The medical physics and engineering of PET

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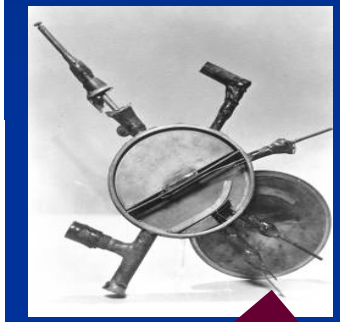
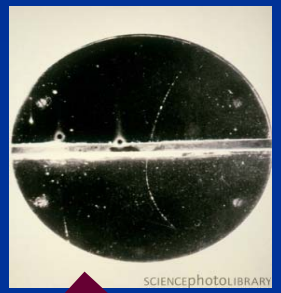
Presentation Overview

- Diagnostic Imaging tools -Overview
- Search for illusive particle – Positron
- Production of artificial radioactive elements – invention of cyclotron
- Physics and Technology of PET and PET/CT
- Experience with commissioning the first PET/CT scanner in Malaysia
- New PET scanners

A Glance at PET History





First PET for human studies
M Phelps, E Hoffman
1974

PET in research

Commercial
PET/CT
2001

Cyclotron
E Lawrence

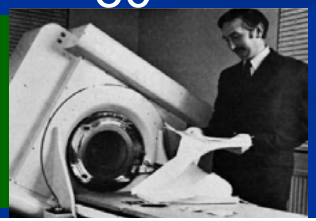
Positron
C Anderson

Clinical
cyclotron

Commercial
PET

1931 1932 70 80 90 2000

First CT
G Hounsfield
1972



Diagnostic Imaging Tools

Overview

Diagnostic Imaging Tools

Modality	Measurement	Information
Computed Tomography (CT)	Photon attenuation	Structure
Magnetic Resonance (MR)	Spin flip time	Structure + Function
Ultrasound (US)	Sound attenuation	Structure
Conventional Nuclear Medicine (NM)	Radioactive tracer uptake	Function
Positron Emission Tomography (PET)	Radioactive tracer uptake	Function
PET/CT		Function + Structure

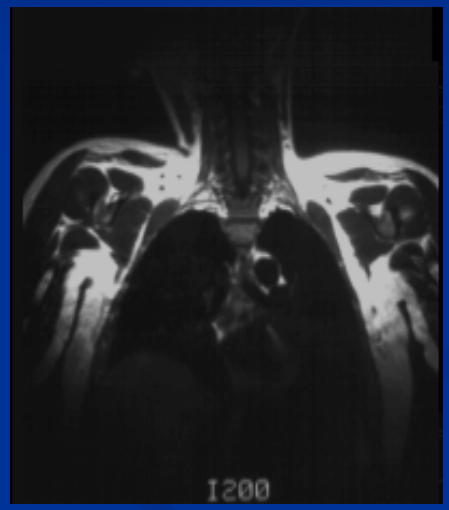
Why PET?

- Isotopes of naturally occurring elements in body (carbon, oxygen, and most commonly fluorine, an analog of hydrogen, and used in FDG)
- High sensitivity
- Uniform high resolution
- Superior attenuation correction
- Superior quantification
- High clinical sensitivity & specificity

Structure vs. Function

X ray

CT



MR

PET

Ca Lung with right adrenal nodule

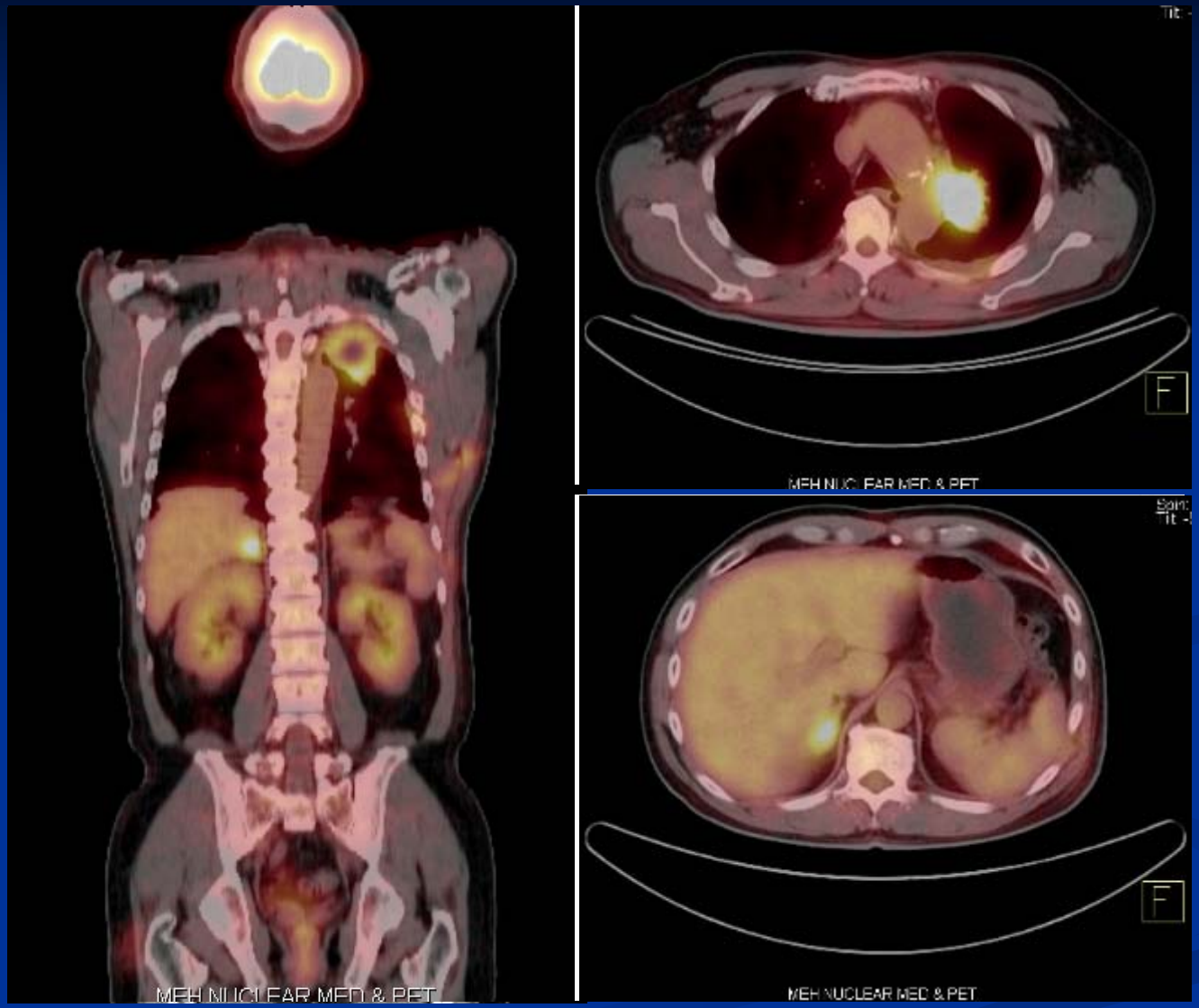
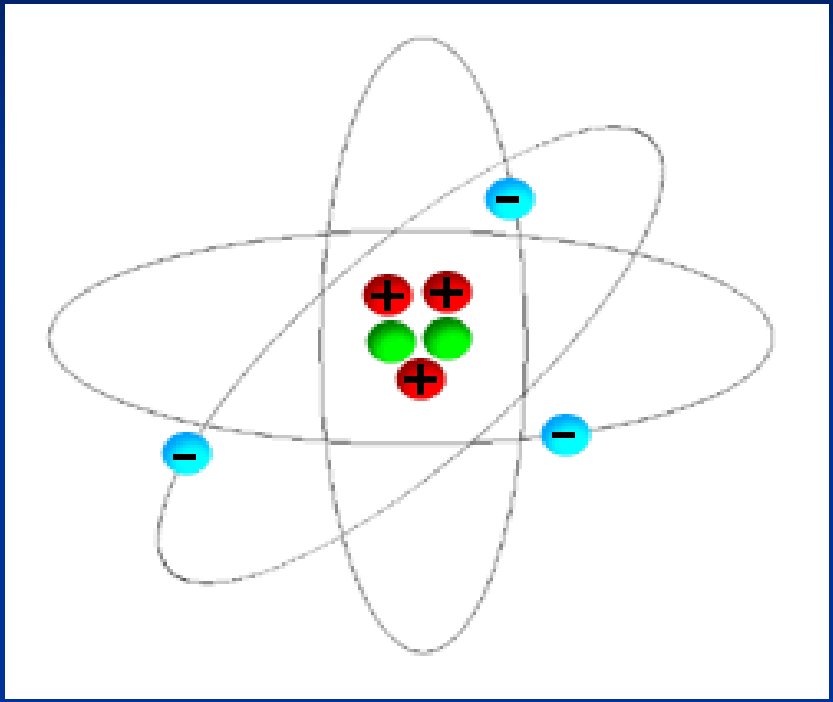


