Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
SAPIENZA UNIVERSITÀ DI ROMA

The SAFEST project

30/09/2024

Lucia Giuliano

Sapienza University of Rome
National Institute of Nuclear Physics, **INFN**

INFN Istituto Nazionale di Fisica Nucleare
FLASH Radiotherapy with hIgh Dose-rate particle beAms
ROME TECHNOPOLE INNOVATION ECOSYSTEM
HEALITALIA Health Extended ALliance for Innovative Therapies, Advanced Lab-research, and Integrated Approaches of Precision Medicine
Finanziato dall'Unione europea NextGenerationEU
MUR Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Experience with low energy electron FLASH LINAC

PHYSICAL REVIEW ACCELERATORS AND BEAMS **24,** 050102 (2021)

Compact *S*-band linear accelerator system for ultrafast, ultrahigh dose-rate radiotherapy

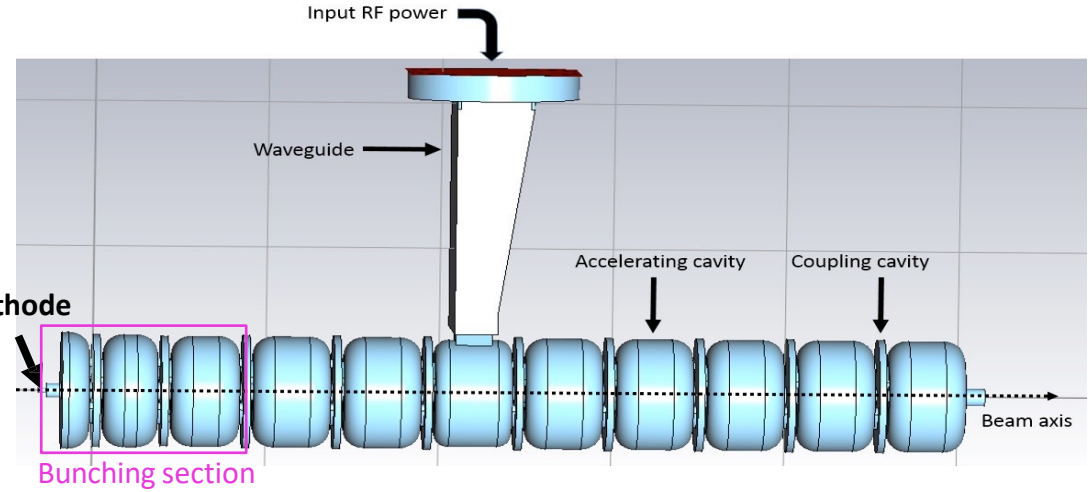
L. Faillace,[1,6,*] S. Barone,[2] G. Battistoni,[3] M. Di Francesco,[2] G. Felici,[2] L. Ficcadenti,[4] G. Franciosini,[4,5] F. Galante,[2] L. Giuliano,[1,4] L. Grasso,[2] A. Mostacci,[1,4] S. Muraro,[3] M. Pacitti,[2] L. Palumbo,[1,4] V. Patera,[1,4] and M. Migliorati[1,4]

applied sciences MDPI

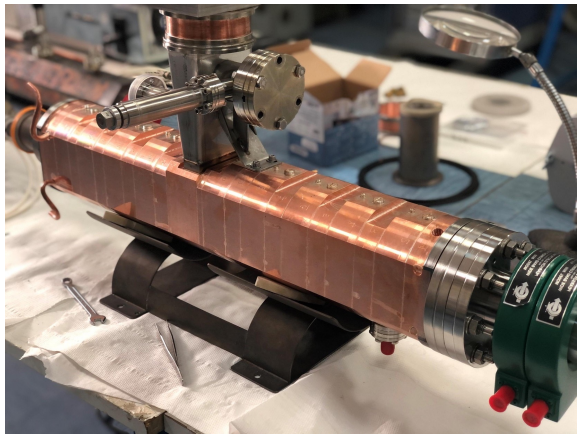
Article

Characterization of Ultra-High-Dose Rate Electron Beams with ElectronFlash Linac

Lucia Giuliano [1,2], Gaia Franciosini [1,2], Luigi Palumbo [1,2,*], Lilia Aggar [3], Marie Dutreix [3], Luigi Faillace [4], Vincent Favaudon [3], Giuseppe Felici [5], Federica Galante [5], Andrea Mostacci [1,2], Mauro Migliorati [1,2], Matteo Pacitti [5], Annalisa Patriarca [6] and Sophie Heinrich [3]

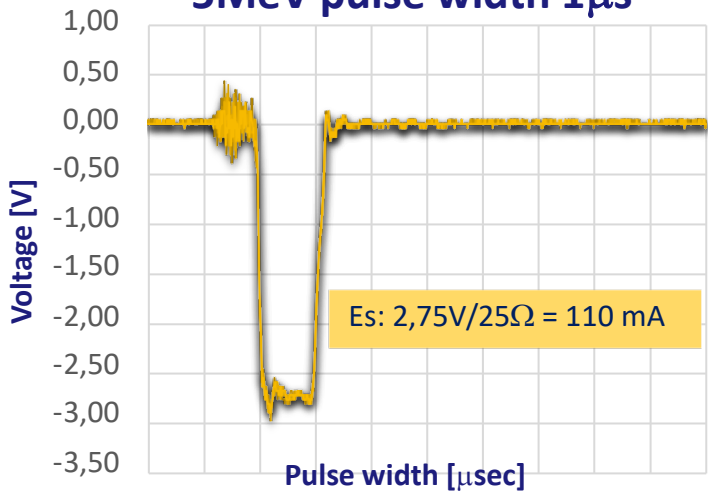


institutCurie

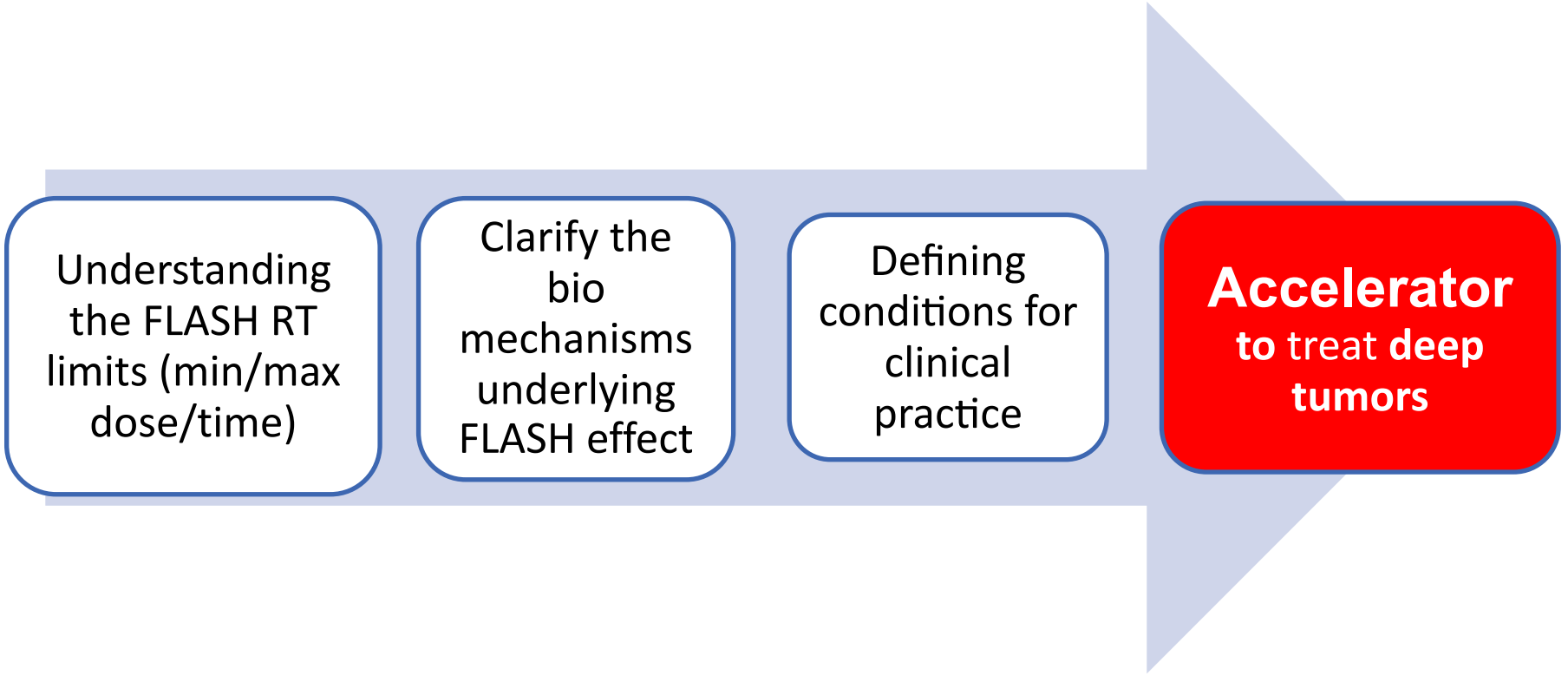


Symbol	Description	Value
PRF	Pulse repetition frequency	0.5 – 250 Hz
t_p	Pulse width	0.5 - 4.0 μs
t_i	Total irradiation time	< 100 ms
$\overline{\dot{D}}$	Time-averaged dose rate	> 100 Gy/s
$\dot{D}_p$	Dose-rate in a single pulse	> 10^6 Gy/s
D_p	Dose in a single pulse	> 3 Gy
I_p	Peak current	> 100 mA

