ACCELERATORS FOR HADRON THERAPY

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IVICFA’s Fridays: Medical Physics

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Introduction: the icon of hadrontherapy

- **Position** of the Bragg peak depends on beam energy
- **200 (400) MeV/u** protons (carbon ions) are needed to reach **30 cm of depth**
- 45+ centres in operation,
- >100’000 patients treated (mostly with protons)

http://www.hollandptc.nl/english/faq/
What accelerators are used/studied for hadrontherapy?

**Cyclotrons:** compact, reliable, easy to operate  
*however... fixed energy beam $\leftrightarrow$ movable absorbers*

**Synchrotrons:** variable energy beam  
*but... $\Rightarrow$ energy modulation in 1-2 s*

**Close to realization**

**Fixed-Field Alternating-Gradient (FFAG) accelerators:**  
high-repetition rate ($\sim$ kHz), active energy modulation  
*but... $\Rightarrow$ so far not so compact*  
$\Rightarrow$ challenging injection and extraction systems (dense lattice!)

**Cyclinacs (cyclotron + RF linac):**  
high-repetition rate ($\sim$ kHz), active energy modulation

**Long-term candidates**

**Dielectric Wall Accelerators (DWA):**  
Compact if required accelerating gradients are achieved (1 $\rightarrow$ 100 MV/m)

**Laser-driven accelerators:**  
Is it possible to get clean, monoenergetic beams?
LINear ACcelerators: The beginnings
Conventional X-ray therapy

2000 patients/year every in 1 million inhabitants

electrons

Courtesy of Elekta
In the world radiation oncologists use 20,000 electron linacs. 50% of all the existing accelerators of energy larger than 1 MeV. 2,000 patients/year every in 1 million inhabitants.
1991: first “all-linac” approach to proton therapy

Schematic layout of the model PL-250 proton therapy linac designed in 1991 by R. Hamm, K. Crandall and J. Potter

1994: “cyclinac” approach to proton therapy

The rationale of proton and carbon tumour therapy
X-rays have two problems:

1. they irradiate unwanted close-by ‘critical’ organs
2. they cannot cure ‘radioresistant’ tumours (about 5%)
Advantages of hadrontherapy:
1. Normal tissues are spared.
Advantages of hadrontherapy:
2. ‘radioresistant’ tumours can be controlled

A carbon ion produces along the track 25 times more ionizations than a proton causing a great number of clustered unrepairable Double Strand Breaks that are not repaired and can kill radioresistant cells.
The present: A.D.A.M. and the Linac for Image Guided Hadron Therapy - LIGHT
This Unit has accelerated protons from 62 to 74 MeV at the same 3 GHz frequency of electron linacs.
First Unit of LIGHT built and power tested by A.D.A.M.: 2011

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

3 GHz klystron
10 MW

Scandinova modulator

Linac for Image Guided Hadron Therapy

41 MeV

30 MeV
The all-linac LIGHT is being built at CERN by A.D.A.M.
The all-linac LIGHT is being built at CERN by A.D.A.M.

proton pulses @ 200 Hz

M. Vretenar et al - CERN

L. Picardi - ENEA
The cyclinac **PERLA** to be built in Tuscany by TERA: 
Protontherapy and Exotic Nuclei from Linked Accelerators

- 24 MeV cyclotron by ACSI (Canada)
- 24 - 230 MeV CCL-LIGHT by A.D.A.M.
- 2 treatment areas for children
- Gantry
- Radiopharmacy

1.7 m

IVICFA, Valencia, 31.10.14 - Alberto Degiovanni -
Unique properties of a linac beam:
fast and active energy variation

- mod on = 4, Ampl = 1.00
- total transmission = 8.5 %
- good/tot(+2.5 MeV) = 99.3 %
- E-mean = 84.45 MeV
- E-std(peak) = 0.25 MeV
- E-std(2mm) = 1.56 MeV

Energy [MeV] vs. dN(E) / N(E)
The dose deposition depth can be adjusted every 3 ms.

The linac pulses 200-300 times per second.

