High-gradient structures fot TULIP

(TUrning LInac for Protontherapy)

Ugo Amaldi

TERA Foundation

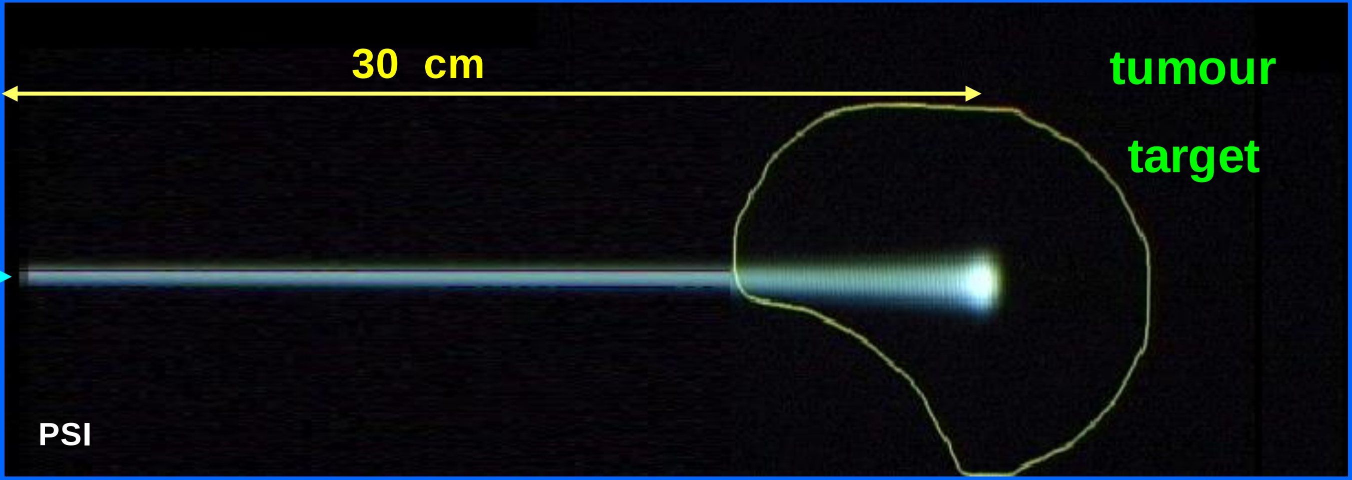
Generalities on protontherapy

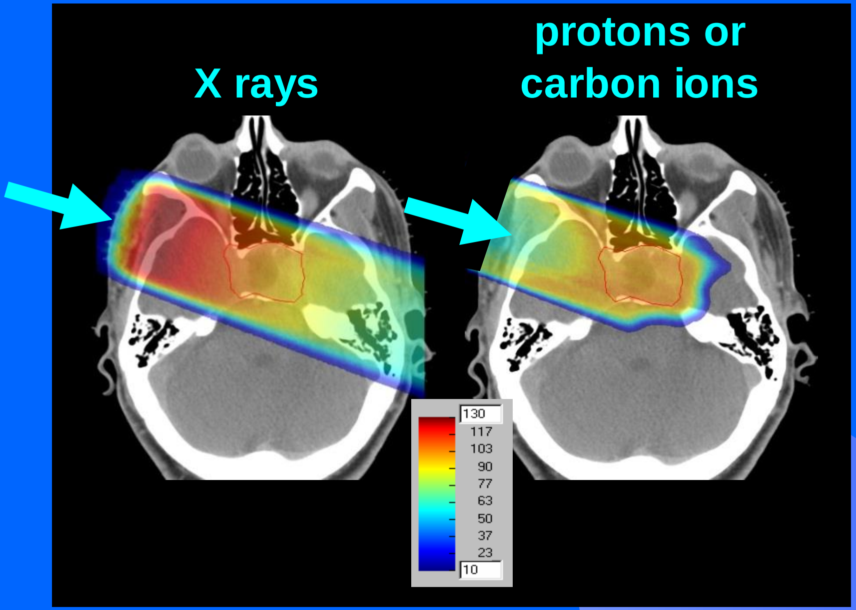
Protons and ions spare healthy tissues

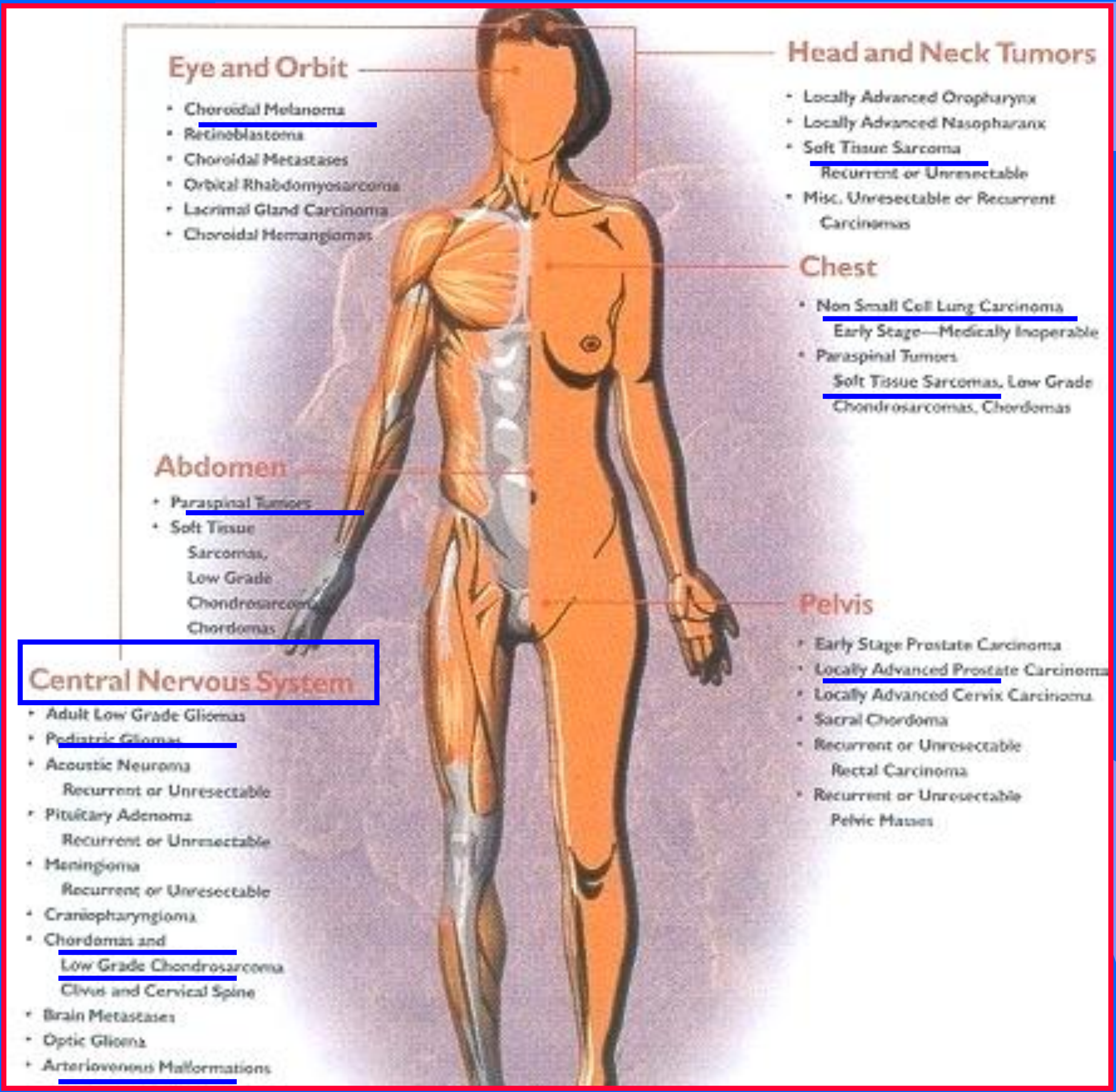
230 MeV
protons
1 nA

5000 MeV
carbon ions
0.1 nA

for 'radioresistant' tumours







The site treated with hadrons

In the world

protons:
100'000 patients
(+10% per year)

carbon ions
8’500 patients

MAINLY IN JAPAN

Numbers of potential patients according to ENLIGHT (2004)

X-ray therapy

for 1 million inhabitants: 2'000 pts/year

Protontherapy

12% of X-ray patients 240 pts/year

Therapy with carbon ions for radio-resistant tumours

3% of X-ray patients 60 pts/year

RADIOTHERAPY & ONCOLOGY
JOURNAL OF THE EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY

Multi-room centre by IBA (Belgium) – 35 in the world)

Eight companies offer turn-key centres for 100-150

If proton accelerators were 'small' and 'cheap', no radiation oncologist would use X rays.

Numbers of potential patients according to ENLIGHT (2004)

X-ray therapy

for 1 million inhabitants: 2'000 pts/year

Protontherapy

12% of X-ray patients 240 pts/year

In 1 'room' ≤ 350 patients/year

↓

1 'single-room' p-facility for ≈ 1.5 million

Therapy with c

Numbers of potential patients according to ENLIGHT (2004)

X-ray therapy

for 1 million inhabitants: 2'000 pts/year

Protontherapy

12% of X-ray patients 240 pts/year

Therapy with c

In 1 'room' ≤ 350 patients/year

↓

1 'single-room' p-facility for ≈ 1.5 million

↓

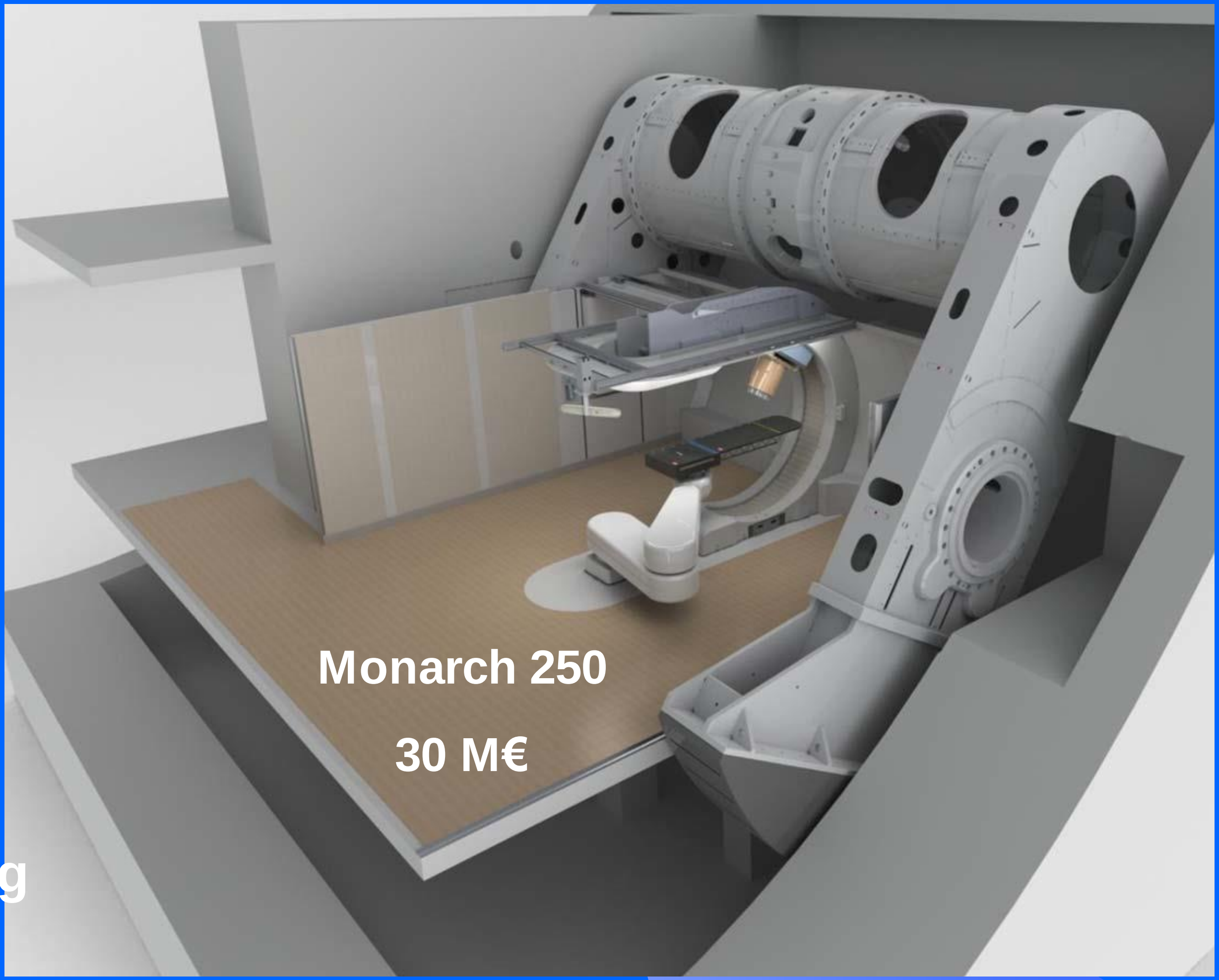
every 8 X-ray rooms

in 3-4 close-by hospitals

serving 1.5 million people

Single-room facility MeVion (the rotating synchrotron was designed by MIT)

