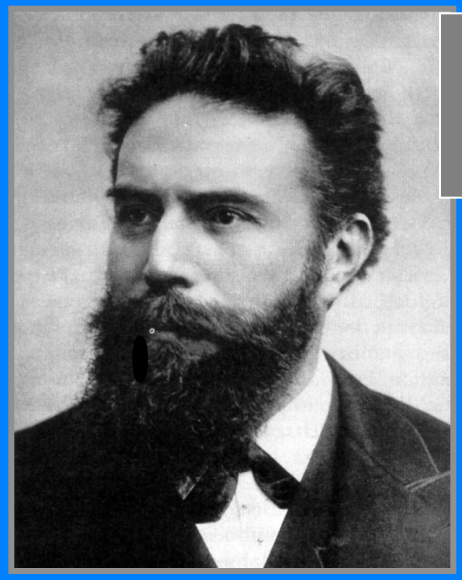
THE IMPACT OF FUNDAMENTAL PHYSICS ON MEDICINE

Ugo Amaldi

The beginnings of fundamental Physics and medical Physics



Wilhelm C. Röntgen

9 November 1895

Discovery of X rays

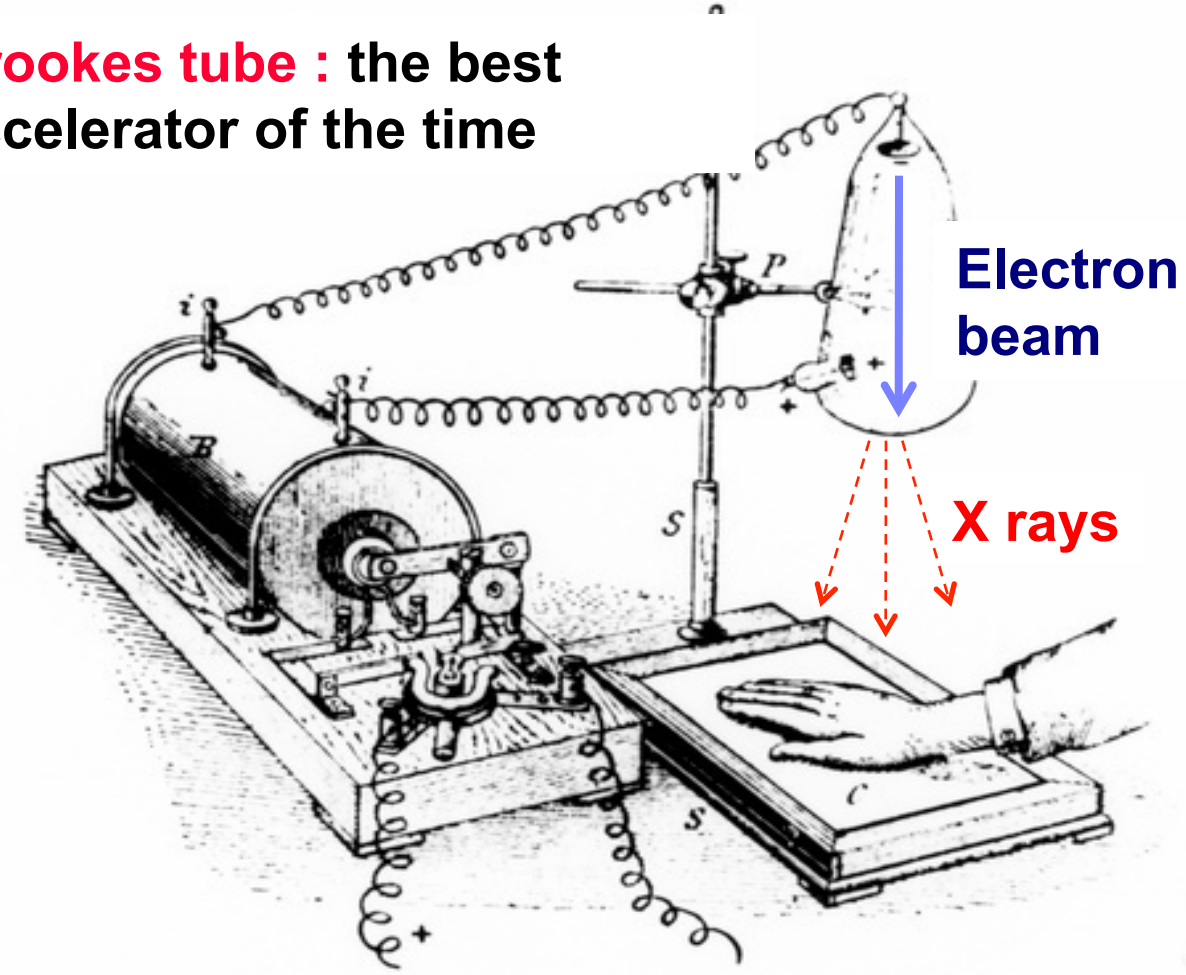
1898

Discovery of radium

Marie Slodowska - Pierre Curie

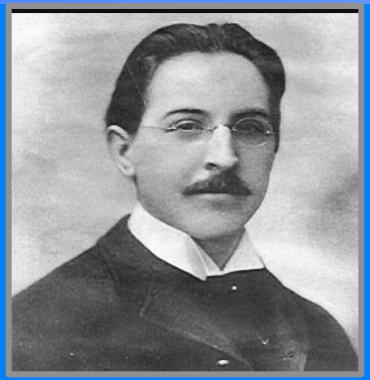
First medical use of an accelerator

Crookes tube : the best accelerator of the time



Announcement: December 28, 1985

First uses of X rays and radium in diagnostics and therapy

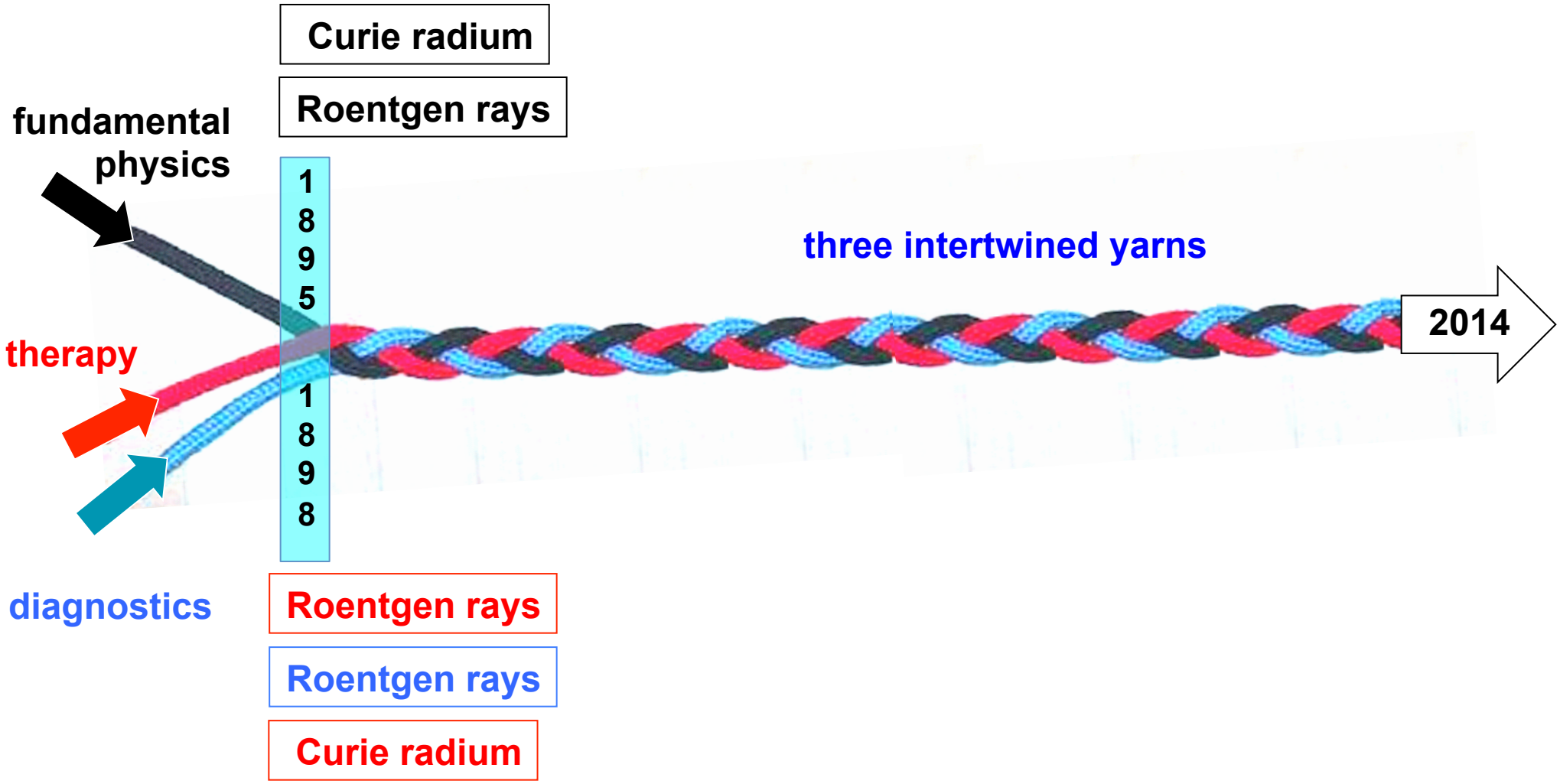


Emile Grubbe
(Chicago)
4 hour irradiation of a breast cancer
January 27,1896

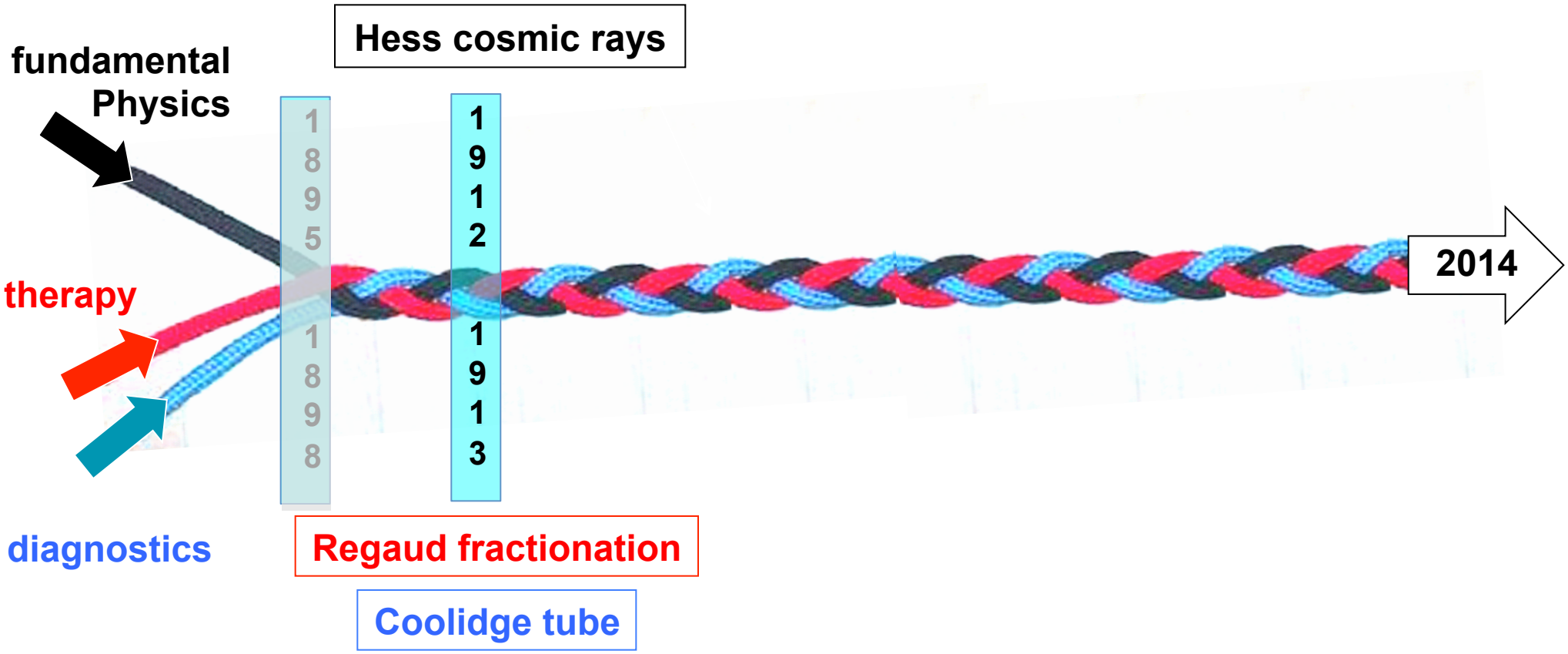
Robert Jones and Oliver Lodge
(Liverpool)
Radiography of a bullet in a hand
February 7, 1896

Henri Danlos
(Paris)
Lupus treatment with radium
1901

120 years of fundamental (beautiful) and medical (useful) physics



120 years of fundamental (beautiful) and medical (useful) Physics

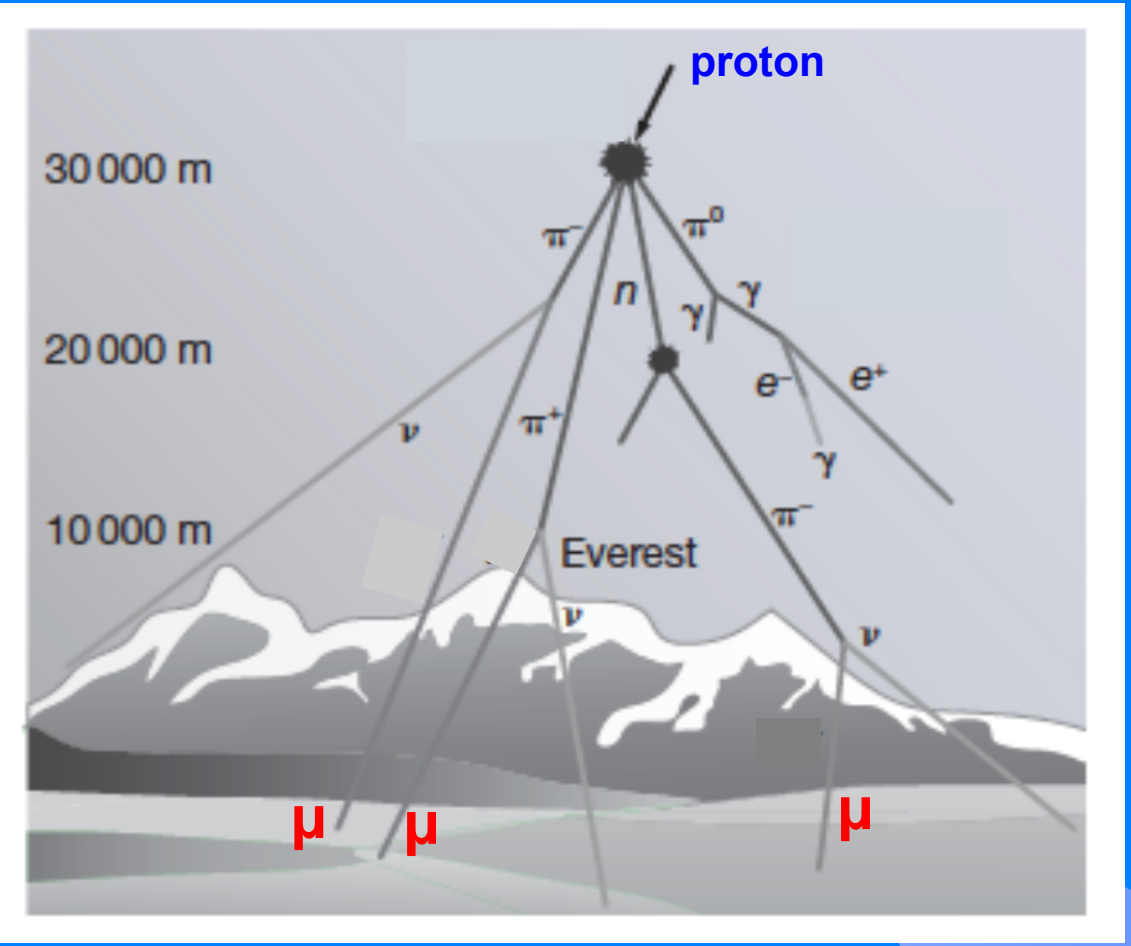


1912: Victor Hess discovers ‘cosmic rays’

100 YEARS AGO

Hess brought precision equipment in ten balloon ascents and discovered that radiation at 5 km altitude is twice larger than at see level.

Thirty years later the mechanism of cosmic rays was understood and marked the beginning of particle physics



muons are ‘heavy electrons’ with a mass that is 200 times larger

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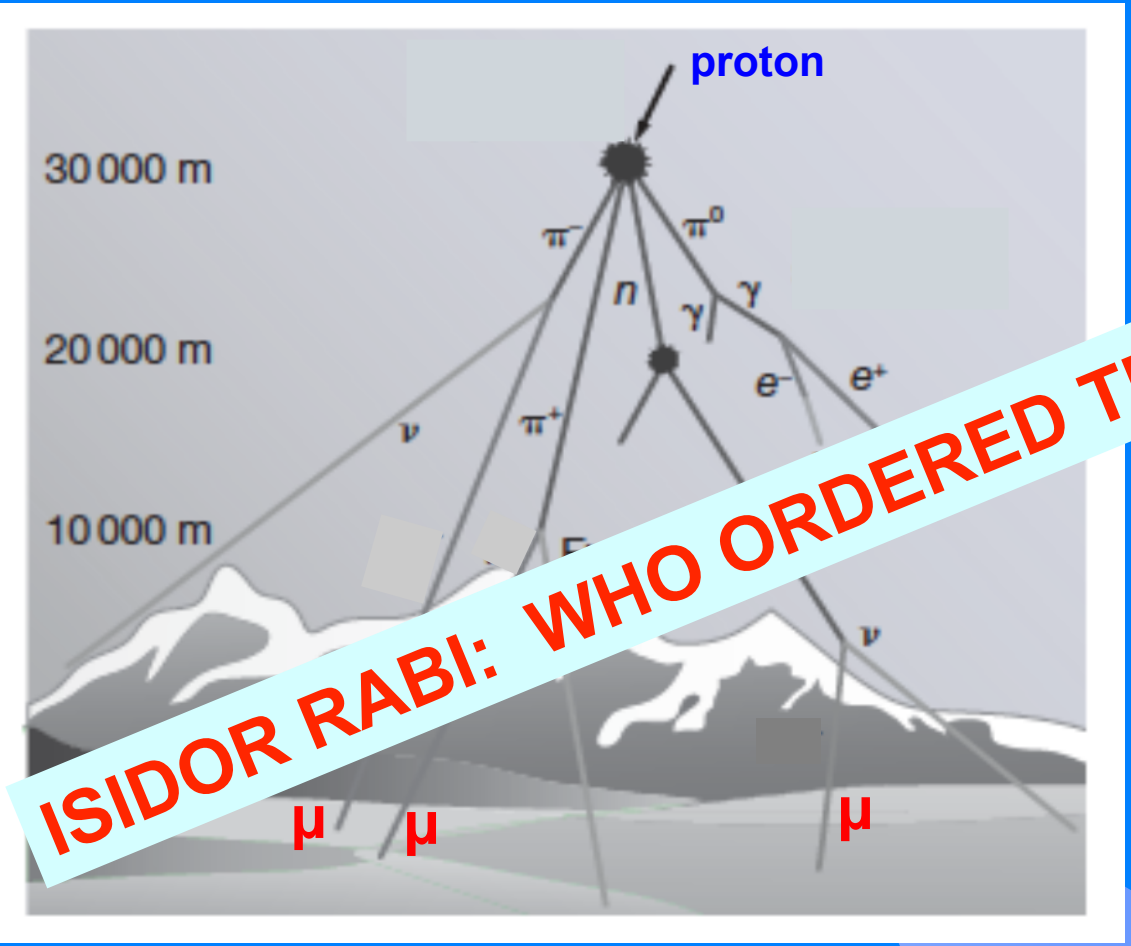
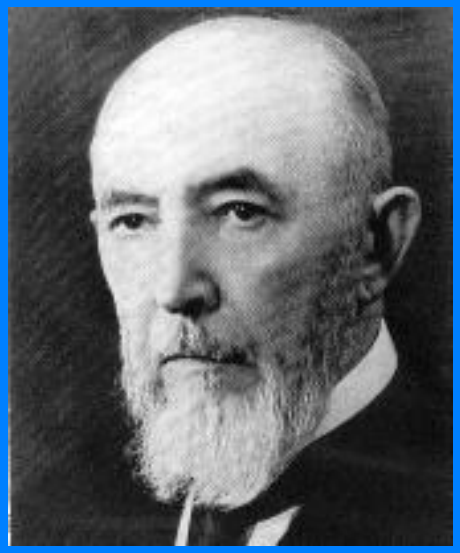


muons are ‘heavy electrons’ with a mass that is 200 times larger

Fractionation in Radiotherapy

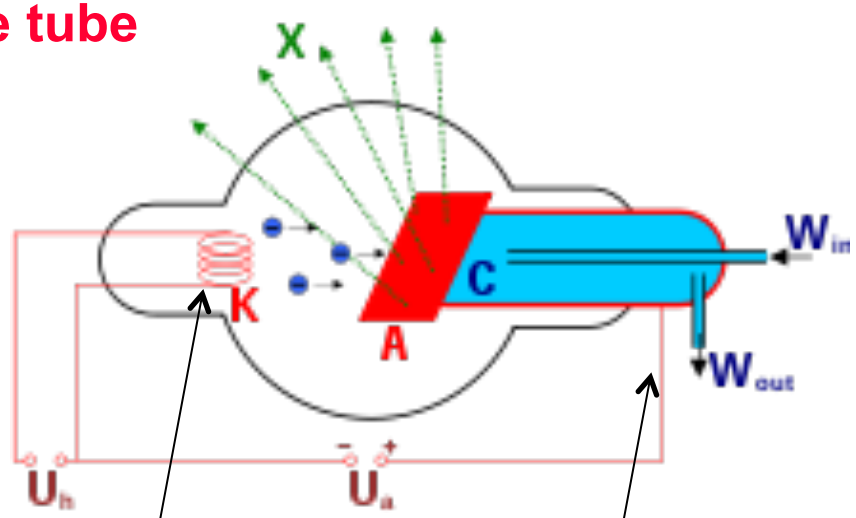
1912 - Paris
Claudius Regaud:
The same dose is more effective if subdivided



Institut du Radium

1930 - Claudius Regaud and Henri Coutard:
Standard at 200 keV = 0,2 MeV:
2 grays per session
5 sessions per week
treatment in 5-6 weeks

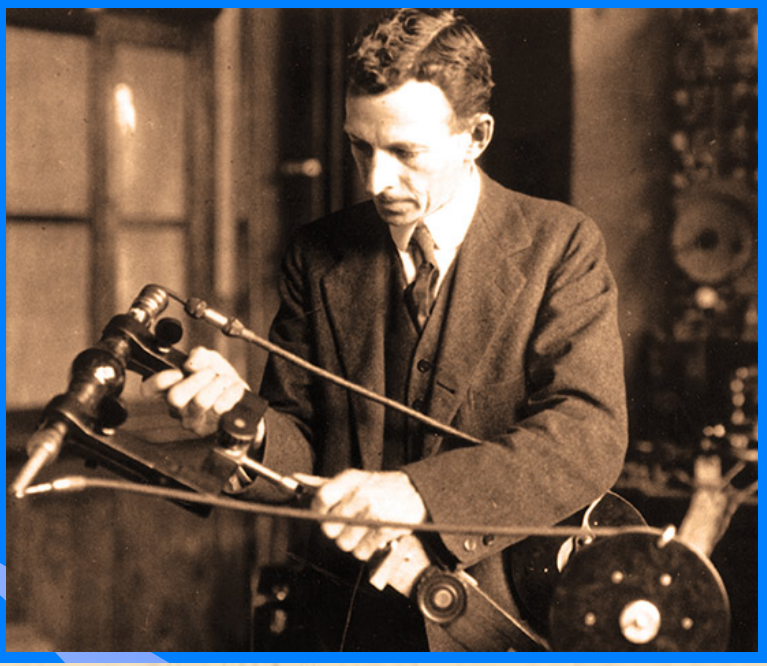
Coolidge tube 1912



Heated tungsten filament

Cooling water

A breakthrough



UNITED STATES PATENT OFFICE.

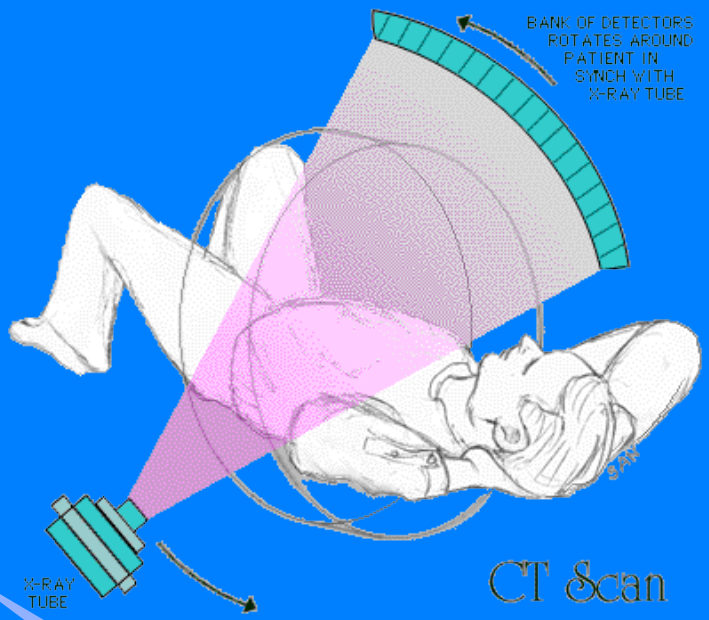
WILLIAM D. COOLIDGE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

TUNGSTEN AND METHOD OF MAKING THE SAME FOR USE AS FILAMENTS OF INCANDESCENT ELECTRIC LAMPS AND FOR OTHER PURPOSES.

1,082,933. Specification of Letters Patent. Patented Dec. 30, 1913.

Application filed June 19, 1912. Serial No. 704,580.

