Estimation of the physical characteristics of an external hardware attenuator in pure PET systems in sinogram space

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Overview

Disclaimers

- Funded by MITACS with Siemens Healthineers Limited;

- This presentation is available on the Indico website;
- All images were produced by PL;
- Work in Progress!

Context: Positron Emission Tomography (PET)

- In Positron Emission Tomography (*PET*), a positron-emitting radiopharmaceutical compound is injected into a subject of interest;
- The produced positron annihilates to create two anti-collinear annihilation photons;
- This method of functional imaging gives insight into functional regions.

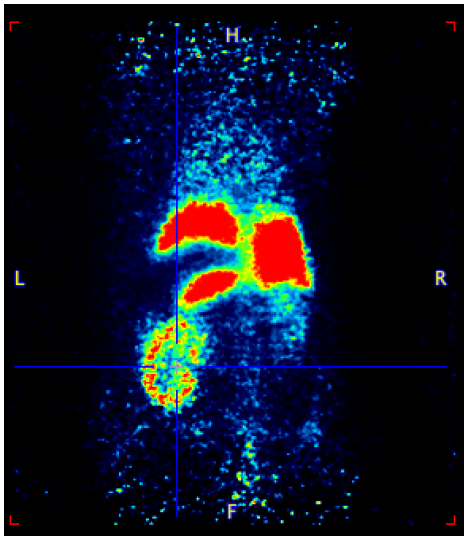

Figure: Temporal timeframe of a rat having been injected with [^{18}]F-Fluoropyridine Candesartan, aggregating (here) in the liver and kidneys.

Context: External Hardware

- A piece of external hardware is a non-emitting object not part of the subject of interest;
- It can be the table (on which the patient lies), a coil, water pouch, etc.;
- This external hardware will affect some of the annihilation photons.

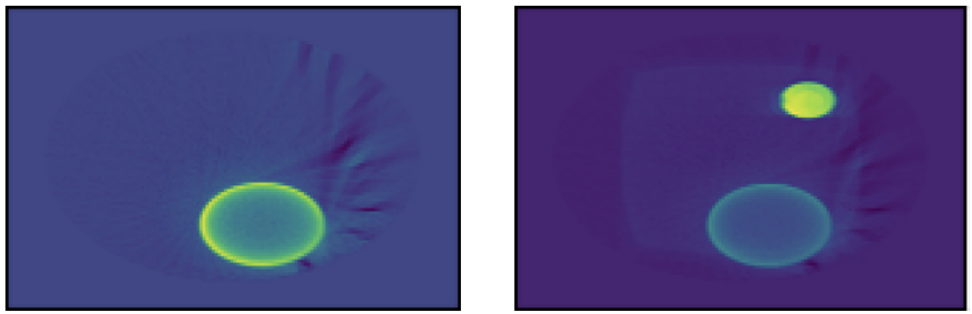

Figure: Axial slices for an acquisition with only a radioactive phantom (no hardware) (left) and with non-emitting hardware (right). The bottom image is a combination of the PET acquisition and MRAC scan.

Goal

- Determine the presence of external hardware;
- Find its position and shape;
- Determine its attenuating properties;
- Correct for the attenuating presence of external hardware using pure PET data.

- Current approach: through **Sinogram/Radon Space**.

Theory: Sinogram Space and Radon transform

- The Radon transform of a 2D object corresponds to line integrals along all straight lines, each uniquely described by a distance ξ and an angle θ;
- The set of line integrals is called the sinogram of the object.

