Basic (physics) principles of quantification using PET

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Outline

1. Positron emission tomography
2. Principles of detection
3. Limiting factors
4. Corrections factors
5. Quantification and quality control

Outline

1. What is positron emission tomography

Introduction

Nuclear medicine uses radionuclides to

study / image the the fate of molecules in the body
damage cancerous tissue (radionuclide therapy)

Imaging is based on the tracer principle

a tracer is a substance that follows ('traces') a physiologic or biochemical process without disturbation

Principles – Radioactivity (1)

Radioactivity originates in a nuclear process caused by nuclear instability

For a sample with N radioactive atoms the average decay rate is given by

$\Delta N/\Delta t = -\lambda N \rightarrow N(t) = N(0)\, e^{-\lambda t}$

with λ the decay constant for the radionuclide

Units: A (Bq) = $| \Delta N/\Delta t | = \lambda N$

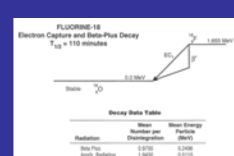
Imaging based on γ-rays (photons)

Principles – Radioactivity (2)

A positron is the antiparticle to an electron (same mass; opposite electric charge)

Positrons are emitted by radio nuclides having an excess of protons ($p \rightarrow n + e^{+} + \nu$)

Example: $^{18}F \rightarrow {}^{18}O + e^{+} + \nu$



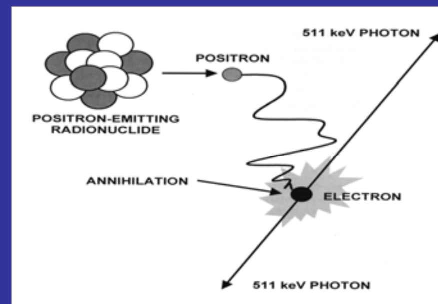
Principles – Difference with CT

Radionuclides are injected into a patient and distribute according to physiological / biological principle. Due to γ-ray production this process can be measured in-vivo (molecular imaging)

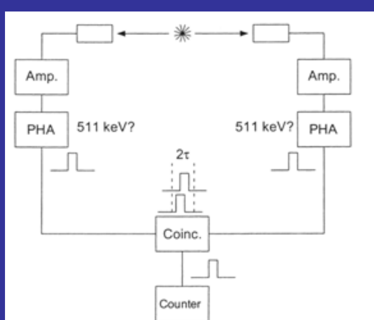
X-rays traverse tissues and can be absorbed (Lambert-Beer): degree of absorption is a measure for tissue density.

- Morphology
- Contrast based on tissue absorption characteristics

From positron to photon



Coincidence detection



Pulse Height Analyzer

6 – 12 nsec

Taken from PET, M.E. Phelps

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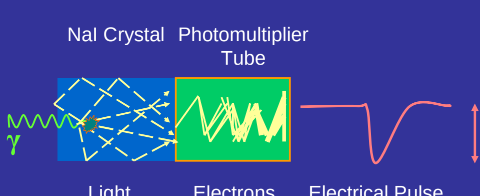
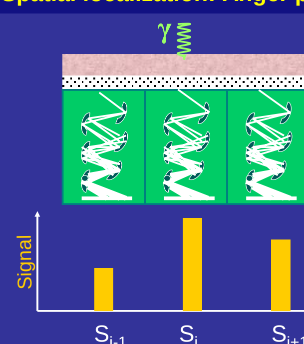
1. **What is positron emission tomography**
2. **Principles of detection**

Until now: PMT based detection

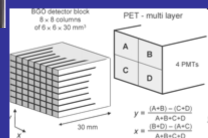


γ-Energy ~ Light ~ Pulse Height

Spatial localization: Anger principle



Block detector



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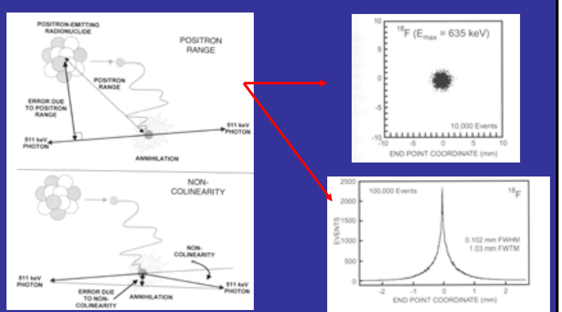
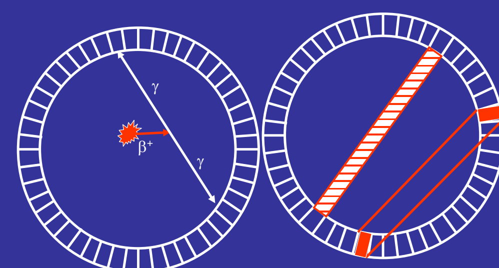
Limiting factors: positron emission



