Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

SAPIENZA UNIVERSITÀ DI ROMA

SAFEST

SApienza Flash Electron Source for radio-Therapy

VHEE-FLASH-RT Research Facility

L. Palumbo

INFN
Istituto Nazionale di Fisica Nucleare

FLASH Radiotherapy with hIgh Dose-rate particle beAms

SIT
Sordina IORT Technologies

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

VHEE23 Conference - DESY Hamburg - 11,14 July 2023

A brief introduction to Sapienza activities

ACCELERATOR PHYSICS AND TECHNOLOGY

Luigi Palumbo
Mauro Migliorati
Andrea Mostacci
Enrica Chiadroni
Luigi Faillace
Luca Ficcadenti
Lucia Giuliano
+ Doc

→

e^+e^- colliders
High brightness photoinjector
Free Electron Lasers
Plasma acceleration
Compton Sources
Medical Linacs

PARTICLE RADIATION TUMOR THERAPY

Vincenzo Patera
Adalberto Sciubba
Alessio Sarti
Marco Toppi
Michela Marfina
Giacomo Traini
Gaia Franciosini
+ Doc

→

Fragmentation of Ions for Therapy
imaging of dose release in Hadrontherapy
real-time Imaging for Hadrontherapy
Charged detector for Imaging in Particle Therapy
Monitor for Neutron Dose in Hadrontherapy
Fast-MC code for proton beam therapy (FRED)
VHEE Treatment Plans

A bit of our story …… about particle therapy

Physics in Medicine and Biology, 62, 7482-7504 (2017)

Fred: a GPU-accelerated fast-Monte Carlo code for rapid treatment plan recalculation in ion beam therapy

A Schiavi[1,2], M Senzacqua[1,2], S Pioli[1,5], A Mairani[3,4], G Magro[3], S Molinelli[3], M Ciocca[3], G Battistoni[6] and V Patera[1,2]

Frontiers Oncology. 2021

Deep Seated Tumour Treatments With Electrons of High Energy Delivered at FLASH Rates: The Example of Prostate Cancer

Alessio Sarti[1,2], Patrizia De Maria[3], Giuseppe Battistoni[4], Micol De Simoni[2,5], Cinzia Di Felice[6], Yunsheng Dong[4], Marta Fischetti[1,2], Gaia Franciosini[2,5], Michela Marafini[2,7], Francesco Marampon[8], Ilaria Mattei[4], Riccardo Mirabelli[2,5], Silvia Muraro[4], Massimiliano Pacilio[6], Luigi Palumbo[1,2], Loredana Rocca[1], Damiana Rubeca[1], Angelo Schiavi[1,2], Adalberto Sciubba[1,9], Vincenzo Tombolini[8], Marco Frascati Toppi[1,9], Giacomo Traini[2], Antonio Trigilio[2,5] and Vincenzo Patera[1,2]*

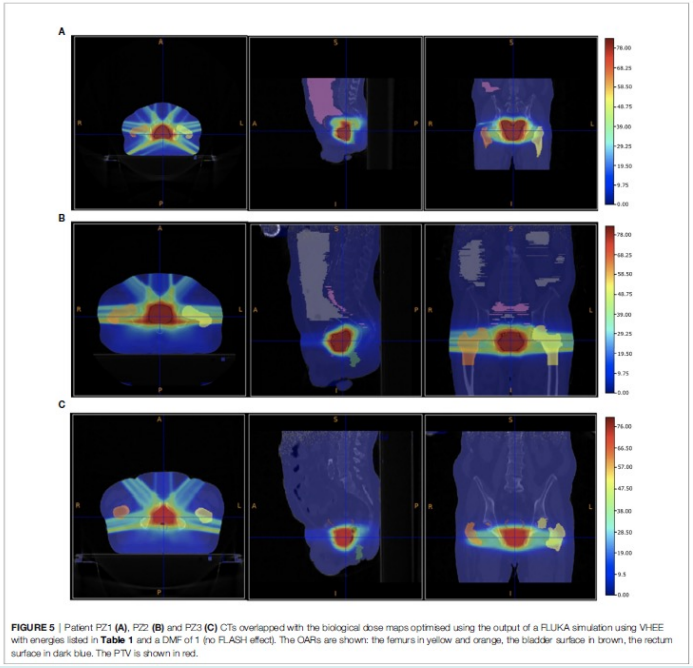


FIGURE 5 | Patient PZ1 **(A)**, PZ2 **(B)** and PZ3 **(C)** CTs overlapped with the biological dose maps optimised using the output of a FLUKA simulation using VHEE with energies listed in **Table 1** and a DMF of 1 (no FLASH effect). The OARs are shown: the femurs in yellow and orange, the bladder surface in brown, the rectum surface in dark blue. The PTV is shown in red.

frontiers | Frontiers in Physics **2023**

Treatment planning of intracranial lesions with VHEE: comparing conventional and FLASH irradiation potential with state-of-the-art photon and proton radiotherapy

A. Muscato[1,2,3], L. Arsini[2,4], G. Battistoni[5], L. Campana[1], D. Carlotti[4,6], F. De Felice[7], A. De Gregorio[4,2*], M. De Simoni[2,8], C. Di Felice[9], Y. Dong[5], G. Franciosini[1,2], M. Marafini[2,3], I. Mattei[5], R. Mirabelli[1,2], S. Muraro[5], M. Pacilio[9], L. Palumbo[1,2], V. Patera[1,2], A. Schiavi[1,2], A. Sciubba[1,10], M. Schwarz[11], S. Sorbino[1], V. Tombolini[7], M. Toppi[1,2], G. Traini[2], A. Trigilio[4,10] and A. Sarti[1,2]

See Giacomo Traini Talk Thursday 12:30

A study case: prostate cancer

MONTECARLO SIMULATIONS

10 MeV Photons

100 MeV Electrons

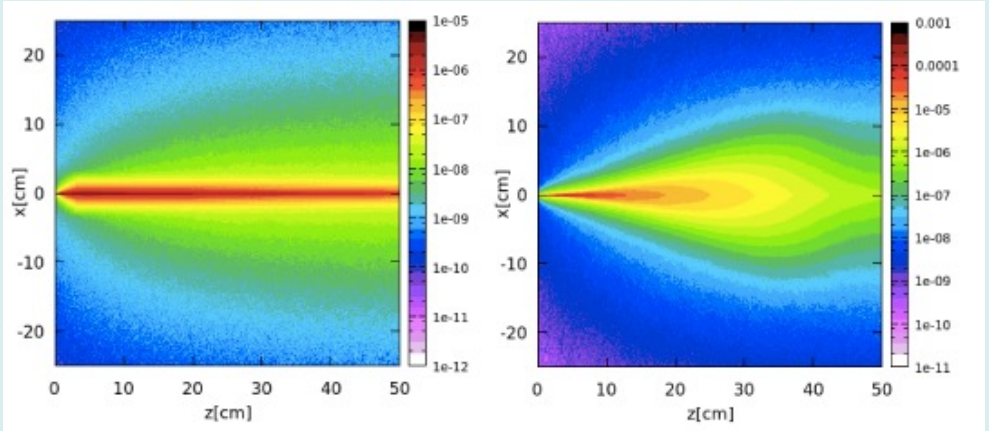


Figure 2. Dose deposition inside water of 10 MeV photons (Left) and 100 MeV electron (Right) beams.

Feasibility study of a prostate cancer FLASH therapy treatment with electrons of high energy

A. Sarti[a,c], P. De Maria[b,c], G. Battistoni[h], M. De Simoni[b,c], C. Di Felice[g], M. Fischetti[a,c], G. Franciosini[a,c], M. Marafini[e,c], F. Marampon[f], I. Mattei[h], R. Mirabelli[b,c], S. Muraro[h], M. Pacilio[g], L. Palumbo[a,c], L. Rocca[a,c], A. Schiavi[*,a,c], A. Sciubba[a,d], V. Tombolini[f], M. Toppi[a,d], G. Traini[c], and V. Patera[a,c]

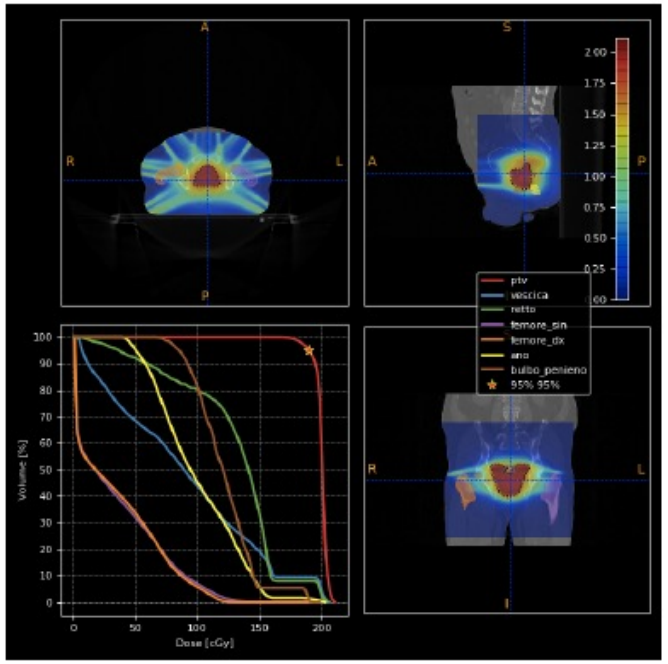


Figure 4. (Top Left, Top Right and Bottom right) Patient CT overlapped with the dose map optimised using the output of a FLUKA simulation using VHEE of 70 MeV and a DMF of 0.8. The OARs are shown: the femurs in purple and orange, the bladder surface in blue, the rectum surface in dark green. (Bottom Left) DVH histograms for the PTV and the OARs, for the 1 fraction foreseen in the patient treatment (2 Gy in total), are shown.

