The CERN Accelerator School

Future Trends in Linacs

Alberto DEGIOVANNI

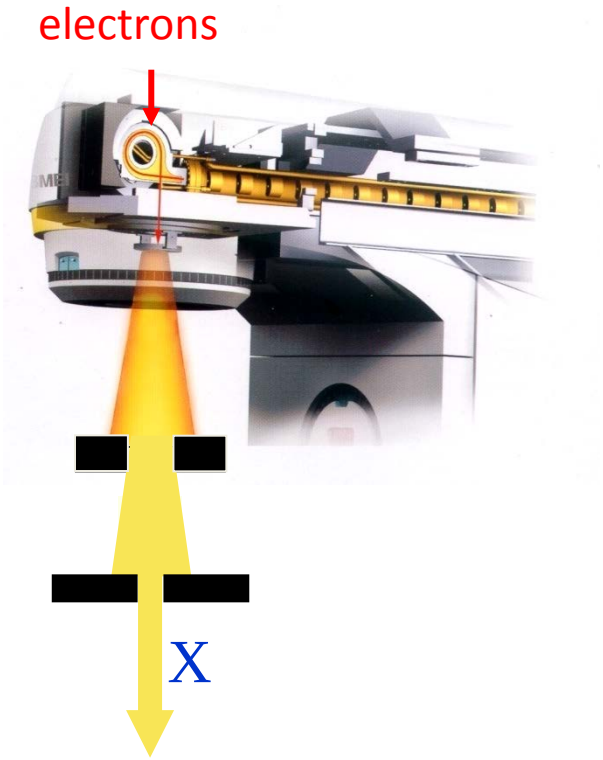
Accelerators for Medical Applications
26 May – 5 June
Vösendorf, Austria, 2015

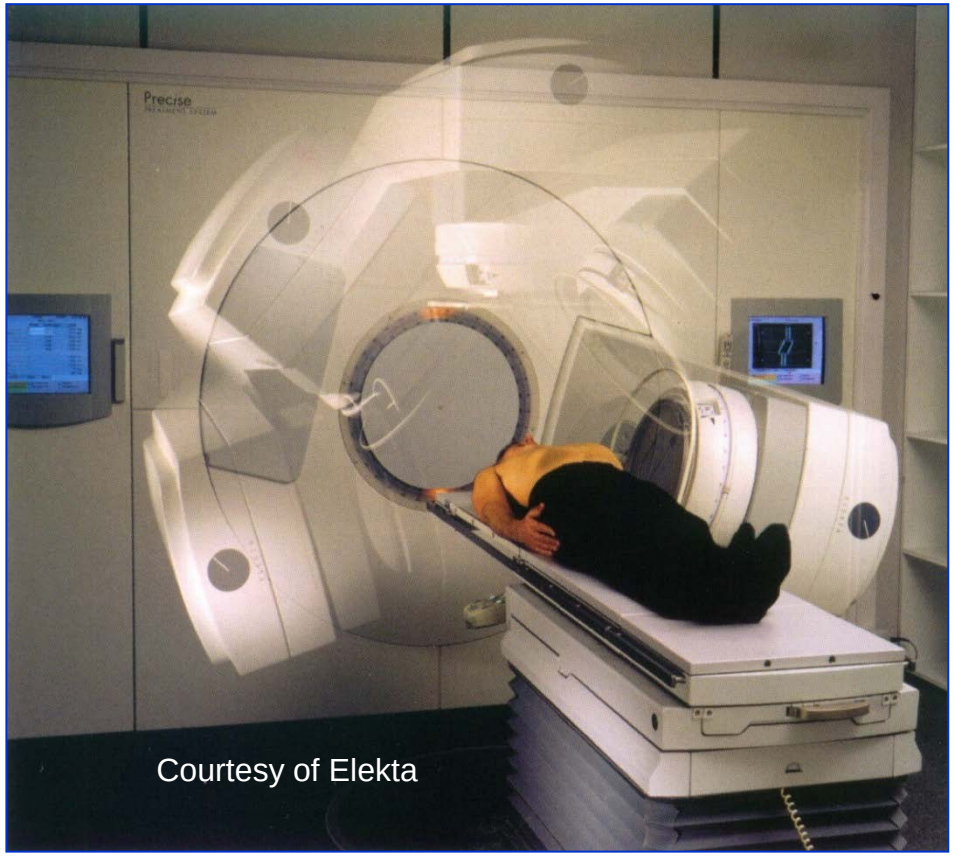
Outline

- **The beginnings**
  - Conventional X-ray therapy
  - The «all-linac» solution for protontherapy
  - The «Cyc-linac» solution for protontherapy
- **The present**
  - LIGHT: Linac for Image Guided Hadrontherapy
- **Studies for the future:**
  - High gradient structures
  - High frequency RFQ
- **The future:**
  - TULIP at high gradient
  - CABOTO at high efficiency

LINear ACcelerators: The beginnings

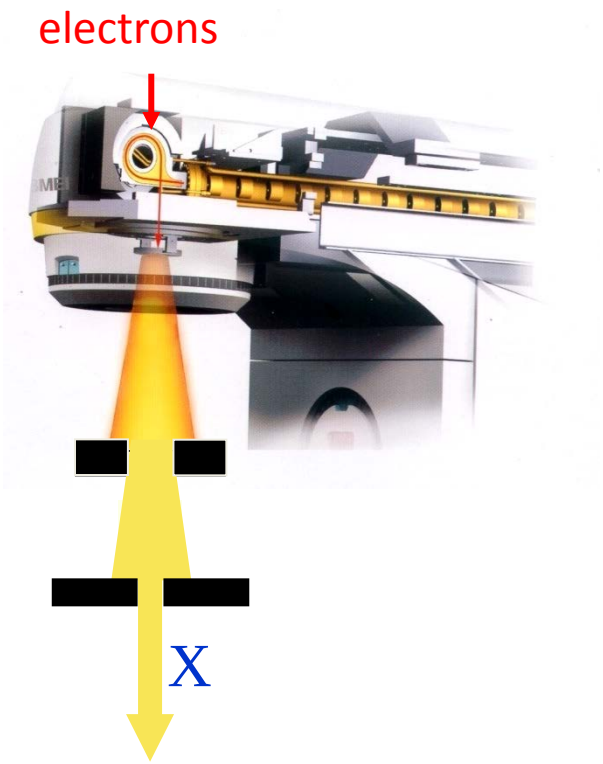
Conventional X-ray therapy



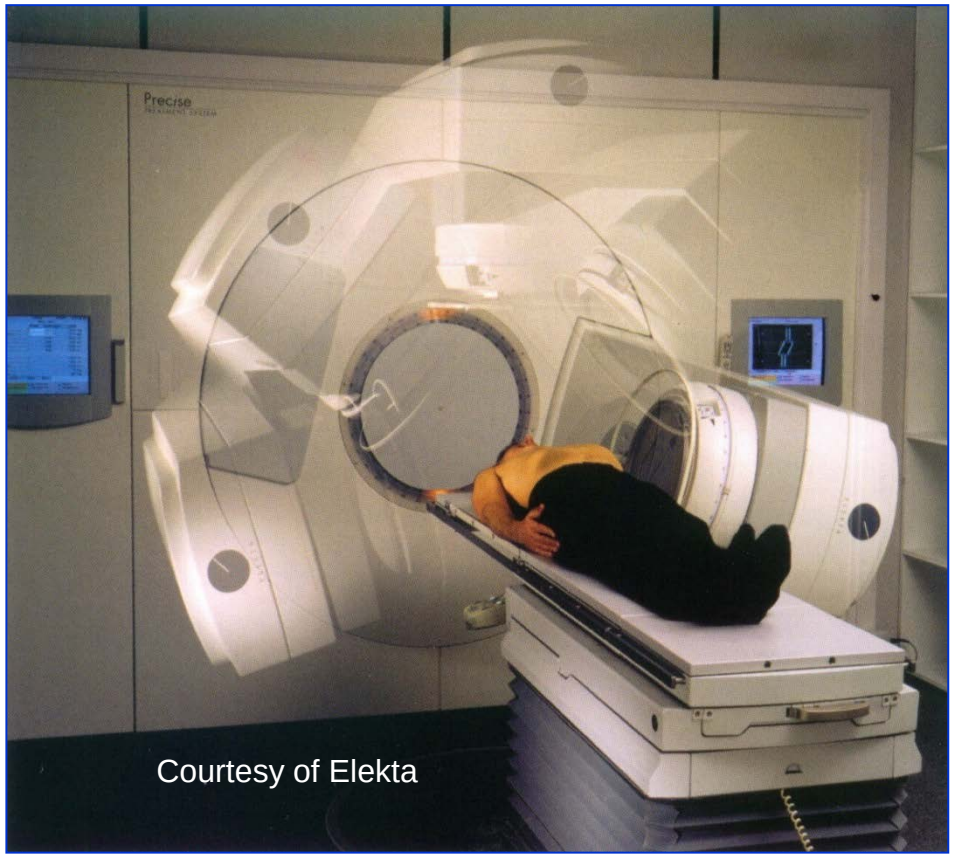


2000 patients/year every
in 1 million inhabitants

Conventional X-ray therapy

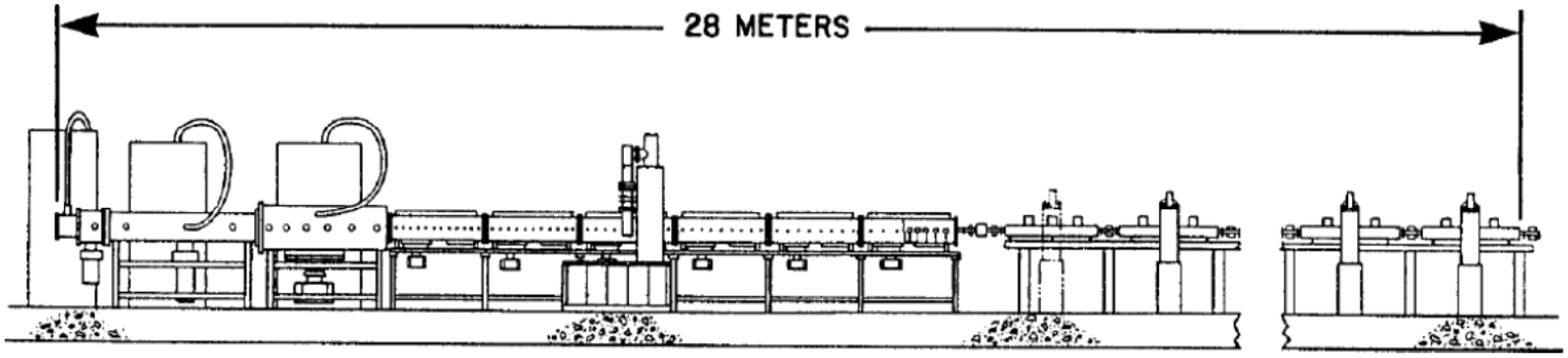


2000 patients/year every
in 1 million inhabitants



In the world radiation oncologists use
20 000 electron linacs
50% of all the existing accelerators of
energy larger than 1 MeV

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

R. W. Hamm, K. R. Crandall and J. M. Potter, Preliminary design of a dedicated proton therapy linac, in *Proc. PAC90*, Vol. 4 (San Francisco, 1991), pp. 2583–2585.

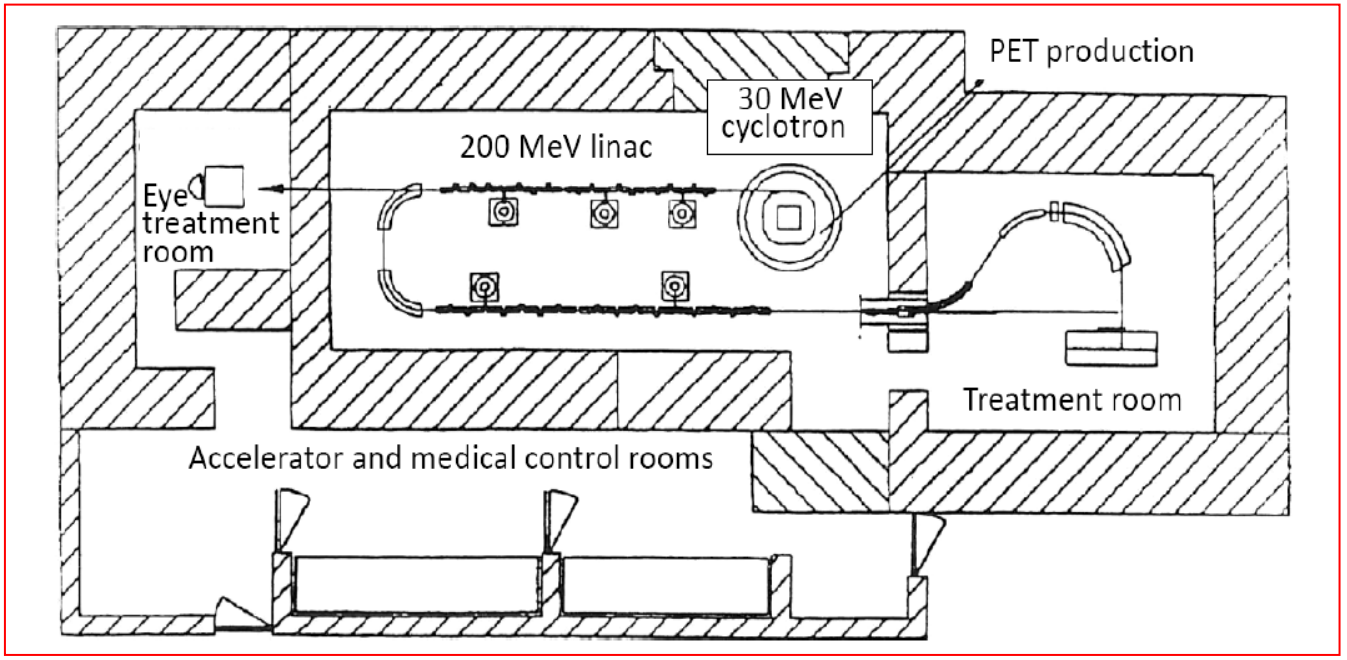
review paper

High Frequency Linacs for Hadrontherapy

Ugo Amaldi Saverio Braccini Paolo Puggioni

Reviews of Accelerator Science and Technology
Vol. 2 (2009) 111–131

1994: "cyclinac" approach to proton therapy



U. Amaldi, The Italian hadrontherapy project, in *Hadron Therapy in Oncology*, eds. U. Amaldi and B. Larsson (Elsevier, 1994), p. 45.

