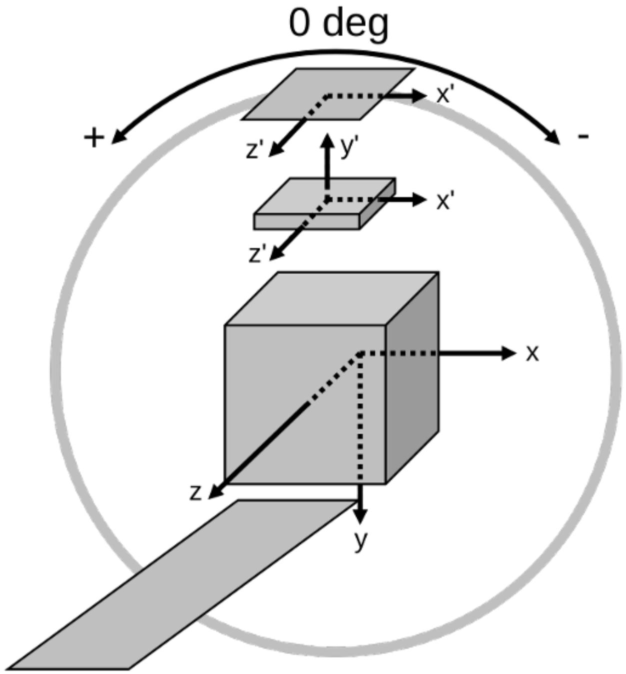

3D SPECT modelling integration for channel-edge pinhole collimators into the open-source STIR framework

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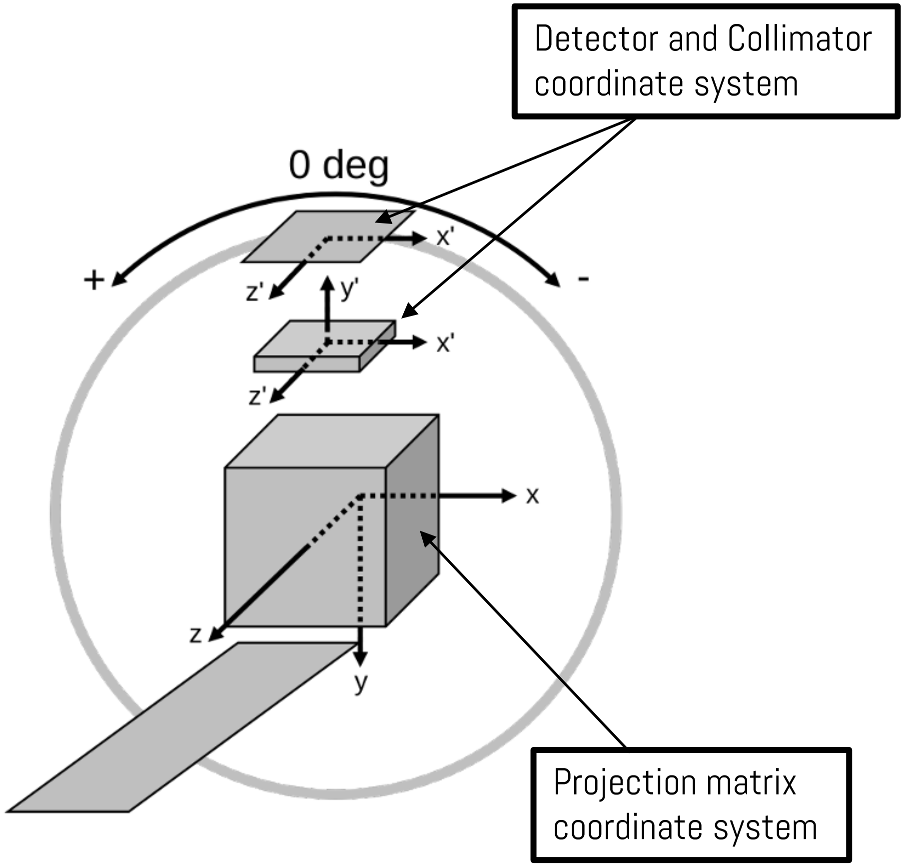
[6]Center of Medical Imaging Computing, UCL, London, UK.

2024 IEEE Nuclear Science Symposium and Medical Imaging Conference

Pinhole SPECT UB

Pinhole SPECT UB Framework



Projection data formatted in interfile:

- Projection matrix
- Pixel scaling factor
- Distance between the crystal surface and the system center of rotation

Detector file:

- Detector Point Spread Function (PSF)
- Depth of Interaction (DOI)
- Acquisition orbit

Collimator file:

- Geometry
- Type (only knife edge collimators were supported)

M. Strugari, C. Falcon, Kjell Erlandsson, B. F. Hutton, K. Brewer, and K. Thielemans, **"Integration of advanced 3D SPECT modelling for pinhole collimators into the open-source STIR framework,"** Frontiers in nuclear medicine, vol. 3, Apr. 2023, doi: https://doi.org/10.3389/fnume.2023.1134774.

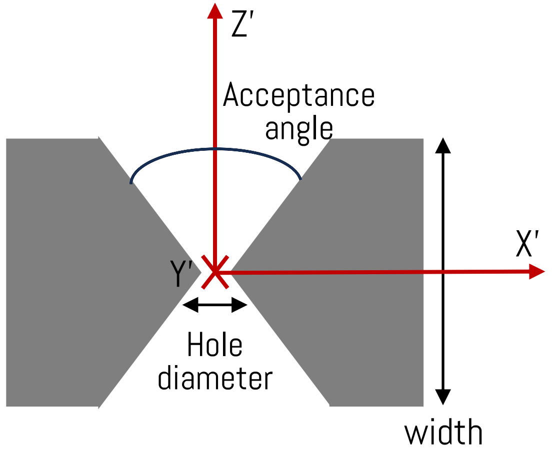
Pinhole SPECT UB

Detector file:
- Detector PSF (Point Spread Function)
- Depth of Interaction (DOI)
- Acquisition orbit

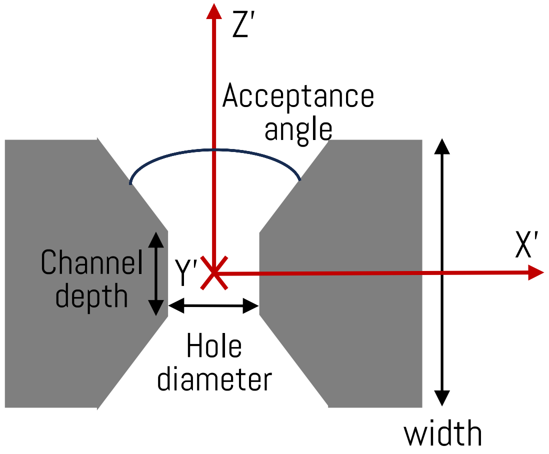
Collimator file:
- Geometry
- Type (only knife edge collimators were supported)

ProjMatrixByBinPinholeSPECTUB projector class
computes the system weight matrix

The system matrix weights determine the contribution of each image voxel along the line of response (LOR) to each detector element.

