Performance evaluation of the EXPLORER Total-body PET/CT scanner based on NEMA NU-2 2018 standard with additional tests for extended geometry

Benjamin A. Spencer[1], Jeffrey P. Schmall[2], Eric Berg[1], Negar Omidvari[1], Edwin Leung[1], Zilin Deng[2], Songsong Tang[2], Yun Dong[2], Yang Lv[2], Weiping Liu[2], Jun Bao[2], Hongdi Li[2], Terry Jones[1], Ramsey D. Badawi[1] and Simon R. Cherry[1]

[1]University of California Davis, Davis, CA
[2]United Imaging Healthcare, Shanghai, China

Disclosures

- UC Davis has a research agreement and a sales-based revenue sharing agreement with United Imaging Healthcare.

uEXPLORER Total-body PET/CT Scanner

- Eight rings of detector modules
- Axial FOV of 194 cm
- 57° acceptance angle

➢ Enhanced sensitivity

uEXPLORER Total-body PET/CT Scanner

- 510(k) approval (Dec. 2018)
- Installed at the EXPLORER Molecular Imaging Center (May 2019)
- First Total-body PET scanner used clinically (Aug. 2019)

Objectives

1. First post-installation characterization of the uEXPLORER scanner following NEMA NU 2-2018
   - Independent analysis software developed at UC Davis
2. Extended geometry measurements to characterize Total-body PET scanners
   - NEMA NU 2 suitable for scanners with <65 cm AFOV
   - Extended geometry: ≈175 cm (world average human)

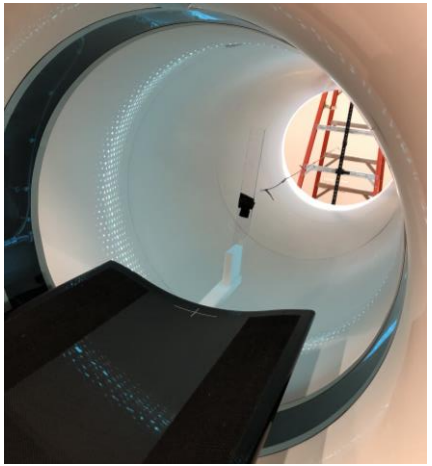
Sensitivity

NEMA NU 2-2018 Protocol

- **70** cm ^{18}F line source in attenuating aluminum sleeves

Extended Geometry

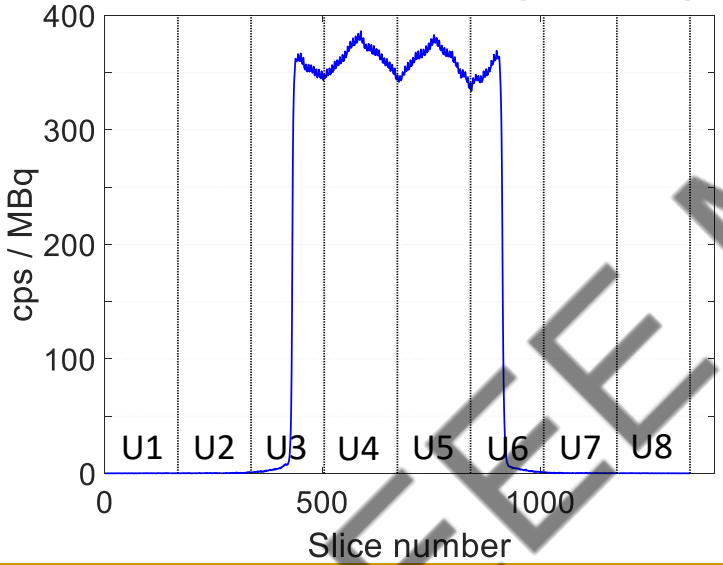
- **170** cm ^{18}F line source
- No aluminum sleeves



Sensitivity

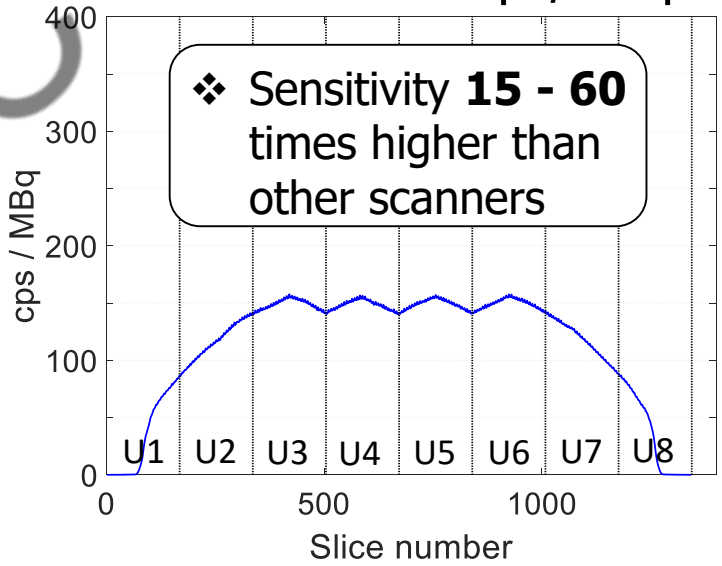
NEMA NU 2-2018 (70 cm)

- Center: 174 kcps/MBq
- 10 cm : 177 kcps/MBq



Extended Geometry (170 cm)

