The Abdus Salam
International Centre
for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2484-14

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

30 September - 4 October, 2013

Molecular Imaging Part II: PET

H. Herzog

Institute of Neuroscience and Medicine - 4 Forschungszentrum Juelich
Germany

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Molecular Imaging Part II:

PET

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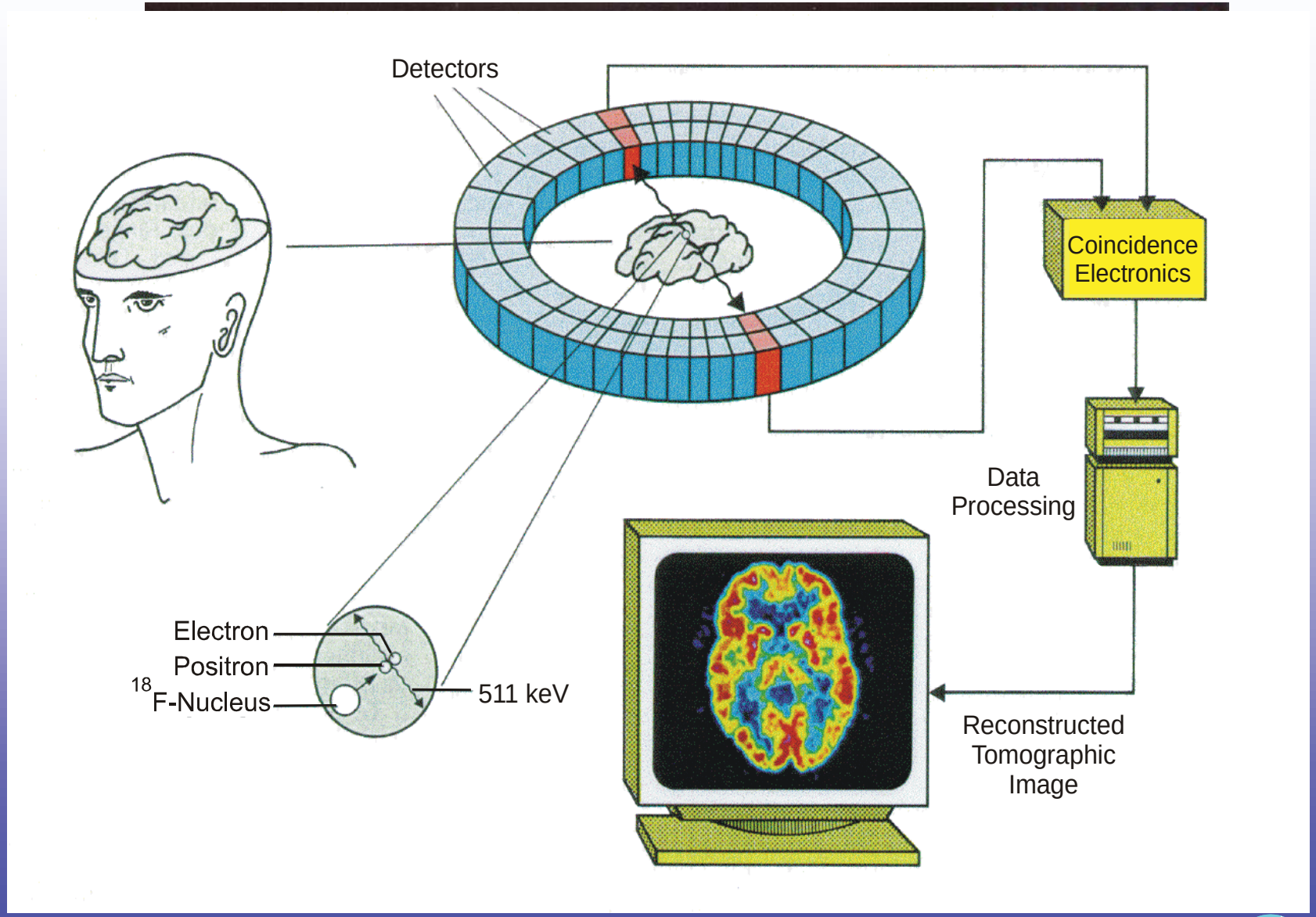
Basics of PET Physics

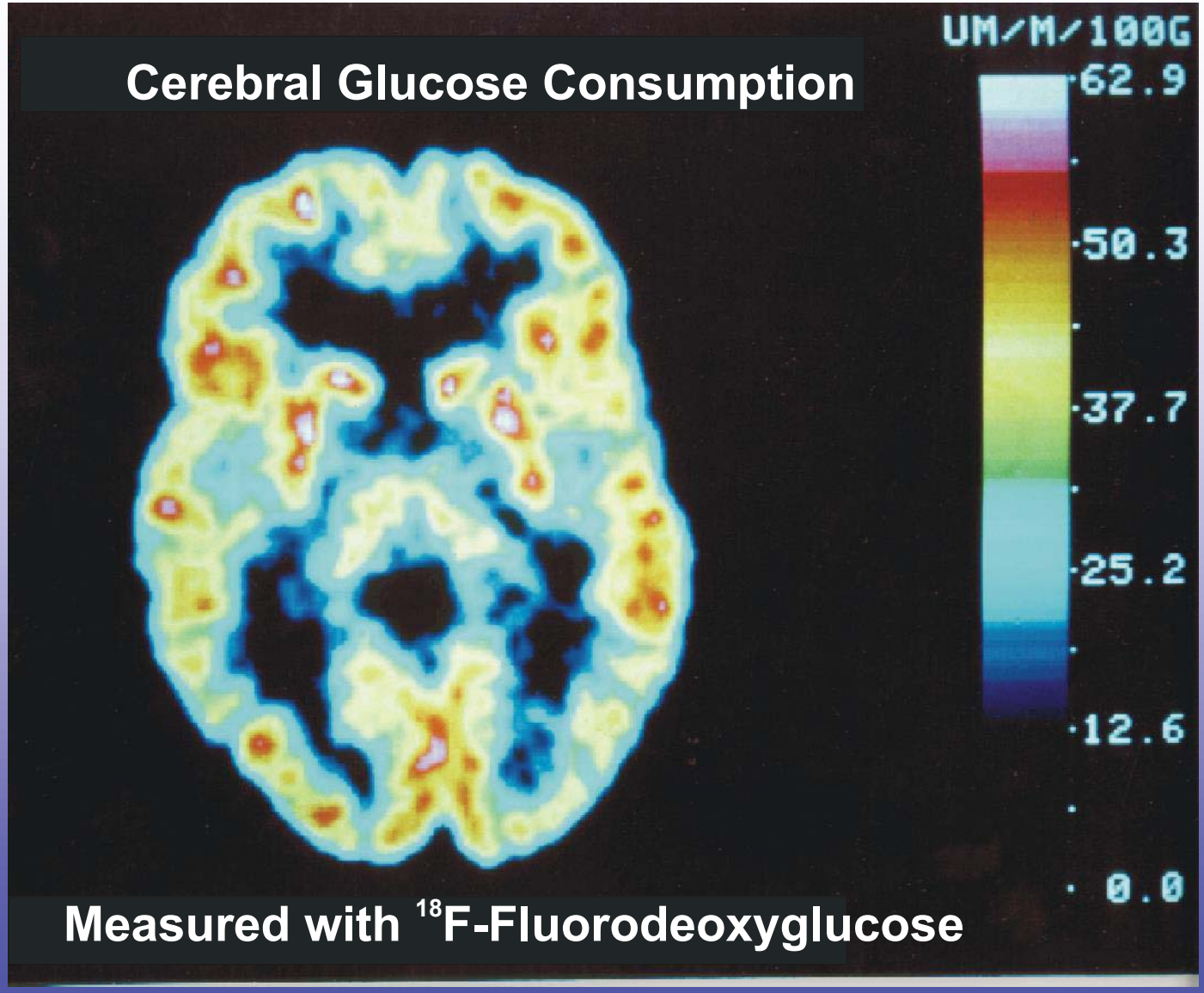
Nuclear Medicine

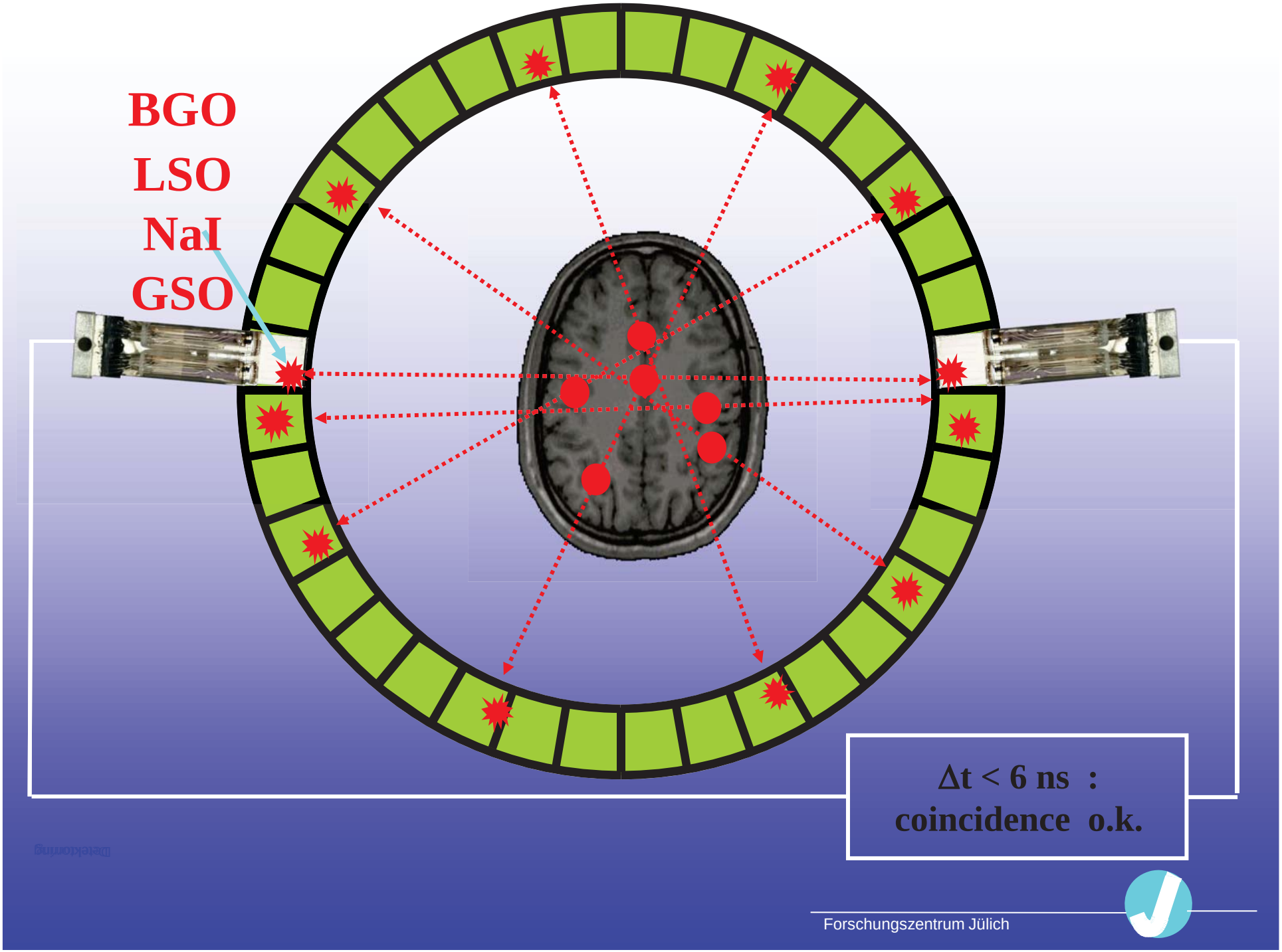
- Planar Scintigraphy:
  Imaging of Metabolism
- SPECT(omography):
  same + spatial localisation
- PET(omography)
  same + quantitative

PET: From the Positron to the Quantitative Image

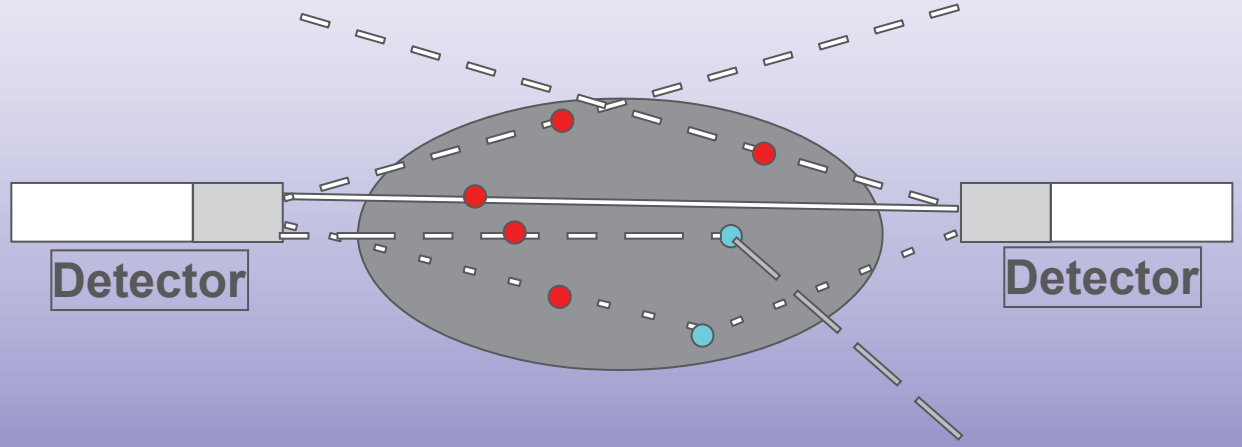


PET: From the Positron to the Quantitative Image




BGO
LSO
NaI
GSO
Δt < 6 ns :
coincidence o.k.

Interactions of 511 keV Photons



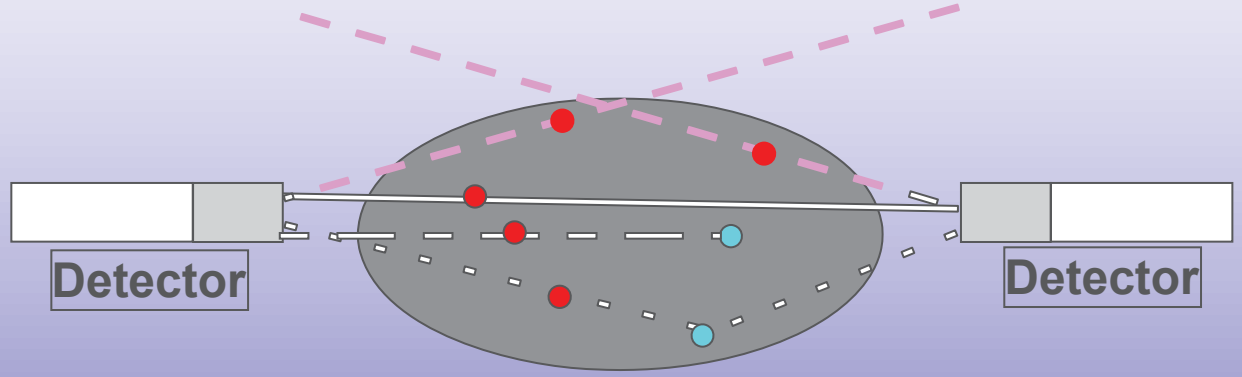
true coincidence

random coincidence

scattered coincidence

absorbed coincidence

Interactions of 511 keV Photons



true coincidence

random coincidence

scattered coincidence

absorbed coincidence

Random Coincidences

Korrektur-Verfahren:

- **Indirect - by calculation:**

  R (random coincidences) $= 2 \tau S(\text{ingles})_i \; S_j$

  τ (coinizidence window) = 12 ns (BGO-Scanner)

- **Direct - electronic:**

  Delayed window - Technique:

  Each count measured by the delayed technique is estimated as random and subtracted from the measuered coinicidences.

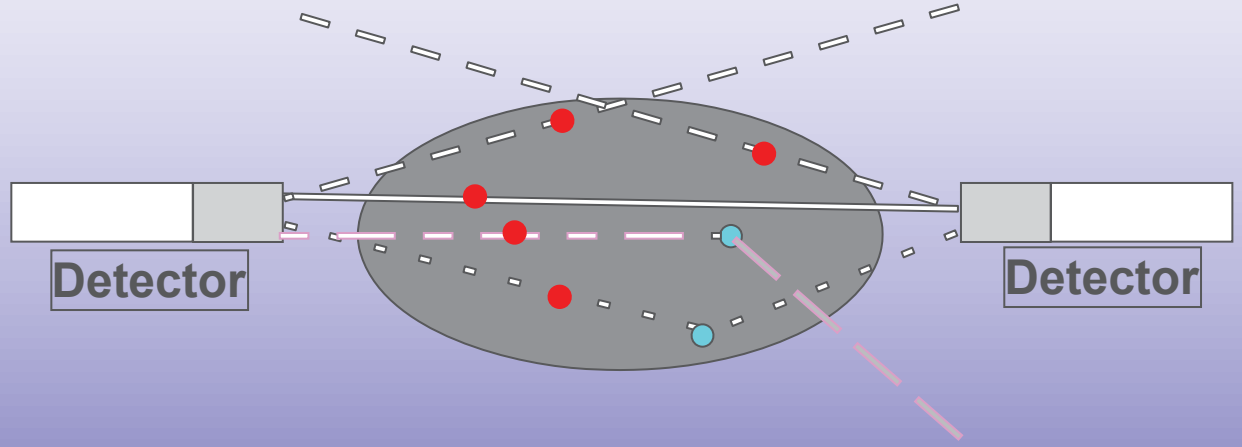
Scintillation Crystals for PET

	NaJ	BaF_2	BGO	LSO	LuAP
Eff. Atom number	50	54	74	59	65
Density	3,7	4,9	7,1	7,4	8,3
Decay constant (ns)	230	630/0,6	300	40	18
Rel. Light yield (%)	100	5/16	8-12	75	25?