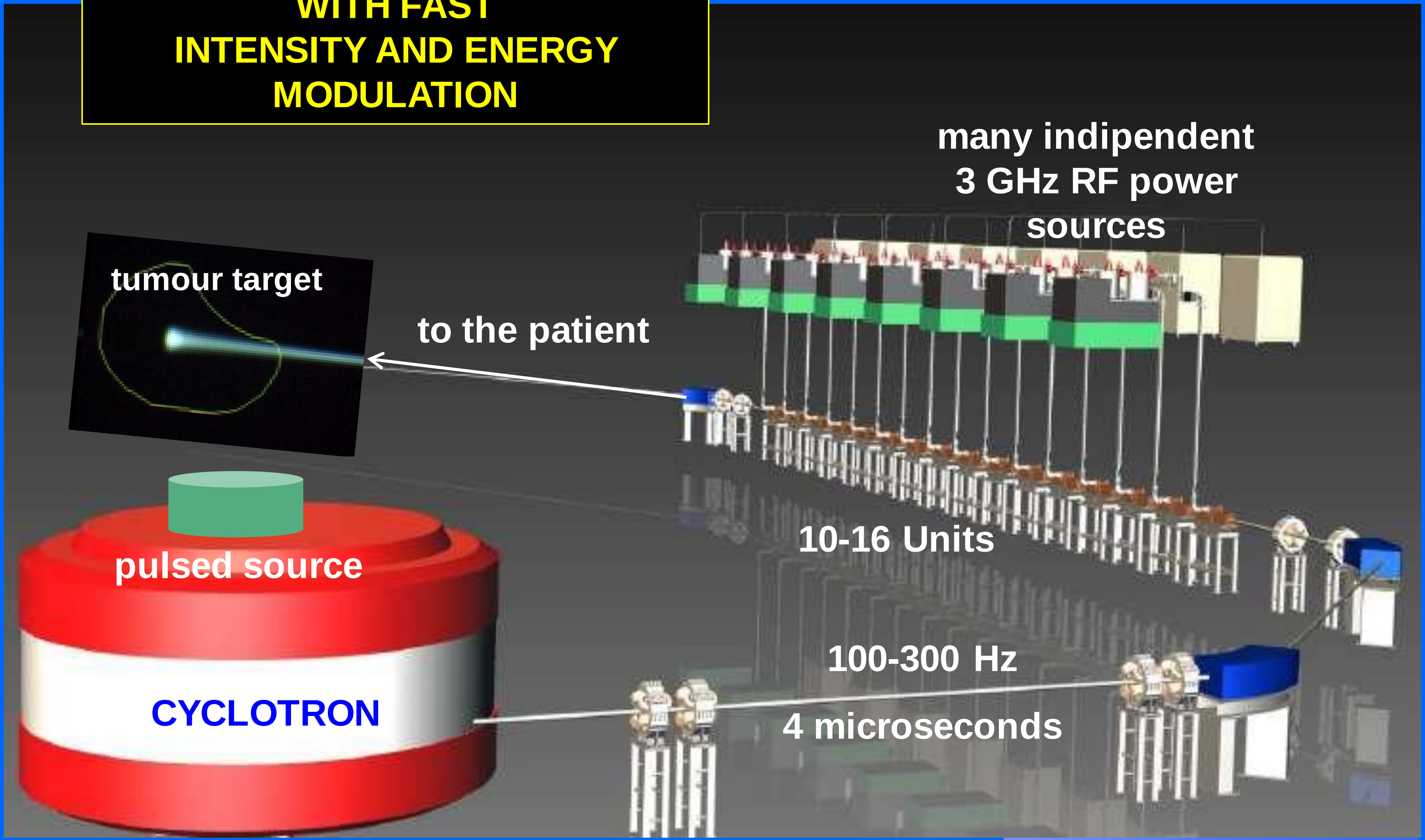
9 tesla superconducting synchrocyclotron



TERA Cell Coupled Linacs

TERA program: development and construction of « cyclinacs »

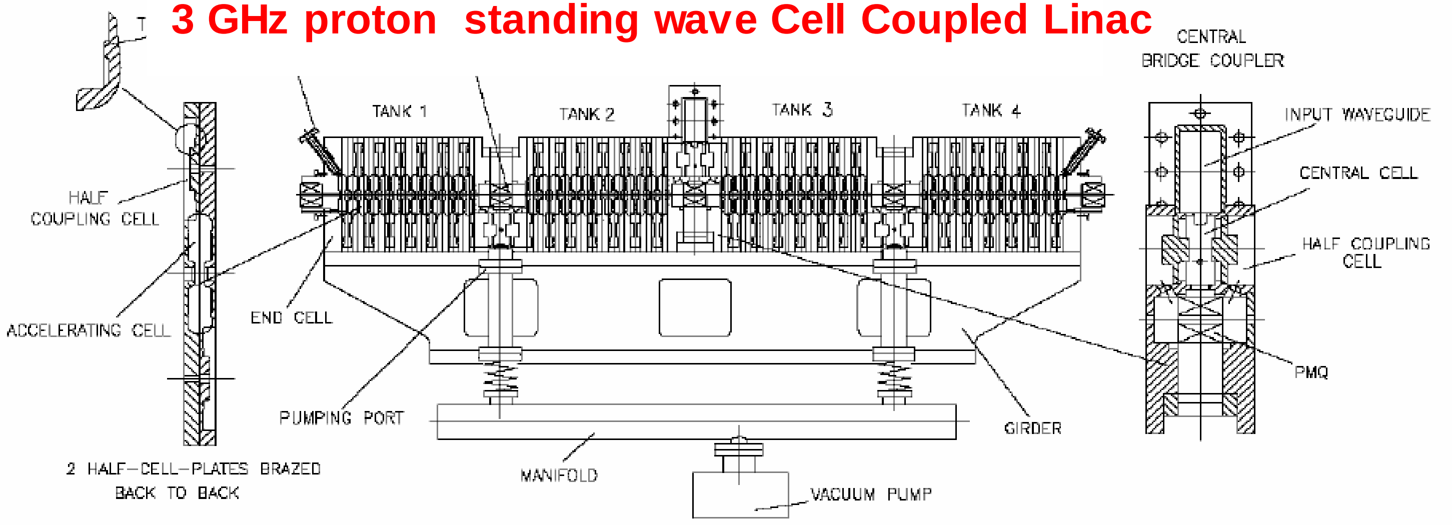
HIGH REP RATE PULSED SPOT WITH FAST INTENSITY AND ENERGY MODULATION



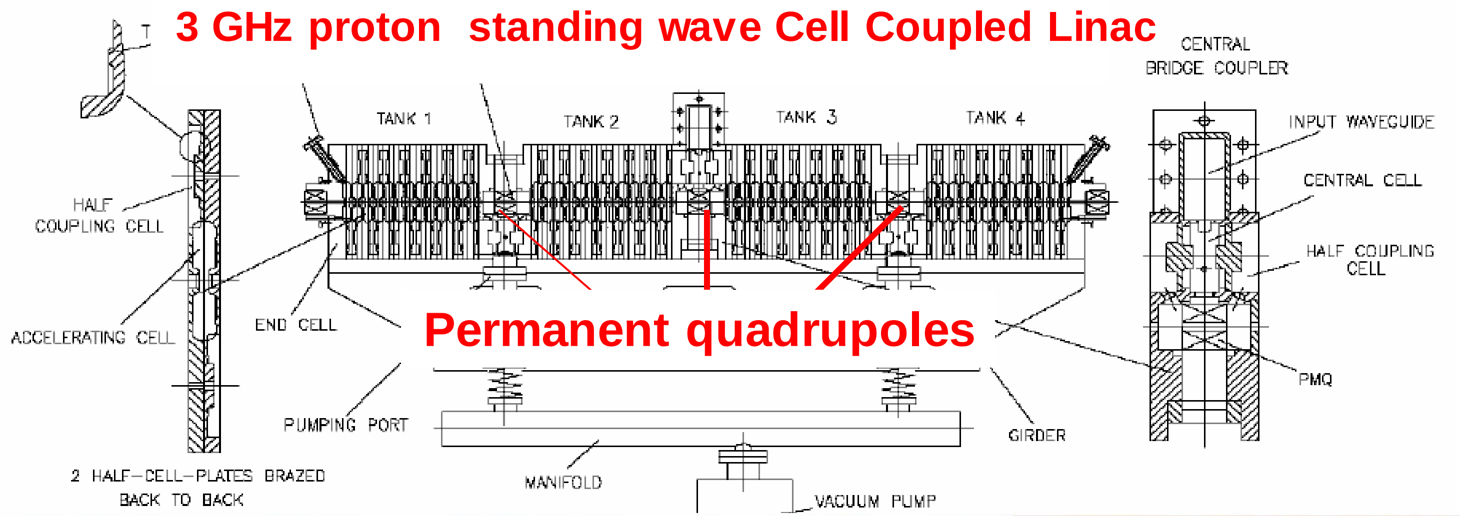
Mario Weiss

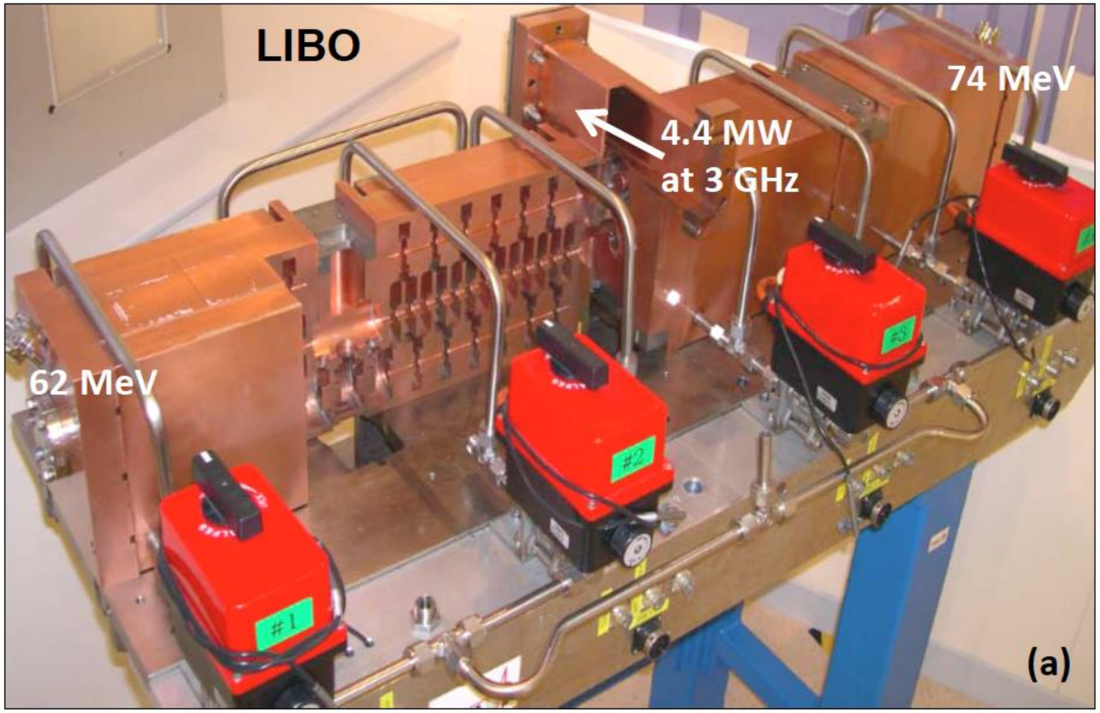
Scientific prototype built and beam tested by TERA-CERN-INFN

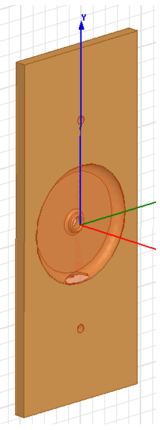
3 GHz proton standing wave Cell Coupled Linac



