Nobel prizes in medical physics

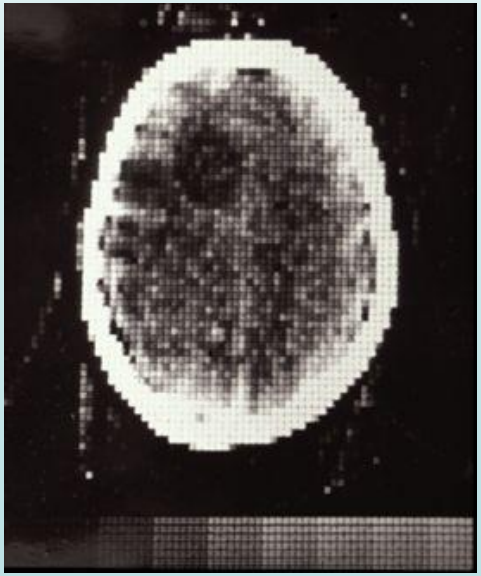
- CT, PET and MRI have been developed, improved and refined since the 1970s
- The developers obtained Nobel-prizes
- The modern devices constitute state-of-the-art diagnostics
- Very fine details (morphological and functional) can be observed in organs of the human body
- The development is still continuing, thousands of researchers work on such improvements around the world

The CT

- The first clinical CT scan on a patient took place on 1st October 1971 at Atkinson Morley's Hospital, in London, England.
- The prototype scanner was developed by Godfrey Hounsfield
- He obtained the

  Nobel prize in 1979
- Then the development

  was very fast



Principle of CT (Computed Tomography)

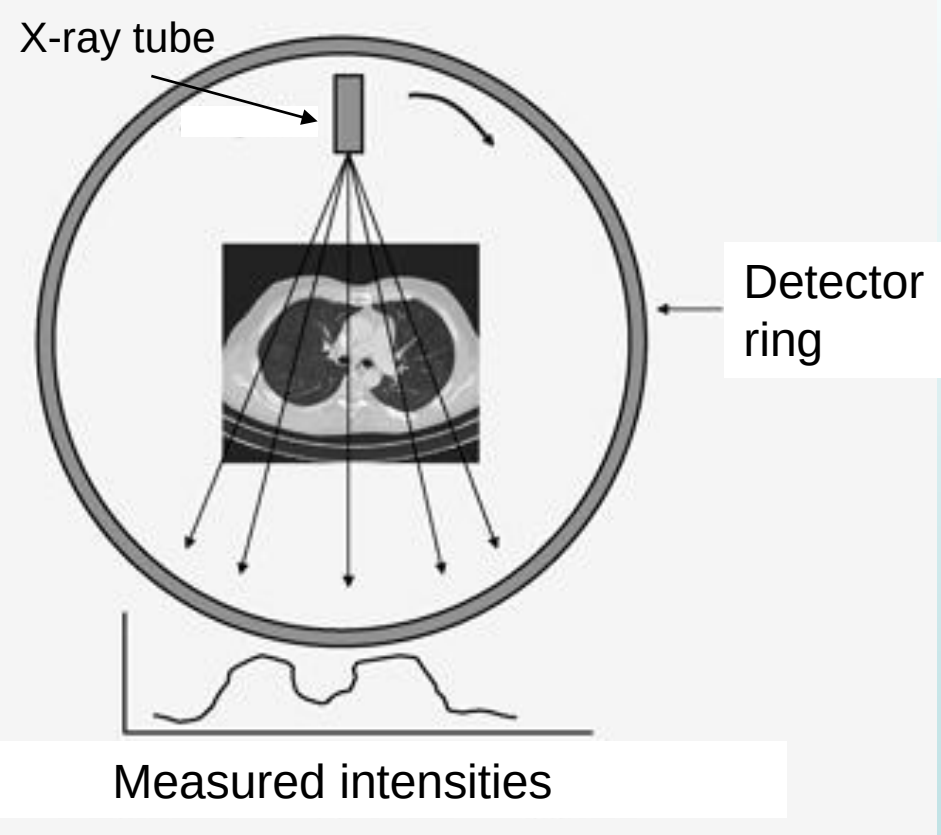
X-rays of properly chosen energy is used

We want to obtain sectional or 3D views about the organs

Therefore, the X-rays must penetrate through the body and detected in lots of directions

Basic principle:

The attenuation of radiation in matter depends on the energy of the radiation, the atomic number and density of the material and the distance it travels in matter



$$I = I_0 e^{-x\left(\frac{\mu}{\rho}\right)\rho} \qquad \mu = \mu(E, Z)$$

Operation of the CT

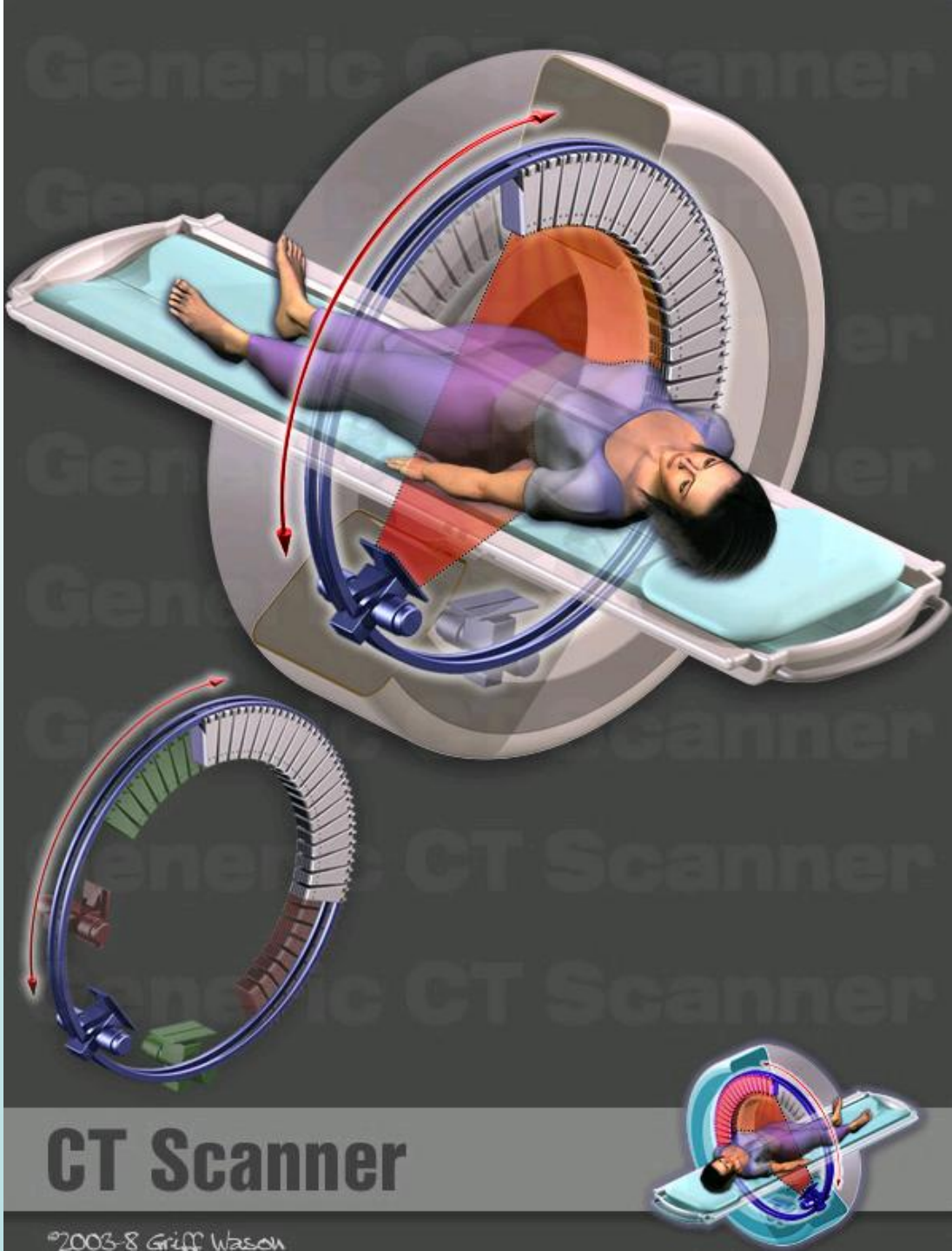
In a modern CT, several hundreds of radiation detectors are applied to measure the intensity of radiation on the opposite side of the patient

