# Deep-PRC: Artificial Intelligence-Based Positron Range Correction in Nuclear Medicine

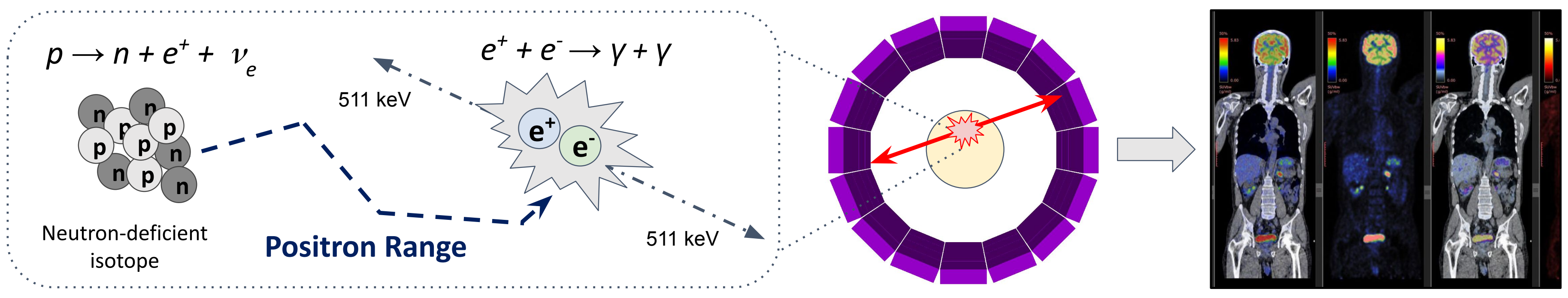
**Nerea Encina-Baranda[1], Alejandro Lopez-Montes[3], Joaquin L. Herraiz[1,2]**

[1] Nuclear Physics Group and IPARCOS, University Complutense of Madrid (IdISSC), Madrid, Spain
[2] Health Research Institute of Hospital Clínico San Carlos (IdISSC), Madrid, Spain
[3] JHU Department of Biomedical Engineering, Johns Hopkins University, Baltimore, Maryland, United States of America

**nencina@ucm.es**

**Grupo de Física Nuclear @ UCM**

**Positron Emission Tomography (PET)** is a medical imaging technique based on beta+ decay and the annihilation of a positron and an atomic electron. Detectors capture the gamma rays emitted, defining the annihilation location and generating an image of the tracer's distribution in the body.



## INTRODUCTION

The **Positron Range (PR)** is the distance travelled by the positron right after the beta+ decay and it varies based on:

- **The electron density of the medium**, influenced by the type of biological tissue (e.g., water, bone, lung, air, muscle).
- **The energy of the positrons emitted** and, therefore, the nuclei (e.g, $^{18}$F, $^{68}$Ga, $^{124}$I).

Many of the proposed radionuclides for PET emit high-energy positrons have a large PR, causing **significant blurring** in the reconstructed images and **degrading PET image resolution**.