review paper

High Frequency Linacs for Hadrontherapy

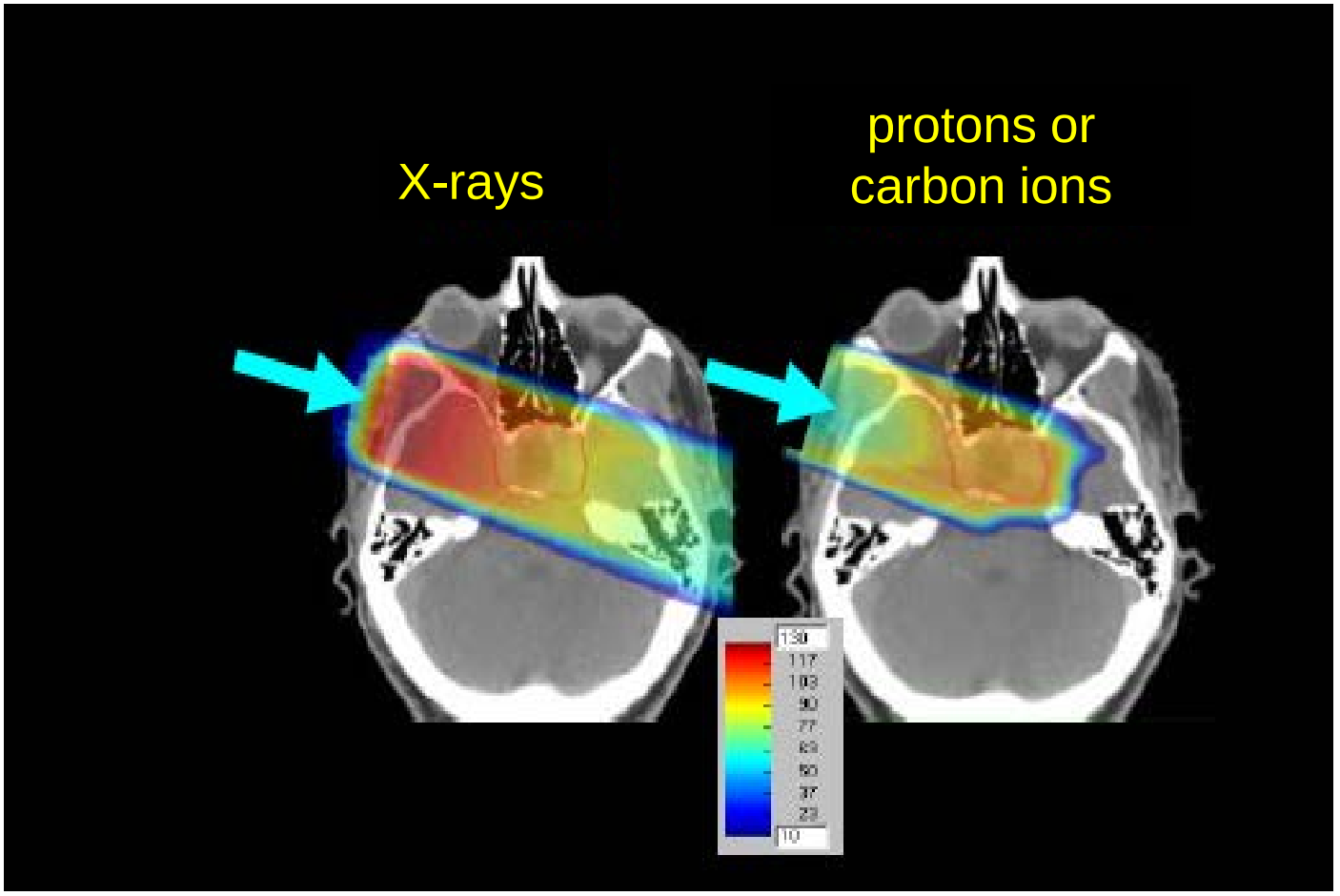
Ugo Amaldi Saverio Braccini Paolo Puggioni

Reviews of Accelerator Science and Technology
Vol. 2 (2009) 111–131

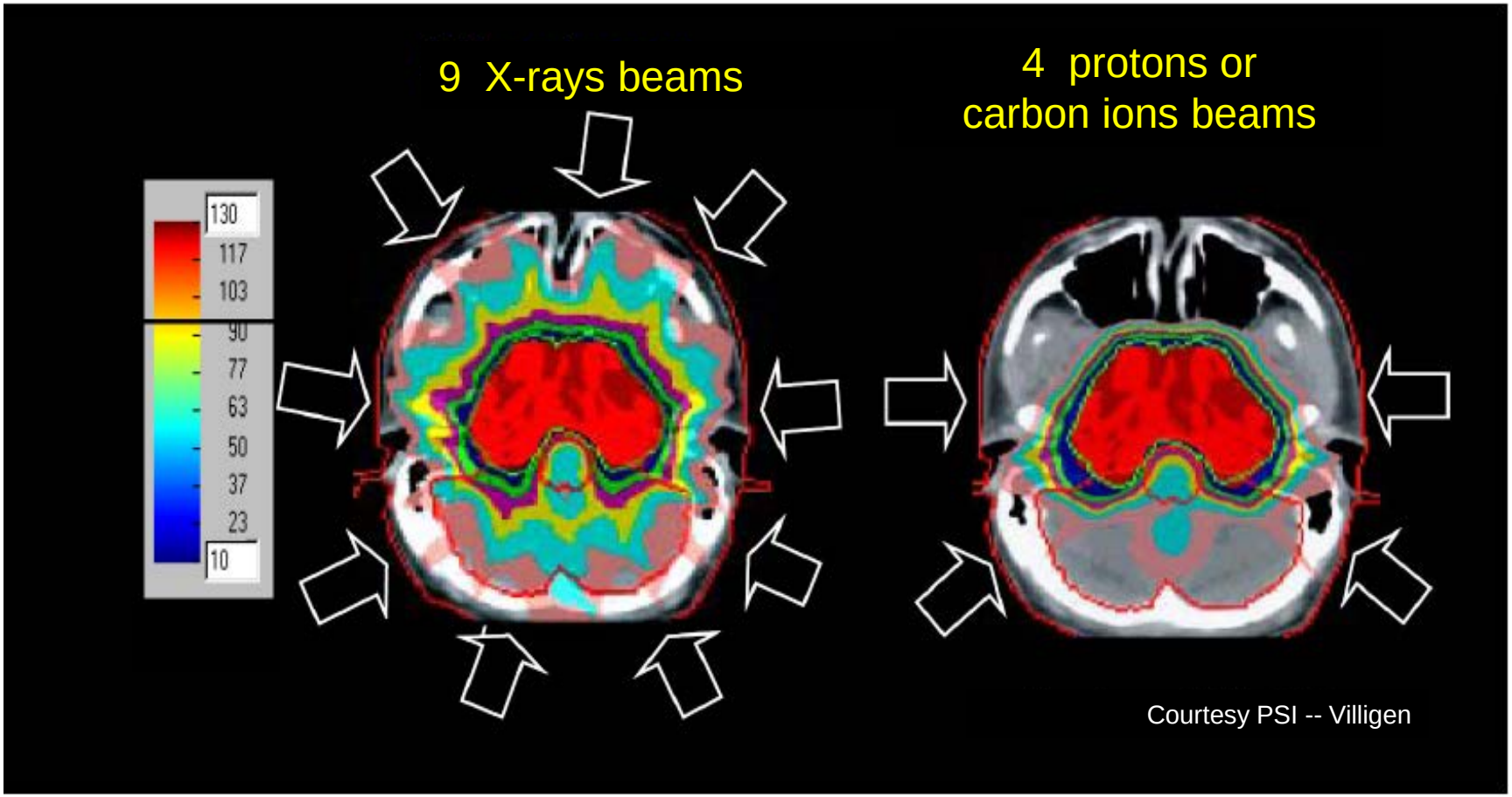
The rationale of proton and carbon tumour therapy

X-rays have two problems :

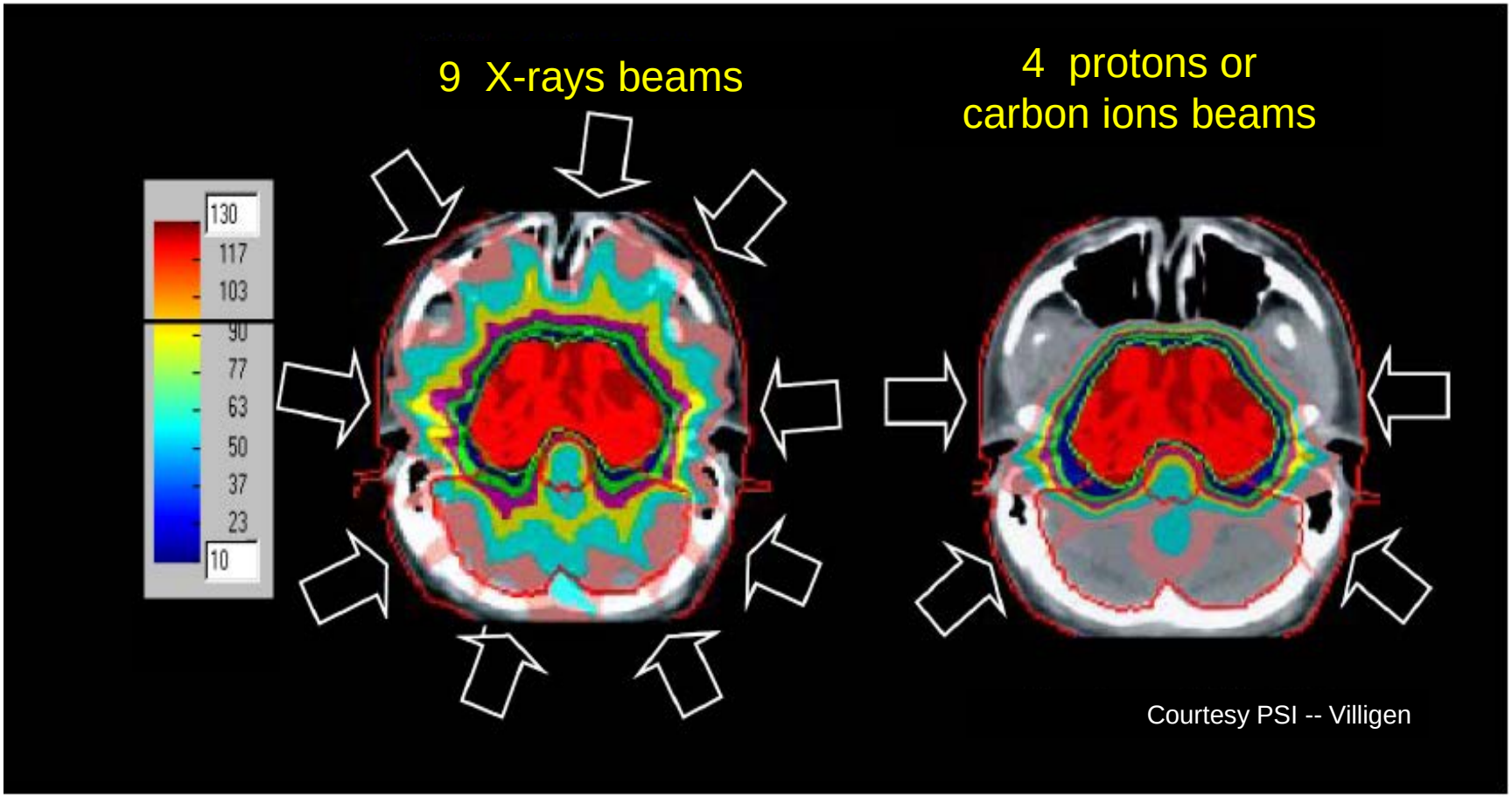
1. they irradiate unwanted close-by 'critical' organs
2. they cannot cure 'radioresistant' tumours (about 5%)