Taken from PET, M.E. Phelp

Parallax effect



Spatial resolution

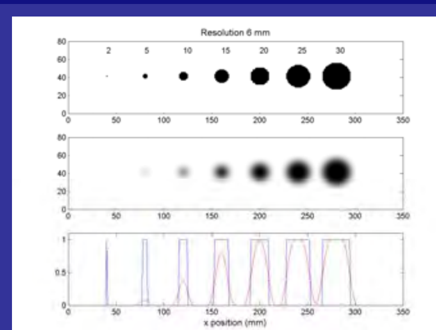
Is determined by:

- Positron energy
- Angle ≠ 180º
- Detector size
- Scanner diameter

^{18}F: 680 keV, 3 mm
^{15}O: 2 MeV, 1 cm

Clinical:	4.5 mm
HRRT:	2.5 mm
MicroPET:	1.5 mm

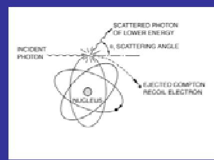
Partial volume effect



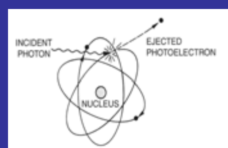
Photon interactions

Compton scattering:

en. loss accompanied by change of direction

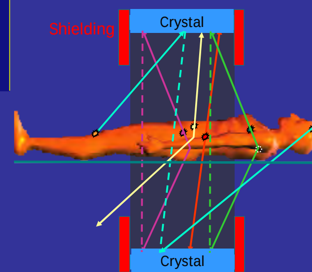


Photoelectric effect:
complete absorption



Pair production
(E > 1.022 MeV)

Prompt coincidences



True

Scattered within

Scattered outside

Random

Attenuation (white)

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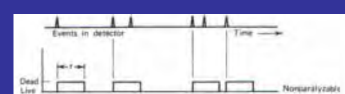
4. **Corrections factors**

Standard corrections on coincidence data

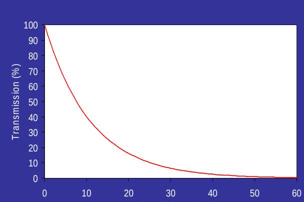
1. **Normalisation: normalized sensitivity of all LORs equal to 1**
2. **Attenuation**
3. **Scatter**
4. **Randoms**
5. **Deadtime**



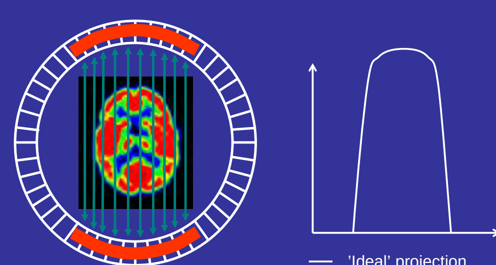
Magnitude of attenuation correction

Attenuation: how big is this problem?

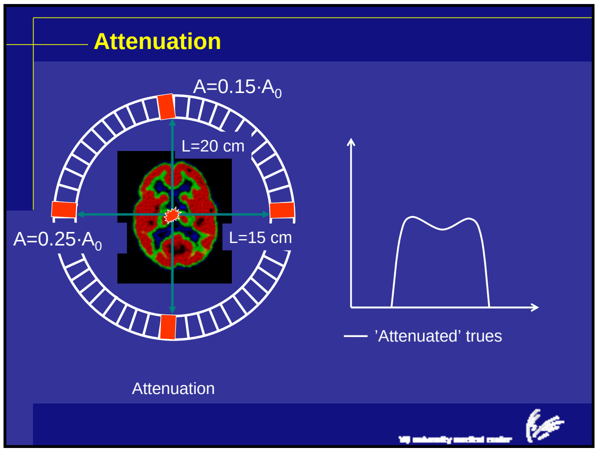
- 50 % of all 511 keV photons are attenuated within 7 cm
- in a 40 cm thick patient, only 2.6 % of all photon pairs starting in a certain LOR reach the detectors unattenuated

