From (particle) physics to medical applications

MANUELA CIRILLI

CERN

MEDICAL APPLICATIONS ADVISER – KNOWLEDGE TRANSFER GROUP

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008548

Disclaimer(s) & Acknowledgments

Of course, I had to select the material to be included.
And of course, Physics ≠ HEP (but a lot of HEP here, and a lot of CERN examples).

The CERN medical applications-related projects presented in this talk are realized by the CERN scientists and engineers: without their skills, ingenuity, and dedication, there would be no knowledge to transfer! Some names are acknowledged on the respective slides, but there are many more.

The KT group and myself are privileged to have the opportunity to support these projects in a tailored way, and to help bridge the gap between CERN technologies and society.

Many thanks to all the colleagues from CERN, CNAO, CHUV, CNRS, GSI, MedAustron, INFN, TERA who have shared their material and wisdom with me; thanks to Ugo Amaldi and Manjit Dosanjh, from whom I first learned about hadron therapy.

I am neither a doctor, nor a medical physicist, nor a technical expert in most of the technologies I present, so the Q&A will be fun! ☺

HITRI plus
Heavy Ion Therapy Research Integration

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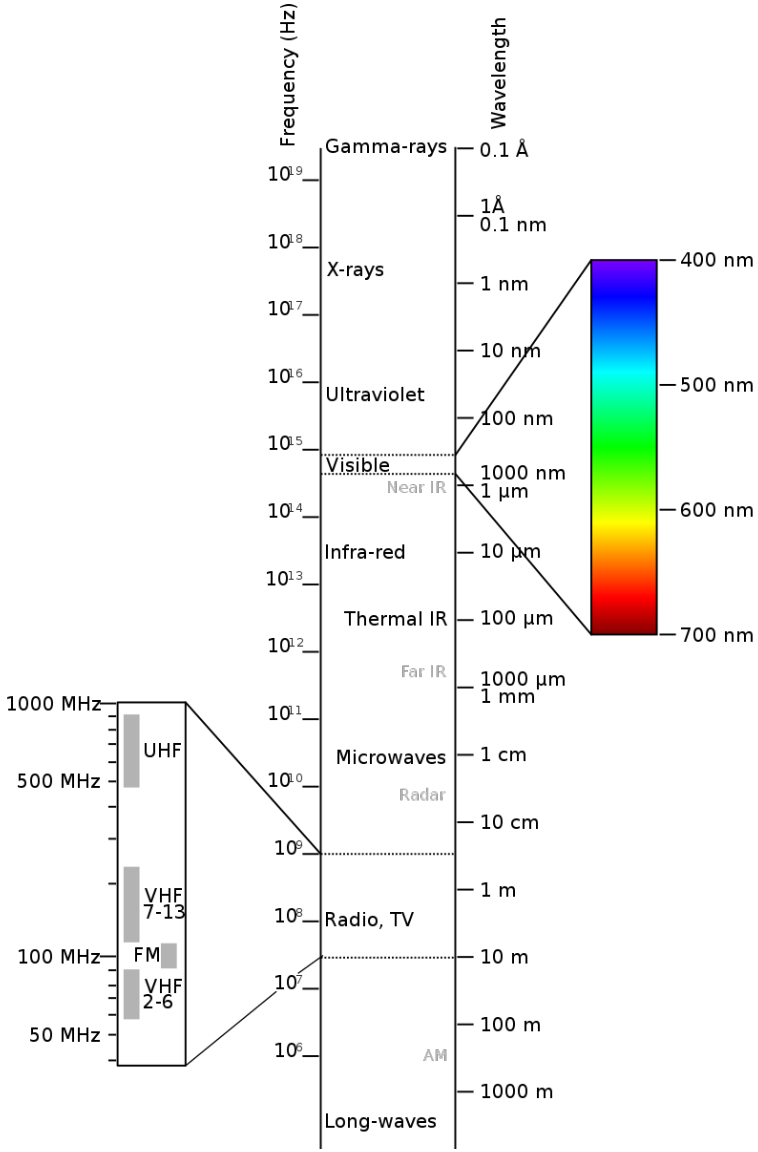
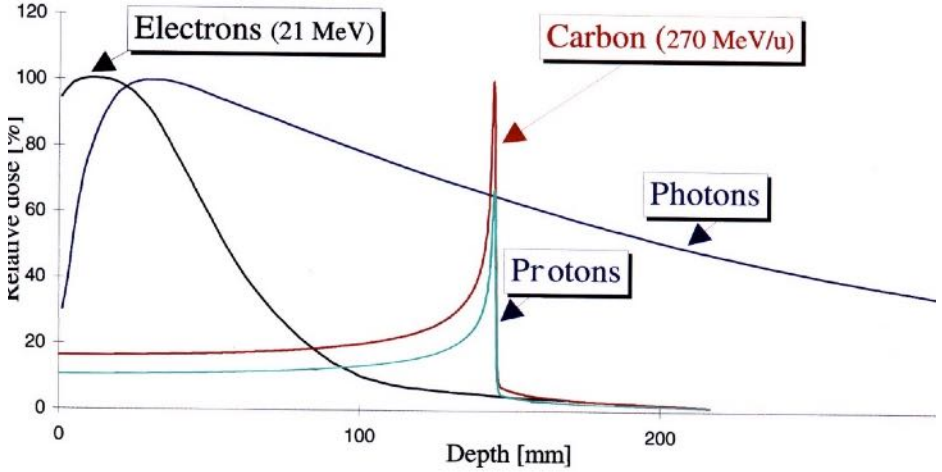
The physics itself



By Original: Penubag Vector: Victor Blacus - Own work based on: Electromagnetic-Spectrum.png, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=22428451



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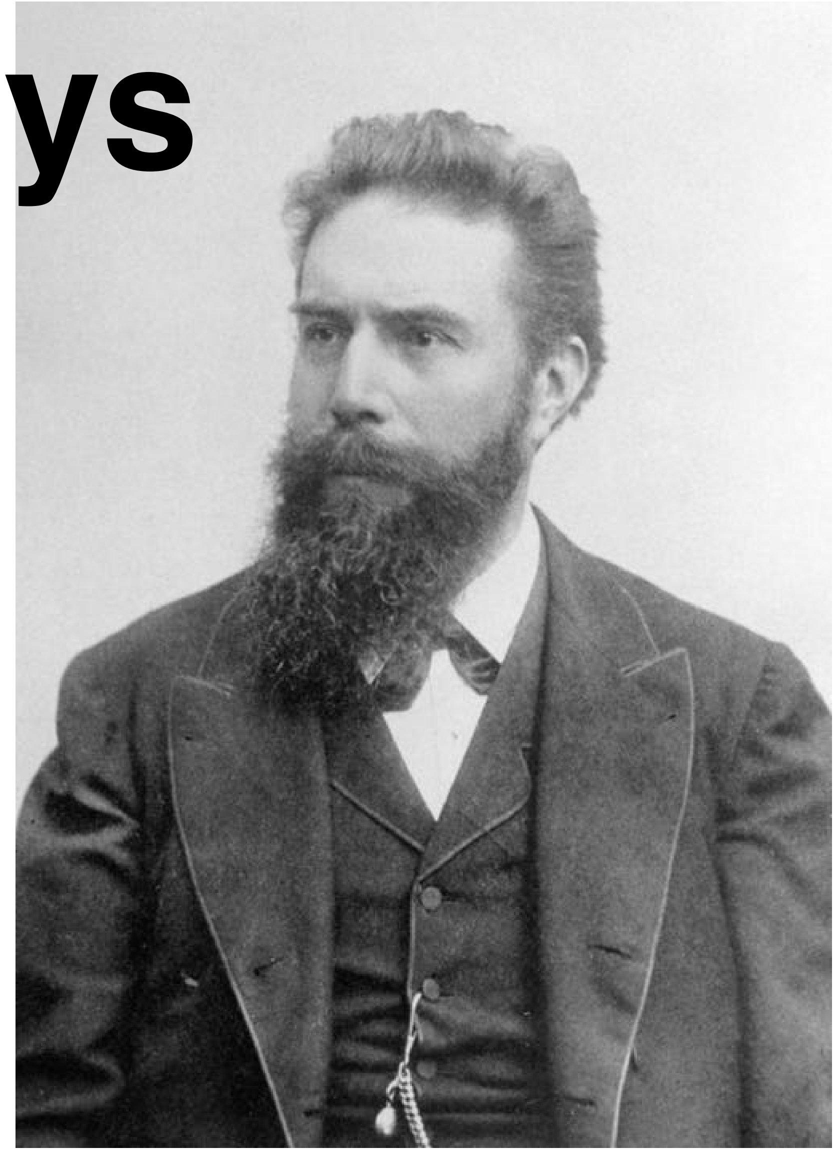
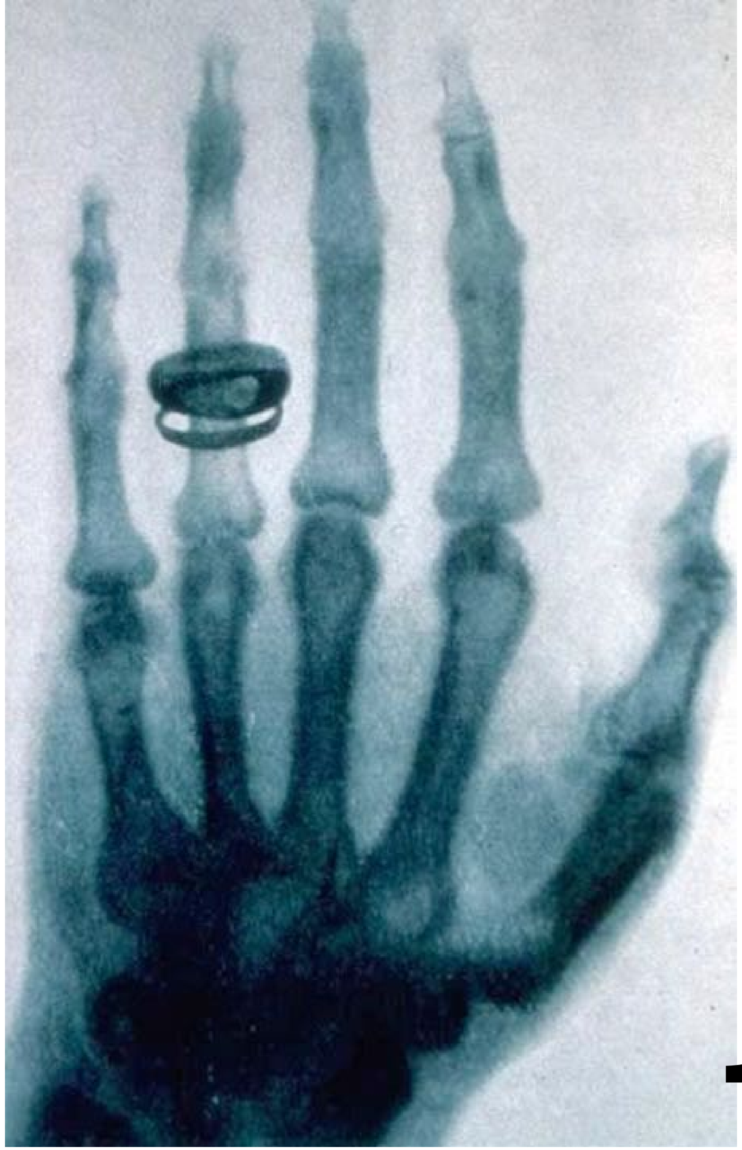
X-Rays





1895

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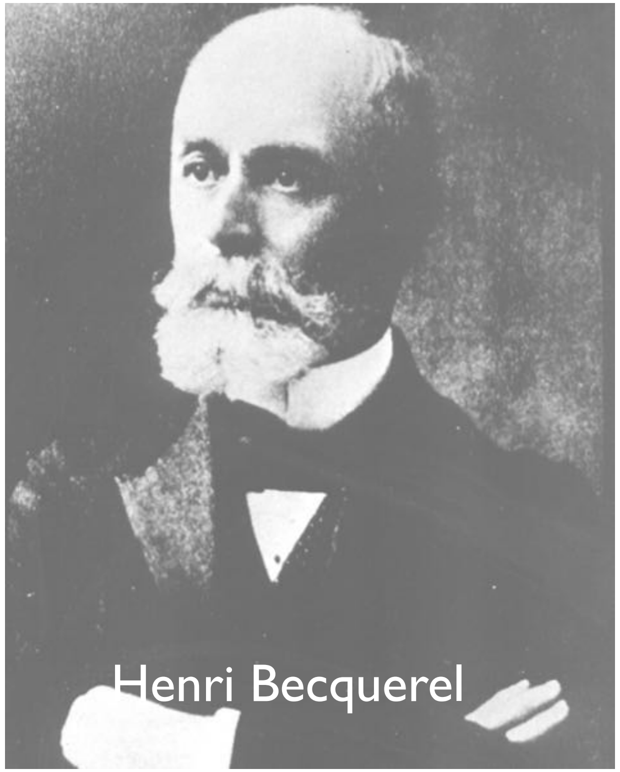
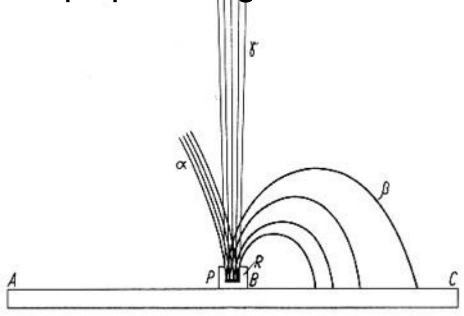
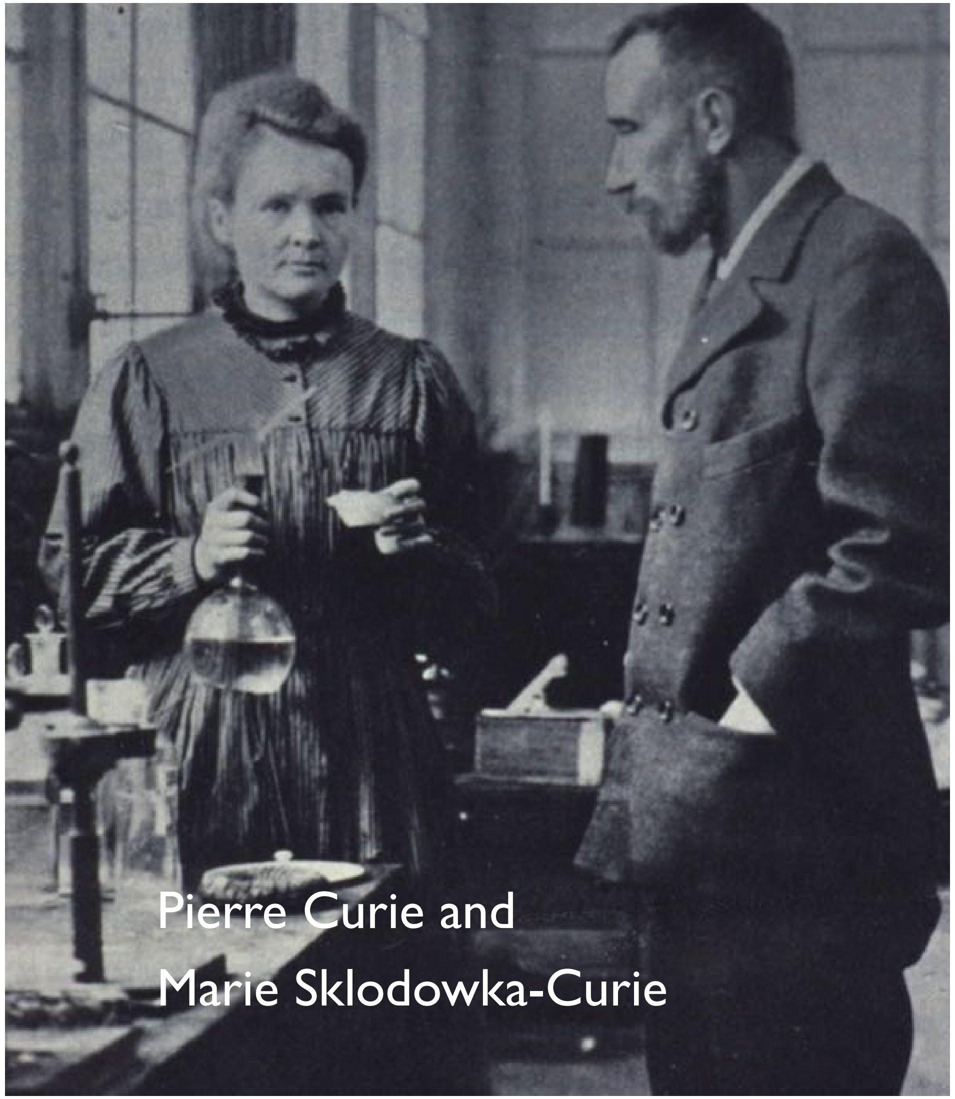


1896: accidental discovery of natural radioactivity

Mme. Curie thesis – 1904
α, β, γ in magnetic field



1898: by studying the strange uranium rays, they soon discovered polonium, thorium, radium



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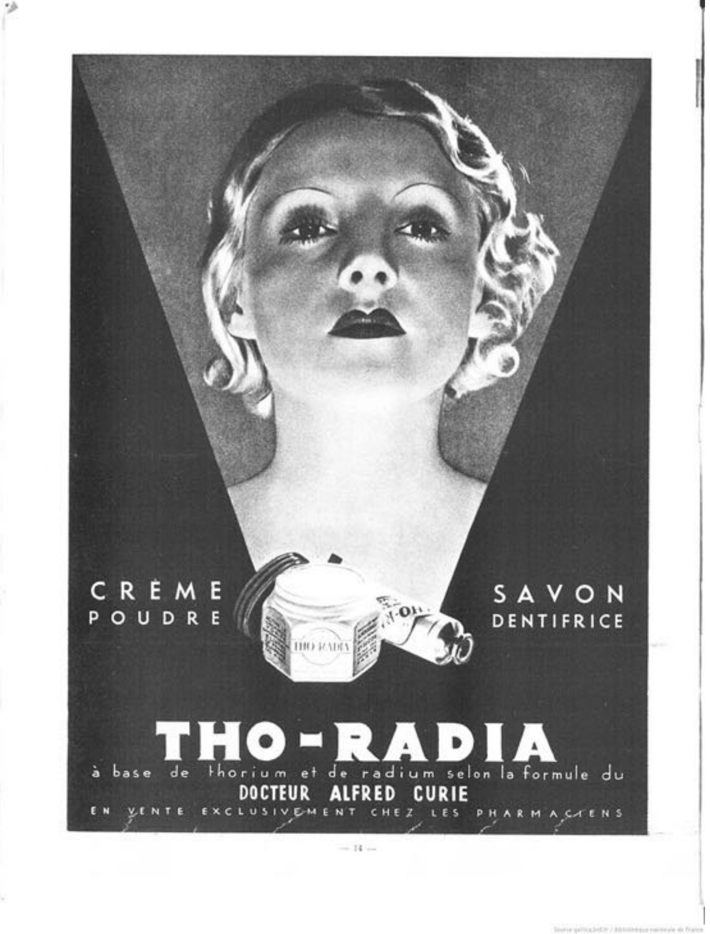
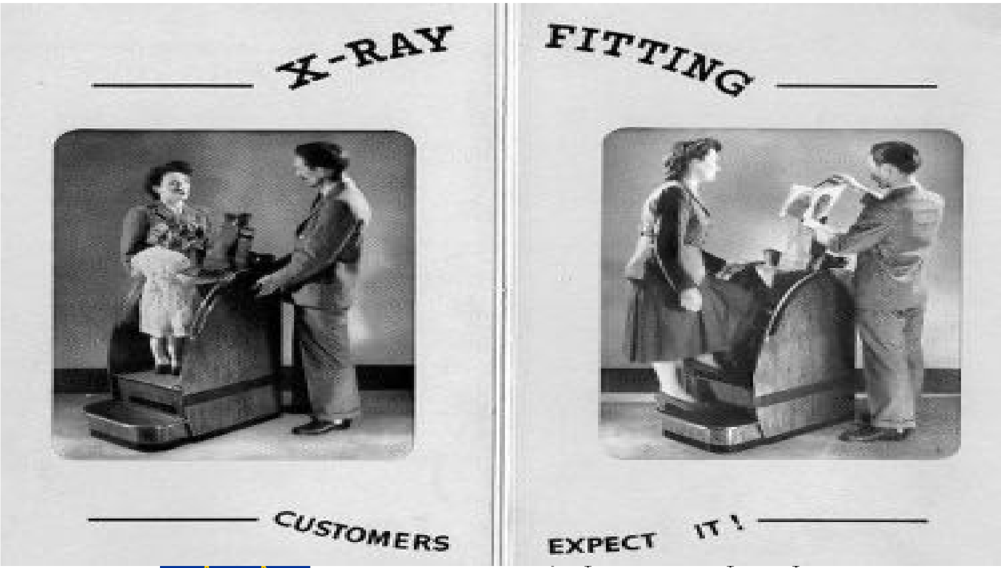


Par Cinémagazine, 14 février 1935 — https://gallica.bnf.fr/ark:/12148/bpt6k2000628h, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=97956453

Par Radior cosmetics — sitead New York Tribune Magazine, page 12, Domaine public, https://commons.wikimedia.org/w/index.php?curid=35047170

Par Sam LaRussa from United States of America — Radithor, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=57841049



https://www.smh.com.au/national/nsw/from-the-archives-1956-ban-urged-of-x-ray-machines-at-shoe-shops-20210318-p57c1m.html

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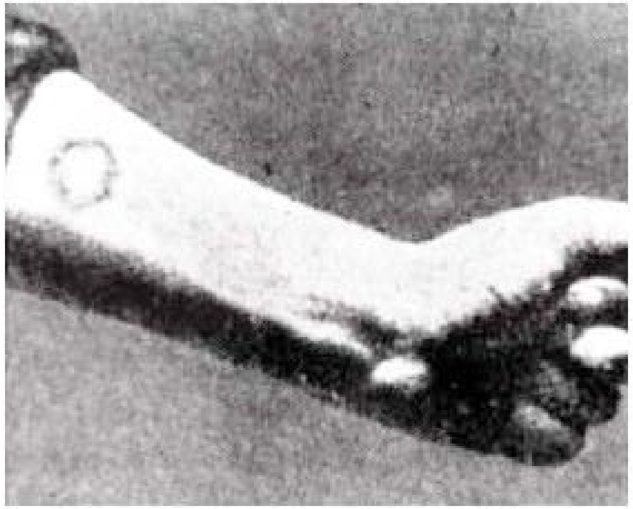
Friedrich Giesel
1852-1927



Burning of Pierre Curie's arm

Pierre Curie
1859-1906

Photo of the "Pierre Curie" arm, burned by radium salt applied for 10 hours. This was also the time when people became aware of the effect of radiation and the possibility of using it for medical purposes. In 1900, the German dentist Walkhoff noted that radium rays act energetically on the skin in a manner analogous to that of X-rays. This observation was confirmed a few weeks later by the German chemist F. Giesel, with whom Pierre and Marie maintained regular correspondence.

