CERN
from particle physics to healthcare

Manjit Dosanjh
Advisor to DG for Life Sciences
& International Organisations

CERN…

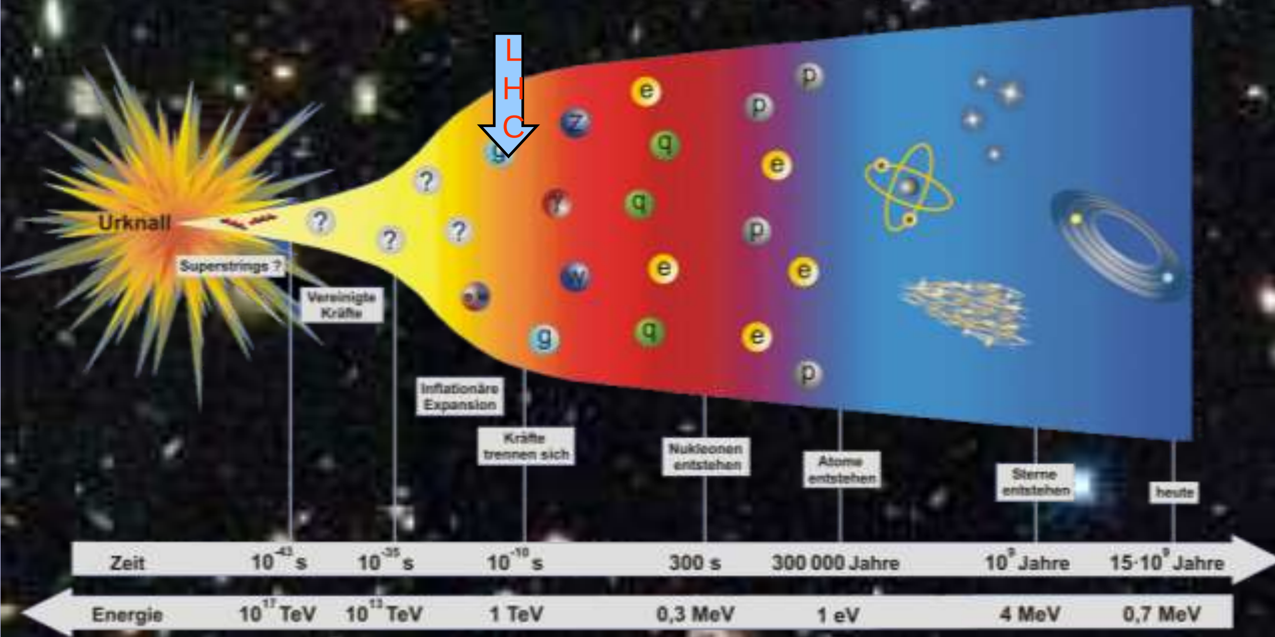
- Seeking answers to questions about the Universe
- Advancing the frontiers of technology
- Training the scientists of tomorrow
- Bringing nations together through science

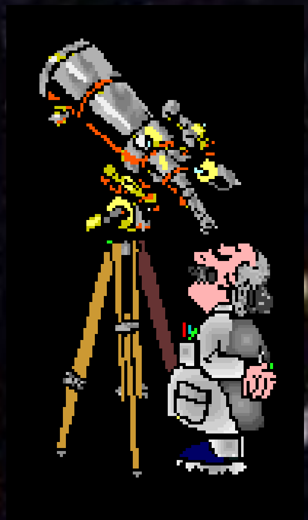
CERN in Numbers

- 2600 staff
- 570 Fellows and Associates
- 7000 users

- Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.
- Observers: India, Israel, Japan, the Russian Federation, the United States of America, Turkey, the European Commission and Unesco

Our view of the Universe






Research
Technology
Training
Collaborating

X-Rays, the fastest technology transfer example

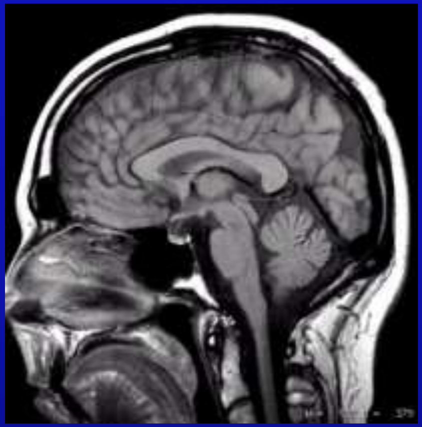
- On November 8, 1895 Röntgen discovered X-Rays
- On November 22, 1895 he takes the first image of his wife's hand

Röntgen received the first Nobel prize in physics in 1901

MRI, Magnetic Resonance Imaging

The Nobel Prize in Physics 1952

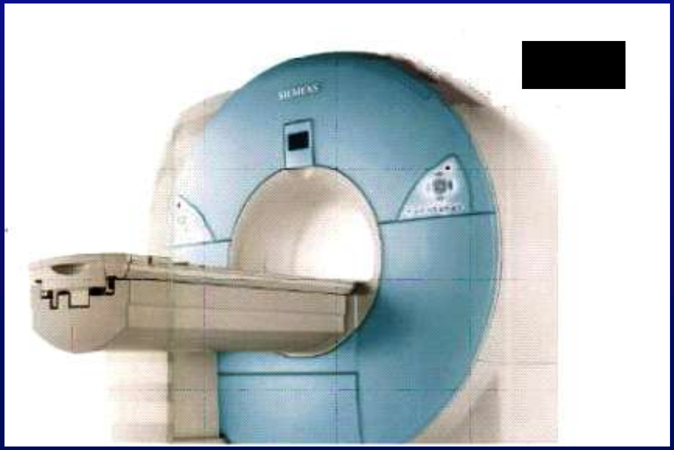
Felix Bloch
Physicist Stanford



Edward M. Purcell
Physicist Harvard

The Nobel Prize in Physiology or Medicine 2003

Sir Peter **Mansfield**
Physicist Nottingham



Paul C.
Lauterbur
Chemist Uni.
Illinois

Key Area

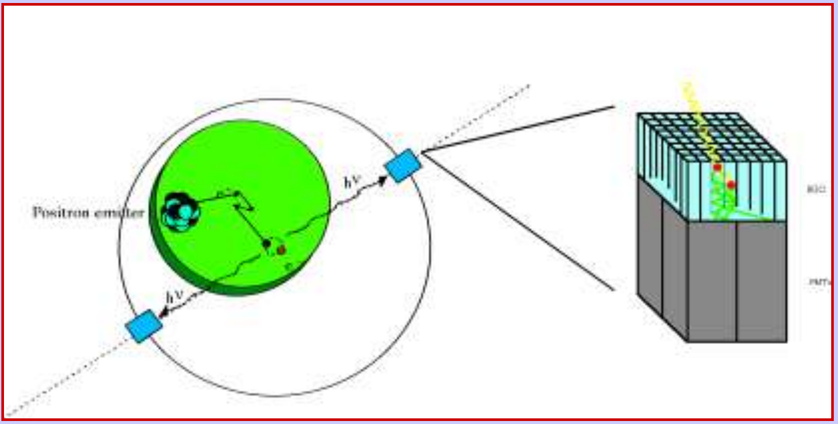
- Imaging detectors for diagnostics
- Accelerators for hadron therapy
- Isotope production
- GRID applications for Health

Bio-medical applications of CERN technologies

- Some properties of HEP apparatus
- Objectives: Particle Physicist
- Highest possible performance
- Lab environment/physicist operated
- Possible complex maintenance
- Possible complex operation
- Single unit production
- Non commercial
- Industry as a manufacturer only
- Networked devices, specialist online

- Some properties of biomedical apparatus
- Objectives: Medical practioners
- Robustness
- Non-specialist operated
- Minimal maintenance
- Simple to operate
- Small series production
- Commercial distribution
- Industry as a partner
- …………

