Nuclear Imaging I (SPECT)

RT4220 – LECTURE #12

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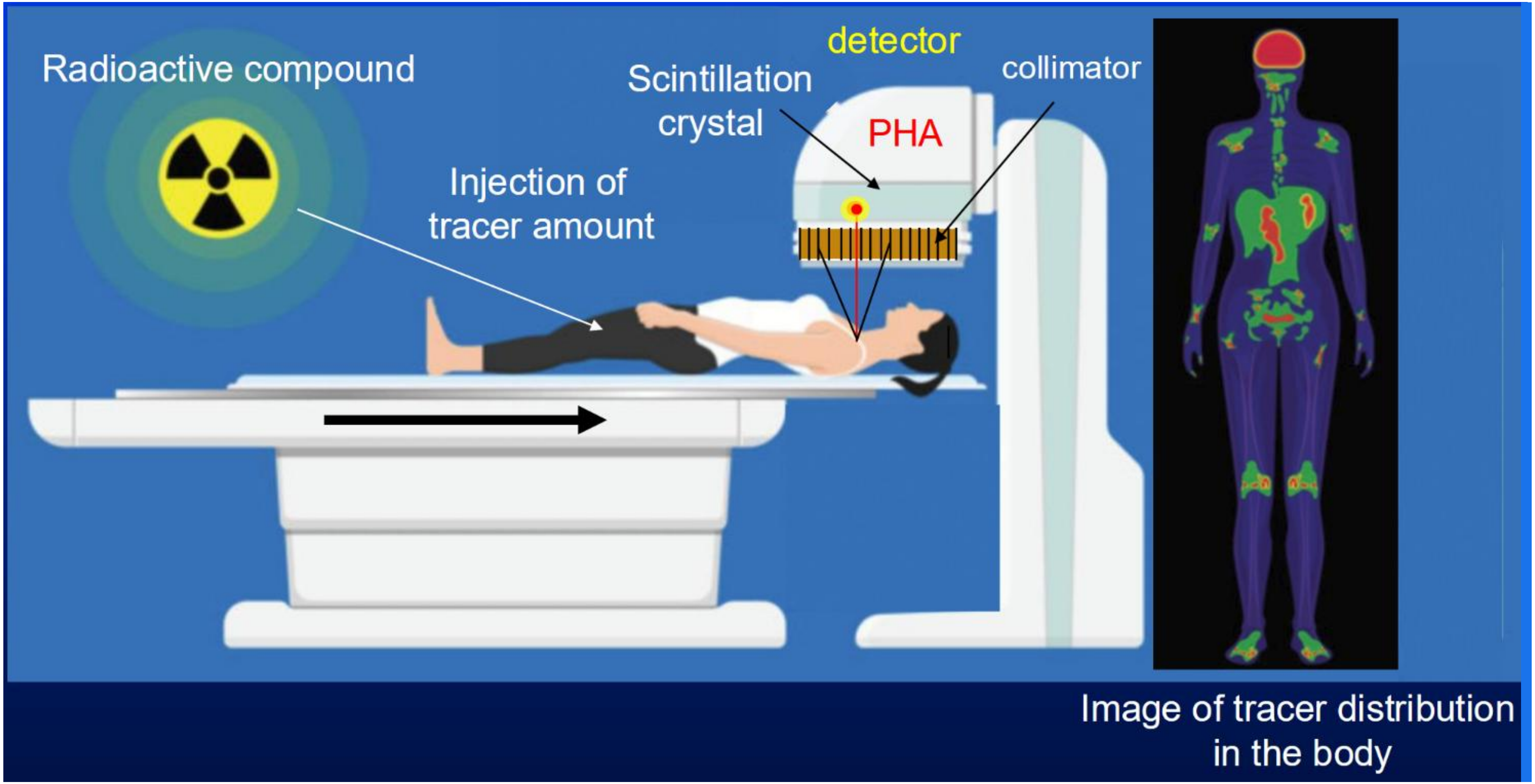
WSU

10/27/2025

Basics of Nuclear Medicine

- Patient presents with a disease → suspected disease can be imaged with a particular radioactive tracer → radioactive tracer is injected → <u>an image is formed of the disease by a machine</u>
- The underlined section is the only difference between **gamma cameras**, single photon emission computed tomography (SPECT), positron emission tomography (PET), and now Compton cameras
- All nuclear medicine detectors are either scintillator or semiconductor based
- Nuclear imaging **permits functional imaging**, exceptionally important!



Radioactive compound
Injection of
tracer amount
Scintillation
crystal
detector
PHA
collimator
Image of tracer distribution
in the body

Modes of Nuclear Imaging I

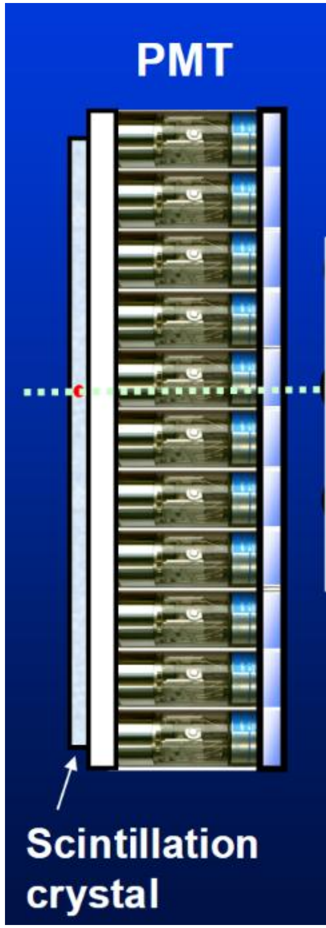
- Gamma Camera
  - **Planar images via projections**
  - Typically scintillators and PMTs
  - Physical collimation
  - Uses low-energy photon emitters
- SPECT
  - **Tomographic imaging (3D) via step-and-shoot planar images**
  - Typically scintillators and PMTs
  - Physical collimation
  - Uses low-energy photon emitters

Modes of Nuclear Imaging II

- PET
  - Intrinsically tomographic data (3D)
  - Typically scintillators, but moving towards semiconductors
  - Electronic collimation
  - Uses positron emitters (high-energy photons)
  - Generally better spatial resolution and sensitivity than SPECT
  - Functional imaging

