Methods for VHEE/FLASH radiotherapy studies and high dose rate dosimetry at the CLEAR user facility

CERN Linear Electron Accelerator for Research

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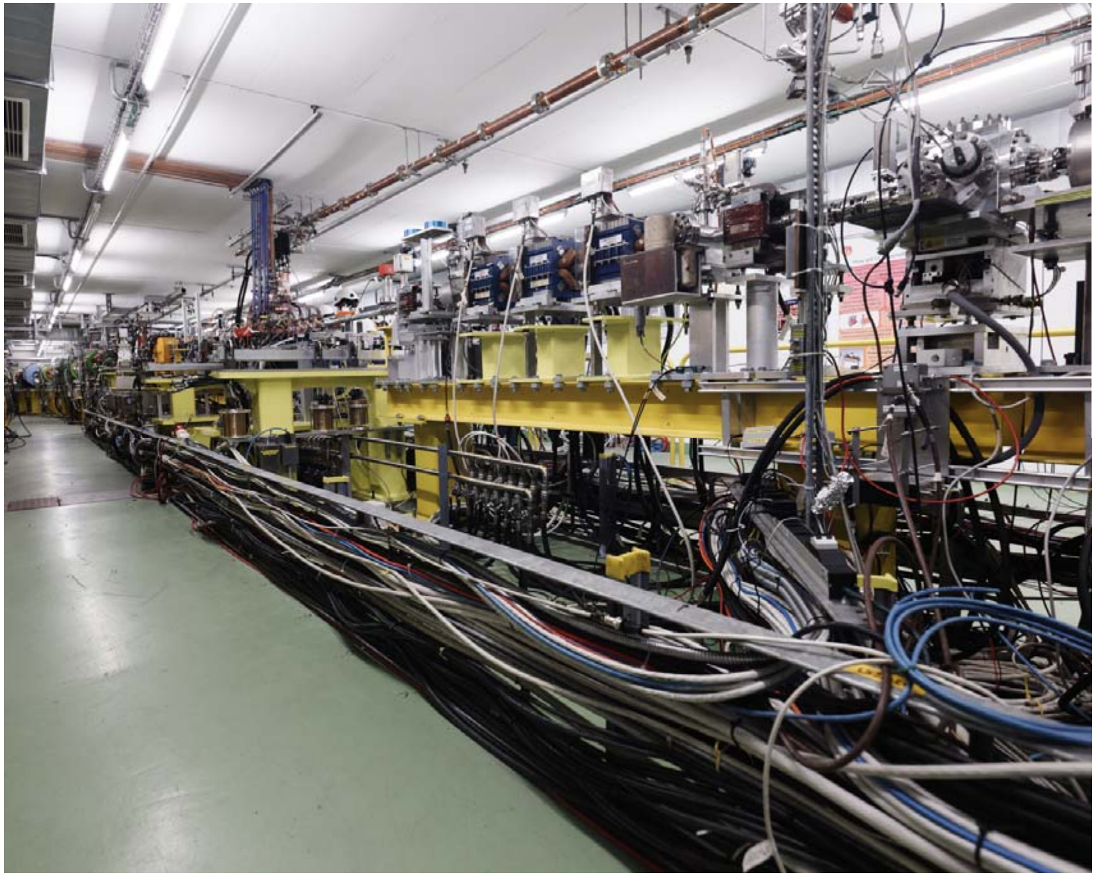
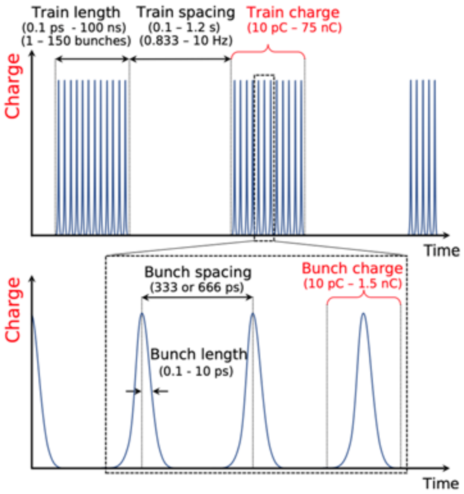
CERN / University of Oxford / University of Oslo

The CERN Linear Electron Accelerator for Research (CLEAR) is a user facility providing electron beams for a varied and large range of experiments.