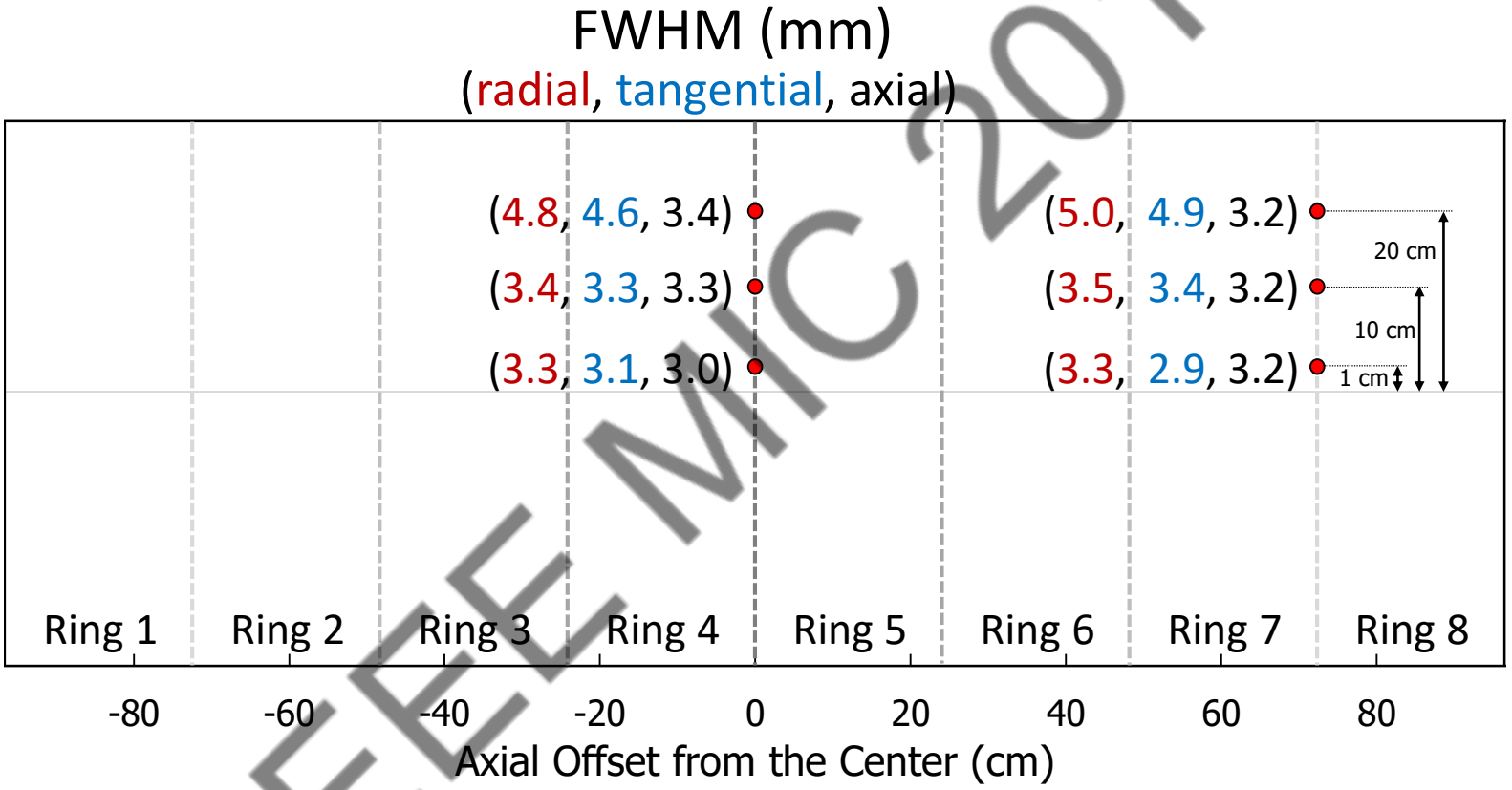
- Center: 147 kcps/MBq
- 10 cm : 151 kcps/MBq



Spatial Resolution

- Measured following the **NEMA NU 2-2018** protocol
  - FBP reconstruction, 0.6 mm isotropic voxels
  - Reduced acceptance angle
- Capillary tube with **1 mm** inner diameter
- ≈ 8 µCi **^{18}F**-FDG

Spatial Resolution

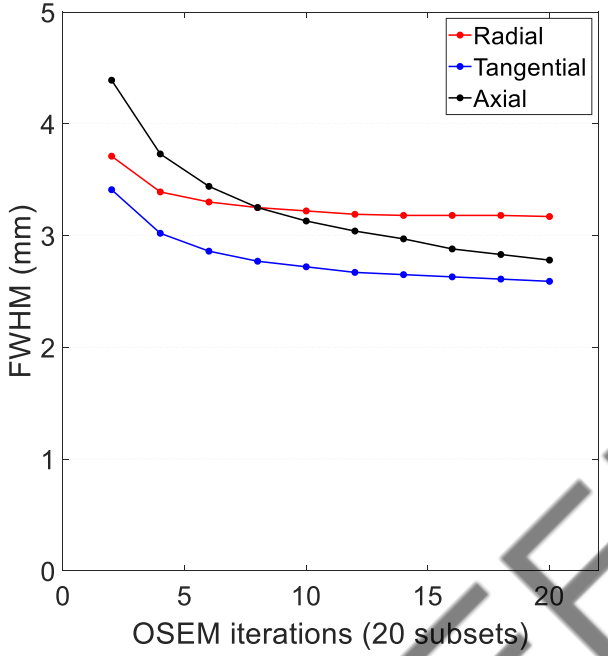


Spatial Resolution – Iterative Reconstruction

- Measured using a **point source** reconstructed in a **warm background** with 3D-OSEM + PSF modeling
- Two separate scans:
  - ^{22}**Na** point source
  - ^{68}**Ge** uniform cylinder
- List-mode data combined with 10:1 image contrast
- 0.5 mm isotropic voxels, 20 iterations, 20 subsets

