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JÜLICH FORSCHUNGSZENTRUM

Selected Aspects of Hybrid MR-PET Imaging

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Topics:

• What is **Hybrid** Imaging?

• Basic Elements of Medical / Biomedical Imaging

• How **Image Fusion** stimulated Hybrid Devices like *SPECT/CT & PET/CT*

• Challenges in Combining **MR + PET = MR-PET**

• Configurations in Operation

What is Hybrid Imaging?

Whenever we consider to combine two different modalities, we call the result a hybrid imaging device:

SPECT/CT, PET/CT, PET/MRI (or MR-PET), SPECT/MRI, PET or SPECT / Optical Imaging Systems, X-ray-Fluoroscopy / MRI, Photoacoustic Tomography, Optical / MRI

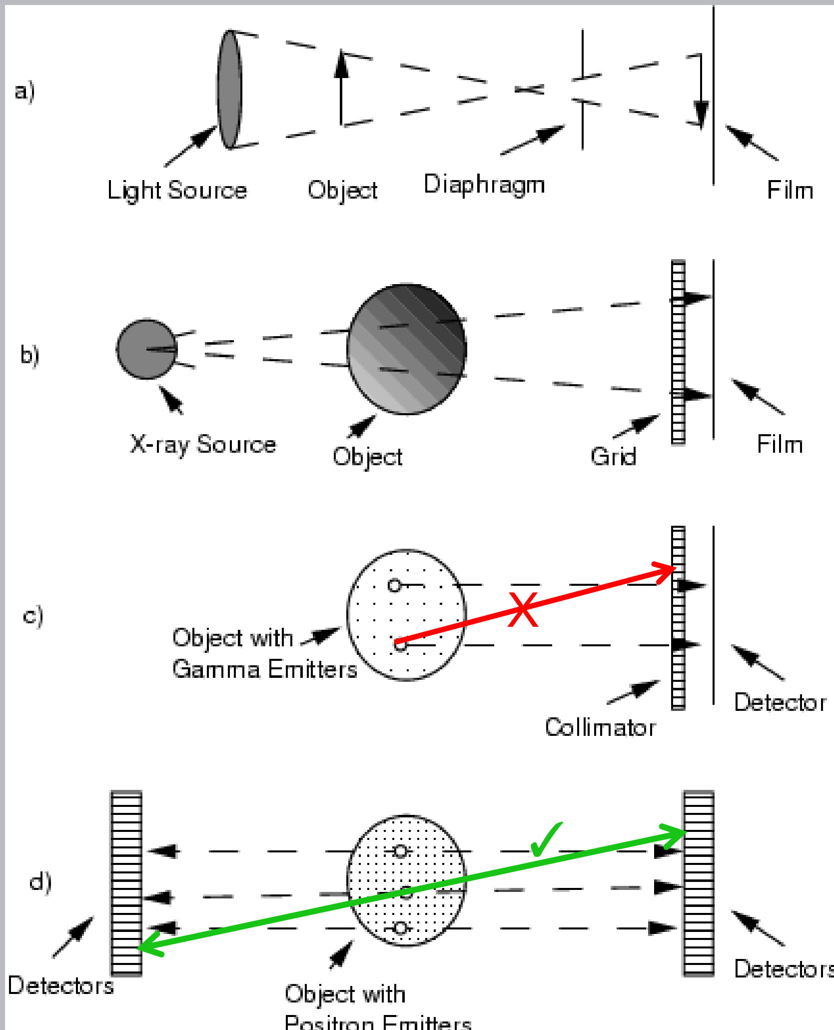
& Appropriate smart probes !!

→ Paradise for Photo Detectors !!

Result: Combined Information / Fused Images

(Inspired by: S. Cherry, Semin Nucl Med 2009; 39:348-353)

The Basic Principle of Imaging



Source (external)

↓

Object (+ Source)

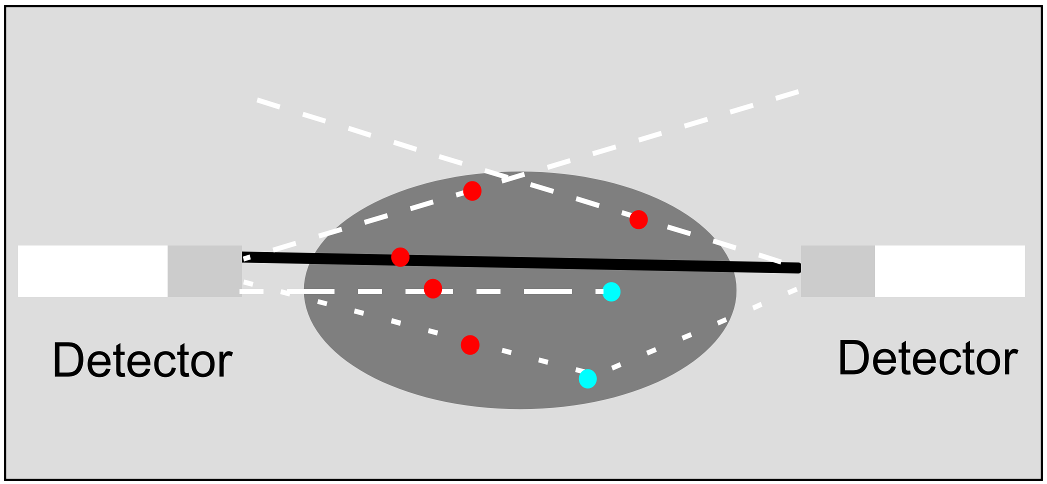
↓

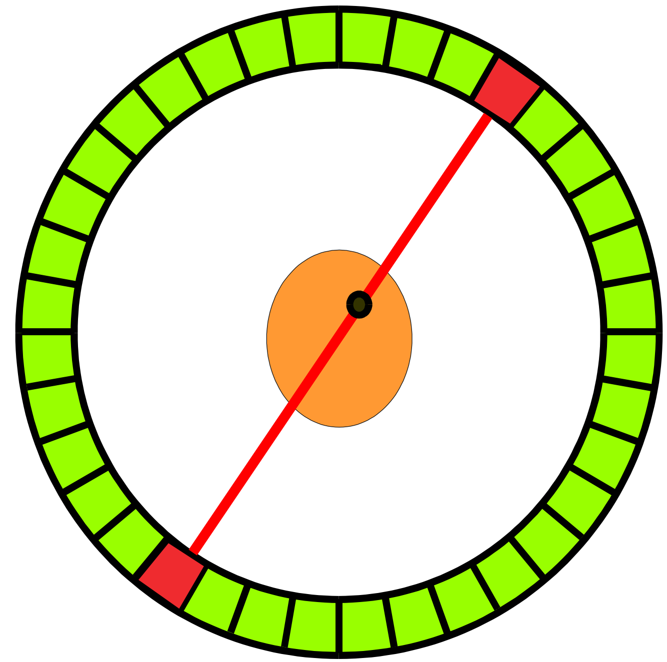
Selection / Definition using:
(a) Diaphragm/Aperture;
(b) Grid;
(c) Collimator;
(d) Coincidence Circuit)

↓

Detector

Basics in Positron-Emission-Tomography (I)

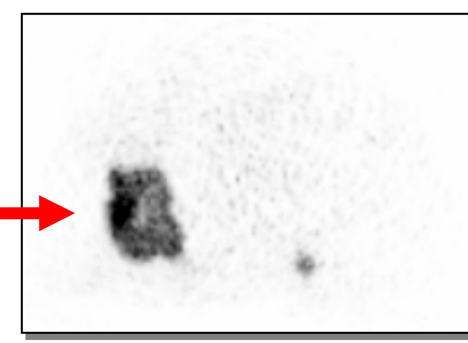




Note

Two co-linear photons ⇒ No collimation!
Need correction for scatter and attenuation!

