JENAS 2019

What is the societal IMPACT of particle physics?

CERN Knowledge Transfer
Accelerating innovation

Manuela Cirilli
CERN Knowledge Transfer Group


WHERE THE
WEB
WAS BORN

TECHNOLOGICAL KNOW-HOW & INNOVATION

(knowledge transfer)

Photo: CERN


The SCIENCE
International COOPERATION
TECHNOLOGICAL KNOW-HOW
& INNOVATION
(knowledge transfer)
Direct ECONOMICAL IMPACT
The PEOPLE
Photo: CERN

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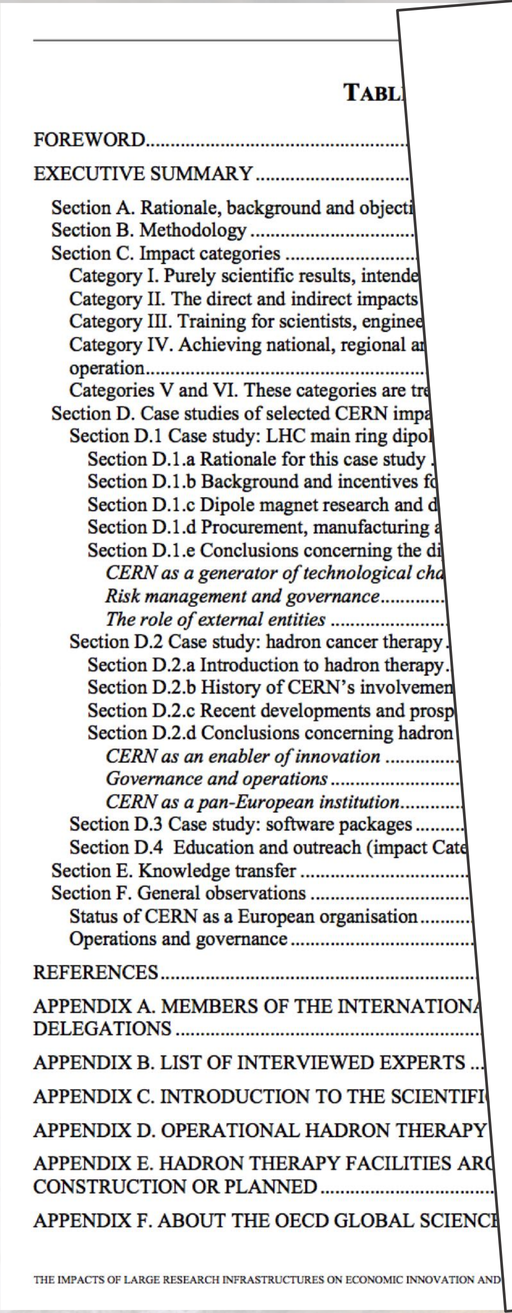


TABL

THE IMPACTS OF LARGE RESEARCH INFRASTRUCTURES ON ECONOMIC INNOVATION AND

The Impacts of Large Research Infrastructures
on
Economic Innovation and on Society:

Case Studies at CERN

OECD

Cost-Benefit Analysis of the Large Hadron Collider to 2025 and beyond

Massimo Florio[1], Stefano Forte[2], and Emanuela Sirtori[3]

[1] *Dipartimento di Economia, Management e Metodi Quantitativi, Università di Milano , via Conservatorio 7, I-20122 Milano, Italy*
[2] *TIF Lab, Dipartimento di Fisica, Università di Milano and INFN, Sezione di Milano, Via Celoria 16, I-20133 Milano, Italy*
[5] *CSIL, Centre for Industrial Studies Corso Monforte 15, I-20122 Milano, Italy*

Abstract

Social cost-benefit analysis (CBA) of projects has been successfully applied in different fields such as transport, energy, health, education, and environment, including climate change. It is often argued that it is impossible to extend the CBA approach to the evaluation of the social impact of research infrastructures, because the final benefit to society of scientific discovery is generally unpredictable. Here, we propose a quantitative approach to this problem, we use it to design an empirically testable CBA model, and we apply it to the the Large Hadron Collider (LHC), the highest-energy accelerator in the world, currently operating at CERN. We show that the evaluation of benefits can be made quantitative by determining their value to users (scientists, early-stage researchers, firms, visitors) and non-users (the general public). Four classes of contributions to users are identified: knowledge output, human capital development, technological spillovers, and cultural effects. Benefits for non-users can be estimated, in analogy to public goods with no practical use (such as environment preservation), using willingness to pay. We determine the probability distribution of cost and benefits for the LHC since 1993 until planned decommissioning in 2025, and we find there is a 92% probability that benefits exceed its costs, with an expected net present value (NPV) of about 3 billion €, not including the unpredictable economic value of discovery of any new physics. We argue that the evaluation approach proposed here can be replicated for any large-scale research infrastructure, thus helping the decision-making on competing projects, with a socio-economic appraisal complementary to other evaluation criteria.

We determine the probability distribution of cost and benefits for the LHC since 1993 until planned decommissioning in 2025, and we find there is a **92% probability that benefits exceed its costs, with an expected net present value of about 3 billion euro, not including the unpredictable economic value of discovery of any new physics.**

Additional reading:

Schopper, Herwig, 2016. "Some remarks concerning the cost/benefit analysis applied to LHC at CERN," Technological Forecasting and Social Change, Elsevier, vol. 112(C), pages 54-64.

E Pugliese, G Cimini, A Patelli, A Zaccaria, L Pietronero, A Gabrielli, Unfolding the innovation system for the development of countries: co-evolution of Science, Technology and Production, arXiv preprint arXiv:1707.05146

A Patelli, G Cimini, E Pugliese, A Gabrielli, The scientific influence of nations on global scientific and technological development, Journal of Informetrics 11, 1229-1237 (2017)

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.

Knowledge Transfer Channels

Dedicated actions to **foster the transfer of technologies and know-how** to other fields than particle physics
(very often with the involvement of industry)

Technology-intensive **procurement contracts**

People
(very hard to quantify but extremely impactful for particle physics)

KNOWLEDGE TRANSFER through PROCUREMENT

Survey of companies involved in technology-intensive procurement contracts with CERN.
178 questionnaires analyzed, related to 503 MCHF procurement budget.

Technological learning	44%
Increased international exposure	42%
Developed new products	38%
Market learning	36%
Started new R&D teams	13%
Would have poorer technological performance without CERN	41%
Would have poorer sales performance without CERN	52%

Dimensione impatto	% risposte positive/tot questionari
Technological competences	31%
Increased sales	28%
Positive return on image	25%
New partnerships/coolaborations	21%
Market learning	17%
New clients	14%
New activities	13%
Higher market shares	12%
New markets	11%

INFN

The HUMAN capital

Salary Differences Between Master’s and Ph.D. Graduates

Average Work-Life Earnings After a Bachelor's Degree				
Major	Bachelor's Degree	Master's Degree	Doctorate Degree	% Difference in Doctorate/Master's Earnings
Biological Science	$2,288,000	$2,757,000	$3,511,000	27%
Business	$2,563,000	$3,257,000	$3,535,000	9%
Communications	$2,333,000	$2,552,000	$3,306,000	30%
Computers and Math	$3,044,000	$3,541,000	$3,890,000	10%
Education	$1,798,000	$2,260,000	$2,802,000	24%
Engineering	$3,349,000	$3,918,000	$4,176,000	7%
Liberal Arts	$2,046,000	$2,448,000	$2,705,000	10%
Literature	$2,083,000	$2,444,000	$2,755,000	13%
Physical Science	$2,527,000	$3,193,000	$3,825,000	20%
Psychology	$2,001,000	$2,366,000	$3,157,000	33%
Science and Engineering Related	$2,587,000	$2,925,000	$3,814,000	30%
Social Science	$2,406,000	$2,986,000	$3,490,000	17%
Visual Arts	$1,966,000	$2,227,000	$2,545,000	14%

Note: *This chart is for 25-64 year olds who are working full-time, year round*

Source: www.census.gov

Today:
>3000 PhD students
in LHC experiments

https://www.wes.org/advisor-blog/salary-difference-masters-phd/

The EuroAtlantic Union Review, Vol. 1 No. 2/2014

Basic Research, Knowledge Transfer and Labor Market: Evidence from CERN's Fellowship Programs

Silvia Bruzzi* and Giovanni Anelli**

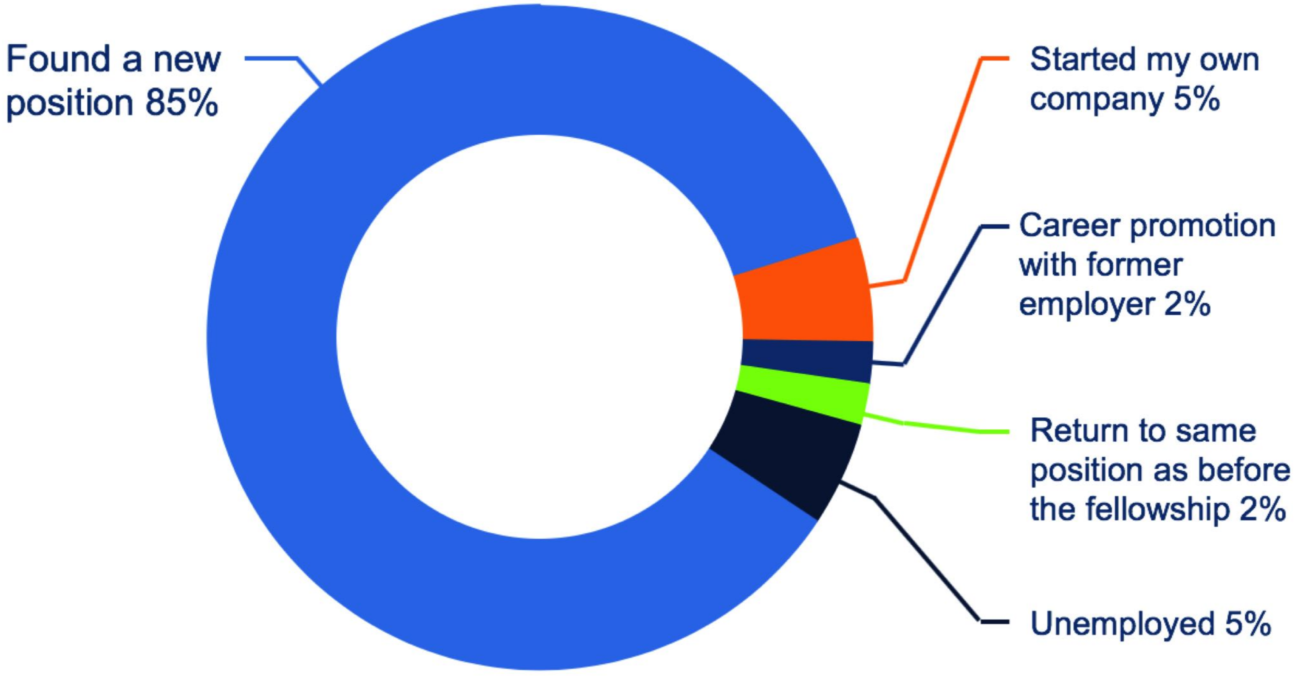
Abstract. *Nowadays, investing in scientific research to produce knowledge is considered a main asset for winning competition and contributing to the creation of economic value for the benefit of global society. Among the different phases of R&D, basic research stands out for its very high costs, risks and a time horizon of long/very long term. Nonetheless, if well-governed, it represents the component of R&D more able to produce positive externalities at a global level. In this framework, this paper aims to focus on the wide socio-economic value generated by basic research, conceived as an irreplaceable engine of innovation. In order to measure the performance of basic research, the paper proposes to refer to the outcome of research activity, i.e. the advancement of knowledge diffused by and through people, and discuss the results of a survey developed at CERN on the past-CERN Fellows, in order to isolate the contribution of the Fellowship Programs of CERN to the Fellows' professional career, in primis in industry. Our findings testify that basic research produces a continued scientific 'fertilisation effect' of the global economic system, contributing to the creation of high skilled and professionalized human resources to the benefit of industry and other employers, so generating positive externalities wider than those measured in terms of patents and publications, the metrics traditionally used to measure the performance of research.*

Keywords: *Basic Research; Knowledge Transfer; Labor Market; CERN.*

2007-2012: 831 Fellows finished their Fellowships

The study targeted the **288 (38%) former fellows that did not have any affiliation (staff, student, user, etc.) with CERN** at time of the survey