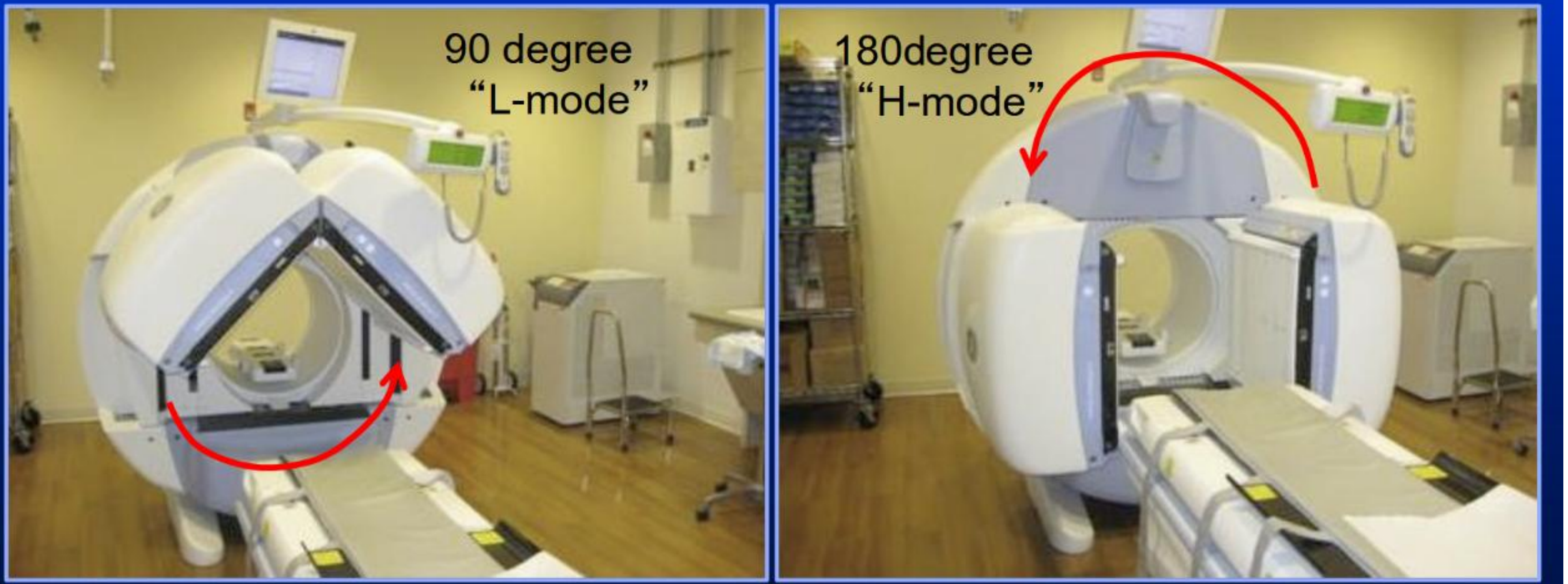
Gamma Camera Basics

1. Injection
2. Gamma photons generated by beta- emitter or Tc-99m
3. Photons leave patient and pass through collimator
4. Remaining photons are scintillated (each keV produces roughly 38 low energy photons in the visible band for NaI(Tl))
5. PMT converts scintillated photons into electronic signal
6. A pulse height analyzer rejects suspected non-valid events
7. A position logic circuit determines the origin location of each signal, now it is counted!
8. Many counts are summed together to form a planar image



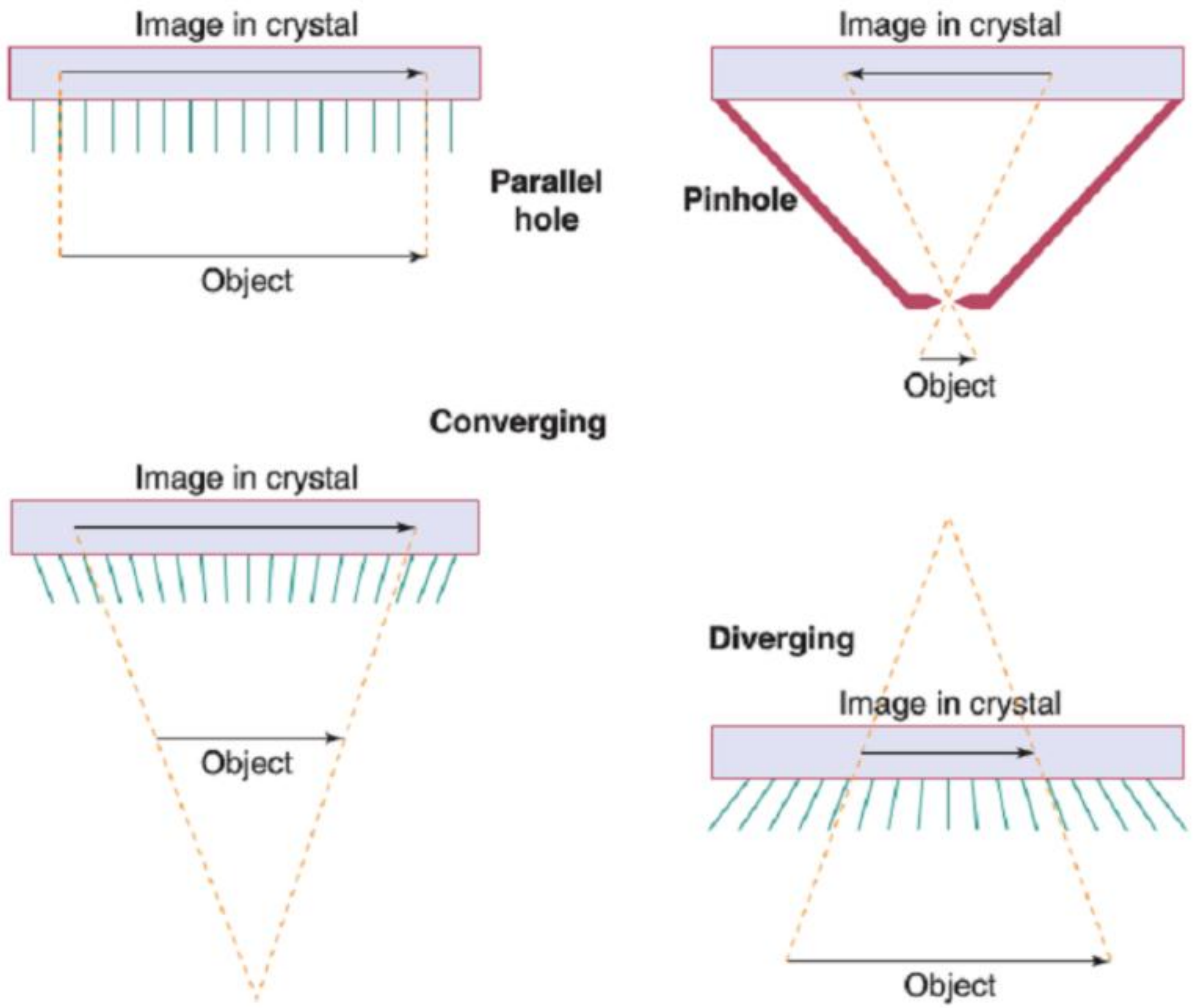
TOMOGRAPHIC IMAGING
SPECT (SPECT/CT)

- **Acquisition of multiple planar images in a step-and-shoot fashion from various angles around the patient allows 3D image recon → 64 projections 10-20s each for 180 arc (128 projections for 360 arc)**