Updated List of CLEAR Beam Parameters

Parameter	Value
Beam Energy	30 – 220 MeV
Beam Energy Spread	< 0.2% rms (< 1 MeV FWHM)
Bunch length rms	0.1 – 10 ps
Bunch frequency	1.5 or 3.0 GHz
Bunch charge	0.005 – 3 nC
Norm. emittance	1 – 20 μm
Bunches per pulse	1 – 150
Max. pulse charge	75 nC
Repetition rate	0.8333 – 10 Hz



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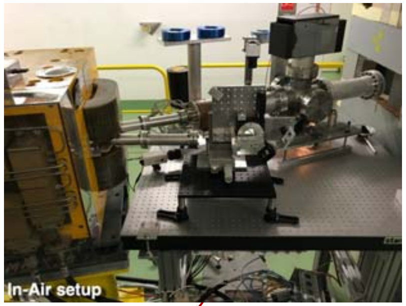
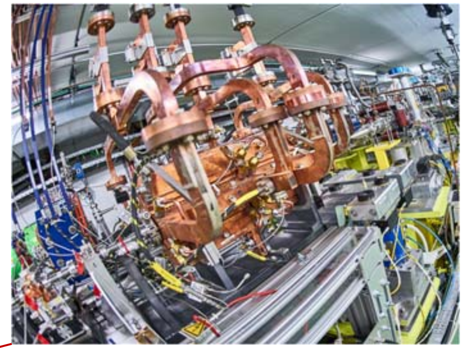


In-air test stand

Testing ground for beam diagnostics R&D and THz radiation studies

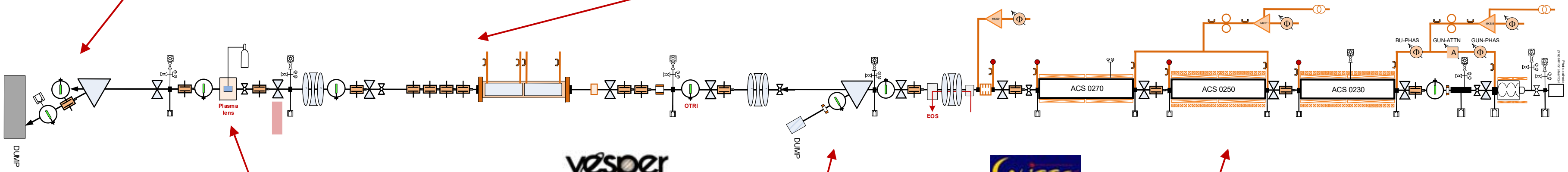
Irradiation for medical and other applications

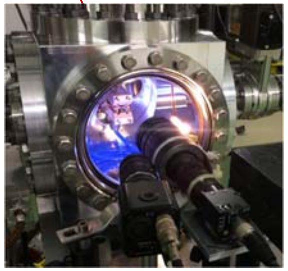


CLIC Test-Stand

High-gradient and linear colliders R&D

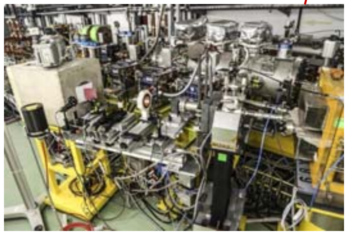
CERN Linear Electron Accelerator for Research





The Plasma Lens Experiment

Novel concepts of plasma-based focusing and acceleration



VESPER

Beam irradiation facility for studies on radiation damage of electronics and medical applications

CALIFES electron linac

Flexible accelerator providing 200 MeV electron beams to all CLEAR users

VHEE/FLASH radiotherapy studies in CLEAR

The idea of investigating the use of very high-energy electron (VHEE) beams (50-250 MeV) for RT recently gained interest, since electrons at these energies can travel deep into the patient.

- Potential advantages:
  - Depth – dose profile better than for X-rays
  - Electrons may be focused and steered
  - Electron beams rather unsensitive to tissue inhomogeneities
  - Electron accelerators comparatively more compact, simpler and cheaper than proton/ion machines
- The last point gained importance given recent advancements on high-gradient acceleration, e.g. X-band CLIC technology.
- Ultra-high dose rate (above 100 Gy/s) radiation delivery (FLASH radiotherapy) showed normal tissue sparing capabilities, retaining tumor control. Electron linacs can relatively easily reach the high beam currents needed for FLASH treatment of large fields.

