Basics of SPECT, PET and PET/CT Imaging

Talk presented at the:

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Electromagnetic Radiation in Medical Imaging

Ionizing

X-Ray

Planar

Tomographic

Nuclear Medicine

Planar

Gamma Camera

Tomographic

PET

SPECT

Radiation Protection

Non-Ionizing

Magnetic Resonance Imaging

Outline

Radiation protection principles

Nuclear medicine

- Tracer principle
- Radionuclid production
- Detection
- Gamma camera
- Tomographic techniques: SPECT/PET

CT

PET/CT

Some useful units

Activity unit:

1 Bequerel = 1 Decay/s

Dosis unit:

1 Gray = 1 J/kg

1 Gy warm 1l Water 0.00025 °C

Siever (Sv) refers to equivalent dose in which we measure not only the deposited energy of the particle per unit mass but the effect of this radiation in the tissue. For the photons and energies used in diagnostic imaging:

1 Gray = 1 Sv

Effective dose for different imaging techniques

Image method	Effective Dose (mSv)
Pelvis or hips (x-ray)	0,83 mSv
CT	10 mSv
PET (FDG)	7 mSv
PET/CT	14 mSv

Effects of whole body exposition

0 -0,25 Sv	no acute effects
1-2 Sv	nausea, vomitus
2-3 Sv	nausea, vomitus on the 1st day recovery after 3 months
3-6 Sv	nausea, vomitus after some hours, hair lose, internal haemorrhages after 2 weeks
6-8 Sv	nausea, vomitus and diarrhea after some hours, mental confusion
50-100 Sv	acute toxic effects, cramps, internal haemorrhages
> 1000 Sv	nerve system damage, dead within seconds

Radiation's effects

Physical: Ionisation and excitation

Physical-chemical: Radicals

Chemical: Reaction of the radicals with bio-molecules

Biological: Cellular dead, mutations

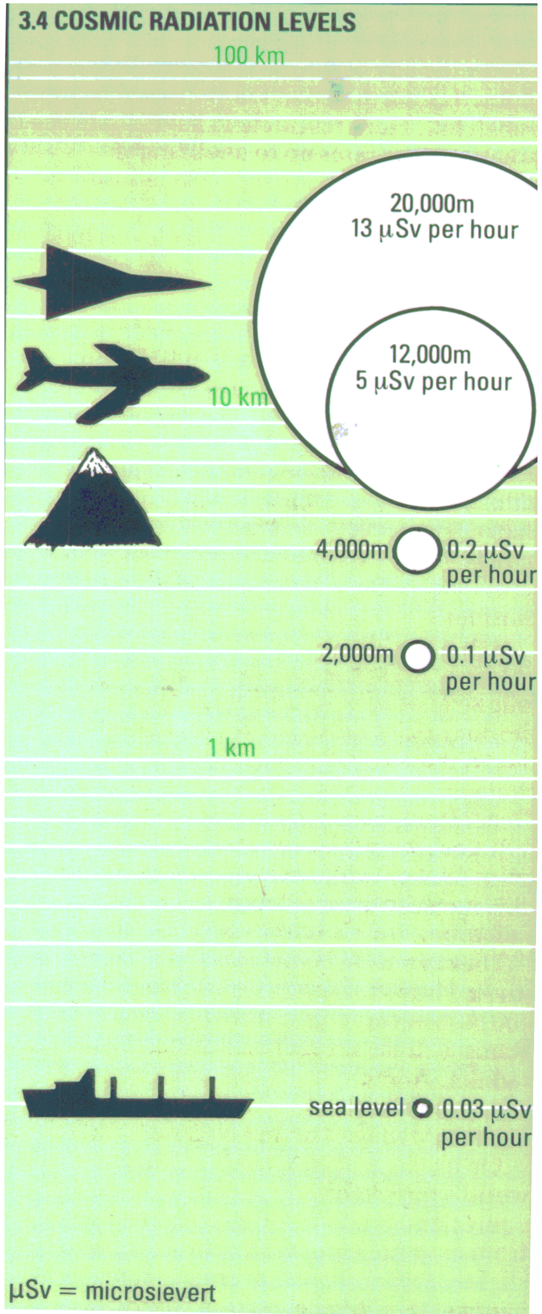
Deterministic effects

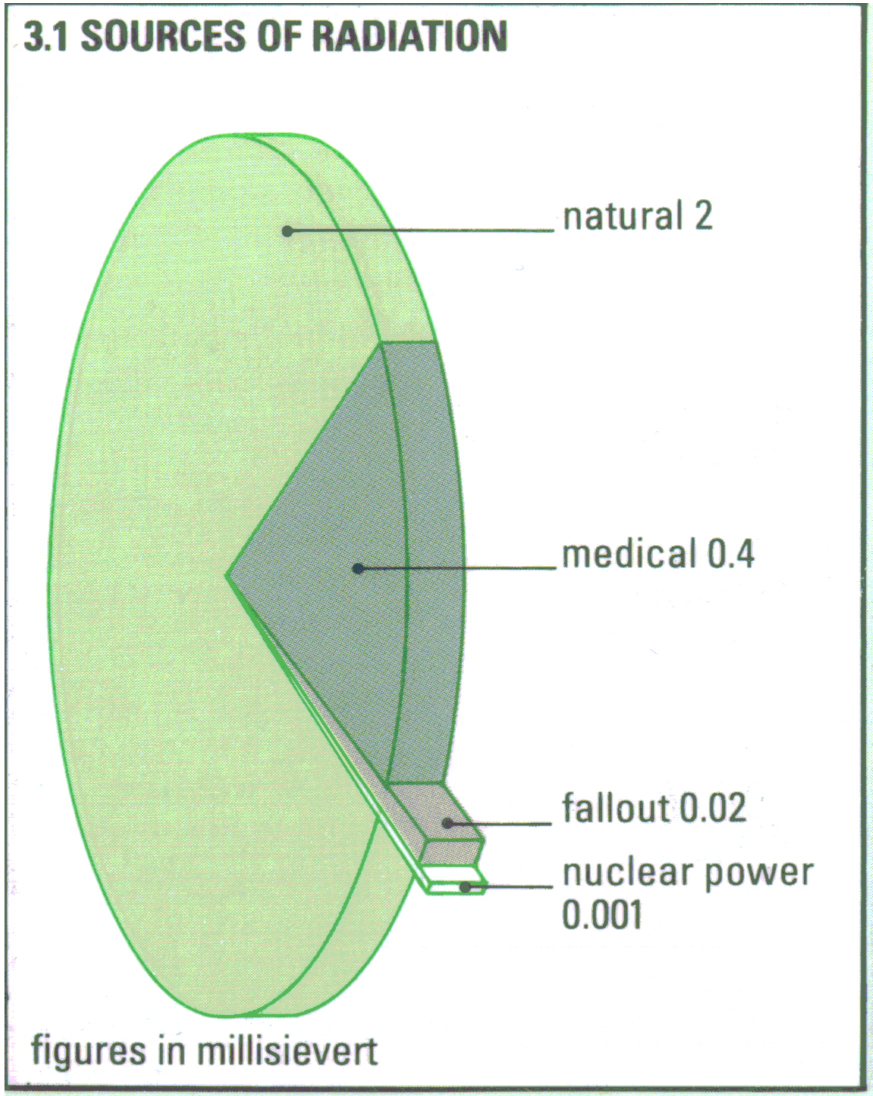
They have a threshold dose and

their severity depends on the received dose

Stochastic effects

There is a probability of occurrence depending on the dose


3.4 COSMIC RADIATION LEVELS
100 km
20,000m
13 μSv per hour
12,000m
5 μSv per hour
10 km
4,000m
0.2 μSv per hour
2,000m
0.1 μSv per hour
1 km
sea level
0.03 μSv per hour
μSv = microsievert


3.1 SOURCES OF RADIATION
natural 2
medical 0.4
fallout 0.02
nuclear power 0.001
figures in millisievert

Radiopharmaceuticals

are compounds of biomedical interest which have attached radionuclides as labels that allow us to quantify specific physiological processes.

Selection
of pharmaceutical based on organ-specific question

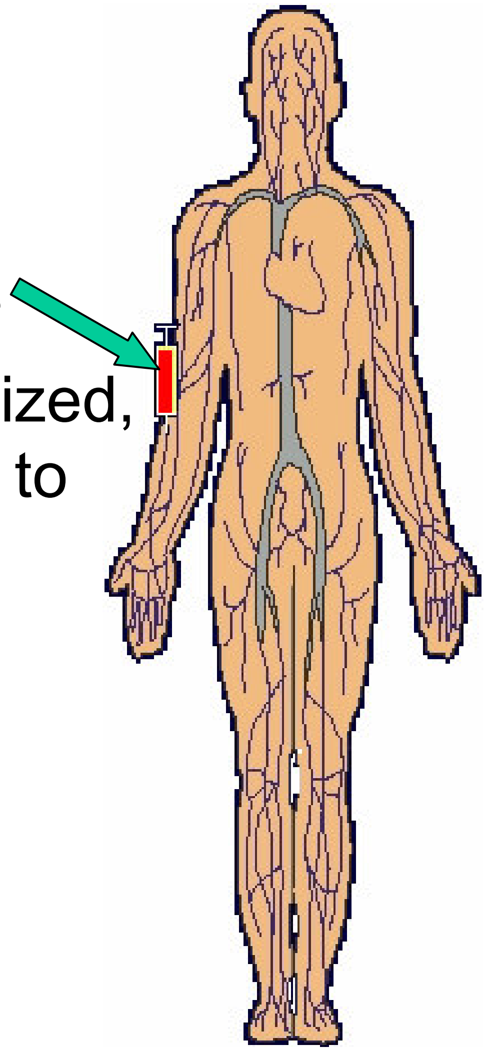
Labelling
of pharmaceutical with radioactive isotopes

Radiopharmaceuticals should **not disturb** the process under investigation

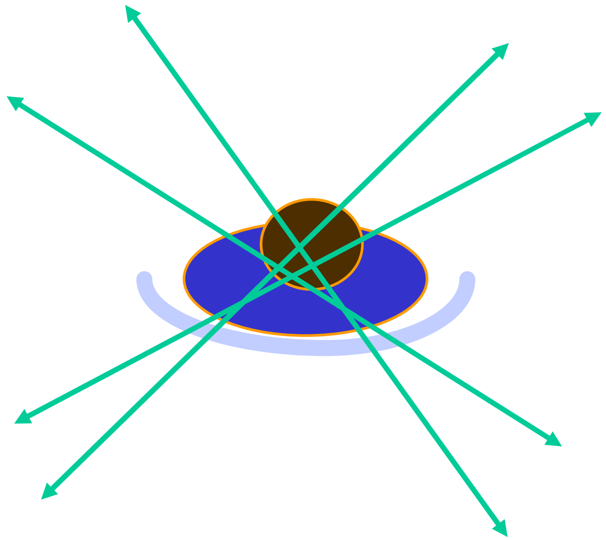
Non invasive determination of physiologic processes

Tracer principle:

Radiopharmaceuticals



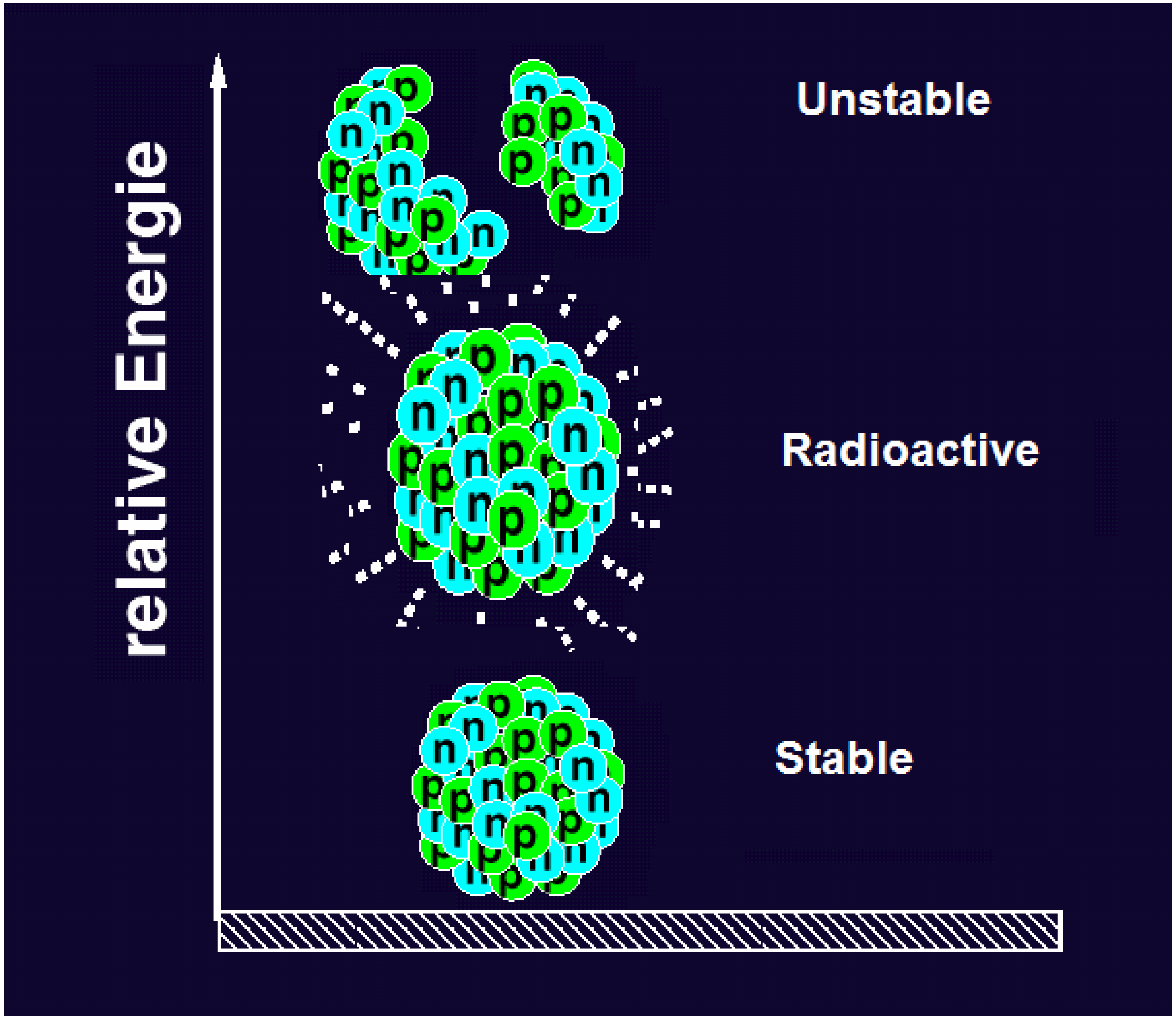
are distributed, metabolized, and excreted according to their chemical structure



Detect and display as:

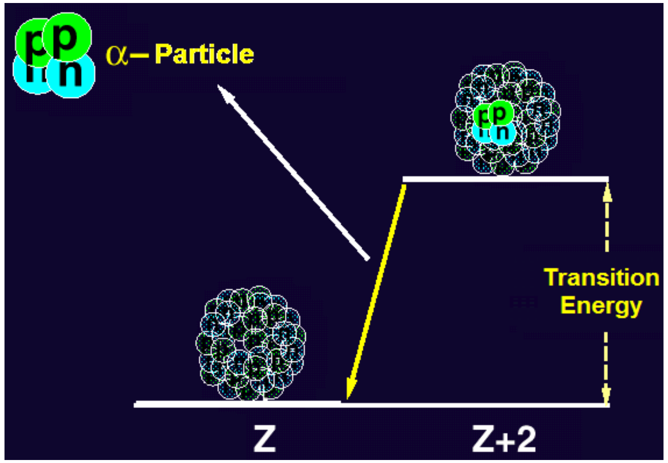
- *Images*
- *Numerical data*
- *Time-activity curves*

