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Two Decades of History …

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Elbasan International Workshop on Medical Physics & Bioengineering in 2016 is a continuation of a serie initiated to promote dialogue between scientists of different countries for development of sciences and good understanding between people having a somewhat different culture..

More important milestones were:

Trieste 1995
Sarajevo 1996 & 1998
Oujda 2000
Thessaloniki 2002
Istanbul-Bogazici 2004
Iasi 2007
Cairo 2009 & 2011
Sarajevo 2014
Shkodra 2014
Ohrid 2015 ….

Physique-Sans-Frontières
Physics-Without-Borders

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NSPA

ESMP

GREISE
Association GREISE

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2015 International Year of Light and techniques using light paid tribute to:

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Ibn Al Haytham, Bassora 965- Cairo 1039, from persan (Iran) origin, is the father of Experimental Physics and Scientific Method that we are all using now.

- He was the promoter of the experimental scientific method; ***(validation of a theory must be done by experimental results)***
- one of the first physicist / theorists to use mathematics in physics in replacement of "philosophic" intuition used previously.
- His pioneering work in the field of physiological optics and optics in general has made Al Haytham's first true scientist.
- In his tribute paid by International year 2015: Asteroid 59239 now bears his name as well as a moon crater

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ELBASAN Workshop 2016 (Tentative Time-Table) V11

Aleksander Xhuvani University with IFMP & CERN

	Monday 4 july	Tuesday 5 july	Wednesday 6 july	Thursday 7 july	Friday 8 july
	Welcome & MP / US basics	US use in Med. Phys.	US Innovations / Cultural day	Brachytherapy (BT)	BT & Trends in Med Phys
8:00 8:30	registration				
8:30 9:30	welcome *Rector, AAPM, IFMP…*	US Transducer *H. Liebgott, Creatis-Lyon, F*	Ultrafast US *H. Liebgott, Creatis-Lyon, F*	Photon Sources *A. Rijnders, Brussels, Be*	Conv. & Stereotactic RT *I. Muçollari, Mother Teresa Hsp.*
9:30 10:30	Med Phys@Albania / IAEA Guidelines *P. Malkaj, UPT Tirana*	US Beamforming *M. Mischi, Eindhoven, NL*	Simulation in Med US *H. Liebgott, Creatis-Lyon, F*	Dosimetry systems *E. Telhaj, Hygeia, Tirana*	QA, Patient Safety in BT *A.Rijnders, Brussels, Be*
coffee break	coffee break	coffee break	coffee break	coffee break	coffee break
11:00 12:00	Medical Imaging Rev.1 *Y.Lemoigne, IFMP F & CERN-CH*	Doppler US - 1 *P.Tortoli, Firenze U, It*	Trip to Lin (Fishermen village & Mosaic chapel)	Radiobiology in BT *A. Rijnders, Brussels, Be*	Innovation in MP *E.Raeisi, Tehran, TBC*
12:00 13:00	Ultrasound basis *C. Cachard, Lyon1 Uni, F*	Contrast Agents *M. Mischi, Eindhoven, NL*	Trip cont' to Pogradec Visit Ohrid lake in Pogradec	Brachytherapy Room *E. Telhaj, Hygeia, Tirana*	Summary & conclusions end of Workshop
Lunch	Lunch	Lunch	visit & Lunch in Pogradec	Lunch	
14:30 15:00	Students'forum	Students'forum	Trip to Korçë (Maliq …)	Students'forum	*departure to Tirana (Possible visit ?)*
15:00 16:00	Medical Imaging Rev.2 *Y.Lemoigne, IFMP F & CERN-CH*	Using US in cardiology *M. Qordja, Mother Teresa Hosp.*	Korçë visit (Saint Risto frescos; Old City centre; Impressionnist museum….)	BT Treatment Plannings *A. Rijnders, Brussels, Be*	
coffee break	coffee break	coffee break		coffee break	Legend:
16:30 17:30	Ultrasound imaging *C. Cachard, Lyon1 Uni, F*	Doppler US - 2 *P.Tortoli, Firenze U, It*	back to Elbasan	Ionising Radiation in RT *U.Gjoka, Tirana*	Generalities Ultrasound US
17:30 18:30	Training & Simulation in RT *Niko Hyka, UPT Tirana*	Using US in Urology *Drilona Kishta, Tirana Uni*		Varian Presentation *A. Mader, Varian Ltd*	Radiotherapy Cultural Program.
19:00					
20:00 23:00	Welcome Coktail			Banquet	

Note : One hour slot means 45 mn lecture and 15 mn discussion.

Students'forum could be oral or poster presentation by students about their work or any topic they think interesting (15 mn max).

Thus 6 students could do oral presentation with Powerpoint. Poster presentations could go up to 12 selected as the best ones.

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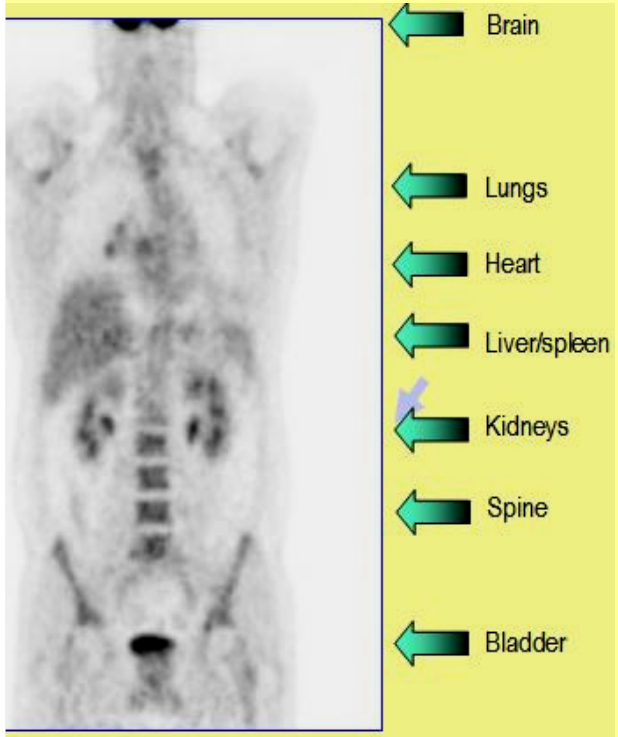
The Role of MEDICAL IMAGING in the Evolution of Medicine

Yves LEMOIGNE, PhD

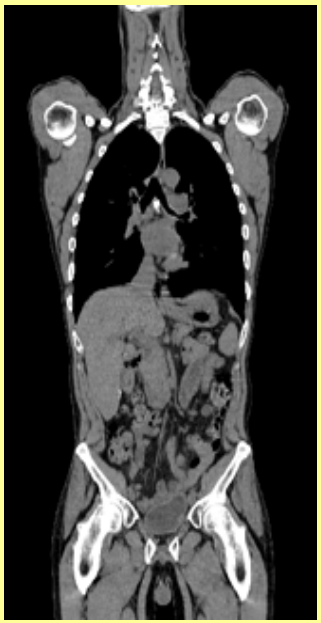
Institut pour la physique médicale, Ambilly
France
CERN, Geneva, Switzerland



PET

Lecture 1 we will be a "classical review " of some devices in use at the clinics. Except ULTRASON which will be explained by Sonic experts (Christian et al.)

Lecture 2 will be in continuation of lecture 1 but will be devoted to hybrid devices, what complementarities are obvious. What they actually bring as decisive progresses at hospital, what are the main trends in evolution ….



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1.INTRODUCTION

First part we will be a ”classical review“ of some devices in use at the clinics. Except ULTRASON which will be explained by Sonic experts (Christian et al.) Lecture 1.

Second part will be devoted to hybrid devices, what complementarities are obvious. What they actually bring as decisive progresses at hospital, what are the main trends in evolution …. Lecture 2.

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First Statement

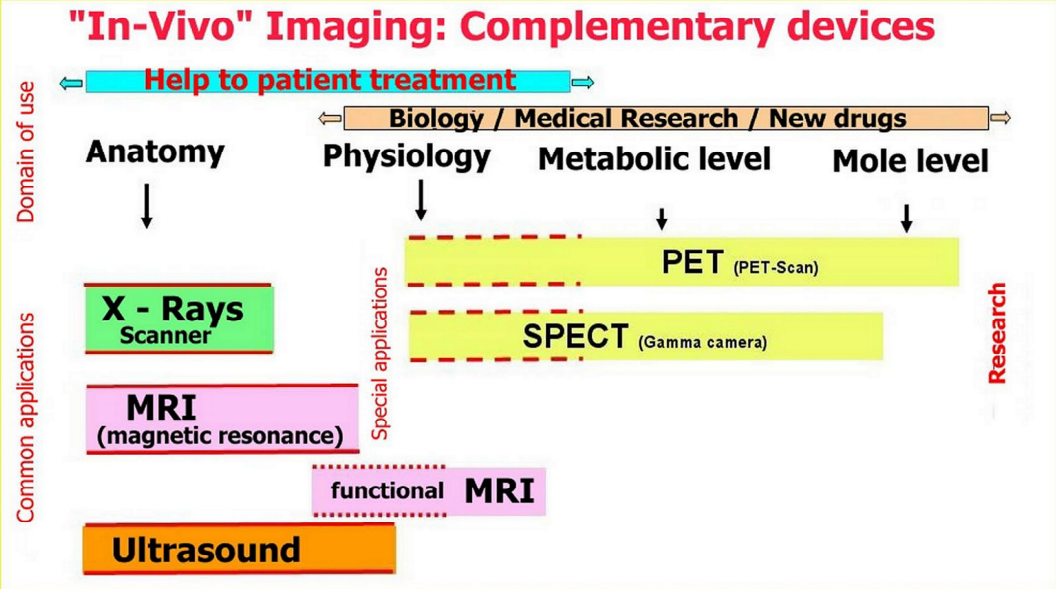
RSNA 2007- Elias Zerhouni NIH Director 2002-2009 cites central role for imaging in medical progress

- Imaging in the 21st century is at the heart of interdisciplinary science for generating, understanding, and using spatially and temporally resolved biological information
- Medical imaging is a model for the style of interdisciplinary science that will propel medical progress through the 21st century
- Imaging will be key because it is nondestructive, inherently quantitative, and multidimensional
- **This combination of technological innovation and biological understanding is now even more at the forefront of what drives scientific change**

April 2016 CERN EP Seminar, 12 April, 2016 Courtesy P. Lecoq CERN 3

What we were saying 15 years ago:

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

"PET-SCAN"

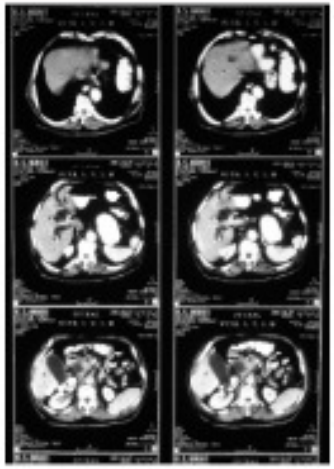
Each technique has its own specificity and thus a particular area of application:

- 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).

