PROTON AND CARBON LINACS FOR HADRONTHERAPY

Ugo Amaldi

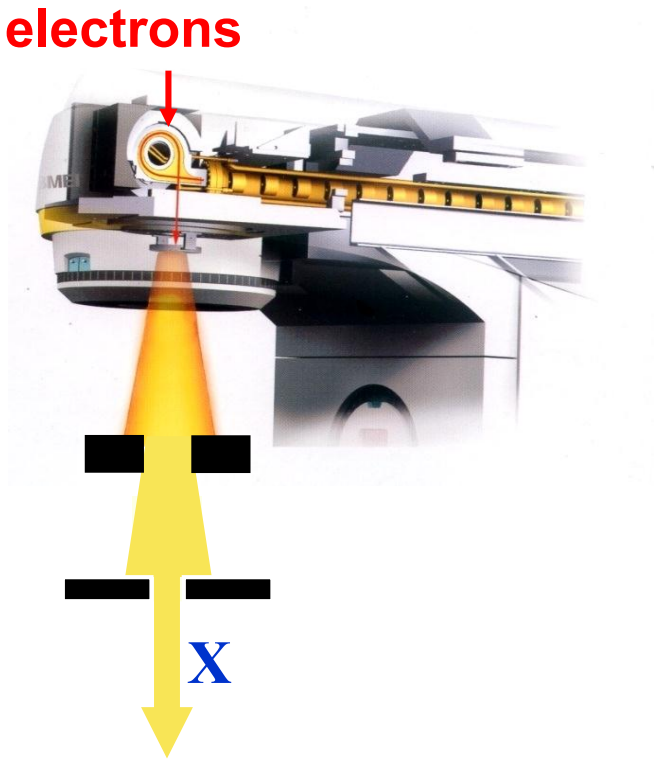
TERA Foundation

Alberto Degiovanni

CERN

The beginnings

Conventional X-ray therapy

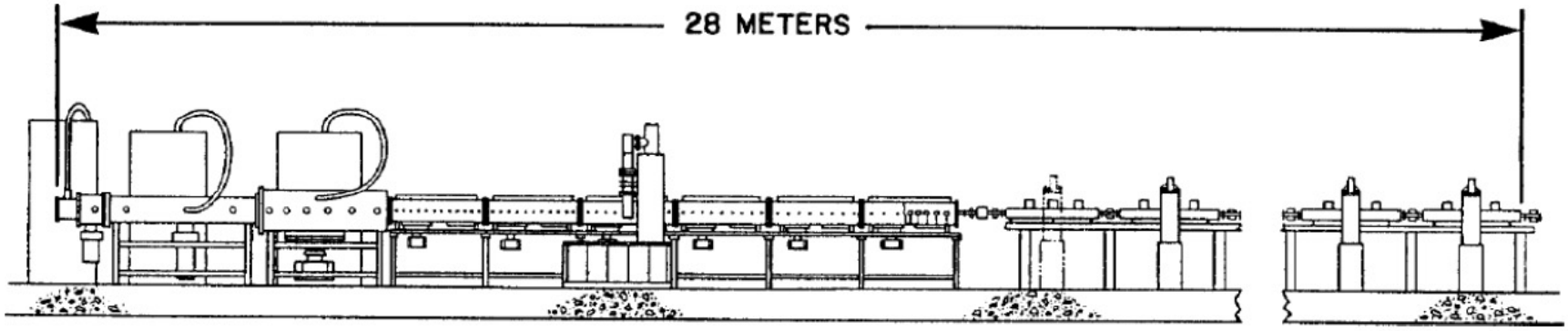


2000 patients/year every in 1 million inhabitants

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.

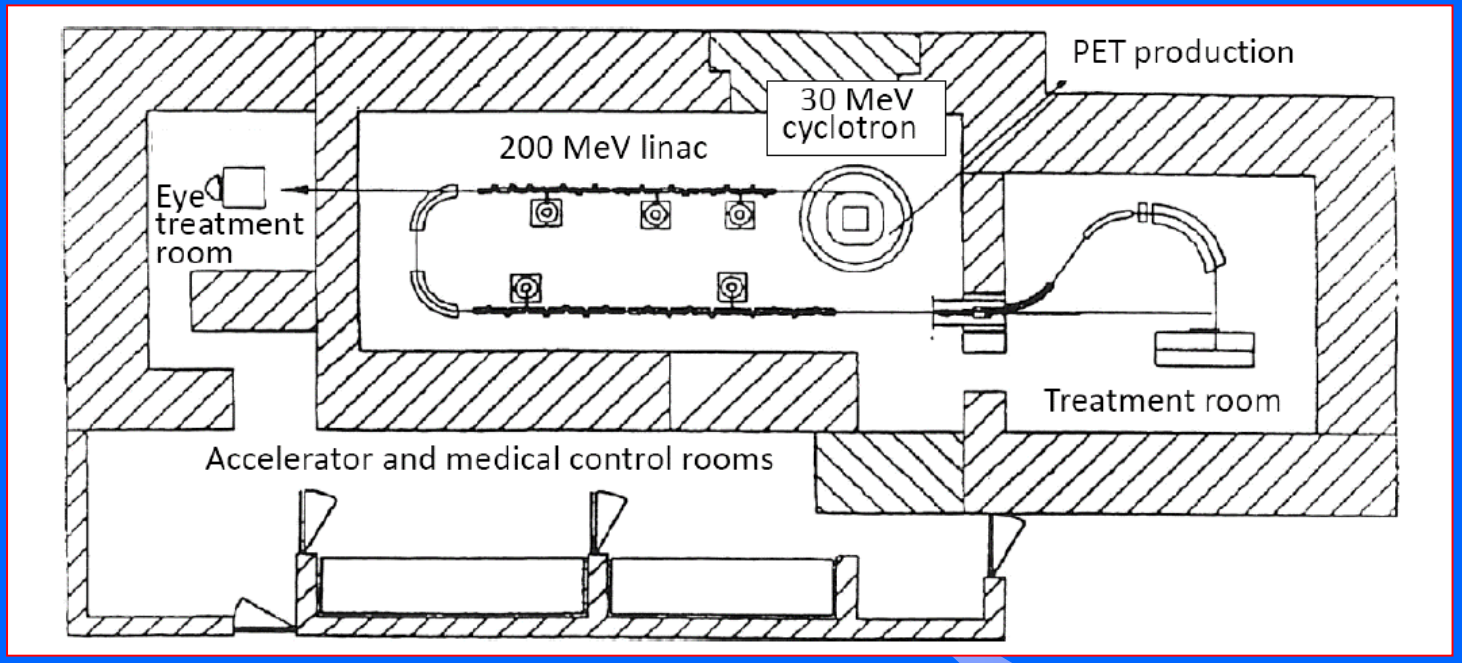
review paper

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

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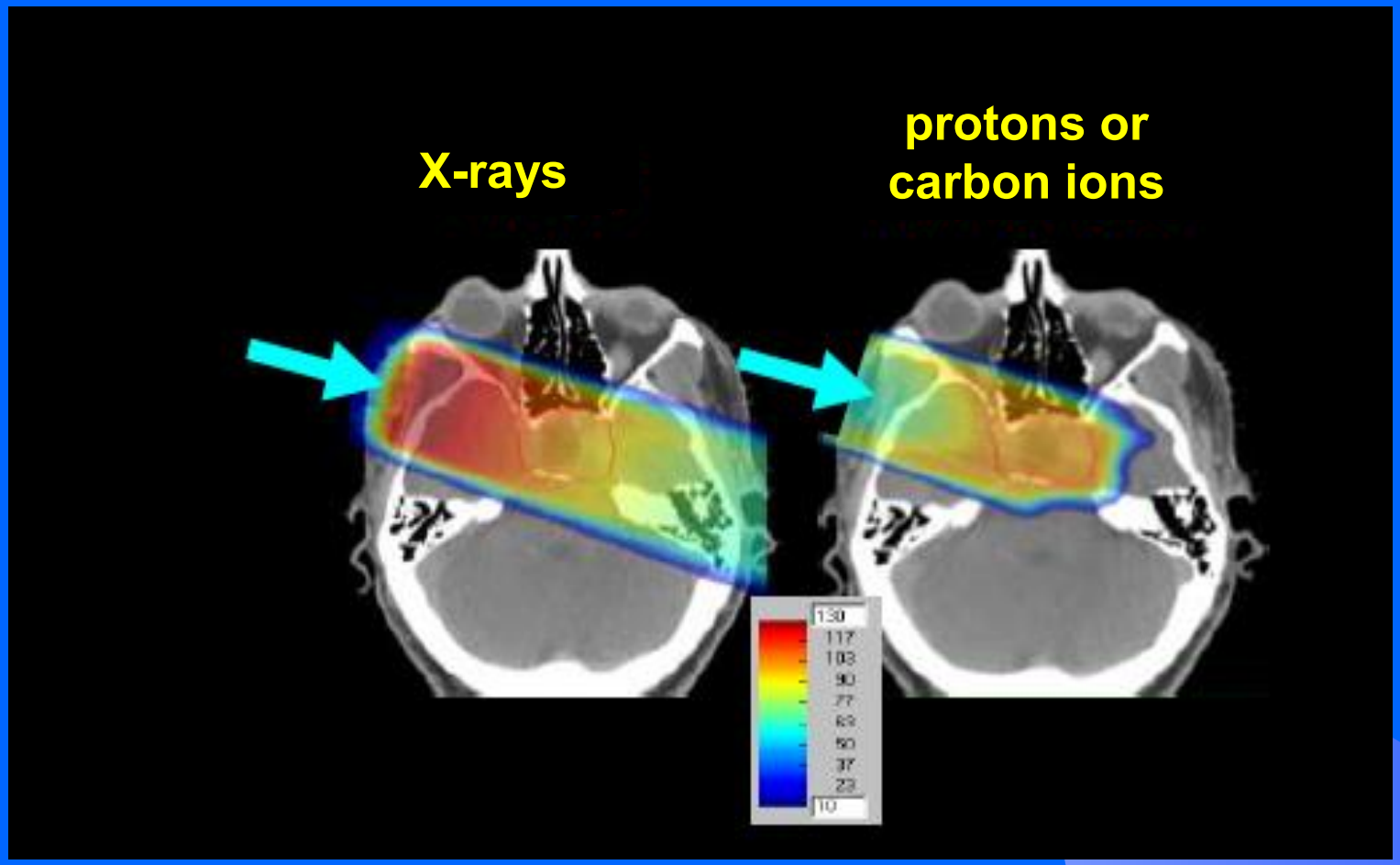
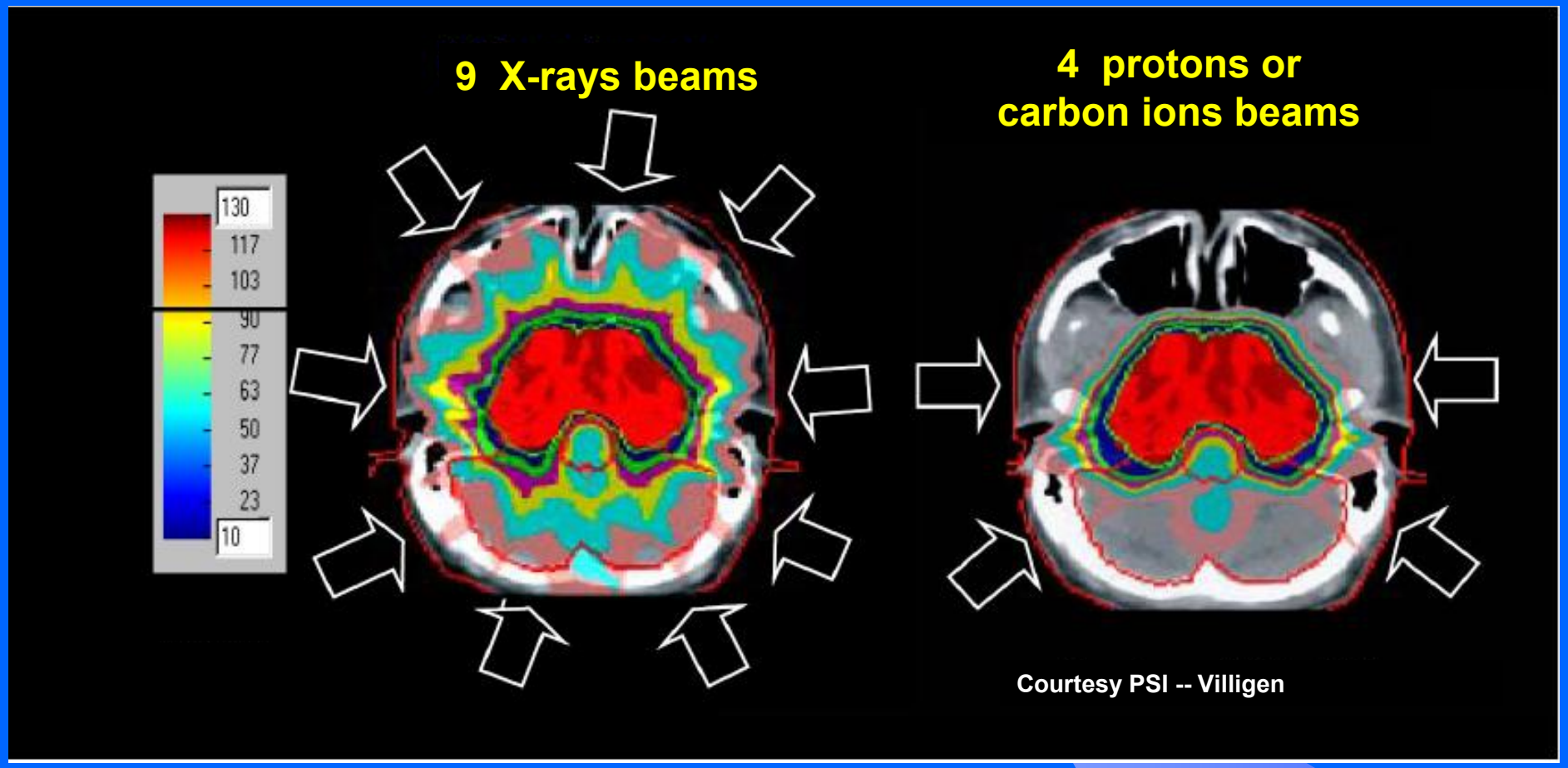
The rationale of proton and carbon tumour therapy

