Medical Applications of Particle Physics

Saverio Braccini

TERA
Foundation for Oncological Hadrontherapy

Outline

- Introduction: a short historical review
- Applications in medical diagnostics
- Applications in conventional cancer radiation therapy

I

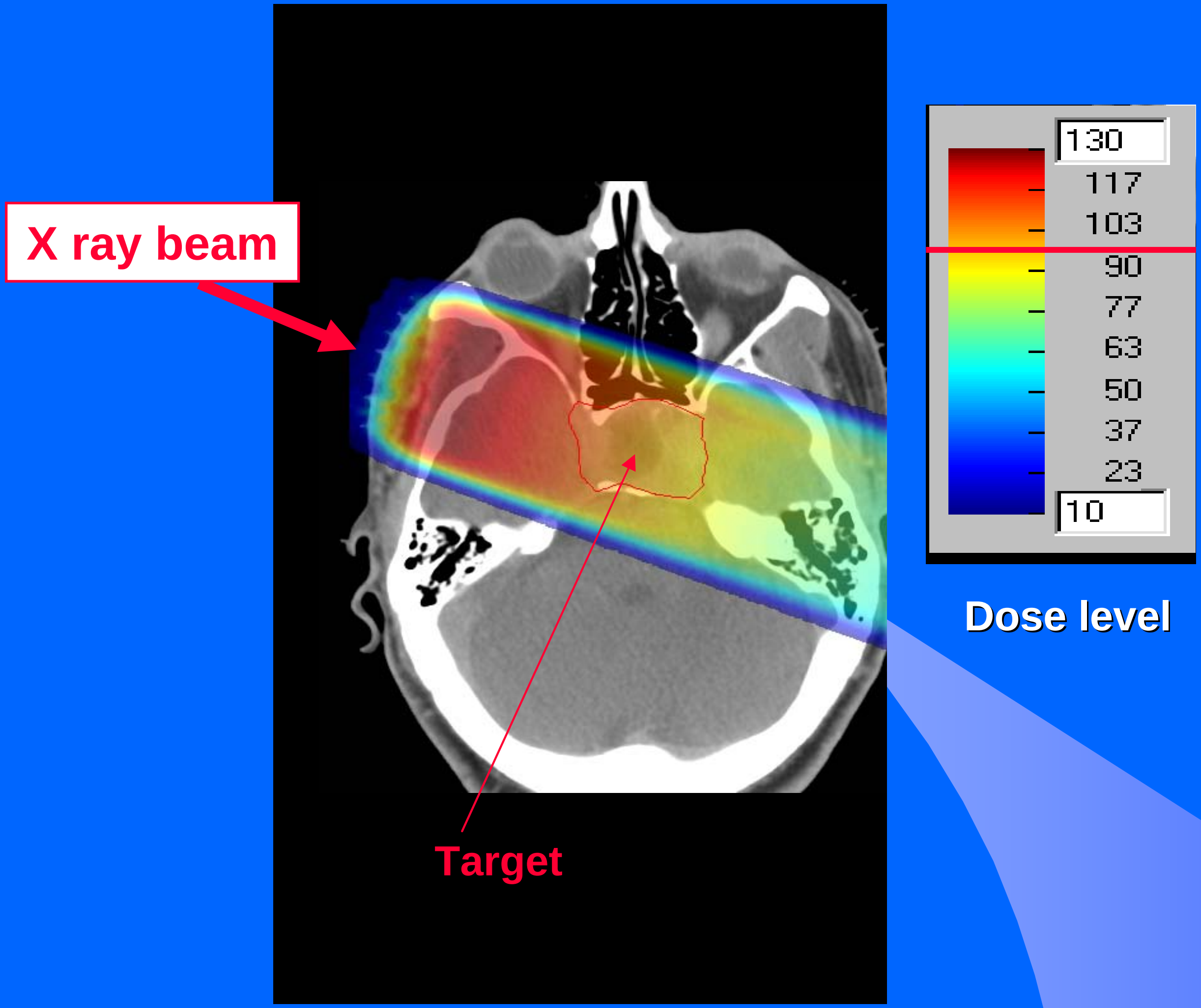
- Hadrontherapy, the new frontier of cancer radiation therapy
  - Proton-therapy
  - Carbon ion therapy
- Conclusions and outlook

II

Hadronthetapy

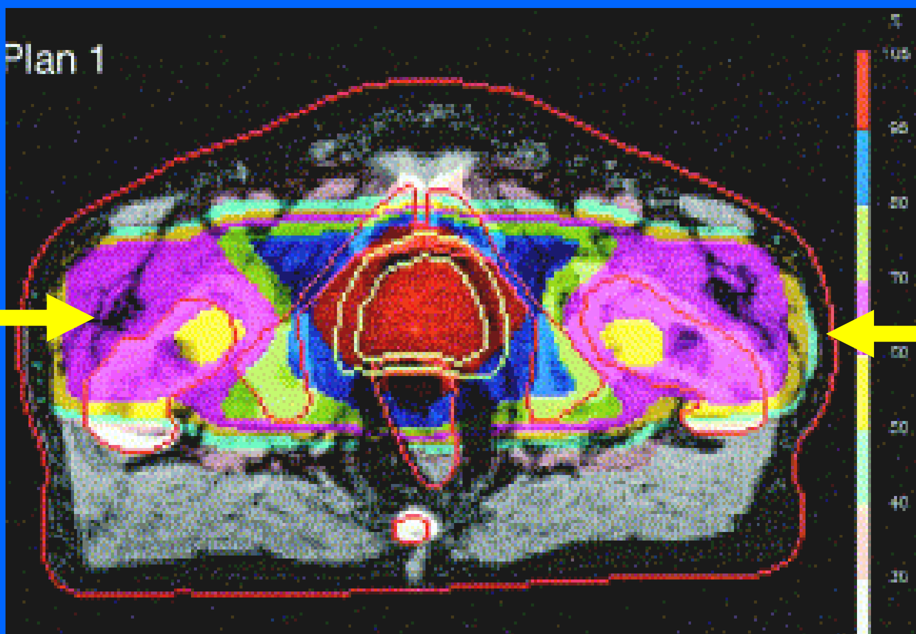
The frontier of cancer radiation therapy

The problem of X ray therapy

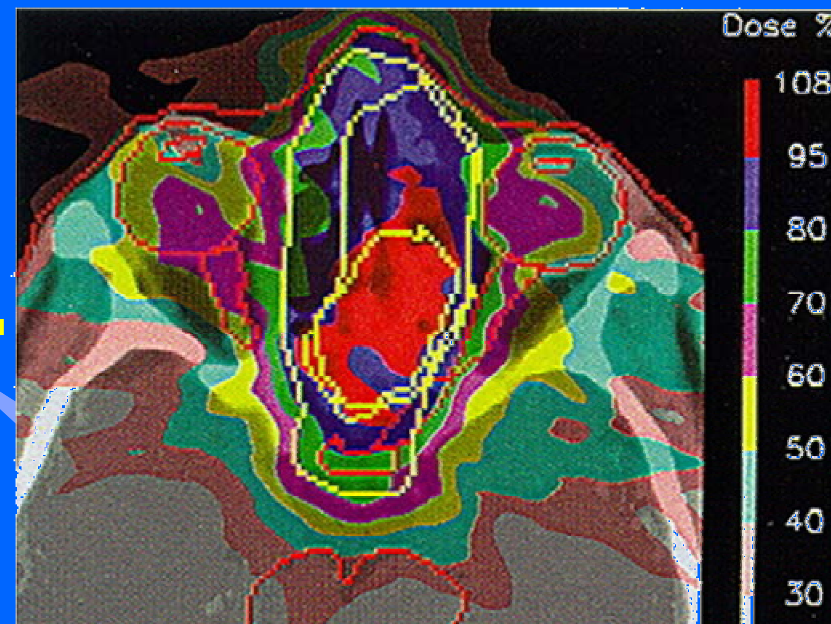


Can we do better than conventional radiotherapy ?

2 X ray beams



9 X ray beams (IMRT)



A question for a particle physicist

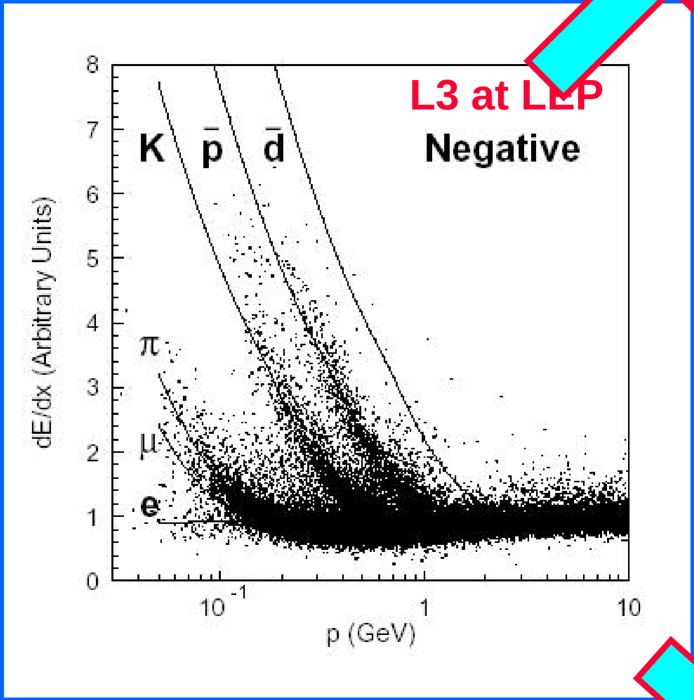
Are there better radiations to attack the tumour and spare at best the healthy tissues?

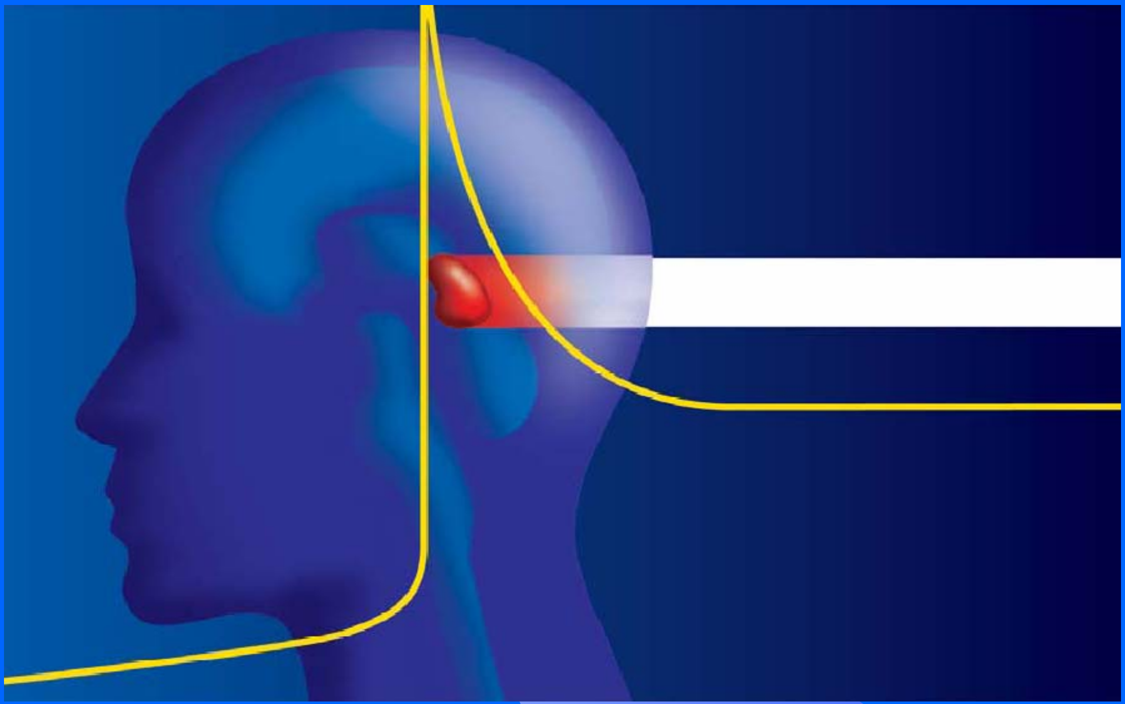
Answer : BEAMS OF CHARGED HADRONS

Let's go back to physics...

Fundamental physics

Particle identification

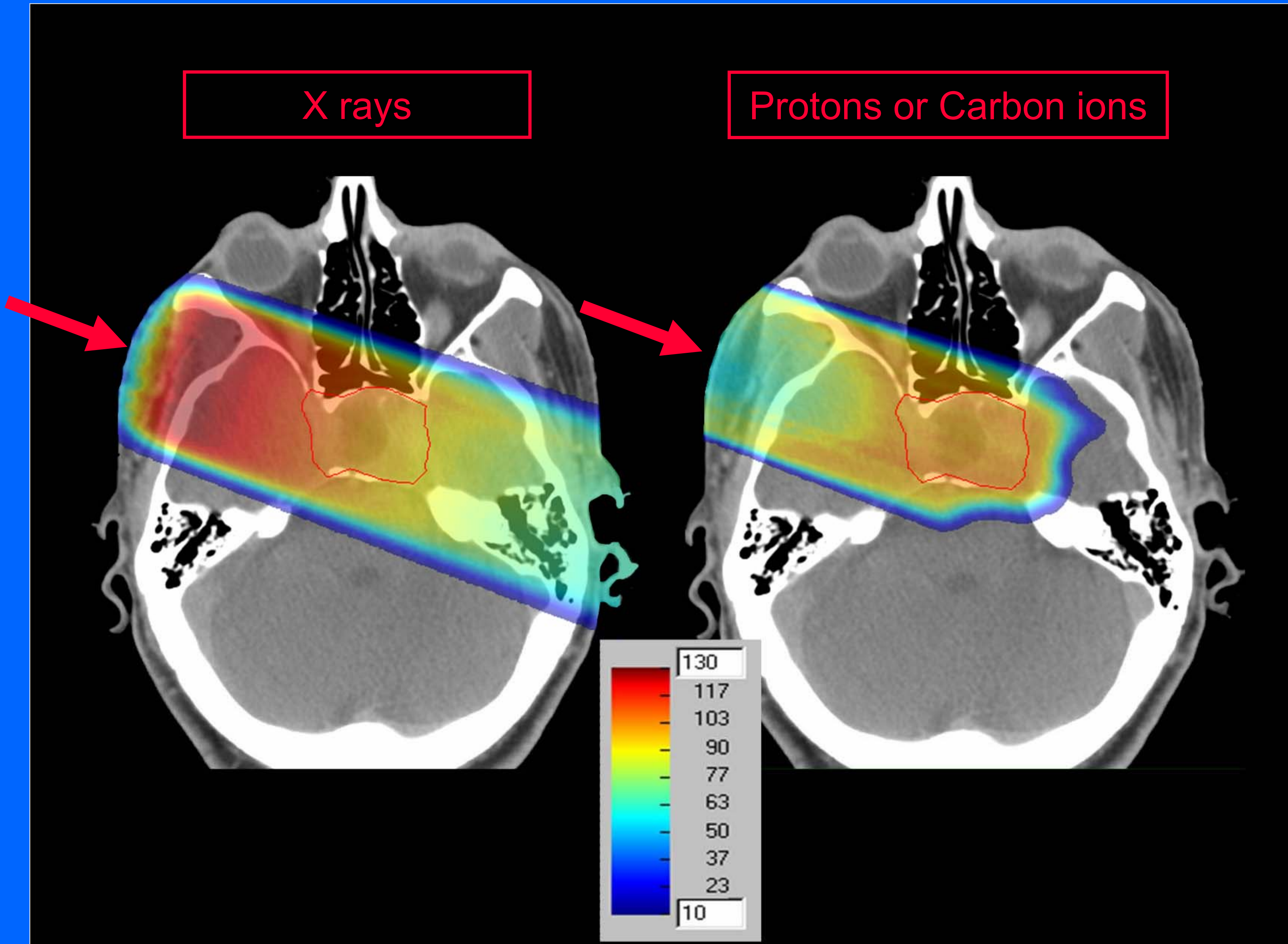




Medical applications

Cancer hadrontherapy

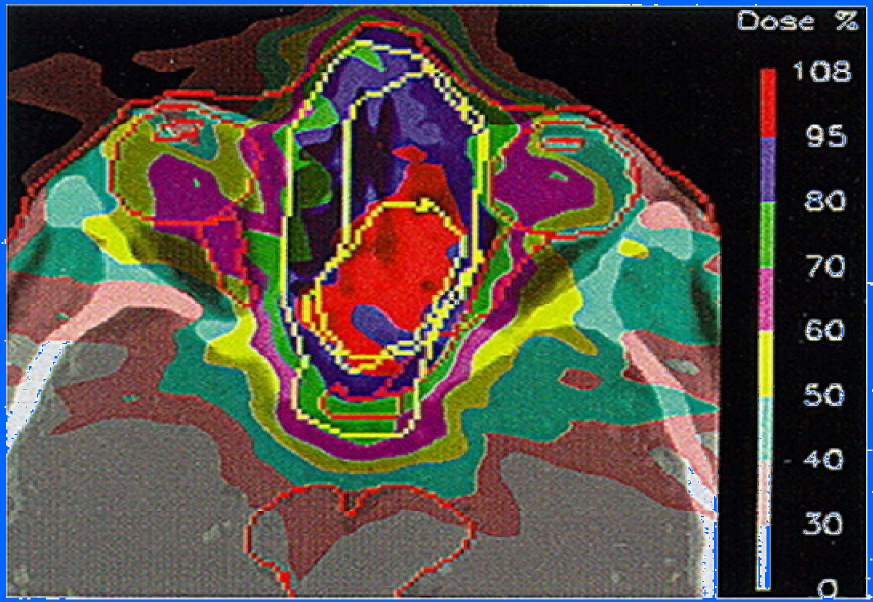
Single beam comparison



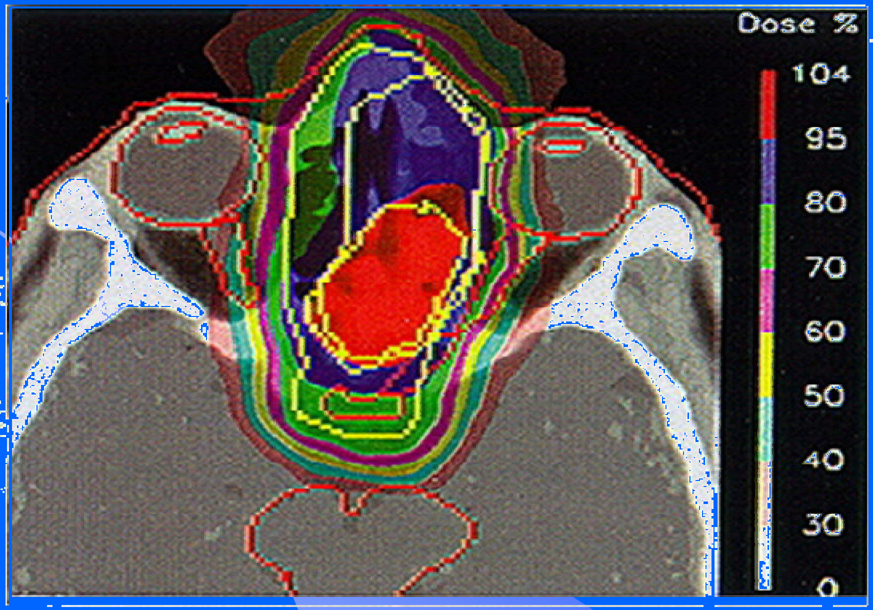
Protons and ions are more precise than X-rays

