Impact of fundamental science on society

CERN-LHC programme and medical imaging

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Science and society

Beside the quest for fundamental knowledge, society has to face a number of challenges

- Develop clean and long term energy sources
- Provide food and water to all
- Provide Education to all
- Fight major disease (AIDS, Malaria, Tuberculosis, Cancer, Parkinson, Alzheimer, …)
- Setup a world of communication (Web, Grid)
- And many others …
• Besides their role in increasing knowledge, all areas of fundamental research should be concerned by their possibilities of innovations to be used for the benefit of society;

• Links and cooperation between different disciplines are not only efficient for their own research but even more so in the success of technology transfer to Society.
Research on plasma physics oriented towards understanding of plasma behaviour first in the universe, then on earth in a magnetic field to increase its life time;

It has led to many applications like welding, changes in material surfaces by heat treatment or implantation, TV screens....

The most important application for the future may be controlled nuclear fusion as a clean and sustainable energy source: ITER

... to be built not so far away from here
ITER

Central Solenoid
Nb$_3$Sn, 6 modules

Outer Intercoil Structure

Toroidal Field Coil
Nb$_3$Sn, 18, wedged

Poloidal Field Coil
Nb-Ti, 6

Machine Gravity Supports
(recently remodelled)

Blanket Module
421 modules

Vacuum Vessel
9 sectors

Cryostat
24 m high x 28 m dia.

Port Plug (IC Heating)
6 heating
3 test blankets
2 limiters
rem. diagnostics

● Divertor
● 54 cassettes

Torus Cryopump
8, rearranged
Science and Society, can CERN contribute?

The Mission of CERN (1954):
“The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto.

But also

Governments should support effective strategies for the dissemination of information on Science and Technology. Both governments and scientists should promote the application of scientific knowledge into tangible benefits for the Society.

OECD, UNESCO

EuroMedIm2006, Marseille - 9 May 2006
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CERN – mission and role

- Research
  - develop, build, run unique ‘frontier’ facilities for European High Energy physics

- Provide an environment for training physicists and engineers

- Facilitate and actively pursue Technology Transfer

- Foster international collaboration
CERN extended mandate

● As a consequence of a strong emphasis on innovations for its own needs, CERN has made the transfer of technologies to society at large its second priority, beyond the main mandate of fundamental HEP research.

● Technology Transfer at CERN covers domains ranging from detector development to medical imaging, from electronics to IT applications, from accelerators to vacuum technology.

*Many examples can be referred to:* WWW, GRID, Synchrotron light, Hadron therapy, material modifications by ion-beam irradiation etc…

*Limited for today’s presentation to medical imaging from the CERN-LHC programme*
CERN and the LHC Programme
CERN in Numbers

- 2600 staff
- 570 Fellows and Associates
- 7000 users
- Budget (2005) 1240MCHF (785M Euro)

- 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...
CERN: the World’s Most Complete Accelerator Complex (not to scale)
The LHC = Proton - Proton Collider

7 TeV + 7 TeV

Luminosity = $10^{34}$ cm$^{-2}$ sec$^{-1}$

Primary targets:
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

The LHC results will determine the future course of High Energy Physics
Cryomagnets interconnect in the tunnel
ATLAS

Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid

Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

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ATLAS Silicon Tracker (SCT)

All four barrel cylinders are complete and at CERN

Assembly of the four barrel cylinders is complete (left), and the SCT barrel is now being prepared for insertion into the TRT barrel
CERN-LHC Scientific Programme
and Science and medical imaging
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
The Nobel Prize in Physiology or Medicine 1979

Allan MacLeod **Cormack**
Nuclear Physicist
Cape Town
Harvard University
Tufts University

Sir Godfrey Newbold **Hounsfield**
English electrical engineer
EMI Research

CAT Scanner
the tomography principle
The multiwire proportional chamber
Low dose X-Ray digital radiography

The Nobel Prize in Physics 1992

Georges Charpak
Physicist CERN
Some history

1977 when PET started at CERN

(Fournes, Tomasson et al.)
Spatial resolution 2.4 mm FWHM
Maximum data rate: 3000 c.p.s.
Sensitivity: 35 c.p.s./1Ci
159: 0.57 x 10^6 Bq
Medical Imaging has only partially benefited from new technologies developed for telecommunications and High Energy Physics detectors:

- New scintillating crystals and detection materials
- Highly segmented and 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)
### Requirements for Medical Imaging

**1. Crystals**
- High density (> 7 g/cm³)
- Fast emission (< 100 ns), visible spectrum
- High light yield
- Moderate radiation resistance

**2. Photodetectors**
- Compact
- High quantum efficiency and high gain
- High stability

**3. Readout electronics**
- Fast shaping, low noise
- Highly integrated

**4. Intelligent and parallel DAQ**
- Reduce dead time

**5. Software**
- Accurate Monte Carlo simulation

**6. General design**
- Compact integration of a large number of channels (> 10’000)
1- Crystals

CMS PbWO₄ production

Crystal Clear LuAP production
2- New pixellised Photodetectors

- **Hamamatsu single channel APD**
- **CMS**
- **LHCB**
- **BrainPET**
- **Hamamatsu 32 channels APD array**
- **Mammography**
- **ClearPEM**
- **Hamamatsu H7546 64 channel PMT**
- **Opera ClearPET**
- **HPD tube manufactured at CERN: 2048 channels**
- **PM flat pannel**
3- Pixel hybrid detector

LHC tracker pixel detectors

Medipix single photon X-Ray detectors
4- Pipeline Architectures

LHC

40 MHz COLLISION RATE

LEVEL-1 TRIGGER

100-50 kHz

1 Terabit/s READOUT 50,000 data channels

500 Gigabit/s

100 Hz FILTERED EVENT Gigabit/s SERVICE LAN

Computing Services

SWITCH NETWORK

DETECTOR CHANNELS

Charge Time Pattern

Digitisation

Pipeline

Event builder

Future PET
5- Simulation

Higgs event at LHC (CMS) with Geant4

ClearPET with GATE: Geant4 Application for Tomographic Emission
6- ClearPET®, small animal PET
Crystal Clear Collaboration

Haderian glands

Medulla oblongata

Olfactory bulb

Glottis / tongue

cerebellum

Rat brain FDG image
Also: Positron Emission Mammography
CRYSTAL CLEAR Collaboration

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

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
Also: Enhanced Compton SPECT
CIMA Collaboration

Use Compton Scattering kinematics to determine
direction of a primary $\gamma$-ray from a measurement of:
Energy $E_{\gamma 1}$ and spatial coordinates $(x,y,z)$ of the $\gamma$-e
in first detector. Use recoil $e^-$ ionization in Silicon.
Point $(x,y,z)$ of full absorption of scattered $\gamma$ and
deposited energy $E_{\gamma 2}$. Use scintillator crystals+PMTs

Detection coincident events between two detectors
Compton scatter equation relates scatter angle $\theta$ and $E_o$
and $E_re$

$$\cos \theta = 1 + \frac{511}{E_o} - \frac{511}{E_o - E_re}$$

Photon direction is determined within conical ambiguity

(courtesy of P. Weilhammer/CERN)
Also: 3D Axial Brain PET Scanner

- 34 cm inner diameter
- 10 cm axial length
- 2496 crystals
- 24 HPDs
- total detection volume 2556 cm$^3$
- F coverage 66%
- W coverage 18%
- Depth of Interaction is measured

Performances using YAP:Ce (lowest bound)
- energy resolution 7-7.5%
- spatial (Transaxial Plane) resol. 1.5-2.2.mm
- sensitivity 3-4 cps/KBq

(courtesy of C.Joram/CERN)
Also: GEM Detector

- Thin, metal-clad polymer foil, chemically pierced by a high density of holes (70-80 $\mu$m 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.
Can we do more?

- Technology transfer from HEP to medicine is strongly encouraged
  **BUT**
- CERN and HEP community main mission is to do particle physics, not medical imaging
- A stronger coordination is needed and must be further developed between physicists and the biomedical world
- A bridge must be built to integrate innovative technologies developed in HEP and other fundamental disciplines, and to validate them in complex systems in a biomedical environment
- No structure exists at the European level for this mission
  
  **Cerimed (European Centre for Research in Medical Imaging) could be a solution**

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CERIMED in the world of imaging

Generic developments
- Conversion materials
- Sensors
- Electronics
- DAQ
- Information technology
- New radiotracers

Integration of Advanced prototypes
Validation of Advanced prototypes
Animal & Clinical

End users
- Hospitals
- Industry
- Animal Imaging platforms

CERIMED