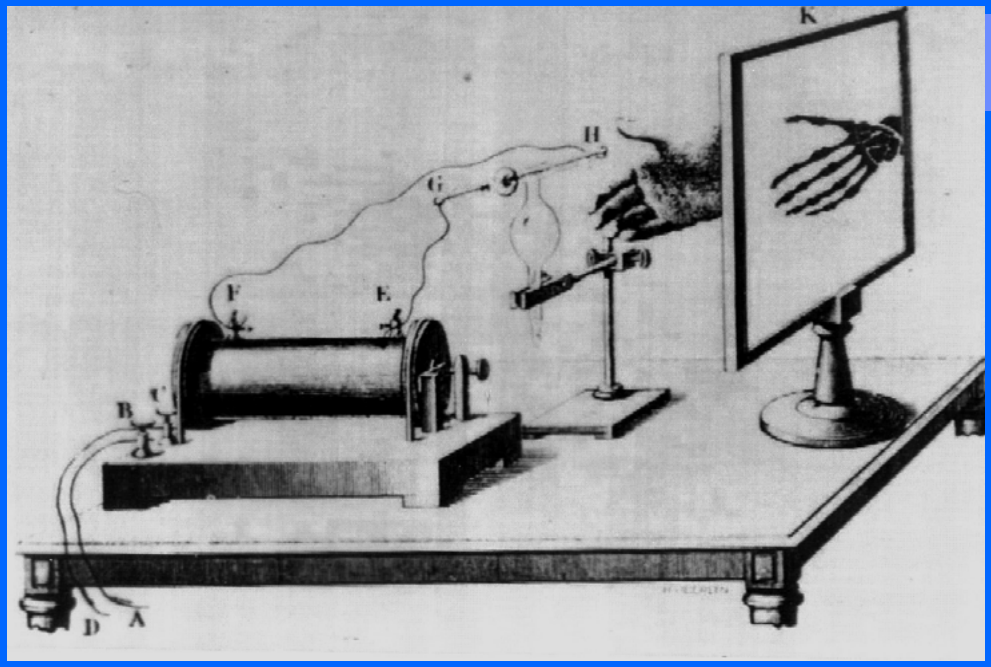
FROM ACCELERATORS TO CANCER THERAPY

Ugo Amaldi

University of Milano Bicocca and TERA Foundation

The starting point



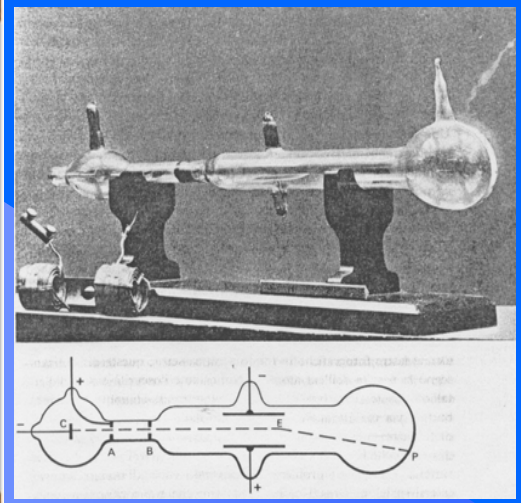
1895
discovery of X rays

Wilhelm Conrad Röntgen

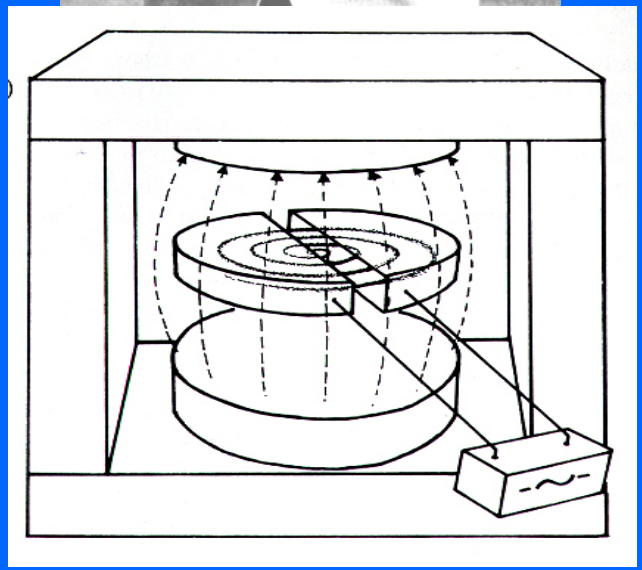
J.J. Thompson

1897

“discovery” of the electron

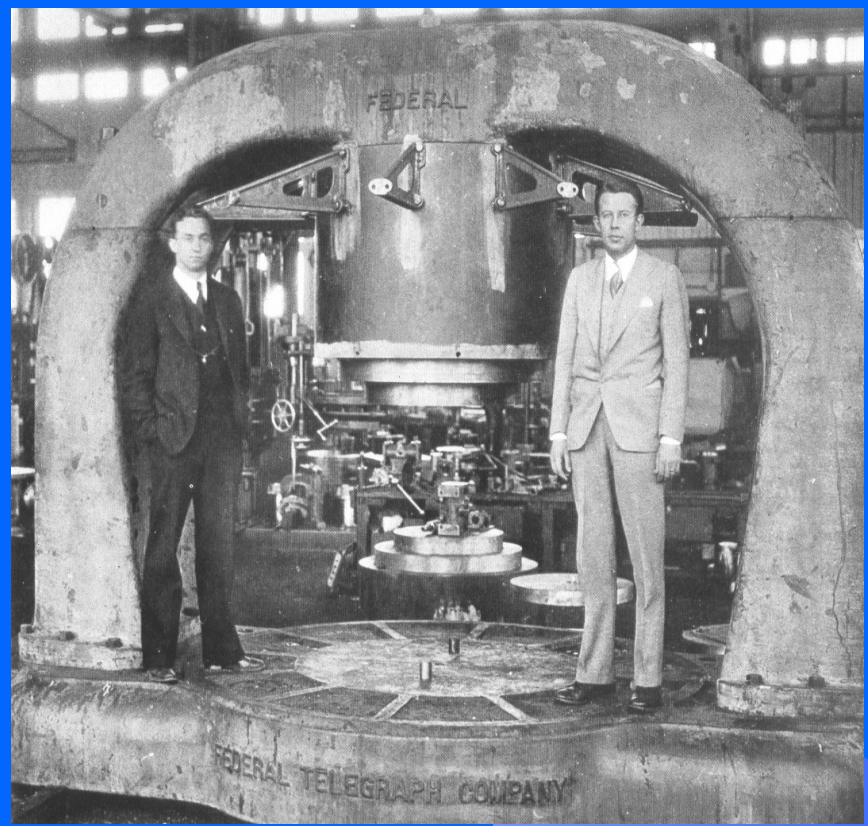


Ernest Lawrence invents the cyclotron 1930



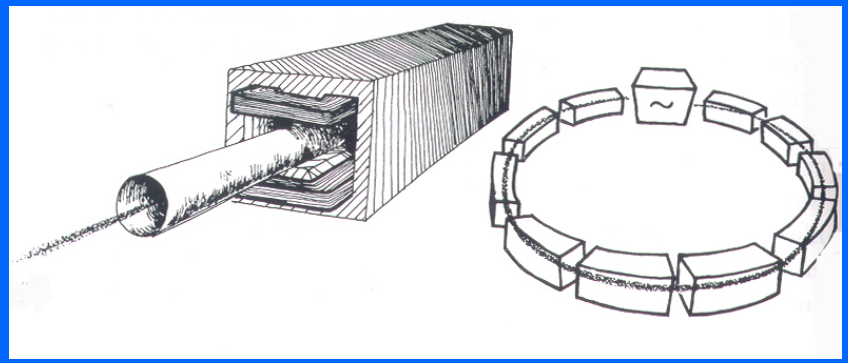
M. S. Livingston and E. Lawrence

with the 25 inches cyclotron



The synchrotron

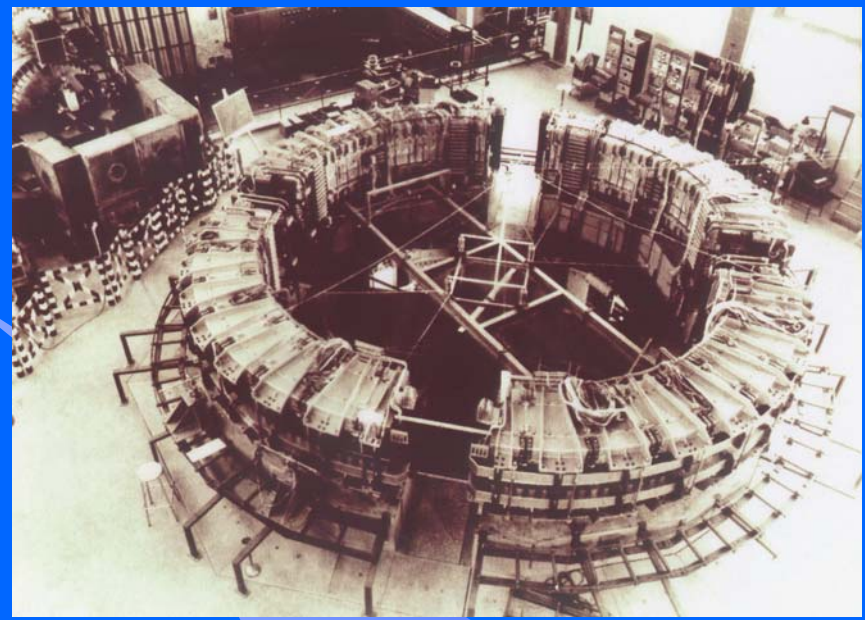
1945: E. McMillan and V.J.Veksler discover the principle of phase stability