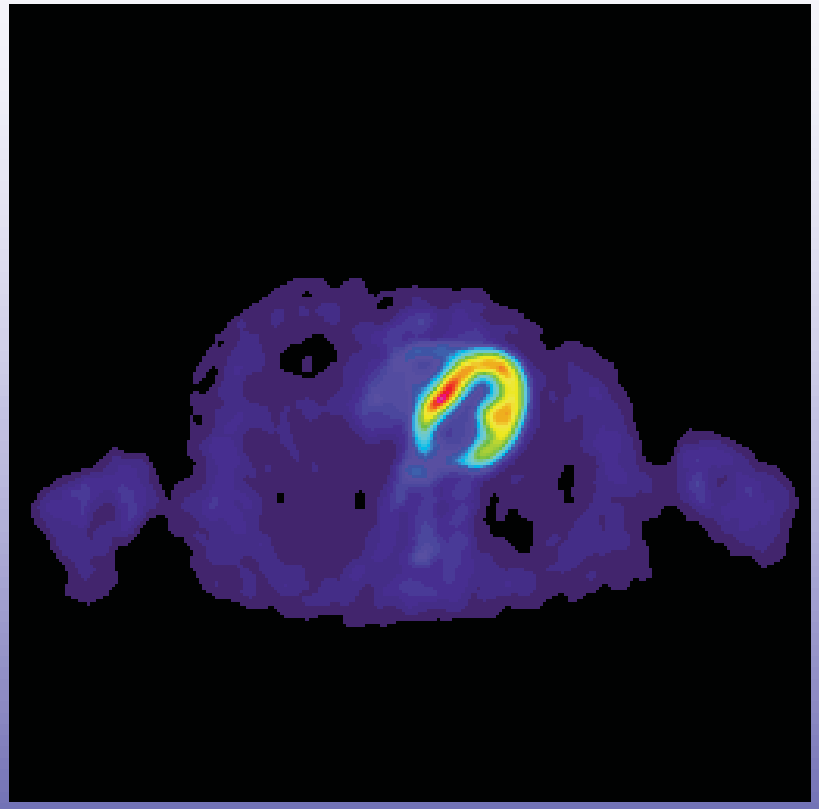
Shorter decay time → ⟶ shorter coincidence window

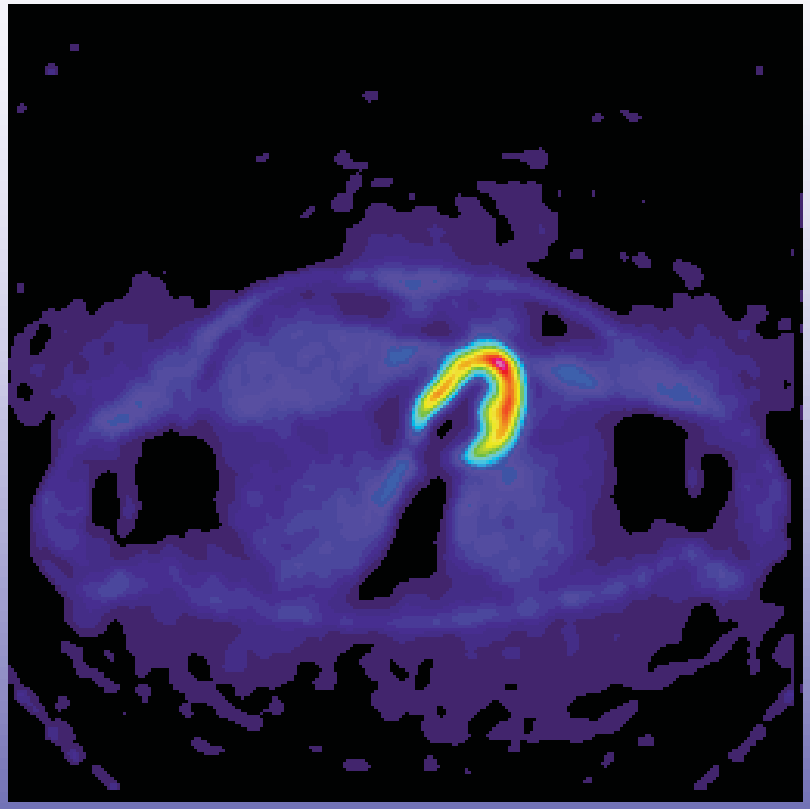
6ns

Interactions of 511 keV Photons



Heart Study with ^{18}FDG





with attenuation correction

without

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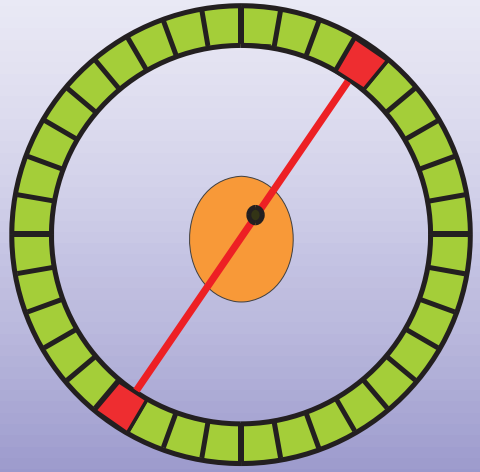
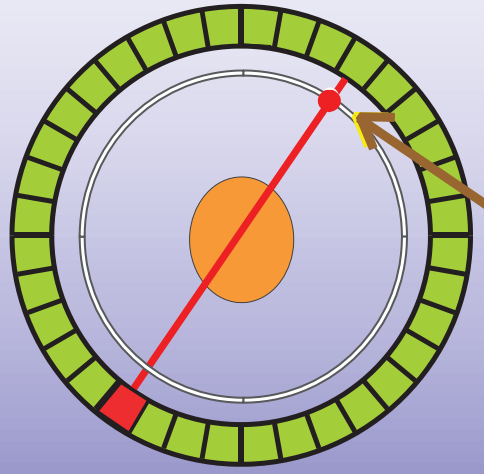
Herz mit/ohne Schwächungskorektur

The combination of emission and transmission measurement allows the quantification of radioactivity within the body

Emissionsmessung



Transmissionsmessung



the detector measures:

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

the detector measures:

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

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

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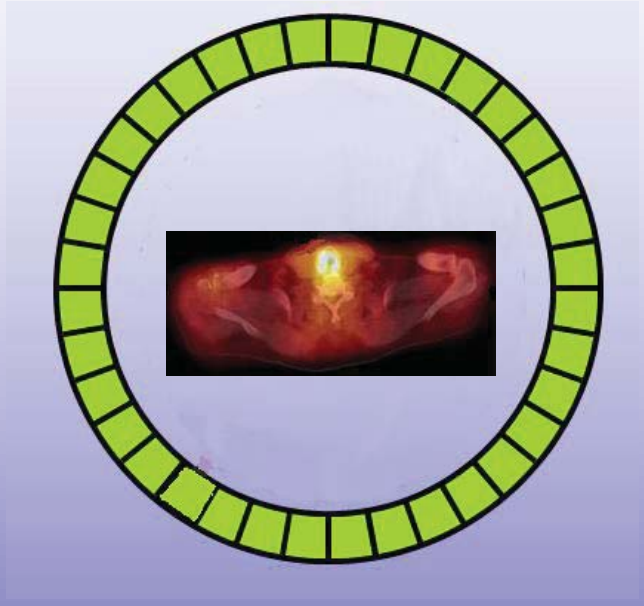
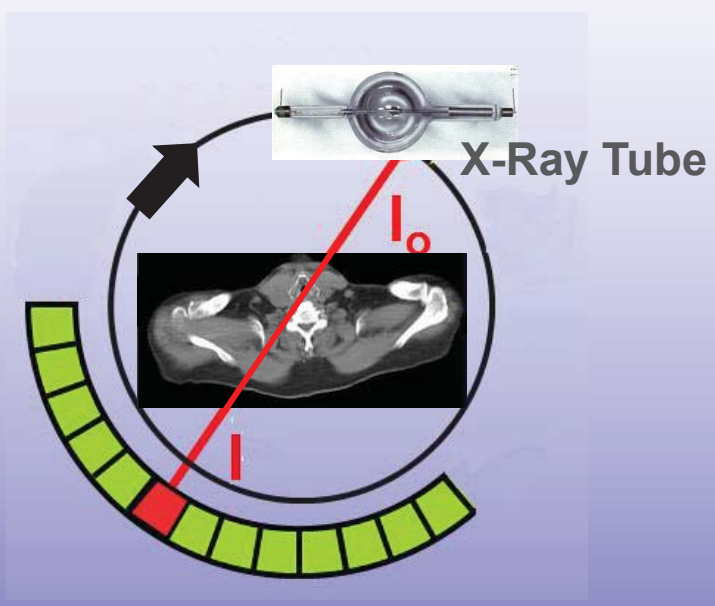
Calculation of Attenuation Map Using a Transmission Scan by CT

Emission Scan



CT Scan



$$\ln \frac{I_o}{I} = \int \mu(x,y)\, dl, \quad \Rightarrow \quad \text{CT: Image of Hounsfield Units (HU)}$$

$$\text{HU} = \mu\,(\text{X-Ray}) \Rightarrow \mu\,(511\ \text{keV})$$

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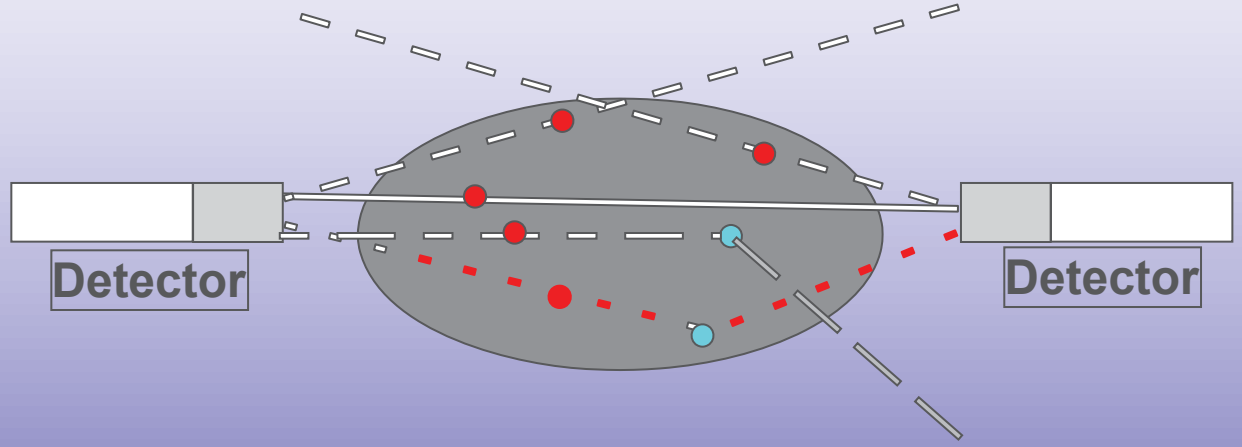
Interactions of 511 keV Photons



