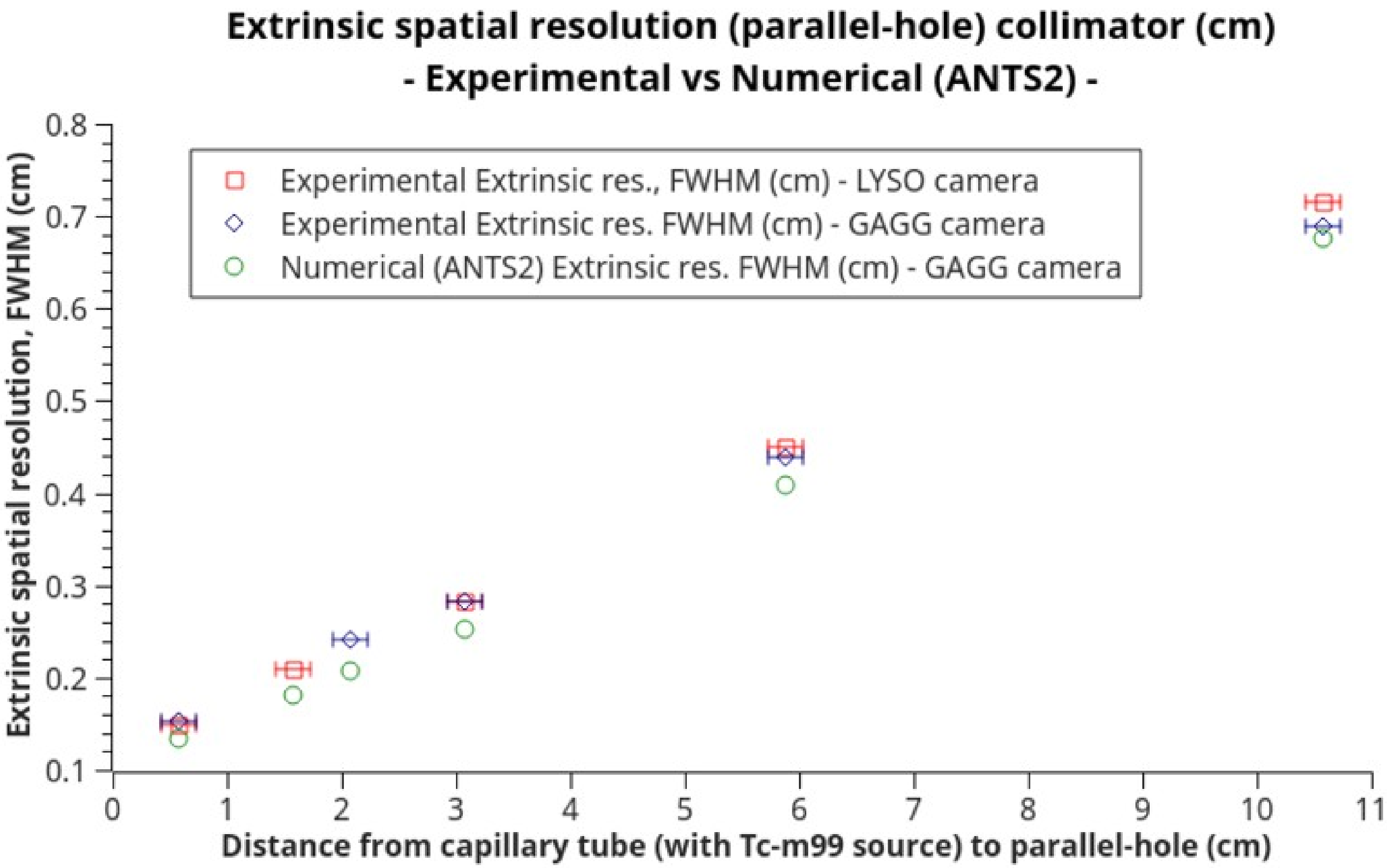
2.8 mm at 31 mm

4.4 mm at 60 mm

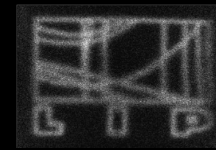
7 mm at 106 mm



Extrinsic spatial resolution



Extrinsic spatial resolution



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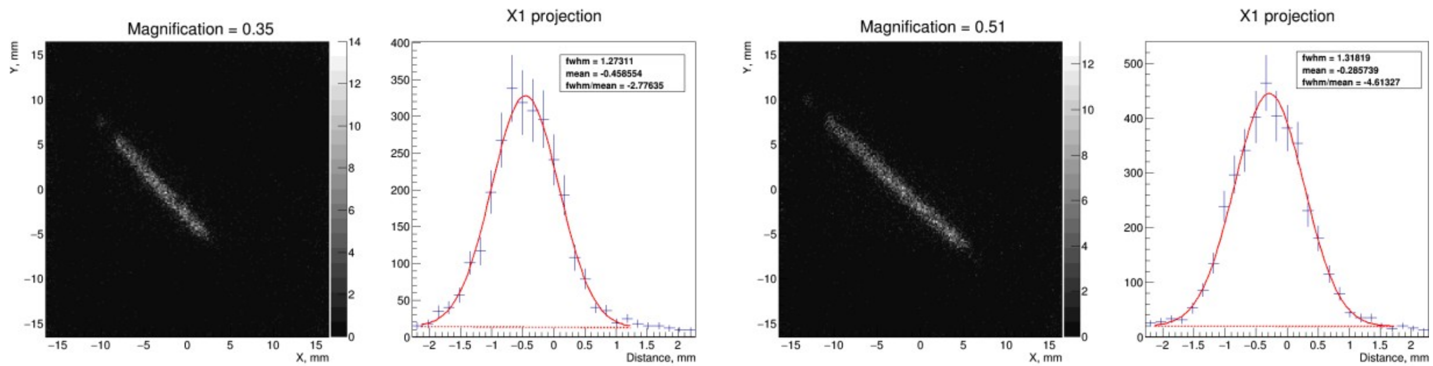
M = 0.36, FWHM = 1.27 mm
(object res. = 3.53 mm FWHM)

