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sense and simplicity

PET/MR Imaging
– How do we got here and where are we going?

Ling Shao, PhD
Director, Advanced Development
Advanced Molecular Imaging Business Unit
Philips Healthcare

Outline

- PET/MR History
- Philips PET/MR
- Challenges
- Next step and PET/MR Adoption

PET/MR History

- 1986: H Iida et al: Use of Magnetic field to reduce Position Range

- 1990: Bruce E. Hammer: Patent – NMR-PET Scanner Apparatus – First PET/MR concept

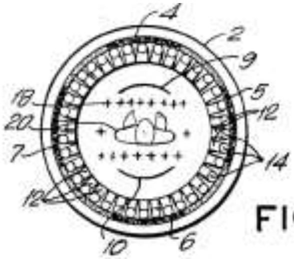
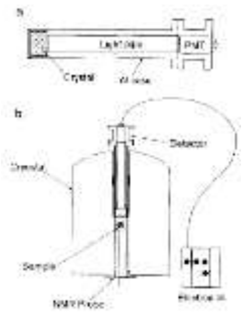


FIG.I

- 1996: M. Buchanan et al: NMR/Radionuclide System



- 1997: Simon Cherry et al: Simultaneous PET/MR images

  (Article In Science Magazine)

Adapted from Dr. Simon Cherry's Presentation

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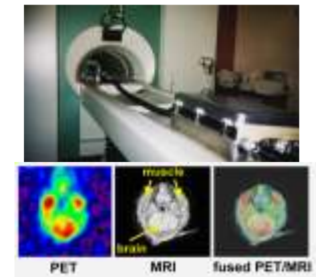
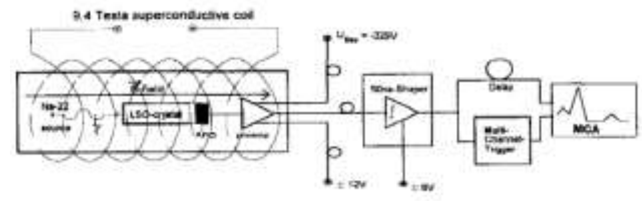
PET/MR History

- 1997: Simon Cherry et al: Simultaneous In Vivo Imaging



- 1997: BJ Pichler et al: LSO-APD Detector at 9.4T



- 2006: Catana et al: Preclinical Insert for Simultaneous PET/MRI at 7T.

- **<u>Software Fusion</u>**: From later 1990 to current – Various Software Fusion capability – Research and products
  - In parallel with PET/CT software fusion

Adapted from Dr. Simon Cherry's Presentation

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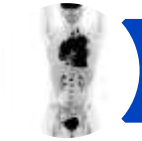
Philips PET/MR – Ingenuity TF PET/MR

(First installed in Feb. 2010 in Mt. Sinai)



State-of-the art PET and MRI

Clinical workflow

Full spectrum of clinical applications

Advanced applications

System Design Goals:

No compromise on both PET and MR system Image qualities

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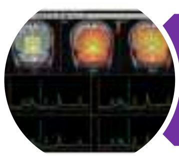
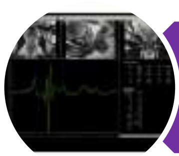
Design Consideration - Applications

MR

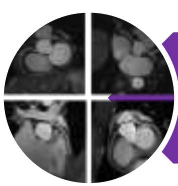
Fast & easy fibertracking



Easy MR brain spectroscopy



Prostate spectroscopy

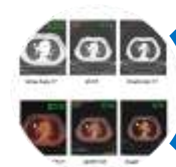


Routine coronary imaging at 3T

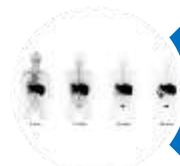
Head-spine imaging without repositioning

PET

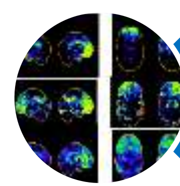
Time-of-Flight PET imaging



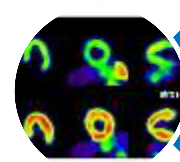
Motion management



Oncology applications



Neurology applications

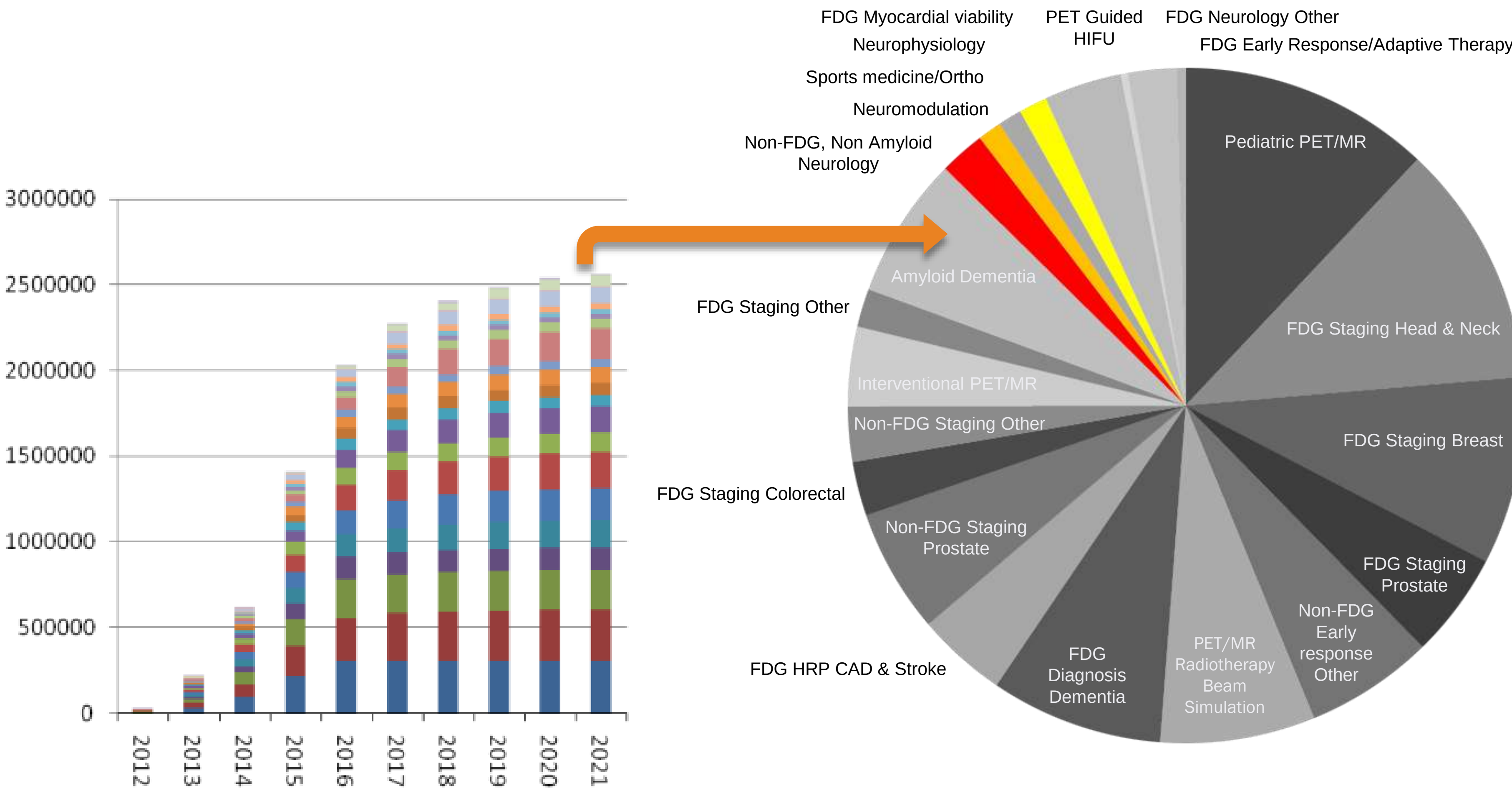


Cardiology applications

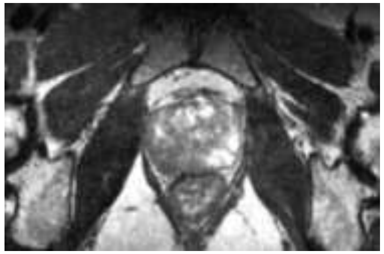
Anticipated Applications for MR/PET

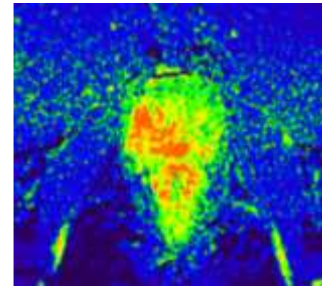
Anticipated clinical indications & relative scan volumes at full market adoption level for MR/PET.

