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# MEDICAL PHYSICS WORKSHOP

## Devoted to PET Developments and Applications

6 - 8 September 2015

| | 6 Sept | 7 Sept | 8 Sept |
|---|---|---|---|
| 8:15 | | Session 3: PET and main applications | Session 7: RP in MP applications |
| 9:15 | Registration | | |
| 10:15 | Coffee break | Coffee break | Coffee break |
| 10:30 | Opening Session | Session 4: More PET imaging applications | Session 8: PET and HEP transfer to medical physics |
| 11:30 | | | |
| 12:30 | Lunch | Lunch | Lunch |
| 14:15 | Session 1: Medical physics in NM | Session 5: PET complements | Session 9: Use of PET in hadrontherapy |
| 15:15 | | | |
| 16:15 | Coffee break | Coffee break | Coffee break |
| 16:30 | Session 2: Medical imaging | Session 6: Hybrids system PET-MRI | Session 10: Open discussions and conclusion END |
| 17:30 | | | |
| 18:30 | | | |
| 19:30 | Welcome cocktail (St. Naum Monastery) | Banquet | |
| 23:00 | | | |

Ss. Cyril and Methodius University in Skopje

Congress Centre - Ohrid, Ohrid, Macedonia

INSTITUTE FOR MEDICAL PHYSICS
AMBILLY, FRANCE

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TERA

VARIAN medical systems

IEEE EMB

HUG Hôpitaux Universitaires Genève

ACIBADEM SISTINA

Bi-MEK

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# Ohrid-Workshop 6-8 September 2015

## PET cameras: Principles, use a hospital & ongoing developments

(# is for15 mn)
(= is for 30 mn)
(= = is for 50 mn)

**Time –table**
31/08/15

| Time | SUNDAY 6/9/15 : Introduction & CT, SPECT | MONDAY 7/9/15 : PET, Hybrid & Applications | TUESDAY 8/9/15 : Rad Protection & Developments |
|---|---|---|---|
| 08:15 |  | *Session 3 :* PET & Main Applications | *Session 7 :* Radiation Protection in MP applications |
| | *9:30 : Registration* | Chair : S. Petkovska | Chair : P. Le Dû, |
| | | == *PET Principle & History* — *I. Rausch, Vienna, A* | = *General Risks with Radiation* — *M. Medvedec, Zagreb, HR* |
| | | == *Clinical application of FDG PET/CT* — *J-N Talbot , Tenon Hospital., Paris-F* | = *Optimisation in Nuclear Medicine* — *M. Medvedec, Zagreb, HR* |
| 10:15 | *10:30* | | == *Patient, Workers, Public protection & Hospital* — *M. Medvedec, Zagreb, HR* |
| | Coffee Break | Coffee Break | Coffee Break |
| 10 :30 | *11:00* *Opening Session* | *Session 4 :* More PET Imaging Applications | *Session 8:* PET and HEP Transfer to Medical Physics |
| | Chair : D. Miladinova | Chair : M. Zdraveska | Chair : I .Rausch |
| | # *Welcome (University Rector or Dean)* | == *clinical PET/CT with other tracers* — *J-N Talbot, Tenon Hospital, Paris-F* | = shielding requirements for PET/CT — *J. Haglund , Fredrikstad, NO* |
| | # *Med. Phys. In MK, S. Petkovska, Skopje* | = *Research Example by Small Animal PET* — *Y.Lemoigne, IFMP & CERN-CH* | == *Transfer from HEP* — *P. Le Dû , IEEE & IPN Lyon-F* |
| | == *Medical Imaging Review* — *Y.Lemoigne, IFMP & CERN-CH* | = *Opportunities in early diagnosis & treatment* — *N. Papapostolou, Varian HA* | = *Developments in PET from HEP* — *L. Litov, Sofia Uni. BG* |
| | = *Interactions of biomedical oscillations* — *T. Stankovski, Skopje-MK* | | |
| 12:30 | *13:00* | | |
| | Lunch | Lunch | Lunch |
| 14:15 | *Session 1 : Medical Physics in NM* | *Session 5 : PET complements* | *Session 9 : Use of PET in Hadrontherapy* |
| | Chair : Y. Lemoigne | Chair : J-N Talbot | Chair : M. Medvedec |
| | == NM Dosimetry: Diagnostic & Therapy — *M. Bardies , Toulouse, F* | == *Pet Quality Control & Quantification* — *I. Rausch, Vienna, A* | == *Hadrontherapy principles* — *P.R. Altieri, INFN & Bari Uni, IT* |
| | = *Dose & risks in Iodine 131 treatment* — *M. Zdraveska, Skopje-MK* | = *Pet in Norway / an example* — *J. Haglund , Fredrikstad, NO* | = *On line dose monitoring* — *P.R. Altieri, INFN & Bari Uni, IT* |
| | = *CT: Computed Tomography* — *J. Haglund , Fredrikstad, NO* | = *Imaging for R. Oncology (CT, PET-CT)* — *S. Petkovska, Skopje-MK* | = *Particle Therapy - the future* — *P. Le Dû, IEEE & IPN Lyon-F* |
| 16:15 | | | |
| | Coffee Break | Coffee Break | Coffee Break |
| 16:30 | *Session 2 : Medical Imaging* | *Session 6 : Hybrids system: PET-MRI* | *Session 10 : Open Discussion & conclusions* |
| | Chair : M. Bardies | Chair : P.R. Altieri | *Chair: D. Miladinova, Y. Lemoigne* |
| | == *SPECT/CT Instrument' & Clinical App* — *D. Miladinova, Skopje-MK* | === *PET-MRI: Principle, Advantages&Problems* — *L. Bidaut, Dundee, UK* | *With: P.A, J.H, M.M , P.LD, I.R , S.P and other persons for very short presentations…* |
| | = *Dose Optimisation in MDCT* — *V. Gershan, Skopje-MK* | = *Ecologic Talk* — *F. Vosniakos, Thessaloniki-Gr* | *End of Workshop* |
| 18:30 | | | |
| 19:30 20:00 23:00 | *WELCOME COKTAIL @ st Naum Monastery* | *BANQUET* | Possibility of Transport to Skopje by Public Bus (Courtesy bus to SKP Airport Wednesday 8:00) |

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# *The (R)EVOLUTION of Hybrid Devices in MEDICAL IMAGING*

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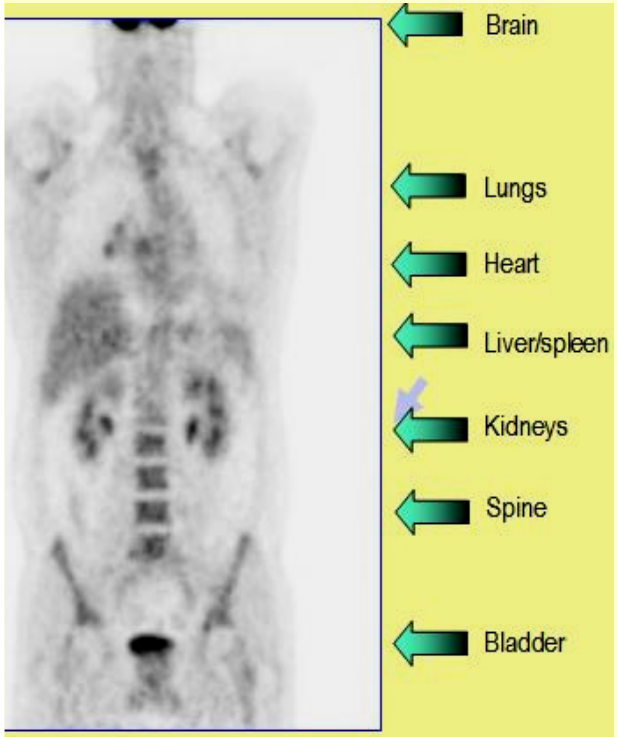
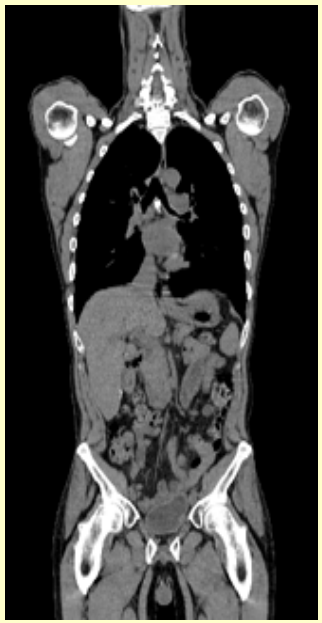
***Yves LEMOIGNE, PhD***

***Institut pour la physique médicale, Ambilly***
**Archamps Biomedical Centre (ABC) Lab.**
**France**
**CERN, Geneva, Switzerland**


PET

1. Intro to Medical Imaging
2. CT-scanner (with X-Rays)
3. MRI
4. SPECT
5. PET
6. Quantification
7. Uses in Hospital
8. Improvements
9. Conclusion



CT

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# 1.INTRODUCTION

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# Imaging modalities today

## Hardware combination ➡ Evolution / Revolution

| Imaging Modality | Spatial Resolution (mm) | Acquisition time per frame(s) | Molecular probe mass required (ng) | Molecular sensitivity (mol/L) | Tissue penetration depth (mm) | Signal quantification capabilities |
|---|---|---|---|---|---|---|
| PET | 1-2 (animal)<br>6-10 (clinical) | 1-300 | 1-100 | $10^{-11}$-$10^{-12}$ | >300 | High |
| SPECT | 0.5-2 (animal)<br>7-15 (clinical) | 60-2000 | 1-100 | $10^{-10}$-$10^{-11}$ | >300 | Medium-High |
| Optical | 2-5 (visible to IR) | 10-2000 | $10^{3}$-$10^{6}$ | $10^{-9}$-$10^{-11}$ | 1-20 | Low |
| MRI | 0.025-0.1 (animal)<br>0.2 (clinical) | 0.1-100 | $10^{3}$-$10^{6}$ | $10^{-3}$-$10^{-5}$ | >300 | High |
| US | 0.05-0.5 (animal)<br>0.1-1 (clinical) | 0.1-100 | $10^{3}$-$10^{6}$ | Not well characterized | 1-300 | Low |
| CT | 0.03-0.4 (animal)<br>0.5-1 (clinical) | 1-300 | NA | Not well characterized | >300 | Medium-High |

From Craig S Levin. Eur J Nucl Med & Mol Imag. 2005, 32(14), S-325-45

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# *EVOLUTION in MEDICAL IMAGING (combination of existing equipment)*

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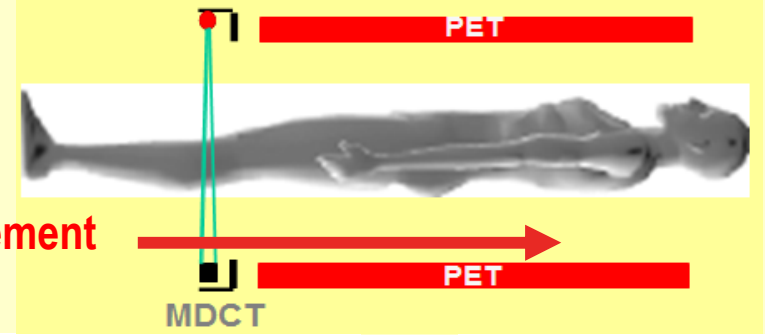
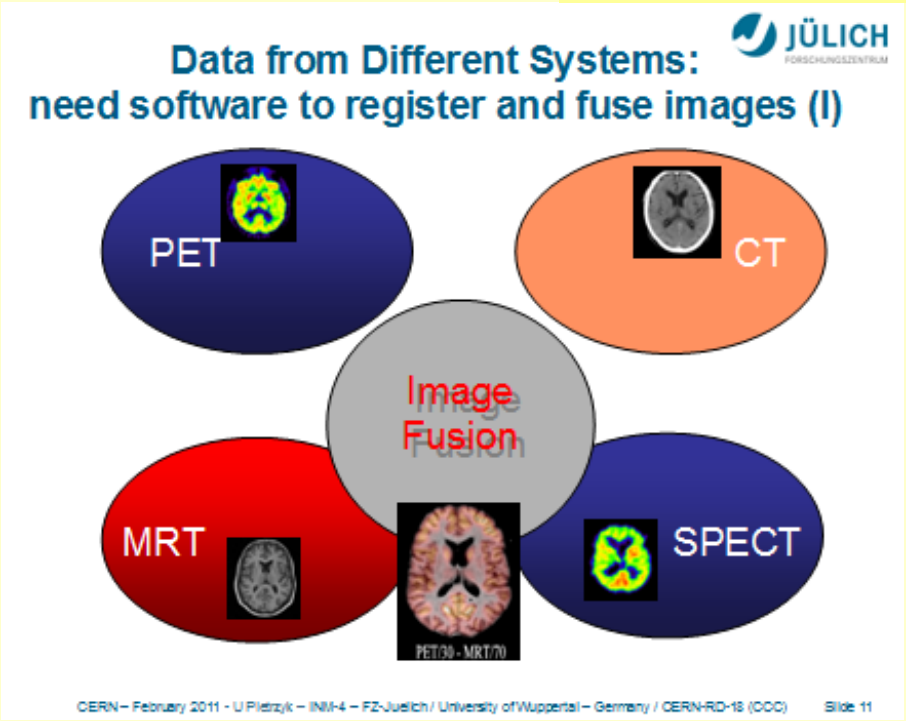
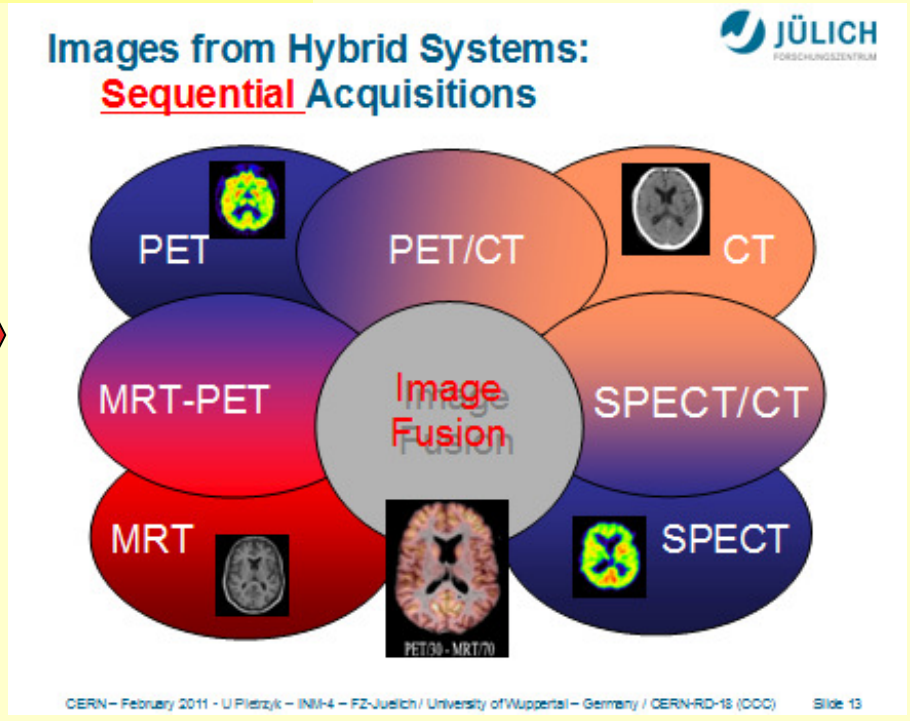
**Example:** **CT**




**PET**




**Data taken at different time / in different configuration / in different places…**

**Fusion only by software**

**Data taken at sequential time / with minimal movement of patient**

**Fusion by software**

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# *REVOLUTION in MEDICAL IMAGING*

## *(Integrated devices from technical developments)*

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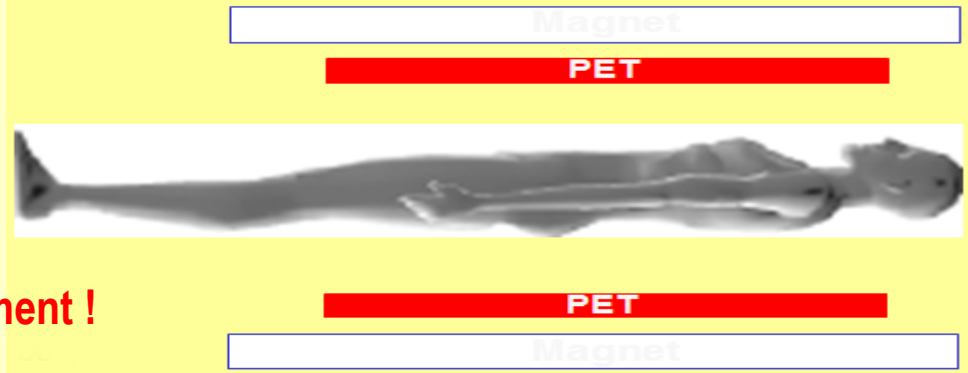
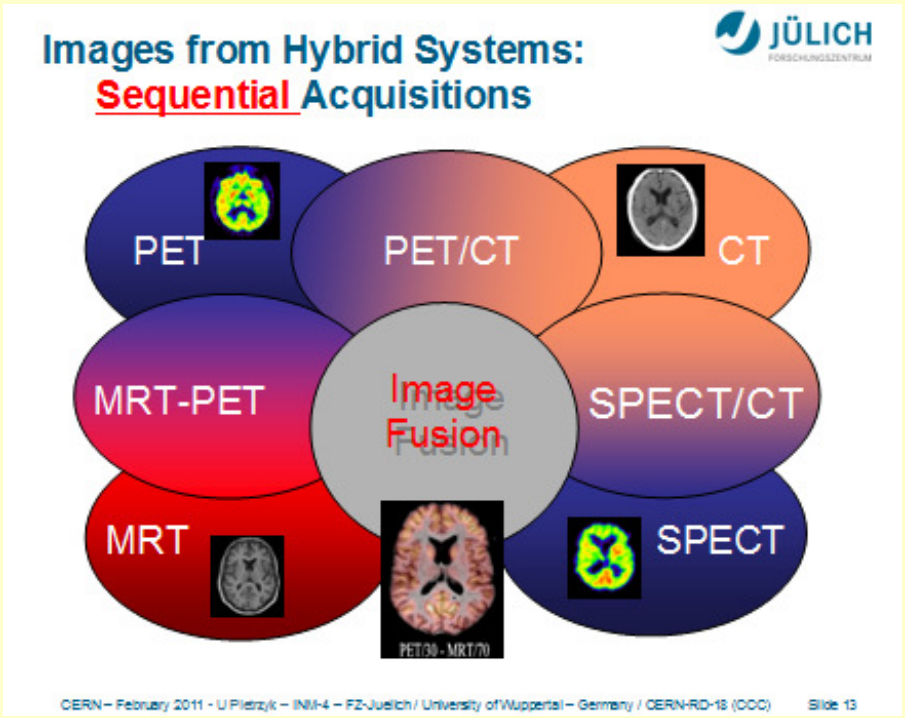
**Example:** **MRT**