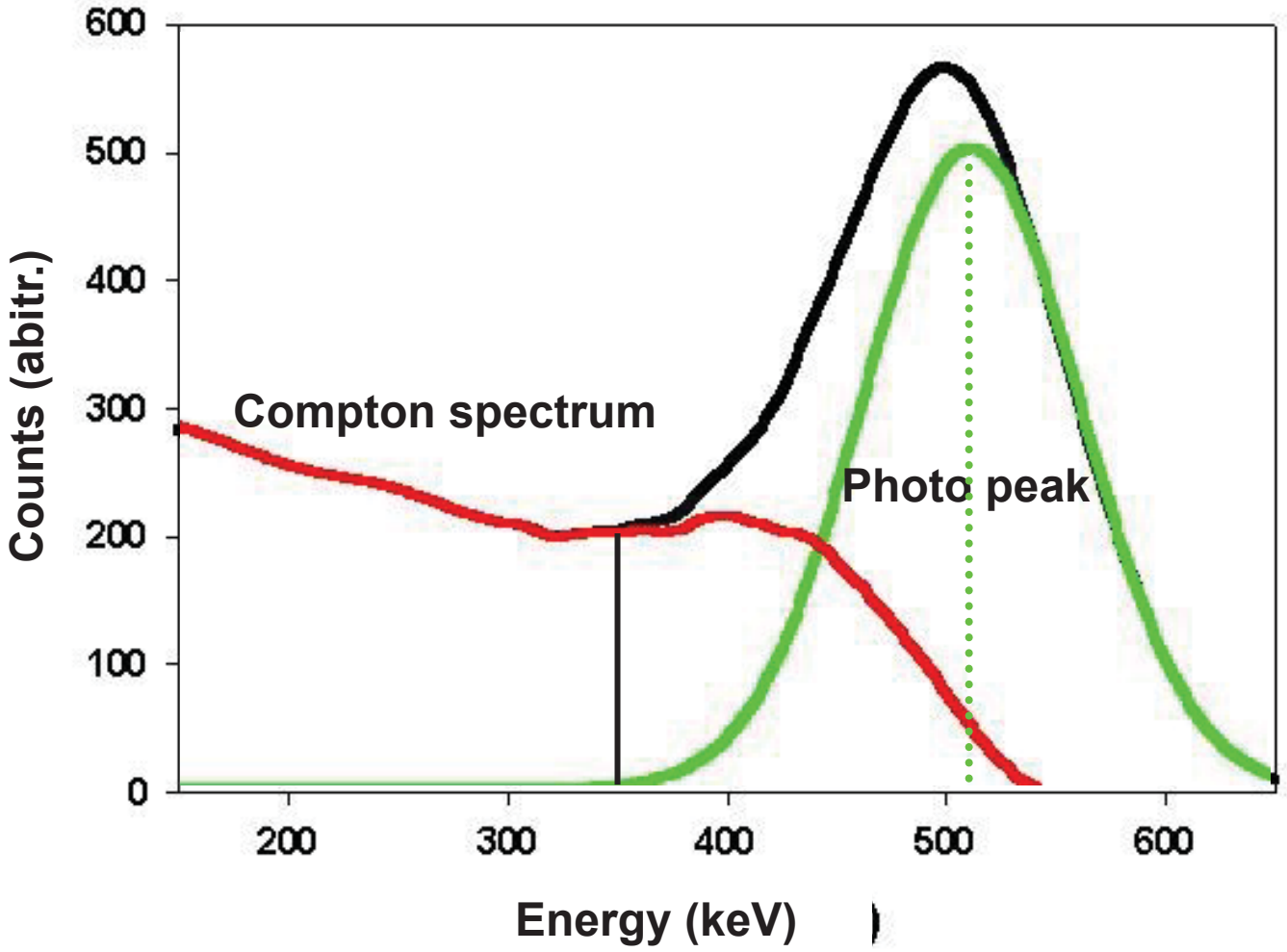
true coincidence

random coincidence

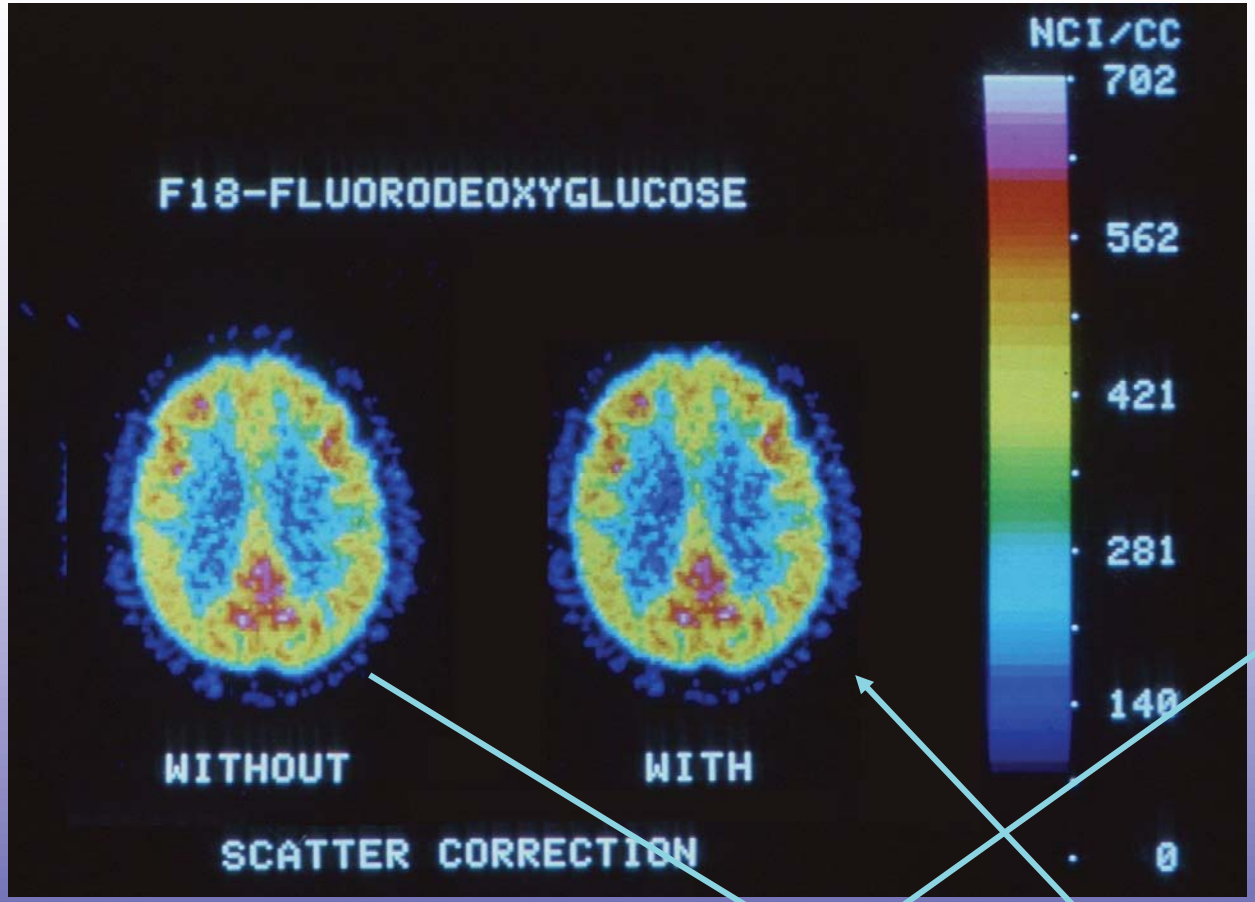
scattered coincidence

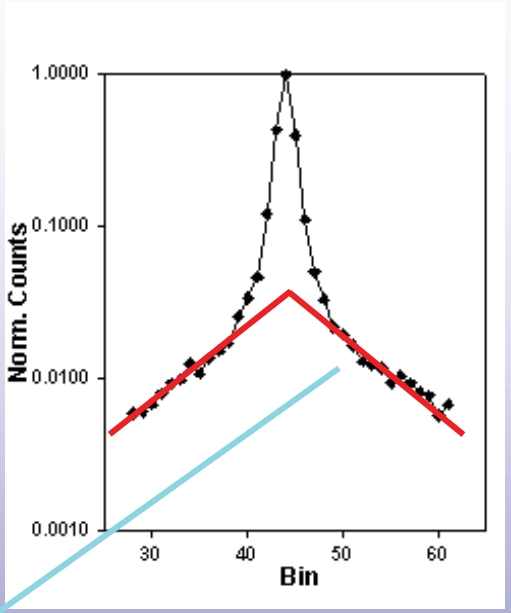
absorbed coincidence

Energy Spectrum of BGO



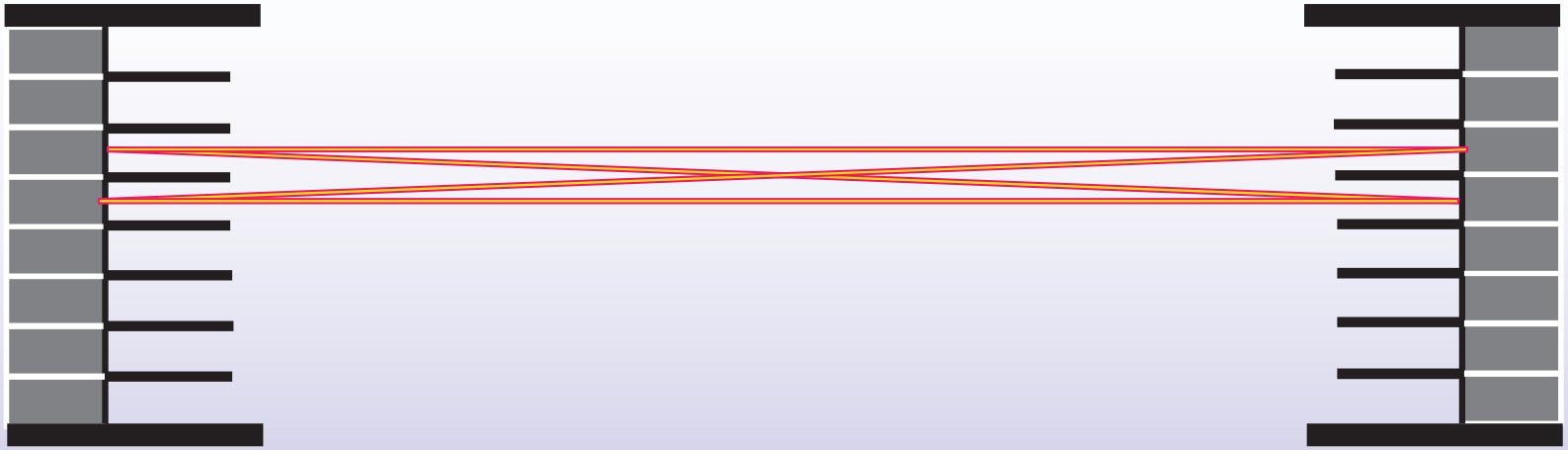
Scatter-Correction in 2D



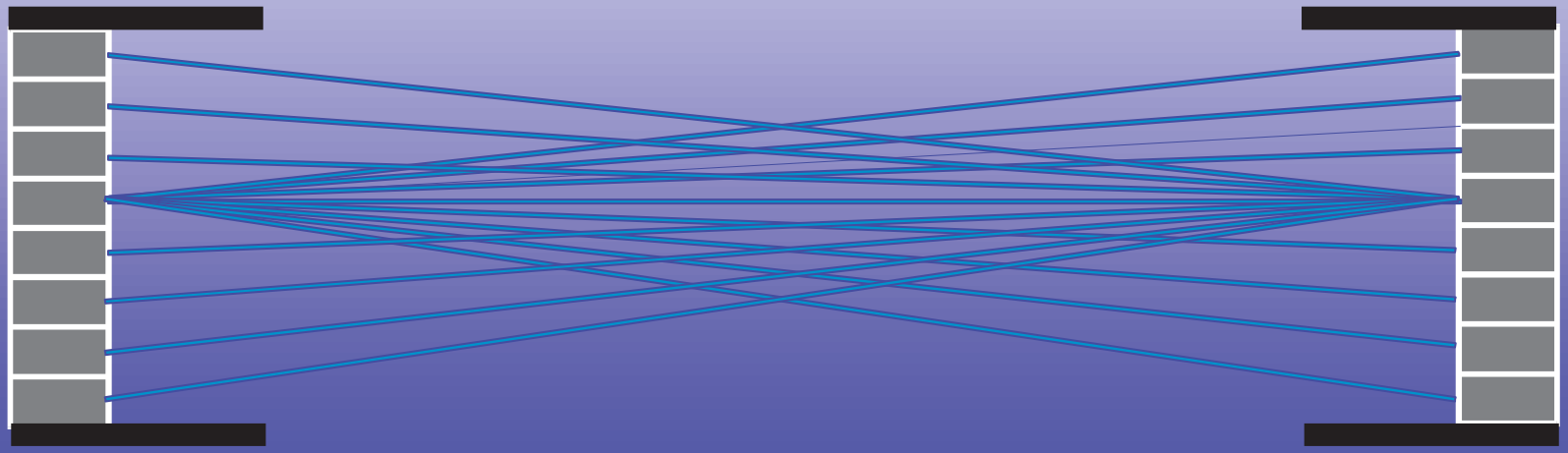


Application of the convolution-subtraction method
(Bergström et al.,1983)

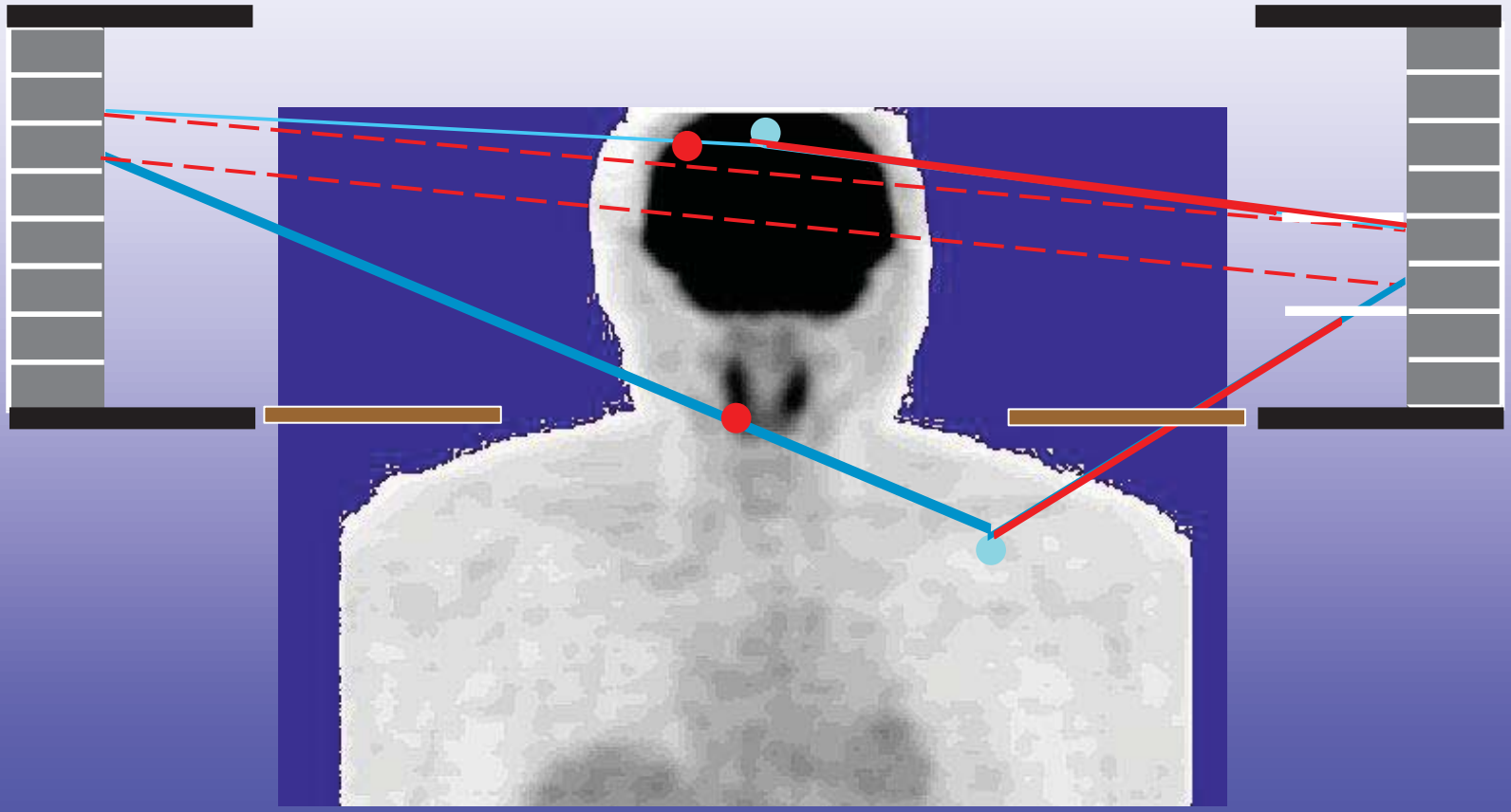
With Septa - 2 D Acquisition Mode



Without Septa - 3 D Acquisition Mode



Scatter is the Enemy !



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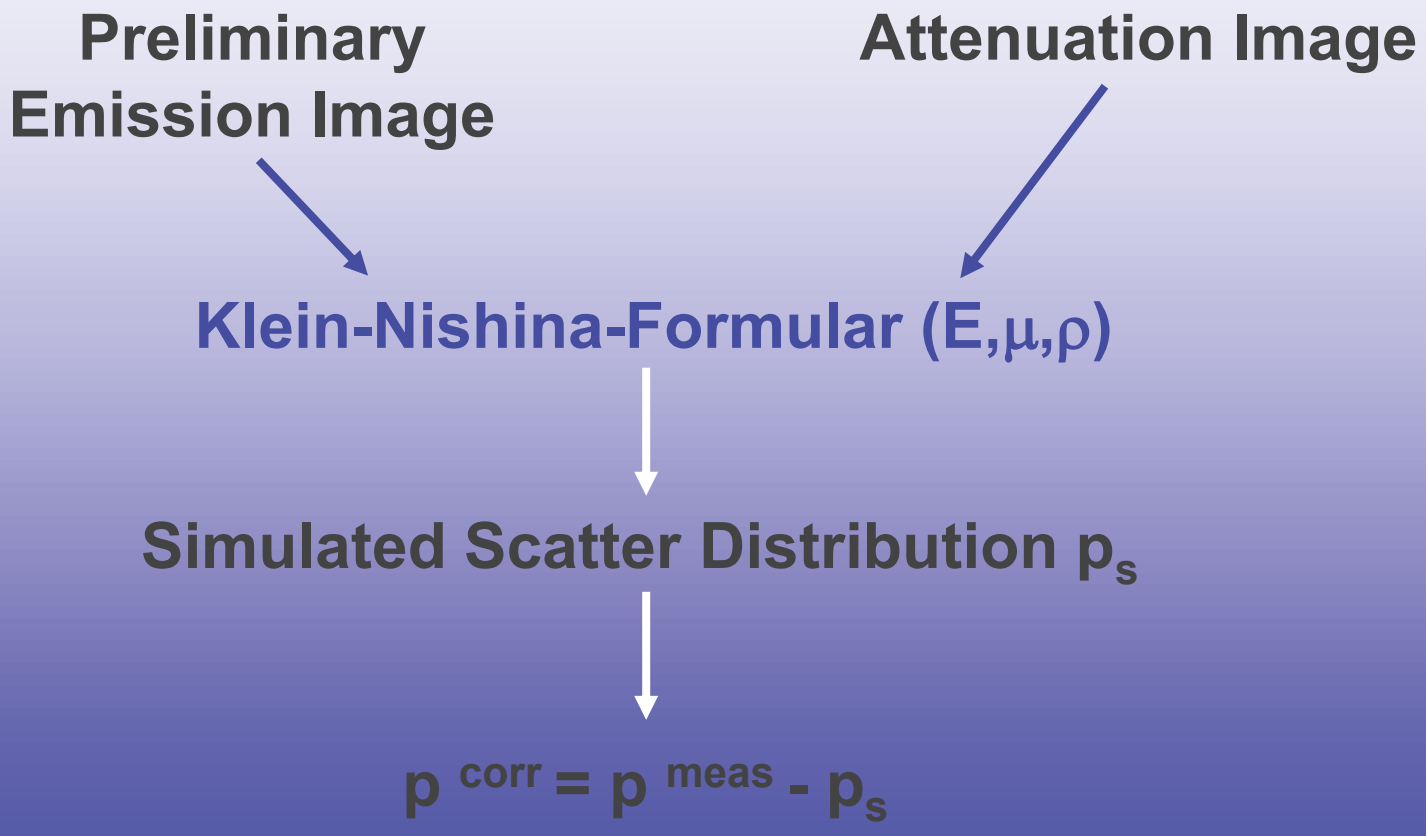
Problem with “out of field“ radioactivity and scatter: Reduction by Neuroinsert

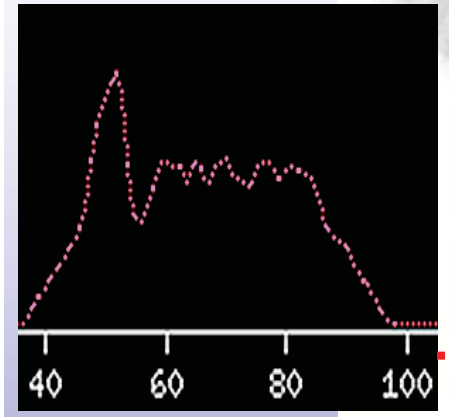
Simulation-Based Scatter Correction

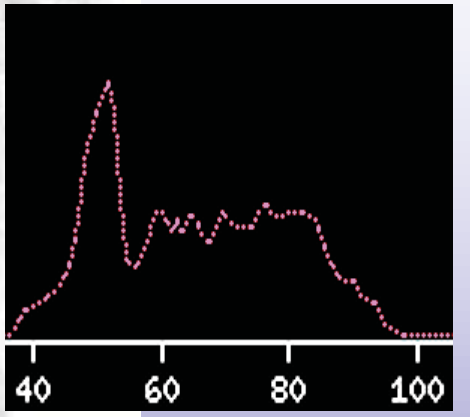
(Watson et al., 1995)



Whole-Body Image

without with





Heart:Lung
= 16:1

Heart:Lung
= 21:1

Scatter-Correction

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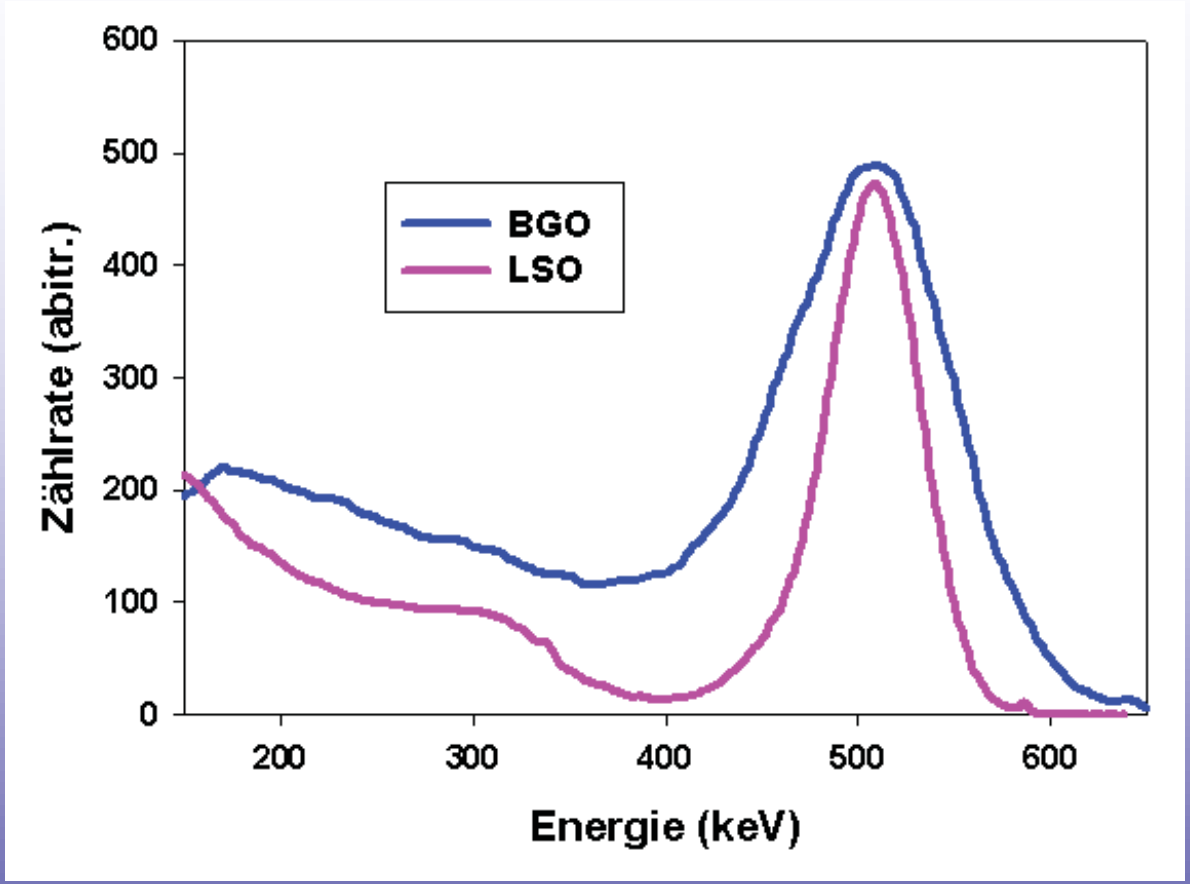
Better Scintillation Crystal

	NaJ	BaF_2	BGO	LSO	LuAP
Eff. Atom number	50	54	74	59	65
Density	3,7	4,9	7,1	7,4	8,3
Decay constant (ns)	230	630/0,6	300	40	18
Rel. Light yield (%)	100	5/16	8-12	75	25?