Nuclear Stability

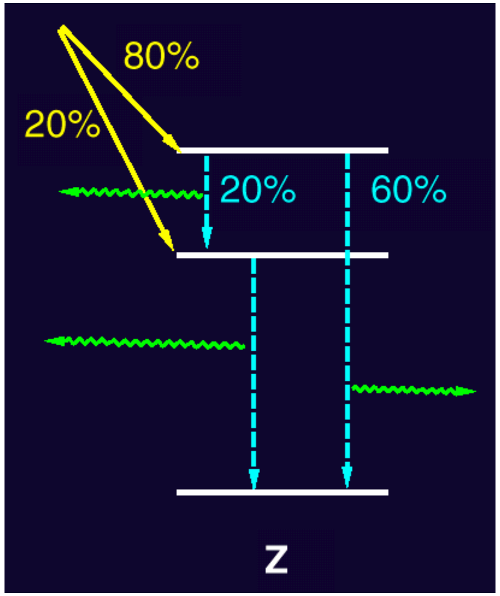


Decay Modes

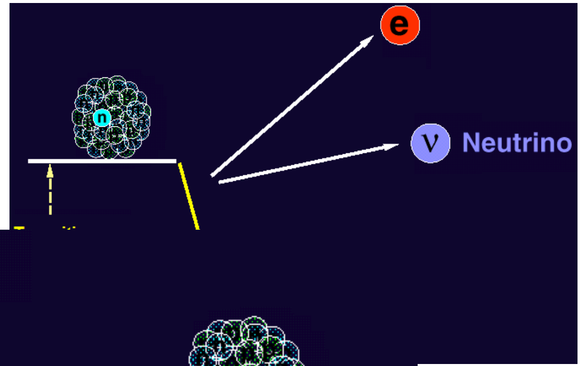
α emission

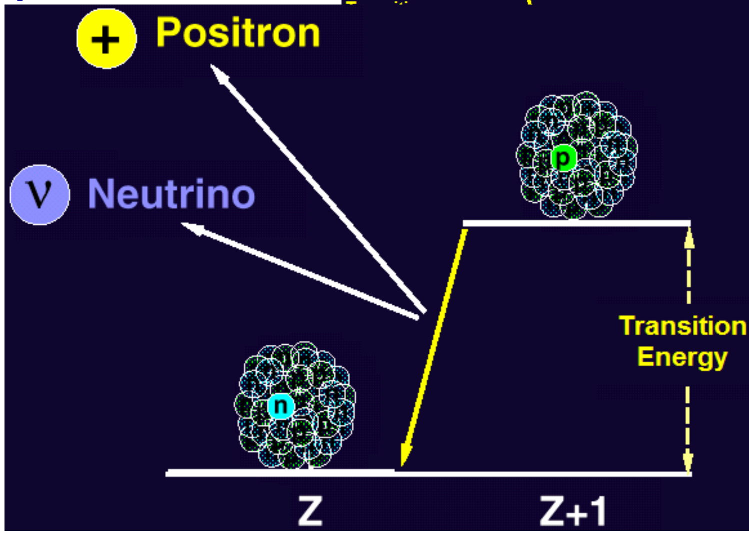


isomeric transition (γ emission)



β^- emission





positron (β^+) emission

internal conversion (IC)

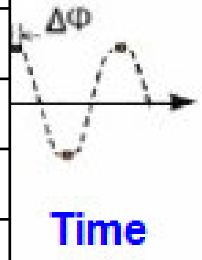
electron capture (EC)

nuclear fission

Particle acceleration:

Cyclotron

Product	Decay Mode	Natural Abundance of target Isotope (%)
^{11}C	β^+, EC	99.6
^{13}N	β^+	99.8
^{15}O	β^+	99.6
^{18}F	β^+, EC	0.20
^{67}Ga	(EC,γ)	18.8
^{111}In	(EC,γ)	48.2
^{123}I	(EC,γ)	2.6
^{201}Tl	(EC,γ)	13.2

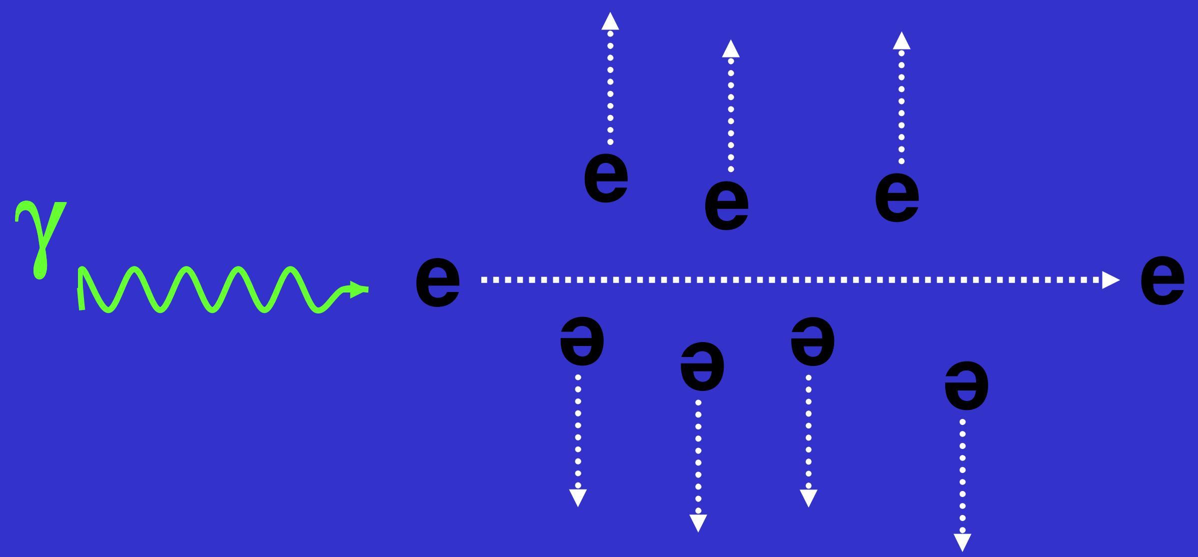


Radionuclide generators

Parent	Half life	Decay mode	Daugther	Half life	Decay mode	Product
^{99}Mo	66,02 h	β^-	^{99m}Tc	6,02 h	Isomer	^{99}Tc
^{188}W	69,4 d	β^-	^{188}Re	16,9 h	β^-	^{188}Os
^{68}Ge	288 d	EC	^{68}Ga	68,3 min	β^+, EC	^{68}Zn
^{82}Sr	25 d	EC	^{82}Rb	1,25 min	β^+, EC	^{82}Kr

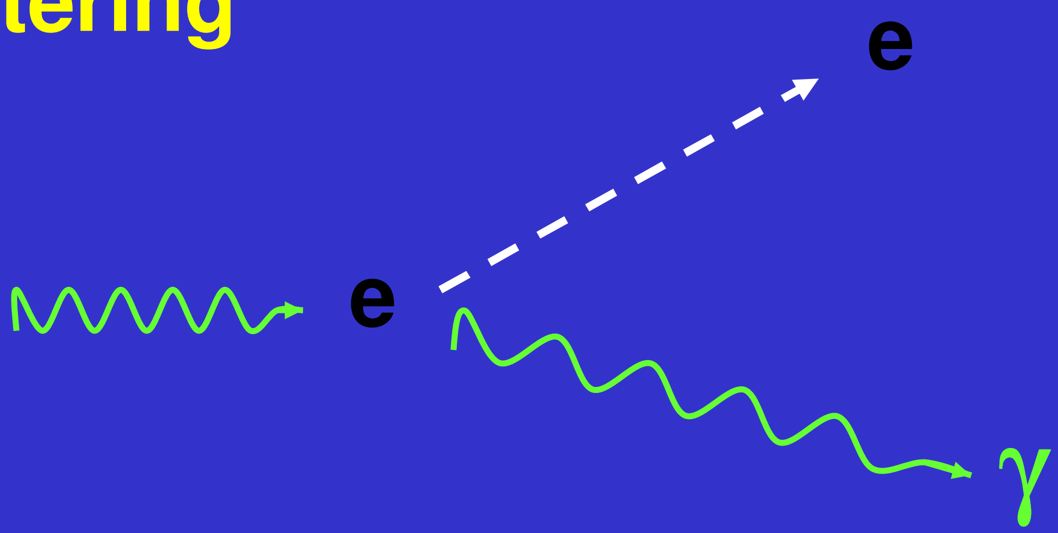
Interaction of Radiation with Matter

Photoelectric effect



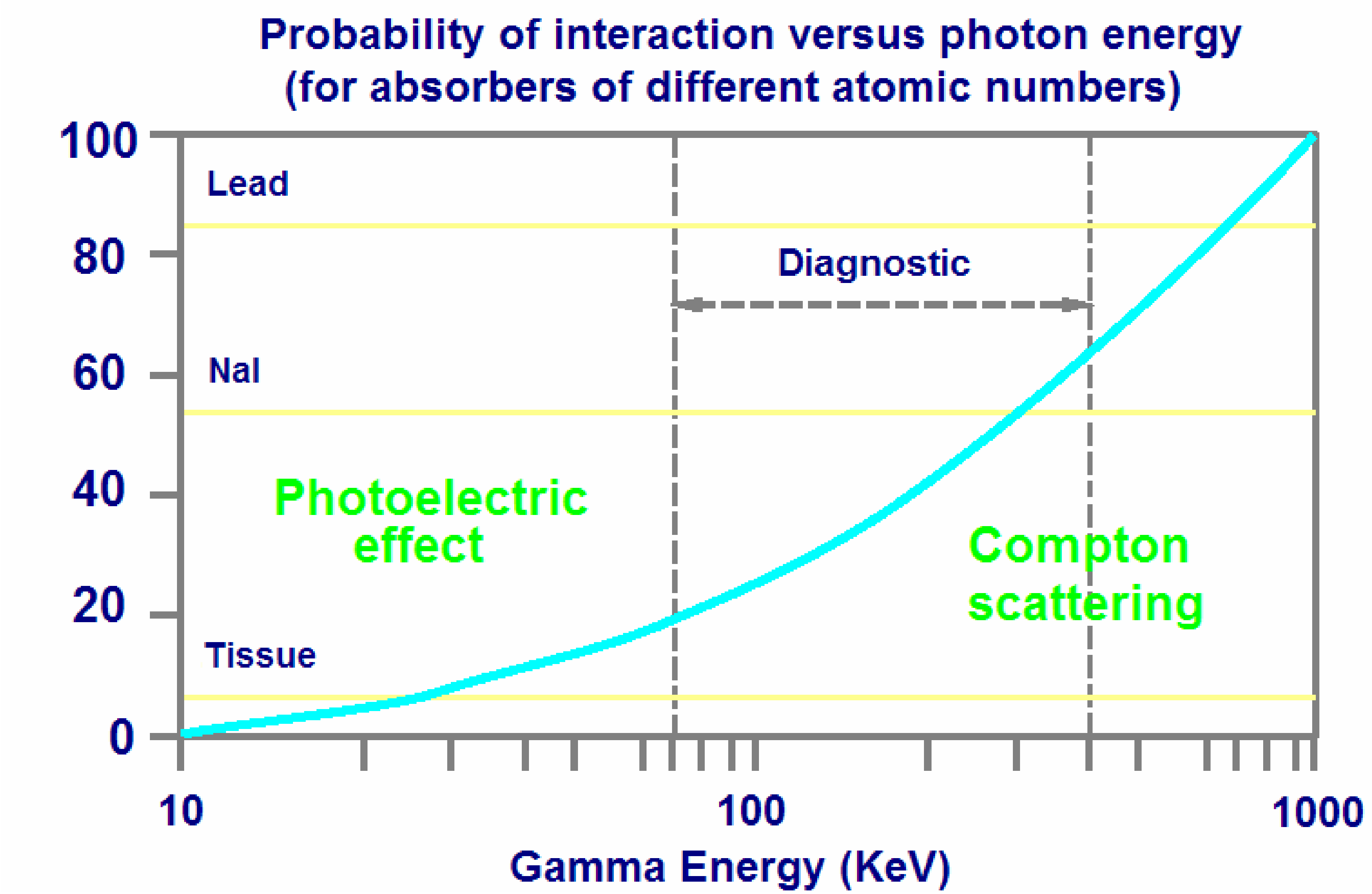
The energy of the Gammaquantum is absorbed

Compton - Scattering



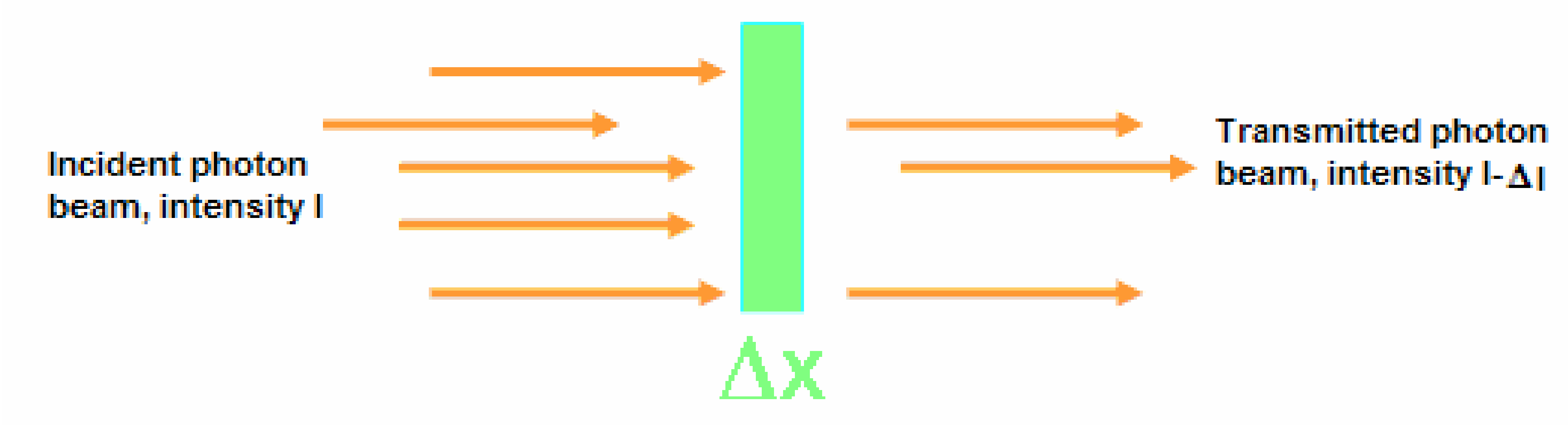
Part of the γ-Energy is passed to the electron
the γ-Quantum changes its Energy and direction

Probability of Interaction



Interaction

May pass through — no interaction
May interact — lose energy & change direction
May interact — transfer all its energy & disappear

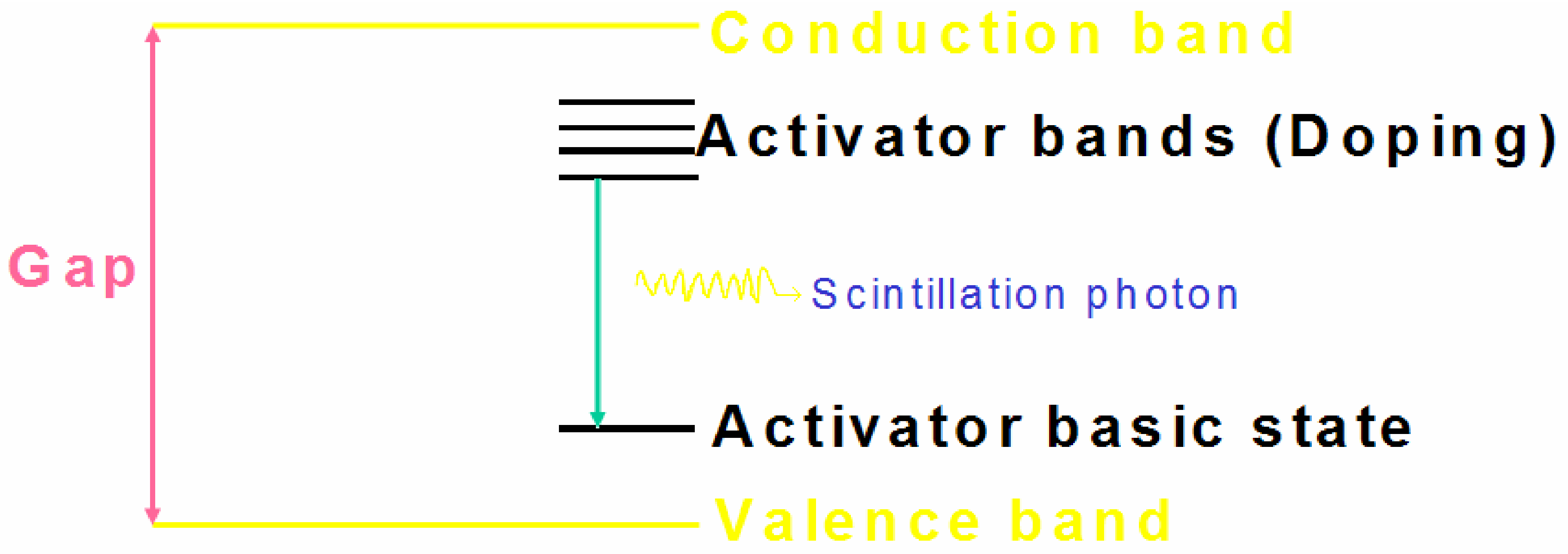


$$\mu_m(mix) = \mu_{m\,1} f_1 + \mu_{m\,2} f_2 + \ldots$$

$$\mu_m = \tau + \sigma + \kappa$$

τ is the part of μ_m due to photoelectric effect
σ is the part of μ_m due to Compton Effect
κ is the part of μ_m due to pair production
μ_m Absorption coefficient involves both absorption and scattering processes.

