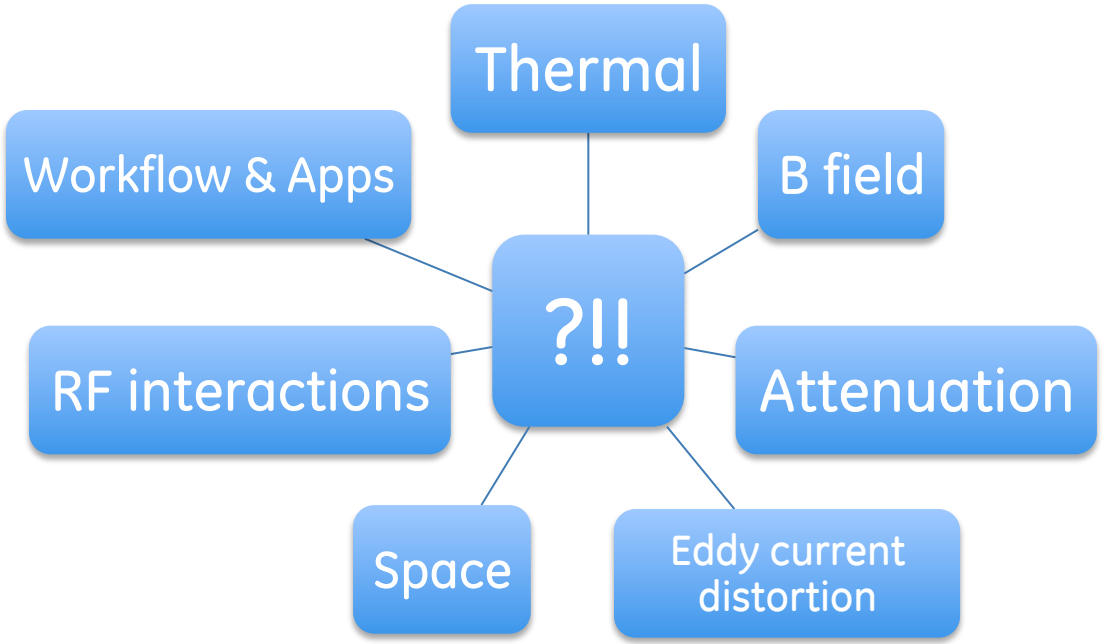
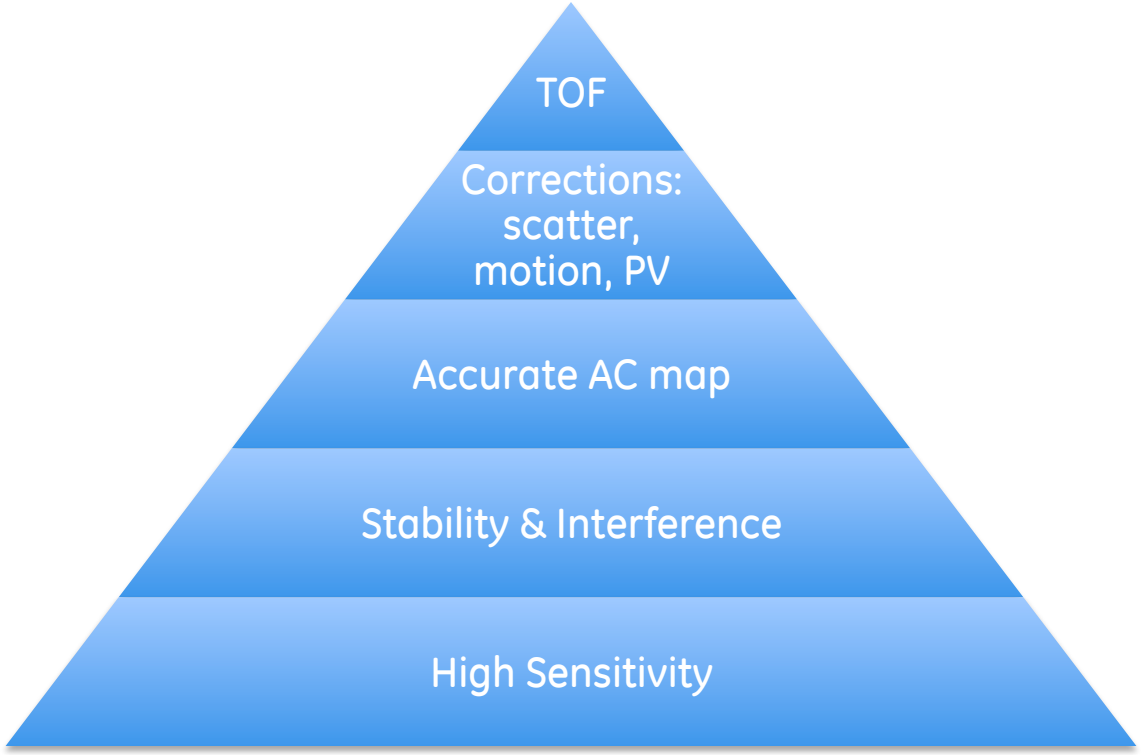
Technological Advances and Challenges: Experience with Time-Of-Flight PET Combined with 3T MRI

