The CLEAR Facility and Program for the JUAS Practical Days

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JUAS Practical Days

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Outline

- CLEAR Beam Line: History & Parameters.
- Selected Experiments performed at CLEAR in 2024.
- JUAS Practical Days.

CLEAR Beam Line: History & Parameters

CLEAR Scientific and Strategic goals

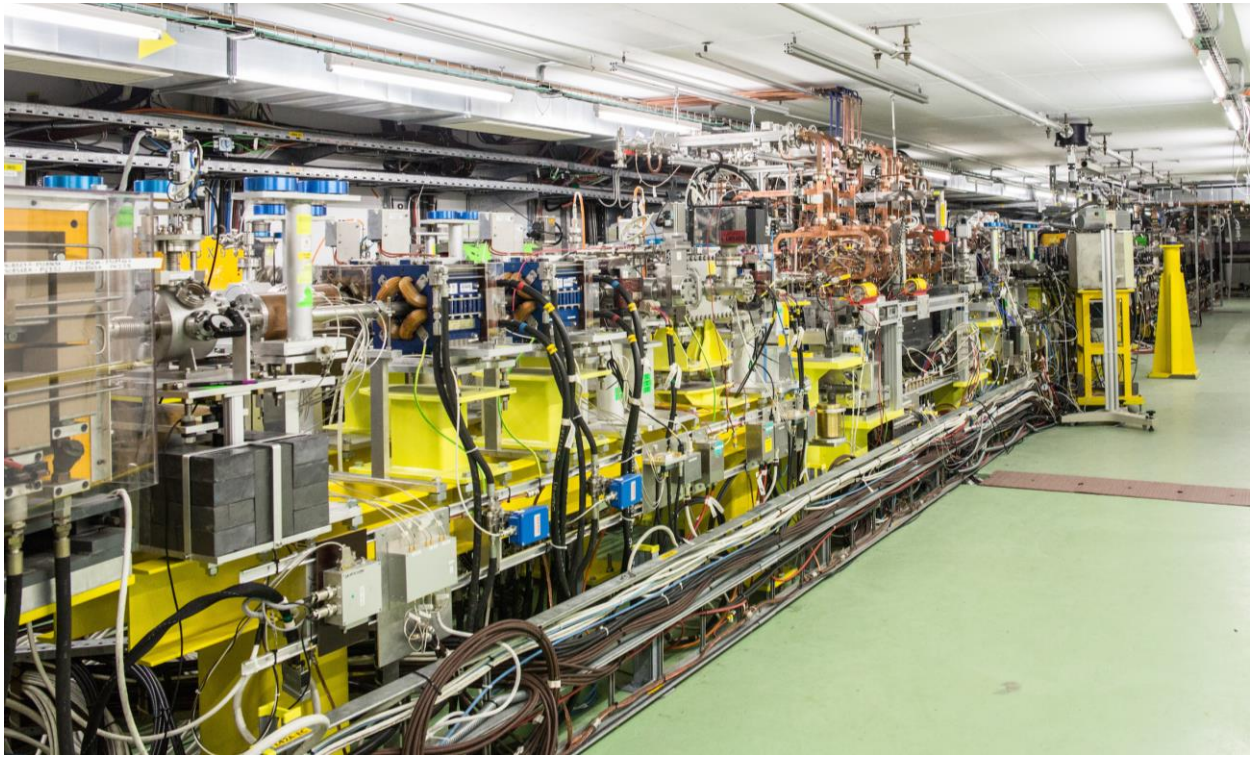
Scientific and strategic goals:

- 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.
- 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 (**including YOU!**).

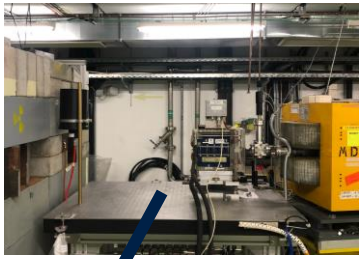
CLEAR is a versatile electron linac and an experimental beamline, operated at CERN as a multi-purpose user facility.

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 30 experiment.
- **2024** → 39 weeks of beam and 32 experiment.

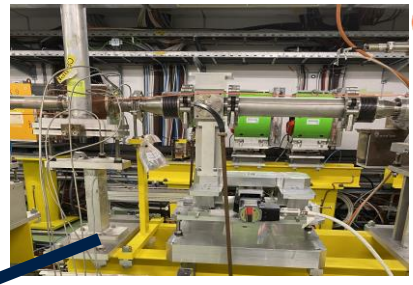


The CLEAR Beam Line in 2025

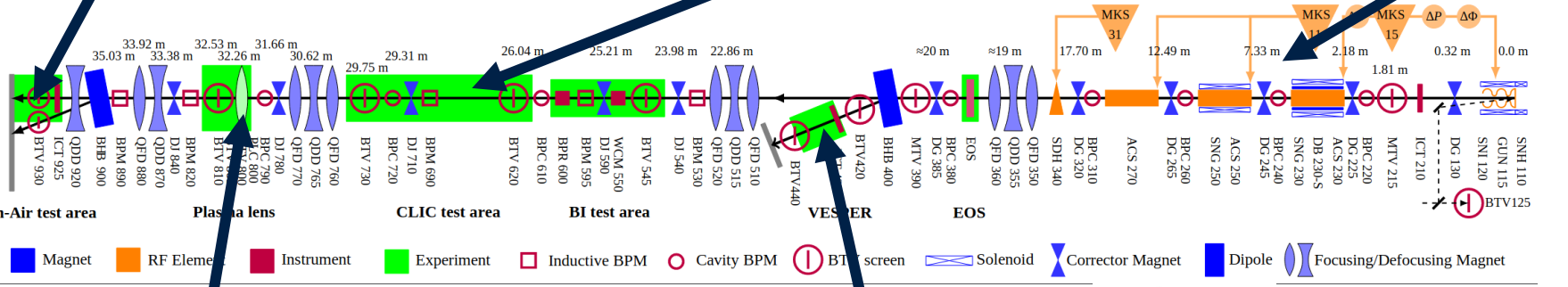


In-Air Test Stand

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

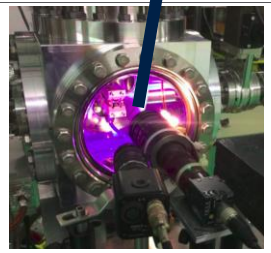


BI Test Stand



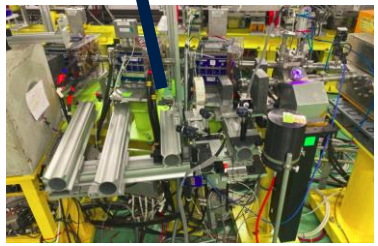
CLEAR Injector

- Flexible Linac
- 60 – 220 MeV



Plasma Lens

- Novel plasma based focusing

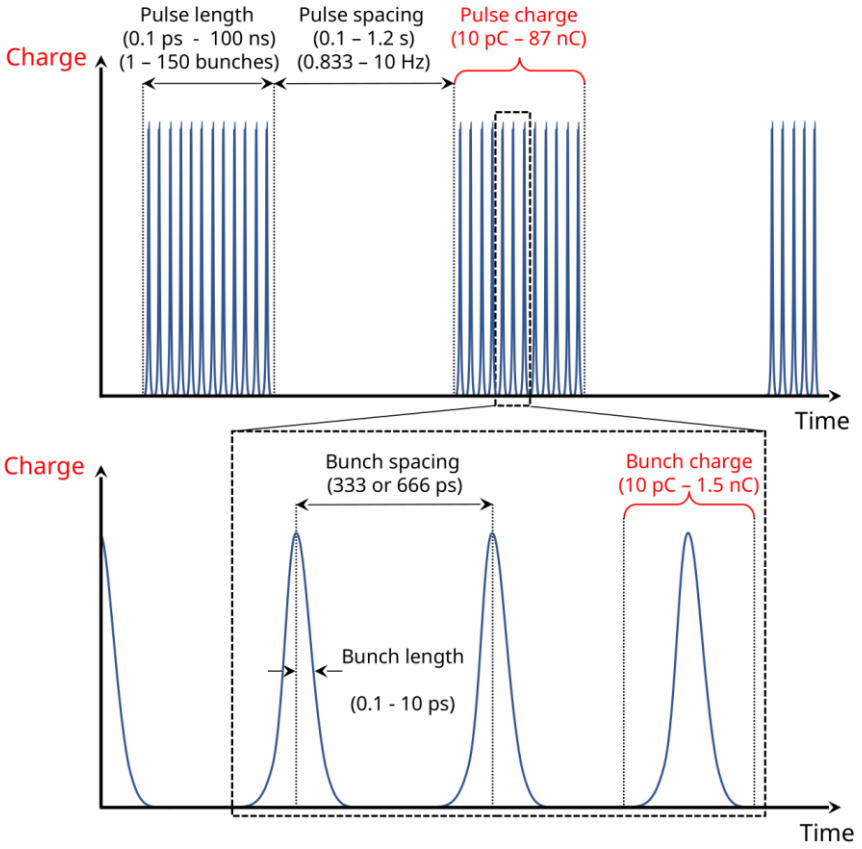


VESPER

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

CLEAR Beam Parameters in 2024

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	**87 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 2024 Program