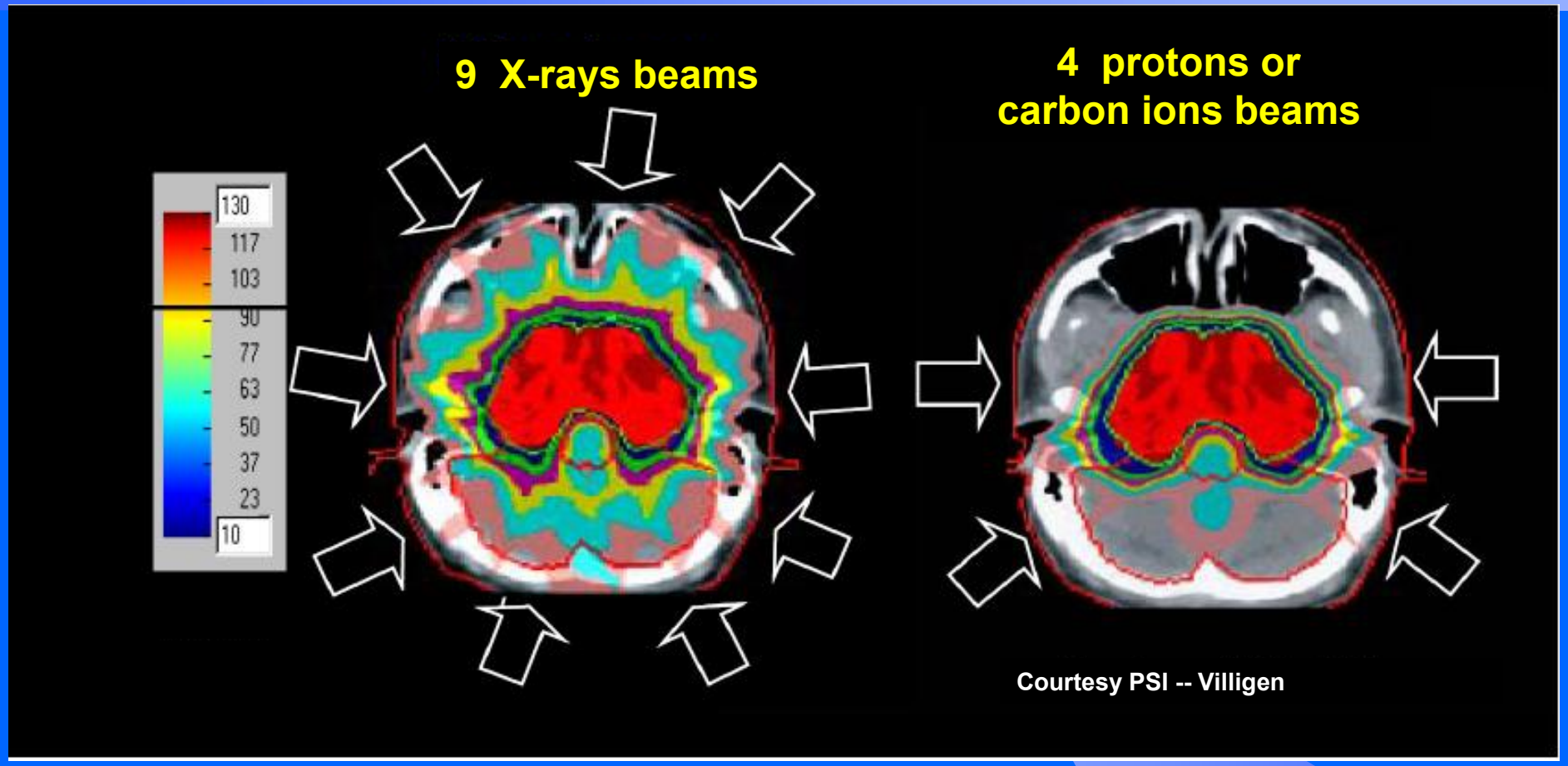
X-rays have two problems :
1. they irradiate unwanted close-by 'critical' organs
2. they cannot cure 'radioresistant' tumours (about 5%)



Advantages of hadrontherapy: 1. normal tissues are speared



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

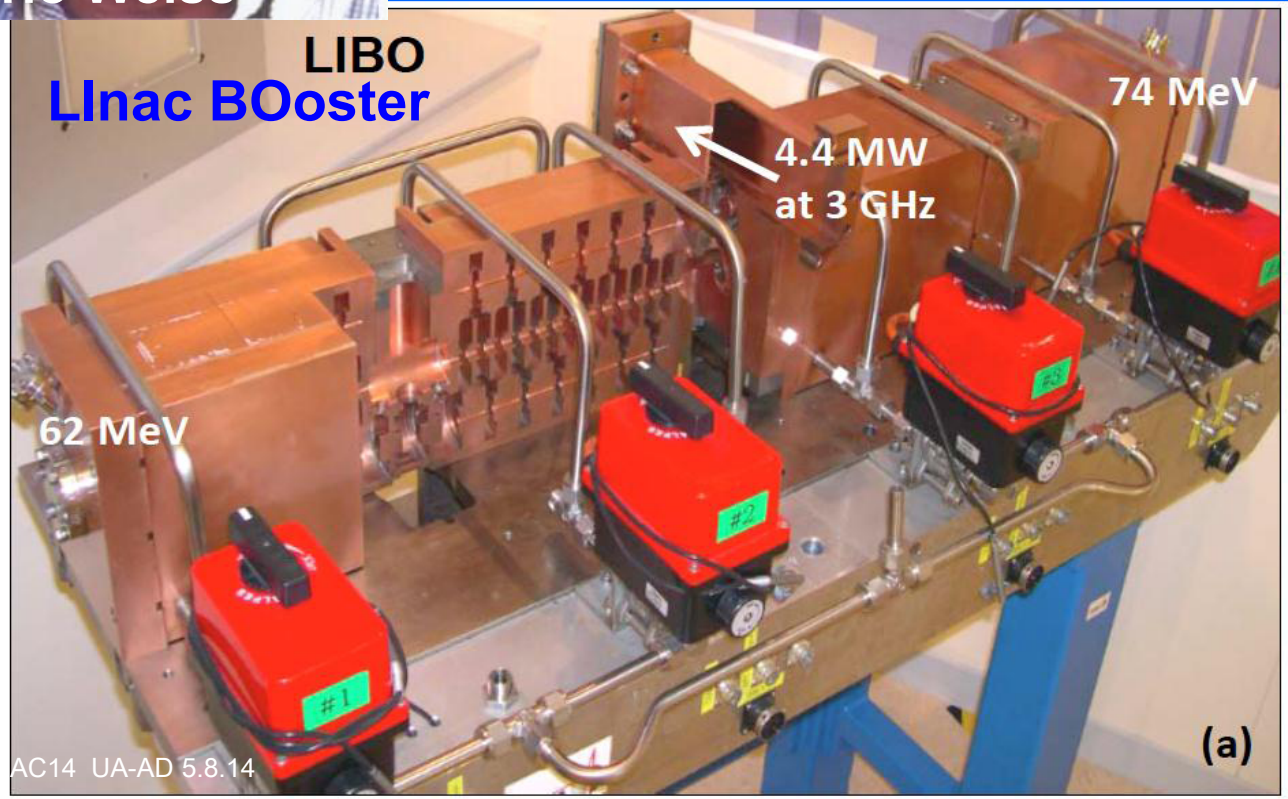
3 GHz LIBO accelerating unit built and tested by TERA – CERN – INFN

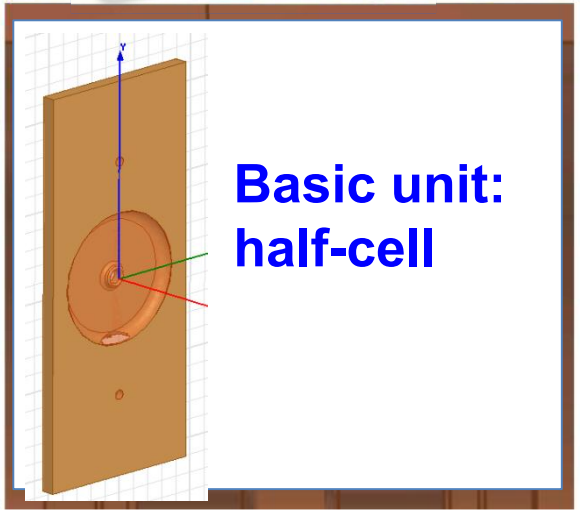
This Unit has accelerated protons from 62 to 74 MeV at the same 3 GHz frequency of electron linacs

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

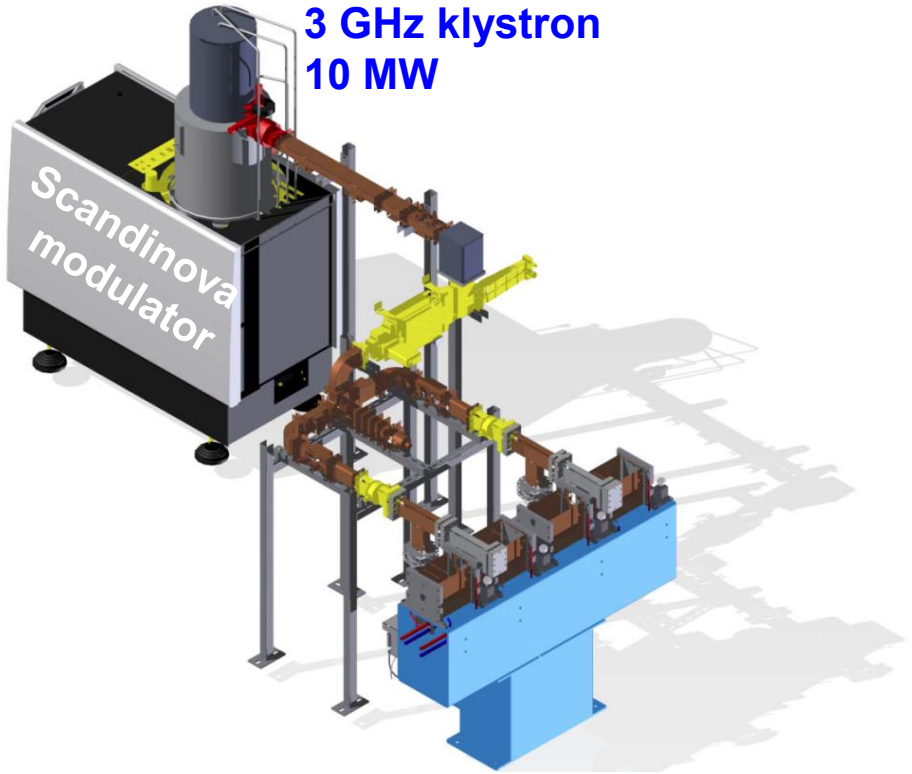
LIBO—a linac-booster for protontherapy: construction and tests of a prototype

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]