Today every CT Scan uses a Coolidge tube



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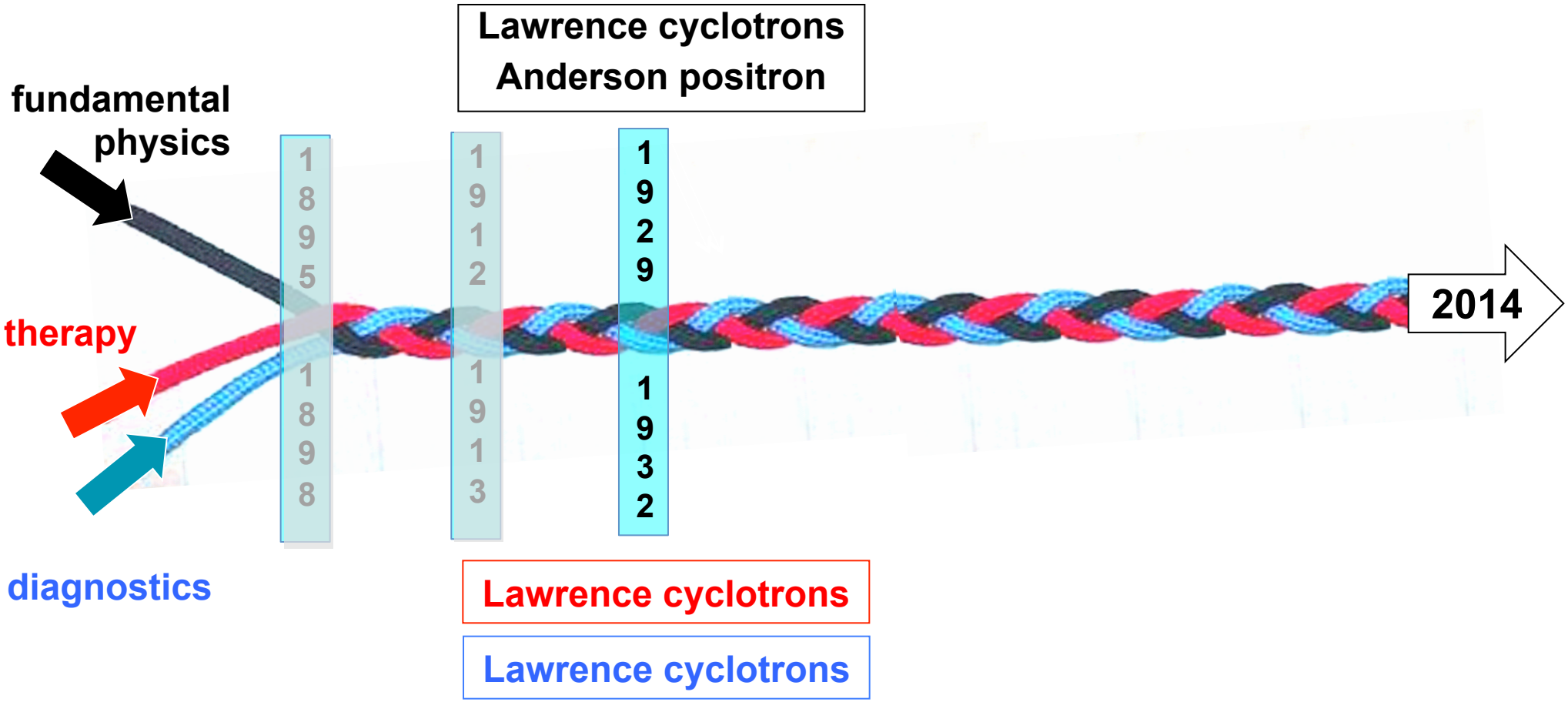
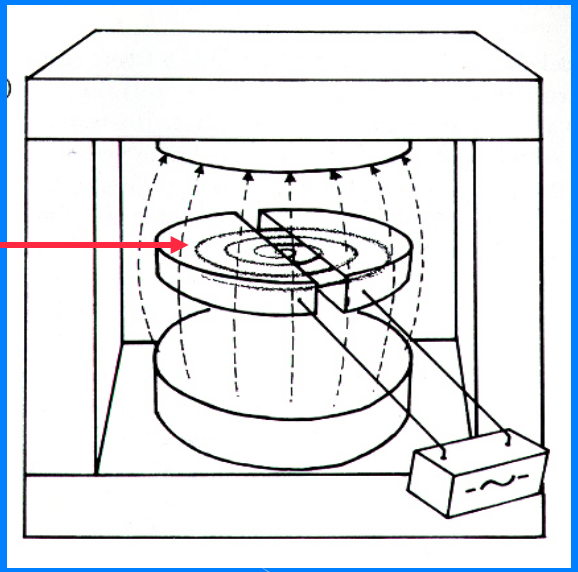


1929: invention of the "cyclotron"

Spiral trajectory of an accelerated particle



Ernest Lawrence -

1 MeV = 1 million electronvolts

= 0.001 GeV

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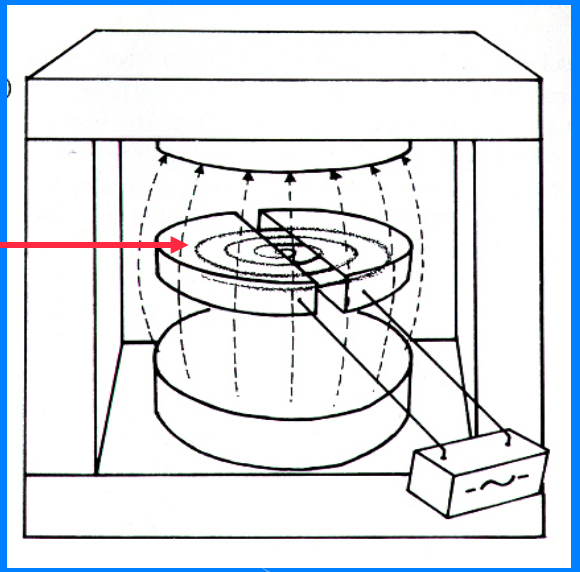


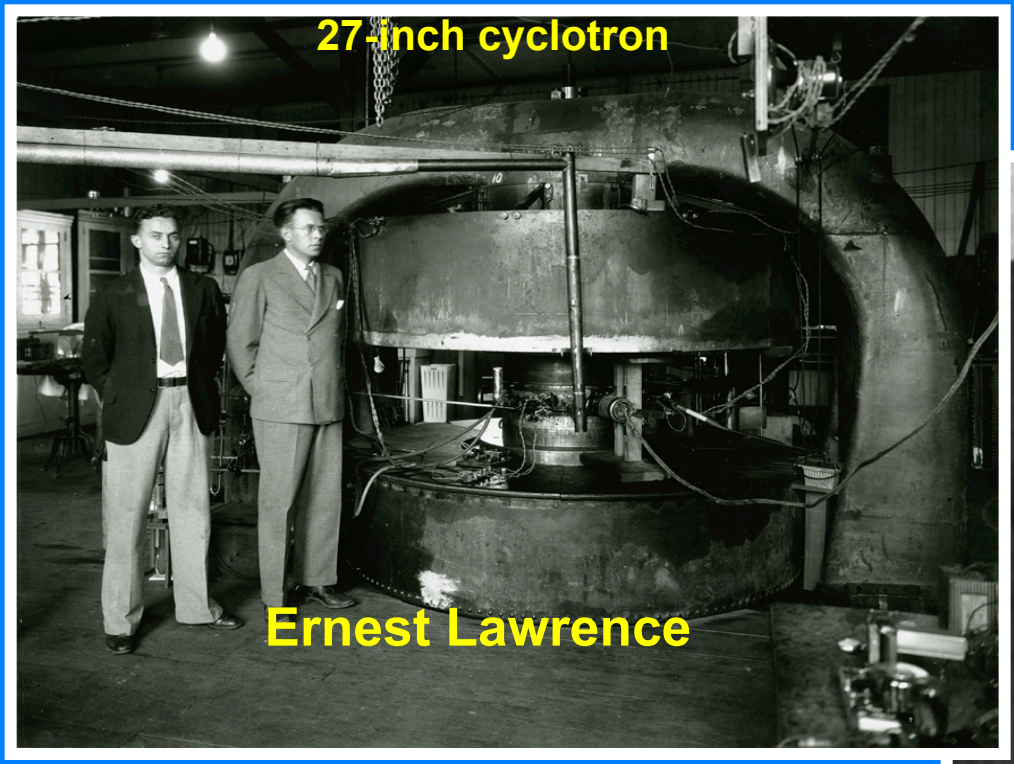
Ernest Lawrence -

Modern 30 MeV cyclotron for radioisotope production

1 MeV = 1 million electronvolts

= 0.001 GeV

Cyclotrons in diagnostics and therapy

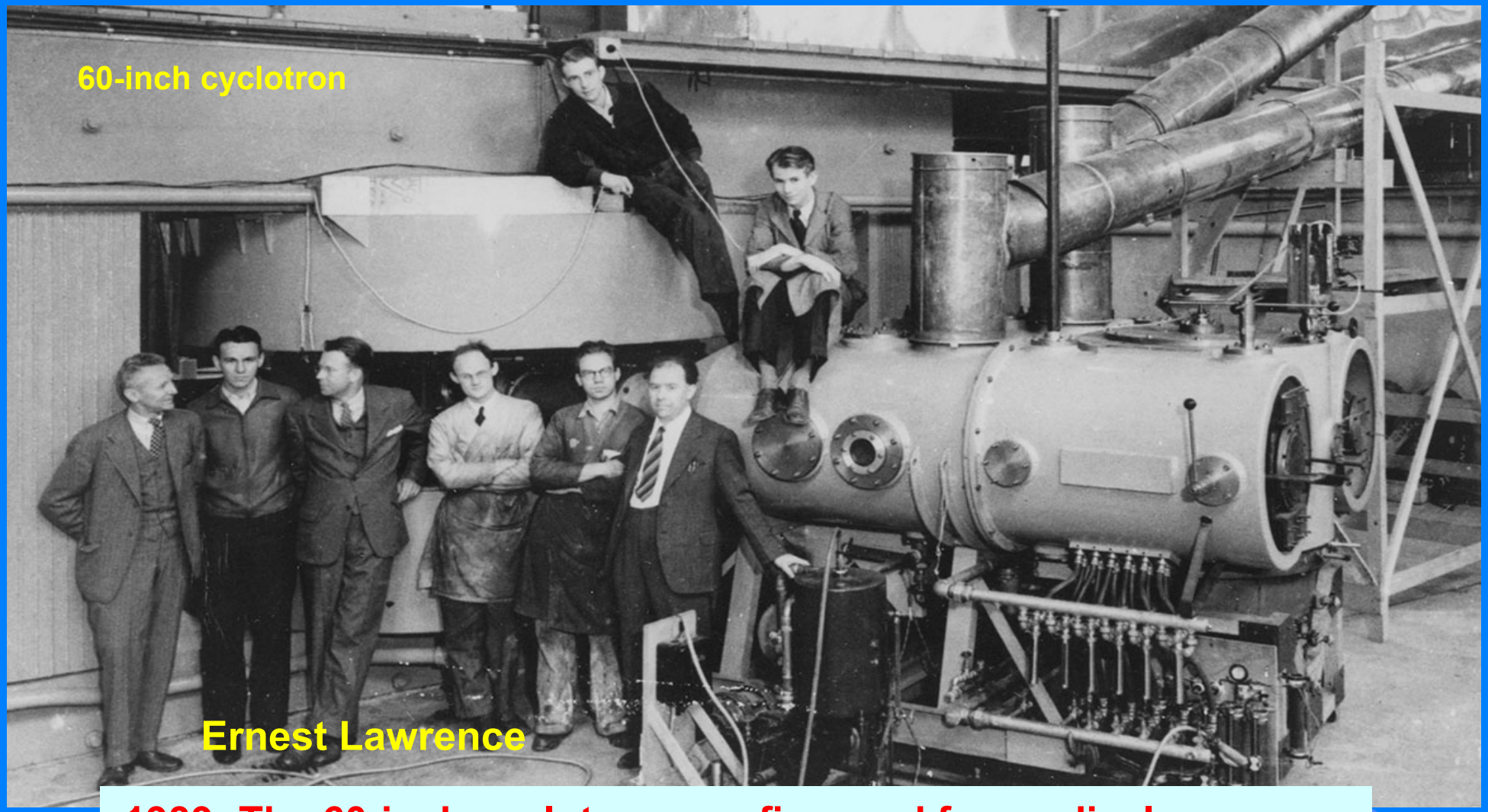


John Lawrence, MD

1936: Radio-sodium to study metabolism

1936: Radio-phosphorus to treat leukaemia

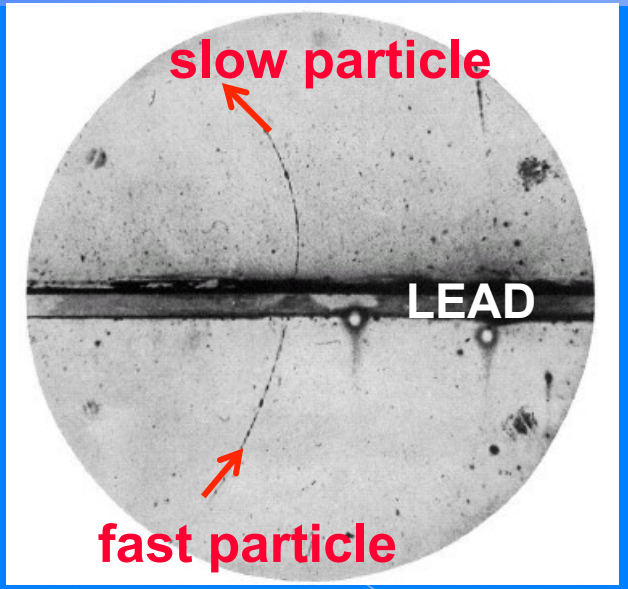
Cyclotrons in diagnostics and therapy

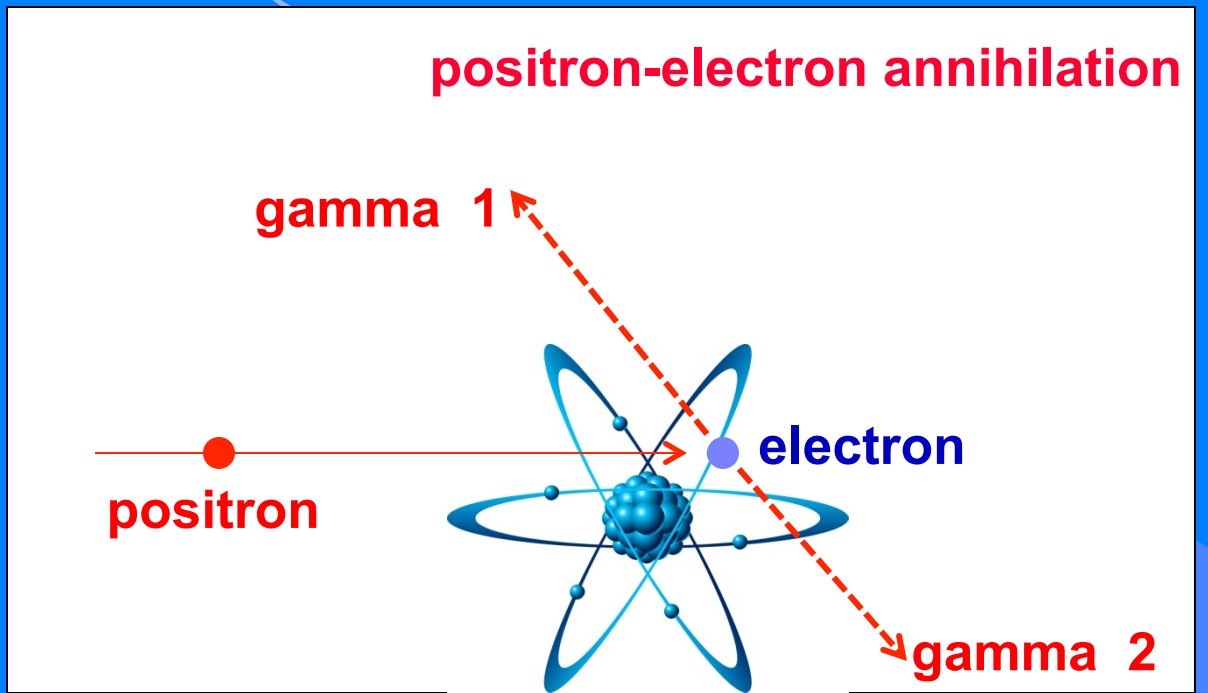


1939: The 60-inch cyclotron was financed for medical purposes and later used to treat patients with neutron beams

