Nuclear Imaging II (PET)

RT4220 – LECTURE #13

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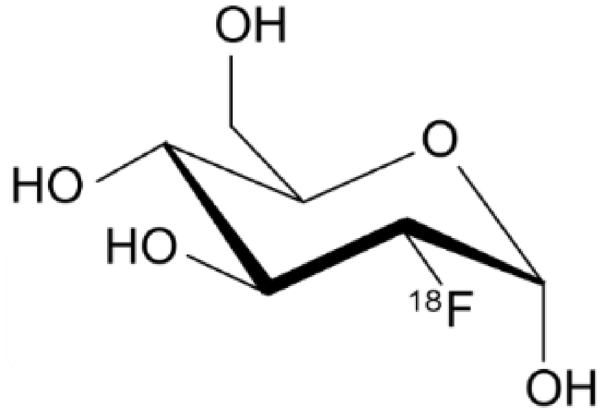
WSU

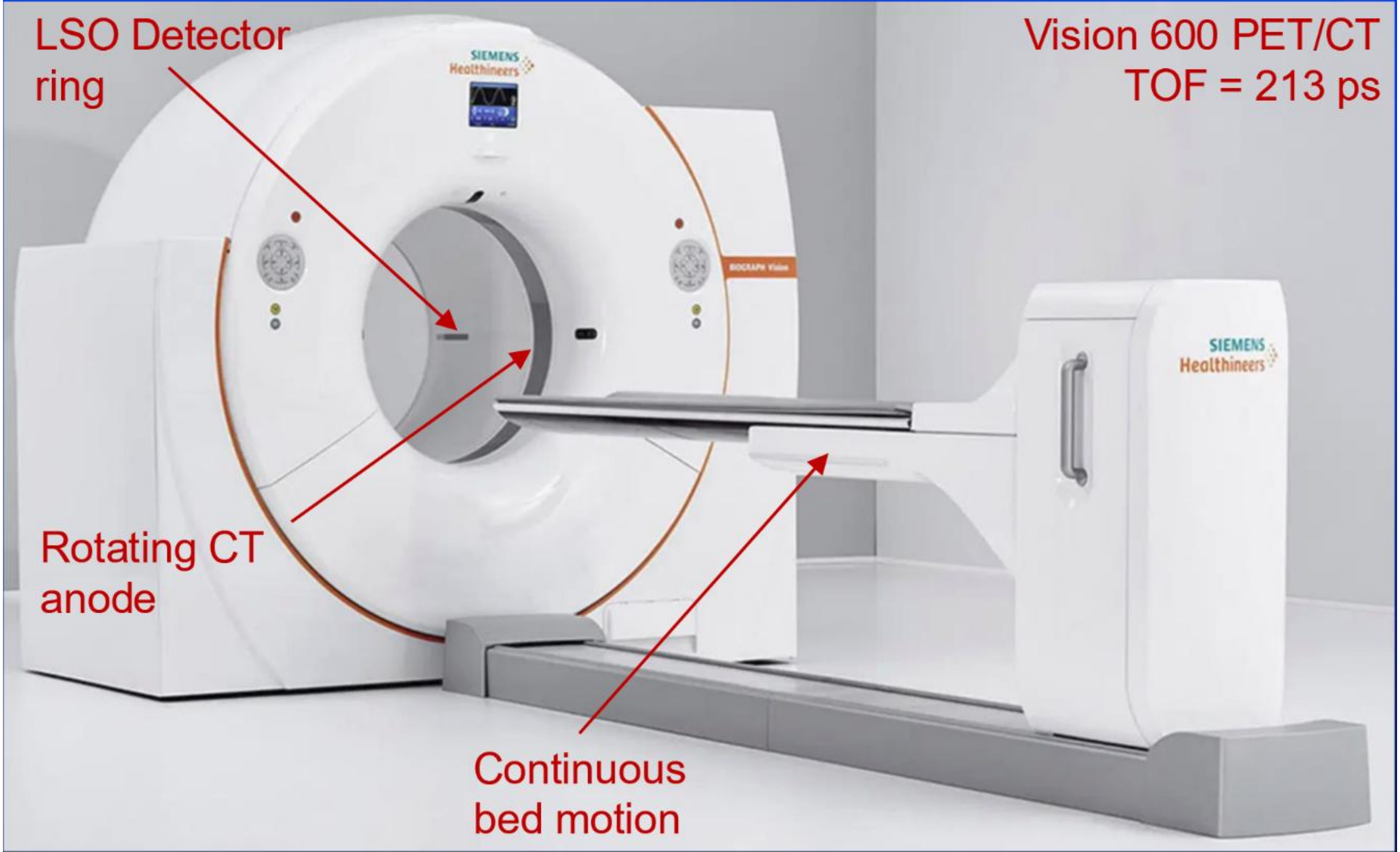
10/30/2025

Basics of PET Imaging

- Positron Emission Tomography → Positron → 2x 511 keV photons oppositely opposed → *near*-simultaneous detection of each photon tells us where it came from → we can **quantify** how much tracer was deposited in a given location
- Extremely short half-life of positron emitters:
  - C-11: 20 mins
  - O-15: 2 mins
  - F-18: 110 mins