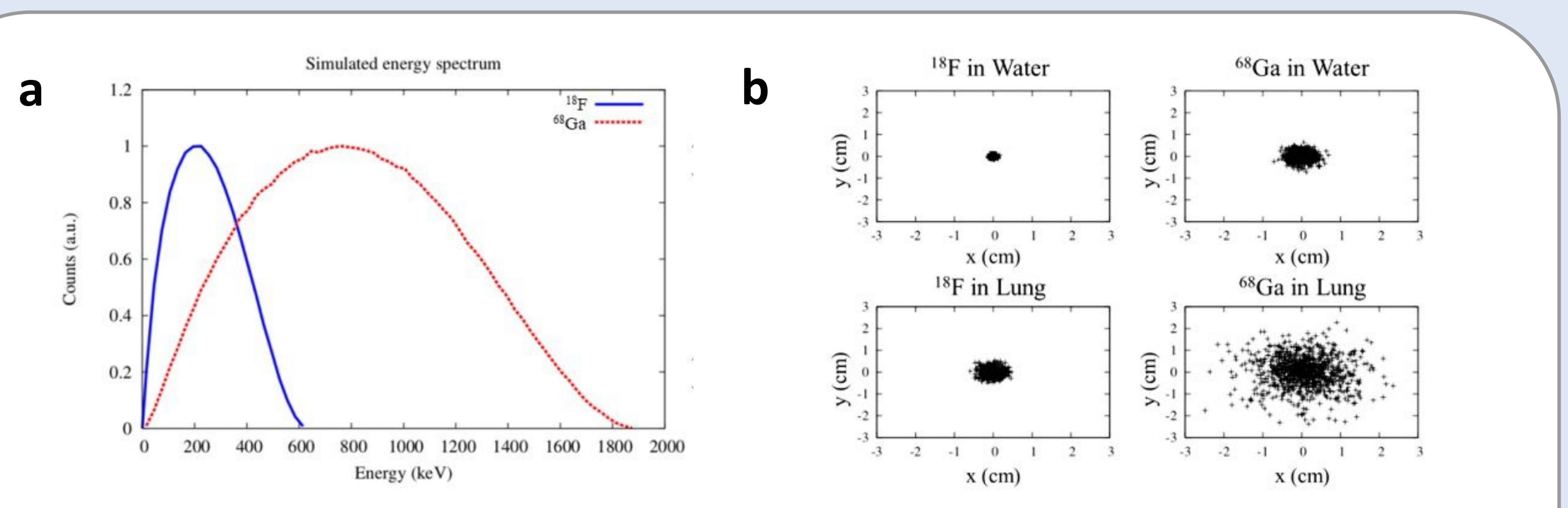


**Fig. 1. a)** Positron emission energy spectrum for $^{18}$F and $^{68}$Ga, **b)** distribution of annihilation points in water and lung. PR can range from hundreds of microns to a few millimeters.

The goal of this work is to **correct the PR (PRC) using Deep Learning** applied as a post-processing step to the reconstructed PET images, specially for those radionuclides with a large PR (i.e: $^{68}$Ga, $^{124}$I).

