

11 - 13 July 2023

Very High Energy Electron Radiotherapy Conference

Scientific Advisory Committee

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- Roberto Corsini (CERN)
- Manjit Dosanjh (CERN and Oxford)
- Deepa Angal-Kalinin (STFC)
- Gerardo D'Auria (Elettra)
- Jean Bourhis (CHUV)
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- Roger Jones (Manchester University)
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- Ulrich Schramm (HZDR)
- Frank Stephan (DESY)
- Sami Tantawi (SLAC)
- Marie Catherine Vozenin (CHUV)
- Steinar Stapnes (CERN)

Local Organizing Team

- Florian Burkart
- Marcel Weschke
- Matthias Kreuzeder
- Arlinda Qelaj
- Julia Koschig



The list of topics to be explored are:

- Current State of the Art
- Treatment Planning, Modelling and Imaging
- Current conventional facilities at intermediate (ELBE, PITZ, Flastron IC, Antwerpen..) and high (CLEAR, CLARA, ARES, ..) energies
- Current and future non-conventional facilities LPA (DRACO, CALA, LOA, KALDERA)
- Planned future facilities (DEFT, FRIDA,...)
- Accelerators R&D and Technologies: distributed coupling, cryogenic copper, millimetric waves or THz sources...
- Interest from Industries



VHEE 23 at Hamburg

It was a pleasure to have you here in Hamburg!

See you at the next VHEE conference!!

VHEE23 in numbers

124 participants

77 on site

18 PhDs

over 1.000 minutes interesting talks

Time	Event	Speaker	Location
13:00	Registration		Seminar Room FLASH (Building 28c, 2nd floor), DESY
14:00	Welcome	Sabine Brock	Seminar Room Flash (Building 28c, 2nd floor), DESY
	Current state of VHEE	Angeles / Marjitt / Roger	Seminar Room FLASH (Building 28c, 2nd floor), DESY
	Summary of FRPT event including clinical	Marie Catherine Vozenin	Seminar Room FLASH (Building 28c, 2nd floor), DESY
15:00	Recent developments in dosimetry for radiotherapy using electron beams with ultra-high pulse dose rates	Andreas Schueler	Seminar Room FLASH (Building 28c, 2nd floor), DESY
	Graphite calorimeter UHDR online dosimetry - [Zoom presentation]	Sam Flynn	Seminar Room FLASH (Building 28c, 2nd floor), DESY
	Scintillating and Optical Fibres for UHDR Real-Time Dosimetry with VHEE	Joseph Bateman	Seminar Room FLASH (Building 28c, 2nd floor), DESY
	2D real time dosimetry in electron UHDR - [Zoom presentation]	Luana de Freitas Nascimento	Seminar Room FLASH (Building 28c, 2nd floor), DESY
16:00	ElectroFlash experience (intermediate-energies) and transition issues to VHEE	Sophie Heinrich	Seminar Room FLASH (Building 28c, 2nd floor), DESY
	Tea Break		Seminar Room FLASH, (Building 28c, 2nd floor), DESY
17:00	ARES - overview - VHEE experiments at 155 MeV	Florian Burkart	Seminar Room FLASH (Building 28c, 2nd floor), DESY
	ARES visit & Young researchers Poster session		
18:00	SINBAD (Bldg. 30), DESY Hamburg		
	Welcome Barbecue		SINBAD (Bldg. 30), DESY Hamburg

11th July 2023

**Setting up the scene for VHEE
 FRPT 2022 summary**

Dosimetry & Detectors

VHEE conventional facilities

ESR posters

- 2023 - VHEE23-Kroll-WIP.pdf
- 2023 - VHEE-Schilz.pdf
- poster_VHEE_2023_Giuliano.pdf
- Poster_VHEE_2023_Senador.pdf
- poster_VHEE23_Avella.pdf
- Poster_VHEE23_Kunz.pdf
- Poster-VHEE23-Riemer.pdf
- VHEE23_GIACCAGLIA_POSTER.pdf
- VHEE_23_Poster_Bateman.pdf
- VHEE poster 2023 robin.pdf

12th July 2023

Time	Topic	Speaker
08:00	Accelerators R&D and Technologies	
08:00	Conference Photo	
08:00	Industries for medical technologies	
08:00	Round Table "Requirements of In vivo experiments"	
08:00	VHEE conventional facilities I	
08:00	VHEE conventional facilities II	
09:00	First results from UHEE cell irradiation with short 1.2 GeV	
09:00	FLASHlab@PITZ Commissioning, first steps, results and next steps	
09:00	Ultra-high dose rate radiobiology with electrons at ELBE and laser accelerators using small animals	Jörk Pawelke
09:00	Updates, Status and Experiments of CLEAR, the CERN Linear Electron Accelerator for Research User Facility	Pierre Korysko
10:00	CLARA - overview - potential for VHEE experiments at 250 MeV	Deepa Angal-Kallin
10:00	VHEE Tsinghua activities - [Zoom presentation]	Jiaru Shi
10:00	Opportunity of studying Flash therapy effects at the Argonne National Laboratory - [Zoom presentation]	Chenguang Liu et al.
11:00	Pulsed Energetic Electrons for Research (PEER) - VHEE activities at ANSTO - [Zoom presentation]	Eugene Tan
11:00	Coffee Break	
11:00	DEFT for the future of FLASH VHEE radiation therapy	
11:00	SAFEST (SAplenza Flash Electron Source for radio-Therapy)	
12:00	Kicker technology for quickly distributing short electron bunches over the treatment area	Gregor Lohsch
12:00	VHEE R&D at SLAC	Sami Tantawi
13:00	VHEE Beam dynamics simulations issues at SAFEST	
13:00	High-gradient RF systems for compact accelerators	
13:00	Lunch	
14:00		

VHEE conventional facilities

VHEE conventional facilities planned

Accelerators R&D Technologies

14:15 - 14:30	Conference Photo: Conference Photo	
14:30 - 14:50	Thales portfolio and roadmap to serve future scientific and medical compact accelerators	Térence Schuermans
15:00	Industries for medical technologies	
15:30 - 15:50	Very High Energy Electrons: Clinical Perspective and Constraints	Giuseppe Felici
16:00	Tea break	
16:10 - 16:30	There are some hurdles to take if one wants to also do in vivo experiments	Marie Catherine Vozenin
16:50 - 17:30		
19:00	Banquet on Boat	
19:00 - 21:00	Port of Hamburg	

Industries for medical technologies

Round table: "in vivo requirements"

ESR poster prize

13th July 2023

<input type="radio"/> Concluding remarks <input type="radio"/> Treatment Planning, Modelling and <input checked="" type="radio"/> VHEE non conventional (Deepa)	
<input checked="" type="radio"/> Young Research session (Manjit)	
08:00	
	DESY perspectives for using laser plasma acceleration for VHEE <i>Andreas Maier</i> Seminar Room FLASH (Building 28c, 2nd floor), DESY 08:30 - 08:50
	DRACO comparing this to laser exos and FLASH with protons <i>Josefine Metzkes-Na</i> Seminar Room FLASH
09:00	
	Laser-driven electron Seminar Room FLASH
	VHEE activities <i>Arnaud Courvoisier</i> Seminar Room FLASH (Building 28c, 2nd floor), DESY 09:30 - 09:50
	Laser driven VHEE activities In INO-Pisa - [Zoom presentation] <i>Leonida Antonio Gizzi</i> Seminar Room FLASH (Building 28c, 2nd floor), DESY 09:50 - 10:10
10:00	
	TWAC: a novel dielectric acceleration project for ultra-high dose rate applications <i>G. Martinet</i> Seminar Room FLASH (Building 28c, 2nd floor), DESY 10:10 - 10:30
	Coffee Break Seminar Room FLASH, (Building 28c, 2nd floor), DESY 10:30 - 10:50
	Imaging challenges for VHEE - [Zoom presentation] <i>Stefan Both</i> Seminar Room Flash (Building 28c, 2nd floor), DESY 10:50 - 11:10
11:00	
	Image guidance for VHEE radiotherapy and Focused dose delivery with VHEE Beams <i>Lucy Whitmore</i> Seminar Room FLASH (Building 28c, 2nd floor), DESY 11:50 - 12:10
12:00	
	VHEE simulations and treatment planning <i>Giacomo Traini</i> Seminar Room Flash (Building 28c, 2nd floor), DESY 12:10 - 12:30
	Lunch Seminar Room FLASH, (Building 28c, 2nd floor), DESY 12:30 - 13:40
13:00	