Floris Jansen,
GE Healthcare
July, 2015

PET/MR 101 : challenges



PET for PET/MR: optimizing for quantitation



PET detectors in PET/MR

Essential:

- Insensitive to magnetic fields
- Compact
- Excellent shielding (no interference)
- Stability (temperature)

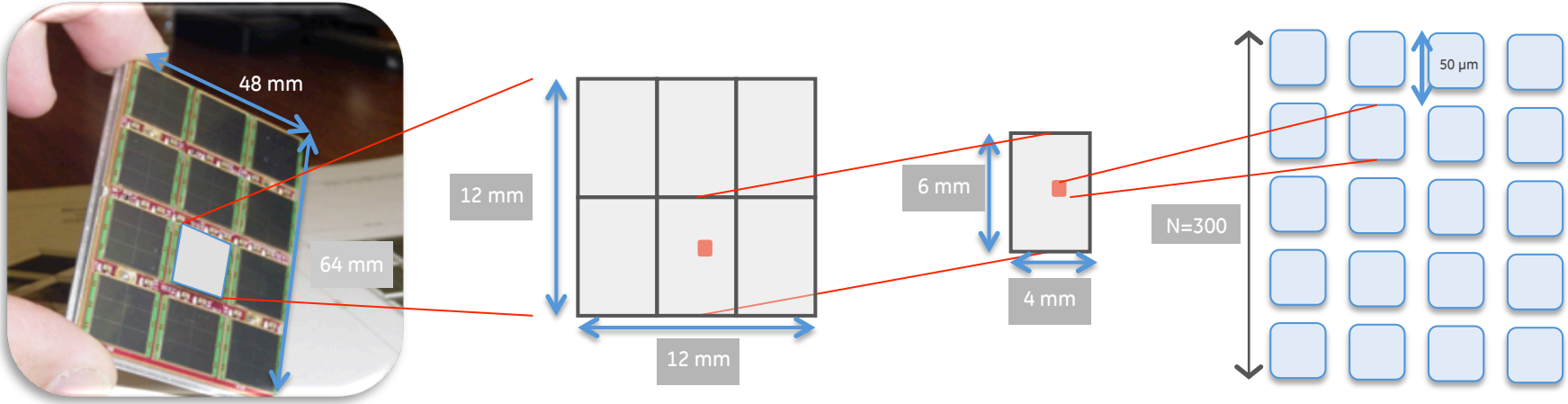
Very useful:

- High sensitivity
- TOF capability

Solid State (Silicon) Photomultiplier

an array of arrays of arrays of microcells

- ✓Small
- ✓Fast
- ✓Low voltage
- ✓Works at 3T



Replaces PMT in PET detector:
smaller size and better timing resolution

Changes required for MRI system

Space for PET detector

Minimize attenuation (coils, table)

Integrated software / workflow

Pulse sequences to estimate attenuation

“Whole body” paradigm: cradle motion

GE PET/MR Design Objectives

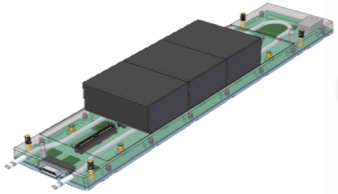
Discovery MR750w

70cm Bore

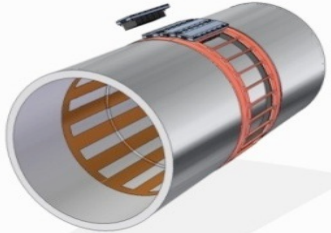
- MR750w 3T MRI Performance
- High Sensitivity (Low Dose) TOF PET
- Fully Integrated Simultaneous System
- Field Upgrade for MR750w