## METHODOLOGY

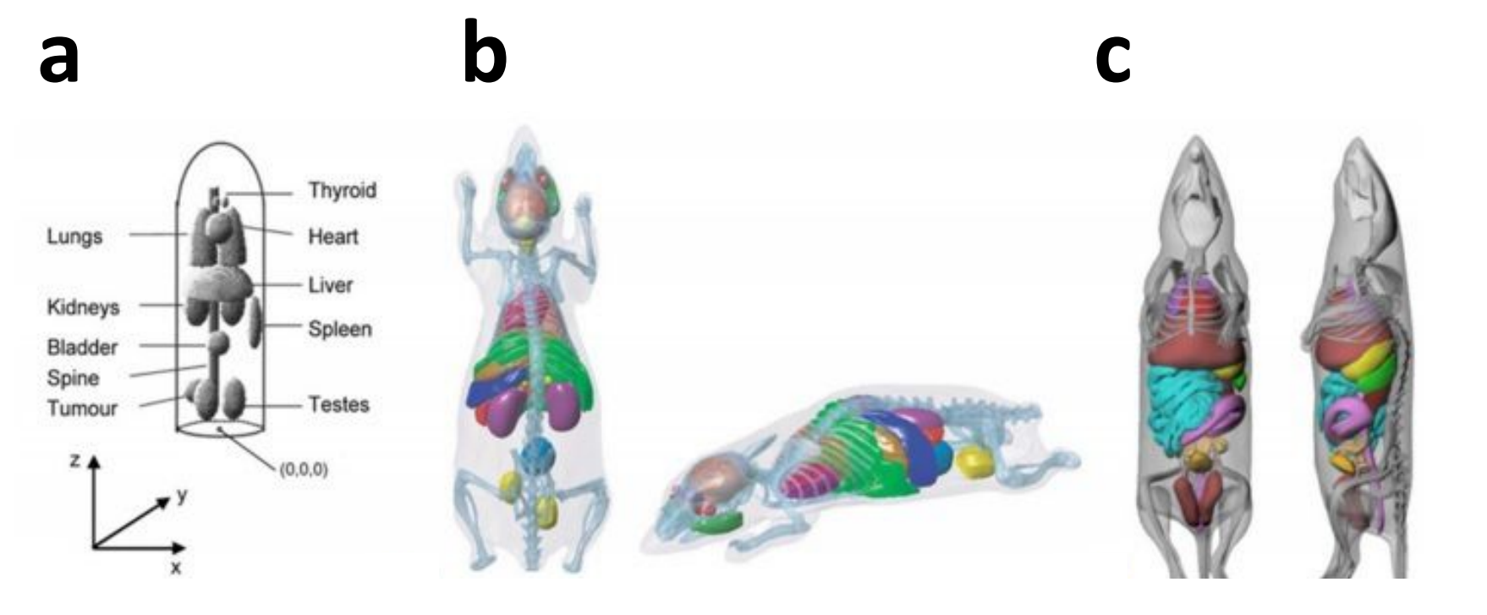
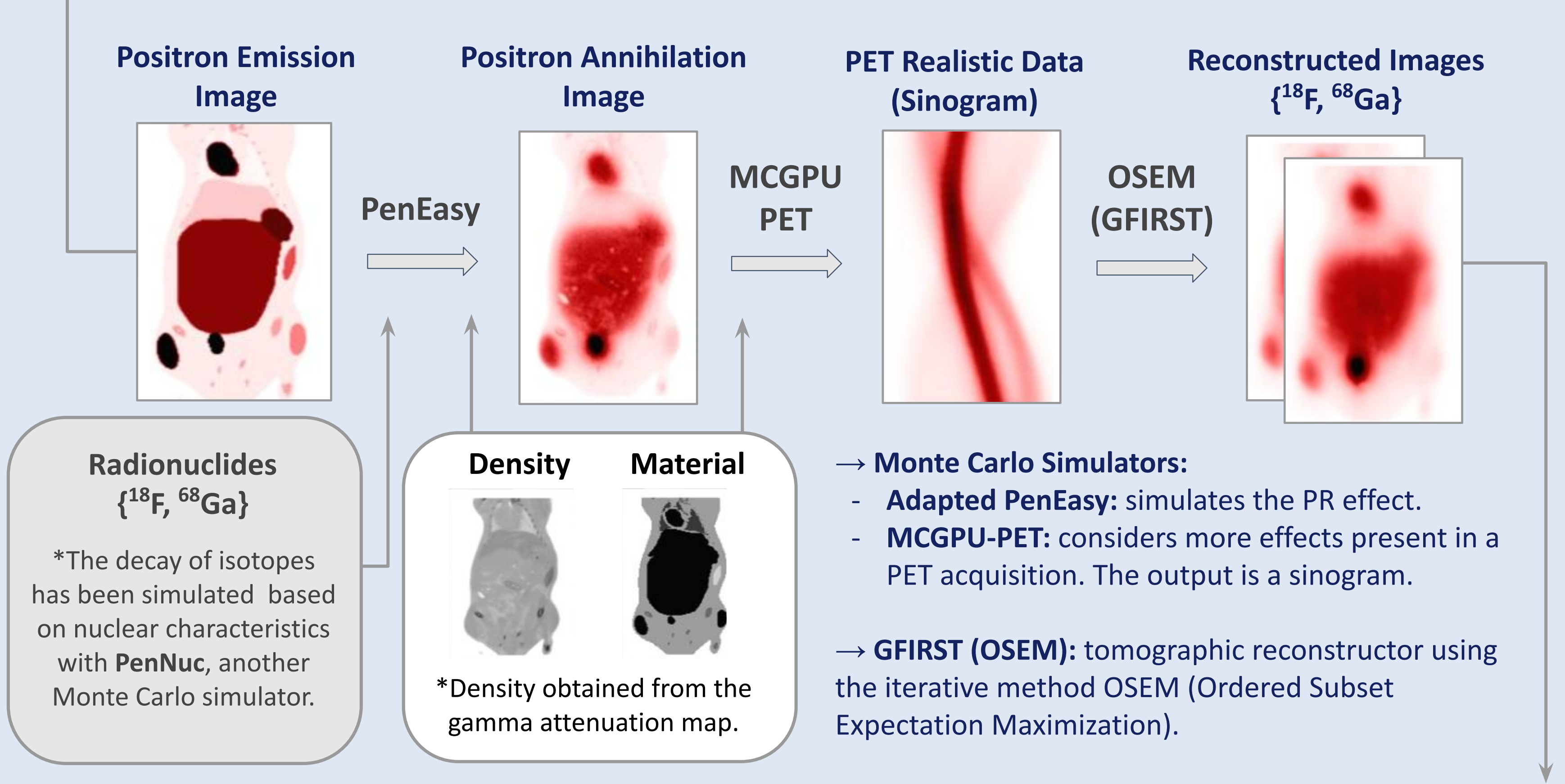


**Fig. 3.** Adapted Numerical Phantoms.

**a)** Anthropomorphic computational mice models have been used to characterize the physics and anatomy of laboratory animals in order to simulate radiation transport and simulate radiopharmaceuticals' behavior, **b)** Digimouse, **c)** MOBY



**Positron Emission Image**

**Positron Annihilation Image**

**PET Realistic Data (Sinogram)**

**Reconstructed Images $\{^{18}F, ^{68}Ga\}$**

PenEasy

MCGPU PET

OSEM (GFIRST)

**Radionuclides $\{^{18}F, ^{68}Ga\}$**

*The decay of isotopes has been simulated based on nuclear characteristics with **PenNuc**, another Monte Carlo simulator.

**Density** **Material**

*Density obtained from the gamma attenuation map.

