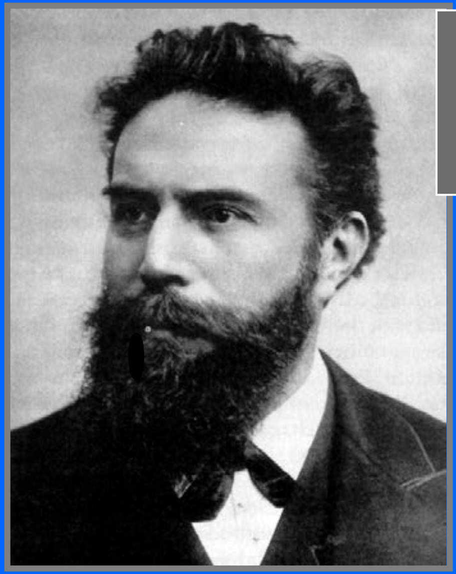
PHYSICS IS BEAUTIFUL

AND USEFUL

The beginnings of fundamental physics and medical physics



9 November 1895

Discovery of X rays

Wilhelm C. Röntgen

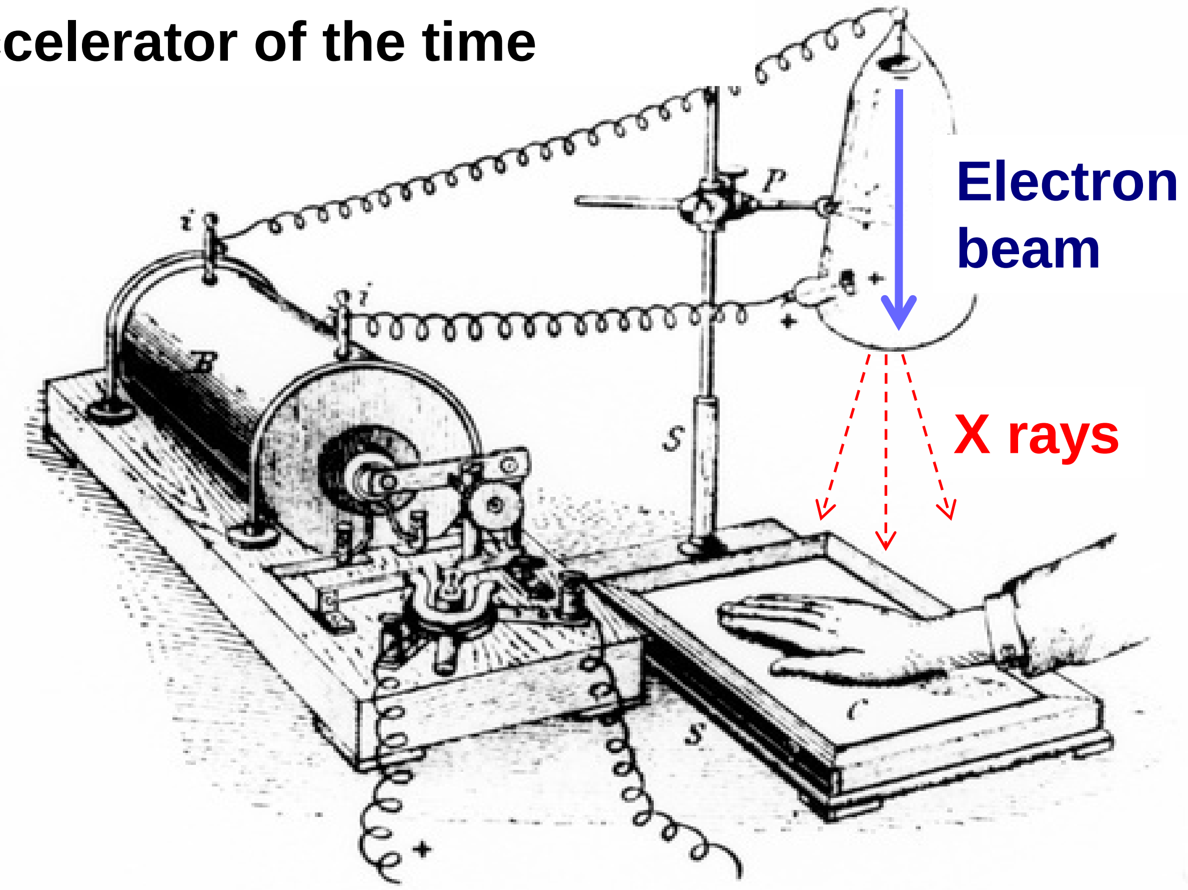
1898

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

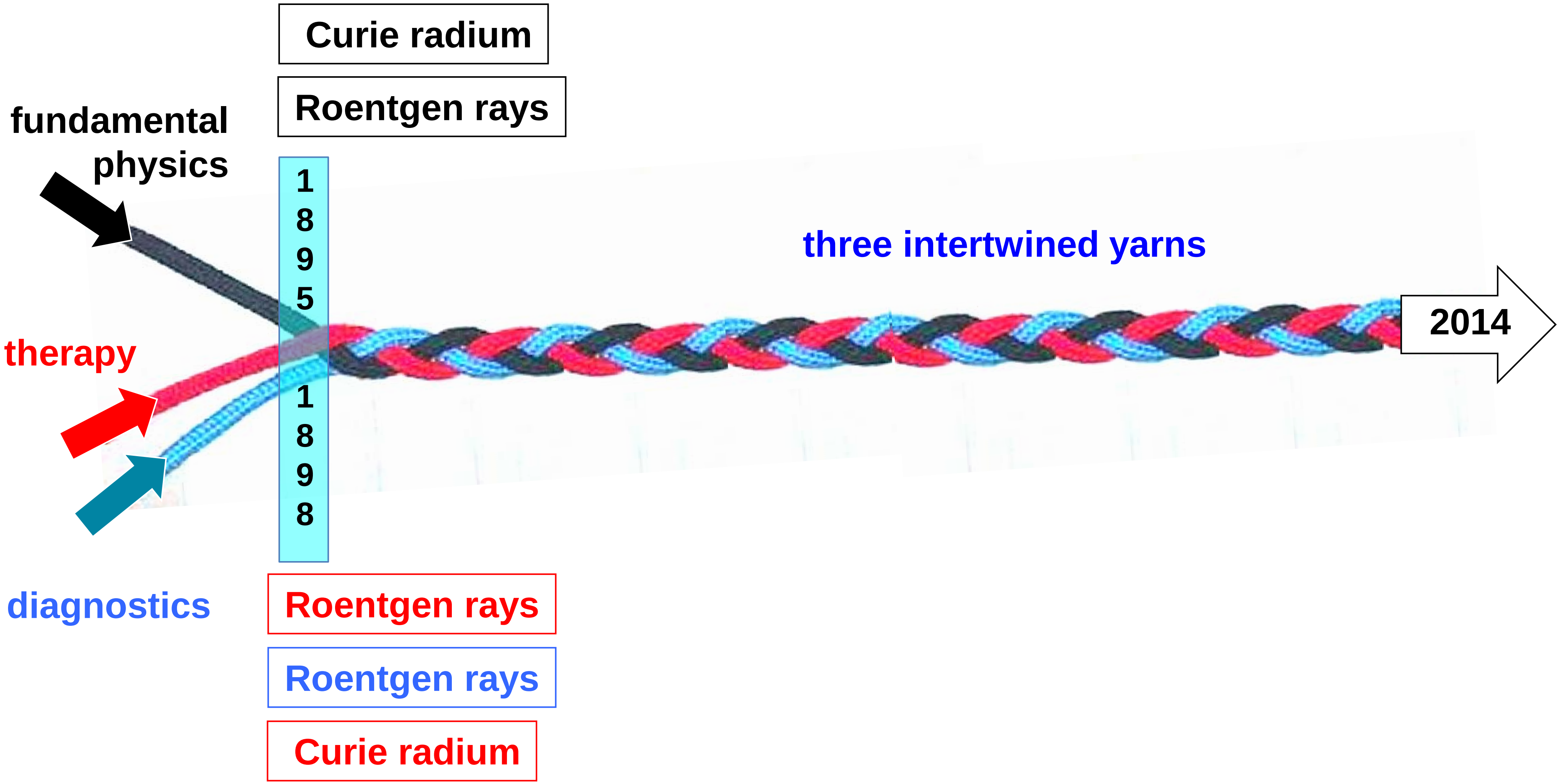
First uses of X rays and radium in diagnostics and therapy

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

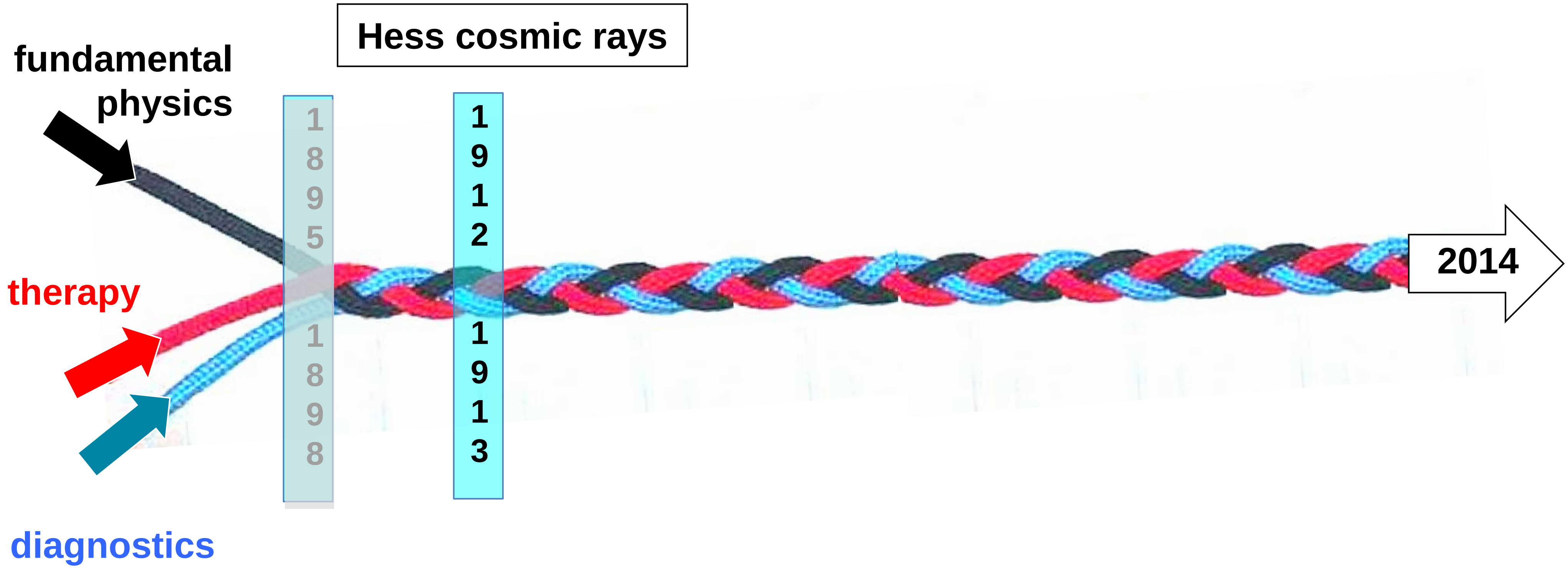
Robert Jones and Oliver Lodge
(Liverpool)
Radiography of a bullet in a hand
February 7, 1896

Henri Danlos
(Paris)
Lupus treatment with radium
1901

120 years of beautiful and useful physics



120 years of beautiful and useful physics

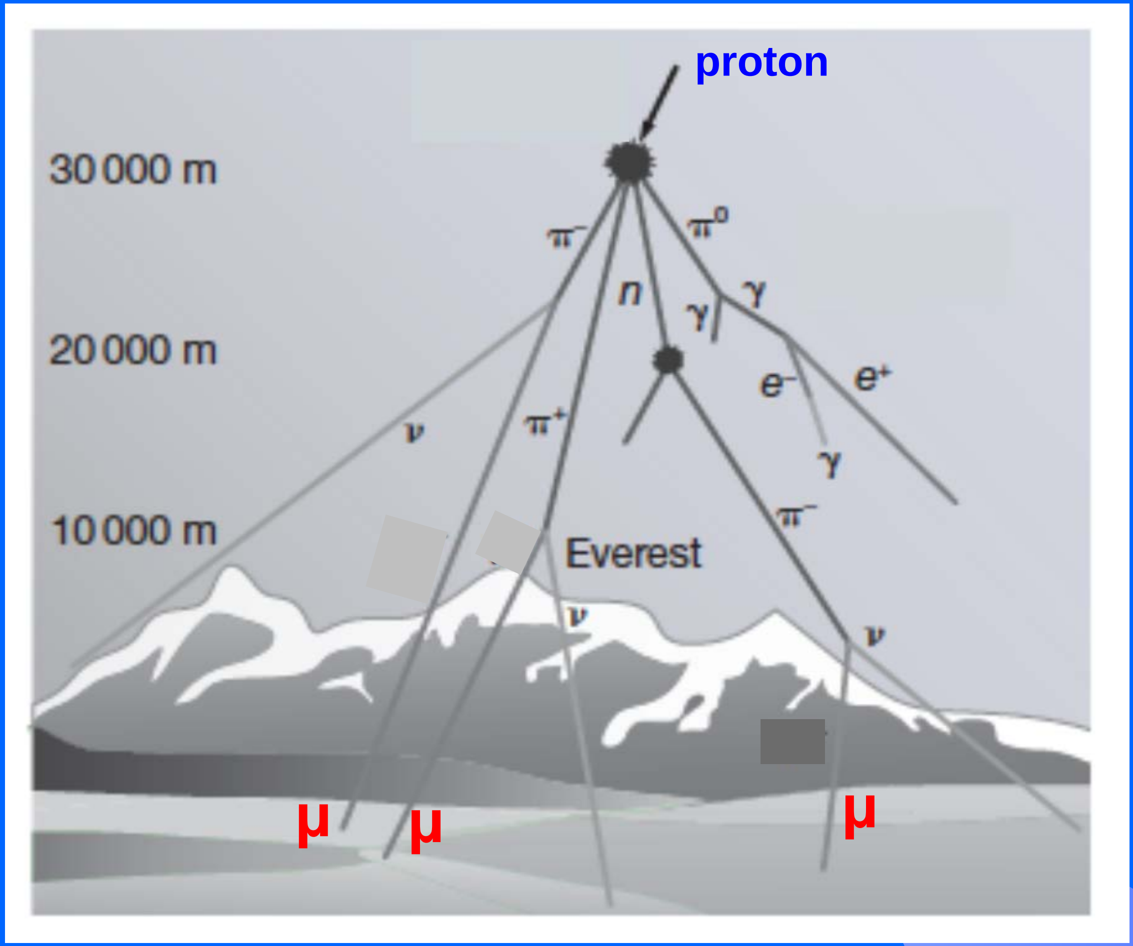


1912: Victor Hess discovers 'cosmic rays'

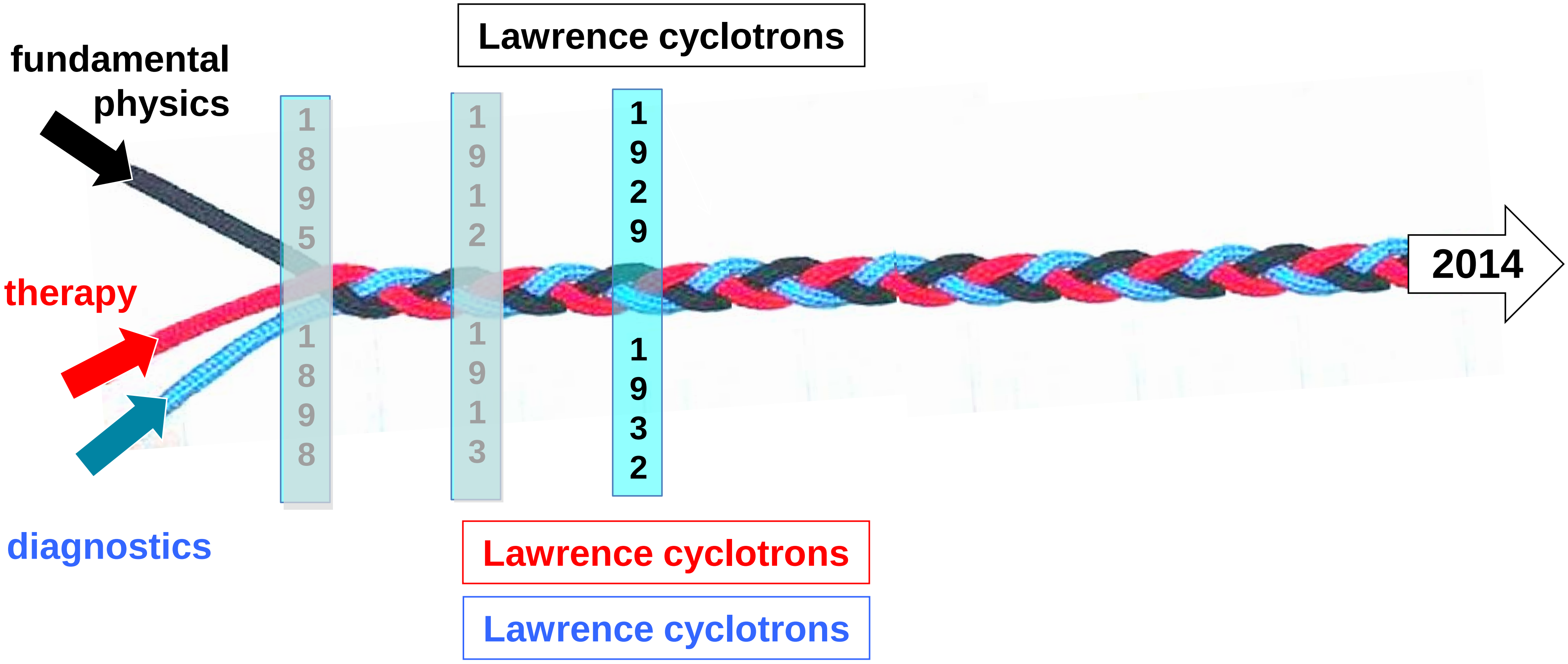
Hess brought precision equipment
in ten balloon ascents
and discovered that
radiation at 5 km altitude
is twice
larger than at see level.

100 YEARS AGO

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

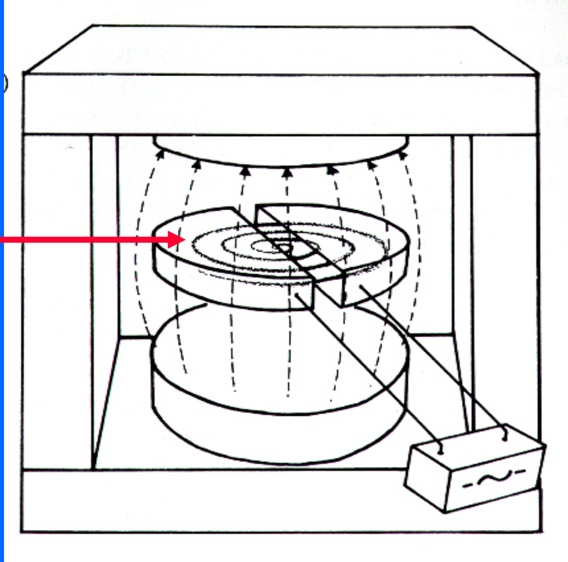


muons are 'heavy electrons' with a mass that is 200 times larger


Lawrence cyclotrons
fundamental physics
therapy
diagnostics
1895
1898
1912
1913
1929
1932
2014
Lawrence cyclotrons
Lawrence cyclotrons

1929: invention of the "cyclotron"

Spiral tajectory of an accelerated particle



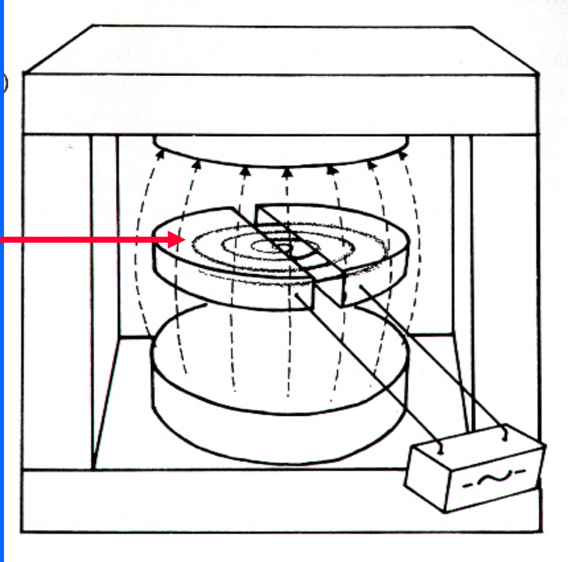
Ernest Lawrence -

1 MeV = 1 million electronvolts

= 0.001 GeV

1929: invention of the "cyclotron"

Spiral tajectory of an accelerated particle



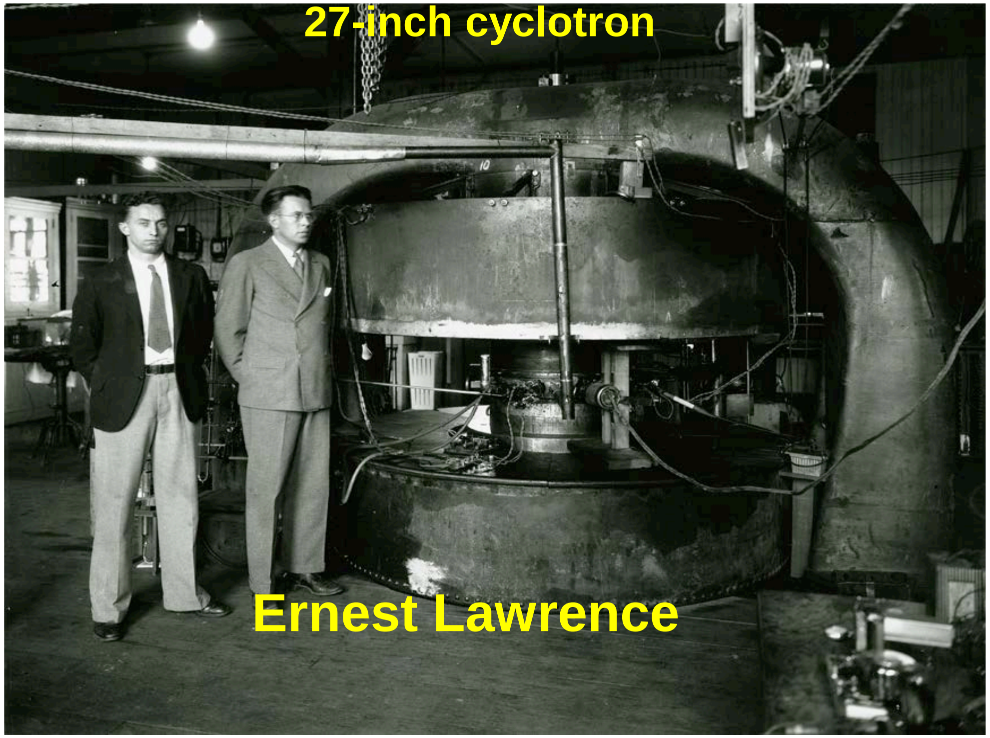
Ernest Lawrence -

Modern 30 MeV cyclotron for radioisotope production

1 MeV = 1 million electronvolts

= 0.001 GeV

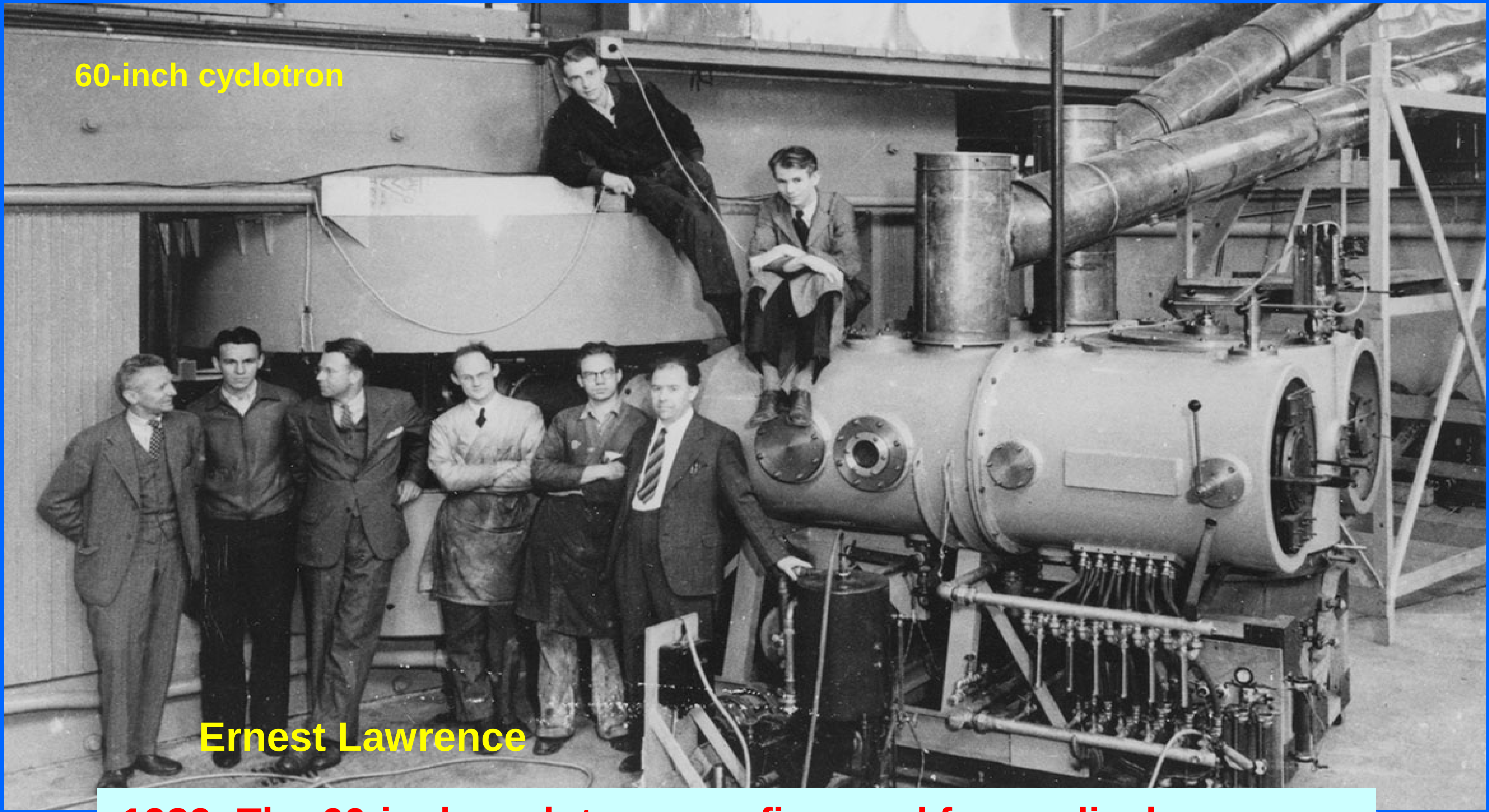
Cyclotrons in diagnostics and therapy



John Lawrence, MD

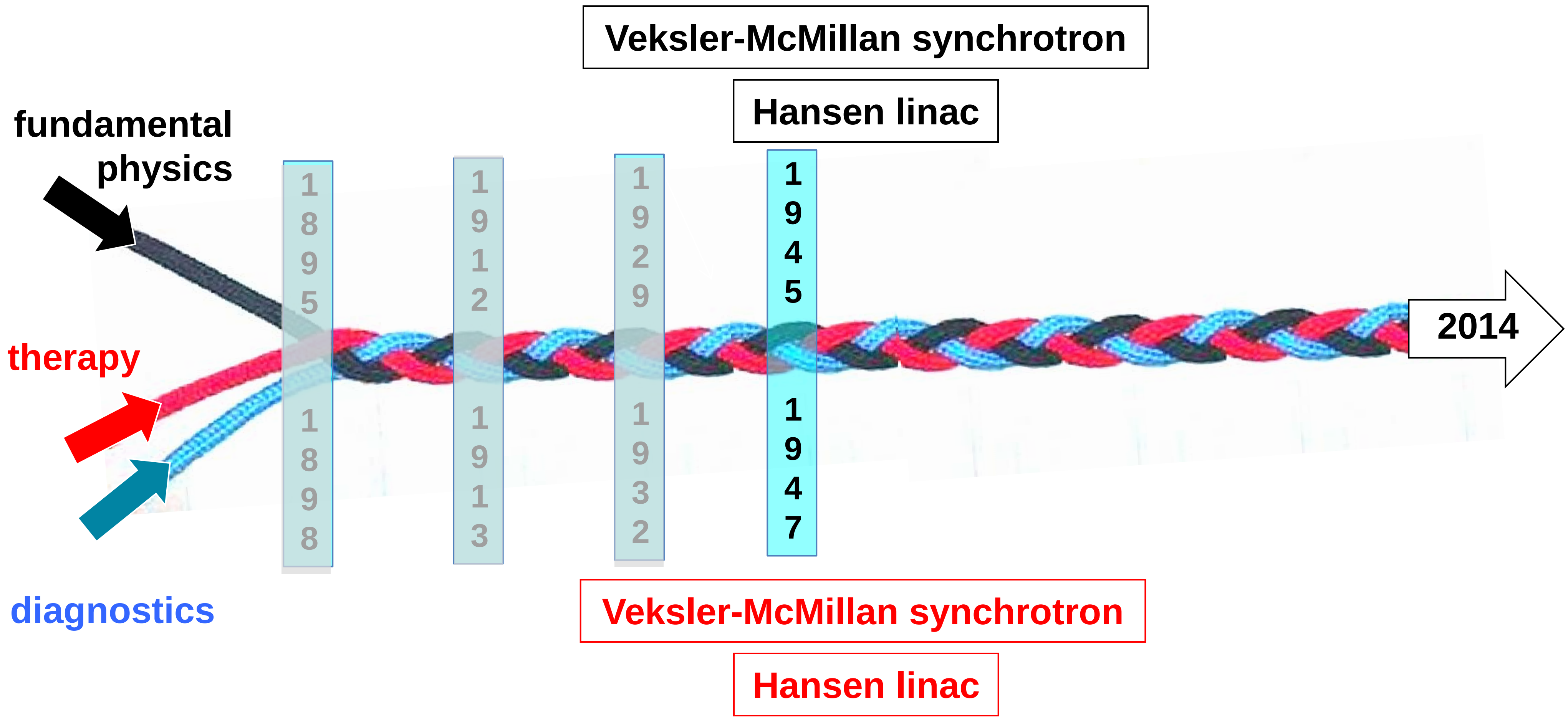
1936: Radio-sodium to study metabolism
1936: Radio-phosphorus to treat leukaemia