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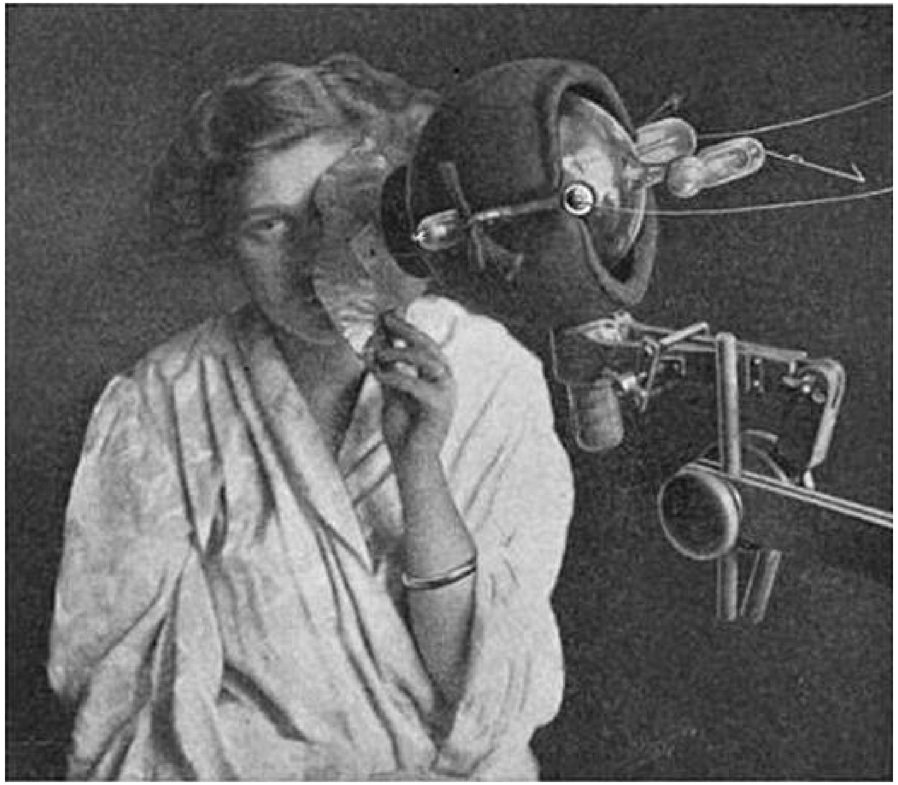

X-ray apparatus used for treatment of epithelioma of the face, 1915.

Small tubes containing radium salts are strapped to a woman's face to treat what was either lupus or rodent ulcer, 1905.

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The Nobel Prize in Physics 1944

Photo from the Nobel Foundation archive.

Isidor Isaac Rabi

Prize share: 1/1

The Nobel Prize in Physics 1944 was awarded to Isidor Isaac Rabi "for his resonance method for recording the magnetic properties of atomic nuclei."

The Nobel Prize in Physics 1952

Photo from the Nobel Foundation archive.

Felix Bloch

Prize share: 1/2

Photo from the Nobel Foundation archive.

Edward Mills Purcell

Prize share: 1/2

The Nobel Prize in Physics 1952 was awarded jointly to Felix Bloch and Edward Mills Purcell "for their development of new methods for nuclear magnetic precision measurements and discoveries in connection therewith."

The Nobel Prize in Physiology or Medicine 2003

Photo from the Nobel Foundation archive.

Paul C. Lauterbur

Prize share: 1/2

Photo from the Nobel Foundation archive.

Sir Peter Mansfield

Prize share: 1/2

The Nobel Prize in Physiology or Medicine 2003 was awarded jointly to Paul C. Lauterbur and Sir Peter Mansfield "for their discoveries concerning magnetic resonance imaging."

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Heavy Ion Therapy Research Integration

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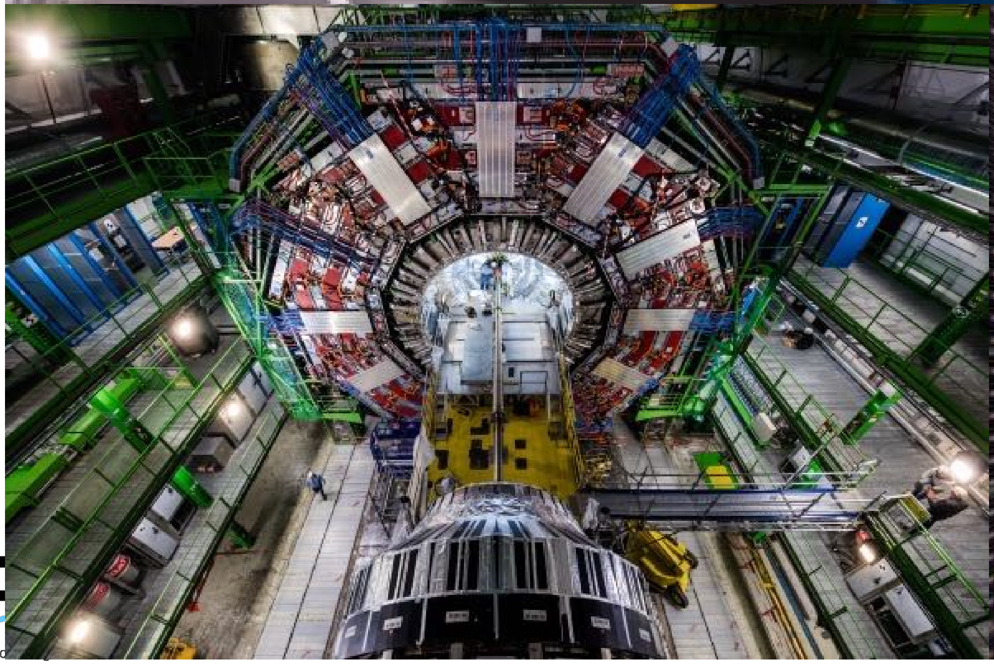
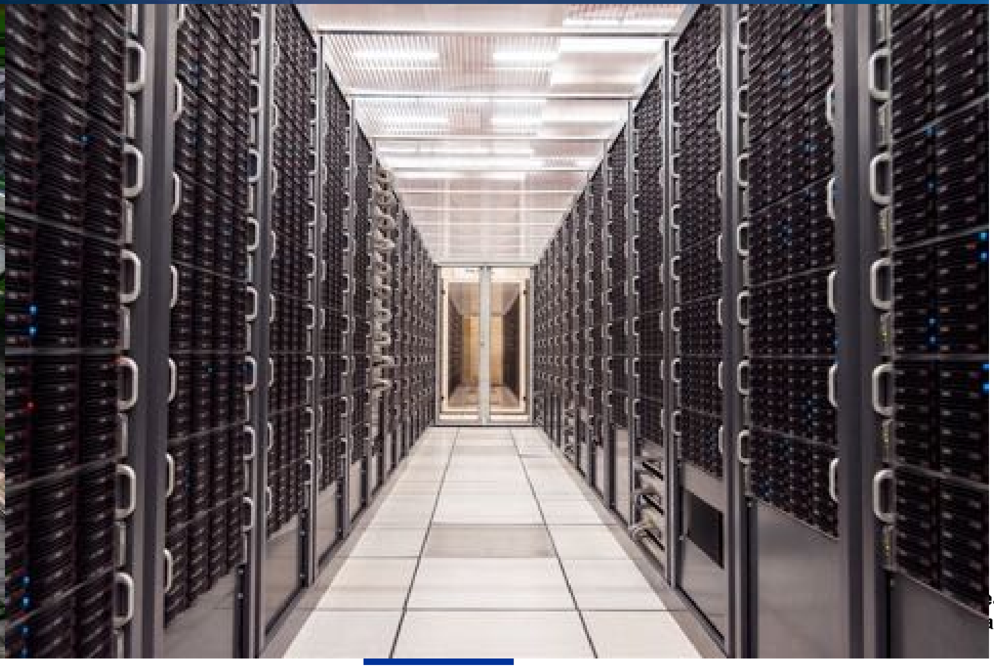
The technologies





Heavy Ion Therapy Researc

an Union's Horizon 2020
agreement No 101008548


sound reproduction
data management
testing satellite components
astronauts' radiation exposure
understanding turbulence
food sterilization
medical implants
finding oil, gas, water
geological dating
homeland security
scientific linux
curing of epoxies and plastics
medical imaging
x-ray diffractometry
spacecraft shielding
radiology
medical equipment sterilization
medical radioisotopes
non-destructive testing
nuclear waste transmutation
ion implantation
shrink wrap
radiotherapy
rad-hard electronics
PET
terrestrial reproduction of space radiation
simulations
industry 4.0
digital data preservation
optimised irrigation systems
drug development
safety
open hardware
WWW
powering complex biological simulations
industrial control systems
power transmission
analysis of satellite data
treatment planning systems
volcano tomography
space applications
sealing food packages
autonomous vehicles
isotope production
smoke detectors
hadron therapy
cultural heritage
MRI
cleaner air and water
ink curing
cargo screening
computer chips manufacturing
studying the retina
medical dosimetry
material science


Accelerators for America's Future
U.S. DEPARTMENT OF ENERGY
Particle physics – it matters
A forward look at UK research into the building blocks of the Universe and its impact on society
In partnership with
Science & Technology Facilities Council
Accelerating science and innovation
Societal benefits of European research in particle physics
Tools, Techniques, and Technology Connections of Particle Physics
Task force chairs:
Marcel Demarteau
Argonne National Laboratory
Katie Yurkewicz
Fermi National Accelerator Laboratory
U.S. DEPARTMENT OF ENERGY
Office of Science
Accelerators and Beams
TOOLS OF DISCOVERY AND INNOVATION
4th Edition
Published by the Division of Physics of Beams of the American Physical Society
APPLICATIONS OF PARTICLE ACCELERATORS IN EUROPE
EuCARD²
Accelerators for Society
Particle accelerators are being applied throughout society. Originally developed for fundamental research, today they are used for a range of applications, from healthcare to manufacturing silicon chips to reducing pollution.
TIARA
From Physics to Daily Life
Applications in Informatics, Energy, and Environment
Edited by Beatrice Bressan
WILEY Blackwell

Over **70 companies and institutes produce accelerators for industrial applications**; these organizations sell more than **1,100 industrial systems per year** — almost twice the number produced for research or medical therapy — at a **market value of $2.2B**.

Over **$1B** of this amount is generated by the sales of accelerators for **ion implantation** into materials — primarily semiconductor devices — whose worldwide value of production is about $300B.

Hamm,R.andHamm,M.(2012).Industrial accelerators and their applications. World Scientific Publishing Co.

As of 2014 there were **42,200** accelerators worldwide:
27,000 (64%) in industry,
14,000 (33%) for medical purposes
1,200 (3%) for basic research.

These figures exclude electron microscopes and x–ray tubes, and the security and defense industries.

Chernyaev, A. P. and Varzar, S. M. (2014). Particle accelerators in modern world. Physics of Atomic Nuclei, 77(10):1203–1215.

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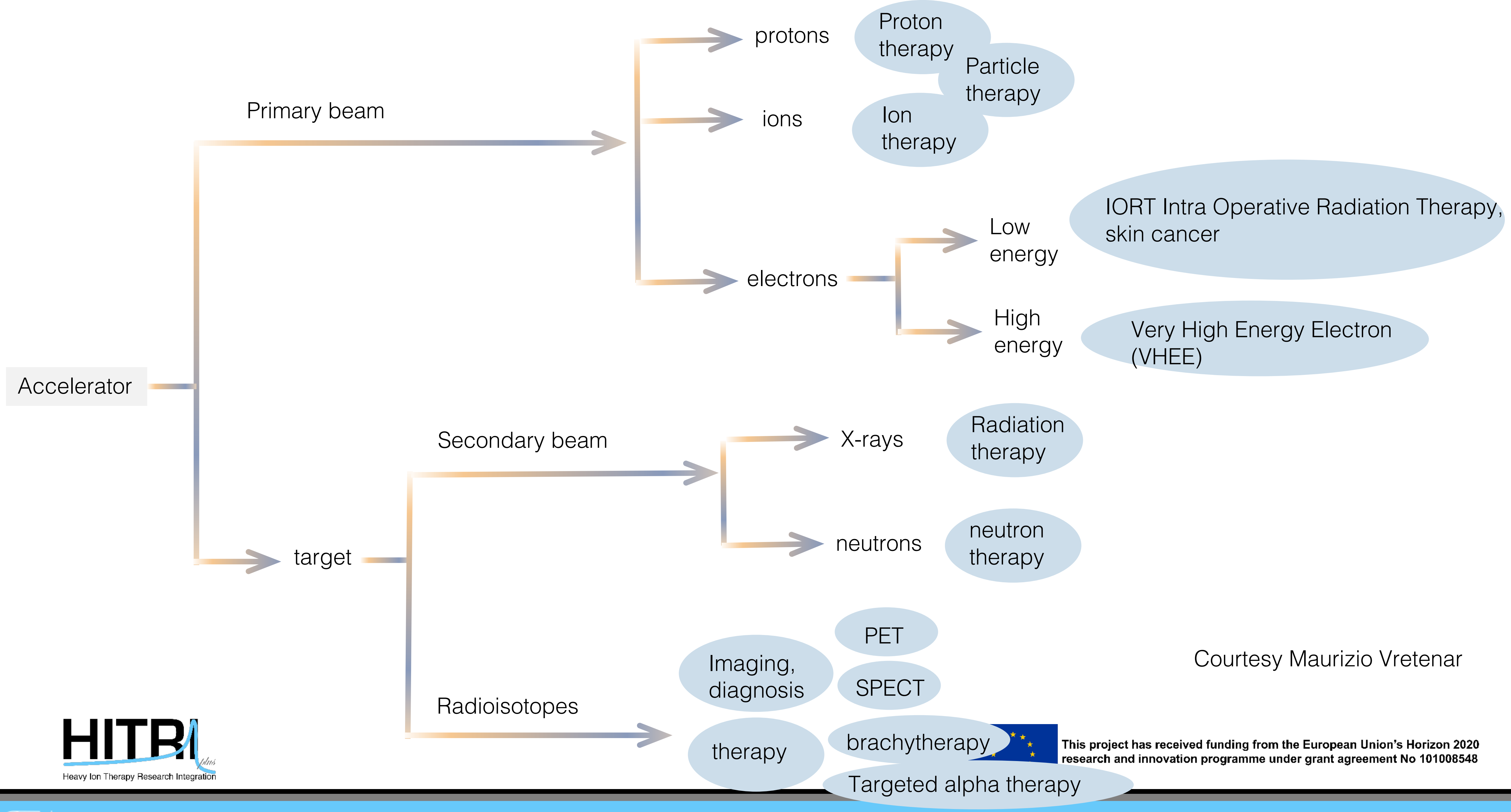

Courtesy Maurizio Vretenar

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Heavy Ion Therapy Research Integration

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Status of Radiation Therapy Equipment

155 Countries

7602 RT Centres

14875 MV Therapy

Click on **Equipment type**, **Income groups** or **Regions** to create your own view. *Ctrl+click to select multiple items*

Equipment type
(Updated on : 23/06/2021 09:19:53)

MV Therapy	14,875
Brachytherapy	3,318
Light Ion Therapy	110

Equipment per income groups
(Updated on : 23/06/2021 09:19:53)

High income (H)	9,365
Upper middle income (UM)	4,165
Lower middle income (LM)	1,303
Low income (L)	39
Temporarily unclassified (NC)	3

Regions: WHO regions
Country:

IAEA DIRAC Directory of RAdiotherapy Centres

HITRIplus Heavy Ion Therapy Research Integration

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Status of Radiation Therapy Equipment

20 Countries

106 RT Centres

110 Light Ion Therapy

Click on **Equipment type**, **Income groups** or **Regions** to create your own view *Ctrl+click to select*

MV Therapy	14,875
Brachytherapy	3,318
Light Ion Therapy	110

Regions: WHO regions

Country:

Equipment per income groups

(Updated on : 23/06/2021 09:19:53)

High income (H)	99
Upper middle income (UM)	10
Lower middle income (LM)	1

IAEA DIRAC Directory of RAdiotherapy Centres

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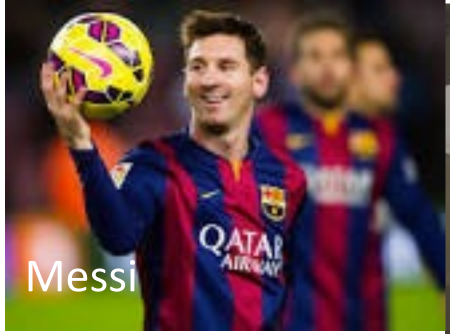
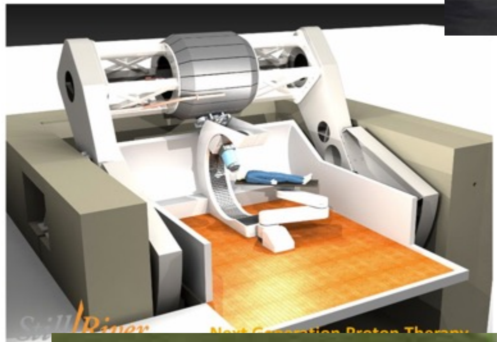
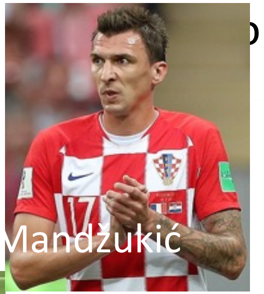
200



Multi heavy ions
(protons + carbon ions)





on multi-room

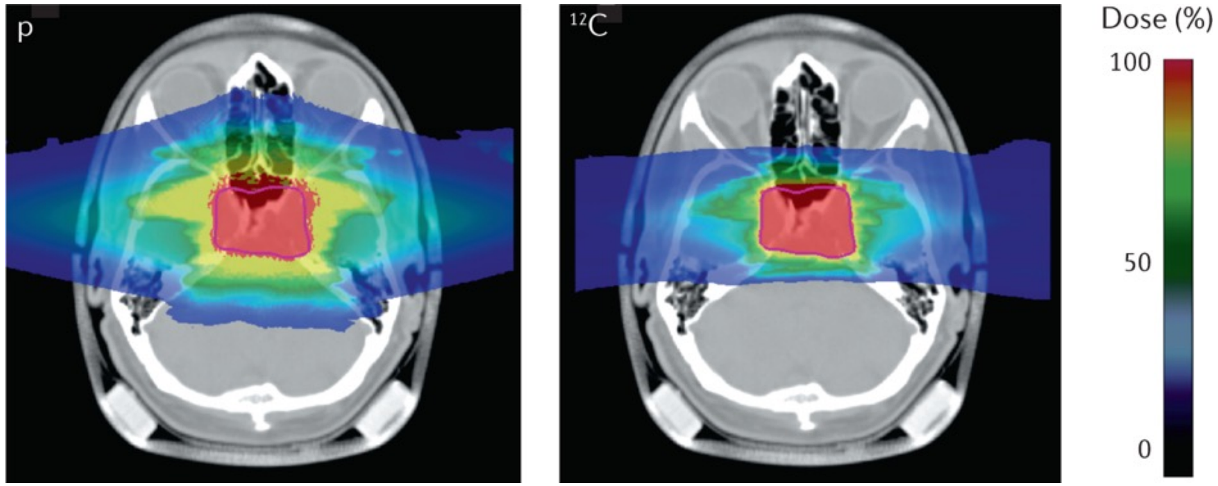
2

single-room

Courtesy
(I'll never thank him enough!)
Marco Durante (GSI)
JENAS 2019
https://indico.ijclab.in2p3.fr/event/5418/timetable/#20191016.detailed

From pioneering rasterscanning & carbon ion pilot project @ GSI

440 patients
1998-2008



The image shows an optimized plan with two opposite fields for a chordoma patient using protons (left) or 12C ions (right).