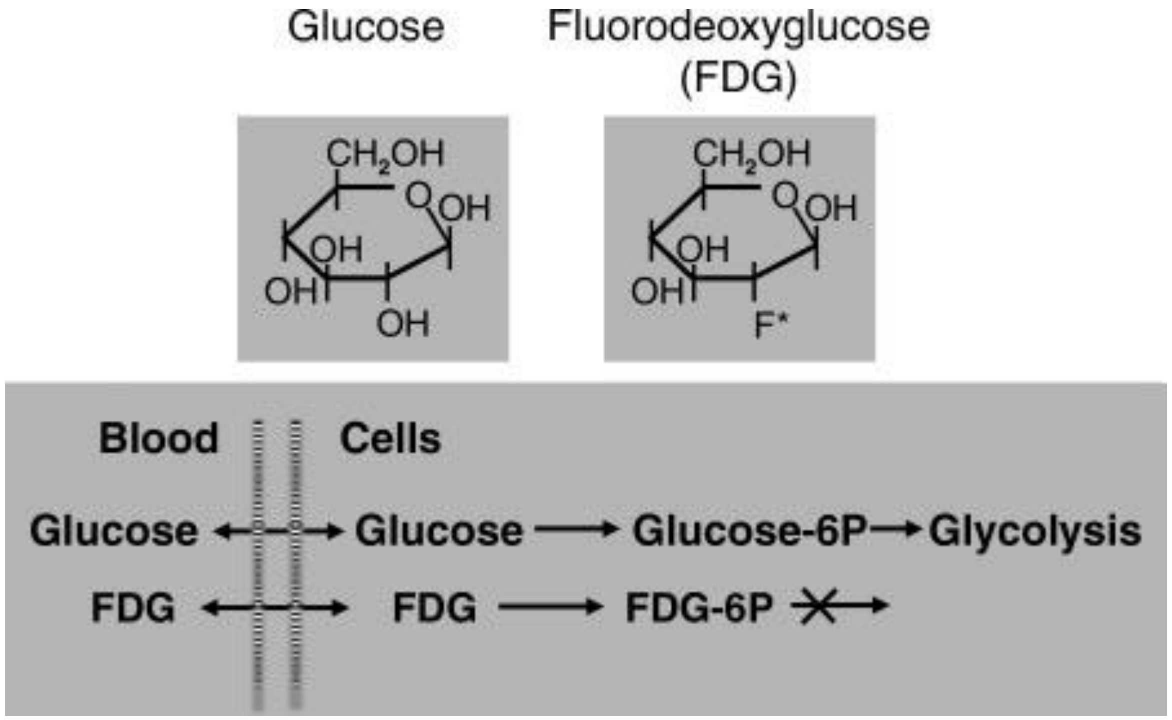


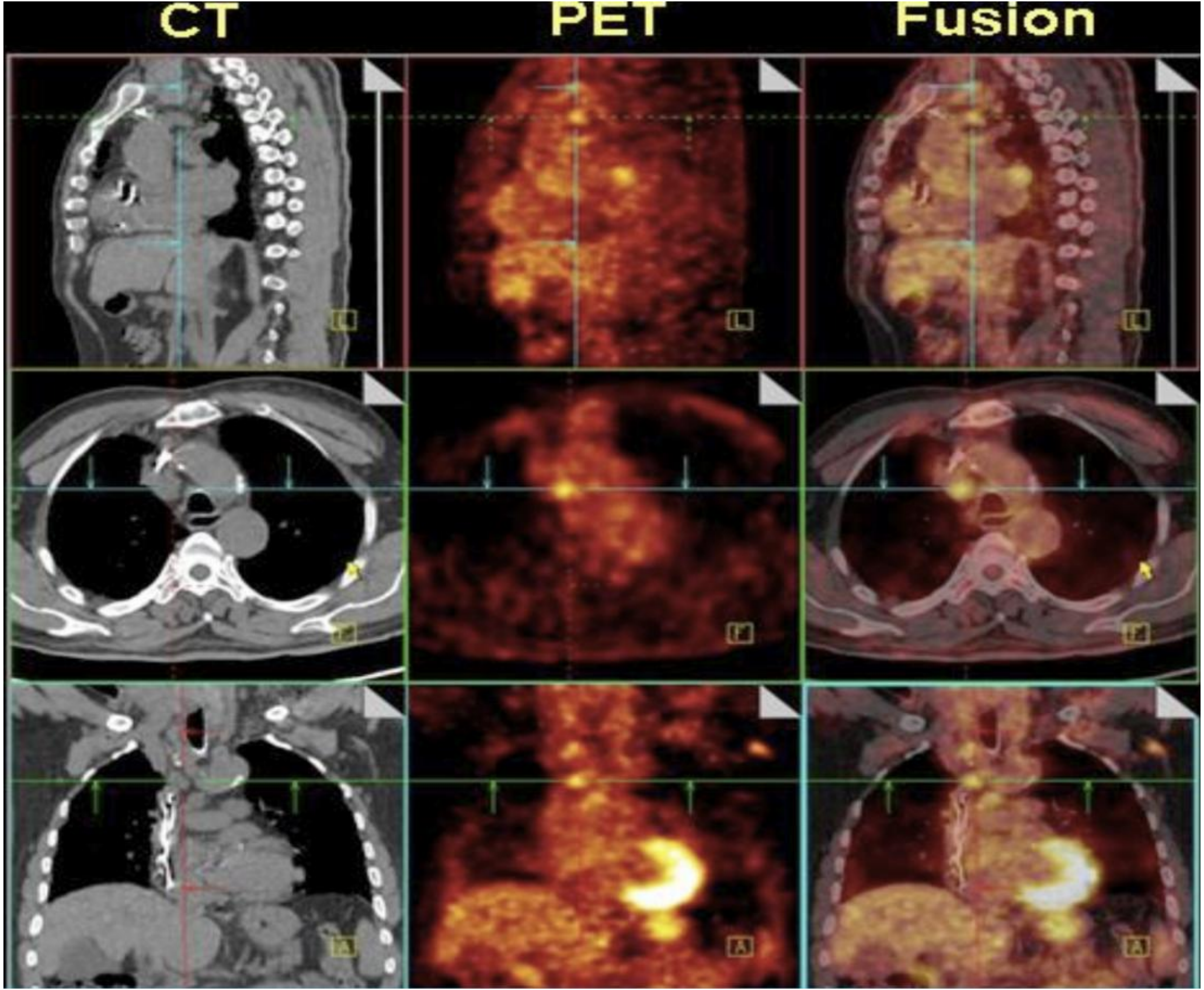
- Short half life **requires** on-site production; we have a generator!
- Most common PET radiopharmaceutical is **F**luoro**D**eoxy**G**lucose (F-18 != FDG)

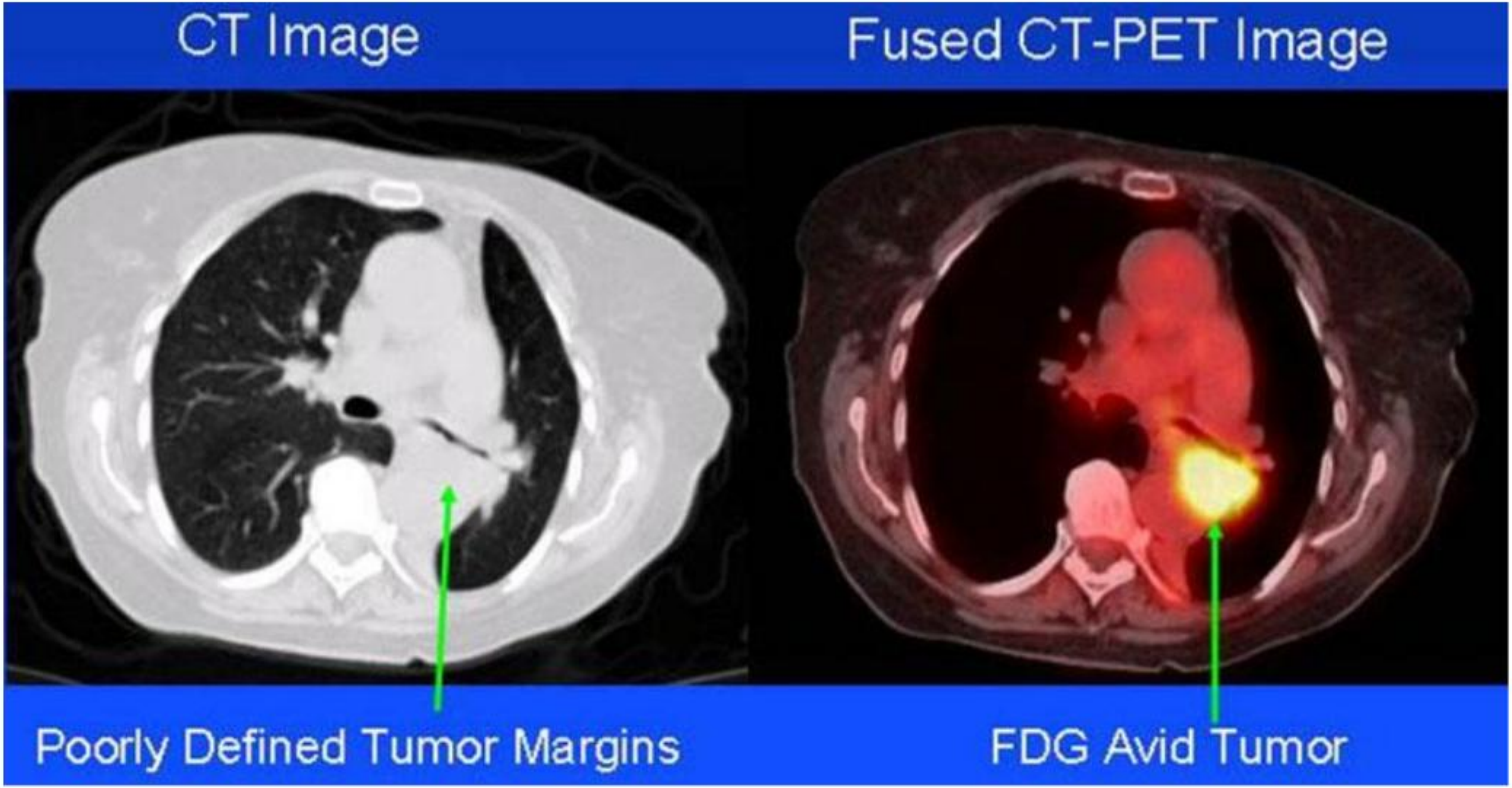

LSO Detector ring
Vision 600 PET/CT
TOF = 213 ps
SIEMENS Healthineers
Rotating CT anode
Continuous bed motion

FDG Scans

- Types of Scans:
  - Tumor imaging and staging
  - Detection of sub-clinical involvement
  - Cardiac tissue viability studies
  - Brain Imaging
- Function:
  - Localizes like glucose in the body but gets stuck




CT
PET
Fusion


CT Image
Fused CT-PET Image
Poorly Defined Tumor Margins
FDG Avid Tumor

Common PET Usage

- Primarily to detect cancer and monitor its progression/metastasis status
- PET/CT has become the primary **imaging** tool for cancer staging
  - There are other great non-imaging tools!
- Apparently, some are using PET to diagnose Alzheimer's?