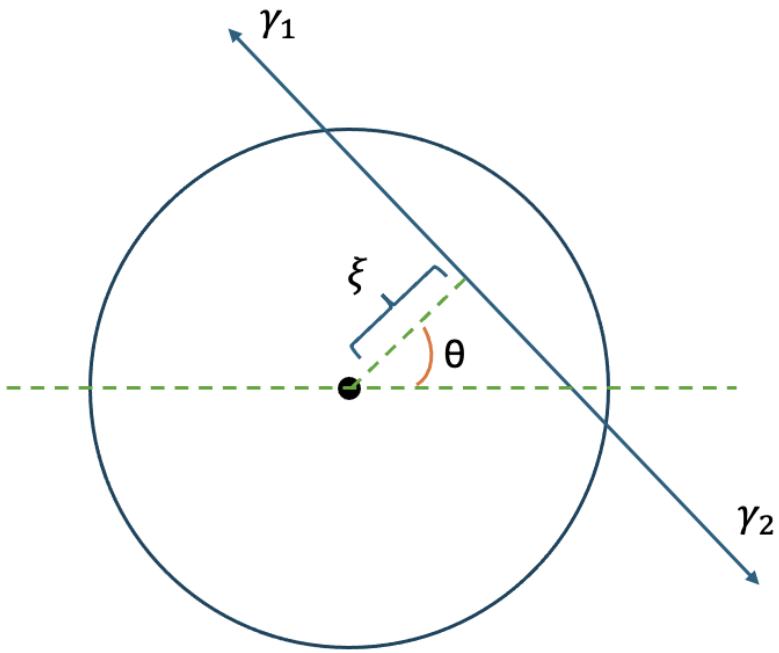

Figure: Schematic representation of one line of response (LOR) with in the sinogram frame (ξ, θ).

Theory: Radon Transform of a Circle

- For a circle of radius R centered at $(0, 0)$, its Radon transform is given by

$$\mathcal{R}f(\xi, \theta) = \begin{cases} 2\sqrt{R^2 - \xi^2} & \text{, if } \xi \in [-R, R] \\ 0 & \text{, otherwise} \end{cases} \tag{1}$$

- For a circle centered at (x_0, y_0), the translational property of the Radon transform can be used:

$$\mathcal{R}[f(x - x_0, y - y_0)](\xi, \theta) = \mathcal{R}f(\xi - x_0 \cos\theta - y_0 \sin\theta) \tag{2}$$

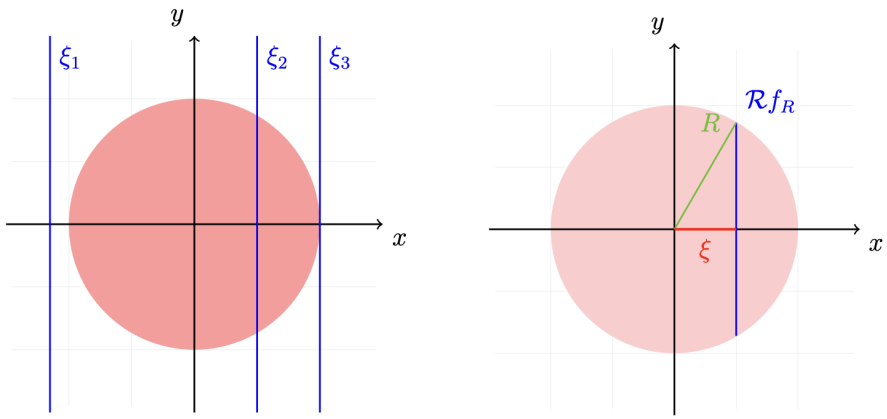

Figure: Schematic derivation for the Radon transform of a circle.

Theory: Radon Eclipse

- When an external hardware is present, some lines of response (LOR) are attenuated;
- In Radon space, this appears as a dimming, called an eclipse;
- This eclipse contains information about the external hardware.

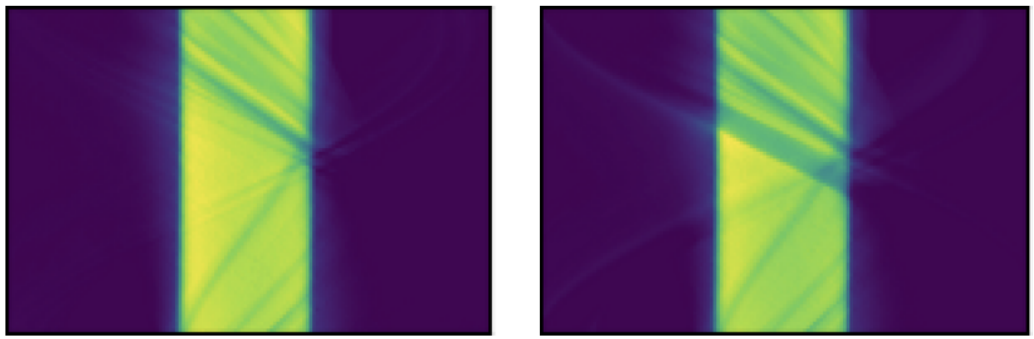

Figure: Sinograms of a slice of an acquisition with only a phantom (left) and phantom and hardware (right).

PET/MRI System and Acquisitions

- Two sets of acquisitions were acquired on the Siemens' PET/MRI system Biograph mMR at Lawson Research Institute (LRI) in London, Ontario;
  1. Calibration phantom f;
  2. Calibration phantom and external hardware f_g;
- Acquisitions lasted 10 minutes and used the MRAC as the spatial ground truth.

