PROGRESS IN HADRONTHERAPY

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TERA
Foundation for Oncological Hadrontherapy
• **Introduction**
  - Radiation therapy with X rays and hadrontherapy

• **Hadrontherapy today**
  - Proton-therapy
  - Carbon ion therapy

• **New ideas for the future:**
  - Innovative cyclotrons
  - CYCLINACs
  - Laser plasma based accelerators

• **Conclusions and outlook**
The basic concept of cancer radiation therapy

Local control of the tumour

1902 1912

STOCKHOLM

 Courtesy J.P. Jerard, MD, Nice (France)
A big step forward…

...in particle physics and in medical diagnostics and cancer radiation therapy due to the development of three fundamental tools:

- Particle accelerators
- Particle detectors
- Computers

M. S. Livingston and E. Lawrence with the 25 inches cyclotron

Geiger-Müller counter built by E. Fermi and his group in Rome
Radiotherapy with X-rays

- Electron linacs to produce gamma rays (called X-rays by medical doctors)
- 20'000 patients/year every 10 million inhabitants

IMRT - 9 different photon beams

The limit is due to the dose given to the healthy tissues!

Especially near organs at risk (OAR)
The basic principles of hadrontherapy

- First idea:
  - Bob Wilson, 1946

- Bragg peak
  - Better conformity of the dose to the target → healthy tissue sparing

- Hadrons are charged
  - Beam scanning for dose distribution

- Heavy ions (Carbon)
  - Higher biological effectiveness
Protons allow a better local control

Tumour between the eyes

IMRT - 9 X-ray beams 1 proton beam
Number 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

**Every 50 M inhabitants**

- Proton-therapy
  - 4-5 centres
- Carbon ion therapy
  - 1 centre

**TOTAL about 3'000 pts/year**

every 10 M
The sites

Up to present

- Proton-therapy: 
  ~45 000 patients

- Carbon ion therapy
  ~2 200 patients
Present and “near” future of hadrontherapy

- Proton-therapy is “booming”! (for information see PTCOG, www.ptcog.com)
  - 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, …)
  - Companies offer turn-key centers (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 eye melanoma treatment at INFN-LNS in Catania

- LNS Supercoducting cyclotron
- 65 MeV protons
- 92 patients (oct 2005)
The Loma Linda University Medical Center

- First hospital-based proton-therapy centre, built in 1993
- Deep seated tumours
- 160/sessions a day
Dose distribution

- Passive spreading
- Active scanning

Longitudinal plane

Transverse plane

beam

tumour volume

patient

energy variation

fast

slow

horizontal scanning

vertical scanning
• Active scanning
• New SC 250 MeV proton cyclotron
• New proton gantry (Gantry2)
**SAMBA: an innovative detector for on-line monitoring**

- Designed for the Gantry2 at PSI
- Beam tests with the Gantry1 at PSI
- Measurement of a “square of dose”
- Uniformity within 1 %

- 2 orthogonal strip ionization chambers
- Segmentation: strips 2 mm
- Very sensitive electronics (Quantum of charge 100 fC)
- Very thin: 50 um capton + 17 um copper foils

**Collaboration TERA-University and INFN Torino**
Carbon ion therapy in Europe

1998 - GSI pilot project (G. Kraft)

200 patients treated with carbon ions
• Direct control of the dose
• First attempts with proton beams

Simulated from TPS

Measured
HIT – University of Heidelberg

- Project started in 2001
- First patient treatment foreseen in 2007
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
New accelerators for the future?

**Medium term**

- “Dual” cyclotrons for protons and carbon ions
- Very compact SC proton synchrocyclotrons
- CYCLINAC = Cyclotron + LINAC

**Long term**

- Laser plasma accelerators
A “dual” cyclotron

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: INFN-LNS
Very compact SC synchrocyclotrons

- 9.5 T SC magnet → ~50 cm diameter for 250 MeV protons

- Innovative double scattering spreading technique based on scatterers made of “low Z” and “high Z” liquid materials

- Project MIT and Still River Systems

- Goal: “One gantry-One room” apparatus

- Very difficult project that could lead to a “change of scale”!!
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
Radioisotope production

Institute for Diagnostics and RAdiotherapy

Cyclotron

30 MeV

Linac BOoster LIBO

210 MeV

Cyclinac

Dose distribution

Ex: PSI new gantry
Bragg curves obtained by switching off klystrons

Variation by dephasing last klystron

A unique feature!
The long term future: laser - plasma “accelerators”?

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

The mechanism

- 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
Conclusions and Outlook

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

Work is in progress...