The X-ray source and the detectors usually rotate together

In a single rotation, as many as 256 slices can be obtained using the state-of-the-art devices

The thickness of a slice can be as low as 0.3 to 0.4 mm

The spatial resolution of the equipment (the distance of two objects lying closest to each other but still recognized as two objects) is approximately 0.3 mm

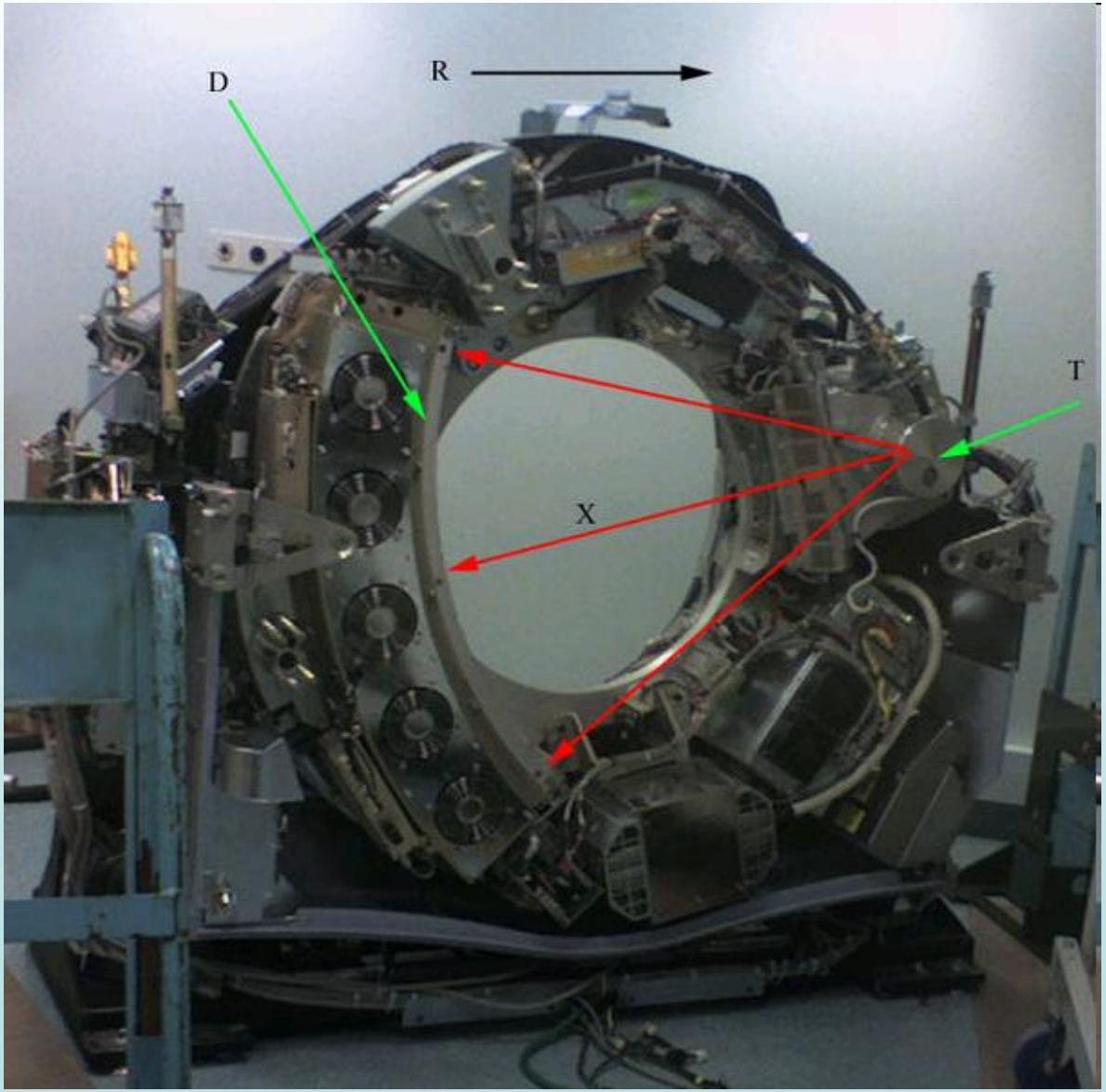


The CT device

T: X-ray source
D: detectors
X: ray lines
R: direction of rotation

In a modern CT, one rotation is done in less than 0.5 s

In this way, moving organds, such as the heart or lungs can also be examined (the motion blur can be significantly reduced)

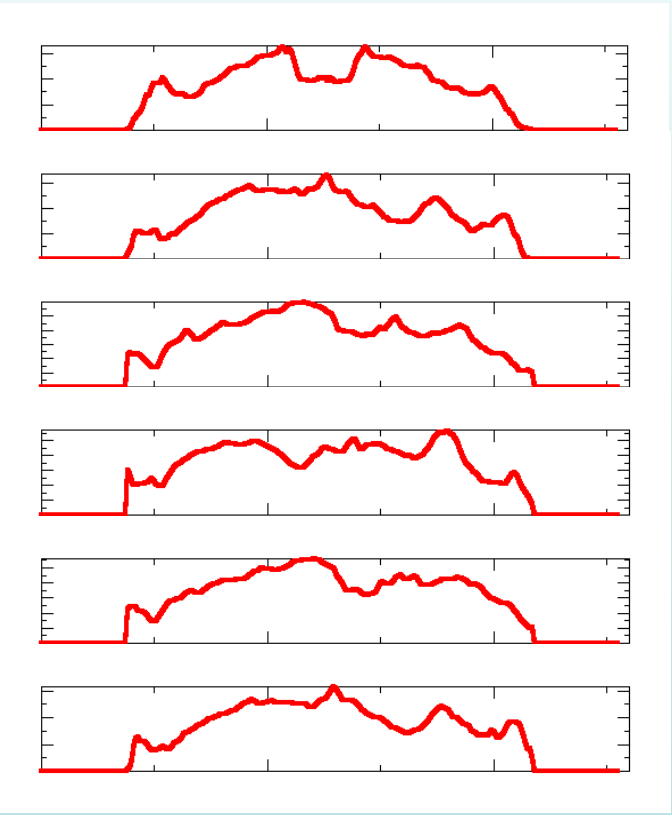


How do we obtain the image?

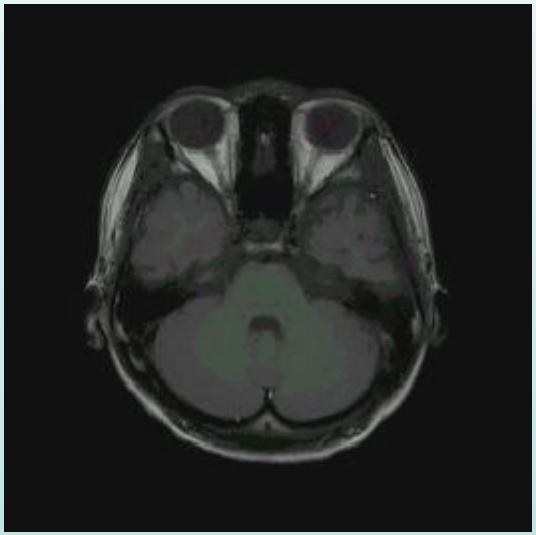
- Mathematical transform to the measured data.
- Reconstruct n dimensional function (image)
  => projection data of n – 1 dimension
- Radon Transform (1917)
  “Two dimensional and three dimensional objects can be reconstructed from the infinite set of projection data”.

