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)
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- Charles Limoli (UCI)
- 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, Antwarpen..) 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

supported by iFAST

Very High Energy Electron Radiotherapy Conference (VHEE23)

11–13 Jul 2023
DESY Hamburg
Europe/Berlin timezone

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

over 1.000 minutes interesting talks

18 PhDs

DESY.

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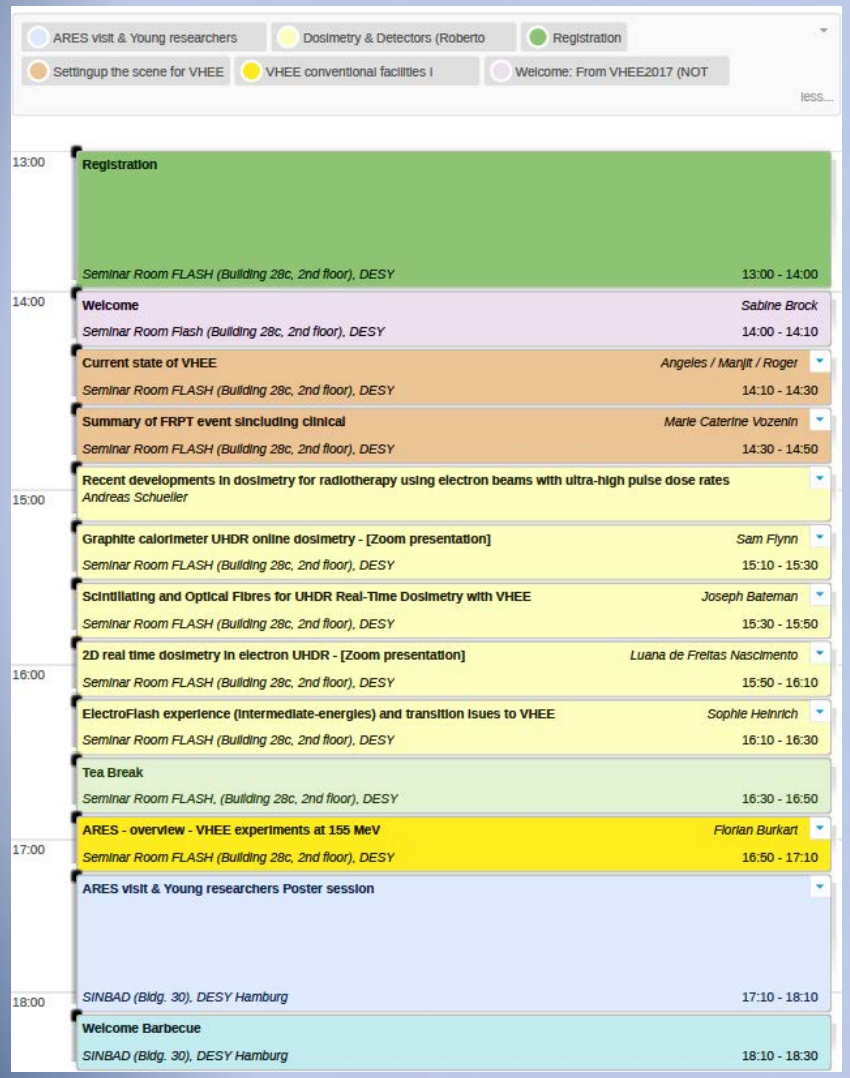

11th July 2023

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

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Very High Energy Electron Radiotherapy Conference (VHEE23)

11–13 Jul 2023
DESY Hamburg
Europe/Berlin timezone

12th July 2023

VHEE conventional facilities

VHEE conventional facilities planned

Accelerators R&D Technologies

Industries for medical technologies

Round table: “in vivo requirements”

ESR poster prize

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Very High Energy Electron Radiotherapy Conference (VHEE23)

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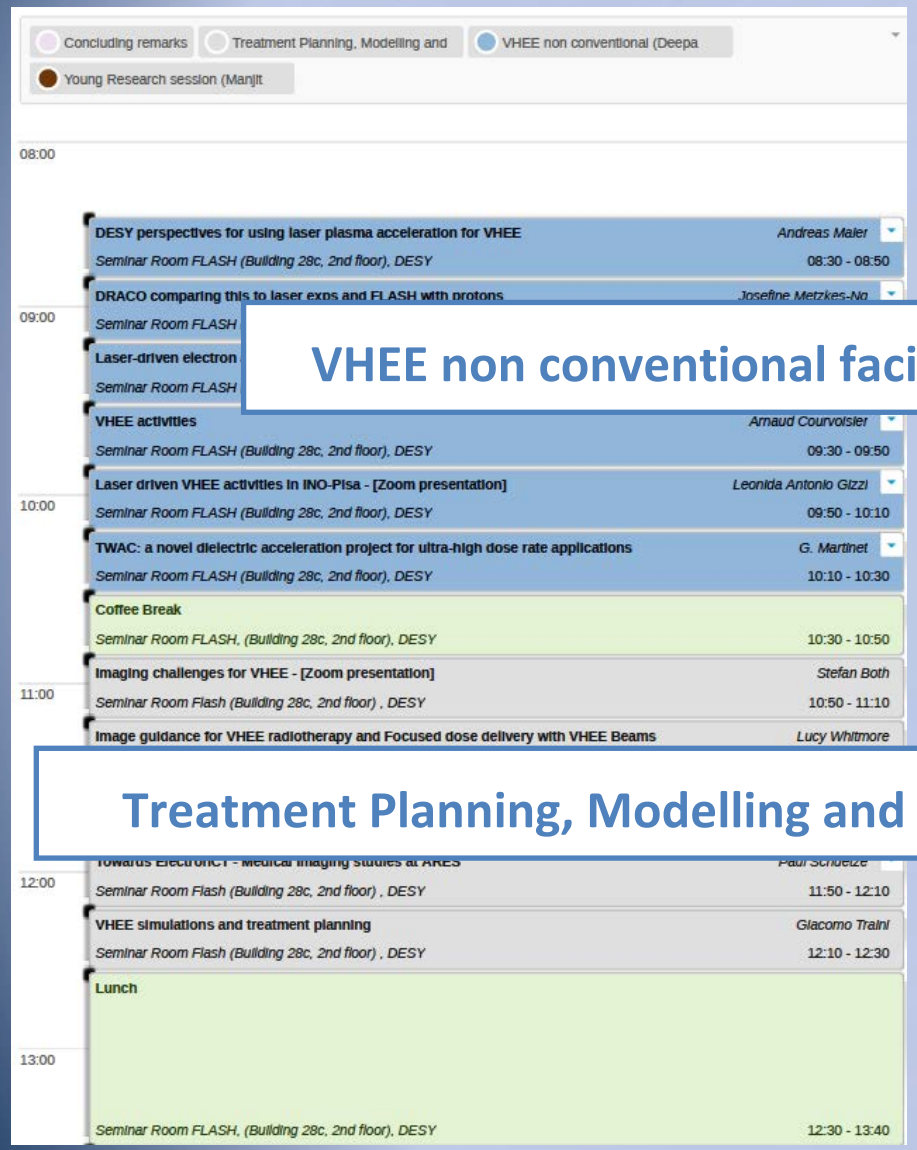
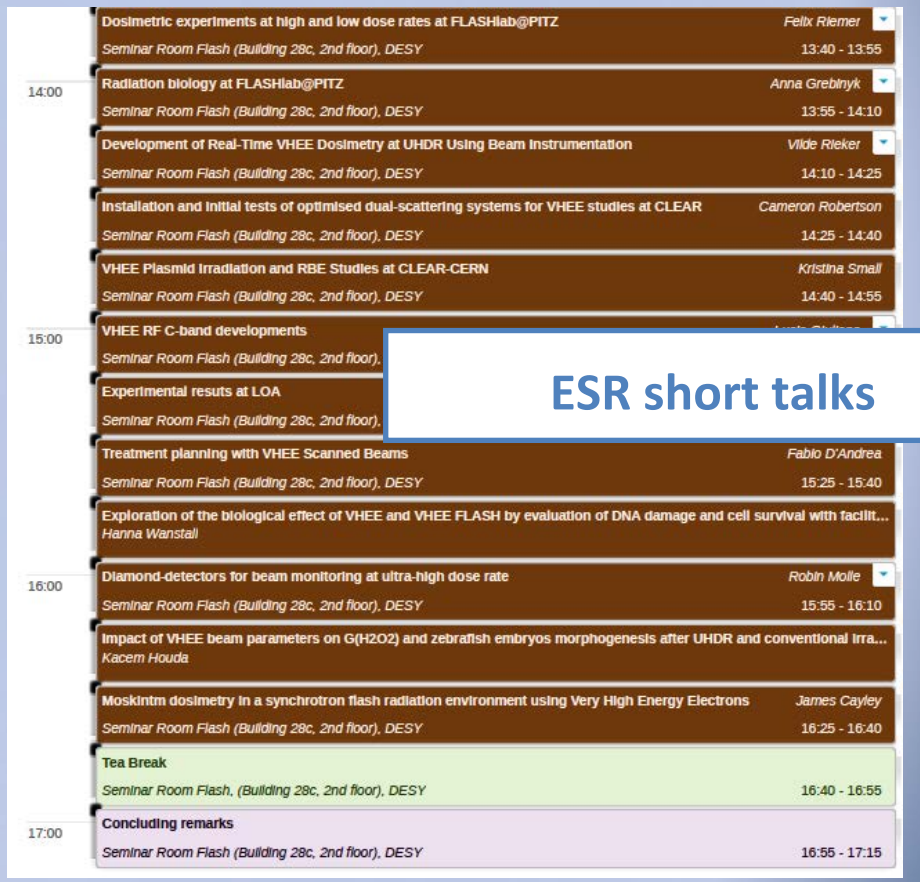
13th July 2023



