Image Quality Evaluation Study of an RF-Penetrable Brain PET Insert: A Phantom Assessment Toward Clinical Translation

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Presentation Overview

- **Identifying the Value of a Dedicated Radiofrequency (RF) Penetrable Brain PET insert:** What can this Brain PET insert offer patients and clinics?
- **First Generation Radiofrequency Penetrable Brain PET Insert for MRI:** How is our system designed and how do we acquire data?
- **Comparative PET Spatial Resolution Performance:** Contextualizing our Brain PET Insert Spatial Resolution against current clinical systems
- **Hoffman Phantom Scans:** Can we anticipate the performance of our PET system when applying the system to patients?
- **Initial Hoffman Phantom Images:** Initial Hoffman phantom images contextualized for clinical translation
- **Comparative Hoffman Images:** Dedicated Brain PET Insert versus GE Signa
- **Future Work:** Improving image quality and experimental sequencing

Combined PET/MRI – Benefits/Limits and Costs

Individual Modalities

- **PET as a modality:** PET provides (a) biodistribution information, (b) excellent depth of penetration, (b) high intrinsic sensitivity (picomolar order)
- **MRI as a modality:** MRI provides (a) anatomical information, and (b) excellent soft tissue

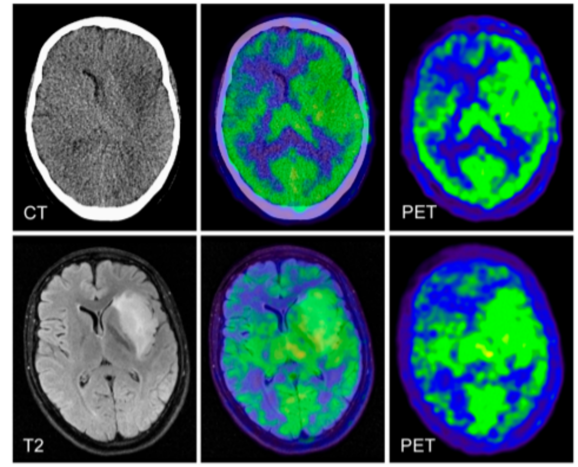


Figure 1: *Comparative imaging study of PET/CT versus PET/MRI on low grade glioma. [1]*

Individual Modality Strength

- **PET/MRI versus PET/CT:** Anatomically slow, excellent contrast, no anatomical radiation emerging attenuation correction (AC) for PET versus anatomically fast, poor contrast, additional dose, and PET AC capable
- **PET/MRI Specific Benefits in Brain:** PET function can be easily localized to sub-brain anatomical features using MRI
- **Economics of PET Insert versus Full PET/MRI Setup:** Easily incorporated in to pre-existing MRI versus full infrastructure development

[1] Boss, Andreas, Sotirios Bisdas, Armin Kolb, Matthias Hofmann, Ulrike Ernemann, Claus D. Claussen, Christina Pfannenberg, Bernd J. Pichler, Matthias Reimold, and Lars Stegger. "Hybrid PET/MRI of intracranial masses: initial experiences and comparison to PET/CT." Journal of Nuclear Medicine 51, no. 8 (2010): 1198-120

Radiofrequency Penetrable Brain Dedicated PET System

Detector Module Design and RF Shielding

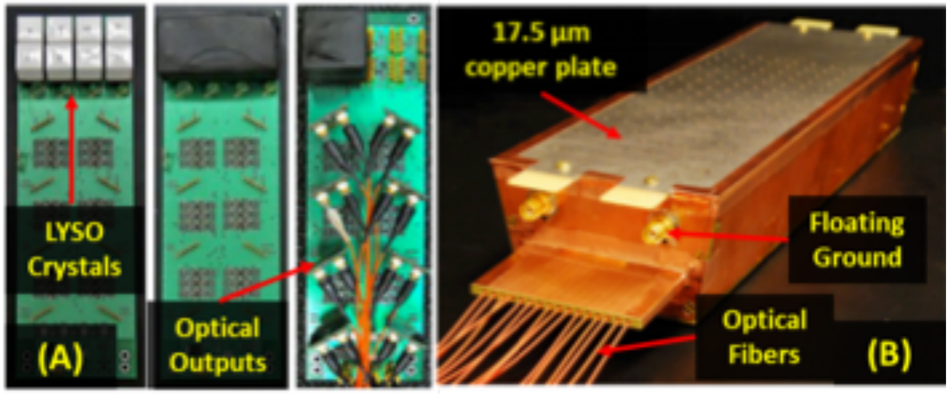


***Figure 2:** (A) Detector Module with LYSO crystals. (B) Shielding detector module held at floating voltage*

- **Detector Module Design:** 3.2 x 3.2 x 20 mm^3 LYSO crystal elements 1-1 coupled to arrays of silicon photomultipliers (SiPM) with a total of 128 crystals