Discovery of the anti-electron

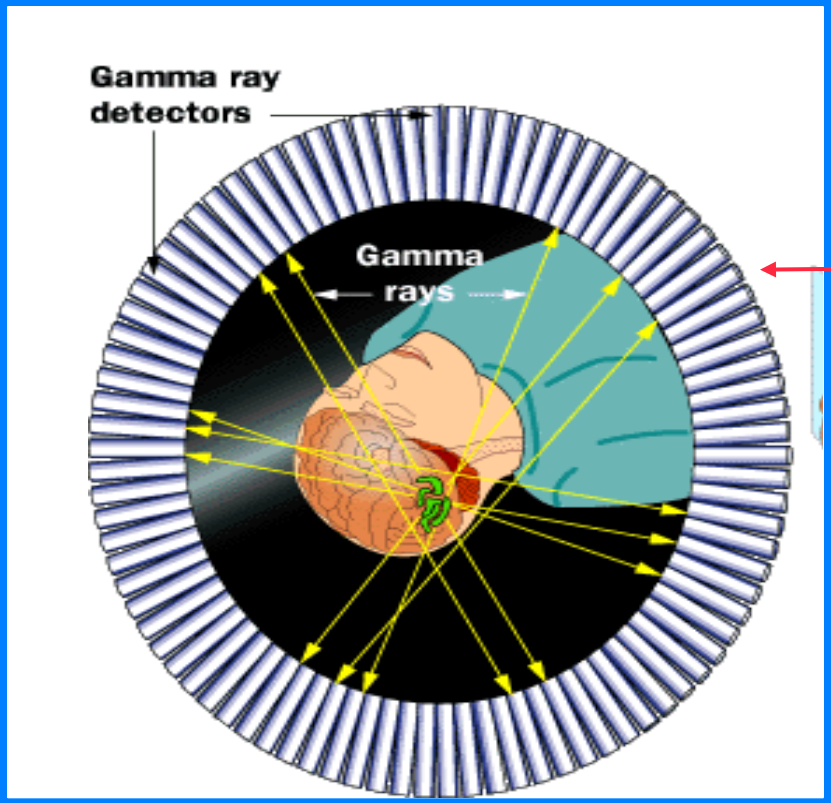
Carl Anderson - CALTECH
1932

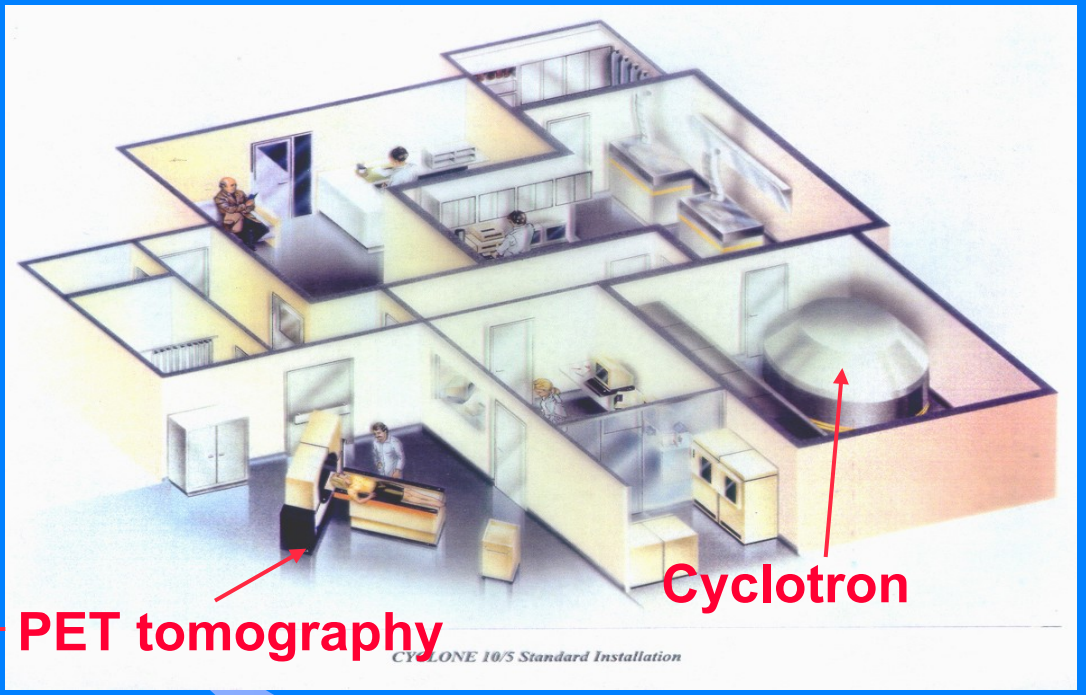


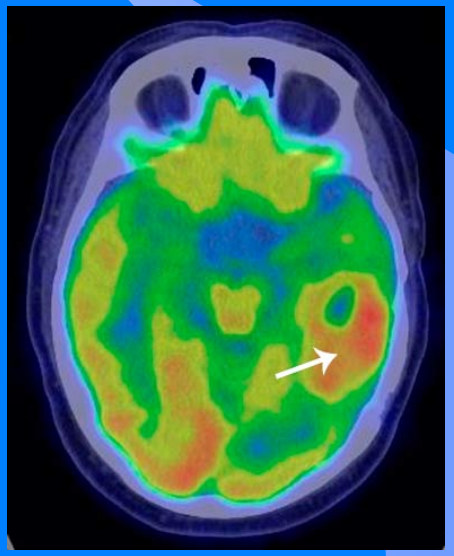


PET centre with a 15 MeV cyclotron

Most used substance
Sugar FDG with Fluorine -18



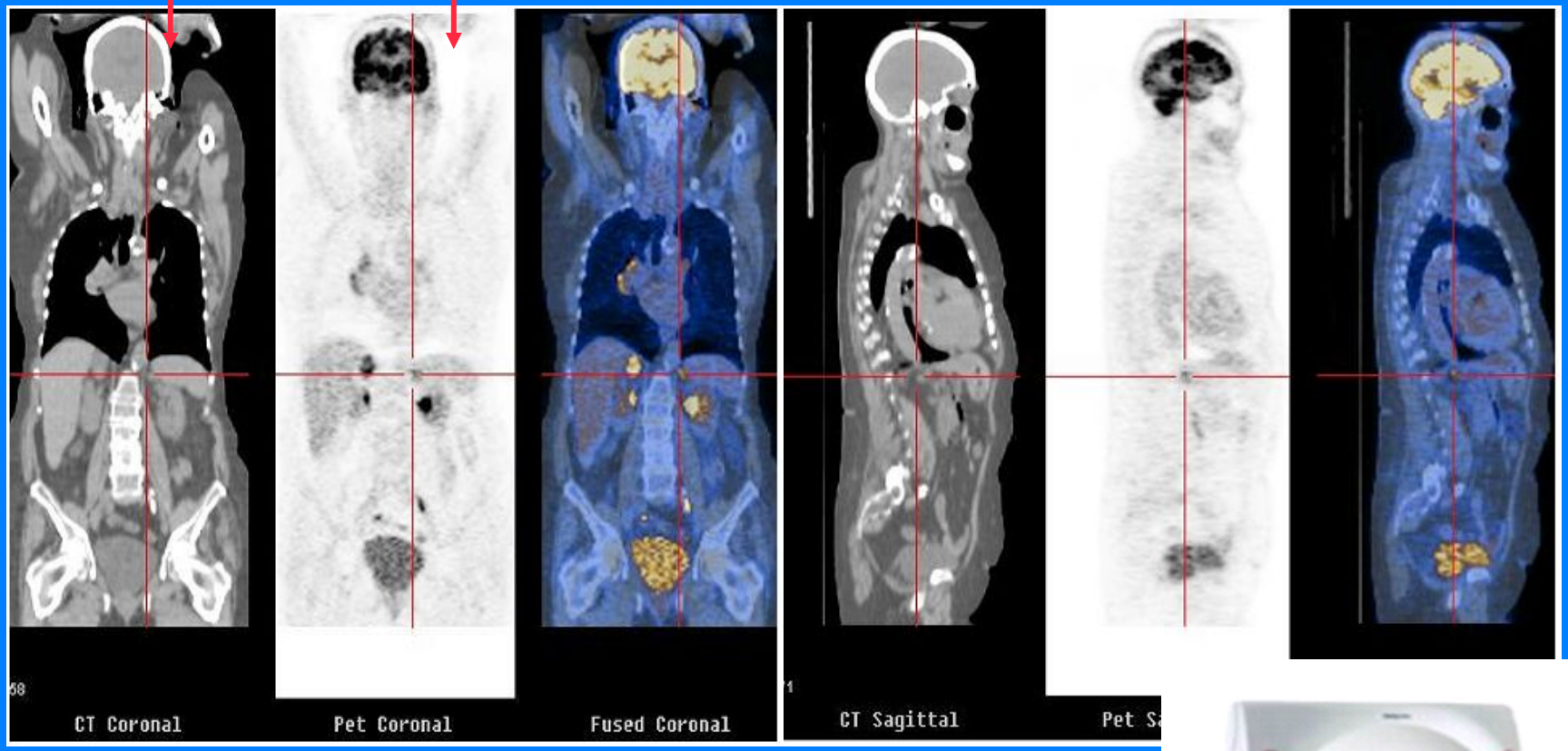




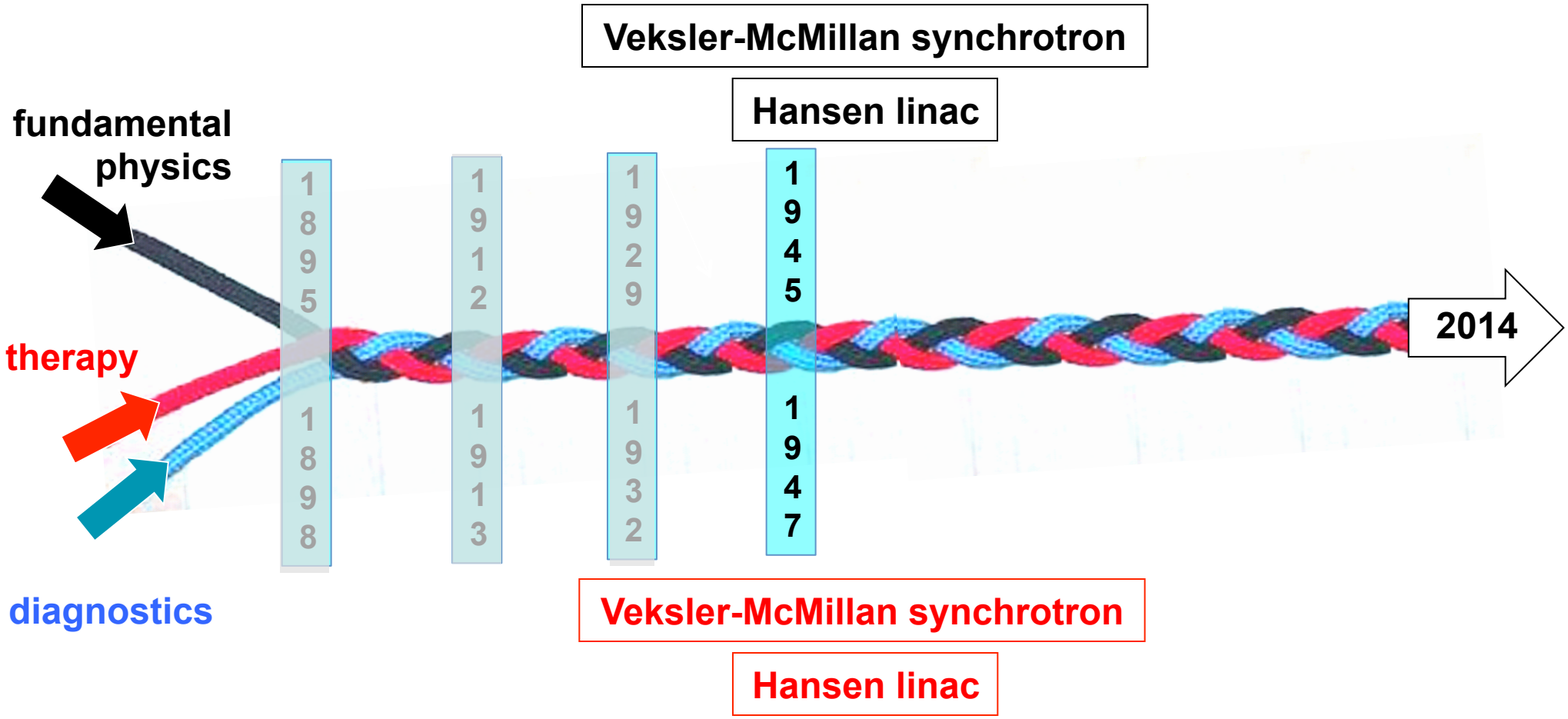
Combination of CT with PET : CT-PET

morphology

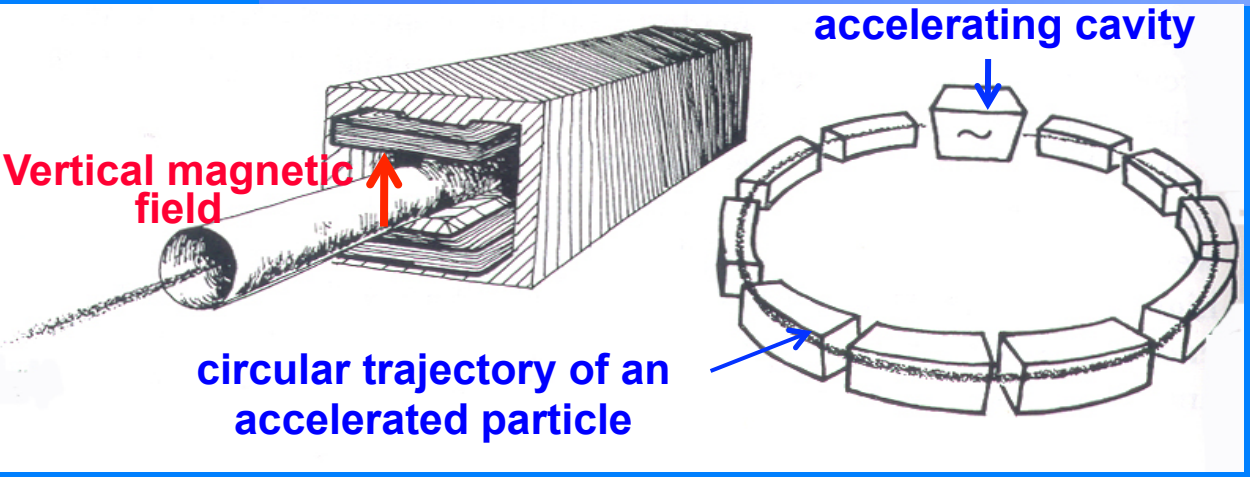
metabolisme



120 years of fundamental (beautiful) and medical (useful) Physics



The invention of the synchrotron came in 1945



E. McMillan and V.J.Veksler

"Phase stability principle"

1959: Veksler visits McMillan at Berkeley

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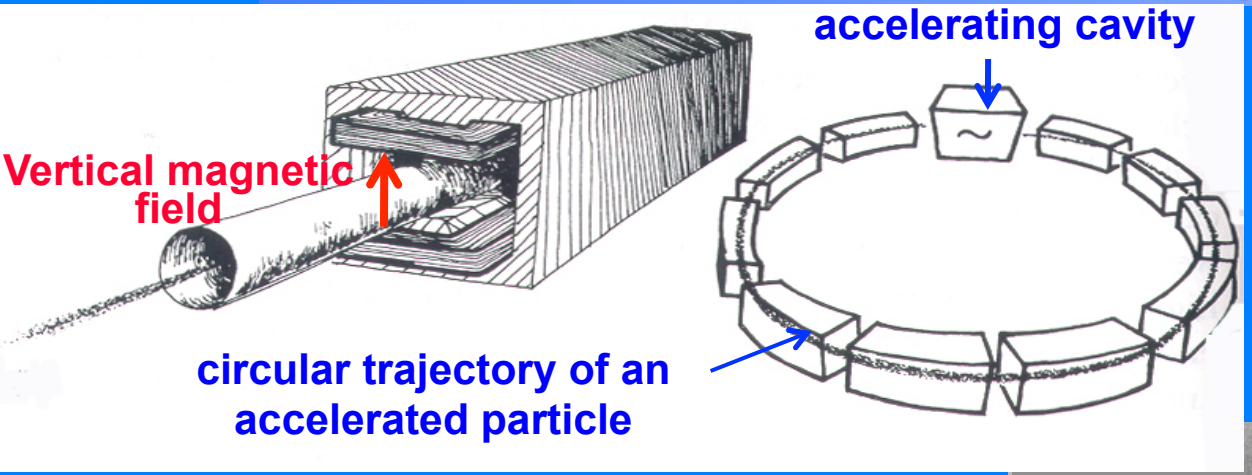

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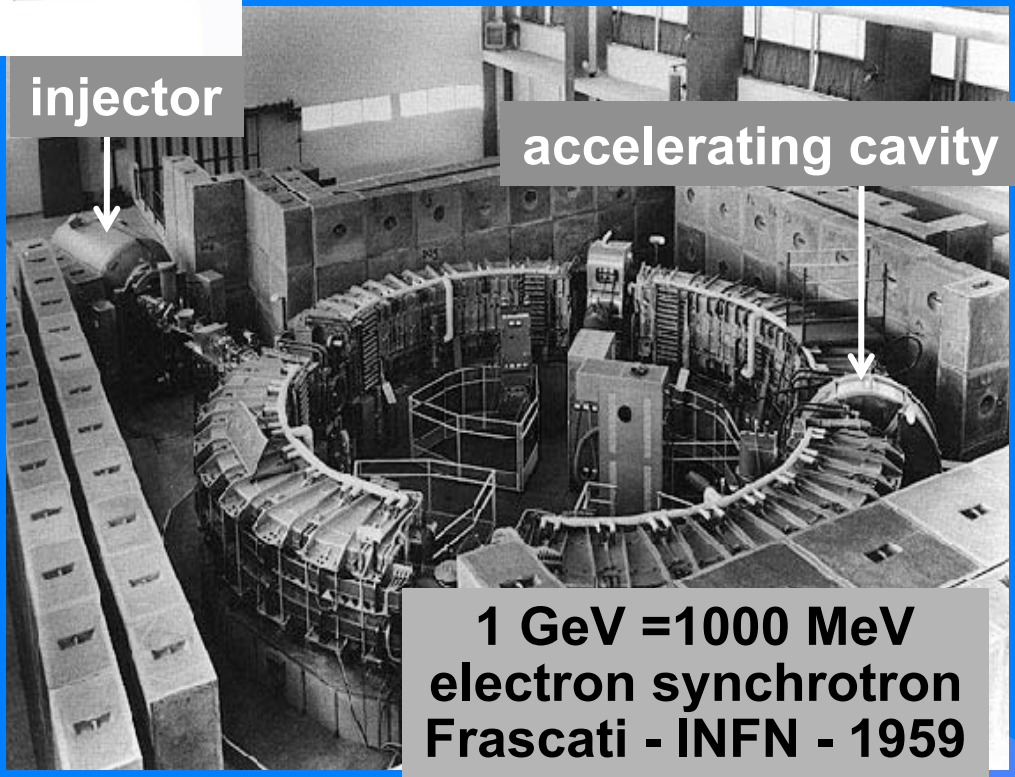
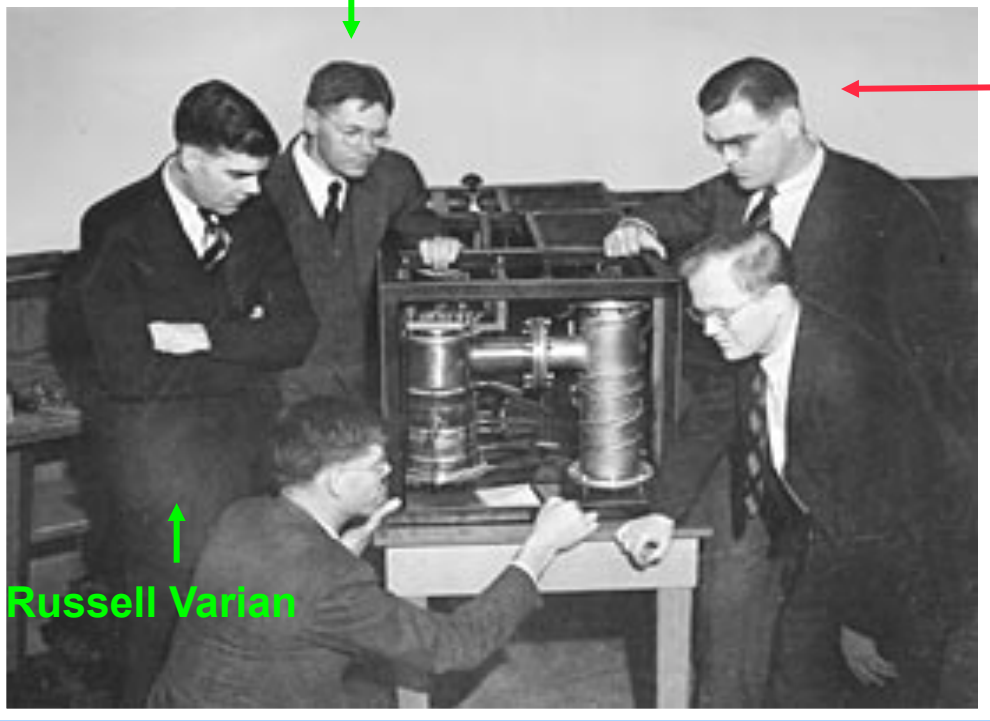


1 GeV =1000 MeV
electron synchrotron
Frascati - INFN - 1959

The first electron linac above 1 MeV

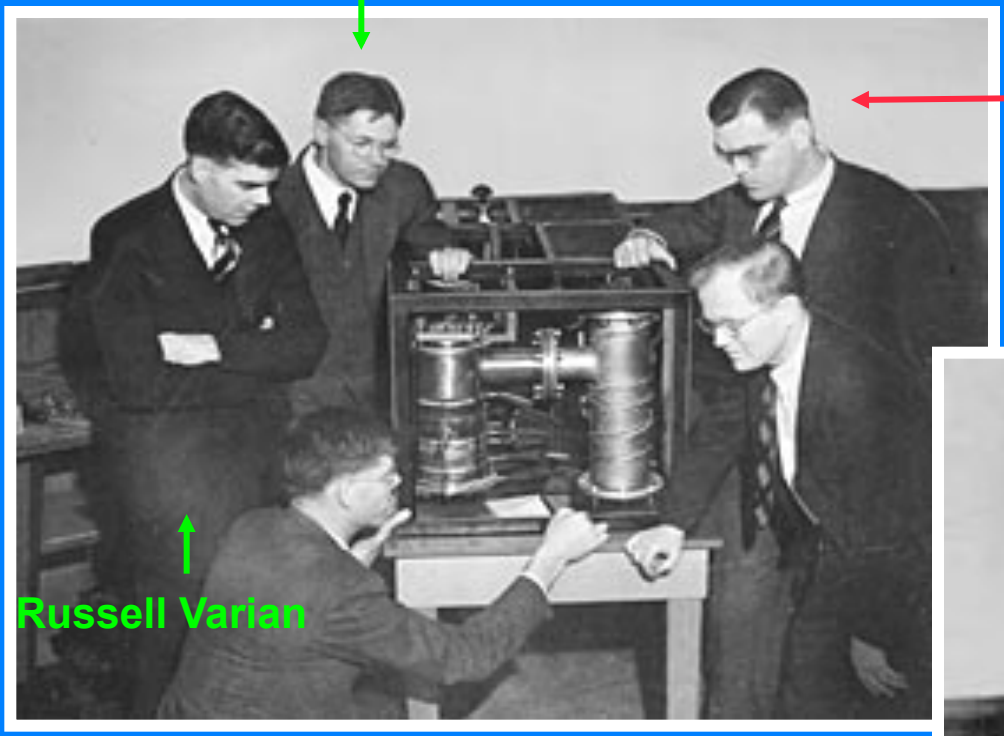


1939

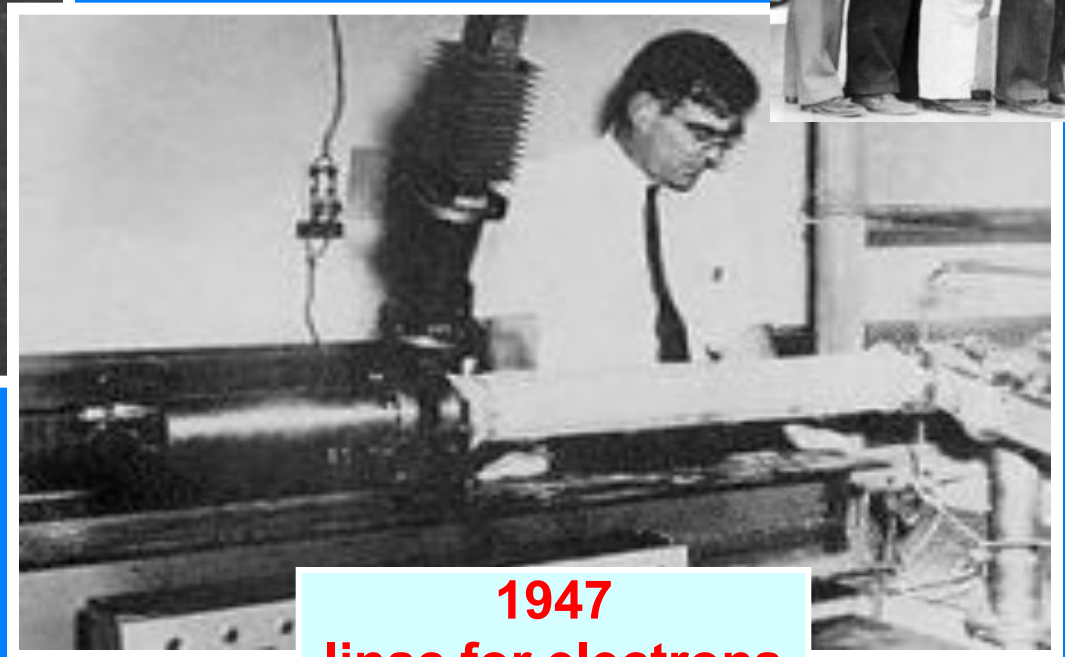
Invention of the klystron

The first electron linac above 1 MeV

Sigmur Varian



William W. Hansen

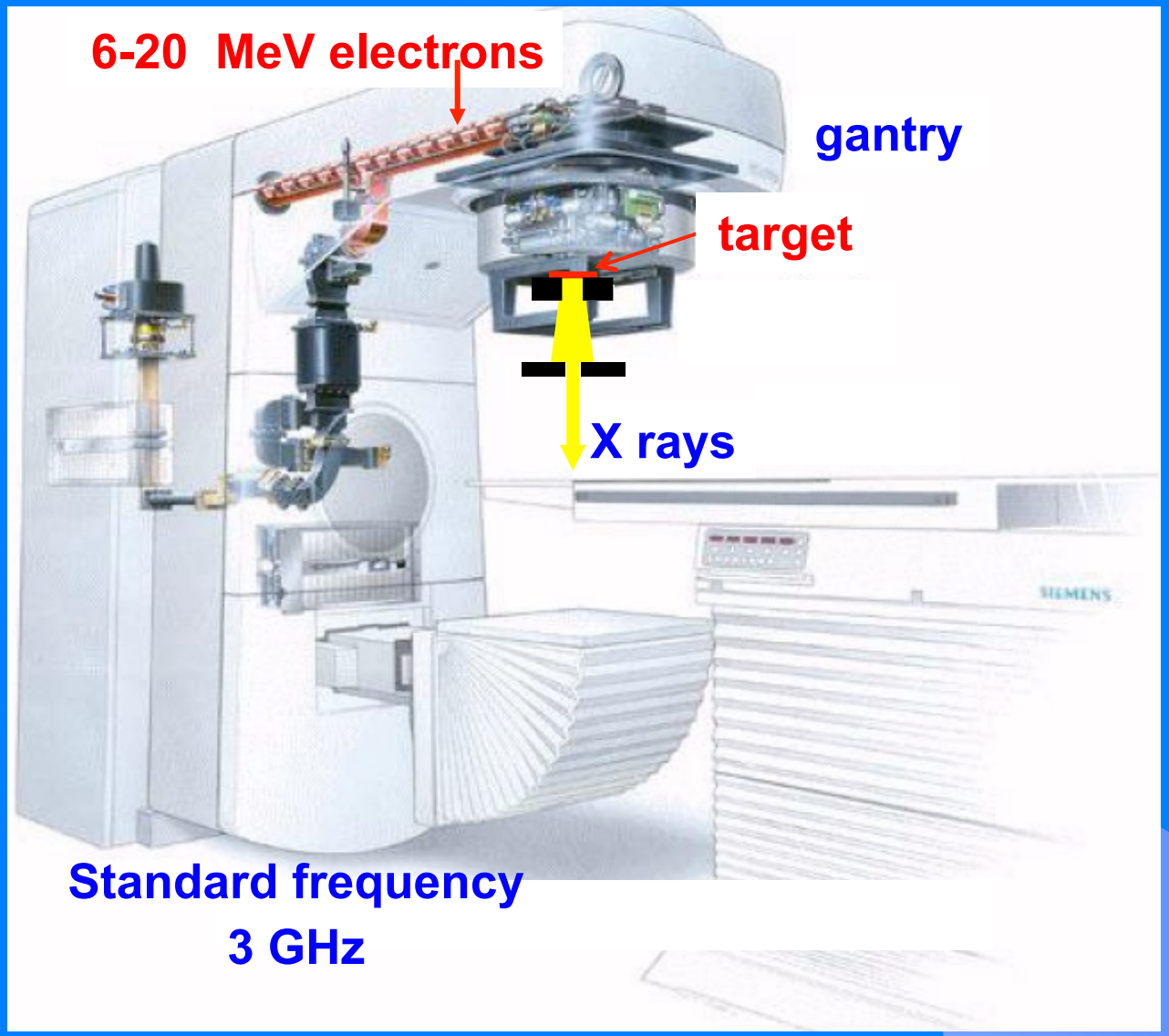


1939

Invention of the klystron

1947
linac for electrons
1.5 MeV at 3 GHz

‘Conventional’ radiotherapy: linear accelerators dominate



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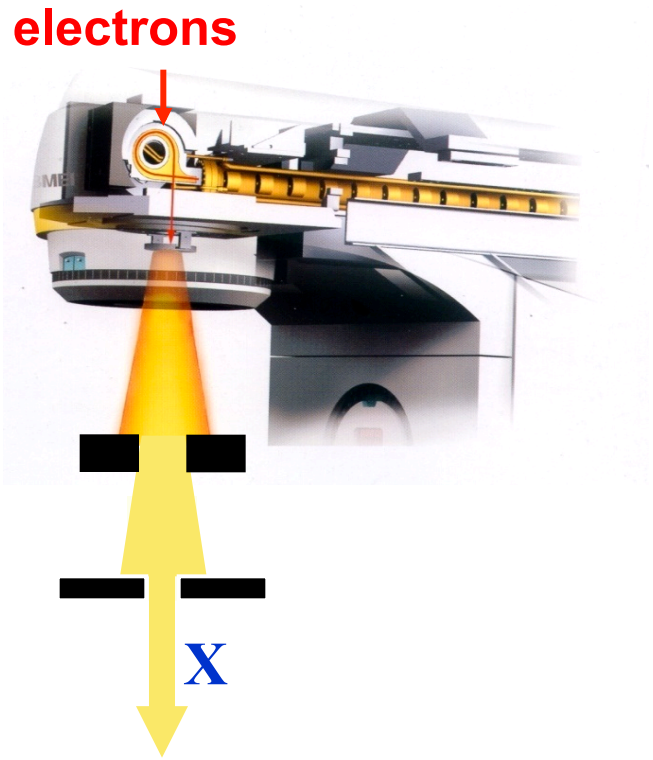
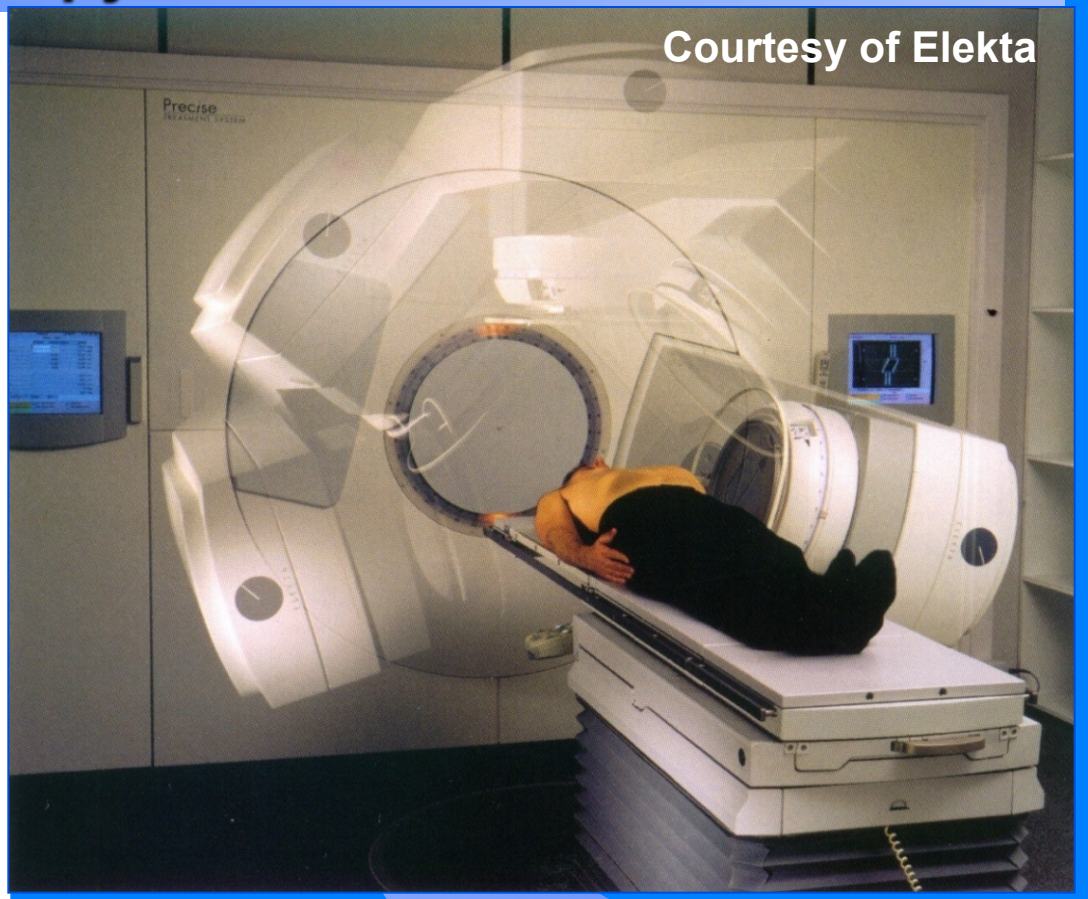


