The Abdus Salam
International Centre
for Theoretical Physics

2484-15

ICTP-IAEA Joint Workshop on Nuclear Data for Science and Technology: Medical Applications

30 September - 4 October, 2013

Molecular Imaging Part IIIa: PET-MR

H. Herzog

Institute of Neuroscience and Medicine - 4 Forschungszentrum Juelich
Germany

Strada Costiera, 11 - 34151 - Trieste - Italy • Tel. +39 0402240111 • Fax. +39 040224163 • sci_info@ictp.it • www.ictp.it
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Molecular Imaging Part IIIa:

PET-MR

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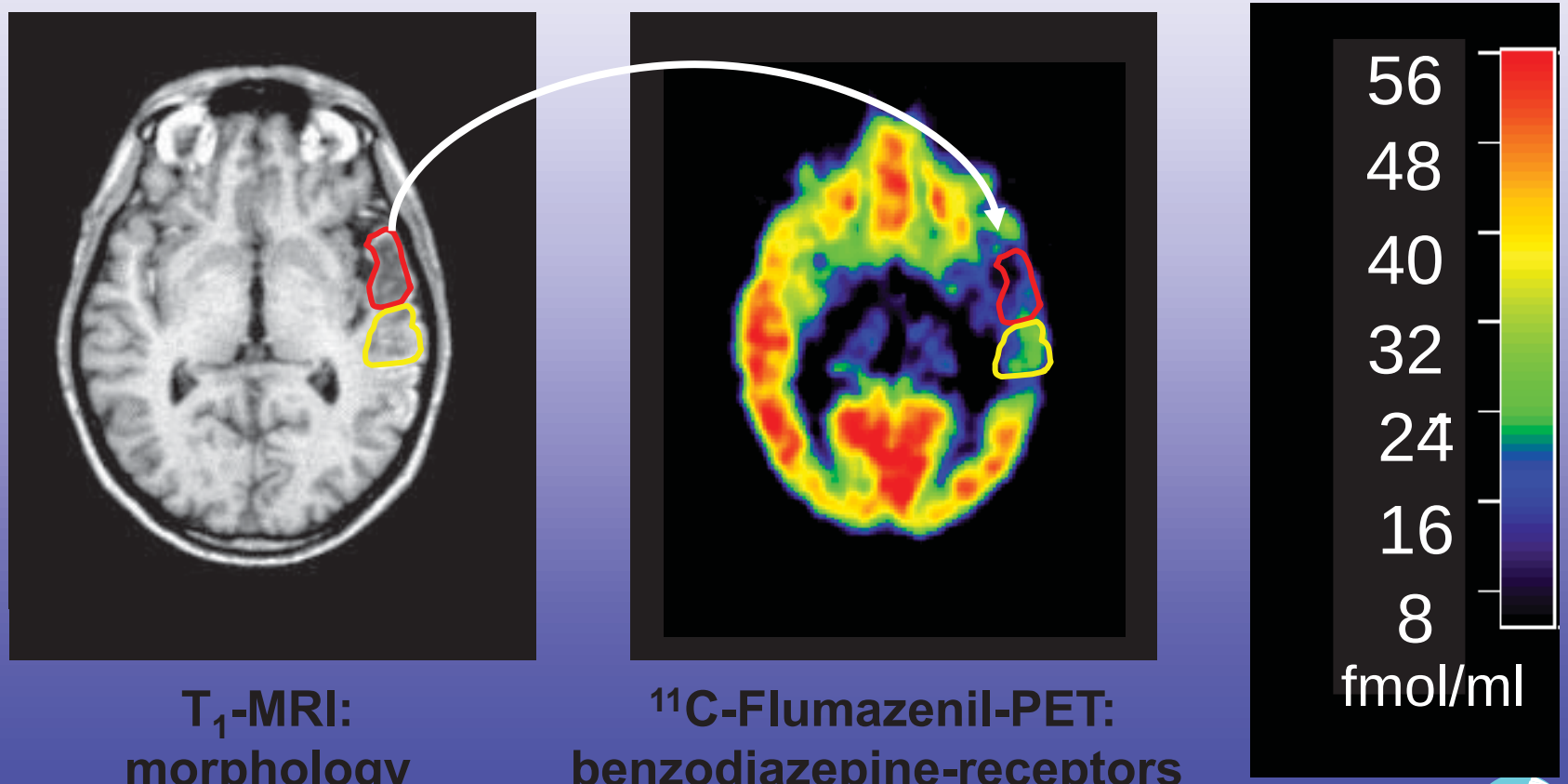
MR Compared to PET

Parameter	MR	PET
Anatomical Detail	Excellent	Poor
Spatial Resolution	Excellent	Gets better
Clinical Penetration	Excellent	Improving
Sensitivity	Poor	Excellent
Molecular Imaging	Limited	Excellent

MR-PET >> MR + PET

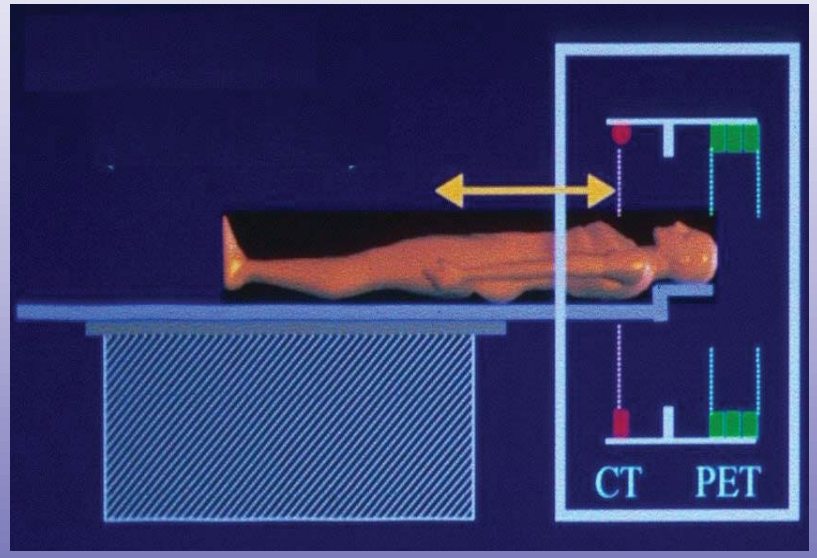
Today‘s Commonly Combined Use of PET and MRI



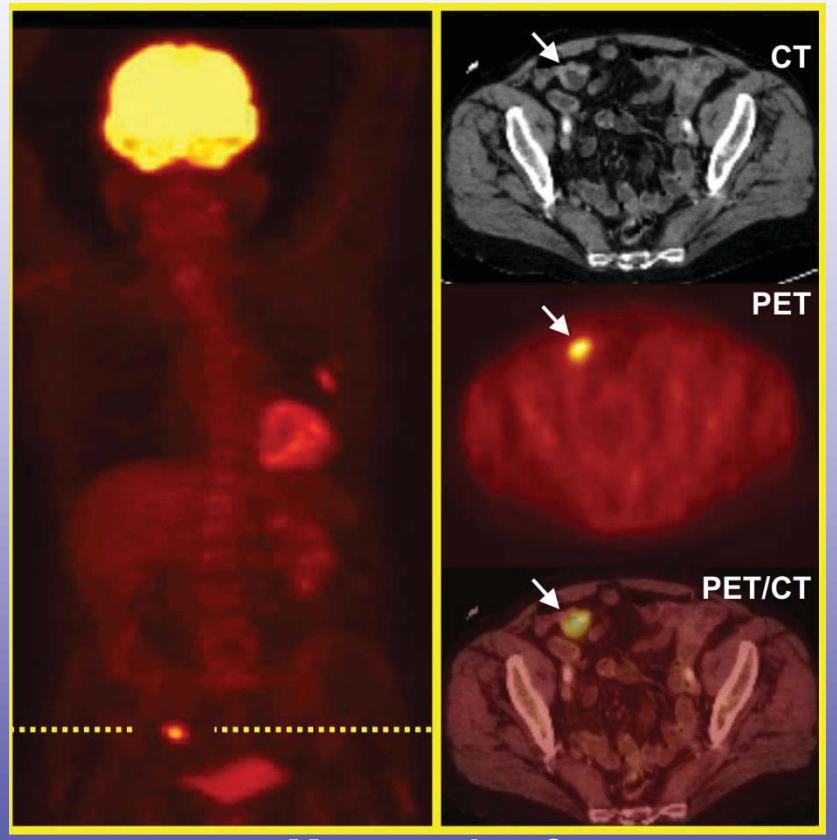
T_1-MRI:
morphology

^{11}C-Flumazenil-PET:
benzodiazepine-receptors

Combing Anatomy and Function with PET/CT

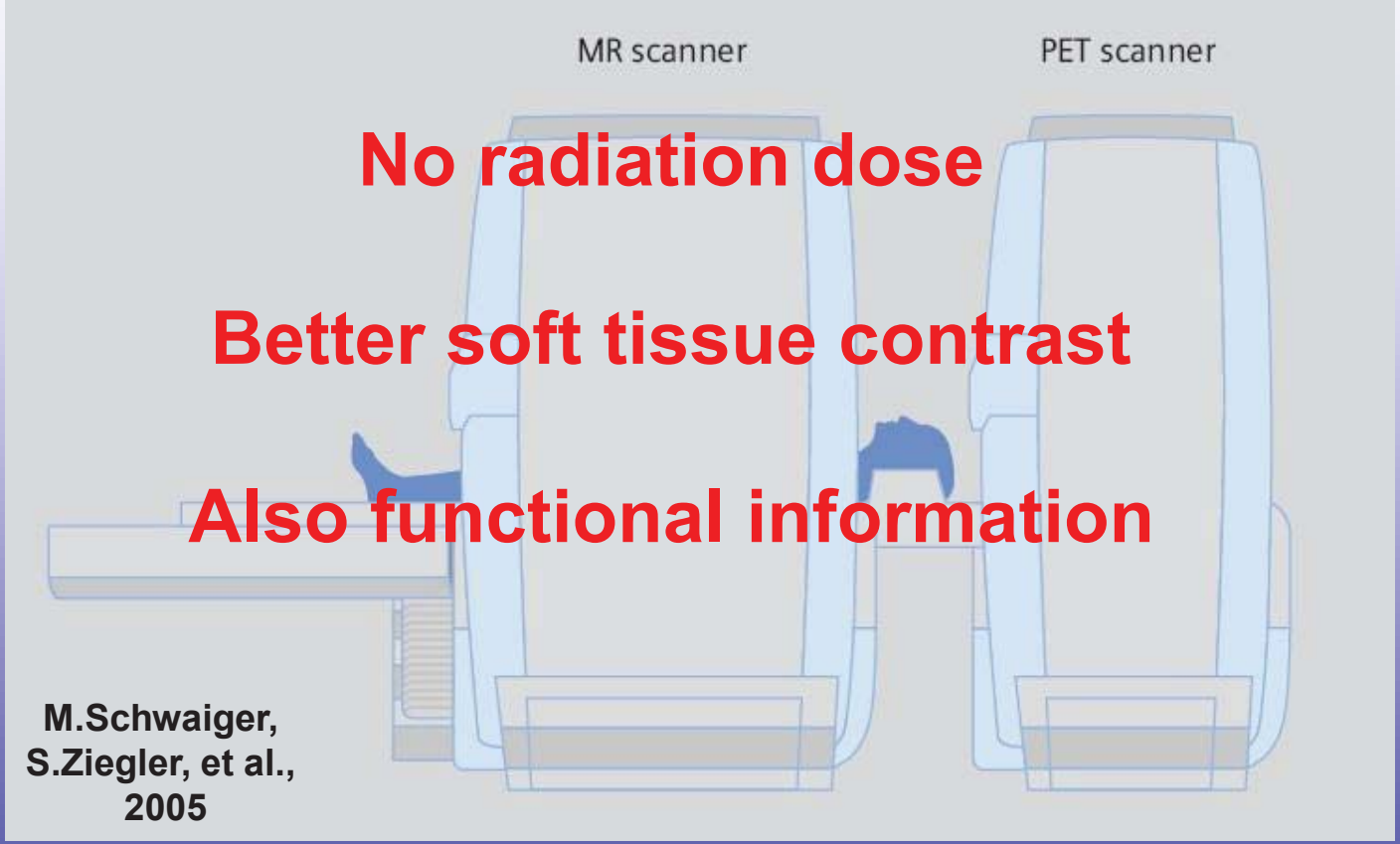


D.Townsend 1995



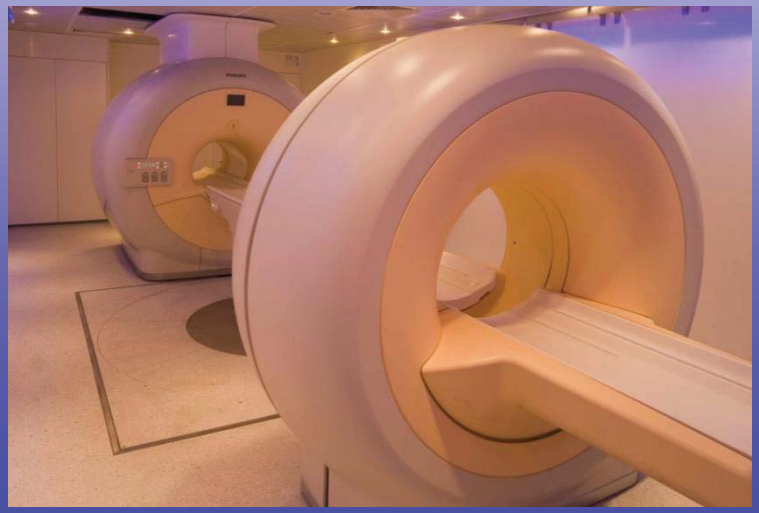
Metastasis of a malignent melanoma

MR instead of CT in PET/CT ?



Siemens (2008): 3TMR-BrainPET
only prototype

Siemens (2010): Biograph mMR
commercial product



Philips (2010): Ingenuity TF PET/MR
commercial product

Siemens (2008): 3TMR-BrainPET only prototype

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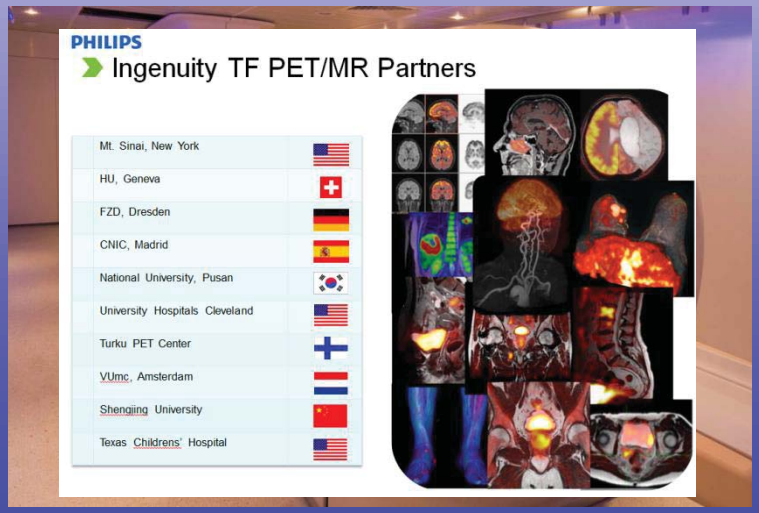
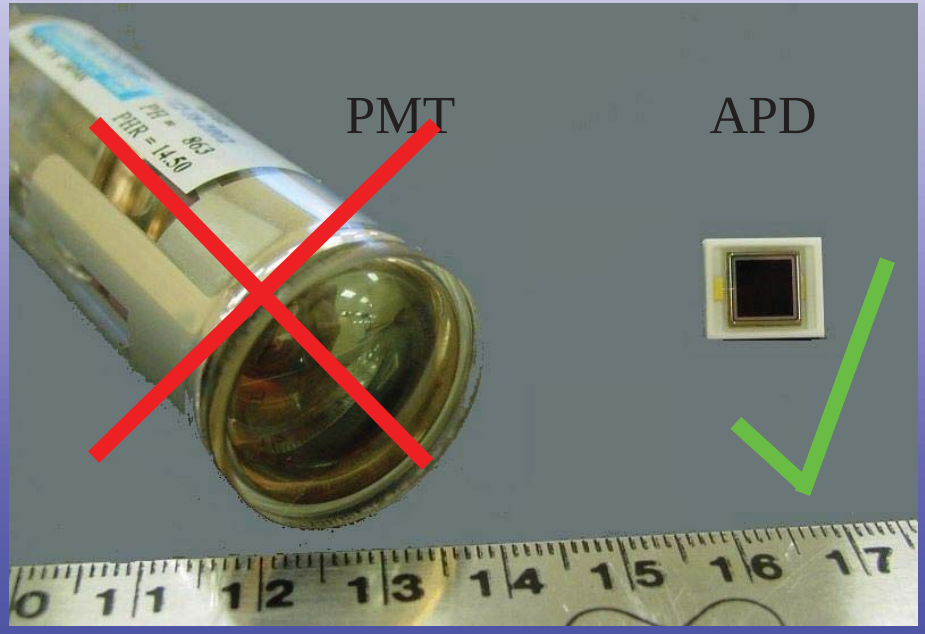


