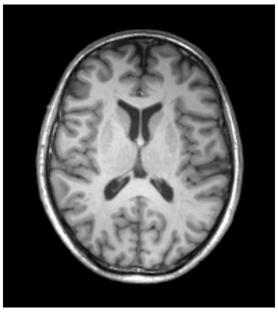
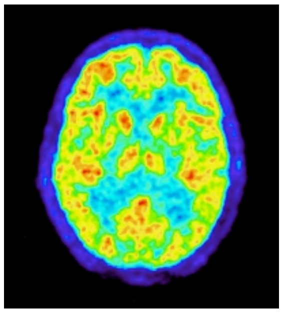
MR-PET: Everything you need to know to get started

Liliana Caldeira | September 14, 2017

Outline

- What is PET?
- MR-PET
  - Why?
  - How does it work?
    - Hardware
    - Software
- Planning a study
- Conclusion and future trends

MRT, CT, PET – What is all that for?

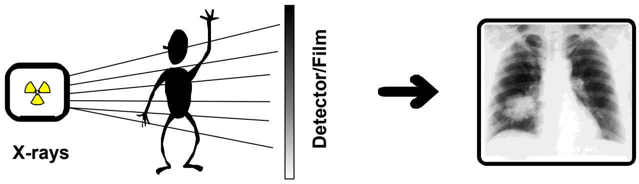
Magnetic resonance tomography (MRT)	X-ray computed tomography (CT)	Positron emission tomography (PET)
		

- Magnetic fields
- Anatomy
- Good soft tissue contrast
- Bad depiction of bone

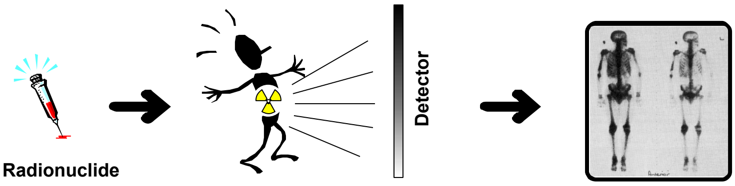
- X-rays
- Anatomy
- Good depiction of bone
- Bad soft tissue contrast

- Radioactive labelled molecules
- Quantitative representation of metabolism
- Limited anatomical information

Radiology – Nuclear Medicine



Transmission
"Durchstrahlung"



Emission
"Aussendung von Strahlung"

Nuclear Medicine – An Overview

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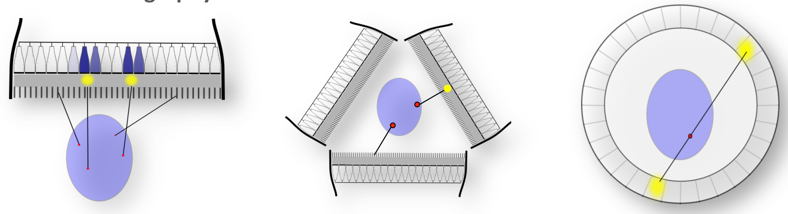
Planar Scintigraphy	SPECT	PET



Planar Scintigraphy	SPECT	PET
• 2D projection of tracer distribution • Gamma emitters • Emission of single photons • Mechanical collimation	• 3D tomography of tracer distribution • Gamma emitters • Emission of single photons • Mechanical collimation	• 3D tomography of tracer distribution • Positron emitters • Electronic collimation • Quantitative • High sensitivity • Biomolecules

The Tracer Principle

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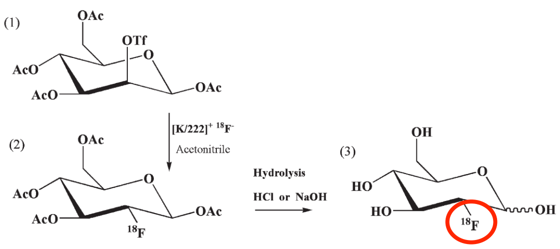
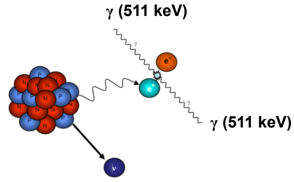
- Labelling of biomolecules with radioactivity
- No alteration of biochemical properties
- Detection of radioactive decay yields spatial information





$^{18}F \rightarrow {}^{18}O$

George de Hevesy
Nobel Prize in
Chemistry (1943)

Some examples of PET-images (Brain)

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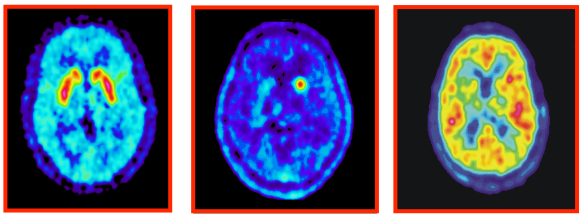
Neuro-Transmitters **Neuro-Oncology** **Neuro-Activation**



^{11}C-Raclopride: **^{18}F-FET-PET** **$H_2{}^{15}O$**

Tracer-Technique:

Radioactive substance administered in tiny quantites !
(nano-molare concentration!)

Relies on the availability of suitable isotopes:
^{18}F ($T_{1/2}$ 109.8 min, meanE_{kin} 0.242 MeV, range: FHWM 0.22 mm)

other: ^{11}C ($T_{1/2}$ 20,3 min), ^{13}N ($T_{1/2}$ 10,1 min), ^{15}O ($T_{1/2}$ 2.05 min)
Produced in a cyclotron!

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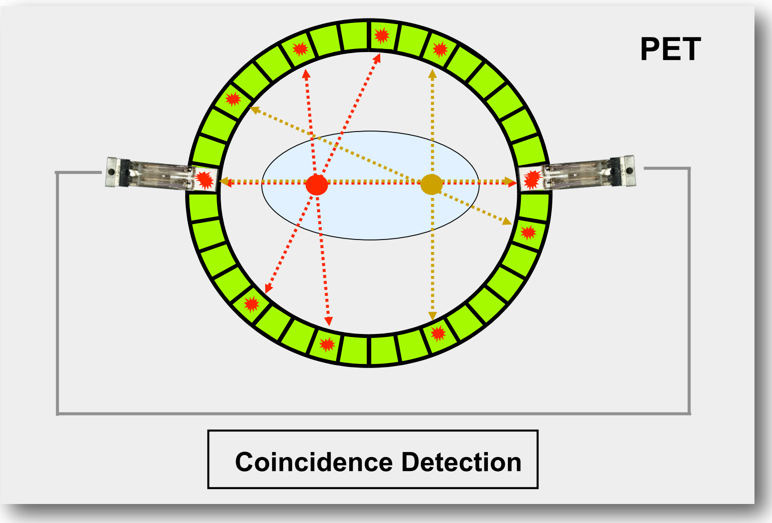
The process of Emission Tomography



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PET – On Site Production of Tracers

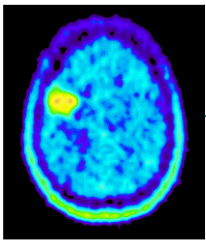
Synthesis of isotopes [^{18}F, ^{11}C, ^{15}O]

→ Isotope

Radiochemistry

Radiopharmaceutical (Tracer)

PET



Tomographic image

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History of Molecular Imaging

time

Developments in (molecular) Imaging

1940s Rectilinear Sampling
1960s Anger Camera and Planar Scintillation
1960 Positron Emission Tomography (PET)
1960 Single Photon Emission Tomography (SPECT)
1970 X-ray Computed Tomography (CT)
1970 Reconstruction Algorithm
1974 Magnetic Resonance Imaging (MRI)
1982 Iterative Reconstruction in SPECT and PET

Development of Hybrid Modalities:

1990 SPECT/CT
2000 PET/CT
2005 PET/MRI
…PET/US and SPECT/MRI

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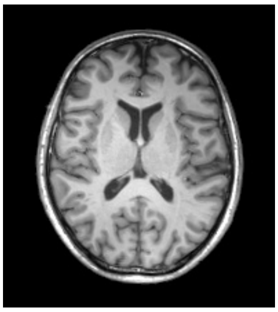
MR-PET Hybrid Imaging

