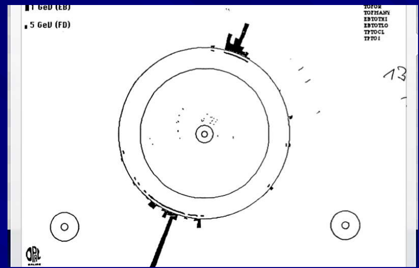
Medical Physics
Part # 1
Introduction

P. Le Dû

patrickledu@me.com

Who I am ? -



- NA3 @ CERN (Di-Muon Drell Yan) : 1974-1980
  - Large MWPC (4x4 m2)
  - **Trigger & DAQ**
- LEP - OPAL @ CERN (1980-1990)
  - TOF system
  - **Trigger & DAQ → First Z^0**
- SSC- SDC @ Dallas/LBL Berkeley (1990-1994)
  - **Trigger L2**
  - Shower Max Detector electronics (APD & SCA)
- LHC- ATLAS @ CERN (1994-2000)
  - **L2 trigger** & LARG calorimeter Read Out electronics (SCA)
- D0 @ FNAL (1996-2005)
  - **L1 Calormeter trigger and L2 trigger**.
- ILC study group (1996-2008)
  - **Trigger & DAQ convener → Software triigeer**
- **2000→Technology transfer advisor for medical application (PET & Particle therap**
- **Ultra fast (picosecond) timing**

Experimental Physicist

-CEA Saclay (1969-2008

-IN2P3-IPN Lyon (2009 .

_NPSS ADCOM

School Liaison

Goals of this presentation

- Using my own experience during the last 50 years of working on Radiation detectors → try to give a flavor of what could be the application of the recent evolution and developments in various fields

Goals of these lectures

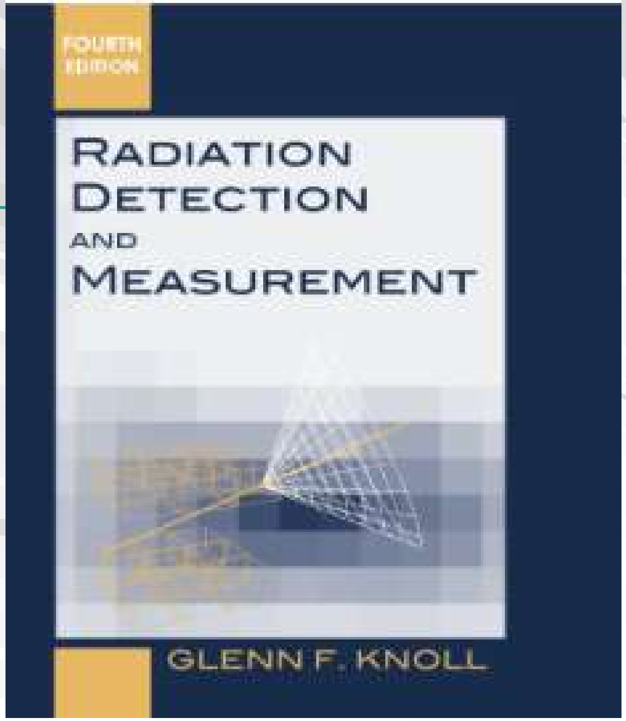
- A very simple basic introduction of Medical Physics seen from a High Energy Physics experimental physicist. (50 years)
- I will present mainly the radiation instrumentation aspect around the nuclear medicine.
- Explain why this domain has strong relationship with our field of interest (HEP) and might interest your future

Outlines of this lecture

- What is medical Physics ?
  - A little bit of history
  - Radiation effects units
  - Basics of Radiology
  - Fighting again cancer
  - Radiotherapy basic
  - Introduction to Nuclear medicine
    - tracers
    - Single Photon Computed Tomography (SPECT)

Few words about Radiation Detectors

Radiation
Instrumentation
The Bible
Glenn Knoll



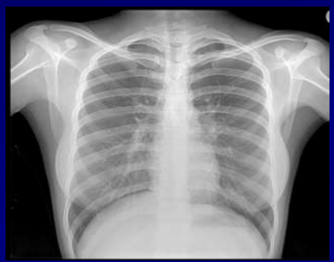
Radiation detectors → Imaging what you cannot see

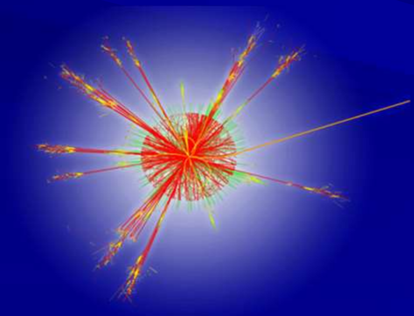
.. or how the development of radiation instrumentation has been crucial for fundamental scientific discoveries and for the improvement of human life...

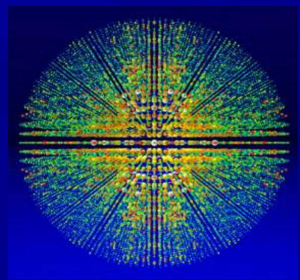
Introduction: Imaging radiation ..

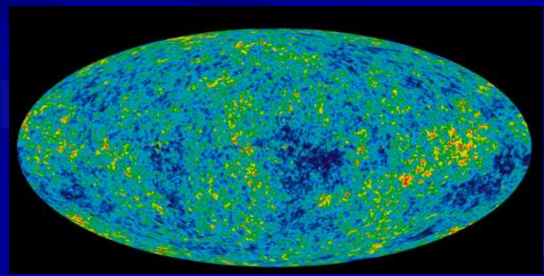
Web cams Smart phones photo cameras

machine vision, automotive, security etc…









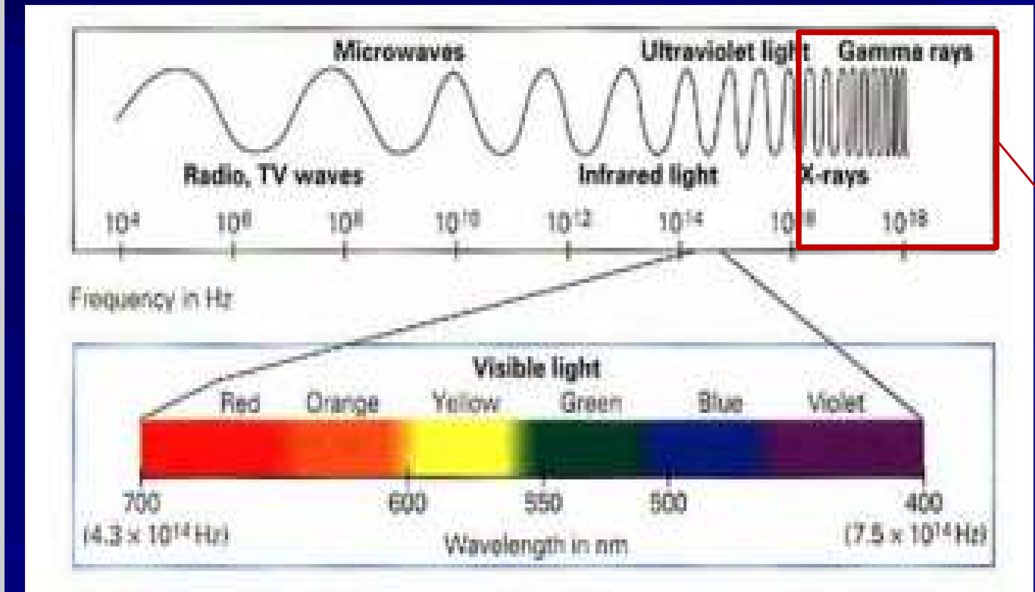
Medical imaging HEP x-ray crystallography cosmology ......

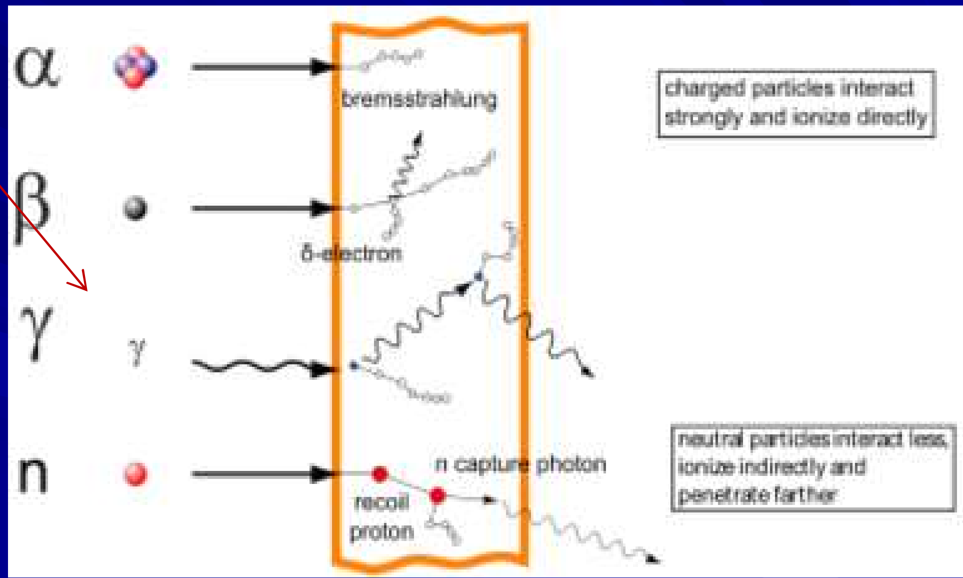
mass spectroscopy, optical tweezers, neutrons, electrons, TOF, SEM/TEM etc…

What is radiation ?

- **Radiation** can be defined as the propagation of energy through space or matter in the form of electromagnetic waves or energetic particles.

When radiation interacts with matter:





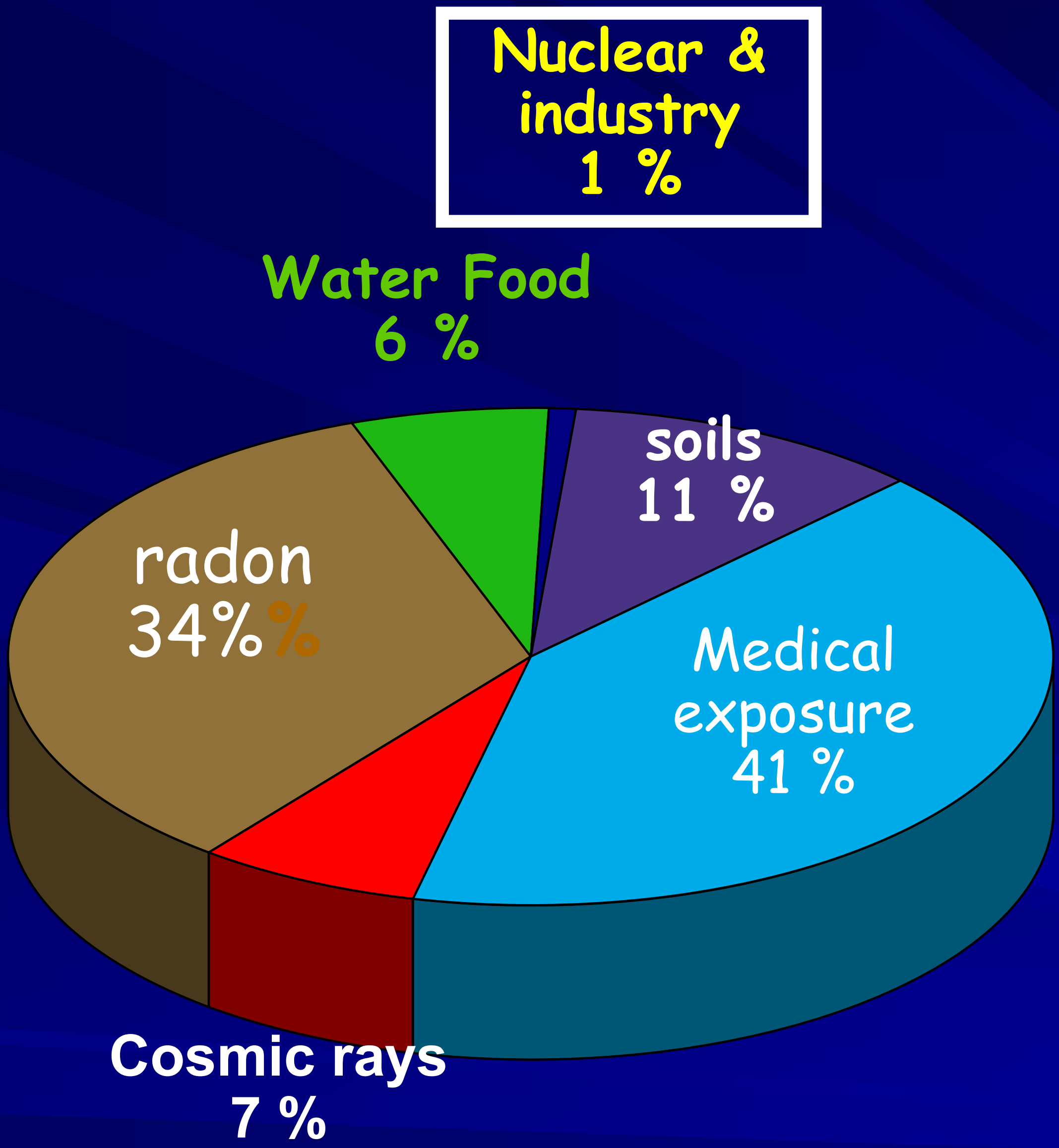
Non-ionizing

does not have enough energy to ionize atoms but in the material it interacts with. At high energy it becomes ionizing

Ionizing

has the ability to knock an electron from an atom, i.e. to ionize..

Main sources of ionizing radiation



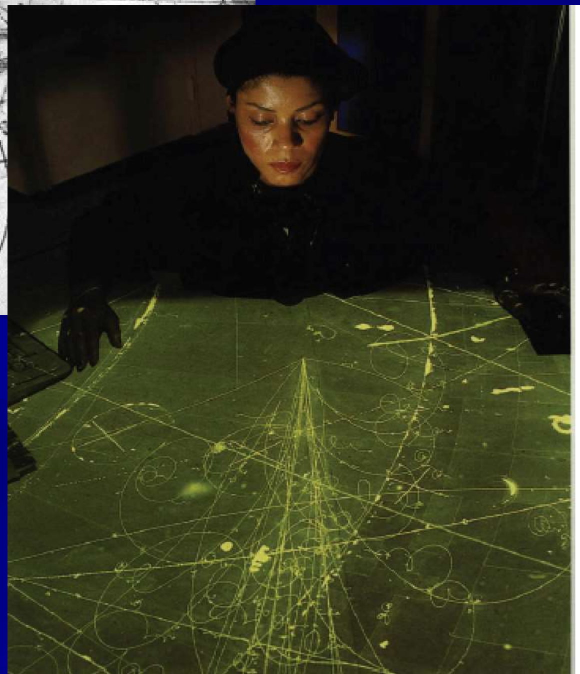
- Earth has been radioactive ever since its formation into a solid mass over 4½ billion years ago. However, we have only known about radiation and radioactivity **for just over one hundred years...**

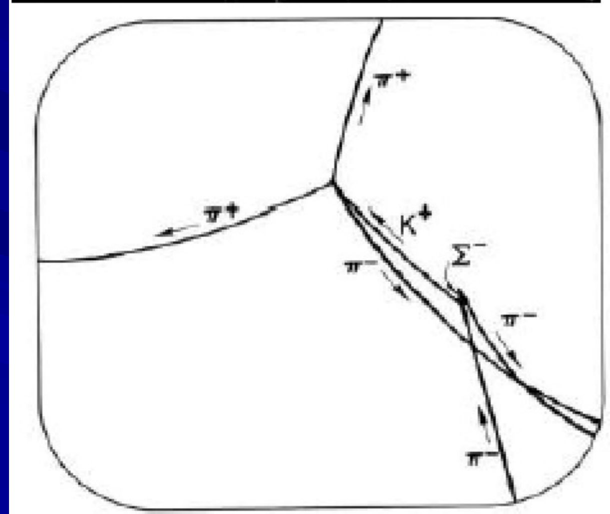
The detectors story

History and evolution of radiation detectors tools of discovery

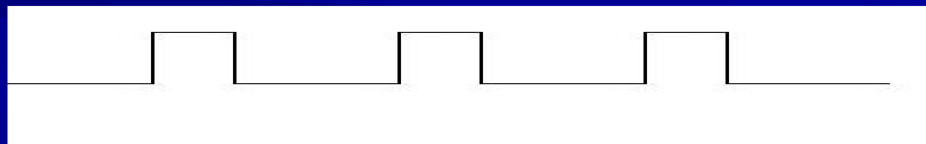
- 1906: Geiger Counter, H. Geiger, E. Rutherford
- 1910: Cloud Chamber, C.T.R. Wilson
- 1928: Geiger-Muller Counter, W. Muller
- 1929: Coincidence Method, W. Bothe
- 1930: Emulsion, M. Blau
- 1940-1950: Scintillator, Photomultiplier
- 1952: Bubble Chamber, D. Glaser
- 1962: Spark Chamber
- 1968: Multi Wire Proportional Chamber, C. Charpak
- 1970: Silicon era
- Etc. etc. etc. → *In blue = Nobel Prize*

The prehistoric world
the Bubble Chamber -1955-1975

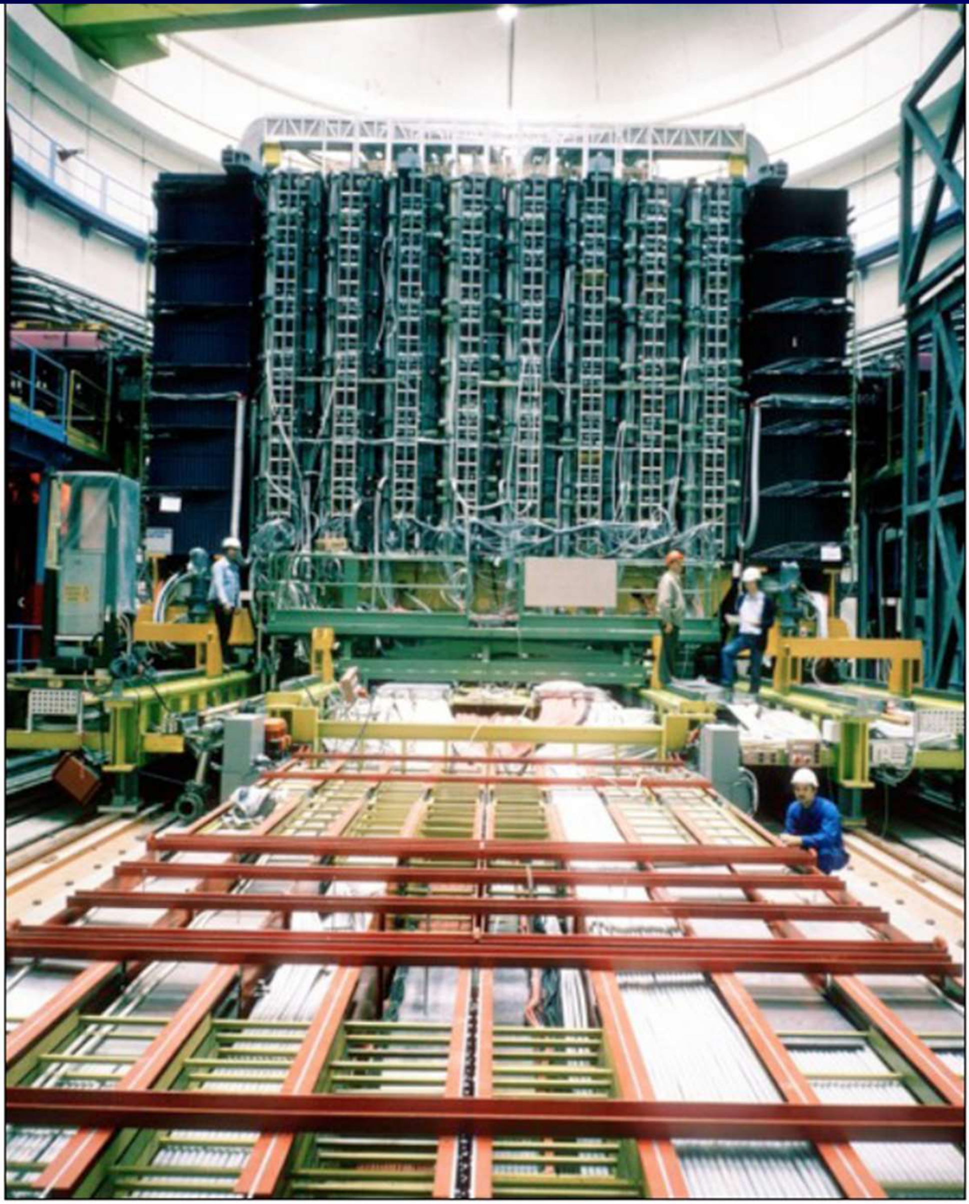




- Our Roots back to 'triggerless DAQ '



the early Electronics image



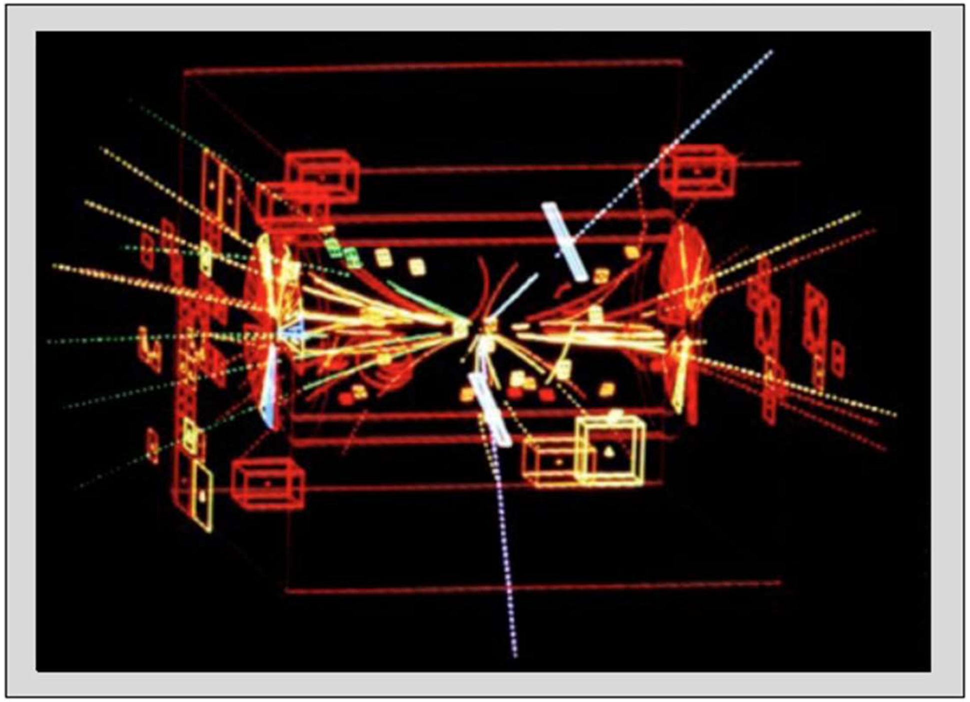
UA1
Detector

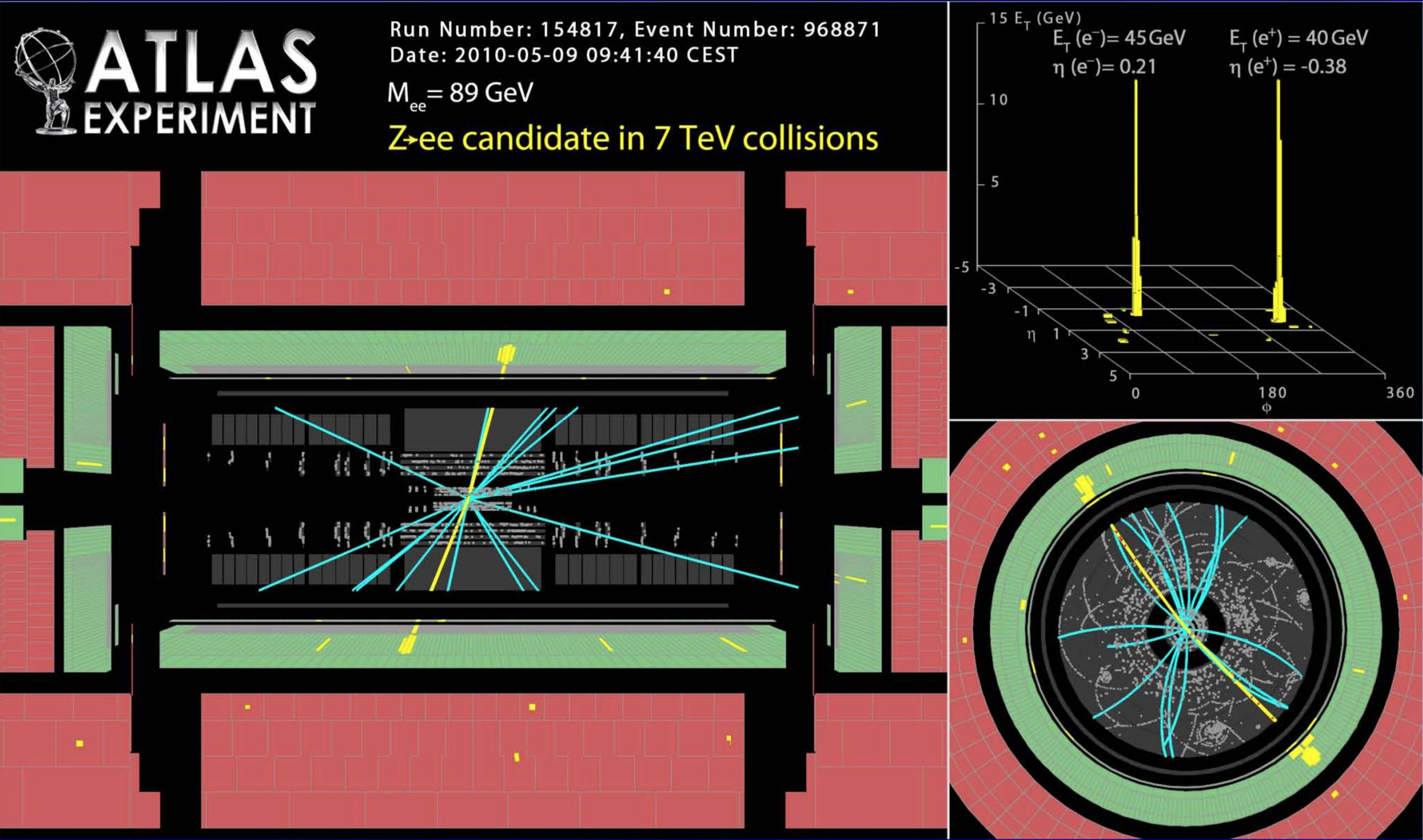
Discovery of the
W/Z boson (1983)

Carlo Rubbia
Simon Van der Meer

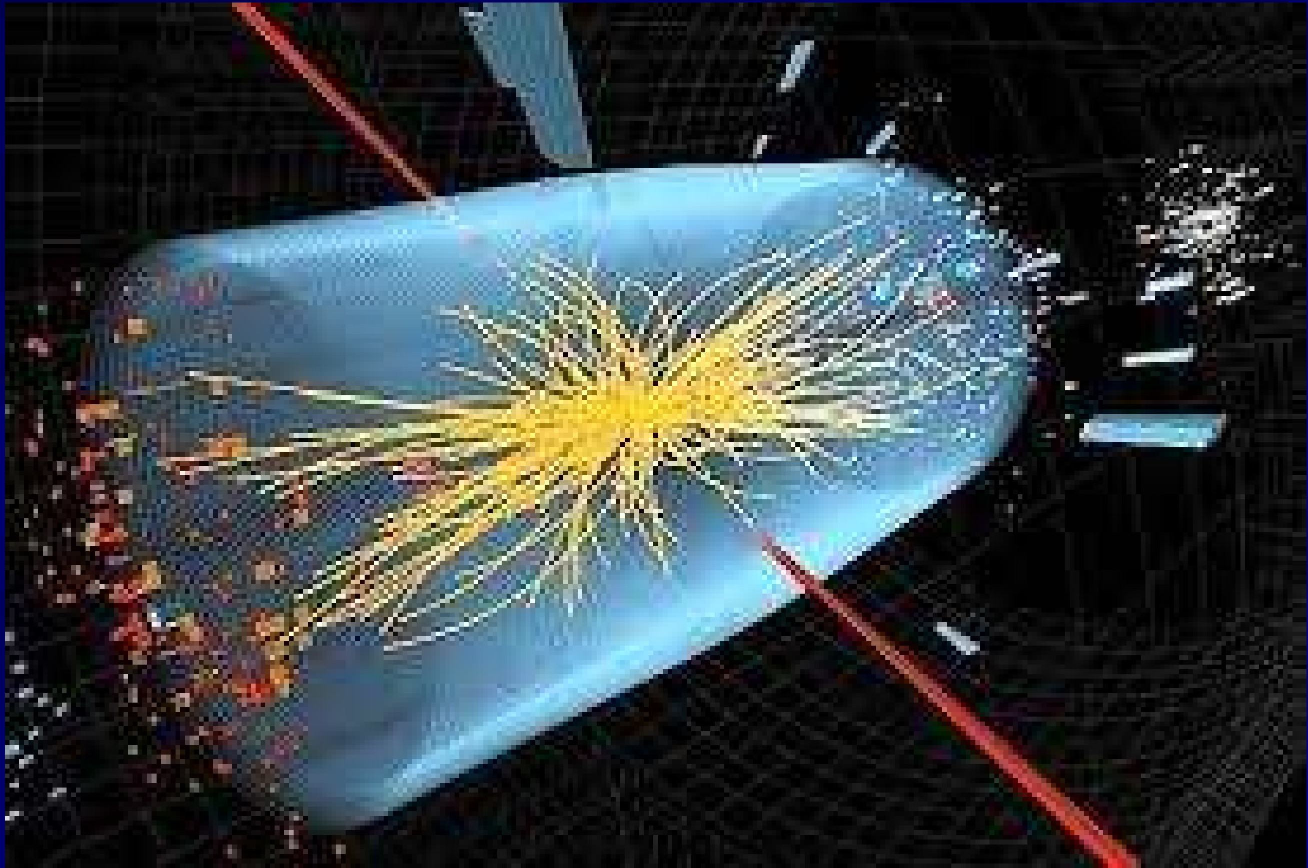
[Nobel prize 1984]

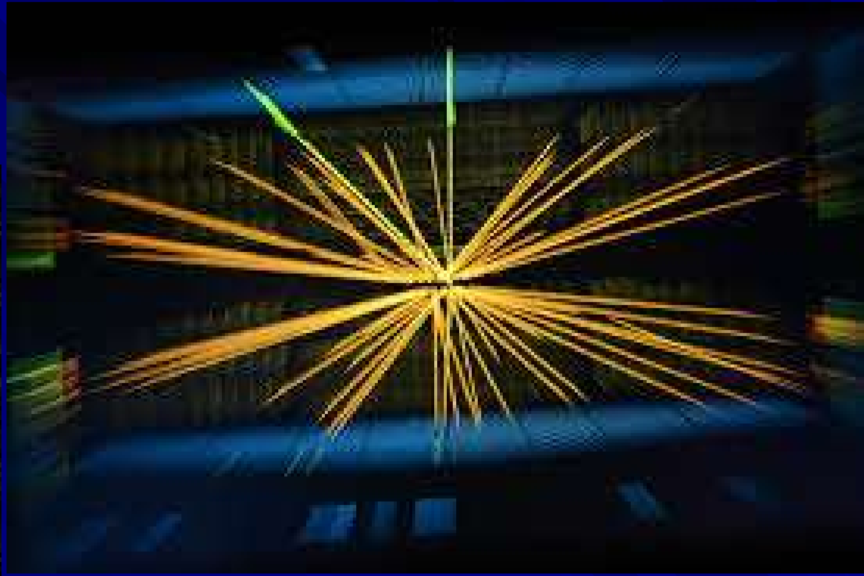
First Z^0 particle seen by UA1

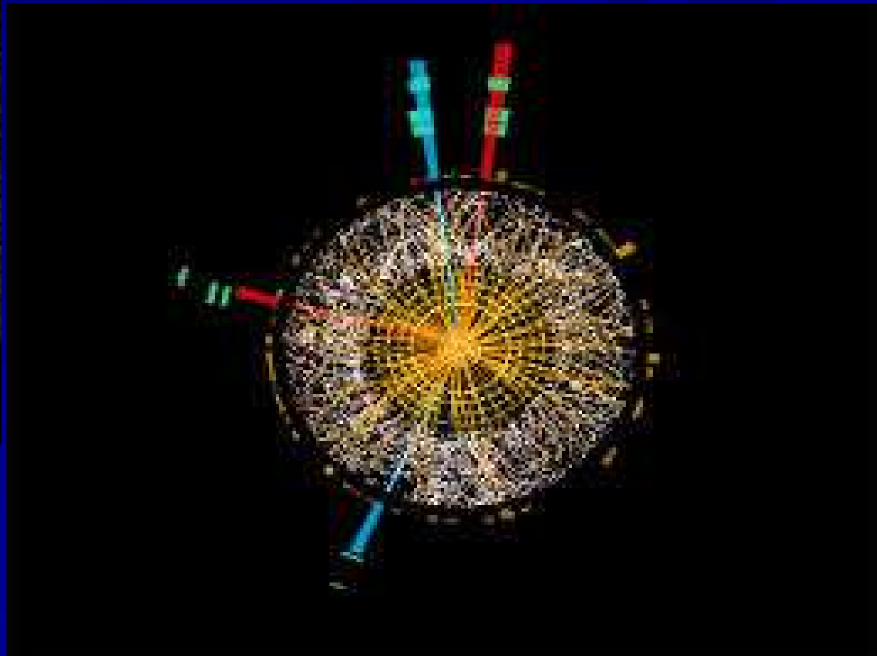



ATLAS EXPERIMENT
Run Number: 154817, Event Number: 968871
Date: 2010-05-09 09:41:40 CEST
M_{ee} = 89 GeV
Z→ee candidate in 7 TeV collisions
15 E_T (GeV)
E_T (e^-)= 45GeV
η (e^-)= 0.21
E_T (e^+) = 40GeV
η (e^+) = -0.38
10
5
-5
-3
-1
η 1
3
5
0
180
360
φ

A Higgs image



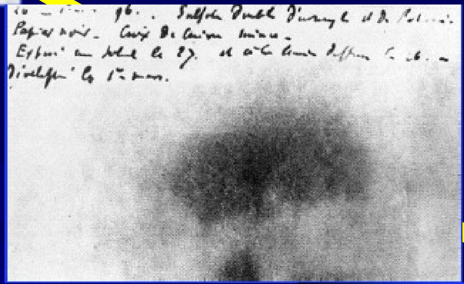




Some history

1895
W.C. Rontgen
Discovery of X Ray

How physics discoveries have impacted our life (1)



1896 - Discovery of the natural radioactivity by Henri Becquerel

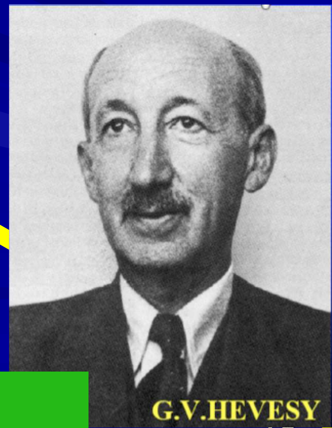
First image of potassium uranyl disulfide

1898
Pierre and Marie Curie
the Radioactivity
Polonium,Radium

1910

X Ray Radiography

1923 - The Tracer principle
`G.V.Hevesy- the father of nuclear medicine



Tracer

How physics discoveries impact our life (2)

Ernest O. Lawrence and his First cyclotron 1932

1932 - The Invention of the cyclotron
Production of radioisotopes

1934 - Artificial radioactivity
Irène and Fréderic Jolio Curie

The discovery of artificial radioactivity in combination with the cyclotron open the door to the production of useful radio indicators. Practically any element could be bombarded in the cyclotron to generate radioactive isotopes.