First Position after Fellowship

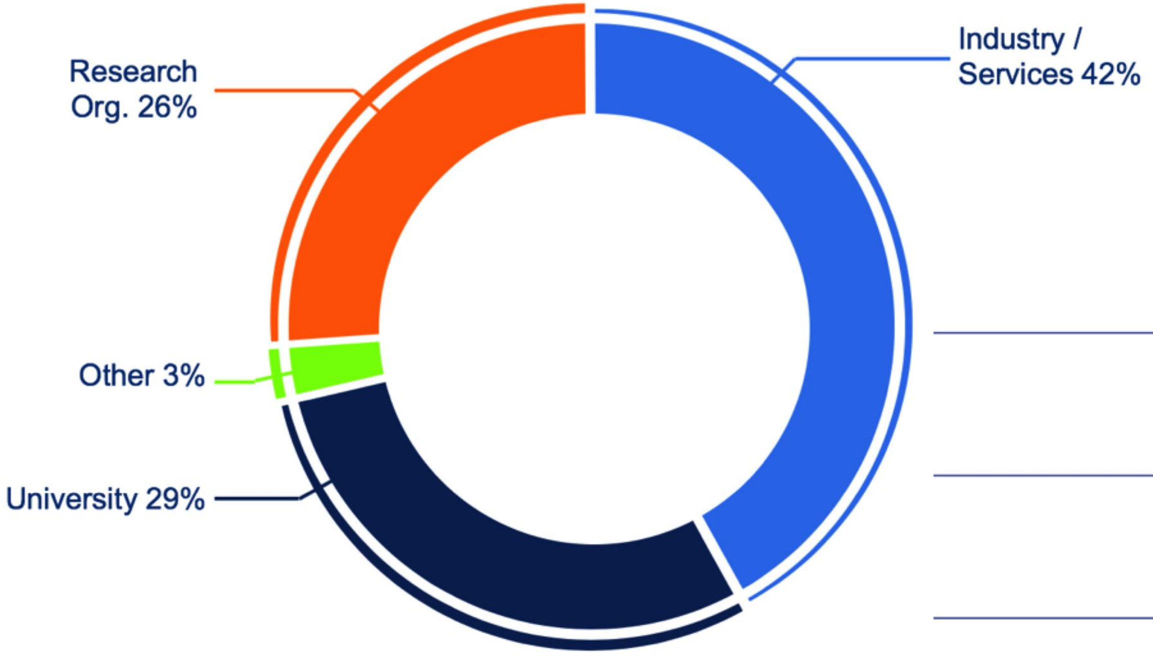


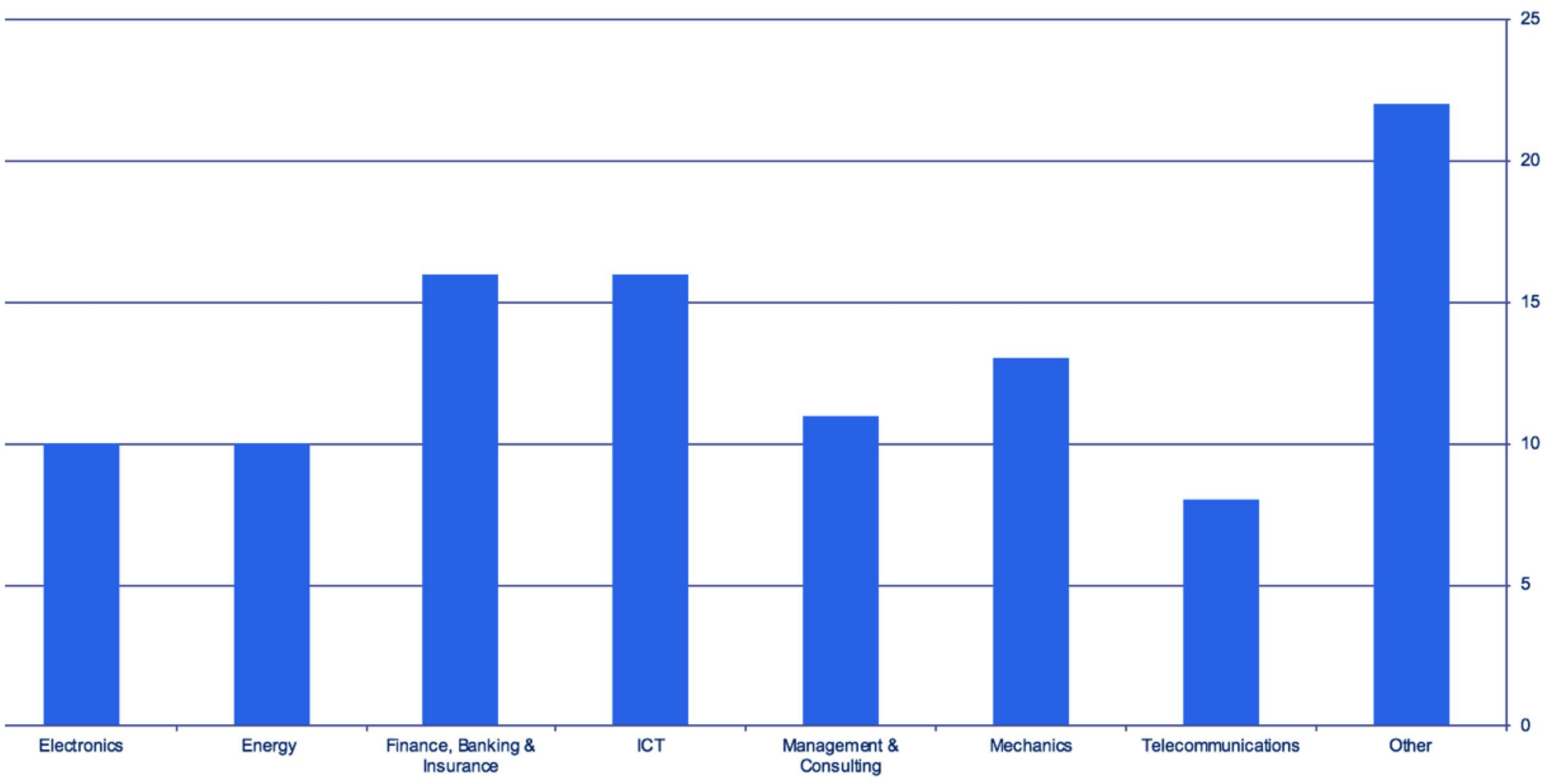
ENTREPRENEURSHIP

Georges Charpak

researcher & entrepreneur

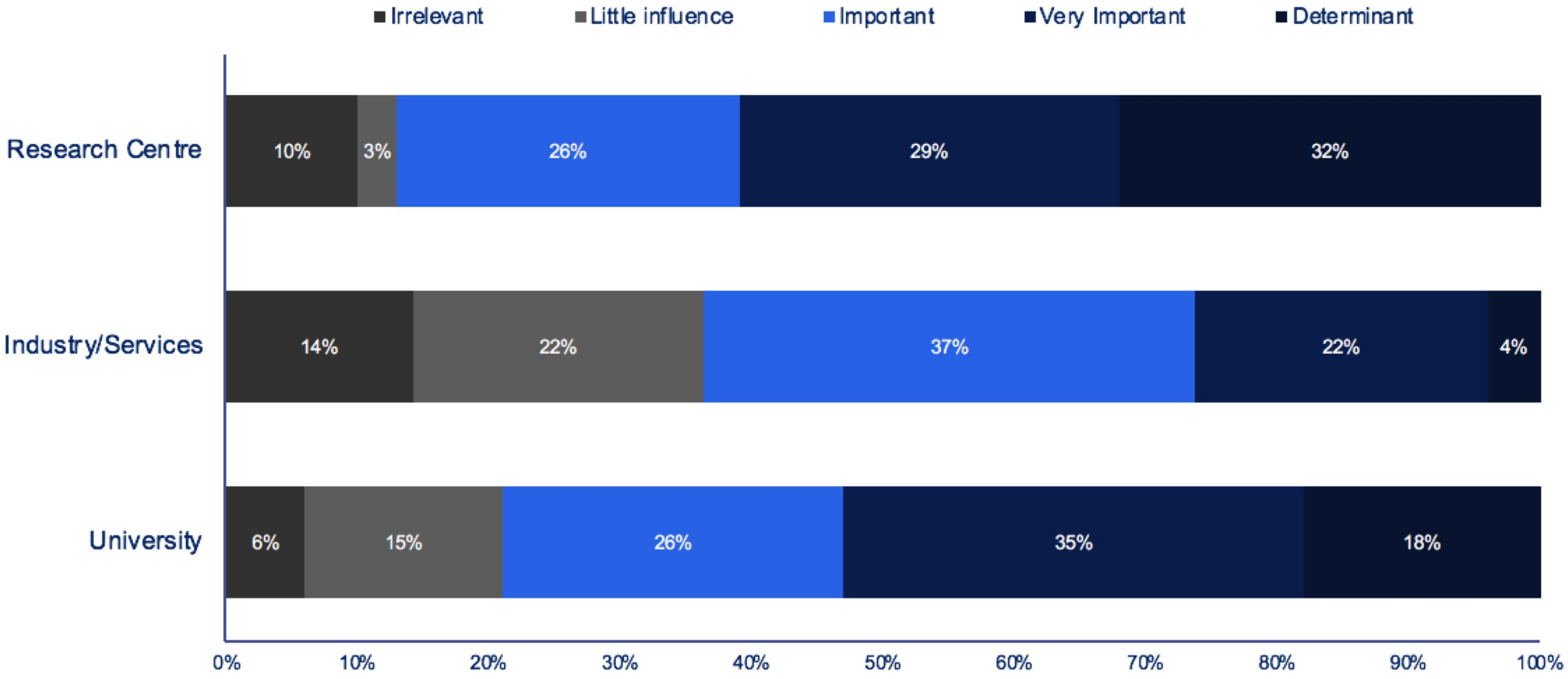
First Position after Fellowship





First Position after Fellowship

How important was the CERN fellowship
to secure your first position after the fellowship?