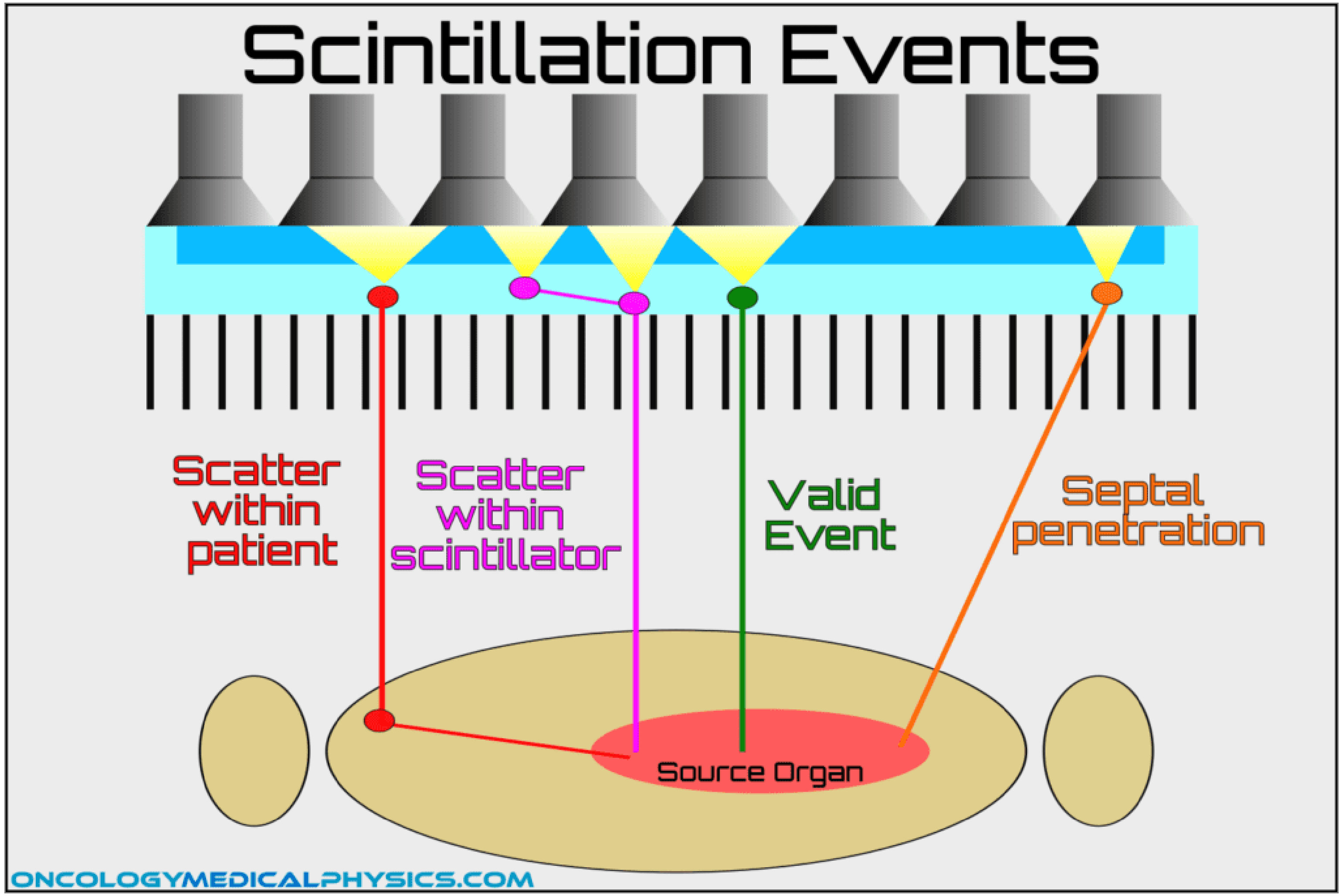


Step Three: Collimation

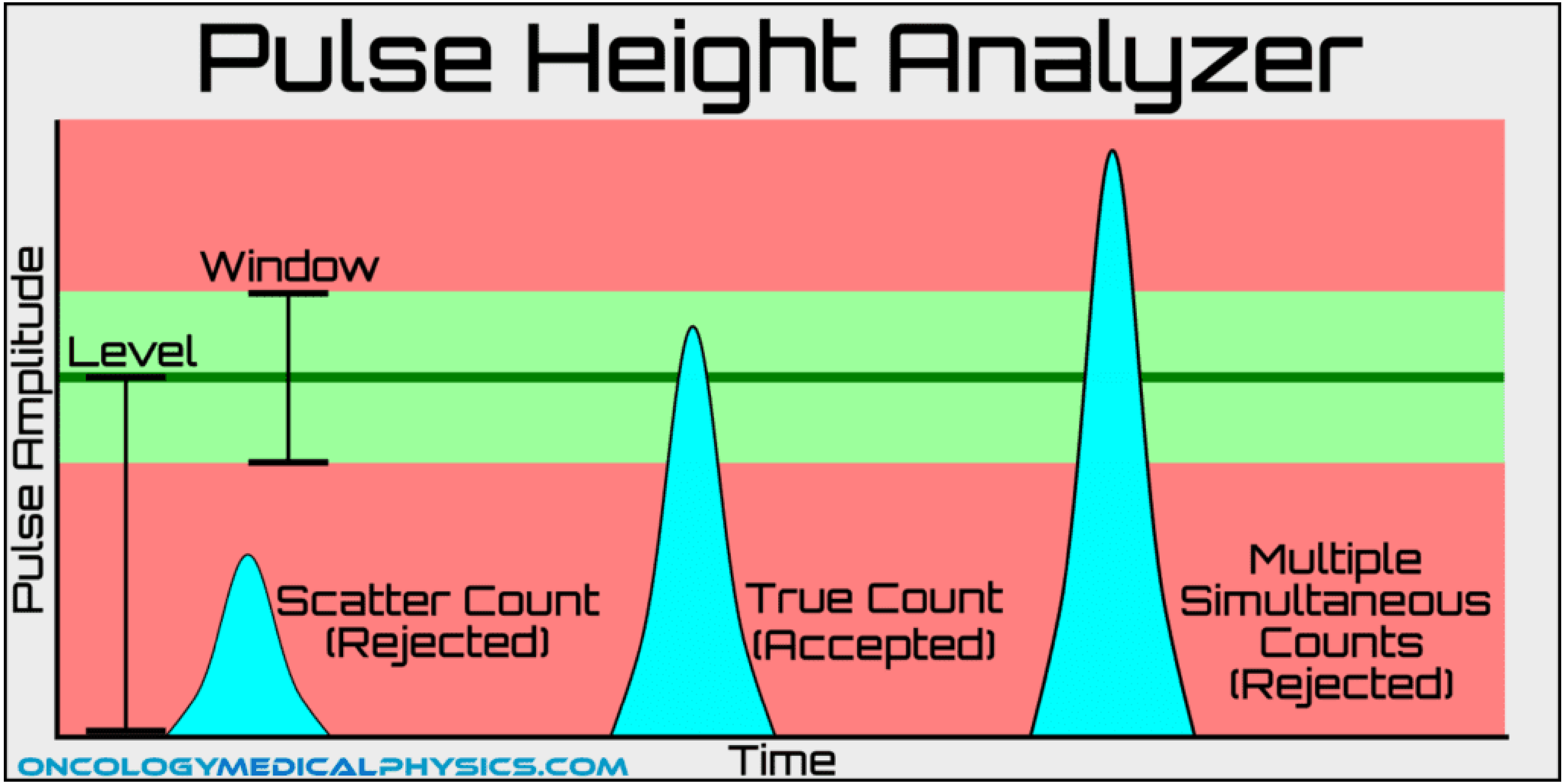
- Parallel hole is most common in nuc. med.
- Pinhole is used for thyroid uptake analysis
- There are other forms of collimation that are gaining prominence, but are too complicated for us