Cyclotrons in diagnostics and therapy

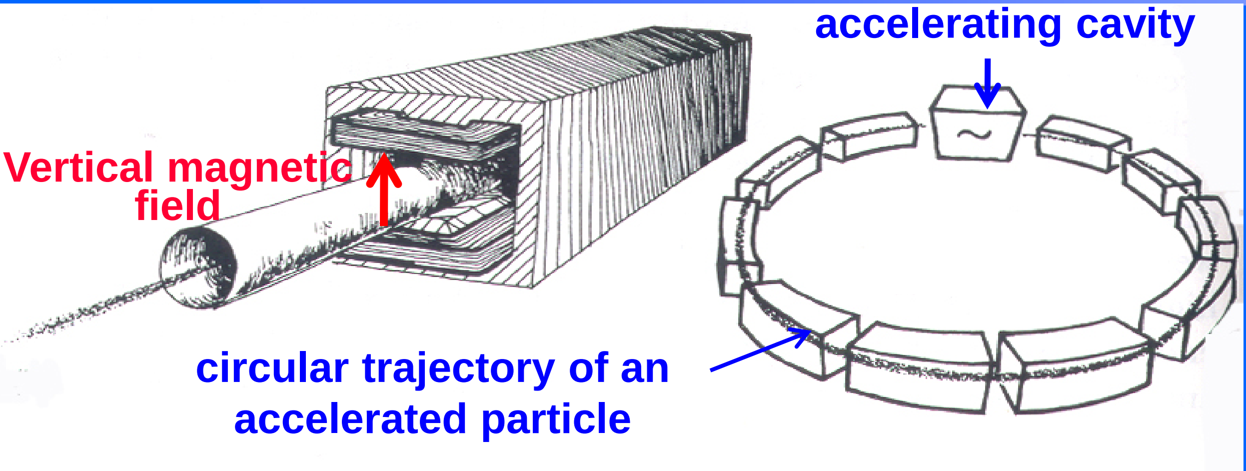


1939: The 60-inch cyclotron was financed for medical purposes and later used to treat patients with neutron beams

120 years of beautiful and useful physics



The invention of the synchrotron came in 1945

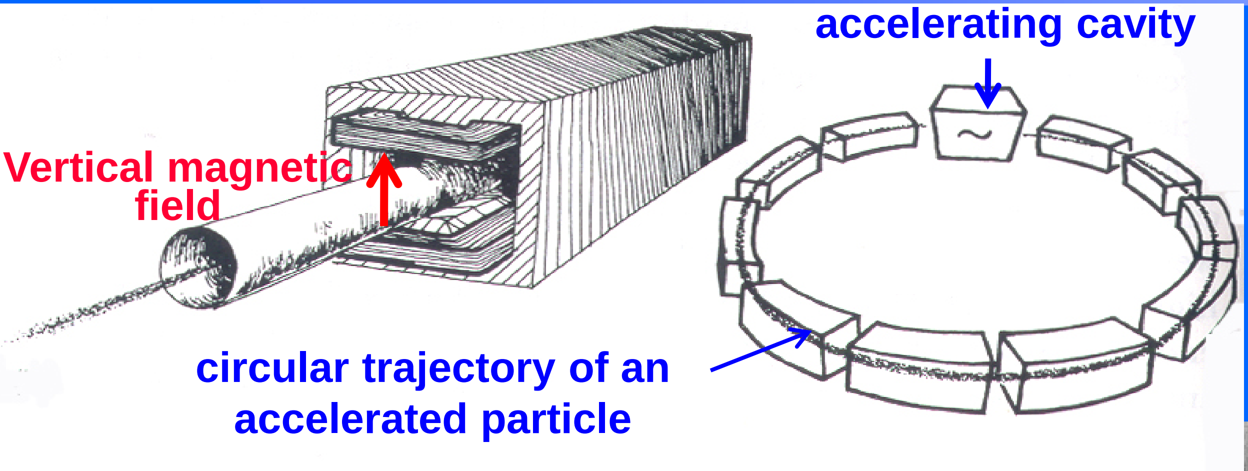


E. McMillan and V.J.Veksler

"Phase stability principle"

1959: Veksler visits McMillan at Berkeley

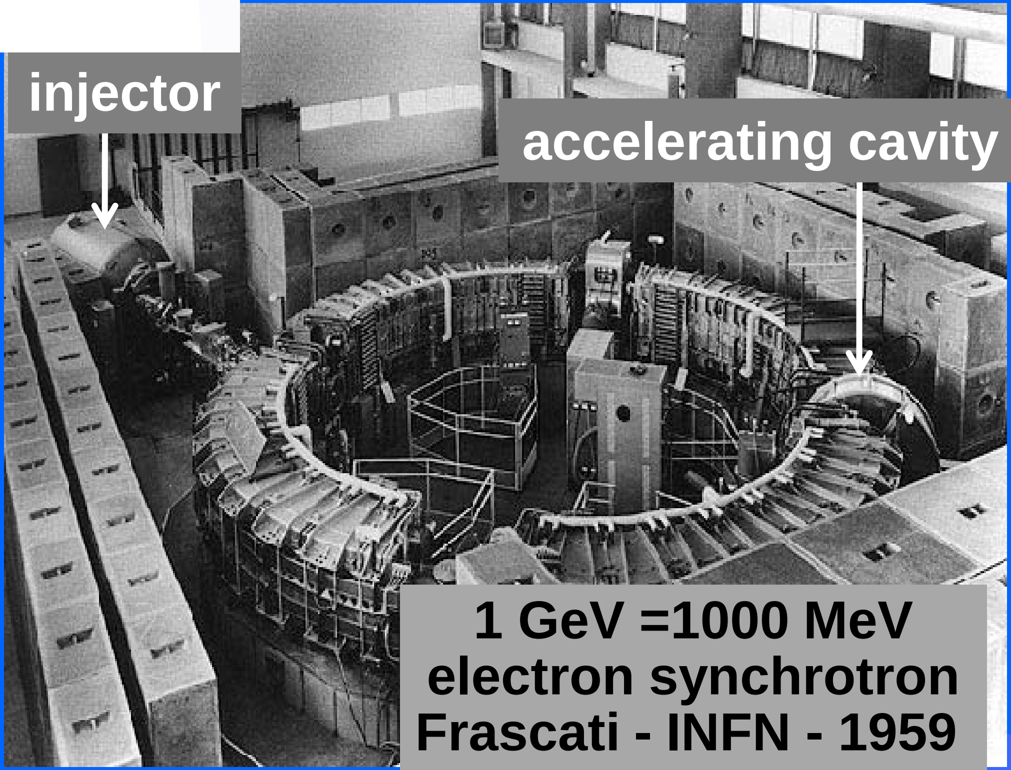
The invention of the synchrotron came in 1945



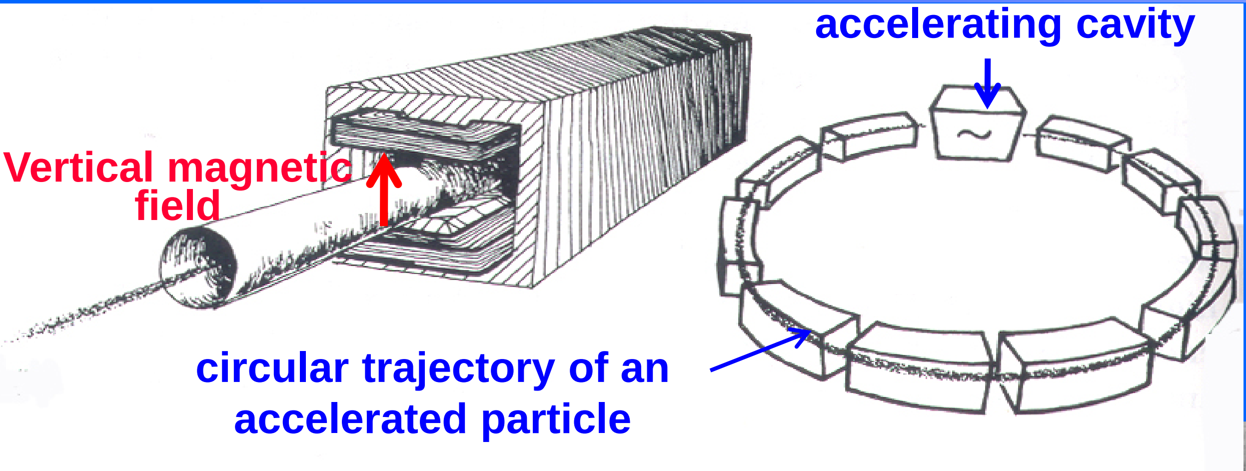
E. McMillan and V.J.Veksler

"Phase stability principle"

1959: Veksler visits McMillan at Berkeley



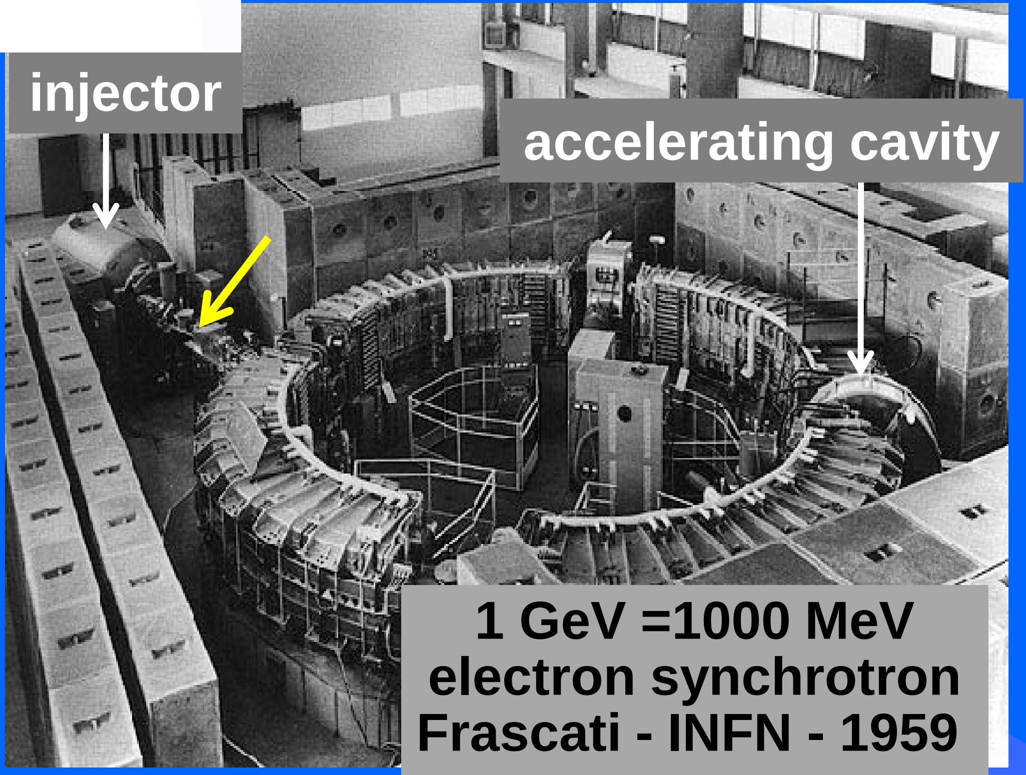
The invention of the synchrotron came in 1945



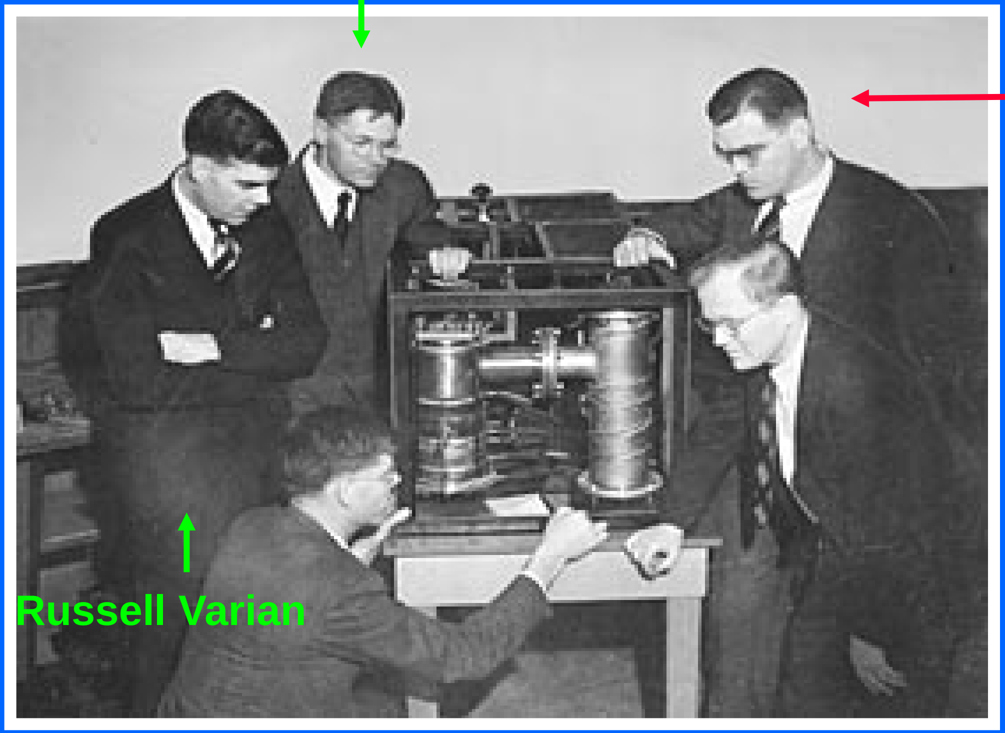
E. McMillan and V.J.Veksler

“Phase stability principle”

1959: Veksler visits McMillan at Berkeley



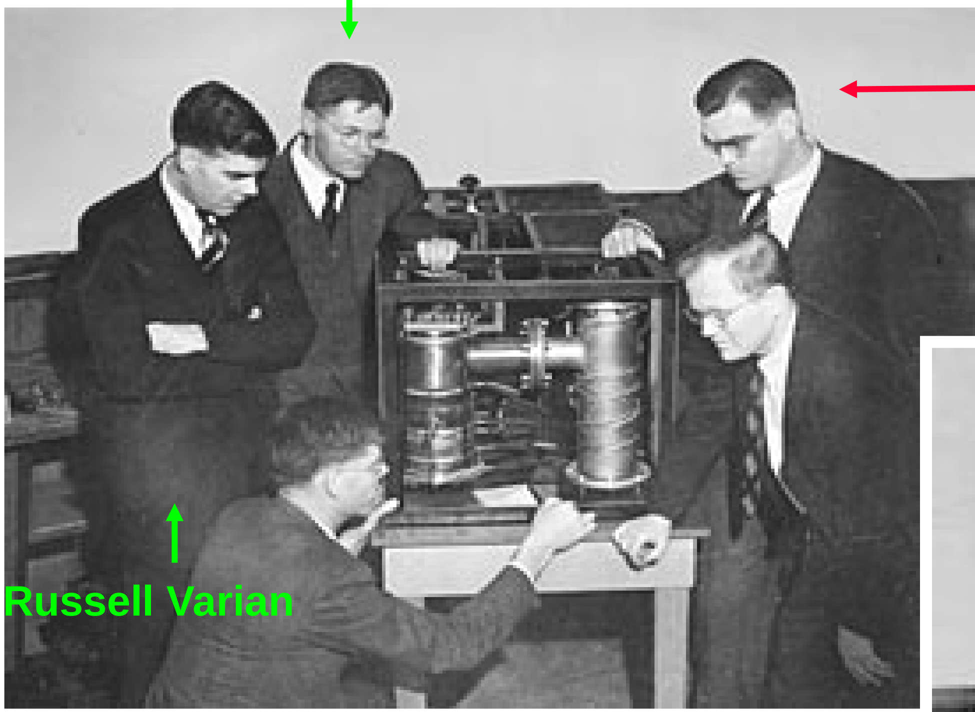
The first electron linac above 1 MeV



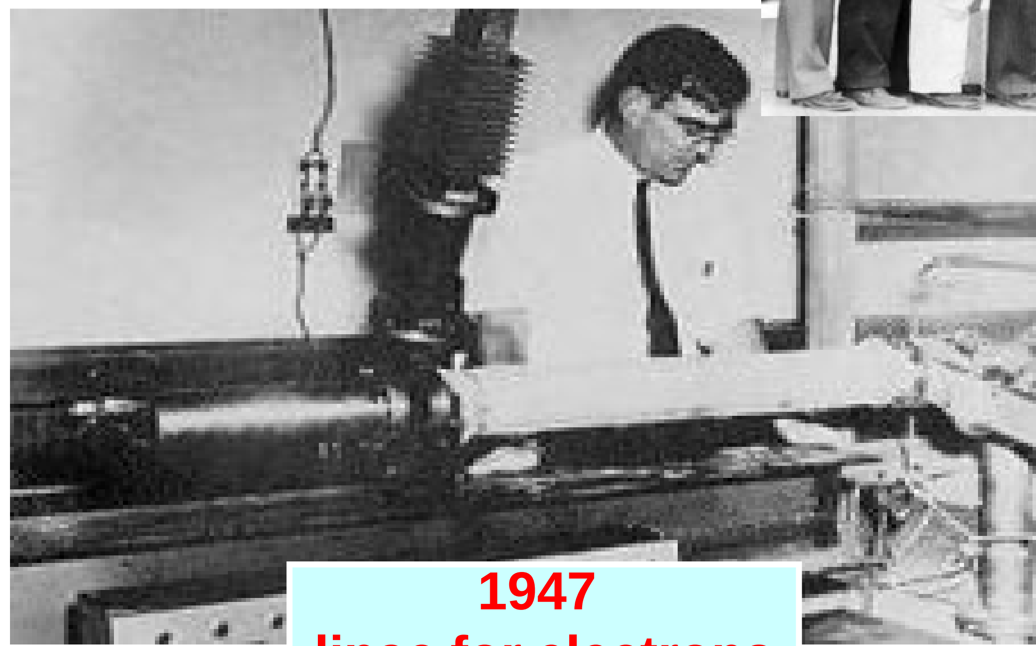
1939

Invention of the klystron

The first electron linac above 1 MeV



William W. Hansen

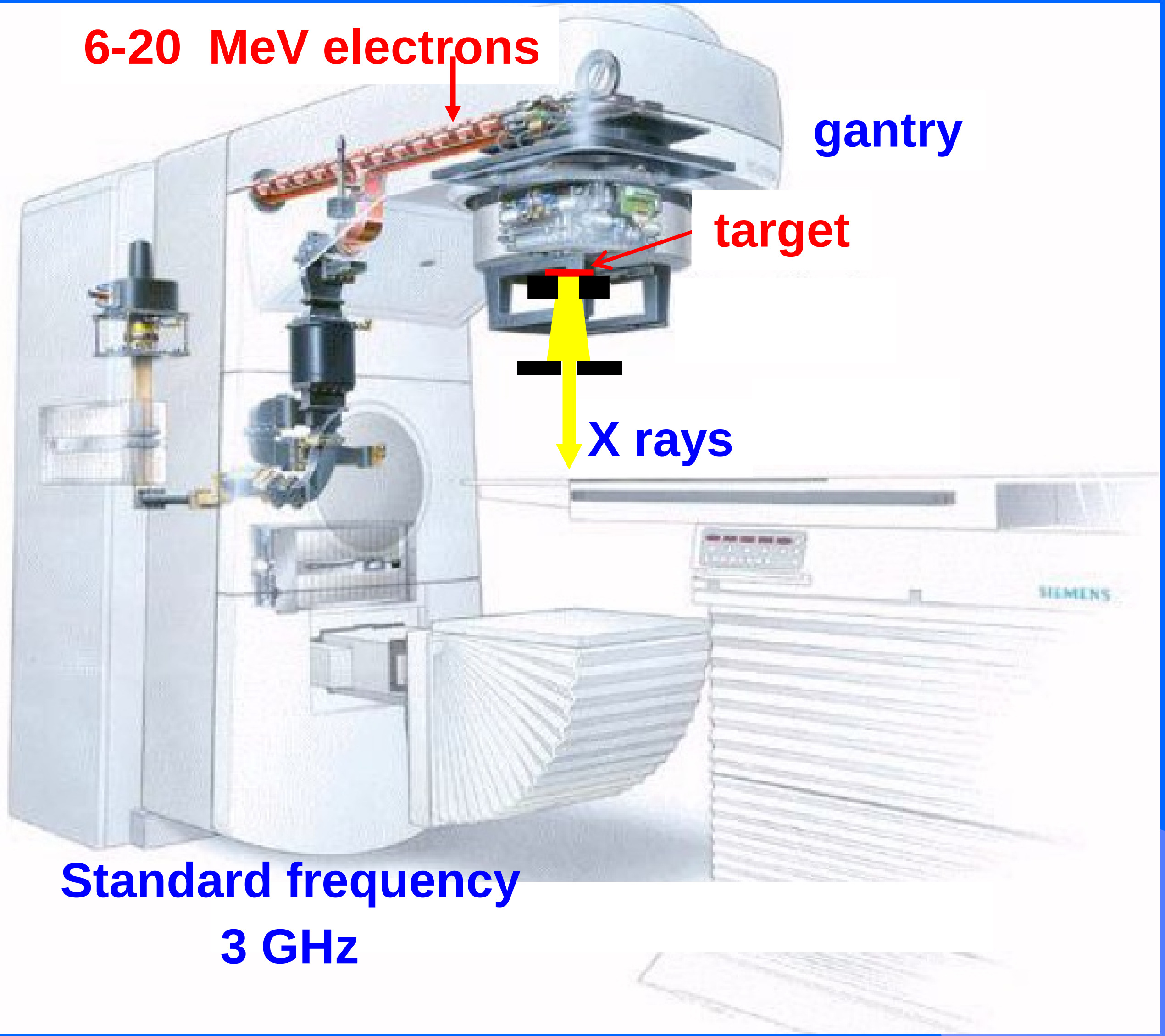


1939

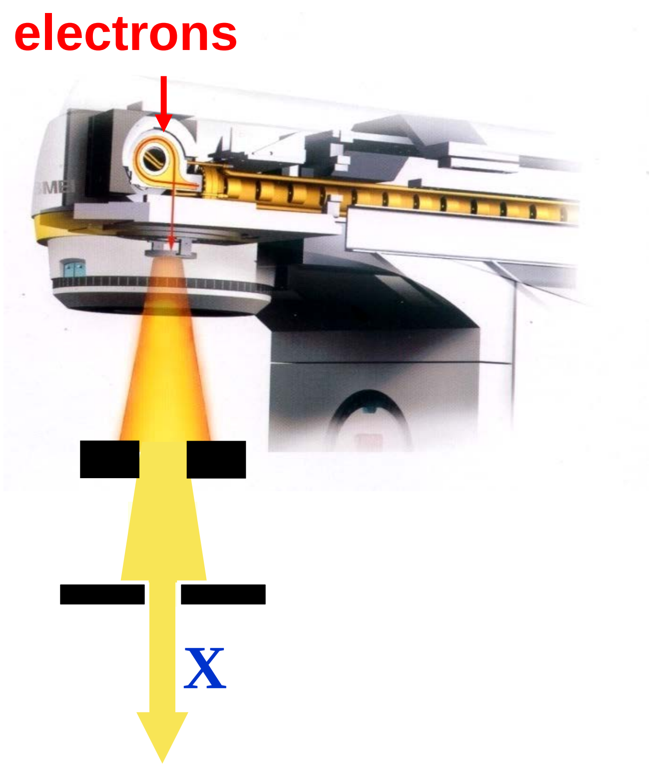
Invention of the klystron

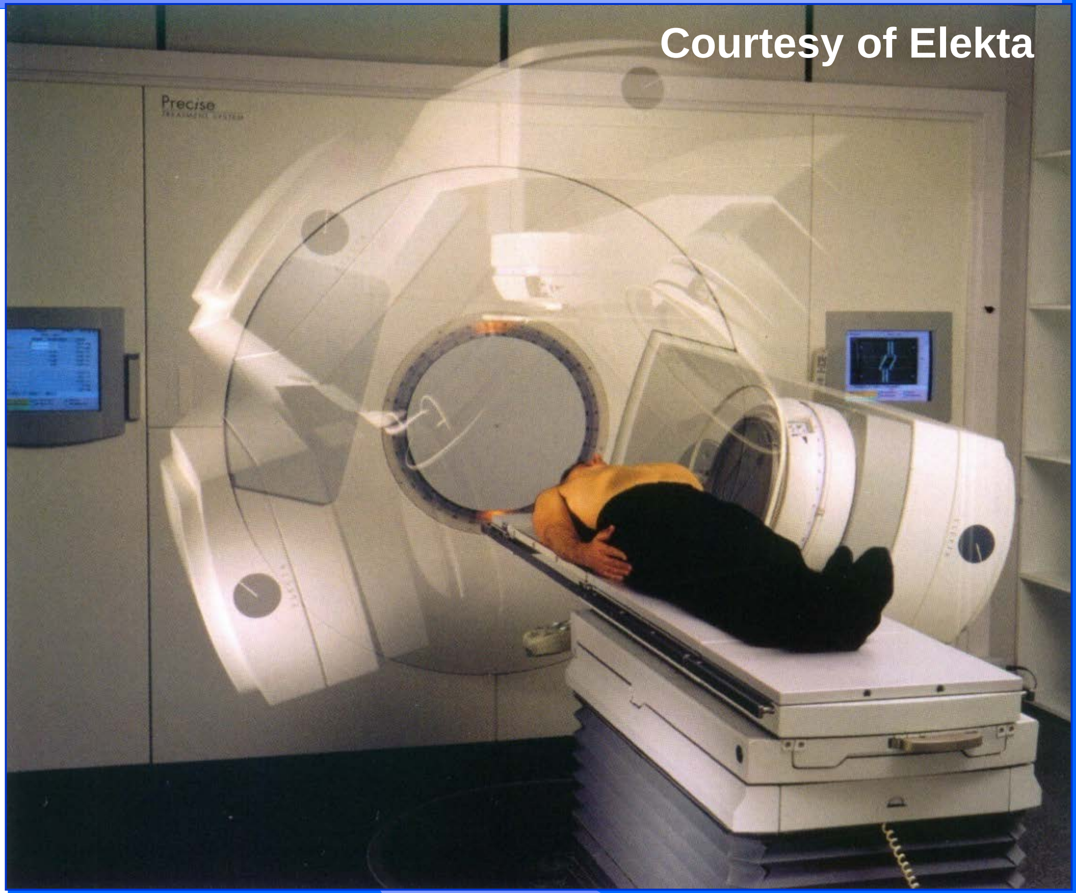
1947
linac for electrons
1.5 MeV at 3 GHz