Experiment #	Experiment	Institute
1	**Machine Development (BBA, BPMs, ML, etc.)**	CERN
2	**Uniform Beam Delivery for VHEE**	CERN/University of Oxford
3	**Joint Universities Accelerator School**	ESI
4	**EURO-LABS Advanced School**	IEM-CSIC/CERN
5	**Hollow Core Fibres**	CERN/RUG
6	**Wall Current Monitor Tests**	Bergoz Instrumentation
7	**Electro-Optical Longitudinal Bunch Profile Monitor for FCC-ee**	KIT
8	**VHEE at UHDR Studies with Biodosimeters**	HUG
9	**Plan Delivery to an Anatomical Phantom**	University of Manchester
10	**Beam Scanning Spatially Fractionated RT Studies**	University of Victoria
11	**VULCAN Target-Moderator-Reflector System Studies**	DAES
12	**Dosimetry Studies for VHEE**	CERN
13	**VHEE at UHDR Studies with Drosophilae**	University of Victoria/EPFL
14	**Resonance of the Internal Clock the Electron Studies**	IJCLab
15	**Sapphire Detector Studies for LUXE**	CERN/INFN
16	**Screen Studies for AWAKE Spectrometer**	CERN/UCL
17	**Gold Nanoparticles Plasmid Studies**	Manchester University
18	**VHEE at UHDR Studies with Cells**	HUG
19	**Fibre Beam Loss Monitor Studies**	CERN/University of Liverpool
20	**Plasma Lens Studies**	University of Oslo
21	**Digital Micro-mirror Device OTR Studies**	University of Liverpool
22	**Micro-Lens Array OTR Studies**	University of Liverpool
23	**VHEE Material Irradiation Studies**	University of Victoria
24	**Passive Streaking for Temporal Diagnostics**	CERN
25	**Radio-Enhancement Effect Studies of Nanoparticles**	Institut Gustave Roussy
26	**ChDR EOSD Studies**	CERN
27	**EOSD In-Air Studies**	CERN
28	**Detector Irradiation Studies for LUXE**	CERN/INFN
29	**Real-Time Dosimetry Studies with Cuvettes**	University of Strathclyde
30	**Chromox Screen Studies**	University of Sheffield
31	**flashDiamond Detector Studies**	Rome “La Sapienza” University
32	**Machine Learning Studies**	University of Naples, Federico II

Selected Experiments performed at CLEAR in 2024:

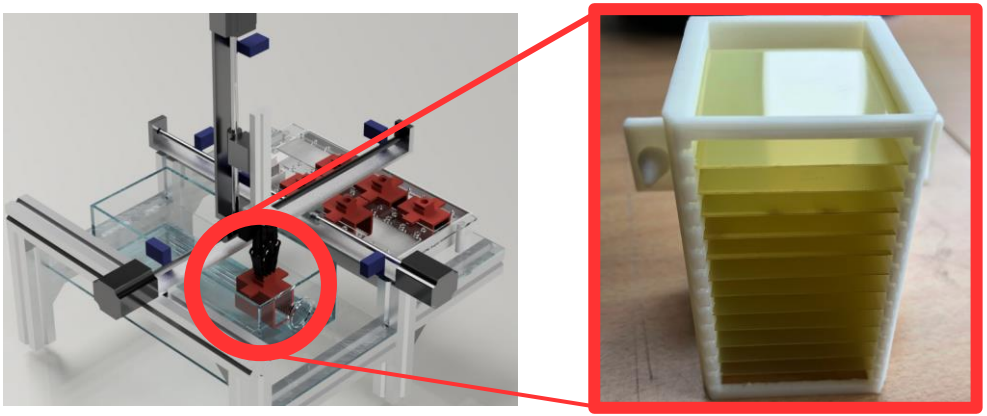
VHEE Strong Focusing

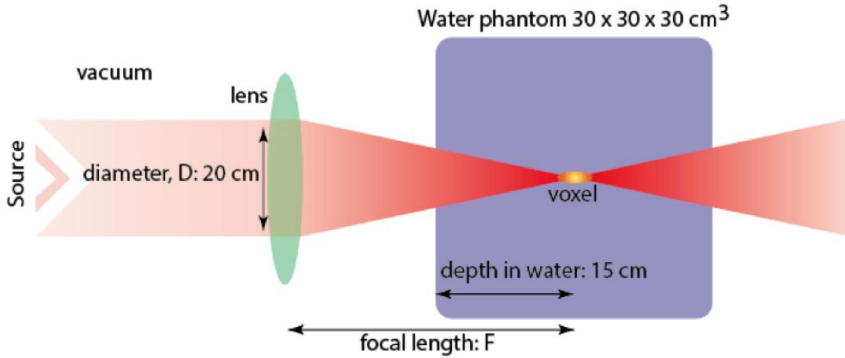
Goal:

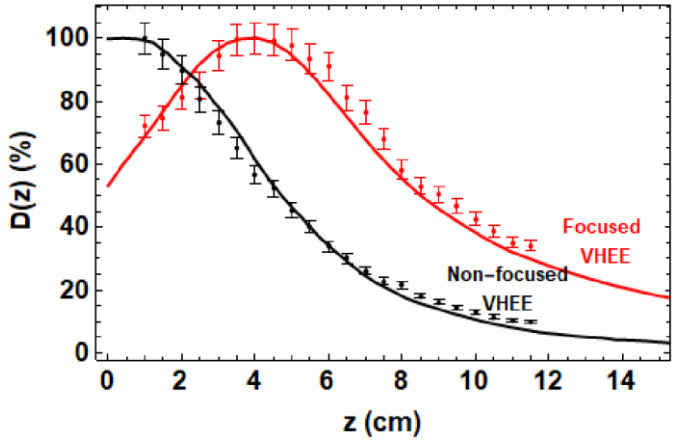
Focus the beam on the tumor to minimize the dose and damage on the nearby healthy tissues.

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 et al, 2024 Nature Scientific Reports

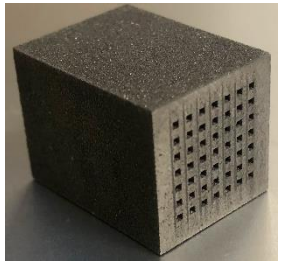
VHEE GRID

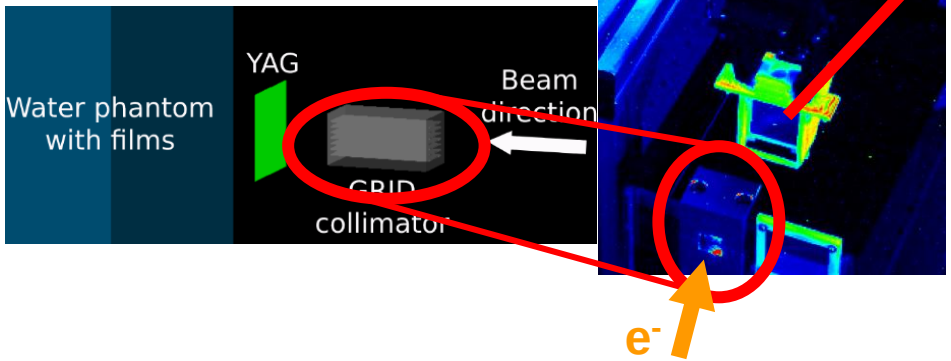
Goal:

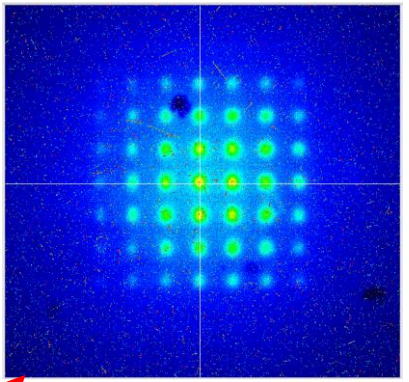
Study the dose at UHDR for highly non-uniform dose distributions using a GRID Collimator (Spatially-fractionated RT, known for normal tissue sparing).

