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Nuclear medicine

Week 2; Lecture 5; Section 2: PET system resolution

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Section 2

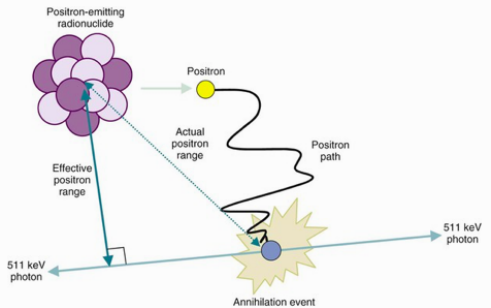
PET: system resolution

Factors that determine system resolution

Intrinsic resolution of PET system degraded by:

- Fundamental physics:
  - Non-zero range of positron as it slows down prior to annihilation
  - Residual momentum of positron at annihilation results in non-colinear photons
- Reconstruction:
  - Depth-of-interaction effect
  - Sampling effect
  - Filter effect

Fundamental physics: positron range



		Extrapolated Range (cm) in			Average Range (cm) in
Radionuclide	E_β^{max} (MeV)	Air	Water	Aluminum	Water
^{3}H	0.0186	4.5	0.00059	0.00022	—
^{11}C	0.961	302	0.39	0.145	0.103
^{14}C†	0.156	21.9	0.028	0.011	0.013
^{13}N	1.19	395	0.51	0.189	0.132
^{15}O	1.723	617	0.80	0.295	0.201
^{18}F	0.635	176	0.23	0.084	0.064
^{32}P	1.70	607	0.785	0.290	0.198
^{82}Rb	3.35	1280	1.65	0.612	0.429

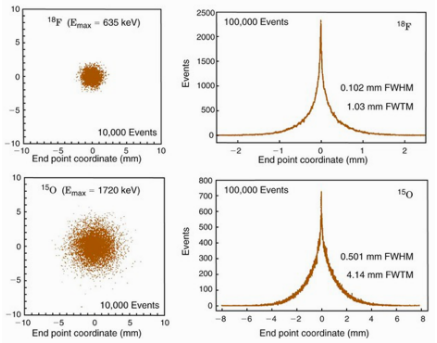
Effective range depends on:

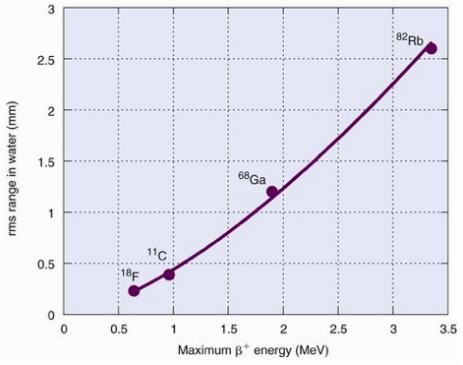
- $E_{\max}$
- Material, i.e. tissue

For relevant PET isotopes:

- $E_{\max}$ in range 0.5–1.8 MeV
- Results in e^+ range in range 2–8 mm

Fundamental physics: positron range





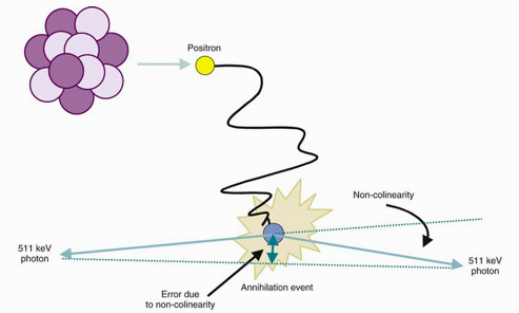
End-point coordinate distribution falls exponentially; certainly not Gaussian!