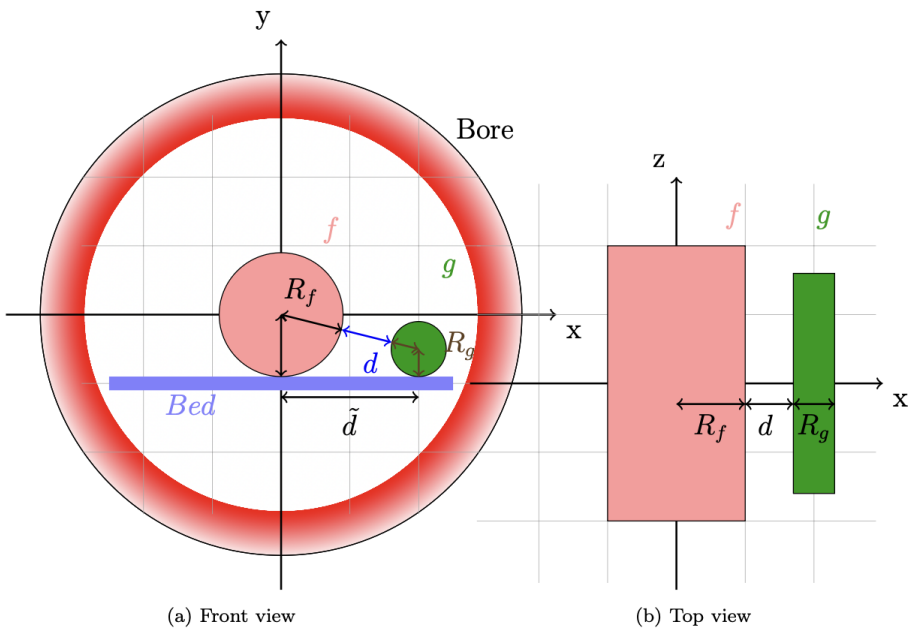

Figure: Experimental setup with the external hardware.

Data Processing/Pipeline

- Recenter the phantom in the acquisitions;
- Obtain the sinograms $\mathcal{R}f$ and $\mathcal{R}f_g$;
- Determine the sinogram ratio $\frac{\mathcal{R}f}{\mathcal{R}f_g}$ (where logical);
- Fit for the data:
  - Position (x, y) and radius r, analytically;
  - Physical properties (x, y), r, μ by Bayesian fitting with *Dynesty* (underway).

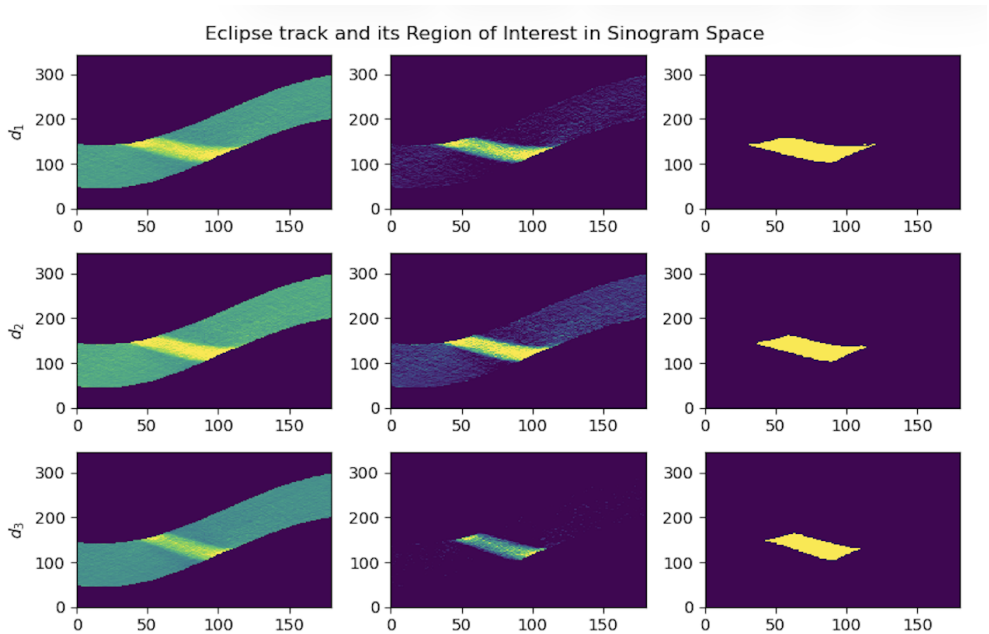

Figure: $\frac{\mathcal{R}f}{\mathcal{R}f_g}$ for various distances of the external hardware.