Imaging Modalities

See lectures from
C.Cachard, P.Tortoli, M.Mischi, H.Liebgott



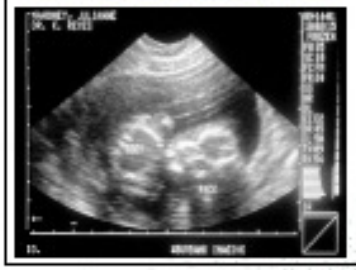
CT

A

Tissue Density, Z
20-50 µm

Anatomy

Ultrasound



A F

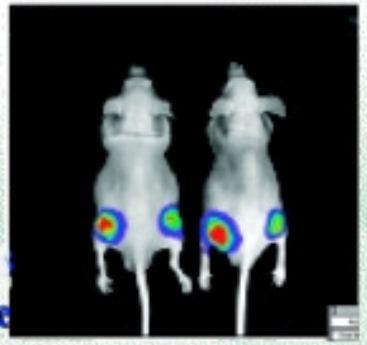
Structure
0.1 mm
Doppler

Optical
(Bioluminescence, fluorescence)

A M

Topography
µm to mm

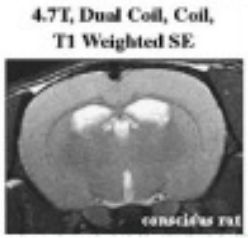
≠ quantitative

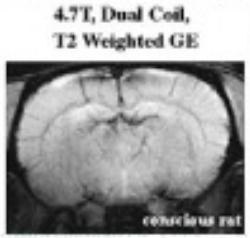


Ionizing radiation

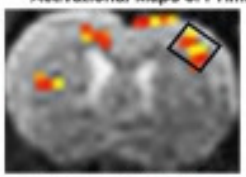
Functional

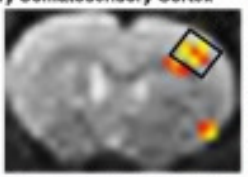
MRI





Activational Maps of Primary Somatosensory Cortex





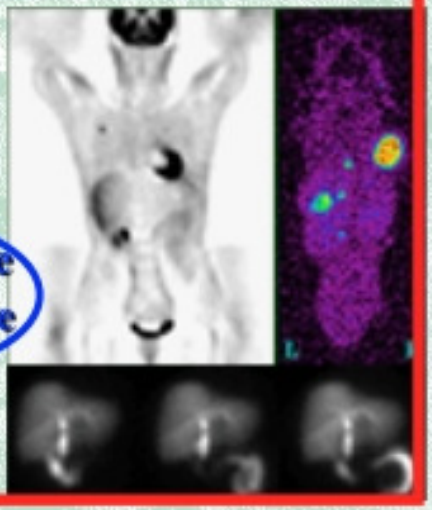
A F M — Molecular

H Concentration
0.1 mm
BOLD, DCE
β-galactocidase
0.1 µmole H / µmole ^{31}P

PET/SPECT

F M

Radiotracer
~1-2 mm
$<10^{-12}$ mole
= quantitative



Imaging targets

- At the level of organs
  - To quantify dynamic metabolic changes over time
    (Including Oncology @ hospital)
- At the cellular level
  - To understand trafficking within cell, in tissues, and for cell-to-cell interactions
    (Including Biomedical Research)
- At the molecular level
  - To delineate molecular pathways
    (Including Biomedical Research)

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2. X-Rays CT

X-Rays Computed Tomography (CT)

- X-Rays-CT has become recognized as a valuable medical tool, for:
- Diagnosis of disease, trauma, or abnormality (Anatomy imaging)
- Planning, guiding, and monitoring therapy (Ex: Treatment Planning preparation)

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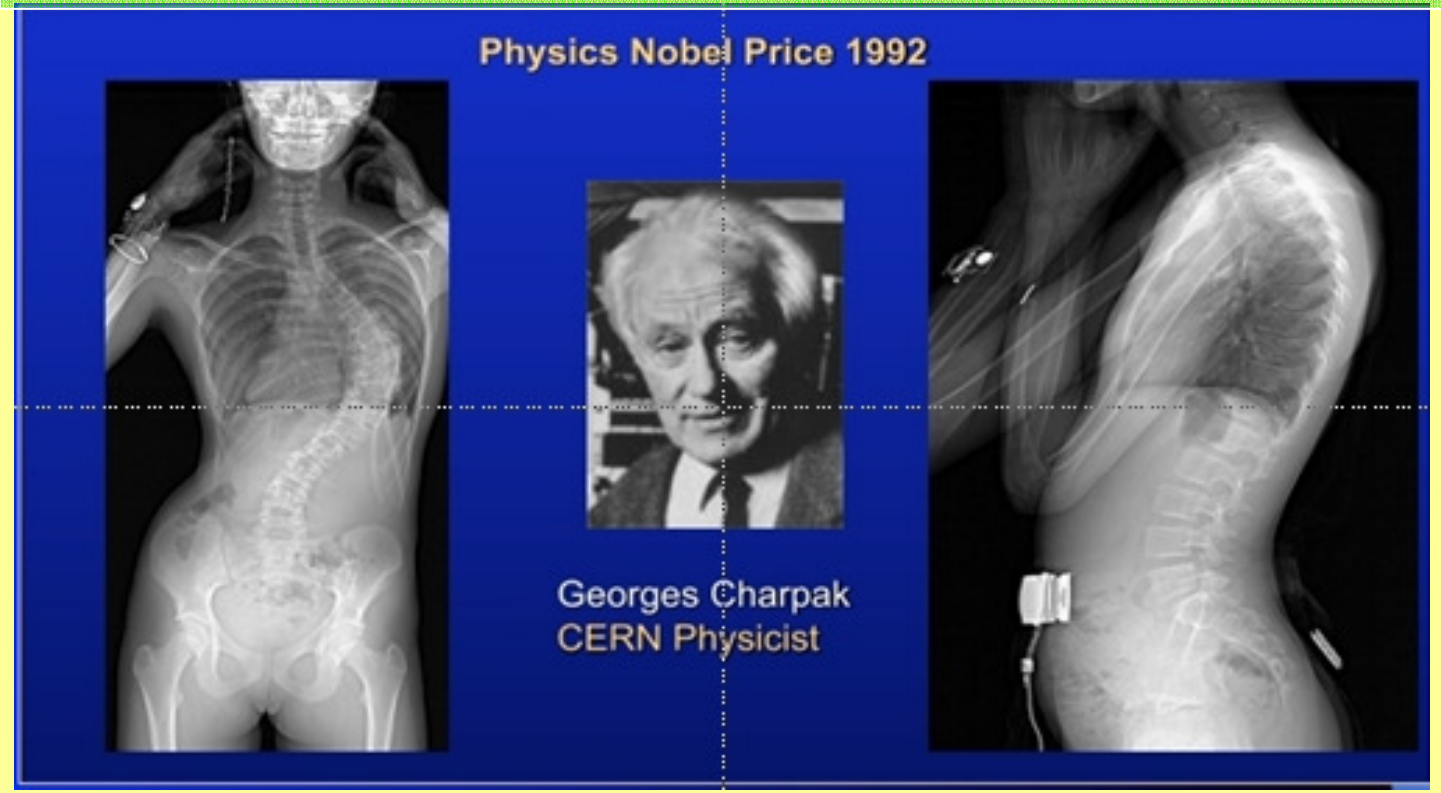
One minute to pay a tribute to the memory of : Georges CHARPAK



Inventor of large area radiation detectors (MWPC) his contribution to Low dose digital X-RAY imaging was decisive (and spectacular in quality of images)

For me, young HEP physicist at this time and working with his group to develop a new particle detector, he told me, as to other colleagues: « what you are doing is ok but look at applications in other fields like Medical Physics »… I followed his advice and I came in medical physics …without return !

