Updates, Status and Experiments of CLEAR, the CERN Linear Electron Accelerator for Research User Facility

P. Korysko*,
on behalf of the CLEAR team.

Very High Energy Electron Radiotherapy Conference (VHEE23)
11-13 July 2023
DESY Hamburg

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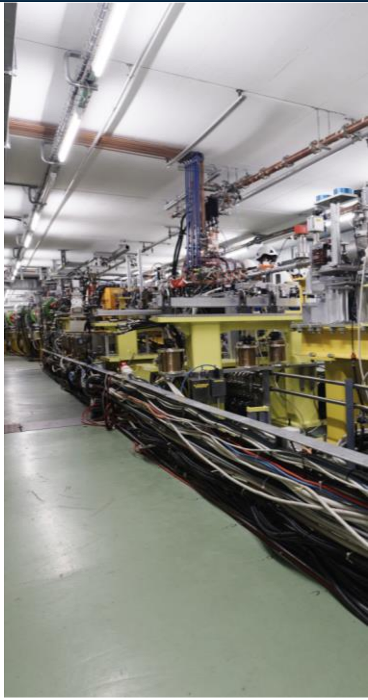
Outline

- CLEAR Beam Line: History & Parameters.
- New tools developed in 2022/2023.
- Overview of Experiments done in 2022/2023.
- Conclusions.

CLEAR Beam Line:
History & Parameters

CLEAR Scientific and Strategic goals

Scientific and strategic goals:

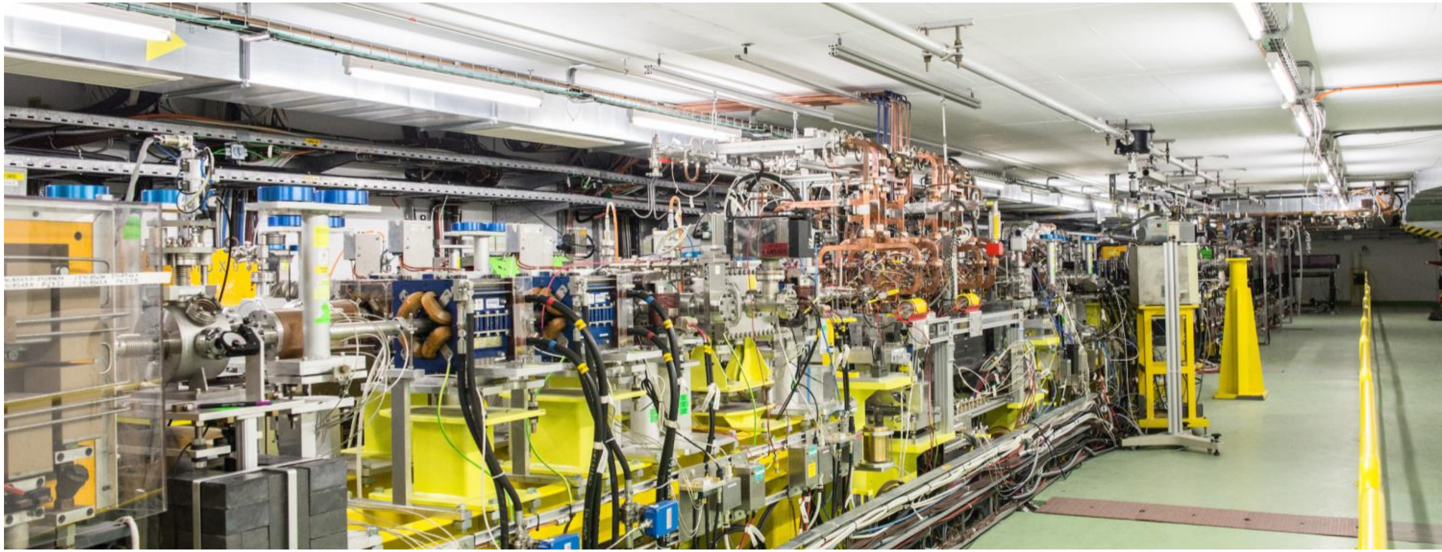


- Providing a test facility at CERN with high **availability**, easy **access** and **high-quality e-beams.**
- Performing **R&D** on **accelerator components**, including beam instrumentation prototyping and high gradient RF technology.
- Providing an **irradiation facility** with Very High Energy Electrons (VHEE), e.g., for testing electronic components in collaboration with ESA or for medical purposes.
- Performing **R&D** on **novel accelerating techniques** – electron driven plasma and THz acceleration.
- Maintaining CERN and European **expertise for electron linacs** linked to future collider studies.
- Using CLEAR as a **training** infrastructure for the next generation of accelerator scientists and engineers.

CLEAR is a versatile electron linac and an experimental beamline, operated at CERN as a multi-purpose user facility.

CLEAR Timeline

- **Approved** December 2016.
- **Began operation** in 2017.
- **Flexible** beam program.
  - 8-12 hours a day.
  - 5 days a week.

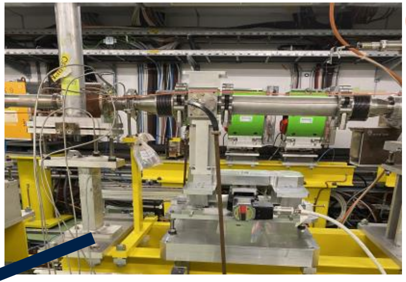


- **Independent** of LHC runs and long shutdowns.
- **2017** → 19 weeks of beam.
- **2018** → 36 weeks of beam.
- **2019** → 38 weeks of beam.
- **2020** → 34 weeks of beam (despite Covid-19).
- **2021** → 35 weeks of beam (despite Covid-19).
- **2022** → 37 weeks of beam and 27 experiments.
- **2023** → 38 weeks of beam and more than 30 experiments planned.

The CLEAR Beam Line in 2023

In-Air Test Stand

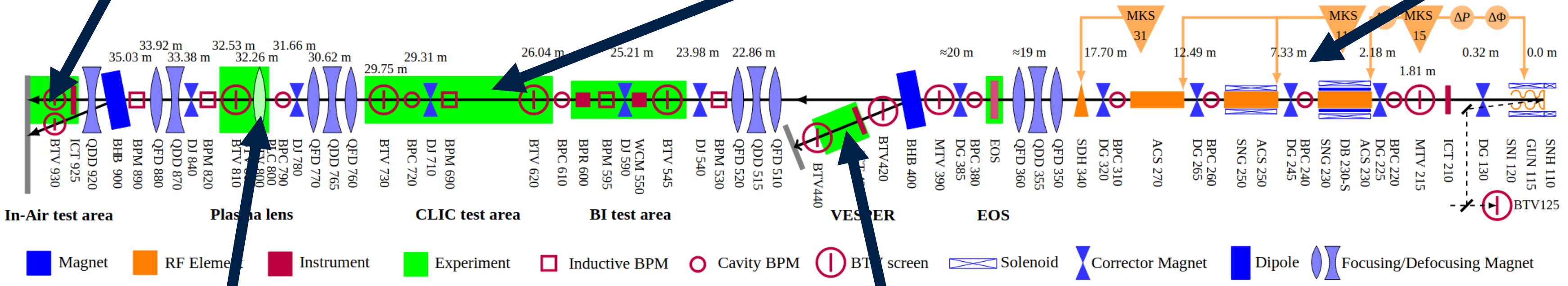
- Diagnostics studies
- Irradiation
  - Electronics
  - **VHEE**