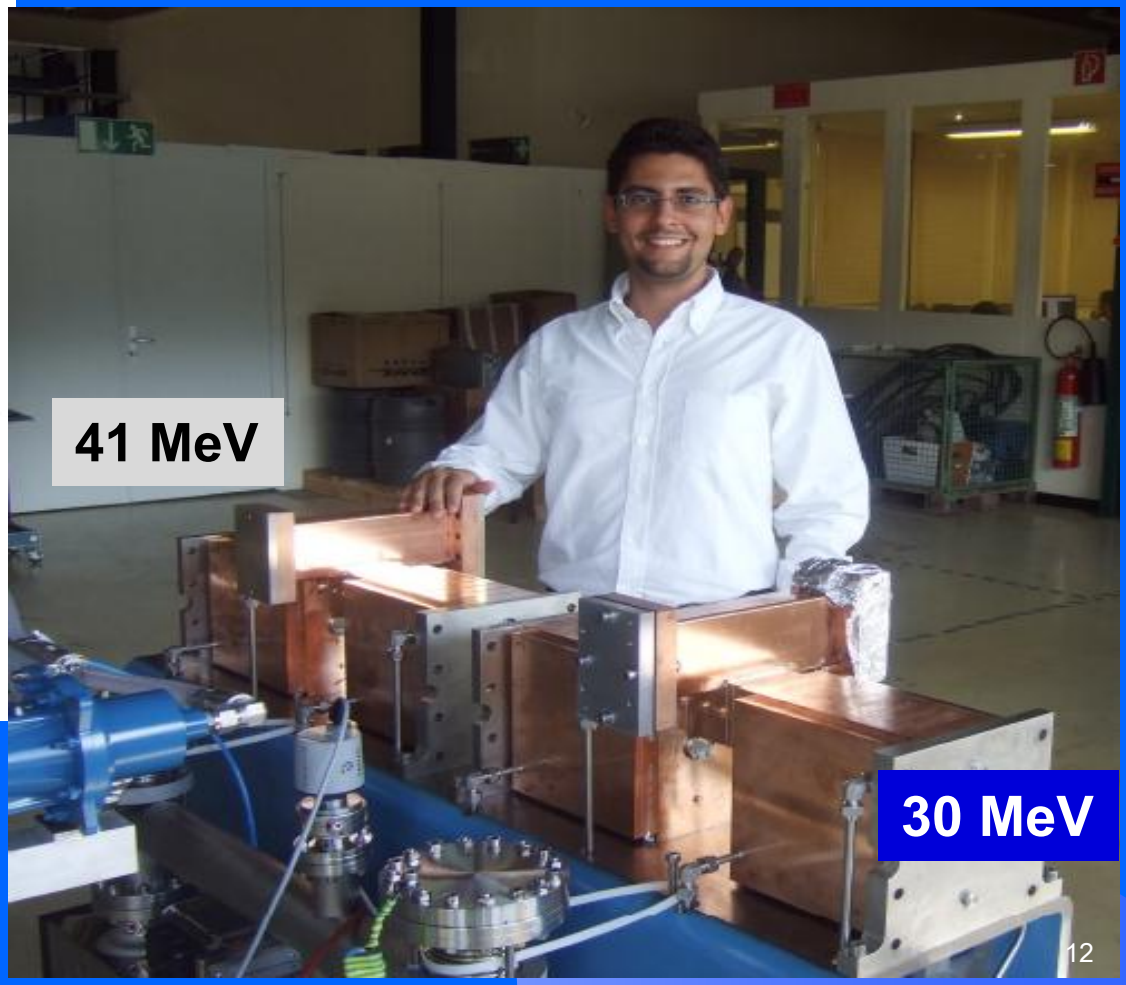


First Unit of LIGHT built and power tested by A.D.A.M.: 2011

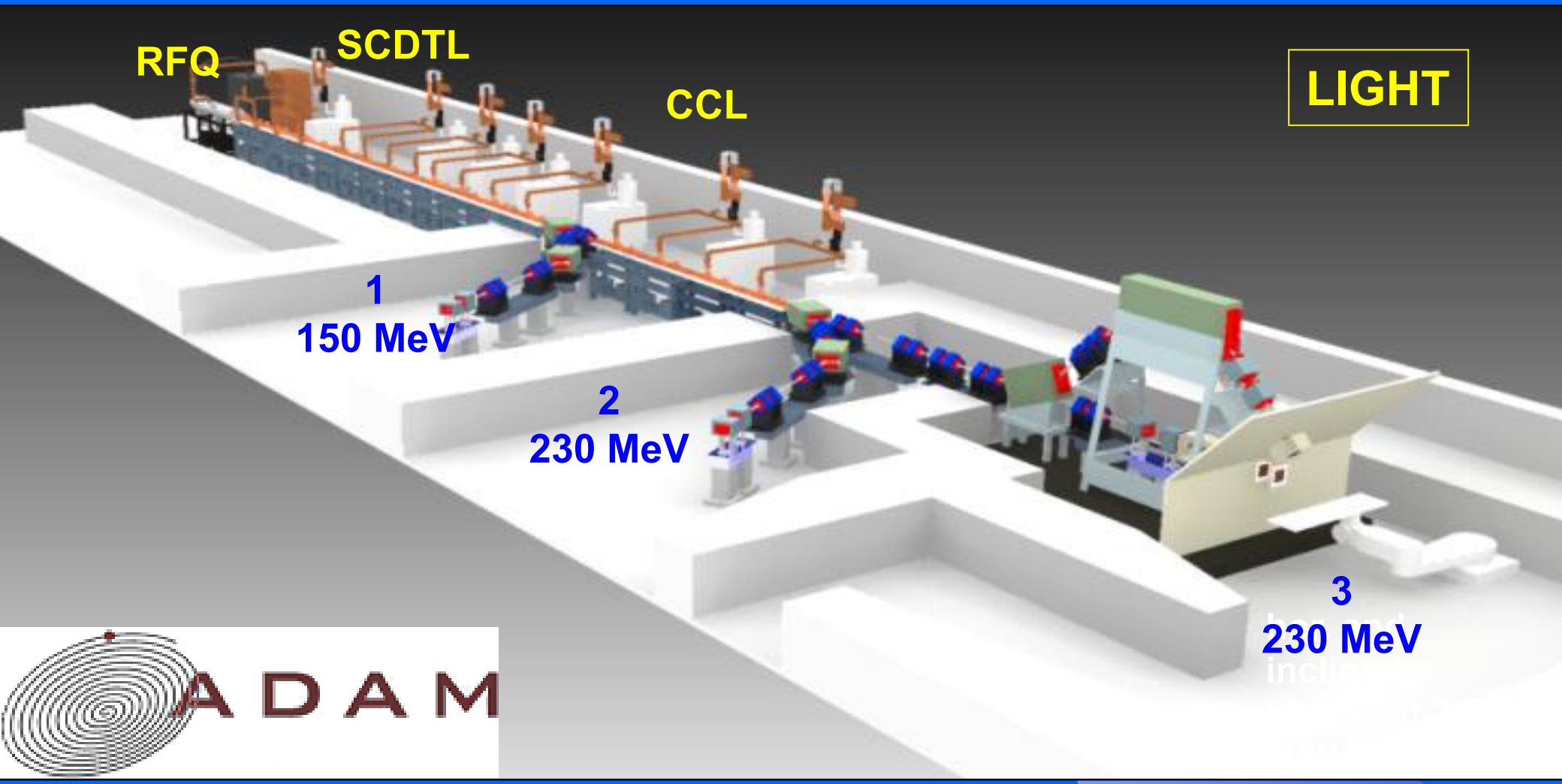


Linac for Image Guided Hadron Therapy

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



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



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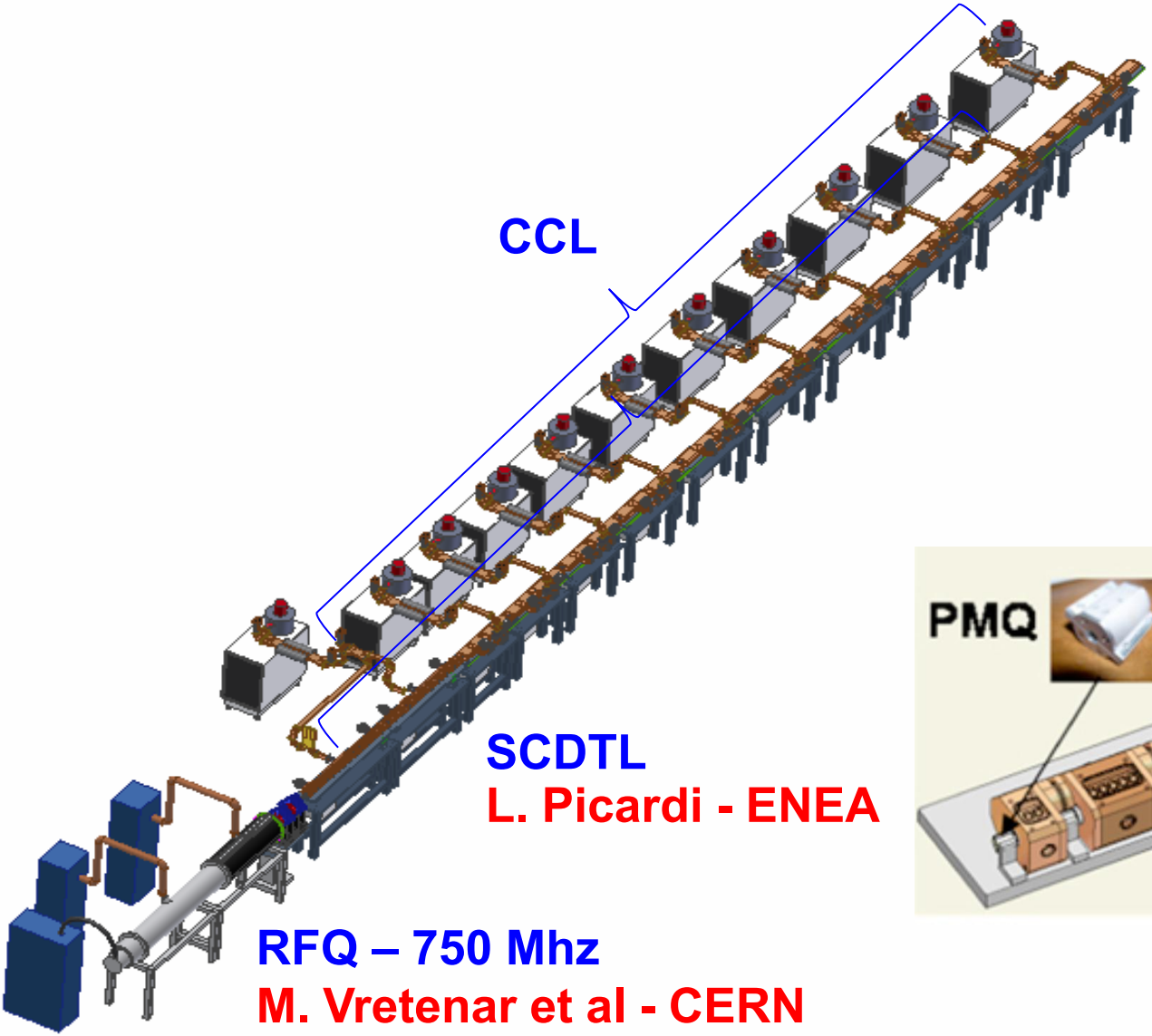
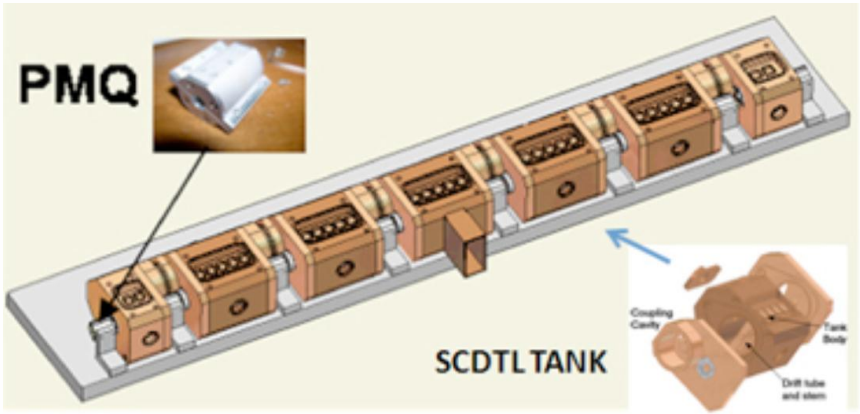


proton pulses @ 200 Hz



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

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

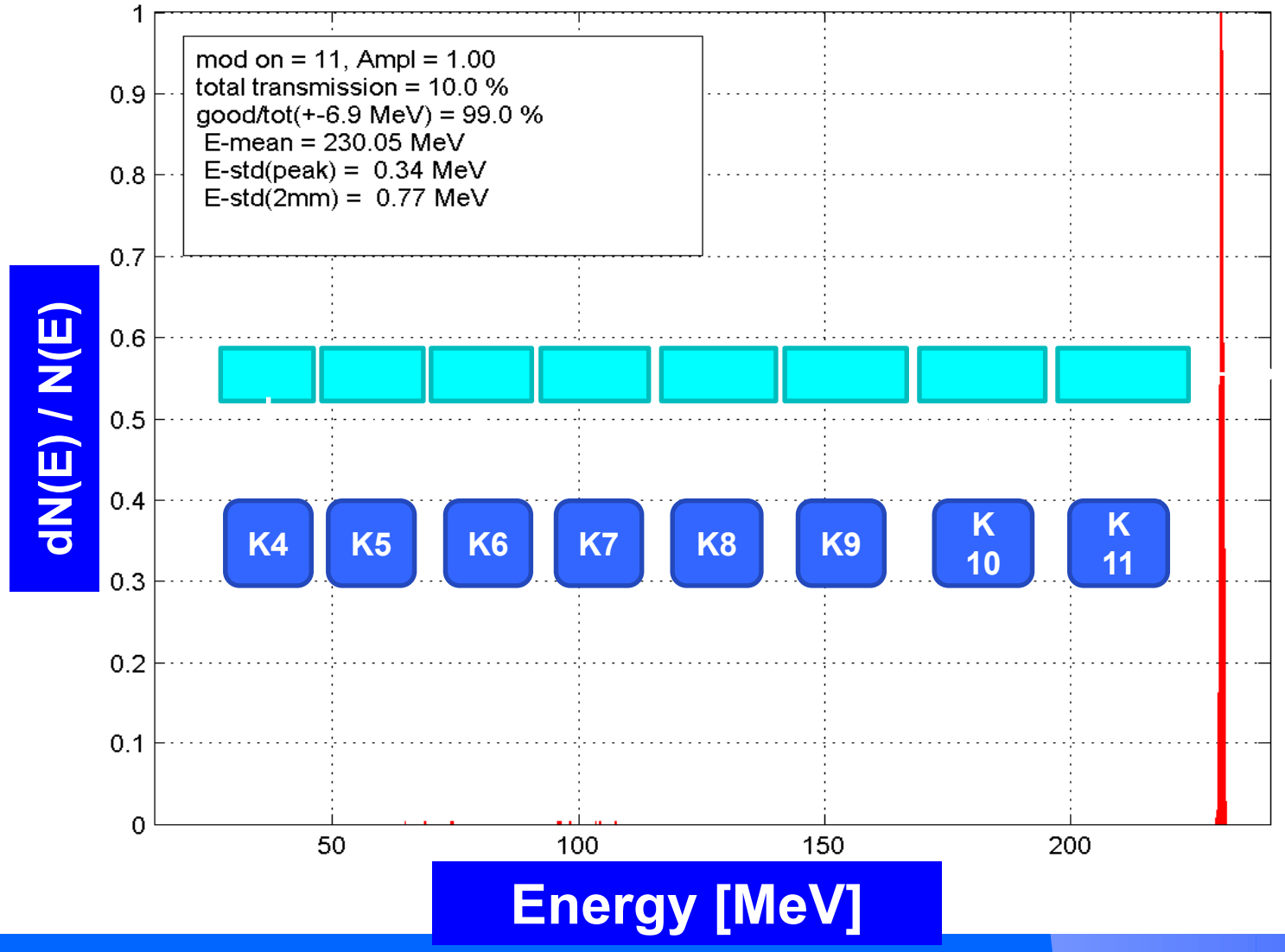
2 treatment areas
for children

gantry

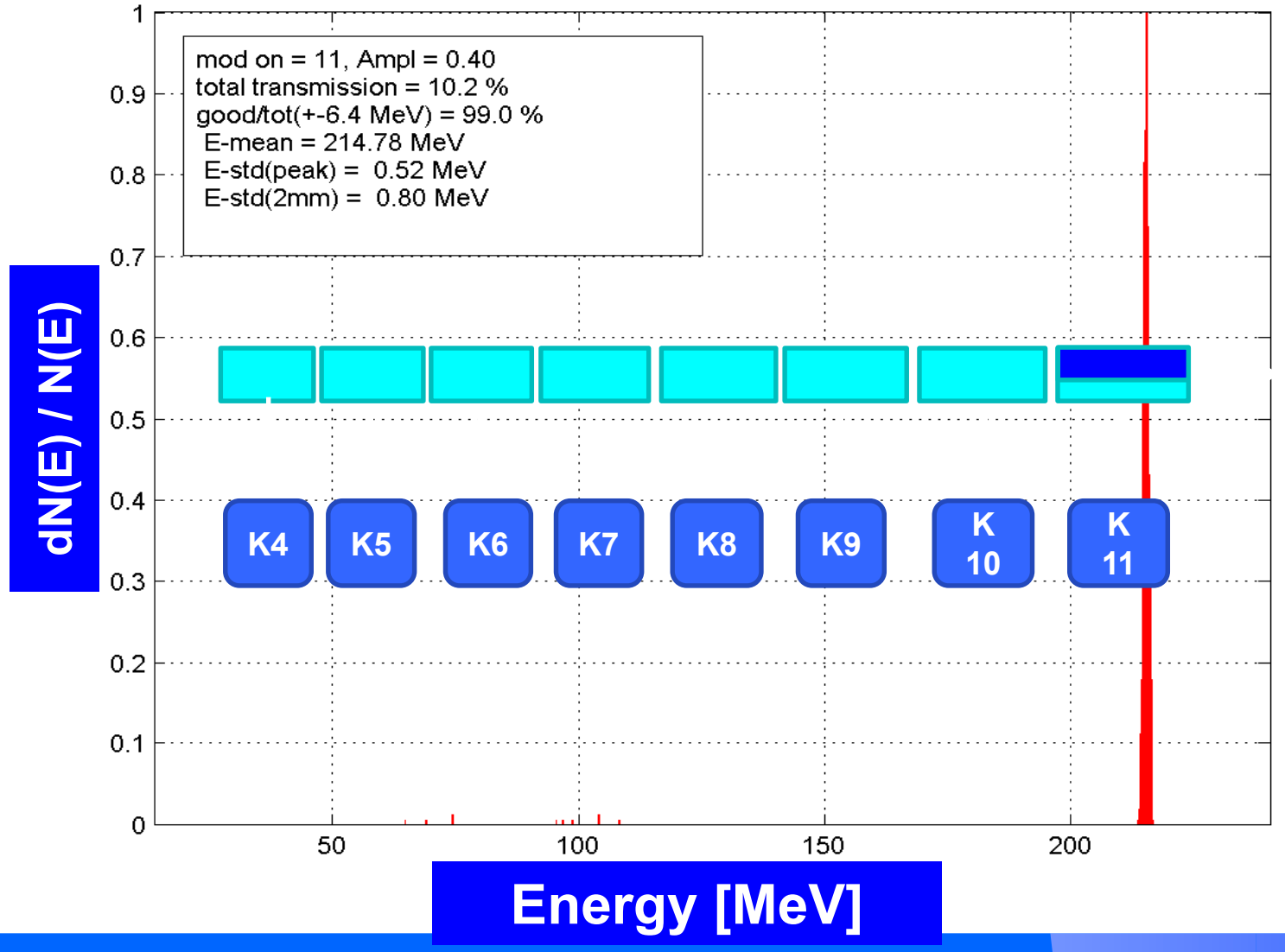
24 MeV
cyclotron
by ACSI
(Canada)