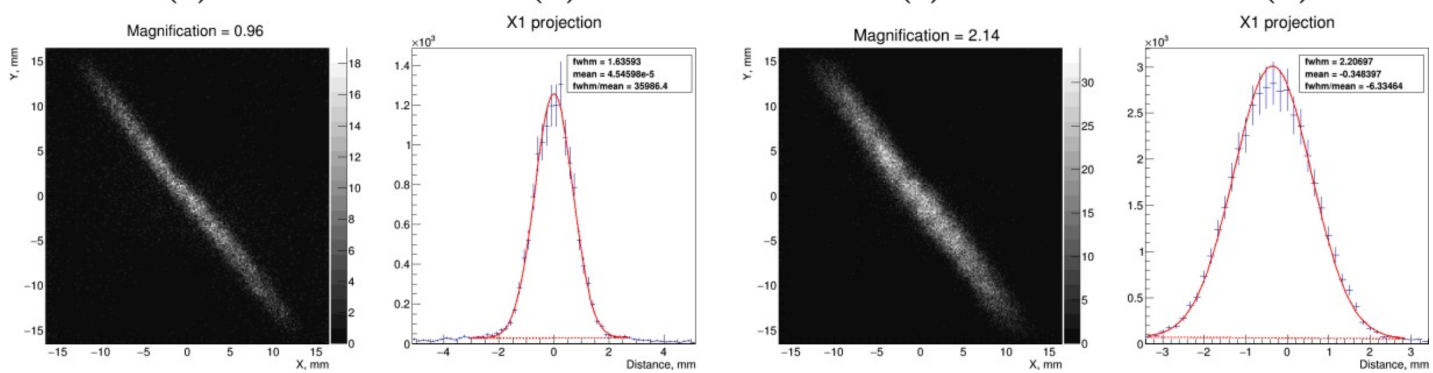
M = 0.50, FWHM = 1.31 mm
(object res. = 2.62 mm FWHM)

Pinhole collimator

^{99m}Tc source solution inside a capillary tube



(a) (b) (c) (d)



M → magnification factor

M = 1.0, FWHM = 1.64 mm
(object res. = 1.64 mm FWHM)

M = 2.24, FWHM = 2.21 mm
(object res. = 0.98 mm FWHM)

Resolution at the object plane = spatial resolution at the detector plane divide by M.

Phantom imaging

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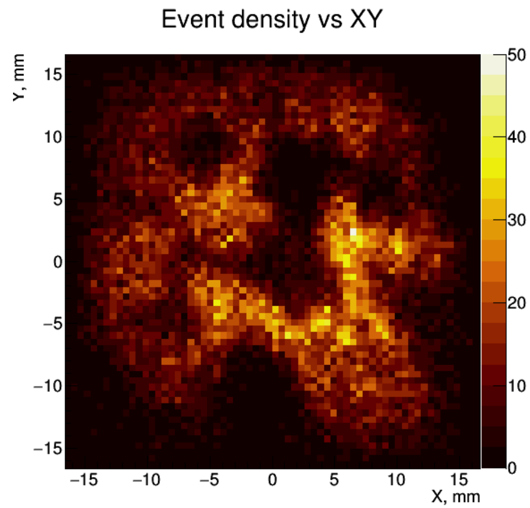
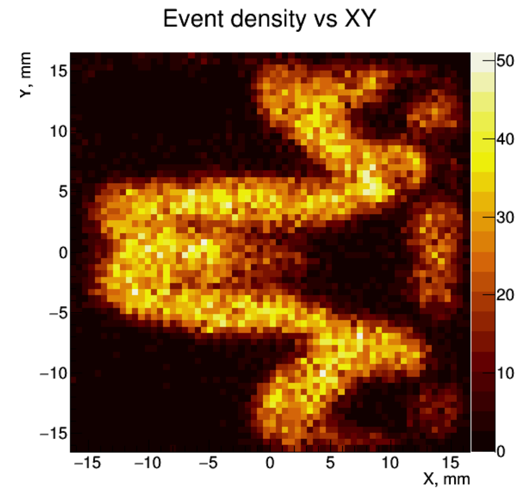
Brain slice phantom