Scintillation Crystals



Ionised electron ➡ Electron-Hole Pair ➡
Activator de-excites by emission of Photons (10^{-7} sec)

Scintillation Crystals

	NaI	BGO	LSO	GSO
	NaI:Tl	$Bi_4Ge_3O_{12}$	$Lu_2SiO_5:Ce$	$Gd_2SiO_5:Ce$
Density (g/cm^3)	3,67	7,1	7,4	6,7
Effective atomic No.	51	73	65	59
photons/MeV	41000	9000	26000	8000
Decay time (ns)	230	300	40	60
Peak emission (nm)	415	480	420	430
Index of refraction	1.85	2.15	1.82	1.85

Scintillation Crystals: Ideal Properties

- High photoconversion
- High light output
- Good stopping power

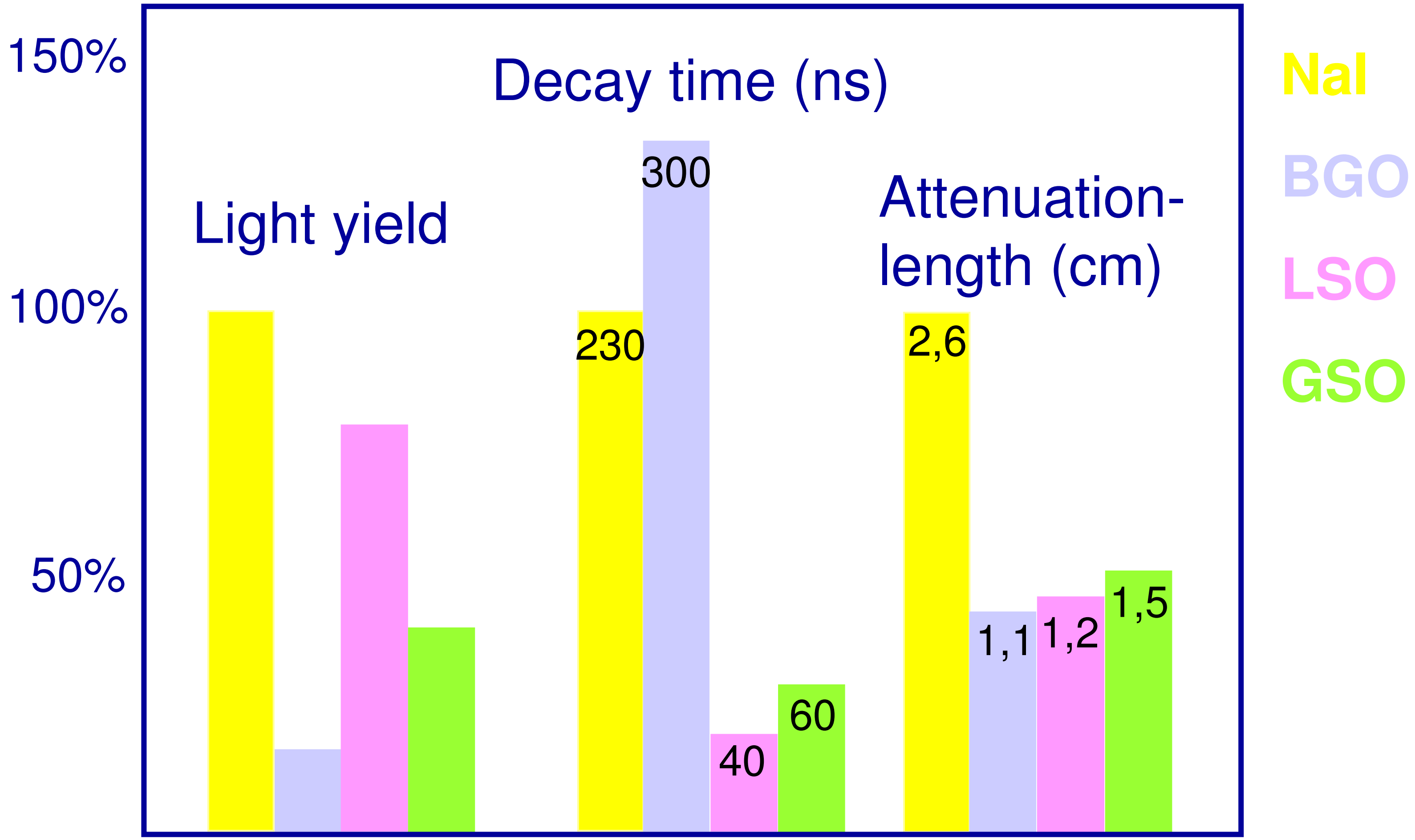
- Fast response

- High optical light transmission and no self-absorption

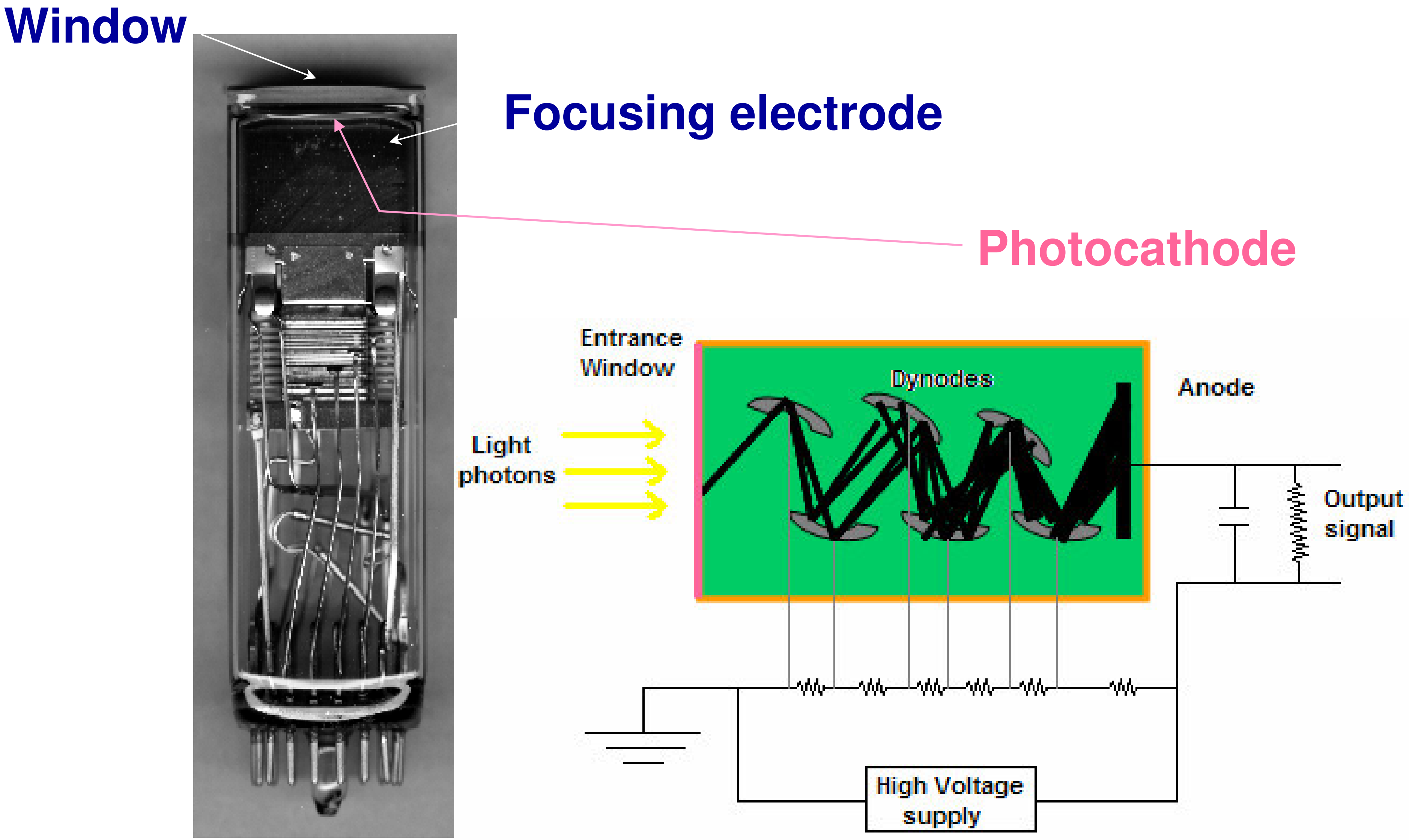
- Index of refraction close to that of the PMT