Philips (2010): Ingenuity TF PET/MR commercial product

3TMR-BrainPET

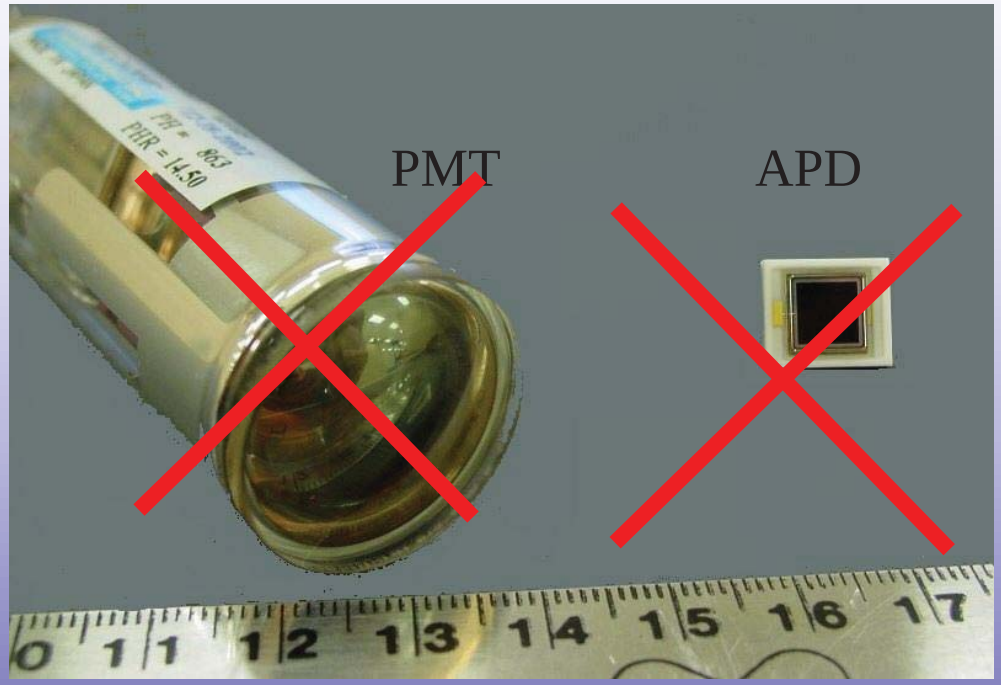
Avalanche Photo Diodes (APD)

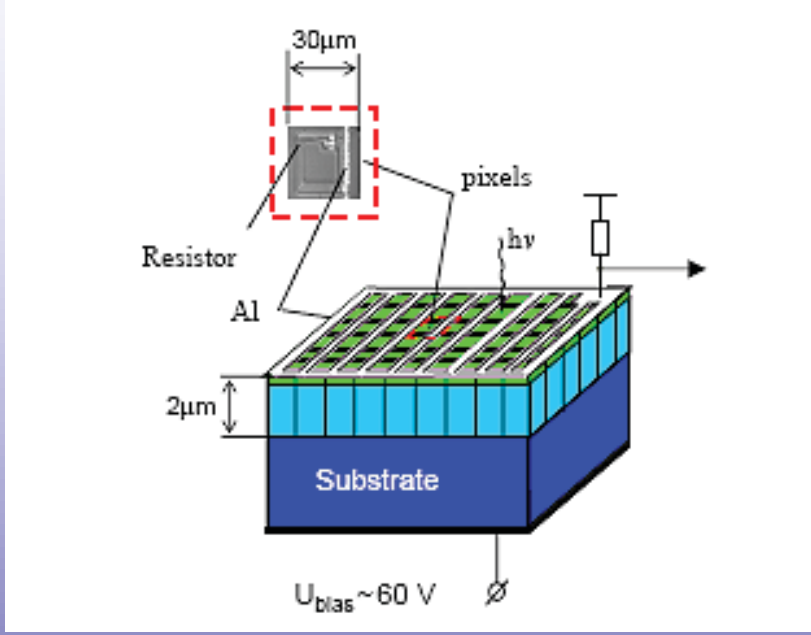
vs. Photo Multiplier Tubes (PMT)



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

Future : SiPMT / GM-APD ?





Otte et al., 2005

Gain: similar to PMT

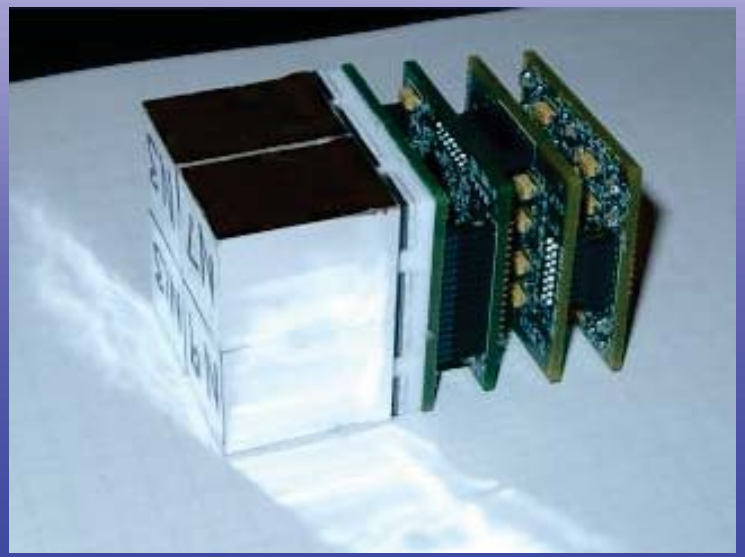
Journal of Nuclear Medicine, April 2011
Sun Il Kwon et al: Development of Small-Animal PET Prototype Using Silicon Photomultiplier (SiPM): Initial Results of Phantom and Animal Imaging Studies

3TMR-BrainPET:

APD-based PET Detector Cassette

Consists of:

- **Six 12 x 12 arrays of 2.5 x 2.5 x 20 mm³ LSO crystals read out by 9 APDs (Hamamatsu)**
- **Preamplifiers & driver electronics**
- **Temperature stability with compressed air**



3MR-BrainPET:

The Head Coils

Birdcage Coil:
TX/RX

8-Channel Coil:
RX

Technical Challenges by Possible Interferences between PET and MR

- Minimal susceptibility (< 0.25 ppm local distortion) to avoid homogeneity distortion
- No generation of time varying fields
- Tolerate vibration due to current changes in the gradient coil in the range of 1-10 μm in the kHz range
- Temperature changes due to average current changes in the gradient coil from 20-70 ^{o}C
- There should be no loss in sensitivity

Some Technical Parameters

Resolution (FWHM, mm) [§] :

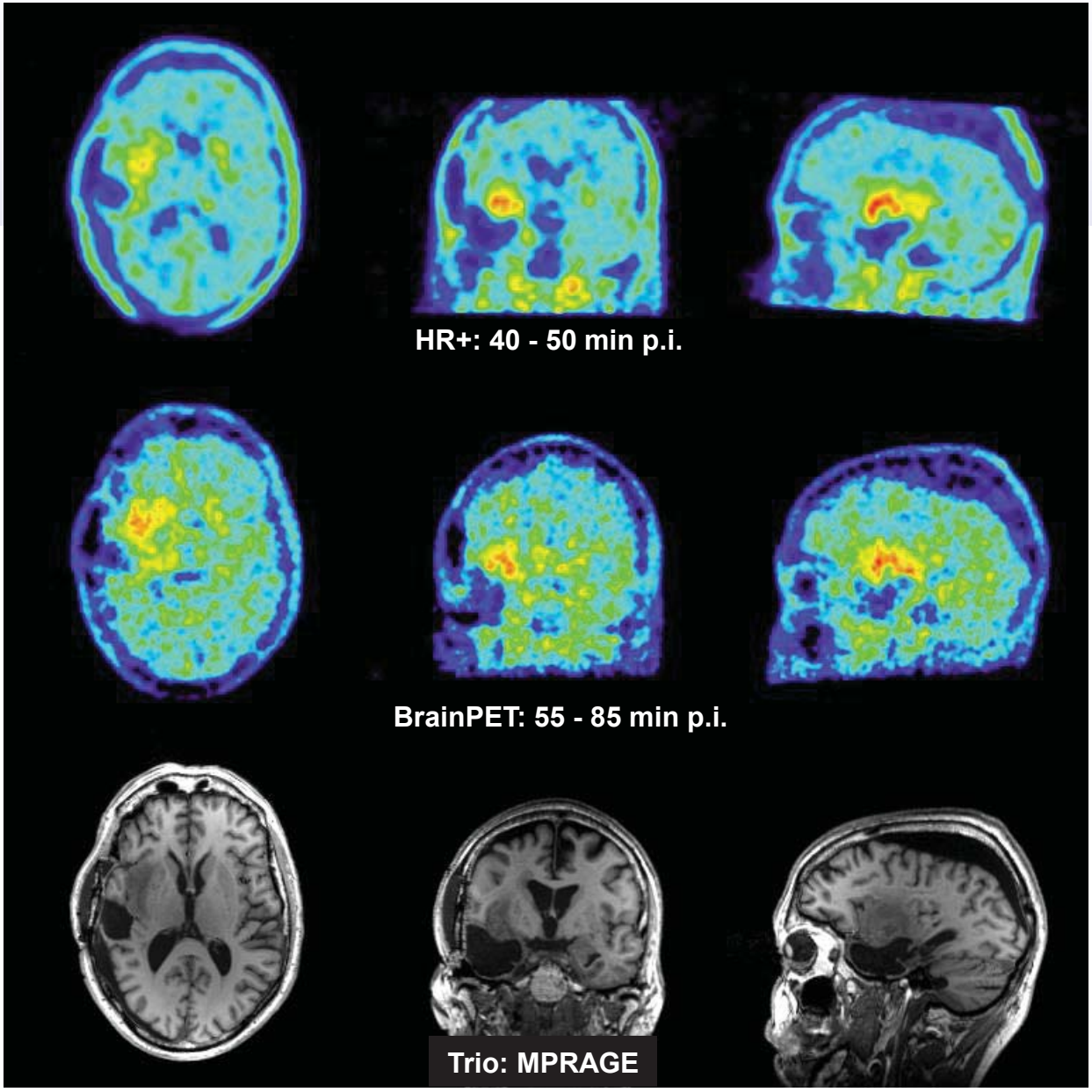
r =	0 cm	2.5 cm	5 cm	7.5 cm	10 cm
Tangential:	3.0	3.0	3.1	3.0	3.8
Radial	2.9	3.0	3.9	4.5	4.9
Z-Direction	3.0		3.6		

Scatter fraction: 27%

Point source sensitivity: 6%

[§] reconstructed with 3DFBP (STIR)

Simultaneous MR-PET in a Brain Tumor



Brain Tumor

studied

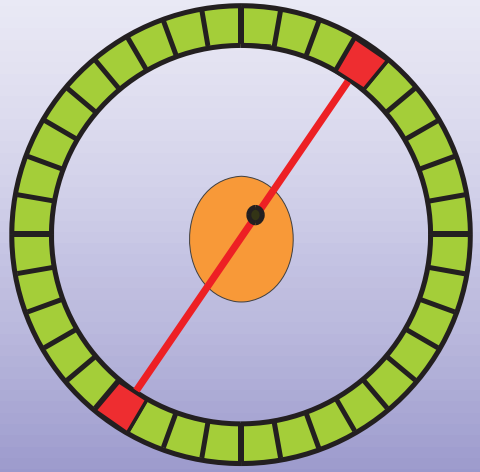
with

[^{18}F]-fluoro-ethyl-tyrosine (FET)

Simultaneous MRI

A Prerequisite for Quantitation: Attenuation Correction

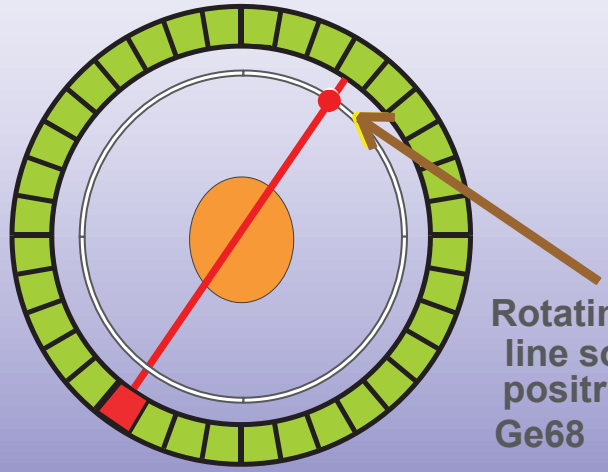
Emissionsmessung



the detector measures:

$$P_E = \int A(x,y)\, dl \; * \; \exp\left(- \int \mu\,(x,y)\, dl' \right)$$

Transmissionsmessung

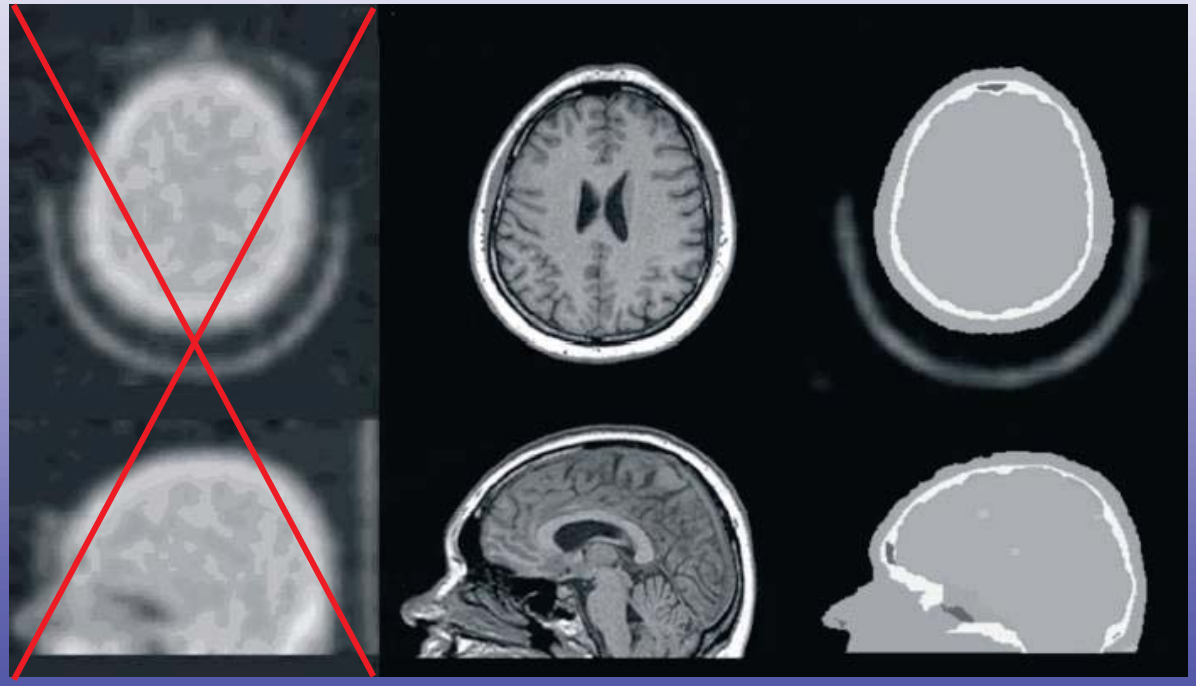


the detector measures:

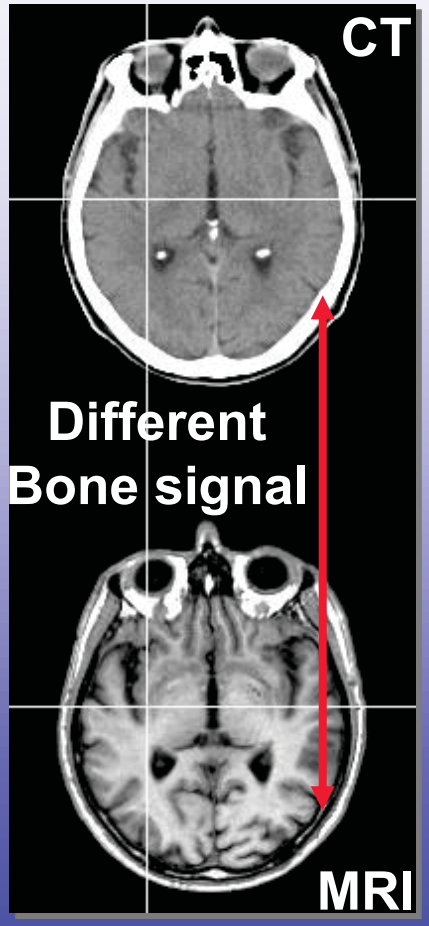
$$AF = \exp\left(- \int \mu\,(x,y)\, dl' \right)$$

$$P_E^{Korr} = P_E / AF = \int A(x,y)\, dl$$

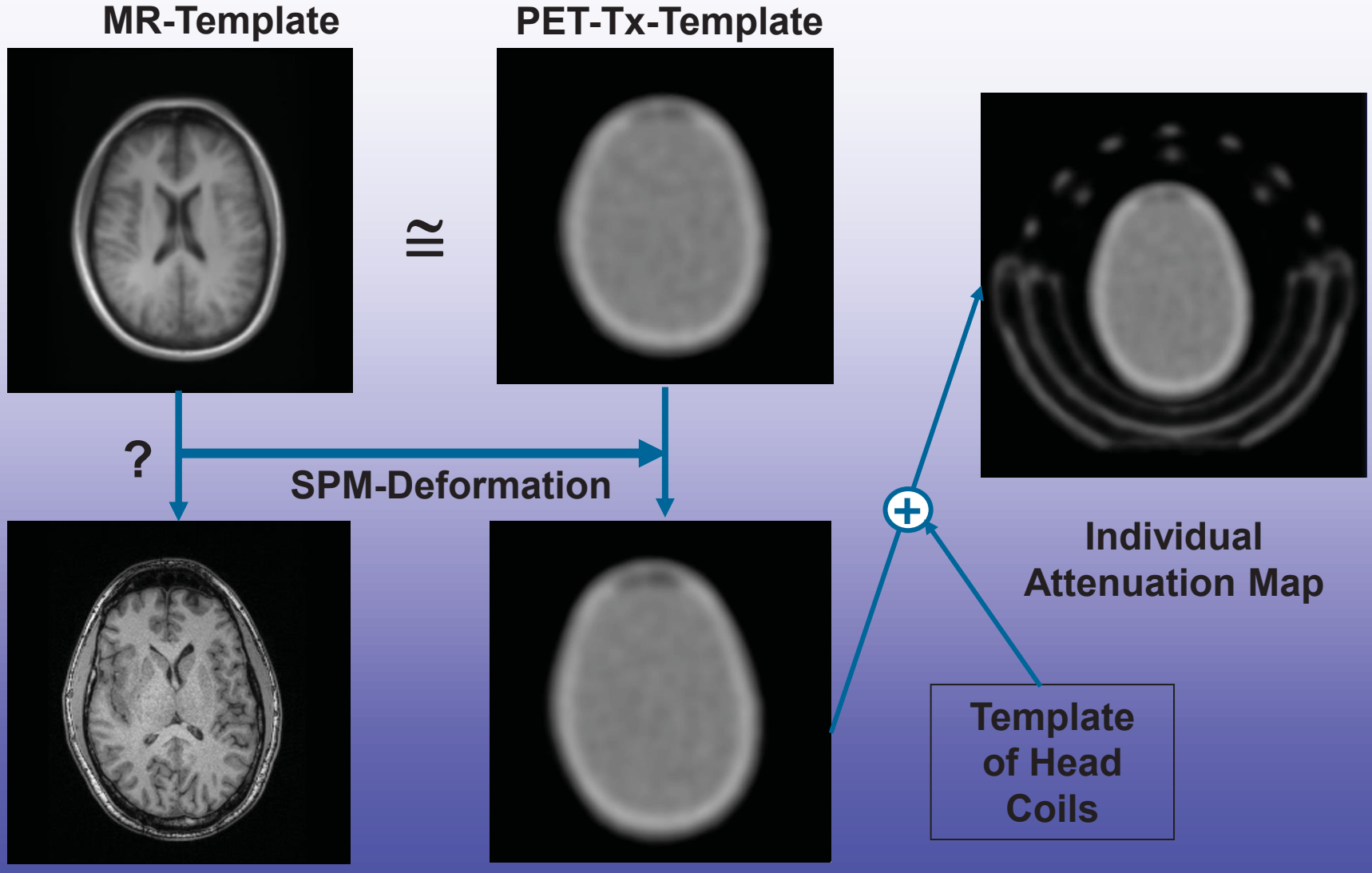
Attenuation Correction No Longer Based on Transmission Measurement !!