VHEE non conventional facilities

Treatment Planning, Modelling and Imaging

	Dosimetric experiments at high and low dose rates at FLASHlab@PITZ <i>Felix Rieker</i> Seminar Room Flash (Building 28c, 2nd floor), DESY 13:40 - 13:55
14:00	
	Radiation biology at FLASHlab@PITZ <i>Anna Grebinyk</i> Seminar Room Flash (Building 28c, 2nd floor), DESY 13:55 - 14:10
	Development of Real-Time VHEE Dosimetry at UHDR Using Beam Instrumentation <i>Vilde Rieker</i> Seminar Room Flash (Building 28c, 2nd floor), DESY 14:10 - 14:25
	Installation and initial tests of optimised dual-scattering systems for VHEE studies at CLEAR <i>Cameron Robertson</i> Seminar Room Flash (Building 28c, 2nd floor), DESY 14:25 - 14:40
	VHEE Plasmid Irradiation and RBE Studies at CLEAR-CERN <i>Kristina Small</i> Seminar Room Flash (Building 28c, 2nd floor), DESY 14:40 - 14:55
15:00	
	VHEE RF C-band developments Seminar Room Flash (Building 28c, 2nd floor),
	Experimental results at LOA Seminar Room Flash (Building 28c, 2nd floor),
	Treatment planning with VHEE Scanned Beams <i>Fabio D'Andrea</i> Seminar Room Flash (Building 28c, 2nd floor), DESY 15:25 - 15:40
	Exploration of the biological effect of VHEE and VHEE FLASH by evaluation of DNA damage and cell survival with facilit... <i>Hanna Wanstall</i>
16:00	
	Diamond-detectors for beam monitoring at ultra-high dose rate <i>Robin Molle</i> Seminar Room Flash (Building 28c, 2nd floor), DESY 15:55 - 16:10
	Impact of VHEE beam parameters on G(H2O2) and zebrafish embryos morphogenesis after UHDR and conventional Irra... <i>Kacem Houada</i>
	Moskintm dosimetry in a synchrotron flash radiation environment using Very High Energy Electrons <i>James Cayley</i> Seminar Room Flash (Building 28c, 2nd floor), DESY 16:25 - 16:40
	Tea Break Seminar Room Flash, (Building 28c, 2nd floor), DESY 16:40 - 16:55
17:00	
	Concluding remarks Seminar Room Flash (Building 28c, 2nd floor), DESY 16:55 - 17:15

ESR short talks

New horizon in therapy & treatment

FRPT 2022

FLASH RADIOTHERAPY & PARTICLE THERAPY

BARCELONA, SPAIN
30 NOVEMBER - 2 DECEMBER 2022



650+ Participants
40+ Countries

www.FRPT-Conference.org | #FRPT2022

Multidisciplinarity

- Accelerator physics
- Medical physics
- Radiochemistry
- Radiobiology
- Clinical Applications

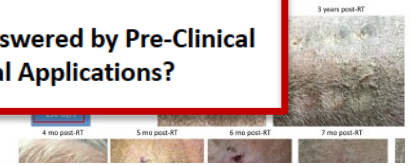
Do we believe in FLASH?

Which Questions Should Be Answered by Pre-Clinical Science to Inform Clinical Applications?

1- Are the conditions and parameters validated in mice translatable to humans?

Volume Fractionation
Dose
Dose rate

=> Definition of dose



2- Are acute response experimental models relevant?

3 cats over 7 developed ORN

Musi, 13 months post FLASH
Hot spots = 125% of the dose

CLINICAL CANCER RESEARCH | TRANSLATIONAL CANCER MECHANISMS AND THERAPY

Dose- and Volume-Limiting Late Toxicity of FLASH Radiotherapy in Cats with Squamous Cell Carcinoma of the Nasal Planum and in Mini Pigs

Arm 1: 5eC
Arm 2: FLASH

3- Are all organs/tumors equally responsive to FLASH?

Preclinical results

15 publications
23 tumor types
Single dose and Hypofractionation
TGD, TC and carcinogenesis
Chabbi et al. study shows fit to FLASH
Not properly powered to show isocytivity

Current clinical studies

Selection of the indication according to the technology
What we can achieve with the technology available



Optimize the technology and knowledge to perform meaningful studies

Abstract and Review 15/12/2022 05:08

Contents lists available at ScienceDirect

Radiation Therapy and Oncology

Journal homepage: www.elsevier.com/locate/rtog

Short Communication

Comparison of ultra-high versus conventional dose rate radiotherapy in a patient with cutaneous lymphoma

Oliver Gaidé^{1,2}, Fernanda Herrera^{1,2,3}, Wendy Jeanneret-Suzi^{1,2}, Patrícia Gonçalves Jorge^{1,2}, Rémy King¹, Claude Balier¹, Frédéric Ducros¹, François Rochoux¹, Jean-François Germond^{1,2}, Manuel Gaudin^{1,2}, Till Bredius^{1,2}, Lisa Schappesser¹, Malin Craxin¹, Raphael Mezzetti¹, Jean Bourlès^{1,2,3}

¹Department of Hematology, University Hospital of Geneva, Geneva, Switzerland; ²Department of Radiation Therapy, University Hospital of Geneva, Geneva, Switzerland; ³Department of Radiation Therapy, University Hospital of Geneva, Geneva, Switzerland

ARTICLE INFO

ABSTRACT

A patient with a cutaneous lymphoma was treated on the same day by 7 distinct sessions with a 11 Gy single electron dose given as either one of 100 conventional sessions (100 Conventional) or 100 FLASH sessions (100 FLASH). There was no difference in acute toxicity, late toxicity, and quality of life.

CONCLUSIONS AND RELEVANCE In this nonrandomized trial, clinical workflow metrics, treatment efficacy, and safety data demonstrated that ultra-high-dose rate proton FLASH radiotherapy was clinically feasible. The treatment efficacy and the profile of adverse events were comparable with those of standard-of-care radiotherapy. These findings support the further exploration of FLASH (radio)therapy in patients with cancer.

JAMA Oncology | Original Investigation

Proton FLASH Radiotherapy for the Treatment of Symptomatic Bone Metastases: The FAST-01 Nonrandomized Trial

Anthony E. Marcus, PhD, Emily C. Daugherty, MD, Yongbin Zhang, MS, Eunsoo Lee, PhD, Divyan Vyas, PhD, Matthew Sontora, PhD, Jennifer Woo, BS, Lari B. Backus, BA, Julie M. McDonald, CCRP, Claire McCann, PhD, Kenneth Russell, MD, Lisa Lavigne, PhD, Rory A. Sharma, MD, PhD, Dee Khunta, MD, Jeffrey D. Bradley, MD, Charles B. Simone Jr, MD, John P. Pientest, MD, John C. Brewster, MD

IMPORTANCE To our knowledge, there have been no clinical trials of ultra-high-dose rate radiotherapy delivered at more than 40 Gy/sec, known as FLASH therapy, nor first-in-human use of proton FLASH.

OBJECTIVES To assess the clinical workflow feasibility and treatment-related toxic effects of FLASH and pain relief at the treatment sites.

CONCLUSIONS AND RELEVANCE In this nonrandomized trial, clinical workflow metrics, treatment efficacy, and safety data demonstrated that ultra-high-dose rate proton FLASH radiotherapy was clinically feasible. The treatment efficacy and the profile of adverse events were comparable with those of standard-of-care radiotherapy. These findings support the further exploration of FLASH (radio)therapy in patients with cancer.

First Investigational Trials Planned with Mobetron FLASH HDR

Transfert clinique @ CHUV (II) : intra-operative FLASH-THERAPY

FLASHKNIFE

FLASHKNIFE
FLASH RADIOTHERAPY

CLIC mini-week 2023

New horizon in therapy & treatment

FRPT 2023

FLASH RADIOTHERAPY & PARTICLE THERAPY

TORONTO & ONLINE
5-7 DECEMBER 2023

Join us in Toronto!

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VHEE RT

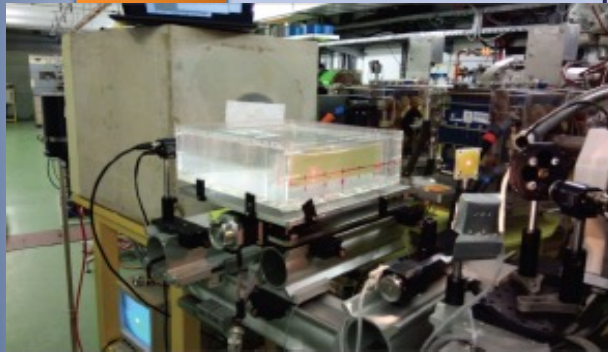
Beam dosimetry and detectors



Time monitor dose system of FLASH



Biological dosimeters- Fish eggs



Beam dosimetry in CLEAR

- Beam Dosimetry studies with **50 – 70 MeV (NLCTA)** and **160 MeV (SPARC)** VHEE beams
- Beam dosimetry experiments with a **135 MeV laser-plasma wakefield accelerator (ALPHA-X)**
- Beam dosimetry in **CLEAR** with **200-250 MeV**
 - **Radiosensitive films** for focusing
 - **Ionisation chambers** for charge
 - **Alanine pellets** for profile depth dose
 - Generate the total dose (**~10 Gy**) on **biological dosimeters** in a single pulse (**<100 ms**) for profile depth dose
- Dosimetry for **ultra-high dose rate** and development of dosimeters is mandatory for a **clinical application (EURAMET - EMPIR 2018)**
- Not many **experiments** to date with **200 – 250 MeV beams** and **focused electron beams on tissue like media** – essential step before **patient treatment planning**

Dosimetry & Detectors

- In VHEE beams commercially available ionization chambers show large deviations due to ion recombination at ultra-high DPP, the same as for FLASH beams of clinical energies.
- A theoretical model was developed for calculation of a correction, which agrees with experiment.
- Ultra-thin ionization chamber prototypes were developed which show linear response in the ultra-high DPP range.
- flashDiamond and SiC-diode detectors were developed which show linear response at ultra-high pulse dose rates.