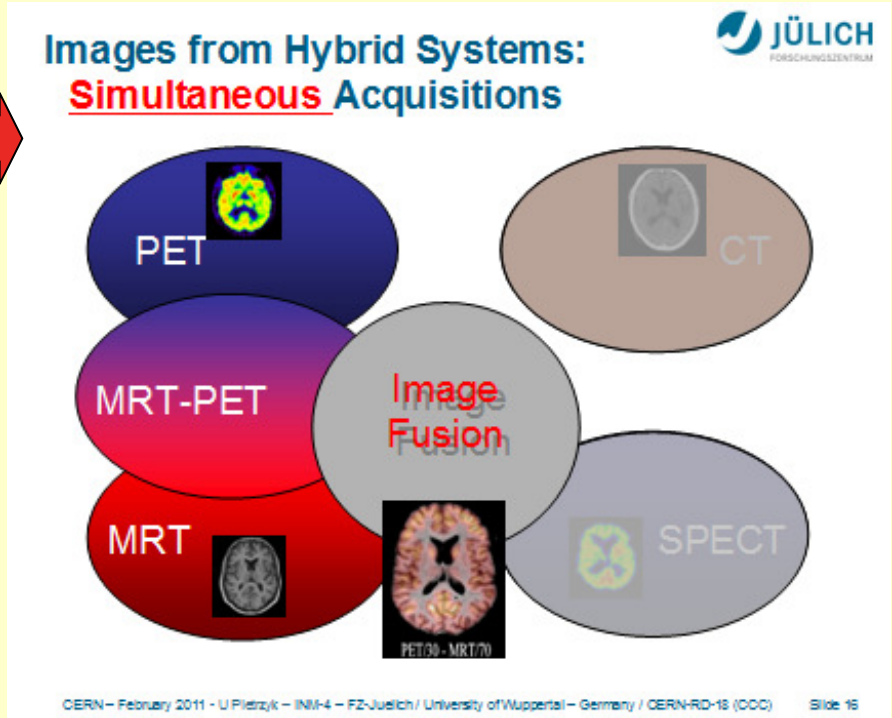



**PET**

**No movement !**

**(same hardware)**




***REVOLUTION is simultaneous Acquisitions without patient deplacement !!***

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**EUROPEAN SCIENTIFIC INSTITUTE (ESI) ARCHAMPS, FRANCE**
**EUROPEAN SCHOOL OF MEDICAL PHYSICS (ESMP)**

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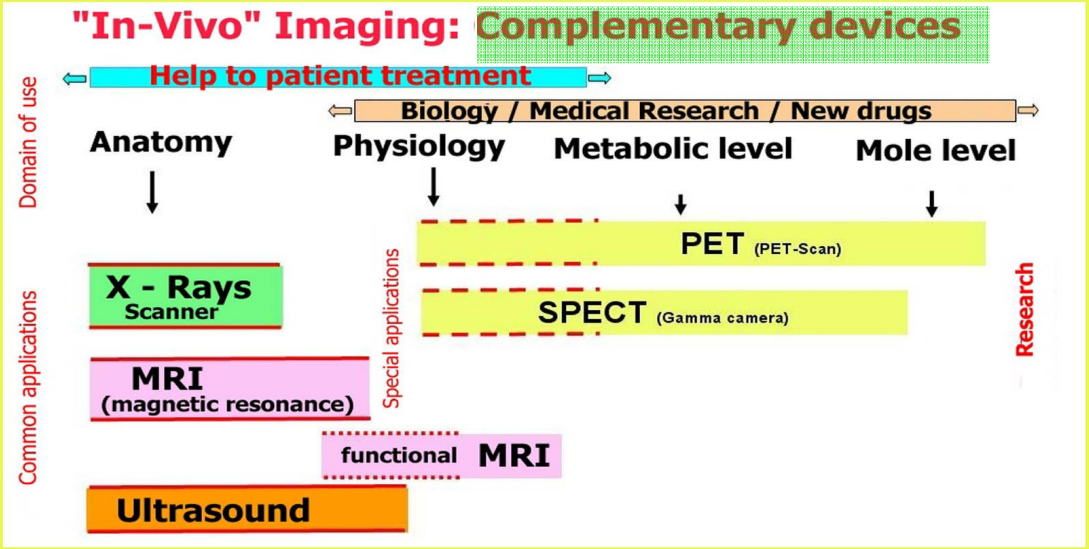
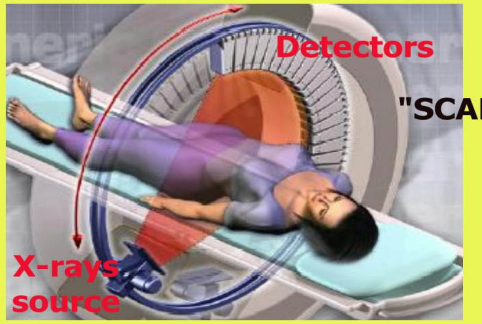
# HOW PHYSICS HELPS IN ESTABLISHING DIAGNOSIS

**Physics has made it possible to create sophisticated devices to "explore" the human body from different perspectives:**
**- anatomical, to see "inside" the human body at a certain moment;**
**- functional, to see how the body functions during a given period of time.**




"SCANNER" - TDM

CT


"PET-SCAN"

**Each technique has its own specificity and thus a particular area of application:**

**- Scanner: TDM with a good space-resolution; ionising X-rays.**

**- PET-SCAN: functional analysis can be VERY sensitive; limited space-resolution. Uses ionising rays (radiotracers).**

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# 2. X-Rays CT

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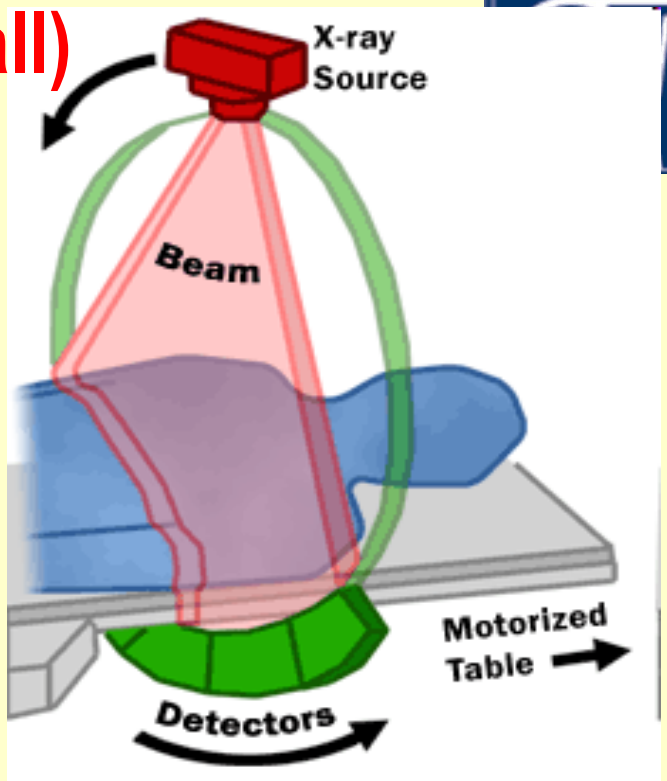
# 2 - CT Principle (recall)

## Description

Computed tomography (CT) scanning is a medical imaging procedure that uses x-rays to show cross-sectional images of the body.

These cross-sectional images are used for a variety of diagnostic and therapeutic preparation purposes.




## How a CT system works:

A motorized table moves the patient through a circular opening in the CT system. While the patient is inside the CT, a x-ray source and detector within the housing rotate around the patient. The x-ray source produces a narrow beam of x-rays that passes through a section of the patient's body.

A detector opposite from the x-ray source records the x-rays passing thru the patient's body as a "snapshot" image. Many different "snapshots" (at many angles through the patient) are collected during one complete rotation and are sent to a computer to recons-truct all individual "snapshots" into one or multiple cross-sectional images (slices) of the internal organs and tissues. (3-D Imaging)

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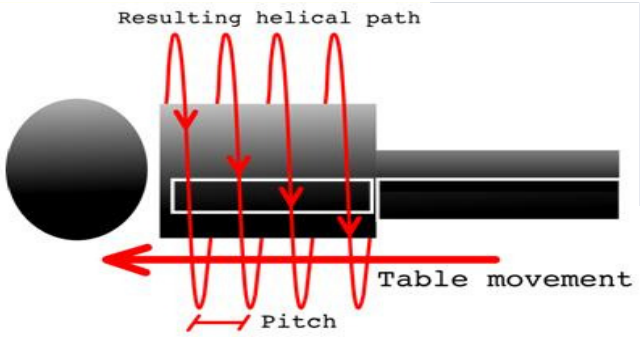
# CT Utility & Definitions




**X-Rays-CT has become recognized as a valuable medical tool, for:**

1. **Diagnosis** of disease, trauma, or abnormality (Anatomy imaging)
2. **Planning, guiding, and monitoring therapy (Ex: Treatment Planning preparation)**

**But:**

**Non-negligeable x-ray radiation exposure:**

- **Typical dose, Computed Tomography (CT)-Body : 10 mSv** (=3 years of natural dose)
- **Classical Chest Radiography: 0.1 mSv** (10 days of natural dose)

Beer's Law for one material: $I = I_0 \exp[-\mu x]$.

where $I_0$ and $I$ are the initial and final X-ray intensity, **μ is the material's linear attenuation coefficient** (units 1/length) and $x$ is the length of the X-ray path. With multiple materials $i$, the equation becomes: $I = I_0 \exp\left[\sum_i (-\mu_i x_i)\right]$.

$$Hounsfield\ unit = \frac{\mu_{tissue/material} - \mu_{water}}{\mu_{water}} \times 1000$$

**An important issue within CT radiology today is how to reduce the radiation dose during CT examinations without compromising the image quality (Target CTA protocol, Adaptive Iterative Dose Reduction …) in some case hopefully 1 mSv can be reached…**

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Typical CT Doses :

| ExaminationTypical | Effective dose (mSv) |
|---|---|
| Chest X-ray | 0.110 |
| Head CT | 1.5 |
| Abdomen CT | 5.3 |
| Chest CT | 5.8 |
| Chest, abdomen and pelvis CT | 9.9 |

The annual per capita exposure to medical radiation in the U.S. increased from 0.54 mSv in 1980 to 3.2 mSv in 2006 !!.

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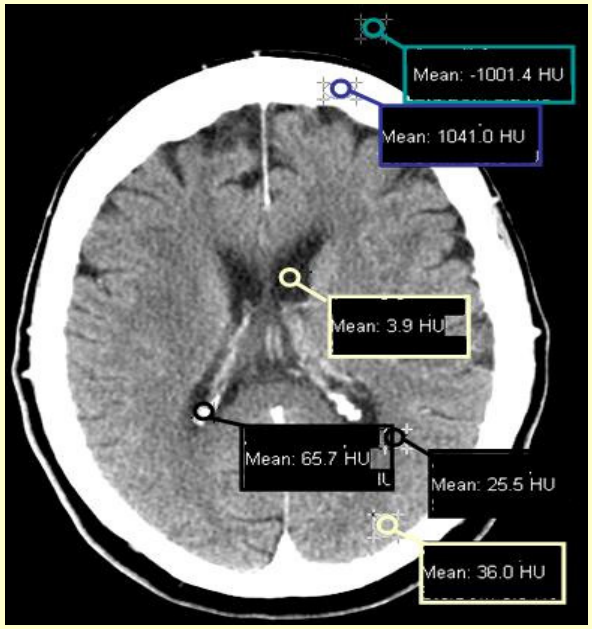
**Low-dose CT scan :**

- Aim is : Reduce the radiation dose during CT examinations without compromising image quality.
- Higher radiation doses => higher-resolution images,
- Lower doses => higher image noise => unsharp images.
- An abdominal CT gives = 300 chest x-rays (for dose).
- Several methods exist to reduce exposure dose :




1- New software technologies: some filters reduce random noise and enhance structures => to get higher quality images and at the same time lower the dose by 30% to 70 %.

2. Individualize the examination and adjust the radiation dose to the body type and body organ examined. Different body types and organs require different amounts of radiation.

3. Prior to every CT examination, evaluate the appropriateness of the exam whether it is motivated or if another type of examination is more suitable. Higher resolution is not always suitable for any given scenario, such as detection of small pulmonary masses.

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# 3. MAGNETIC RESONANCE IMAGING

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# *MRI : Overall picture of how it works…*

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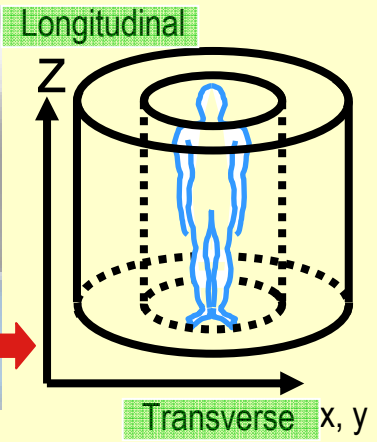
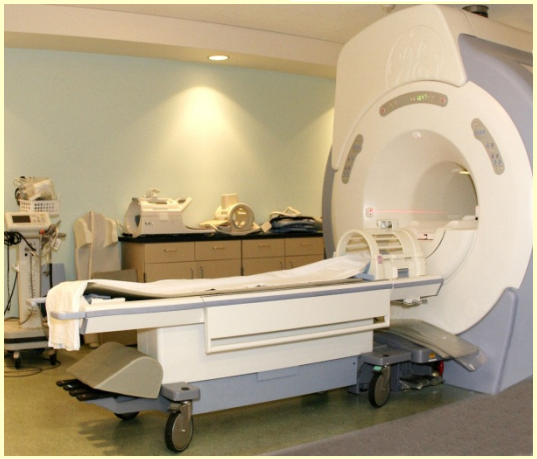
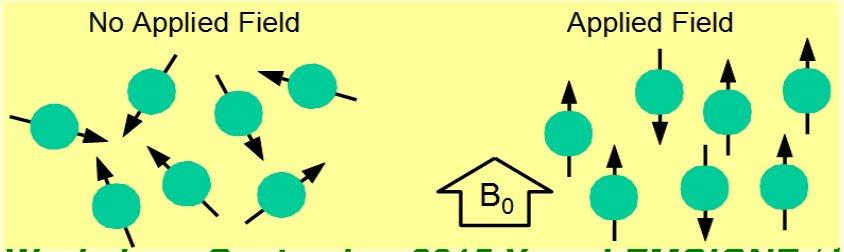
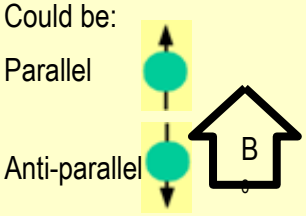
- Our bodies are made up of roughly **63% water**
- MRI machines use hydrogen atoms
- **The hydrogen atoms act like little magnets,** which have a north and south pole ("Spin").
- The atoms inside our body are aligned in all different directions


- The MRI is basically a large magnet
- Patient lies within scanner where magnetic field is created
- Magnetic force causes nuclei with hydrogen (proton) to line with the field-referred to as parallel, there is also antiparallel
- Electromagnetic radiation (radio waves) are emitted from machine






Anti-Parallel have higher Energy than Parallel ones

Radio waves are emitted when coming back to equilibrium

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# Precession

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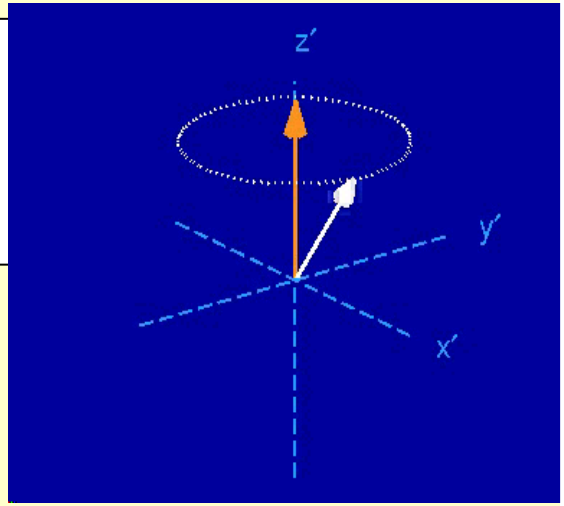
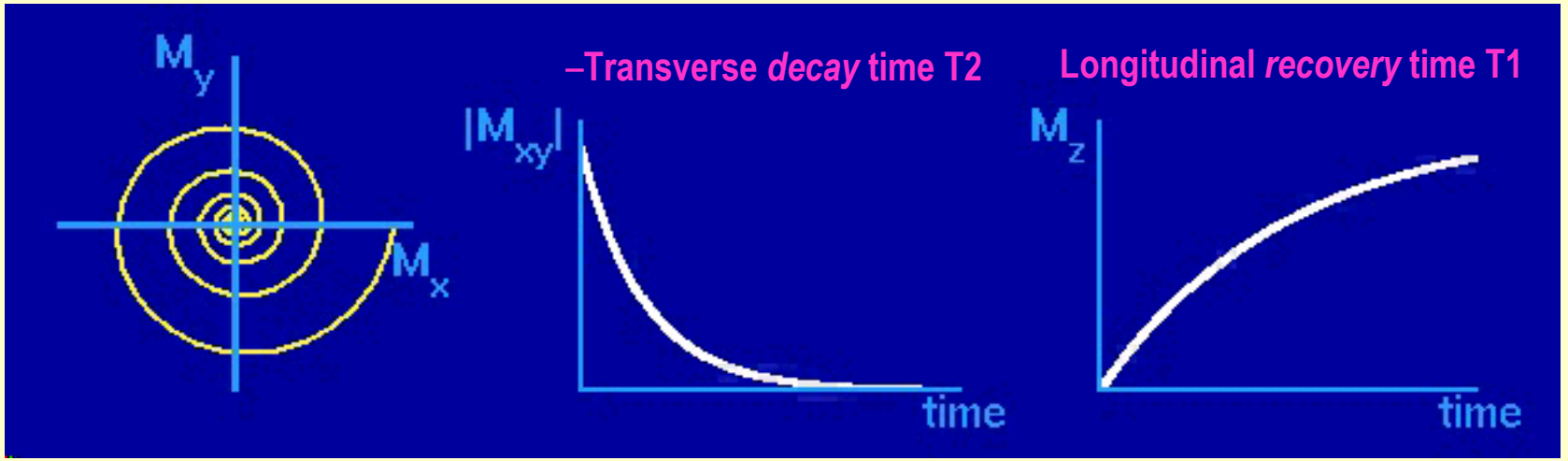
- Spins precess about applied magnetic field, $B_0$, that is along z axis.
- The frequency of this precession is proportional to the applied field.