Common SPECT Usage

- SPECT primarily for tracking the progression of heart disease (blocked coronary arteries)
- There are also radiotracers for detecting bone, gall bladder, and intestinal disorders
- Apparently, some people have used it to help diagnose Parkinson's?

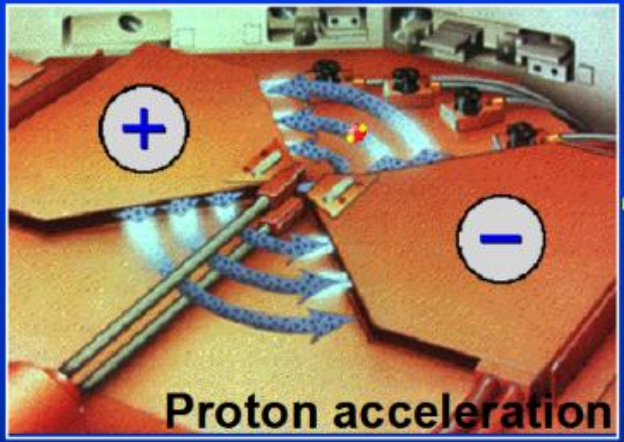
PET ALLOWS AUTORADIOGRAPHY IN VIVO

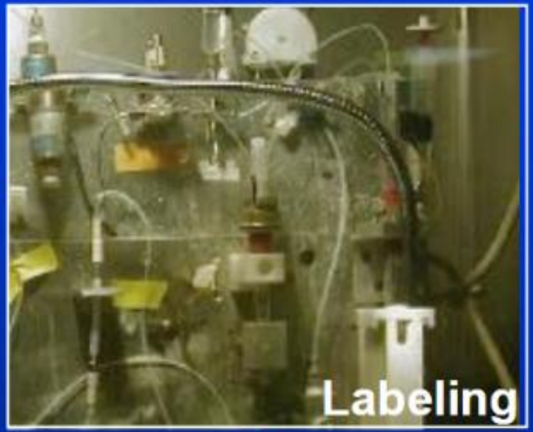
- Positron Emission Tomography allows radiography in vivo - absolute quantification of radioactivity concentration in different parts of the human body (due to exact attenuation correction)

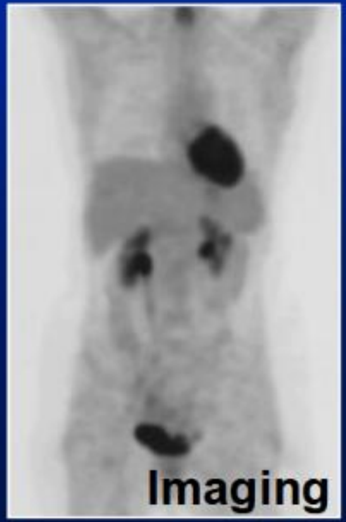
- Use of electronic collimation instead of lead collimation - high sensitivity and efficiency (picomolar concentration range)

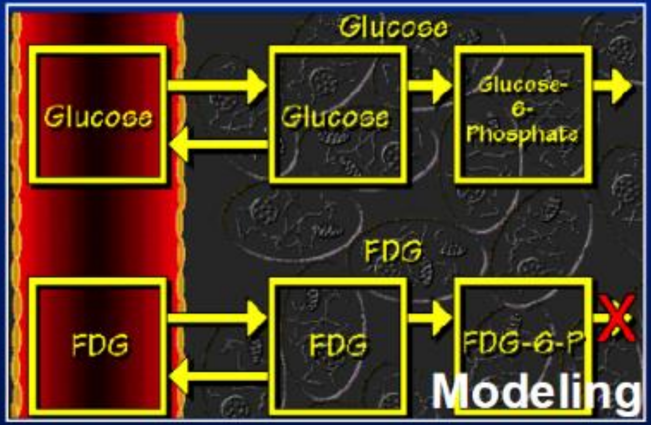
- Use of short-lived biologically active radio-pharmaceutical: C-11flumazenil, N-13 ammonia, O-15 water, F-18 deoxy-glucose