radiopharmacy

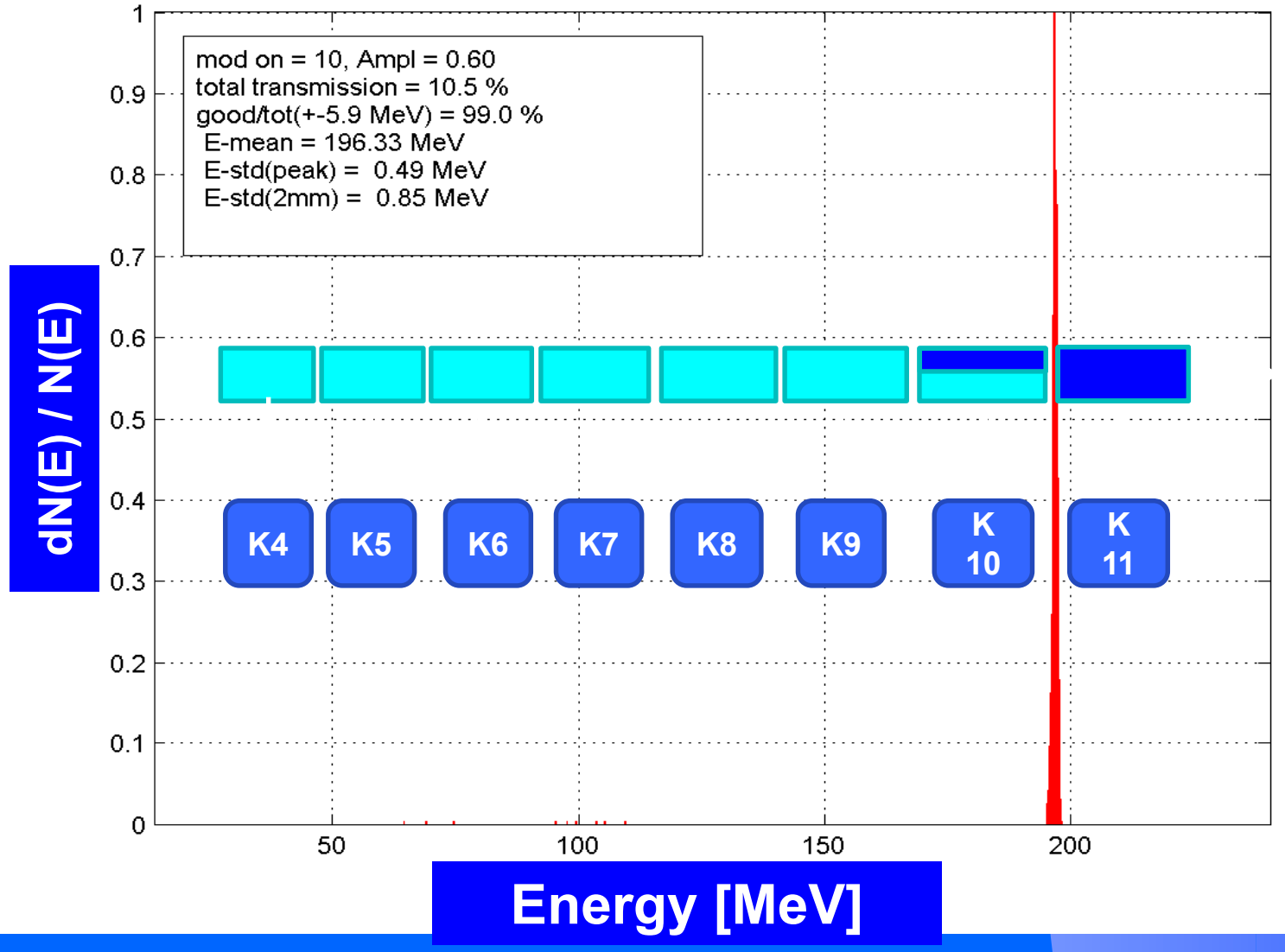
Unique properties of a linac beam: fast and active energy variation



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



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



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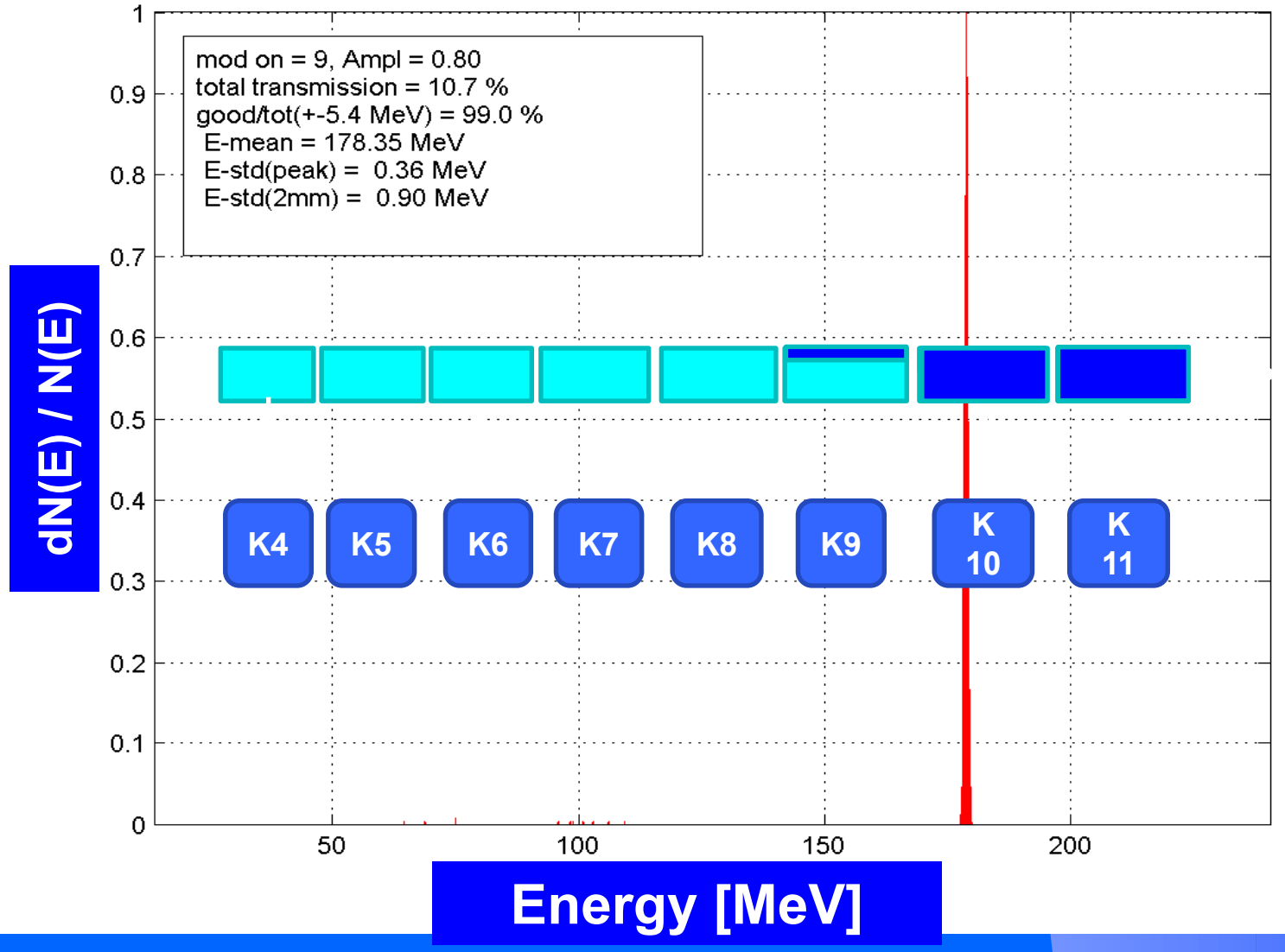

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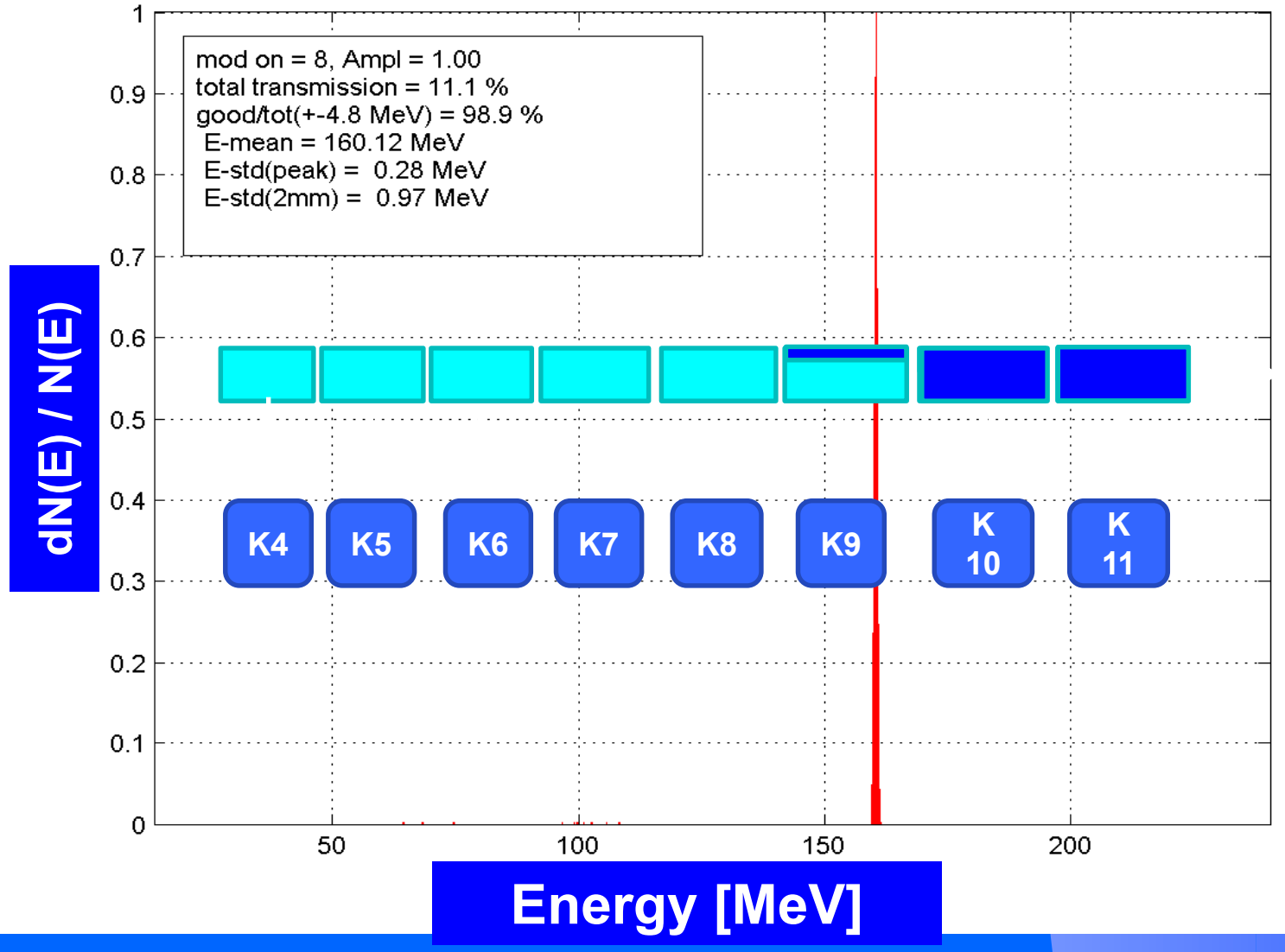
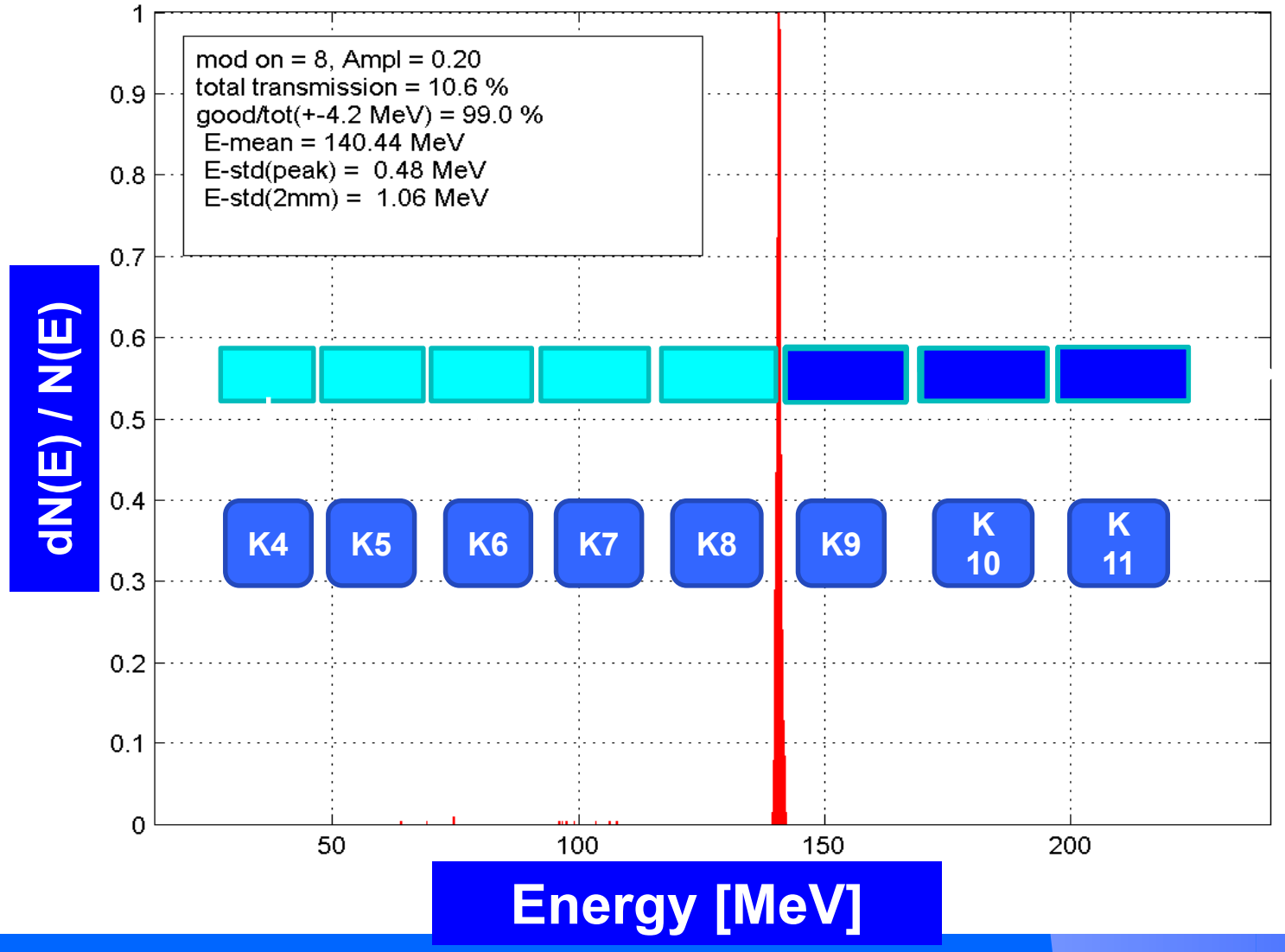
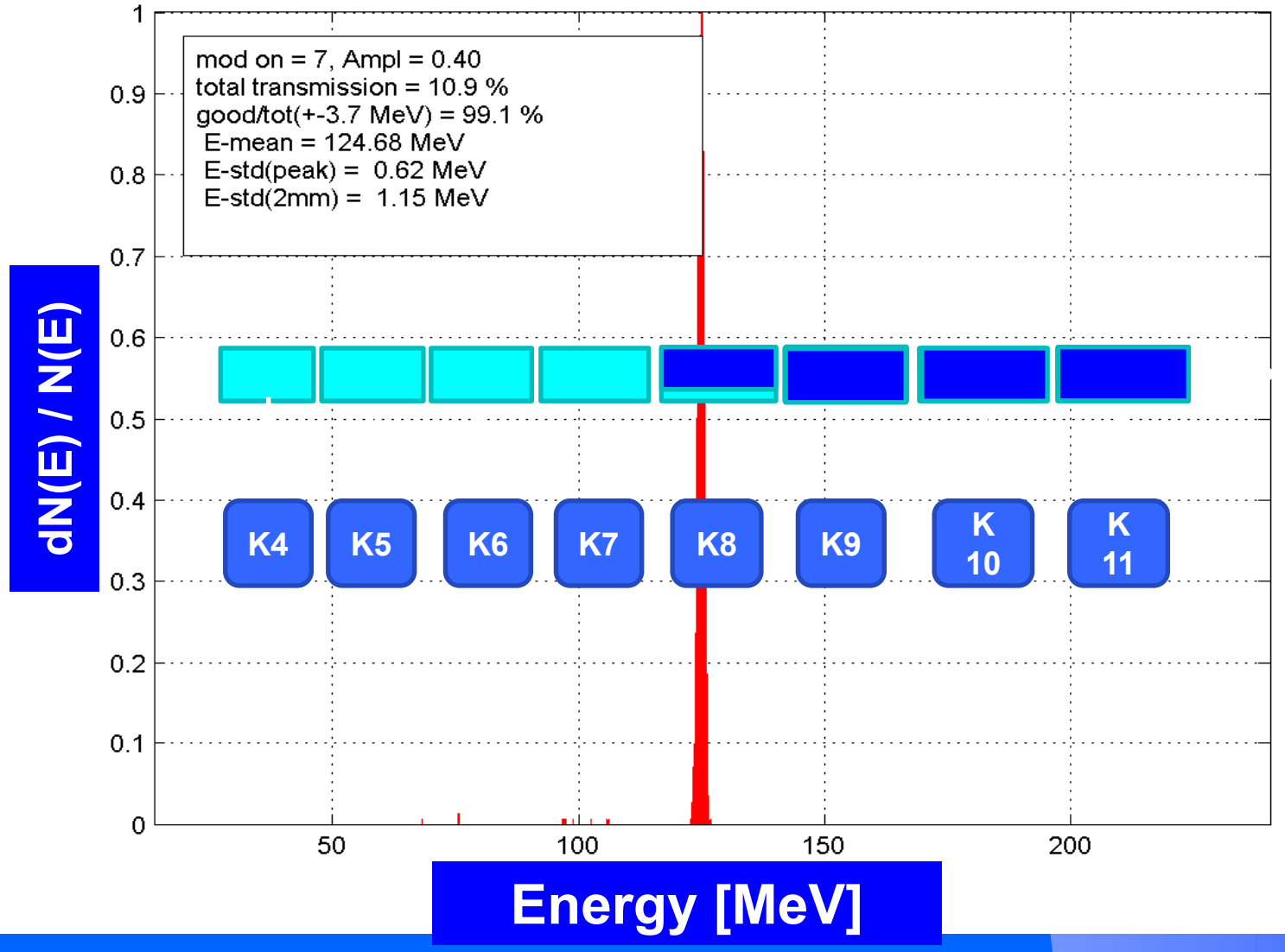