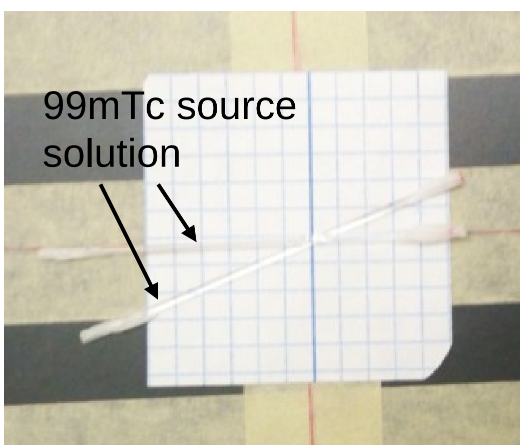
Pinhole collimator

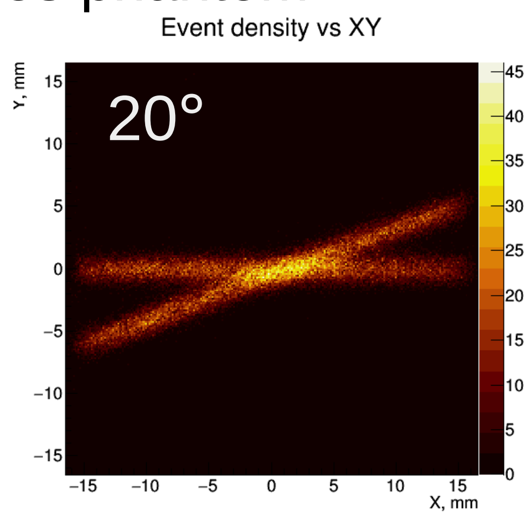


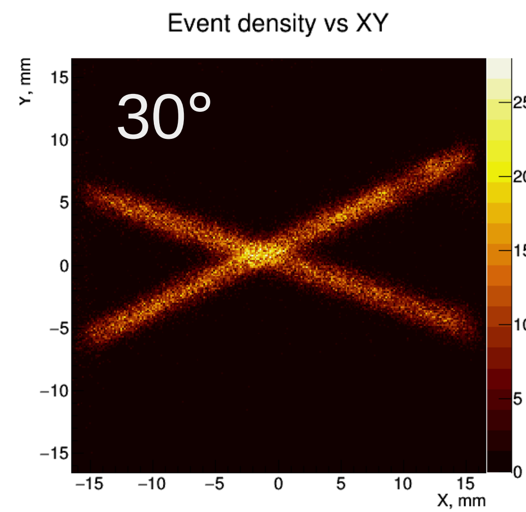
Parallel-hole collimator



Crossed capillary tubes phantom







Conclusions and future work

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Summary of developed work

- Lightguide optimization for GAGG prototype
- Two collimators designed and manufactured
- Assembed two compact gamma camera prototypes
- Development of 64-channel FEE and readout system

- Assessment of prototype intrinsic performance:
    - *LYSO prototype*: 0.72 mm FWHM
    - *GAGG prototype*: 0.90 mm FWHM
    - Absolute linearity better than 0.3 mm

- Gamma camera resolution (with collimator):
    1.0 mm FWHM (pinhole and 2x magnification)
    1.5 mm FWHM at 6 mm source to parallel-hole collimator

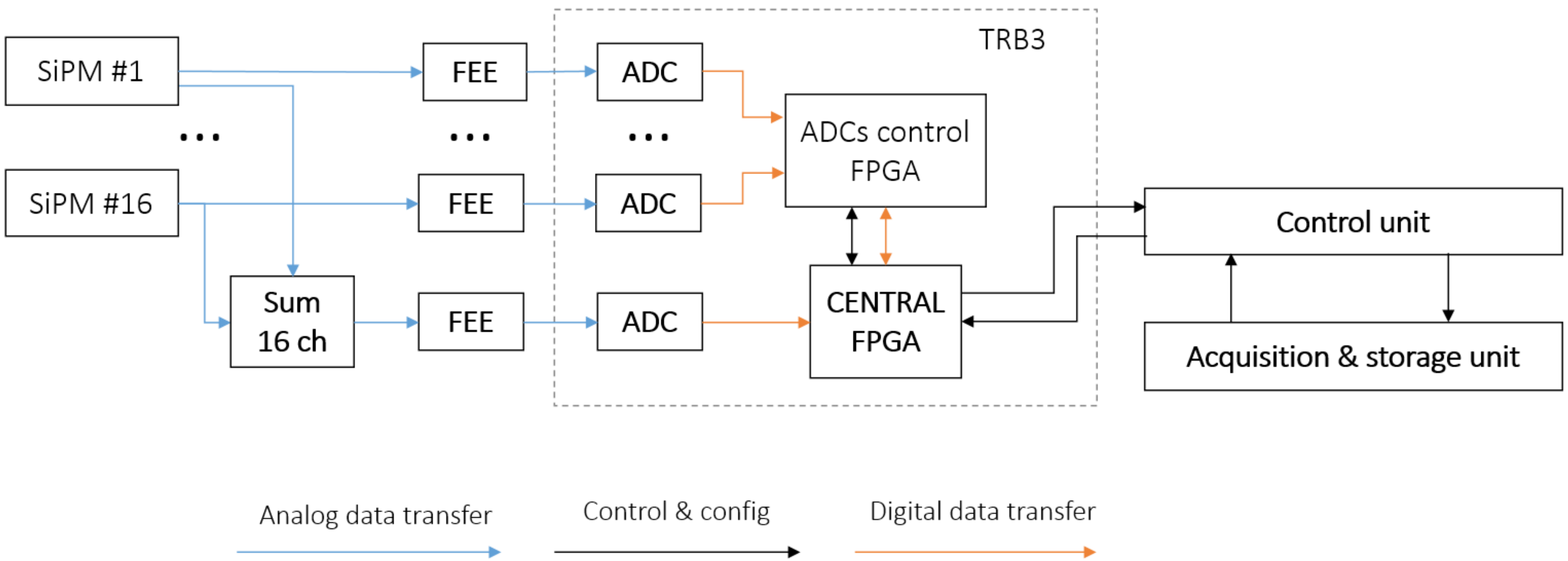
Future work

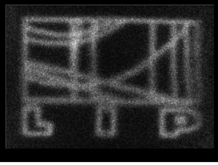
- Clinical test of full-scale camera (50x50 mm²) for thyroid imaging at nuclear medicine department of University Hospital of Coimbra

Thank you.

EXTRA MATERIAL

ACQUISITION ELECTRONICS CHAIN



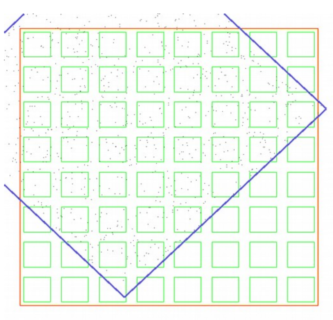


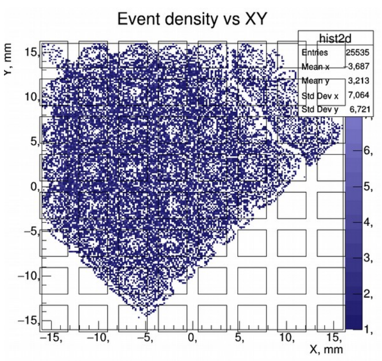
Self-organizing maps

SOM is an unsupervised iterative learning algorithm that has a training phase.

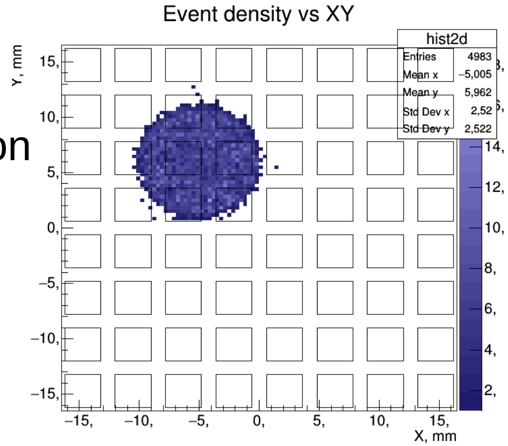
For a gamma camera response model, a bi-dimensional map (grid of cells) is built saving in each cell a vector with the average sensor signals which correspond to a source position at the camera FOV.