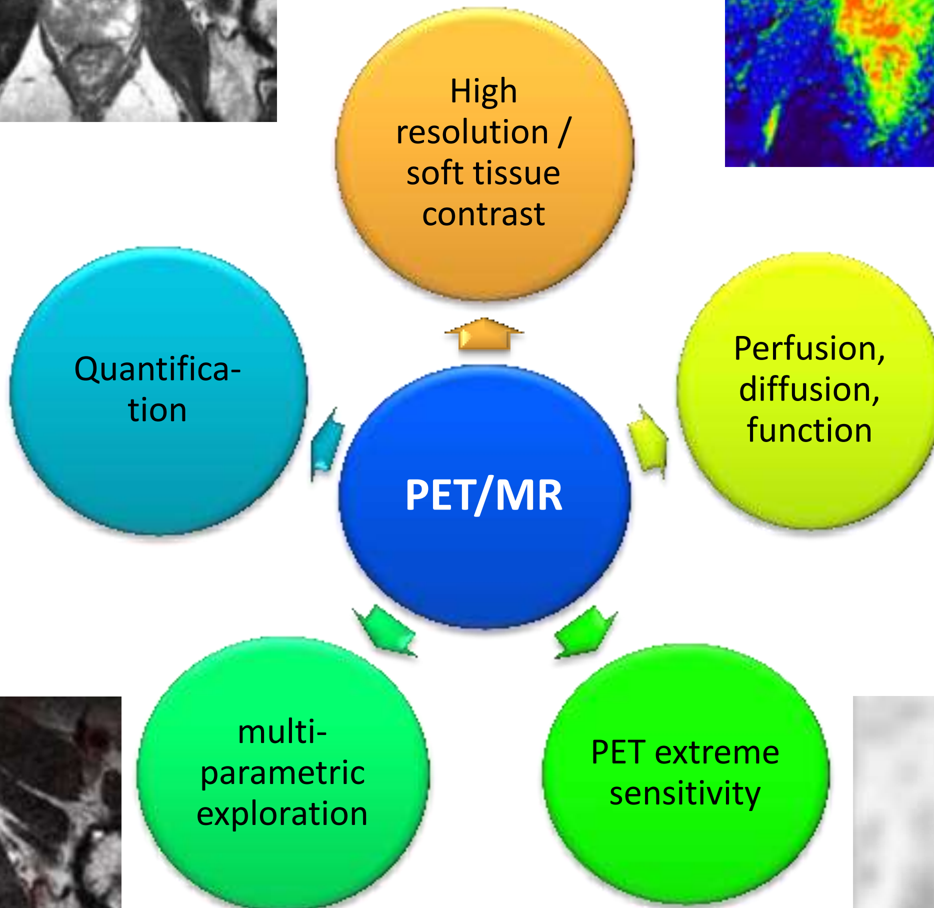
(MR/PET Focus Group Meeting, September 2011, Philips Healthcare)

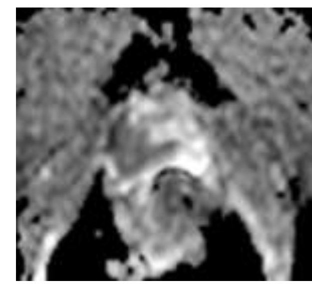


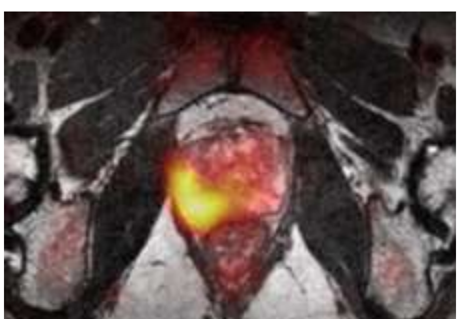
Design Consideration – Quantitation

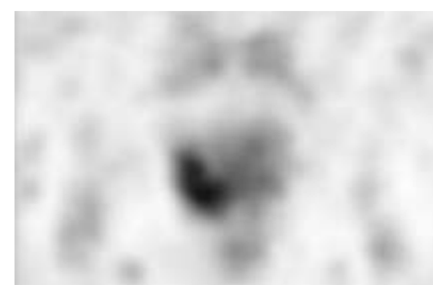








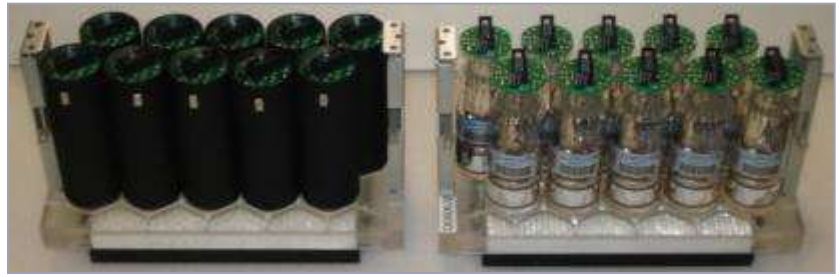




Design Considerations –Technical (Examples)

Ingenuity TF PET/MR Magnetic Shielding

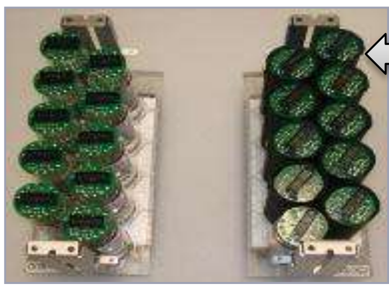
Individual PMT Shield Placement



Ingenuity TF PET/MR Crystal Module

Ingenuity TF PET/CT Crystal Module

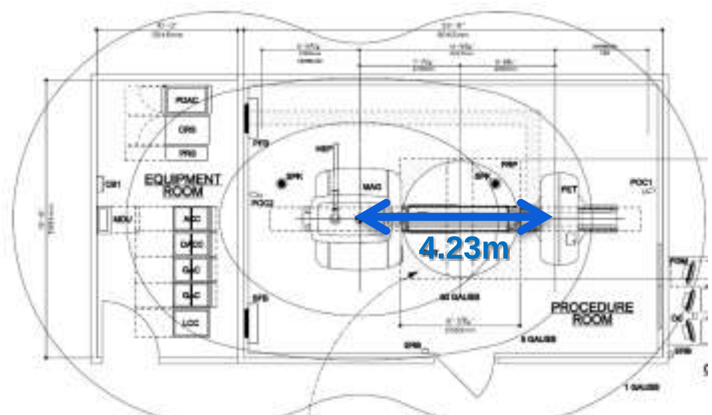
Magnetic shielding of individual PMTs



PMTs' photocathode orientation aligned with the magnetic field flux to eliminate any forces from defocusing the photoelectrons & electrons

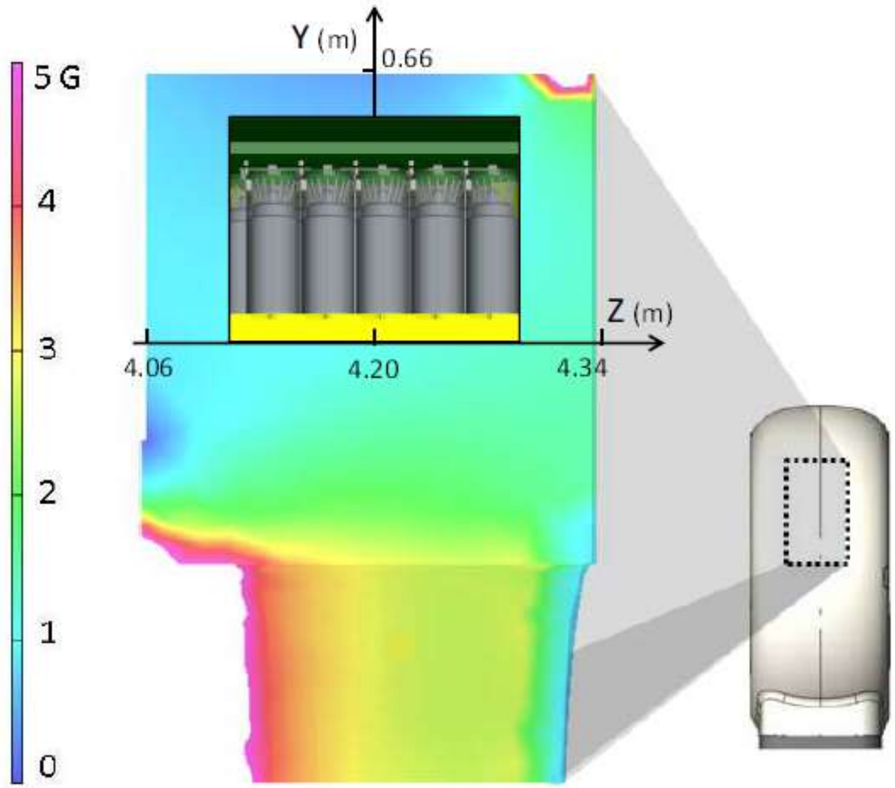
Ingenuity TF PET/MR Gantry with laminated steel shield

- Modular shielded construction in gantry
- Laminated transforming steel cover on PET gantry MR face