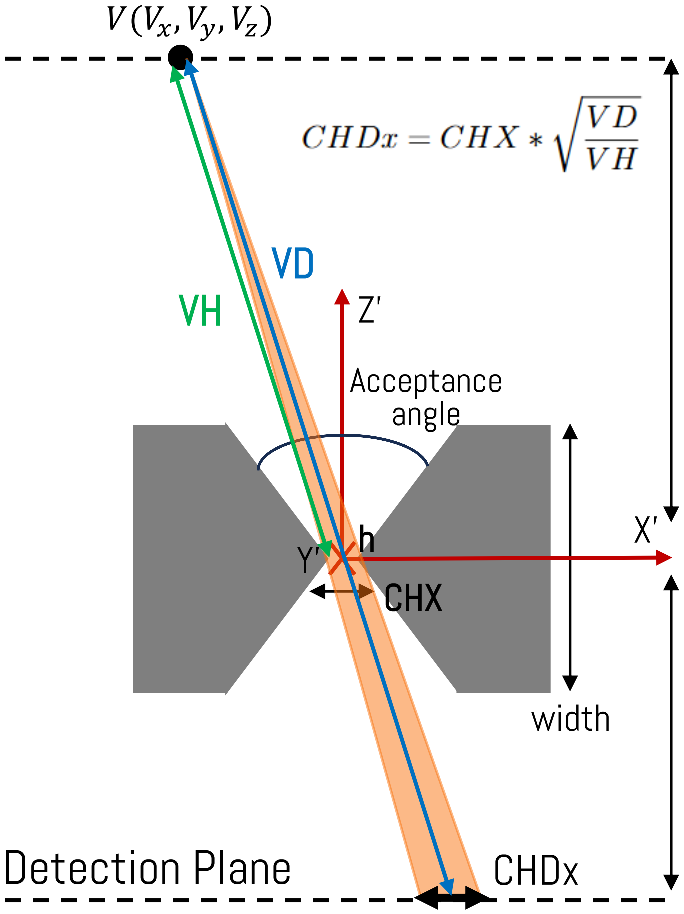


Channel-edge geometry implementation

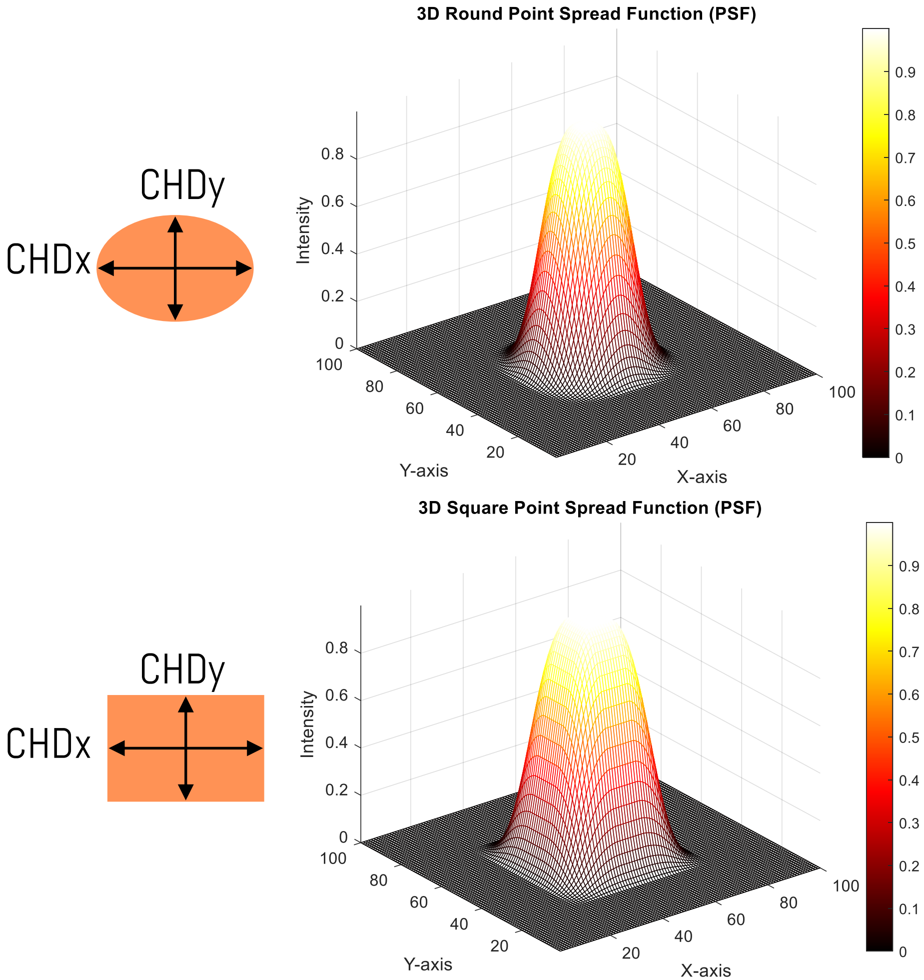


ProjMatrixByBinPinholeSPECTUB projector

The geometric approach to obtain the system weight matrix evaluates the area that each image voxel projects through the pinhole knife-edge hole onto the detection plane.



The obtained shadow of the hole is then reshaped according to the hole shape (square or round)



When applying PSF modelling, the projection of the channel is then convoluted with the intrinsic PSF of the detector to evaluate the system weight matrix.