Unknown tracer-distribution in an environment of unknown denstity



Basics in Positron-Emission-Tomography (II)

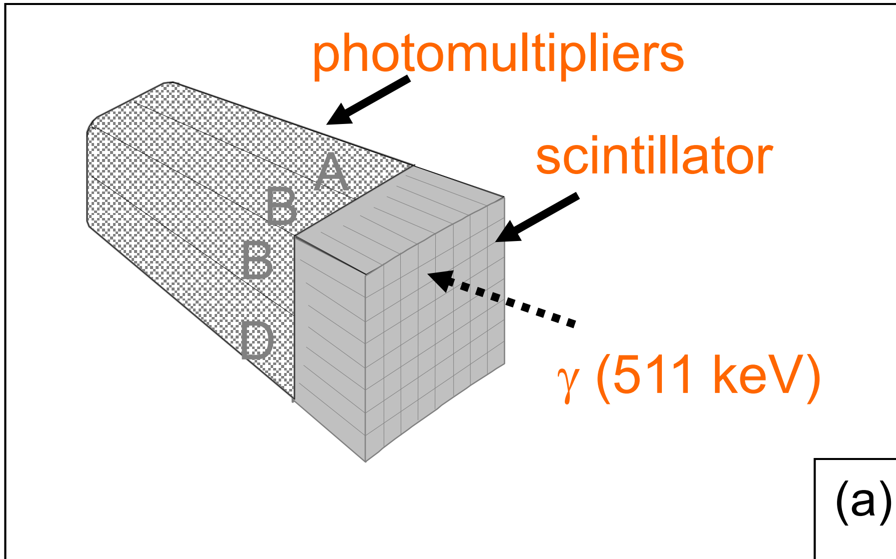
Imaging System Components:

- Detector → high resolution and high sensitivity
- Scintillators (LSO / GSO, ...) → PMT or APD → fast electronics
- highly specific tracers, → „smart probes";

  → nano molar concentrations
- suitable isotope: ^{18}F (T1/2 109.8 min, avg. E_{kin} 0.242 MeV,

  range: FHWM 0.22 mm)
- precise image reconstruction incl. corrections

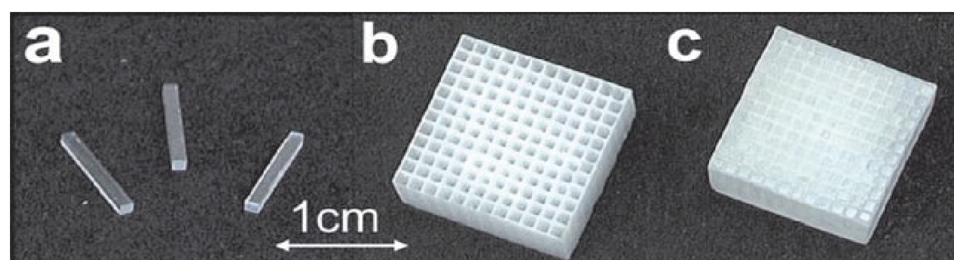
Basics in Positron-Emission-Tomography (III)



(a) 1×1×10mm LSO crystals,

(b) polyurethane grid and

(c) completed 12 × 12 scintillator array.



Fundamental Difference Bridged by Hybrid devices & Image Fusion!

Functional Imaging

PET and SPECT

Nuclear Medicine:

PET = Positron Emission Tomography

SPECT= Single Photon Emission Computed Tomography

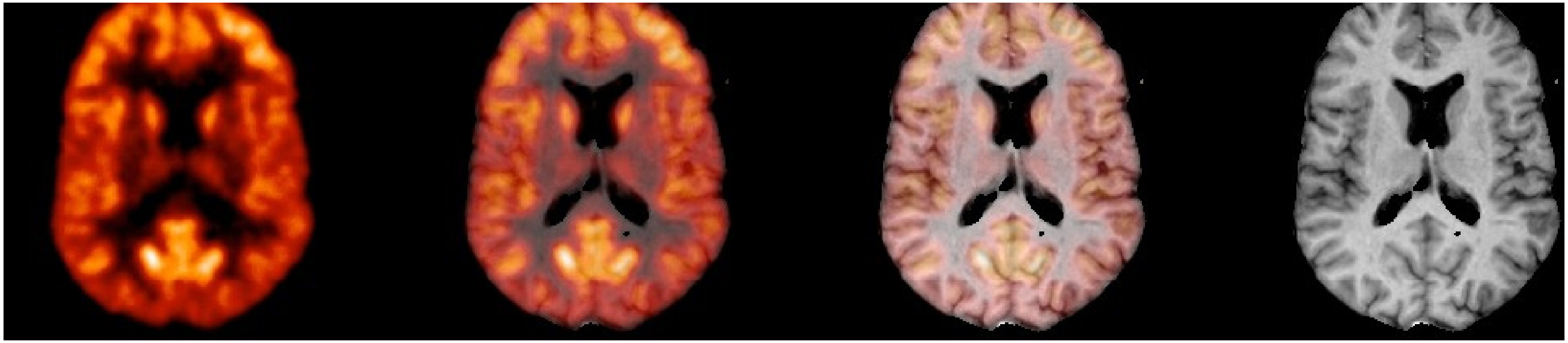
Structural Imaging

CT and MRI

Radiology:

CT= X-Ray Computed Tomography

MRI= Magnetic Resonance Imaging



Aspects of Fusing Multimodality Image (I)

Structure without Function is a Corpse ... Function without Structure is a Ghost (Stephen Wainwright)

**(from: D.W. Townsend,
Dual-Modality Imaging: Combining Anatomy and Function,
J Nucl Med 2008; 49:938-955)**

Image Fusion ...

is to give Life back to the Corpse and show the Ghost where it comes from

Aspects of Fusing Multimodality Image (II)

→Image Fusion – expectation ~20 Years ago (~1991)

... Software based Image Fusion will guide us to what we would like to see as hybrid imaging devices ...

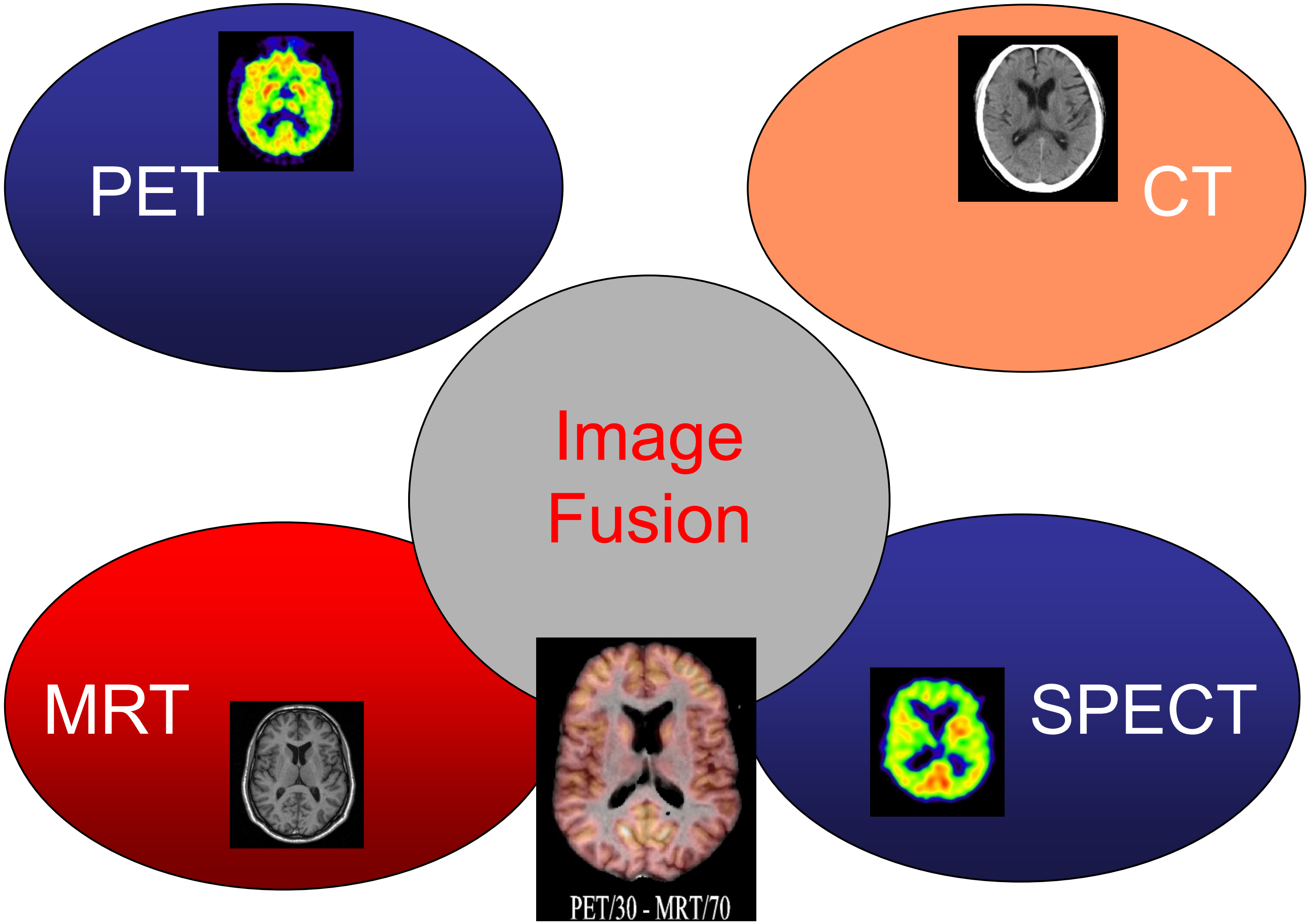
→Image Fusion – reality today (2011)

... Software based Image Fusion has guided us to what we now see as hybrid imaging devices ...