Scientific prototype built and beam tested by TERA-CERN-INFN



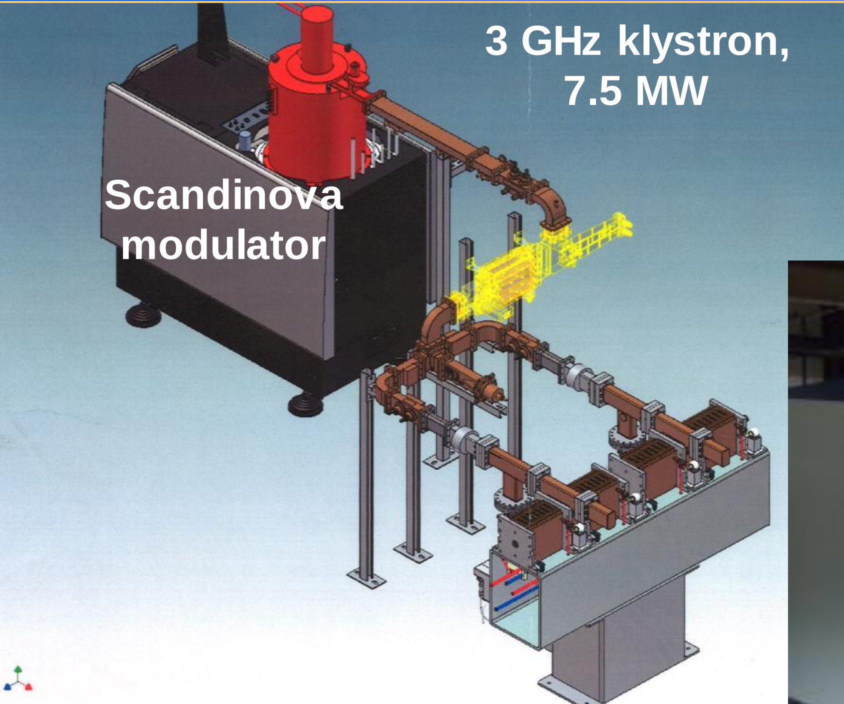


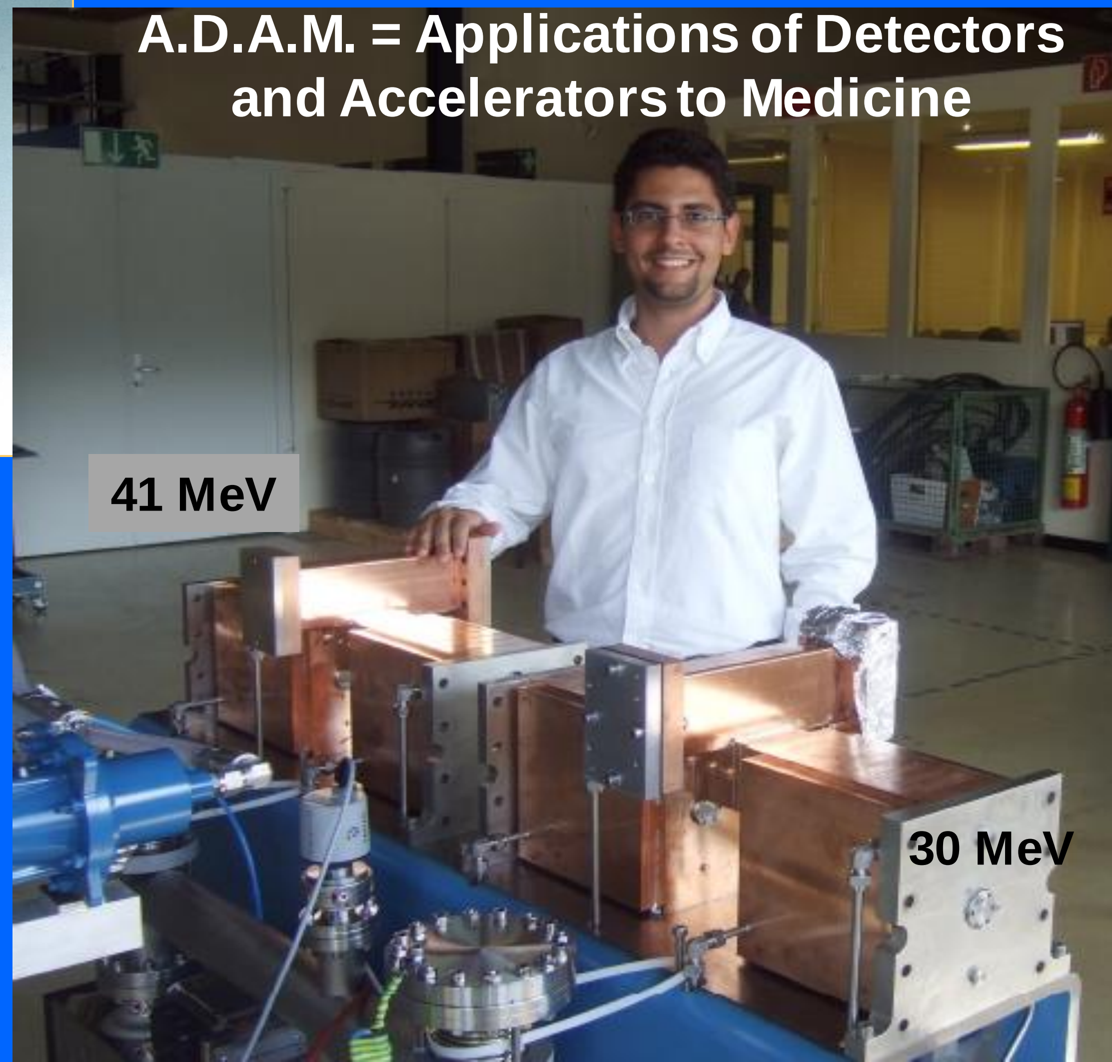


Basic unit:

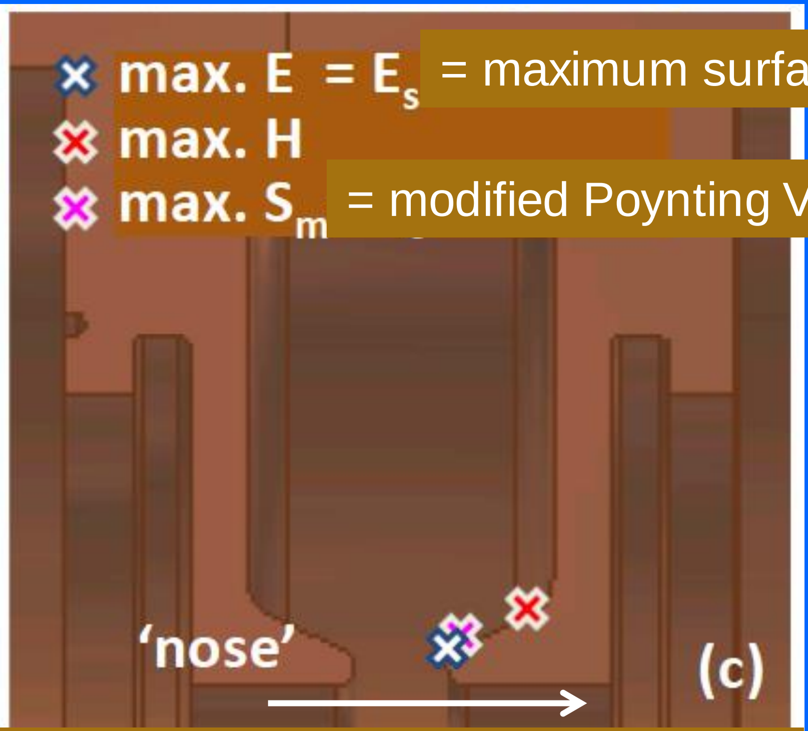
half-cell

Commercial prototype built and power tested by A.D.A.M.





Breakdowns and the 'nose' in a CCL structure



E_0 = average accelerating E-field

(*) A. Grudiev, S. Calatroni and W. Wuensch, *New Local Field Quantity Describing the High Gradient Limit of Accelerating Structures*, Phys. Rev. ST Accel. Beams 12, (2009) 102001.

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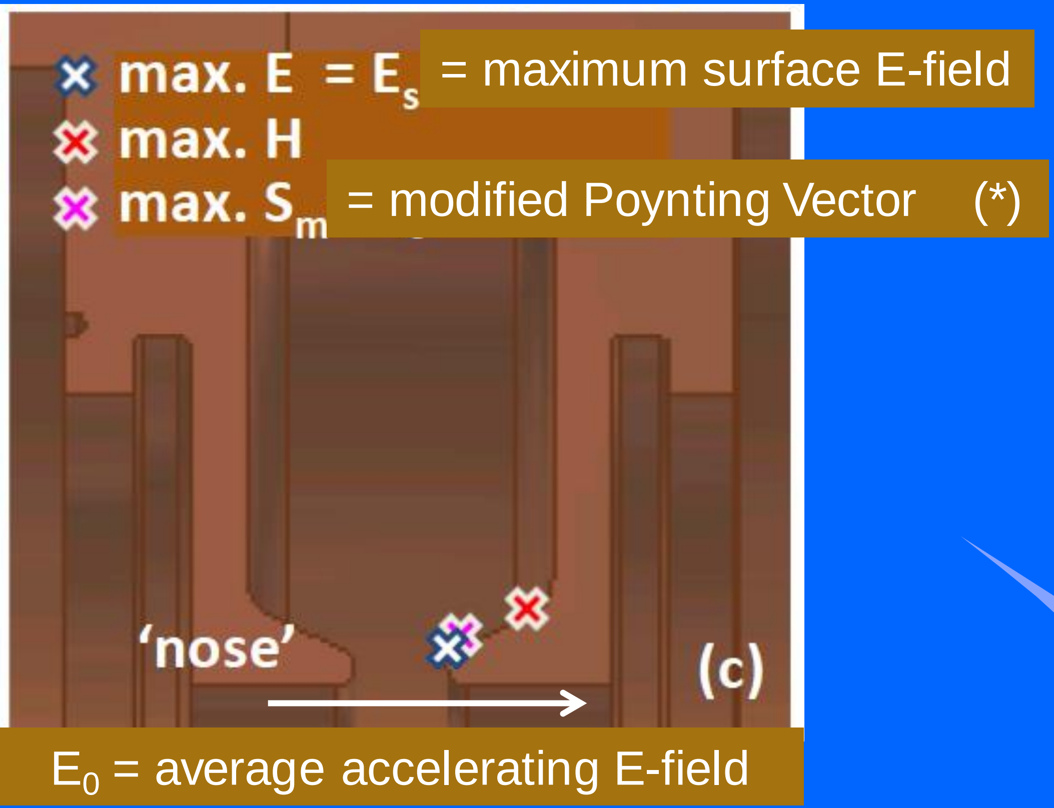

Ratio E_s / E_0 =

4.5 in a CCL structure

2 in a CLIC structure

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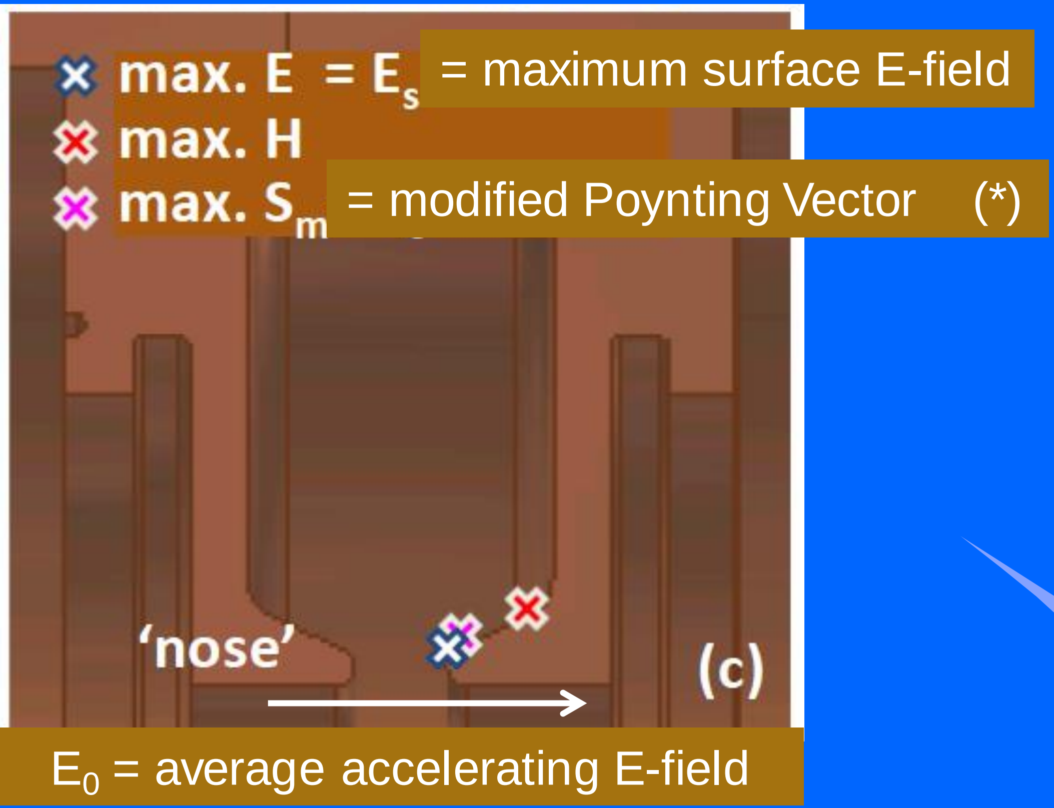