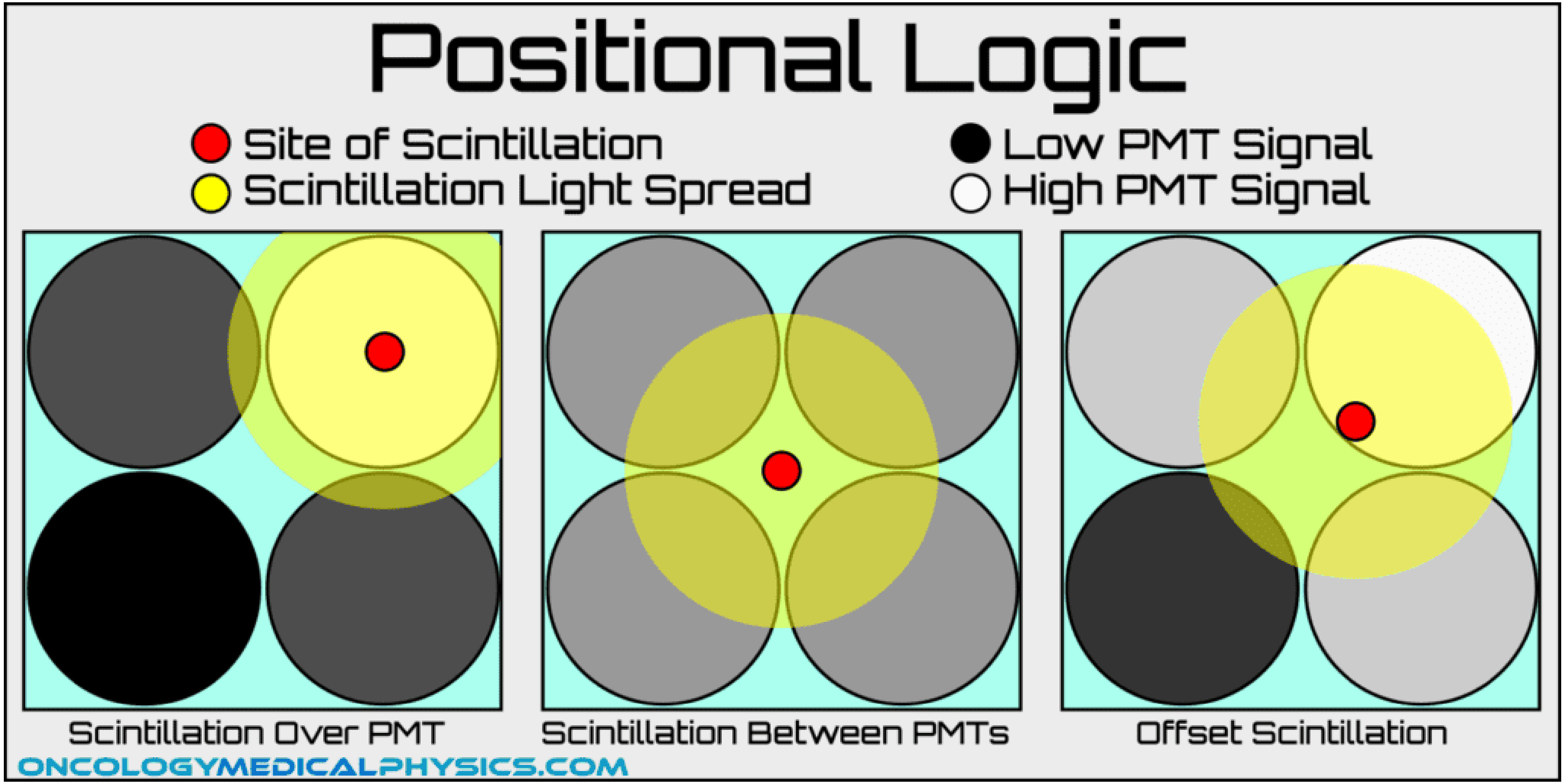
Step Four: Possible Photon Fates



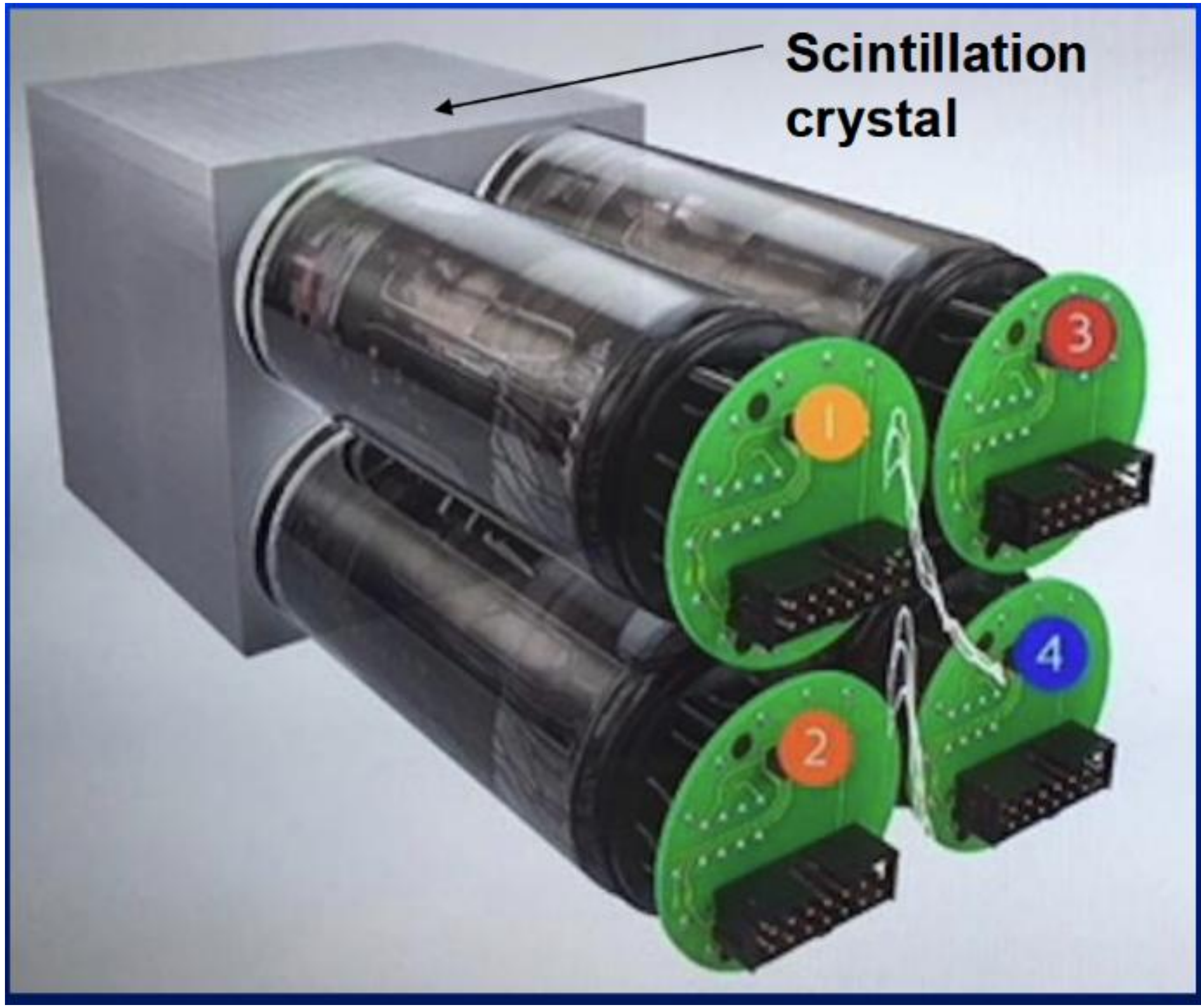
Step Six: Discrimination of Energy

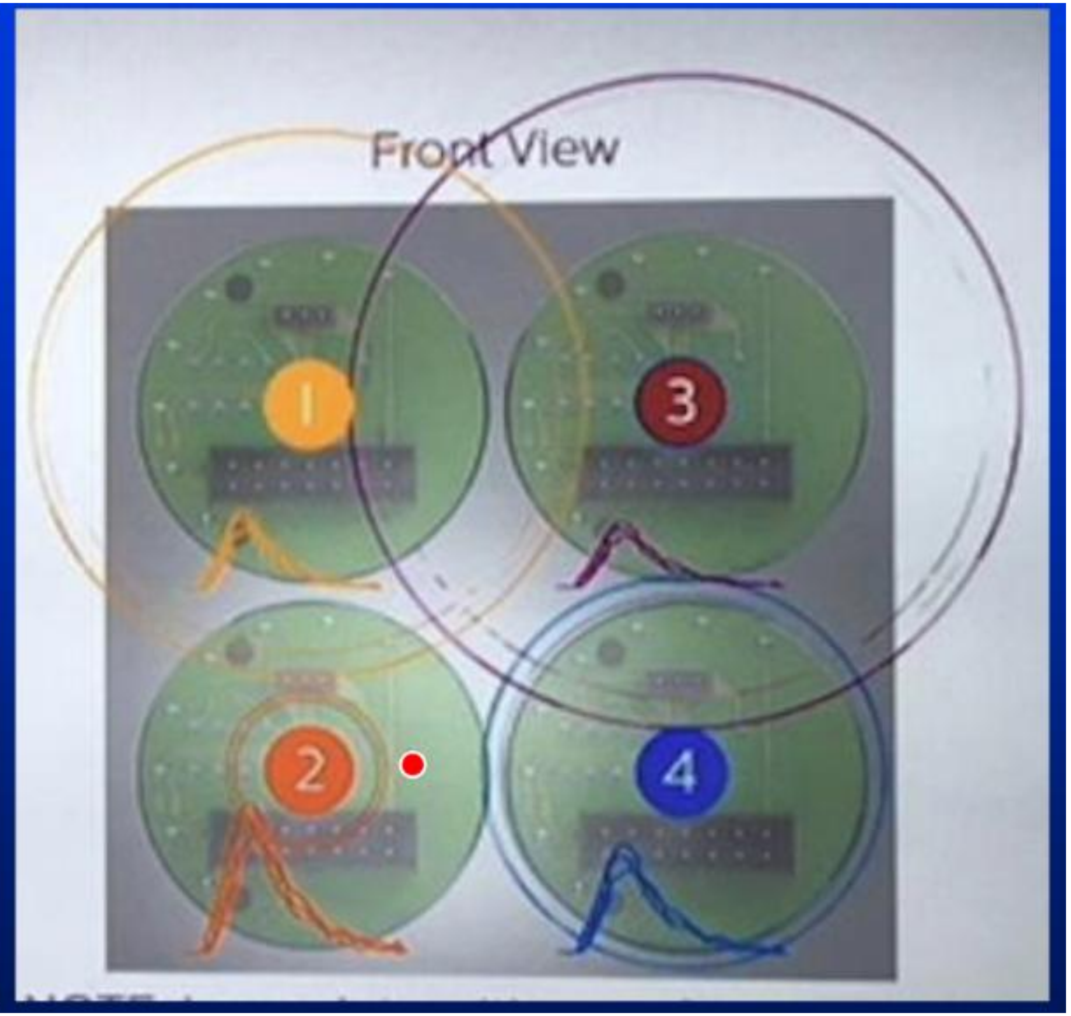


Step Seven: Event Localization



Step Seven Continued

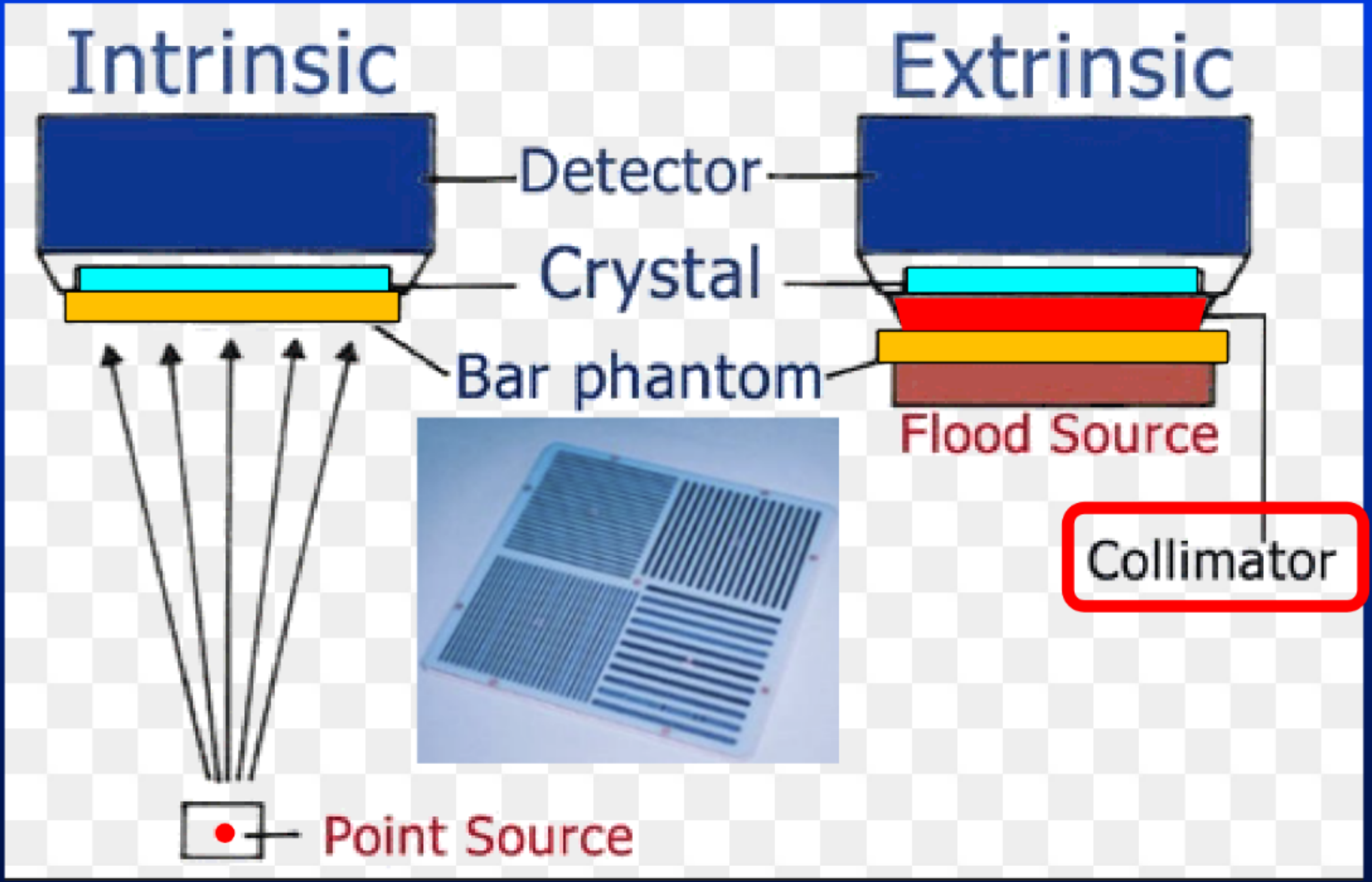




Common Procedures

- Ask the nuc. med. people what they see most (Almost all are Tc-99m based)
- Bone Scans
  - Cancer
  - Occult Fractures
  - Osteomyelitis/Arthritis
- Cardiac Scans
- Metastatic Cancer
- Prostate Cancer
- Neurological Scans

INTRINSIC / EXTRINSIC RESOLUTION



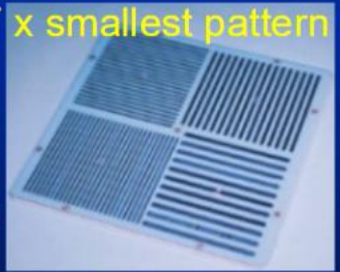
PERFORMANCE SPECIFICATION

- **Intrinsic** spatial resolution (3.5 – 4.5 mm)
- System (**extrinsic**) spatial resolution (8 - 12 mm)