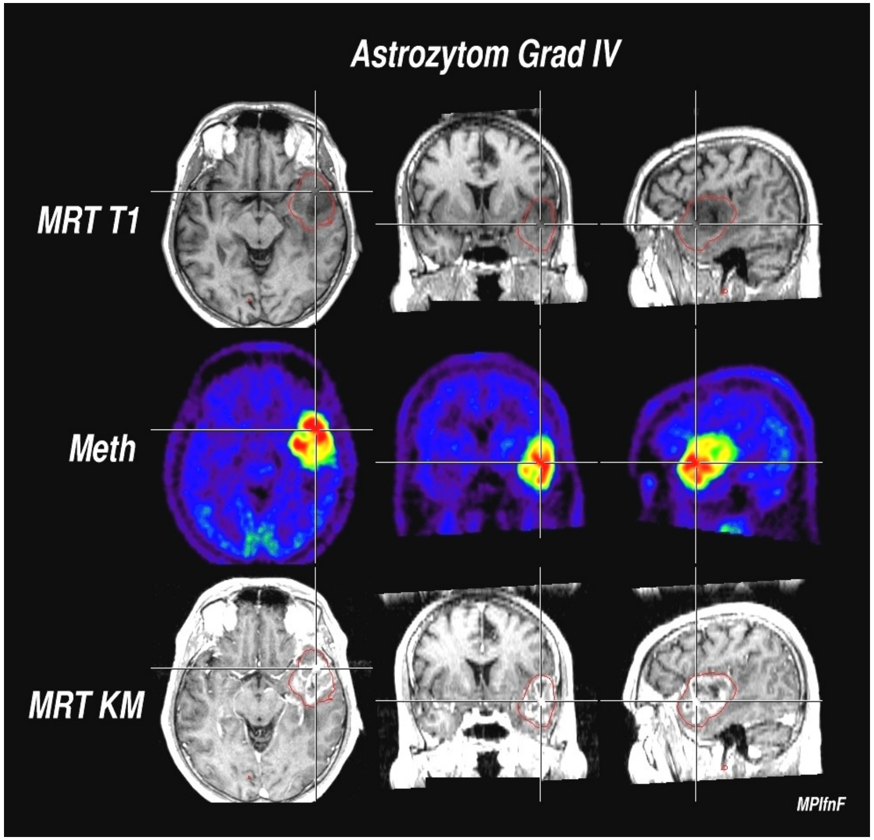
Note:

We always apply *Software* to obtain „Fused Images“!!

Data from Different Systems: need software to register and fuse images (I)



Data from Different Systems: need software to register and fuse images (II)



MRI-guided PET (~1994)

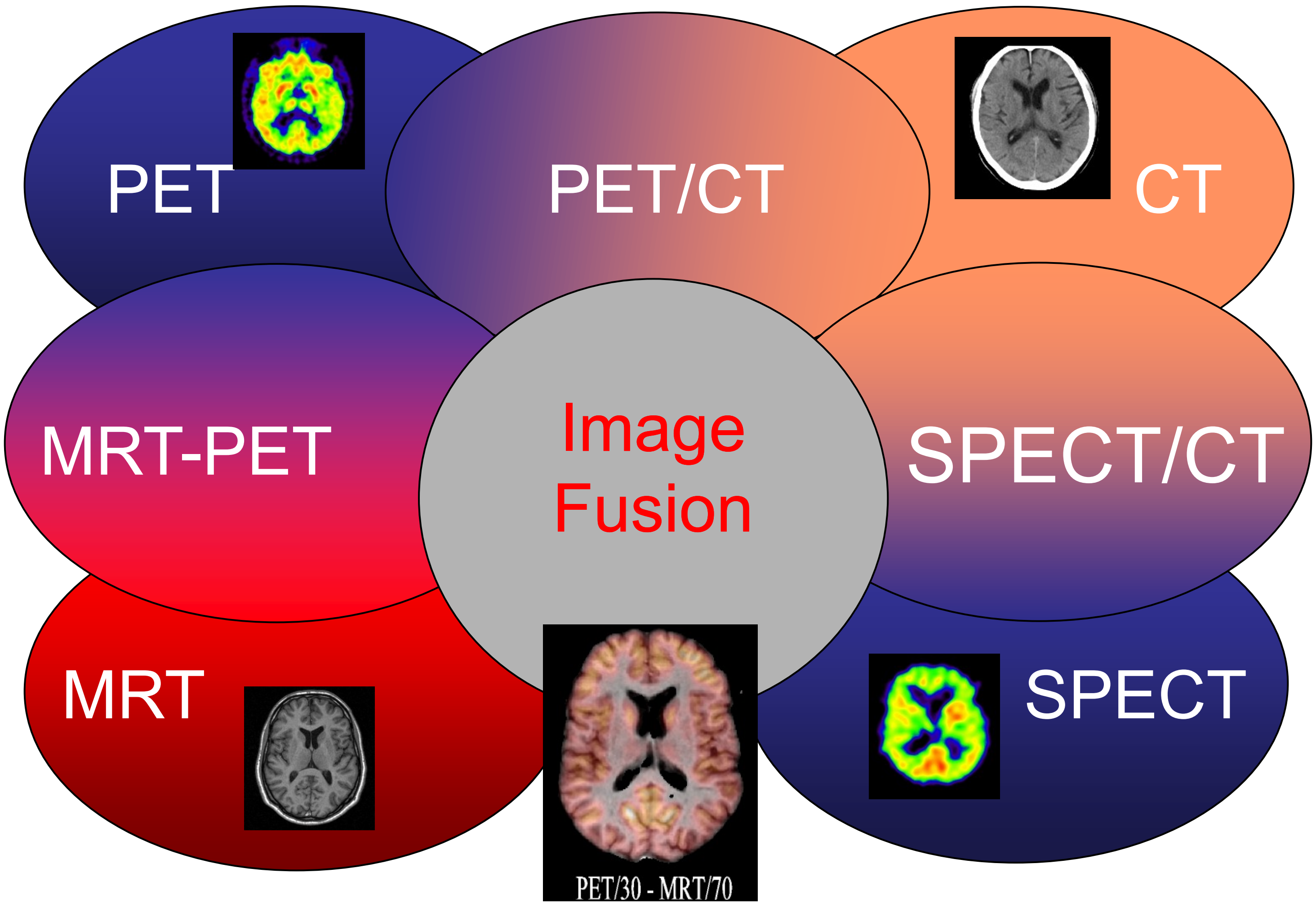
S u c c e s s

of software based registration in *brain studies* has promoted hardware based fusion!