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

3 GHz LIBO accelerating unit built and tested by TERA – CERN – INFN

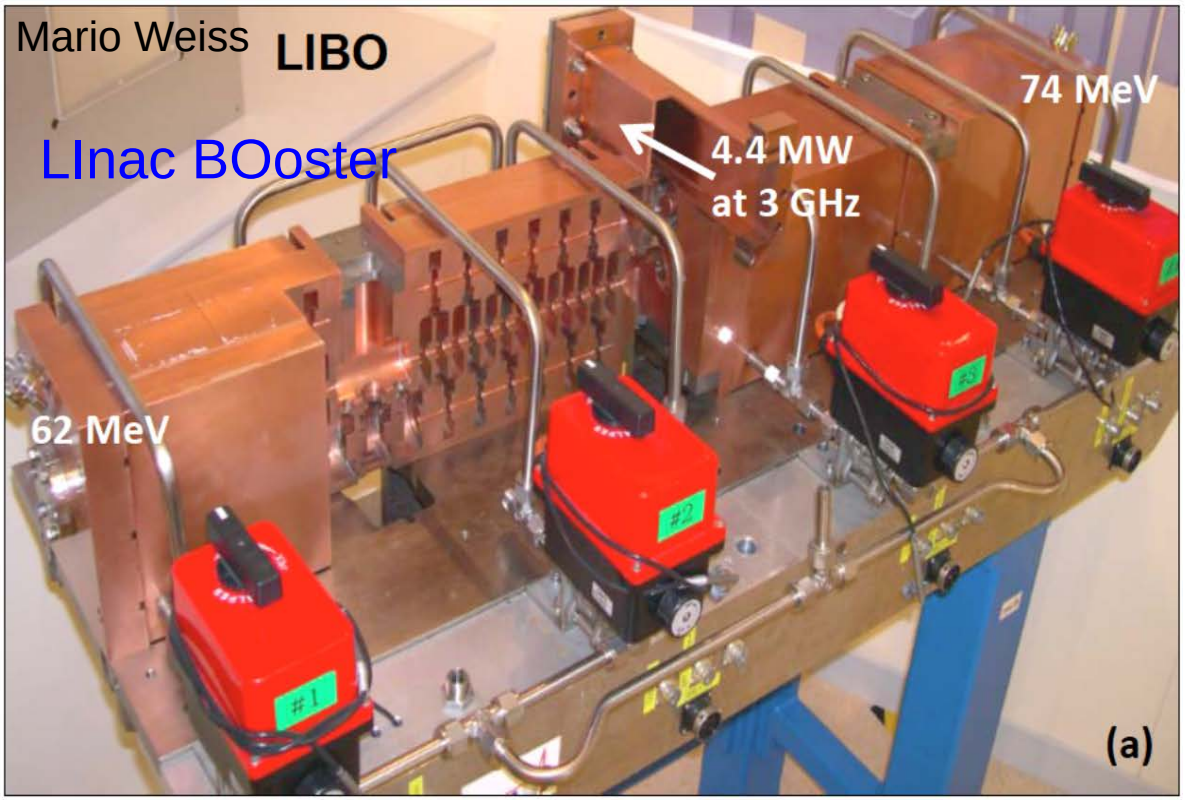
This Unit has accelerated protons from 62 to 74 MeV

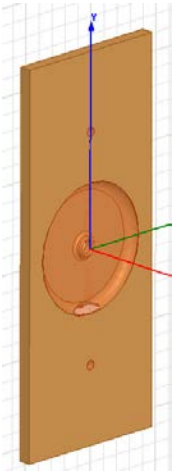
at the same 3 GHz frequency of electron linacs

Nuclear Instruments and Methods in Physics Research A 521 (2004) 512–529

LIBO—a linac-booster for protontherapy: construction and tests of a prototype

U. Amaldi[a,*,1], P. Berra[a], K. Crandall[a], D. Toet[a], M. Weiss[a], R. Zennaro[a], E. Rosso[b], B. Szeless[b], M. Vretenar[b], C. Cicardi[c,d], C. De Martinis[c,d], D. Giove[c,d], D. Davino[e,f], M.R. Masullo[e,f], V. Vaccaro[e,f]

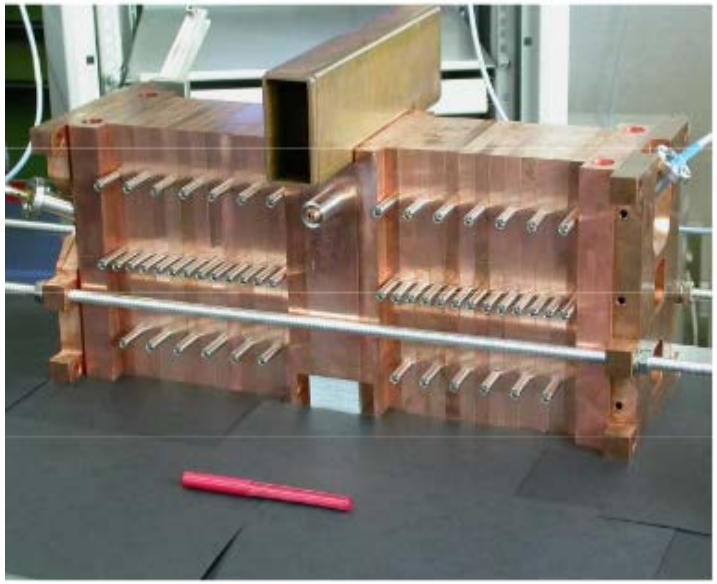




Side Coupled Linac

Basic unit: half-cell

ACLIP – INFN Naple-Milan-Bari



Assembly of the first module

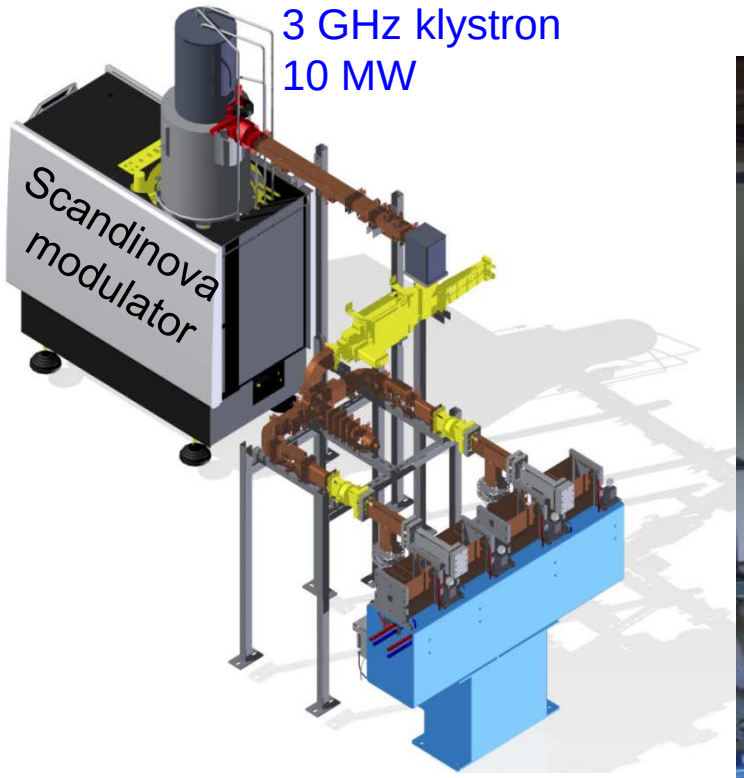
Cyclotrons and Their Applications 2007, Eighteenth International Conference
V. G. Vaccaro et al.
ACLIP: A 3GHz SIDE COUPLED LINAC FOR PROTONTHERAPY TO BE USED AS A BOOSTER FOR 30 MEV CYCLOTRON

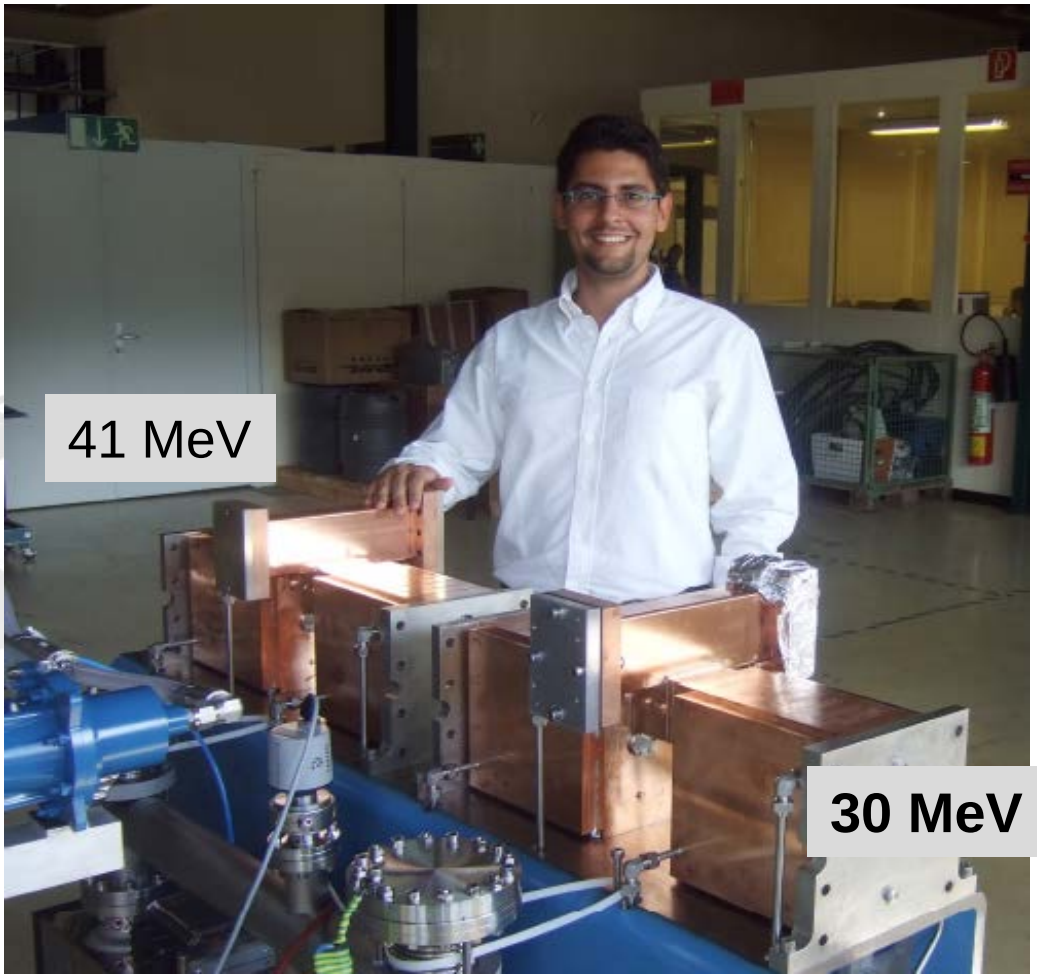
Particle Accelerator Conference 2009,
V. G. Vaccaro et al.
RF HIGH POWER TESTS ON THE FIRST MODULE OF THE ACLIP LINAC

The ACLIP module high power RF test set

First Unit of LIGHT built and power tested by A.D.A.M.: 2011

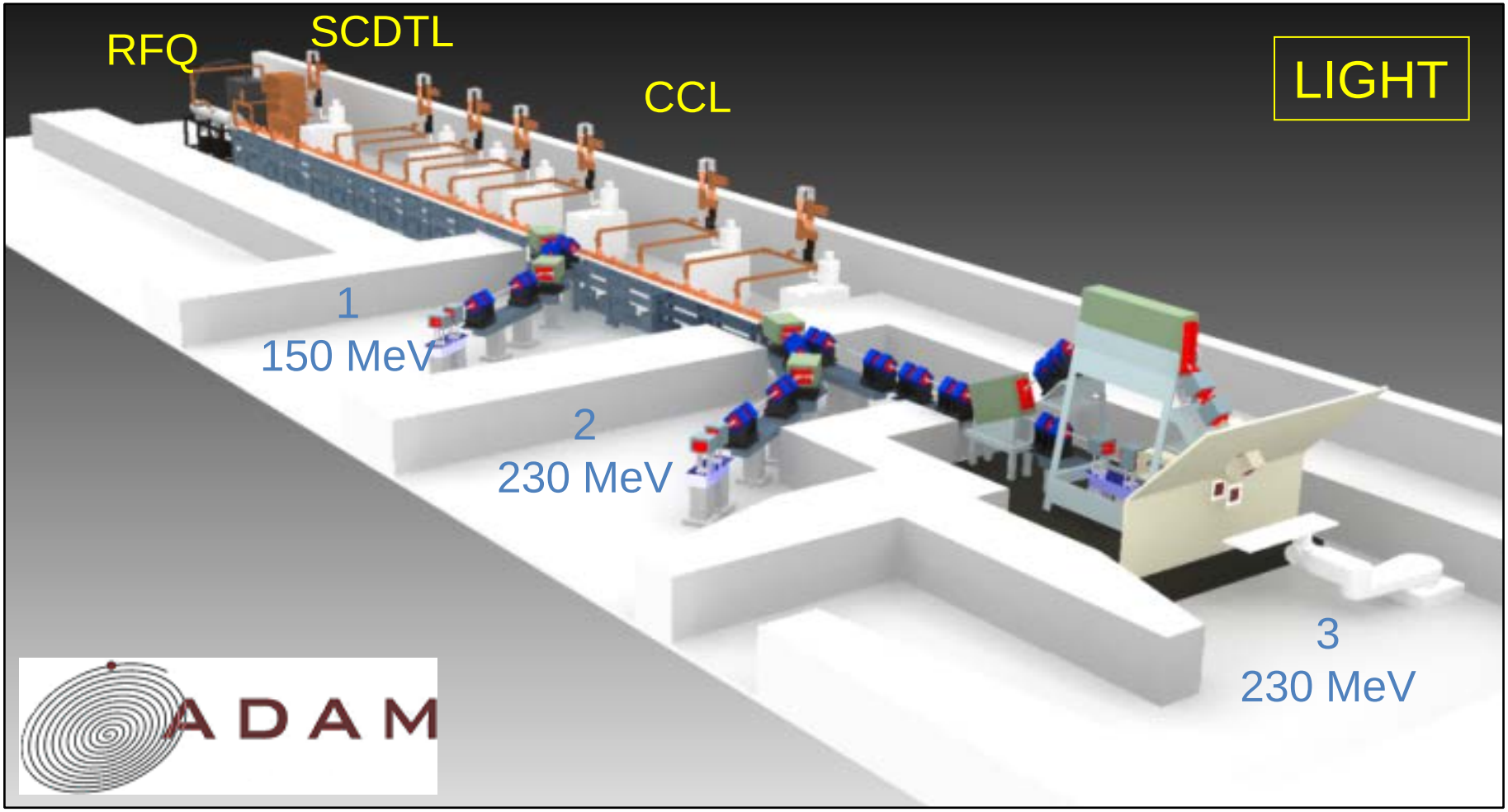
A.D.A.M. = Applications of Detectors and Accelerators to Medicine