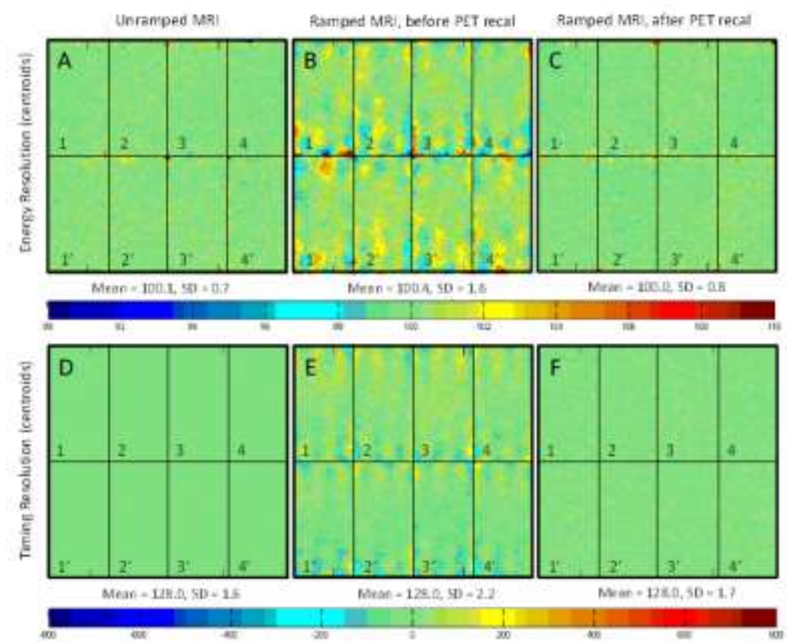


Z-axis distance reduces magnetic impact

Ingenuity TF PET/MR Magnetic Shielding



Magnetic flux density inside the PET gantry



Energy and timing resolution crystal maps

Design and performance evaluation of a whole-body Ingenuity TF PET–MRI system, H Zaidi et al, Phys. Med. Biol. 56 (2011) 3091–3106

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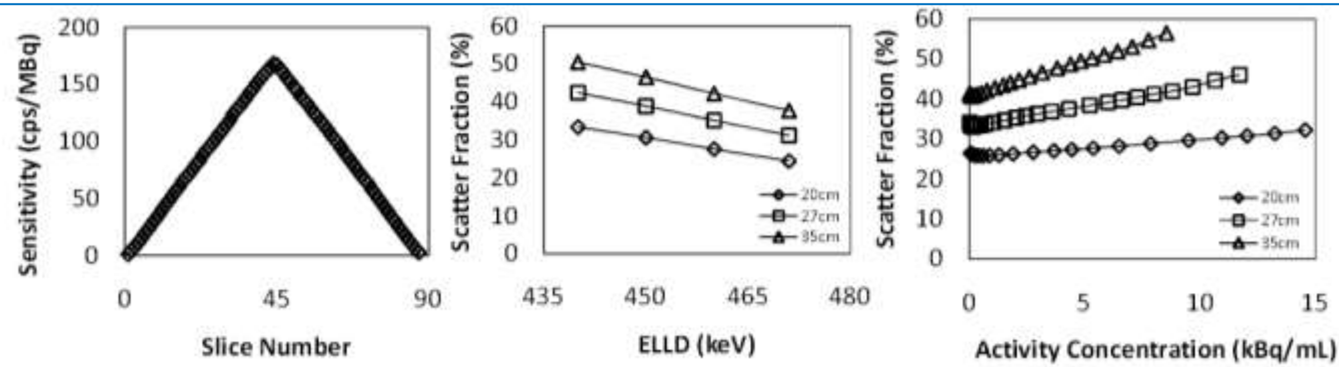
Ingenuity TF PET/MR

Identical NEMA & TOF performance with PET/CT

Spatial Resolution	Ingenuity TF PET-MR		Gemini TF PET-CT	
	FWHM (mm)	FWTM (mm)	FWHM (mm)	FWTM (mm)
Transverse, 1 cm	4.72 ± 0.1	9.42 ± 0.2	4.7	9.7
Axial, 1 cm	4.57 ± 0.1	9.49 ± 0.1	4.7	9.6
Radial, 10 cm	4.95 ± 0.1	9.85 ± 0.1	5.1	10.3
Axial, 10 cm	5.04 ± 0.1	9.69 ± 0.1	4.8	9.6
Tangential, 10 cm	5.30 ± 0.1	10.45 ± 0.1	5.1	10.2



Design and performance evaluation of a whole-body Ingenuity TF PET–MRI system, H Zaidi et al, Phys. Med. Biol. 56 (2011) 3091–3106

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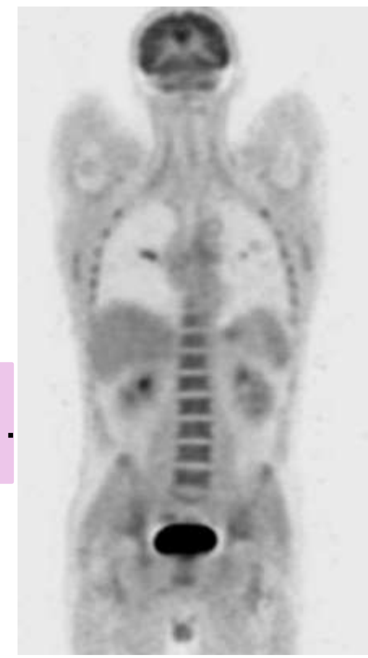
Key Considerations on PET/MR image reconstruction

MR data

Segmentation methods
μ value assignment
(metal artifact, non-uniformity, disease impact)

Attenuation Map → … → Truncation compensation → … → Scatter correction → …

MRAC PET



Listmode PET data

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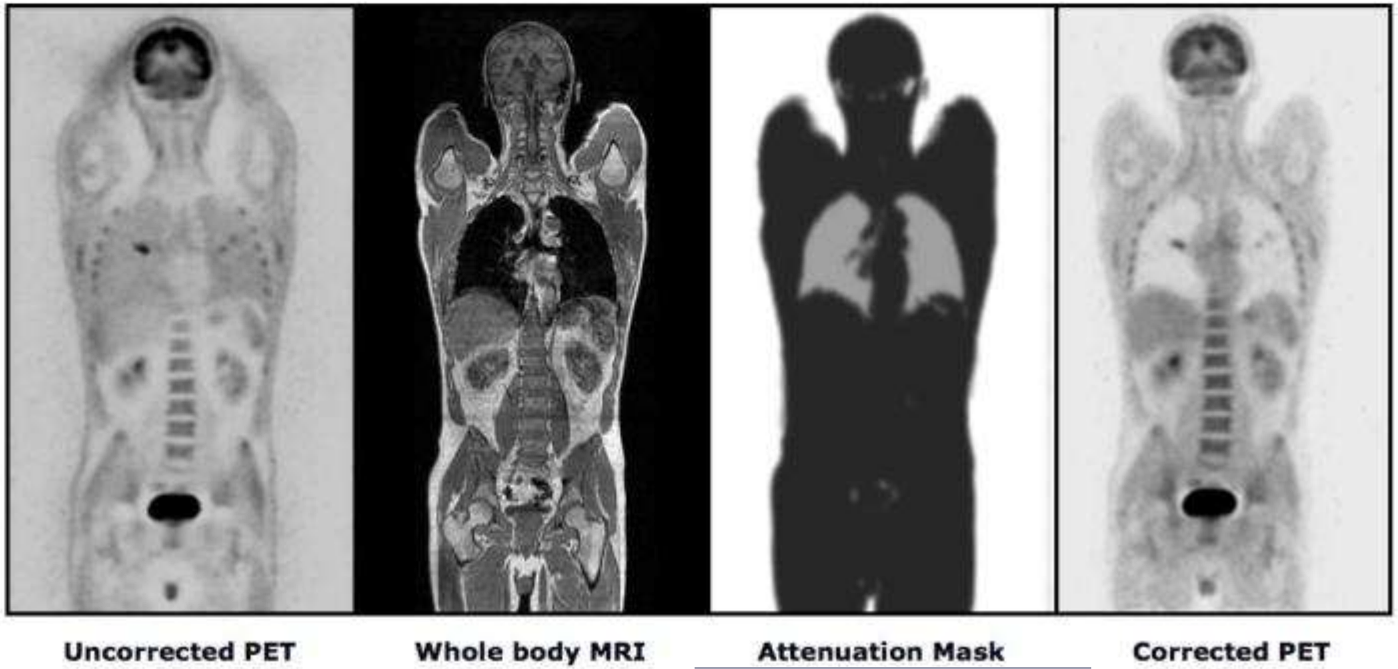
MR-based Attenuation Correction