Concept of CT image reconstruction

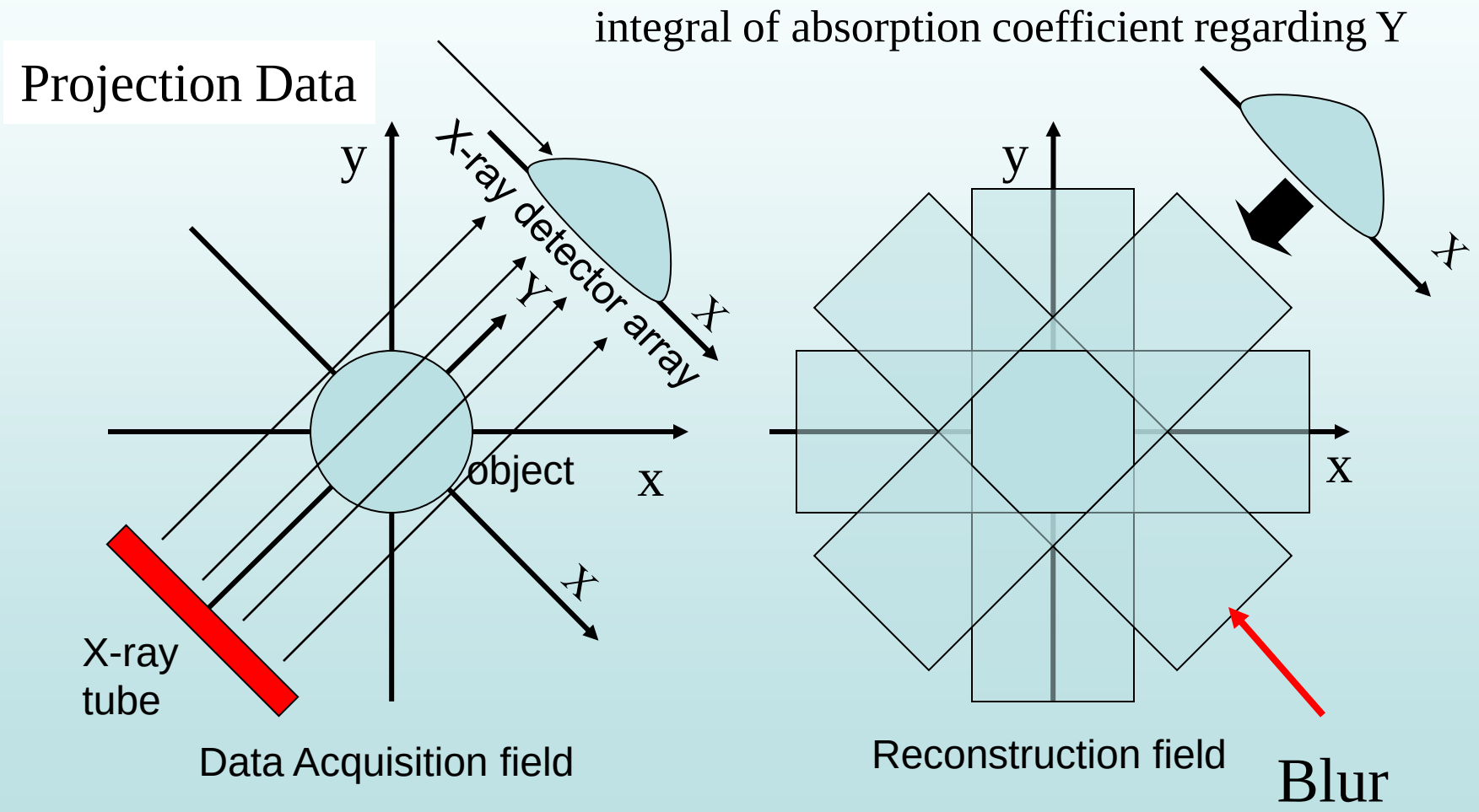
- Getting the shape by back projection of the projection data.
- For example, outward view is the quadrangle => it is the cylinder