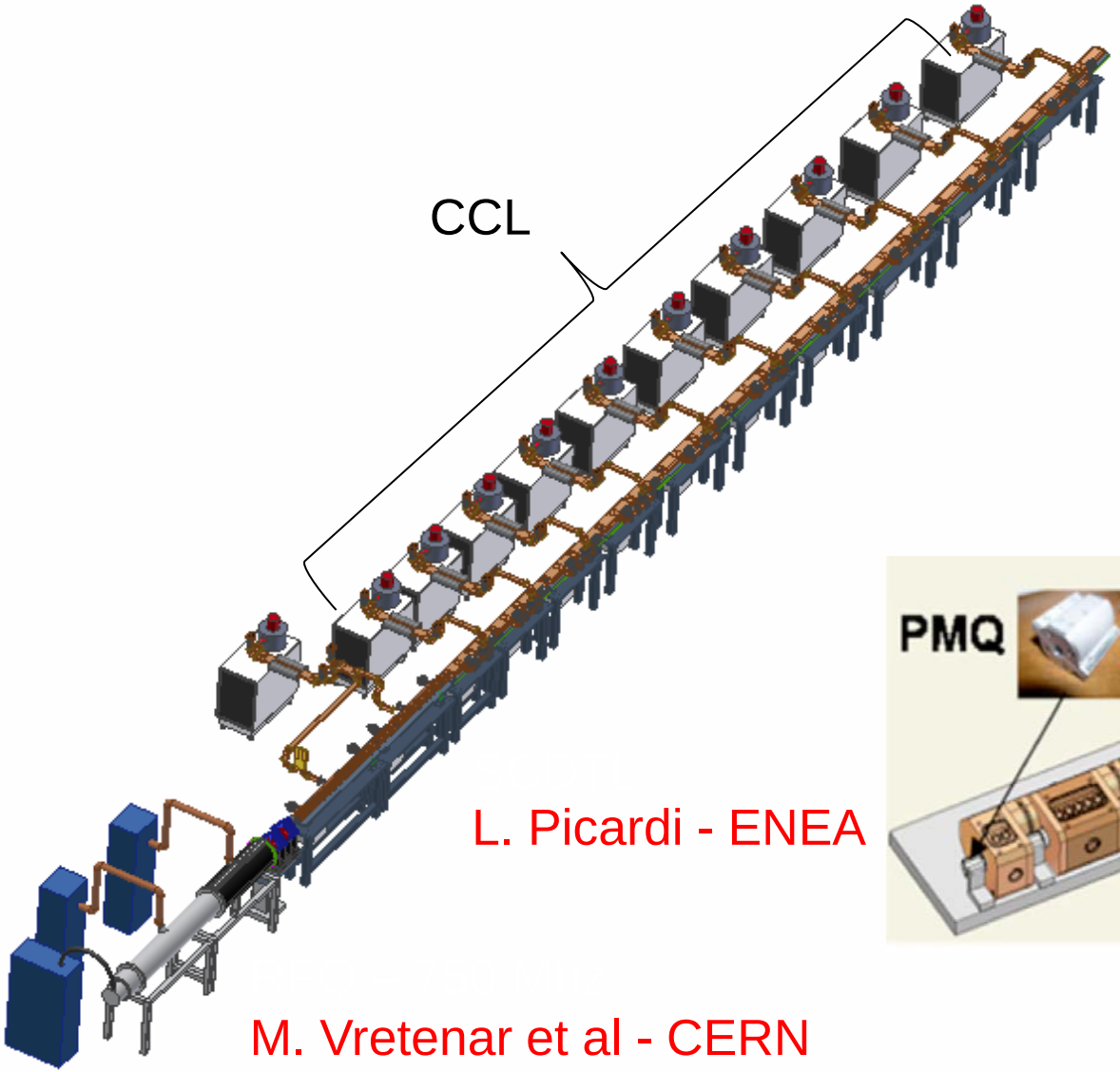


Linac for Image Guided Hadron Therapy

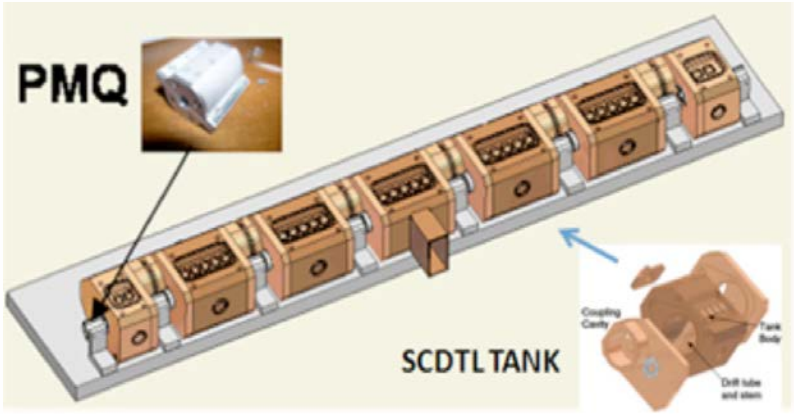
The all-linac LIGHT is being built at CERN by A.D.A.M.



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



proton pulses @ 200 Hz



L. Picardi - ENEA

M. Vretenar et al - CERN

The cyclinac PERLA to be built by TERA: Protontherapy and Exotic Nuclei from Linked Accelerators

24 -230 MeV
CCL- LIGHT
by A.D.A.M.