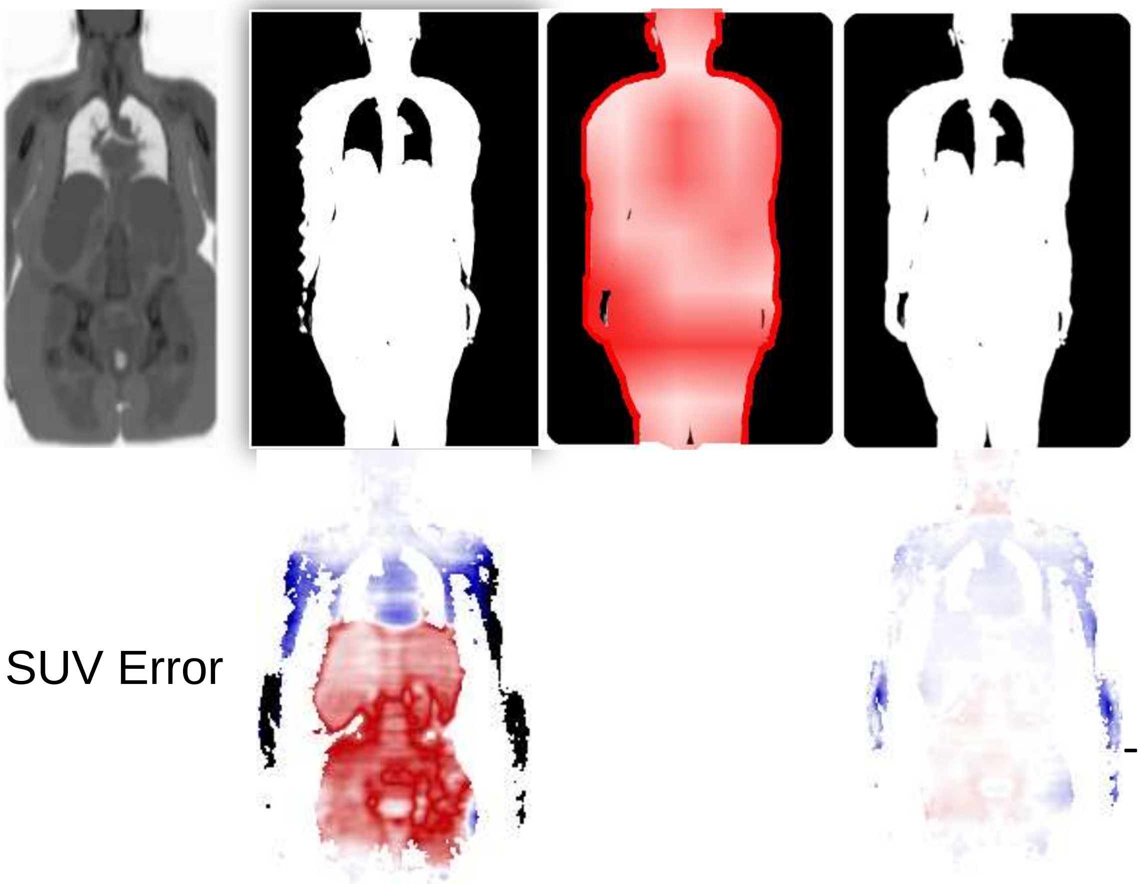


Air, Tissue, Lung

- T1w Fast Field Echo with 10° flip angle
  - 3x3x5 mm^3
- Fully automated Segmentation
- No bone consideration

MRAC – Truncation Artefacts and Compensation

atMR | map | ToF info | Compensated

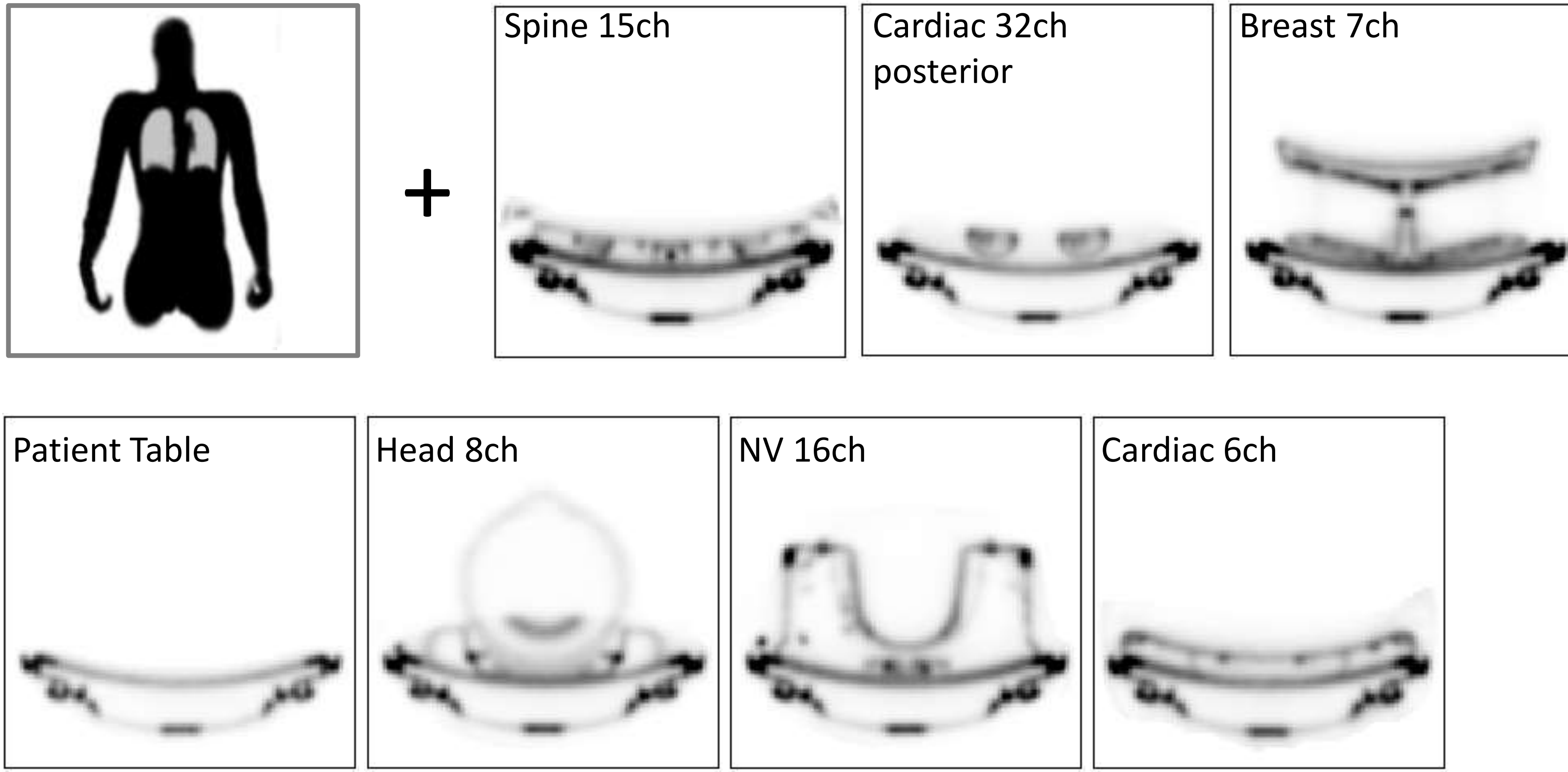


SUV Error

-30% +30% SUV error map

	Heart	Liver	Bladder
Uncorrected	~16%	~9%	~3%
Corrected	<1%	<1%	<1%

MR-based Attenuation Correction – Different Colis



Astonish TF - Unique PET Reconstruction

Eliminate artifacts

No sinogram interpolation.
Improved Spatial Resolution

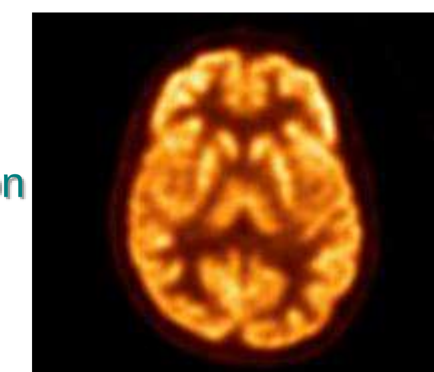
Improved image quality

Accurate quantification

LOR-TOF: No extra uncertainty from time binning
Dramatically Improved SNR

2mm Spatial Resolution
+ 2mm Voxel Reconstruction

Excellent PET Image Quality & Quantification



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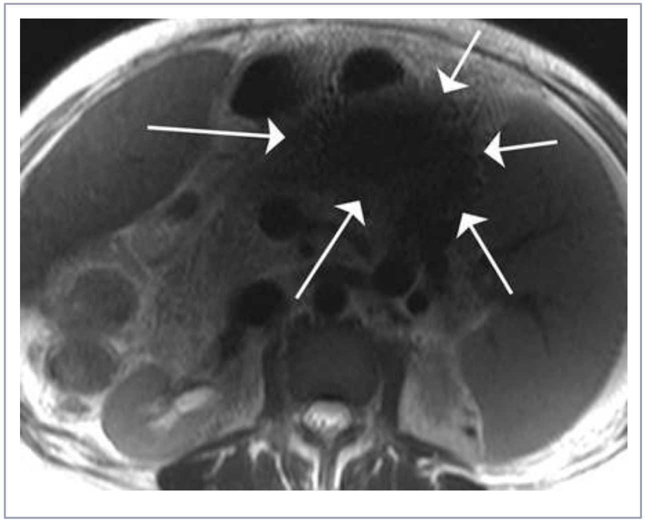
Challenges of 3T MR (conventional)
Poor Uniformity - Dielectric Shading