COURTESY VINCENZO PATERA

… and medical accelerators

SIT Sordina IORT Technologies

2020

7 MeV FLASH S- band LINAC - ElectronFlash

SIT Sordina IORT Technologies

2021

12 MeV FLASH C- band LINAC - LIAC

SAFEST

2022

VHEE FLASH C-band LINAC

2020 Electron ELECTRON-FLASH 7 MeV – SIT Company

EF features	Value
Output energy	5 or 7 MeV
Pulse repetition frequency	1 - 250 Hz
Pulse width	0.5 - 4 μs
Maximum peak beam current	120 mA
Maximum Istantaneous Dose rate	$7.5x10^6$ Gy/s
Maximum Average Dose rate	7500 Gy/s
Max Dose per pulse	30 Gy in a circular surface of Ø 10 mm

applied sciences 2023 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]

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

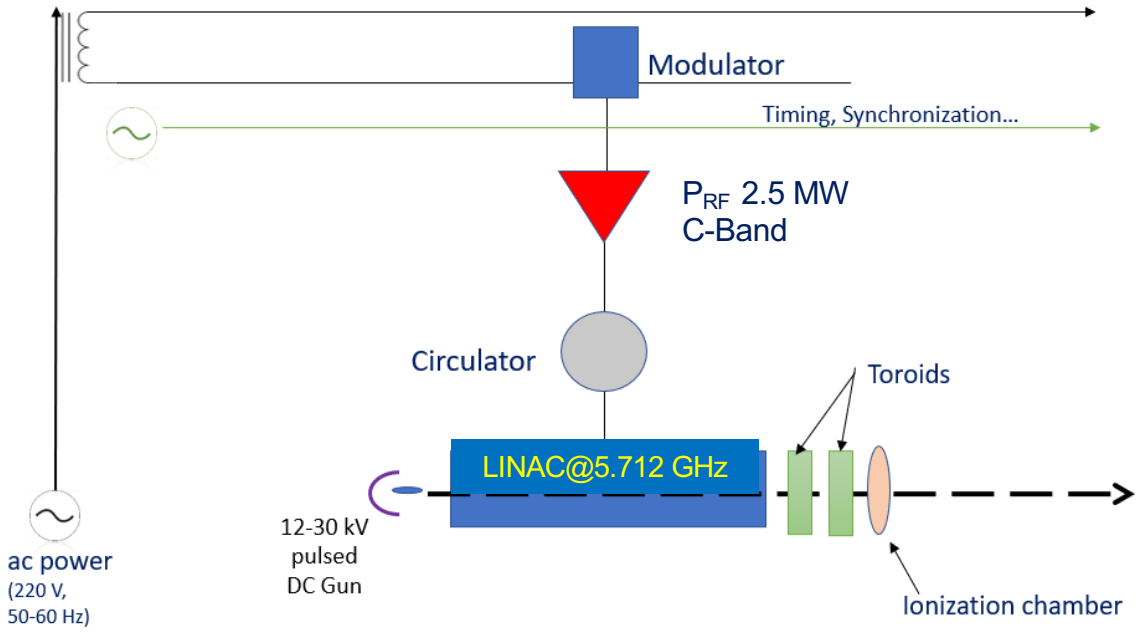
Compact *S*-band linear accelerator system for ultrafast, ultrahigh dose-rate radiotherapy

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]

2021 Design of C-band LINAC 12 MeV, for FLASH

Parameters	
Surface resistance (Rs)	$\propto f^{\frac{1}{2}}$
Quality factor (Q_0)	$\propto f^{-\frac{1}{2}}$
Shunt impedance per unit length (R)	$\propto f^{\frac{1}{2}}$
$\frac{R}{Q}$	$\propto f$
Power dissipation (P)	$\propto f^{-\frac{1}{2}}$

Parameter	Value
Frequency	5.712 GHz
Magnetron Power	2.5 MW
Number of accelerating cells	32
Linac length	~82 cm
Output Energy	12 MeV
Output Beam Current	50 mA



2023 MDPI

Article

RF design and measurements of a C-band prototype structure for a Ultra High Dose Rate medical linac

Lucia Giuliano [1,4*], Fabio Bosco [1,4], Martina Carillo[1,4], Giuseppe Felici [2], Luca Ficcadenti [1,4], Andrea Mostacci [1,4], Mauro Migliorati [1,4], Luigi Palumbo [1,4], Bruno Spataro [3] and Luigi Faillace [3]

SAFEST

SApienza Flash Electron Source for radio-Therapy

Proposal of a

VHEE-FLASH-RT Research Facility

February 2022

D. Alesini[2], D. Alvaro[1], M.G. Bisogni[6], 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[5], 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. Schlavi[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

STUDY GROUP REPORT 2022

EXPERIENCE WITH C-BAND TRAVELLING WAVE ACCELERATING STRUCTURES

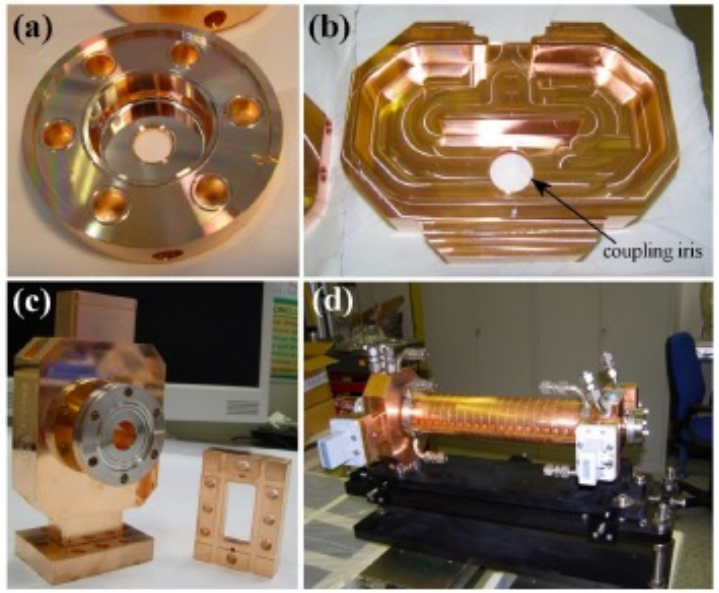
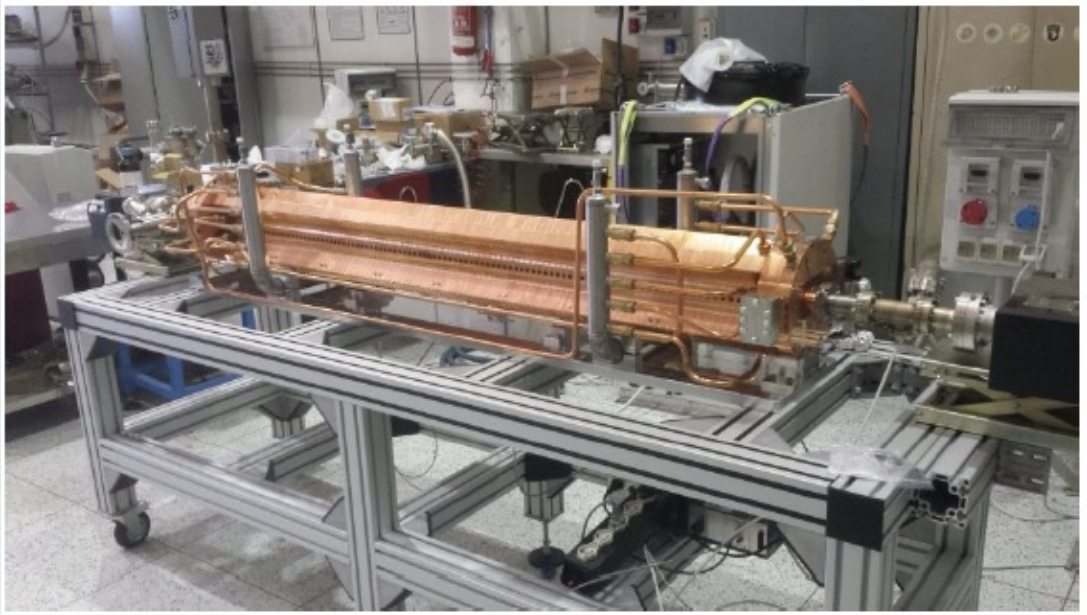


Figure 7. (a) Regular cell; (b) input coupler; (c) output coupler and (d) final prototype.



Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

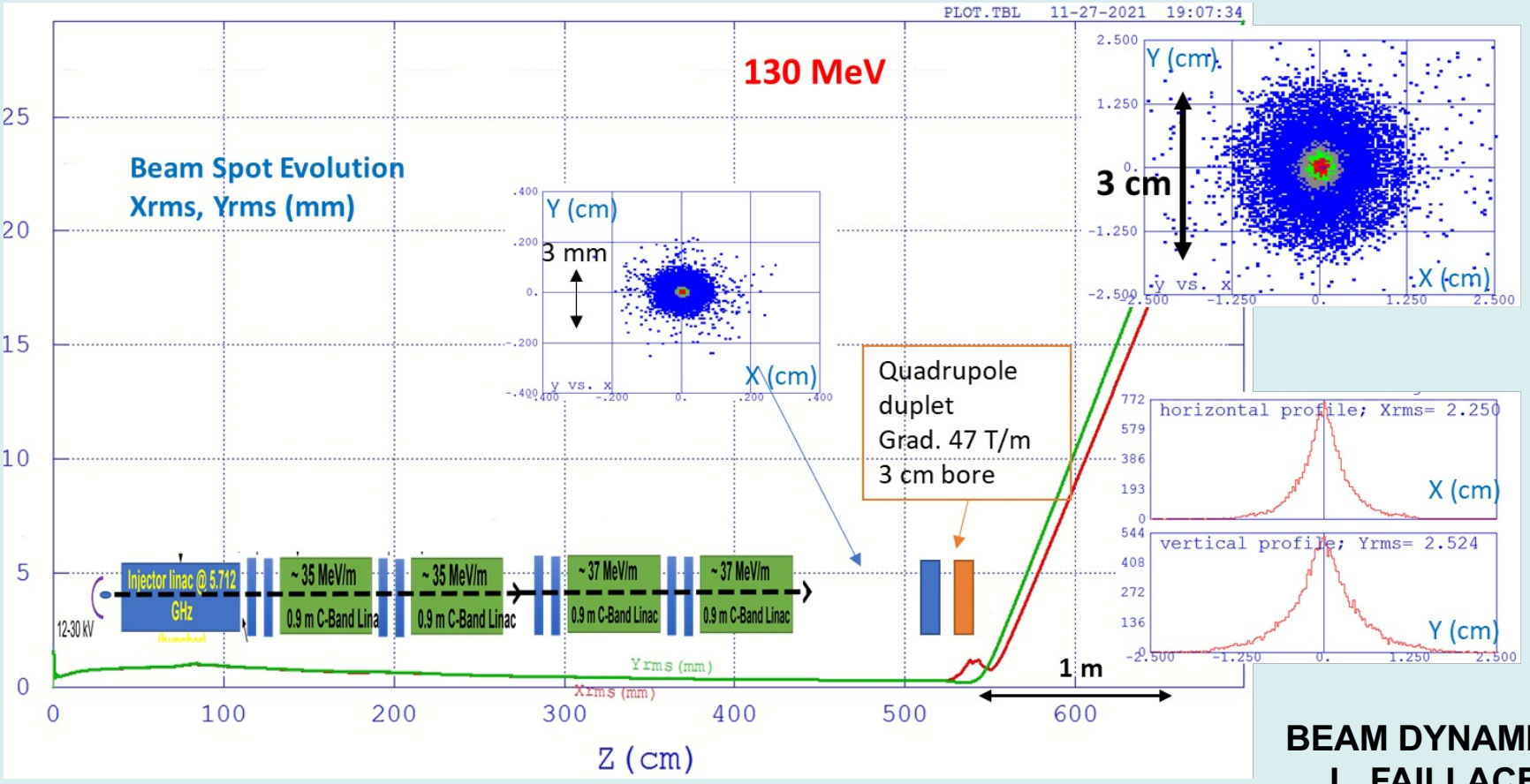
Design, realization and test of C-band accelerating structures for the SPARC_LAB linac energy upgrade

D. Alesini [a], M. Bellaveglia [a], M.E. Biagini [a], R. Boni [a], M. Brönnimann [b], F. Cardelli [c,d], P. Chimenti [a], R. Clementi [a], G. Di Pirro [a], R. Di Raddo [a], M. Ferrario [a], L. Ficcadenti [c,d], A. Gallo [a], R. Kalt [b], V. Lollo [a], L. Palumbo [c,d], L. Piersanti [c,d,*], T. Schilcher [b]

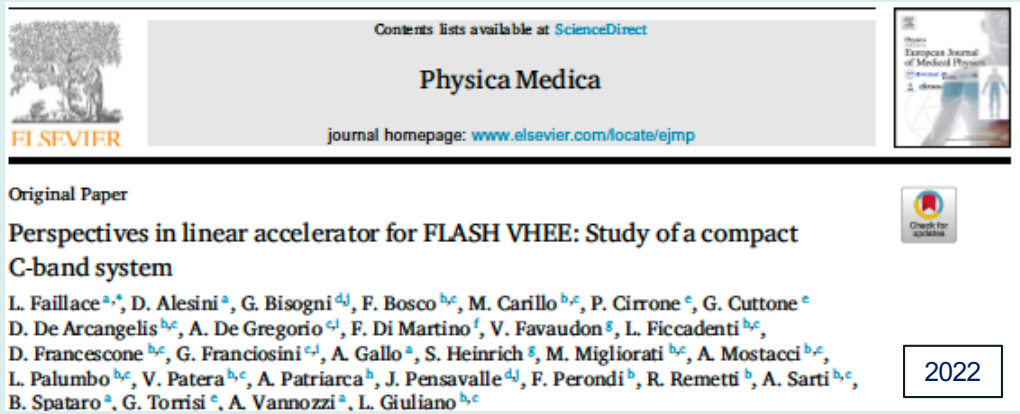
Proceedings of IPAC2016, Busan, Korea MOPMW004

REALIZATION AND HIGH POWER TESTS OF DAMPED C-BAND ACCELERATING STRUCTURES FOR THE ELI-NP LINAC

D. Alesini†, M. Bellaveglia, S. Bini, R. Boni, P. Chimenti, F. Cioeta, R. Di Raddo, A. Falone, A. Gallo, V. Lollo, L. Piersanti, A. Variola, S. Pioli, INFN-LNF, Frascati, Italy
L. Ficcadenti, F. Pellegrino, V. Pettinacci, INFN Roma, Rome, Italy
F. Cardelli, M. Magi, A. Mostacci, L. Palumbo, University of Rome "La Sapienza", Rome, Italy
F. Poletto, P. Favaron, LNL-INFN, Legnaro, Italy



BEAM DYNAMICS
L. FAILLACE



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,j], F. Di Martino [f], V. Favaudon [g], L. Ficcadenti [b,c], D. Francescone [b,c], G. Franciosini [c,j], 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]

2022

	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	20 Gy*
$\dot{D}_p$	In-Pulse Dose-Rate	> 10^7 Gy/s

*Ø 3 cm applicator, homogeneous (95%) field size at 55 cm of the exit window

VHEE LINAC

	Description	Proposed Value for New Linac
E	Beam Energy	60 - 130 MeV
f	RF frequency	5.712 GHz
PRF	Pulse repetition frequency	> 100 Hz
t_p	Pulse width	1 - 3 μs
Q_p	Pulse Charge	200 - 600 nC
I_p	Pulse Current	200 mA
$\dot{D}_p$	In-Pulse Dose-Rate	>> 10^7 Gy/s

- Explore the FLASH effect both in the fixed field and pencil beam case;
- Beam intensity modulation: Pulse-to-pulse and intra-pulse;

TOWARD VHEE LINACS FOR DEEP TUMORS

FUNDINGS ?

INFN PROJECT 2021-23
FRIDA

R&D

FLASH Radiotherapy with hIgh Dose-rate particle beAms

PNRR NATIONAL PROJECT 2022-25

SAFEST

HEALITALIA

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

FLASH Radiotherapy with hIgh Dose-rate particle beAms

FRIDA Project (INFN Gr.V call)

Budget ~1 ME, Project Approved - 2021/2024

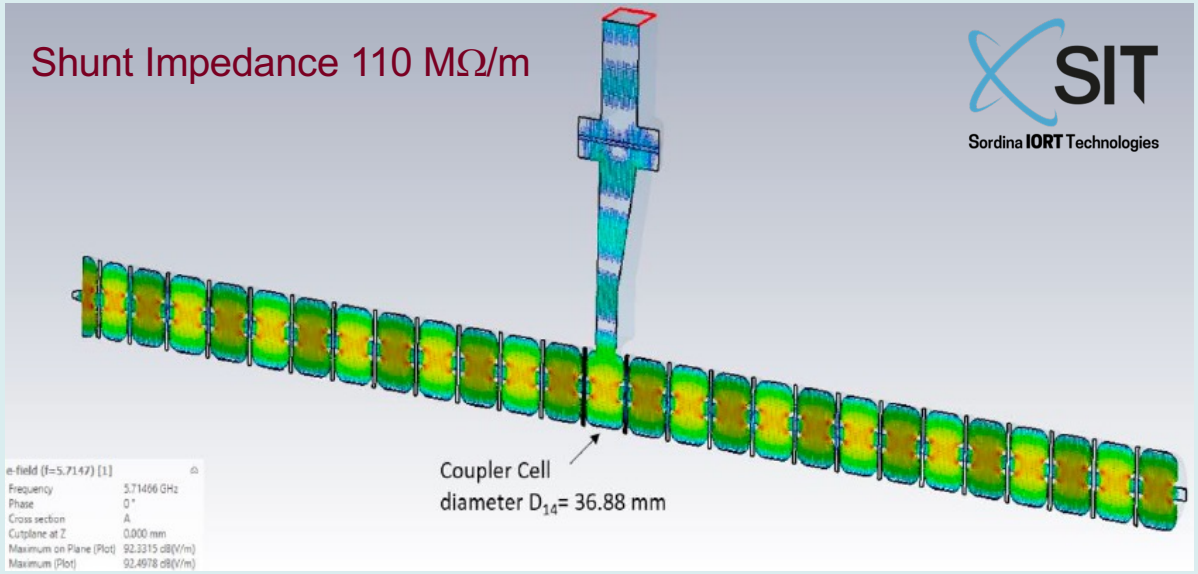
FLASH **R**adiotherapy with h**i**gh **D**ose-rate particle be**A**ms

FRIDA is interdisciplinary project addressing crucial areas related with FLASH therapy.