Larmor law: $\omega = \gamma B$




- Magnetization returns **exponentially** to equilibrium:
  - Longitudinal *recovery* time constant is $T_1$
  - Transverse *decay* time constant is $T_2$
- Relaxation and precession are independent.

## Relaxation




Precession Decay Recovery

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# MRI : how it works (Cont'd)…

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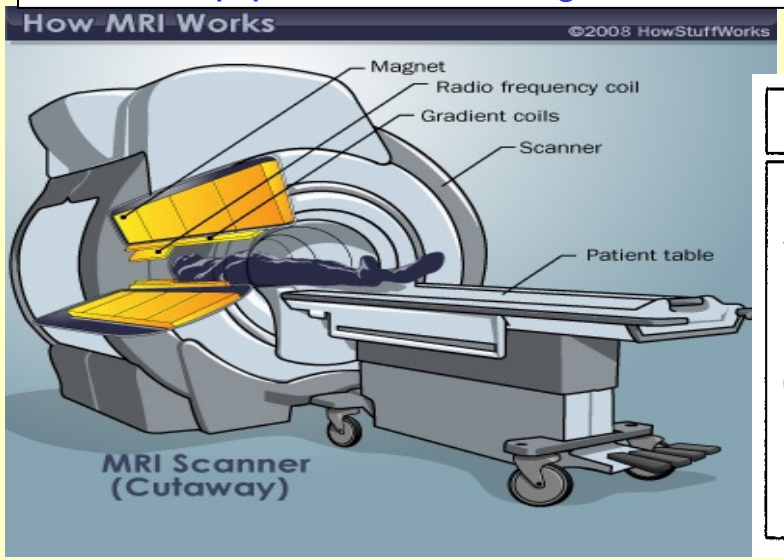
An MRI consists of:
- a big magnet creates the magnetic field by coiling electrical wire and running a current through the wire
- gradient magnets: to alter precisely the magnetic field and allow image slices of the body to be created.
- a coil: emits the radiofrequency pulse allowing disturbence of the alignment of the protons / also Receiver

Larmor Equation $\omega_o = \gamma.\beta_o$ For $H^1$ : $\gamma = 2.675x_{10^8}$ $\beta_0 = 1.5T$ $\omega_0 = 63.864MHz$

- Protons align parallel or anti-parallel to the magnetic field generated
- Larmor Frequency: magnetic moment of proton within external field
- Protons that are parallel=lower energy
- Protons can oscillate back and forth between states, but majority line up parallel with magnetic field

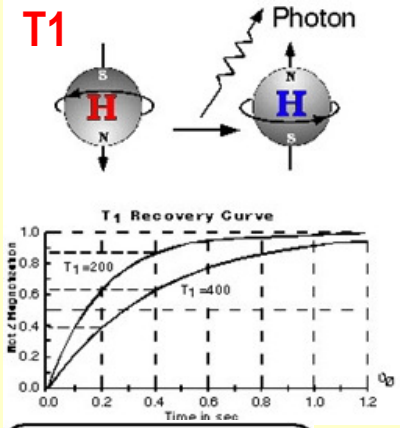



**Different relaxation times T1 & T2 help to recognize different matters**

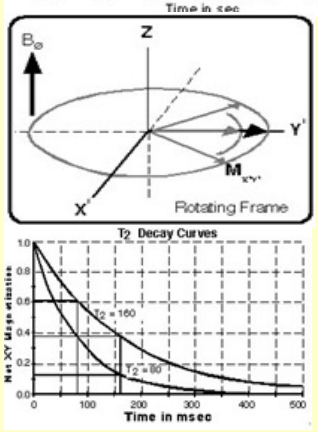
| Tissue | $T_1$ (ms) | $T_2$ (ms) |
|---|---|---|
| gray matter (GM) | 950 | 100 |
| white matter (WM) | 600 | 80 |
| muscle | 900 | 50 |
| cerebrospinal fluid (CSF) | 4500 | 2200 |
| fat | 250 | 60 |
| blood | 1200 | 100-200[3] |

**Relaxation:**

**T1**




**T2**



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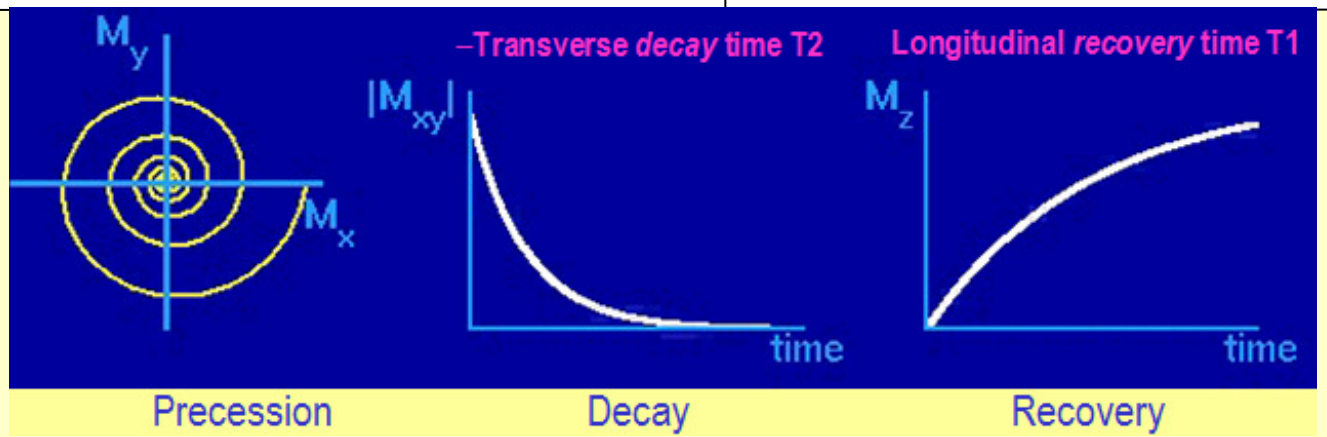
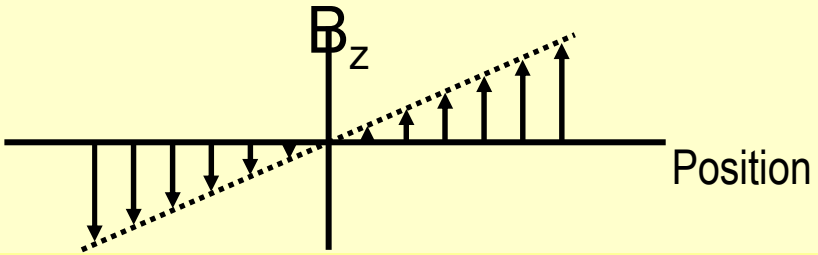
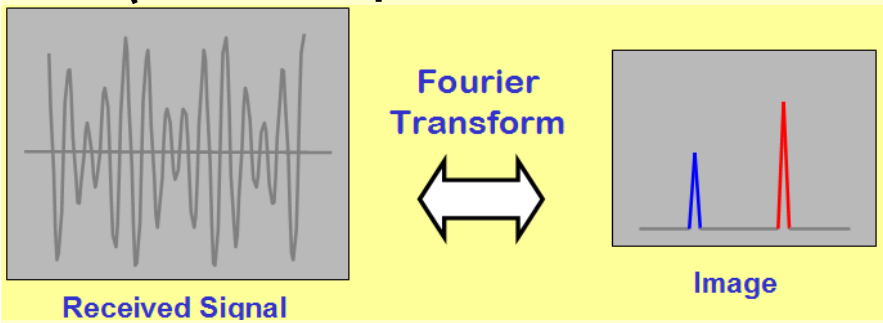
# MR Image Formation

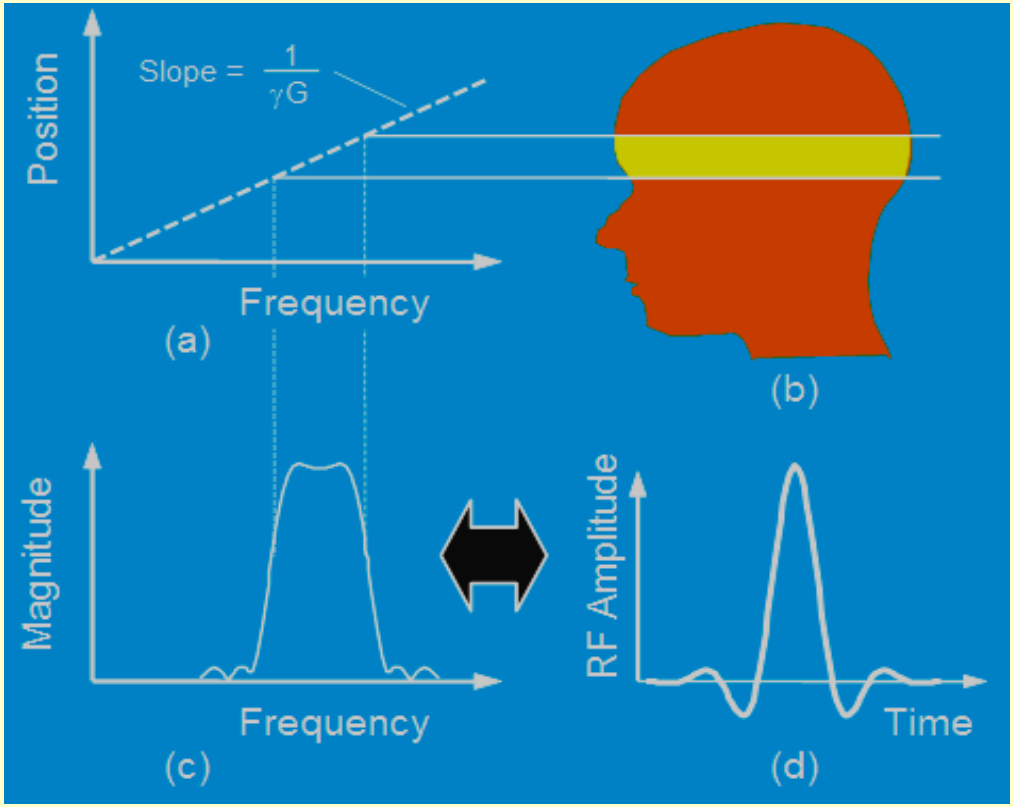
## Selective Excitation




- **Gradient coils provide a linear variation in $B_z$ with position.**
- Result is a resonant **frequency variation** with position.



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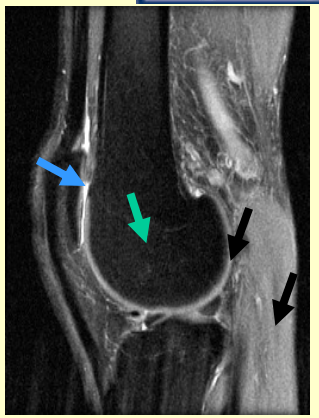
# Different types of MRI

CERN

Advantages:
- Excellent / flexible contrast
- Non-invasive
- No ionizing radiation
- Arbitrary scan plane

Challenges:
- New contrast mechanisms
- Faster imaging

Advantages:
- Various acquisition sequences
- Large range of contrast
- Excellent space resolution:
  25 µm (animal research )
  200 µm (@clinic)



- Interventional MRI :

  Used to guide in some noninvasive procedures

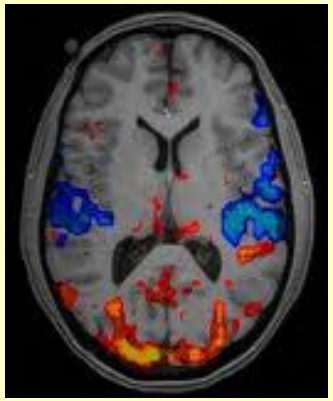
- Real Time MRI

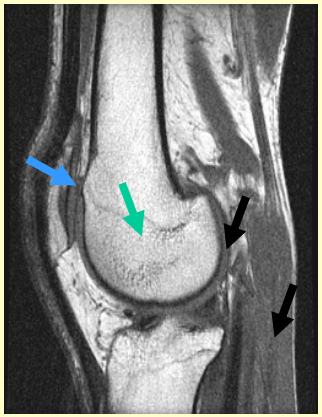
  Continuous filming/ monitoring of objects in real time

- Functional MRI (fMRI)

  Measures signal changes in the brain due to changing neural activity

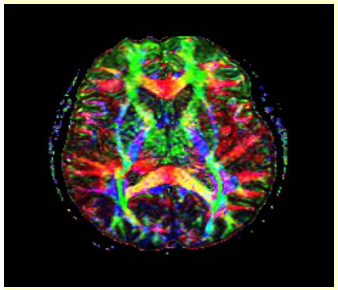
- MRS (MR spectroscopy)

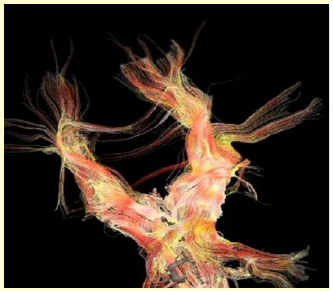




Resonance frequencies of common nuclei

| Nucleus | Resonance Frequency (1.5Tesla) MHz |
|---|---|
| $^{1}H$ | 63.86 |
| $^{2}D$ | 9.81 |
| $^{13}C$ | 16.05 |
| $^{14}N$ | 4.62 |
| $^{19}N$ | 6.57 |
| $^{23}F$ | 60.07 |
| $^{31}Na$ | 16.89 |
| $^{31}P$ | 25.86 |
| $^{35}Cl$ | 6.27 |
| $^{39}K$ | 2.97 |





MRI showing nerve connections inside the brain.

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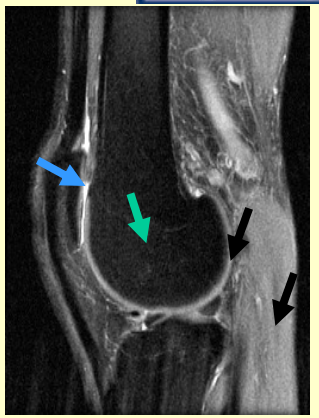

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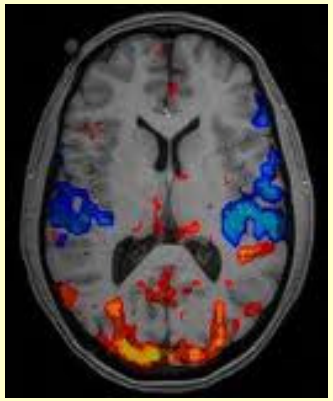

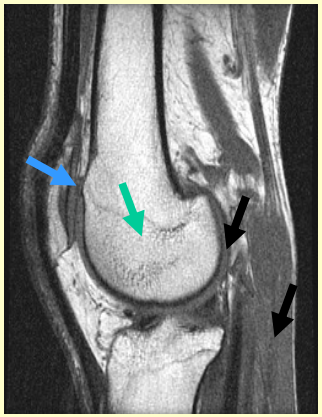

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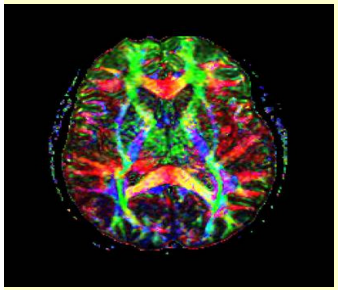

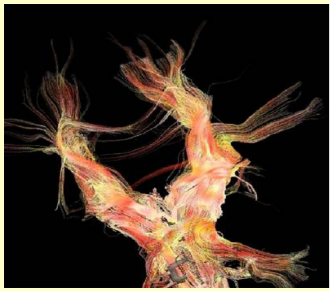

MRI showing nerve connections inside the brain.