CT
Algorithm



Reconstruction of 2 dimensional image



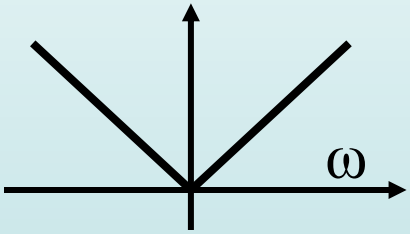
Simple Backprojection

Reconstruction of 2 dimensional image

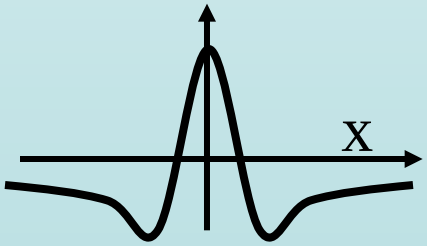
Projection Data

*

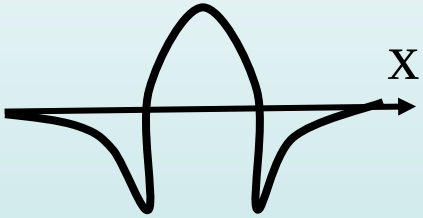
Reconstruction Filter



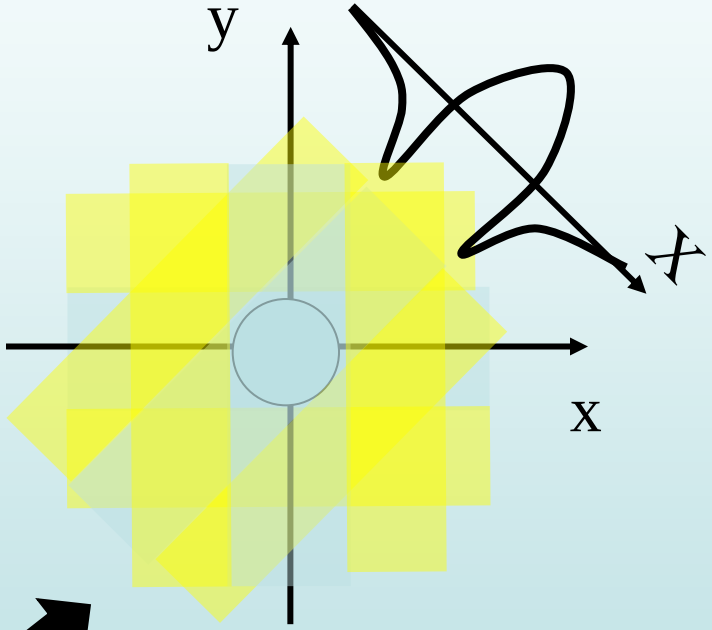
or



Filtered Projection data

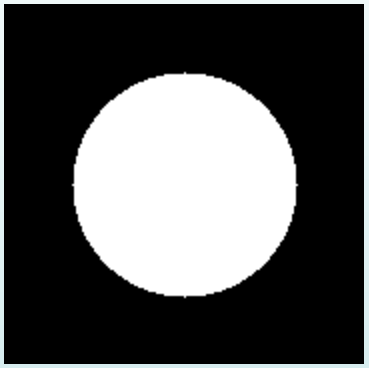


Multidirectional Backprojection

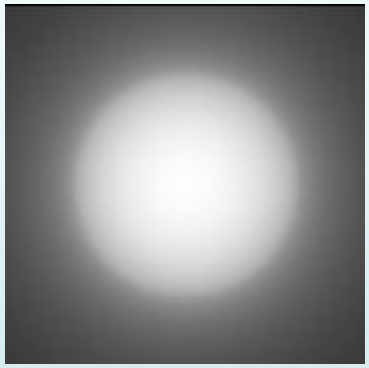


Filtered Backprojection

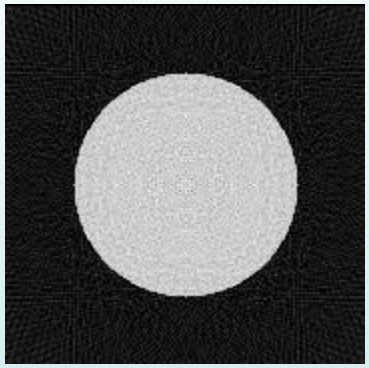
Example of Simulation



Model Image



Simple Backprojection

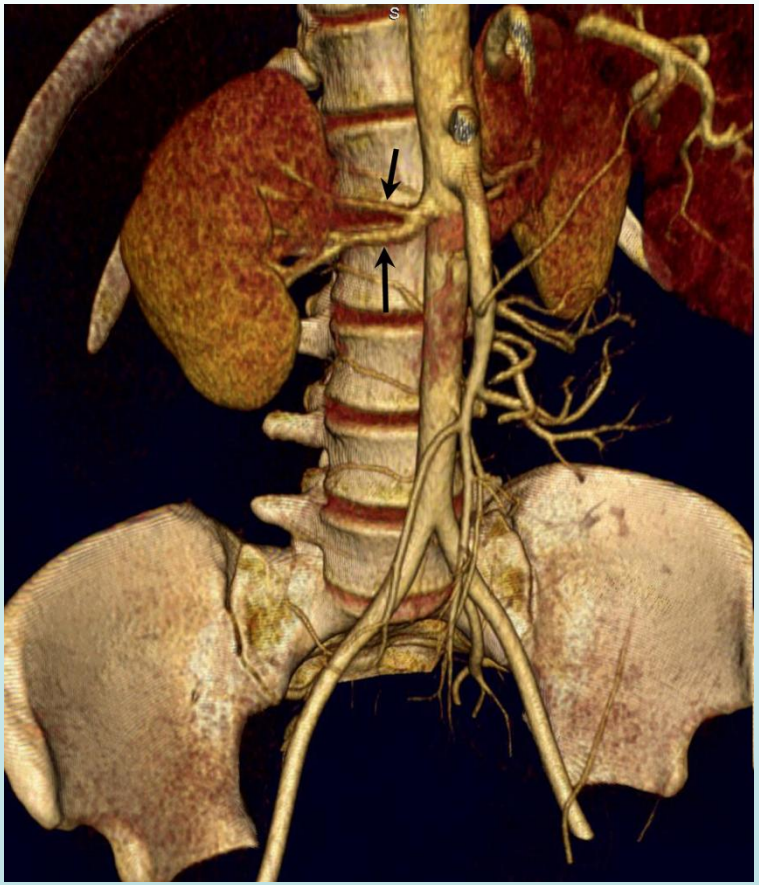


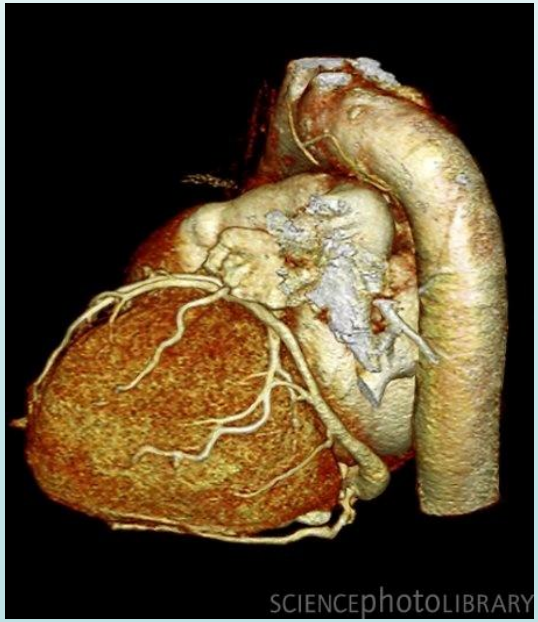
Filtered Backprojection

What is the CT good for?

- Provides anatomical images of high resolution
- Different organs and different tussue types can be distinguished
- The mutations / modifications caused by certain illnesses can be revealed
- Using contrast materials the veins can also be seen
- …

What does it show?





The MRI (Magnetic Resonance Imaging)

- Magnetic Resonance Imaging is a medical diagnostic technique that creates images of the human body using the principle of nuclear magnetic resonance. It can generate thin-section images of any part of the human body - from any angle and direction. MRI is able to make a picture of the human body when the body is exposed to an electromagnetic field.
- In 1937, Columbia University Professor Isidor I. Rabi observed the quantum phenomenon called nuclear magnetic resonance (NMR). He recognized that the atomic nuclei show their presence by absorbing or emitting radio waves when exposed to a sufficiently strong magnetic field.
- Isidor I. Rabi received the Nobel Prize for his work.

History of MRI

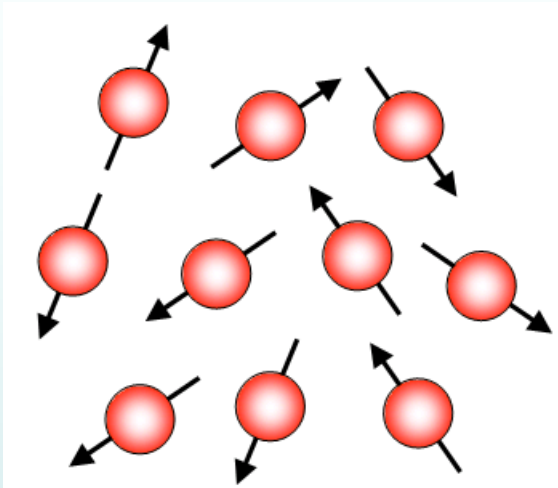
- Raymond Damadian discovered that hydrogen signal in cancerous tissue is different from that of healthy tissue because tumors contain more water. More water means more hydrogen atoms. When the MRI machine is switched off, the bath of radio waves from cancerous tissue will linger longer then those from the healthy tissue.
- In 1973, Paul Lauterbur, a chemist and an NMR pioneer produced the first NMR image.
- In 1977, nearly five hours after the start of the first MRI test, the first human scan was made with the first MRI prototype.

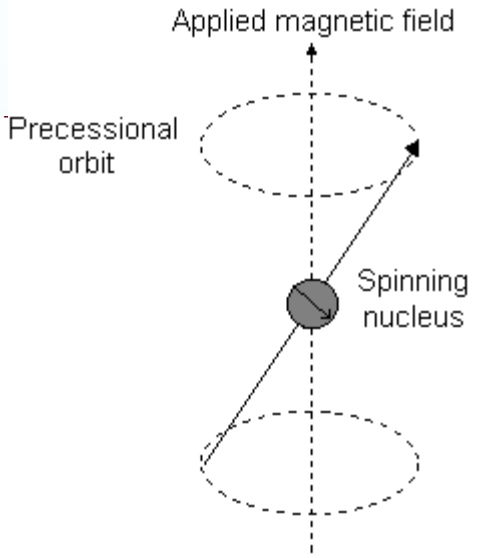
The MRI

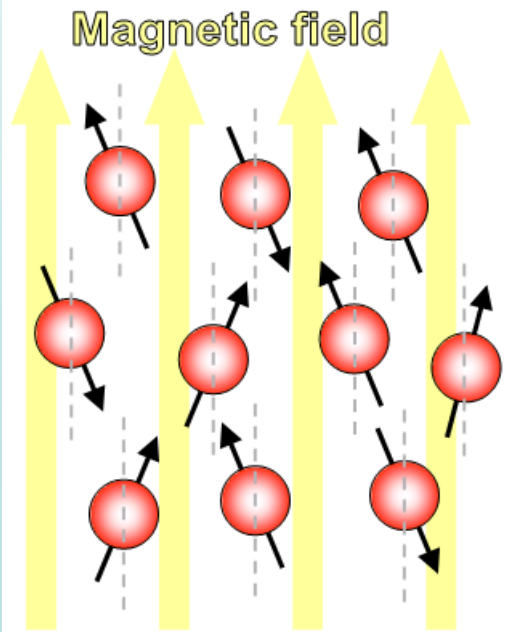
MRI creates a strong magnetic field and the small biological "magnets" in the human body consisting of protons located in the nucleus of the hydrogen atom are magnetized. The proton possess fundamental magnetic properties.