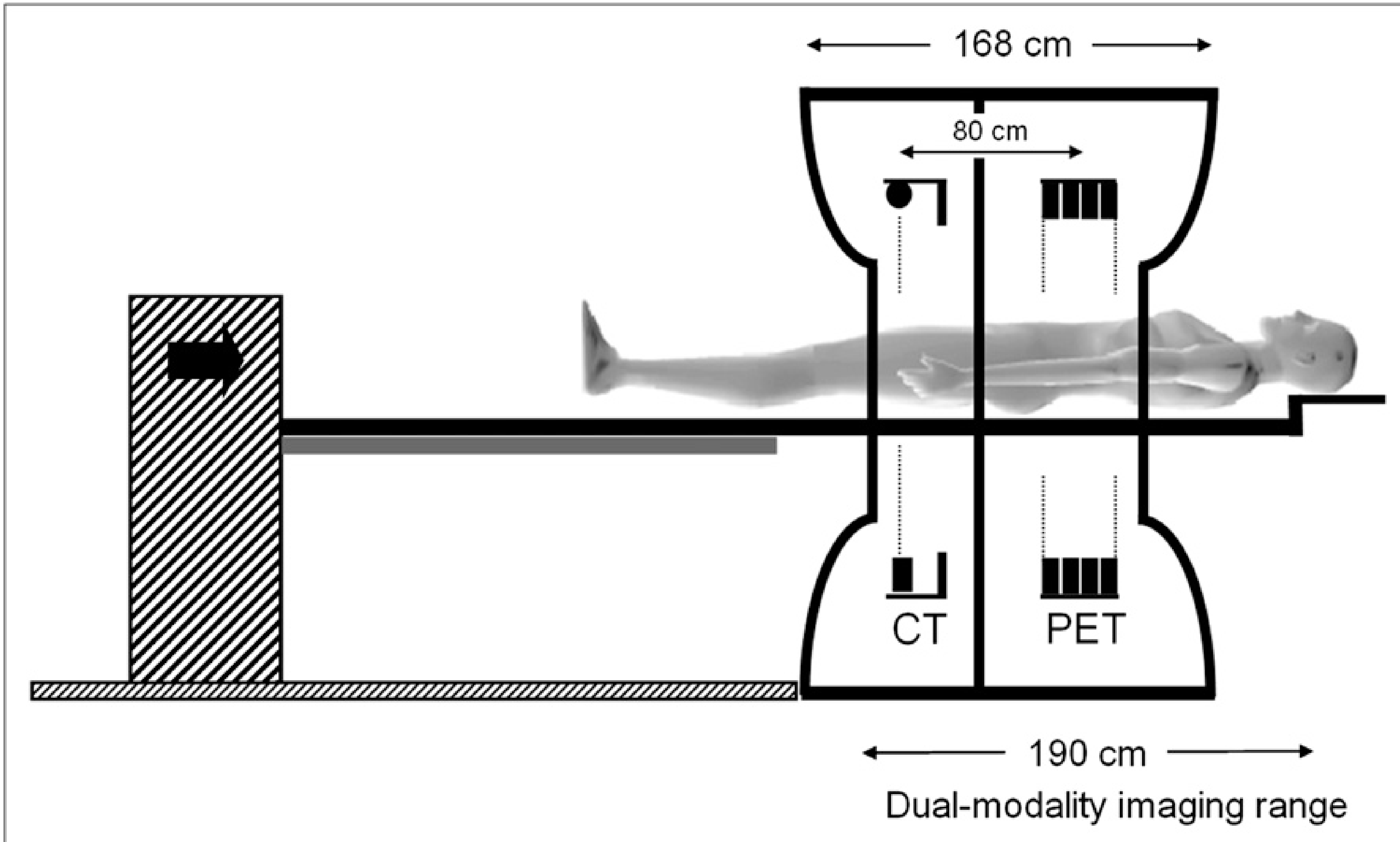
F a i l u r e

of software-based registration in *extra-cranial studies* (motion and displacement of organs) has promoted dual-modality systems!

Images from Hybrid Systems: <u>Sequential</u> Acquisitions



Images from Hybrid Systems: Sequential Acquisitions (PET/CT)

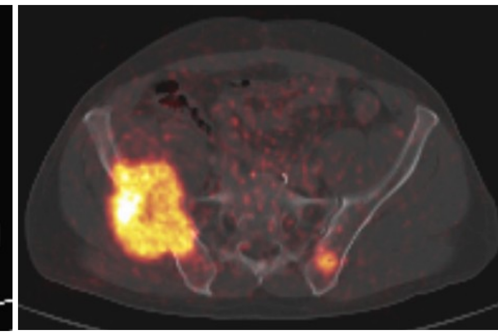


[D.W. Townsend, J Nucl Med 2008; 49:938-955]

Typical Application for PET/CT

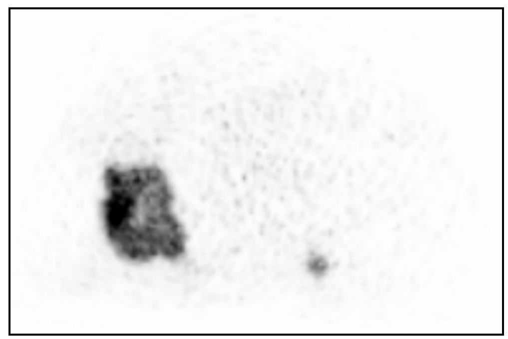
CT

Fusion



•Highly specific tracer
•Focal uptake

80 MBq, 4h pi,
6 min / bed position

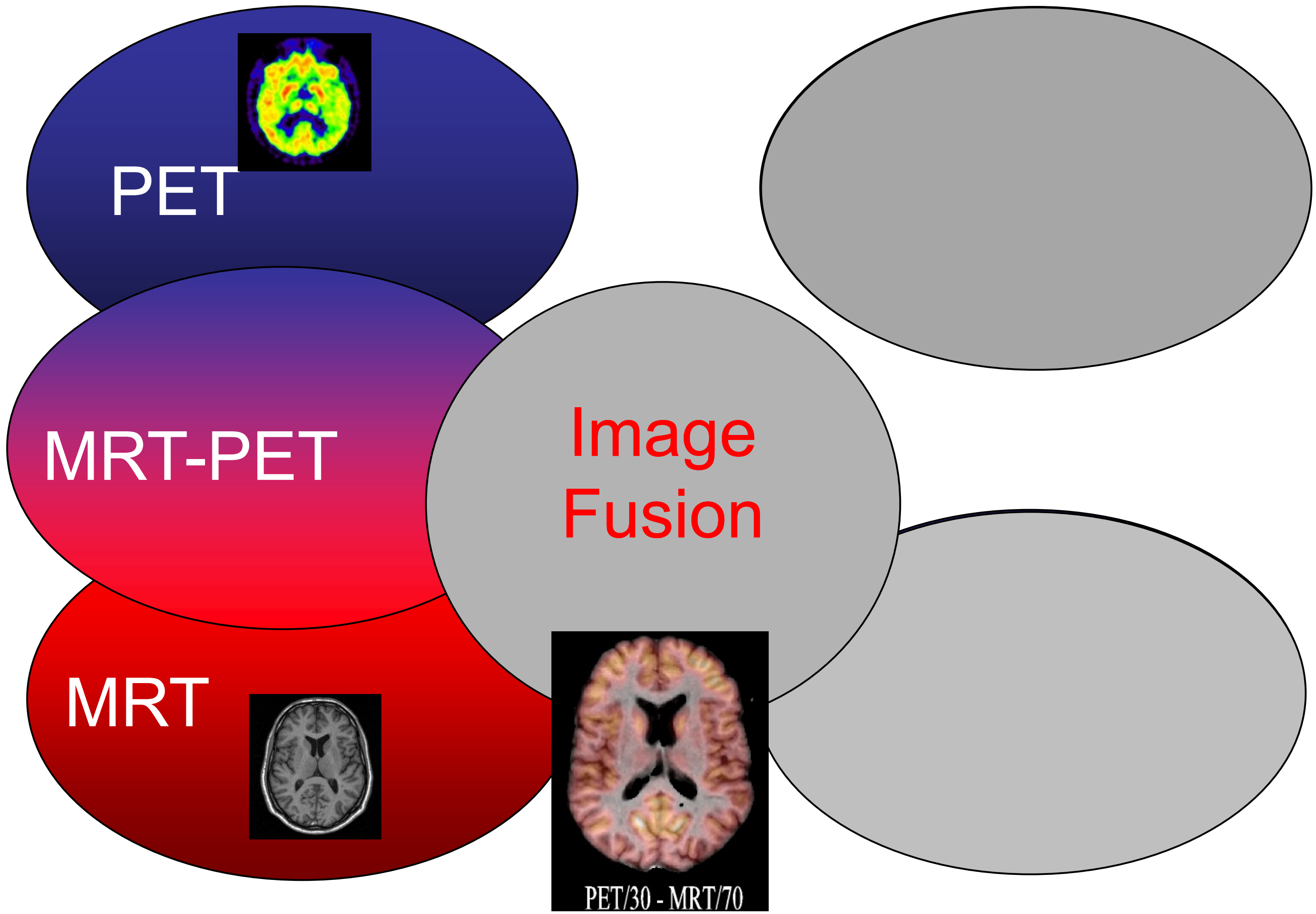


^{68}Ga-DOTATOC

(M Hofmann)

BUT: PET/CT is not truly simultaneous ->
Danger of movement -> artefacts in quantitative PET images