Dosimetry for ultra-high pulse dose rate beams

Irradiation facilities / providers

- QUBES UNIVERSITY BELFAST
- HEMANTZ CENTRAL OF RADIATION PHYSICS
- eli
- INSPIREPROJECT
- MedAustron
- SIT
- PAUL SCHERRER INSTITUT
- IntraOp
- PIPER

Detector developers

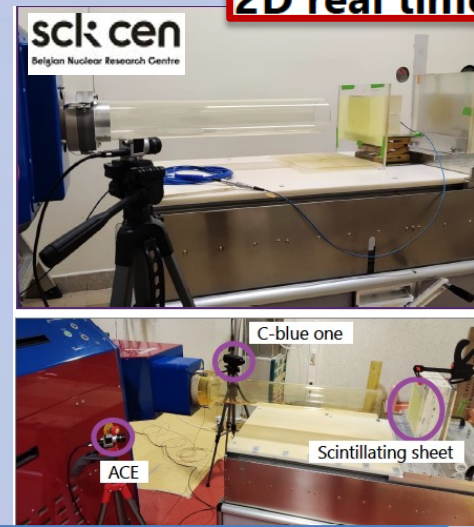
- ADVACAM
- USC
- PTW
- CSIC
- POLITECNICO MILANO
- bergoz
- ScandiDos
- TOR VERGATA
- varian
- loc
- RLSE
- SUN NUCLEAR
- iba
- TECHNISCHE UNIVERSITÄT DRESDEN
- UNIVERSITE LAVAL
- DETECTOR
- INSTRUMENTATION TECHNOLOGIES

Metrology Institutes

- PTB
- NPL
- CI
- METAS
- scck cen

A. Schüller et al., Physica Medica 80 (2020) 134-150

2D real time dosimetry in electron UHDR

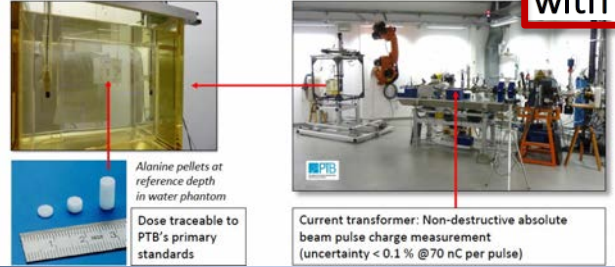


- Scintillation imaging can provide real-time 2D dosimetry of X-ray conventional radiation, proton and Carbon therapy beams.
- Results show that the scintillation light was not affected by saturation effects in UHDR electron beams up to 9 MeV, demonstrating the potential to be used at these extreme dose rate regimes.
- Their application in VHEE RT looks promising but requires further investigation

Recent developments in dosimetry for radiotherapy using electron beams with ultra-high pulse dose rates

Scintillating and Optical Fibres for UHDR Real-Time Dosimetry with VHEE

Ion recombination corrections of ionization chambers
Ultra-high pulse dose rate reference electron beam



Dosimetry & detectors

Intermediate energy ElectronFlash experience & transition to VHEE (Real-life dosimetry)

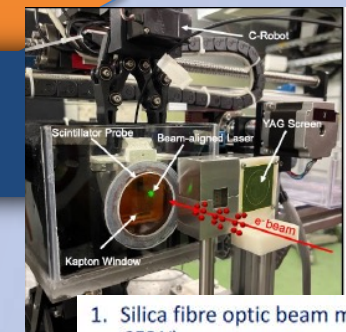
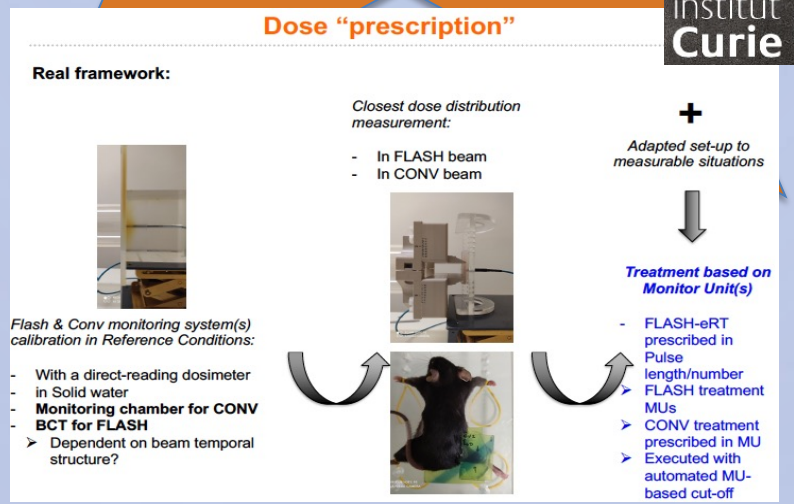
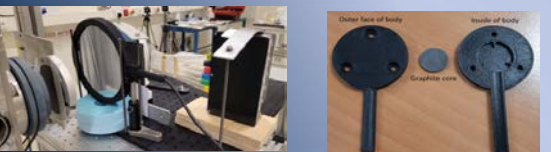


Figure 5. (a) The test-stand at the CLEAR facility, with the calorimeter, ion chamber and monitor chamber placed along the beam line with the beam travelling from right to left. The calorimeter core can be seen at the end of the PMMA sleeve (b). This shows the front surface of the custom PMMA phantom with beam monitor insert placed to the right of the calorimeter sleeve. The PMMA build-up blocks, used to ensure the reference depth of the detectors was at 8 cm, are not included in the photographs.

- Calorimeters used at CLEAR, 200 MeV e^- beam, to understand ion chamber response in UHDR
- Used in combination with alanine (an offline chemical dosimeter) to study ion recombination
- Underlying physics of calorimeters make them dose rate independent (equally suitable for pulsed or continuous beams)

Use of Calorimetry for UHDR online dosimetry

- Calorimetry is a suitable technique for the dosimetry of UHDR beams, demonstrated in VHEE and proton beams
- Research is ongoing to make calorimetry more accessible to the radiotherapy community via secondary standard calorimeters



- Silica fibre optic beam monitor development (University of Oxford and CERN)
- Plastic scintillator-coupled fibre dosimetry (University of Victoria and Université Laval)
- PROOF (PRecision dOSimetry in FLASH radiotherapy with Optical Fibers) (University of Bern)

- Fibre optic detector can measure beam profile and showed linear response well into the UHDR regime - could be a promising alternative for real-time beam monitoring for FLASH.
- PSD able to provide real-time dosimetry measurements at the dose rates required for FLASH, and retained linearity after high levels of radiation.
- GAGG scintillating fibre also showed linearity and promising as alternative for real-time dosimetry.

VHEE RT

Accelerator Conventional Facilities



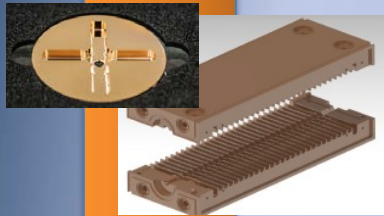
VHEE beams (50 - 250 MeV) are delivered by different types of accelerator facilities based in conventional RF linacs **NC** or **SC**:

- **NC RF linacs**, is the most used technology for the VHEE research. The main advantages are flexibility, compactness and cost. Some of the current operational facilities are:
 - **CLEAR (CERN)** NC X-band linac CLIC technology (50 - 250 MeV, 0.01 - 0.4 nC, 1-5 Hz)
 - **CLARA (Daresbury)** NC S-band linac (40 MeV, 10 Hz, 100 pC)
 - **AWA (ANL)** NC X-band linac (6 - 63 MeV, 0.1 – 100 nC, 0.5 – 10 Hz)
 - **ARES (DESY)** NC S-Band linac (20 – 160 MeV)
- **SC RF linacs**, is less extended for this type of application. Some available facilities in EU are:
 - **ELBE (HZDR)** SC 1.3 GHz ILC technology (40 MeV, 0.01 - 80 pC, from single pulse to 13 MHz)
 - **PITZ (DESY)** SC 1.3 GHz ILC technology (22 MeV, customized time structure 0.1 -1 MHz, optimum 4.5 MHz, trains repetition until 10 Hz)

Any others, are also available like: **ELSA (Bonn)** or **ANSTO (Melbourne)**...

VHEE dedicated facilities are in **design** and there are plans for **construction** as **DEFT (CHUV)** or **SAFEST (Sapienza)**, ...

