Advances in PET technology

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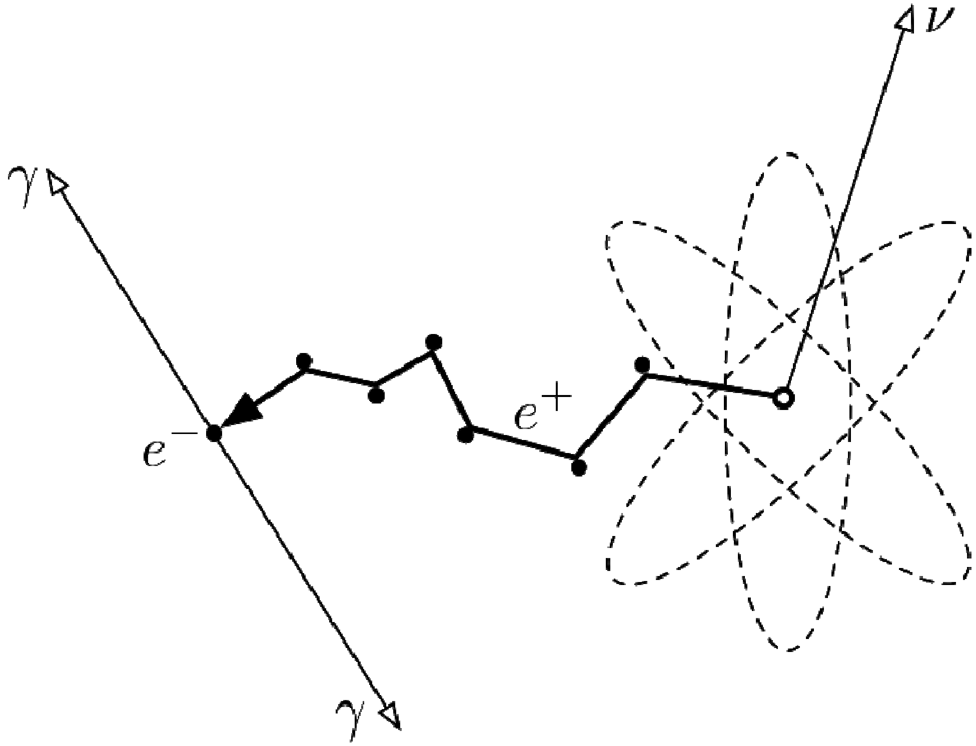
Outline

- Introduction
- Detectors
- Time-of-flight PET
- PET / MRI
- Conclusions

Introduction



- Fluor-18; FDG

- β^+ decay

  $p \rightarrow n + e^+ + \nu$

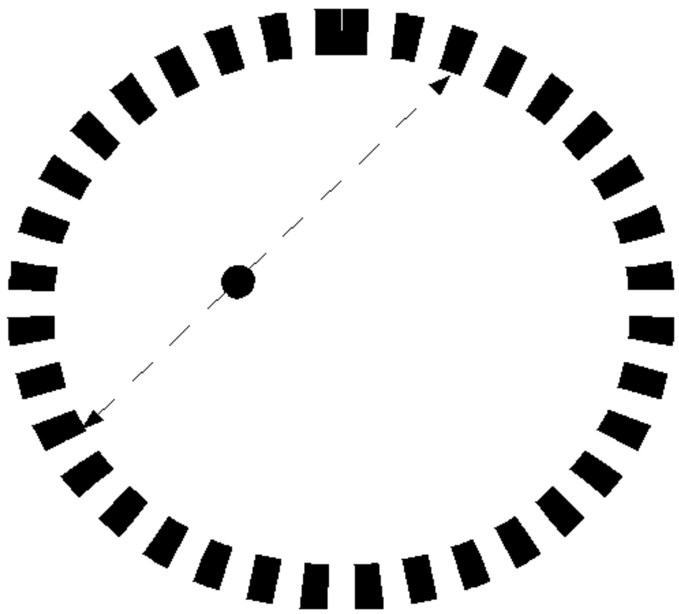
- Annihilation

Introduction

- Coincidence detection

- True coincidence
  - Photons sent out back-to-back
  - Photons don't interact in tissue
  - Photons detected in photopeak
  - Correct LOR determined