2 treatment areas
for children

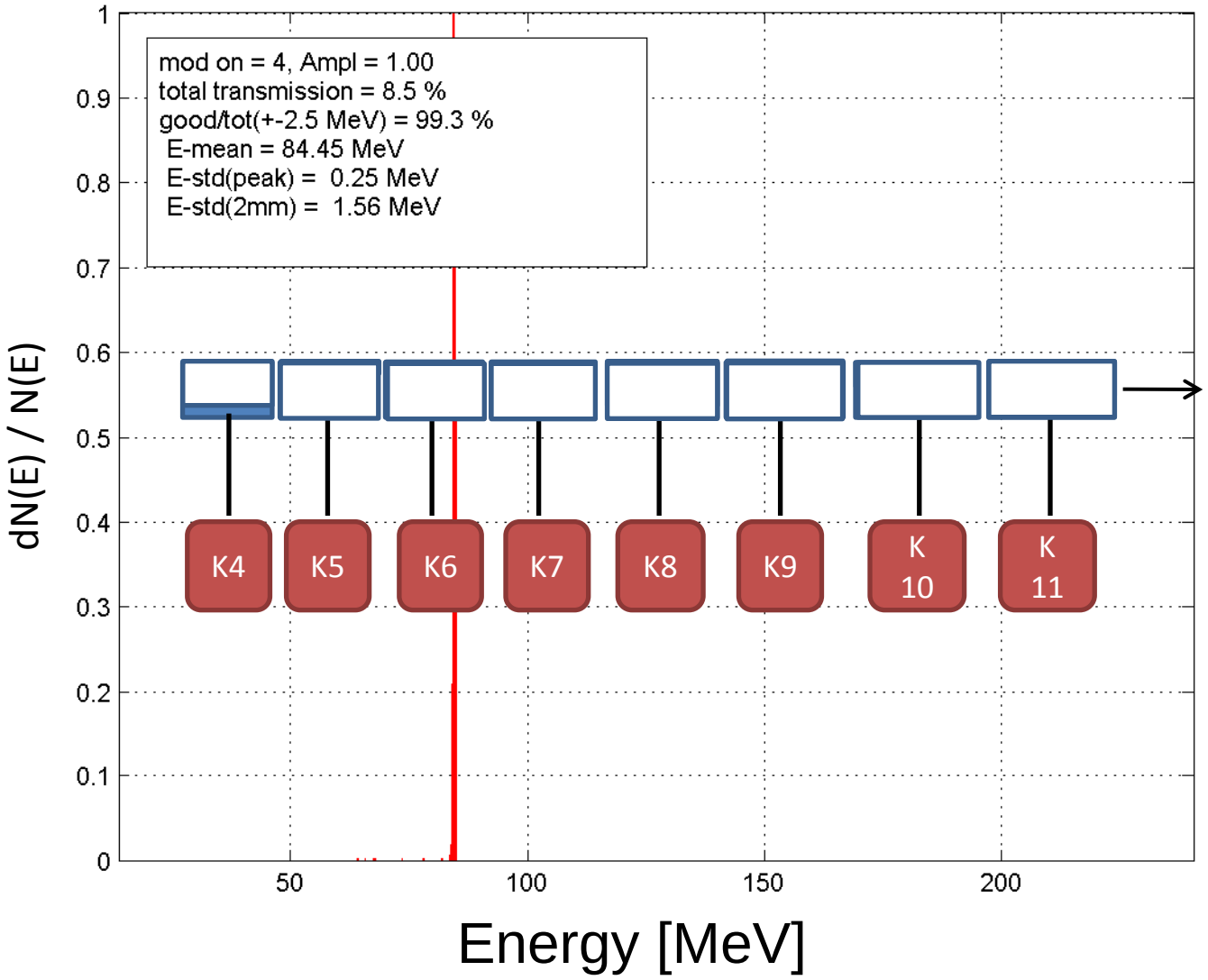
gantry

radiopharmacy

24 MeV cyclotron by ACSI (Canada)

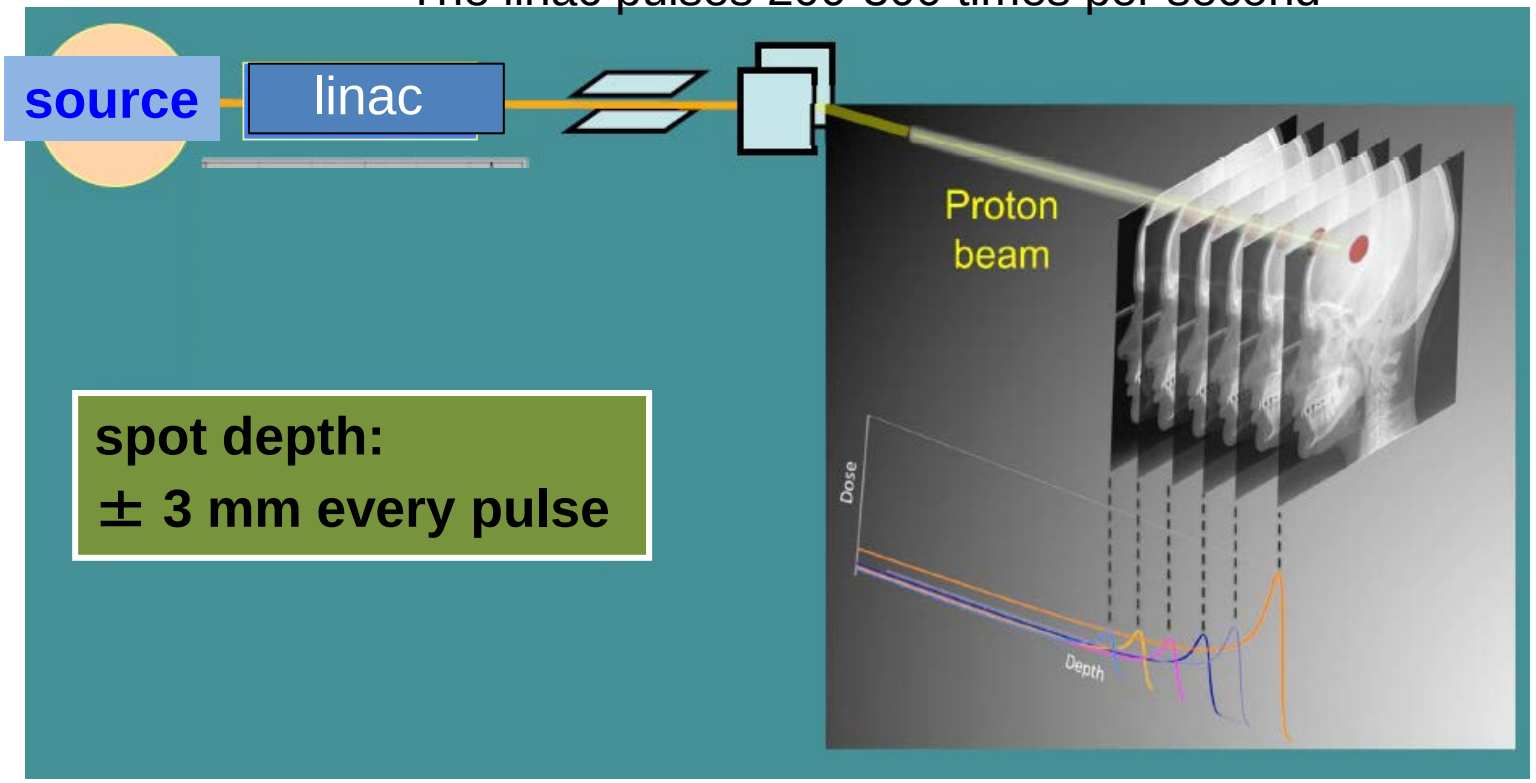
TERA

Unique properties of a linac beam: fast and active energy variation



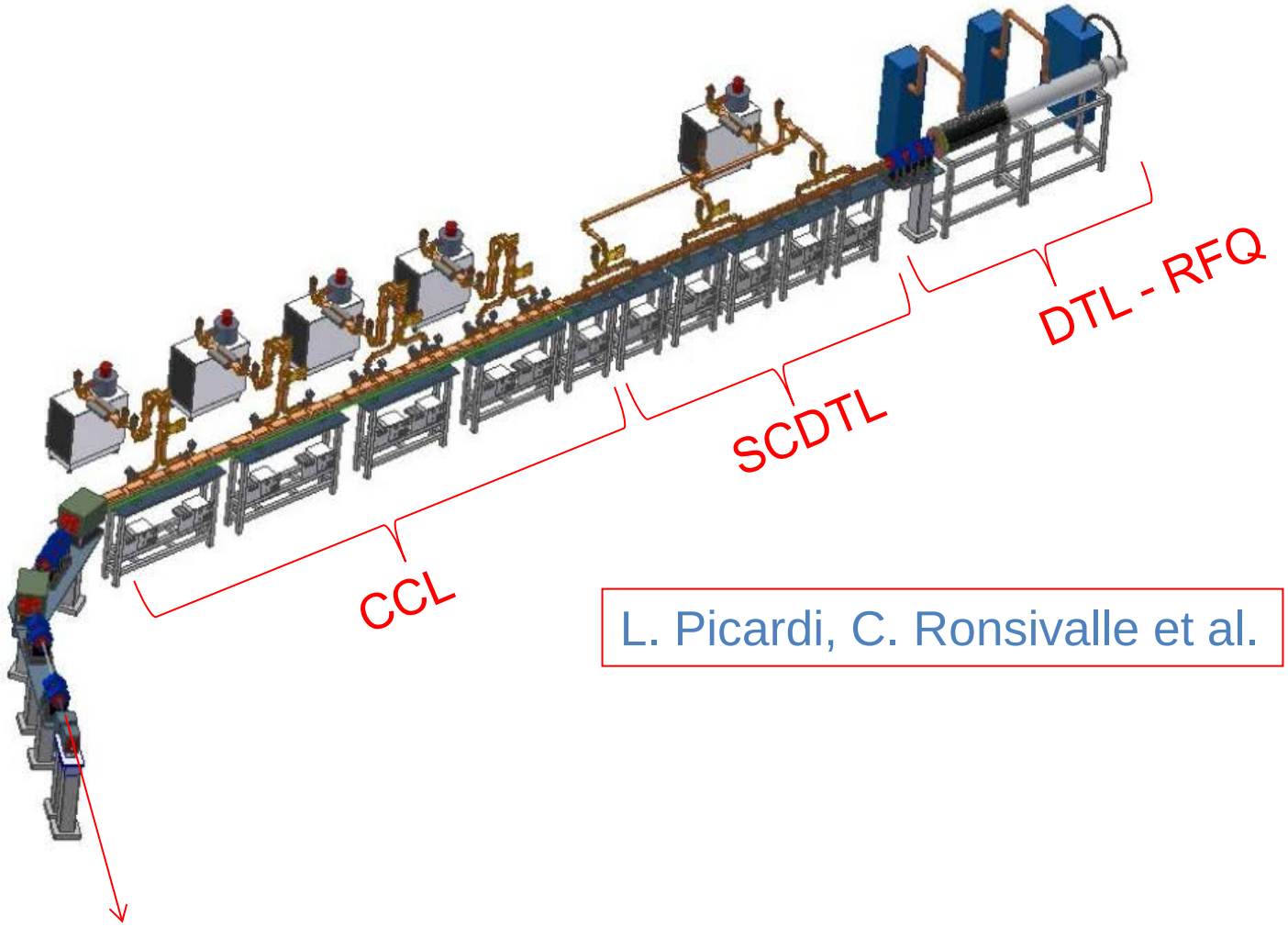
The dose deposition depth can be adjusted every 3 ms

The linac pulses 200-300 times per second



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

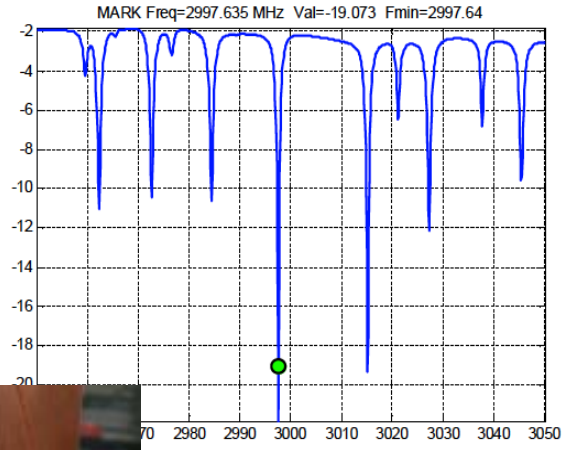


L. Picardi, C. Ronsivalle et al.

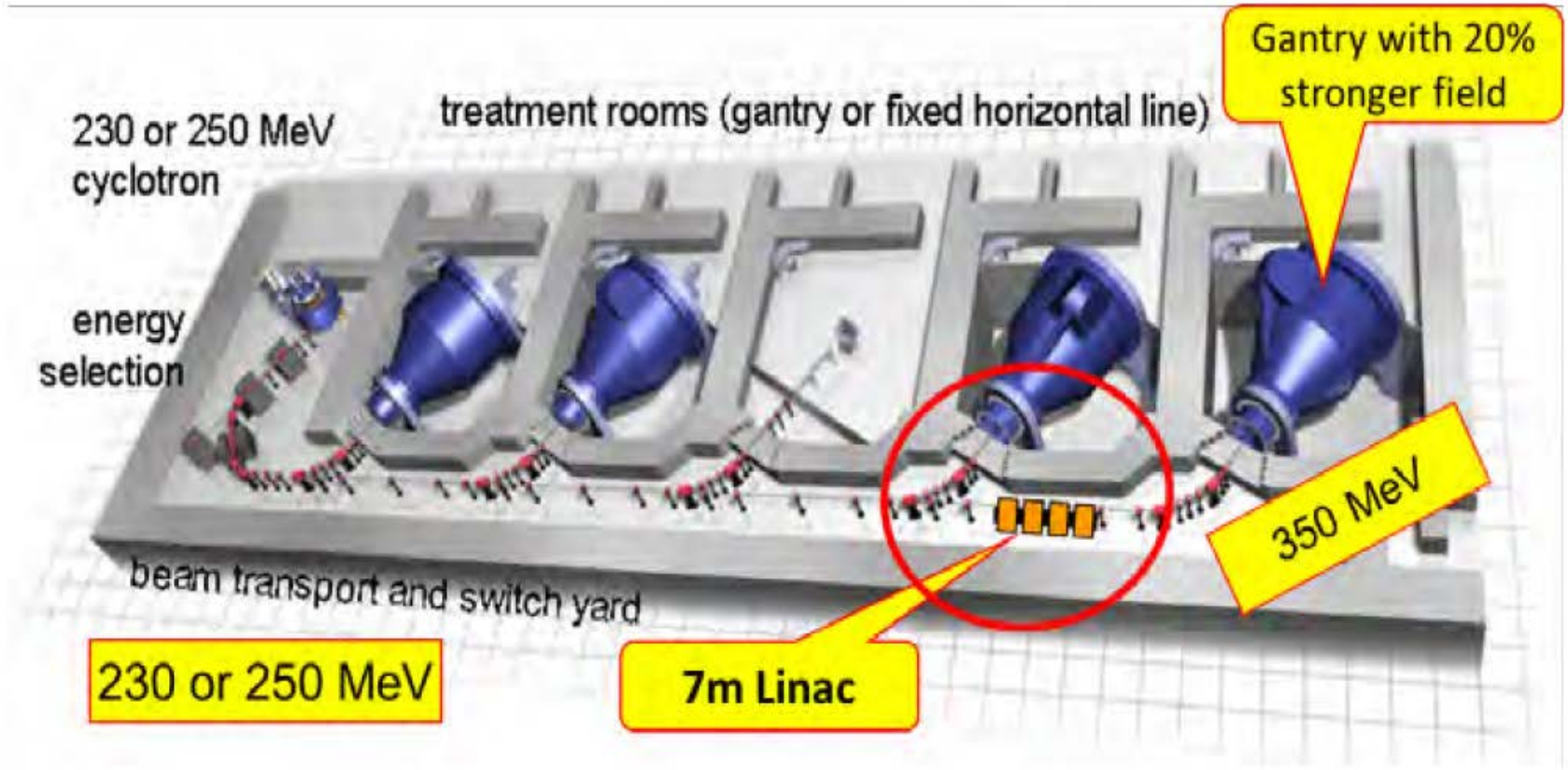
ENEA (Frascati) is building IMPLART= Intensity Modulated Proton Linear Accelerator for RadioTherapy

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



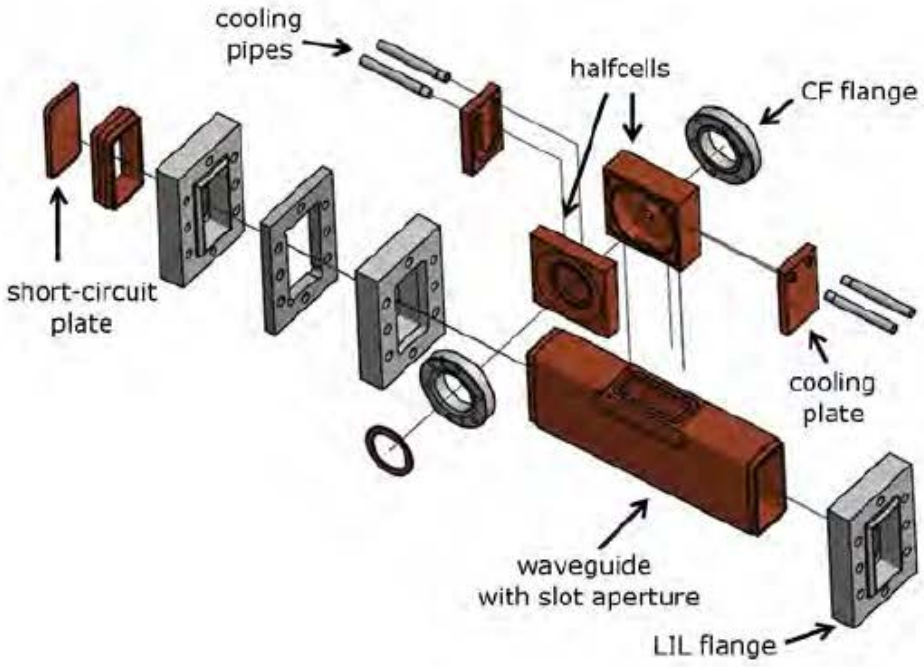
IMPULSE study (PSI-TERA)



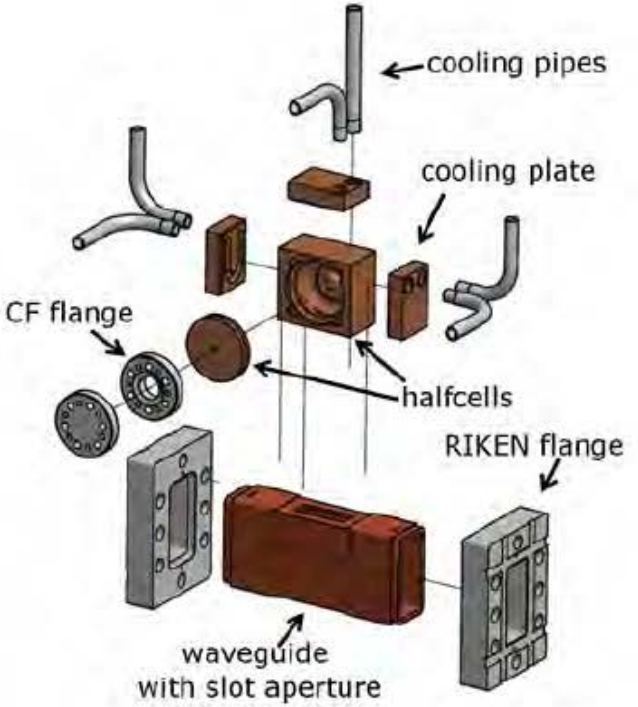
M. Schippers, A. Lomax, L. Stingelin, U. Amaldi, J. Bilbao, A. Degiovanni, and F. Sauli. A next step in proton therapy: boosting to 350 MeV for therapy and radiography applications. PTCOG Conference - Seoul, May 2012.