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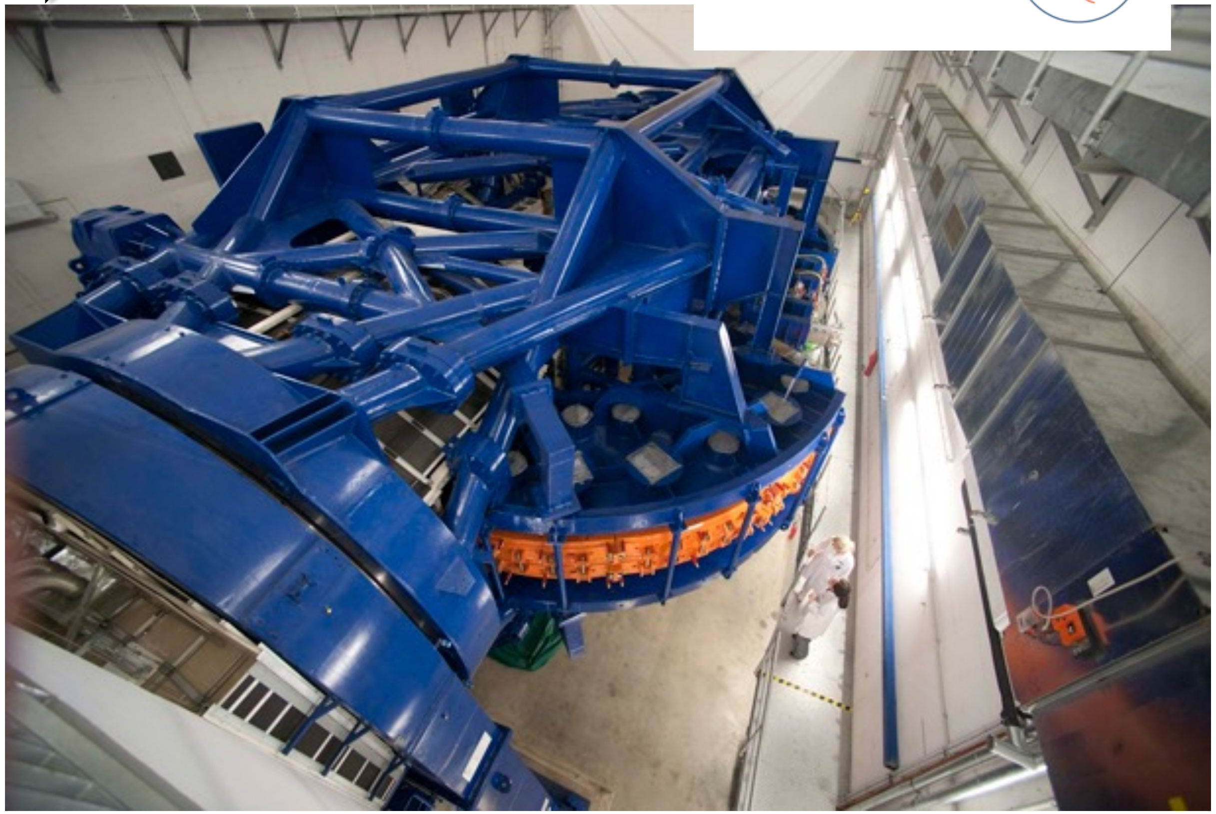
HIT Heidelberger Ionenstrahl-Therapiezentrum



Since 2009*:
2841 patients with p
3793 patients with C-ion

* Until Dec 2020, source ptcog.ch

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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN - PS DIVISION

CERN/PS 2000-007 (DR)

PROTON-ION MEDICAL MACHINE STUDY (PIMMS)
PART II

Accelerator Complex Study Group*
supported by the Med-AUSTRON, Onkologie-2000 and the TERA Foundation
and hosted by CERN

ABSTRACT

The Proton-Ion Medical Machine Study (PIMMS) group was formed following an agreement between the Med-AUSTRON (Austria) and the TERA Foundation (Italy) to combine their efforts in the design of a cancer therapy synchrotron capable of accelerating either light ions or protons. CERN agreed to support and host this study in its PS Division. A close collaboration was also set up with GSI (Germany). The study group was later joined by Onkologie-2000 (Czech Republic). Effort was first focused on the theoretical understanding of slow extraction and the techniques required to produce a smooth beam spill for the conformal treatment of complex-shaped tumours with a sub-millimetre accuracy by active scanning with proton and carbon ion beams. Considerations for passive beam spreading were also included for protons. The study has been written in two parts. The more general and theoretical aspects are recorded in Part I and the specific technical design considerations are presented in the present volume, Part II. An accompanying CD-ROM contains supporting publications made by the team and data files for calculations. The PIMMS team started its work in January 1996 in the PS Division and continued for a period of four years.

*Full-time members: L. Badano[1)], M. Benedikt[2)], P.J. Bryant[2)] (Study Leader), M. Crescenti[1)], P. Holy[3)], A. Maier[2)+4)], M. Pullia[1)], S. Reimoser[2)+4)], S. Rossi[1)],
Part-time members: G. Borri[1)], P. Knaus[1)+2)]
Contributors: F. Gramatica[1)], M. Pavlovic[4)], L. Weisser[5)]
1) TERA Foundation, via Puccini. 11, I-28100 Novara.
2) CERN, CH 1211 Geneva-23.
3) Oncology-2000 Foundation, Na Morani 4, CZ-12808 Prague 2.
4) Med-AUSTRON, c/o RIZ, Prof. Dr. Stephan Korenstr.10, A-2700 Wr. Neustadt.
5) Sommer & Partner Architects Berlin (SPB), Hardenbergplatz 2, D-10623 Berlin.

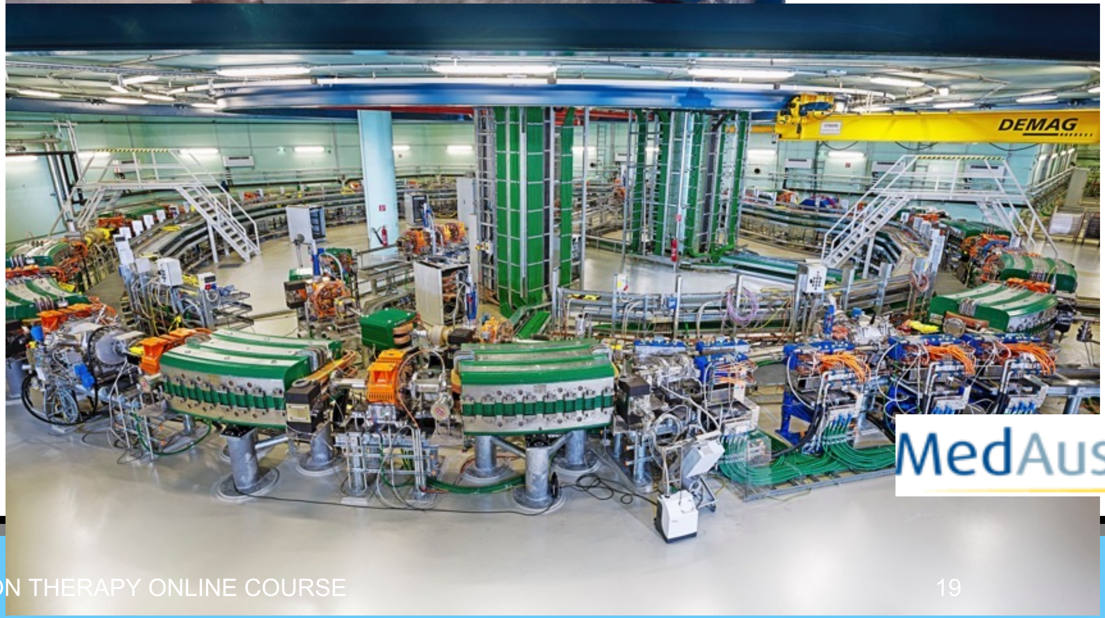
Geneva, Switzerland
May 2000

PIMMS August 2000

From PIMMS @ CERN → TERA

INFN

fondazione CNAO



MedAustron

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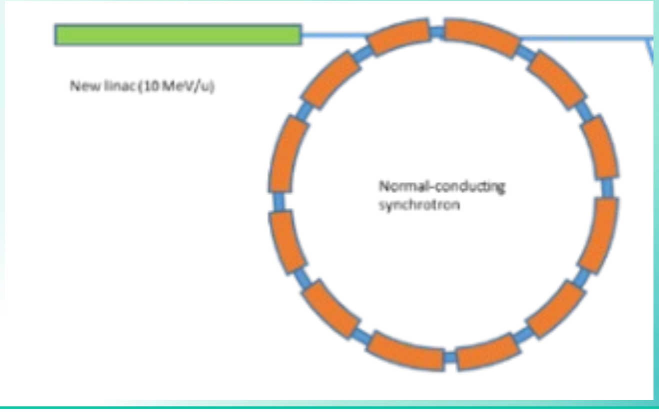
Three alternative accelerator designs

nimms

Improved synchrotron (warm)

Equipped with several innovative features: multi-turn injection for higher beam intensity, new injector at higher gradient and energy, multiple extraction schemes, multi-ion.

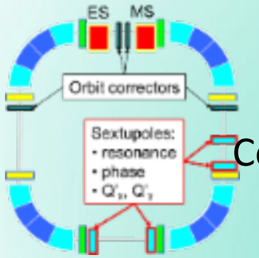
Circumference ~ 75 m



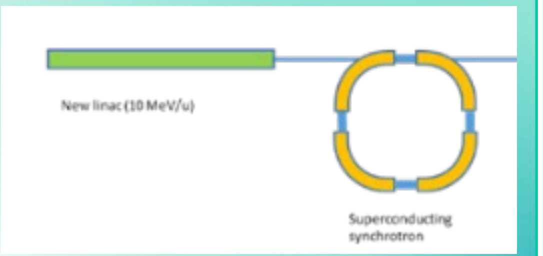
Improved synchrotron (superconducting)

Equipped with the same innovative features as warm, but additionally 90^0 superconducting magnets.

Circumference ~ 27 m



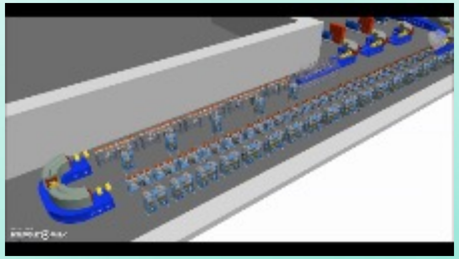
Courtesy: TERA

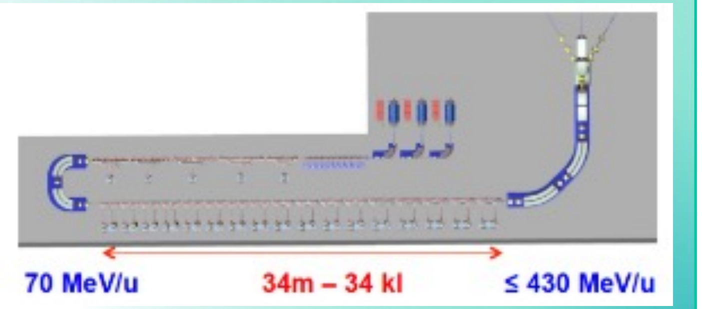


Linear accelerator

Linear sequence of accelerating cells, high pulse frequency.

Length ~ 53 m





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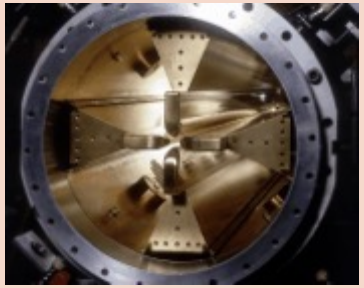
Protons:
the LINAC way

1990 RFQ2 200 MHz 0.5 MeV /m Weight :1200kg/m Ext. diametre : ~45 cm	2007 LINAC4 RFQ 352 MHz 1MeV/m Weight : 400kg/m Ext. diametre : 29 cm	2014 HF RFQ 750MHz 2.5MeV/m Weight : 100 kg/m Ext. diametre : 13 cm
		

Compact High-Frequency Radio Frequency Quadrupole (RFQ)

M. Vretenar, A. Dallocchio, V. A. Dimov, M. Garlaschè, A. Grudiev, A. M. Lombardi, S. Mathot, E. Montesinos, M. Timmins, "A Compact High-Frequency RFQ for Medical Applications", in Proc. LINAC2014, Geneva, Switzerland, September 2014

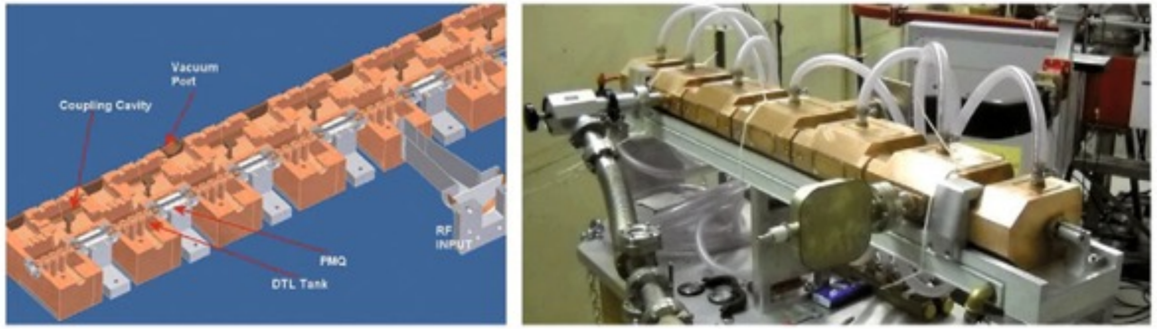
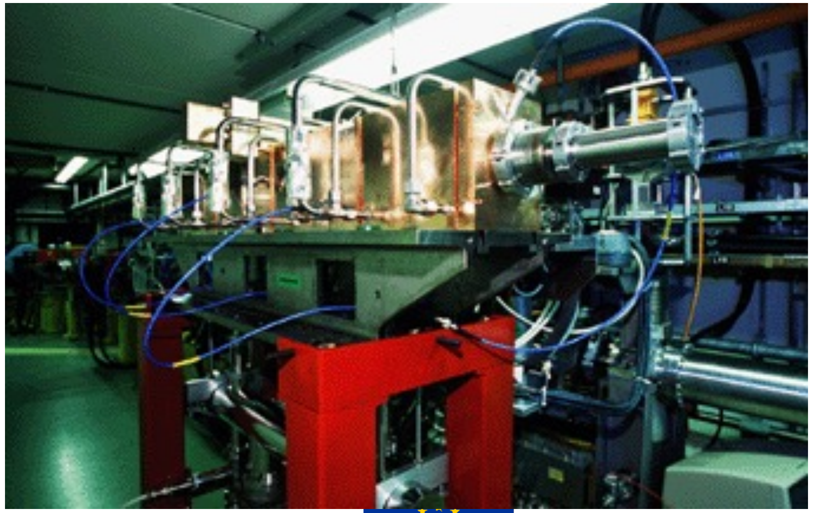


Fig. 4. TOP-IMPLART SCDTL structure: (left) schematic (right) 18–24 MeV booster built for the SPARKLE Company.

TOP IMPLART

C. Ronsivalle, M. Carpanese, C. Marino, G. Messina, L. Picardi, S. Sandri, E. Basile, B. Caccia, D.M. Castelluccio, E. Cisbani, S. Frullani, F. Ghio, V. Macellari, M. Benassi, M. D'Andrea, L. Strigari, The TOP-IMPLART project, Eur. Phys. J. Plus 126: 68 (2011) 1–15, http://dx.doi.org/10.1140/epjp/i2011-11068-x.

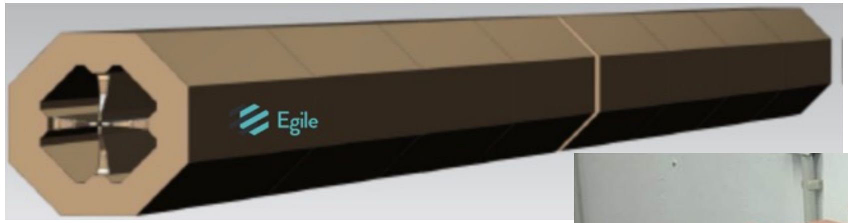


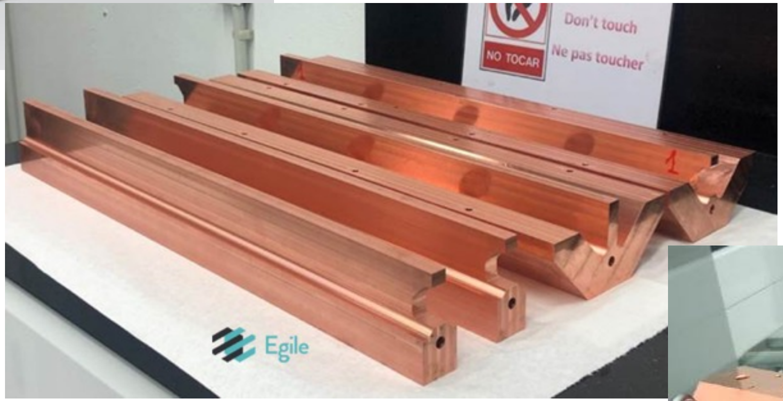
This project has received funding from the European Union's Horizon 2020

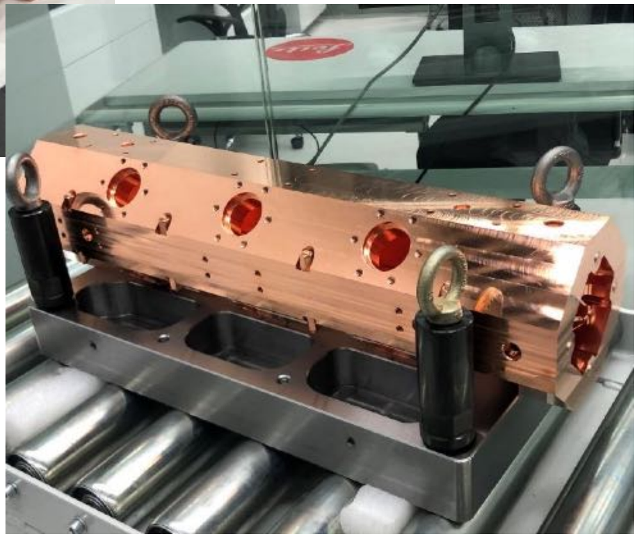
LInac BOoster (LIBO)

U. Amaldi et al., "LIBO-a linac booster for protontherapy: construction and test of a prototype," Nucl. Instrum. Meth- ods Phys. Res. A, vol. 521, pp. 512-529, 2004.

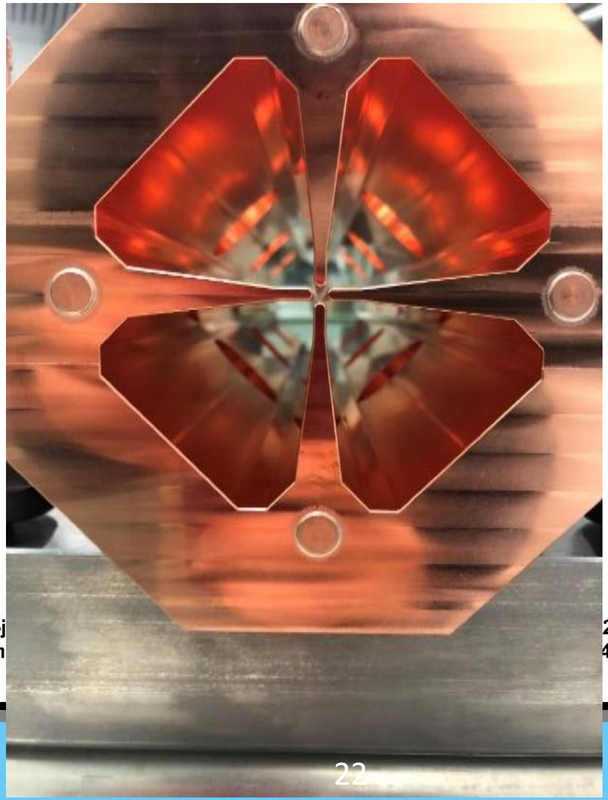
The RFQ for C^{6+} LINAC option







First (of 4 sections) completed



Collaboration CERN-CIEMAT-CDTI-Spanish industry
2.0 m long
750 MHz
Will deliver Carbon (or Helium) at 5 MeV (total energy)
Designed at CERN built in Spanish Industry

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This proj… research… 20 …48

FLASH therapy – a growing clinical interest

NATURE May 23, 1959 VOL. 183

Modification of the Oxygen Effect when Bacteria are given Large Pulses of Radiation

D. L. DEWEY
J. W. BOAG

Research Unit in Radiobiology,
British Empire Cancer Campaign,
Mount Vernon Hospital,
Northwood.

> Sci Transl Med. 2014 Jul 16;6(245):245ra93. doi: 10.1126/scitranslmed.3008973.

Ultrahigh dose-rate FLASH irradiation increases the differential response between normal and tumor tissue in mice

Vincent Favaudon [1], Laura Caplier [2], Virginie Monceau [3], Frédéric Pouzoulet [4], Mano Sayarath [4], Charles Fouillade [4], Marie-France Poupon [4], Isabel Brito [5], Philippe Hupé [6], Jean Bourhis [7], Janet Hall [4], Jean-Jacques Fontaine [2], Marie-Catherine Vozenin [8]

Affiliations + expand

PMID: 25031268 DOI: 10.1126/scitranslmed.3008973

In vitro studies suggested that sub-millisecond pulses of radiation elicit less genomic instability than continuous, protracted irradiation at the same total dose. To determine the potential of ultrahigh dose-rate irradiation in radiotherapy, we investigated lung fibrogenesis in C57BL/6J mice exposed either to short pulses (≤ 500 ms) of radiation delivered at ultrahigh dose rate (≥ 40 Gy/s, FLASH) or to conventional dose-rate irradiation (≤ 0.03 Gy/s, CONV) in single doses. The growth of human HBCx-12A and HEp-2 tumor xenografts in nude mice and syngeneic TC-1 Luc(+) orthotopic lung tumors in C57BL/6J mice was monitored under similar radiation conditions. CONV (15 Gy) triggered lung fibrosis associated with activation of the TGF-β (transforming growth factor-β) cascade, whereas no complications developed after doses of FLASH below 20 Gy for more than 36 weeks after irradiation. FLASH irradiation also spared normal smooth muscle and epithelial cells from acute radiation-induced apoptosis, which could be reinduced by administration of systemic TNF-α (tumor necrosis factor-α) before irradiation. In contrast, FLASH was as efficient as CONV in the repression of tumor growth. Together, these results suggest that FLASH radiotherapy might allow complete eradication of lung tumors and reduce the occurrence and severity of early and late complications affecting normal tissue.