VHEE non conventional facilities

Treatment Planning, Modelling and Imaging



ESR short talks

https://indico.desy.de/event/38194/timetable/#20230711

650+ Participants

40+ Countries

Multidisciplinarity

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

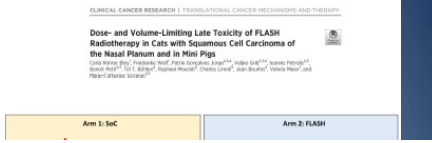
Do we believe in FLASH?

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?

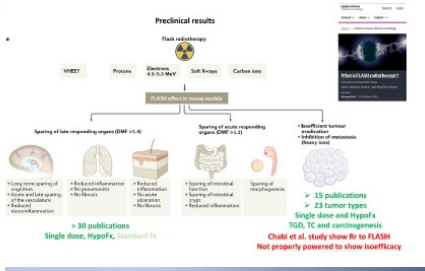
Volume
Fractionation
Dose
Dose rate

=> Definition of dose



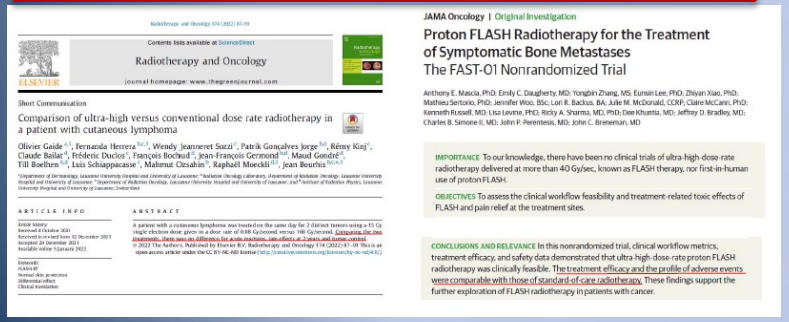
3- Are all organs/tumors equally responsive to FLASH?

2- Are acute response experimental models relevant?



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

First Investigational Trials Planned with Mobetron FLASH HDR

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

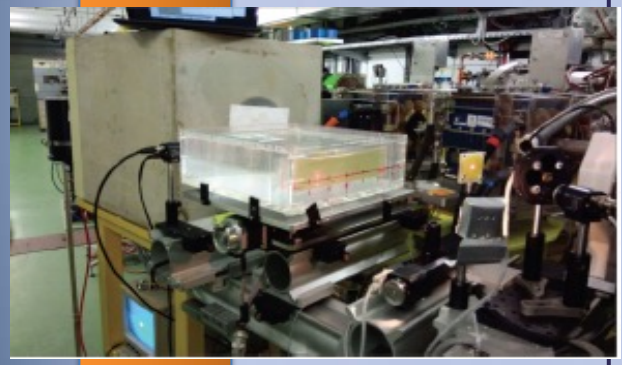
FLASHKNiFE
FLASH RADIOTHERAPY

VHEE RT

Beam dosimetry and detectors

Time monitor dose system of FLASH

Biological dosimeters- Fish eggs



Beam dosimetry in CLEAR

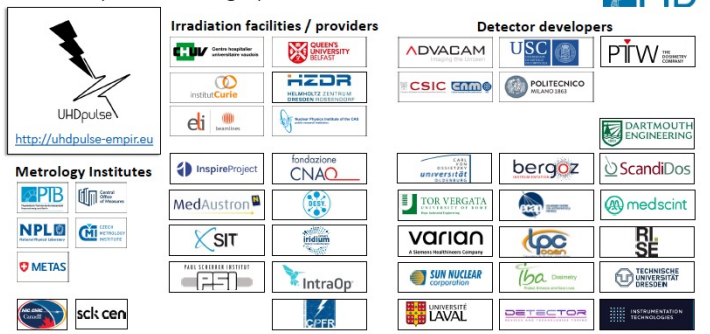
- Beam Dosimetry studies with 50 – 70 MeV (NLCTA) and 160 MeV (SPARC) VHEE beams
- Beam dosimetry experiments with a 135 MeV laser-plasma wakefield accelerator (ALPHA-X)
- Beam dosimetry in CLEAR with 200-250 MeV
  - Radiosensitive films for focusing
  - Ionisation chambers for charge
  - Alanine pellets 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

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.

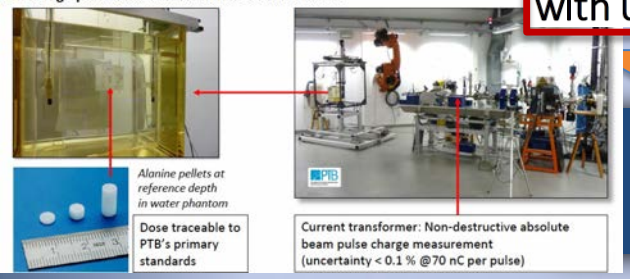
Dosimetry for ultra-high pulse dose rate beams



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

Ion recombination corrections of ionization chambers

Ultra-high pulse dose rate reference electron beam



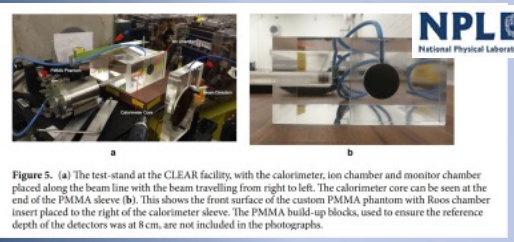


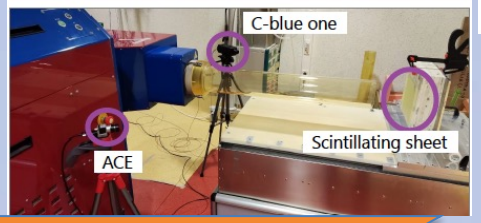
Figure 5. (a) The test-stand at the CLEAR facility, with the calorimeter, ion chamber and monitor chamber placed along the beam line with the beam travelling from right to left. The calorimeter core can be seen at the end of the PMMA sleeve (b). This shows the front surface of the custom PMMA phantom with Roos chamber 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

2D real time dosimetry in electron UHDR

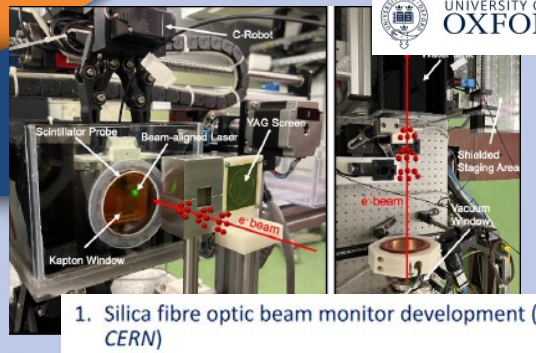


- Scintillation imaging can provide real-time 2D dosimetry of X-ray conventional radiation, proton and Carbon therapy beams.
- Results show that the scintillation light was not affected by saturation effects in UHDR electron beams up to 9 MeV, demonstrating the potential to be used at these extreme dose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

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

UNIVERSITY OF OXFORD

JAI John Adams Institute for Accelerator Science



1. Silica fibre optic beam monitor development (*University of Oxford and CERN*)
2. Plastic scintillator-coupled fibre dosimetry (*University of Victoria and Université Laval*)
3. 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.