→ **Monte Carlo Simulators:**
- **Adapted PenEasy:** simulates the PR effect.
- **MCGPU-PET:** considers more effects present in a PET acquisition. The output is a sinogram.

→ **GFIRST (OSEM):** tomographic reconstructor using the iterative method OSEM (Ordered Subset Expectation Maximization).

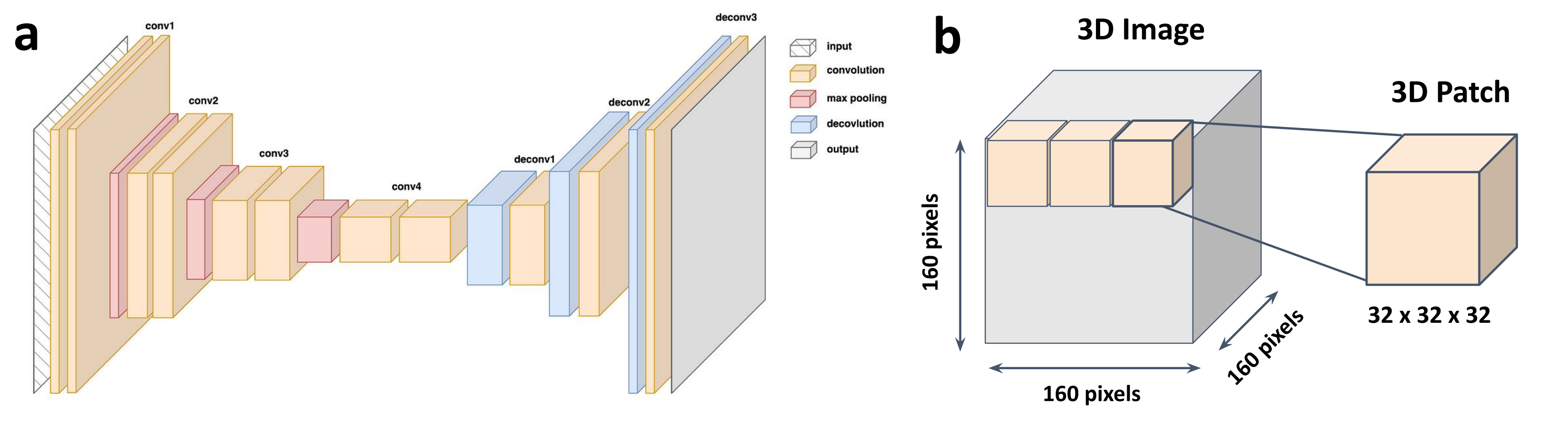


**Fig. 3.** Deep-PRC. **a)** U-NET Architecture, **b)** multiple overlapping 3D patches extracted from the 3D images were utilized to train the U-NET. This technique significantly increased the number of training samples and enhanced the robustness of the neural network.

### - Iterative Standard PRC Method

Considering a point-like source emitting positrons, it is possible to obtain the distribution of annihilation points in 3D (PSF, Point Spread Function) and project it onto the Z direction to obtain a 2D distribution. Once the PSF image is available, deconvolution is performed using the **Richardson-Lucy** (R-L) method to correct the blurring due to PR.