Otto Hahn, 1944 Nobel Prize

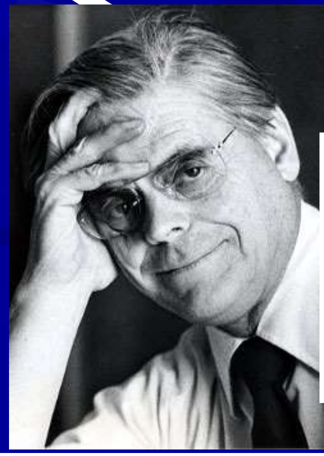
Enrico Fermi

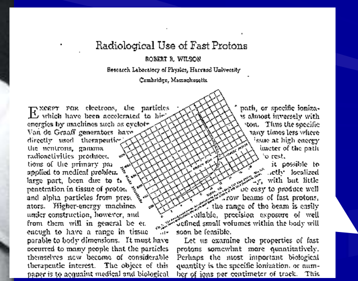
O.Hahn
E. Fermi

1938-1942 Fission of Uranium

From discovery to first graphite miler in Chicago
To the Production of long lived
radio-isotopes

1946 - R.R.Wilson
The origin of particle therapy
Using the Bragg peak discovery (1903)

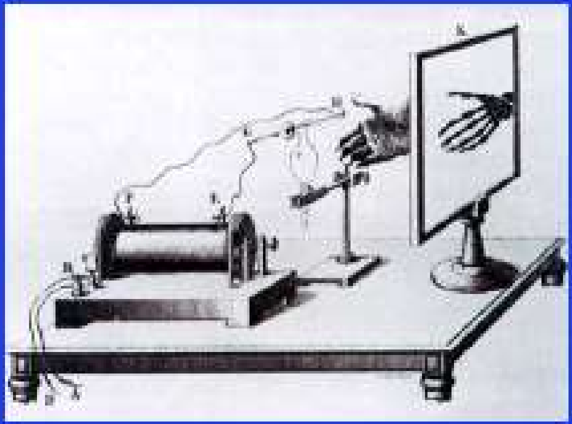




Radiological Use of Fast Protons

ROBERT R. WILSON

18 Nov, 1895 W.C. Rontgen discovers Xrays



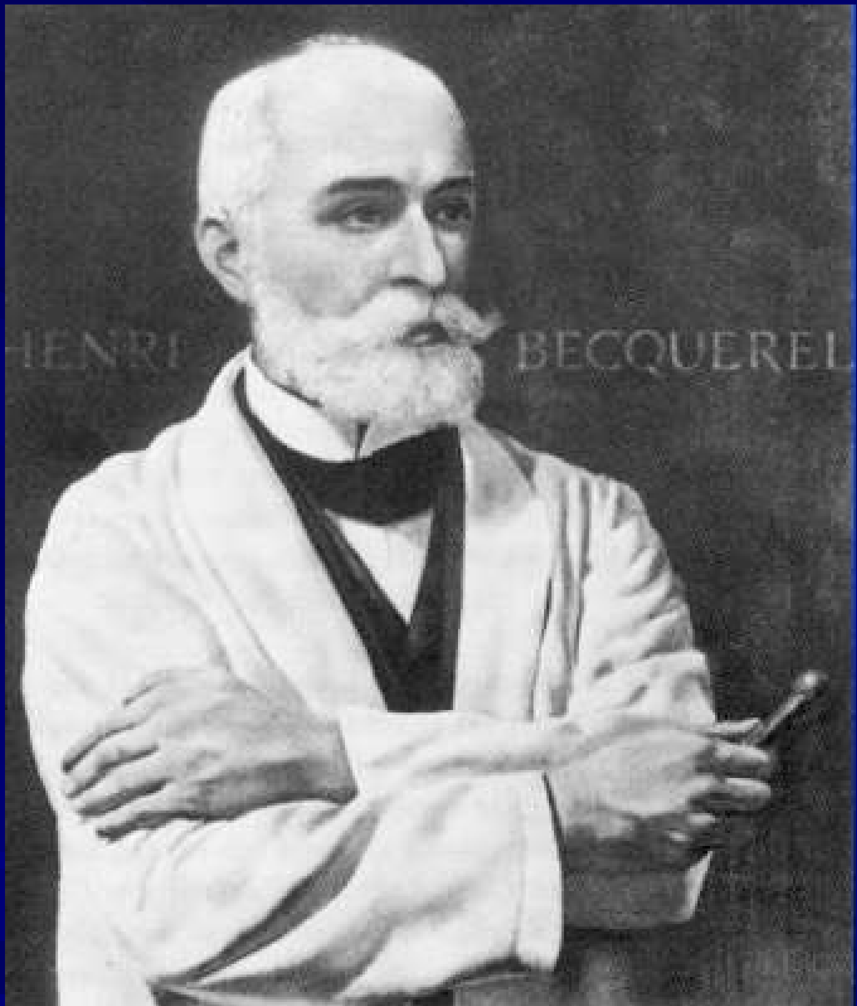
W.C.Röntgens experiment in Würzburg

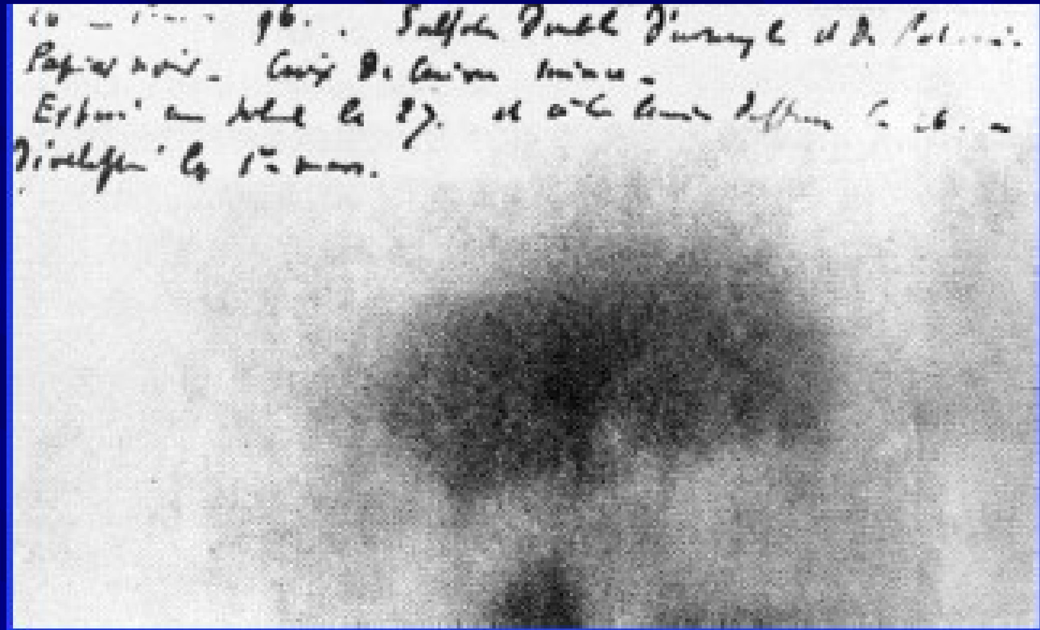
An early XX^{th} century

X-ray tube

Radiograph of Mrs.Röntgens hand, the first x-ray image ever taken, 22.Dec.1895, published in The New York Times January 16, 1896

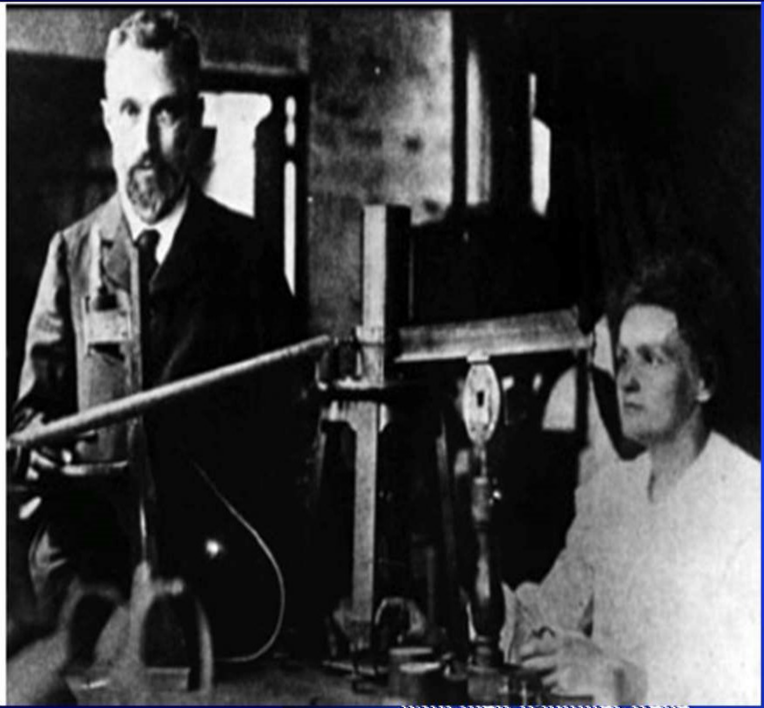
1996 - Discovery of the natural radioactivity by Henri Becquerel





- First image of potassium uranyl disulfide

1898 the Radioactivity



RADIOACTIVITY

1898 Polonium
Radium

1903 Nobel Prize
together with Pierre

1911 Nobel Prize
allone

1897 Becquerels friend, Pierre Curie, also Prof. of physics in Paris suggested to his young bride, Marie, that she study the phenomena discovered by H.Becquerel for her thesis. She found soon that some components of Uranium minerals were much more radioactive than Uranium itself. "**We shall call the mysterious rays 'radioactivity'**," she told to her husband Pierre, and the substances that produce the rays "**radioelements**".

1898 Pierre started to join Marie in the study of the mysterious rays. In **July** that year they reported the discovery of **Polonium** (^{210}Po) and in **December** they announced the discovery of the **Radium** (^{226}Ra)

1923 - The Tracer principle

G.V.Hevesy:
The Absorption and Translocation of Lead (ThB) by Plants [ThB = ^{212}Pb]
Biochem.J. **17**, 439 (1923)

Measurements of the tracer's Radioactivity provided thousand fold increases in sensitivity and accuracy over existing chemical assays. The foundation and basic rationale of much of Hevesy visualized that **a radioactive atom might be used as a "representative" tracer of stable atoms of the same element** whenever and wherever it accompanied them in biological systems.

1943 Nobel Prize Chemistry

the father of Nuclear Medicine

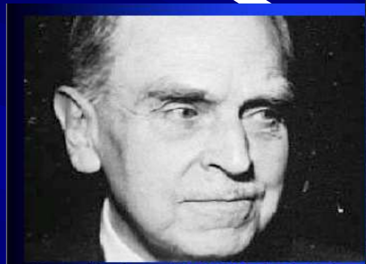
How physics discoveries impact our life (2)

Ernest O. Lawrence and his First cyclotron 1932

1932 - The Invention of the cyclotron
Production of radioisotopes

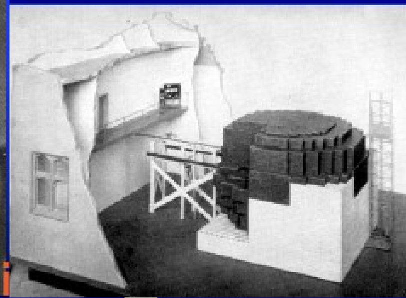
1934 - Artificial radioactivity
Irène and Fréderic Jolio Curie

1938-1942 Fission of Uranium



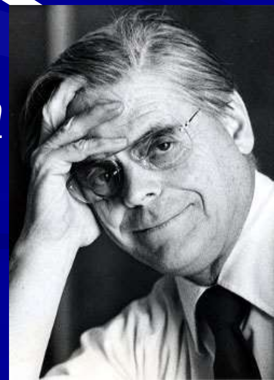
Otto Hahn, 1944 Nobel Prize

Enrico Fermi

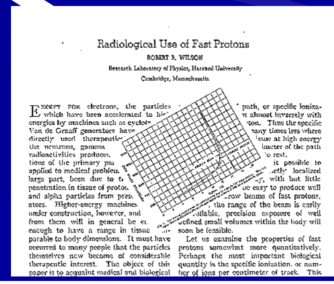


O.Hahn
E. Fermi

From discovery to first graphite miler in Chicago To the Production of long lived radio-isotopes



1946 – R.R.Wilson
The origin of particle therapy Using the Bragg peak discovery (1903)



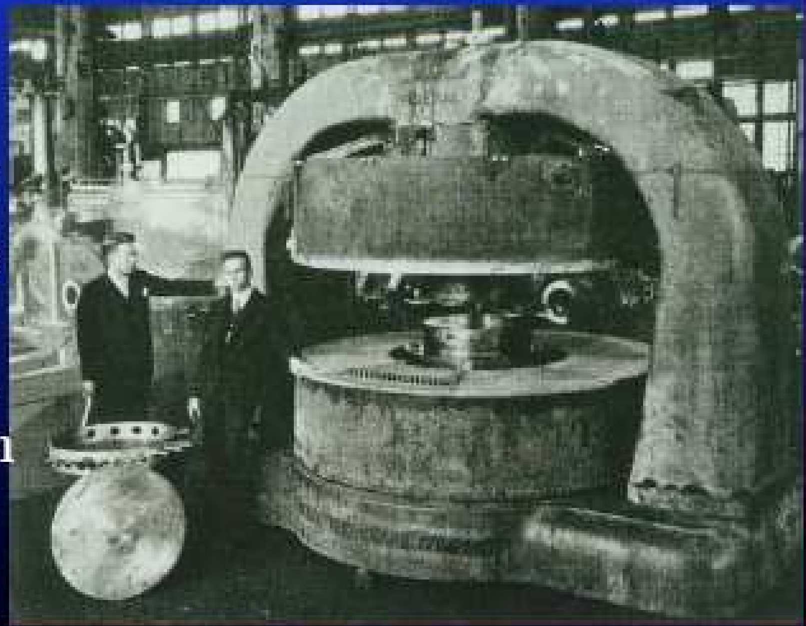
Radiological Use of Fast Protons
ROBERT R. WILSON
Research Laboratory of Physics, Harvard University
Cambridge, Massachusetts

1932 - The Invention of the cyclotron

Ernest O. Lawrence and his First cyclotron 1932

E.O.Lawrence and M.S. Livingston "The production of high speed Light ions without the use of high voltages", A milestone in the production of usable quantities of radionuclides.

E.O Lawrence and M.S.Livingston with the 27-inch cyclotron at Berkeley 1933, the first cyclotron that produced radioisotopes



1934 - Artificial radioactivity
Irène & Frederic Joliot-Curie

1934	Nature, February 10
1935	Nobel Prize

"Our latest experiments have shown a very striking fact: when aluminum foil is irradiated on a polonium preparation, the emission of positrons does not cease immideatly when the active preparation is removed. The foil remains radioactive and the emission of radiation decays exponentially as for an ordinary radioelement. We observed the same phenomena with boron and magnesium."

$^{27}Al\ (\alpha,n)\ ^{30}P$ and $^{10}B\ (\alpha,n)\ ^{13}N$

- The ombination with the cyclotron open the door to the production of useful radio indicators. Practically any element could be bombarded in the cyclotron to generate radioactive isotopes.

1935 Nature **136**, 754 O.Chievitz and G.V.Hevesy
Radioactive indicators in the study of phosphorus metabolism in rats (^{32}P)

1937 Radiology **28**, 178 J.G.Hamilton, R.S.Stone:
The administration of radio-sodium (^{24}Na)

1938 Proc.Soc.Exp.Biol.Med. **38**, 510 S.Hertz, A.Roberts, R.D.Evans
Radioactive iodine (^{128}I) – Study of thyroid physiology

1939 Proc.Soc.Exp.Biol.Med. **40**, 694, J.H.Lawrence, K.G.Scott:
Metabolism of phosphorus (^{32}P) in normal and lymphomatous animals

1940 Am.J.Physiol. **131**, 135 J.G.Hamilton, M.H.Soley:
Studies of **iodine** metabolism by thyroid in situ

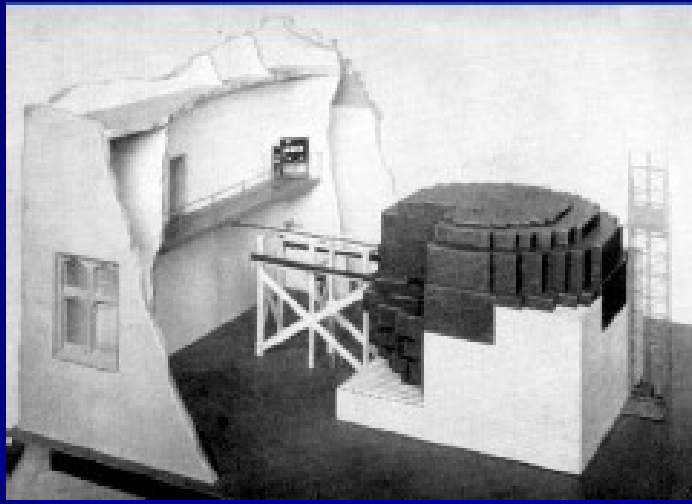
1940 J.Biol.Chem. **134**, 543 J.F.Volker, H.C.Hodge, H.J.Wilson
The adsorption of fluoride (^{18}F) by enamel, dentine, bone and hydroxyapatite

1945 Am.J.Physiol. 145, 253 C.A.Tobias, J.H.Lawrence, F.Roughton
The elimnination of 11-C-Carbon monoxide from the human body

1938-1942 Fission of Uranium

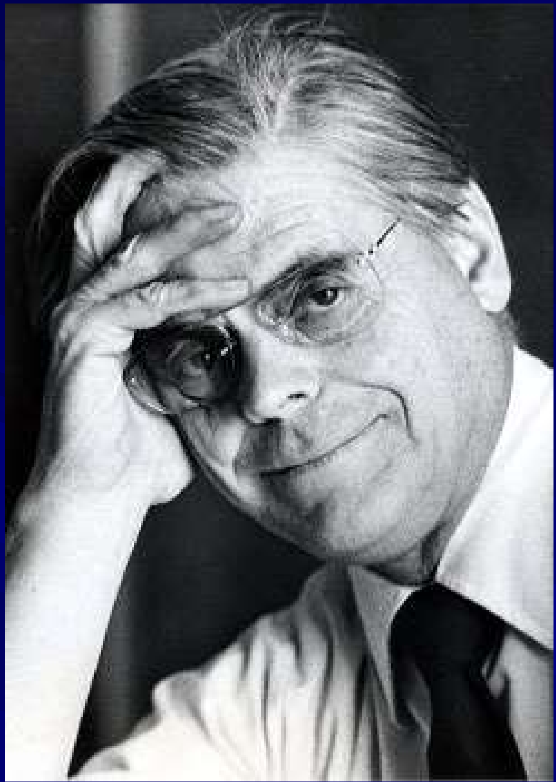
$^{235}U + n = [^{236}U] \longrightarrow {}^{140}Ba + {}^{94}Kr + 2\,n + \gamma + Energy$

Otto Hahn, 1944 Nobel Prize

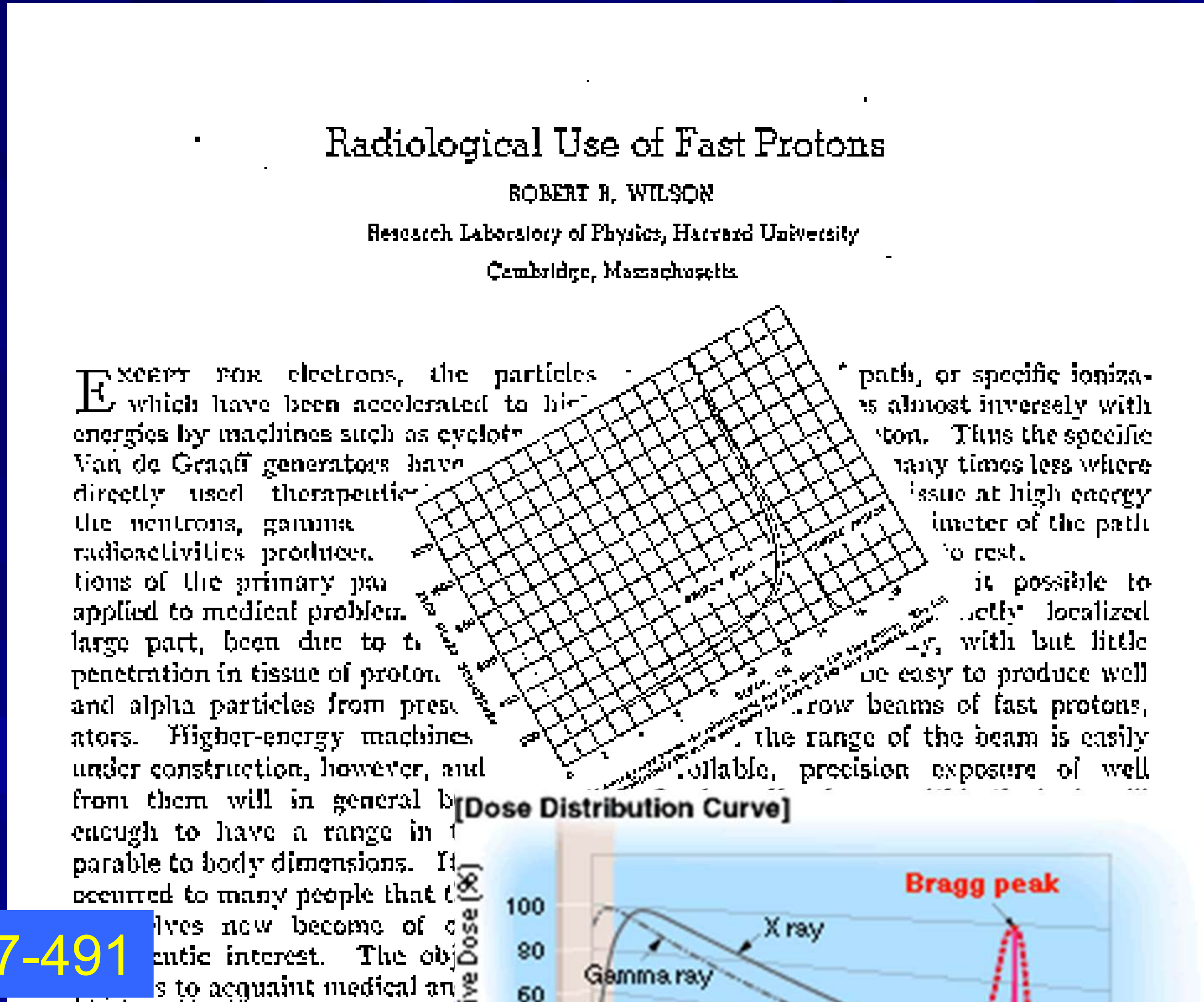


- From discovery to first graphite miler in Chicago
- Production of long lived radio-isotopes

1946 - The origin of particle therapy



R.R. Wilson, Radiology 47(1946), 487-491


Radiological Use of Fast Protons

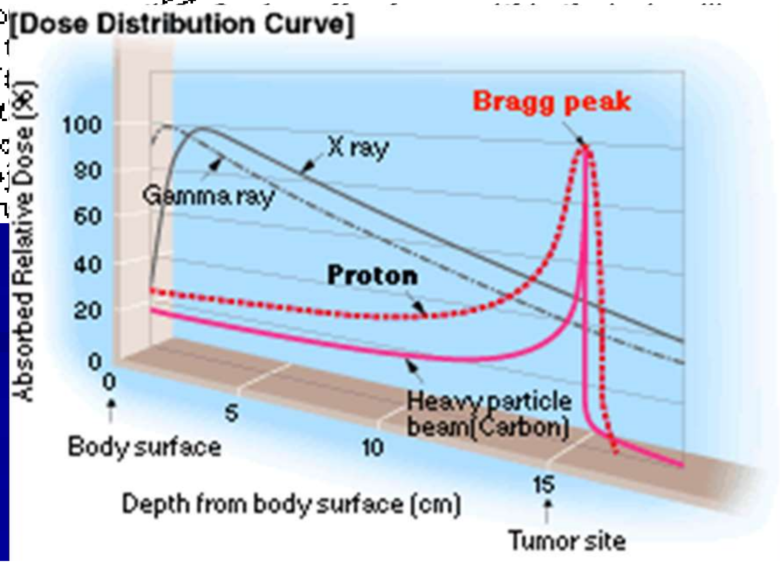
ROBERT R. WILSON

Research Laboratory of Physics, Harvard University

Cambridge, Massachusetts

EXCEPT FOR electrons, the particles which have been accelerated to hi… energies by machines such as cyclotr… Van de Graaff generators have… directly used therapeutic… the neutrons, gamma… radioactivities produced… tions of the primary pa… applied to medical problem… large part, been due to t… penetration in tissue of proton… and alpha particles from pres… ators. Higher-energy machines… under construction, however, and from them will in general b… enough to have a range in t… parable to body dimensions. It… occurred to many people that t… …lves now become of c… …eutic interest. The obj… …s to acquaint medical an…

… path, or specific ioniza… …s almost inversely with …ton. Thus the specific …any times less where …issue at high energy …imeter of the path …o rest. … it possible to …ctly localized …y, with but little …be easy to produce well …row beams of fast protons, … the range of the beam is easily …ollable, precision exposure of well



- The origin of particle therapy using the Bragg peak discovery (1903)

Isotopes in medicine

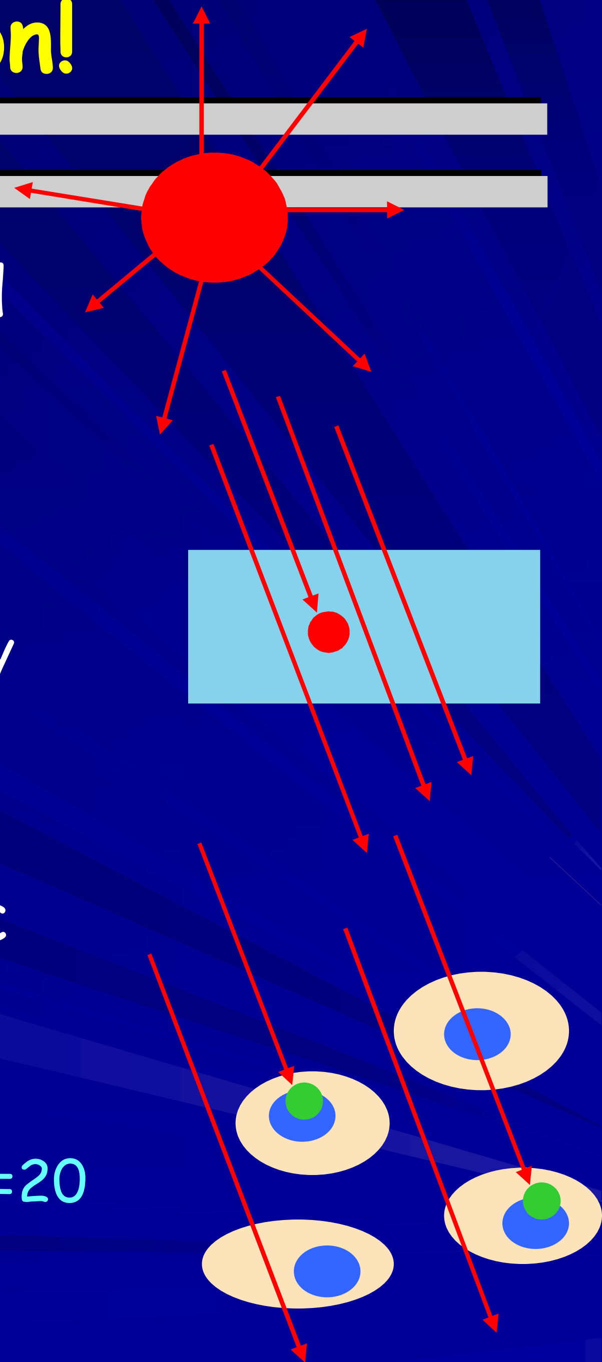
DIAGNOSIS		THERAPY		
in vitro	in vivo	internal		external
		systemic	sources	tele radio
^{14}C ^{3}H ^{125}I others	**^{99}Mo-^{99m}Tc** ^{201}Tl ^{123}I ^{111}In ^{67}Ga ^{81}Rb-^{81m}Kr others ß+ emitters for PET ^{18}F, ^{11}C, ^{13}N, ^{15}O ^{86}Y, ^{124}I ^{68}Ge-^{68}Ga ^{82}Sr-^{82}Rb	^{131}I, ^{90}Y ^{153}Sm, ^{186}Re ^{188}W-^{188}Re ^{166}Ho, ^{177}Lu, others α-emitters: ^{225}Ac-^{213}Bi ^{211}At, ^{223}Ra ^{149}Tb e^--emitters: ^{125}I	sealed sources ^{192}Ir, ^{182}Ta, ^{137}Cs many others needles for brachytherapy: ^{103}Pd, ^{125}I many others stands ^{32}P and others seeds ^{90}Sr or ^{90}Y, others applicators ^{137}Cs, others	^{60}Co gamma knife ^{137}Cs blood cell irradi-ation

Effects of radiation on human body

What is a Curie, Bequerel, Seivert?