Rota Kops et al., IEEE 2006

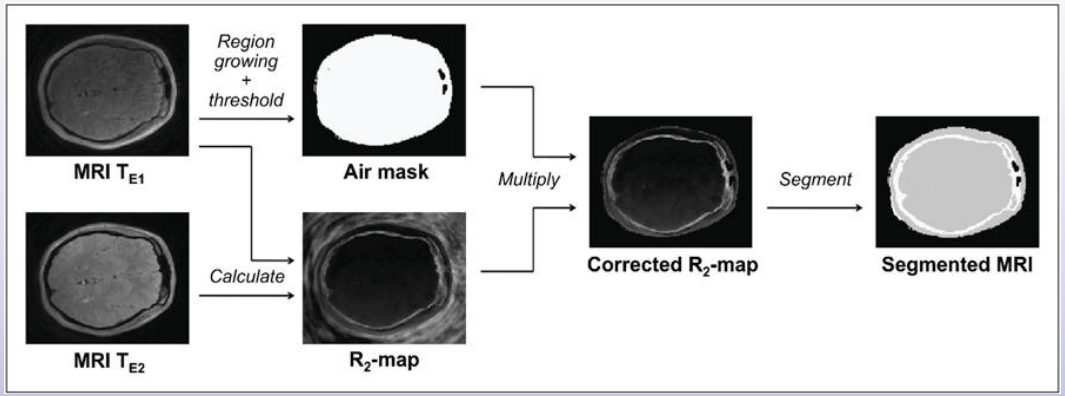


Determination of Attenuation Map

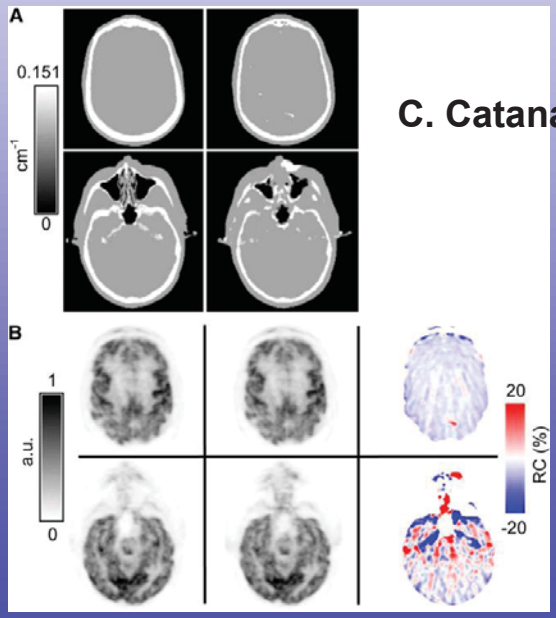


E. Rota Kops, IEEE MIC 2008

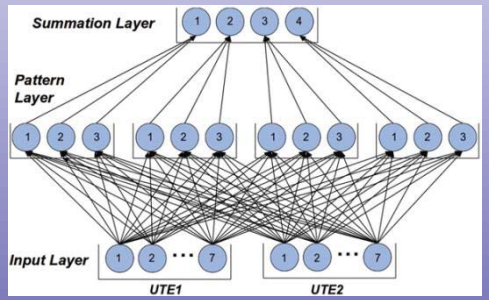
MR-Based Attenuation Correction Using UTE Sequences

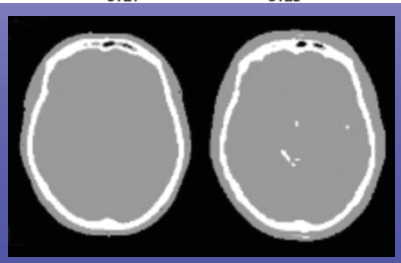


V. Keereman, JNM 2010



C. Catana, JNM 2010

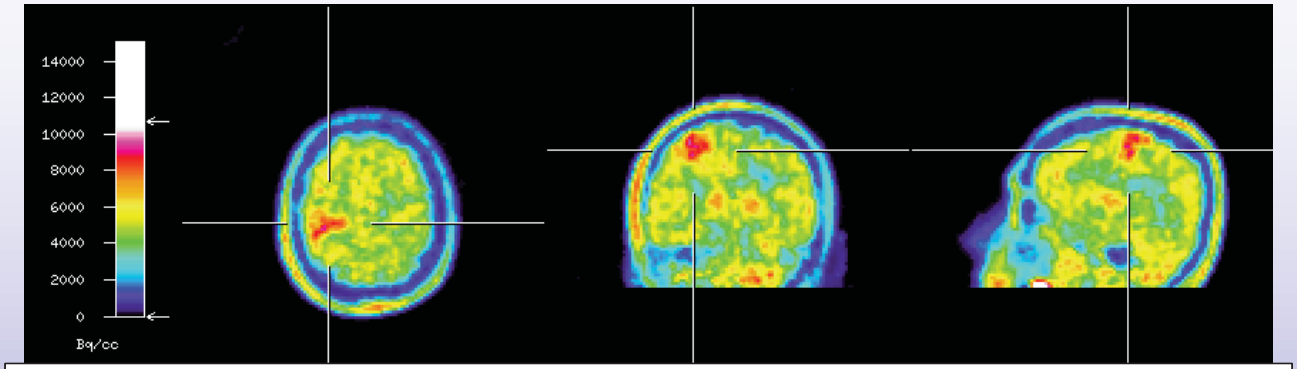




CT UTE-based

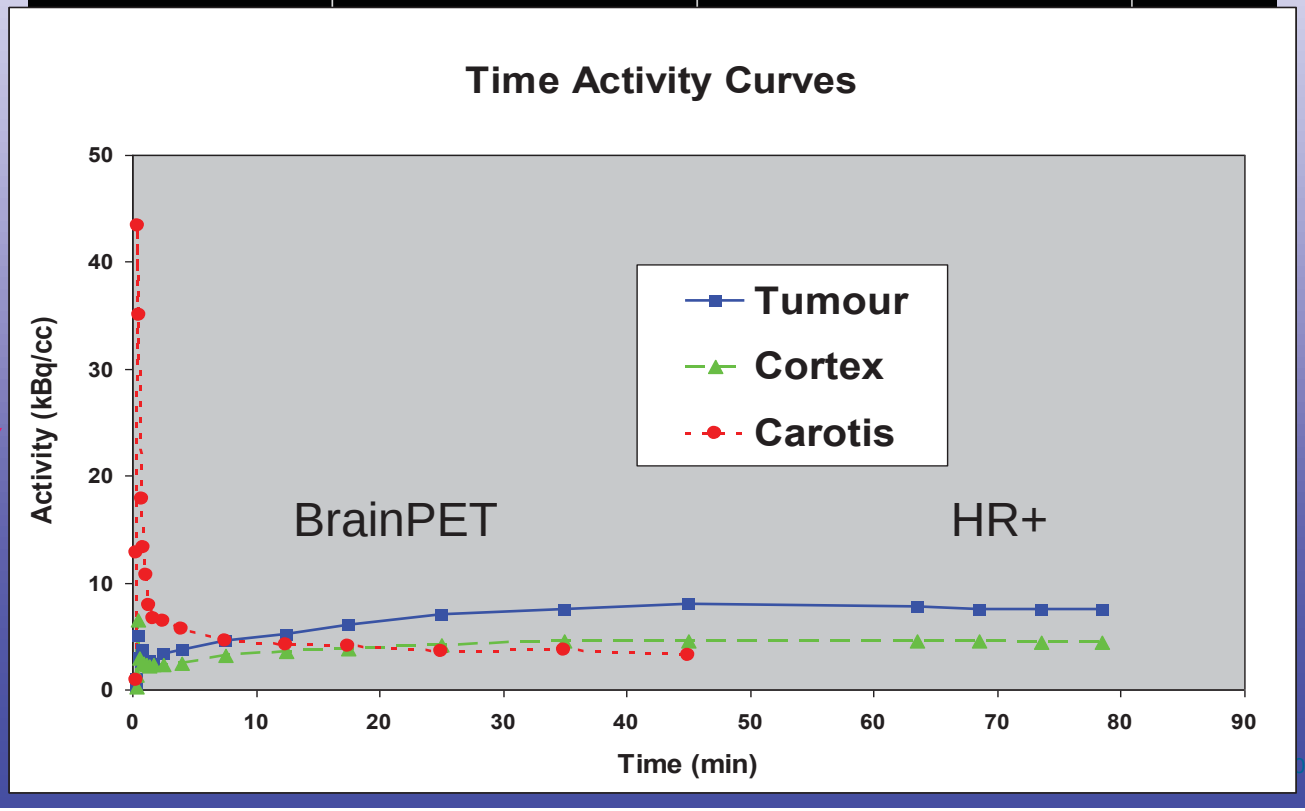
A. Ribeiro, NIMA 2012

FET- Dynamics Recorded in the 3TMR-BrainPET

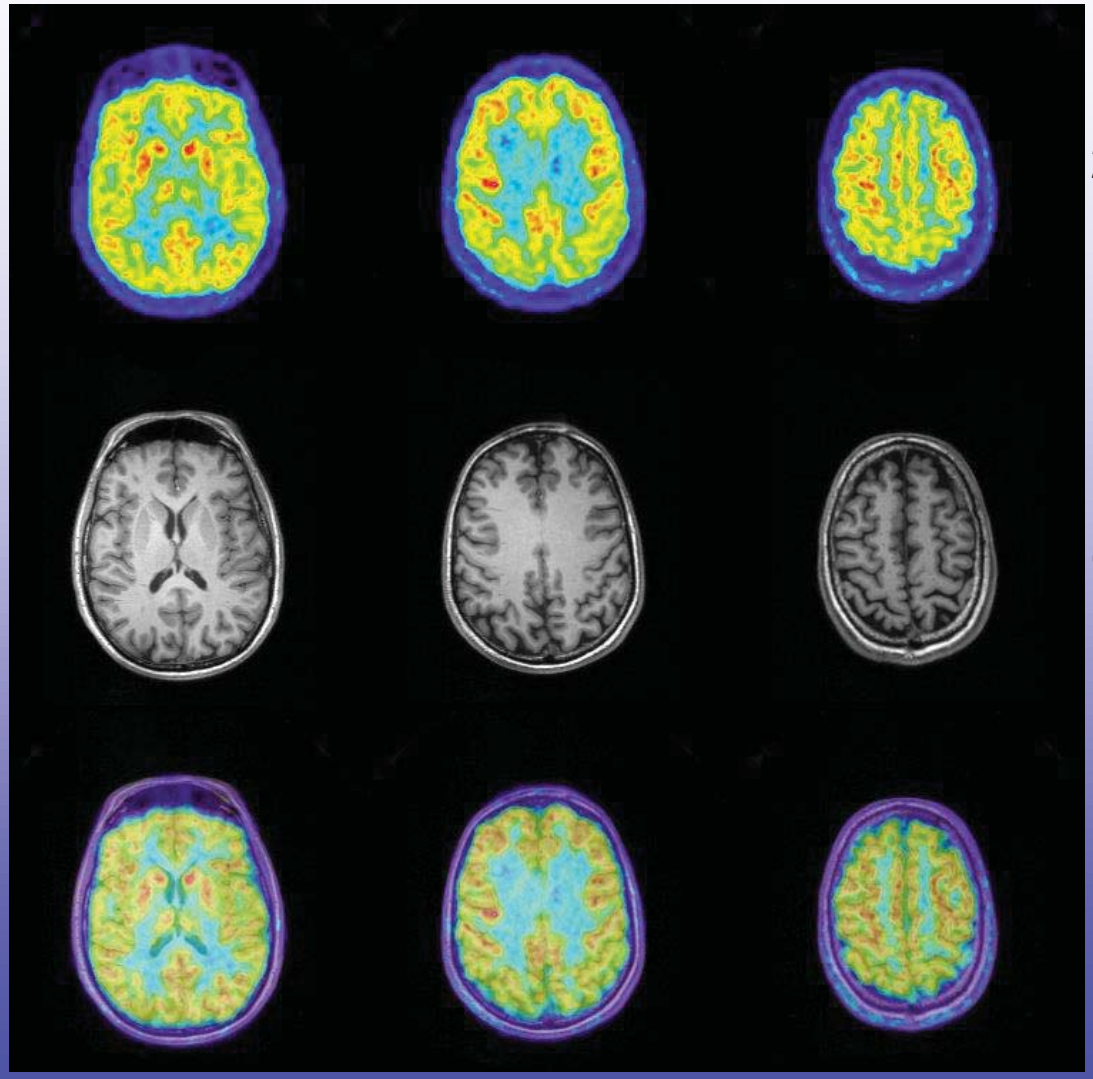


The time-activity curves of the BrainPET and HR+ match !

Quantitation achieved !

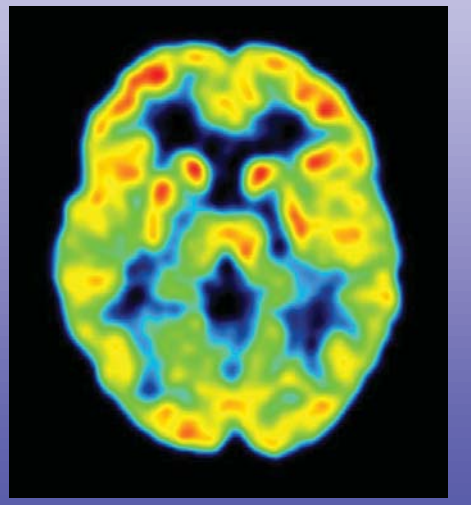


MR-FDG-BrainPET



20-50 min p.i. ^{18}FDG-PET

Simultan
T1 MPRAGE



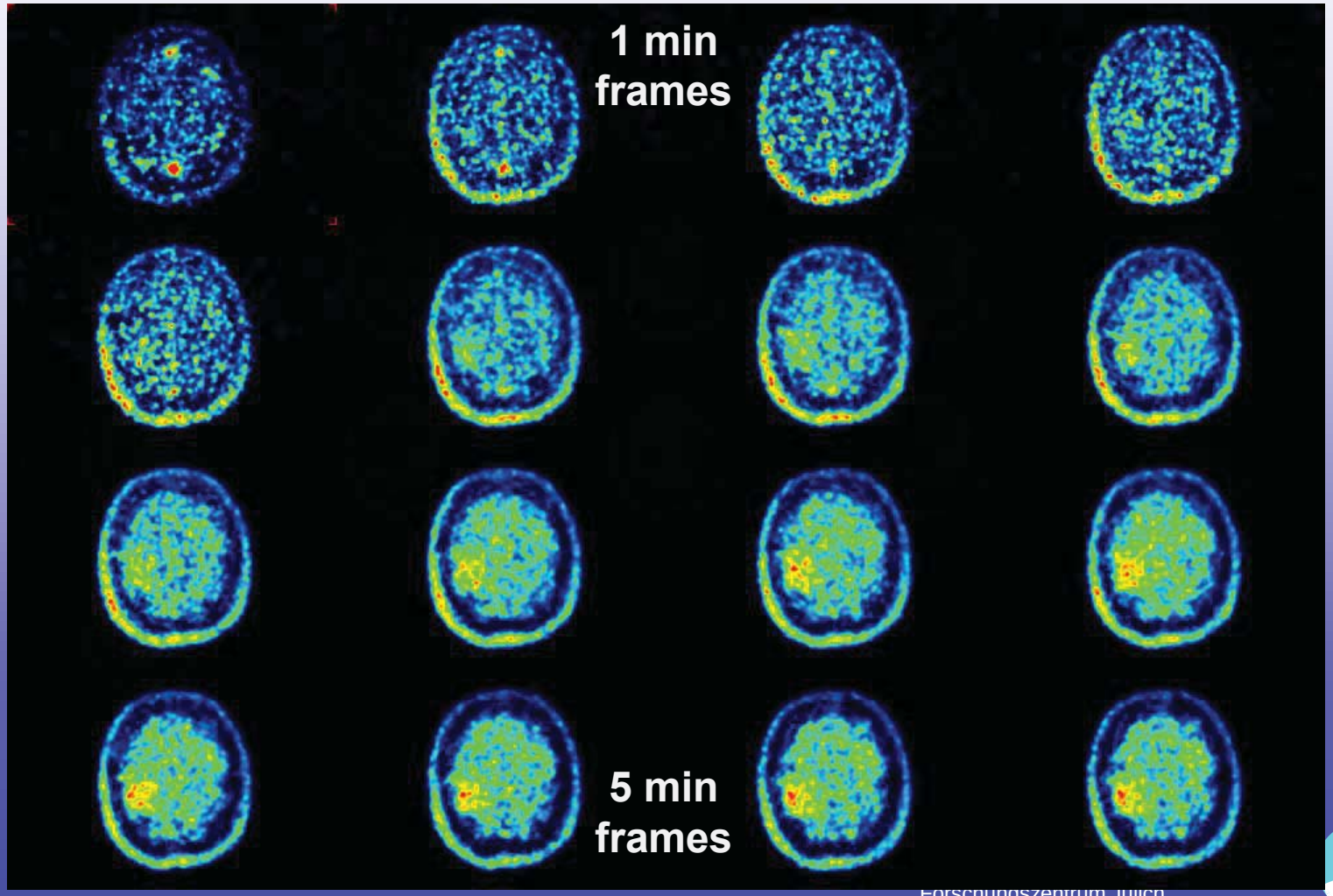
Fusion

HR+

Clinical Applications

FET- Dynamics Measured with 3TMR-BrainPET

BrainPET: 0 - 50 min p.i.