Results: Spatial Distance

- The distance d between the attenuator (radius R_f) and the object (radius R_g) can be found in two ways:

$$d_{\text{total}} = \pi - 2\arccos\left(\frac{R_f - R_g}{R_f + R_g + d}\right)$$

$$d_{\text{partial}} = \pi - 2\arccos\left(\frac{R_f + R_g}{R_f + R_g + d}\right)$$

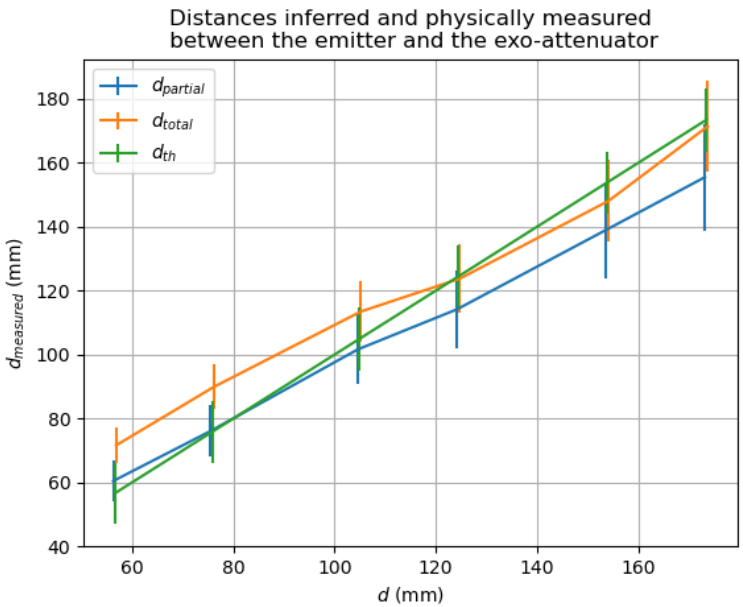

Figure: Measured distance and sinogram-determined distances.

Results: Physical Properties

- By fitting directly the ratio of sinograms, one can find the position, radius, and attenuation factor, up to some extent...