1959: Veksler visits McMilan at Berkeley

1 GeV electron synchrotron

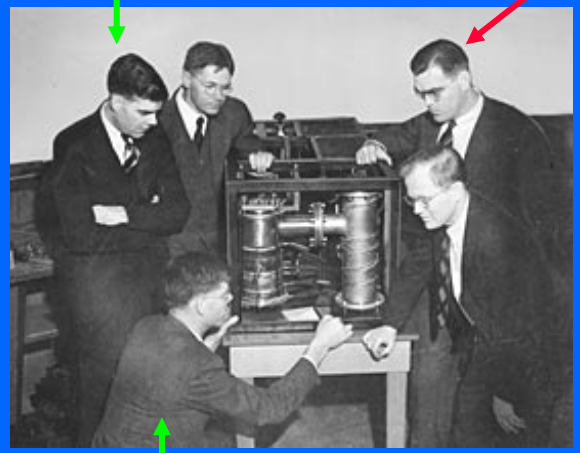
Frascati - INFN - 1959



The electron linac

Sigmur Varian

William W. Hansen



Russell Varian

1939

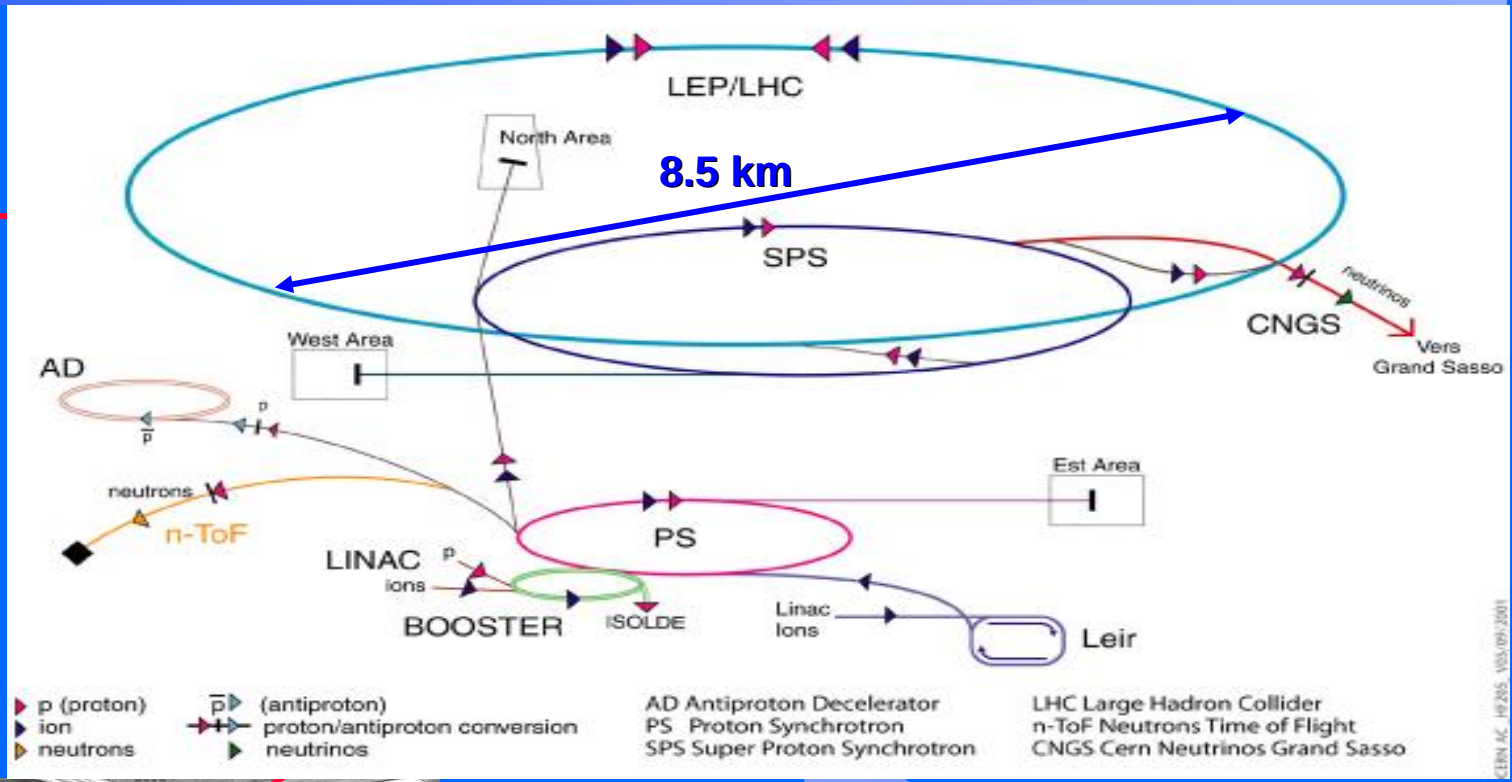
Invention of the klystron

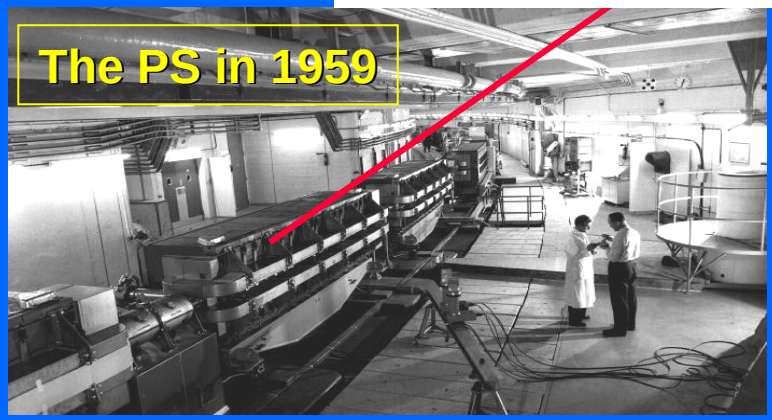
1947
first linac for electrons
4.5 MeV and 3 GHz

All the CERN strong-focusing synchrotrons

Large Hadron Collider

2007



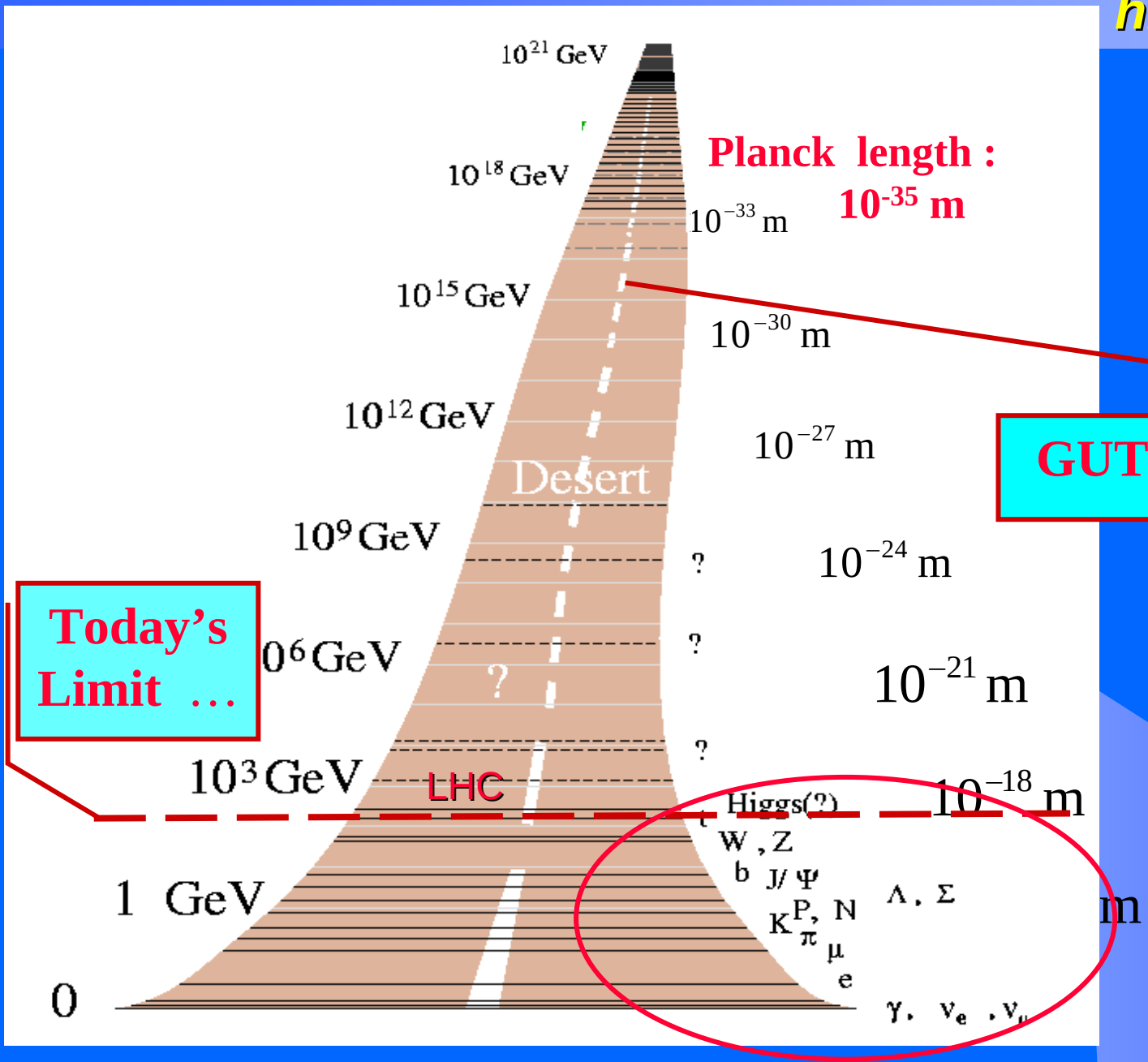


In 1952 the "strong-focusing" method

invented at BNL (USA)

was chosen for the CERN PS

We advance on the highway with accelerators of higher and higher energies



Gerard 't Hooft highway

Accelerators running in the world

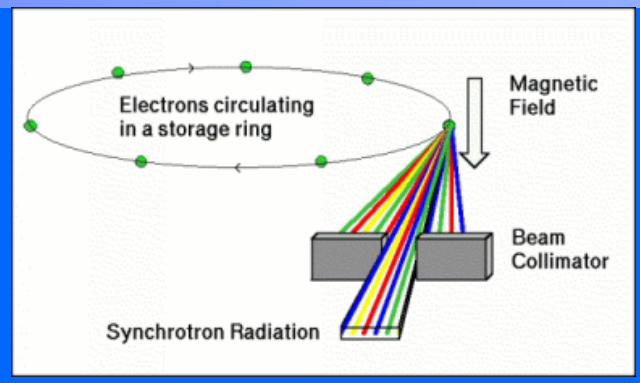
CATEGORY OF ACCELERATORS	NUMBER IN USE (*)	
High Energy acc. (E >1GeV)	~120	
Synchrotron radiation sources	>100	
Medical radioisotope production	~200	9000
Radiotherapy accelerators	> 7500	
Research acc. included biomedical research	~1000	
Acc. for industrial processing and research	~1500	
Ion implanters, surface modification	>7000	
TOTAL	> 17500	