Compressed Sensing Readout

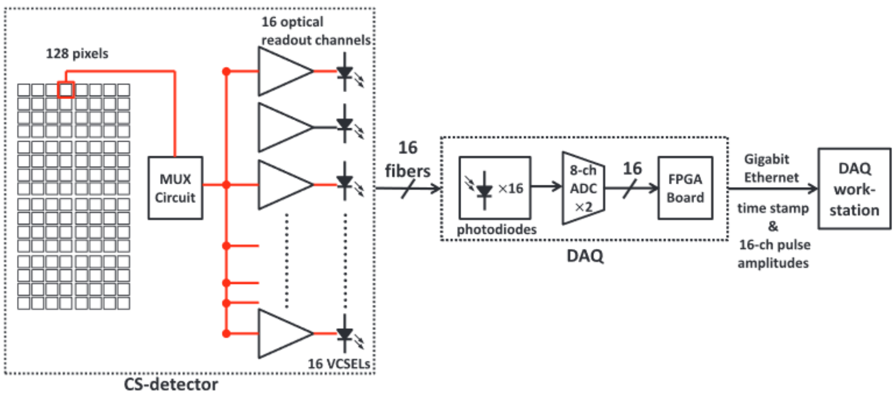


***Figure 3:** Compressed sensing channel reduction method. Patterns describe energy, timing, and spatial positioning*

- **Compressed Sensing:** Front end electronics reduce 128 pixels to 16 rather than using 1:1 pixel to channel ratio
- **Event Information:** 16 channel yield energy, timing, and spatial position of each event

[2] Chang, Chen-Ming, Alexander M. Grant, Brian J. Lee, Ealgoo Kim, KeyJo Hong, and Craig S. Levin. "Performance characterization of compressed sensing positron emission tomography detectors and data acquisition system." Physics in Medicine & Biology 60, no. 16 (2015): 6407.

Radiofrequency Penetrable Brain Dedicated PET System

PET System Assembly and System DAQ

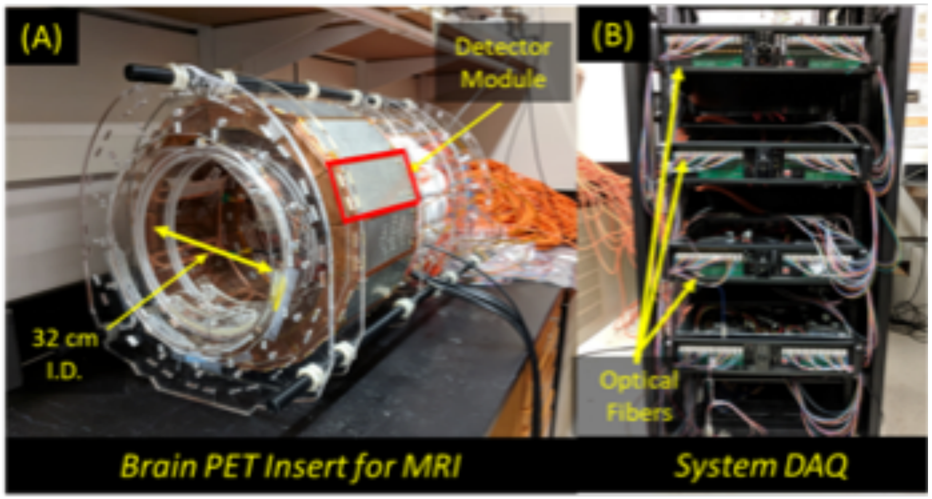


Figure 4: *(A) 16 module detector ring (B) System DAQ with 256 optical channels*

- ❑ **BrainPET System General Geometry:** 16 modules form a 32-cm I.D. and 40-cm O.D. which can be inserted into a 3T MR system
- ❑ **Active Field of View:** 128 crystals from a 3 cm axial FOV for this prototype system