More Light Yield → smaller energy window

→ reduced scatter accepted

Better Scintillation Crystal



More Light Yield → smaller energy window

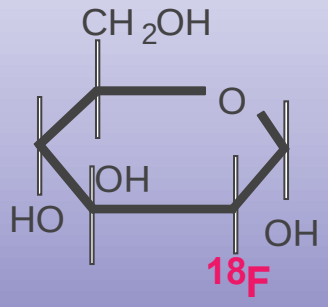
→ reduced scatter accepted

PET Applications

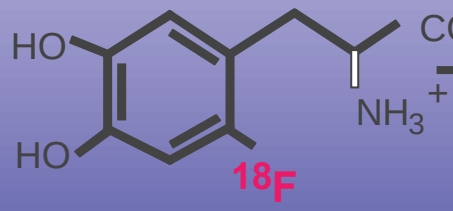
Metabolic Functions Visualised by "Natural" Tracer Molecules Labelled with Positron Emitters

$H_2{}^{15}O$ → Perfusion

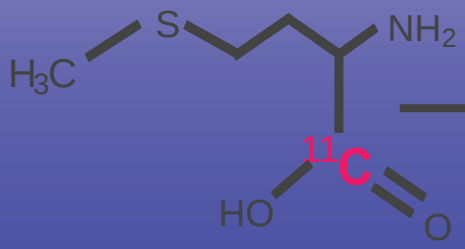
${}^{15}O_2$ → Oxygen Consumption



→ Glucose Consumption



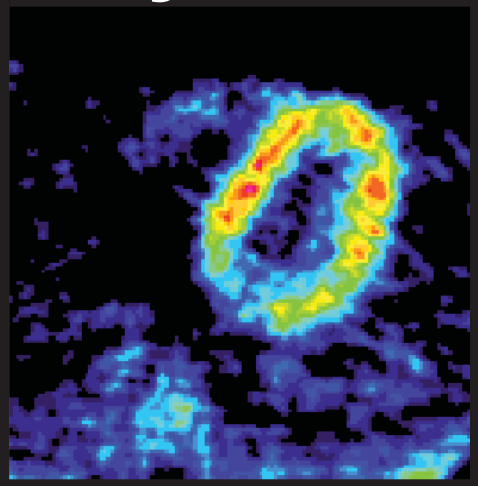
→ Dopamine Pool

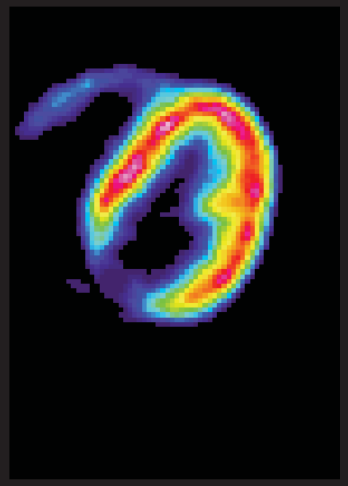


→ Transport of Amino Acids

Viability of the Heart Muscle

Normal

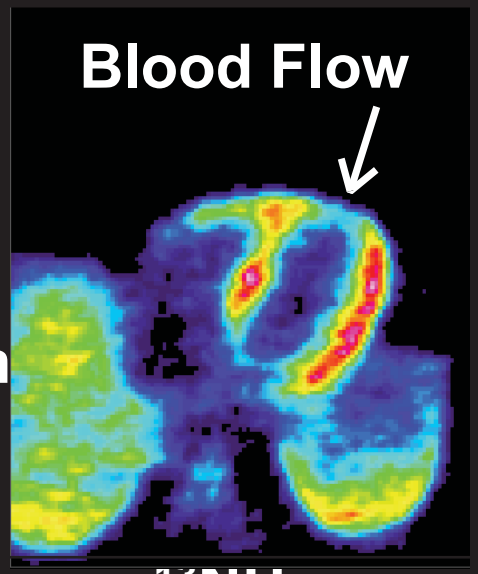




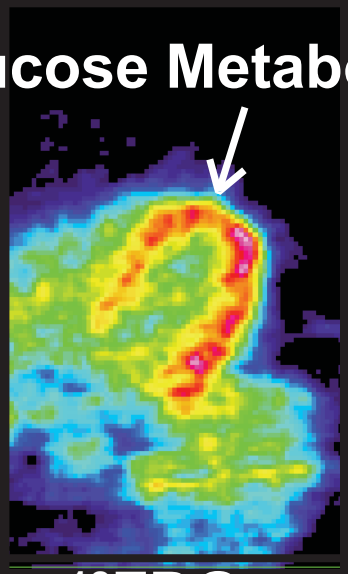
Blood Flow

Glucose Metabolism

After Infarction

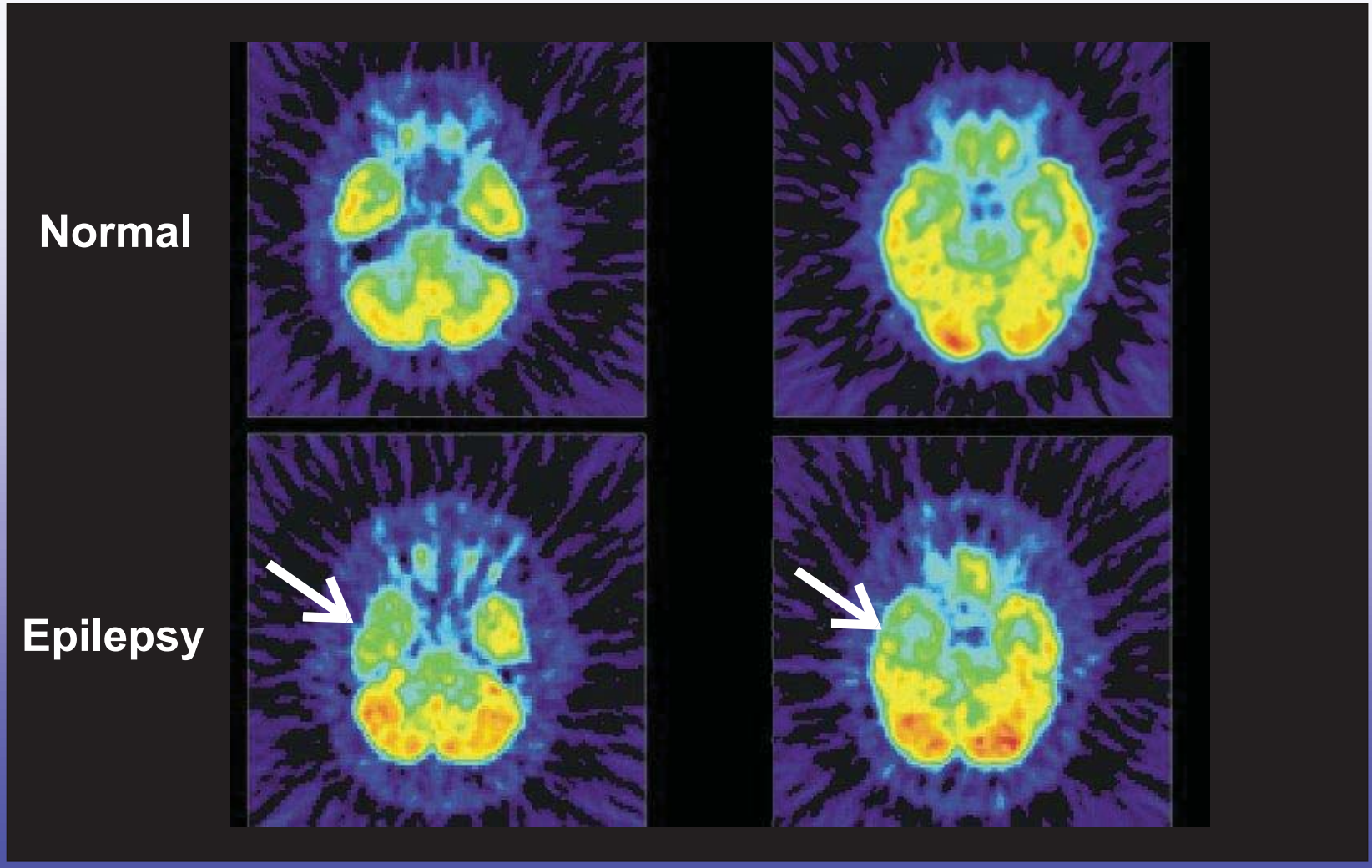


$^{13}NH_3$

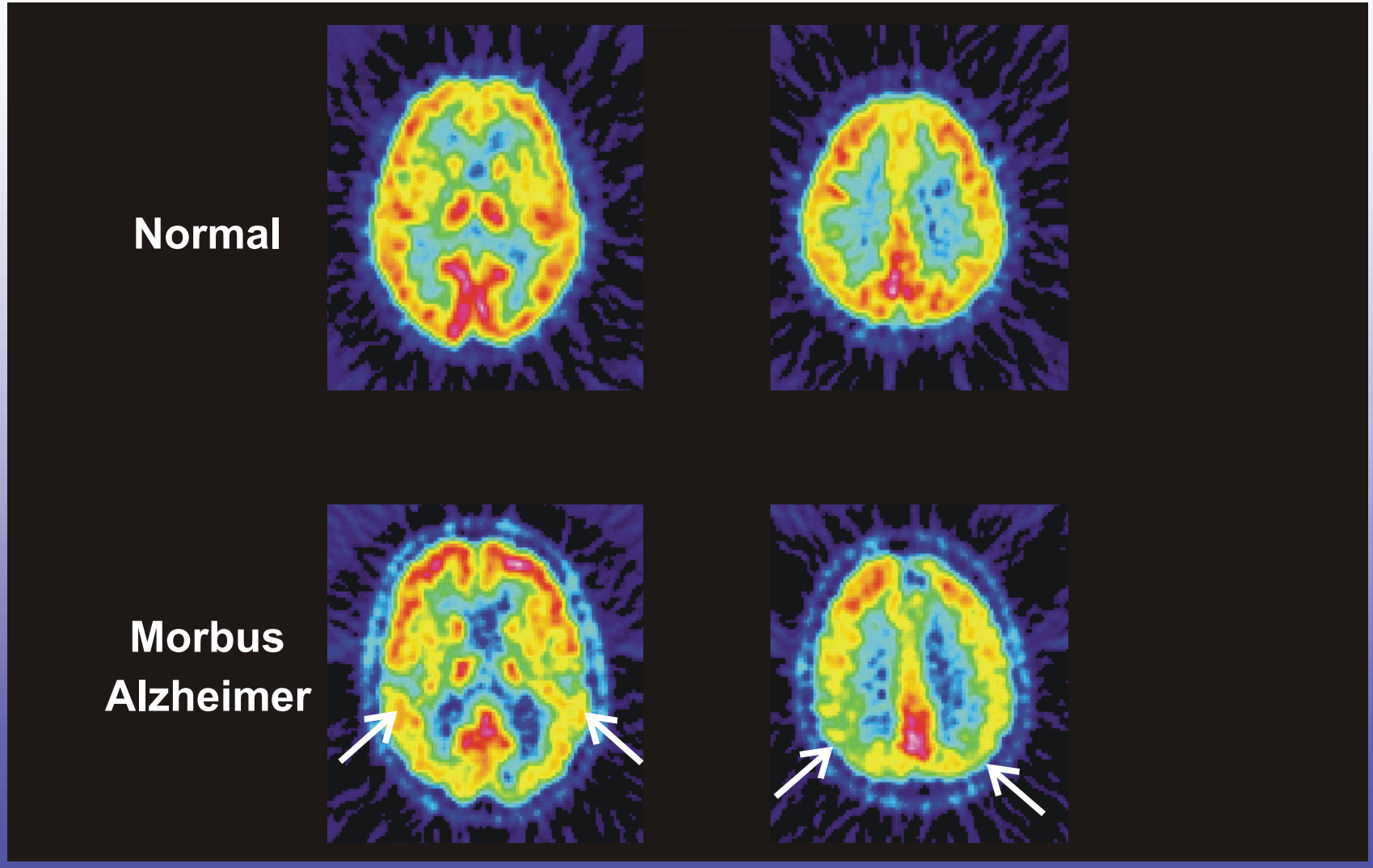


^{18}FDG

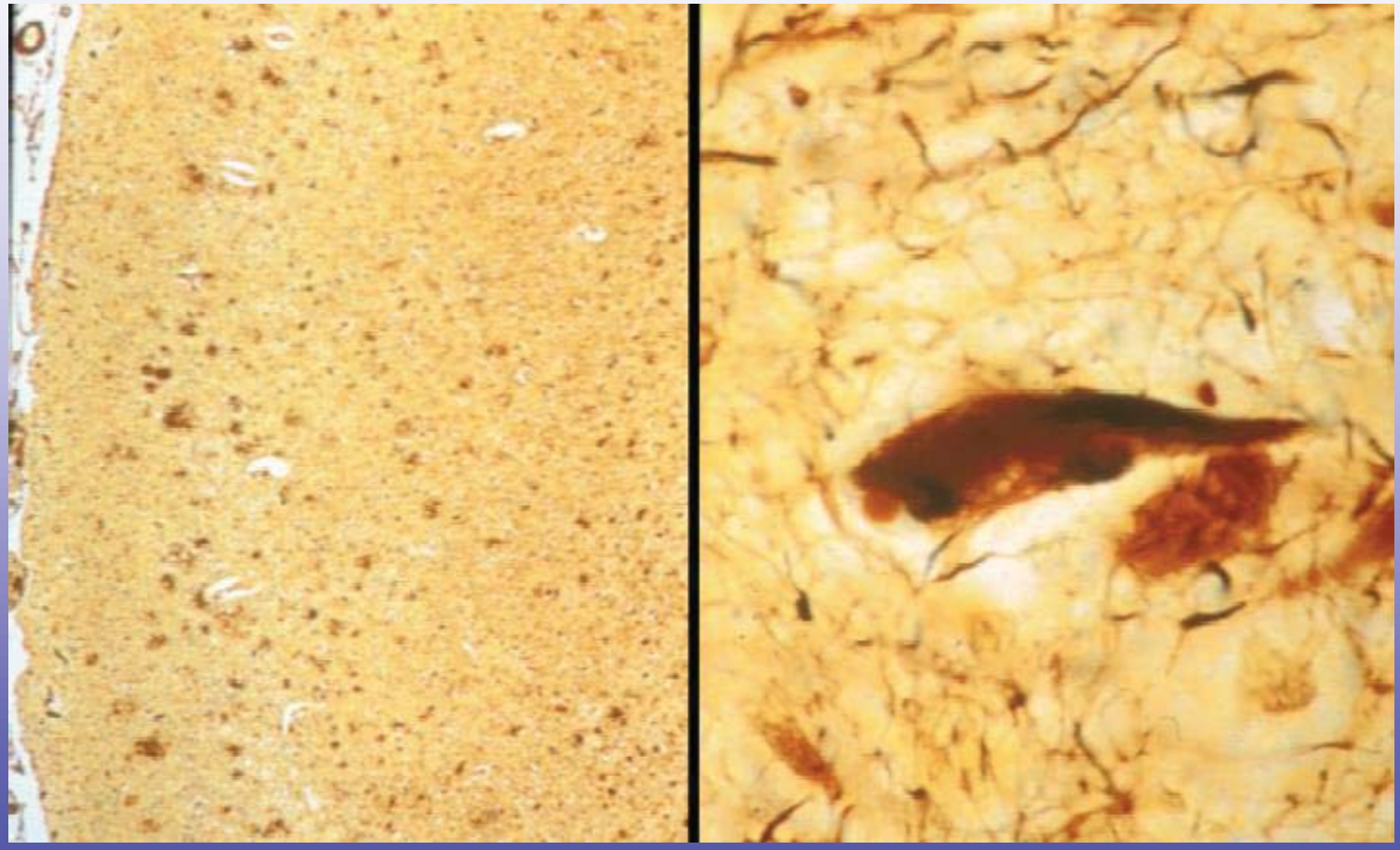
Focal Decrease of Glucose Consumption Measured with ^{18}FDG in Partial Epilepsy