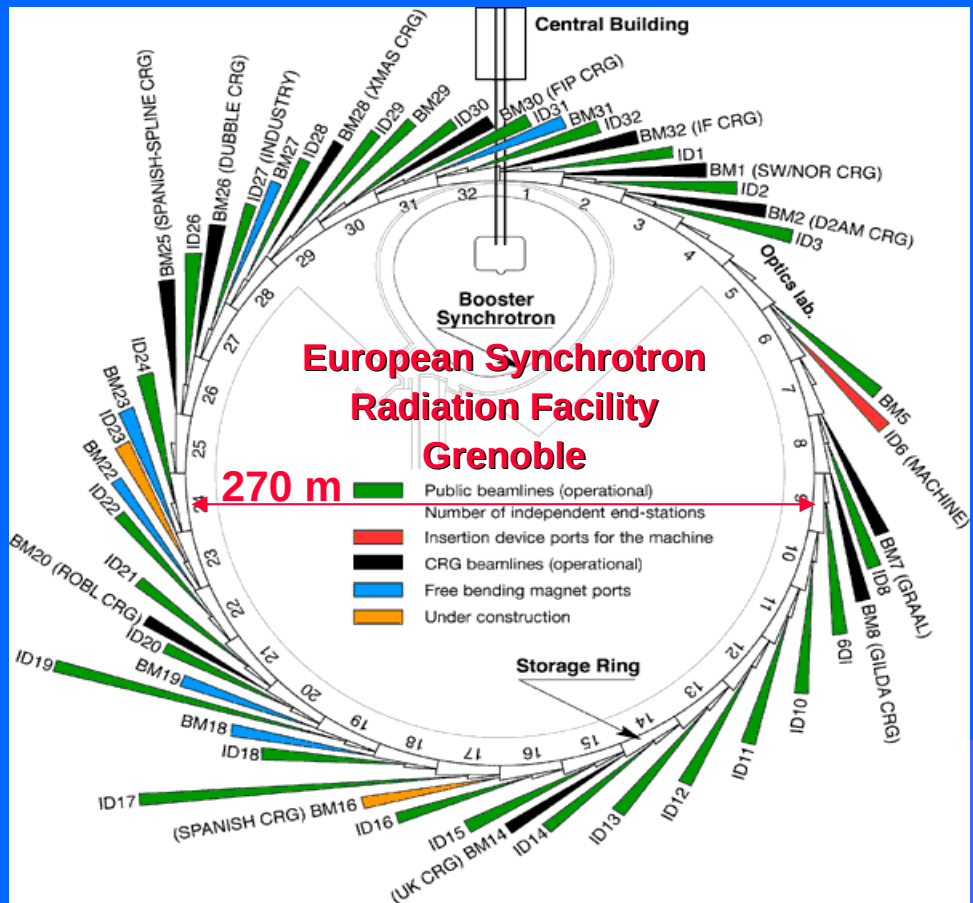
(*) W. Maciszewski and W. Scharf: Int. J. of Radiation Oncology, 2004

Synchrotron Light Sources: X-rays in science and industry

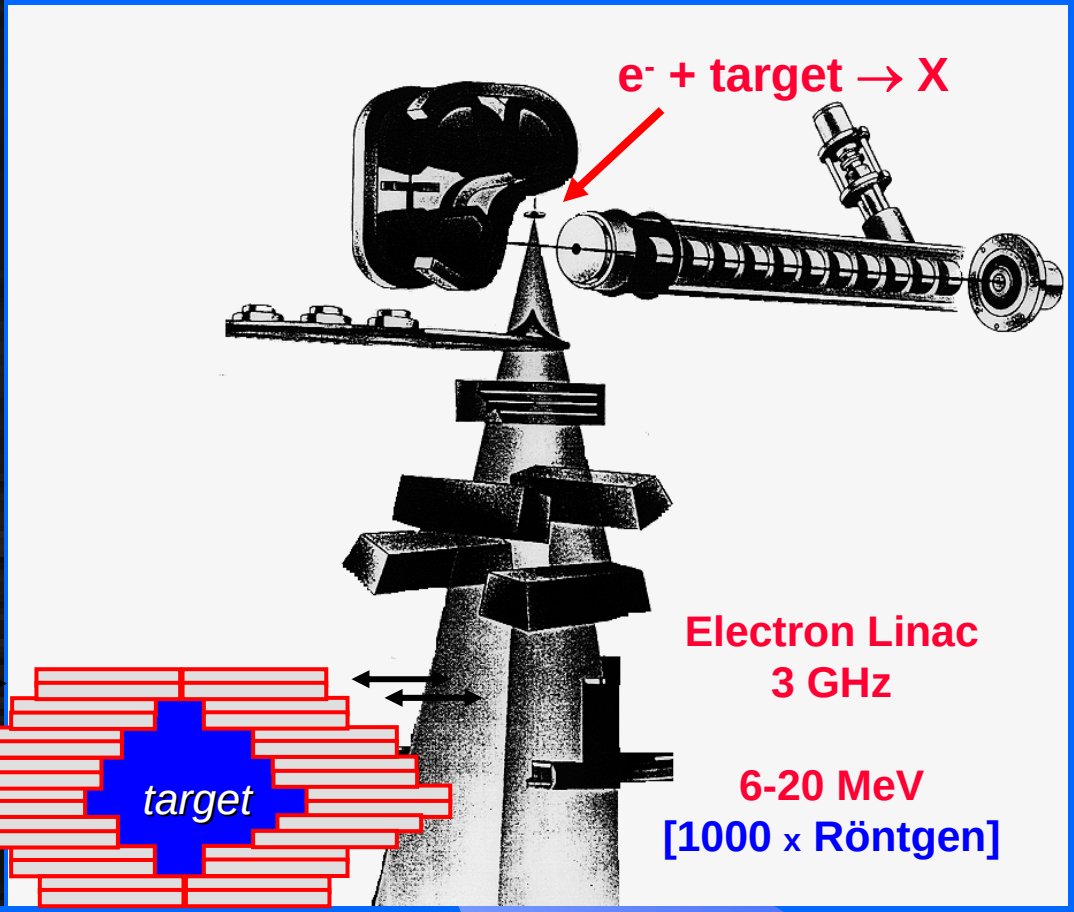
Main applications in

- **Physics / Chemistry**
  - crystallography
  - materials analysis
  - fast chemical reactions
- **Biology / Medicine**
  - structural biology
  - biological imaging
  - medical imaging
  - microbeam radiotherapy
- **Enginering**
  - litography
  - micromachining





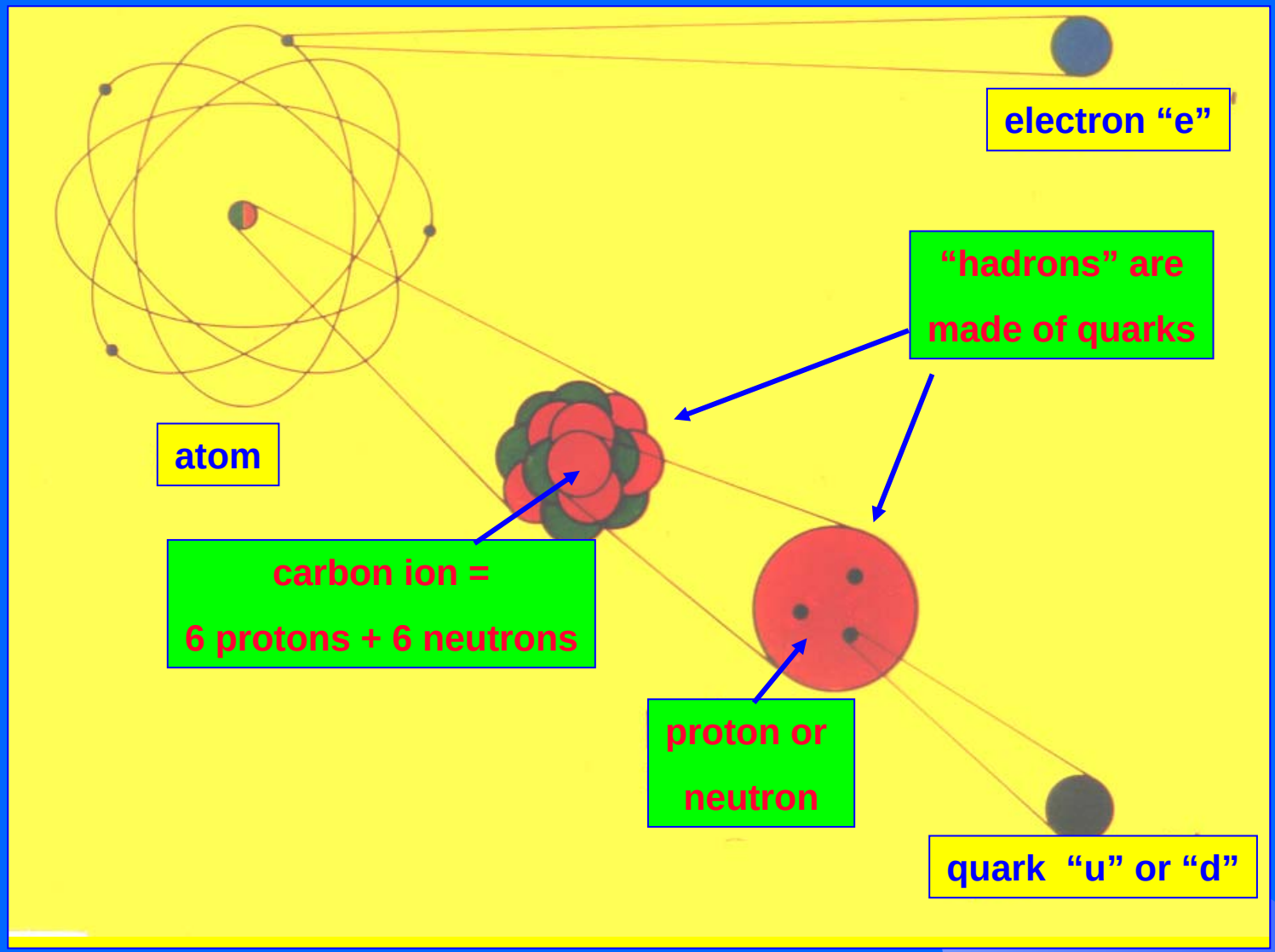
X-rays in radiotherapy: linacs



Radiotherapists only use one type of accelerator:

the electron linac

"Hadrontherapy" uses beams of hadrons

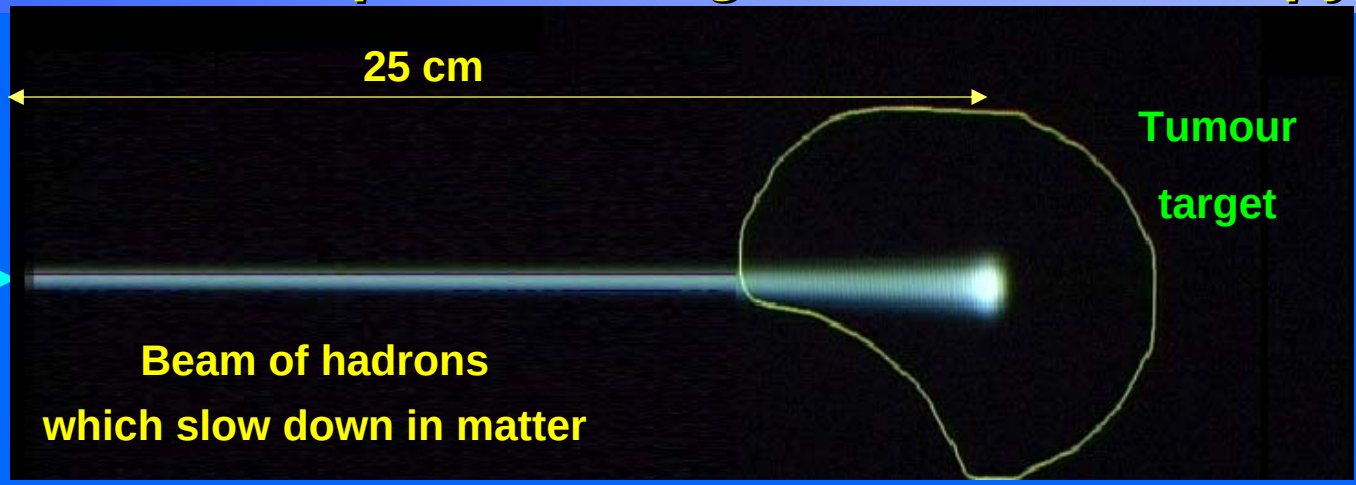


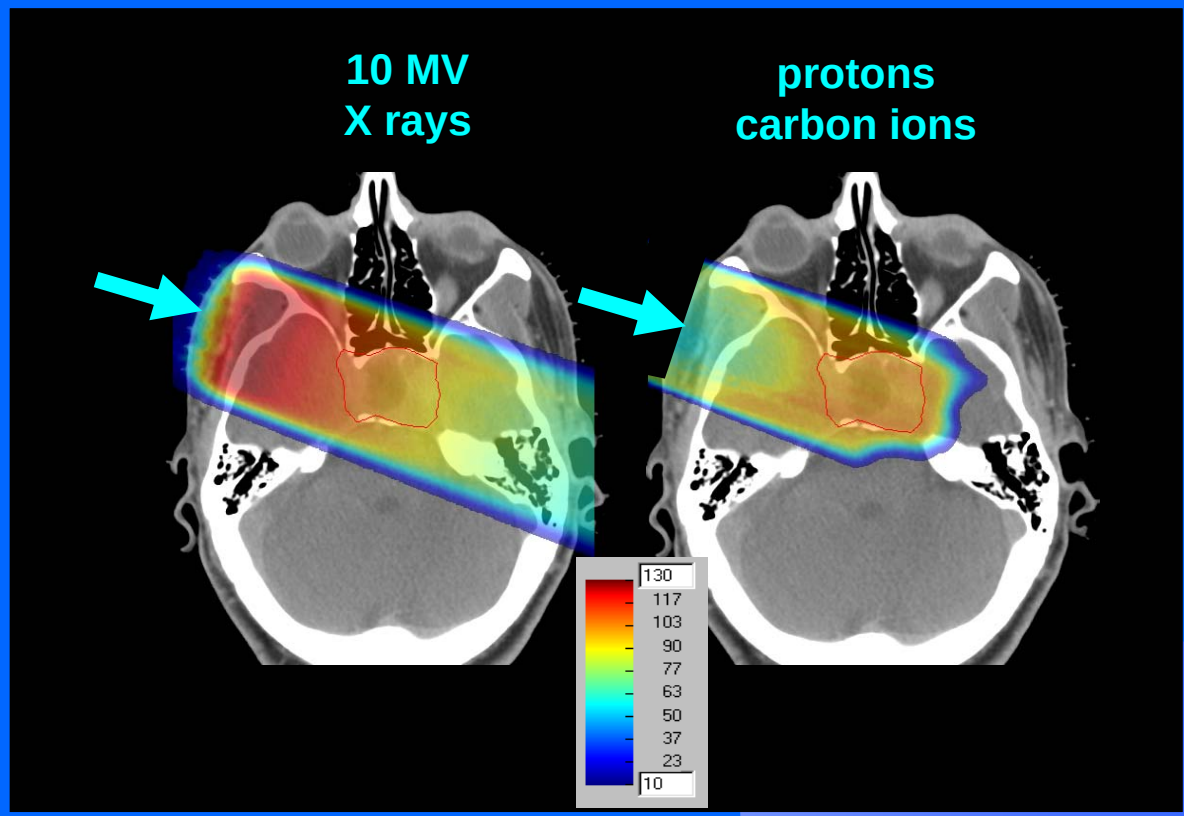
Macroscopic advantages of hadrontherapy

To control radioresistant tumours

carbon ions 4800 MeV

protons 200 MeV



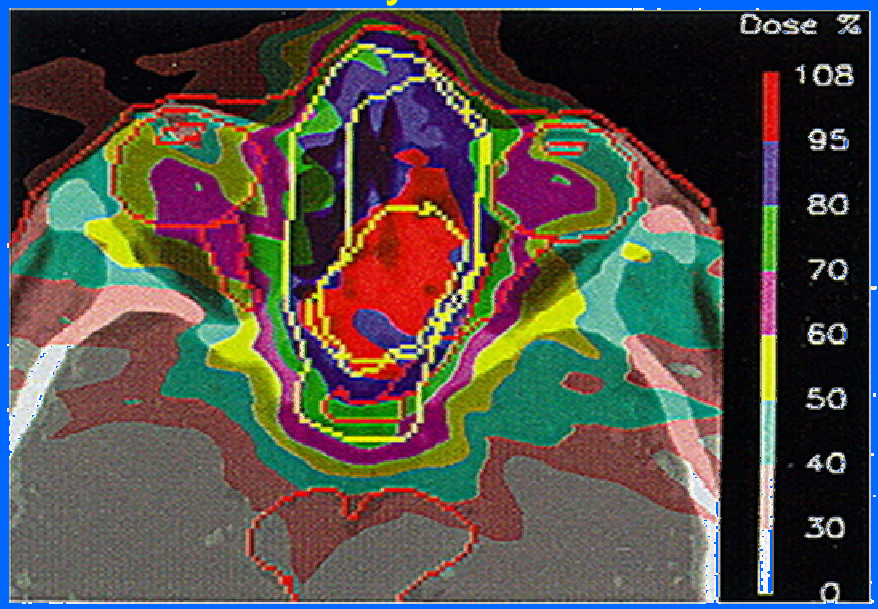


Single beam comparison

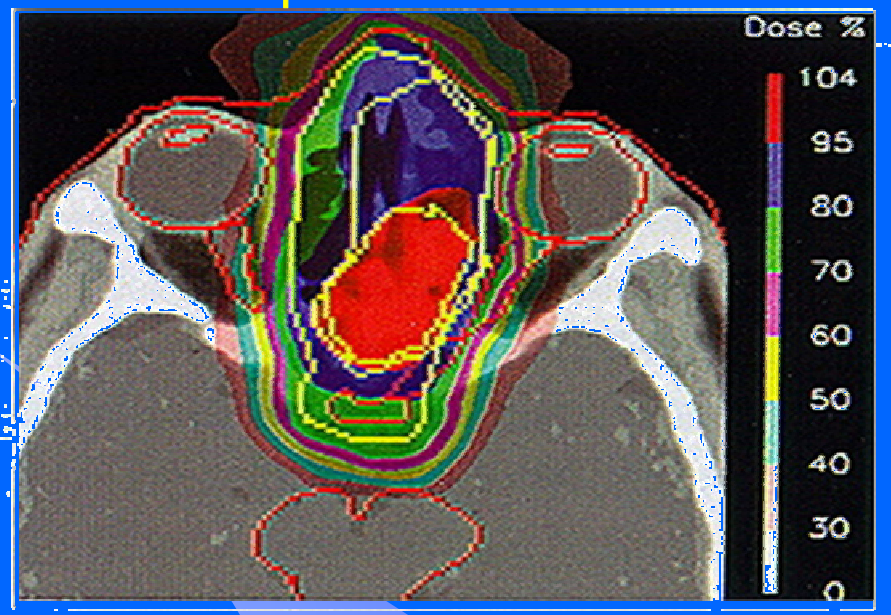
Protons and ions are more precise than X-rays

Tumour between the eyes

9 X –ray beams

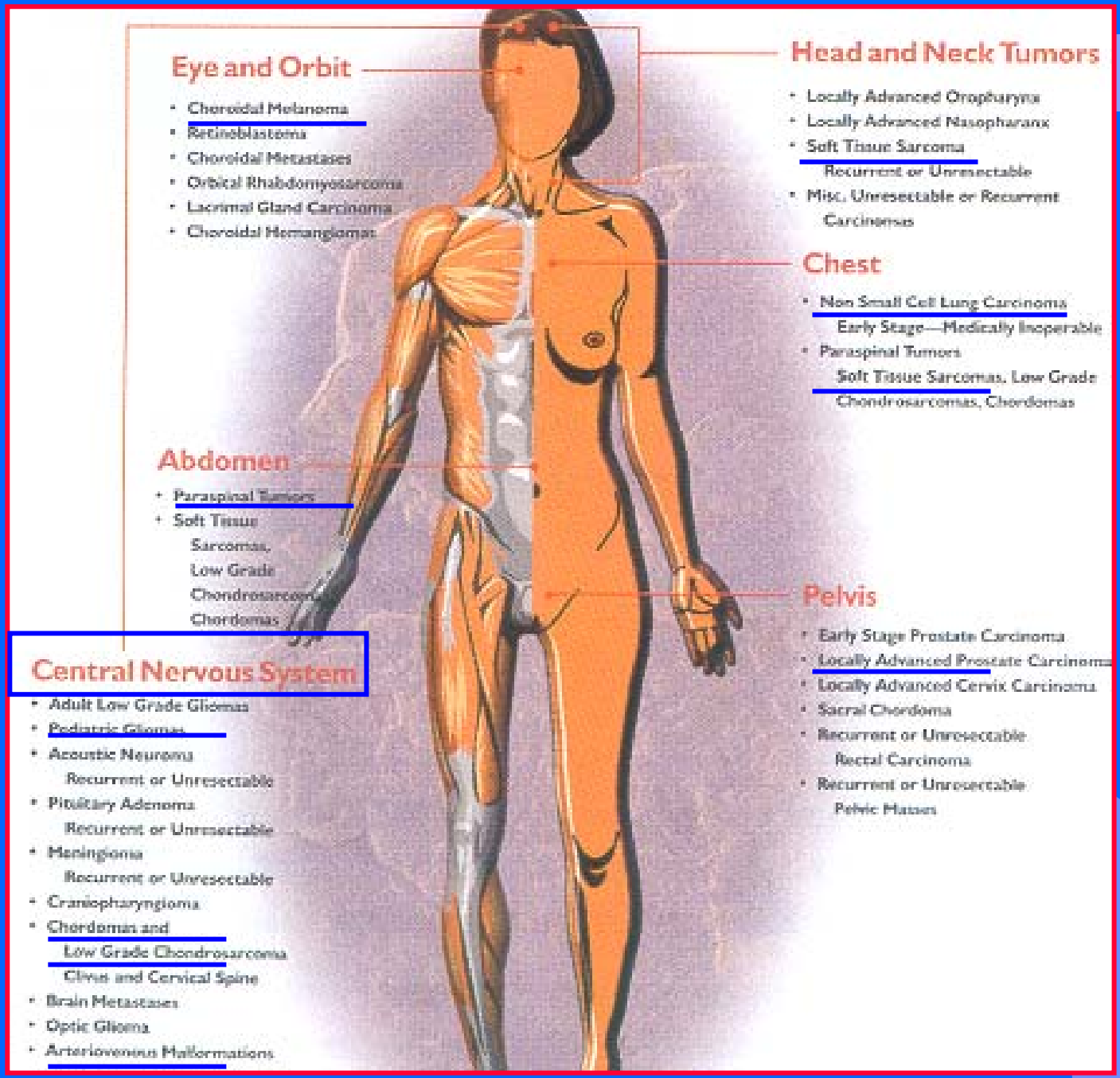


1 proton beam



Carbon ions are even better

The sites



Protontherapy:

35 000 patients

Cost about 20000 Euro

2-3 x X-rays

If cost would be the same as for X-rays

90% of the treatments would be with protons !

Hospital centres for deep protontherapy (>500 pts/year)

5 in USA, 4 in Japan, 2 in China, 1 in Switzerland, 1 in Germany, 1 in Korea, 1 in Italy

(running or financed)

Four companies offer turn-key centres

Radiobiological efficiency of carbon ions

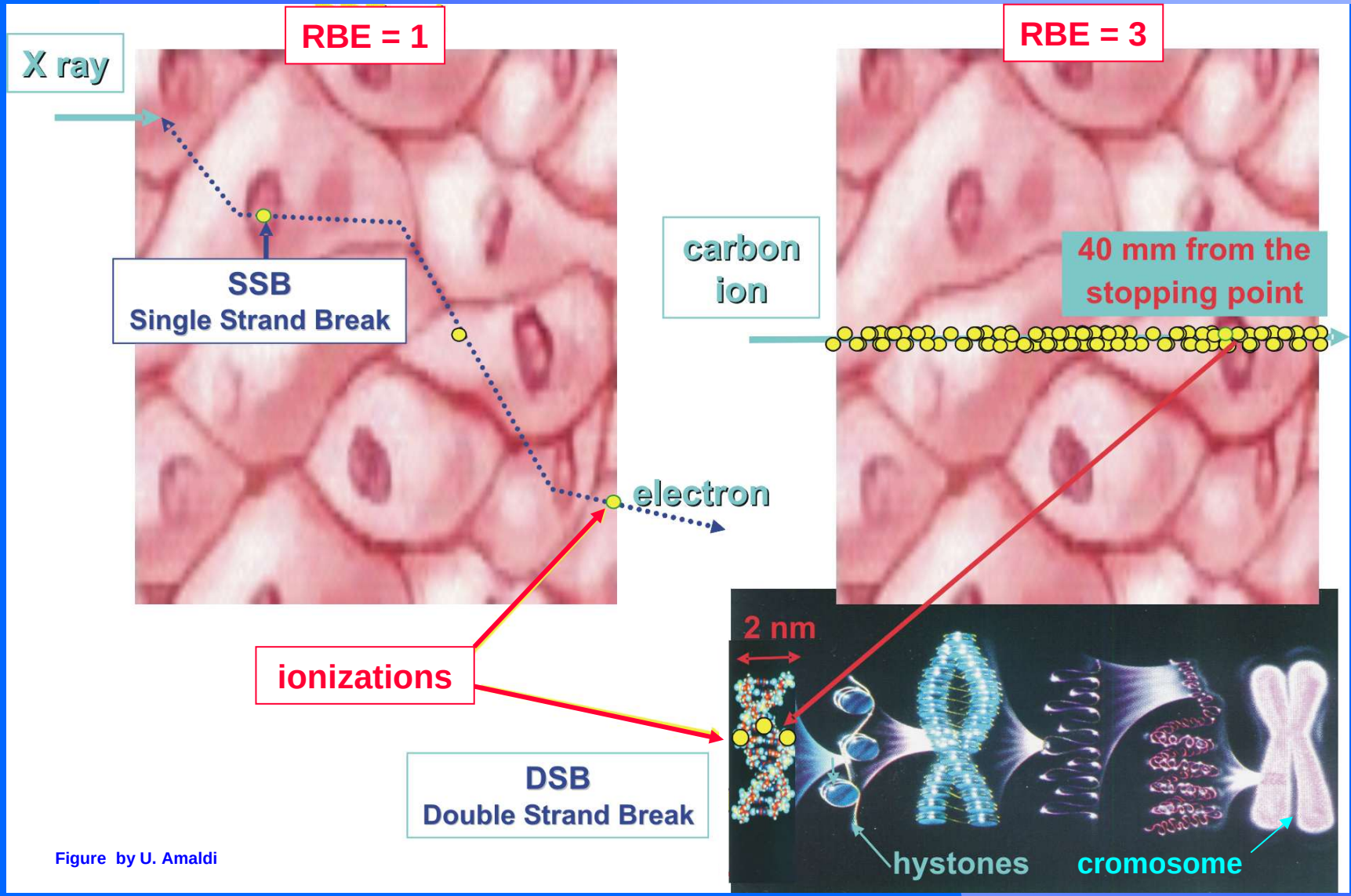


Figure by U. Amaldi

Numbers of potential patients

X-ray therapy every 10 million inhabitants: 20'000 pts/year

Protontherapy

12% of X-ray patients = 2'400 pts/year

Therapy with Carbon ions for radio-resistant tumour

3% of X-ray patients = 600 pts/year

TOTAL about 3'000 pts/year

every 10 M

Japan: 4 proton Centres and 2 carbon ion centres

WAKASA BAY PROJECT
by Wakasa-Bay Energy Research Center
Fukui (2002)
protons (≤ 200 MeV) synchrotron
(Hitachi)
1 h beam + 1 v beam + 1 gantry

HYOGO MED CENTRE
Hyogo (2001)
protons (≤ 230 MeV) - He and C ions (≤ 320 MeV/u)
Mitsubishi synchrotron
2 p gantries + 2 fixed p beam + 2 ion rooms

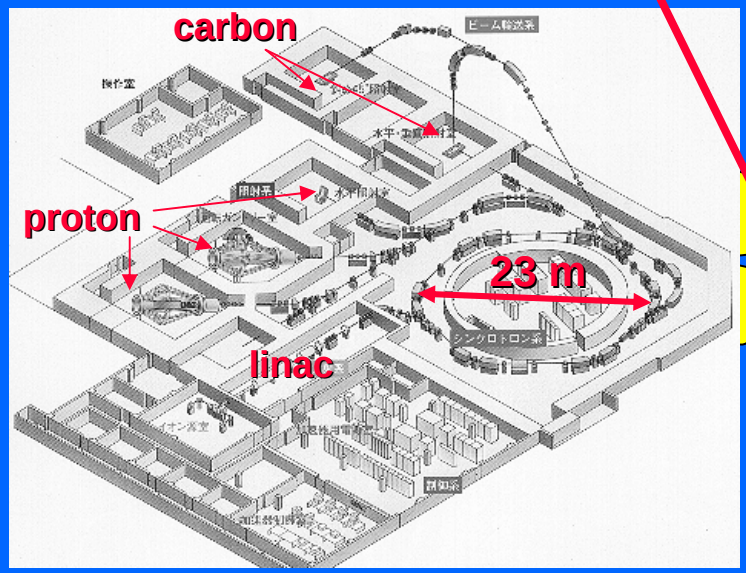


Figure by U. Amaldi

TSUKUBA CENTRE
Ibaraki (2001)
protons (≤ 270 MeV)
synchrotron (Hitachi)
2 gantries
2 beam for research

KASHIWA CENTER
Chiba (1998)
protons (≤ 235 MeV)
cyclotron (IBA – SHI)
2 Gantries + 1 hor. beam

HEAVY ION MEDICAL ACCELERATOR
HIMAC of NIRS (1995)
He and C (≤ 430 MeV/u) 2 synchrotrons
2 h beams + 2 v beams

2000 patients with carbon ions

SHIZUOKA FACILITY
Shizuoka (2002)
Proton synchrotron
2 gantries + 1 h beam

1998 - GSI pilot project

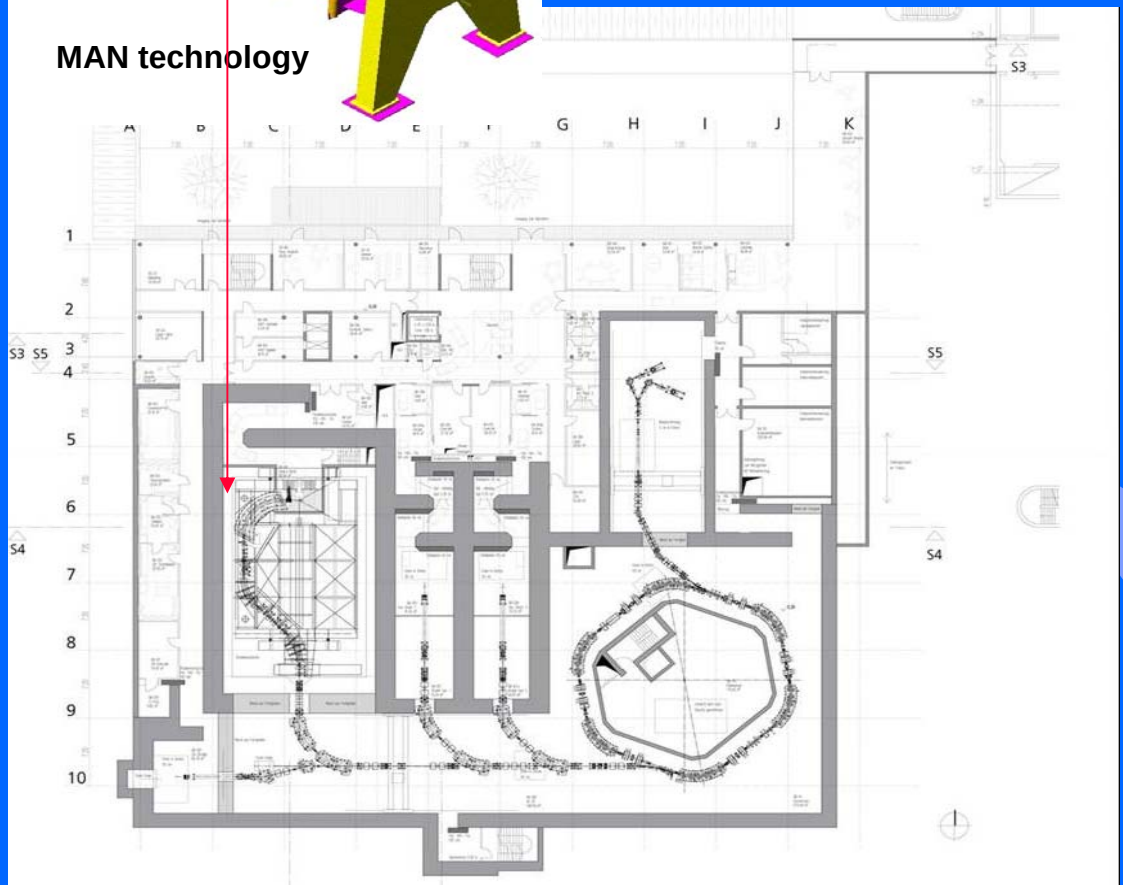
G. Kraft

200 patients treated with carbon ions under J. Debus (Heidelberg)