020
548

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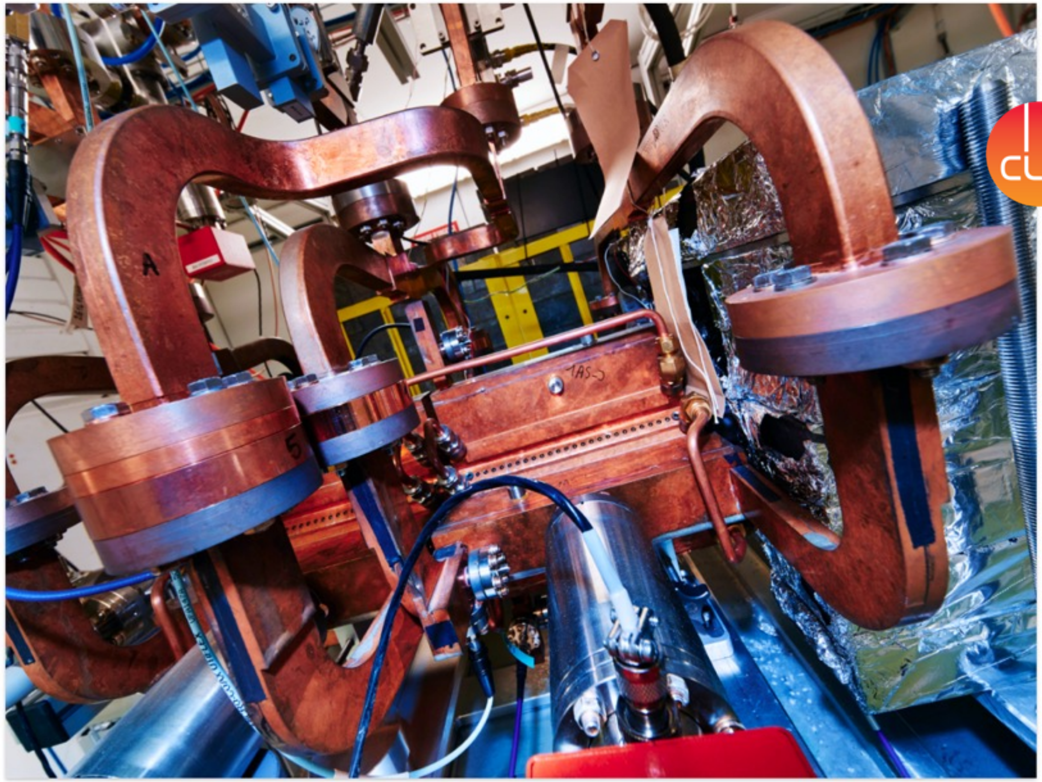
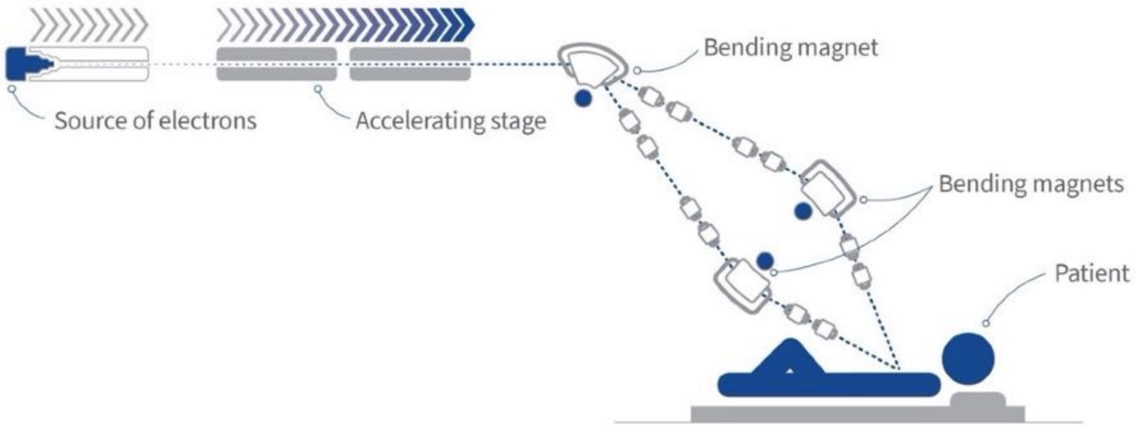
CERN – CHUV - THERYQ collaboration on FLASH VHEE therapy

CLIC technology for a FLASH VHEE facility designed in collaboration with CHUV and realized by THERYQ



Close-up of the Compact Linear Collider prototype, on which the electron FLASH design is based (Image: CERN)



An intense beam of electrons is produced in a photoinjector, accelerated to around 100 MeV and then is expanded, shaped and guided to the patient.

Jean Bourhis from CHUV:
“The clinical need that we have really converges with the technological answer that CERN has.”

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This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101008548

The remarkable connection between CLIC technology and FLASH electron therapy

Very intense electron beams

CLIC – to provide brightness needed for delicate physics experiments

FLASH – to provide dose fast for biological FLASH effect

Very precisely controlled electron beams

CLIC – to reduce the power consumption of the facility

FLASH – to provide reliable treatment in a clinical setting

High accelerating gradient (that is high beam energy gain per length)

CLIC – fit facility in Lac Leman region and limit cost

FLASH – fit facility on typical hospital campuses and limit cost of treatment

CERN KT Seminar on April 26th, 2021
https://indico.cern.ch/event/975980/

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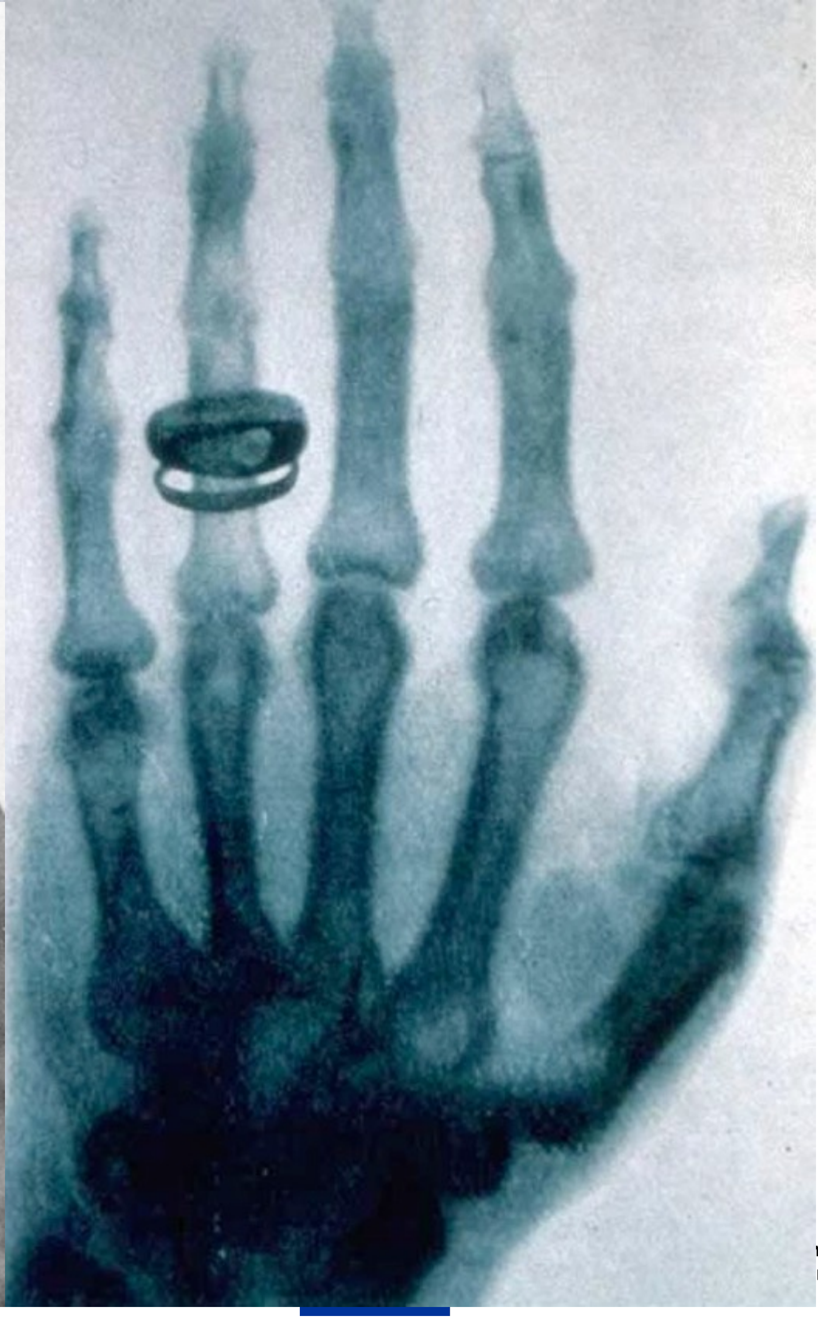
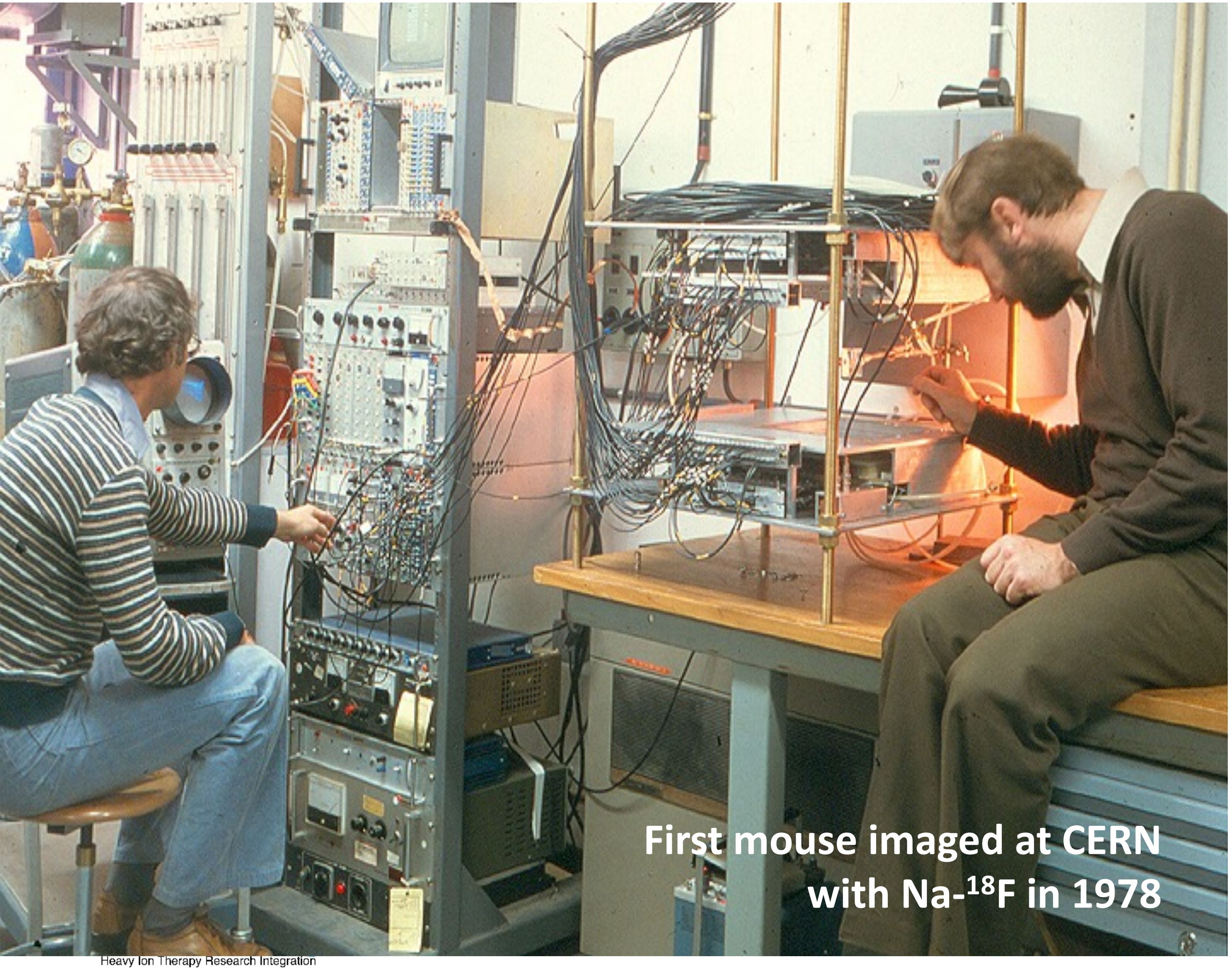
IMAGING



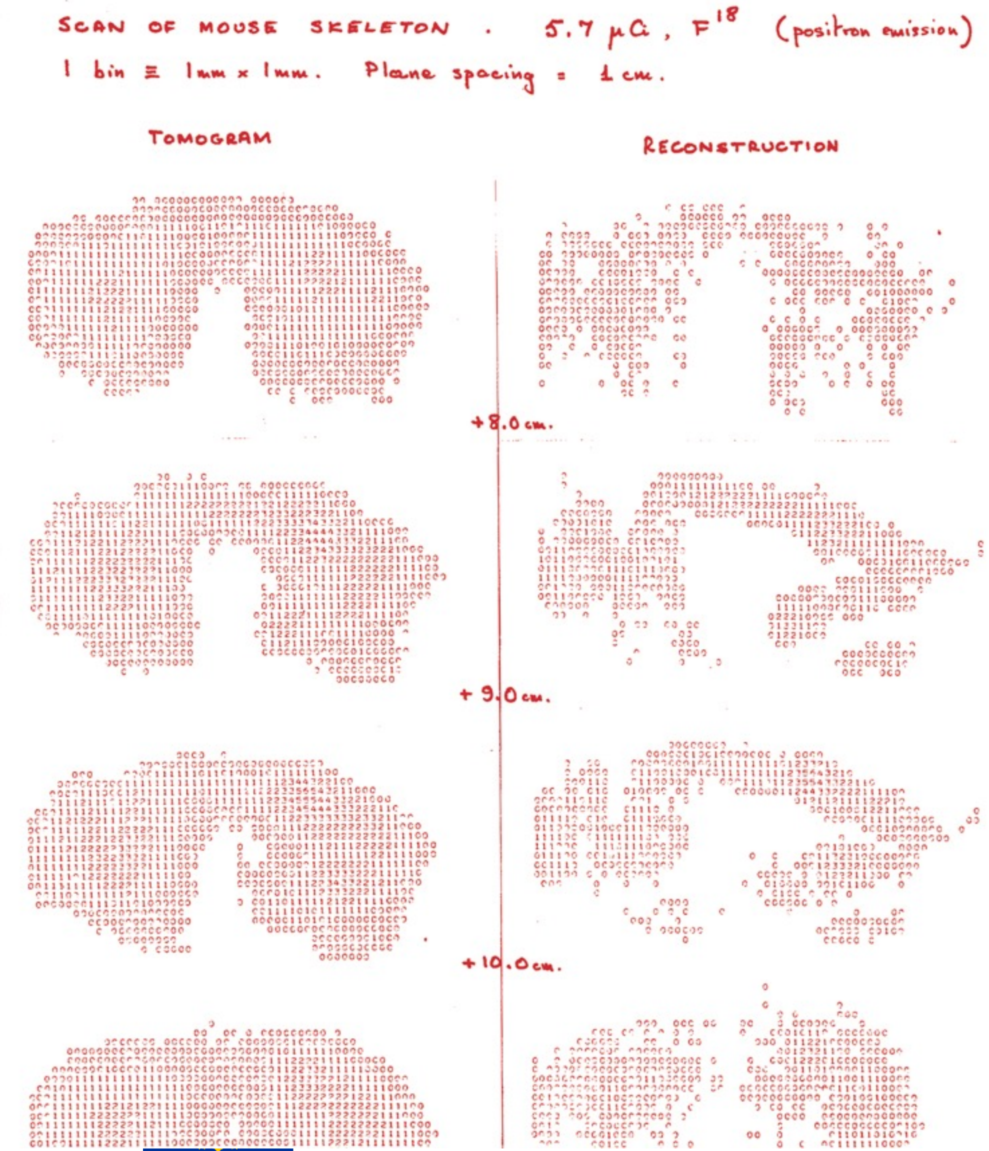
Heavy Ion Therapy Research Integration

…the European Union's Horizon 2020
…nder grant agreement No 101008548

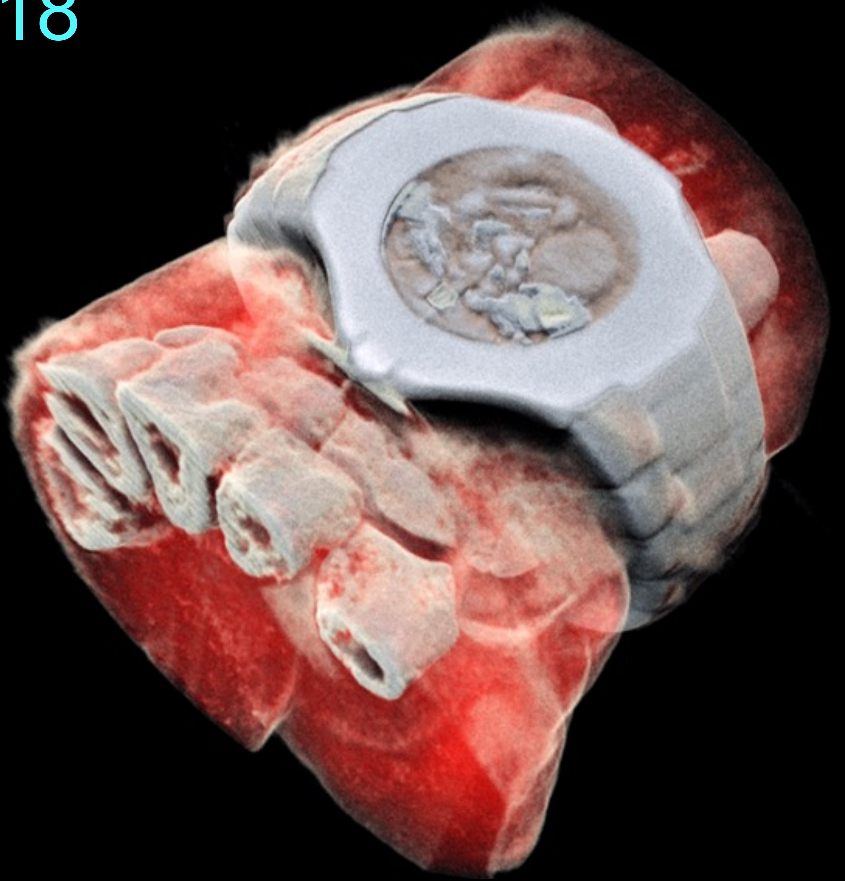
David Townsend, Alan Jeavons



First mouse imaged at CERN with Na-^{18}F in 1978

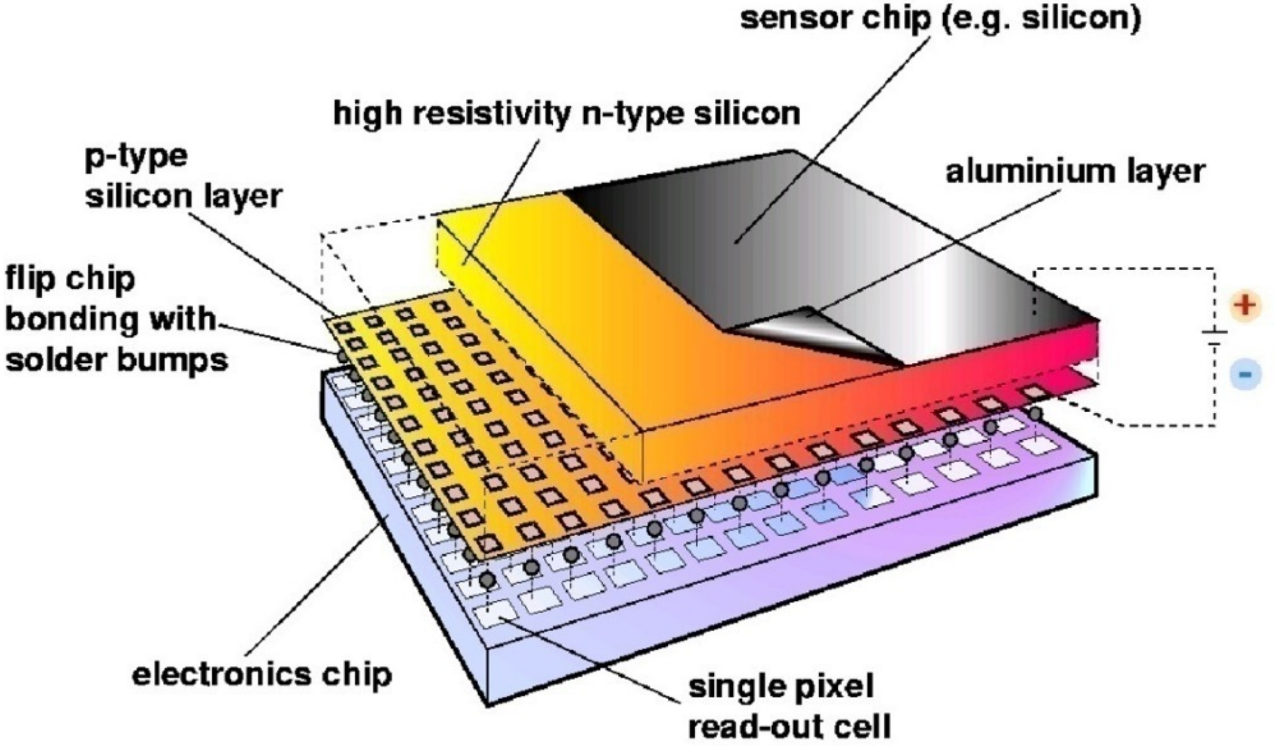


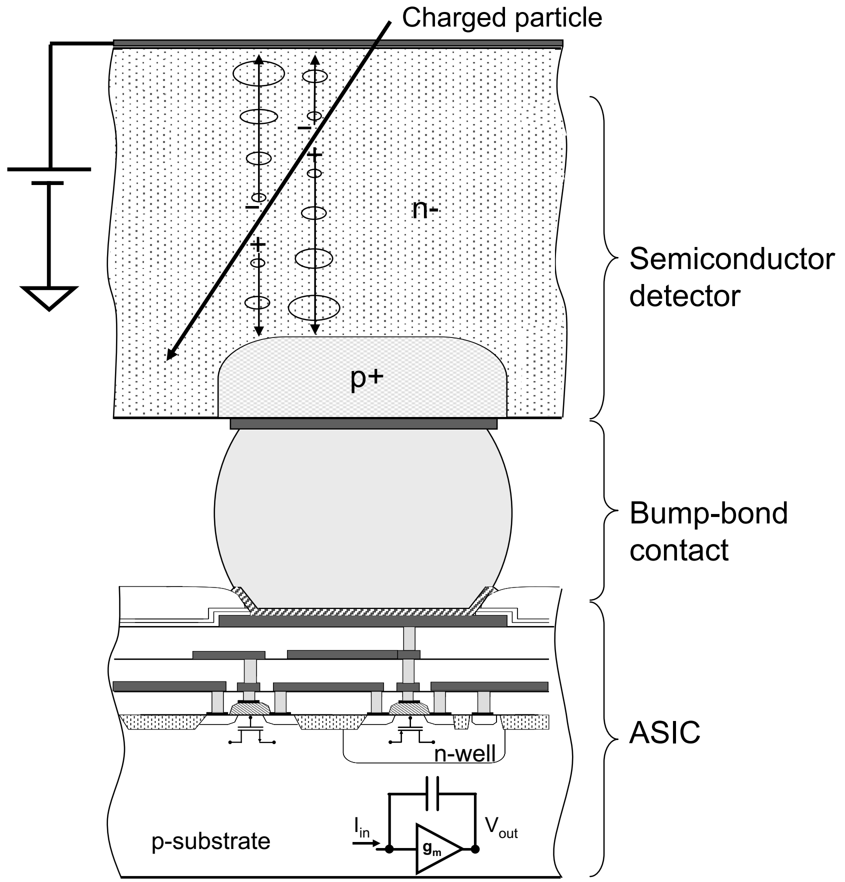
Fast forward to 2018



First 3D colour X-ray of human extremities using the Medipix3 technology developed at CERN

