Radiation detectors: from particle physics to medicine (*with a bias toward cancer*)

Dr Barbara Camanzi

STFC – UKRI

Rutherford Appleton Laboratory

UKRI Science and Technology Facilities Council

An introduction to myself

- Born and grew up in Ravenna – Italy
- Italy: University of Ferrara
  - Laurea (1990) and PhD (1995) in particle physics
  - Post-doc in medical physics (1995 – 1997)
- UK
  - Brunel University: post-doc in particle physics (1997 – 2002)
  - CCLRC / STFC (RAL): Particle Physics Department (2003 – 2012)
  - University of Oxford: Visiting Lecturer (2009 – 2019)
  - STFC: Cancer Care Strategy Leader (2009 – 2013) and Head of Healthcare (2013 – present)
- Switzerland: CERN
  - Scientific associate (2001 – 2002)

Outline

1. Why medicine?
2. The present
3. The future
4. Summary

1. WHY MEDICINE?

My answer

- Because medicine:
  1. Saves lives
  2. Improve quality of life
- There is a long history of successful applications of particle physics technologies to medicine

From particle physics to medicine

*"From new medicines to cancer treatment, the tools of **particle physics** play an important role in **hospitals** around the world.*
*The same **particle-physics technology** used to understand the universe is also used to improve health and **medicine**."*

K. Izlar, "How particle physics can save your life", Symmetry (2013) available at: http://www.symmetrymagazine.org/article/november-2013/how-particle-physics-can-save-your-life

*"Do you want to see **particle physics** in action? Walk into a **nuclear medicine** department and look around you!"*

Prof P. Evans, University of Surrey

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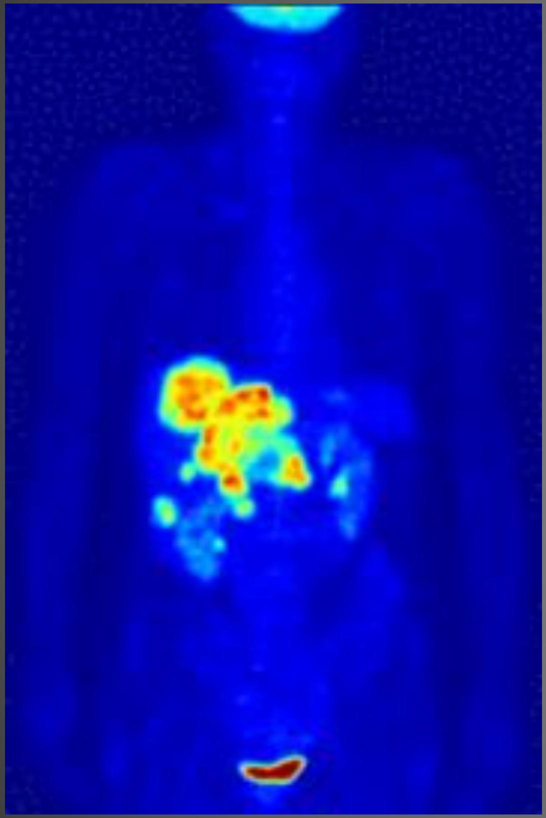
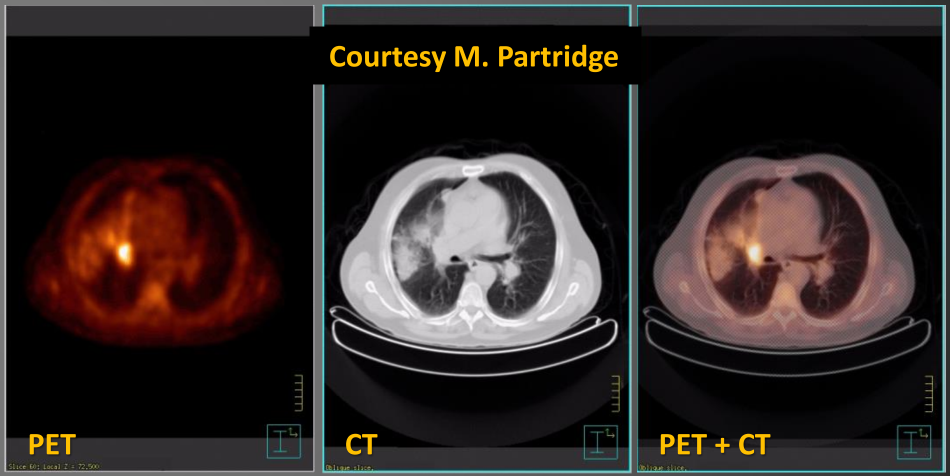
Positron Emission Tomography