Tumour between the eyes

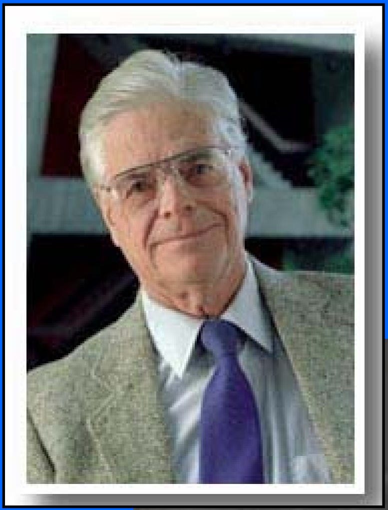
9 X ray beams



1 proton beam



The first idea – Bob Wilson, 1946



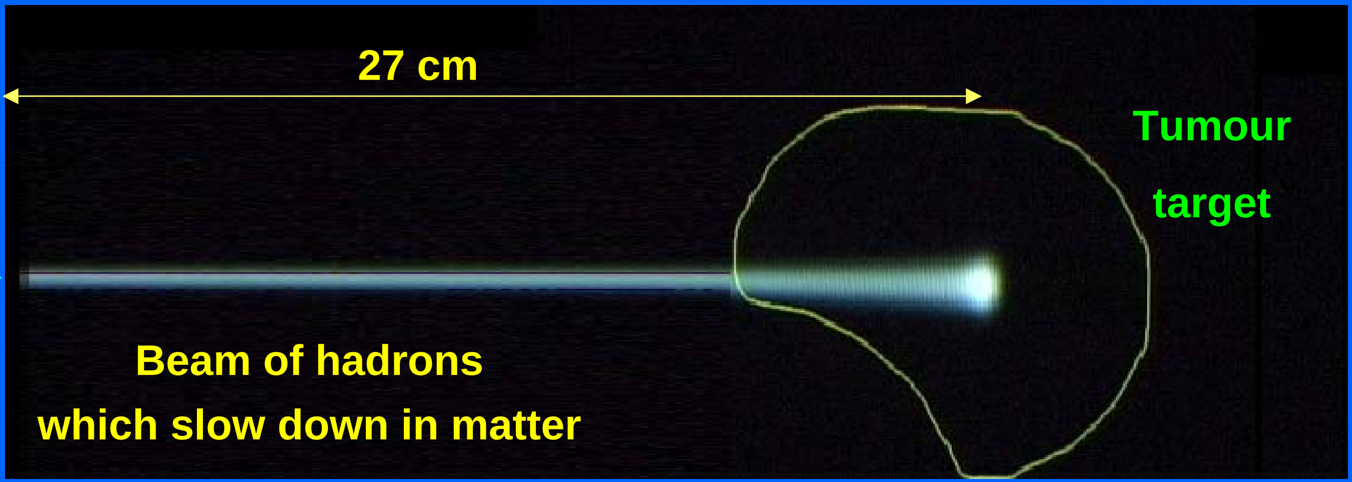
- Bob Wilson was student of Lawrence in Berkley
- Study of the shielding for the new cyclotron
- Interdisciplinary environment = new ideas!
- Use of protons and charged hadrons to better distribute the dose of radiation in cancer therapy

R.R. Wilson, Radiology, 47 (1946) 487

The basic principles of hadrontherapy

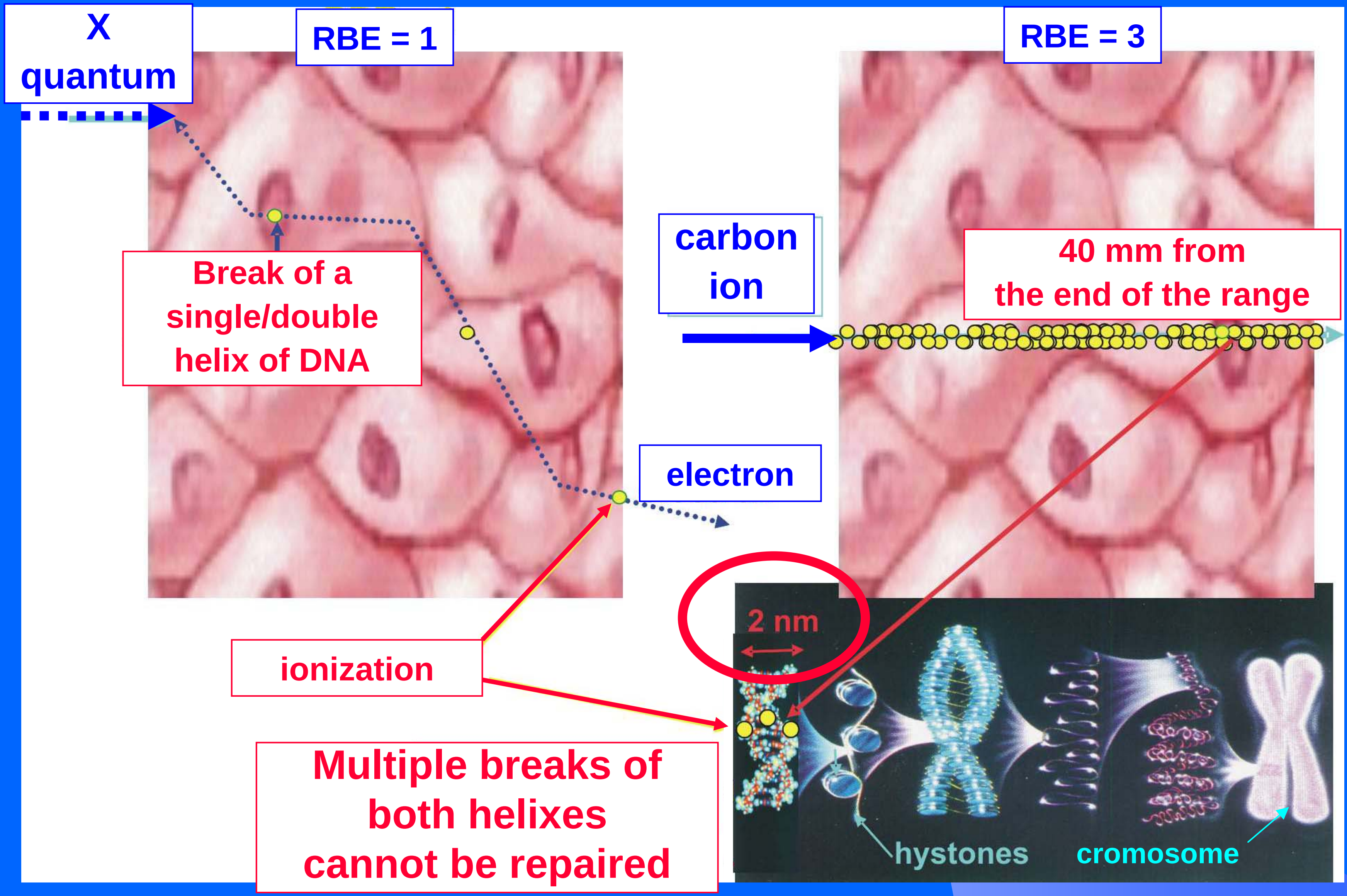
Protons
200 MeV
1 nA

Carbon ions
4800 MeV
0.1 nA



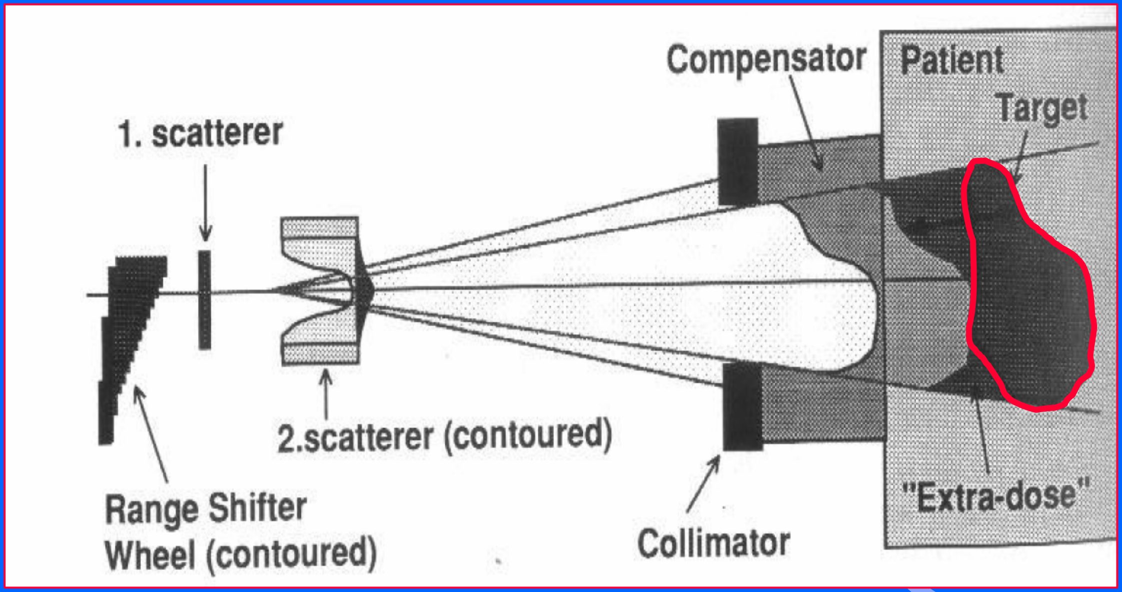
- Bragg peak
  - Better conformity of the dose to the target → healthy tissue sparing
- Hadrons are charged
  - Beam scanning for dose distribution
- Heavy ions
  - Higher biological effectiveness

Why ions have a large biological effectiveness?

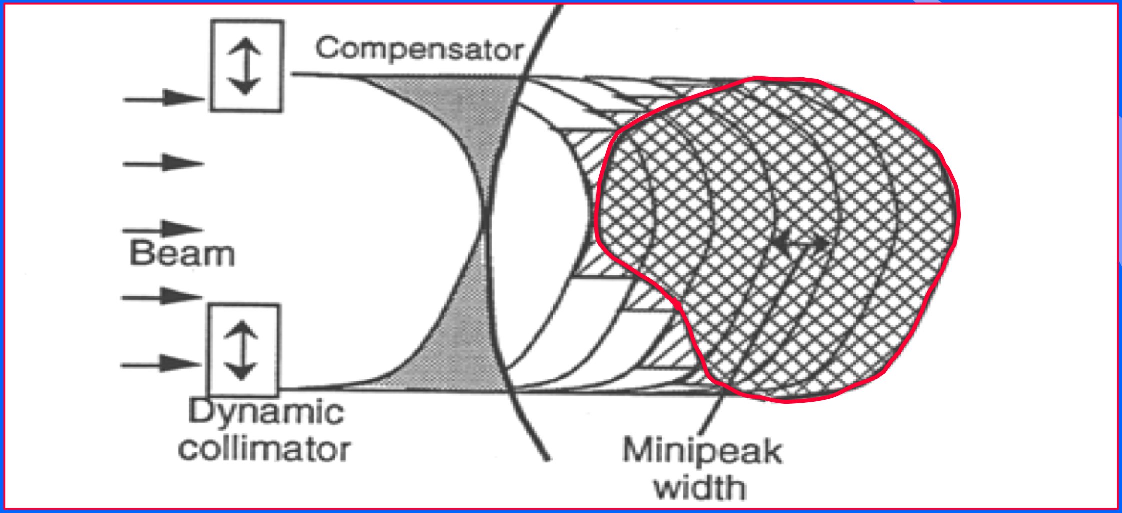


A ganrty for proton therapy

Dose distribution: passive spreading

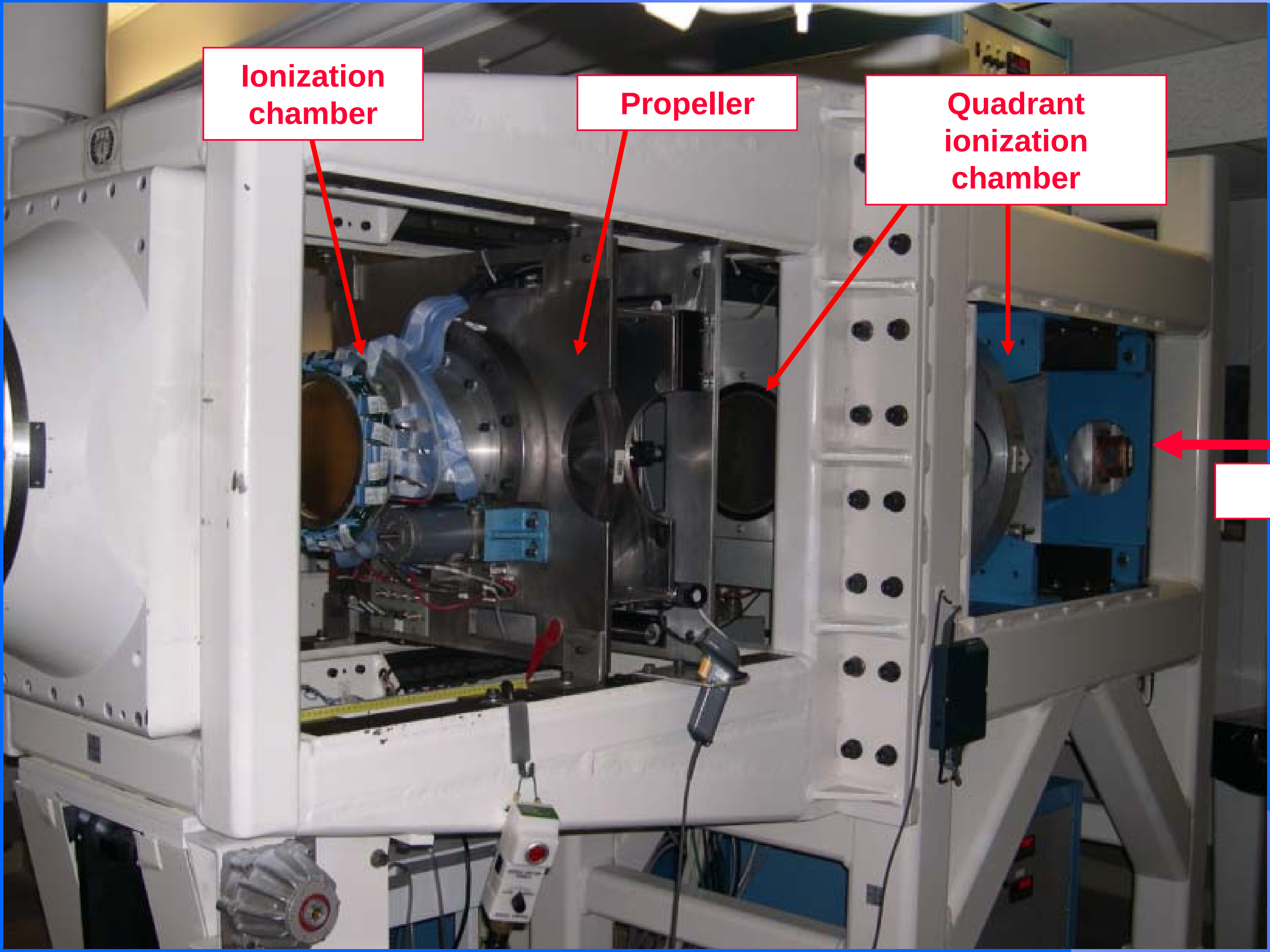


'Double scattering'