Ratio E_s / E_0 =

4.5 in a CCL structure

2 in a CLIC structure

100 MV/m in CLIC

correspond to

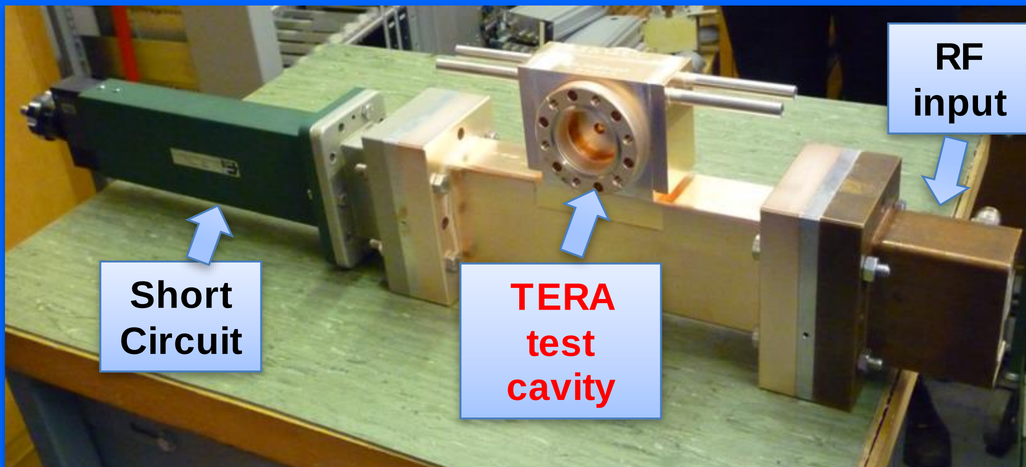
45 MV/m in CCL

(with 0.2 μs pulses)

(*) A. Grudiev, S. Calatroni and W. Wuensch, *New Local Field Quantity Describing the High Gradient Limit of Accelerating Structures*, Phys. Rev. ST Accel. Beams 12, (2009) 102001.

TULIP is based on high-gradient structures

3 GHz high-gradient tests: comparison with CLIC results



Universitat de València
DEPARTAMENT DE FÍSICA ATÒMICA MOLECULAR I NUCLEAR

High-gradient accelerating structure studies and their application in hadrontherapy

TESI DOCTORAL
Silvia Verdú Andrés
Octubre de 2012

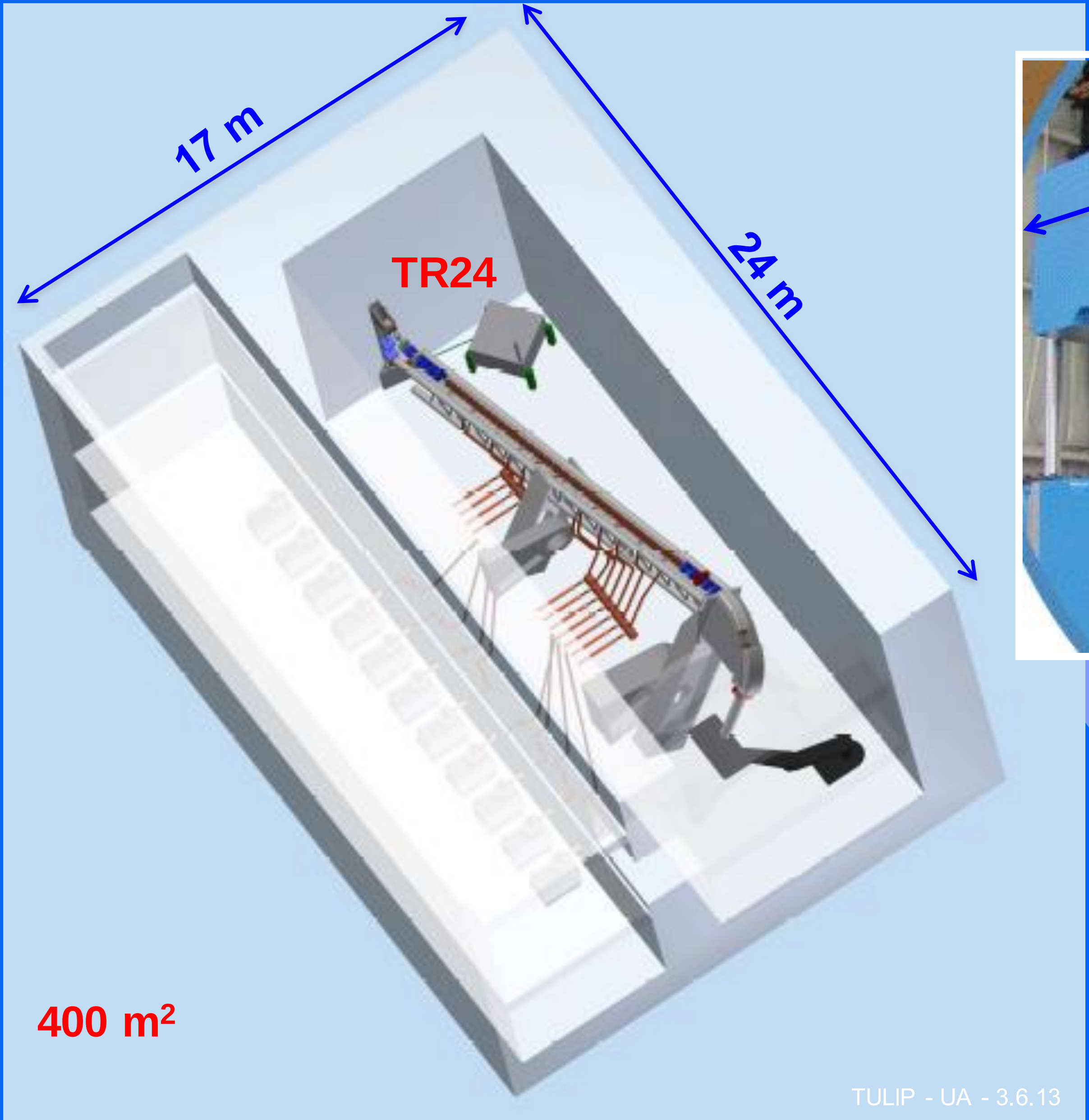
Supervisors:
Ugo Amaldi
Ángeles Faus-Golfe

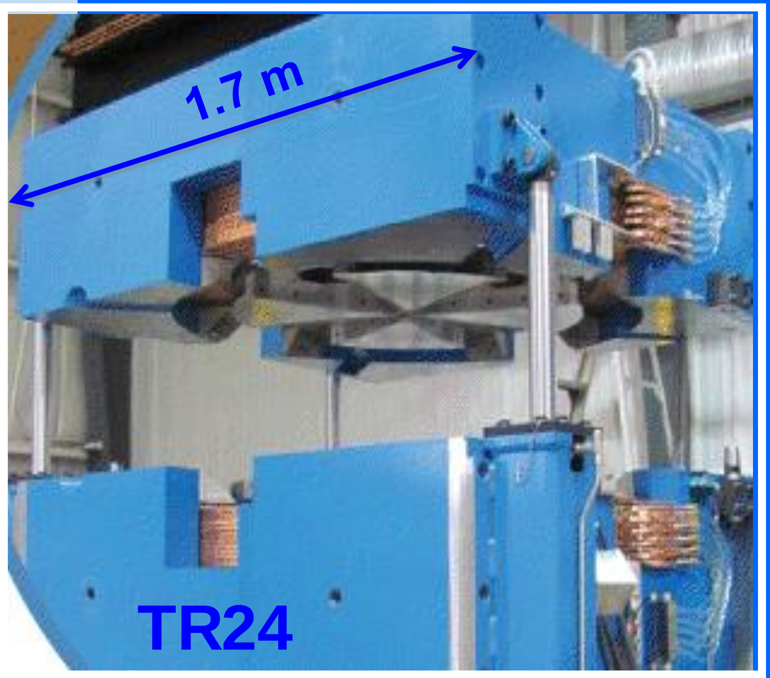
High-power test results of a 3 GHz single-cell cavity

U. Amaldi[1], D. Bergesio[1], R. Bonomi[1,4], A. Degiovanni[1,2], M. Garlasché[1,4], P. Magagnin[1], S. Verdú-Andrés[1,3] and R. Wegner[4]
[1] TERA Foundation, Via Puccini 11, 28100 Novara, Italia

arXiv:1206.1930v2 [physics.acc-ph] 15 Jun 2012

TULIP at 3 GHz and high gradients (E_0 = 30 MV/m)





24 MeV cyclotron

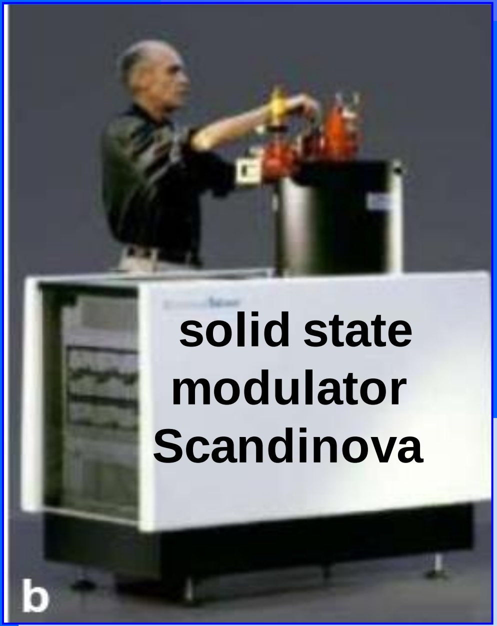
by

Advanced Cyclotron Systems

(Canada)

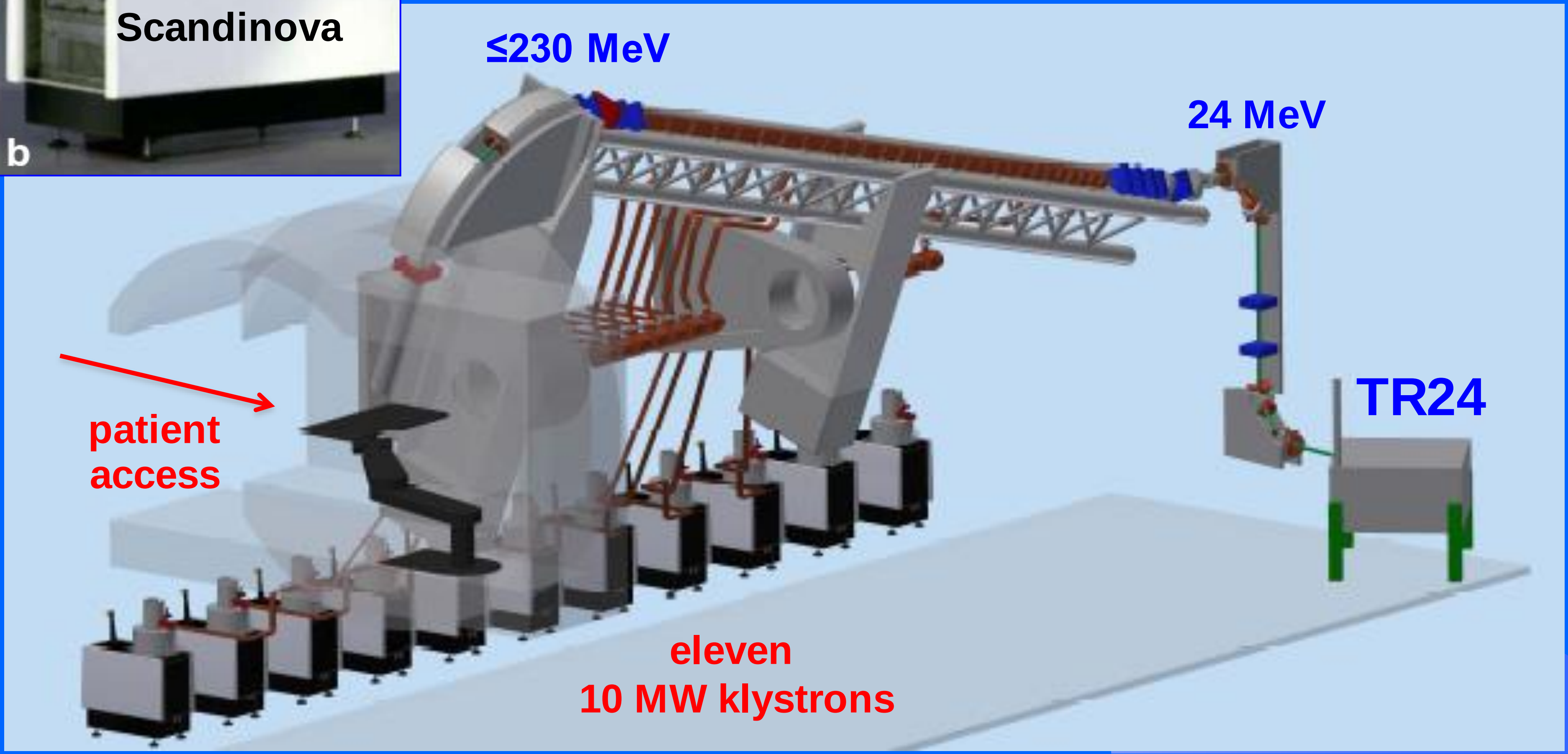
A TR24 is installed at IPHC (Strasbourg)