**spot depth:**
± 3 mm every pulse

To follow moving organs in 4D - with spot scanning, motion feedback and more than 10 paintings - the beam time structure of linacs is better than the ones of cyclotrons and synchrotrons.
ENEA (Frascati) is building IMPLART = Intensity Modulated Proton Linear Accelerator for RadioTherapy

L. Picardi, C. Ronsivalle et al.

150 MeV protons
ENEA (Frascatl) is building IMPLART=
Intensity Modulated Proton Linear Accelerator for RadioTherapy

SCDTL module 1 (11.6 MeV): operating;
module 2 and 3 (27 MeV): ready for end of the year

Module 1 at CECOM (Guidonia, RM)
During construction and tests
ACLIP – INFN Naple-Milan-Bari

Assembly of the first module

Particle Accelerator Conference 2009,
V. G. Vaccaro et al.
RF HIGH POWER TESTS ON THE FIRST MODULE OF THE ACLIP LINAC

The ACLIP module high power RF test set

Cyclotrons and Their Applications 2007,
Eighteenth International Conference
V. G. Vaccaro et al.
ACLIP: A 3GHz SIDE COUPLED LINAC FOR PROTON THERAPY TO BE USED AS A BOOSTER FOR 30 MEV CYCLOTRON
Studies for the future: high-gradient hadron structures
Test cavities at 3 and 5.7 GHz have been built and tested by TERA in collaboration with CLIC group (W. Wuensch et al).

Test cavities at 3 and 5.7 GHz have been built and tested by TERA.

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The future high-gradient linac: **TULIP**

**TUrning LIinac for Protontherapy**
TULIP by TERA with to-day technology: 30 MV/m

present technology : 30 MV/m

Int. Particle Accel. Conf. 2013,
A. Degiovanni et al.
DESIGN OF A FAST-CYCLING HIGH-GRADIENT ROTATING LINAC FOR PROTONTHERAPY
New high-gradient “backward” TW structure

‘NEW’ bwTW
50 MV/m
BDR = 10^{-6} m^{-1}
(20% more power for same gradient)

PROPOSED by
A. GRUDIEV /CLIC
financed by KT

‘OLD’ SW CCL
30 MV/m
BDR = 10^{-6} m^{-1}

With recirculation:
I. SYRATCHEV

accelerating cavities

coupling cavities
CLIC technology: 50 MV/m prototype is being built by CERN and TERA

RF DESIGN OF A NOVEL BACKWARD TRAVELLING WAVE LINAC FOR PROTON THERAPY
New compact RFQ design at CERN

750 MHz RFQ
4 MODULES
40 keV-5 MeV in 2 m

Modulation machining test on a minor vane

RFQ Module 3D model

LINAC Conference 2014,
M. Vretenar et al.
A COMPACT HIGH-FREQUENCY RFQ FOR MEDICAL APPLICATIONS
The future high-efficiency linac: CABOTO
CAarbon BOoster for Therapy in Oncology
The cyclinac CABOTO runs at 300 Hz

Patients area
1900 m²

control room and technical areas
600 m²

footprint
75 x 59 = 4400 m²

33m – 32 kl

70 MeV/u ≤ 400 MeV/u
The all-linac CABOTO runs at 300 Hz

Patients area 1900 m²
hor. beam
vert. beam
hor. beam

control room and technical areas 600 m²
modulators and power supplies
cooling and power supplies
7 m SCDTL for A/Ze2
7 MeV/u CNAO injector
70 MeV/u linac complex
footprint 75 x 65 = 4900 m²

33m – 32 kl

70 MeV/u ≤ 400 MeV/u
The all-linac CABOTO runs at 300-400 Hz and consumes 1 MW.
• 3 GHz linacs produce hadron beams that are better suited than those of cyclotrons and synchrotrons to treat moving organs with the multi-painting spot scanning technique

• Low-velocity SCDTL and high-velocity CCL accelerating structures have been built and tested by ENEA, TERA and INFN

• The CERN Spin-off company A.D.A.M. is building at CERN an all-linac facility that will be transferred to a hospital to treat patients

• TERA and the CERN CLIC group are developing high-gradient and high-efficiency structures with the support of the Knowledge Transfer group

• In future this will lead to TULIP, a compact proton linac rotating around the patient, and to CABOTO, a high-efficiency linac for the therapy of deep-seated radioresistant tumours with carbon ions
ACKNOWLEDGMENTS

THANK YOU FOR YOUR ATTENTION!