Physics to medicine



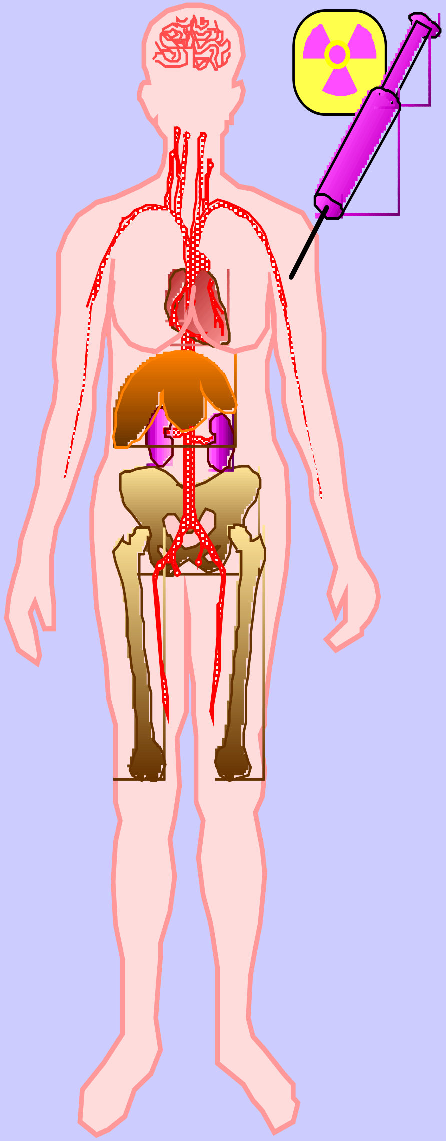
Idea of PET

Photon detection used for calorimetry

PET today

CMS calorimeter

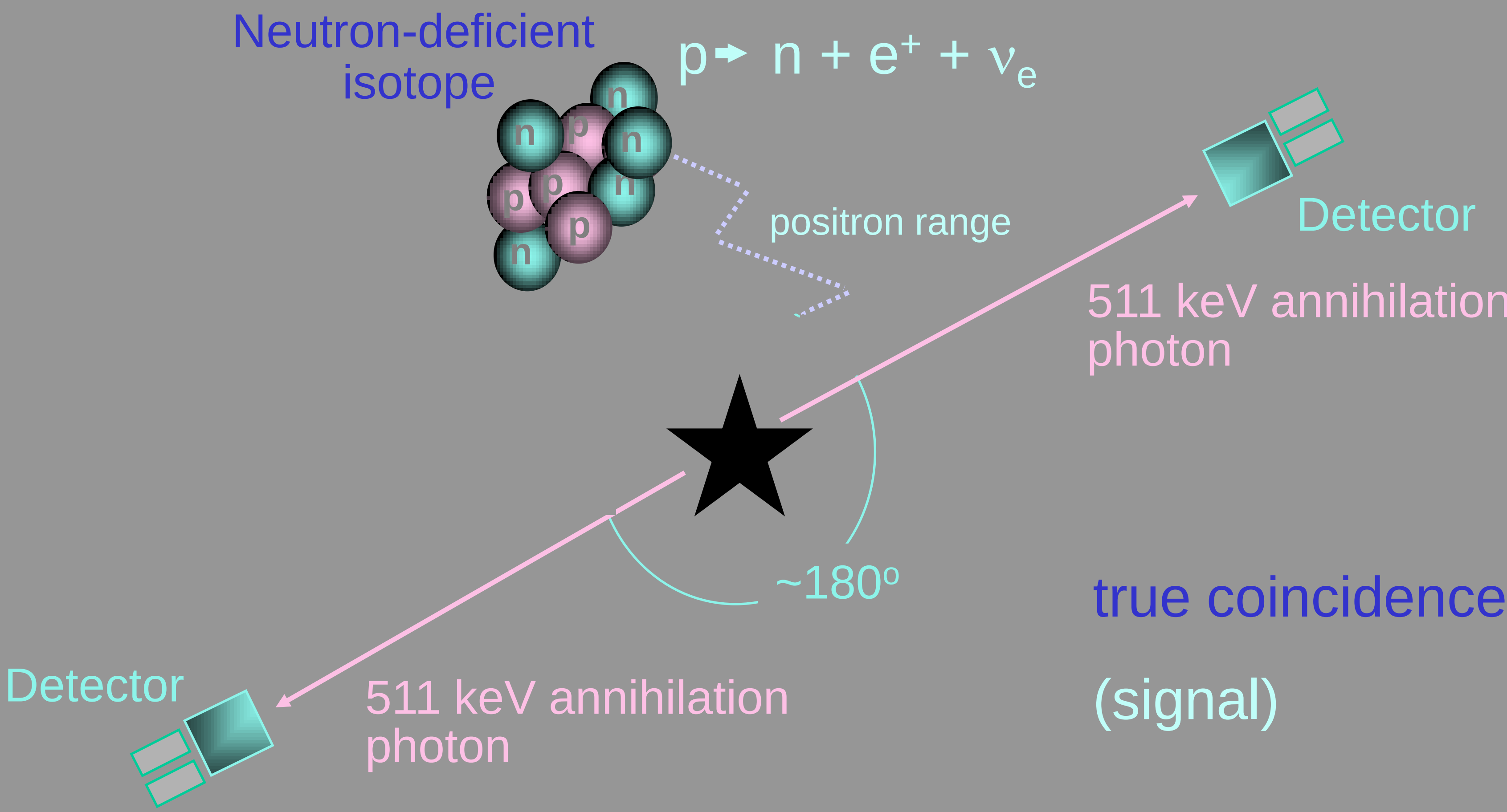
Inject Patient with Radioactive Drug



- Drug is labeled with positron (β^+) emitting radionuclide.
- Drug localizes in patient according to metabolic properties of that drug.
- Trace (pico-molar) quantities of drug are sufficient.
- Radiation dose fairly small (<1 rem).

Drug Distributes in Body

PET: true events



true coincidences (T)

(signal)

Similar challenges for PET and HEP detectors

- New scintillating crystals and detection materials
- Compact photo-detectors
- Highly integrated and low noise electronics
- High level of parallelism and event filtering algorithms in DAQ
- Modern and modular simulation software using worldwide recognized standards (GATE)

Crystal Clear Collaboration

-New scintillators :

- LuAP, phoswich LuAP-LSO (CERN patent)
- other crystals

- new photodetectors (Avalanche PhotoDiodes)

-new low noise front end electronics

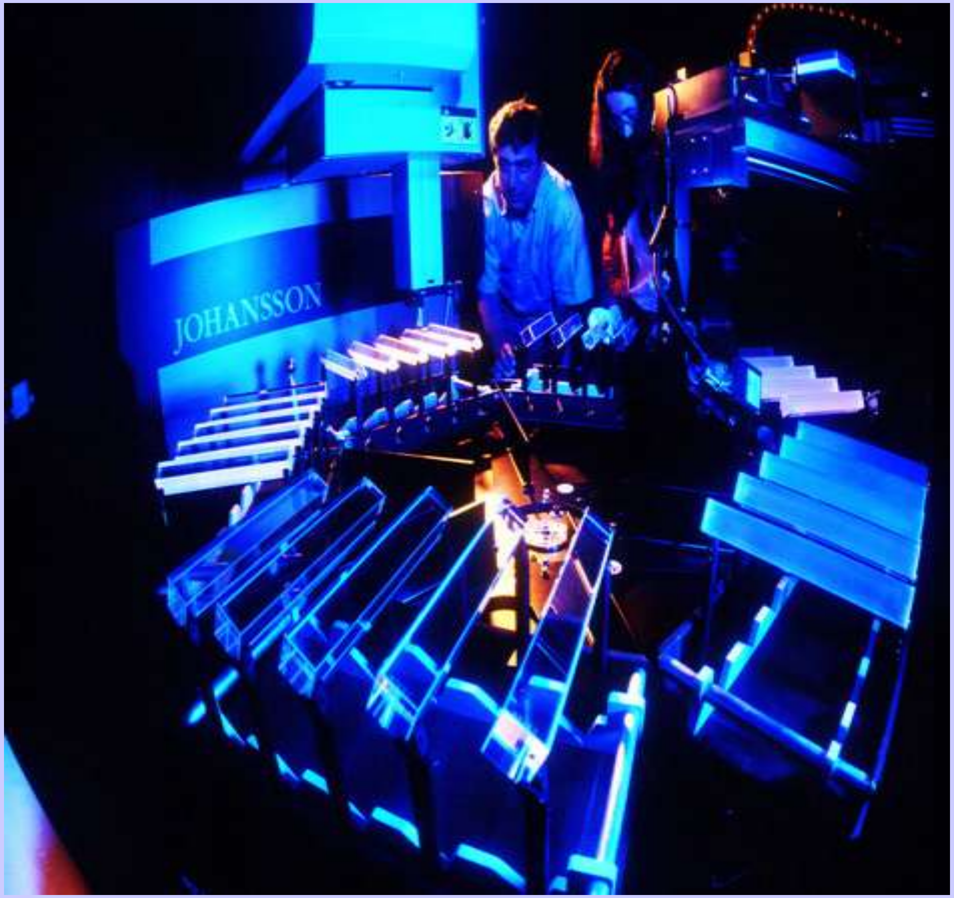
-new intelligent DAQ systems with pipeline and parallelized architecture