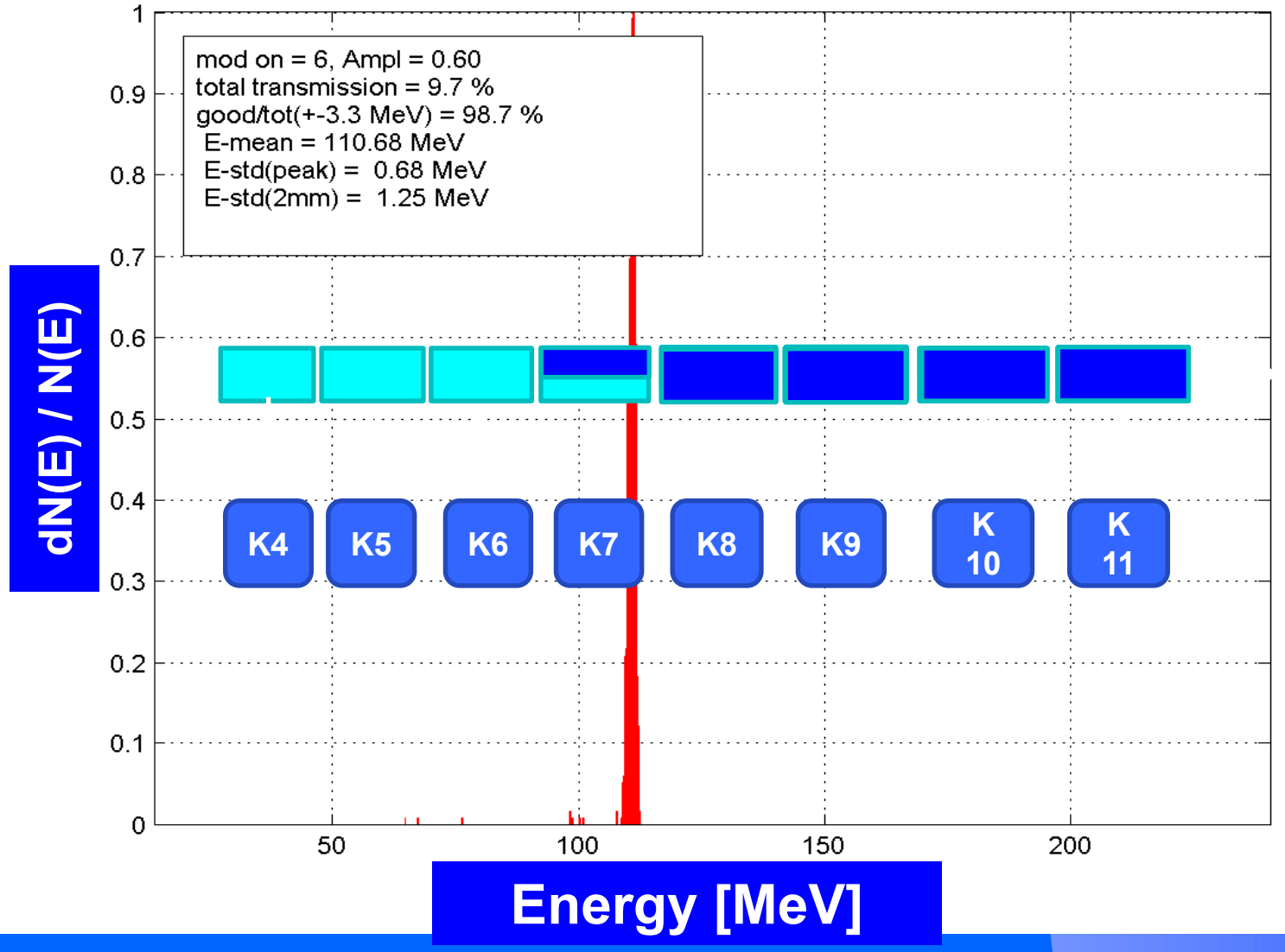
Unique properties of a linac beam: fast and active energy variation