Conventional facilities



CLIC X-band RF technology



TW S-band RF technology

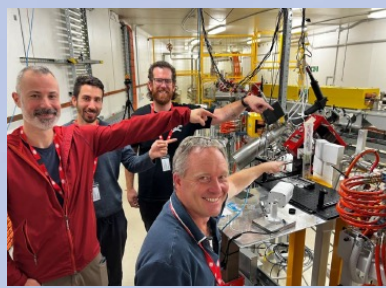
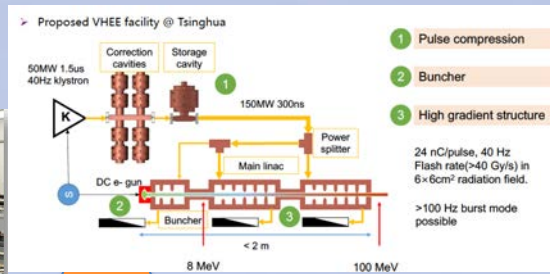
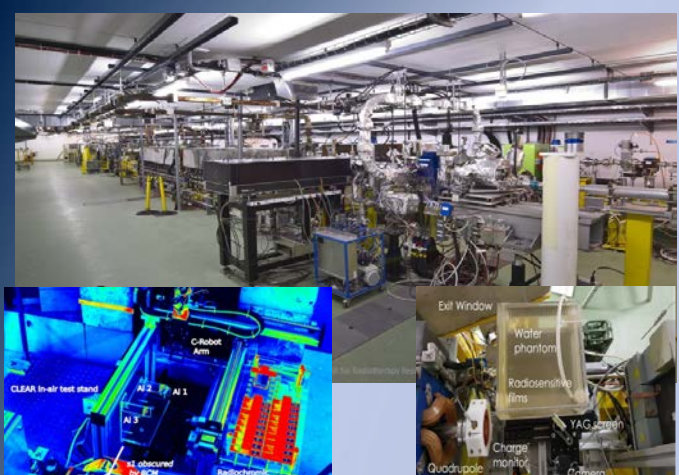


SC 1.3GHz 9 cell cavity



The currently longest superconducting accelerator in the world

CLEAR CERN



TSINGHUA UNIV.

booster synchrotron
0.5 GeV - 1.6 GeV

stretcher ring
0.5 GeV Direct transfer from Booster

- part of storage ring only used as transfer beamline
- variable beam energy up to 1.2 GeV
- fixed spill duration $t = 250$ ns
- up to 2.5 nC per spill ($\approx 15 \times 10^9$ electrons)
- max rate 50 Hz (currently 0.1 Hz)

beam line for detector tests

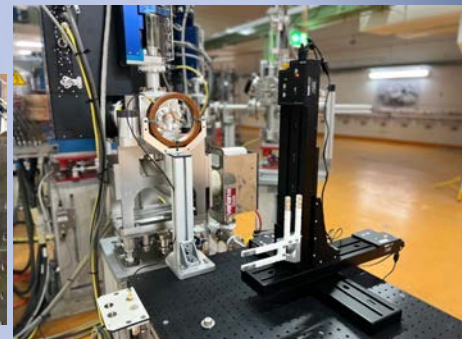
FLASH@ELSA

ELSA BONN

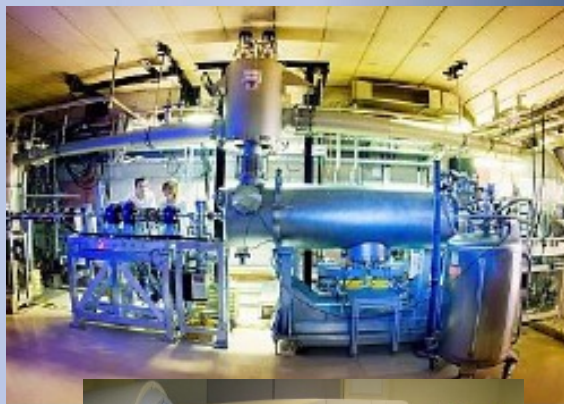
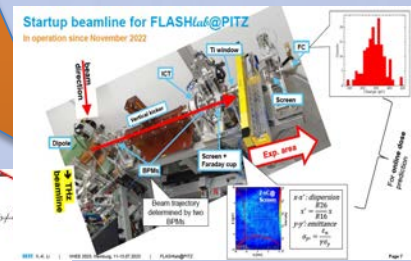
PEER ANSTO

ARES DESY

VHEE conventional

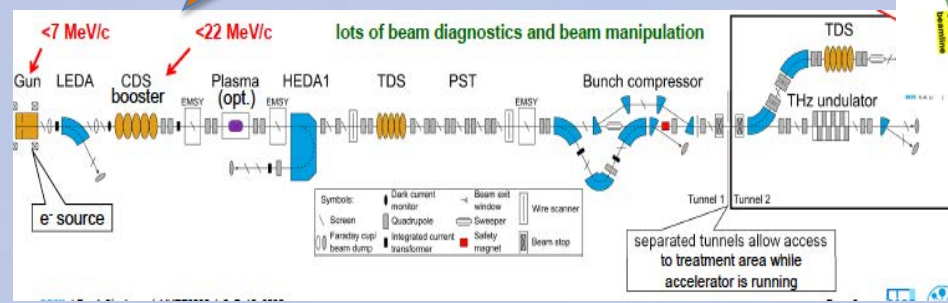


FLASHlab PITZ DESY

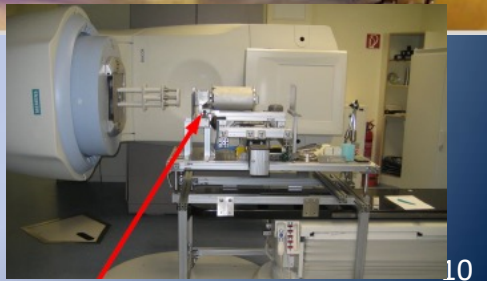


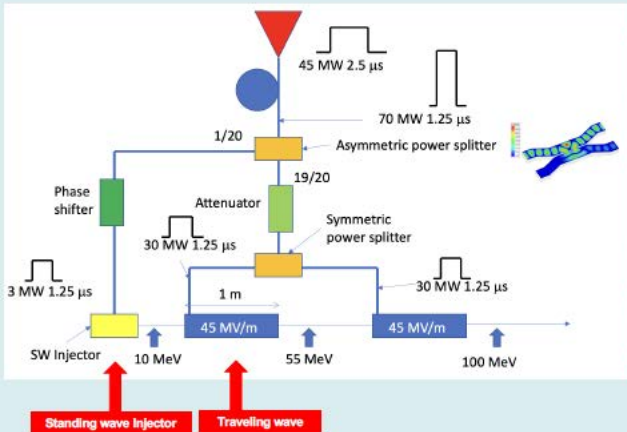
CLARA STFC CI

AWA ANL

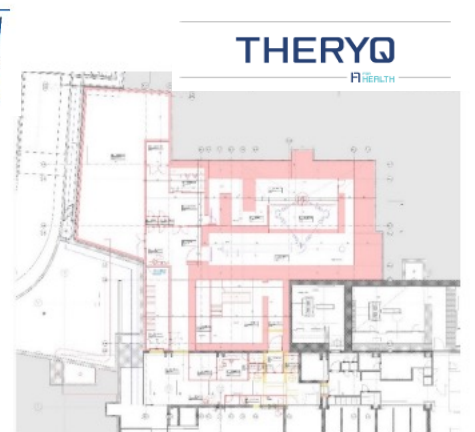
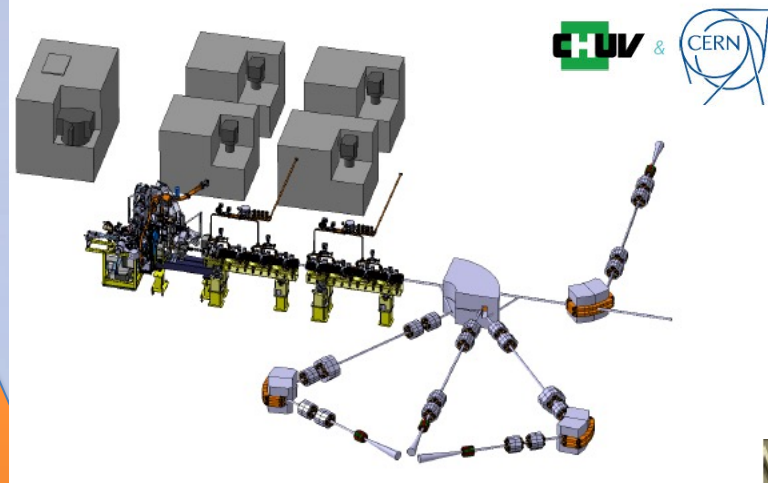