With him we also initiated the series of South-Eastern Europe scientific meetings whose Elbasan is the more recent one…

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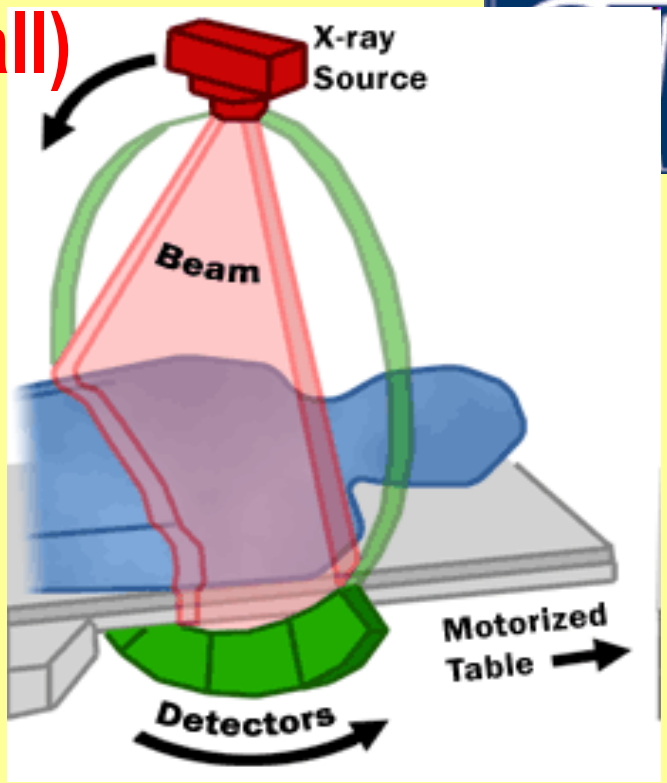
2 - CT Principle (recall)

Description

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

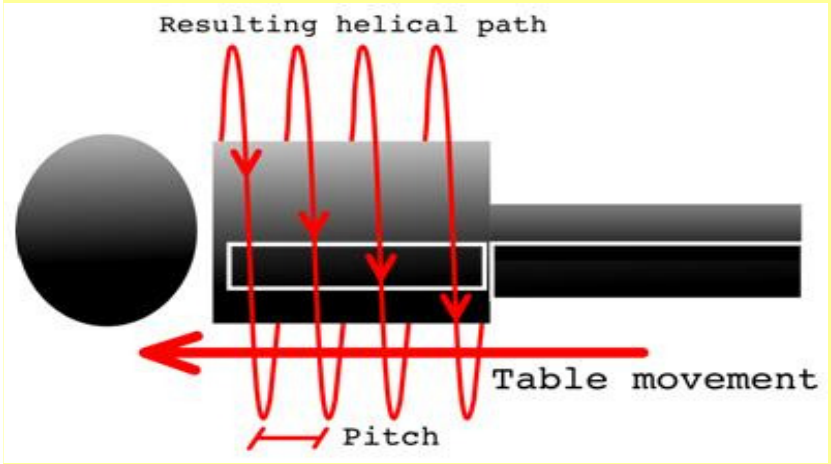
These cross-sectional images are used for a variety of diagnostic and therapeutic preparation purposes.



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. in a narrow beam passing 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)

CT Utility & Definitions



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:

$$I = I_0 \exp\left[\sum_i (-\mu_i x_i)\right]$$

Simple

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

Well known , Efficient…

But:

Non-negligeable x-ray radiation exposure:

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

An important issue : 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 :

Examination Typical	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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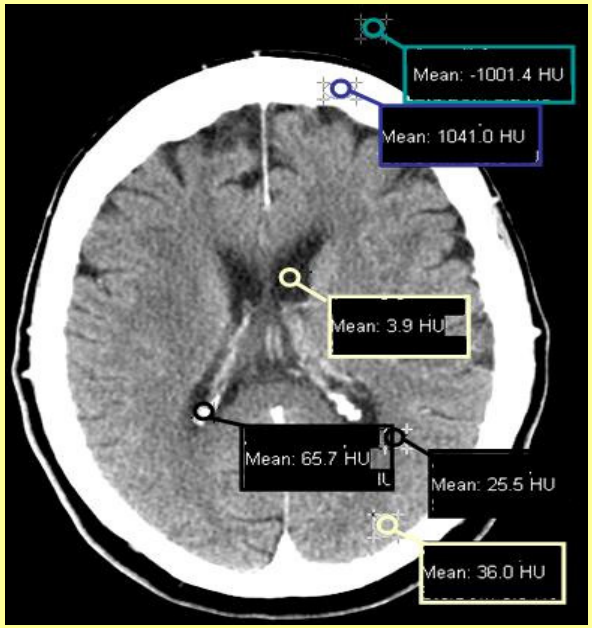
Low-dose CT scan :

- Reduce the radiation dose / same image quality.
- doses ⇧ = image resolution ⇧ ?
- doses ⇩ = noise ⇧ (unsharp images) ?.

(An abdominal CT gives = 300 chest x-rays for dose).



- Several methods to reduce exposure dose :

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

2. Individualize the examination : Different body types & organs require different Rad amounts

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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Some prices for CT devices (see www.info.blockimaging.com)

- GE Lightspeed : ~175 K $
- GE VCT 16 : ~180 K $
- Philips BRILLANCE : ~183 K $
- Siemens EMOTION 16: ~ 230 K $
- Toshiba AQUILION 16: ~ 255 K $
- GE VCT 32 : ~260 K $ →
- Siemens SENSATION 64: ~ 270 K $


GE VCT 32

Philips Brilliance 16 CT Scanner


Siemens Emotion


Siemens Sensation


Toshiba Aquilon

Next slide:

Example of Info targetting large public on capacities of Modern CT (by GE) on a French TV

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- A video displayed at French TV for a large public at a time of great audience to convince them of high quality of « General Electric (GE) » products… we could evaluate or critize after looking at it.
- Pdf is unable to diplay videos. You have to exit pdf reader and use you video browser for file: GE VCT PUB EN Subtittled2.mp4 it.
- Then come back to pdf browser to continue lecture…..

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3. M R I

Magnetic Resonance Imaging

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MRI : Overall picture of how it works…

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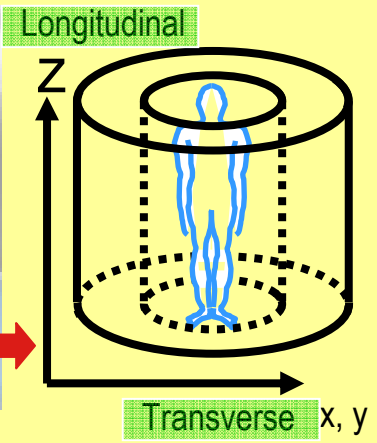
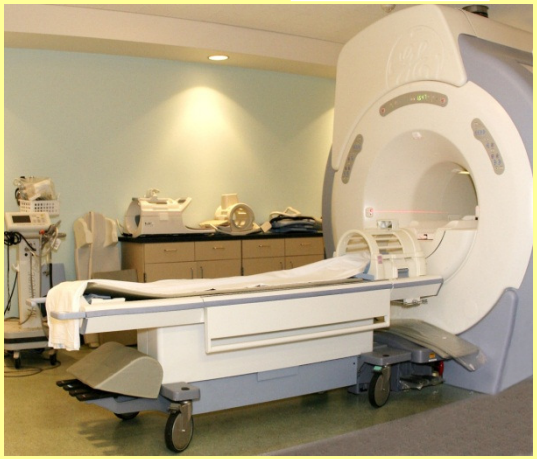
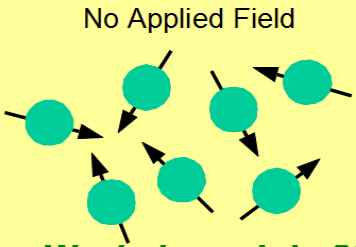
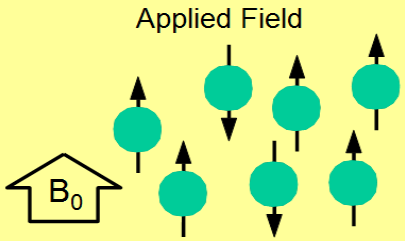
- Our bodies are made up of roughly **63% water**
- MRI machines use atoms like hydrogen atoms
- **The hydrogen atoms act like little magnets,** which have a north and south pole ("Spin").
- The atoms inside our body are aligned in all different directions

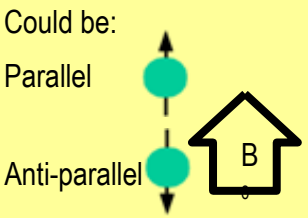


- The MRI is basically a large magnet
- Patient lies within scanner where magnetic field is created
- Magnetic force causes hydrogen nuclei (a proton) to line with the field-referred to as parallel, there is also antiparallel one
- Electromagnetic radiation (radio waves) are emitted from machine after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









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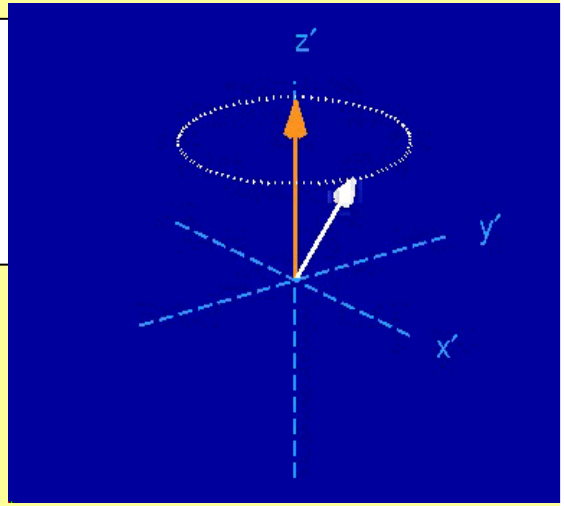
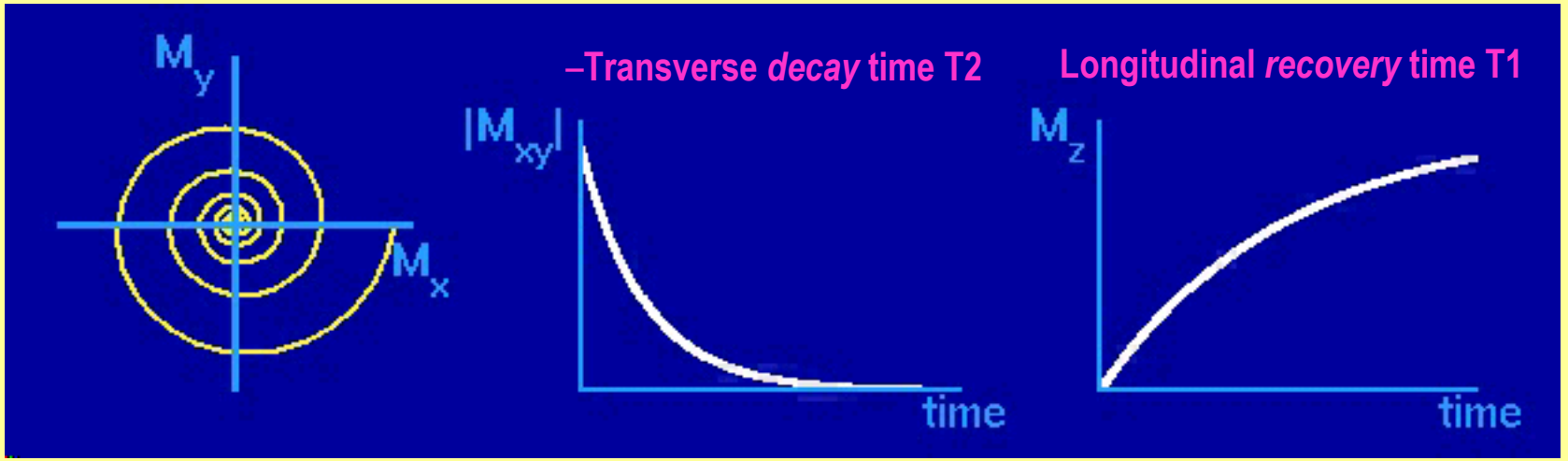
- Spins precess about applied magnetic field, B_0, that is along z axis.
- The frequency of this precession is proportional to the applied field.

