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

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

11th Beam Telescopes and Test Beams Workshop
April 21, 2023

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Outline

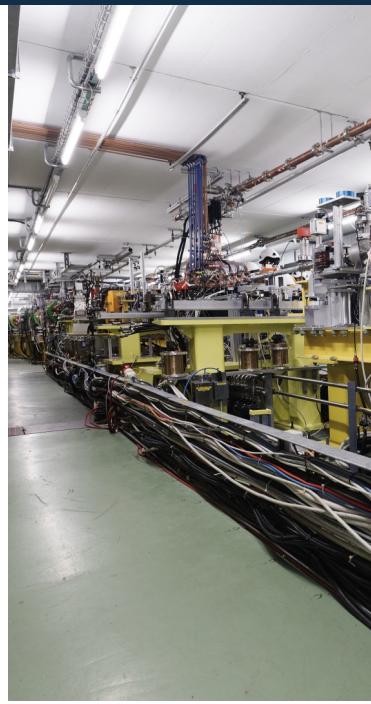
- CLEAR Beam Line: History & Parameters.
- New tools developed in 2022.
- Overview of Experiments done in 2022.
- CLEAR in the press.
- Conclusions.

CLEAR Beam Line: History & Parameters

CLEAR Scientific and Strategic goals

Scientific and strategic goals:

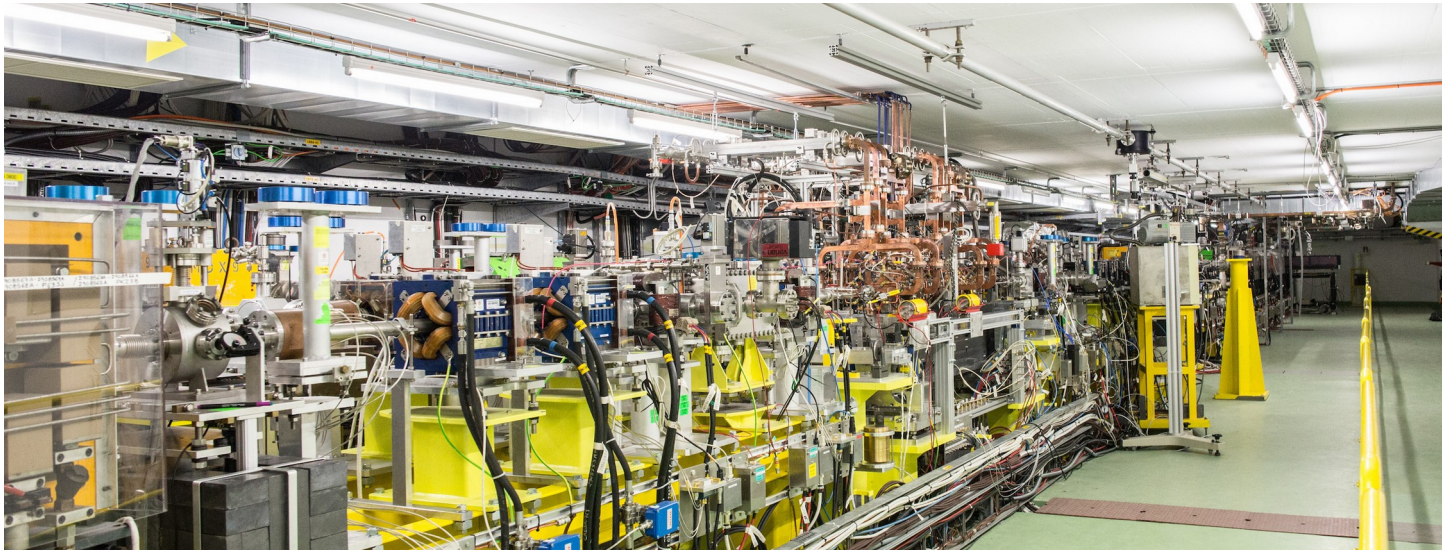
- Providing a test facility at CERN with high **availability**, easy **access** and **high quality e-beams.**
- Performing **R&D** on **accelerator components**, including beam instrumentation prototyping and high gradient RF technology.
- Providing an **irradiation facility** with Very High Energy Electrons (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.



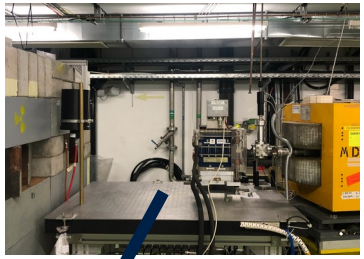
CLEAR is a versatile electron linac and an experimental beamline, operated at CERN as a multi-purpose user facility.

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.