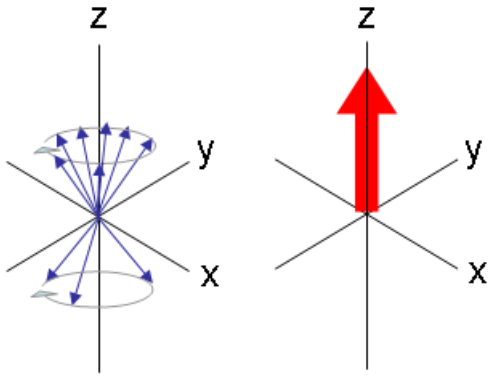
1. MRI creates a steady magnetic field within the human body by placing the body in a steady magnet.
2. MRI stimulates the body with radio waves to change the steady-state orientation of protons.
3. MRI machine stops the radio waves and registers the body's electromagnetic transmission.
4. The transmitted signal are used to construct internal images of the body by computerized axial tomography.

The frequency of radio waves depends on the magnetic field strength







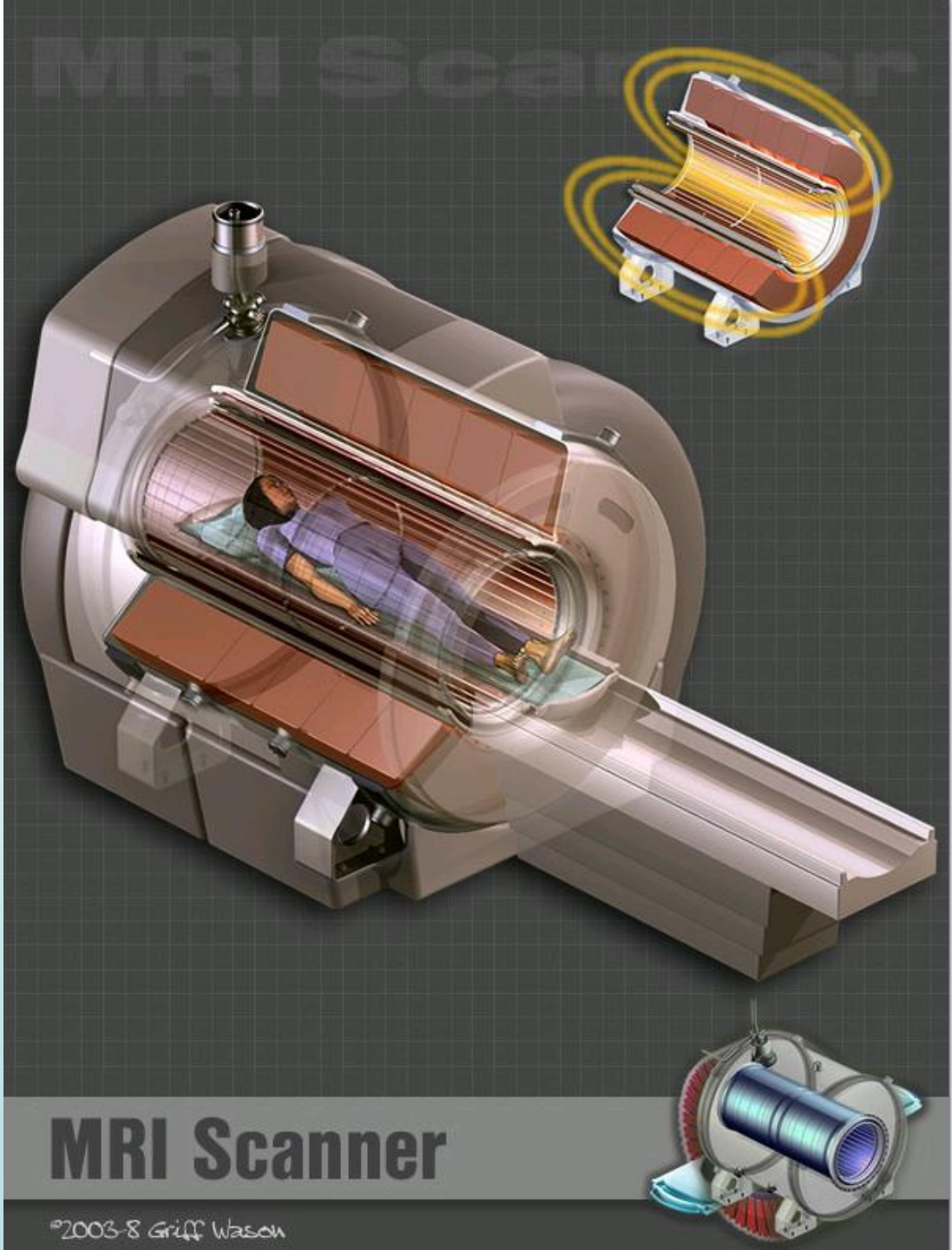


Overall magnetisation of nuclei = Sum of vectors from individual nuclei

The MRI magnets

The extremely strong magnetic field is produced by superconducting magnets. In this way, the electric current can flow without resistance. The superconductors are cooled by liquid helium

The strenght of the magnetic field is usually between 0.5 and 3 tesla (10 to 60 thousand times that of the magnetic field of the earth).



Operating principle of MRI

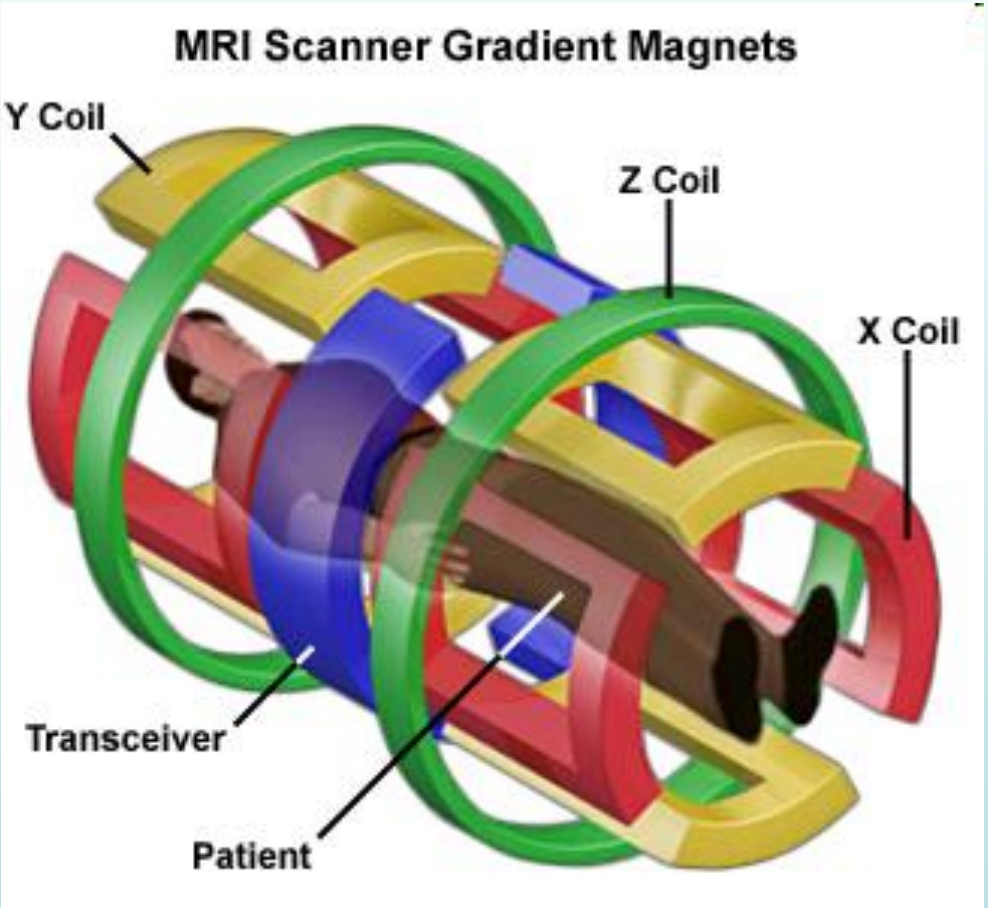
The so called gradient magnets are used to create magnetic field that is changing in space