Larmor law: $\omega = \gamma B$



- Magnetization returns **exponentially** to equilibrium:
  - For Longitudinal *recovery* time constant is T_1
  - For 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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A MRI device consists of:

- a big magnet which creates the magnetic field with a coil of electrical wire where current is running through the wire (now superconducting for high Mag field)
- gradient magnets: to alter precisely the main magnetic field and allow image slices of the body to be created.
- an antheńa coil to emits the radiofrequency pulse allowing disturbence of the alignment of the protons / it is also Receiver.

Larmor Equation $\omega_o = \gamma.\beta_o$ **For H¹ :** $\gamma = 2.675 x_{10^8}$ $\beta_0 = 1.5T$ $\omega_0 = 63.864MHz$

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

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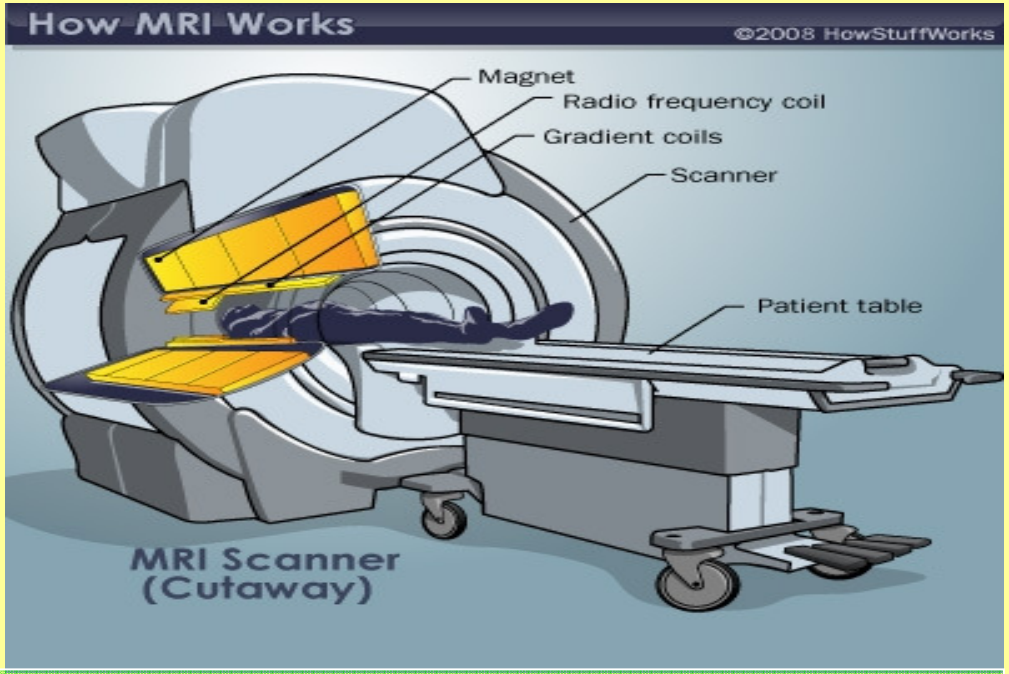
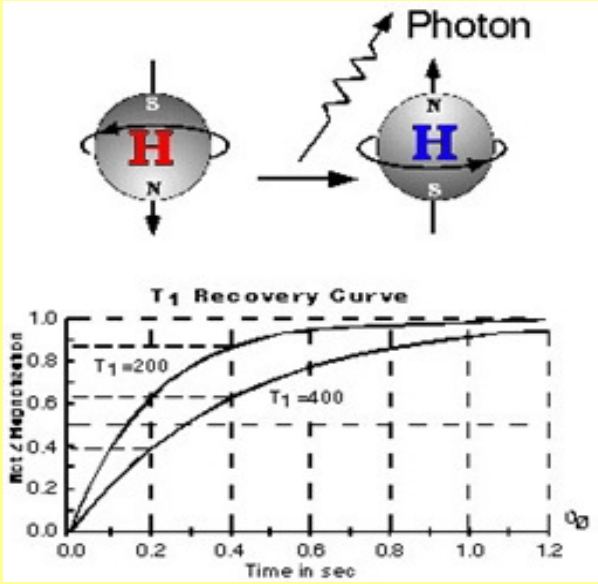
MRI : how it works (Cont'd)…

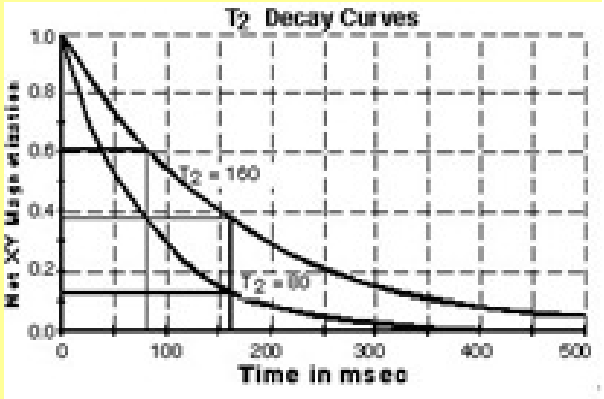


Relaxation:

T1

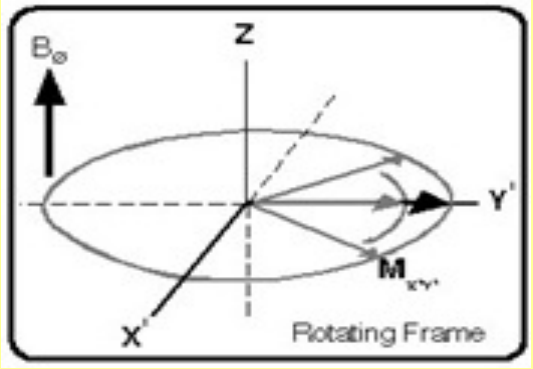


T2



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]



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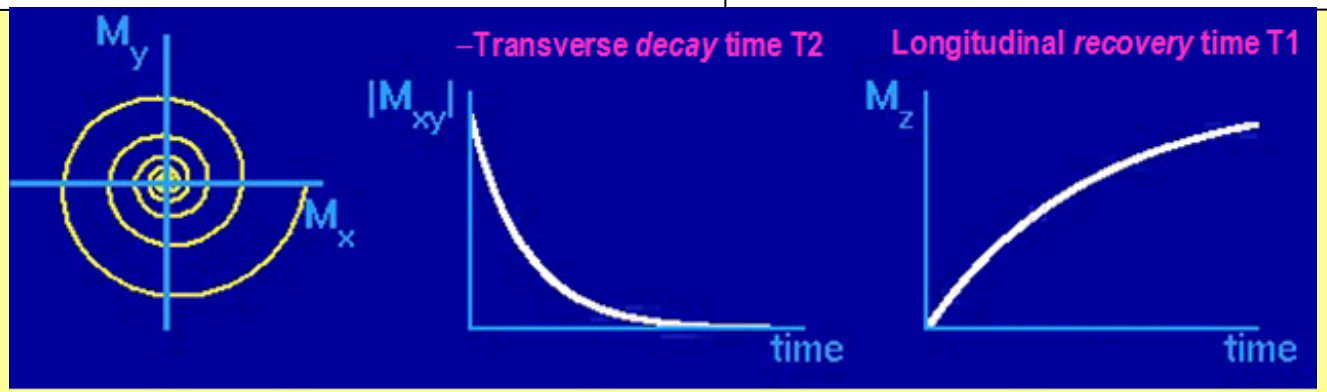
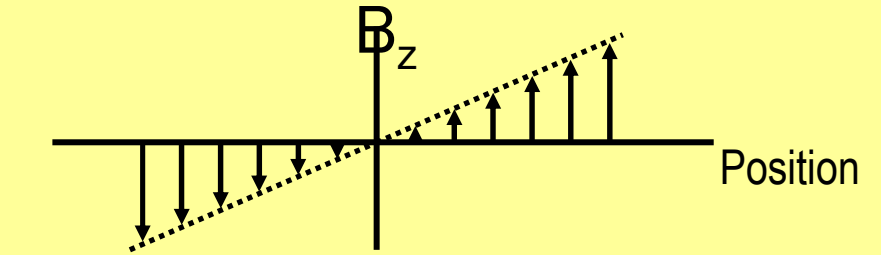
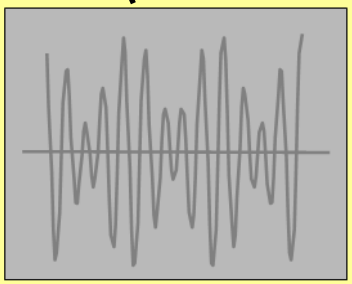
MR Image Formation

Selective Excitation



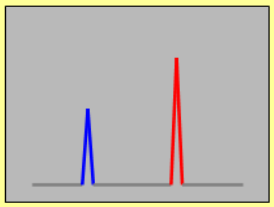
- **Gradient coils provide a linear variation in B_z with position.**
- Result is a resonant frequency variation with position.