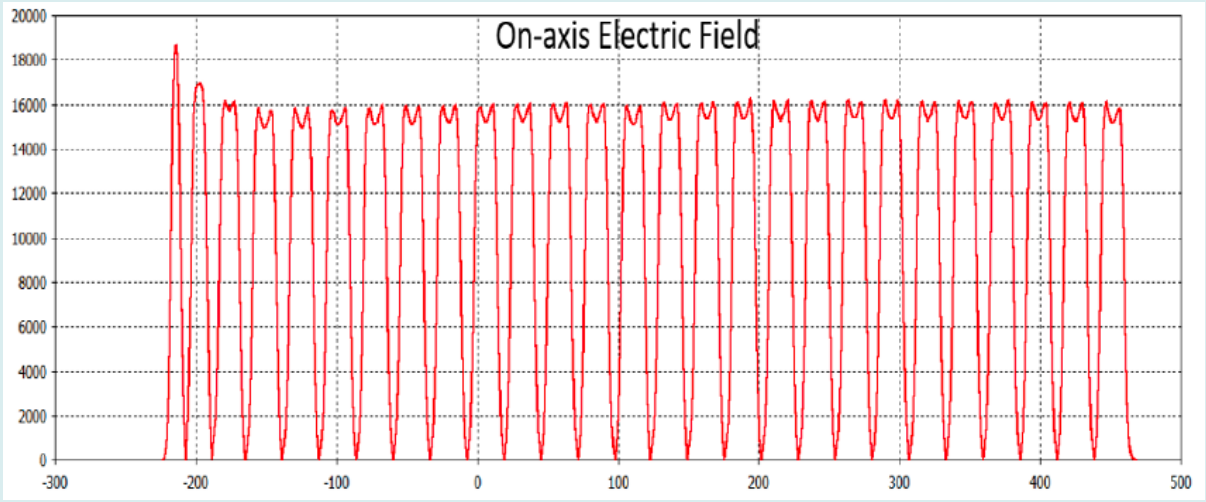
4 work-packages:

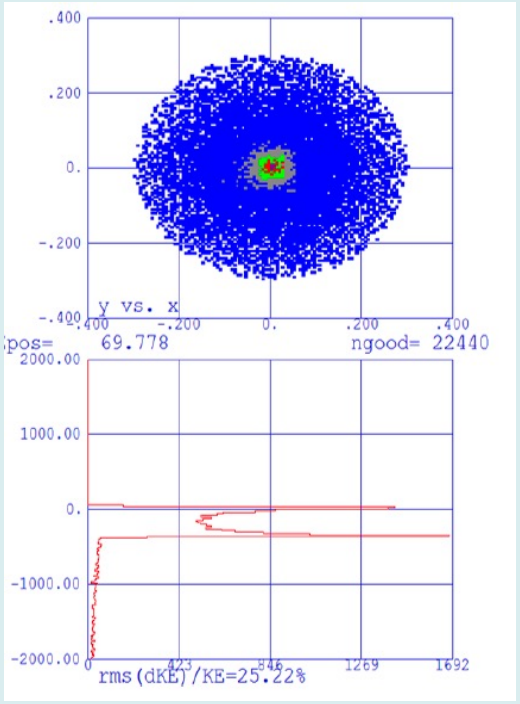
- ✓ **mechanism modelling & radio-biology experiments;**
- ✓ **R&D RF Structure and Pulse Compressor (200 KE)**
- ✓ **Detectors for beam monitoring;**
- ✓ **treatment planning development**

Design and prototype of SW biperiodic $\pi/2$



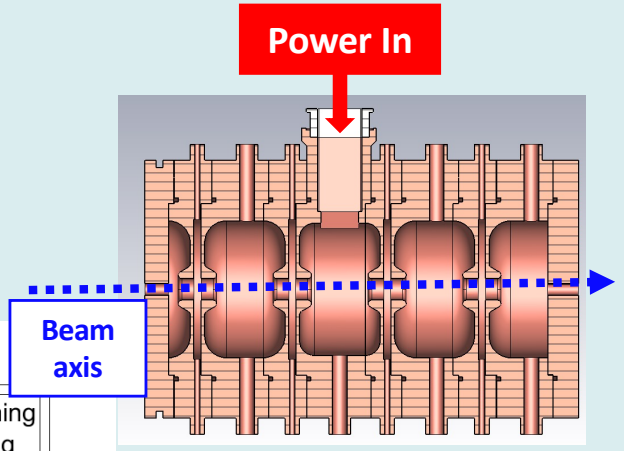
Parameter	Value
Frequency	5.714 GHz
Magnetron Power	2.5 MW
Number of accelerating cells	27
Linac length	70 cm
Output Energy	10 MeV
Output Beam Current	100 mA

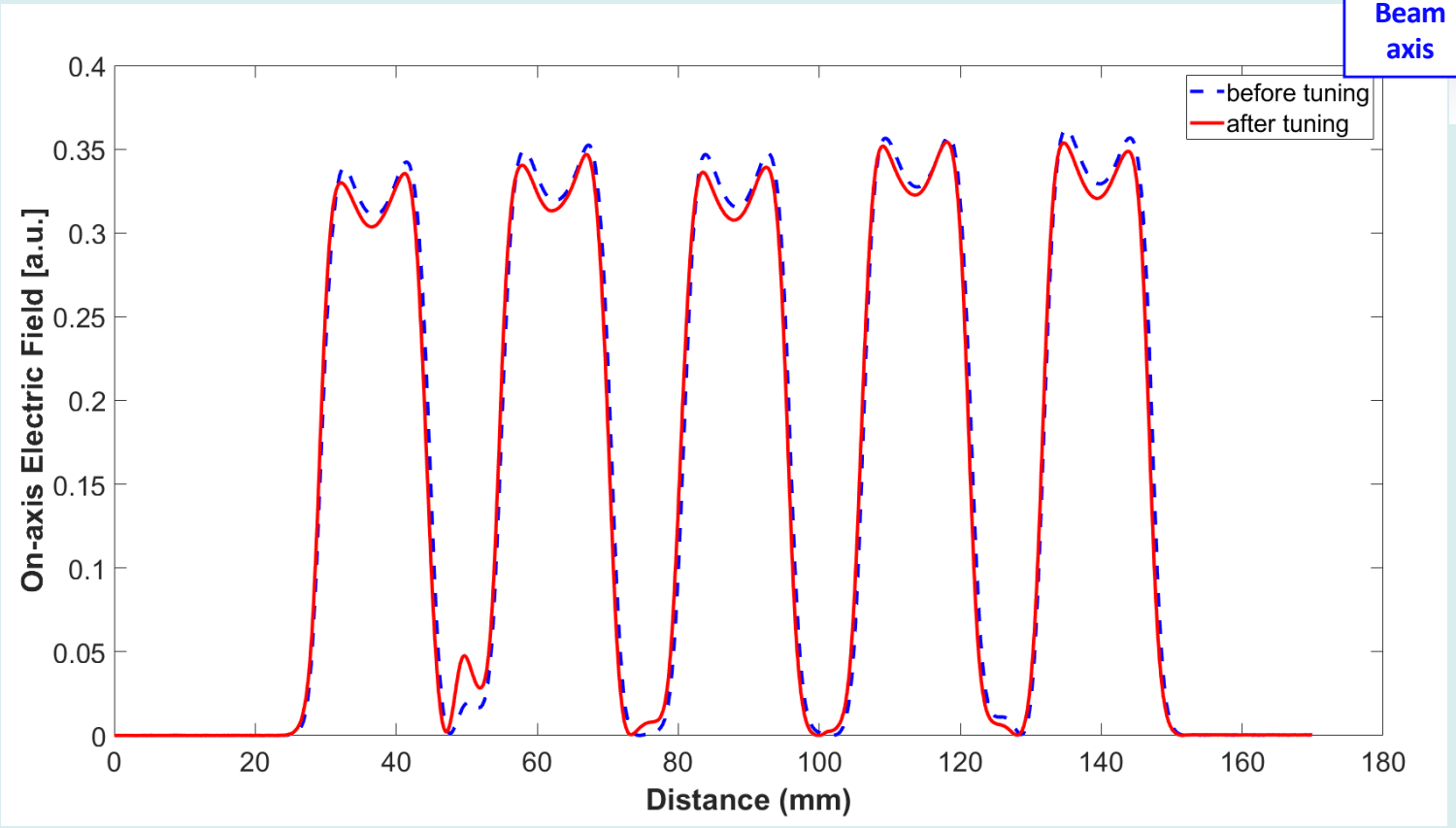


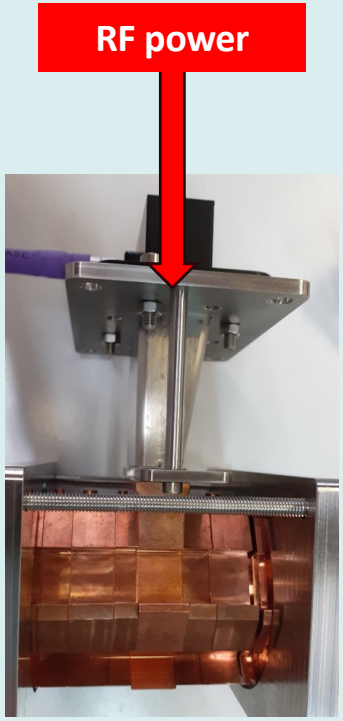


(Lucia Giuliano talk Thursday)