Image Fusion

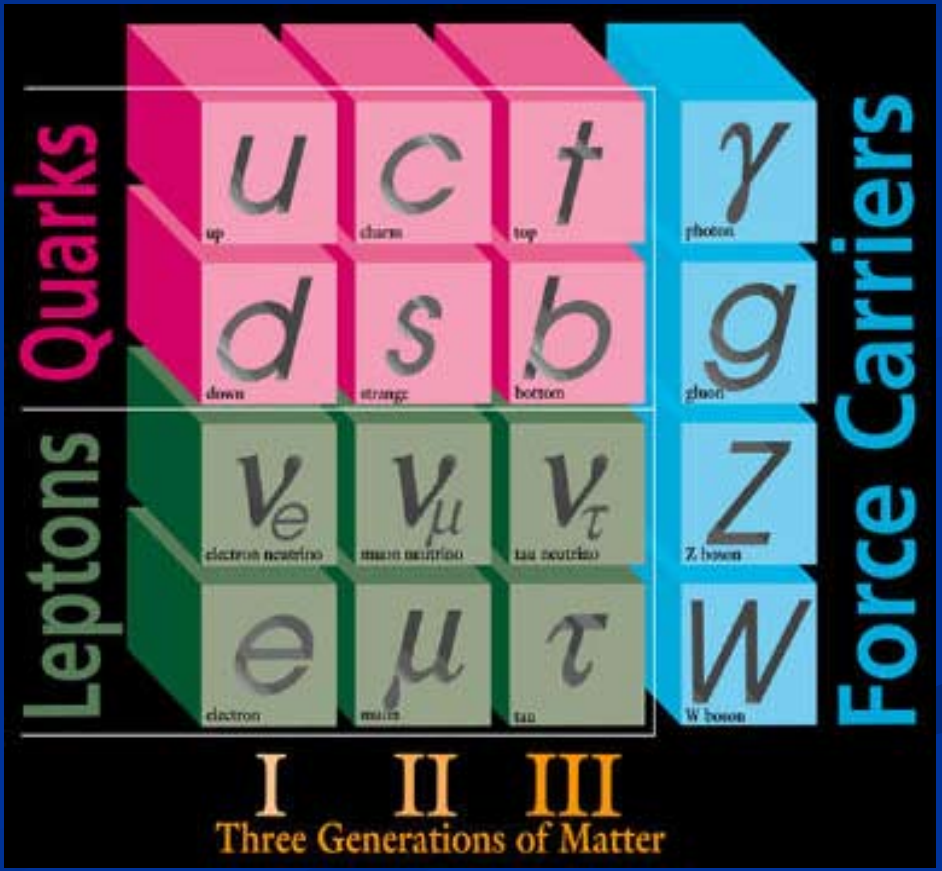
Courtesy of Dr. Shahid Mahmood, Mount Elizabeth Hosp

Search for illusive particle – the Positron

Atomic Structure



What is inside the atom?



Fermilab

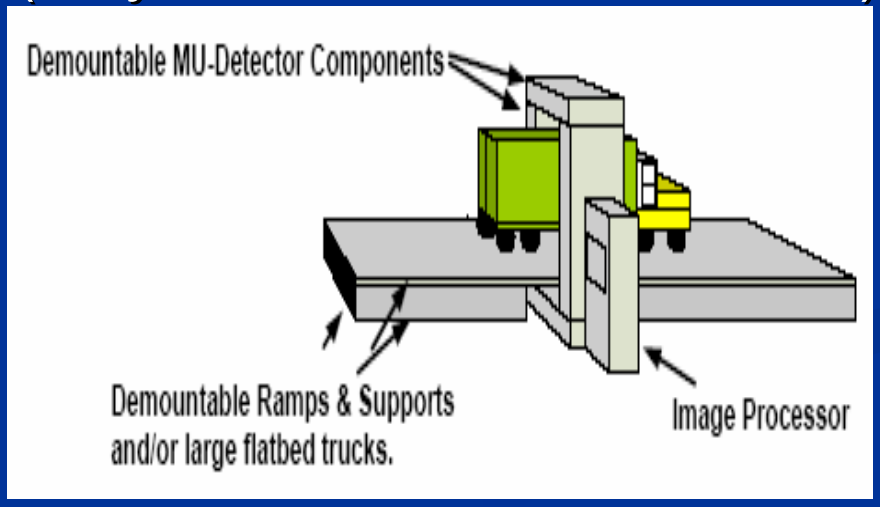
Elementary Particles

- Positron is the first anti-matter particle discovered

  Electron with a + ve charge

- Muon imaging

  (dirty bomb, nuclear materials)



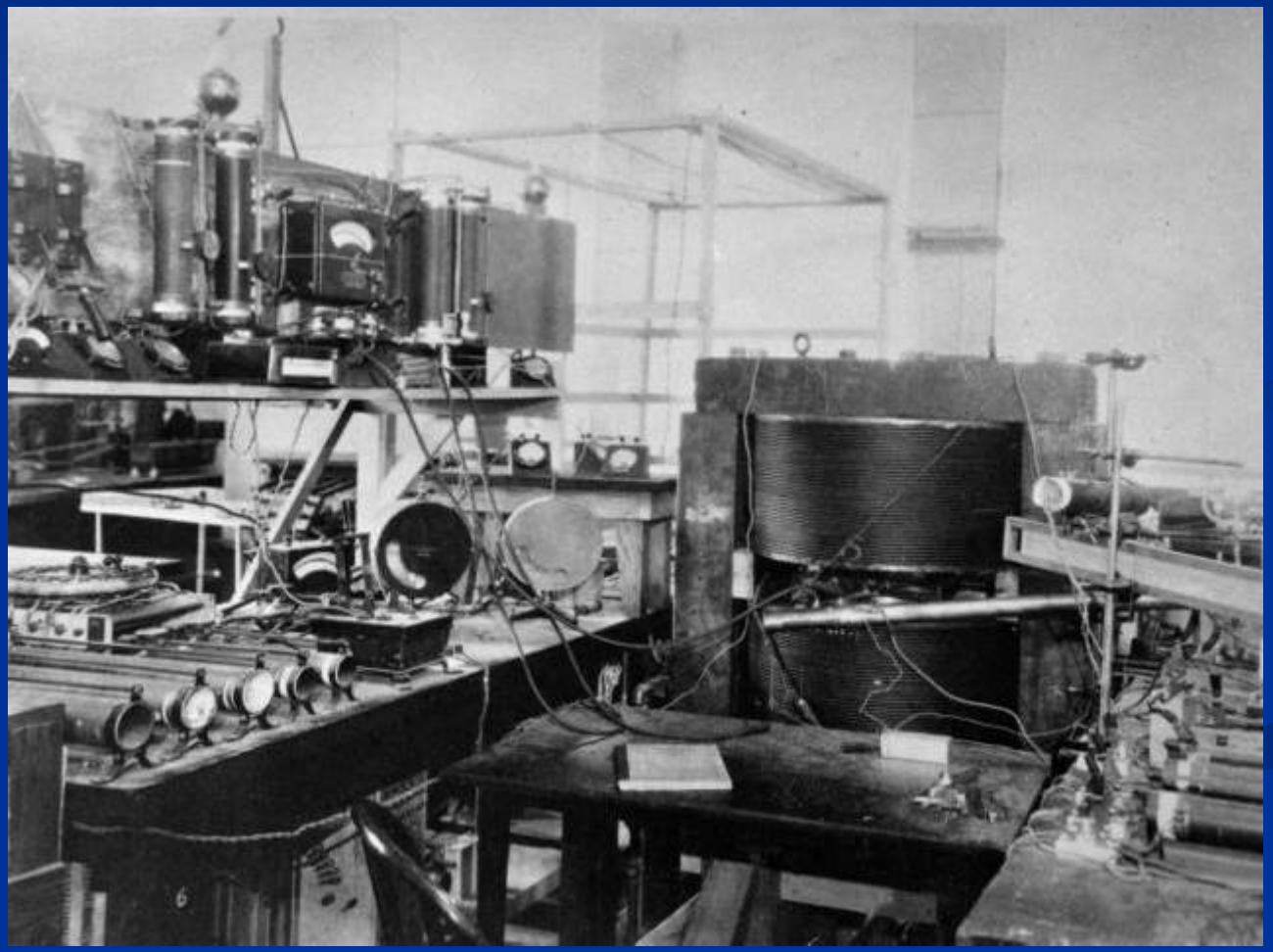
Production of artificial radioactive elements

Invention of the Cyclotron

The First Cyclotron

Ernest Lawrence 1931

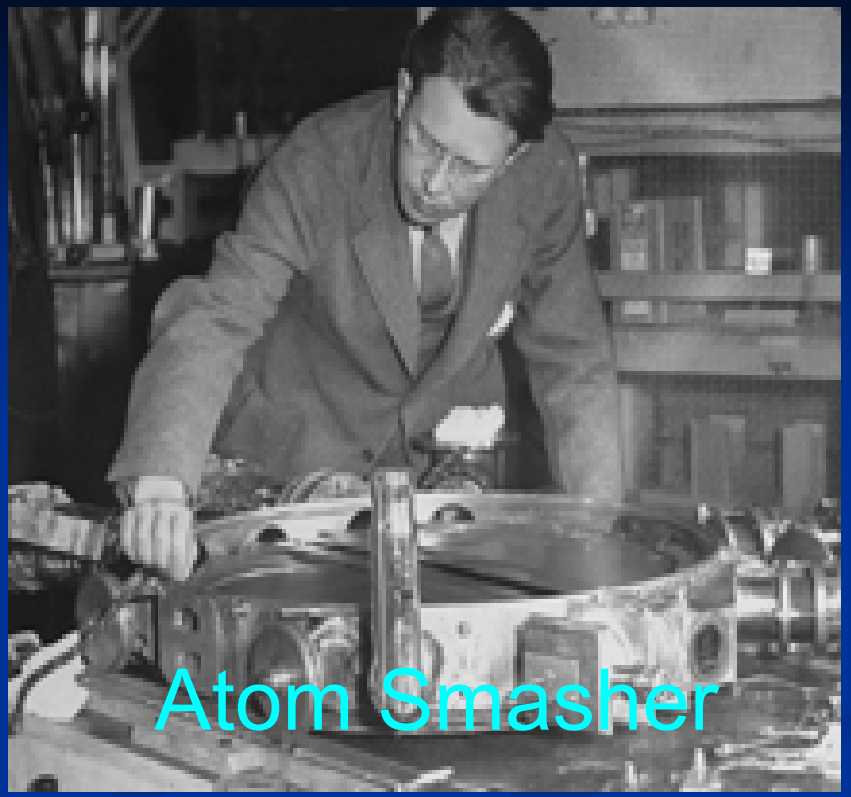
University of California Berkeley



Lawrence Berkeley National Laboratory

"for the invention and development of the cyclotron and especially for the results attained by means of this device in the production of artificial radioactive elements."