Studies for the future:
high-gradient hadron structures

Cavities at 3 and 5.7 GHz have been built and tested by TERA in collaboration with CLIC group (W.Wuensch et al)



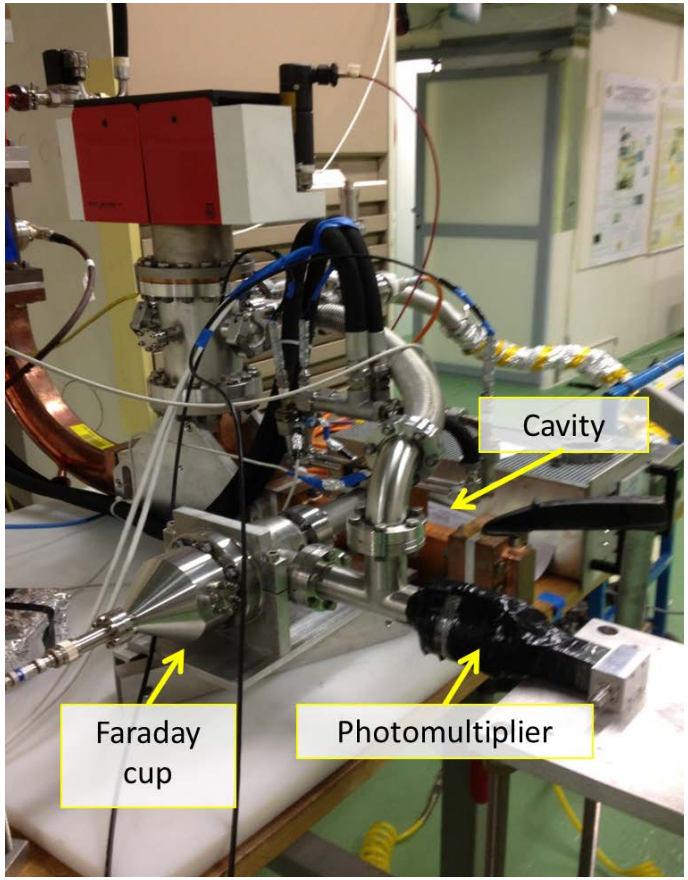
(a) S-band test cavity

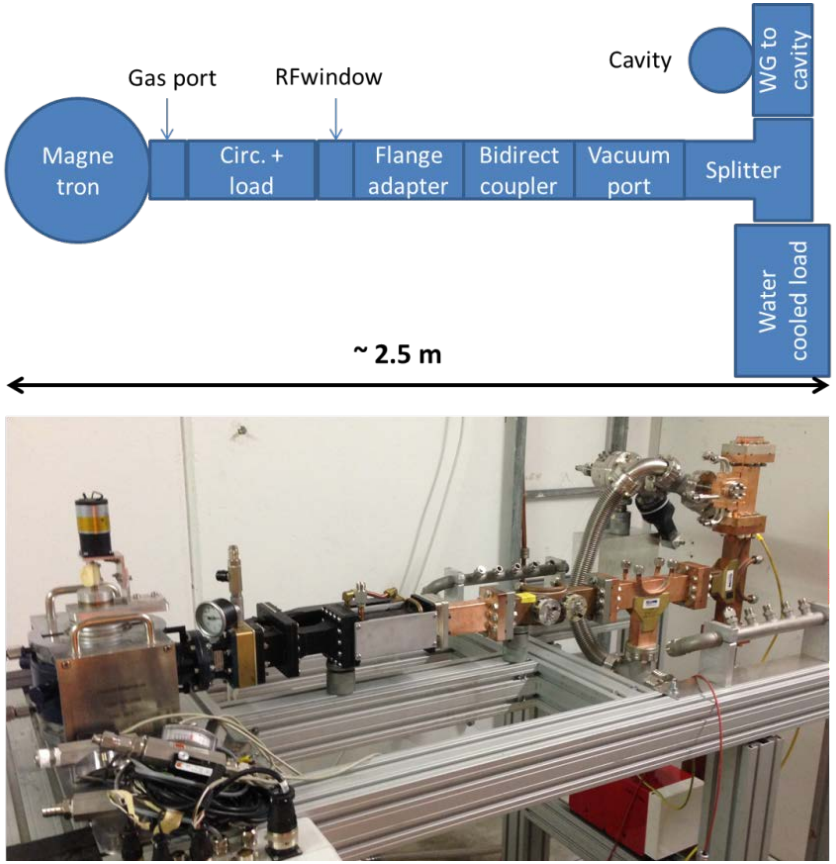


(b) C-band test cavity

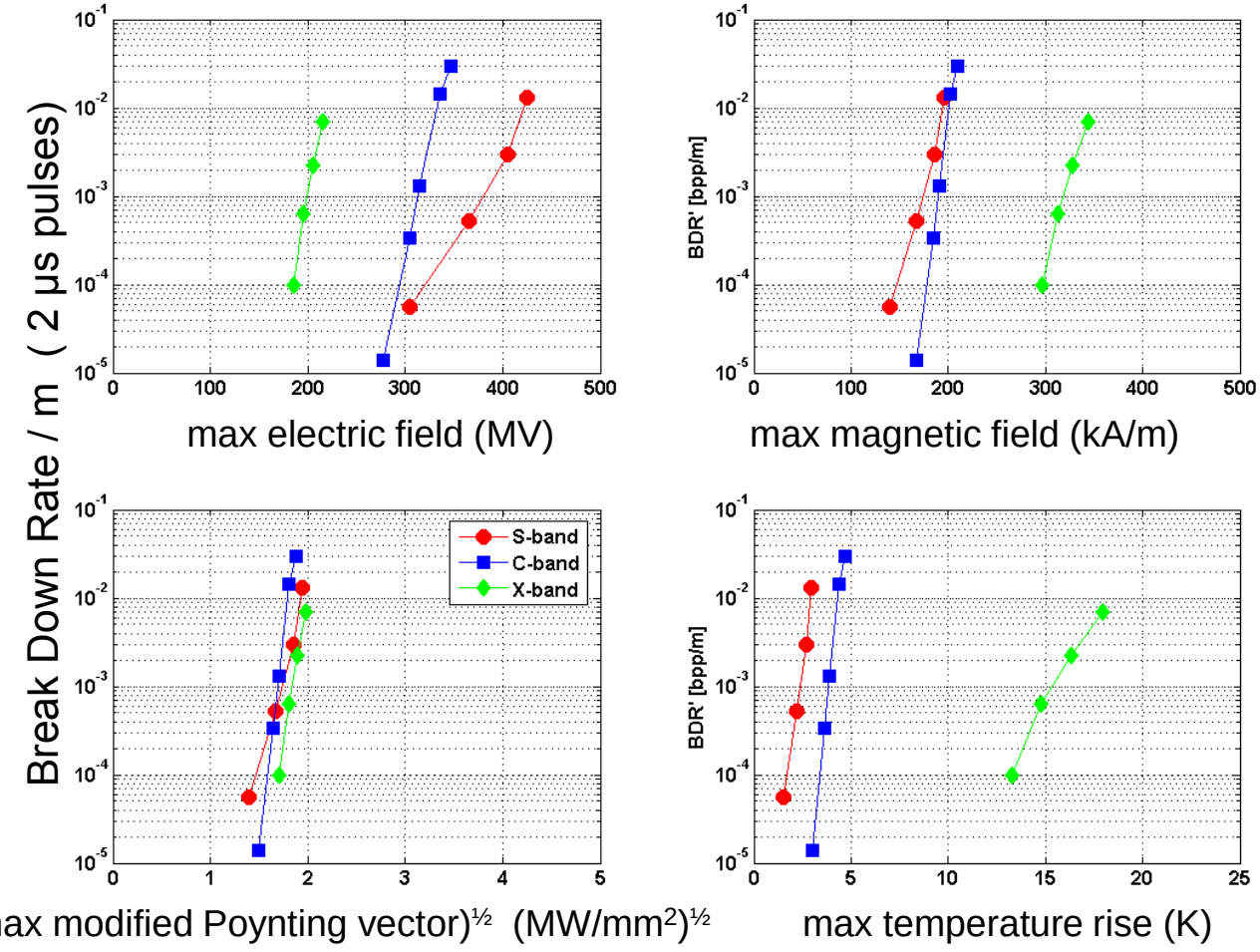
S. Verdú Andrés. *High-gradient accelerating structure studies and their application in hadrontherapy.* PhD thesis, Univeristat de València, 2013.

High power test setup



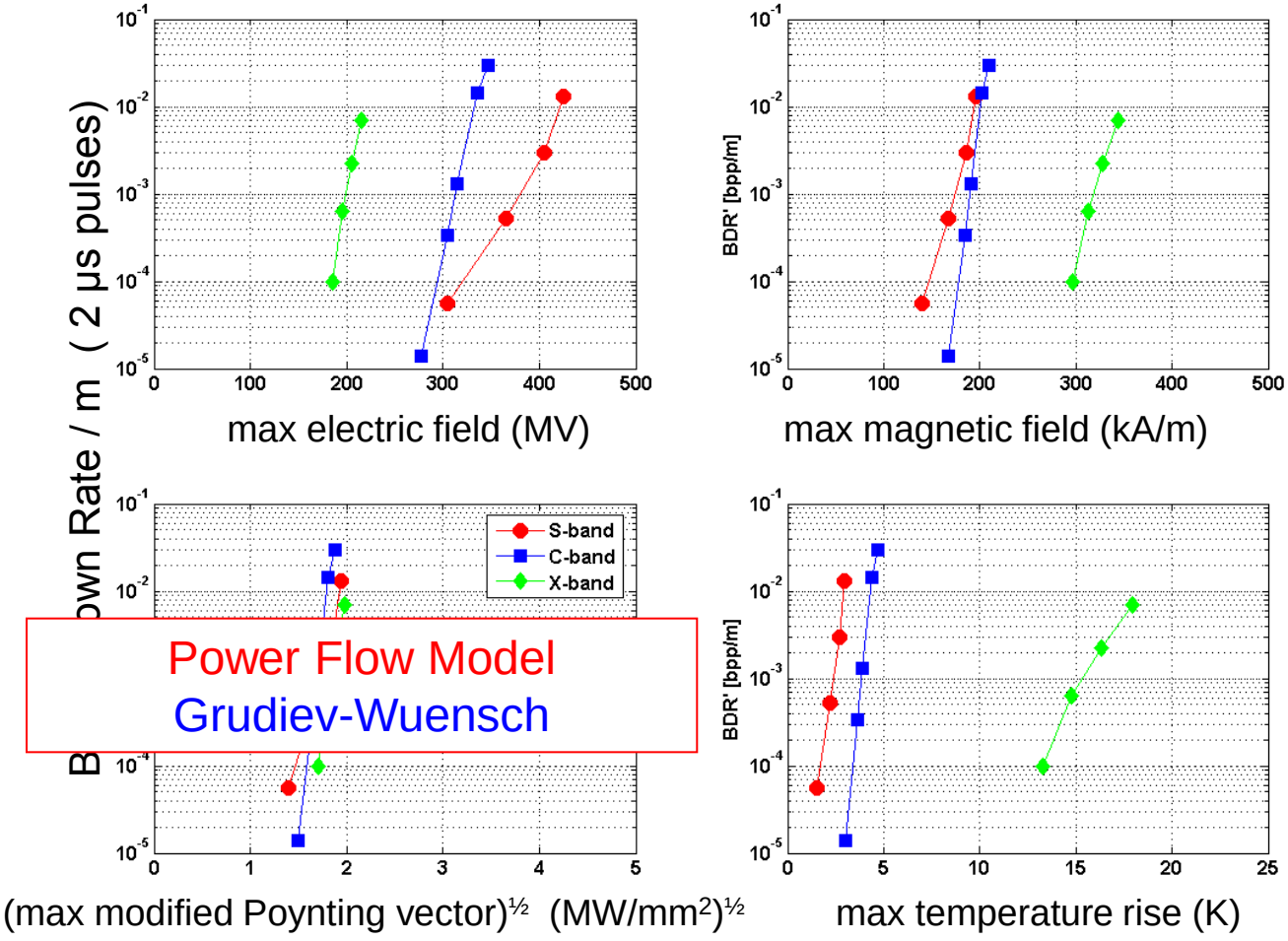


Test cavities at 3 and 5.7 GHz have been built and tested by TERA



A. Degiovanni, *High Gradient Proton Linacs for Medical Applications*, PhD Thesis 6069 EPFL

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



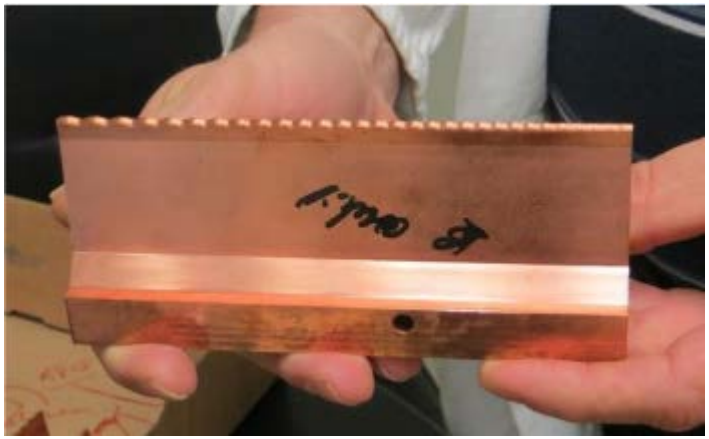
A. Degiovanni, *High Gradient Proton Linacs for Medical Applications*, PhD Thesis 6069 EPFL

The High Frequency RFQ for medical applications

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

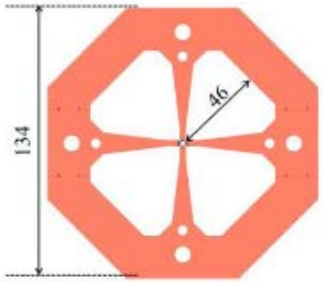
1. Injector for proton therapy linac
2. Two units (10 MeV) for radioisotope production