2000 patients/year every in 1 million inhabitants

1 treatment in 30 sessions

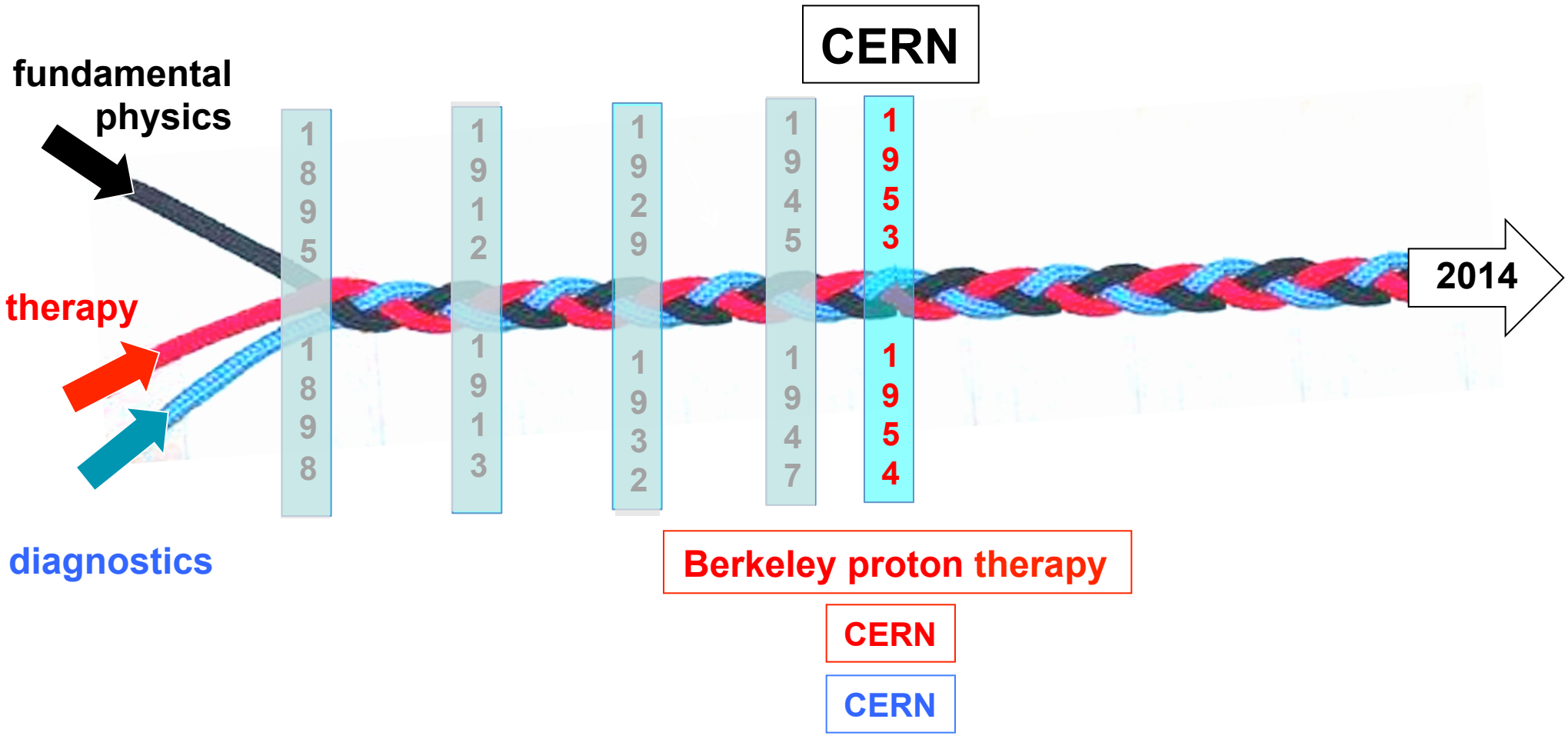


In the world radiation oncologists use 20 000 electron linacs

50% of all the existing accelerators

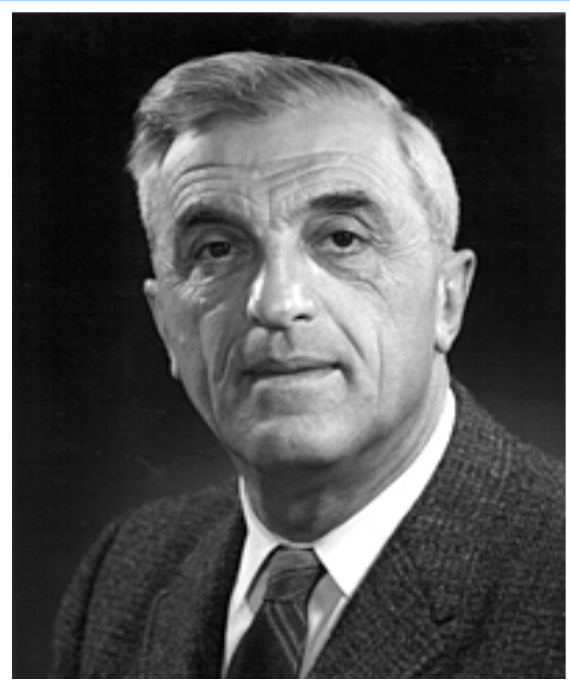
70 years later VARIAN is still the market leader

120 years of fundamental (beautiful) and medical (useful) physics



Following the black yarn: particle physics at CERN

60 years ago: creation of CERN



Pierre Auger

Science Director of UNESCO

Edoardo Amaldi

Secretary General of provisional CERN 1952-1954

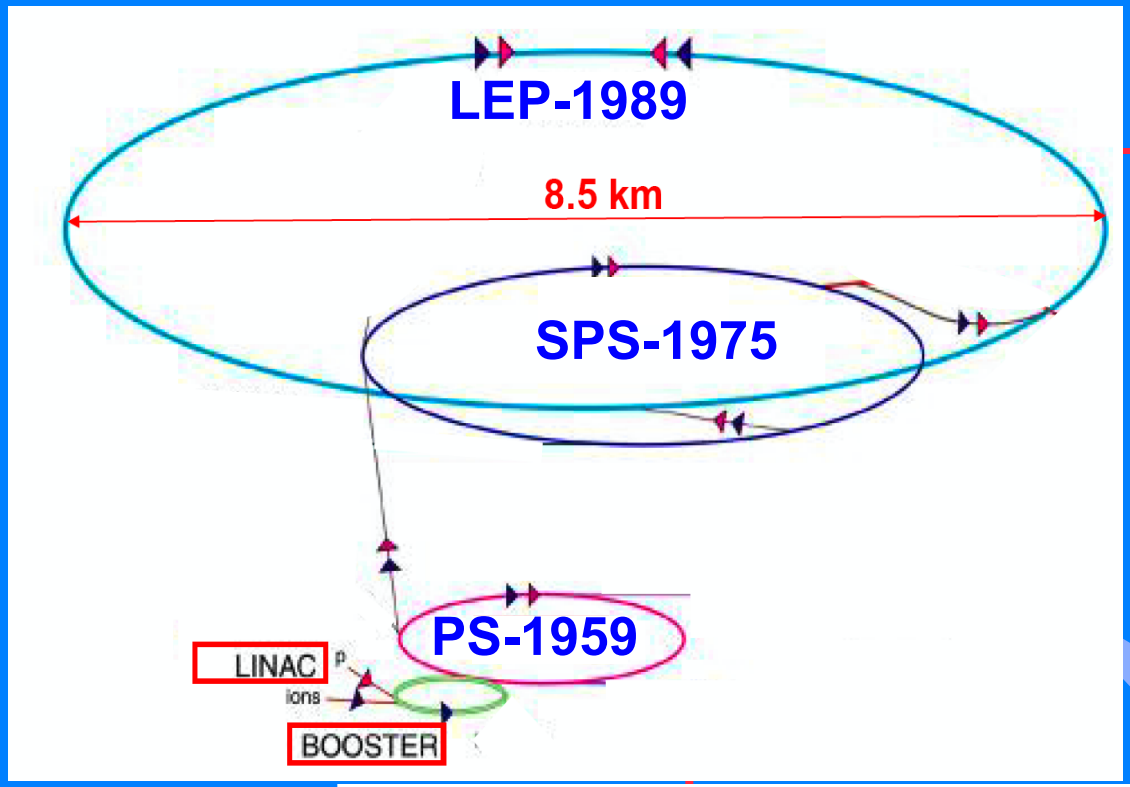
Felix Bloch

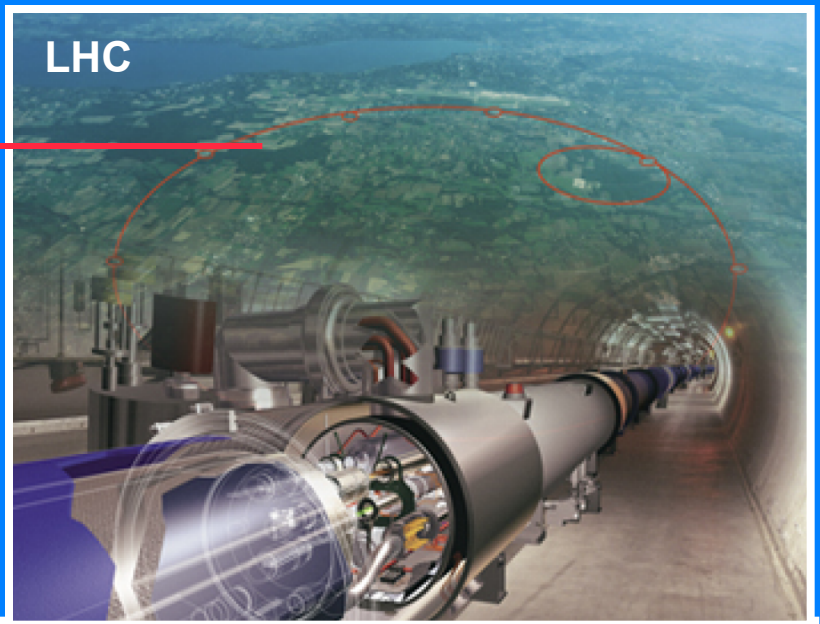
Physics Nobel Prize in 1952

First CERN Director General 1954-1955

CERN aerial view with the Geneva Airport

CERN accelerators are synchrotrons used as “colliders”





LHC in 2012

Large **H**adron **C**ollider

4 000 + 4 000 GeV

PS nel 1959 – 25 GeV

To focus only on the most important discovery made with CERN accelerators we most go back to 'cosmic rays'

100 YEARS AGO

Hess brought precision equipment in ten balloon ascents and discovered that radiation at 5 km altitude is twice larger than at see level.

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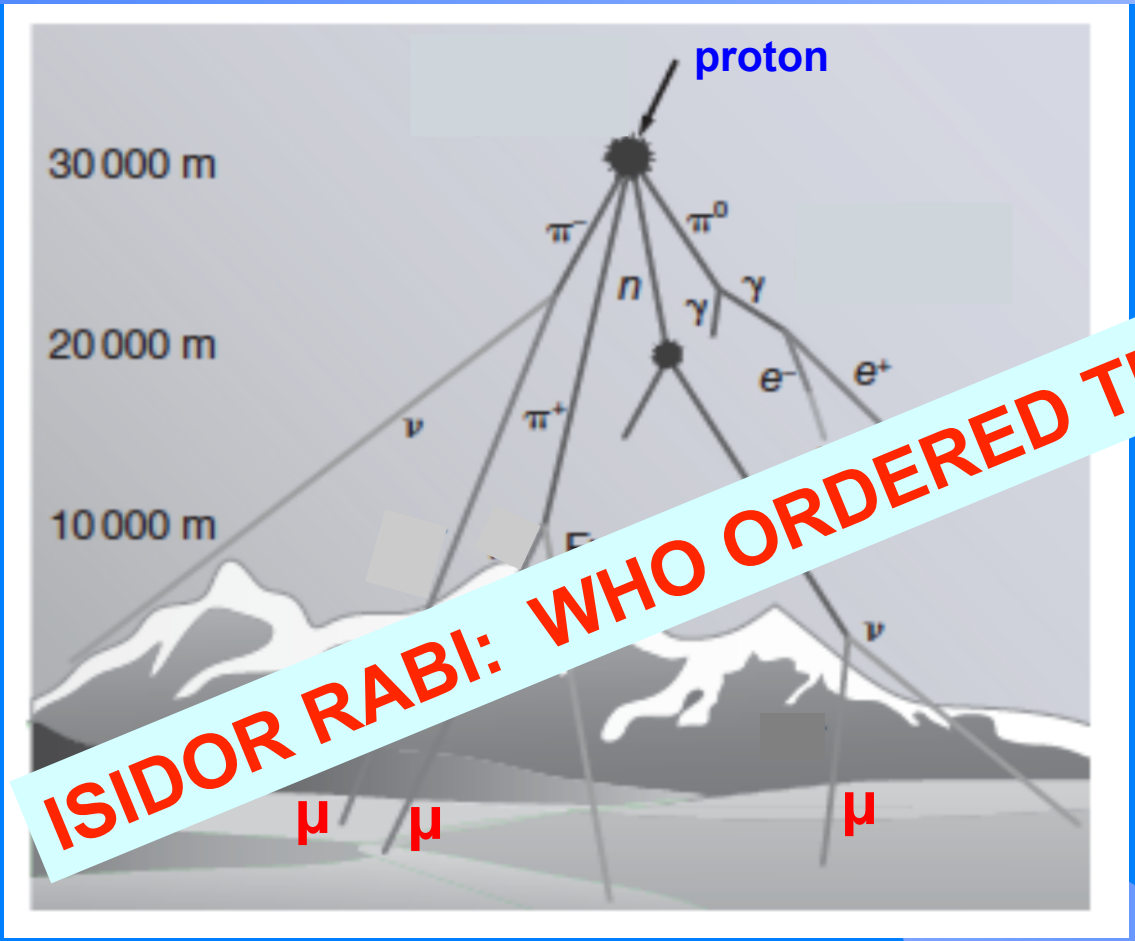
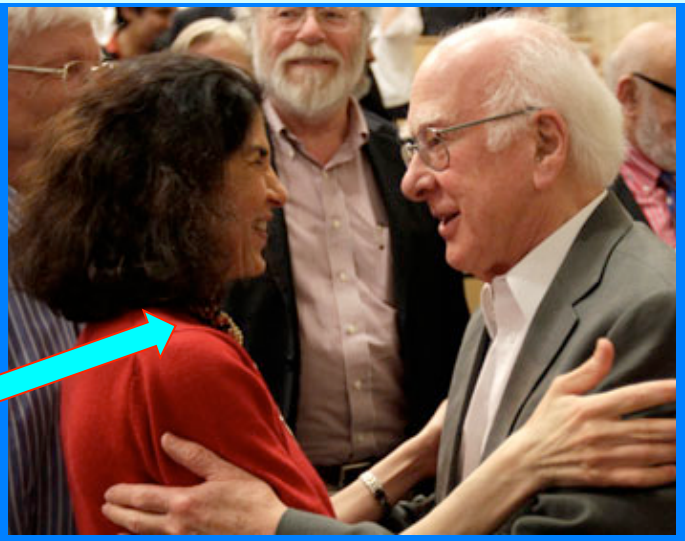


ISIDOR RABI: WHO ORDERED THAT ?

muons are 'heavy electrons' with a mass that is 200 times larger

From cosmic rays to the' Higgs particle'

CERN – 2012
Fabiola Gianotti Peter Higgs



1912
Victor Hess

100 years

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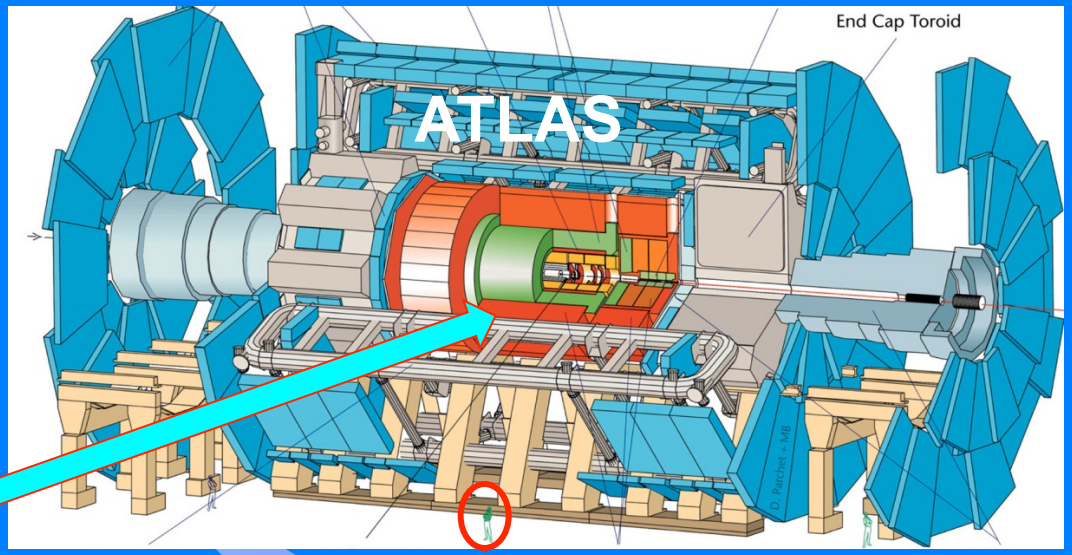

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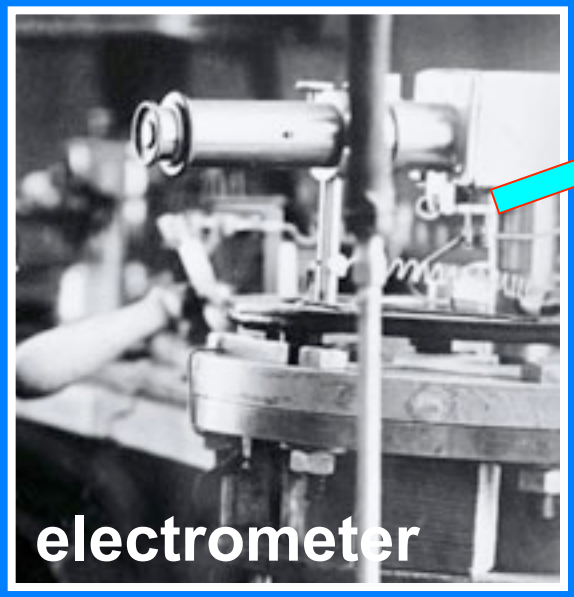


100 years

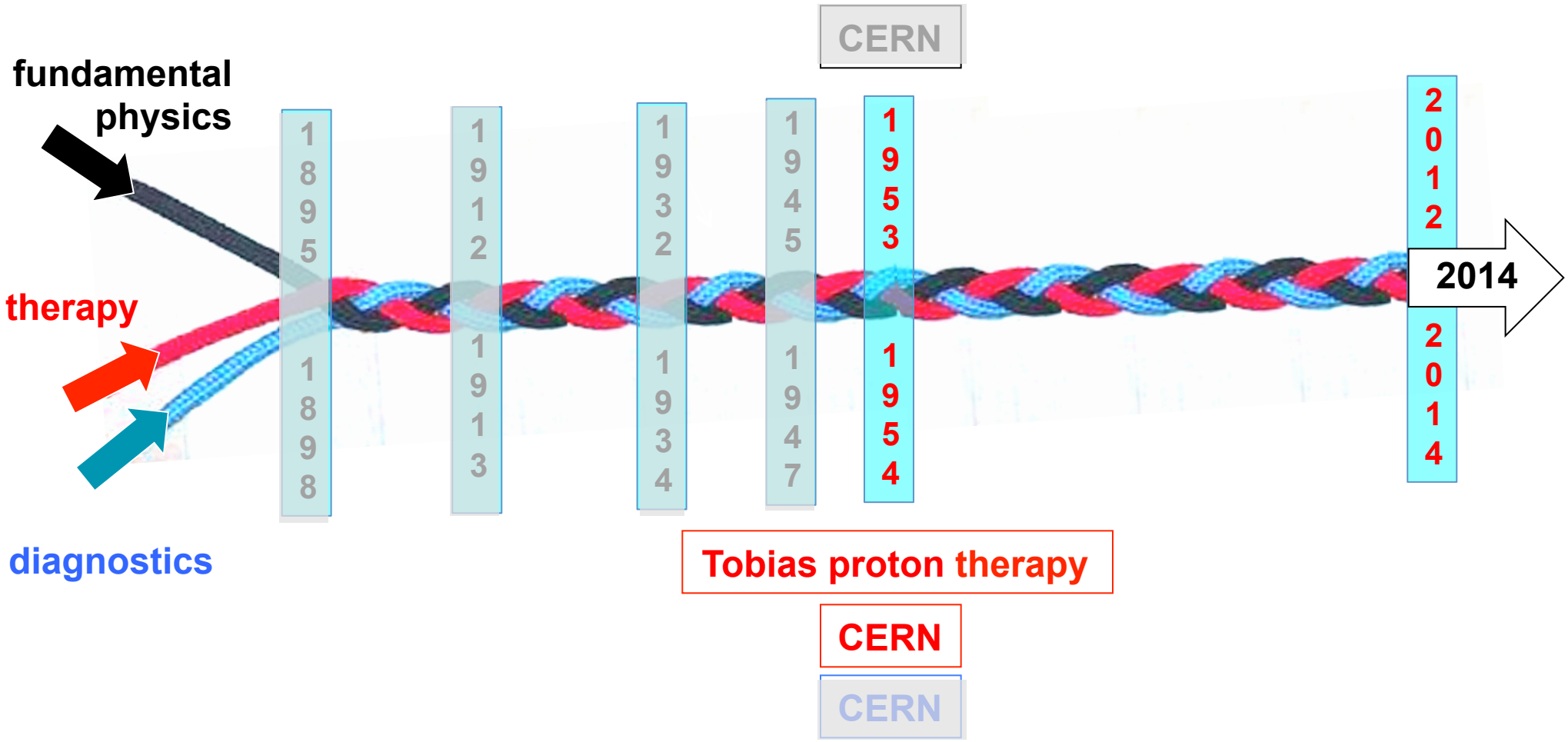
2013: the Nobel prize winners

François Englert Peter Higgs

Fabiola Gianotti Peter Higgs

Following the red yarn

120 years of fundamental (beautiful) and medical (useful) Physics



Hadrontherapy (particle therapy)

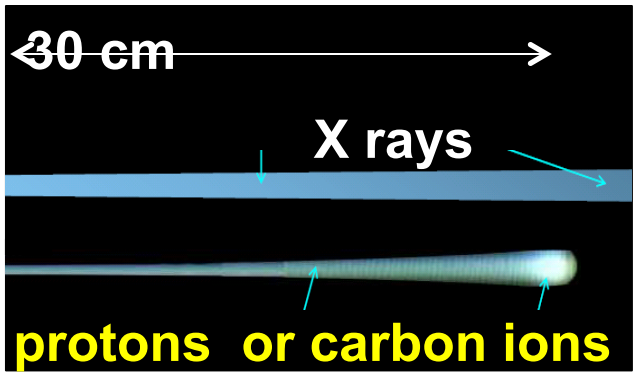
1946 : « Bob » Wilson proposes to use protons, helium and carbon ions

Lawrence PhD student

Founder and first Director of FERMILAB (Chicago) 1967-1978

Advantages of protons and carbon ions

protons: 230 MeV
C ions : 5000 MeV



1. Healthy tissues are spared by protons and carbon ions

Advantages of protons and carbon ions

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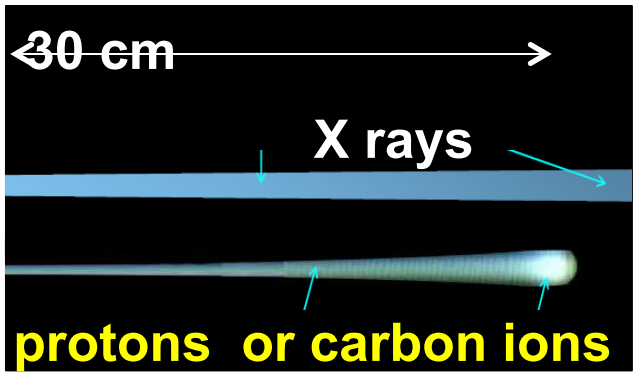

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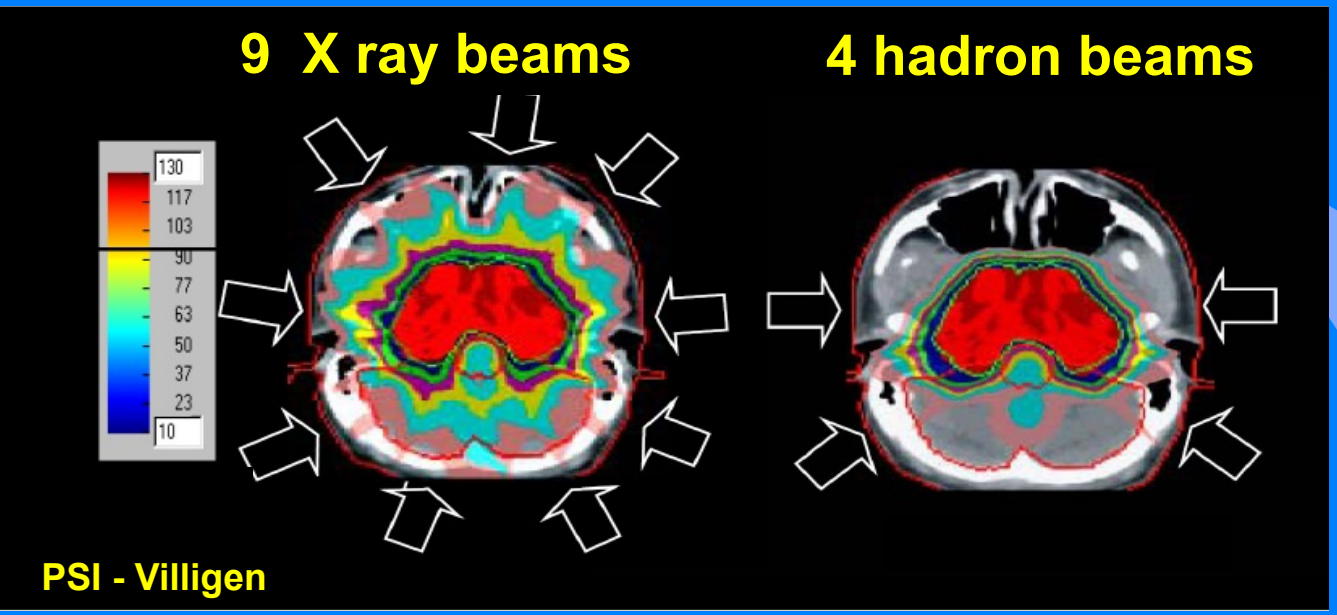

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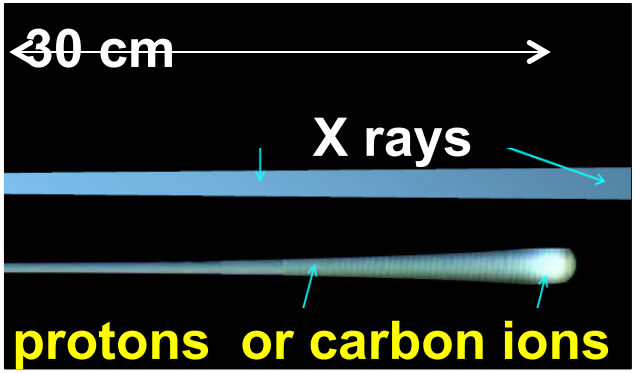