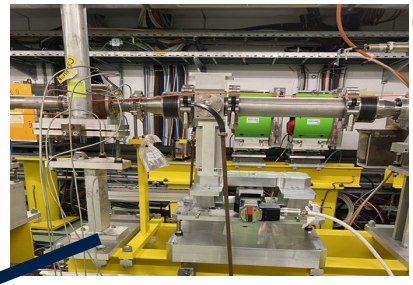


The CLEAR Beam Line in 2022

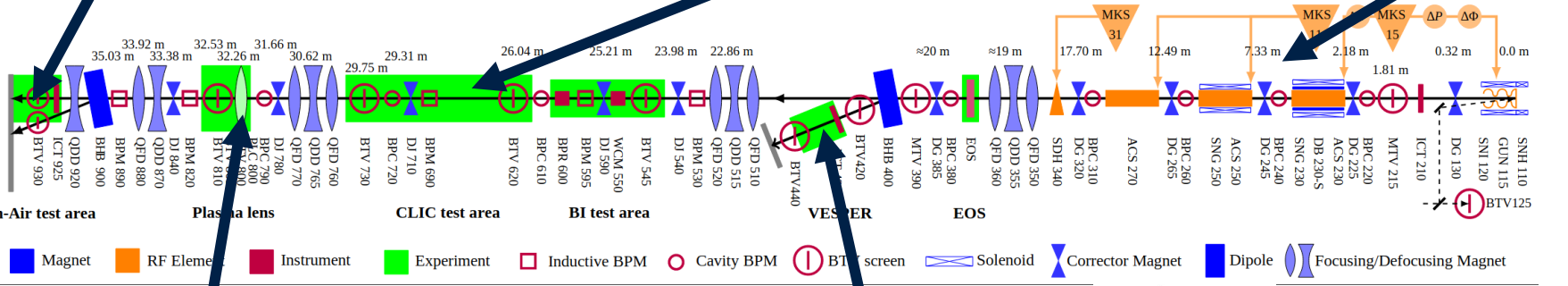


In-Air Test Stand

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

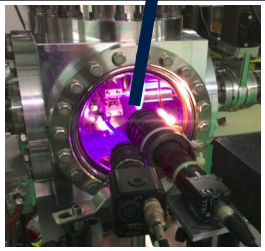


BI Test Stand



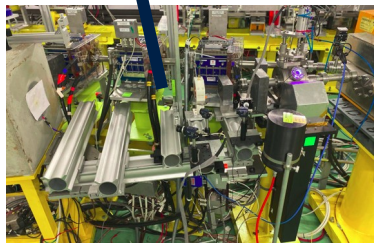
CLEAR Injector

- Flexible Linac
- 60 – 220 MeV



Plasma Lens

- Novel plasma based focusing

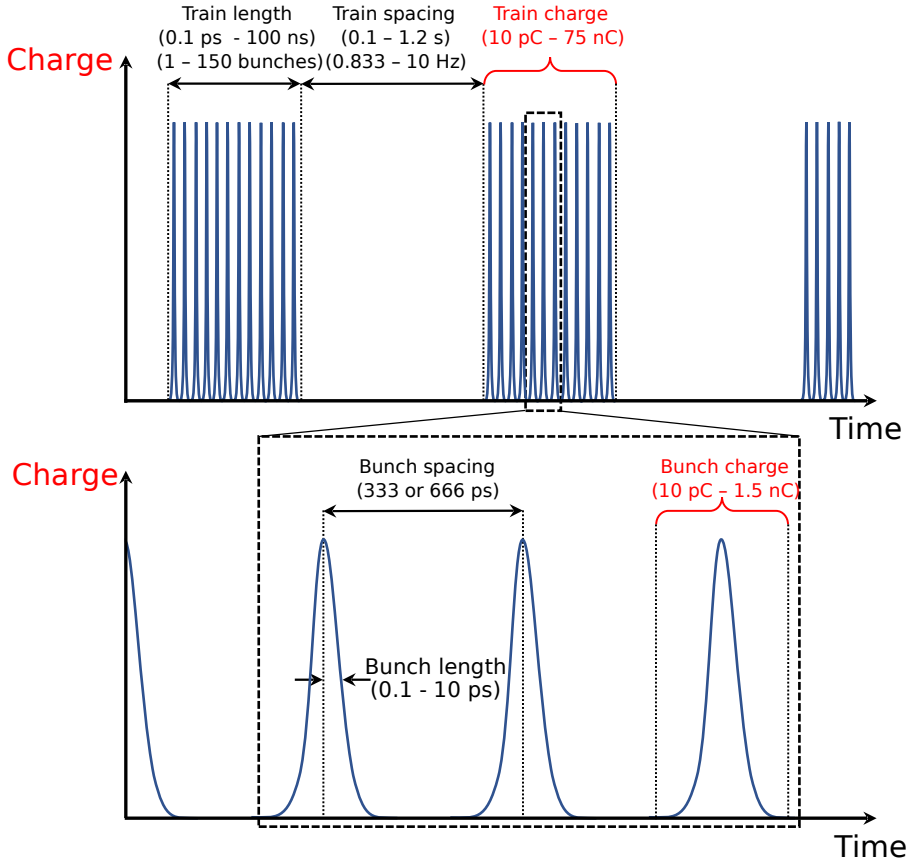


VESPER

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

CLEAR Beam Parameters in 2022

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.

CLEAR in 2022

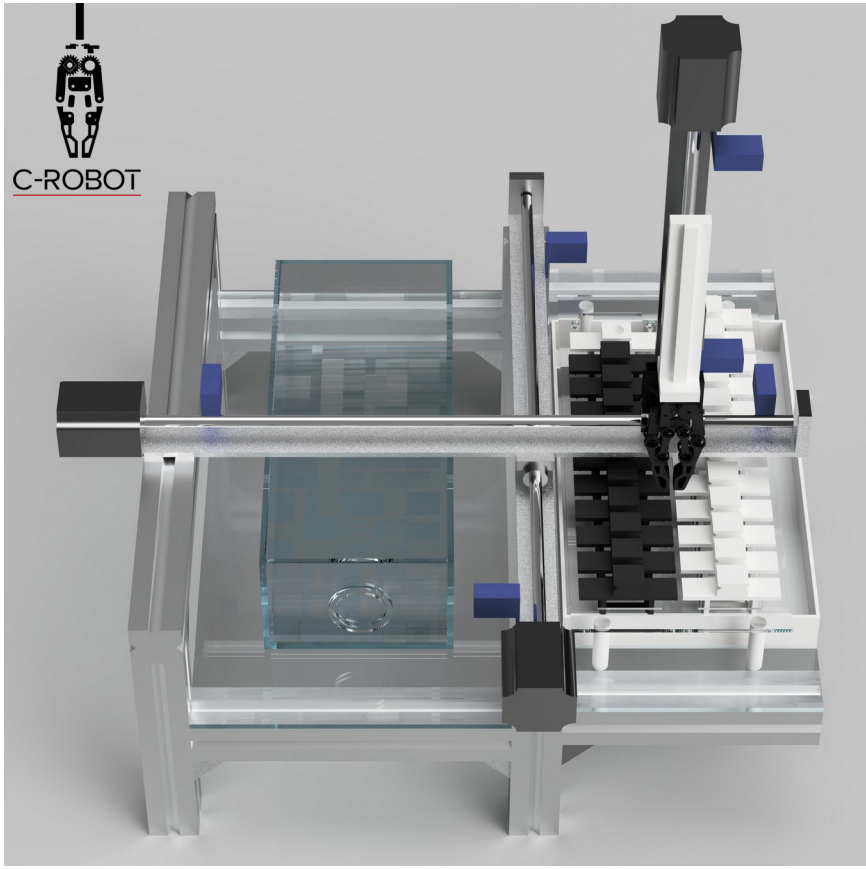
- **37 weeks** of beam.
- **New tools** were installed (C-Robot, cameras, scintillating screens, instrumentation, etc).
- **More than 25 different experiments** performed.
- **Scientists and students** from more than **15 institutes/universities/companies** had beam in CLEAR (CHUV, INFN, University of Manchester/Oxford/Bern/Victoria/Laval, Bergoz, etc.).
- Leading 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 **20 tours** of CLEAR were given for **students, artists, journalists, companies, CERN personnel**, etc.
- CLEAR was mentioned in **5 international newspapers** and **4 CERN articles.**

Selected tools developped in 2022: The C-Robot

C-Robot, what is it?

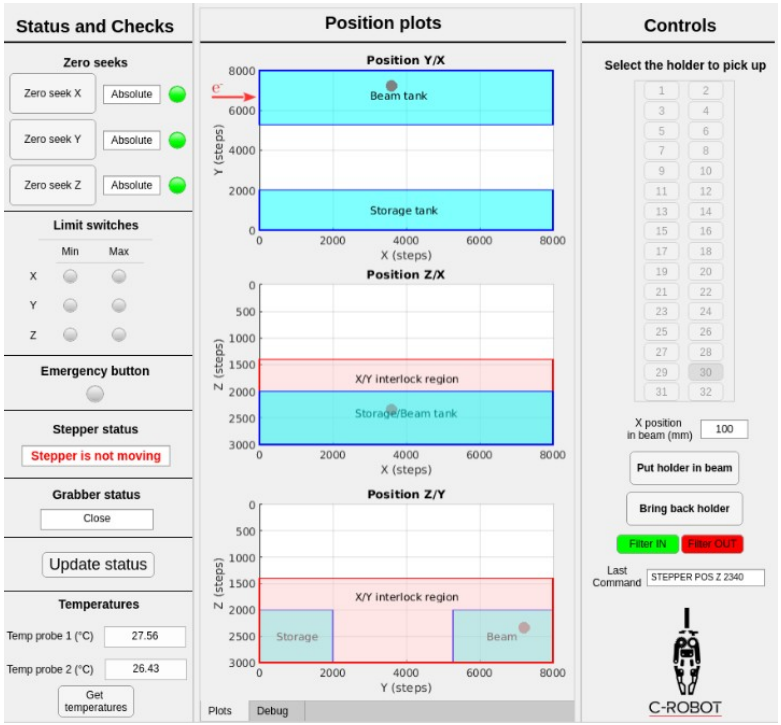
- In order to **facilitate** the **precise control** of **samples** for **multiple irradiations**, the CLEAR-Robot (**C-Robot**) was designed and built by members of the CLEAR Operation Team.
- It consists of **3 linear stages**, **6 limit switches**, a **3D-printed grabber**, **two water tanks** and 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