- Nonhygroscopic and robust

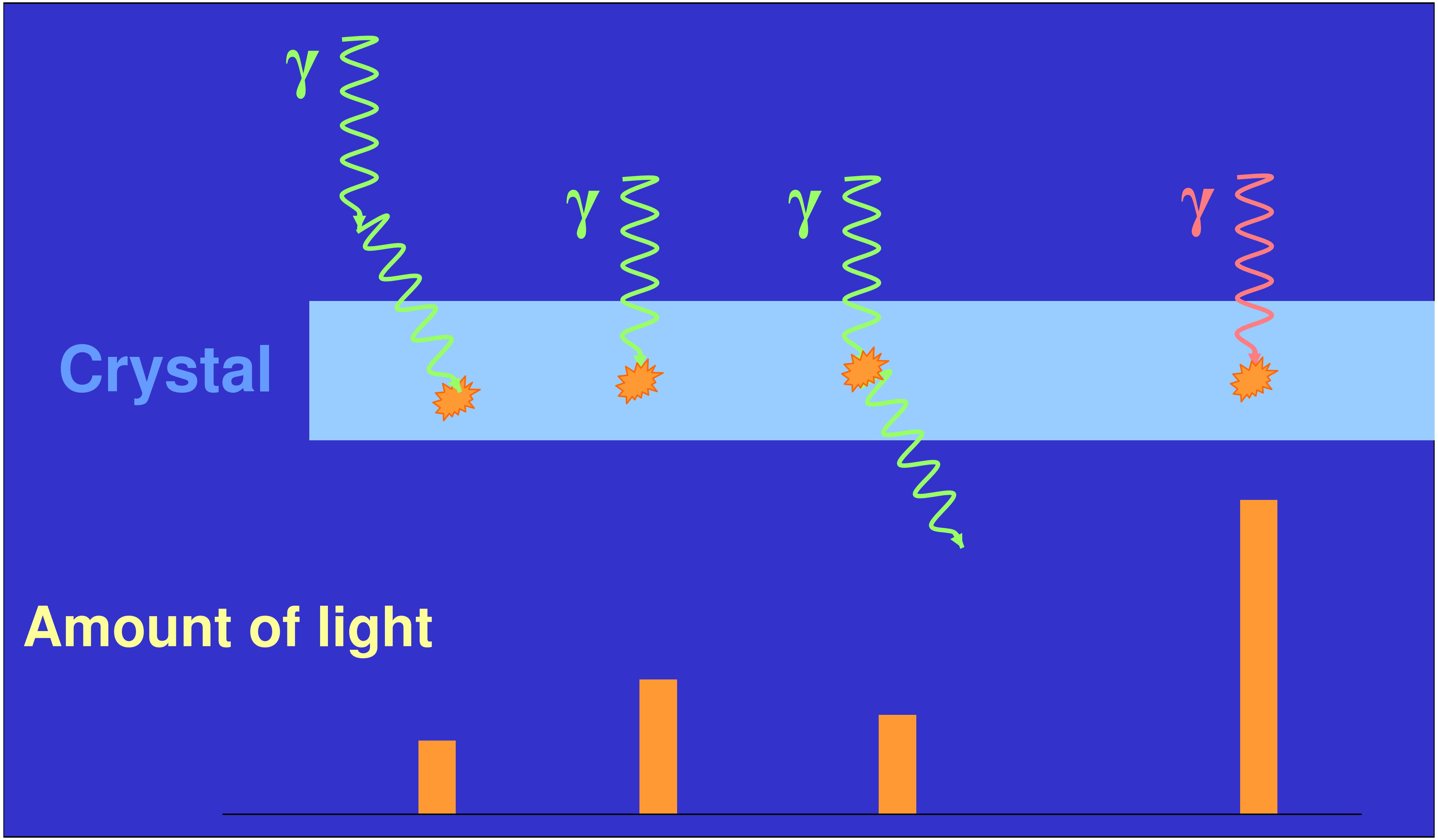
Scintillators



Photomultiplier Tubes

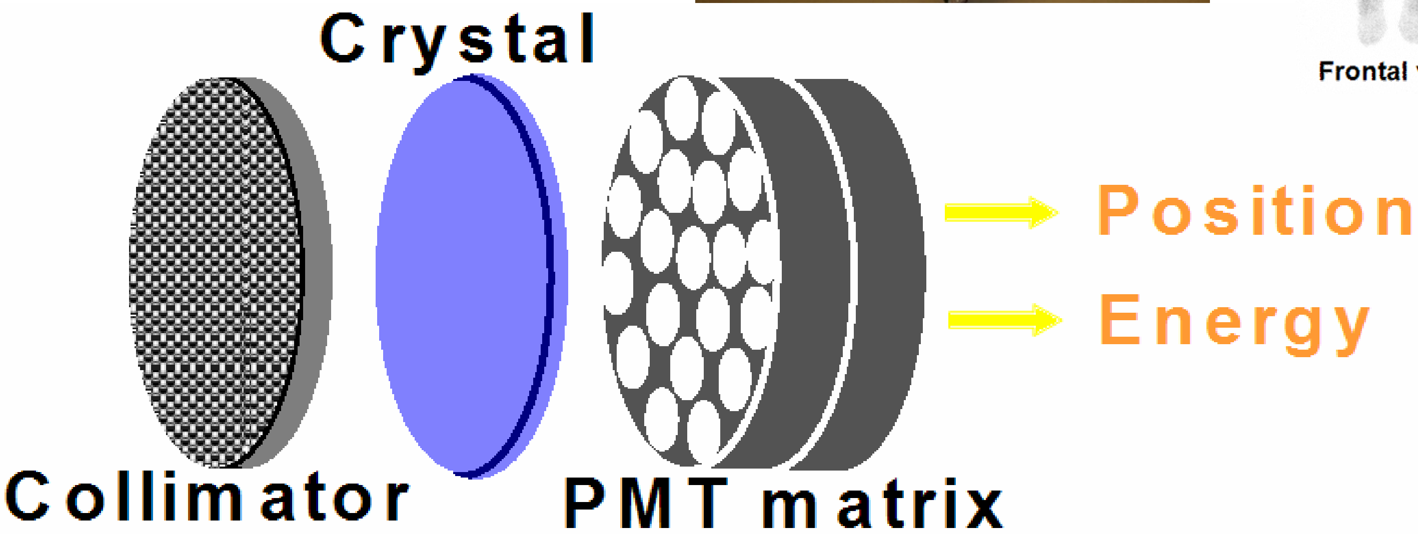


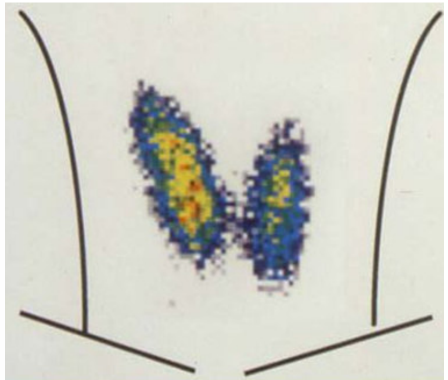
Scintillation Crystal



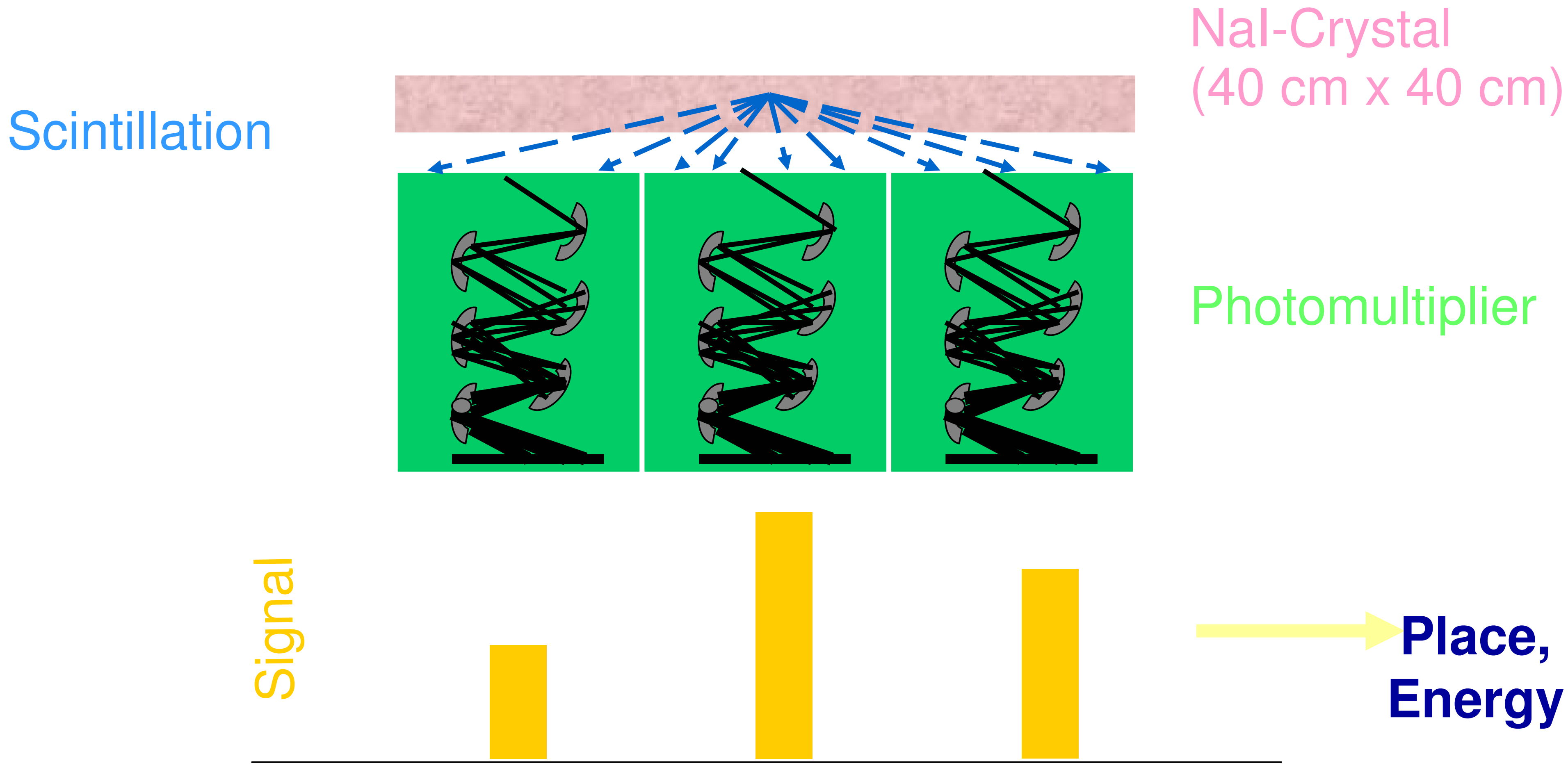
The Gamma Camera

Frontal view Dorsal view

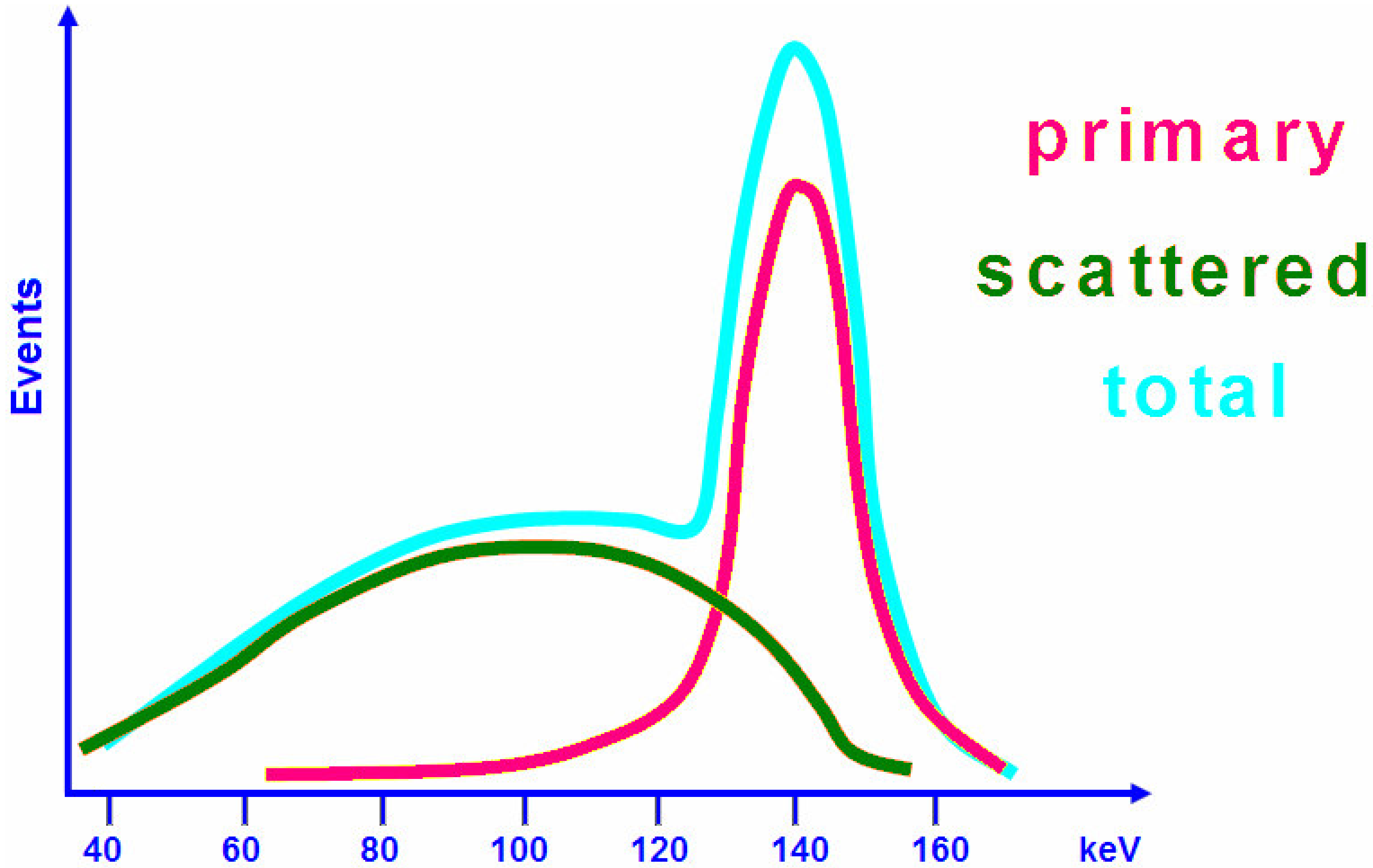




Principle of the Gamma Camera



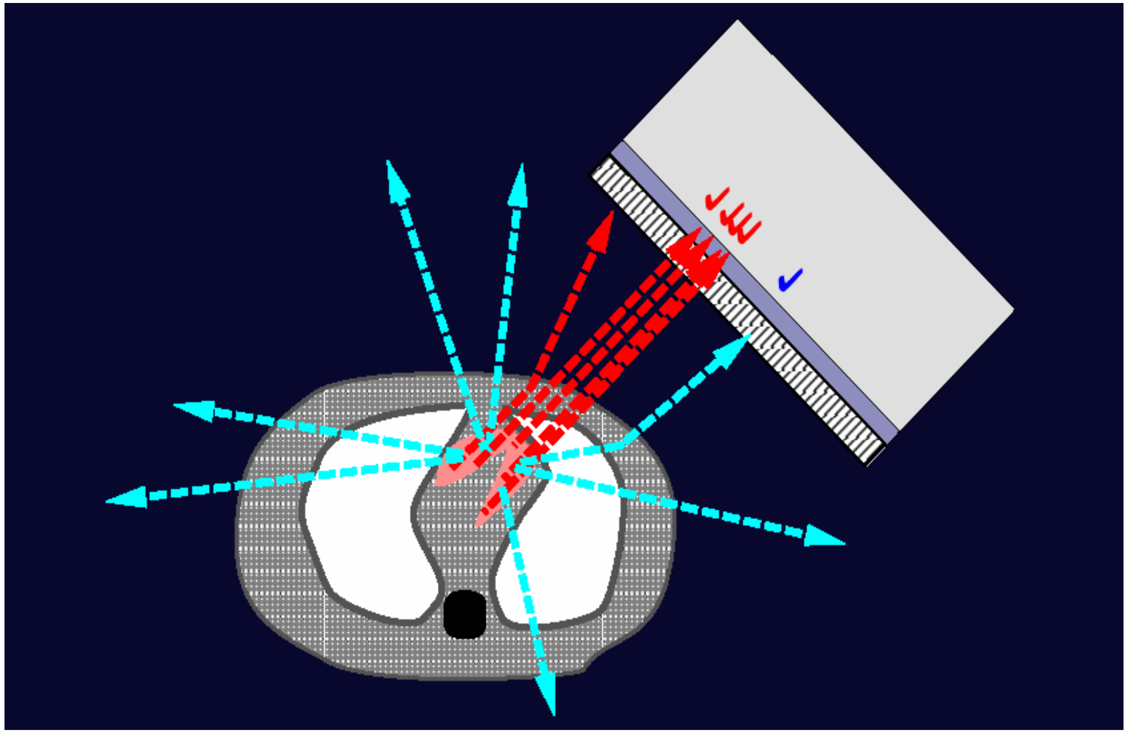
Energy Spectrum

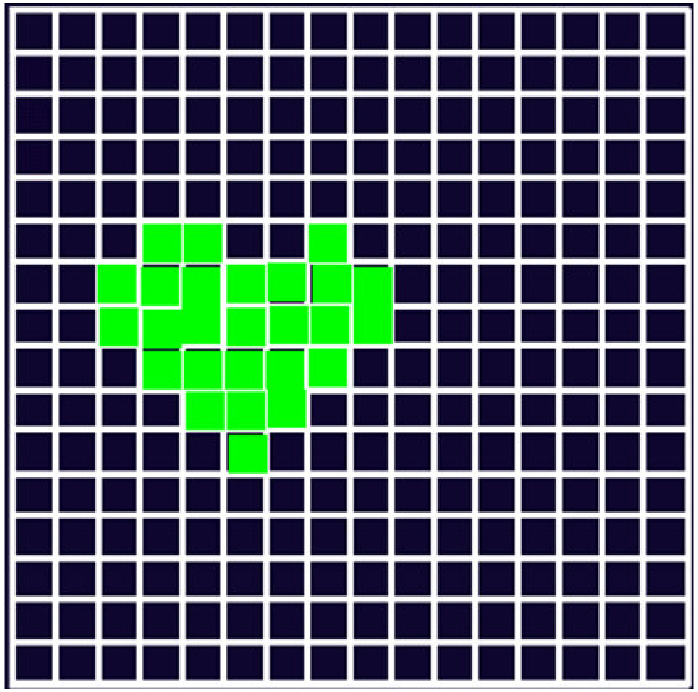


Collimators

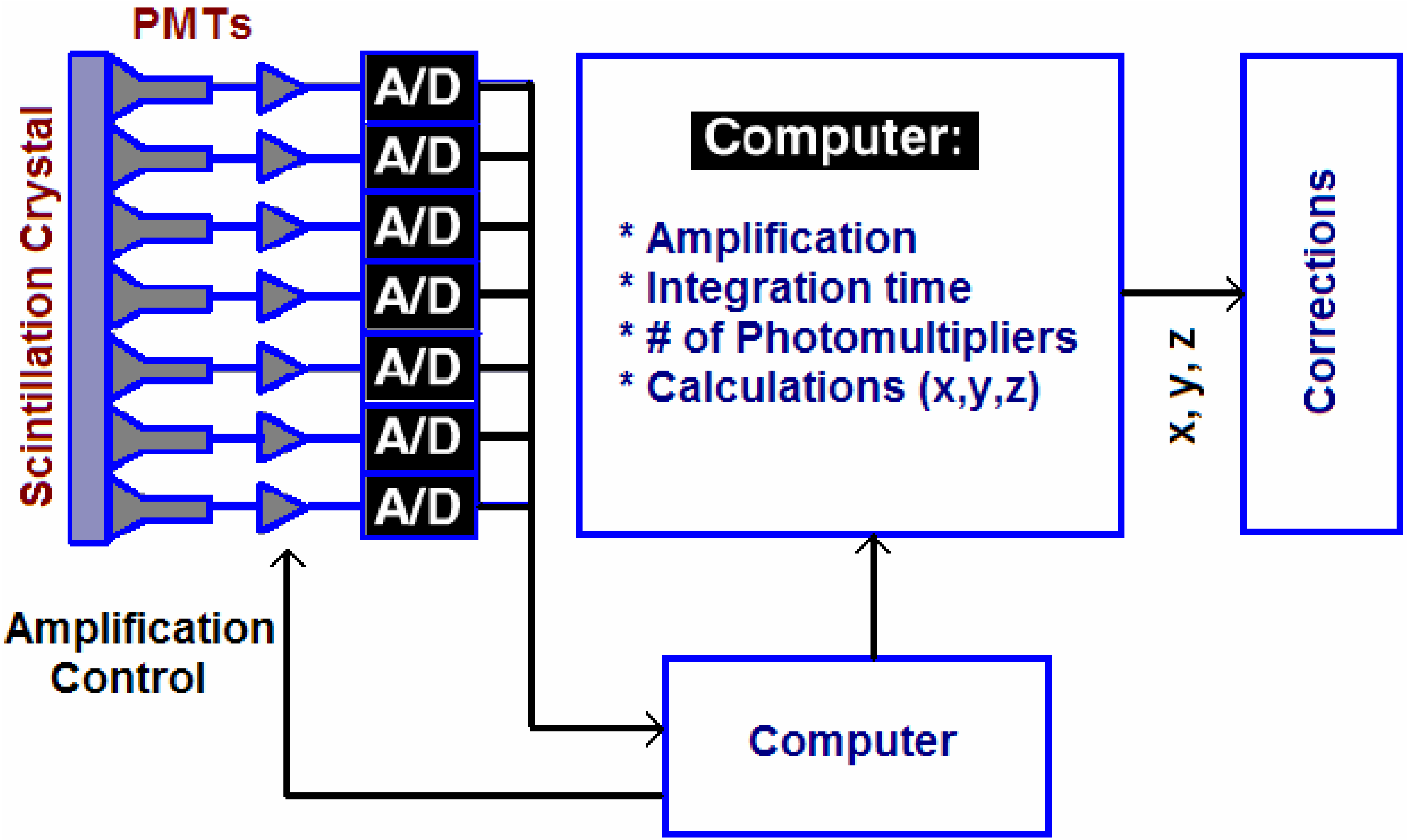
- Diverging Hole
  - Large FOV; minifies large objects
  - Poor sensitivity, resolution
- Parallel Hole
  - No magnification
    - FOV, sensitivity constant with distance
    - Resolution limited by camera intrinsic resolution
- Pinhole, Converging Hole
  - Magnification of small objects
  - Sensitivity and resolution good at close distances

The Objective of the Gamma Camera is to get an image of the distribution of the activity