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

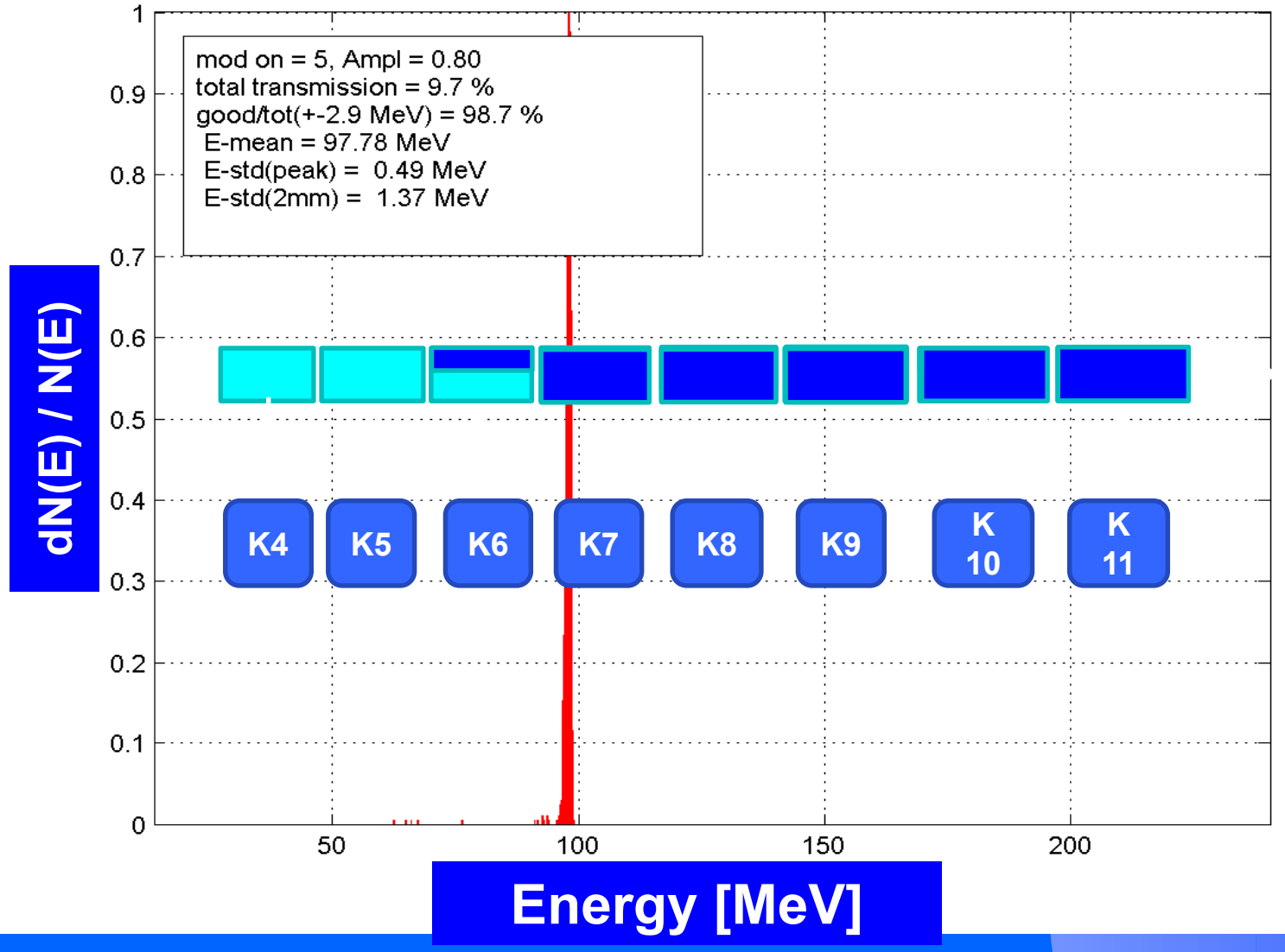


Unique properties of a linac beam: fast and active energy variation



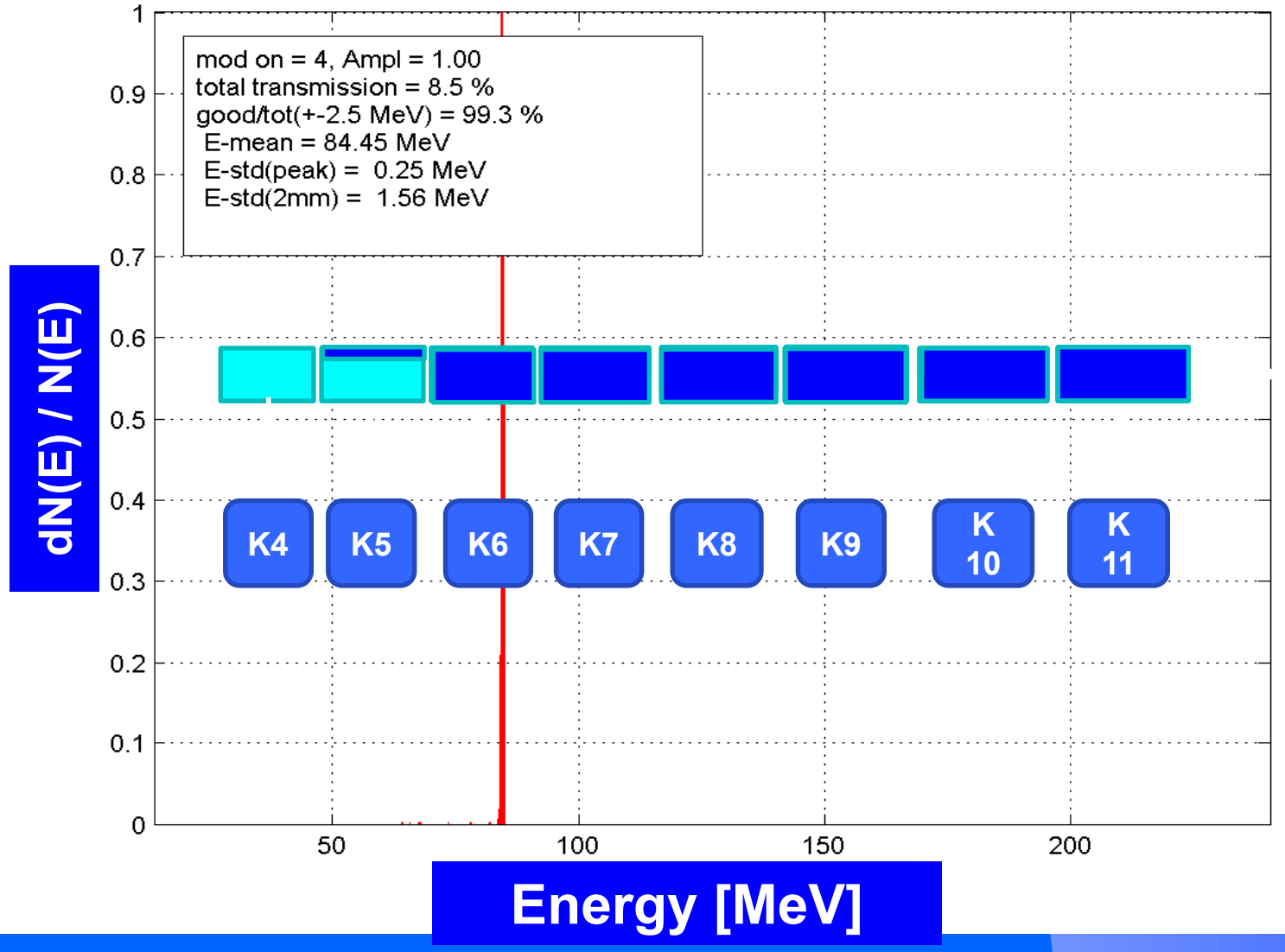
111 MeV

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

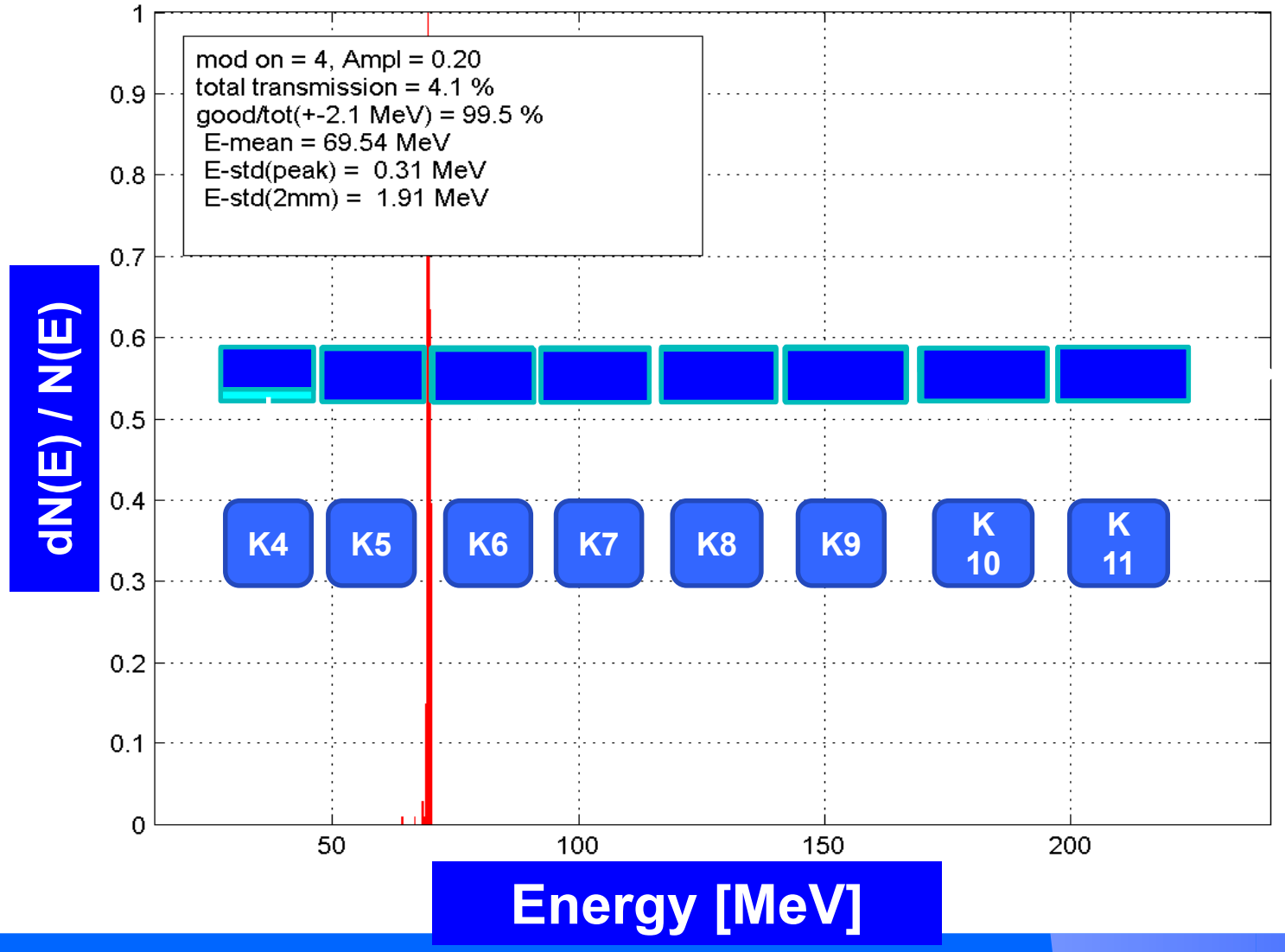


98 MeV

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

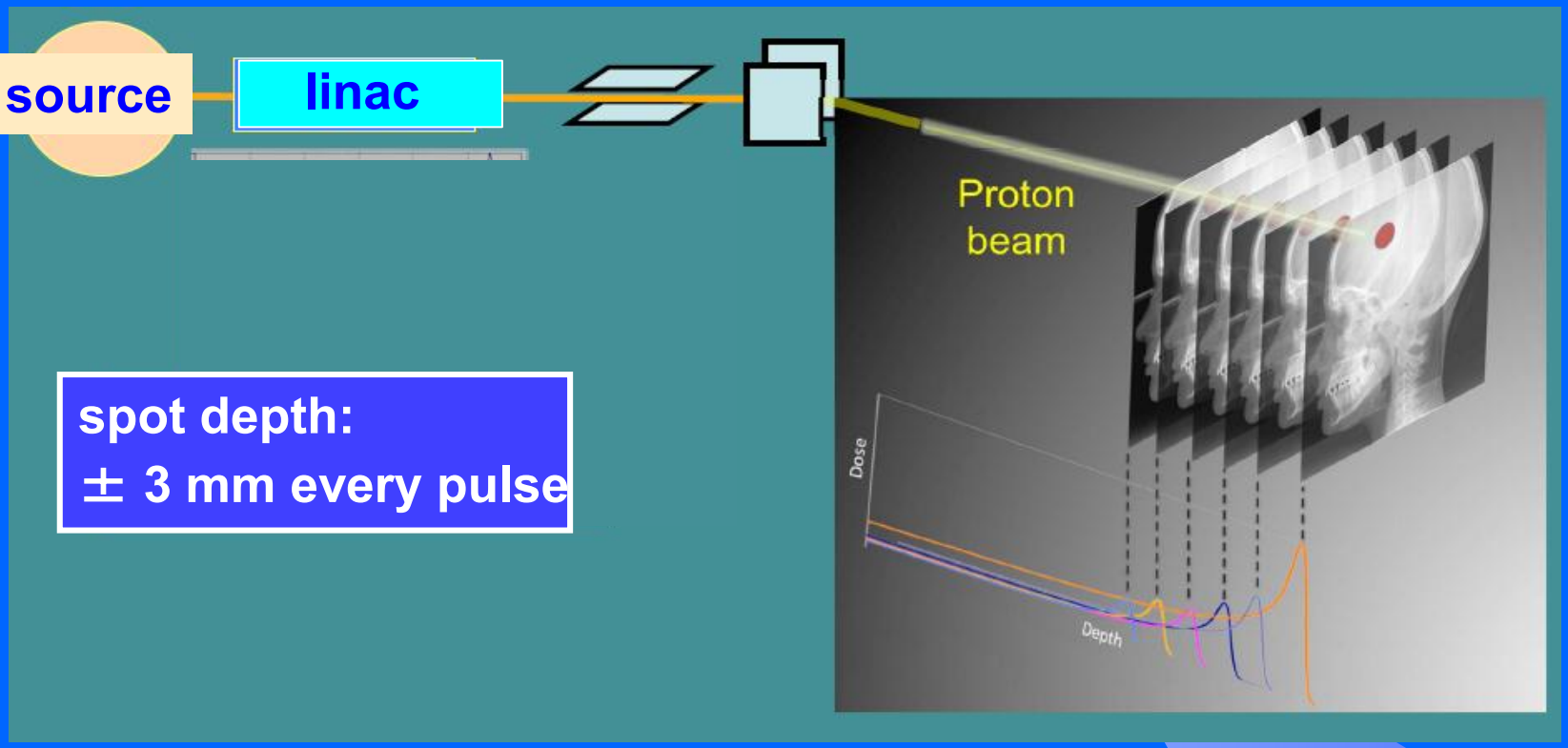


Unique properties of a linac beam: fast and active energy variation



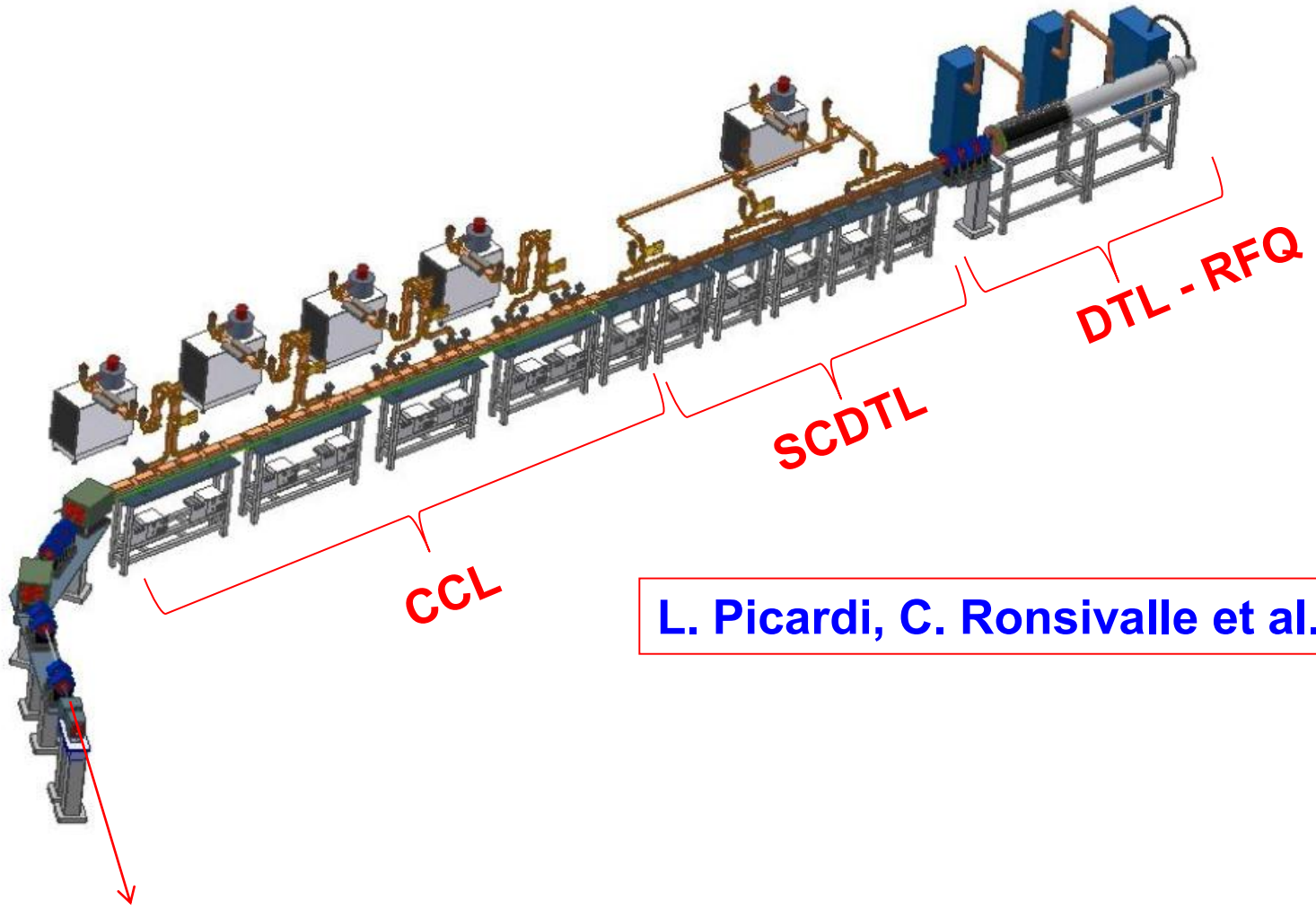
The dose deposition depth can be adjusted every 3 ms

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

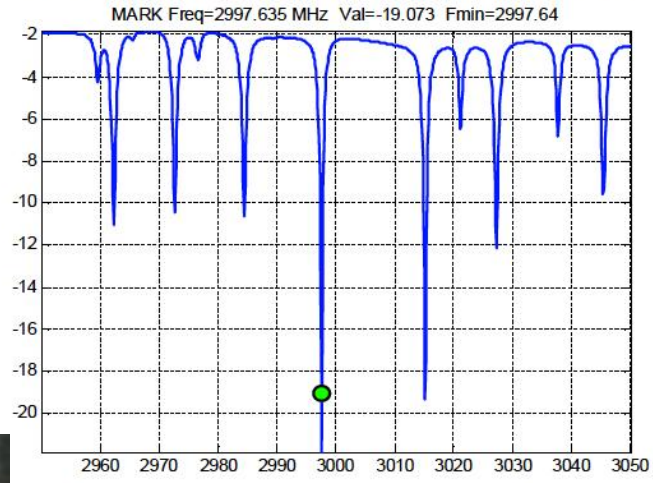


L. Picardi, C. Ronsivalle et al.

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

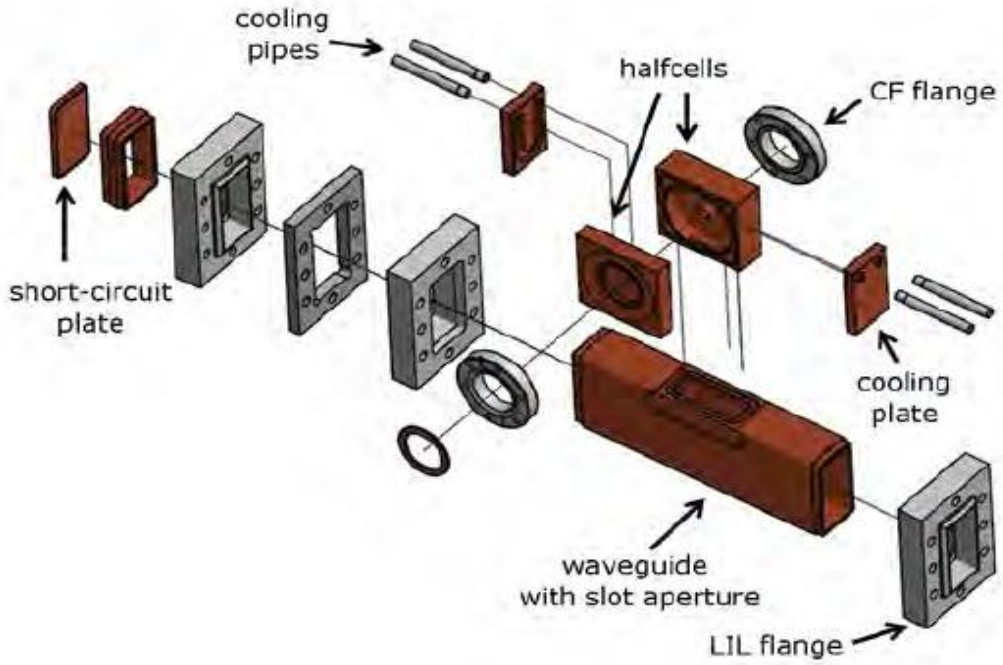
SCDTL module 1(11.6 MeV): operating;
module 2 and 3 (27 MeV): ready for end of the year