-better simulation GEANT 4

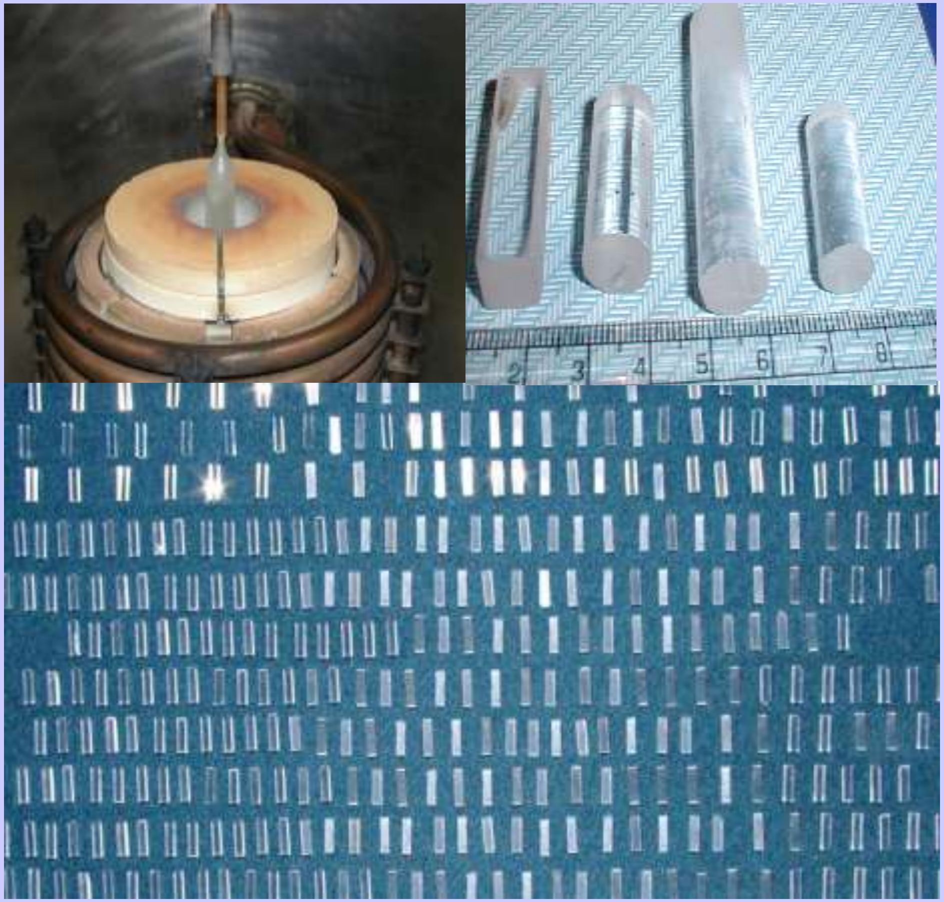
-- better reconstruction algorithms

1- Crystals

CMS $PbWO_4$ production



Crystal Clear LuAP production



The ClearPET™
LYSO/LuYAP Phoswich Scanner
A high Performance Small Animal PET System
Higher ef[illegible] spatial resolution

The Design

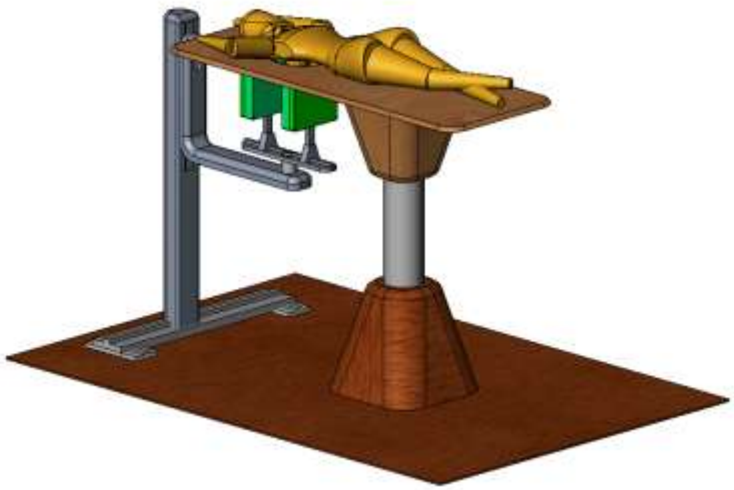
- 20 detector cassettes on the ring
- each cassette has 4 PM in line
- each PM has 64 photocathodes
- each photocathode reads 1 phoswich
- each phoswich has 2 crystals LYSO and LuYAP
- each crystal is 2 x 2 x 10mm³
- open gantry diameter adjustable 120 - 240mm
- rotation 360 degree

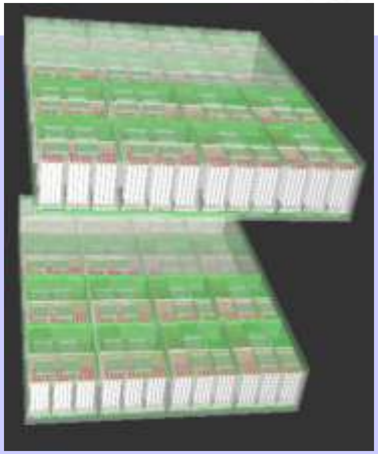
T_{cosine} resolution 2 ns FWHN
Spatial resolution 1.5 mm at centre
Peak sensitivity >4%

By Courtesy of Raytest, Germany

Positron Emission Mammography CRYSTAL CLEAR Collaboration

Model of the PEM detector





Dedicated breast PET detector allowing high sensitivity to the small tumor detection

- **Spatial resolution 1-2 mm**
- **High counting sensitivity**
- **Short PET exams**
- **Compatible X-Ray mammography**
- **Compatible stereotactic biopsy**

Technical characteristics:

- 6000 crystals 2x2x20 mm
- Avalanche Photodiodes (APD)
- Low noise electronics
- High rate data acquisition
- Spatial resolution 1-2 mm
- Breast and axila region

What is Medipix?

The Medipix is an electronic chip similar to the electronic imaging chip in a digital camera. One difference is that the Medipix chip is sensitive to xrays instead of visible light. What is unique about the Medipix chip is that it can create the first true colour images with x-rays. Thus, it permits us to move from black and white x-ray images to full colour x-ray images. The chip also can be read out very rapidly. This allows the use the chip for colour x-ray digital movies or for fast colour x-ray CT scans

MEDIPIX: Allows counting of single photons in contrast to traditional charge integrating devices like film or CCD