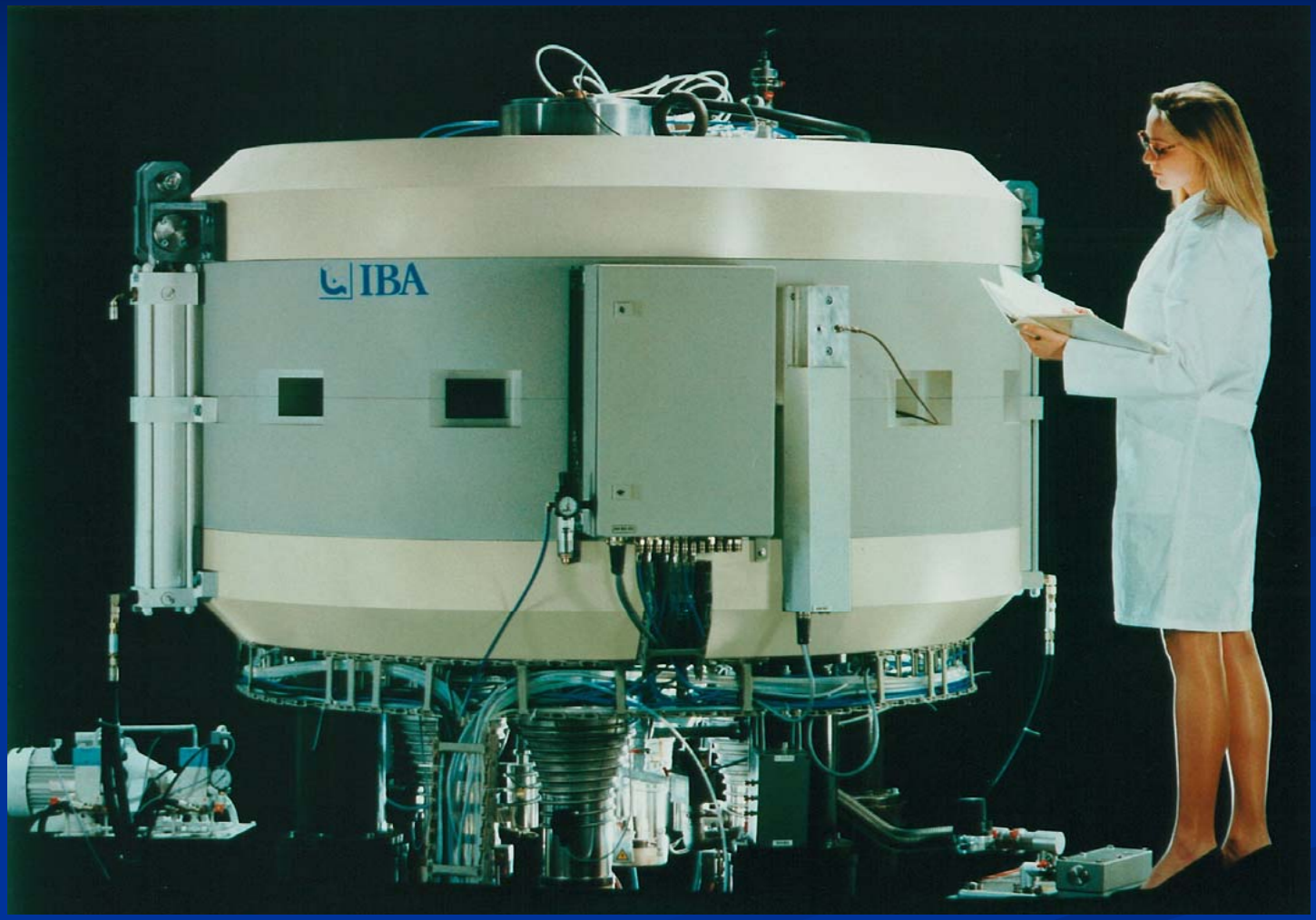
Nobel citation



Ernest O. Lawrence
1901-1958

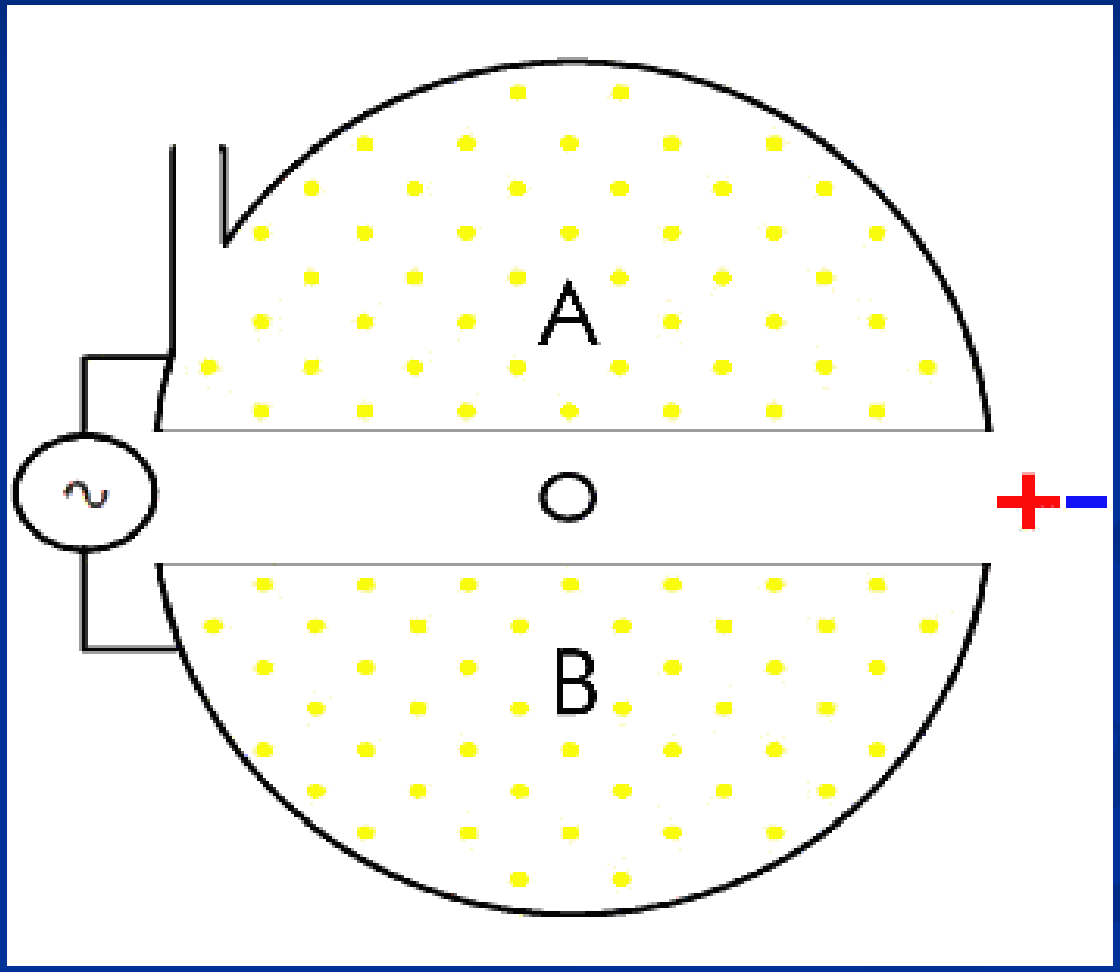
http://www.lbl.gov/Science-Articles/Archive/rev-idea.html