5MeV pulse width 1µs



Toward deep tumors



To treat deep tumor we need very high-energy electrons (> 100 MeV): **VHEE machine**

Joint Study Group Sapienza – Infn

SAFEST

SApienza Flash Electron Source for radio-Therapy

Proposal of a

VHEE-FLASH-RT Research Facility

D. Alesini[2], D. Alvaro[1], M.G. Bisogni[5], F. Bosco[1], F. Cardelli[2], V. Cardinale[1], M. Carillo[1,3], G. Cenci[1], E. Chiadroni[1,2], I. Chiarotto[1], P. Cirrone[4], M. Coppola[1], G. Cuttone[4], D. De Arcangelis[1], F. De Felice[1], A. De Gregorio[1,3], G. De Vincentis1, F. Di Martino[7], R. Di Raddo[2], R. Faccini[1,3], L. Faillace[2], M. Feroci[1], L. Ficcadenti[3], A. Filippini[1], D. Francescone[1,3], G. Franciosini[1,3], G. Franzini[2], A. Gallo[2], E. Gaudio[1], L. Giuliano[1,3], V. Lollo[2], M. Magi[1,3], C. Mancini Terracciano[1,3], M. Marafini[3,8], F. Marampon[1], M. Migliorati[1,3], G. Minniti[1], A. Mostacci[1,3], A. Muscato[1], A. Napolitano[1], R. Negri[1], M. Osti[1], M. Pacilio[6], G. Pellacani[1], F. Palma[1], L. Palumbo[1,3], R. Pani[1], M. Pasquali[1], L. Passalacqua[1], V. Patera[1,3], F. Perondi[1], M. Petrarca[1,3], R. Petrucci[1], F. Pitolli[1], R. Remetti[1], A. Sarti[1,3], A. Schiavi[1,3], A Sciubba[1,3], B. Spataro[2], V. Tombolini[1], M. Toppi[1,3], G. Torrisi[4], G. Traini[3], A. Trigilio[1,3], A. Vannozzi[2].

(1) Università La Sapienza
(2) INFN, Laboratori Nazionali di Frascati
(3) INFN, Sezione di Roma
(4) INFN, Laboratori Nazionali del SUD
(5) Università di Pisa & INFN Pisa
(6) Fisica Sanitaria, Azienda Ospedaliera Policlinico Umberto I, Roma
(7) Fisica Sanitaria, Azienda Universitaria Ospedaliera Pisana, Pisa
(8) Centro Ricerche Enrico Fermi , Roma

Contents lists available at ScienceDirect

Physica Medica

journal homepage: www.elsevier.com/locate/ejmp

Original Paper

Perspectives in linear accelerator for FLASH VHEE: Study of a compact C-band system

L. Faillace [a,*], D. Alesini [a], G. Bisogni [d,j], F. Bosco [b,c], M. Carillo [b,c], P. Cirrone [e], G. Cuttone [e], D. De Arcangelis [b,c], A. De Gregorio [c,i], F. Di Martino [f], V. Favaudon [g], L. Ficcadenti [b,c], D. Francescone [b,c], G. Franciosini [c,i], A. Gallo [a], S. Heinrich [g], M. Migliorati [b,c], A. Mostacci [b,c], L. Palumbo [b,c], V. Patera [b,c], A. Patriarca [h], J. Pensavalle [d,j], F. Perondi [b], R. Remetti [b], A. Sarti [b,c], B. Spataro [a], G. Torrisi [e], A. Vannozzi [a], L. Giuliano [b,c]

Possible beam Parameters of a new VHEE-Linac

	Description	Measured Value
E	Beam Energy	7 MeV
f	RF frequency	2.998 GHz
PRF	Pulse repetition frequency	> 100 Hz
t_p	Pulse width	1 - 4 µs
Q_p	Pulse Charge	500 nC
I_p	Pulse Current	125 mA
D_p	Dose in a single pulse	19 Gy in Ø 3 cm applicator*
$\dot{D_p}$	In-Pulse Dose-Rate	> 10^7 Gy/s

* homogeneous (95%) field size at 55 cm of the exit window

Possibility of beam intensity modulation

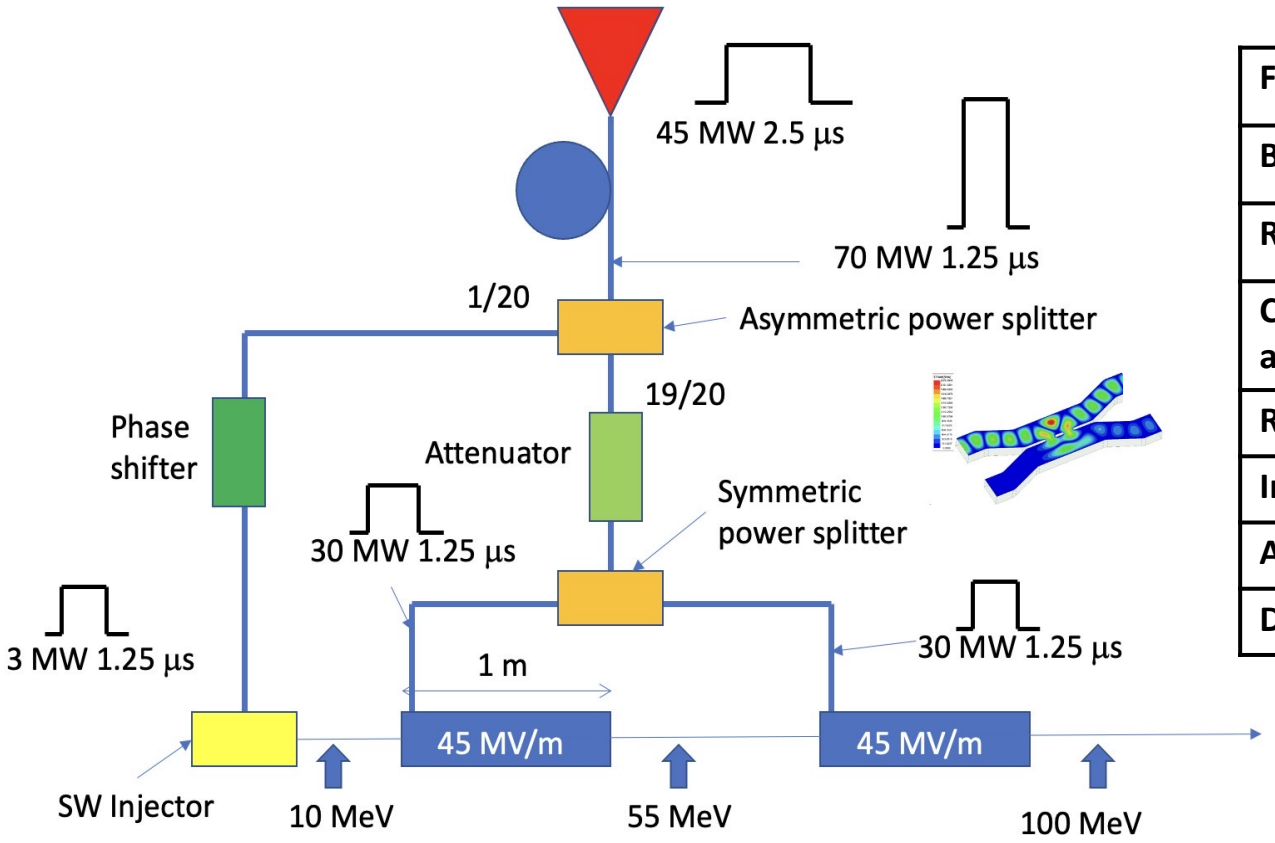
Explore the FLASH effect both in the large field and pencil beam case

Scaling to high energy the beam parameters for FLASH irradiation at 7MeV energy range

	Description	Proposed Value for New Linac #
E	Beam Energy	65 - 100 MeV
f	RF frequency	5.712 GHz
PRF	Pulse repetition frequency	> 100 Hz
t_p	Pulse width	1 - 3 µs
Q_p	Pulse Charge	100 - 300 nC
I_p	Pulse Current	100 mA
D_p	Dose in a single pulse	>10 Gy **in Ø 5 cm**
$\dot{D_p}$	In-Pulse Dose-Rate	> 10^7 Gy/s

"Beam characterization of the ultra-high dose rate research linac ElectronFLASH for preclinical study" *Appl. Sci.* **2023**, *13*(1), 631; https://doi.org/10.3390/app13010631

SAFEST project general layout



Frequency	5.712 GHz
Beam Energy	**65 - 100 MeV**
RF Repetition rate	100 Hz
C-band average accelerating gradient	45 MV/m
RF pulse duration	1 – 3 µs
In pulse dose rate	> 10^6 Gy/s
Average dose rate	> 100 Gy/s
Dose per pulse	>> 1 Gy

- **Hybrid configuration** with SW Injector and TW accelerating structures with **one klystron**
- An asymmetric power splitter allows **avoiding the circulator** for the SW
- C-band combines a **high shunt impedance** with a **high transmission efficiency**: high peak current for FLASH regime.