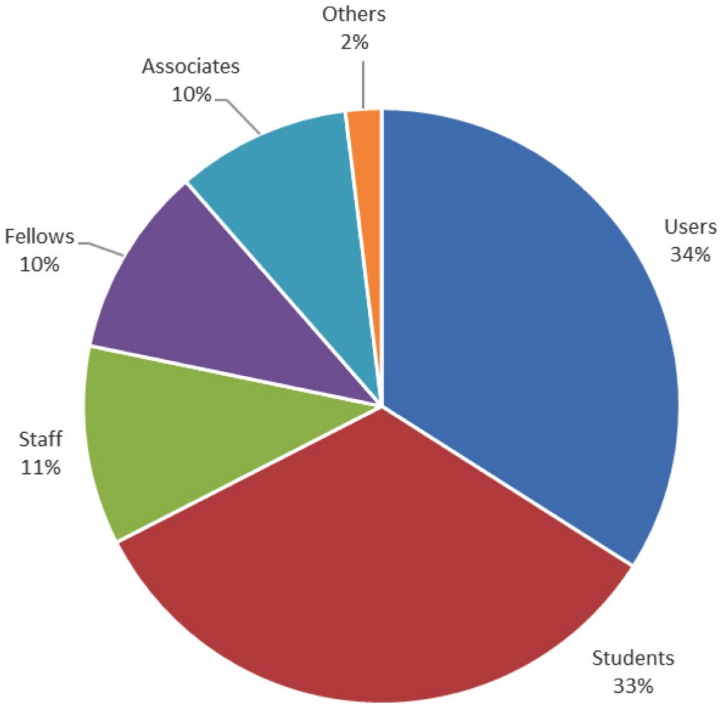


The CERN alumni network

✓ 67% alumni
✓ 19% to leave within a year
✓ 23% women
✓ 57% between 21 and 35

5400 today

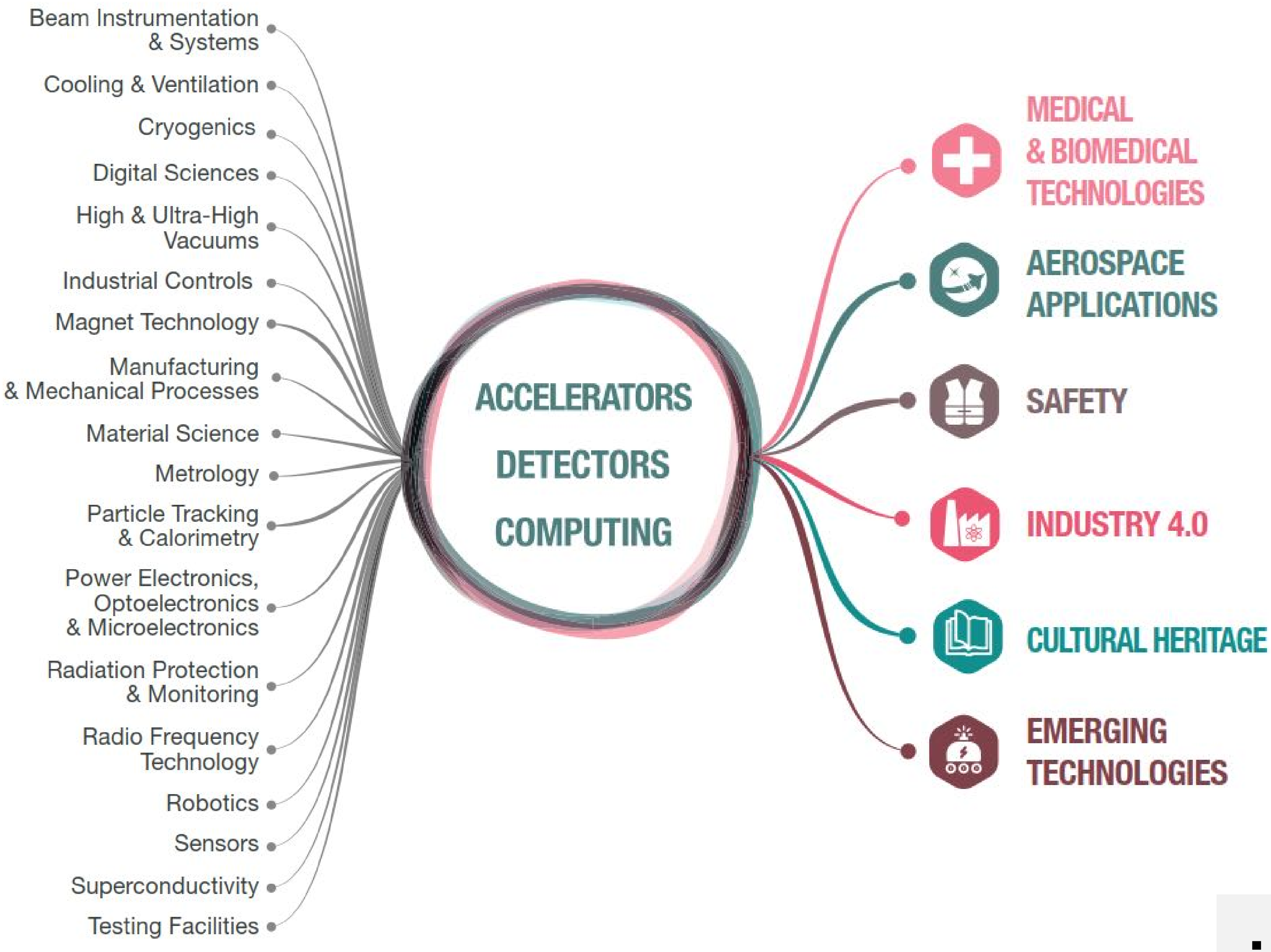
✓ 77% former users, associates or students
✓ 10% former fellows
✓ 66% are nationals from a MS
✓ IT, FR, DE, GB, US ES, GR, CH, PL nationals are most represented



✓ Spread over 99 countries
✓ 68% live & work in the Member States
✓ Mostly CH, FR, US, GB, DE, IT, ES

Join at https://alumni.cern/signup

From particle physics technologies...

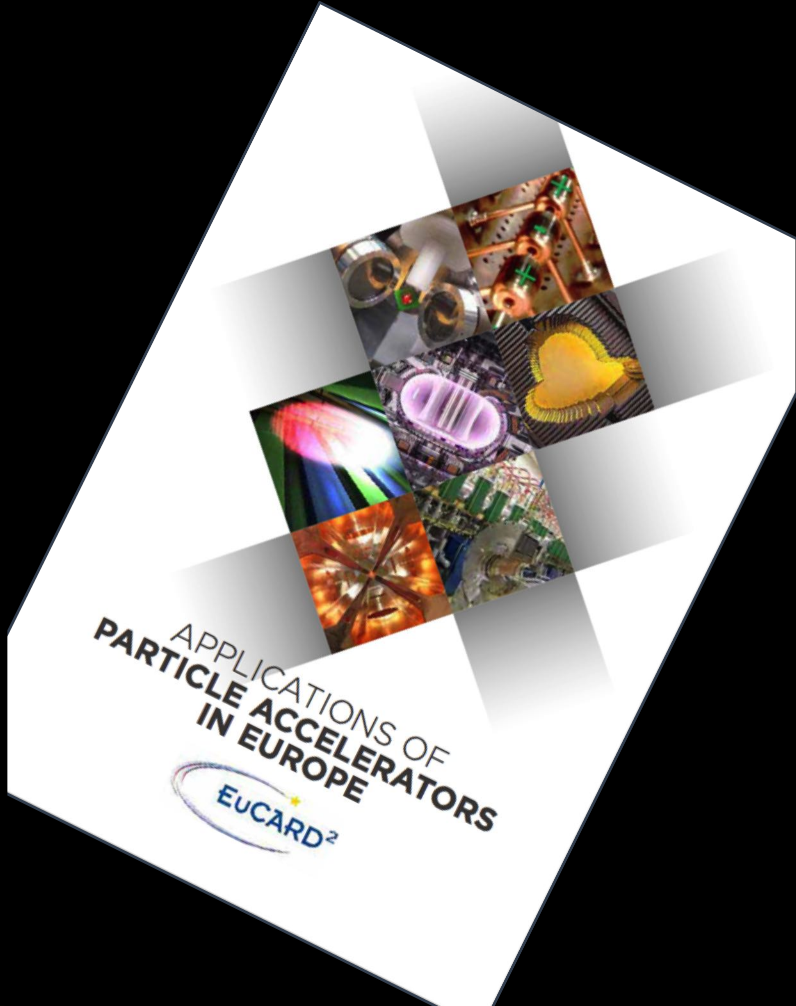


...to Society


2009
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
2009
In partnership with
Science & Technology Facilities Council
IOP Institute of Physics
2013
Accelerating science and innovation
Societal benefits of European research in particle physics
2014
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
APS physics
2014
2017
Applications of Particle Accelerators in Europe
EuCARD²

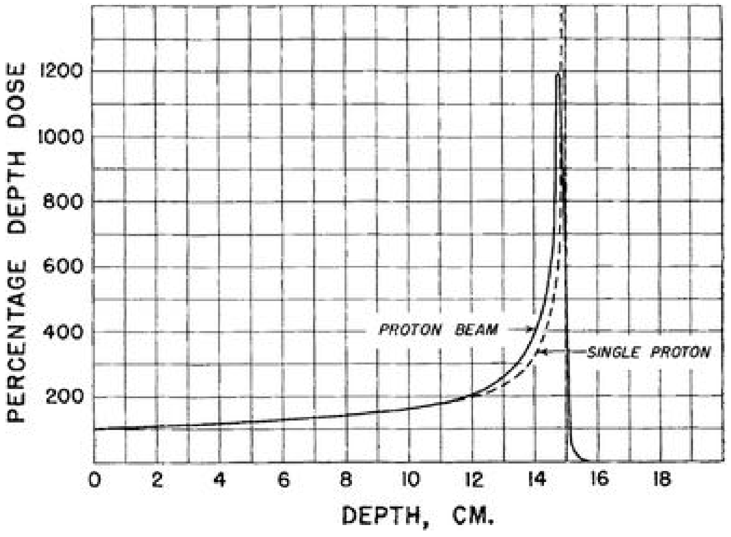
sound reproduction
data management
testing satellite components
astronauts' radiation exposure
understanding turbulence
food sterilization
medical implants
finding oil, gas, water
homeland security
geological dating
scientific linux
curing of epoxies and plastics
medical imaging
x-ray diffractometry
spacecraft shielding
radiology
medical equipment sterilization
medical radioisotopes
non-destructive testing
nuclear waste transmutation
ion implantation
rad-hard electronics
shrink wrap
radiotherapy
PET
terrestrial reproduction of space radiation
simulations
industry 4.0
digital data preservation
optimised irrigation systems
drug development
WWW
safety
open hardware
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

Area	Application	Beam	Accelerator	Beam energy/MeV	Beam current/mA	Number
Medical	Cancer therapy	e	linac	4-20	10^{-2}	>14000
		p	cyclotron, synchrotron	250	10^{-6}	60
		C	synchrotron	4800	10^{-7}	10
	Radioisotope production	p	cyclotron	8-100	1	1600
Industrial	Ion implantation	B, As, P	electrostatic	< 1	2	>11000
	Ion beam analysis	p, He	electrostatic	<5	10^{-4}	300
	Material processing	e	electrostatic, linac, Rhodatron	≤10	150	7500
	Sterilisation	e	electrostatic, linac, Rhodatron	≤10	10	3000
Security	X-ray screening of cargo	e	linac	4-10	?	100?
	Hydrodynamic testing	e	linear induction	10-20	1000	5
Synchrotron light sources	Biology, medicine, materials science	e	synchrotron, linac	500-10000		70
Neutron scattering	Materials science	p	cyclotron, synchrotron, linac	600-1000	2	4
Energy – fusion	Neutral ion beam heating	d	electrostatic	1	50	10
	Heavy ion inertial fusion	Pb, Cs	Induction linac	8	1000	Under development
	Materials studies	d	linac	40	125	Under development
Energy – fission	Waste burner	p	linac	600-1000	10	Under development
	Thorium fuel amplifier	p	linac	600-1000	10	Under development
Energy – bio-fuel	Bio-fuel production	e	electrostatic	5	10	Under development
Environmental	Water treatment	e	electrostatic	5	10	5
	Flue gas treatment	e	electrostatic	0.7	50	Under development



Radiotherapy

Berkeley
1931 Invention of cyclotron (Ernest Lawrence)
1946 RR Wilson published his seminal paper on particle therapy
1952 First biological investigation with accelerated nuclei (C Tobias and JH Lawrence)
1954 First therapeutic exposure of humans to protons and alphas (Tobias and JH Lawrence)
1975 Clinical trials with accelerated light ions at LBL (Castro)



Gustav Werner Institute and Theodor Svedberg Laboratory
1949 Synchrocyclotron at the Gustav Werner Institute (Uppsala)
1950s Pre-therapeutic physical experiments with high energy protons (B. Larsson)
1957 First patient treated with proton beam

π^- beam therapy

1935 Yukawa theory on pi meson

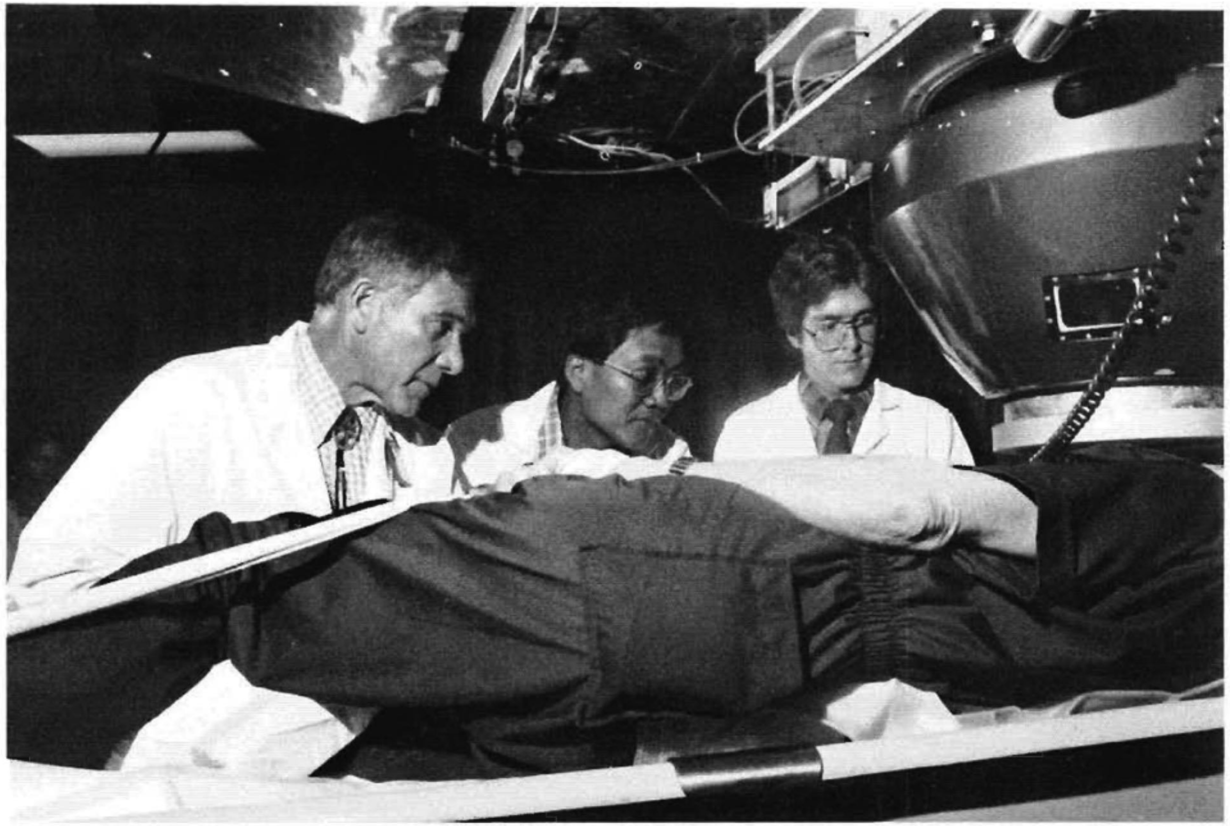
1947 Discovery of pions

1951 Possibility of using negative pions for cancer therapy (Tobias and Richman)

1961 Clinical use of π^- advocated (Fowler and Perkins, Nature 1961)

'70-'80s Clinical trials of negative pions at LAMPF, TRIUMF, PSI and Stanford

William T. Chu
EO Lawrence Berkeley National Laboratory
PTCOG From 1985 to Present and Future



In a pilot experimental program at LAMPF's Biomedical Facility, about 250 patients were treated with negative pions for a variety of advanced deep-seated tumors. Compared to conventional x-ray therapy, pion therapy is expected to provide improved dose localization and biological effectiveness. Shown positioning a patient under the pion radiotherapy beam are (left to right) Dr. Morton Kligerman, former Director of the University of New Mexico's Cancer Research and Treatment Center, a visiting radiotherapist from Japan, and Dr. Steven Bush, formerly of the University of New Mexico. The hardware at the upper right includes a beam collimator, a dose monitor, and a device for changing the penetration depth of the pions.