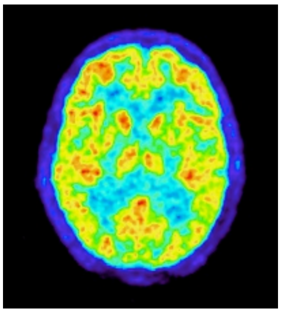
Magnetic resonance tomography (MRT)

Hybrid MR-PET

Positron emission tomography (PET)



Radiology



Nuclear Medicine

Simultaneous measurement of anatomy and metabolism for improved diagnostics in e.g. brain tumours

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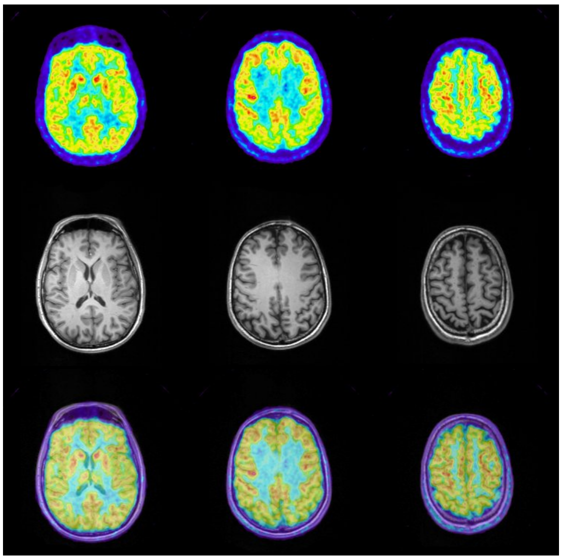
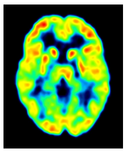
Glucose Consumption of the Brain - ^{18}F-FDG



^{18}F-FDG PET

T1-MRT

Fusion



FDG-PET acquired at Siemens HR+

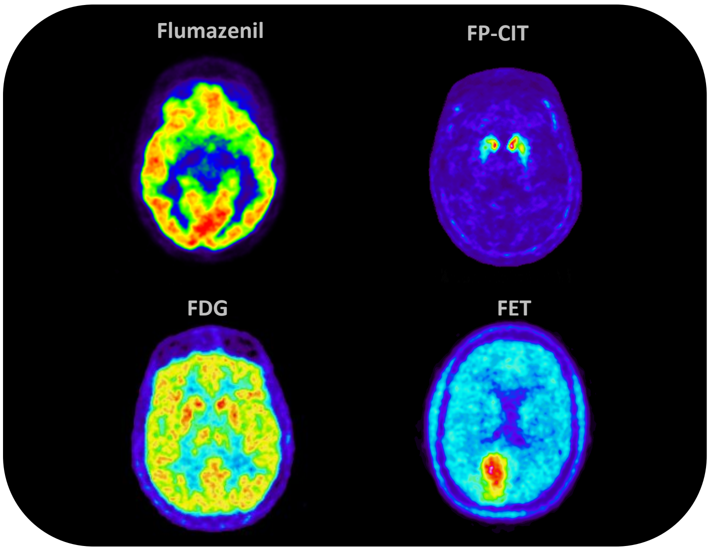
Example of different distributions

F18 FLT

F18 NaF

F18 FDG

Variety of PET Tracers
- Examples from Jülich, measured with the 3T MR-BrainPET



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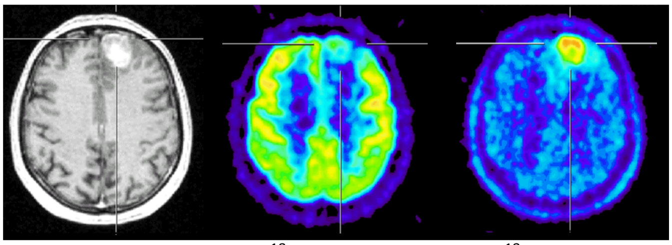
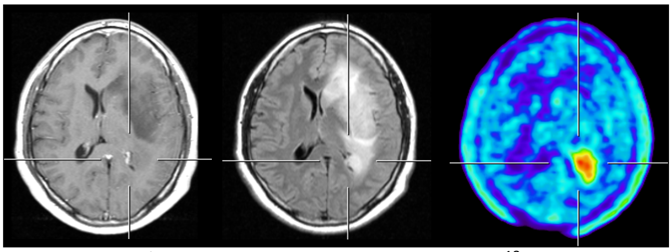
Advantages of Amino Acid PET – ^{18}F-FET





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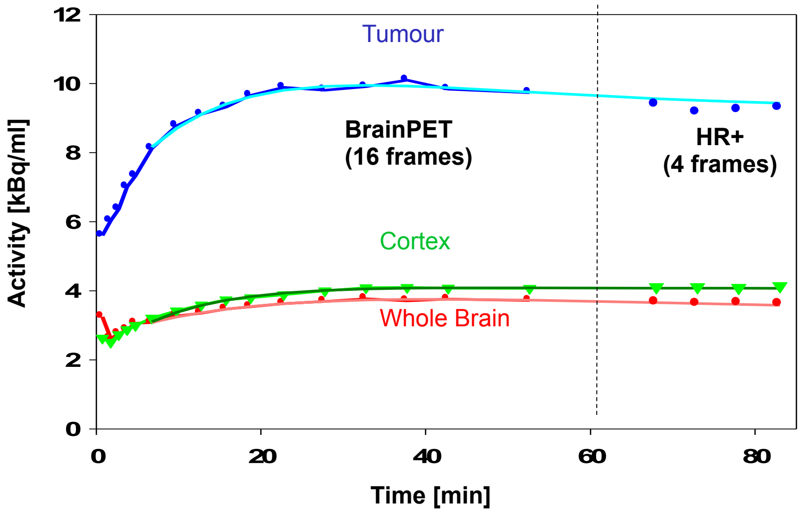
Time Activity Curves (TAC)



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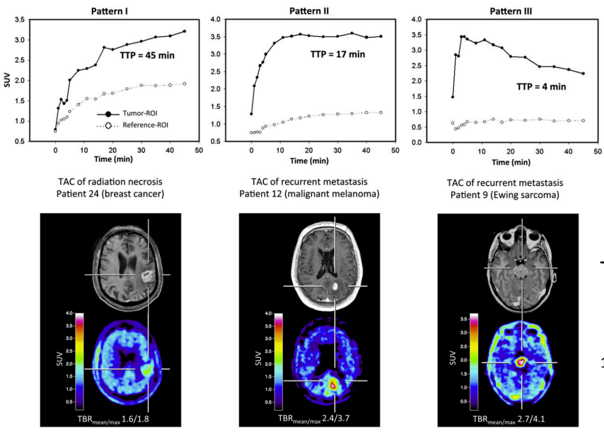
TAC as Tool for Improved Diagnostic in Brain Tumours



Different curvature of TAC helps to distinguish between radiation necrosis and metastasis, and is helpful for grading of brain tumours.