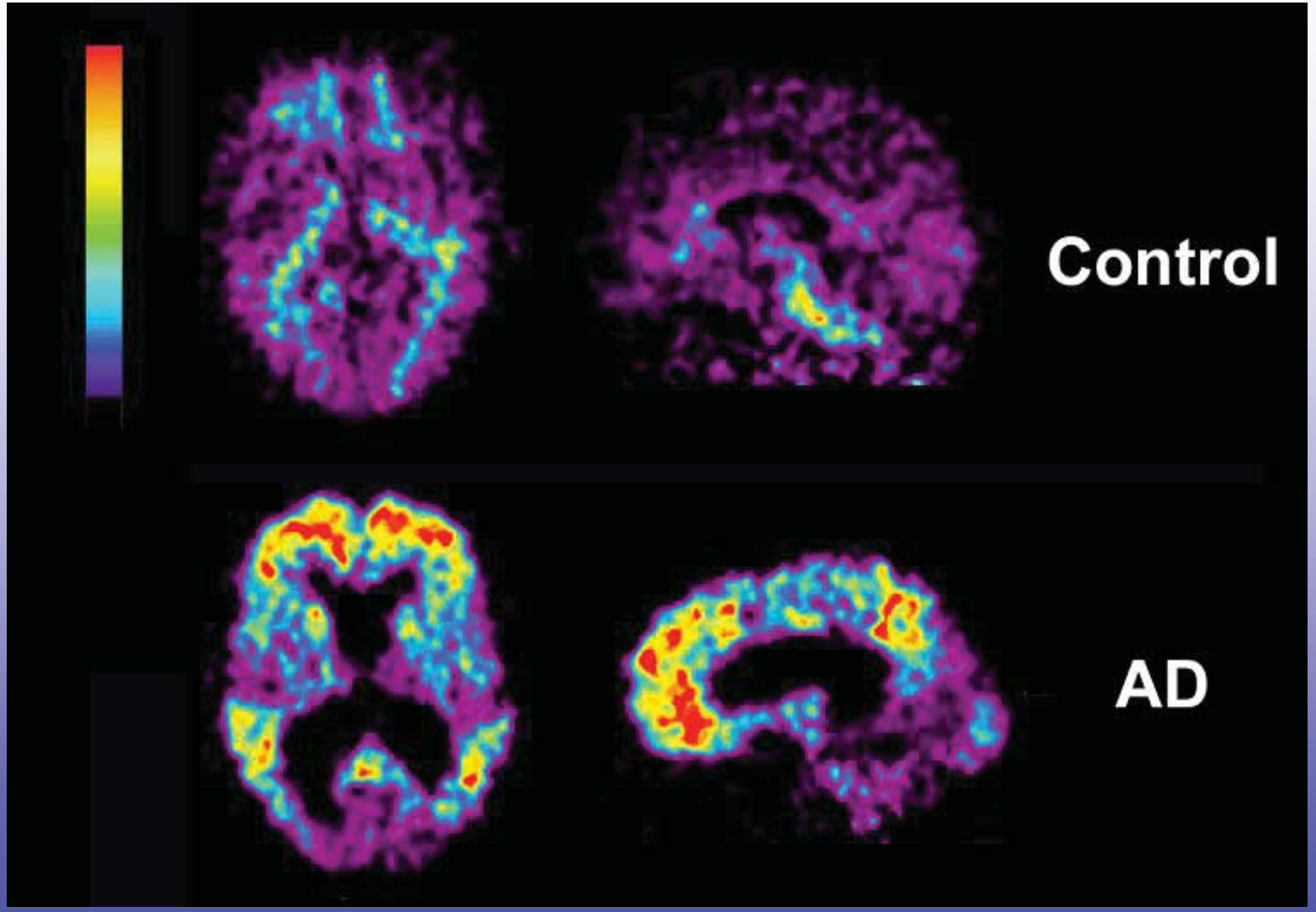
Morbus Alzheimer: Decrease of Glucose Consumption In Parietal Cortex Measured with ^{18}FDG



Histology: Amyloid-Plaques

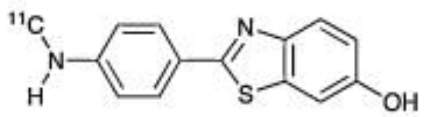


Direct Imaging of the Plaques with [^{11}C]6-OH-BTA-1

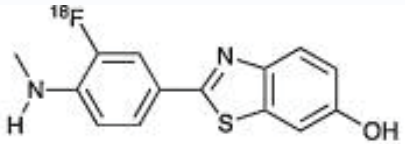


Klunk et al., Ann Neurol 2004

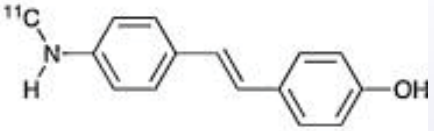
Industrial developments for Plaques Imaging

(a) 

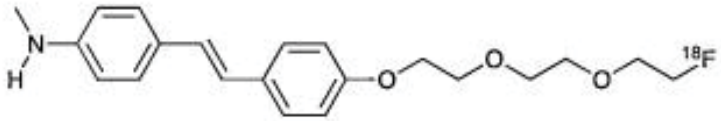
^{11}C-PiB

(b) 

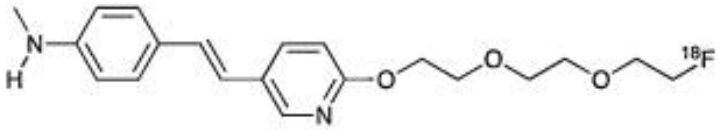
^{18}F-Flutemetamol
(GE)

(c) 

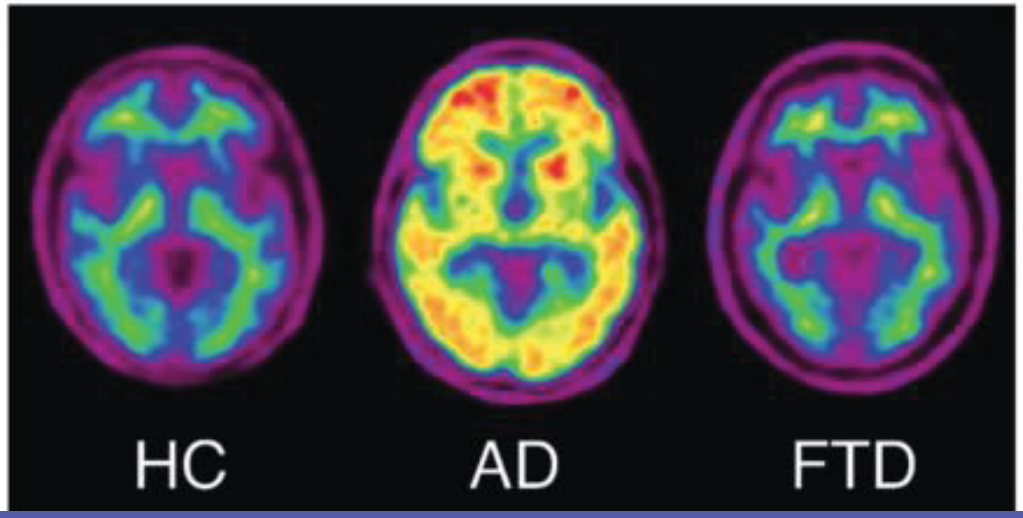
^{11}C-SB-13

(d) 

^{18}F-Florbetaben
(Piramal)

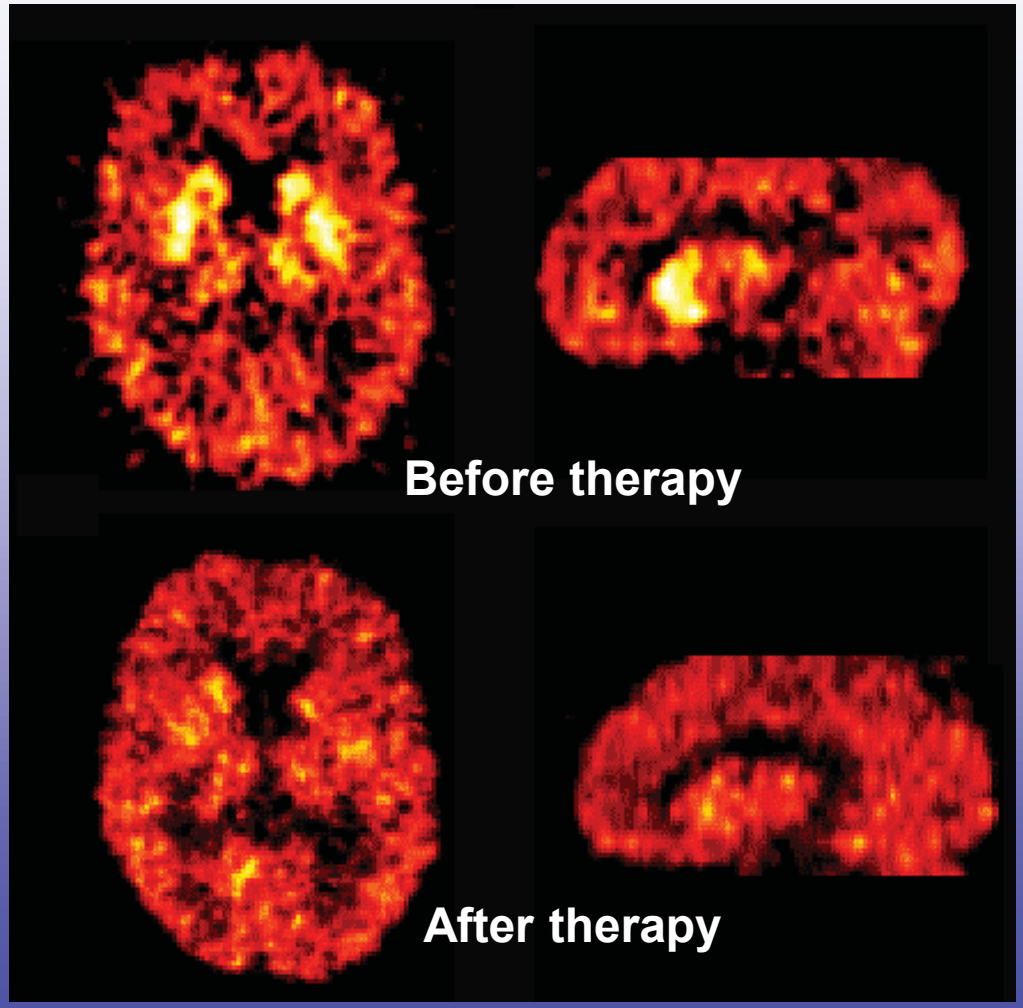
(e) 

^{18}F-Florbetapir
(Avid)

(f) 

Rowe CC , Villemagne VL, JNM 2011

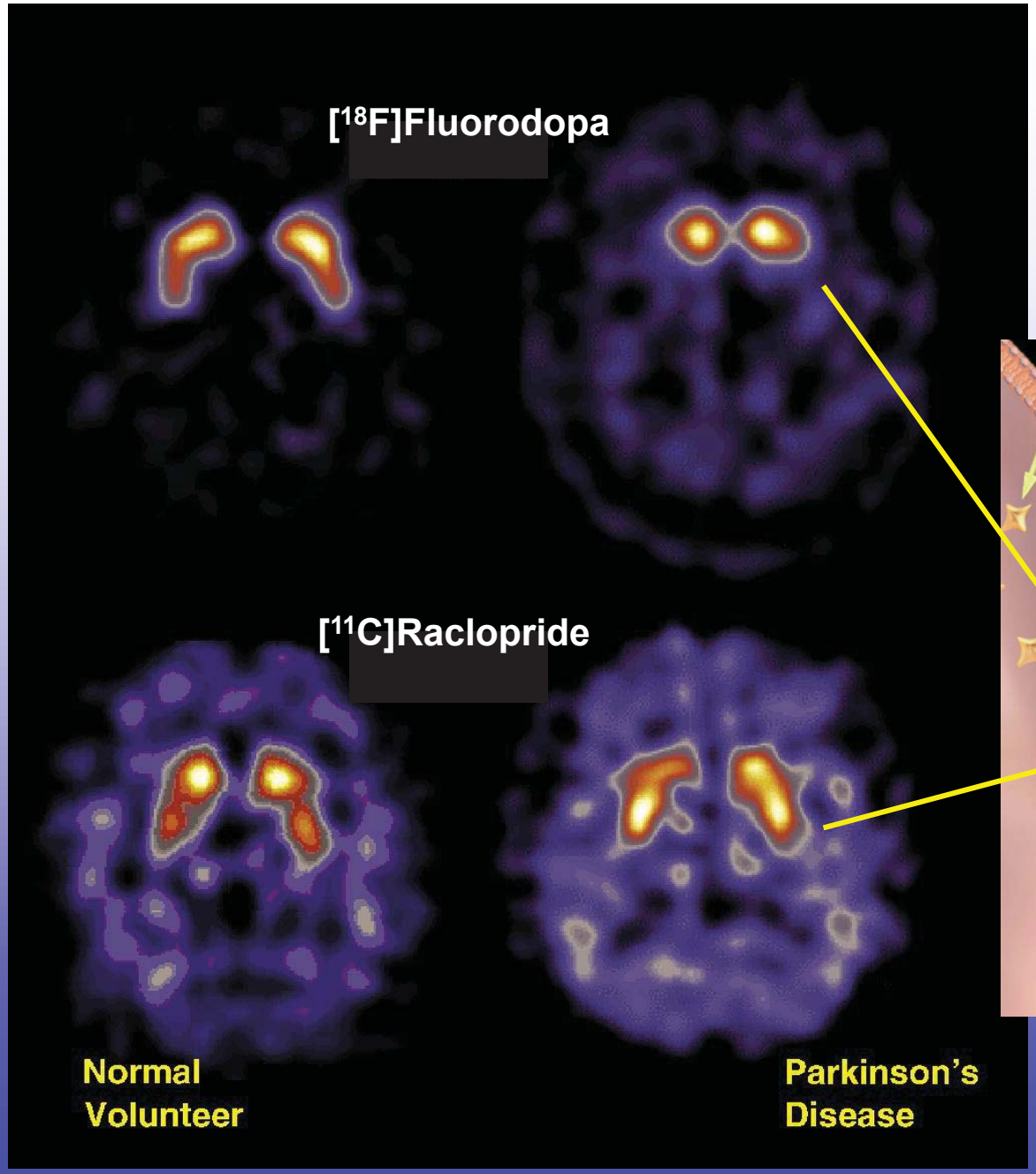
Interaction of Drugs which Bind to the Dopaminergic Receptor

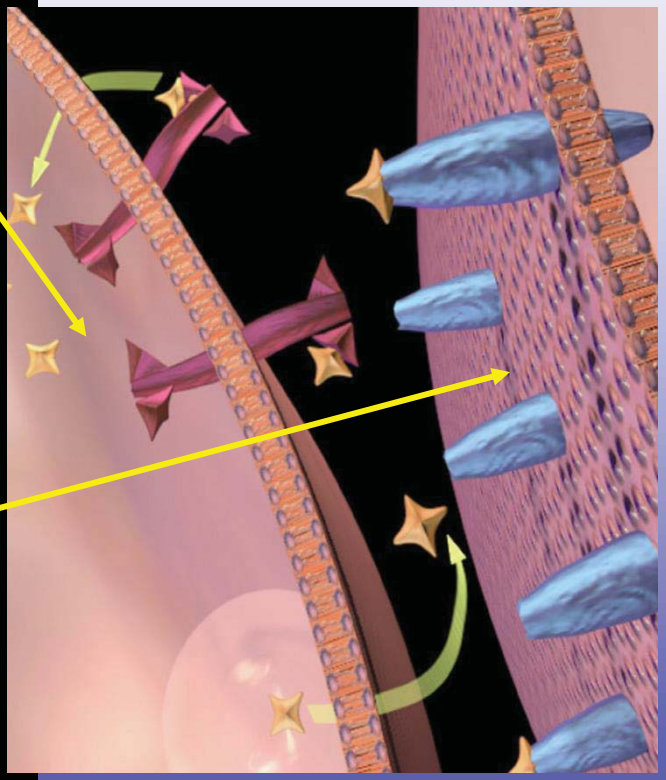


Images of the dopaminergic receptor ligand [^{11}C]SDZ GLC756

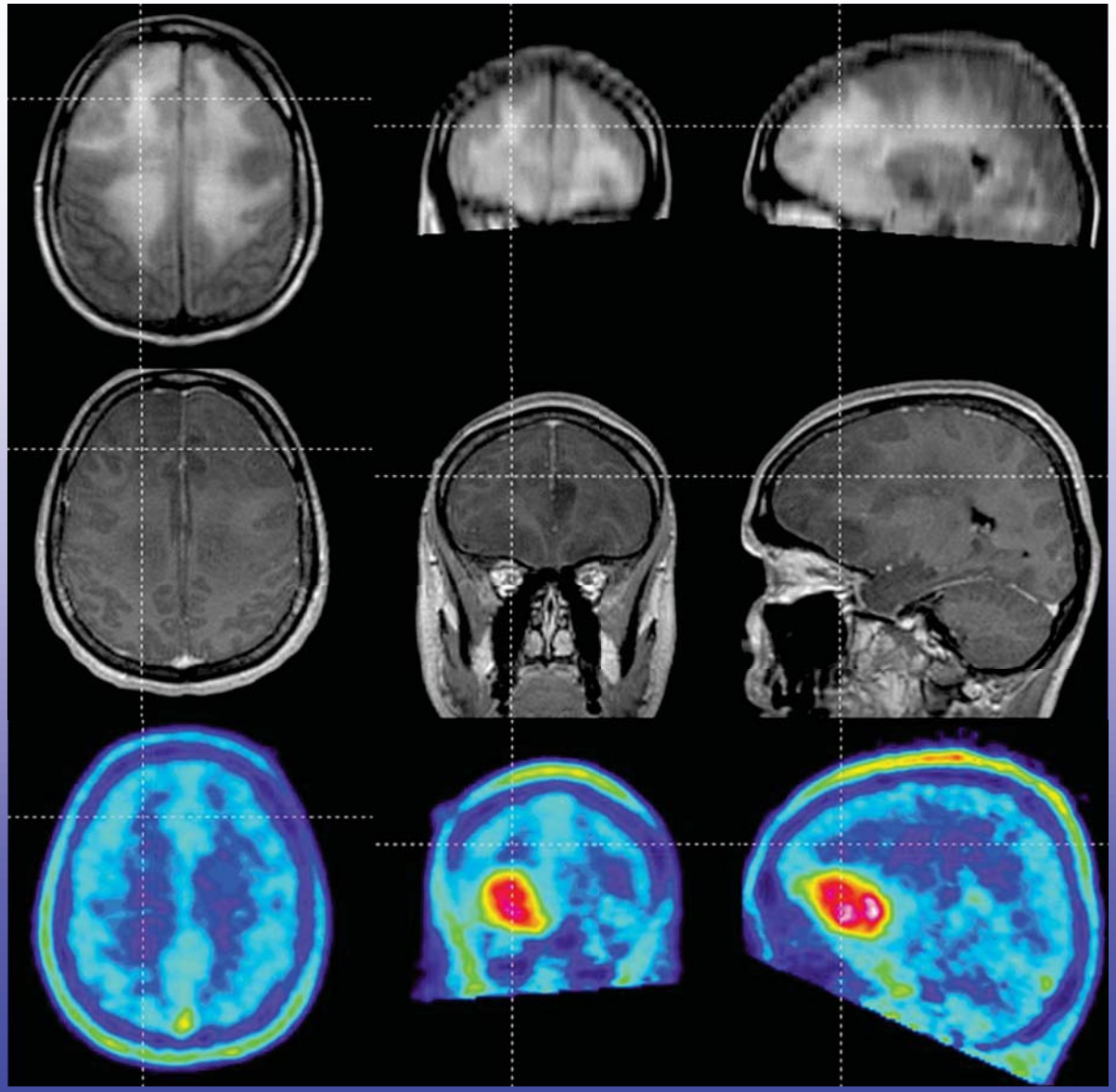
Blockade of receptors caused by the antipsychotic treatment with the neuroleptic drug olanzipine