→ Exploit CERN expertise in accelerators, especially the one on high-gradient electron machines developed by the CLIC study.

→ The CLEAR user facility offers also a unique opportunity for experimental VHEE and FLASH studies with a high-current 200 MeV e- beam.

What CLEAR has

M-C. Vozenin

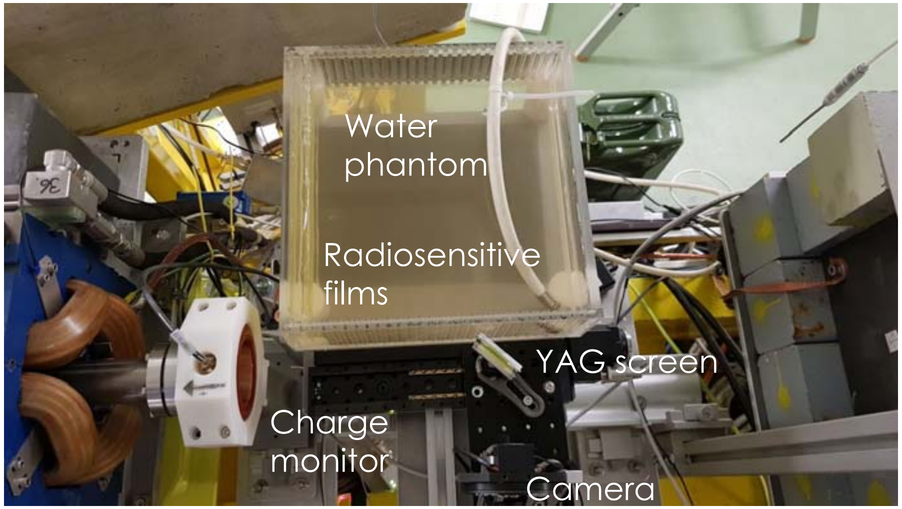
It can shorten the <u>time</u> of exposure like no other beam

VHEE/FLASH radiotherapy studies in CLEAR

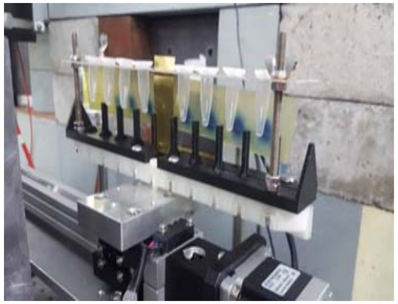
Initial interest: Manchester Univ. *(A. Langzda, R. Jones, L. Whitmore et al.)*

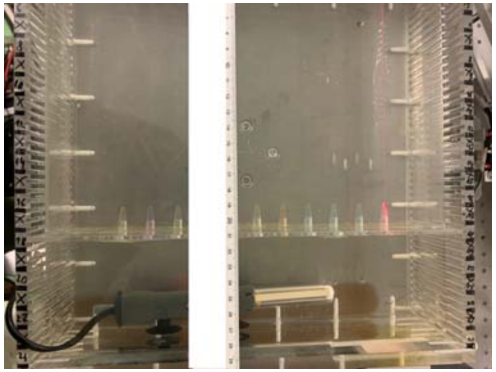
Further measurements campaigns:

Nat. Phys. Lab. UK	*(A. Subiel et al.)*
Strathclyde University	*(K. Kokurewicz et al.)*
Oldenburg Univ. - PTW	*(B. Poppe, D. Poppinga et al.)*
CHUV Lausanne	*(M.C. Vozenin, K. Houda, C. Bailat, R. Moeckli et al.)*
Oxford University	*(P. Burrows, M. Dosanji, J. Bateman, C. Robertson)*



VHEE strong focusing set-up, Manchester University/Strathclyde University groups

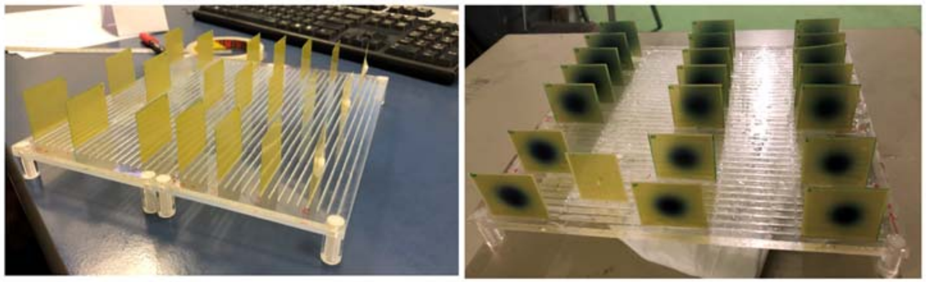

Wet plasmid samples in Eppendorf tubes. EBT-XD film placed behind samples, Manchester University *(K. Small, R. Jones et al.)*