- **High Energy Physics original development:**

Particle track detectors

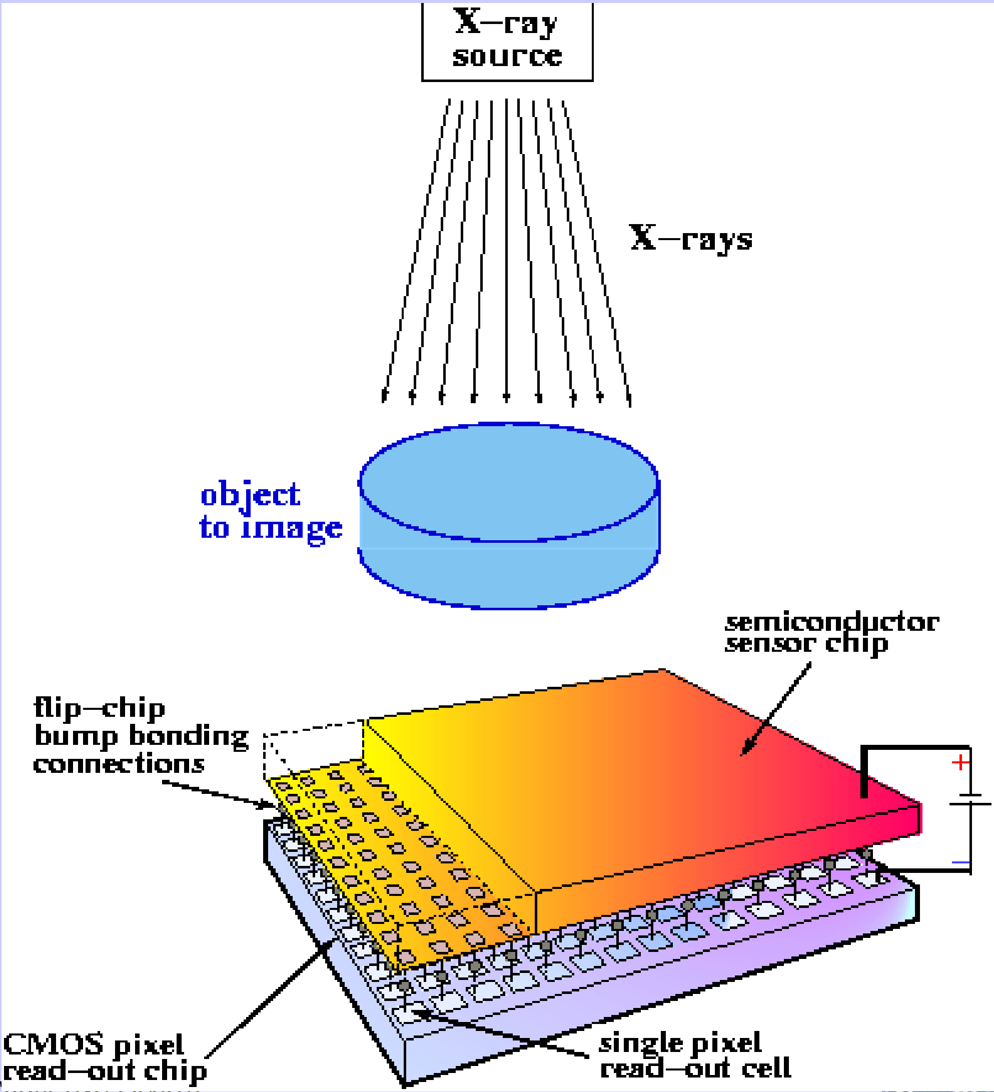
- **Main properties:**

Fully digital device

Very high space resolution

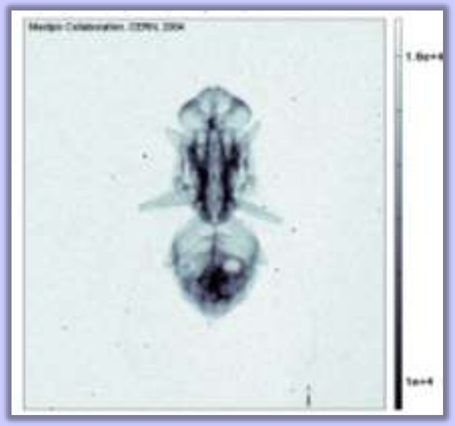
Very fast photon counting

Good conversion efficiency of low energy X-rays

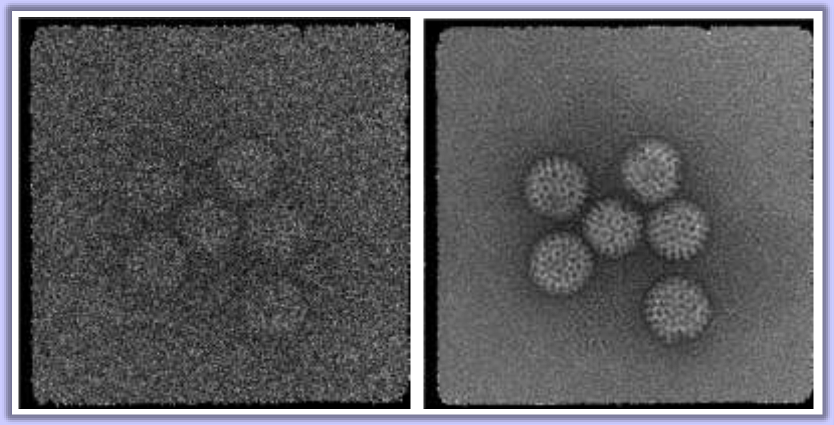


Applications using Medipix2

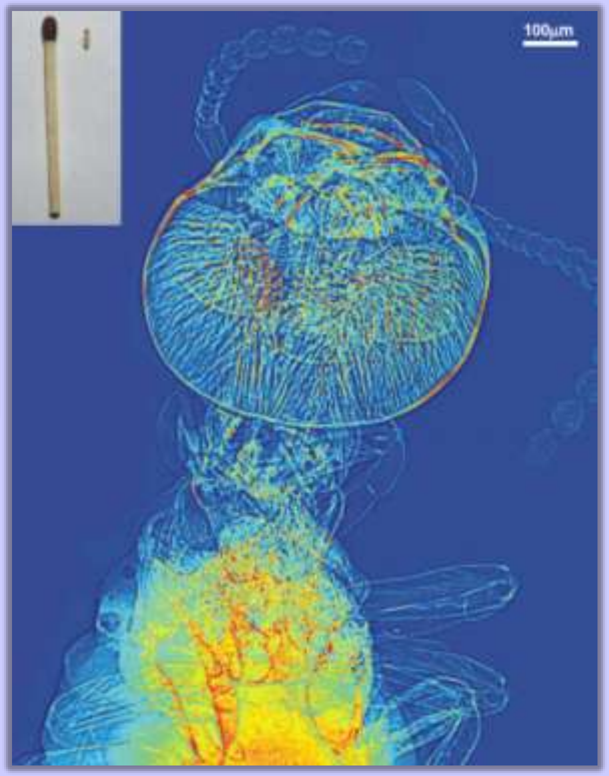
- Applications: Adaptative optics, X-ray diffraction, Micro-radiography, Neutron imaging, Computed tomography, Autoradiography, Gamma imaging, Electron microscopy, energy weighting, In vivo optical and radionuclide imaging, Micro-patterned gas detectors, Mammography…



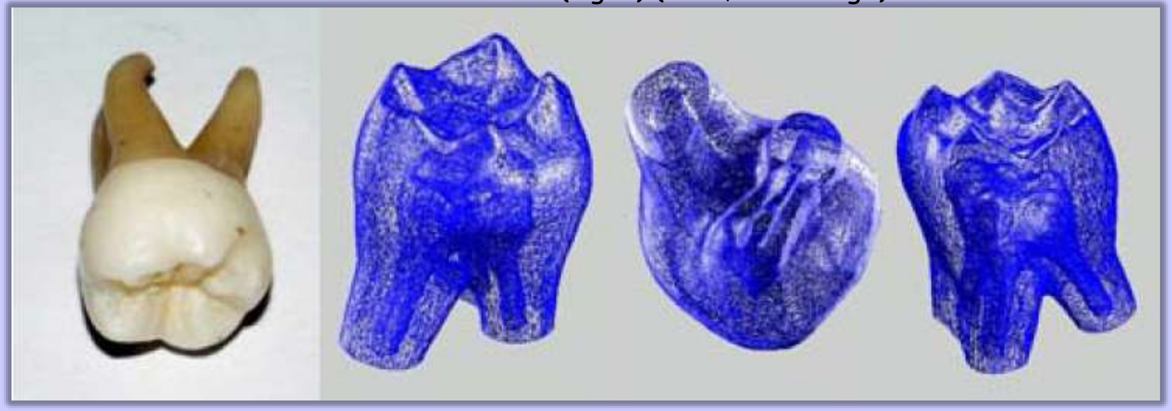
X-ray image of a house fly (CERN)



Electron microscopy: Rotavirus with 1.6 (left) and 160 (right)
e^-/pixel, equivalent to: 0.04 e^- /$Å^2$ at specimen (left) and 4 e^- /$Å^2$ (right) (MRC, Cambridge)



Micro-radiography: Assembled radiograph of a termite. Real size of the image is approximately 1.4 mm x 1.7 mm (IEAP, Prague)