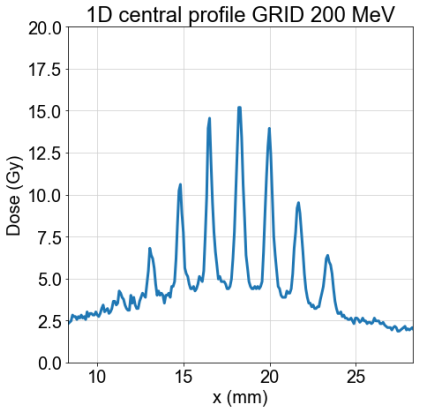
Experiment:

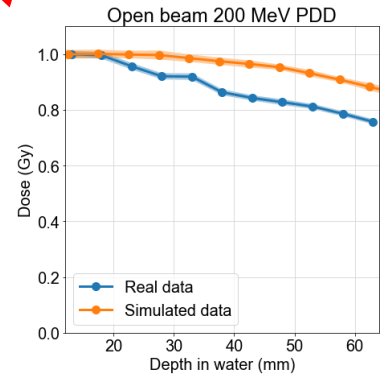
Compare the dose values and profiles with and without the GRID collimator inserted for different water depths, with the YAG screen and films.

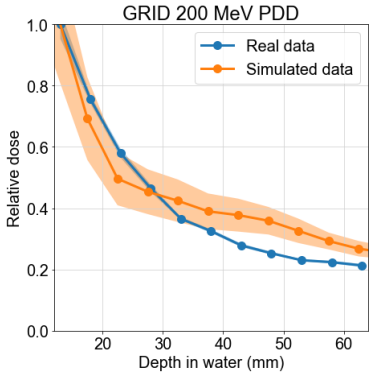












N. Clements *et al* 2024 *Phys. Med. Biol.*

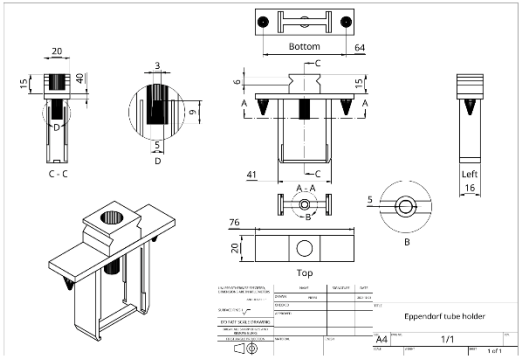
Zebra Fish Eggs Irradiations

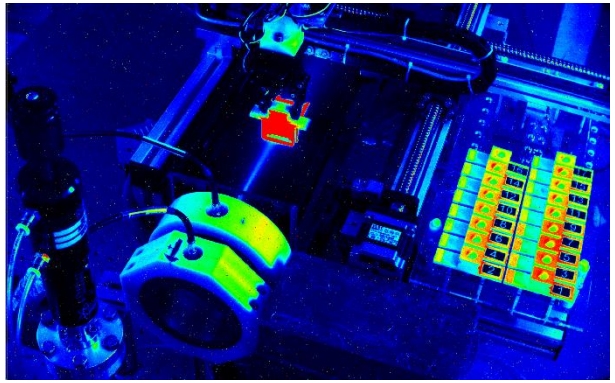
Goal :

Measure the response effect of the dose and the dose rate on Zebra Fish Eggs (ZFE) with VHEE.

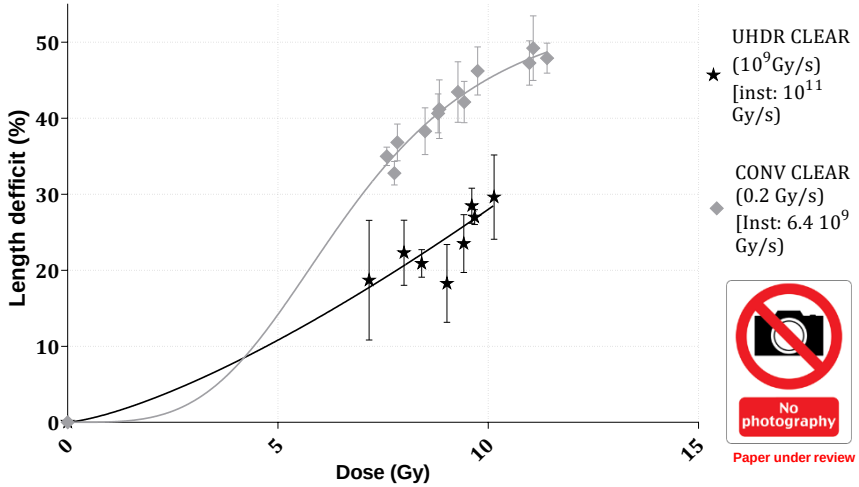
Experiment :

Irradiate ZFE with numerous doses and dose rates: UHDR (Ultra High Dose Rate) and CDR (Conventional Dose Rate) and measure the length defficit.





Preliminary results



Paper under review

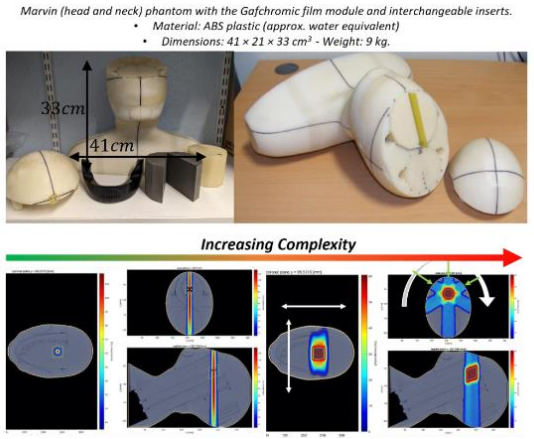
M-C Vozenin & J. Ollivier

Medical Applications done in 2024

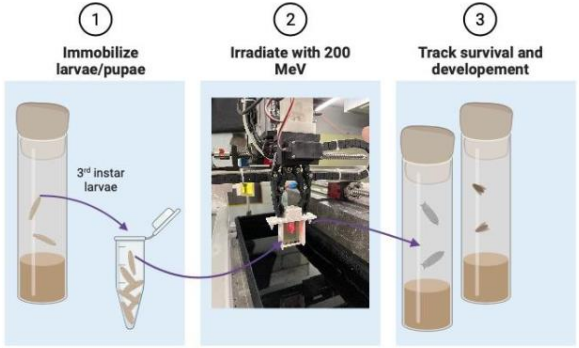
VHEE at UHDR Studies with Liposomes
VHEE at UHDR Studies with Biodosimeters
VHEE at UHDR Studies with Short Peptides & LCMS
VHEE at UHDR Studies with Cells

Goal: explore dose and dose rate parameters for both healthy and cancerous cells.