A Modern Cyclotron

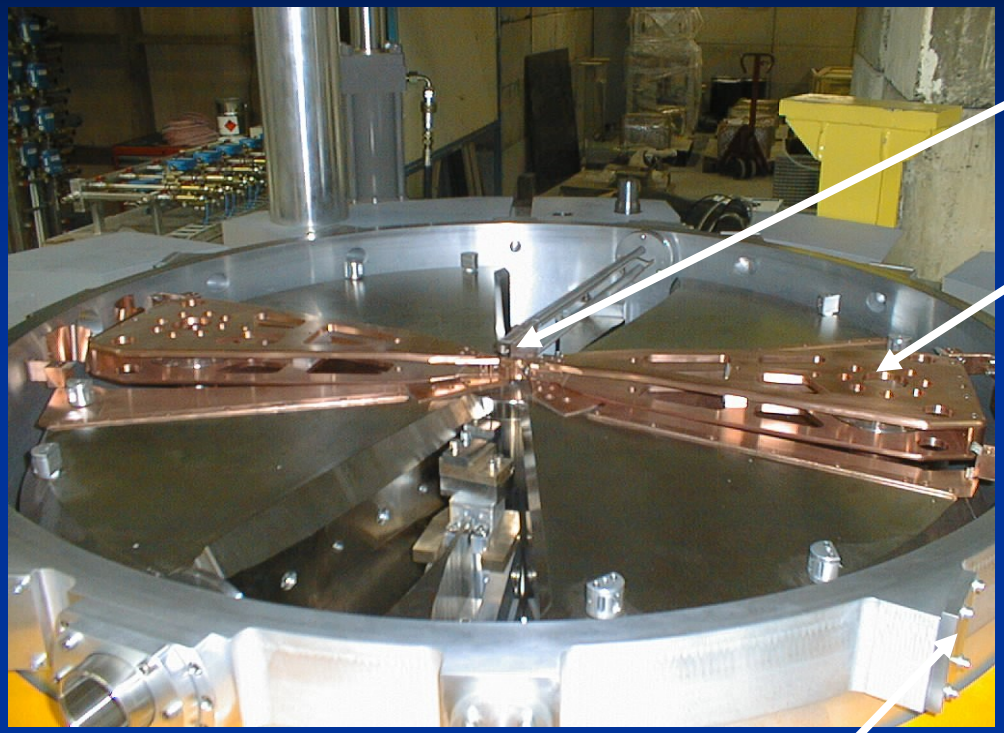


18 MeV protons 9 MeV deuterons

How does a cyclotron work?



Inside the Cyclotron

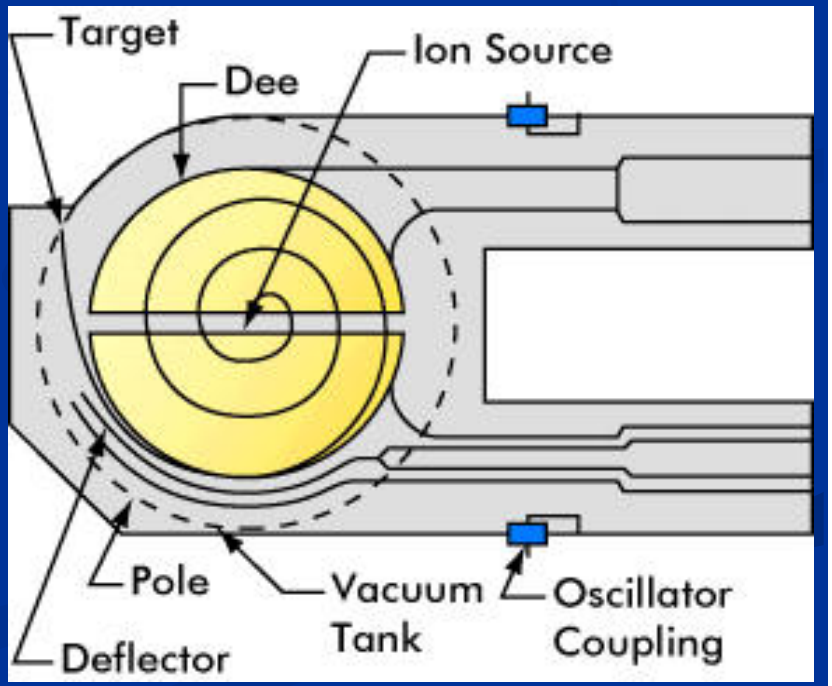


Source

Dees
accelerating electrodes

IBA

Target
irradiation



SLAC

Nuclear reactions taking place

Radioisotope	Reaction	Half life (min)
^{18}F	$^{18}O\ (p,n)^{18}F$	110
^{15}O	$^{14}N\ (p,n)^{15}O$	2
^{13}N	$^{16}O\ (p,\alpha)^{13}N$	20
^{11}C	$^{14}N\ (p,\alpha)^{11}C$	10

“Common” PET Isotopes

Can all be synthesized with proton energy >9.5 MeV

Isotope	Half-life	Target Product	Labelling Applications
^{15}O	2 min	$[^{15}O]O_2$ $[^{15}O]\ CO_2$	O
^{13}N	10 min	$[^{13}N]\ NH_3$	N
^{11}C	20 min	$[^{11}C]CO_2$	C
^{18}F	110 min	$[^{18}F^-]$ $[^{18}F]F_2$	F, H or OH

Source: Roger Price

Other Cyclotron-produced Isotopes

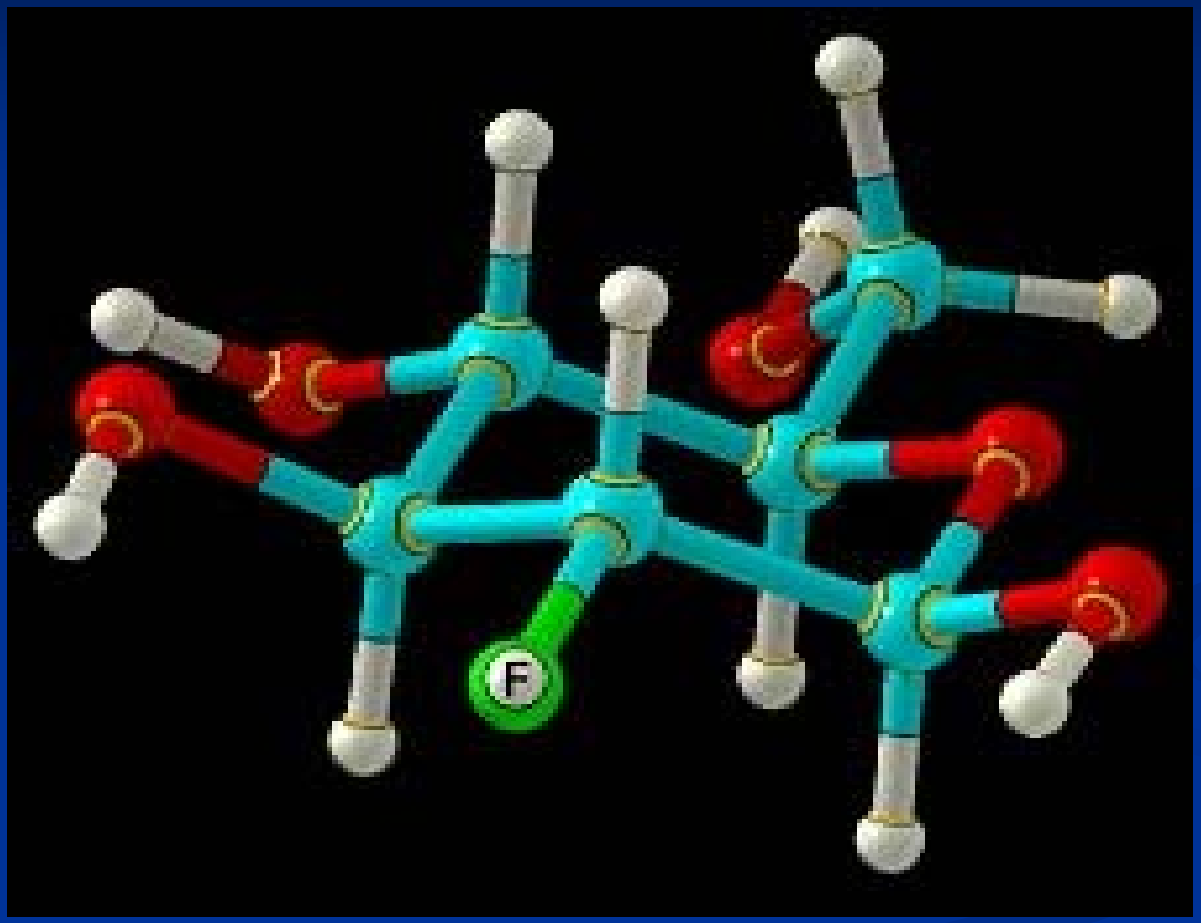
Isotope	Half Life	Application
^{82}Rb (K anal.)	6.2hrs	Blood flow Myocardial perfusion
^{62}Cu	10 min	Blood flow Myocardial infusion
^{68}Ga	68 min	Tumour imaging
^{86}Y	15 hrs	Dosimetry for ^{90}Y
^{96}Tc (not β+)	4.3 days	Cardiology

Physiological Applications

$[^{15}O]\ O_2$	Blood flow (CO_2, H_2O) Blood volume (CO)
$[^{13}N]\ NH_3$	Myocardial blood flow
$[^{11}C]$ CH3-X-R (X = O,N,S)	Neurological function (N- methyl- PK11195; O- methyl - Raclopride; N- methyl- Flumazenil)
$[^{18}F]$	Glucose metabolism (2-Fluoro-2-deoxy-D-glucose, i.e. FDG) Neurotransmitter function (L-6-Fluoro-Dopa)