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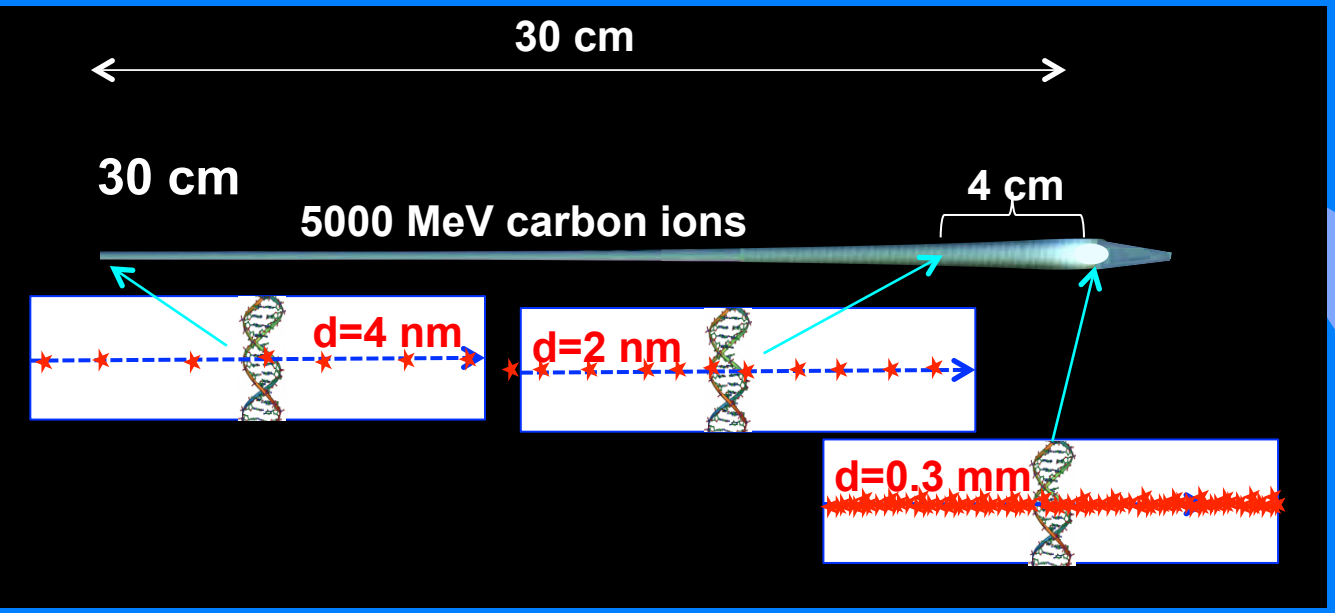

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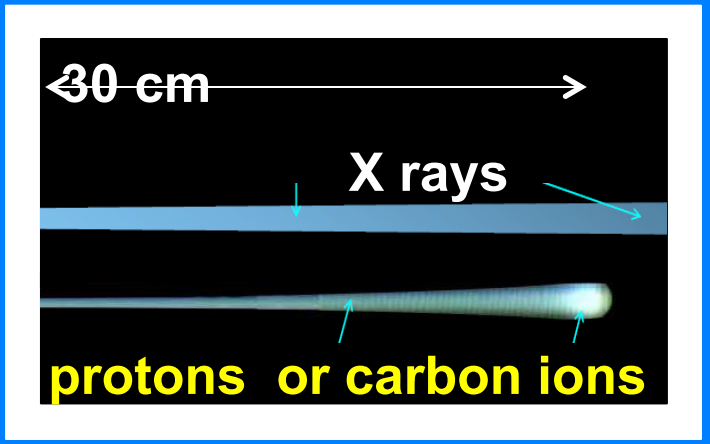

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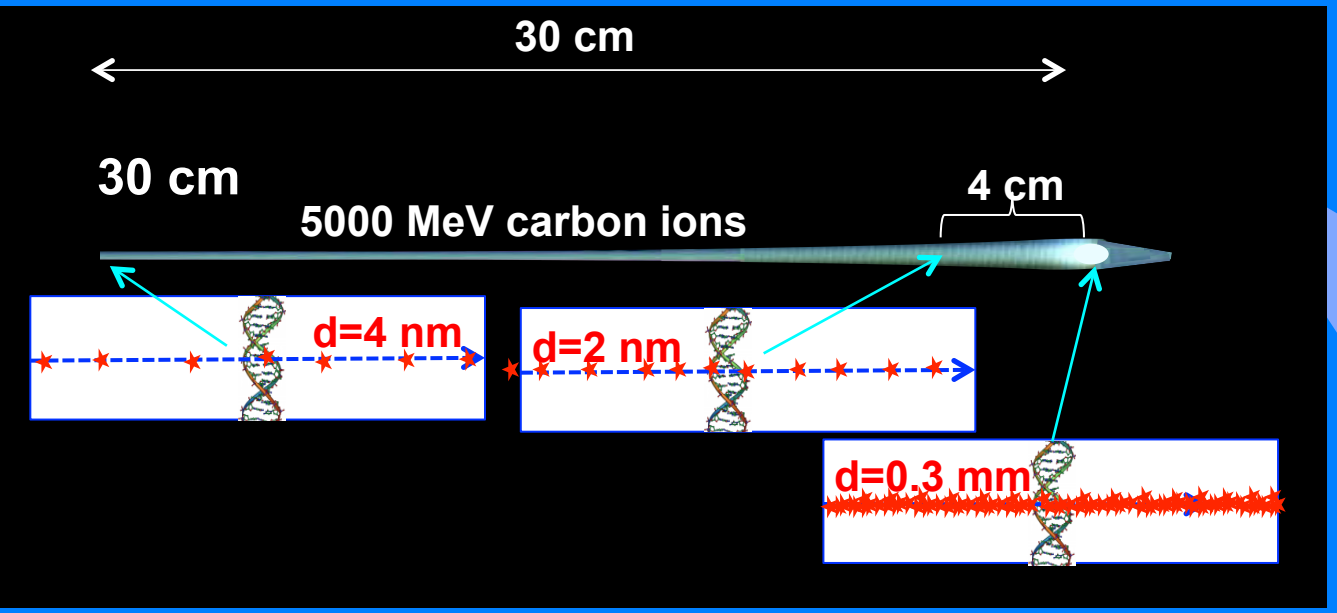
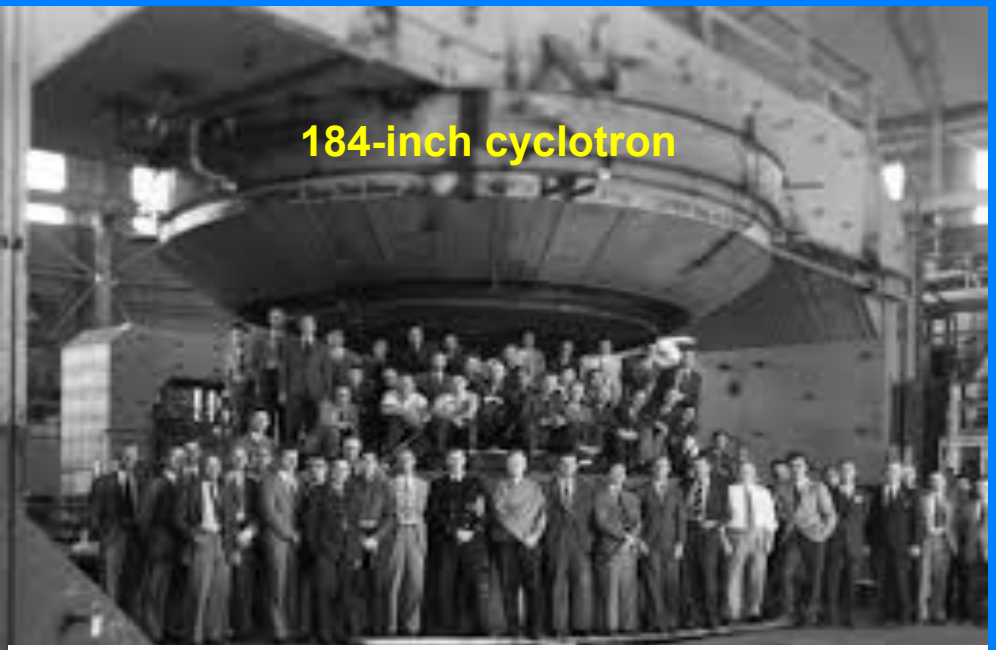


2. Carbon ions have charge = 6 and produce in the DNA clustered unrepairable damages

thus killing at the end of the range the cells which are radioresistant to both X rays and protons.

60 years ago: first proton treatment at Berkeley



Cornelius Tobias

"Toby"

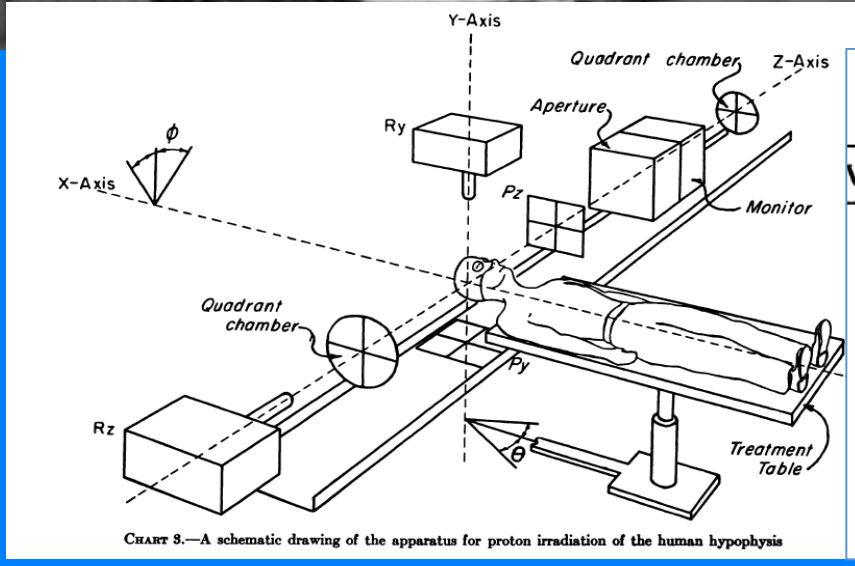


CHART 3.—A schematic drawing of the apparatus for proton irradiation of the human hypophysis

CANCER RESEARCH

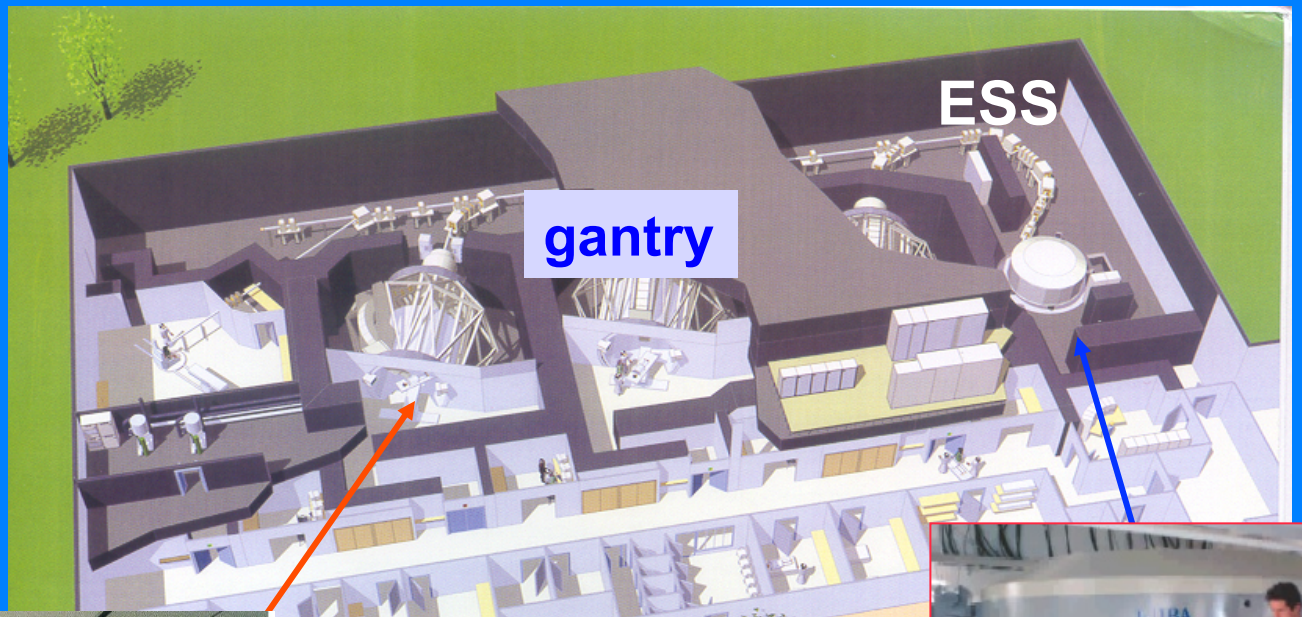
VOLUME 18 FEBRUARY 1958 NUMBER 2

Pituitary Irradiation with High-Energy Proton Beams
A Preliminary Report*

C. A. TOBIAS, J. H. LAWRENCE, J. L. BORN, R. K. McCOMBS, J. E. ROBERTS, H. O. ANGER, B. V. A. LOW-BEER,† AND C. B. HUGGINS‡

(*Donner Laboratory of Biophysics and Medical Physics, Donner Pavilion, and the Radiation Laboratory, University of California, Berkeley, Calif.*)

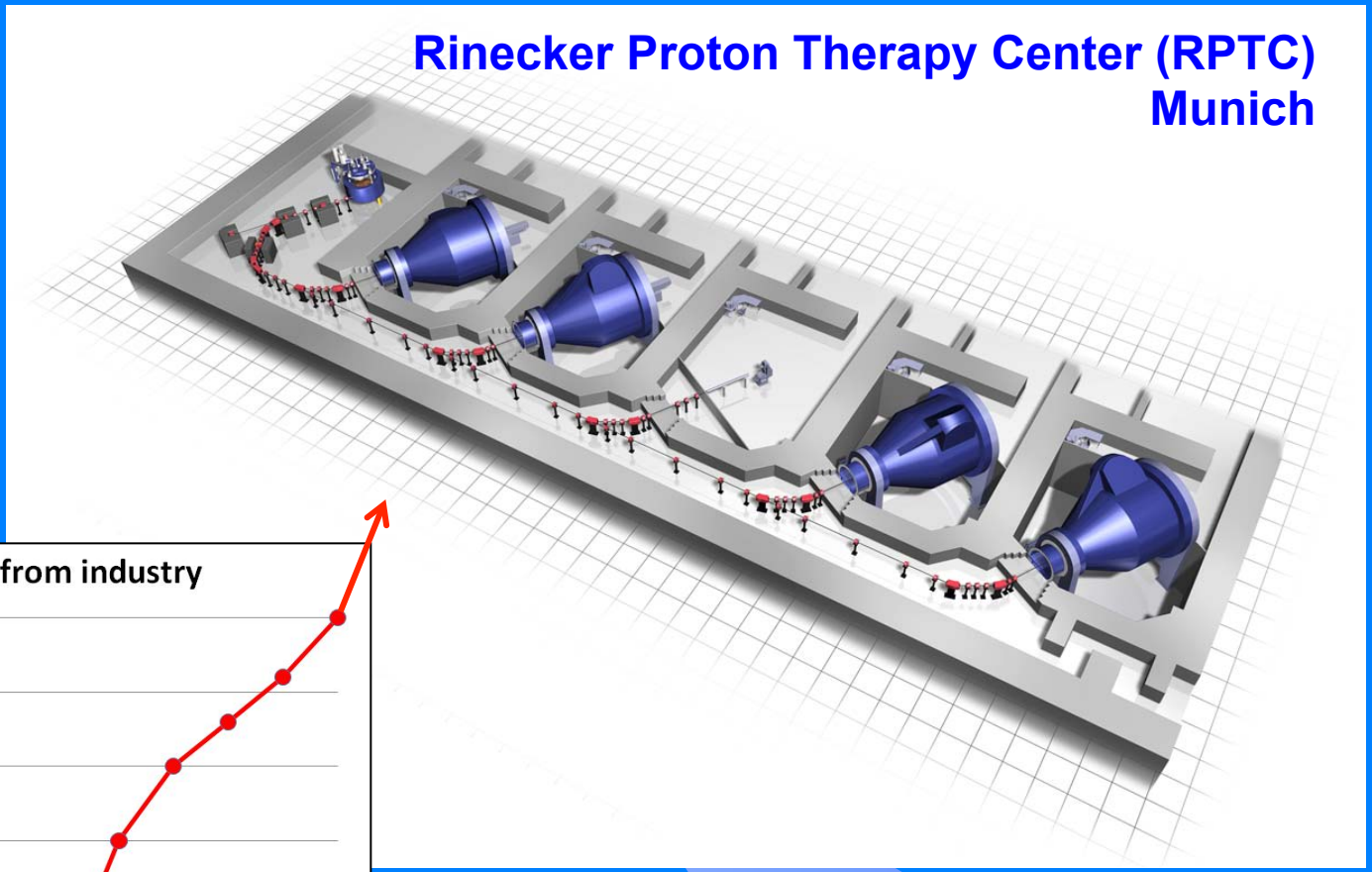
Cyclotron solution for protons by IBA - Belgium

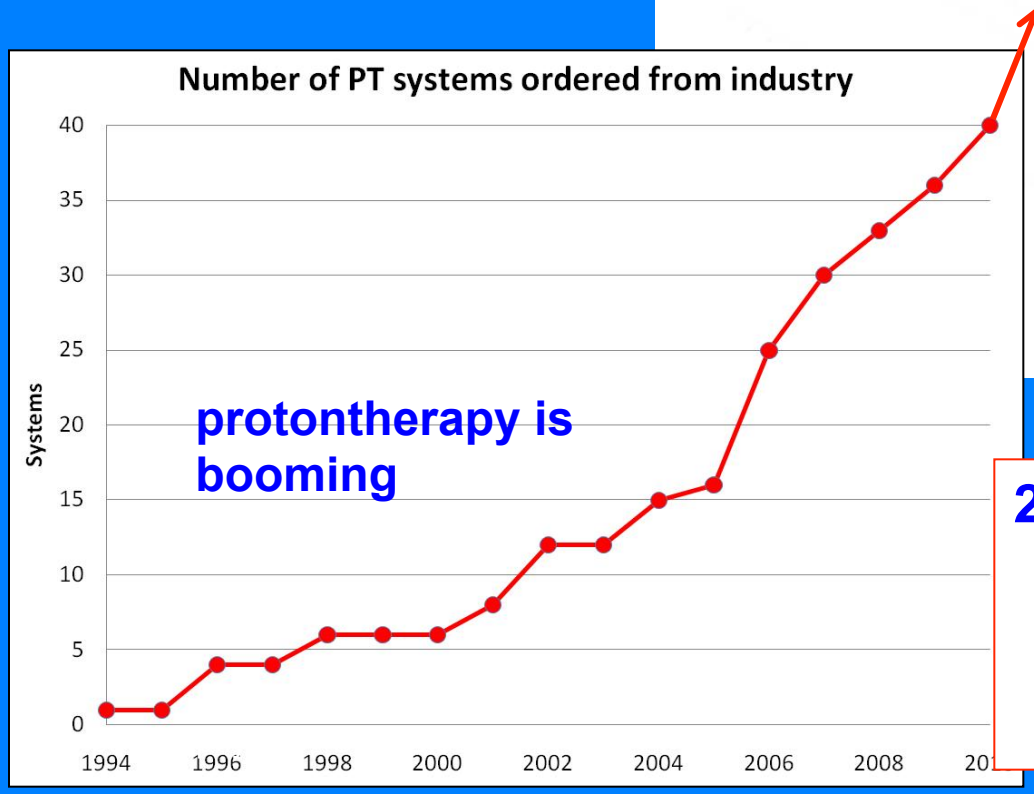


Seven companies offer turn-key centres with 2-3 gantires for 120-150 M€.

If proton accelerators were 'small' and 'cheap', no radiation oncologist would use X rays.

Superconducting cyclotron solution by Varian





20-25 sessions per patient

European cost of a full treatment:

IMRT: 8-10 k€

Protontherapy: 20-25 k€

HIMAC in Chiba is the pioner of carbon therapy

Yasuo Hirao

[15] Hirao, Y. et al, "Heavy Ion Synchrotron for Medical Use: HIMAC Project at NIRS Japan" Nucl. Phys. A538, 541c (1992)

Hirohiko Tsujii

8500 pts 1994-2014

The GSI pilot project : 1997-2008

J. Debus

450 patients treated with carbon ions

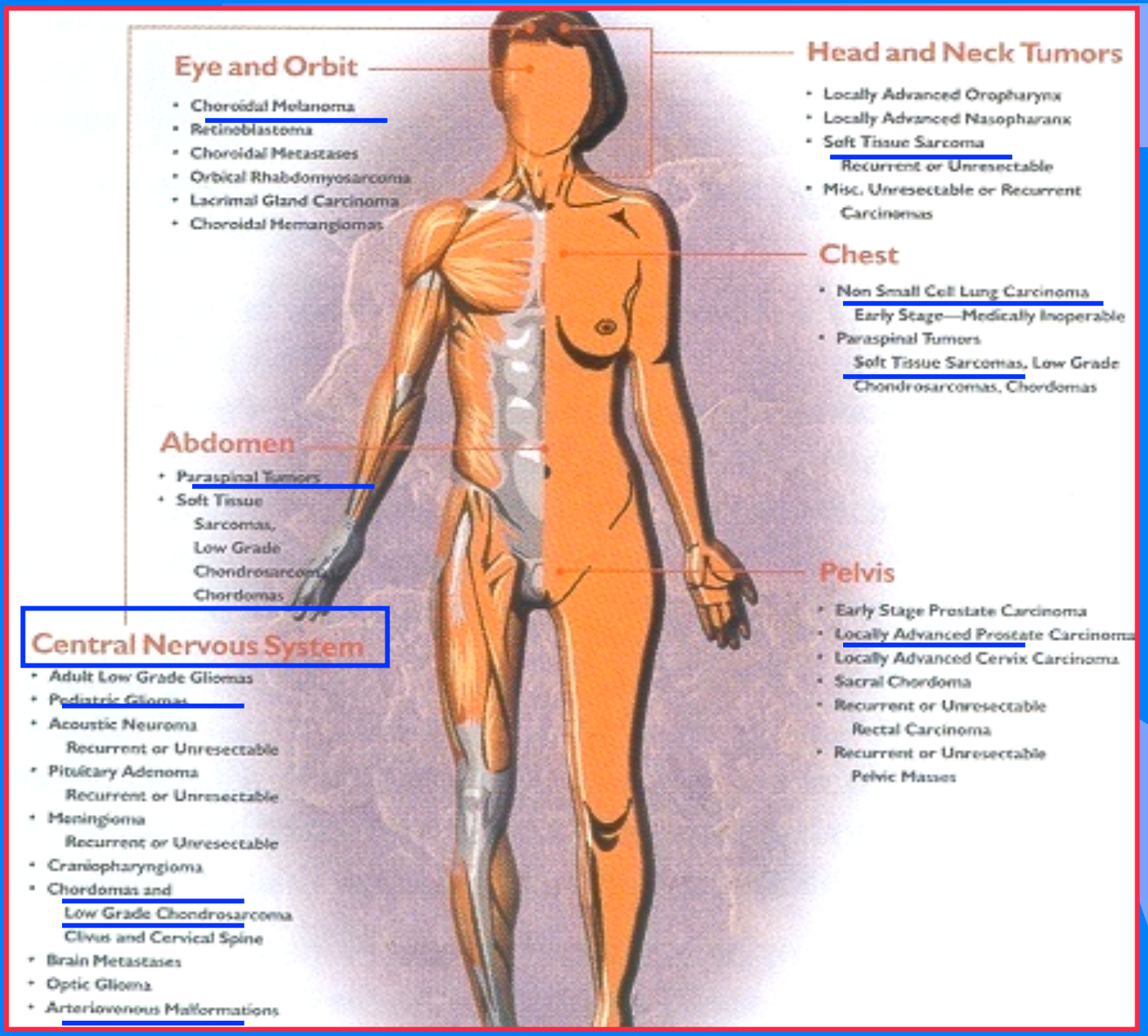
The GSI pilot project : 1997-2008

J. Debus

450 patients treated with carbon ions

GSI designed HIT (Heidelberg Ion Therapy centre) where 1800 patients have been treated since 2009

The site treated with hadrons



In the world

protons:

100'000 patients

(8% per year)

carbon ions

10’000 patients

(most at HIMAC)

Numbers of potential patients by European Network for Light Ion Therapy

X-ray therapy

for 1 million inhabitants: 2'000 pts/year

Protontherapy

12% of X-ray patients 240 pts/year

Therapy with carbon ions for radio-resistant tumour

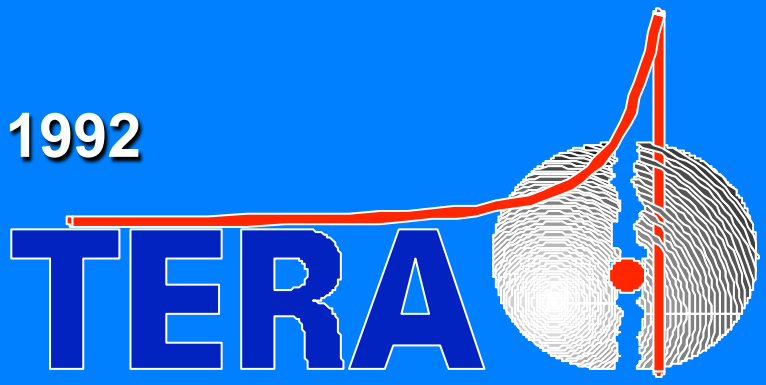
(comparisons with proton therapy are needed to define sites and protocols)

3% of X-ray patients 60 pts/year

TOTAL for 1 M 300 pts/year

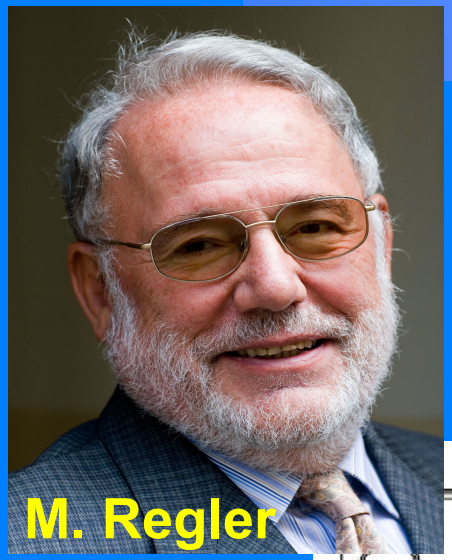
ENLIGHT coordinator: Manjit Dosanjh

- Non-profit Foundation created in 1992



- Two programmes :
  - Synchrotron for C ions (and protons): CNAO in Pavia
  - Linacs for protons and carbon ions : A.D.A.M.