Accelerating Field measurement $ tuning

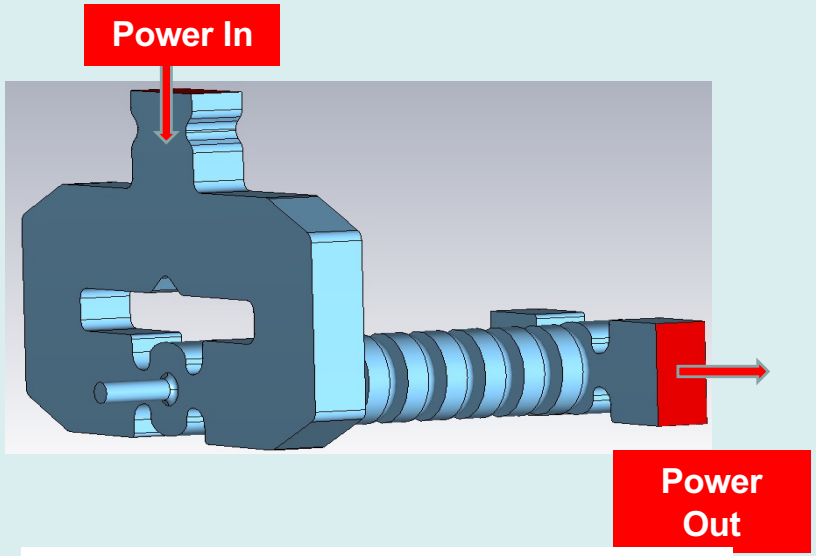




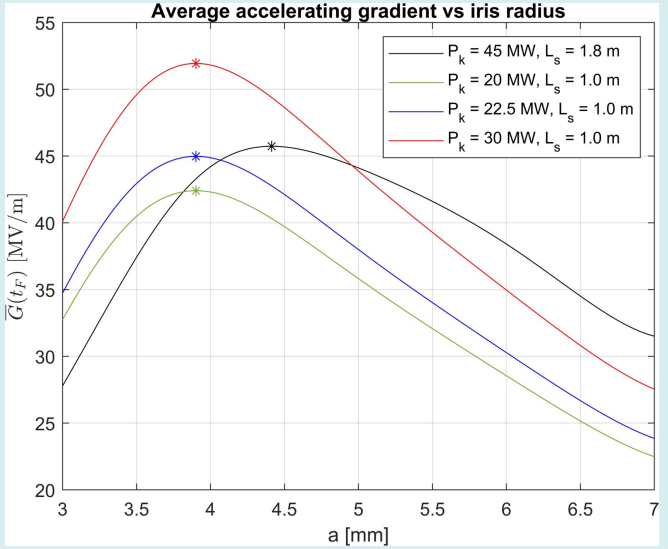


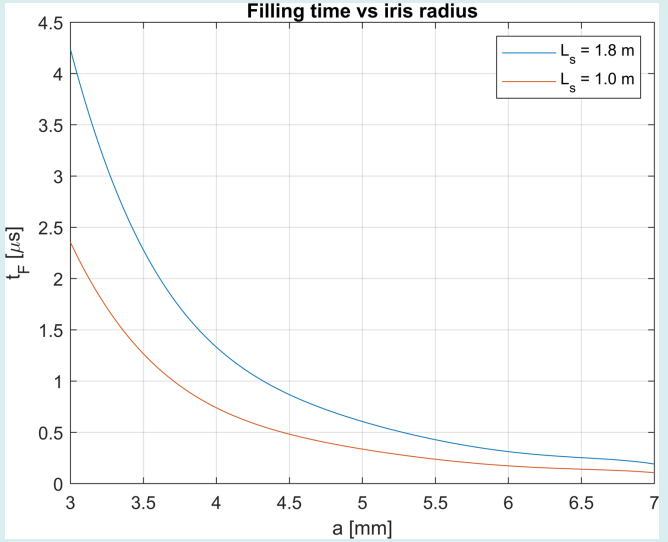
FLASH Radiotherapy with hIgh Dose-rate particle beAms

Design of TW 2π/3



Description	Value
Structure length	1 m
Type	Constant Impedance
Iris radius	5 mm
Gradient@30MW	45 MV/m
Filling Time	0.350 μs
Quality factor	10.000
Shunt impedance	100 MΩ/m

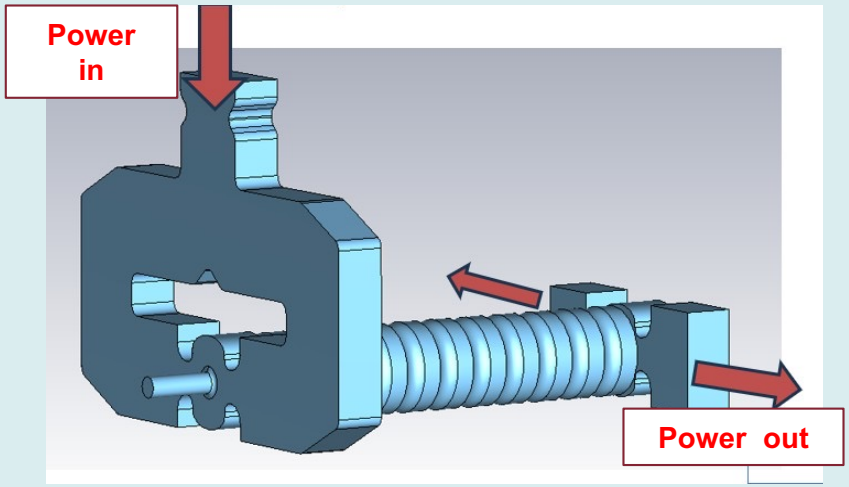


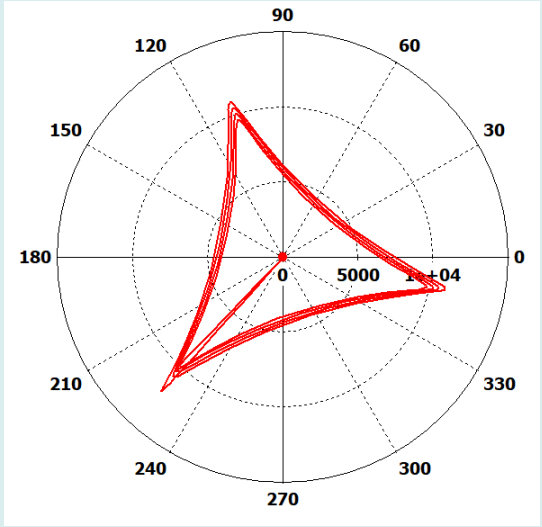


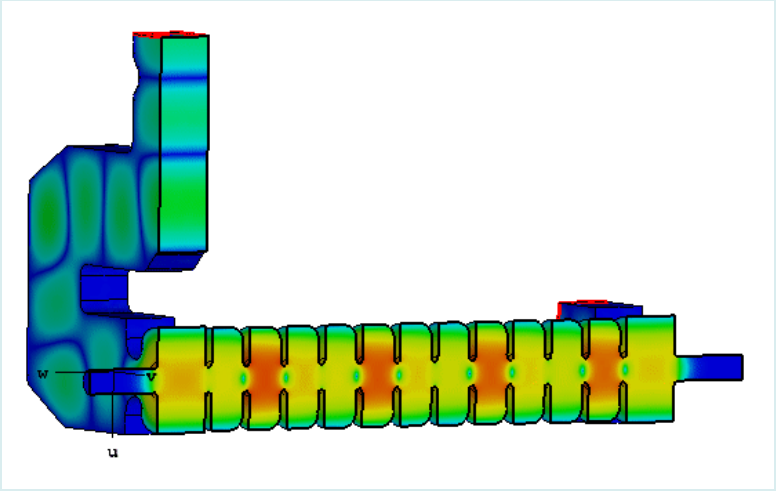
(Lucia Giuliano talk Thursday)