- Some of first PET images from CERN in late 1970s

- Multi-modality imaging: PET + CT



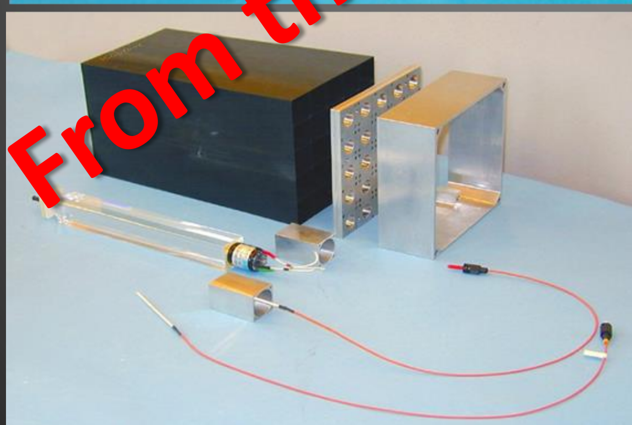
Radiation detectors in medicine

*"The significant advances achieved during the last decades in material properties, **detector** characteristics and high-quality electronic system played an ever-expanding role in different areas of science, such as **high energy**, nuclear **physics** and astrophysics. And had a reflective impact on the development and rapid progress of **radiation detector technologies used in medical imaging**."*

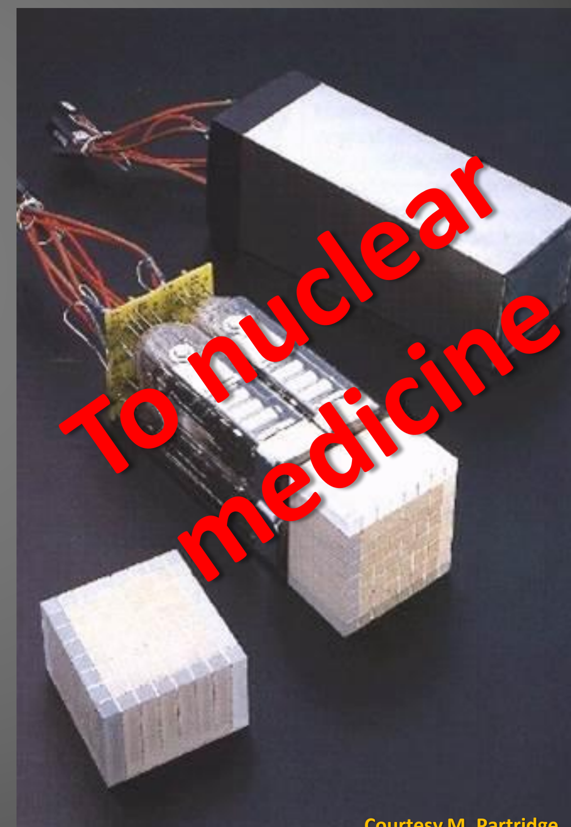
D. G. Darambara, "State-of-the-art radiation detectors for medical imaging: demands and trends", Nucl. Inst. And Meth. A 569 (2006) 153-158

Which is which?