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# 4. SPECT

# ISOTOPIC TRACERS AND THEIR USE WITHIN SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY

**The technique of isotopic tracers consists in the fact that one or more atoms of the molecules at work in the studied reaction are replaced by another isotope of the same chemical element, but radioactive. This isotope, having the same number of protons and electrons as the atom which it substitutes, behaves chemically like the latter and therefore it does not interfere, but it makes it possible to "trace" the molecule to which it links.**

**Some isotopes uses:**

| Isotope | Half-life |
|---|---|
| Technetium-99m | 6 hours |
| Iode-131 | 8 days |
| Iode-123 | 13 hours |
| Indium-111 | 2.8 days |
| Thallium-201 | 3 days |
| Fluor-18 | 2 hours |
| Carbon-11 | 20 minutes |
| Azote-13 | 10 minutes |
| Oxygen-15 | 2 minutes |
| Gallium-68 | 68 minutes |

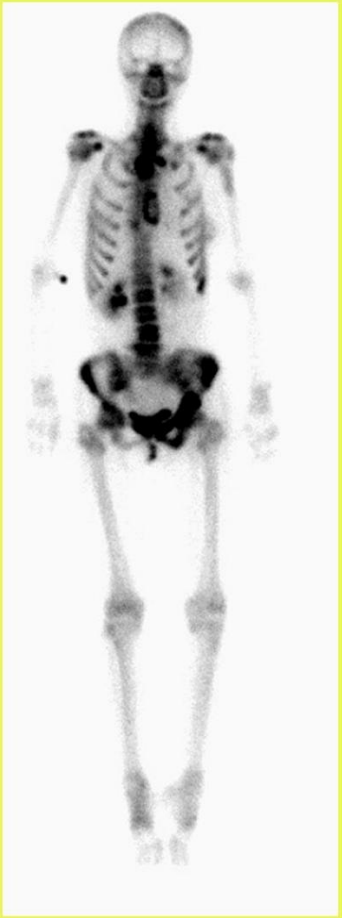
**In medicine it is necessary that the radioactivity should disappear quickly enough (short half-life) and that the quatity of tracer applied to the patient should be very small (measured in micro-moles and even in pico-moles). The sensivity of the apparatus used is thus crucial.**

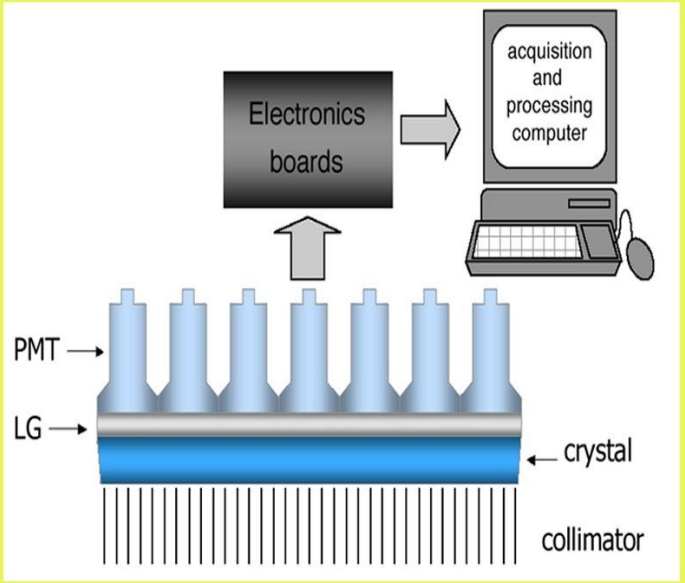
**Some isotopes emit gamma photons, others emit positrons (see PET).**

**In monophotonic tomography, the patient receives marked molecules whose biological behaviour is known. The detectors will recognise the photons emitted and therefore they will allow to recognstitute one or more images data processing (which is a complex process).**

# MONOPHOTONIC TOMOGRAPHS or GAMMA CAMERAS / SPECT

**Very popular in Nuclear Medicine because they require only standard radiotracers.**




A radiotracer (Technetium-99m, by example) is injected into the patient to depose into the target-organ.

The radiotracer emits gamma photons of 140 KeV energy which are detected by the crystals and the photomultipliers (PM).

The collimator removes the photons not directly emitted by the organ targeted.

The signals are collected by the electronic components and also by the computer to reconstitute the images.

To fight background noise, the device can use only two Tools :
- the selection on the energy specific to the detected photon (in this case, 140 KeV);
- the photon origin imposed by the collimator.

The device shows here allows anyway to obtain images of the whole-body of the patient by the succesive translation, as in the photo above.

D. NEAMTU, Y. LEMOIGNE, ESI-Archamps

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# *Emission Computed Tomography*

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**Aim: -** to measure and display the concentration of a gamma ray-emitting radioisotope within individual slices of the body

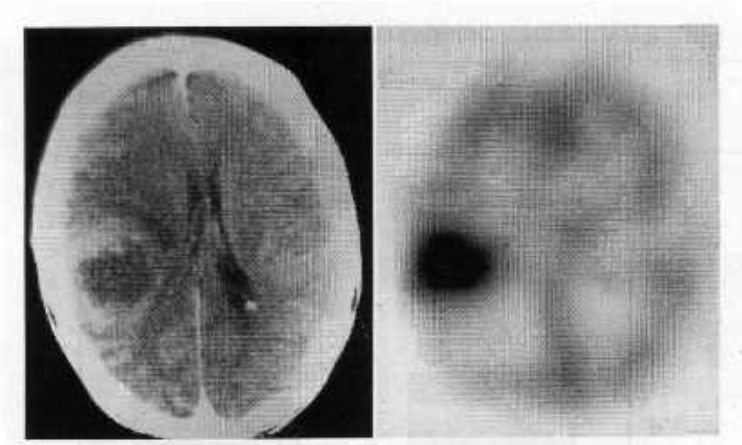
**SPECT**: Single photon emission computed tomography with tracers such as Tc-99m using either a rotating gamma camera or a dedicated ring camera

## Advantages over planar imaging:

- improved image contrast
- better localisation
- improved detection rates
- quantification (see later)

## Example

*SPECT brain scan using a 99mTc labelled blood flow tracer showing high perfusion in the tumour*



*X-ray CT scan* *SPECT blood flow scan*

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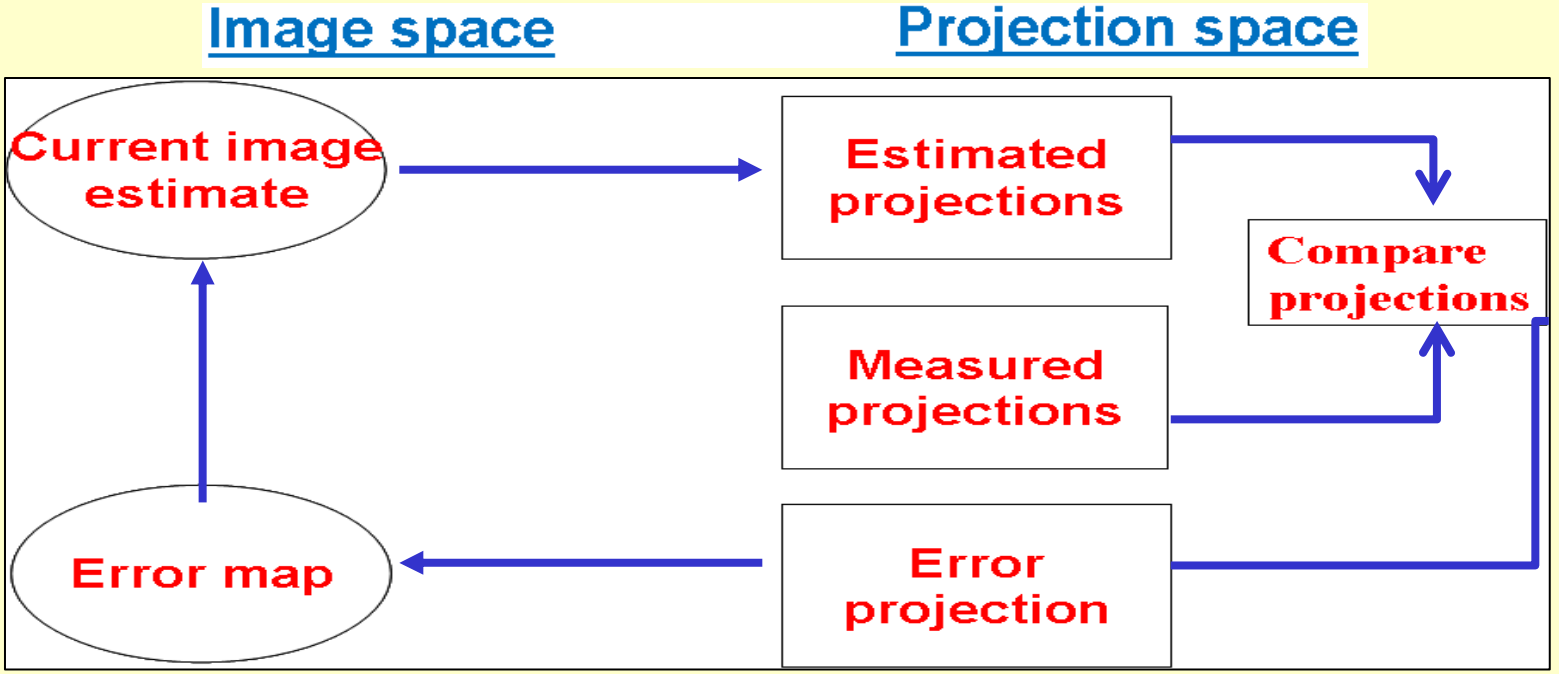
# Image reconstructions proceed thru projections:

- Similar to X-ray CT : take 1D profiles or 2D projections at discrete angles around the object
- Assume that each profile/projection point = sum of activity elements along detector LOR

## Principles of iterative reconstruction :




**A very popular algorithm: Ordered Subset Expectation Maximisation (OSEM)**

**A fast variation of the ML-EM algorithm using subsets of the projections**

For example 64 projections used 8 at a time for 8 separate image production procedures (requires substantial data storage space). Thanks to Progress in Computers….

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# Now: SPECT/CT in the clinic

(From D. Townsend 2014)

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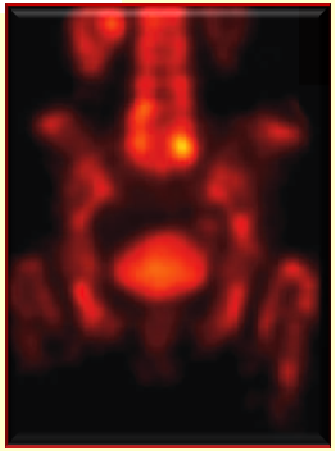
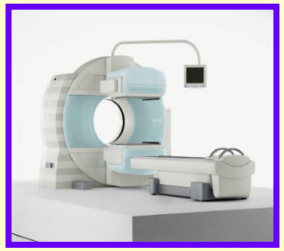
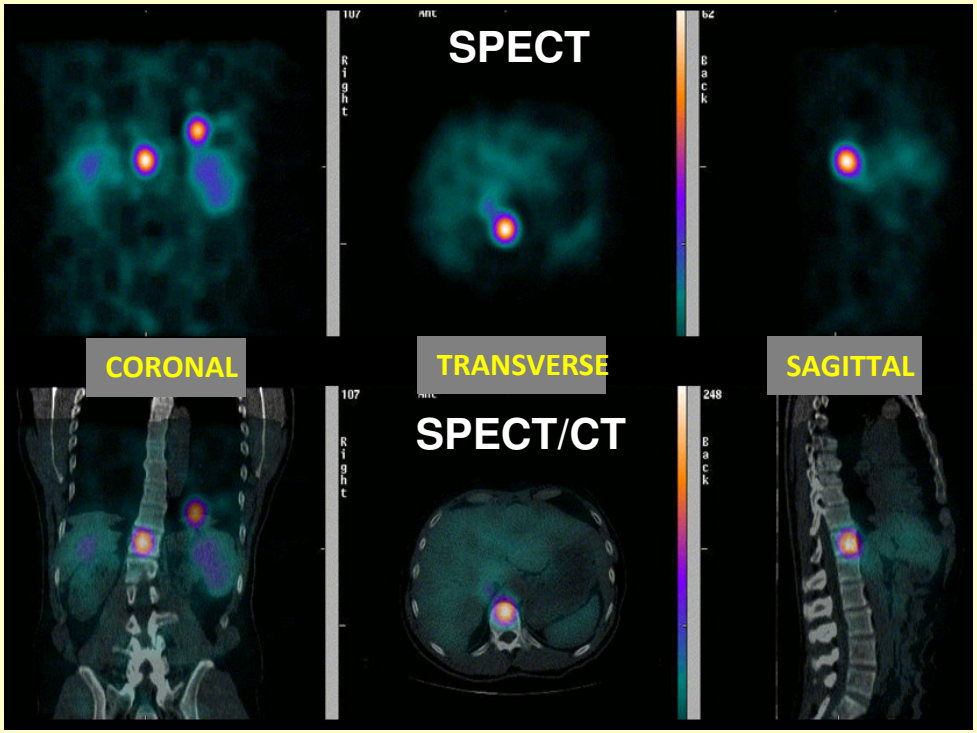
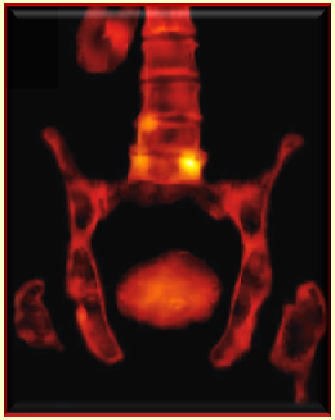


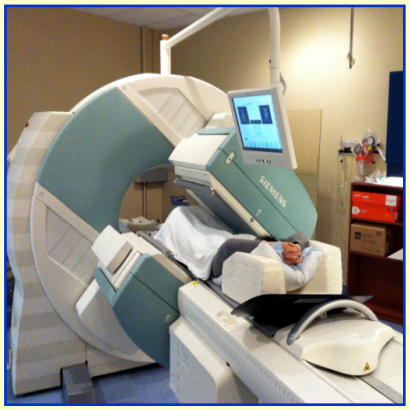
Conventional SPECT





SIEMENS xSPECT



Symbia TX

Discovery NM/CT 670

## "CT is potentially more valuable for SPECT than for PET"

*Bailey* DL. Eur J Nuc Med & Mol Imag 2003; 30(7):1045-1046

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# 5. PET

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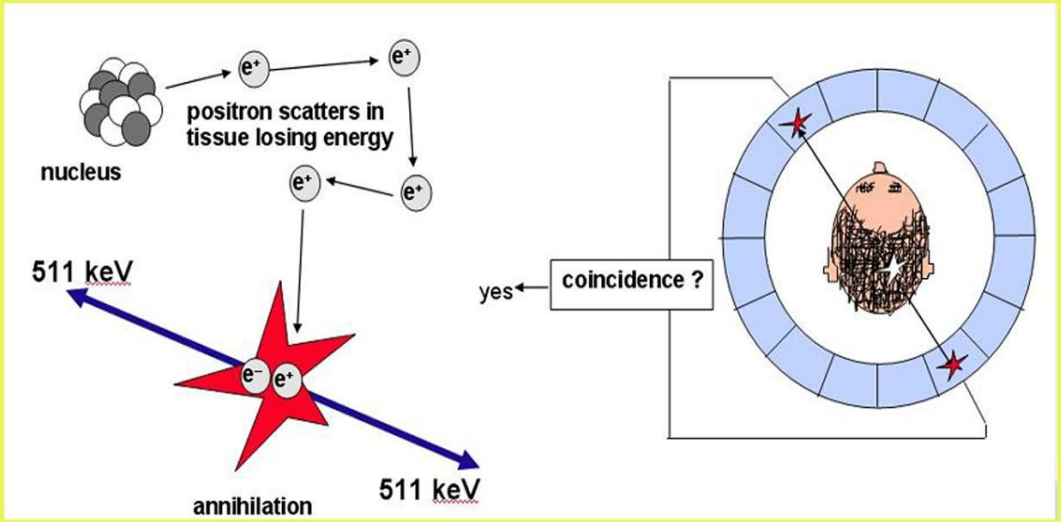
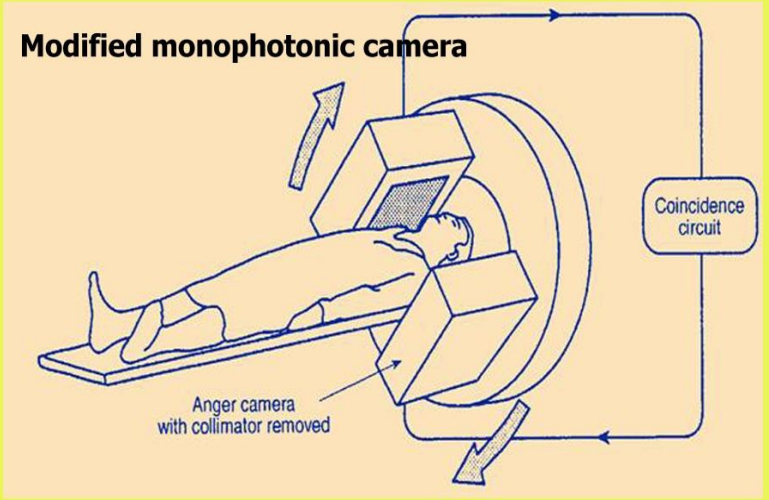
# DIPHOTONIC TOMOGRAPH or PET CAMERA

## ANTI-MATTER ON CENTER STAGE!

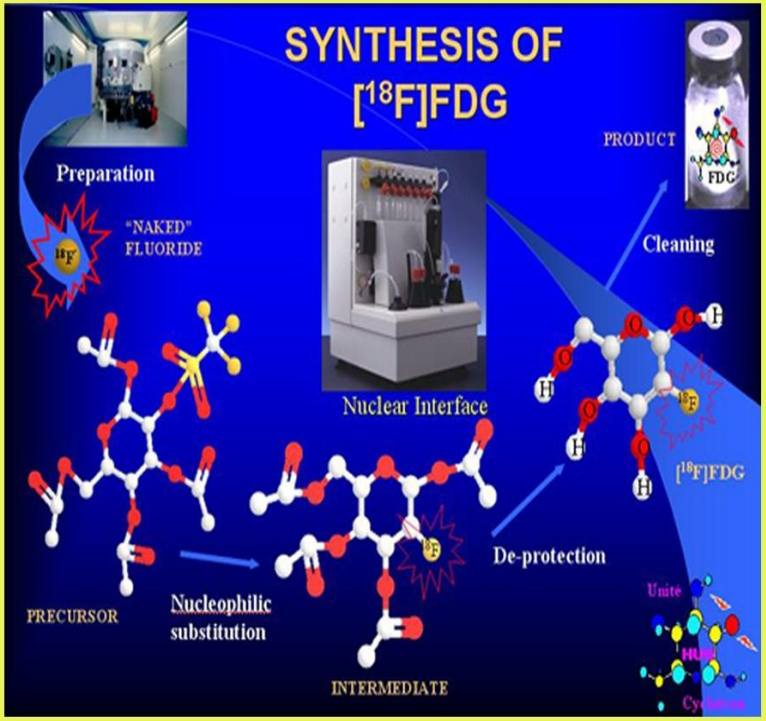
e e e

**Some isotopes desintegrate by emitting a positron (anti-electron) which, by successive collisions with the matter, will lose its energy and will produce matter-antimatter annihilation with an electron from one of the atoms encountered. This process results in two "back-to-back" photons of well-established energy (511 KeV) and emitted simultaneously. Consequently, we can suggest that two opposed detectors should emit two simultaneous signals (see the diagram). With all this constraints, the PET camera eliminates the background noise much better than the Gamma camera and thus reaches a higer sensitivity.**