Set-up in the water tank. Zebra fish eggs, alanine pellets, gafchromic films, CHUV Lausanne *(M.C. Vozenin, C. Bailat, R. Moeckli et al.)*

Activities:

- Experimental verification of dose deposition profiles in water phantoms
- Calibration of operational medical dosimeters – nonlinear effects with short pulses
- Enhanced local dose deposition with focused beams
- Chemical and biological effects at Ultra-High Dose Rates

High dose rate dosimetry



Films set-up for profile depth dose, CHUV Lausanne
(M.C. Vozenin, C. Bailat, R. Moeckli et al.)

a b

Calorimeter and ROOS chamber, Nat. Phys. Lab. UK
(A. Subiel et al.)

Advance Markus chambers and SRS Array, Oldenburg University and PTW
(B. Poppe, D. Poppinga et al.)

Methods for dosimetry

Irradiated film

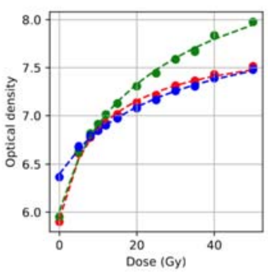
Radiochromic films change colour macroscopically due to polymerisation caused by ionising radiation. The change in colour is related to the accumulated dose.

In CLEAR, various types of Gafchromic films are used: EBT3 (with a range from 0.1 to 10 Gy), MD-V3 (1-100 Gy) and HD-V2 (10-1000 Gy).

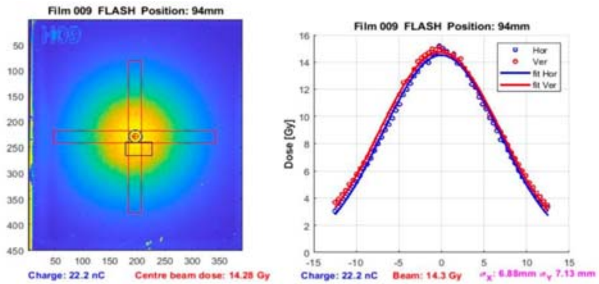
The dose can also be measured with **Radio-photoluminescence** (RPL) dosimeters. They are silver activated phosphate glass cylinders of 1.5 mm diameter and 8.5 mm length which work on the principle of radiation induced luminescence centers.

Films are calibrated at the **eRT6 linac** in the Centre Hospitalier Universitaire Vaudois (CHUV).

Following the irradiation, the films are scanned using a 16-bit Epson Perfection V800 Photo scanner at 300 dpi, to retrieve dose profiles.