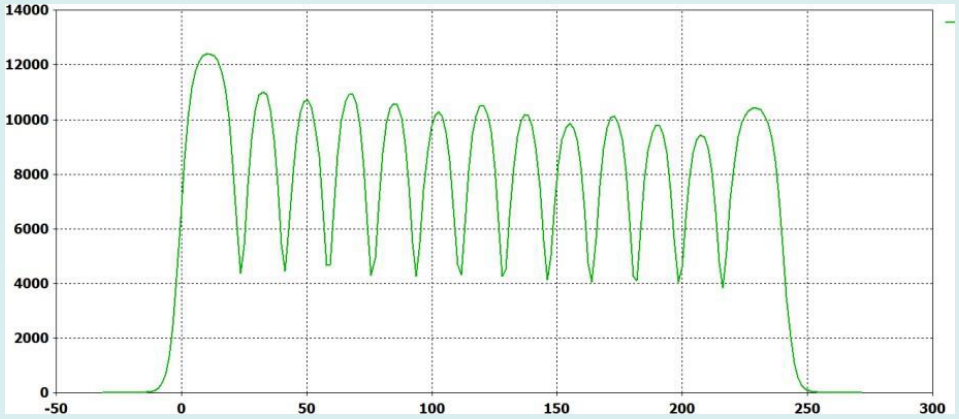
FLASH Radiotherapy with hIgh Dose-rate particle beAms

Prototype design of TW





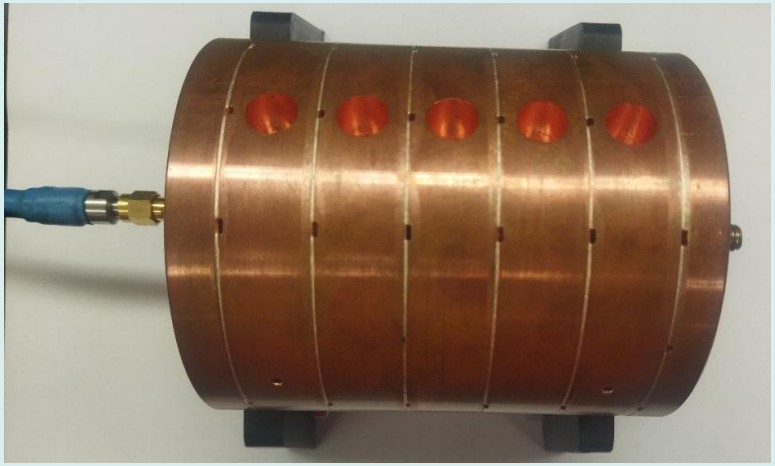


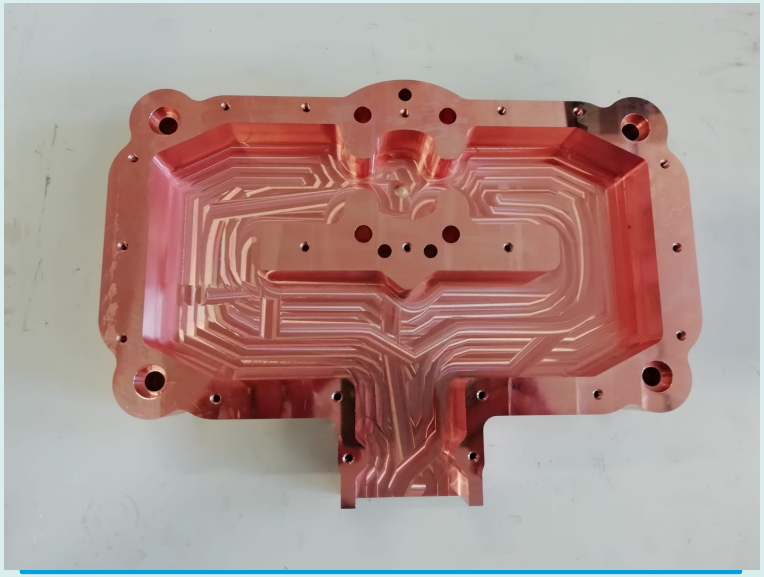


FLASH Radiotherapy with hIgh Dose-rate particle beAms

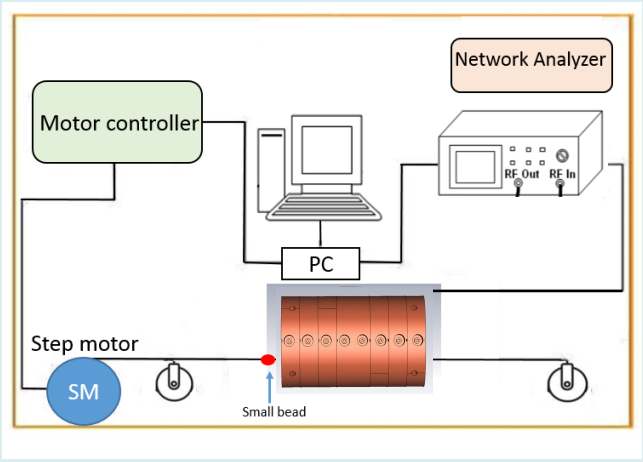
5 cells prototype for vacuum and RF tests

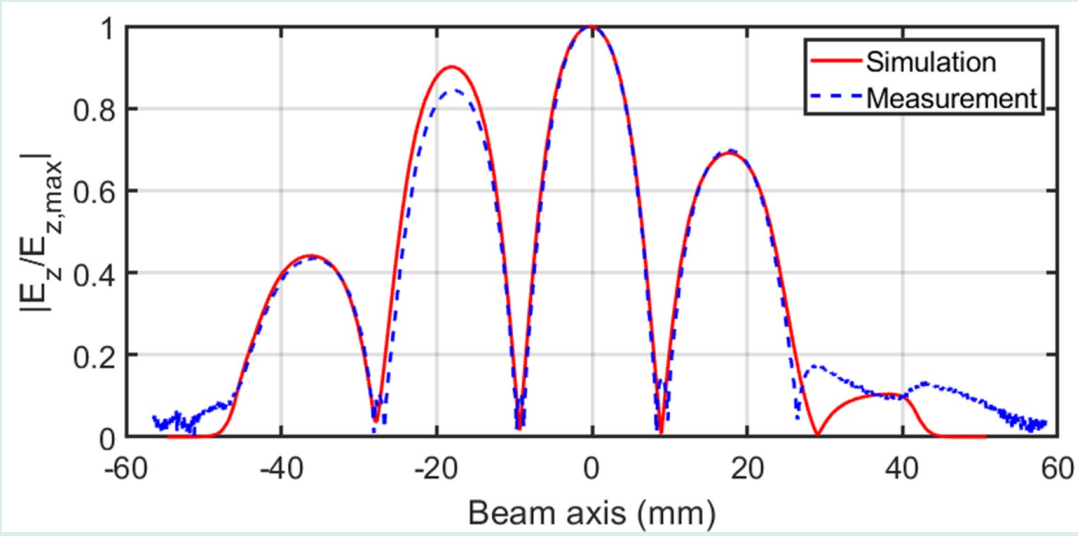
RF signal





The **bead-pull technique** was used to measure the on-axis electric field inside the prototype.





FLASH (SAFEST) IN THE PROJECT HEAL_ITALIA (PNRR recovery f.)