From Prof. Aurengo - Hopital de la Salpetriere - Paris

The Units - a bit of definition!



- Activity = Number of decays per second
  - Becquerel Bq : 1 decay / second
  - Curie Ci : 37 x 10^9 Bq (37 GBq)
- Dose : specificity of radiation effects
  - ionisation,modification of biogical activity
  - absorbed energy / mass unit
  - Gray Gy : 1 joule / kilogram
- Effective dose : indication of global risc
  = absorbed dose x WR* x WT**
  - Sievert Sv
    - WR*= 1 pour RX, beta and gamma, p=5, α=20
    - WT** = 0.05 for thyroïd, 0.01 for skin

Effective dose values

- 10.000 mSv : high irradiation / rapid death
- 1.000 mSv : moderate irradiation / clinical visible signs (burn…)
- 5 mSv : annual irradiation in Clermont-Ferrand (volcanic soil)
- 2,5 mSv : annual irradiation in Paris
- 1 mSv : legal limit irradiation in France
- 1 mSv : average annual medical irradiation in France

A simple exemple

a 'standard' Scintigraphy exam

	W_R	W_T	%
RX : 100 mGy / 50 cm² skin	1	0,01	30 %
^{131}I : 10 mGy / thyroïde	1	0,05	100 %

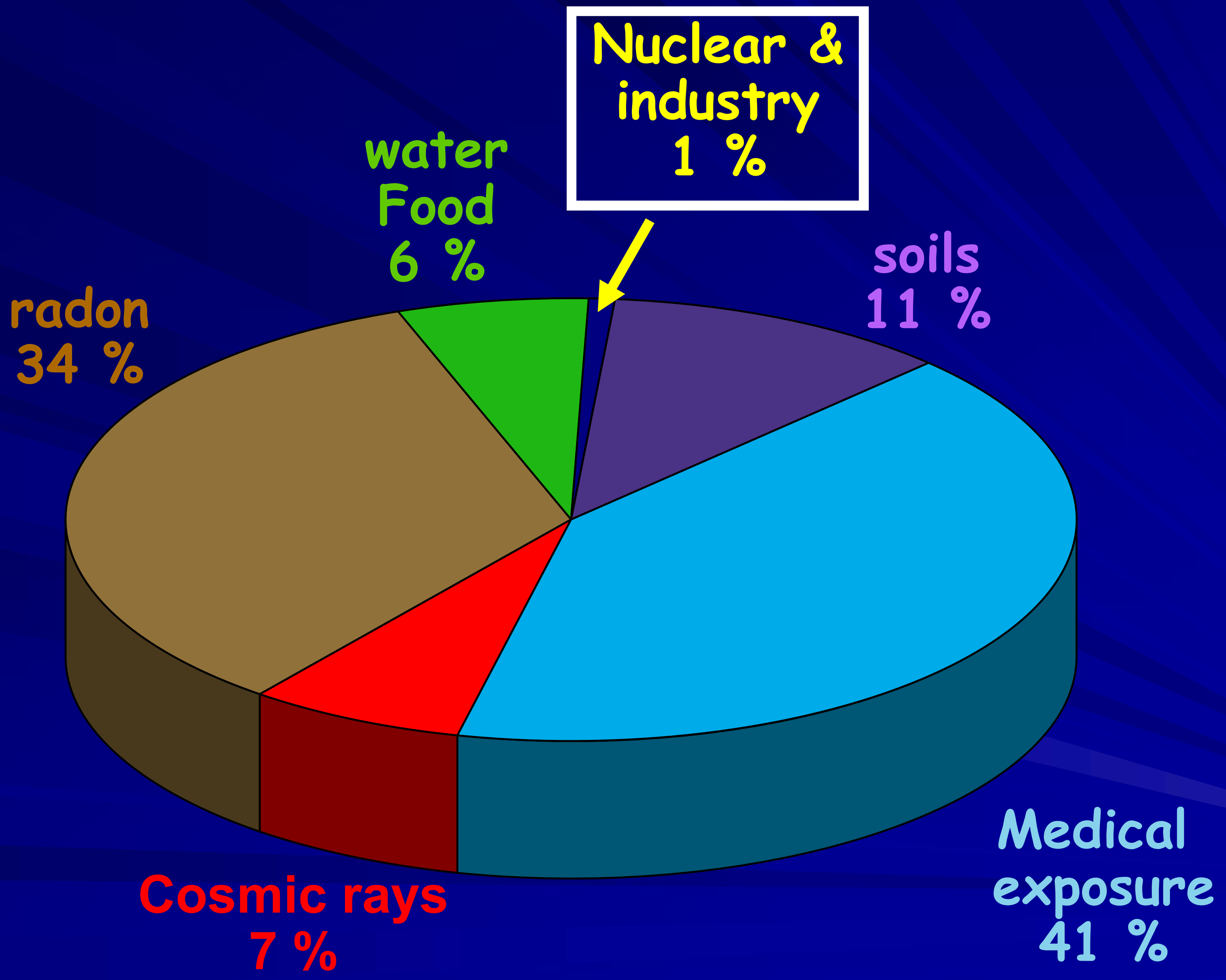
Effect dose = (100 x 1 x 0,01 x 0,30) + (10 x 1 x 0,05 x 1)
= 0,8 mSv

- Sv= Unit well adapted to radioprotection
- However : why this official' limit of 1 mSV/ year is so low ?
  - No sanitary argument : industrial irradiation :10 -15 µSv
  - Interpretation of the 'low' absolute value might be controversial!
- Do not take into account debit and age ..an personal sensitivity

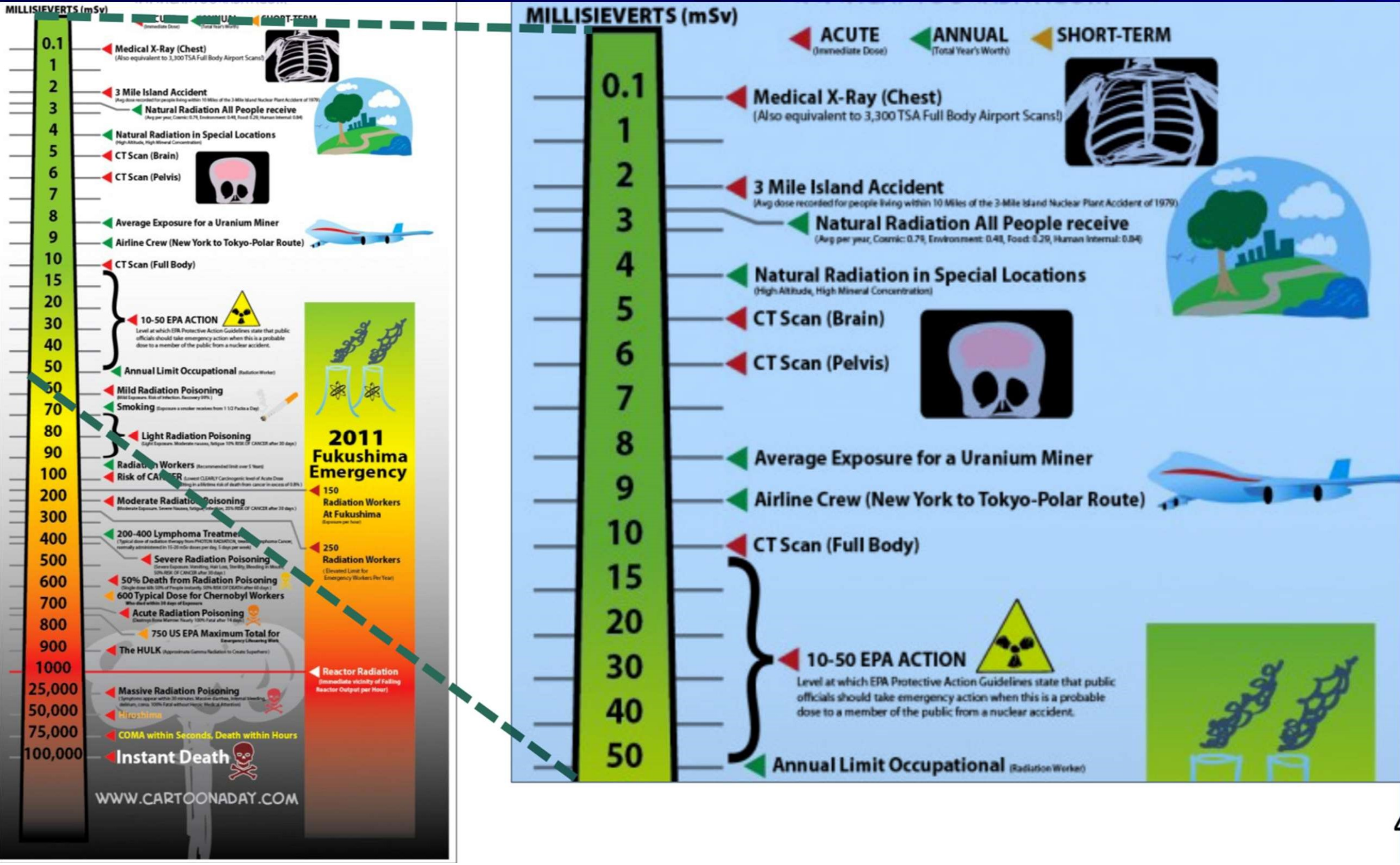
Variation of natural radioactivity

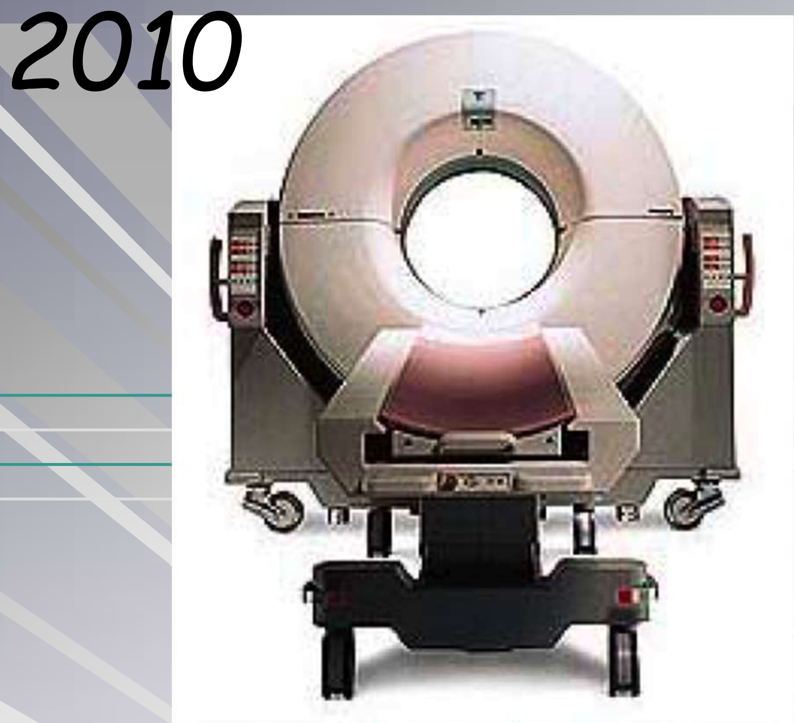
- Cosmic rays
  - sea level 0,25 mSv / year
  - Mexico (2240 m) 0,80 mSv / year
  - La Paz (3900 m) 2,00 mSv / year
- External exposure due to earth exposure
  - average 0,9 mSv / year
  - Espirito Santo (Bresil) 35 mSv / year
  - Maximum (Iran) 250 mSv / year
  - Marseille (France) 0,20 mSv / year
  - Limousin (France) 1,20 mSv / year
- Internal exposure due to water
  - Evian water 0,03 mSv / year
  - St Alban water 1,25 mSv / year

Natural versus medical irradiation



Typical radiation doses





Radiology

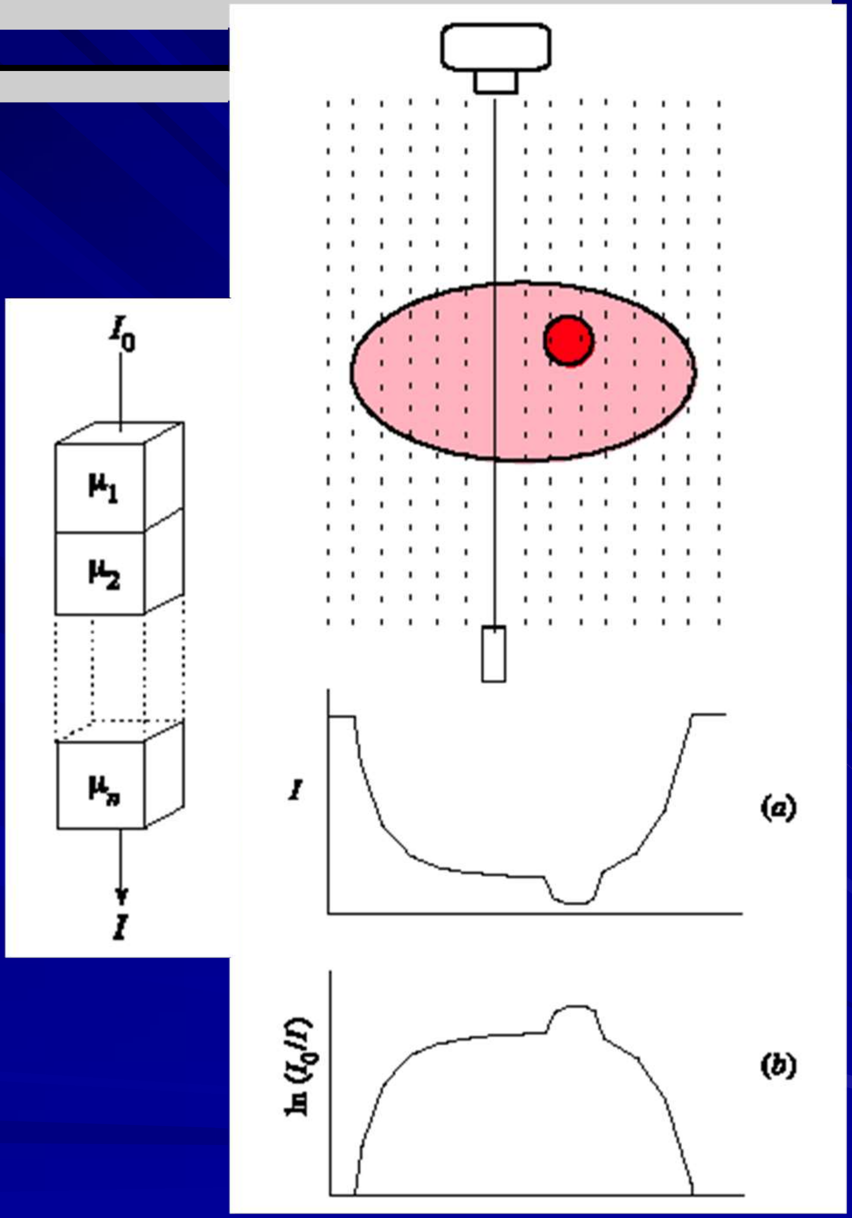
Common tools & techniques

Radiology principle

- The most common exam
- Transmission of X rays through tissue

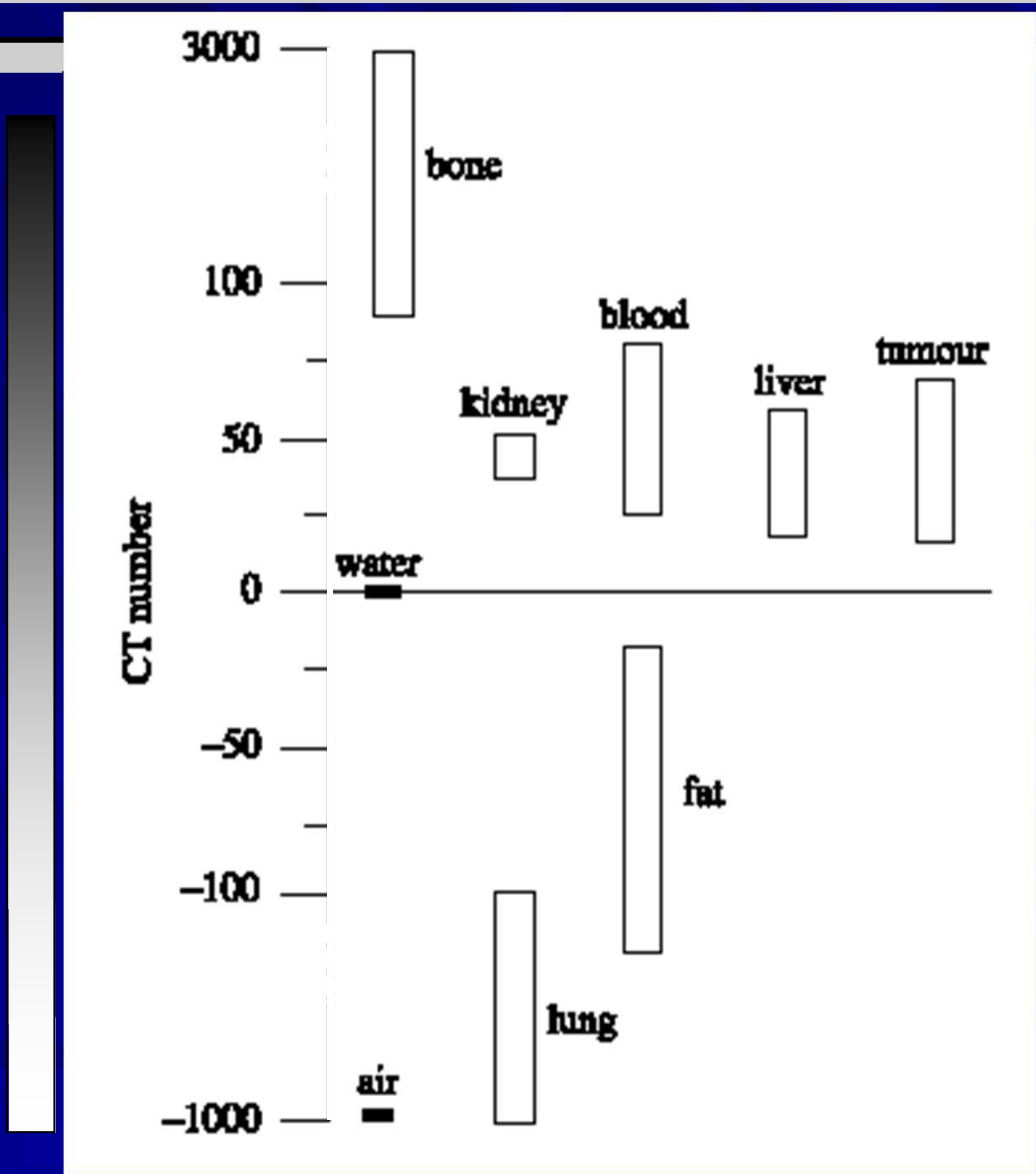
$$I = I_0 \exp\left(-x \sum_{i=1}^{n} \mu_i\right)$$

$$\ln \frac{I_0}{I} = x \sum_{i=1}^{n} \mu_i$$



Radiology problem = contrast

- How to get the best contrast?

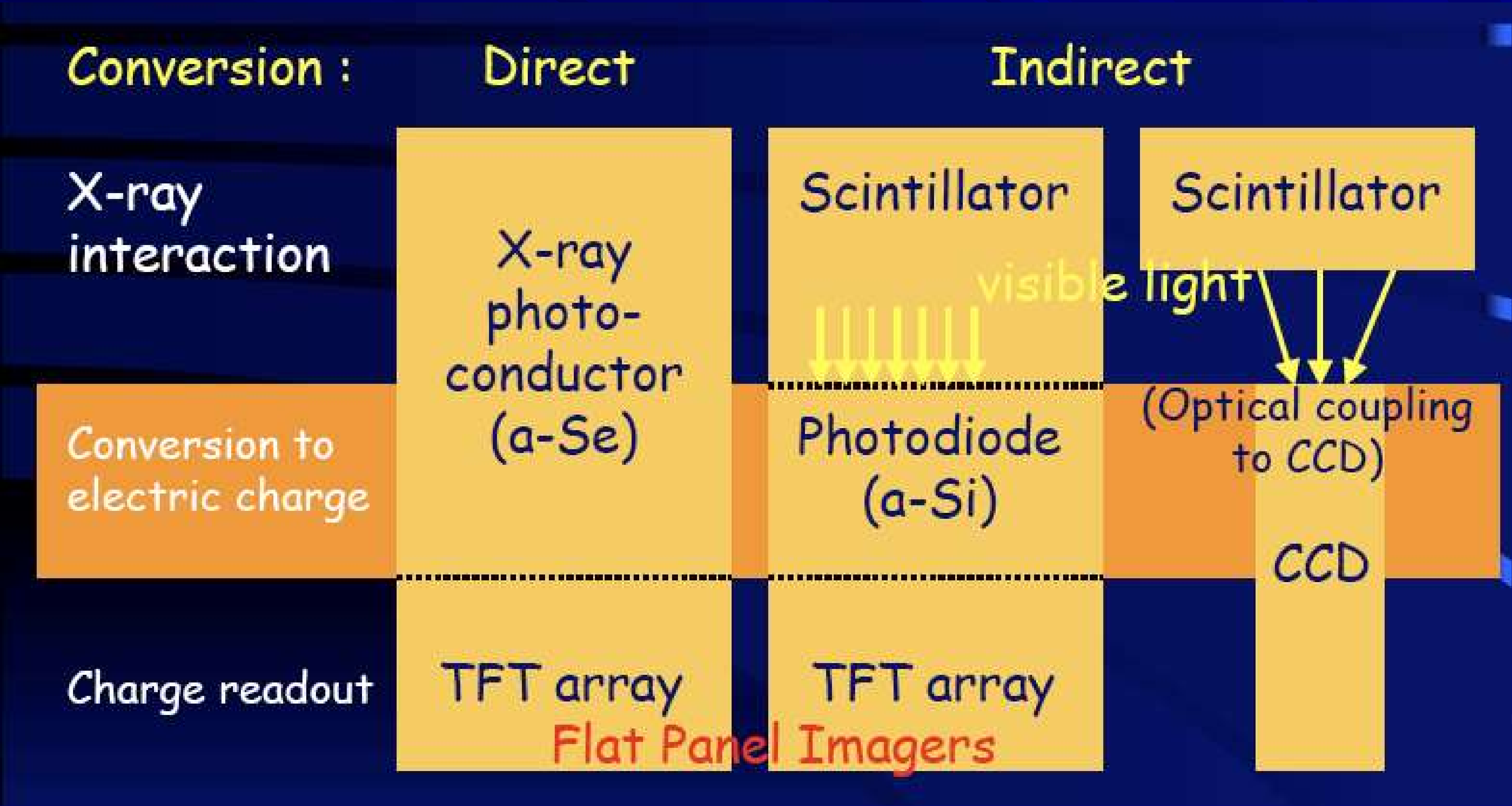


Detection techniques

- The standard : film scren system
- How to replace the film
  - More sensitive --> better contrast
  - Less dose
  - Affordable ?

Type of detector	Dynamic range
film-screen system	30:1
image intensifier	100:1
CCD detector	1000:1
flat panel detector	10,000:1
computed radiography	40,000:1

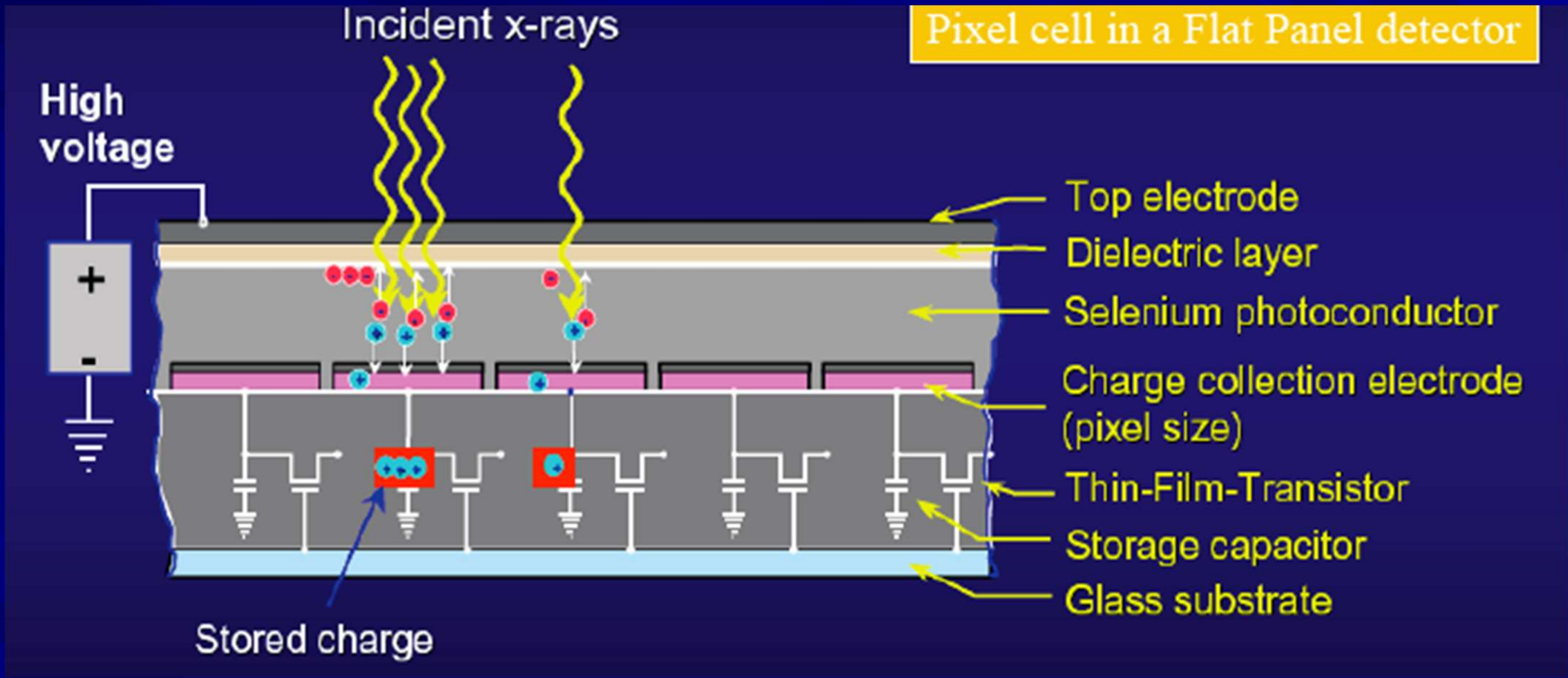
Radiology survey of electronically readable detectors



Radiology: Flat panel direct detection

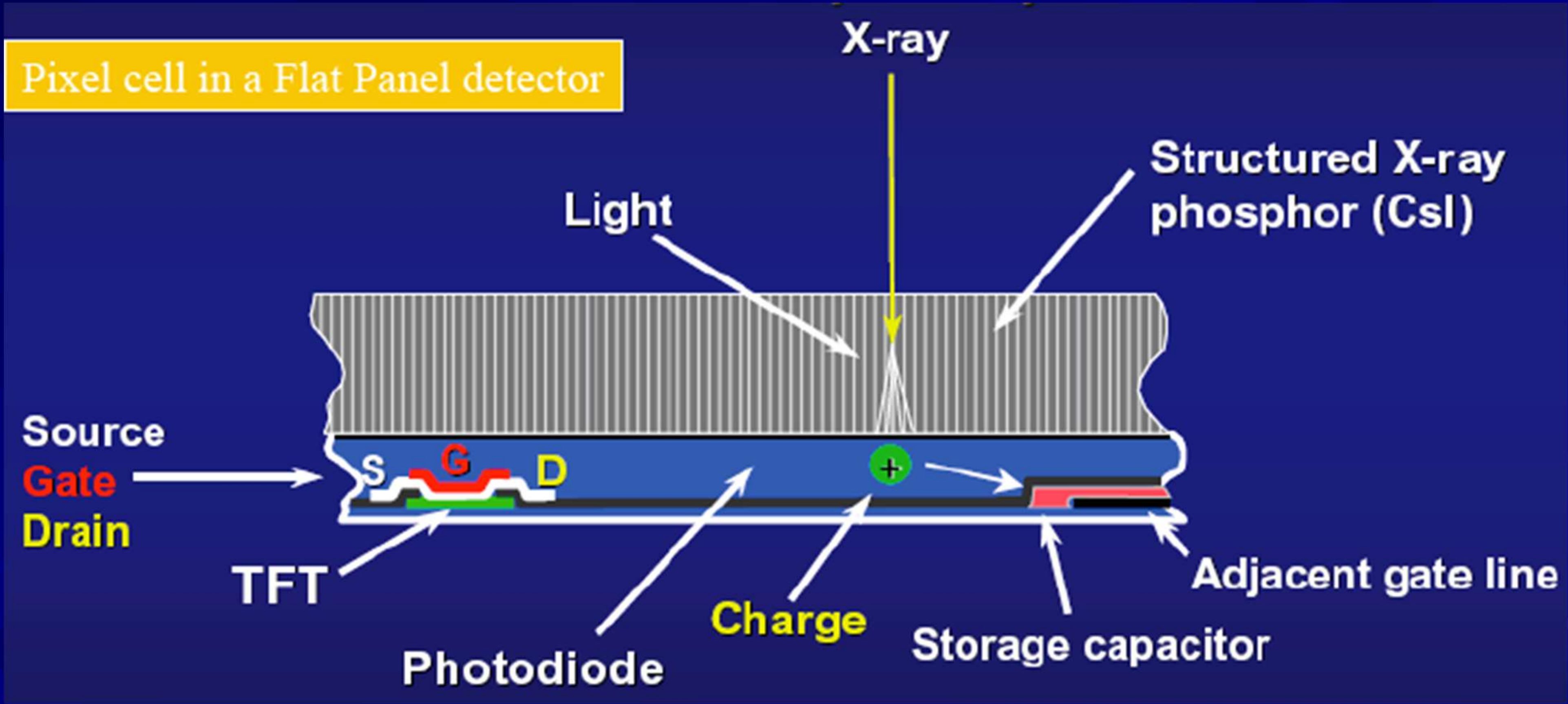
- Xray ---> electron --> electric signal

Selenium



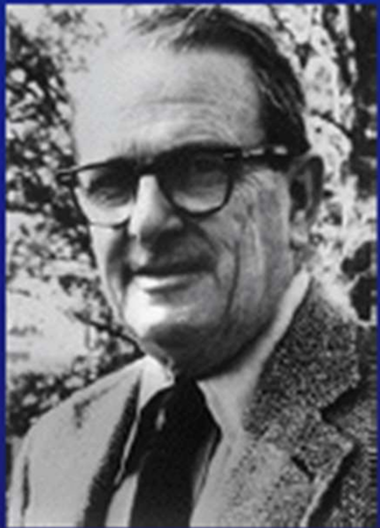
Radiology :Flat panel indirect detection