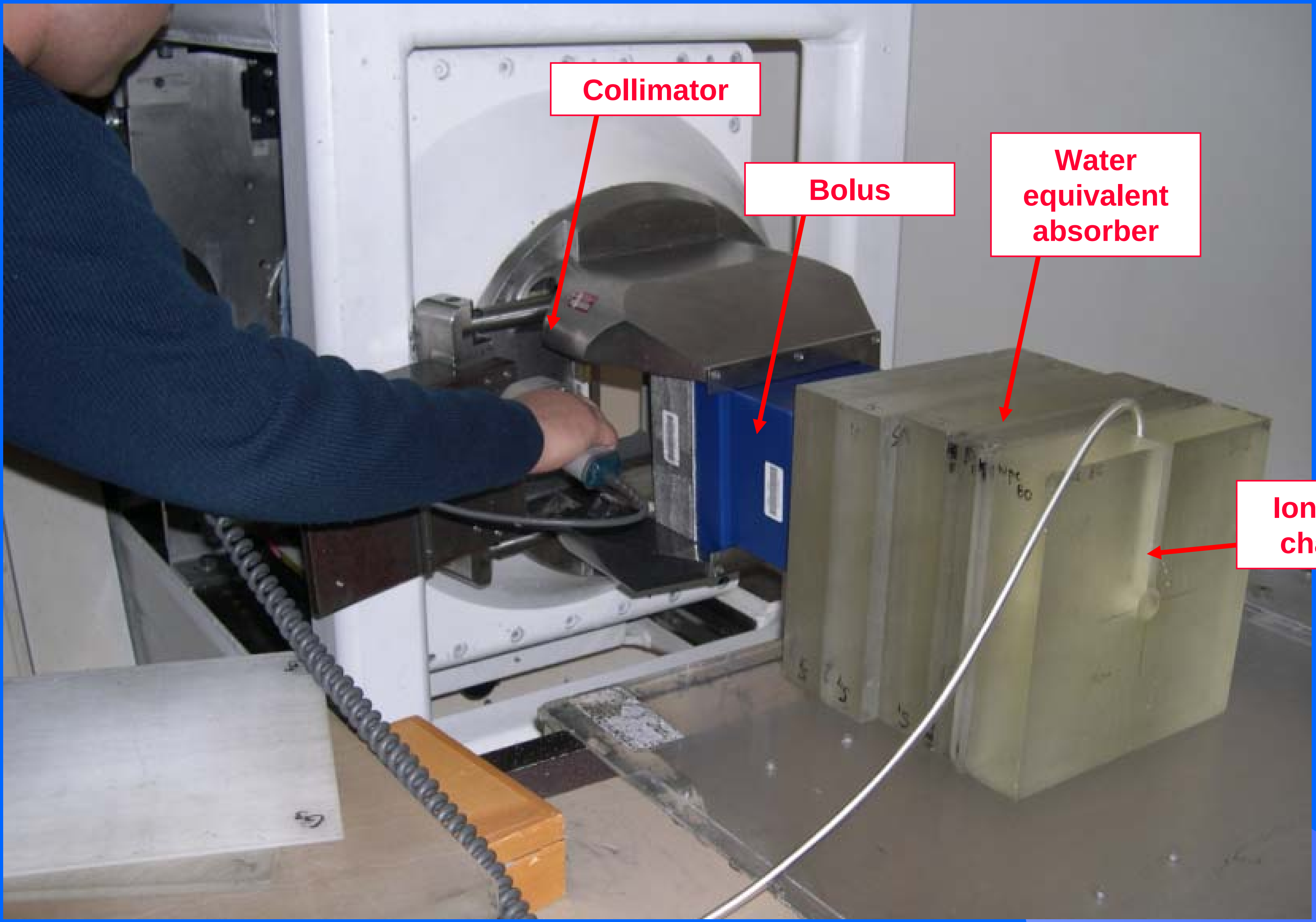


'Layer stacking'