TULIP at 3 GHz and high gradients (E_0 = 30 MV/m)



Thales 10 MW
klystron

Rotation: +-110° wrt the horizontal plane



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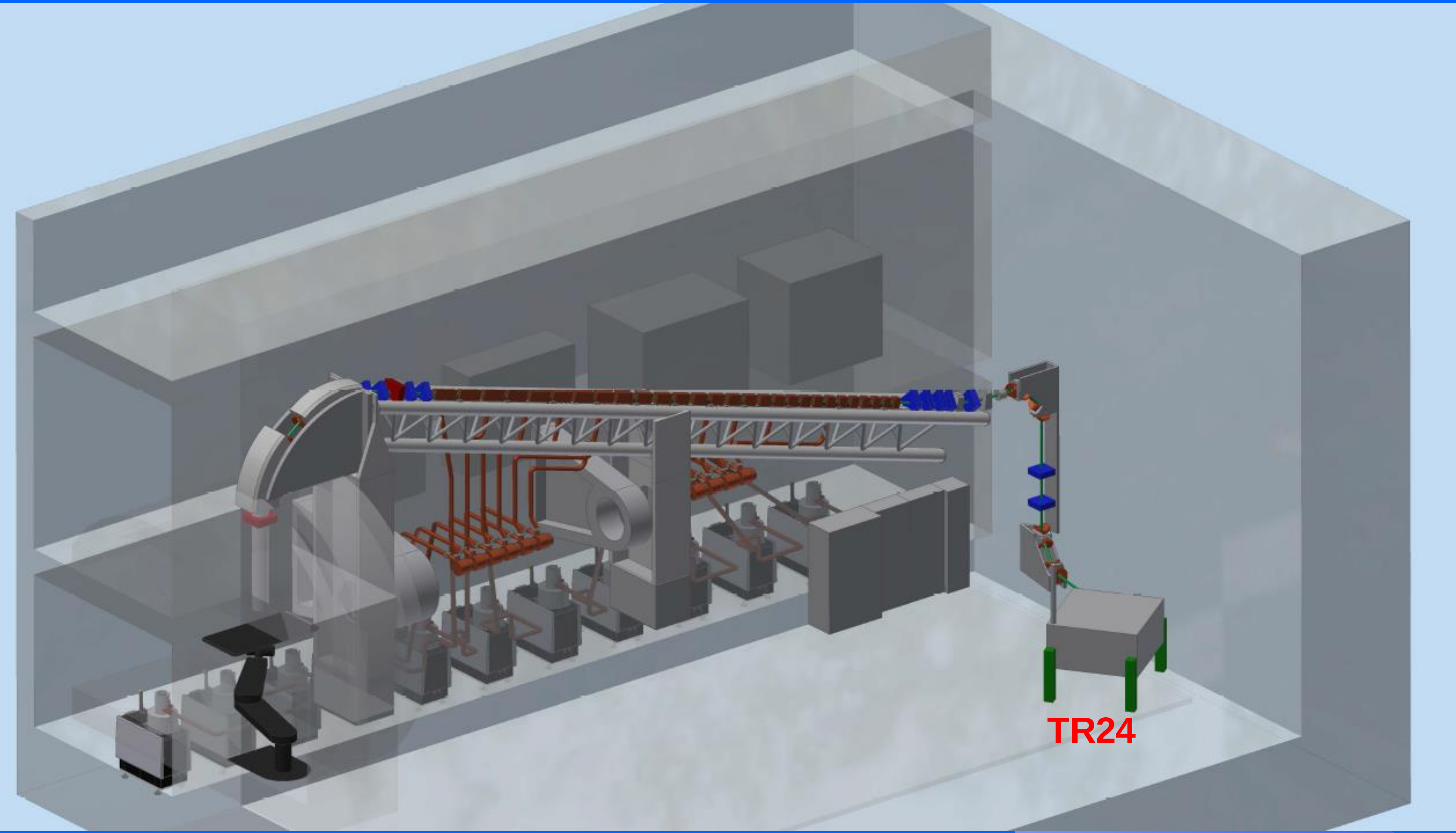

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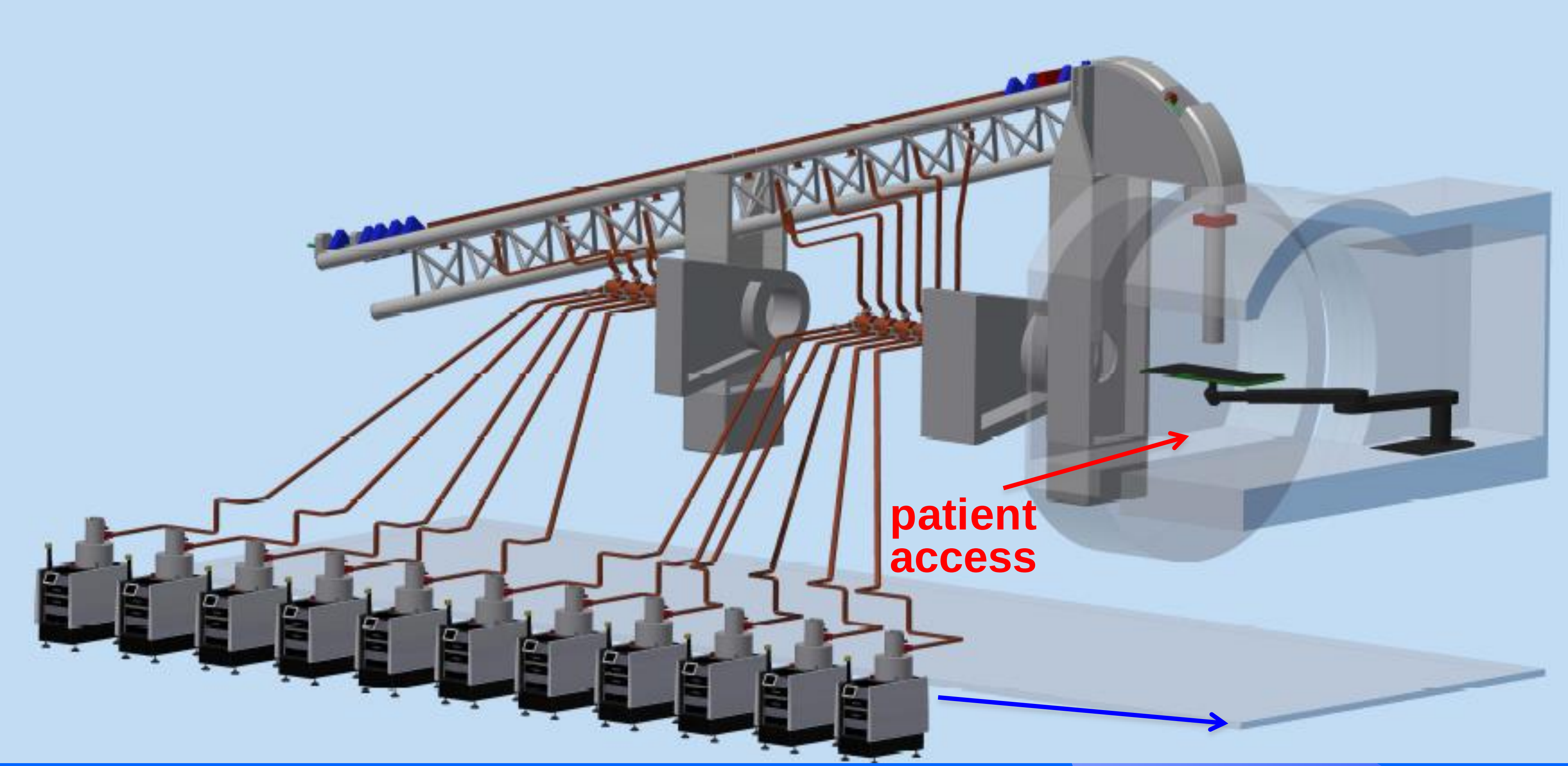

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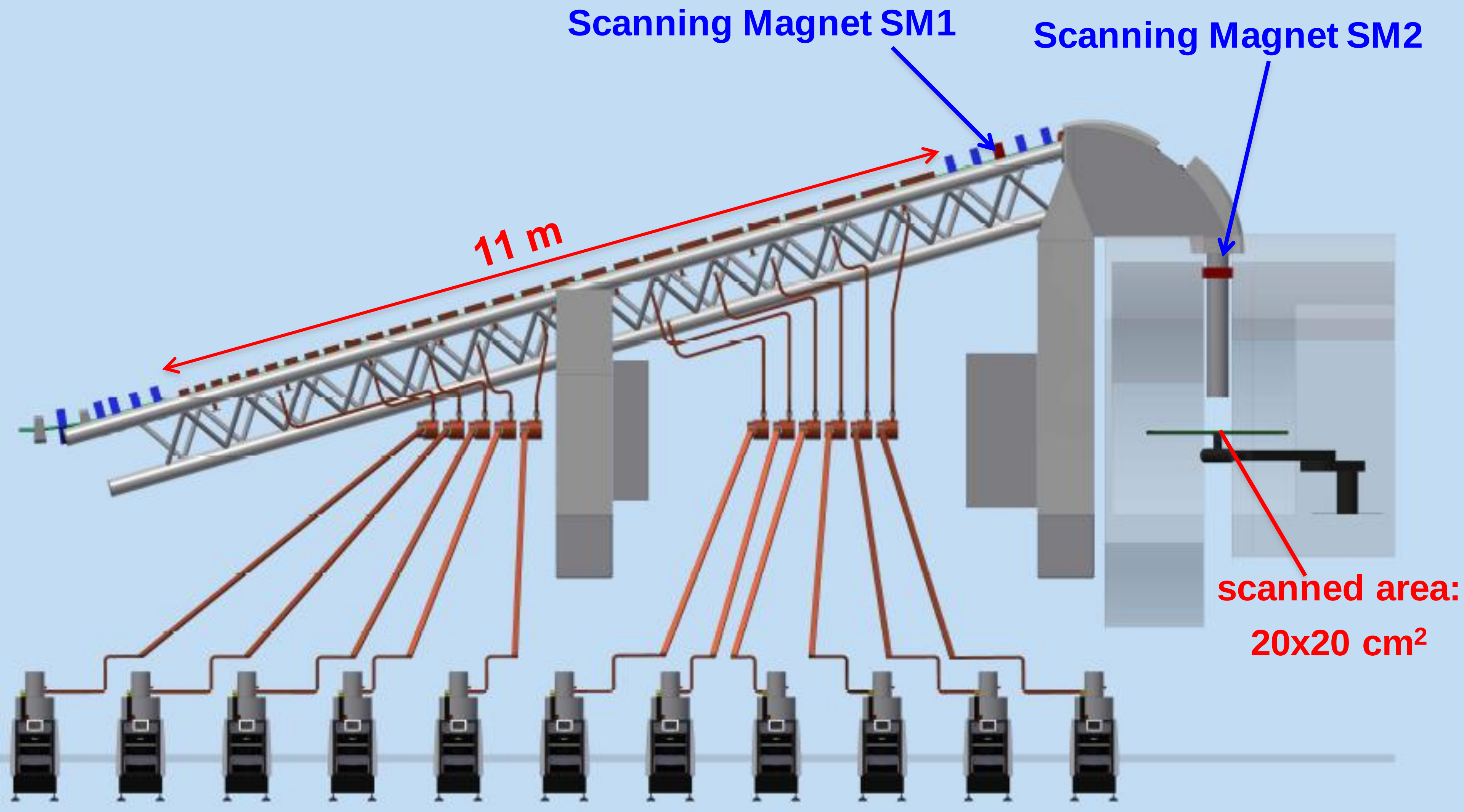