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Financial support

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A compact C-band Linac for FLASH therapy: accelerator and dosimetry study (2020)

- **Commissione Scientifica Ateneo**
- **Sapienza medie attrezzature**
- **SBAI Contracts**
- **JointLab**

Tot 260 kE

INFN call 2021
FRIDA

FLASH Radiotherapy with hIgh Dose-rate particle beAms

- **R&D RF Structure 120 kE**
- **Pulse compressor 70 kE**

PNRR NATIONAL PROJECT 2022

HEALITALIA

Health Extended ALliance for Innovative Therapies, Advanced Lab-research, and Integrated Approaches of Precision Medicine

Basic VHEE Prototype
SAPIENZA 1.500M euro
SIT 230K euro

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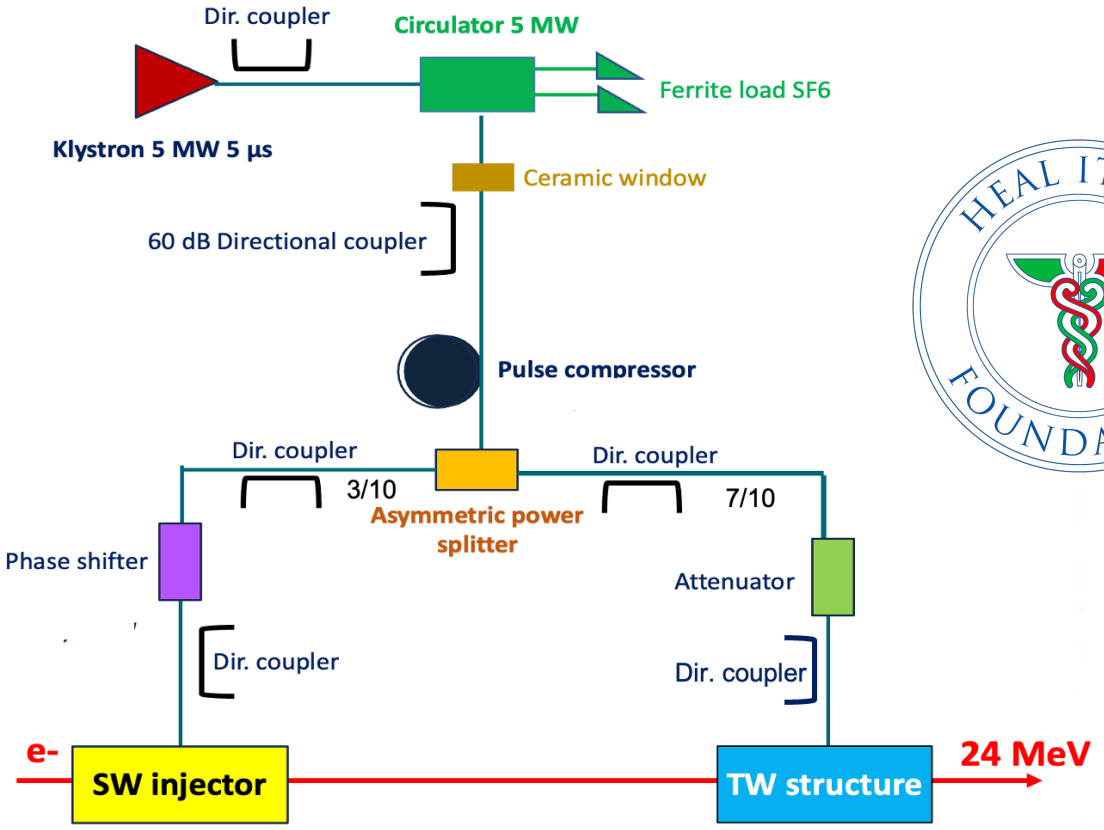
FLASH Linac@Sapienza

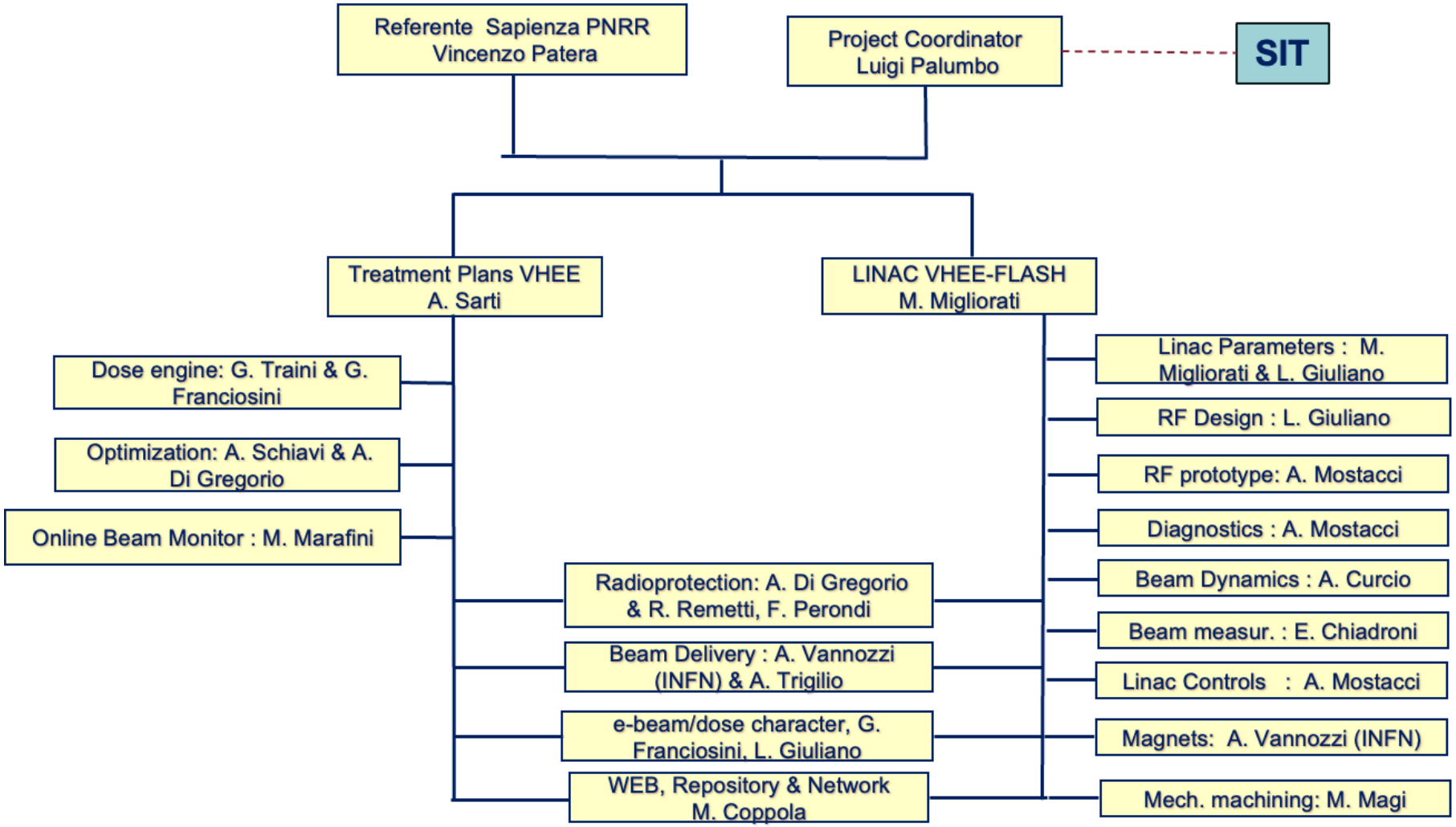
- Machine for pre-clinical studies of FLASH was in part funded with budget of **1.6 ME from Heal Italia (PNRR)**
- Pulse compressor and traveling wave **R&D founded from INFN**



Parameters	Value
Frequency	5.712 GHz
RF pulse length	5 µs
Klystron Power	5 MW
Peak power with pulse compressor	24.4 MW (β = 3)
Linac length	~ 1.5 m
Nominal beam energy	**24 MeV**
Beam pulse current	**100 mA**

We will install and test a system for FLASH VHEE

PE6 : Flash-lab@Sapienza



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FLASH Radiotherapy with hIgh Dose-rate particle beAms

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PE6 : Flash-lab Sapienza-INFN

ACCORDO DI COLLABORAZIONE

TRA

l'Università degli Studi di Roma "Sapienza" con sede in Roma P.le Aldo Moro,5 C.f. n.80209930587, P.IVA n.02133771002 in persona del Rettore Prof. Antonella Polimeni, (d'ora innanzi denominata Sapienza)

E

L'Istituto Nazionale di Fisica Nucleare (INFN) con sede legale in Frascati, Via Fermi, 54, Codice Fiscale e Partita IVA 84001850589,legalmente rappresentato dal Presidente Prof. Antonio Zoccoli, (d'ora innanzi denominato INFN), a ciò autorizzato con delibera del Consiglio Direttivo n.

le parti convengono di firmare il presente Accordo di Collaborazione

Articolo 1: Scopo dell'Accordo

Sapienza e INFN intendono collaborare nel campo degli acceleratori di particelle per la radioterapia del cancro e in particolare negli acceleratori lineari ad elettroni ottimizzati per la terapia oncologica.

Articolo 2: Progetto Linac VHEE per Radioterapia

Sapienza e INFN intendono collaborare nel progetto di un Linac medicale compatto, con sezioni ad elevato gradiente, in grado di generare fasci di elettroni di energia ≥ 50 MeV, con ratei di dose maggiori di 100 Gy/s, in regime FLASH.