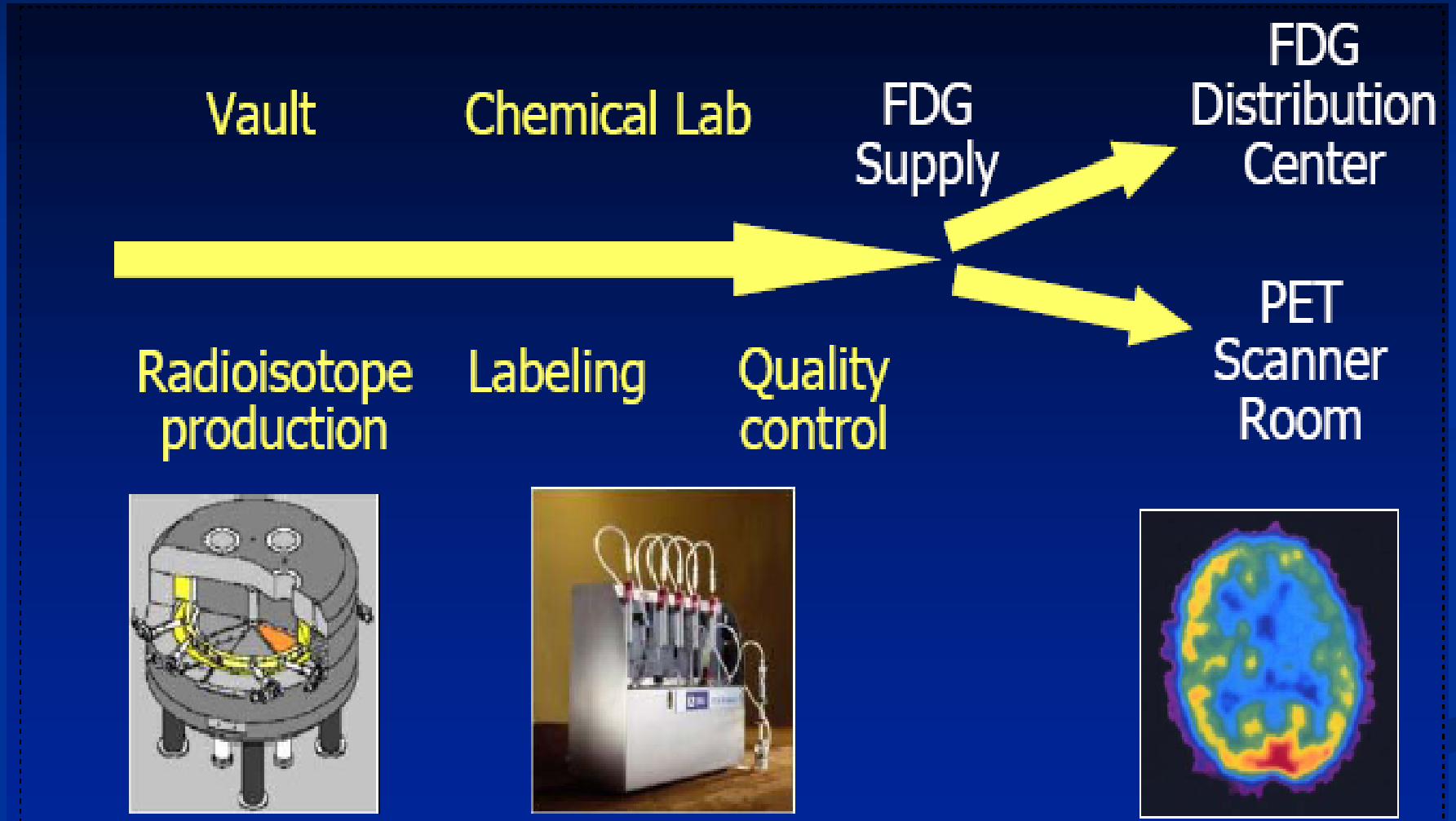
Source: Roger Price

How a FDG molecule looks like



2-deoxy-2-[18F]fluoro-D-glucose

Radioisotope Production & Distribution



Courtesy: IBA

Radioisotope Production

Cyclotron Beam

Target

Target materials

$H_2{}^{18}O$ enriched ($\rightarrow {}^{18}F$)

$H_2{}^{16}O$ natural ($\rightarrow {}^{13}N$)

^{14}N natural ($\rightarrow {}^{11}C$)

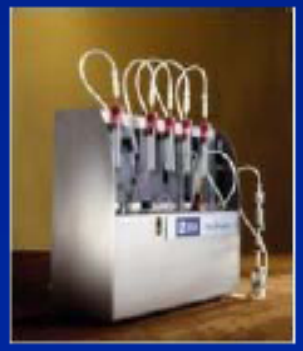
^{14}N natural ($\rightarrow {}^{15}O$)