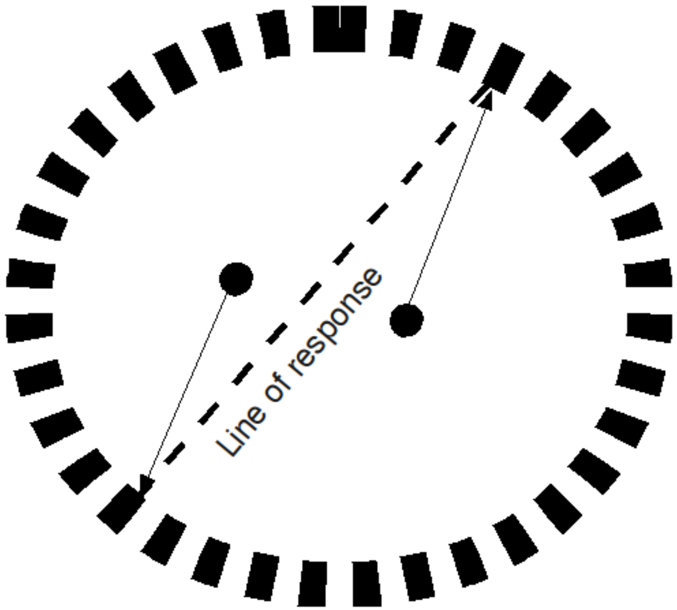
True coincidence



Introduction

- Random coincidence
  - Photons from different annihilations are detected within the timing window
  - False LOR determined

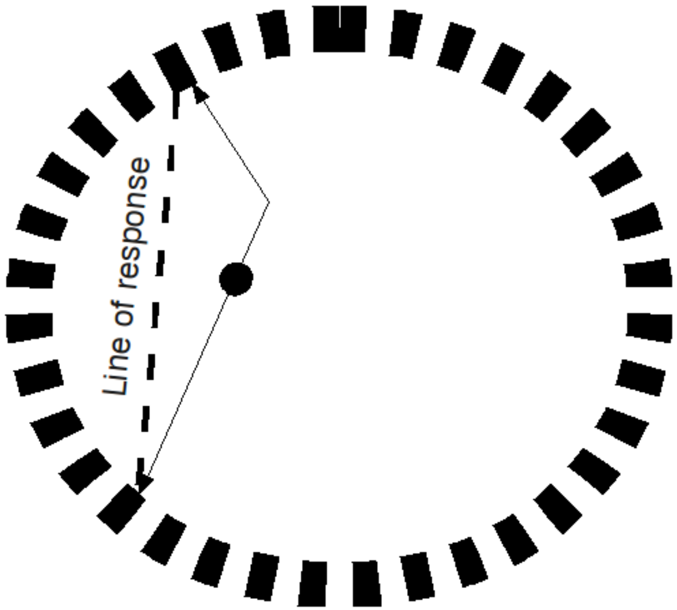
Random coincidence



Introduction

- Scattered coincidence
  - One or both of the photons are Compton scattered in the tissue
  - False LOR determined

Scattered coincidence



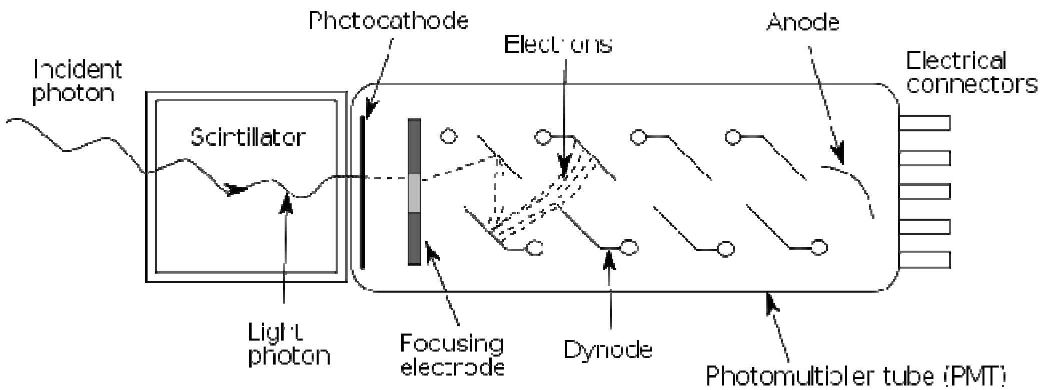
Detectors

Detectors: Scintillation crystals

- Scintillation crystals
  - BGO, LSO, LYSO, LuAP
- Absorbs energy from 511 keV photons
- Emits photons with energy corresponding to visible light
- Coupled to photomultipliers
- Important parameters:
  - Stopping efficiency for 511 keV photons
  - Light output
  - Decay time