Therefore, the frequency emitted by protons will be different from location to location

The time dependence of how the spins relax back is influenced by the molecule in which the hydrogen atom is located

Using the signals received, slices of arbitrary directions may be obtained with the aid of complex mathematical algorithms

A 3D image can also be created



The device

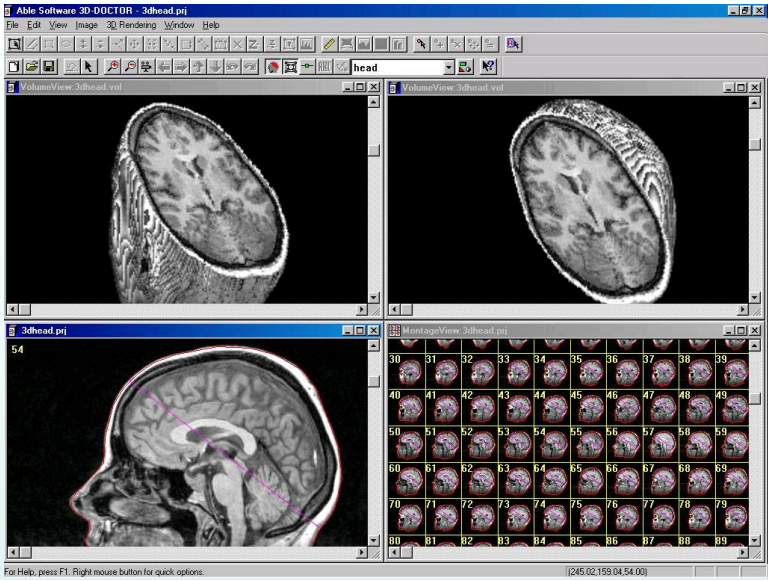
The device is usually very expensive (a few million USD), depending on the strength of the magnet. Plus there is a significant cost related to cooling

The strength of the magnet determines the spatial resolution (tenth of a mm to 2 mm)

The MRI has better soft tissue contrast than that of the CT

+ there is no radiation dose to the patient

What does it show?

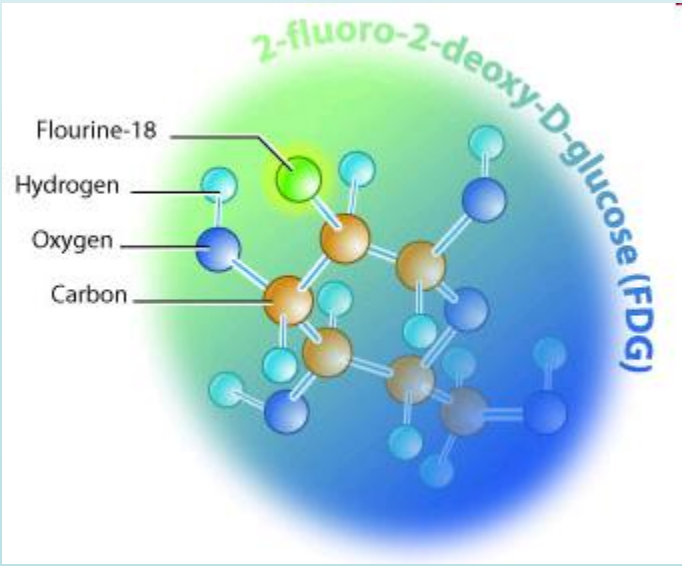


The strong magnetic field may cause trouble …

Positron Emission Tomography (PET)

A radioactive tracer, or radioactive label, is a chemical compound in which one or more atoms have been replaced by a radioisotope so by virtue of its radioactive decay it can be used to explore the mechanism of chemical reactions by tracing the path that the radioisotope follows from reactants to products.

This process is often called radioactive labeling. The power of the technique is due to the fact that radioactive decay is much more energetic than chemical reactions. Therefore, the radioactive isotope can be present in low concentration and its presence detected by sensitive radiation detectors. George de Hevesy won the 1943 Nobel Prize for Chemistry "for his work on the use of isotopes as tracers in the study of chemical processes".



A PET (Positron Emission Tomography)

PET principle is based on the positive beta decay of certain isotopes. In this process, a positron is emitted

When this postiron encounters an electron, the annihilite and 2 pieces of gamma photons are produced, flying in opposite directions, but having the same energy

The positive beta decaying isotope is produced in an accelerator, usually on site

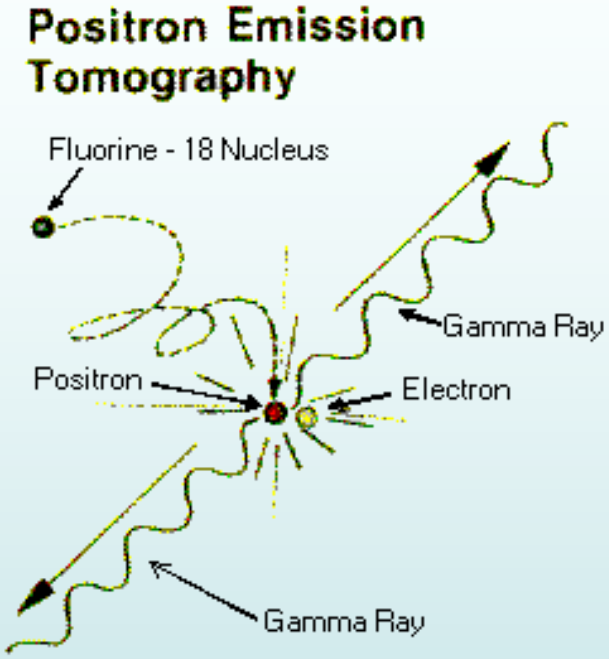
Therefore, the examination is very expensive

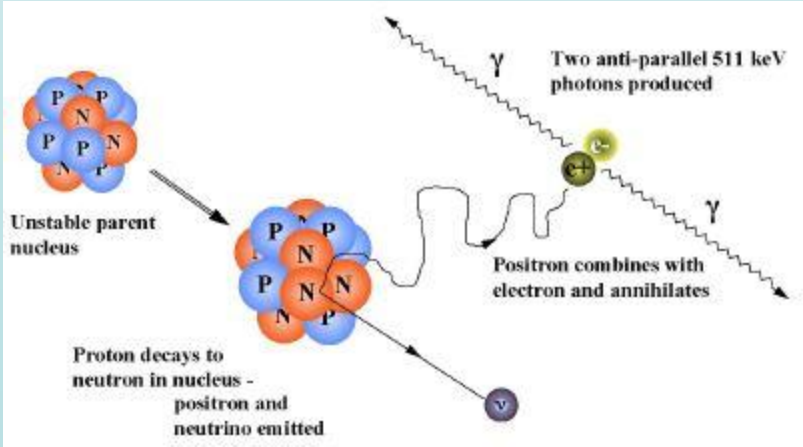
After the isotope is produced, it is used to label a molecule (usually glucose)