SIGNA PET/MR

60cm Bore

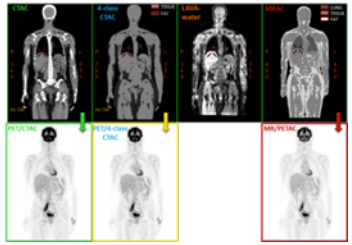


MR Compatible PET Detector



PET/MR Hardware Integration

Software / Workflow Integration

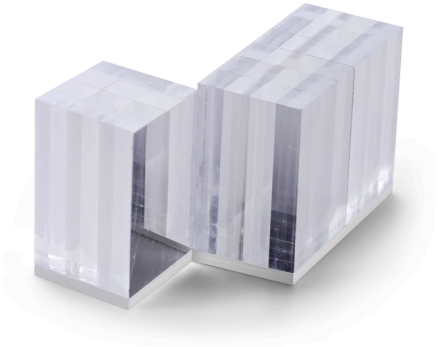


MR Based PET Attenuation Correction

Design elements that enable Time of Flight

- Fast, bright scintillator: LBS
- Fast, high PDE detector: SiPM
- High gain photosensor: SiPM
- Light collection efficiency: light guide
- Low noise electronics: ASIC
- Fast TDC: 13 ps LSB
- In-bore electronics
- Precise calibration
- Good stability/corrections

Design elements that enable high sensitivity



+

= 21 cps/kBq

25 mm LBS

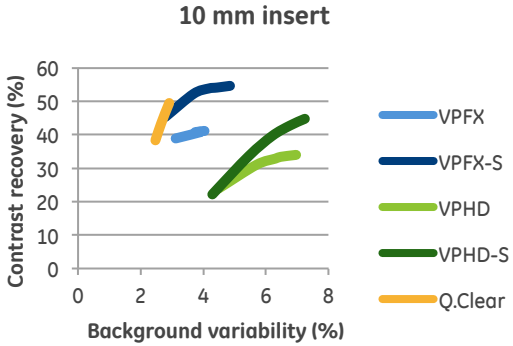
Integrated electronics
Compton Scatter Recovery (+20%)
25 cm axial FOV
62 cm detector face to face

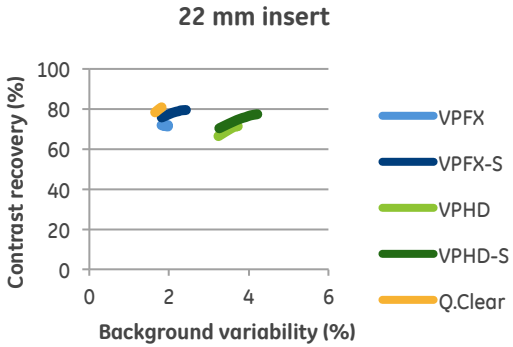
The value of TOF in PET/MR

- Faster convergence
- Better CNR at equal count density
- Robust truncation completion
- Reduced sensitivity to attenuation map defects

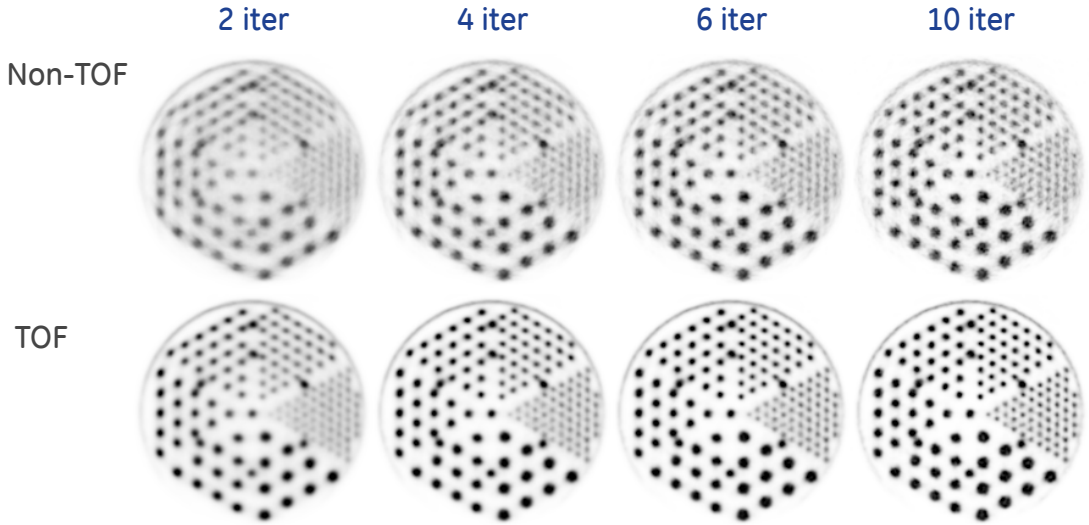
Impact of TOF - phantoms

NEMA phantom: CNR





Derenzo phantom: 5 slice sum (14 mm slab)