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

institut Curie

Dose "prescription"

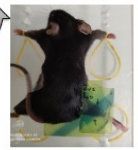
Real framework:

Flash & Conv monitoring system(s) calibration in Reference Conditions:

- With a direct-reading dosimeter in Solid water
- **Monitoring chamber for CONV**
- **BCT for FLASH**
  - Dependent on beam temporal structure?

Closest dose distribution measurement:

- In FLASH beam
- In CONV beam



+

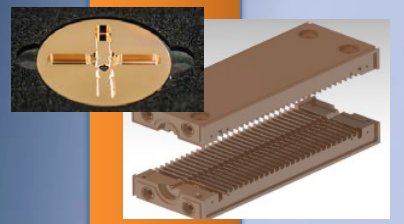
Adapted set-up to measurable situations

Treatment based on Monitor Unit(s)

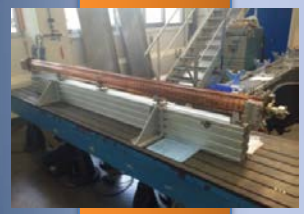
- FLASH-eRT prescribed in Pulse length/number
  - FLASH treatment MUs
  - CONV treatment prescribed in MU
  - Executed with automated MU-based cut-off

VHEE RT

Accelerator Conventional Facilities



CLIC X-band RF technology



TW S-band RF technology

SC 1.3GHz 9 cell cavity

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)**

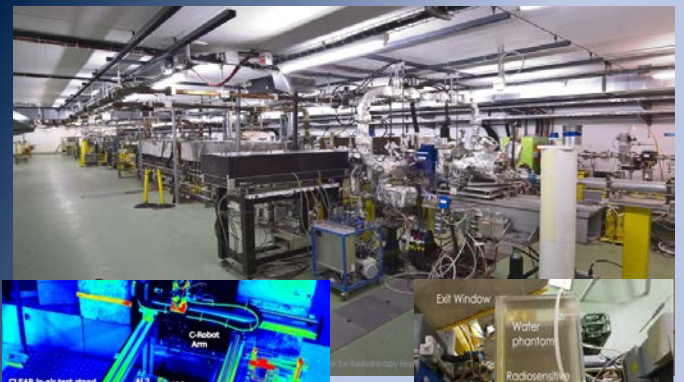
- **SC RF linacs, is less extended for this type of application. Some available facilities in EU are:**
  - **ELBE (HZDR) SC 1.3 GHz ILC technology (40 MeV, 0.01 - 80 pC, from single pulse to 13 MHz)**
  - **PITZ (DESY) SC 1.3 GHz ILC technology (22 MeV, customized time structure 0.1 -1 MHz, optimum 4.5 MHz, trains repetition until 10 Hz)**

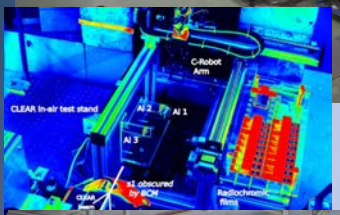
Any others, are also available like: ELSA (Bonn) or ANSTO (Melbourne)…
VHEE dedicated facilities are in design and there are plans for construction as DEFT (CHUV) or SAFEST (Sapienza), …

Conventional facilities

VHEE conventional

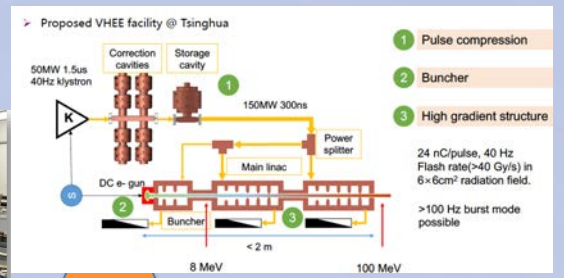
CLEAR CERN



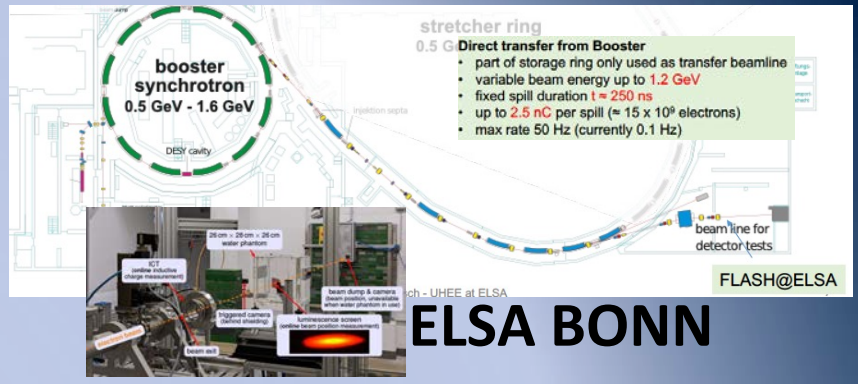


PEER ANSTO

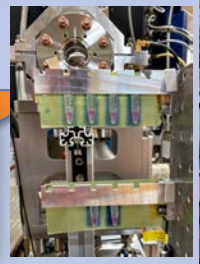
TSINGHUA UNIV.