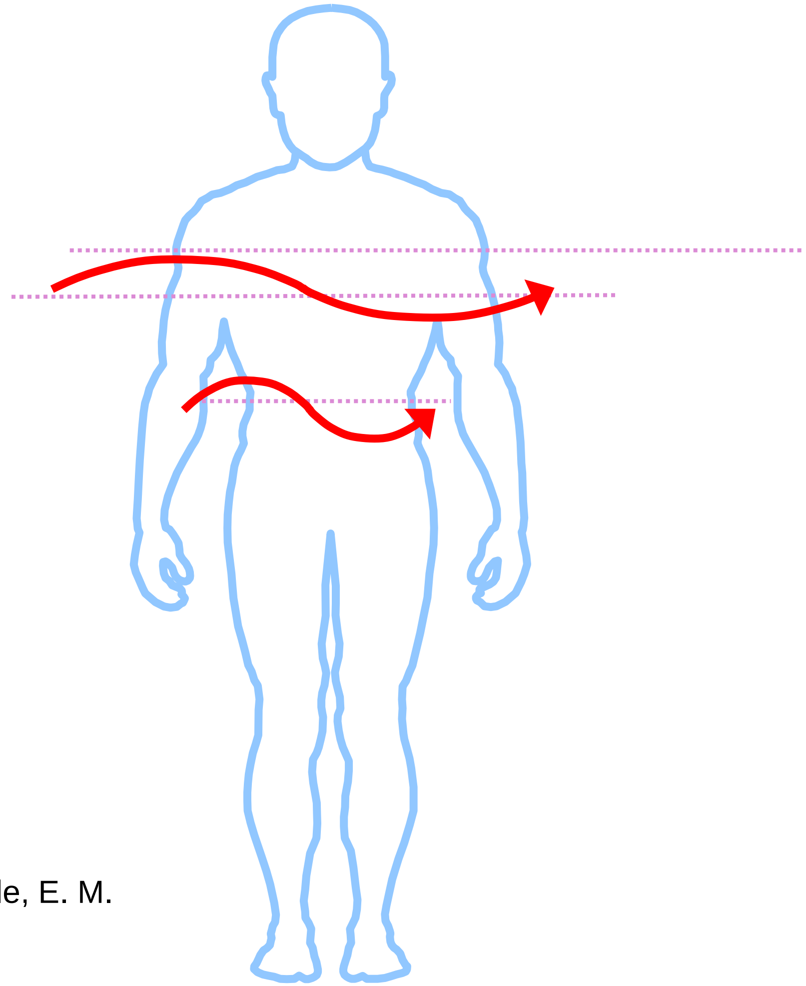
As B_0 increases so does Proton MR RF

1.5T in λH_20 = 52cm 64MHz

3.0T in λH_20 = 26cm 128MHz



Source: Merkle, E. M. et al. Am. J. Roentgenol. 2006;186:1524-1532



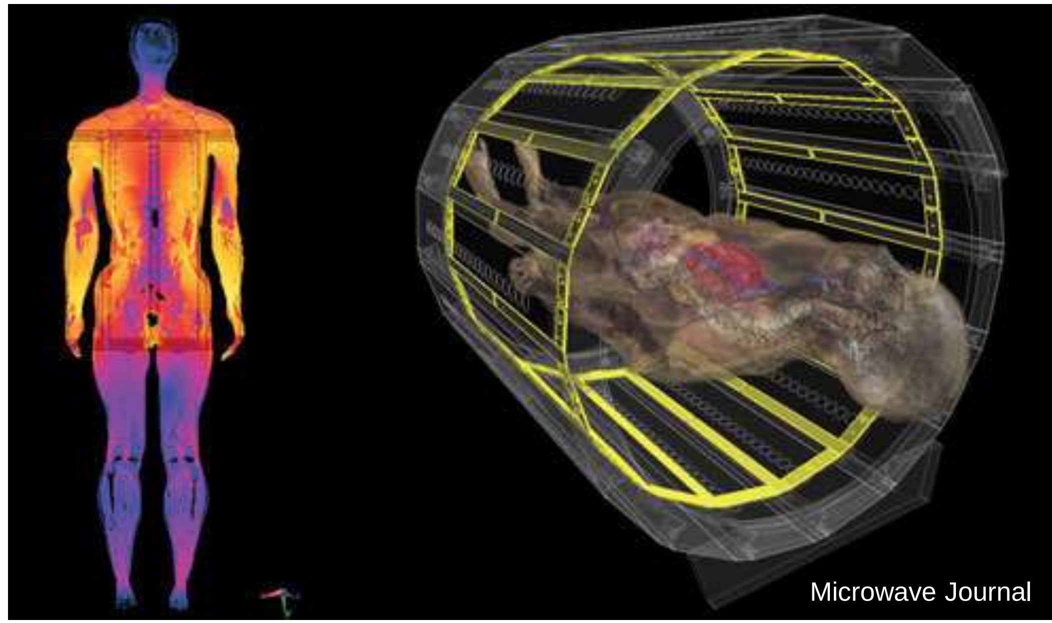
Challenges of 3T MR (conventional)

#2: Specific Absorption Rate (SAR)

3T = **4** x SAR of 1.5T

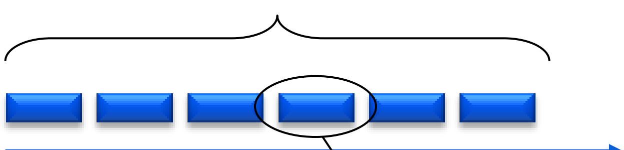
→ Warming up of the subject,

→ safety limits quickly exceeded



1.5T at SAR Limit

MR Image



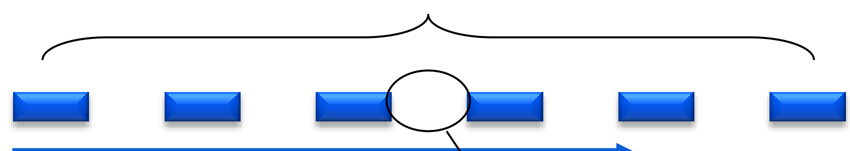
time

Acquisition segment

Identical Sequence

3T exceeds SAR Limit → Breaks

MR Image



time

Longer Repetition Times

Multi-Transmit MR

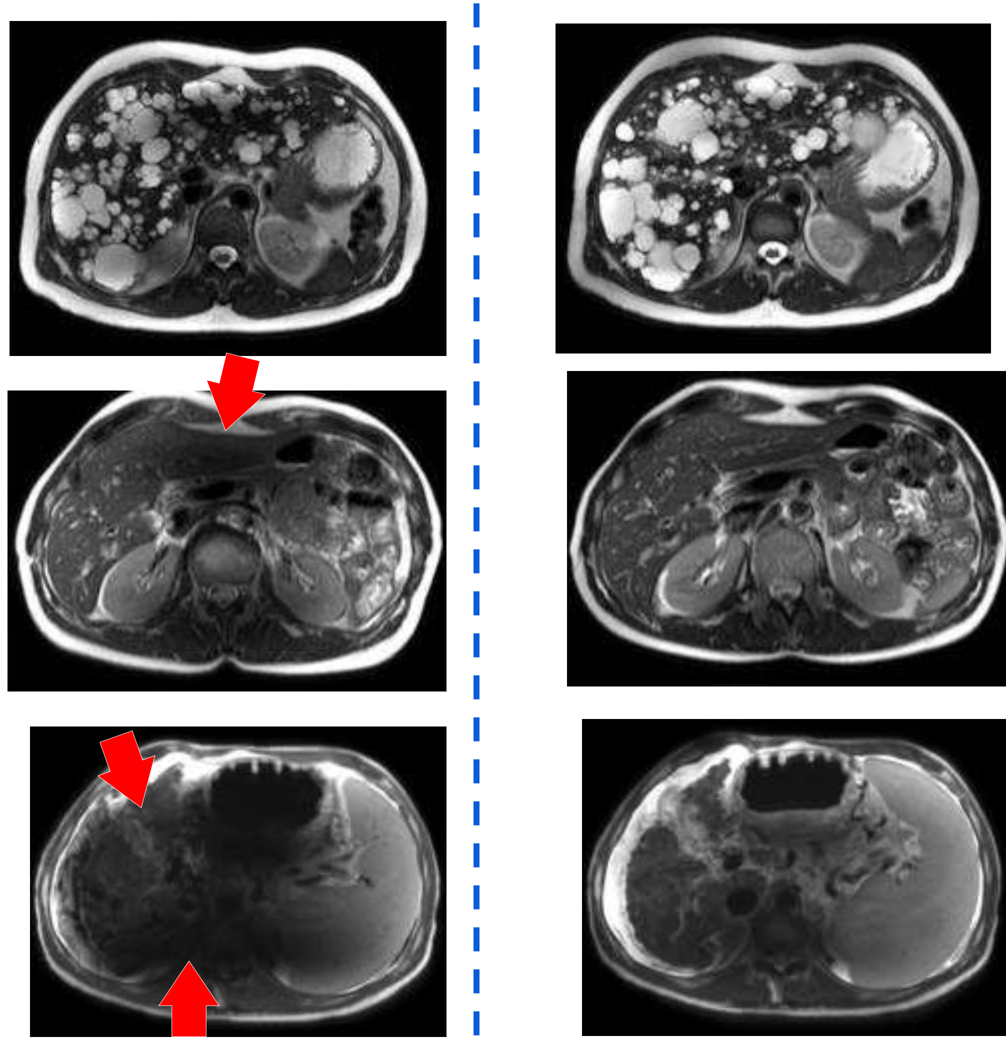
Image Quality

Slight uniformity improvement

Medium uniformity improvement

Large uniformity Improvement (ascites)