PET on-line

HIT – University of Heidelberg

MAN technology



Financed with 72 MEuro:

State: 36

loan: 36

Heidelberg: J. Debus

U. Weber

GSI: H. Eickhoff

Th. Haberer

Project started in 2001

First patient: end 2006

Projects of the TERA Foundation

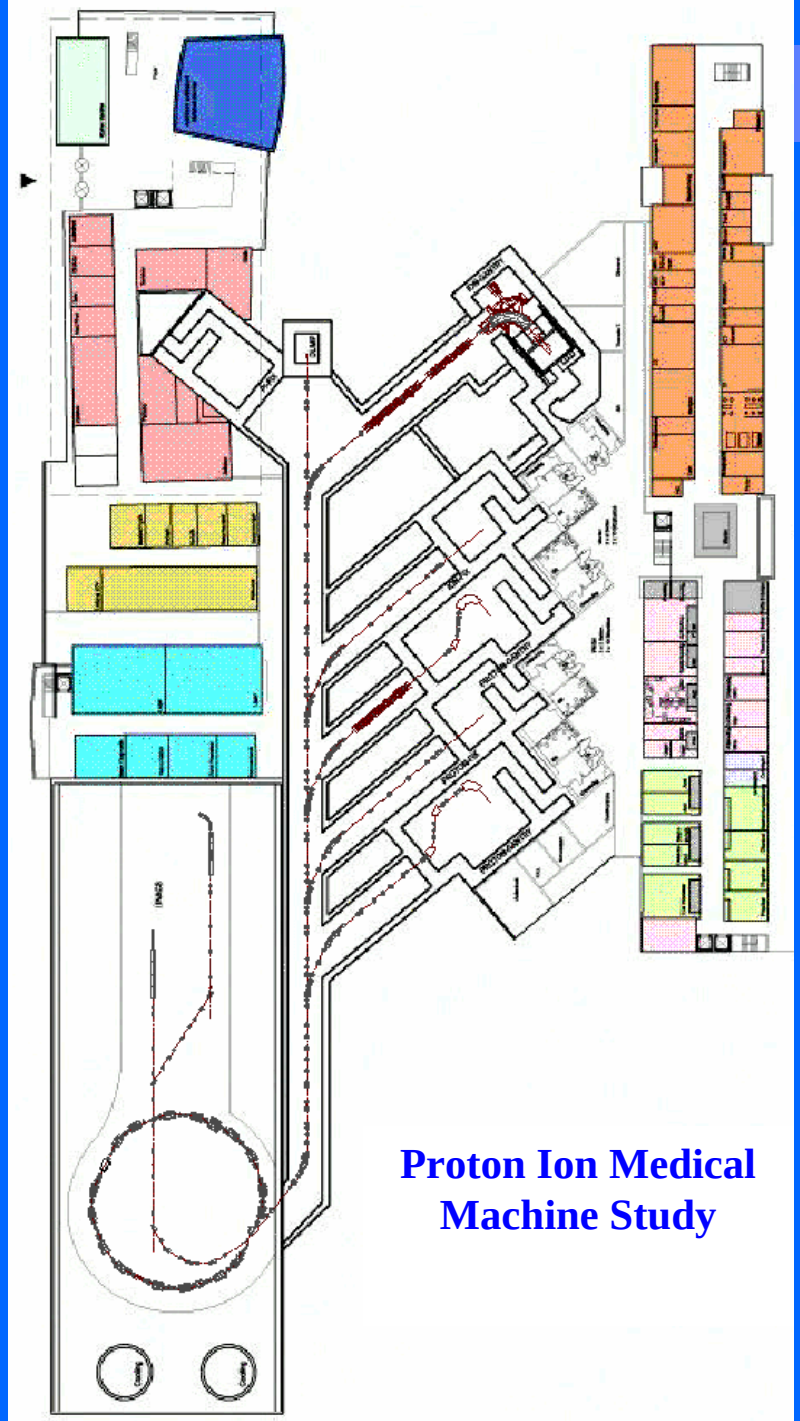
TERA has proposed and designed a National Centre for carbon ions:

The Italian National Centre is being built in Pavia

TERA is developing a novel technique for diagnostics and protontherapy

The “cyclinac”

PIMMS: 1996 - 2000



Proton Ion Medical Machine Study

Proton Ion Medical Machine Study

CERN – TERA – Med-Austron

Project leader: P.Bryant

PAC Chairman: G. Brianti

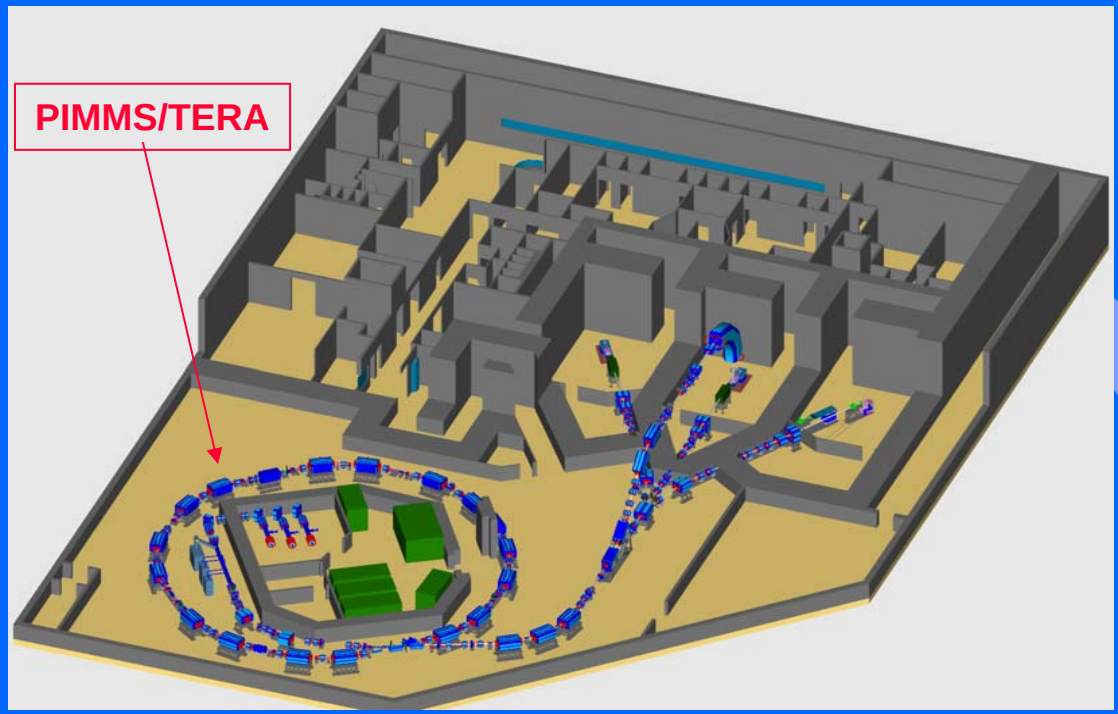
PIMMS/TERA

- One linac à la GSI inside the ring
- Multiturn injection
- Short beam lines

CNAO = Centro Nazionale di Adroterapia

CNAO Foundation was created by the Italian Government in 2001 to realize CNAO: 4 Hospitals in Milan, 1 Hospital in Pavia and TERA INFN is Institutional Participant

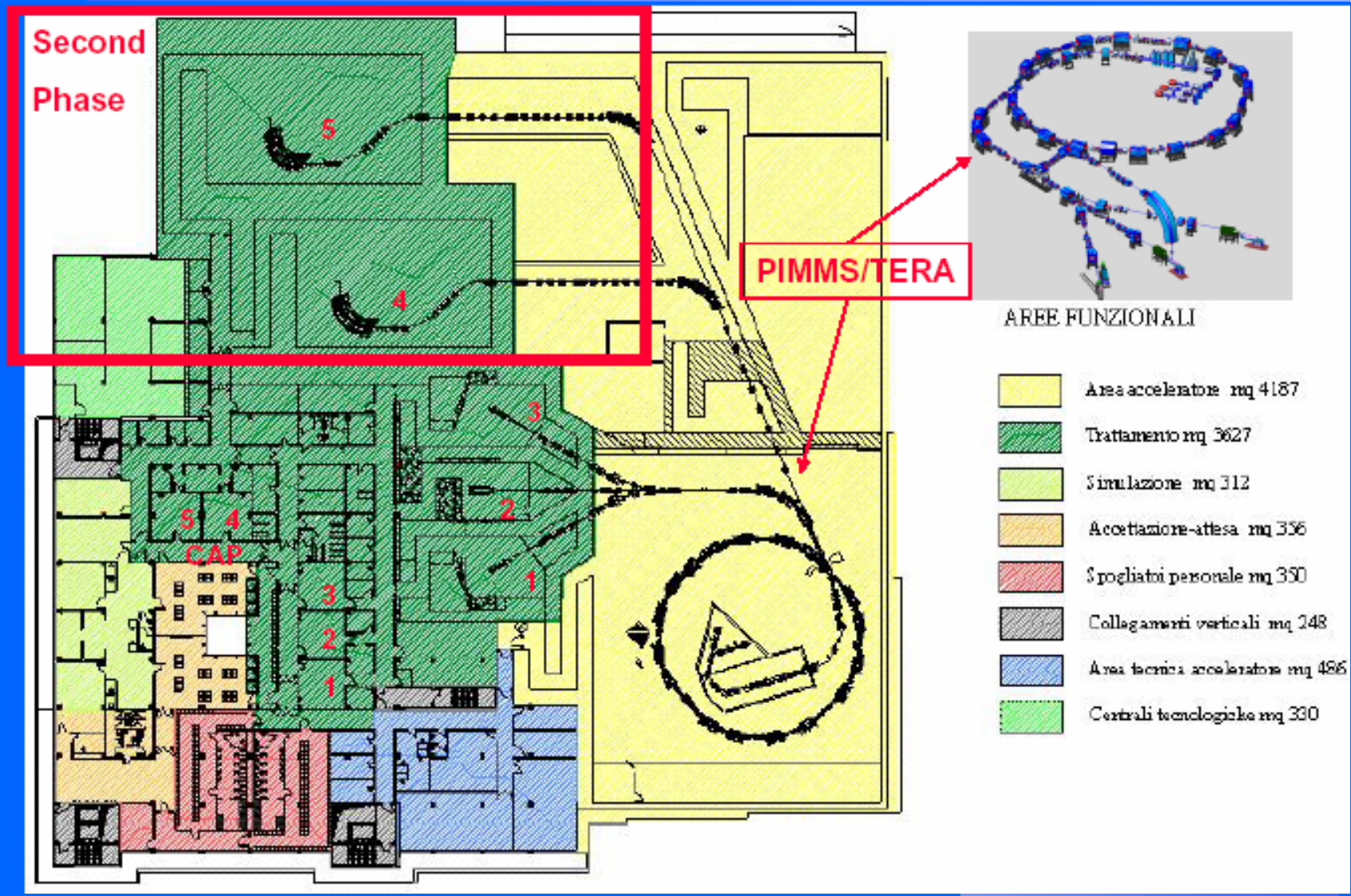
In September 2003 TERA has completed and passed to CNAO the design of the high-tech part of CNAO and 25 people