Radioactive products

^{18}F, ^{13}N, ^{11}C, ^{15}O

Labeled compounds

^{18}FDG, $^{13}NH_3$, $^{11}CO_2$, $^{15}O_2$



Injection

PET Scan

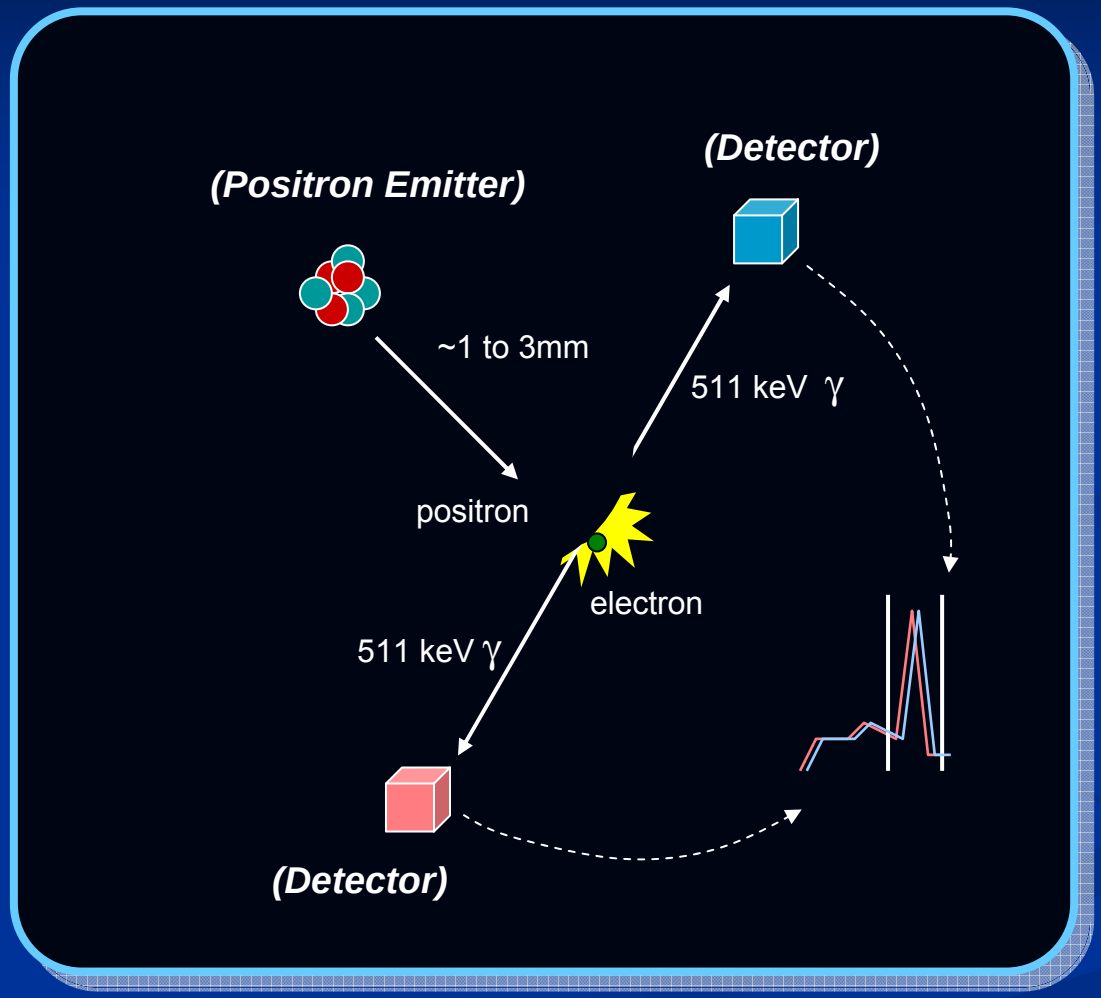
Courtesy: IBA

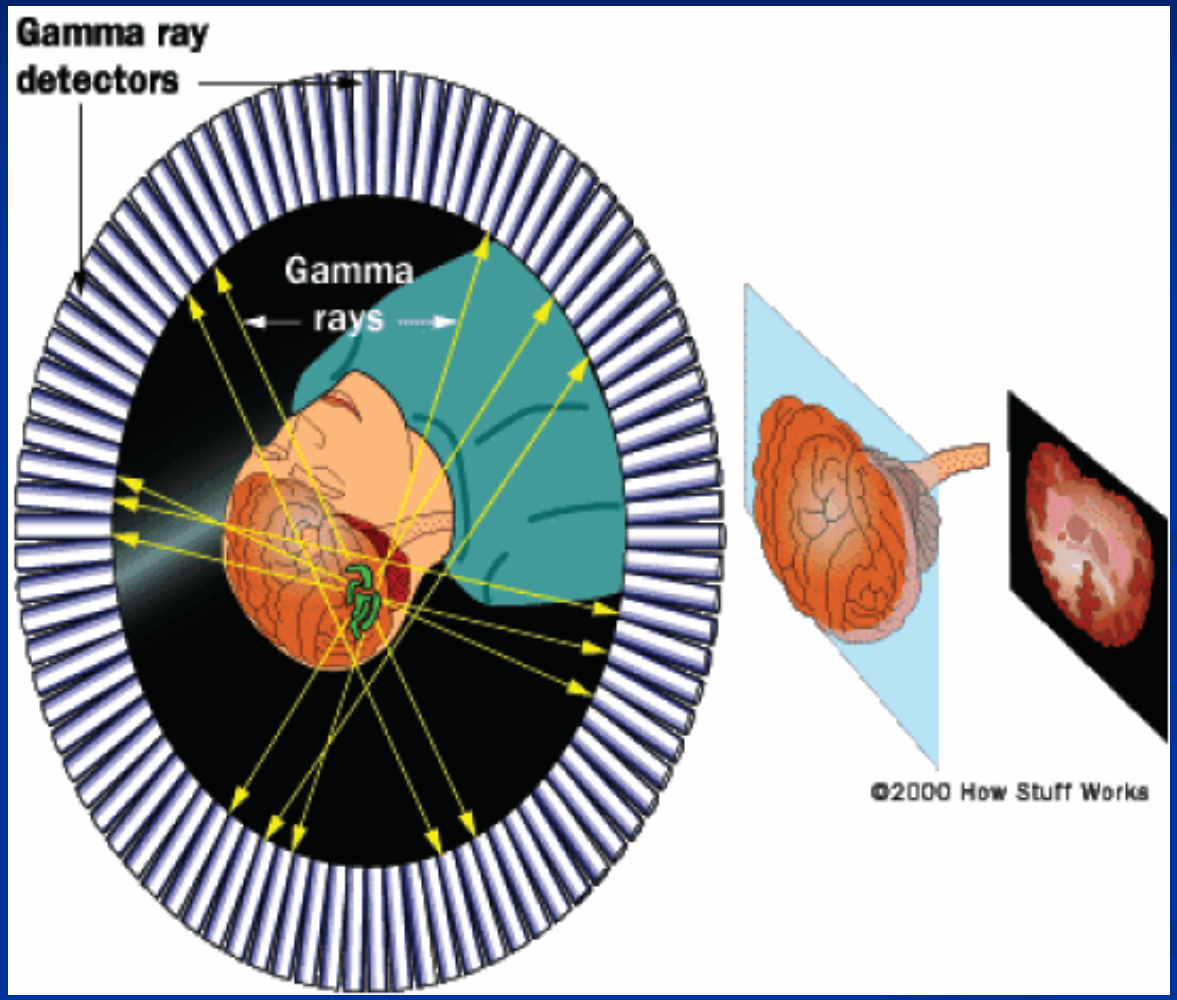
Besides physics, radiochemistry, radio-pharmacy; running a cyclotron requires specialised engineering expertise:

- Vacuum technology
- Radio frequency
- High voltage
- Computing and electronics

Physics and Technology of PET and PET/CT

Essentials of PET Imaging

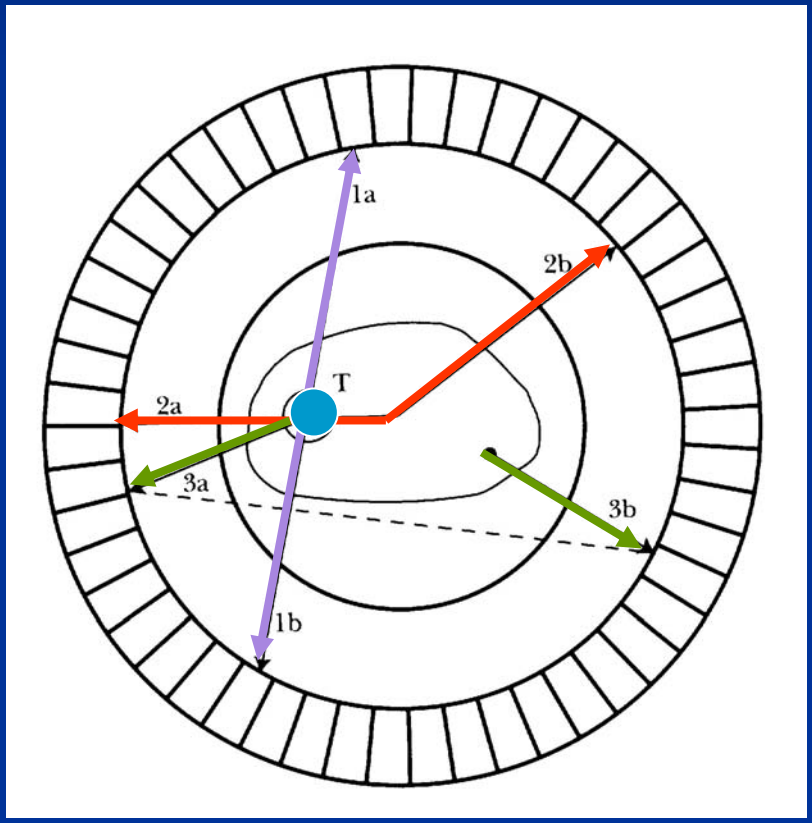




- Positron-emitting radioisotope
- 360º coincidence counting
- Axial rings of detectors

Courtesy of HowStuffWorks

Essentials of PET Imaging



Selecting “pure” colinear coincidence events

- 1a - 1b: ideal coincidence detection
- 2a- 2b, may be rejected by discriminator electronics if scattering angle too high
- 3a, 3b may be rejected because of lack of temporal coincidence, non-colinear geometry, or both.

Courtesy of Roger Price

Current PET/CT models

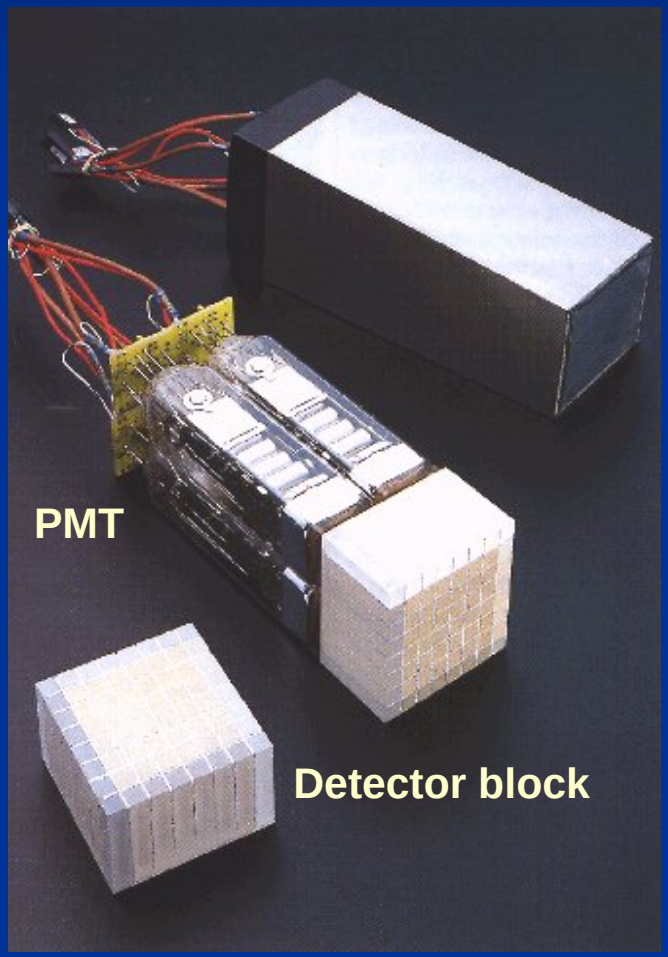
Some Current models

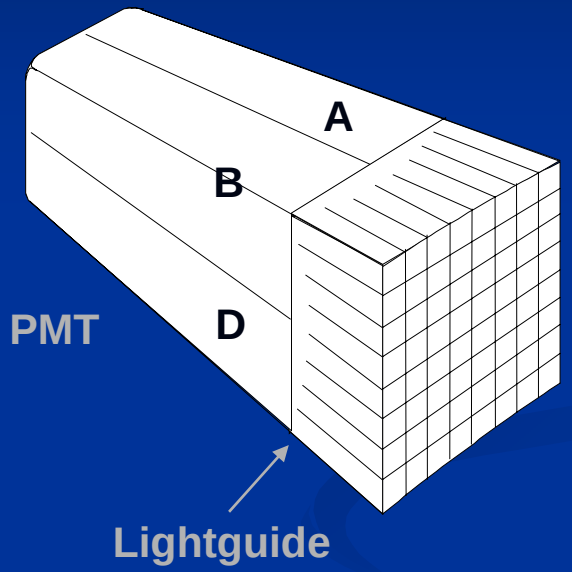
Manufacturer	Product	CT scanner	PET camera	Detector
Siemens	Biograph	Sensation (up to 64 slice)	ECAT ACCEL	**LSO**
GE	Discovery LS, ST	Lightspeed (4, 8, 16 slice)	Discovery ST	**BGO**
Philips	GEMINI	MX8000 (2 slice) Brilliance (16 slice)	Allegro	**GSO**