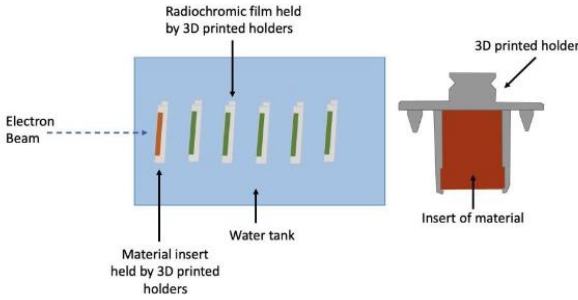
Plan Delivery to an Anatomical Phantom



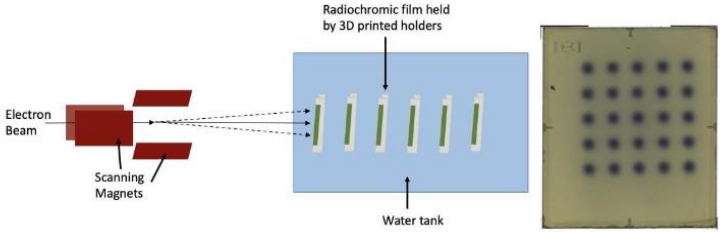
VHEE at UHDR Studies with Drosophilae



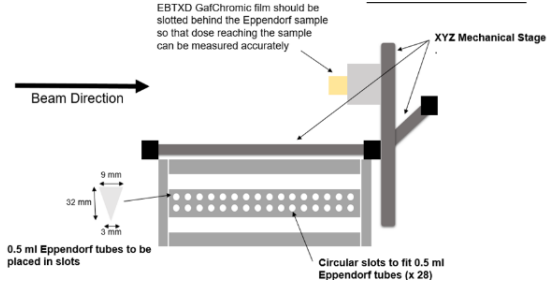
VHEE Material Irradiation Studies



Beam Scanning Spatially Fractionated RT Studies



Radio-enhancement effect of Nanoparticles in VHEE beams & Gold Nanoparticles Plasmid Studies

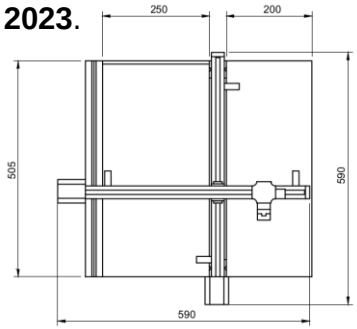


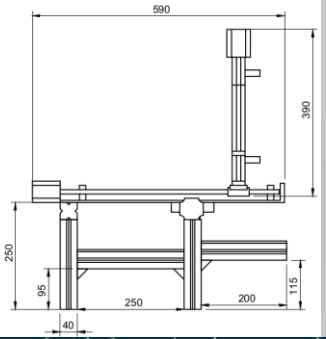
Tools and Methods used for Irradiations

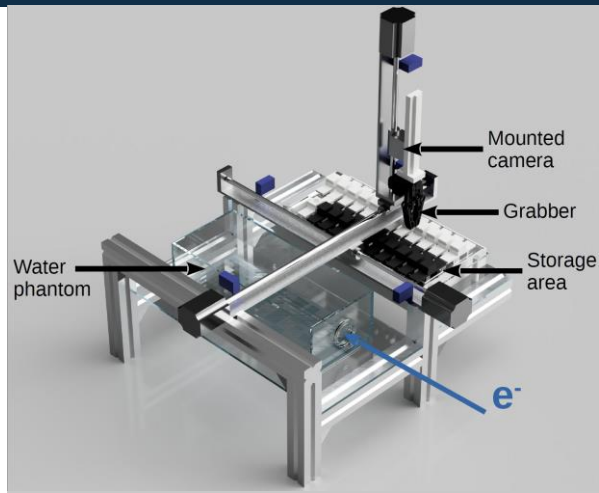
The C-Robot

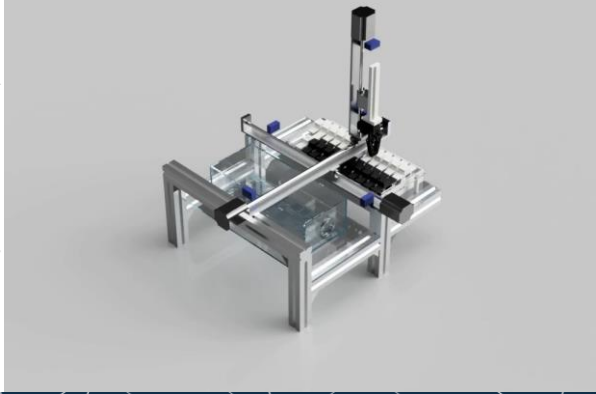
- In order to **facilitate** the **precise control** of **samples** for **multiple irradiations**, the CLEAR-Robot (**C-Robot**) was designed and built by members of the CLEAR Operation Team.
- It consists of **3 linear stages**, **6 limit switches**, a **3D-printed grabber**, **two water tanks** and 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
- Used for **100% of Medical Applications** in CLEAR in **2023**.

C-ROBOT



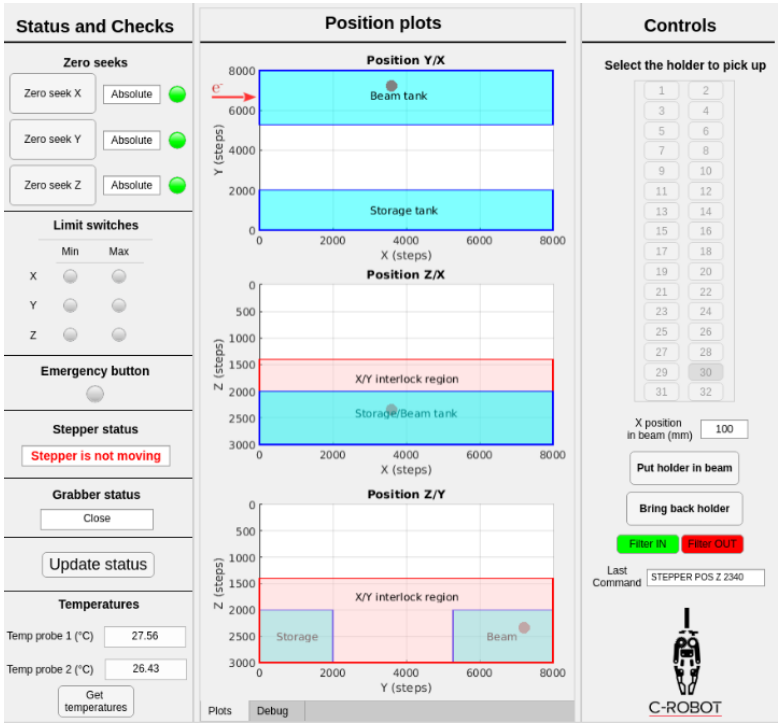




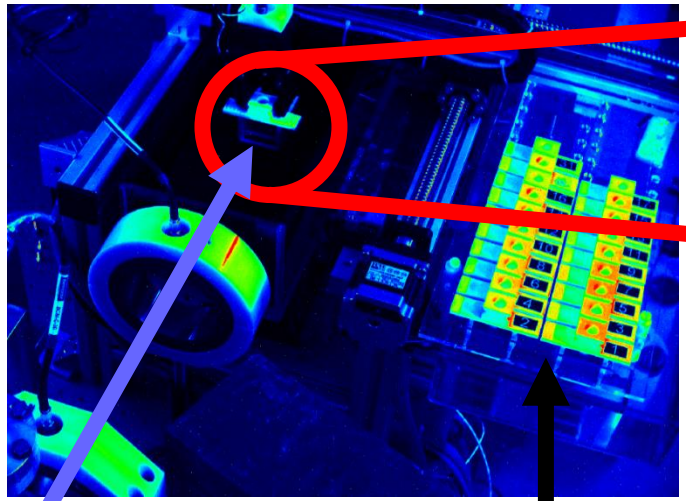


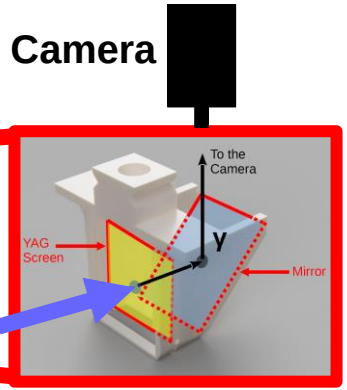
What can the C-Robot do?