LAMPF: a dream and a gamble

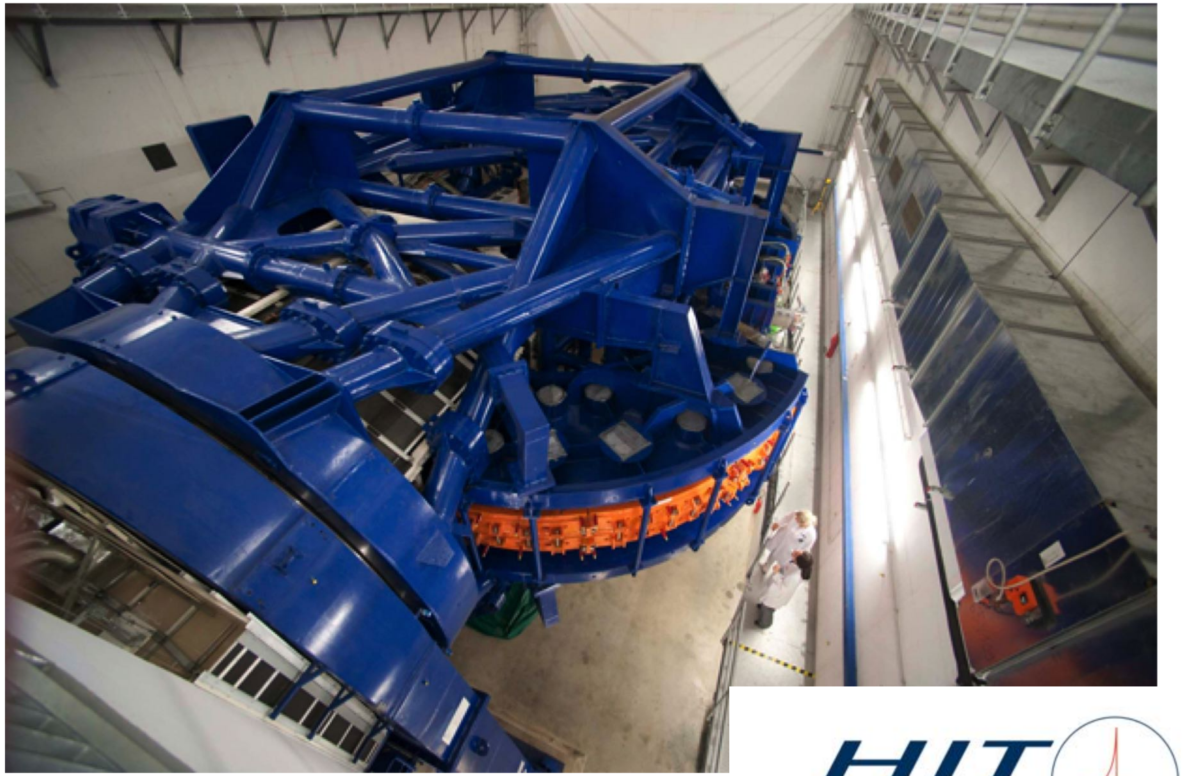
From the
PIMMS Study @ CERN → TERA

INFN

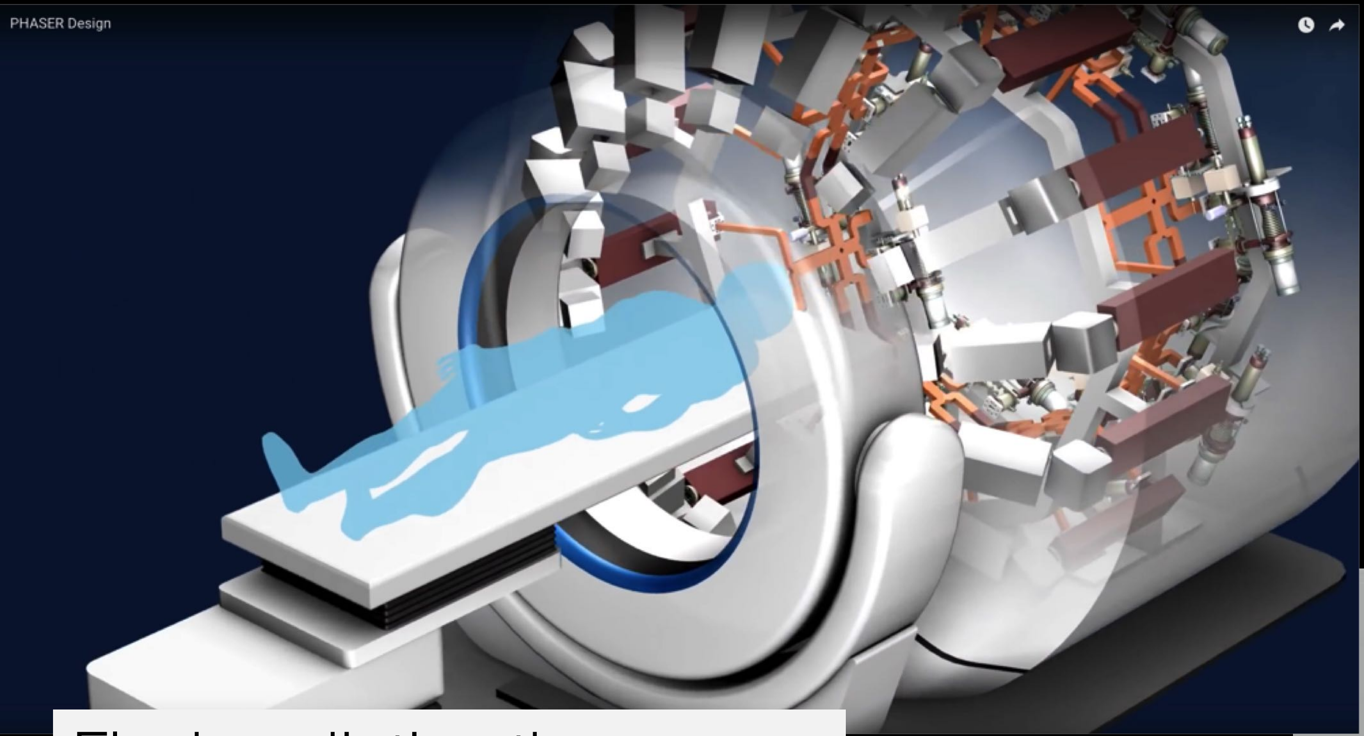
fondazione CNAO

ebg MedAustron

From pioneering
rasterscanning &
carbon ion pilot project @ GSI



HIT
Heidelberger Ionenstrahl-Therapiezentrum

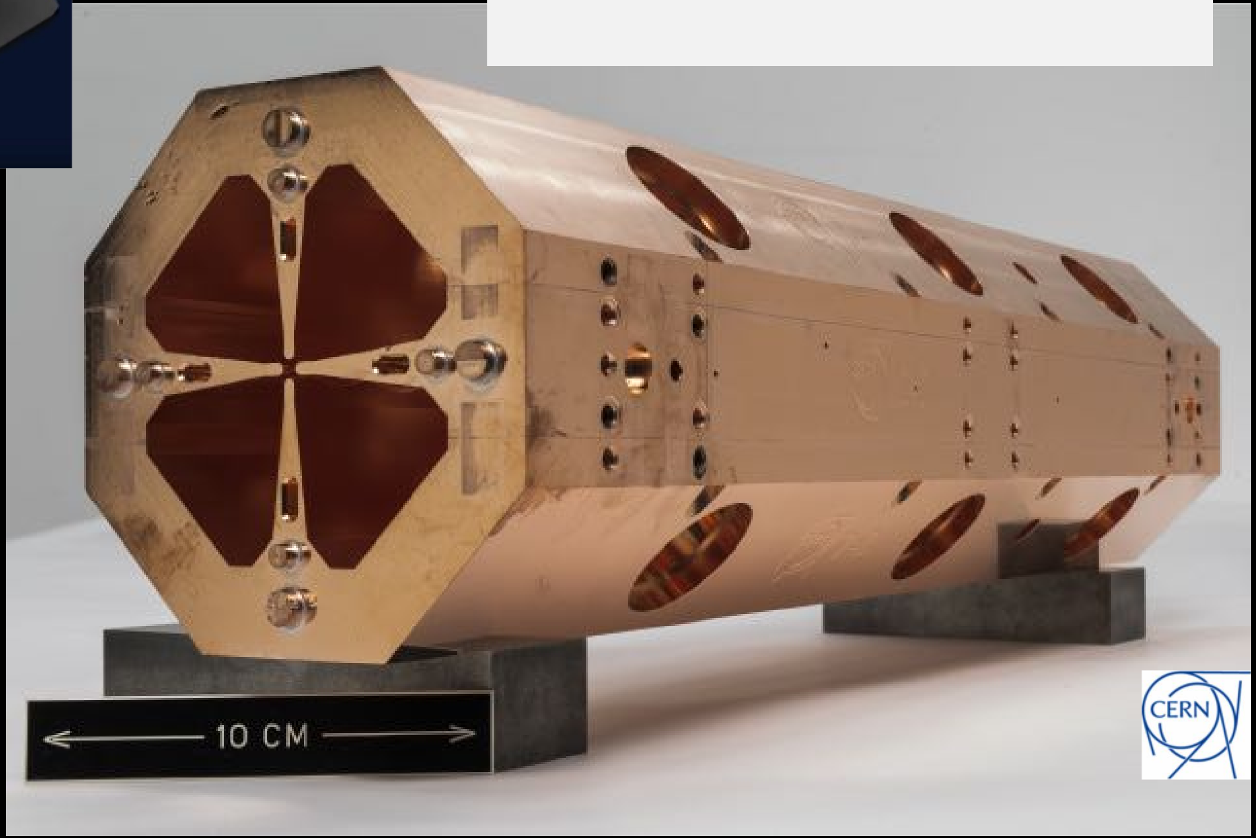


Linear accelerators for proton therapy

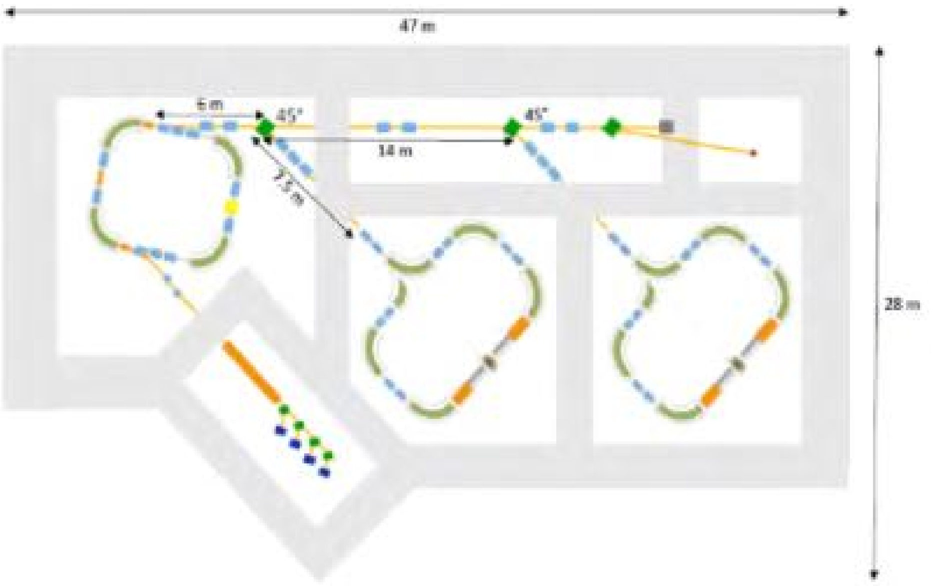
LIGHT - ADAM/ AVO
TOP-IMPLART - ENEA

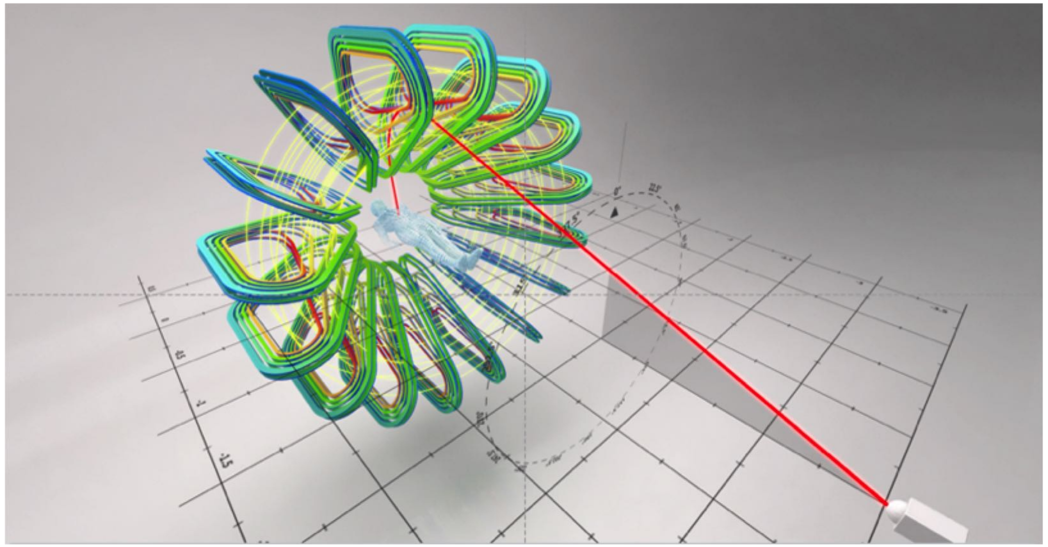
Flash radiation therapy

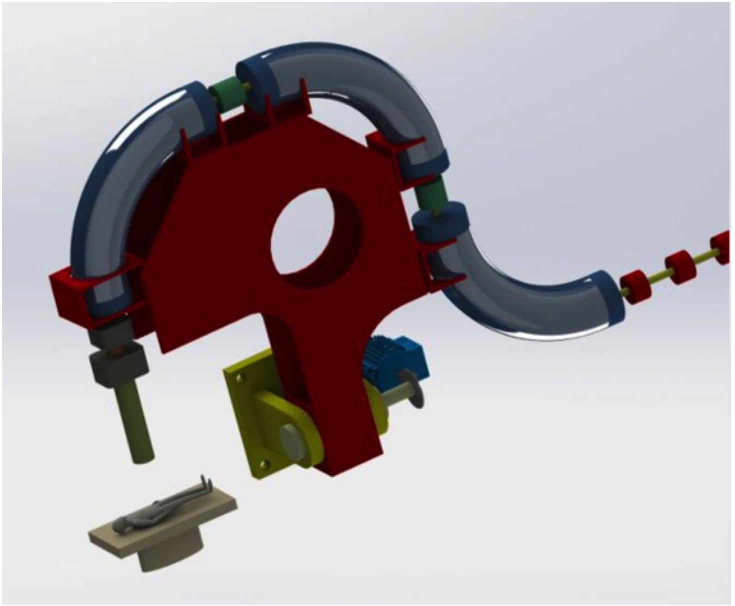
PHASER - SLAC/Stanford
Varian
IBA

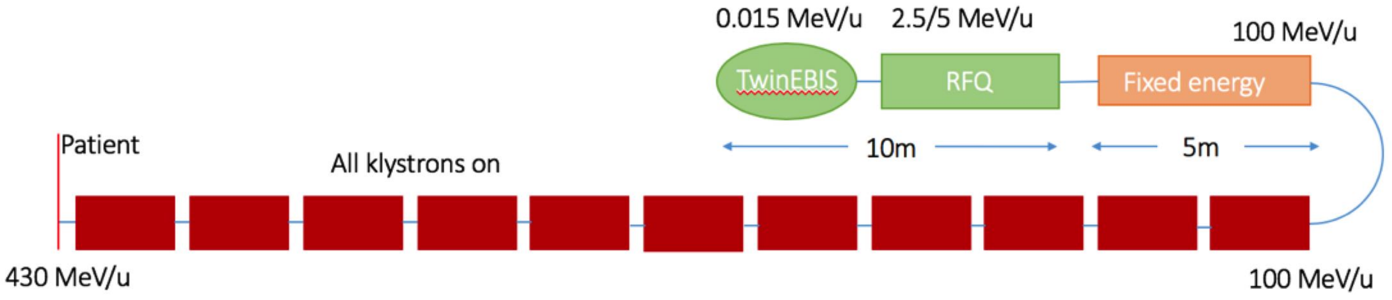


Next-generation ion therapy facilities









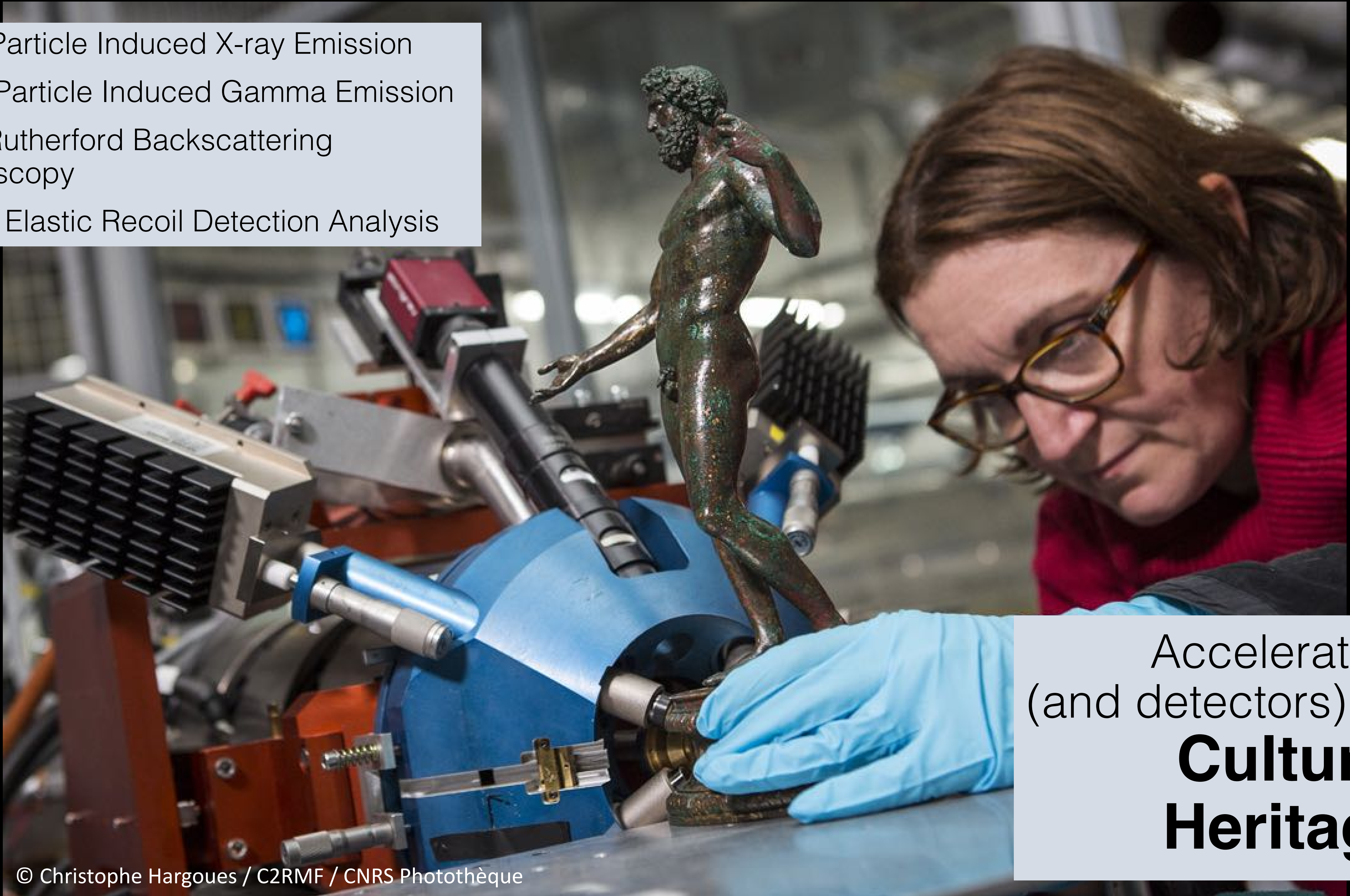
several initiatives starting/ongoing involving (among others) CERN, CNAO, GSI, MedAustron, PSI, SEEIST…