PET DATA ACQUISITION AND ANALYSIS

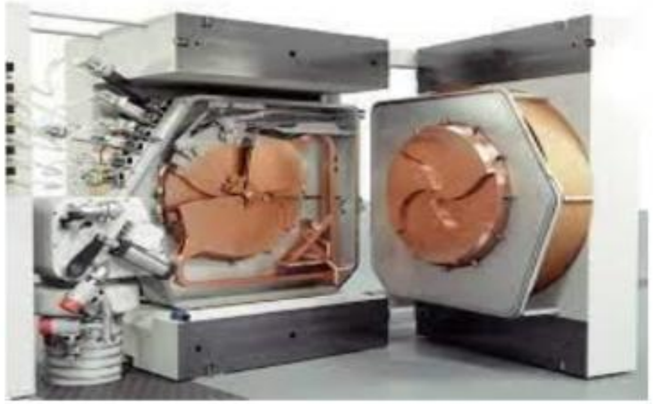








FDG workflow



Irradiation:
1- 2 h

Starting activity:
3-12 Ci

→

Assembly and radiosynthesis:
~ 2 h

FPV:
2 - 10 Ci

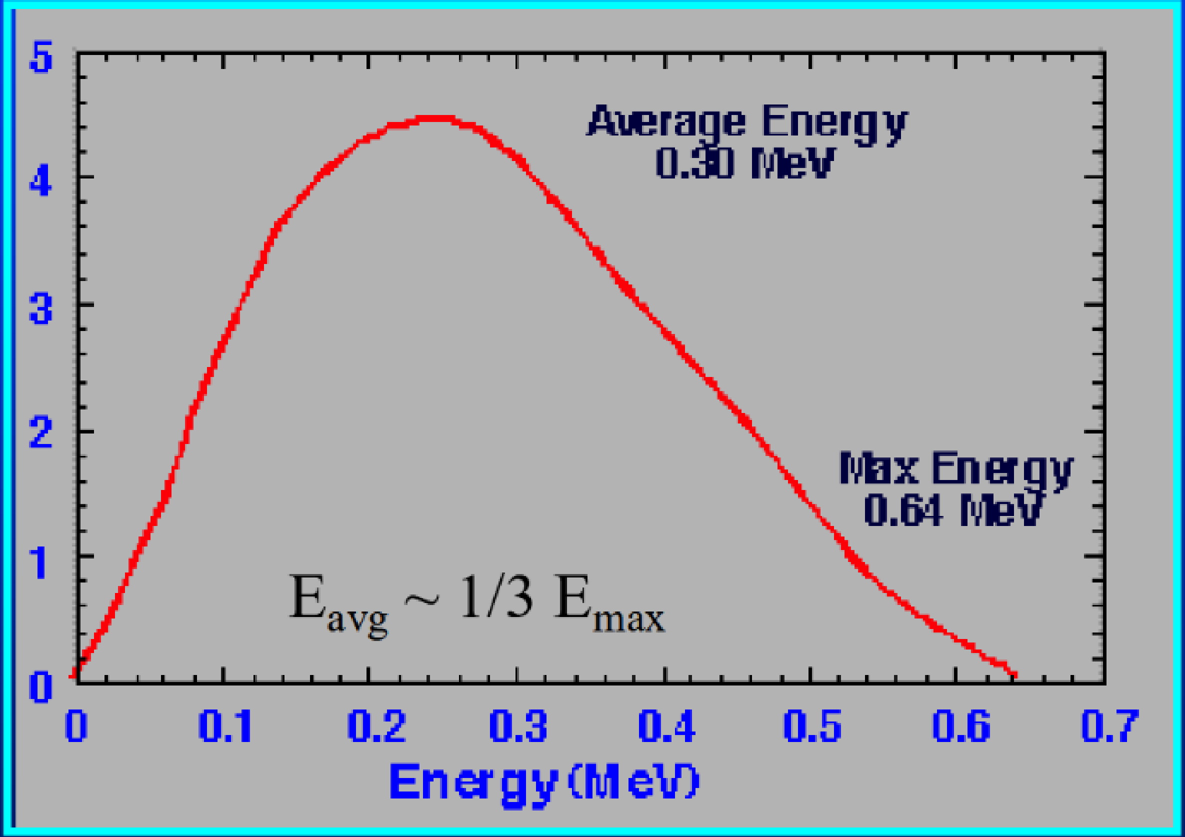
→

Quality Control & drug release

~ 30 min

Overall time: 3 - 5 h
Expiration: 12 h

ENERGY DISTRIBUTION OF EMITTED POSITRONS

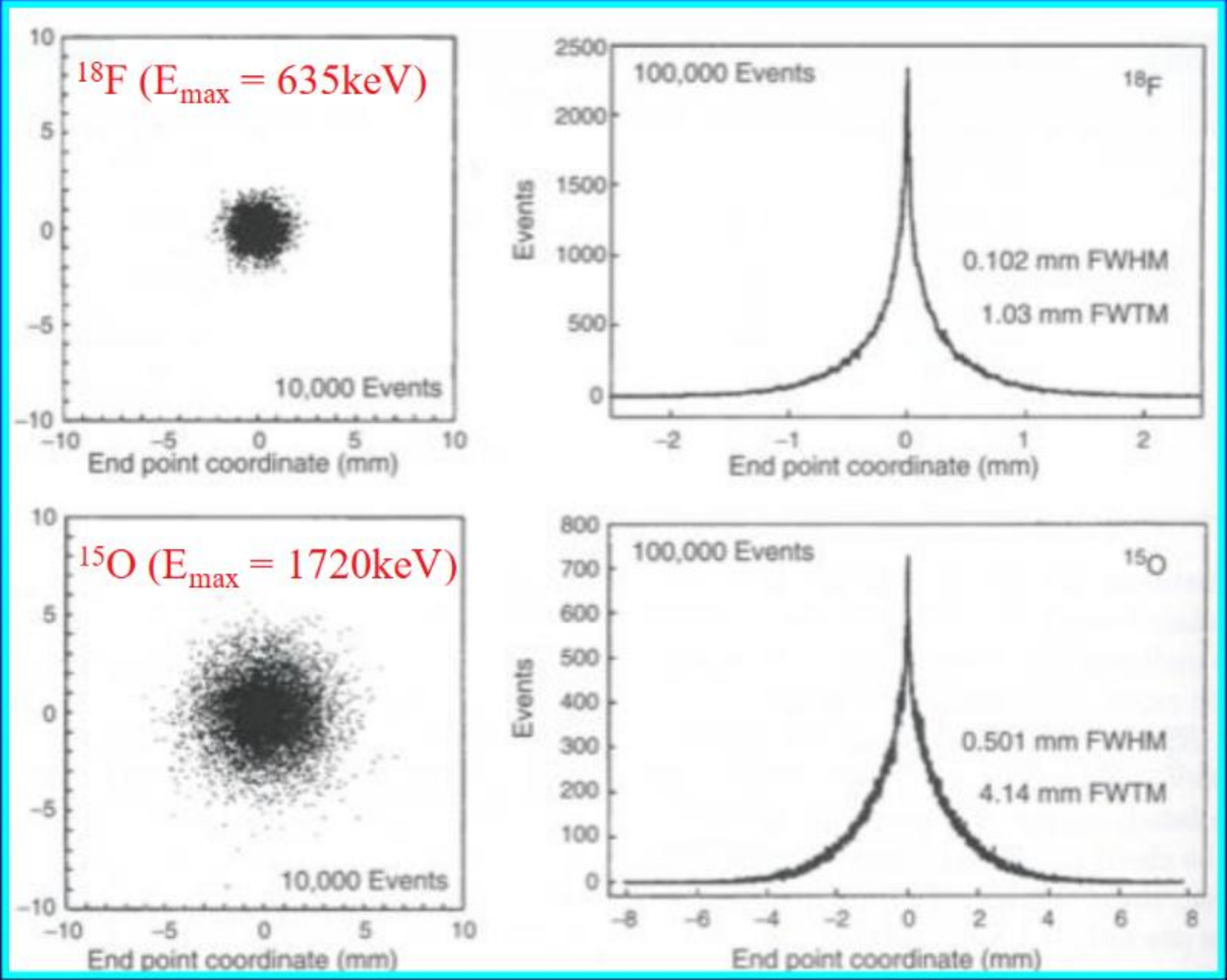


Energy spectrum of a positron emitted from ^{18}F

$^{18}_{9}F \dashrightarrow \beta^{+} + ^{18}_{8}O + n$

The positron travels a distance before it annihilates dependent on its energy

SPATIAL DISTRIBUTION OF ANIHILATION EVENTS



Pathlength of positron is a random walk

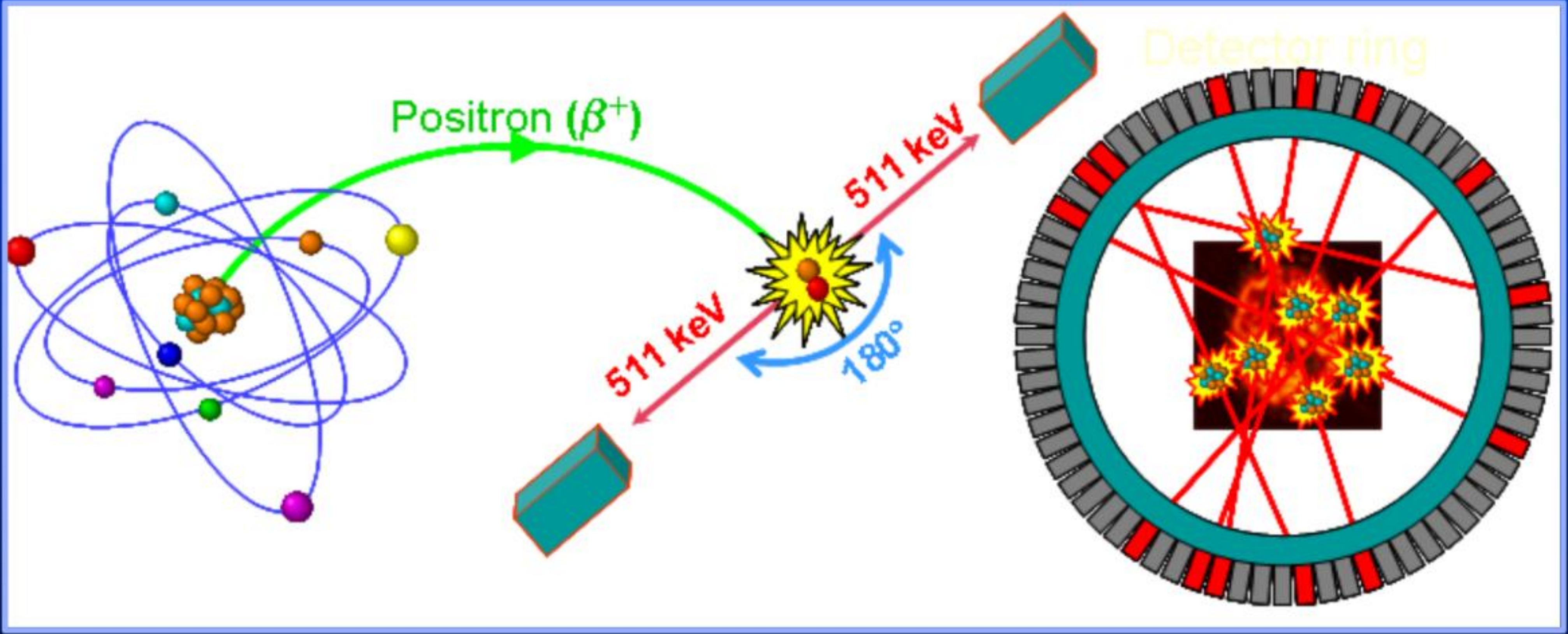
Exponential distribution

Monte-Carlo simulation (100,000 histories)