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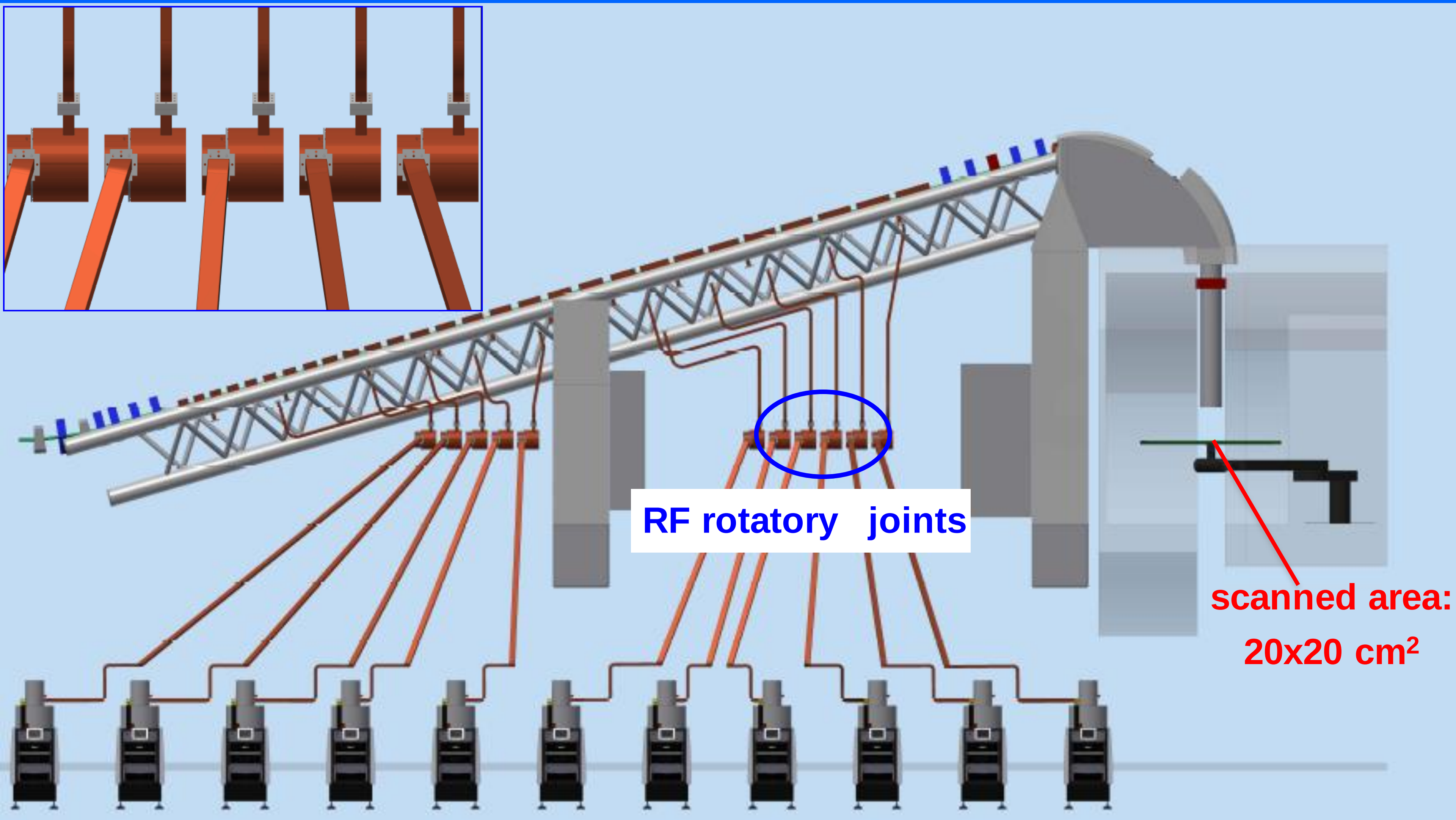
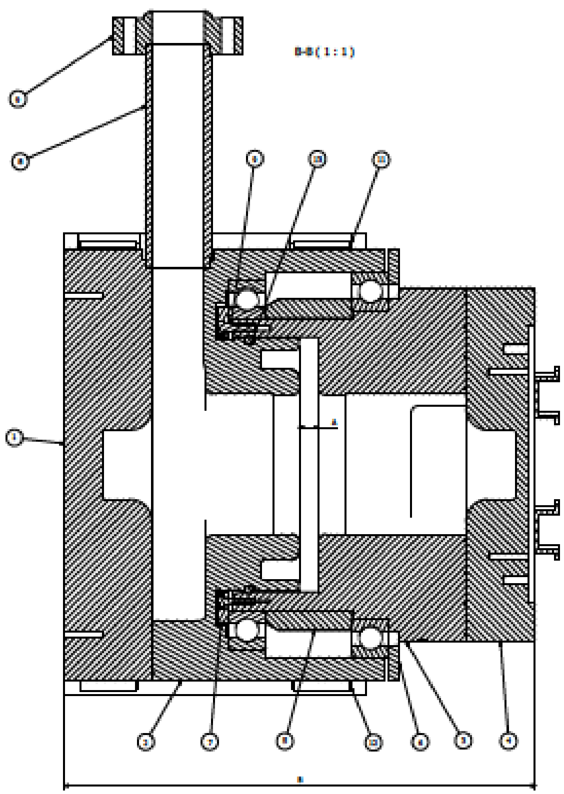


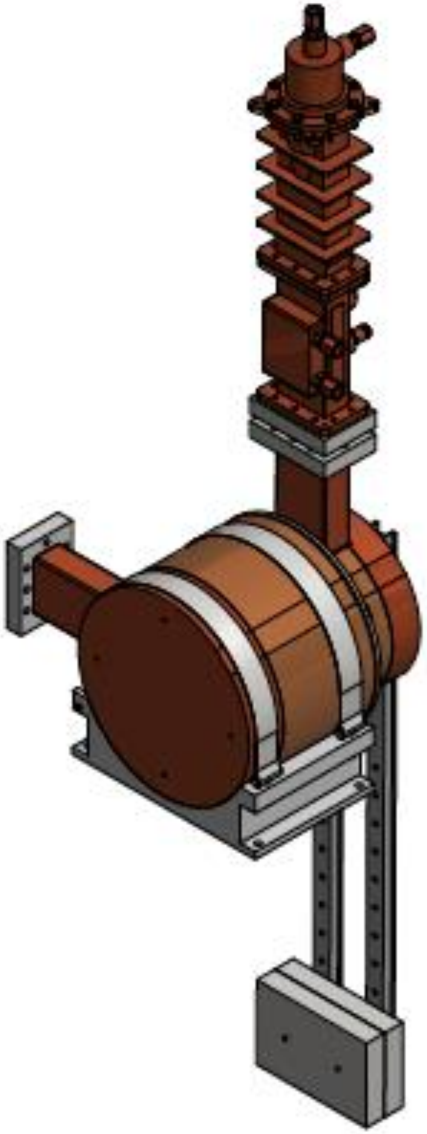
The RF rotating joint was designed by Igor Syratchev



Mechanical design by

Paolo Magagnin - TERA

NOTE:
- For production steps refer to TLPRJ_001;
- (final gap after spacer remachining A=11.24± 0.04 mm)



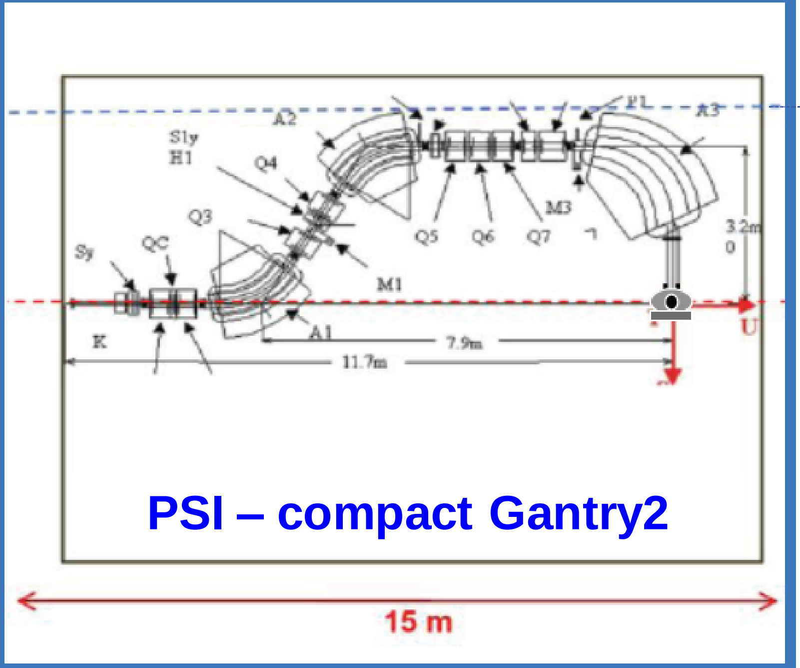
TULIP at 3 GHz and high gradients (30 MV/m)

SOME NUMBERS

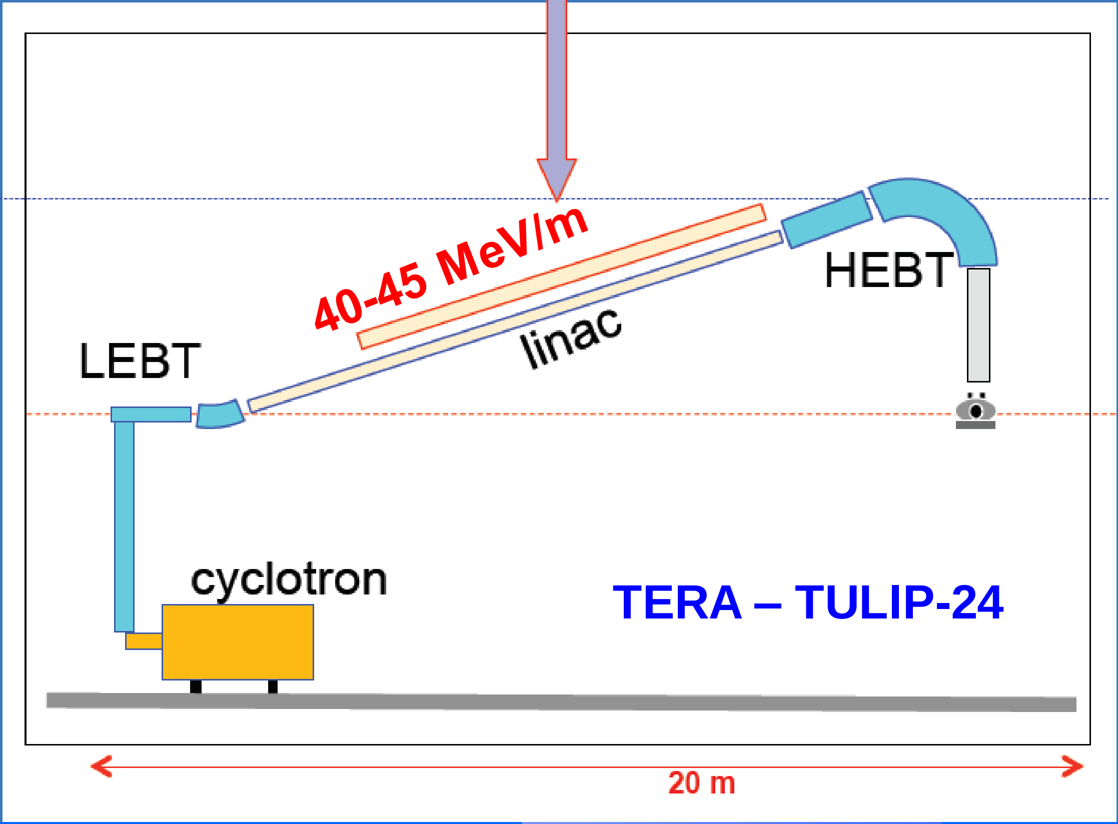
- 11 klystron x 10 MW = 110 MW of peak power
- 120 Hz with 4 microsecond RF pulses: duty cycle = $5\ 10^{-3}$
- Average RF power = 55 kW; plug power = 160 kW
- Maximum number of protons per spot = $5\ 10^{7}$
- Each voxel visited at least 12 times
- Sources produces a DC proton beam of 300 microamperes
- For protontherapy it will be chopped at 120 Hz and 5 microseconds so that the average current would be only 0.18 microamperes
- The chopping device is under discussion with ACSI

Next step: from 30 MV/m to 45 MV/m

A new Travelling Wave structure is being prototyped with CLIC (CERN): length from 11 m to 8 m