Enhanced Uniformity & Inter-patient IQ Consistency



Conventional

MultiTransmit

Courtesy: Bonn University Hospital, Germany

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Quality Control for PET/MR

- Same QC procedures from PET and MR are applied

- Additions
  - SUV Calibration
    - Use salt water (standard hospital grade saline solution) to match tissue characteristic for MR imaging
    - Use segmented MR as AC Map
  - Alignment (less than one pixel)
    - Mechanical
    - Imaging space (Important to have a good MR linearity)
      - Sequential and simultaneous
    - Time between PET and MR AC Map acquisitions: 1-5 min (similar to PET/CT)
  - Smaller MR FOV
    - Proper positioning to minimize truncation

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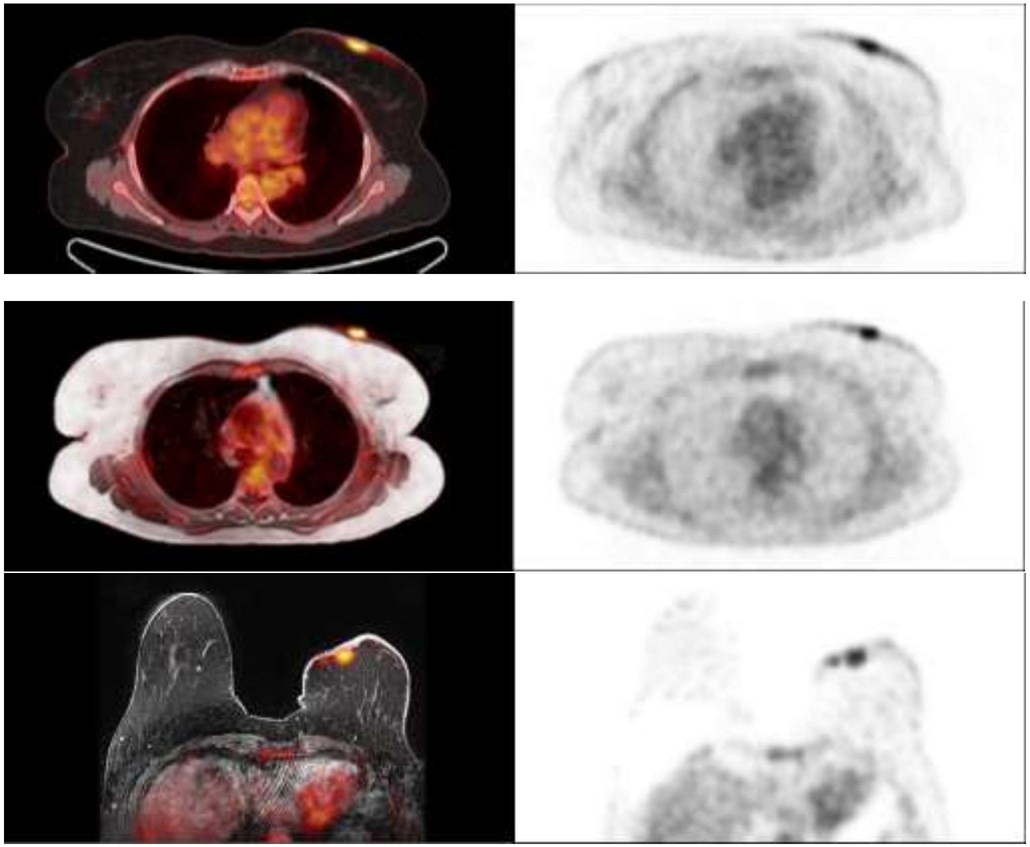
Challenges/Opportunities

– Areas for continuous innovations and improvements

- Breast Imaging
  - Attenuation, Scatter, and imaging FOV
- Pediatric Imaging
  - Segmentation, Attenuation
- Truncation
  - Limited MR FOV, Large Body Size
- Scatter Correction
  - Assumed attenuation (Patient Dependent)
- Metal Artifact
  - Fair amount of patients have metals inside bodies
- MR Attenuation Correction
  - Map Optimization (MR sequence – mDxion, UTE, better segmentation method)
- Reconstruction
  - Anatomic info (a prior)
  - TOF Info - constraint
  - New way of Recon because of MR info

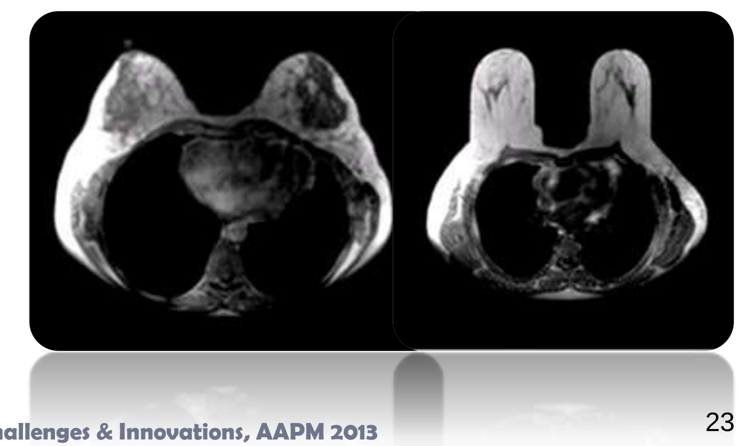
Example #1 – Breast Imaging



Supine PET/CT

Supine PET/MR

Prone PET/MR



Coil raises patients vertically, causing MR truncation!

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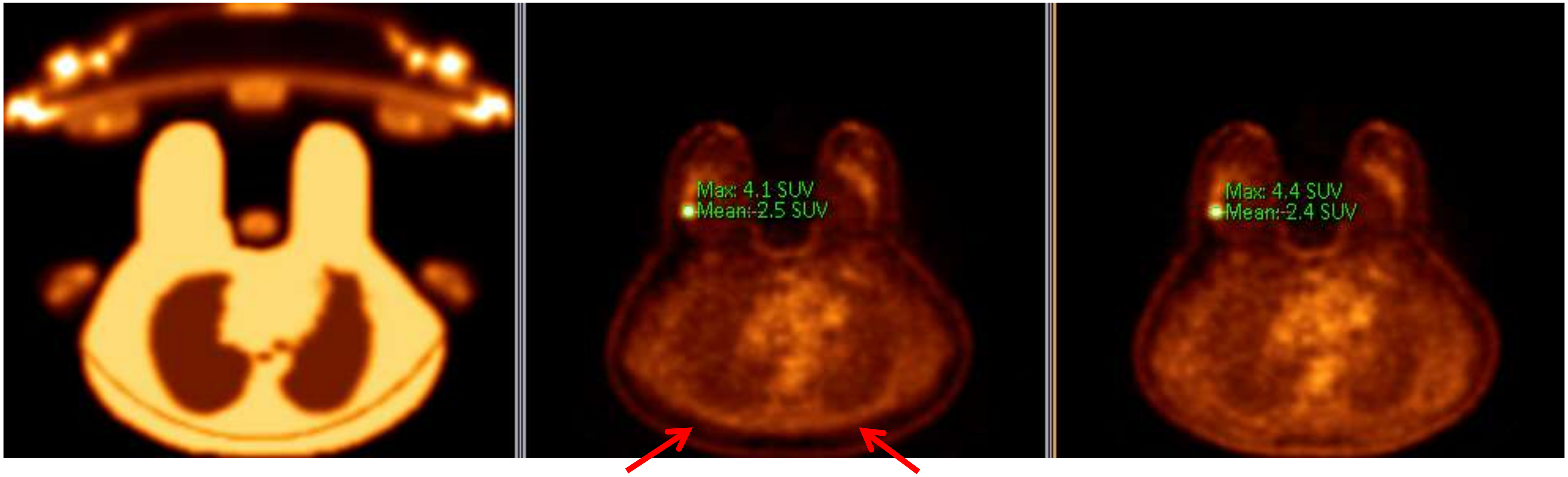
Result: PET images comparison w/ and w/o TC

AC map

PET w/o TC

PET w/ TC
(using TOF info)



- Image uniformity improved;
- SUV increased less than 10%

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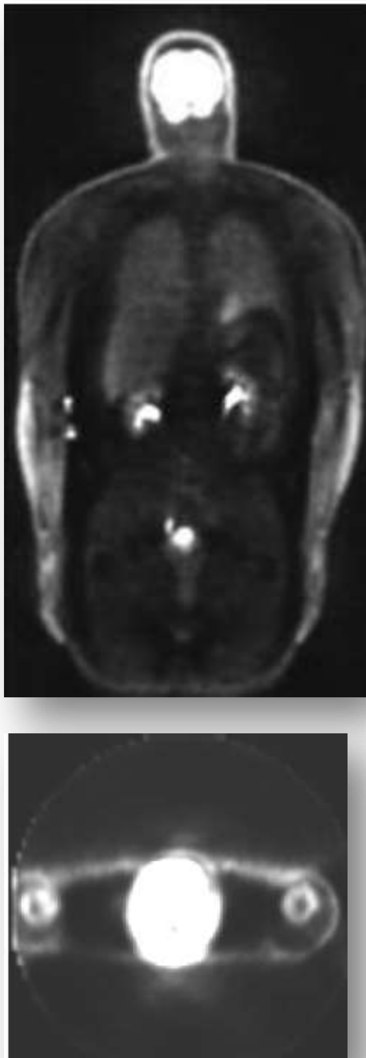
Example #2 – Whole body imaging