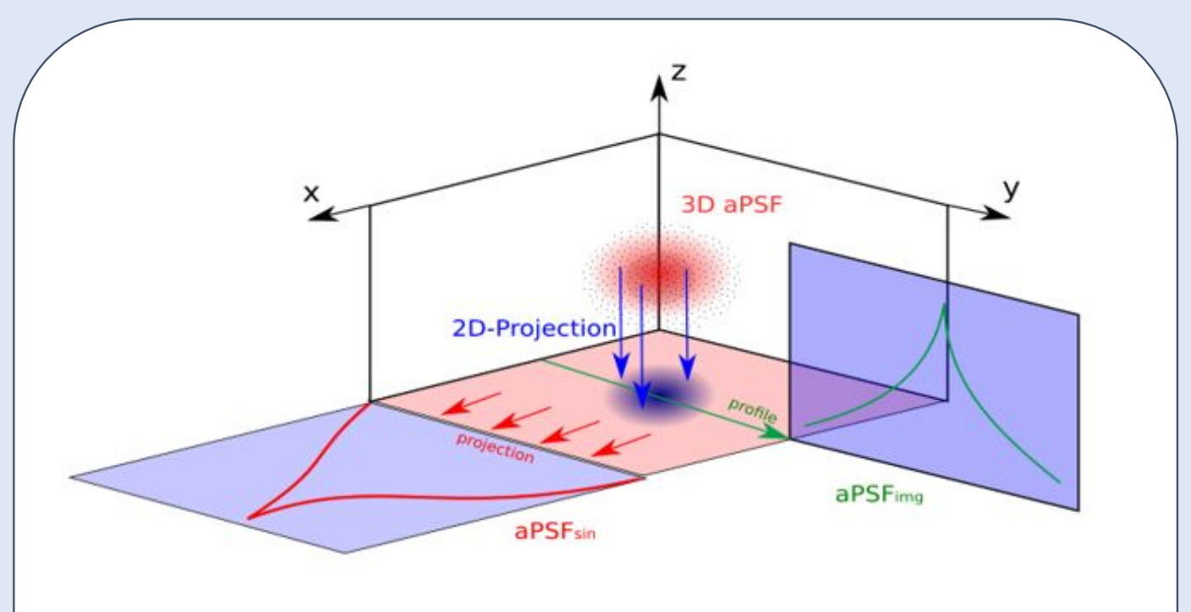


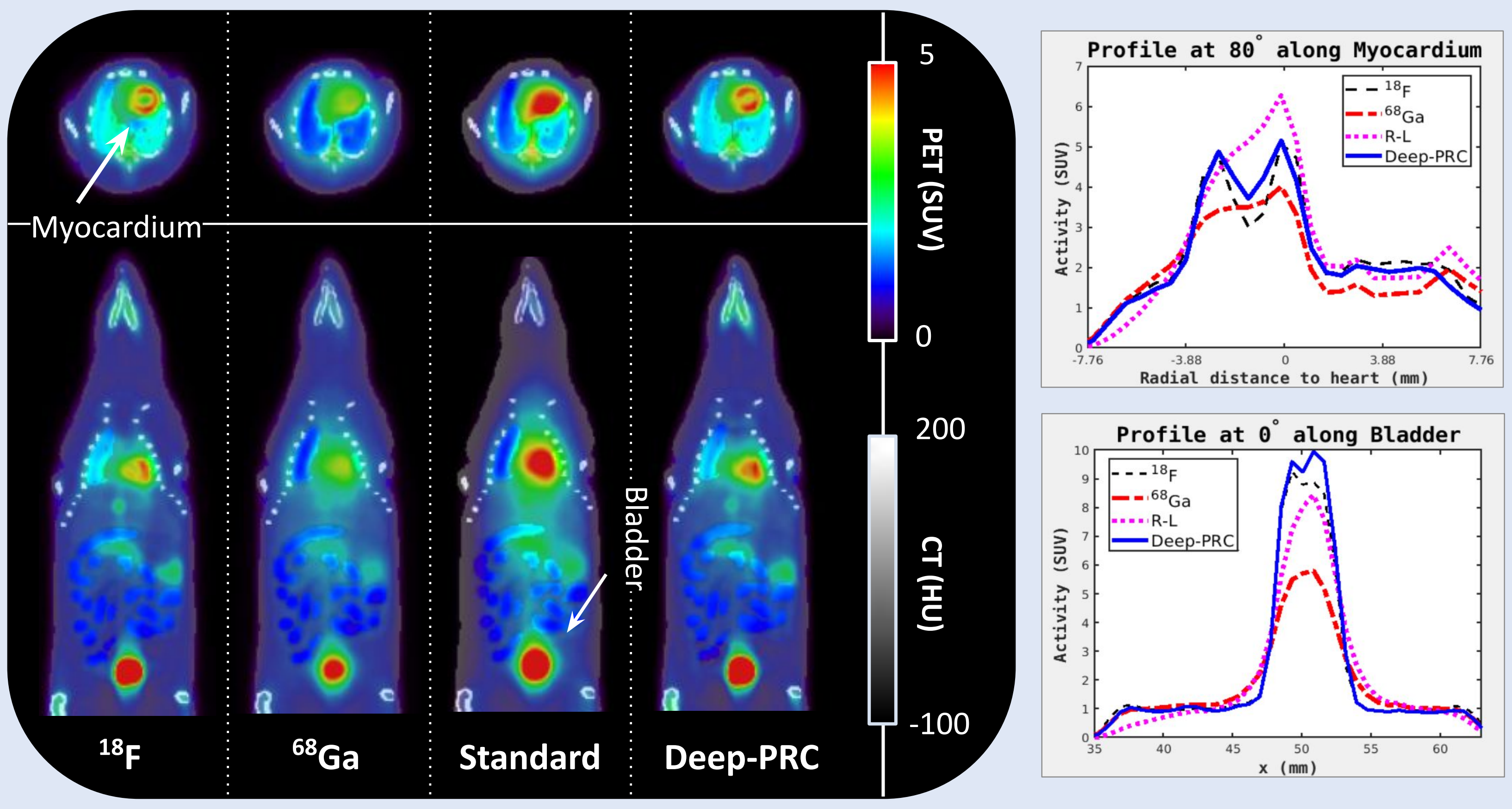
**Fig. 4.** Constant PSF Projection [1]