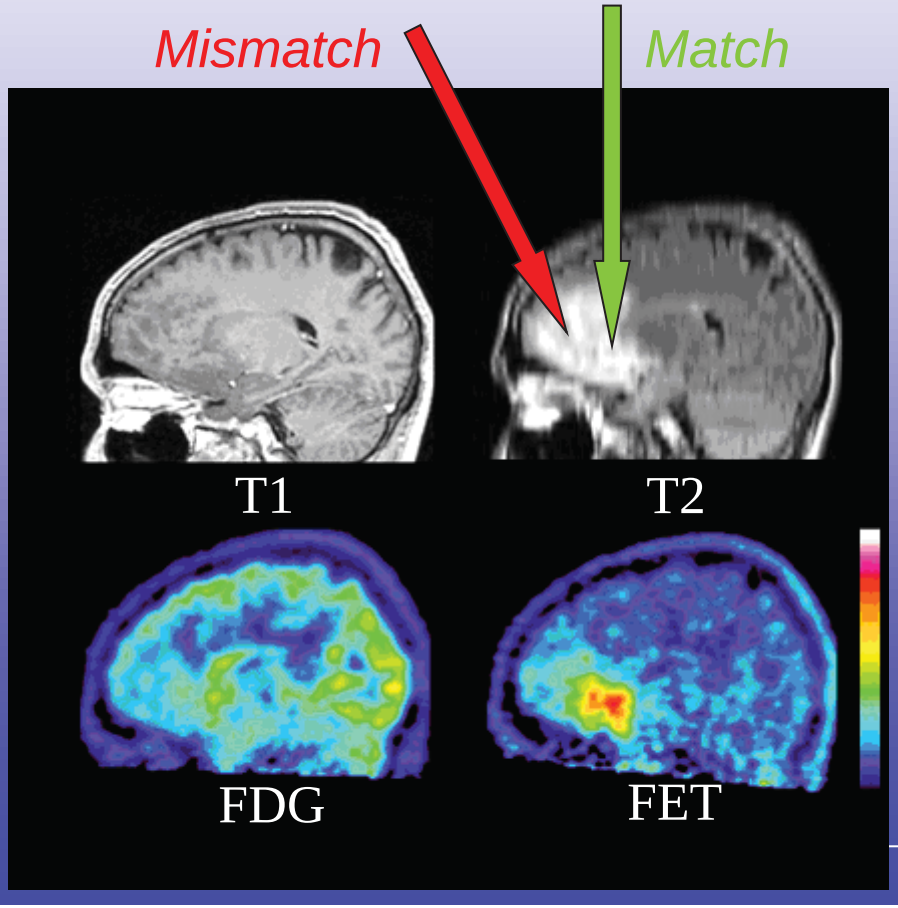


Cerebral Gliomas:
PET with O-(2-[^{18}F]fluoroethyl)-L-tyrosine (FET) Completes MRI Based Diagnosis

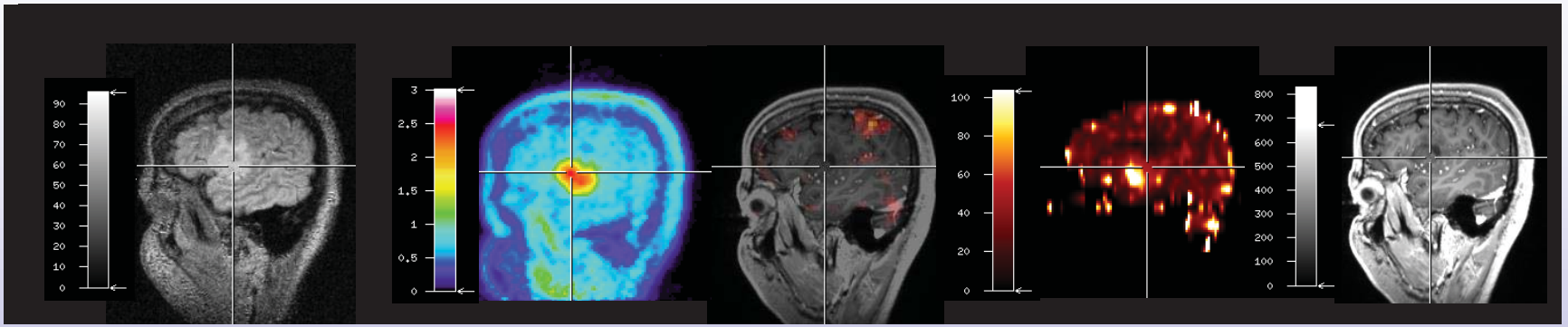
Preoperative determination of tumor extent in FET-PET and MRI

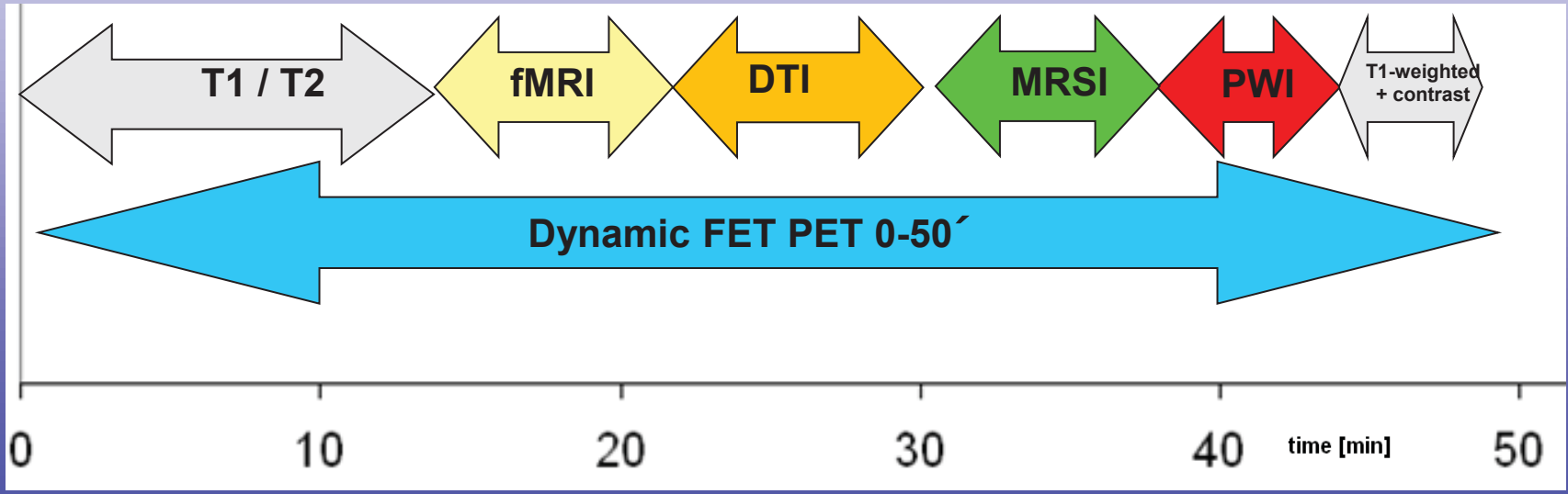
	MRI:	MRI+FET:
Sensitivity:	96 %	93 %
Specificity:	53 %	94 %

Pauleit et al. Brain 2005



Hybrid MR-PET imaging

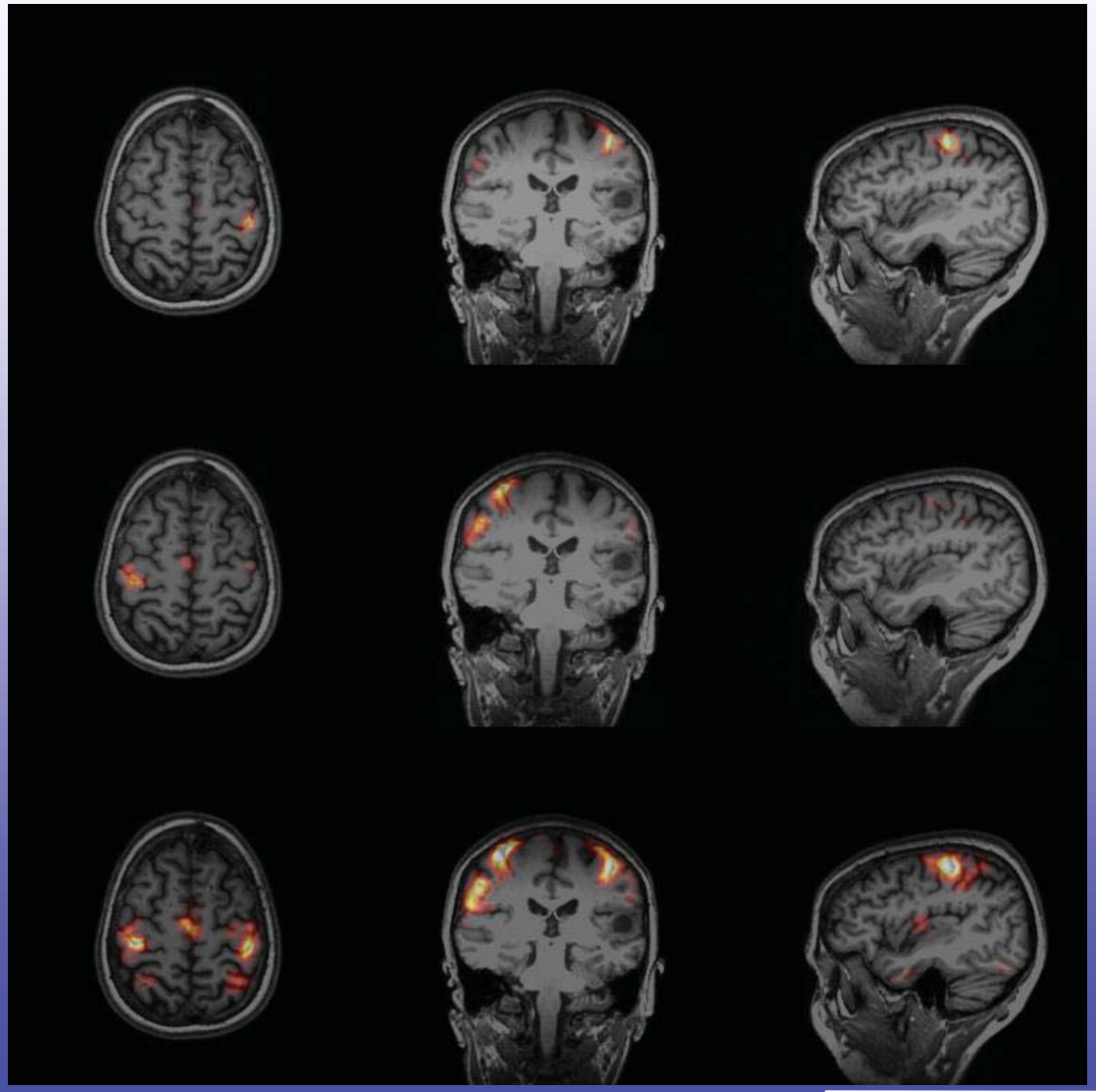




Neuroactivation by Finger Tapping

EPI-Study for 12 min

R

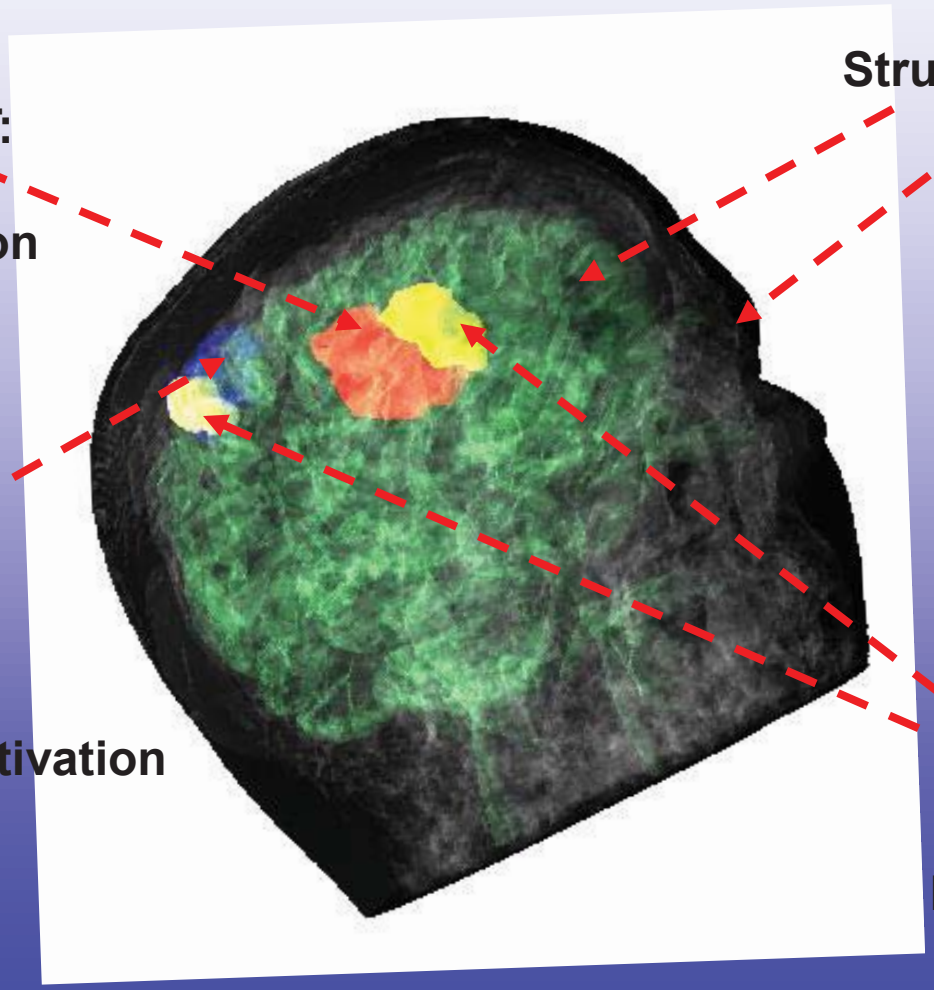


right

left

bi-manual

One-stop-shop Examination:
Identifying the Cortical Motor Area Affected by the Brain Tumor