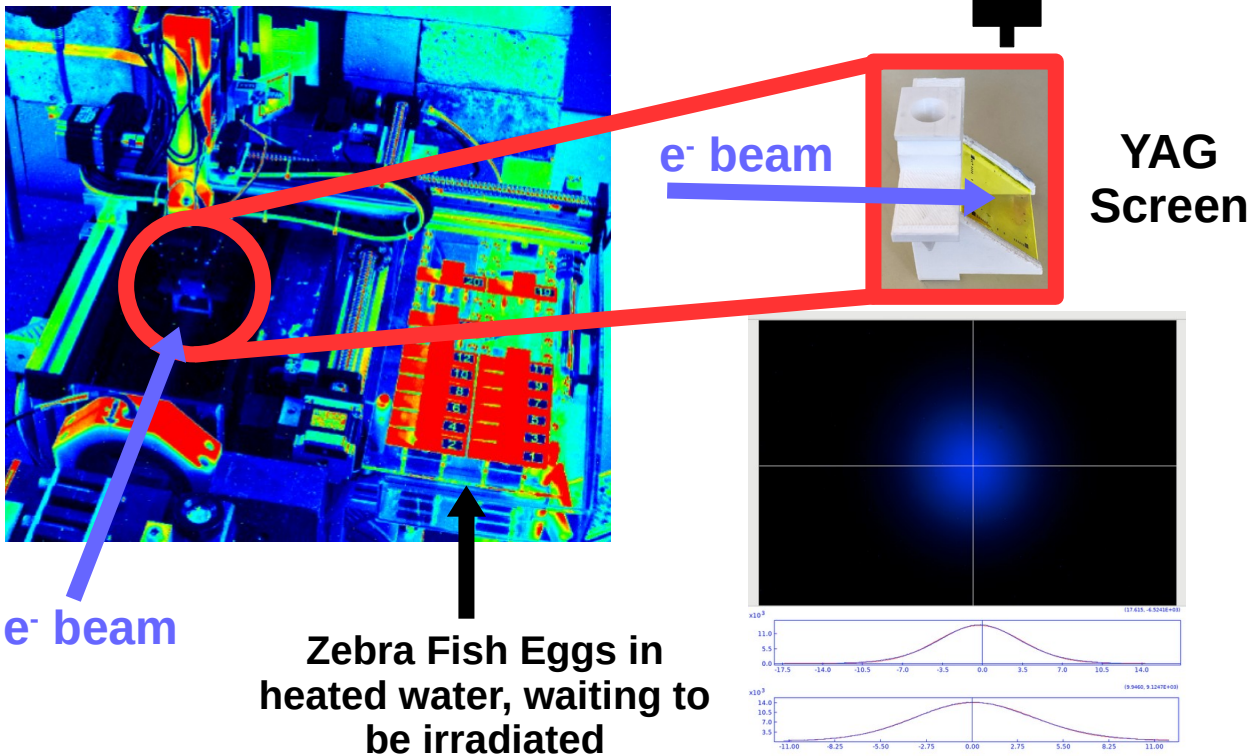


C-Robot, what can it do?