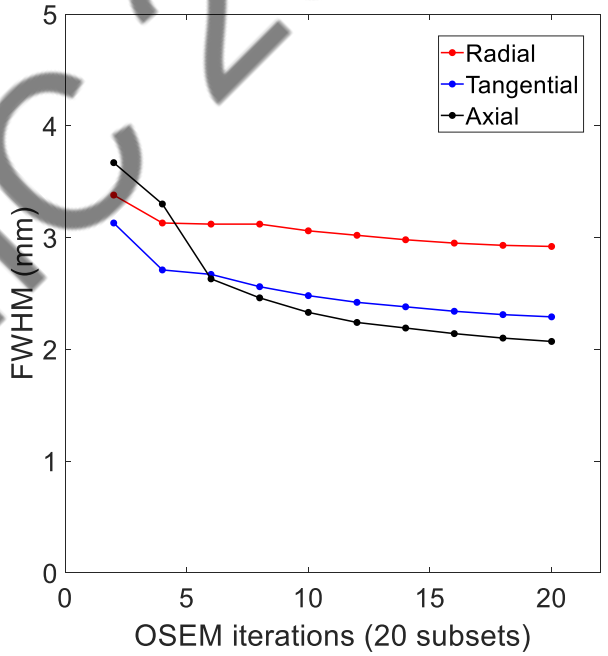
Spatial Resolution – Iterative Reconstruction

Center AFOV – **1** cm offset



Rad. = 3.2 mm
Tang. = 2.6 mm
Axial = 2.8 mm

1/8th AFOV – **1** cm offset

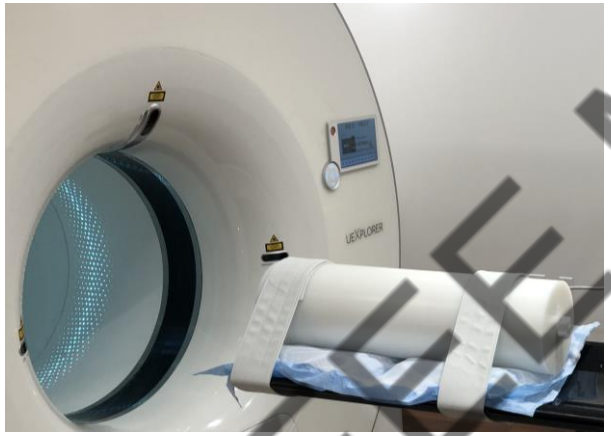


Rad. = 2.9 mm
Tang. = 2.3 mm
Axial = 2.1 mm

Count Rate Performance

NEMA NU 2-2018

- **70** cm scatter phantom
- Activity ≈ 20 mCi
- Elevated 15 cm (bed to center)



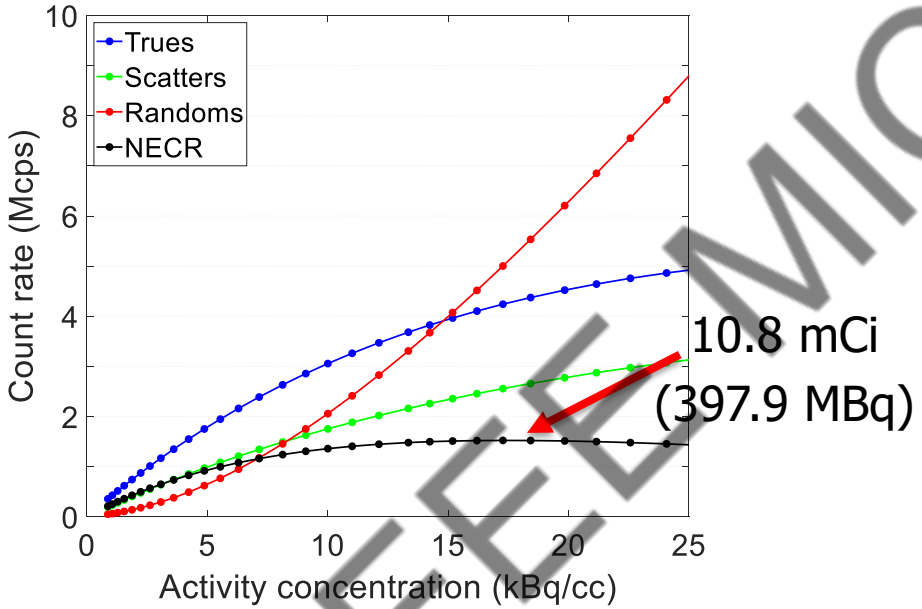
Extended Geometry

- **175** cm scatter phantom
- Activity ≈ 20 mCi
- Elevated 15 cm (bed to center)

Noise Equivalent Count Rate (NECR)

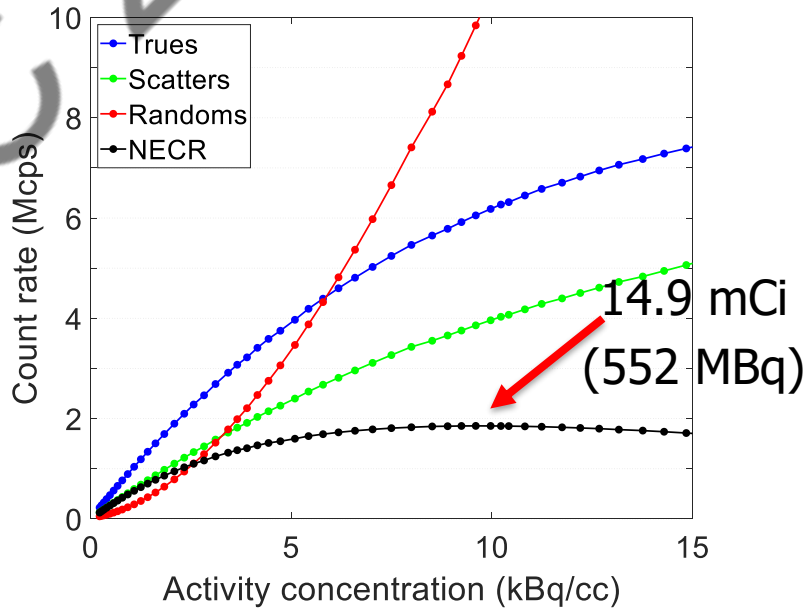
NEMA NU 2-2018 (70 cm)