ELBE HZDR

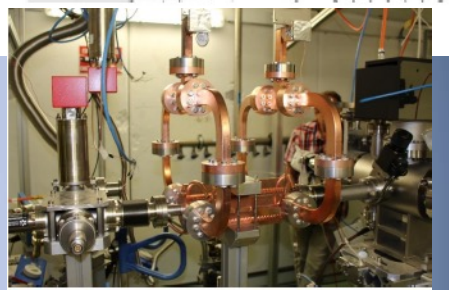




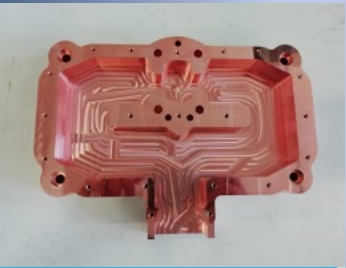
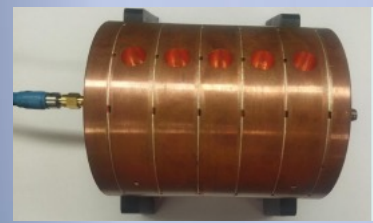
Frequency	5.712 GHz
Beam Energy	65 - 100 MeV
RF Repetition rate	100 Hz
Current	100 mA
C-band average accelerating gradient	45 MV/m
RF pulse duration	1.2 - 2.5 μs
In pulse dose rate	> 10 ⁶ Gy/s
Average dose rate	> 100 Gy/s
Dose per pulse	>> 1 Gy



THERYQ
HEALTH



SAFEST Sapienza

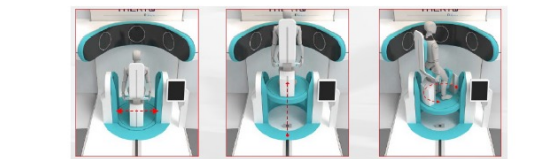
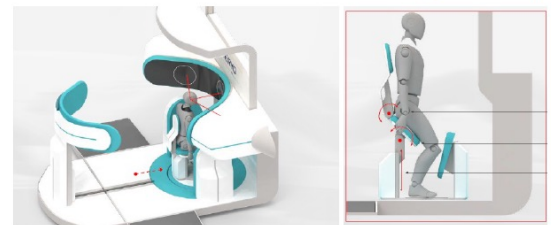


VHEE conventional planned

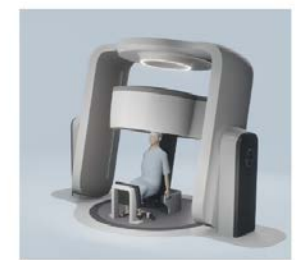


DEFT CHUV

FLASHDEEP: Patient Positioning Concept

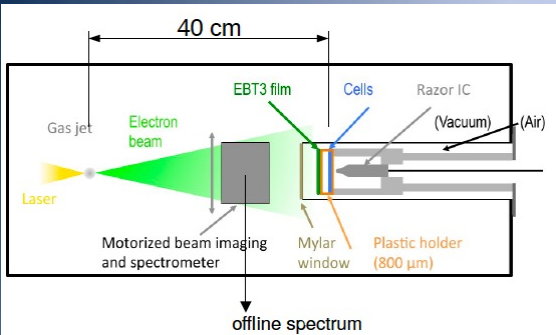


FLASHDEEP: Vertical Scanner Concept

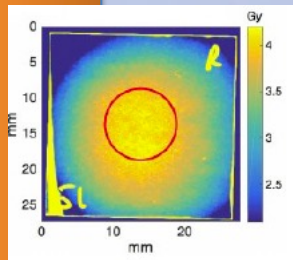
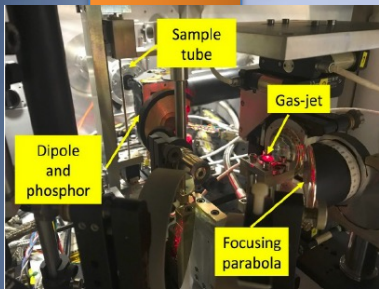


- FLASHDEEP will overcome this limitation with the use of **Very High Energy Electron (VHEE) beams**, with energies of 100-200 MeV
- FLASHDEEP will be the first FLASH radiotherapy device able to treat **every kind of solid tumor** up to a depth of 20 cm





Laser setup LOA



IDRA LOA future facility

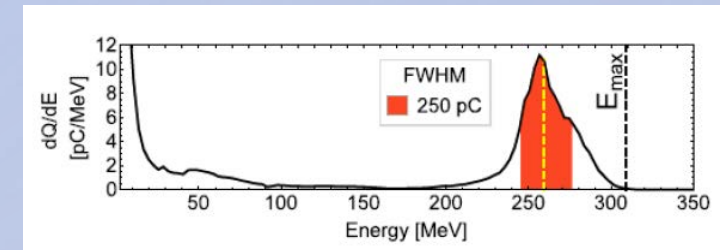
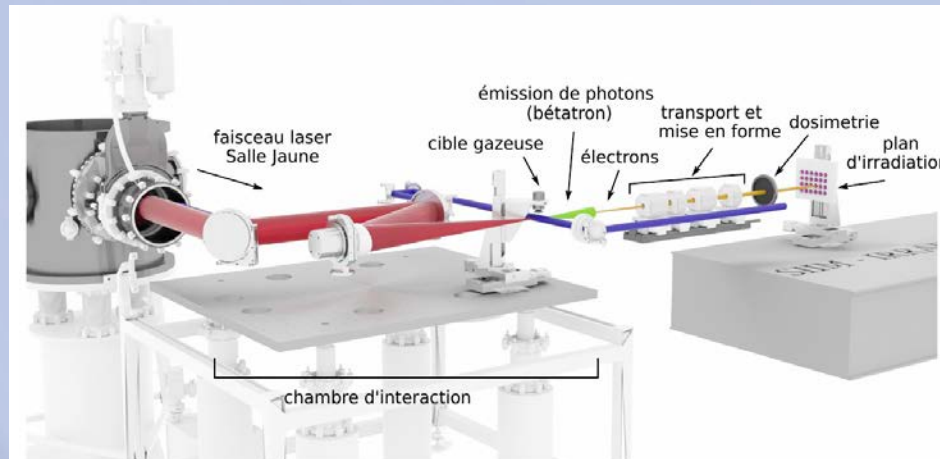
VHEE RT

Laser Plasma Accelerators

LPA technology is a very dynamic field and an enormous number of facilities are booming worldwide. The **PERFORMANCE** of **e- BEAMS** are **IMPROVING** and some of them are able to deliver **VHEE beams**

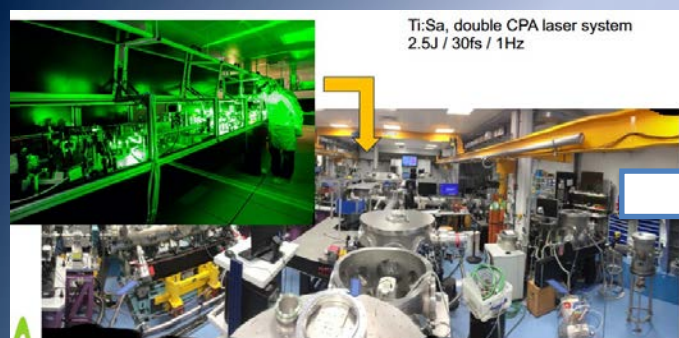
- **LPA:** Some of the current operational facilities are:
 - **DRACO (HZDR)** 1 PW laser (50 - 400 MeV, 500 pC, 1 Hz)
 - **LOA (IPP)** (100– 150 MeV, 10 pC to nC)
 - **ILIL (INO)** 1 PW laser (100 – 200 pC, 1 Hz)

Given the fast development, in a next future many others will be available soon...



VHEE beam generation at DRACO

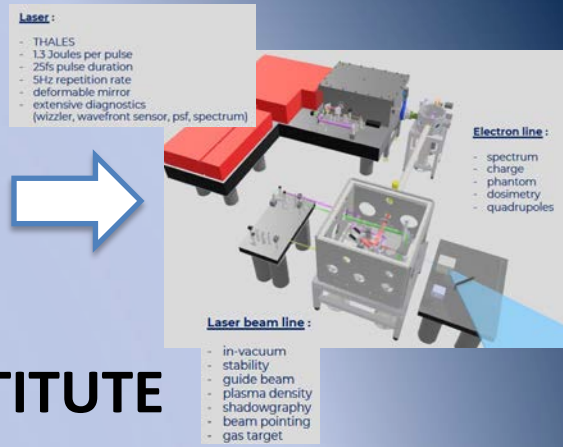
Advanced facilities



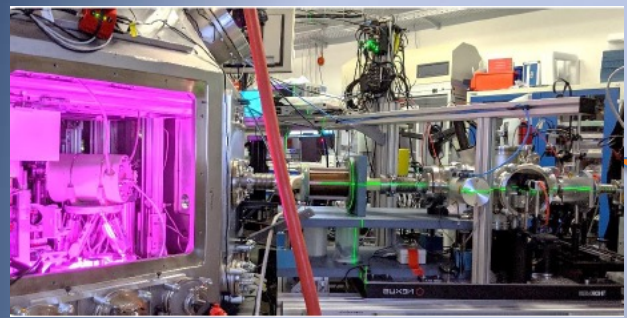
Ti:Sa, double CPA laser system
2.5J / 30fs / 1Hz



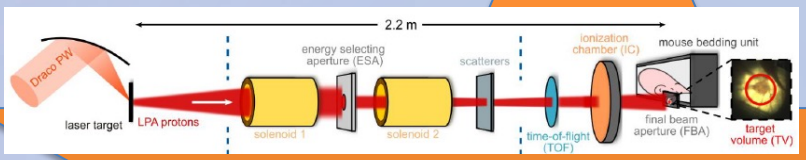
Laplace/HC: novel technological challenge of (i) (compact-) laser-driven accelerator, (ii) high average power, (iii) joule-class VHEE.
Starting 2024!