- Xray -->Light--> electron ---> electronic signal

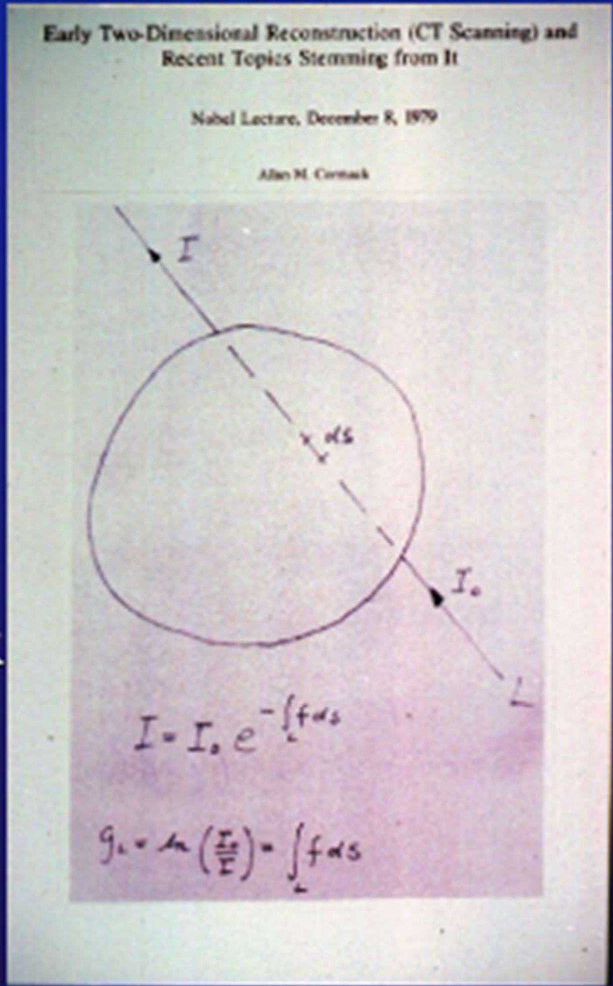


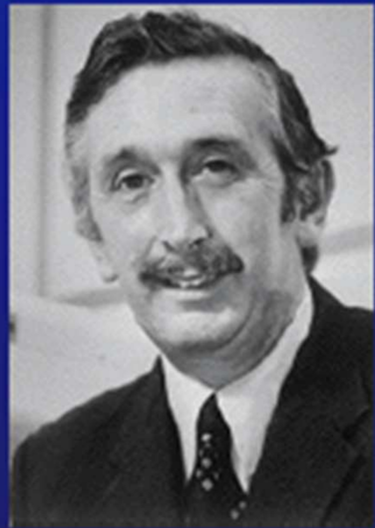
State of the art :Computed Tomography (CT)

Nobel Price Physiologiy and Medecine 1979



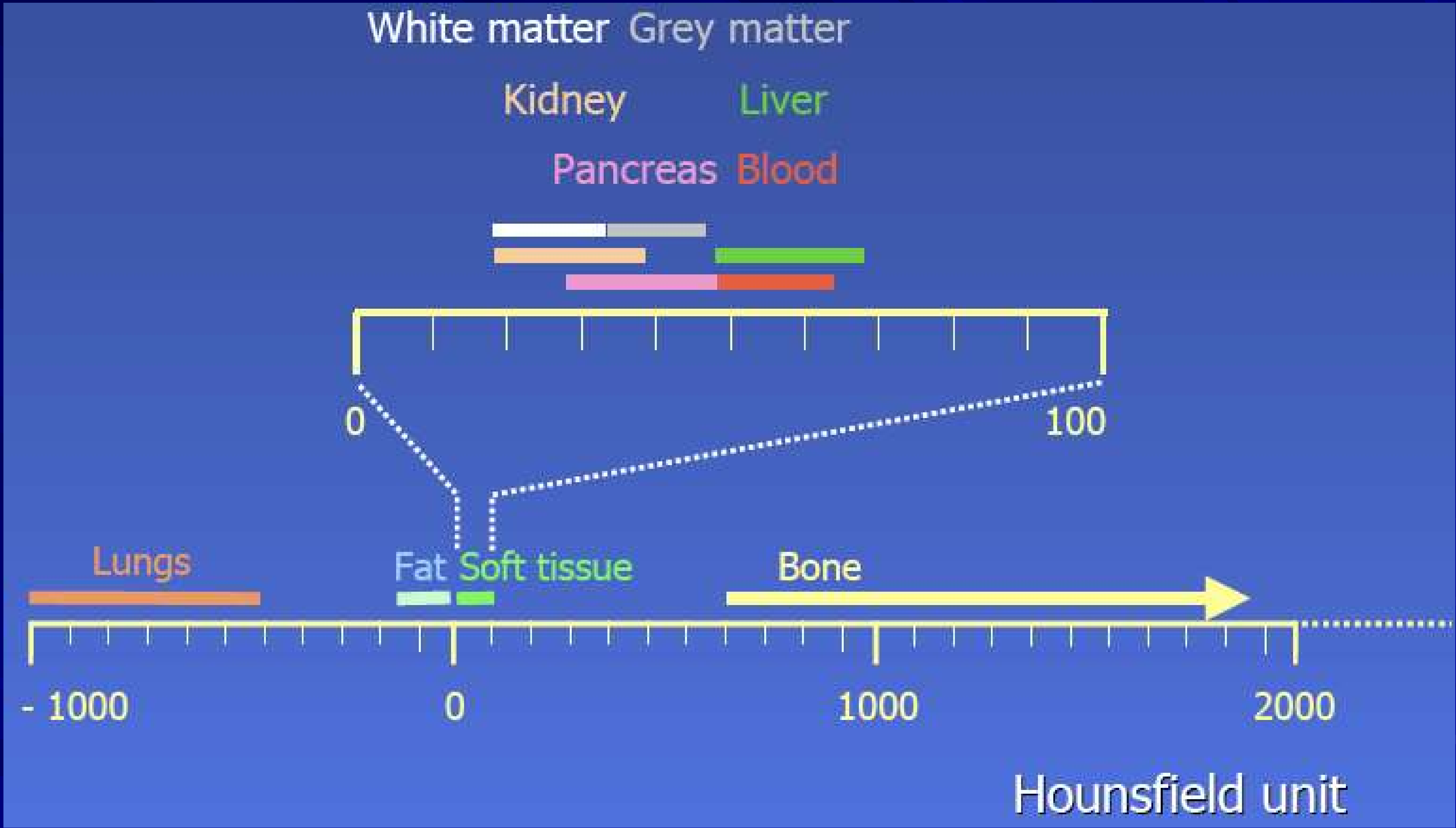
Allan MacLeod **Cormack**
Physicien Nucléaire
Cape Town
Harvard University
Tufts University



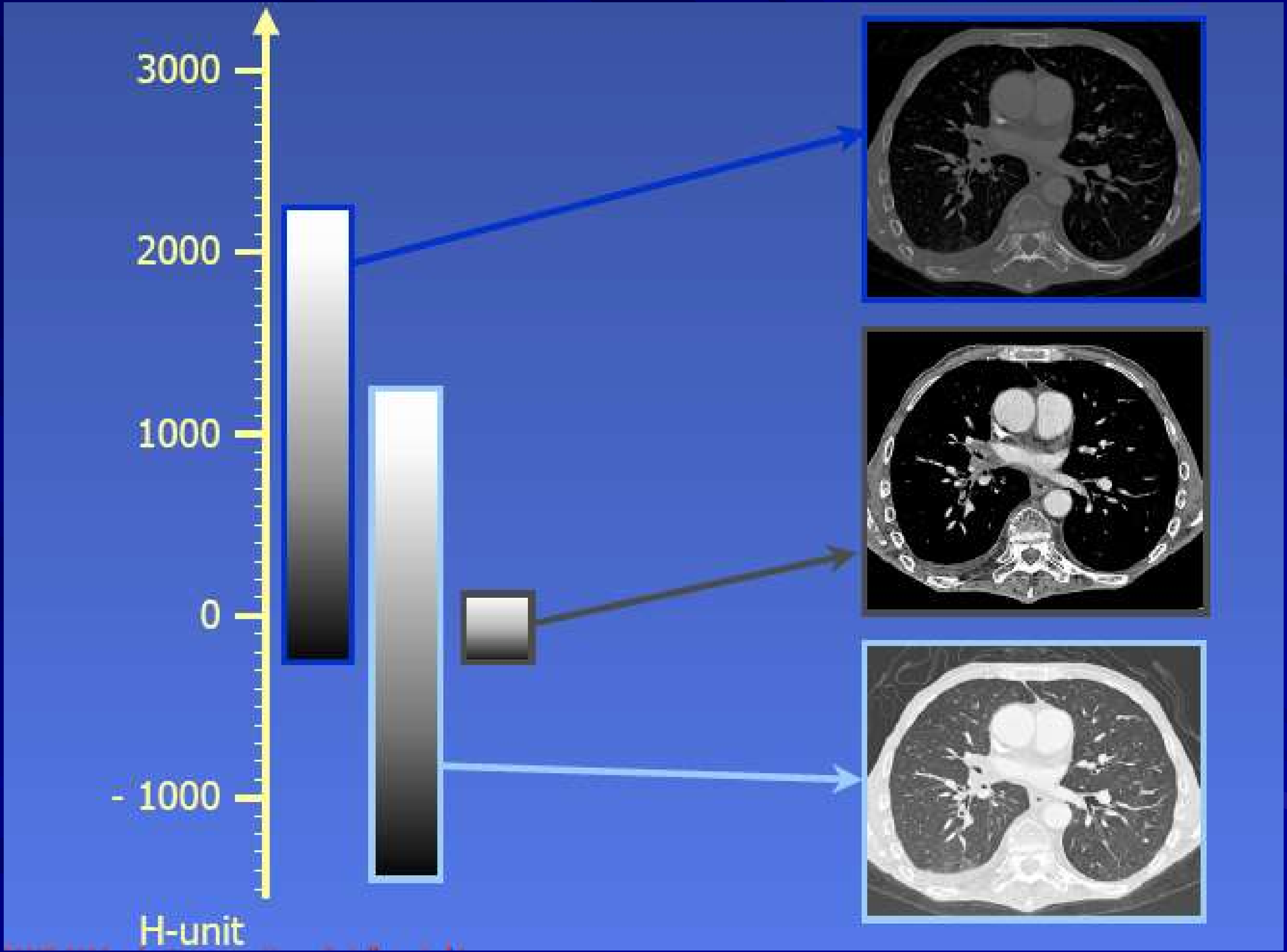


Sir Godfrey N. **Hounsfield**
Electrical engineer
EMI Research

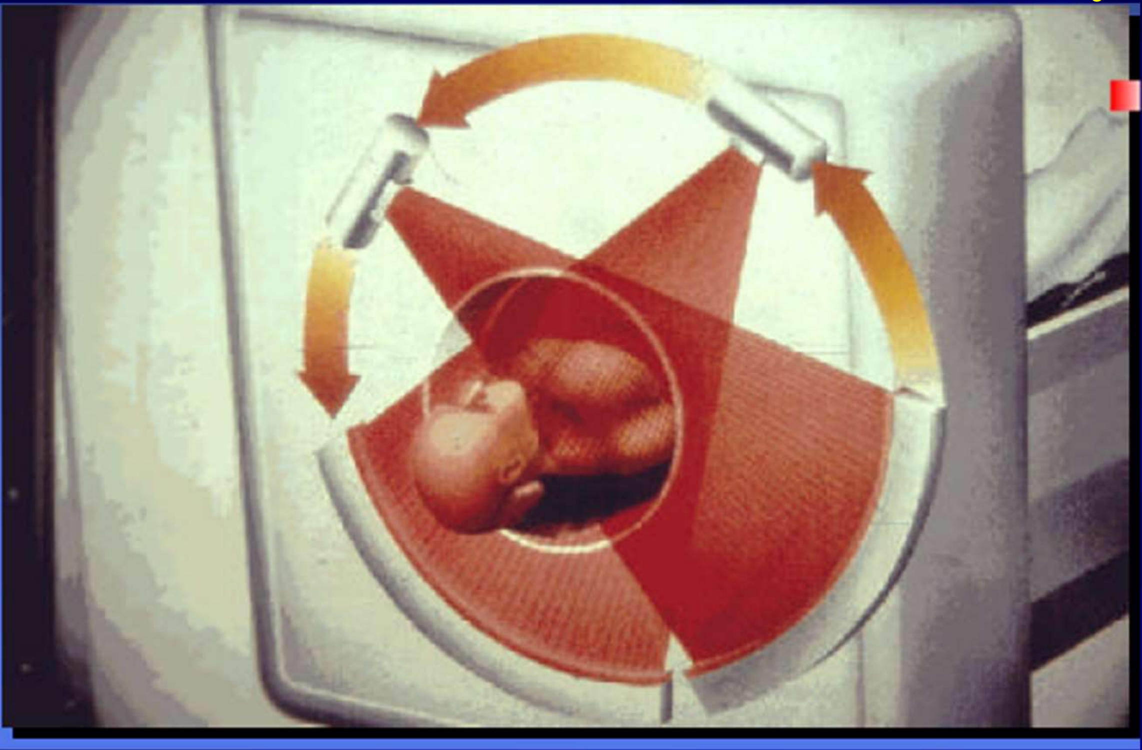
Contrast (Houndsfield) units



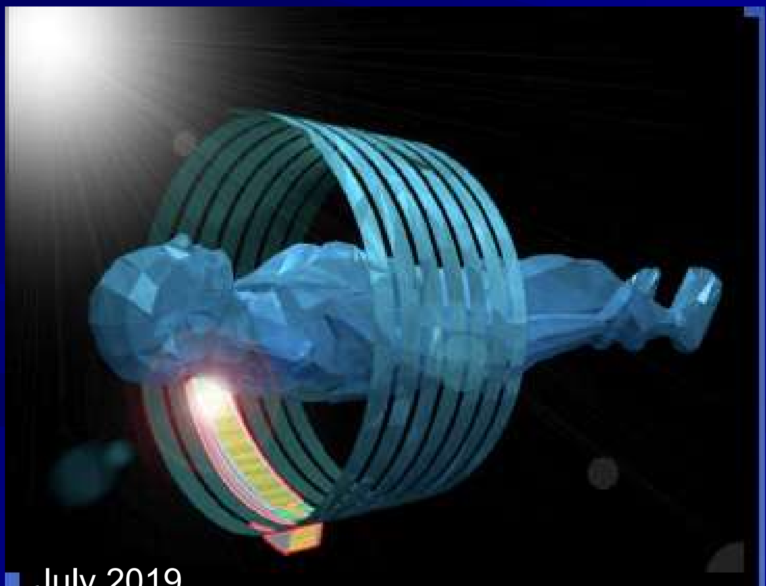
From Hounfield units to image



CT Scaner principle

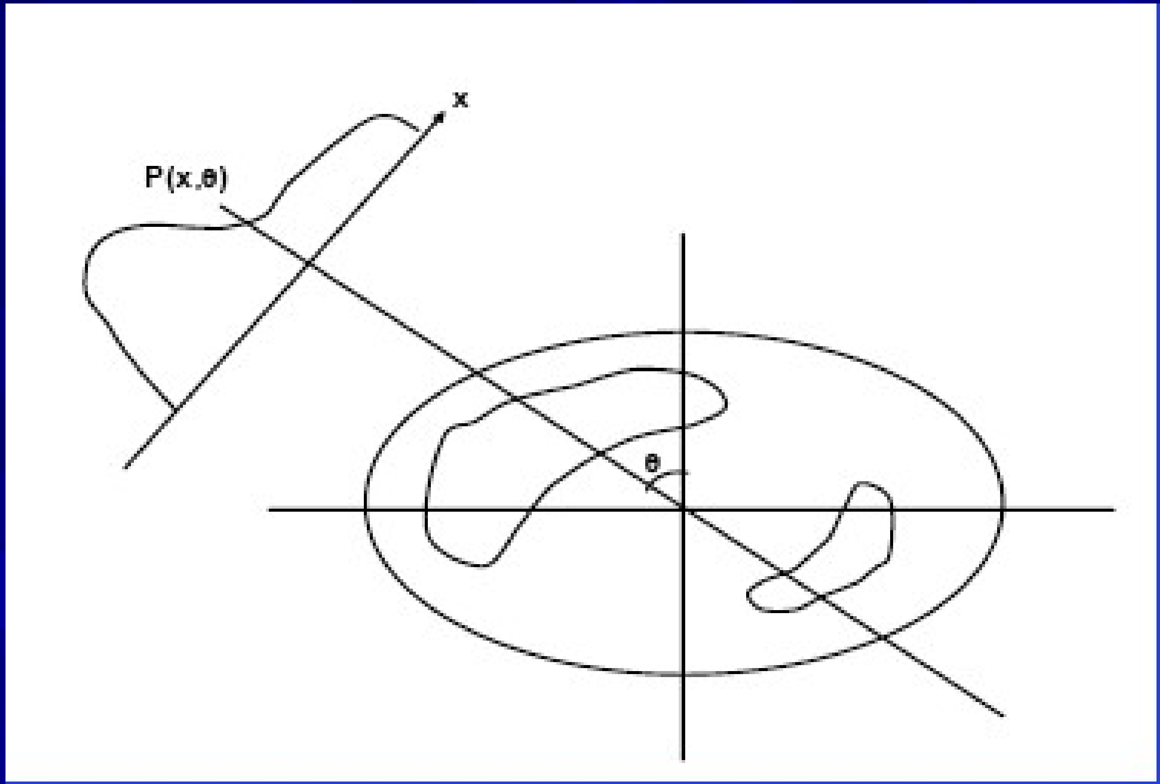


- Spatial resolution and speed
  - 64 … 320 detector rows
  - Slice thickness 0.33 … 0.6 mm
  - Tube rotation time 0.3 s
    - Organ in a sec
    - Whole body < 10 sec
  - dual source (180° → 90°)
  - Volume coverage with one rotation: 4 … 16 cm



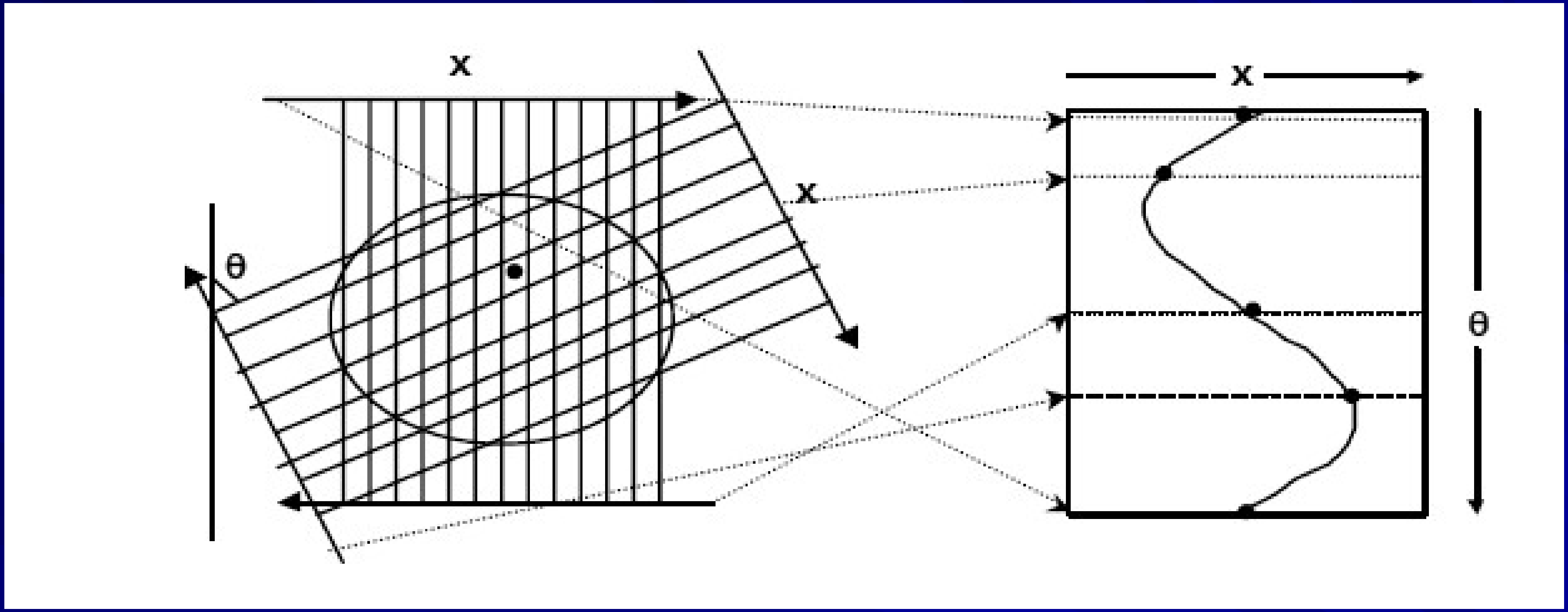
Computed Tomography
Basic method of Image reconstruction

- Take 1D profiles or 2D projection at discrete angle around the object
- Assume that each measured point = sum of actvity elements along the Line of Response (LOR)



Raw data can be displayed as a 'sinogram'

Computed Tomography
Basic method of Image reconstruction



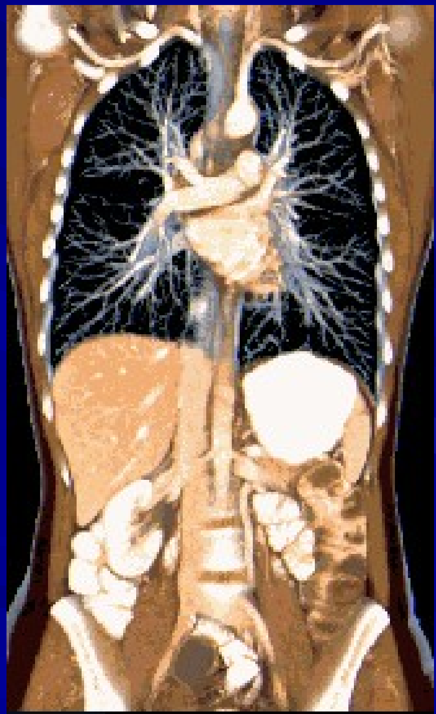
Projection

Sinogram

Raw data can be displayed as a 'sinogram'
Then a lot of corrections .....

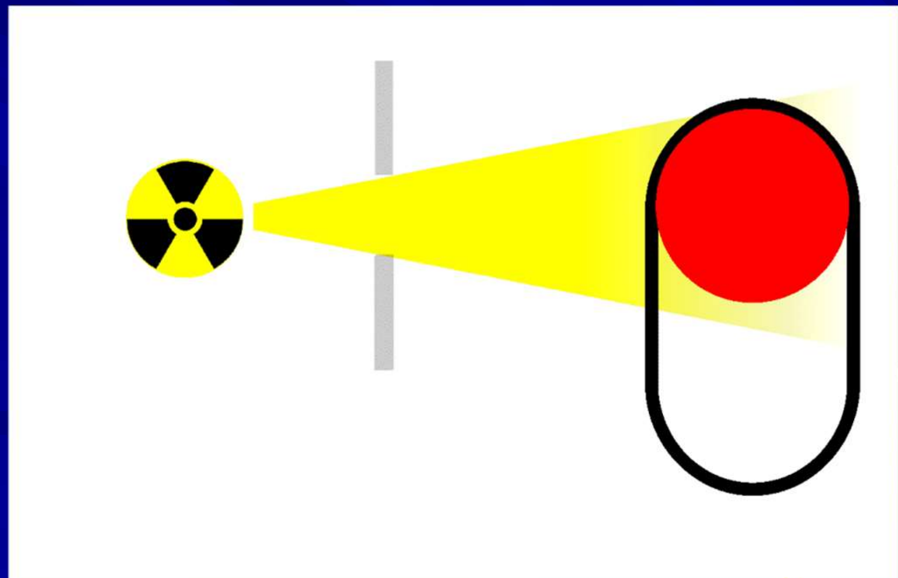
Computed Tomography scaner (CT)

- The best device widely used for precise exam
  - Whole body
  - Cardiology
- Still a lot of radiation = 20-50 mSv
  - Standard radiography = 0.1 m Sv



State o the art : 4D CT

- Position influenced by the breathing motion

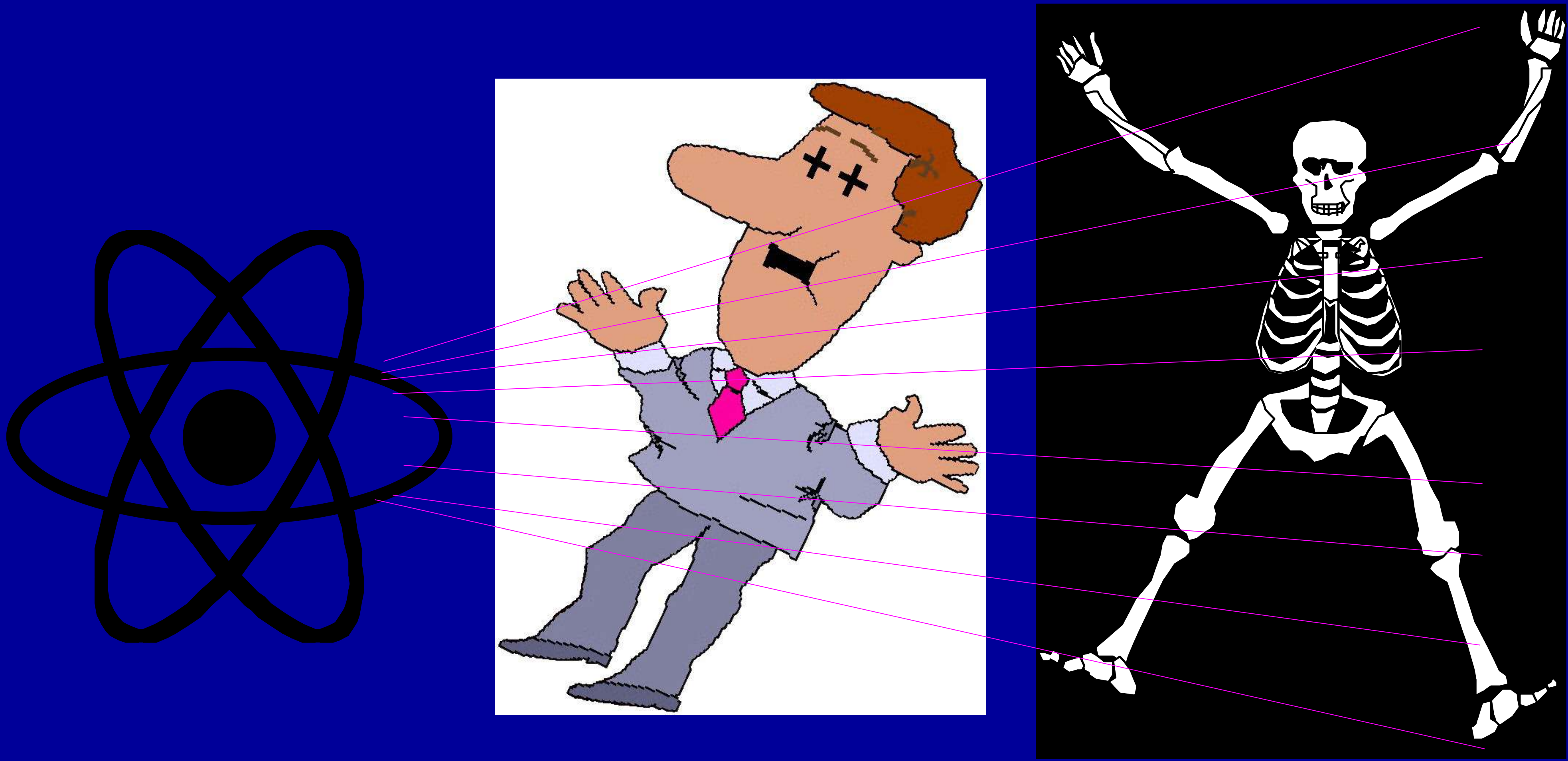


Exposure for radiological exams

- Some examples

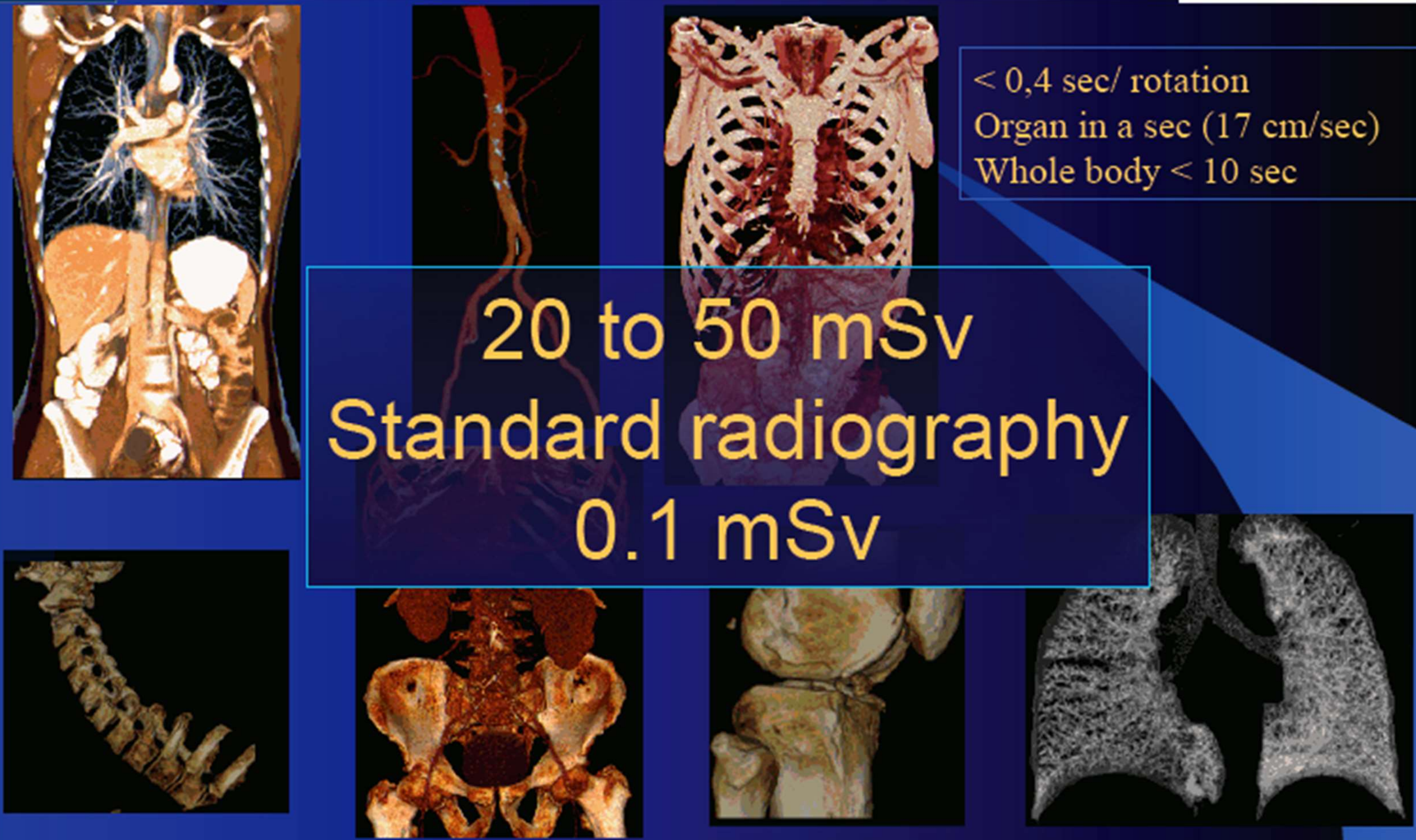
organ	dose skin mGy	effective dose mSv
Thorax, face	0,2 - 0,5	0,015 - 0,15
Lumbar region	4 - 28	1,5
Urography	40 - 60	3
Brain scan	7 - 78	1
Whole Body scan	30 - 60	4 - 10
Mammography	7 - 25	0,5 - 1

Patient Radiation Dose is Limited!