'Conventional' radiotherapy: linear accelerators dominate



‘Conventional’ radiotherapy: linear accelerators dominate





2000 patients/year every in 1 million inhabitants

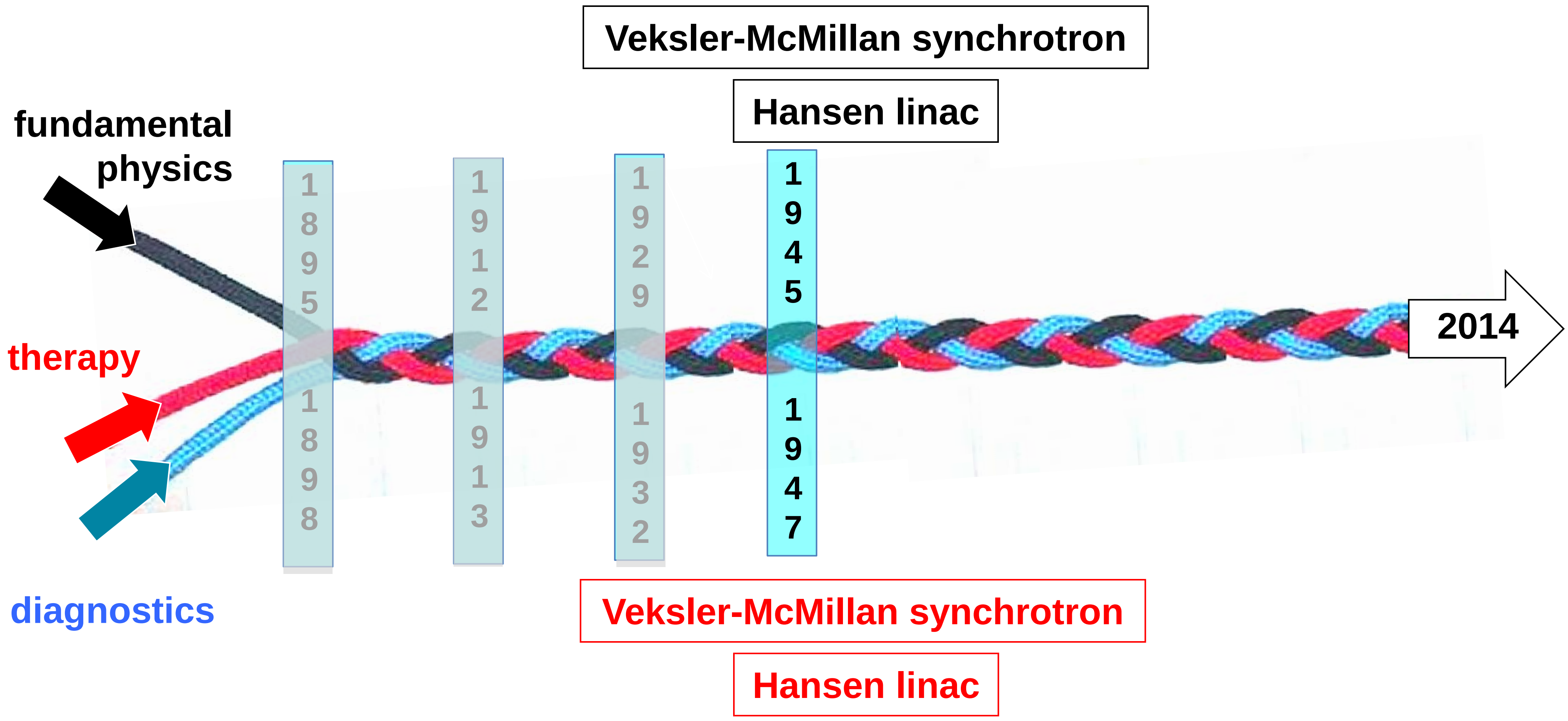
1 treatment in 30 sessions

In the world radiation oncologists use 20 000 electron linacs

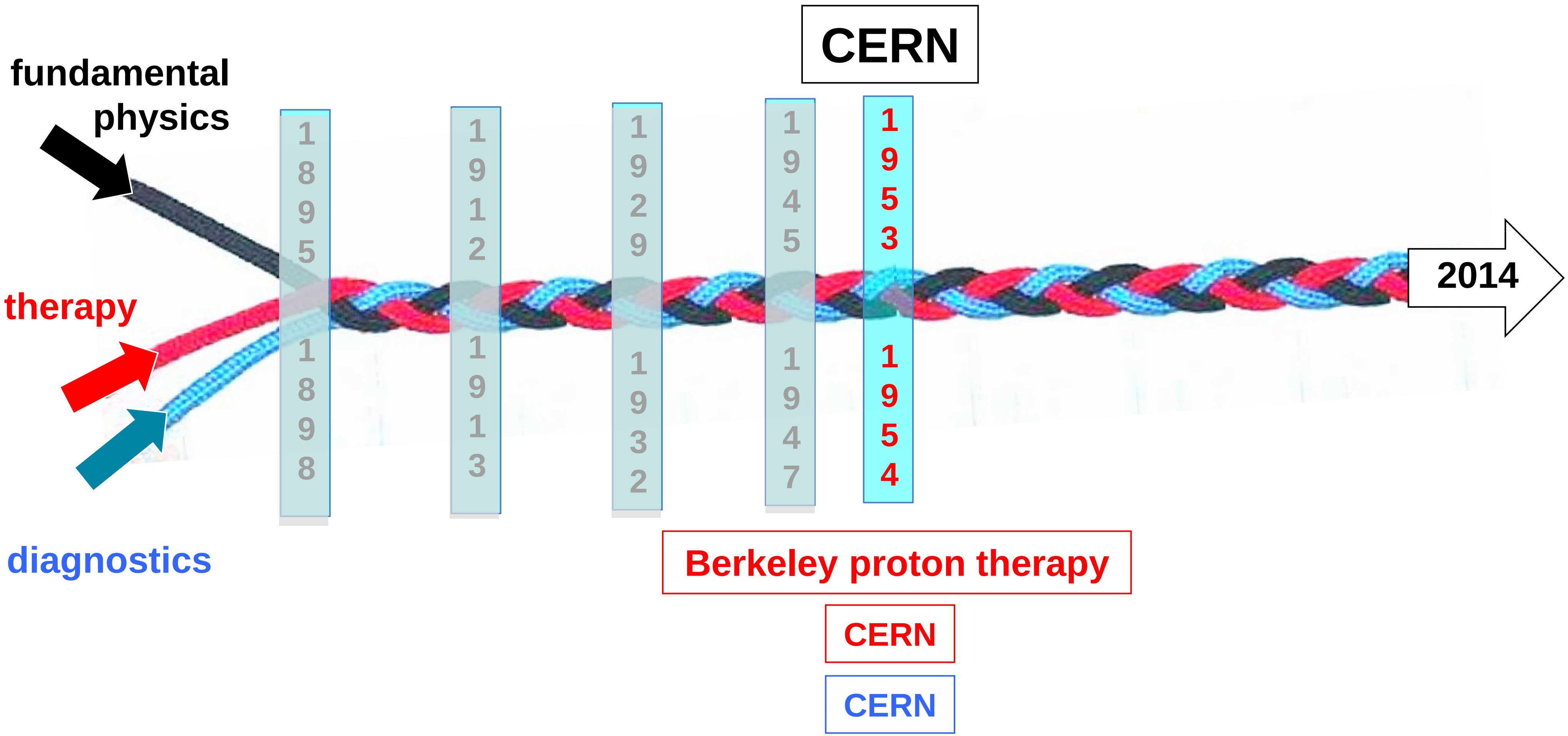
50% of all the existing accelerators

70 years later VARIAN is still the market leader

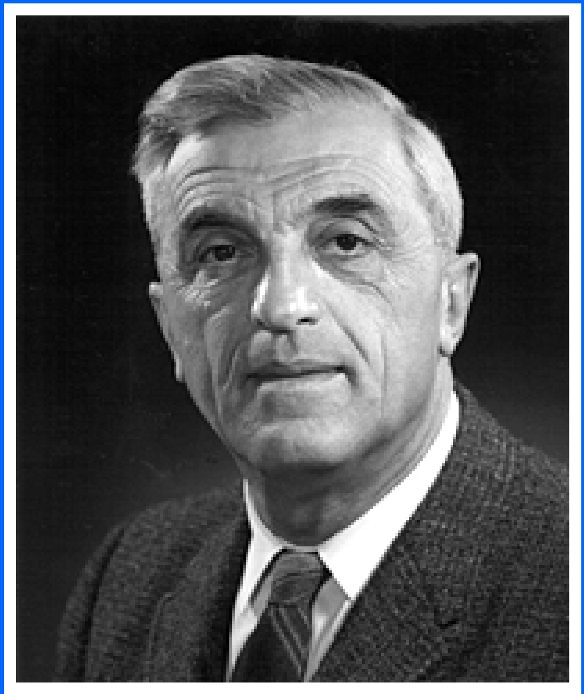
120 years of beautiful and useful physics



120 years of beautiful and useful physics



60 years ago: creation of CERN



Pierre Auger

Science Director of UNESCO

Edoardo Amaldi

Secretary General of provisional CERN 1952-1954

Felix Bloch

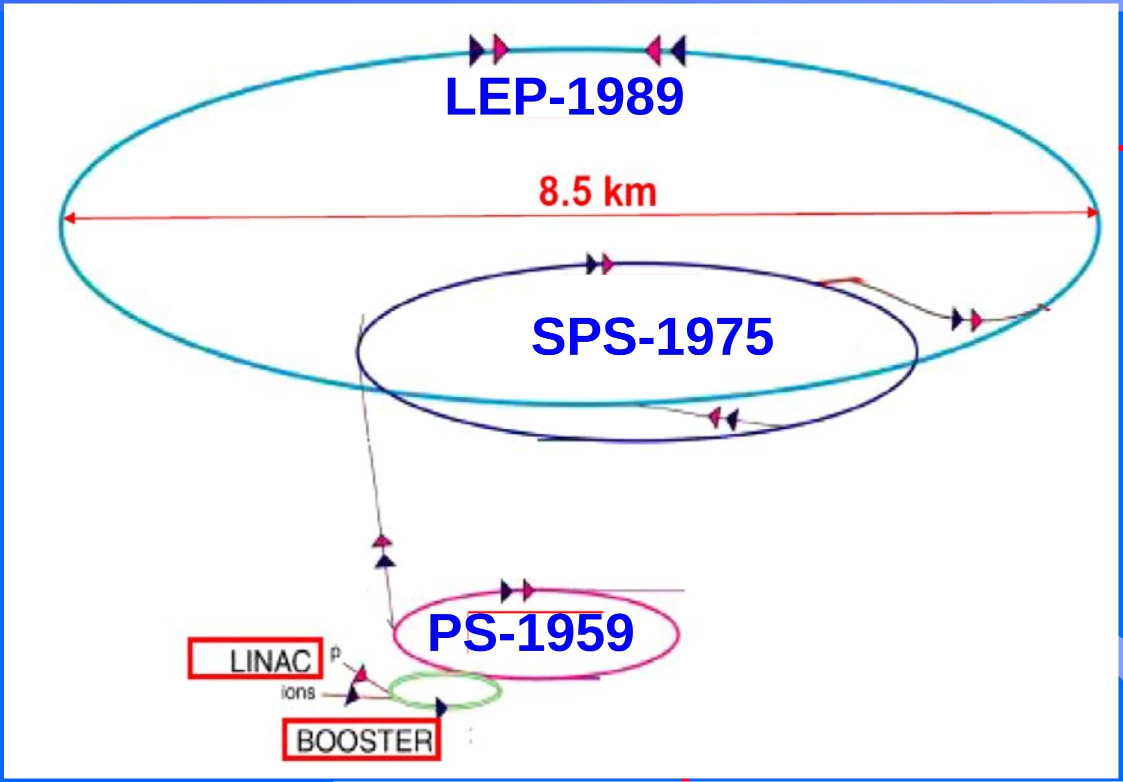
Physics Nobel Prize in 1952

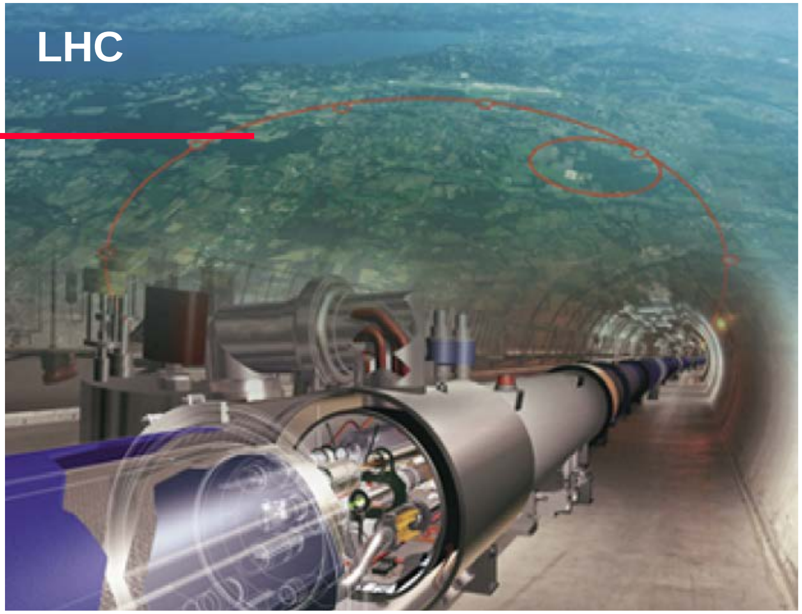
First CERN Director General 1954-1955

Following the black yarn: particle physics at CERN

CERN aerial view with the Geneva Airport

CERN accelerators are synchrotrons used as "colliders"

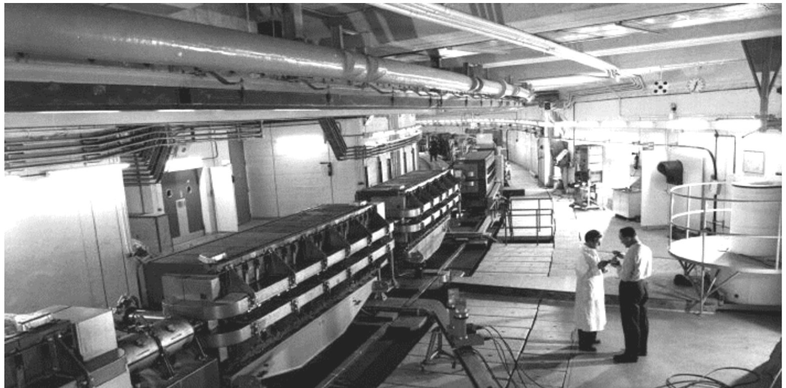




LHC in 2012

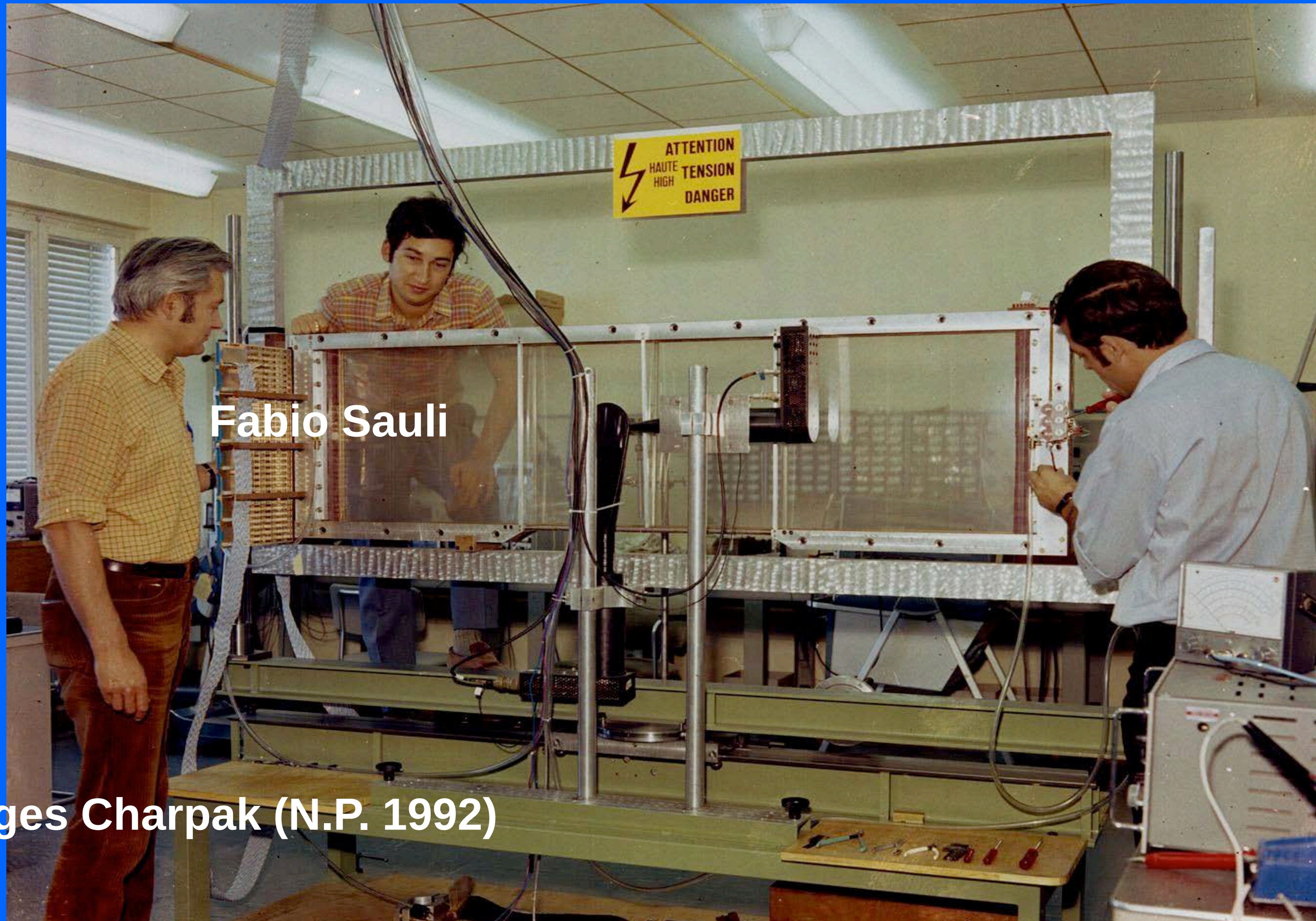
Large **H**adron **C**ollider

4 000 + 4 000 GeV



PS nel 1959 – 25 GeV

HIGHLIGHTS: 1968 - G. Charpak invents the 'wire chamber'



G.C. was the first to apply CERN detectors to biomedical imaging

HIGHLIGHTS: 1968 - G. Charpak invents the 'wire chamber'

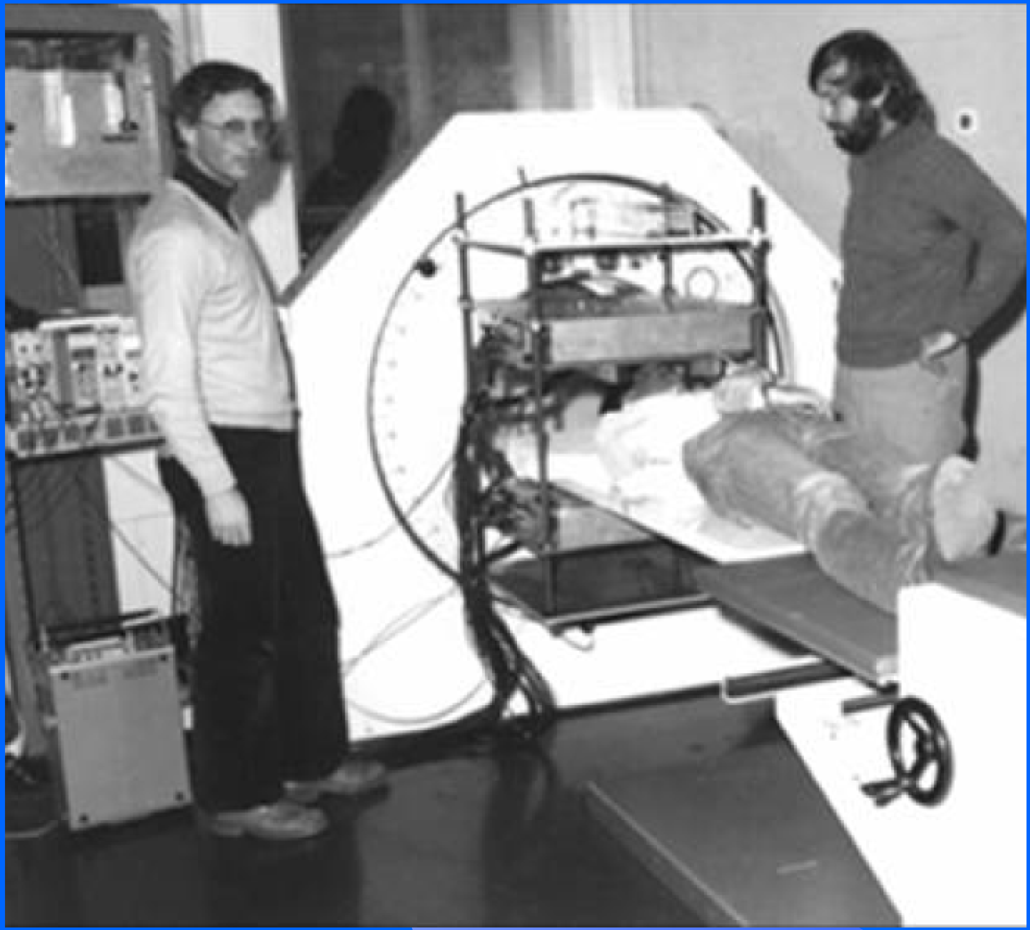
1970

Alan Jeavons and David Townsend

built and used in Geneva

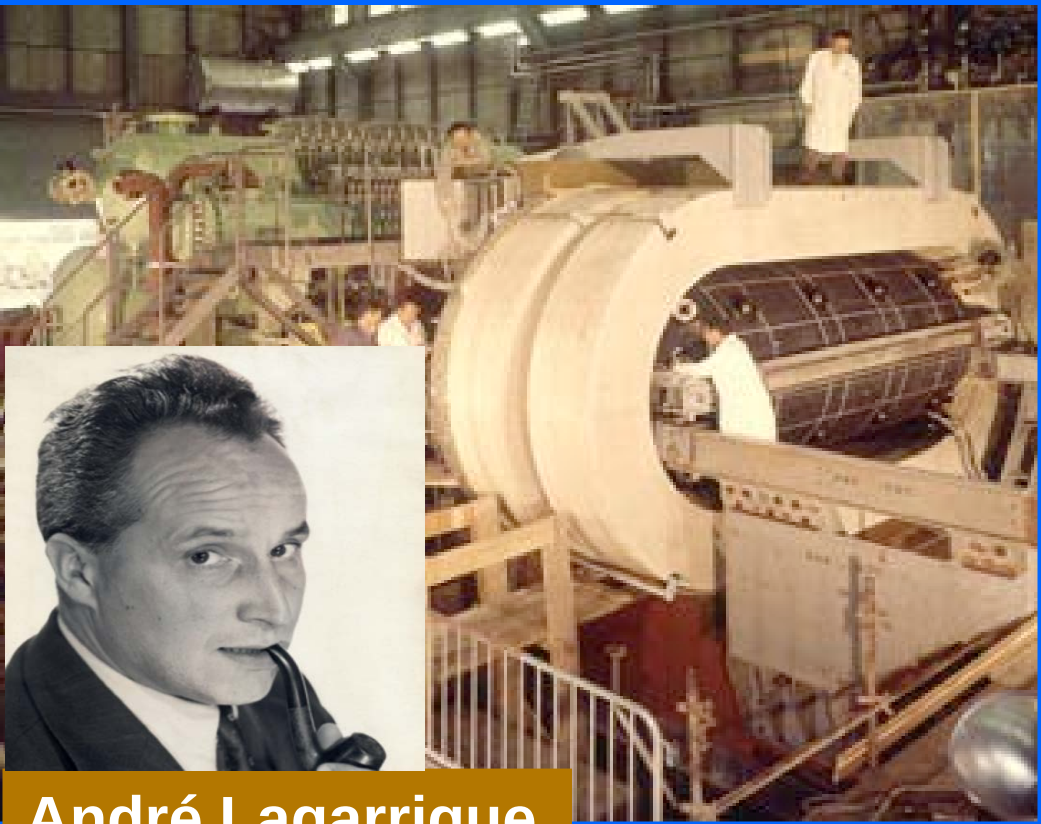
the first PET system

based on gas detectors



HIGHLIGHTS: 1973 - A. Lagarrigue is spokerperson of the Gargamelle Coll. which discovers the 'weak neutral' force

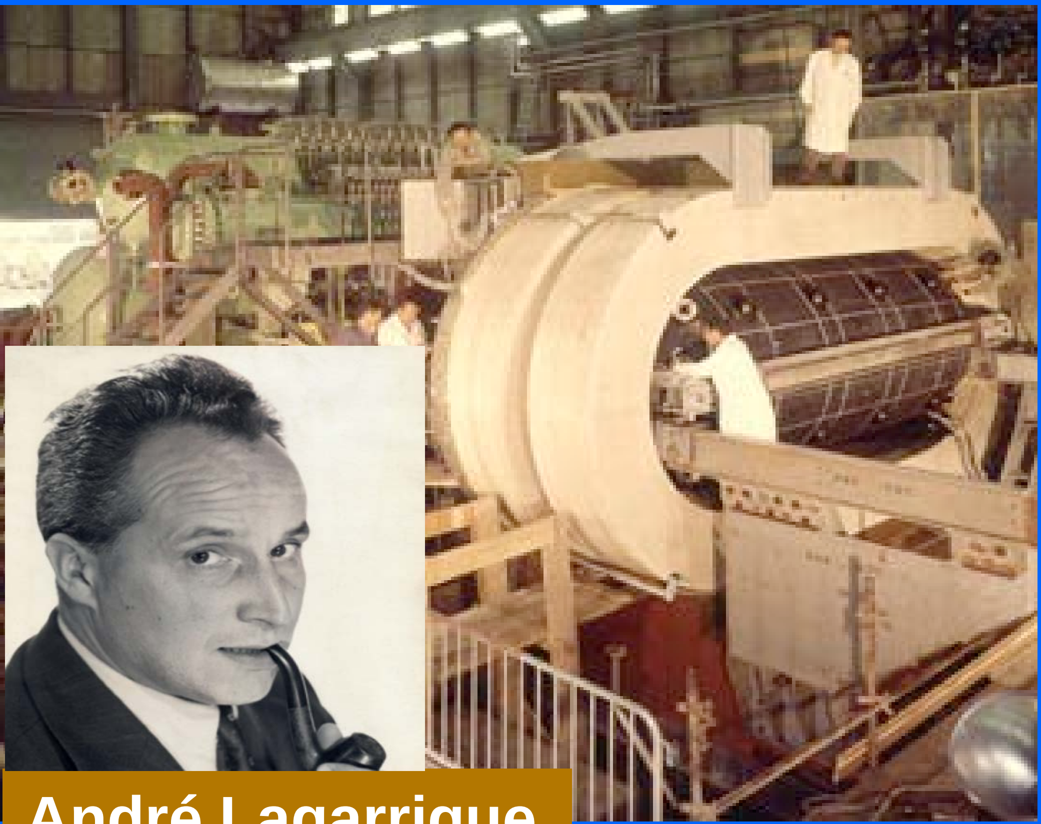
Bubble chamber Gargamelle



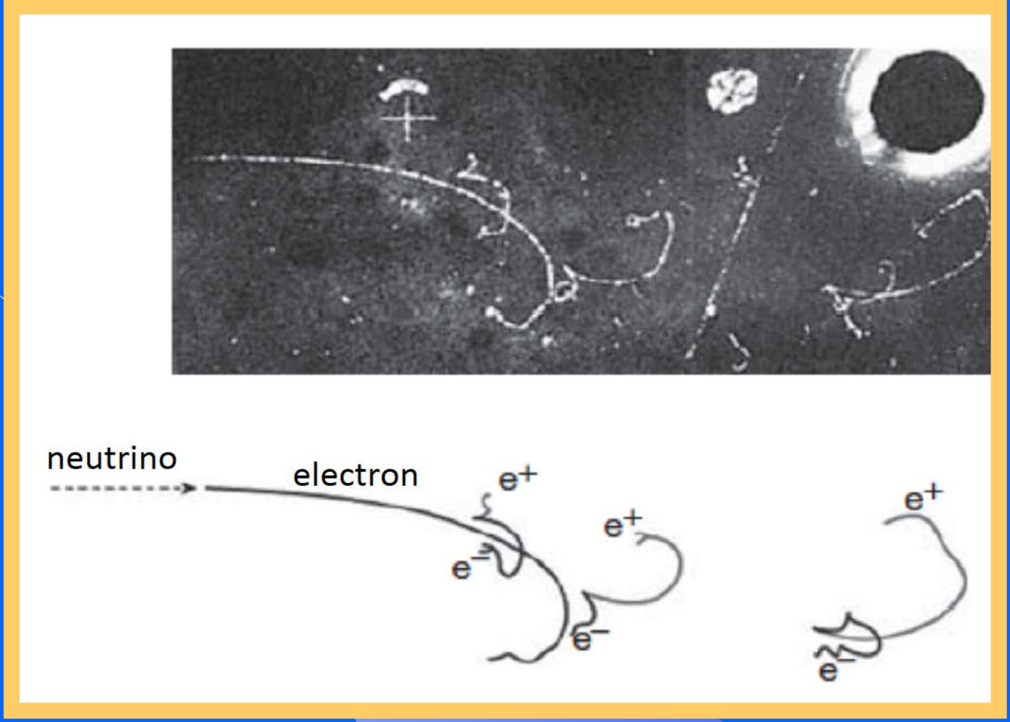
André Lagarrigue

HIGHLIGHTS: 1973 - A. Lagarrigue is spokerperson of the Gargamelle Coll. which discovers the ‘weak neutral’ force