In the reconstruction phase, the event position is obtained as the cell position for which the vector of expected signals has the smallest Euclidean distance to the vector of measured signals.

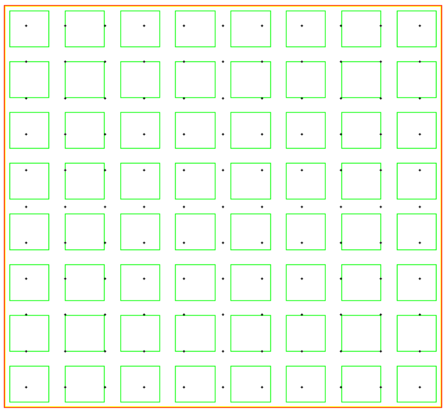


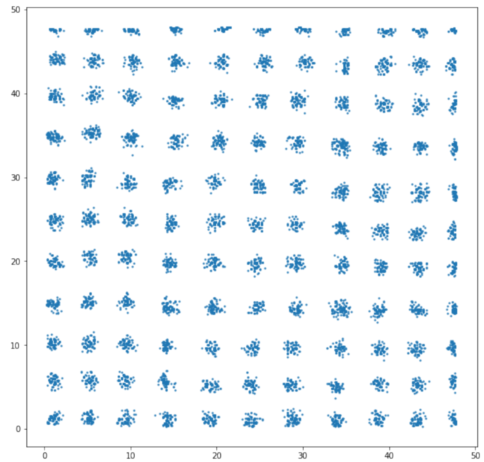


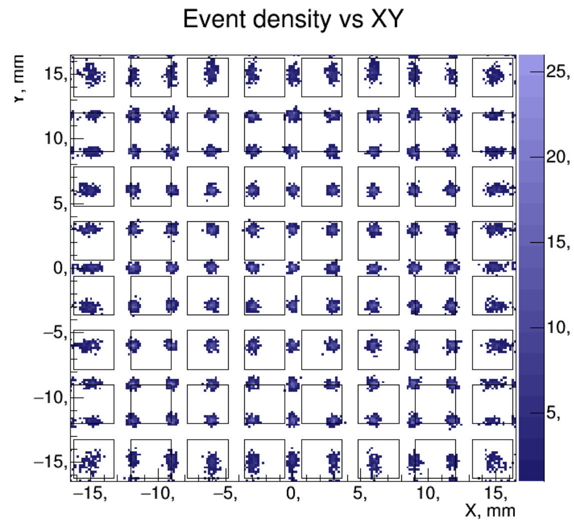
SOM reconstruction of a source with a round shape



Grid of 11x11 pencil beam sources





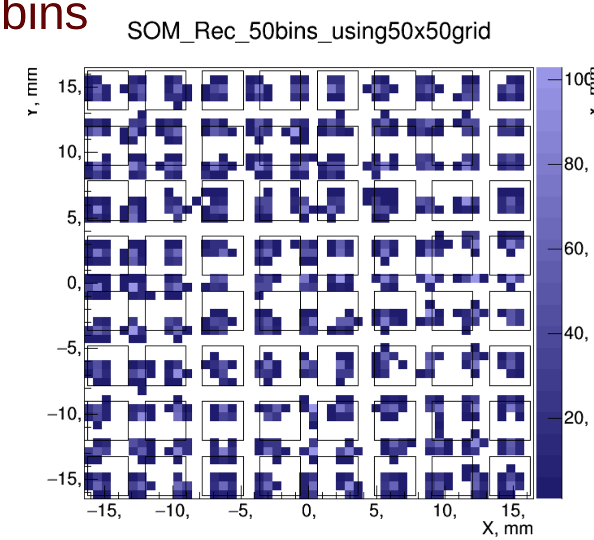


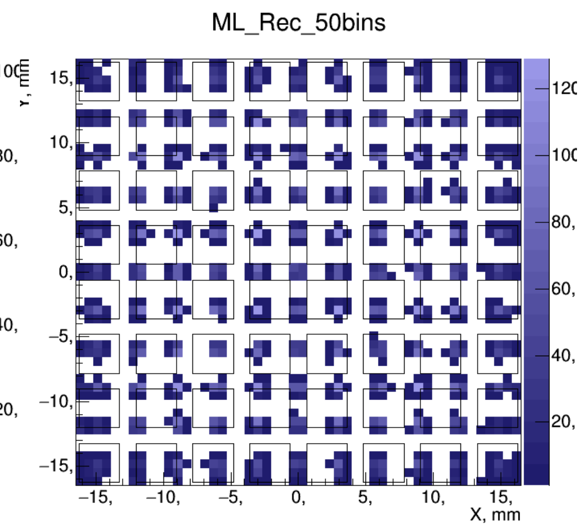
SOM rec.

ML rec.