RF Compatibility and Sensing

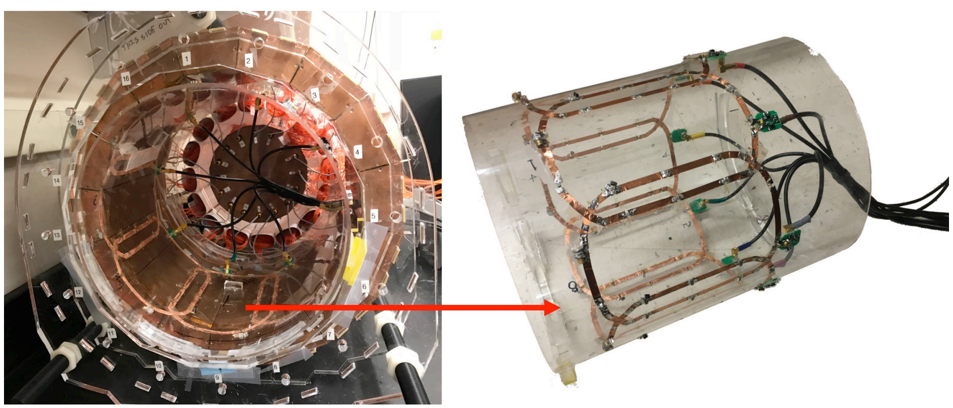
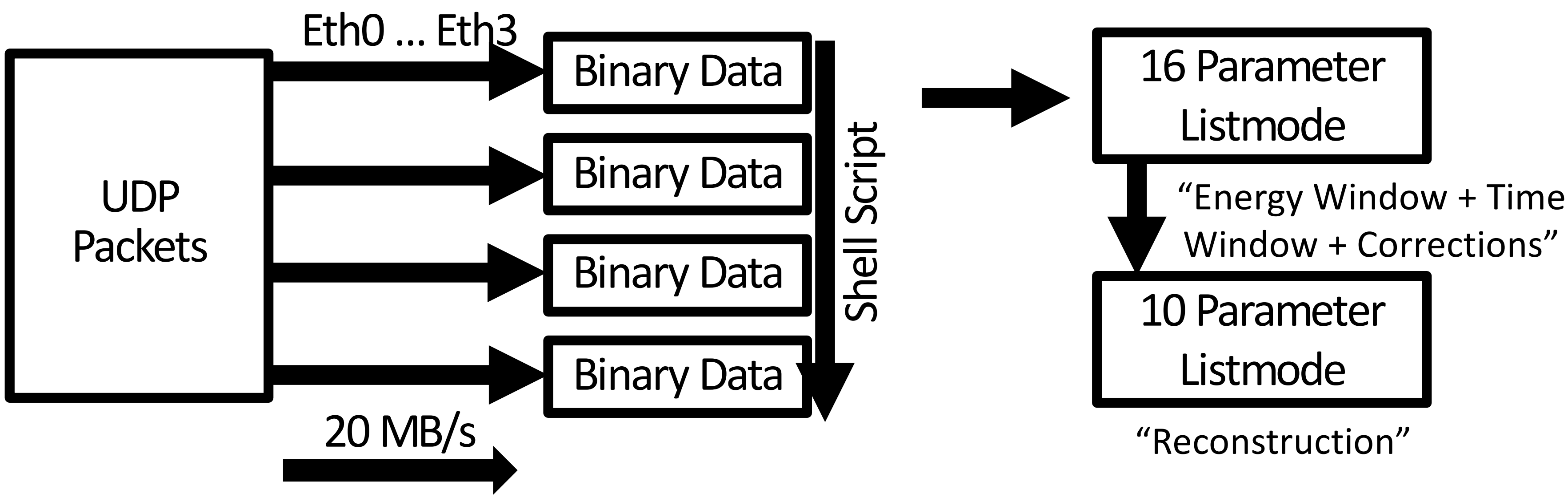


Figure 5: *Phased array coil insert used for receiving data*

- ❑ **RF Penetrability:** System is electrically floating and detector modules are separated by 1 mm
- ❑ **Receiver Coil:** Attenuation is limited to one direction as a body coil/phased array coil combination is employed

PET Data Processing

Data Acquisition Method and Processing – Parallel



- **Brain PET Header Information**
  - Source port – (DAQ System) – FPGA Firmware Coded: "192.168.1.1"
  - Destination Port – (PC) – BrainPET Hardcoded: "192.168.1.2"

- **Modified Brain PET Header Information for Parallel Processing**
  - Source port – (DAQ System) – FPGA Firmware Coded: "192.168.1.1"
  - Destination Port – (PC) – BrainPET *User Defined*: "X.X.X.X"