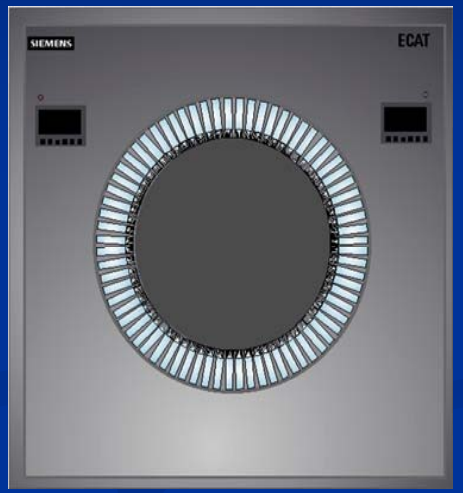
What do the symbols stand for

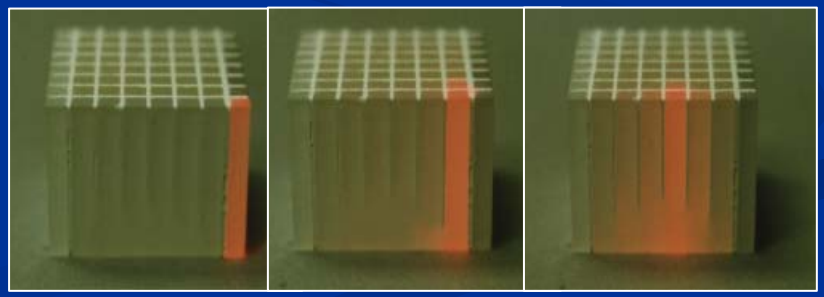
- BGO Bismuth Germanate
- LSO Lutetium Oxyorthosilicate
- GSO Gadolinium Oxyorthosilicate

Scintillation Detectors









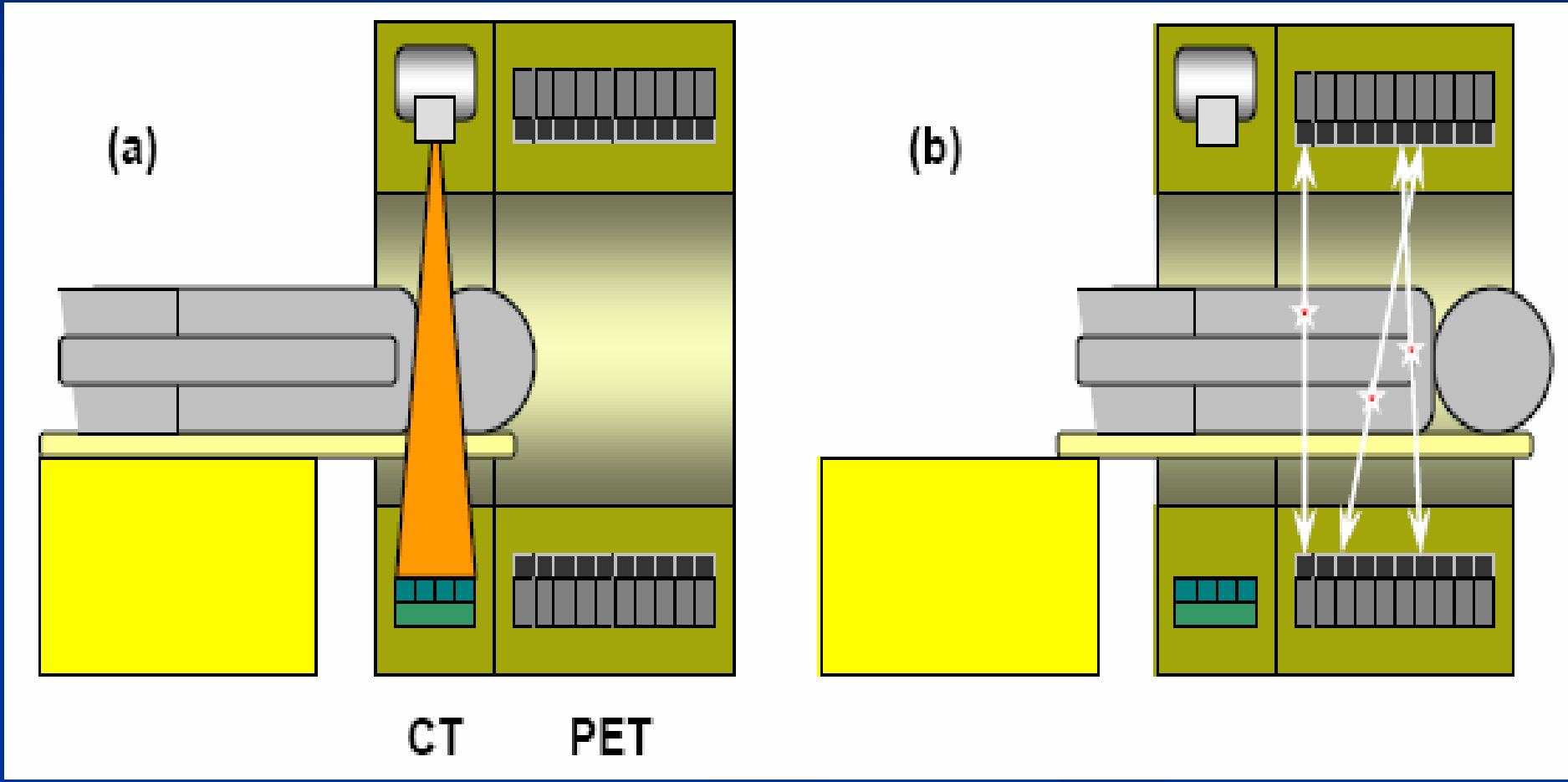
Channeled scintillation light

Courtesy of Siemens

Detector characteristics

- NaI (TI) (1940s)
  - √ *high light output*
  - × *hygroscopic, low atomic number, low density, slow*
- BGO (1970s)
  - √ *high density and atomic number, rugged and non hygroscopic*
  - × *low light output, slow*
- GSO (1980s)
  - √ *high density, fast, non hygroscopic*
  - × *low atomic number, low light output, cleaving*
- LSO (1990s)
  - √ *high light output, fast, high density, high atomic number, rugged, non hygroscopic*
  - × *intrinsic radioactivity*

An example of PET/CT system



Courtesy of ImPACT

Local Experience with commissioning the first PET/CT scanner in Malaysia

Commissioned the first PET/CT scanner in Malaysia, Penang Hospital Jan 26- 29, 2005