Glucose behaves differently in healthy and cancerous tissues

The labelled molecule is injected to the patient

We want to examine the distribution of the molecule in the different organs





Operating principle of PET

There are many thousands of detector needles surrounding the patient

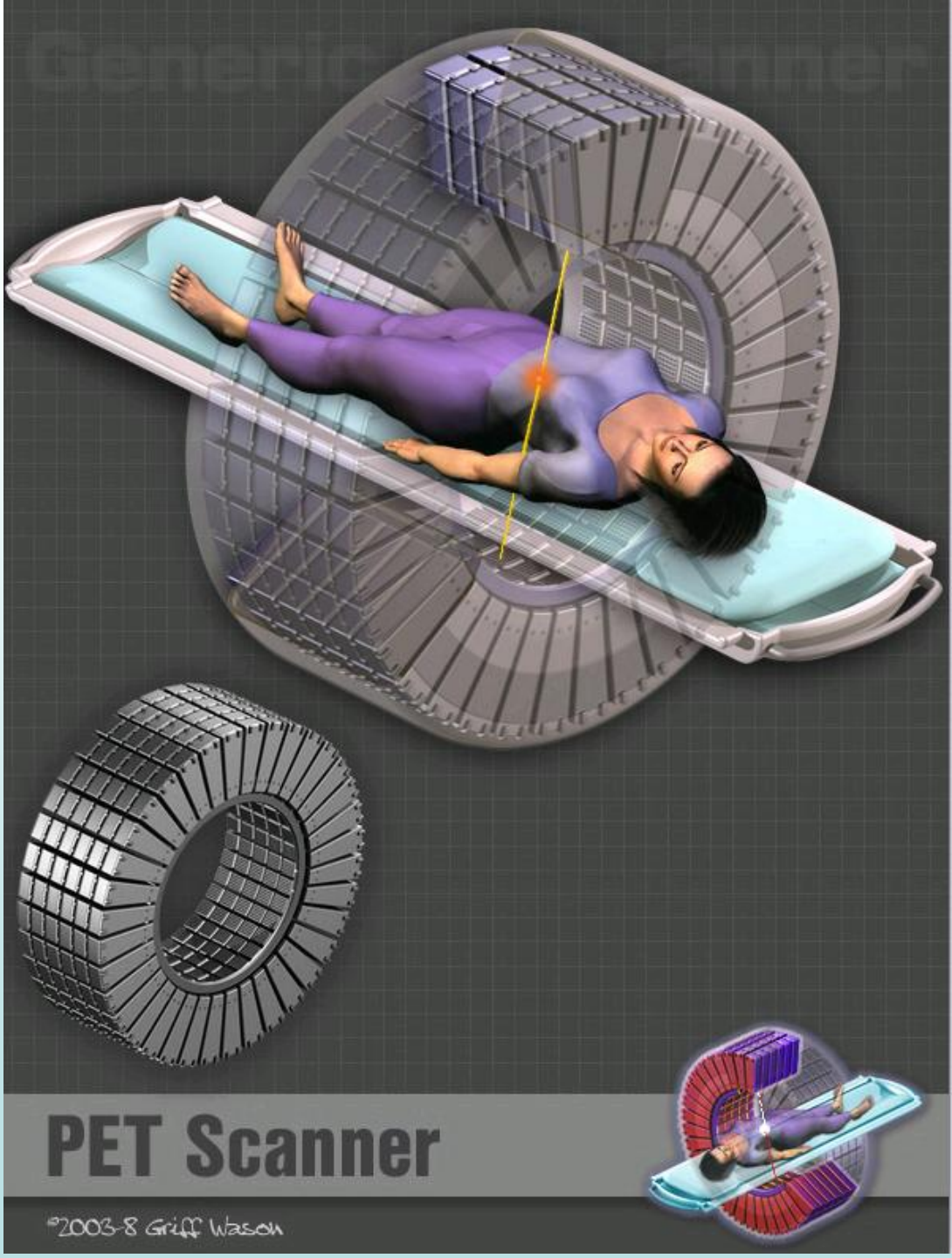
We accept a signal detection if two detectors „blink” at the same time (coincide)

The coincidence events are connected by straight lines

The point of emission was on this line

Because there are many millions of lines, they can be used to reconstruct the image

The spatial distribution of the isotope (concentration of the labelled molecule) can be determined



What does it show

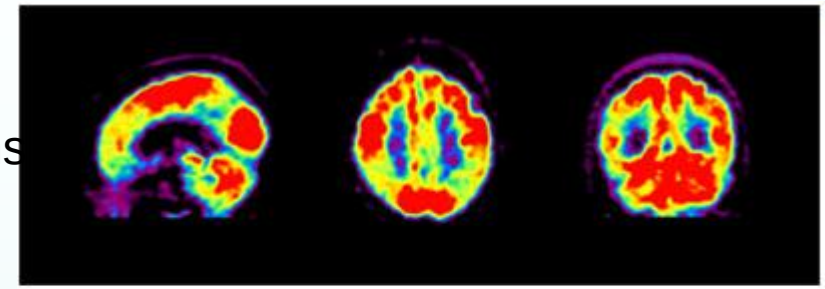
Information on the functioning of tissues, organs

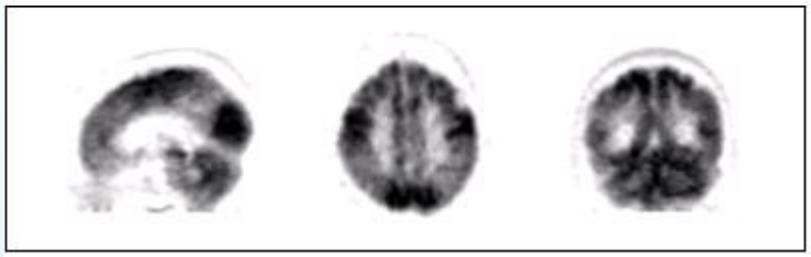
Tumors and metastasis can be revealed

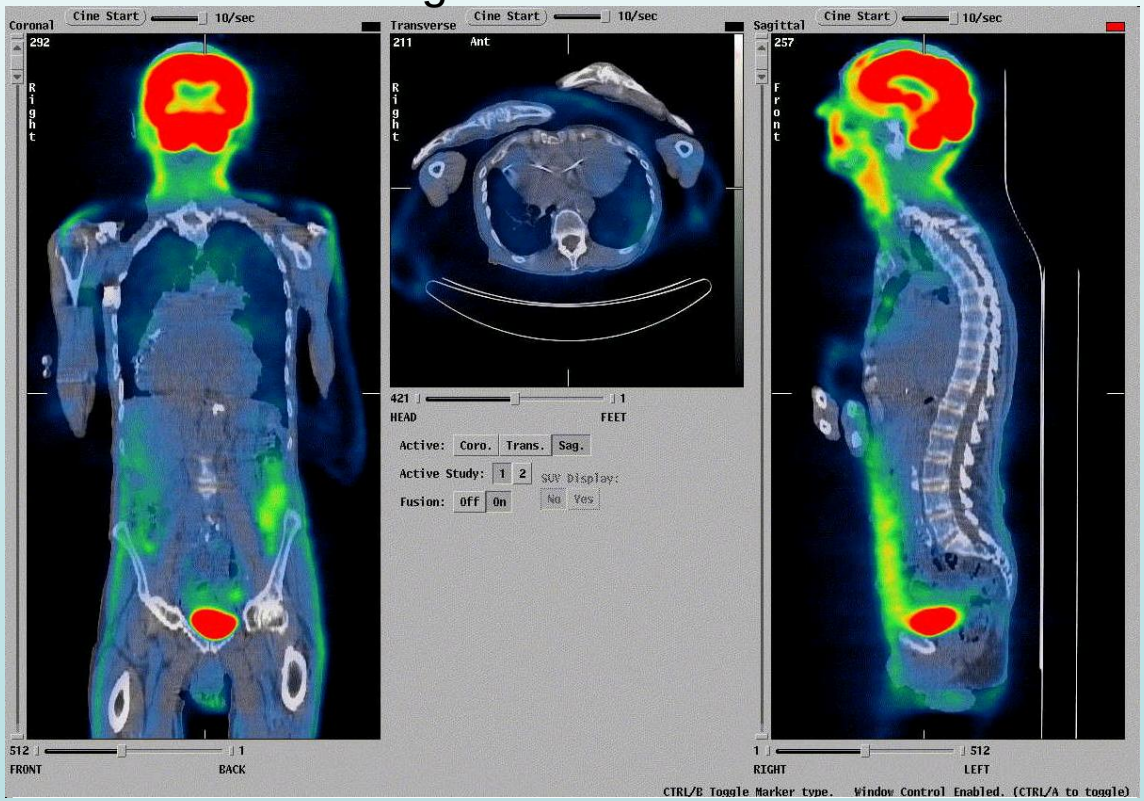
The brain functions can be investigated, also for research