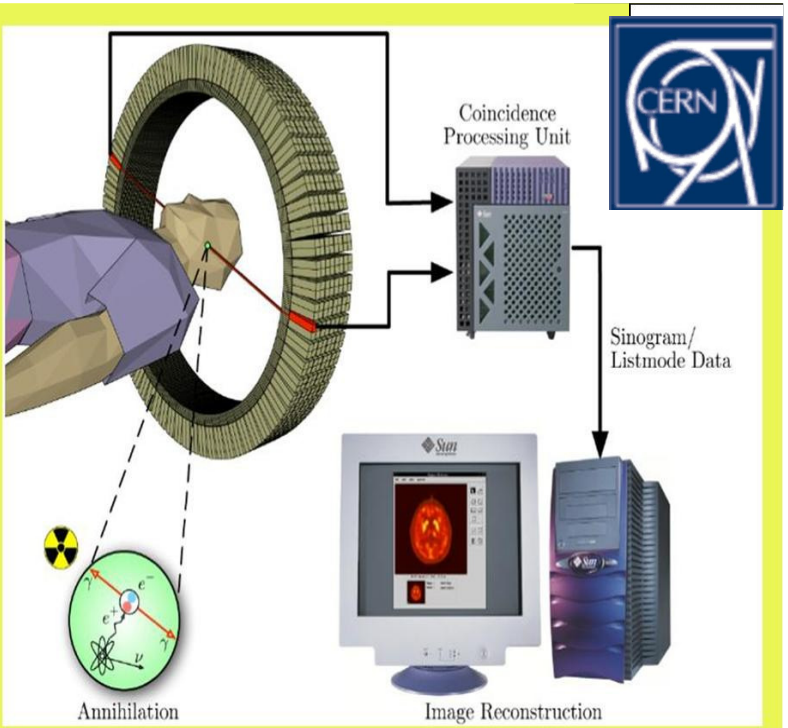


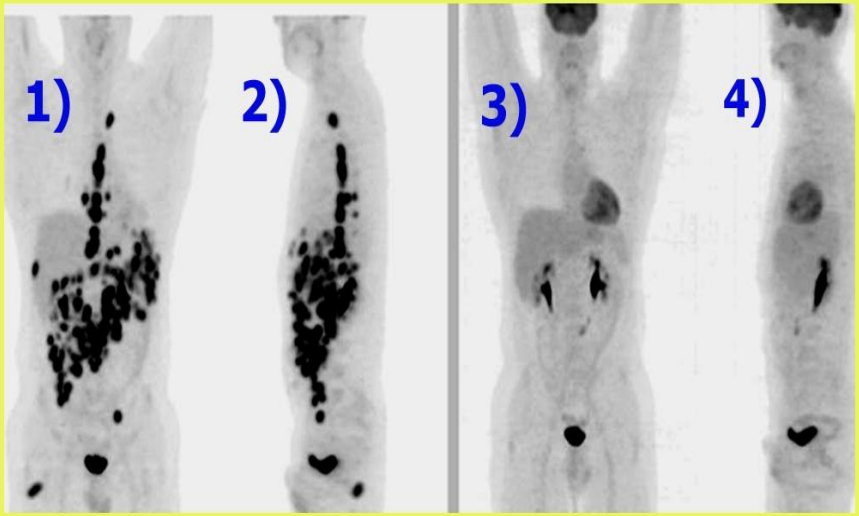

**The first PET were simply Gamma cameras, from which the collimators had been removed and coincidence added between opposed detectors. Thereafter, better optimised PET equipments were built. For the human PET, several rings of detectors (crystals and PM) are assembled together.**




The tracers for PET are more difficult to use because their half-life is shorter.
A cyclotron and a synthesis laboratory are necessary.



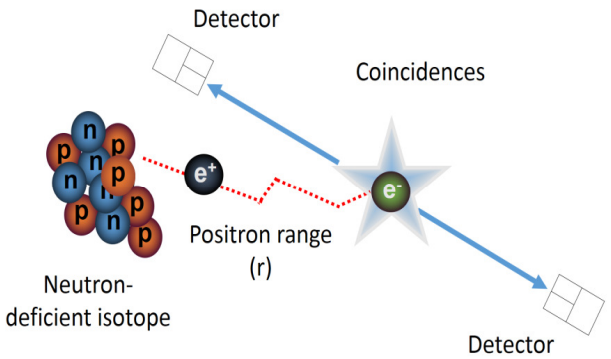

The most used isotopic tracer is FluoroDeoxyGlucose (FDG), which has the Fluor atom replaced by Fluor-18 which disintegrates by positron emision. The FDG accumulates in the cells with abnormal metabolism, i.e. cancer cells. It is phosphorylated (then trapped in cell) By hexokinase to FDG-6-$PO_4$ not metabolised further in the Glycolitic pathway

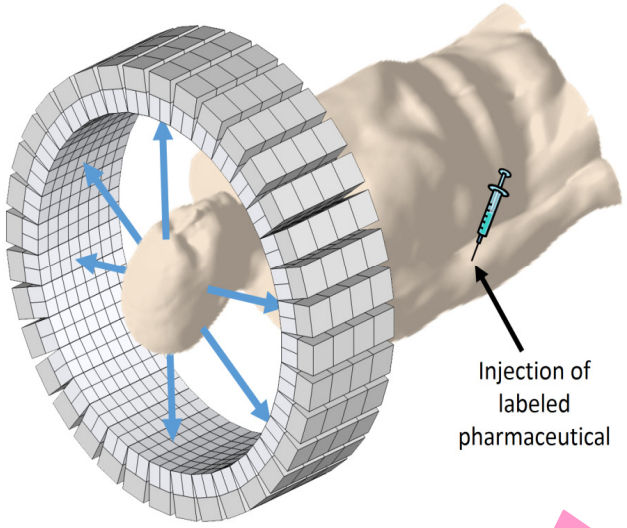


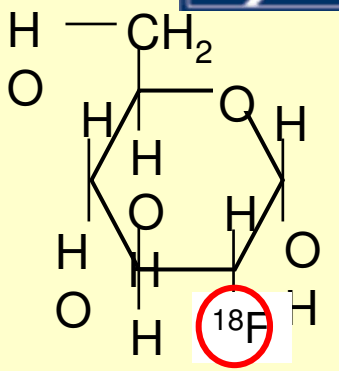

PET and cancer:
1) & 2): front and side view before treatment;
3) & 4): front and side view after chemotherapy.
FDG accumulates naturally in the brain, kidneys, bladder and the heart; in this case chemotherapy was very effective.
Only the PET can do that!

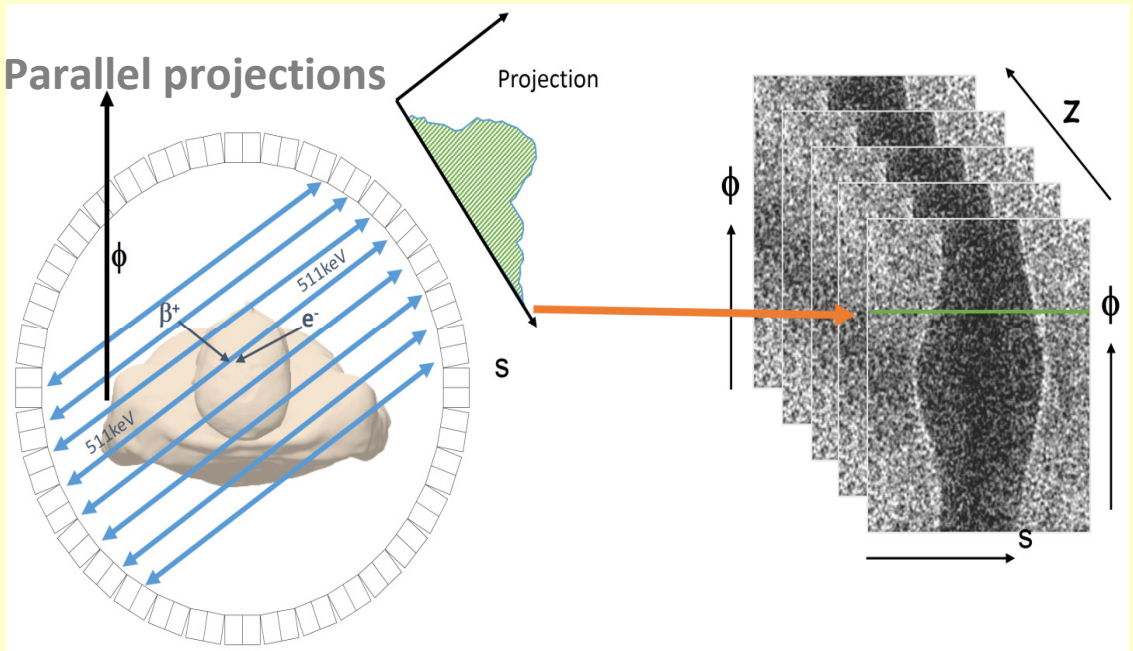
# Positron Emission Tomography: how it works

## SUMMARY

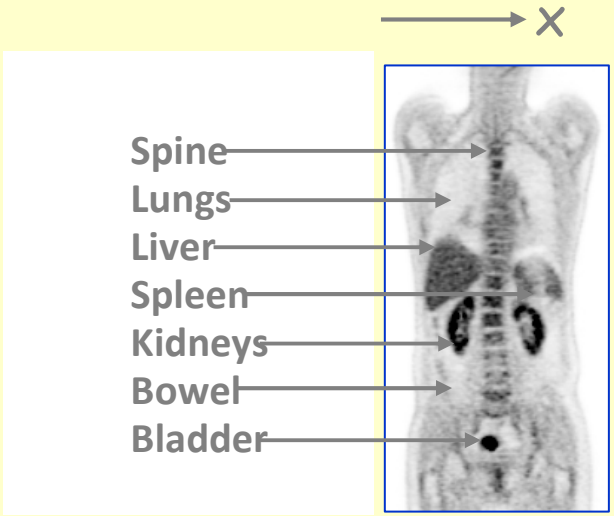



Sinograms




PET images

From D. Townsend 2014

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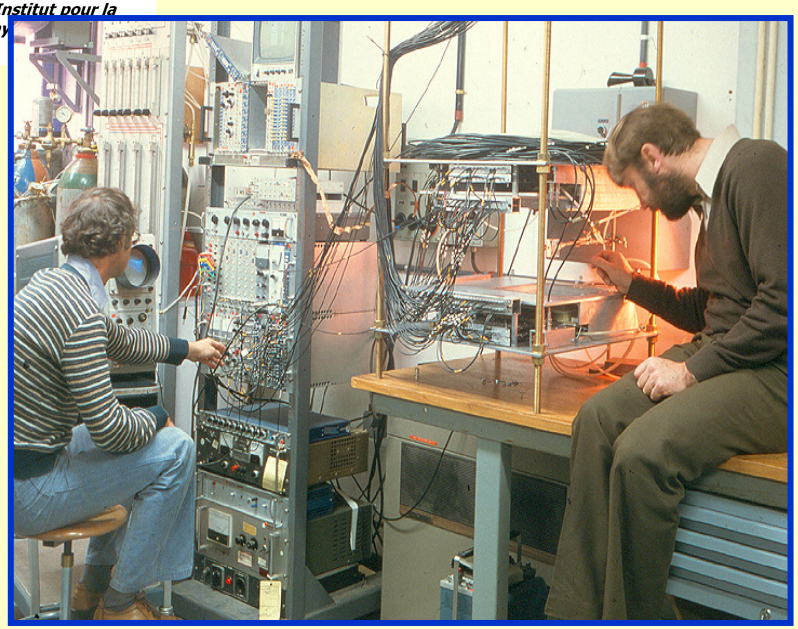
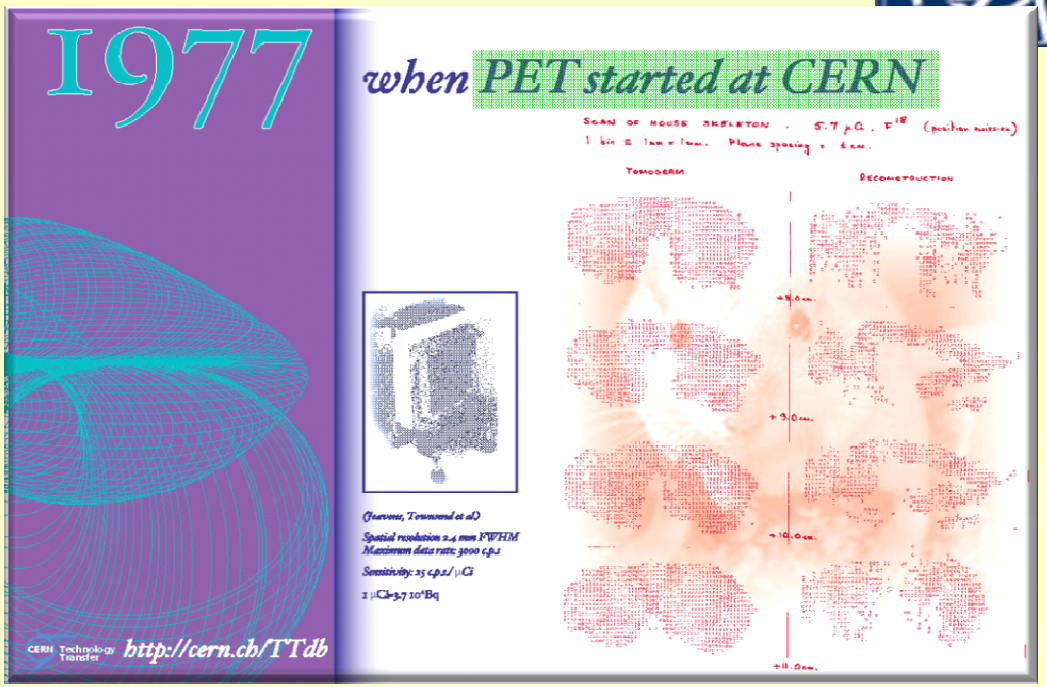
# The HIDAC Camera Project, 1977-1988 CERN & HCU, Geneva

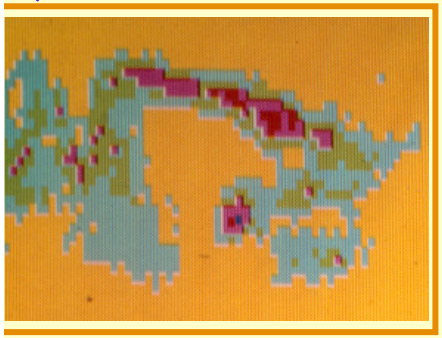
From D. Townsend 2014

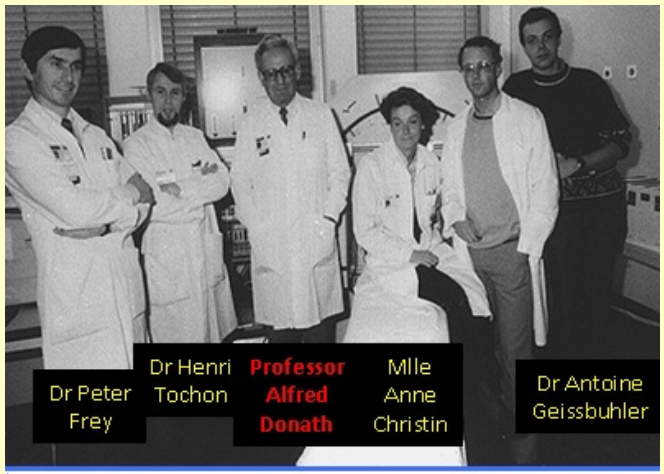





First mouse imaged at CERN with Na-$^{18}$F in 1978

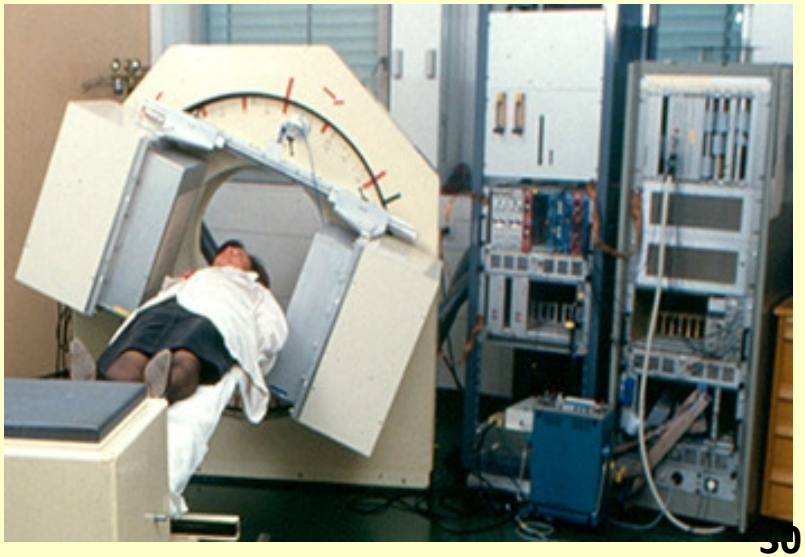
1978 at CERN






Tribune de Genève, January 1988

Team & HIDAC PET Camera at HCUGE



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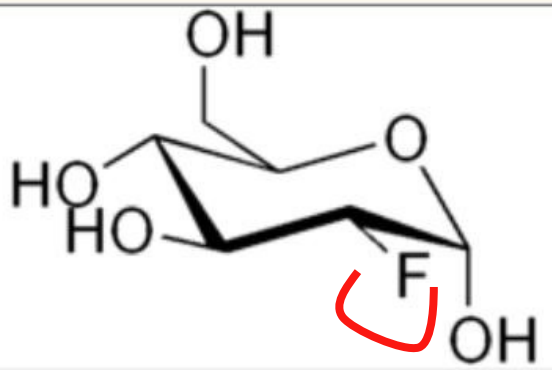
# Why FDG Works So well?