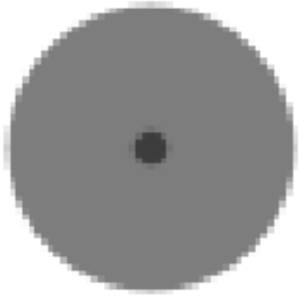


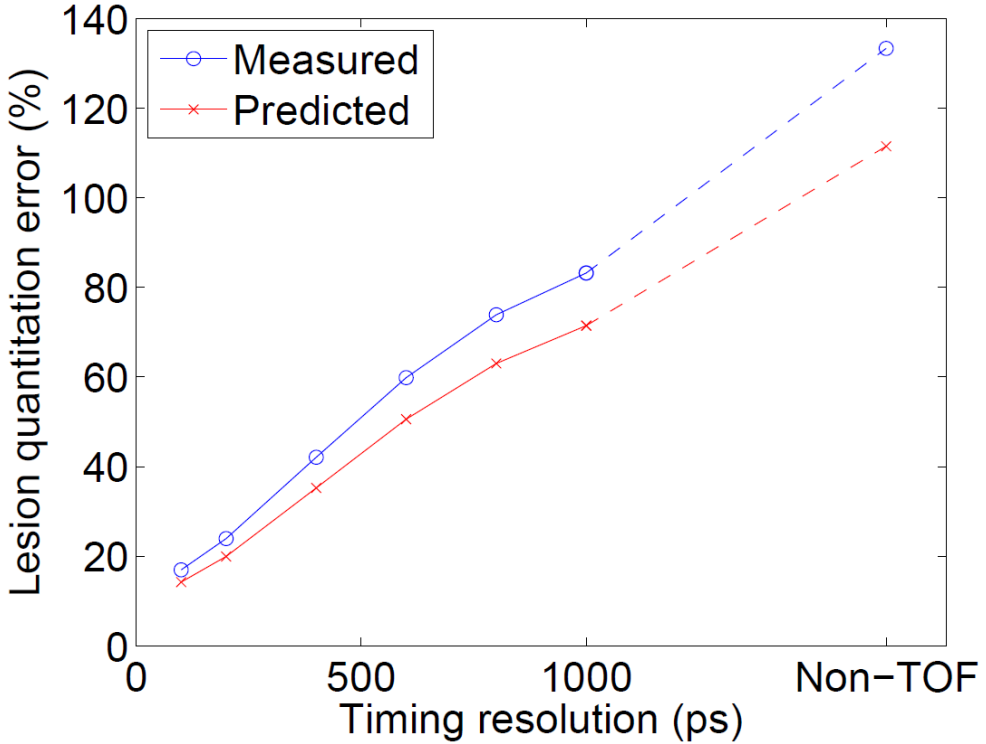
Better resolution, better contrast recovery and lower noise

Quantifying the importance of TOF for AC

Actual AC map
(25 cm 0.1 /cm)