LNS Collaboration

- G. Cuttone
- G. Torrisi (Pulse compresor)
- P. Cirrone

LNF Collaboration

- RF Design : L Faillace, Alesini
- RF prototype: Faillace, Alesini
- Diagnostics : G. Franzini
- Beam Dynamics : L. Faillace
- RF Linac Controls : S. Gallo
- Magnets: A. Vannozzi
- Beam delivery : A. Vannozzi
- C power test: Cardelli/Pioli
- Controls: Piersanti
- Brasatura: Lollo, Di Raddo

INFN Roma Collaboration

- L. Ficcadenti
- Facilities (off. Meccanica)

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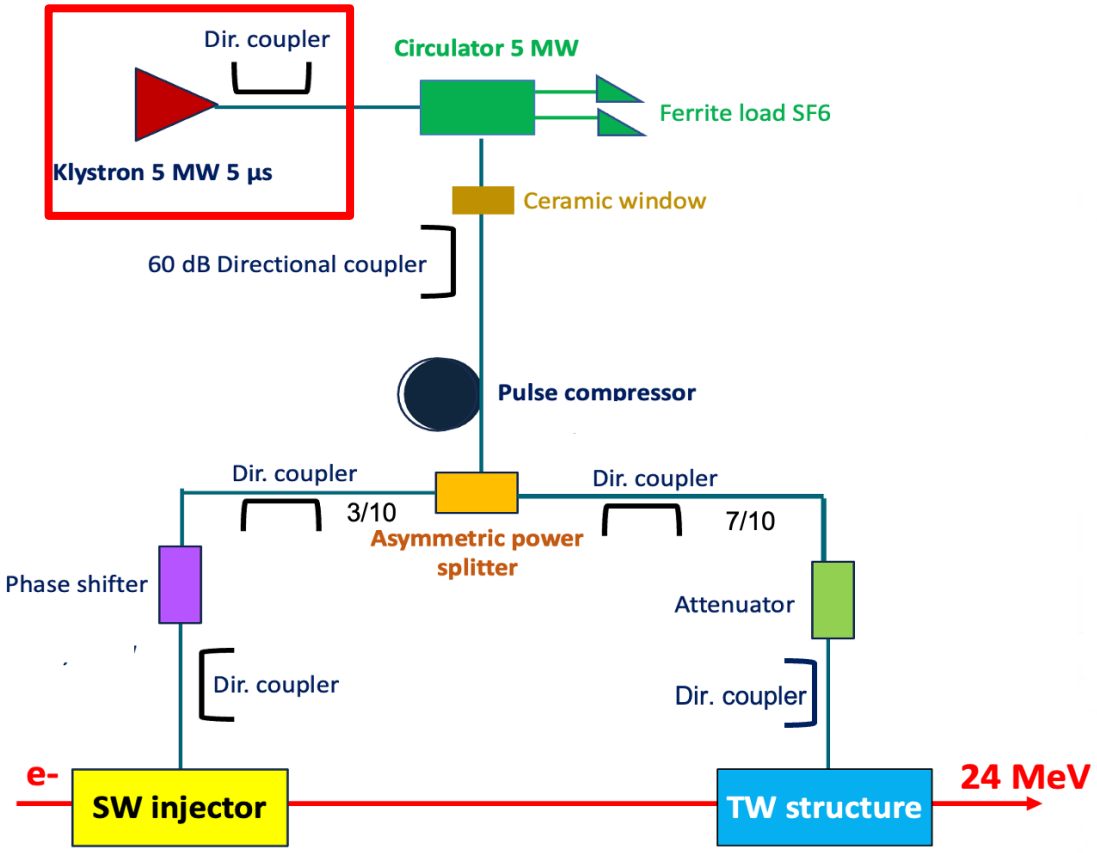

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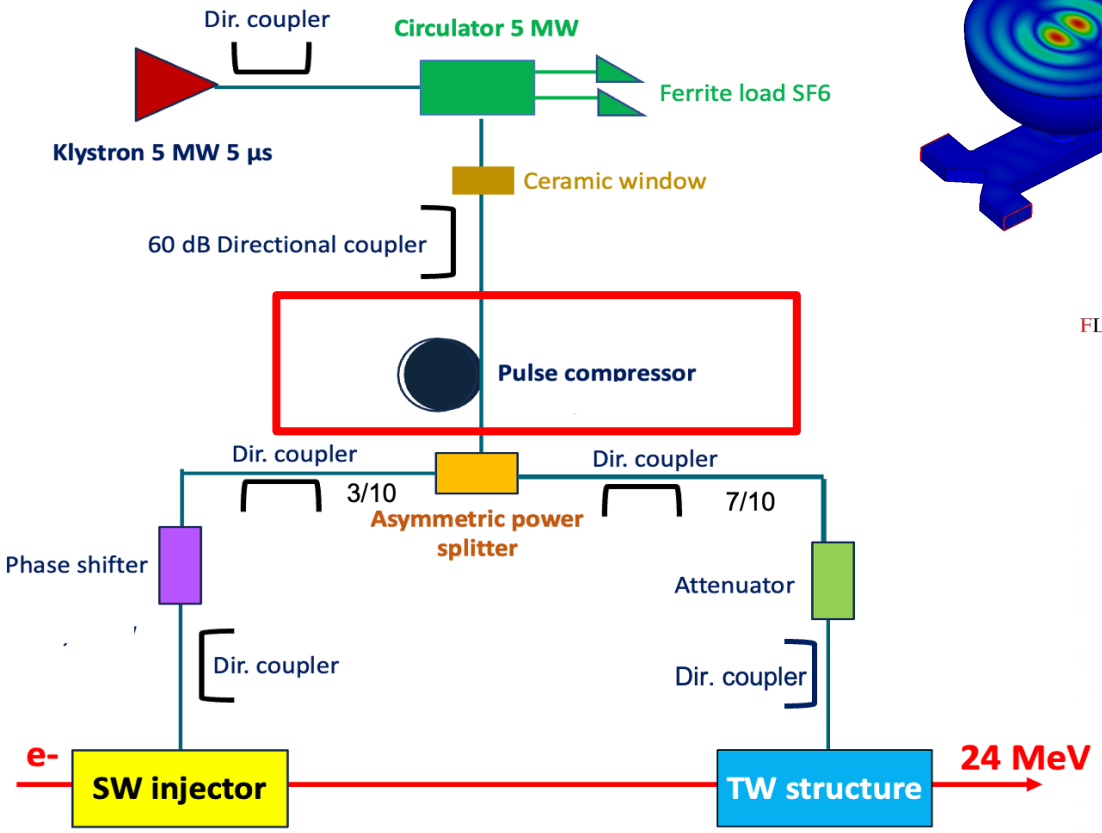

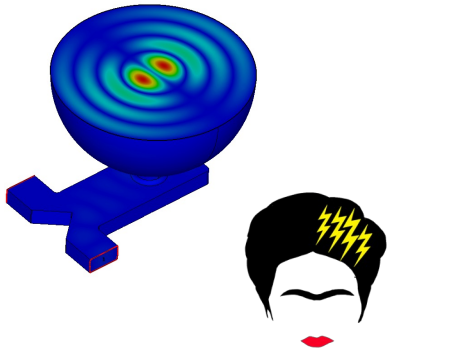

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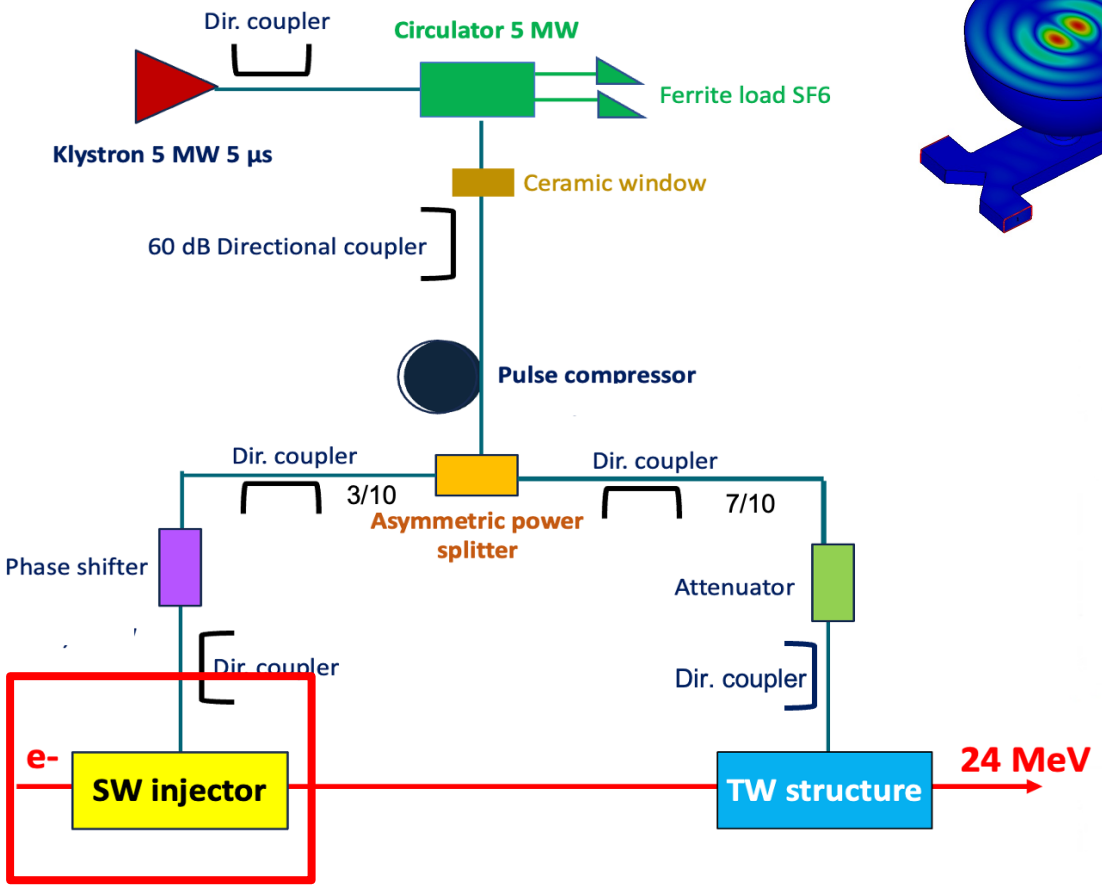