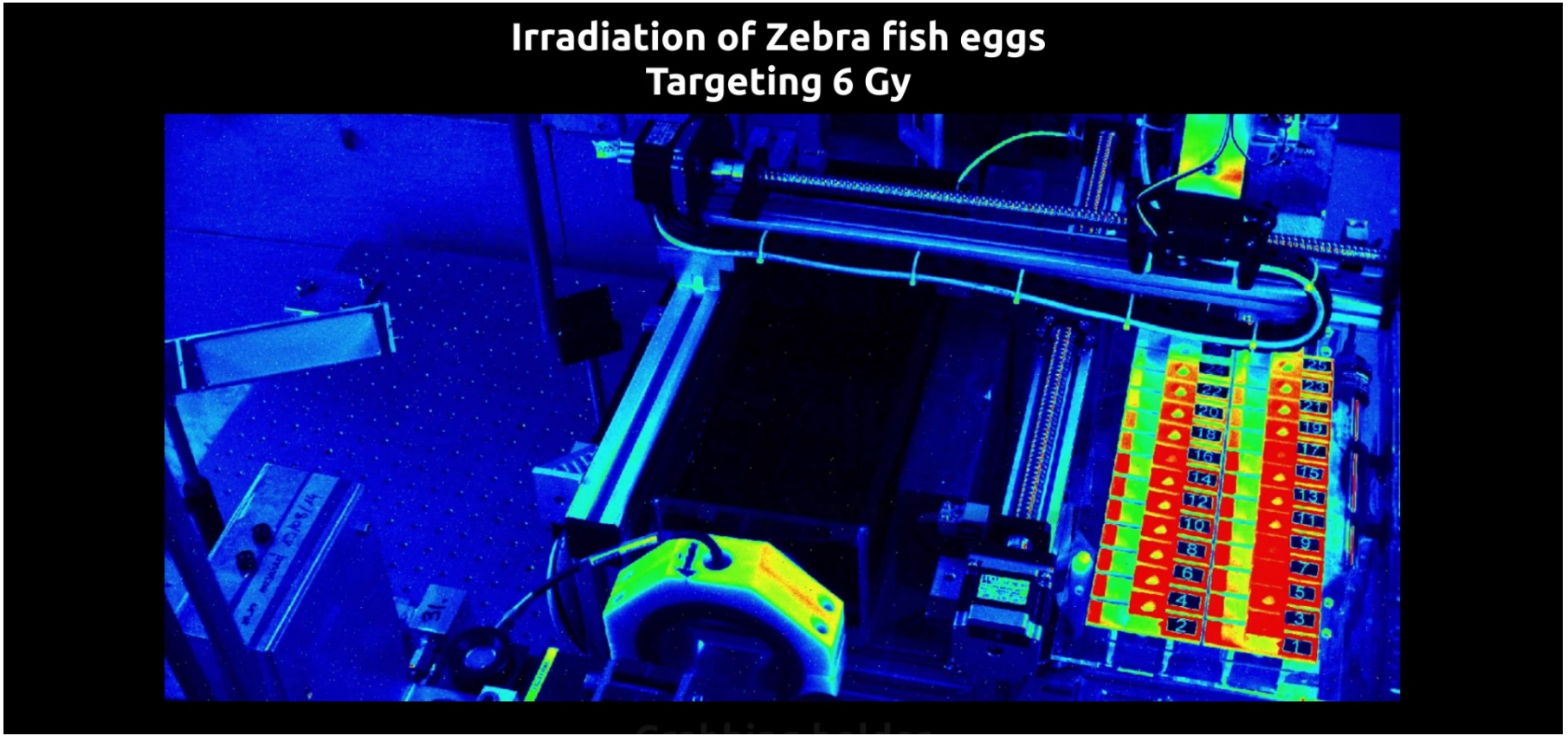
Graphical User Interface



Experiment setup w/ beam



C-Robot in action with Beam



2022 Experiments

CLEAR Experiments in 2022

Experiment	Main conctact	Institutes
CChDR sampling by KAPTEOS electro optical probes	Andreas Schloegelhofer	CERN
Passive-time VHEE UHDR dosimetry	Vilde F. Rieker	CERN
Beam Profiler detector for the LUXE experiment	Marco Bruschi	INFN Bologna
Scintillating Fibres VHEE UHDR Real-Time Dosimetry	Joseph Bateman	University of Oxford
Scintillating/Optical Fiber UHDR Dosimeters	Pierluigi Casolaro	University of Bern
ChDR Bunch Length Monitor	Can Davut	University of Manchester
AWAKE Cherenkov Diffraction Radiation BPM	Collette Pakuza	CERN
VHEE Scatterers	Cameron Robertson	University of Oxford
VHEE Detectors	Joseph Bateman	University of Oxford
Beam Current Transformer	Frank Stulle	Bergoz Instrumentation
R2E FLASH+EDI	Andrea Coronetti	CERN
R2E Measurement neutron fluence with SEL-sensitive SRAM memories	Matteo Cecchetto	CERN
Irradiation of collimator materials - benchmarking of Monte Carlo code	Raphael Moeckli	CHUV
Irradiation of biological and chemical samples and plasmids with VHEE at UHDR	Marie-Catherine Vozenin	CHUV
FLASH and spatially fractionated radiotherapy	Magdalena Bazalova-Carter	University of Victoria
VHEE at depths >10 cm into a water phantom	Lucy Whitmore	Manchester University

CLEAR Experiments

CLEAR EXPERIMENTS

Show 100 entries

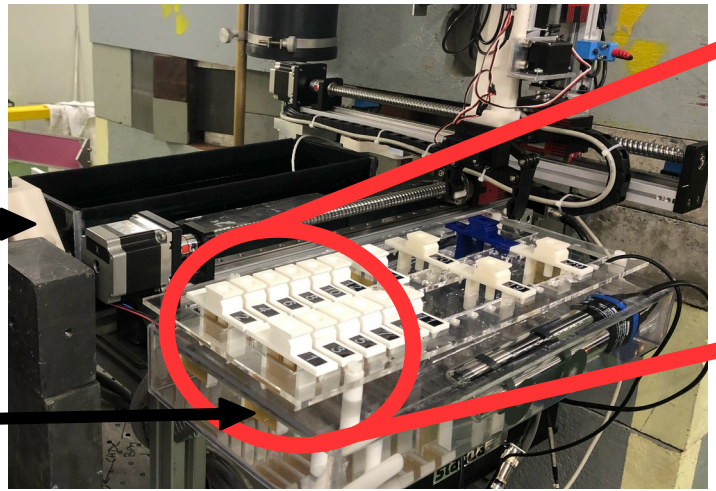
Search:

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

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

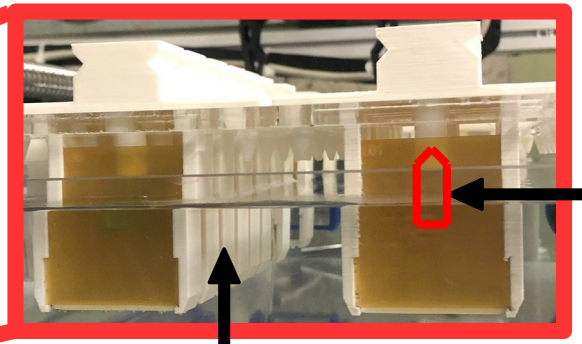
Selected Experiments Performed in 2022

Experimental Setup & Dosimetry for VHEE UHDR irradiations

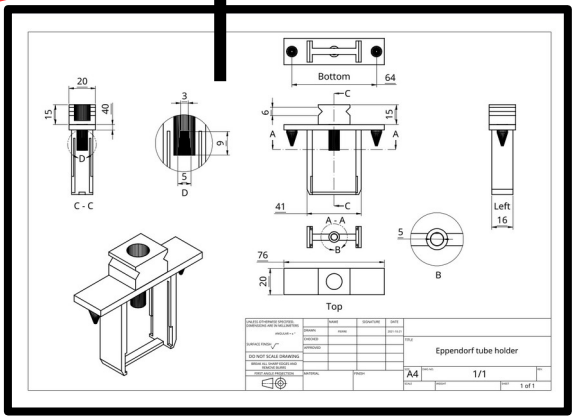


Beam water tank

Heated storage water tank



Eppendorf tube with sample to irradiate

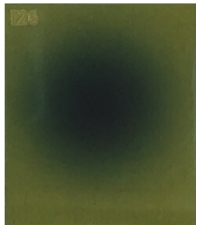


3D printed holder with 2 films: one before and one after the sample

Gafchromic films to measure the delivered dose

Dose range: 1 – 100 Gy

Before irradiation

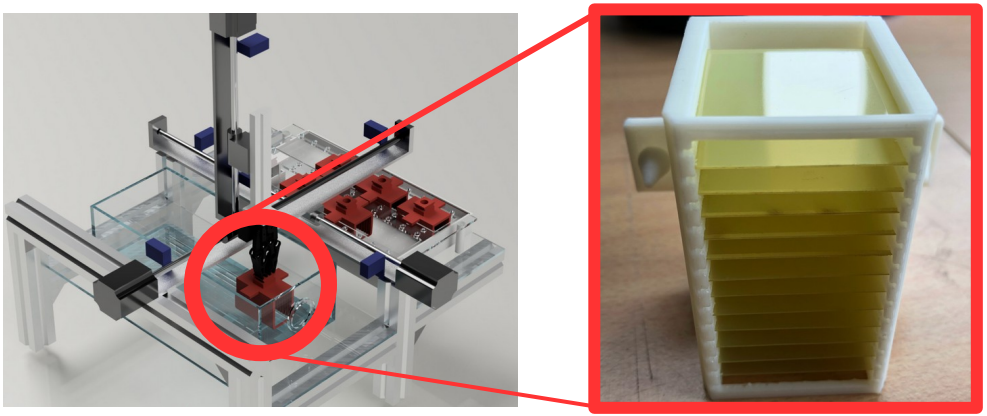


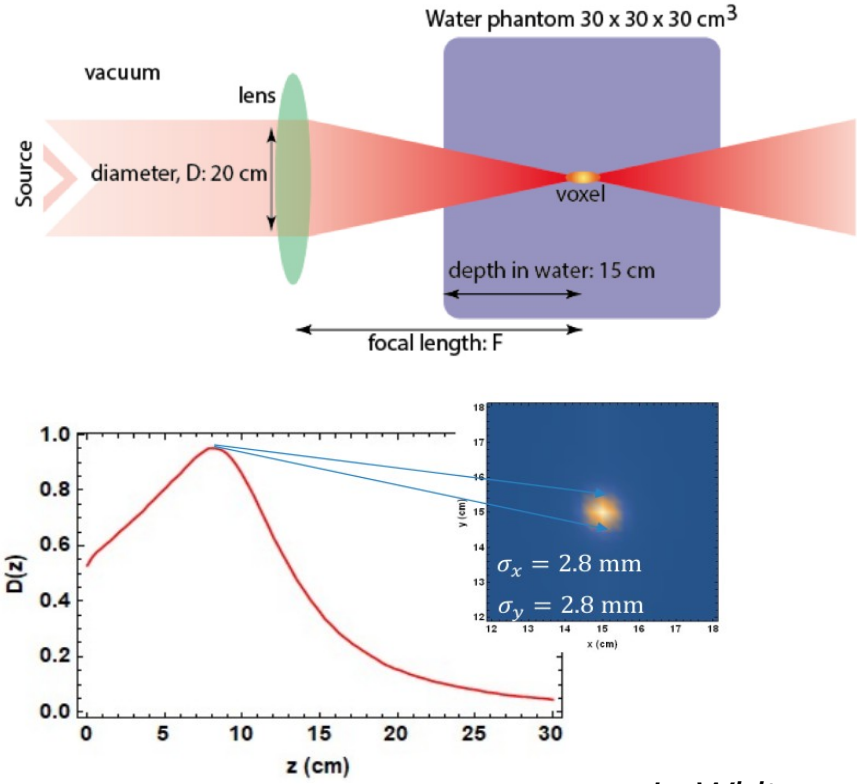
After irradiation

V. Rieker & J. Bateman

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.