Images from Hybrid Systems: Simultaneous Acquisitions

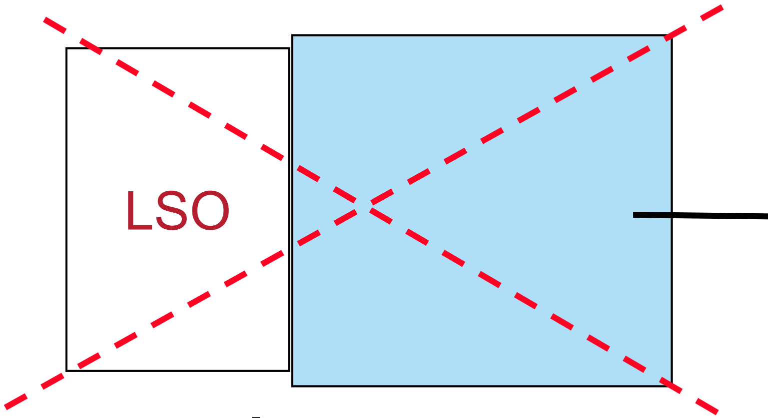


Complementary Devices: Hybrid Imaging with MRI-PET

Parameter	MRI	PET
Anatomical Detail	Excellent	Poor
Spatial Resolution	Excellent	Compromised
Clinical Penetration	Excellent	Limited
Sensitivity	Poor	Excellent
Molecular imaging	Limited	Excellent

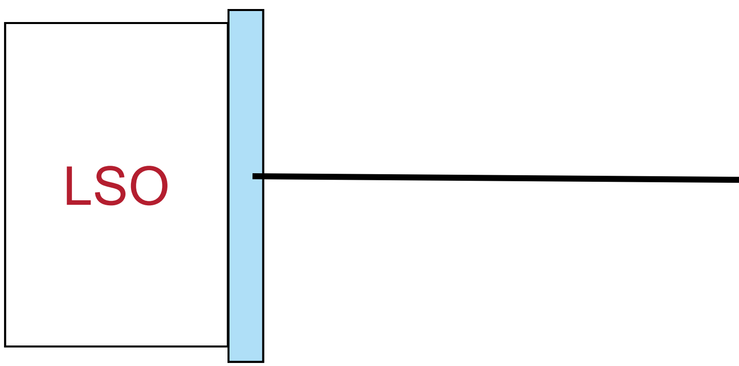
Note: Already today, PET is mostly available as a combined modality, namely PET/CT

Current Developments for PET (1)



PMT:
Size:10-50 mm
Gain: up to 10^6
Risetime: 1 ns
QE: 20 %

Classic solution:
Scintillator + PMT



APD:
Size:5x5 mm^2
Gain: up to 200
Risetime: 5 ns
QE: 60

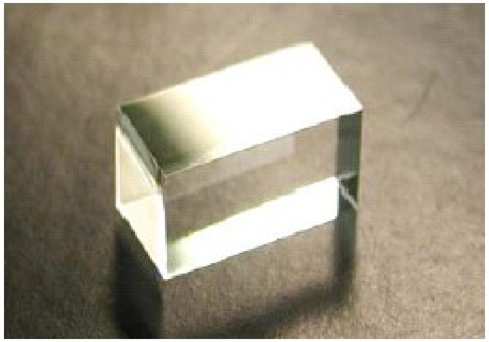
SiPM:
Size:5x5 mm^2
Gain: 10^5-10^6
Risetime: 1 ns
QE: 30%

Modern solution:
Scintillator +
APD / SiPM

More Compact!

Current Developments for PET (2)