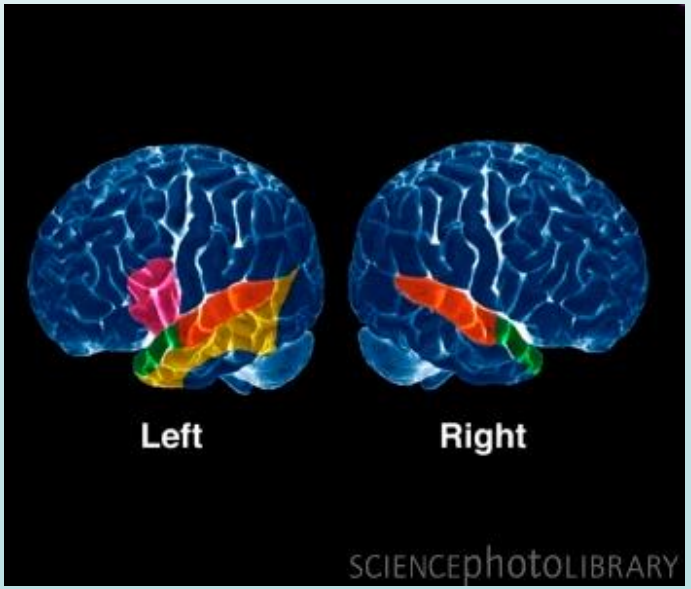
Cardiomuscular investigations are possible

No anatomical image!!!

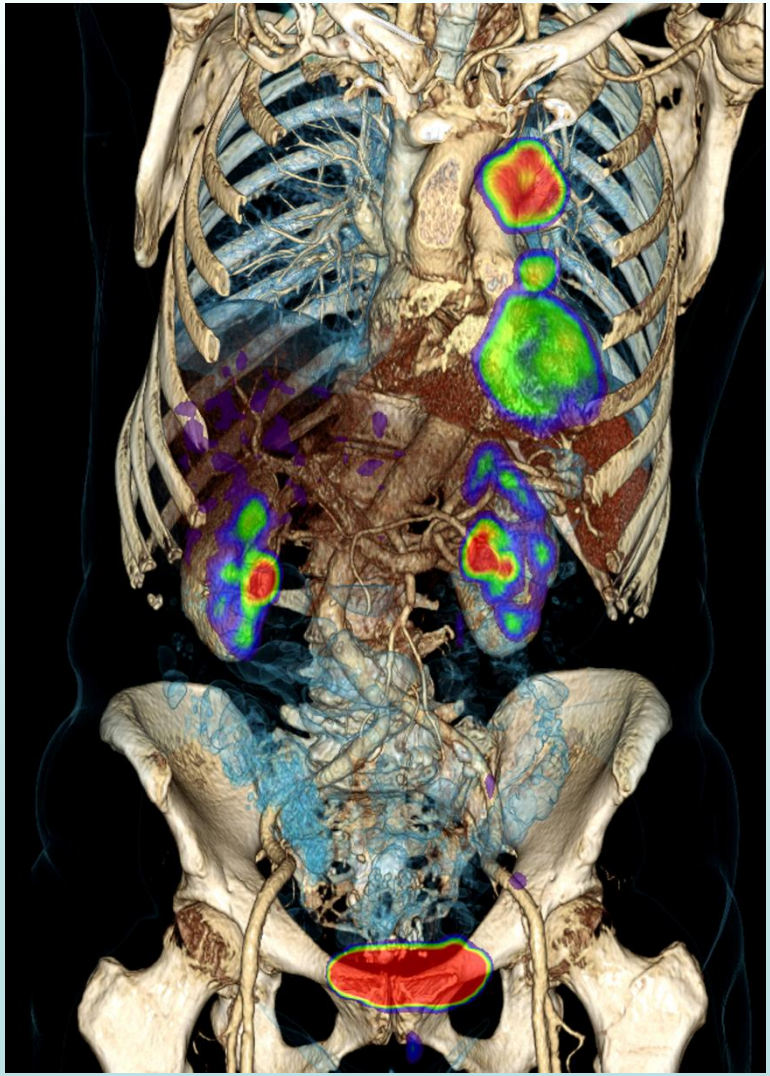


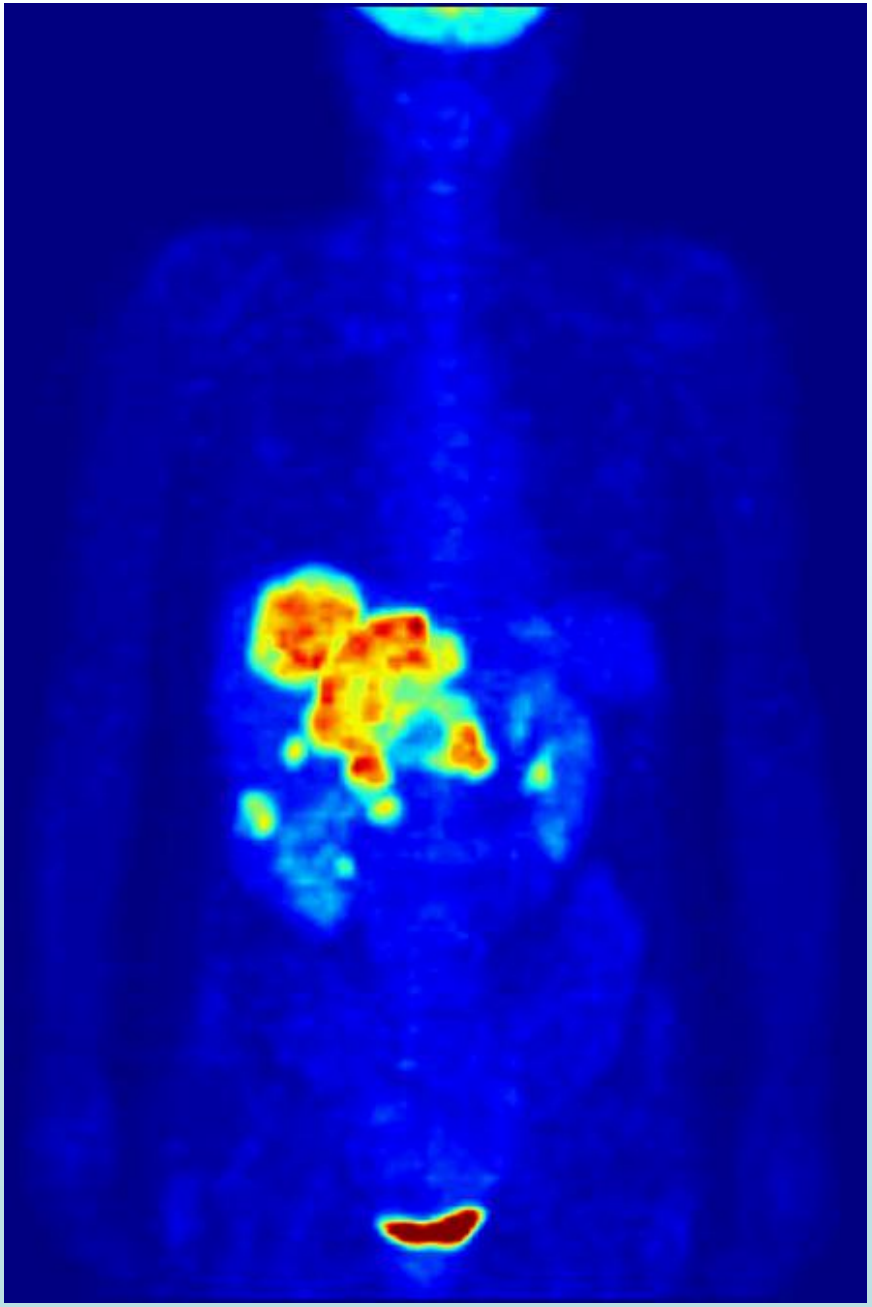






PET images





PET-CT

PET is only functional information

CT provides very good quality anatomy image

By performing the two sns at the same time, the two images can be fusioned

This gives doctors lot more useful information