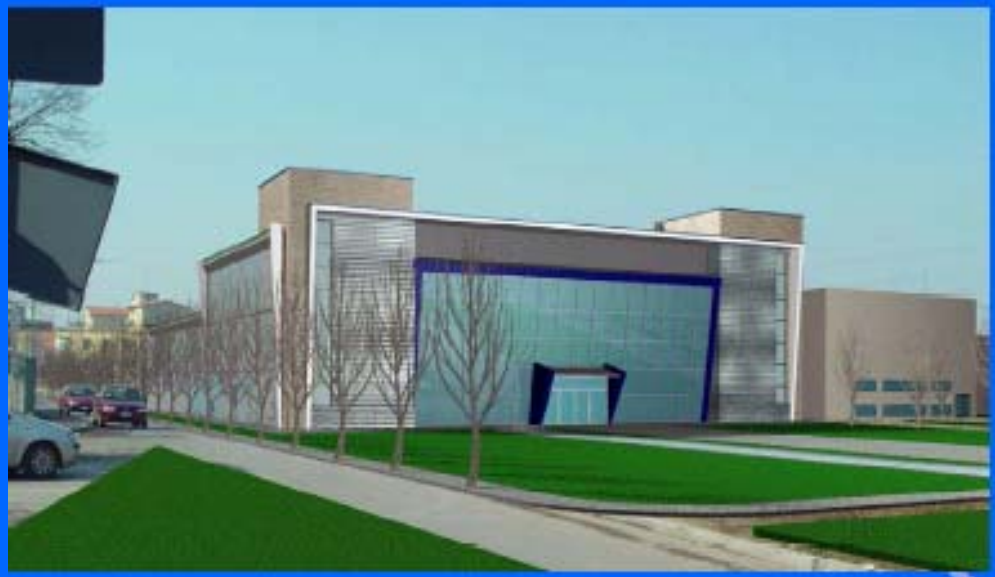
President: E. Borloni

Med. Dir.: R. Orecchia
Tech. Dir: S. Rossi

The underground level of CNAO



CNAO on the Pavia site



Project: Calvi –TEKNE

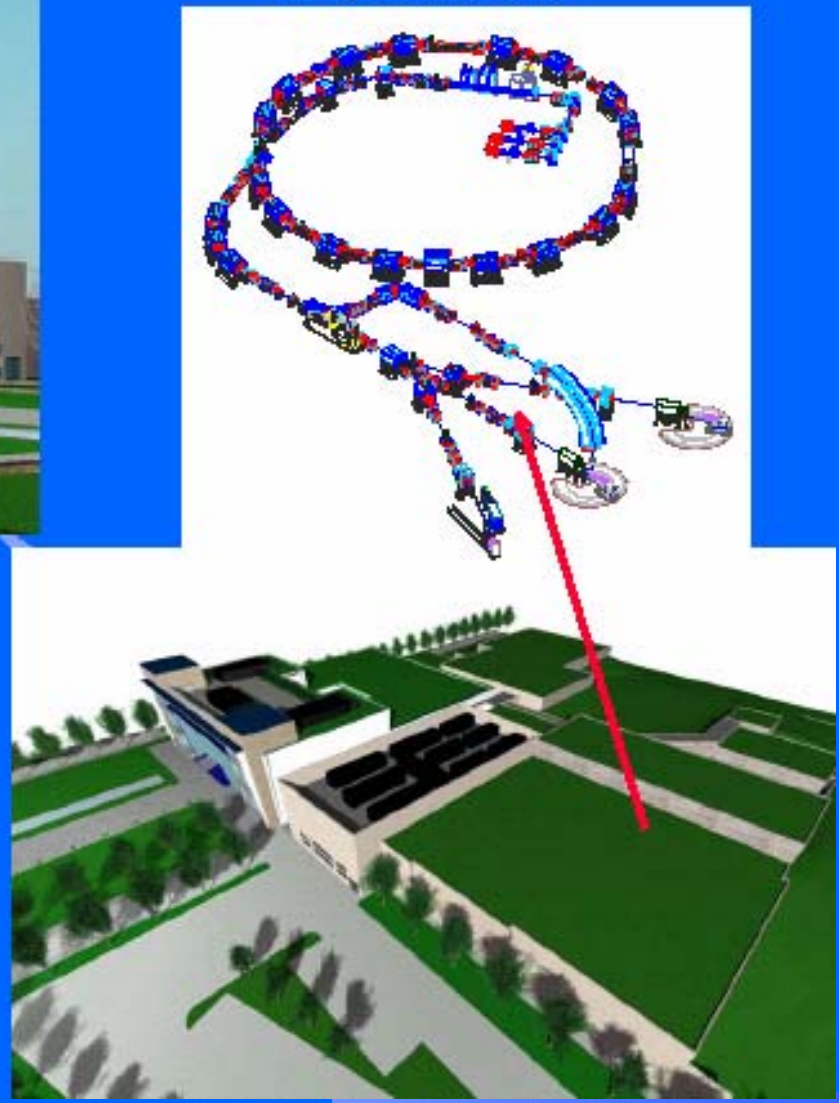
Magnets ordered

August 2004:

17 companies applied for the civil enginerering construction

First patient: end of 2007

Project: TERA

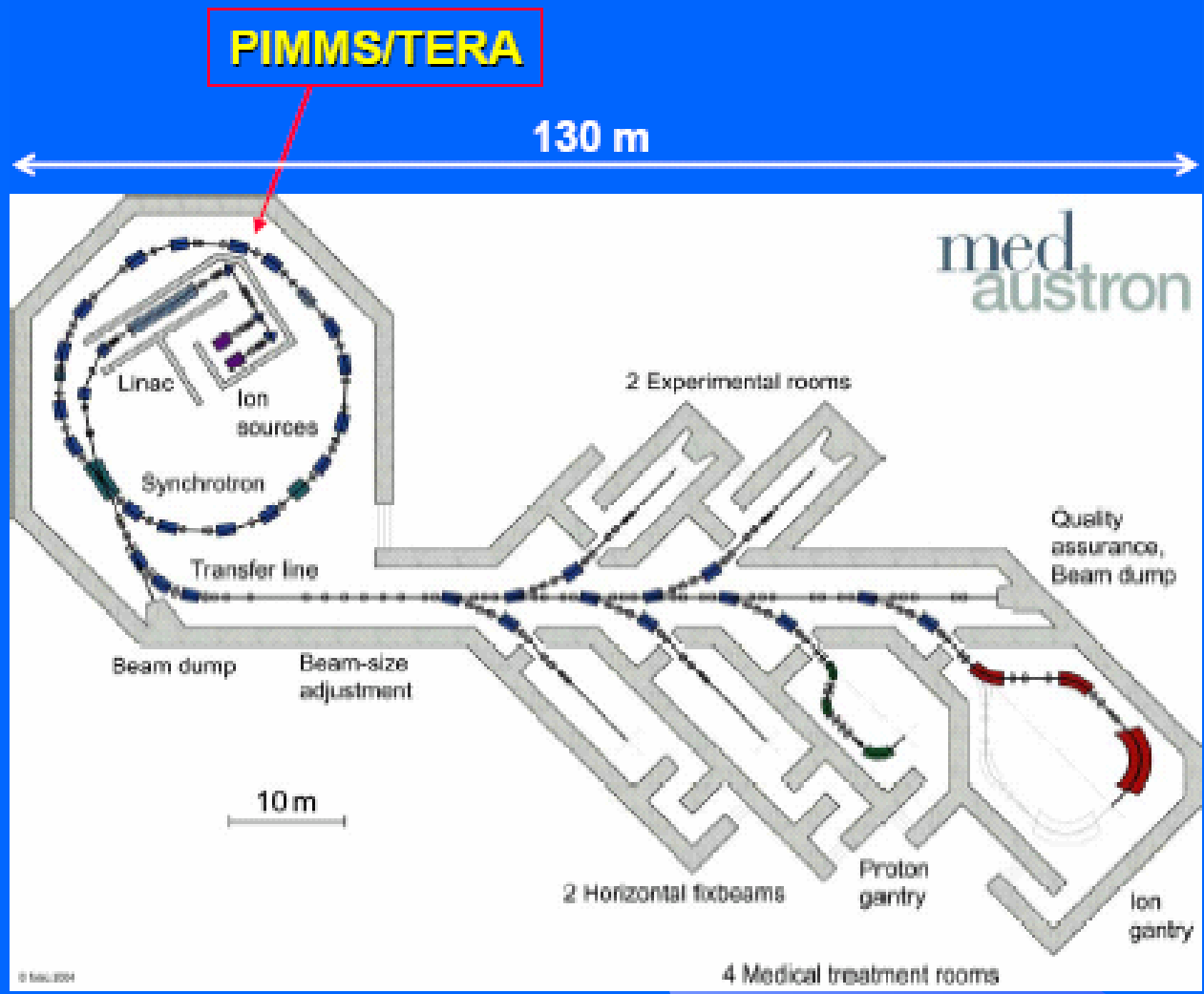


Other European projects: MedAustron in Wiener Neustadt

Approval expected: this year

Chairman: R. Pötter

Med. Dir.: T. Auberger
Tech. Dir: E. Griesmeyer



ENLIGHT and the European projects

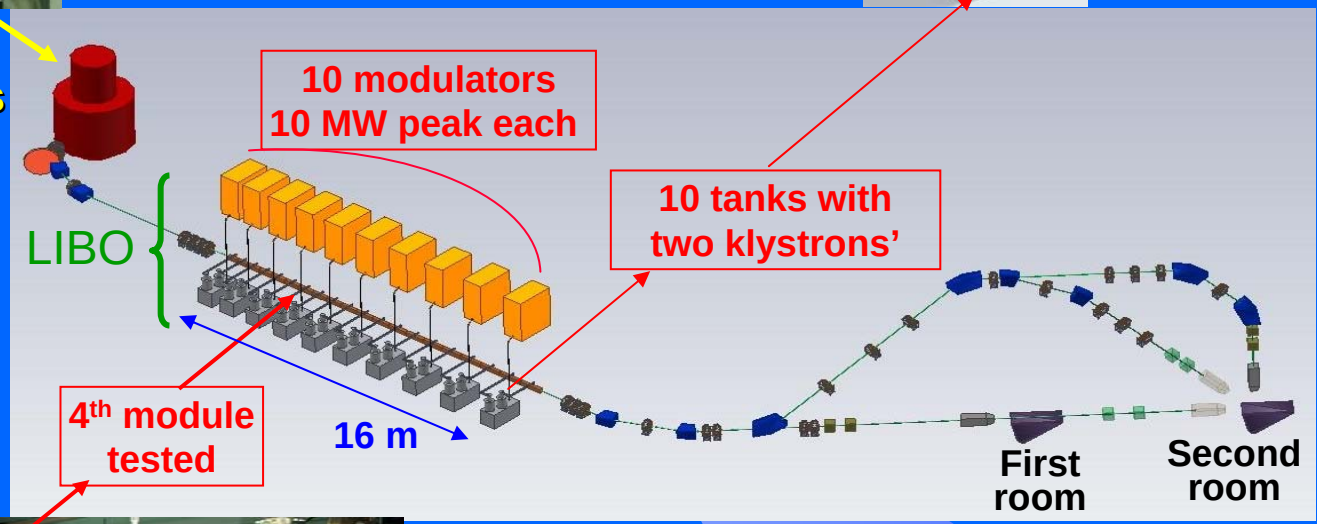
European Network for LIGHt-ion Therapy

- **GSI project for the University of Heidelberg Clinics**
- **TERA project for CNAO in Pavia**
- **Med-Austron for Wiener Neustadt**
  partner of PIMMS since 1996
- **ETOILE in Lyon**
  started in 1997 by TERA – Preliminary design by IN2P3 and CEA

  [ASCLEPIOS in Caen in 2004]
- **Baltic Centre in Stockholm**
  Preliminary design by TERA: NIM B184 (2001) 569

TERA new instrument for hadrontherapy: the cyclinac

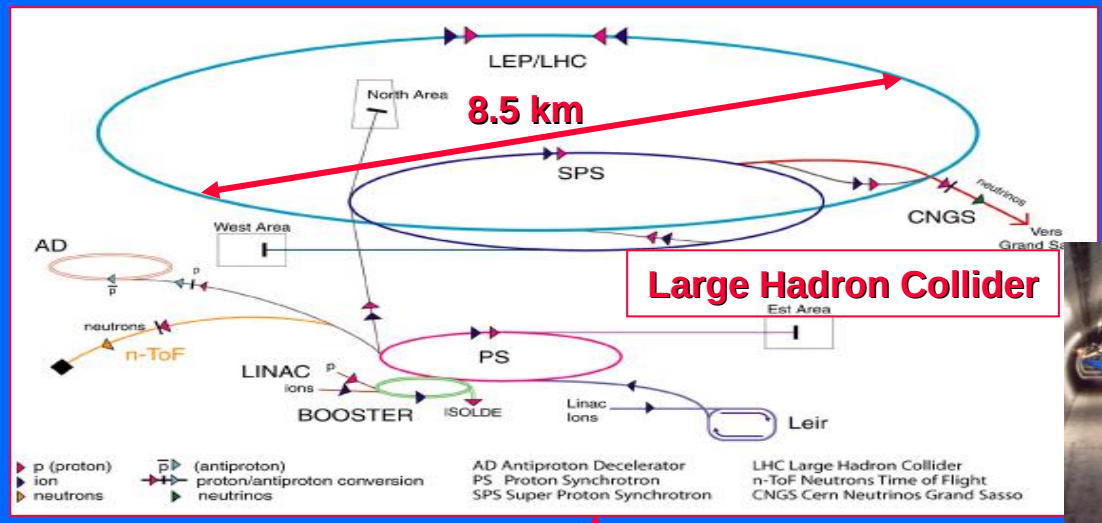
IBA Cyclone 30
produces radioisotopes
for diagnostics
and therapy



3 GHz

17 MV/m

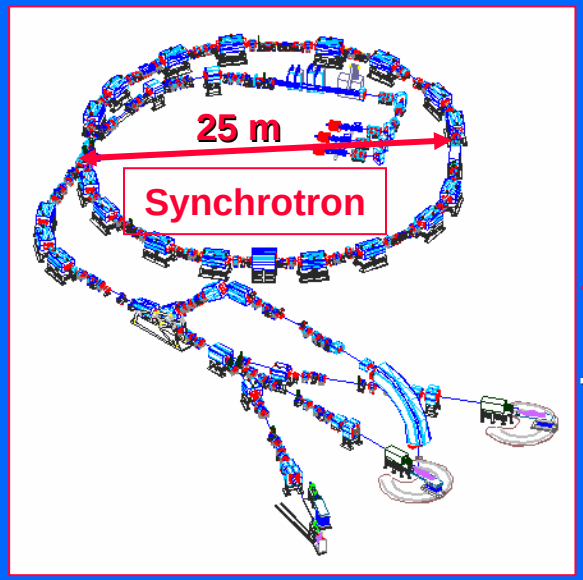
Linear accelerators have
a brilliant future!

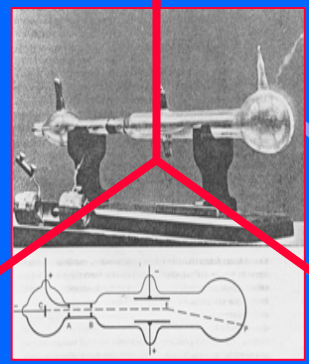


2007 – 110 years later

Research in fundamental physics

2007

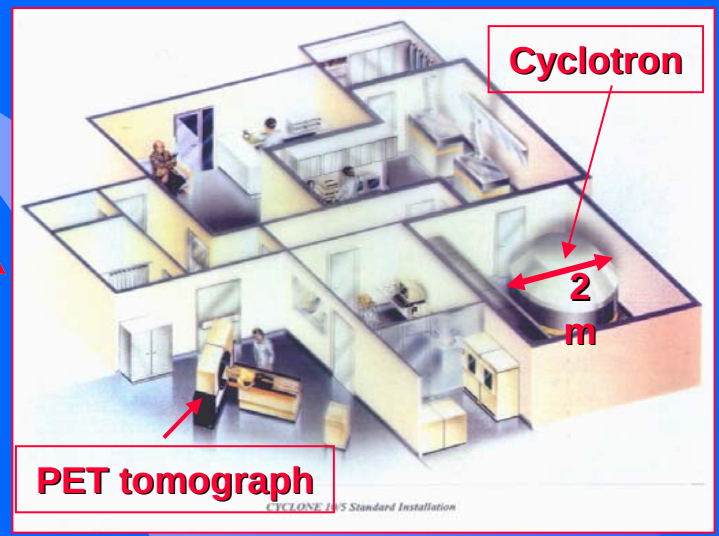




1897

Therapy

Diagnostics



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http://www.tera.it/ise.cgi?lang=2

Ugo Amaldi studied physics at Rome University where he finished his post-graduate studies in 1960. At the Rome "Istituto di Sanità" he worked in radiation physics and introduced two new experimental methods: Electron Momentum Spectroscopy (in atomic physics) and (e,e'p) reactions (in nuclear physics). In 1973 Amaldi moved to CERN. Since then his research activities are woven around the physics of elementary particles At the ISR he co-discovered the proton-proton rising cross-section. In 1975 he founded with K. Winter the CHARM Collaboration, which performed many fundamental experiments on neutrino scattering. Since 1980 to 1993 he served as spokesman for the DELPHI Collaboration at the electron-positron storage ring LEP. In 1991, using the first LEP data he gave a widely recognized contribution to the understanding of the unification of the electroweak and strong forces. The hadron cancer therapy project of the TERA Foundation at Novara, founded in 1992, is Amaldi's most recent initiative At present he is Professor of Medical Physics at the University of Milano Bicocca. About one quarter of all the Italian high-school pupils study physics on his text books.

Abstract:
The discovery of quarks as components of all the strongly interacting particles (the hadrons) and the construction of the Standard Model would not have been possible without the development of particle accelerators. These accelerators, invented and improved with the aim of understanding the inner working of the subatomic world, have since their beginnings - i.e. since the discovery of X rays - also been used to cure cancer. About half of the accelerators running in the world are installed in hospitals to treat, for every 10 million people, about 20'000 patients per year. The story of how X-ray tubes, cyclotrons, synchrotrons and linear accelerators have become essential instruments in cancer care proves that also apparently exotic technologies invented for basic research have practical applications. The last frontier – on which Europe is particularly active - is the use of beams of protons and carbon ions. This kind of radiotherapy was proposed in 1946 by Bob Wilson who later became the founder and first director of Fermilab. Not by chance this approach is called "hadrontherapy".

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Highlighting Science, Technology & Innovation in Europe

ECFA

Japan patients with tumours that resist to treatments with both X-rays and proton beams are irradiated with Carbon ions in two centres in the Provinces of Chiba and Hyogo. In Europe two centres for Carbon ion therapy are under construction: HICAT in Heidelberg (Germany) and CNAO in Pavia (Italy). They have been designed by GSI (Darmstadt) and TERA Foundation (Novara) respectively. The two centres feature the same "injector", that pre-accelerates the Carbon ions. On July 15, 2004, an agreement has been signed between GSI and the CNAO Foundation - (responsible for the realisation of the Italian centre) - following which GSI will realise for CNAO an injector identical to the one under construction for Heidelberg.

Recent publications:
http://www.tera.it/ise.cgi?oid=268

TERA acknowledges the financial support of the Monzino Foundation, Milan