PET Imaging of Parkinson‘s Disease





Brain Tumor Imaging: ^{18}F-Fluor-Ethyl-Tyrosine (FET)



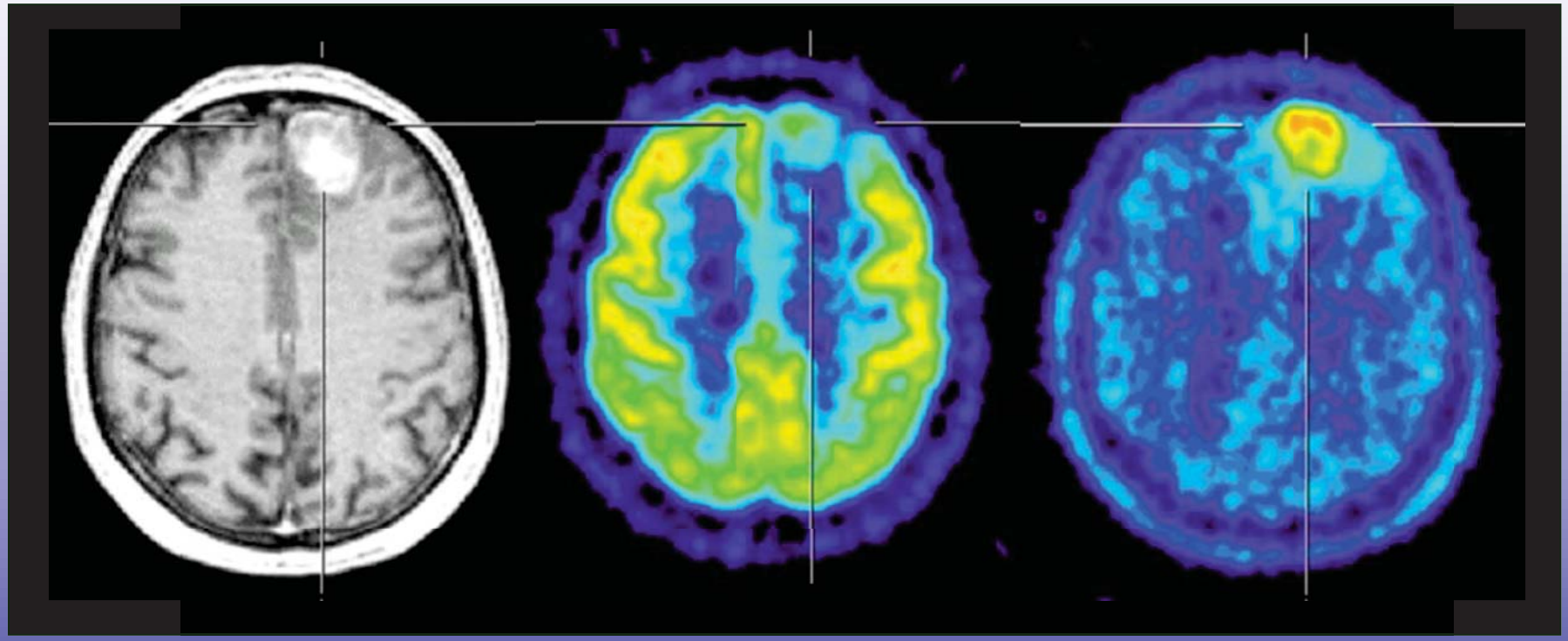
MR-Flair

MR-T1 (KM)

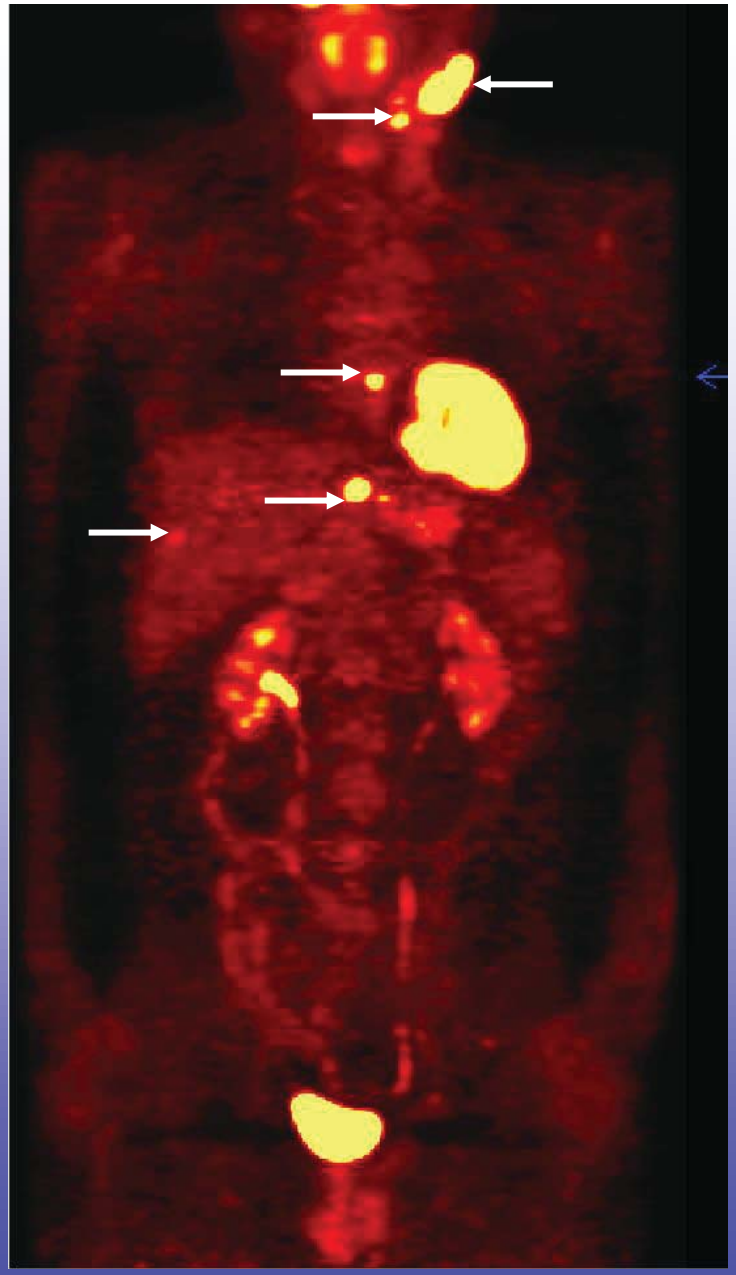
FET-PET

Brain Tumor Imaging

FDG versus Amino Acids



MR-T1 FDG-PET FET-PET



Anterior View

Melanoma at Head-Neck:

Metastases viusualized with FGG-PET

Consequence:

Stop of local radiation

Instead:

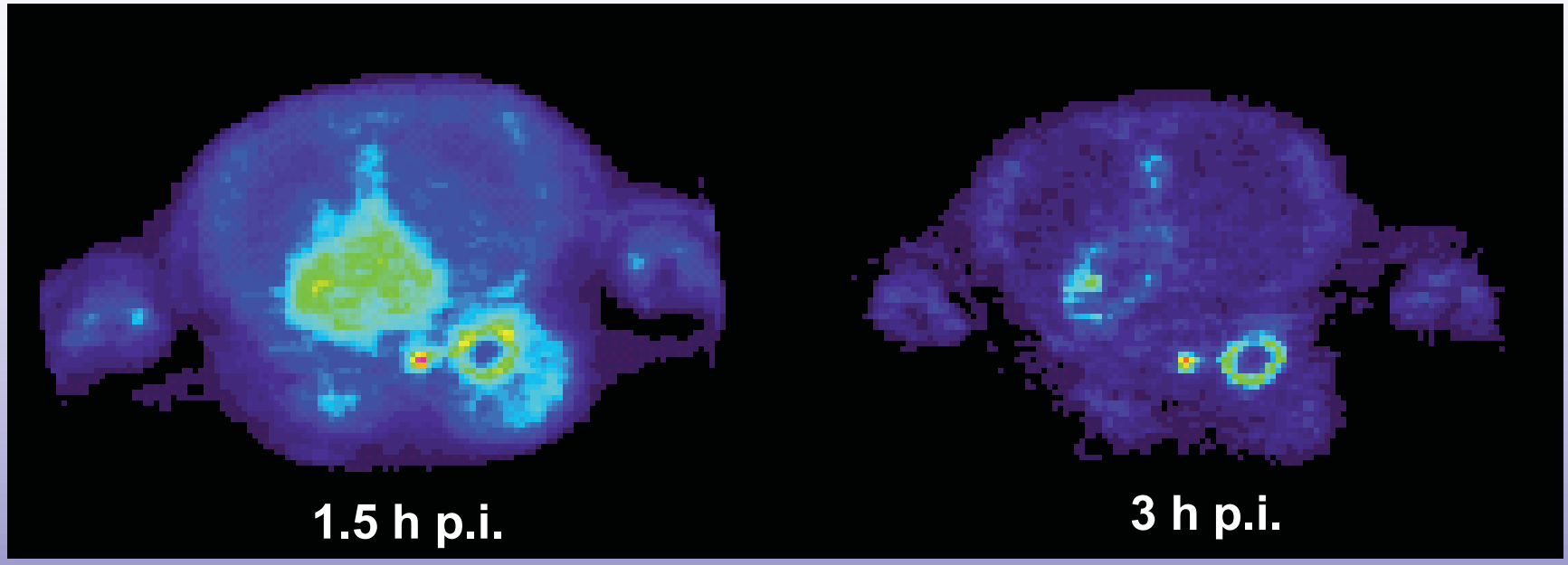
Chemotherapy !!

SUV = Standard-Uptake-Value

FDG-PET to find suspicious metastasis 3 years after colon-Ca

Synonyms for SUV: DUR, DUV

Contrast of FDG uptake may be time dependent

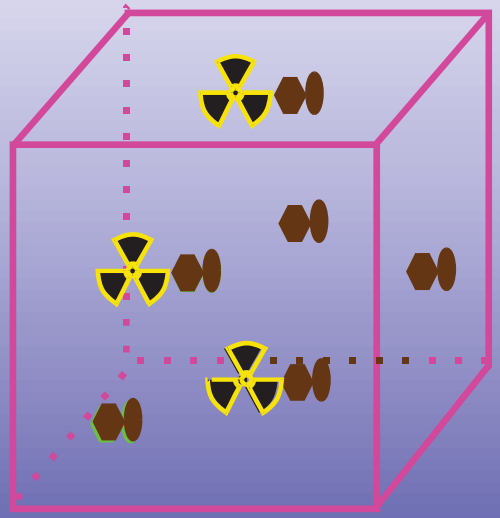


n = 29	1.5 h p.i. median ± SEM	3 h p.i. median ± SEM	Increase (%)
SUV	6.6 ± 5.0	11.8 ± 6.6	180

From the PET measured radioactivity concentration (kBq/ml)

to the mass concentration of

the metabollically active substrate (μmol/ml)

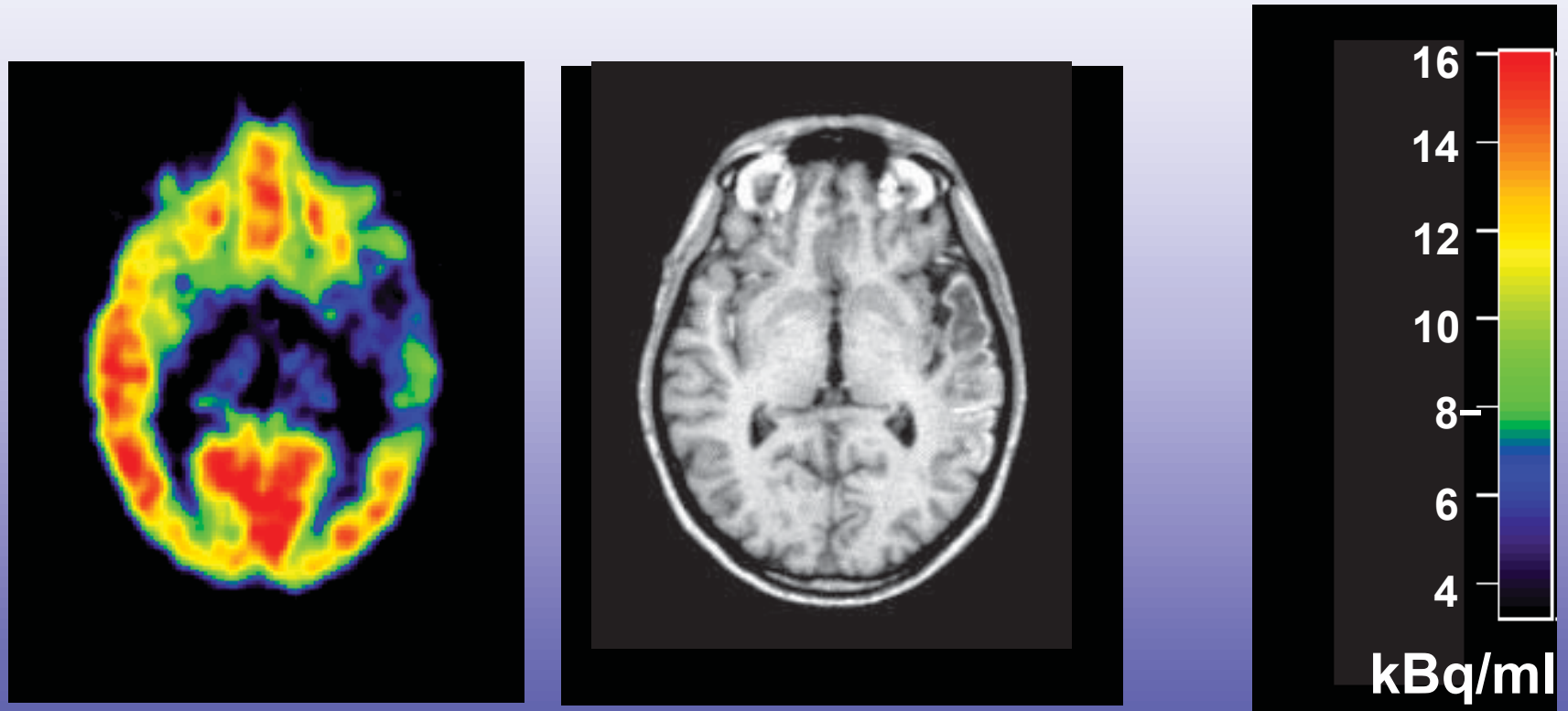


$$\frac{m_{Tissue}}{c_{PET}} = \frac{m_{Syringe}}{c_{Syringe}}$$

Spezific Activity^{-1}

Institut für Medizin
Forschungszentrum Jülich

Quantification of Radioactivity Concentration:



Imaging of Benzodiazepine Receptors Using ^{11}C-Flumazenil

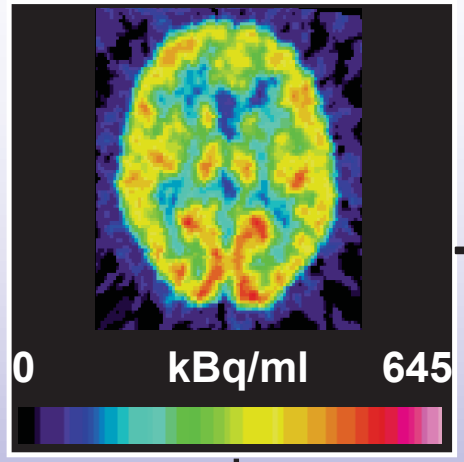
Quantification of Mass Concentration:

Imaging of Benzodiazepine Receptors Using ^{11}C-Flumazenil

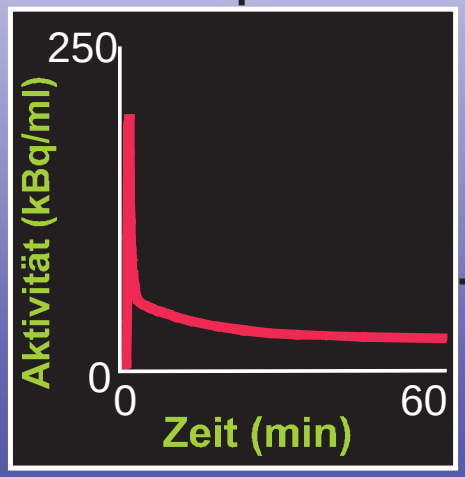
Quantifizierung der Aktivitätskonzentration

Measurement of Cerebral Glucose Consumption

Activity Image

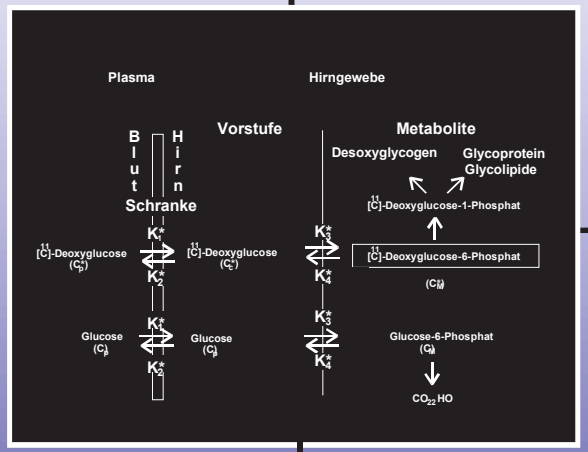


Cross-Calibration

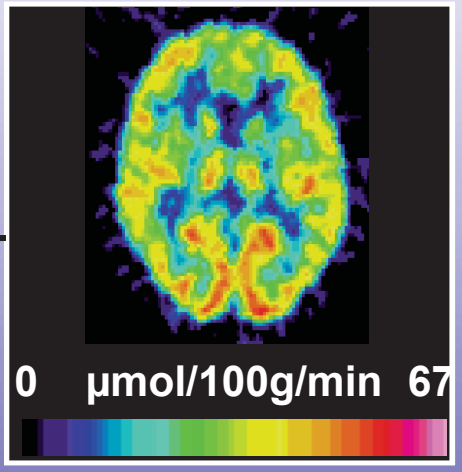


Blood Data

Deoxyglucose Model
(by Sokoloff, 1977)