using Time of Flight information to compensate for truncation

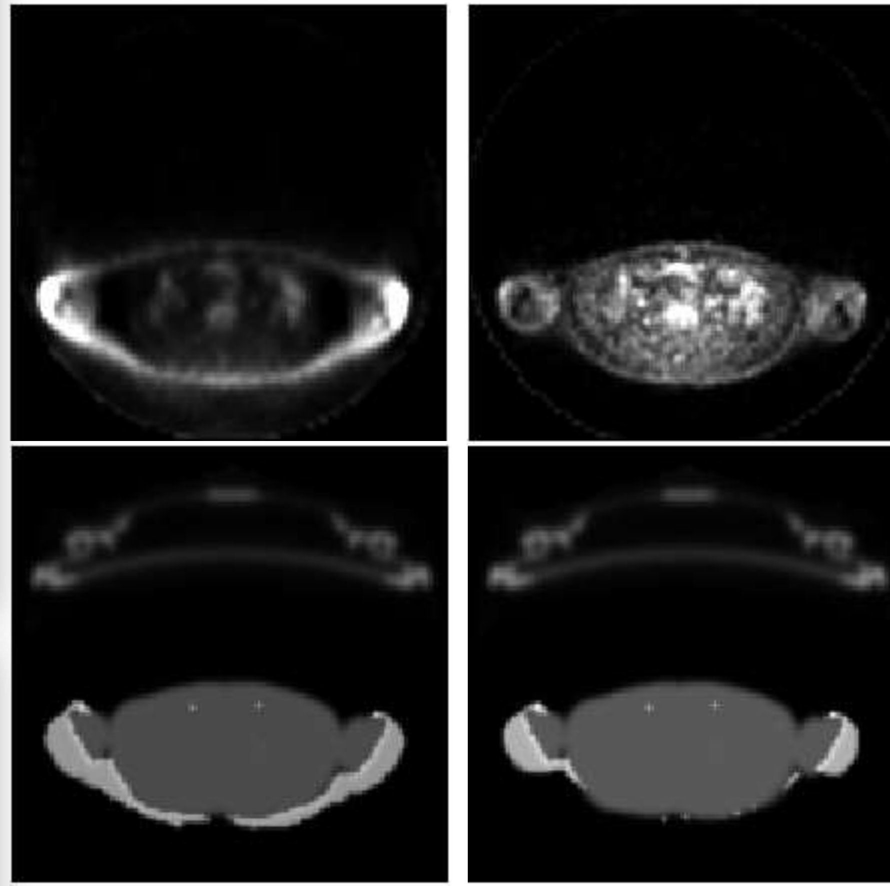
NAC PET



TOF-NAC PET

NAC PET

TOF-NAC PET



Truncation compensated AC maps

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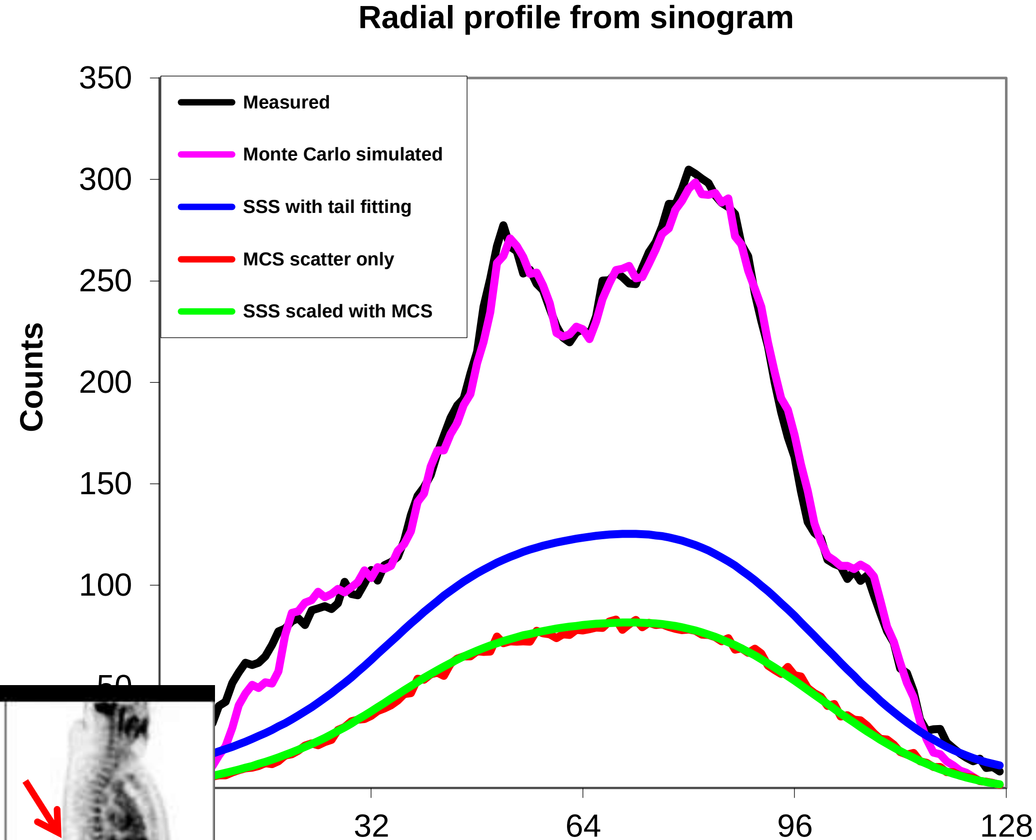
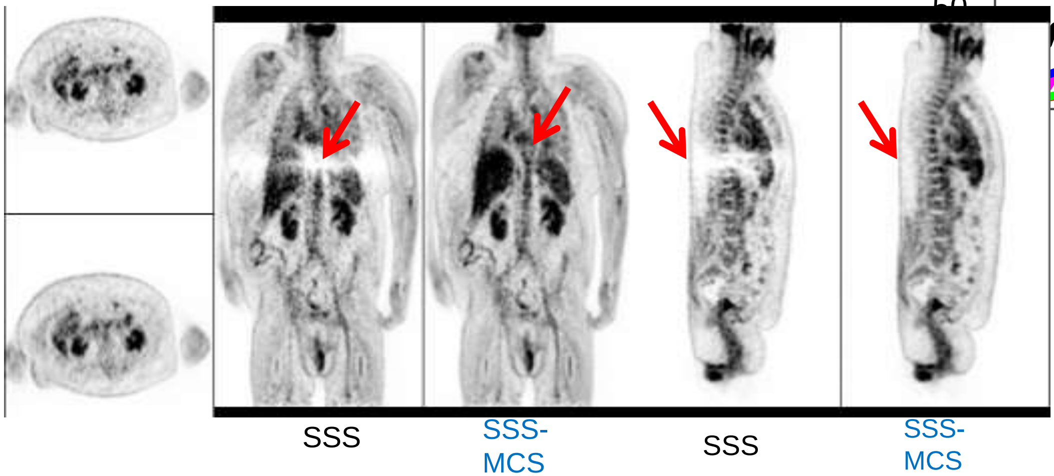
Example #3 - Accurate Scatter correction

SSS vs. SSS scaled with MCS

SSS – Single Scatter Simulation
MCS – Monte-Carlo Scaling





For large size body or truncated body SSS tends to over correct scatter.

SSS-MCS brings the scatter to the right level

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Summary from 1st International Workshop on PET/MR Imaging, March 19-23 2012 Tubingen, German

- PET/MR Technology is available for patient management and research
- The current search for a single clinical “killer application” for PET/MR continues and may eventually prove elusive
- Even without such “killer application”, the convenience of easier patient handling, intrinsic image alignment, improved contrast for clinical practice as well as research
- Pre-clinical PET/MR already added enormous value.