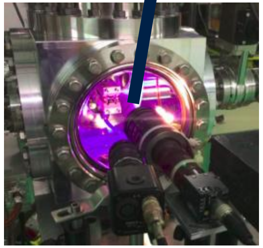


BI Test Stand

CLEAR Injector

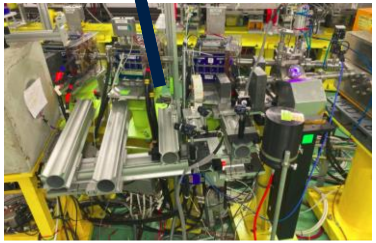
- Flexible Linac
- 60 – 220 MeV





Plasma Lens

- Novel plasma based focusing



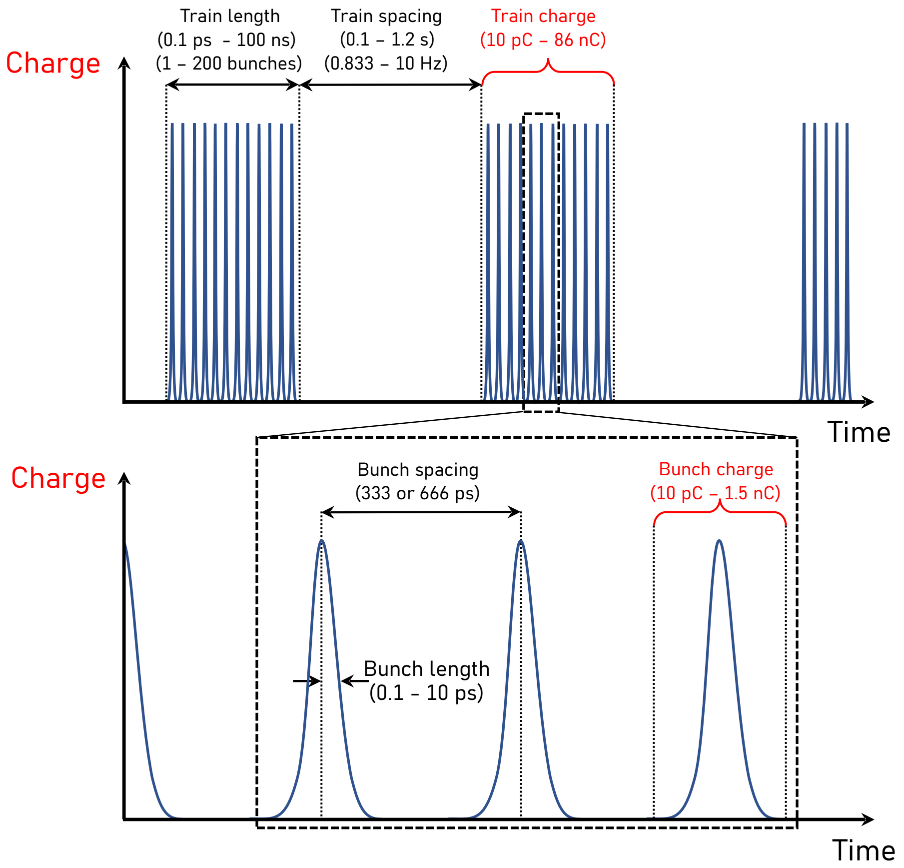
vesper

- Irradiation facility
  - Space probes
  - Electronics
  - **VHEE**

clear

CLEAR Beam Parameters in 2023

Parameter	Value
Energy	**60 – 220 MeV**
Energy spread	< 0.2 % rms (< 1 MeV FWHM)
Bunch length	**0.1 – 10 ps RMS**
Bunch charge	10 pC – 1.5 nC
Normalised emittance	3 – 20 µm
Bunches per pulse	1 – 200
Max. charge per pulse	**86 nC**
Repetition rate	**0.833 – 10 Hz**
Bunch spacing	1.5 or 3.0 GHz



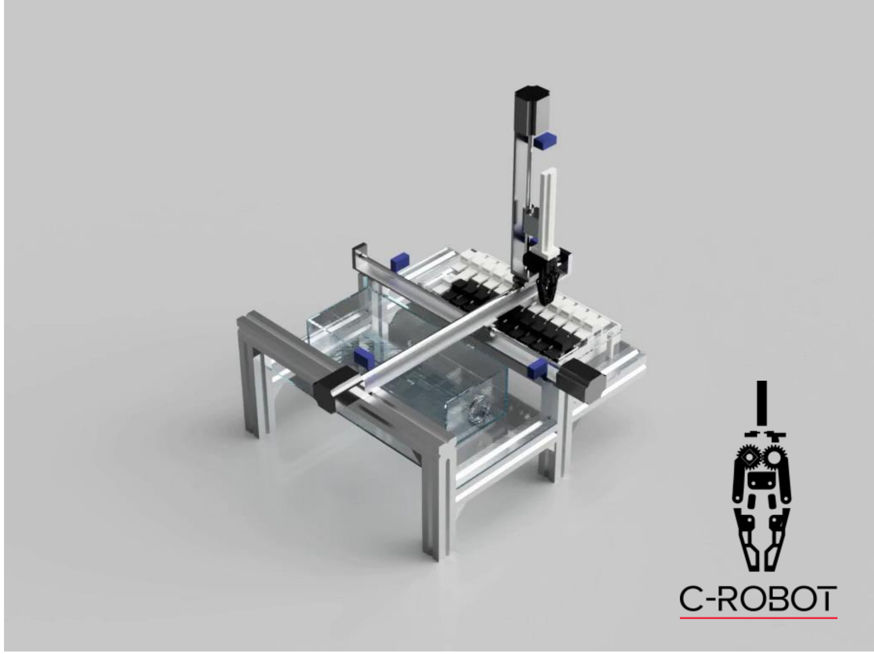
What does CLEAR offer?

- Really **versatile beam parameters** (energy, size, dose, charge, length, repetition rate, position, etc.).
- **Flexible** beam program.
  - 8-12 hours a day (more, if needed).
  - 5 days a week (on the weekend, if needed).
- A **large range of existing hardware** available (C-Robot, linear stages, YAG screens, cameras, controls, etc.).
- **Numerous tools available to design and build the experiments** (milling, grinding, drilling machines, saws, 3D-printer, laser cutter, etc.).
- **Adaptive software** to remotely control the hardware and log the measured data.
- Some members of the CLEAR Operation team can help the users to **develop, design, build, install and uninstall both hardware and software** components needed for the experiment.
- **Dedicated experts** to **operate the machine and solve issues**.
- A **follow up** after the experiment to **share, filter and understand** the recorded data.

Selected tools developped in 2022:
The C-Robot

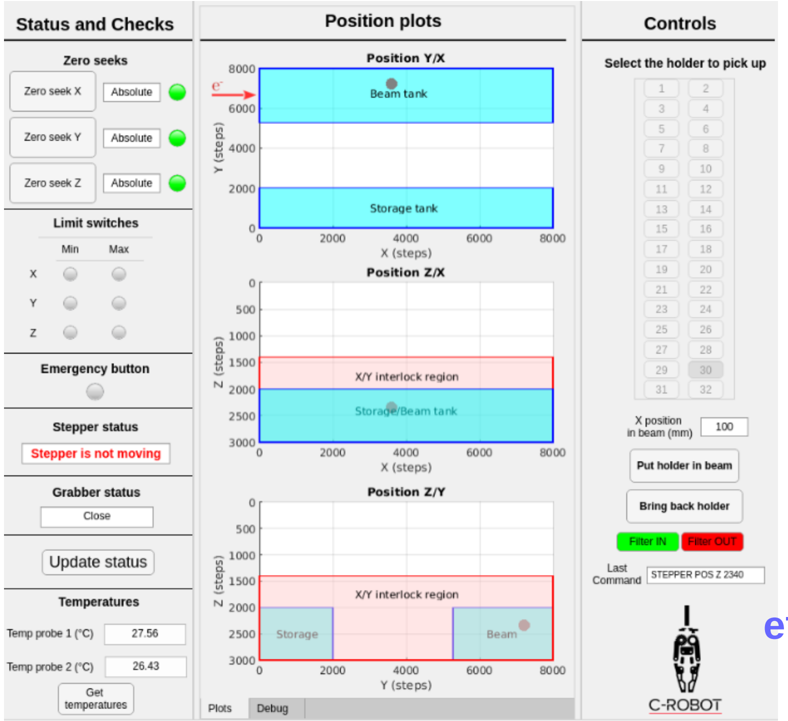
The C-Robot

- In order to **facilitate** the **precise control** of **samples** for **multiple irradiations**, the CLEAR-Robot (**C-Robot**) was designed and built by members of the CLEAR Operation Team.
- It consists of **3 linear stages**, **6 limit switches**, a **3D-printed grabber**, **two water tanks** and an **Arduino board**.
- It has a **precision in position** in 3 axis of **50 µm**.
- It is **fully remotely controllable** from the **CERN Technical Network**.
- Thanks to a **mounted camera**, it can also measure the **beam sizes** and **transverse positions** at the longitudinal position of the sample.
- It is an **open-source project**: **pictures**, **3D renders**, **drawings** and all the **codes** for the **Arduino** and the **Graphical User Interface** can be found on: https://pkorysko.web.cern.ch/C-Robot.html

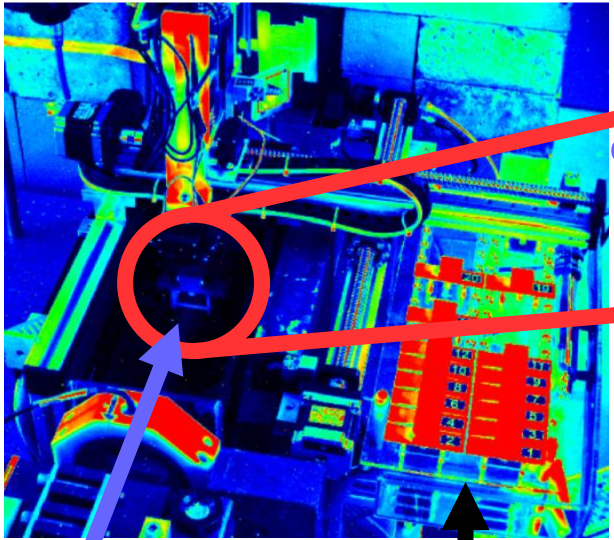


What can the C-Robot do?