Only 50 bins

SOM reconstructs better the events in the camera periphery

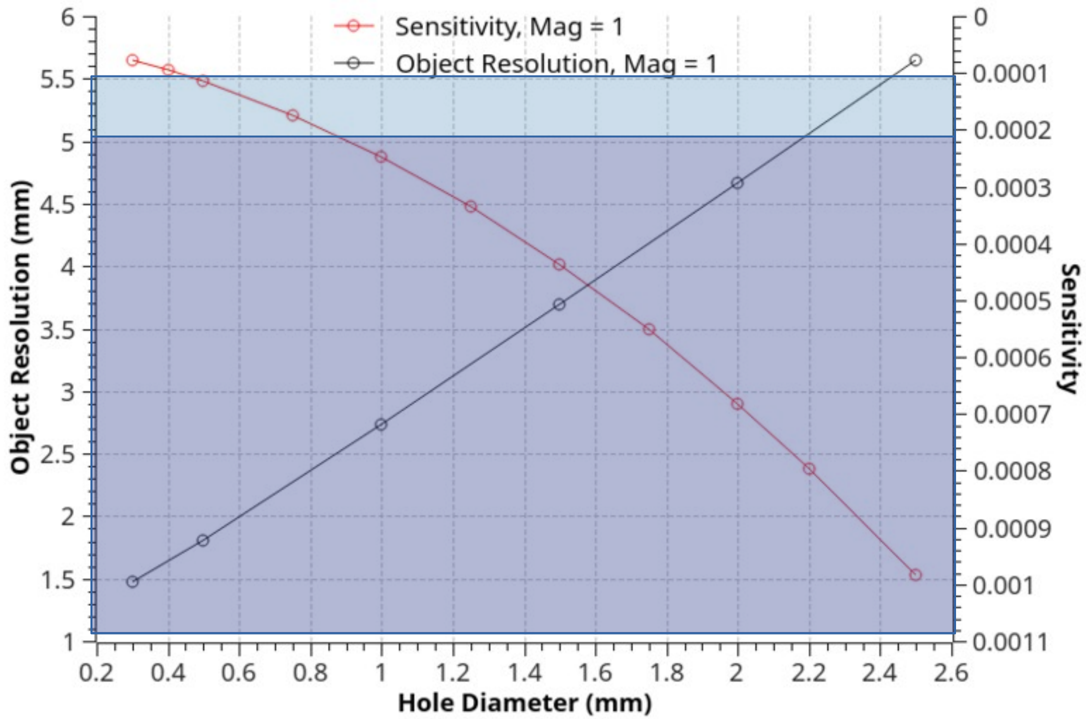




Collimators design

Pinhole collimator trade-of curves

Acceptable region of sensibility   Acceptable region for resolution

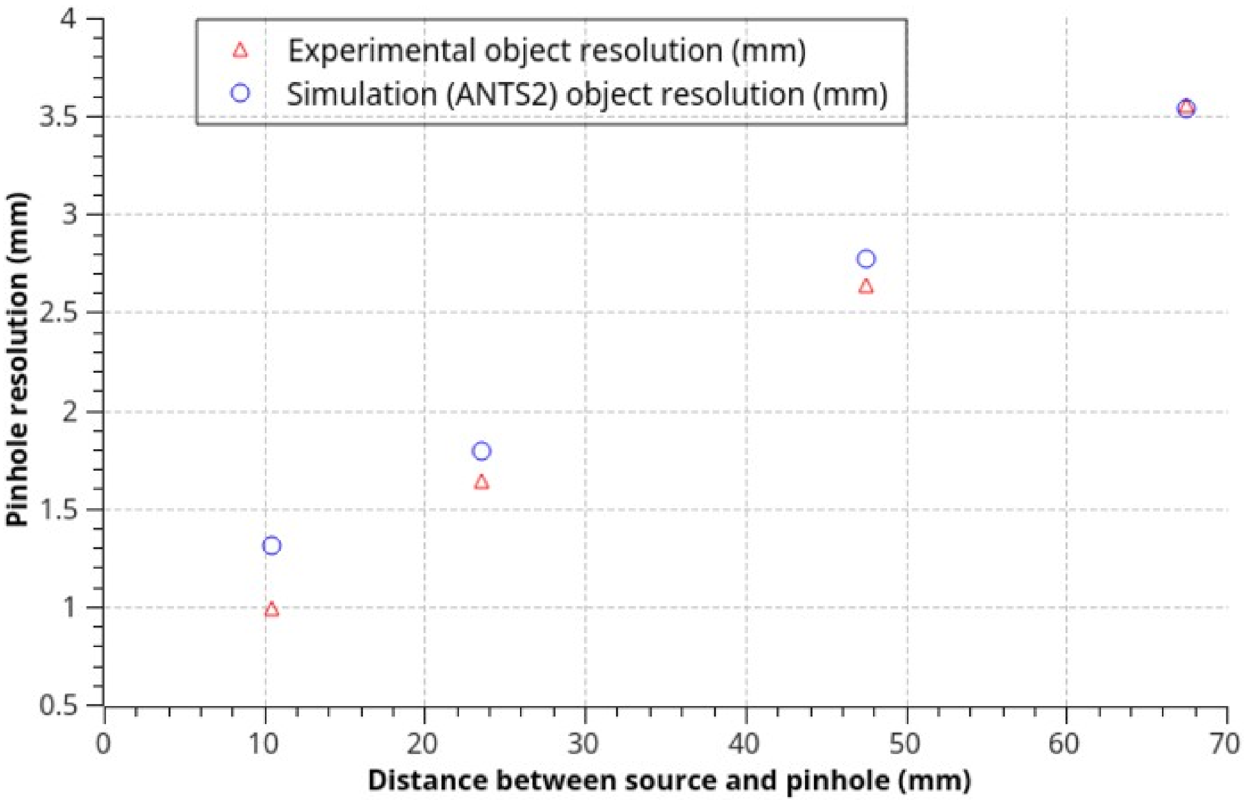


Target parameters:

Spatial resolution:
< 0.5 cm at 5 cm (source-to-collimator)

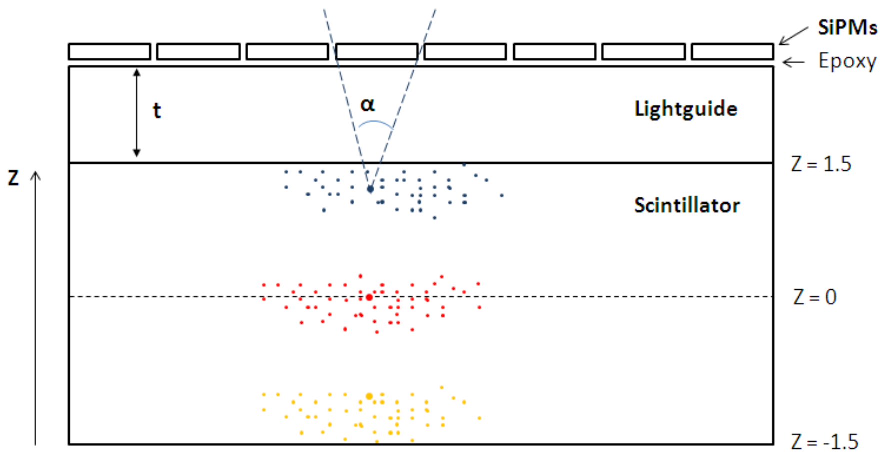
Efficiency:
> 0.0001
(**100 cps/MBq**)