$NECR_{peak}$ = **1.52** Mcps @**17.3** kBq/cc



Extended Geometry (175 cm)

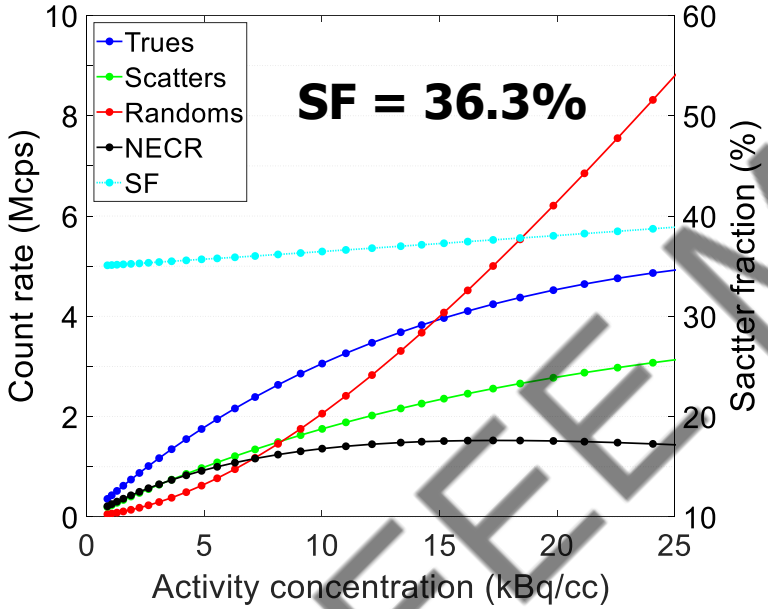
$NECR_{peak}$ = **1.86** Mcps @**9.6** kBq/cc



Scatter Fraction (SF)

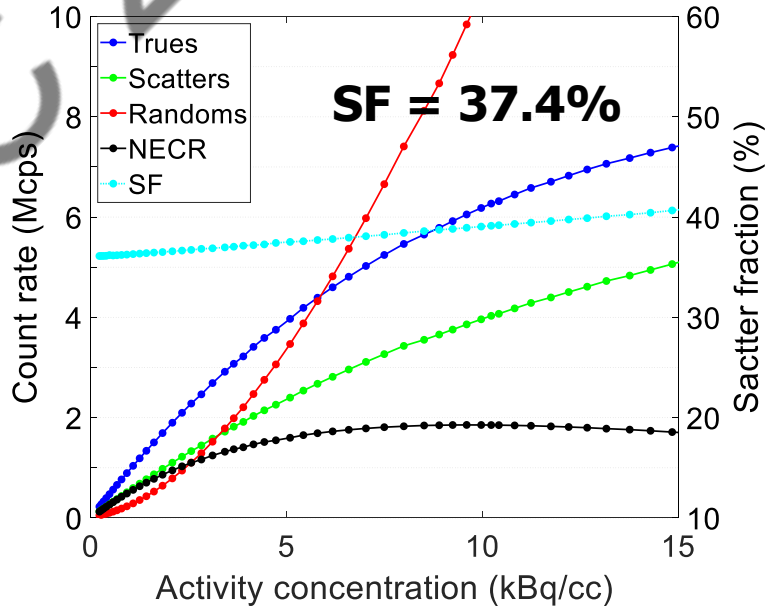
NEMA NU 2-2018 (70 cm)

$NECR_{peak}$ = **1.52** Mcps @**17.3** kBq/cc



Extended Geometry (175 cm)

$NECR_{peak}$ = **1.86** Mcps @**9.6** kBq/cc



Time-of-Flight Resolution

NEMA NU 2-2018

- 70 cm scatter phantom with ^{18}F line source

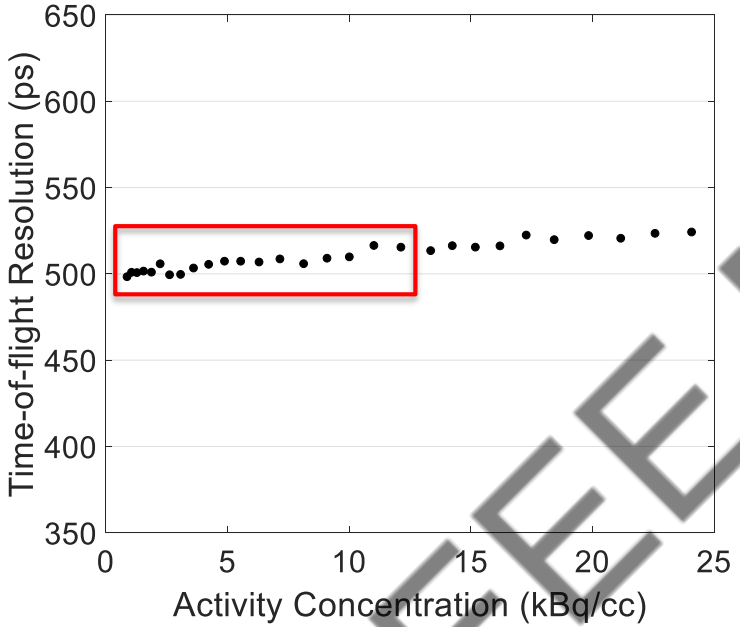
Additional TOF Measurements

- Additionally, using 70 cm scatter phantom measured TOF resolution of:
  - single detector ring
  - detector block-to-block
  - single crystal-to-crystal

Time-of-Flight Resolution

NEMA NU 2-2018

505 ps at 5.3 kBq/cc (low activity)



Additional TOF Measurements

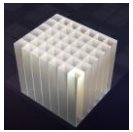
Using counts from 0 - 12 kBq/cc

Single detector ring:

- **497 ps**

Detector block-to-block:

- **461 ± 10 ps**



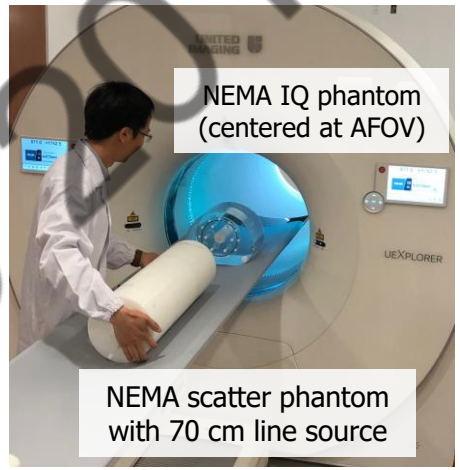
Single crystal-to-crystal:

- **412 ± 35 ps**

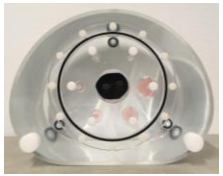
NEMA Image Quality and Accuracy of Corrections

Activity distribution and scan protocol

- Sphere-to-background ratio: **4.07**
- Bkg. activity conc.: **5.03 kBq/ml**
- Total activity: **4.6 mCi**
- Acquisition duration: **30 min**
- 3D-TOF OSEM with all corrections, 4 iterations, 20 subsets

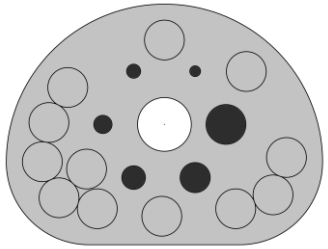


Sphere diameters (mm):
10, 13, 17, 22, 28, 37



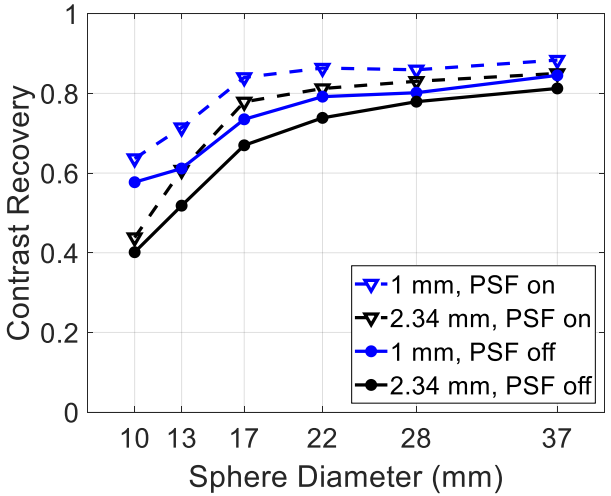
NEMA IQ Tool

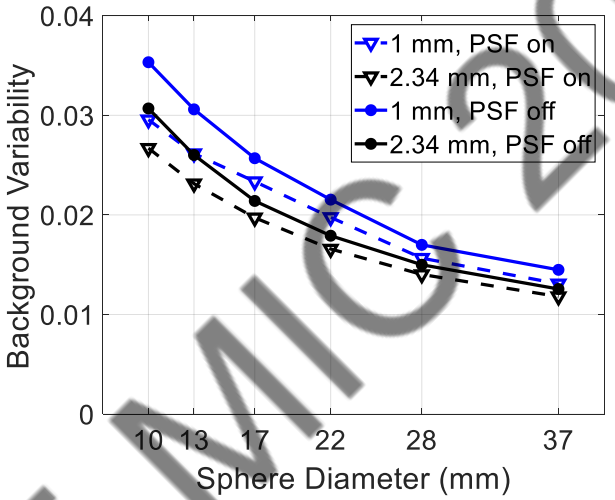
- Semi-automated analysis tool in MATLAB
- Sphere centers found by parabolic fitting
- 2D ROIs defined automatically



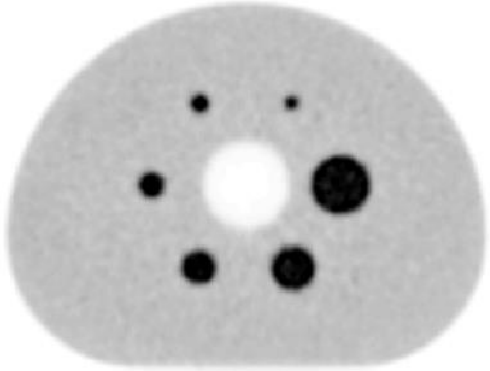
ROIs defined in AutoCAD

NEMA Image Quality and Accuracy of Corrections





1 mm, PSF on



- Using 1 mm voxels and PSF modelling:
  CRC **>63%** and background variability **<4%** achieved for **all sphere sizes**

Image Quality Throughout the AFOV

- NEMA image quality and scatter phantom scanned at **5 axial bed positions**
- Acquisition length adjusted for activity decay: **same total counts**