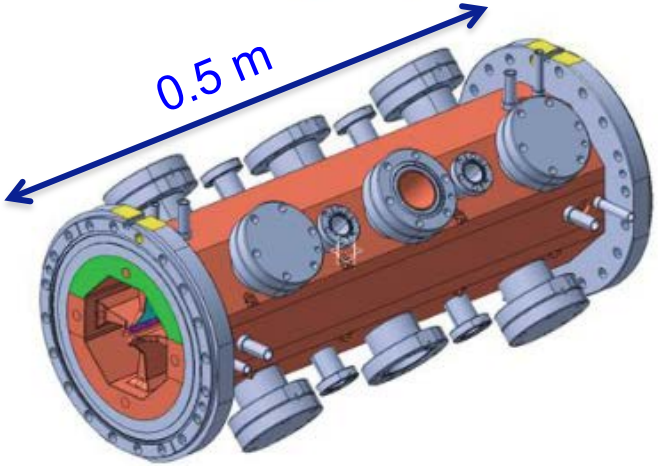
Modulation machining test on a minor vane

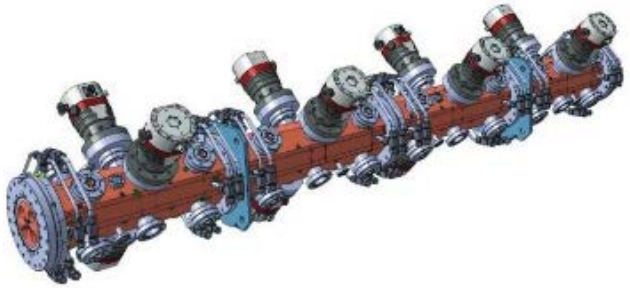


LINAC Conference 2014,
M. Vretenar et al.
A COMPACT HIGH-FREQUENCY RFQ FOR MEDICAL APPLICATIONS

IPAC Conference 2015,
A. Lombardi et al.
BEAM DYNAMICS IN A HIGH FREQUENCY RFQ



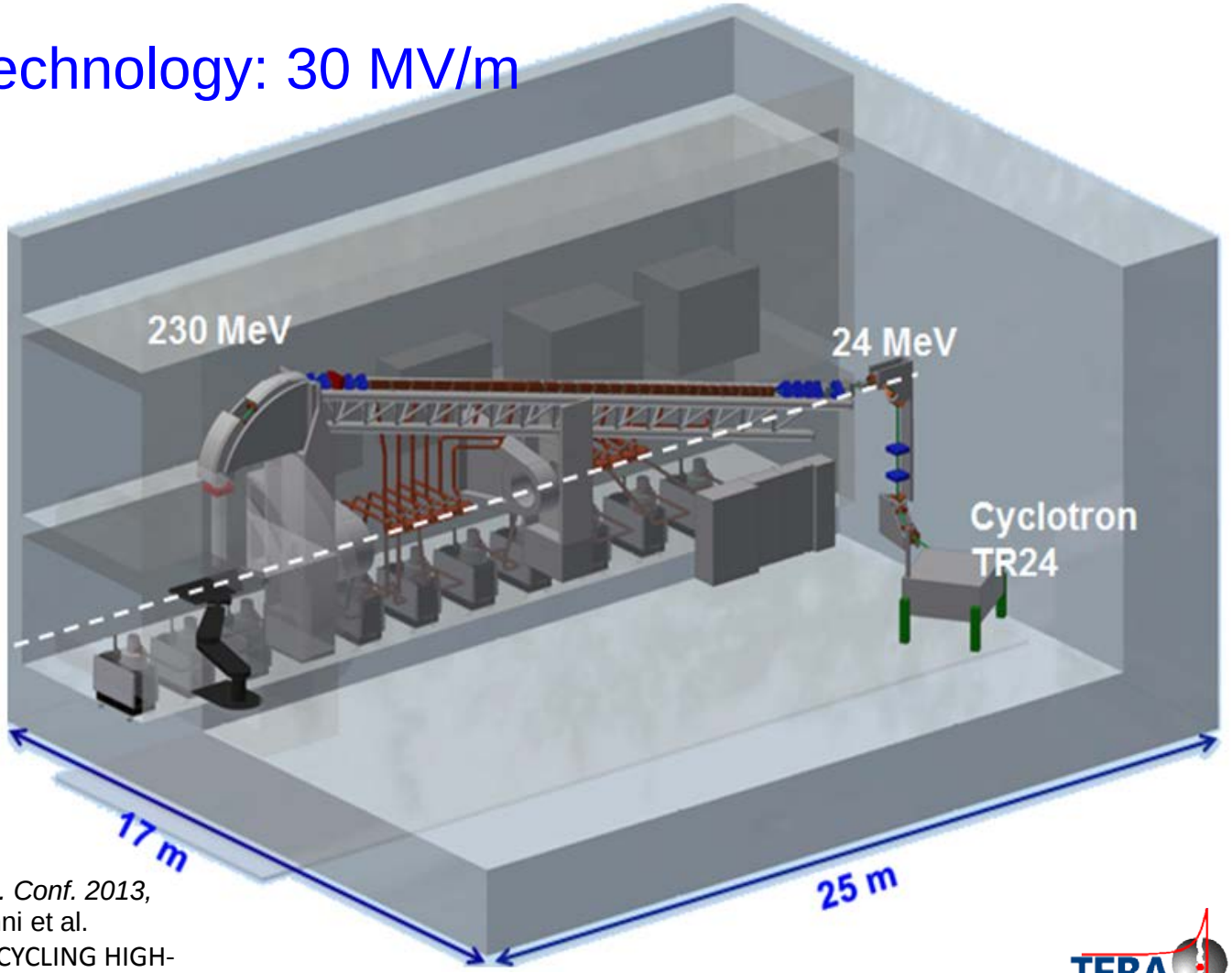




The future high-gradient linac: TULIP
TUrning LInac for Protontherapy

TULIP by TERA
with to-day technology: 30 MV/m

present technology: 30 MV/m



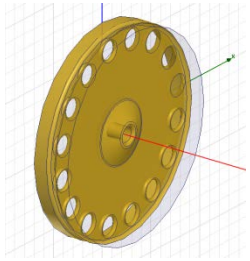
Int. Particle Accel. Conf. 2013,
A. Degiovanni et al.
DESIGN OF A FAST-CYCLING HIGH-GRADIENT ROTATING LINAC FOR PROTONTHERAPY

New high-gradient "backward" TW structure

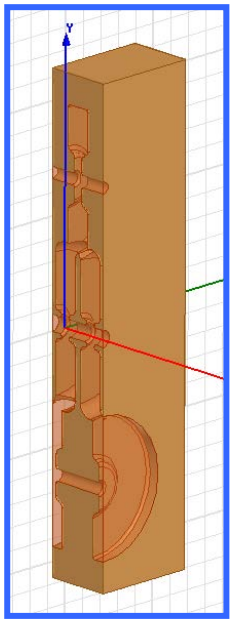
'NEW' bwTW
50 MV/m
BDR = 10^{-6} m^{-1}
(20% more power for same gradient)

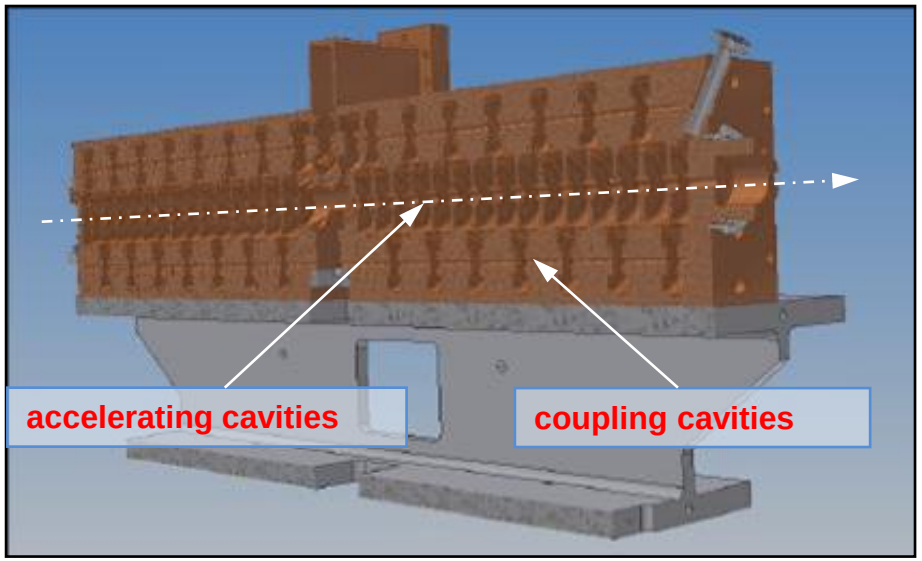
PROPOSED by A. GRUDIEV /CLIC
financed by KT