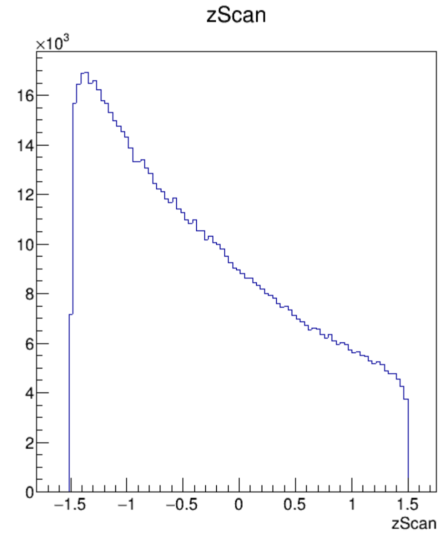
Extrinsic assessment



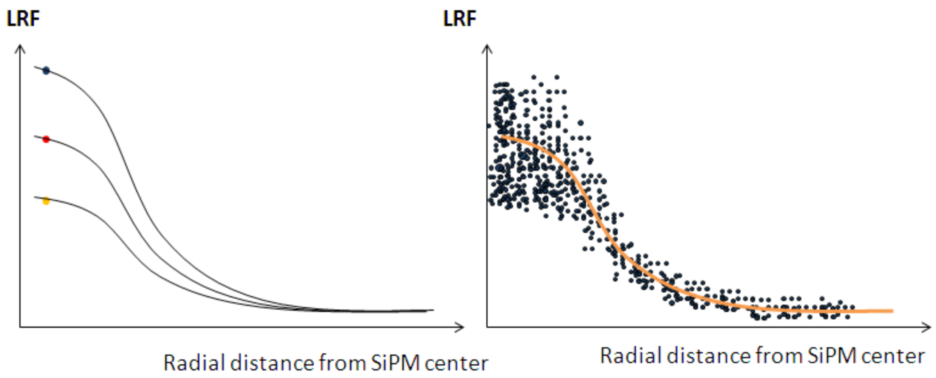
Depth of interaction in GAGG

Depth of interaction in a **3 mm thick GAGG** scintillator





Ilustration of the light response function of a photosensor (camera response model)



Remover??

Compact camera optimization

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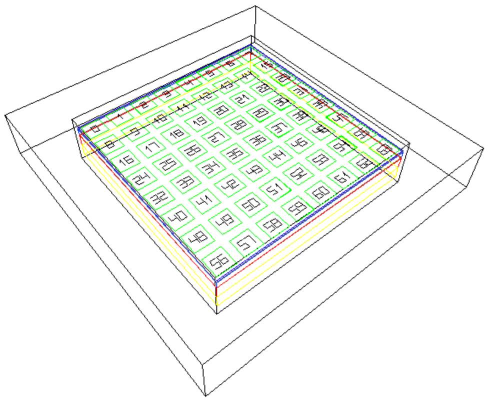
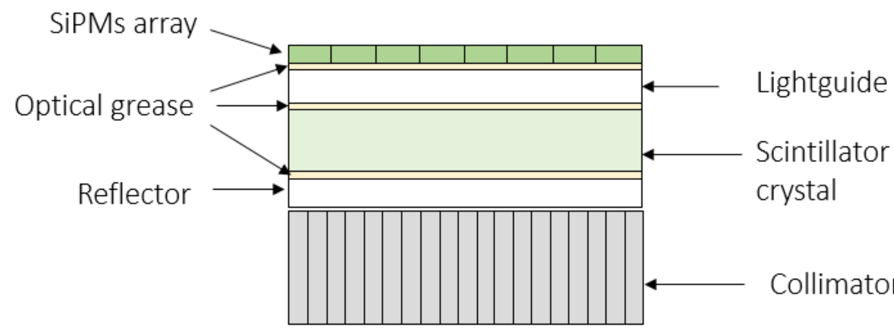
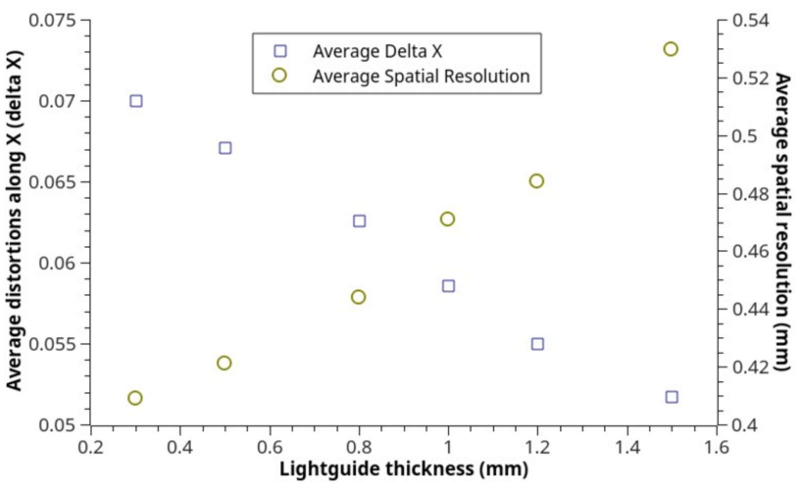
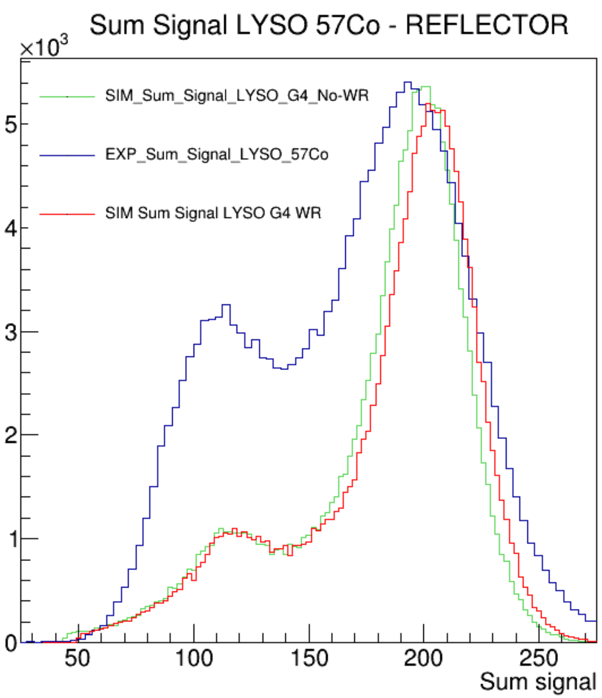
GAGG prototype optimization using ANTS2 and Geant4