PIXE = Particle Induced X-ray Emission

PIGE = Particle Induced Gamma Emission

RBS = Rutherford Backscattering Spectroscopy

ERDA = Elastic Recoil Detection Analysis



Accelerators
(and detectors) for
Cultural Heritage

New AGLAÉ – Accélérateur Grand Louvre d'Analyse Élémentaire

CENTRE DE RECHERCHE ET DE RESTAURATION DES MUSÉES DE FRANCE

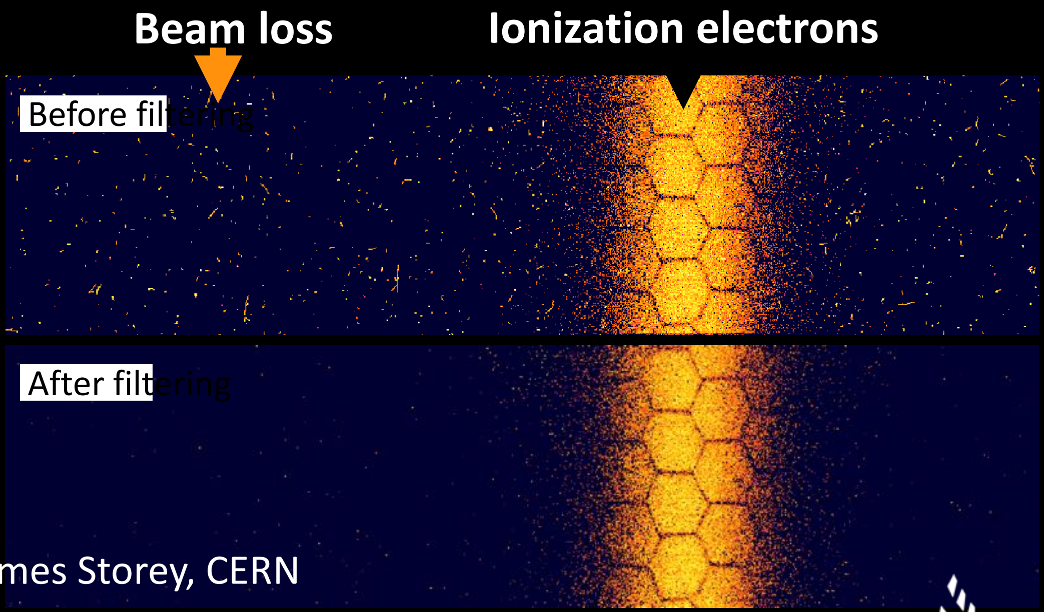
cnrs

MACHINA

Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis

Photo: INFN

Construction of a compact, transportable accelerator

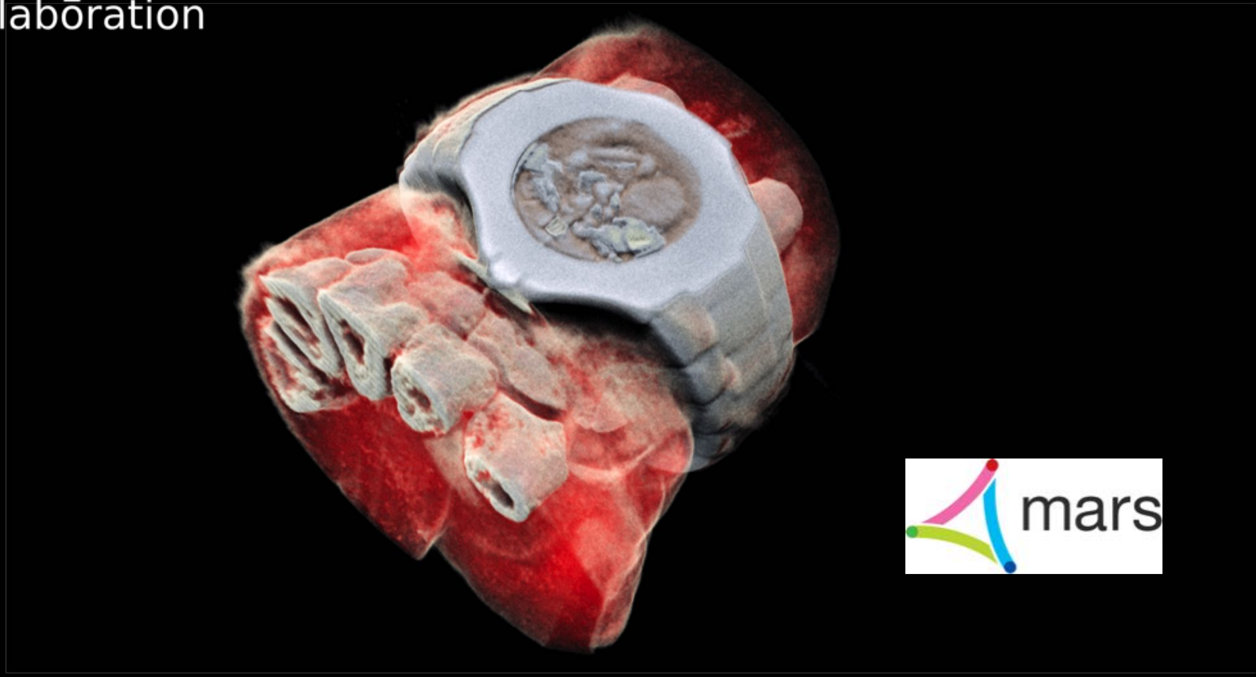


James Storey, CERN

medipix
collaboration

© NASA, photo ref. no. iss036e006175

INSIGHTART



mars

20th anniversary symposium on Medipix and Timepix https://indico.cern.ch/event/782801/timetable/