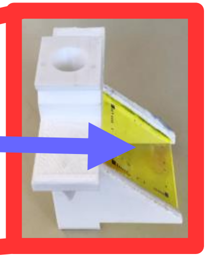
Graphical User Interface



Experiment setup w/ beam

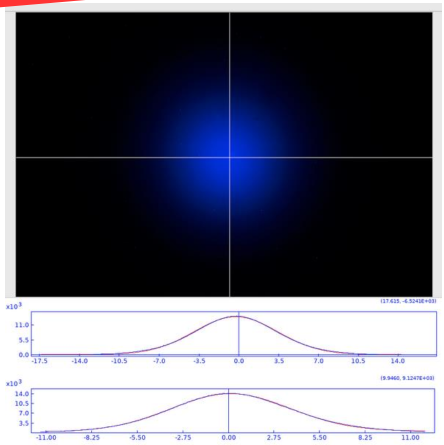


Camera



e⁻ beam

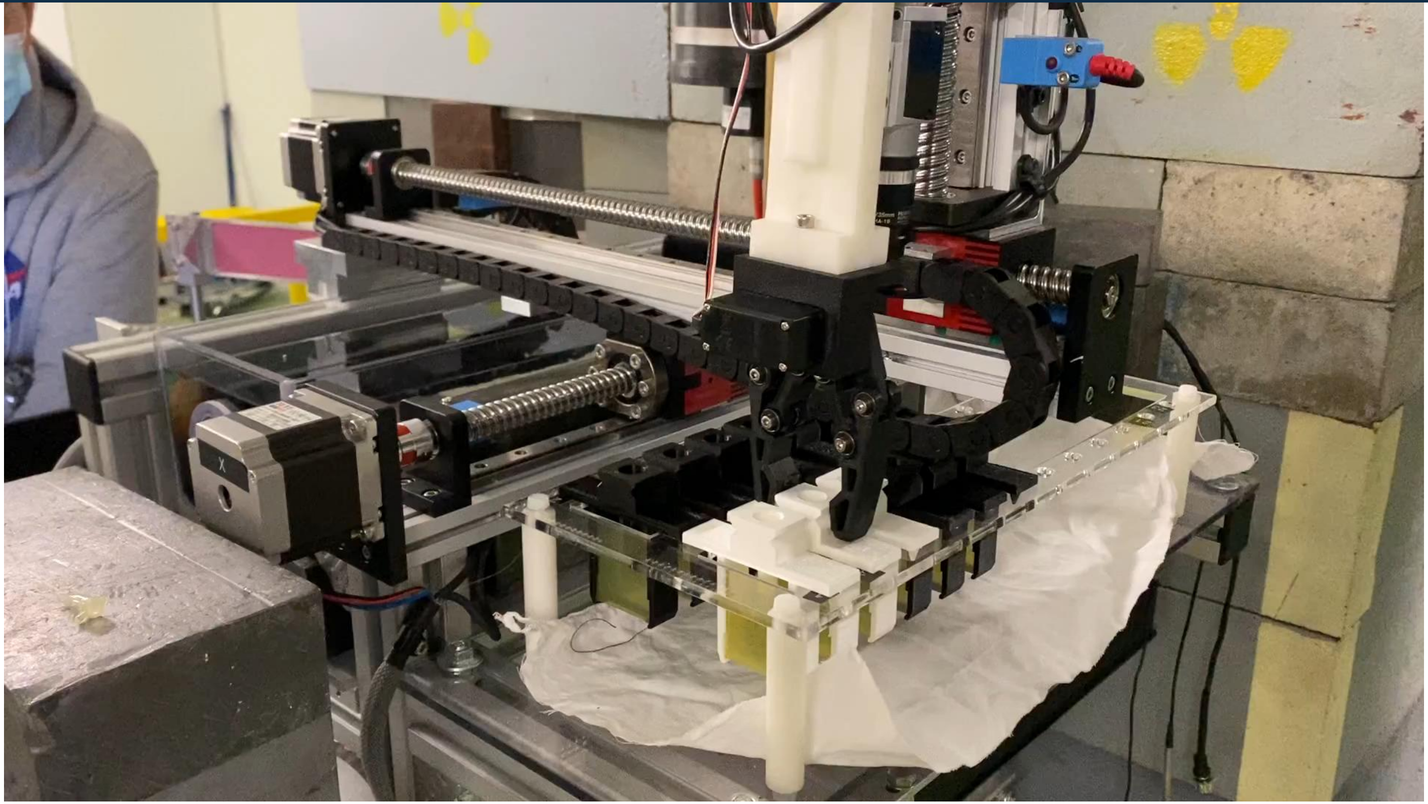
YAG Screen



e⁻ beam

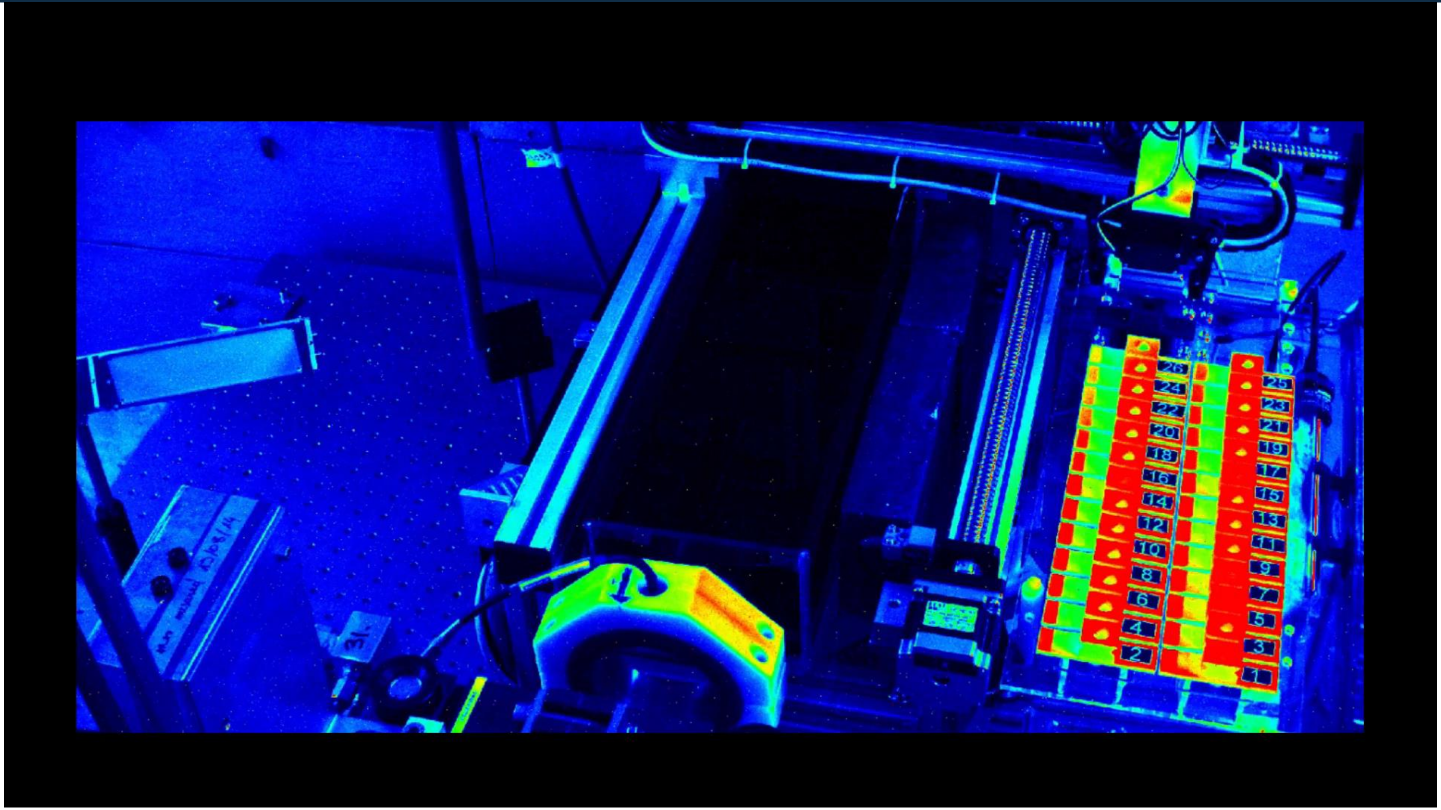
Zebra Fish Eggs in heated water, waiting to be irradiated