T1-MRT with contrast agent

^{18}F-FET PET

From: Role of O-(2-18F-Fluoroethyl)-L-Tyrosine PET for Differentiation of Local Recurrent Brain Metastasis..., Galldiks *et al.* 2012, The Journal of Nuclear Medicine

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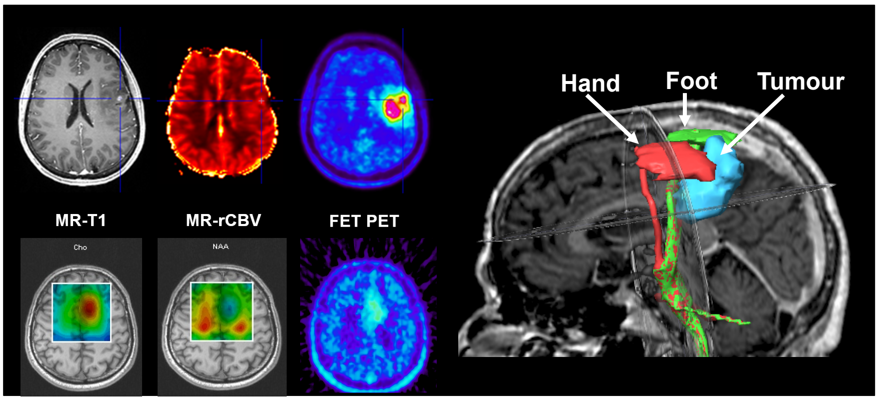
MR-PET Hybrid Imaging of Brain Tumours

^{18}F-FET PET / fMRI / PWI / DTI / MRS



Thanks to K.-J. Langen *et al.*

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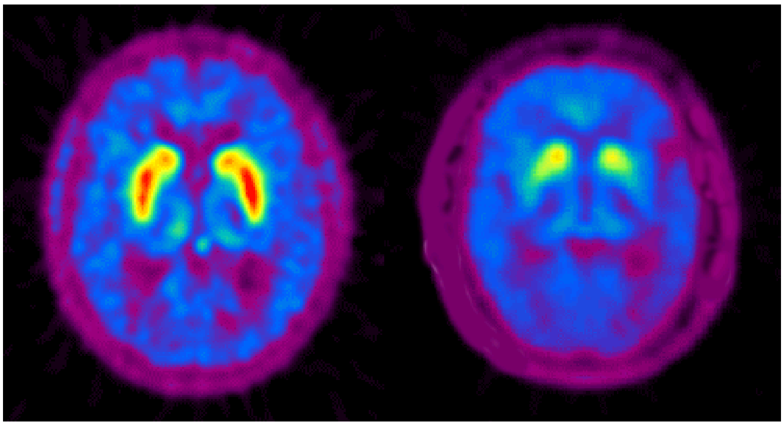
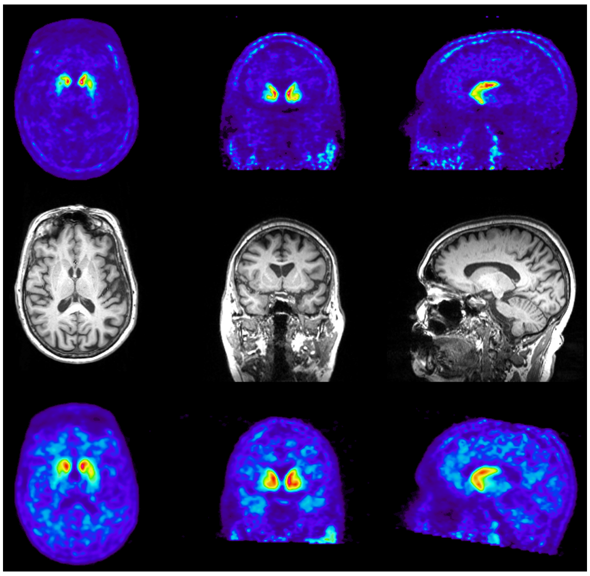
Parkinson´s Disease

- 18F-DOPA PET



Healthy brain | Morbus Parkinson

MR-PET in a Patient with Parkinson´s Disease

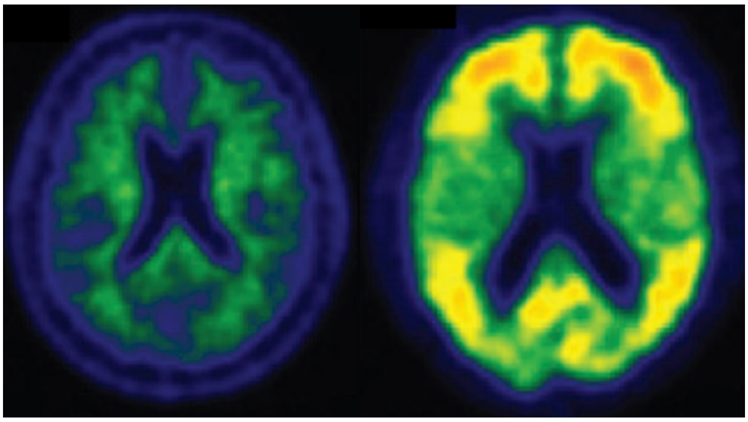


PET after injection of the dopaminergic transporter ligand ^{18}F-FP-CIT

T1-MRT

Fusion

Alzheimer´s Disease
- Visualisation of plaques using ^{11}C-PiB



Healthy Brain   Alzheimer

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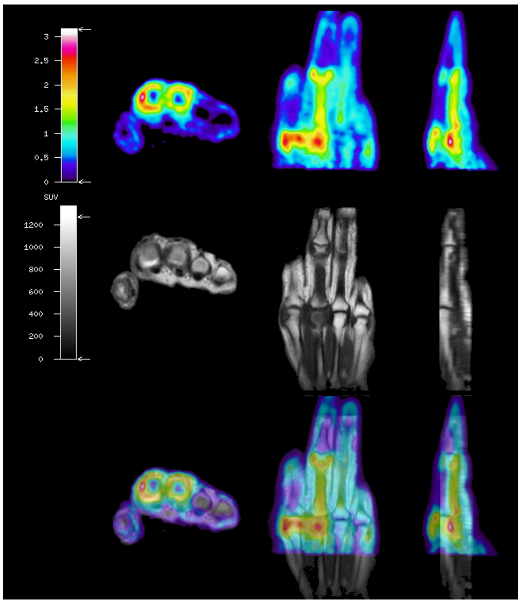
^{18}F-FDG MR-PET of Rheumatoid Arthritis of the Hand



PET 80-110 min after injection of 340 MBq FDG

T1-MRT

Fusion

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Questions and Answers

- 1) How many tracers exist for PET?

  One: F18-FDG
  Many
  Two: C11 and F18.

- 2) Which is the “older” medical imaging modality: PET, MR or CT?
  PET

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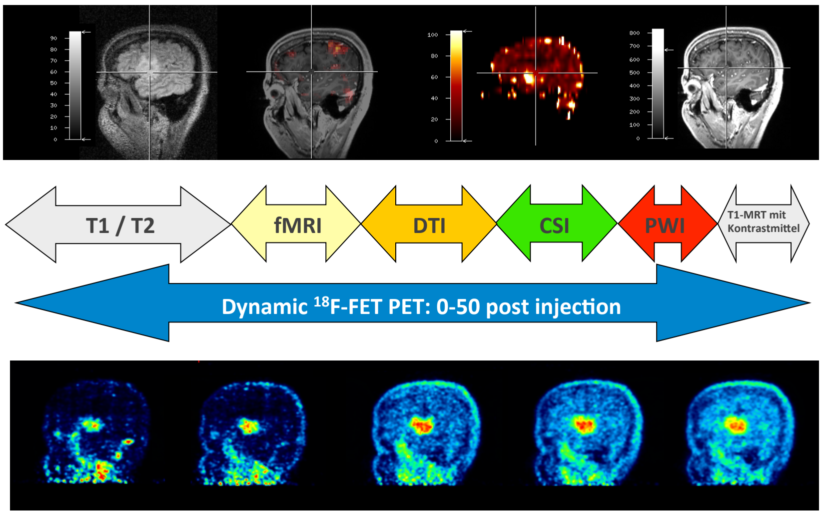
Simultaneous MR-PET

- Patient comfort: pediatric and severely ill patients
- Logistics/Time saving
- Radiation reduction
    - What is the “killer application”?
- When a measurement has to be repeated under the same conditions
- Great potential for neurosciences!