Passive spreading: the nozzle



Passive spreading: calibration before treatment

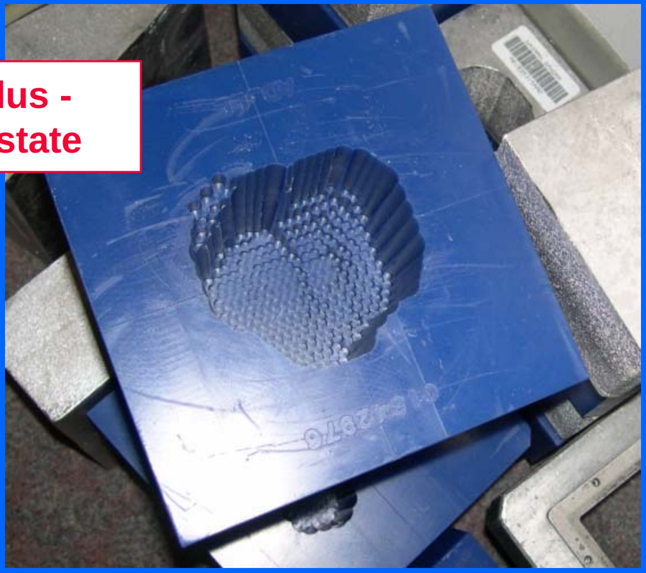


Passive spreading: personalized devices

Propeller

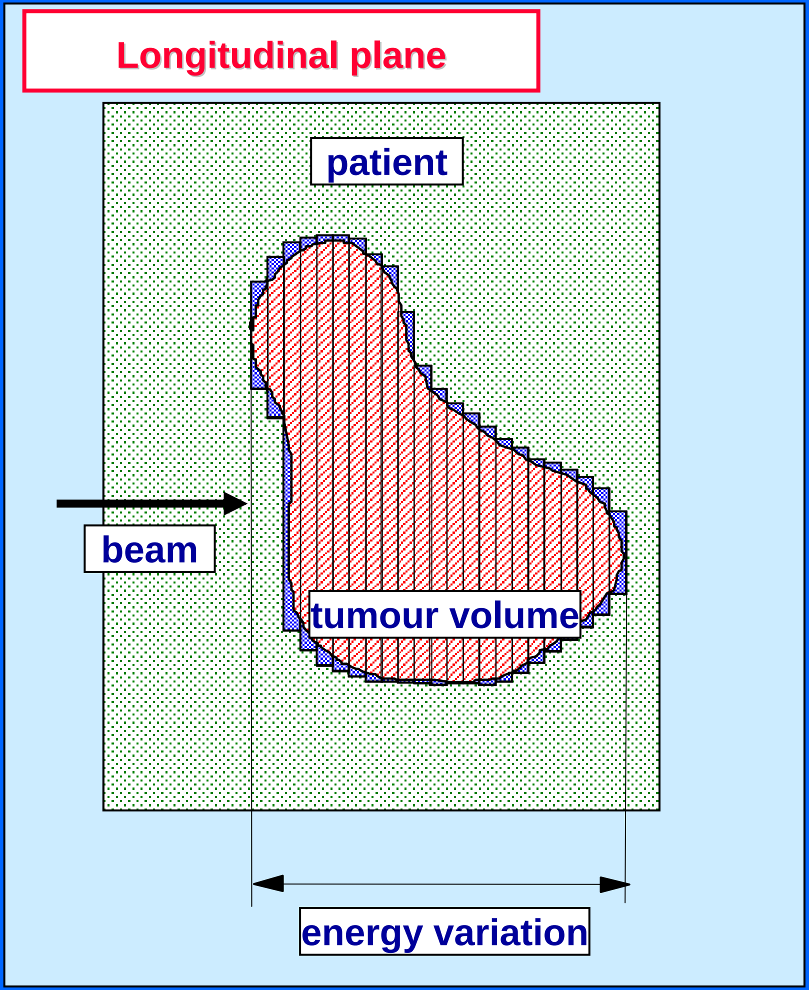
Collimator

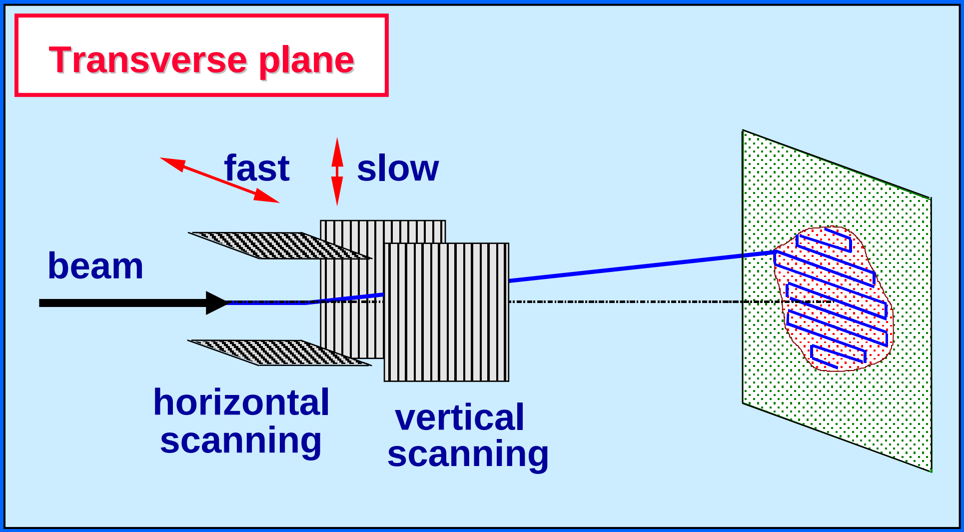
Bolus - prostate

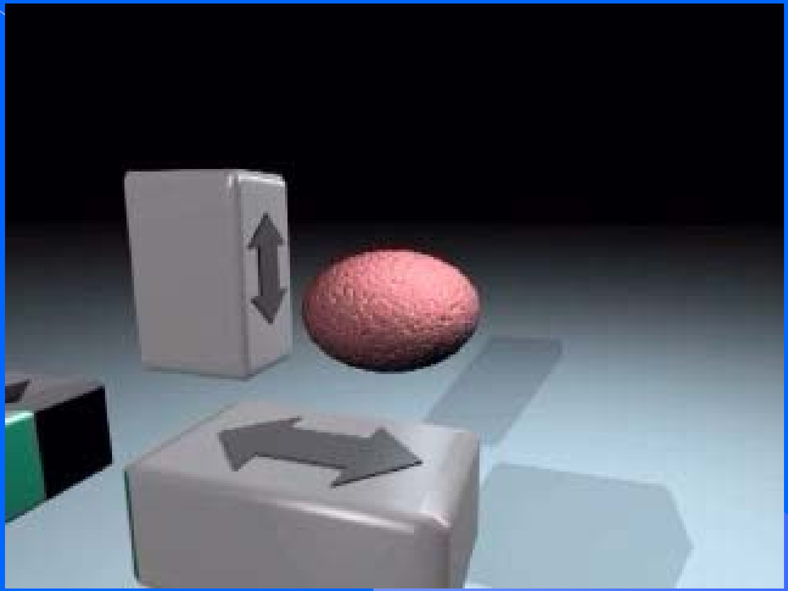


Bolus - liver

Dose distribution: active scanning

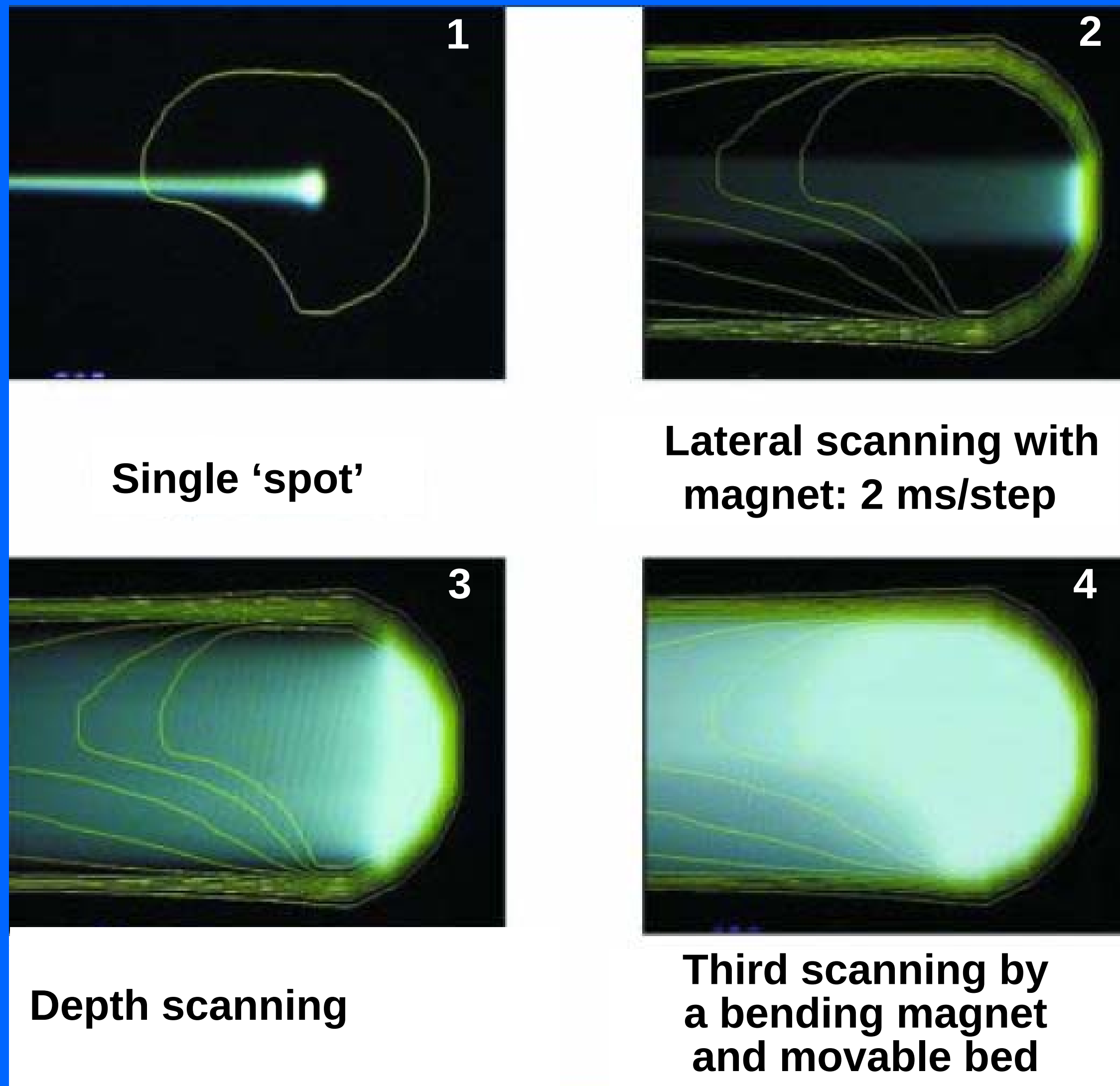




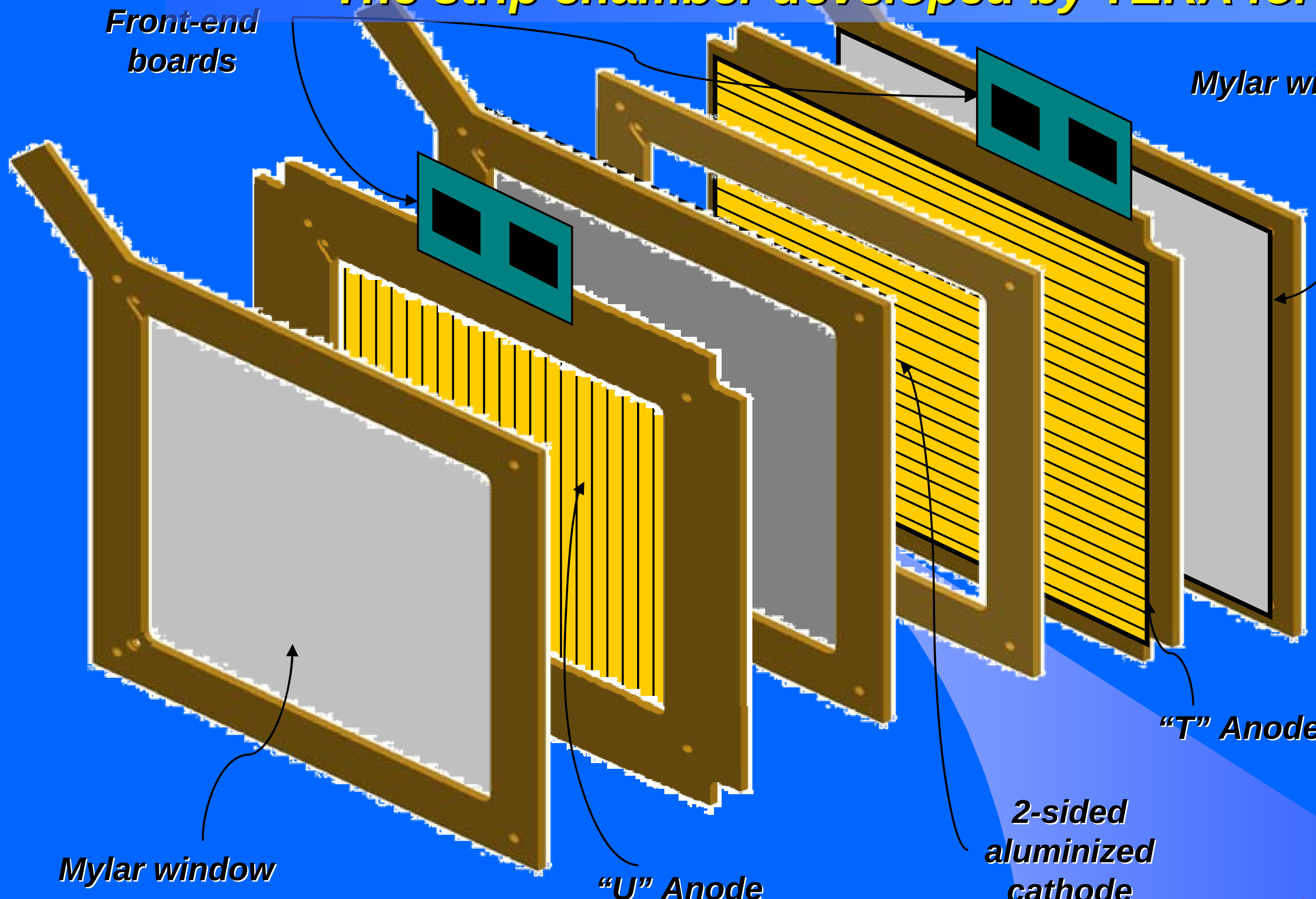


New technique developed mainly at GSI and PSI

Active "spot scanning" a la PSI



A detector for spot scanning: The strip chamber developed by TERA for PSI

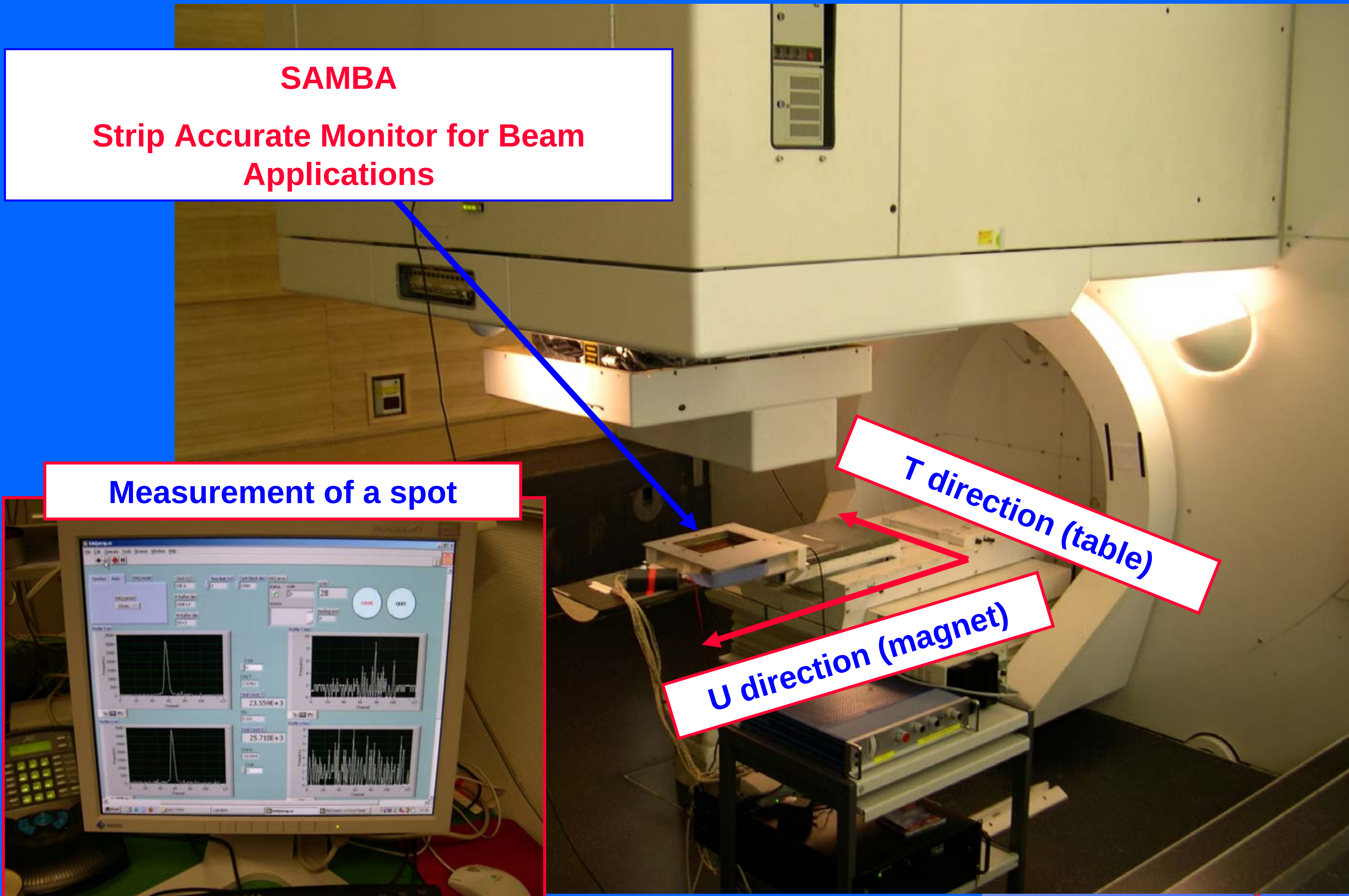


In collaboration with University and INFN Torino

Beam tests on Gantry1 at PSI

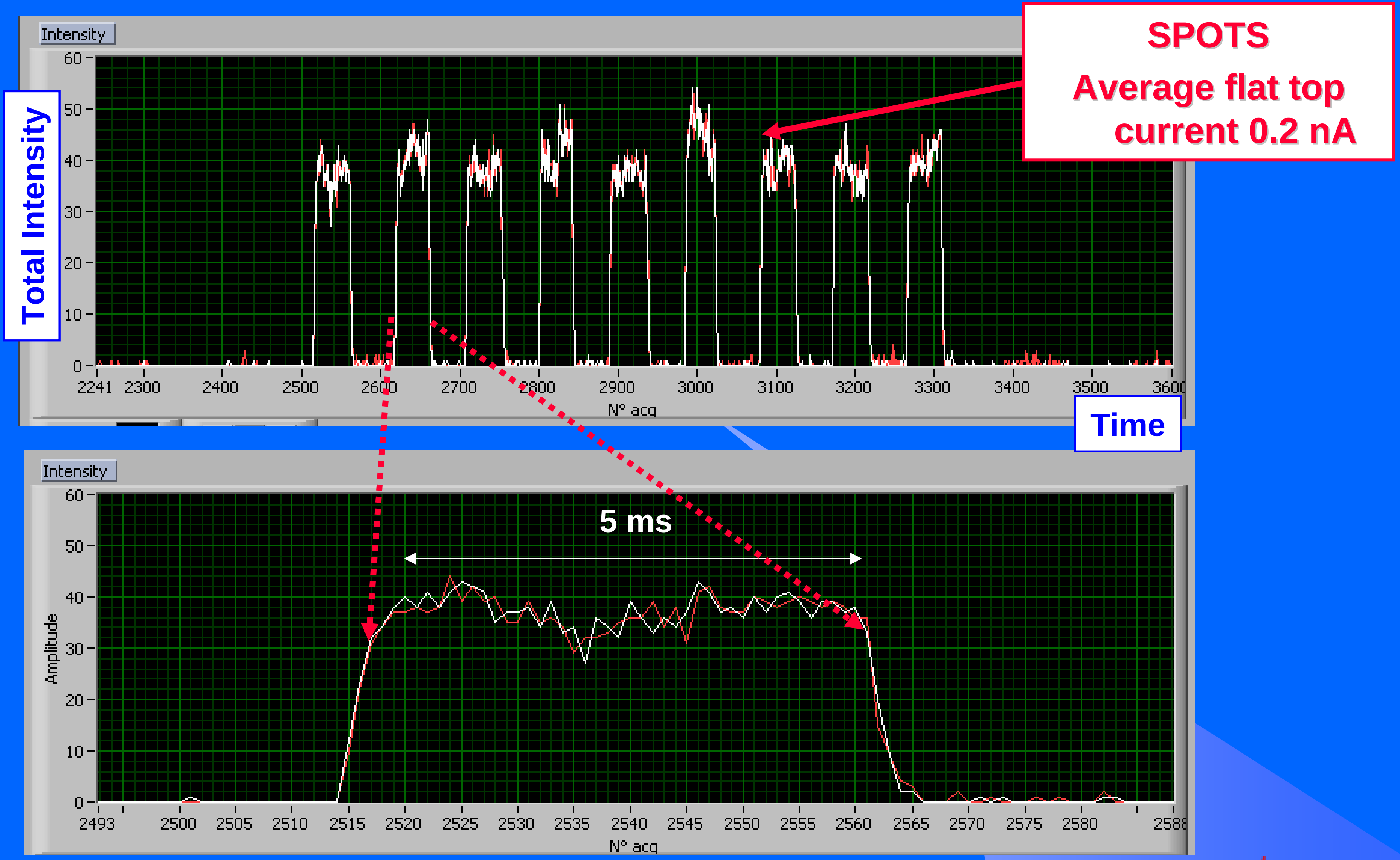
SAMBA

Strip Accurate Monitor for Beam Applications

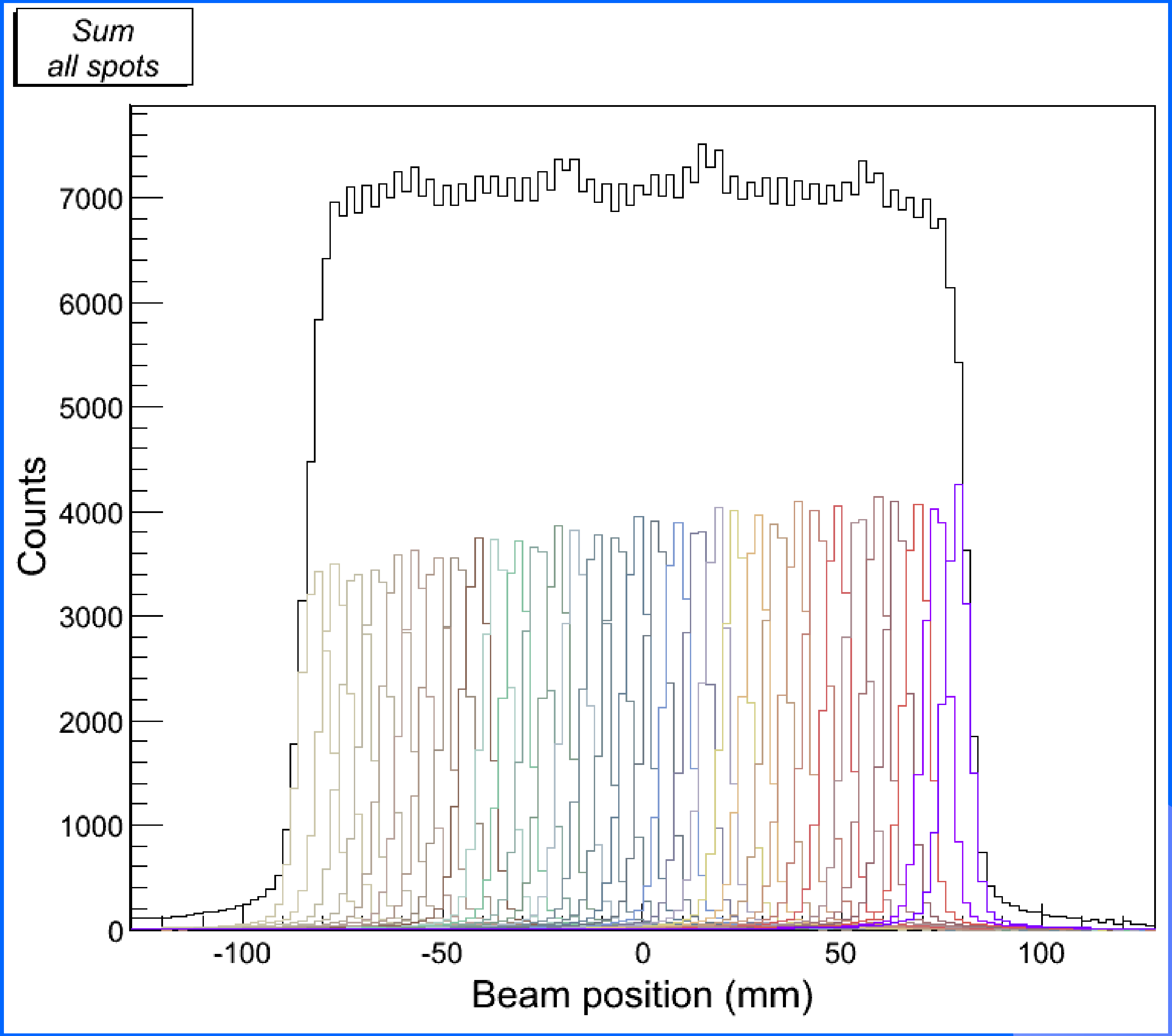


Measurement of a spot

Time profile of the clinical beams



A line of dose made of spots



Number of potential patients

Study by AIRO, 2003
Italian Association for Oncological Radiotharapy

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

<u>Protontherapy</u>

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

<u>Therapy with Carbon ions for radio-resistant tumours</u>

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

<u>Every 50 M inhabitants</u>

- Proton-therapy

4-5 centres

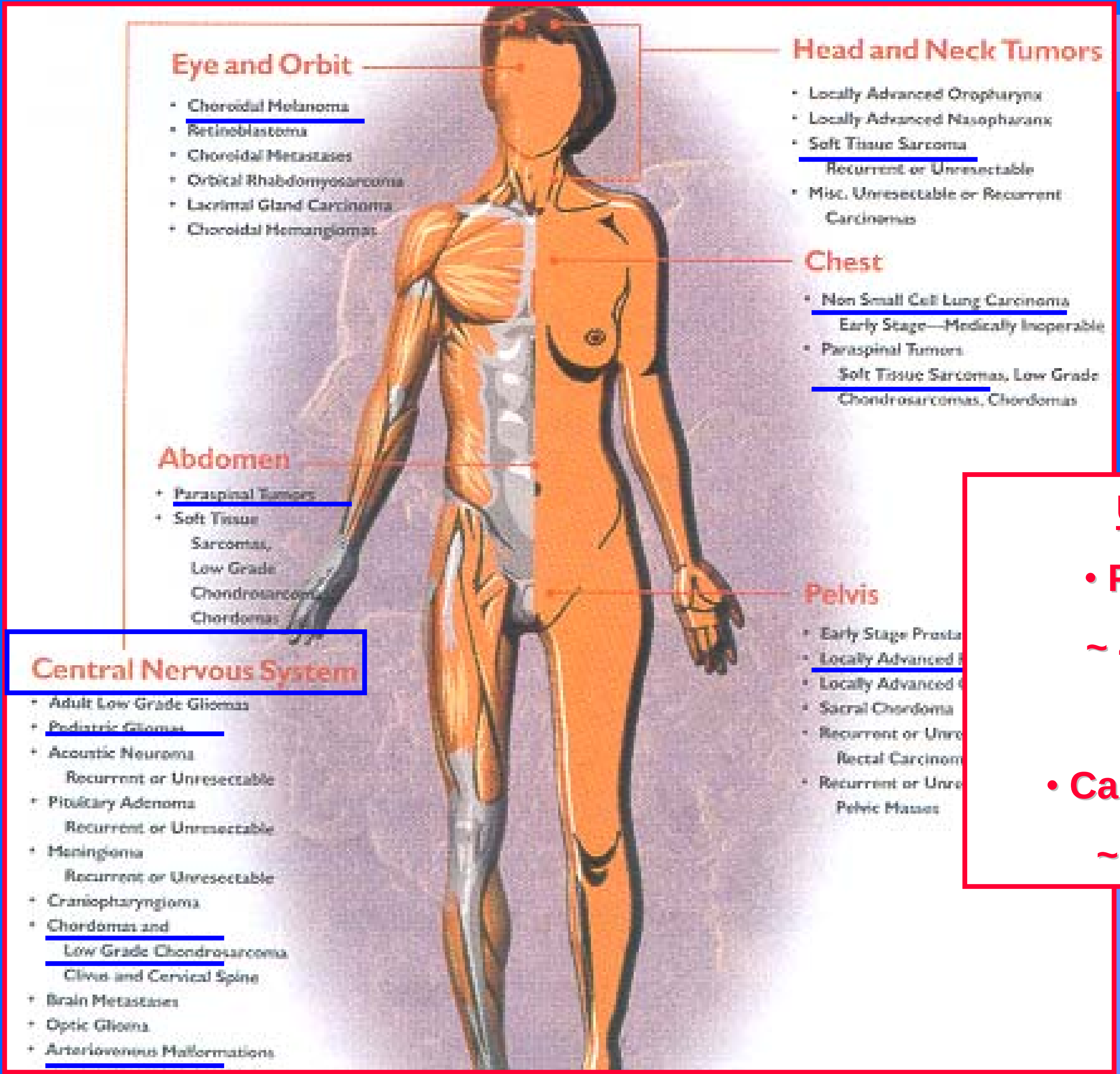
- Carbon ion therapy

1 centre

<u>TOTAL about 3'000 pts/year</u>

<u>every 10 M</u>

The sites



Up to present

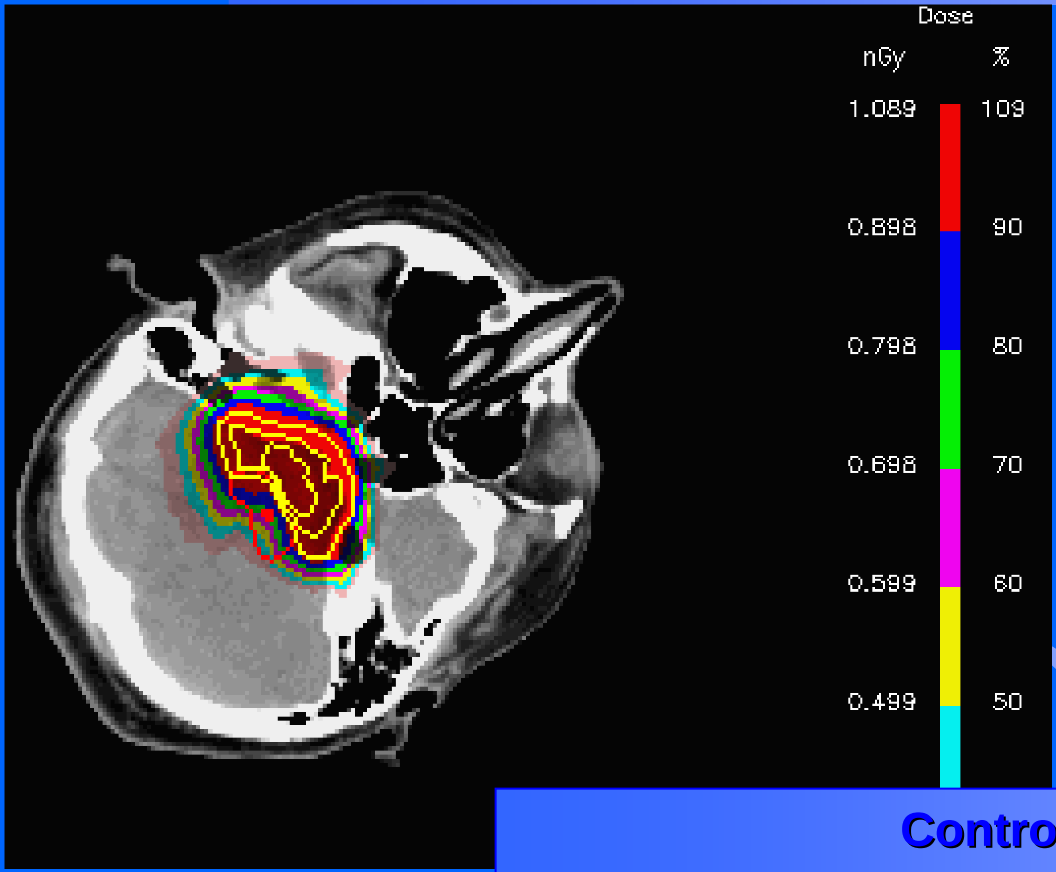
• Proton-therapy:

~ 40 000 patients

• Carbon ion therapy:

~ 2 200 patients

Tumours of the central nervous system



Control at 5 years

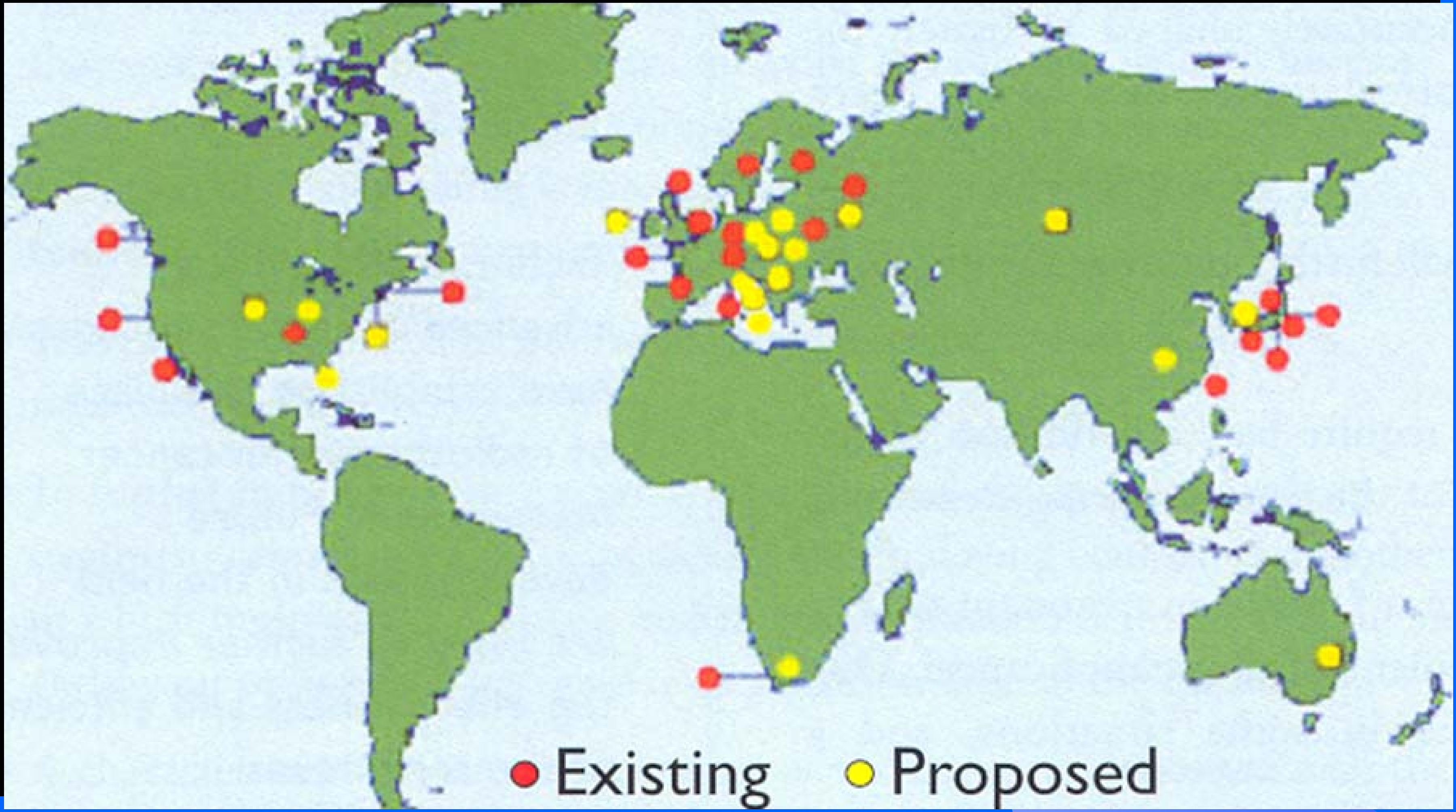
	RT	Protons
Chordomas	17-50%	73-83%
Chondrosarcomas	50-60%	90-98%

Present and "near" future of hadrontherapy

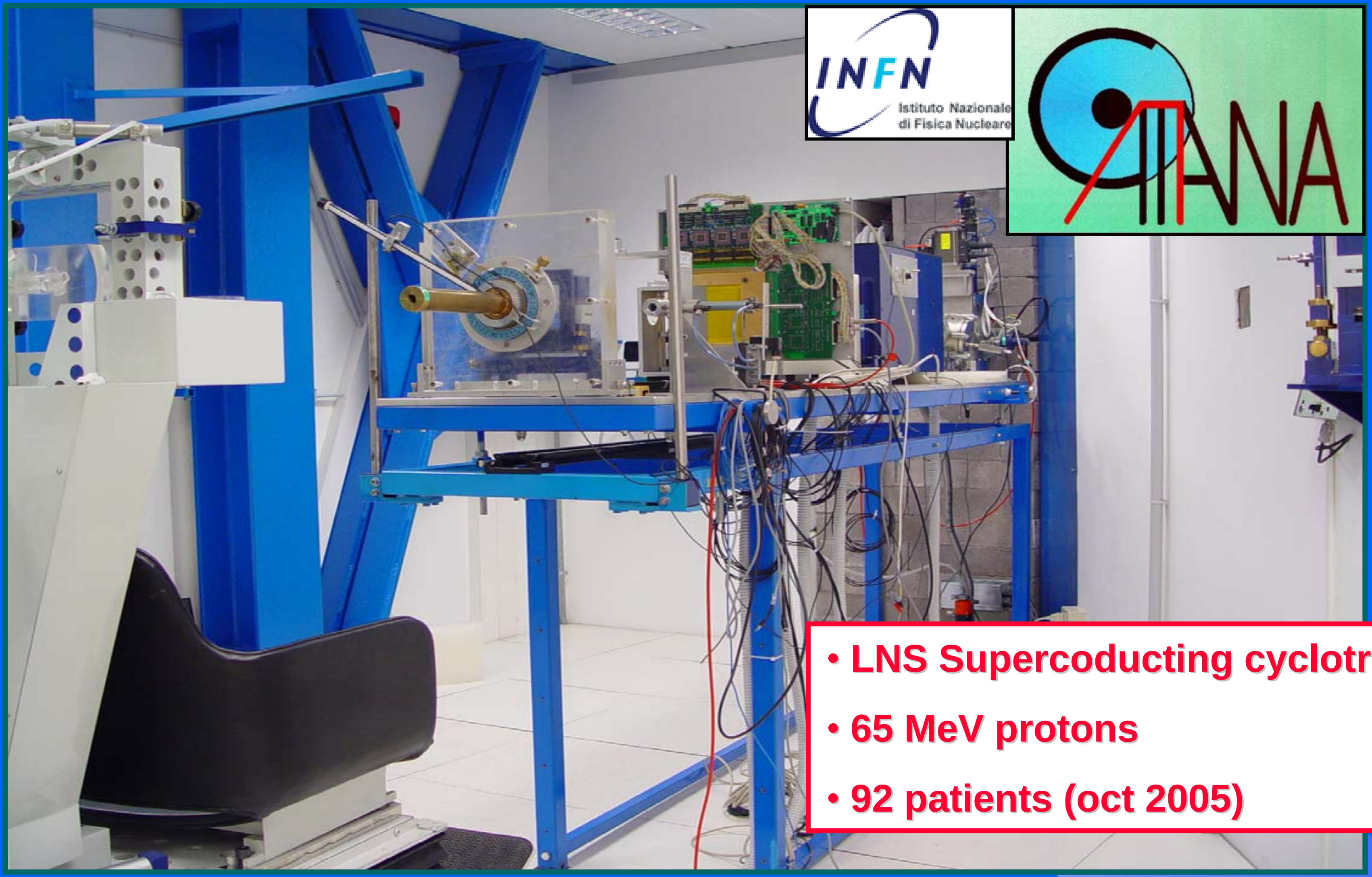
- **Proton-therapy is "booming"!** *(for information see PTCOG, ptcog.web.psi.ch)*
  - **Laboratory based centres: Orsay, PSI, INFN-Catania, …**
  - **Hospital based centres: 3 in USA, 4 in Japan and many under construction (USA, Japan, Germany, China, Korea, Italy, …)**
  - **Companies offer "turn-key" centres (cost: 50-60 M Euro)**

- **Carbon ion therapy**
  - **2 hospital based centres in Japan**
  - **Pilot project at GSI**
  - **2 hospital based centres under construction in Germany and Italy**
  - **2 projects approved (France and Austria)**
  - **European network ENLIGHT**

The map of hadrontherapy



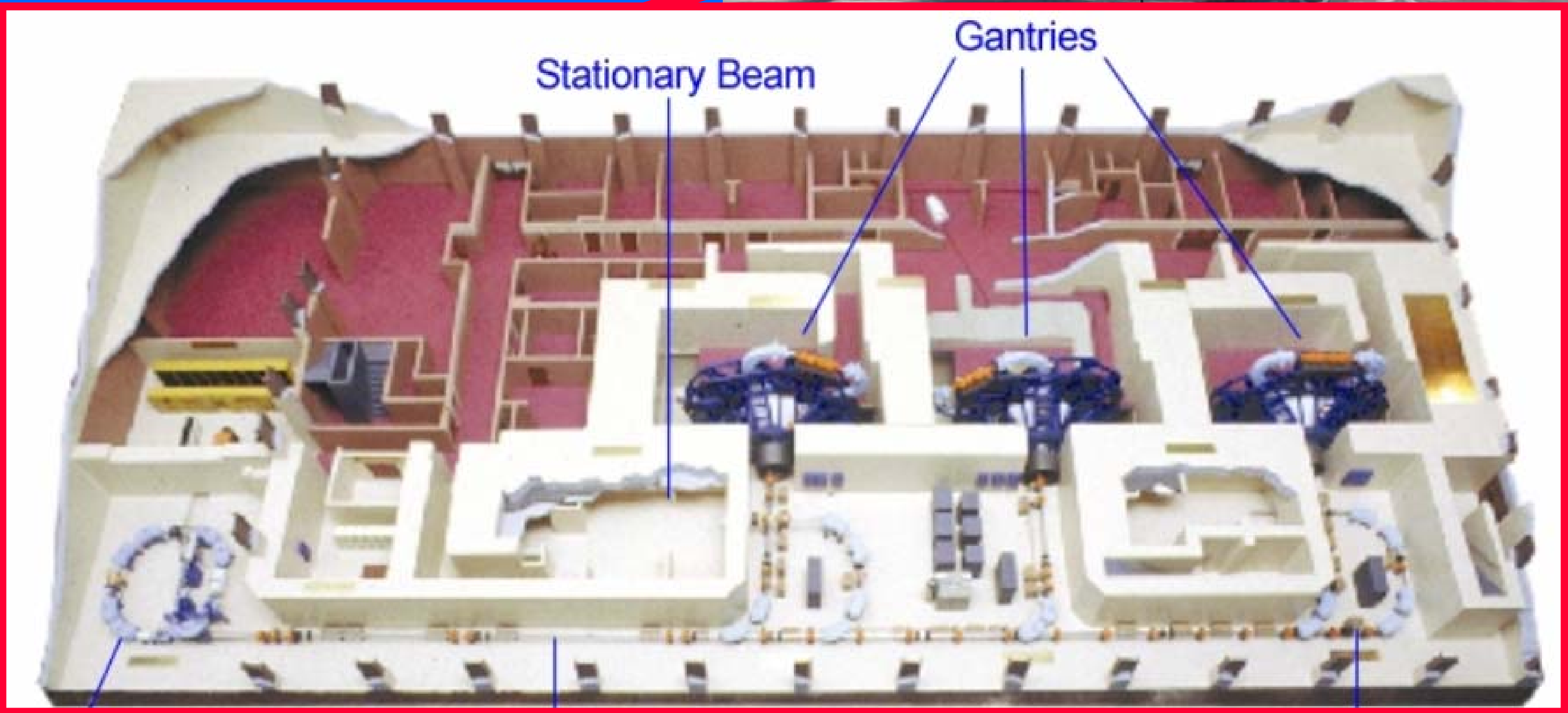
The eye melanoma treatment at INFN-LNS in Catania



- LNS Supercoducting cyclotron
- 65 MeV protons
- 92 patients (oct 2005)

The Loma Linda University Medical Center (USA)

- First hospital-based proton-therapy centre, built in 1993
- ~160/sessions a day
- ~1000 patients/year

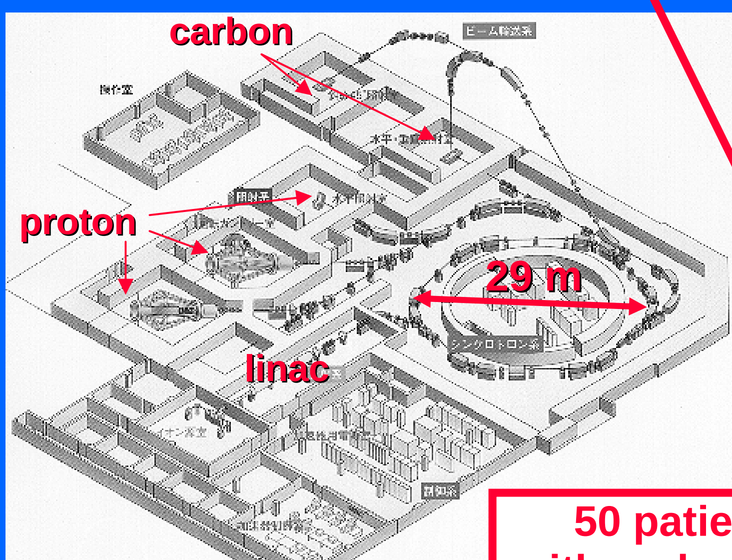


What a patient sees…

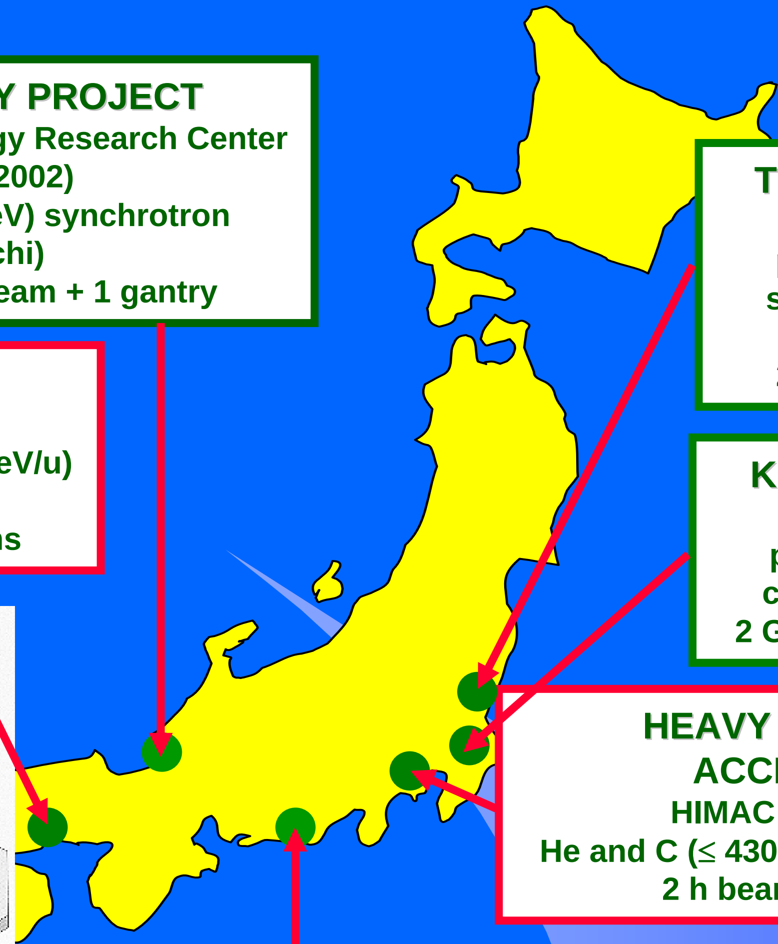
Japan: 4 proton and 2 carbon ion therapy centres

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



50 patients with carbon ions



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

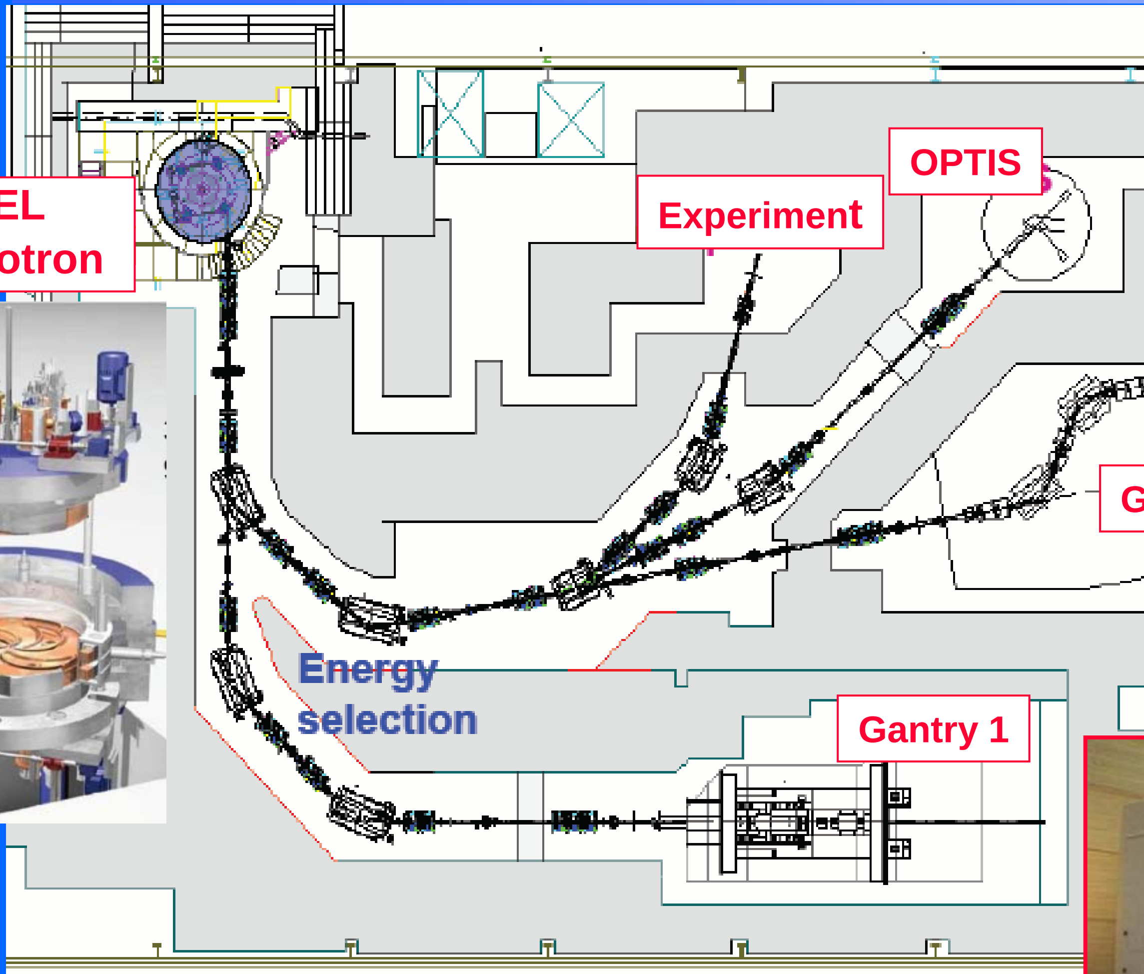
KASHIWA CENTER
Chiba (1998)
protons (≤ 235 MeV)
cyclotron (IBA – SHI)
2 Gantries + 1 hor. beam