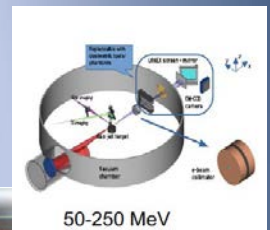
WEIZMAN INSTITUTE



DRACO HZDR



ILIL INO PISA



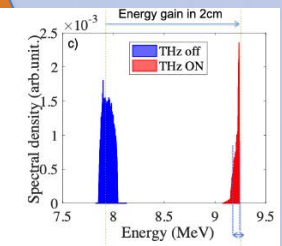
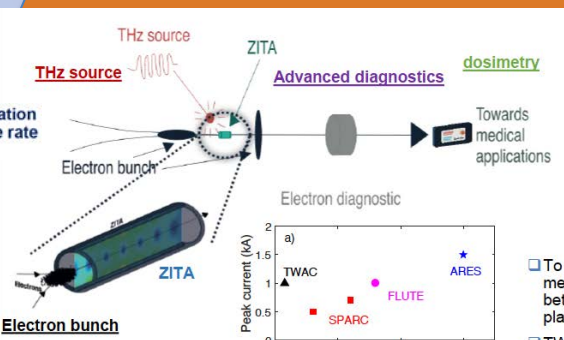
VHEE non-conventional



LUX Laser-Plasma Accelerator

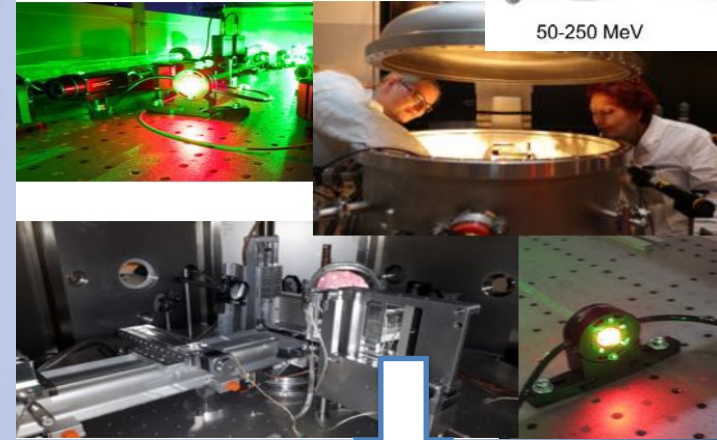
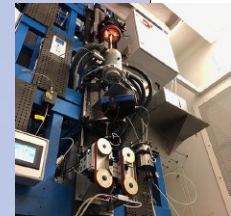
- 24-hour operation at 1 Hz
- Few-10 up to 100 pC
- 200 - 300 MeV
- Percent-level energy stability
- Beam manipulation and controls (quadrupoles, BPMs, screen...)
- Focus on reliability and repeatability
- Control system integration

A novel dielectric acceleration project for ultra-high dose rate applications



- To demonstrate a high energy gain per meter accelerating structure in the gap between the RF technologies and laser plasma accelerators
- TWAC will offer a high current electron source on a meter scale compared to RF accelerators

TWAC IJCLAB



100 Hz, J-scale laser beamline

Installation now in progress

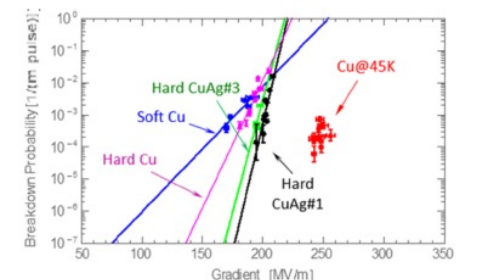


LUX DESY

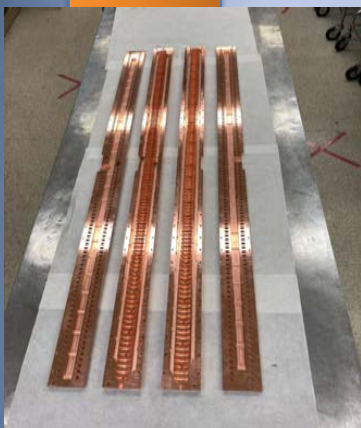
KALDERA: High Average Power Laser Development

VHEE RT

Accelerator Technologies



Hard Cu characteristics



X-band RF with 3D distributed coupling



110 GHz, 230 MV/m structure

Recent advances in RF technologies, especially in **HG RF (> 100 MV/m)** are now achievable in the **LAB** environment and are transforming the landscape for VHEE RT. New technologies could enable **ULTRA-COMPACT** structures, with **HIGHER REPETITION RATES** and **HIGHER CURRENTS (FLASH)**. An international **R&D** effort is ongoing focused on:

- **Material origin and purity, surface treatments and manufacturing technologies**
- **Consistency and reproducibility of the results**

Some promising R&D are:

- **Distributed coupling accelerator** to more efficiently and uniformly distribute the RF power
- **Cryogenic copper** operating at 77 K (liquid nitrogen) with 150 MV/m (C³ project)
- **Higher frequency mm waves (100 GHz) and higher repetition rates (THz sources)**

For **LPA** technologies and in particular for medical applications the main challenges are:

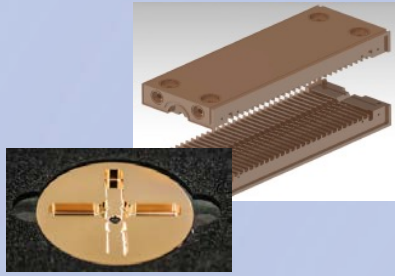
- **Beam performance and availability**
- **Consistency and reproducibility of the results**

These issues are currently the subject of a wide global study (EU EUPRAXIA and I.FAST)

HIGH-GRADIENT RF

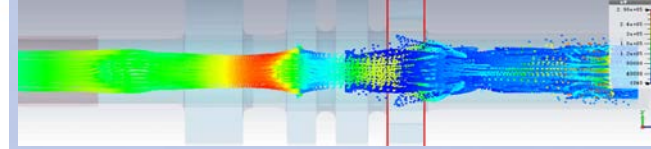
>100 MeV/m is now achievable in labs

12 GHz RF structure

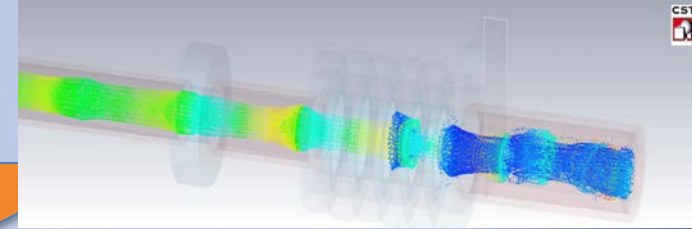


HIGH EFFICIENCY KLYSTRONS

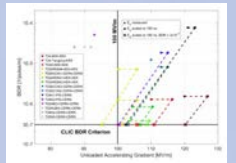
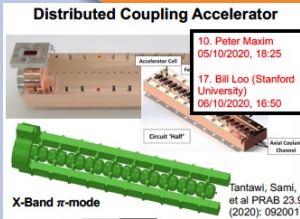
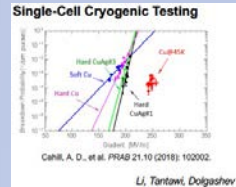
Retro-fit High Efficiency 8 MW, 12 GHz klystron



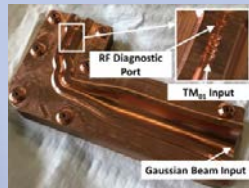
High Efficiency (66%) 50 MW, 12 GHz klystron (CERN- CPI collaboration)



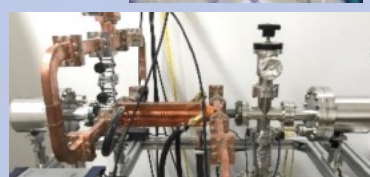
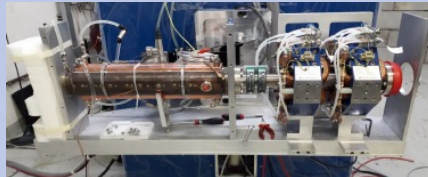
Accelerator Technologies