GEANT4
A SIMULATION TOOLKIT

Space applications

European Space Agency

- Geant4 Space Users' Home Page
- ESA Project Support
- XMM-Newton Radiation Environment.
- Space Environment Information System (SPENVIS)
- Dose Estimation by Simulation of the ISS Radiation Environment (DESIRE)
- Physics Models for Biological Effects of Radiation and Shielding
- Geant4 Radiation Analysis for Space (GRAS)
- MUlti-LAyered Shielding SImulation Software (MULASSIS)

GLAST

- Gamma Ray Large Area Space Telescope

MEGAlib

- Medium Energy Gamma-ray Astronomy library

Medical applications

G4DNA
: Geant4-DNA project

G4MED (in Japanese)
: Geant4 Medical Physics in Japan

G4NAMU
: Geant4 North American Medical User Organization

GAMOS
: Geant4-based Architecture for Medicine-Oriented Simulations

GATE
: Geant4 Application for Tomographic Emission

GHOST
: Geant4 Human Oncology Simulation Tool

TOPAS
: Geant4 Monte Carlo Platform for Medical Applications

+ industrial applications

Notably, non-destructive testing

nature International weekly journal of science

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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

Established isotopes → Industrial suppliers

^{99m}Tc, ^{18}F, ^{123,125,131}I, ^{111}In, ^{90}Y

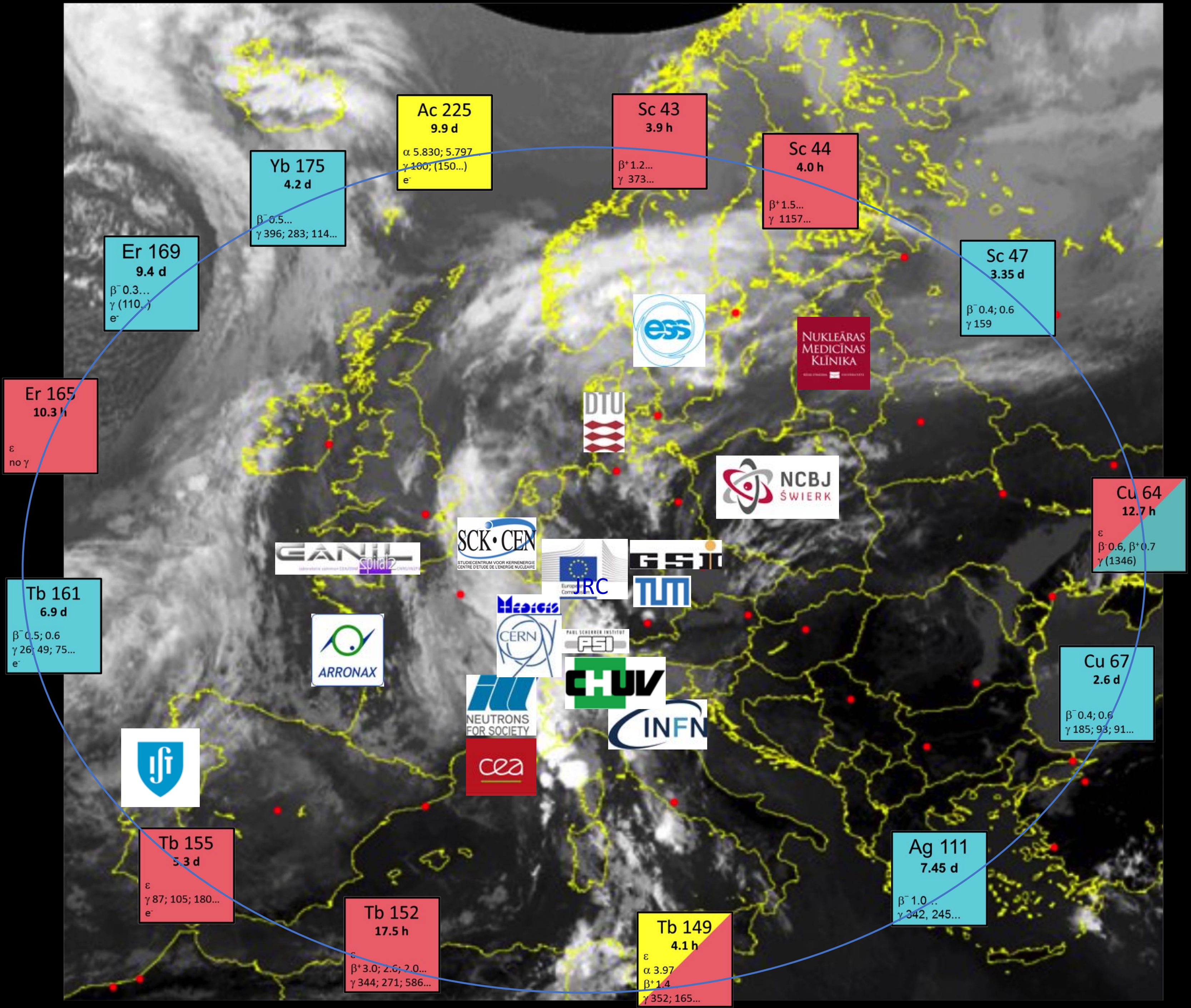
Emerging isotopes → Small innovative suppliers

^{68}Ga, ^{82}Rb, ^{89}Zr, ^{177}Lu, ^{188}Re

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,…

PRISMAS-MAP:
PRoduction of hIgh purity iSotopes by MAss Separation for Medical Application