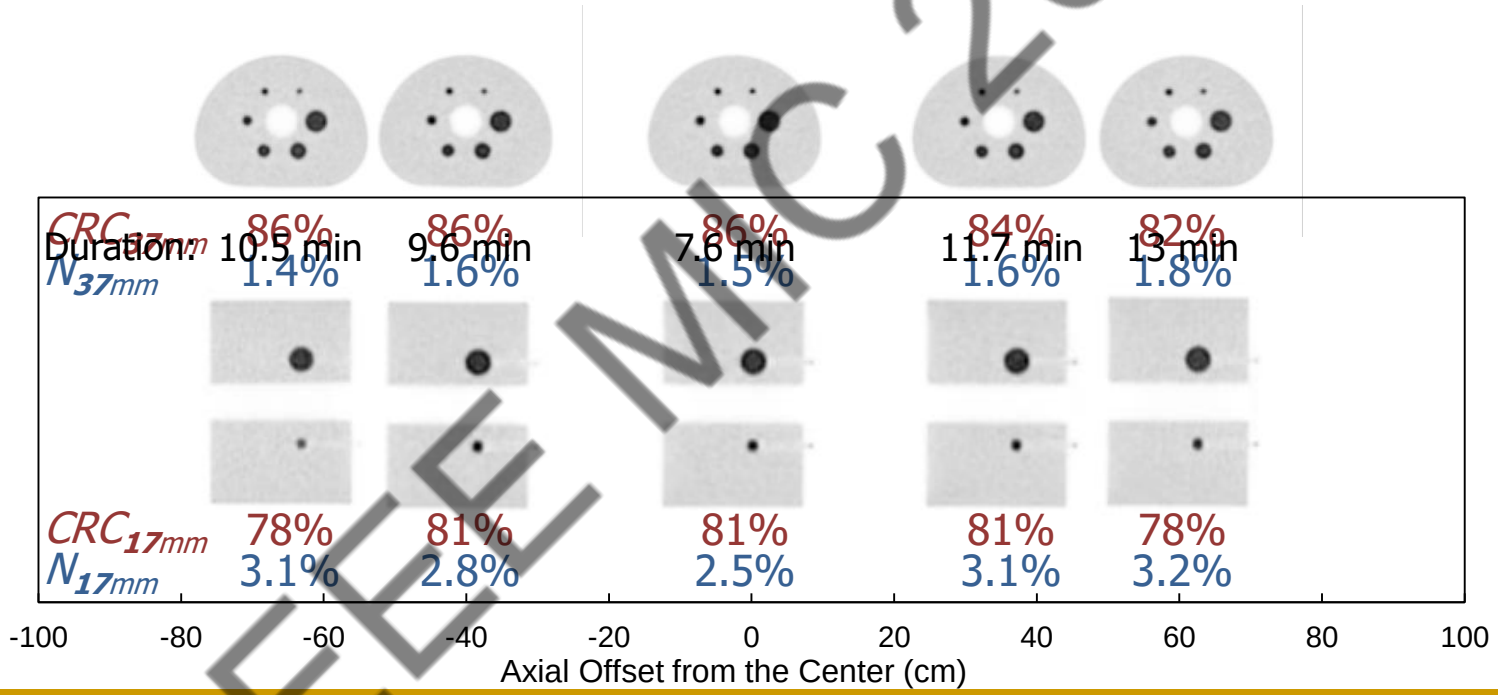


Image Quality at Reduced Dose or Scan Time

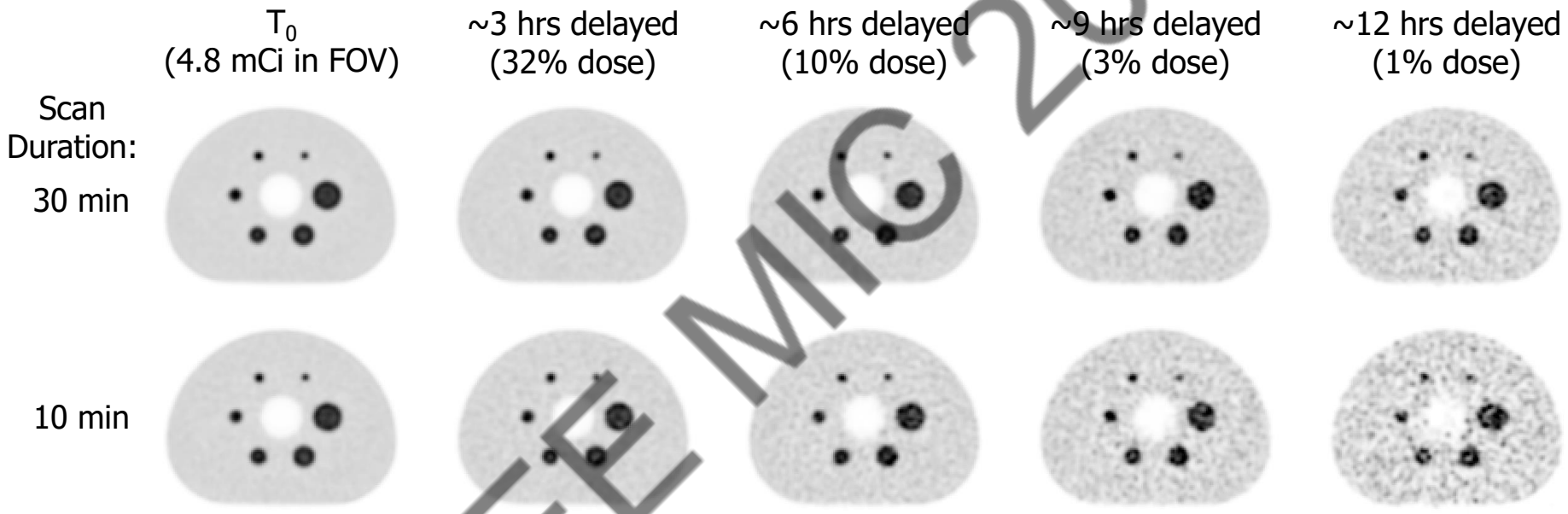
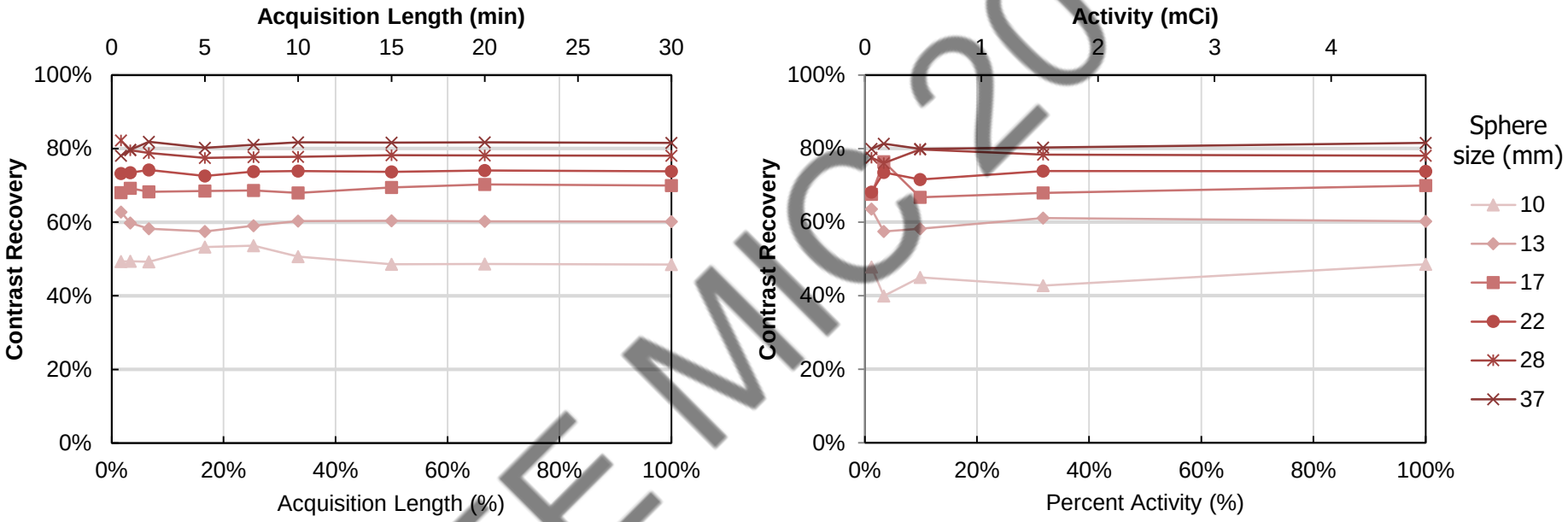
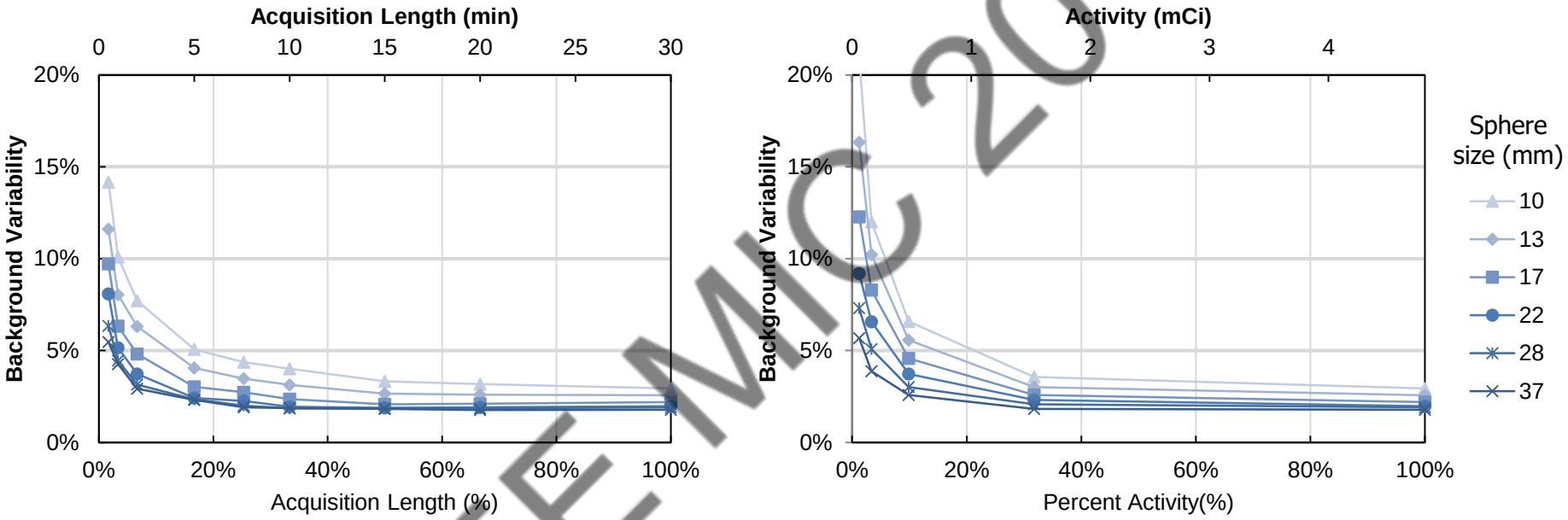


Image Quality at Reduced Dose and Reduced Scan Time