CMS ECAL module



PET scanner module



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2. THE PRESENT

The patient journey

1. Detection/Diagnosis
2. Treatment
3. Post-treatment

Barbara.Camanzi@stfc.ukri.org

Detecting/diagnosing a disease

- Imaging:
  1. Computed Tomography
  2. MRI
  3. Planar X-ray imaging
  4. Positron Emission Tomography
  5. Single Photon Emission CT
  6. Ultrasound

- Endoscopy
- Tests on samples:
  1. Tissue (biopsy)
  2. Blood
  3. Body fluids

Treating cancer with radiation

- External beam radiotherapy:
  1. X-ray beam
  2. Electron beam
  3. Proton/light ion beam
- Internal radiotherapy:
  1. Sealed sources (brachytherapy)
  2. Radiopharmaceuticals
- Binary radiotherapy:
  1. Boron Neutron Capture Therapy (BNCT)
  2. Photon Capture Therapy (PCT)

Detector applications in medicine

- **Detection/diagnosis**
  1. Imaging systems in secondary care

- **Treatment of cancer**
  1. Imaging systems in secondary care for treatment planning and monitoring
  2. Dosimetry
  3. Beam monitoring and Quality Assurance

Detector technologies

Particle physics

- Solid state detectors (Si, diamond)
  (Beam location and abort, vertex reconstruction, tracking)
- Gas detectors
  (Tracking, calorimetry, muon detectors)
- Scintillating materials + photon detectors
  (Calorimetry)

Medical physics

- Detectors for particle physics and medicine have different requirements:
  - Detector for medical application is a *"special detector"* → custom design → avoid the trap of "a solution looking for a problem"

A *"special detector"*: an example

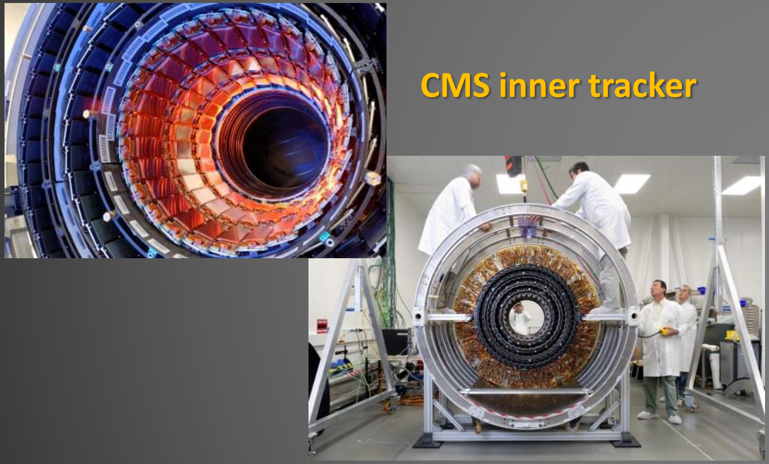
μ-strip silicon detector

	Particle physics	Medical physics
Application	Charged particle tracking	Digital radiology: X-ray imaging
Typical dimensions	5x5 cm^2, thickness ≤ 500 μm	20x20 cm^2, thickness 300 μm ÷ 3 mm
Electronics	For MIP (70 keV in 300 μm): • Low noise: 500 ÷ 1000 e^- • Reasonably fast: 100 ÷ 1000 ns • VLSI	For X-rays (down to 10 keV): • Low noise: 200 e^- • Fast: 10 ÷ 100 ns • VLSI
Trigger	External trigger	Self-triggering
DAQ	For collider: • Low multiplicity • Fast acquisition	For digital radiology: • 5×10^4 Hz/mm^2 → 2×10^9 Hz on 20x20 cm^2 • 1 s acquisition time
N. of channels	$10^5 \div 10^7$	$10^3 \div 10^4$
Event size	10^6 bytes (raw data, level 1 trigger)	1 bit – 10 bytes
Sellable units	1 (maybe 2!)	$10^3 \div 10^6$

Solid-state detectors

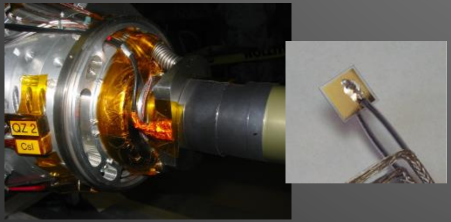
In particle physics

- Silicon detectors for tracking, beam location and vertex reconstruction



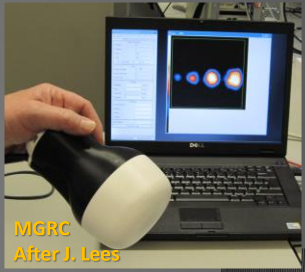
CMS inner tracker

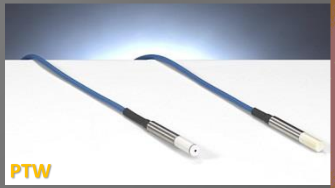
- Diamond detectors for the beam-abort system in BaBar