Bubble chamber Gargamelle



André Lagarrigue



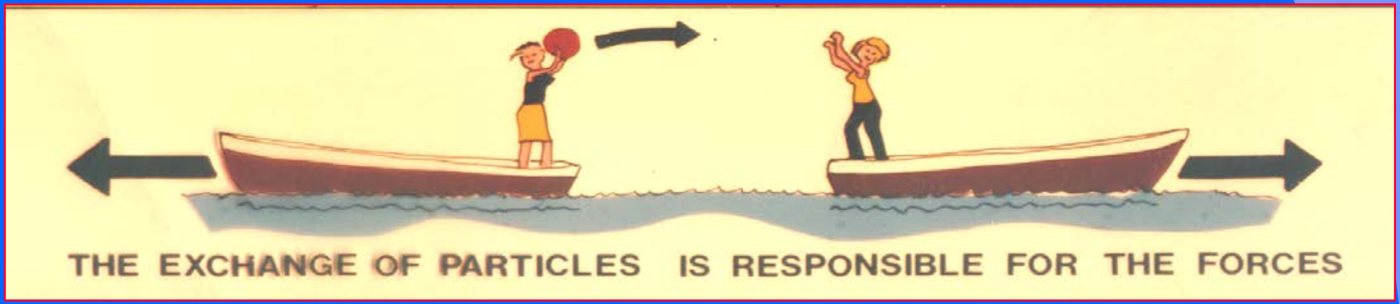
The weak neutral force is due to the exchange of a 'photon' γ

Scattering of two matter-particles

e^- = electron

photon γ mediator of the electric force (force-particle)

e^- = electron



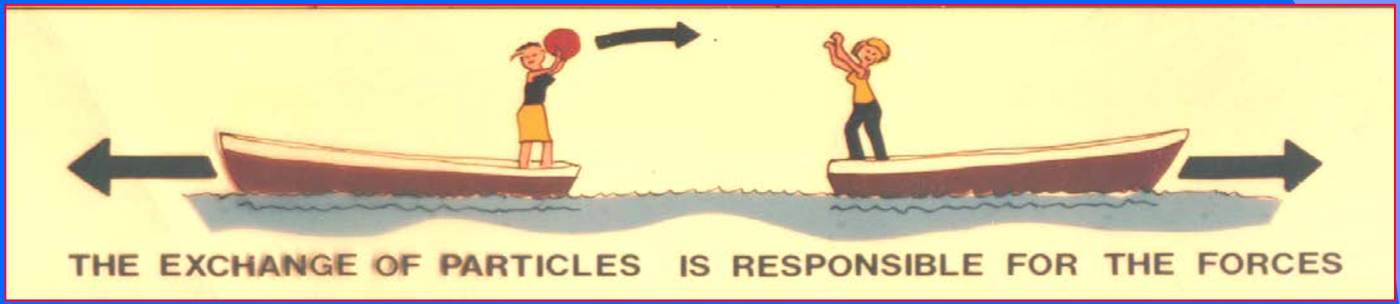
The weak neutral force is due to the exchange of an ‘intermediate boson’ Z

Scattering of two matter-particles

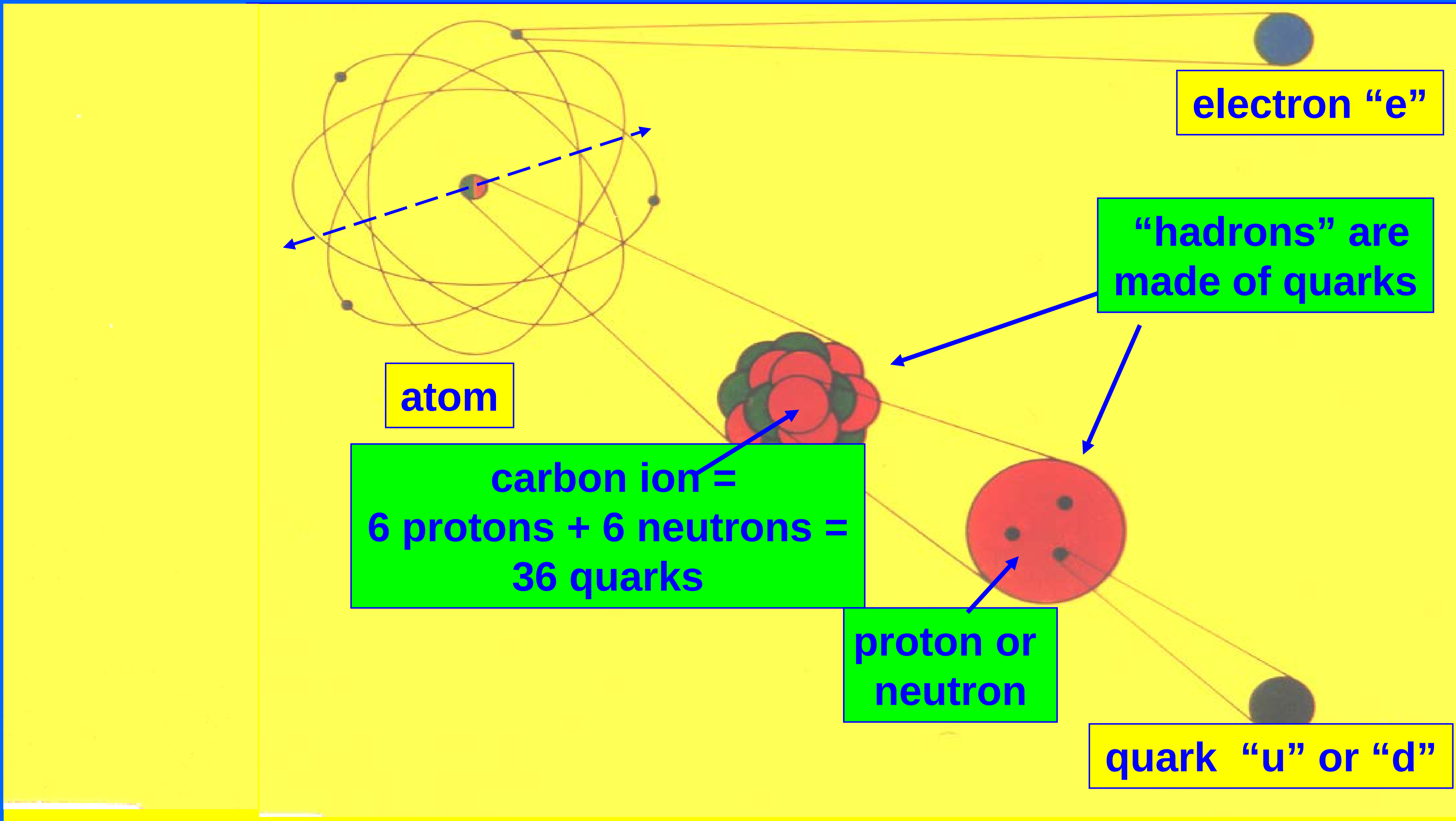
e^- = electron

intermediate boson Z mediator of the ‘weak’ force (force-particle)

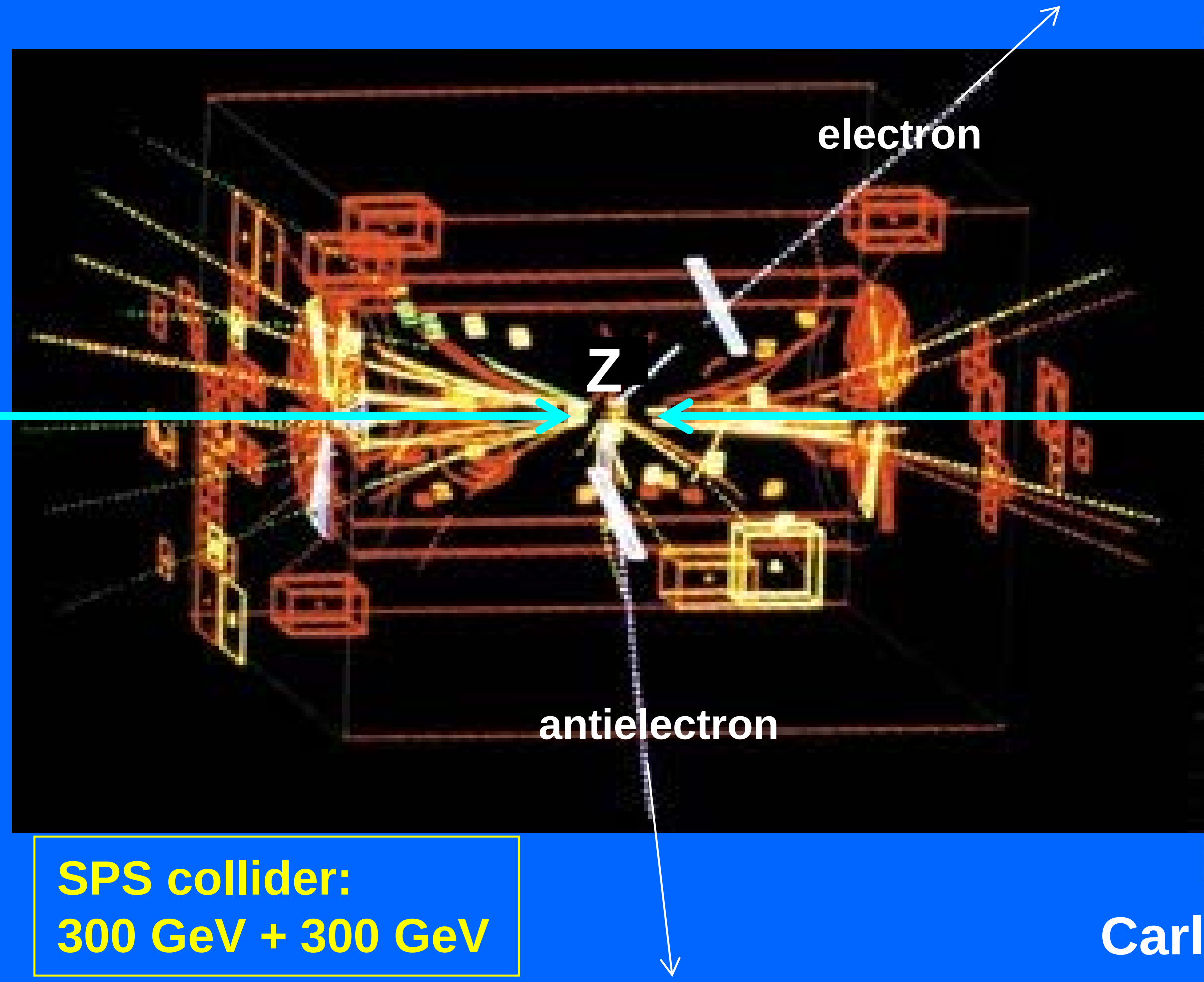
neutrino ν = neutral electron



In the following years quarks were discovered



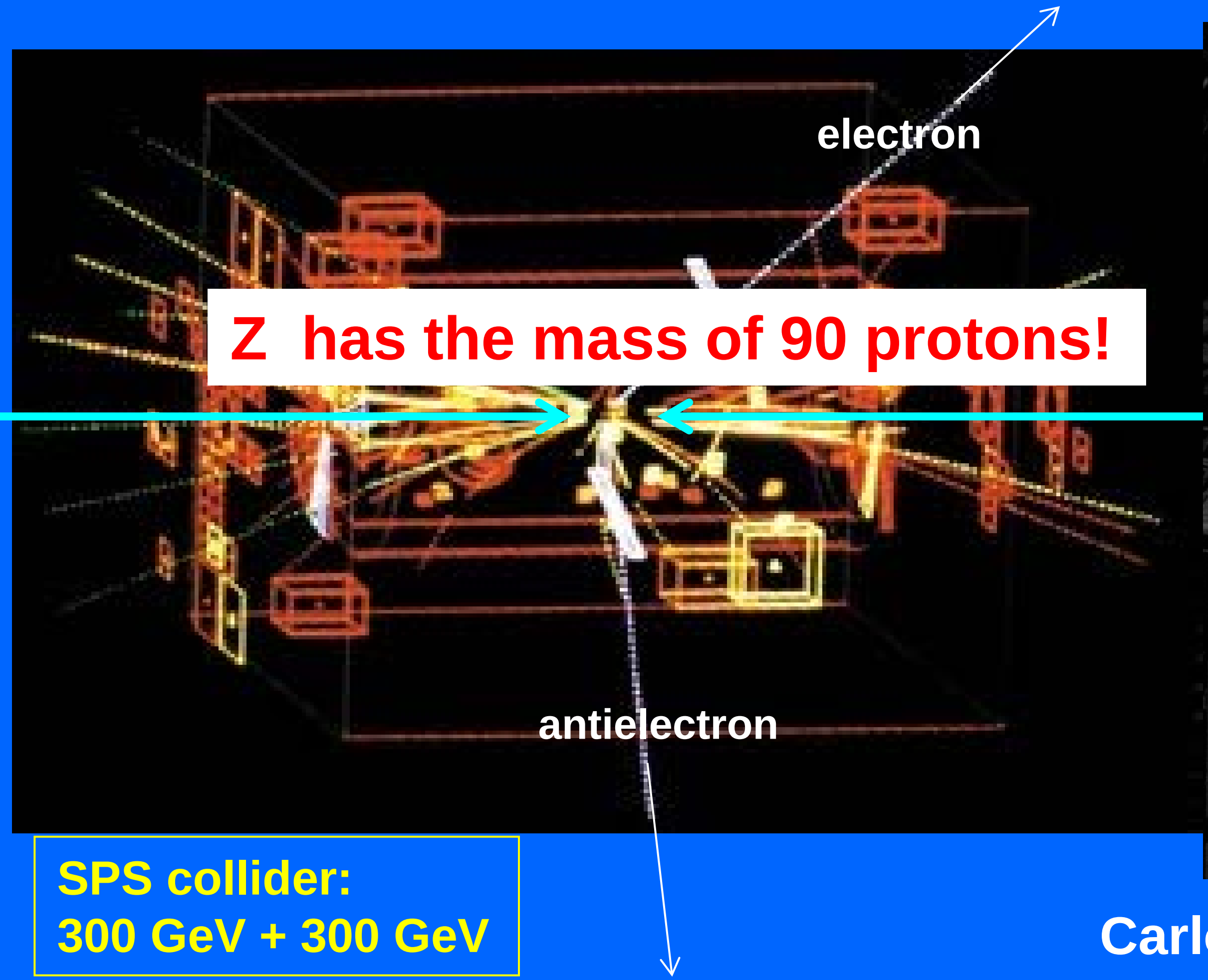
HIGHLIGHTS: 1983 – C. Rubbia is spokesperson of the UA1 Coll. which discovers the mediator of weak ‘neutral’ force



Carlo Rubbia   Simon van der Meer

SPS collider:
300 GeV + 300 GeV

HIGHLIGHTS: 1983 – C. Rubbia is spokesperson of the UA1 Coll. which discovers the mediator of weak 'neutral' force



SPS collider:
300 GeV + 300 GeV

Carlo Rubbia   Simon van der Meer

The problem

electrons, heavy electrons (muons), u-quarks, d-quarks…
are some of the 24 matter-particles

photons, intermediate bosons….
are some of the 12 force-particles

electrons, heavy electrons (muons), u-quarks, d-quarks…
are some of the 24 matter-particles

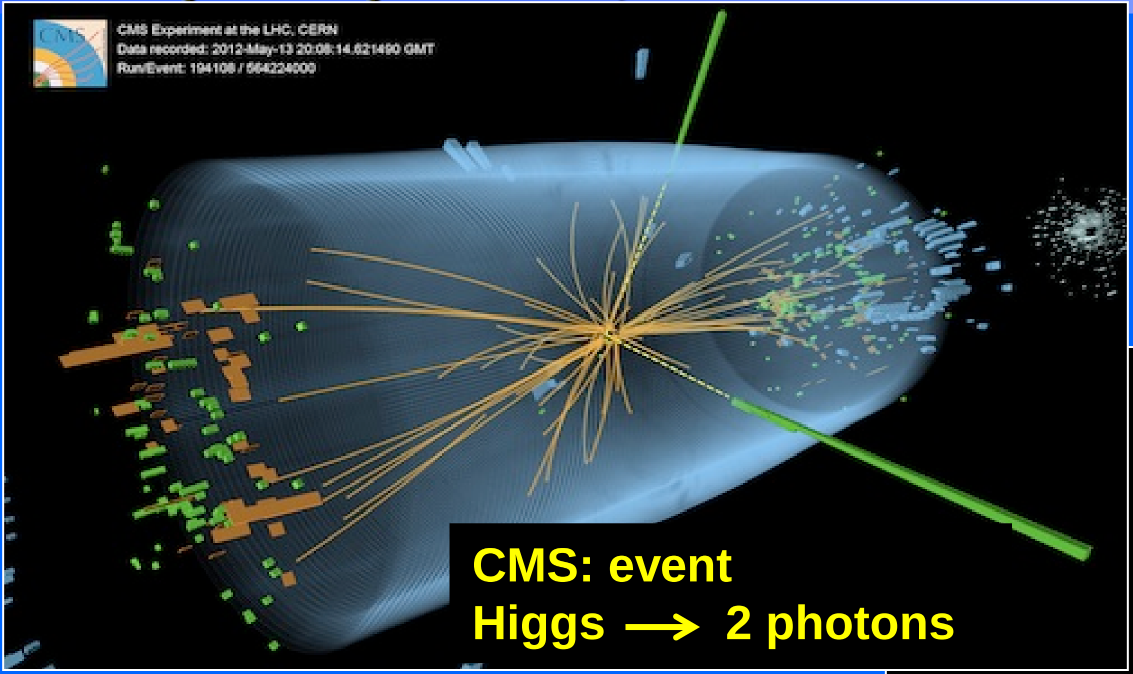
photons, intermediate bosons….
are some of the 12 force-particles

WHY THE MASSES ARE SO DIFFERENT?

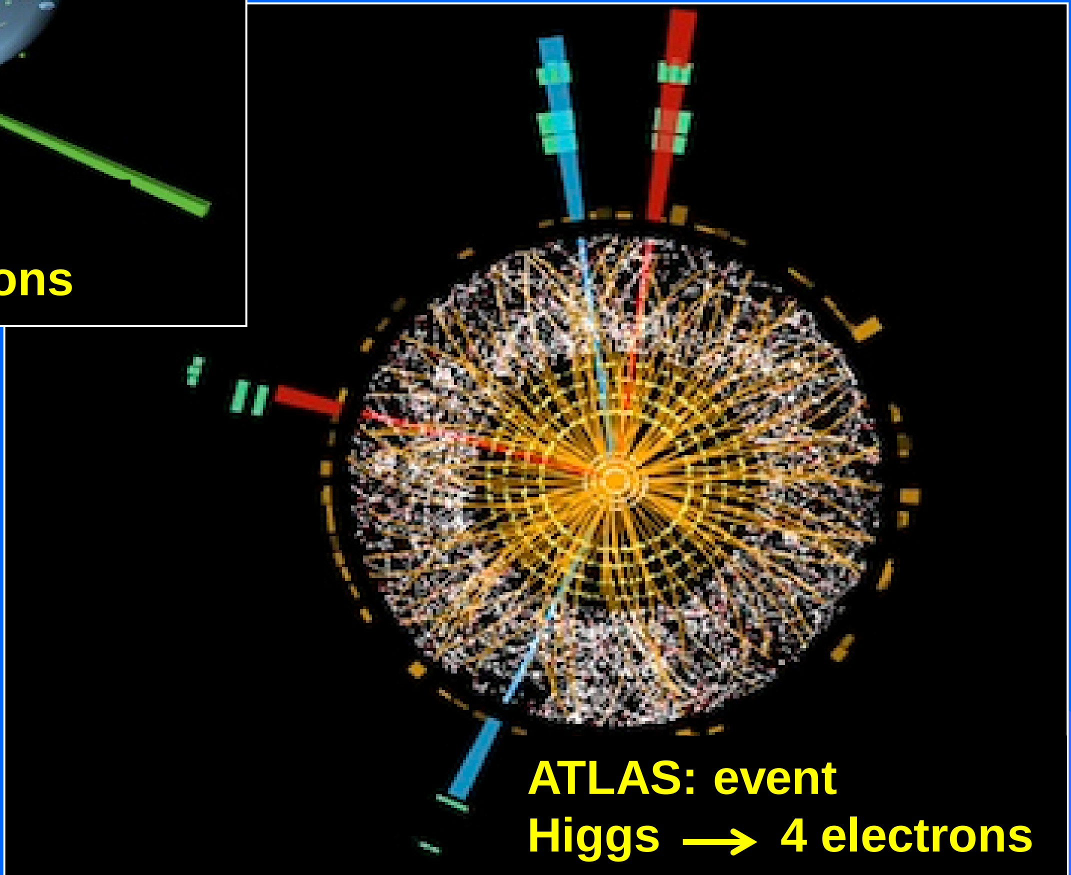
Why the photon has mass = 0
and the Z has mass = 90 protons?

Why the muon is 200 times heavier than the electron?