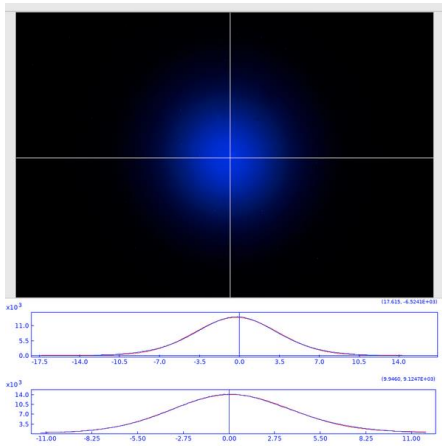
Graphical User Interface



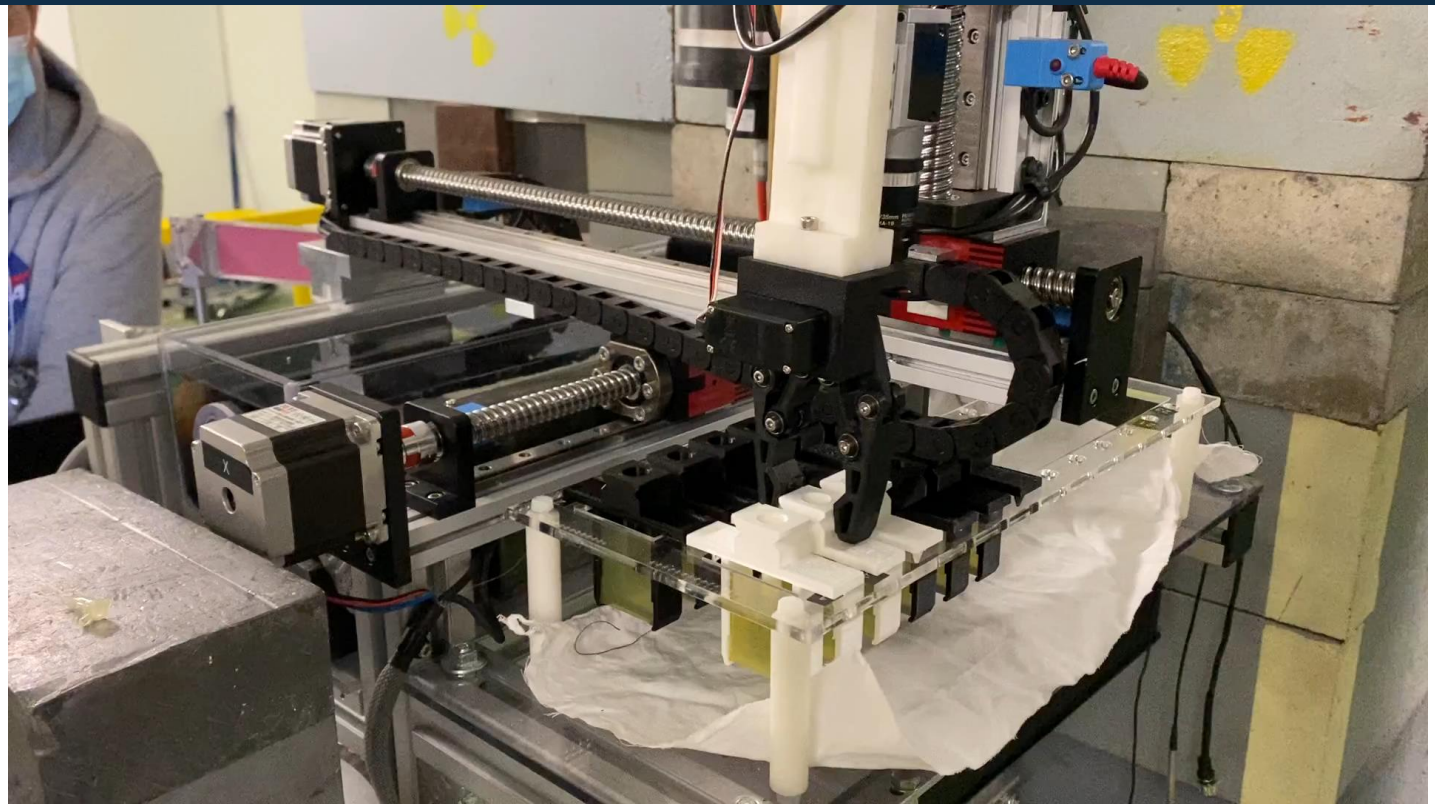
Experiment setup w/ beam







The C-Robot in action in CLEAR



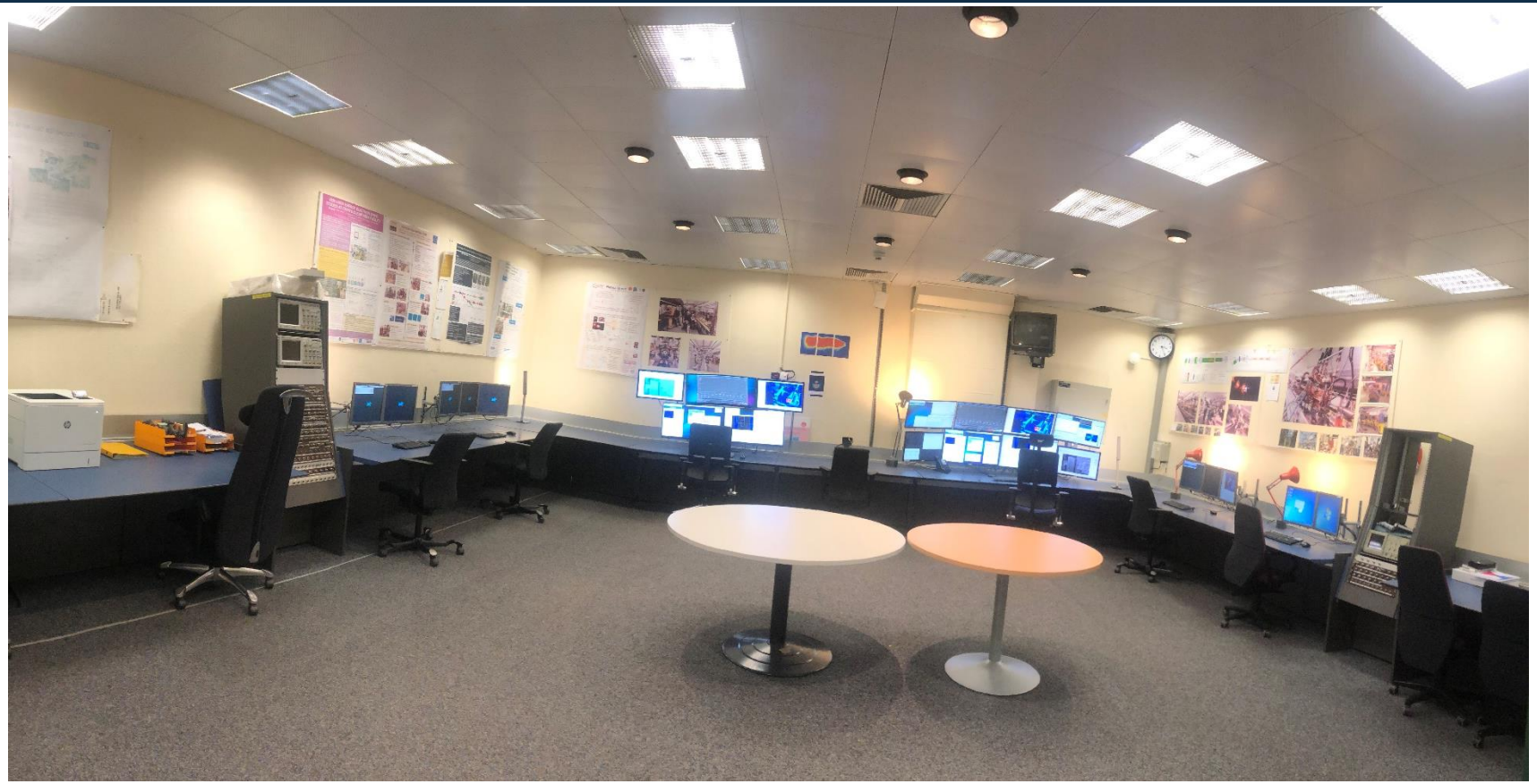
[Link to Video]