## RESULTS

### - MC Simulation Results

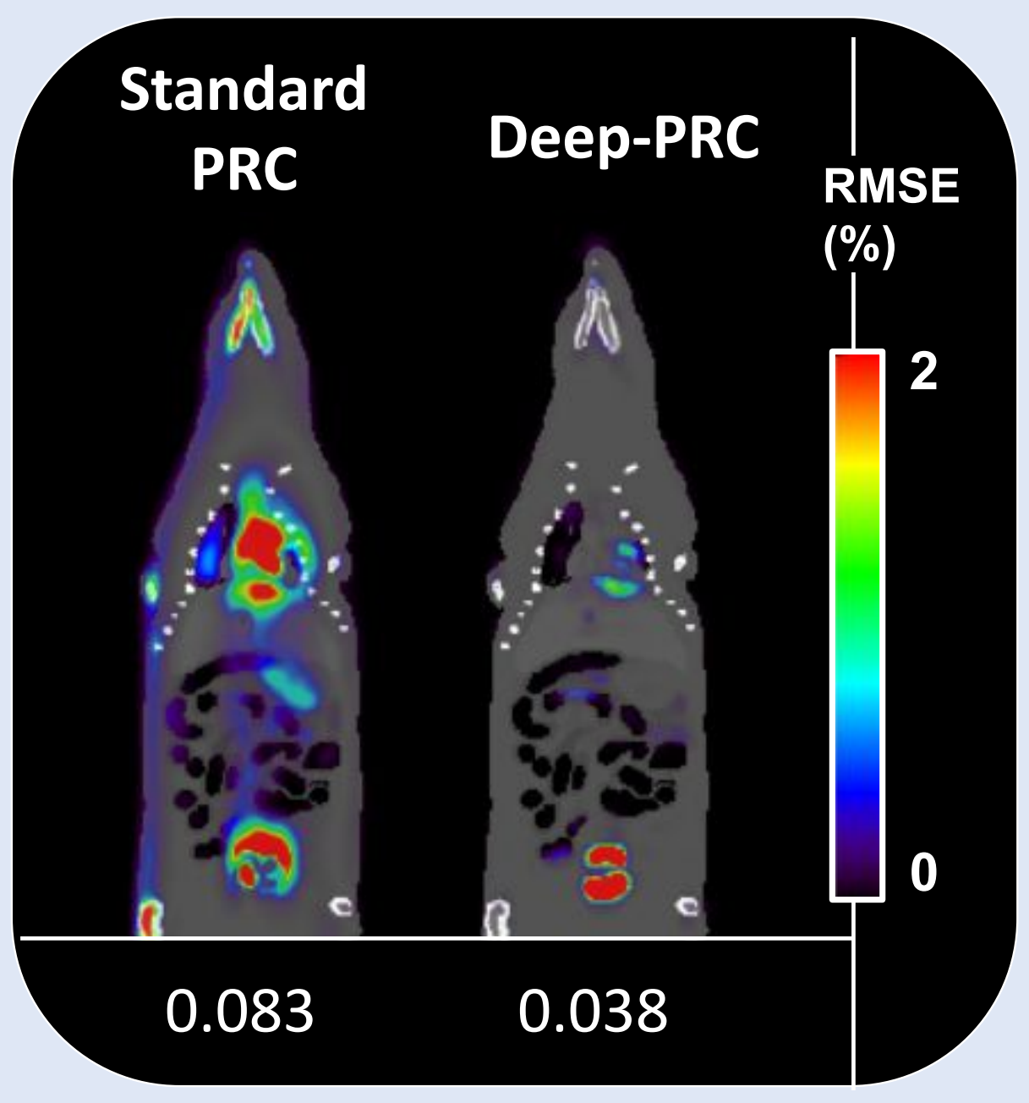
The image obtained using $^{18}$F was established as ground truth. The $^{68}$Ga image represents the target for correction through the Deep-PRC technique and an iterative-standard PRC method using a constant PSF.