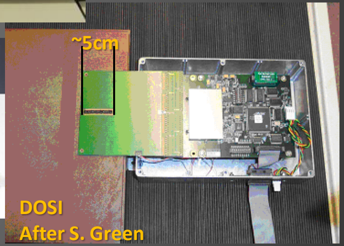


In medicine

- Silicon detectors for imaging, dosimetry and beam location





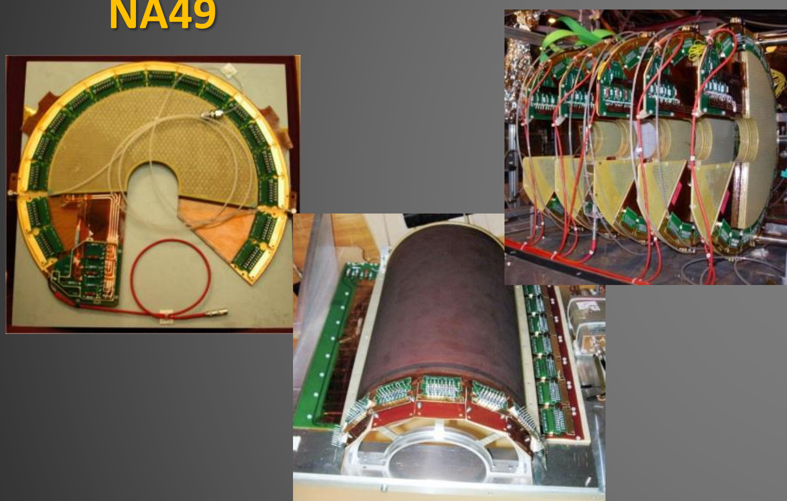


- Diamond detectors for dosimetry

Gas detectors

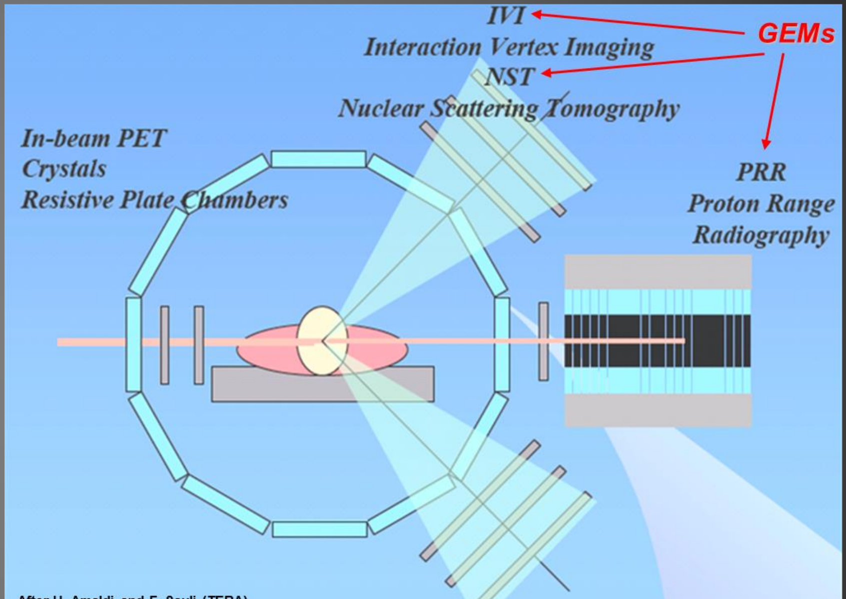
In particle physics

- Gas Electron Multipliers (GEMs): used in TOTEM, COMPASS and NA49



- Resistive Plate Chambers: used in ALICE

In medicine



After U. Amaldi and F. Sauli (TERA)

- Full imaging system for proton beam radiotherapy proposed by U. Amaldi and F. Sauli using GEM detectors and Resistive Plate Chambers