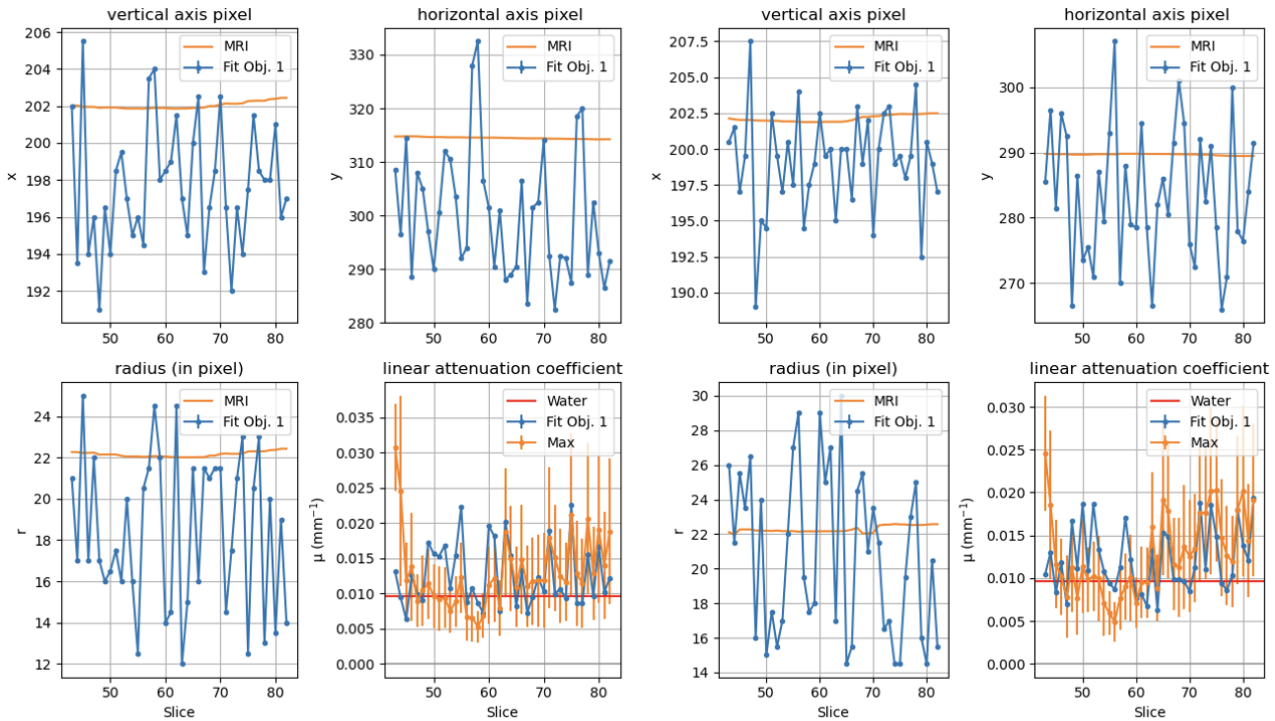

Figure: Physical properties extracted using Bayesian fitting for two hardware situations.

Next Steps

- Redoing the work on the Siemens Biograph One;
- Working with more complex geometries;
- Quantifying the impact on the actual PET reconstruction;
- Quantifying the impact on objects, i.e. interesting subjects of interest.

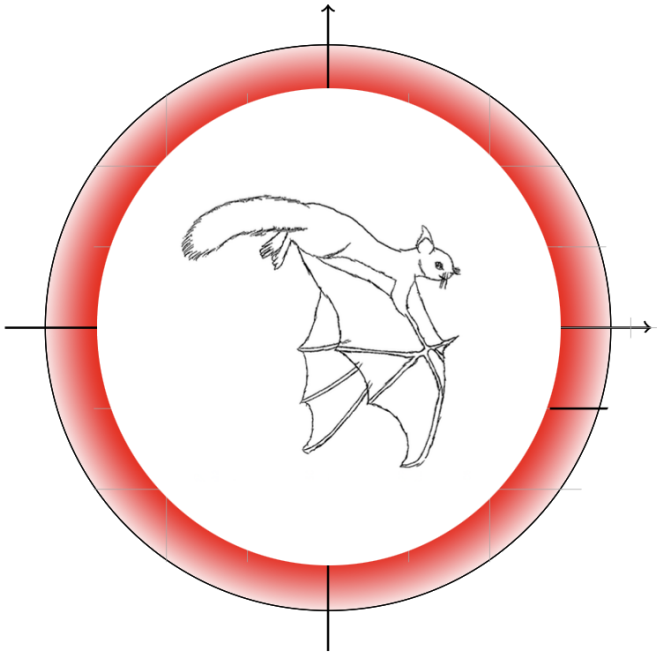

Figure: Imaging a fascinating Chauve-Cureuil/SquirBat.

Selected References

1. Cherry, S.R. et Dahlbom, M. *PET : Physics, Instrumentation and Scanners*. Springer: Londres. 2006.
2. Laporte, P., Carrier, J.-F., 2024. TRU-IMP: techniques for reliable use of images in medical physics; a graphical user interface to analyze and compare segmentations in nuclear medicine. Biomed. Phys. Eng. Express. 10.
3. Laporte, P., Moran, G., Théberge, J., 2026. The Radon Transform in Applied Mathematics and Engineering. *Submitted*.
4. Laporte, P., Moran, G., Huston, Y., Théberge, J., 2026. Measurement of the Distance between an emitter and an attenuator from the Sinogram Space. *Submitted*.
5. Natterer, F., 2001. The Mathematics of Computerized Tomography. Society for Industrial and Applied Mathematics, Philadelphia.
6. S. Speagle, Joshua, "Dynesty: a dynamic nested sampling package for estimating bayesian posteriors and evidences," Monthly Notices of the Royal Astronomical Society, vol. 493, pp. 3132–58, April 2020.

Acknowledgements

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Directly Acquired Sinogram

- It would be better to work directly with the acquired sinogram (less back-and-forth);
- Difficult on account of the corrections to apply.