Hybrid MR-PET

- Dynamic ^{18}F-FET PET with simultaneous MRT



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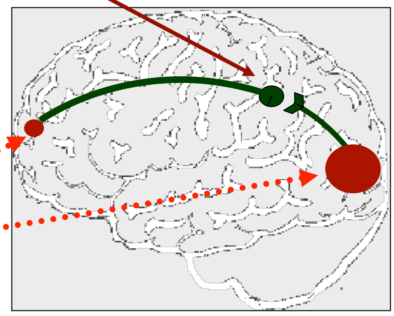
The Two Parts of Cerebral Communication

Chemical interface at the synapses modulated by internal neurotransmitters or drugs

Domain of PET



Centers of cerebral data processing

Domain of fMRI

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Timing of a Combined PET-MRI-fMRI Study

Bolus ^{11}C-Flumazenil

Infusion ^{11}C-Flumazenil

t — **PET Listmode Acquisition** — t + 100

Neurostimulation (Emotion)

MRI Acquisitions

localizer	MPRAGE	ASL	EPI	MRS	EPI	ASL
2	5	6	2 x 5	20	40	6

Unit: min

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Timing of a Combined PET-MRI-fMRI Study

Bolus ^{11}C-Flumazenil

Infusion ^{11}C-Flumazenil

t — PET Listmode Acquisition — t + 100

Neurostimulation (Emotion)

MRI Acquisitions

Anatomy localizer		CBF	Function	Physiology	Function	CBF
2	5	6	2 x 5	20	40	6

Unit: min

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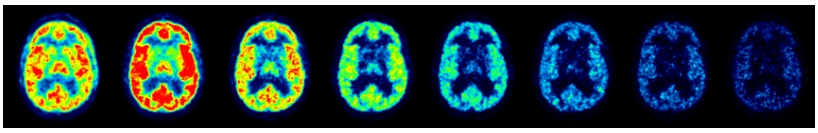
Timing of a Combined PET-MRI-fMRI Study

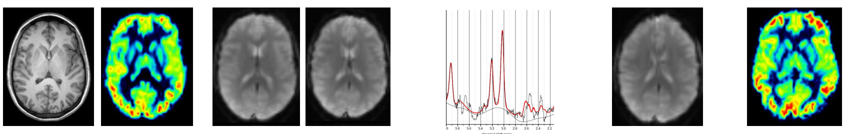


t — PET Listmode Acquisition — t + 100 min

Dynamics of ^{11}C-Flumazenil

Neurostimulation (Emotion)

MRI Acquisitions



Anatomy CBF 2 x fMRI MRS fMRI CBF

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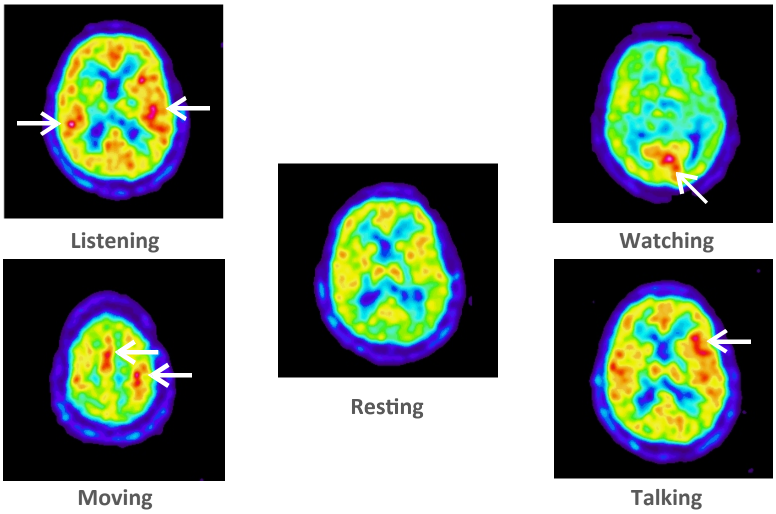
Measurement of Cerebral Blood Flow using $H_2{}^{15}O$-PET



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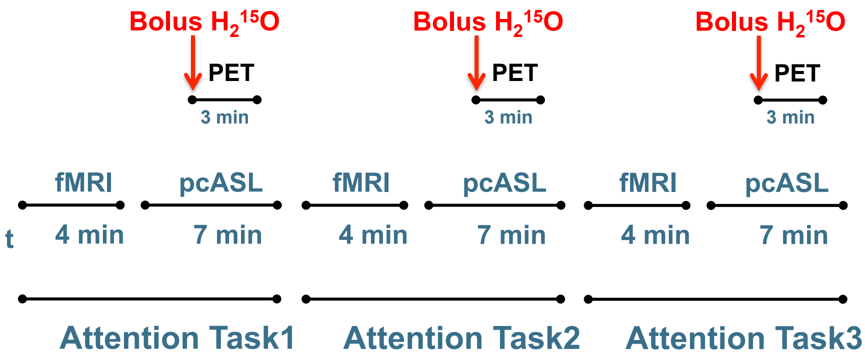
Global (fMRI) and regional (PET,MRI) changes of cerebral blood flow measured with PET--MRI--fMRI



[pcASL – pseudo-continuous arterial spin labeling]

Measurement of Cerebral Blood Flow: ^{15}O-Water-PET versus ASL (MRI)

(ASL = Arterial Spin Labelling)

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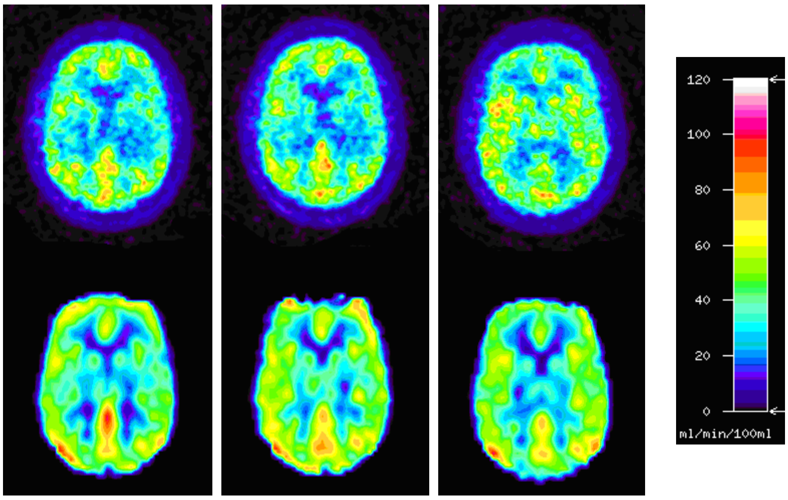
^{15}O-Water-PET

ASL (MRI)



Task1 Task2 Task3

Questions and Answers

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- 1) How long does a PET acquisition take?
  20-50 min
- 2) How long does a MR acquisition take?
  30-50 min
- 3) Can PET and MR measurements be truly simultaneous?
  YES

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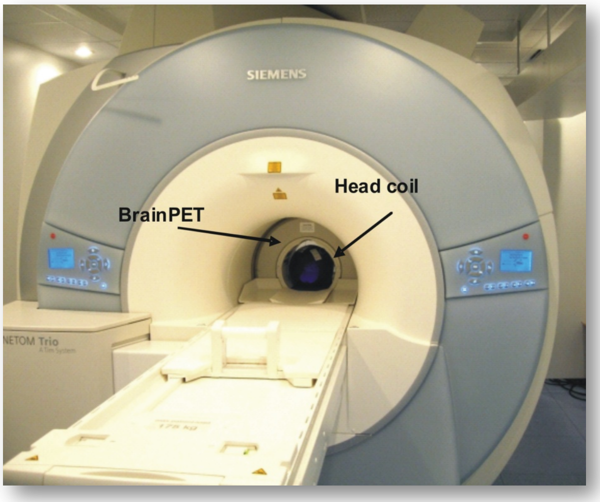
Simultaneous 3T MR-PET Hybrid Measurements



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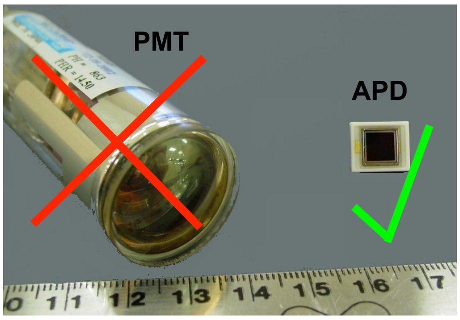
Avalanche Photodiodes (APD) vs. Photomultiplier Tubes (PMT)