The C-Robot in action in CLEAR



[Link to Video]

The C-Robot in action with beam



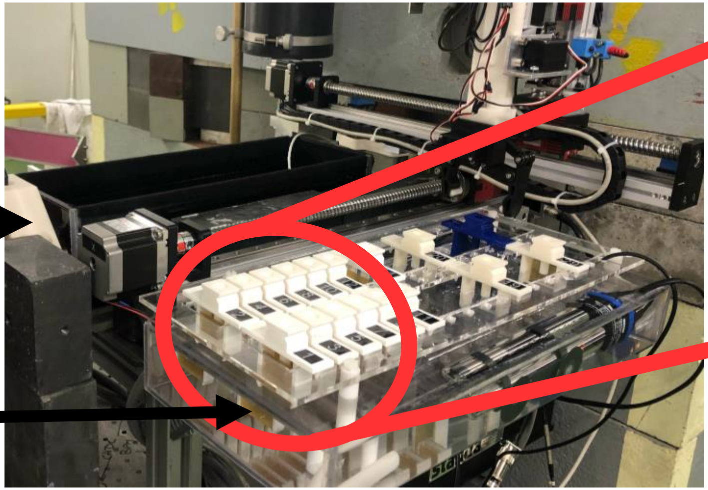
[Link to Video]

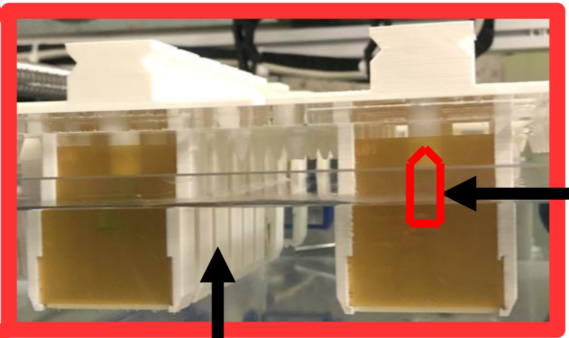
Selected Experiments Performed in 2022/2023

Experimental Setup & Dosimetry for VHEE at UHDR irradiations

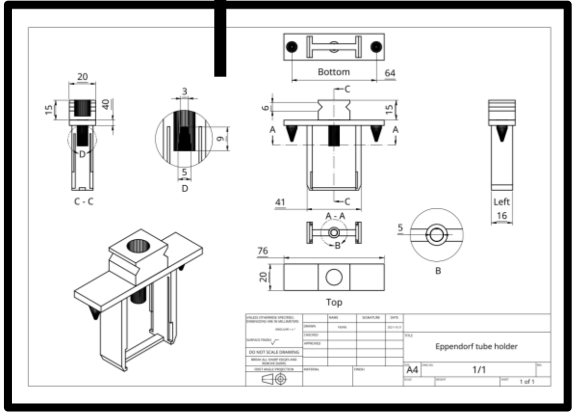
Beam water tank

Heated storage water tank





Eppendorf tube with sample to irradiate



3D printed holder with 2 films: one before and one after the sample

Laser cut Radiochromic films to measure the delivered dose

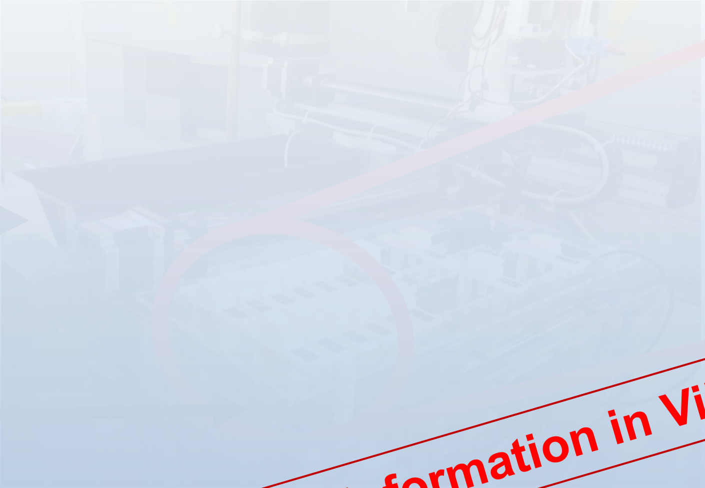
Dose range: 1 – 100 Gy

Before irradiation

After irradiation

V. Rieker & J. Bateman

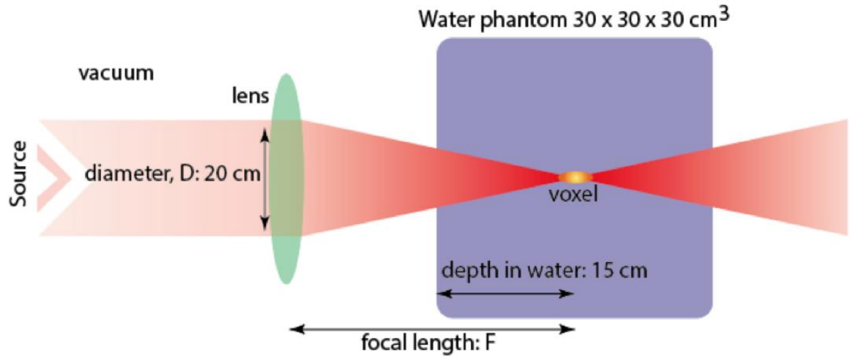
Experimental Setup & Dosimetry for VHEE at UHDR irradiations

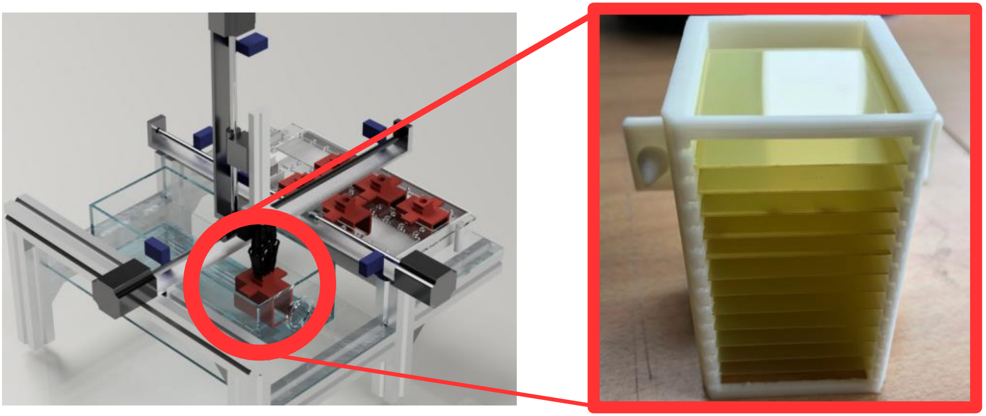


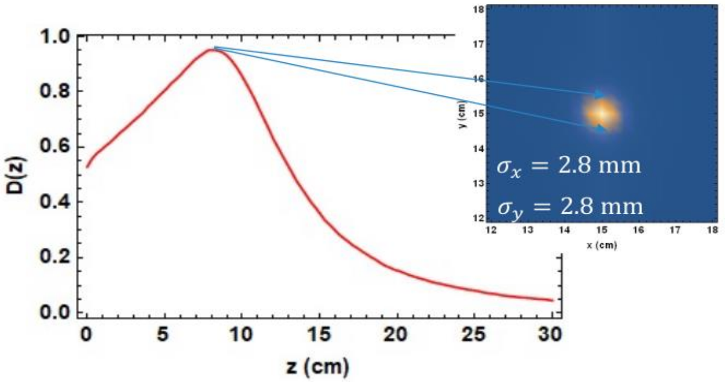
More information in Vilde's talk tomorrow at 14:10

VHEE Strong Focusing

Goal:
Focus the beam on the tumor in order to minimize the dose and damage on the nearby healthy tissues.
Experiment:
Measure the beam sizes on a YAG screen in the water phantom (good model of the human body) and perform irradiations on long dosimetry films holders placed at different longitudinal positions.