Notably, a distinct enhancement in image quality was observed with the implementation of the deep-prc approach. Specifically, when focusing on the bladder and myocardium line profile, **Deep-PRC demonstrated a superior recovery of activity compared to the Iterative Standard method (R-L).**



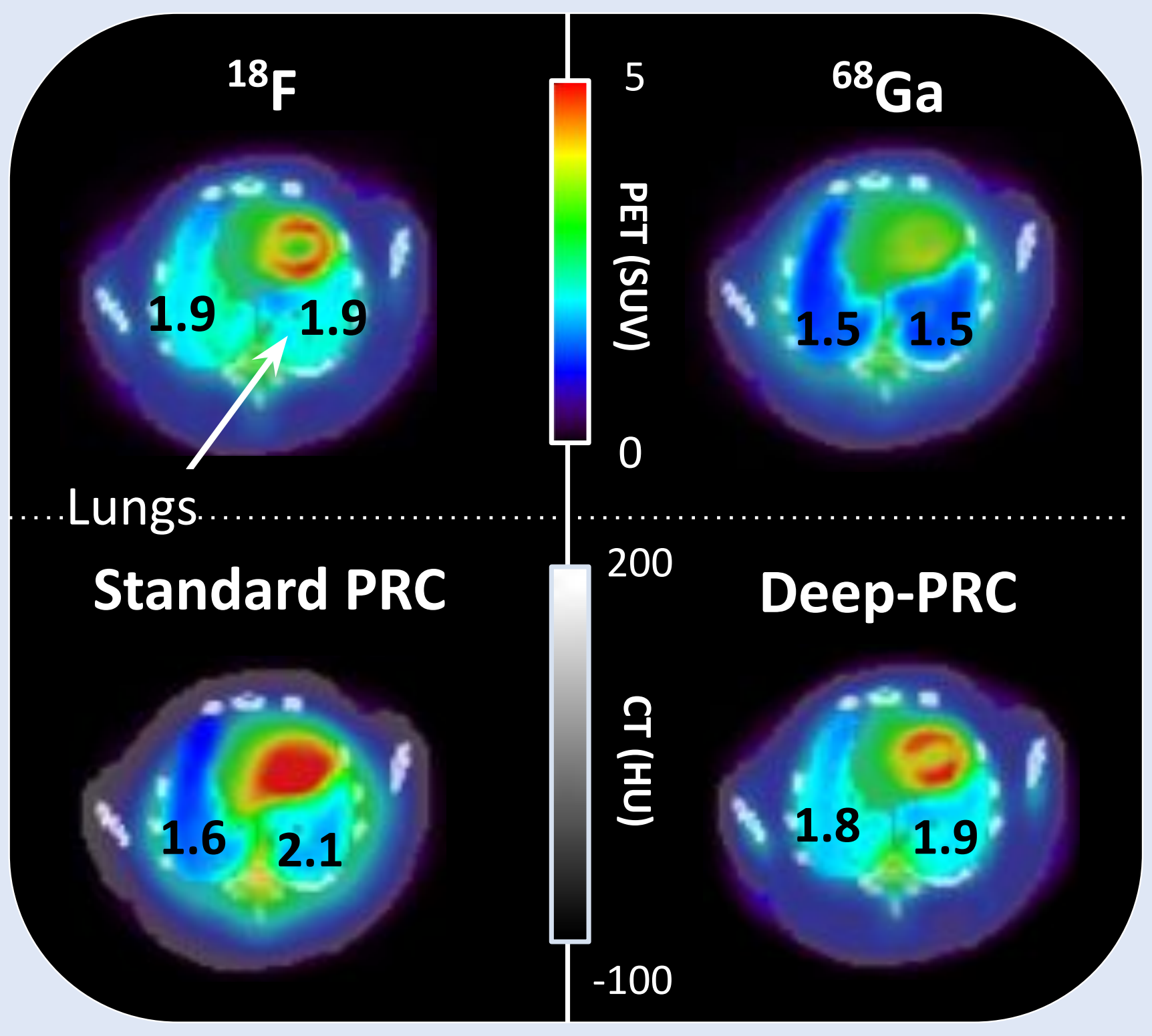
### - Results Quantification

The corrected images have been quantified with Root Mean Square Error (RMSE) using $^{18}$F as reference. Also, the results have been compare using **Noise, Contrast** and **Spatial Resolution** (FWHM) using the bladder as Region of Interest.