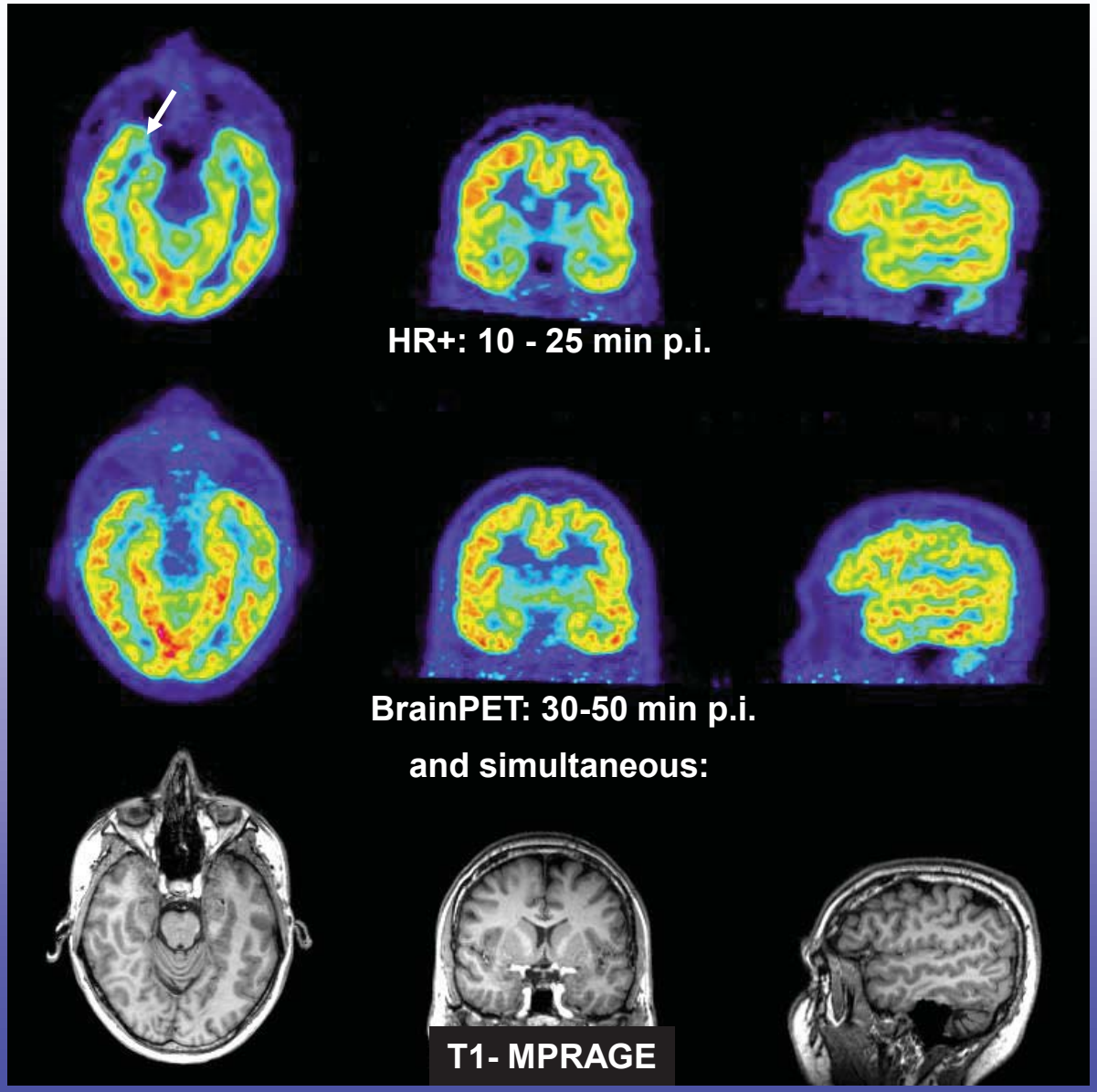
MPRAGE:
Structural MR Imaging

FET-PET:
Tumor-
Delineation

fMRI:
Right Hand Activation

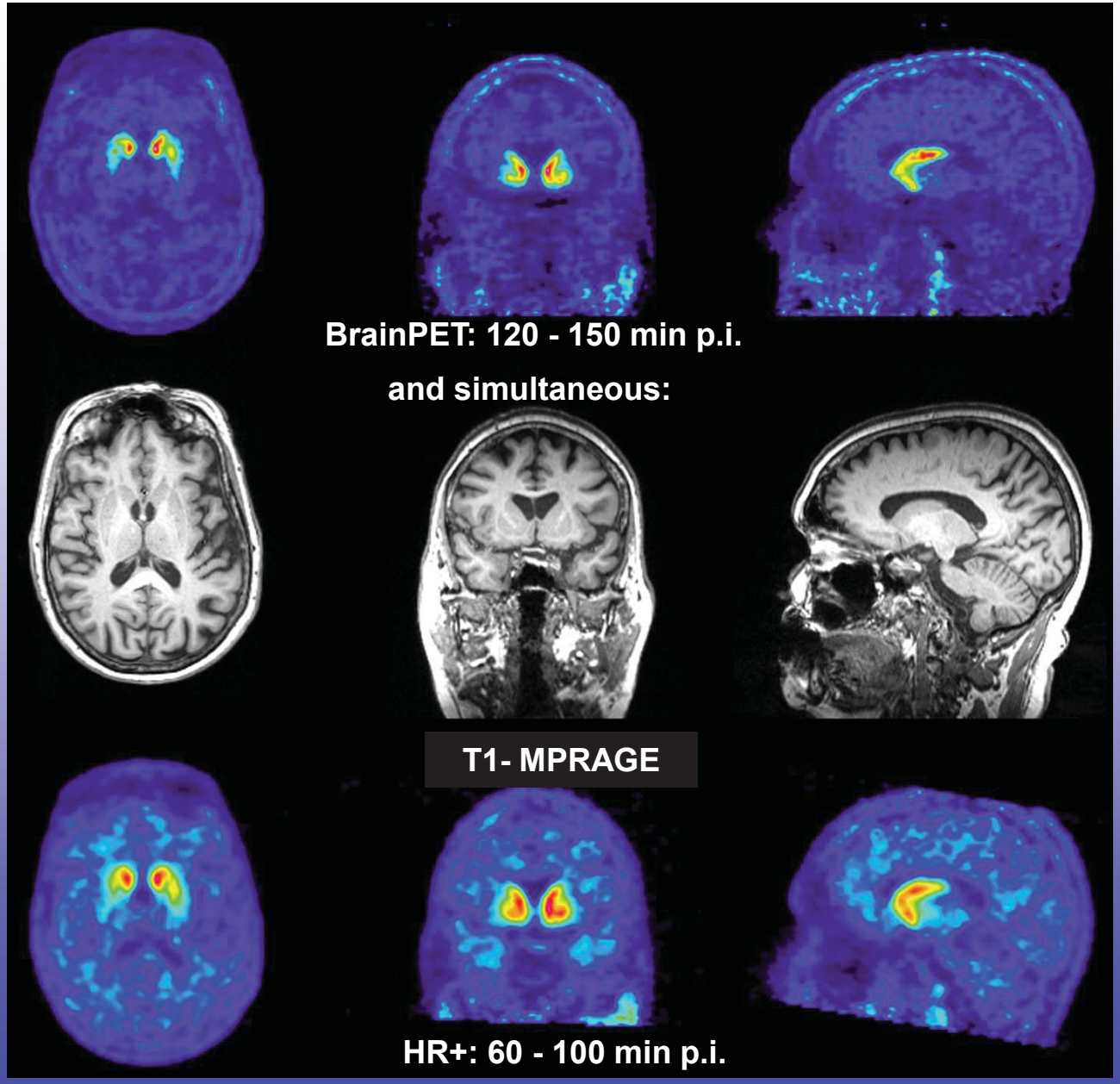
fMRI:
Left Hand Activation

MR-PET in a Patient with Epilepsy



PET after injection of the GABAnergic receptor ligand ^{11}C-flumazenil: Looking for the epileptical focus

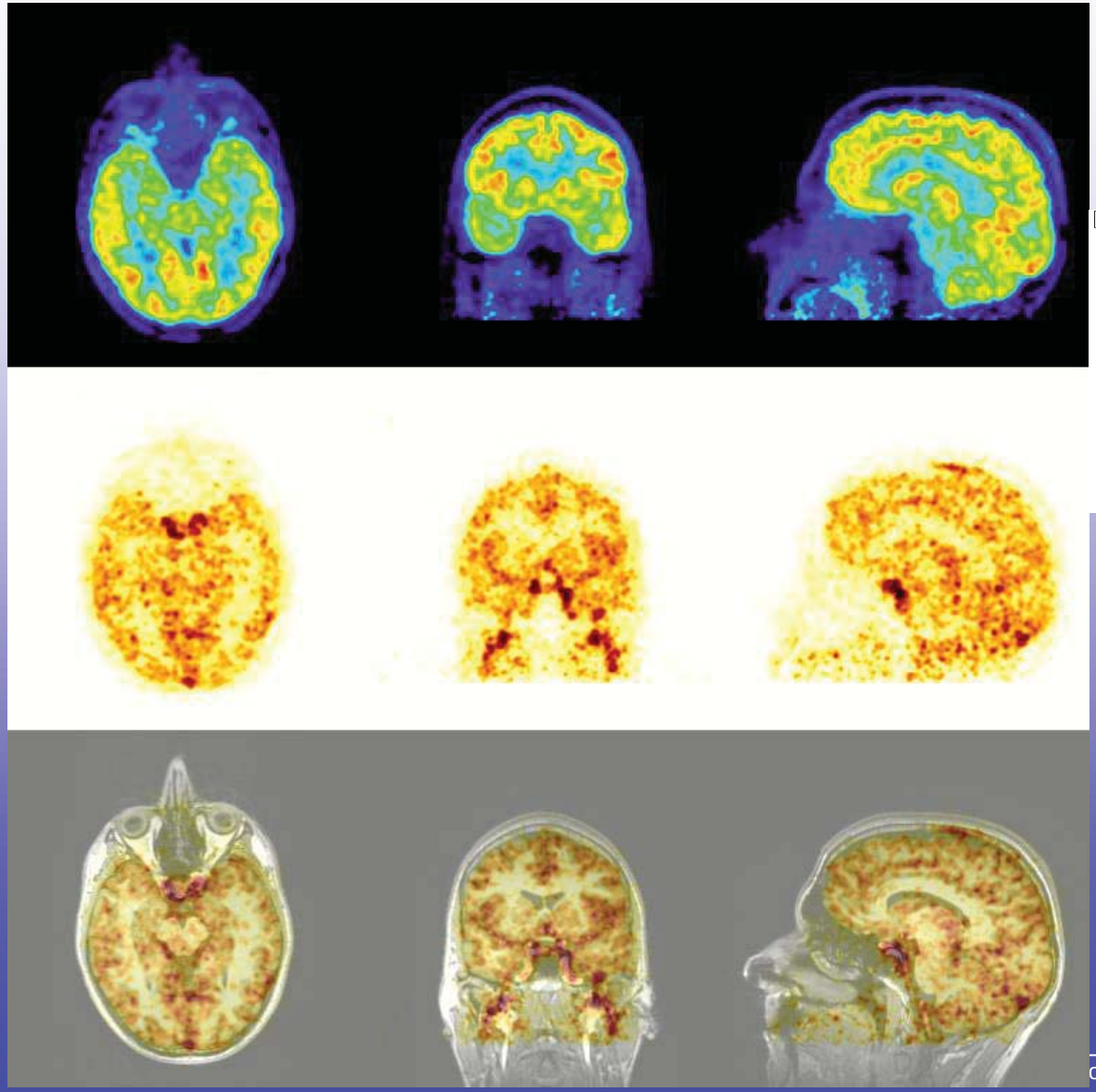
MR-PET in a Patient with Parkinson's Disease



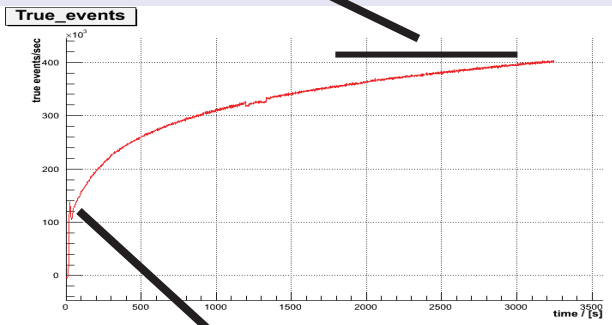
PET after injection of the dopaminergic transporter ligand ^{18}F-FP-CIT

Dynamic MR-FDGPET

Aim: to measure cerebral glucose consumption



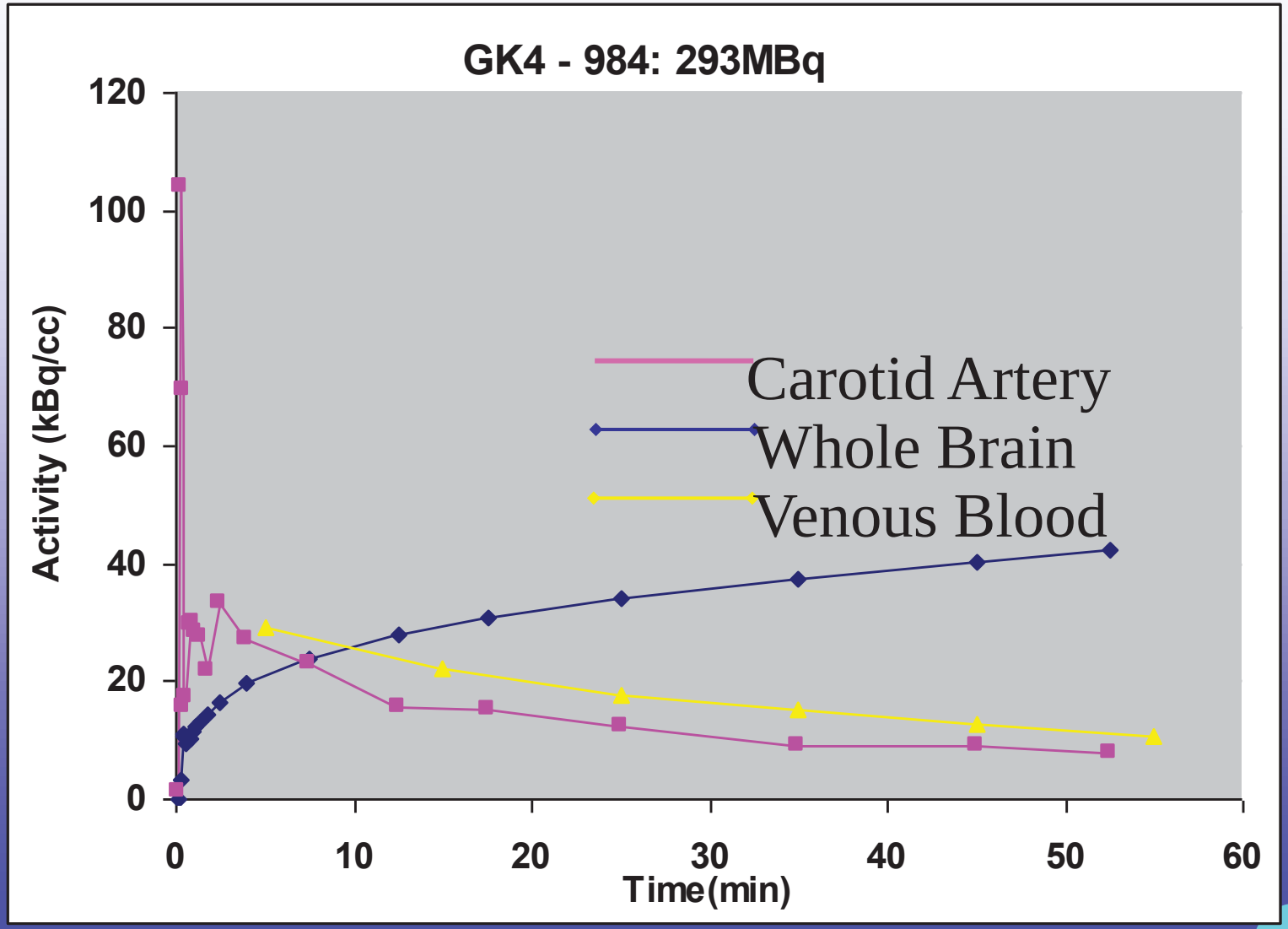
30-50 min p.i. FDG-PET reconstructed with Siemens OSEM3D



15 – 75 s after injection: Arterial phase

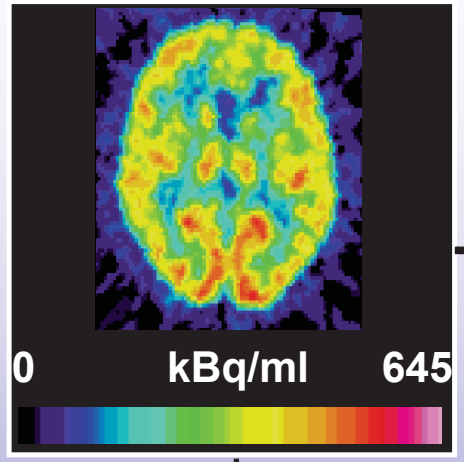
Arterial phase together with T1-MPRAGE

FDG- Dynamik

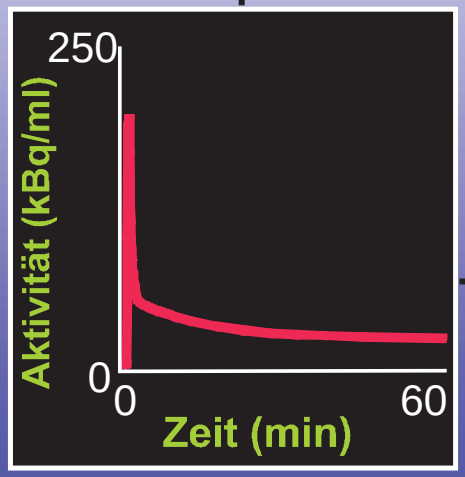

GK4 - 984: 293MBq
Activity (kBq/cc)
120
100
80
60
40
20
0
0
10
20
30
40
50
60
Time(min)
Carotid Artery
Whole Brain
Venous Blood

Measurement of Cerebral Glucose Consumption

Activity Image

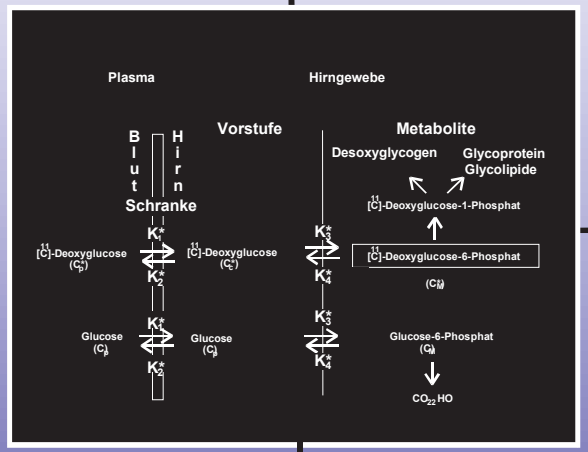


Cross-Calibration

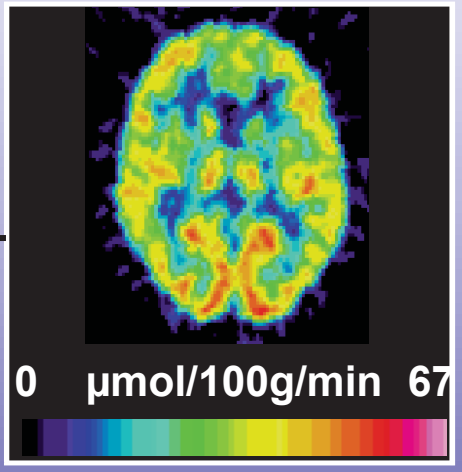


Blood Data

Deoxyglucose Model
(by Sokoloff, 1977)