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

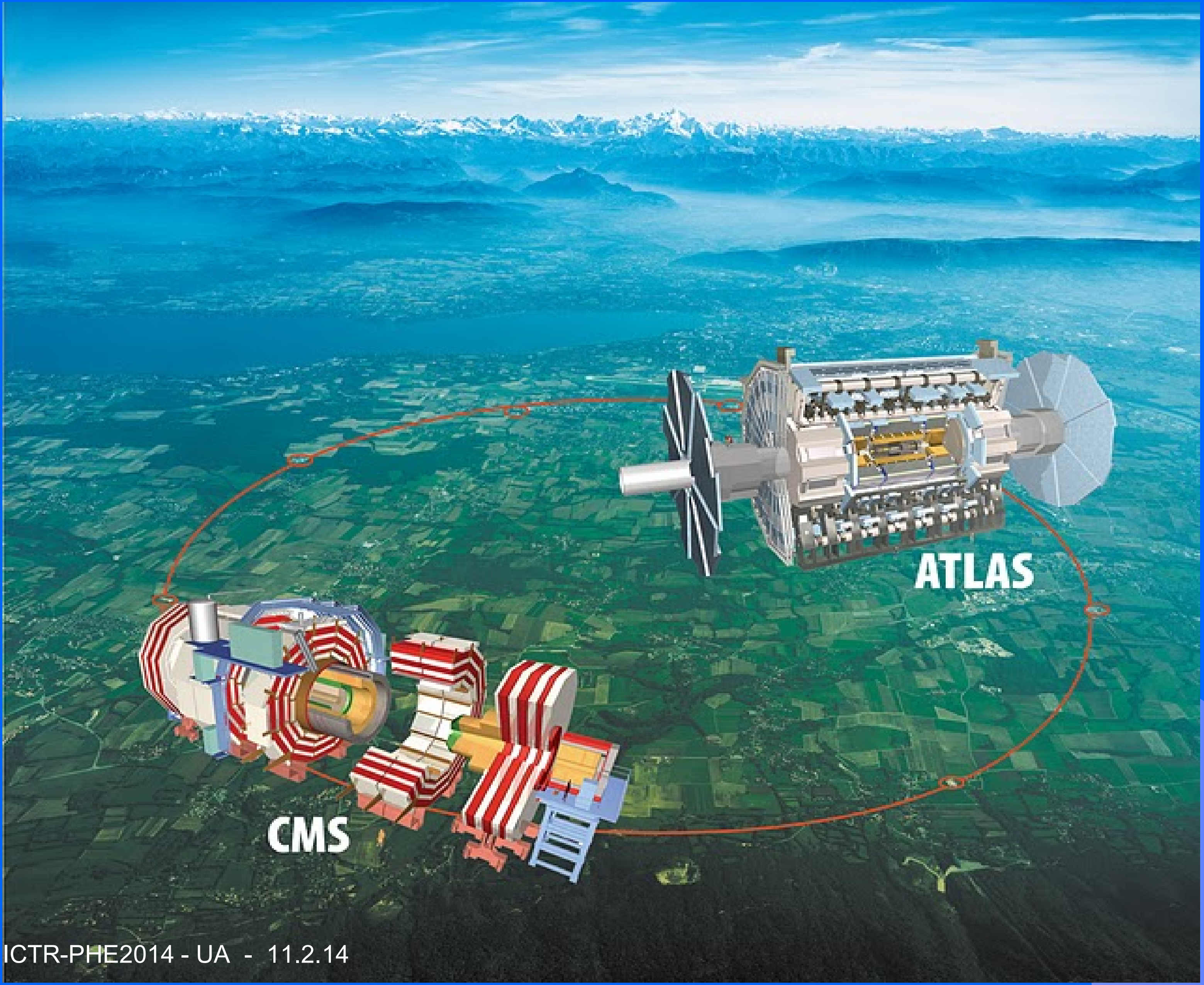


CMS: event
Higgs ⟶ 2 photons

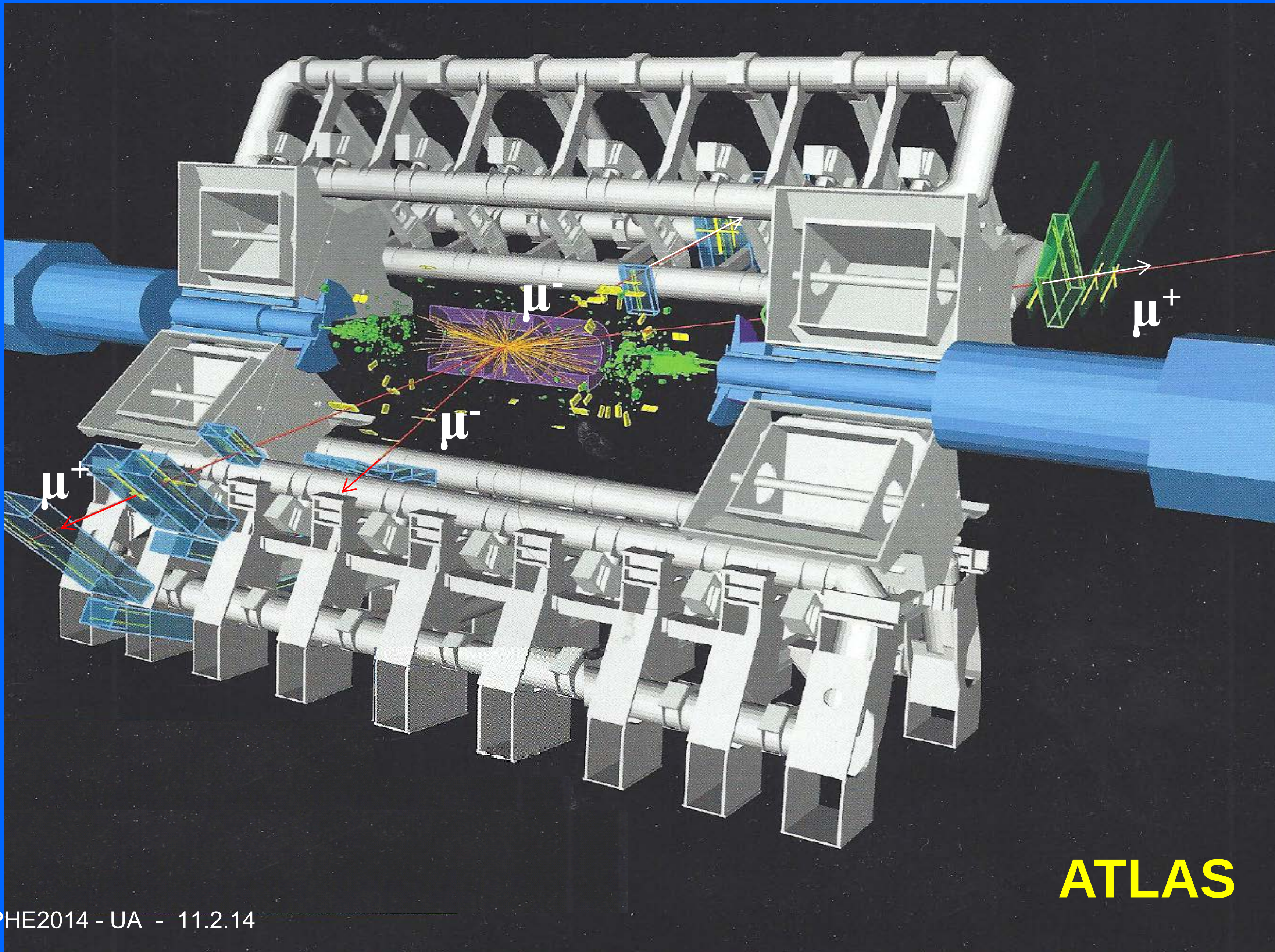


ATLAS: event
Higgs ⟶ 4 electrons

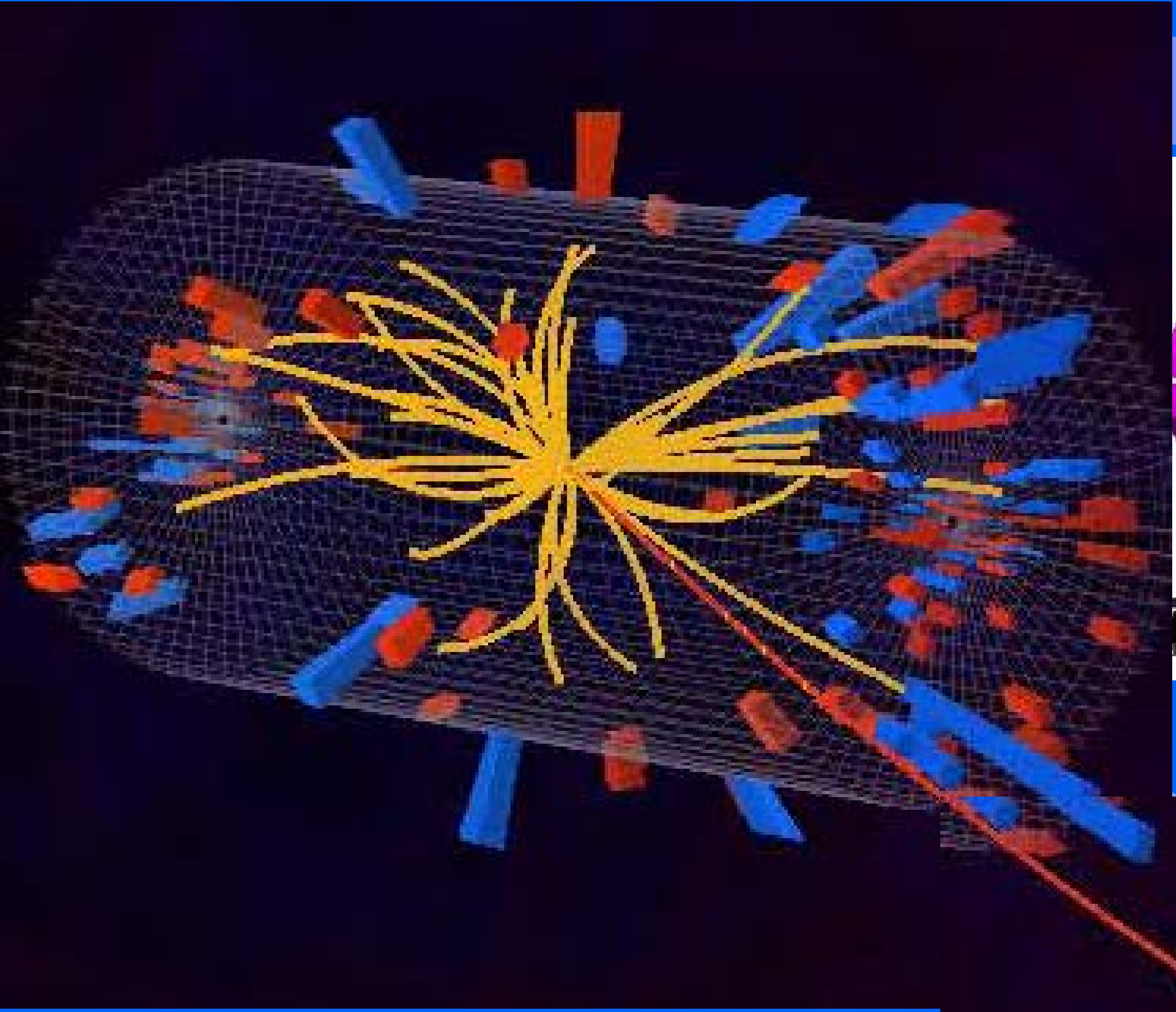
Two large ‘detectors’ at LHC

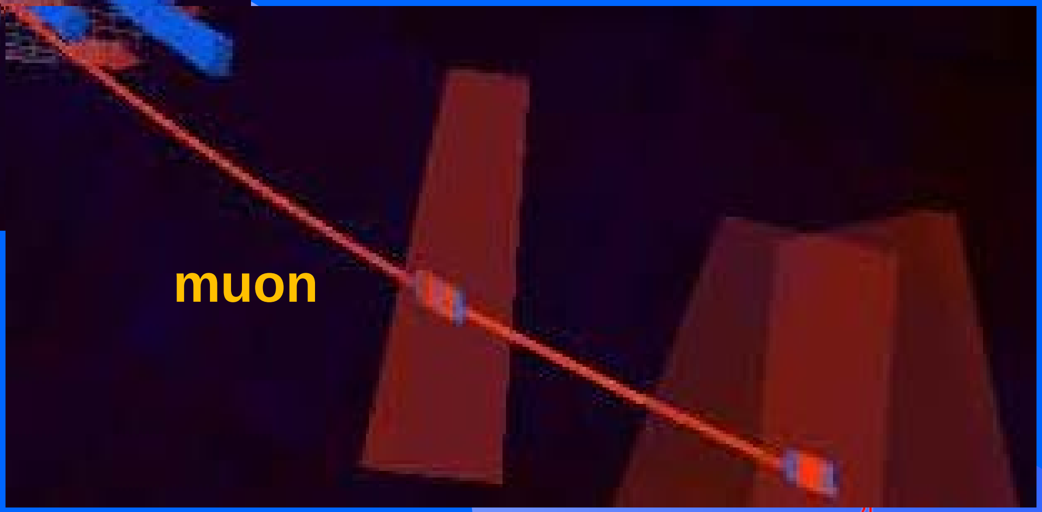


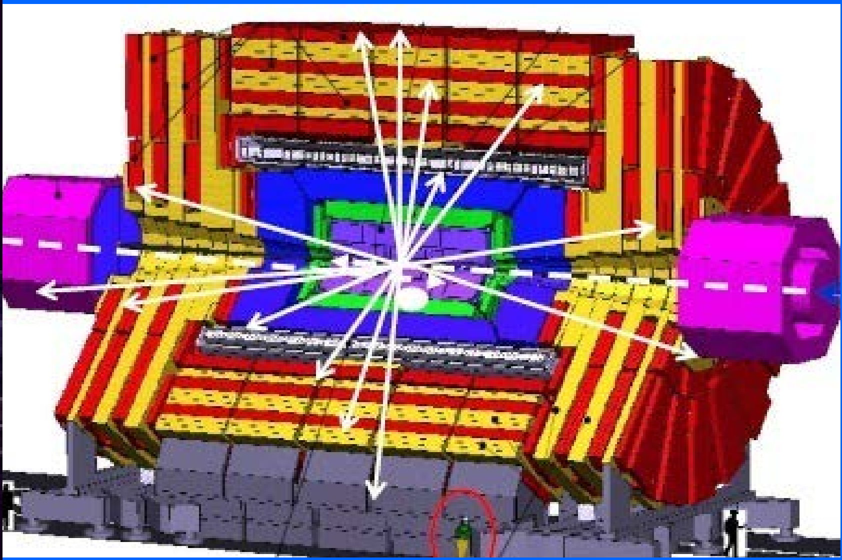
Event in ATLAS: production of 4 muons=heavy electrons



Event in CMS







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

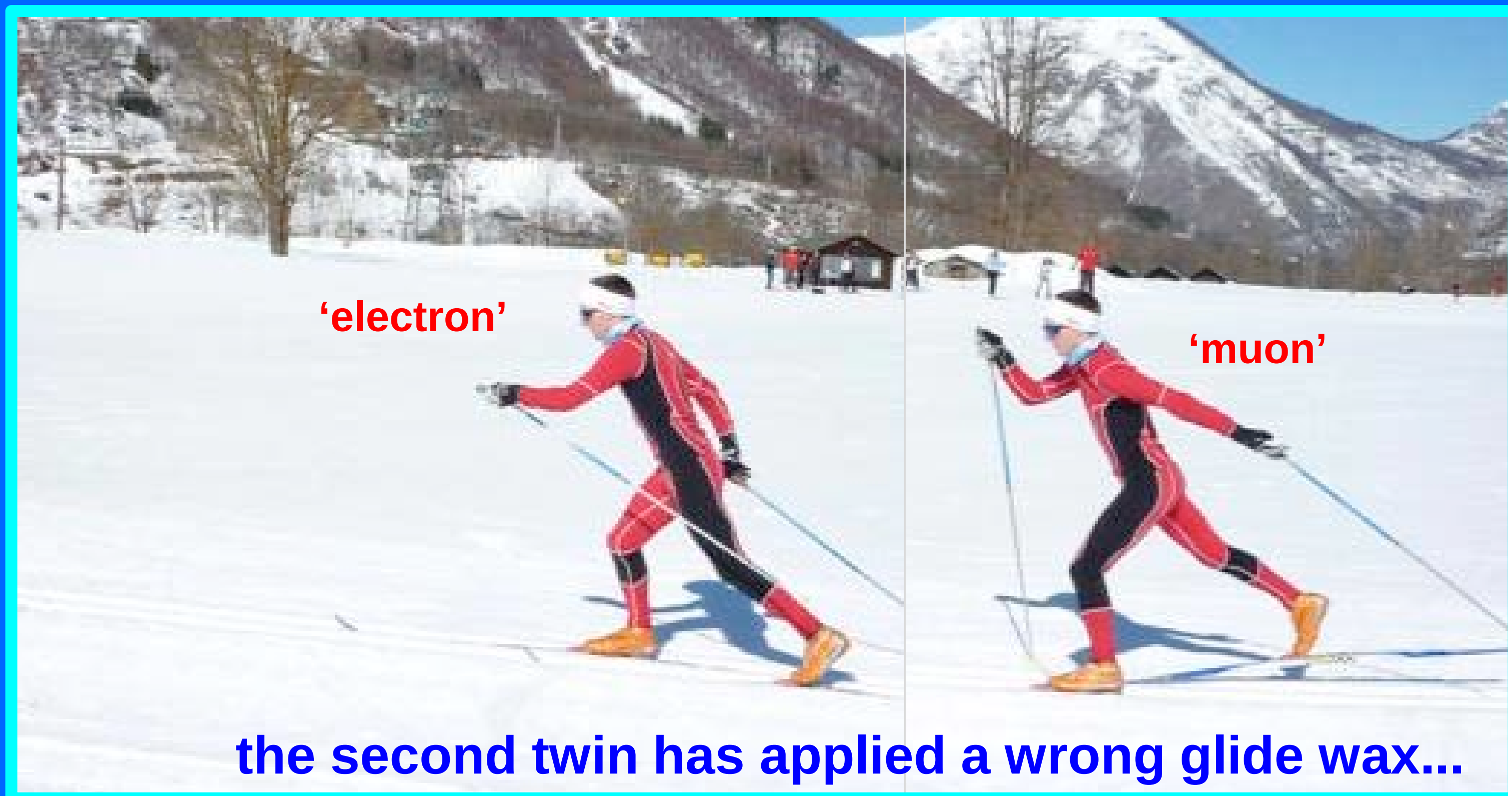
the Higgs 'field' is a continous medium that fills the space since one hundredth of a billionth of a second (10^{-11} s) after the Big Bang

The 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



Metaphor of the two twins practicing Nordic sky

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

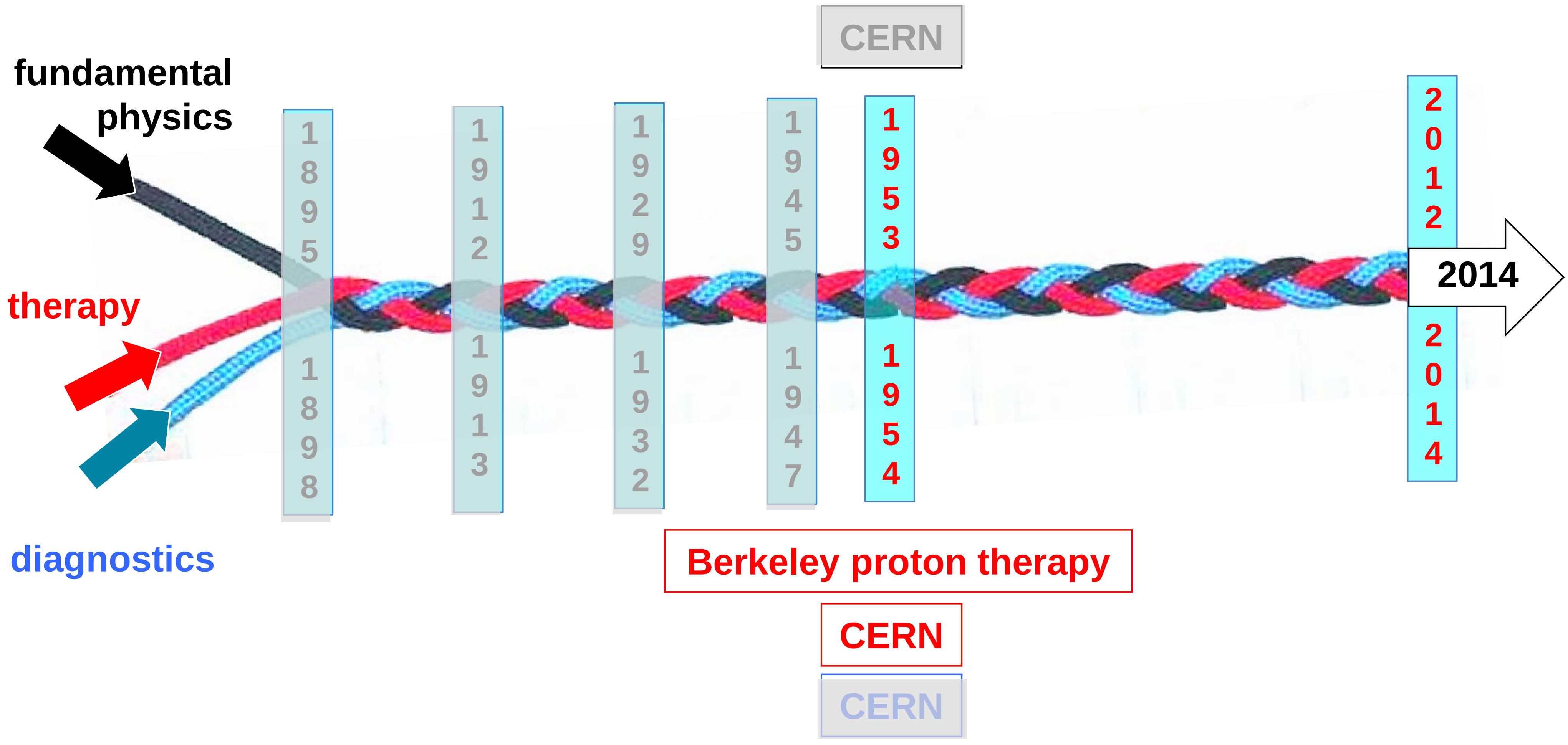
2013: the Nobel prize winners

François Englert Peter Higgs

Fabiola Gianotti Peter Higgs

Following the red yarn

120 years of beautiful and useful physics



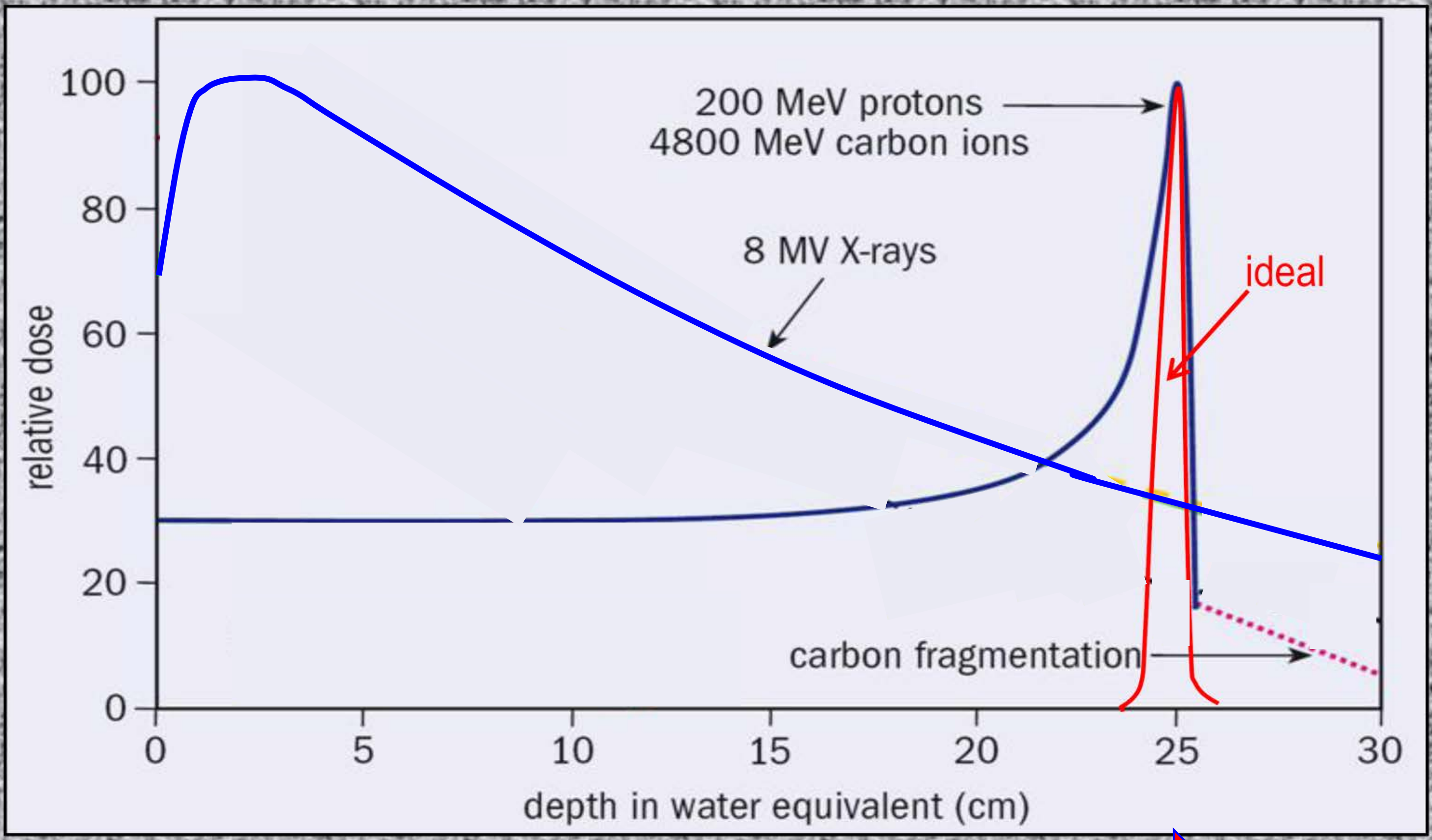
1946 : « Bob » Wilson proposes to use protons, helium and carbon ions

Lawrence PhD student

Founder and first Director

of FERMILAB (Chicago)

1967-1978



Radiation beam in matter

60 years ago: first proton treatment at Berkeley

Cornelius Tobias

"Toby"

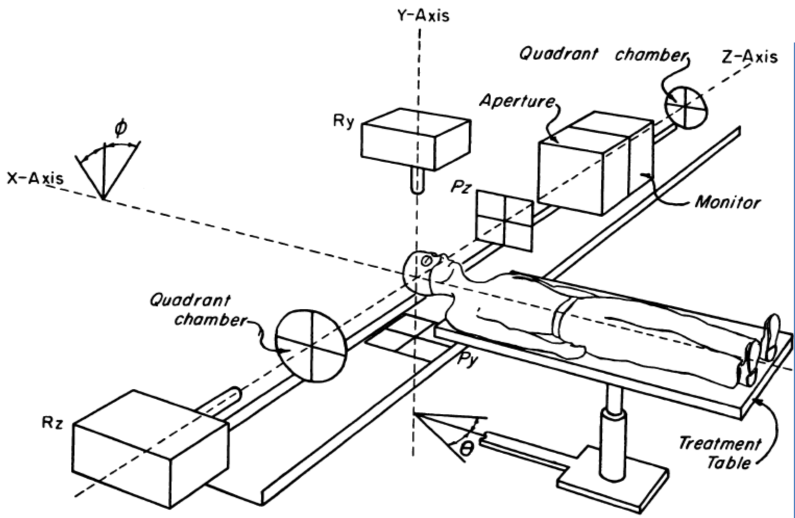


CHART 3.—A schematic drawing of the apparatus for proton irradiation of the human hypophysis

CANCER RESEARCH

VOLUME 18 FEBRUARY 1958 NUMBER 2

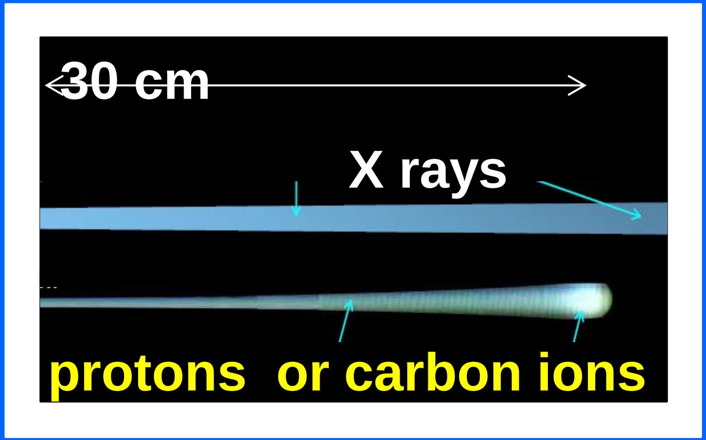
Pituitary Irradiation with High-Energy Proton Beams
A Preliminary Report*

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.)

Avantages of protons and carbon ions

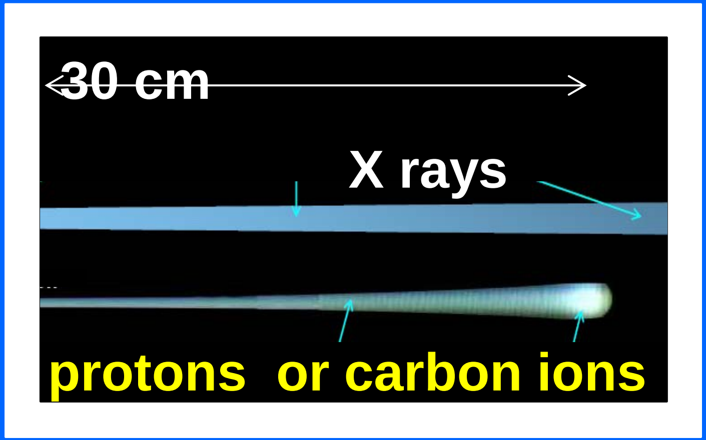
protons: 230 MeV
C ions : 5000 MeV



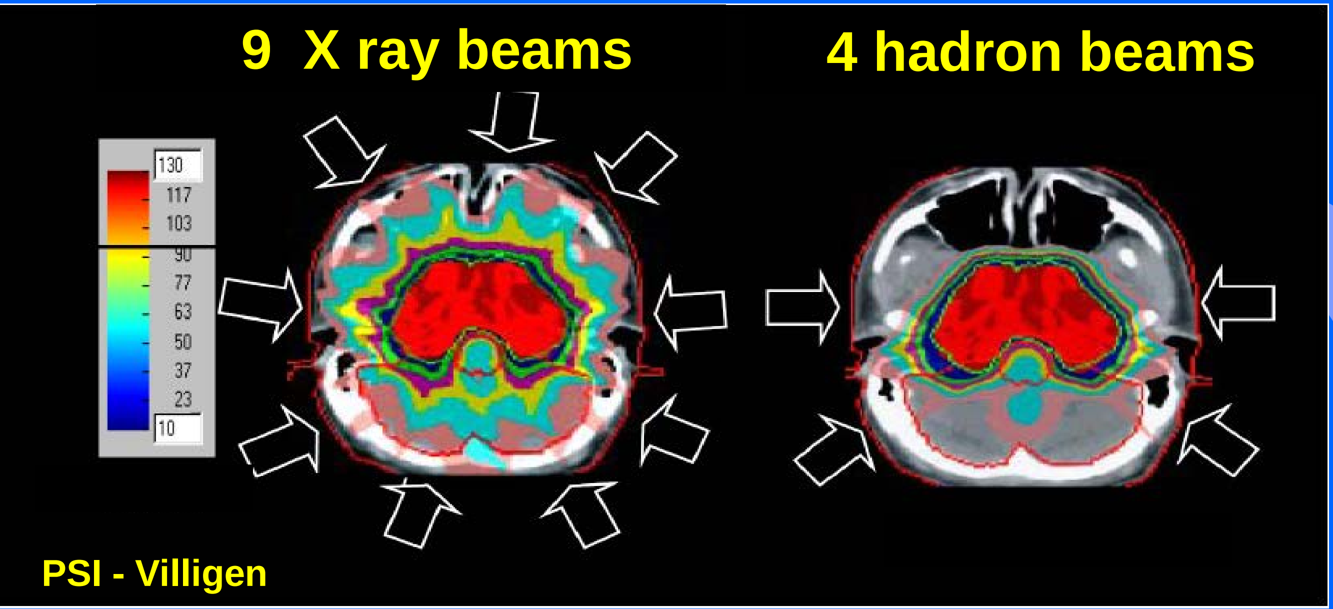
1. Healthy tissues are spared by protons and carbon ions

Avantages of protons and carbon ions

protons: 230 MeV
C ions : 5000 MeV

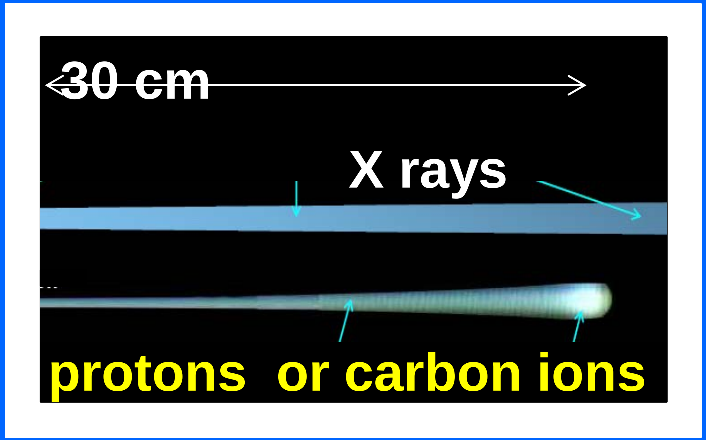


1. Healthy tissues are spared by protons and carbon ions

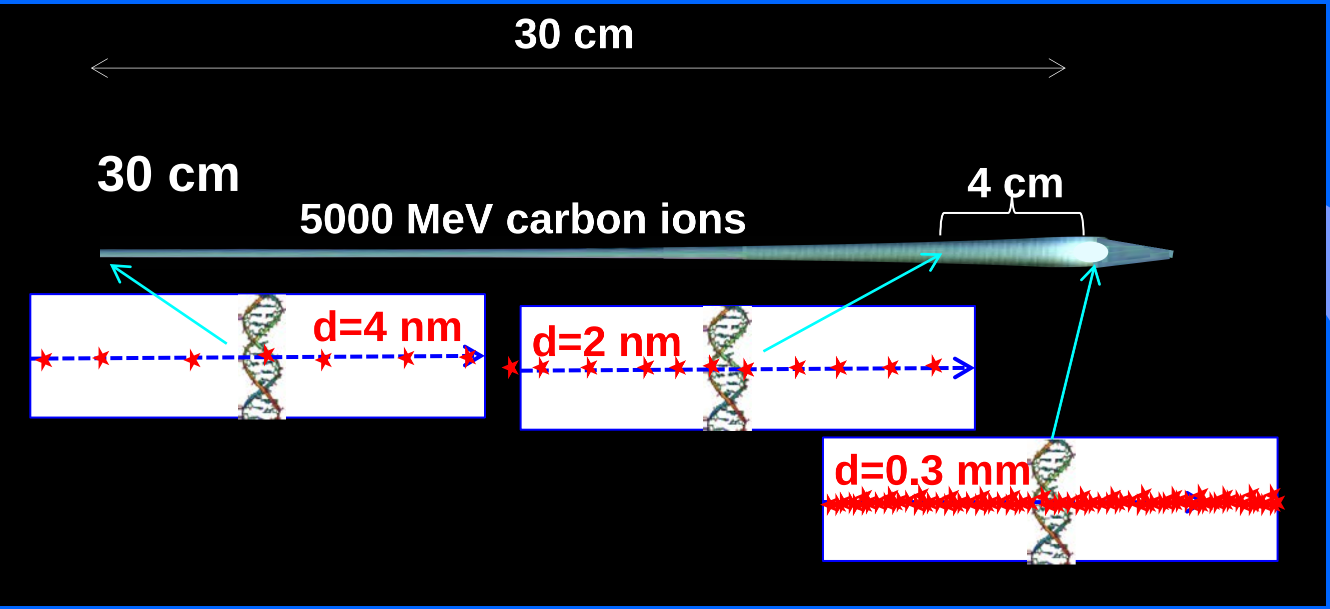


Avantages of protons and carbon ions

protons: 230 MeV
C ions : 5000 MeV

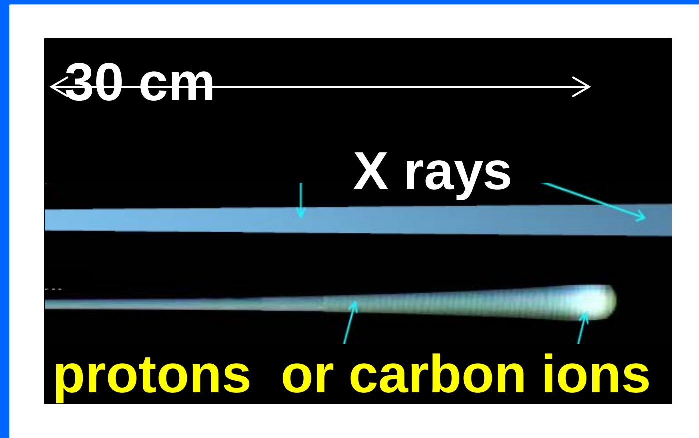


1. Healthy tissues are spared by protons and carbon ions

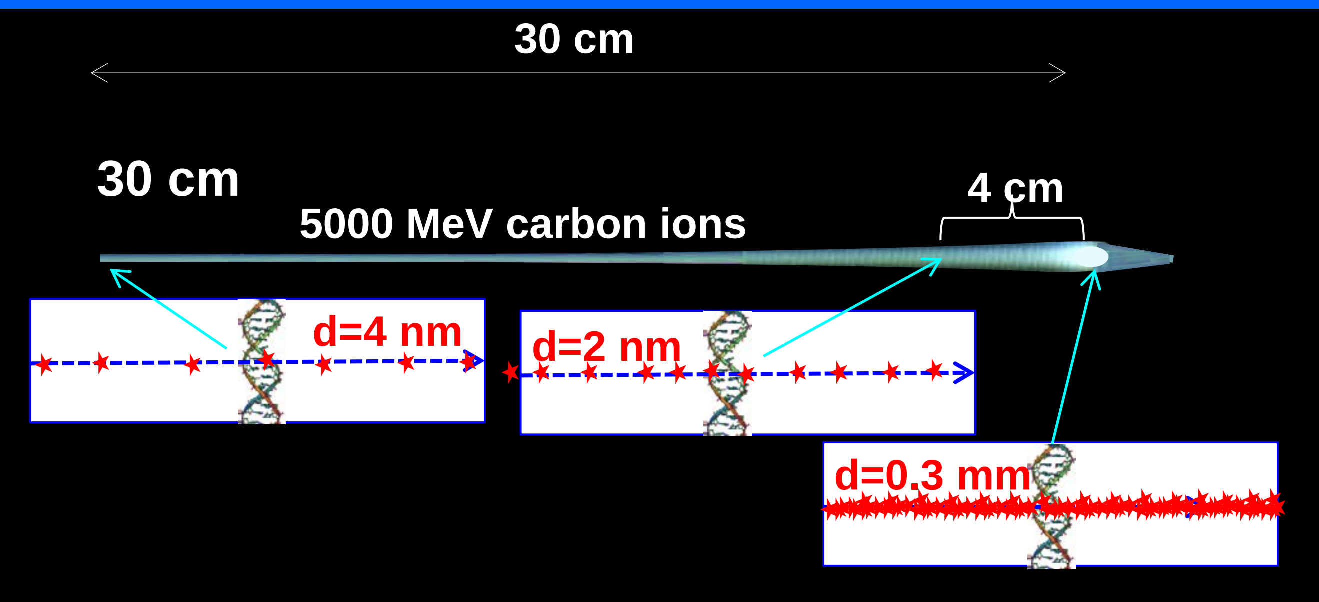


Avantages of protons and carbon ions

protons: 230 MeV
C ions : 5000 MeV



1. Healthy tissues are spared by protons and carbon ions



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.