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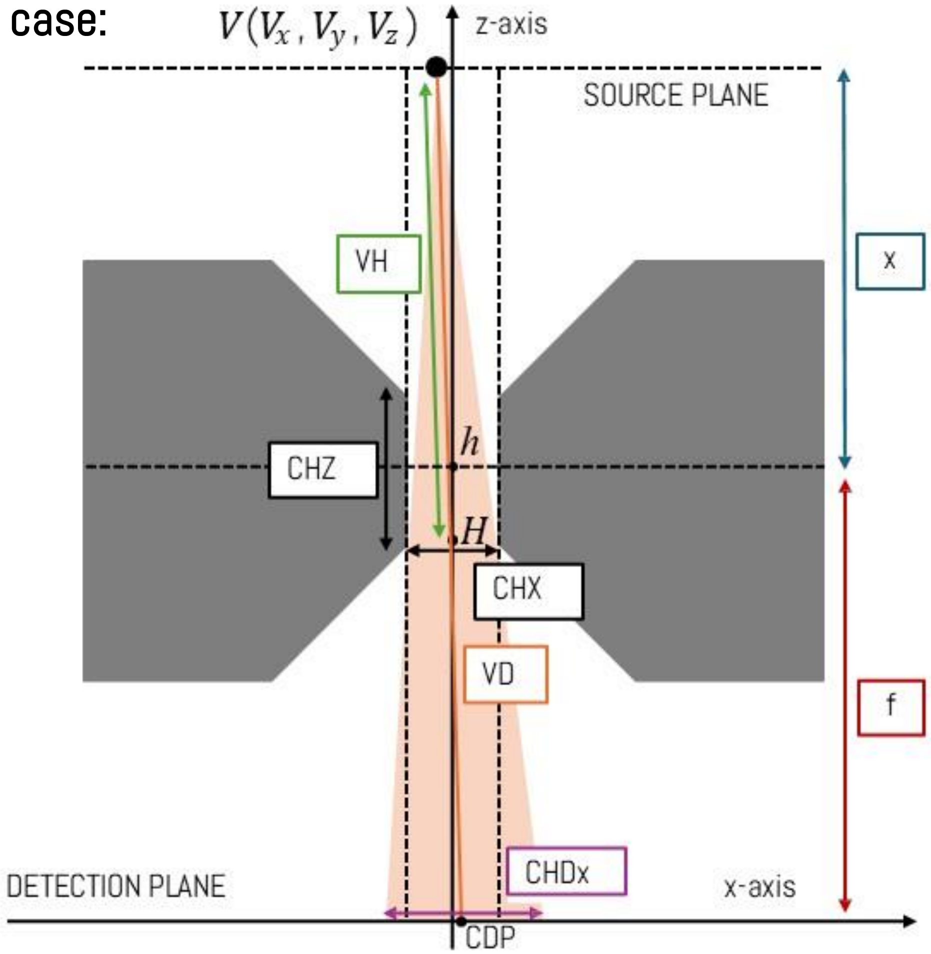
Channel-edge Implementation

The main difference between channel-edge collimator and knife-edge collimators is that **the effective size of the hole that is projected onto the detection plane, changes according to the voxel position in the image plane.** We need to divide the problem into three cases depending on the point position.

First case:



For simplicity, we consider the straightforward case of a point **V (Vx, Vy, Vz)** moving solely in the x direction

CHDx is the hole shadow onto the detection plane along the x-axis

$$CHDx = CHX * \sqrt{\frac{VD}{VH}}$$

VD is the distance from the voxel V to the detection plane passing through H

VH refers to the distance from the voxel V to point H

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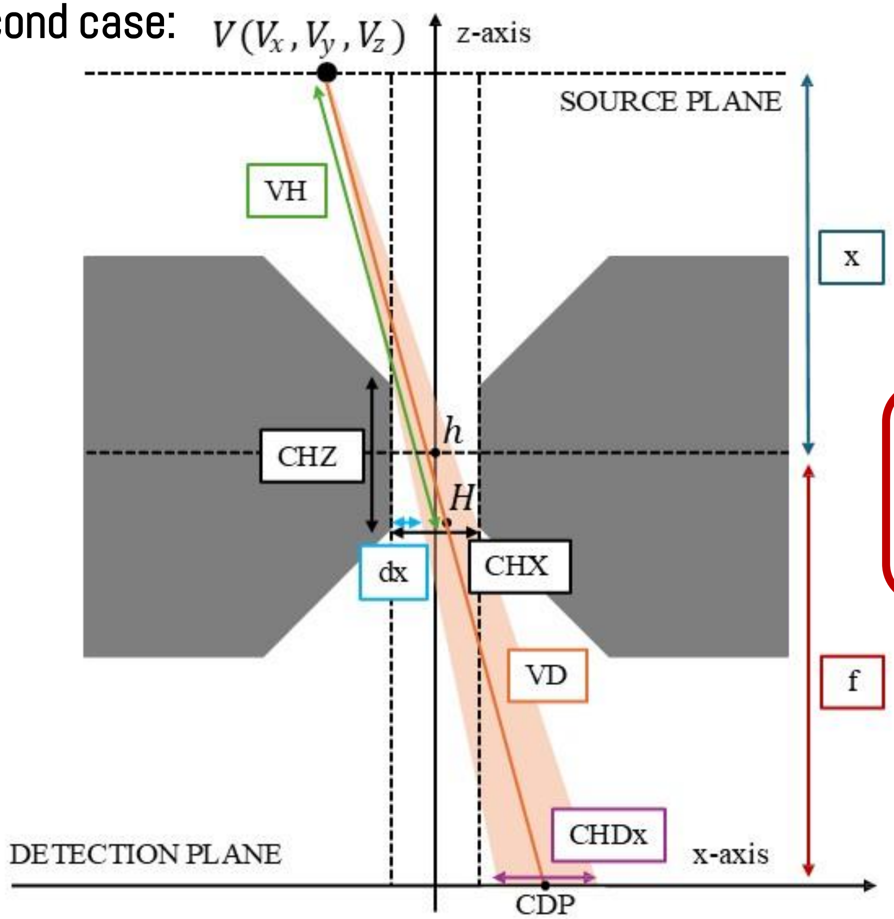
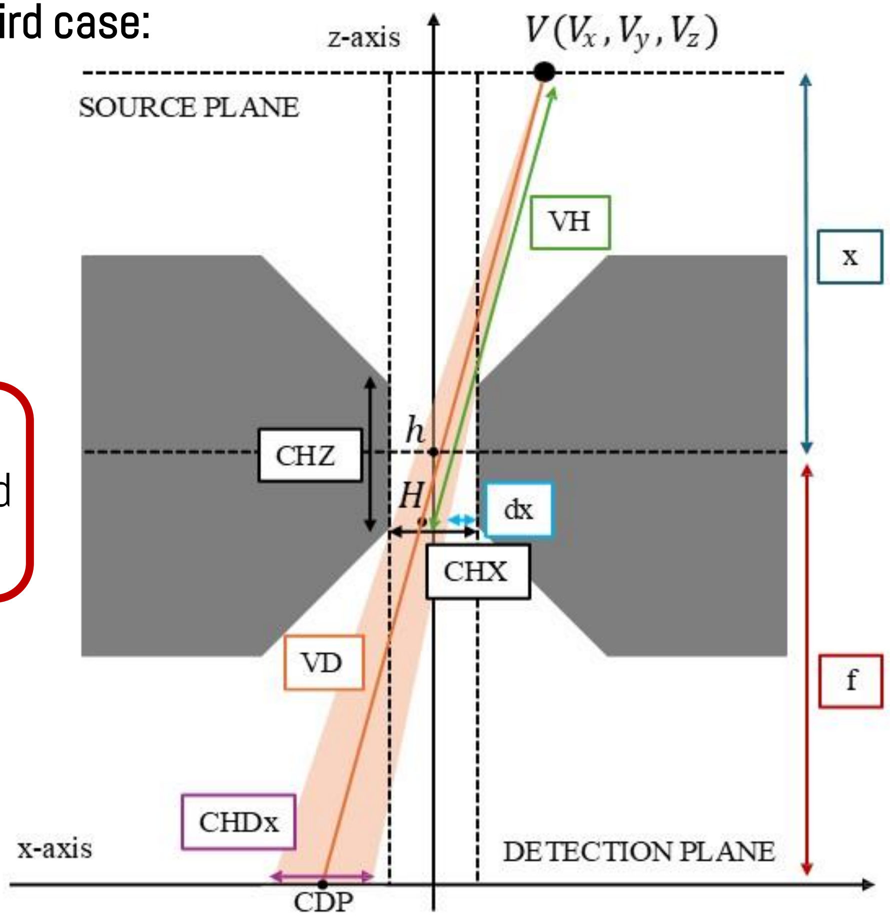
Channel-edge Implementation