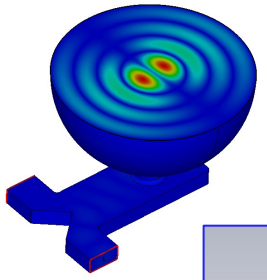

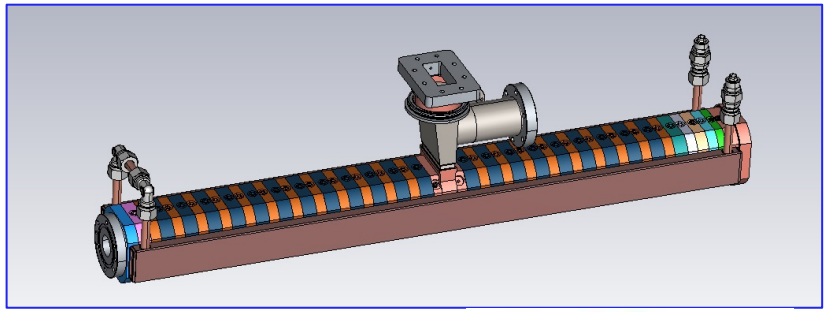

SIT

FLASH Linac@Sapienza

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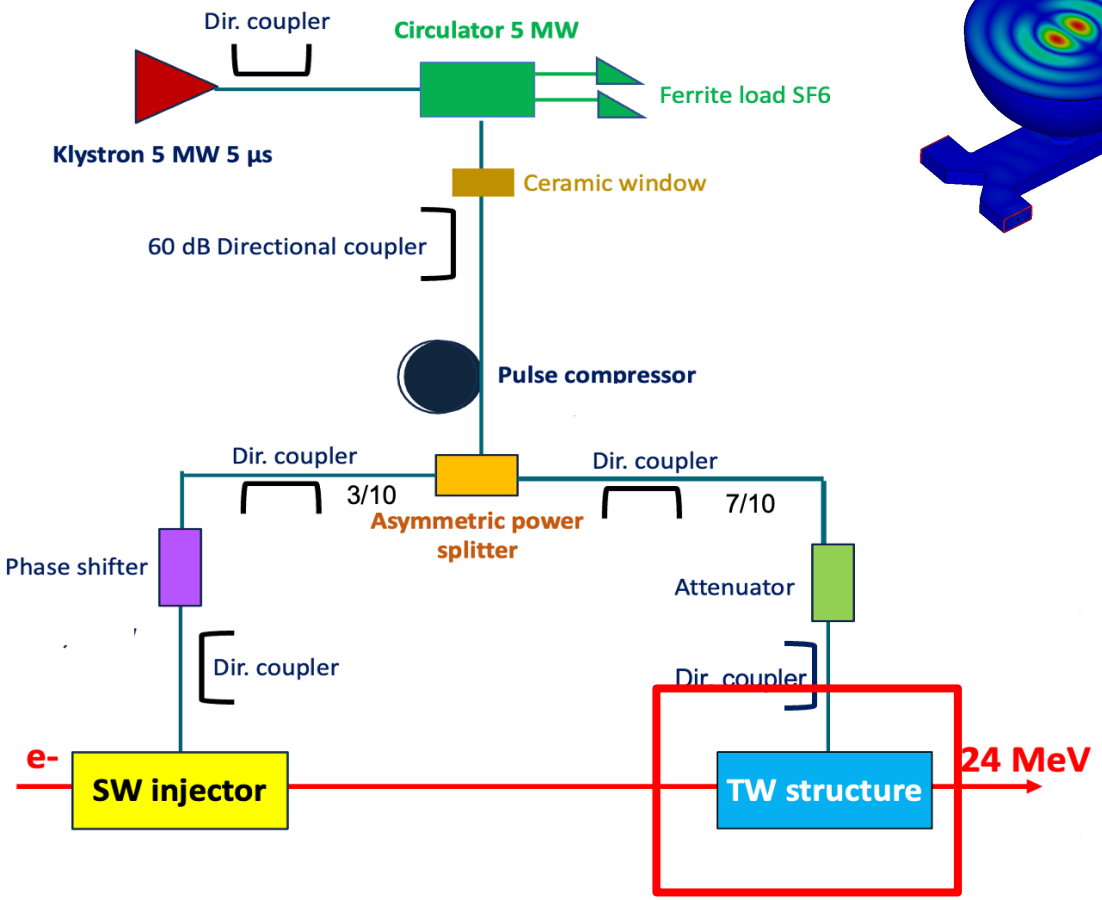
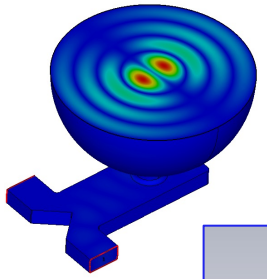
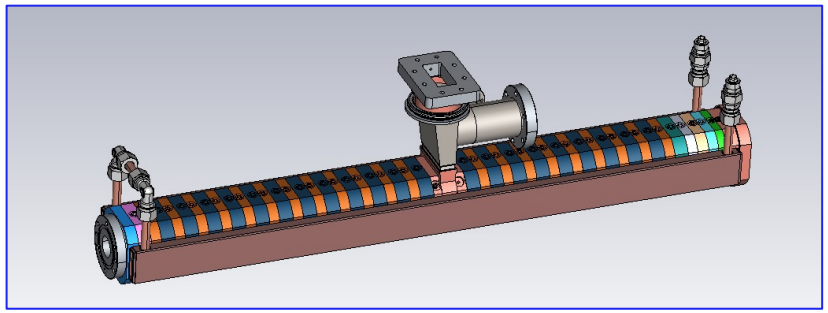
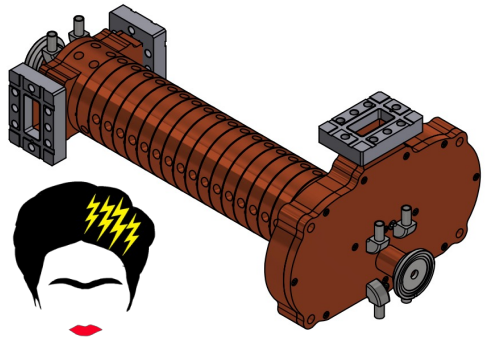




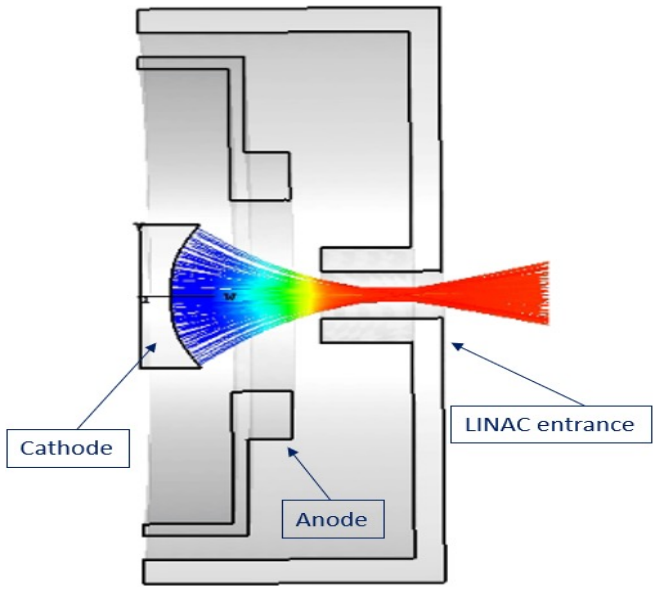




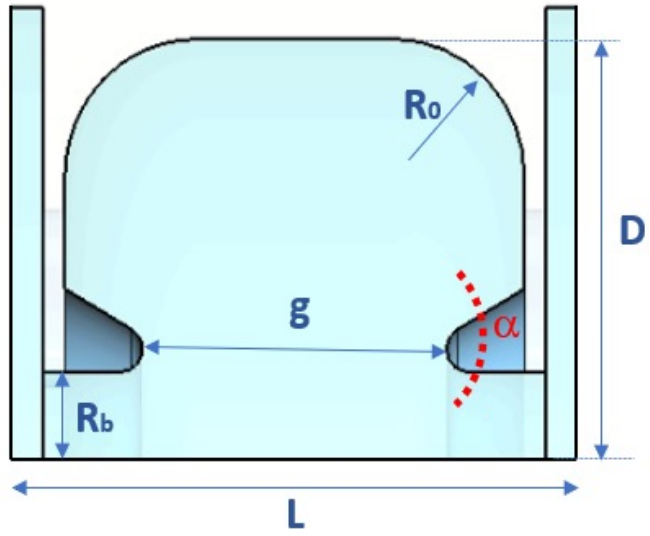
FLASH Radiotherapy with hIgh Dose-rate particle beAms

Standing Wave Injector

Electron source: **pulsed DC thermionic gun** at 15 kV.