- **Energy** resolution (9 – 10%)
- **Intrinsic sensitivity** 200-300 cpm/uCi (~ **0.7%**)
- **Clinical sensitivity** (number of photons generated in the patient relative to the number of photons measured) is only ~ 1 in 10,000 (**0.01%**)
- This is due to absorption/**Compton scatter** in patient and absorption by the **collimator** (to create image)

GAMMA CAMERA
QUALITY CONTROL

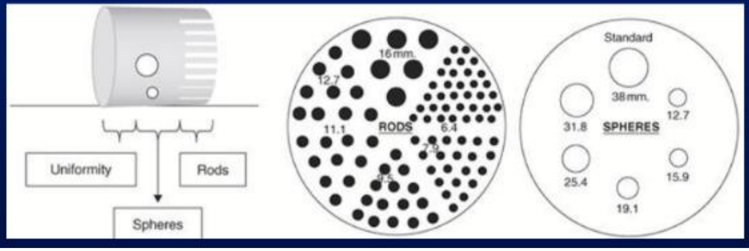
- **Daily QC > Flood phantom to test uniformity**
  (Differential / Integral Uniformity < 5%)
  Peaking of energy (remove background)
- **Weekly QC > Bar phantom to monitor spatial resolution**
- **Monthly QC > Jascszak phantom to test spatial resolution**
- **Quarterly QC > Sensitivity test**
- **Annual QC > Rotational uniformity**
  Dead-time test