Optimal lightguide thickness: 0.8 mm – 1.0 mm





Validation of collimators design equations

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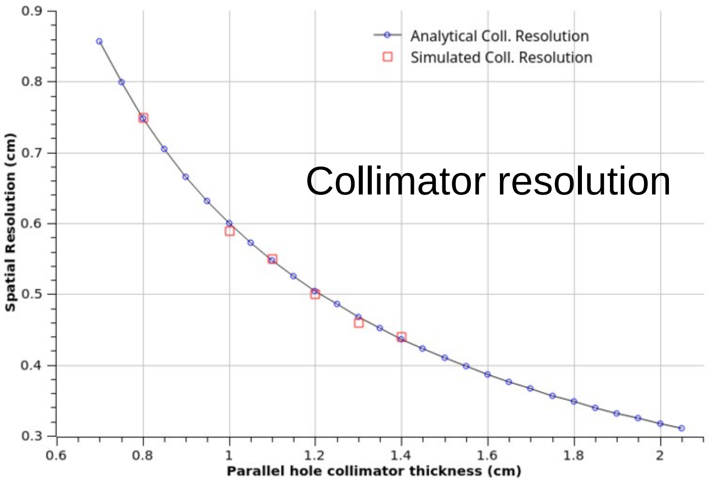
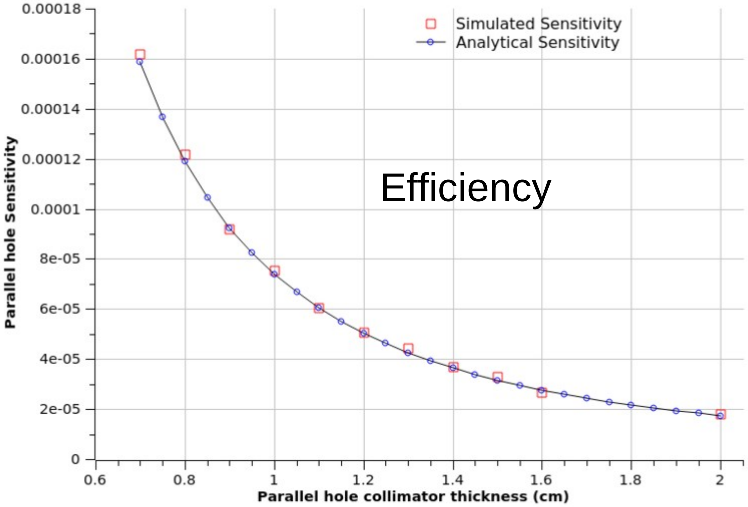
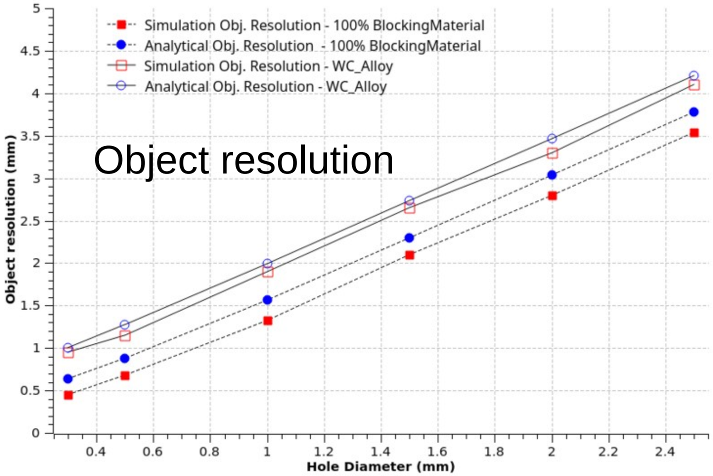
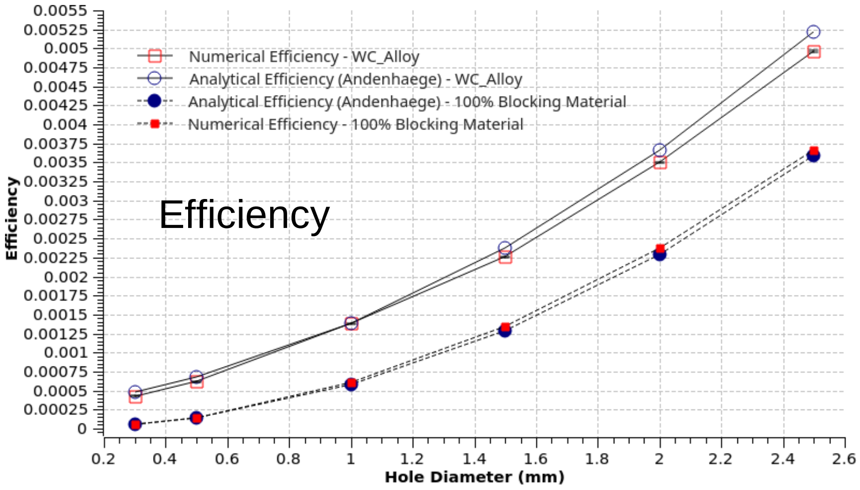
Parallel-hole collimator