Second case:



Third case:



The projected area shrinks approaching the minimum and maximum acceptance angle.

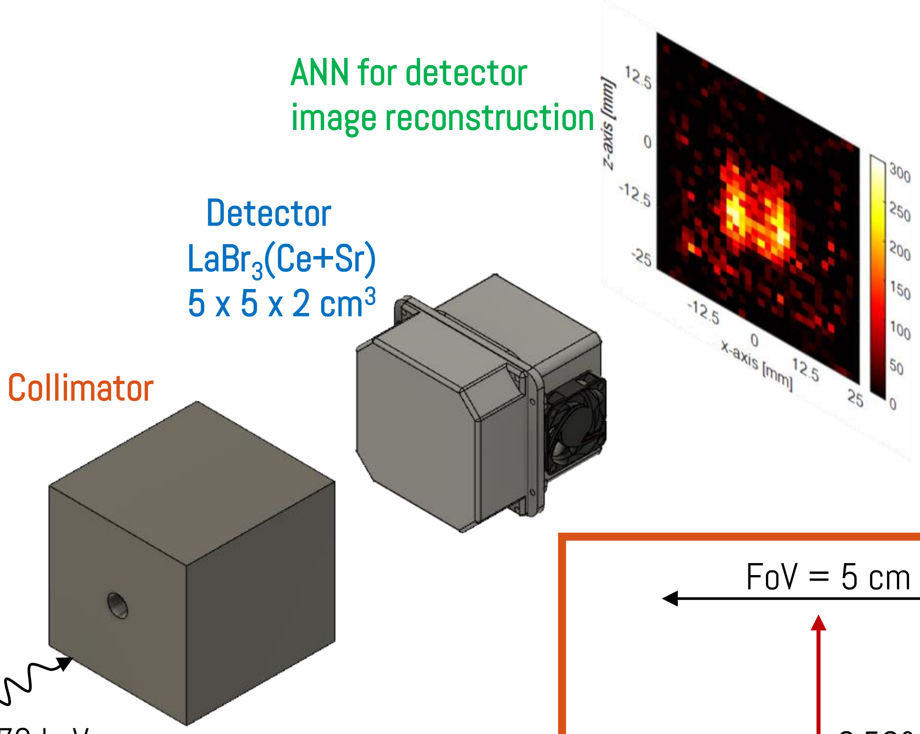
$$CHDx = (CHX - dx) * \sqrt{\frac{VD}{VH}}$$

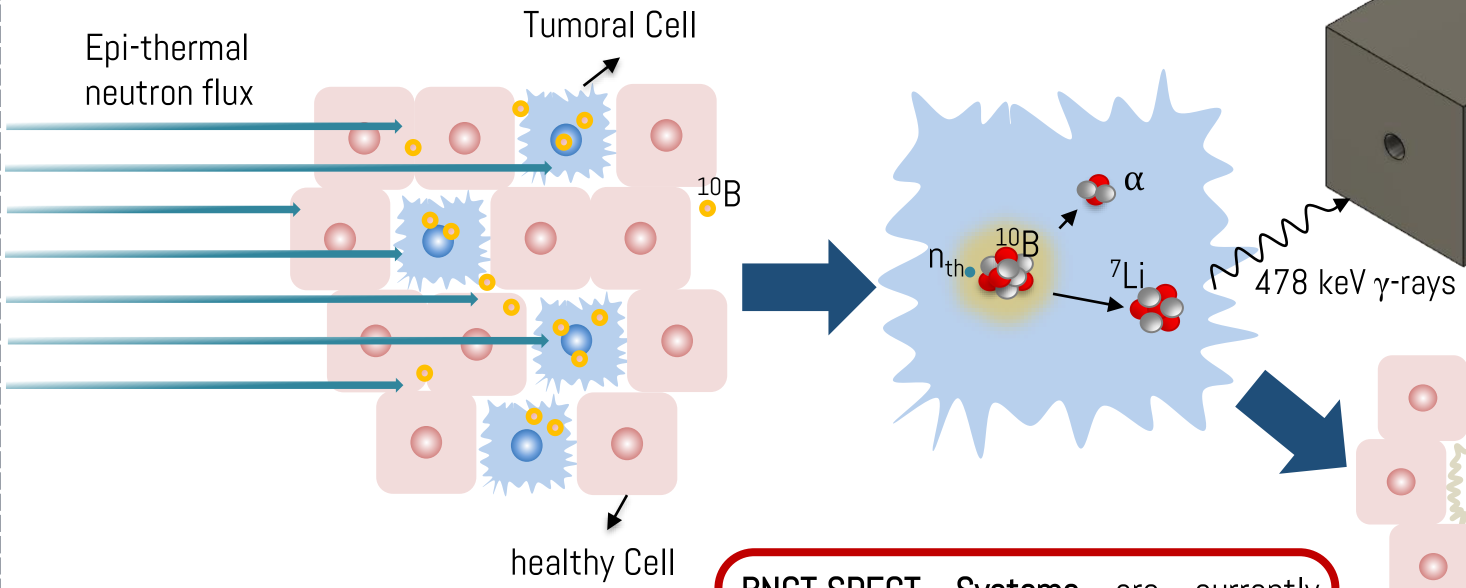
The reported calculations were extended in the code implementation to consider the y coordinate different from zero.