L. Whitmore

VHEE Strong Focusing

Goal:
Focus the beam on the tumor in order to minimize the dose and damage on the nearby healthy tissues.
Experiment:
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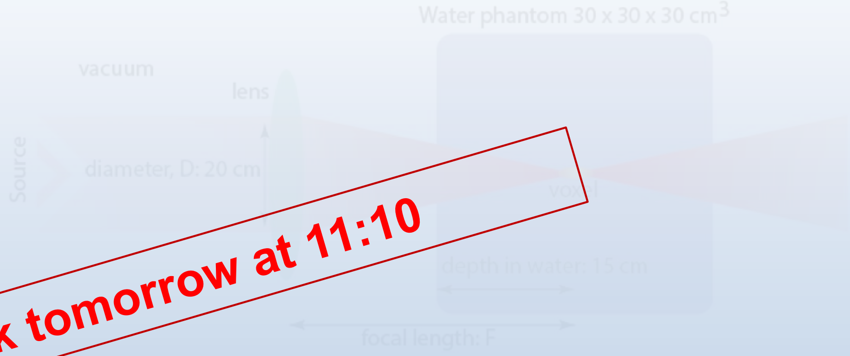
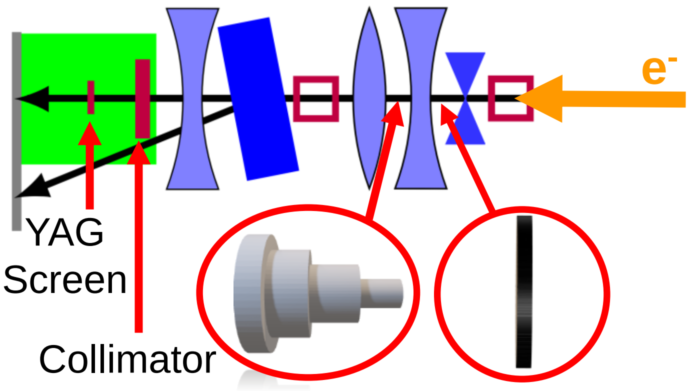


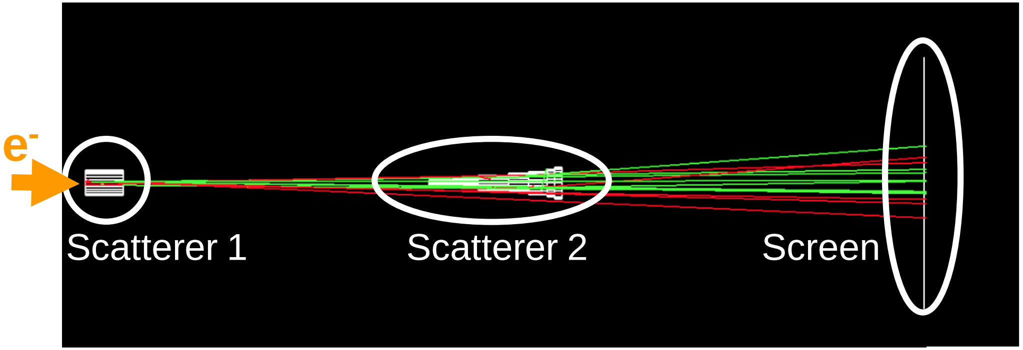
More information in Lucy's talk tomorrow at 11:10

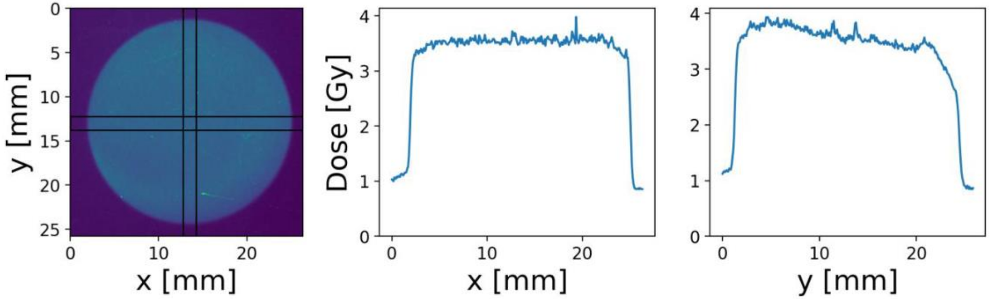
VHEE Scatterers

Goal:
Obtain a flat beam that has a constant transverse distribution at patient's tumor in order to minimize the dose and damage on the nearby healthy tissues.

Experiment:
Measure beam profiles, sizes and intensity on a YAG screen and films after carefully inserting two scatterers with the beam with the C-Robot.







X and Y beam profile

C. Robertson

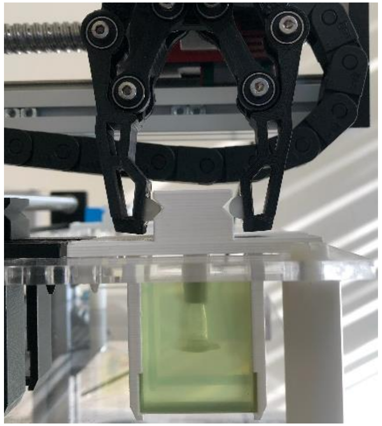
VHEE Scatterers

Goal:
Obtain a flat beam that has a constant transverse distribution at patient's tumor in order to minimize the dose and damage on the nearby healthy tissues.
Experiment:
Measure beam profiles, sizes and intensity on a YAG screen and films after carefully inserting two scatterers with the beam with the C-Robot.

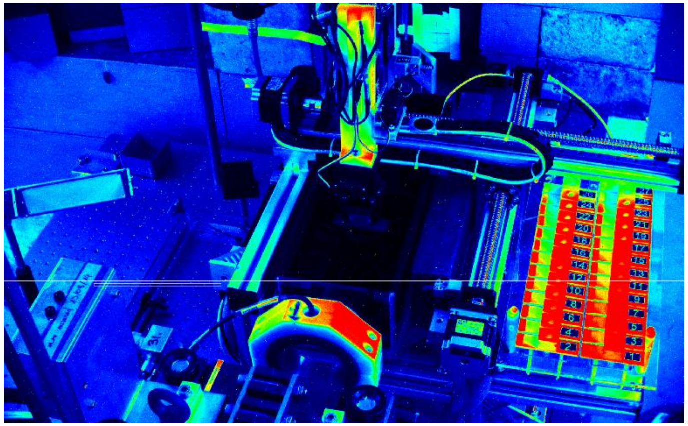
More information in Cameron's talk tomorrow at 14:25

VHEE Chemistry Studies

Experiment:
Measure and compare the lipid peroxidation at Conventional Dose Rate (CONV) and Ultra High Dose Rate (UHDR).