- Image Noise Is Limited by Counting Statistics
- Cannot Increase too much Source Strength

< 0,4 sec/ rotation
Organ in a sec (17 cm/sec)
Whole body < 10 sec

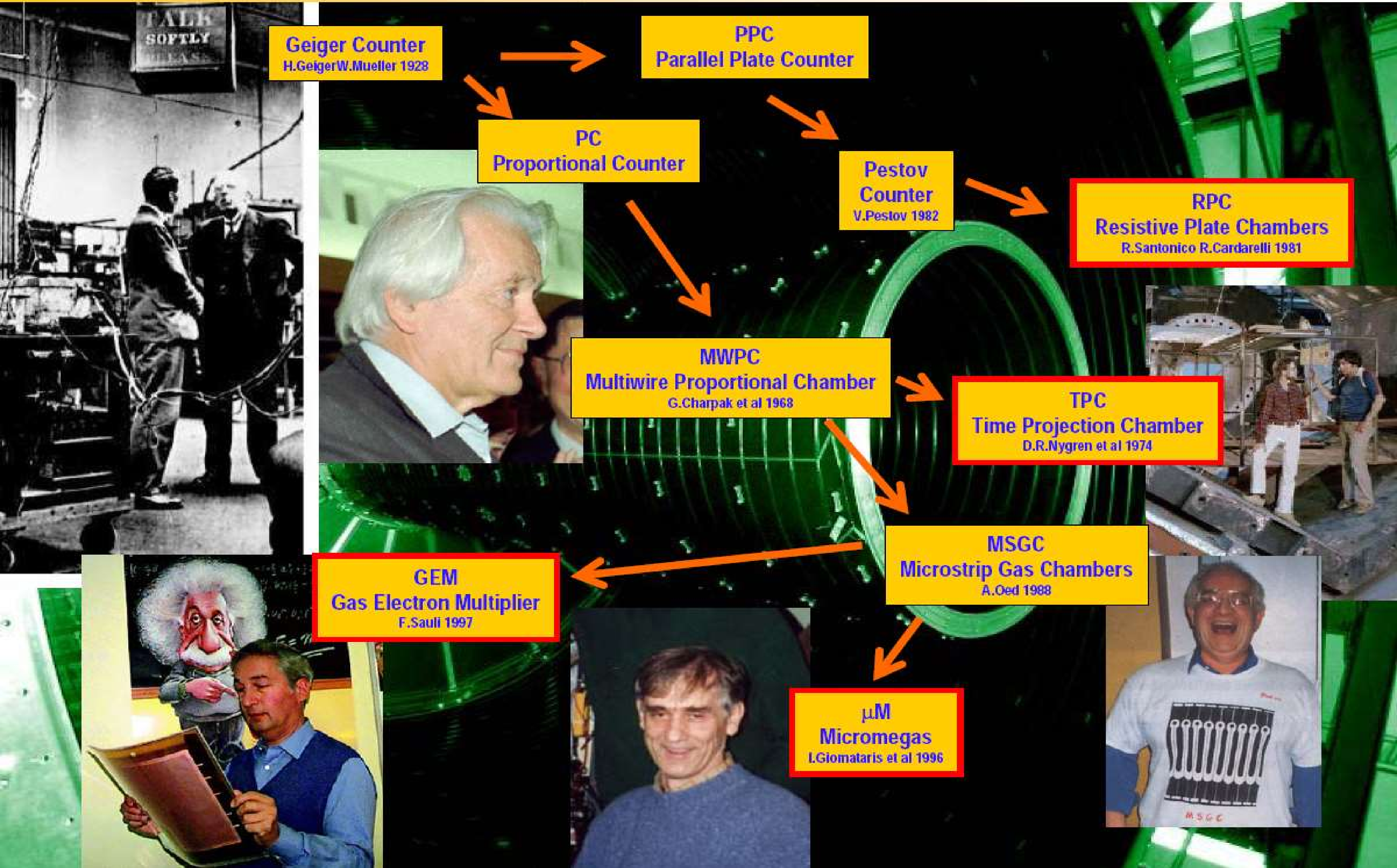


20 to 50 mSv
Standard radiography
0.1 mSv

Deacreasing the dose with HEP Gazeous detector

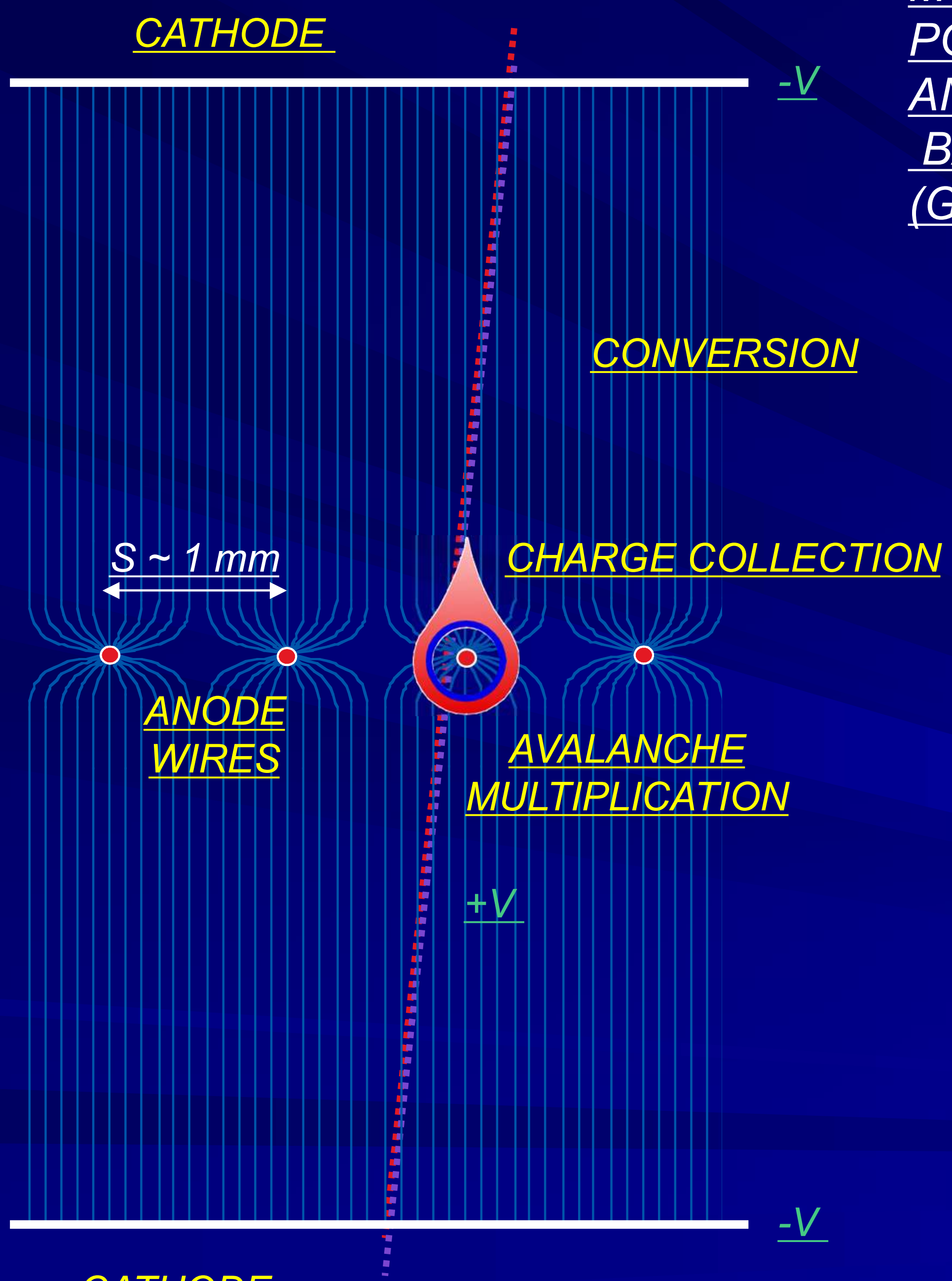
The Future?

Gas Detector History

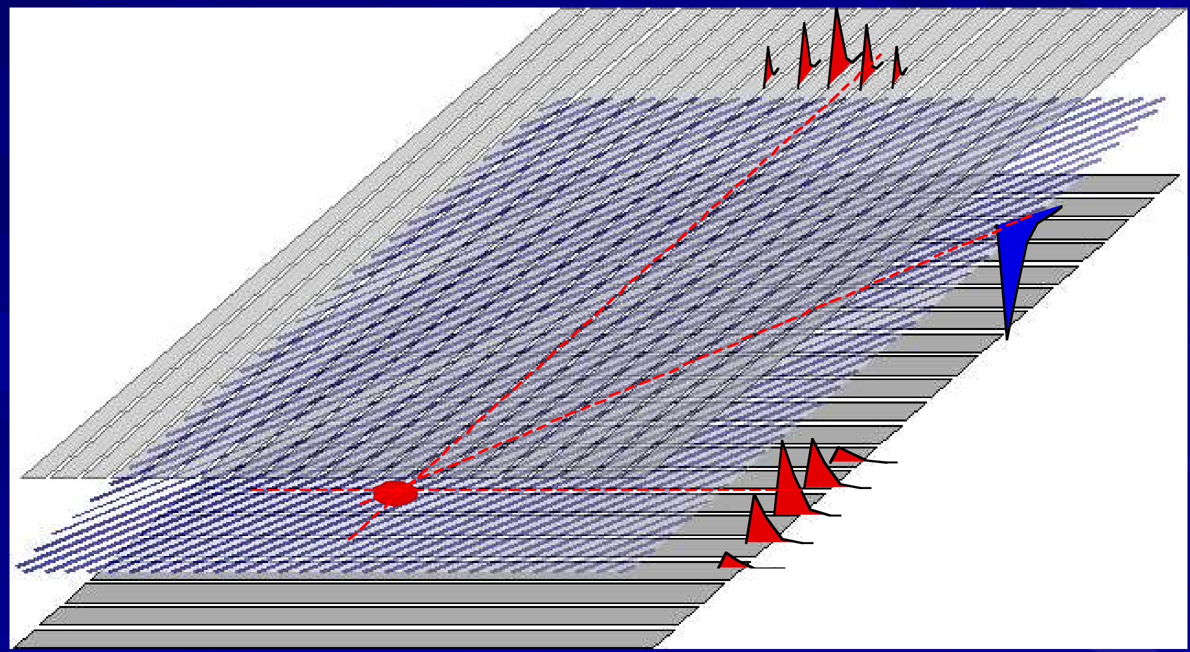


Multi Wires Proportional chambers MWPC

MODERN GASEOUS DETECTORS:
POWERFUL TOOLS FOR RADIATION DETECTION
AND LOCALIZATION IN PARTICLE PHYSICS,
BASED ON THE MULTIWIRE PROPORTIONAL CHAMBER
(Georges Charpak, 1967)



TWO-DIMENSIONAL MWPC READOUT CATHODE
INDUCED CHARGE (Charpak and Sauli, 1973)

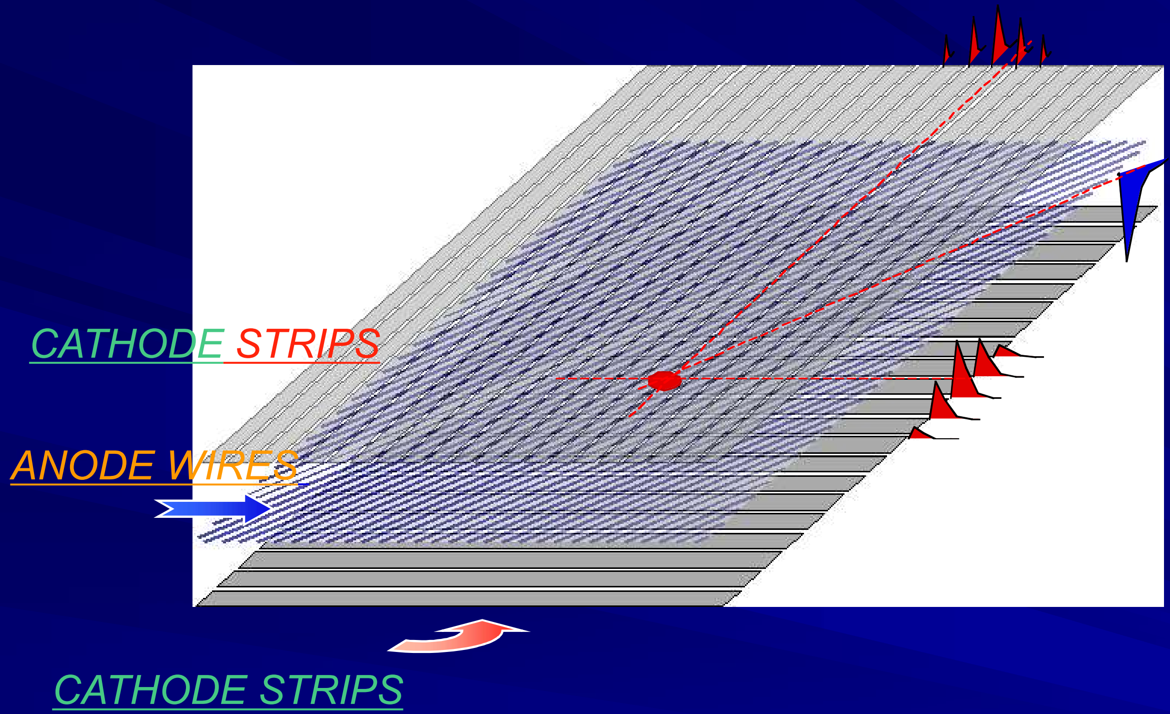


Spatial resolution determined by: Signal / Noise Ratio
Typical (i.e. 'very good') values: S ~ 20000 e: noise ~ 1000e
Space resolution < 100 μm

E. Gatti et al, Optimum geometry for strip cathodes … , Nucl. Instr. and Meth. 163(1979)83

TWO-DIMENSIONAL LOCALIZATION

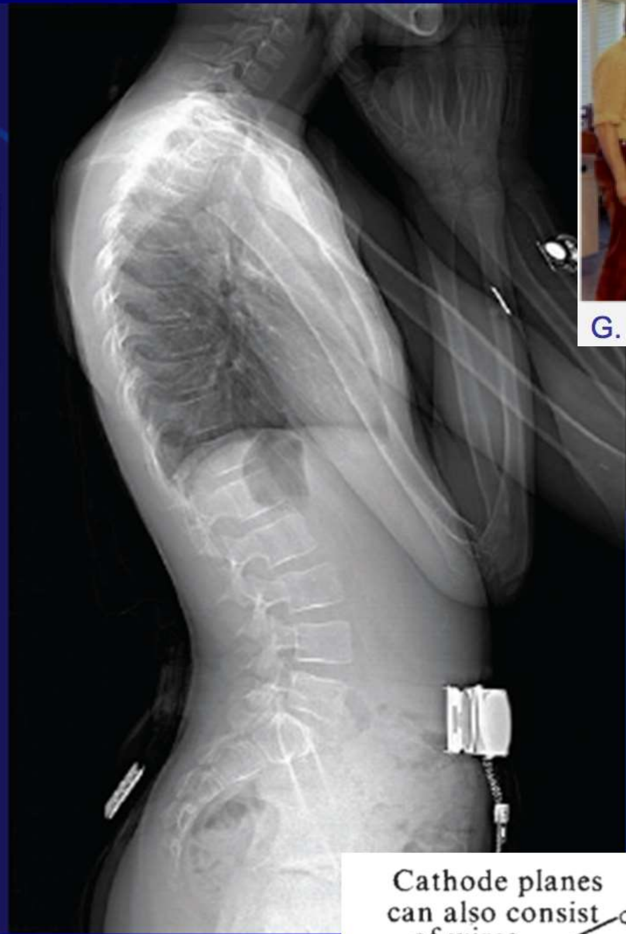
TWO-DIMENSIONAL LOCALIZATION FROM SIGNALS INDUCED ON CATHODE PLANES (Charpak & Fabio Sauli, ~1973)

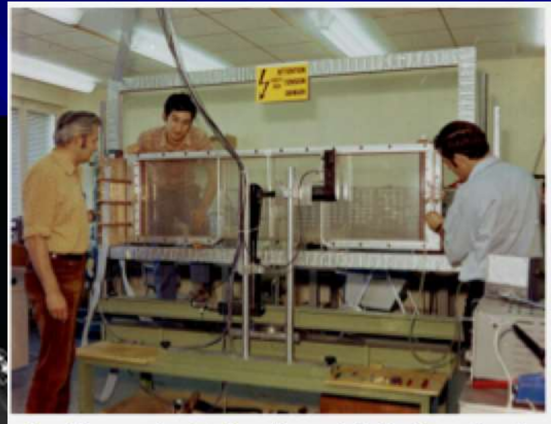


LOW-DOSE DIGITAL RADIOGRAPHY
WITH MWPC:
CHARPAK'S HAND (2002):

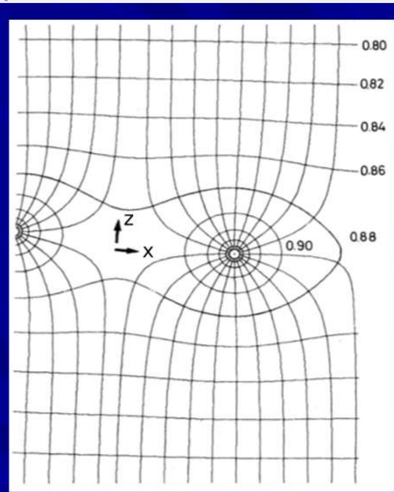
The 1970's dream : Digital radiography with MWPC
A tribute to George Charpak

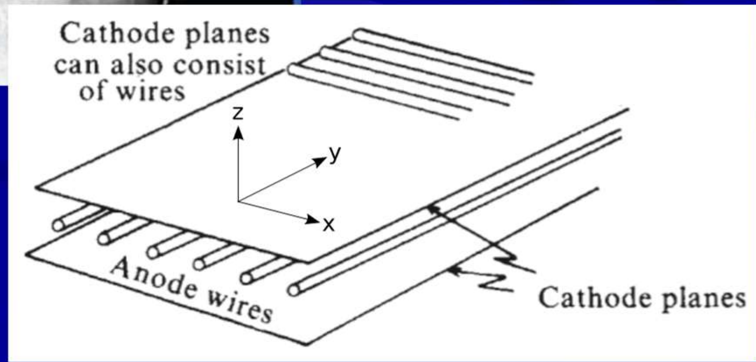
- With 10 time less dose





G. Charpak, F. Sauli and J.C. Santiard





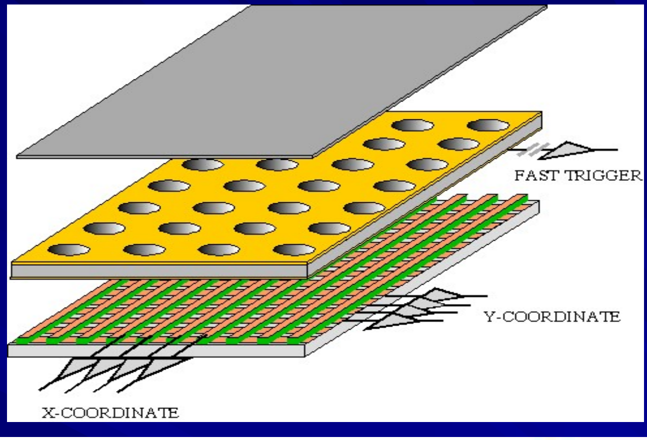
X Ray imaging

Wire Chamber Radiography:

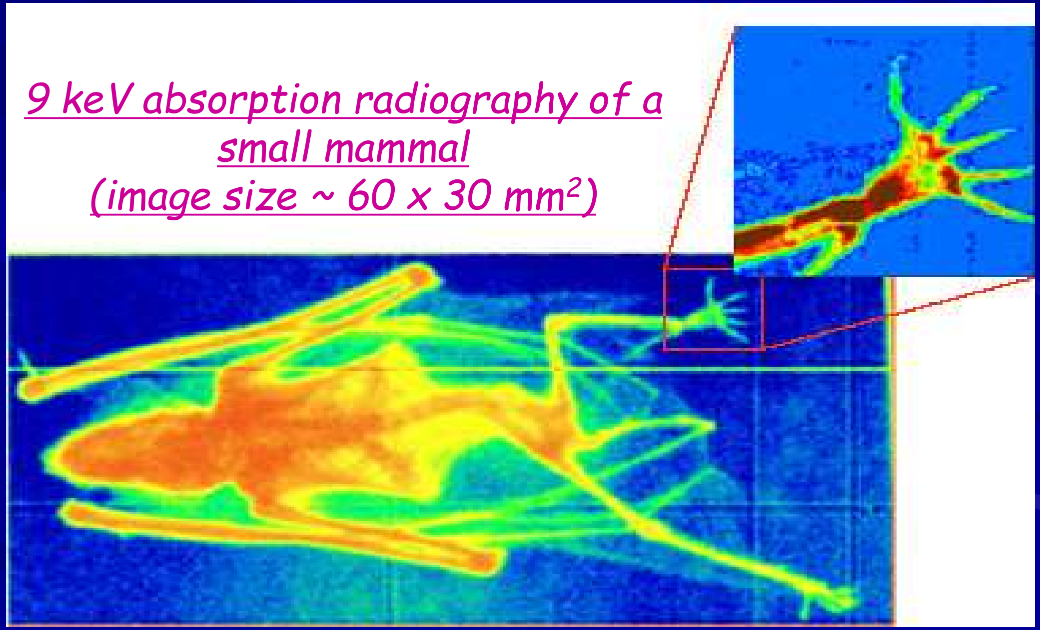
Position resolution ~ 250 μm

GEM for 2D Imaging:

Using the lower GEM signal, the readout can be self-triggered with energy discrimination:



9 keV absorption radiography of a small mammal (image size ~ 60 x 30 mm^2)



Position resolution ~ 100 μm (limited by photoelectron range in the gas)

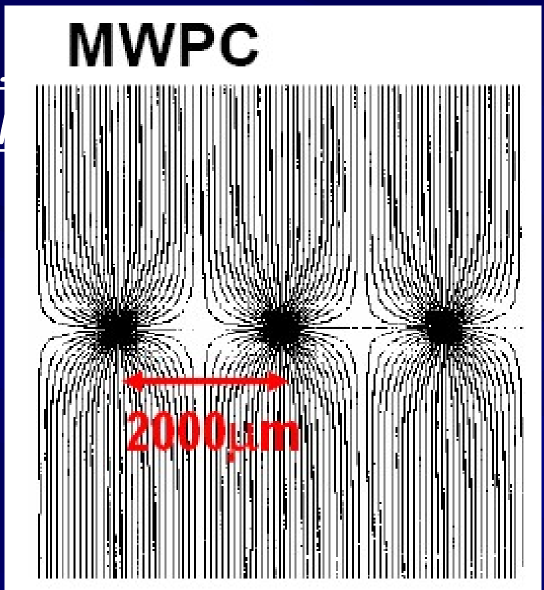
A. Bressan et al, Nucl. Instr. and Meth. A 425(1999)254
F. Sauli, Nucl. Instr. and Meth.A 461(2001)47
G. Charpak, Eur. Phys. J. C 34, 77-83 (2004)
F. Sauli, http://www.cern.ch/GDD

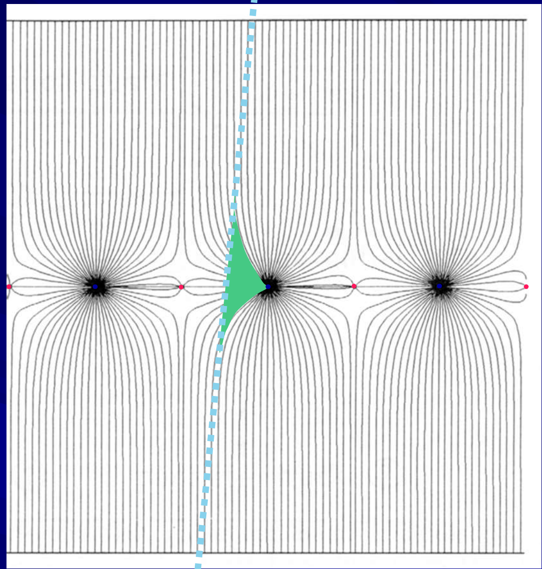
From MWPC's to MGPD's

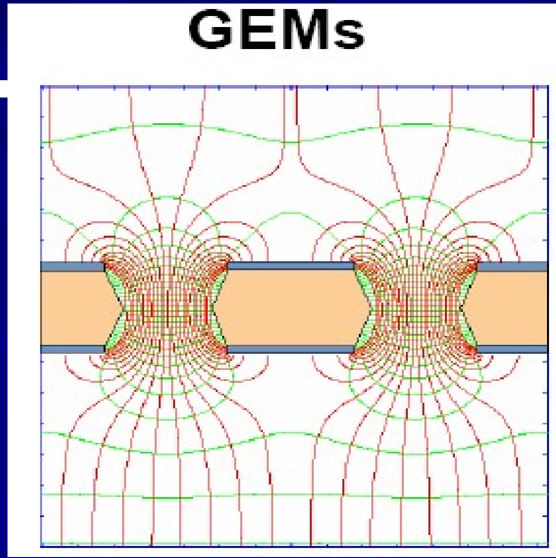
MGPD

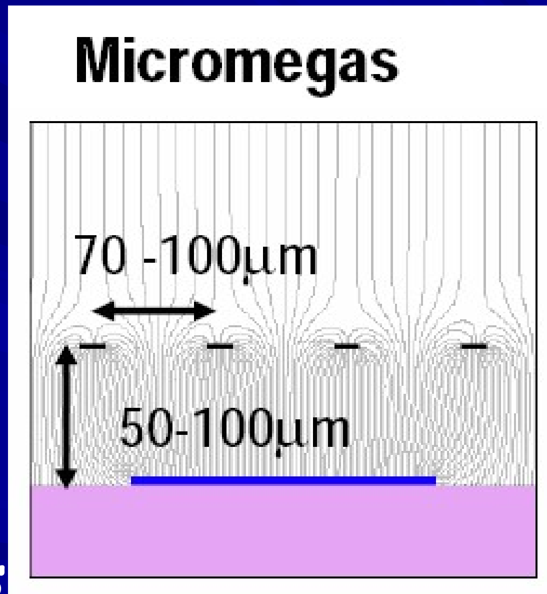
MWPC

Drift Chamber









1975 - 1995

UA2-LEP

1990 -

Multiwire Proportional Chamber

Georges Charpak 1968

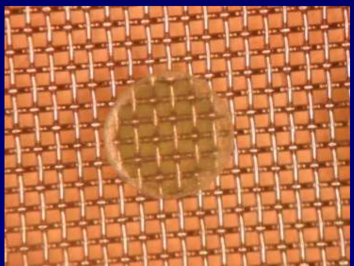
GEM F.Sauli)

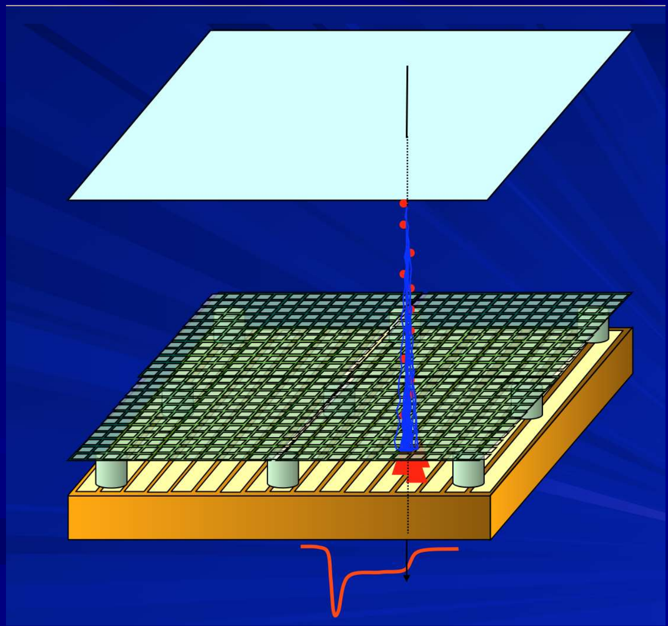
Micromegas Y. Giomataris

MPGD

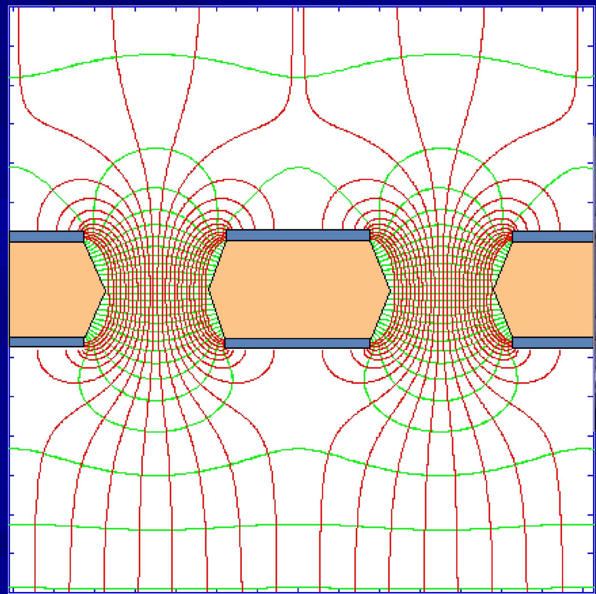
- From 1988-1998 Micro-technologies and etching techniques allowed development of Micro Patter Gaseous Detectors

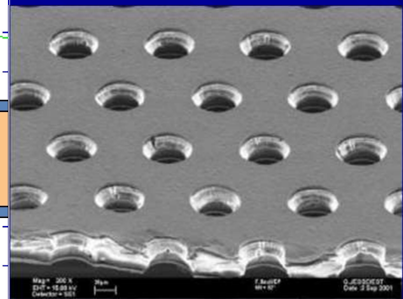
- MICROMEsh GAseous Structure
  - Thin gap Parallel Plate Chamber: micromesh stretched over readout electrode.





- Gas Electron Multiplier
  - Thin, metal-coated polymer foil with high density of holes, each hole acting as an individual proportional counter.