Detectors: PMT

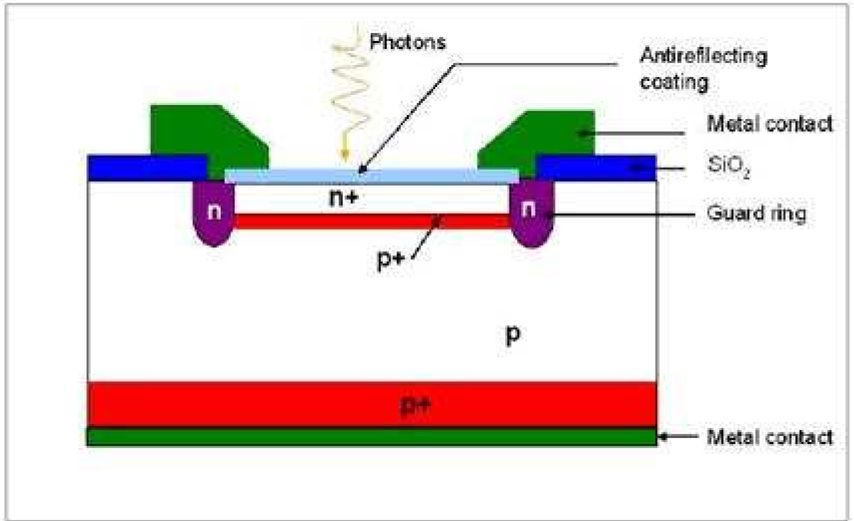
- Traditionally, PhotoMultiplier Tubes (PMTs) have been used for PET
- Well-known technology, high gain, good SNR
- Large, affected by magnetic fields



http://en.wikipedia.org/wiki/File:Photomultipliertube.svg

Detectors: APD

- Avalanche PhotoDiodes is a semiconductor detector
- Compact, insensitive to magnetic fields
- Less gain, sensitive to changes in temperature and bias voltage

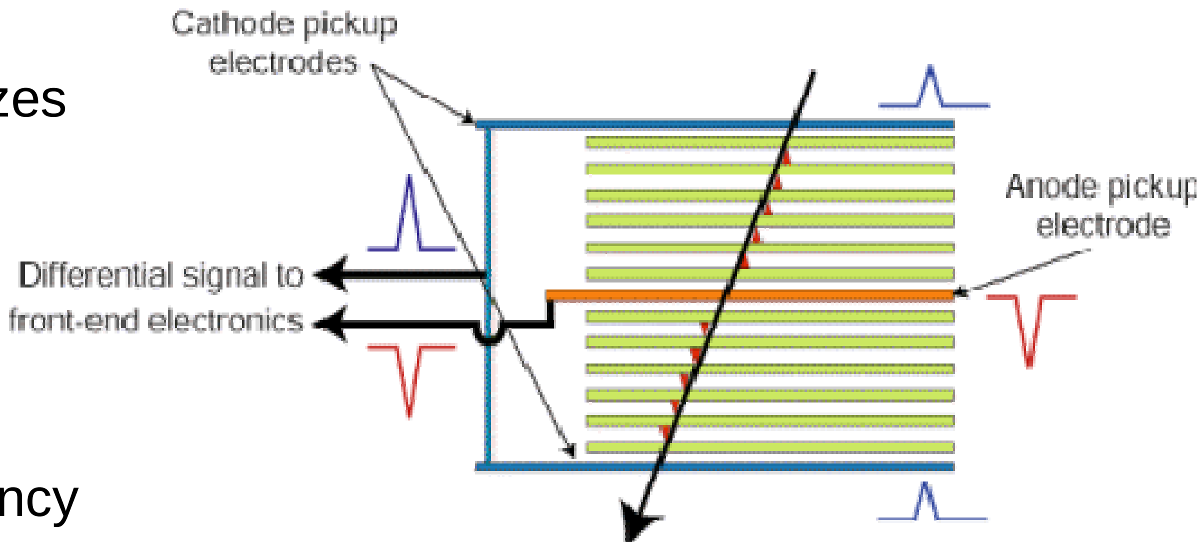


https://wikihost.uib.no/ift/index.php/File:MAPD_structure.jpg

Detectors: RPC

- RPC = Resistive Plate Chambers
- Gas detector with gas and glass in layers

- Incoming photon ionizes the gas
- High voltage creates an avalanche of electrons
- Several layers gives good detection efficiency
- Thin layers gives better timing properties

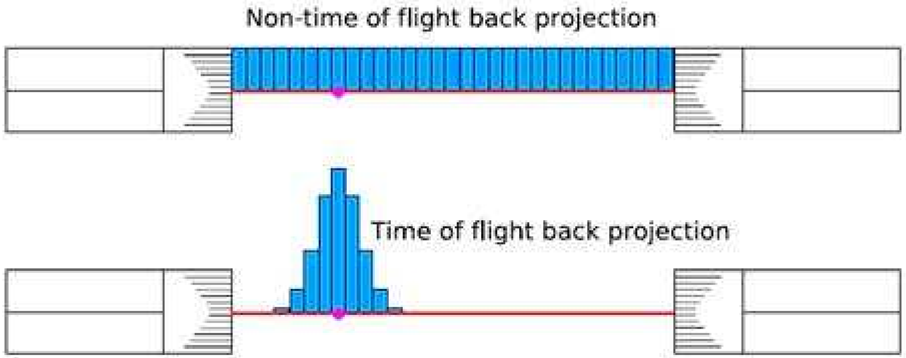


http://aliceinfo.cern.ch/Public/en/Chapter2/Chap2_TOF.html

Time-of-flight

Time-of-flight

- In conventional PET, the annihilation may have taken place anywhere along the LOR
- In TOF-PET, the time difference between to coincident photons is used to determine where along the LOR the annihilation took place



https://wikihost.uib.no/ift/index.php/PET_Project

$$\Delta t = 2\,\Delta d / c$$

Δt – time difference between photons

Δd – distance from center of the LOR

c – speed of light

Time-of-flight [1–2]