TERA

Cyclotron solution for protons by IBA - Belgium

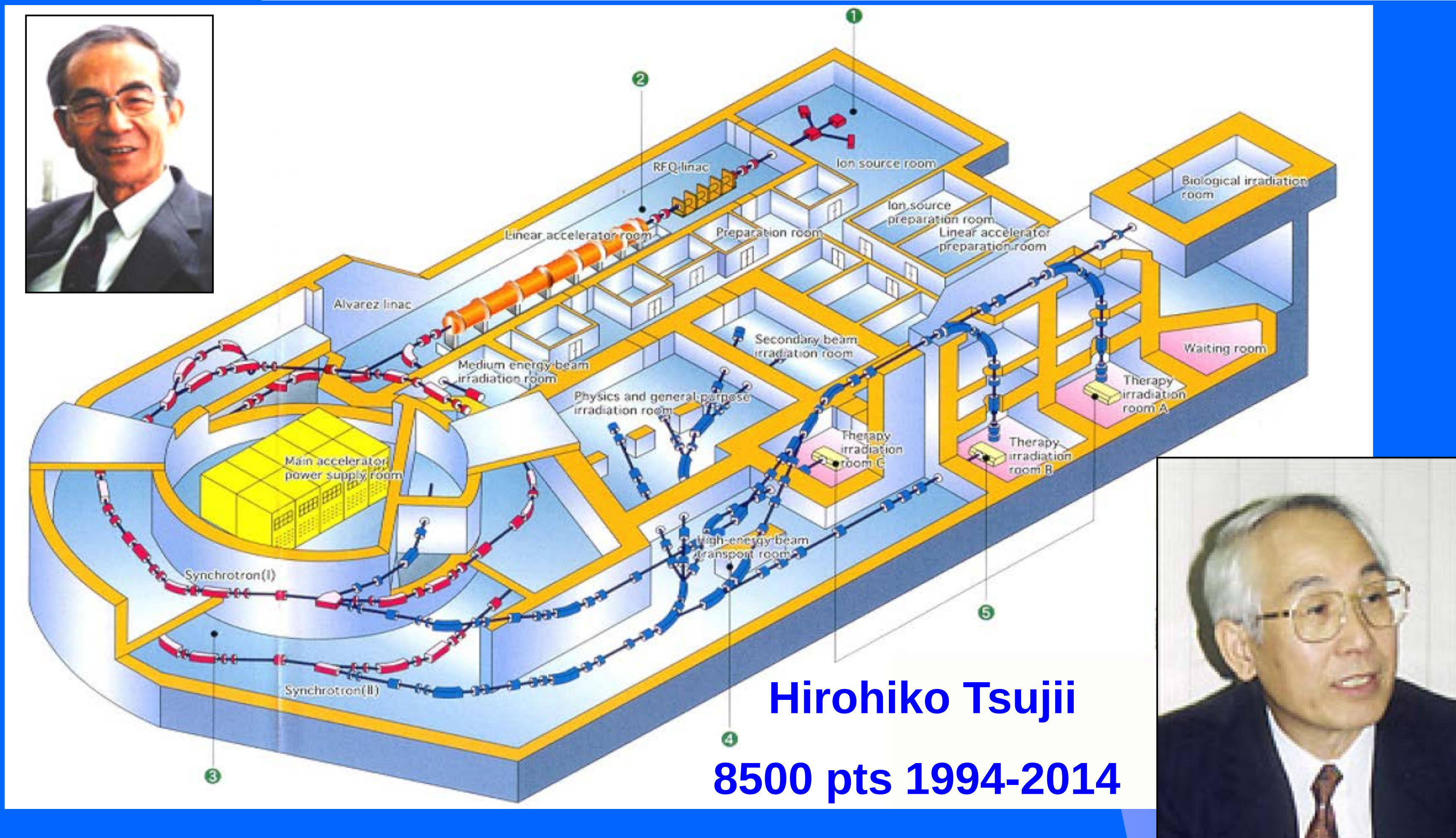
Eight companies offer turn-key centres for 120-150 M€.

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

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

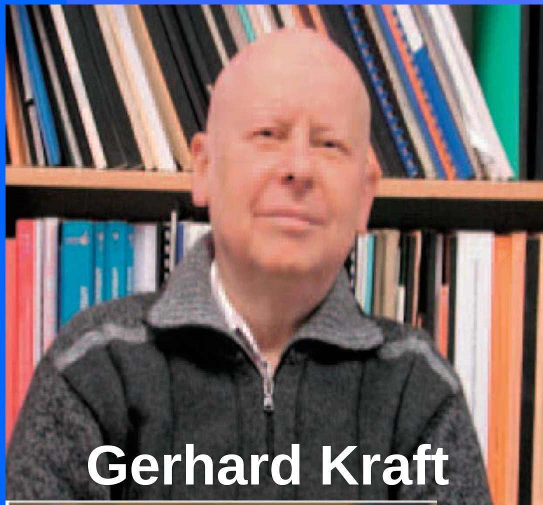
Gerhard Kraft

J. Debus

450 patients treated with carbon ions

GSI - Darmstadt

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

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

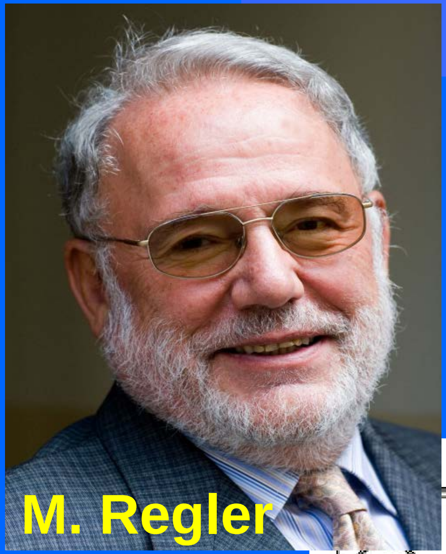
TOTAL for 1 M 300 pts/year

ENLIGHT coordinator: Manjit Dosanjh

- **Nonprofit 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

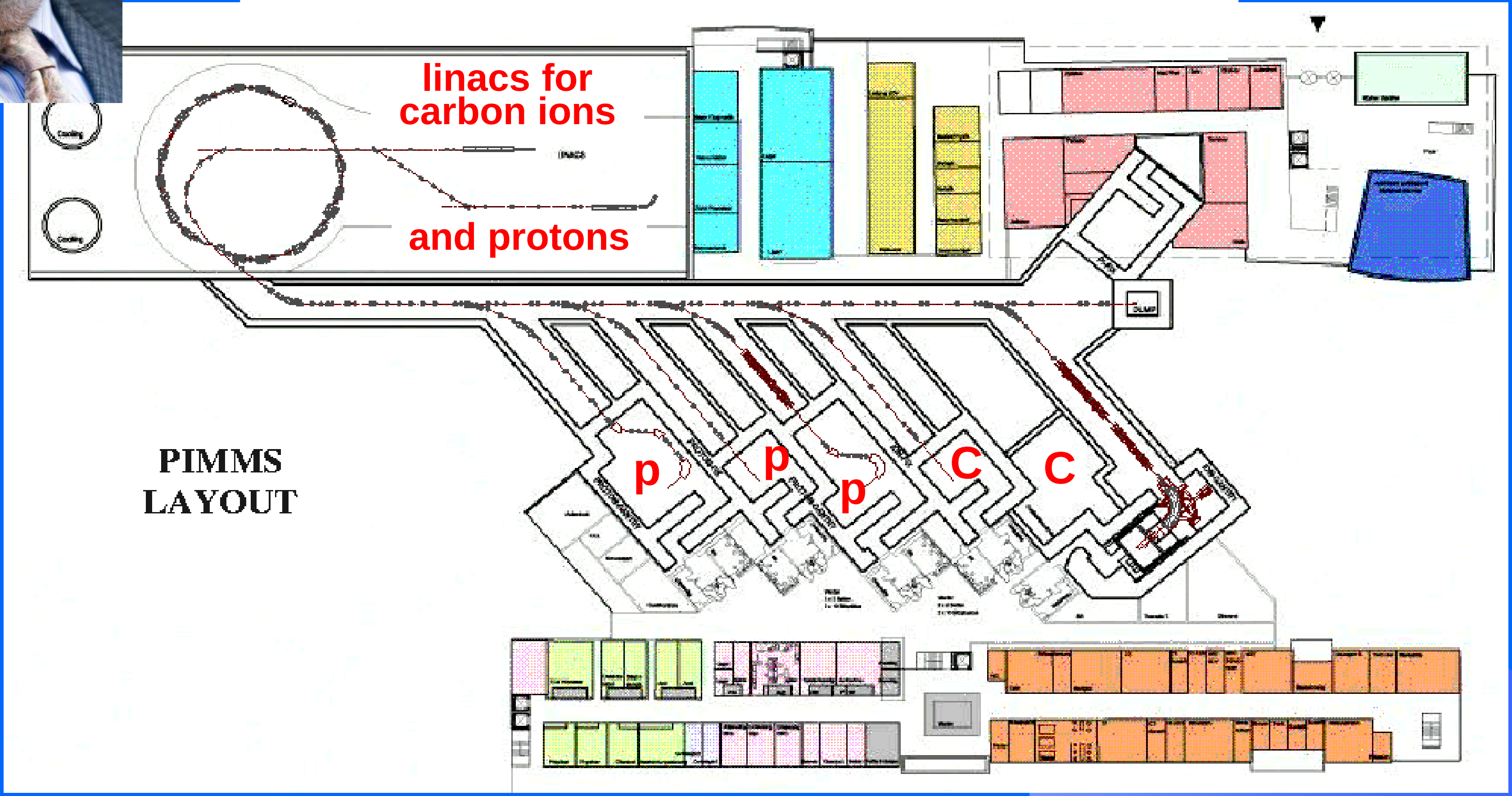


Optimized synchrotron for therapy

Project Leader: Phil Bryant

Chair of PAC: Giorgio Brianti

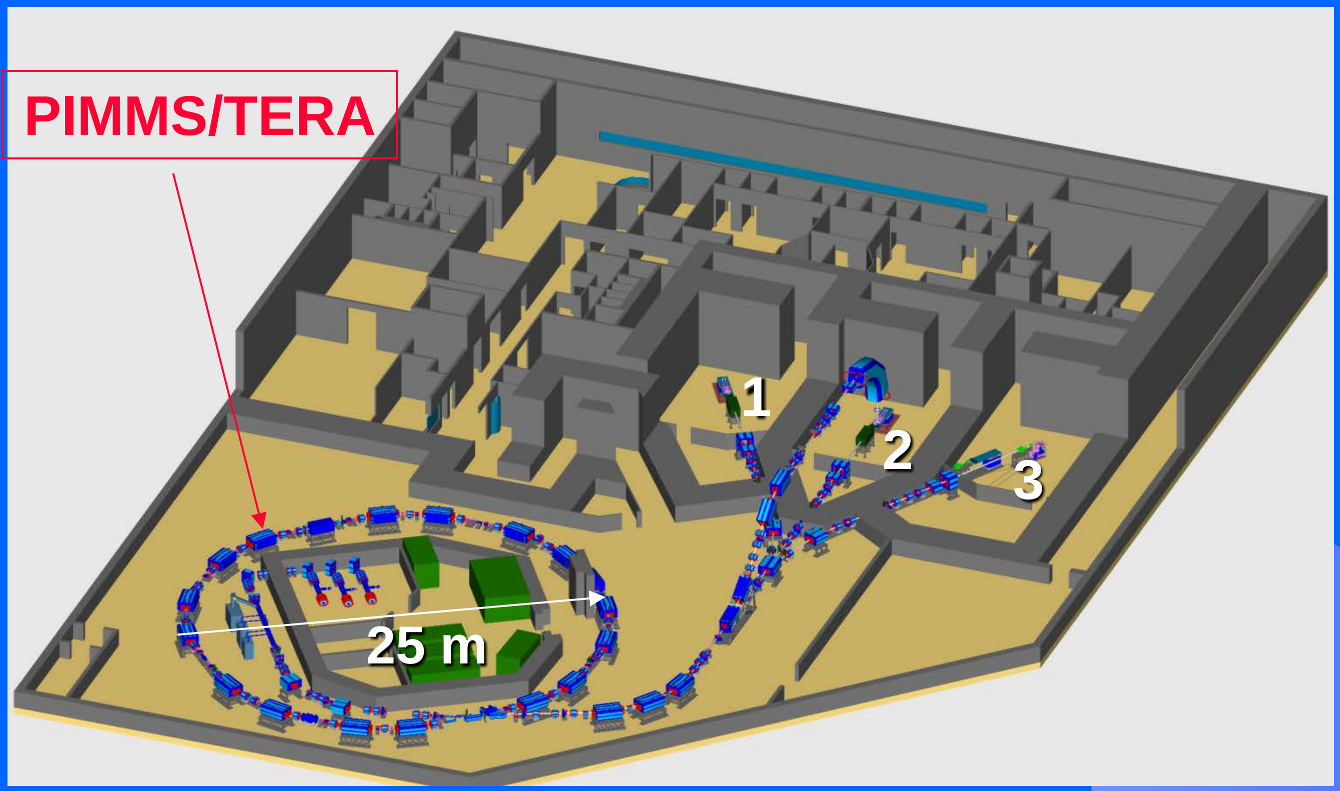
1996-2000



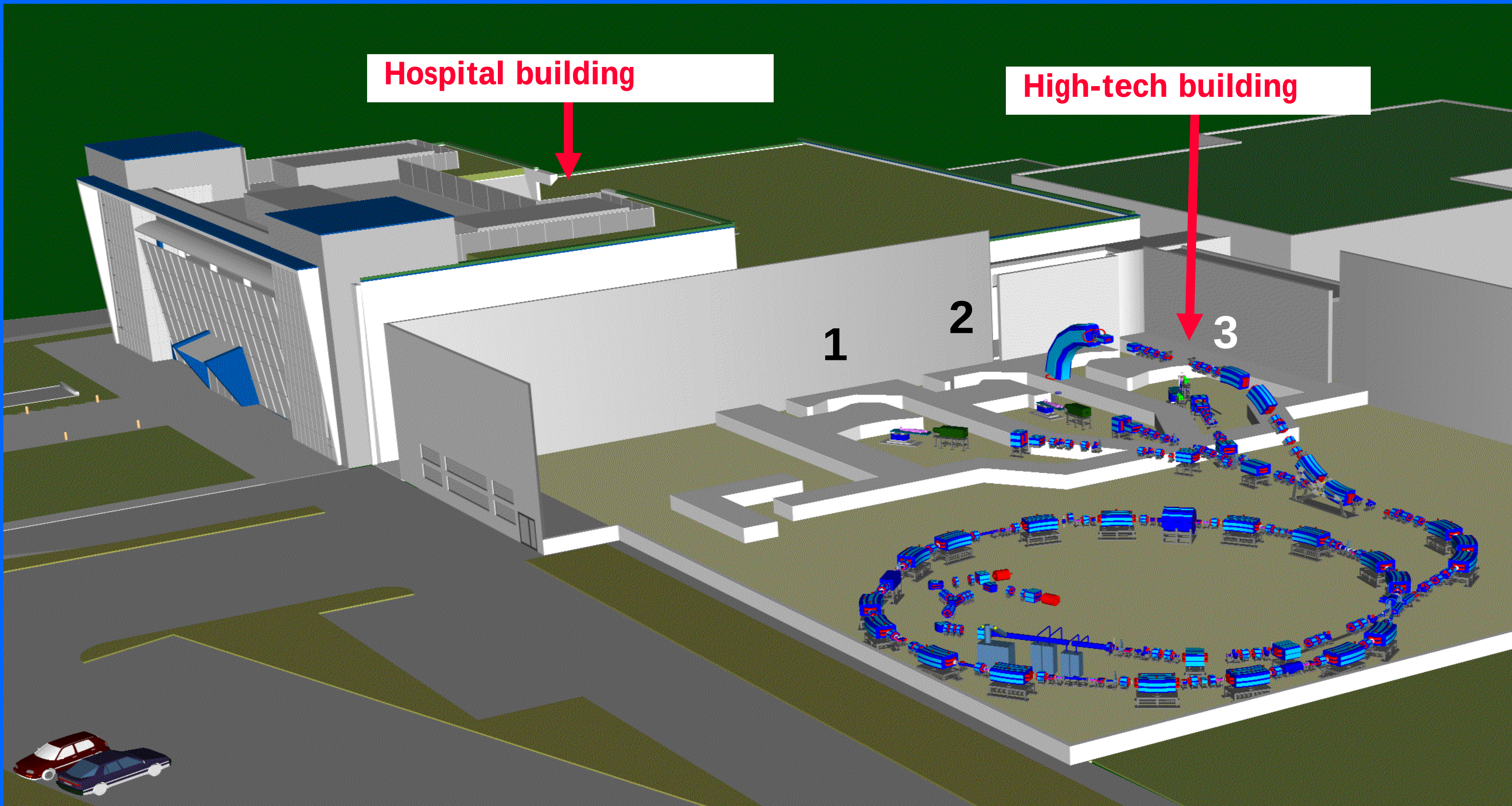
CNAO = Centro Nazionale di Adroterapia Oncologica

CNAO Foundation created by the Italian Government in 2002:
4 Hospitals in Milan, 1 Hospital in Pavia and TERA

In October 2003 TERA passed to CNAO
the design of CNAO (2000 pages) and 25 people



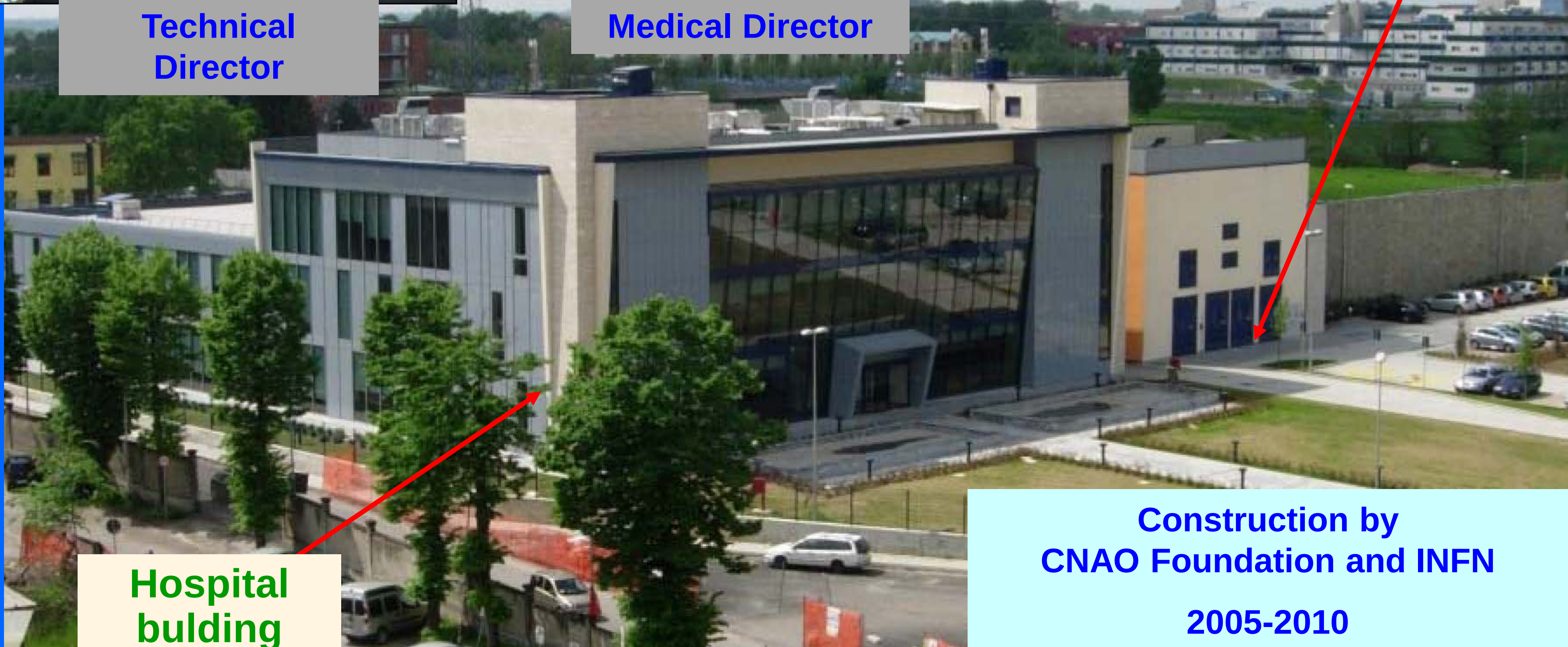
CNAO = Centro Nazionale di Adroterapia Oncologica in Pavia