FWHM ~ 1.7 x smallest pattern



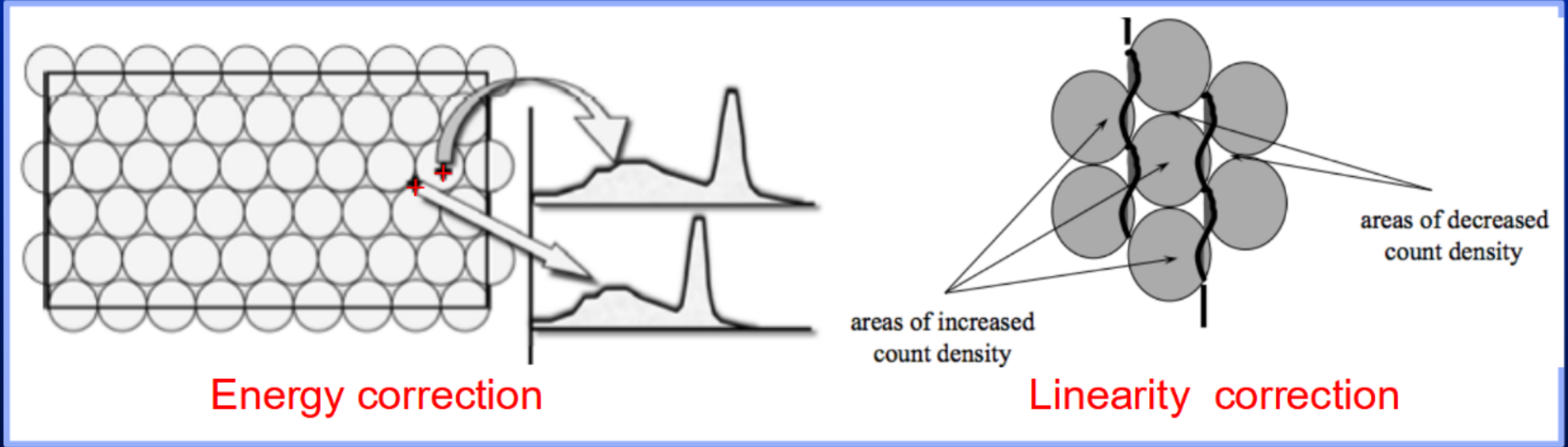
bar phantom

Jascszak phantom



SPECT CORRECTIONS

- Regional spectra shifts > Energy Correction
- Miss-positioning of events > Spatial Linearity Correction
- Regional count differences > Uniformity Correction
- Count rate losses > Pulse Pile-up Correction

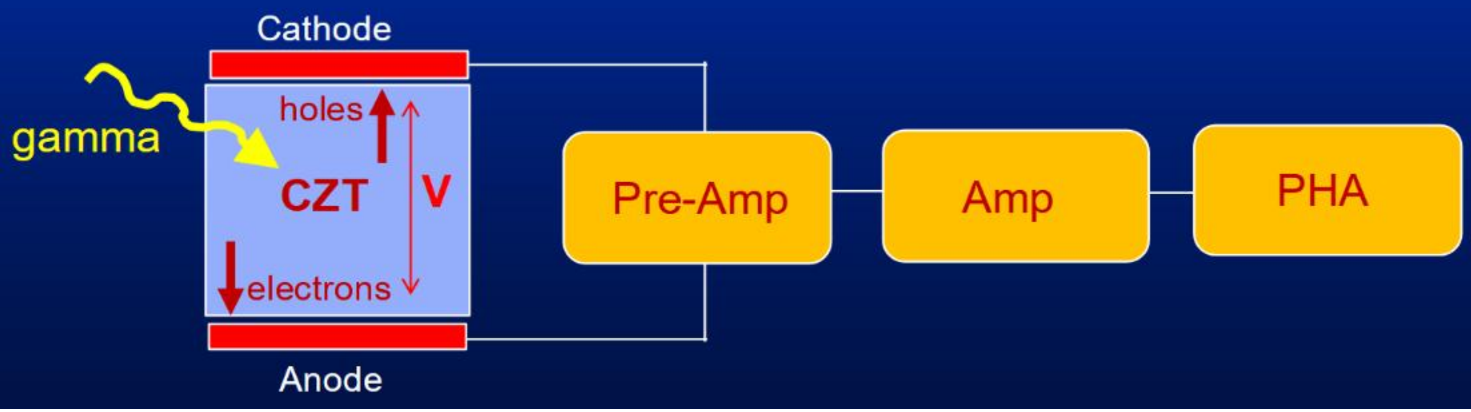


NEW DEVELOPMENTS IN NUCLEAR MEDICINE

- Novel semiconductor detectors (CZT)
- SPECT Ring design using Focused Detectors
- Use of SiPM instead of PMT for scintillation crystals
- Photon counting technology

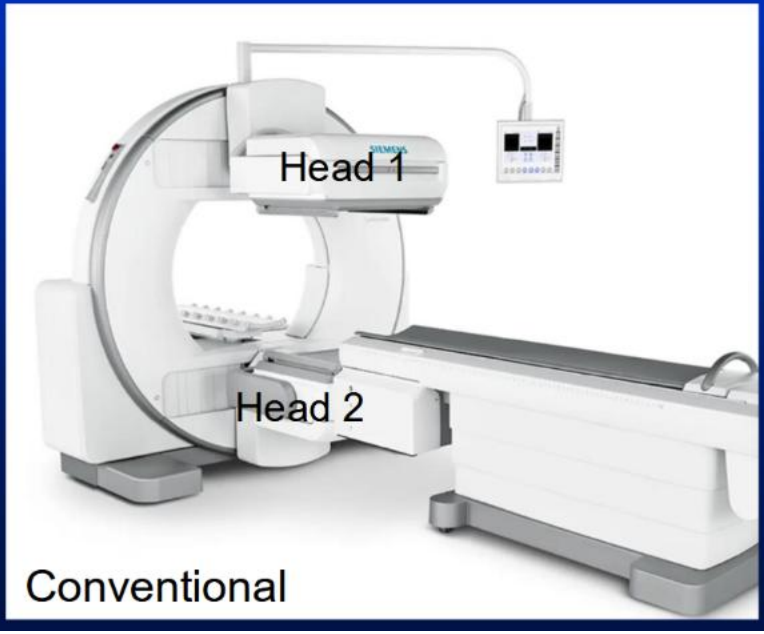
CADMIUM ZINC TELLURIDE (CZT) SEMICONDUCTOR DETECTOR

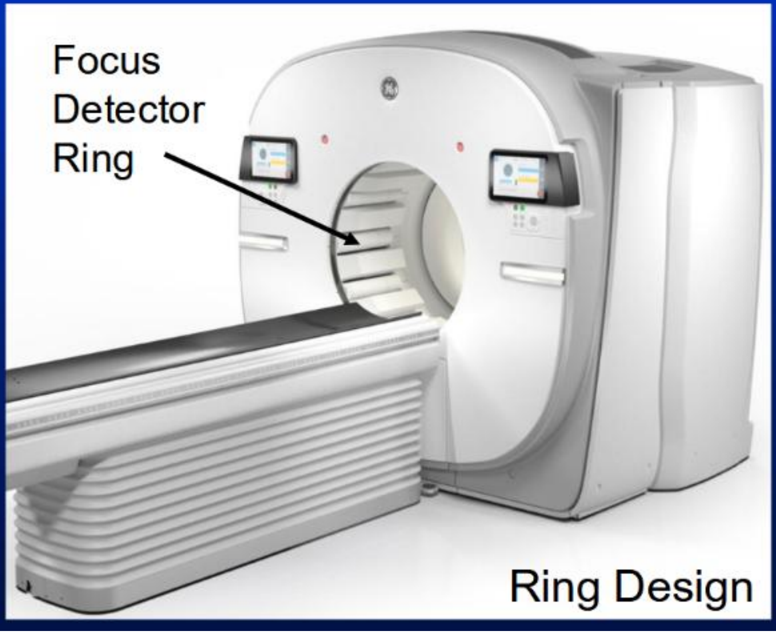
- **Direct** conversion of gamma rays into electrical charge
- **Room temperature** semiconductor (E gap ~ 1.6 eV) with high resistance resulting in very low leakage current
- High **sensitivity** due to high density (5.8 g/cm³, NaI - 3.7g/cm³)
- Excellent E resolution (~5%, NaI >10%)