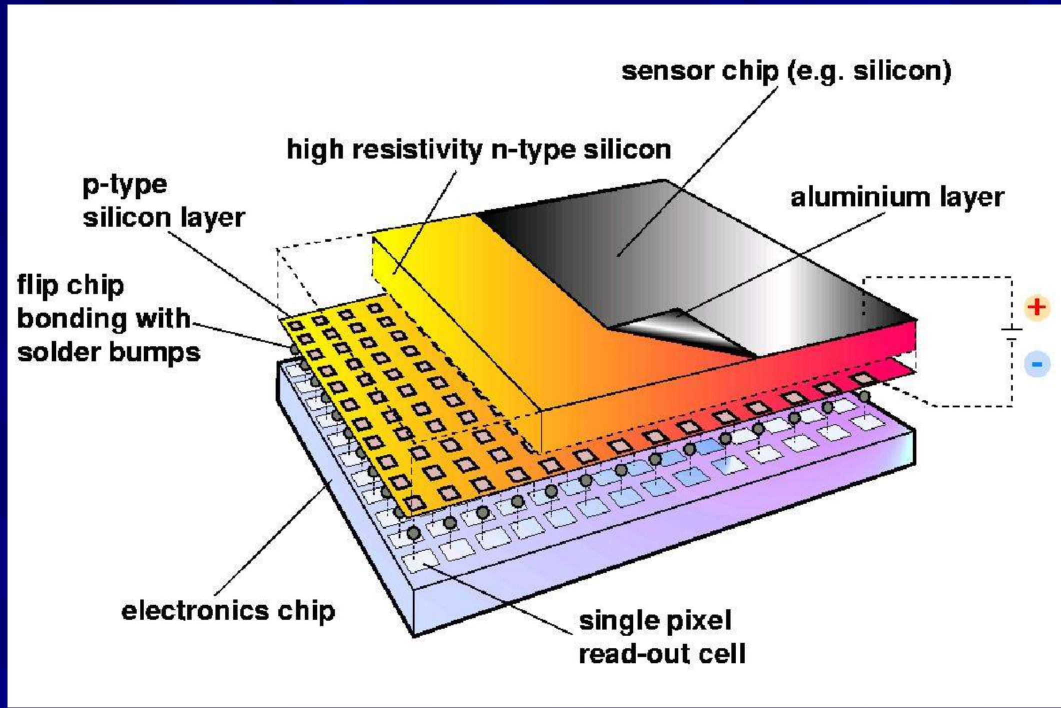


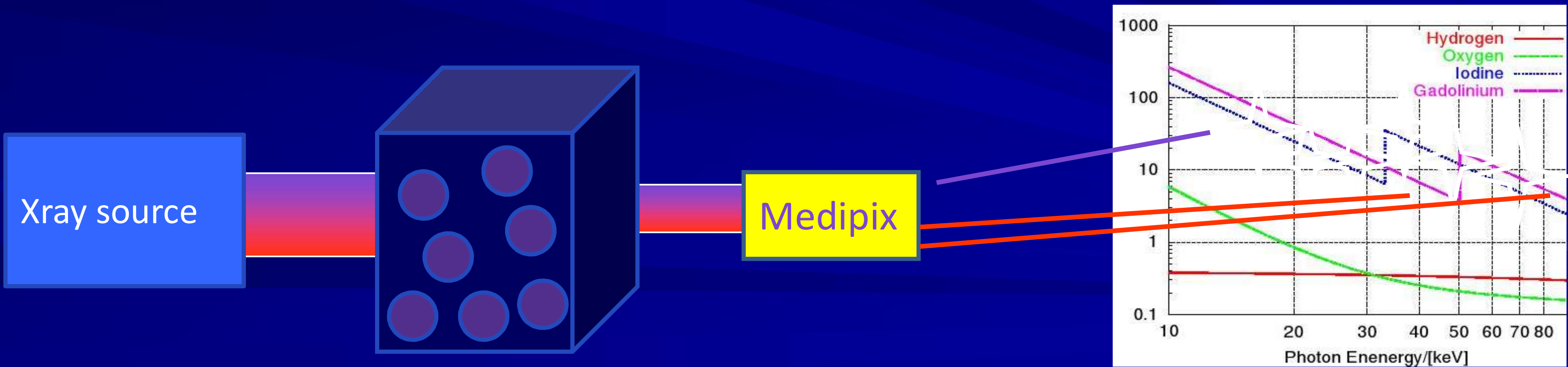


The Future : New Si detector and signal processing On the way to photon counting?

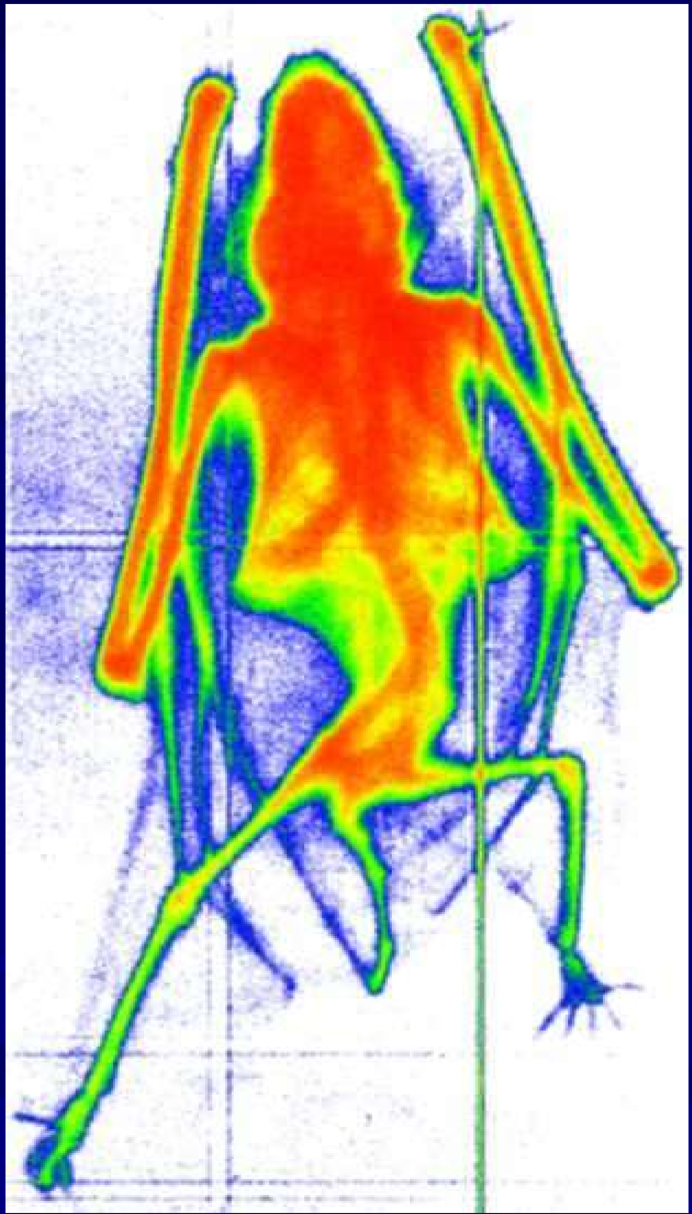
Medipix3

- 8 simultaneous energies
- 55 µm isometric resolution
- Excellent energy resolution
- 10^8 photons per second per mm^2



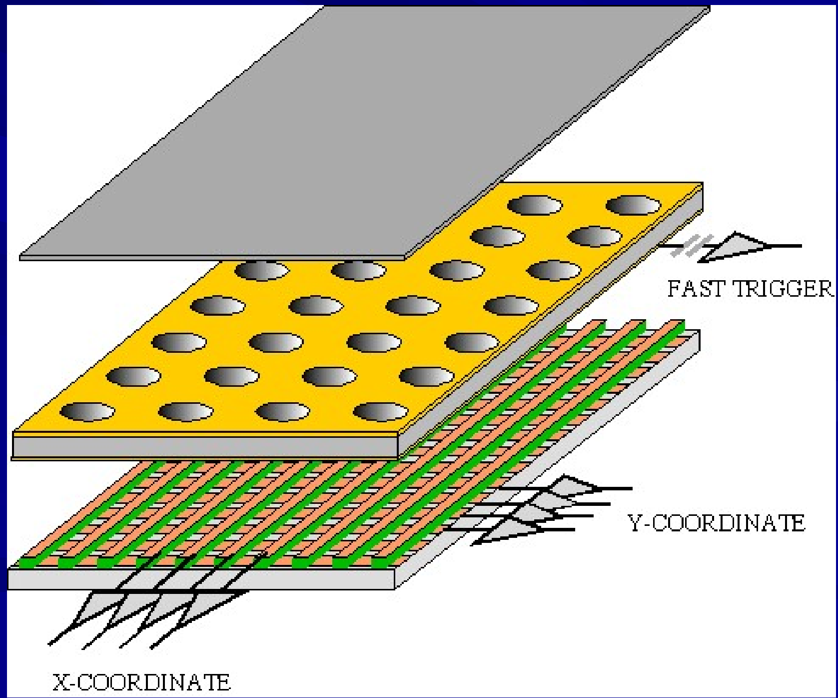


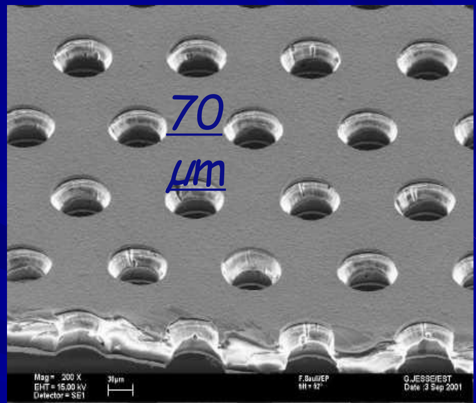
Exemple with GEM Detector

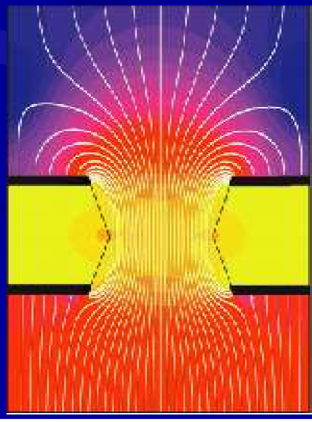


F.Sauli & al.

- Thin, metal-clad polymer foil, chemically pierced by a high density of holes (70-80 μm diameter).
- On application of a difference of potential between the two electrodes, electrons released by radiation in the gas on one side of the structure drift into the holes, multiply and transfer to a collection region.
- Cascading several foils results in high multiplication factors.

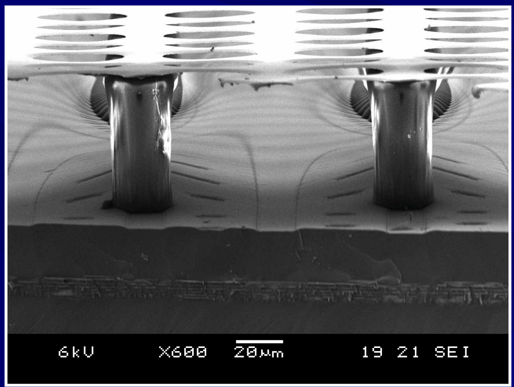




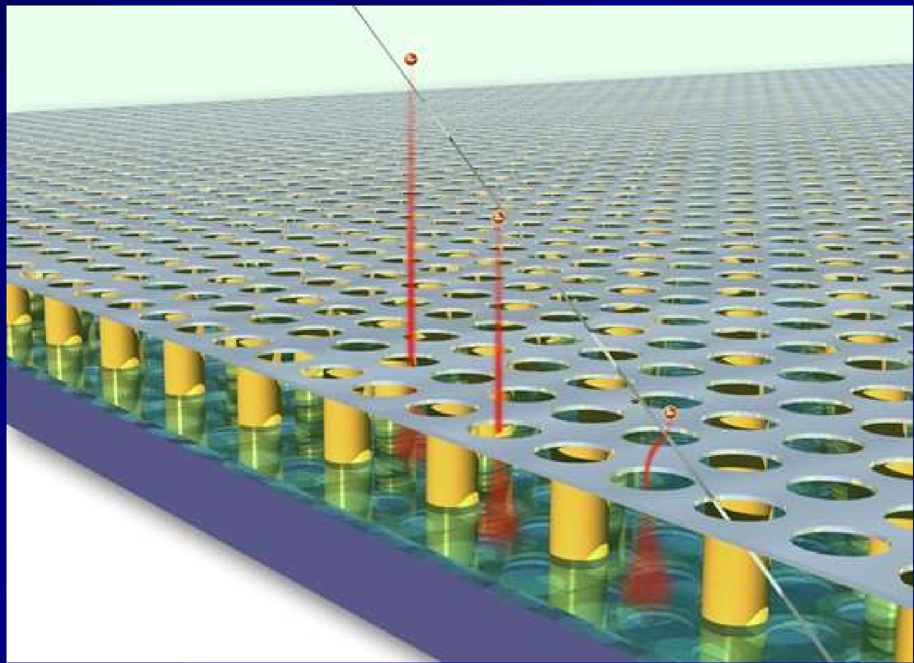


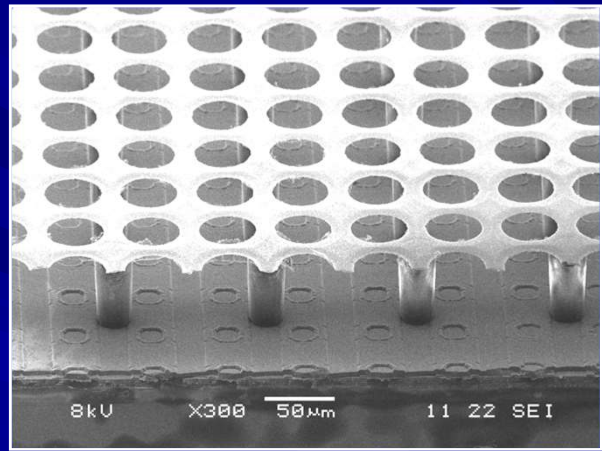
Next → INGRID

- InGrid :integrate the Micromegas/GEM concept on top of a MediPix pixel CMOS chip (Timepix)
  - pixel size: 55 x 55 μm^2
  - per pixel: preamp – shaper – 2 discr. –
  - Thresh. DAQ - 14 bit counter



metalized foil
~100 µm ~1mm



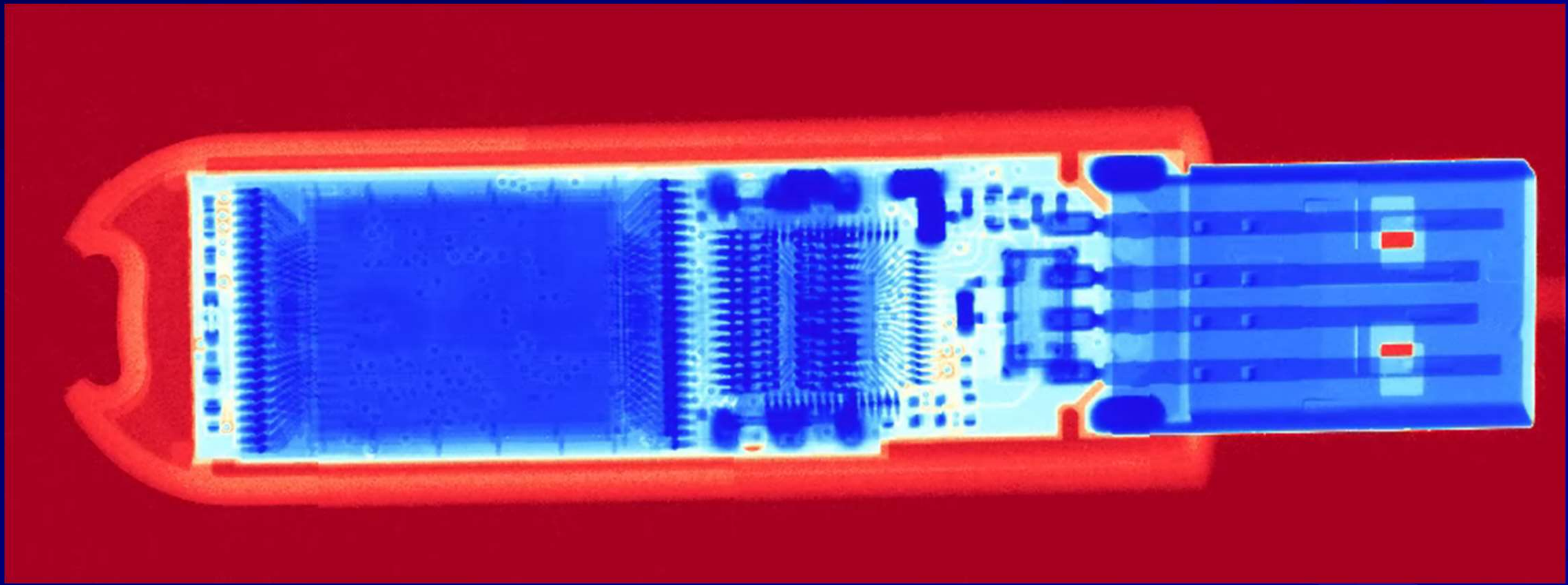


66Cmos Medipix chip

- Use → Large Trackers & Calorimeters

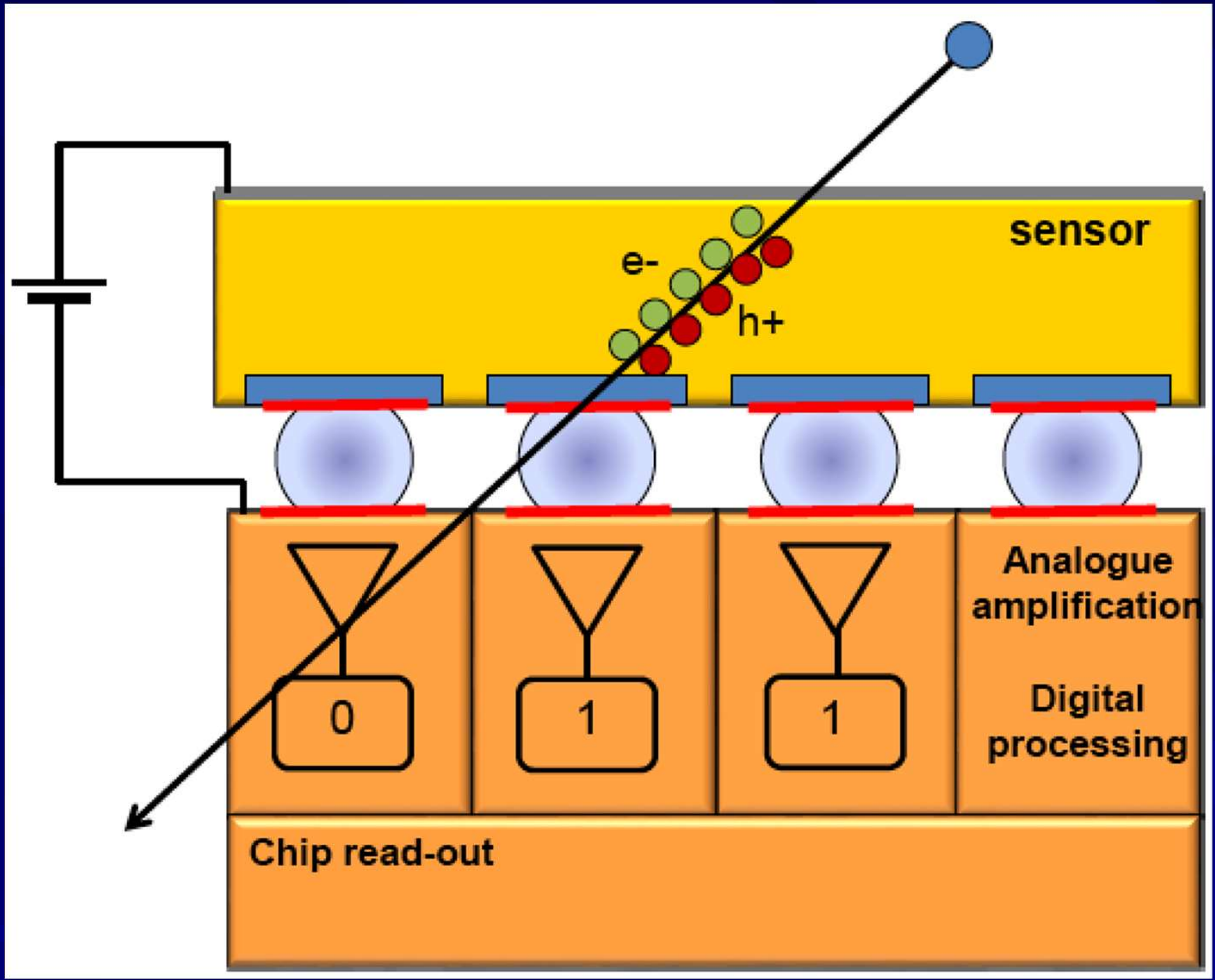
Medipix-CT setup for detector investigations & material analysis

Example → USB flash drive



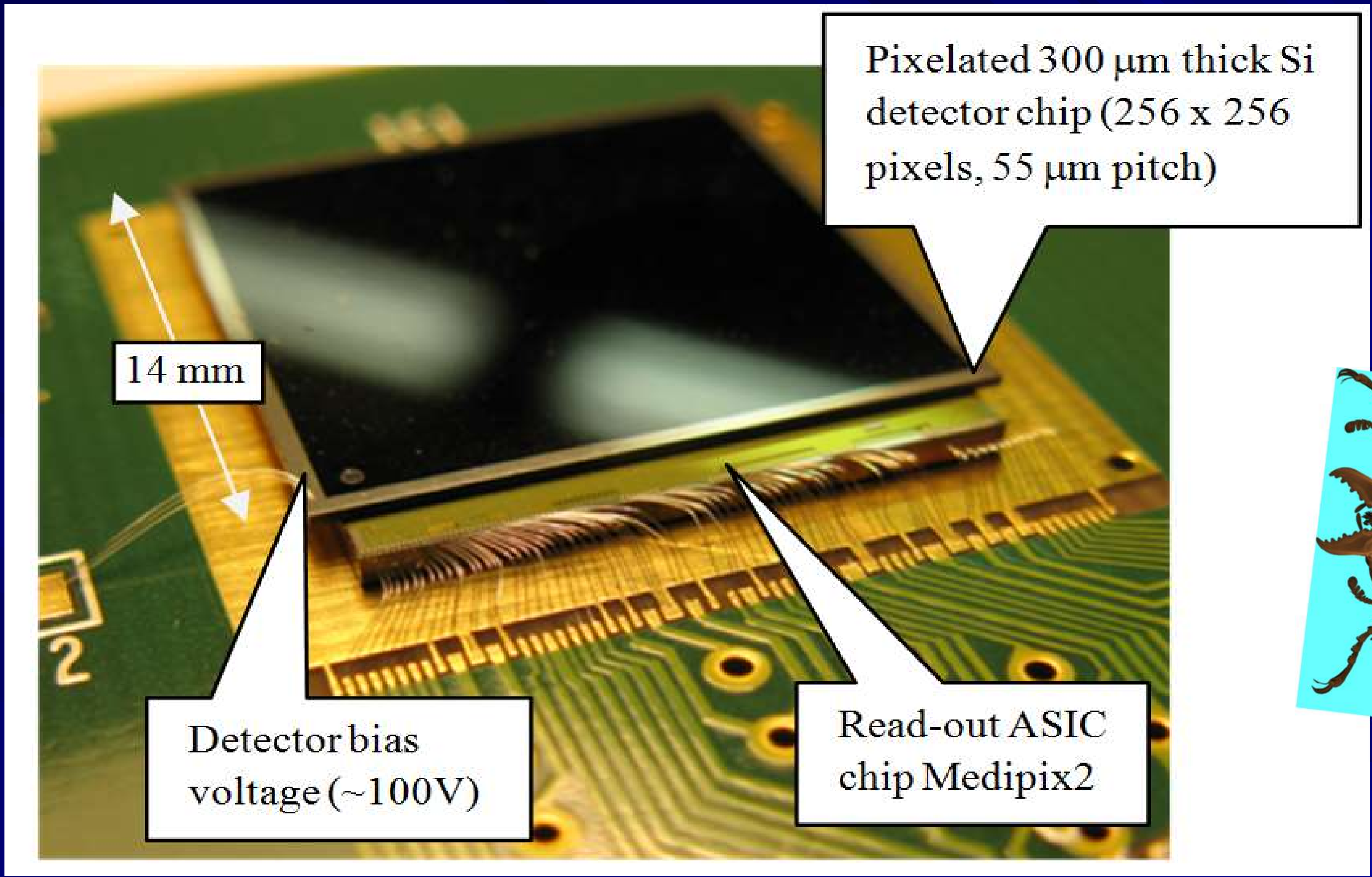
TPX 110μm + CdTe 2mm
8x2 tiles / mag. 1.5x
65kV / 200μA

Hybrid Pixel detector principle



- An ionising particle deposits charge in the silicon sensor
- The reverse biasing of the sensor diode structure drives the charge to the readout chip
- The charge is shaped and a threshold applied
- Digital processing occurs
- The data is read out off the chip

Medipix-Timepix family



PORTAL IMAGING

PORTAL IMAGING: VERY HIGH RATE GAMMA RAYS DETECTION

ROYAL INSTITUTE OF TECHNOLOGY AND KAROLINSKA HOAPITAL (STOKHOLM)

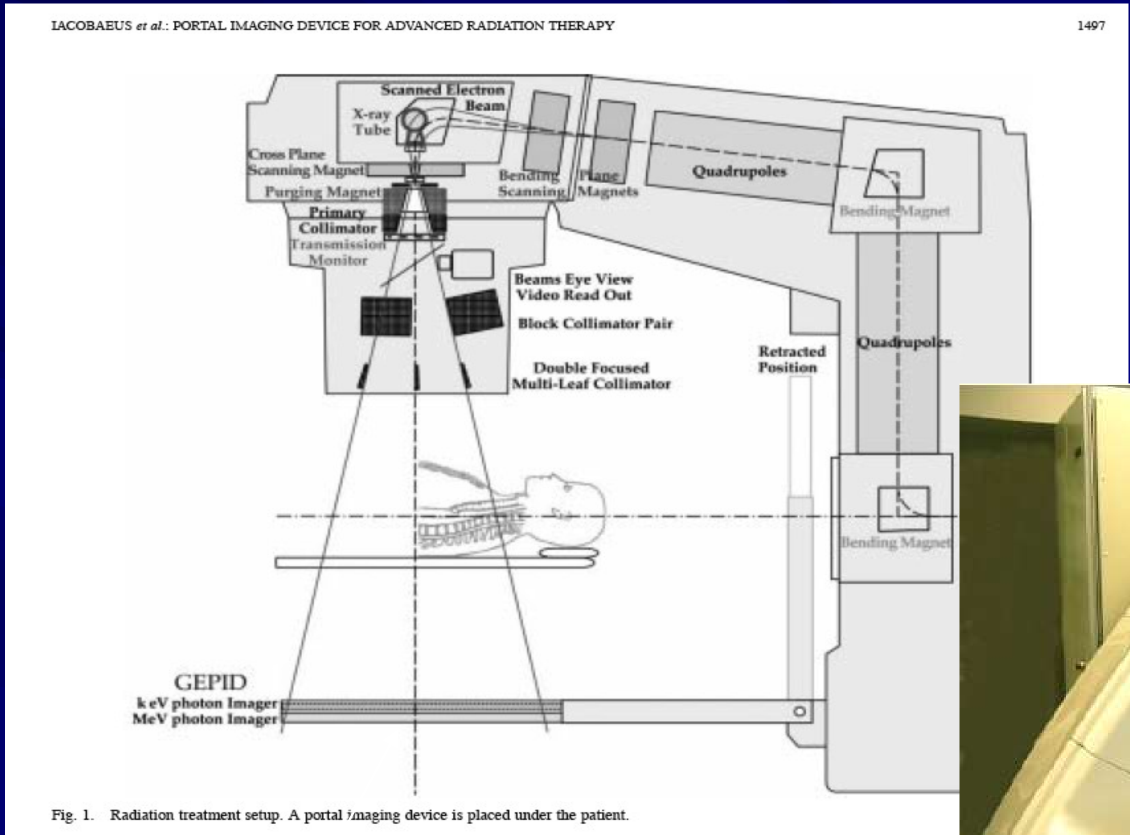
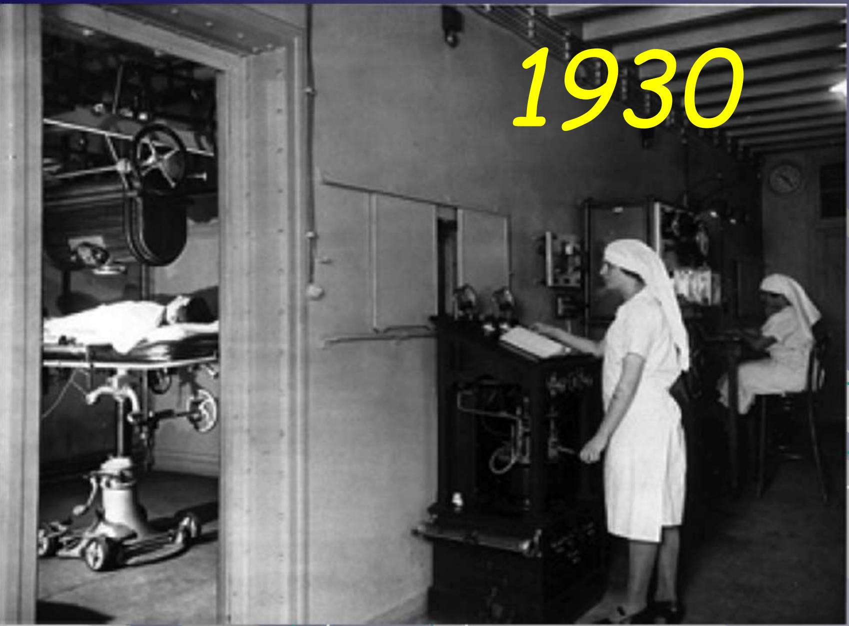

IACOBAEUS *et al.*: PORTAL IMAGING DEVICE FOR ADVANCED RADIATION THERAPY 1497

Fig. 1. Radiation treatment setup. A portal imaging device is placed under the patient.

Real Time Imaging and Dosimetry

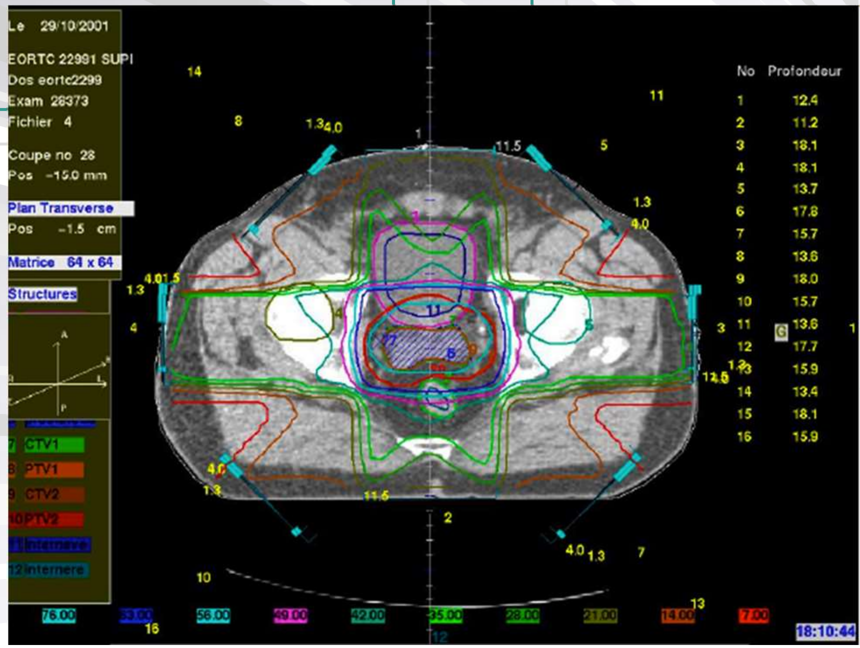
GEM-BASED PIXEL DETECTOR

C. Iacobaeus et al, IEEE Trans. Nucl. Sci. NS-48 (2001)1496



Radiotherapy

Common tools & techniques

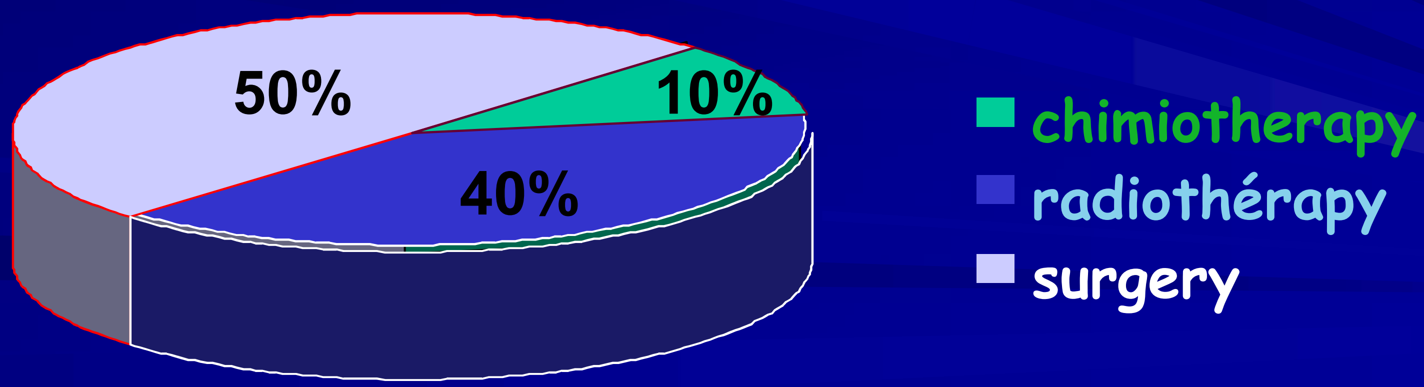


Cancer in Europe – a growing challenge

- 3.4 millions of new cases in Europe per year
- About 50% will develop cancer at some point of their life
- Main cause of death between the age of 45-65
- Second most common cause of death

Fight again cancer – Radiotherapy

- Local irradiation to kill tumour → 100 Gy = 90 % of sterilization
- Frequent treatment (2/3 of cases).
- Efficient treatment: cure → 40 to 50% of recovery
- Allow good quality of life and tolerance
- non invasive, itinerant and without important physical effects.
- Cheap (< 10%) of the cancer budget (France)
- Essentially X rays
  - (Linear accelerators) & photons (curietherapy)



About Cancer

- France→around 230 000 new cases per year
- → Cure (35-40 %)

  Health budget = 130 Billions Euros

  CANCER = 10 Billions Euros
- Targeting 2030 → Cure > 50 %

First step →
Improve diagnostics tools (imaging)
Future → screening possibility ?