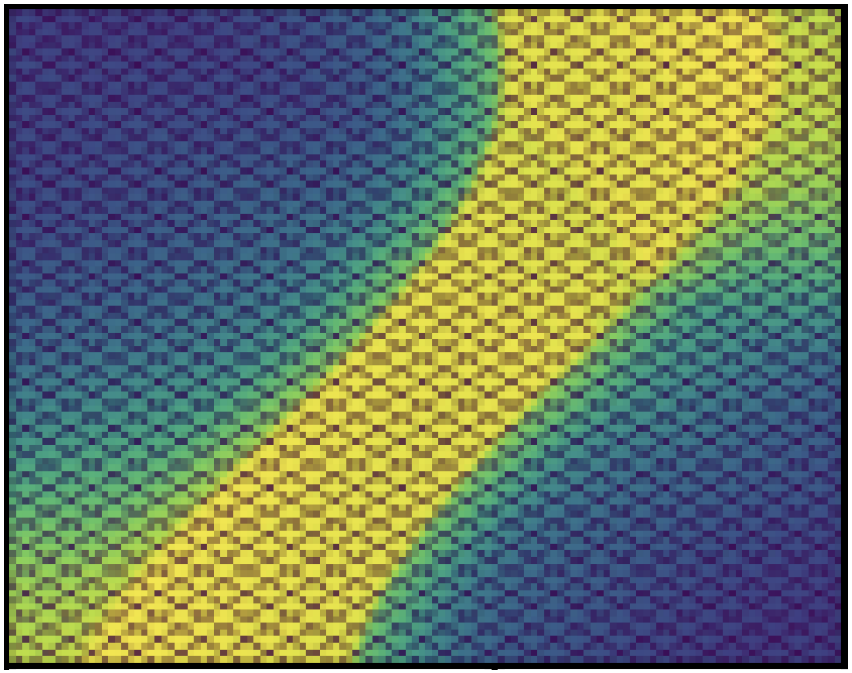

Figure: Directly acquired sinogram of a phantom.

Recentering the Phantom

- The recentering is done via a segmentation in Sinogram space converted back to Cartesian space

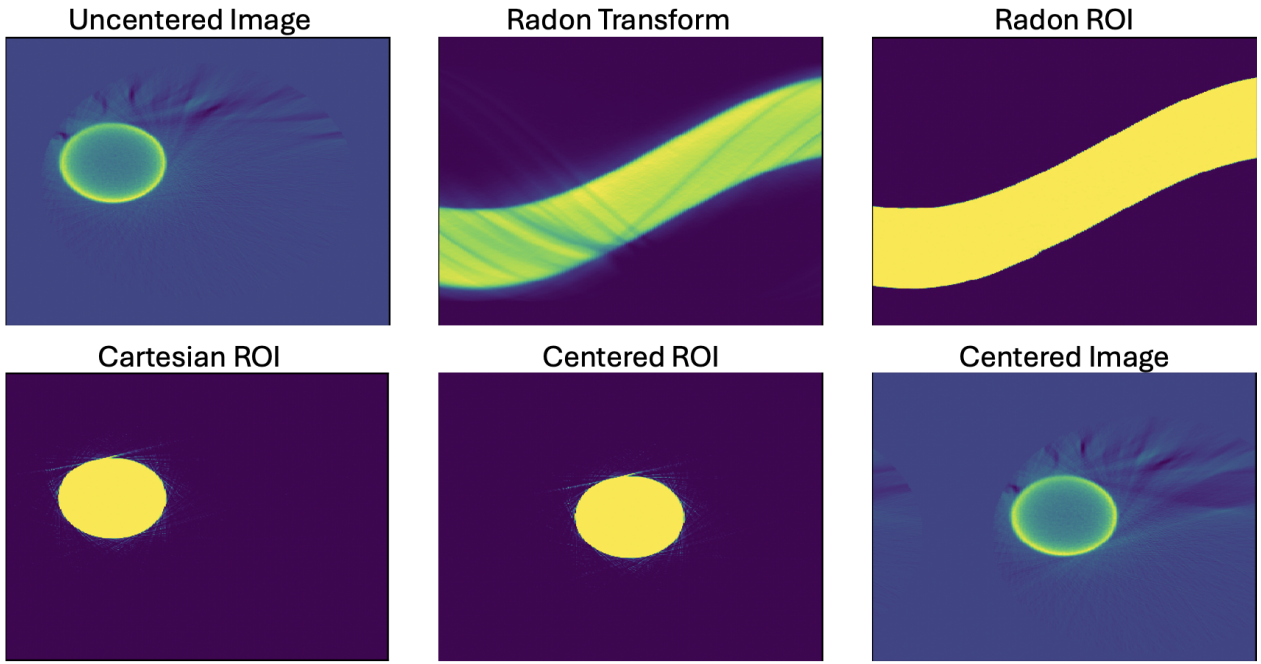

Figure: Centering of the phantom via a segmentation in sinogram space. The segmentation is done via an ICM.