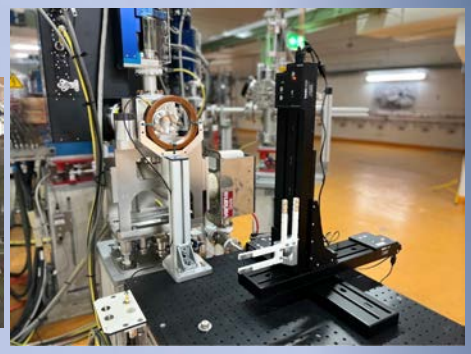


ELSA BONN

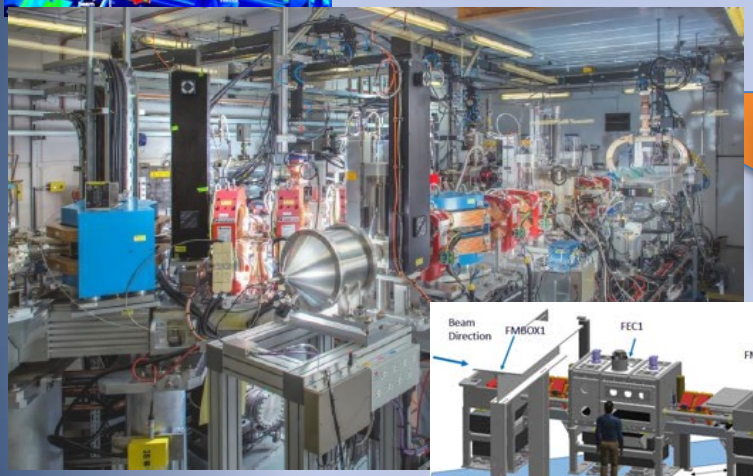


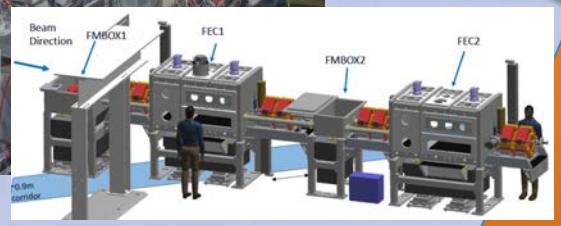
ARES DESY



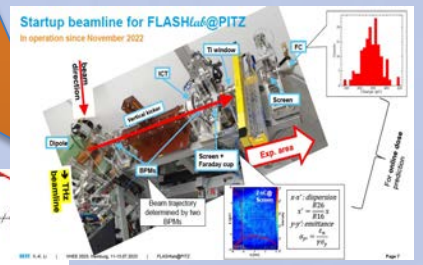


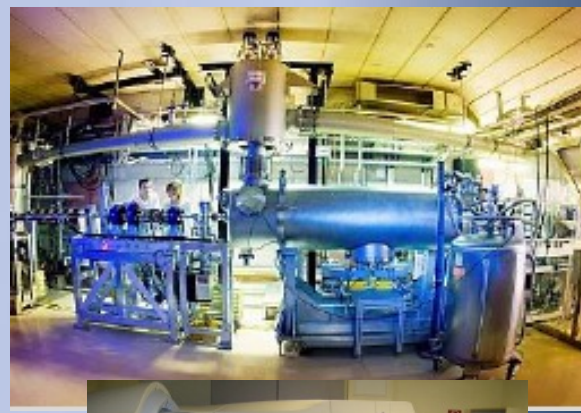
CLARA STFC CI



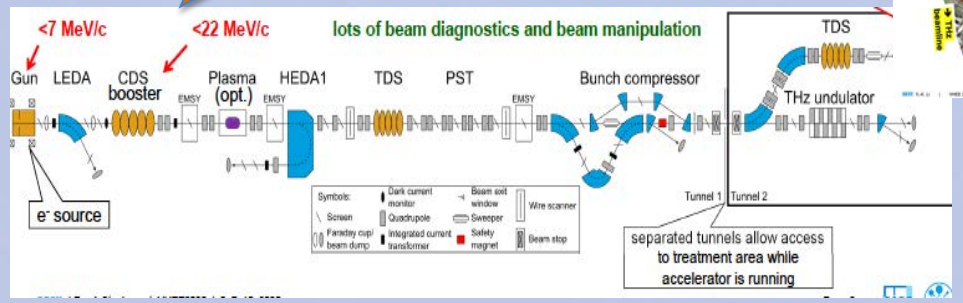


FLASHlab PITZ DESY

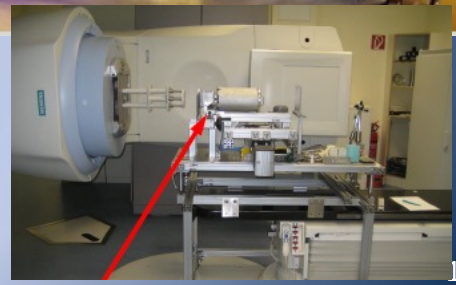




AWA ANL



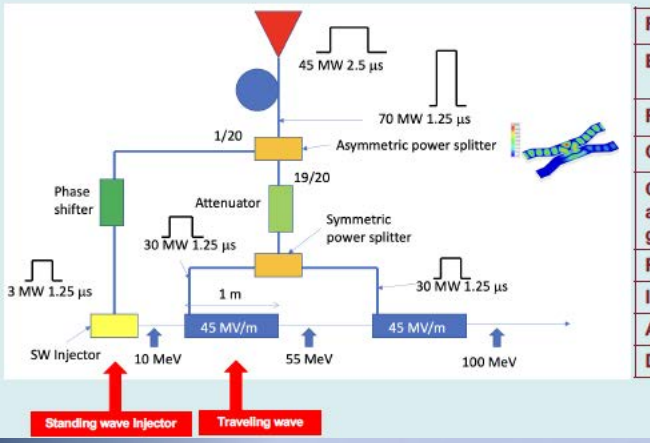
ELBE HZDR



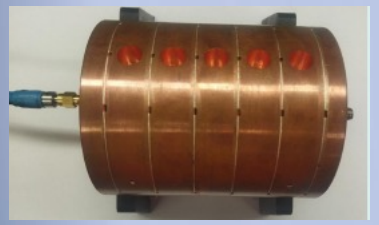
VHEE conventional planned

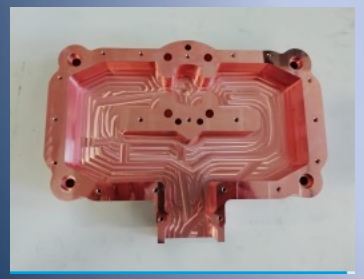
SAFEST Sapienza

SCHEME FOR 100 MeV Linac

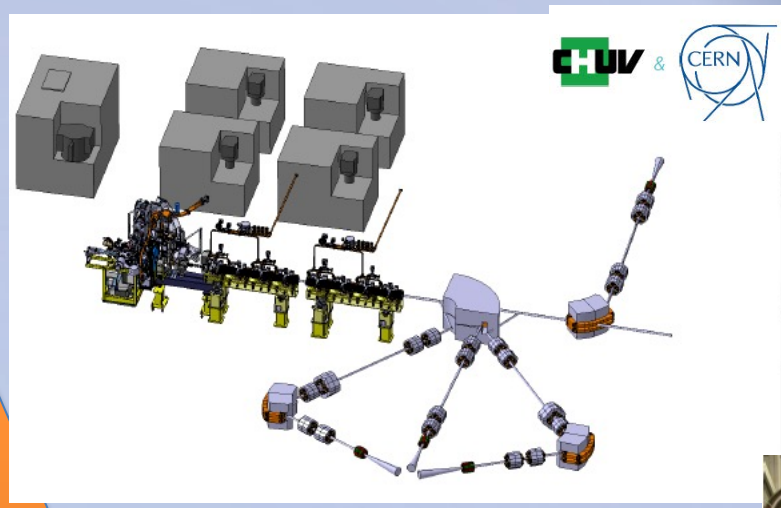


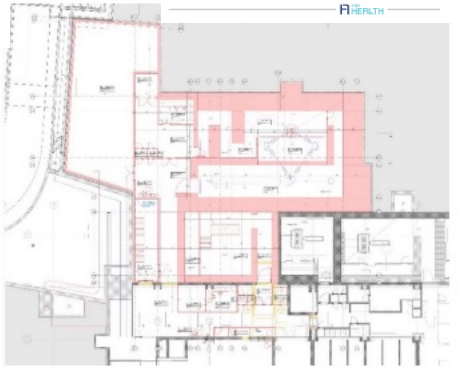
Frequency	5.712 GHz
Beam Energy	65 - 100 MeV
RF Repetition rate	100 Hz
Current	100 mA
C-band average accelerating gradient	45 MV/m
RF pulse duration	1.2 – 2.5 µs
In pulse dose rate	> 10^6 Gy/s
Average dose rate	> 100 Gy/s
Dose per pulse	>> 1 Gy