Hybrid Silicon Pixel Detectors





Noise-hit free particle detection

Standard CMOS can be used allowing on-pixel signal processing

Sensor material can be changed (Si, GaAs, CdTe..)

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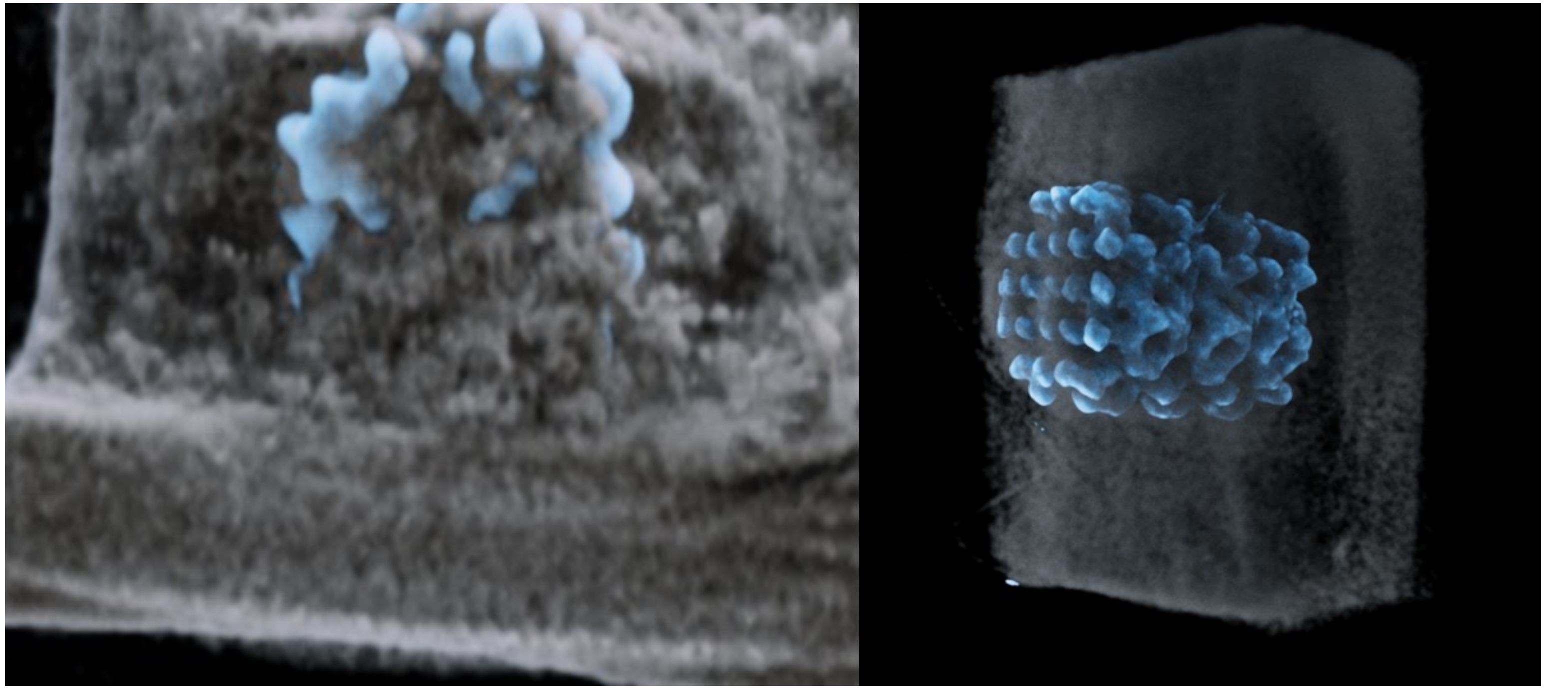
S. Procz et al.

This ... pean Union's Horizon 2020
rese ... nt agreement No 101008548

Spectral imaging of joints

Titanium implant in sheep bone



Enables better understanding of
- process of bone ingrowth
- bone / implant interface

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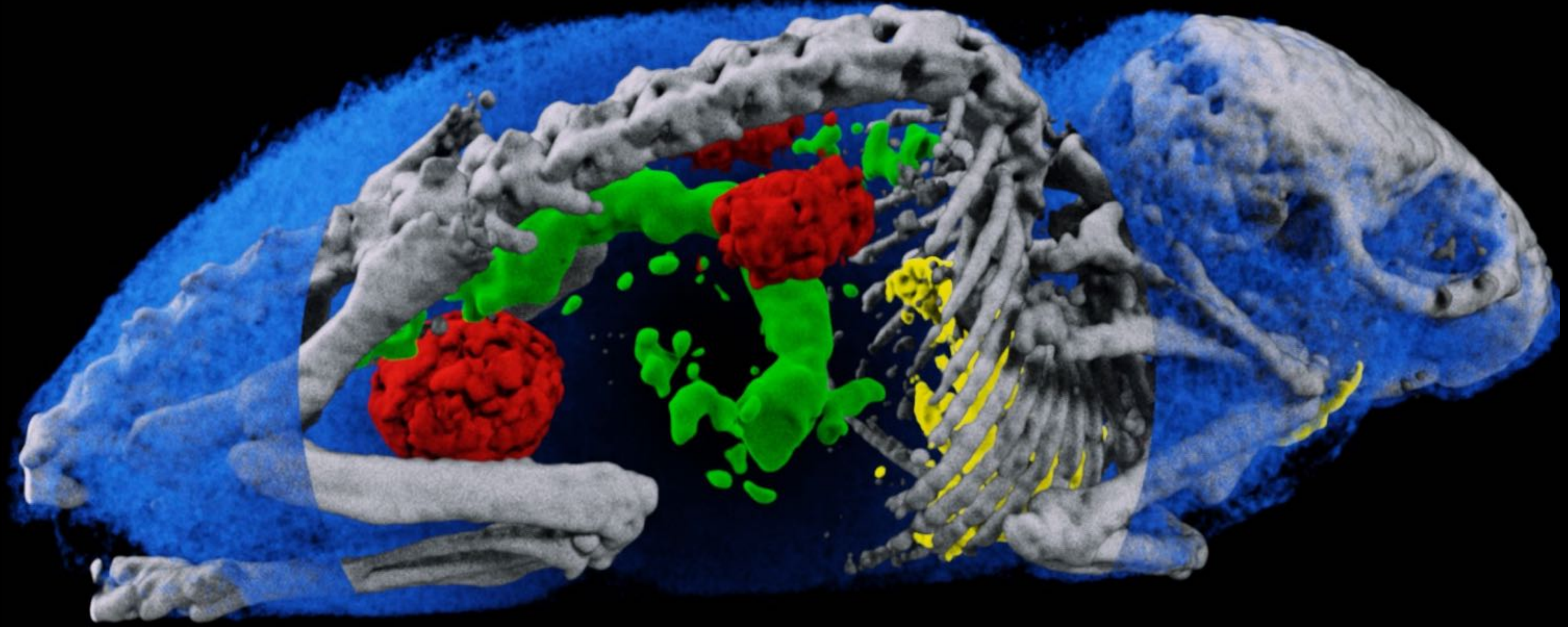
Slide courtesy of A. Butler, University of Otago, New Zealand and MARS Bio-Imaging

Spectroscopic information permits material separation

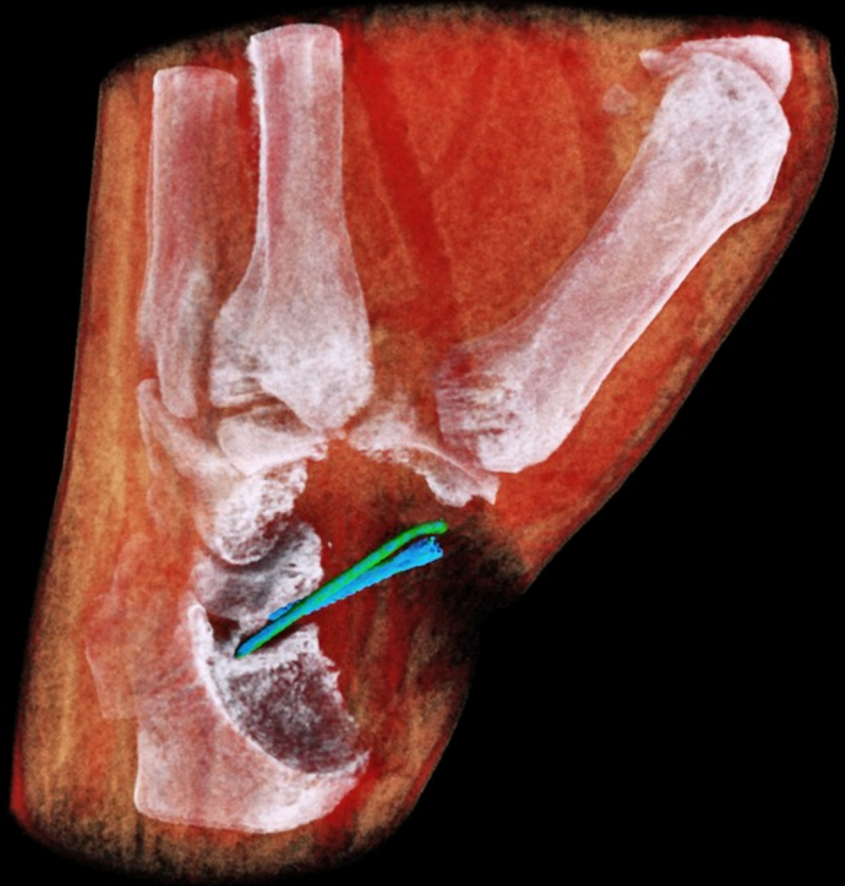


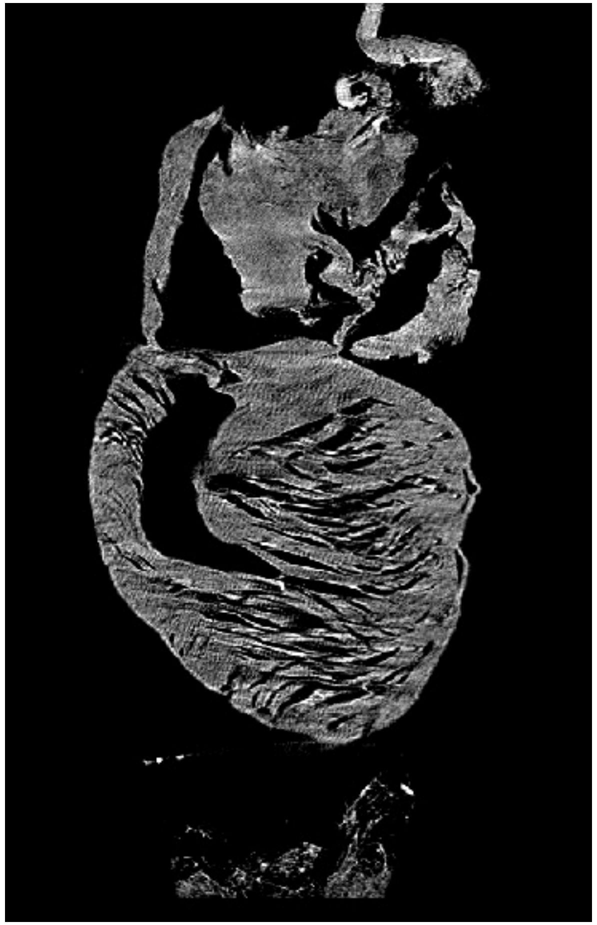
The water has been partly cut away to reveal the bone, gold, gadolinium and iodine

Images presented at the European Congress of Radiology, Vienna, March 2017.

A. Butler, University of Canterbury

Spectral CT image showing wrist implant





Ethanol-preserved mouse heart scanned using the WidePIX$_{10x5}$ detector
60 kVp tungsten spectrum
720 projections, 5 seconds per projection (one hours total)
Spatial resolution ca. 7 µm
Reconstructed using Volex, visualized using CTVox and Amide software

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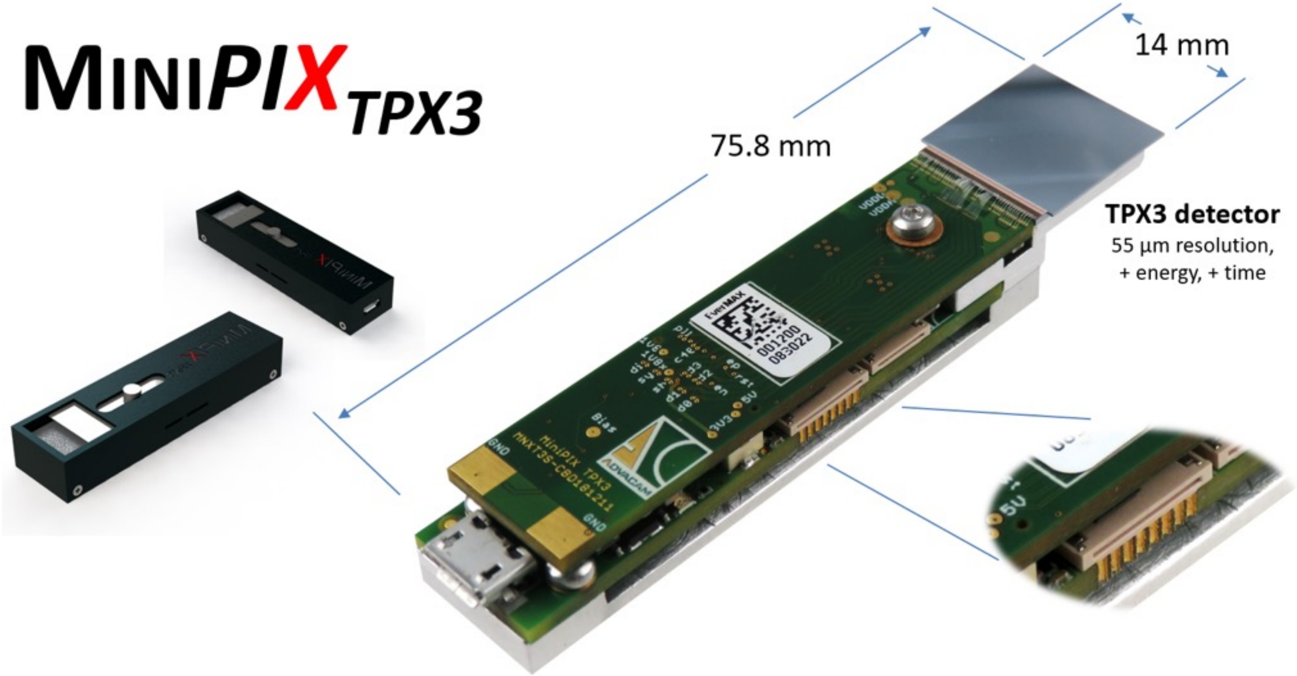
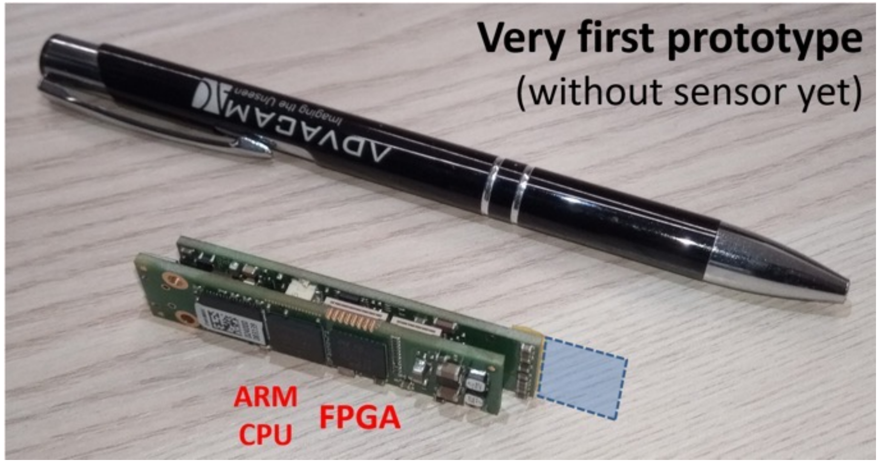
Slide courtesy of J. Dudak, IEAP, Czech Technical University

MiniPIX TPX3

Miniaturized spectral camera supporting Si and CdTe sensors



It's really small...