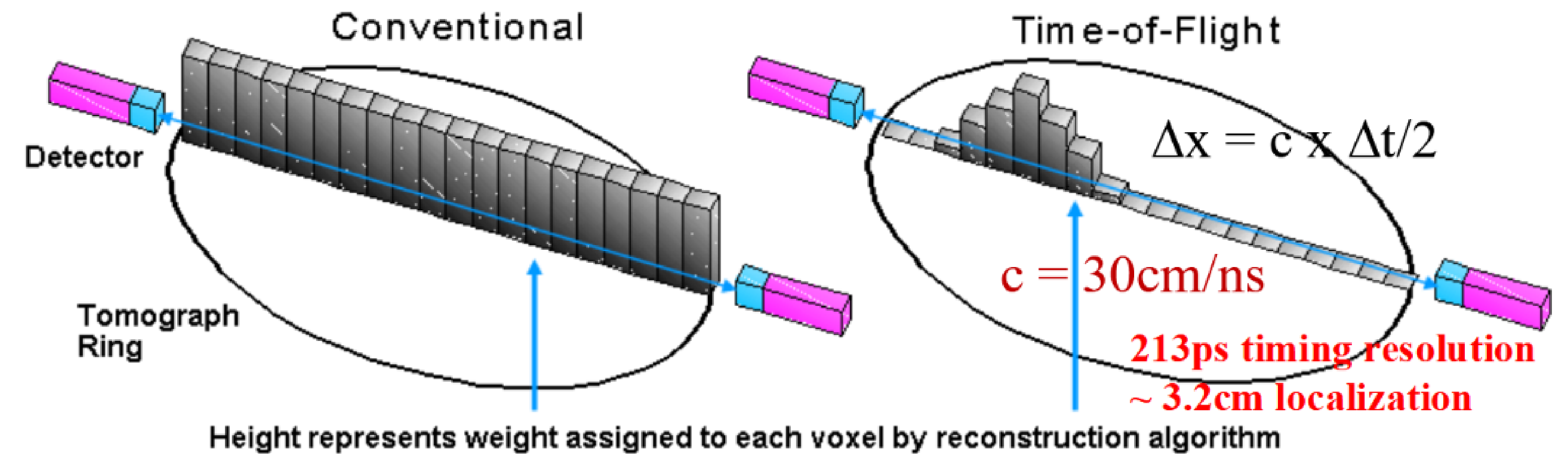
COINCIDENCE DETECTION

- Coincidence events occur during time window τ

  τ typically 5 ns



TIME-OF-FLIGHT (TOF) DATA ACQUISITION



Conventional:

- Detected event projected to *all* voxels between detector pairs
- Statistical noise from activity in one voxel adds noise to *all* voxels

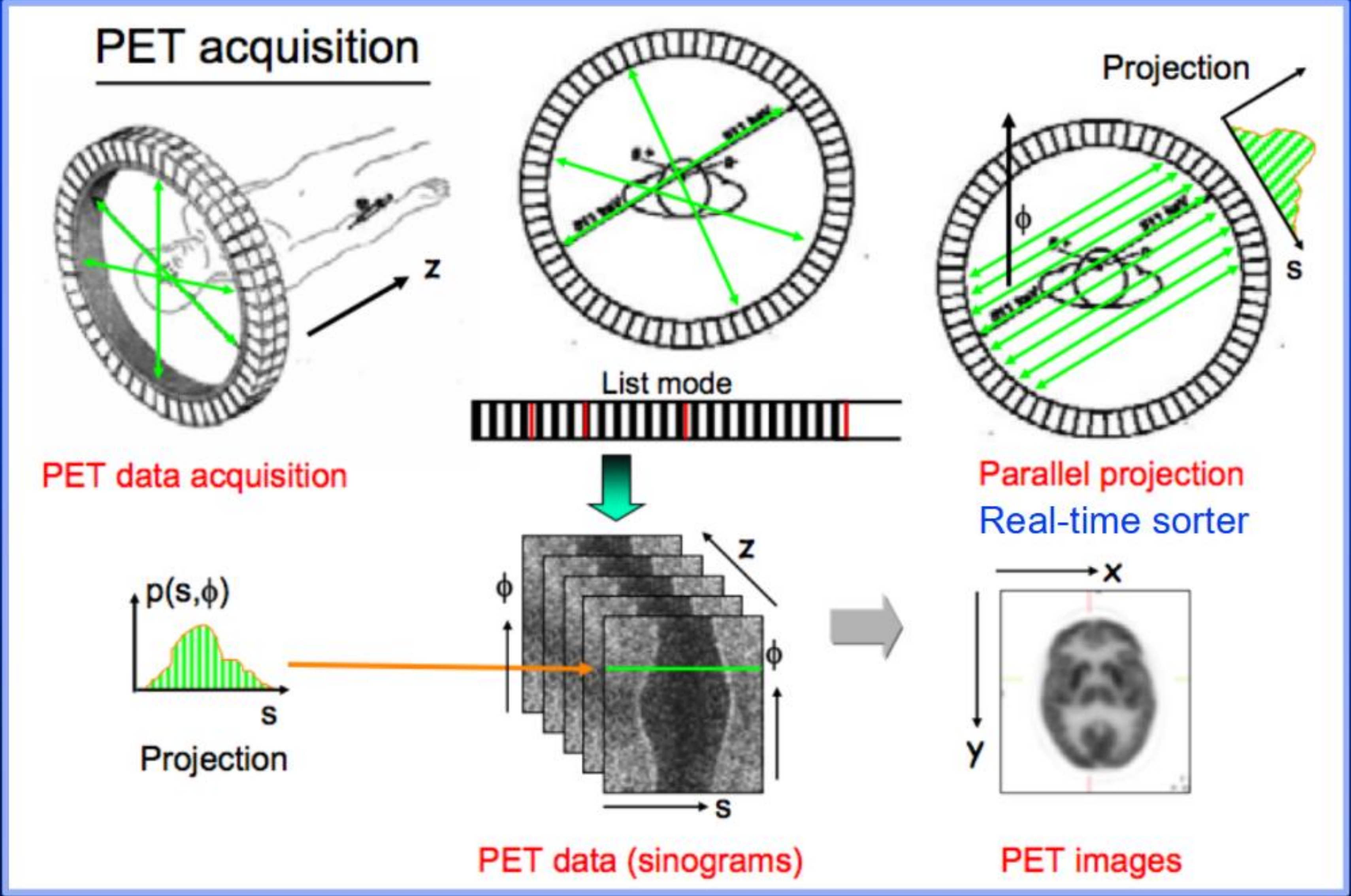
⇒ Large Noise Amplification

Time-of-Flight:

- Detected event projected *only* to voxels consistent w/ measured time
- Statistical noise from one voxel adds noise to *only a few nearby* voxels