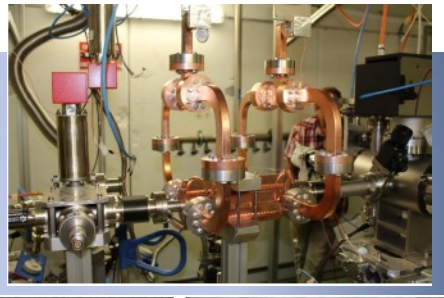


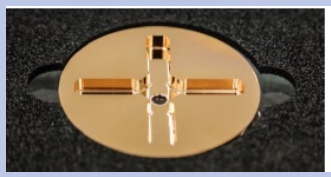


DEFT CHUV

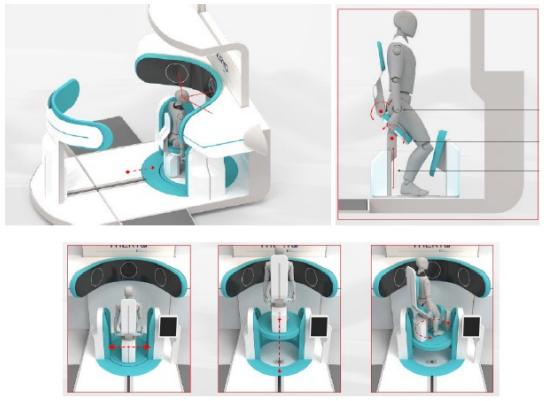




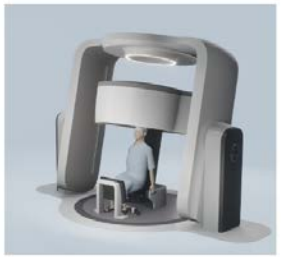




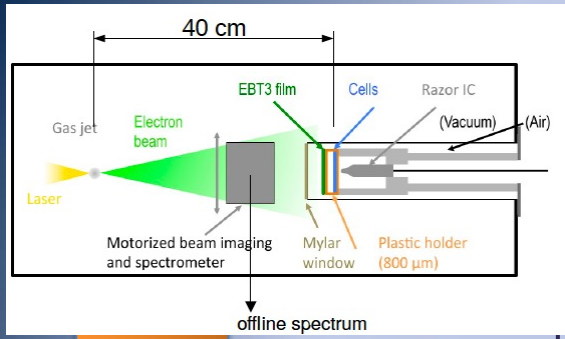
FLASHDEEP: Patient Positionning Concept



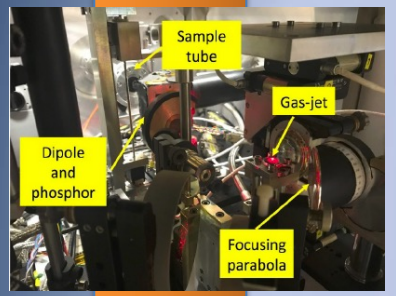
FLASHDEEP: Vertical Scanner Concept

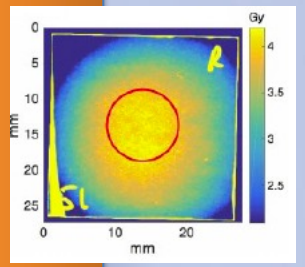


- FLASHDEEP will overcome this limitation with the use of Very High Energy Electron (VHEE) beams, with energies of 100-200 MeV
- FLASHDEEP will be the first FLASH radiotherapy device able to treat every kind of solid tumor up to a depth of 20 cm



Laser setup LOA





IDRA LOA future facility

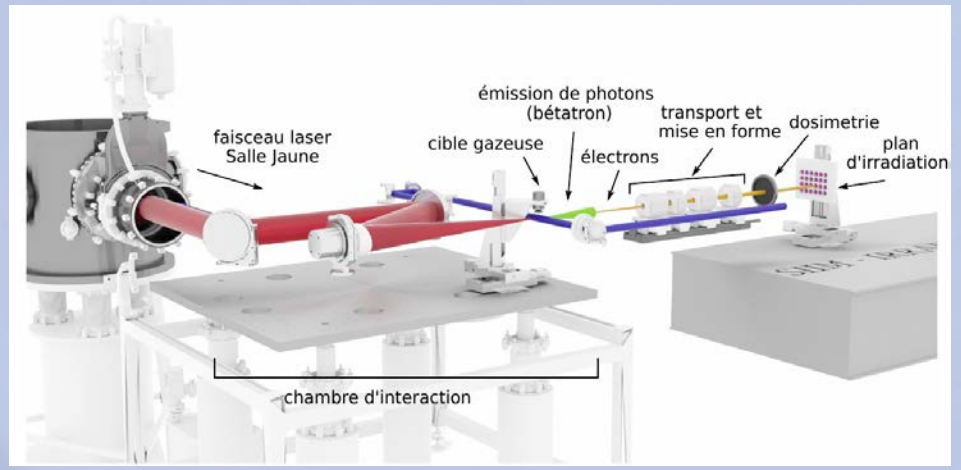
VHEE RT

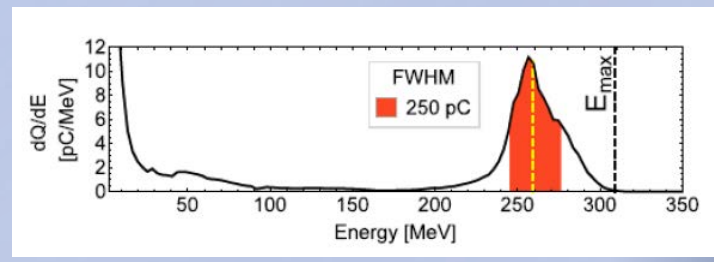
Laser Plasma Accelerators

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…

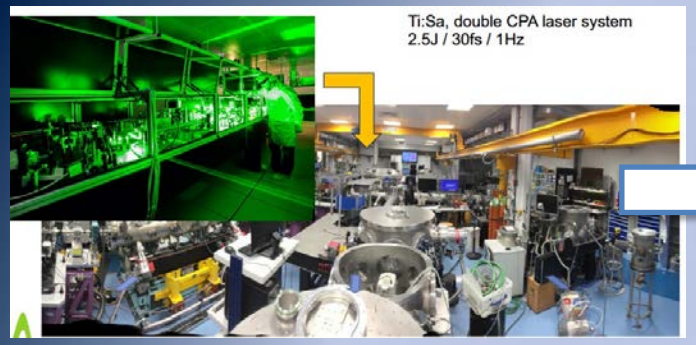




VHEE beam generation at DRACO

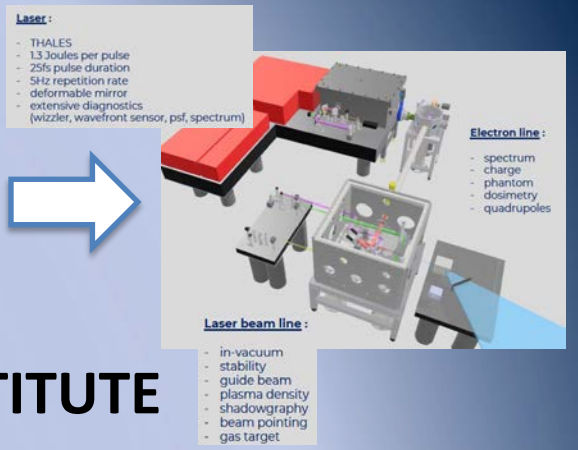
Advanced facilities

VHEE non-conventional

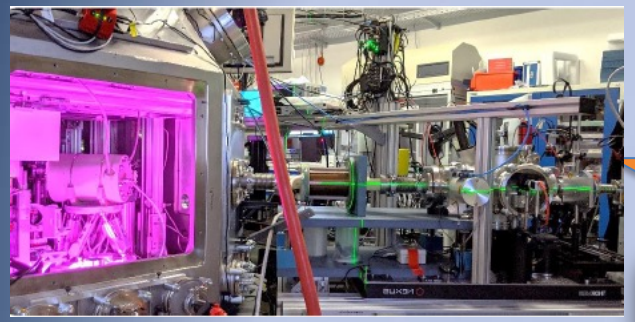


Salle Jaune LOA

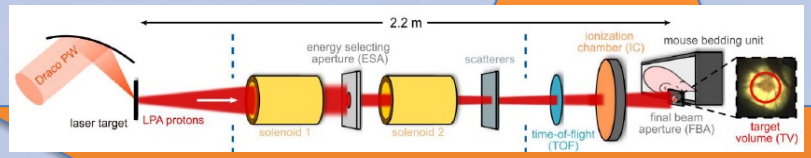
Laplace/HC: **novel technological challenge** of (*i*) (compact-) laser-driven accelerator, (*ii*) high average power, (*iii*) joule-class VHEE. **Starting 2024!**