In 1995 U.A. and M. Regler convinced CERN to start Proton Ion Medical Machine Study, PIMMS

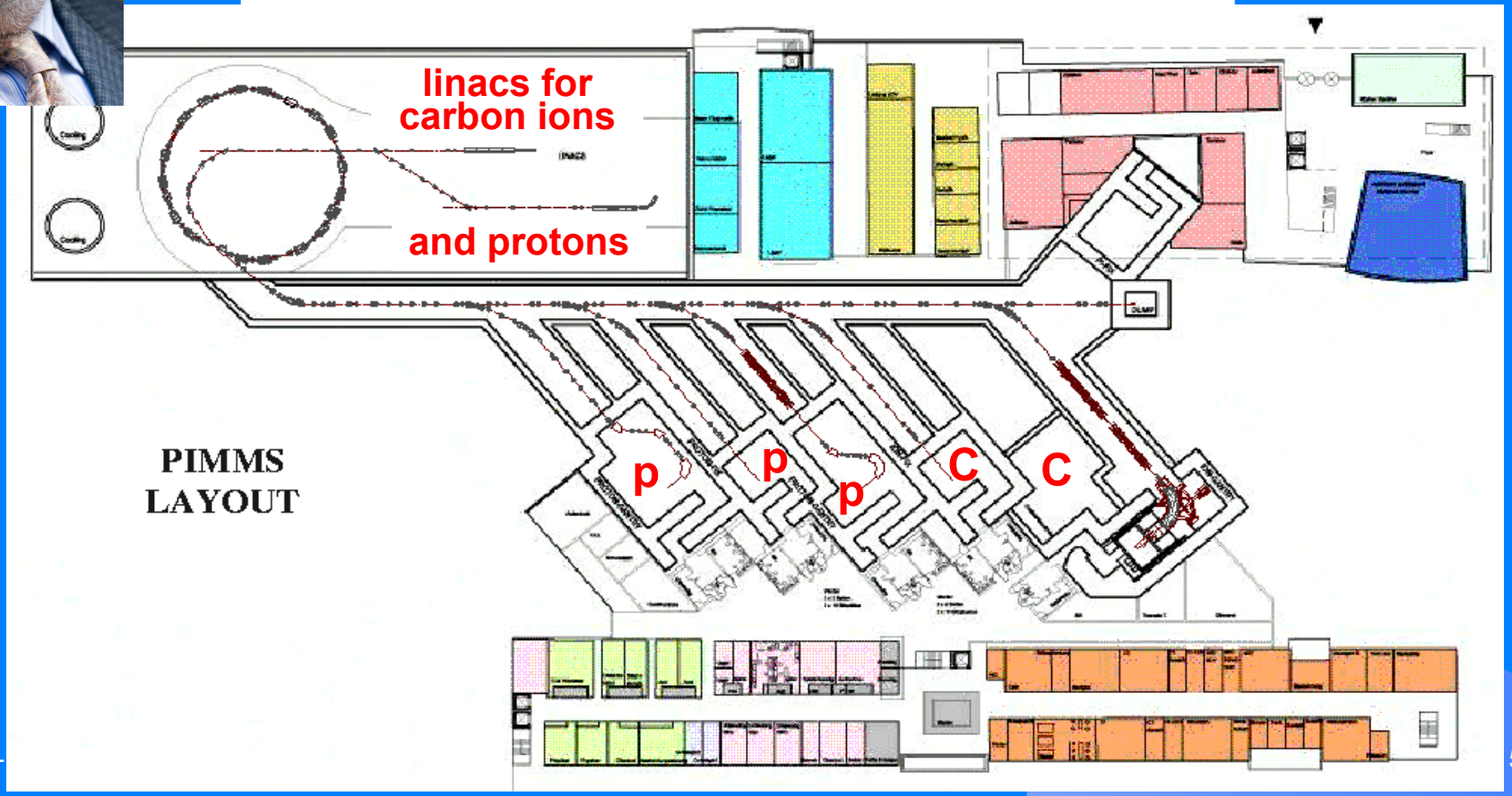


Optimized synchrotron for therapy

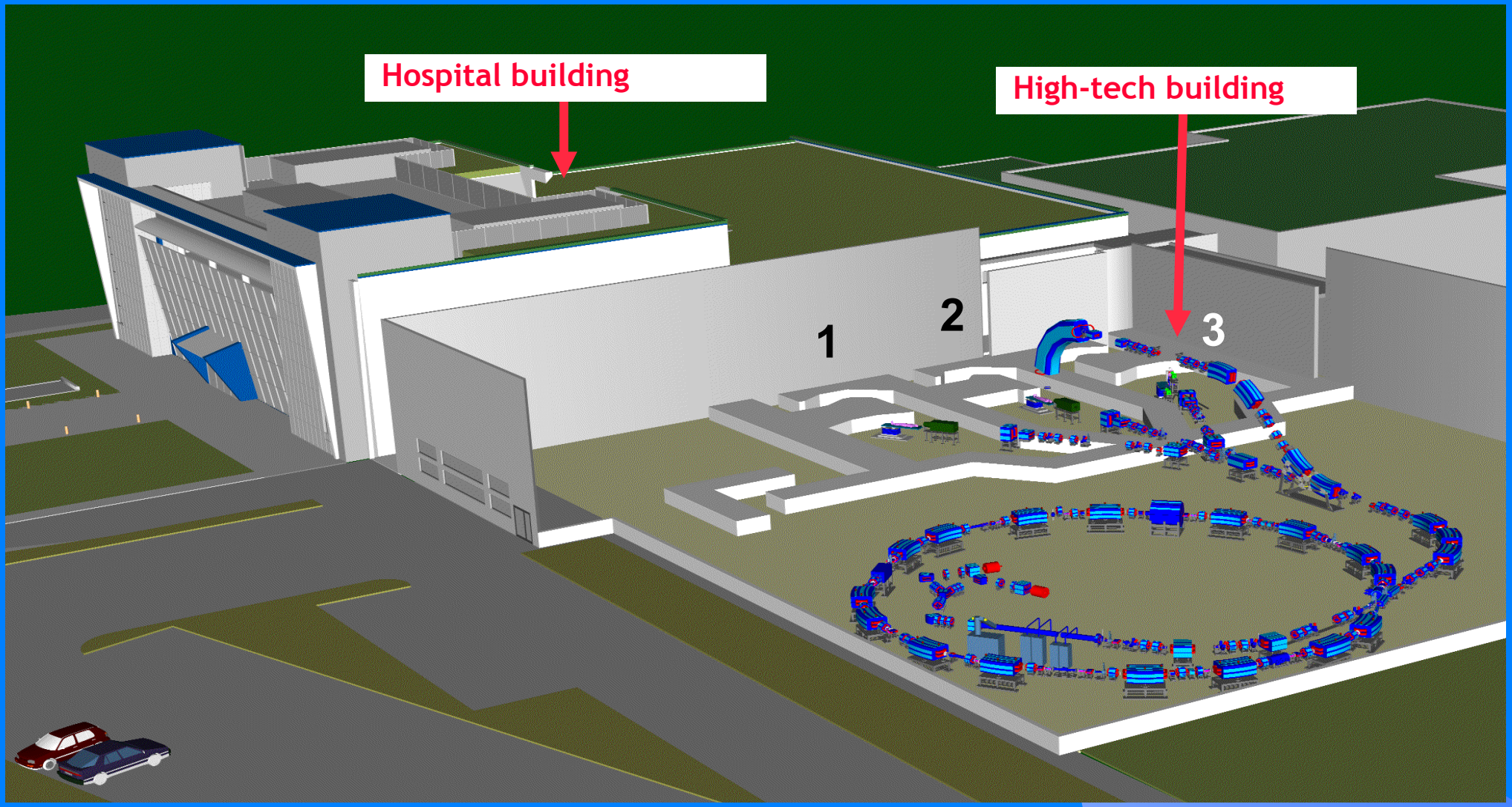
Project Leader: Phil Bryant

Chair of PAC: Giorgio Brianti

1996-2000



CNAO = Centro Nazionale di Adroterapia Oncologica in Pavia



CNAO = Centro Nazionale di Adroterapia Oncologica

Sandro Rossi
Technical
Director

Roberto Orecchia
Medical Director

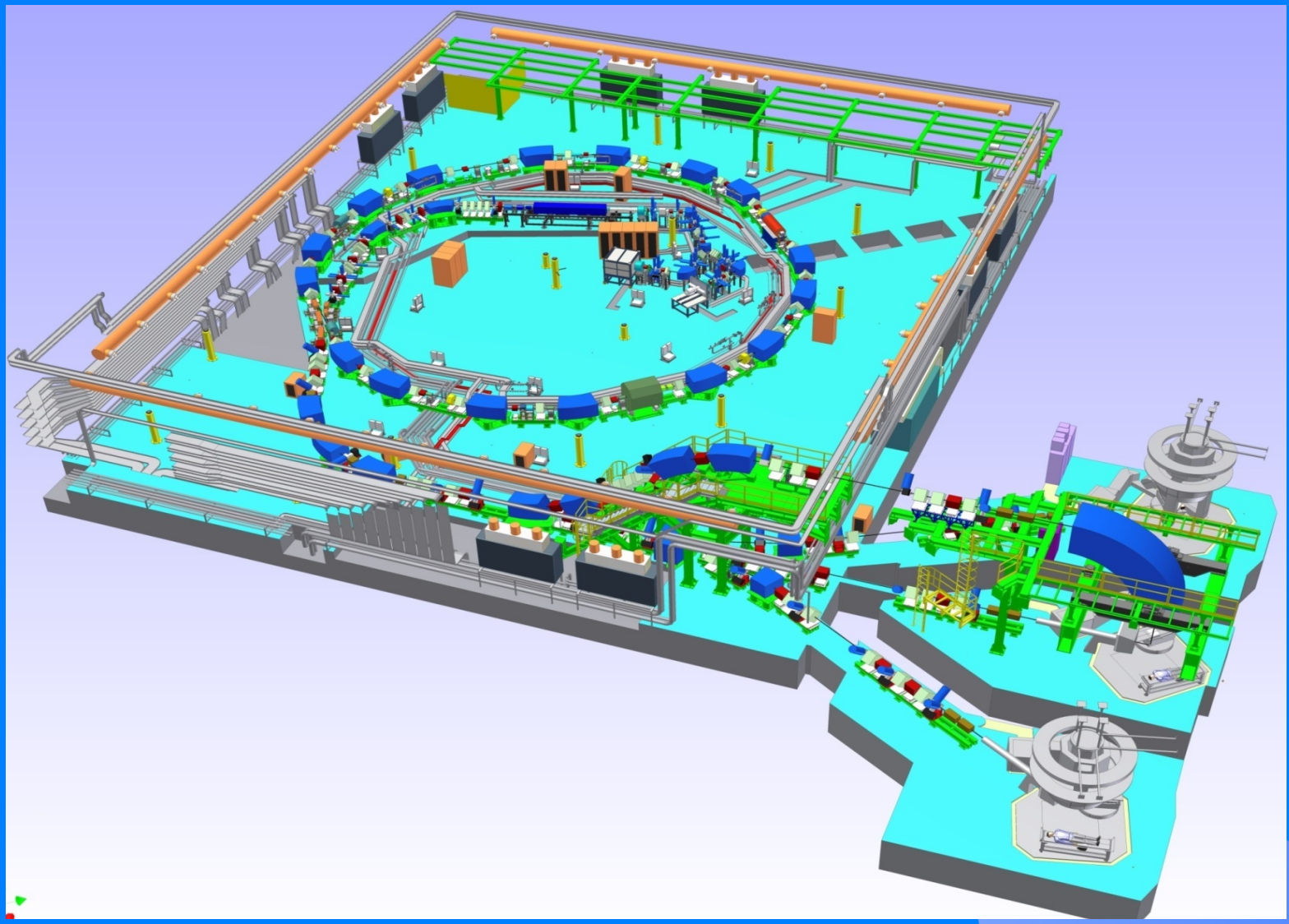
Synchrotron
building

Hospital
bulding

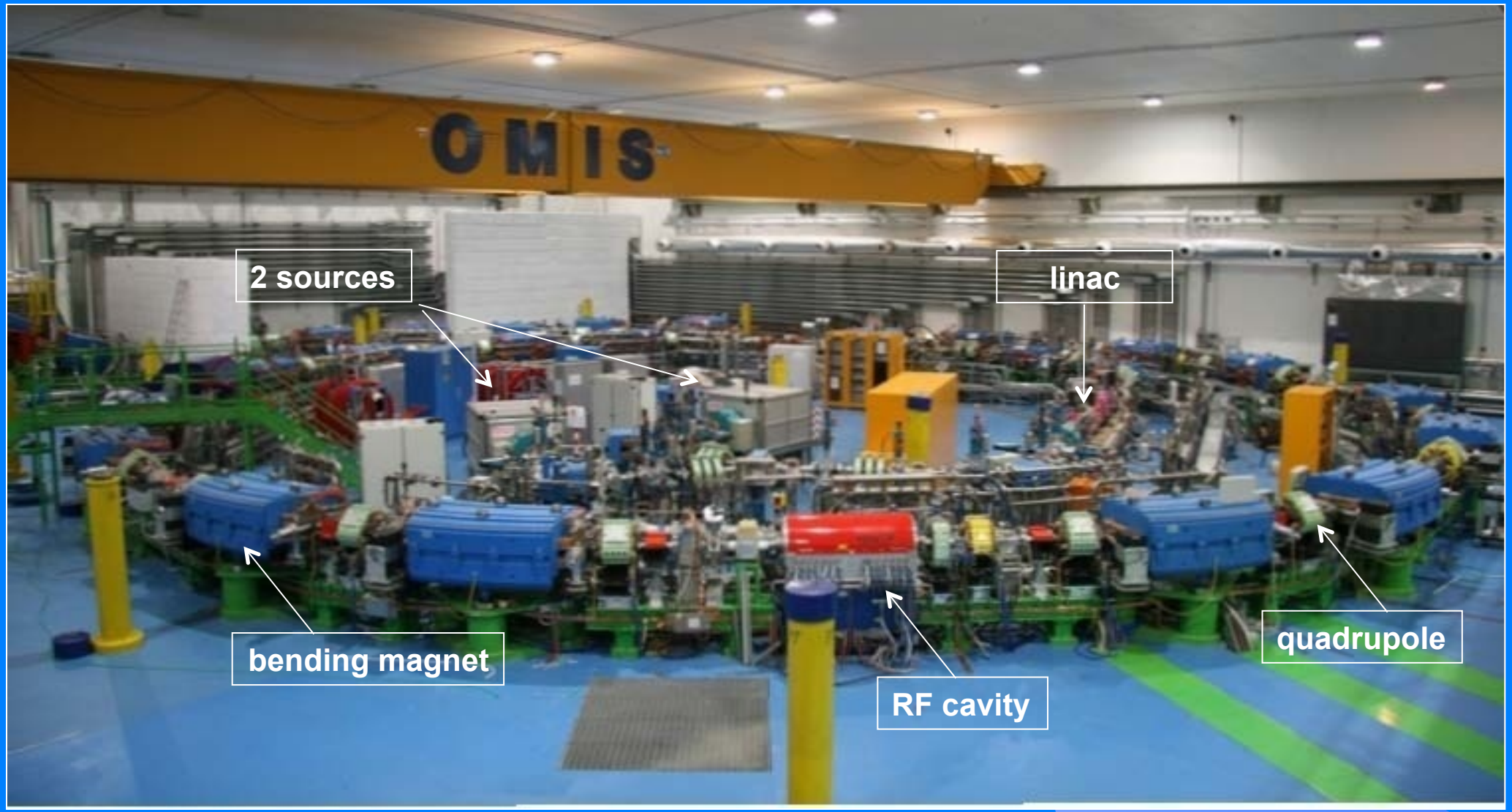
Construction by
CNAO Foundation and INFN