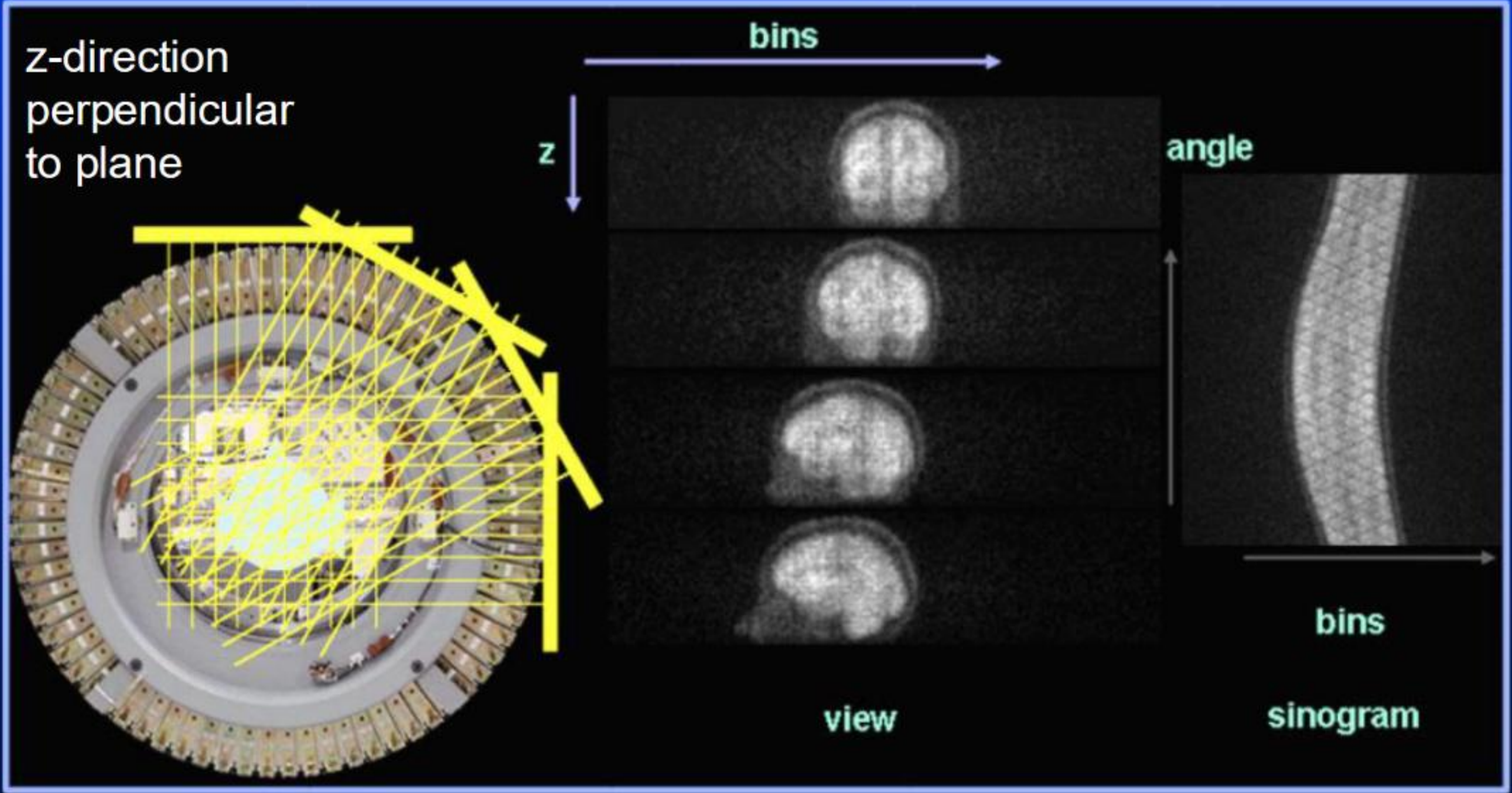
⇒ Small Noise Amplification

REFORMATTING THE DATA INTO SINOGRAMS



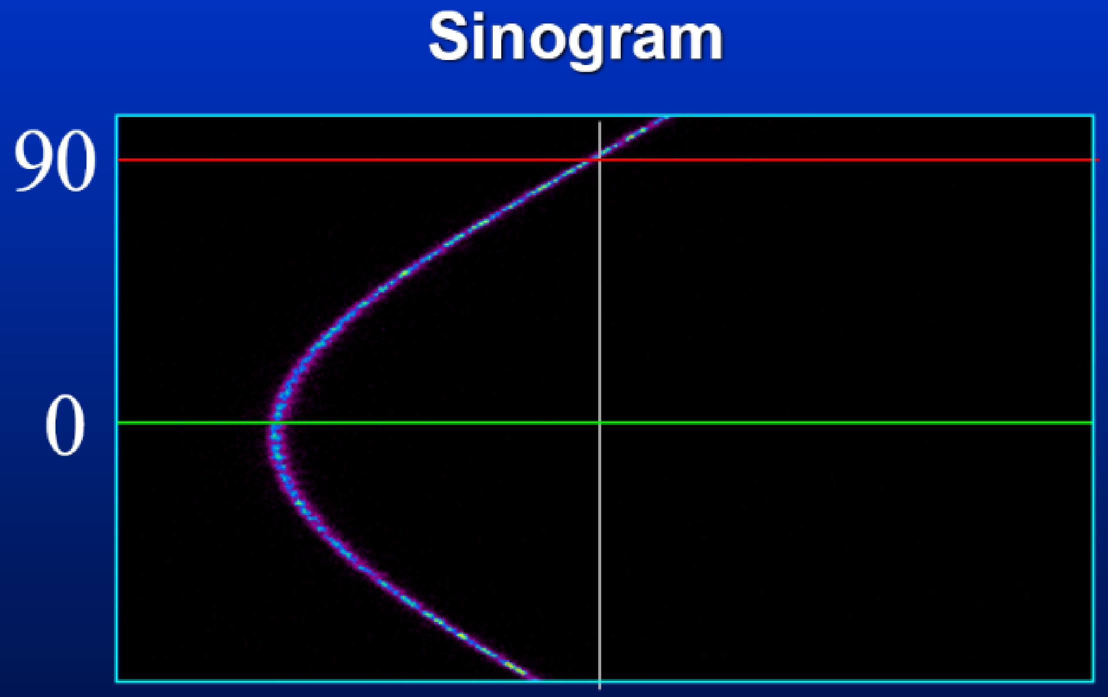
RECONSTRUCTION FROM PROJECTIONS

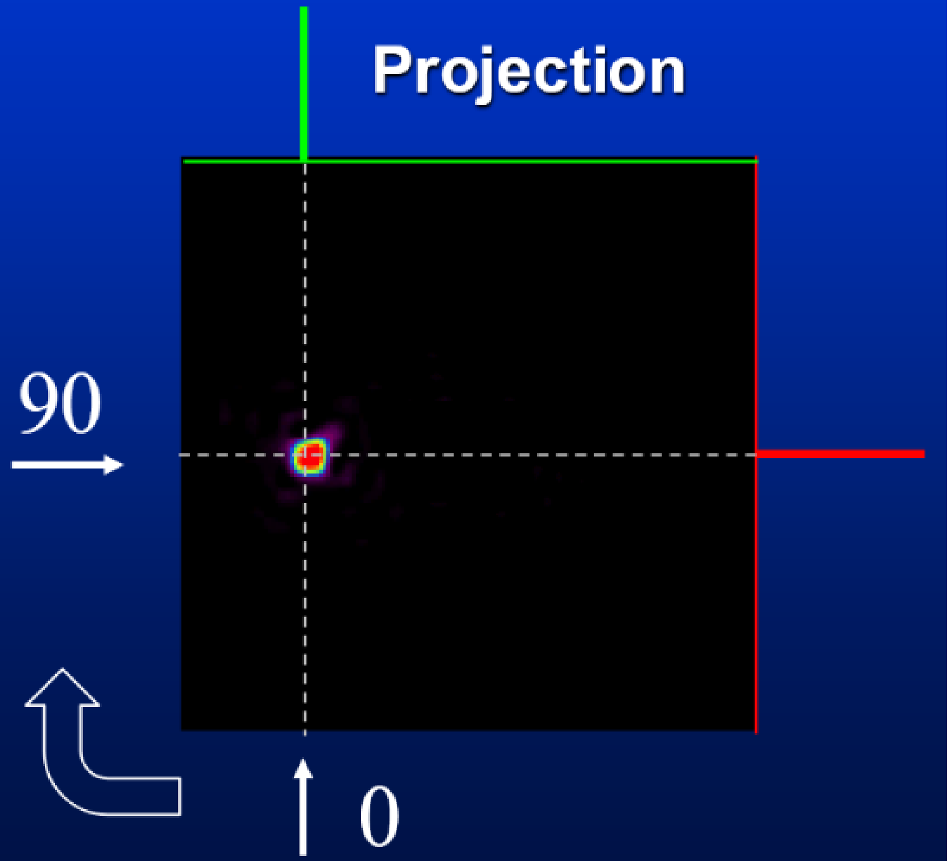
- **Ring of detectors acquires 360 degrees projections of 511 keV photons emitted from patient**