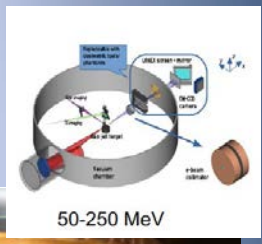


WEIZMAN INSTITUTE

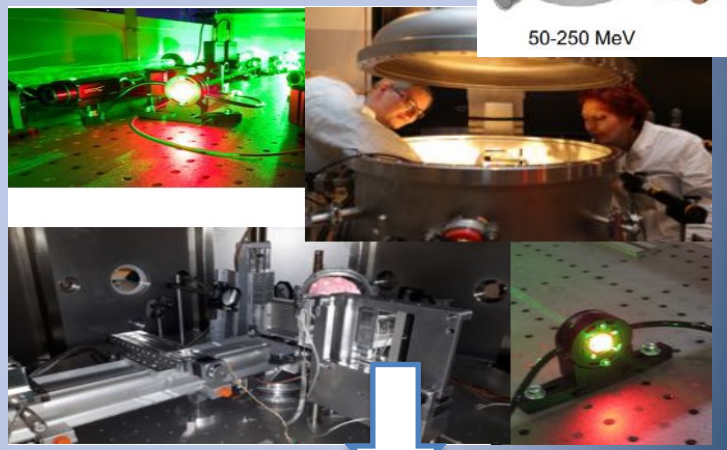


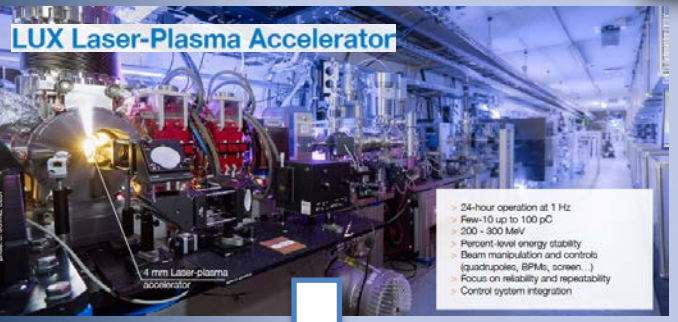
DRACO HZDR

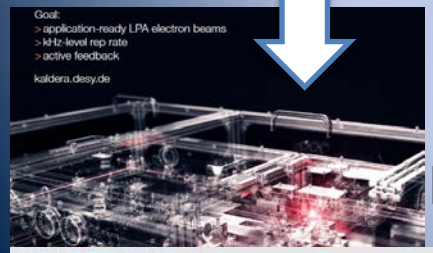




ILIL INO PISA

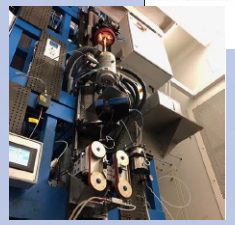






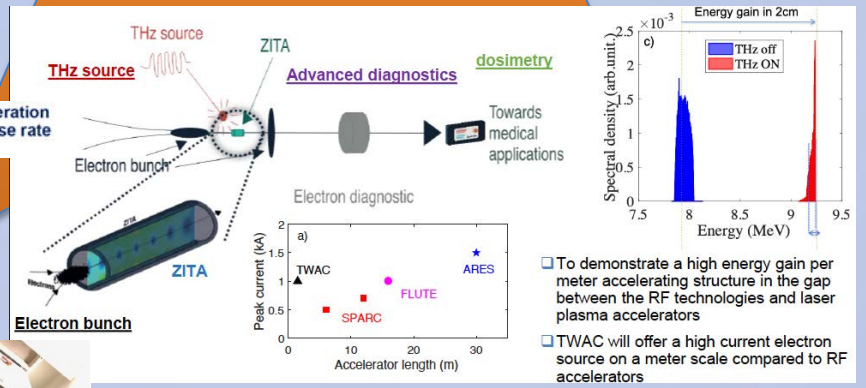
LUX DESY

KALDERA: High Average Power Laser Development



TWAC

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



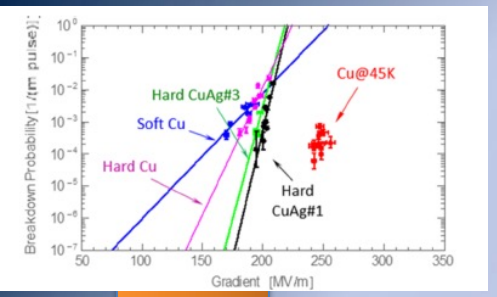
- To demonstrate a high energy gain per meter accelerating structure in the gap between the RF technologies and laser plasma accelerators
- TWAC will offer a high current electron source on a meter scale compared to RF accelerators

TWAC IJCLAB

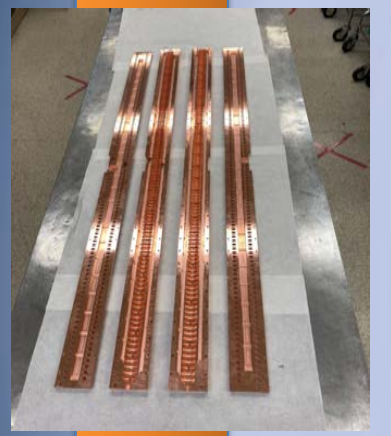
100 Hz, J-scale laser beamline

VHEE RT

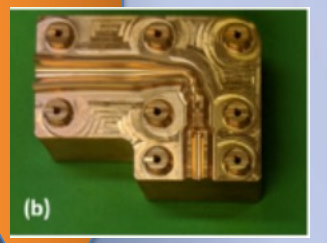
Accelerator Technologies



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 REPETION 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 (C^3 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

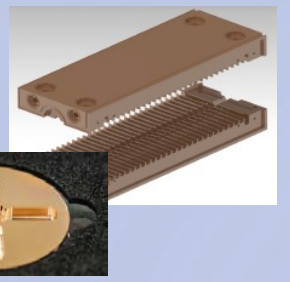
These issues are currently the subject of a wide global study (EU EUPRAXIA and I.FAST)

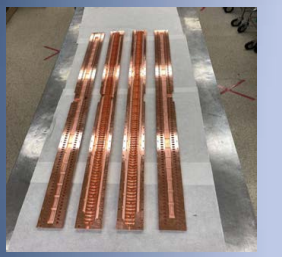
Accelerator Technologies

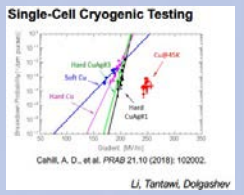
HIGH-GRADIENT RF

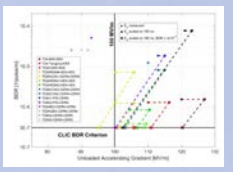
>100 MeV/m is now achievable in labs

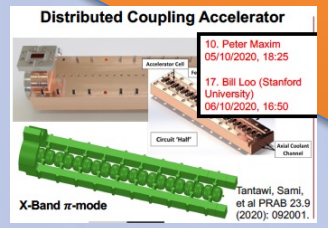
12 GHz RF structure





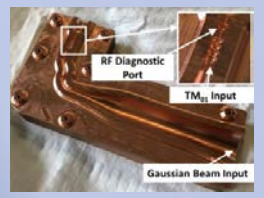


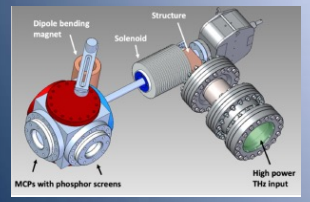




Short tunable pulse length Laser

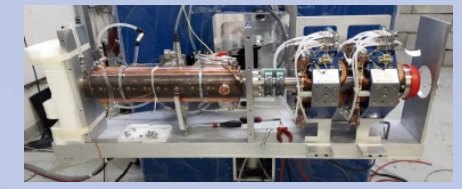
110 GHz RF structure



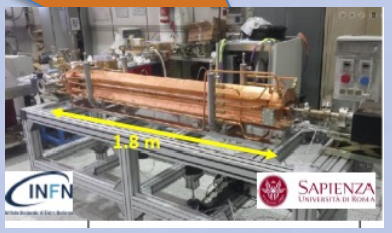


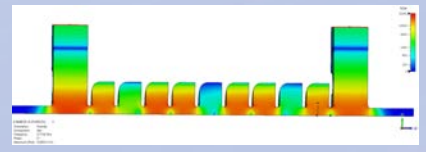
SAPIENZA UNIVERSITÀ DI ROMA

2.998 GHz RF structure



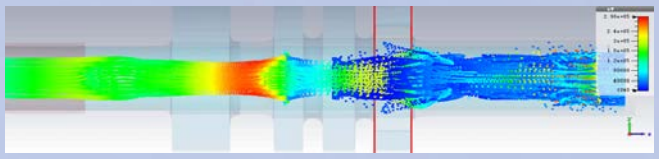
5.712 GHz RF structure



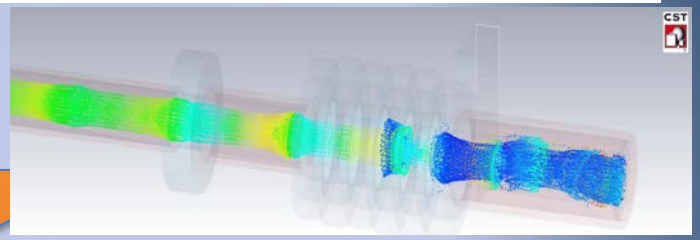


HIGH EFFCIENCY KLYSTRONS

Retro-fit High Efficiency 8 MW, 12 GHz klystron



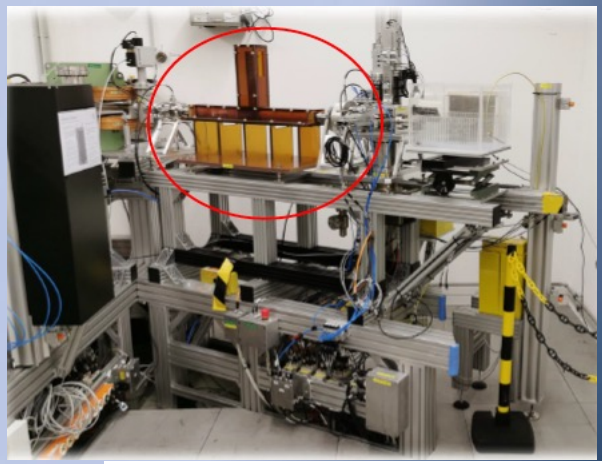
High Efficiency (66%) 50 MW, 12 GHz klystron (CERN- CPI collaboration)