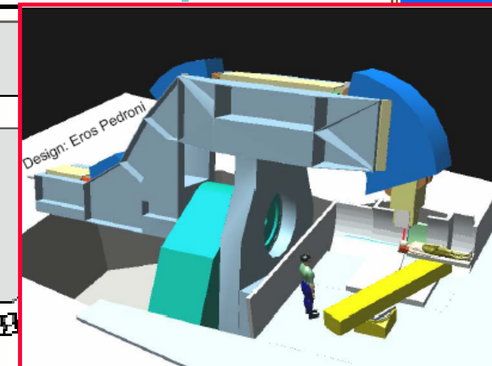
HEAVY ION MEDICAL ACCELERATOR
HIMAC of NIRS (1995)
He and C (≤ 430 MeV/u) 2 synchrotrons
2 h beams + 2 v beams

2000 patients with carbon ions

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

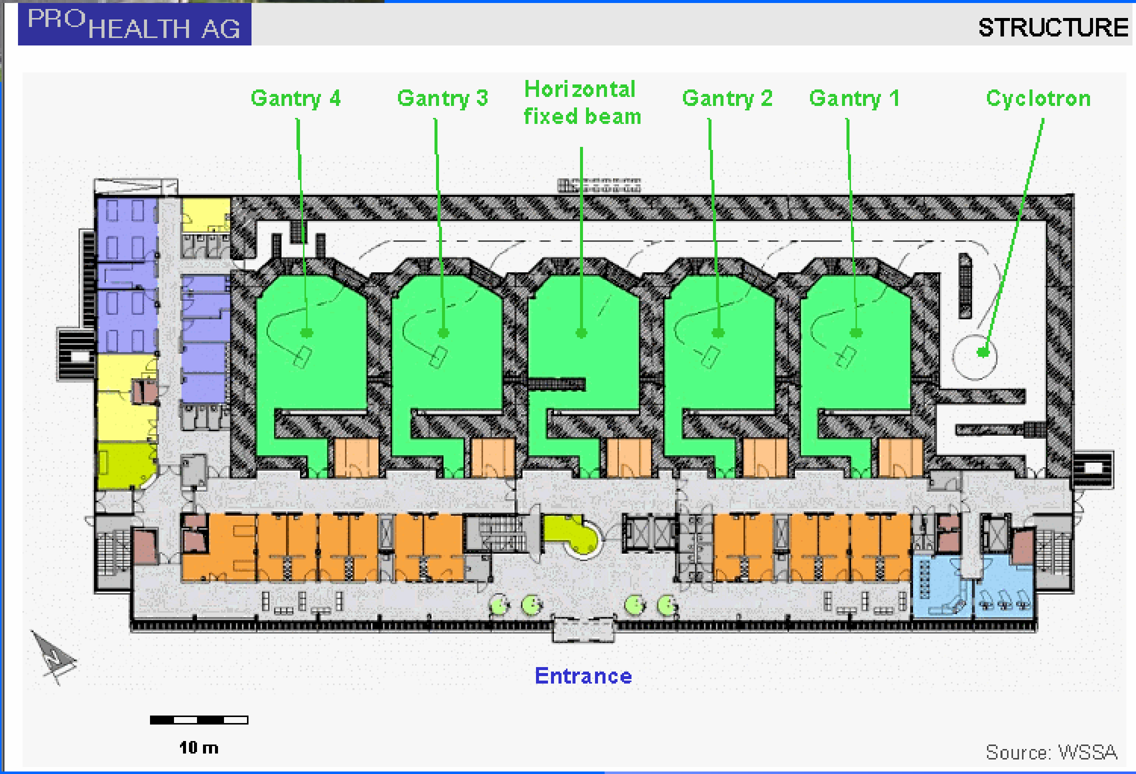
PROSCAN project at PSI





- New SC 250 MeV proton cyclotron – Installed
- New proton gantry

Rinecker - Munich



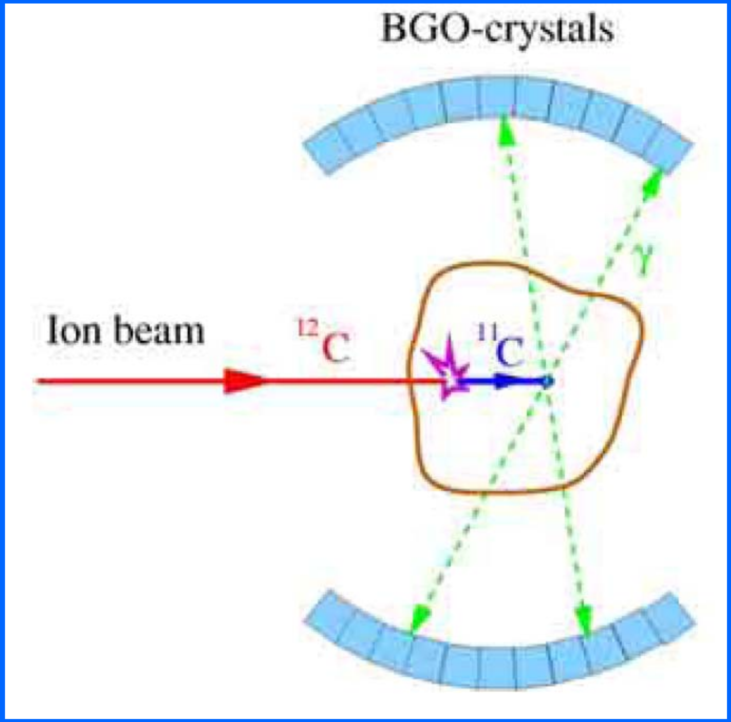
Almost ready

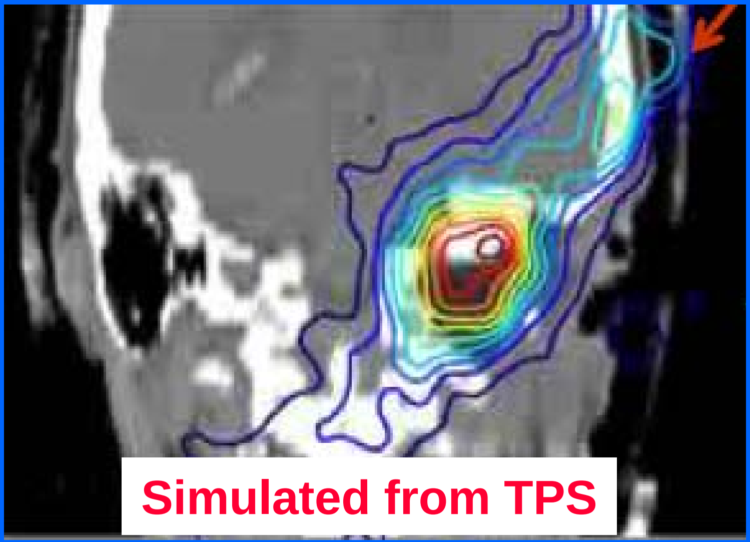
Carbon ion therapy in Europe

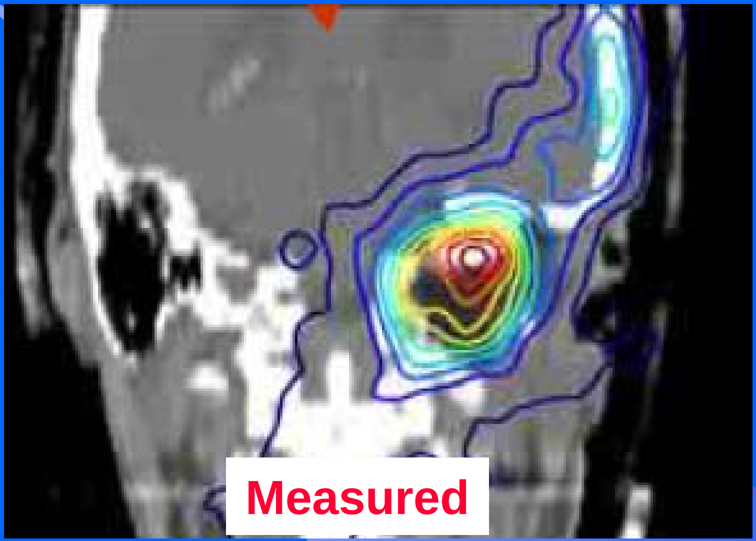
1998 - GSI pilot project (G. Kraft)

200 patients treated with carbon ions

PET on-beam

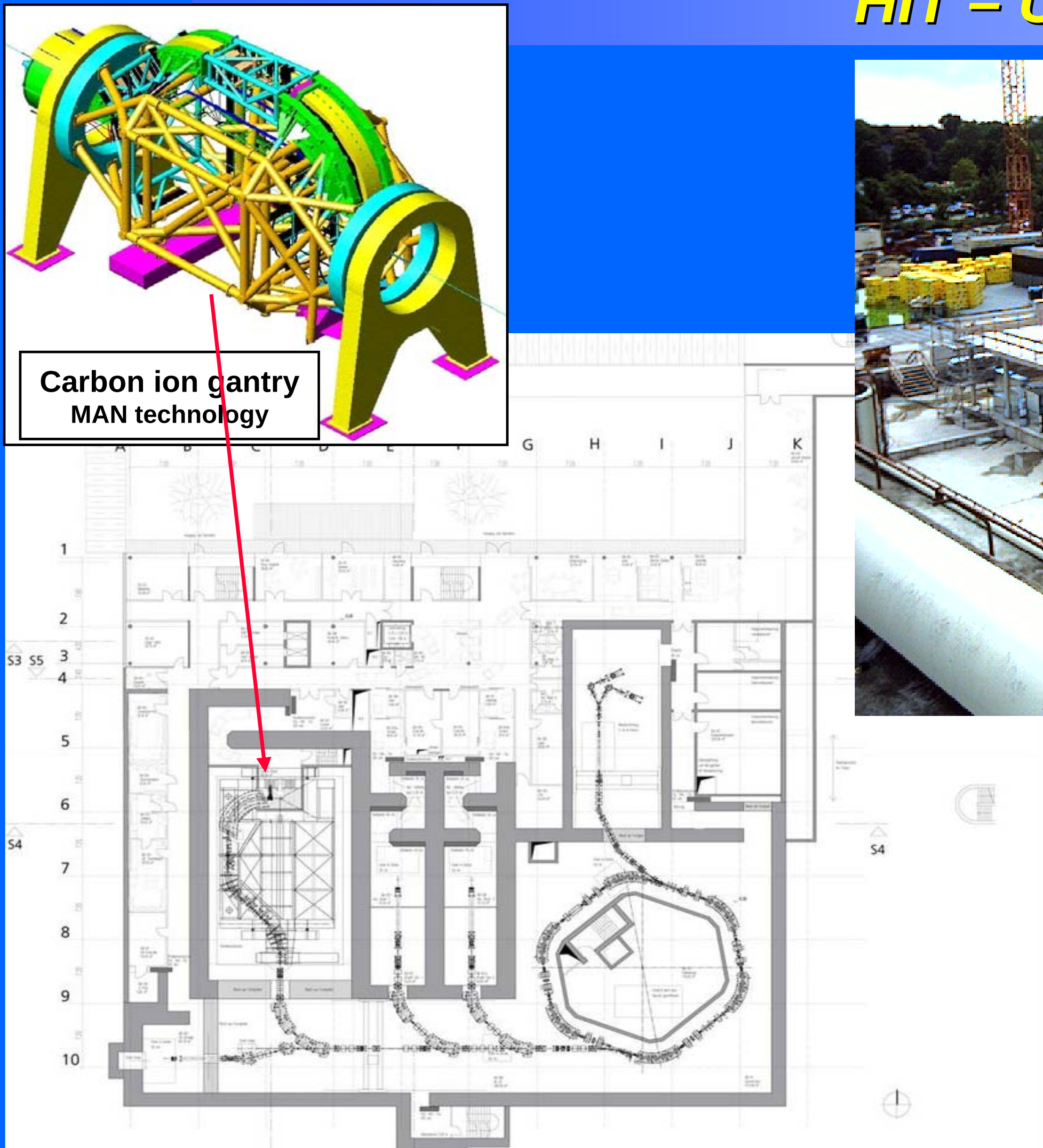






Measurement of the "real" dose given to the patient

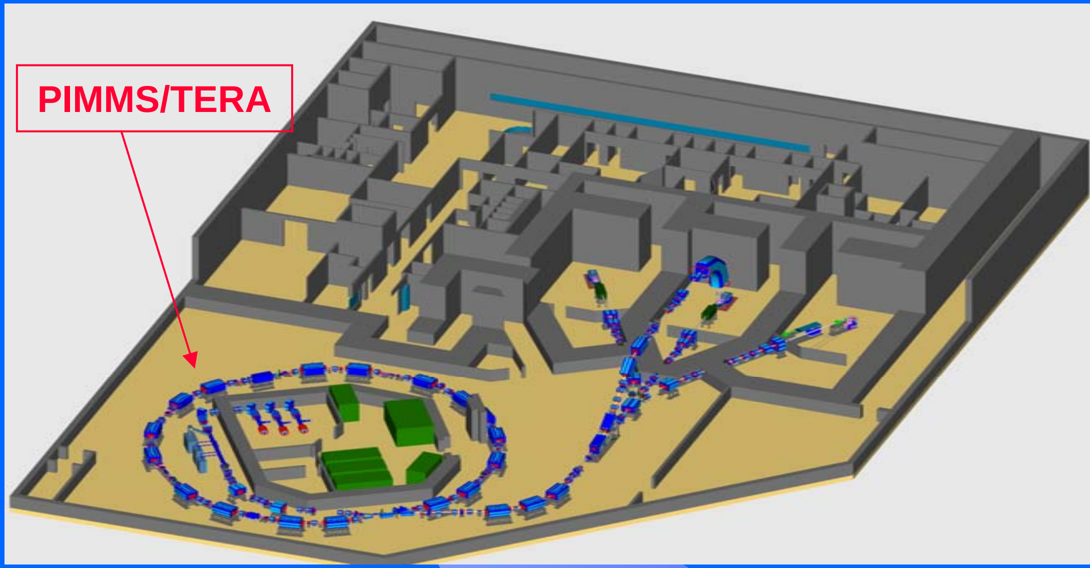
HIT – University of Heidelberg



- **Hospital based centre**
- **Project started in 2001**
- **First patient treatment foreseen in 2007**

The TERA Foundation

- Not-for-profit foundation created in 1992 by Ugo Amaldi and recognized by the Italian Ministry of Health in 1994
- Research in the field of particle accelerators and detectors for hadron-therapy
- First goal: the Italian National Centre (CNAO) now under construction in Pavia



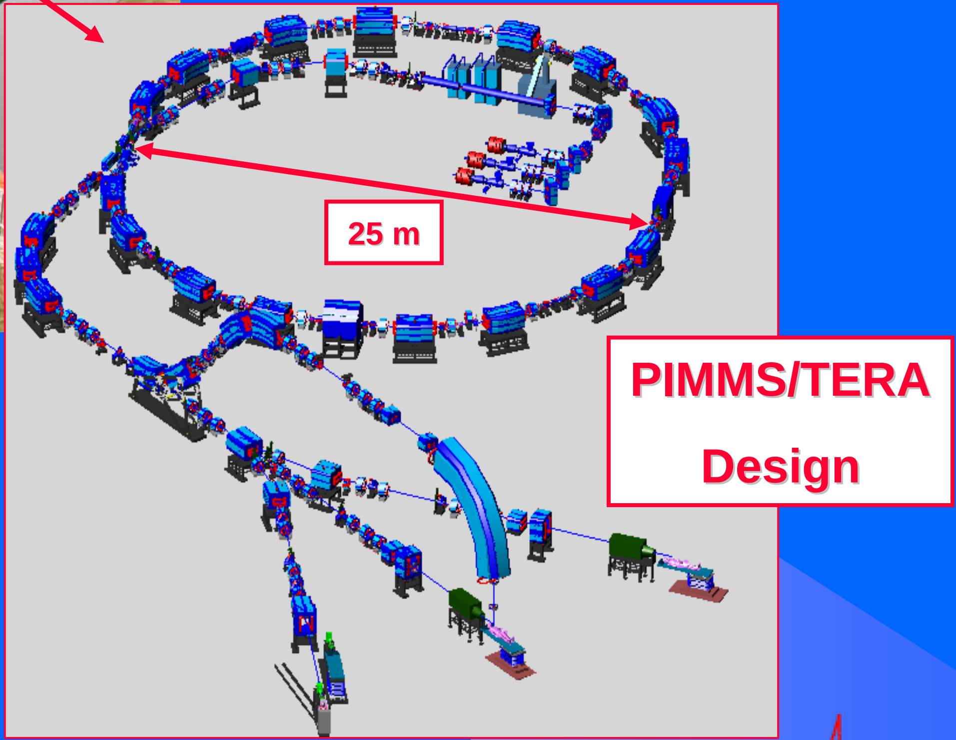
- Collaborations with many research institutes and universities
  - in particular CERN, INFN, PSI, GSI, JRC, Universities of Milan, Turin and Piemonte Orientale