$C_6H_{11}FO_5$

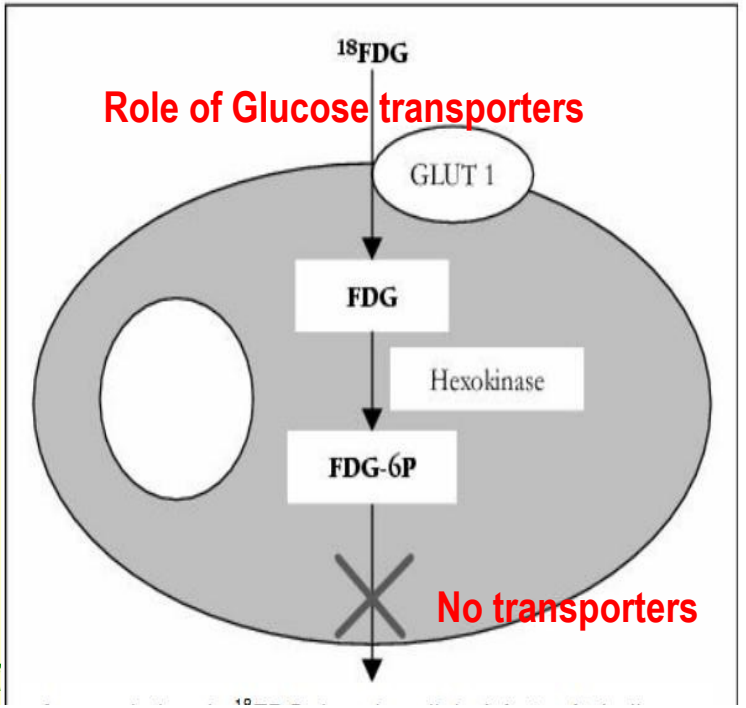
**Fluorodeoxyglucose** is a glucose analog. Its full chemical name is **2-fluoro-2-deoxy-D-glucose**, commonly abbreviated to FDG.

FDG is most commonly used in the medical imaging modality positron emission tomography (PET): the fluorine in the FDG molecule is chosen to be the positron-emitting radioactive isotope fluorine-18, to produce $^{18}$F-FDG. After FDG is injected into a patient, a PET scanner can form images of the distribution of FDG around the body. The images can be assessed by a nuclear medicine physician or radiologist to provide

**Fluorodeoxyglucose**




| | |
|---|---|
| Chemical name | 2-Deoxy-2-fluoro-D-glucose |
| Other names | 2-Fluoro-2-deoxy-D-glucose<br>FDG |

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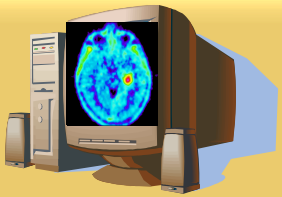
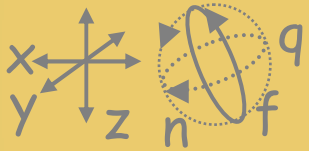
# Fusion imaging: from software to hardware

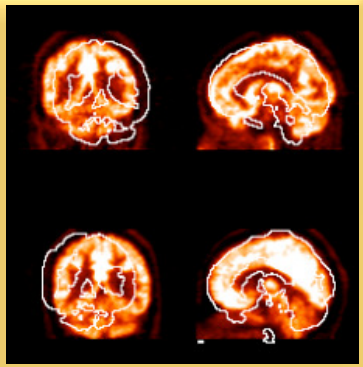
(from D. Townsend 2014)

CERN

## 1990





Software-based fusion (semi-automated)

## 1993 - 1998

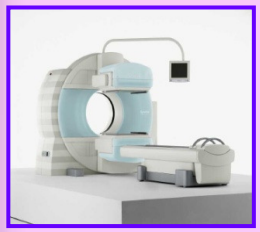


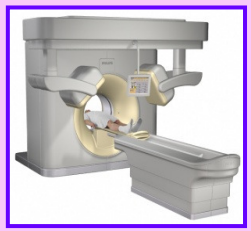
Hardware-adjunction: Prototype designs

## 2001

Hardware-adjunction: Commercial PET/CT

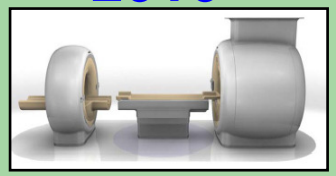
## 2004

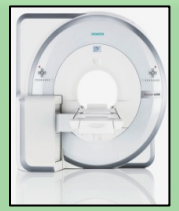


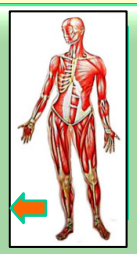


Hardware-adjunction: Commercial SPECT/CT

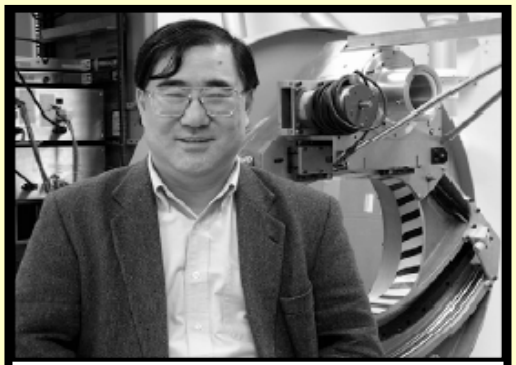
## 2010







Hardware-based fusion: Commercial PET/MR



Bruce H Hasegawa, PhD, 1951-2008
Participant ESI, Archamps In 1997

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# Why Imaging (SPECT, PET..)

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## is useful in Oncology for

- Help in **Diagnosis**
- Help in **Treatment plannings**
- Help **Post-treatment survey**

**SPECT-CT & PET-CT are better than SPECT & PET alone….**

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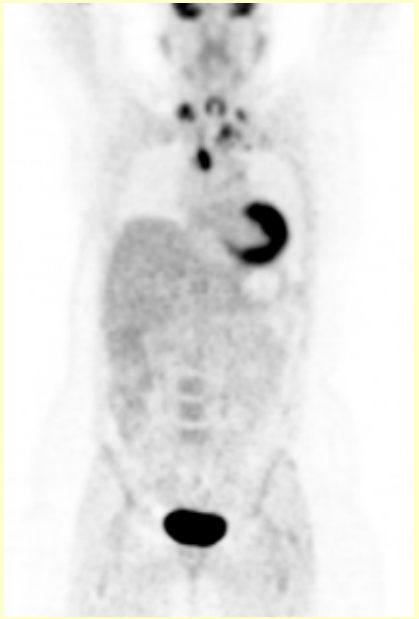
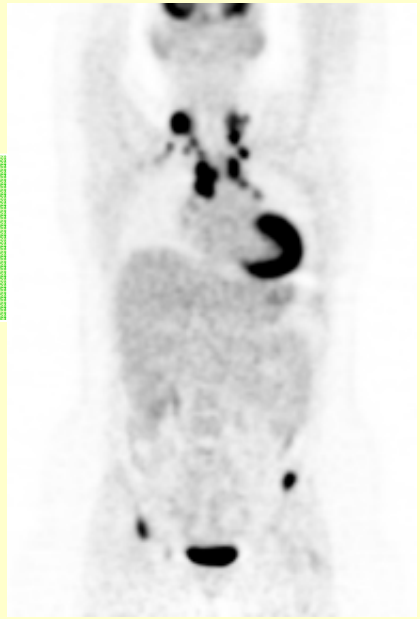
# disease progression SURVEY (ex: Breast cancer)

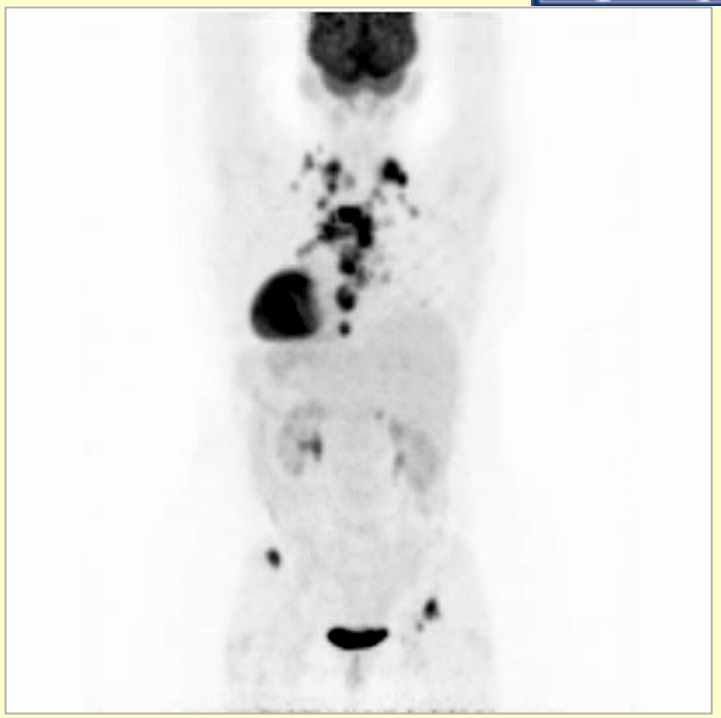
CERN

*



Two imagings at a 9 months interval :





**28 min** (8/05)

**10.6 mCi, 115 min pi**
**4 min/bed, 7 beds**
**3i / 8s; 6f**

**15 min 9 months later** (5/06)

**10.5 mCi, 104 min pi**
**3 min/bed, 5 beds**
**3i / 8s; 6f**

**Scan duration: 15 min**

*Biograph*

48 year-old female (200 lbs) with history of breast cancer. First PET showed intense uptake in bilateral supraclavicular, mediastinal and right parasternal nodes and the thyroid. 9 months later PET showed significant disease progression including sternum and pelvic region

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# ½ year Post / Pre treatment Survey

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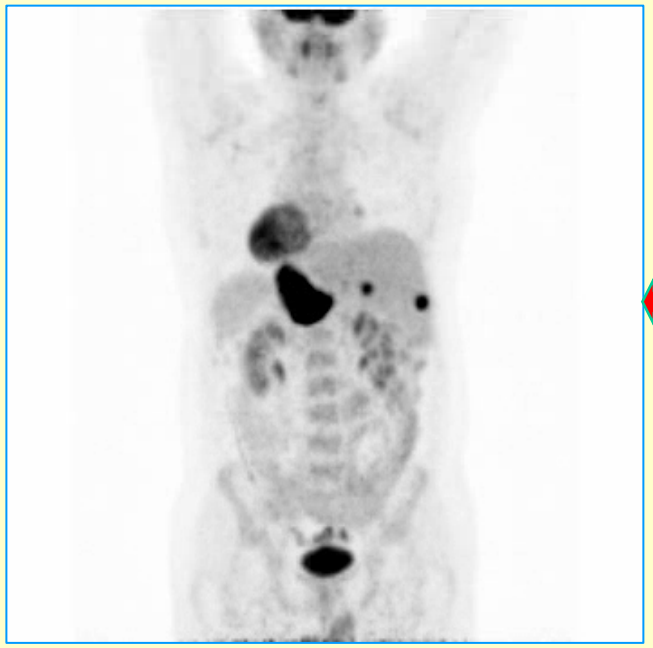
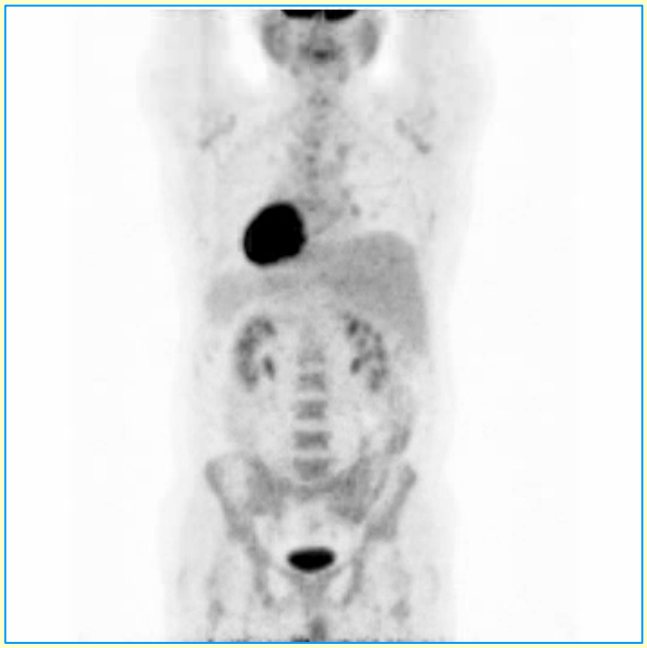
Restaging gastric cancer



Pre-therapy (4/06)

With Biograph

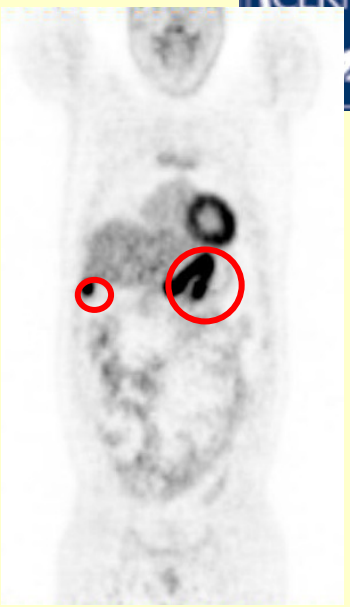


Post-therapy (10/06)

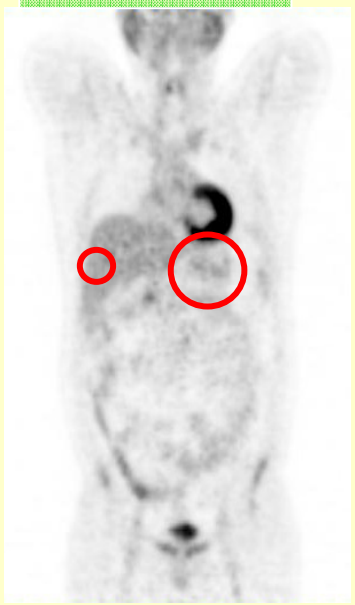
6 months later

**Scan duration: 15 min**
**5 beds; 3 min/bed; 8s/3i/6F**
**10.6 mCi; 90 min post-injection**

**Scan duration: 15 min**
**5 beds; 3 min/bed; 8s/3i/6F**
**9.8 mCi; 90 min post-injection**



Pre-therapy



Post-therapy

A 52 year-old male patient with history of gastric cancer imaged pre- and post-therapy (after ½ year)

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# TREATMENT PLANNINGS

(Will be explained later by Alex Rijnders)

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**Treatment plannings are compulsory for correct treatment**

**The Software start from Images**

CT-SCAN ⟷ MRI or / and PET

- external contours
- densities
- anatomical structures
- beam data library

- anatomical structures

BEAM DEFINITION

**TREATMENT PLANNING SYSTEM**

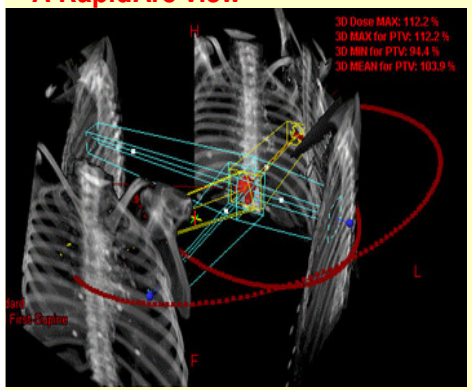
OPTIMISATION

- Dose distribution
- Dose-Volume Histograms
- Biological indices

**Most Popular systems:**

Pinnacle (Philips Medical systems)
ADAC -> Pinnacle3(Philips)
Monaco (CMS/Elekta)
Eclipse (Varian Medical Systems)
RapidArc: see(varian.com/us/oncology/treatments/treatment_techniques/rapidarc/resources.html
.....

A RapidArc view




- Reconstructed radiographs (DRR)

SIMULATOR and/or ELECTRONIC PORTAL IMAGING

- Field shape or
- Position of leaves

BLOCK CUTTING DEVICE or MLC

- Treatment parameters
- Treatment time (monitor units)

ACCELERATOR

VERIFIY AND RECORD SYSTEM

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# 6. QUANTIFICATION

## (SPECT & PET)

*Ohrid Workshop September 2015 Yves LEMOIGNE / IFMP – Ambilly – France & CERN-Geneva-Switzerland*

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# Definition of SUV (Standardized Uptake Value):

Coeficient used in Oncology for semiquantitative analysis

The percent injected dose per gram of tissue:

$$SUV = CT.Ws / d_T.Dinj$$

Where: $C_T$ (in mCi/cc) is obtained from counts/pixel/time from PET ROI.