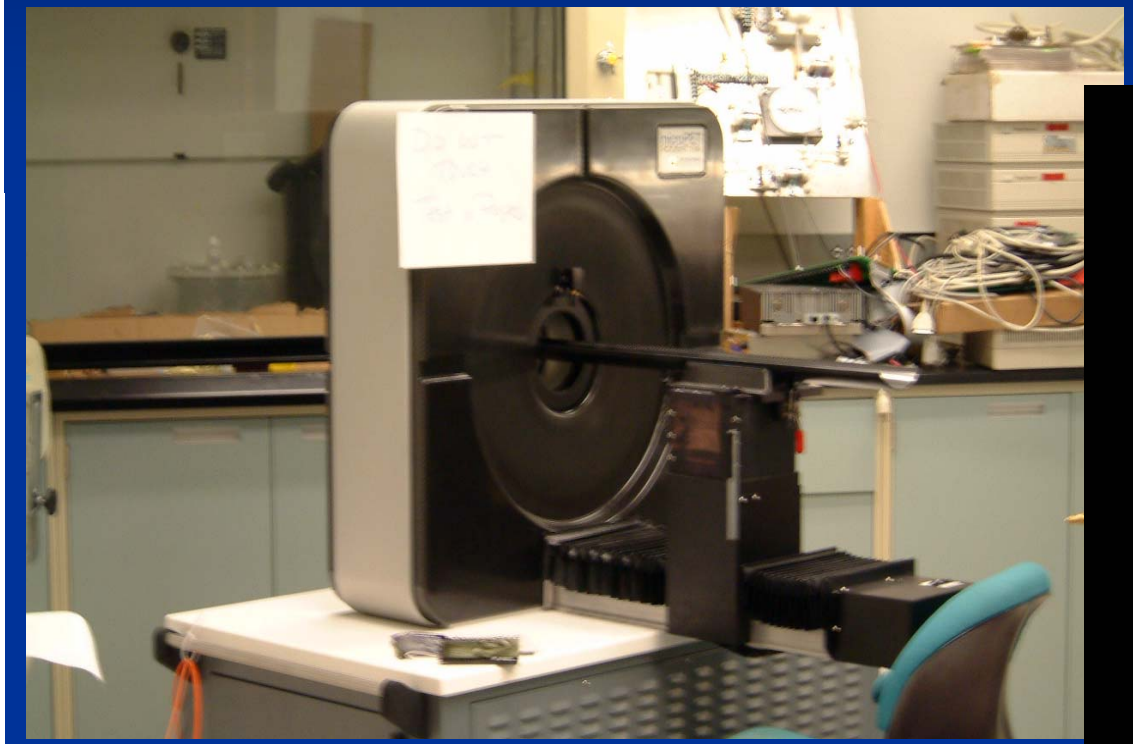
Testing and Commissioning in progress

First consignment of F-18 landed in Malaysia 26 Jan 2005

New PET scanners

microPET – mouse PET

Research in molecular imaging



U Texas Research Imaging Center, SA

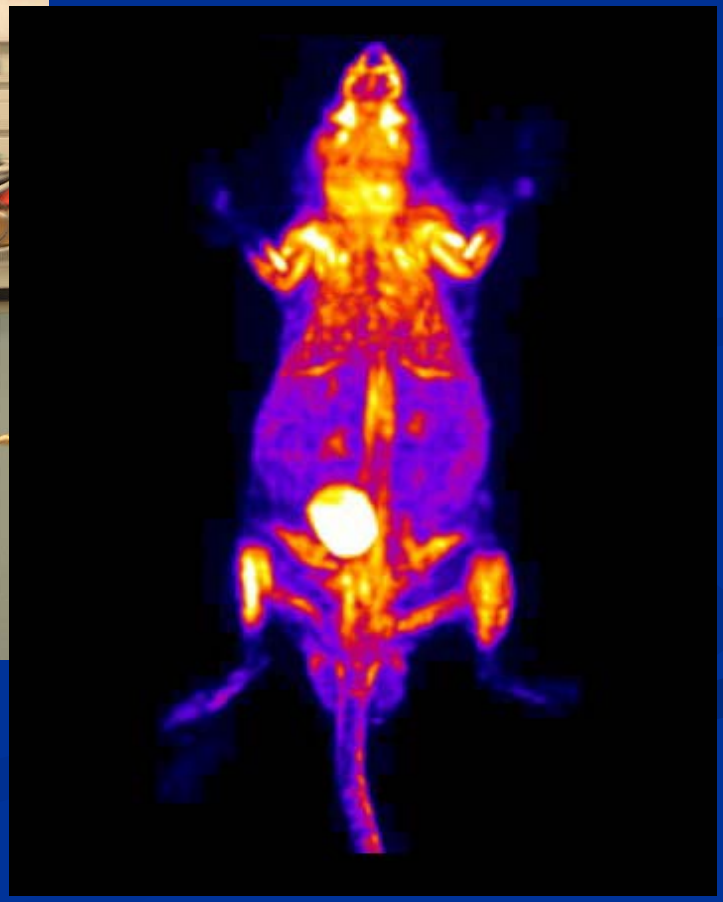
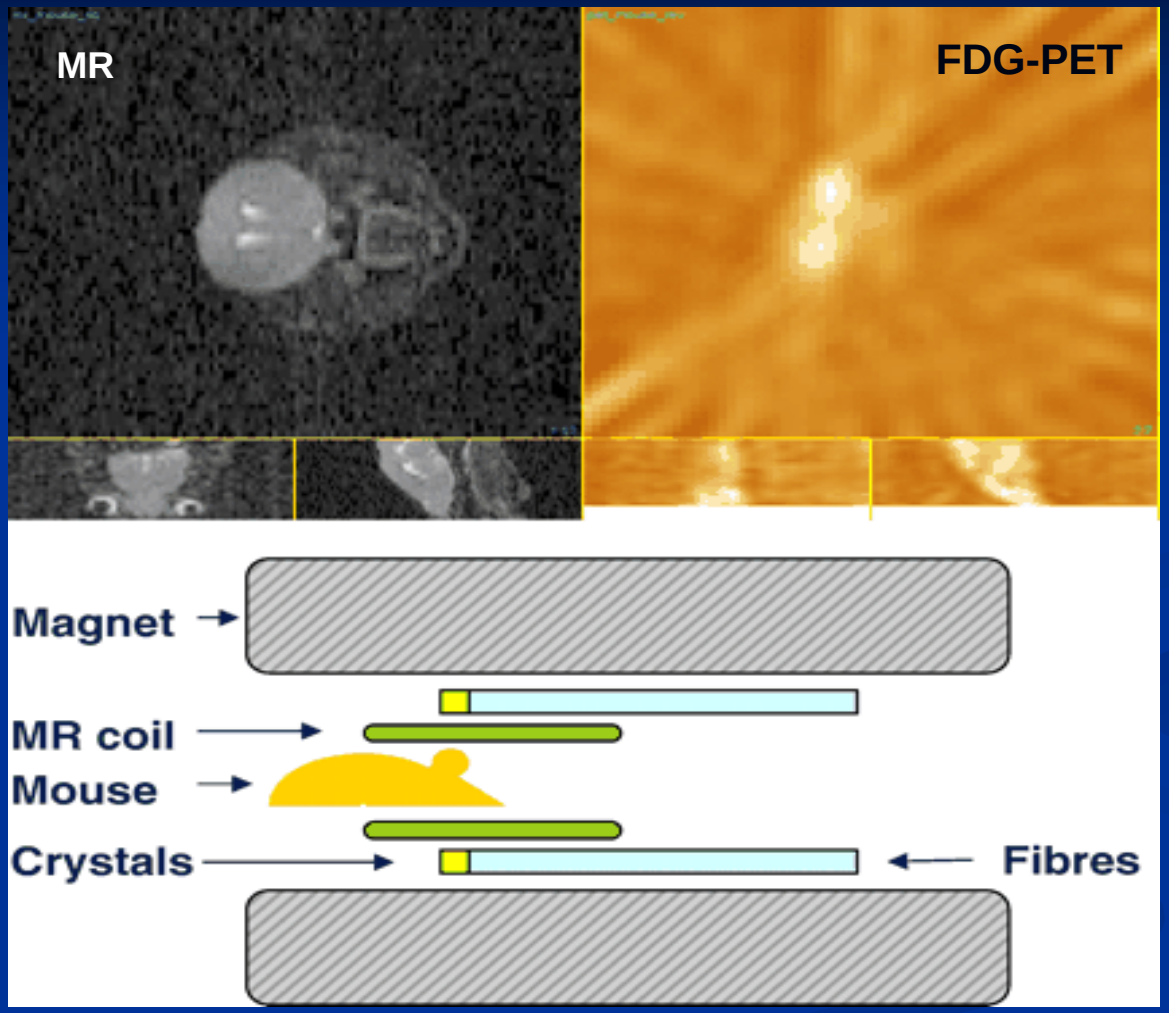


Image courtesy Dr. Martin Pomper, Johns Hopkins

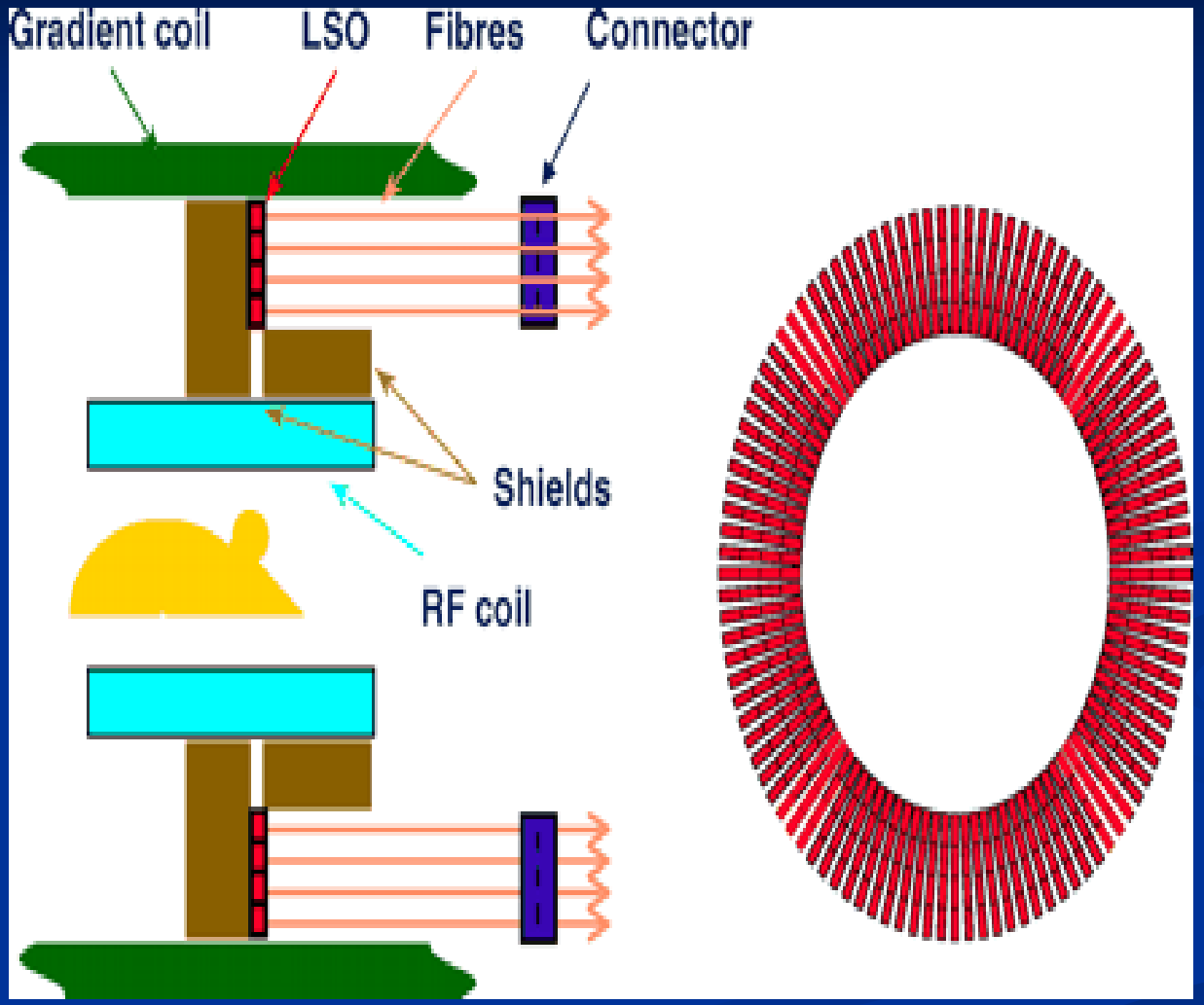
Prototype PET-MR



BJR 75 (2002)

Images of the brain of a mouse. The MR image was acquired in a 4.7T, 30 cm bore MR system. The 3D PET volume image was acquired by stepping the mouse through the PET scanner in 2 mm steps (10 min per step).

Prototype PET-MR



BJR 75 (2002)

A new system currently under construction. This is a multilayer design which has an order of magnitude greater sensitivity than the current prototype, allowing tracer uptake to be followed dynamically for small regions of interest.