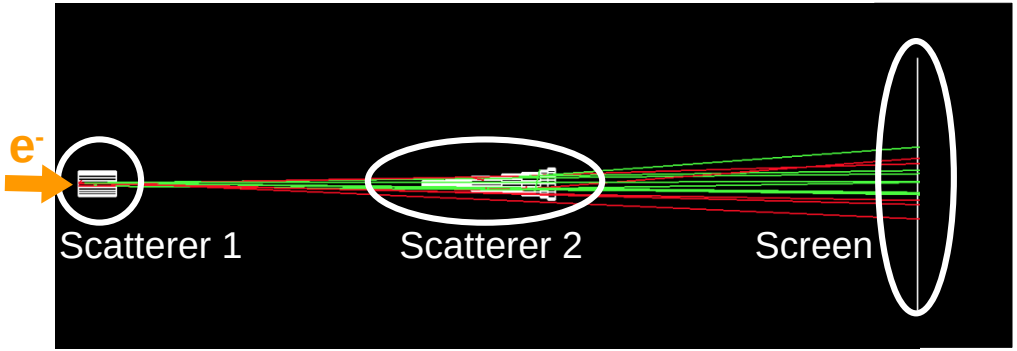


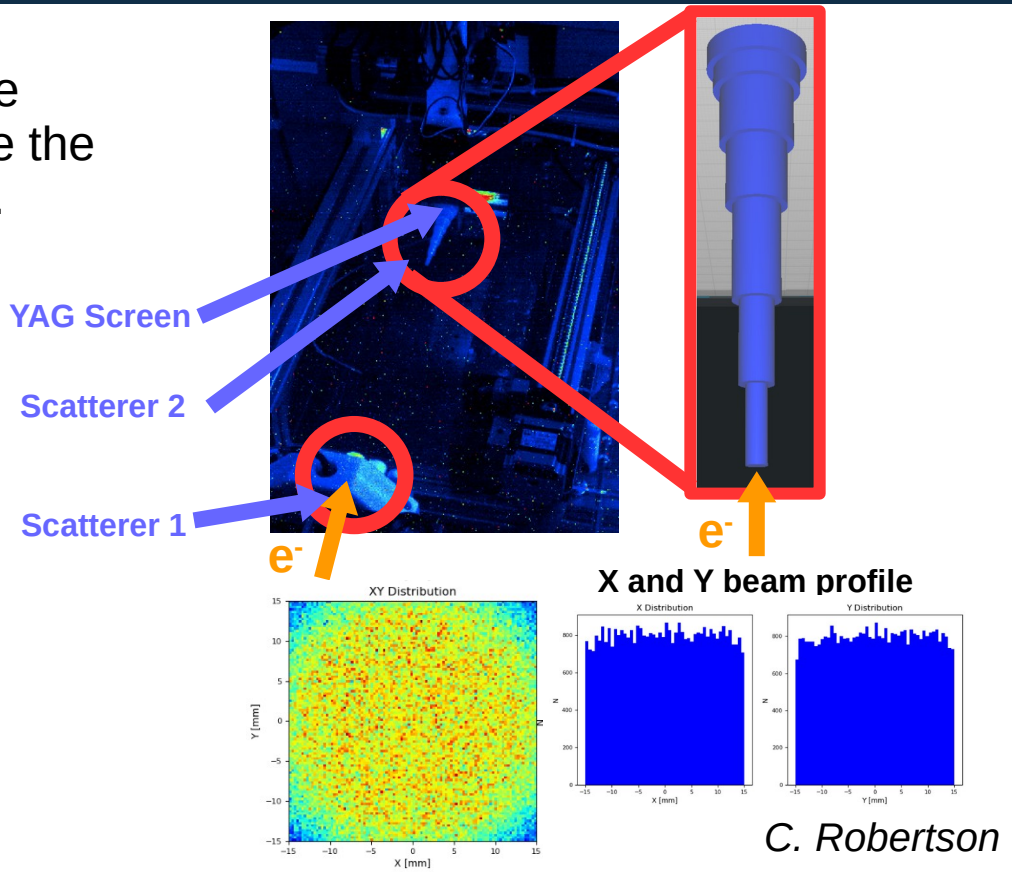


L. Whitmore

VHEE 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.