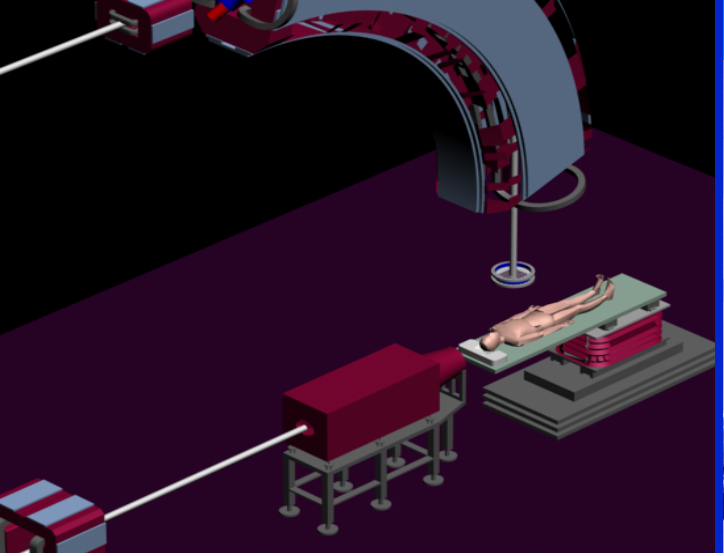
2005-2010

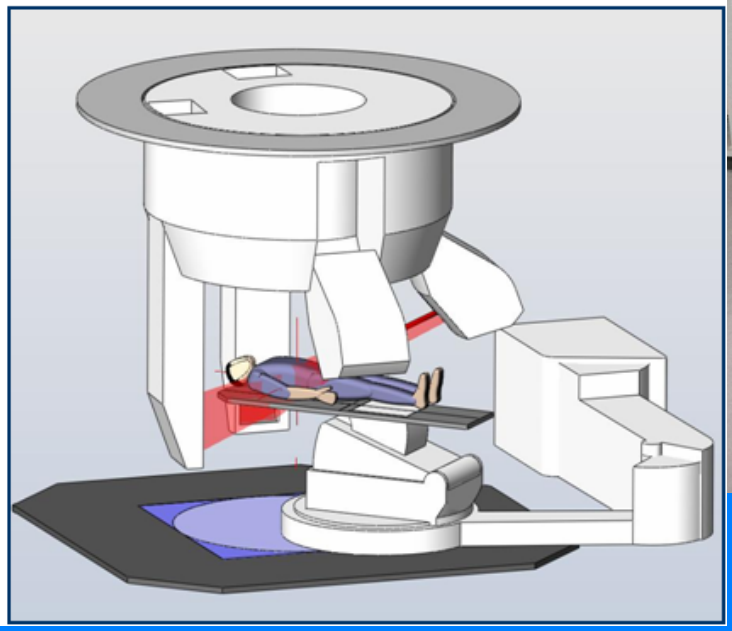
CNAO at Pavia

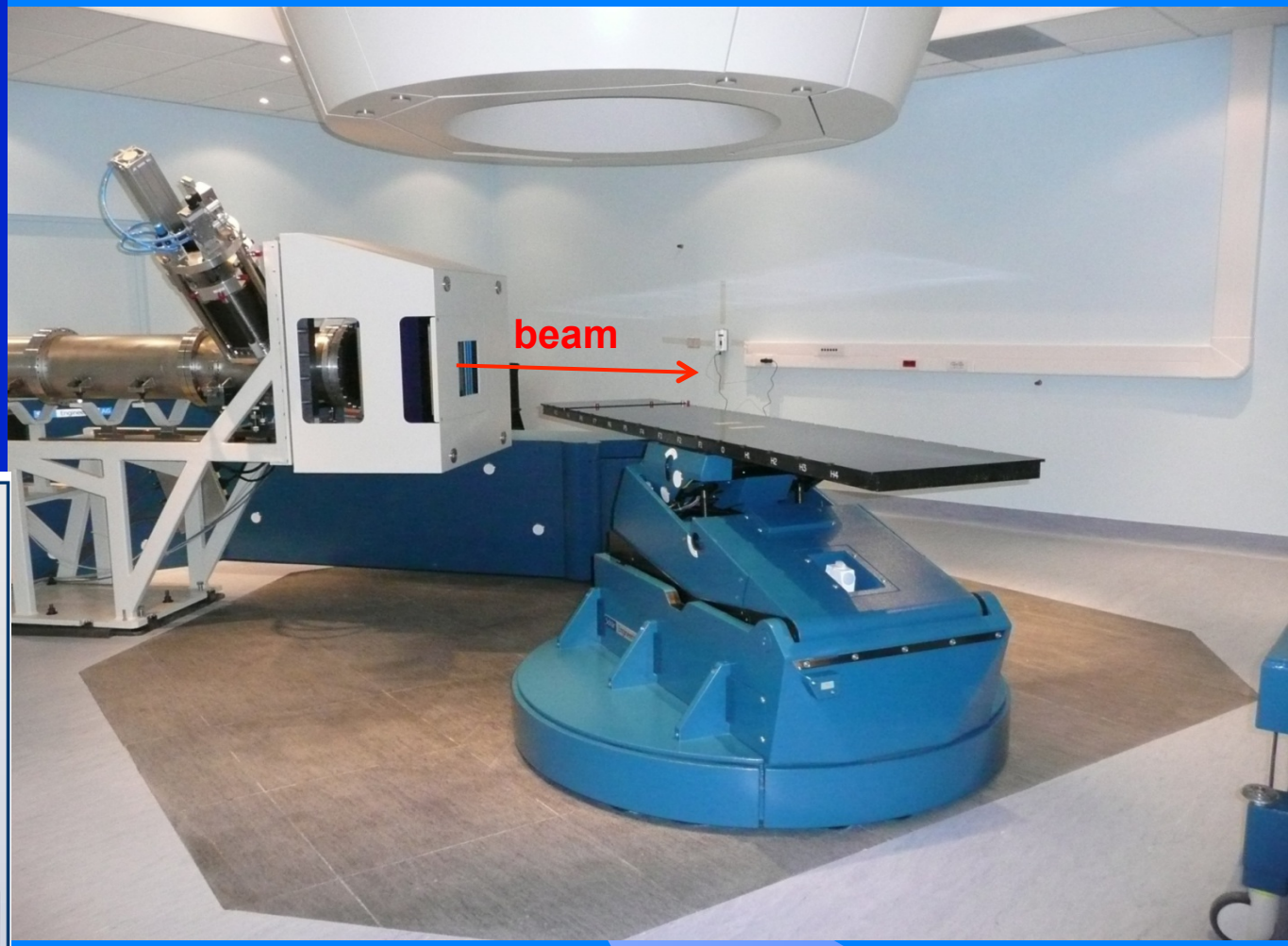


The synchrotron







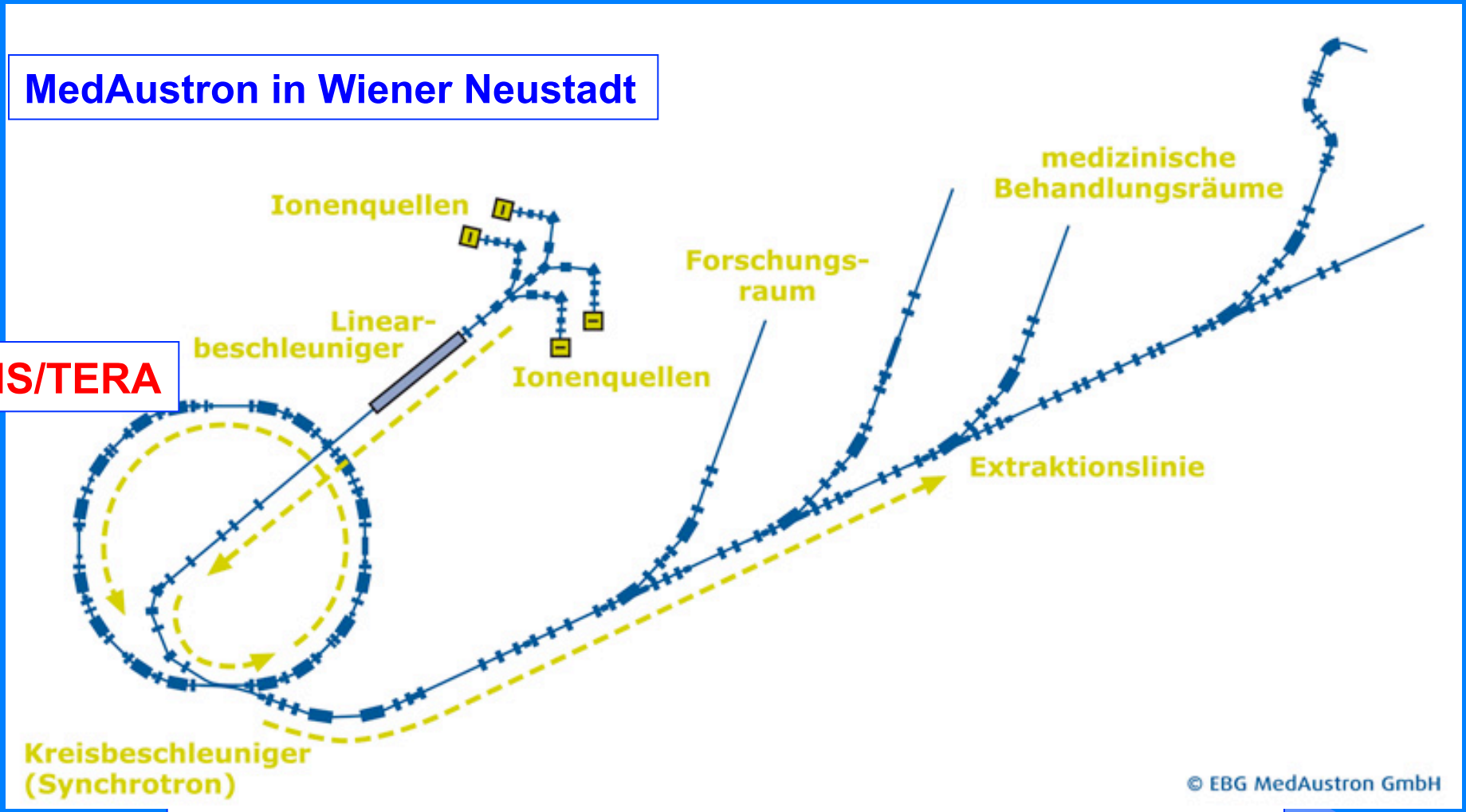


January 2014: 200 patients treated

MedAustron promoted and participated in PIMMS

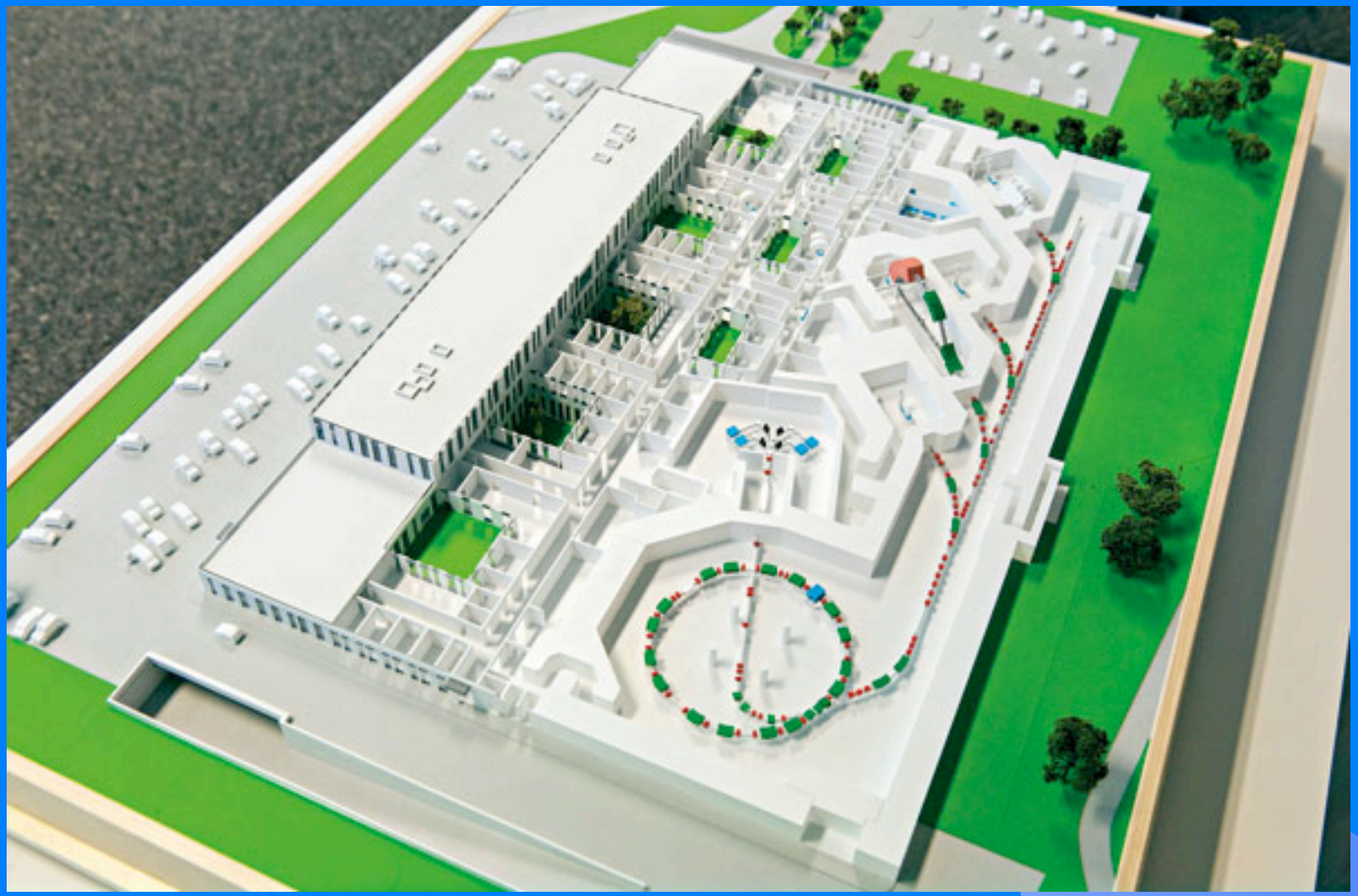
MedAustron in Wiener Neustadt

PIMMS/TERA

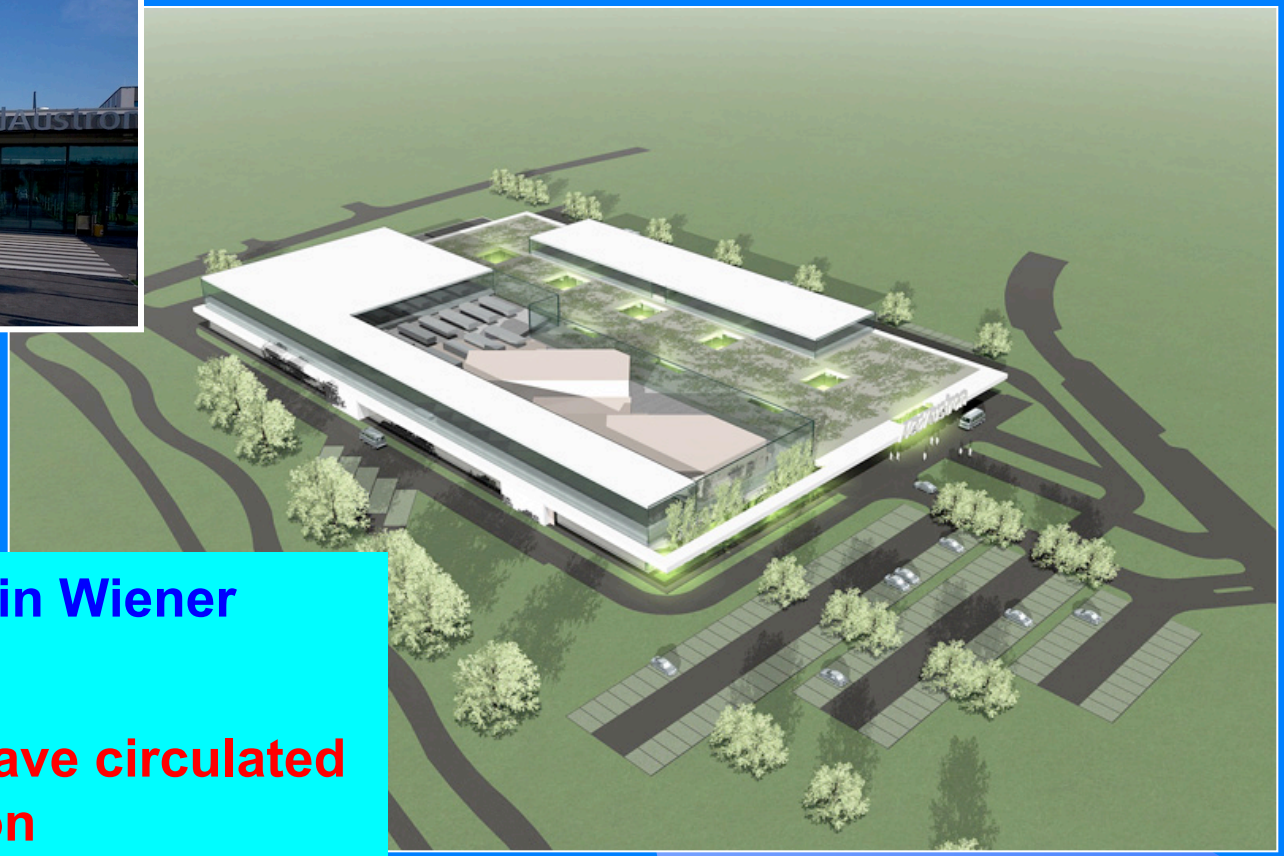


MedAustron has acquired form CNAO Foundation the construction drawings

MedAustron promoted and participated in PIMMS



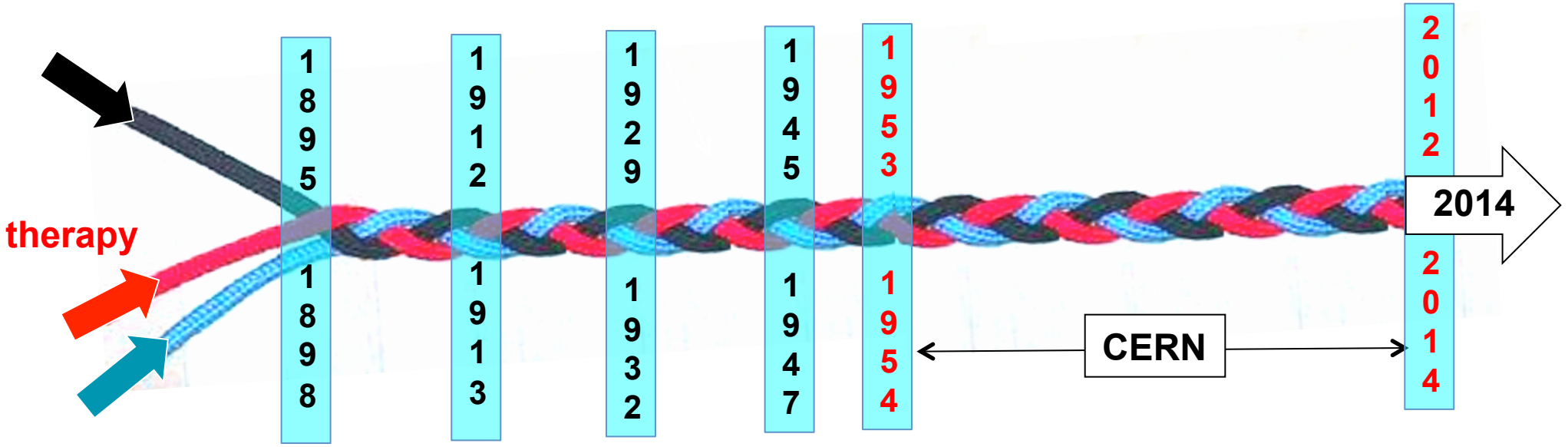
MedAustron promoted and participated in PIMMS



Construction completed in Wiener Neustadt:

three days ago the protons have circulated in the synchrotron

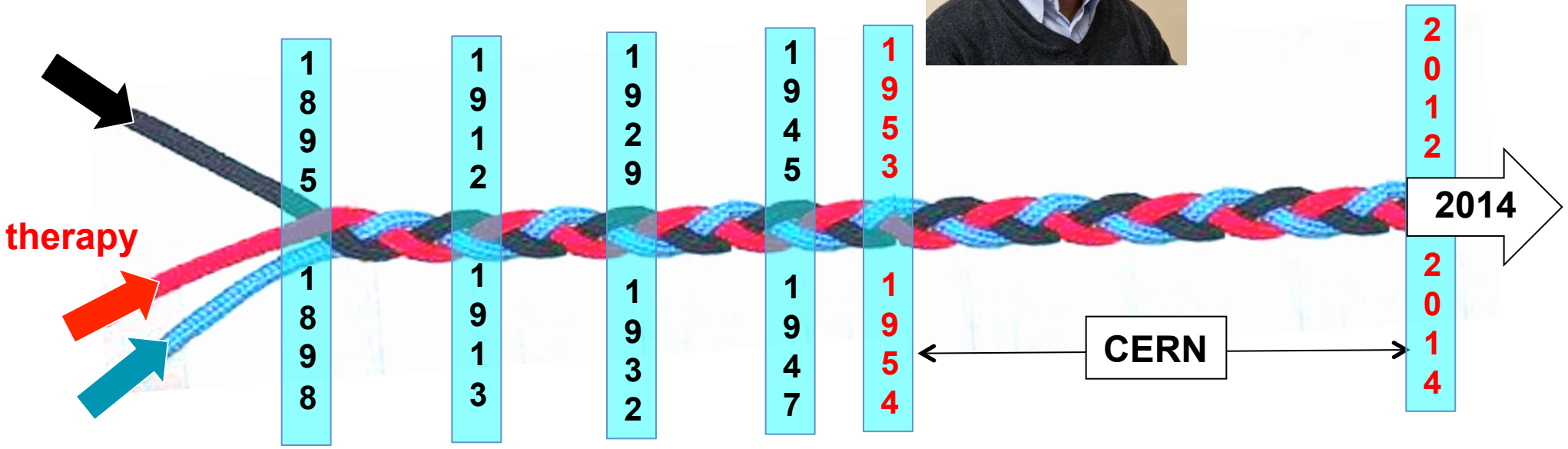
To conclude: in 2014 a further step has been made



To conclude: in 2014 a further step has been made

Office for CERN Medical Applications

1st January 2014
Steve Myers



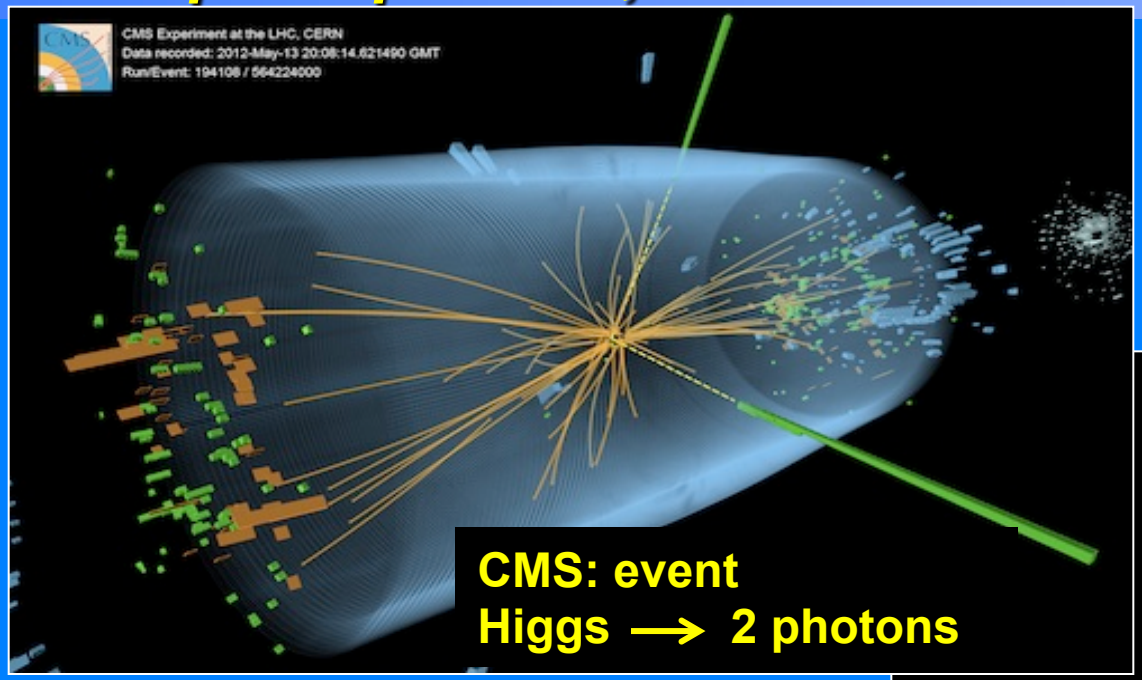
CERN

CERN

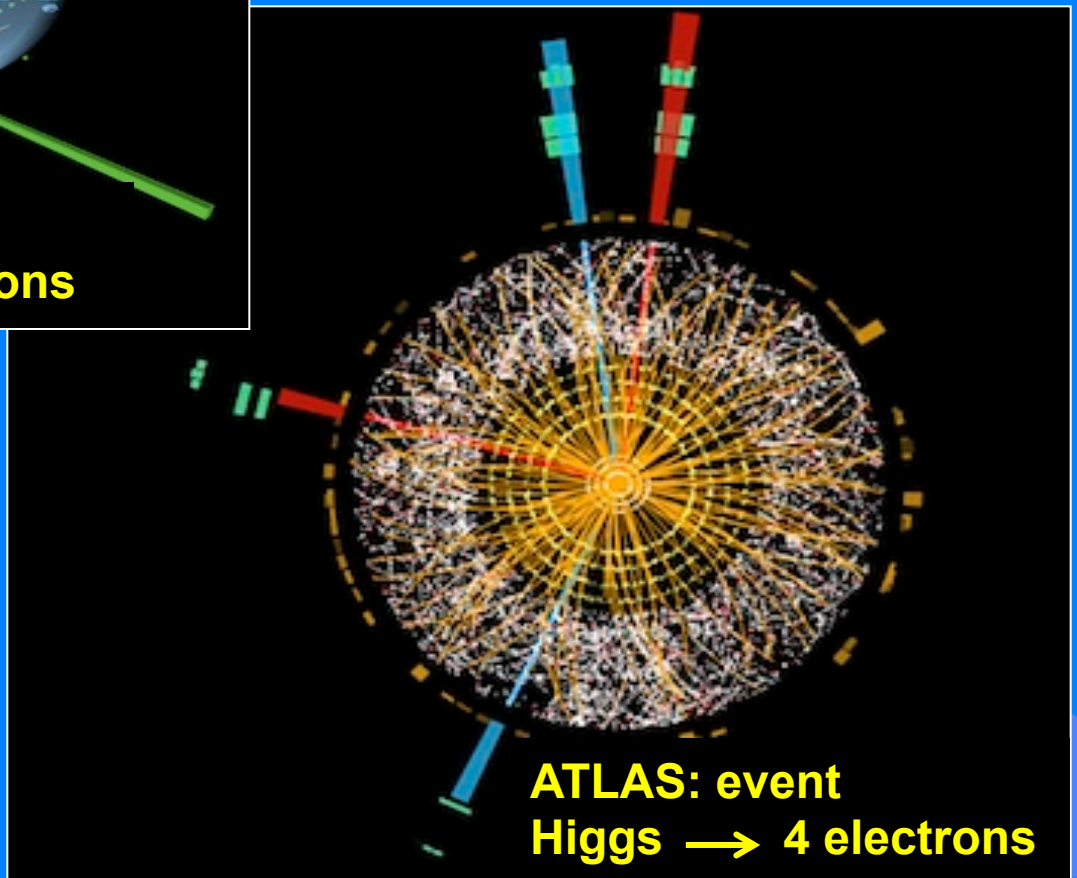

CNAO at Pavia
PHYSICS IS BEAUTIFUL AND USEFUL
Physik ist schön und nützlich
La Physique est belle et utile
La Fisica è bella e utile

The importance of the Higgs "field"

HIGHLIGHTS: 2012 – F.Gianotti and J. Incandela, ATLAS and CMS spokespersons, announce the discovery of the 'Higgs field'

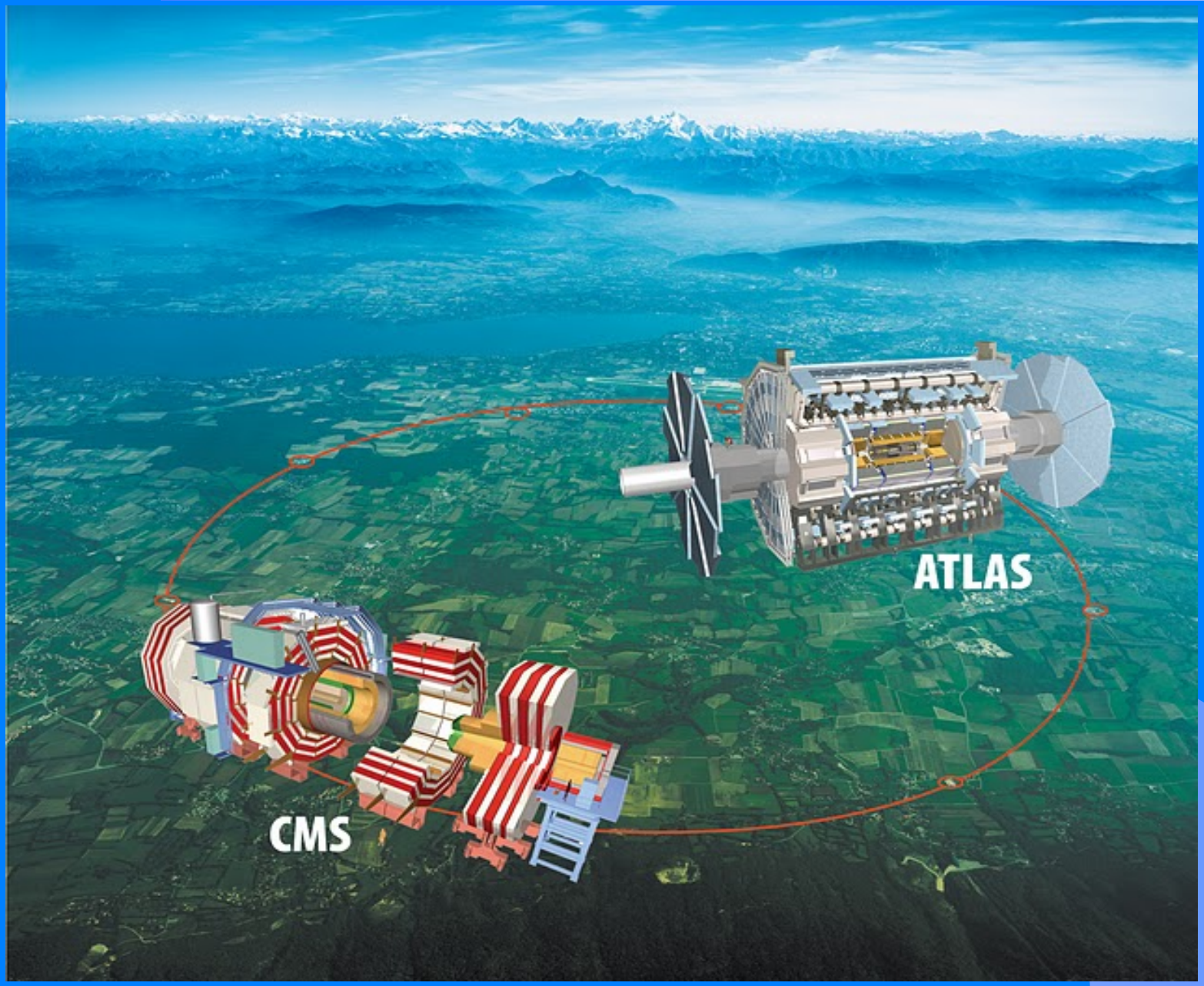


CMS: event
Higgs ⟶ 2 photons

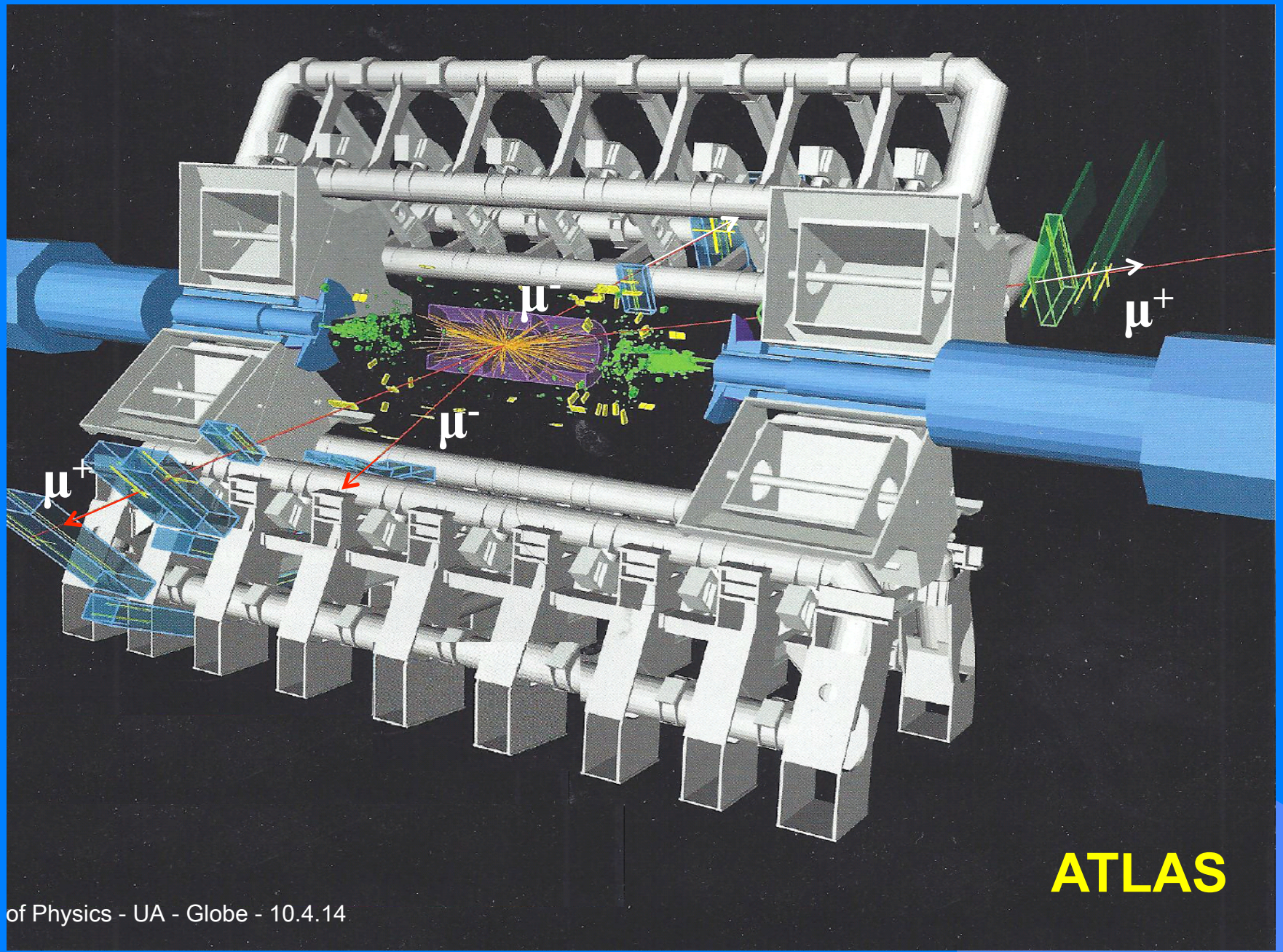


ATLAS: event
Higgs ⟶ 4 electrons

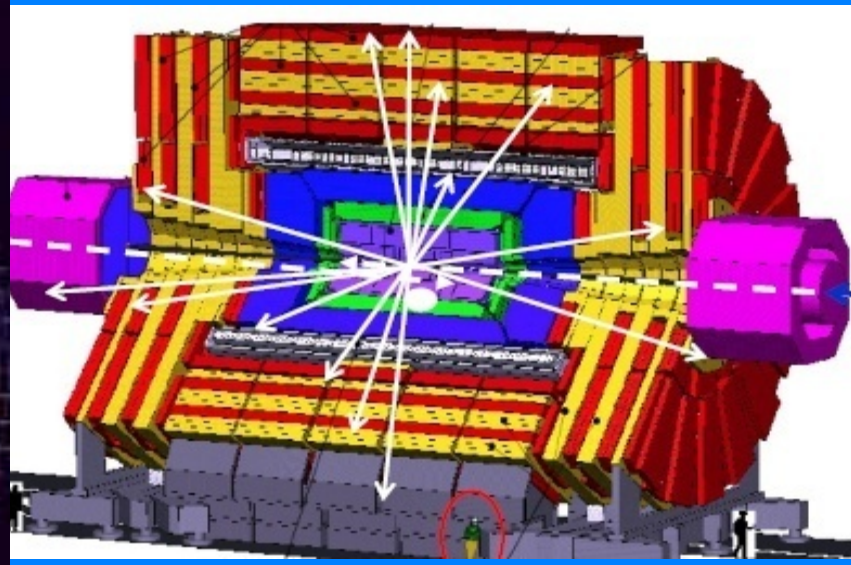
Two large ‘detectors’ at LHC



Event in ATLAS: production of 4 muons=heavy electrons



Event in CMS



muon

The Higgs particle is the 37th field but it is the most important one because…

the Higgs ‘field’ is a continous medium that fills the space since one hundredth of a billionth of a second (10^{-11} s) after the Big Bang