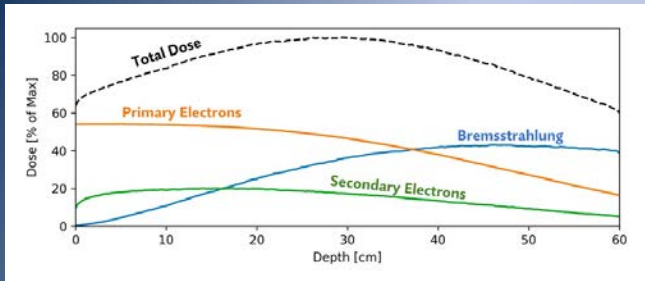
KIT Karlsruher Institut für Technologie

DESY.

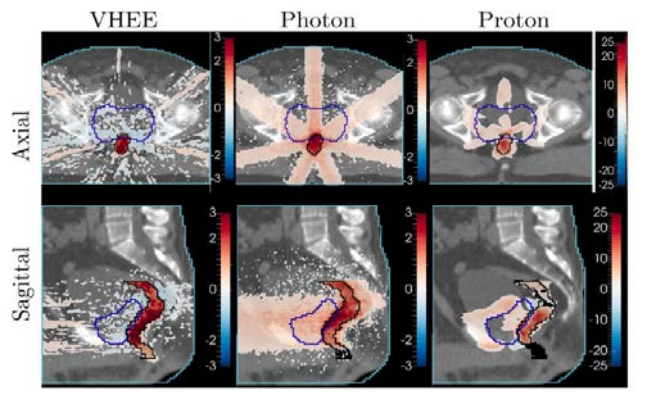
KICKERS



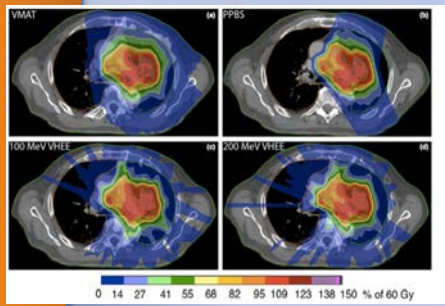
Kicker installation at PITZ



Percentage Dose Depth for 250 MeV e- in water



Dose difference after/before rectal volume emptiyng



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:

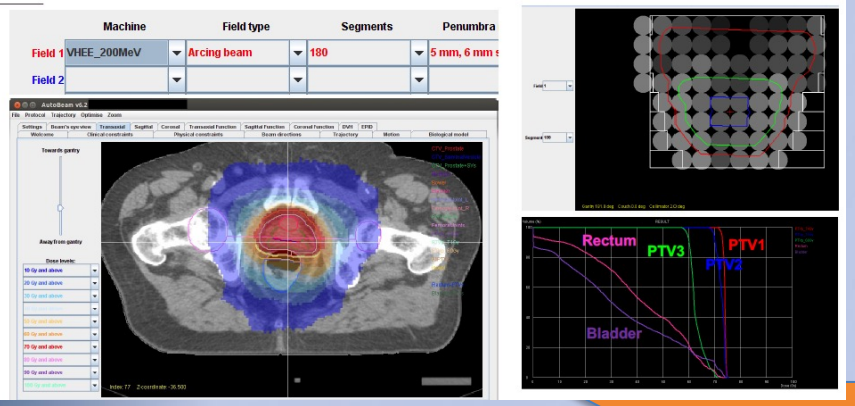
- Worth noting that the dose of VHEE beams is a mixing of primary (85%), secondary (20%) e- and bremsstrahlung
- First TP confirm significant insensitivity to inhomogeneities and less susceptible to dosimetric changes from changes in patient geometry
- Comparisons with photons and protons are ongoing for targeted well know cases (prostate). VHEE and photons share a scale whereas proton requires a wider range. VHEE TP shows less diference 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

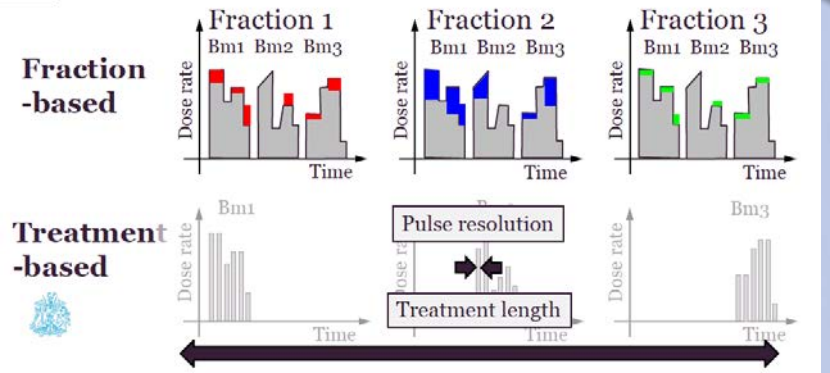
Example 200 MeV VHEE prostate plan

The ROYAL MARSDEN



FLASH studies

Progression of treatment planning



- 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

TP & Imaging

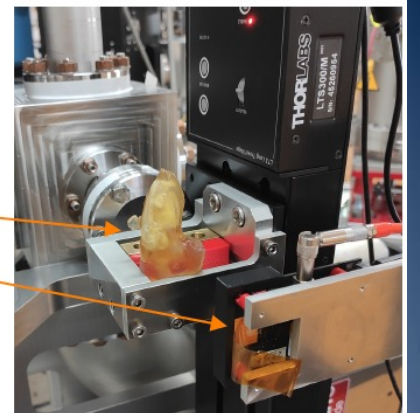
DESY.

electron CT VHEE

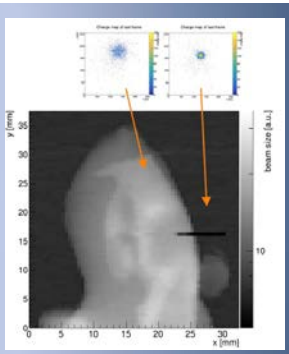
electronCT Setup

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

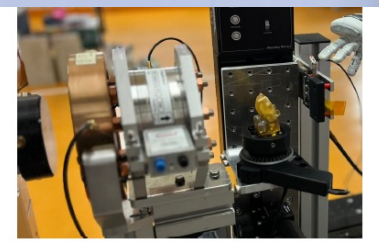


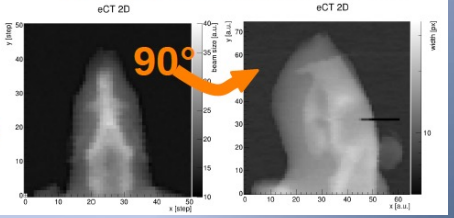
eCT 2D Measurement @ ARES



3D electronCT

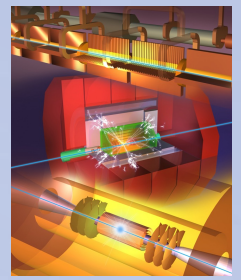
- Integration of rotation stage
  - ➔ Perform rotation scan & reconstruct via inv. Radon transform
- Further test beam campaigns scheduled
  - Improvements to 2D scanning procedure
    - ➔ Reduce measurement time
  - Beam optimisation after ARES upgrade
  - Commissioning of rotation stage
  - Performance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