SPECT/CT

- Conventional SPECT uses a **Two-head** detector system in **step-and-shoot mode**
- **12 digital CZT detectors** that automatically move within mm of the patient's body

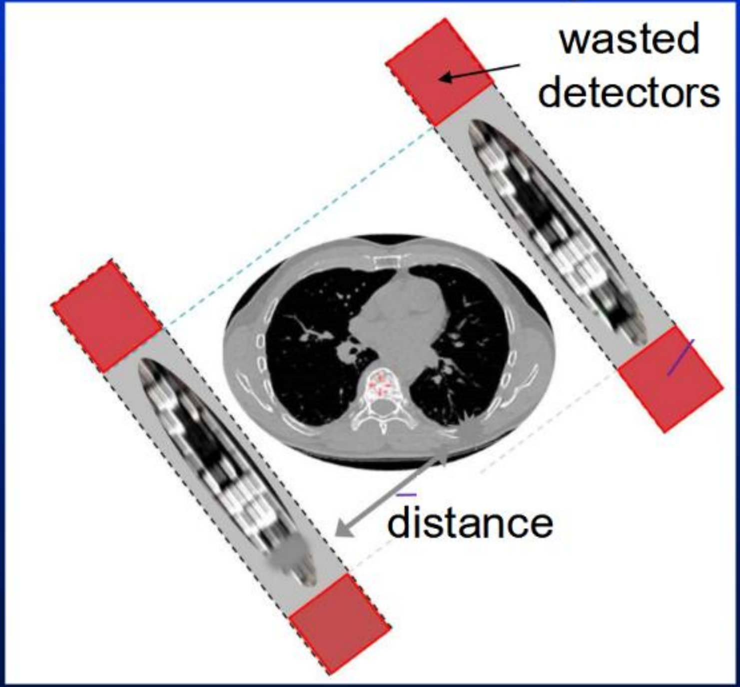




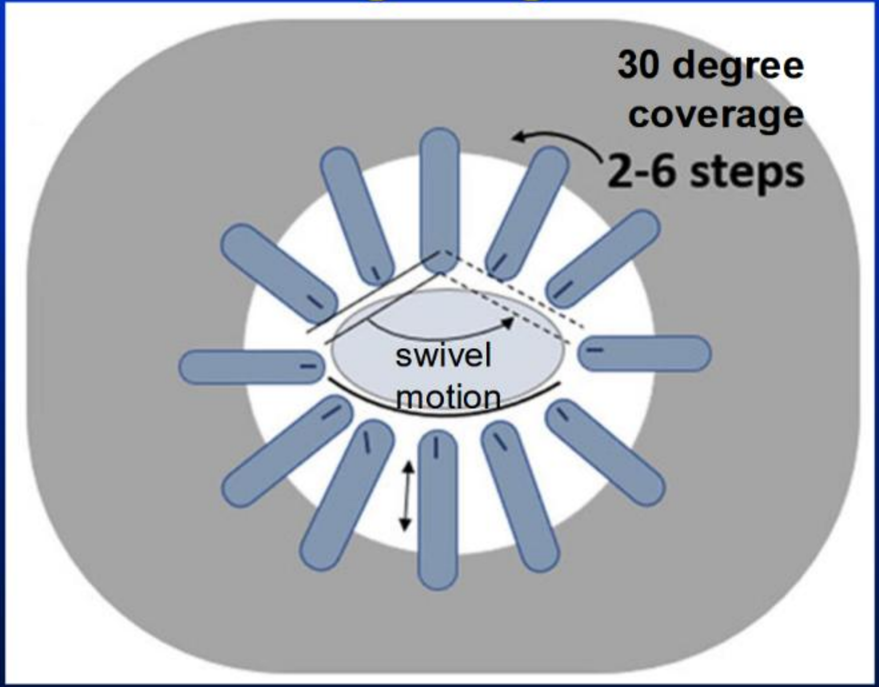
SPECT RING DESIGN

- Ring design allows **faster scanning** due to increased detector number and **decreased distance** between detector and patient

Conventional design



Ring design



SPECT RING DESIGN
ADVANTAGES / DRAWBACKS

- **Advantages**

  Detectors closer to patient – improved resolution
  No “wasted” detector space
  Only 2-6 steps required – faster scanning
  CZT semiconductor detector – compact detector

- **Drawbacks**

  Non-exchangeable collimator – limited energy range
  No true sinogram
  Expensive

LEHR collimator:
40 – 250 keV

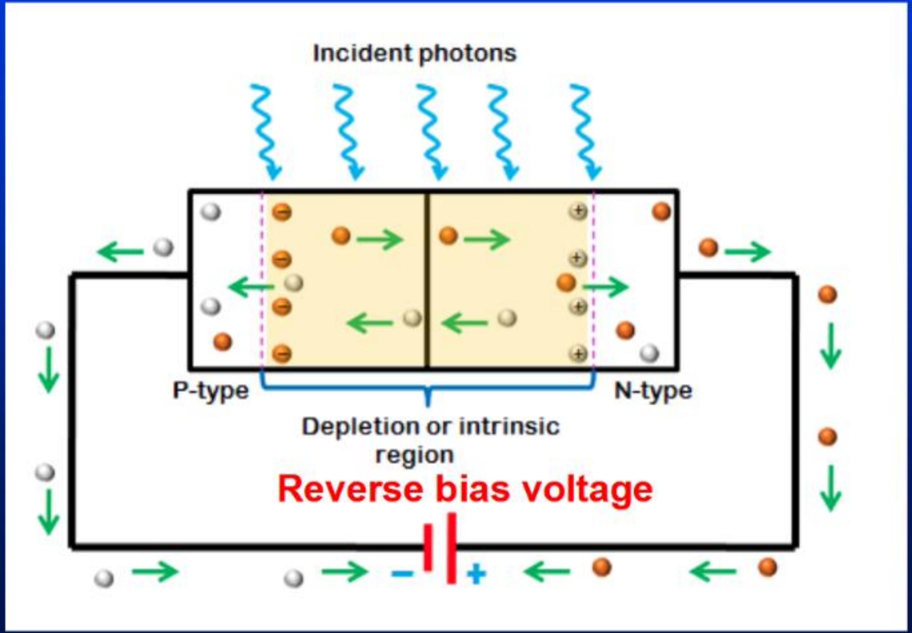
FROM PMT TO PHOTON COUNTING USING SiPM

- **APD → Avalanche Photodiode provides amplification prior to breakdown (analog signal)**
- **SiPM → array of small APDs, each of which is in Geiger mode allows photon counting (digital signal)**

	PMT	APD	Analog SiPM	Digital photon counting Digital SiPMs
TOF capability*	analog, time-of-flight	N/A	analog, time-of-flight	digital, time-of-flight
Operational stability	medium	low	medium	high
Signal amplification	10^6	10^{2-3}	10^6	not needed
Level of integration	low	medium	medium	high
Signal readout	analog	analog	analog	digital

AVALANCHE PHOTO DIODE (APD)

Voltage below breakdown = Avalanche mode
Voltage above breakdown = Geiger mode



MODE OF OPERATION DEPENDS ON BIAS VOLTAGE

- Analog to gas detectors (but "Avalanche" is used differently)