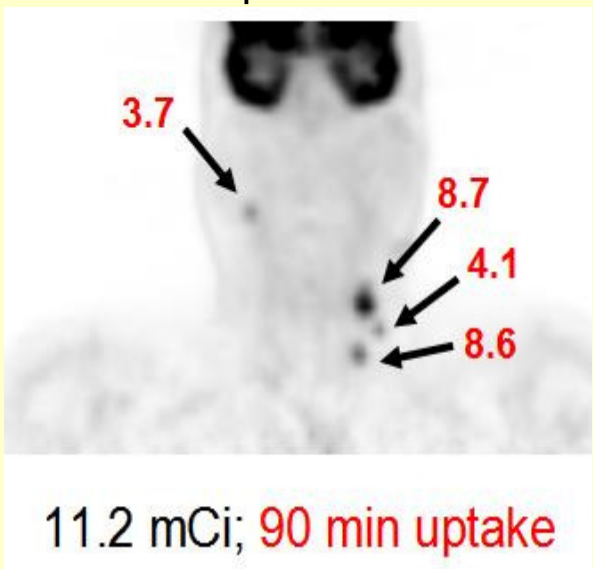
$d_T=W_T/V_T$ (weigth to volume of studied tissue) is the density in the region (often 1 g/cc)

$D_{inj}$ being the injected dose

Ws is the total weight of the patient)

SUV=unitless parameter (from 1 to about 10)

Example of SUV



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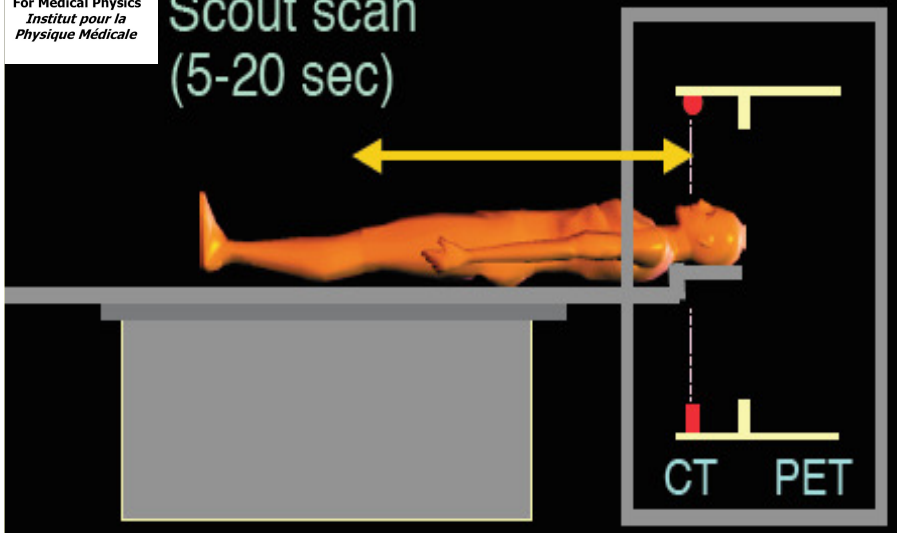
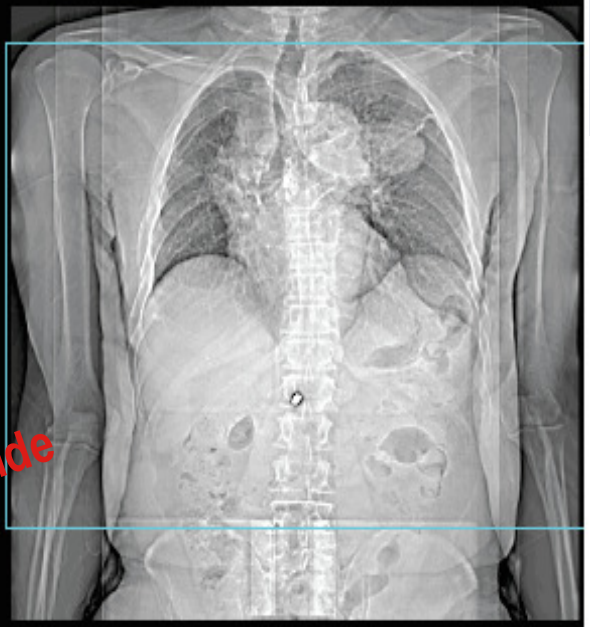
# 7. EXAMPLES OF USES @ HOSPITAL

# PET/CT (SPECT/CT) Scan protocol

Scout scan (5-20 sec)



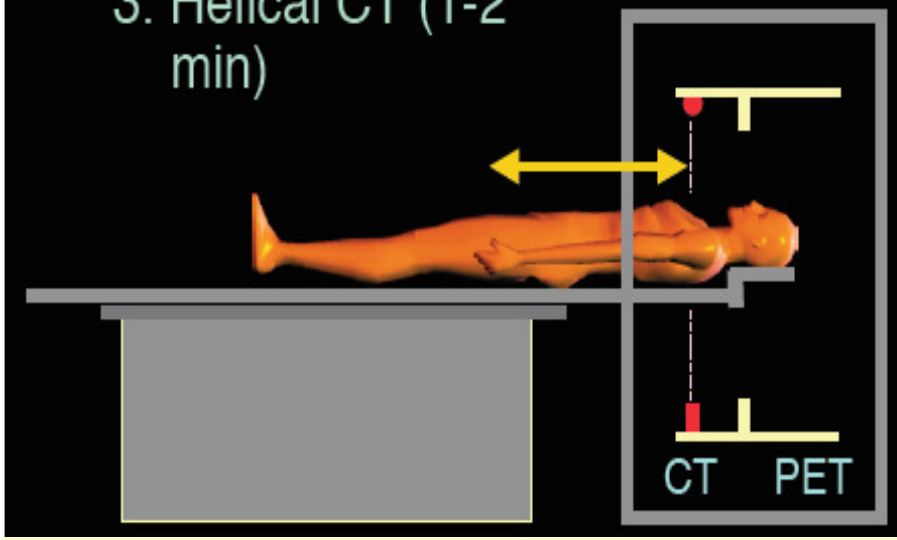

2. Selection of scan region (1-2 min)



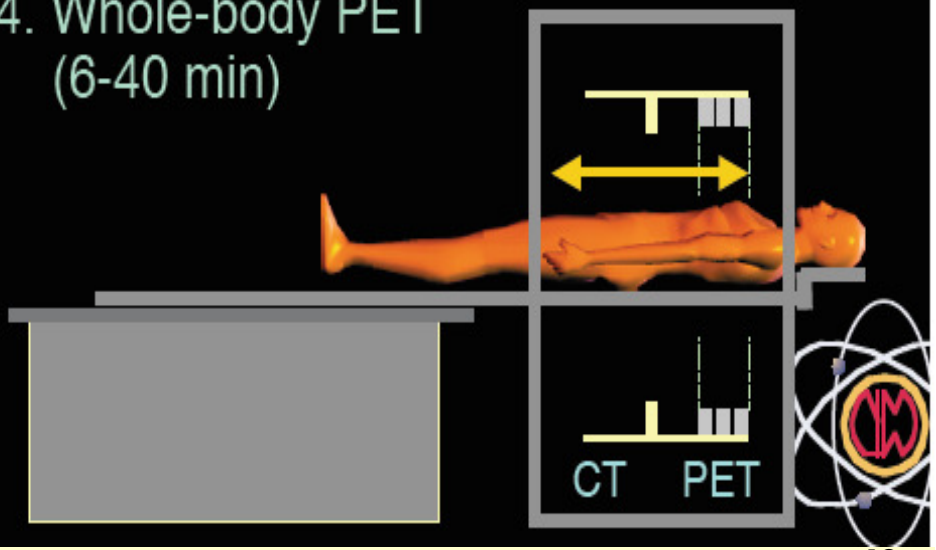
Scout scan image

4000 PET/CT scanners operational worldwide

3. Helical CT (1-2 min)




4. Whole-body PET (6-40 min)

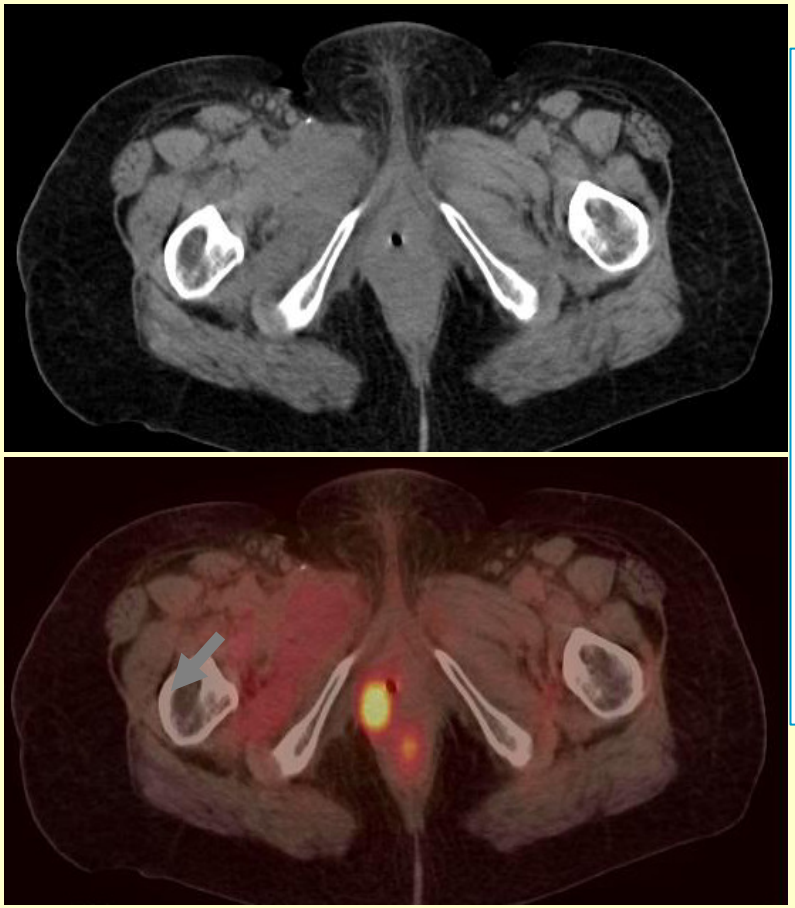


# SURVEY : Vaginal cancer

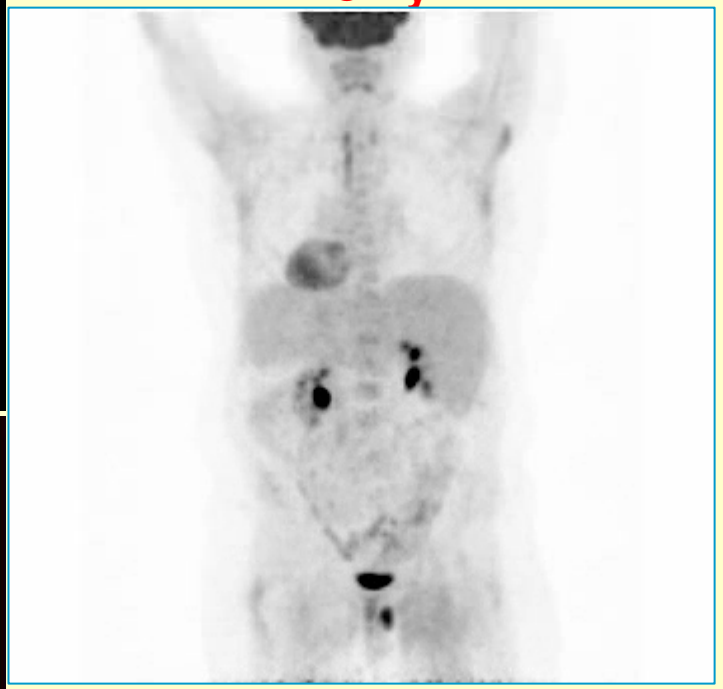
## PET-CT is more powerful than PET alone….

CT only

PET+CT



* PET only



Biograph Scan duration: 15 min

5 beds; 3 min/bed; 8s/3i/6F

10.6 mCi; 90 min post-injection

A 50 year-old female patient restaged for vulvar cancer with history of NHL (Non-Hodgkin lymphoma),. The PET/CT scan shows focal uptake in right aspect of the vulva (SUV: 10.3). Adjacent focal anorectal uptake (SUV: 5.5). CT is negative with no abnormality seen. Only combination of CT and PET can show that!

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# 8. IMPROVEMENTS

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# Last years Improvements in PET cameras

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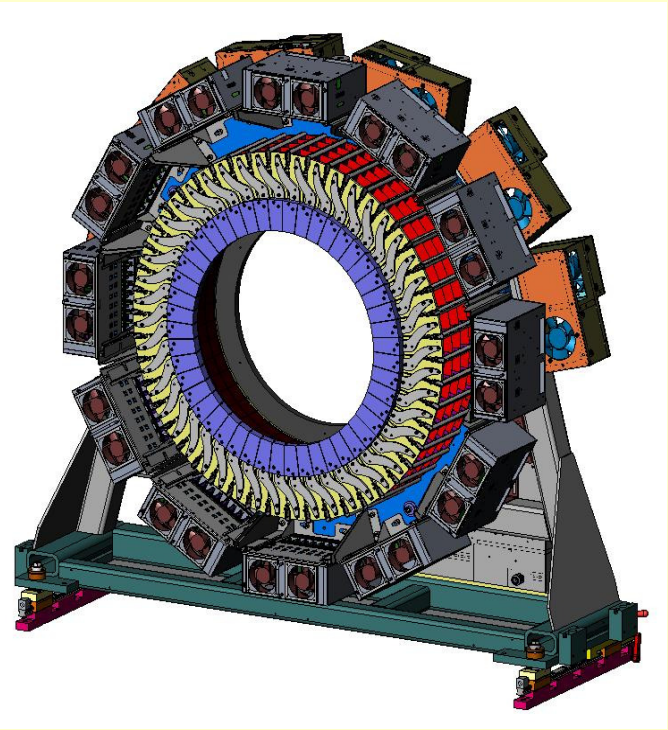
- **Better Crystals** (Ex: more ph/MeV with LSO, LYSO, LuBr3…)
- **Spatial resolution** (Ex : Crystal size 4 x 4 mm or smaller)
- **New reconstruction algorithms**
- **Efficiency** (Septa removed in PET)
- **Time-of-Flight** (Tof)
- **MRI-PET** Devices:

## Complementary nature of MRI & PET

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

Hence: The Sum of PET and MRI should be excellent and even better **MRI + PET << MRI-PET**



Ex: Biograph TruePoint PET•CT (Biograph TP)

# Time-of-Flight (TOF)

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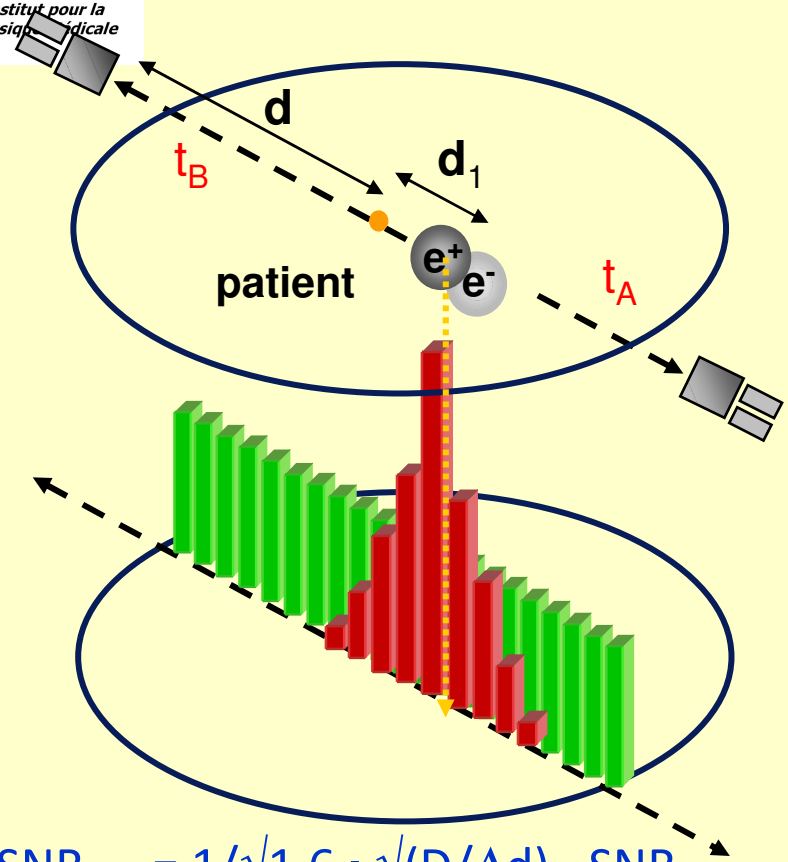
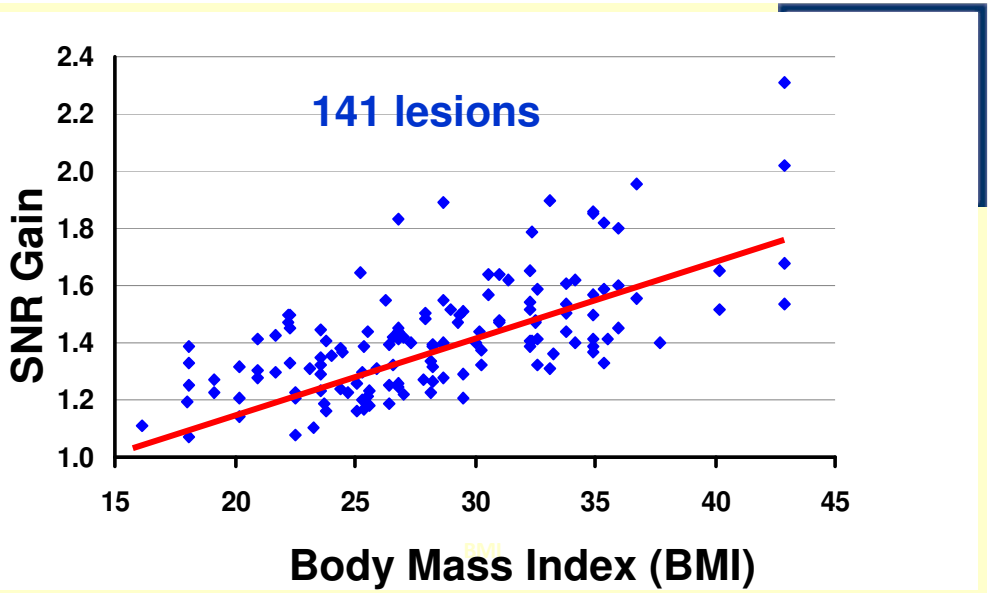
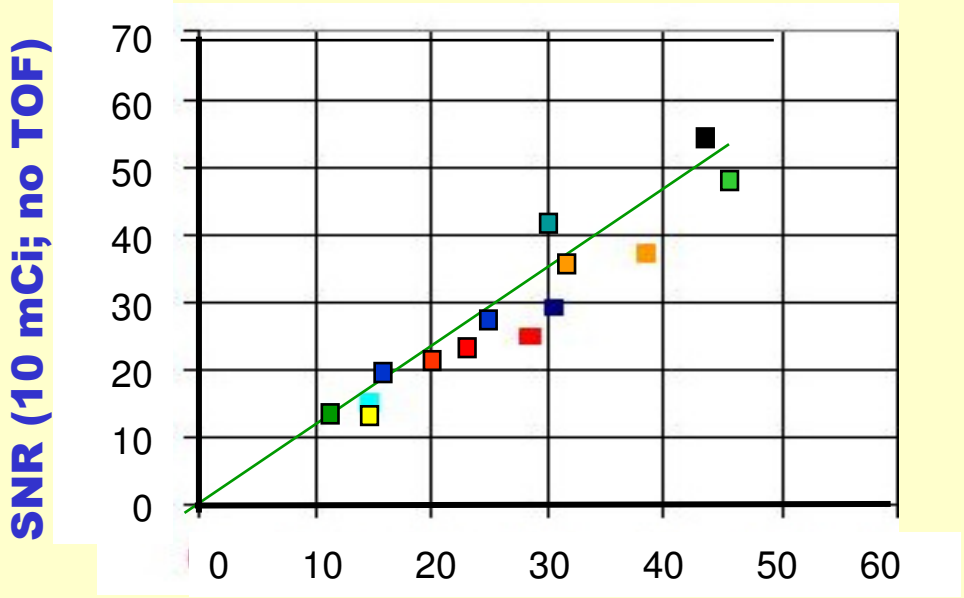



$$SNR_{TOF} = 1/\sqrt{1.6} \cdot \sqrt{(D/\Delta d)} \cdot SNR_{conv}$$

| Ds (ps) | Dx (cm) | SNR gain |
|---|---|---|
| 100 | 1.5 | 5.2 |
| 300 | 4.5 | 3.0 |
| 500 | 7.5 | 2.3 |
| 1200 | 18.0 | 1.5 |