Module 1 at CECOM (Guidonia, RM)
During construction and tests

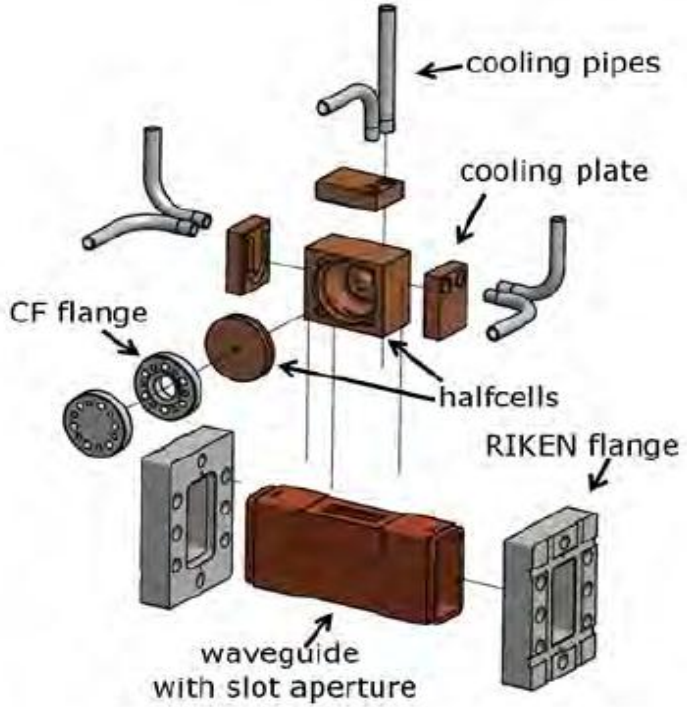


Studies for the future: high-gradient hadron structures

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

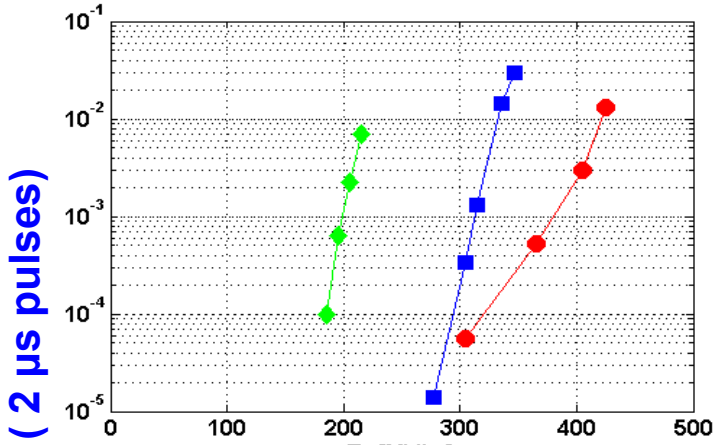


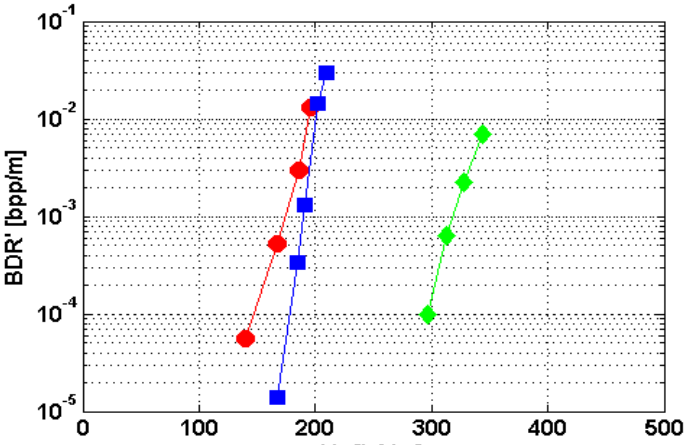
(a) S-band test cavity

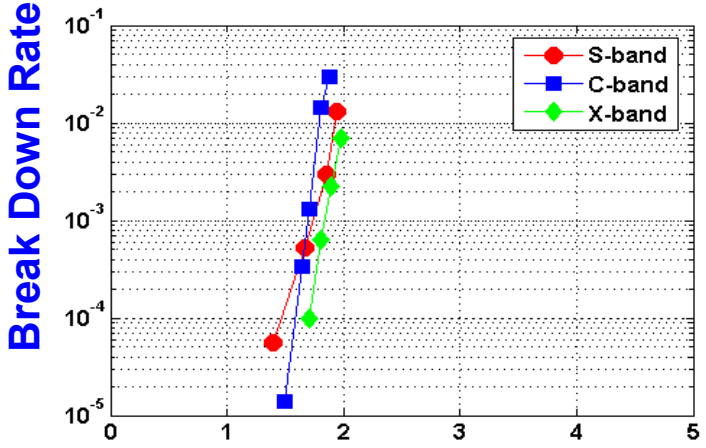


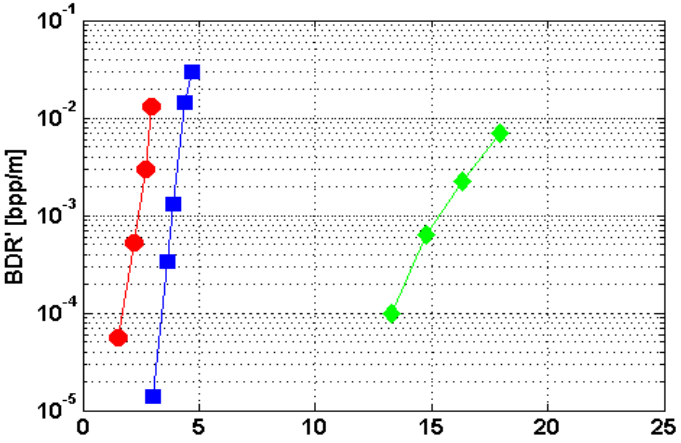
(b) C-band test cavity

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



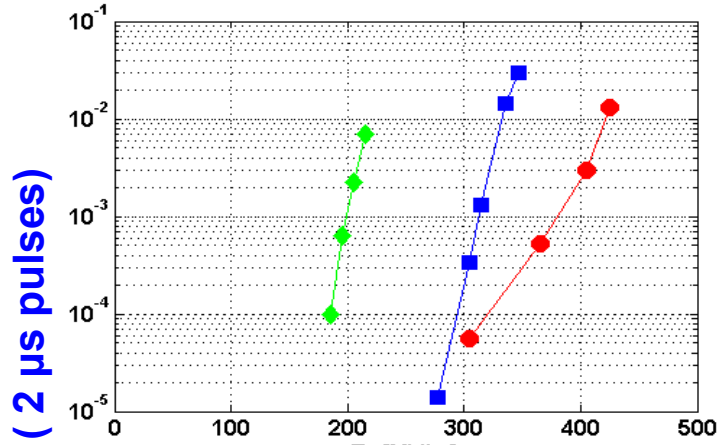




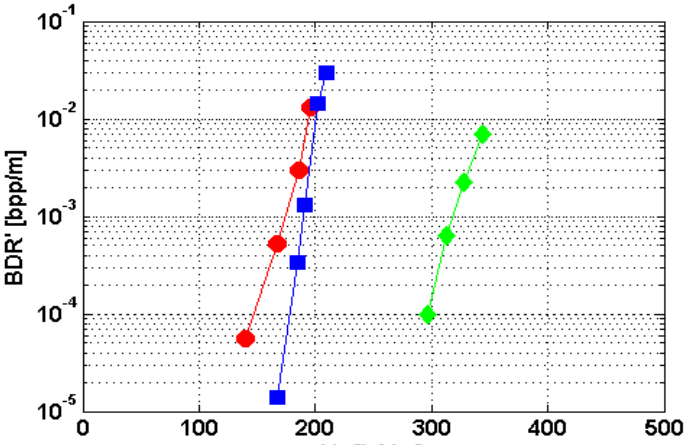


EPFL thesis by A. Degiovanni

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



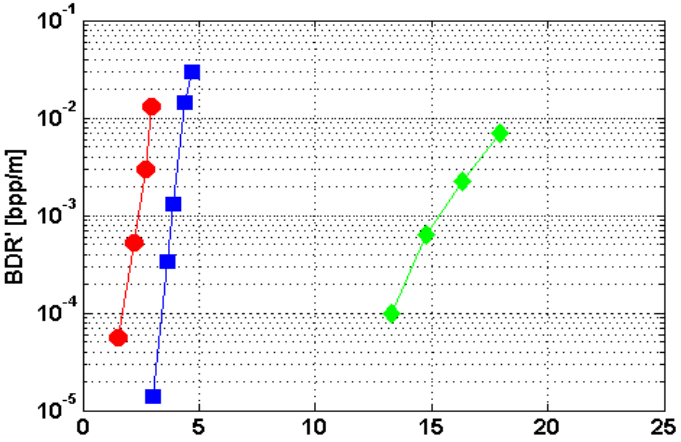
max electric field (MV)



max magnetic field (kA/m)v

Power Flow Model
Grudiev-Wuensch

(max modified Poynting vctr)$^{1/2}$ (MW/mm^2)$^{1/2}$

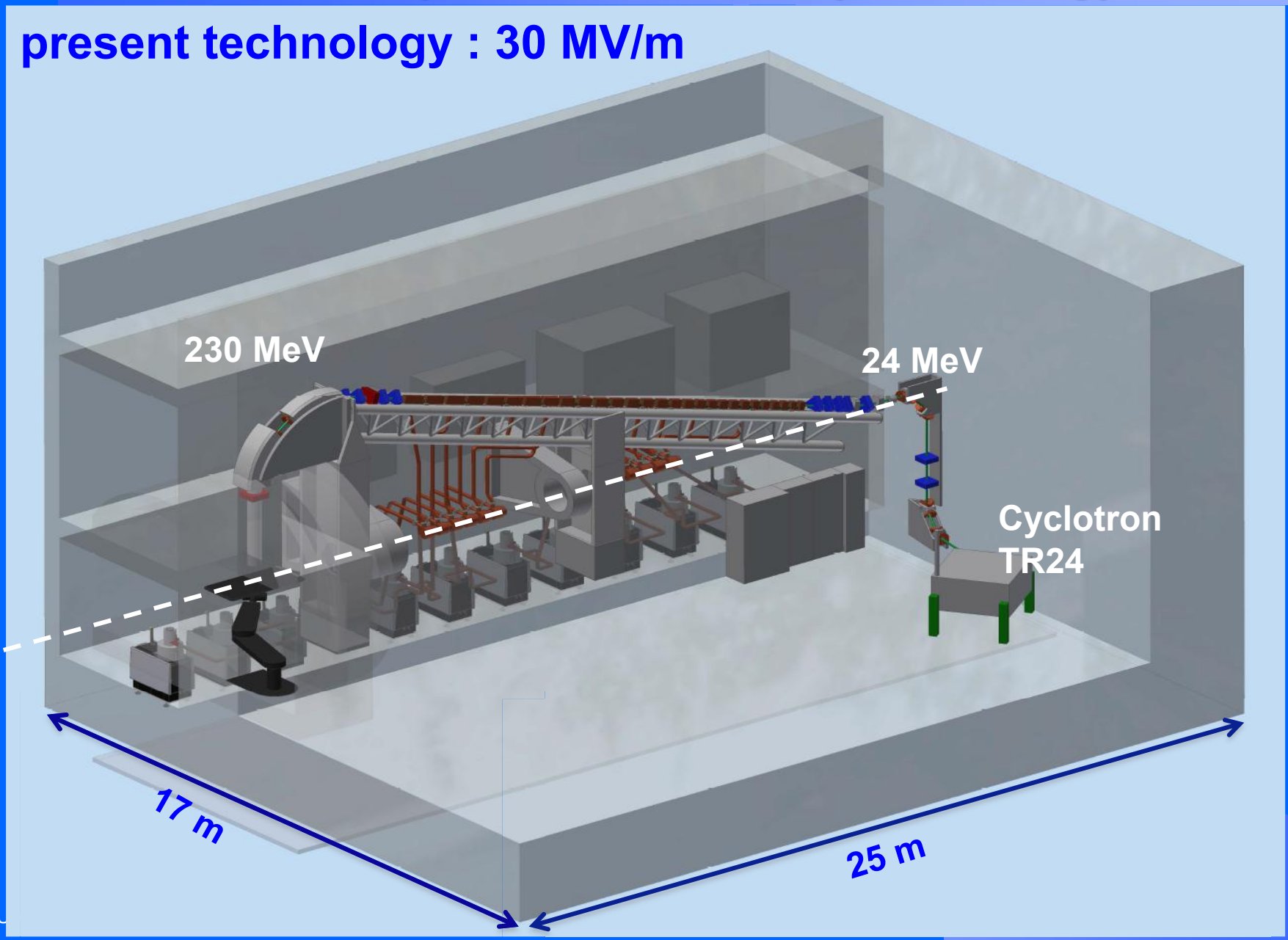


max temperature rise (K)

EPFL thesis by A. Degiovanni

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

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

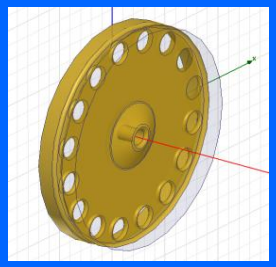


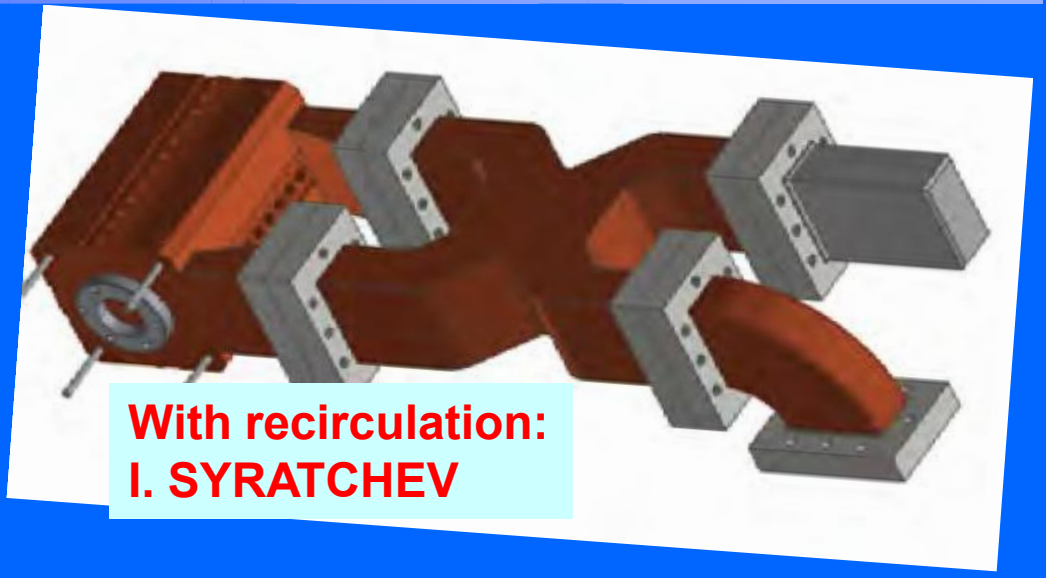
New high-gradient "backward" TW structure

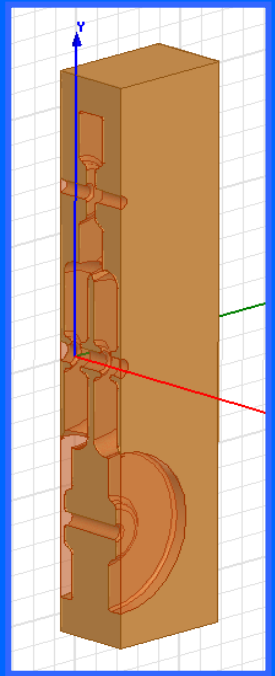
'NEW' bwTW
50 MV/m
BDR = 10^{-6} m^{-1}
(20% more power for same gradient)

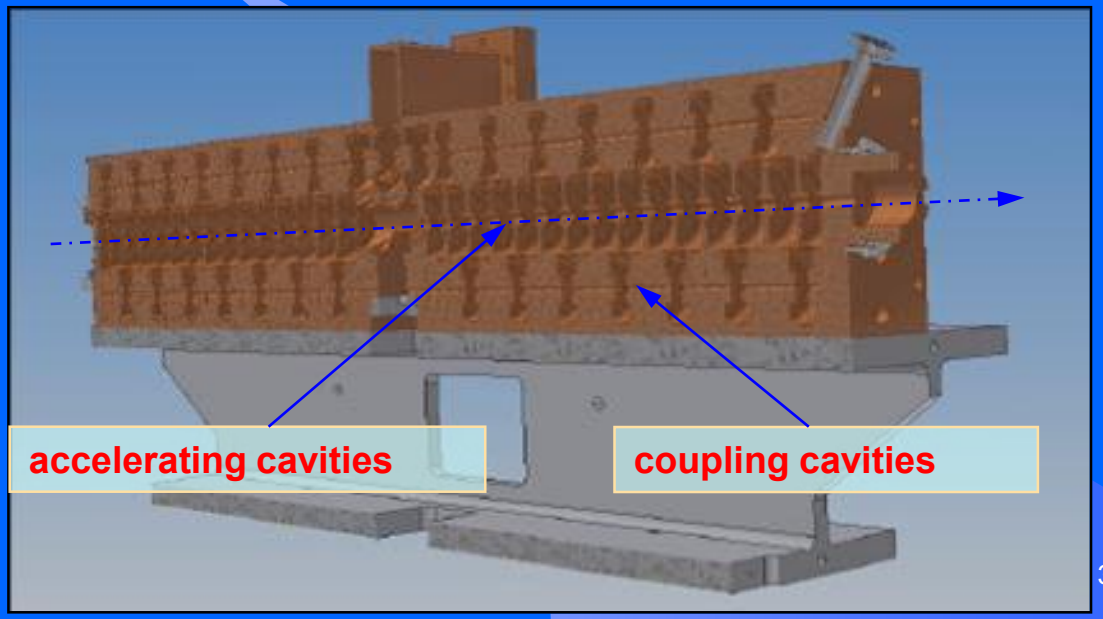
PROPOSED by A.GRUDIEV /CLIC
financed by KT
(see THPP061)