CNAO = Centro Nazionale di Adroterapia Oncologica

Sandro Rossi
Technical
Director

Roberto Orecchia
Medical Director



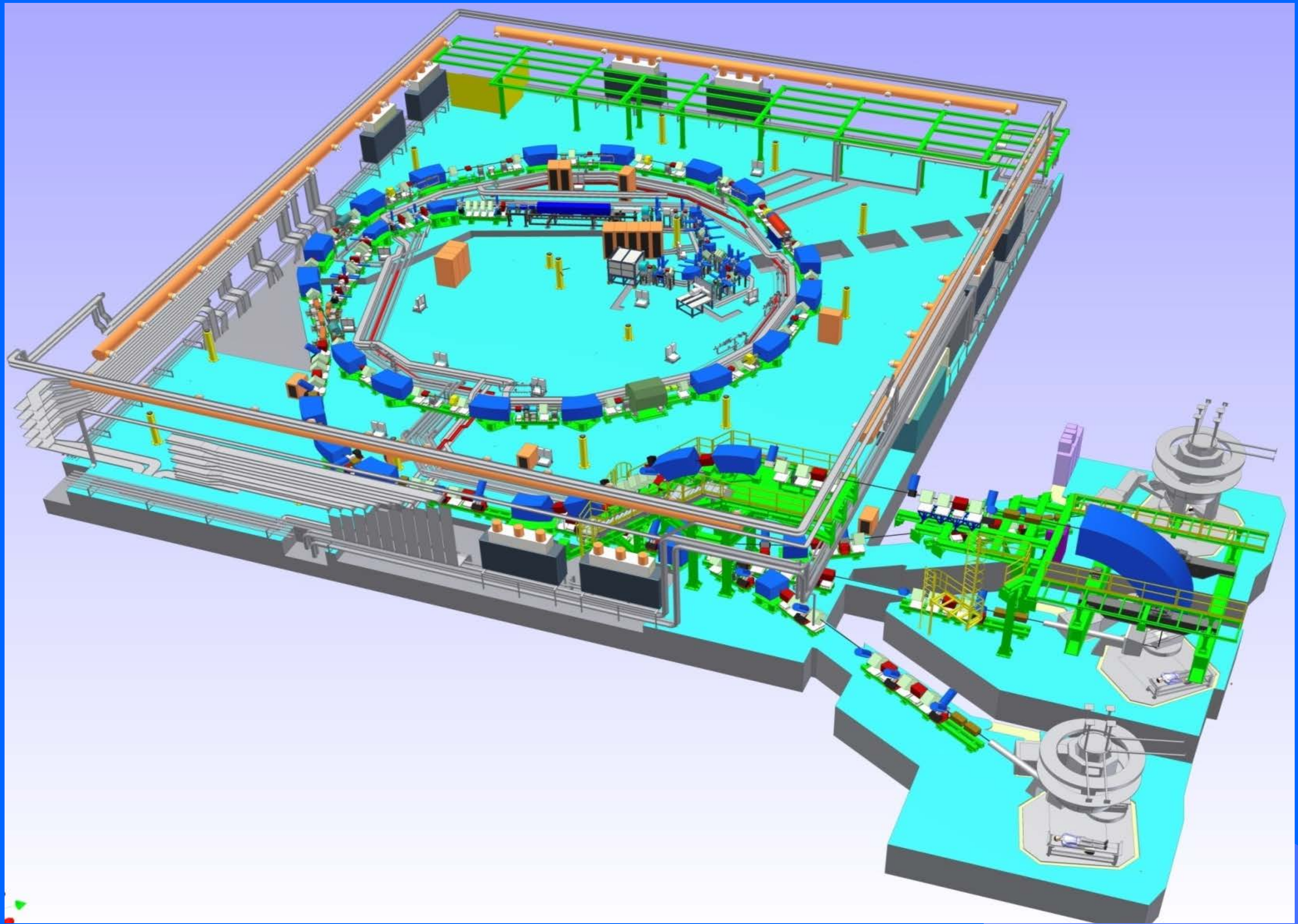
Synchrotron building

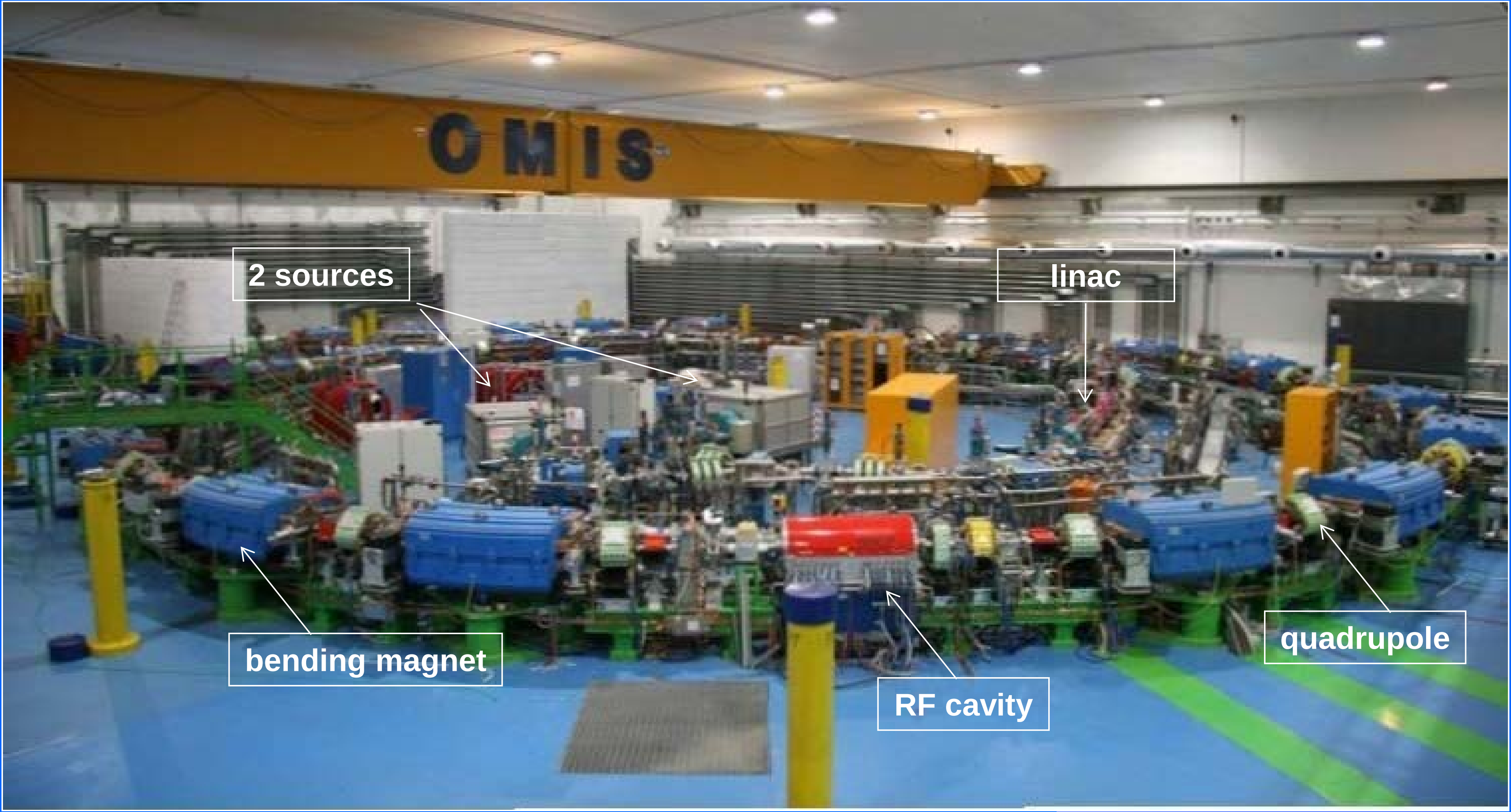
Hospital bulding

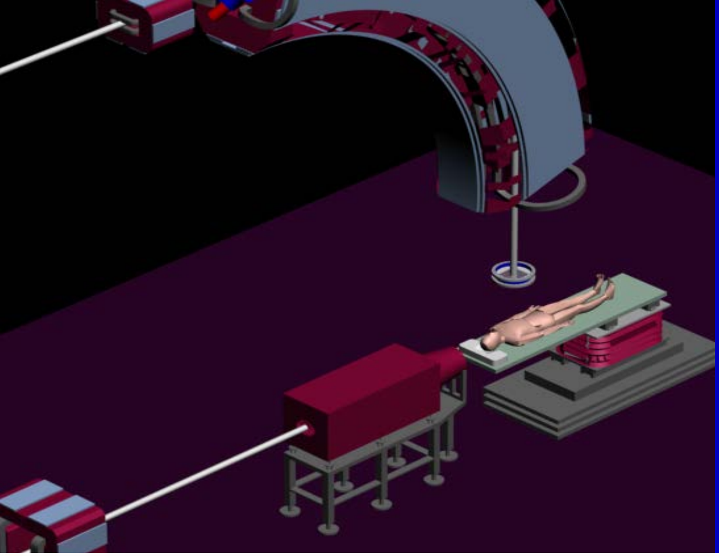
Construction by
CNAO Foundation and INFN

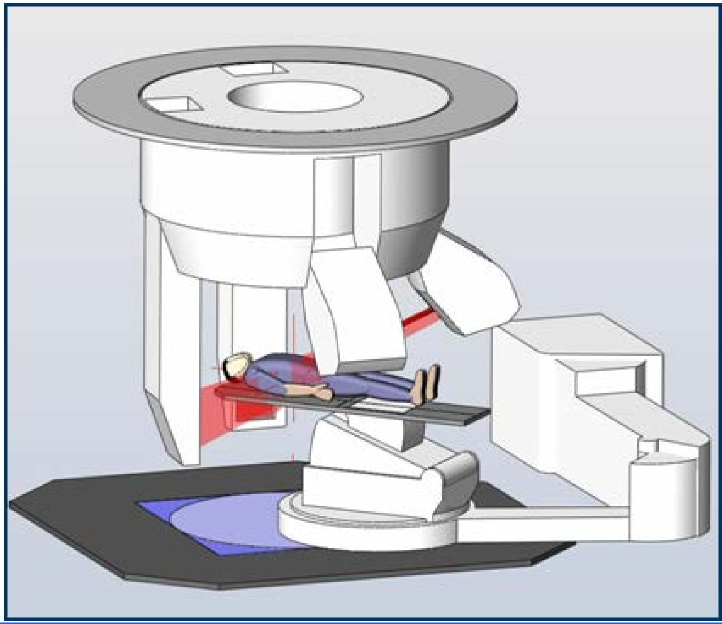
2005-2010

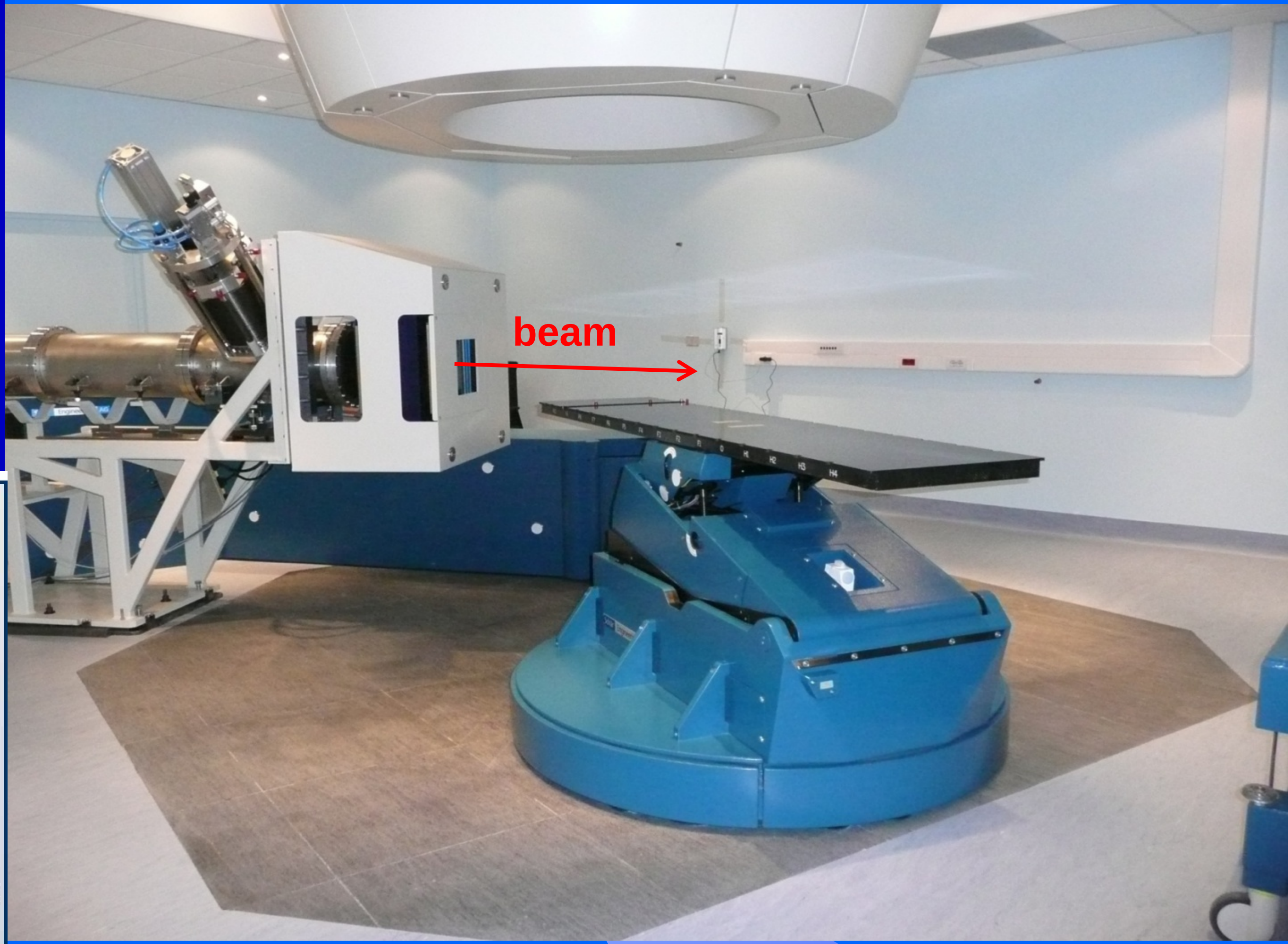
CNAO at Pavia




OMIS
2 sources
linac
bending magnet
RF cavity
quadrupole

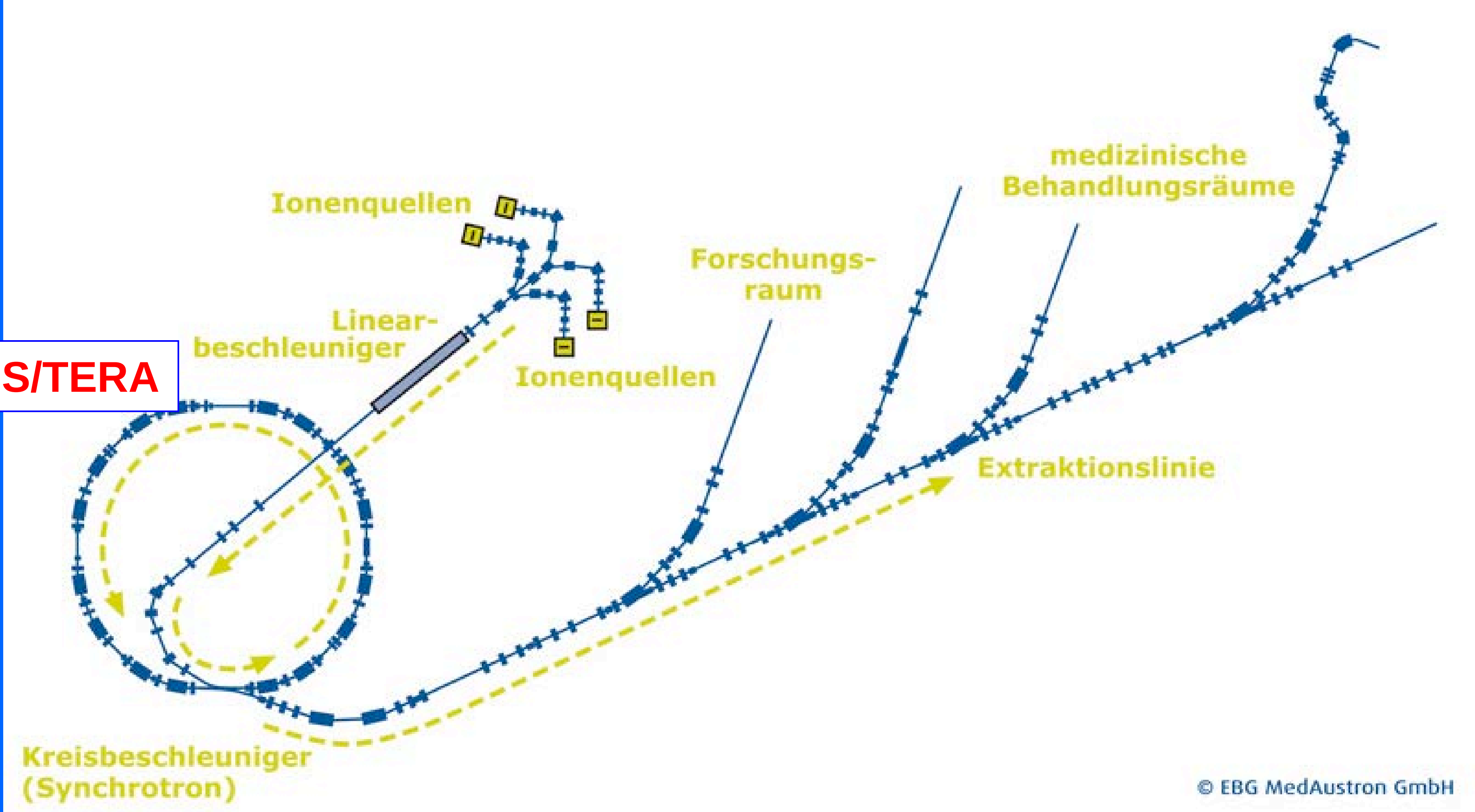






January 2014: 200 pantients treated

MedAustron promoted and participated in PIMMS



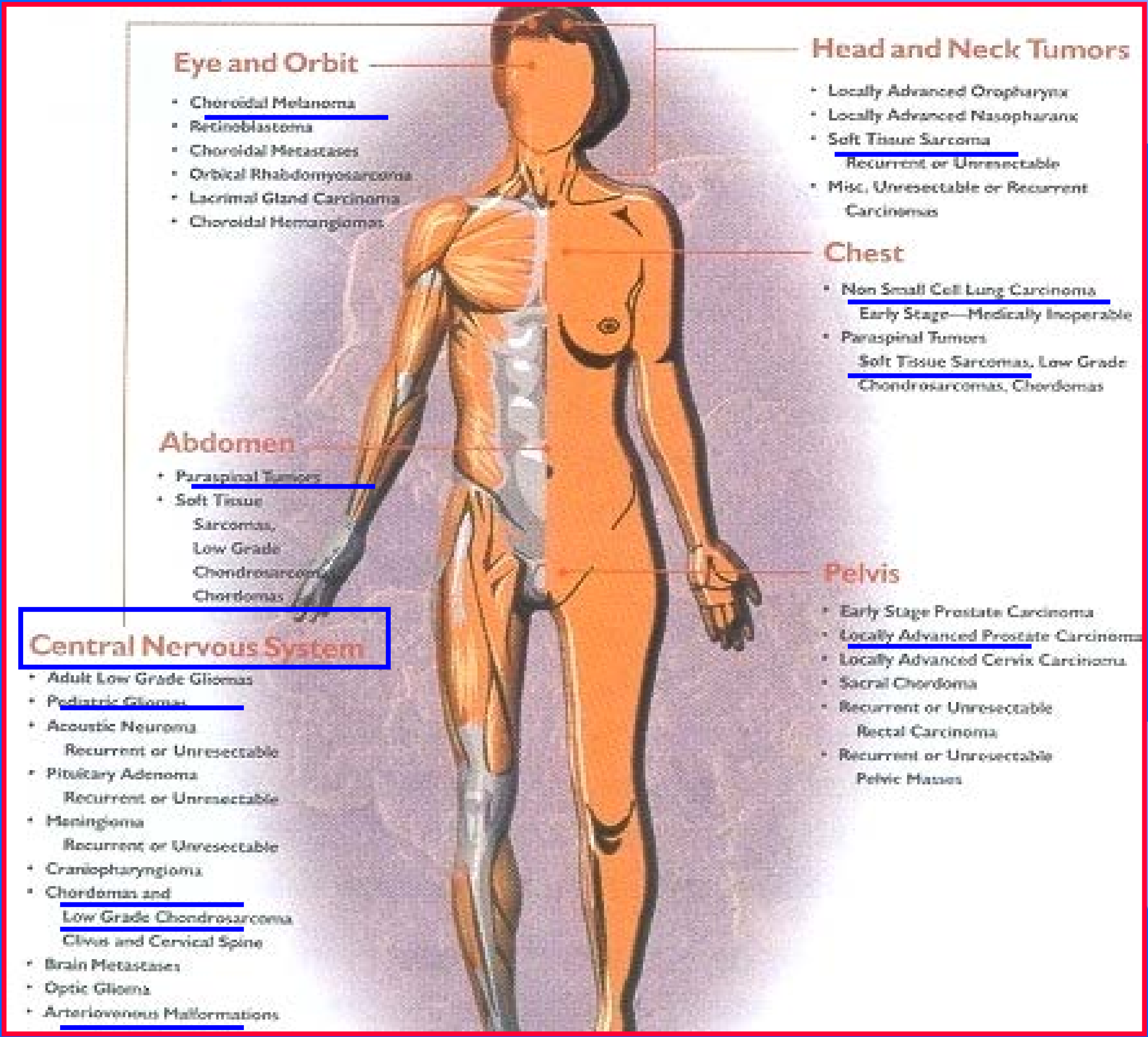
PIMMS/TERA

MedAustron has acquired form CNAO Foundation the construction drawings

TERA

MedAustron promoted and participated in PIMMS

Construction completed by 2015 in Wiener Neustadt



The site treated with hadrons

In the world

protons:

100'000 patients

(8% per year)

carbon ions

10’000 patients

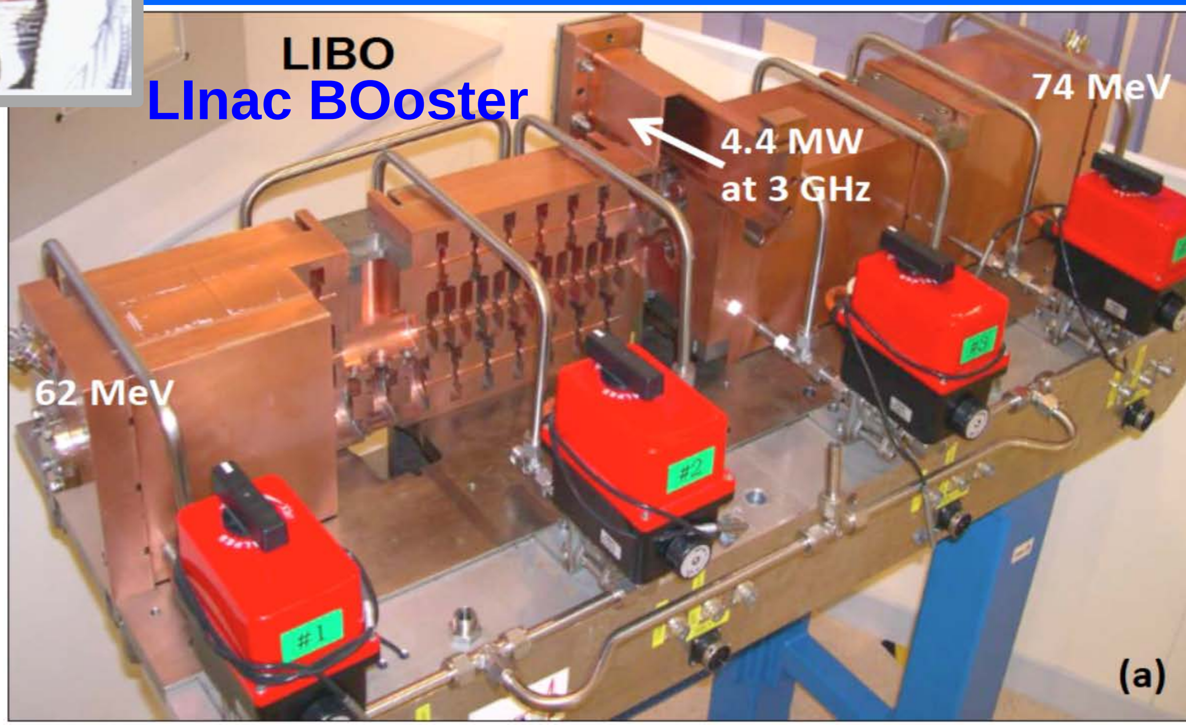
(most at HIMAC)

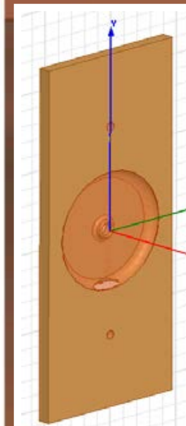
Linacs for proton therapy

Inauguration of the new linac by the CERN DG

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

Mario Weiss

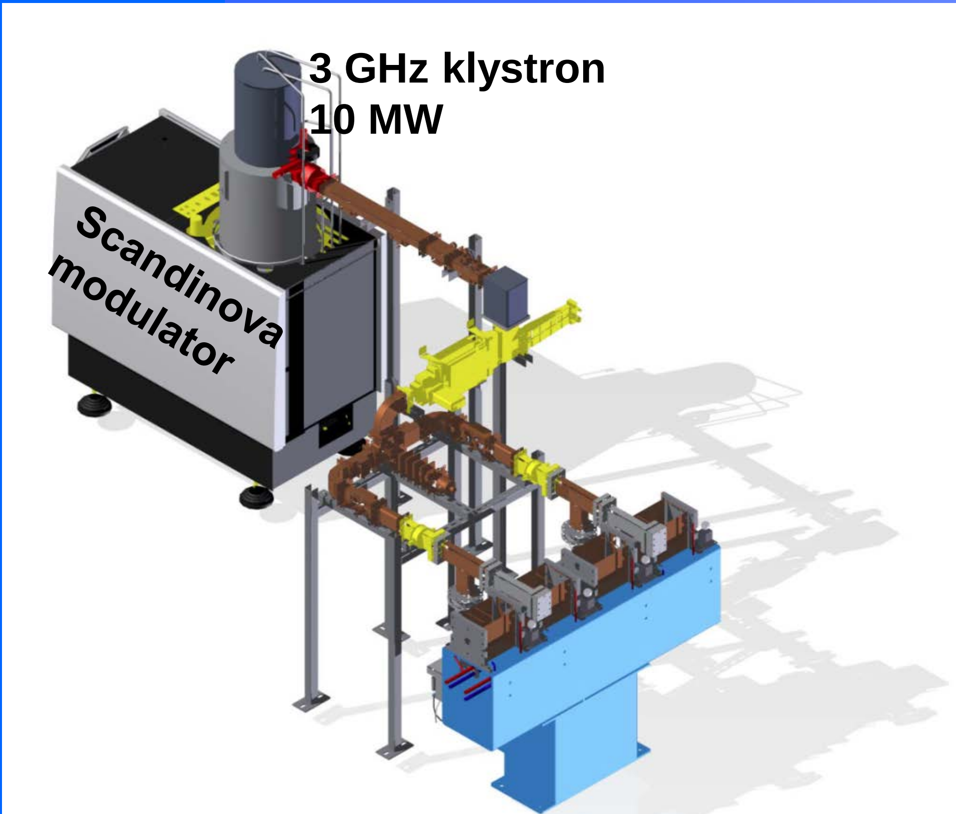




Basic unit: half-cell

3 GHz proton Linac

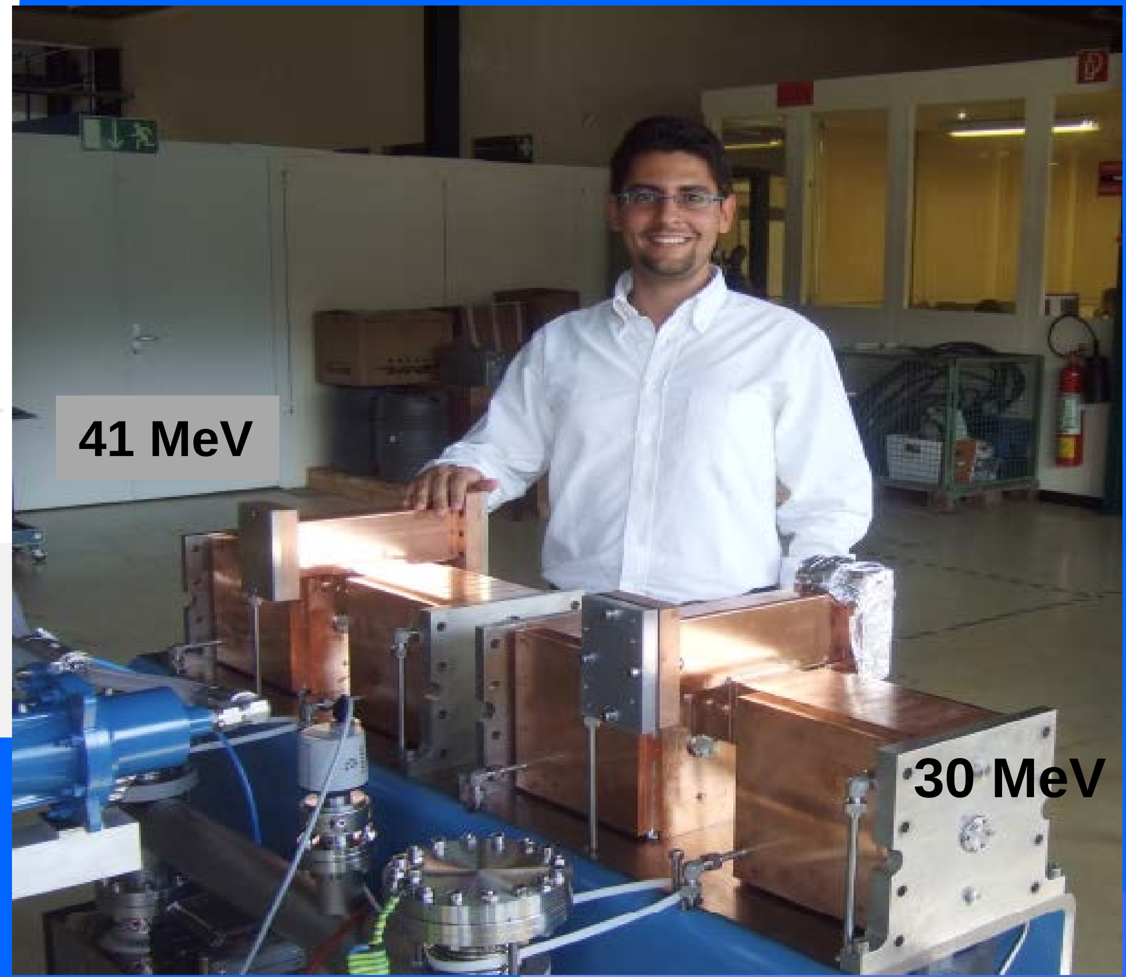
Commercial prototype built and power tested by A.D.A.M.: 2011