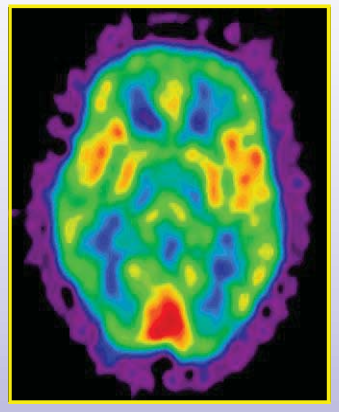
Glucose Consumption

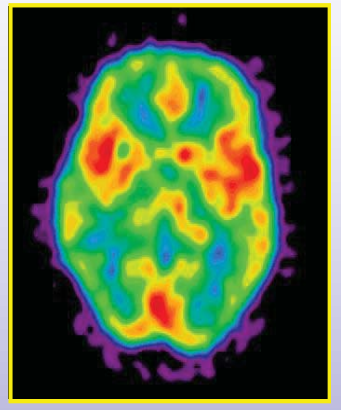


$$LCMRGlc = \frac{c_P\left[c_T(T) - K_1 e^{-(k_2+k_3)T}\int_0^T c_P^*(t)\bullet e^{(k_2+k_3)}dt\right]}{LC\left[\int_0^T c_P^*(t)dt - e^{-(k_2+k_3)T}\int_0^T c_P^*(t)\bullet e^{(k_2+k_3)}dt\right]}$$

Quantification of Brain Blood Flow with PET and ^{15}O-Butanol

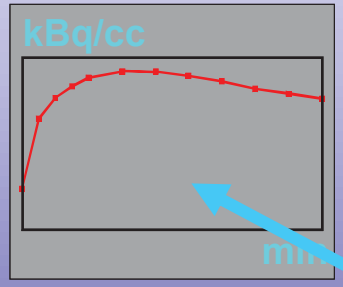
pCO_2 = 30 mmHg



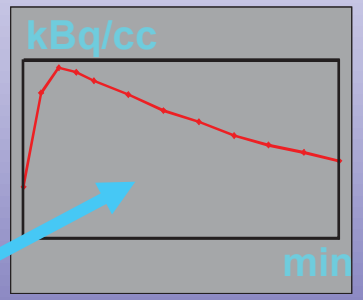


pCO_2 = 60 mmHg

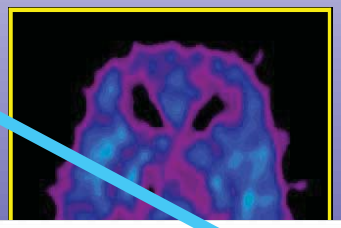
Act. = 251 kBq/cc

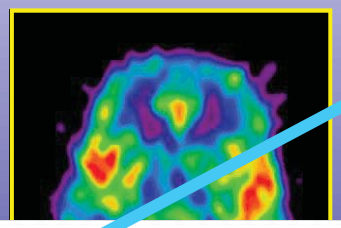


Act. = 249 kBq/cc



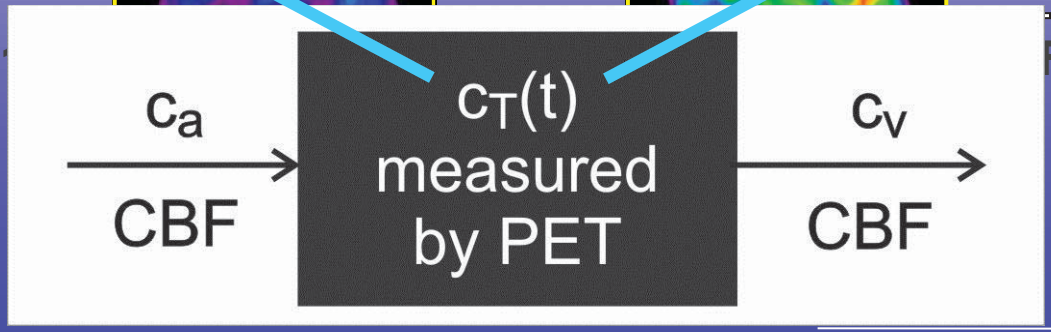
Images of Radioactivity





CBF = 61 ml/min/

F = 174 ml/min/100g



PET today

- 85% of PET studies:

  Oncology

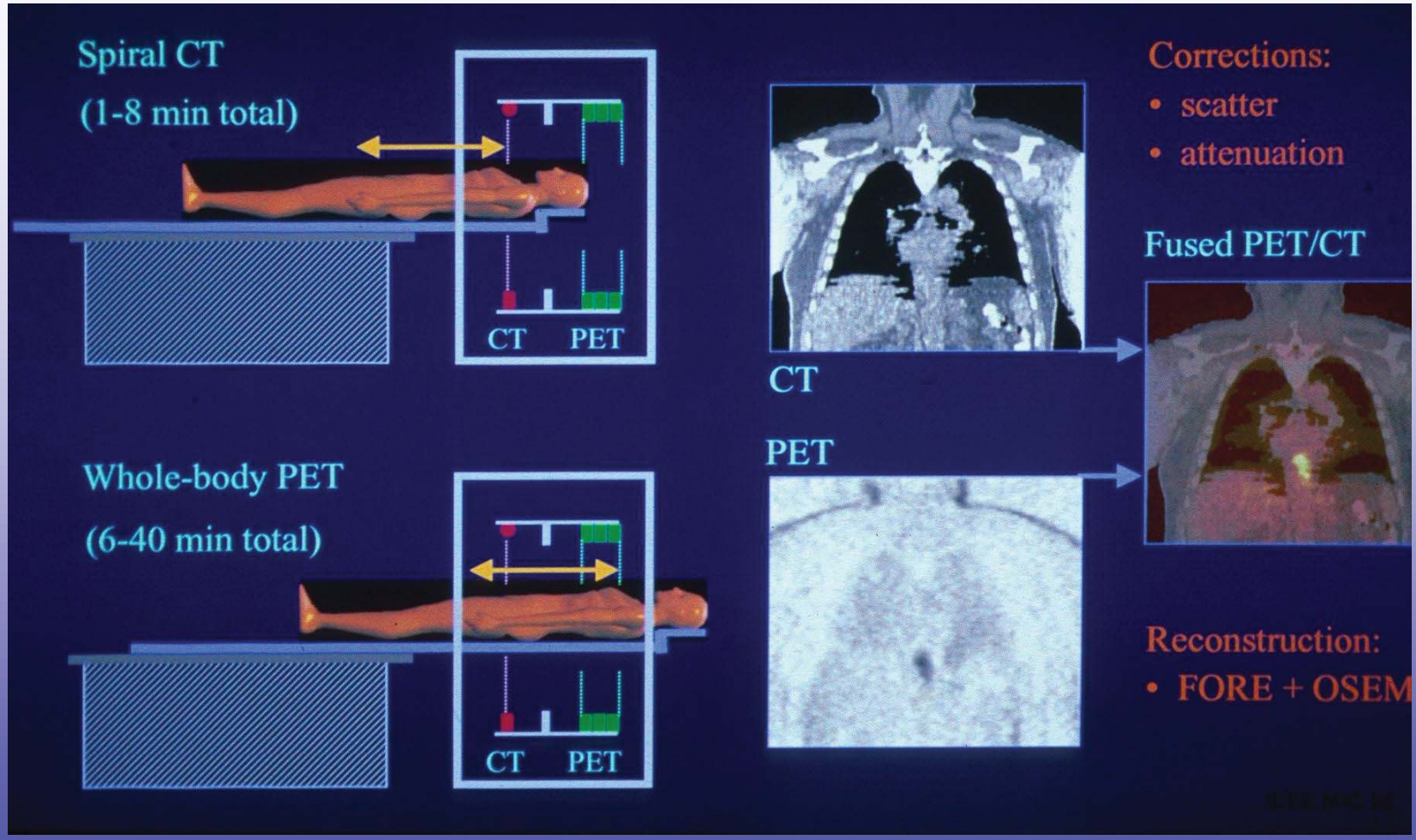
- 5% of PET studies:

  Cardiology

- 10% of PET studies:

  Neurology

PET/CT



Courtesy to D. Townsend, Knoxville

PET/CT Scanners

GE: Discovery

Philips: GEMINI TF

Siemens: Biograph mCT

Mediso: AnyScan (+ SPECT)

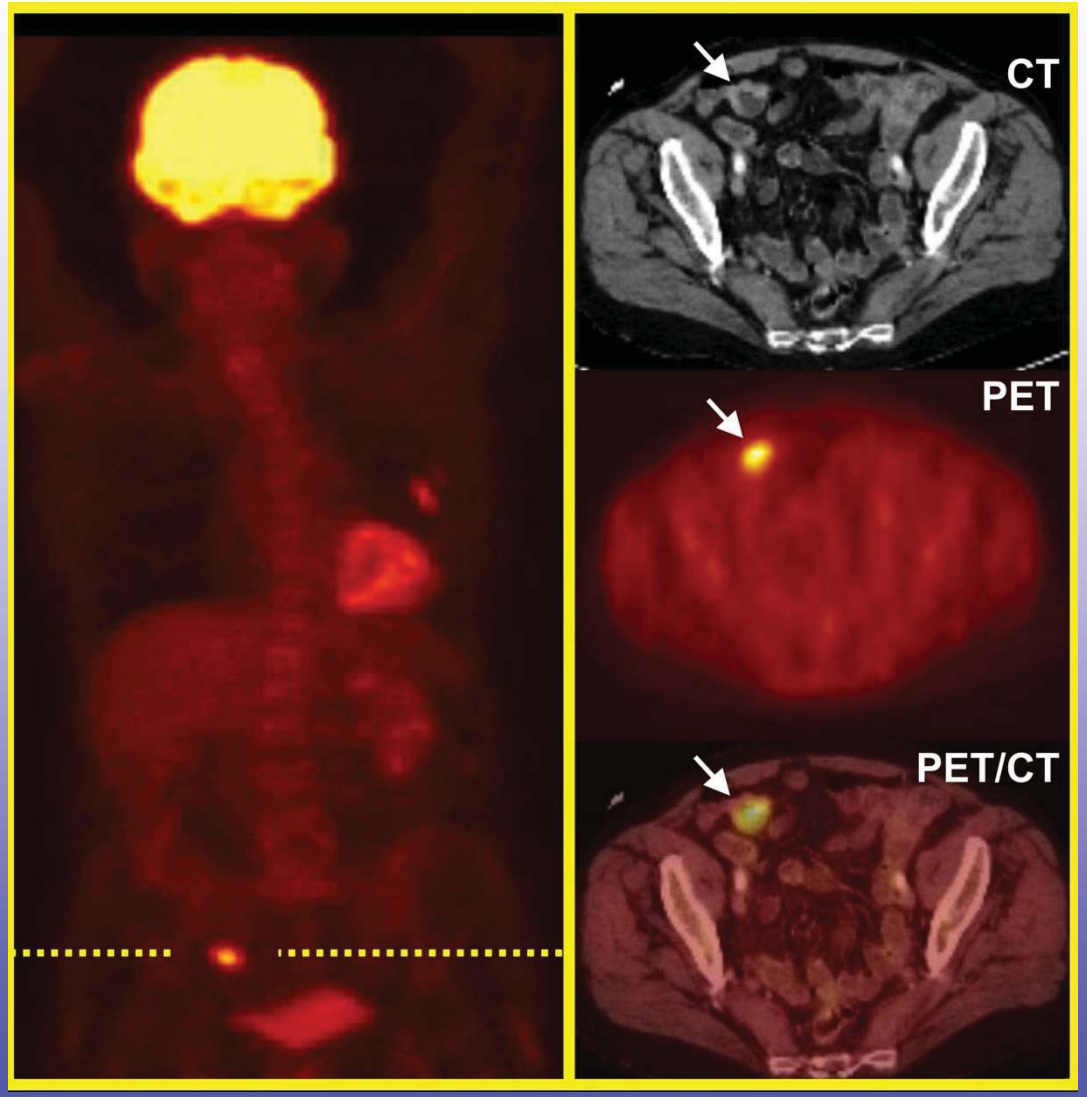
Specification and Performance

	Discovery	Gemini	Biograph
Crystal	LYSO	LYSO	LSO
Crystal Size (mm^3)	4.2 x 6.3 x 25	4 x 4 x 22	4 x 4 x 20
Transaxial FOV (cm)	70	70	70
Axial FOV (cm)	15.7	18	21.6
Scatter Fraction (%)	38	30	34
Sensitivity (cps/kBq)	7	7	9.5
Coincid. Window (ns)	4.9	3.8	4.1
L. Energy Thresh. (keV)	425	440	435
Peak NECR: kcps@kBq/ml	110@20	110@16 HR+: 26@8.3	175@28

Specifications and Performance

	Discovery	Gemini	Biograph
Crystal Size (mm^3)	4.2 x 6.3 x 25	4 x 4 x 22	4 x 4 x 20
Resolution (FWHM, mm)			
transaxial 1cm(10cm)	4.9 (5.5)	4.7 (5.2)	4.4 (4.9)
axial 1cm(10cm)	5.6 (5.9)	4.7 (5.2)	4.5 (5.9)
Time-of-Flight	yes	yes	yes
Detect. Resp. Mod.	yes	yes	yes