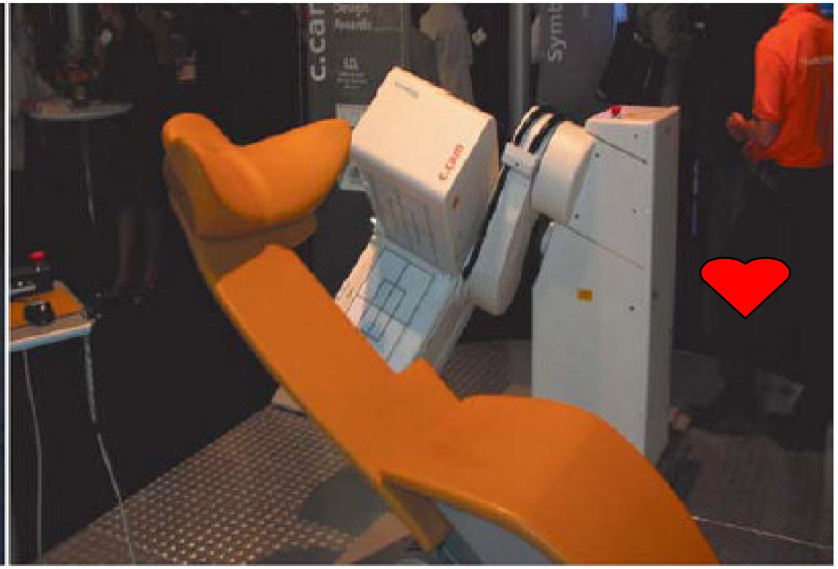




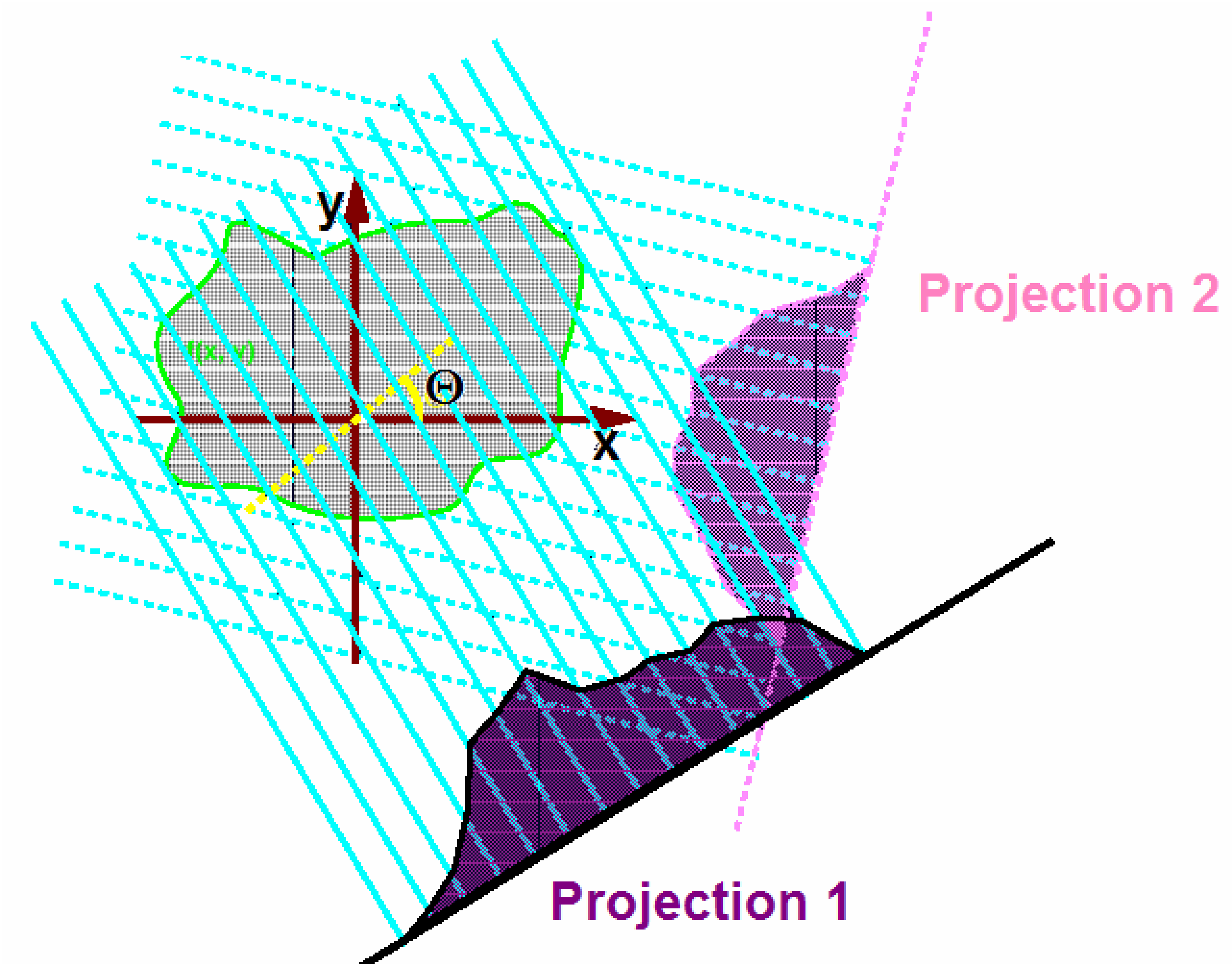
Behind the scene…



SPECT



Tomographic Images



Measurement of projections in many views

Mathematical reconstruction

Volume of activity distribution

Measured data grouped into projections: **SINOGRAM**

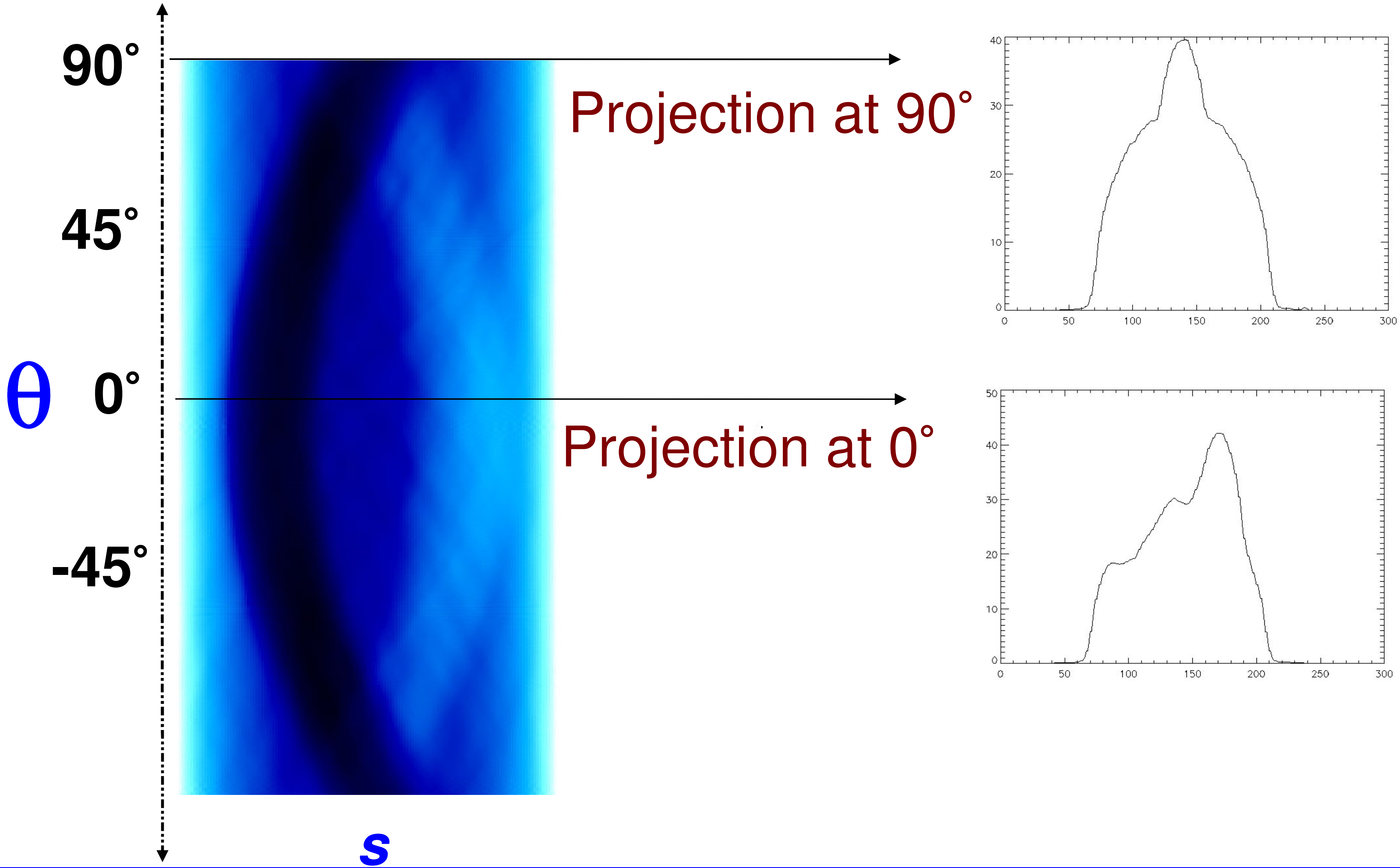


Image Reconstruction Methods

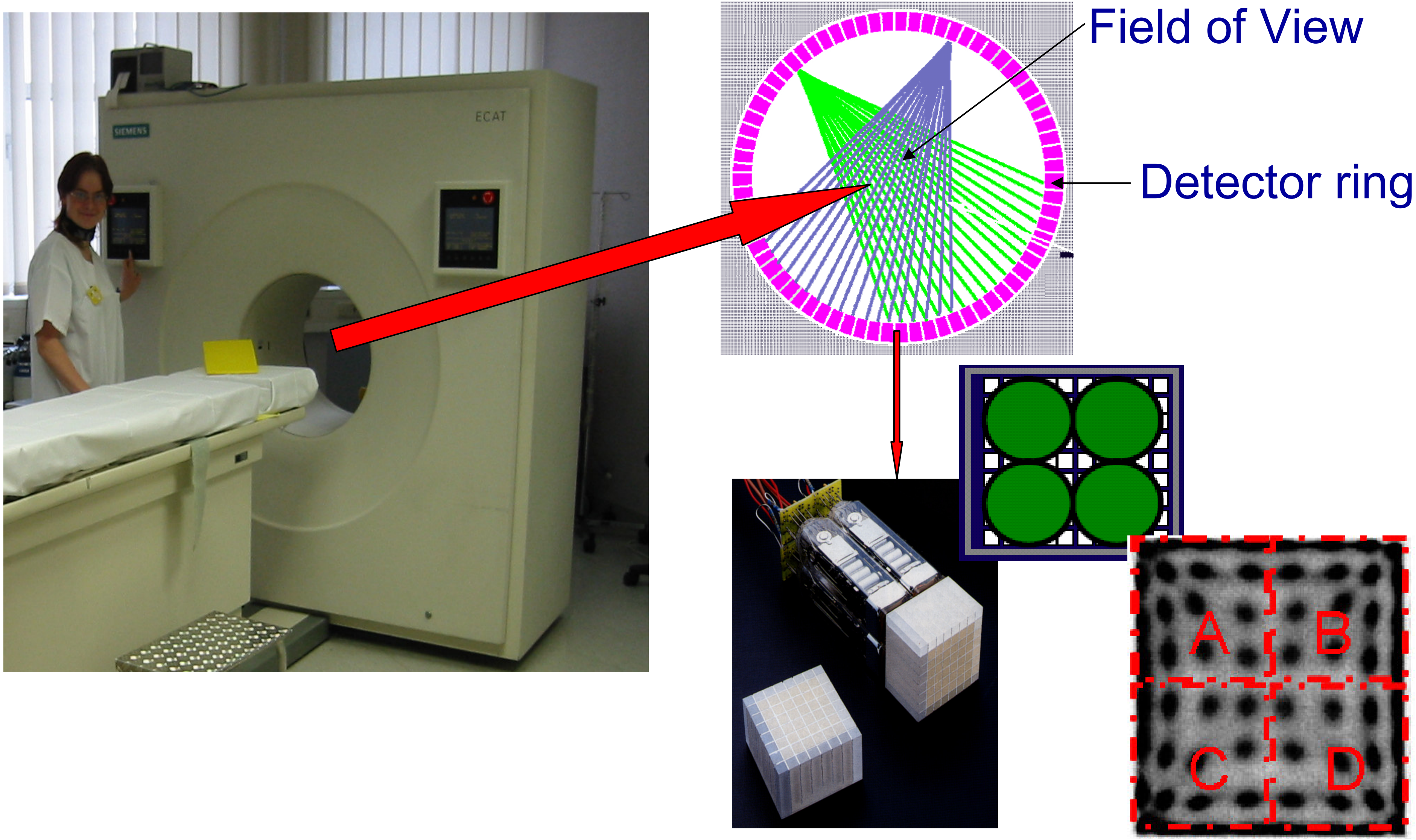
Simple Backprojection

Filtered Backprojection

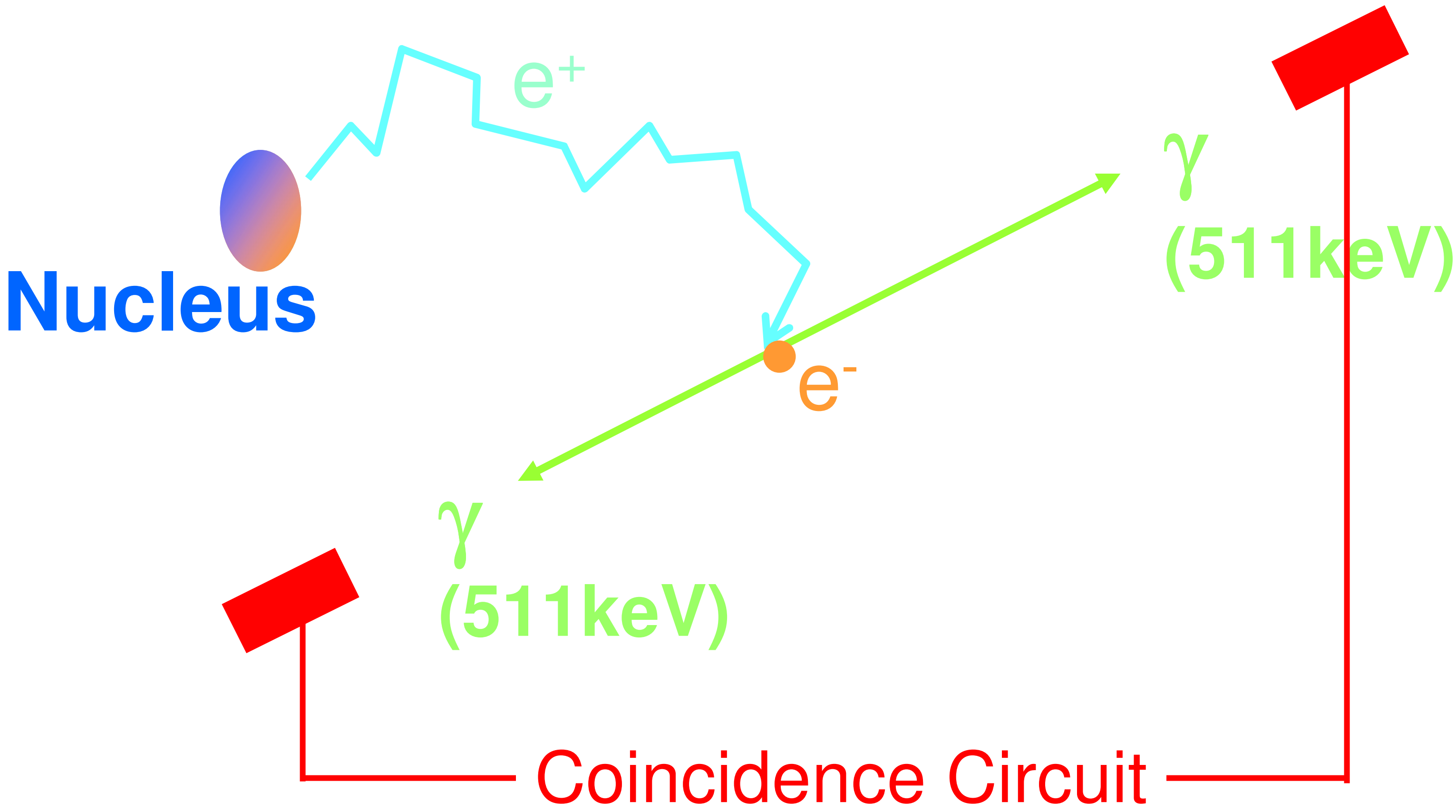
Fourier Transformation

Iterative Algorithms

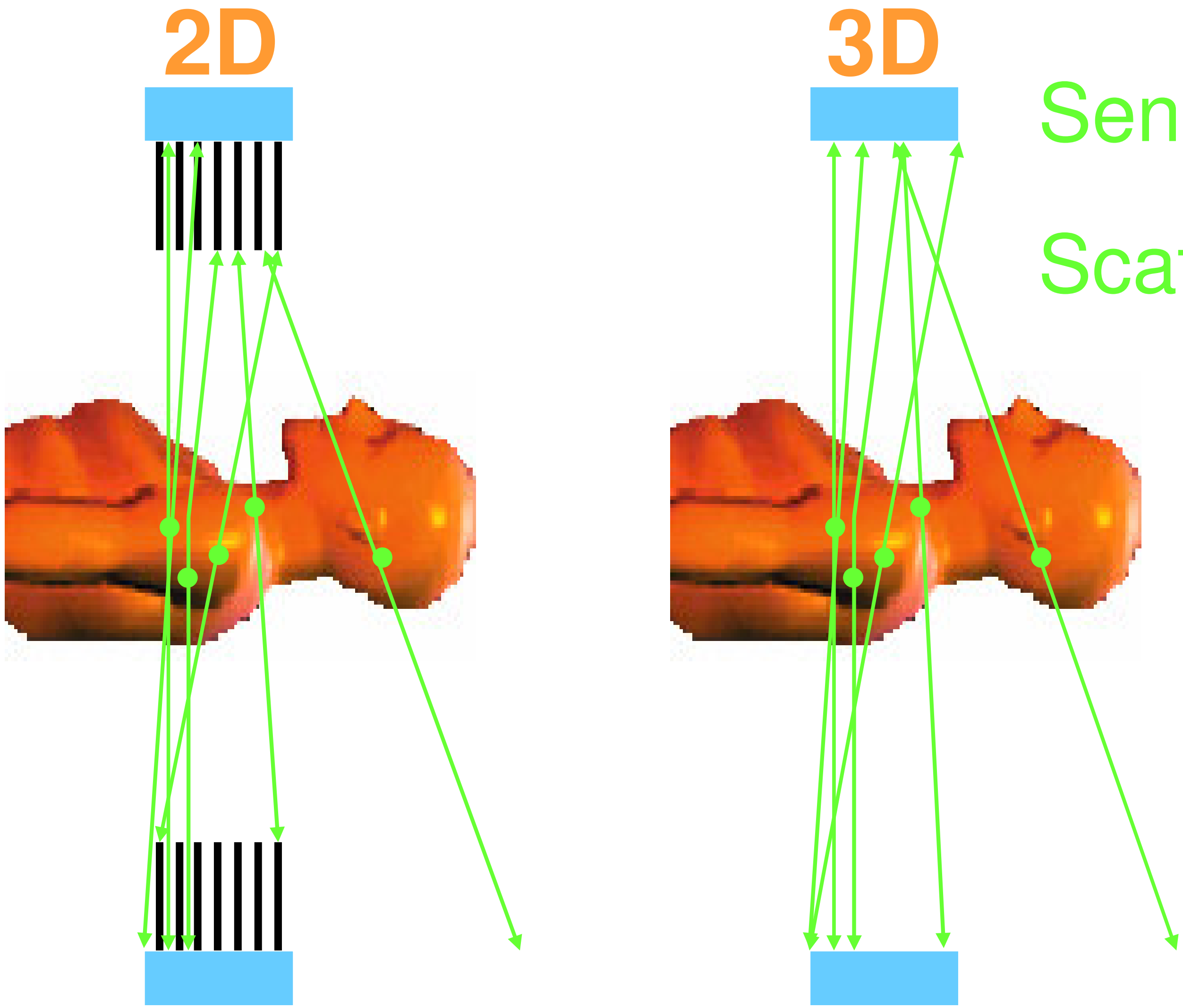
PET



Electronic Collimation



PET Acquisition Modes

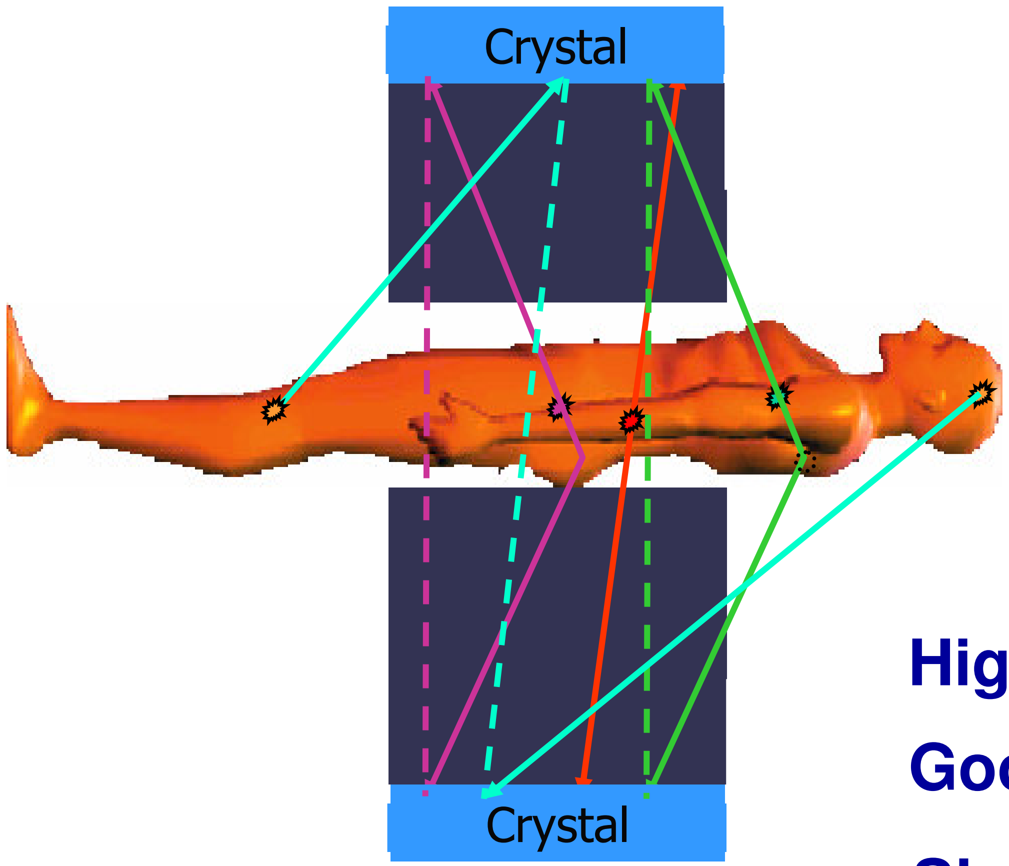


Sensitivity ↑

Scatter ↑