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

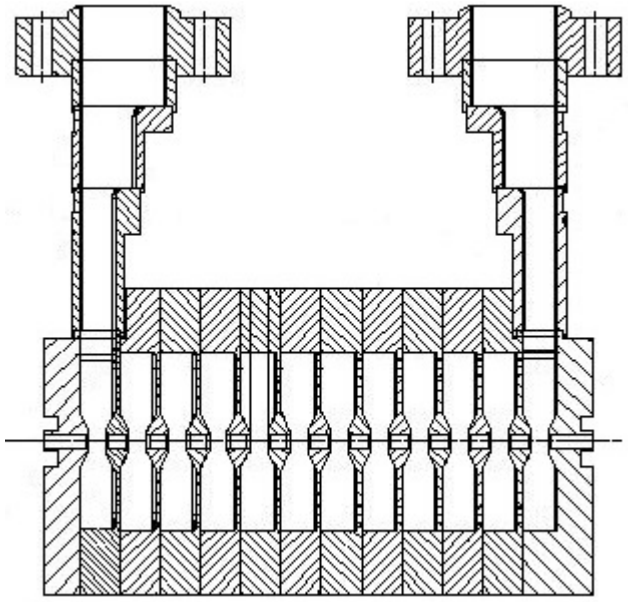


With recirculation:
I. SYRATCHEV

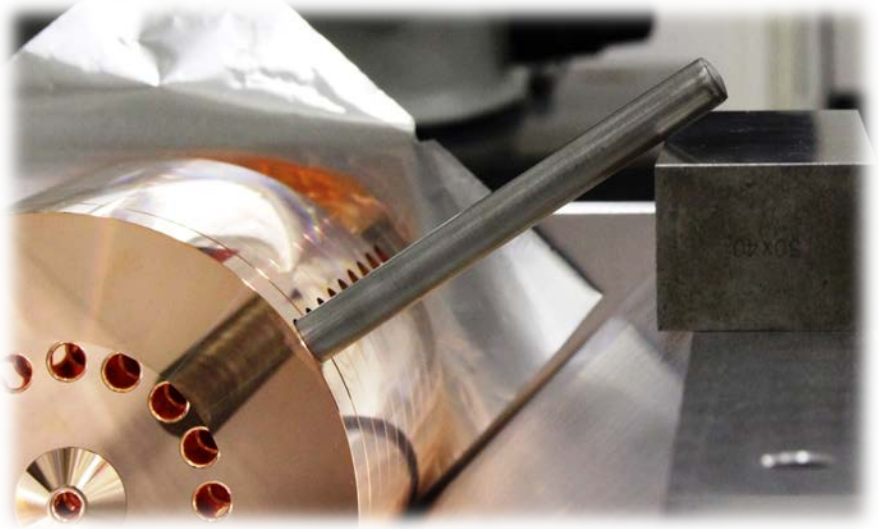




Travelling wave linac prototype



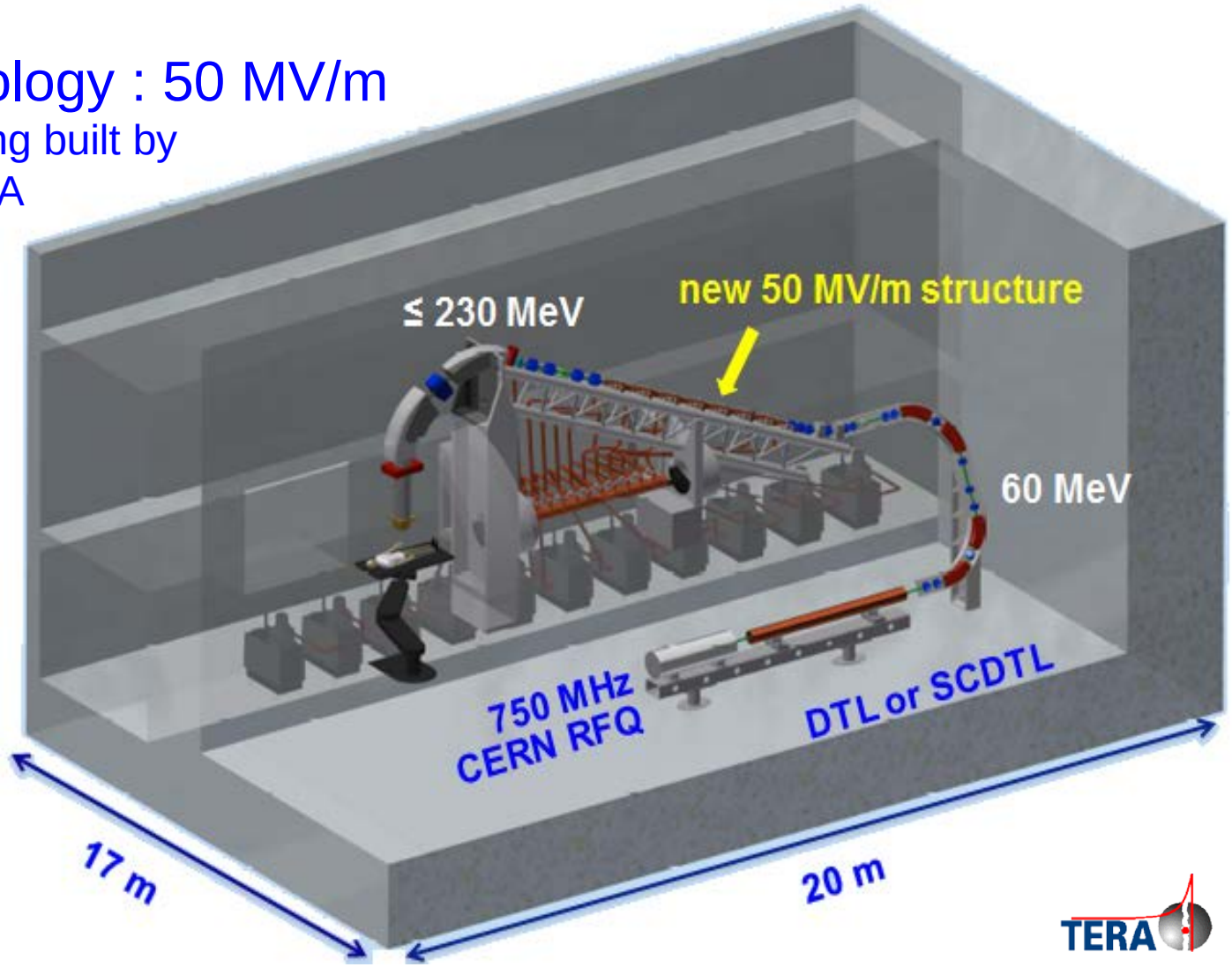
LINAC Conference 2014,
S. Benedetti et al.
RF DESIGN OF A NOVEL BACKWARD TRAVELLING WAVE LINAC FOR PROTON THERAPY



TULIP 2-0 by CERN and TERA

CLIC technology : 50 MV/m

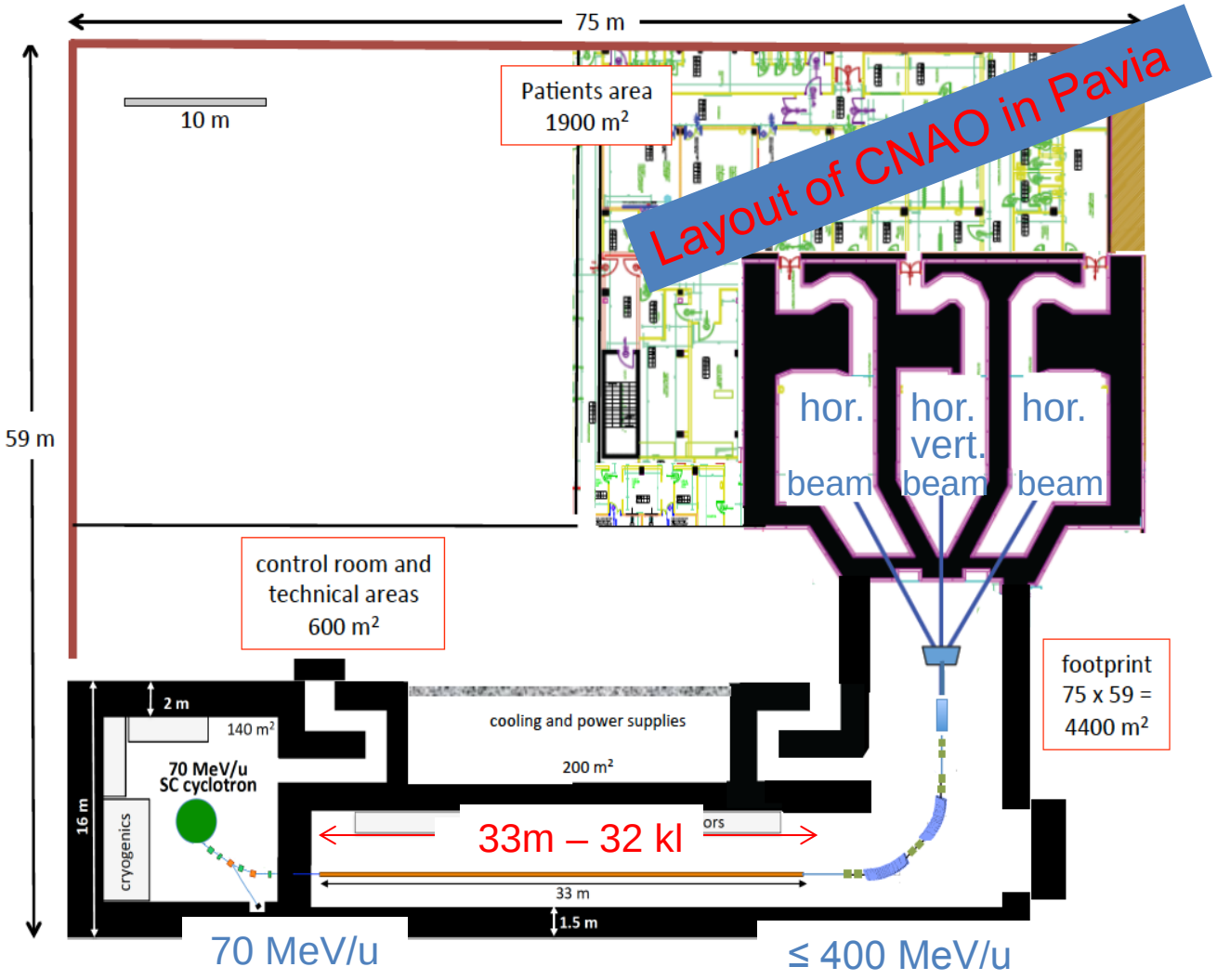
prototype is being built by
CERN and TERA



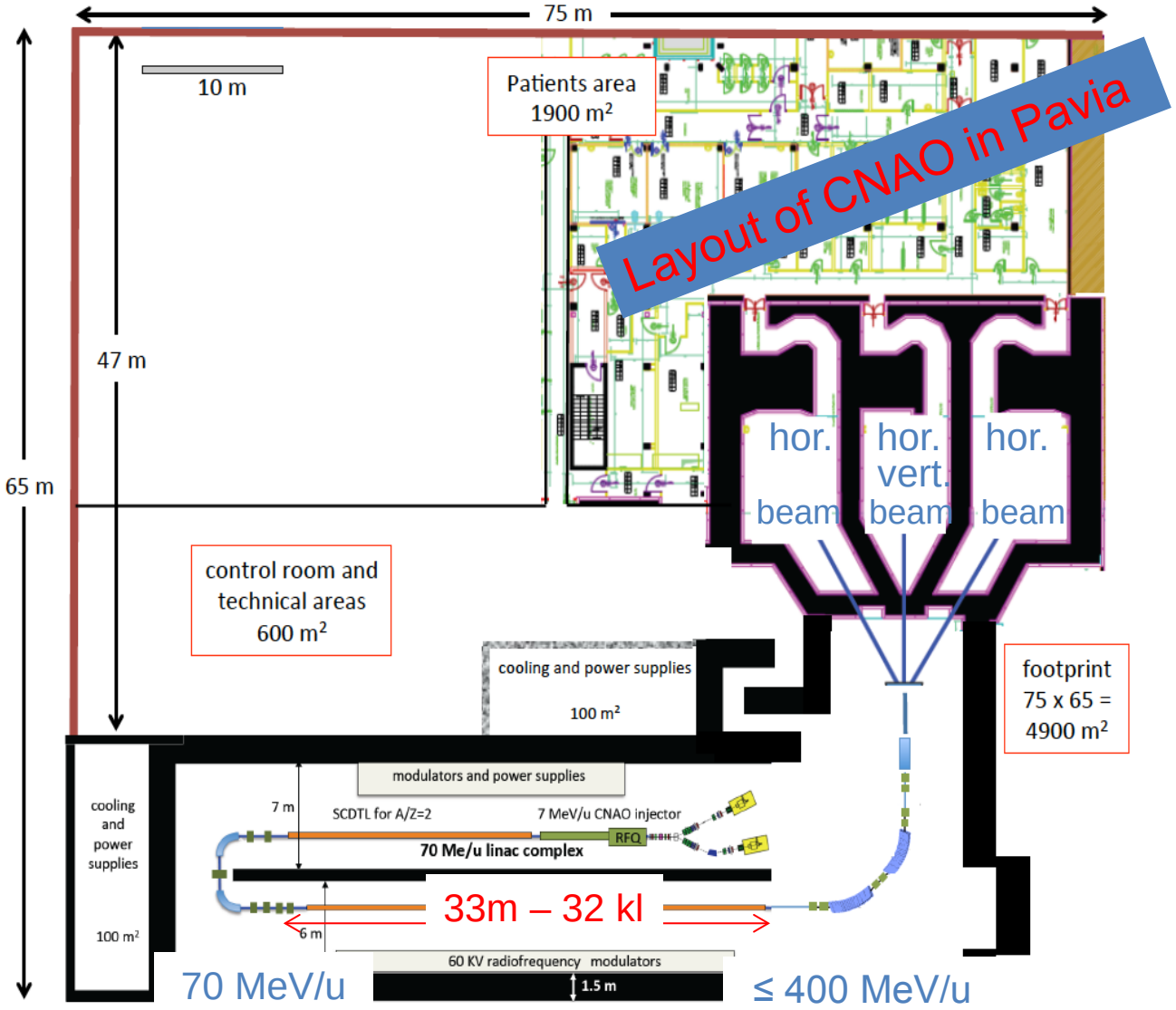
The future high-efficiency linac: CABOTO

CArbon BOoster for Therapy in Oncology

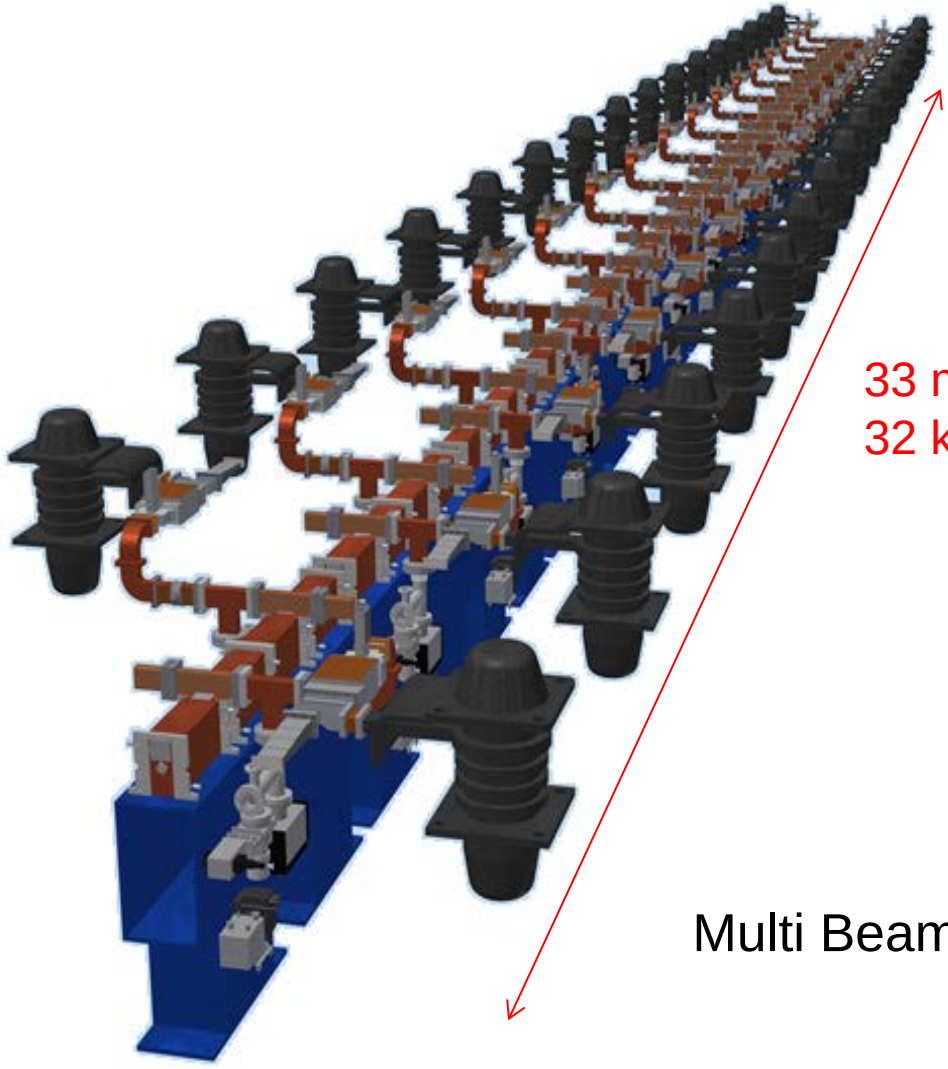
The cyclinac CABOTO runs at 300 Hz



The all-linac CABOTO runs at 300 Hz



High-efficiency CABOTO using MBK will consume 1 MW



33 meters
32 klystrons

Novel
Multi Beam Klystrons

Summary

- 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 an hospital to treat patients
- The prototype of an high-frequency RFQ is being built at CERN with the support of the CERN medical application office.
- 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