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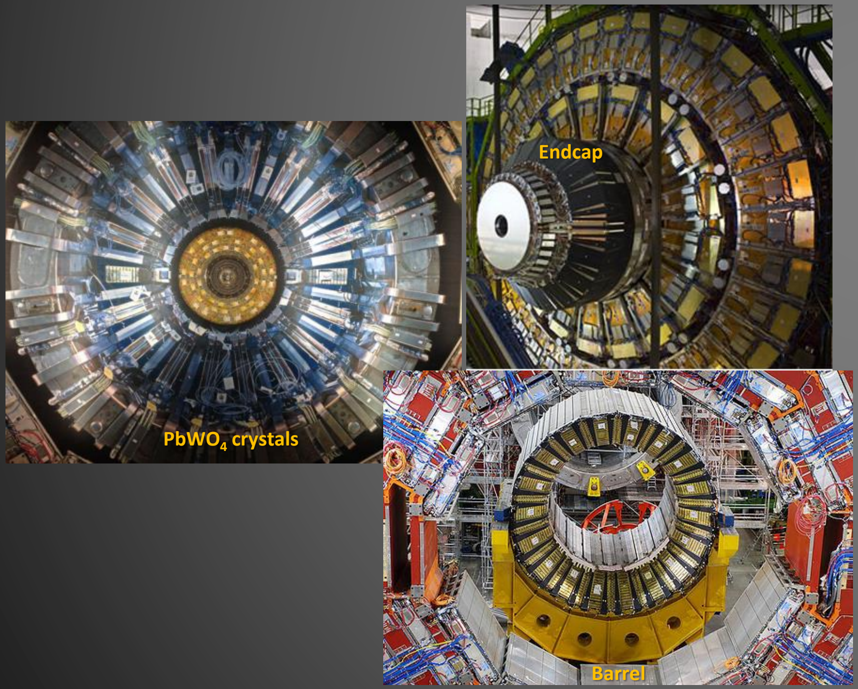
Scintillators and photon detectors

In particle physics

- Various scintillating materials and photon detectors used for calorimetry systems