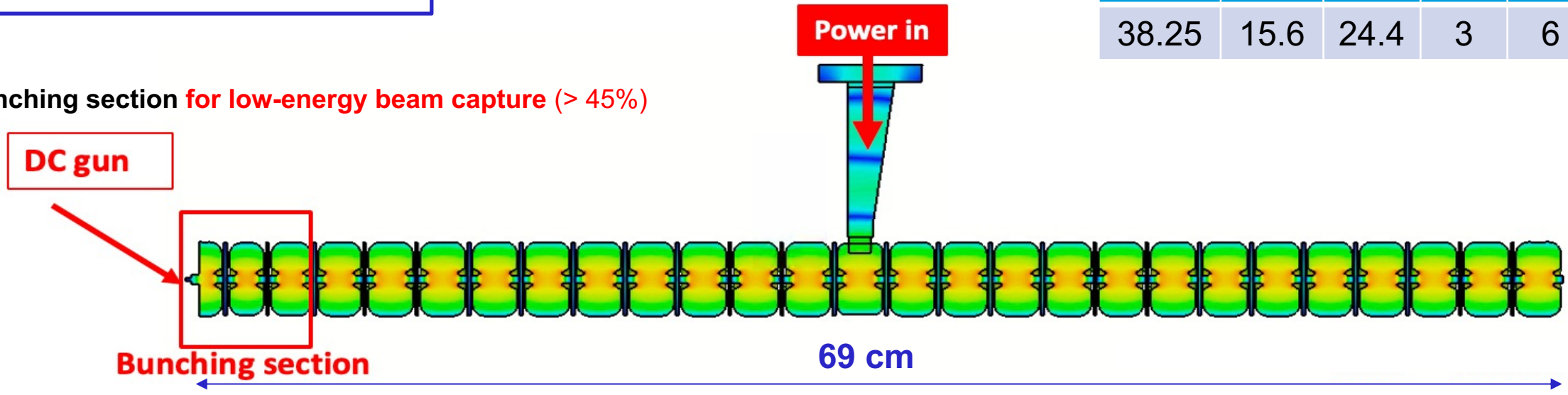
Parameters	Value
Mode of operation	Bi-periodic π/2
N of cells	27
Shunt Impedance	103 MΩ/m
Quality factor	10178
Coupling coefficient	1.58
Beam capture	45%
Filling Time	0.220 μs
Beam output energy	**10 MeV**
Beam pulse current	**100 mA**



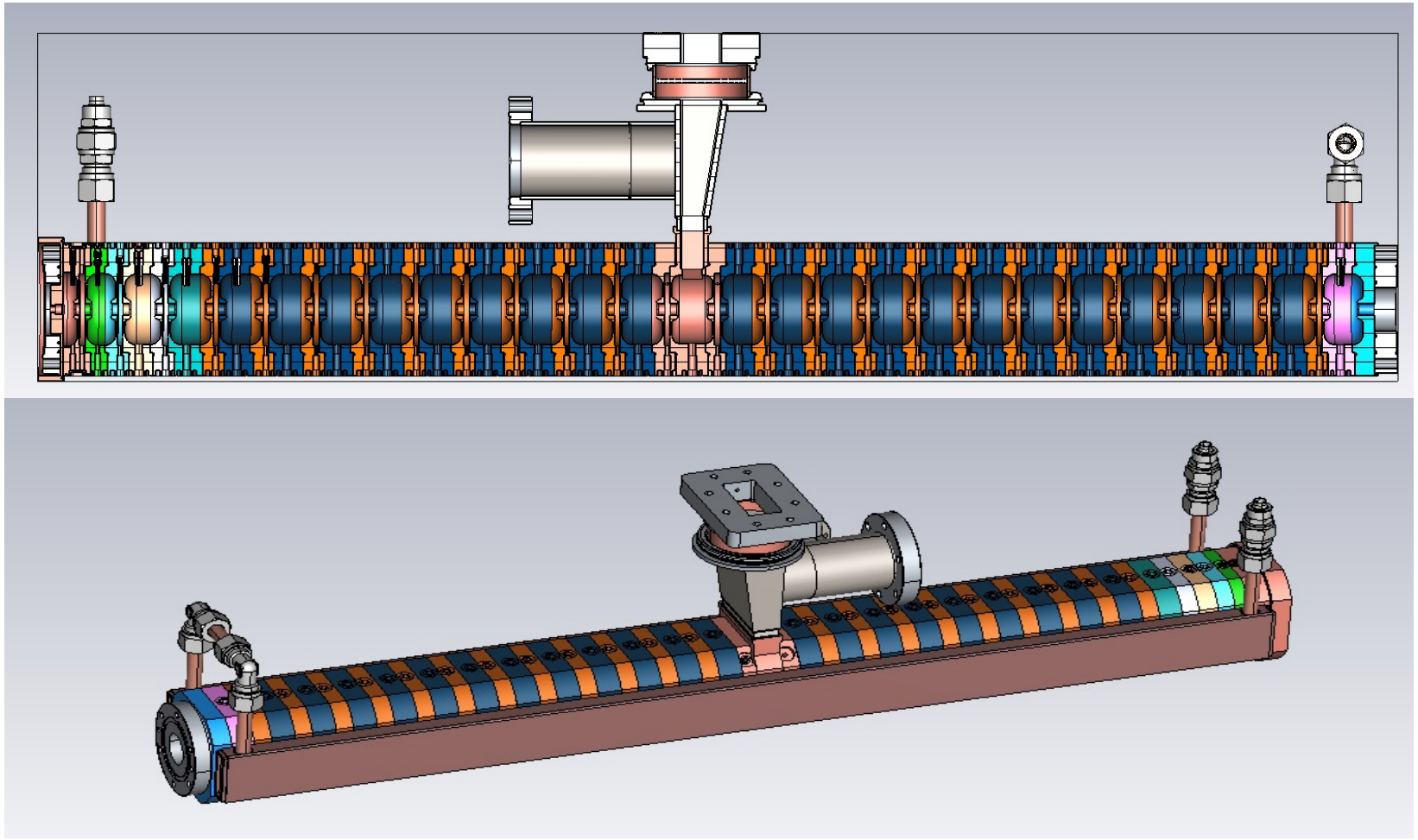
Single cell parameters [mm]

D	g	L	Rb	R0	α
38.25	15.6	24.4	3	6	30°

Bunching section for low-energy beam capture (> 45%)

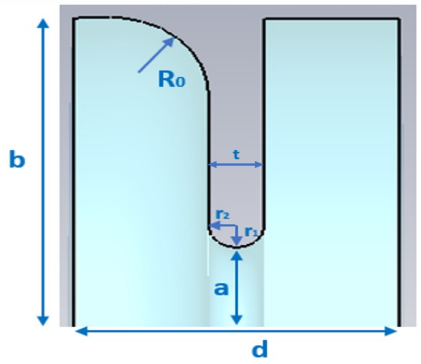


Mechanical drawing of the SW linac (SIT)



Prototyping on going

Traveling Wave design



Asymmetric cell to facilitate in house realization.

a	b	d	R_0	t	r_1/r_2
5	21.03	17.5	6	3	1.25

Single cell RF parameters in mm

Parameters	Value
Structure type	Constant Impedance
Shunt impedance	107 MΩ/m
Quality factor	10127
Filling time	0.143 μs
Group velocity	0.01c
Mode of operation	$2/3\pi$
Final beam energy	**24 MeV**
Beam pulse current	**100 mA**

Power in

3D Electric field of the TW with CST

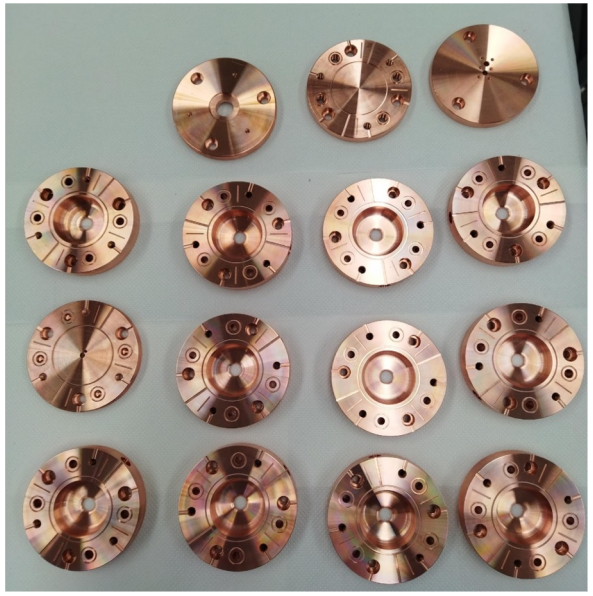
Power out

43.23 cm

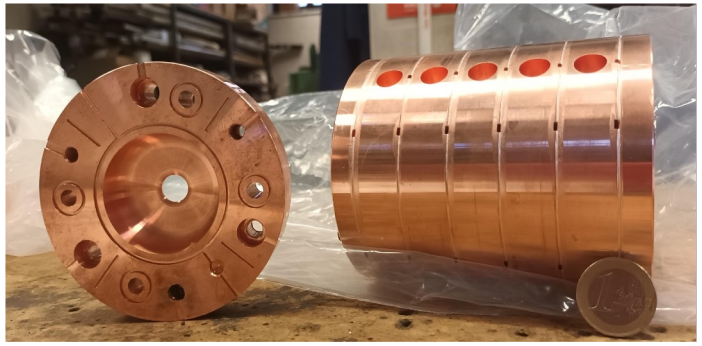
FLASH Radiotherapy with hIgh Dose-rate particle beAms