CNAO on the Pavia site

- Investment: 75 M€
- Main source of funds:

Italian Health Ministry

- Ground breaking: March 2005
- Treatment of the first patient foreseen by the end of 2007



- Hospital based centre
- Protons and carbon ions


CNAO today
March, 2006
Courtesy Sandro Rossi,
Fondazione CNAO

Some new ideas for the future

Medium term

- “Dual” cyclotrons for protons and carbon ions
- CYCLINAC = Cyclotron + LINAC

Long term

- Laser plasma accelerators

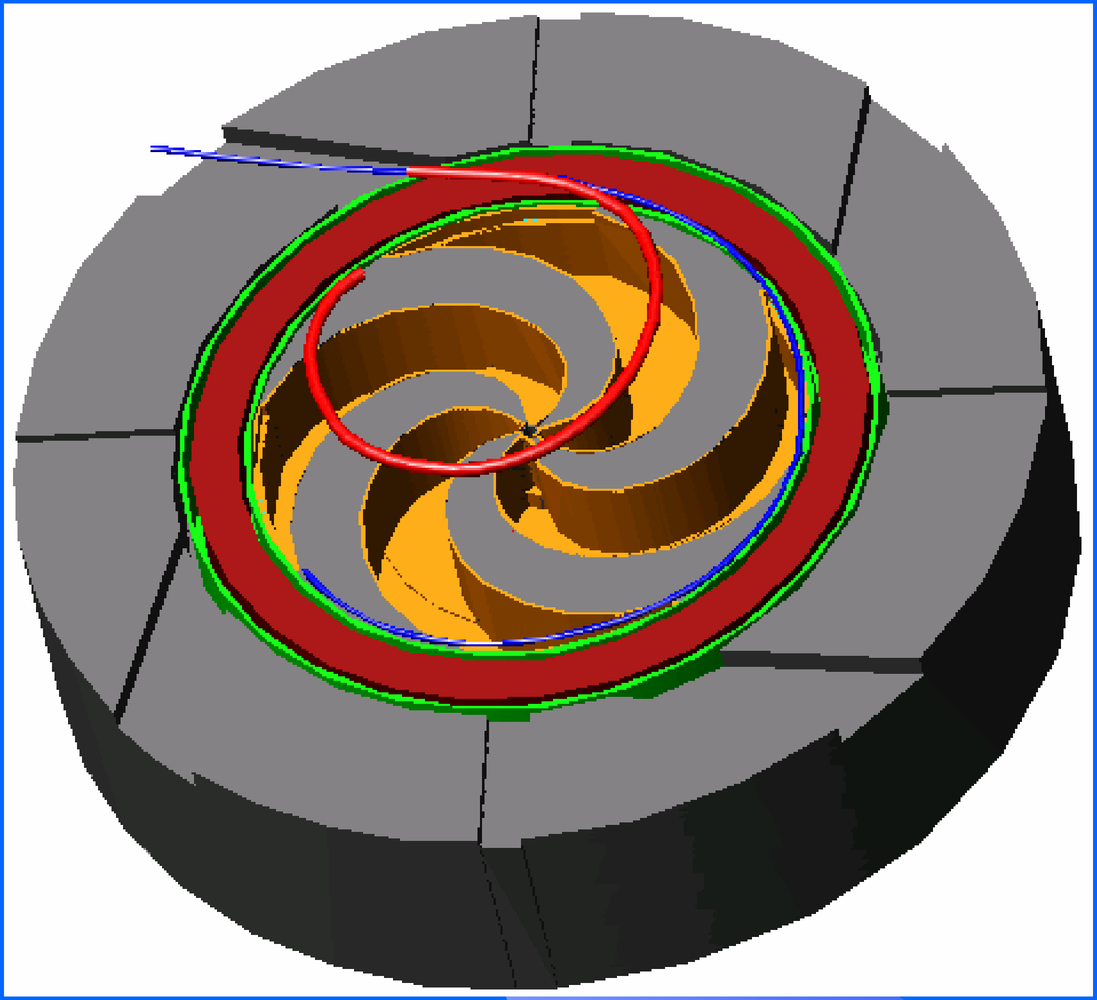
250 MeV/u SC cyclotron

- H_2^+ molecules

  250 MeV proton beam for deep seated cancer treatment

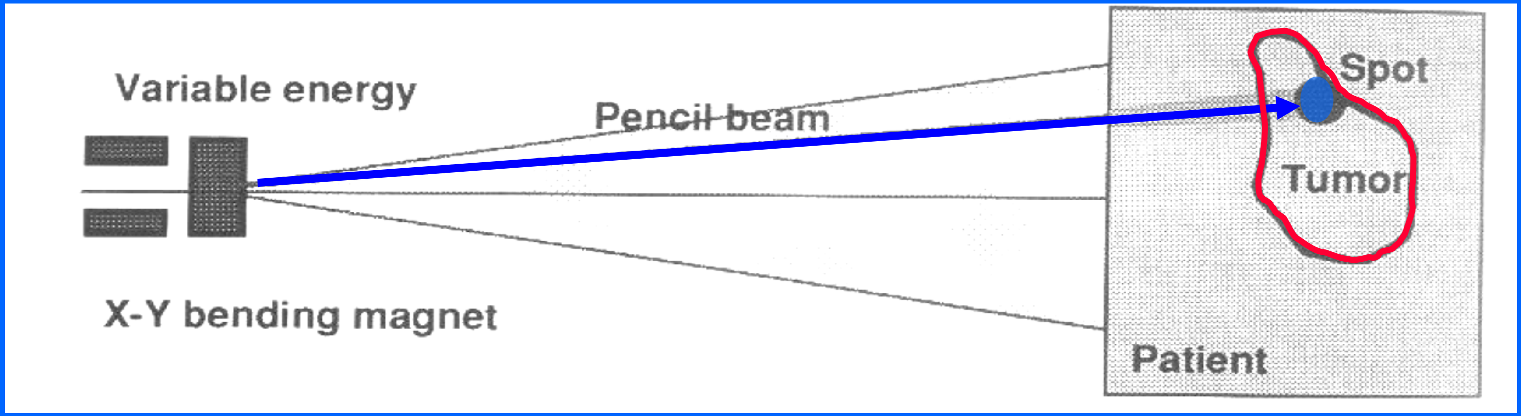
- 250 MeV/u fully stripped C ions

  maximum penetration of 12 cm in water

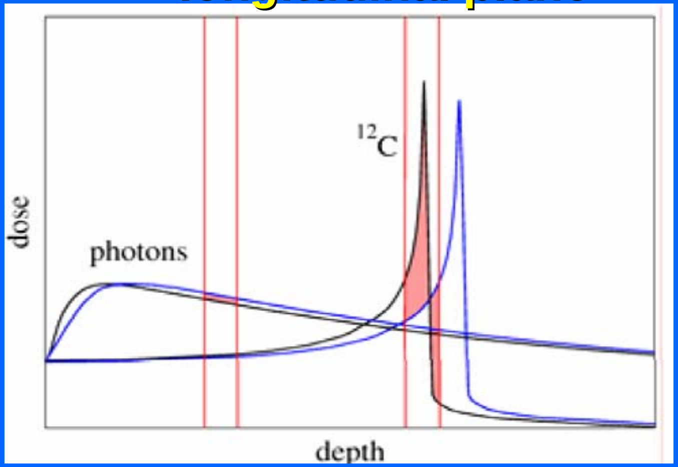


Project of INFN LNS

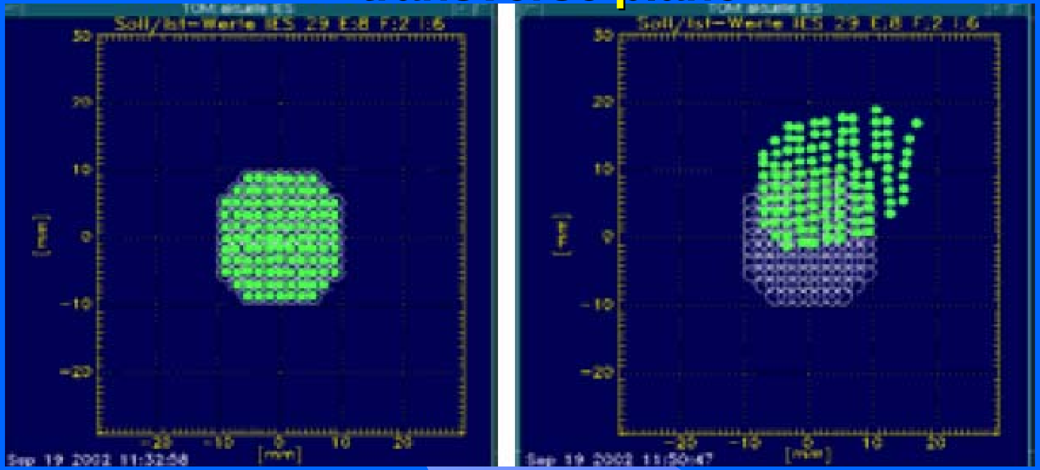
"Spot scanning" is sensitive to movements



longitudinal plane



transverse plane



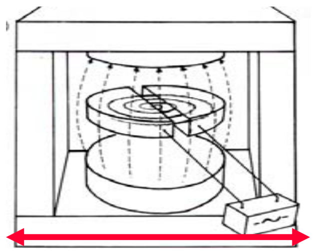
Two approaches can be combined:

1. multiple 'repainting, of the tumour target
2. feedbacks in the tranverse and energy dimensions

The accelerators used today in protontherapy

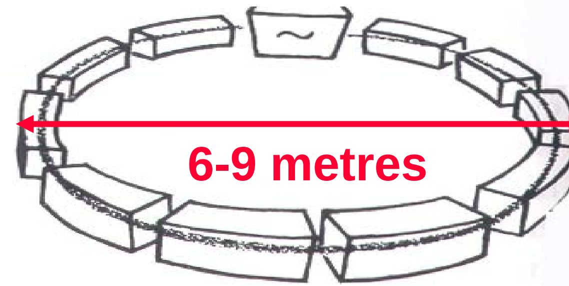
- 200-250 MeV protons

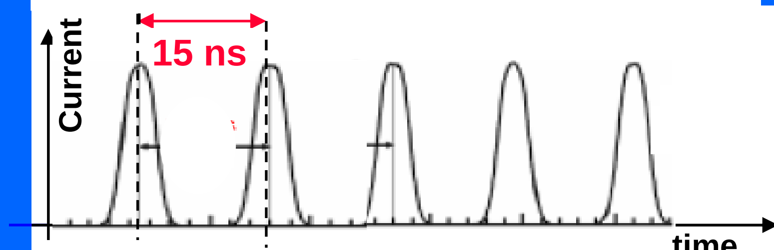
CYCLOTRONS (Normal or SC)