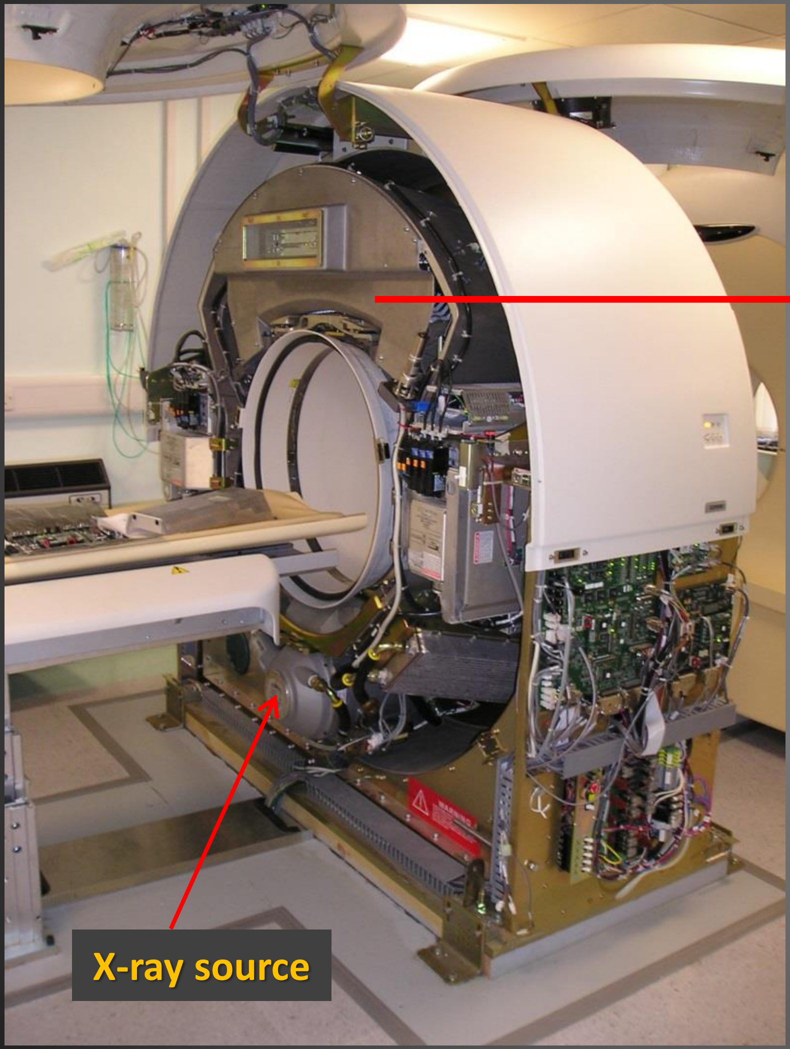


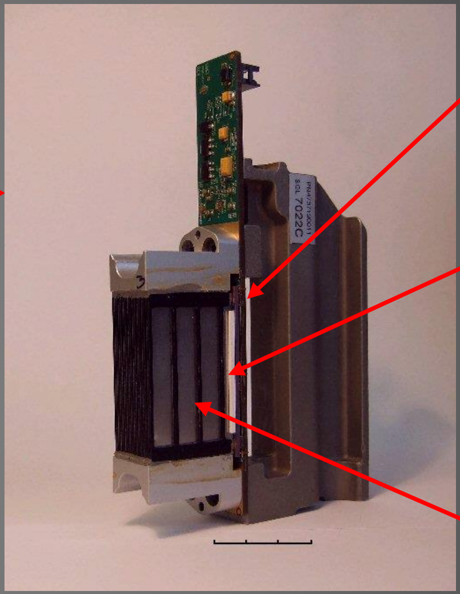
CMS ECAL

In medicine

- Various scintillating materials and photon detectors used in nuclear medicine imaging:
  1. Computed Tomography (CT)
  2. Positron Emission Tomography
  3. Single Photon Emission CT

Computed Tomography





CT scanner:

- 120 keV X-ray source
- Diametrically opposite detector unit
- X-ray source and detector unit rotate around the patient

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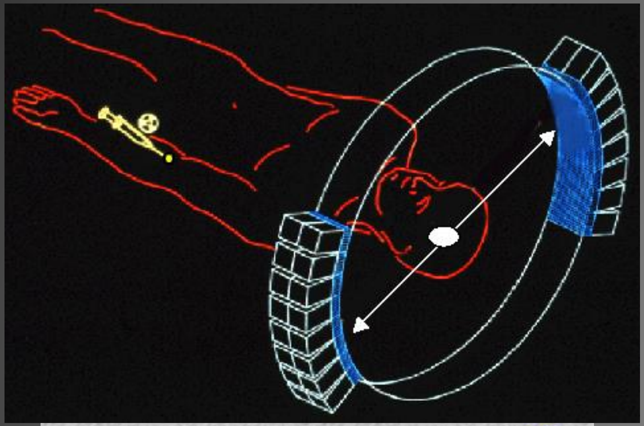
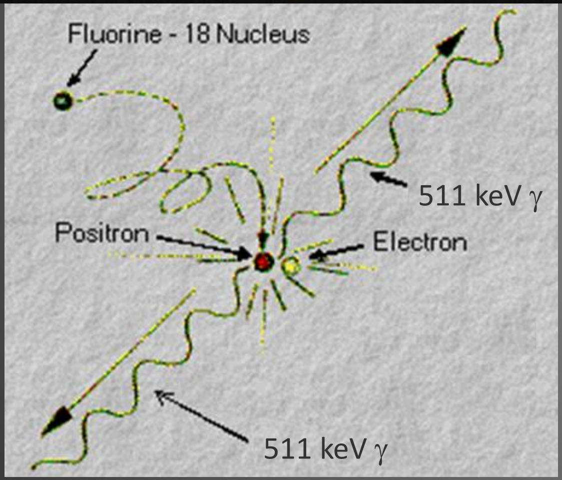
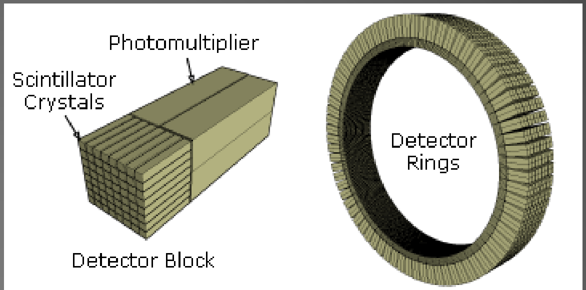
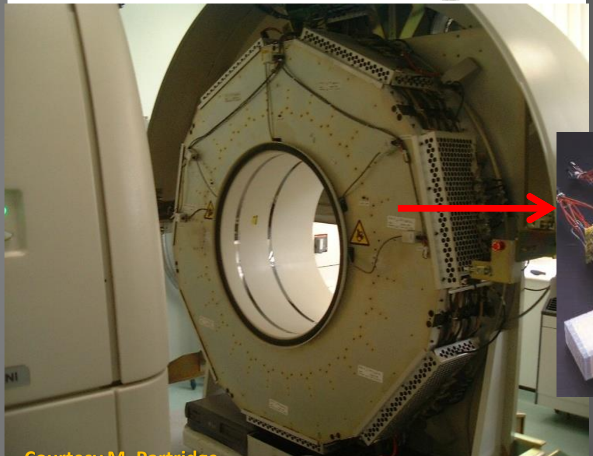
Positron Emission Tomography