Practical Days

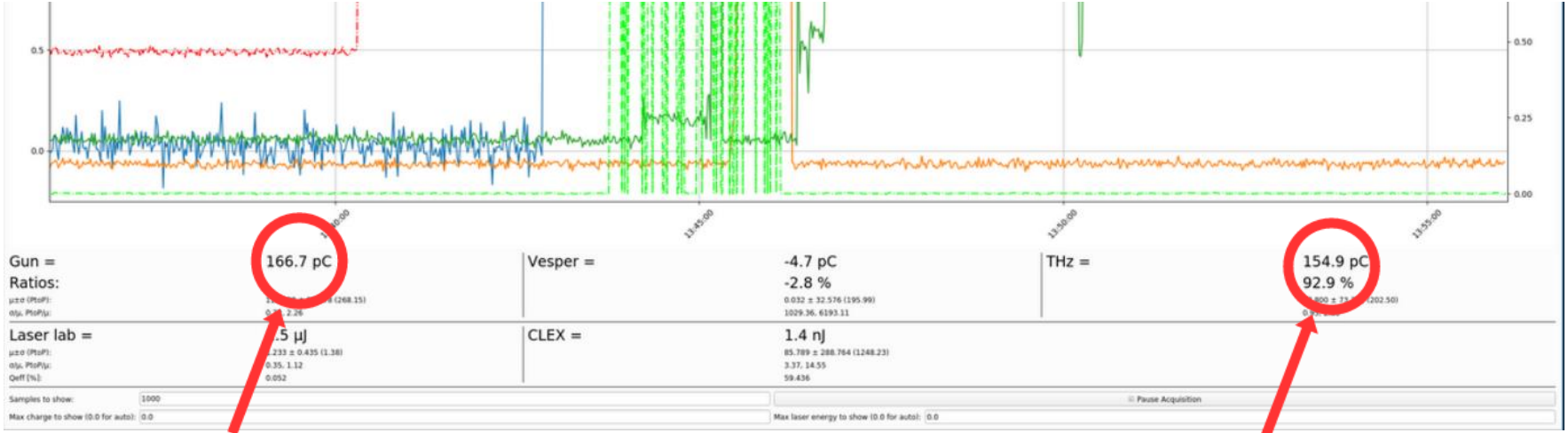
What will you do?

- **Start** the CLEAR **RF**, **optimise phases** and **send** the **laser** to the **photocathode.**
- **Measure** the **beam energy** thanks to the spectrometer line.
- **Transport** and **align** the beam from the electron gun to the end of the machine using the beam instrumentation devices along the line and the steering magnets.
- **Measure** the **beam charge** with the Integrating Current Transformers.
- **Measure** the **beam position** and **size** with scintillating screens and cameras.
- **Perform quadrupole scans** to measure the emittance and the Twiss parameters.
- **Measure** the **photo-cathode quantum efficiency**.
- **Use** the C-Robot to **irradiate samples**.
- **Operate** the accelerator from start to end.

The CLEAR Control Room



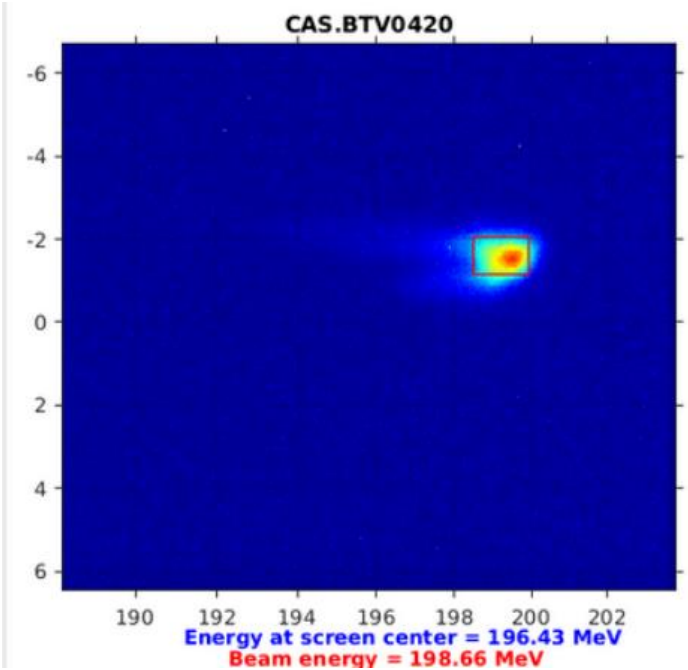
Beam charge measurement and transport



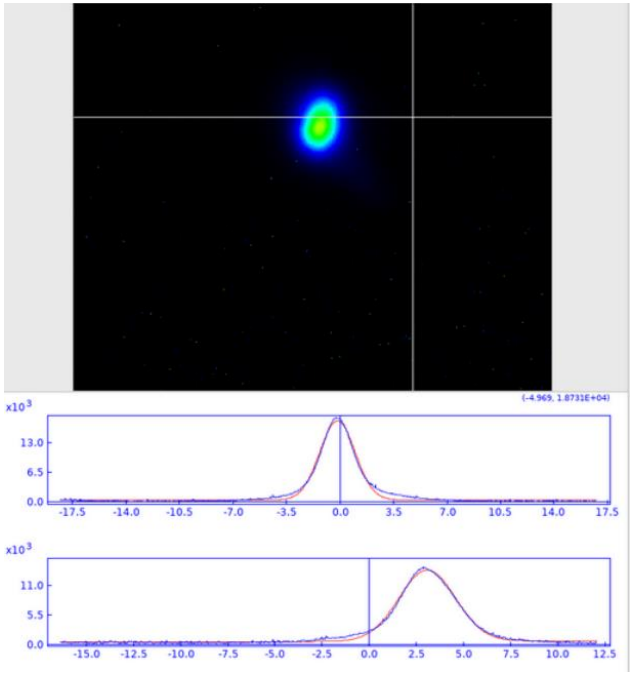
Beginning of the line:
Beam charge = 167 pC

End of the line:
Beam charge = 155 pC
Beam transport = 93 %

Beam Energy and Transverse Profile

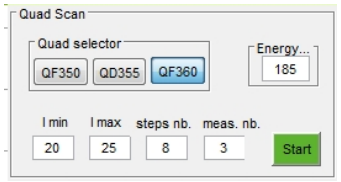


Measurement of the beam energy with the spectrometer line (VESPER)



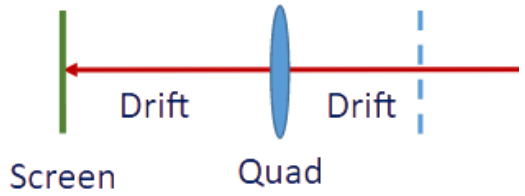
Measurement of the beam profile, position and size at the end of the line (THz)

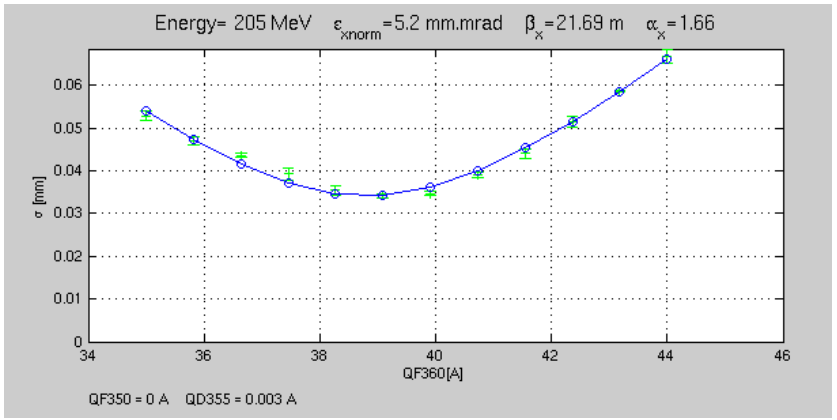
Quadrupole Scans



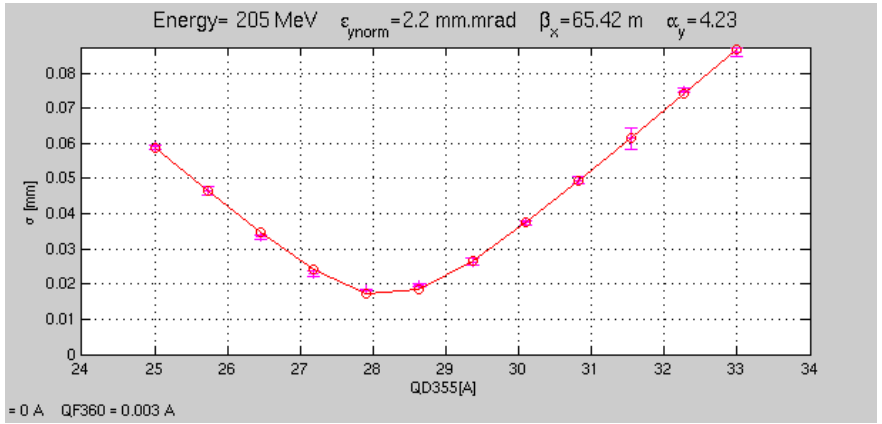
$$\begin{pmatrix} \beta_s & -\alpha_s \\ -\alpha_s & \gamma_s \end{pmatrix} = \begin{pmatrix} A_{0S} & B_{0S} \\ C_{0S} & D_{0S} \end{pmatrix} \begin{pmatrix} \beta_0 & -\alpha_0 \\ -\alpha_0 & \gamma_0 \end{pmatrix} \begin{pmatrix} A_{0S} & C_{0S} \\ B_{0S} & D_{0S} \end{pmatrix}$$

$$\begin{pmatrix} \beta_{s,1} \\ \beta_{s,2} \\ \vdots \\ \beta_{s,n} \end{pmatrix} \epsilon = \begin{pmatrix} A_1^2 & -2A_1B_1 & B_1^2 \\ A_2^2 & -2A_2B_1 & B_2^2 \\ \vdots & \vdots & \vdots \\ A_n^2 & -2A_nB_n & B_n^2 \end{pmatrix} \begin{pmatrix} \beta_0 \\ \alpha_0 \\ \gamma_0 \end{pmatrix} \epsilon$$