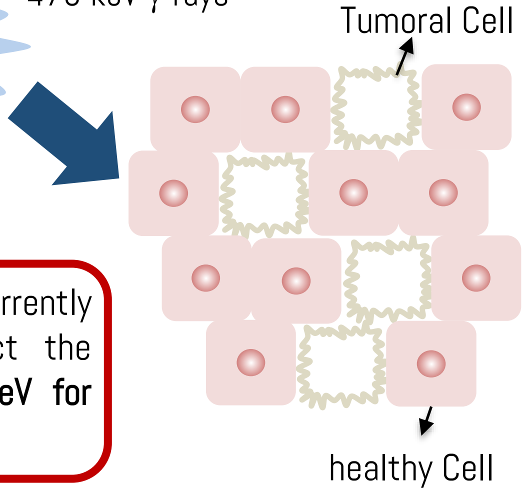
Testing and Validation

The code was tested on simulated and experimental data **using a channel-edge pinhole collimator designed for Boron Neutron Capture Therapy (BNCT)**

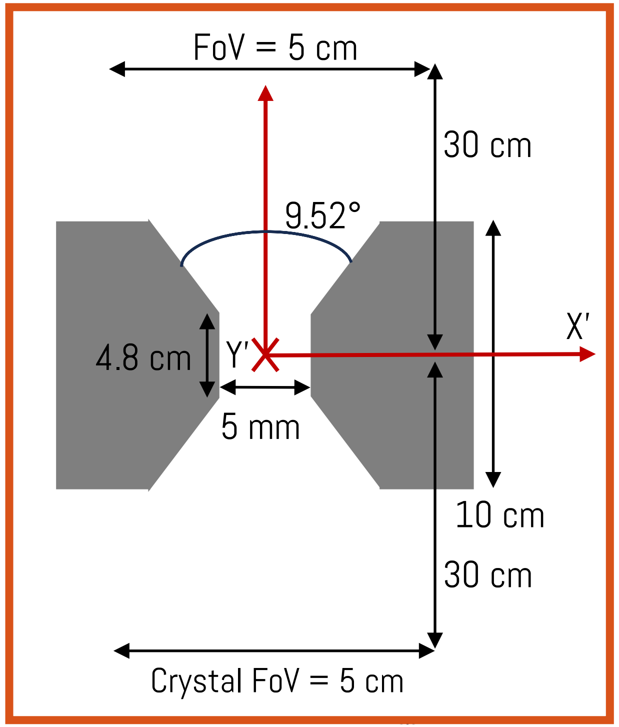
- In **BNCT,** Boron compounds are selectively absorbed by cancer cells;
- Tissues are irradiated with an **epi-thermal neutron flux**;
- **Neutron capture by** ^{10}**B** generates high-LET secondary particles, destroying cancer cells and sparing normal cells;