System Spatial Resolution – BrainPET versus GE Signa

Resolution Phantom Layout and Design

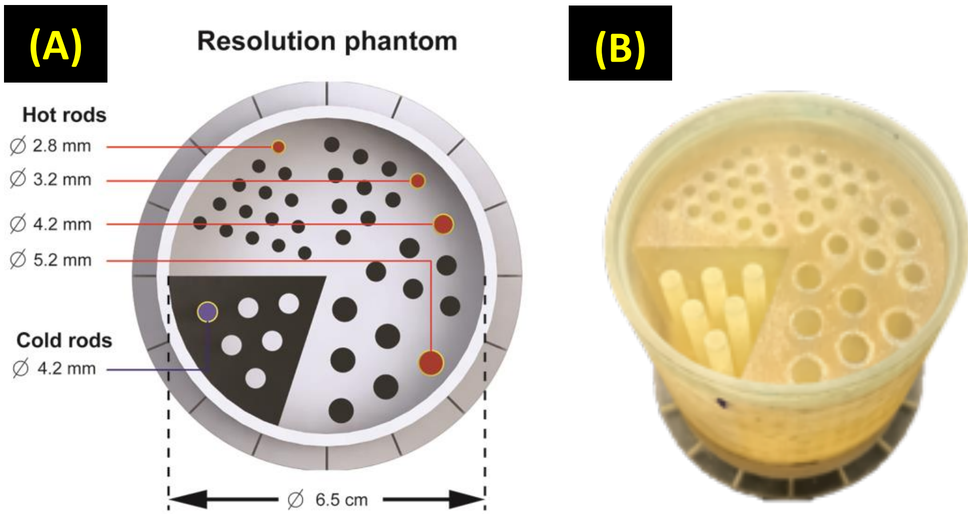


Figure 6: *(A) Sketch of custom 3D printed phantom. (B) Actual 3D phantom.*

- ❑ **Custom Resolution Phantom:** 3D-printed phantom for spatial resolution [3]
- ❑ **Hot Rod Dimensions:** 5.2 mm, 4.2 mm, 3.2 mm, and 2.8 mm
- ❑ **Cold Rod Dimensions:** 4.2 mm

Resolution Phantom Experimental Parameters

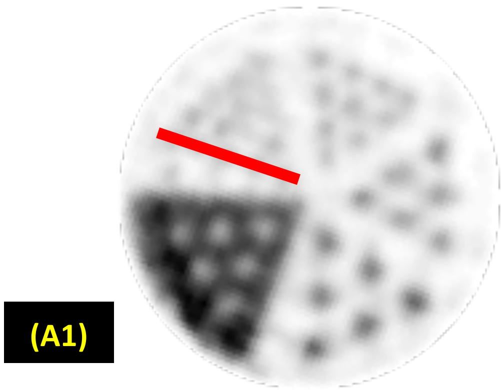
- ❑ **BrainPET Acquisition Parameters:** 300 µCi and scanned for 45 minutes. Reconstruction was performed with our OSEM with voxel sizes of 1 x 1 x 1 mm^3
- ❑ **GE Signa Acquisition Parameters:** 500 µCi and scanned for 30 minutes. Reconstruction was performed with the native OSEM algorithm provided by the system with voxel sizes of 1.17 x 1.17 x 2.78 mm^3

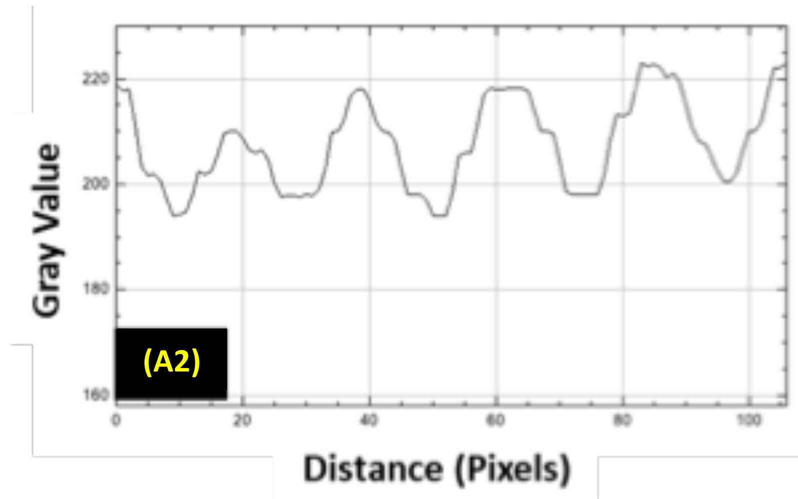
[3] Bieniosek, Matthew F., Brian J. Lee, and Craig S. Levin. "Characterization of custom 3D printed multimodality imaging phantoms." Medical physics 42, no. 10 (2015): 5913-5918.