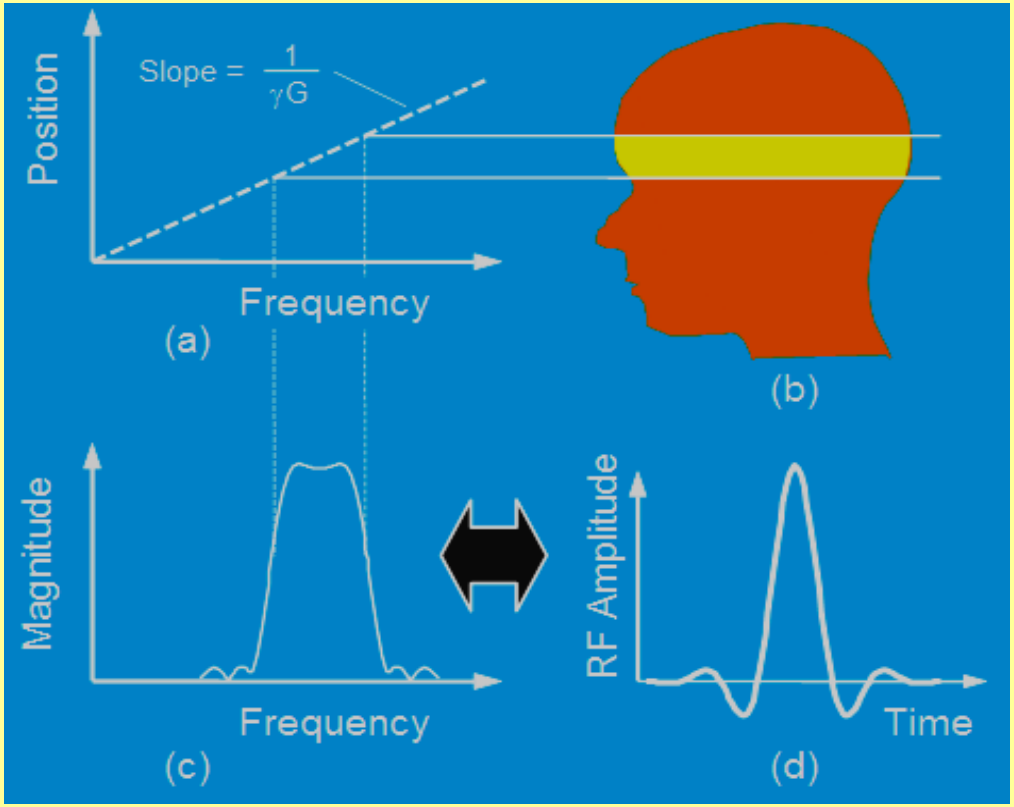


Received Signal

Fourier Transform



Image



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Different types of MRI

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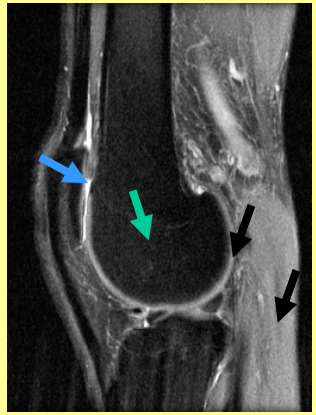
Advantages:
- Excellent / flexible contrast
- Non-invasive (no ionizing rad)
- Arbitrary scan plane

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 no-invasive proced

- Real Time MRI: Continuous filming/ monitoring of objects in real time

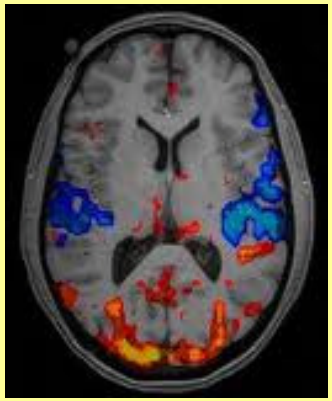
- Functional MRI (fMRI)

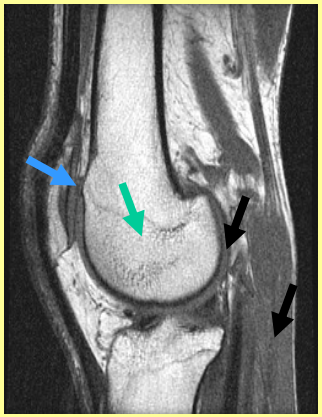
Ex: Measures signal changes in the brain due to changing neural activity

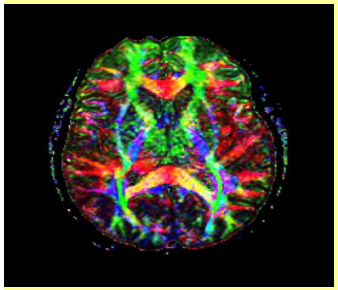
- MRS (MR spectroscopy)

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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4. SPECT

Single Photon Emitted Computed Tomography

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. (by its radioactivity)

Some isotopes uses:

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

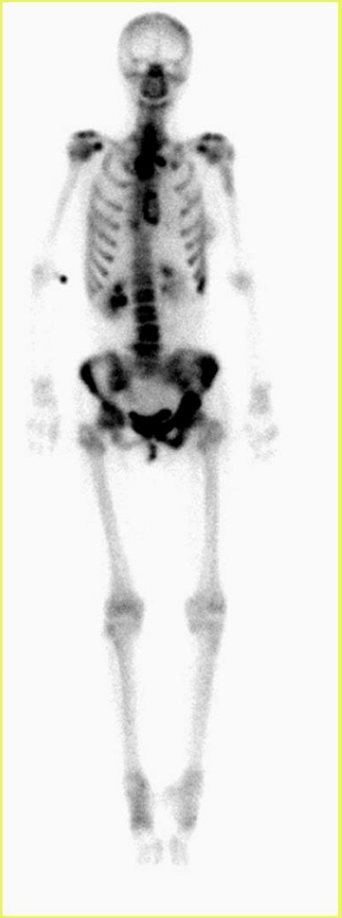
In medicine it is necessary that the radioactivity should disappear quickly enough (short half-life) and that the quatity of tracer applied to the patient should be very small (measured in micro-moles and even in pico-moles). The sensivity of the apparatus used is thus crucial.

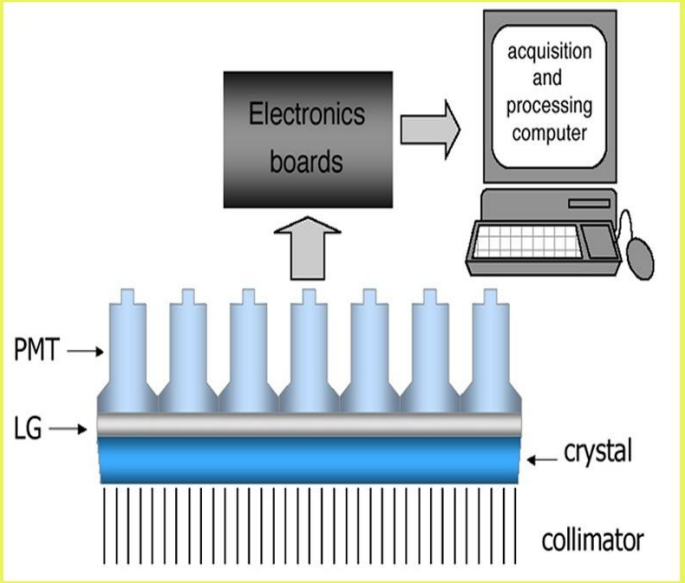
Some isotopes emit gamma photons, others emit positrons (see PET).

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 (x, y) concentration of a gamma ray-emitting radioisotope within individual slices (z) 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