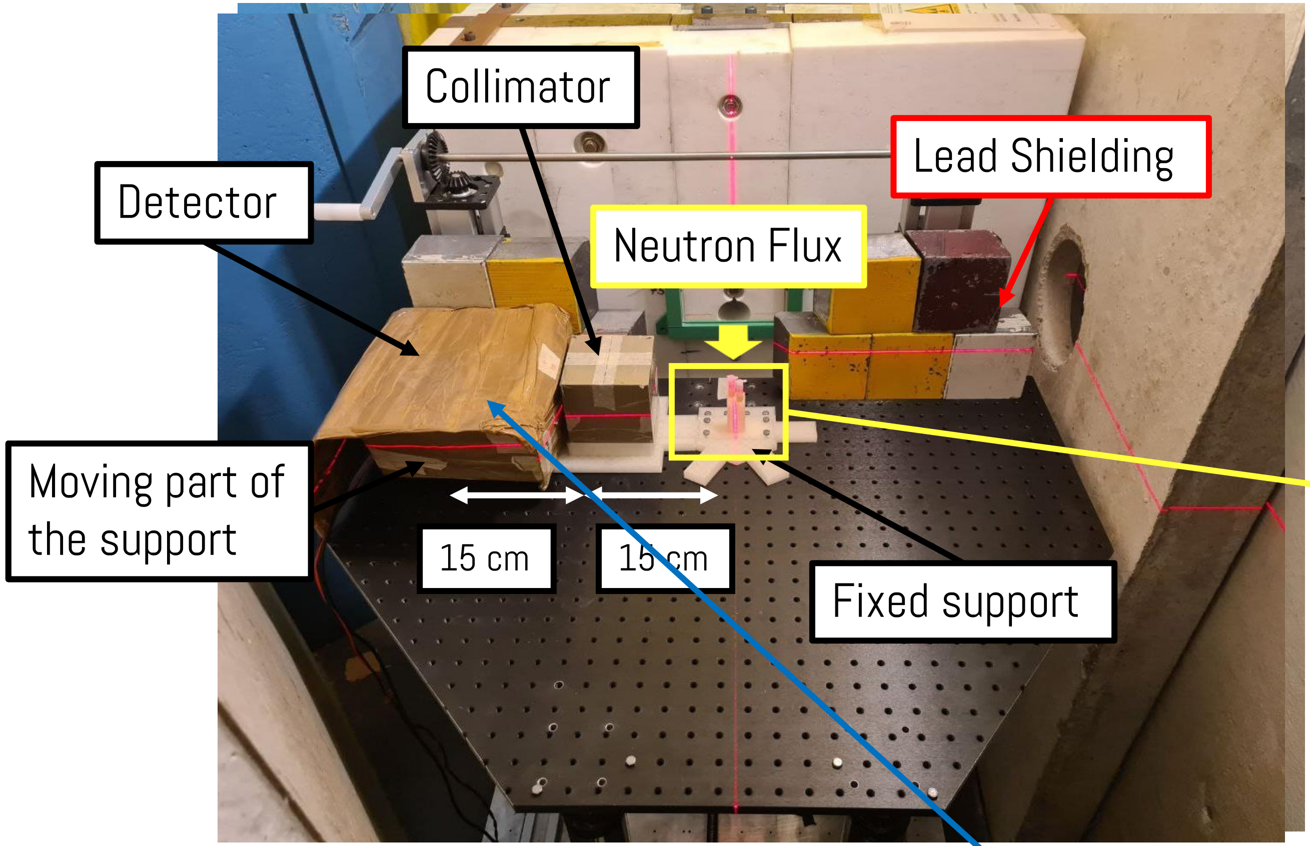


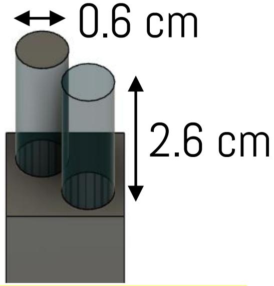
BNCT-SPECT Systems are currently under developement to detect the emitted gamma rays at **478 keV for dose monitoring and localisation.**

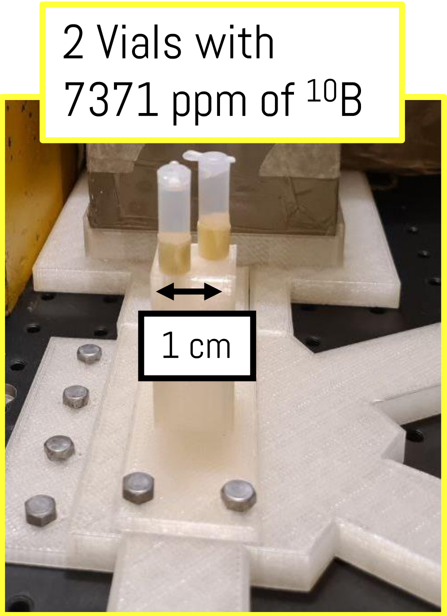


First Tomographic Measurements: Setup

TRIGA Mark II reactor of Pavia University (Italy).







Due to limited space in the irradiation room, the system is constrained to perform only partial rotations
(Chosen 0°, 60°, 120°, 180°).

For each position we acquired two measurements at 70 kW reactor power (corresponding to a **neutron flux of 1.75 x 10^6 m/cm^2/s**), one with the vials filled with boron and a background measurement by replacing the vials with other two filled only with distilled water.

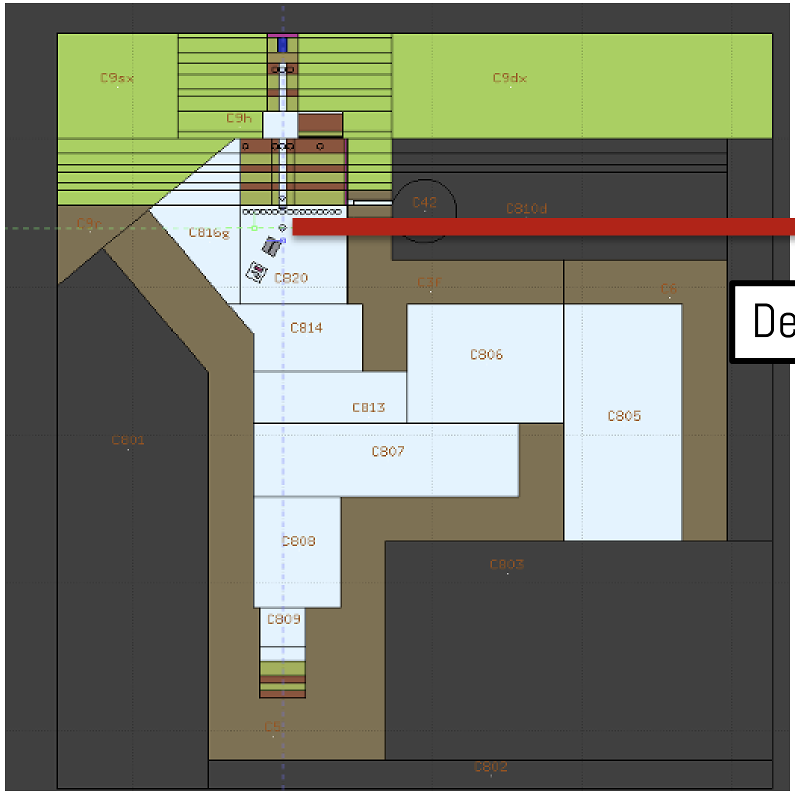
The detector is wrapped in Cd foils to avoid thermal neutrons from reacting with ^{10}B inside the electronics