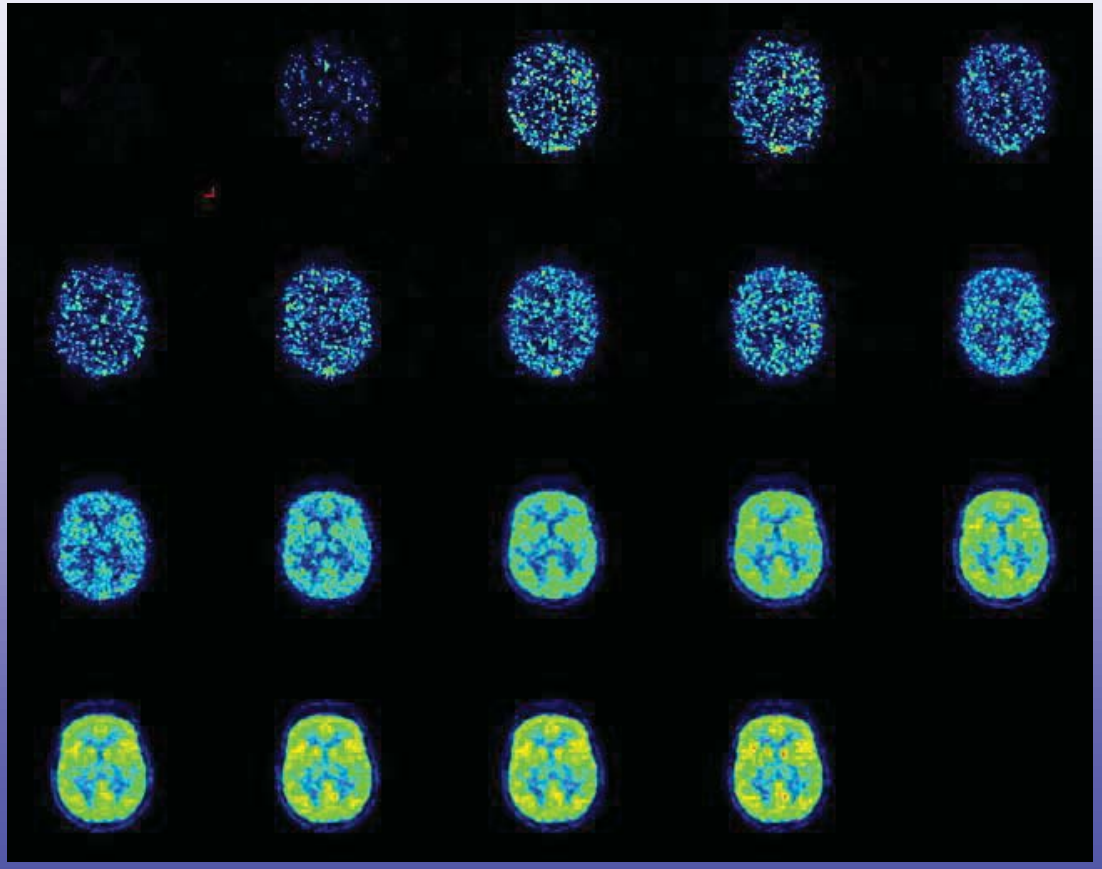
Glucose Consumption



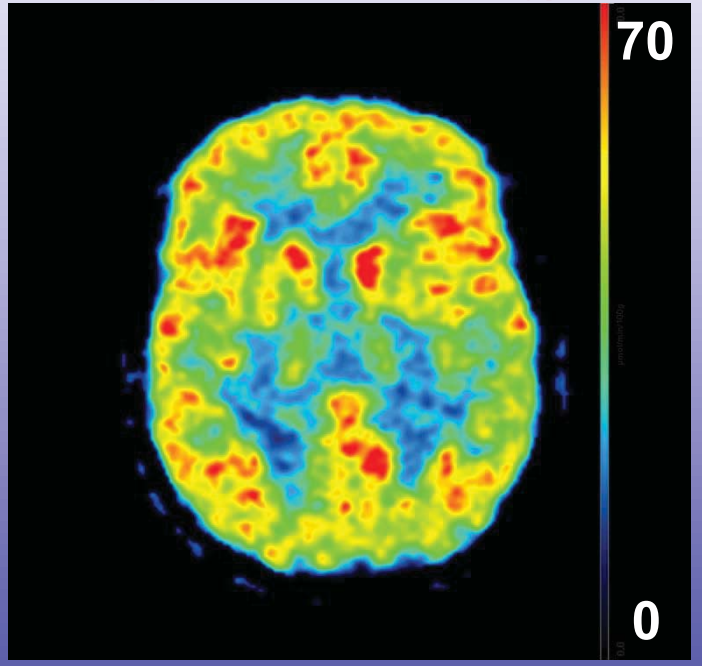
$$LCMRGlc = \frac{c_P\left[c_T(T) - K_1 e^{-(k_2+k_3)T}\int_0^T c_P^*(t)\bullet e^{(k_2+k_3)}dt\right]}{LC\left[\int_0^T c_P^*(t)dt - e^{-(k_2+k_3)T}\int_0^T c_P^*(t)\bullet e^{(k_2+k_3)}dt\right]}$$

Measurement of Cerebral Glucose Consumption without Blood Sampling

Activity Images = f(Time)



Metabolic Activity (mmol/min/100g)

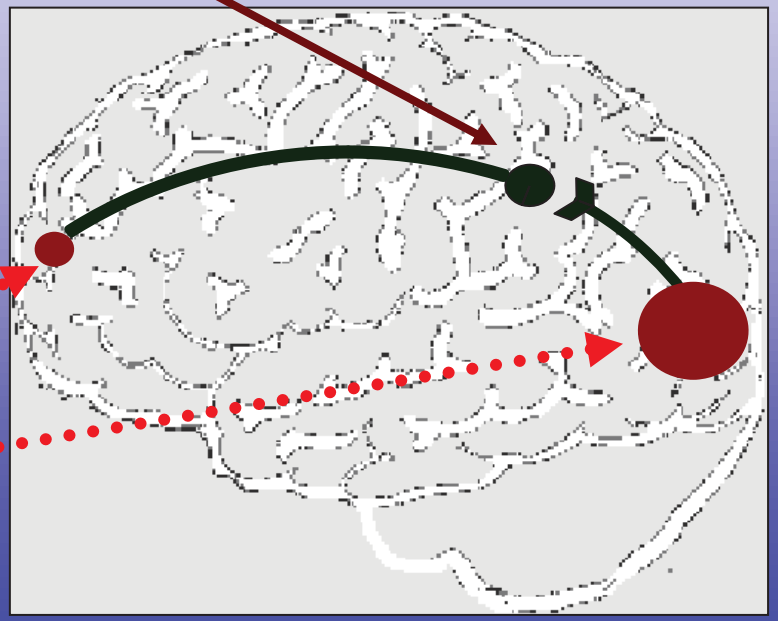


Research Applications

The Two Parts of Cerebral Communication

Chemical interface at the synapses modulated by internal neurotransmitters or drugs

Domain of PET

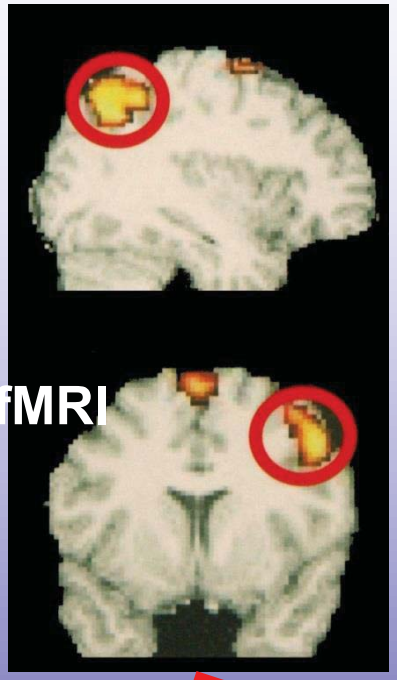


Centers of cerebral data processing

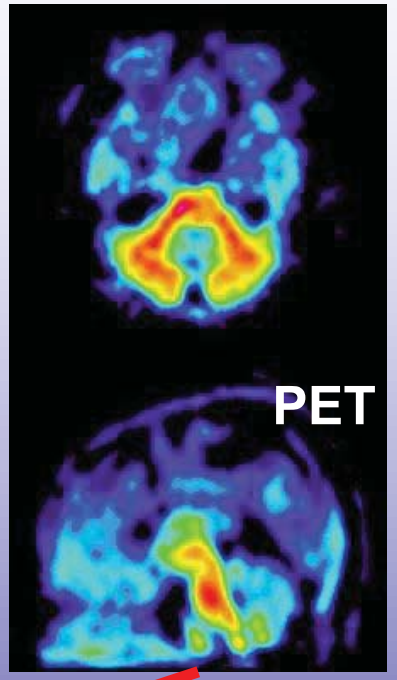
Domain of fMRI

fMRI and Receptor-PET with a Pharmaco-Challenge

Centers of increased alertness after 1mg nicotine



Thiel et al., 2005

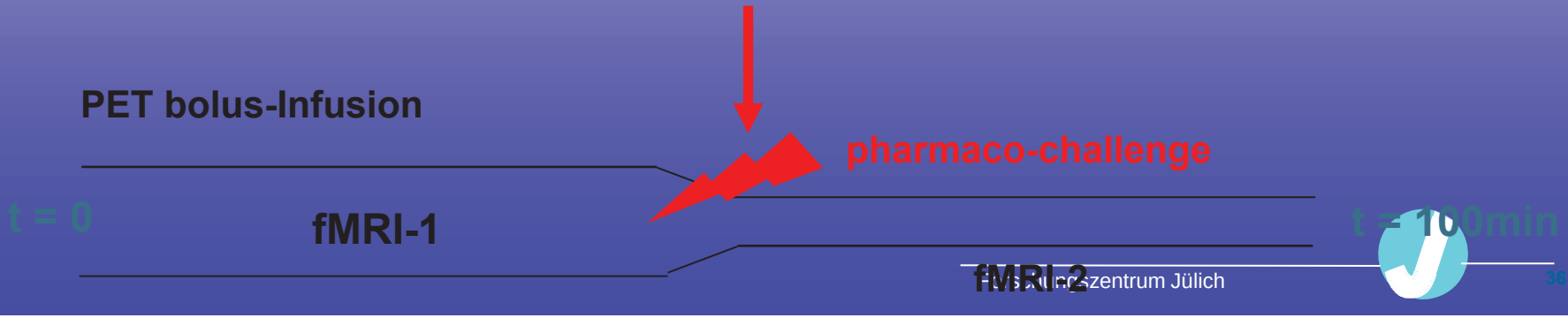


Distribution volume of [^{18}F]-2-A-85830:

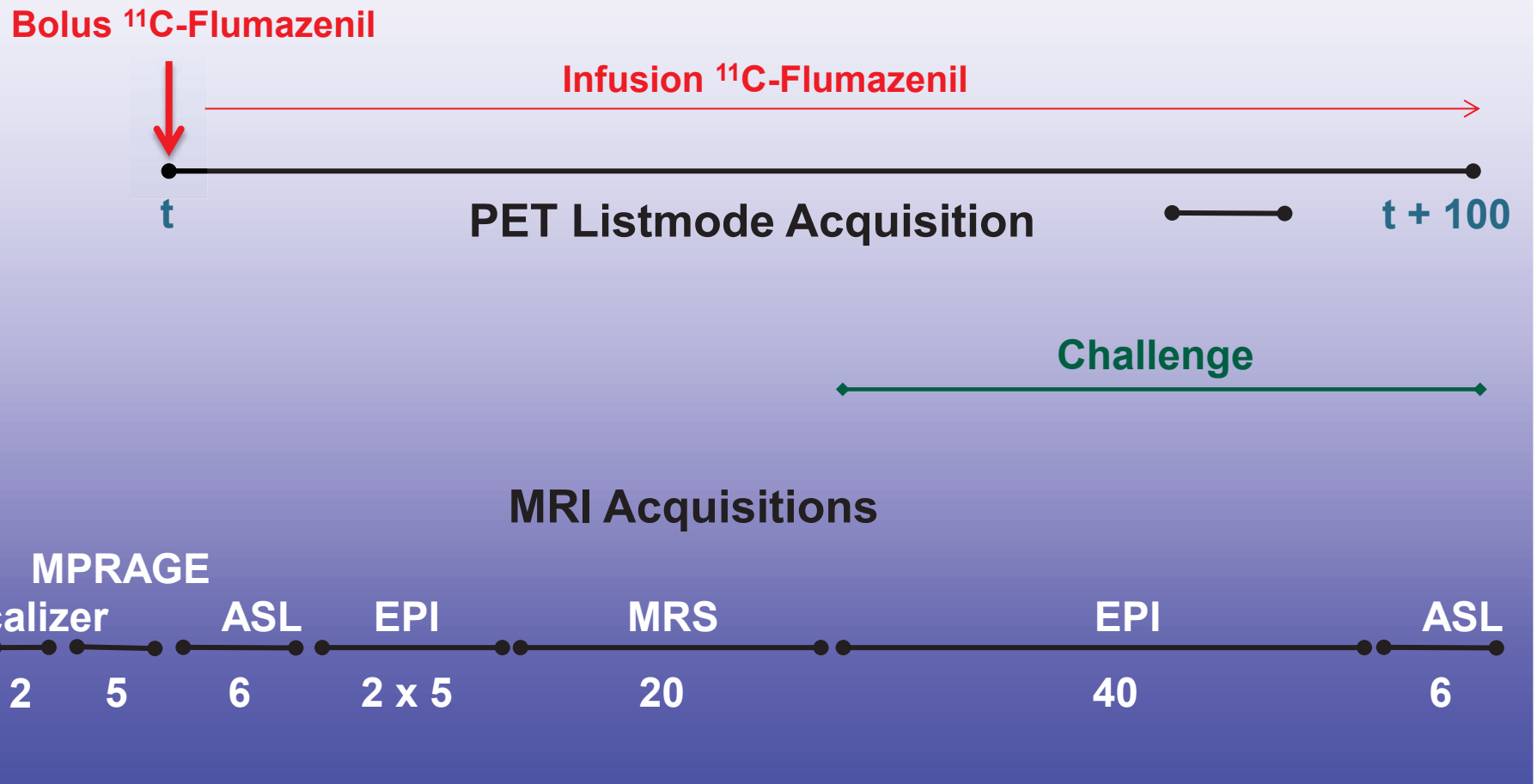
Smokers minus nosmokers

Herzog et al., 2006

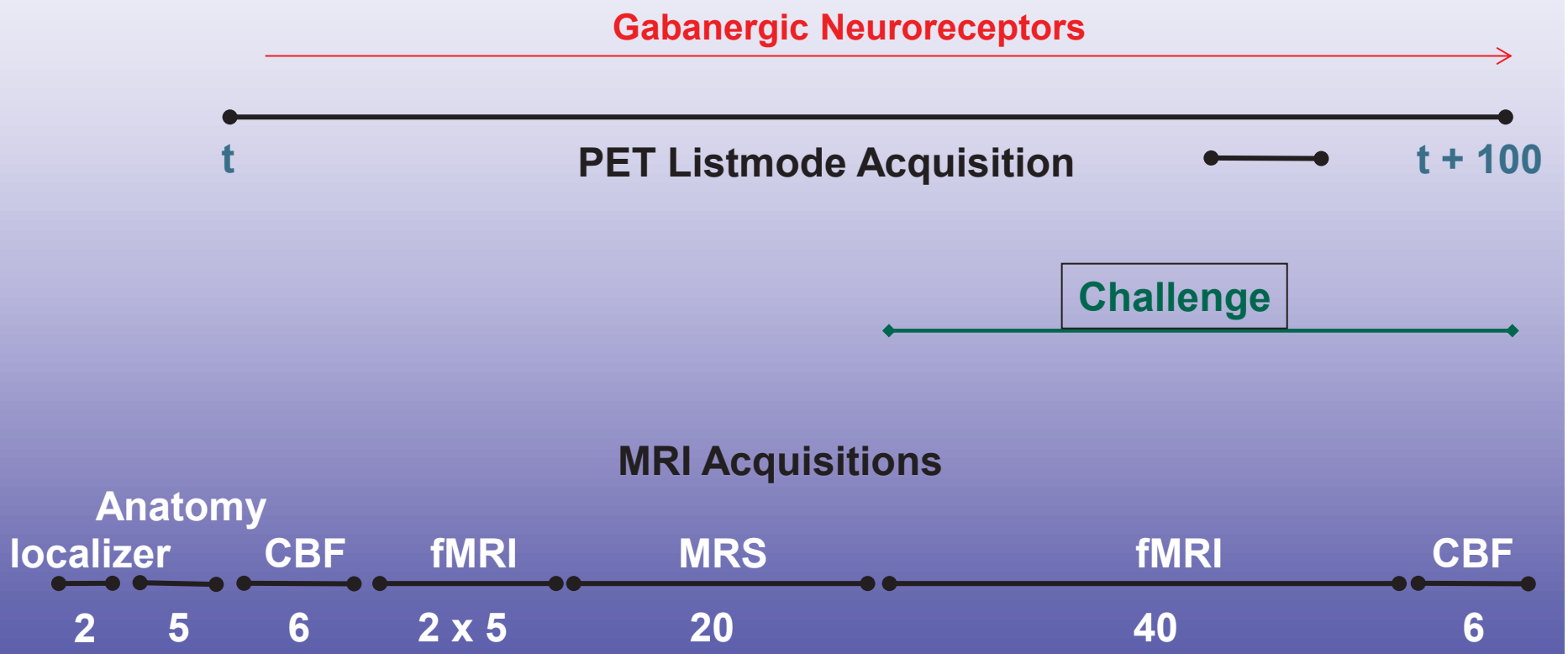
Now such studies can be combined with PET/MRI !!