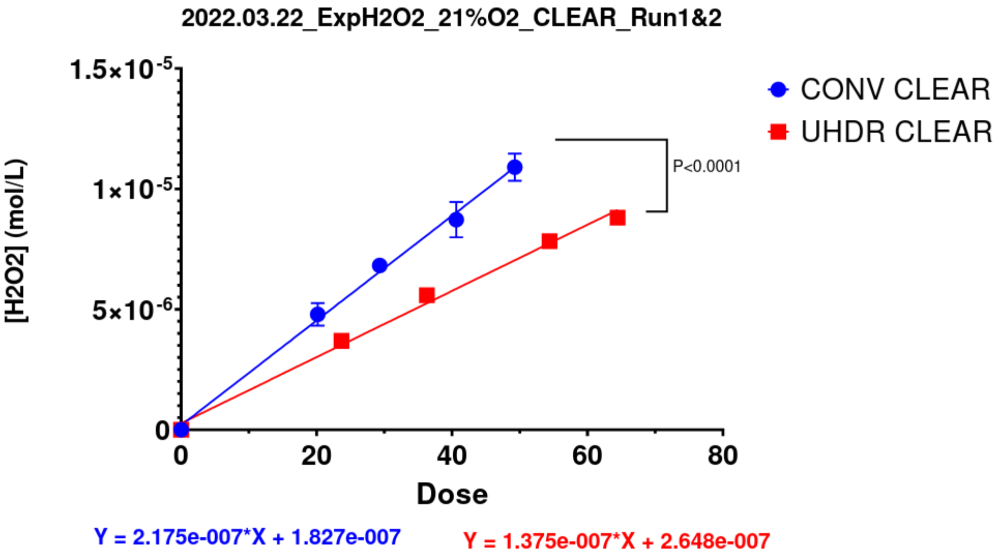


Holder with films and Eppendorf tube



C-Robot view when performing irradiations for chemistry studies

UHDR=1.2. 10^9 Gy/s CONV=0.15-0.41 Gy/s



H. Kacem, M-C. Vozenin

VHEE Chemistry Studies

Experiment:
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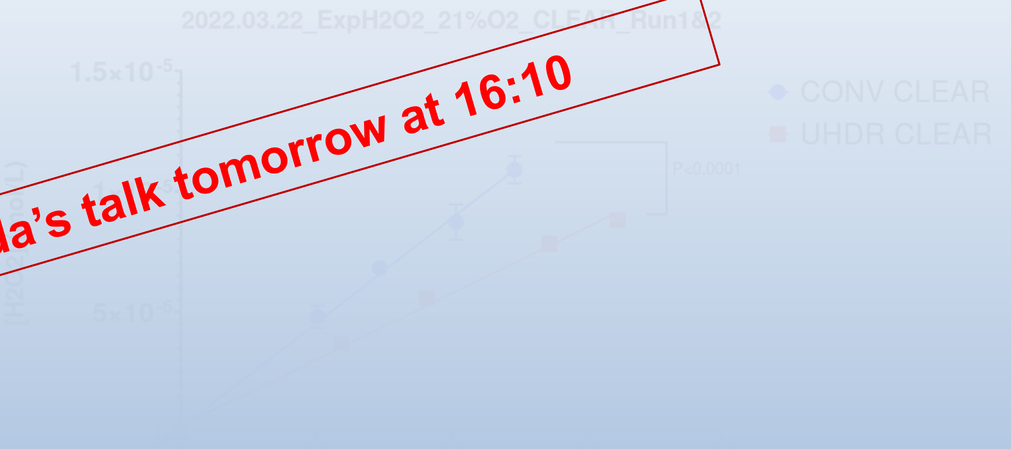
UHDR=1.2. 10^9 Gy/s CONV=0.15-0.41 Gy/s



More information in Houda's talk tomorrow at 16:10

VHEE Plasmids irradiation

Goal:
Measure the Relative Biological Effectiveness (RBE) of VHEE and determine how much DNA damage is created at higher electron energies.

Experiment:
Irradiates the plasmids with three radical scavenger concentrations at beam energies from 100 to 220 MeV and at CDR and UHDR.

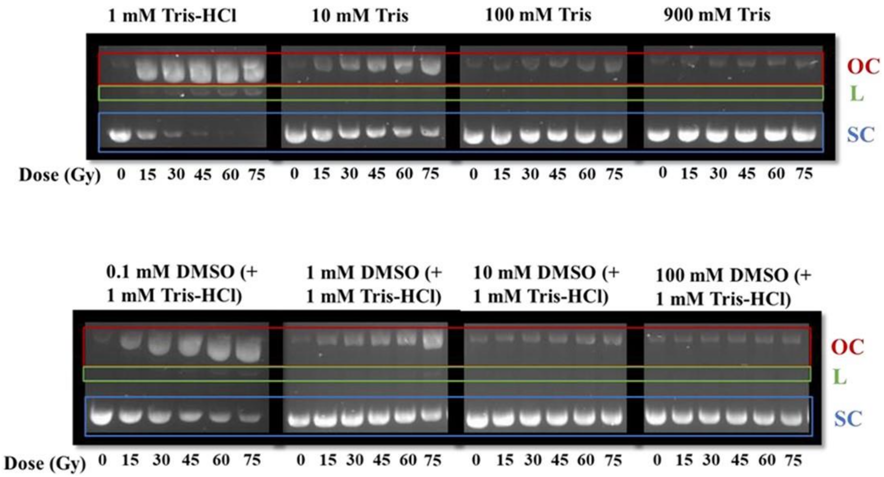


Image from agarose gels of X-ray irradiated samples where bands on the gel represent the pBR322 plasmid DNA,

H. Wanstall

VHEE Plasmids irradiation

Goal:
Measure the Relative Biological Effectiveness (RBE) of VHEE and determine how much DNA damage is created at higher electron energies.

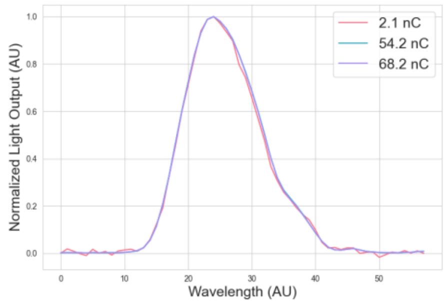
Experiment:
Irradiates the plasmids with three radical scavenger concentrations at beam energies from 100 to 220 MeV and at CDR and UHDR.

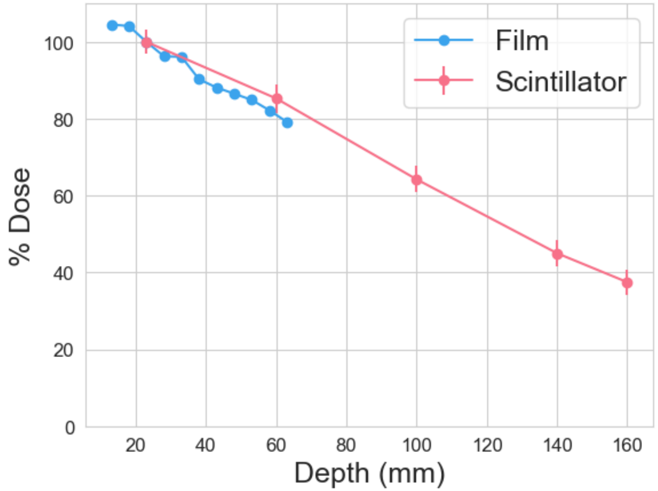
More information in Hannah’s talk tomorrow at 15:40

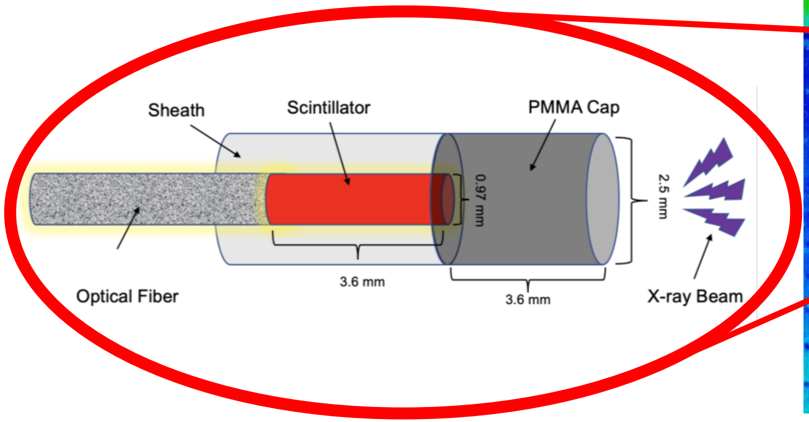
VHEE Scintillator Dosimetry

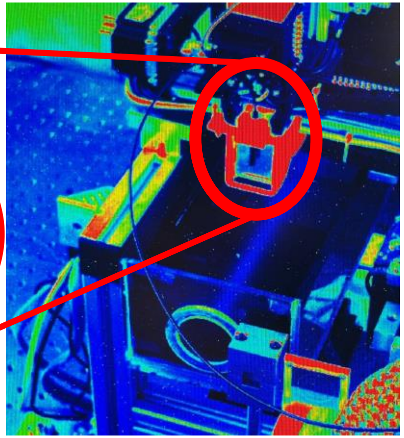
Goal:
Measure the dose at ultrahigh dose-rate with a real-time readout and a high spatial resolution thanks to a scintillator and an optical fiber.