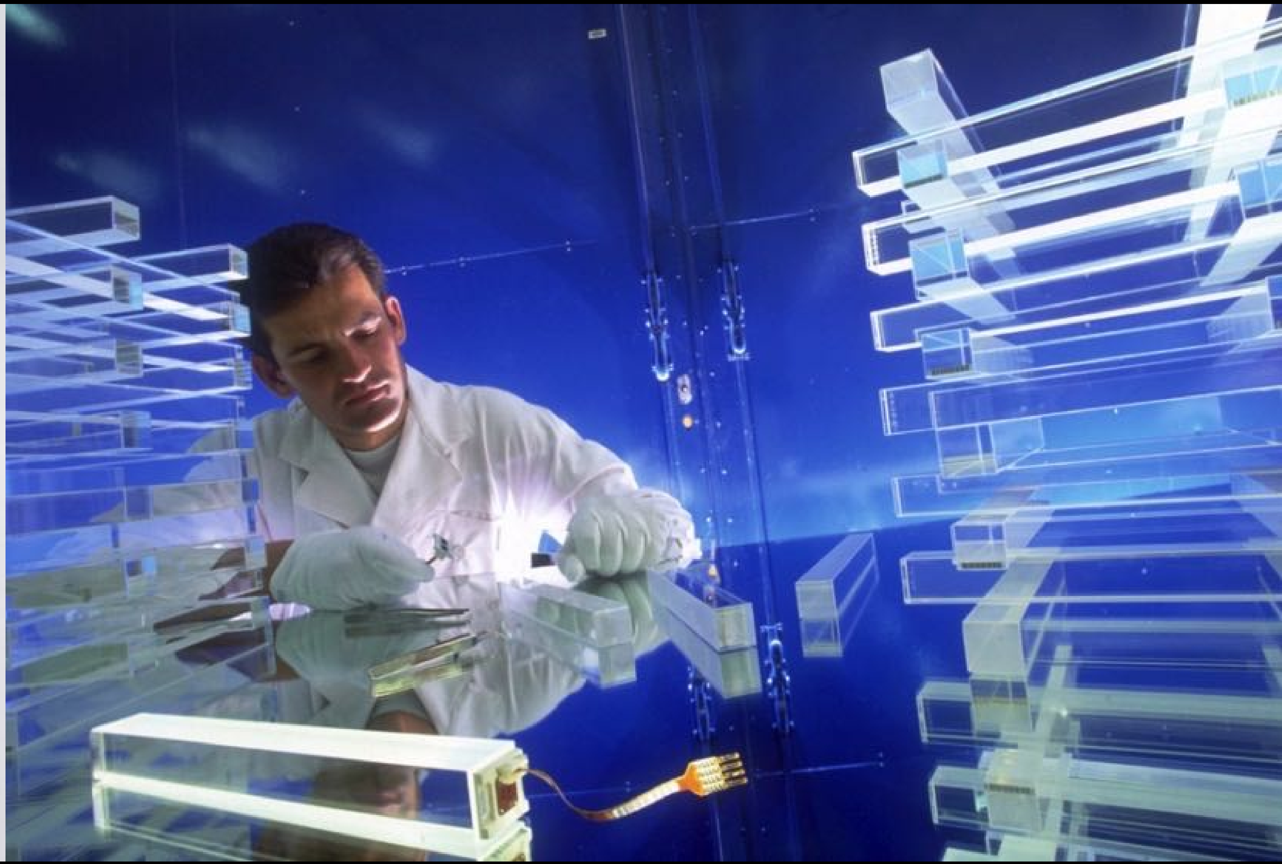


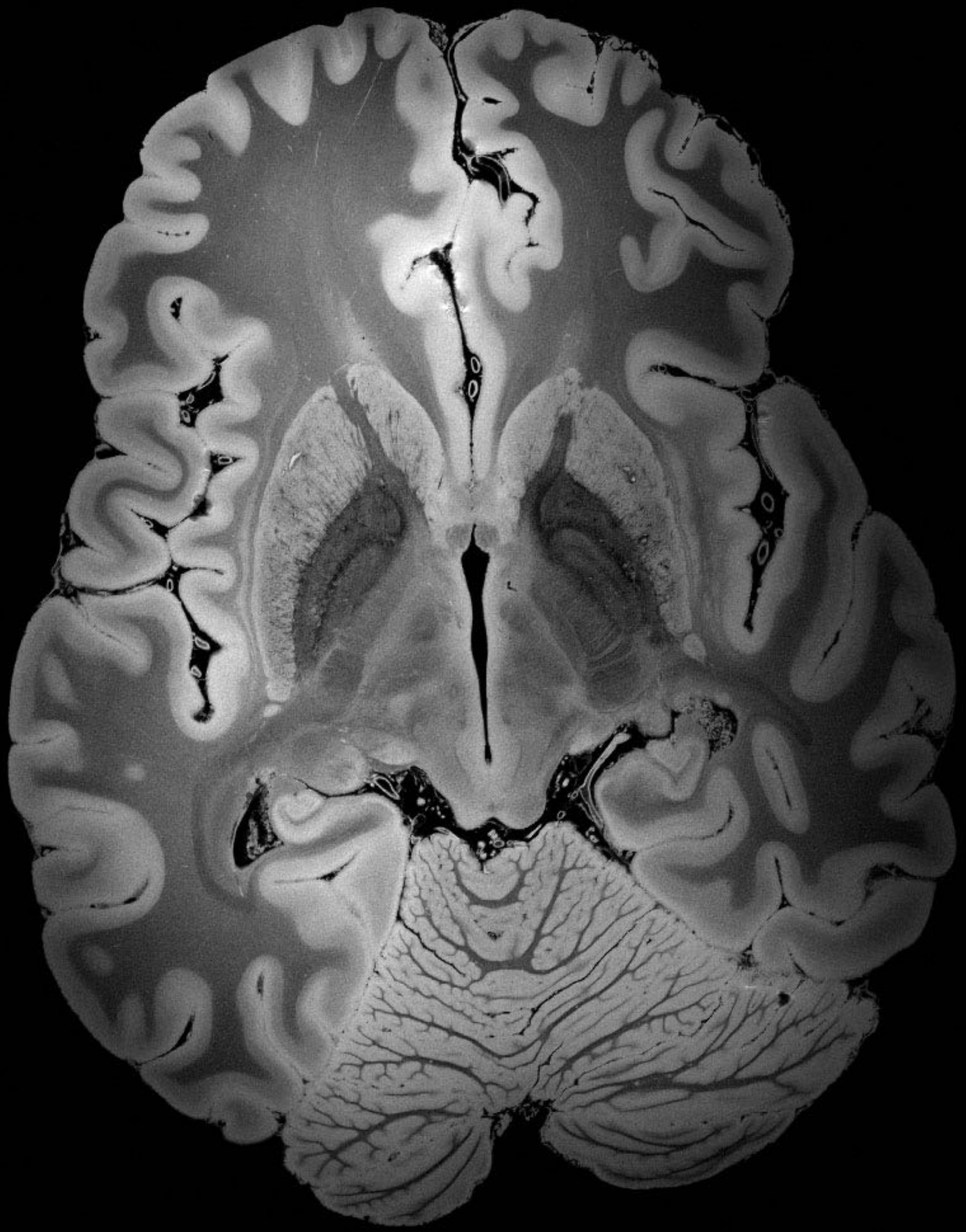
Next H2020-INFRA call

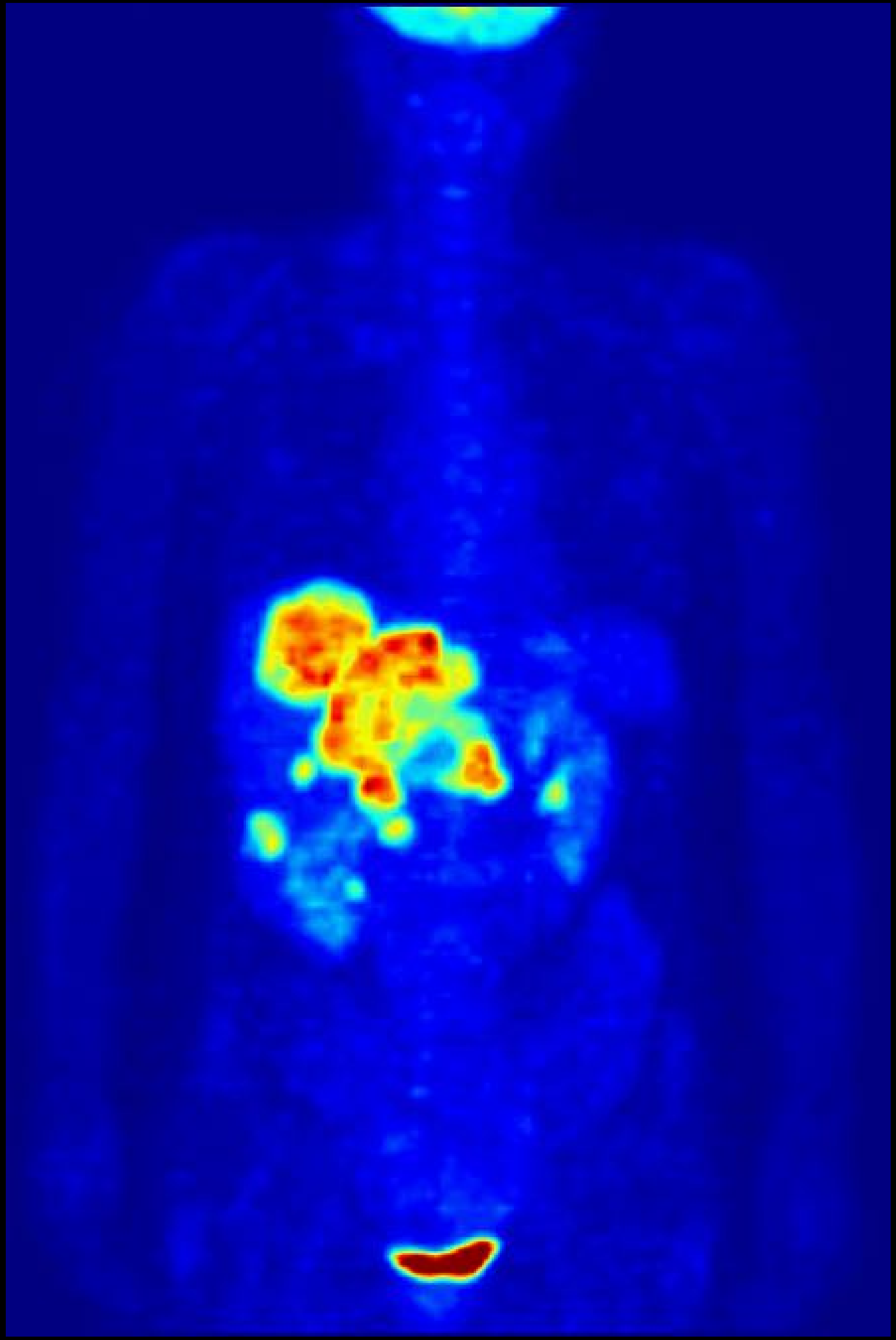
Inspired by the NIDC

Courtesy of / contact
Thierry.stora@cern.ch

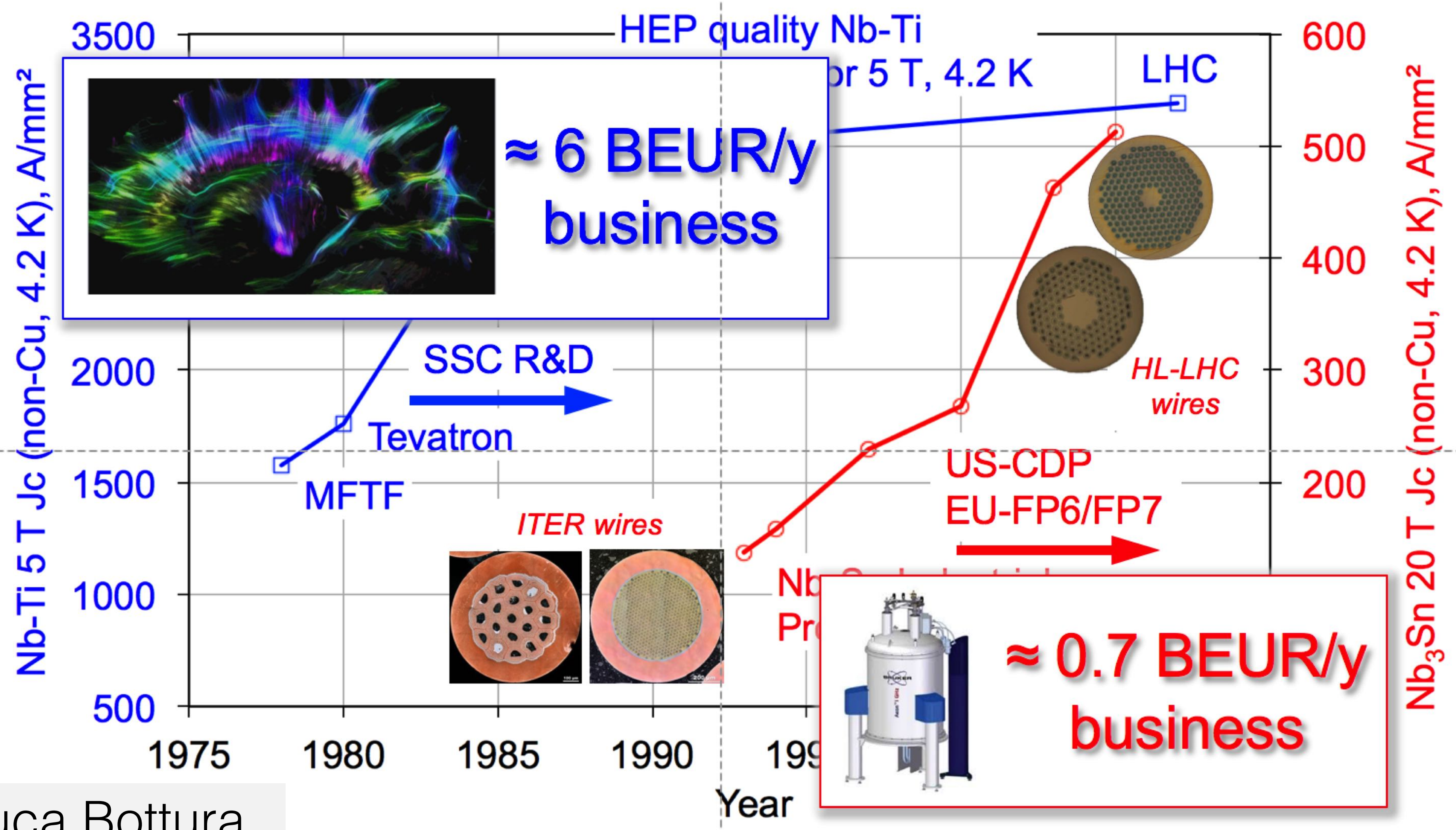
A long and winding road…





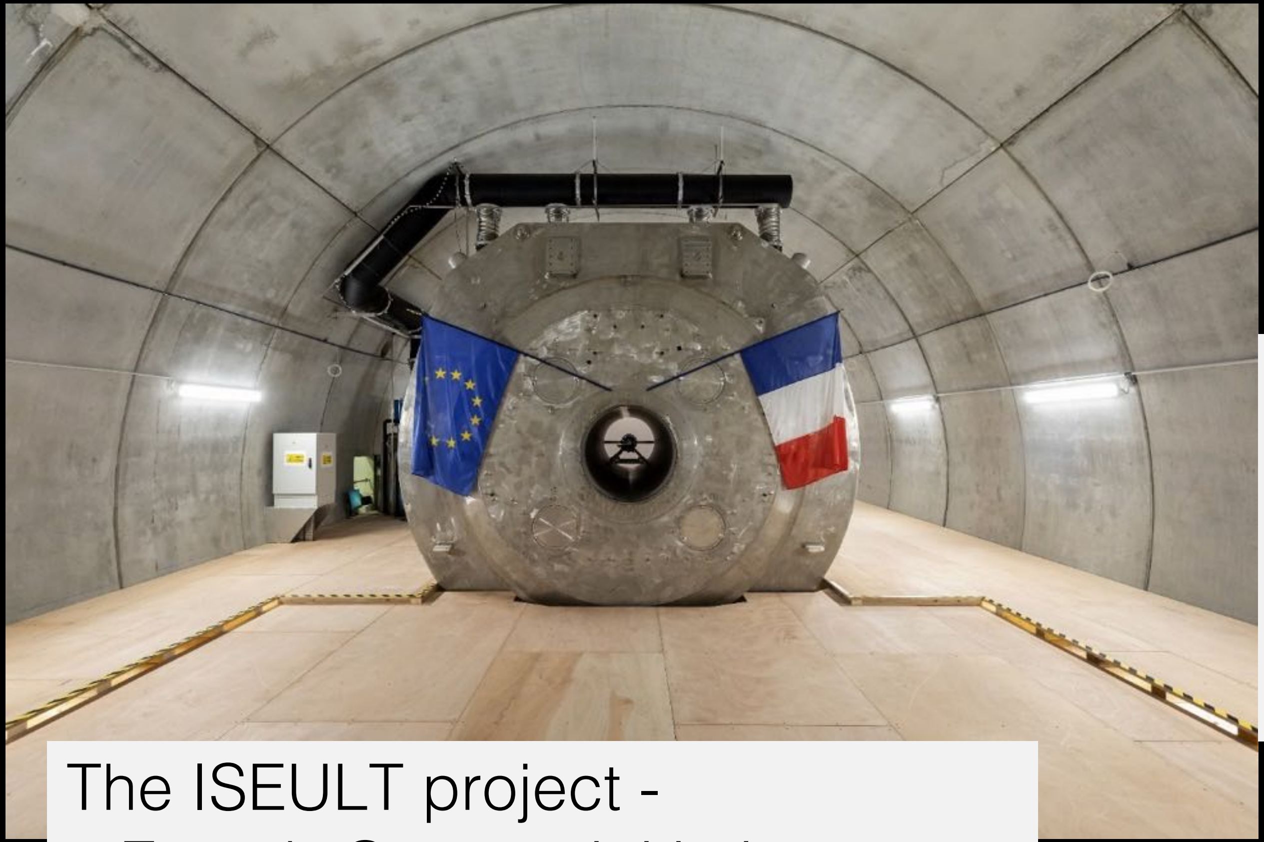


BRIAN L. EDLOW, M.D. OF MASSACHUSETTS GENERAL HOSPITAL



Courtesy Luca Bottura, see his talk yesterday

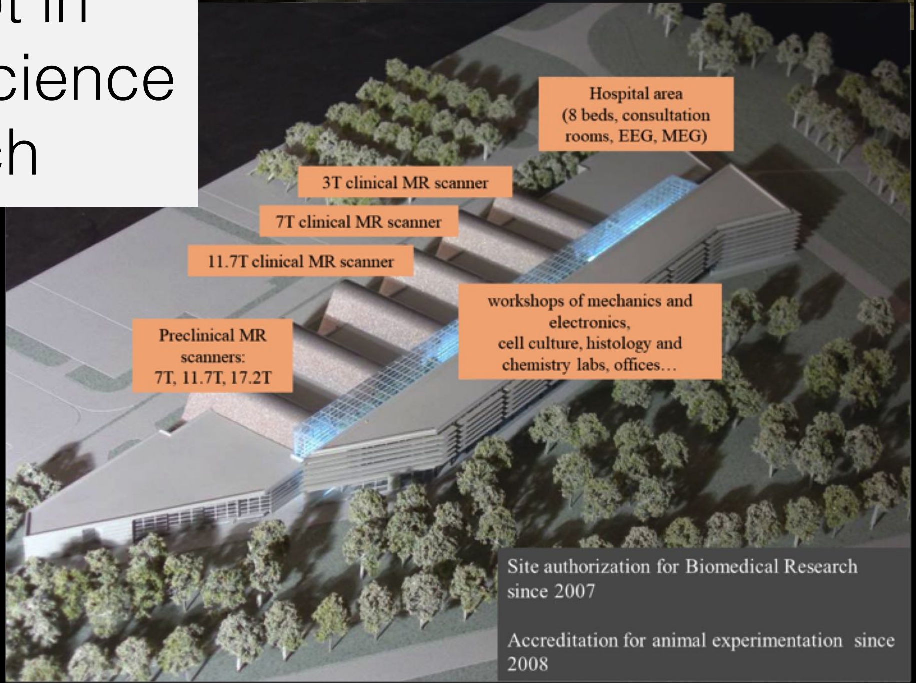
The ISEULT whole body 11.7 T MRI magnet



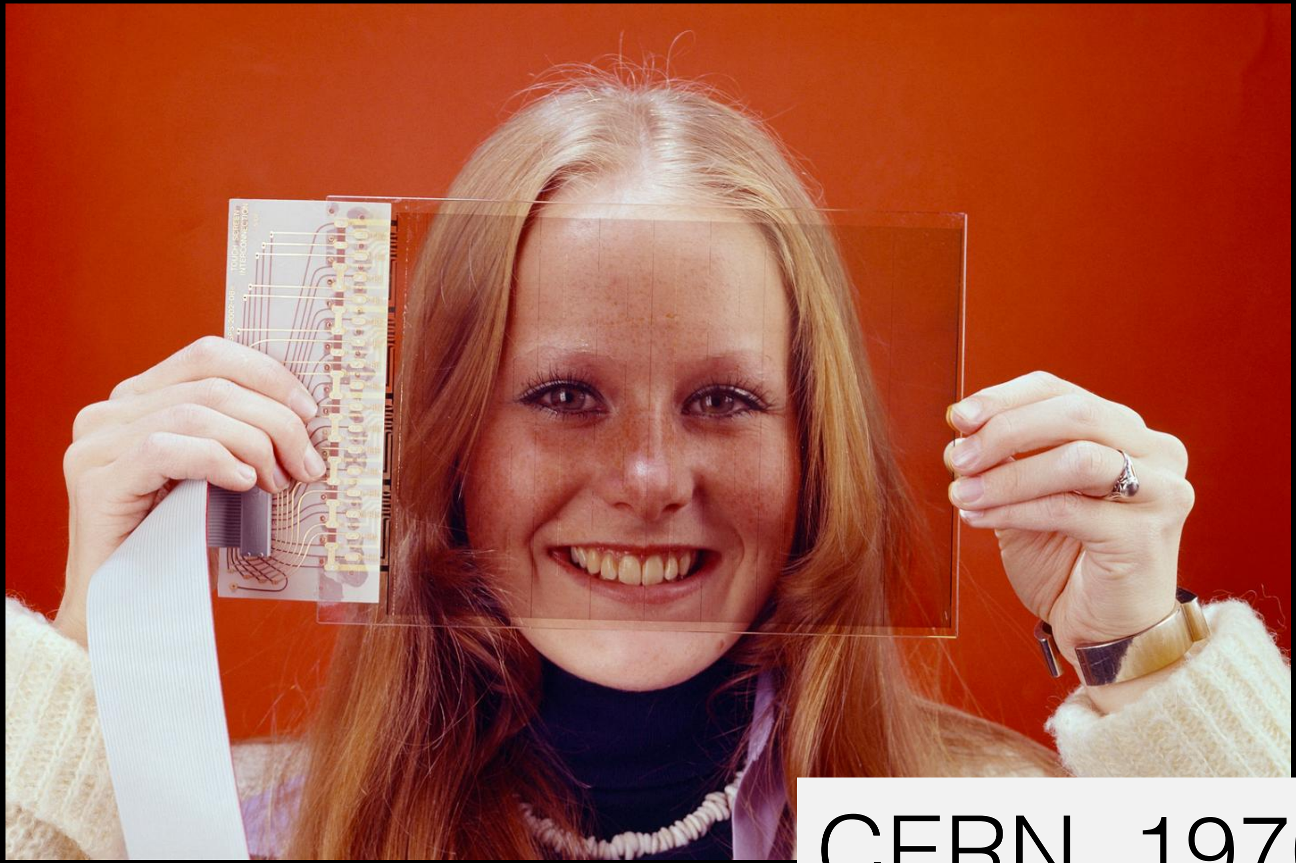
The ISEULT project -
a French-German initiative

Full field of 11.72 teslas
achieved the 18th of July 2019

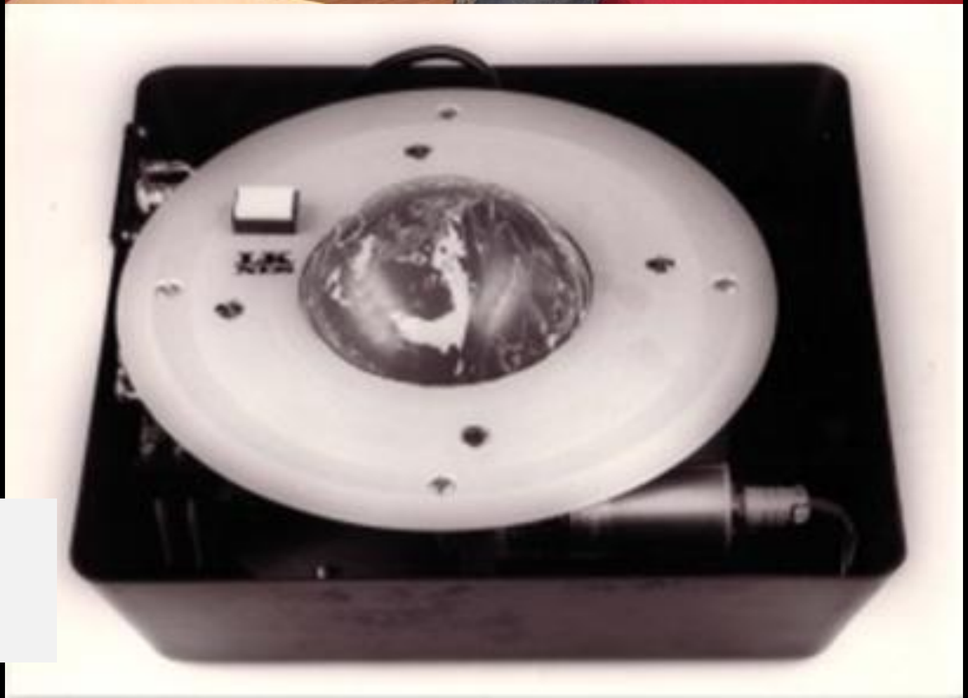
NEUROSPIN:
a unique
concept in
neuroscience
research



How do we MAXIMISE IMPACT?



CERN, 1970s



SCIENCE AND TECHNOLOGY BRIEFINGS
PARLIAMENTARY OFFICE FOR SCIENTIFIC AND TECHNOLOGICAL ASSESSMENT

Briefing n° 12 — February 2019

Large particle accelerators

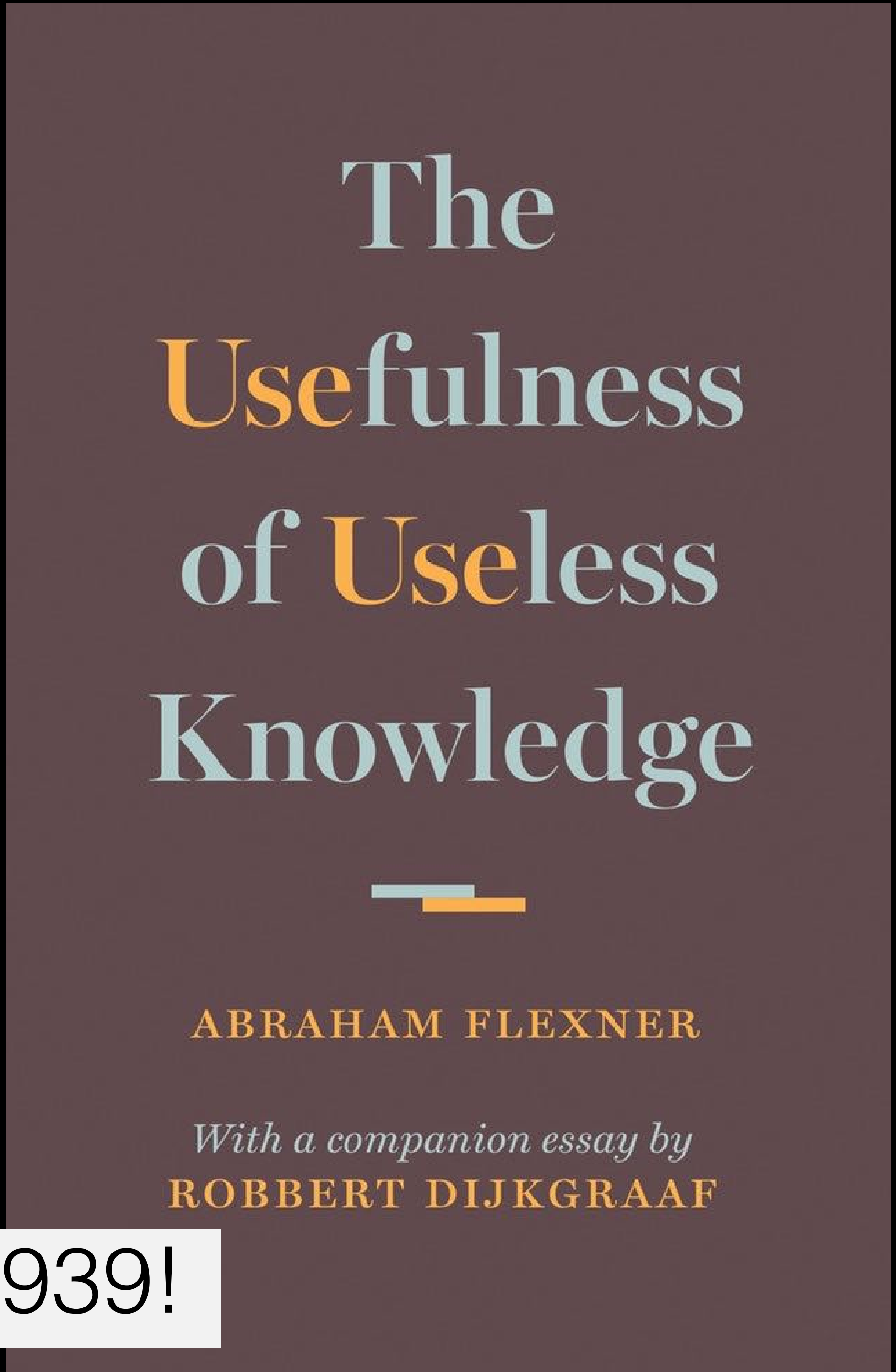
Ring segment of a particle accelerator
© fotonat67 / Adobe Stock

Summary

- *Particle accelerators, like other kinds of "very l… (VLRI), make it possible to manage cutting-e… strategic issues: acquiring knowledge, enhan… preparing for technological breakthroughs, sci…*
- *CERN, the European particle physics labora… biggest circular particle accelerator in the wor… the highest energies produced to date.*
- *A decision by the Japanese government is ex… accelerator project, the ILC, proposed sin… scientific community.*
- *Thinking on the future European strategy for particle physics began in 2018 and should be presented in spring 2020. If the Japanese government confirms its interest in ILC, this European strategy must take account of this fact: a possible contribution from Europe, and particularly France, must be assessed in terms of scientific return, cost and industrial benefits.*

Mr. Cédric Villani, MP (National Assembly), First Vice-Chairman

CERN has also had a very strong societal impact via **the creation of the *World Wide Web* (WWW)** in 1989[21] under the leadership of Tim Berners-Lee and his collaborator Roger Cailliau. It was originally a response to researchers' need to exchange a high volume of data simply and instantaneously for



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.

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