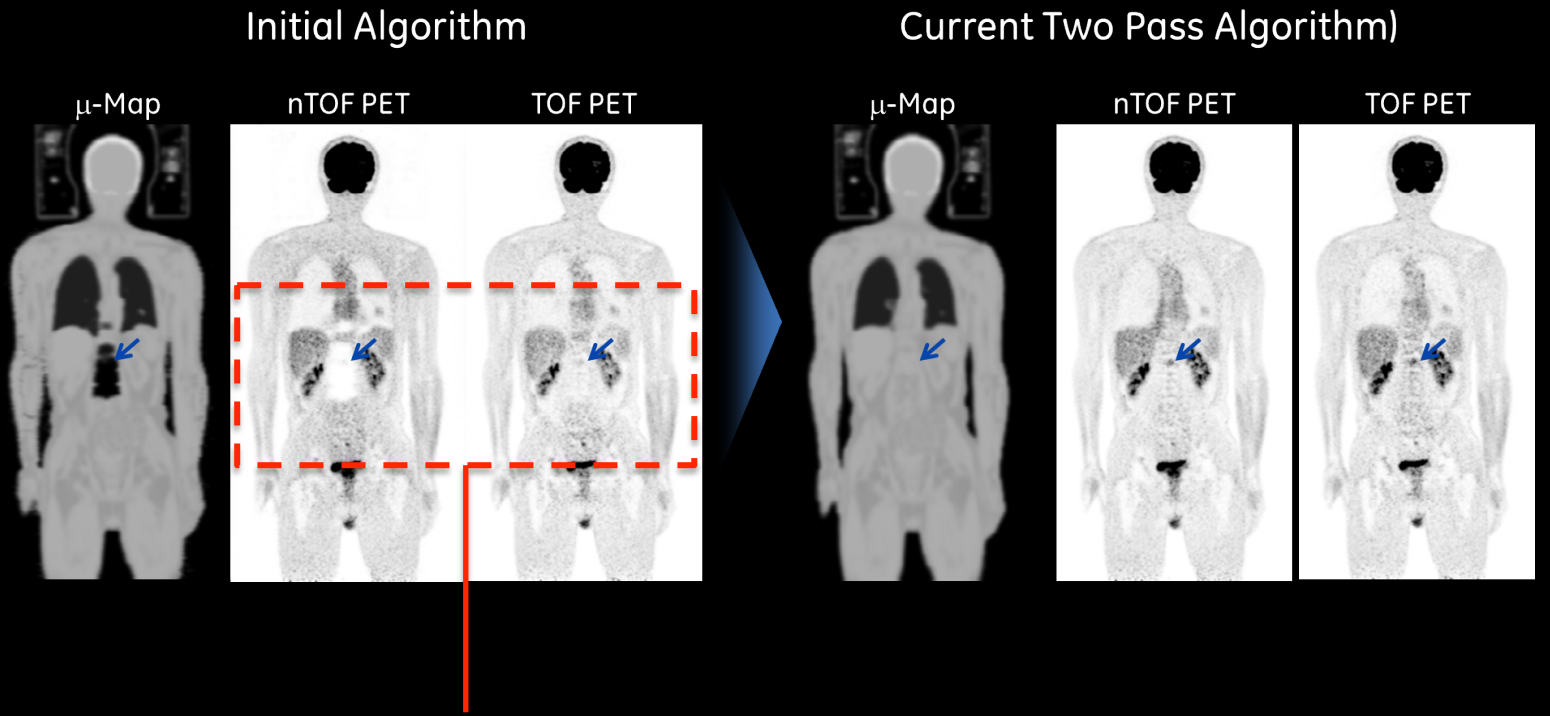
Simulated
AC map
(3 cm, 0.15 /cm)





Ahn et al,"*Analysis of the Effects of Errors in Attenuation Maps on PET Quantitation in TOF PET*", MIC 2014

Clinical example – MRAC Robustness



TOF reduces sensitivity to MRAC segmentation errors

Stability and shielding

Stability:

- SiPM detector gain is sensitive to temperature
- Liquid cooling and ceramic heat sink insufficient
- Thermal compensation mechanism maintains stability across range of pulse sequences

Shielding:

- Optical communication, double shielded cables, differential signaling, choice of clock frequencies

Robustness to (mutual) interference

Key PET NEMA measurements barely affected by MR

	No MR	With MR
Energy resolution (FWHM)	10.3%	10.5%
Timing resolution (FWHM)	382 ps	393 ps
Peak NECR (kcps)	218	215
Sensitivity (kcps/MBq)	22.9	22.5
Spatial resolution	unchanged	

Data courtesy Craig Levin, Stanford University

MR specs unchanged from 750w:

SNR unchanged/ better
Transmit power increased
Magnet uniformity / shim unchanged
Gradients unchanged
Narrower patient bore (70 cm → 60 cm)

Attenuation correction

MRI good for contrast, but no direct determination of photon attenuation

MRI cannot “see” bone very well

MRI FOV smaller than PET FOV → need to estimate out-of-field mu map

TOF PET can provide outline

CT derived head atlas provides bone information

TOF reconstruction less sensitive to AC map errors

TOF derived Joint Estimation may improve AC (bone, metal, lung)

ZTE sequences may visualize bone

Attenuation correction challenges

- Density of lung
- Bone density
- Implants
- Motion
- Floating coils
- MR-invisible hardware

Looking to the future

Quantitative accuracy

- Solve remaining challenges for MRAC

Establish clinical relevance:

- Build evidence of clinical impact / advantages
- Cost / reimbursement
- Workflow / speed
- Technologist / radiologist dual certification
- Referrals / acceptance