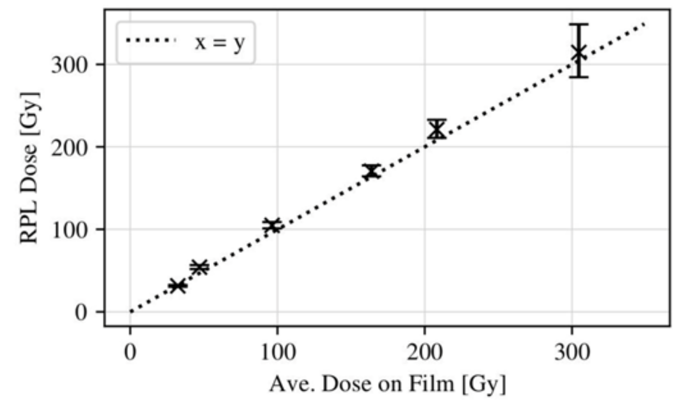


Film calibration for different color channels

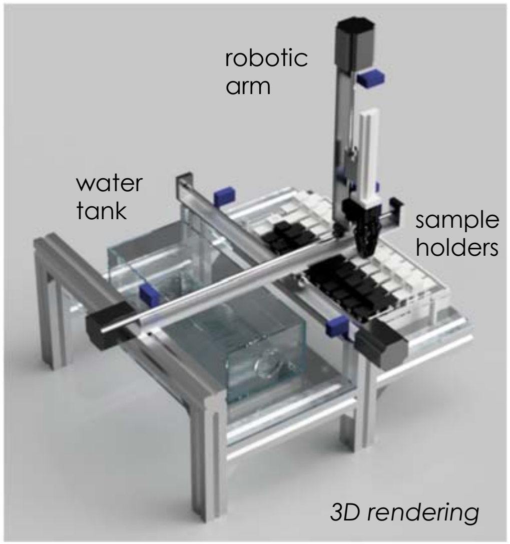


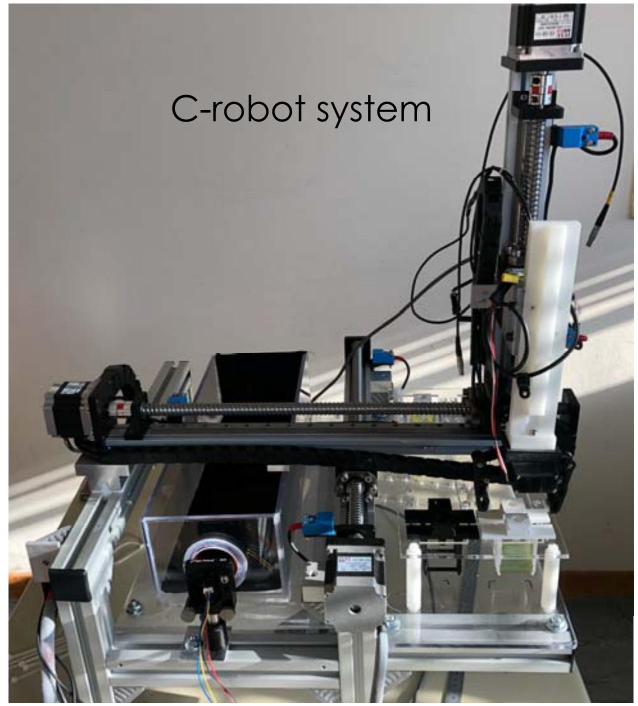
Measured dose profile
In UHDR conditions

Comparison between Gafchromic films and RPLs



Development of equipment: The C-robot system





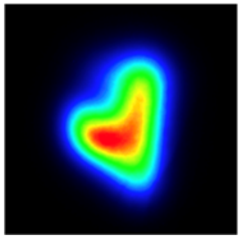
https://pkorysko.web.cern.ch/C-Robot.html

robotic arm and sample holder with Eppendorf tube and gaschromic films

The robot is made made of **3 linear stage**s for X,Y and Z axis, **6 limit switches** (2 for each axis), a **3D printed grabber**, a **mounted-camera system with a moving filter** and **two areas,** one sample storage area and one irradiation area that can host a water tank.

Initiated using a grant from GMEE to A. Gilardi
Development: P. Korysko, K. Sjobaek, W. Farabolini

THANKS FOR YOUR ATTENTION



Acknowledgements

P. Korysko, J. Bateman, C. Robertson, W. Farabolini, L. Dyks, V. Rieker, other members of the CLEAR operation team, CERN technical support groups, and all CLEAR users cooperating at CLEAR on VHEE/FLASH studies.

More details at poster session:

THPOPA06
(THPOPA05)

Some VHEE radiotherapy-related publications based on CLEAR experiments

- **A. Lagdza**, R. Jones et al., Influence of heterogeneous media on Very High Energy Electron (VHEE) dose penetration and a Monte Carlo-based comparison with existing radiotherapy modalities, Nuclear Inst. and Methods in Physics Research, B, 482 (2020) 70-81.
- **K. Small**, R. Jones et al., Evaluating Very High Energy Electron RBE from nanodosimetric pBR322 plasmid DNA damage, Nature Scientific Reports (2021) 11-3341.
- **M. McManus**, A. Subiel, The challenge of ionisation chamber dosimetry in ultra-short pulsed high dose-rate Very High Energy Electron beams, Nature Scientific Reports (2020) 10-9089.
- **D. Poppinga** et al., VHEE beam dosimetry at CERN Linear Electron Accelerator for Research under ultra-high dose rate conditions, Biomed. Phys. Eng. Express 7 015012, (2021).
- **K. Kokurewicz**, D. Jaroszynski et al., An experimental study of the dose distribution of focused very high energy electron (VHEE) beams for radiotherapy, Nature Commun Phys 4, 33 (2021).