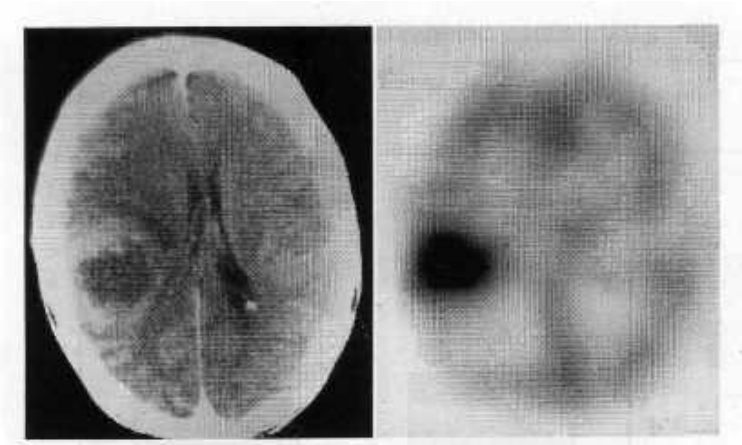
= O

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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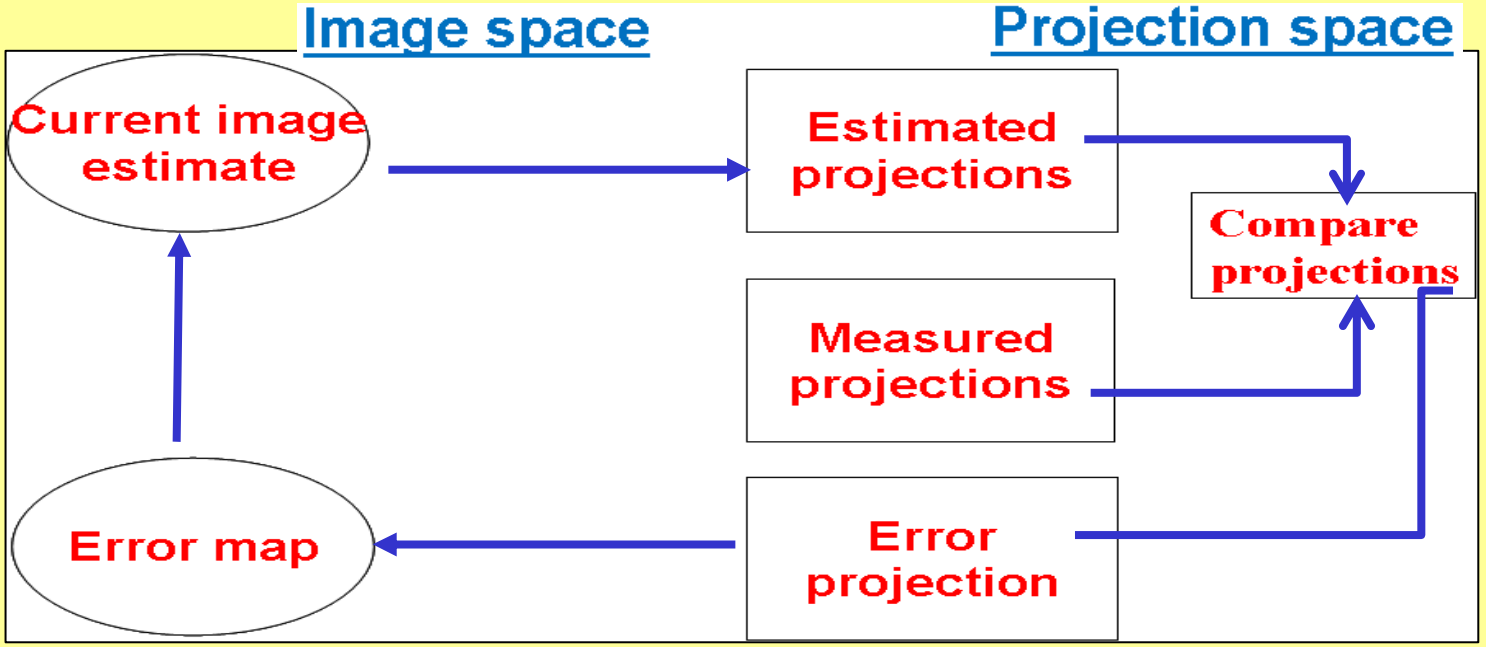
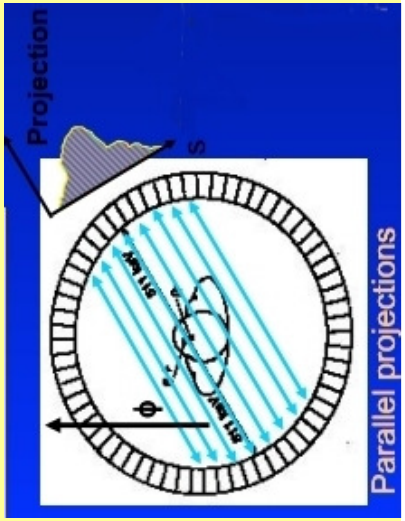
Image reconstructions proceed thru projections:

- 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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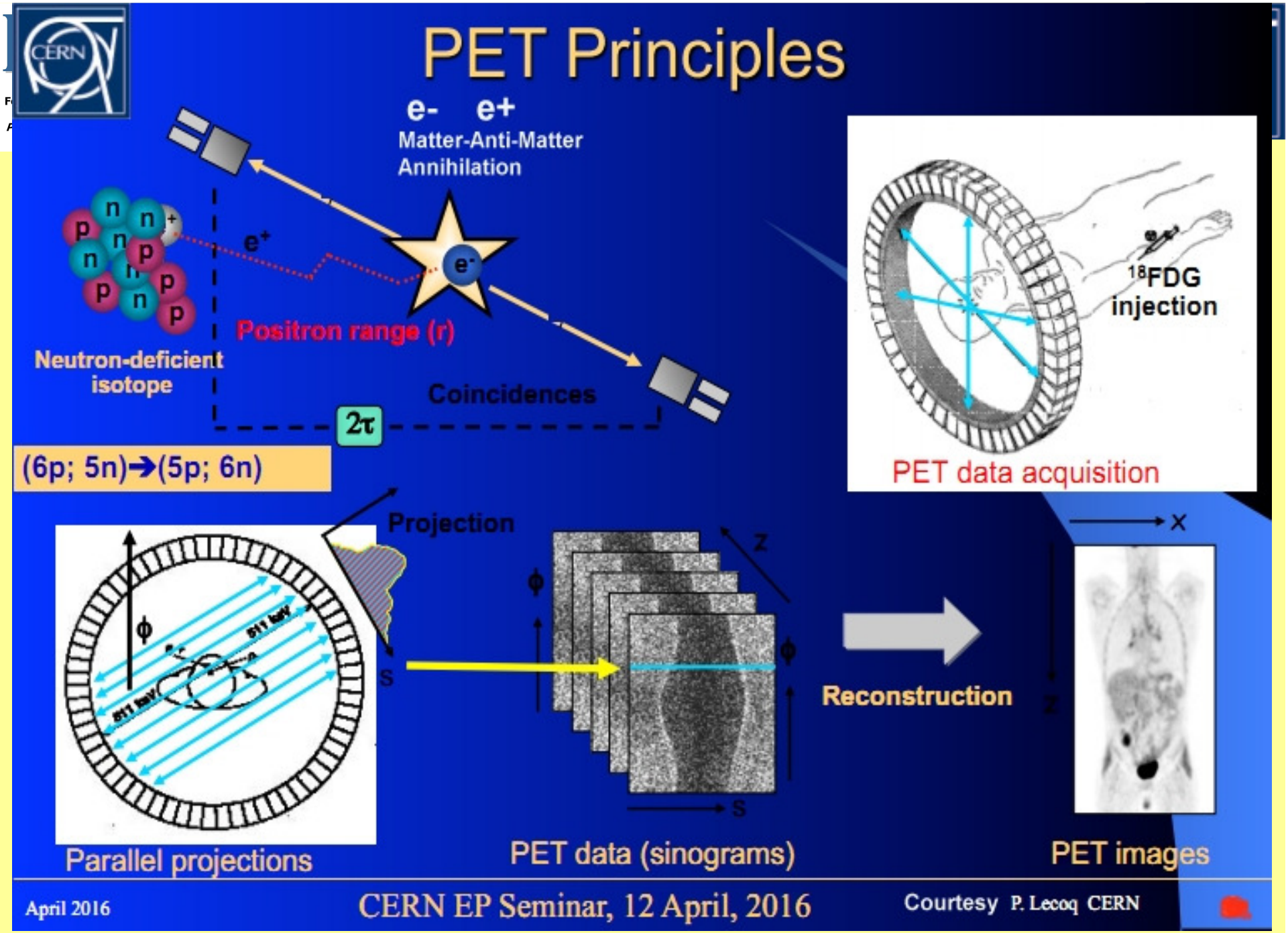
5. PET

Positron Emission Tomography

PET Principles



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DIPHOTONIC TOMOGRAPH or PET CAMERA

ANTI-MATTER ON CENTER STAGE!

e
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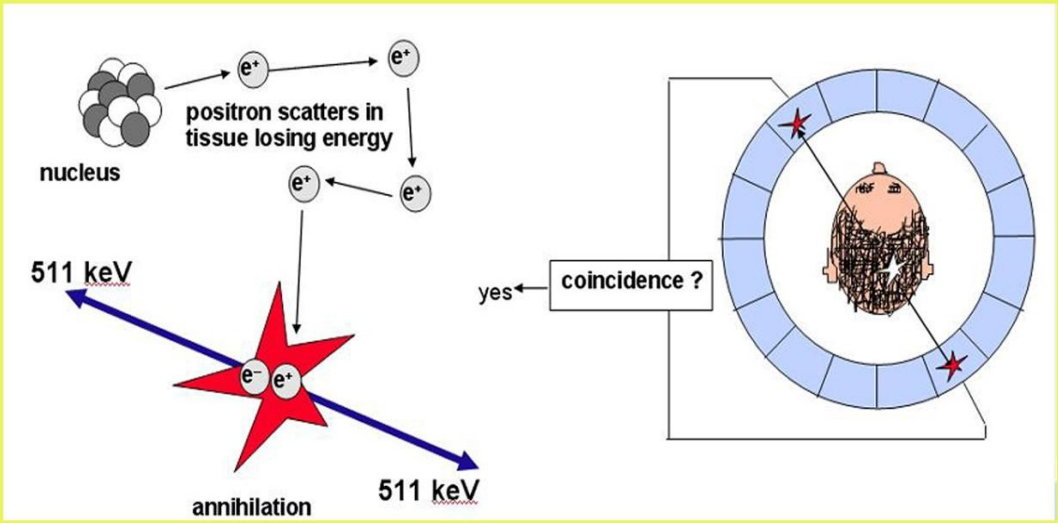
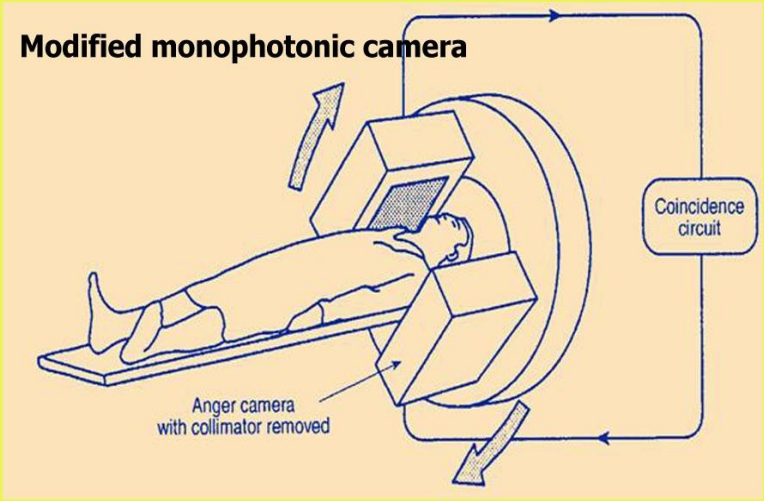
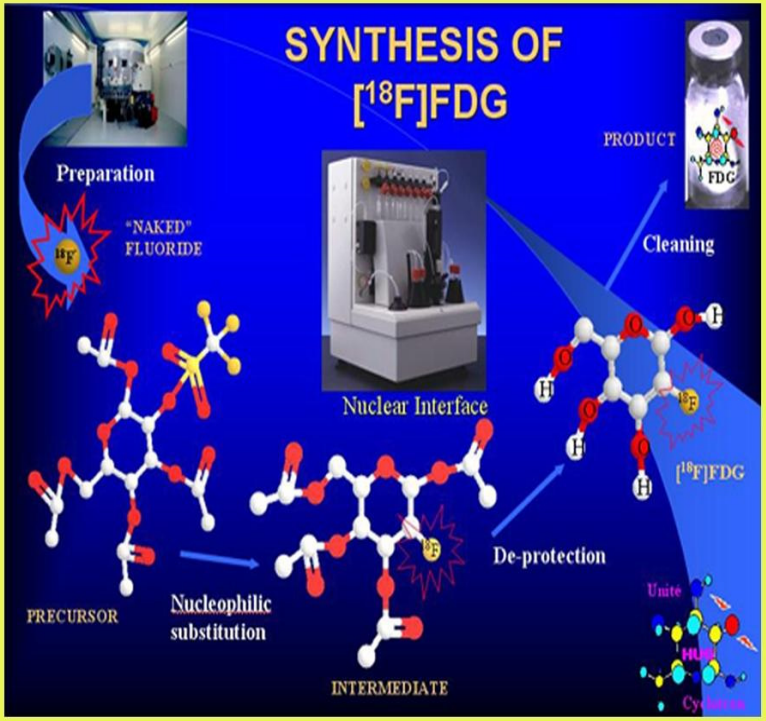
e

Some isotopes disintegrate 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.