ADVACAM
Imaging the Unseen

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Gamma camera applications: Thyroid diagnostic

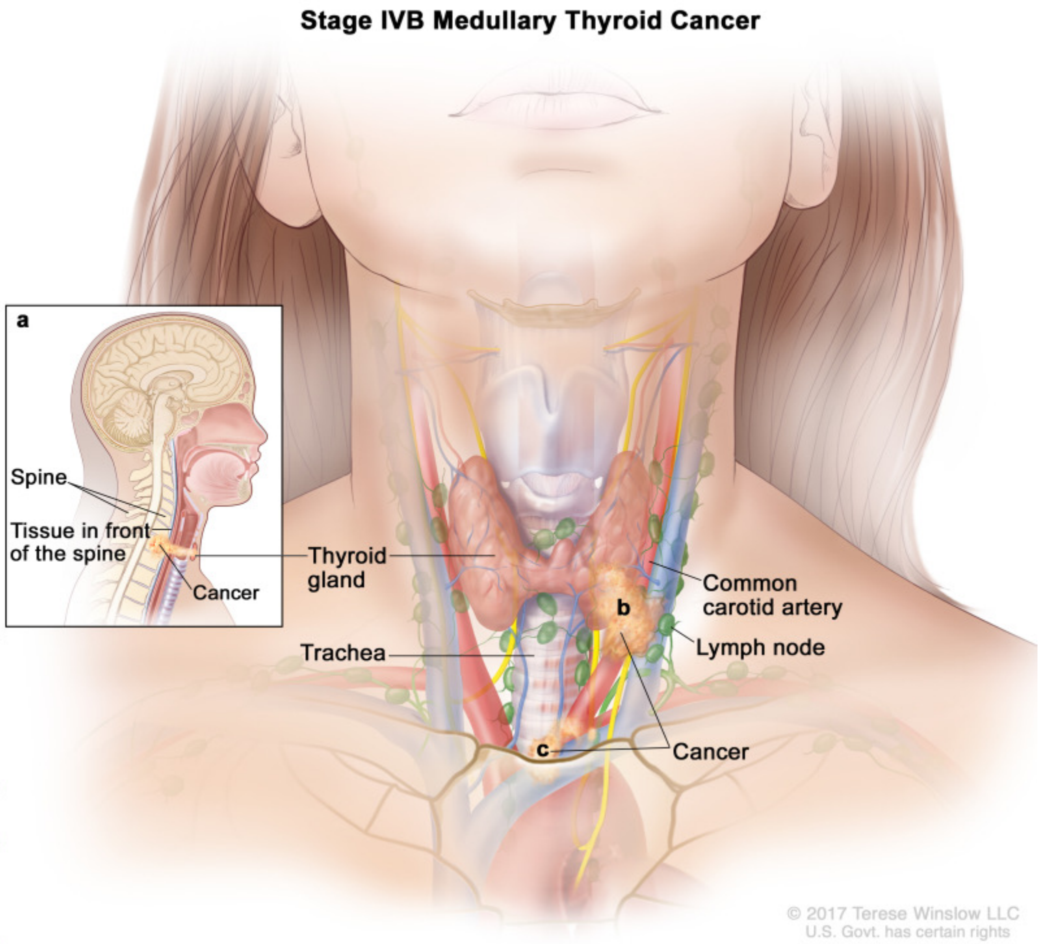
Thyroid cancer diagnostics and treatment monitoring:

The second most frequent cancer for women (after breast can

Current imaging methods offer resolution of about 12 mm in 2

This technology allows

- 5 times better resolution and 3D (2.5 mm)
- 4 times lower dose



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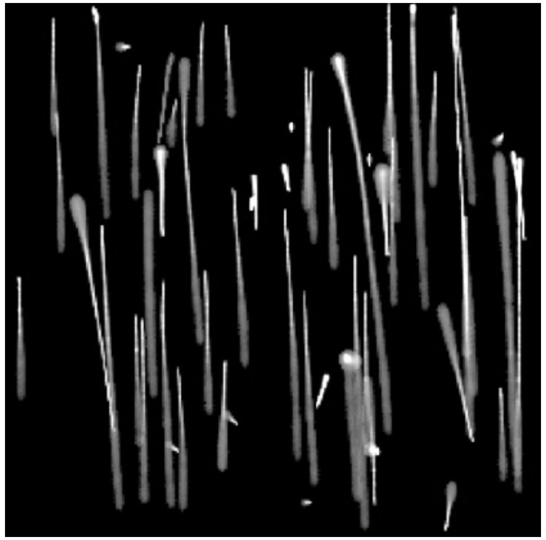
In-line images of a hadron therapy beam

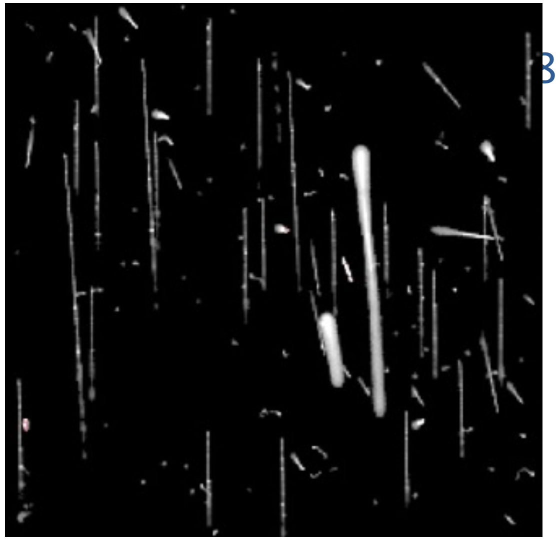
Protons 221 MeV

Carbons 89 MeV/u

Carbons 430 MeV/u

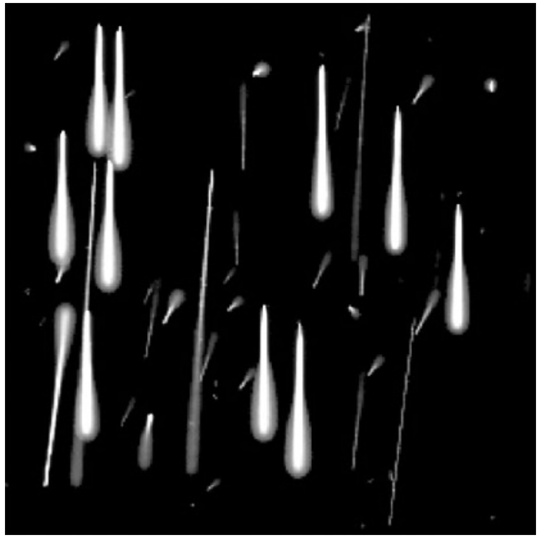


Only protons and their scattering, no secondaries.

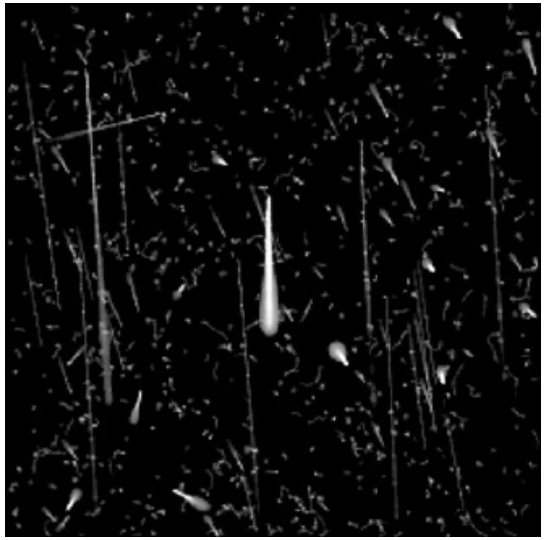


3 MeV

Many secondaries, (delta electrons fragments).



Carbons and protons and their scattering, no secondaries.



Carbons and many secondaries.

Timepix chip combined with Si detector

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Slide courtesy Jan Jakůbek (IEAP, Prague)

TimePIX 3 photon fluence measurement in hospital theatres

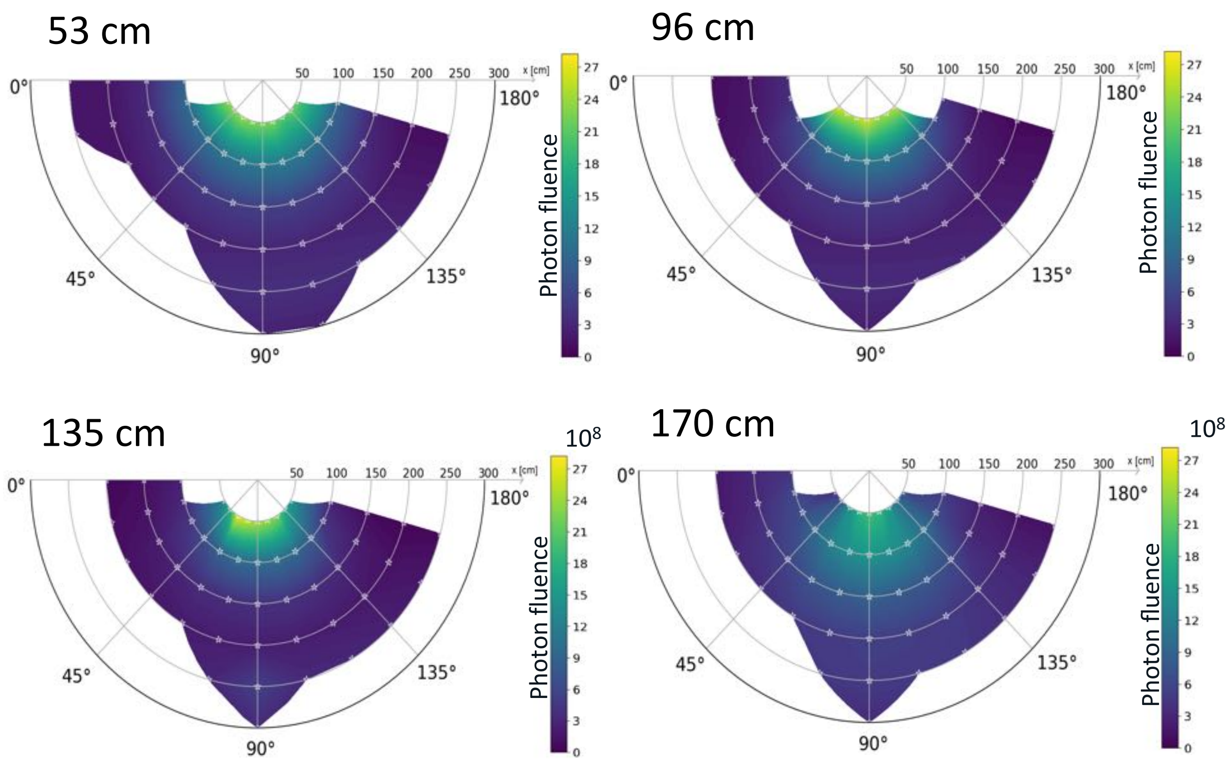
Reference person: 1.76 m

Eye lens - 170 cm

Chest - 135 cm

Belt - 96 cm

Knee - 53 cm



Colour maps of the photon fluence measured with a Timepix III in an hospital theatre at four horizontal eights.

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Courtesy of M. Nowak

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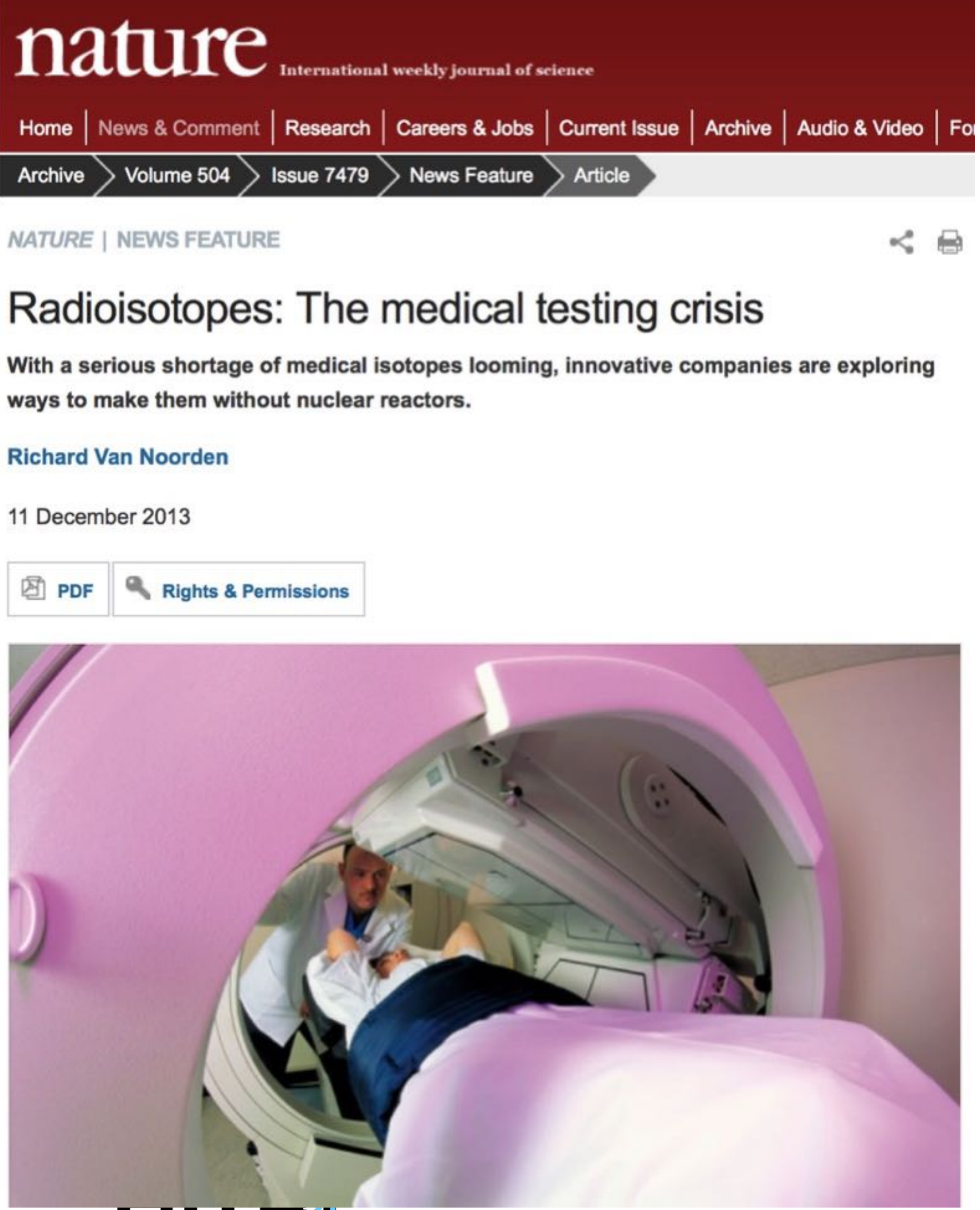
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Archive > Volume 504 > Issue 7479 > News Feature > Article

NATURE | NEWS FEATURE

Radioisotopes: The medical testing crisis

With a serious shortage of medical isotopes looming, innovative companies are exploring ways to make them without nuclear reactors.

Richard Van Noorden

11 December 2013

PDF | Rights & Permissions

Radioisotopes & Nuclear Medicine

Classification of isotopes for Medicine:

1. Established isotopes → Industrial suppliers
^{99m}Tc, ^{18}F, ^{123,125,131}I, ^{111}In, ^{90}Y

2. Emerging isotopes → Small innovative suppliers
^{68}Ga, ^{82}Rb, ^{89}Zr, ^{177}Lu, ^{188}Re

3. R&D isotopes → Research labs
^{44,47}Sc, ^{64,67}Cu, ^{134}Ce, ^{140}Nd, $^{149, 152, 155, 161}$Tb, ^{166}Ho, ^{195m}Pt, ^{211}At, $^{212, 213}$Bi, ^{223}Ra, ^{225}Ac,…

Courtesy U. Koester

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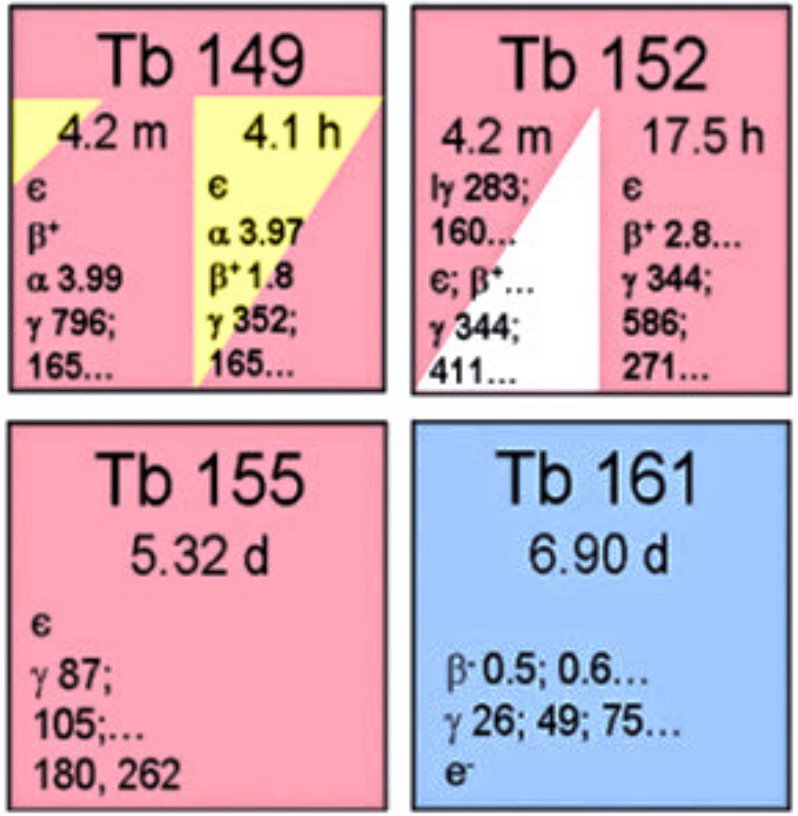
ramme under grant agreement No 101008548

Theranostics



A Unique Matched Quadruplet of Terbium Radioisotopes for PET and SPECT and for α- and β⁻-Radionuclide Therapy: An In Vivo Proof-of-Concept Study with a New Receptor-Targeted Folate Derivative
Cristina Müller, Konstantin Zhernosekov, Ulli Köster, Karl Johnston, Holger Dorrer, Alexander Hohn, Nico T. van der Walt, Andreas Türler and Roger Schibli
Journal of Nuclear Medicine December 2012, 53 (12) 1951-1959; DOI: https://doi.org/10.2967/jnumed.112.107540

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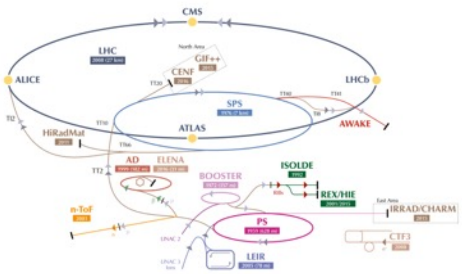
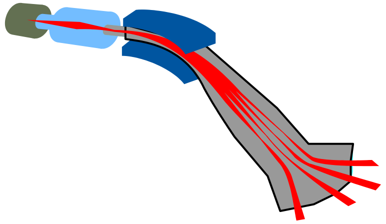
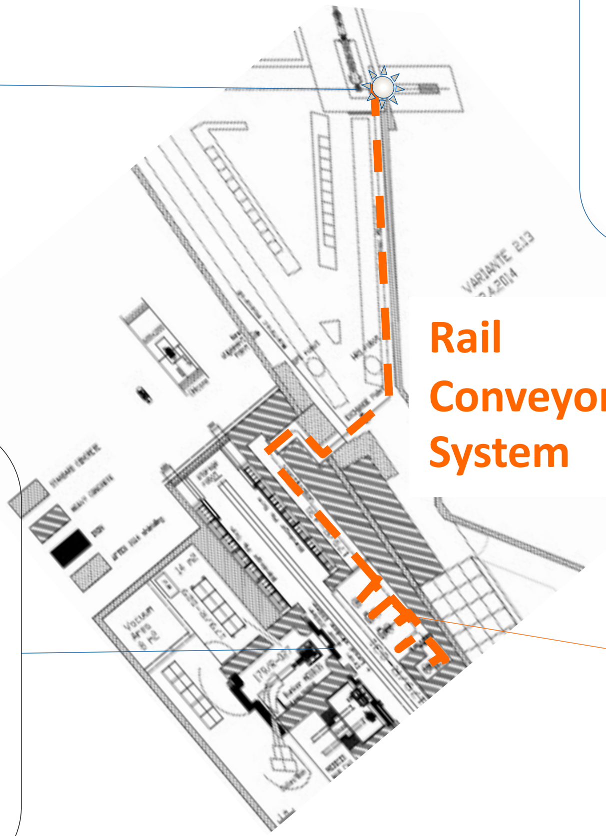
Principle of isotope production

CERN protons



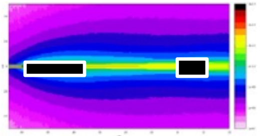
MEDICIS Laboratory





Rail Conveyor System

MEDICIS Target Irradiation



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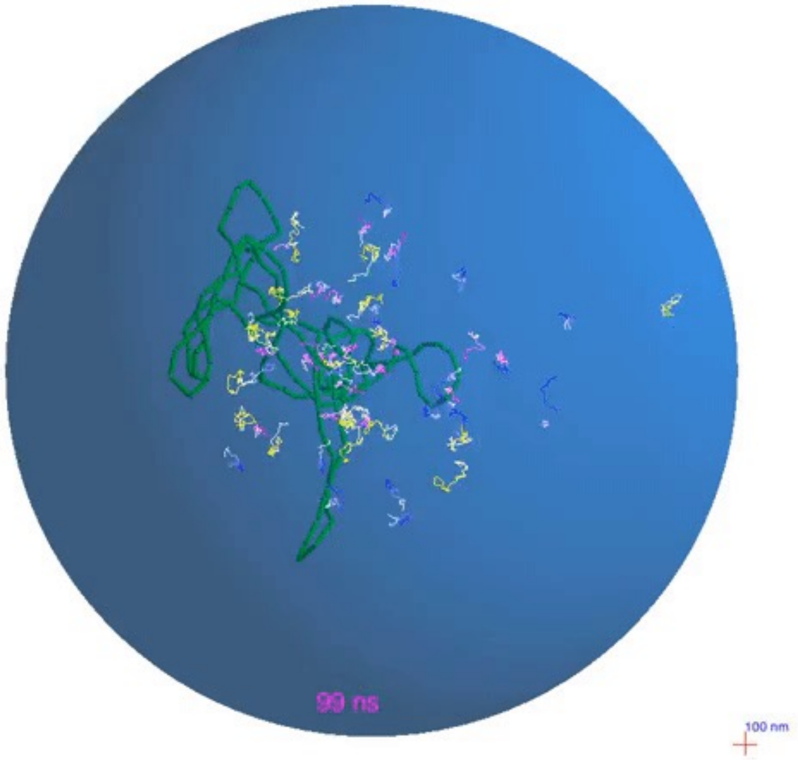
Digital Technologies

HITRI plus
Heavy Ion Therapy Research Integration

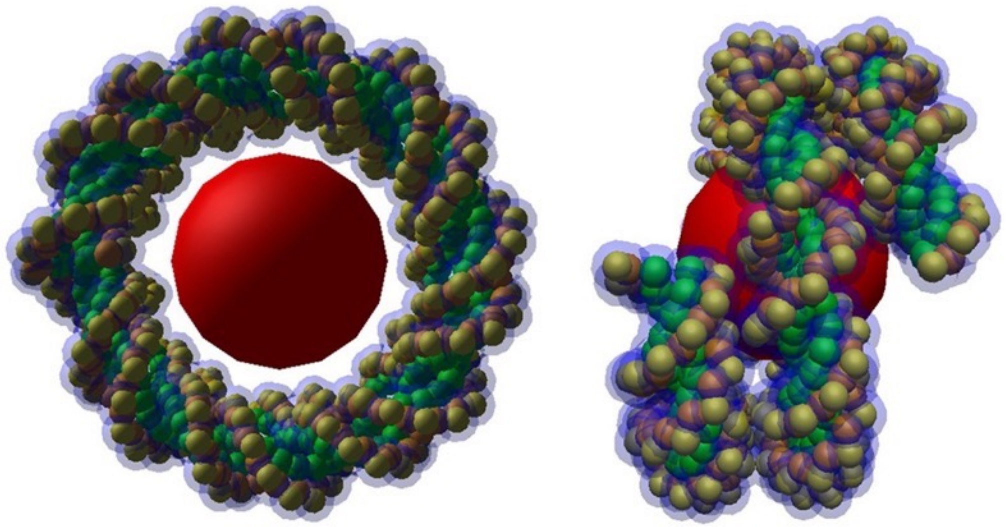
the European Union's Horizon 2020
der grant agreement No 101008548

Geant4-DNA applications

Simulation using Geant4-DNA of irradiation of a pBR322 plasmid, including radiolysis



- movie courtesy of V. Stepan (NPI-ASCR/CENBG/CNRS/IN2P3/ESA



Model of nucleosome created using DnaFabric*, imported into Geant4 to model irradiation, repair mechanisms.