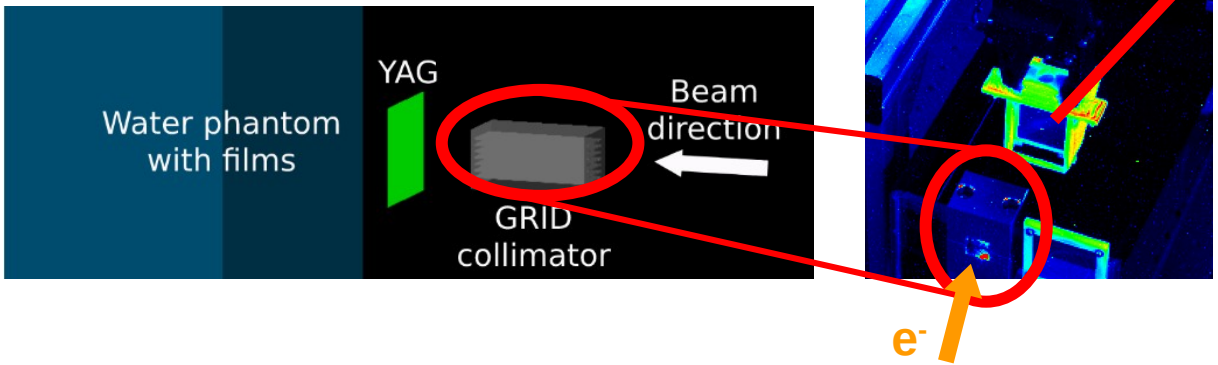


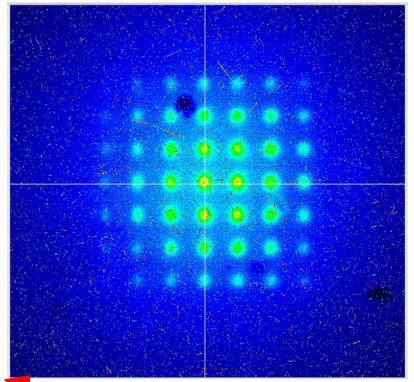


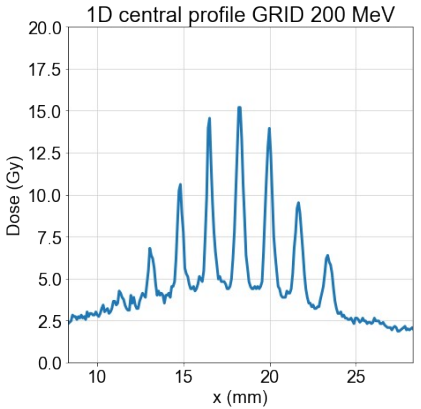
C. Robertson

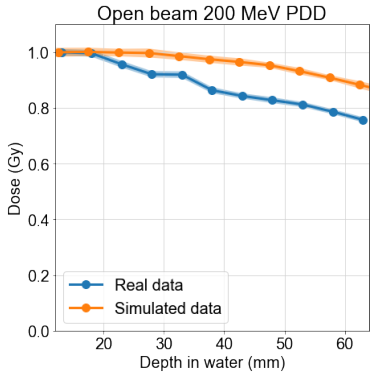
VHEE GRID

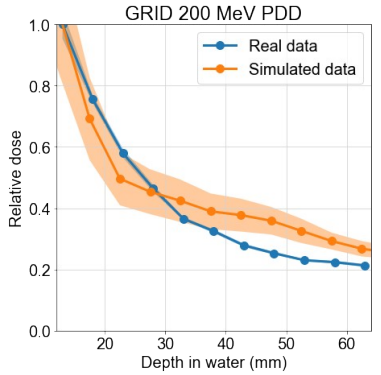
- **Goal:**
  Study the dose at UHDR for highly non-uniform dose distributions using a GRID Collimator (Spatially-fractionated RT, known for normal tissue sparing).
- **Experiment:**
  Compare the dose values and profiles with and without the GRID collimator inserted for different water depths, with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











N. Clements, N. Esplen & A. Hart

Selected Experiments planned in 2023

CLEAR EXPERIMENTS 2023

clear

- More than 30 experiments planned in CLEAR in 2023 including:

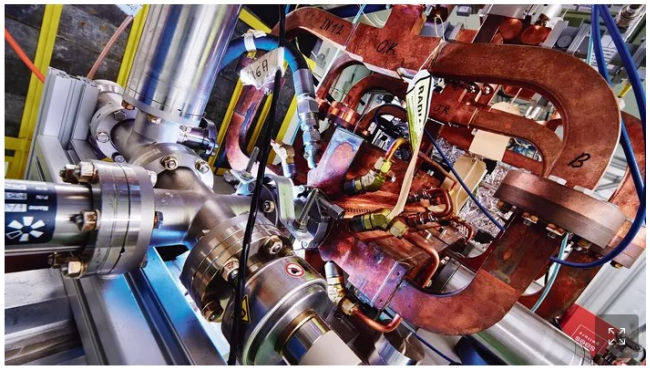
  - Comparison of different **neutron monitors**.
  - **Beam Profiler Detector** for the LUXE experiment.
  - **Plasmid Irradiations**.
  - **VHEE Detectors** and **Scatterers**.
  - **AWAKE** Cherenkov Diffraction Radiation **BPM**.
  - **Passive** and **Real-Time Dosimetry**.
  - **Uniform beam profile** generation.
  - **BBA, DFS corrections.**
  - **Large pattern microBPM** tests.
  - **Bunch Length Measurement** with ChDR-EOSD
  - **Plasma Lens** studies.
  - **EOS** for **FCC-ee.**
  - **VHEE UHDR Scintillator.**
  - And many more.

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



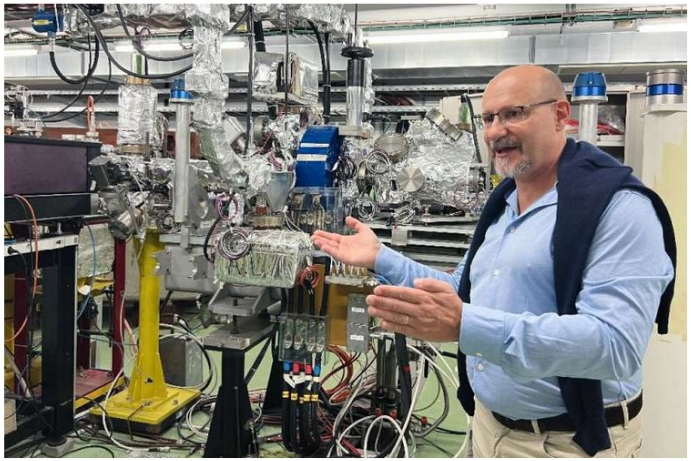
Située sur le campus du Cern, l'installation Clear est une technologie de pointe au service de l'innovation scientifique et médicale. *2020-2022 CERN*

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

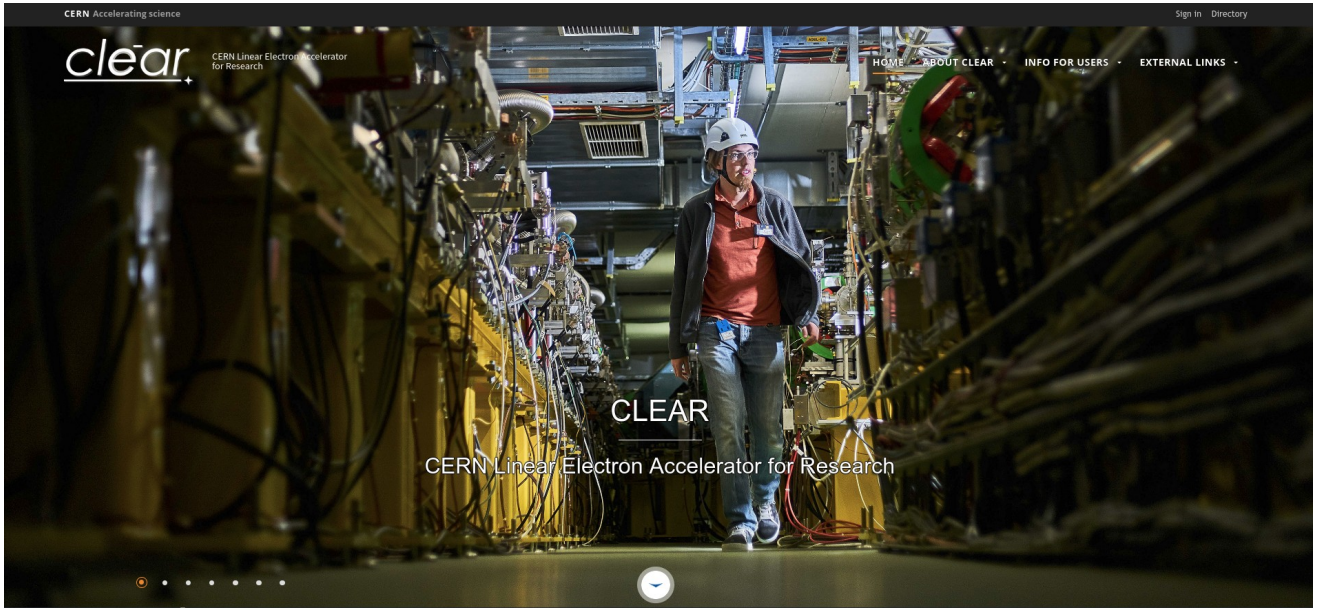
How do you kill hard-to-reach tumors? Particle physics is on the case.