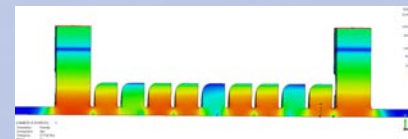
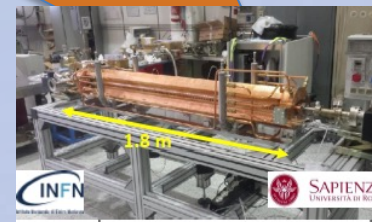
110 GHz RF structure



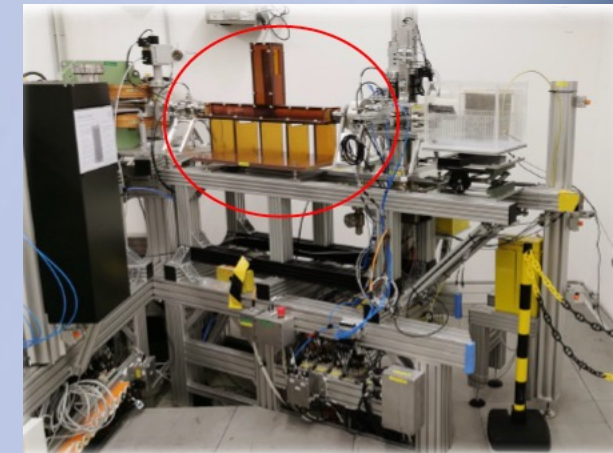
2.998 GHz RF structure



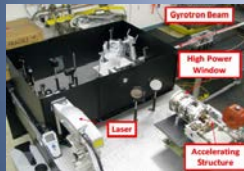
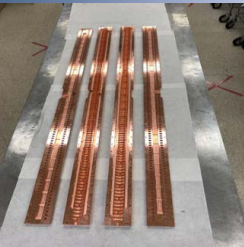
5.712 GHz RF structure



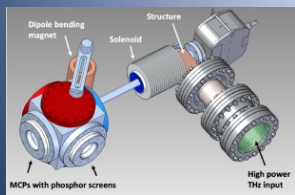
KICKERS

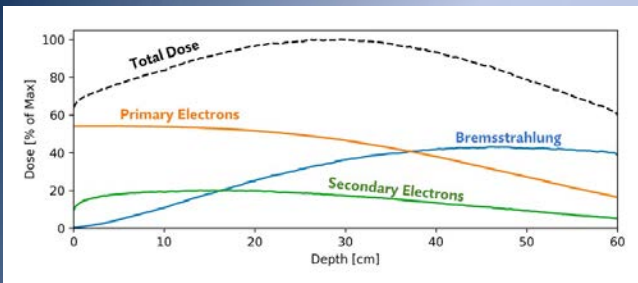


Kicker installation at PITZ

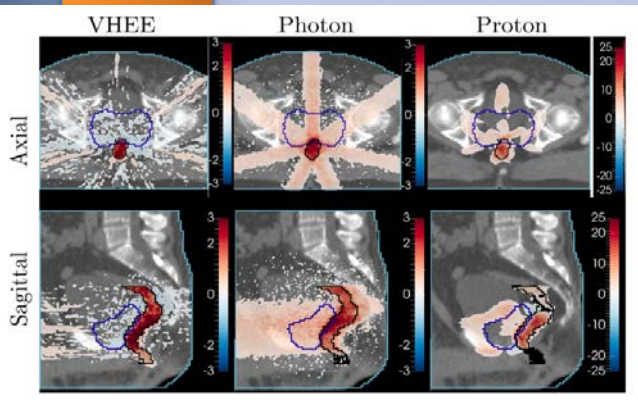


Short tunable pulse length Laser

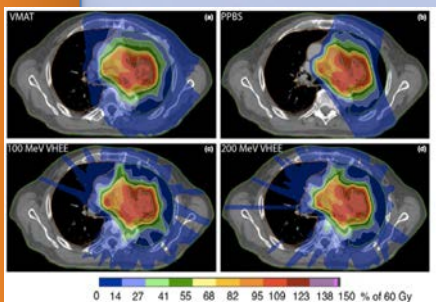




Percentage Dose Depth for 250 MeV e- in water



Dose difference after/before rectal volume emptying



TPs comparison



VHEE RT

Treatment Planning, Imaging and Modelling

TREATMENT PLANNING (TP) is an **ESSENTIAL TOOL** to any RT treatment, first results for VHEE TP are being developed, in particular:

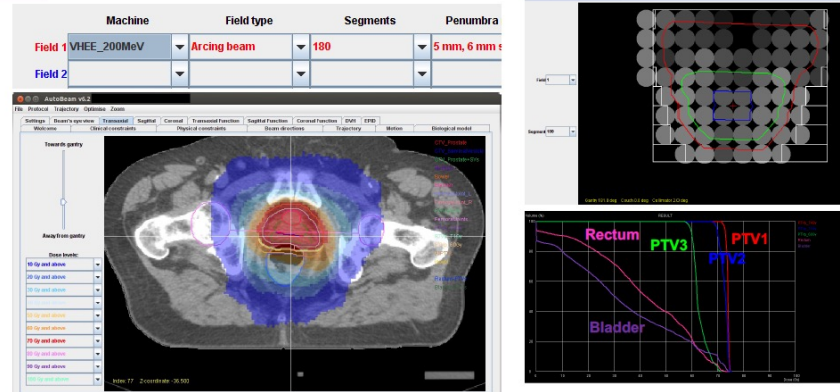
- Worth noting that the **dose** of VHEE beams is a **mixing** of primary (85%), secondary (20%) e- and bremsstrahlung
- First TP confirm significant **insensitivity to inhomogeneities** and less susceptible to dosimetric changes from changes in patient geometry
- Comparisons with photons and protons are ongoing for targeted well know cases (prostate). VHEE and photons share a scale whereas proton requires a wider range. VHEE TP shows **less difference in dose** compared to photons and protons.
- Effective **penetration range** in combination with **energy** and **beam size**, as well as the use of **multiple beams** to deliver accurate TPs are being investigated.
- Use of **quadrupoles arrays** has demonstrated strong potential to **reduce entrance/exit dose**. **Geometrical models** with small pencil beams to broad-focused beams with arbitrary focal length in water are enabling full 3D **dose deposition** in **good agreement with MC simulations**.
-

Treatment Planning, Modelling & Imaging

VHEE TREATMENT PLANNING

The ROYAL MARSDEN

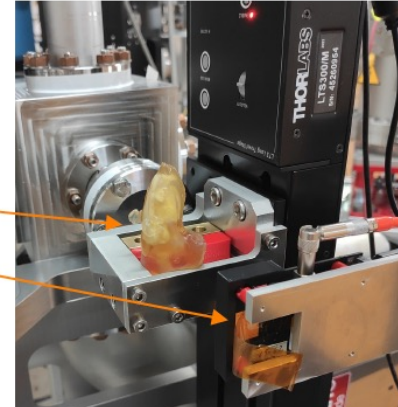
Example 200 MeV VHEE prostate plan



electronCT Setup

Setup for first single-shot 2D eCT measurements

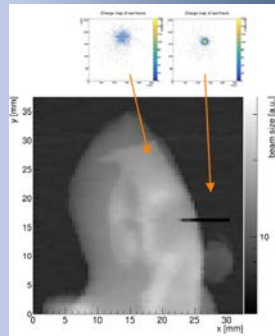
- Rat phantom "Alfred"
 - Medical phantom – 3D printed skull, gelatinous tissue
 - Fixed on motion & rotation stages
- Timepix3 assembly mounted on fixed stand downstream
- Minimising distances for beam size & detector occupancy
 - Limited by mechanics



electron CT VHEE

eCT 2D Measurement @ ARES

@ ARES

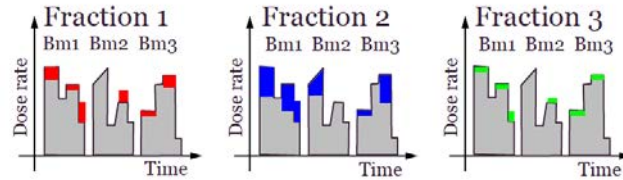


TP & Imaging

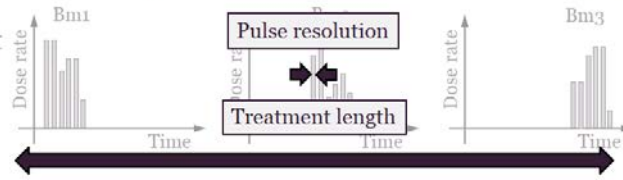
FLASH studies

Progression of treatment planning

Fraction-based



Treatment-based



Need to decide on energy: depth dose versus penumbra

Focusing useful for obtaining both advantages

VHEE appears beneficial compared to photons

Planning: pulse resolution and overall treatment

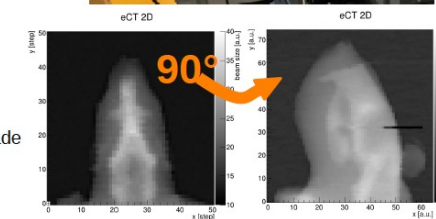
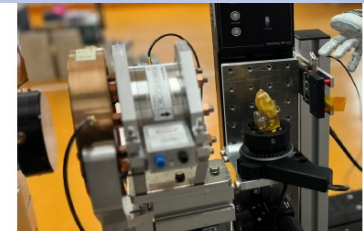
Discrete ordinates solvers have role to play