System Spatial Resolution – BrainPET versus GE Signa

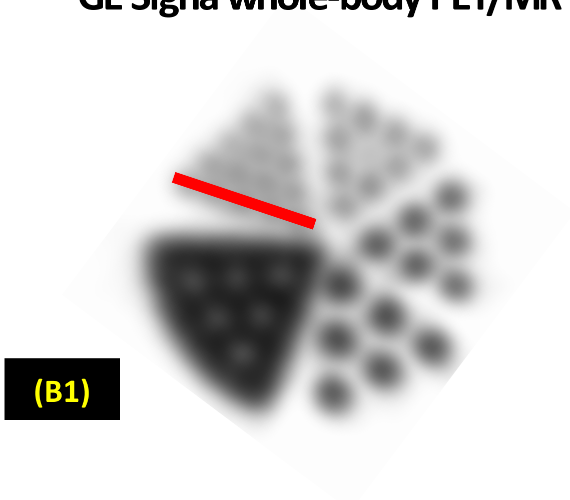
Comparative Resolution Phantom Results – BrainPET Versus GE

Prototype brain-sized PET insert





GE Signa whole-body PET/MR



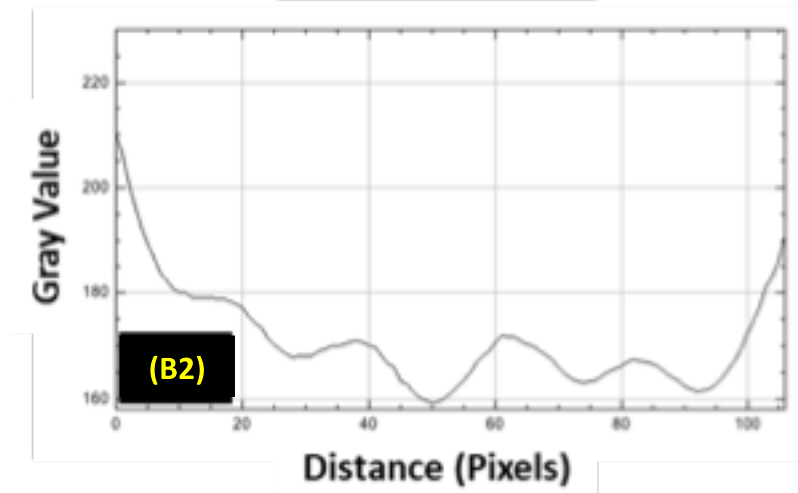


Figure 7: *(A1) Reconstructed spatial resolution phantom. (A2) 2.8 mm rod cross-section profile. (B1) GE Signa reconstructed resolution phantom. (B2) 2.8 mm rod cross-section profile*