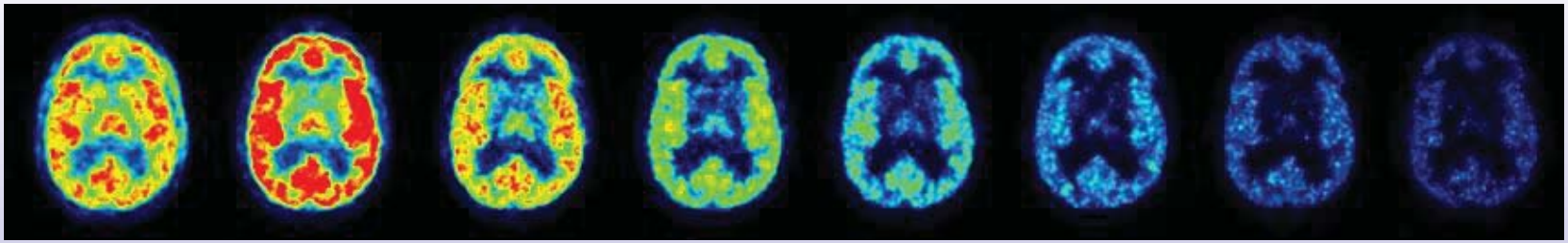
Timing of a Combined PET-MRI-fMRI Study



Timing of a Combined PET-MRI-fMRI Study



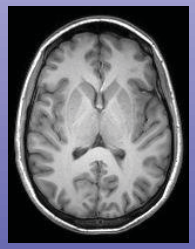
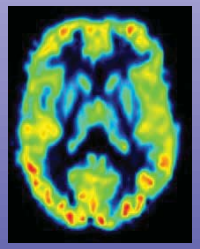
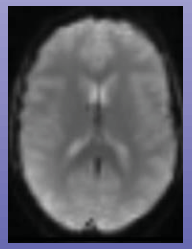
Combined PET-MRI-fMRI Study

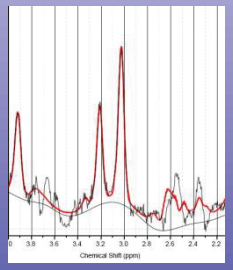
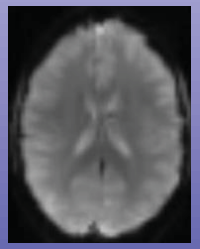
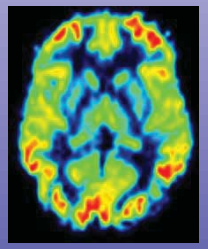


t Dynamics of ^{11}C-Flumazenil t + 100 min

Challenge

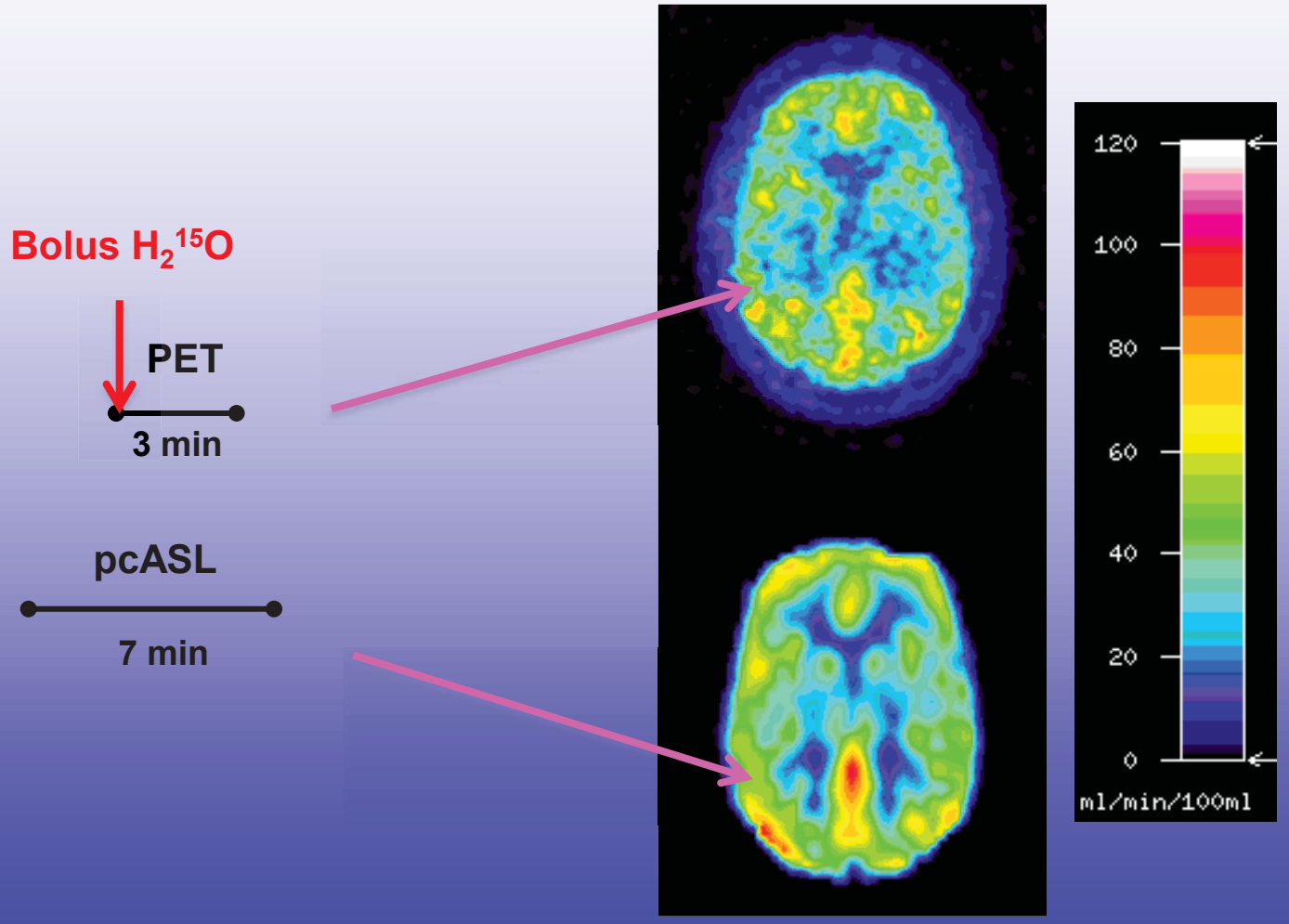
MRI Acquisitions

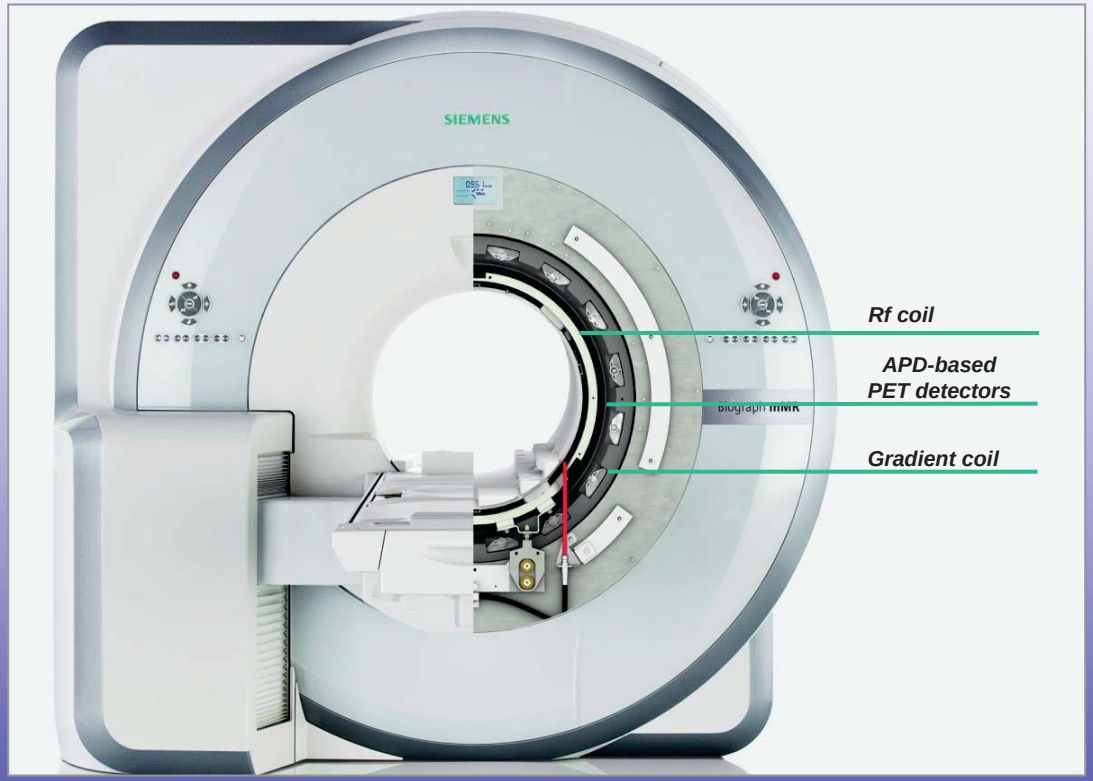




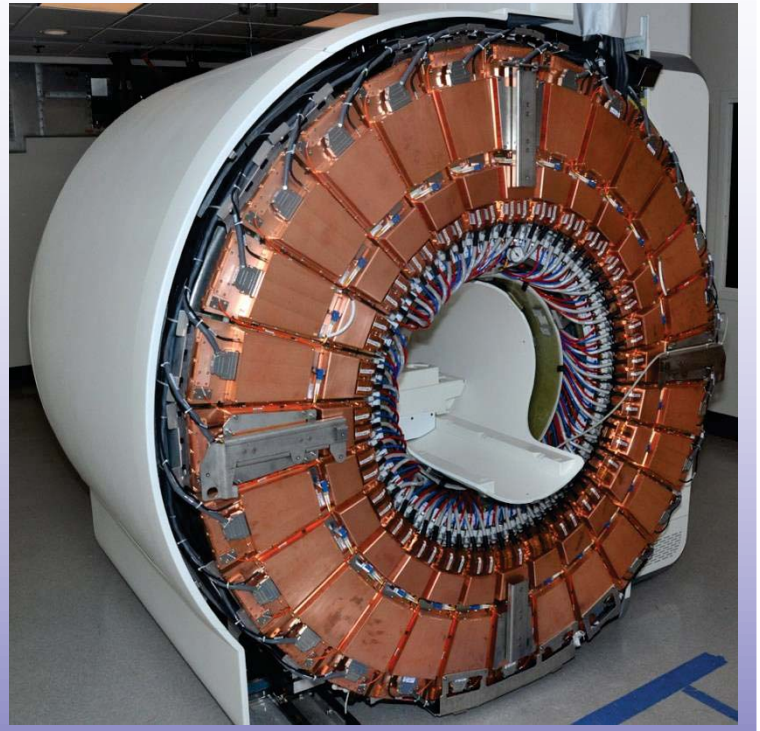
Anatomy CBF 2 x fMRI MRS fMRI CBF

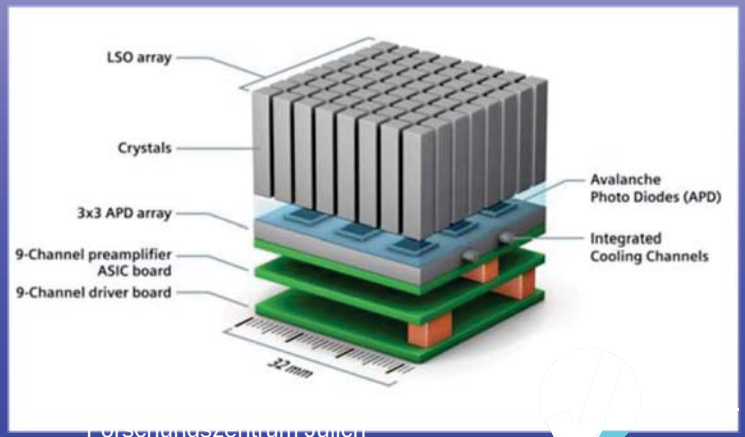
First Truly Simultaneous Comparison of CBF Assessed by ^{15}O-Water PET and ASL



Siemens Biograph mMR







Courtesy of Siemens,
S. Ziegler and C. Catana

Some Technical Parameters

Detector ring diameter	65.6 cm
Bore diameter	60 cm
Axial FOV	25.8 cm
Crystal	4 x 4 x 20 mm^3 LSO
Concidence window	6 ns
Energy window	430 – 610 keV

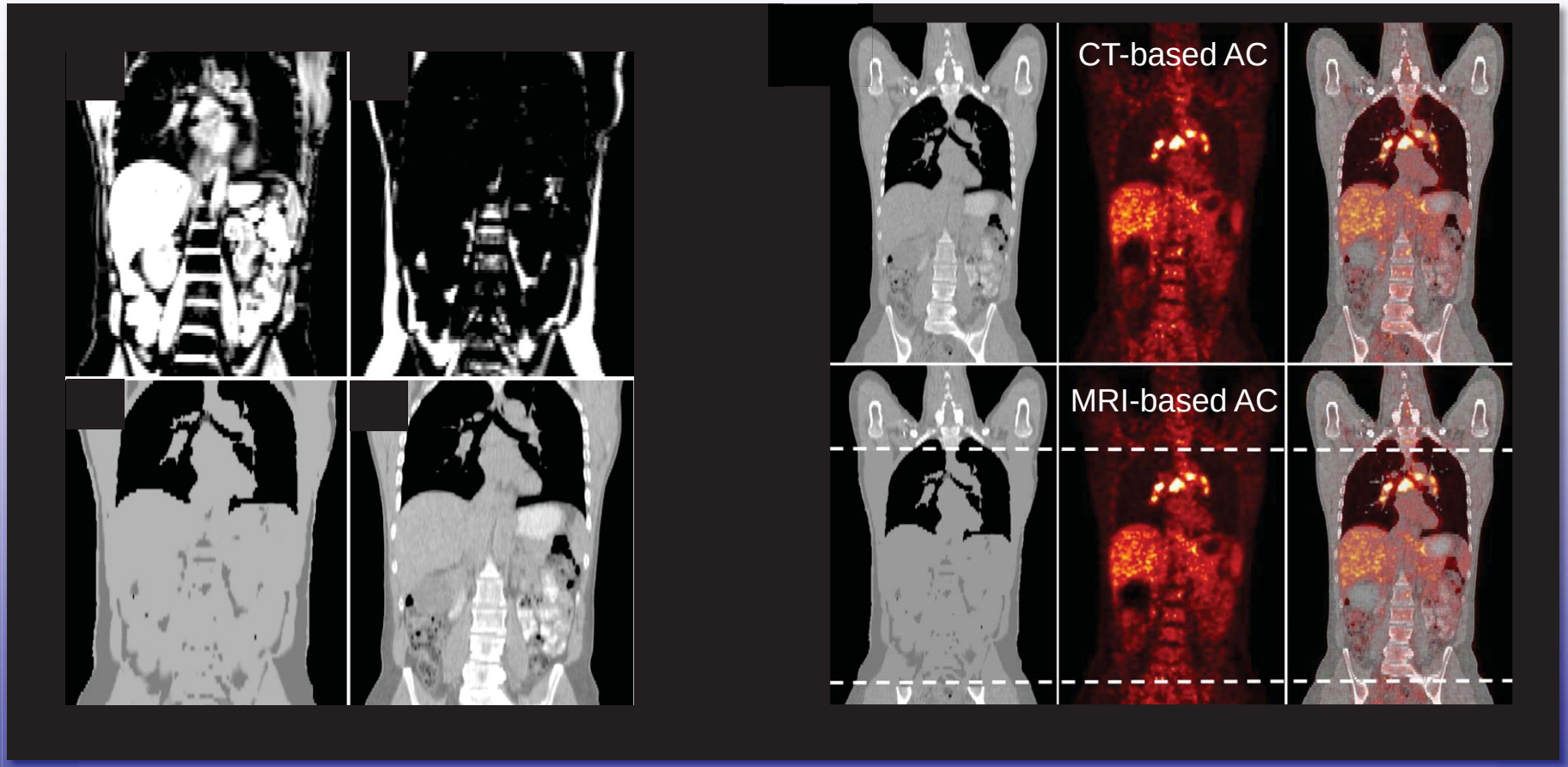
Resolution (FWHM, mm) [§] :		
r =	1 cm	10 cm
Tangential:	4.3	4.8
Radial	4.3	5.2
Z-Direction	4.3	66