CANCER DEATHS BY SITE

SITE	DEATHS
Lung	163,700
Colorectal	57,100
Breast	40,200
Prostate	28,900
Pancreatic	30,000
Female Reproductive	26,800
Lymphoma	24,700
Malignant Melanoma	9,800
Hodgkin's	1,300

US statistics

Radiatherapy X

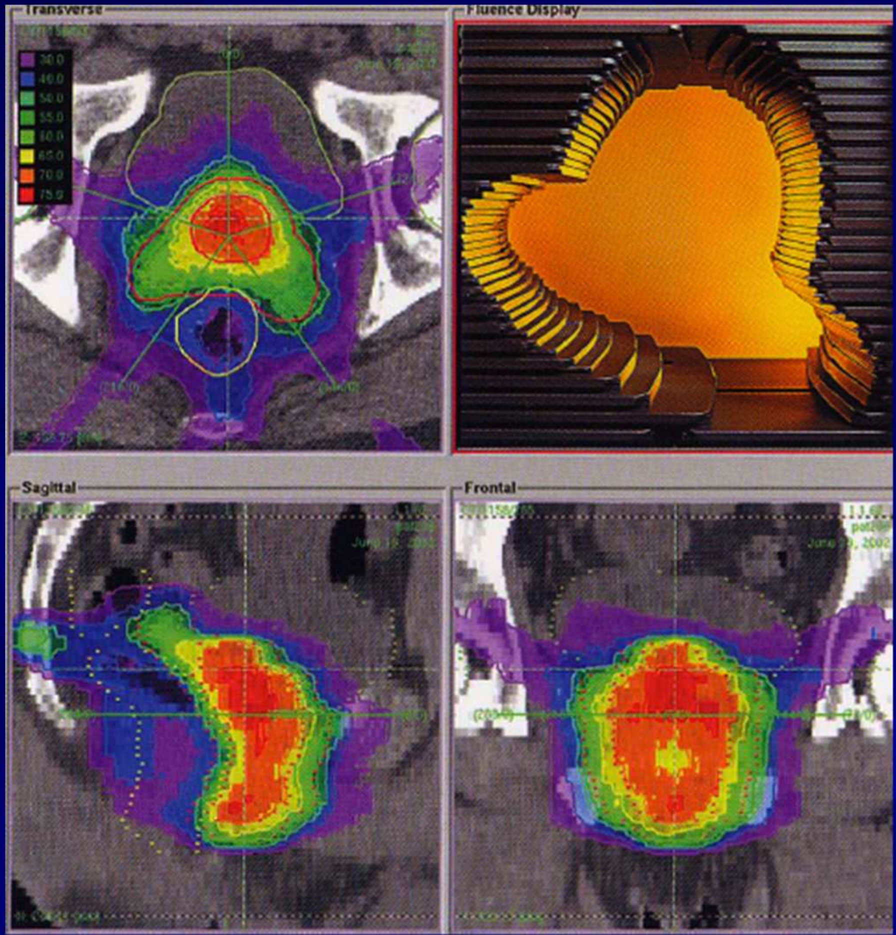
- No substitute for RT in the near future
- Number of patient increasing
- Present limitation of RT→ 30 % of patients recurs
- Why Radiotherapy X is NOT 100 % efficient?
  - Complication < 5 %
  - Tolerance of saine tissue is the limiting factor
    - Close to Organ at Risk
  - Failures due to radioresistant tumors!
  - Second cancer 30 years after Radio Therapy (from recent statistics)
    - Adult : 1.1
    - Chidren : 6

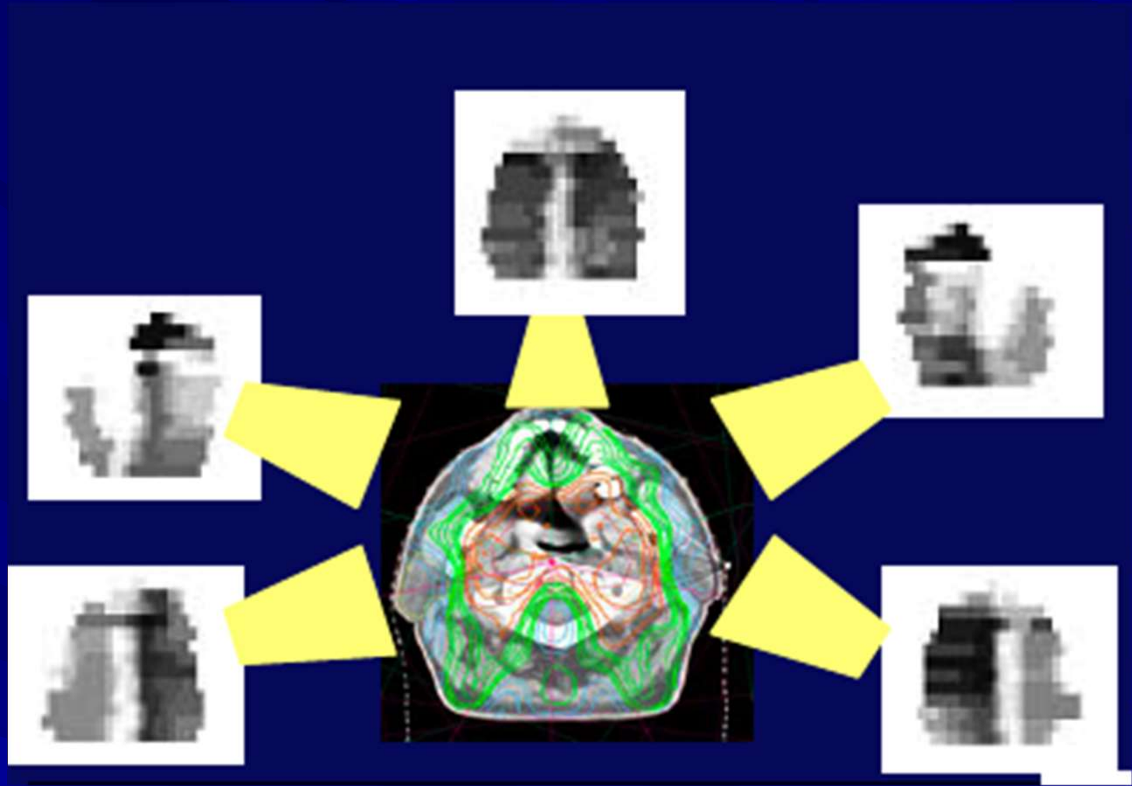
→Particle therapy
→Around 25% of the case
My last lecture!

RT modern techniques

- Conformal RT
- Intensity Modulated (IMRT)
- Image guided (IGRT)
- Robotic Stereotactic

'standard' RT devices

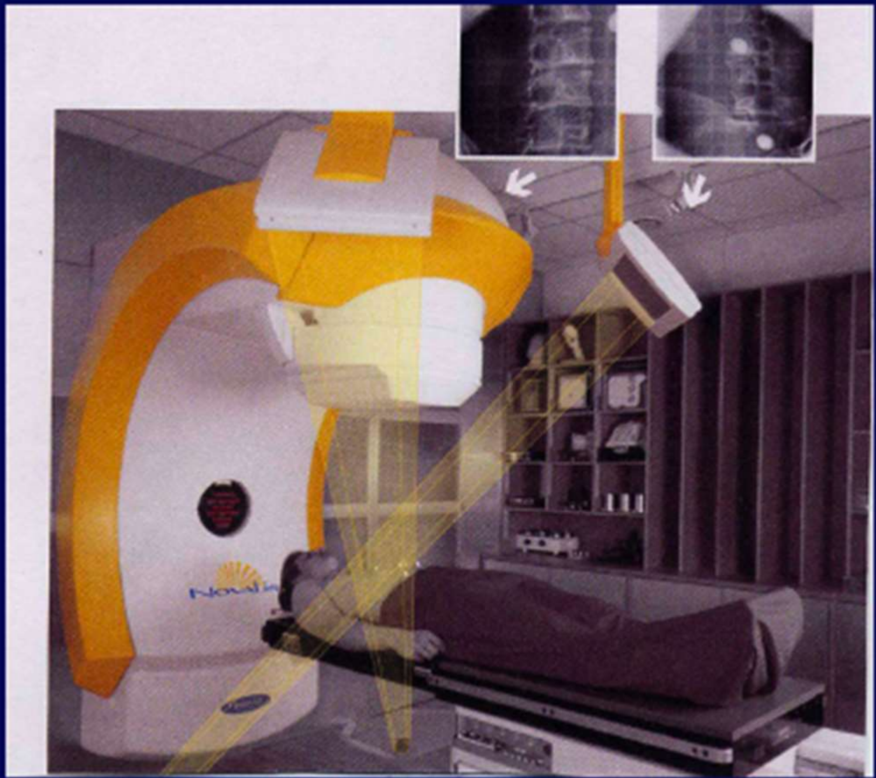


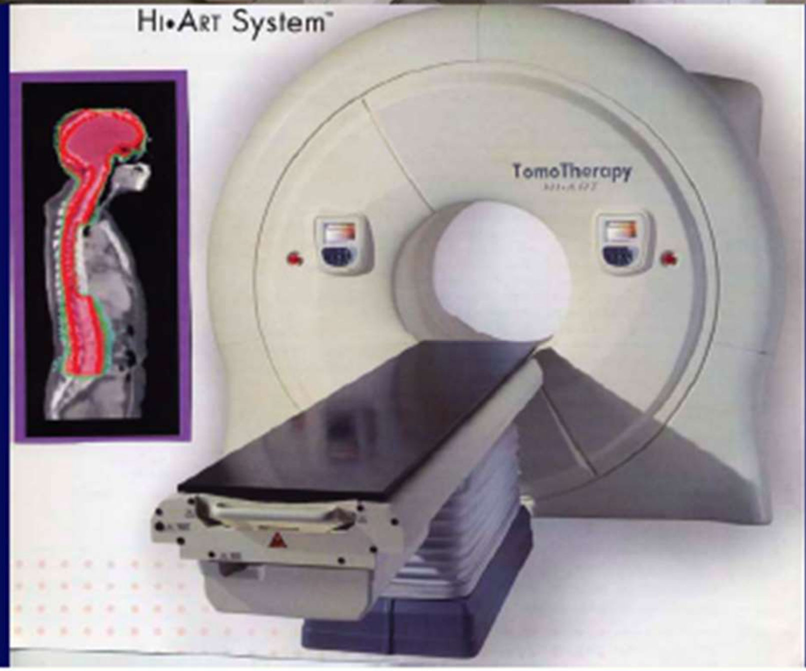


Intensity Modulated (IMRT)

Conformal 3D radiotherapy

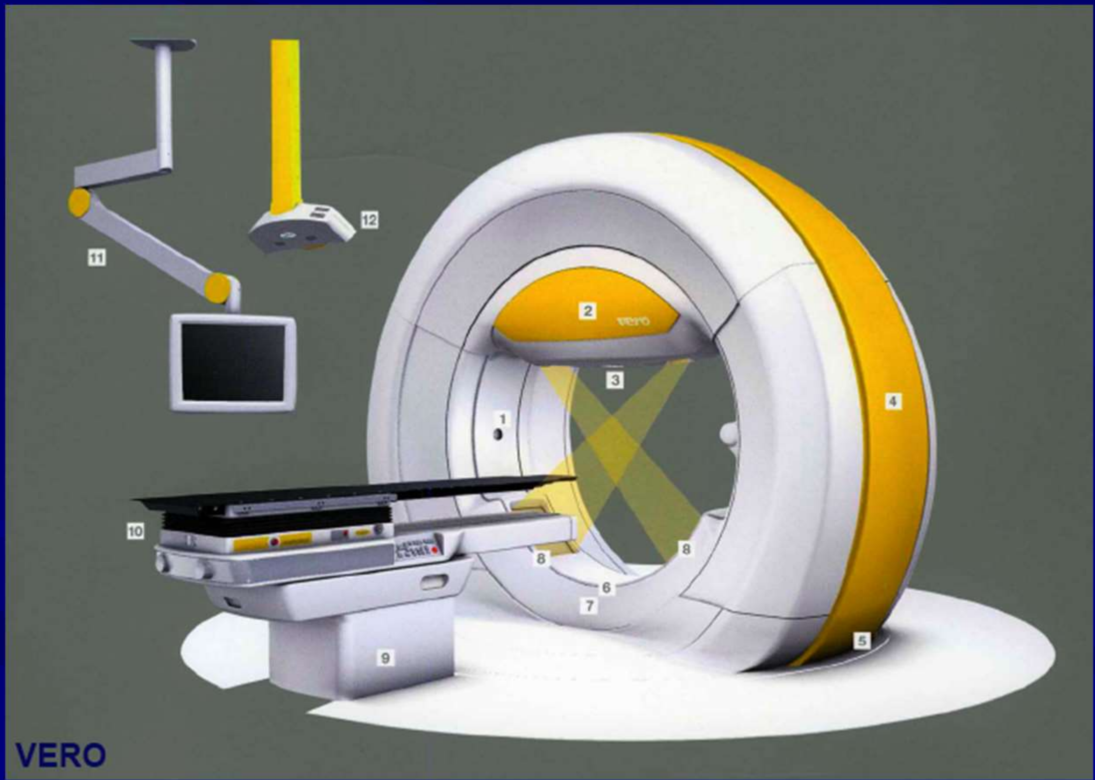
IGRT : Image guided

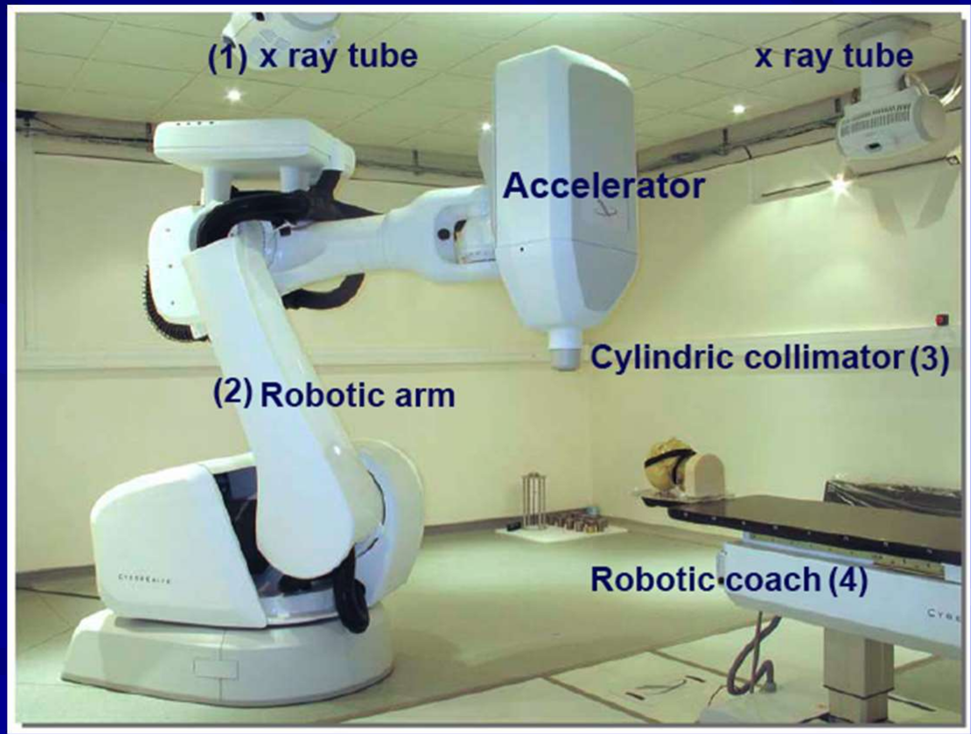




Sate of the art: Robotic Stereostatic RT

- Multiple beams
- High Precision 1 mm
- Dedicated & invasive (radiochirurgy)





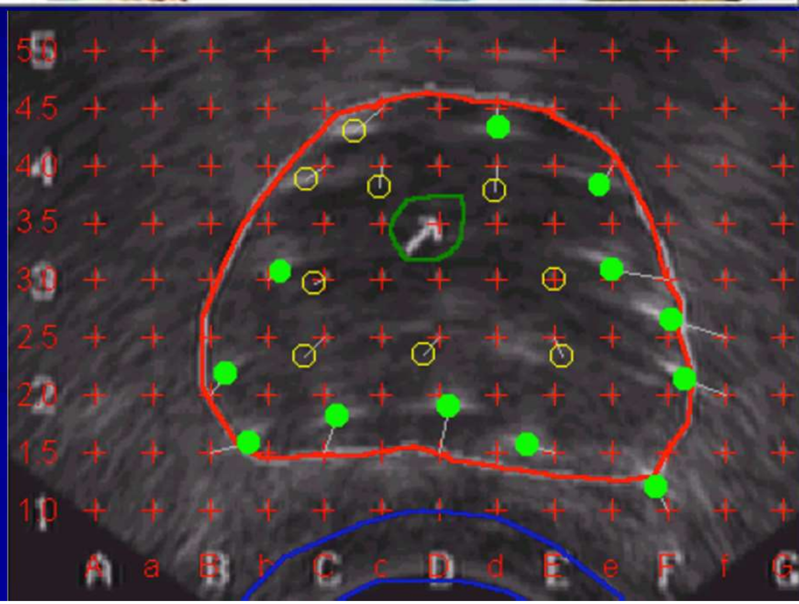
Cyberknife TM

Some words about dosimetry

Curietherapy/Brachytherapy

1910 — *Today*

- Local (contact) deposit of the dose by needles or implants



First cancer cure by brachy (ulcus rodens, basal cell carcinoma): Goldberg and London in Moscow, 1903

Originalarbeiten.

XXIV.

(Aus der Abteilung für allgemeine Pathologie des Kaiserlichen Instituts für experimentelle Medicin und aus dem Maximilian-Krankenhaus in St. Petersburg.)

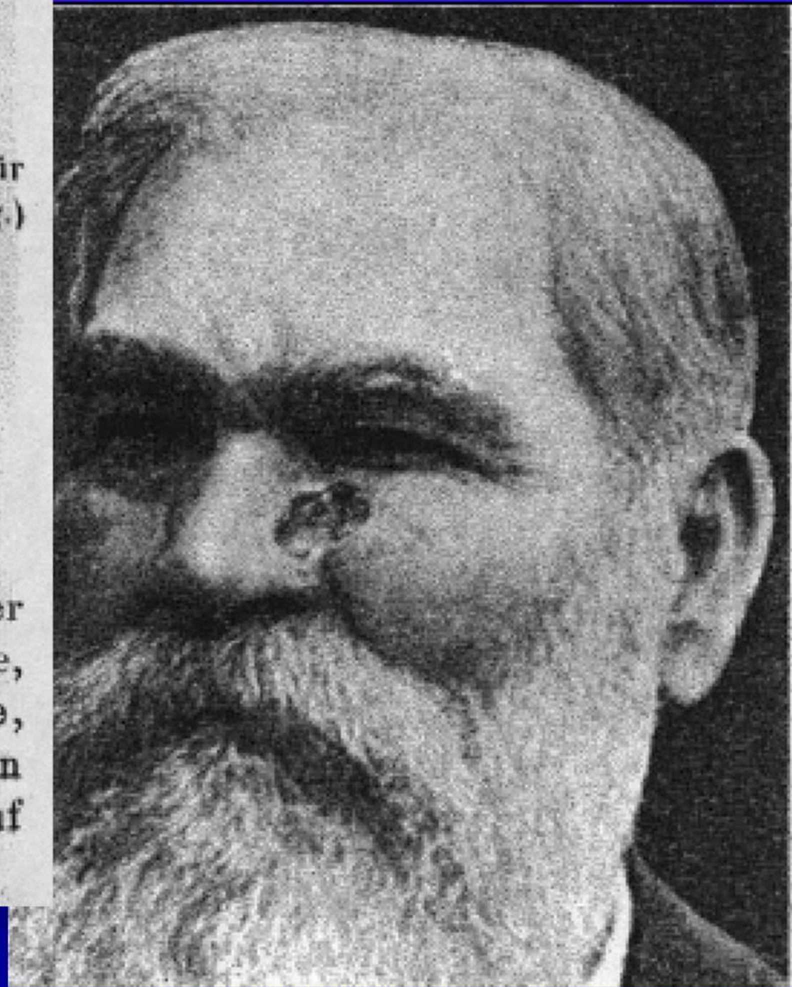
Zur Frage der Beziehungen zwischen Bequerelstrahlen und Hautaffectionen[1].

Von

S. W. GOLDBERG und E. S. LONDON

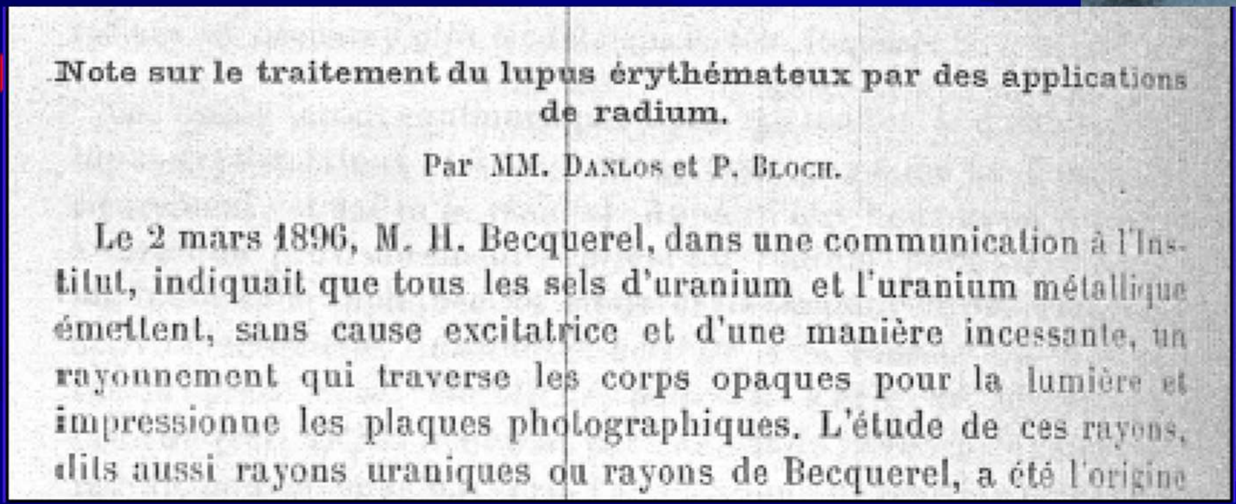
in St. Petersburg.

Die neueren Errungenschaften der Verwendung verschiedener Formen der strahlenden Energie in der dermatologischen Therapie, sowie die experimentellen Arbeiten von Giesel, P. Curie, Bequerel, Aschkinass, Freund, Doulos u. a. veranlassten uns, die Wirkung der Bequerelstrahlen bei Ulcus rodens auf die Probe zu stellen.



First brachy treatment, any disease, generally credited t

- Henri Alexandre Danlos,
- Parisian dermatologist,
- exhibiting a woman who he
- successfully treated for
- *lupus vulgaris* of the
- face. Pierre Curie loaned
- him the source and he



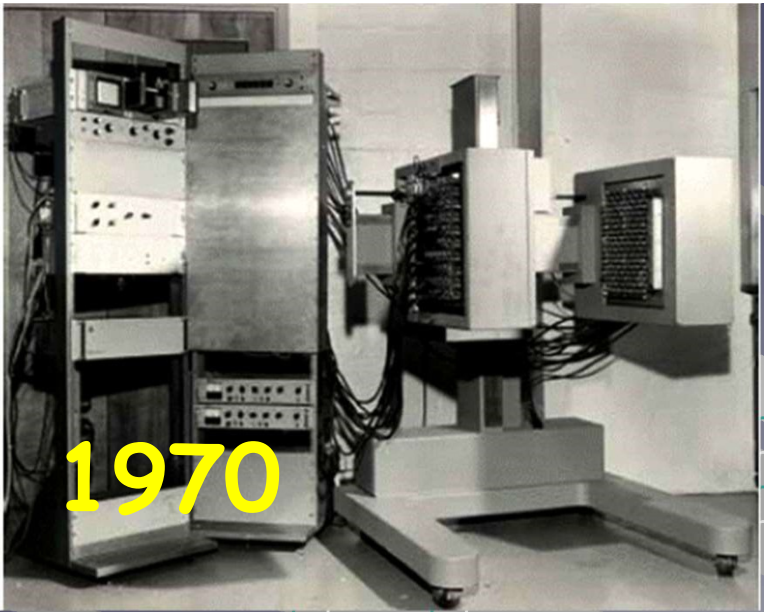
Note sur le traitement du lupus érythémateux par des applications de radium.

Par MM. Danlos et P. Bloch.

Le 2 mars 1896, M. H. Becquerel, dans une communication à l'Institut, indiquait que tous les sels d'uranium et l'uranium métallique émettent, sans cause excitatrice et d'une manière incessante, un rayonnement qui traverse les corps opaques pour la lumière et impressionne les plaques photographiques. L'étude de ces rayons, dits aussi rayons uraniques ou rayons de Becquerel, a été l'origine

BRT (typically 10-20% of patients)

- 1) Radiation sources placed in the tumor, ergo less toxicity
- 2) Dose homogeneity in the target not an issue
- 3) Conformal treatment without complicated technological
- tools
- 4) Generally invasive (except intracavitary)
- 5) In BRT timing is critical
- 6) Overall risk of a second cancer is claimed to be lower for
- brachy
- ***A. The actual dose delivered can be precisely known*** (a
- double-edged sword…)
- ***B. Full QC*** (operator-independent treatment)
- ***C. Ideal for focal therapy*** (radiobiology not needed)

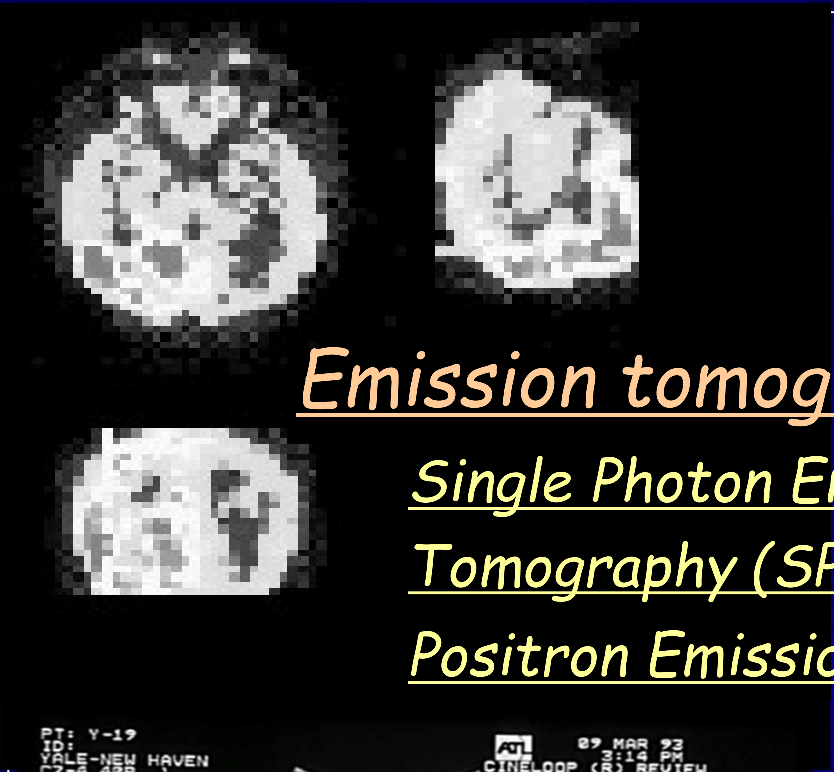


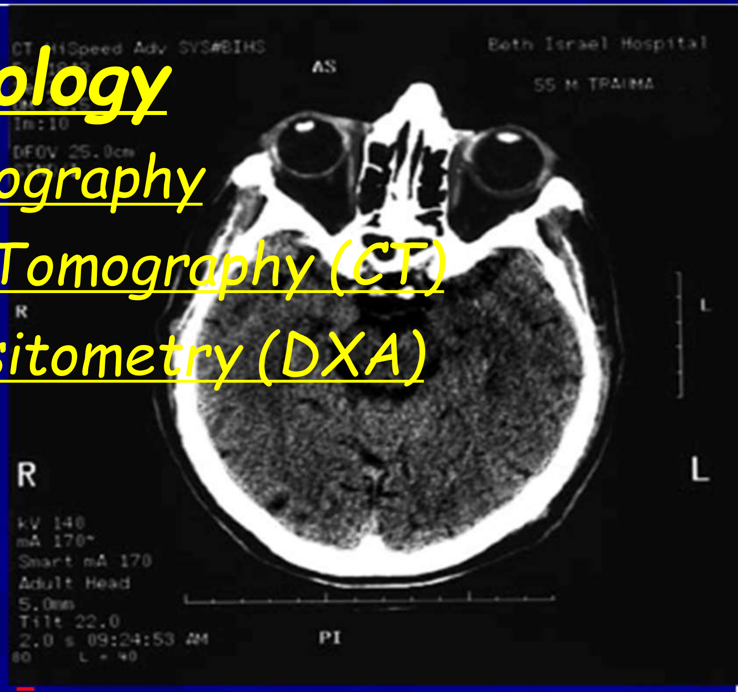
Nuclear medicine

What is Nuclear medicine ? Definition

- Use in vivo of radioactive elements (tracers) injected to the patient orally or by blood injection to image the function of the body
- Functional and metabolic (scintigraphy)
- In vivo biochemistry
- Study of a radioactive molecule in a living organism
  - Images are Static 2D/3D (x,y,z)
  - Or 4D (+time) --> dynamic
  - Or 5D (+ Energy) --> Multisotopes /multitracers

Medical Imaging Modalities



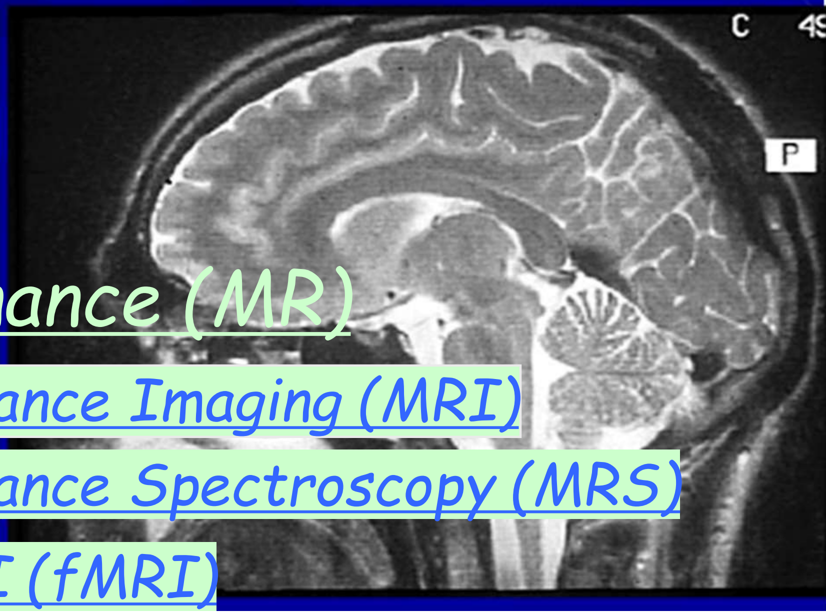


X-ray radiology

- X-ray Radiography
- Computed Tomography (CT)
- Tomo-Densitometry (DXA)