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!



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

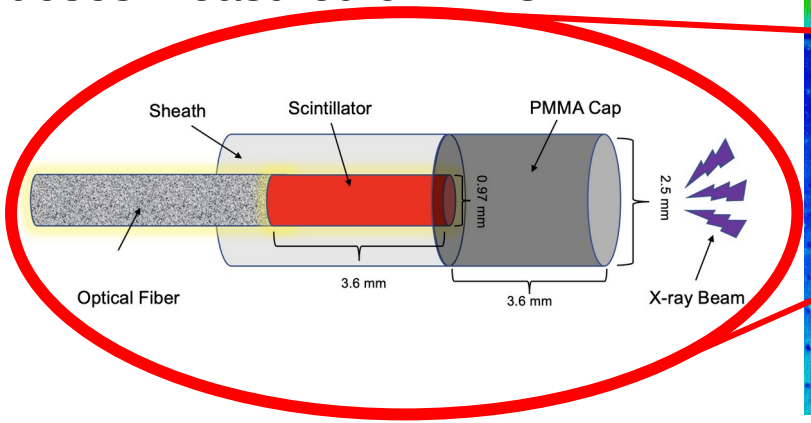
- **Really successful run** in CLEAR in 2022:
- **37 weeks of beam.**
- **CLEAR parameter ranges were increased** (beam charge, repetition rate, stability, beam size, etc.)
- **More than 25 different experiments** were performed.
- Leading to **18 conference proceedings**, **5 journal papers** (published or being reviewed), **7 PhD Thesis** (defended or being written) and **numerous presentations** at workshops and conferences.
- **More than 20 tours** of CLEAR were given in 2022 for students, artists, journalists, companies, CERN personnel, etc.
- **More than 30 experiments** are already planned for 2023.

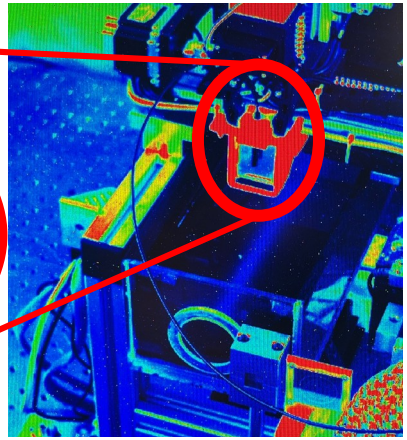
Thank you

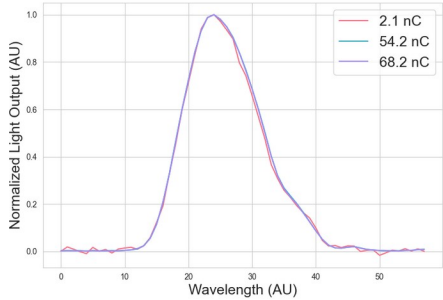
Extra Slides

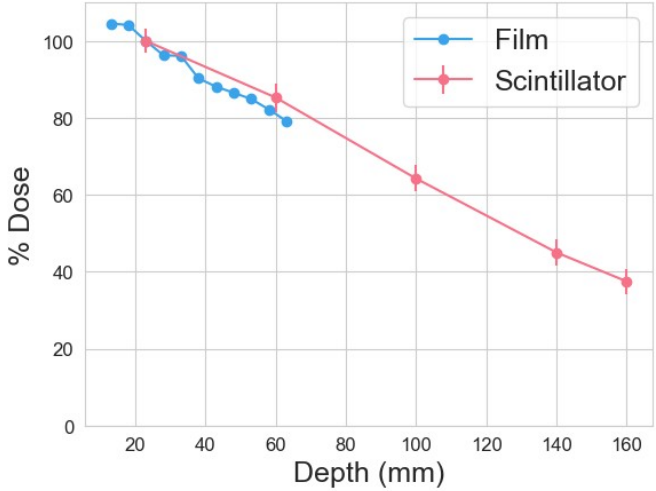
VHEE Scintillator Dosimetry

- **Goal:**
  Measure the dose at ultrahigh dose-rate with a real-time readout and a high spatial resolution thanks to a scintillator and an optica
- **Experiment:**
  Measure the responses of the scintillator for different doses and water depths and compare them with the doses measured on films.





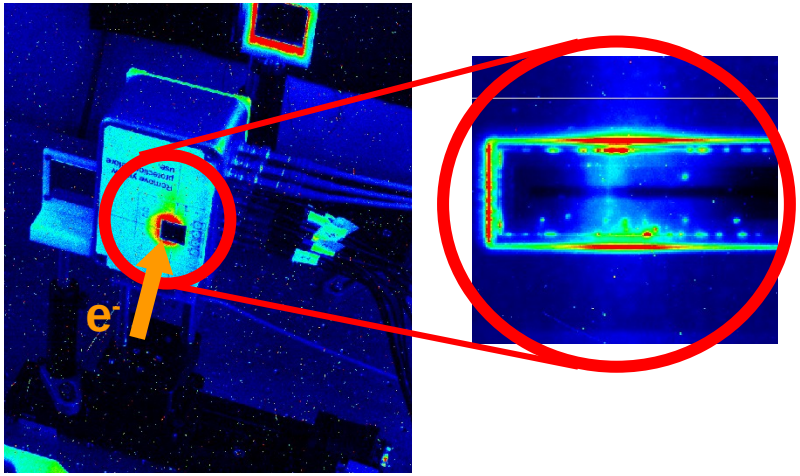


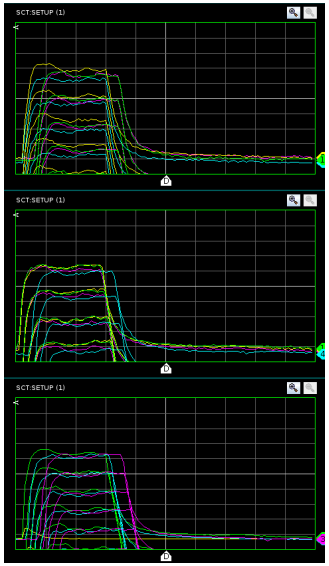


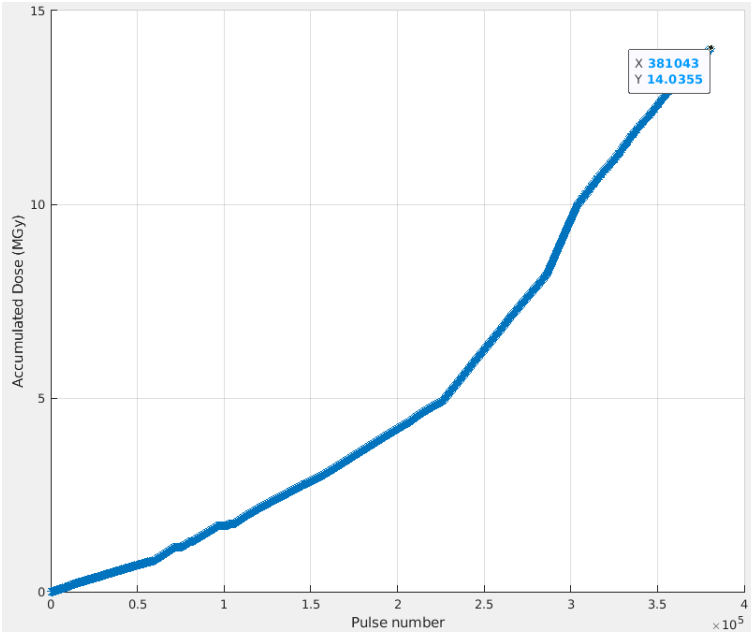
A. Hart & C. Giguère

LUXE Beam Profiler

- **Goal:**
  Test the Beam Profiler of the LUXE experiment (DESY).
- **Experiment:**
  Irradiate the probe with a beam spot area of 1 mm^2, a 2 nA beam to get a local dose rate of 1 MGy/hour.
  Repeat this 10 times for each sensor.