Pinhole collimator (magnification factor = 2)





Prototypes performance

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Summary of prototypes performance

Prototype	Uniformity[a] Int, Diff X, Diff Y (%)	Linearity[b] Abs, Diff (mm)	Spatial resolution (mm)	Energy resolution (%)	Extrinsic spatial resolution (mm)		
					@ 6 mm (P.H.)[c]	@ 50 mm (P.H.)	@ 47 mm (Pin.)[d]
GAGG	72.6, 78.9, 79.9	0.214, 0.191	0.90	29	1.53	3.9	1.64
LYSO	77.7, 82.2, 82.7	0.269, 0.096	0.72	29	1.49	3.9	1.64

Table 6.3: Gamma camera prototypes performance parameters. The parameters were assessed for the UFOV of 28×28 mm^2. In the extrinsic spatial resolution assessment, the reported values correspond to distances measured from the source to the collimator face in the case of the parallel-hole collimator and to distances measured from the source to the detector in the case of the pinhole collimator.

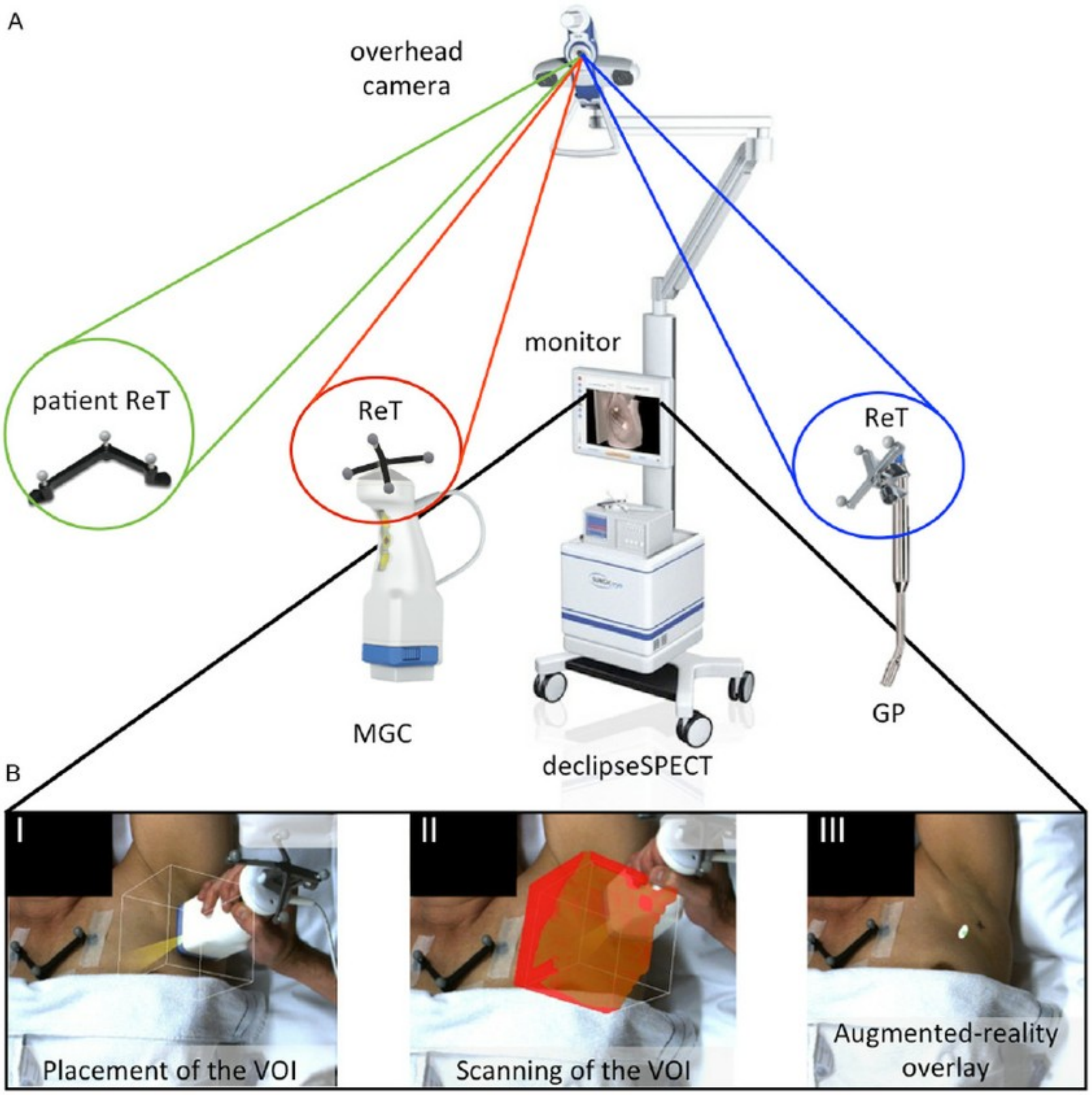
[a] Uniformity is reported as the integral (Int) and differential uniformity in X and Y (Diff X, Diff Y).

[b] Linearity is reported as the absolute (Abs) and differential (Diff) linearity, according to NEMA standard [82].

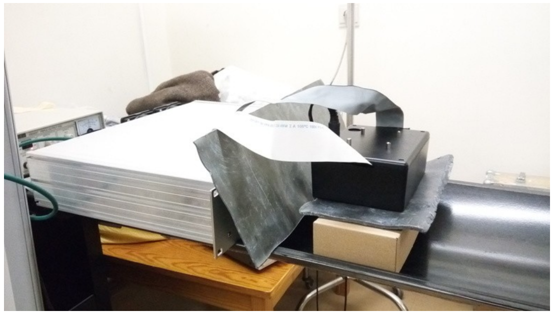
[c] "P.H." is a short for Paralle-hole collimator.

[d] "Pin." is a short for Pinhole collimator. Note that the focal lenght is 23.5 mm, so for a source-to-detector distance of 47 mm, the source-to-pinhole distance is also 23.5 mm, which results in no magnification.

Conclusions and future work



Prototypes characterization



Parallel bars
(manufactured in LIP workshop)