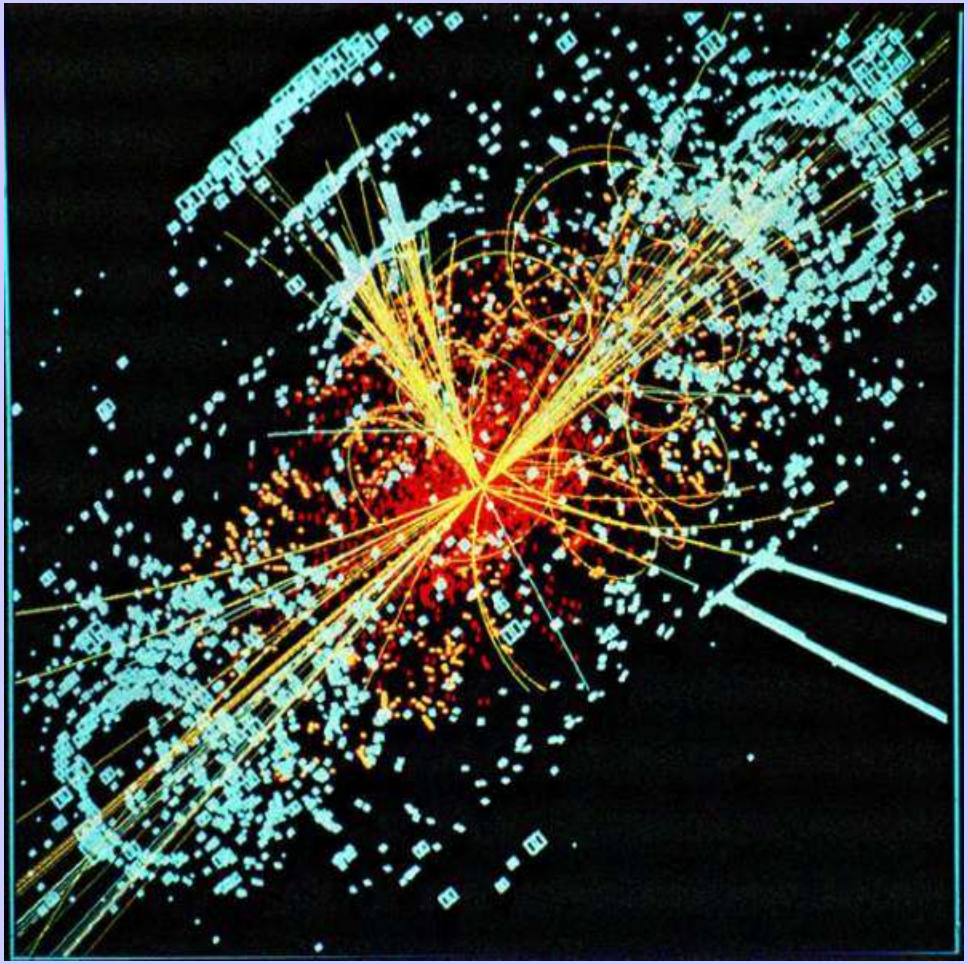


Neutron imaging: Photograph and tomographic 3D reconstructions of a tooth (IEAP, Prague)

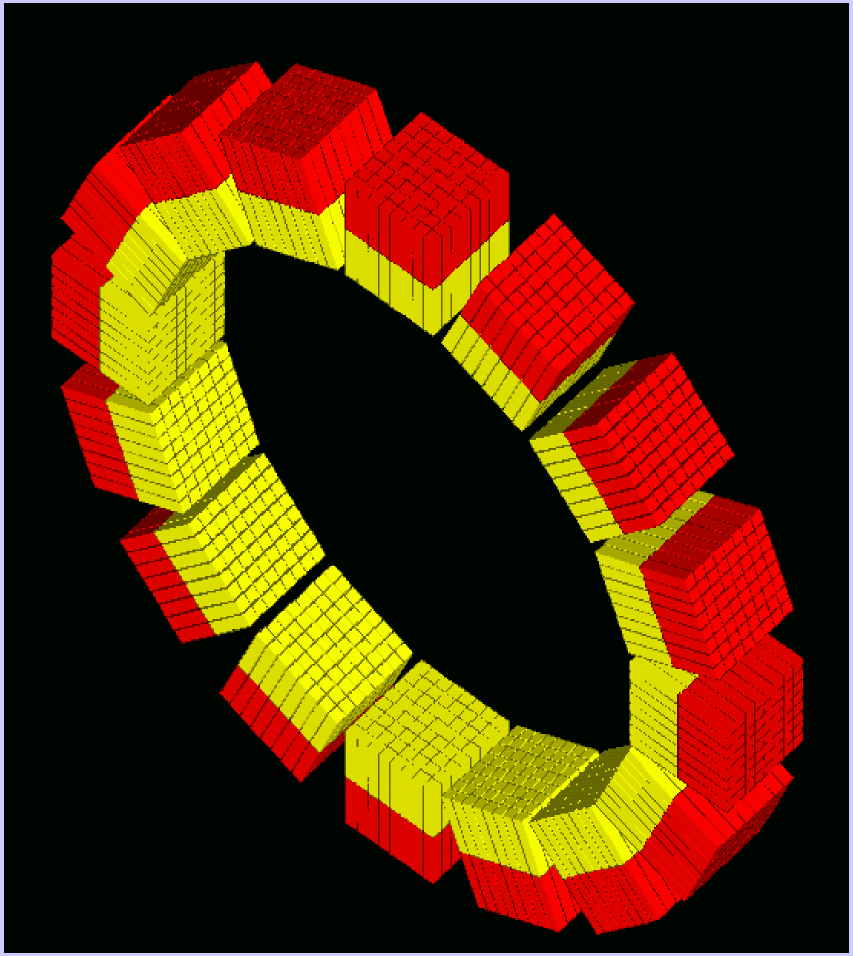
http://www.cern.ch/MEDIPIX

5- Simulation

Higgs event at LHC (CMS) with Geant4



ClearPET with GATE: Geant4 Application for Tomographic Emission



Multi-modality imaging

Primary lung cancer imaged with the SMART scanner. A large lung tumor, which appears on CT as a uniformly attenuating hypodense mass, has a rim of FDG activity and a necrotic center revealed by PET.

Hybrid machines:

Use of Accelerators for cancer treatment

Cancer

Ideal cancer treatment would be to eliminate all tumour cells without affecting any normal cells

Physics : 100% of the dose on target
0% of the dose in surrounding healthy tissues or critical organs

Biology : differential effect
kill 100% of cancer cells
"protect" normal cells

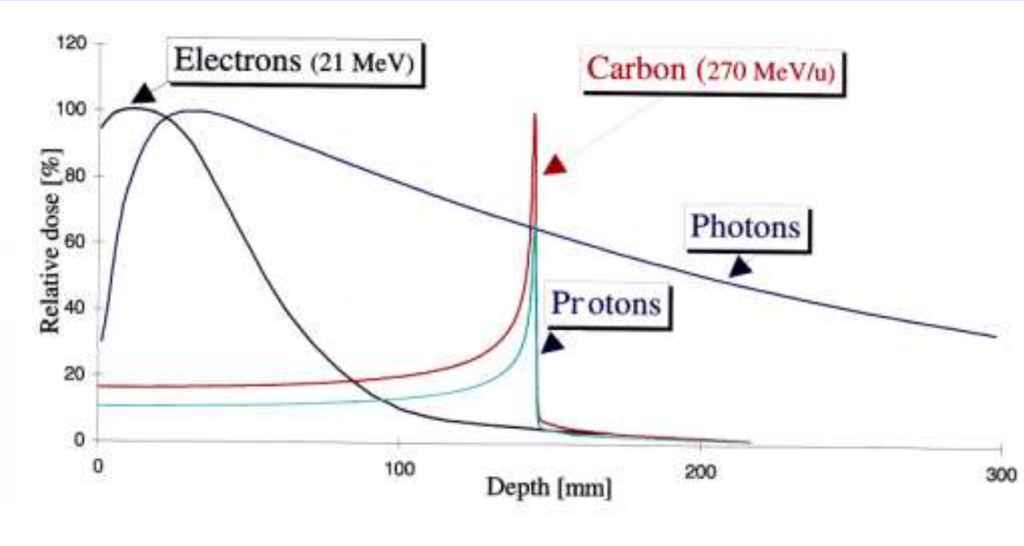
Radiation Therapy is non-invasive, has short-term side effects and is used to cure about 50% of all cancers with 5% of the total cancer treatment budget

Radiotherapy in the 21st Century

- RT is, nowadays, the least expensive cancer treatment method
- There is no substitute for RT in the near future
- The rate of patients treated with RT will likely increase in the years to come

(Acta Oncol, Suppl:6-7, 1996)