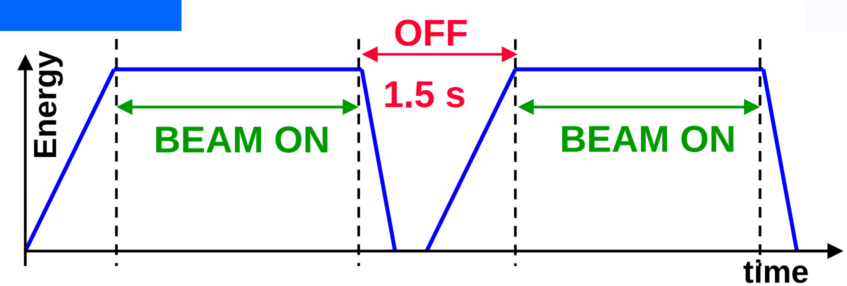


OR

SYNCHROTRONS







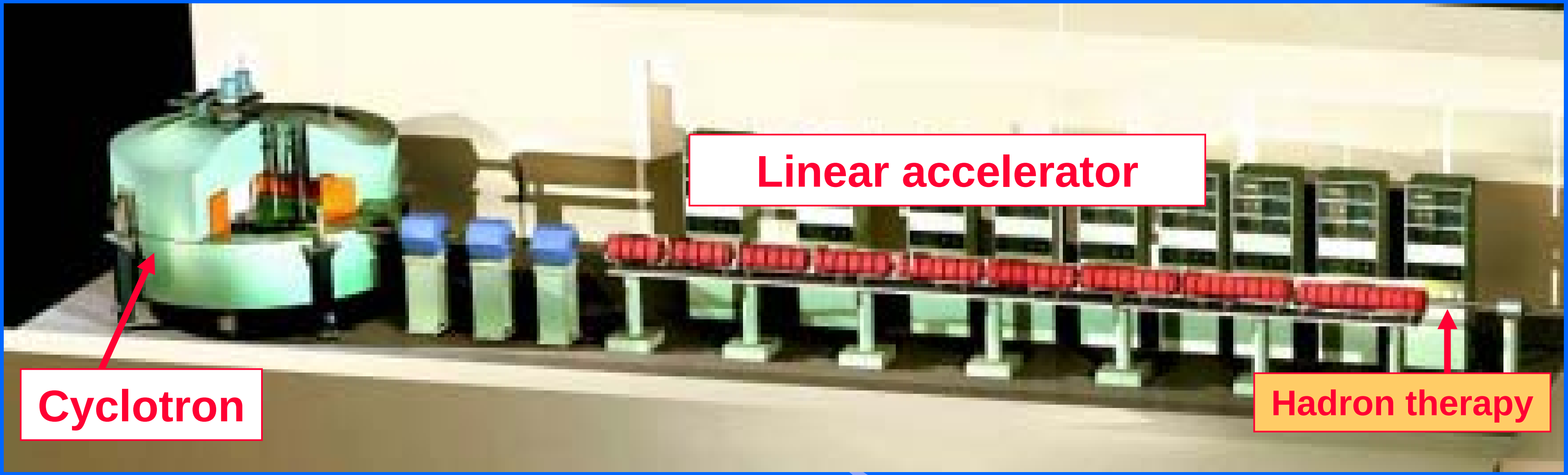
CYCLOTRONS

- Almost continuous beam
- Fixed energy

SYNCHROTRONS

- Beam ON and OFF
- Continuous energy

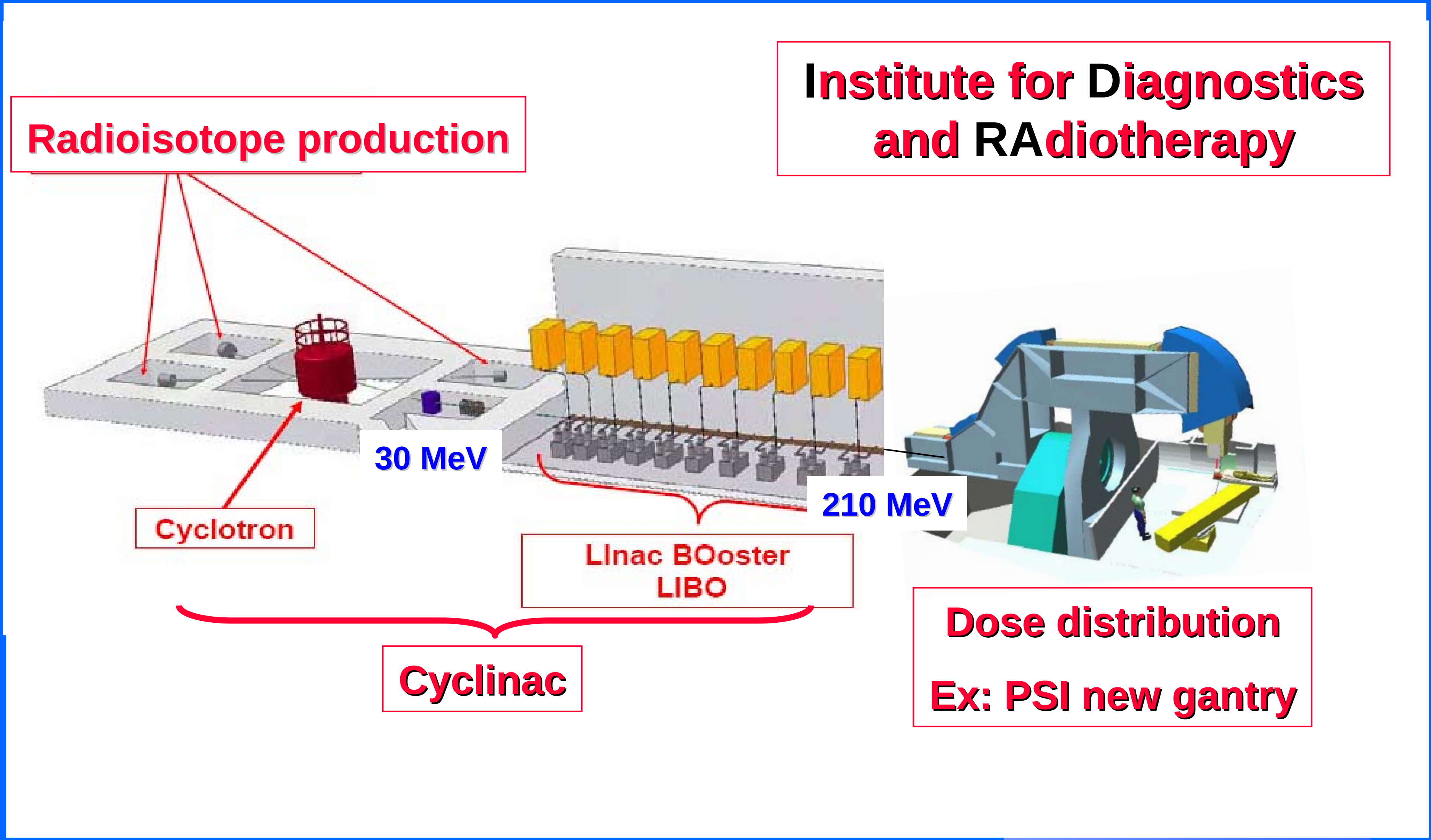
The CYCLINAC: the new project of TERA



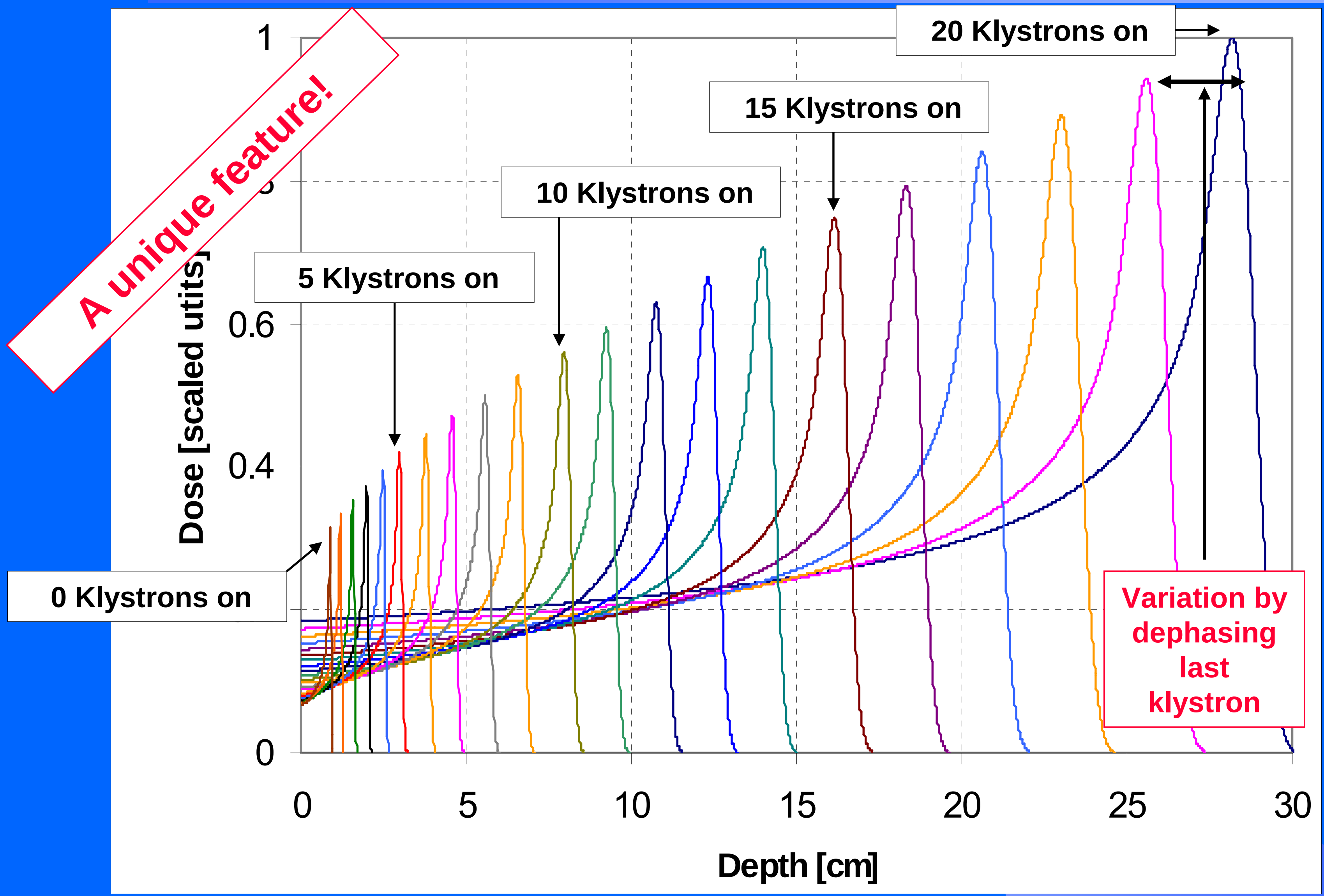
- **CYCLINAC = CYClotron + LINAC**
- **Commercial cyclotron for the production of radioisotopes**
- **Linac to boost the beam energy for hadron-therapy**

Two main functions

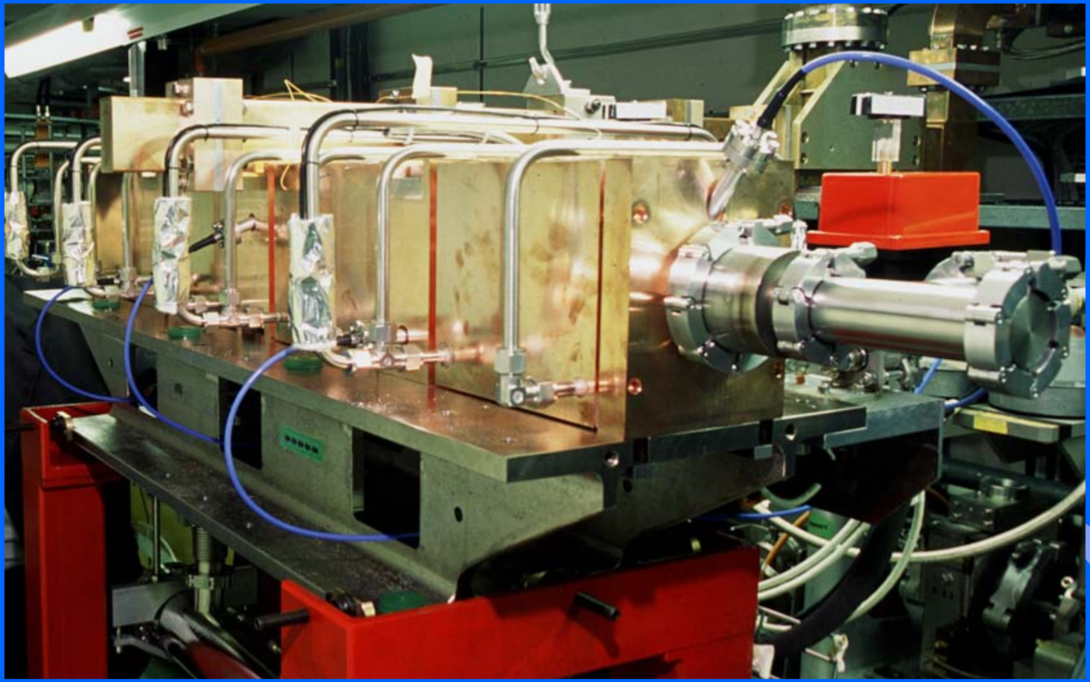
DIAGNOSTICS + THERAPY

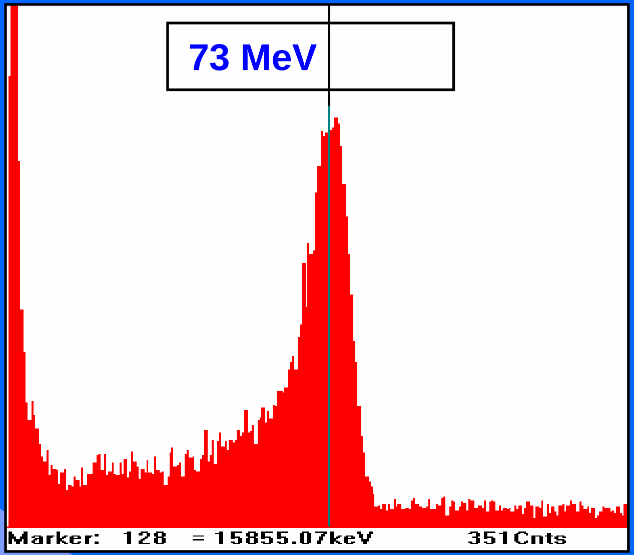

Institute for Diagnostics
and RAdiotherapy
Radioisotope production
30 MeV
210 MeV
Cyclotron
LInac BOoster
LIBO
Cyclinac
Dose distribution
Ex: PSI new gantry

Bragg curves obtained by switching off klystrons



Prototype of LIBO (go and see it in Microcosm at CERN)





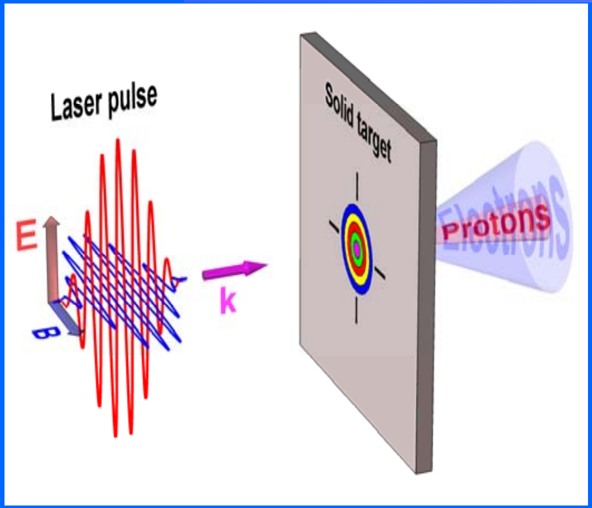
Collaboration INFN-CERN-TERA 1999-2002

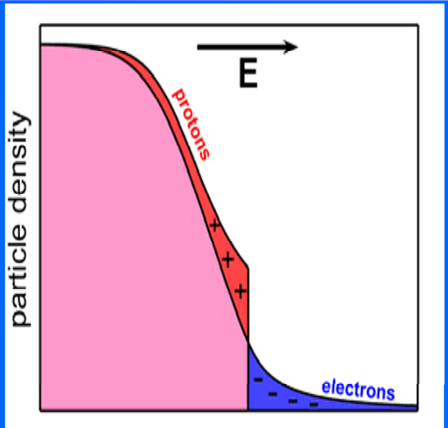
Module tested at LNS of INFN, Catania

NIM A 521 (2004) 512

Accelerated beam from the 60 MeV cyclotron of LNS

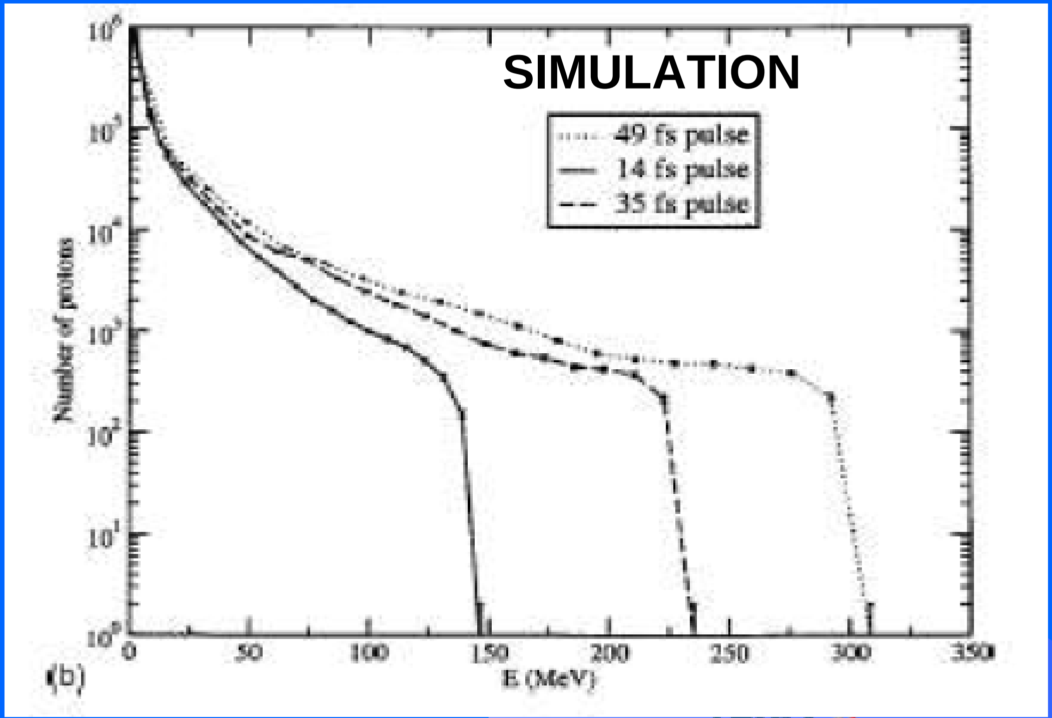
The long term future: laser - plasma "accelerators"?





The mechanism

- ~ 10^{13} protons measured
- Proton energy: 58 MeV (LLNL)



- Laser: 50 fs, 50 J (Petawatt!)
- $I = 10^{21}$ W/cm^2
- $>10^{11}$ protons up to 300 MeV

MANY YEARS OF WORK

Suitable for protontherapy?

- Is the number of protons reproducible from pulse to pulse?
- Is it possible to control the intensity of the proton beam?
- Moreover the beam is neither monochromatic nor well collimated (with respect to standard accelerators)

New ideas are needed, in particular for an "ad hoc" dose distribution system

- Since the beginning of particle physics, more than one-hundred years go…

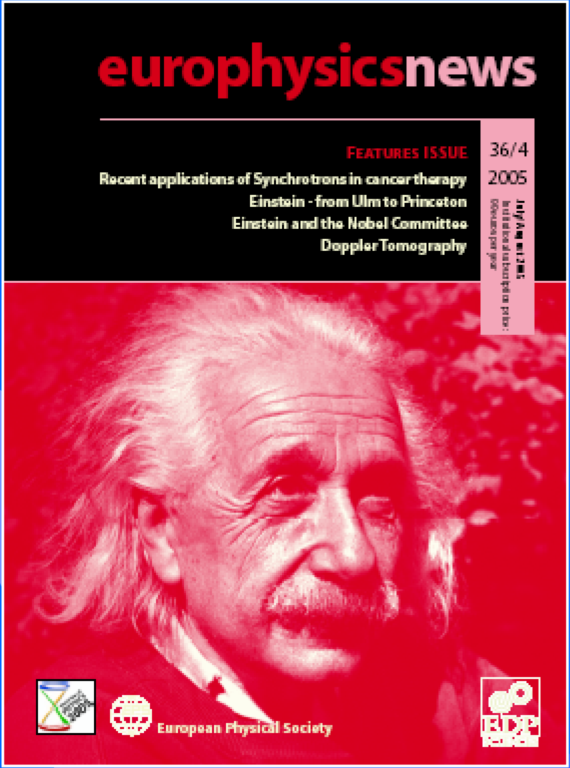
Particle physics offers medicine and biology very powerful tools and techniques to study, detect and attack the disease

To fully exploit this large potentiality, all these sciences must work together!

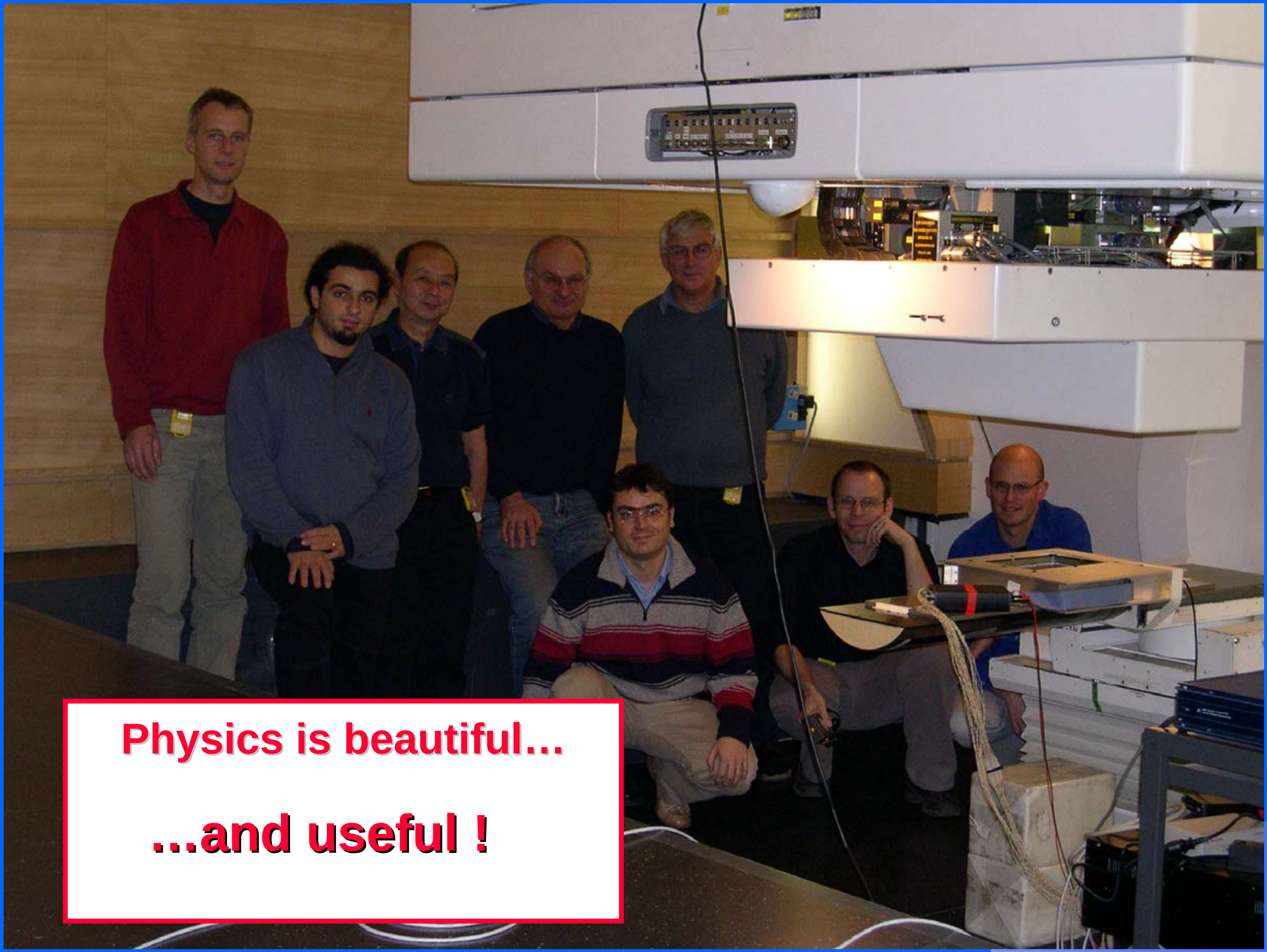
Conclusions and Outlook

- **Hadrontherapy is becoming a reality!**
  - **Proton therapy is “booming”**
  - **Many carbon ion facilities are under construction or approved**
  - **Still a lot of R&D is needed in the near future**

- **For more information:**
  - **U. Amaldi and G. Kraft, on Europhysics News**



Work is in progress…



Physics is beautiful…

…and useful !