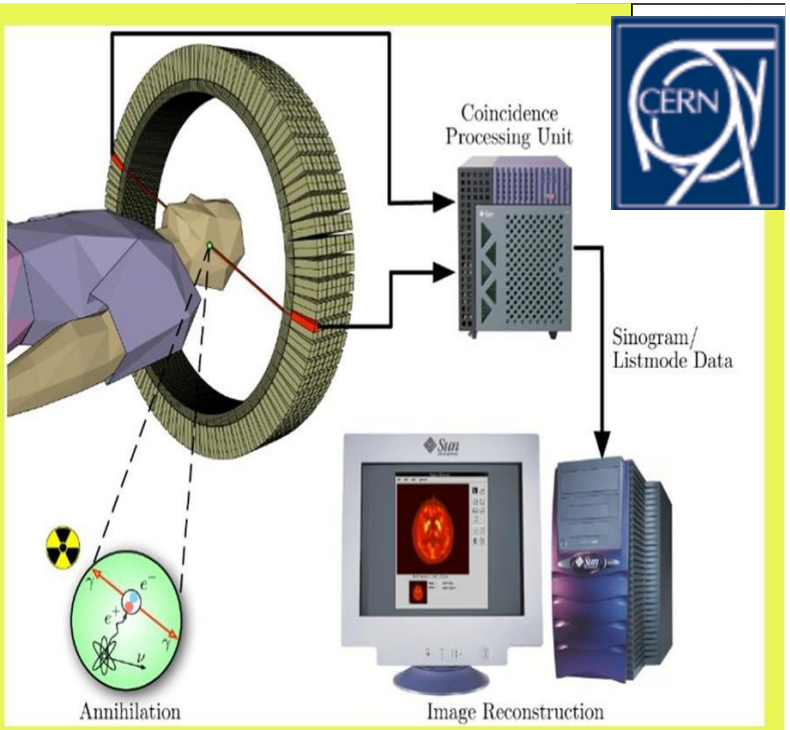




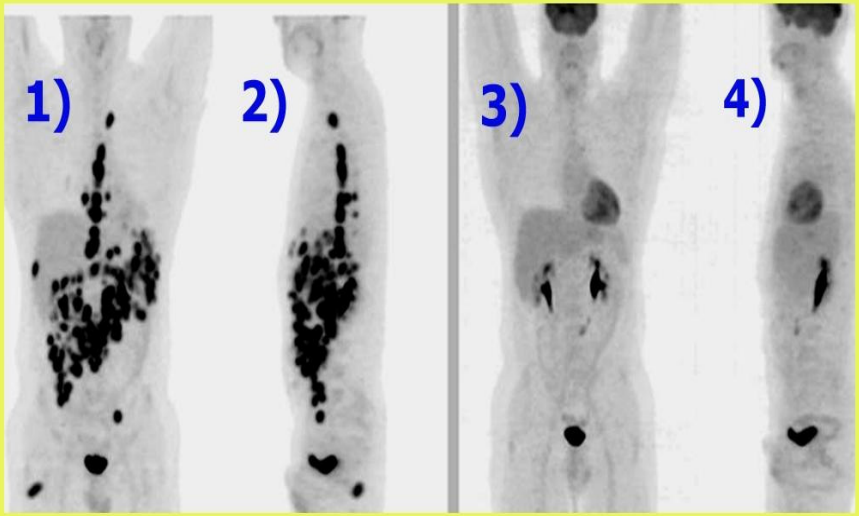
The first PET were simply Gamma cameras, from which the collimators had been removed and coincidence added between opposed detectors. Thereafter, better optimised PET equipments were built. For the human PET, several rings of detectors (crystals and PM) are assembled together.



The tracers for PET are more difficult to use because their half-life is shorter.
A cyclotron and a synthesis laboratory are necessary.
(Not too far)



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!

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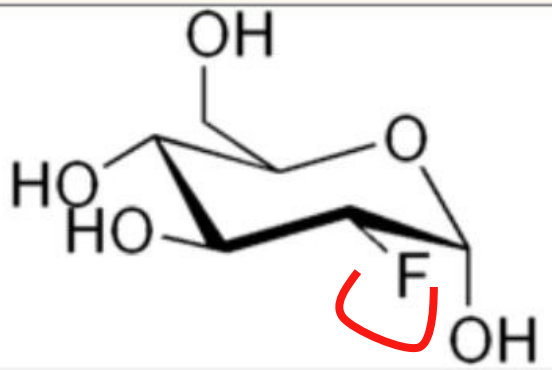
Why FDG Works So well?

$C_6H_{11}FO_5$

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

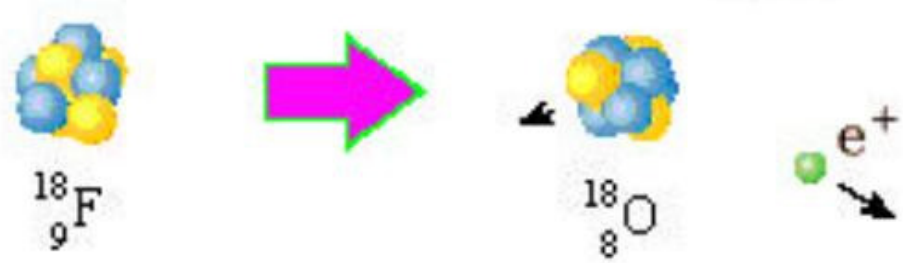
FDG is most commonly used in the medical imaging modality positron emission tomography (PET): the fluorine in the FDG molecule is chosen to be the positron-emitting radioactive isotope fluorine-18, to produce ^{18}F-FDG. After FDG is injected into a patient, a PET scanner can form images of the distribution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

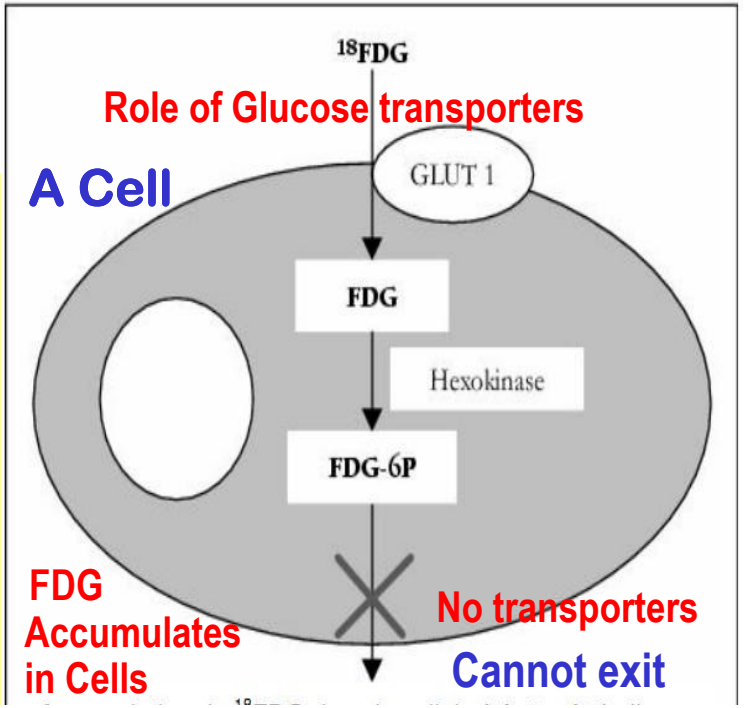
Fluorodeoxyglucose



Chemical name	2-Deoxy-2-fluoro-D-glucose
Other names	2-Fluoro-2-deoxy-D-glucose FDG

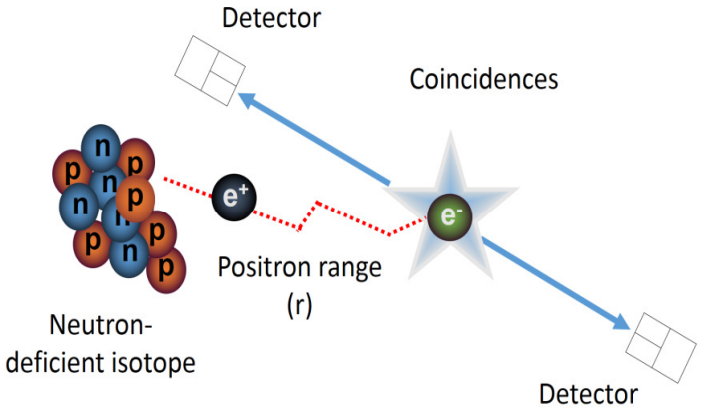
$F^{18} \Rightarrow O^{18} + W^+$; $W^+ \Rightarrow e^+ + \text{neutrino}$