* S. Meylan et al, Comp. Phys. Comm. 204 (2016) p159

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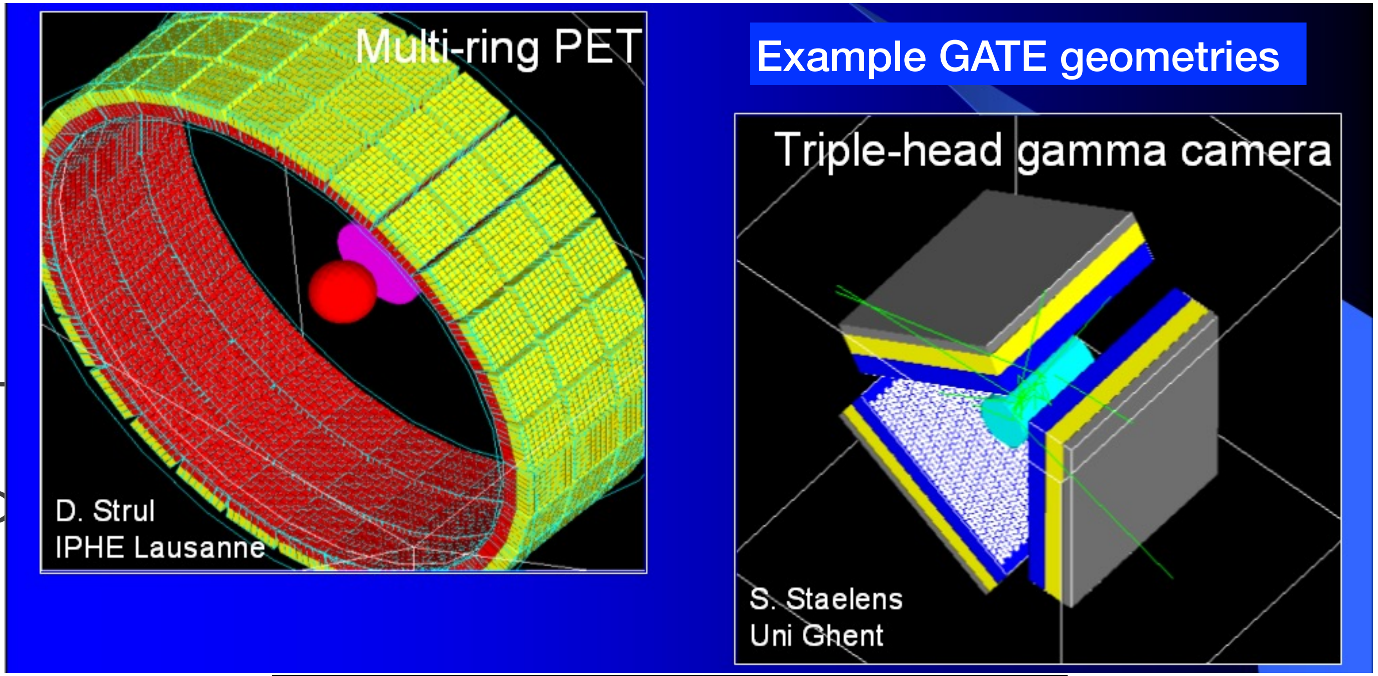
Tools for specific applications

based on Geant4

Tools provide specific capabilities for crea

- create setup, steer simulation via 'text c
- output adapted for application-area

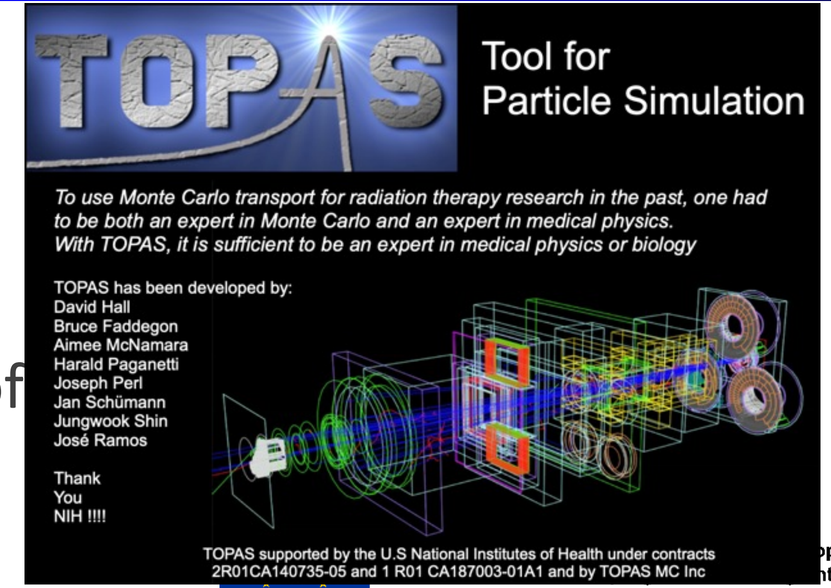


GATE (FR, DE, GR, PL, AT) - PET/SPECT,

TOPAS (US) - protontherapy

GAMOS (ES) - for nuclear medicine applications

Developed by external parties - using capabilities of



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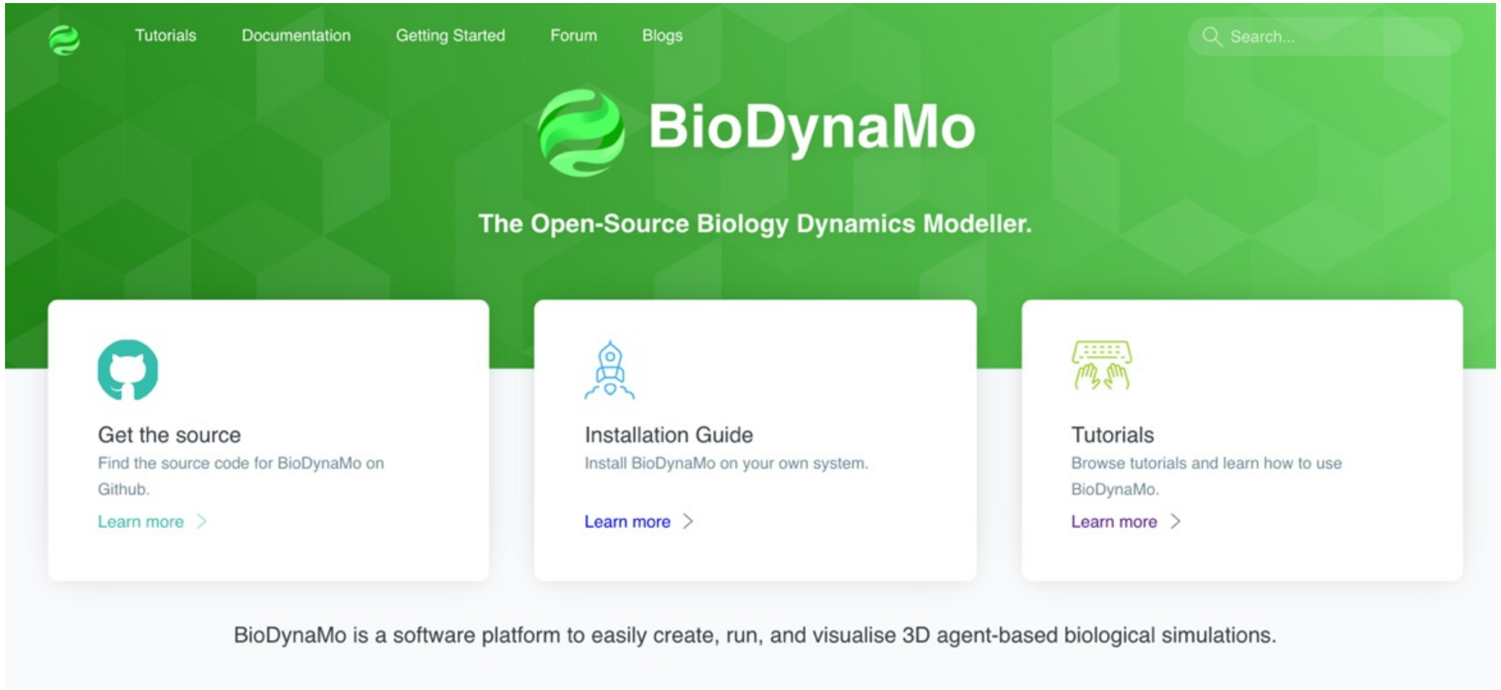
...t agreement No 101008548

BioDynaMo: An open-source software framework



An open-source software platform to easily create, run, and visualise 3D agent-based simulations, built up around CERN-developed technologies

Newcastle University
CERN
University of Cyprus
GSI
Scimpulse foundation
UNIVERSITÉ DE GENÈVE
UNIVERSITY OF SURREY
Statistics Netherlands
ImmunoBrain Checkpoint

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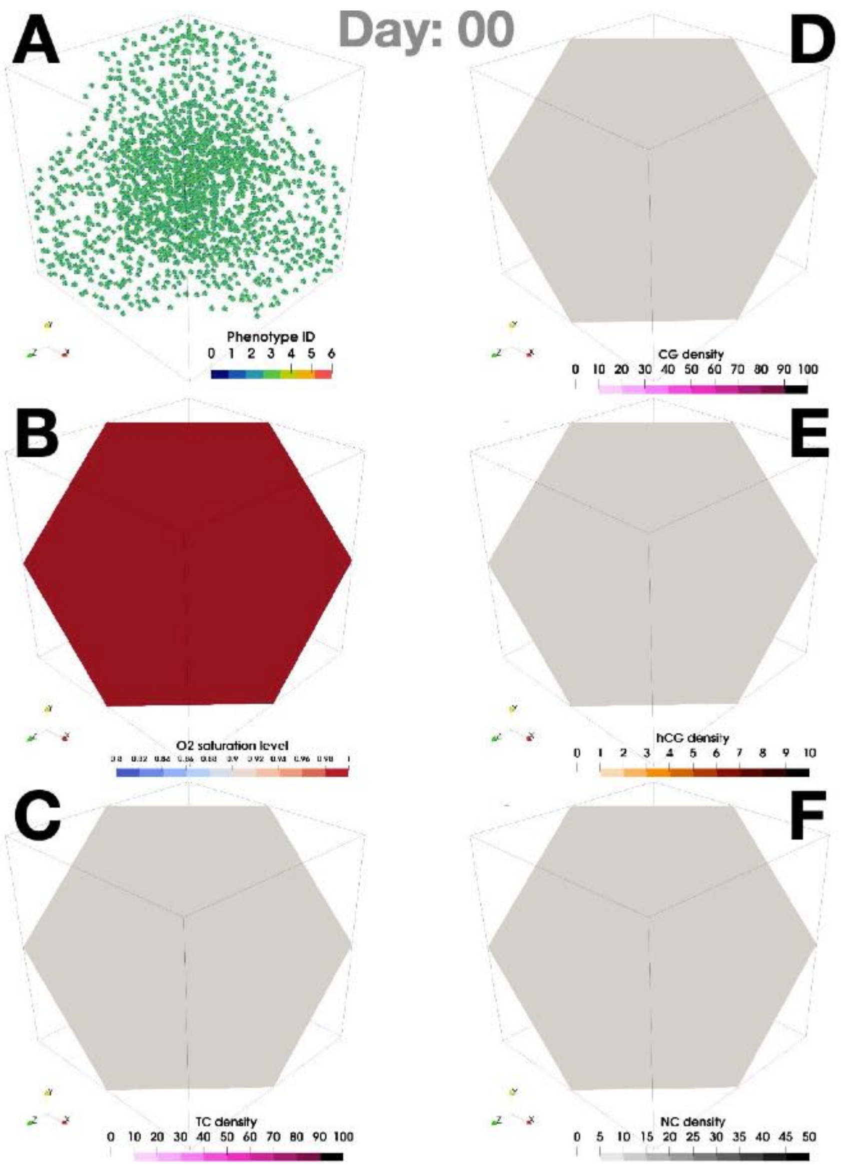
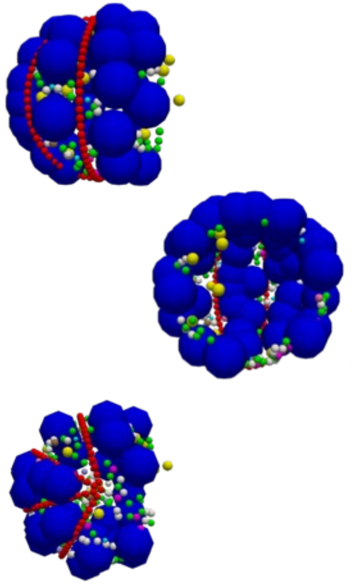
www.biodynamo.org

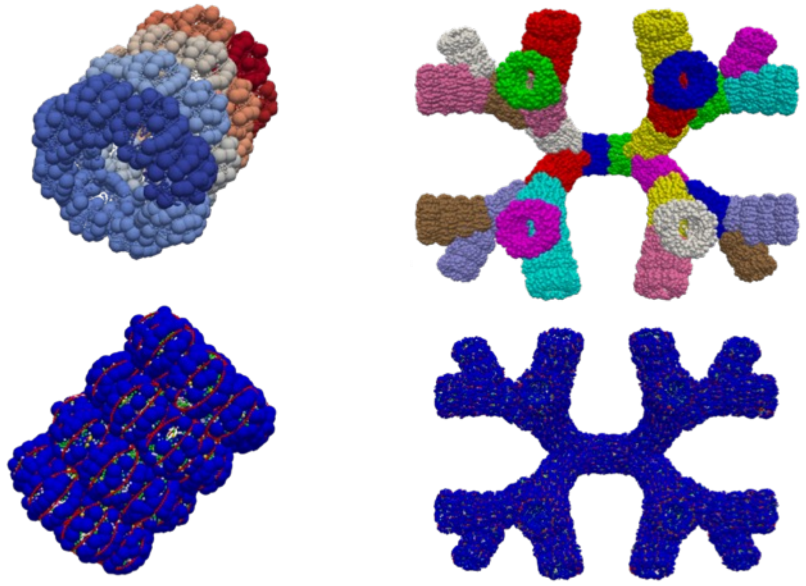
research and innovation programme



From De Montigny et al., Methods, 2020

BIODYNAMO
BIOLOGY DYNAMICS MODELLER





Courtesy Nicolo Cogno, TU Darmstadt (Germany)

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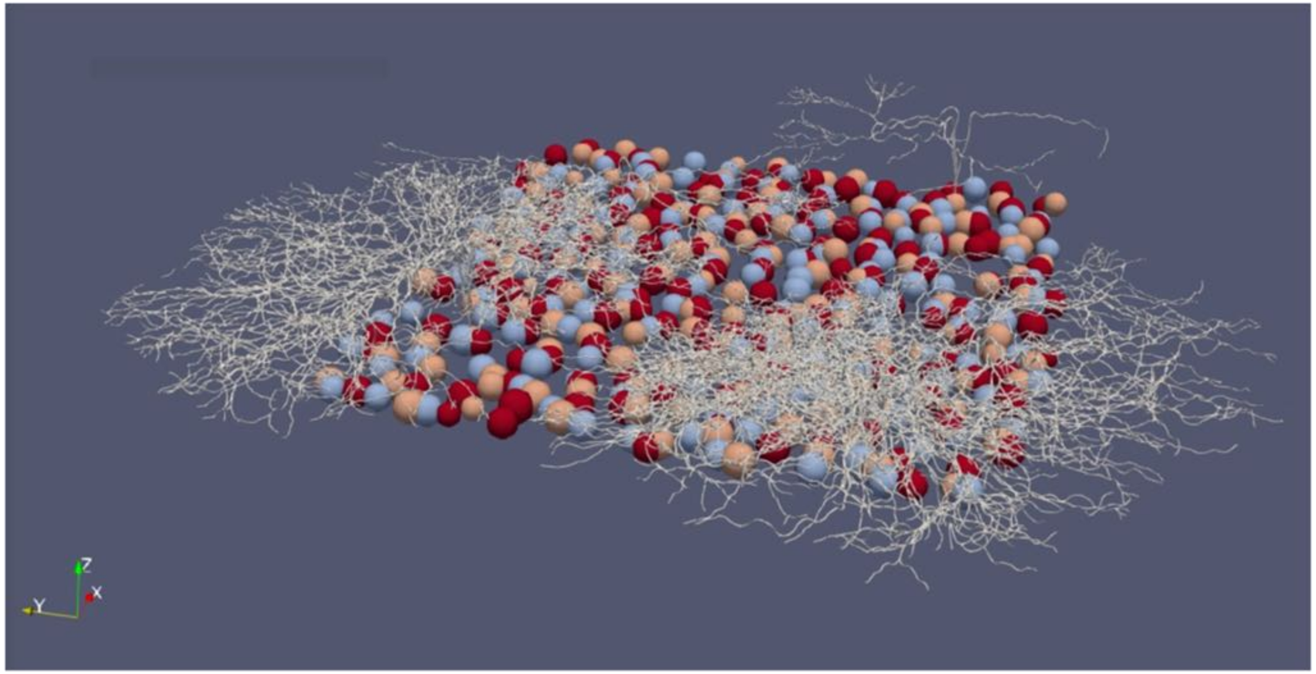
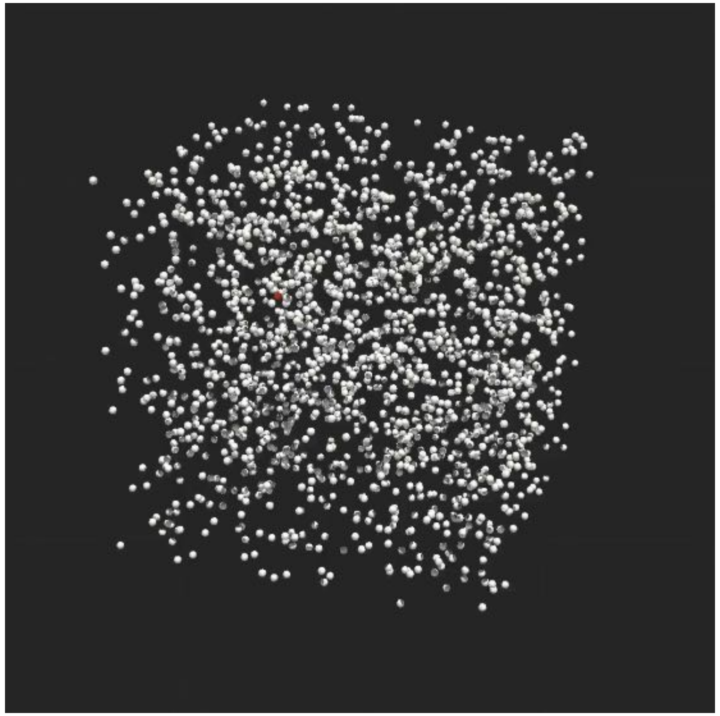


Courtesy Jean de Montigny and Roman Bauer



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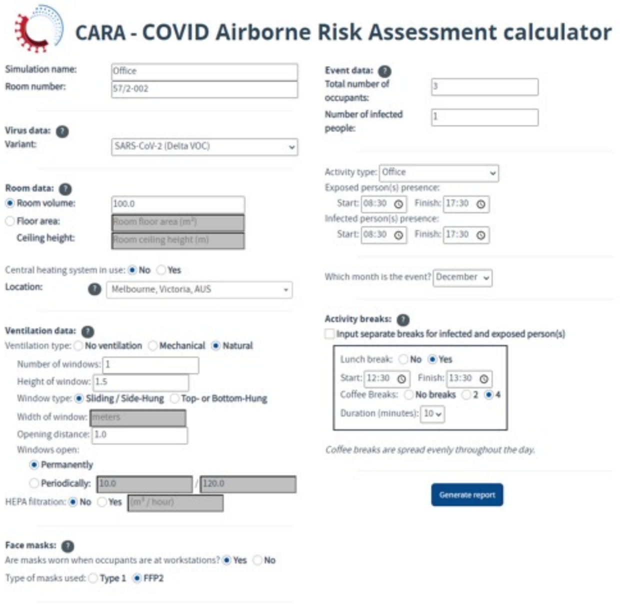
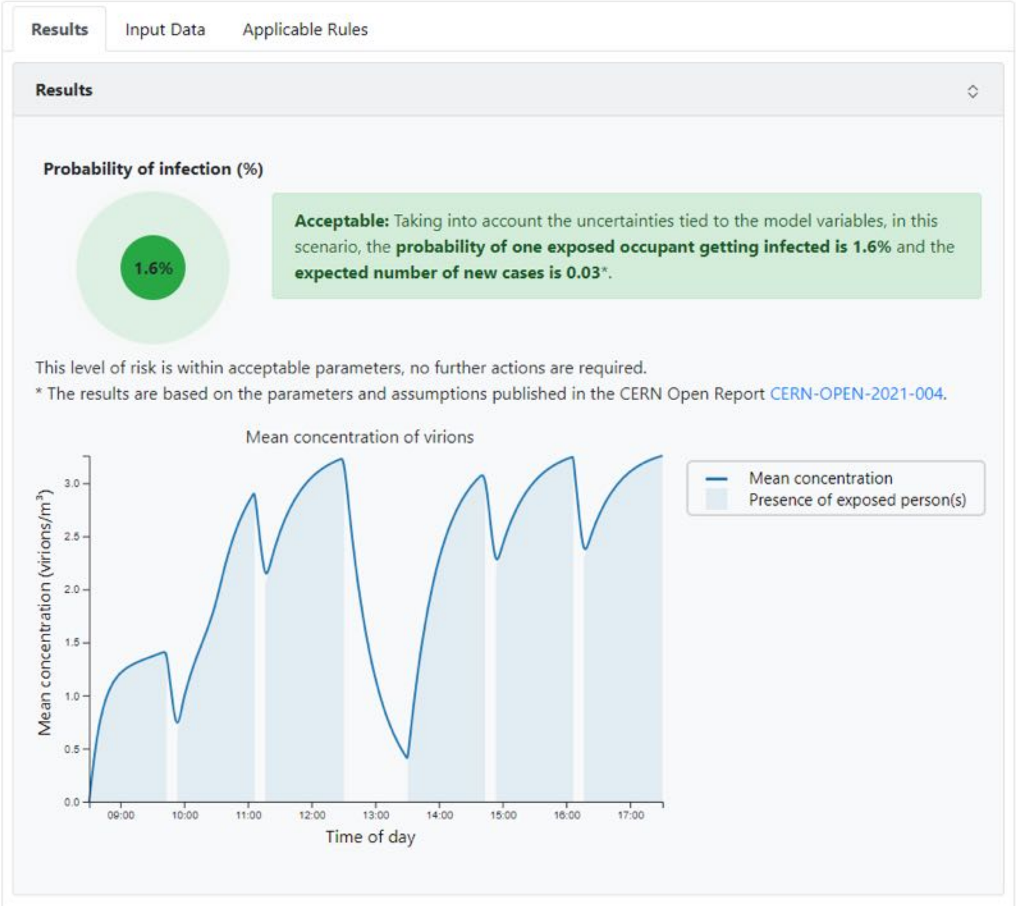
COVID Airborne
Risk Assessment



Developed by CERN personnel to assess the COVID airborne risk in indoor spaces with a risk-based approach.