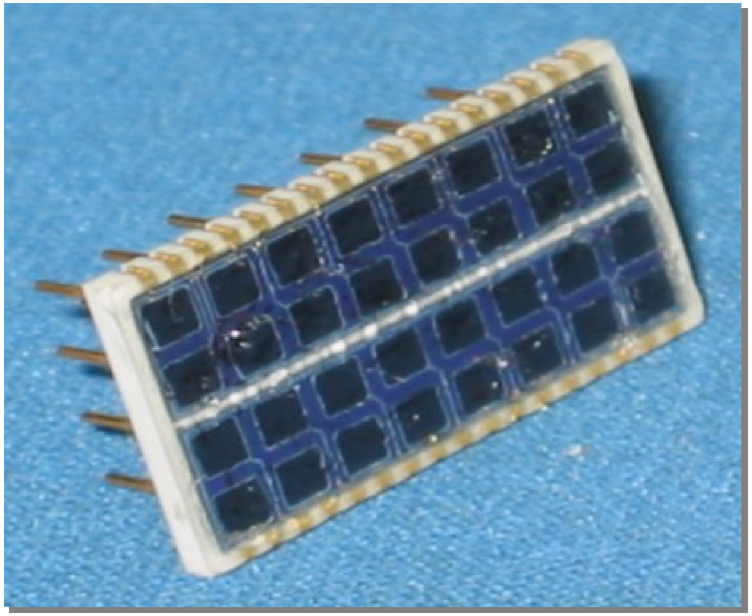
pixelized
scintillator
block



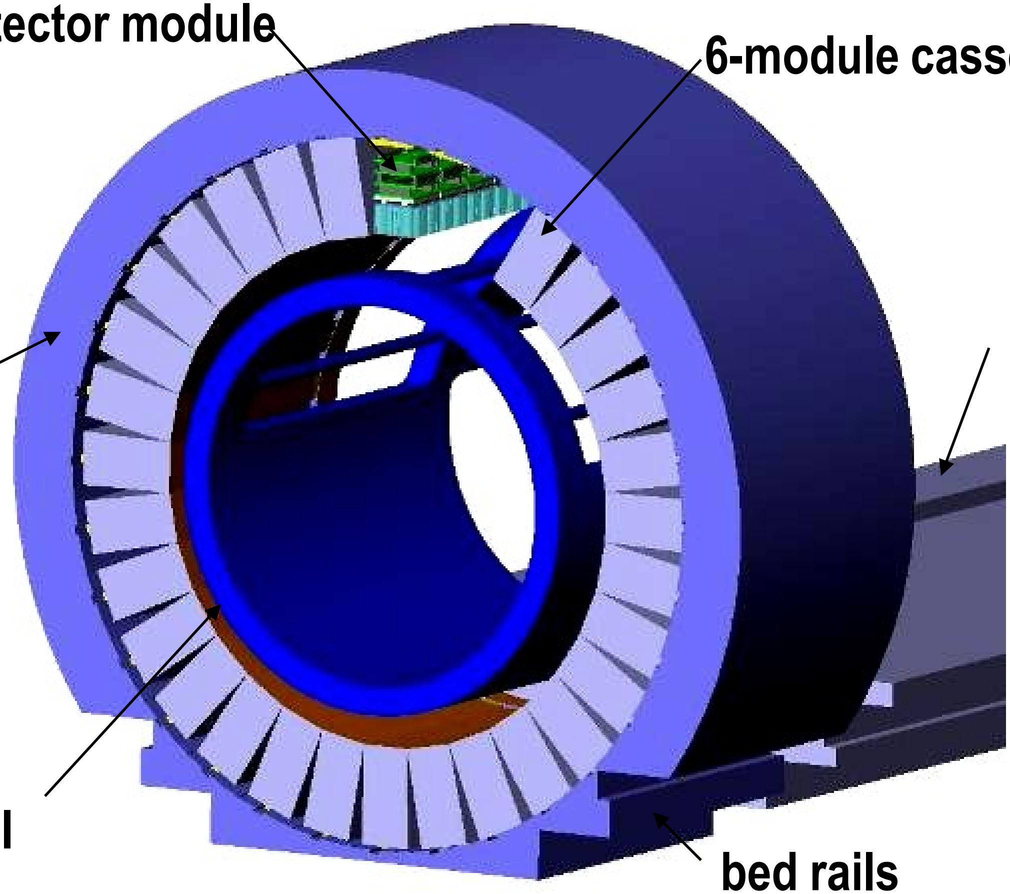
monolithic
scintillator
block

- more compact PET
- much less “dead space”
- higher sensitivity

APD
Hamamatsu
4x8 elements
10.5x20.7 mm^2



Current MR-PET Design for Brain Imaging

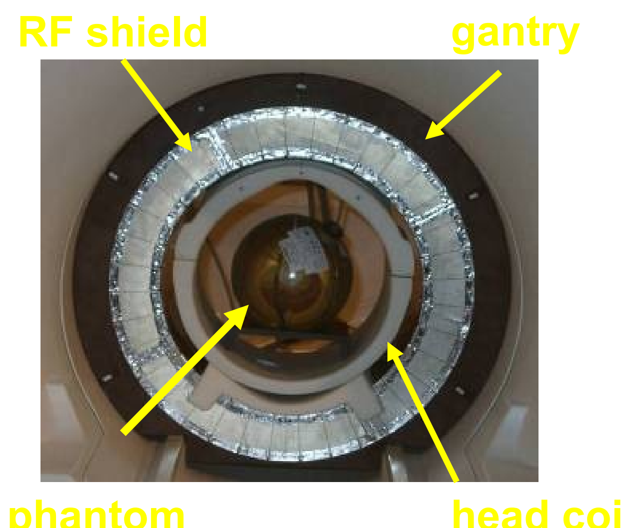


Siemens

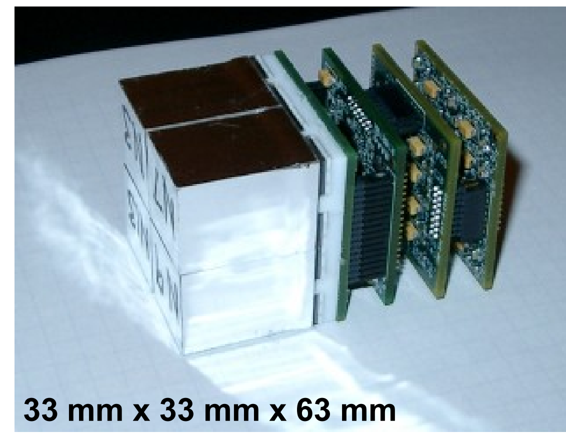
Scanner size: 36cm dia. x 20cm FOV

MR-BrainPET: Major PET-Components

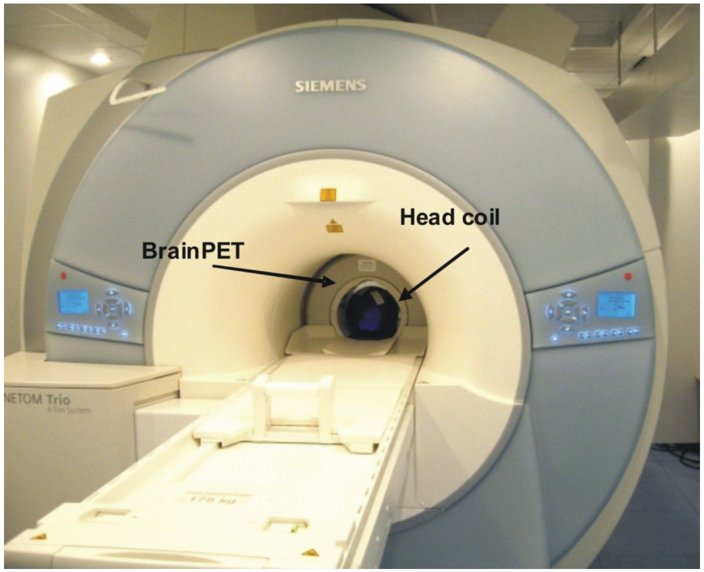
PET insert



new integrated detector block



BrainPET in a 3T-MRI-scanner Siemens MAGNETOM Trio



H. Herzog, Jülich

Detector: 12x12 LSO crystals 2.5 x 2.5 x 20 mm^3

Readout: 3 x 3 APDs (**Hamamatsu)**

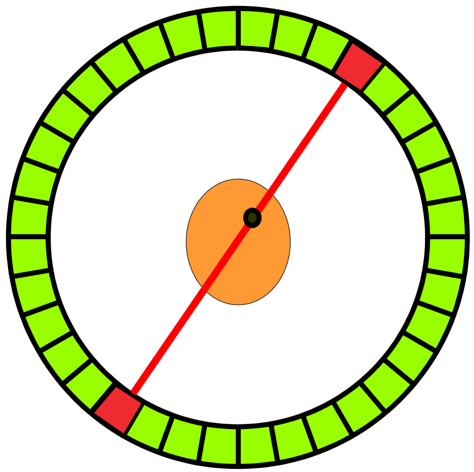
Resolution (FWHM, mm) : r =	**0 cm**	**2.5 cm**	**5 cm**
Tangential:	2.3	2.4	2.0
Radial	2.0	2.4	3.3
Z-Direction	2.5		3.1

Still need to get the attenuation map in MR-PET Imaging!!!

Correction for Photon Attenuation

Classic approach for stand-alone **PET**:

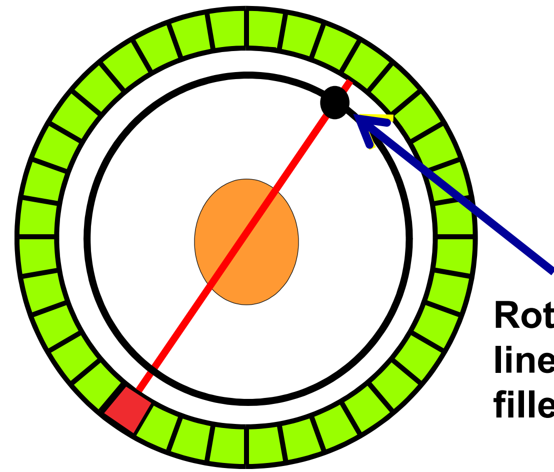
Emission measurement



The detector measures

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

Transmission measurement



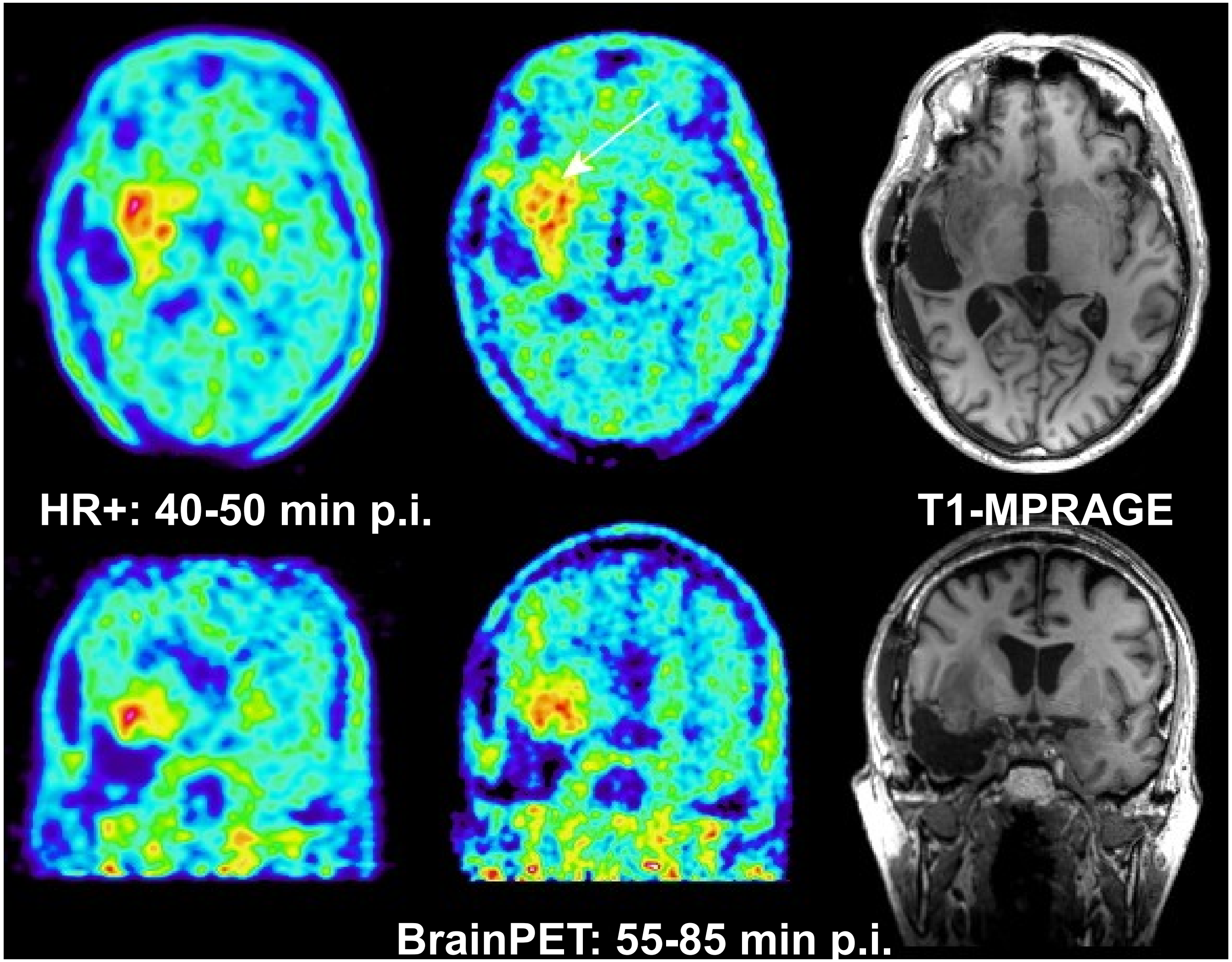
The detector measures

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

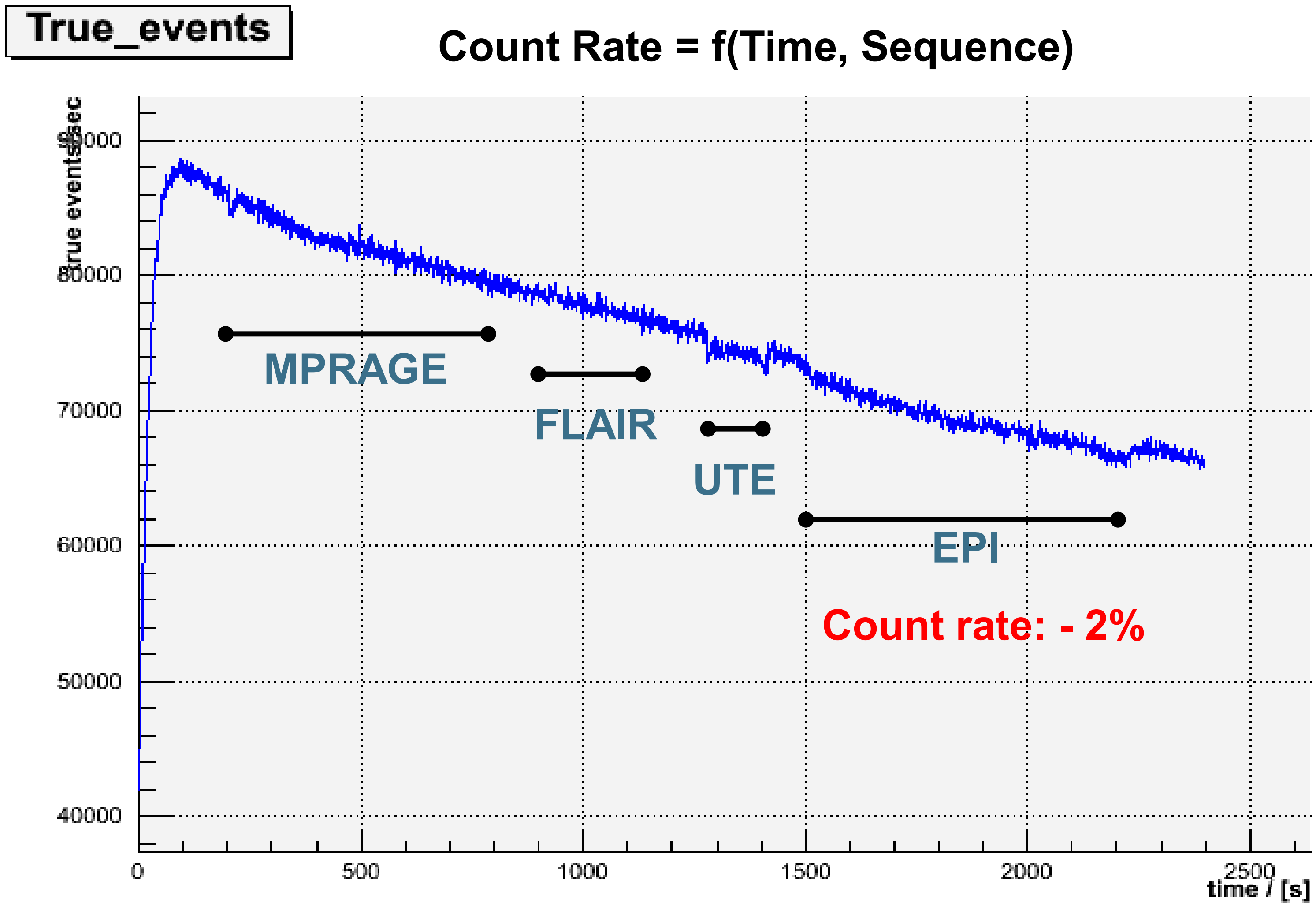
$$\rightarrow \; P_E^{corr} = P_E / AF = \int A(x,y)\, dl$$

Approach for **PET/CT**: AF calculated from CT-values!!

Simultaneous MR-BrainPET measurement of a brain tumor after injection of [^{18}F]-FET



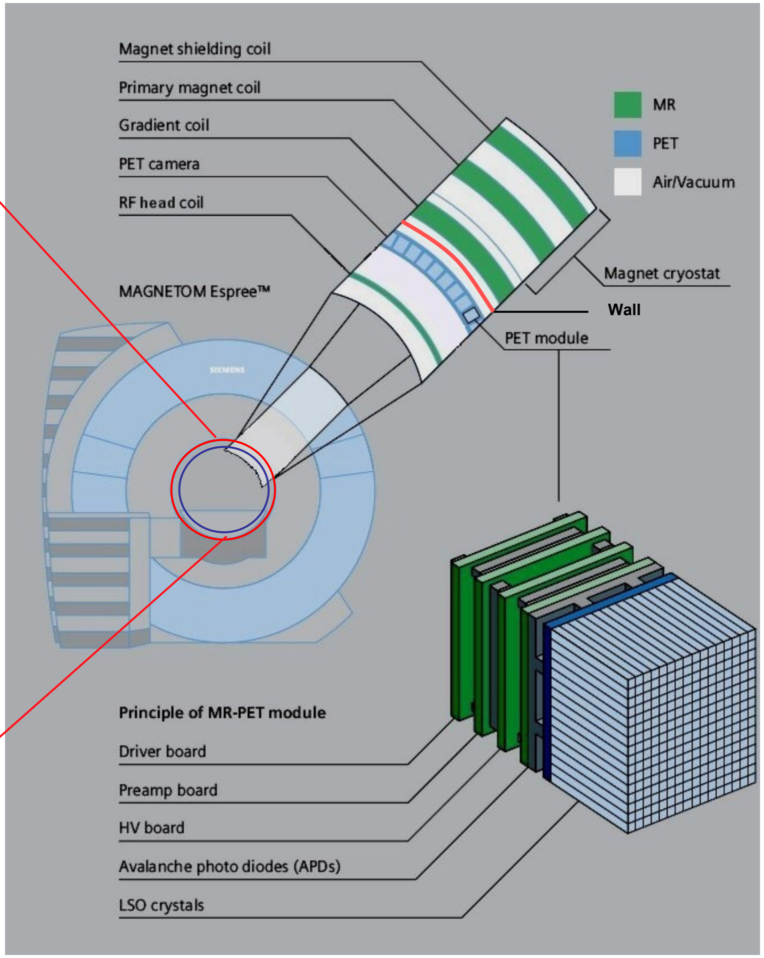
Mutual Influence in MR-PET –
a Challenge for Quantitative Imaging ??!!