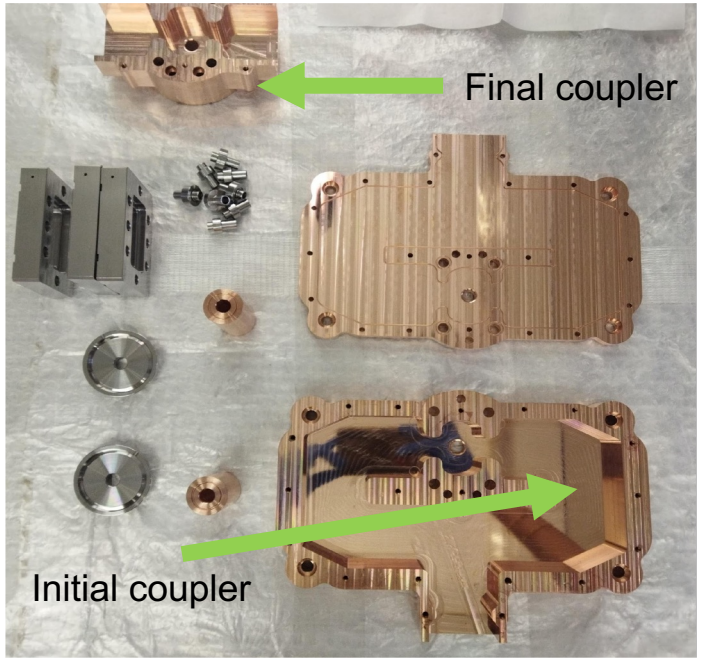
Prototyping

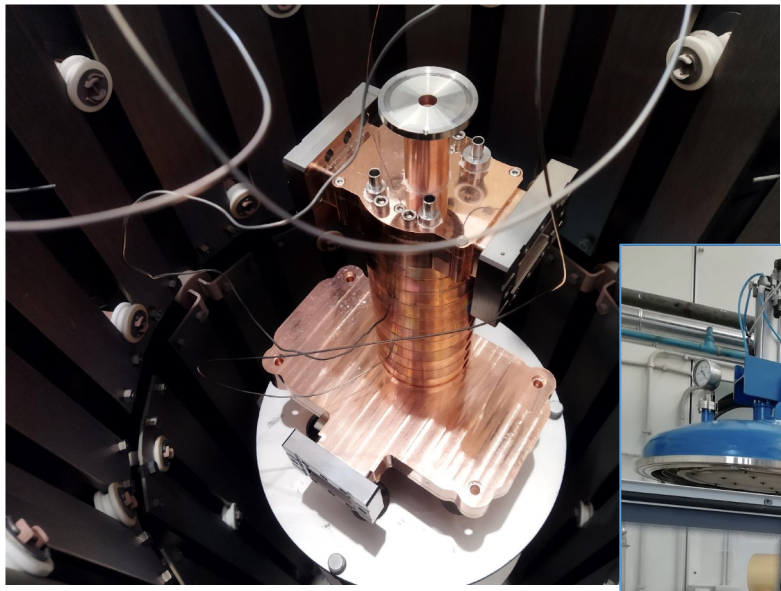
A prototype of **12 cells with couplers** has been brazed @INFN LNF –FRASCATI oven



In house building of the accelerating cavities







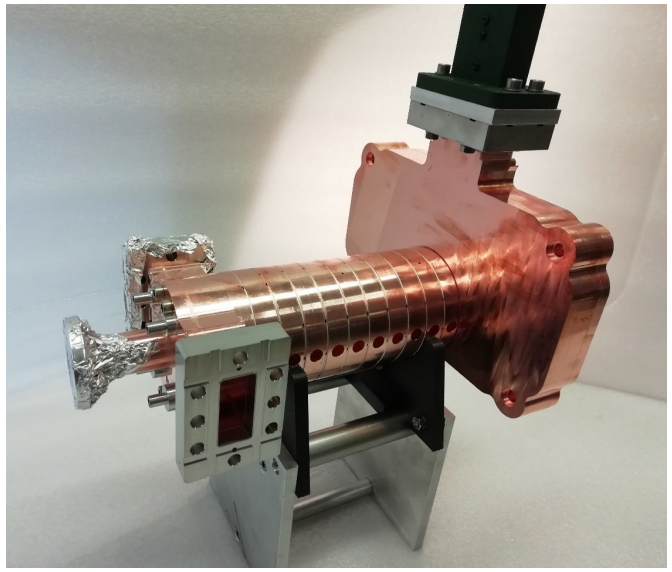
Heat treatment to join cells @INFN LNF –FRASCATI

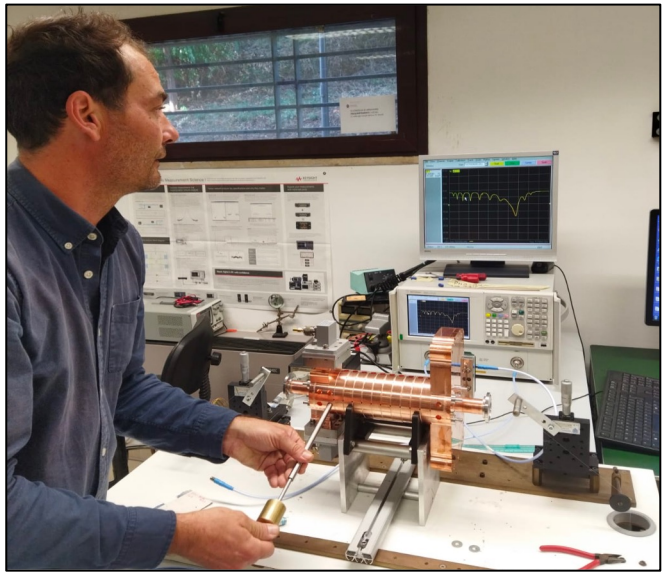
Structure in the INFN LNF – FRASCATI oven ready to be brazed

Main contributors: D. Alesini, **R. Di Raddo**, L. Faillace, L. Giuliano, **M. Magi**, M. Migliorati

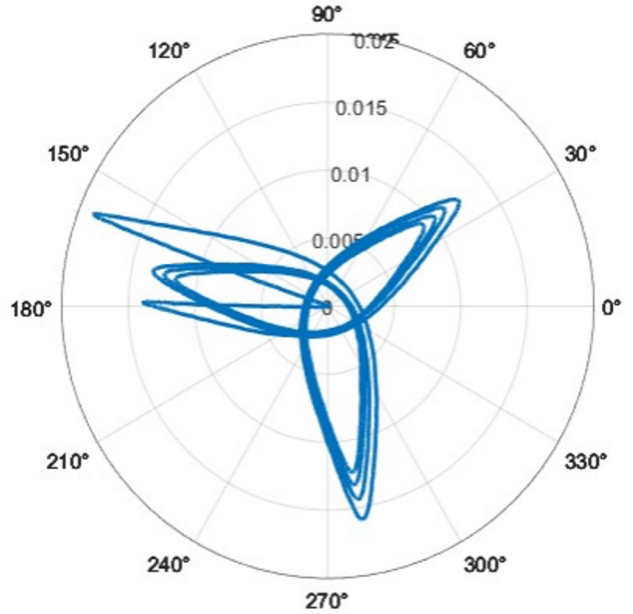
Finanziato dall'Unione europea NextGenerationEU