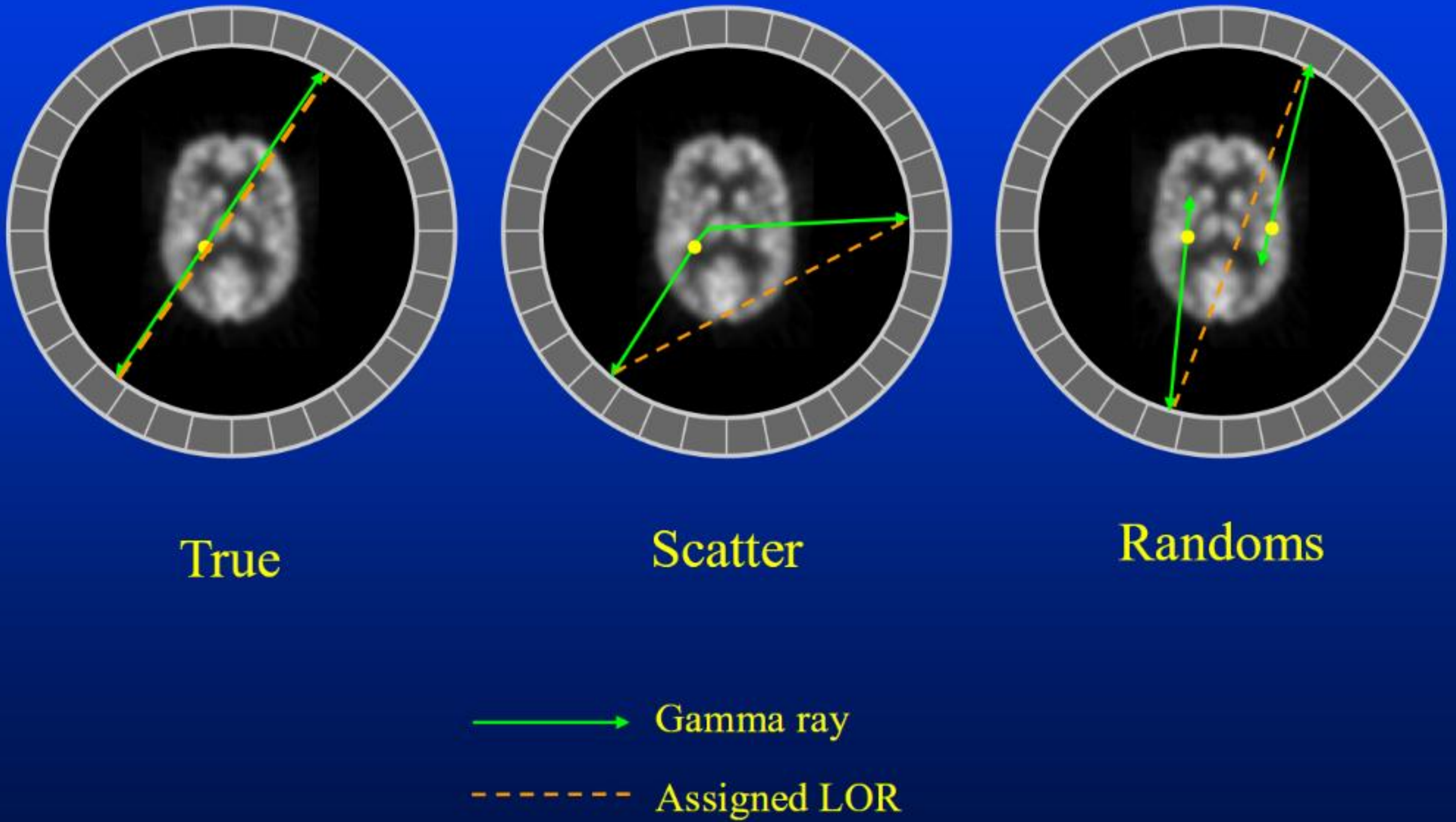
SINOGRAM OF A POINT SOURCE

- Path of a point source follows a sine curve





TYPES OF COINCIDENCE EVENTS



Other Nuclear Imaging

ALL THE THINGS I NEVER SAW

Nuclear Medicine Therapy

- I-131 Radionuclide Therapy
  - Iodine collects in the thyroid gland
  - Small doses can induce cancer in the thyroid, large doses can kill thyroid cancers
  - Accidental exposure can be flushed out of system with non-radioactive iodine (I-127) such as potassium iodide (KI)

The thyroid controls many body processes including heart rate, blood pressure, body temperature and childhood growth and development

I-131 Therapy

- I-131 (administered orally) is intended for:
  - Treating thyroid diseases (ie. hyperthyroidism: 4-10mCi)
  - Treating thyroid carcinomas (100-150mCi)
  - Post thyroidectomy or thyroid lobectomy (75-150mCi)
  - Treatment of distant metastases (150->200mCi)
  - Diagnostic studies (I-131: 4-10µCi or I-123: 100-200 µCi)

- Therapeutic patients:
  - Must avoid contact with pregnant women, infants and young children for a few days post treatment
  - Should not sleep in the same bed with another person for a few days post treatment

Hospitals may quarantine therapeutic patients

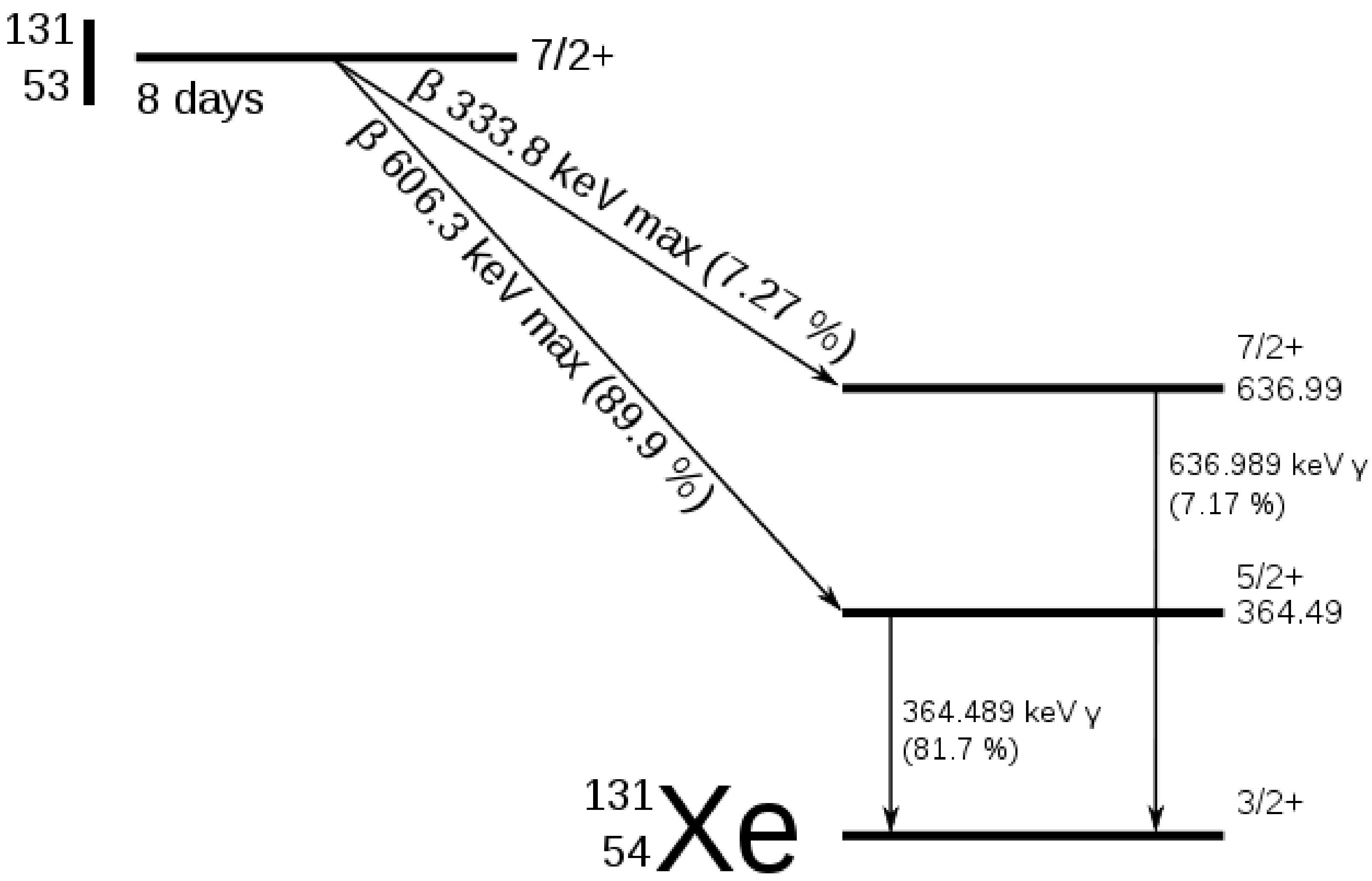
I-131 Therapy

Hospital room setup for a therapeutic I-131 patient

I-131 Therapy

- Beta minus decay
  - 8.01 day half life
  - 90% of Decays have:
    - Max beta particle energy = 606.3keV
    - Average energy of 190keV (~1/3 MaxE)
  - Beta energy absorbed within 0.6 to 2.0mm of tissue thickness
- ~637 keV & 365 keV gamma emitted
  - Can be used for imaging or uptake measurement
  - I-131 is never used solely for diagnostic purposes