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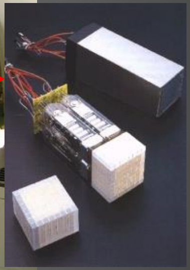
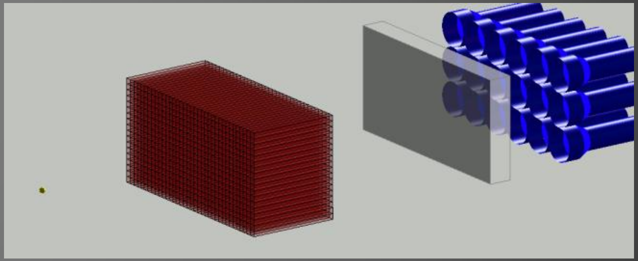


PET scanner:

- **Source = β^+ emitter injected into body → two back-to-back 511 keV γ from positronium decay**
- **Stationary rings of detectors**

Single Photon Emission CT



SPECT scanner:

- Source = $^{99}Tc^{m}$ injected into body → one 141 keV γ
- Two or three rotating detector heads
- Each head = gamma camera

3. THE FUTURE

The future: precision medicine

- The future is precision medicine, but what is it?
  - Intervention targeted to each individual, no more one size fits all
  - Better quality of life during and after intervention
- Particle physics can help by providing new detectors for:
  1. Better and earlier diagnosis
  2. Better radiotherapy treatments
  3. Better patient monitoring

Better and earlier diagnosis

- The challenge = the sooner a disease is diagnosed the higher the probability of cure
- Novel detector technologies are needed for:
  - Improved anatomical imaging systems for screening
  - Reliable and (low-tech) easy to use systems for early diagnosis in primary care
  - More accurate, more quantitative and highly repeatable imaging, with less associated dose for functional imaging systems for diagnosis in secondary care

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Better radiotherapy treatments

- The challenge = provide radiotherapy that achieves higher local tumour control + less side-effects, including lower probability of secondary cancer
- Novel detector technologies are needed for:
  - Low-dose, high-quality imaging for Image Guided RadioTherapy (IGRT), organ motion management and treatment planning
  - Beam monitoring and Quality Assurance
  - Dosimetry

Barbara.Camanzi@stfc.ukri.org
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Better patient monitoring

- The challenge = patients need to be followed-up:
  - Short-term: to monitor the response to treatment
  - Long-term: to check for late effects (and other diseases/secondary tumours)
- Novel detector technologies are needed for:
  - Low-dose, high-quality imaging systems
  - High throughput

4. SUMMARY

Summary

- In its quest for uncovering the secrets of the Universe, particle physics has been and is pushing the limits of a large variety of detector technologies
- The application of these technologies to medicine has already had a great impact
- The future looks very bright if we keep applying our technologies from particle physics to medicine

Thanks for listening…

…any question?

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Barbara.Camanzi@stfc.ukri.org