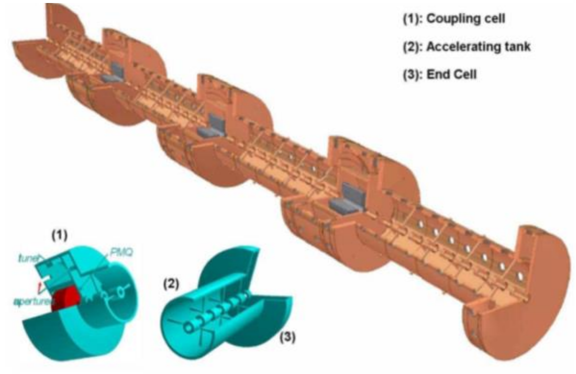
PSI – compact Gantry2



TERA – TULIP-24

Next step: from 30 MV/m to 45 MV/m for a total length ≤ 8 m

High-efficient CLUSTER



New bwTW structure

24 MeV **70 MeV** **≤ 230 MeV**

≤ 2 m **≤ 6 m**

Dynamics calculations.: H. Shaker **Daniel Schulte**

High-gradients for proton therapy KT Fund project

Walter Wuensch

CLIC A. Grudiev
I. Syratchev
M. Garlasché

TERA: U.A.
A. Degiovanni
P. Magagnin
S. Benedetti

Next step: from 30 MV/m to 45 MV/m

- Quasi-periodic PMQ FODO lattice

- The cells in each ‘tank’ have the same length, while from one tank to the next, the cell length increases:

β tapering in the range 0.22-0.60

bore aperture = 5 mm

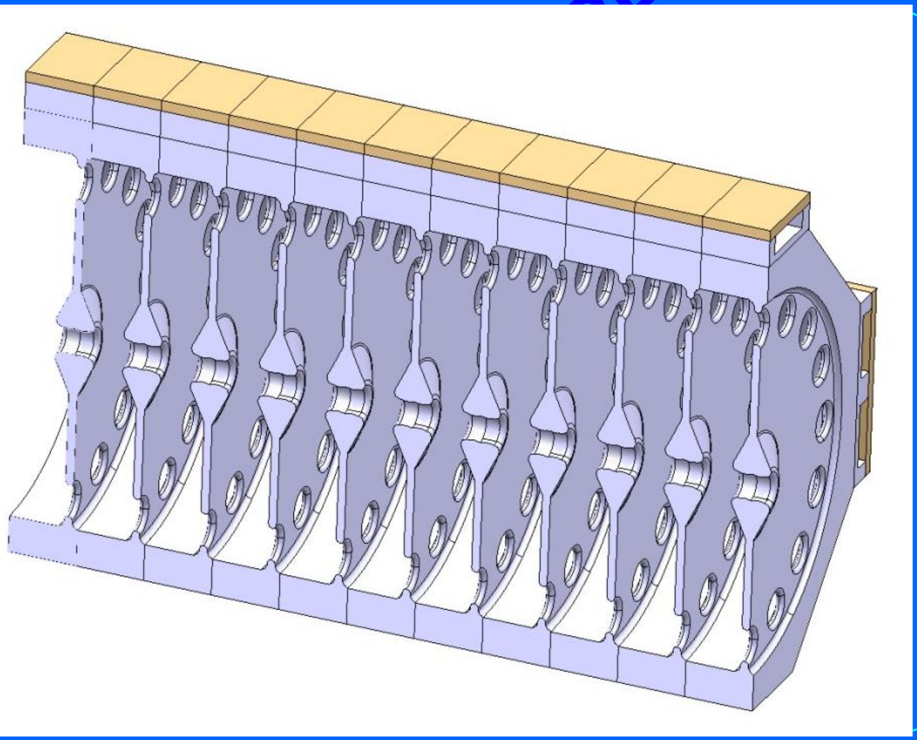
- Max BDR: 1 BD per treatment session (~ 5 min) on the whole linac length (~ 10 m).

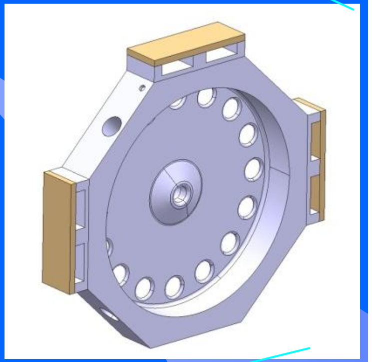
→ BDR ~ 10^{-6} bpp/m (as for CLIC)

Comparison between optimized TW structure and CCL

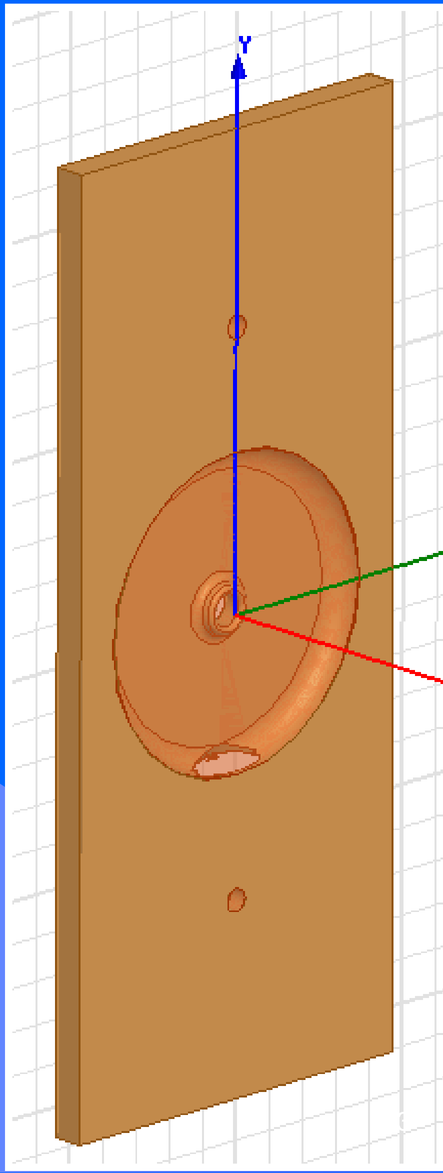
Tapered structures:

the coupling holes are smaller along the structure





Half-cell of LIBO/LIGHT



PROs and CONs of bTW compared to standard SCL design

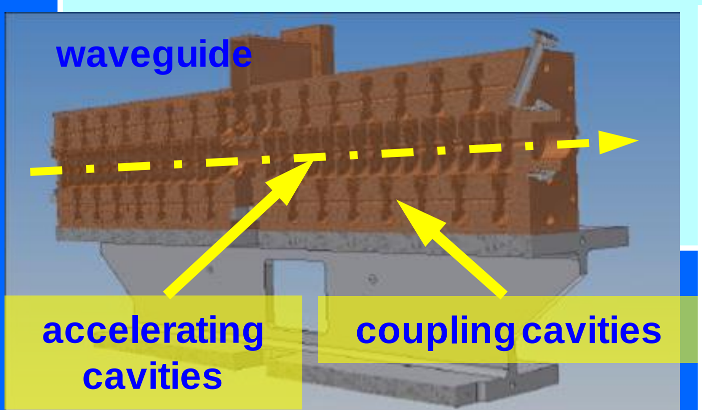
PROs

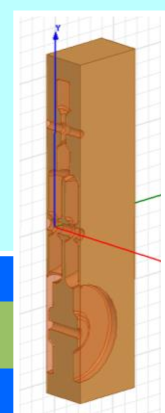
+ simpler mechanically
+ less material and brazing needed (lower number of cells)
+ easier tuning for TW
+ shorter filling time
+ no bridge couplers

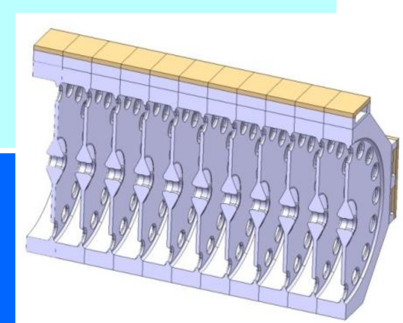
CONs

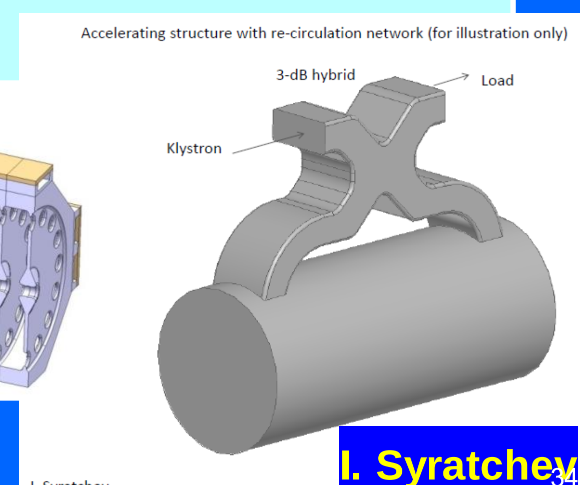
- small wall thickness
- material properties change during brazing
- Dissipated power is higher (half power goes to the load even with **recirculator):**

power for TW 20% higher than for SW CCL structure



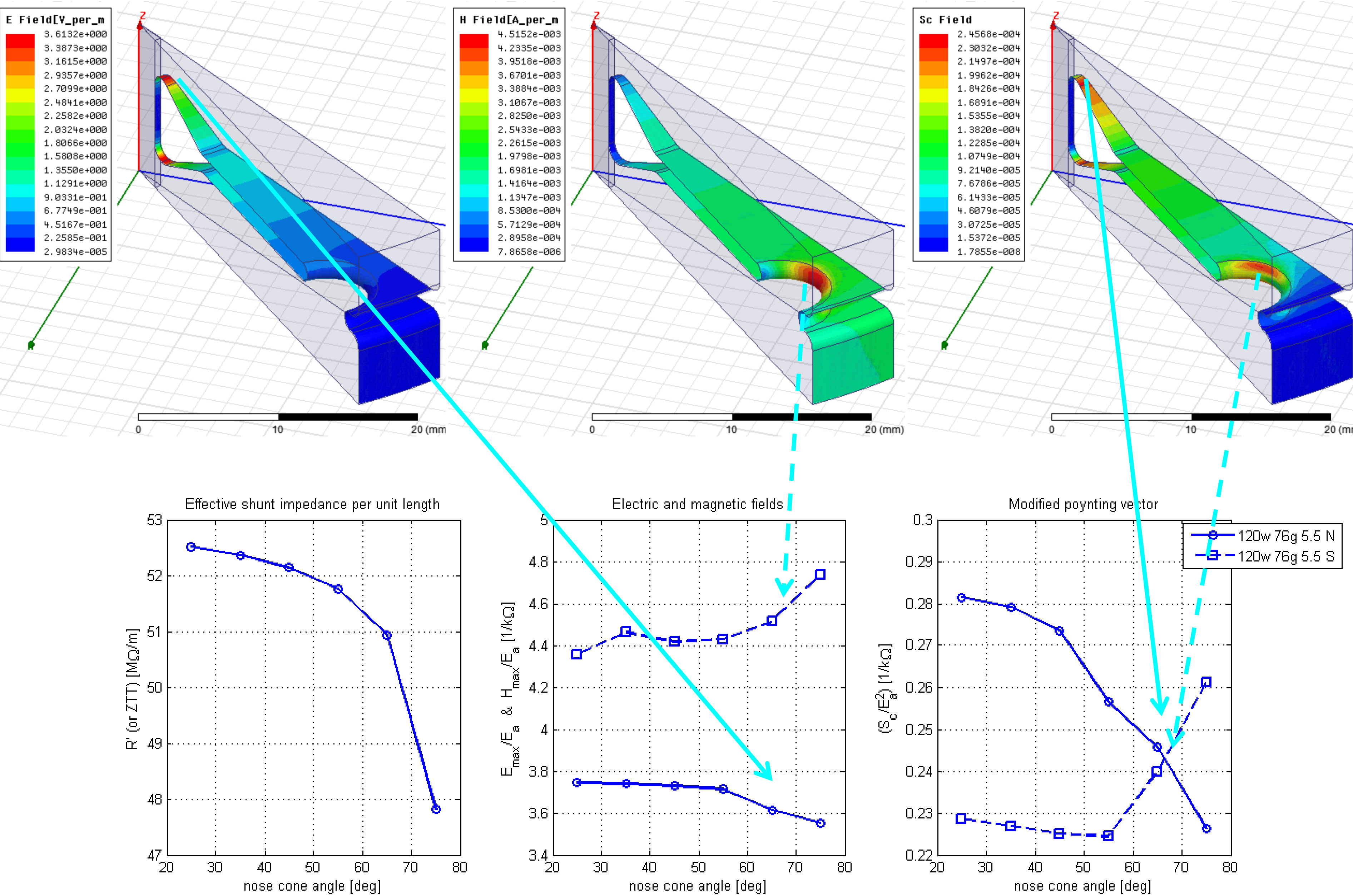




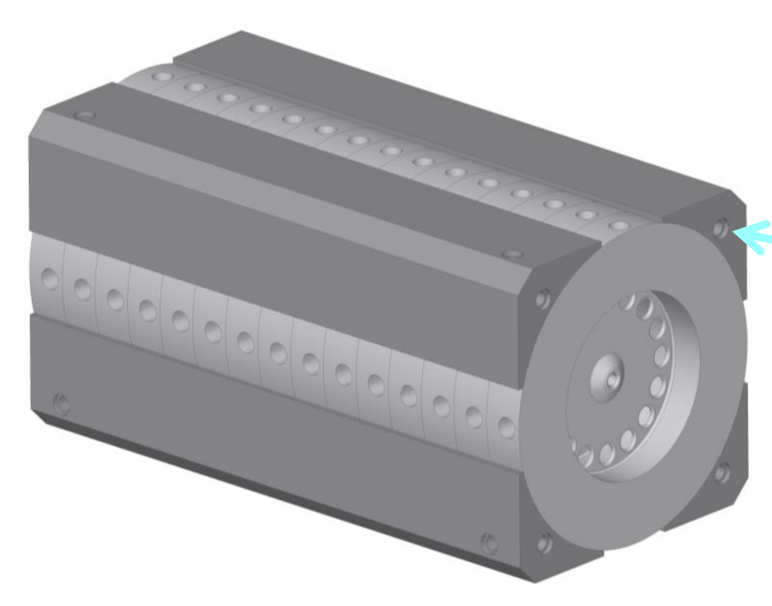


I. Syratchev

Optimization plots – fields (A. Degiovanni)