❖ **Contrast recovery** not significantly affected by reducing **scan time** or **dose** to **10%**

Image Quality at Reduced Dose and Reduced Scan Time

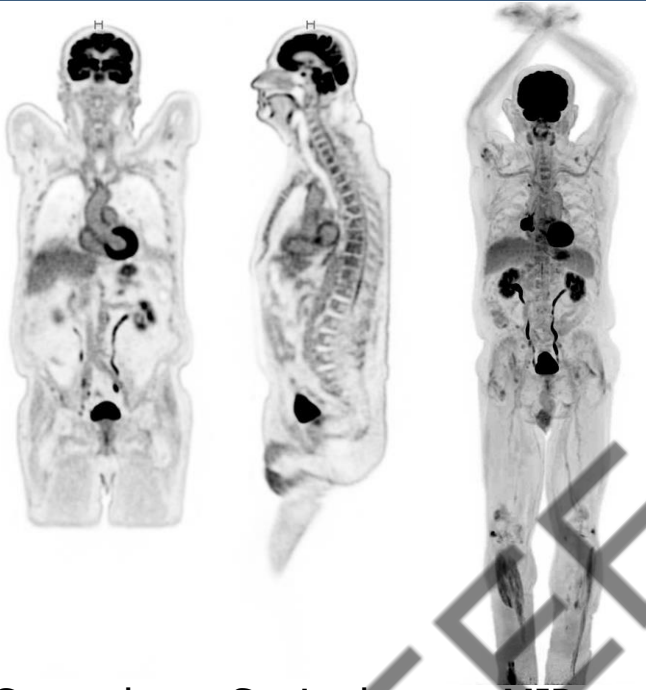


❖ **Background variability** still below **5%** by reducing **scan time** or **dose** to **20%**