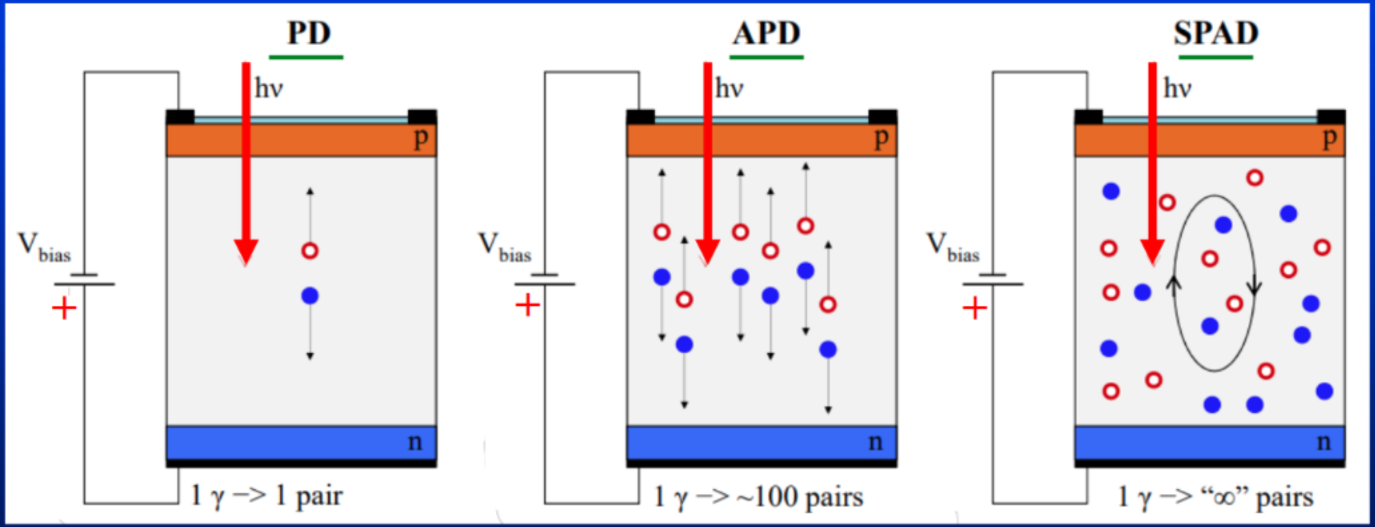


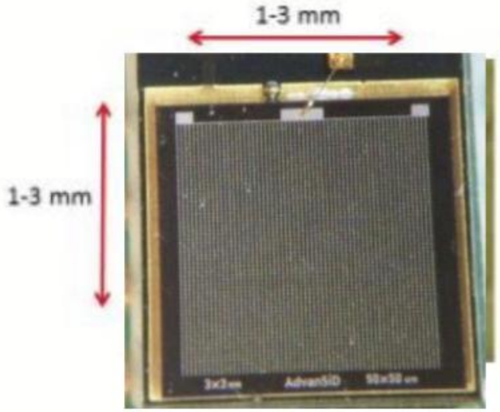
Photo Diode (PD)	Avalanche PD (APD)	Single Photon APD
Only primary electrons	Linear amplification V(bias) < V(breakdown)	Continuous current V(bias) > V(breakdown

ANALOG SILICON PM (SiPM)

2D array of APDs, biased above breakdown voltage (Geiger mode)

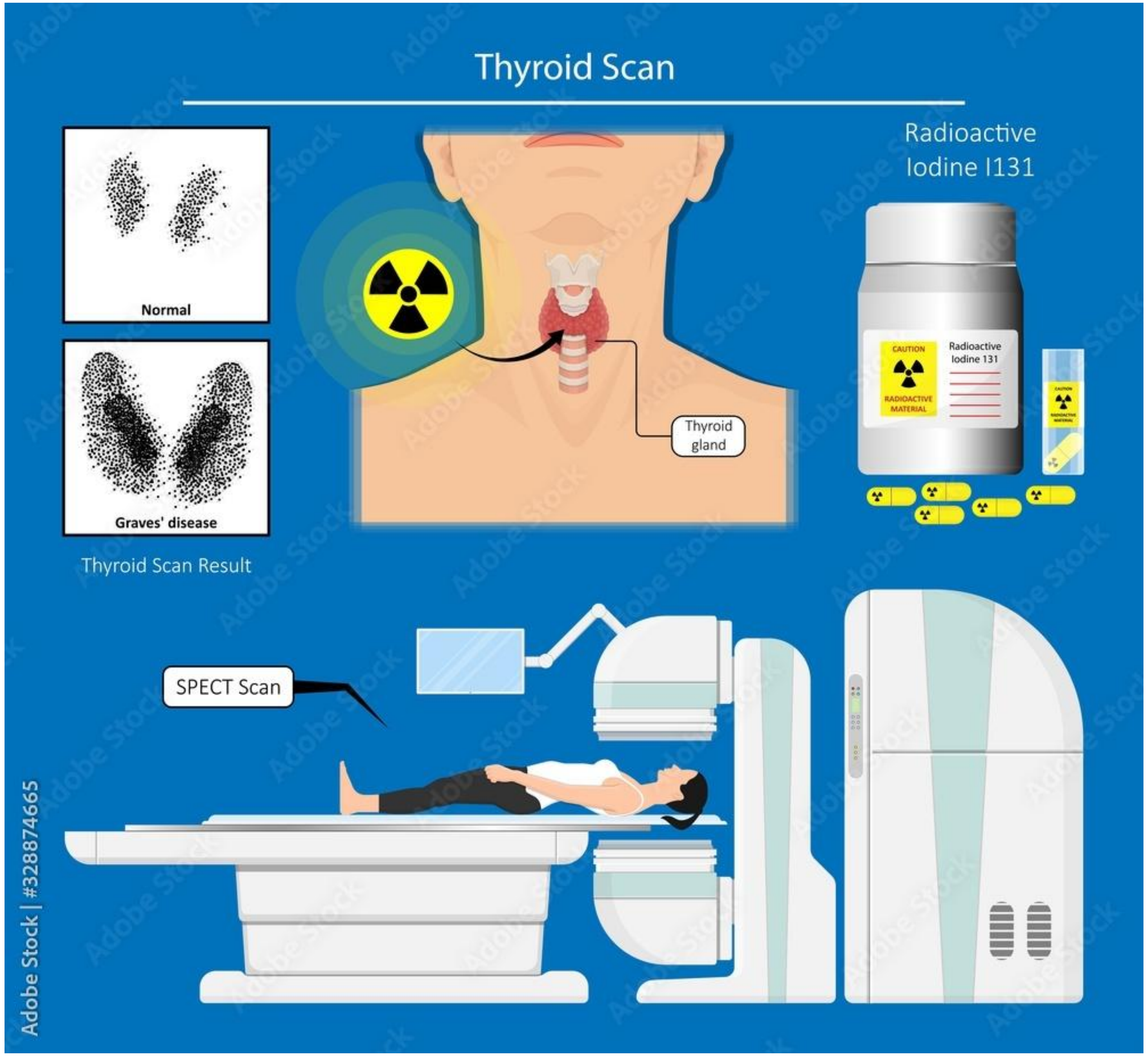
Silicon Photo-Multiplier (SiPM)

- Compact Device
- Operating voltage (30-120V)
- Resolution - Single photon detection
- Response time – ~100 ps
- High gain - 10^6
- High Quantum Efficiency – 90%
- High Photon Detection Efficiency – 60%
- Immunity to Magnetic Field



Each cell 25 x 25 um^2


Captus® 4000e
Captus 4000e


Thyroid Scan
Normal
Graves' disease
Thyroid Scan Result
Radioactive
Iodine I131
Thyroid
gland
CAUTION
RADIOACTIVE MATERIAL
Radioactive
Iodine 131
SPECT Scan
Adobe Stock | #328874665