Includes hourly fluctuations in outdoor temp (GVA data) and detail window modelling for natural ventilation, complex occupancy and ventilation profiles.



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Andre Henriquez (CERN)

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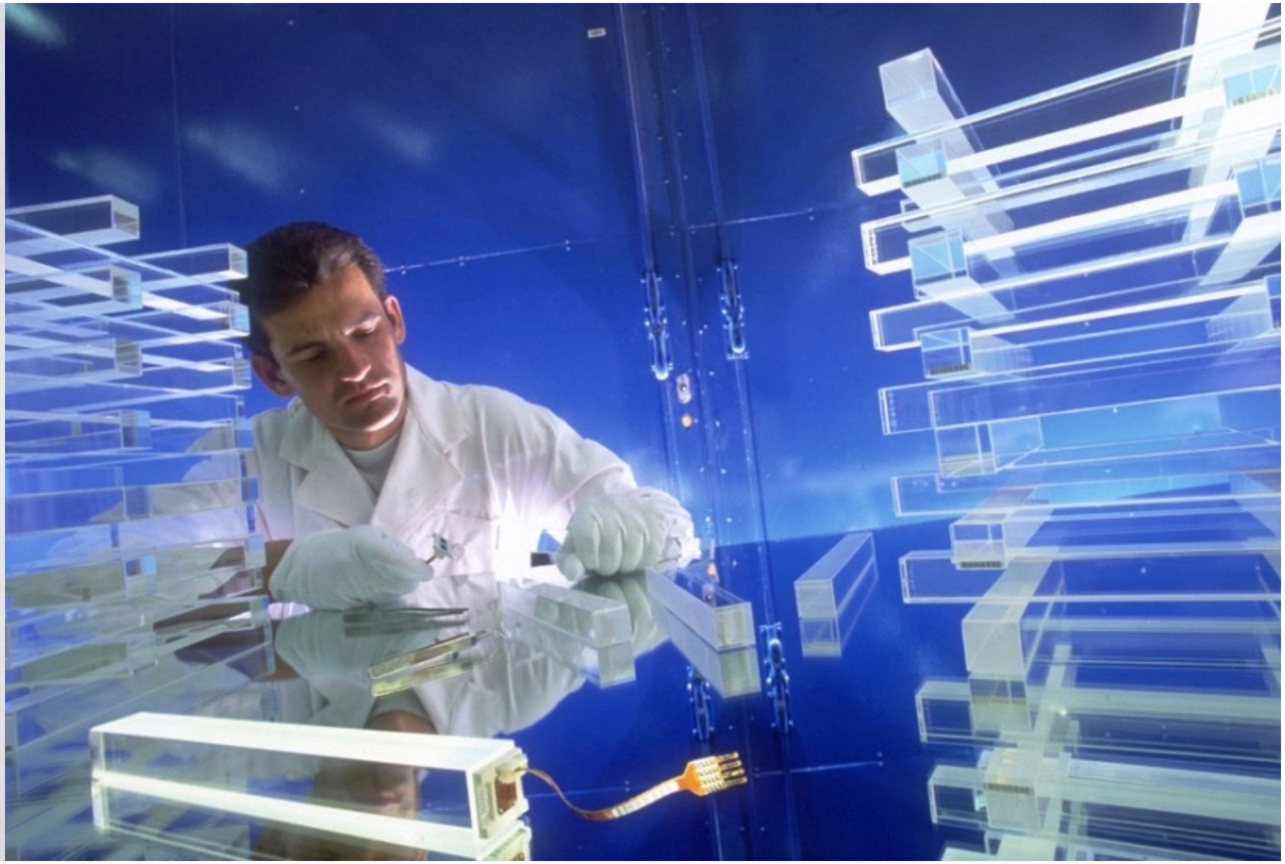
From HEP to society:
a **long and winding road…**

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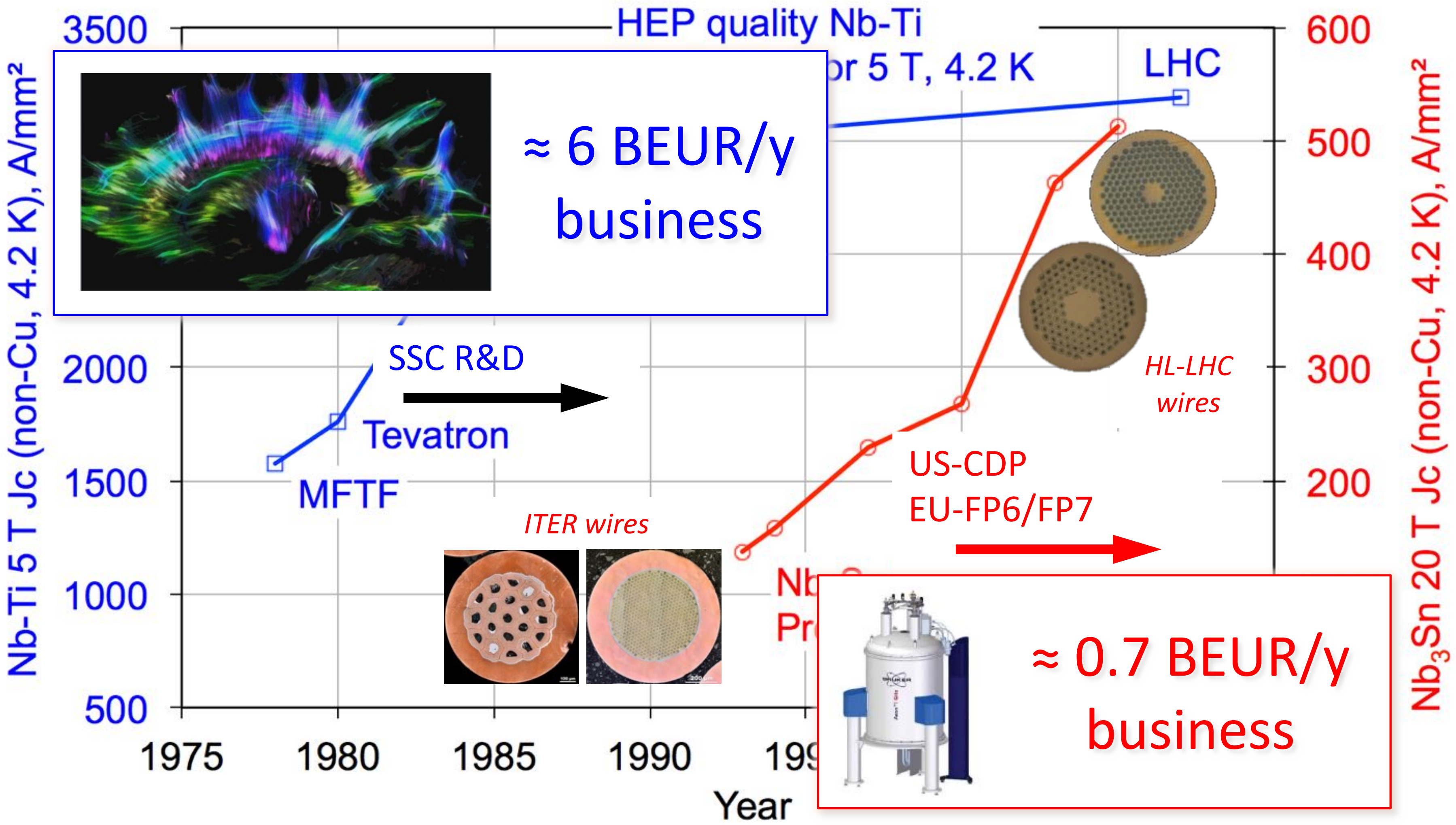

On the unreasonable request of high J_C

Courtesy Luca Bottura (CERN)

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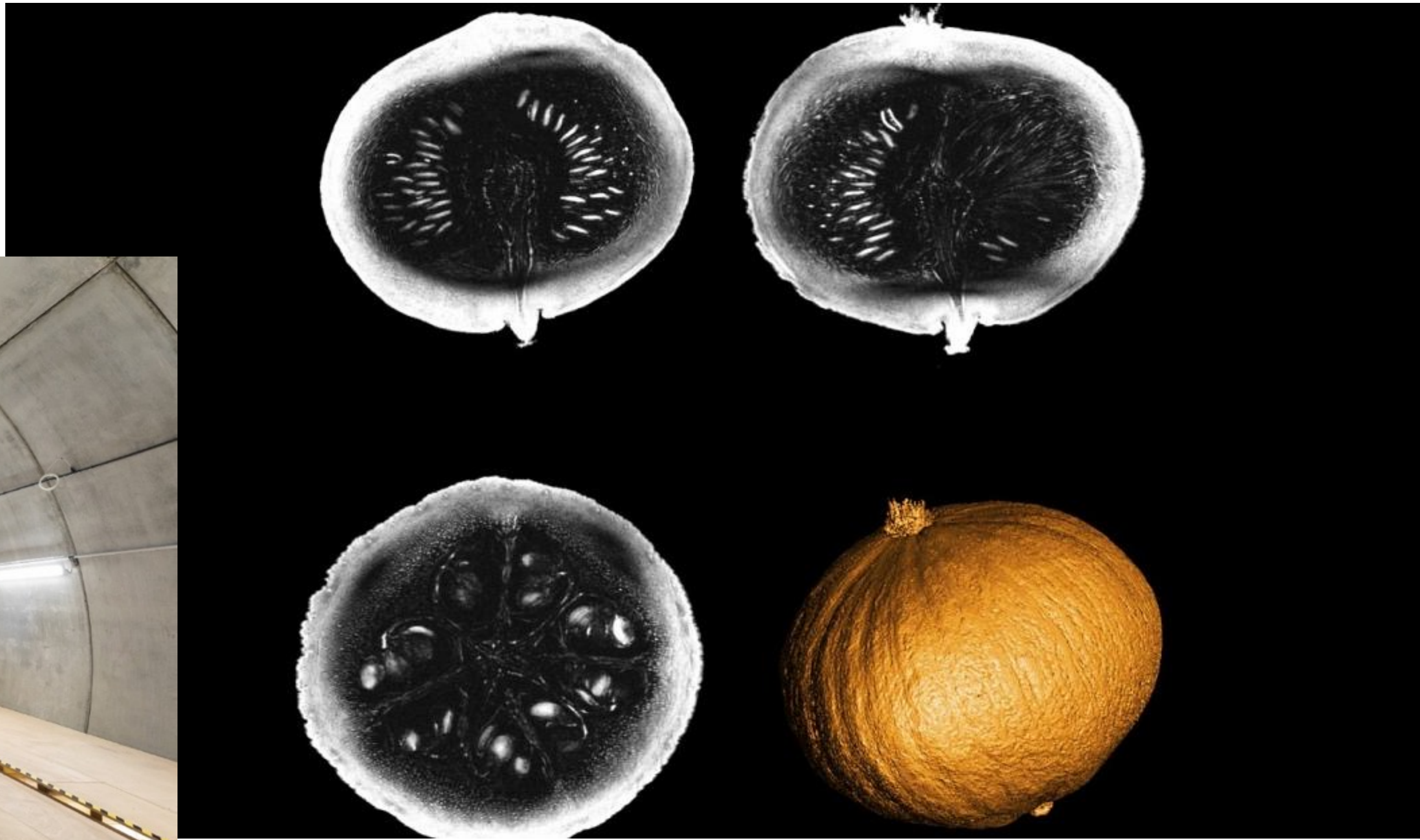
The ISEULT whole body 11.7 T MRI magnet

The ISEULT magnet -
a French-German initiative

Full field of 11.72 teslas achieved on July 18, 2019



First images released Oct. 7, 2021

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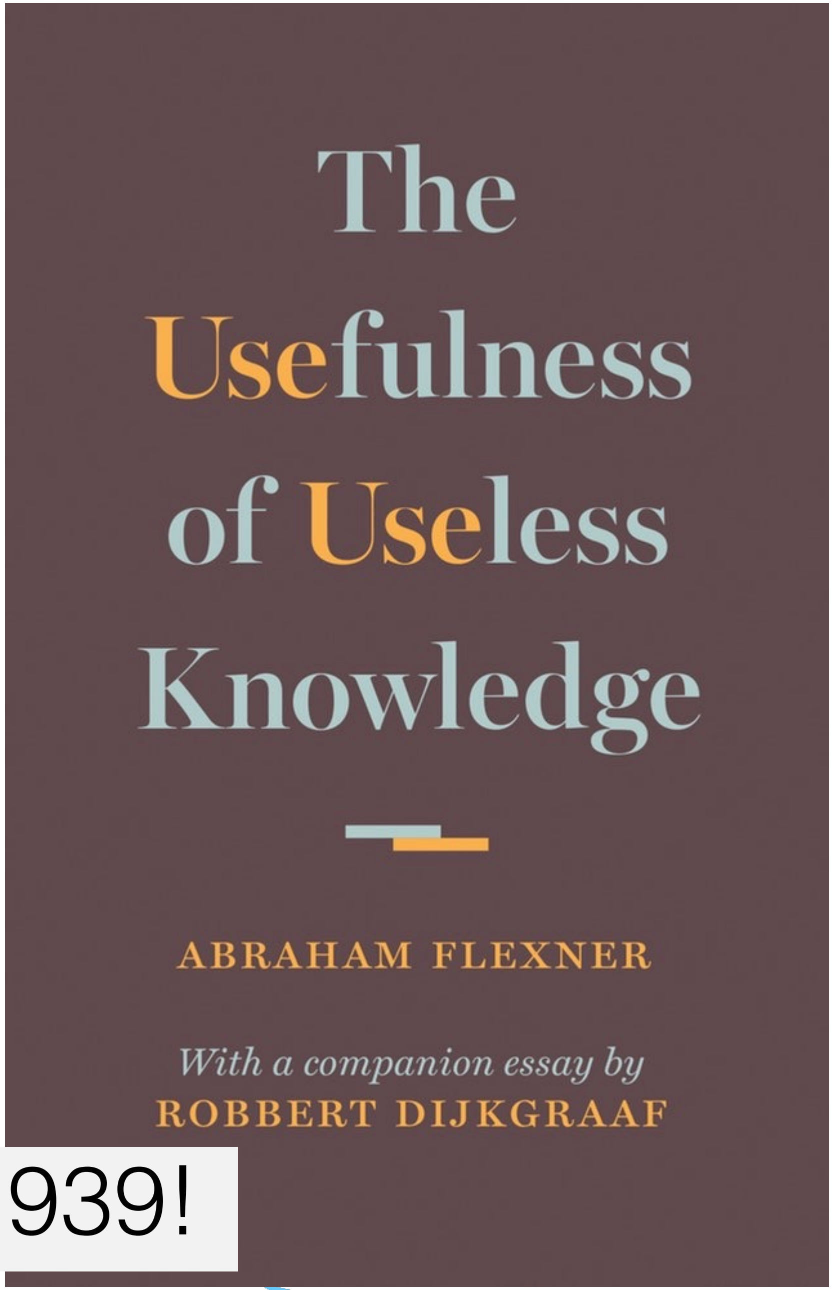
sciences-c This project has r research and innc



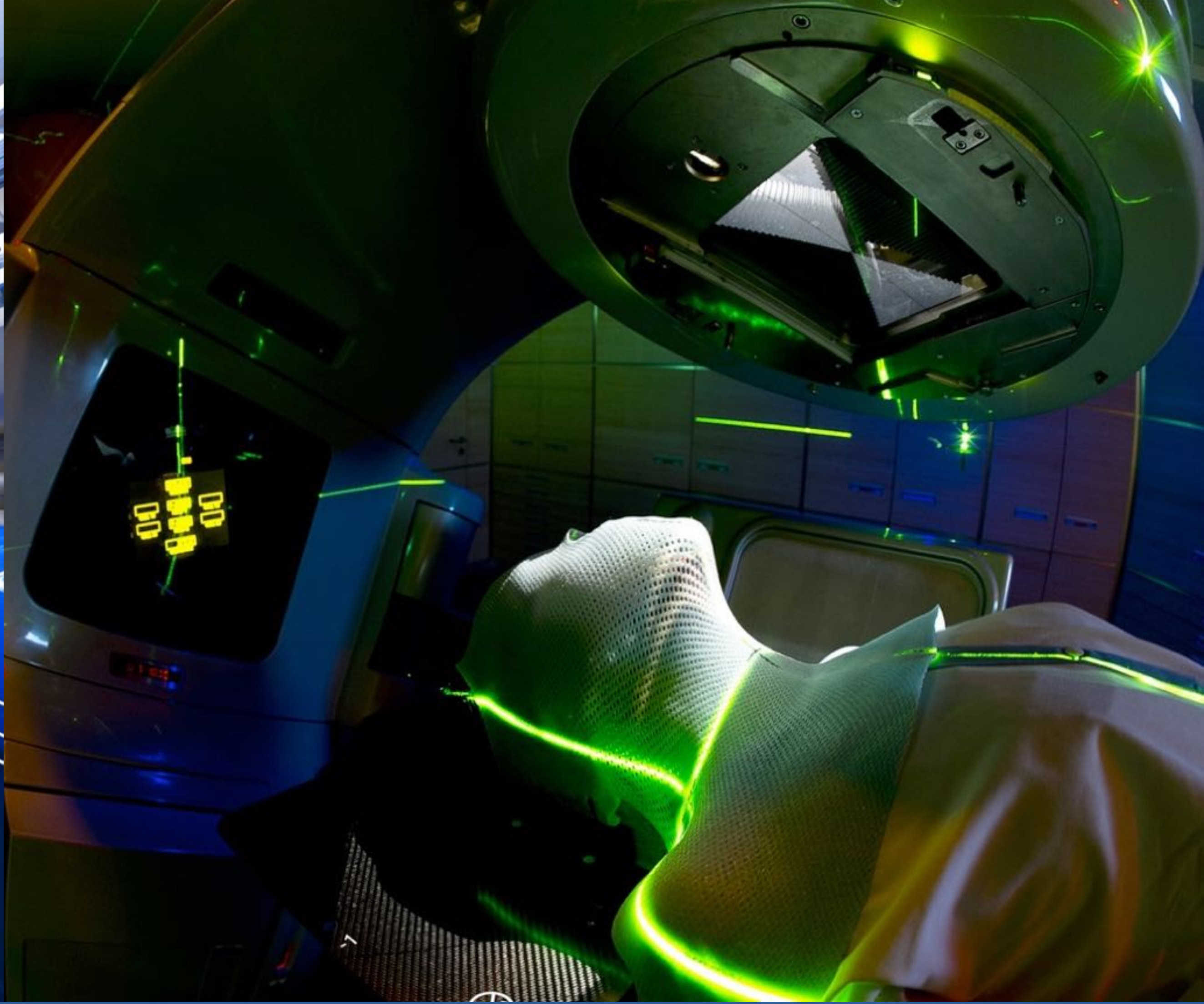
1939!

In the end, utility resulted, but it was never a criterion to which his (*Faraday's, ndr*) ceaseless experimentation could be subjected.

I am not for a moment suggesting that everything that goes on in laboratories will ultimately turn to some unexpected practical use or that an ultimate practical use is its actual justification.

Heavy Ion Therapy Research Integration

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008548



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