Hadrontherapy vs. radiotherapy



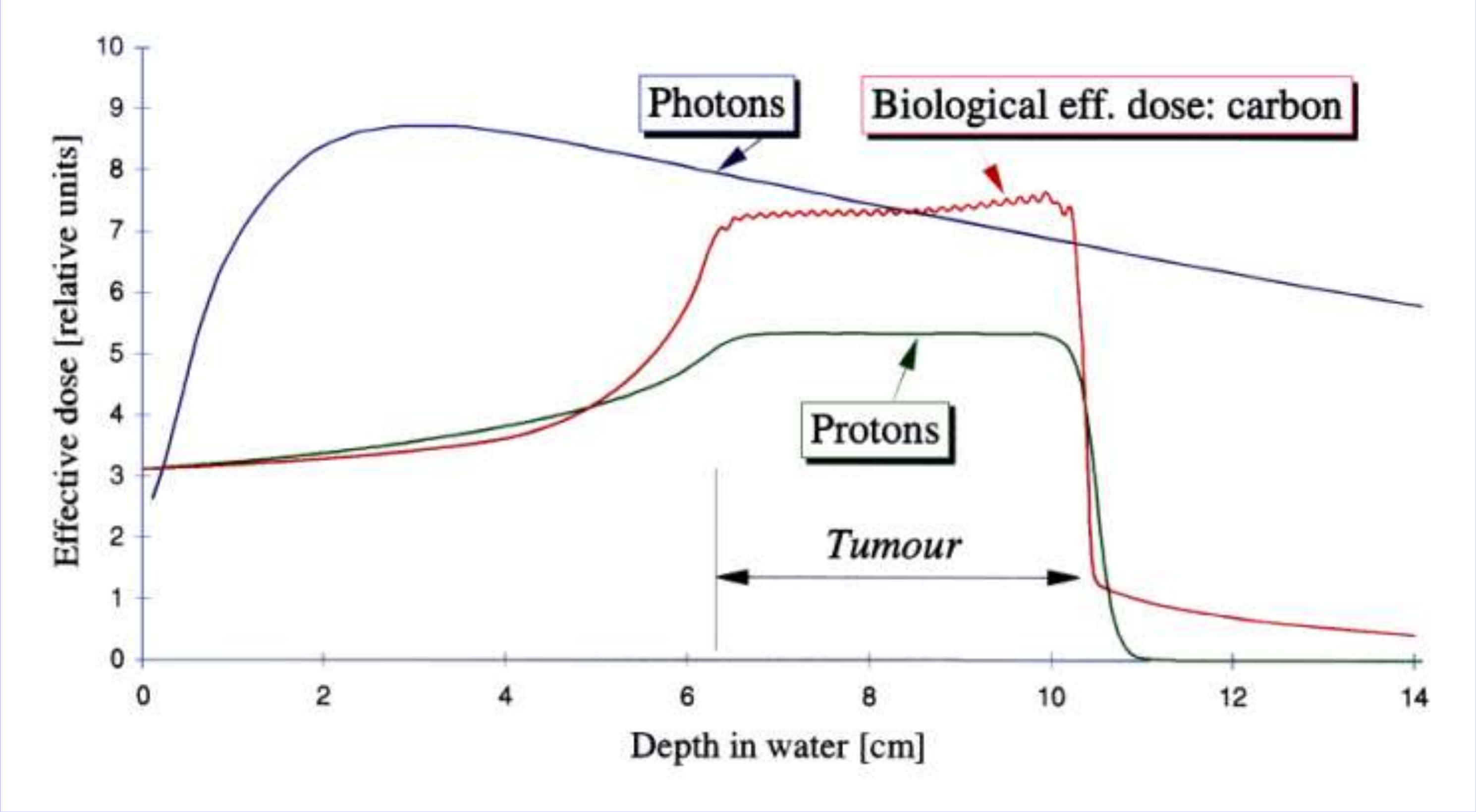
- Tumours close to critical organs
- Tumours in children
- Radio-resistant tumours

Photons and Electrons vs. Hadrons

Photons and Electrons	Hadrons
Physical dose high near surface	Dose highest at Bragg Peak
DNA damage easily repaired	DNA damage not repaired
Biological effect lower	Biological effect high
Need presence of oxygen	Do not need oxygen
Effect not localised	Effect is localised

Considerations for ion beam treatment

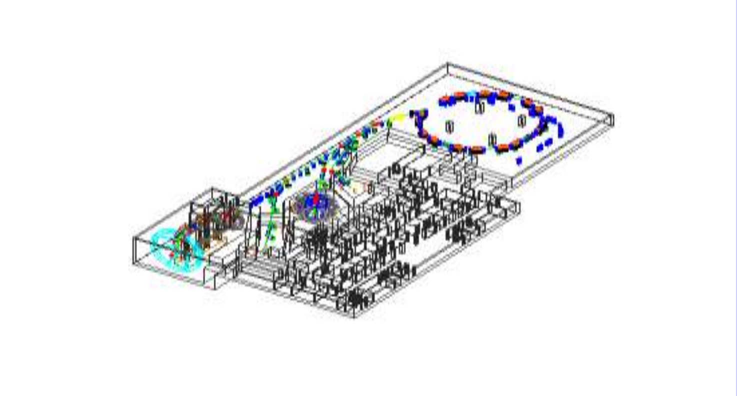
- Deep seated tumour
- Hypoxic tumour
- Tumour close to critical organ(s)
- Tumour in young children