MR-PET Design for Whole Body Applications

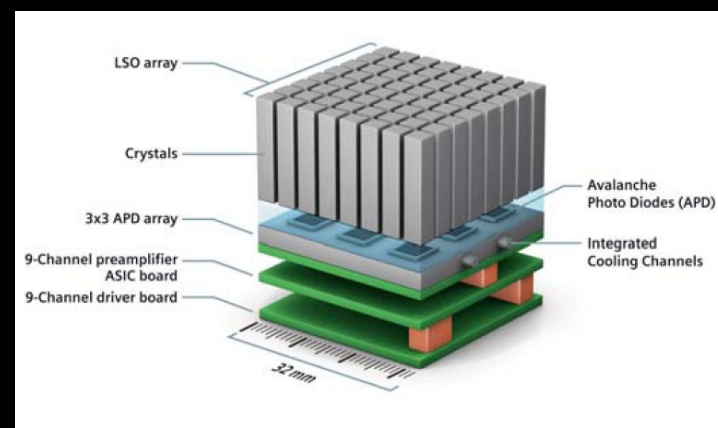
PET ring inside gradient:

1. Easy removal of PET ring for maintenance and repair
2. Higher S/N for PET
3. Annihilation photons need only traverse RF coil --> minimal scatter
4. Gradients need more current
5. Stronger coupling of RF coil



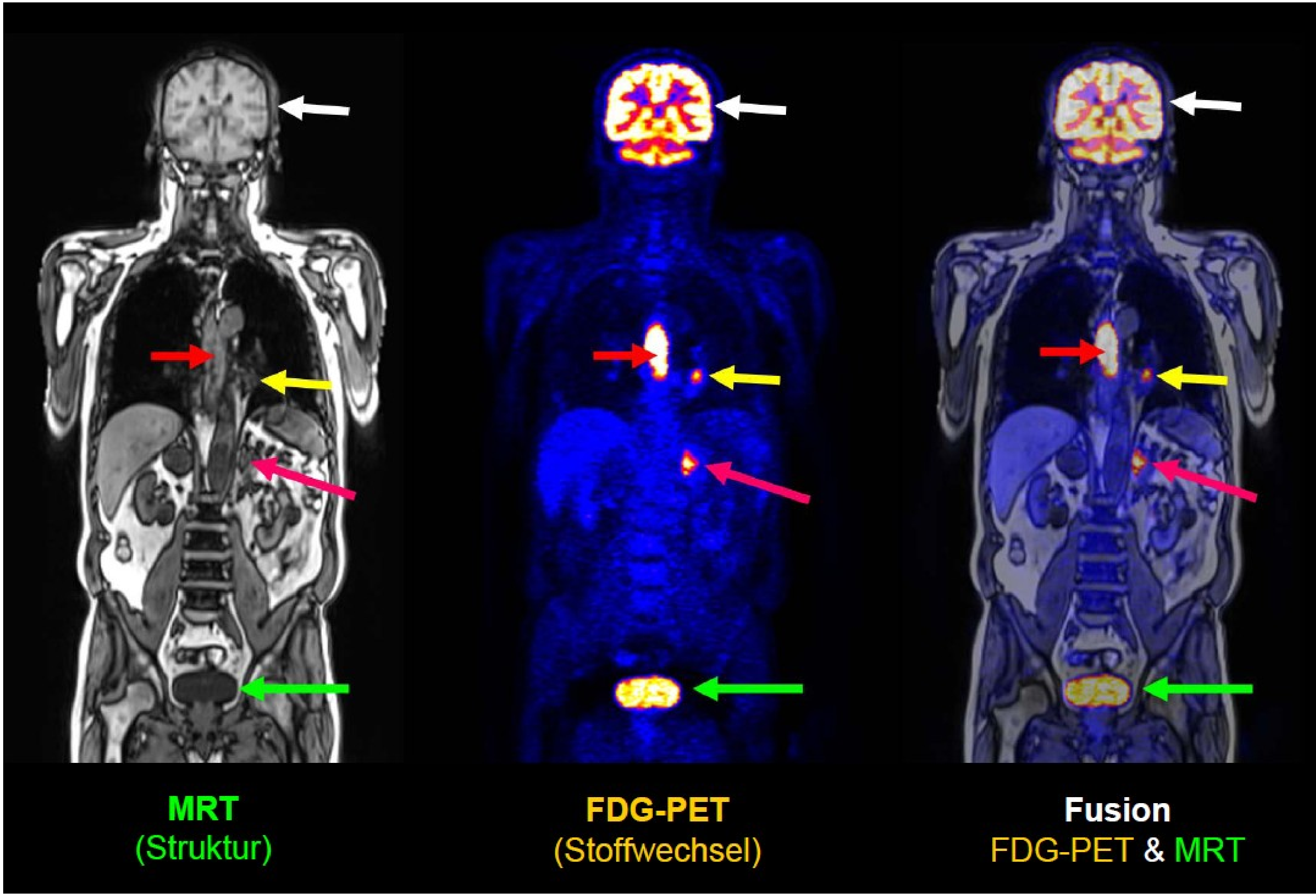
Schwaiger, Ziegler et al., 2005

MR-PET Design for Whole Body Applications



Courtesy: Sibylle Ziegler, TU Munich, Fall 2010)

MR-PET Design for Whole Body Applications

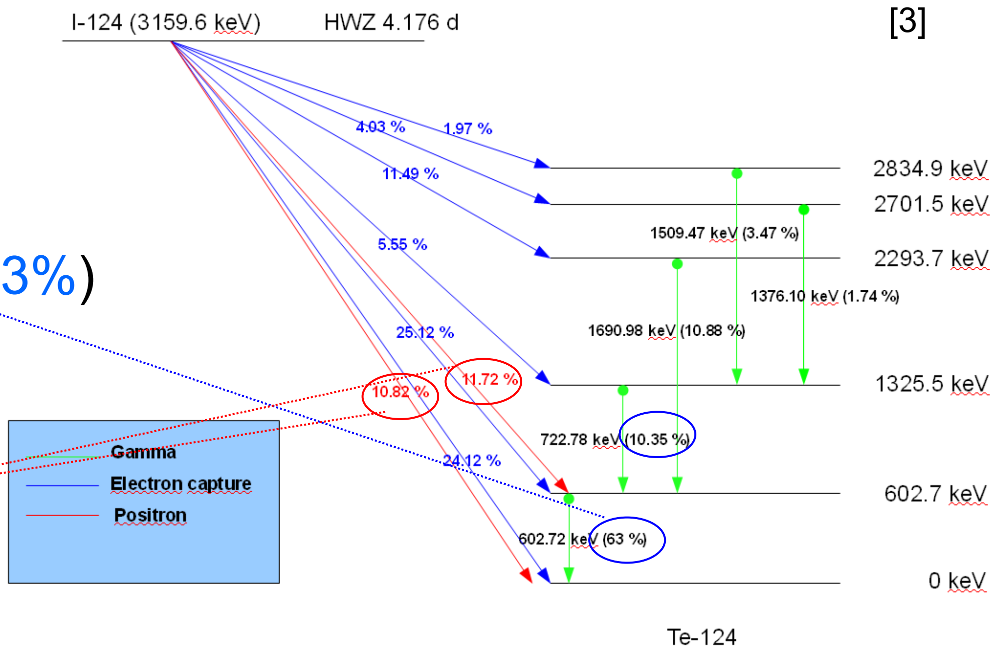


Courtesy: Sibylle Ziegler, TU Munich, Fall 2010)

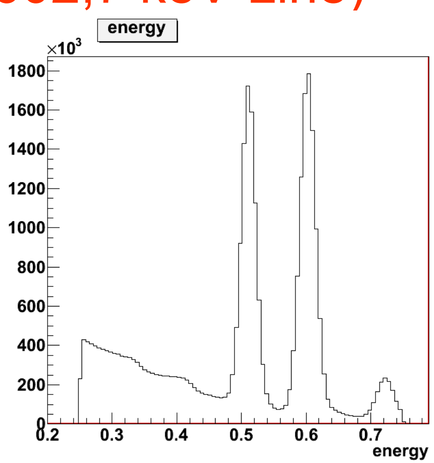
Finally: Why we really need good energy resolution!!

Decay scheme of I-124:

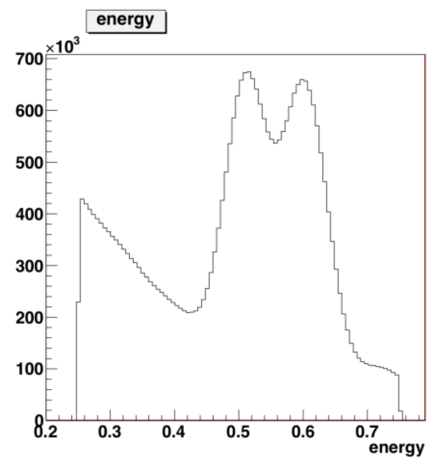
- Separate γ-Lines:
  - additional Emission to e⁺–Annihilation
  - 602,7 keV-Line dominant (63%) & within standard Energy Window (250 bis 750 keV)
- e⁺–Emission: 22,54% (11,72% in Coincidence with 602,7 keV-Line)



[3] http://www.nndc.bnl.gov/nudat2/



dE/E=5 %



dE/E=15 %

GATE-Simulations by Sophie Sauerzapf Uni Freiburg

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Christoph Parl	(ZEL, FZ-Juelich)
Matthias Streun	(ZEL, FZ-Juelich)

&

all Members of the Crystal Clear Collaboration
&
all Members of the OpenGATE Collaboration

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