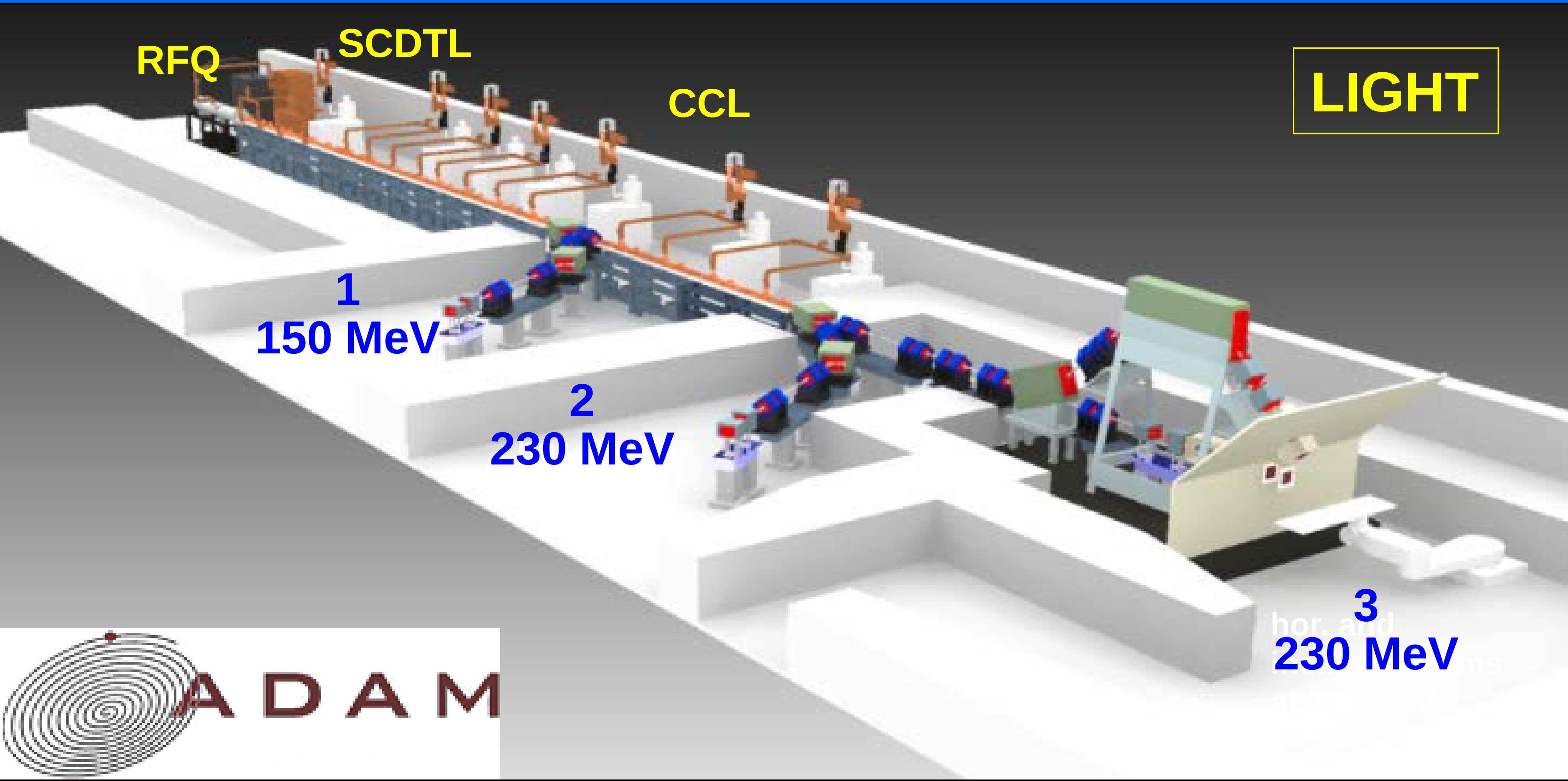
First Unit of LIGHT

Linac for Image Guided Hadron Therapy

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

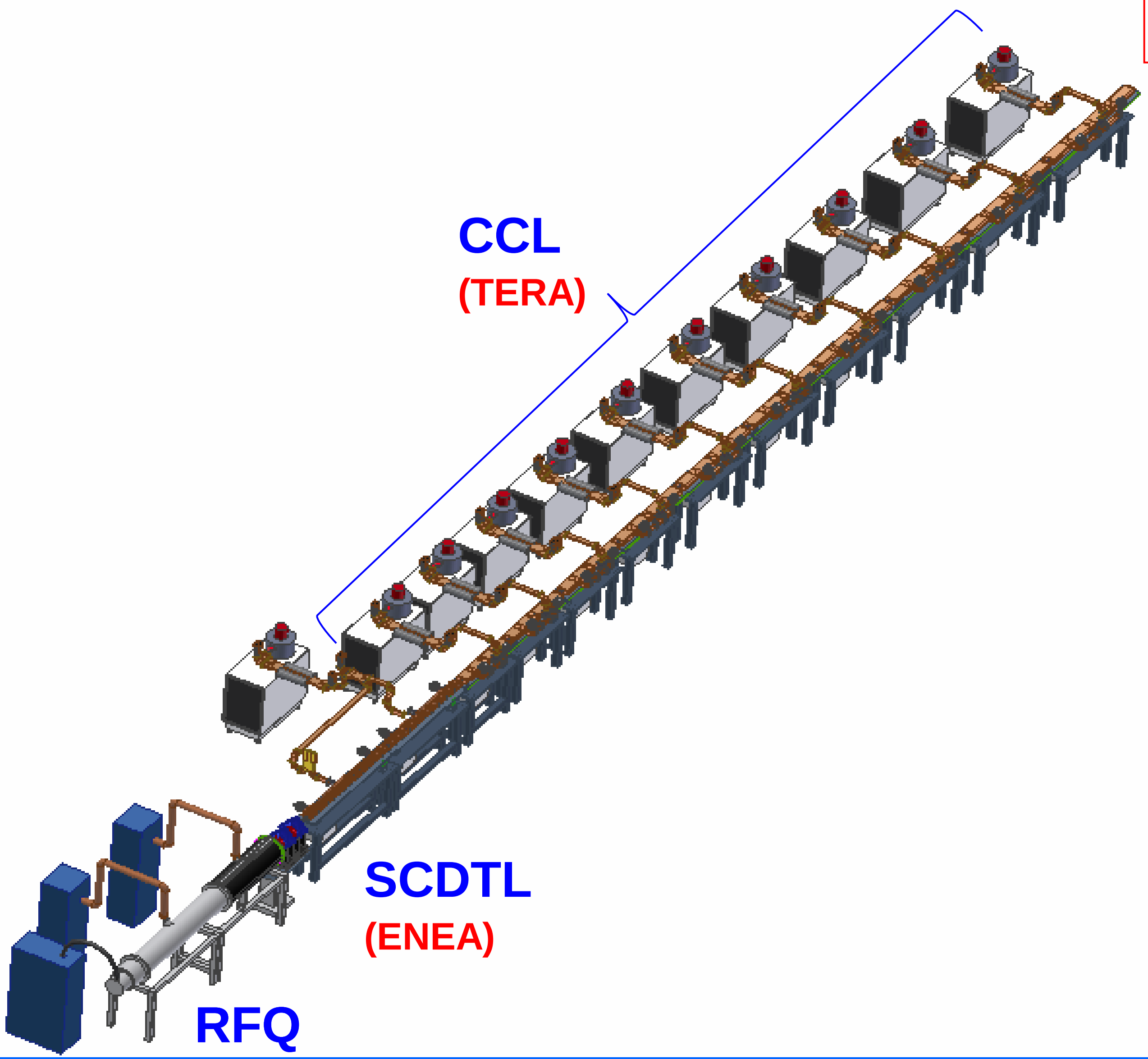


Centre offered by A.D.A.M. - CERN spin-off Company acquired by Advanced Oncotherapy in 2013



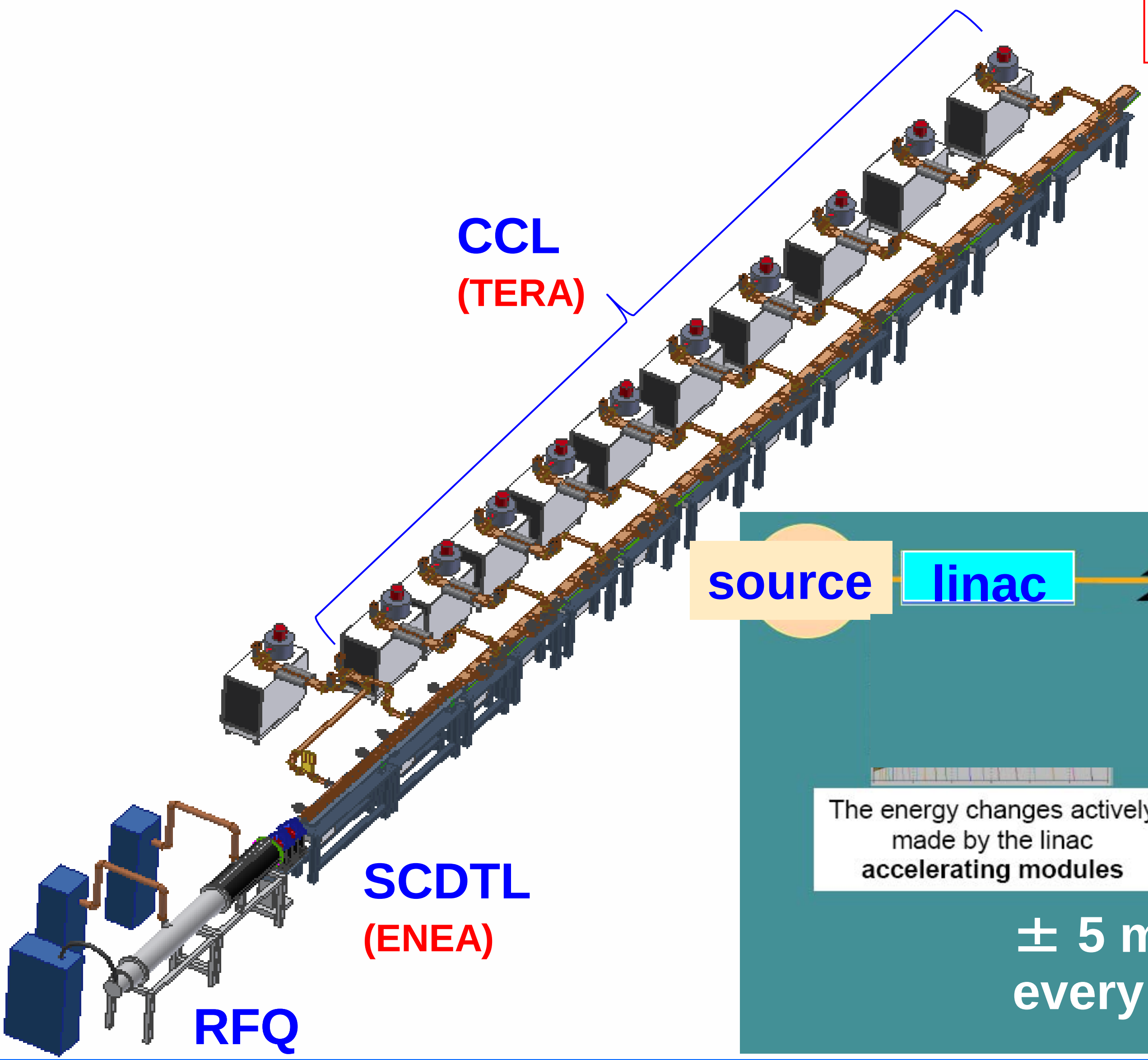
Linac for Image Guided Hadron Therapy

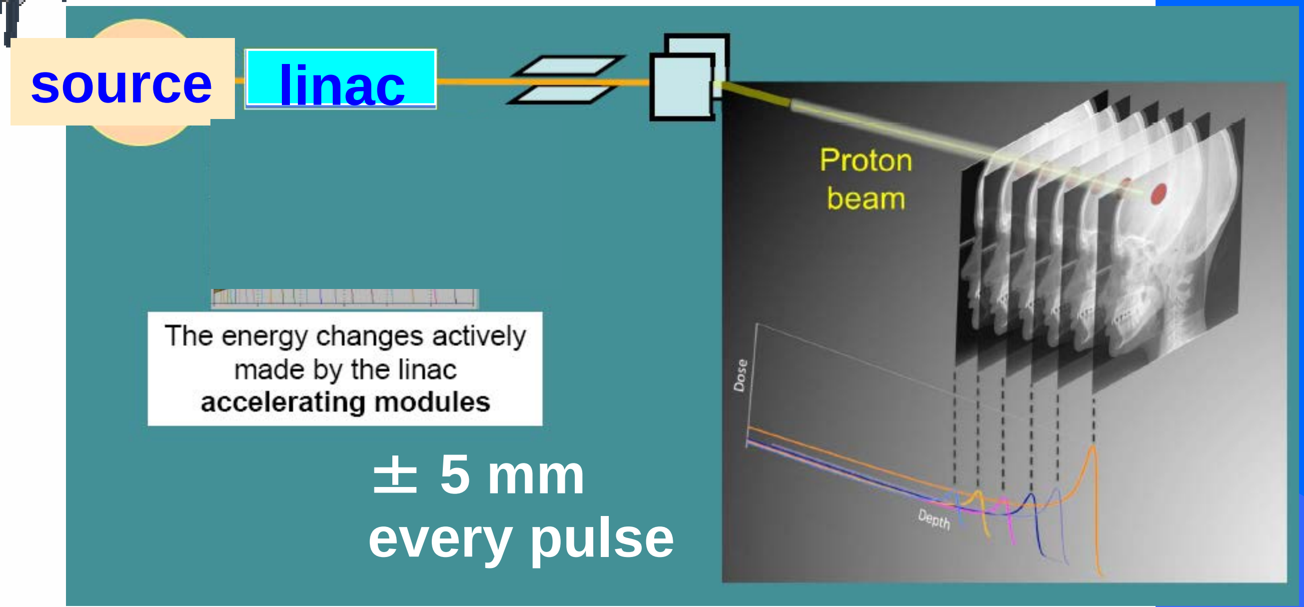
pulses @ 200times per second



Linac for Image Guided Hadron Therapy

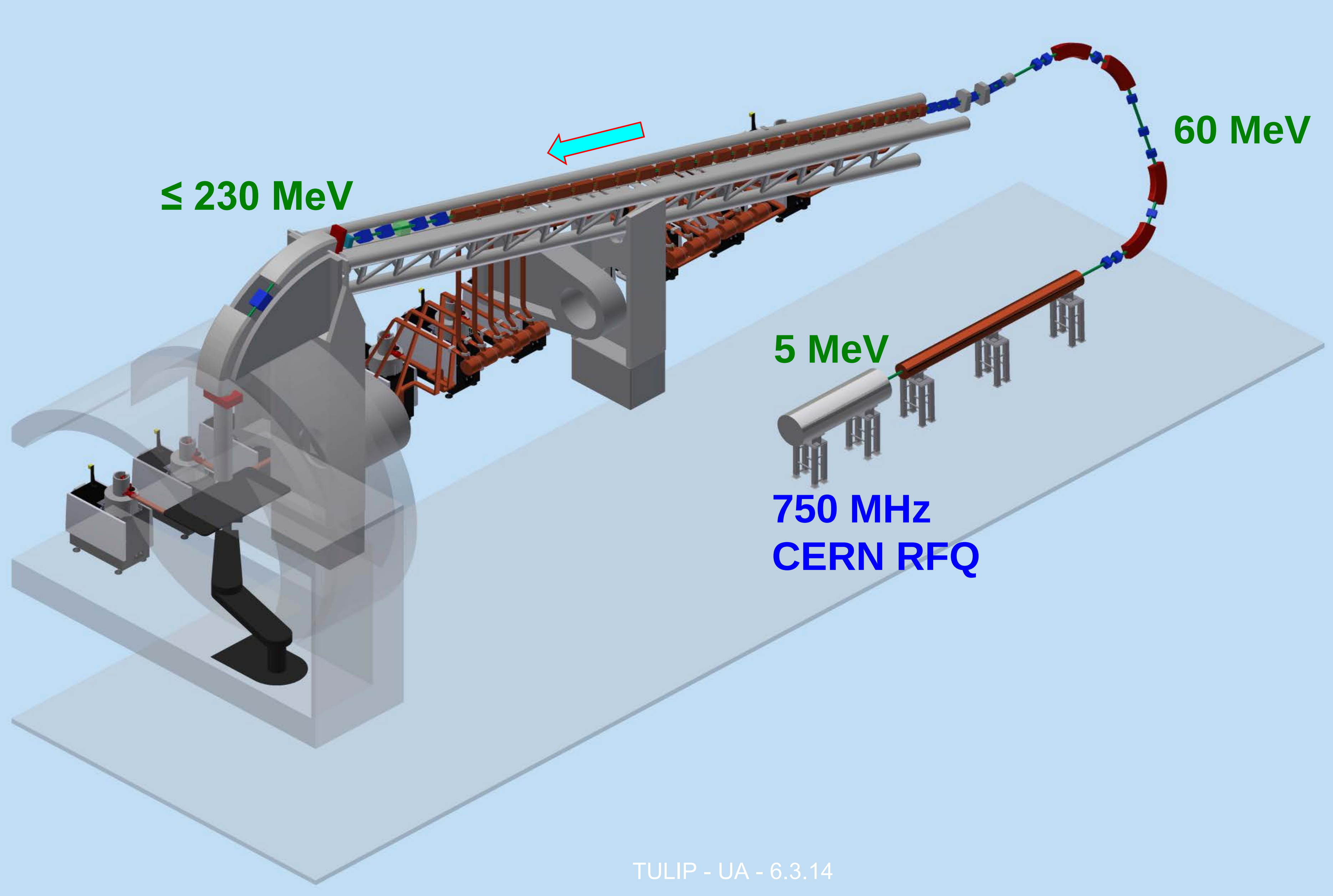
pulses @ 200times per second



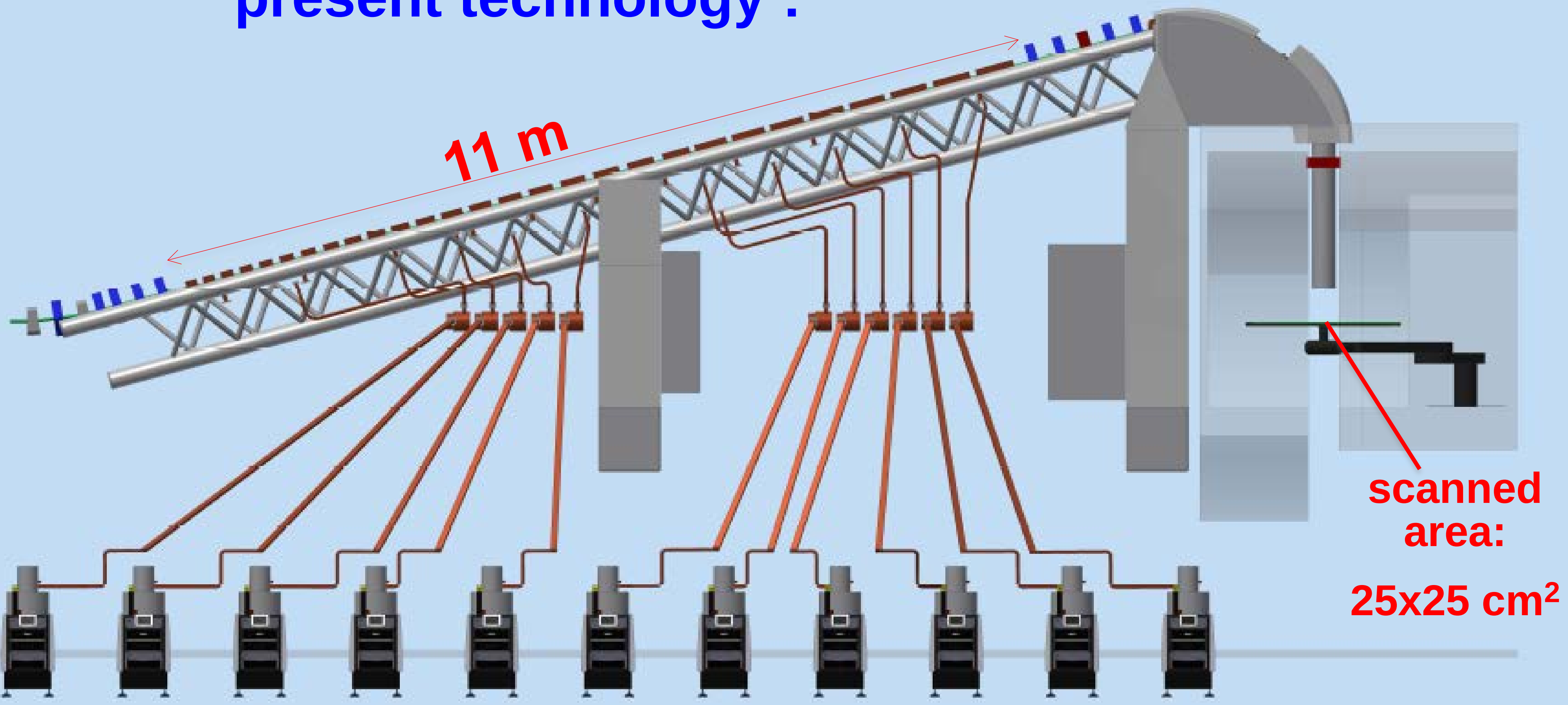


A future application of most recent CERN technologies CLIC = Compact Linear Collider

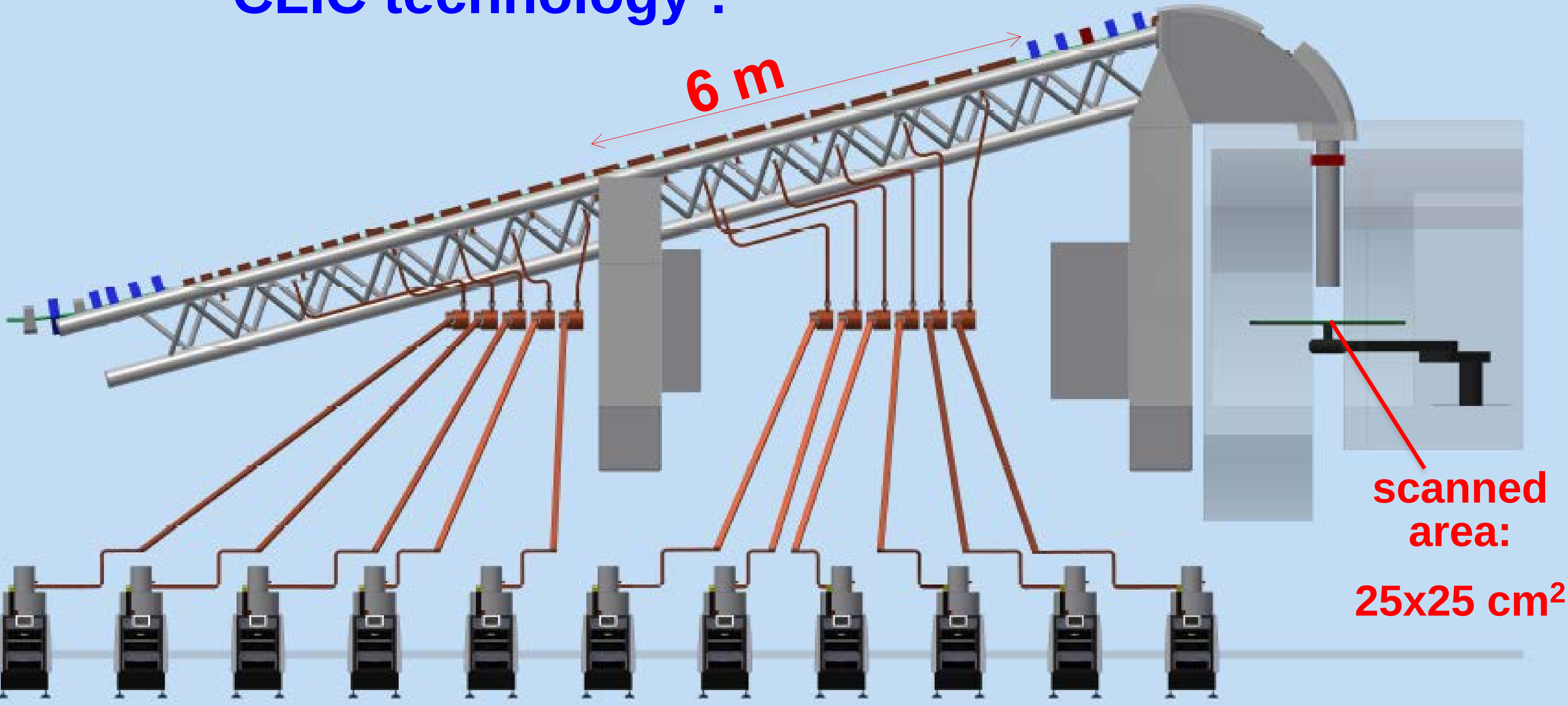
TULIP = Turning Linac for Protontherapy

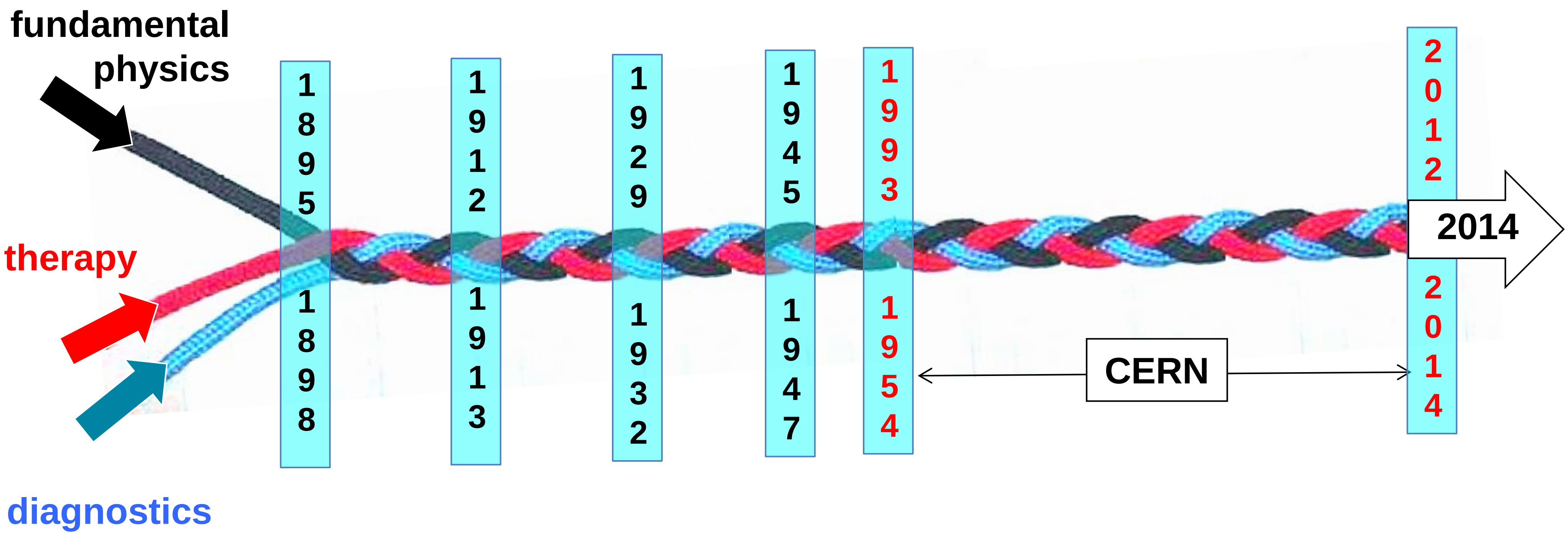


present technology :



CLIC technology :

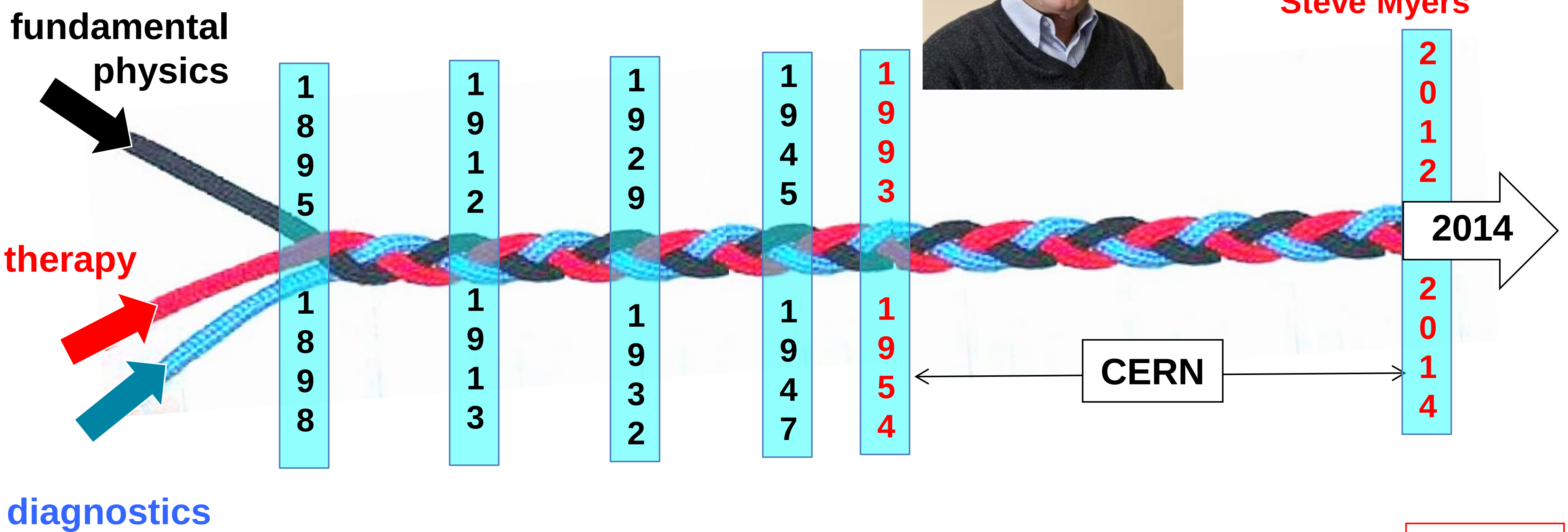



fundamental physics
therapy
diagnostics
1895
1898
1912
1913
1929
1932
1945
1947
1993
1954
2012
2014
2014
CERN

In 2014 a further step

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

Abstract

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. This is no coincidence: indeed, the beauty of particle physics has always been going hand in hand with useful applications.

These "useful" activities follow from the technical developments in particle accelerators and radiation detectors that have brought to the discoveries of neutral currents (1973), of its mediator, the Z boson (1984) and of the Higgs (2012).

The beginning of 2014 is thus the proper time to first describe these "beautiful" physics results, together with their consequences in our description of the events that took place in the first millionth of a second of the Universe life. The second part of the lecture will review CERN contributions to both diagnostics and therapy and conclude with an overview of possible future developments.