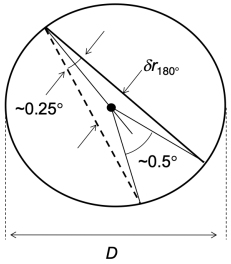
RMS of the effective range distribution used: FWHM: R_{range}; resolution: σ_{range}

Resolution improves as $E_{\max}$ falls

- ^{18}F gives improved resolution over other commonly used isotopes

Fundamental physics: non-colinearity





Non-colinearity angular distribution:

- Sufficiently Gaussian, use FWHM
- FWHM approximately 0.5°

Geometrically:

$$R_{180} = \frac{D}{2} \times 0.25 \frac{\pi}{180} = 0.0022 \times D$$

and so resolution is $\sigma_{180} = \frac{R_{180}}{2}$

System resolution

System resolution, taken to be the resolution of the hardware, may now be evaluated:

- In terms of FWHM:

$$R_{\text{sys}} = \sqrt{R_{\text{int}}^2 + R_{\text{range}}^2 + R_{180}^2}$$

- In terms of resolution:

$$\sigma_{\text{sys}} = \sqrt{\sigma_{\text{int}}^2 + \sigma_{\text{range}}^2 + \sigma_{180}^2}$$

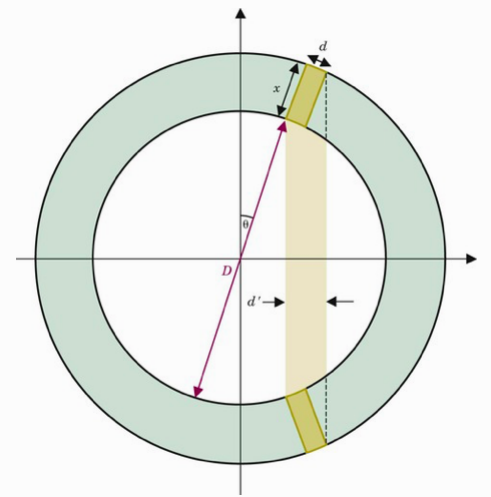
Example: clinical PET scanner:

- 5 mm scintillator: $R_{\text{int}} = 2.5\,\text{mm}$
- ^{18}F-labelled tracer: $R_{\text{range}} = 0.6\,\text{mm}$
- 800 mm diameter scanner: $R_{180} = 1.8\,\text{mm}$

Yields:

- $R_{\text{sys}} = 3.1\,\text{mm}$

Reconstruction: depth-of-interaction (DOI) effect



Thickness of scintillator used to stop 511 keV γ introduces a reconstruction uncertainty

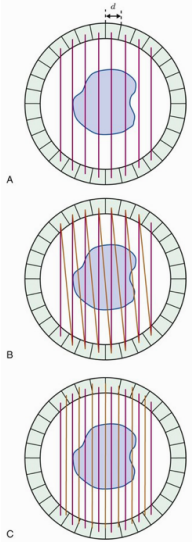
For the case sketched, the apparent width of the detector, d', is given by:

$$d' = d\cos\theta + x\sin\theta$$

Can now use d' in the formulæ for, e.g., R_{int}

In a typical system, the DOI effect causes a degradation of $\sim 40\%$ in the resolution at a distance of 100 mm from the centre

Reconstruction: sampling effect



The intrinsic resolution is determined by the detector size, d

A) Sampling "frequency" determined by spacing, also d
Limits minimum feature size that can be resolved

B) Record neighbouring coincidences
Improved sampling; can reduce minimum feature size

c) Treat "neighbouring coincidences" (B) as additional samples
Implementation leads to improvement in detail in image

Reconstruction: filter effect

Image reconstruction exploits techniques such as filtered back projection

Filters are used to suppress noise, but, removing frequencies from the Fourier transform of the image can also remove detail from the image

Image-processing strategies need to be tailored to the situation, e.g. brain scans may require different strategies to abdominal scans

Summary of section 2

Overall resolution of PET system determined by:

- "Physics":
  - Positron range;
  - Positron momentum at annihilation $\Rightarrow$ photon non-colinearity
- "Reconstruction":
  - Depth-of-interaction (DOI) effect;
  - Sampling effect
  - Filter effect