Hoffman Brain Phantom

Hoffman Brain Phantom Reference Images

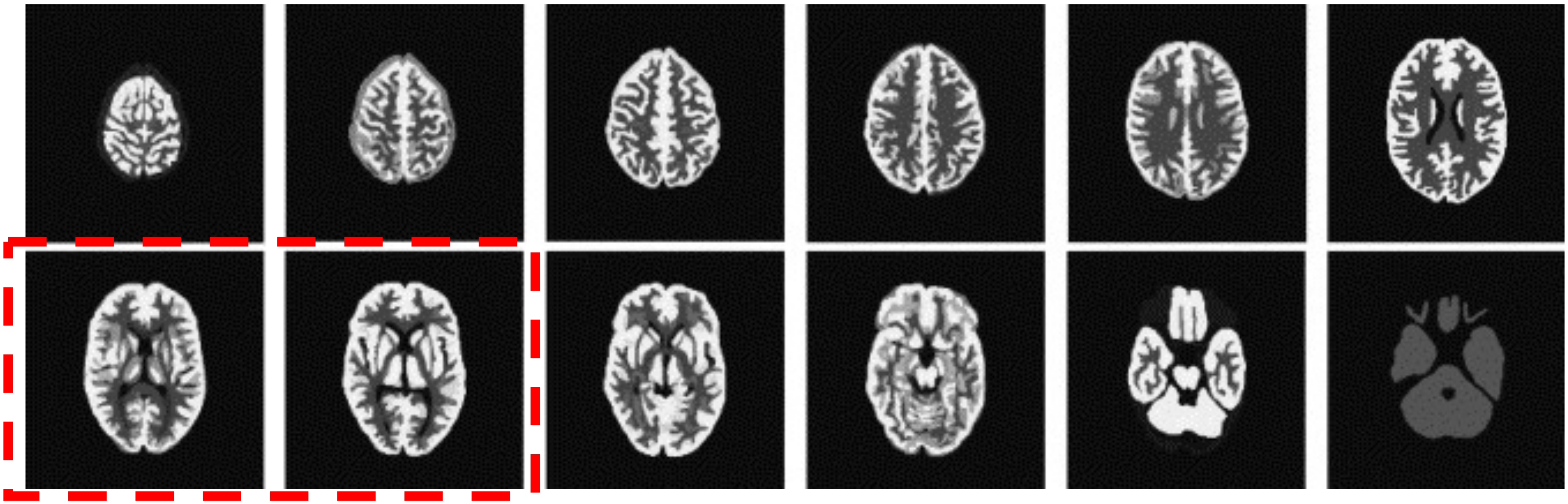


Figure 8: *Digital Hoffman brain phantom. Targeted features of first [4]*

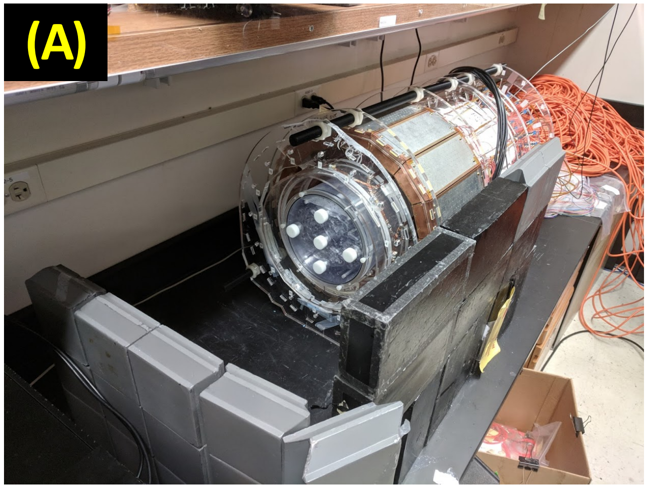
- ❑ **Hoffman Phantom:** Designed to simulated blood flow and metabolism with 4:1 uptake between grey and white matter.

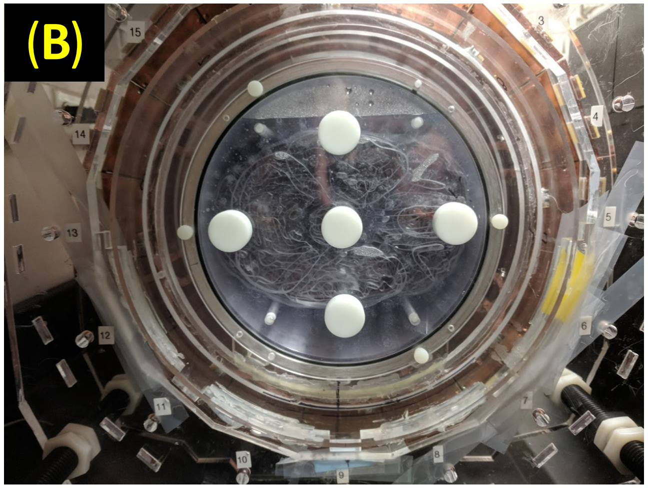
- ❑ **High Resolution System:** Anticipation of improved axial midbrain (highlighted RED box) resolution provided by PET insert (2.8 mm vs. >4 mm)

[4] Beekman, F. J., C. Kamphuis, M. A. King, P. P. Van Rijk, and M. A. Viergever. "Improvement of image resolution and quantitative accuracy in clinical single photon emission computed tomography." Computerized Medical Imaging and Graphics 25, no. 2 (2001): 135-146.