	PMT	APD
Magnetically	sensitive	insensitive
Size	10-52 mm dia.	5x5 mm
Gain	Up to 10^6	Up to 200
Rise time	~ 1 ns	~ 5 ns

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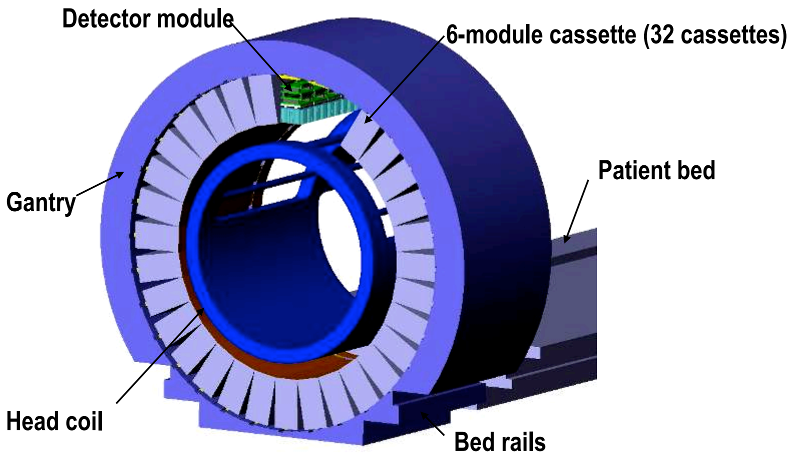
MR-BrainPET – Conceptual Design

Scanner size: 36cm dia. x 20cm FOV



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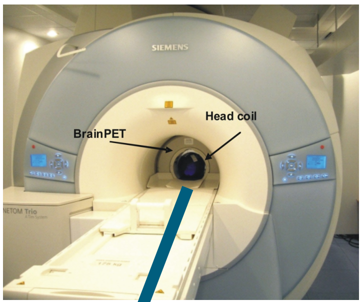
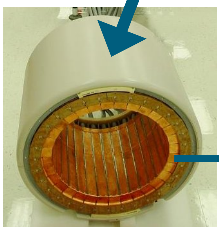
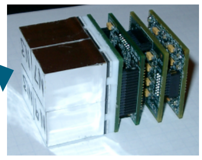
Hybrid MR-PET at 3T and 9.4T





- 32 shielded detector cassettes
- 6 detector blocks/cassette
- 144 LSO-scintillation crystals/block
- 3x3 APDs/block



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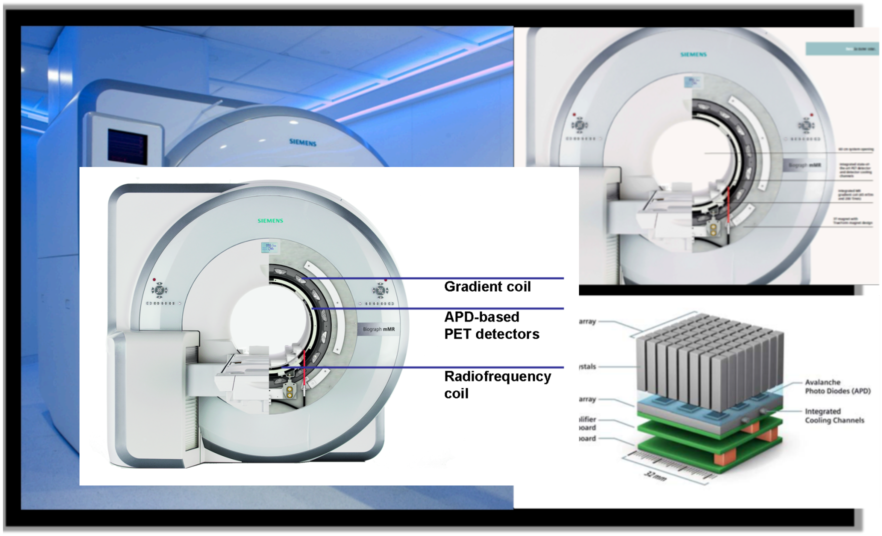
The Siemens Whole-Body PET/MRI: mMR



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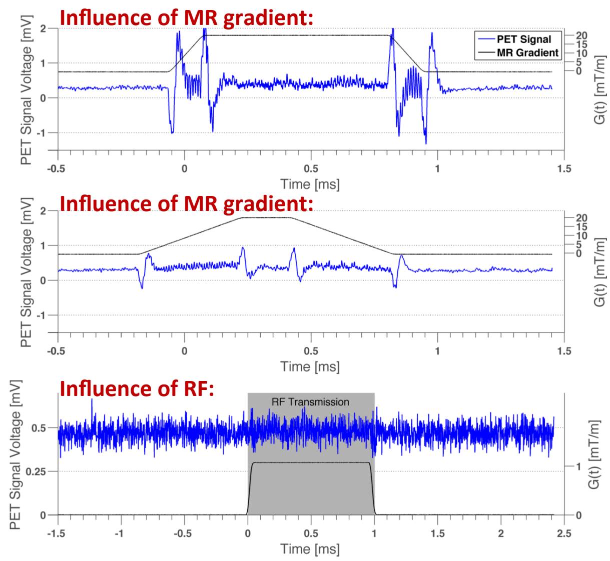
Interference of MRT with PET



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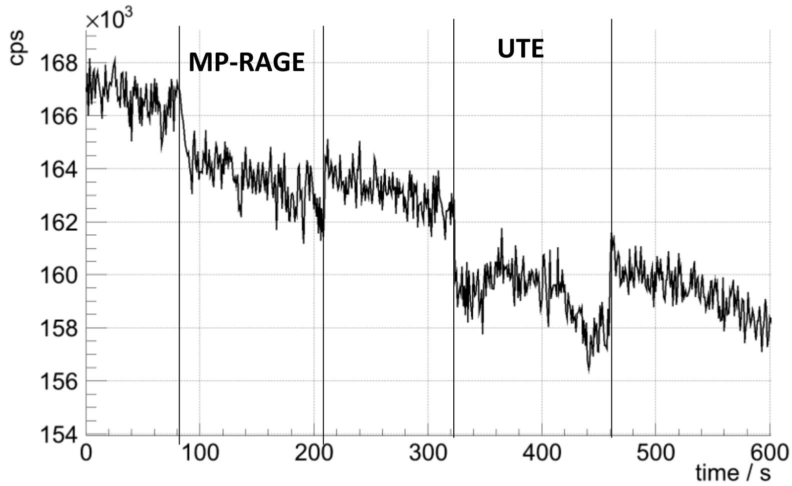
Interference of MRT with PET



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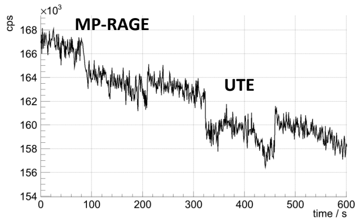
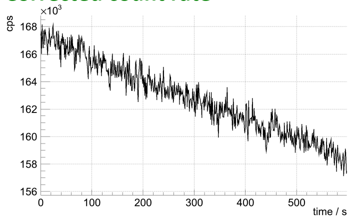
Corrections of MRT Influence

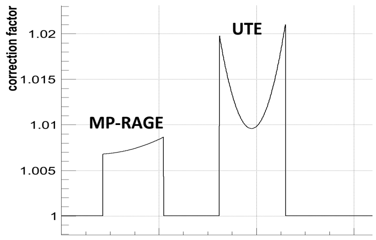
Uncorrected count rate



Corrected count rate



Correction factor



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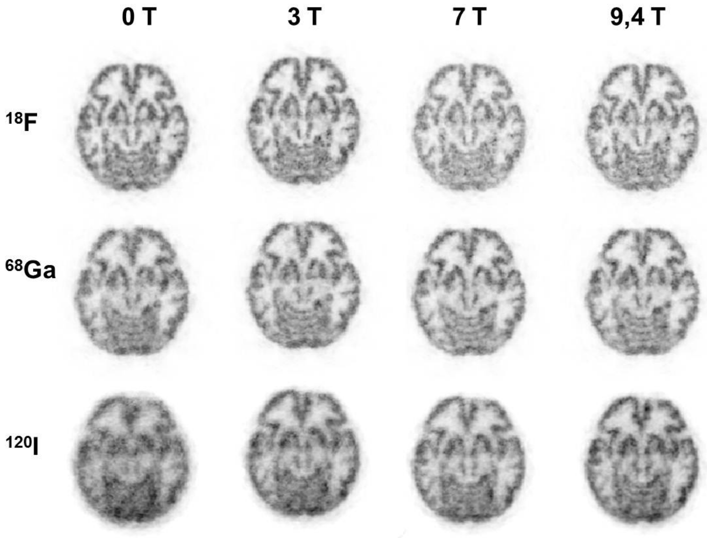
Magnetic Fields and Positron Range



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Questions and Answers

- 1) Which part of the PET does not work inside the magnetic field?