PET/CT



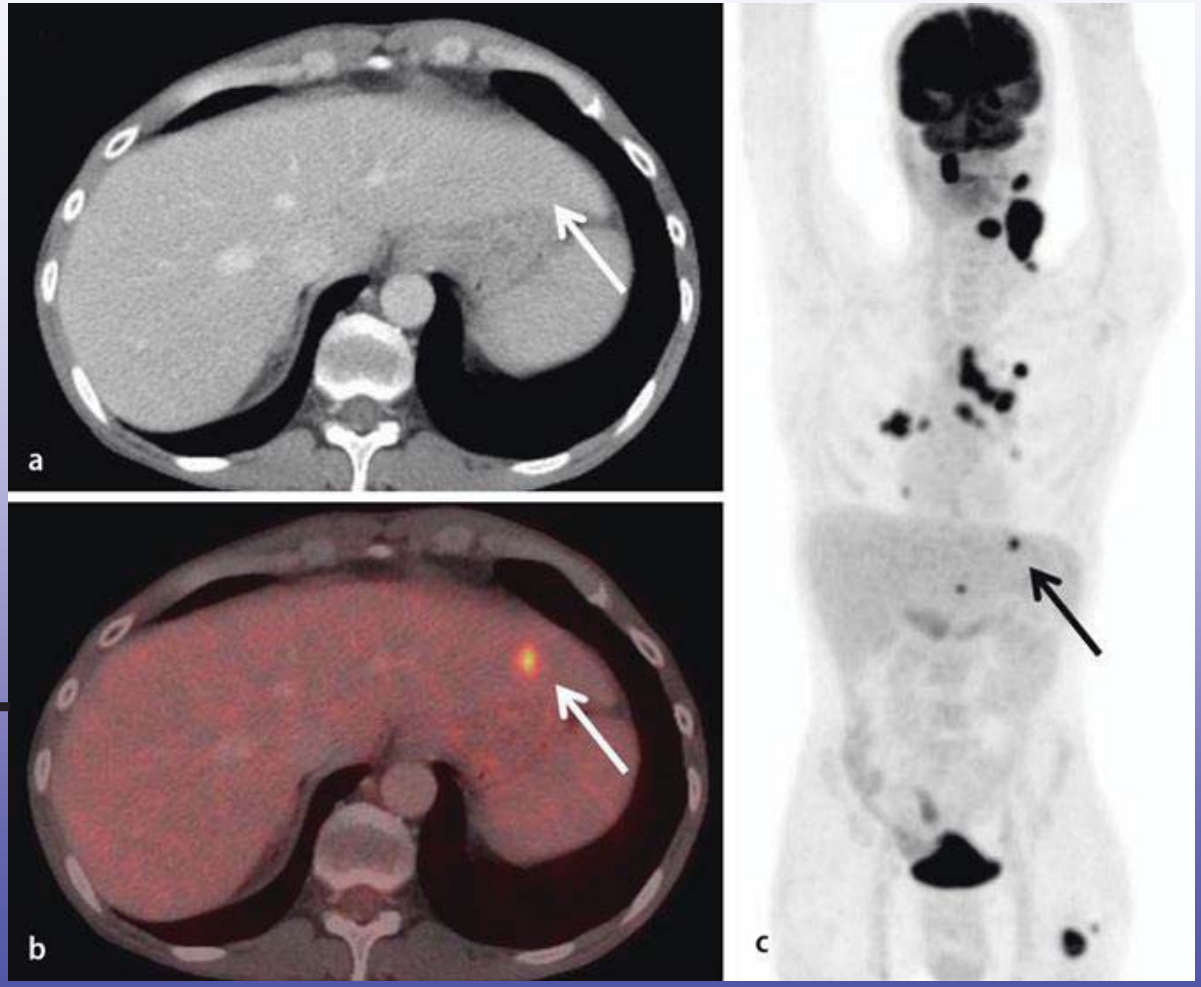
Courtesy to S. Müller, Essen

Metastasis of a malignent melanoma

PET/CT:
Metastases of a Rectal Carcinoma

CT

PET/CT

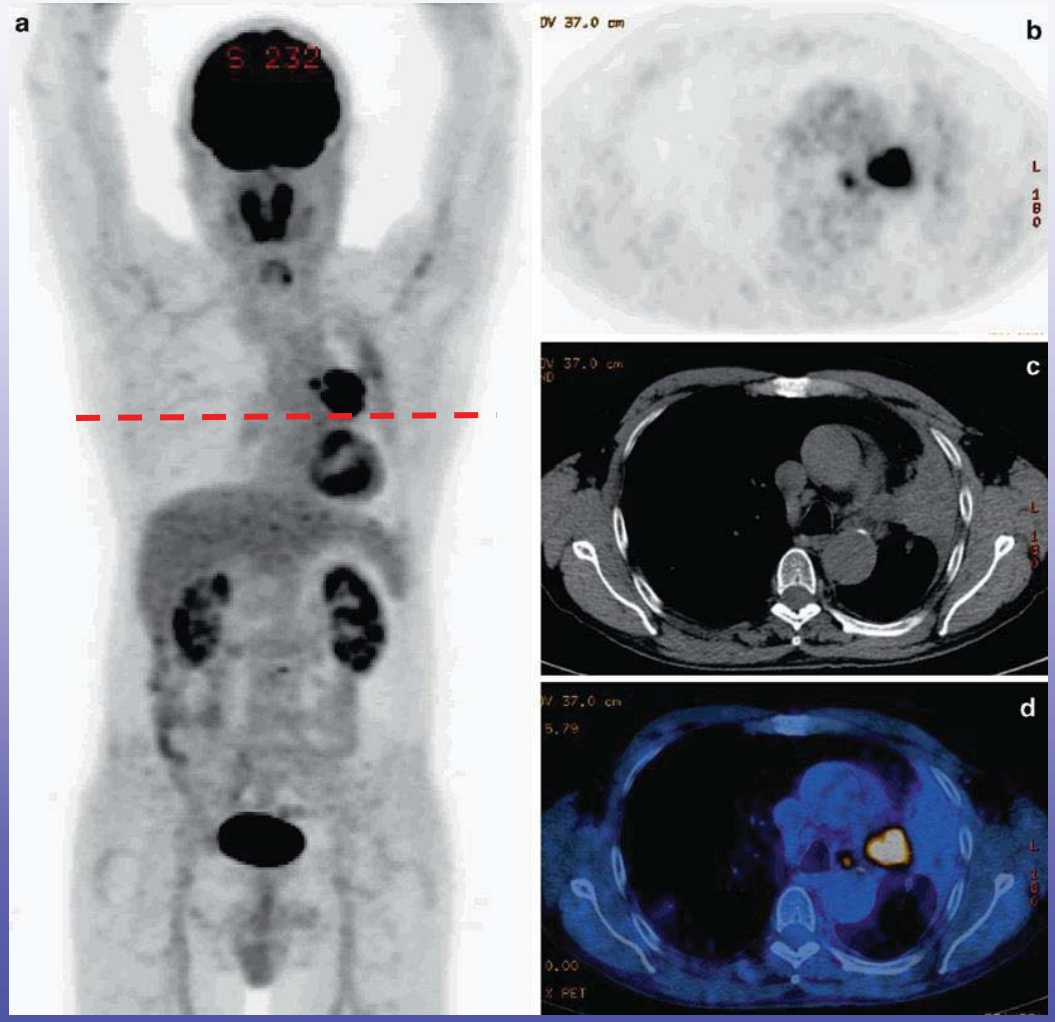


[^{18}F]-FDG

Klasen, Radiologe 2011

PET/CT:
Lung Carcinoma

[^{18}F]-FDG



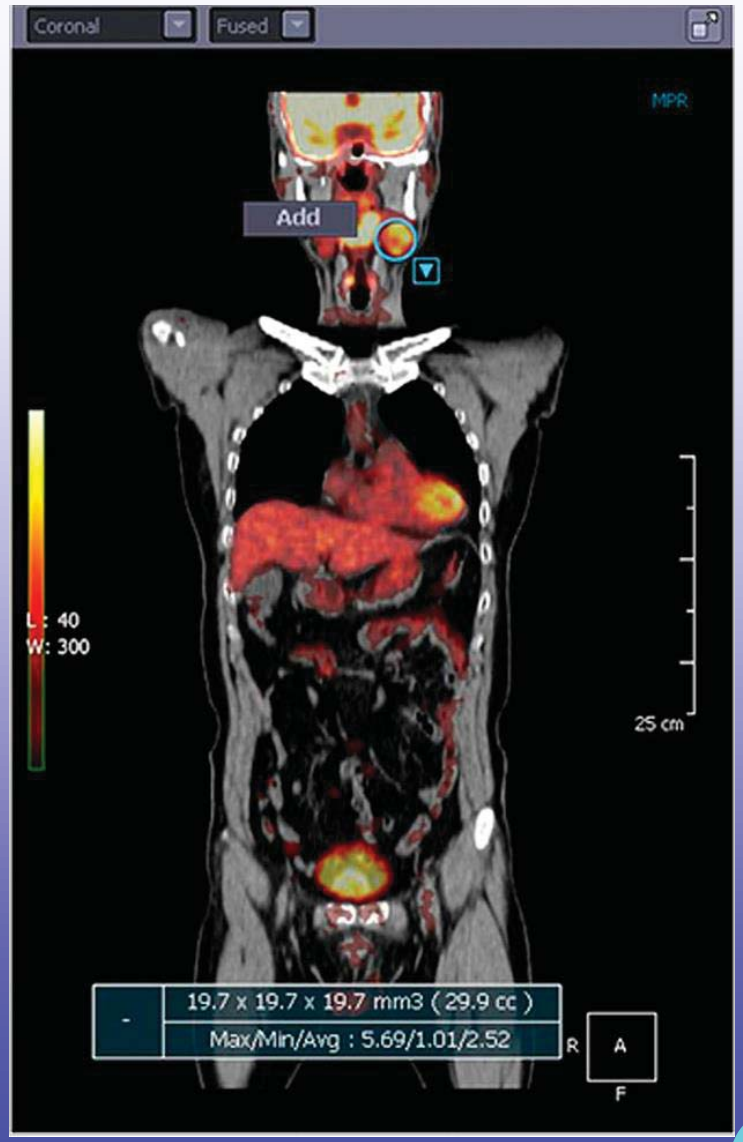
[^{18}F]-FDG

CT

PET/CT

Steinert, Methods Mol Biol. 2011

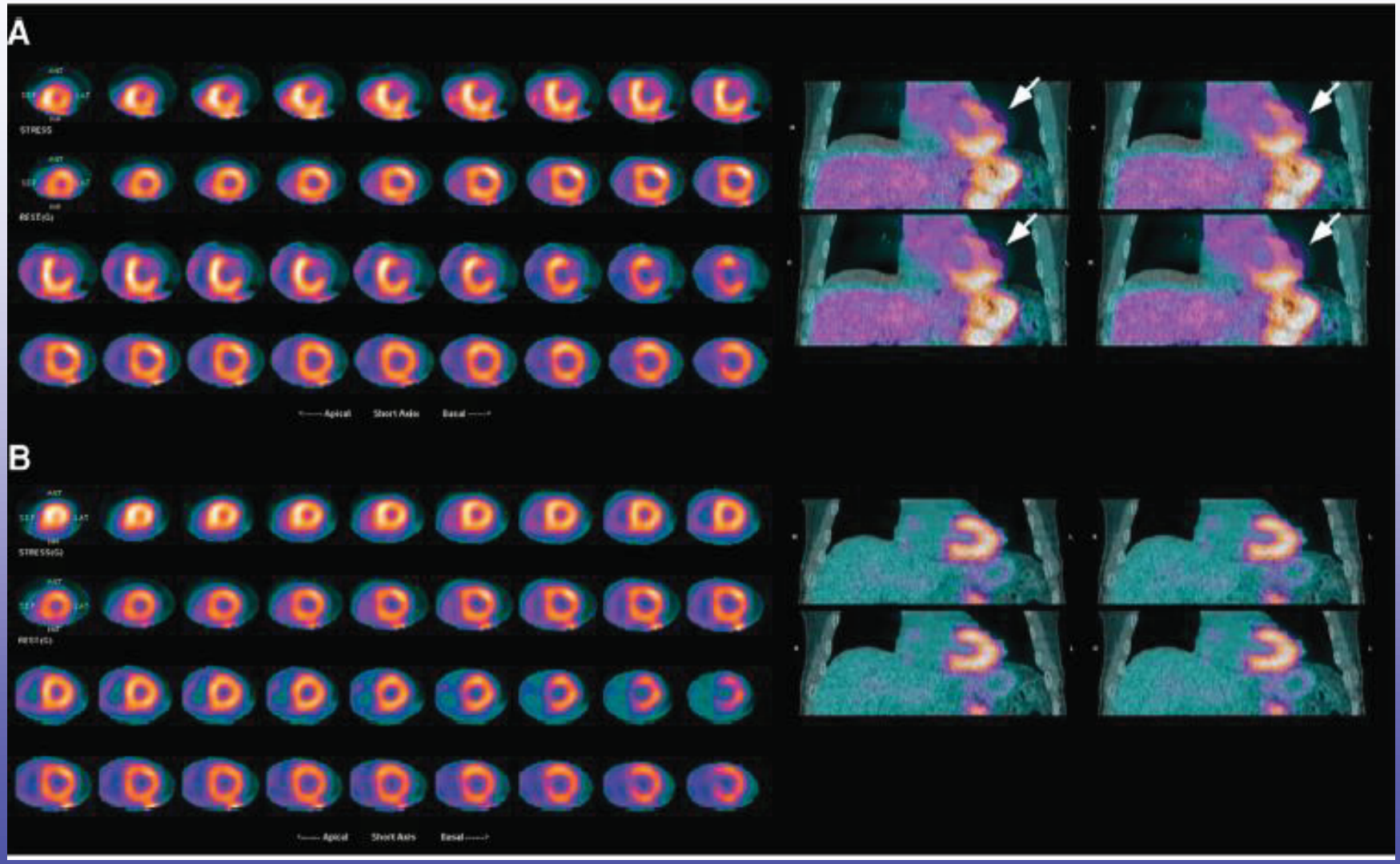
PET/CT



FDG in
Salivary Gland Carcinoma

Rye et al., JNM 2013

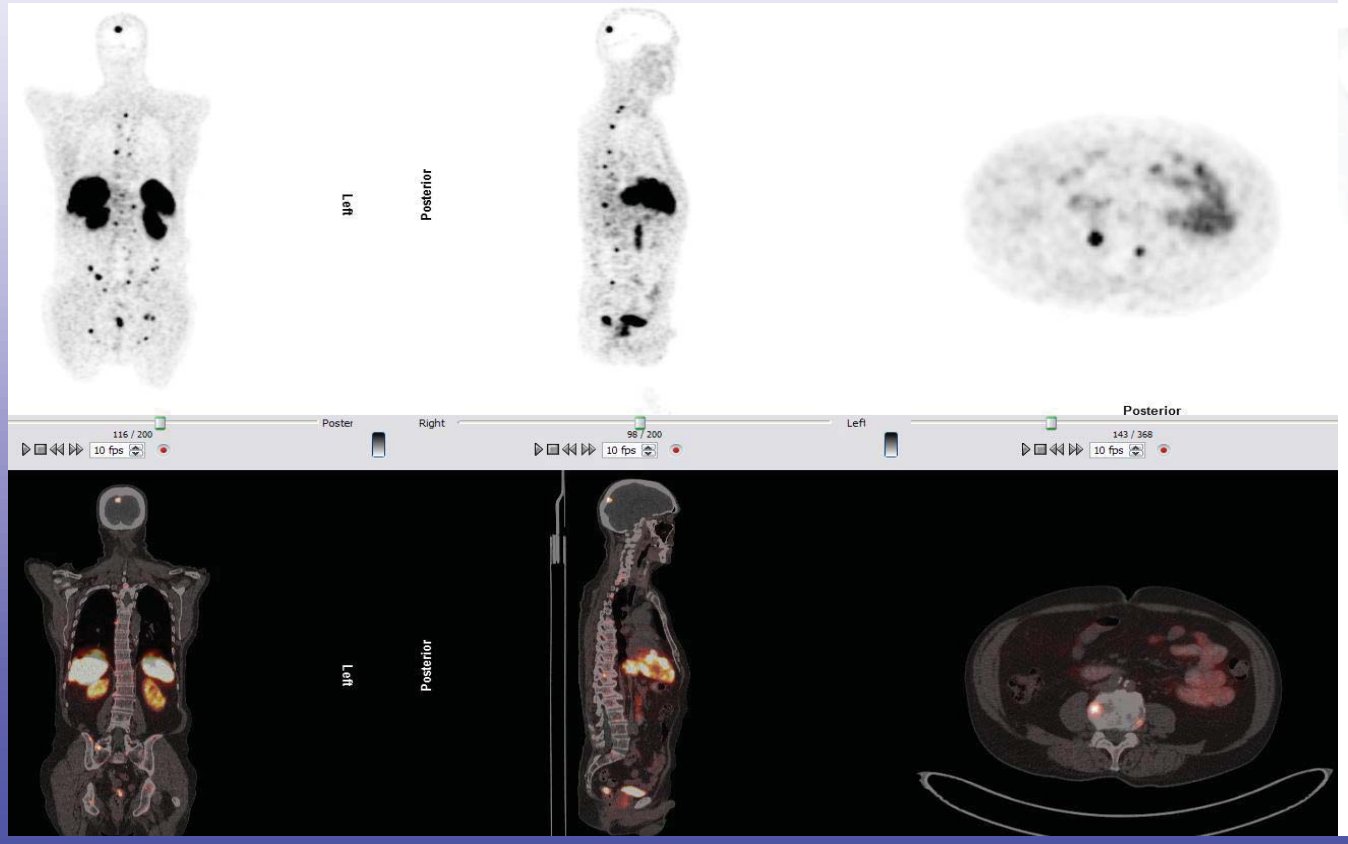
Problem of PET-CT-Mismatch

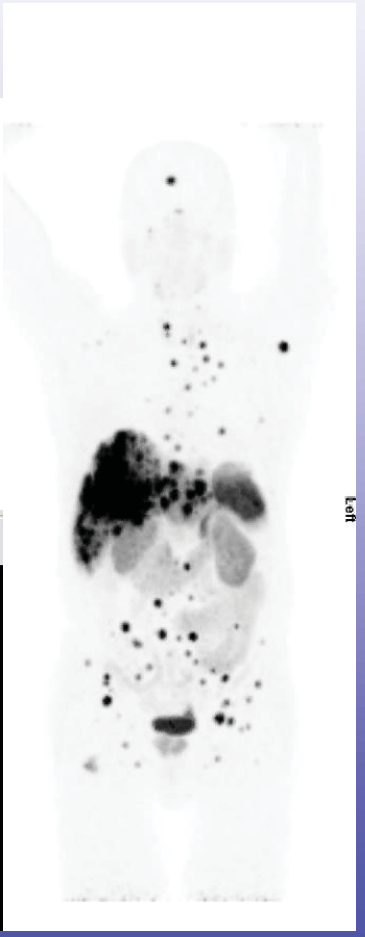


Di Carli, JNM 2007

PET/CT
in an Endocrinal Tumor

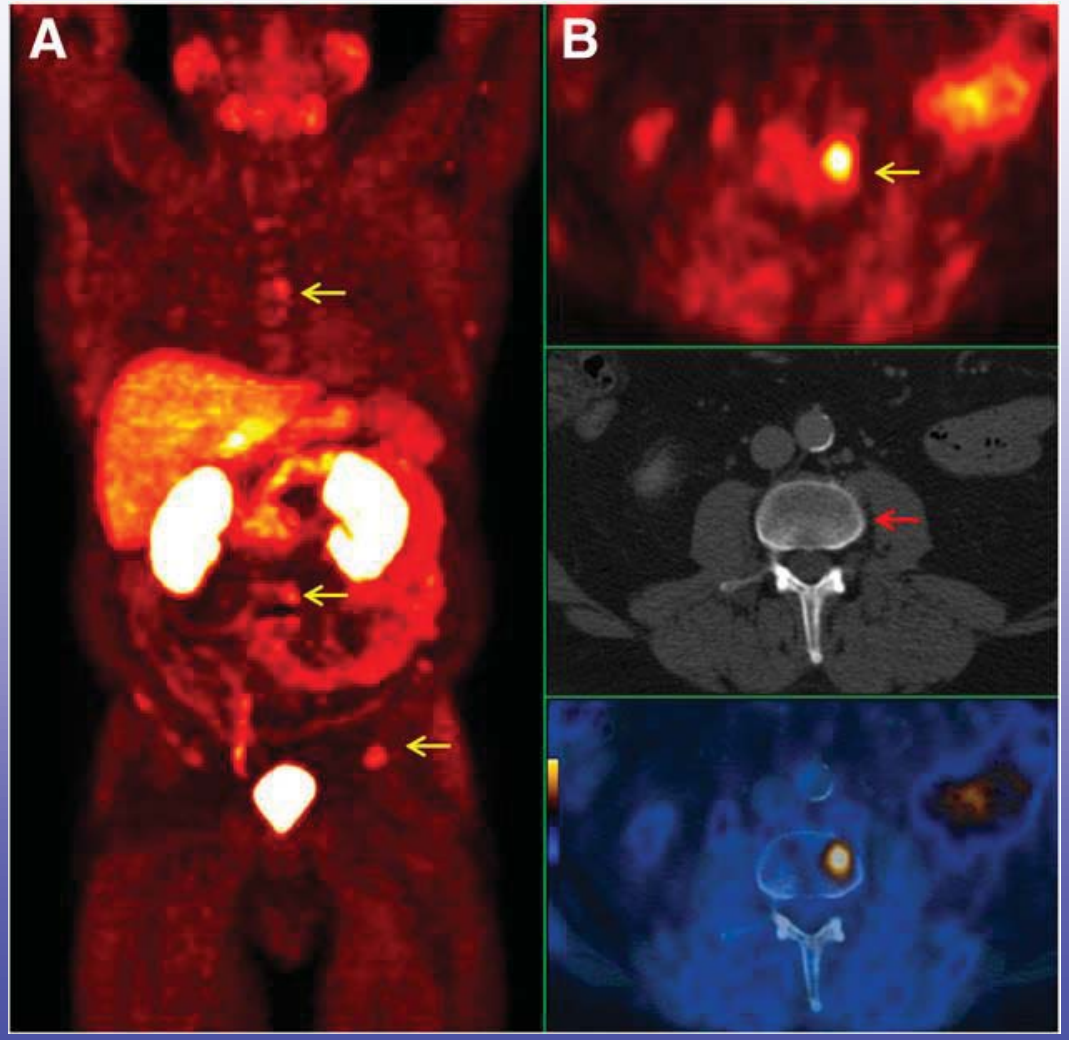
[^{68}Ga]-DOTATATE
(180 MBq iv; 3 min/bed scan)





D. Bailey,
Royal North Shore Hosp., Australia

PET-CT
[18F]Choline in Prostate Cancer



Beheshti M et al., JNM 2013

Thank you

for your kind attention