Experiment:
Measure the responses of the scintillator for different doses and water depths and compare them with the doses measured on films.





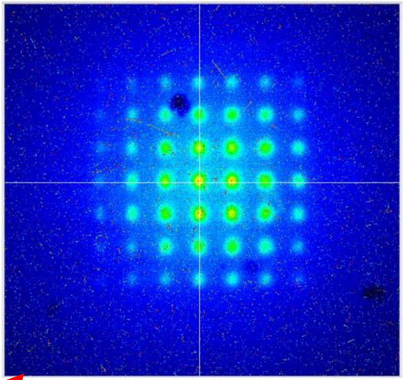


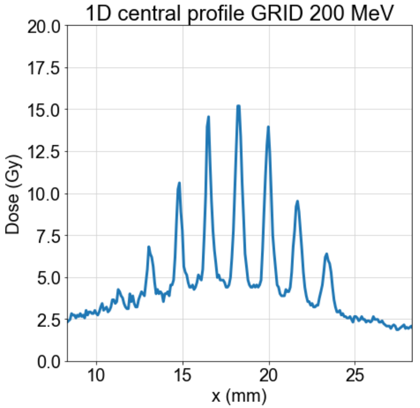


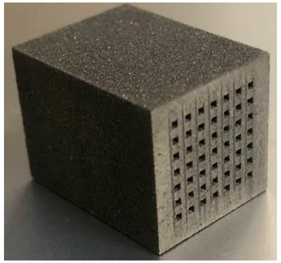
A. Hart & C. Giguère

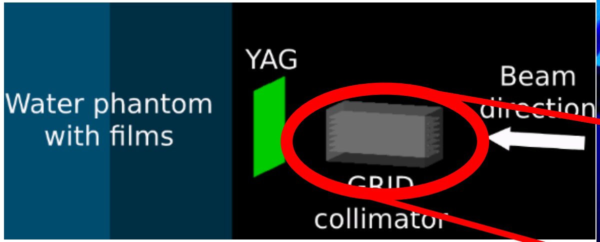
VHEE GRID

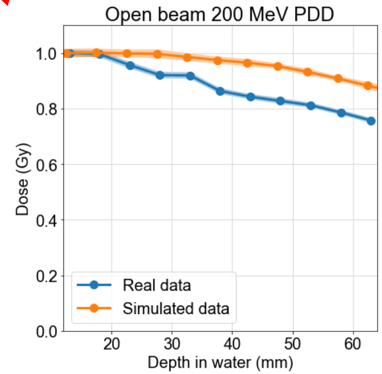
Goal:
Study the dose at UHDR for highly non-uniform dose distributions using a GRID Collimator (Spatially-fractionated RT, known for normal tissue sparing).
Experiment:
Compare the dose values and profiles with and without the GRID collimator inserted for different water depths, with the YAG screen and films.

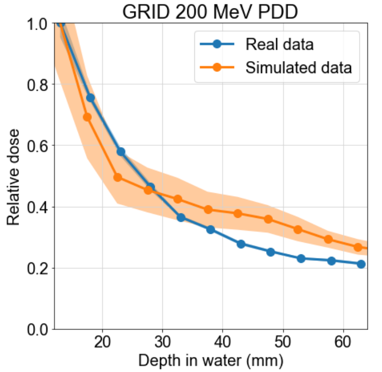












N. Clements, N. Esplen & A. Hart

Database of CLEAR Experiments

CLEAR EXPERIMENTS

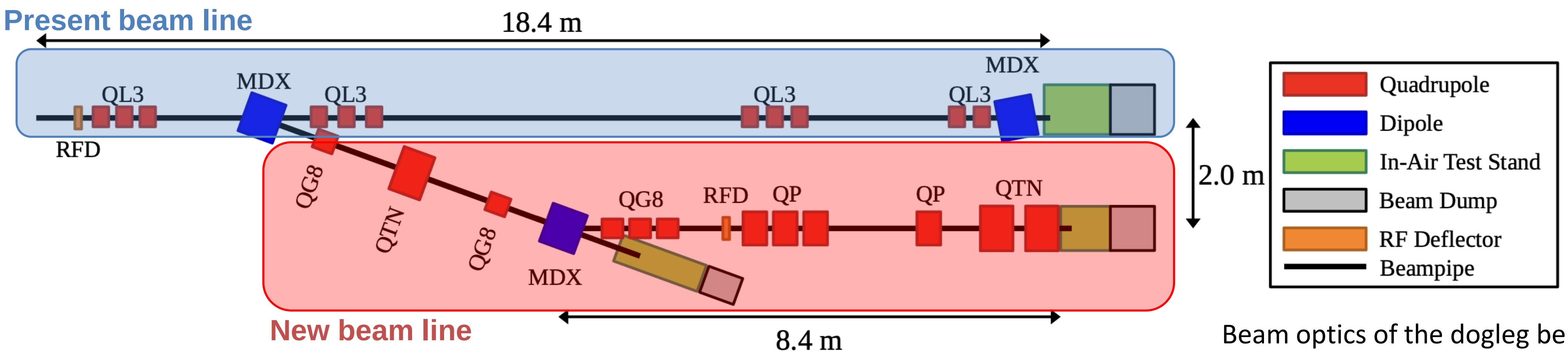
Show 100 entries

Search:

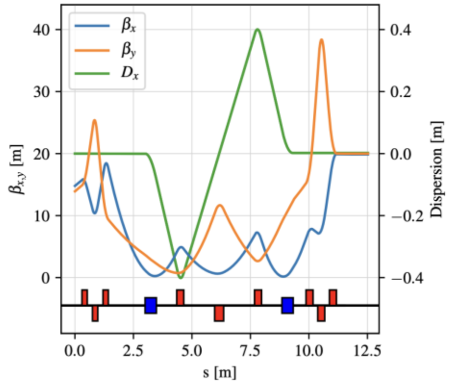
Date	Experiment	Main conctact	Institutes	Beam Time Request	Pictures	Experiment Review	Presentations	Publications
2022-05	AWAKE Cherenkov Diffraction Radiation BPM	Collette Pakuza	CERN	PDF			P	Proceeding
2022-04	R2E FLASH+EDI	Andrea Coronetti	CERN	PDF			P	Journal Paper
2022-10	CChDR sampling by KAPTEOS electro optical probes	Andreas Schloegelhofer	CERN	PDF		PDF	P	
2022-05	VHEE Scatterers	Cameron Robertson	University of Oxford	PDF			P	
2022-04	VHEE Detectors	Joseph Bateman	University of Oxford	PDF			P	Proceeding
2021-05	Study of coherent ChDR emitted by short bunch	Thibaut Lefevre	CERN / RHUL / Tomsk University	PDF			P	Proceeding
2021-03	CLIC WFM/kick	Kyrre Ness Sjobak	University of Oslo / CERN	PDF			P	PhD Thesis
2021-03	High frequency beam position monitor (BPM) for the AWAKE experiment	Eugenio Senes	CERN	PDF			P	Proceeding

A list of all the Experiments done in CLEAR can be found on:
https://pkorysko.web.cern.ch/CLEAR/Table/CLEAR_experiments.html

New Beam line in 2024



Beam optics of the dogleg bend



New Beam Line:

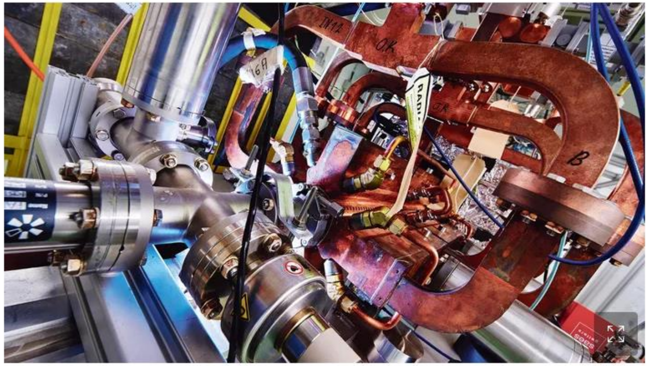
- One (or two) in-air test stands.
- Dedicated to irradiations and medical applications.
- Beam line with flexible optics to increase even more the range of beam parameters (beam charge, size, energy spread, etc.).
- New robot (C-Robot 2.0) installed on the final in-air test stand.