  Avalanche Photodiodes
  Photomultiplier Tube (PMT)
  Scintillator Crystals

- 2) Are there interferences from the MR in the PET measurement?

  Negligible

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Reconstruction and Quantification

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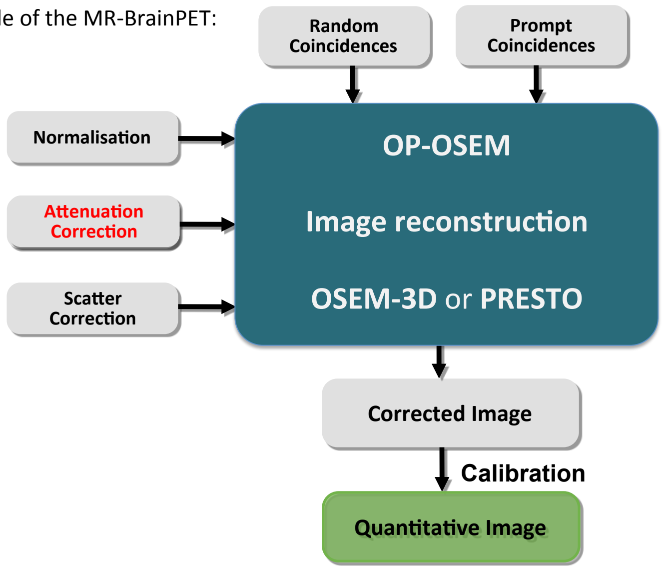
Example of the MR-BrainPET:



Physical Effects and Corrections

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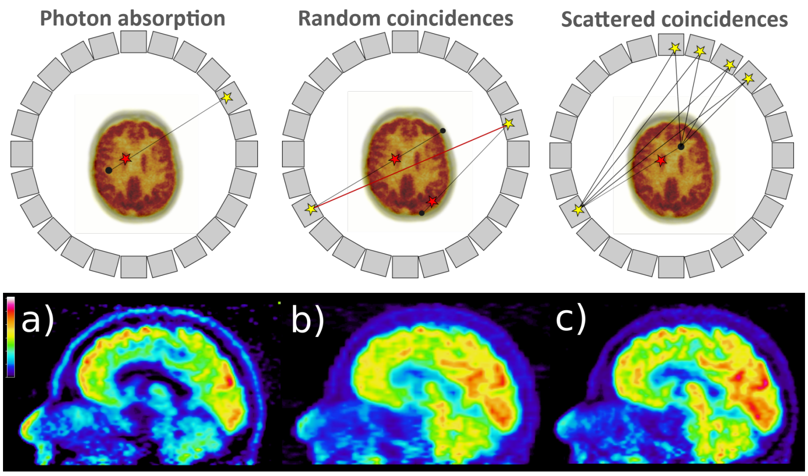
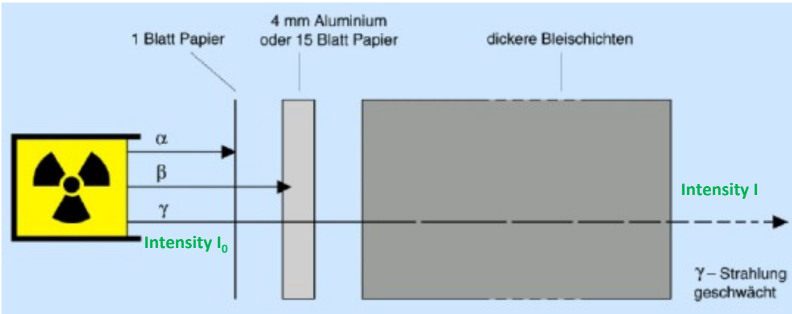


a) Not corrected for absorption, not corrected for scatter
b) Corrected for absorption, not corrected for scatter
c) Corrected for absorption, corrected for scatter

Attenuation Correction



$I < I_0$

- Depends on the material and photon energy

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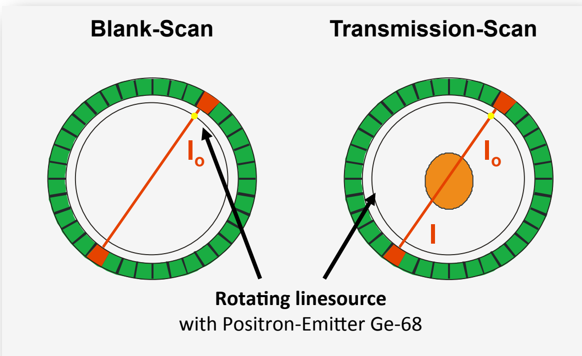
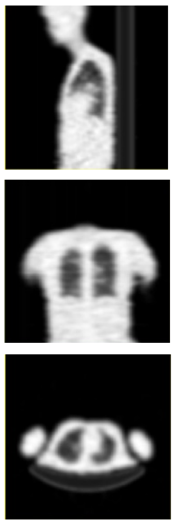
Attenuation Correction

Classic PET Scan





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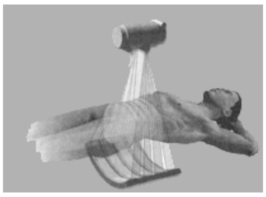
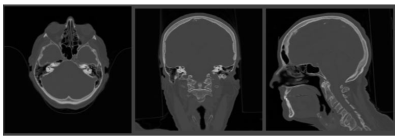
Attenuation Correction
PET/CT Scan

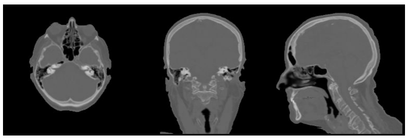


CT Measurement:

Transmission measurement

↓





Air = -1024 HU
Water = 0 HU
Skull ≥ 200 HU

Hounsfield-Units

→

Air = 0 cm^{-1}
Water = 0.096 cm^{-1}
Skull ≥ 0.11 cm^{-1}
} for 511 keV

Attenuation coefficients

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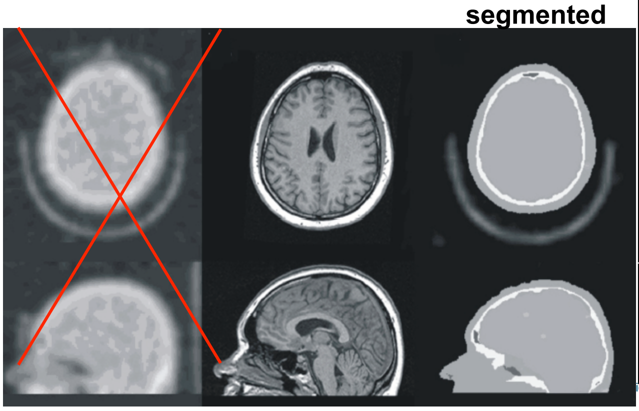
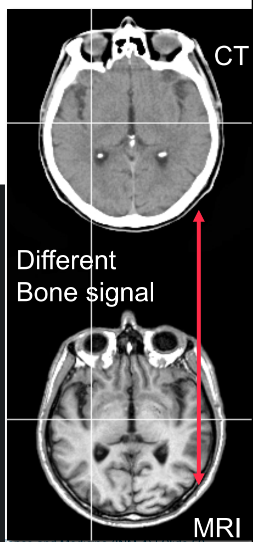
Attenuation Correction in PET/MR