HEAL ITALIA

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

2023-2025

12 UNIVERSITIES

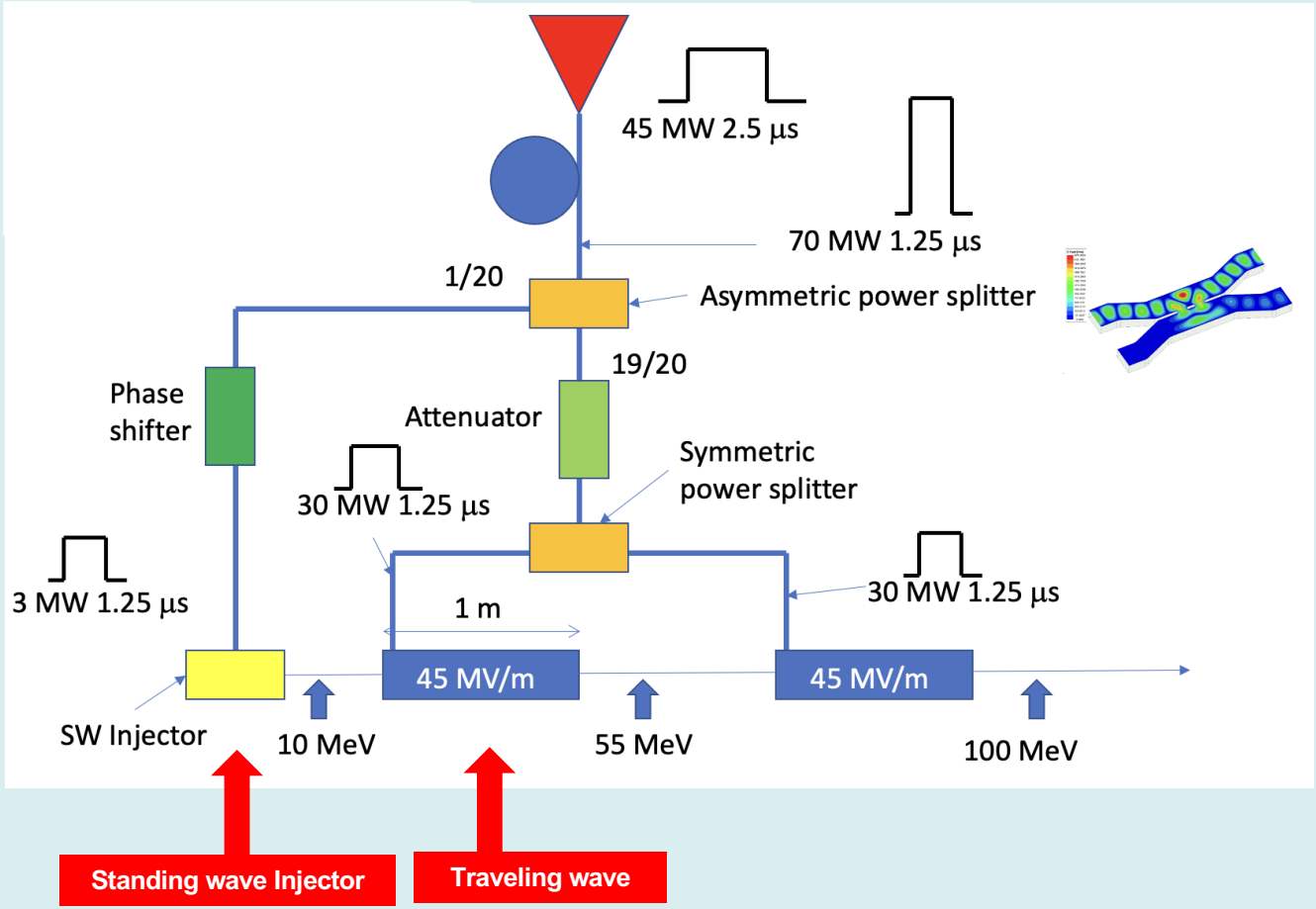
12 PARTNERS

SIT
Sordina IORT Technologies

A *second* target will be materials and instrumentation for **precision therapy**: on one hand, we will develop new scaffolds, implants and *nanostructures for regenerative medicine*; on the other, we will focus our efforts on fabrication and validation of prototypes for *flash radiotherapy*, a novel revolutionary technique for cancer treatment.

2022-2025 PROJECT APPROVED WITH A BURGET OF 114.7 ME

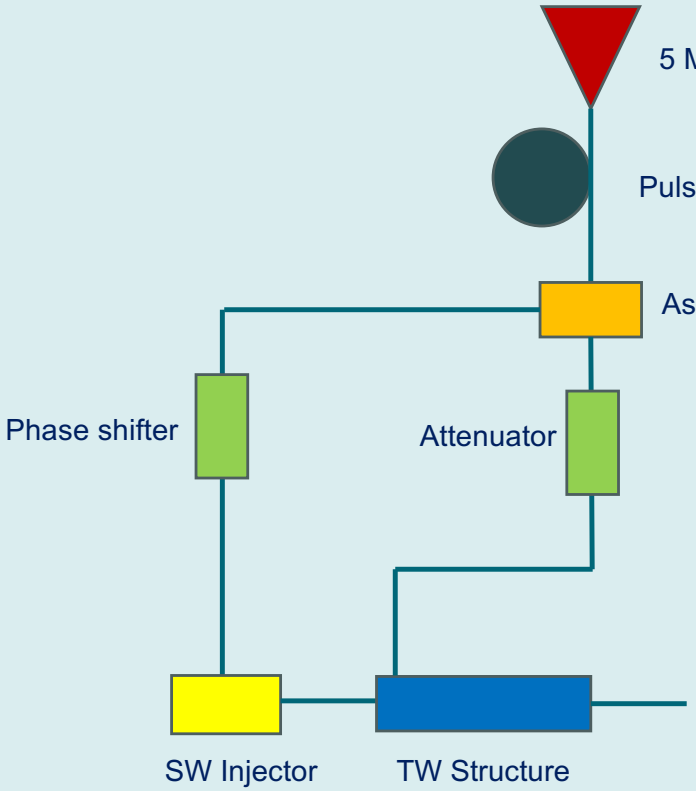
SCHEME FOR 100 MeV Linac



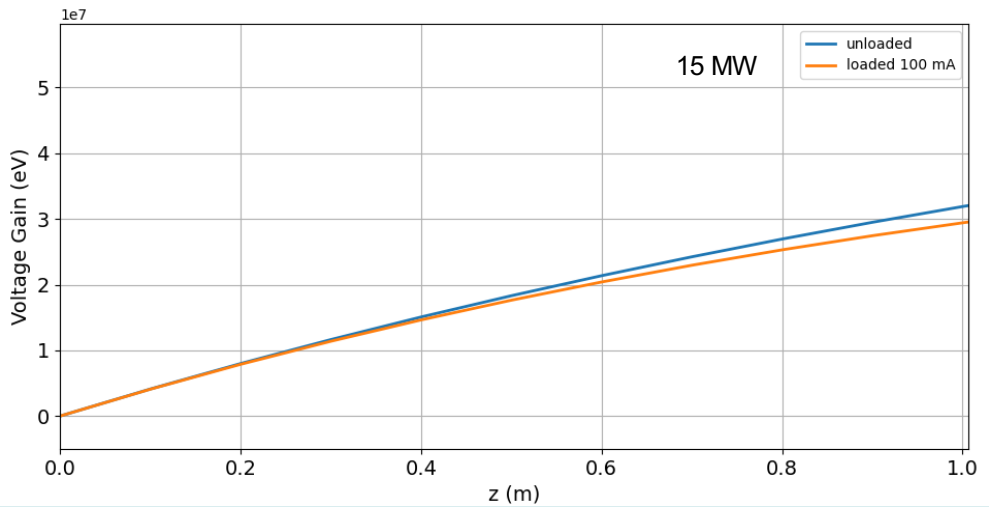
Frequency	5.712 GHz
Beam Energy	65 - 100 MeV
RF Repetition rate	100 Hz
Current	100 mA
C-band average accelerating gradient	45 MV/m
RF pulse duration	1.2 – 2.5 µs
In pulse dose rate	> 10^6 Gy/s
Average dose rate	> 100 Gy/s
Dose per pulse	>> 1 Gy