PET Coincidence Types

3D



True Coincidences

Scattered within FOV

Scattered outside FOV

Random Coincidences

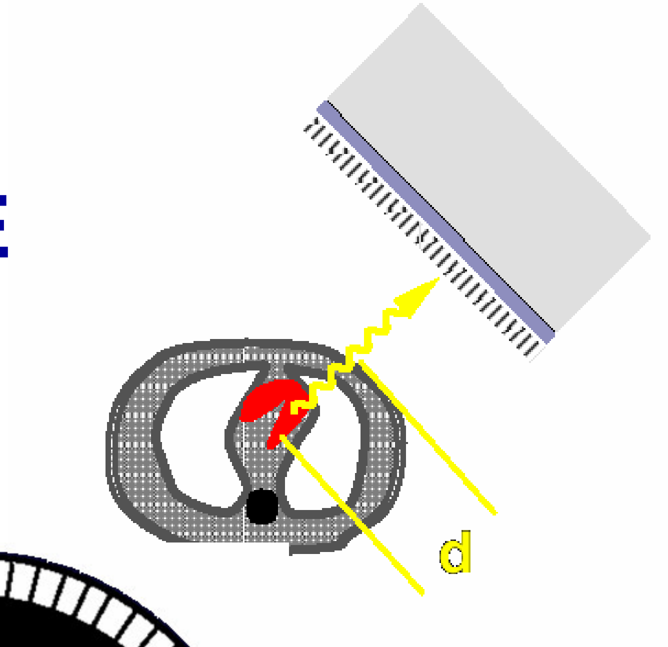
High Crystal Efficiency

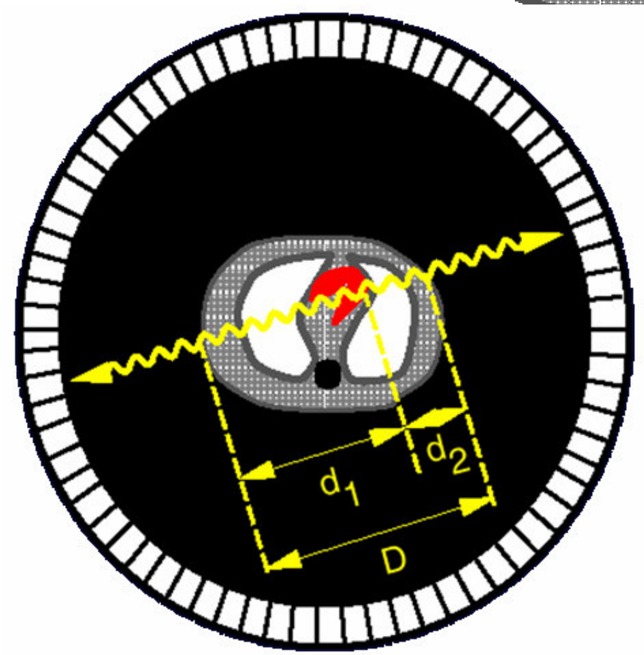
Good Energy Resolution

Short Coincidence Window

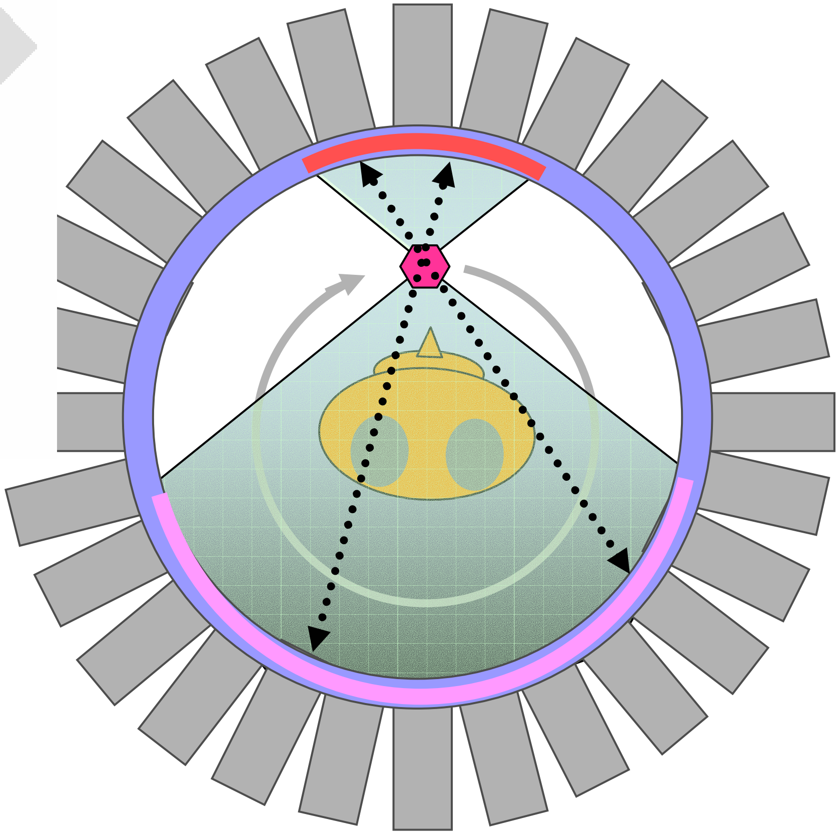
Attenuation: Transmission Scan

SPE





PET



PET Clinical Applications

Brain

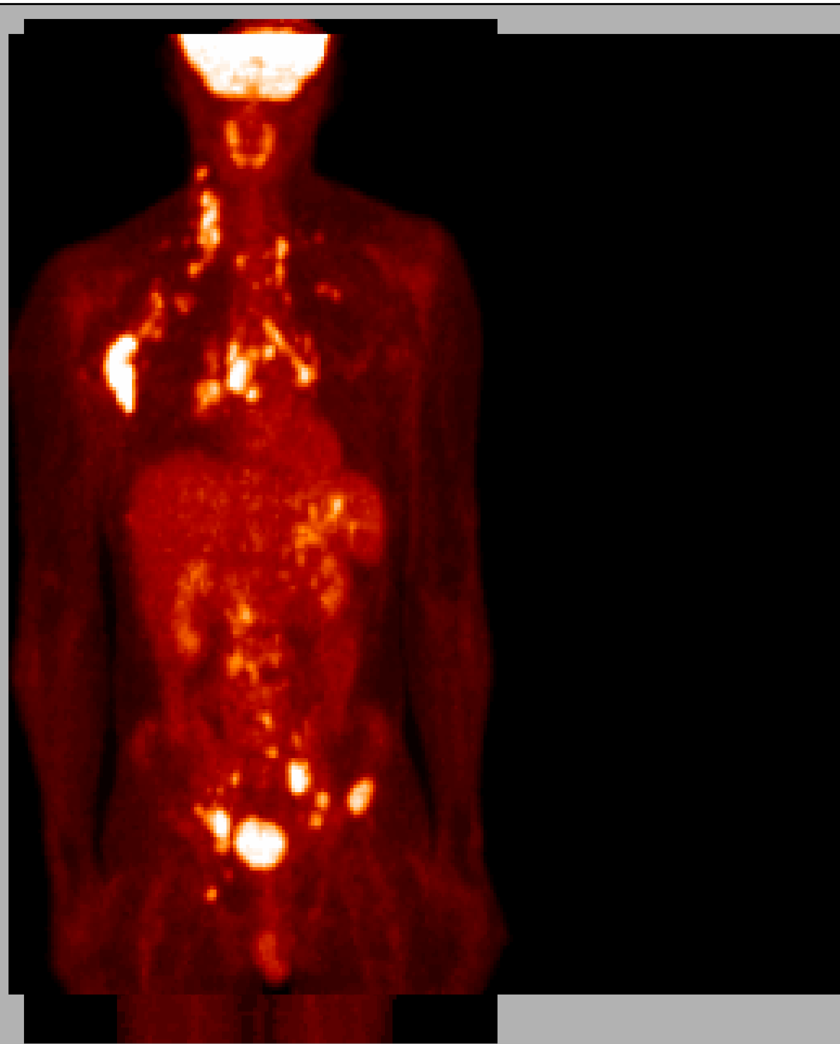
48 years old patient

Malign Lymphoma

Kidney

Bladder

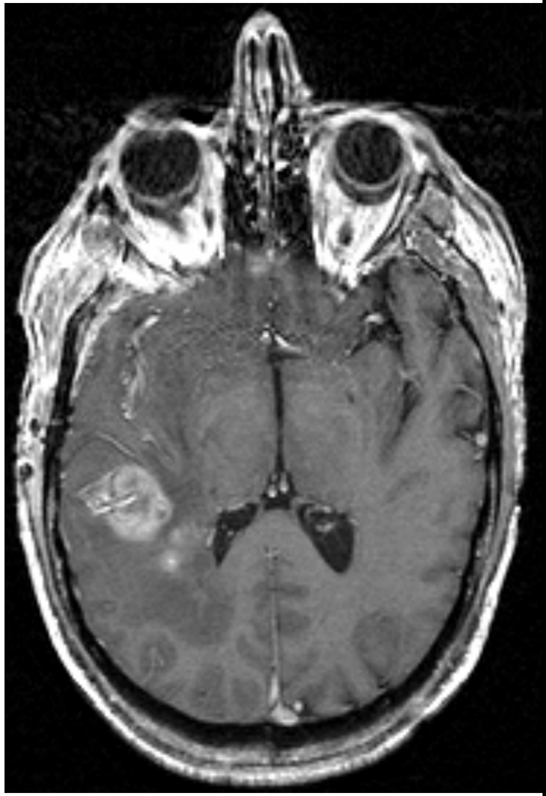
Normal Person



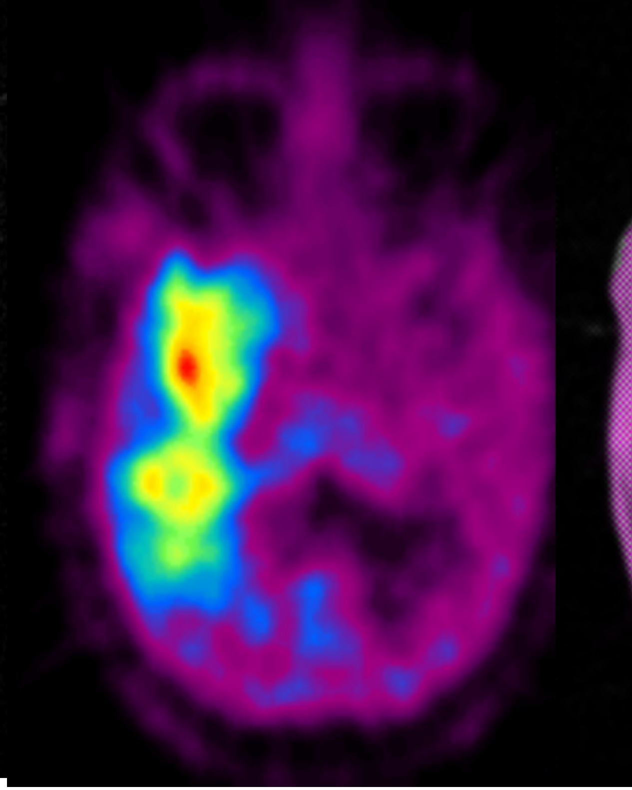
PET Clinical Applications

Definition of tumor extension

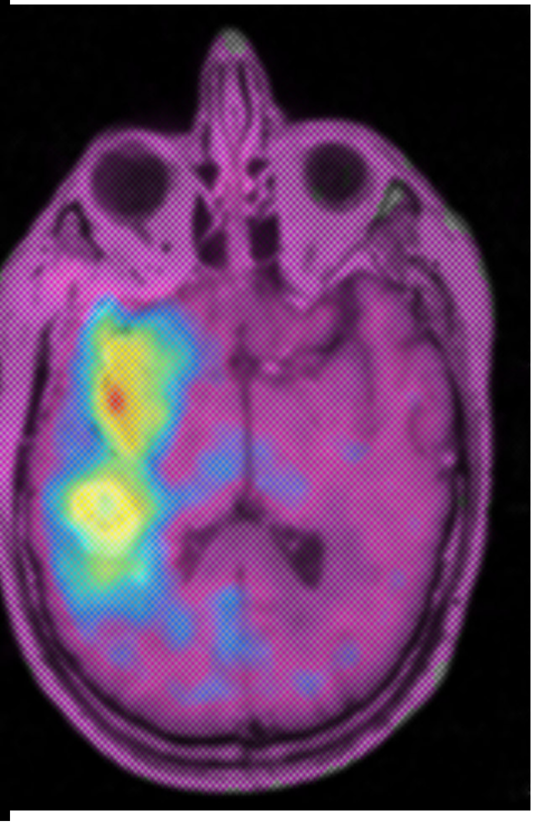
MRI (T1, Gd-DTPA)