✓ **Improved signal-to-noise**




✓ **Reduced radiation dose**

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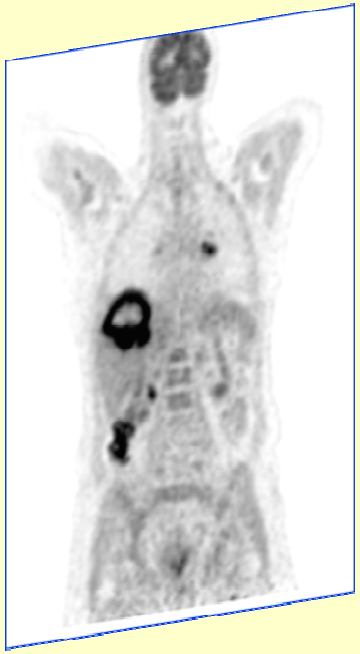
# 2010: PET/MR



Over 30+
years of
development

(1980)


# in the clinic

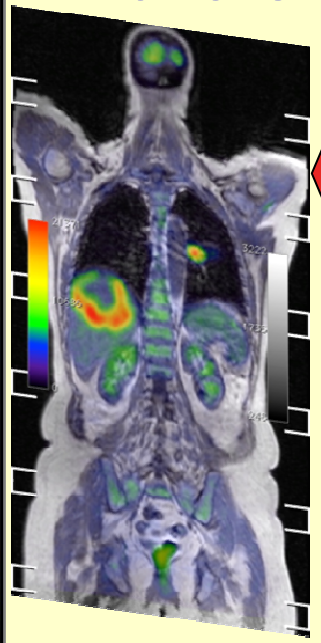
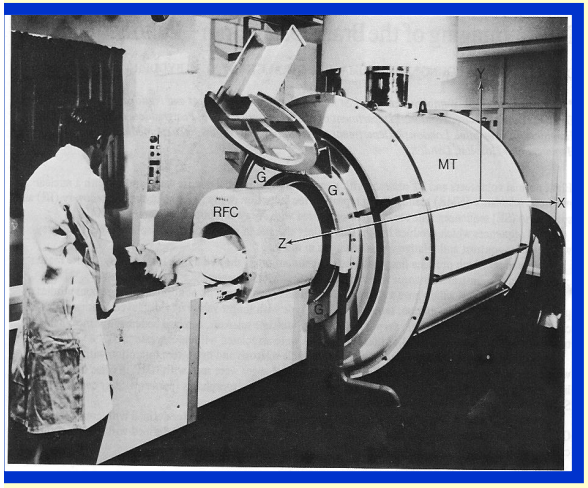
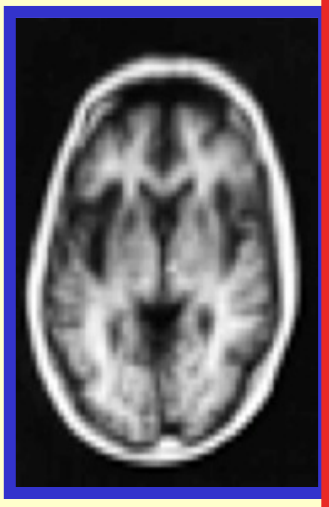


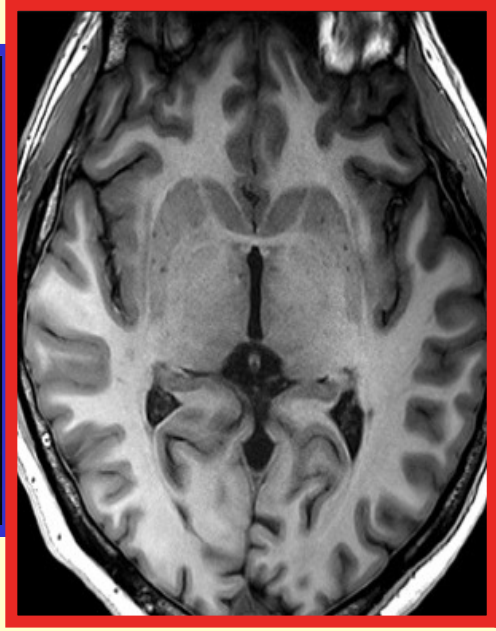
Image Quality

SIEMENS Skyra
MRI scanner
(2013)



First patient on Aberdeen MRI (1980)



# Solid state photodetectors for integrated PET/MR

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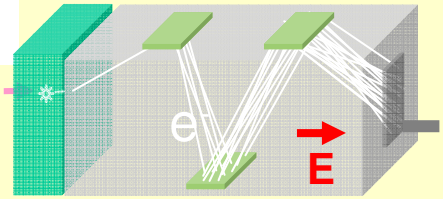
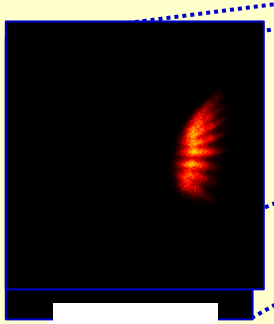
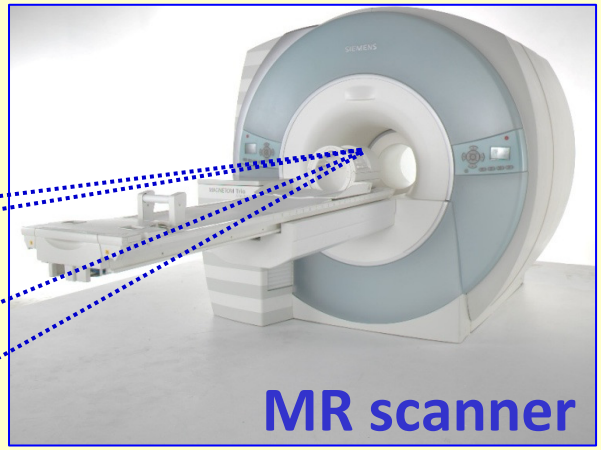


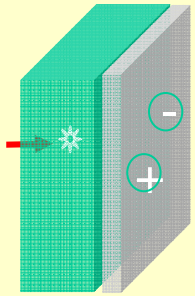

Block detector



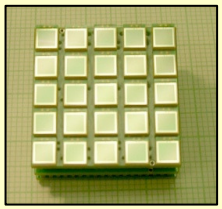
B = 1.5 T



MR scanner



APD-based PET detector



SiPM-based PET detector

## Photodetectors

| | PMT | APD | SiPM | dSiPM |
|---|---|---|---|---|
| MR compatible | No | Yes | Yes | Yes |
| TOF capability | Yes | No | Yes | Yes |
| Stability | Good | Good | Unknown | Unknown |
| Amplification | High ($10^6$) | Low ($10^3$) | High ($10^6$) | N/A |
| Compactness | Bulky | Compact | Compact | Very compact |
| Power<br>Readout | HV, ASIC<br>Analog | HV, ASIC<br>Analog | LV, ASIC<br>Analog | LV, simple<br>Digital |

PHILIPS VEREOS PET/CT

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# *Combined whole-body PET/CT to PET/MR..*

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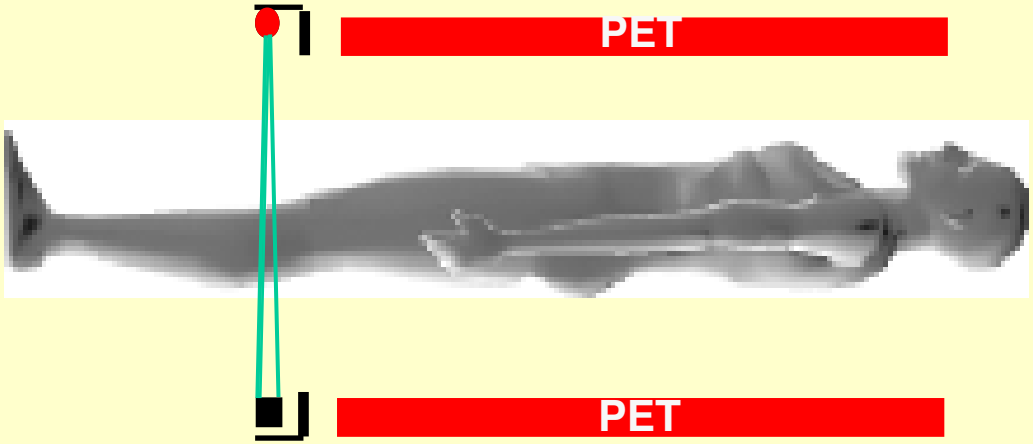
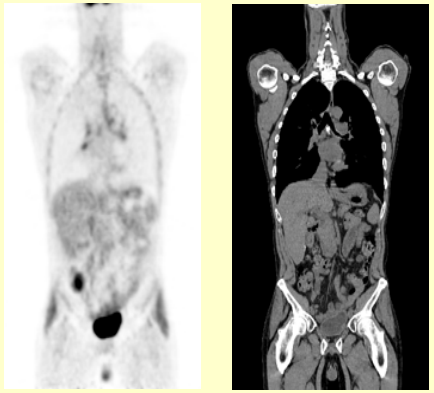
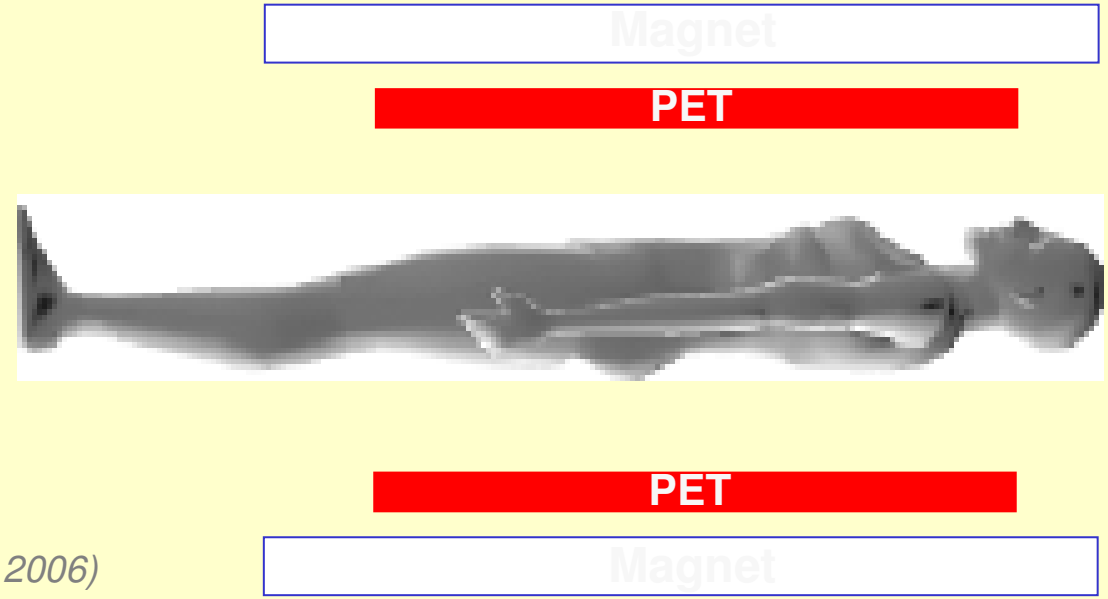
***PET/CT***

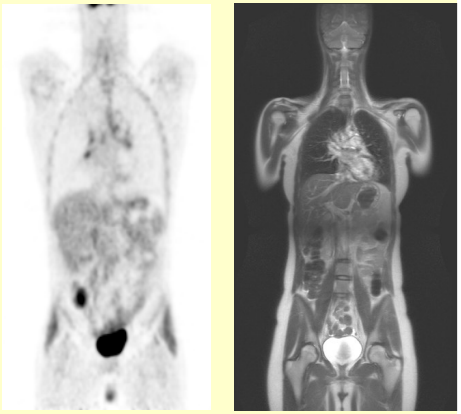


***PET*** ***CT***

***PET/MR***



***PET*** ***MR***

*(S.R. Cherry, 2006)*

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# Challenges for PET/MR

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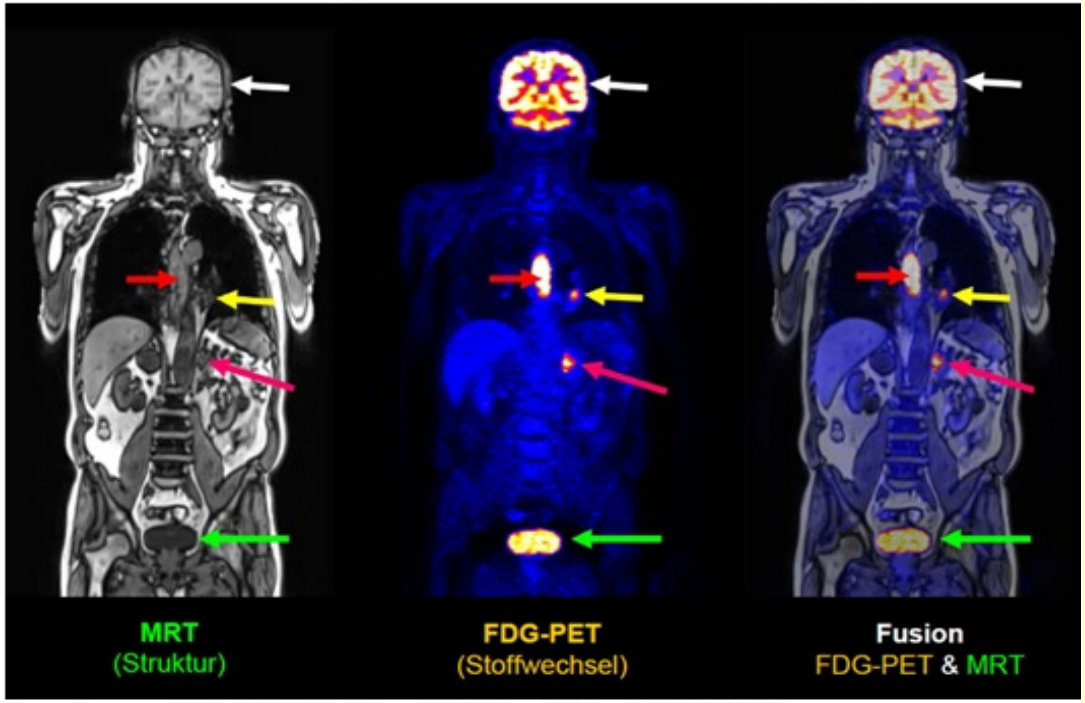
- MR-compatible PET detectors from technics (APD,Si-PM..)
- PET attenuation correction factors from MR images
- role for simultaneous MR and PET acquisition?
- financial cost (eventually) of the PET/MR system
- Used routinely for Small Animal PET then for patientd (L. Bidaut)

**But already exceptionnal images …**

**See Luc BIDAUT talks tomorrow…**

MR-PET Design for Whole Body Applications




Courtesy: Sibylle Ziegler, TU Munich, Fall 2010)

# As conclusion:
# Radiation doses for clinical imaging procedures

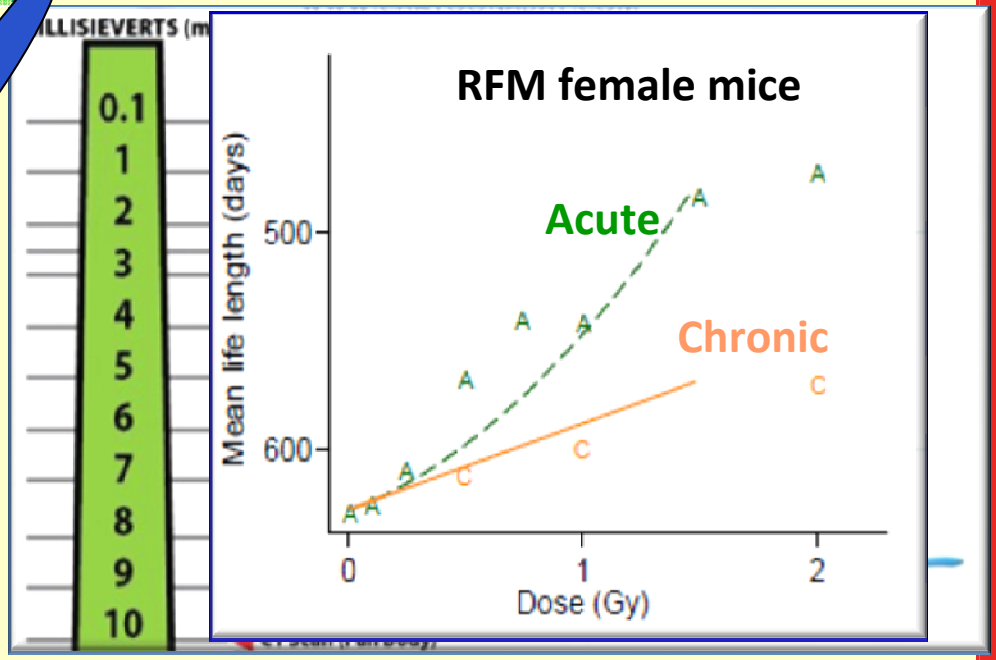
Annual Background Radiation

No reliable data on effects of radiation

Lower limit for known effects of radiation

- CT Abdomen / Pelvis
- PET/CT (FDG)
- Myocardial Perfusion Scan
- Chest CT
- Virtual Colonscopy
- CT Screening Lung Cancer
- PET/MR (FDG)
- MBI (8 mCi)
- Mammogram + tomosynthesis
- Mammogram
- Chest X-ray
- Bone Densitometry

*Patient dose Reduced*




Very Low Dose

Low Dose

0 5 10 15 20 25 30 35 40 45 50 55 60 100

Radiation Dose (mSv)

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# 9. CONCLUSION

During last decade: Impressive progress in Medical Imaging

Due to enormous work on the technical front:

- New detectors
- Software
- Training
- Radiation Protection

About 4000 PET/CT scanners operational worldwide (start in 2000')

PET/MR scanners are beginning now

All that is for the main benefit of patients….

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# Thanks a lot for the gentle attention!