- **No CT**
- **No Transmission source**

PET-Tx | **MRI-T1** | **MRI-T1 segmented**





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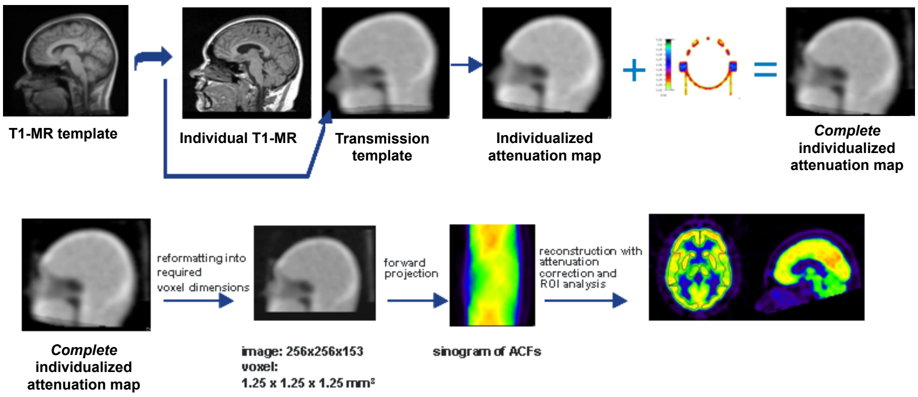
Attenuation Correction in Hybrid MR-PET

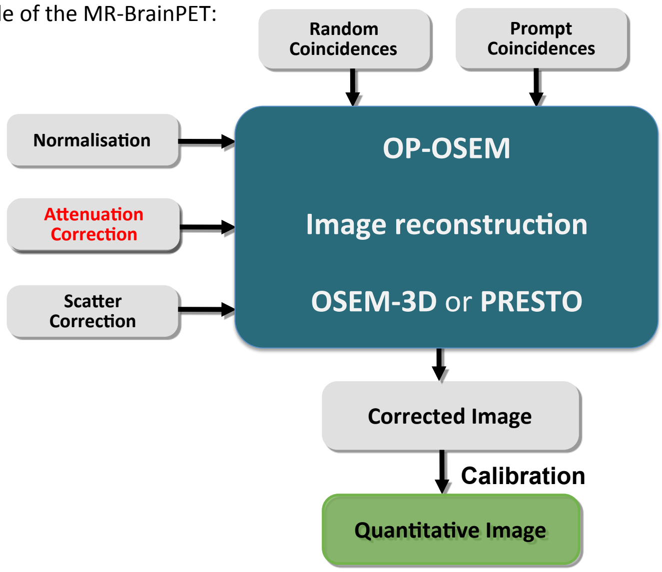


From: Rota Kops et al., *IEEE-MIC* 2008

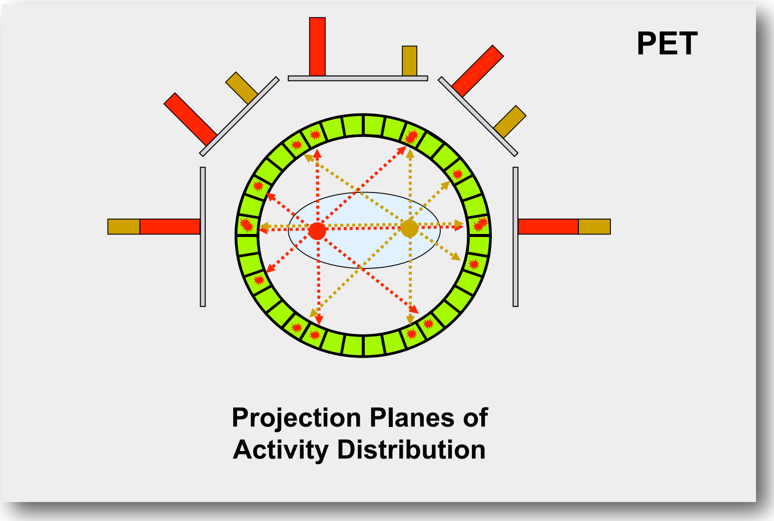
Image: 256x256x153

Reconstruction and Quantification

Example of the MR-BrainPET:

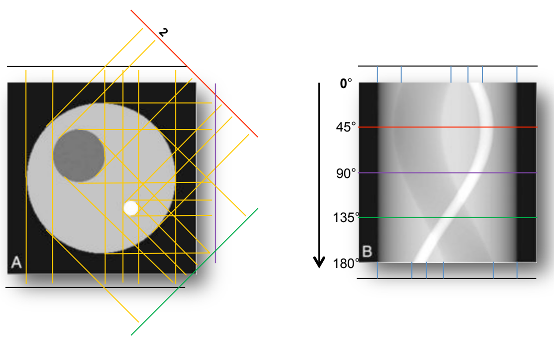


The Process of Emission Tomography



The Process of Emission Tomography

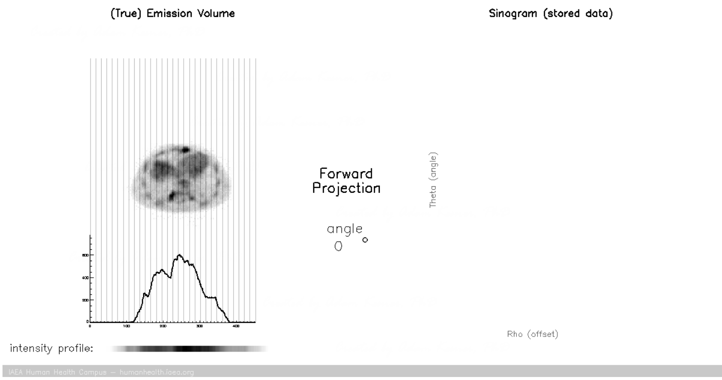
Sinogram



Images courtesy of Andrew Goertzen, Ph.D., University of Manitoba, Winnipeg, MB, Canada

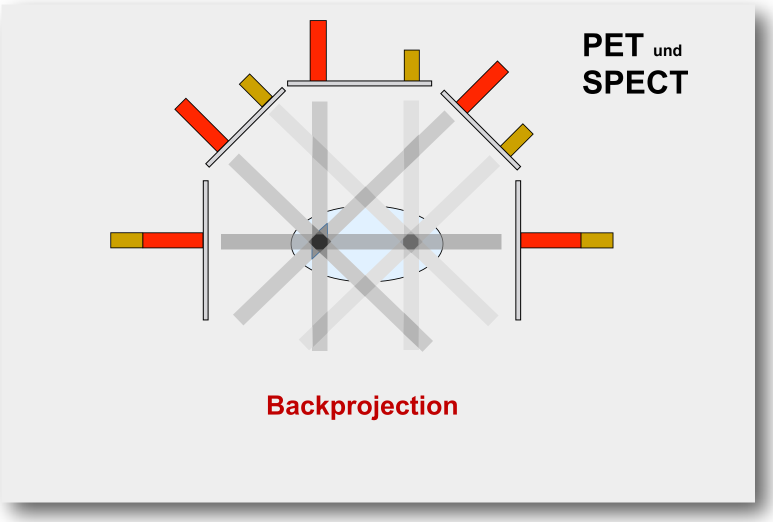
The Process of Emission Tomography

Sinogram



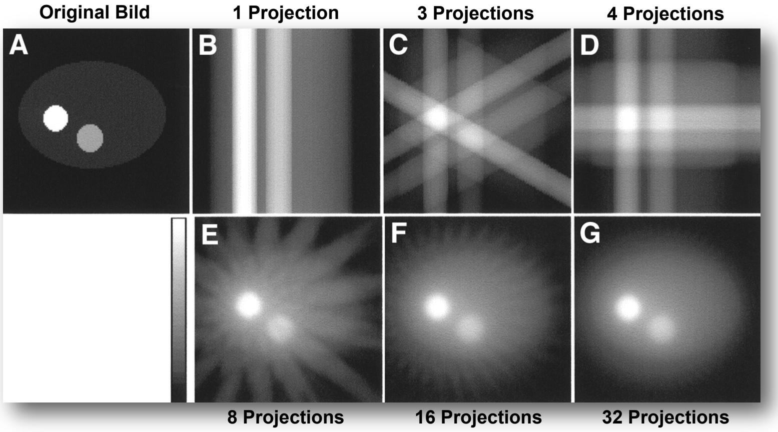
https://humanhealth.iaea.org/HHW/MedicalPhysics/NuclearMedicine/ImageAnalysis/3Dimagereconstruction/index.html