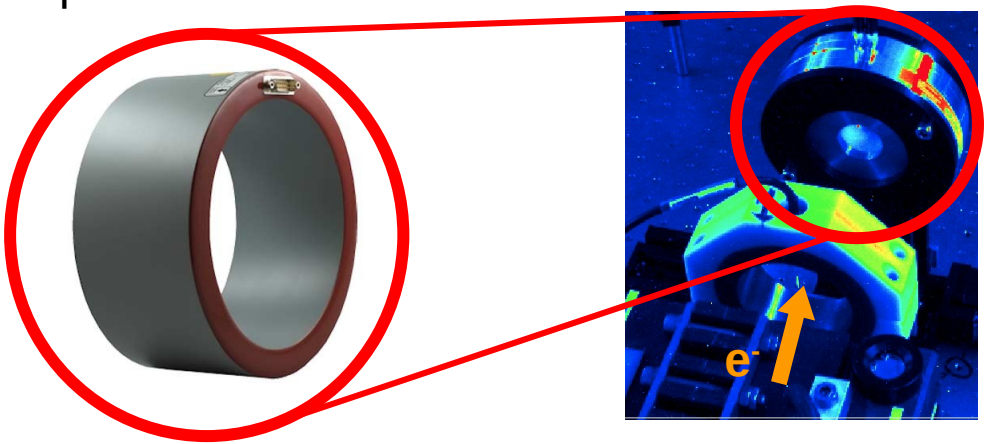


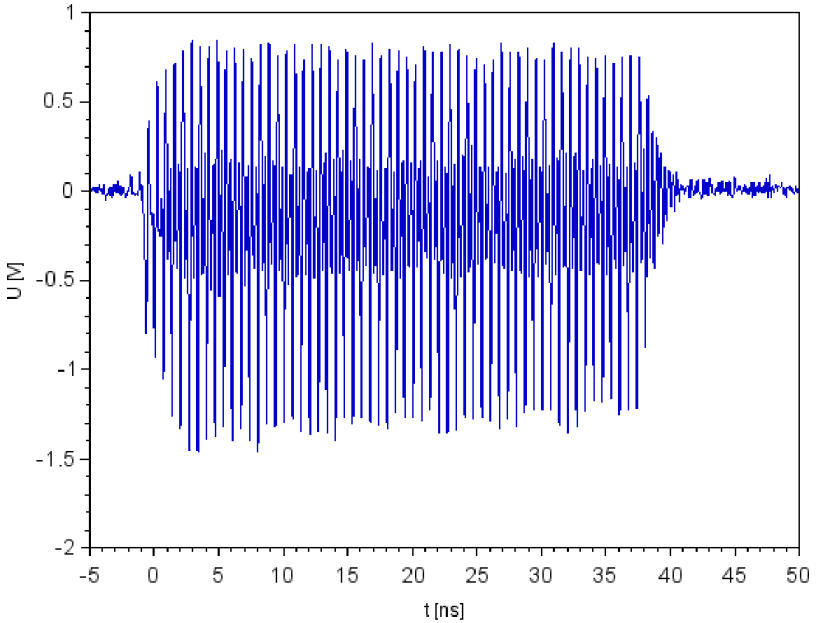
Total Charge delivered: 2.748 mC
Total Dose delivered: 14.0355 MGy
(Target = 14 MGy)

M. Bruschi & al.

Bergoz WCT

- **Goal:**
  Test the new Bergoz Wall Current Transformer (WCT), a newly developed diagnostics system for fast beam current monitoring.
- **Experiment:**
  Measure the response of the WCM for different number of bunches per pulses and transverse positions.



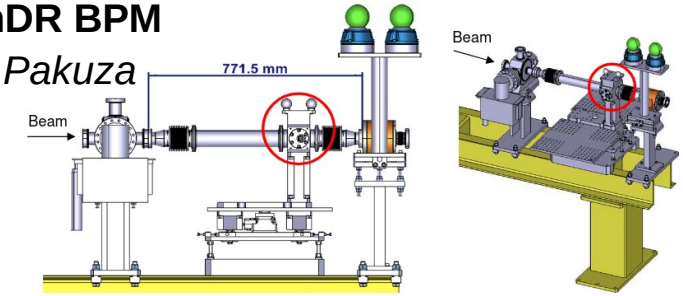


Macropulse of 60 bunches
1.5 GHz repetition rate.

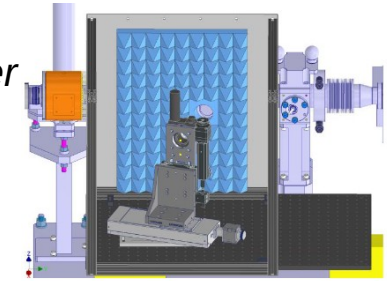
F. Stulle

More CLEAR Experiments in 2022

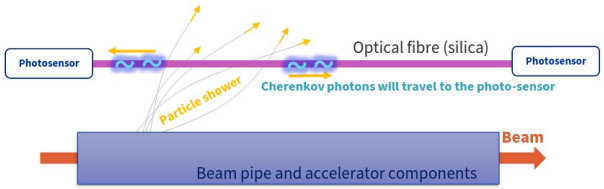
ChDR BPM
C. Pakuza



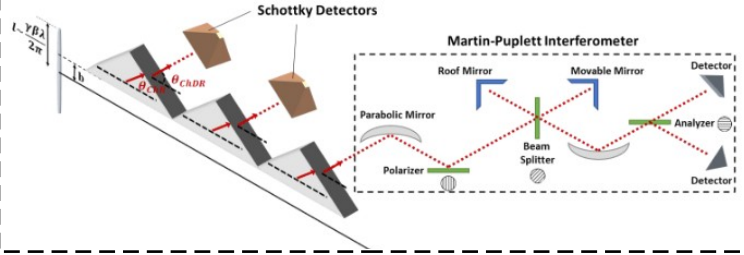
CChDR
A. Schloegelhofer



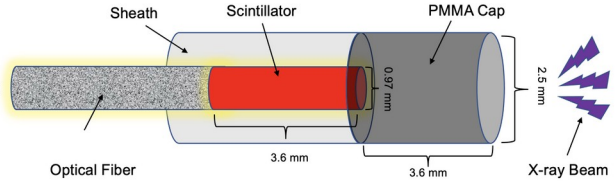
Beam Loss Monitors
S. Benítez



ChDR Bunch Length Measurements
C. Davut



Real Time Dosimetry
A. Hart & C. Giguère



VHEE UHDR Plasmids
M-C Vozenin, Kacem Houda