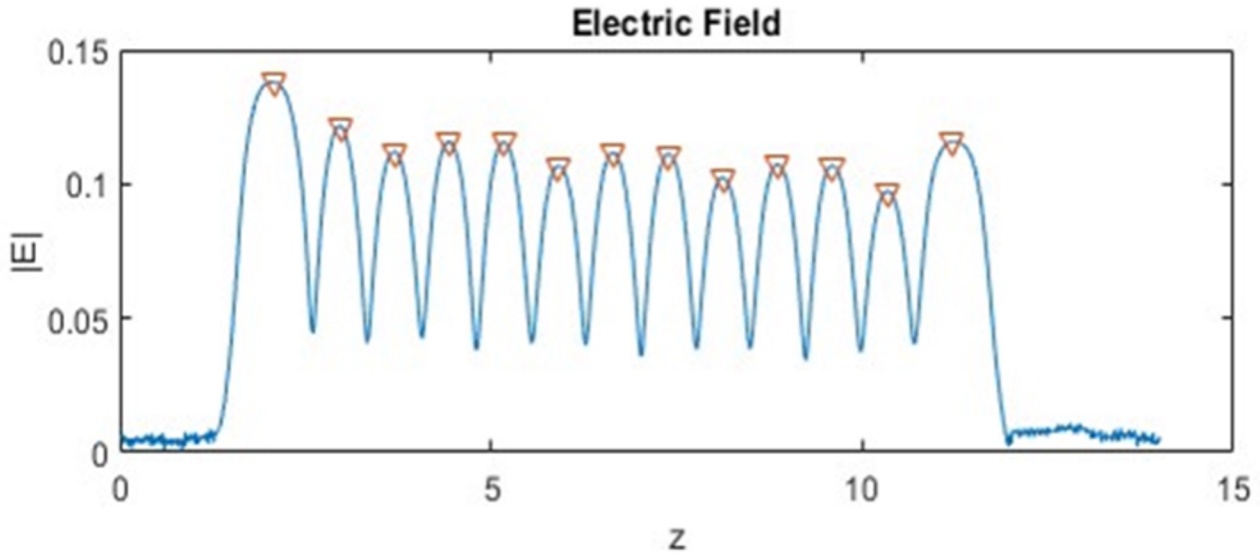
TW first prototype: tuning test





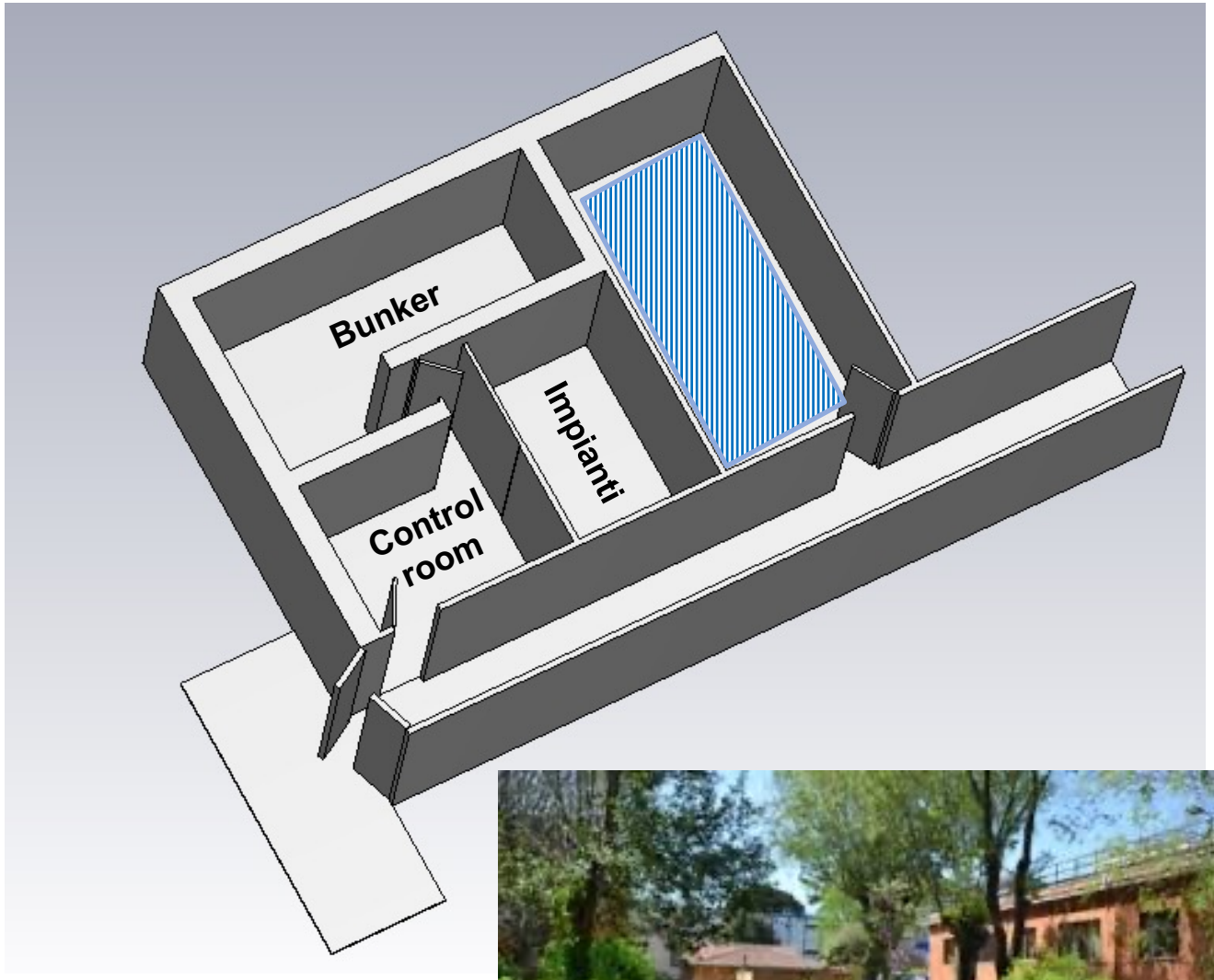
In house realization of the TW structure @ La Sapienza & INFN

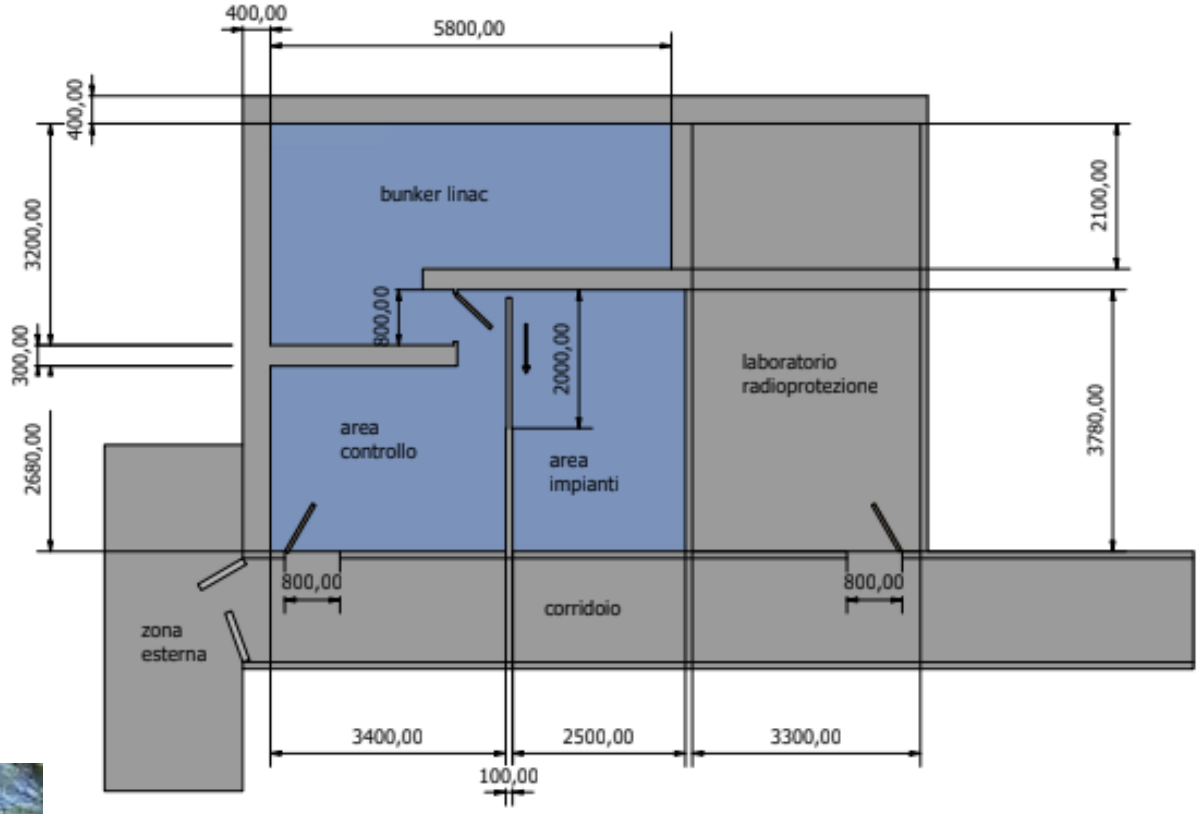




FLASH Radiotherapy with hIgh Dose-rate particle beAms

FlashLab@Sapienza





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Dose-rate particle beAms

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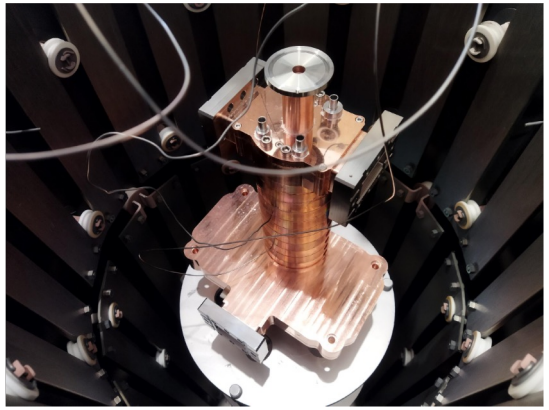
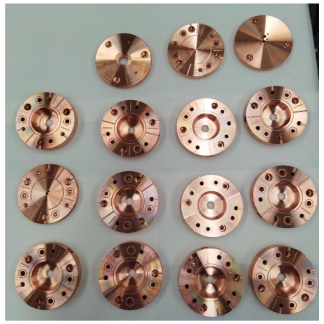
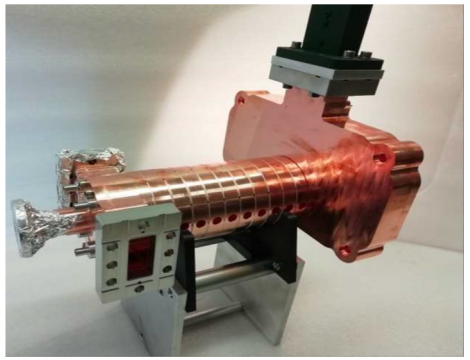
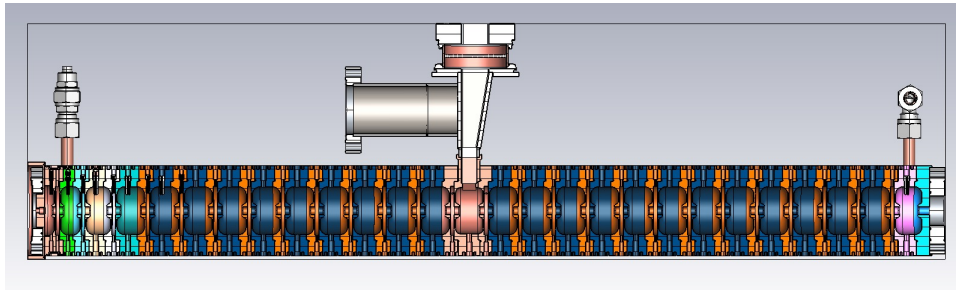

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Thank you !

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