methionine-PET



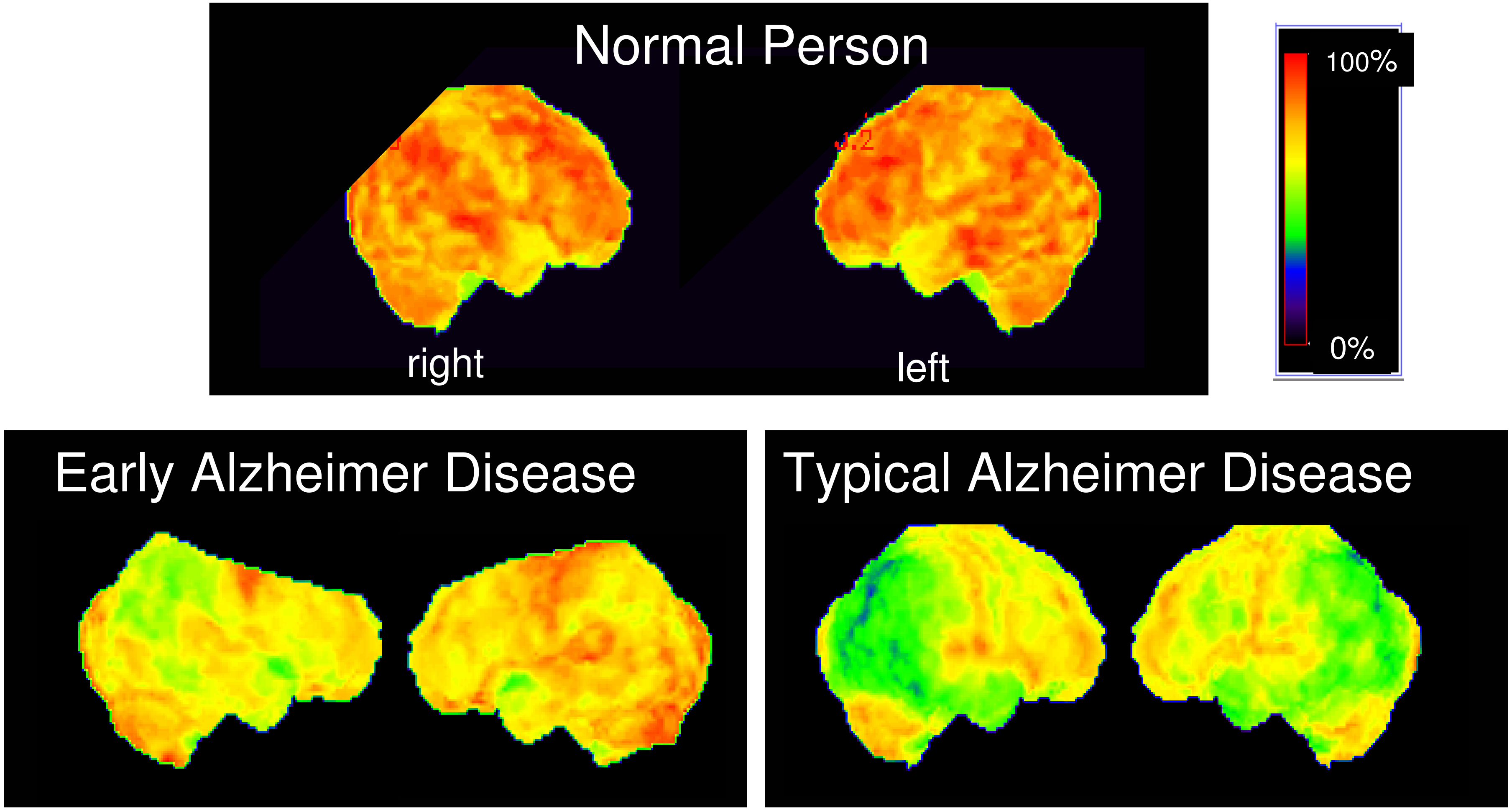
„image fusion“



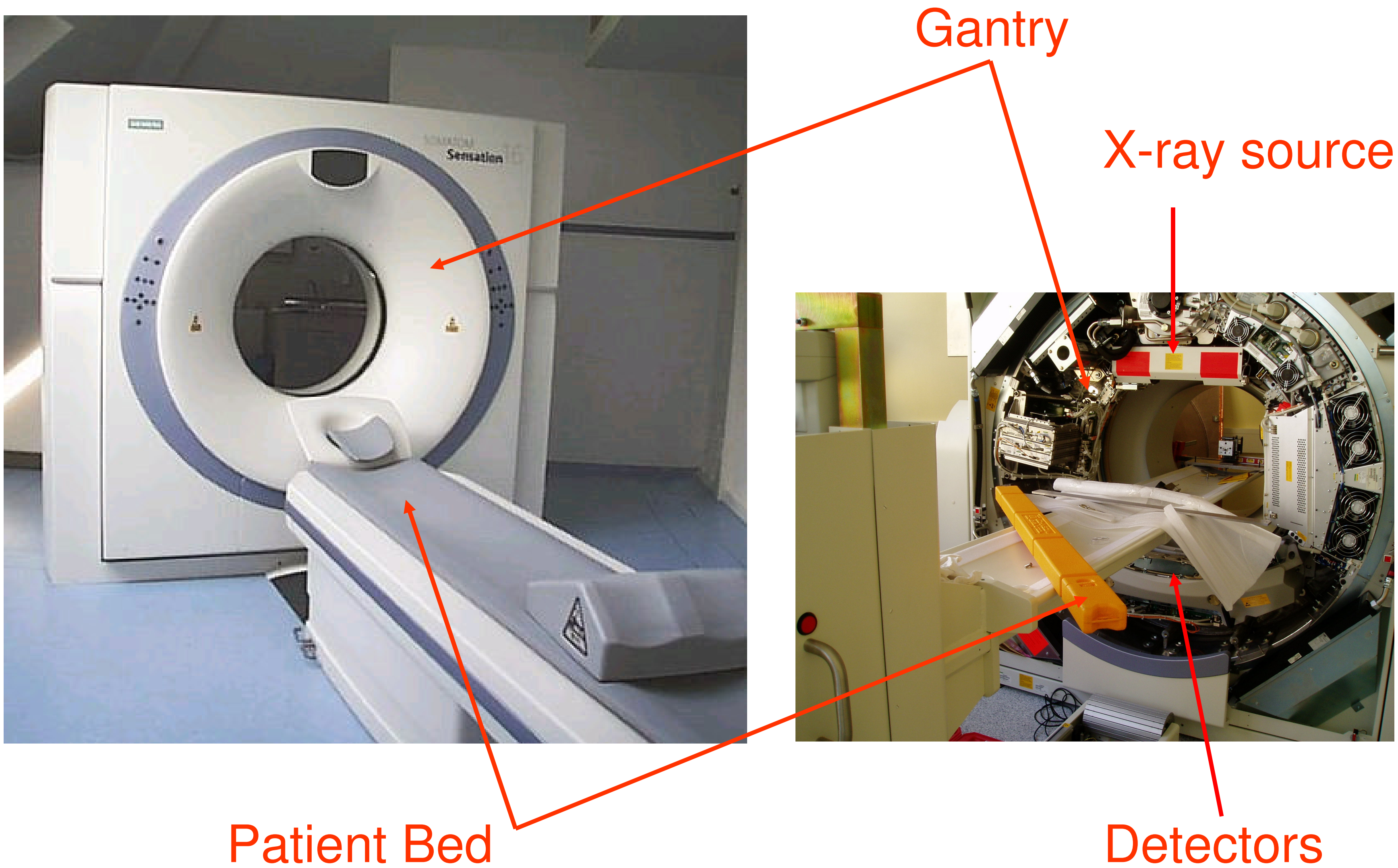
tumor volume: 4 ml

tumor volume: 72 ml

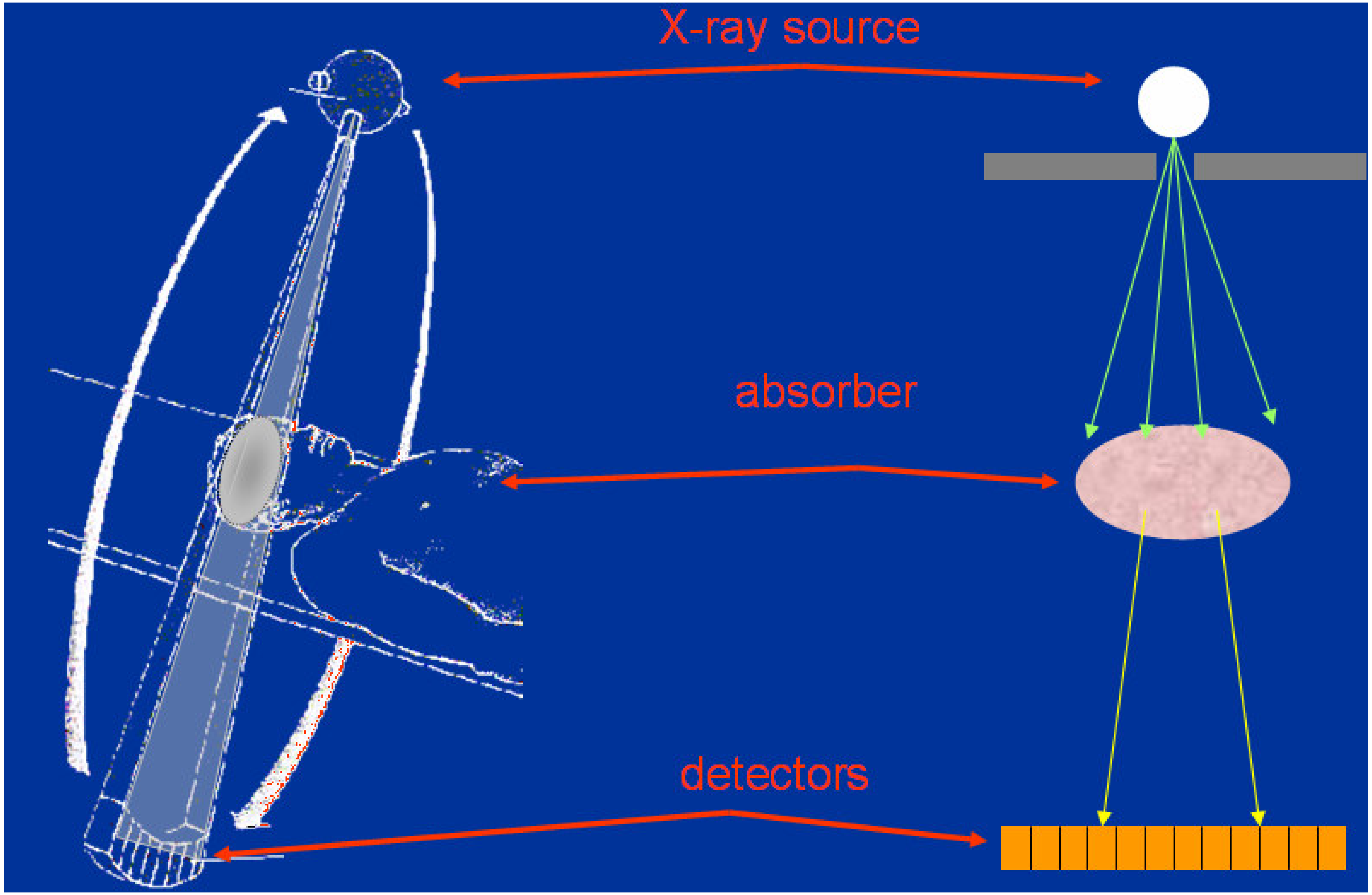
PET Clinical Applications
Glucose Metabolism in the Brain
Surface Projections