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



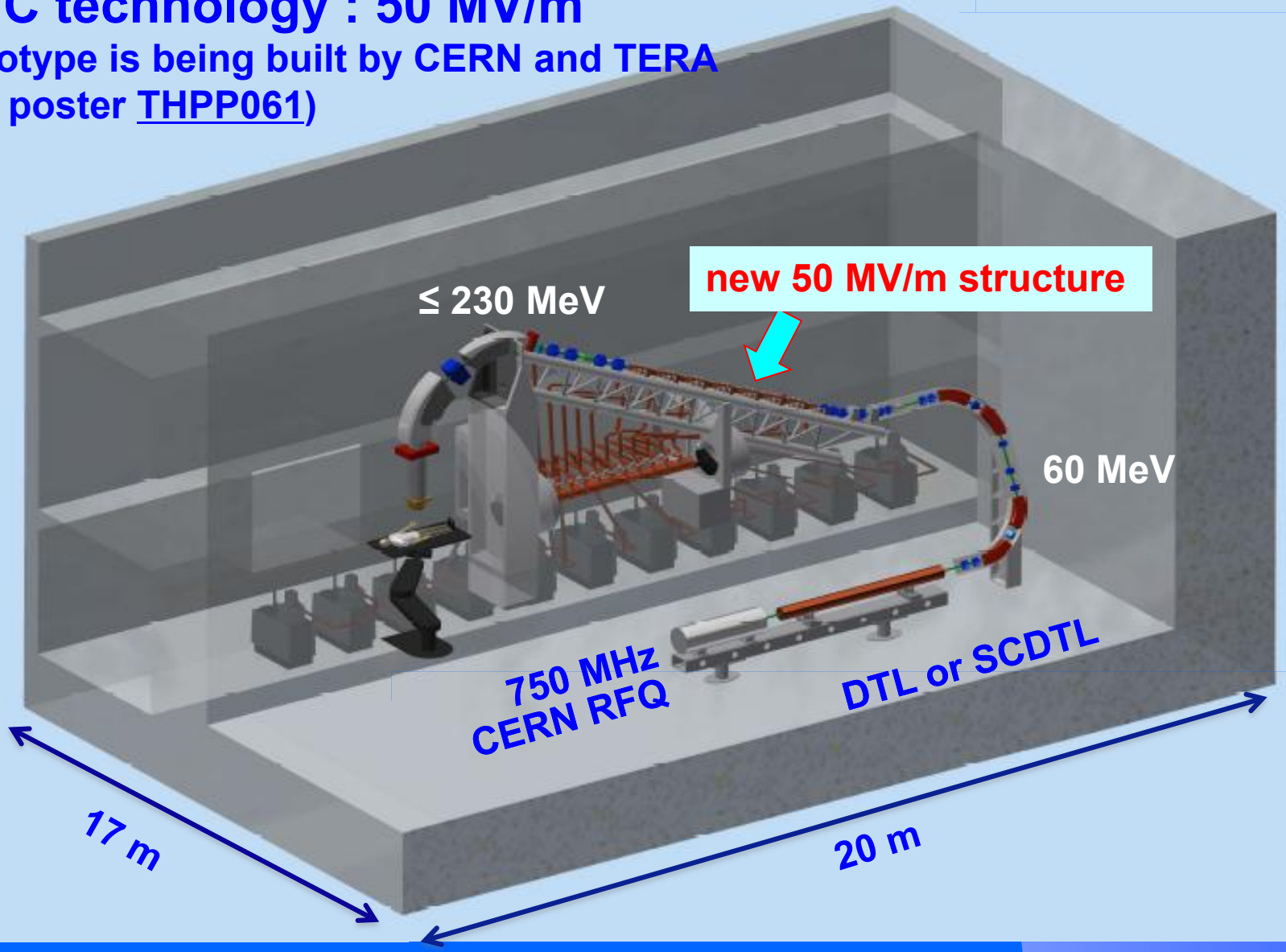






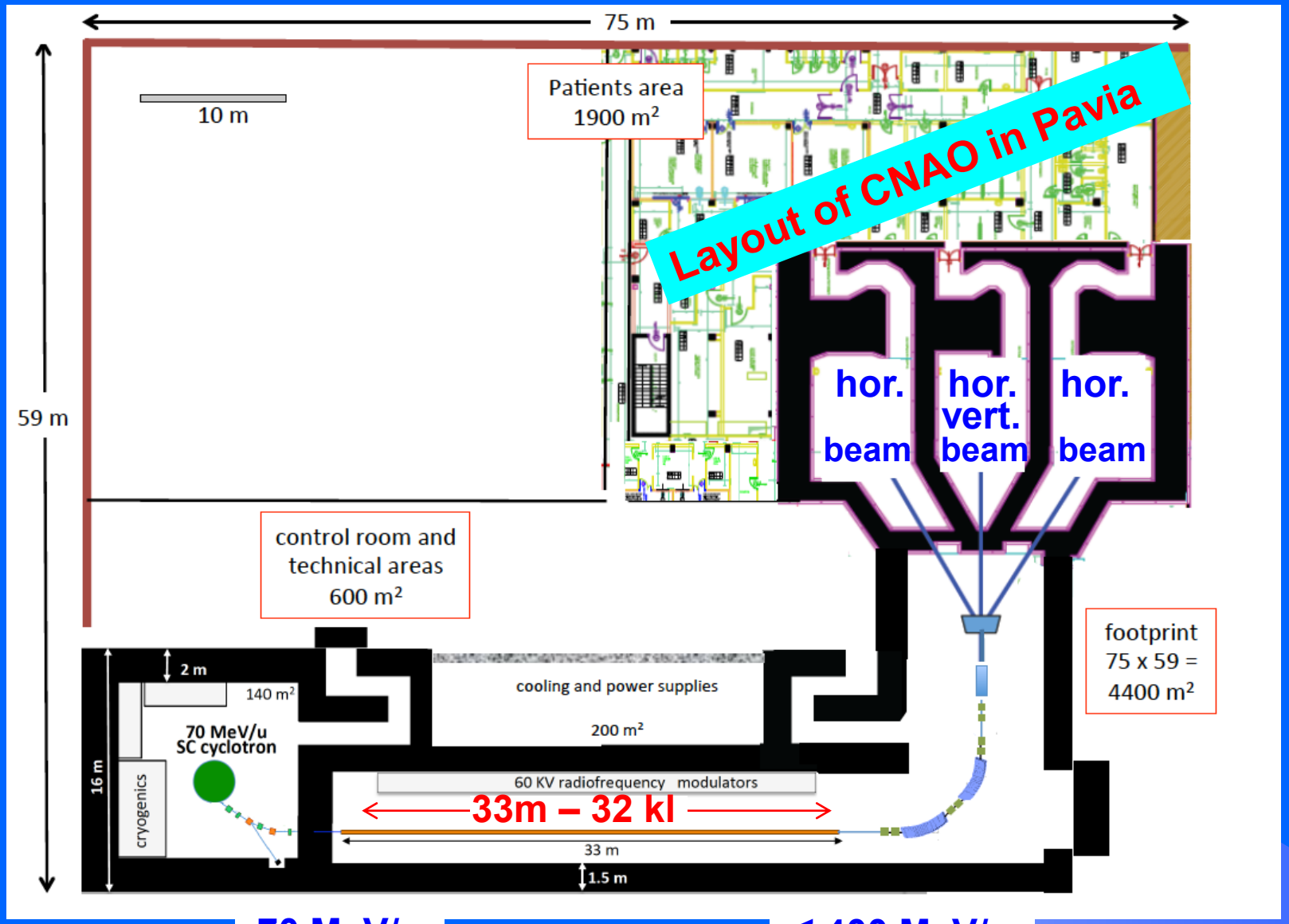
CLIC technology : 50 MV/m

prototype is being built by CERN and TERA
(see poster THPP061)

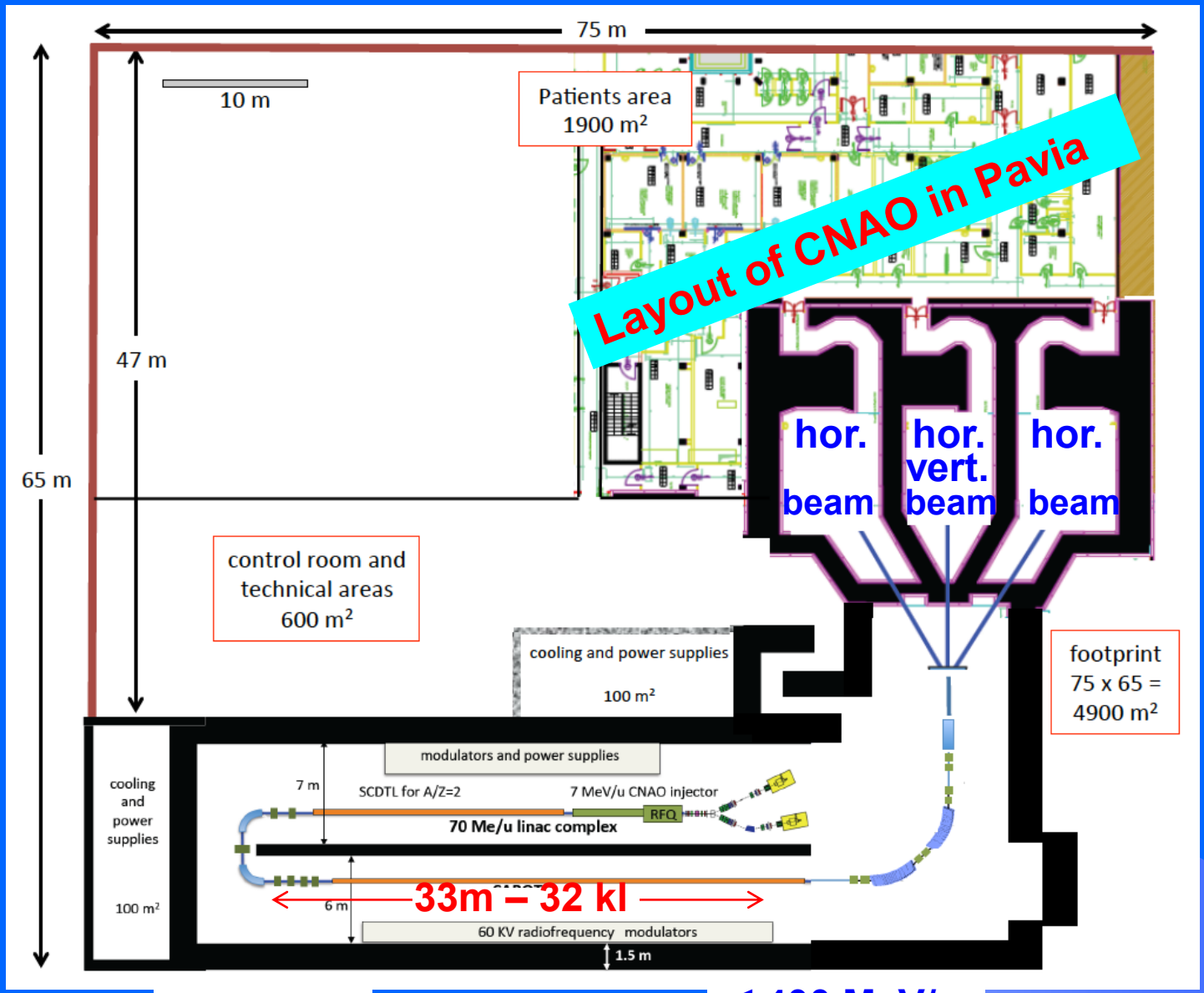


The future high-efficiency linac: CABOTO
CArbon BOoster for Therapy in Oncology

The cyclinac CABOTO runs at 300 Hz

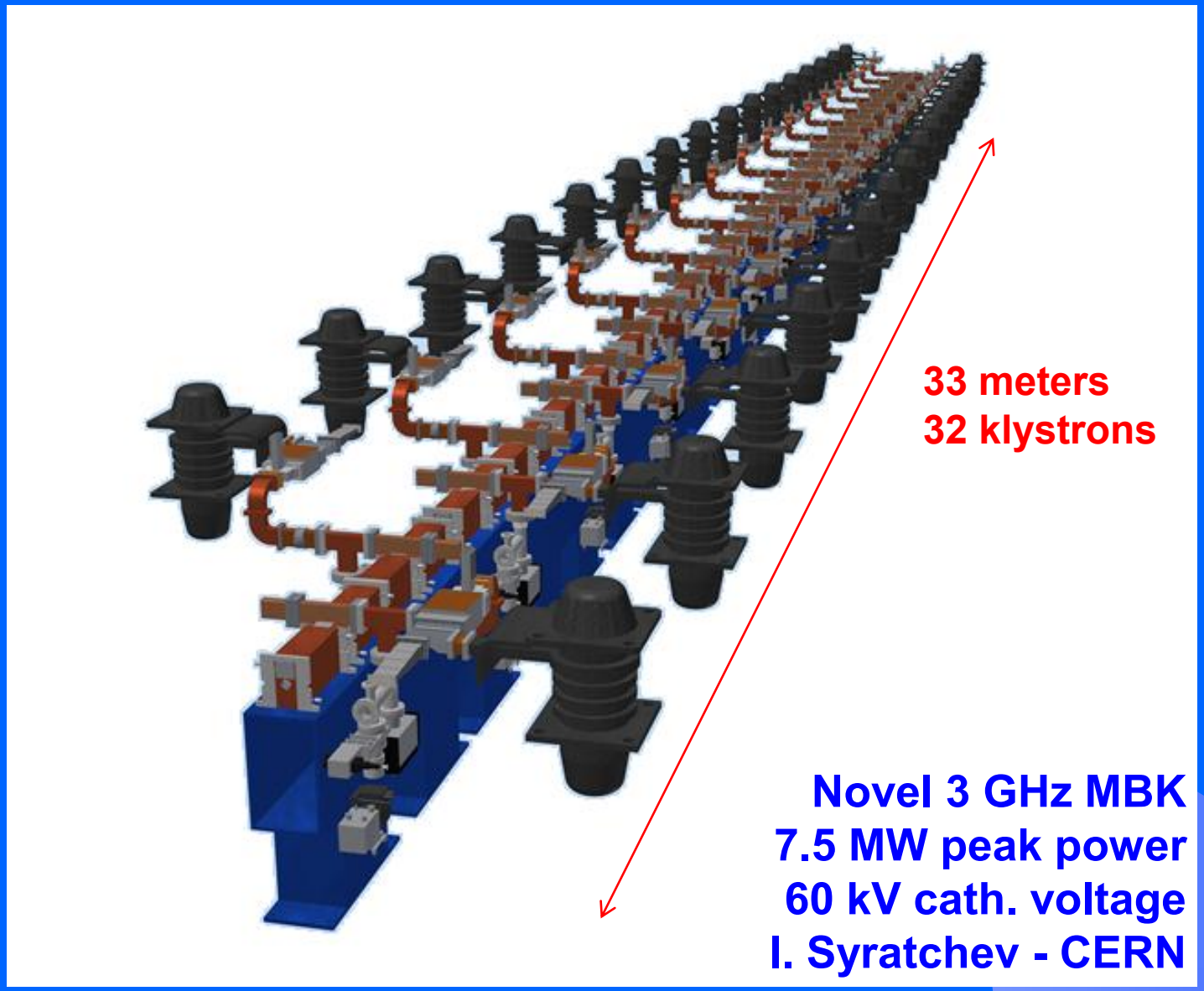


The all-linac CABOTO runs at 300 Hz



70 MeV/u **≤ 400 MeV/u**

The all-linac CABOTO runs at 300-400 Hz and consumes 1 MW



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 and TERA respectively
- A.D.A.M. is building at CERN an all-linac facility that will be transferred to an 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

THANK YOU FOR YOUR ATTENTION !