Comparative Treatment Planning: Large Skull Base Chordoma

4 photon fields with x-rays   2 fields with carbon ions

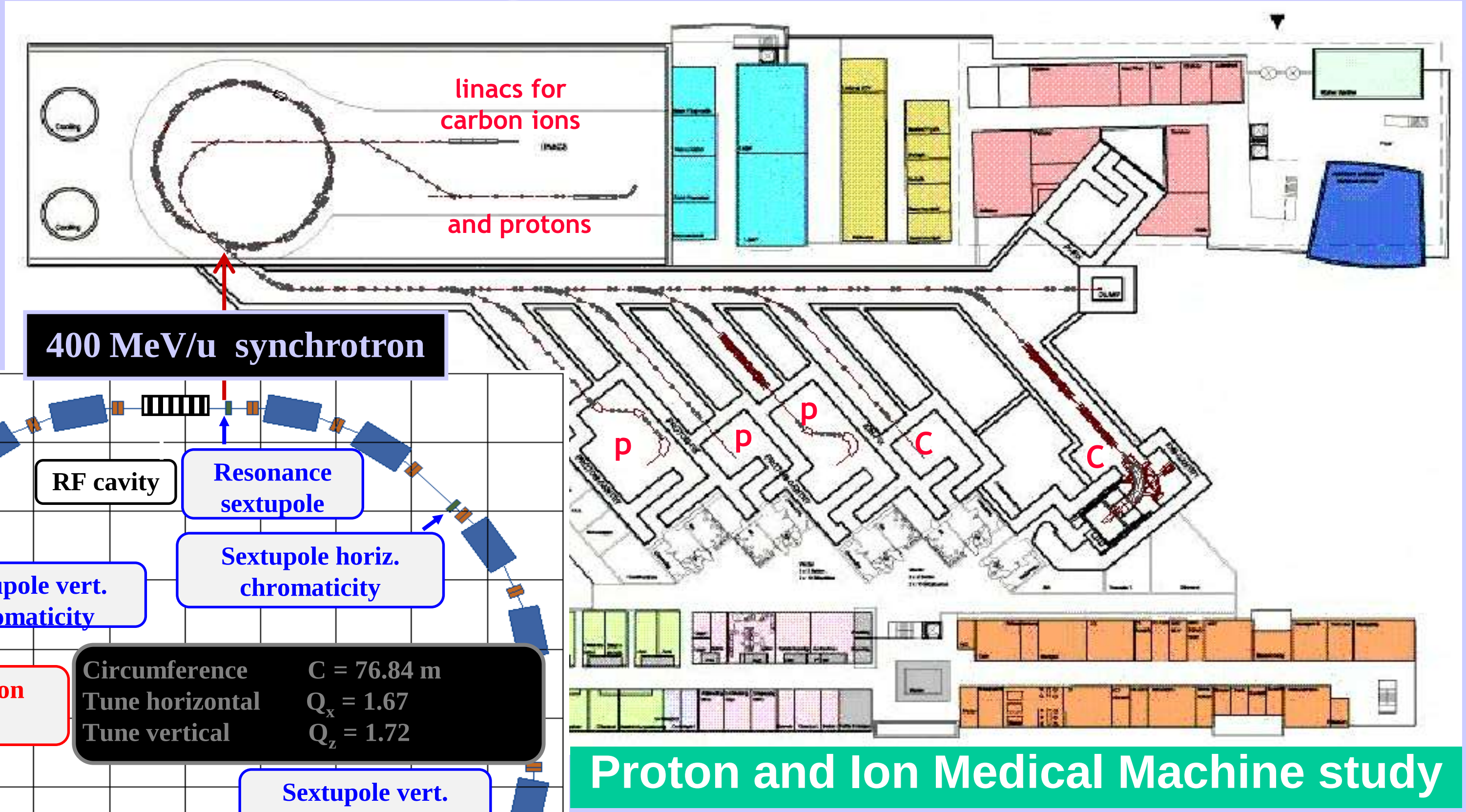
The PIMMS Collaboration

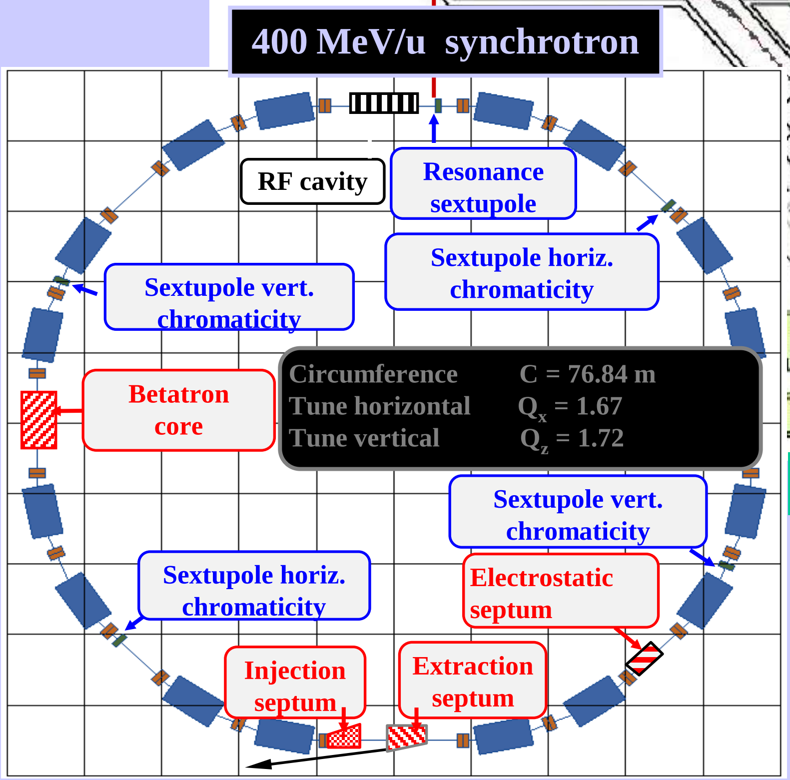


- Collaboration was formed in 1996 following an agreement between Med-AUSTRON (A) and TERA (I)
- CERN agreed to host and support the study in PS-Division
- The study was later joined by ONKOLOGY 2000 (CZ)
- Close contacts were kept with GSI (D)
- Work started in January 1996 and continued for 4 years.
- Final report is now available (CD ROM;CERN Yellow Report)

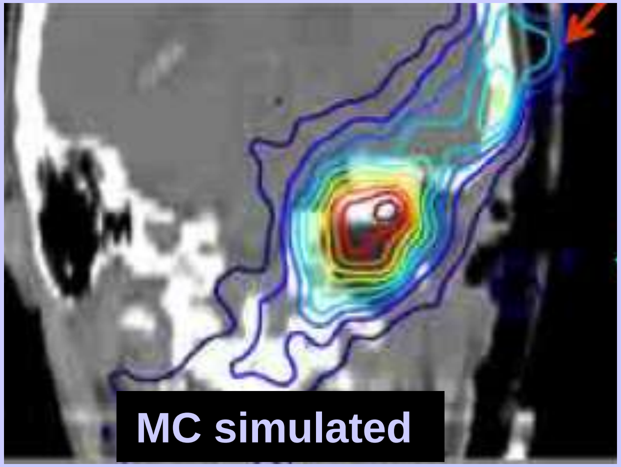
PIMMS at CERN in 1996 - 2000

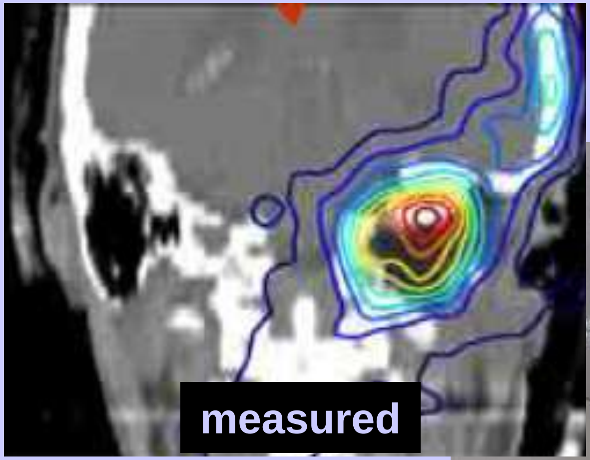
CERN–TERA–MedAustron Collaboration for optimized medical synchrotron





5. In-beam-PET for Quality Assurance of treatments





On-line determination of the dose delivered
First time in 110 years!

Modelling of beta^{+} emitters:
- Cross section
- Fragmentation cross section
- Prompt photon imaging
- Advance Monte Carlo codes

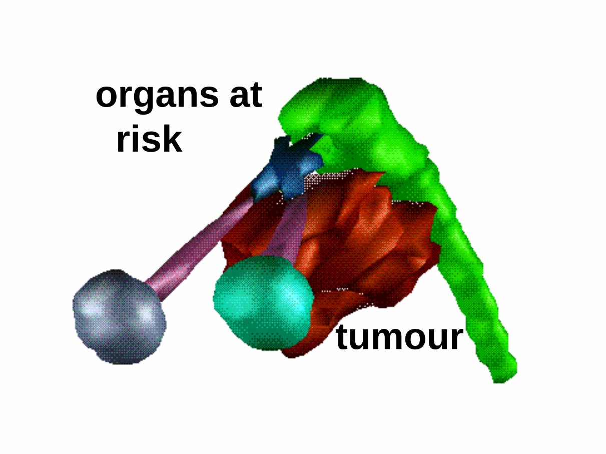
Hadrontherapy goals

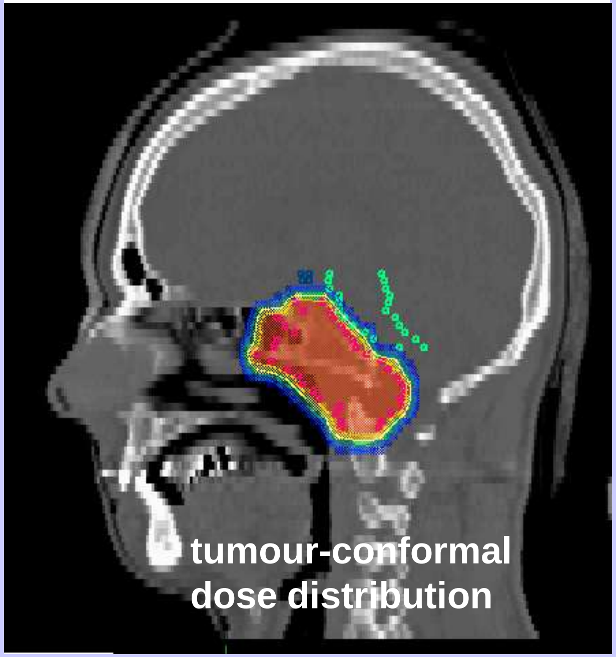
- Provide the irradiation technology and the detection systems to optimally use the advantageous properties of heavy charged particles in external radiotherapy

- Optimize dose to tumour conformity by beam scanning and adaptation of the delivery to the organ motion

- Treat patients and perform clinical trials using low-LET (p, He) and high-LET (C, O) beams

- Conduct technical, physical and clinical R+D





ENLIGHT: European Network for Light Ion Therapy

- Creation of common interdisciplinary environment
- Define and Collaborate in areas needing further research at the European level
- Profit from each others experience in building, managing, operating
- Reduce Duplication, Increase Quality, profit from best ideas, concepts
- Creation of maximum possible uniformity
- Inter-facilities uniformity and comparison
- Ease of exchange of information.

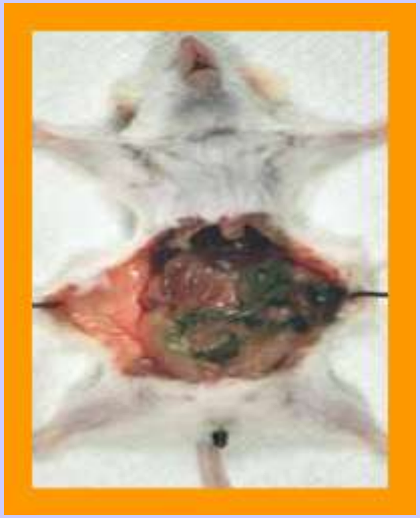
Production of isotopes

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 -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 stants ^{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