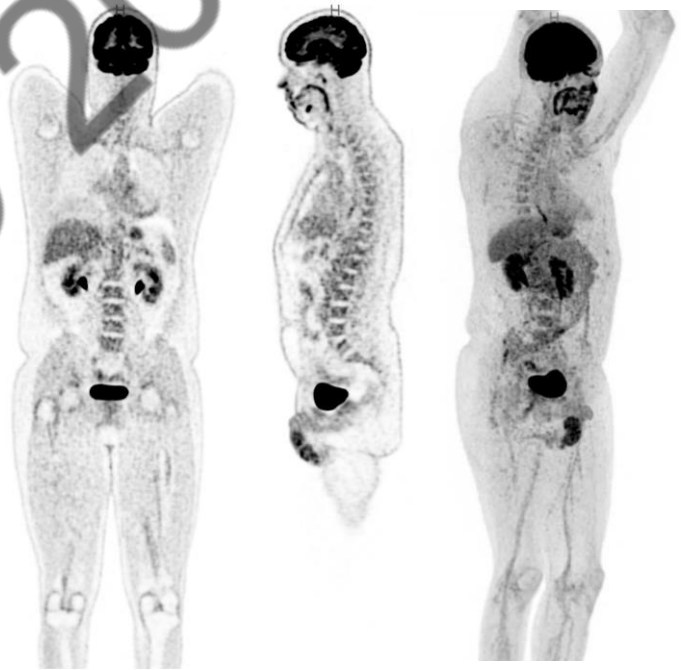
Human Images

Clinical Scan: **5 mCi** @90 min

Research Scan: **0.5 mCi** @90 min



Parameters: 3D-TOF OSEM, 4 it., 2.344 isotropic voxels, 20 min

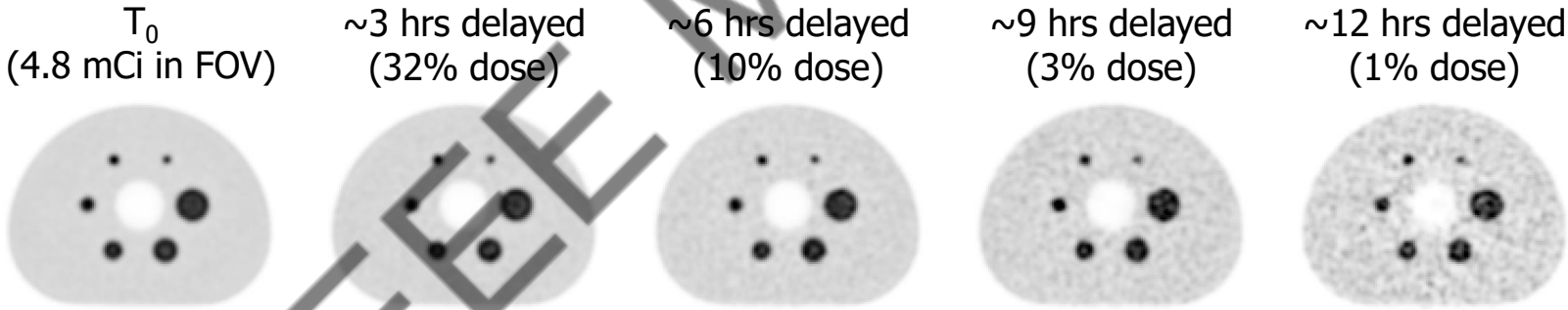


Coronal Sagittal MIP

Coronal Sagittal MIP

Conclusion

- First physical characterization of the uEXPLORER total-body PET scanner has been performed
  - ~15-60 times higher sensitivity than other PET scanners
  - ~3 mm spatial resolution
  - Uniform IQ throughout AFOV, consistent CRC down to 10% activity



Acknowledgments

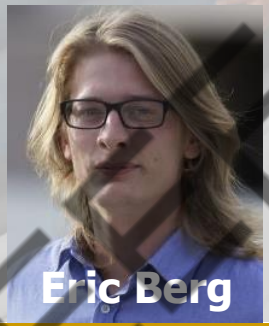
MIPET Team:
Simon Cherry
Ramsey Badawi
Terry Jones
Jinyi Qi
Lorenzo Nardo
Guobao Wang
Martin Judenhofer
Emilie Roncali
Sun Il Kwon
Edwin Leung
Julien Bec
Xuezhu Zhang
Liz Li

Clinical Operations:
Cameron Foster
Denise Caudle
Stephen Wetzel
Michael Rusnak
Mikey Nyguen
Kristin McBride
Heather Hunt

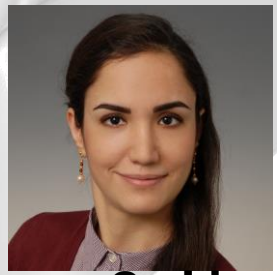
United Imaging:
Hongdi Li
Jun Bao
Weiping Liu
Yun Dong
Tianyi Xu
Zilin Deng
Songsong Tang
Yang Lv
Peng Liu

Funding:

R01 CA170874
R01 CA206187
also supported by NIBIB and the Office of the Director
R35 CA197608


Eric Berg


Jeff Schmall


Negar Omidvari

Thank you!