I-131 Decay Chart

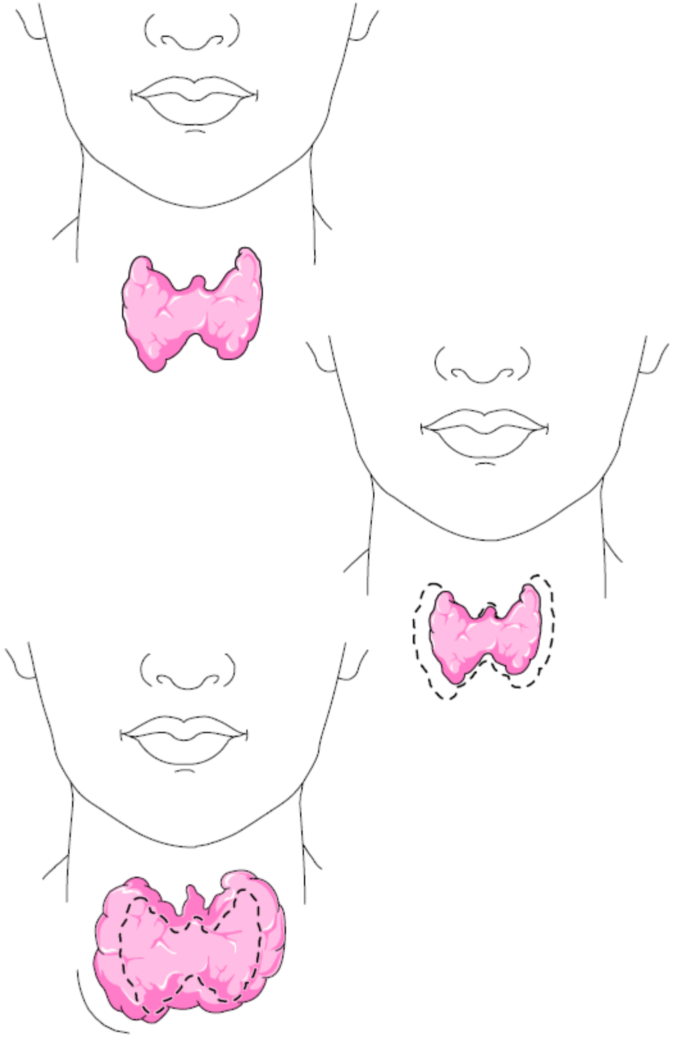


I-123 Diagnostic Studies

- I-123 has a short half-life (13.3hr)
  - I-131 half-life was 8.01 days
  - 97% Beta Minus, 3% EC
  - Emits 159keV gammas
  - Allows for much lower dose to patient
- Patient studies are performed 6-24hrs after ingestion
  - Allows time for accumulation in the thyroid
- Gamma camera's NaI detector is efficient due to the 159keV photons that emitted

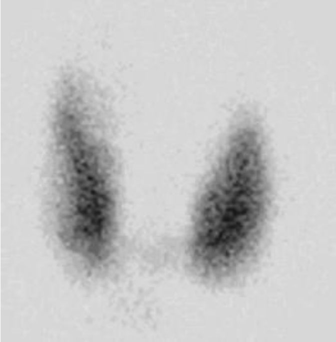
I-123 Diagnostic Studies

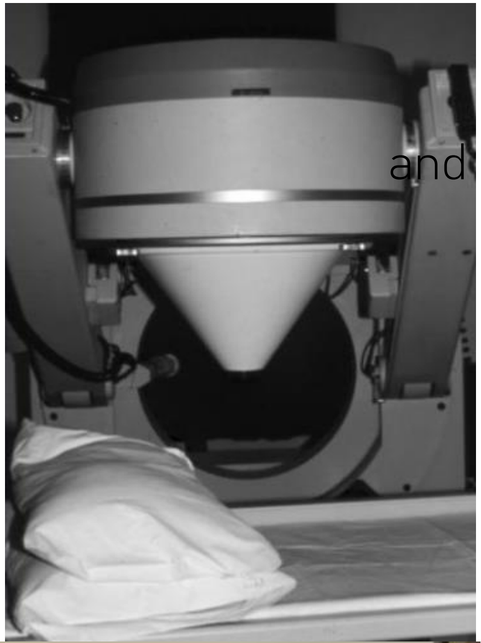
- Thyroid uptake study:
  - Determine thyroid functionality by counting how much radioactivity is taken into the thyroid
  - Normal uptake = 15–25%
    - Hypo: <10%
    - Hyper: >30%
  - Performed using a gamma camera with a **pinhole collimator** or a scintillation detector called a "thyroid probe"



I-123 Diagnostic Studies

- Imaging with Gamma Camera
  - Used to find abnormalities in absorption and uptake of iodine in the thyroid





- Thyroid Uptake Probe
  - Scintillation counting system
  - Used to find uptake of iodine in the thyroid
  - Images are not created with the uptake probe

Iodine Thyroid Uptake Study

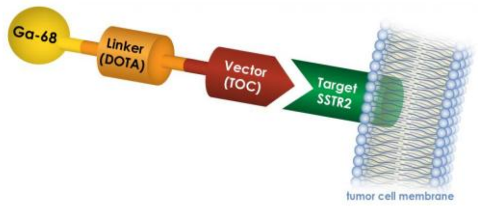
- Radioiodine thyroid uptake:

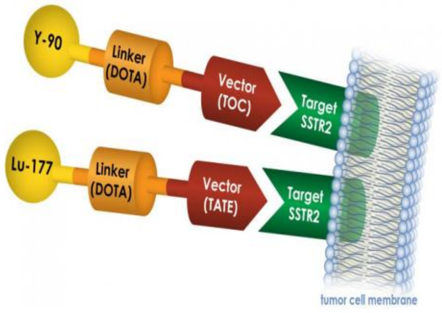
$$\% \boldsymbol{Uptake} = \frac{Neck\ counts\ (cpm) - Thigh\ Counts(cpm)}{Administed\ counts\ (cpm) - Background\ (cpm)} x\ 100\%$$

  - The "administered counts" are found by measuring the ingested dose in a neck phantom and correcting for decay
  - The "thigh counts" subtract out background absorption in the body

Theranostics

- Thera(-peutic / Diag-)nostics
- Links radionuclides to specific receptors
  - SSTR2 – Somatostatin Receptor
    - Expressed in NETs
      - NeuroEndocrine Tumors
- Ga-68 is a positron emitter (PET)
- Lu-177 DOTATATE = “Lutathera”





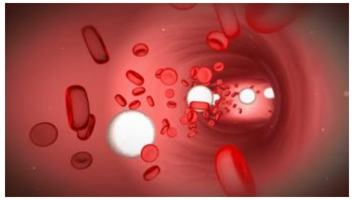
Current Theranostic Treatments of Interest

- Xofigo: Ra-223 Dichloride
  - Bone Metastases following Prostate Cancer
- Unnamed: Lu-177 PSMA
  - Prostate-Specific Metabolic Antigen
- Lutathera
  - GEP (Gastroentero-pancreatic)-NETs
- SIR-Spheres & TheraSphere: Y-90 MicroSpheres
  - HCC (Hepatocellular Carcinoma, a liver cancer)
- Ac-224 PSMA
  - Alpha emitter

Xofigo®
radium-223 dichloride

Advanced Accelerator Applications
LUTATHERA®
(lutetium Lu 177 dotatate)
injection, for intravenous use

SIR-Spheres®
Y-90 resin microspheres



Trends in Theranostics

- What kind of tumors?
- GEP-NET's (small percentage)
- Prostate
    - You'll probably have to work with these someday

Typical workflow in Theranostics

- Radiation Safety Protocol Development
  - Transportation of drug from hot lab to clinic to storage
  - Clinic safety
    - Policies for the room
    - Training of staff (physician through housekeeping)
  - Patient education paperwork
- Package Acceptance, Verification, and Storage
  - Wipe test, check U/mCi, label for tx
- Preparation of Drug for Delivery
- In-Clinic Drug Delivery Assistance
- Cleanup of Room, Radioactive Waste
- Storage and Disposal of Radioactive Waste

Dosimetry in Theranostics

- Xofigo: 1.49 uCi/kg of patient weight sent, delivered in syringe
- Lu-177 PSMA: Measure out 200mCi in a 10cc syringe.
- Lutathera: Standard dose of 200mCi sent in vial, delivered to all patients via gravity method
  - Or, if you're a maverick, via 60cc syringe and a chemotherapy pump