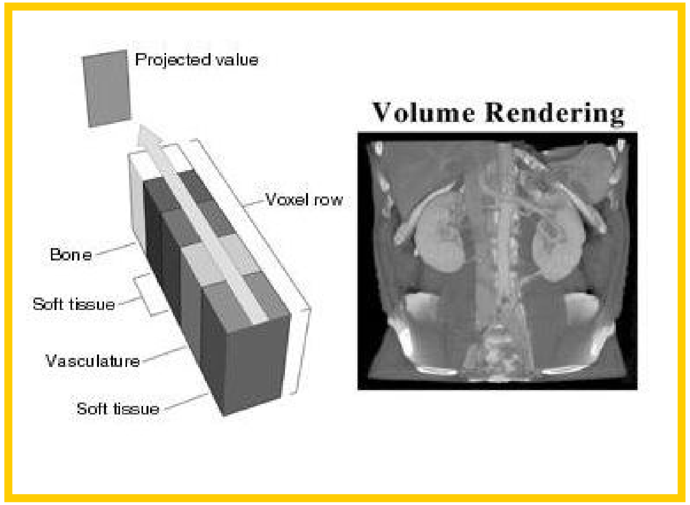
CT

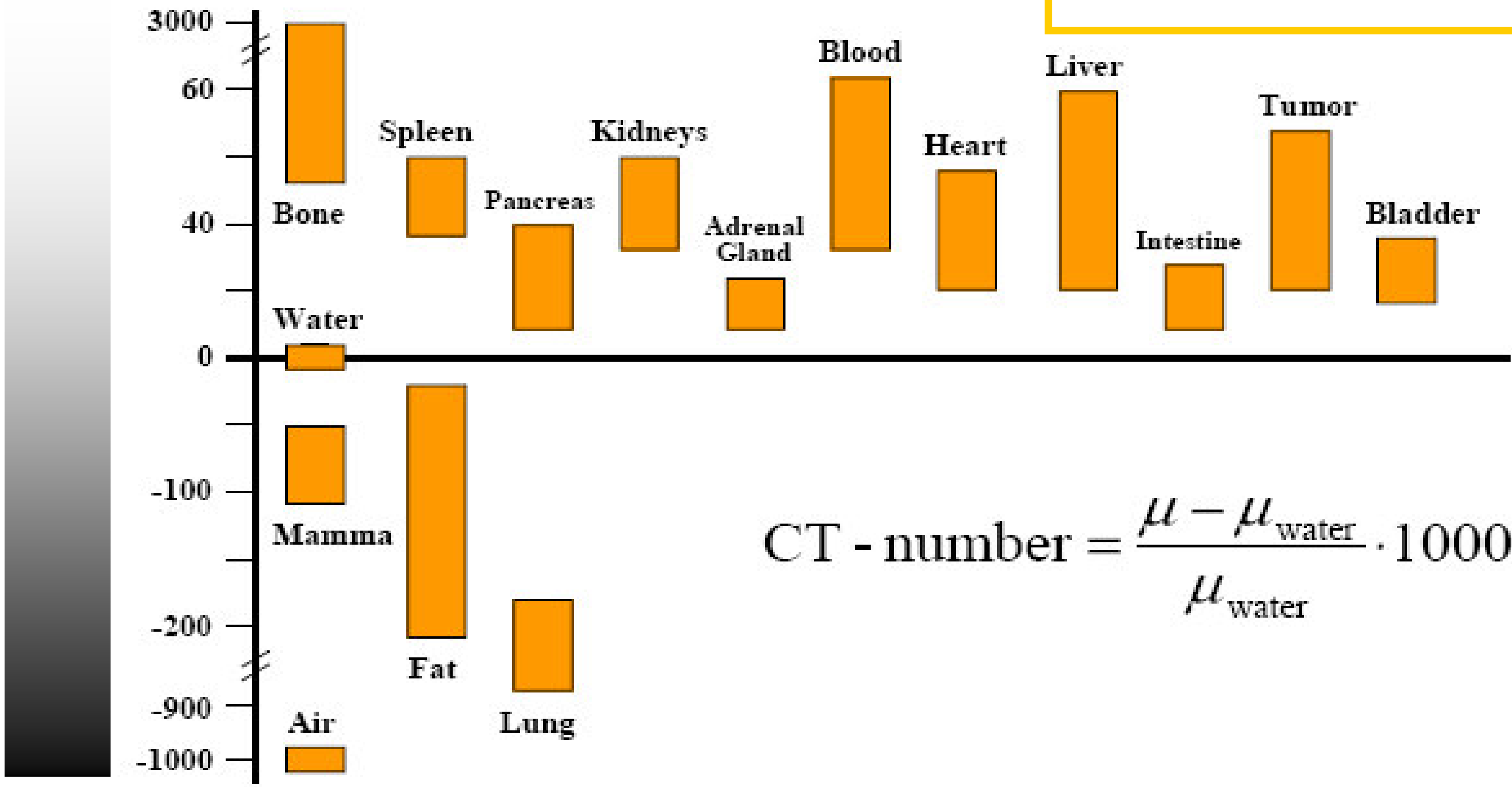


CT



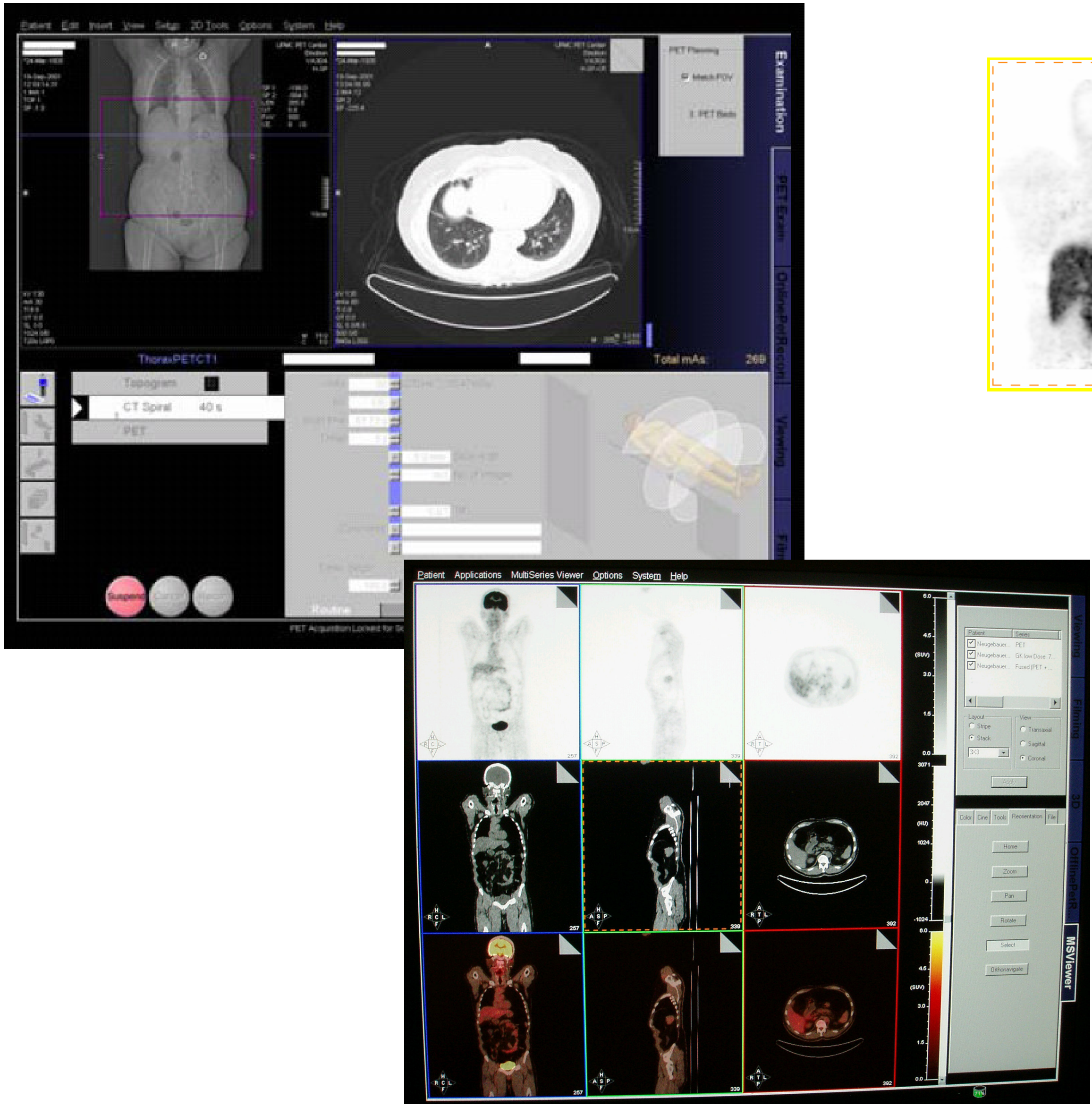
Hounsfield Scale





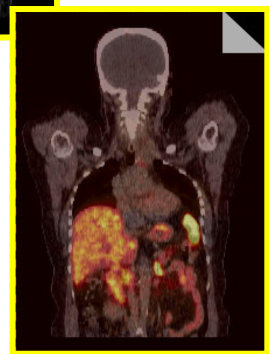
$$\text{CT - number} = \frac{\mu - \mu_{\text{water}}}{\mu_{\text{water}}} \cdot 1000$$

PET/CT



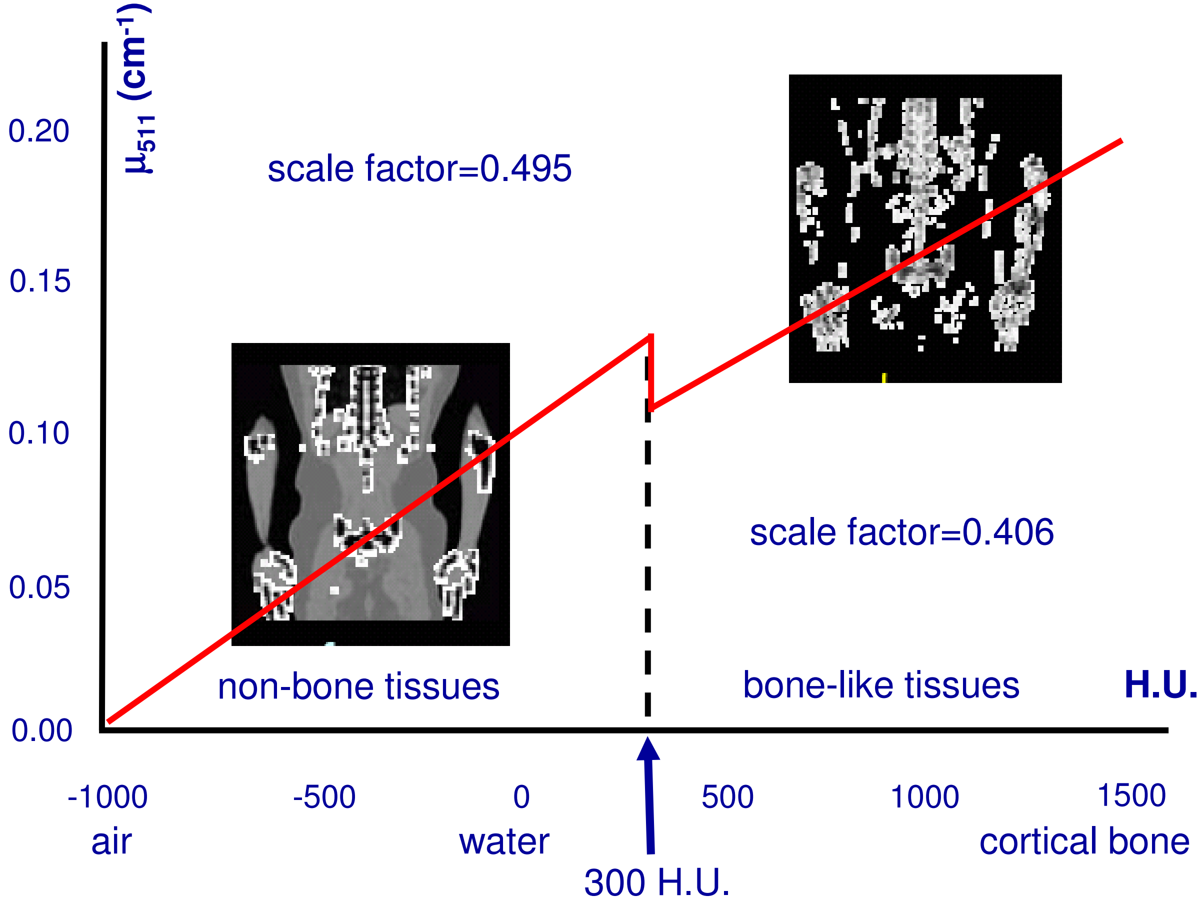
PET

CT



Fused Image

CT–based attenuation coefficients



Research at NMK in KRI

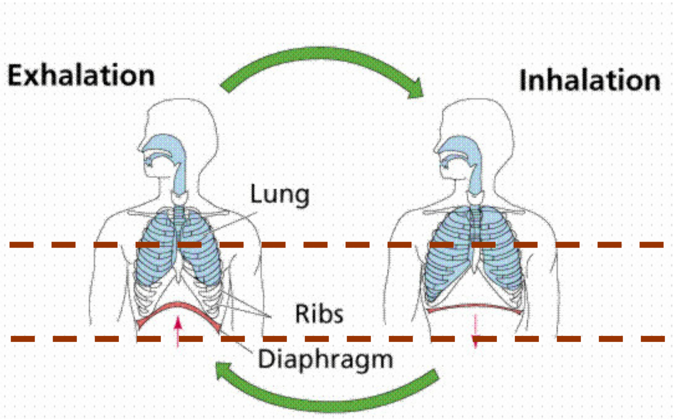
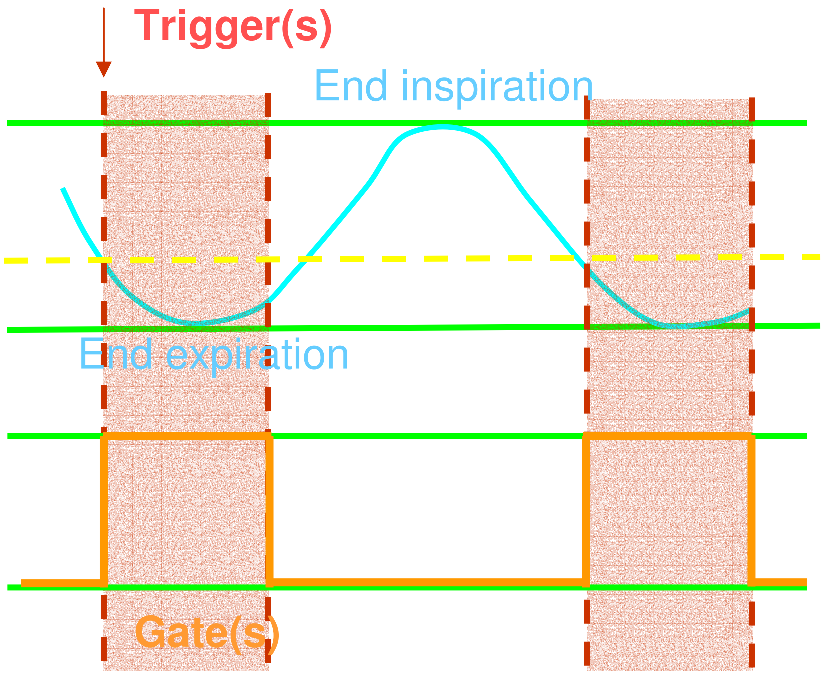
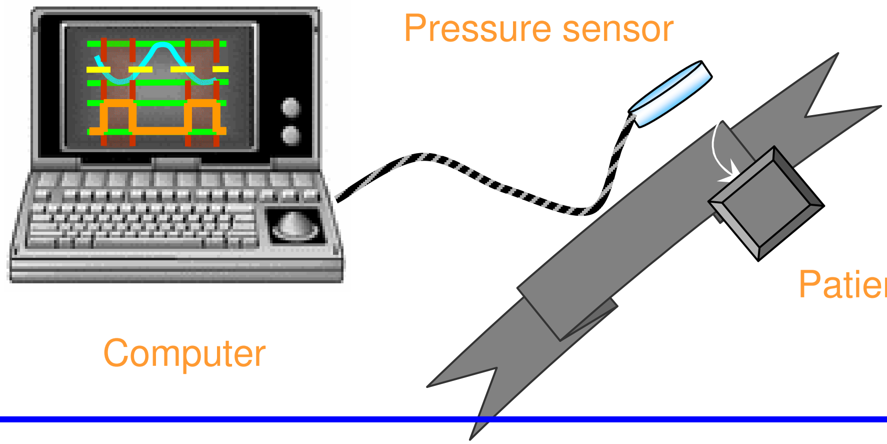


Image taken from http://www.jcu.edu/biology/RESP4.JPG



Respiratory gating system:



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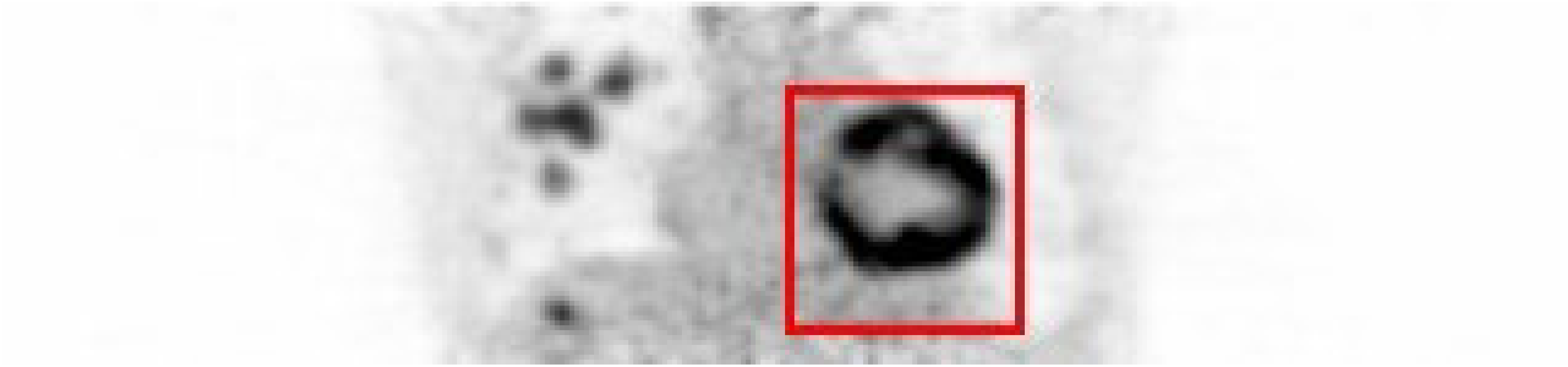
List Mode Acquisition

Respiratory Movement



… and the winner is…

Thanks to our Russian colleagues for the great time together

Thank you very much for your attention

Hey, there is some time left today and It‘s Tuesday …

let‘s go BOWLING!!!!!