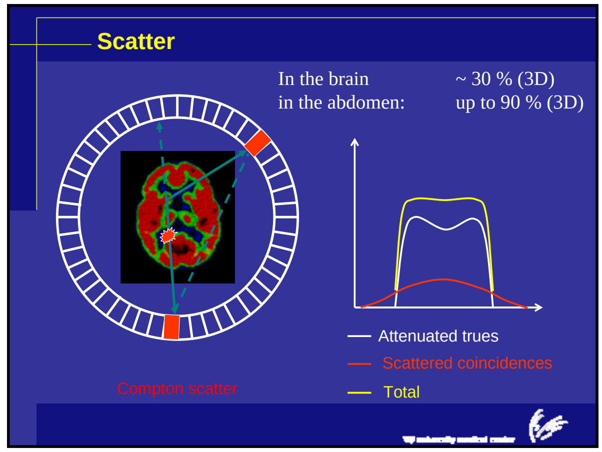


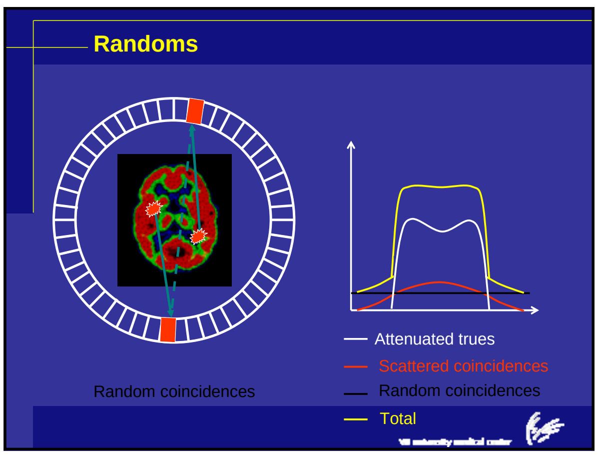
Attenuation

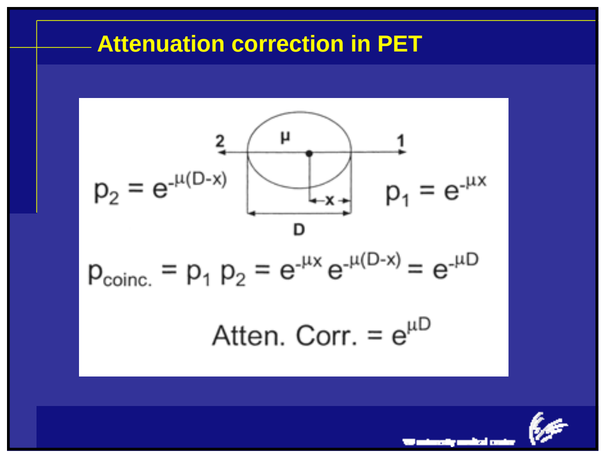


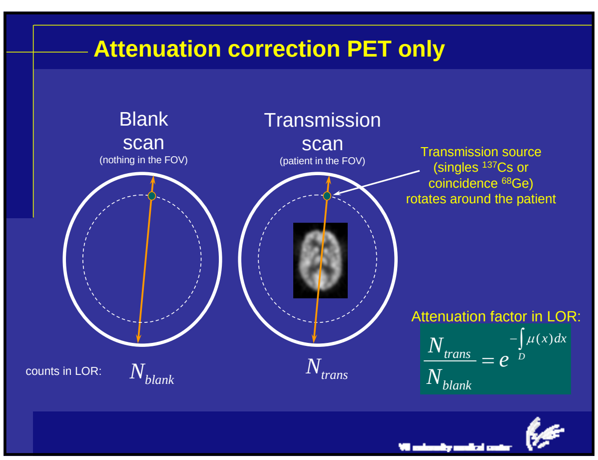
Parallel projections

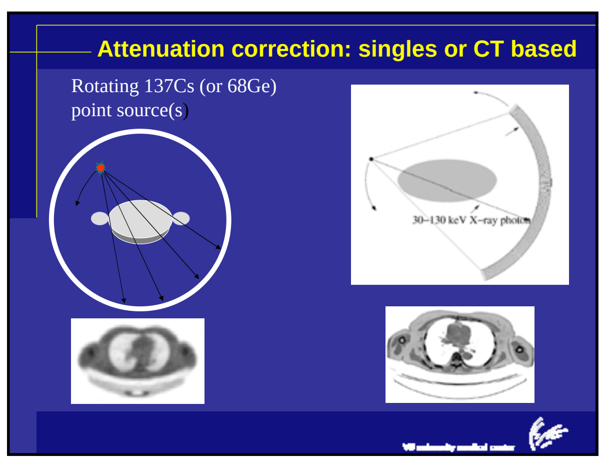

Attenuation
A=0.15·A0
L=20 cm
A=0.25·A0
L=15 cm
'Attenuated' trues
Attenuation


Scatter
In the brain
in the abdomen:
~ 30 % (3D)
up to 90 % (3D)
Attenuated trues
Scattered coincidences
Total
Compton scatter

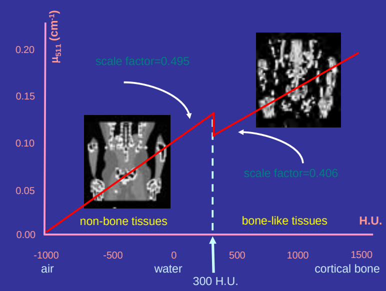

Randoms
Attenuated trues
Scattered coincidences
Random coincidences
Total
Random coincidences


Attenuation correction in PET
2
μ
1
p2 = e-μ(D-x)
x
p1 = e-μx
D
pcoinc. = p1 p2 = e-μx e-μ(D-x) = e-μD
Atten. Corr. = eμD

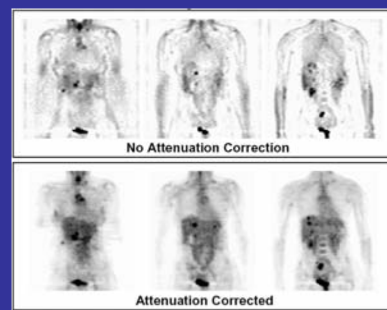

Attenuation correction PET only
Blank
scan
(nothing in the FOV)
Transmission
scan
(patient in the FOV)
Transmission source
(singles 137Cs or
coincidence 68Ge)
rotates around the patient
Attenuation factor in LOR:
counts in LOR:
N blank
N trans


Attenuation correction: singles or CT based
Rotating 137Cs (or 68Ge)
point source(s)
30–130 keV X-ray photons

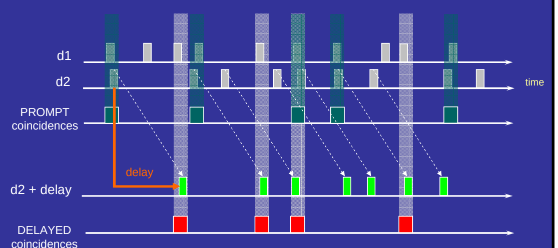
CT based attenuation correction



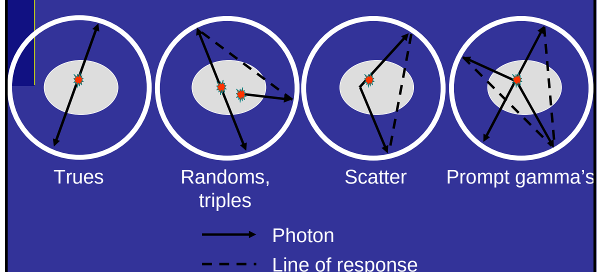
Is the image attenuation corrected?



Randoms estimate: delayed coincide window



Which type of coincidences are detected



Standard corrections on coincidence data

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Levels of quantification

Diagnostic images; Bq/ml

Semi-quantitative: SUV

tracer kinetic model

Harmonization of scan / reconprotocols

- **Correction for weight of patient and injected dose converts images in Bq/ml to SUV**
- **Necessary for response studies**
- **Reproducibility? NEDPAS initiative**
  - Cross calibration of activity concentration between dose calibrator and PET scanner
  - Recovery coefficients to correct for the partial volume effect within a limited range