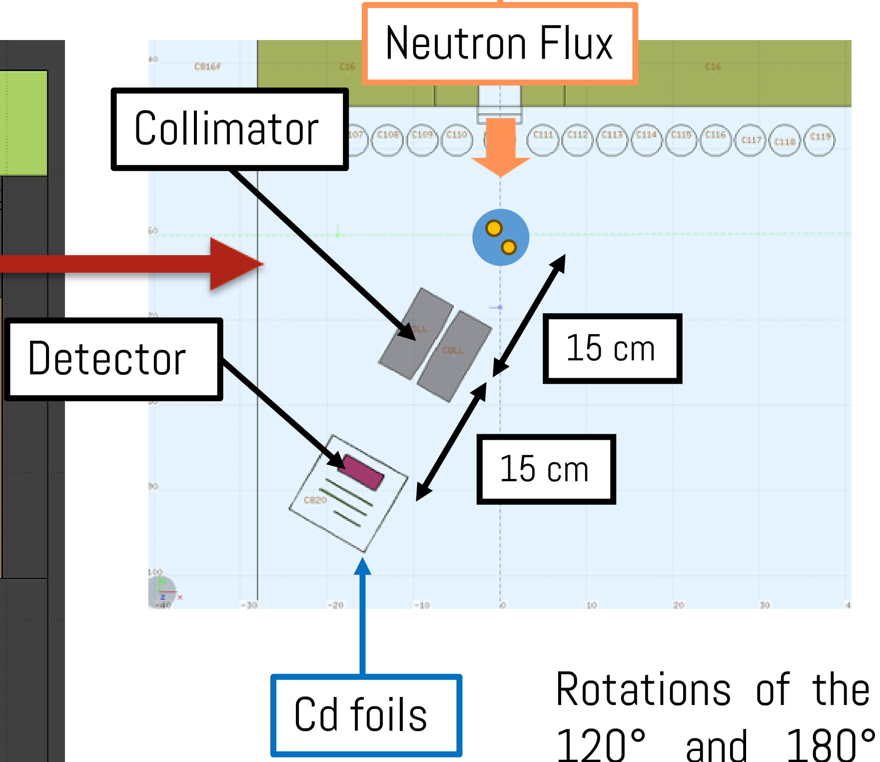
Colombo, G., et al. "**Study of the thermal neutron activation of a gamma-ray detector for BNCT dose monitoring.**" *Journal of Instrumentation* 19.05 (2024): P05047.

First Tomographic Measurements: Fluka Simulations

The FLUKA code is a general-purpose Monte Carlo allowing to simulate particle interaction with matter.

Replicated planimetry of the **TRIGA Mark II** reactor of Pavia University (Italy).





The neutron spectrum is for **97% thermal neutrons** an **3% epi-thermal and fast neutrons**. It has been **measured experimentally at 10 kW** of reactor power and **then rescaled to the actual power of the measurement**

Rotations of the system around the vials at 0°, 60°, 120° and 180° angle were performed to extract information about **detected events at 478 keV** and the **expected reconstructed images** to compare them with the experimental measurements.

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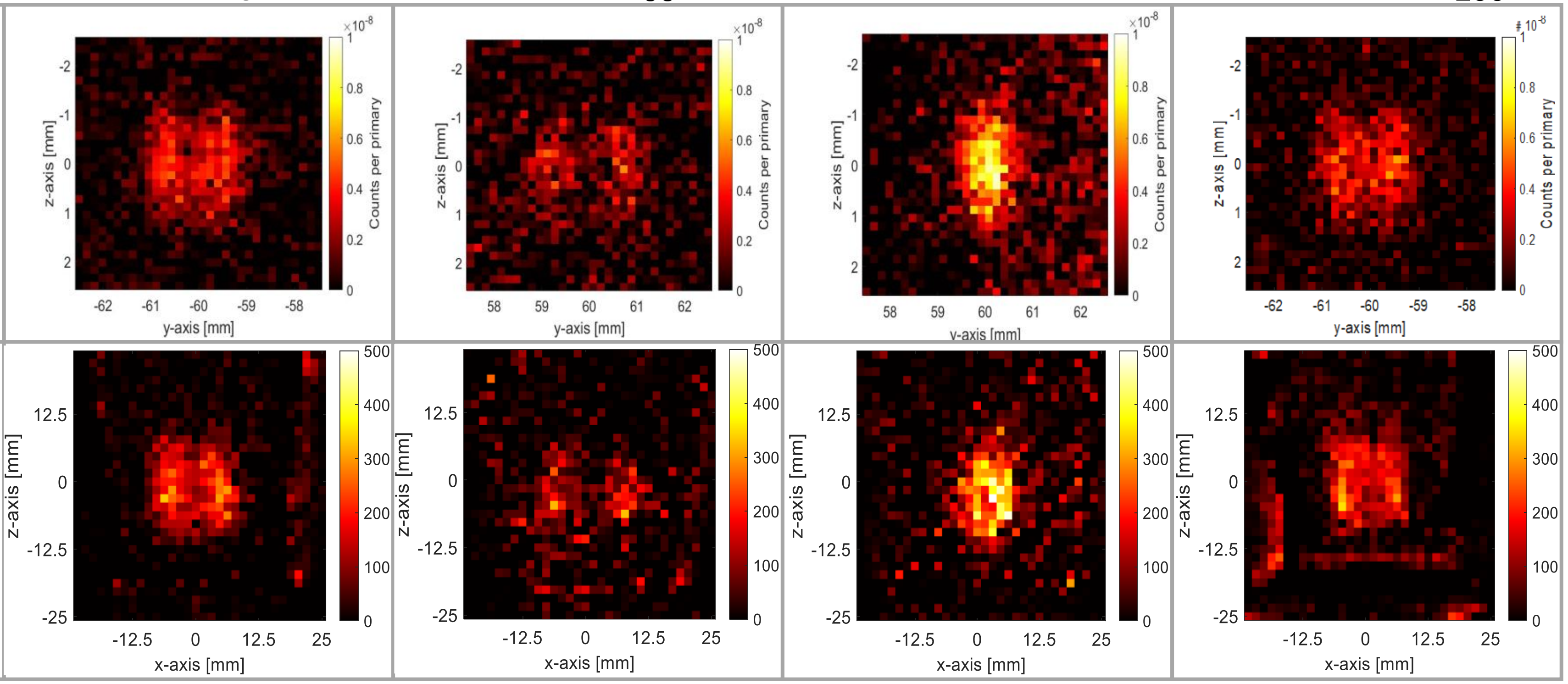
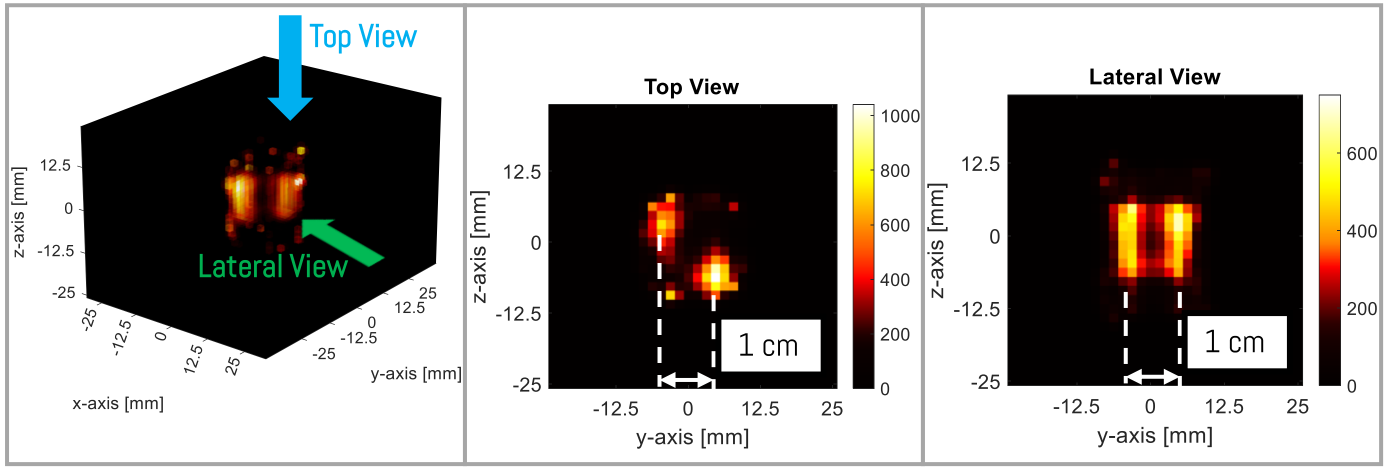
Imaging Results