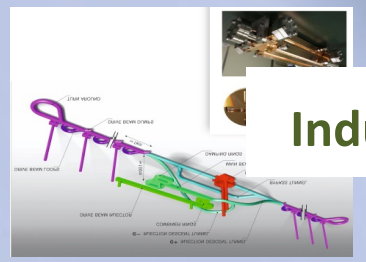




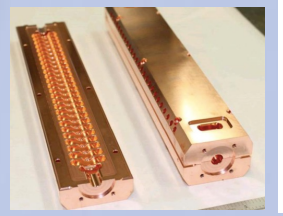
HG NCRF X-band

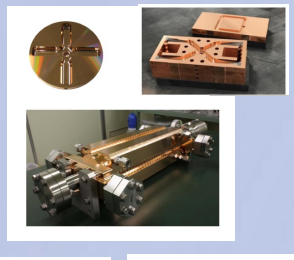
RIs & TIs

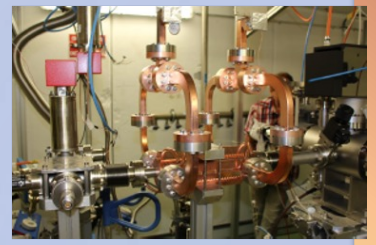


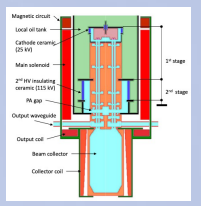


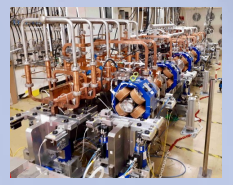
Industries for medical

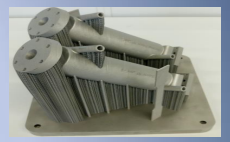


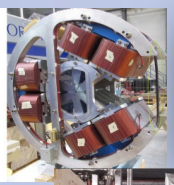






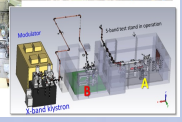






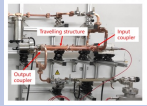
RF facilities: Operational and Commissioning (and construction)

- KEK: NEXTEF
- CERN: XBox-2,3 and SBox
- Tsinghua: TPot
- Valencia: IFIC VBox
- Trieste: FRMI S-Band
- SLAC: Cryo-systems
- LANL: CERF-NM
- INFN Frascati: TEX
- Melbourne: AusBox

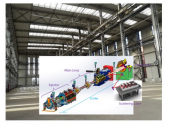


Beam facilities: Preparation

- 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



VIGAS

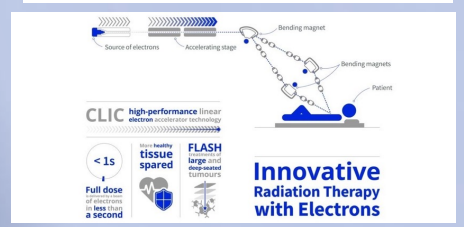


Beam facilities: Operational and Commissioning

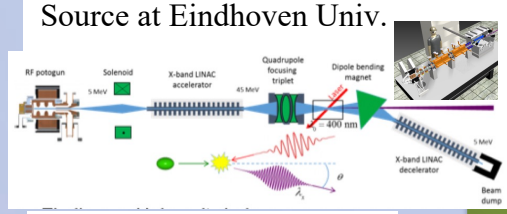
- Trieste, FERMI: Linearizer
- SwissFEL: Linearizer and PolariX deflector
- SARI: Linearizer, deflectors
- CERN: XBox-1 with CLEAR, accelerator
- DESY: FLASHForward and FLASH2, PolariX deflectors
- SLAC: NLCTA, XTA
- Argonne: AWA

Applications

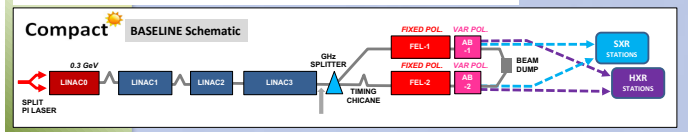
DEFT FLASH TF at CHUV



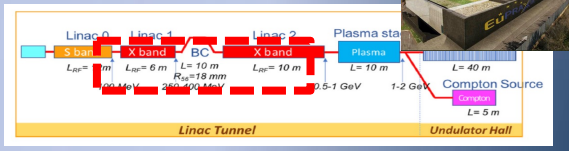
SMART*LIGHT Compton Source at Eindhoven Univ.



CompactLight
26 academic and industrial partners:



EuPRAXIA@SPARC_LAB
at LNF Frascati



Industrialization

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)

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

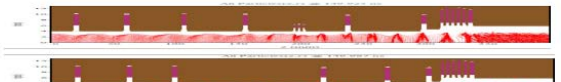
- CPI Products:
  - High Voltage X-Ray Generators
  - Customized User Interface, Power and Control Systems
  - Highly Integrated Solutions
  - Microwave Devices
  - Power Grid Devices

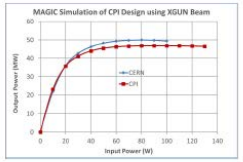
VKS8252 5 MW S Band Klystron

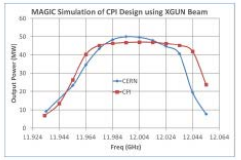
12/11/23 cpii.com

In collaboration 

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



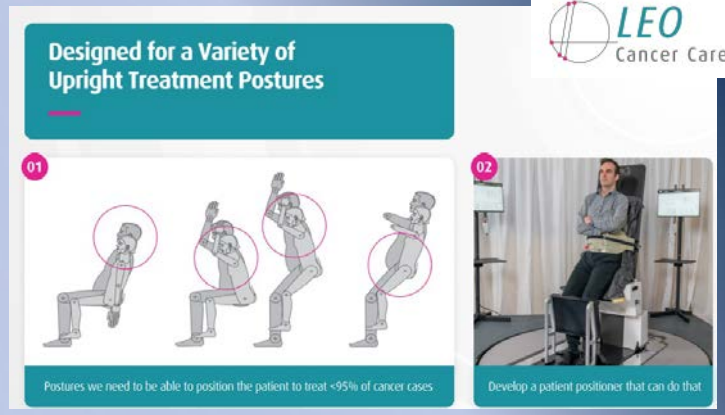




- CERN & CPI collaboration to develop a 50 MW 12 GHz High Efficiency Klystron
- Two stable designs with predicted RF efficiency of over 60%
- Received contract from INFN in March 2023
- Prototype will be based on existing VKX-8311A with new electron gun & new RF circuit designs
- Delivery will be February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

11-13 July 2023 VHEE23 cpii.com

Industries

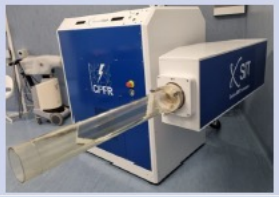


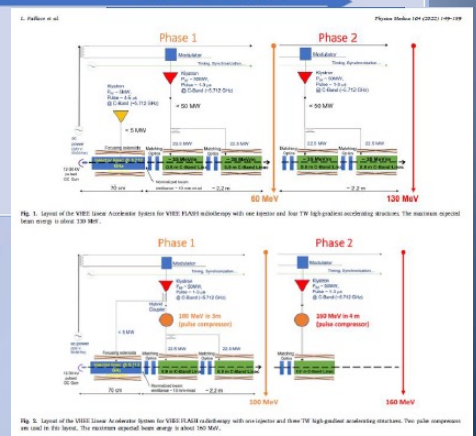
LEO Cancer Care

TREATMENT POSTURES

SIT Sordina IORT Technologies

Radiobiology, basic investigation	First clinical application IOeRT and dermatologic cases	Deep seated tumours – VHEE (Very High Energy Electrons)
ElectronFlash	LIAC Flash	VHEE FLASH





VHEE linacs

In collaboration

SAPIENZA UNIVERSITÀ DI ROMA

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.

ESR contributions

Excellence in Physics for Fabio D'Andrea

Excellence in Dosimetry for Joseph Bateman

Excellence in Applications of Biology for Camilla Giaccaglia


Thanks to all VHEE collaborators
PARTICLE
ACCELERATORS
AND PEOPLE