The Process of Reconstruction



The Process of Reconstruction

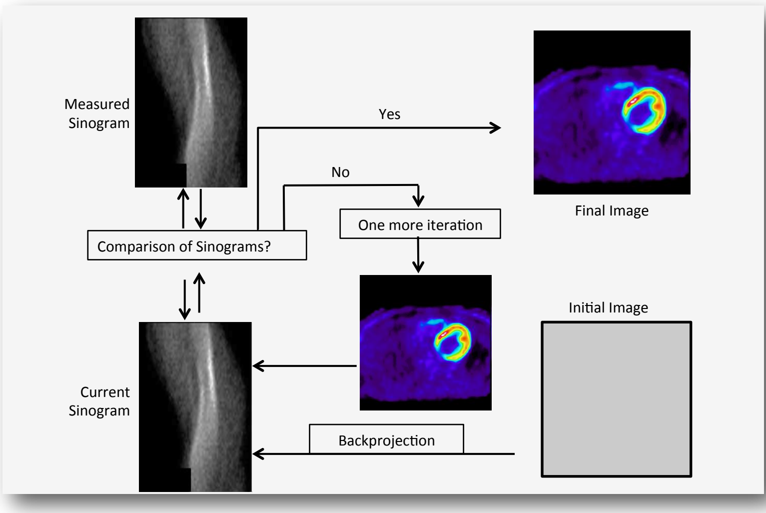
Backprojections



Philippe P. Bruyant J Nucl Med 2002;43:1343-1358

The Process of reconstruction

Iterative Reconstruction



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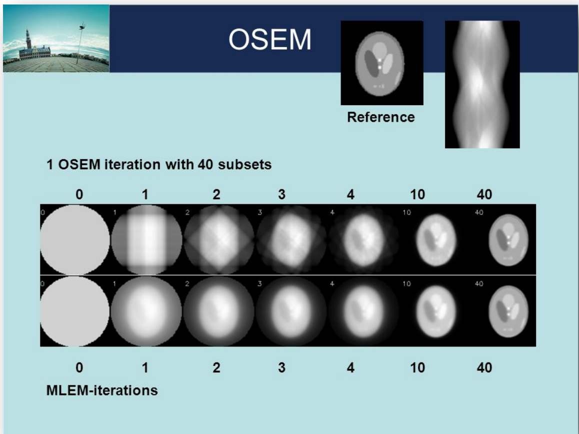
The Process of reconstruction

Iterative Reconstruction



http://slideplayer.com/slide/4813503/: Statistical Image Reconstruction; Katholieke Universiteit Leuven

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Questions and Answers

- 1) Which of these have to be corrected for attenuation?

  Coils
  Patient
  Both

- 2) Does MR have information about attenuation?
  No

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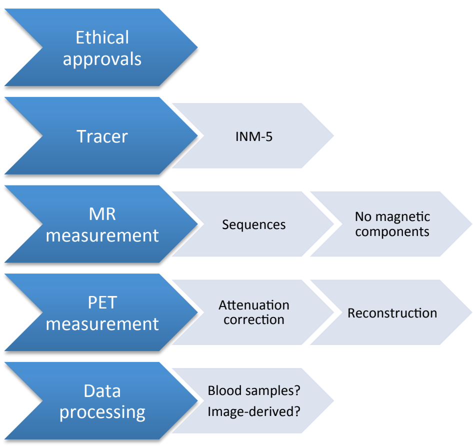
Outline

- What is PET?
- MR-PET
  - Why?
  - How does it work?
    - Hardware
    - Software
- Planning a study
- Conclusion and future trends

Planning a study



Outline

- What is PET?
- MR-PET
  - Why?
  - How does it work?
    - Hardware
    - Software
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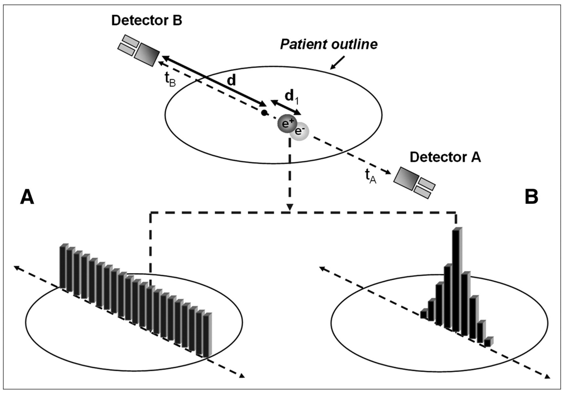
- Conclusion and future trends

Conclusion

- PET is a quantitative imaging technique
- MR/PET has great potential!
- Our 3T and 9.4T MR-BrainPET is the perfect tool for neuroscience studies
- Most issues have been (reasonably) solved

Time-of-Flight PET

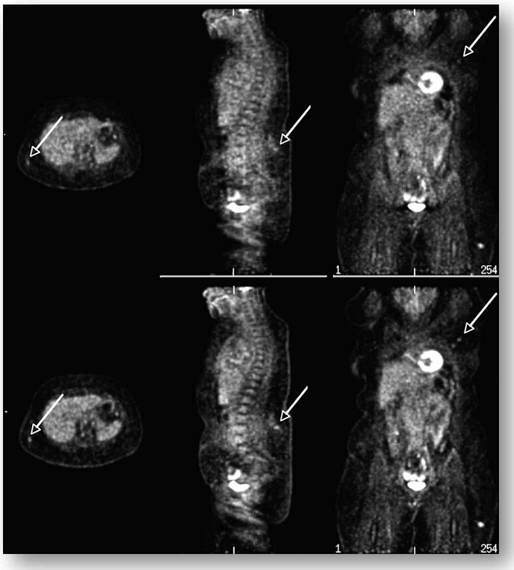


Townsend *et al.*, *J Nucl Med 2008*

- Dedicated detector technology
- Dedicated reconstruction algorithm

- ➢ Higher SNR in the reconstructed Images
- ➢ Higher spatial resolution

Advantages in TOF-PET



Philips Gemini TF PET/CT
CRT: 660 ps
Tracer: ^{18}F-FDG
T_A = 3 min/bed position
T_0 = 60 min p.i.

From: Karp et. al, Benefit of Time-of-Flight in PET: Experimental and Clinical Results, 2007

Who we are….

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PET Group Members

Elena Rota Kops
Liliana Caldeira
Kornelia Frey
Silke Frensch
Suzanne Schaden
Christoph Lerche
Jürgen Scheins
Lutz Tellmann
Theodoros Kaltsas
Xu Hancong
Ma Bo

Associated Members

Mirjam Lenz (PET Detector Tech.)
Nuno da Silva (MRI)
Philipp Lohmann (Brain Tumors)
Jörg Mauler (MRI)

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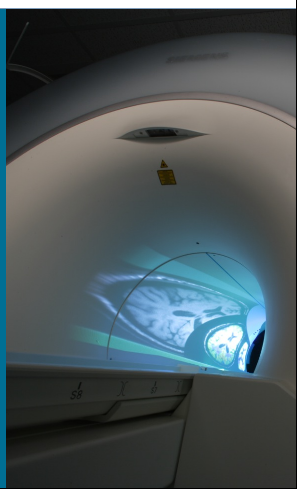
Thank you for your attention

Liliana Caldeira | July 11, 2017
contact: l.caldeira@fz-juelich.de



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