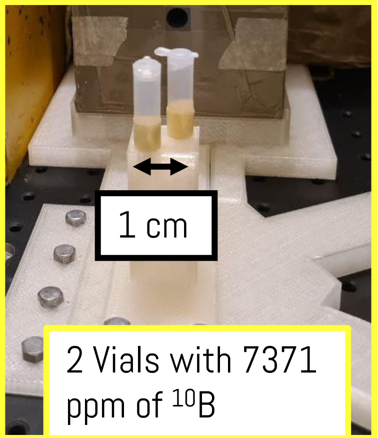
	0°	60°	120°	180°
Fluka Simulations				
Reactor power = 70 kW Measurement time = 36 min Neutron flux = $1.75 * 10^6\ n/cm^2/s$				



For each gamma ray interacting, we compute the centroid of every compton or photoelectric energy deposition to create an image.

The reconstructions were obtained using **10 iterations of the OSEM algorithm.**



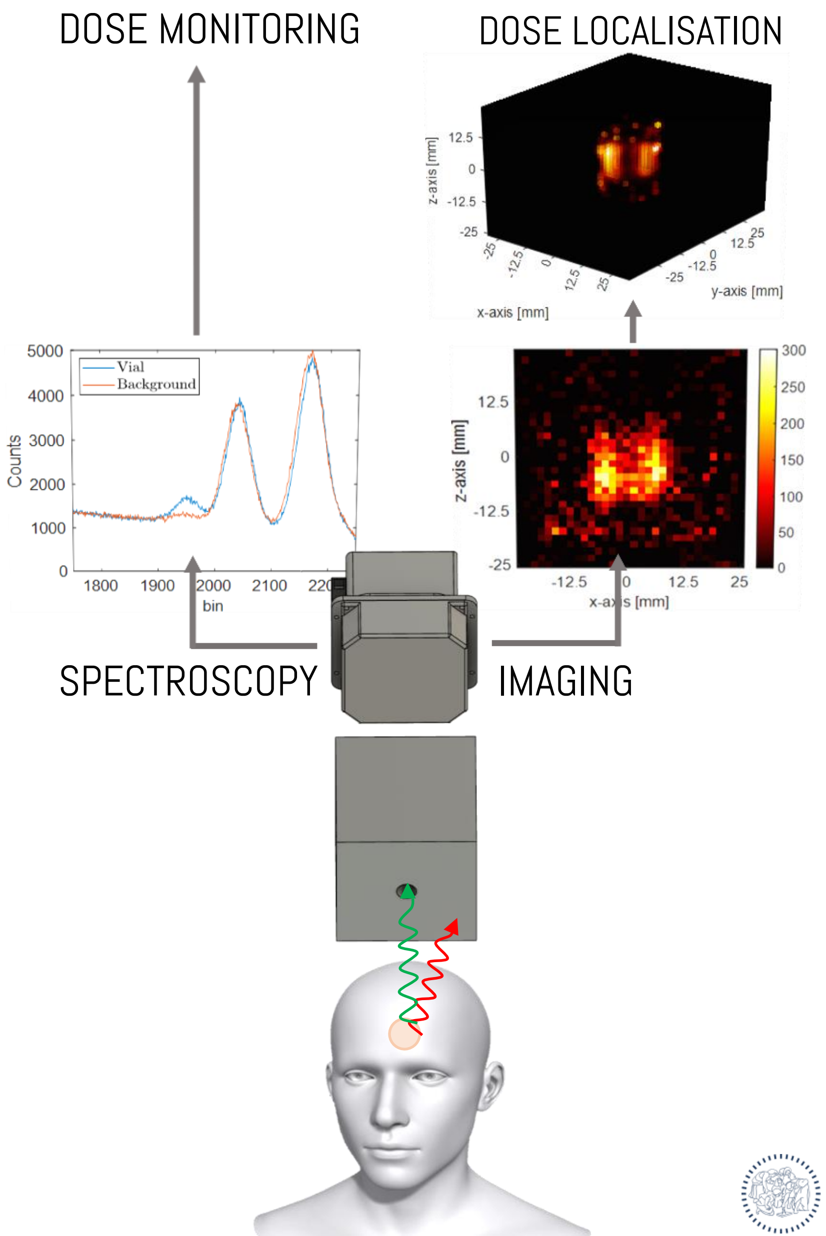


Conclusions and Future Developements

Conclusions:

The newly implemented channel-edge geometry in the pinholeSPECTUB framework has been **successfully integrated** into previous code **leaving invariant the previously implemented functionalities.**

Regarding this BNCT application, implementing the channel-edge geometry in the STIR reconstruction framework allowed **good 3D reconstruction of a boron sample starting from partial projections. This represent a first step towards the building of a clinical system for dose monitoring.**



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Thank you for your attention!

Interested in more details about our first tomographic measurements with our BNCT-SPECT system?
See more at:
M-20- System Design and Validation for Treatment Monitoring for BNCT by using Tomographic Reconstruction
Saturday 2 October at 10.20 a.m.