Scatter fraction: 36.7%

[§] reconstructed with 3D-FRP

Courtesy of G. Delso and S. Ziegler

MR-Based AC: Dixon Imaging for Fat/Water Separation



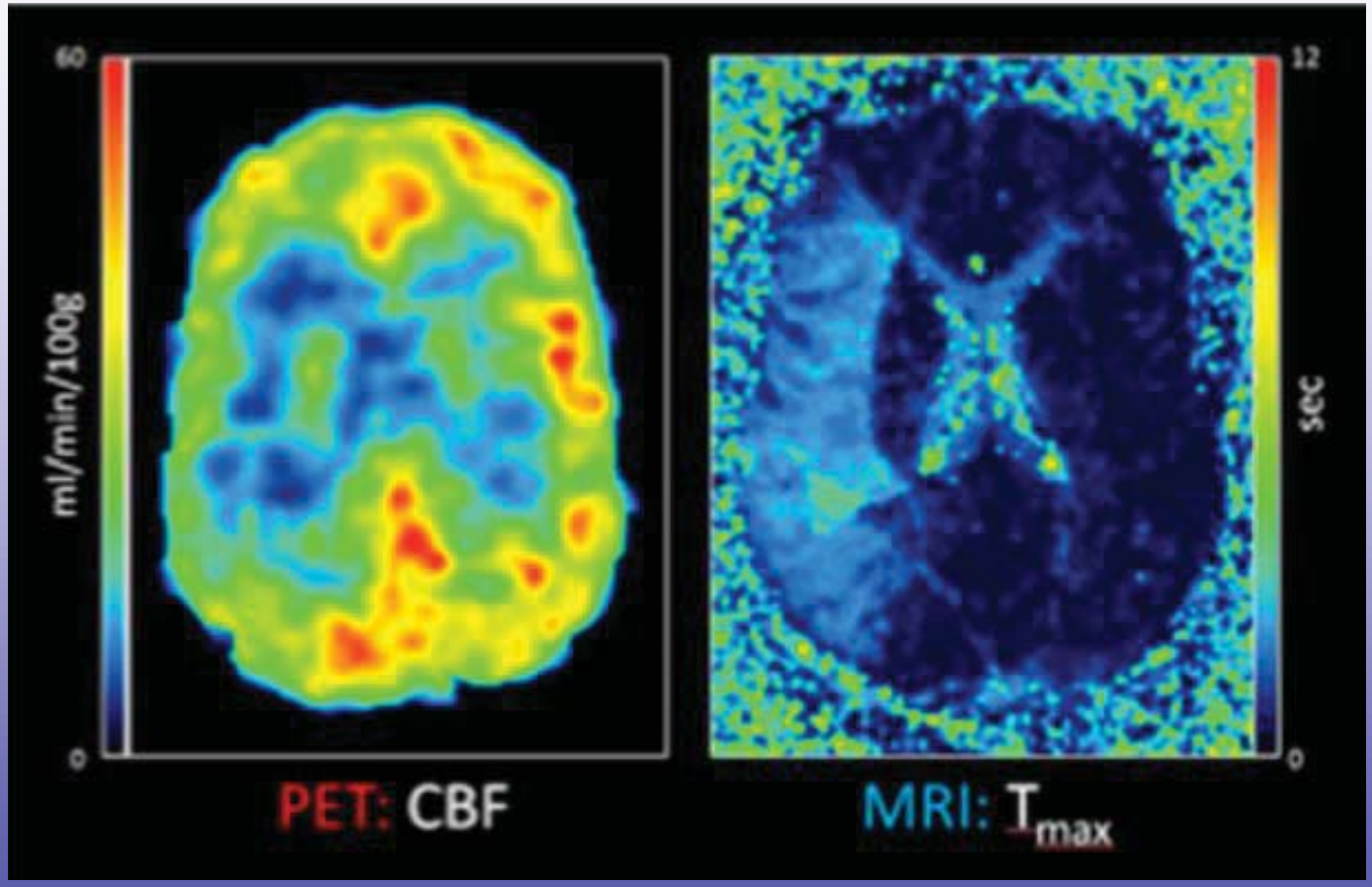
The method based on segmentation is fast and reliable.

Some bias (5-13%) for osseous lesions due to neglecting bone.

Martinez-Möller A et al., JNM 2009

^{15}O-Water-PET vs. PWI-MRI

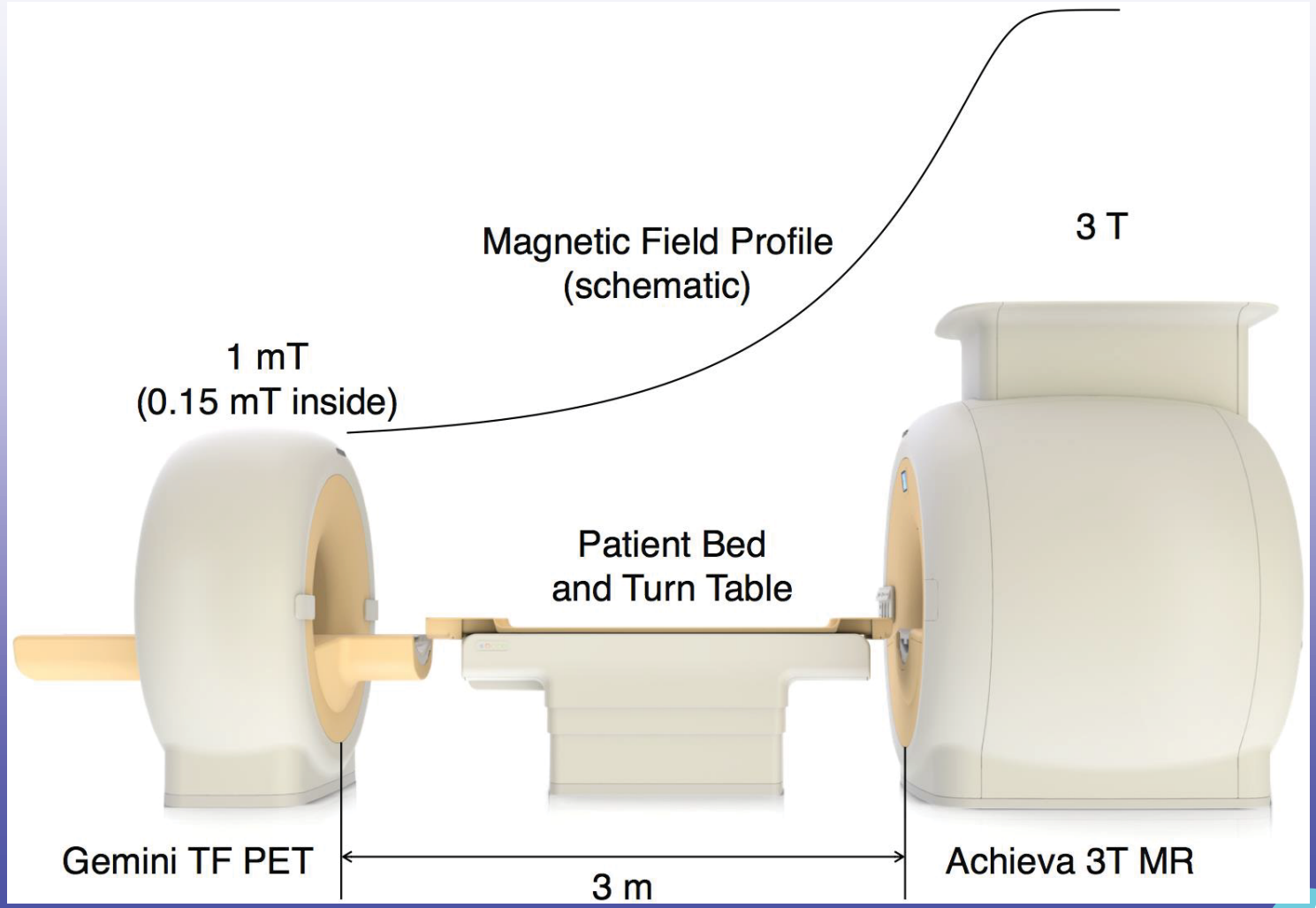
in Acute Ischemic Stroke



Courtesy of H. Barthel

Mol Imaging Biol (2013)
DOI: 10.1007/s11307-013-0623-1

Ingenuity TF PET/MRI



Some Technical Parameters

Detector ring diameter	90.3 cm
Bore diameter	60 cm (PET 70.7 cm)
Axial FOV	18.0 cm
Crystal	4 x 4 x 22 mm^3 LYSO
Concidence window	6 ns
Energy window	460 – 665 keV
TOF capability	

Resolution (FWHM, mm) [§] :

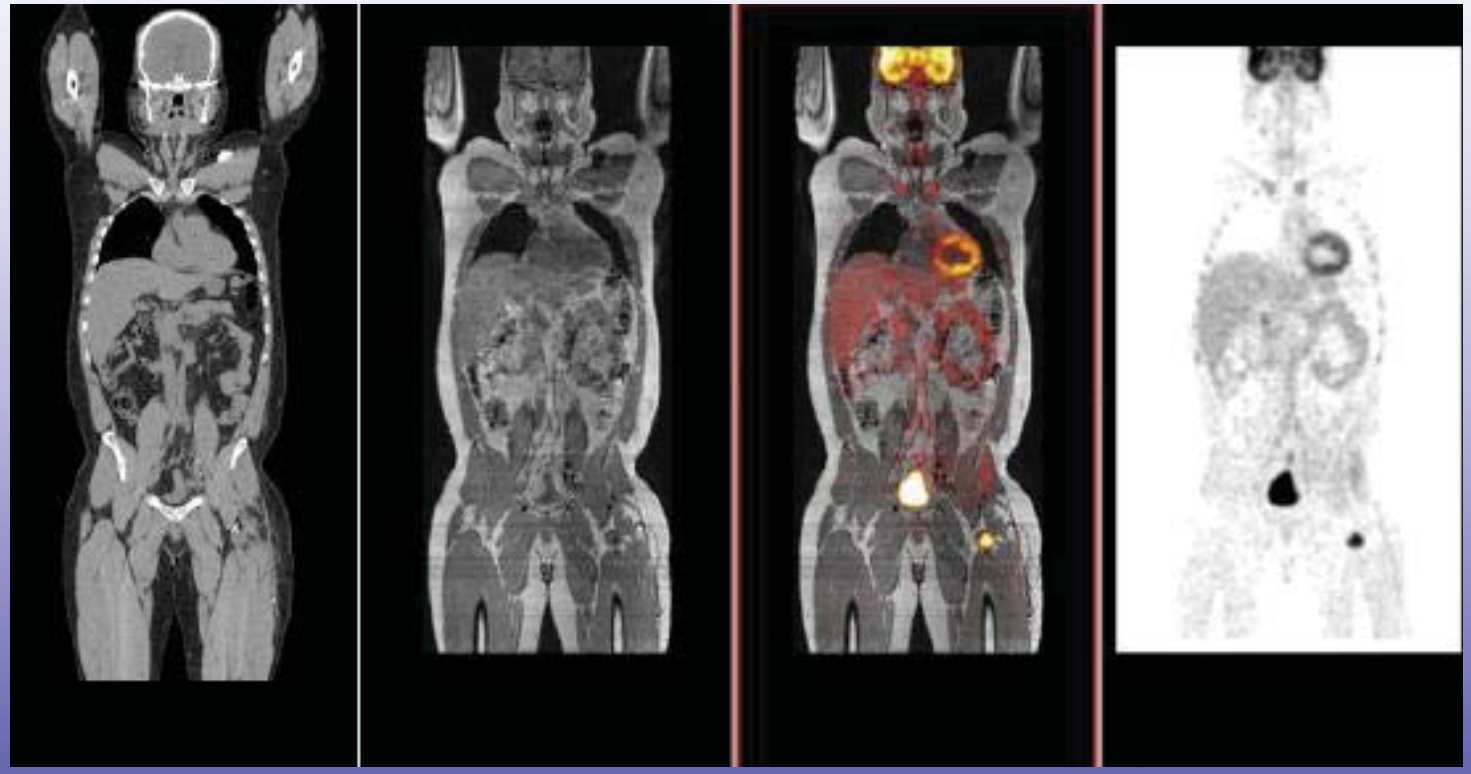
r =	1 cm	10 cm
Tangential:	4.7	5.3
Radial	4.7	5.0
Z-Direction	4.6	5.0

Scatter fraction: 26% - 35%

[§] reconstructed with 3D-FRP

Zaidi H, Phys Med Biol, 2011

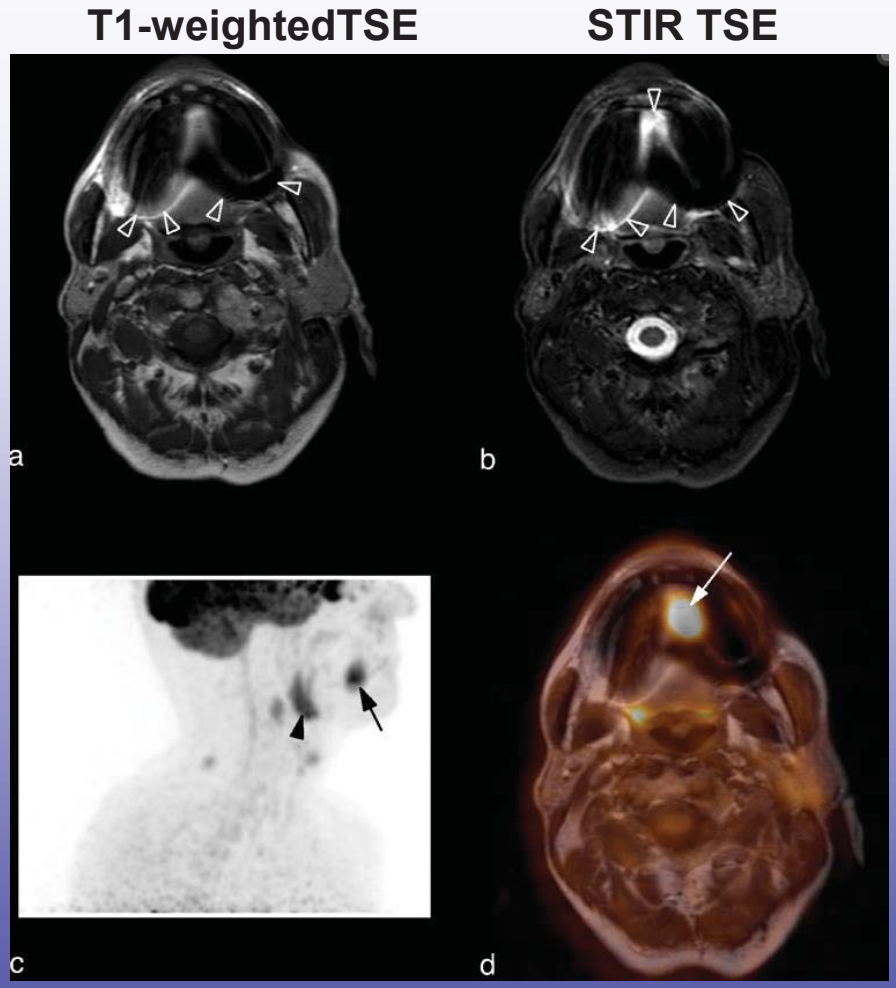
CT and PET/MR in a Patient with Ewing Sarkoma



CT MR PET/MR PET

Courtesy of O. Ratib, 2nd Juelich MR-PET Workshop 2010

Patient with Head/Neck Cancer



I. Platzek et al., EJNMMI 2013

Multiparametric Imaging

MR and MRS

Drug concentration

Connectivity

Morphology

Perfusion

Atrophy

Magnetization transfer

Metabolites

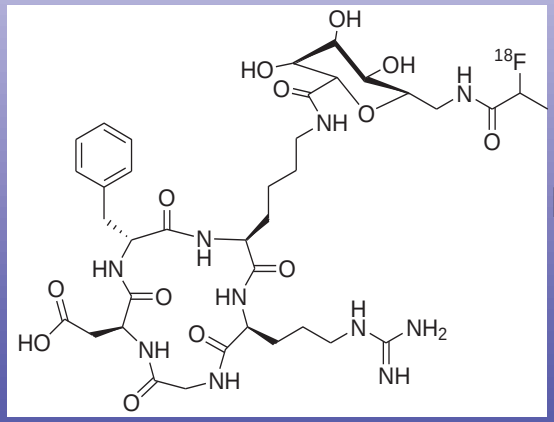
pH

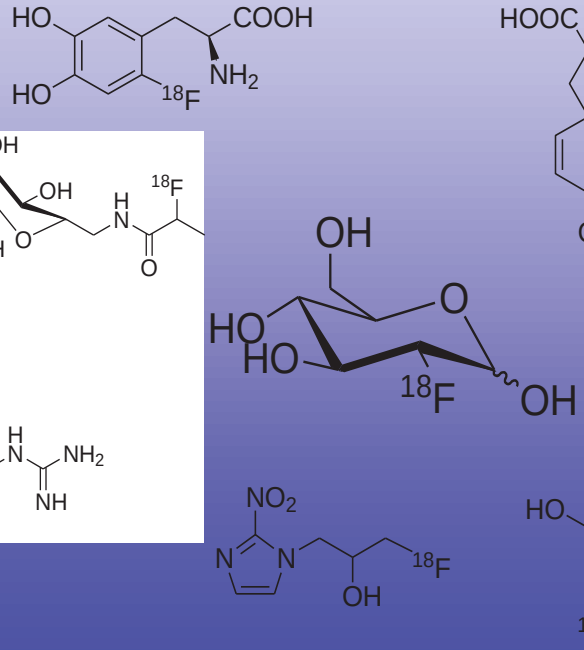
Diffusion

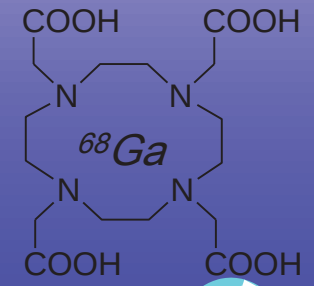
Cell labelling

Relaxometry

PET







Courtesy of T. Kuwert @ 1st Juelich MR-PET Workshop 2008

Thank you

for

your attention