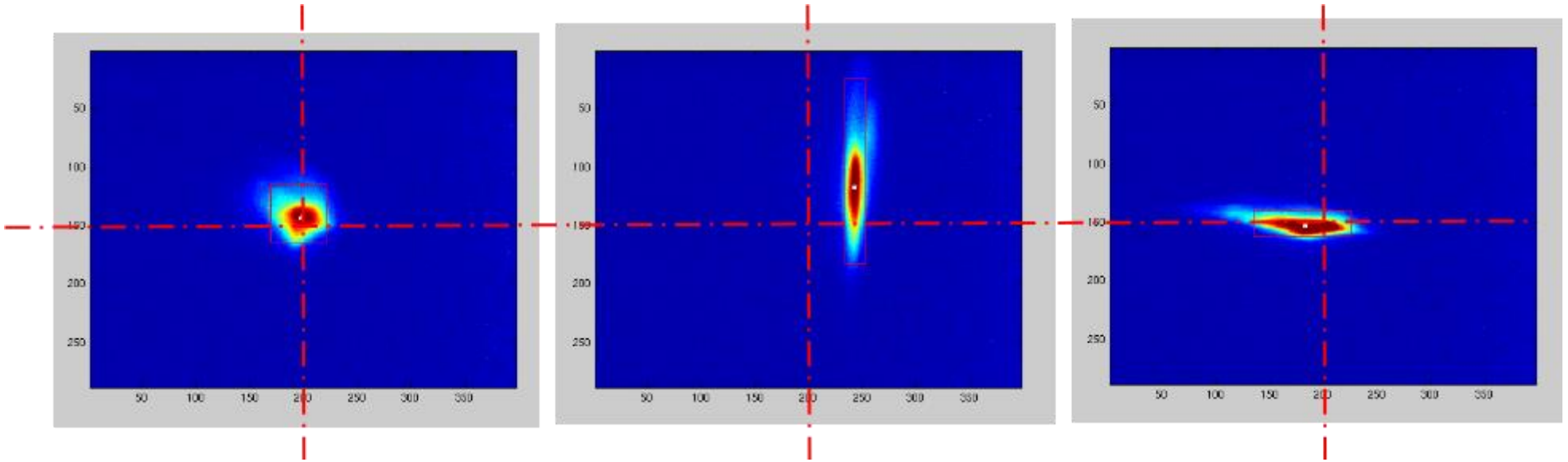


Horizontal beam size as a function of the quadrupole current



Vertical beam size as a function of the quadrupole current

Alignment of the beam in the quadrupoles

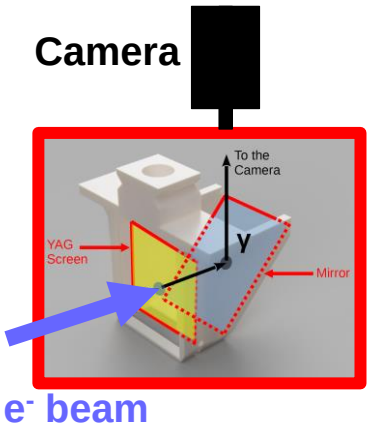


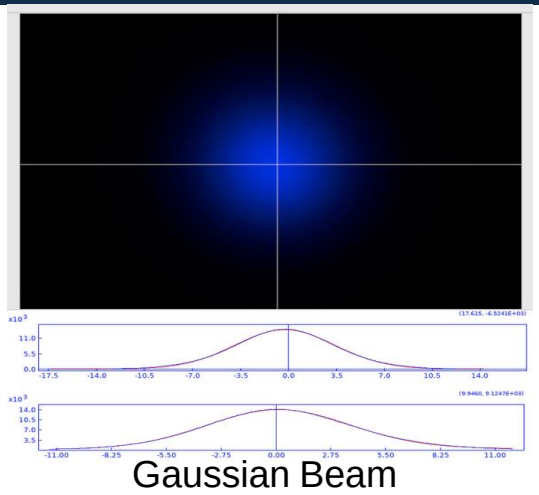
Quads Off

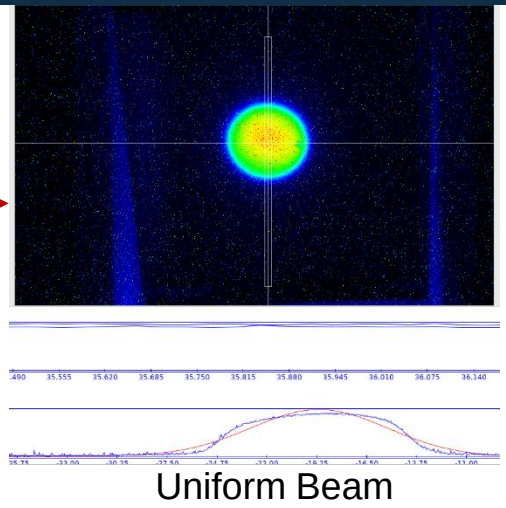
Horizontal focusing quad with beam offset in both axis

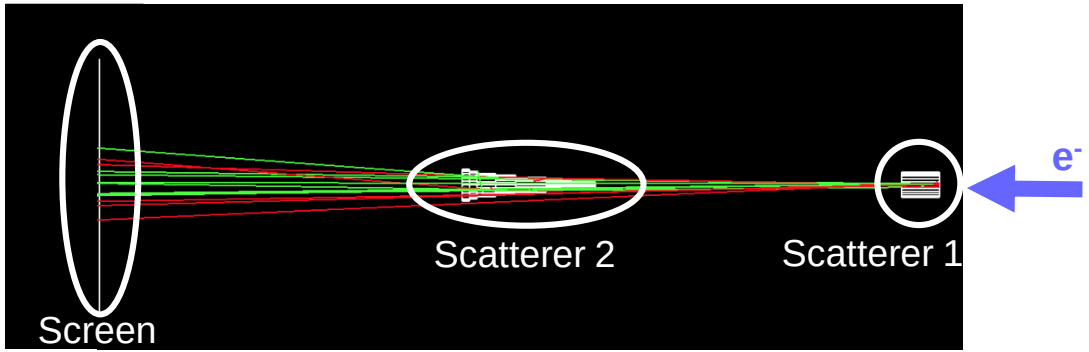
Vertical focusing quad with Horizontal beam offset