Hoffman Brain Phantom

Hoffman Phantom System Orientation





Hoffman Phantom Acquisition from Saturation – Coincidence Events Per Second

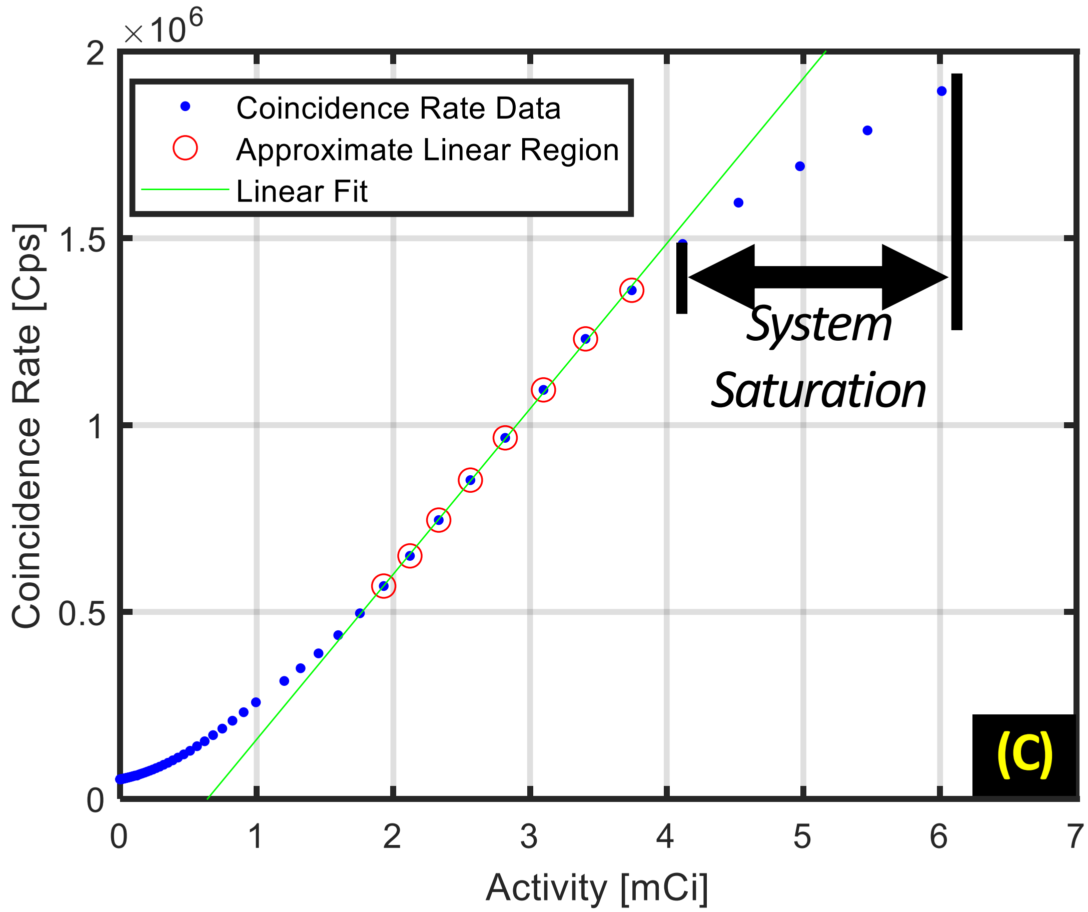
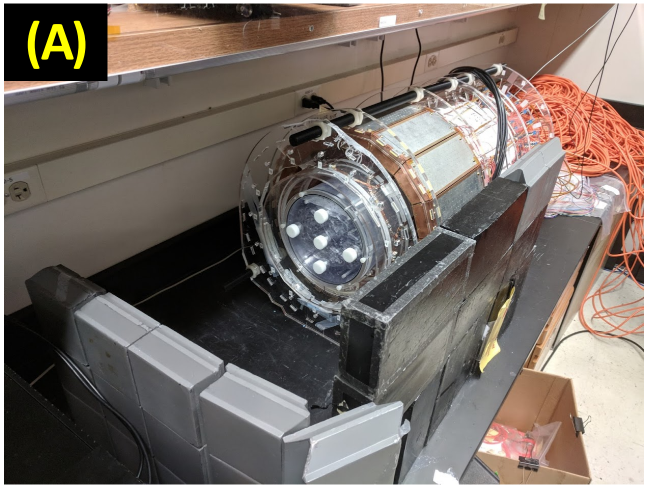


***Figure 9:** (A,B) Hoffman phantom setup. (C) Initial Hoffman saturation curve intended to describe absolute system limitations.*

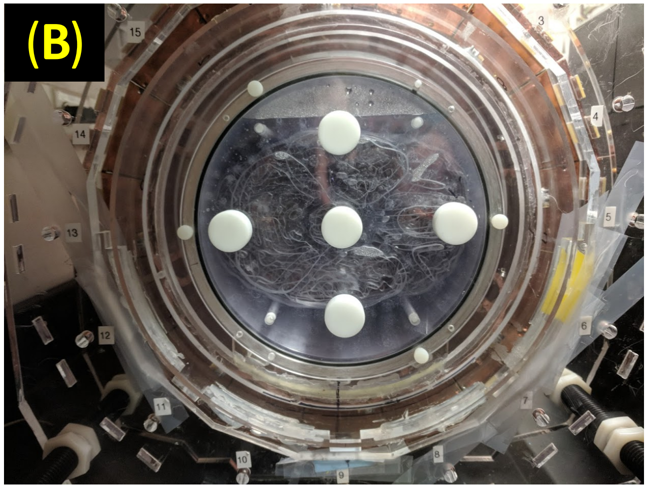
Hoffman Brain Phantom

Hoffman Phantom System Orientation

(A)



(B)



Hoffman Phantom Scan with Fully Integrated Counts (Non-Clinical Condition) versus GE Signa

Hoffman Images Removed

Figure 10: *(A,B) Hoffman phantom setup. (C) BrainPET fully time integrated image. (D) GE Provided brain phantom.*

Hoffman Experiment Parameters

- **BrainPET Acquisition Parameters:** 10 mCi initial activity, 9 hrs imaging (1 hr coincidence/10 minute randoms), 2 mm x 2 mm x 2 mm voxels
- **GE Signa Phantom Data:** Provided by GE with 3.125 mm x 3.125 mm x 2.78 mm voxels