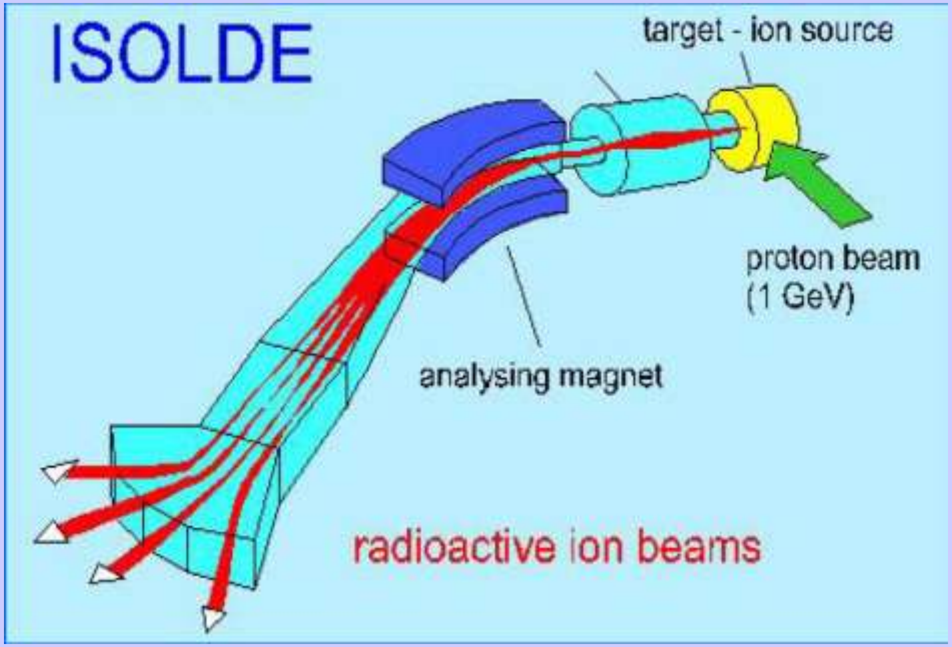
G.J.BEYER, HUG Geneva, 2002

Terbium produced with 1 GeV protons + ISOLDE



Tumour

No tumour after treatment with ^{149}Terbium



Experimental evidence of the usefulness of immunoconjugates for micro-metastases

ISOLDE allows the production of novel isotopes

Grids and e-health

LHC data challenge

- 40 million collisions per second
- After filtering, 100 collisions of interest per second
- 10^{10} collisions recorded each year

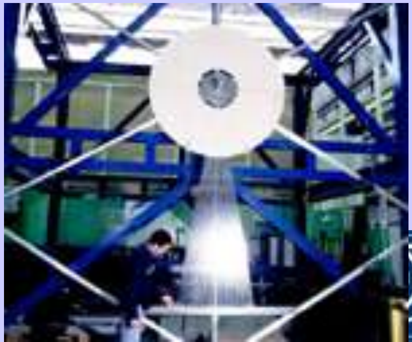
~10 Petabytes/year of data
~10 000 times the world annual book production,
~20km CD stack

CMS

LHCb

ATLAS

ALICE



The Web

- Was a response to the needs of a distributed collaborating community
- And saved time and effort in fetching information from other places
- It made sharing information so much easier

The GRID

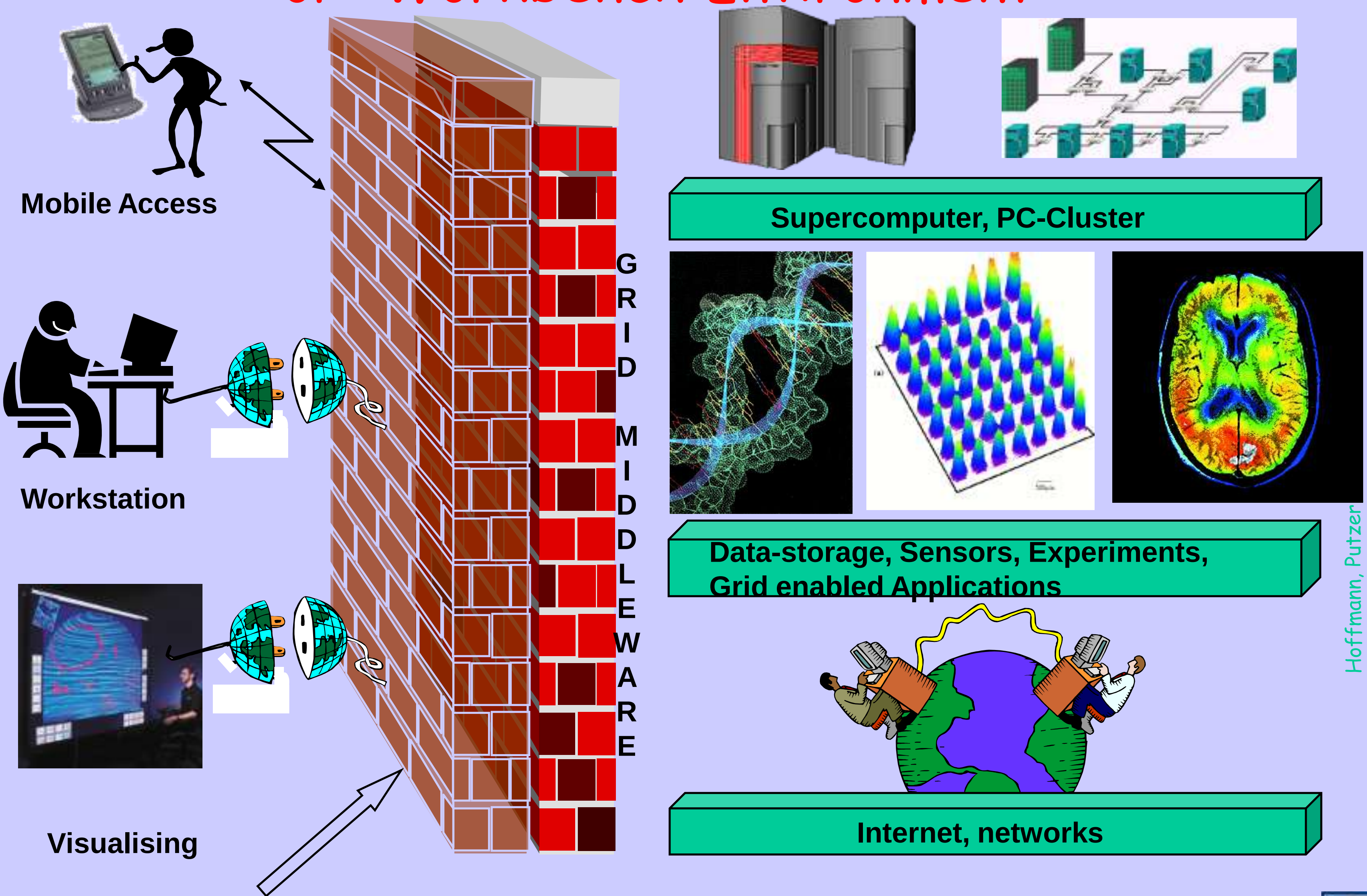
The Aim of the GRID is to give access,

again easily and transparently,

Not only to simple information,

But also to all of the computing resources and storage distributed around the world

The User connects to his "Virtual Laboratory" or "Workbench Environment"



MammoGrid Objectives

- Acquisition of large sample of mammograms
- Standardization of mammograms
- Annotation of mammograms by humans as well as CADe software
- Distributed data management system, cross-institute, cross-country queries
- Sharing of computing resources for the purpose of optimizing data storage and execution of computing-intensive algorithms
- Proof of concept with active clinical participation

MammoGRID

A pan-European distributed database of mammography images using GRID technologies

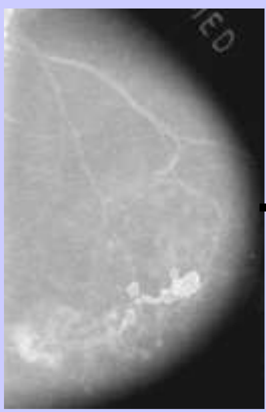
- To manage health care information for screening
- To assist health operators in their work environment and exchange data and practices
- To integrate latest technical developments in clinical practices
- 2 Main pilot applications:
  - CADe for quality controls (DICOM standards,GRID compliant, SMF Software)
  - Breast Density measurements

At work at Cambridge Hospital

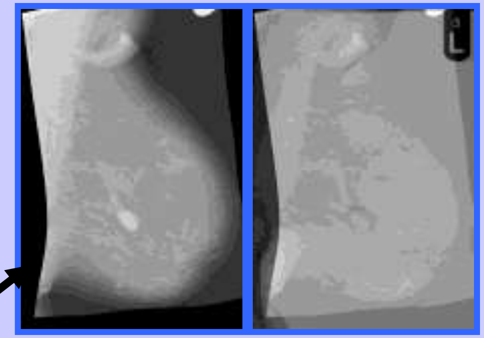
32 MB / Image   2 x 2 images: 128MB per visit
400 TB / year of information to be preserved for UK screening
Breast tumours: 24% not visible at screening, 80% of biopsies are negative

eDiaMoND Project

Mammograms have different appearances, depending on image settings and acquisition systems



Standard Mammo Format



Temporal mammography

Computer Aided Detection

3D View

The Grid links a large federated database of normalised digital mammograms shared initially by 4 hospitals

Health-e-Child on a slide