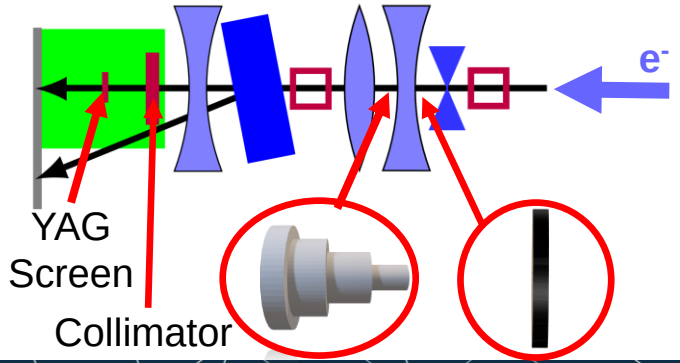
Obtain a Uniform Beam



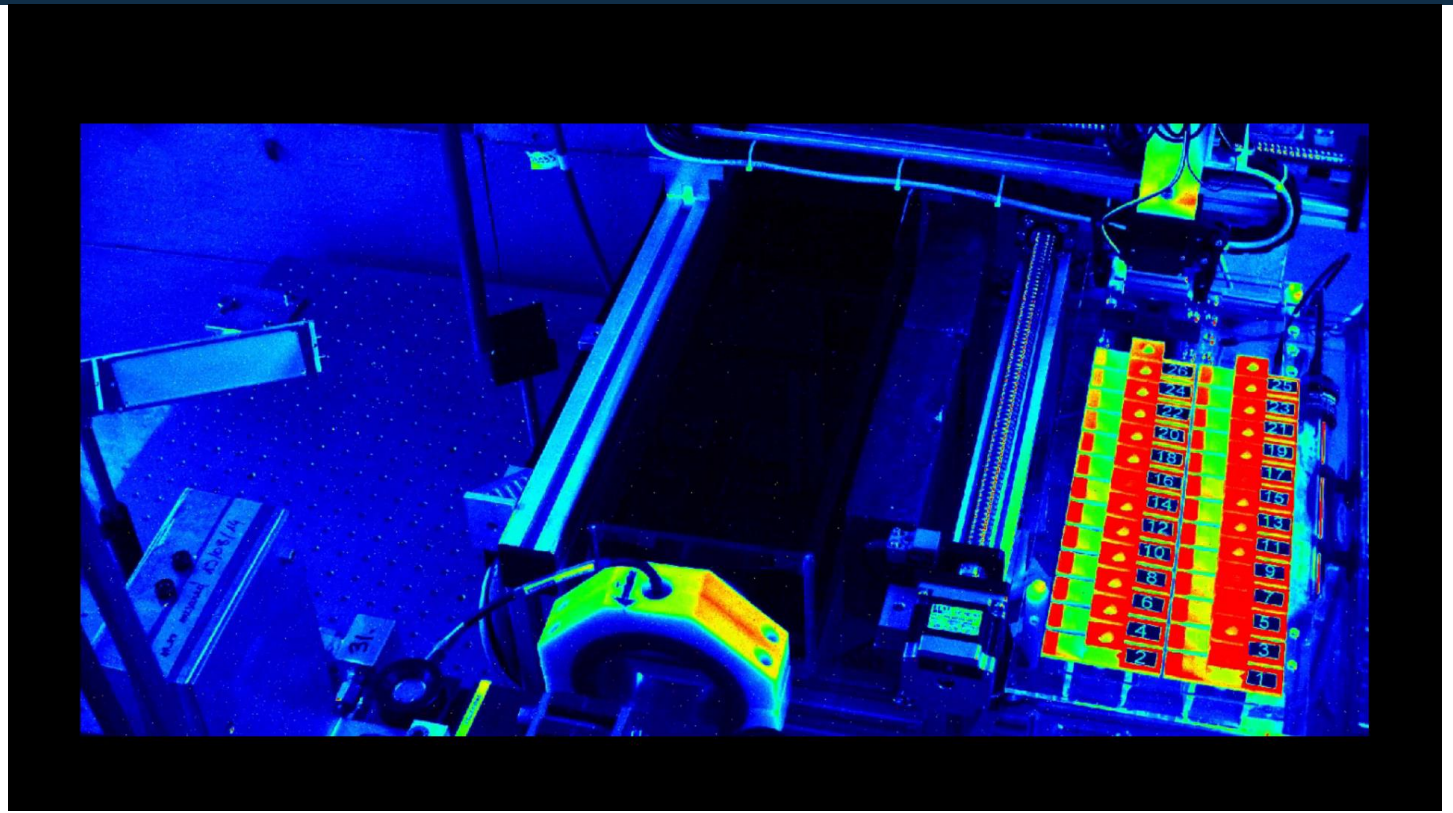

Gaussian Beam


Uniform Beam



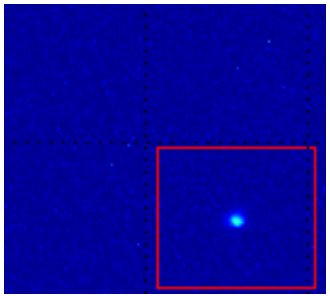


Irradiate Samples

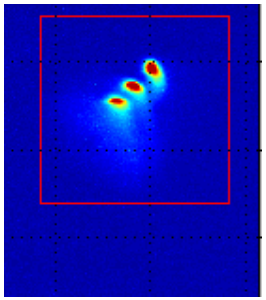


[Link to Video]

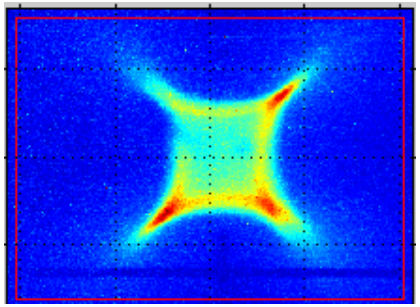
Beam Shape Contest: Take part !



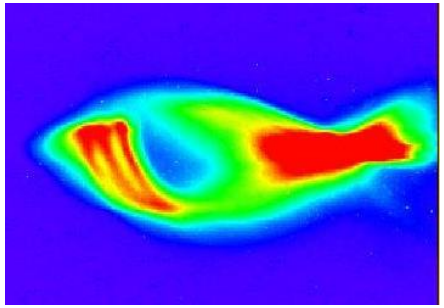
Smallest beam: 37 um x 33 um



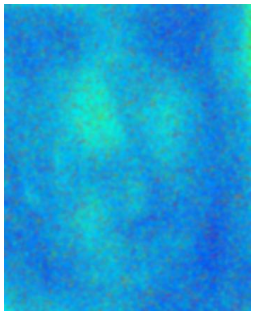
3 bunches with transverse space separation



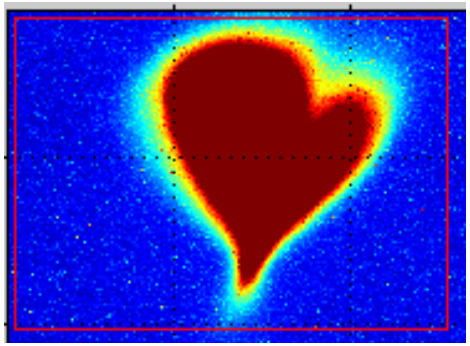
Octupolar fields



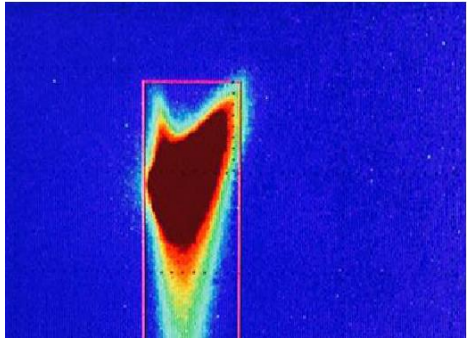
Fishy Beam



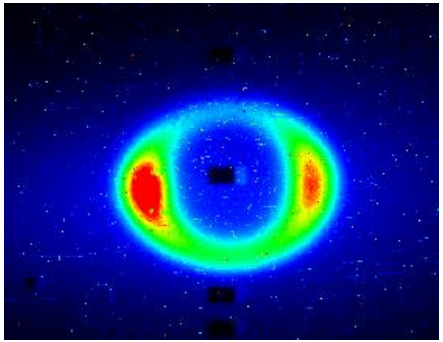
Demon's face



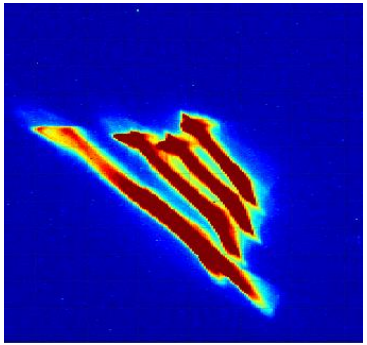
Valentine's day beam



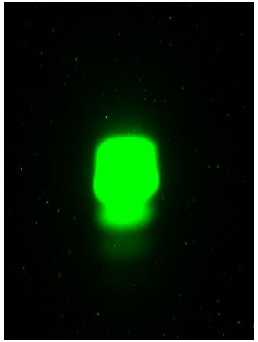
Cat head



Sauron



Monster claws



Lego Head

Pictures from JUAS 2016



Thank you