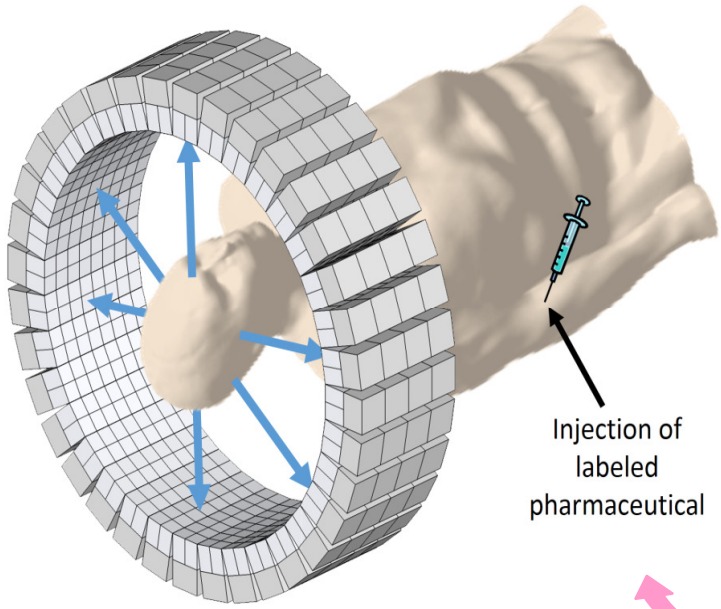


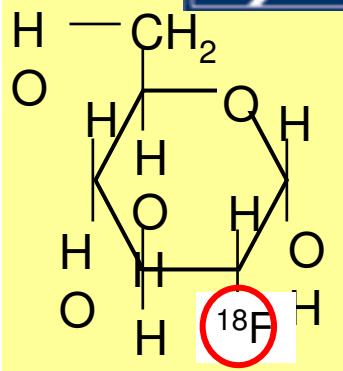


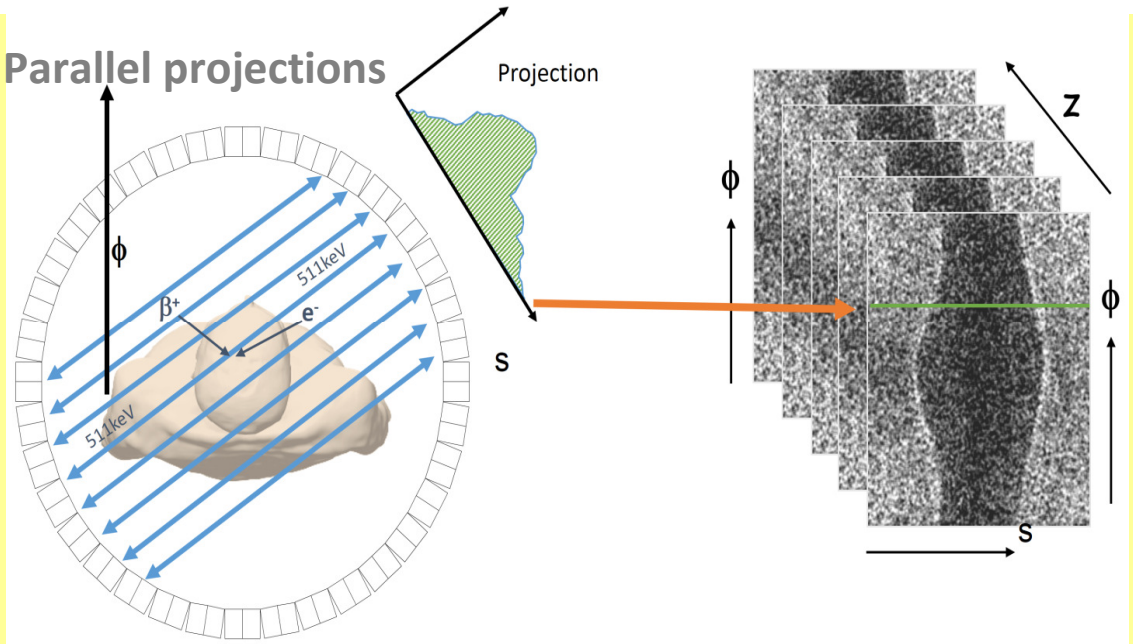
Positron Emission Tomography: how it works

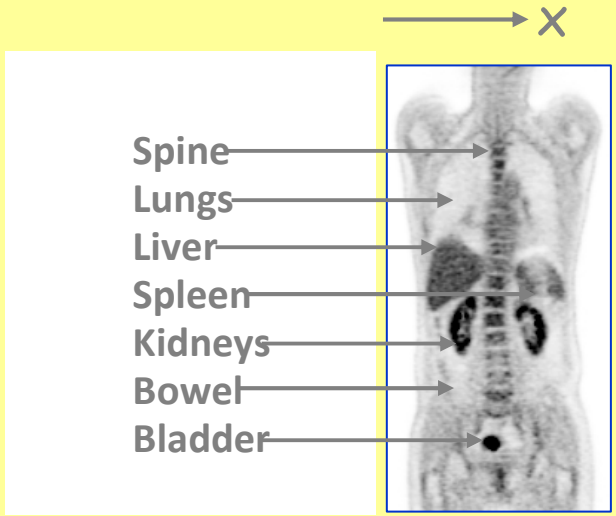
SUMMARY











From D. Townsend 2014

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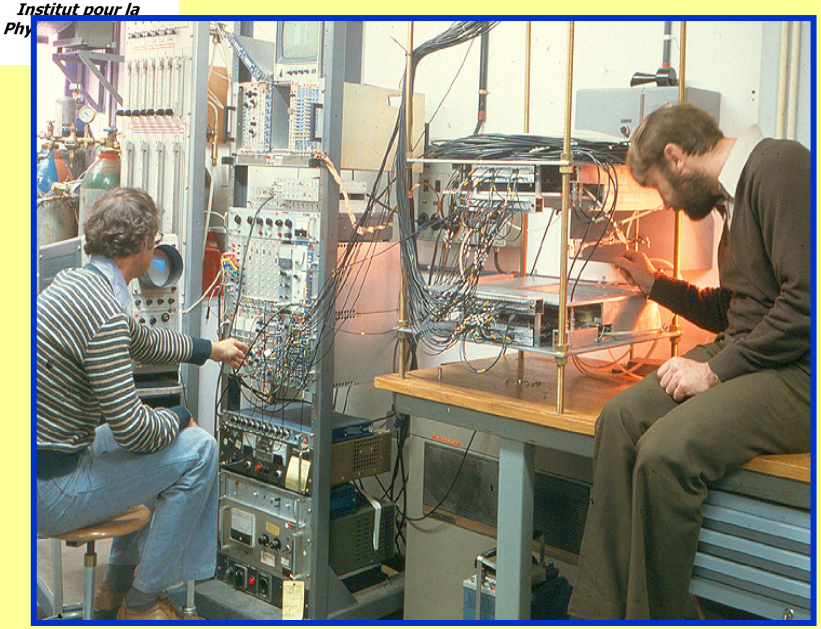
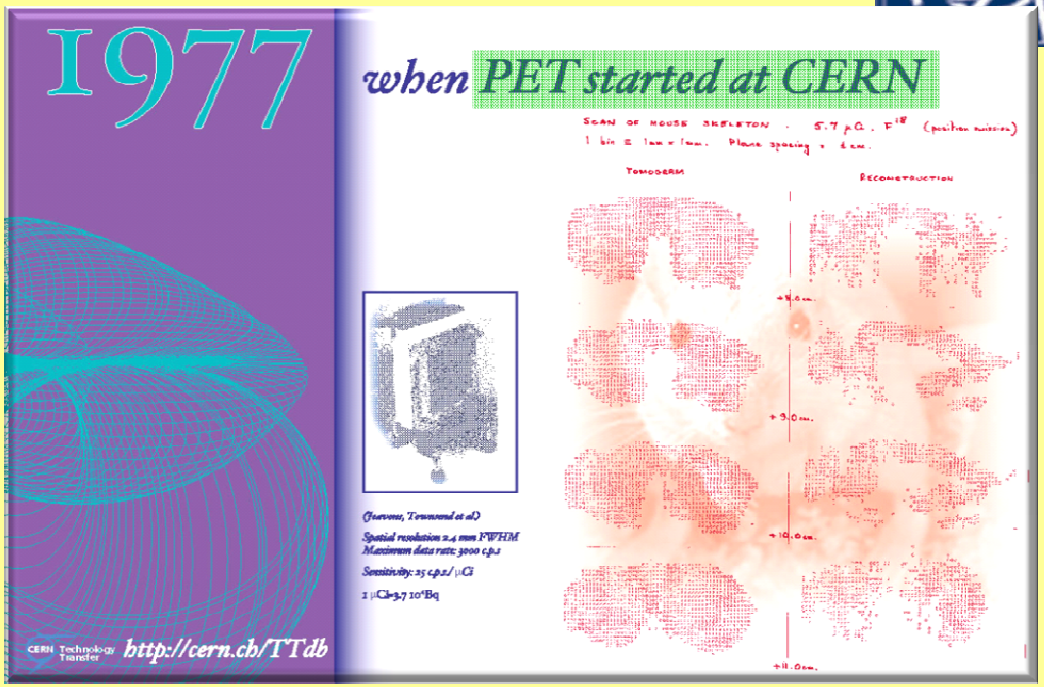
The HIDAC Camera Project, 1977-1988 CERN & HCU, Geneva

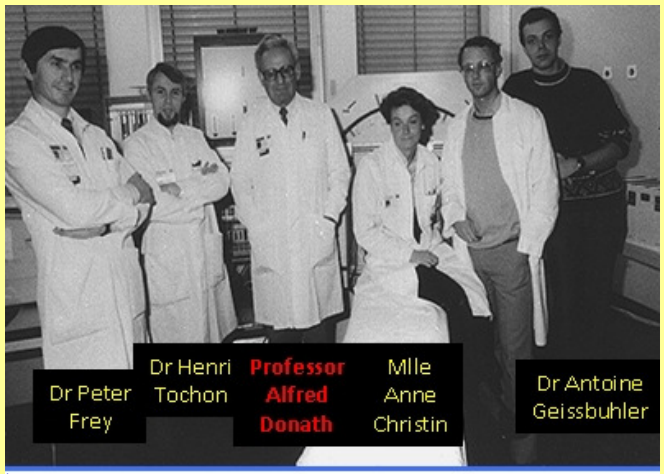
From D. Townsend 2014





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