Emission tomography

- Single Photon Emission Computerized Tomography (SPECT)
- Positron Emission Tomography (PET)



Ultrasonic imaging

Magnetic Resonance (MR)

- Magnetic Resonance Imaging (MRI)
- Magnetic Resonance Spectroscopy (MRS)
- Functionnal MRI (fMRI)

The various types (modalities) of imaging

Organ Function Cell

- Complementary !
- Depends on what you want to see

MRI/MMR = Magnetic resonnance*

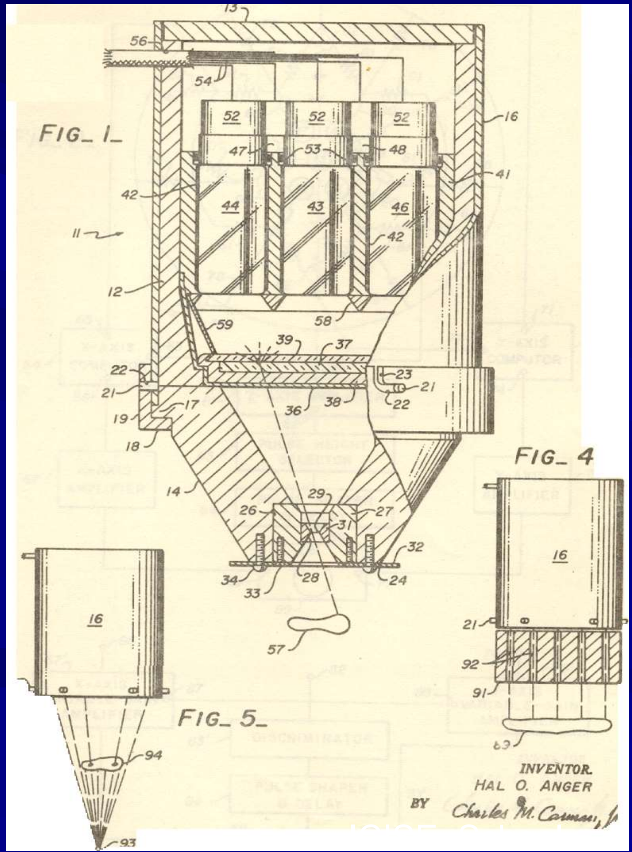
Common Tracers

Application	Requirement	Isotope
DIAGNOSIS In vivo SPECT	single photons no particles biogenic behavior $T_{½}$ = moderate	^{99m}Tc, ^{123}I, ^{111}In, ^{201}Tl,
DIAGNOSIS in vivo PET	$ß^{+}$-decay mode biogenic elements $T_{½}$ = short	^{11}C, ^{13}N, ^{15}O, ^{18}F

Anger Camera

Anger camera invented in 1957

First camera had 7 PMTs



First commercial Anger camera was delivered by Nuclear Chicago to W. Myers, Ohio State 1962

Clinical Images mid-1960's

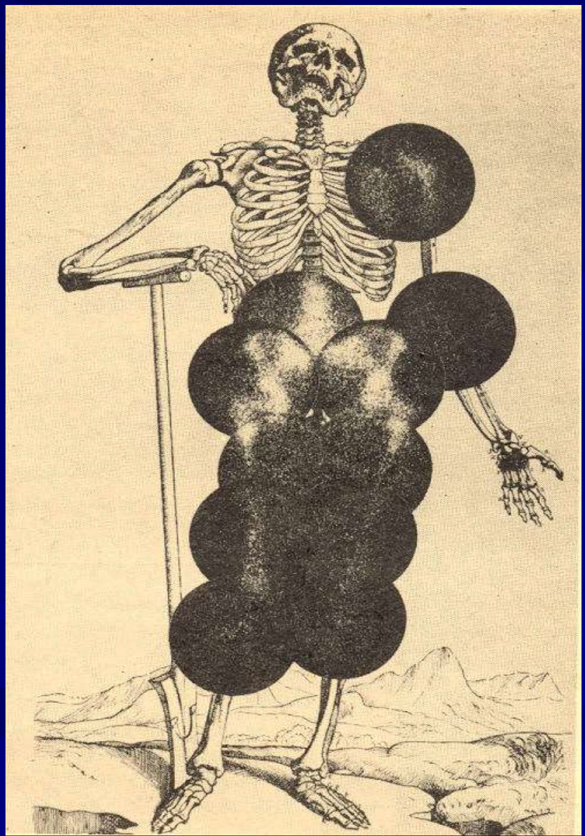
Image quality comparable to rectilinear scanner

Limitations include:

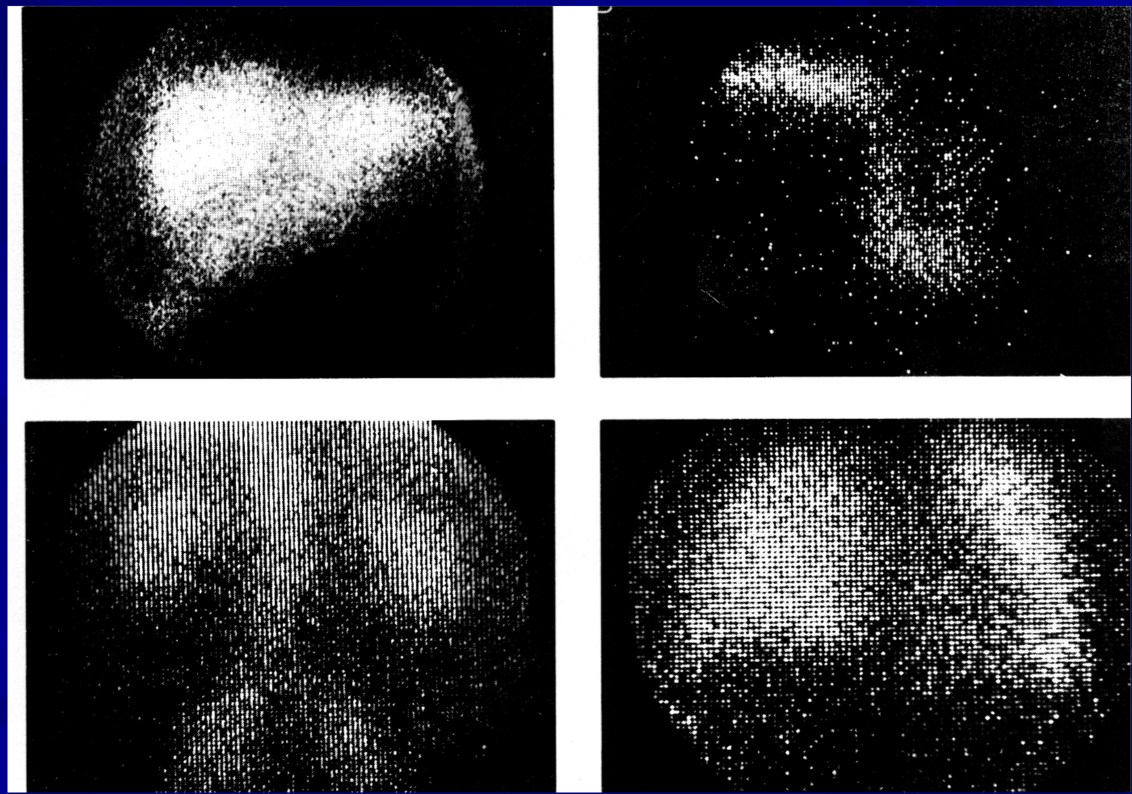
Small field-of-view

Poor spatial resolution

In 1960's the primary application was not clear: Tc-99m generators developed mid 60's, first kits available in 1970

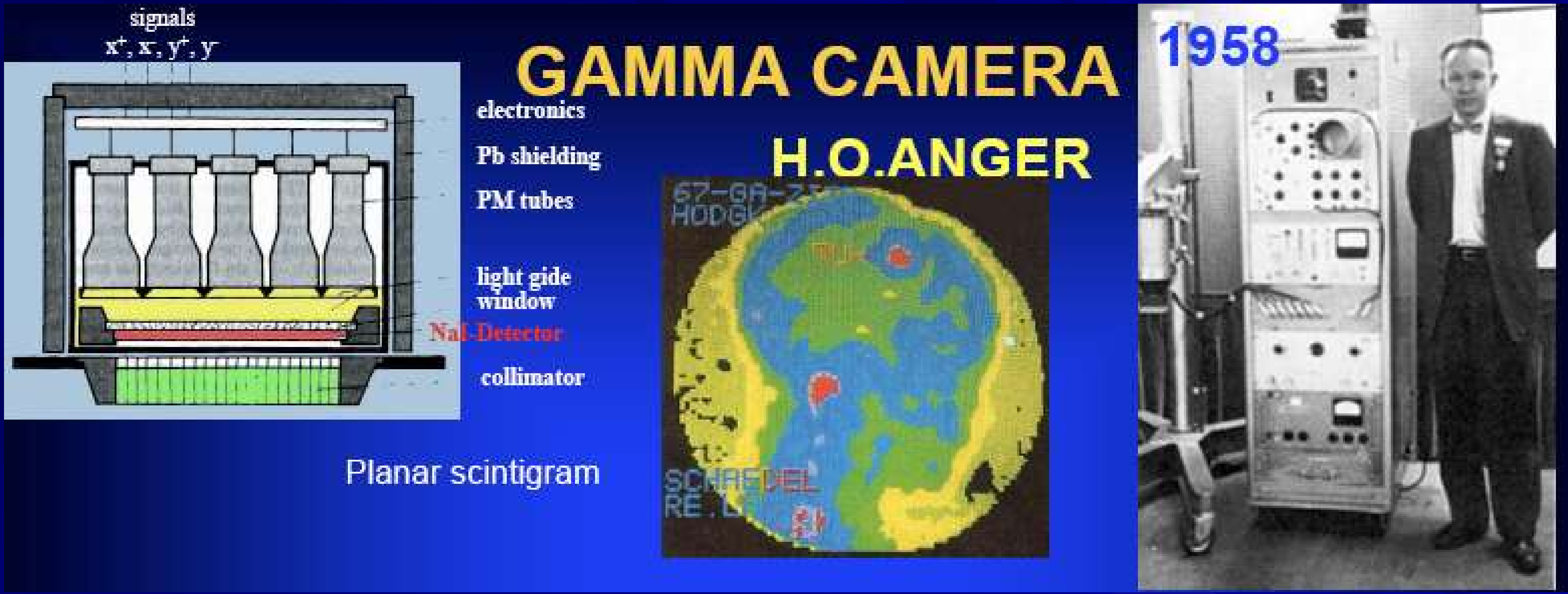


1965



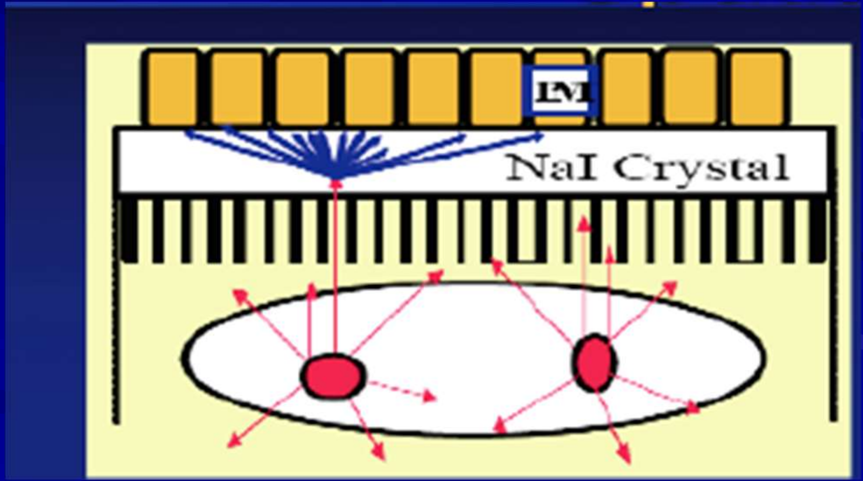
1968

The first gamma camera (Hanger,1956)



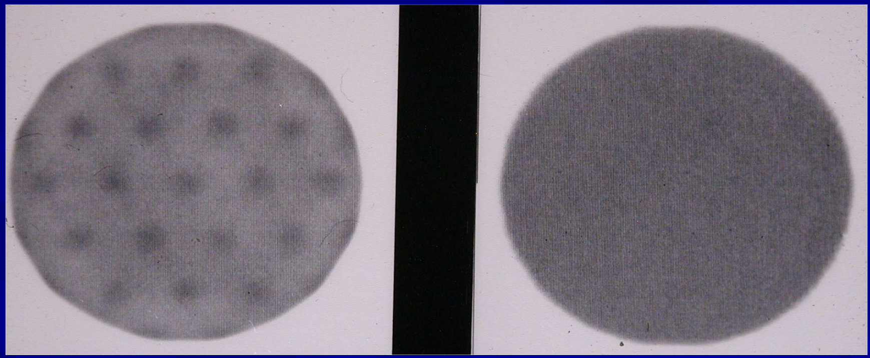
SPECT Gamma camera components

- Collimator
  - Ability to localize the photon sourse in the patient (6-12 mm)
- Detection system
  - Ability of the large NaI scintillator and photomultiplier to localize the photon interaction in the crystal
- Problem :
  - only few useful photons
  - 1:100 000

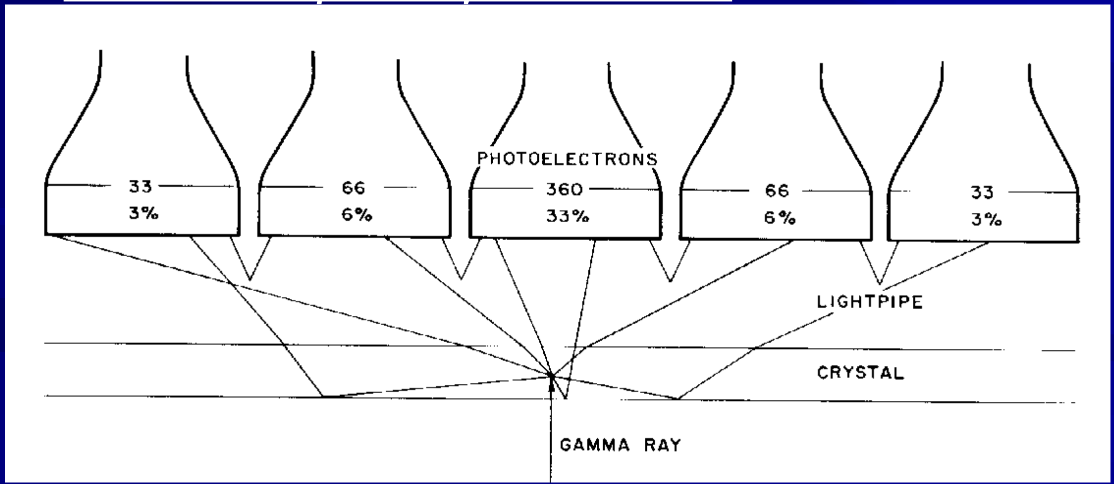


Improvements to Anger Camera

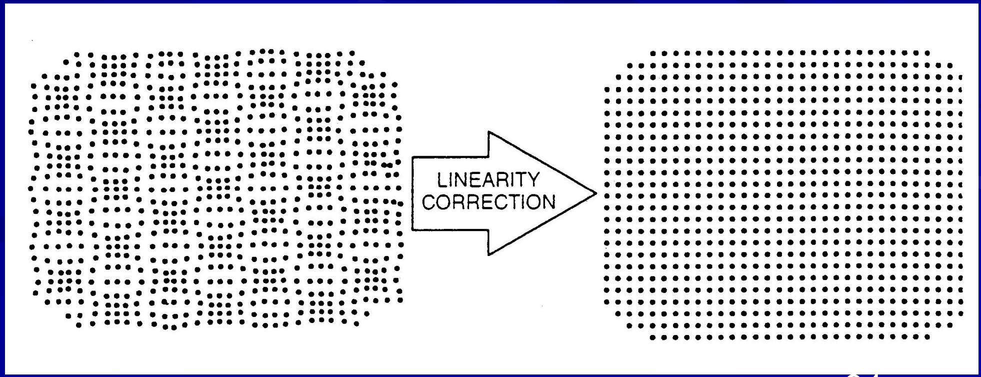
- *Intrinsic spatial resolution in 1970's: (13 mm to < 4 mm)*
  increased to 37 PMTs, improved QE (biakali photocathodes)
  improved collimator technology (4000 holes to >80,000 holes)
- *Field of view (to 15 inch) 1979*
- *Rectangular detectors 1985*
- *Uniformity, linearity and energy correction improvements through digital processing*



Non-linear preamplifier: 1971

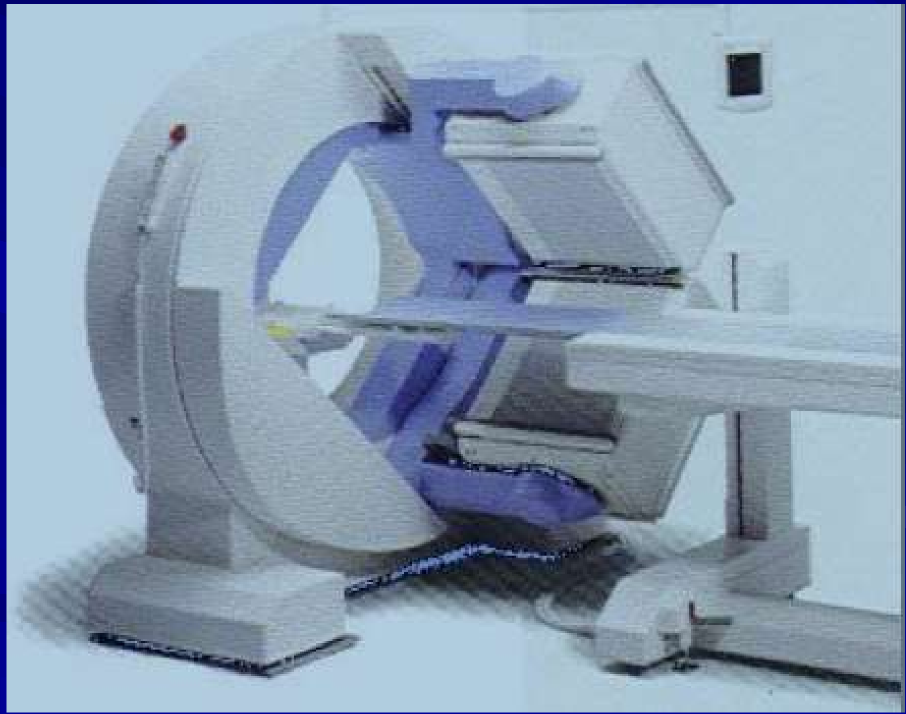


Distortion removal: invented 1970, in practice 1980 with digital technology



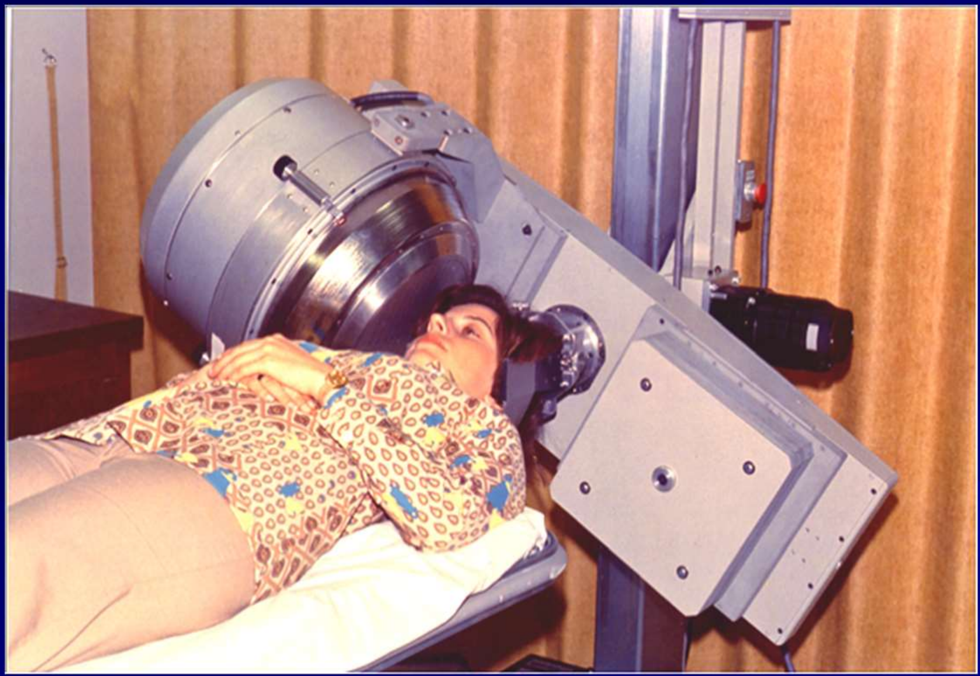
Single Photon Emission Computed Tomography (SPECT)

- Two ways
  - Tc ^{99} tracer and a gamma camera
  - Positron emitting tracers with positron camera



SPECT with Anger cameras

Single head

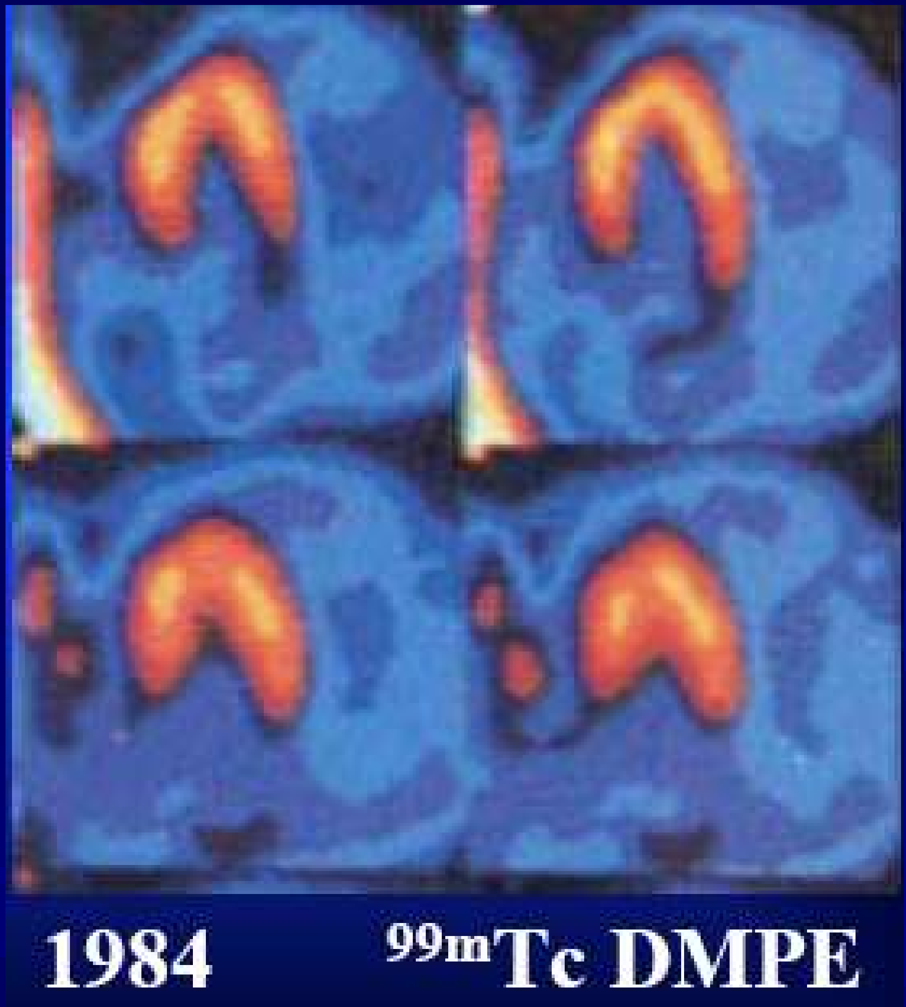


Searle: 1974 - 1976

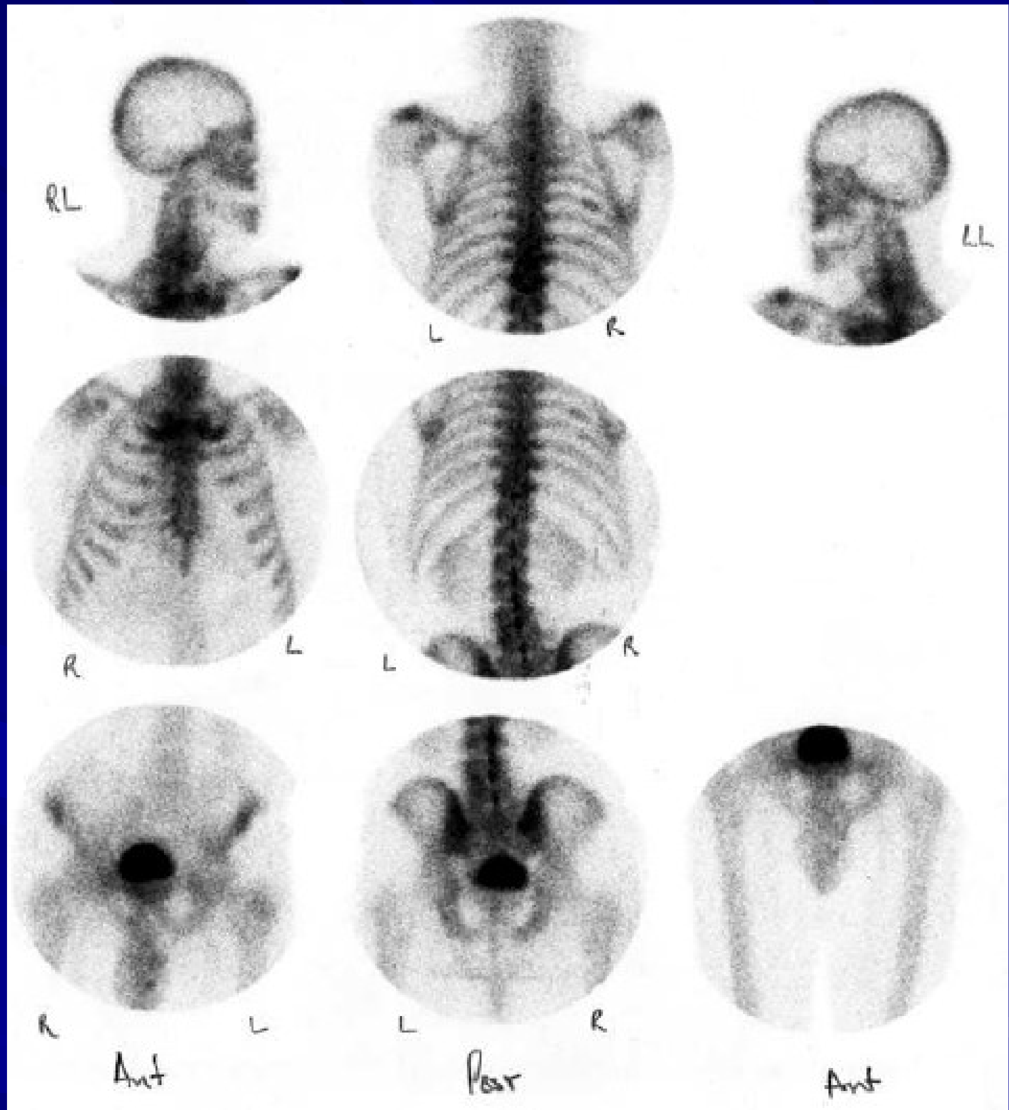
Dual head

Searle: 1977 - 1979

SPETCT images

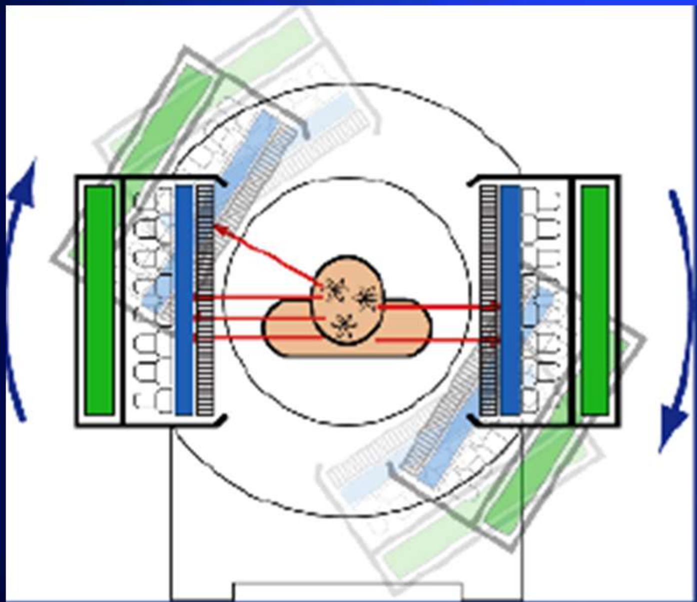


Hearth

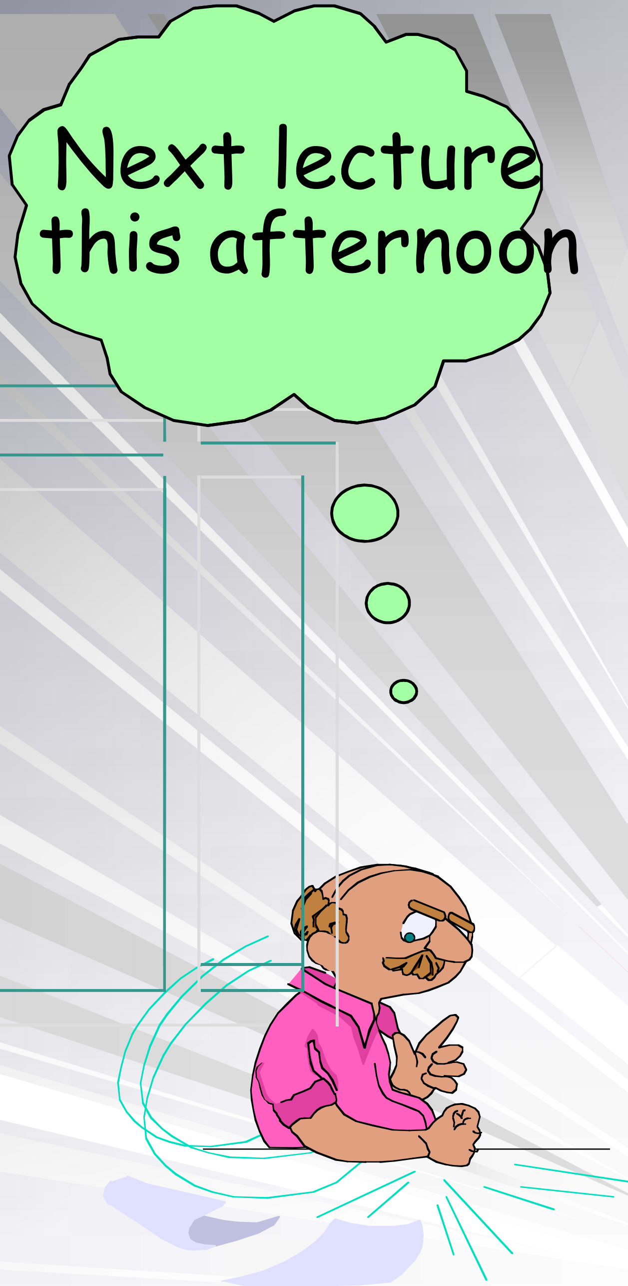


Multiview skeleton with Tc^{99}

Modern SPECT camera



End of this lecture



Questions?