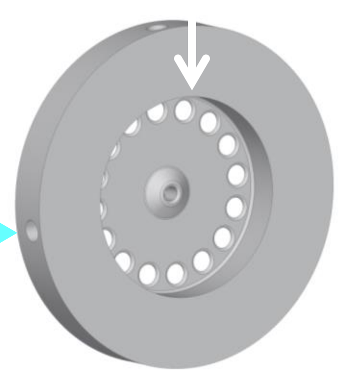


Mechanics (P. Magagnin)

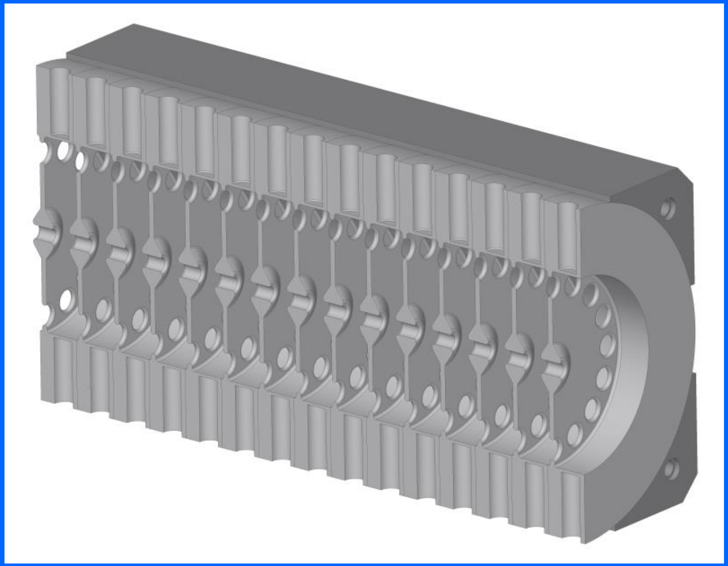


Cooling plates

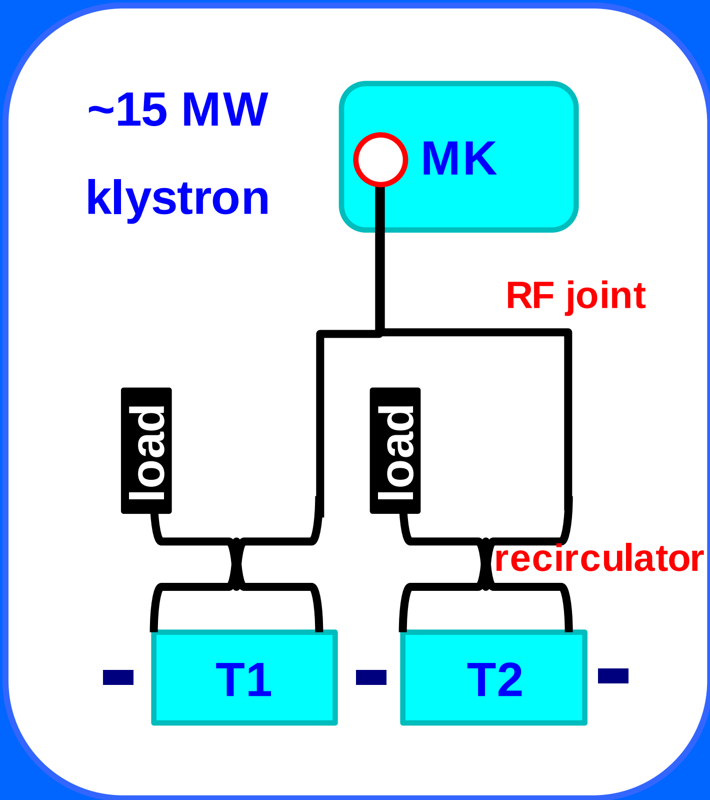
Accelerating elements

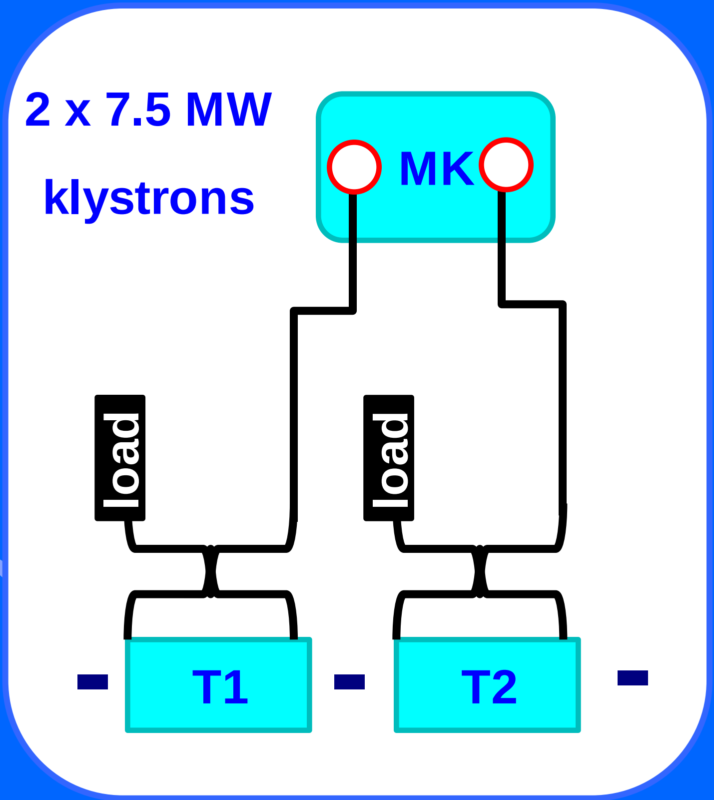


4 holes for dimpler tuners



How to power the 5.5 m long bwTW structure?

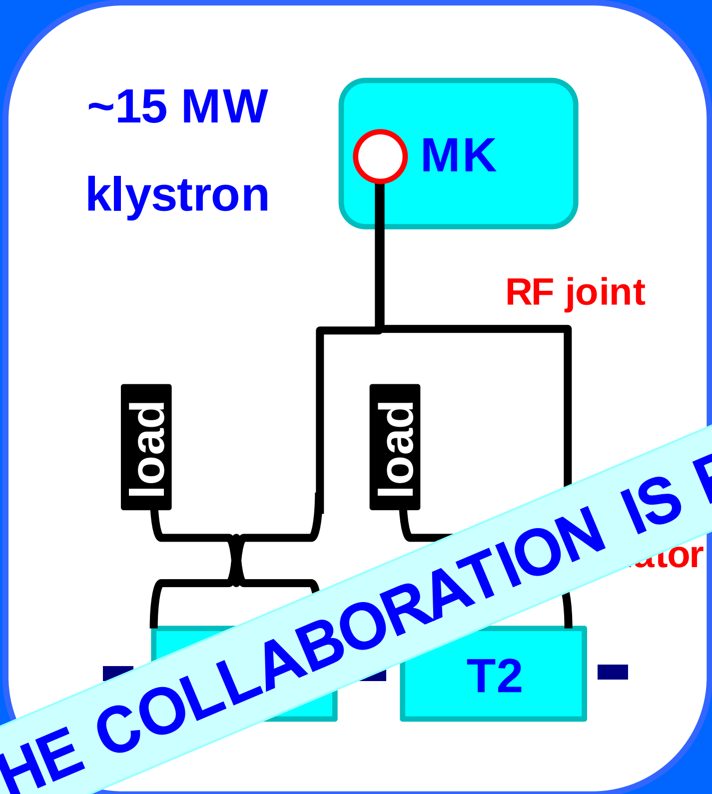


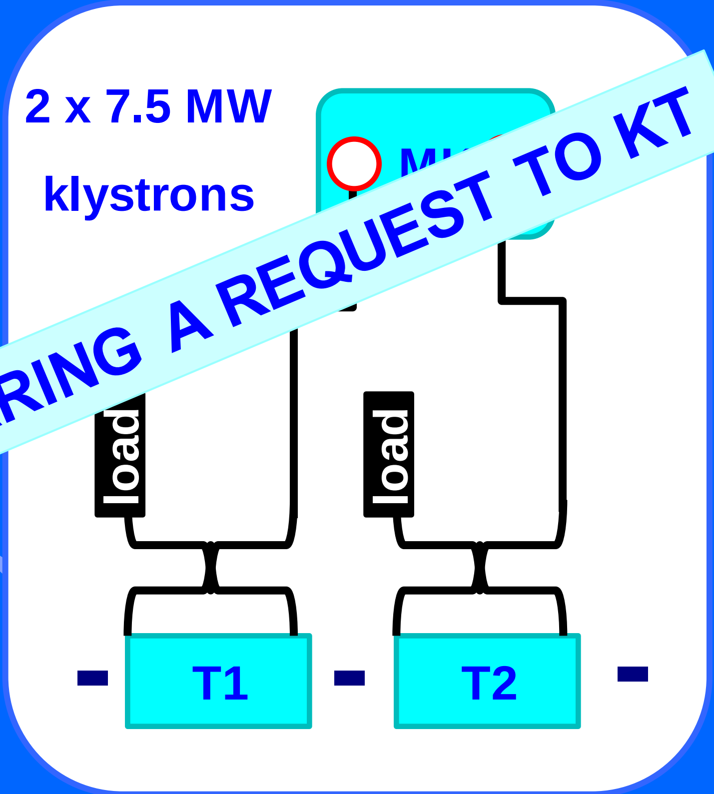


Present plans: 8 modulators for 16 tanks. Total peak power 120 MW

(average plug power = 200 kW)

How to power the 5.5 m long bwTW structure?





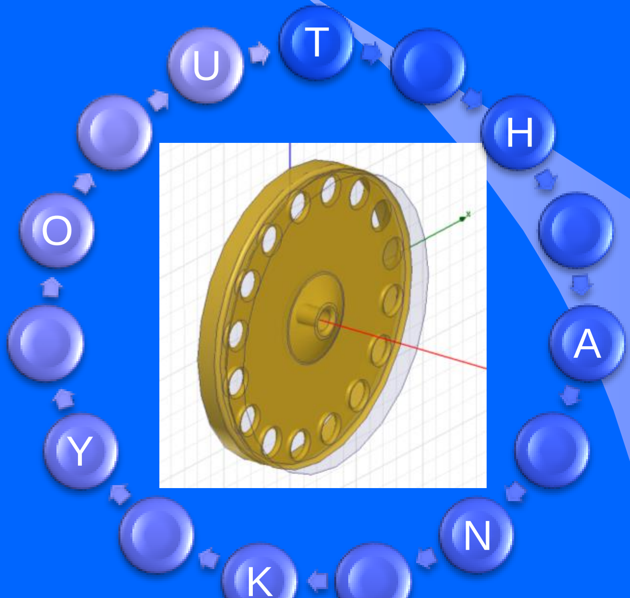
THE COLLABORATION IS PREPARING A REQUEST TO KT

Present plans: 8 modulators for 16 tanks. Total peak power 120 MW

(average plug power = 200 kW)

- Optimization of TW structures for high gradient operations has been performed
- The RF design of the input and output coupler is now ongoing.
- The optimization of the whole linac layout needs some iterations, but looks promisig

- **THE DESIGN OF SUITABLE MODULATOR/KLYSTRON SYSTEMS IS AN OPEN PROBLEM**



Visit f the TERA group to the TR24 cyclotron in Strasbourg