Hoffman Brain Phantom Continuation

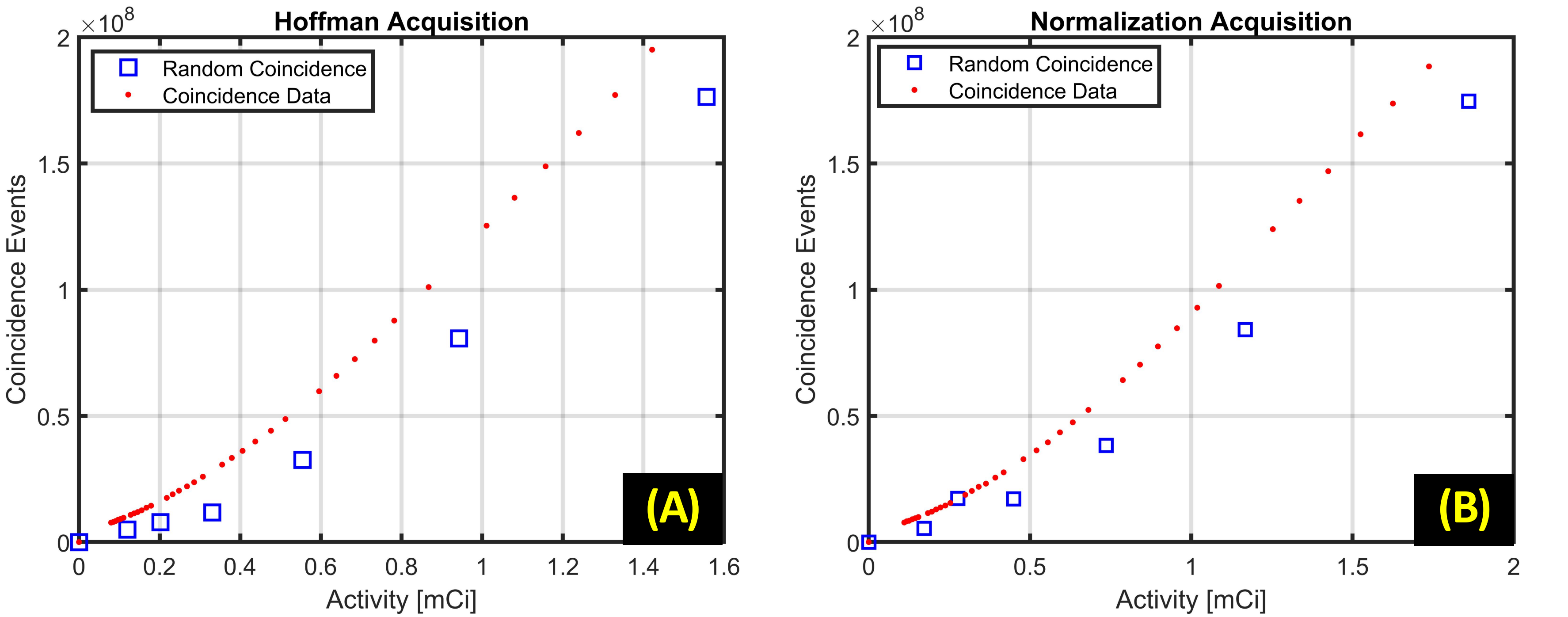


Figure 10: *(A) Hoffman Brain Phantom Coincidence measurement versus activity with coincidence events and random coincidence data (B) Normalization measurement versus activity with coincidence events and random coincidence data*

- ❑ **Hoffman Phantom Acquisition:** Manual acquisition of 10 minute intervals of coincidence data in sequences of 6 followed by single random coincidence acquisition
- ❑ **Normalization Data:** Manual acquisition of 10 minute intervals of coincidence data in sequences of 6 followed by single random coincidence acquisition

Hoffman Phantom Images by Hour of Acquisition

Reference

Hoffman Brain Phantom Images (3 – 5)

Hoffman Images Removed

GE Signa

Hoffman Brain Phantom Images (6 – 8)

Hoffman Images Removed

Conclusions and Future Work

Post-Processing Image Improvements

- **Clinic Application Potential:** Without image corrections, 1 Hr (or slighty longer) studies for clinical translation are reasonably the lower limit of acquisition time
- **GE Signa versus BrainPET:** Our system lacks proper AC, randoms correction, and Monte-Carlo based scatter correction contributing to the discrepancy in image

Future Work

- **Normalization:** Switching between normalization cylinder and a normalization ring
- **Randoms Correction:** Normalization and Hoffman phantom random data available but needs to be applied
- **GRAY Monte Carlo based scatter correction:** Using in house simulation software to remove scatter in 410 keV to 610 keV range
- **Quantification:** Use image quality metrics to precisely describe performance (e.g. CNR)

Acknowledgments

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