- TOF-PET was developed in the 1980's
- Problems with crystal properties
  - Ligth output vs. decay time
- New crystals
  - LSO, LYSO, LuAP, $LaBr_3$
- Philips TruFlight TOF-PET
  - First commercial TOF PET scanner
  - Timing resolution: 585 ps (low activity)
  - Timing resolution : 650-700 ps (clinical activity)

Time-of-flight [1]

$$\mathrm{SNR}_{\mathrm{TOF}} = \sqrt{\frac{D}{\Delta x}}\,\mathrm{SNR}_{\mathrm{nonTOF}} \qquad (1)$$

$$\mathrm{NEC} = \frac{T^2}{T + R + S}$$

$$\mathrm{NEC}_{\mathrm{TOF}} = \frac{D}{\Delta x}\,\mathrm{NEC}_{\mathrm{nonTOF}} \qquad (2)$$

Time-of-flight [2]

Sensitivity gain*

Patient size D [cm]	Time resolution Δt [ps]		
	300	600	1000
20	4.4	2.2	1.3
27	6.0	3.0	1.8
35	7.8	3.9	2.3

*Gain in sensitivity calculated by equation (2)

Time-of-flight [1]

TOF NEC Gain for different timing resolutions and patient diameters

Δt [ps]	Δx [cm]	TOF NEC Gain (10 cm diameter)	TOF NEC Gain (40 cm diameter)
100	1.5	6.7	26.7
300	4.5	2.2	8.9
500	7.5	1.3	5.3
1000	15.0	0.7	2.7

RPC detectors til TOF-PET [3–5]

- Very cost-effective
- Very good timing resolution
  - < 300 ps
- High sensitivity
  - Possibly more than 20 times better sensitivity than today's crystal based technology
- Very good spatial resolution
  - 0.52 mm FWHM with filtered backprojection
  - 0.31 mm FWHM with ML-EM algorithm

PET / MRI

PET / MRI – Challenges [1]

- Available space
- PMTs sensitive to magnetic fields
- Homogeneous main magnetic field (B_0)
- Uniform RF pulse
- Eddy currents
- RF noise from detector electronics
- Mechanical vibrations

PET / MRI – different solutions

Long optical fibres from the scintillation crystals to PMTs outside the magnetic field [2–4]

- Original solution
- Still under development

Advantages

- Well-known detector technology
- Little disturbance between the two modalities

Disadvantages

- Poor energy resolution
- Poor timing resolution
- Space demanding

PET / MRI – different solutions

APDs coupled directly to the scintillation crystals [1, 5]

- APDs are insensitive to magnetic fields
- APDs are small / compact

Advantages

- Field-of-view
- Good energy resolution
- Good timing resolution
- Not space demanding

Disadvantages

- Disturbances
- Poor SNR due to shielding

PET / MRI – different solutions

Short optical fibres from the scintillation crystals to APDs outside the MR FOV [1, 6, 7]

<u>Advantages</u>

- Less disturbance
- Good resolution

<u>Disadvantages</u>

- More complex
- Limited FOV for PET
- Space demanding

PET / MRI – different solutions

Split magnet with optical fibres [8-10]

Advantages

- PMTs can be used
- Many detector elements possible

Disadvantages

- Custom-built magnet
- Only for weak magnetic fields (~1 T)

Optical fibres are used, but these are only ~1 meter long, and take up little space inside the MR bore

PET / MRI – different solutions

Field-cycled MRI [1, 11]

Advantages

- PMTs can be used
- Interesting image contrast has been shown

Disadvantages

- Only weak magnetic fields
- Dead time for PET detector

Conclusions: TOF PET

- Crystal based technology
  - Well-known
  - Demands fast crystals
  - Crystals are expensive

- RPC detectors
  - New technology (for PET purposes)
  - Several interesting properties

Conclusions: PET / MRI

- PMTs
  - The magnetic field sensitivity leads to new solutions
- APDs
  - Represents a more traditional approach to PET – with new detectors
  - More ’difficult’ than PMTs
  - Works well with magnetic fields
- Split magnet and field-cycled MR
  - Different approach

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TOF-PET

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