The Higgs particle is the 37th particle but it is the most important one because…

the Higgs ‘field’ is a continous medium that fills the space since one hundredth of a billionth of a second (10^{-11} s) after the Big Bang

the particles interact differently with the Higgs field and thus they have different masses

Metaphor of the two twins practicing Nordic sky on a flat snow "field"

Metaphor of the two twins practicing Nordic sky on a flat snow "field"

…but if the snow 'field' is not seen he is slower because has a larger mass

2013: the Nobel prize winners

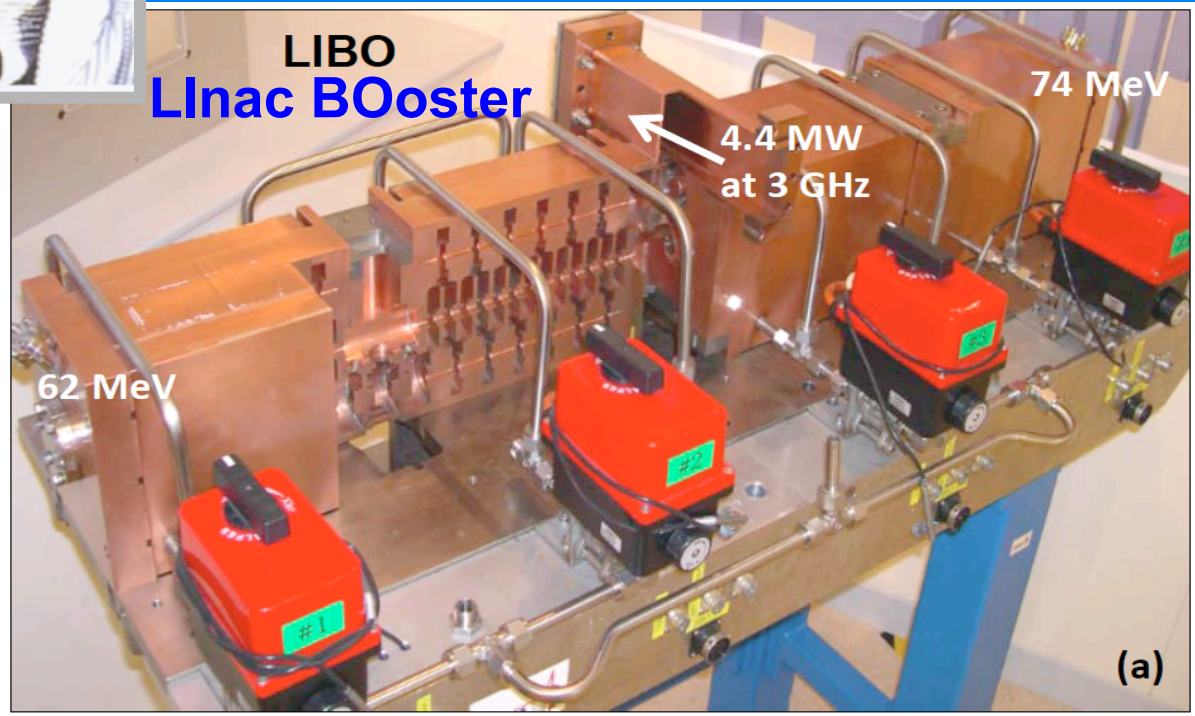
François Englert Peter Higgs

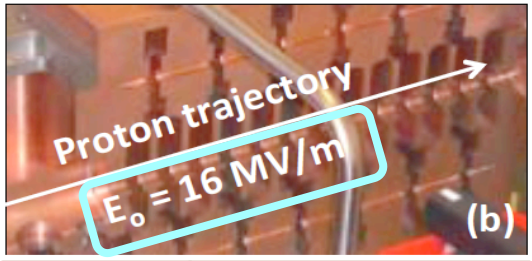
Fabiola Gianotti Peter Higgs

TERA novel accelerators for cancer therapy: proton linacs

Prototype of CCL built and beam tested by TERA-CERN-INFN: 2003

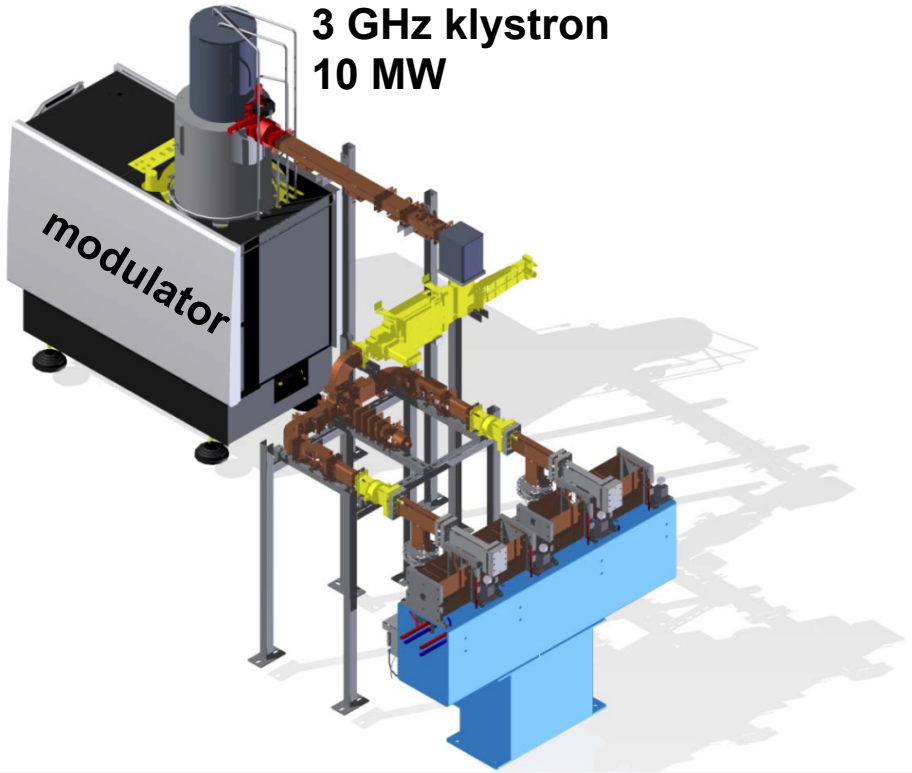
Mario Weiss





3 GHz proton Linac

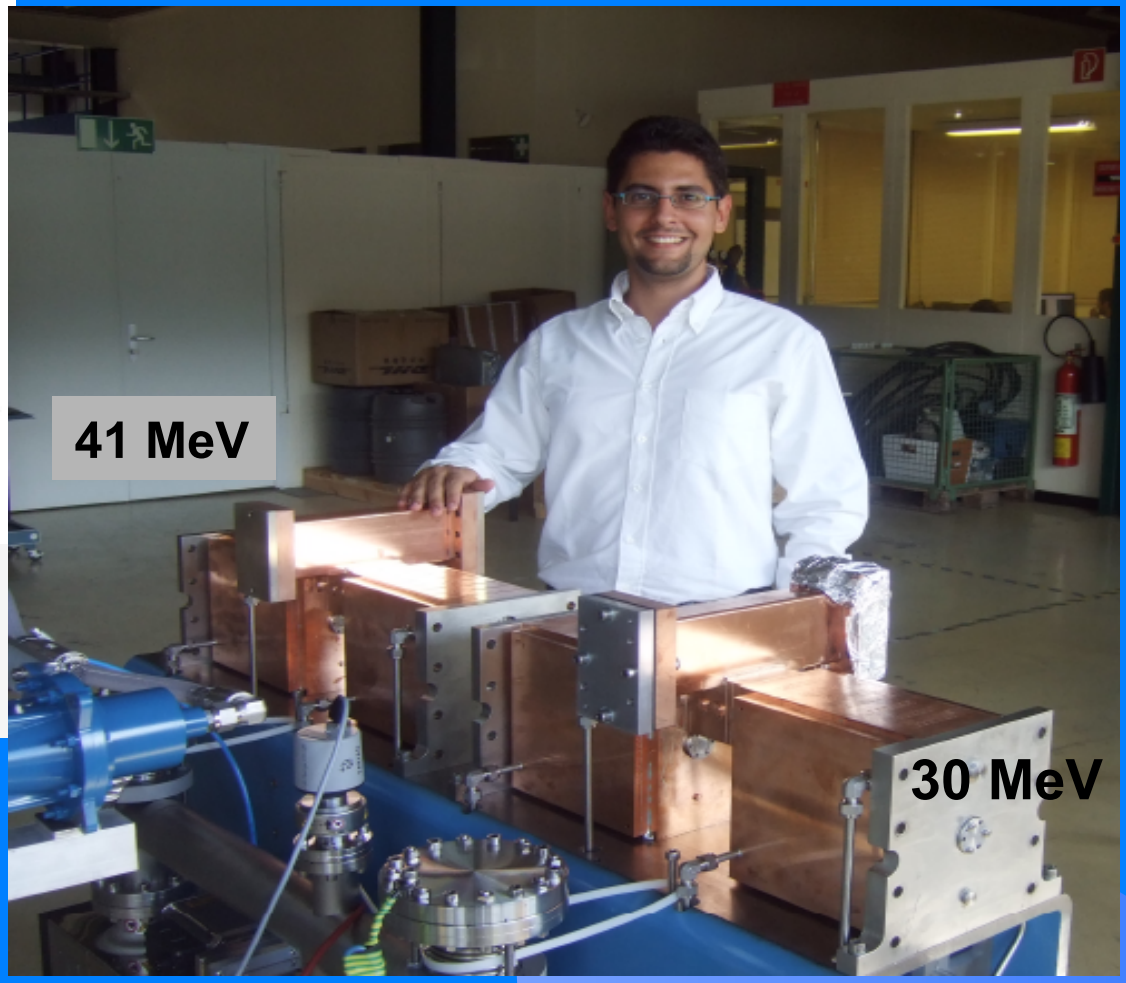
Commercial prototype built and power tested by A.D.A.M.: 2011



First Unit of LIGHT

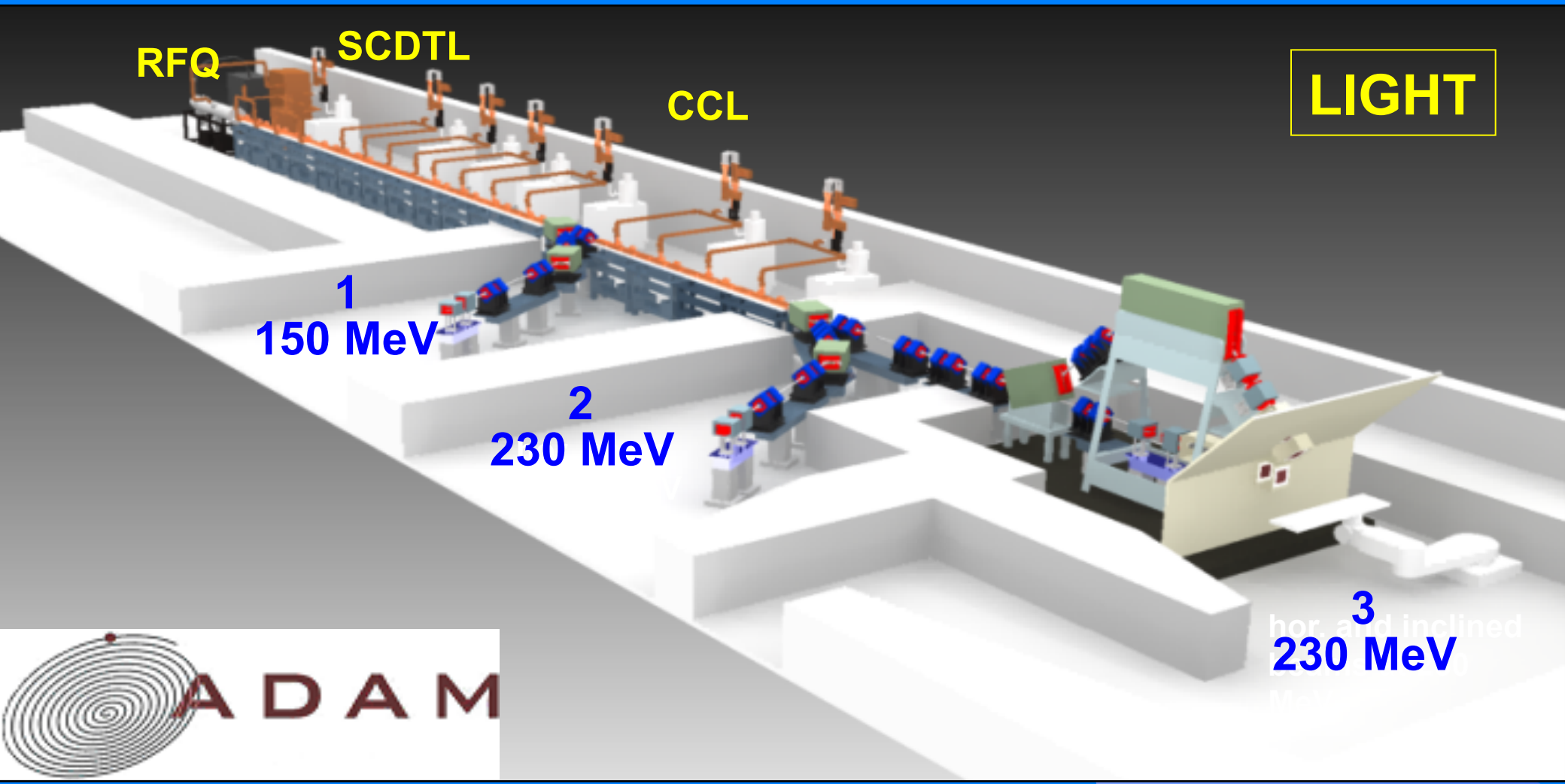
Linac for Image Guided Hadron Therapy

A.D.A.M. = Applications of Detectors and Accelerators to Medicine



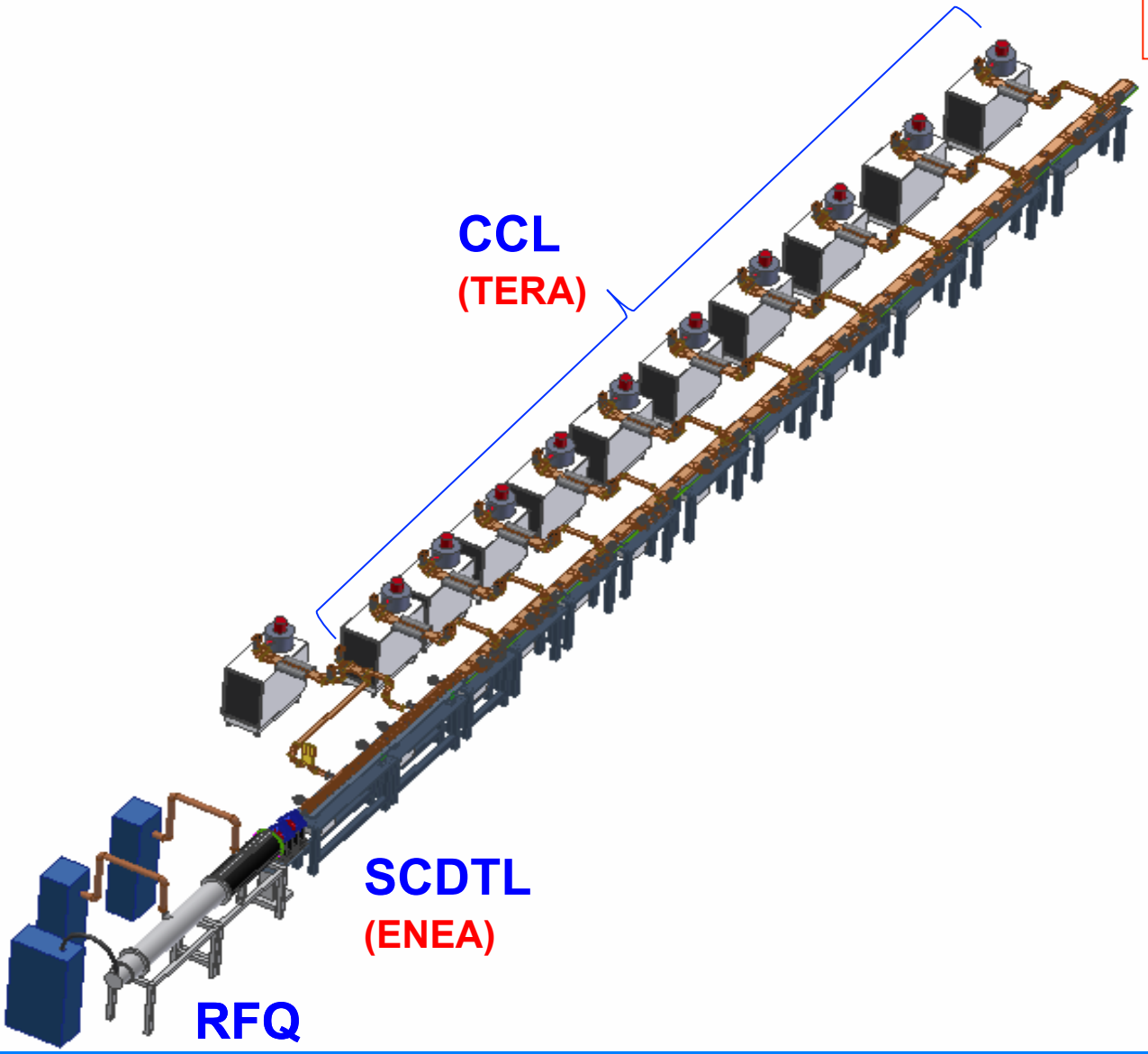
Inauguration by the CERN DG

Centre offered by A.D.A.M. - CERN spin-off Company acquired by Advanced Oncotherapy in 2013



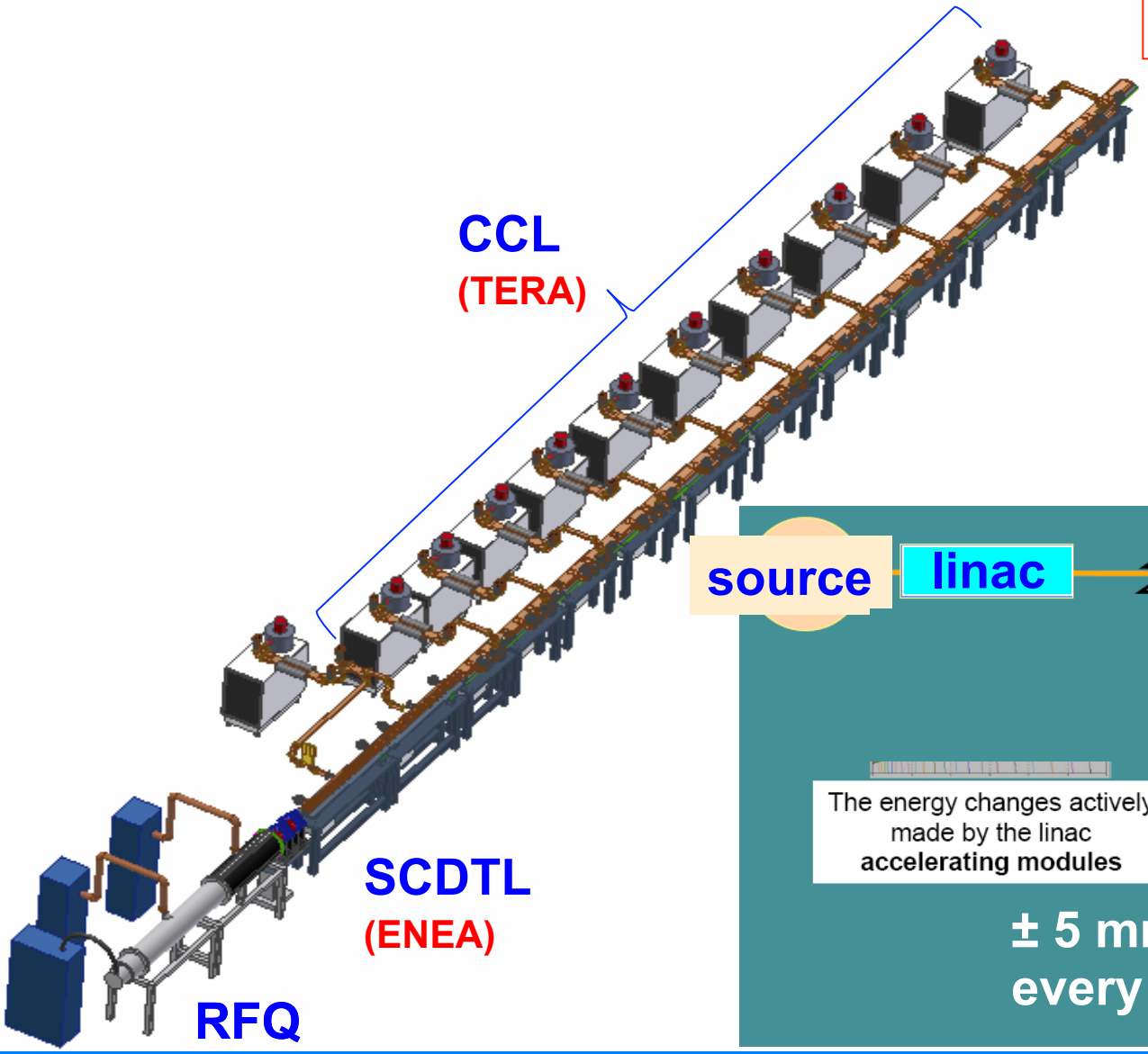
Linac for Image Guided Hadron Therapy

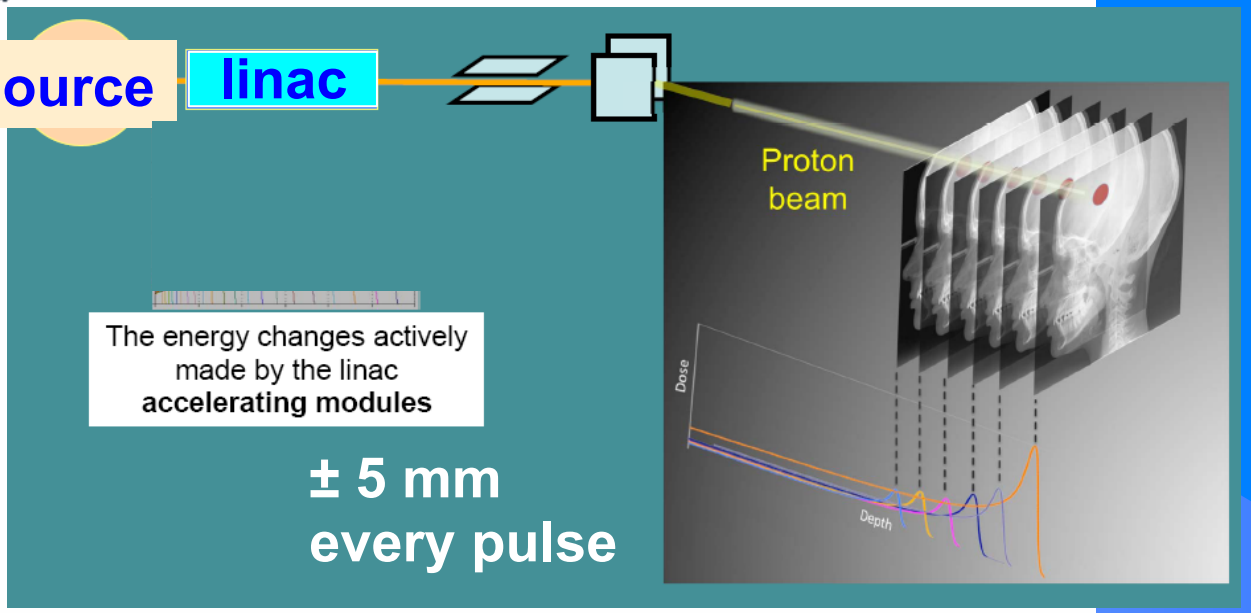
pulses @ 200times per second



Linac for Image Guided Hadron Therapy

pulses @ 200times per second





It is clear to anybody who visits a hospital that Physics applications are everywhere. Medical doctors use Physics when they measure a blood pressure, when they perform an ultrasound scan to determine the sex of an unborn child, when they take radiography or a CT scan. In particular fundamental physics, which aims at understanding how particles and forces act in the subatomic world and are organized to form everything we observe around us, has numerous medical applications.

Everything started in 1895 with the discovery of X-rays by Roentgen, who was using the best particle accelerator of the time. In the lecture the theme of the title will be exposed by following the 120 years long story of particle accelerators used to cure tumours. The time is well chosen because the year 2014 marks the 60th anniversary of CERN, the largest particle physics laboratory in the world, and of the first cancer treatment with protons done at Berkeley.