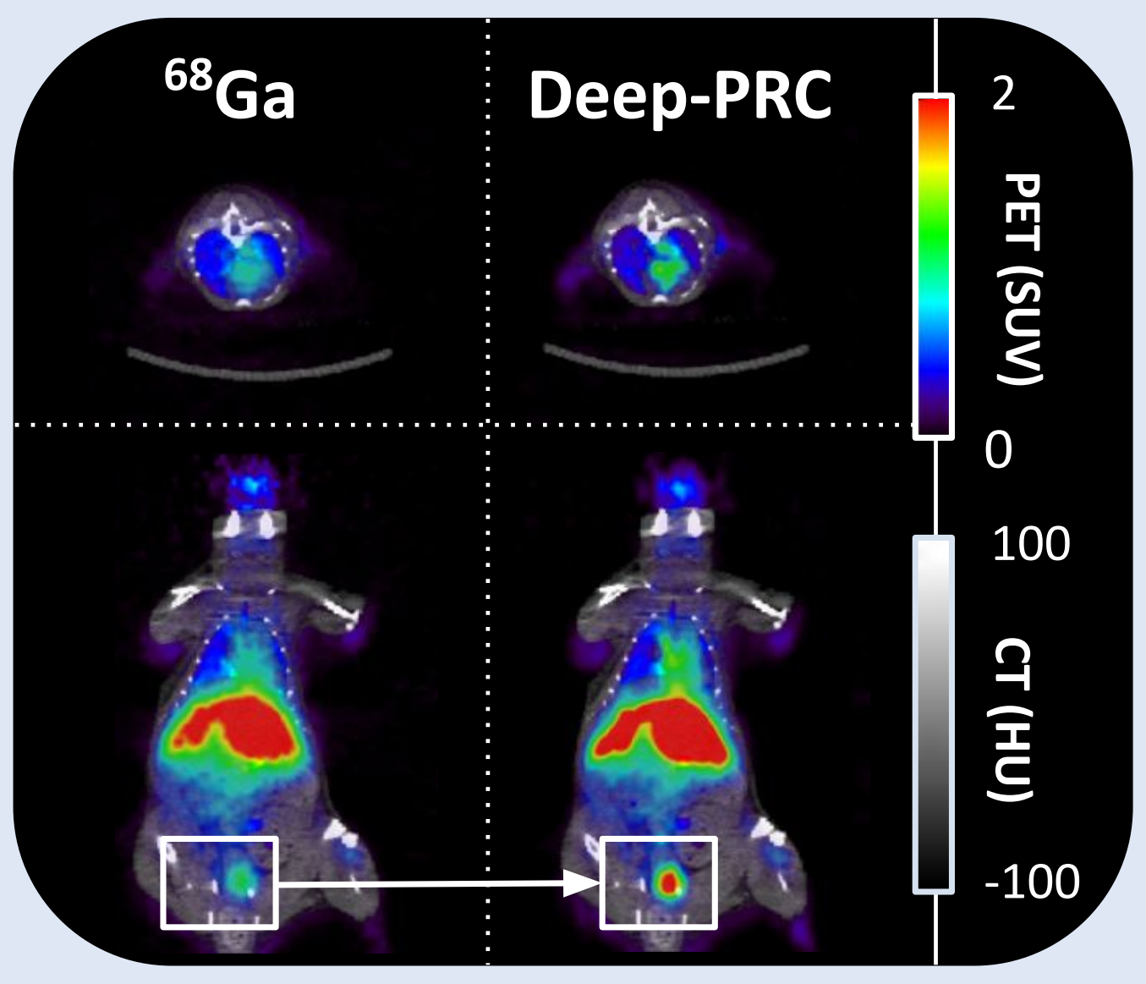


| **Table 1.** Results | **Noise [%]** | **Contrast [-]** | **FWHM [mm]** |
|---|---|---|---|
| **$^{68}$Ga Image** | 9.51 | 3.37 | 8.80 ± 0.30 |
| **$^{18}$F Image** | 8.86 | 5.41 | 6.40 ± 0.38 |
| **Iter. Standard Method** | 24.40 | 5.16 | 7.72 ± 0.10 |
| **Deep-PRC Method** | 5.37 | 5.56 | 6.28 ± 0.36 |

Another effect that has been observed in the results is Deep-PRC's ability to **recover lost activity in low-density regions** like the lungs. This effect is evident when dealing with nuclei emitting positrons with large PR.



Deep-PRC has been tested on **real $^{68}$Ga acquisitions** of the Inveon Scanner from Memorial Sloan Kettering Cancer Center Hospital (New York, EEUU).



## CONCLUSION

Deep-PRC offers a rapid and precise Positron Range Correction (PRC) approach to restore resolution and activity loss in PET studies, as well to minimize noise, particularly with radionuclides like $^{68}$Ga that emit positrons with significant PR, outperforming the standard PRC method.

→ **Deep-PRC could help to identify pathologies that could be overlooked when dealing with specific radionuclides.**

## Acknowledgement

Collaboration with **Siemens Healthineers** (Art. 83) for the implementation of Deep-PRC in acquisitions involving human patients using the clinical Biograph Vision PET/CT Scanner.

## References

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