Technology Development for Future – Example

Development of the Digital Silicon Photomultiplier

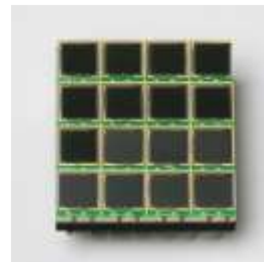
PMT

CRT ~ 250 ps

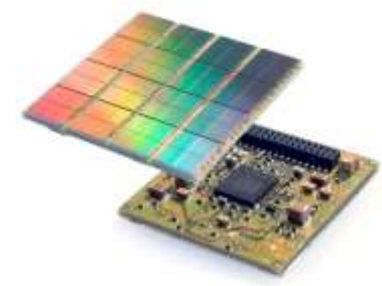
APD

CRT ~ 1000 ps

aSiPM

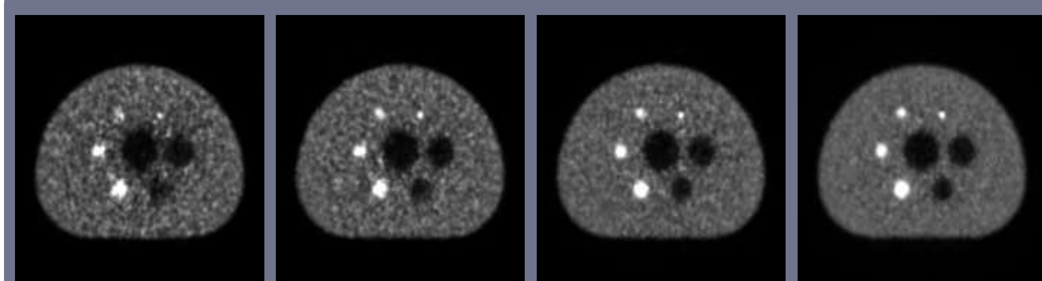


dSIPM



CRT ~ 250 ps
aim: 100 ps

Perspective for Time-of-Flight



non-TOF	500 ps	250 ps	100 ps
	Product	...developing	Future

Images courtesy of H. Wieczorek, T. Dey, & A. Trinidade, Philips Research

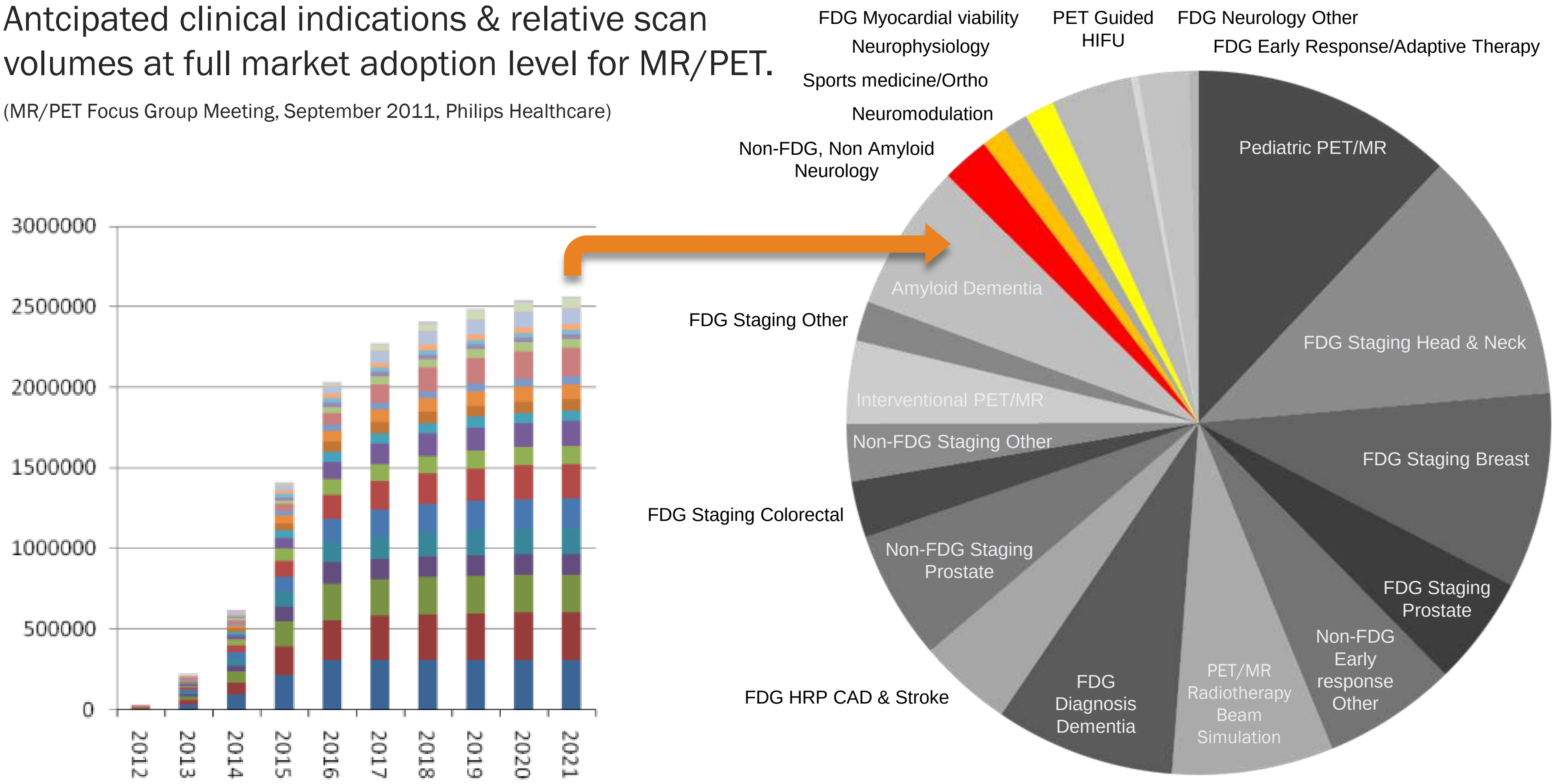
Additional Benefits

- significantly reduced temperature sensitivity ($\sim 10^{-1}$)
- active quenching reduces after pulsing & crosstalk ($\sim 10^{-1}$)
- individually addressable cells enable dark count control ($\sim 10^{-2}$)
- better linearity (&correction)
- no analog electronics, no TDCs, no ADCs, no ASICs

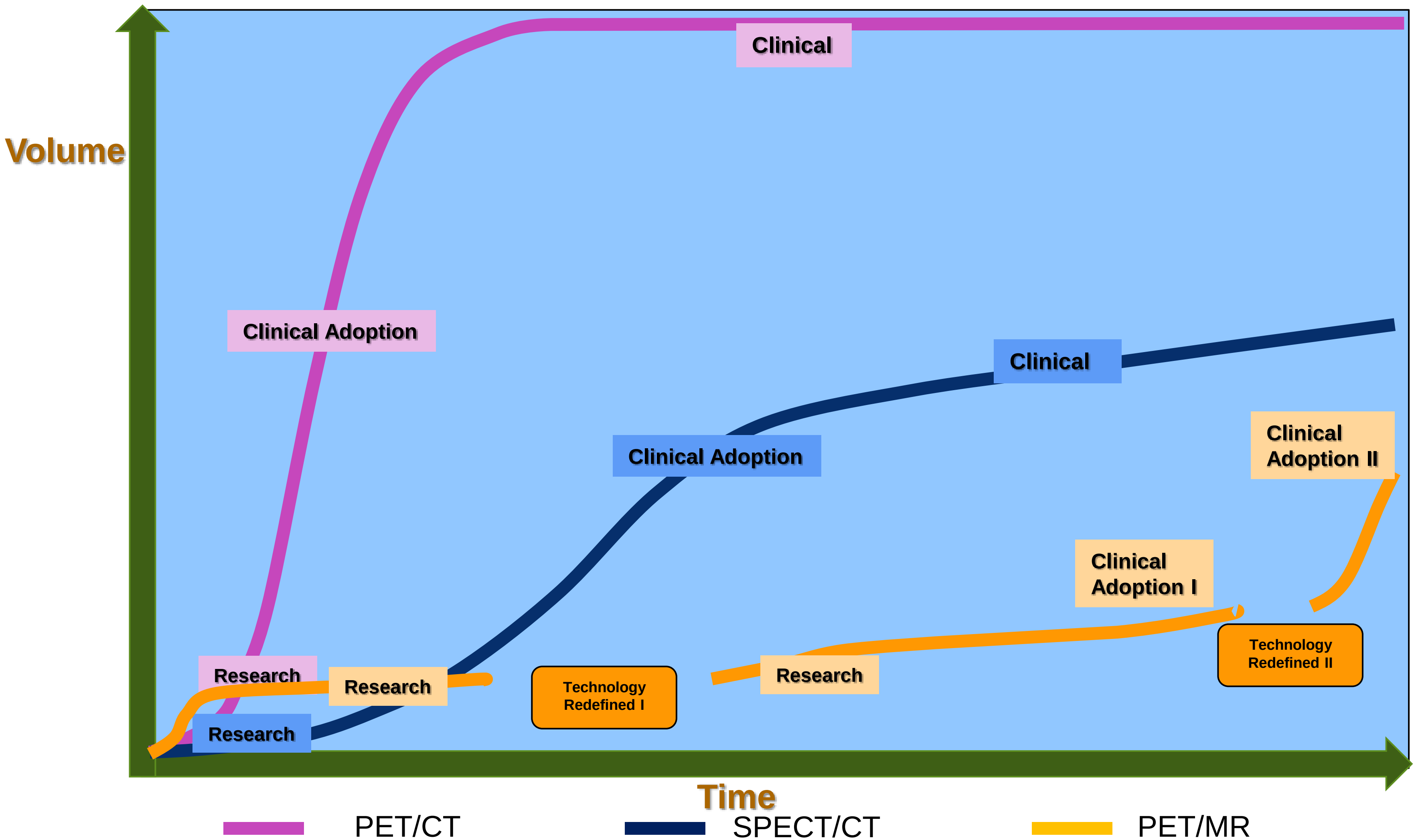
Technology Development for Future –Example
Anticipated Applications for MR/PET

Antcipated clinical indications & relative scan volumes at full market adoption level for MR/PET.

(MR/PET Focus Group Meeting, September 2011, Philips Healthcare)



Summary: Predict PET/MR Clinical Adoption



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Summary

- Technology is available for patient management and research
- The current search for a single clinical “killer application” for PET/MR continues and may eventually prove elusive
- Even without such “killer application”, the convenience of easier patient handling, intrinsic image alignment, improved contrast for clinical practice as well as research
- Pre-clinical PET/MR already added enormous value.

- **Continue the journey for “Killer” applications**
- **Continue technology innovations**
- **High priority on Quantitation**
- **MR has greater potential than CT for overall system optimization**
- **Long journey for research**
- **Cost must go down**