CLEAR in the Press in 2022

Sciences

Le futur de la radiothérapie s'écrit au Cern à Genève

Par Pauline Fréour
Publié le 06/11/2022 à 18:28, mis à jour le 06/11/2022 à 18:28



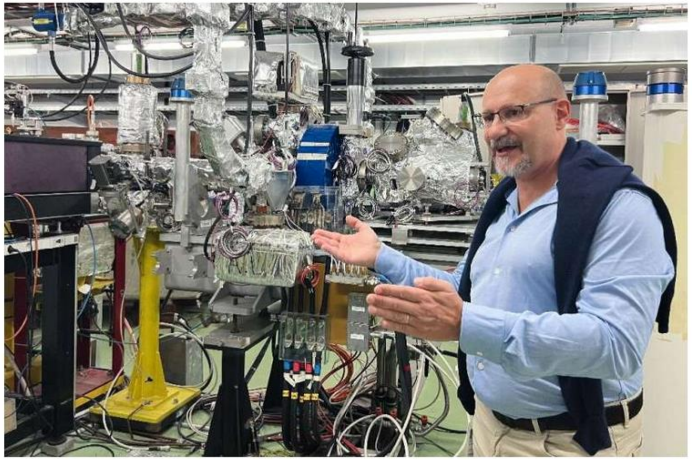
Située sur le campus du Cern, l'installation Clear est une technologie de pointe au service de l'innovation scientifique et médicale. 2020-2022 CERN

PHYS.ORG — JAPANTODAY

OCTOBER 22, 2022

Particle physics pushing cancer treatment boundaries

by Nina LARSON



Facility coordinator Roberto Corsini shows off a 40-metre linear particle accelerator at CER...

NATIONAL GEOGRAPHIC

A cancer patient receives radiation therapy in at the Auguste Victoria Hospital in East Jerusalem, Israel. While radiotherapy is an effective way to fight cancer, current technologies cannot reach tumors deep inside the body. Physicists are hoping to change that.
PHOTOGRAPH BY CORINNA KERN, LAIF/REDUX

SCIENCE

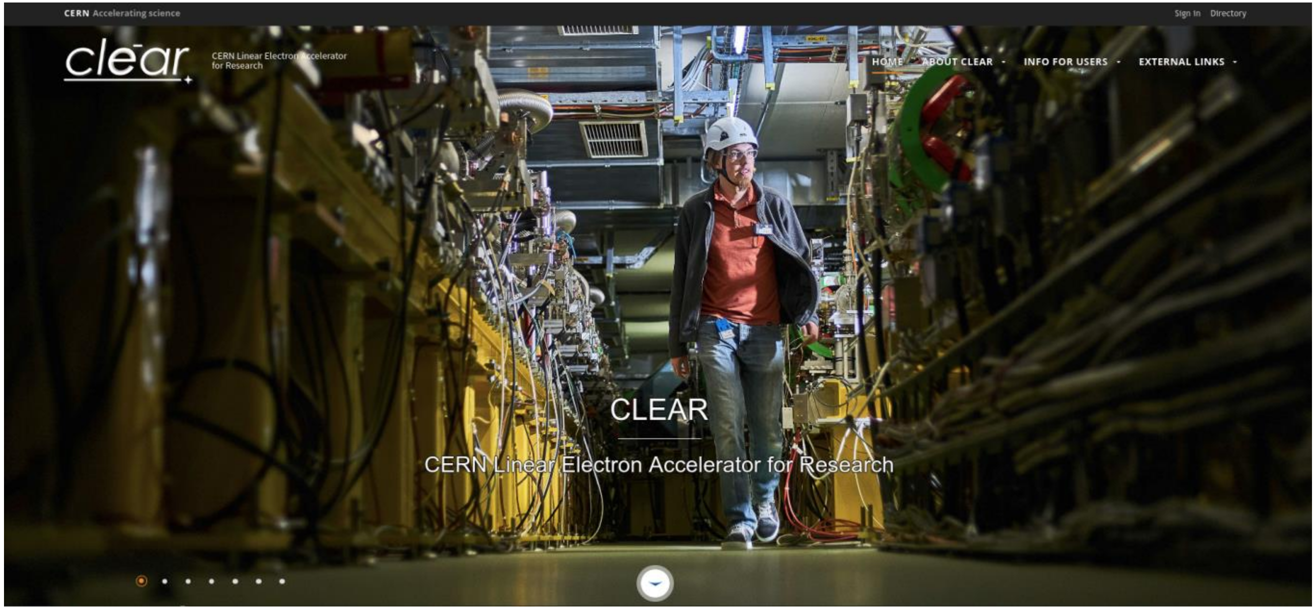
How do you kill hard-to-reach tumors? Particle physics is on the case.

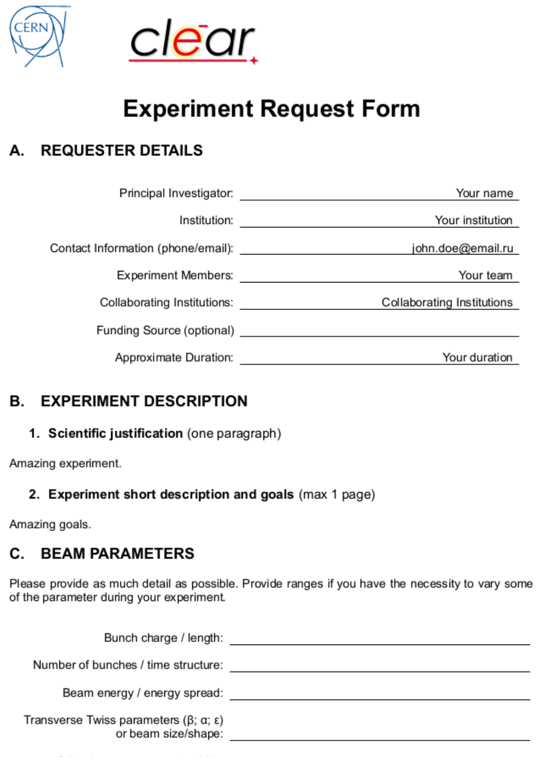
Take part!

You have an experiment in mind, and you want to test it in a linear electron accelerator?

Find more information on our Website: https://clear.cern/

And fill out our Beam Request Form!





CERN clear

Experiment Request Form

A. REQUESTER DETAILS

Principal Investigator: Your name

Institution: Your institution

Contact Information (phone/email): john.doe@email.ru

Experiment Members: Your team

Collaborating Institutions: Collaborating Institutions

Funding Source (optional)

Approximate Duration: Your duration

B. EXPERIMENT DESCRIPTION

1. **Scientific justification** (one paragraph)

Amazing experiment.

2. **Experiment short description and goals** (max 1 page)

Amazing goals.

C. BEAM PARAMETERS

Please provide as much detail as possible. Provide ranges if you have the necessity to vary some of the parameter during your experiment.

Bunch charge / length:

Number of bunches / time structure:

Beam energy / energy spread:

Transverse Twiss parameters (β; α; ε) or beam size/shape:

Conclusions

- **Really successful run in CLEAR in 2022 and promising run in 2023**:

- **37 weeks** of beam in **2022** and **38 weeks** planned for **2023.**

- **CLEAR parameter ranges were increased** (beam charge, repetition rate, stability, beam size, etc.)

- **27 experiments** were performed in **2022** and **more than 30 experiments** planned for **2023**.

- In 2022, it led to **18 conference proceedings**, **5 journal papers** (published or being reviewed), **7 PhD Thesis** (defended or being written) and **numerous presentations** at workshops and conferences.

- **More than 30 tours** of CLEAR were given in **2022/2023** for students, artists, journalists, companies, CERN personnel…

- **New beam** line dedicated to **irradiations** and **medical applications** in **2024**.

Thank you