FLASH FUNDED WITH BUDGET 1.6 ME

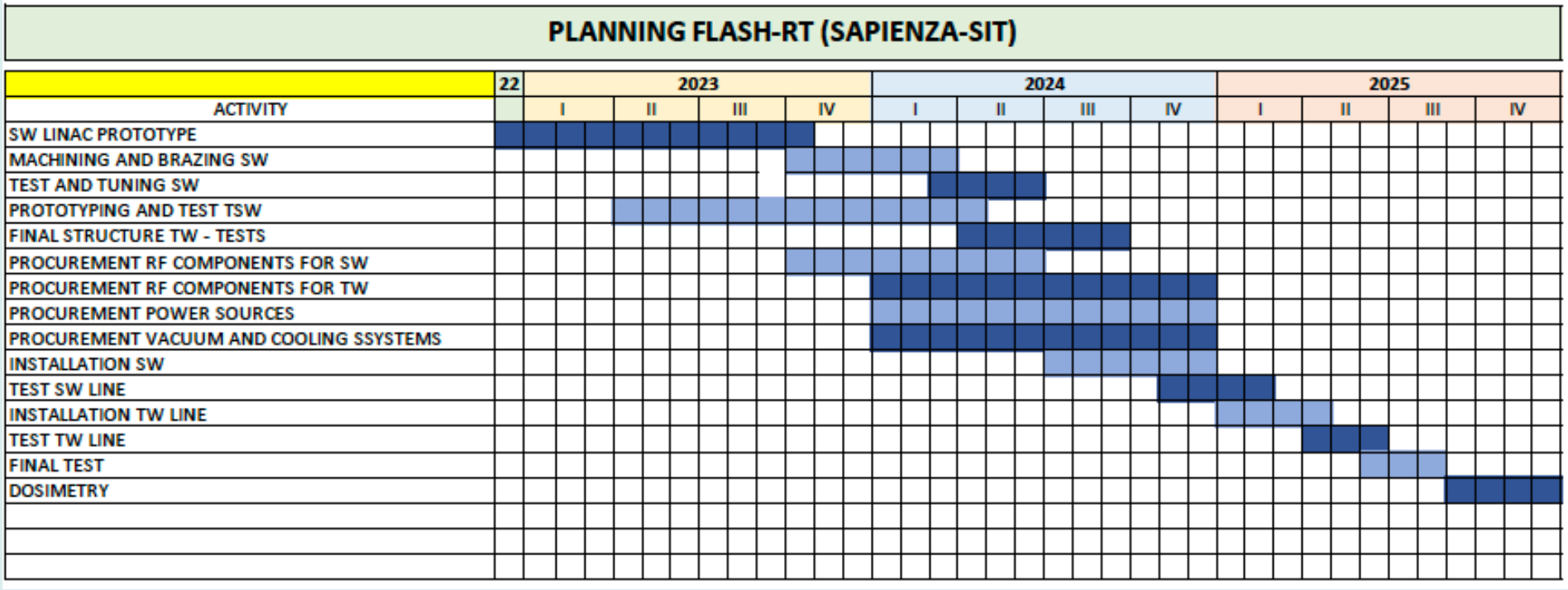
C-BAND BASIC SYSTEM @ SAPIENZA



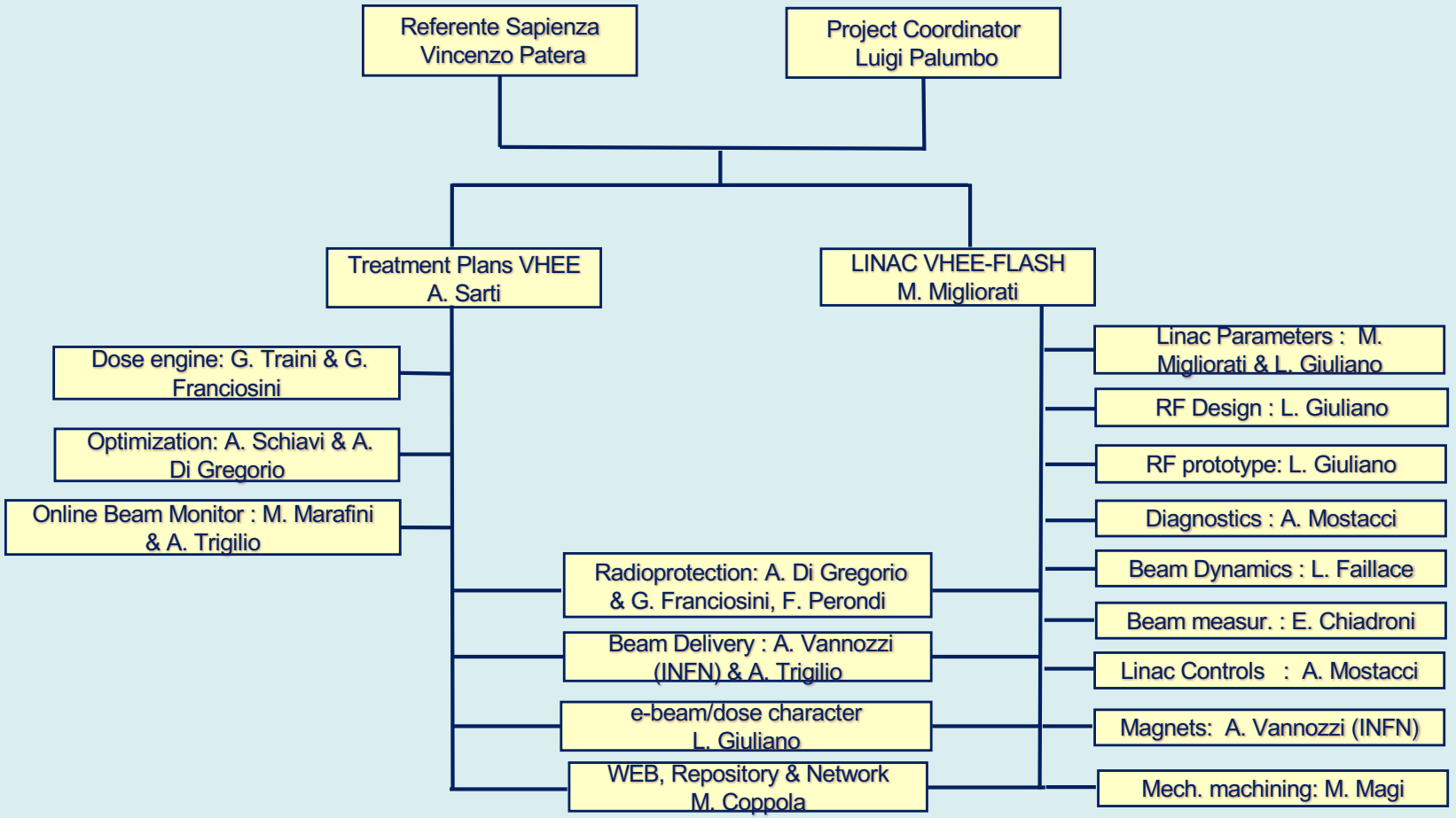
2023



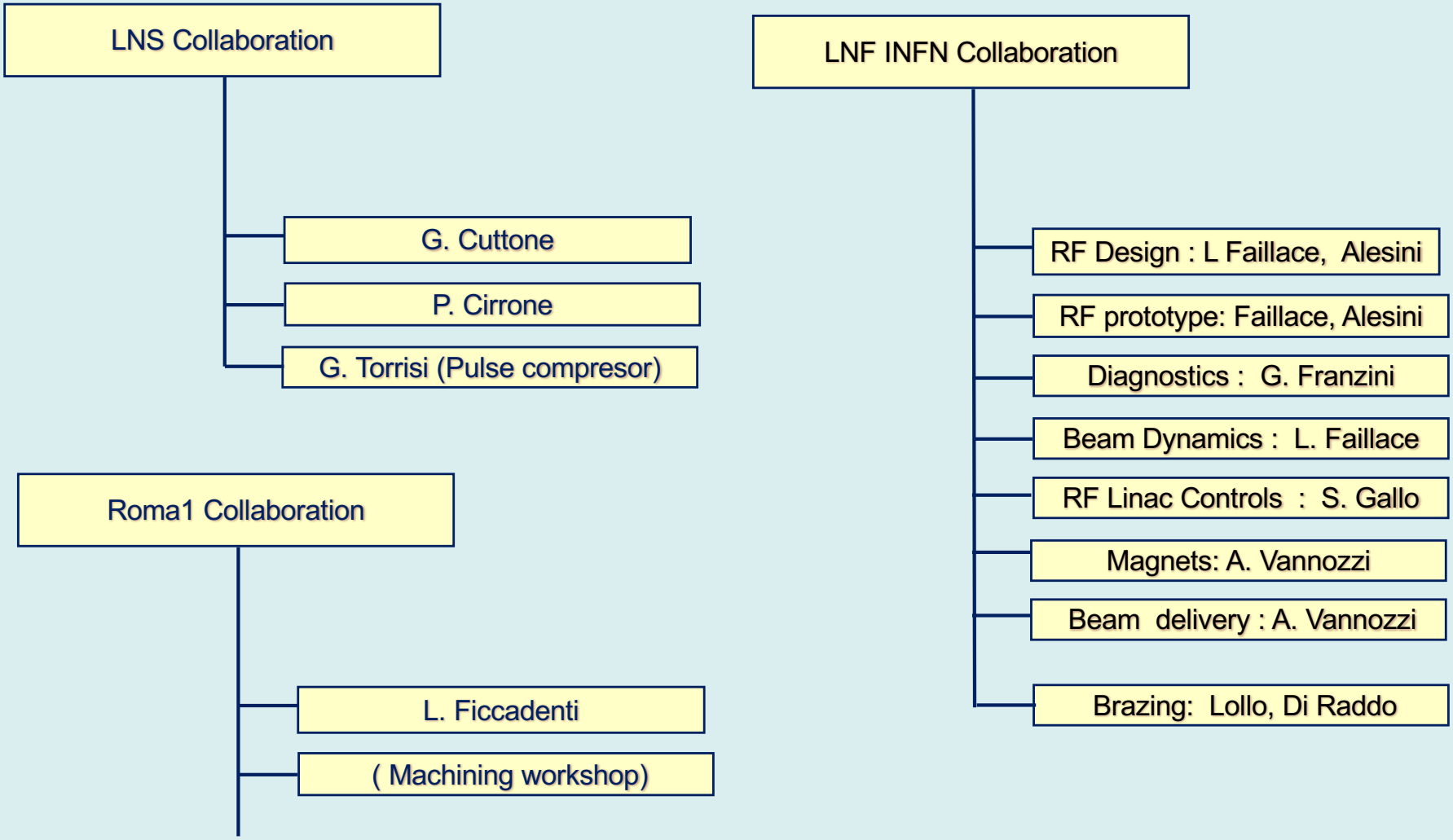
PLANNING FLASH-RT (SAPIENZA-SIT)



HEAL_ITALIA VHEE-FLASH



INFN COLLABORATION



CONCLUSIONS

- FOR A LONG TIME SAPIENZA HAS BEEN INVOLVED IN TUMOR PARTICLE THERAPY RESEARCH
- THE ACCELERATOR TEAM WAS INVOLVED IN ELECTRON FLASH @LOW ENERGY FOR INDUSTRY (SIT)
- 2021 SAPIENZA AND INFN: DESIGN STUDY OF A VHEE FLASH BASED ON C-BAND (SAFEST)
- 2022 R&D PROJECT FUNDED BY INFN (FRIDA)
- 2023 BASIC VHEE SYSTEM FUNDED BY NATIONAL PNRR (HEAL_ITALIA)
- PROTOTYPES OF THE SW INJECTOR AND TW STRUCTURE ARE BEING DEVELOPED IN HOUSE
- BIG EFFORT AND CHALLENGES TO BUILD A BASIC SYSTEM AT LA SAPIENZA UNIVERSITY
- THE SYSTEM HAS TO BE COMPLETED BY THE END OF 2025
- ALL THE ACTIVITIES BENEFIT FROM THE ROBUST SUPPORT OF INFN