FLASH: currently benefits are in the high-dose region

Lower energy electrons also useful for FLASH

3D electronCT

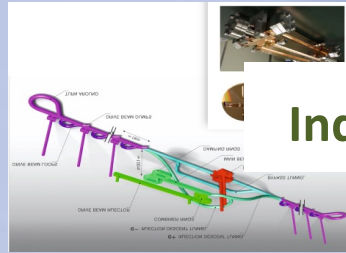
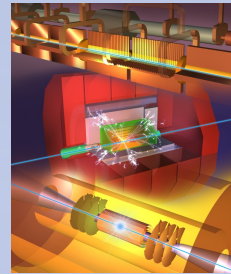
- Integration of rotation stage
 - Perform rotation scan & reconstruct via inv. Radon transform
- Further test beam campaigns scheduled
 - Improvements to 2D scanning procedure
 - Reduce measurement time
 - Beam optimisation after ARES upgrade
 - Commissioning of rotation stage
 - Performance of rotation scans



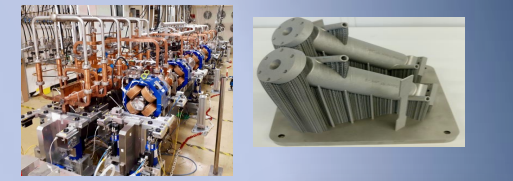
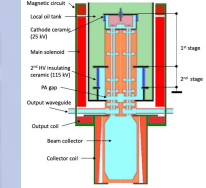
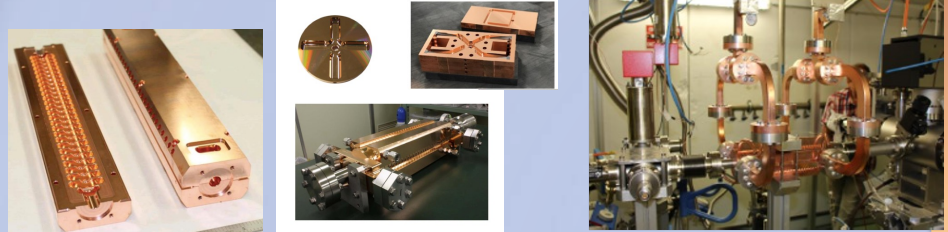
HG NCRF X-band



RIs & TIs



Industries for medical



RF facilities: Operational and Commissioning (and construction)

- KEK: NEXTEF
- CERN: XBox-2,3 and SBox
- Tsinghua: TPlot
- Valencia: FIC S-Box
- Trieste: FRM1 S-Box
- SLAC: Cryo-systems
- LANL: CERF-NM
- INFN Frascati: TEX
- Melbourne: ApsBox

Beam facilities: Preparation

- TU Eindhoven: SMART*LIGHT, ICS
- Tsinghua: VIGAS, ICS
- CERN: AWAKE electron injector
- INFN Frascati: EuPRAXIA@SPARC_LAB, accelerator
- DESY: SINBAD/ARES, deflector
- CHUV/CERN: DEFT, medical accelerator
- Daresbury: CLARA, linearizer
- Trieste: FERMI energy upgrade

Beam facilities: Operational and Commissioning

- Trieste: FERMI: Linearizer
- SwissFEL: Linearizer and PolariX deflector
- SARI: Linearizer, deflectors
- CERN: XBox-1 with CLEAR, accelerator
- DESY: FLASHForward and FLASH2, PolariX deflectors
- SLAC: NLCTA, XTA
- Argonne: AWA

Applications

DEFT FLASH TF at CHUV

Innovative Radiation Therapy with Electrons

FLASH: ultra-short electron pulses for tissue sparing

SMART*LIGHT Compton Source at Eindhoven Univ.

CompactLight
26 academic and industrial partners:

EuPRAXIA@SPARC_LAB
at LNF Frascati

THERYQ (FR)

VDL (NL), LT-Ultra (DE), Yvon Boyer (FR), DMP (ES), Morikawa (JP), KERN (DE)

CINEL (IT), VDL (NL), BACMI (FR), CECOM (IT), Reuter (DE), Nihon (JP), COMEB (IT), Viztrotech (KR)

Industrialization

Thermocompact (FR), BACMI (FR), Multivalent (NL)

SWISSto12 (CH), 3T RPD (UK), Concept Laser (DE) INITIAL (FR), Protoshop (DE)

Scandinova (SE), Jema (ES), Ampegon (CH)

Thales (FR), CPI (US), CANON (JP)

HIGH EFFICIENCY KLYSTRONS

Medical Market

CPI Products:

- High Voltage X-Ray Generators
- Customized User Interface, Power and Control Systems
- Highly Integrated Solutions
- Microwave Devices
- Power Grid Devices



VKS8252 5 MW S Band Klystron

cpil.com CPI Communications & Power Industries

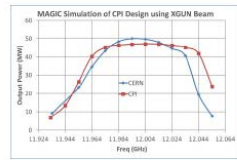
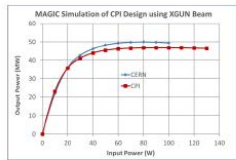
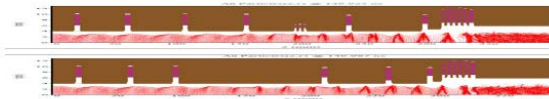
12/11/23

In collaboration



Industries

Development of VKX-8311A3, 11.994 GHz, 50 MW High Efficiency Klystron

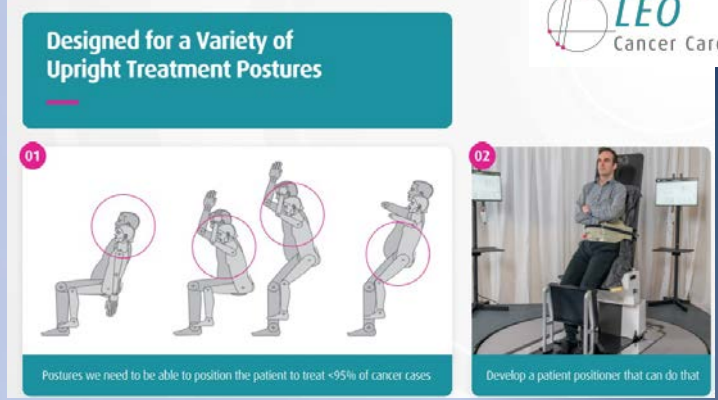


- CERN & CPI collaboration to develop a 50 MW 12 GHz High Efficiency Klystron
- Two stable designs with predicted RF efficiency of over 60%
- Received contract from INFN in March 2023
- Prototype will be based on existing VKX-8311A with new electron gun & new RF circuit designs
- Delivery will be February 2025

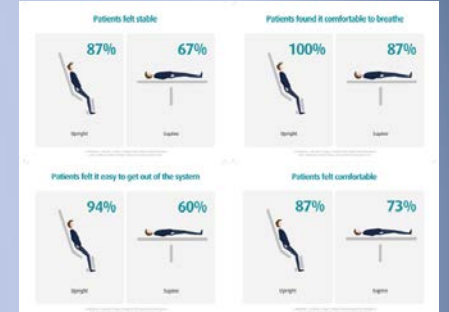
VHEE23

cpil.com CPI Communications & Power Industries

11-13 July 2023

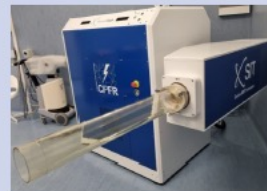


TREATMENT POSTURES



Radiobiology, basic investigation

ElectronFlash



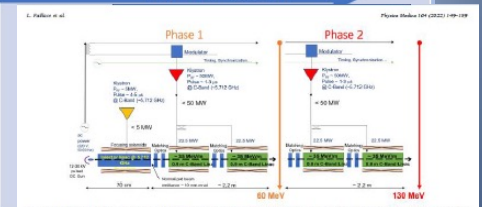
First clinical application IOeRT and dermatologic cases

LIAC Flash



Deep seated tumours – VHEE (Very High Energy Electrons)

VHEE FLASH



VHEE linacs

In collaboration



The Committee had a hard time to choose the best posters, but in the end they were able to agree. Prof. Roger M. Jones, as Chair of the Poster Prize Committee, took on the honorable function of recognizing the selected Young Researchers.



Excellence in Dosimetry for Joseph Bateman

ESR contributions

Excellence in Physics for Fabio D'Andrea



Excellence in Applications of Biology for Camilla Giaccaglia

A collage of images showing various components of a particle accelerator, including metallic structures, a yellow heart-shaped component, and a central vertical assembly with green markings.

Thanks to all VHEE
collaborators

PARTICLE
ACCELERATORS
AND PEOPLE