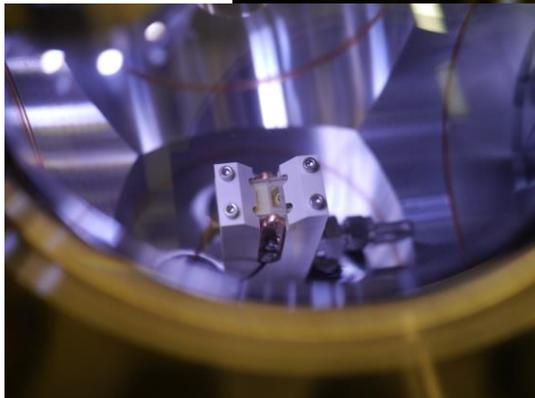
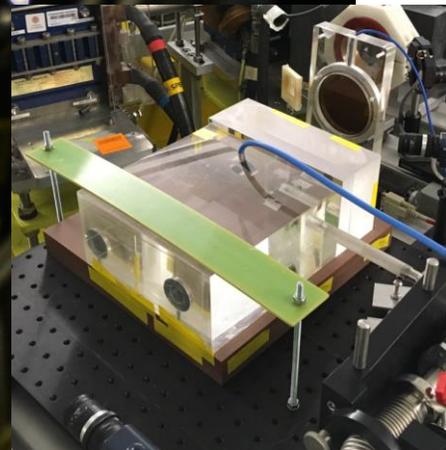
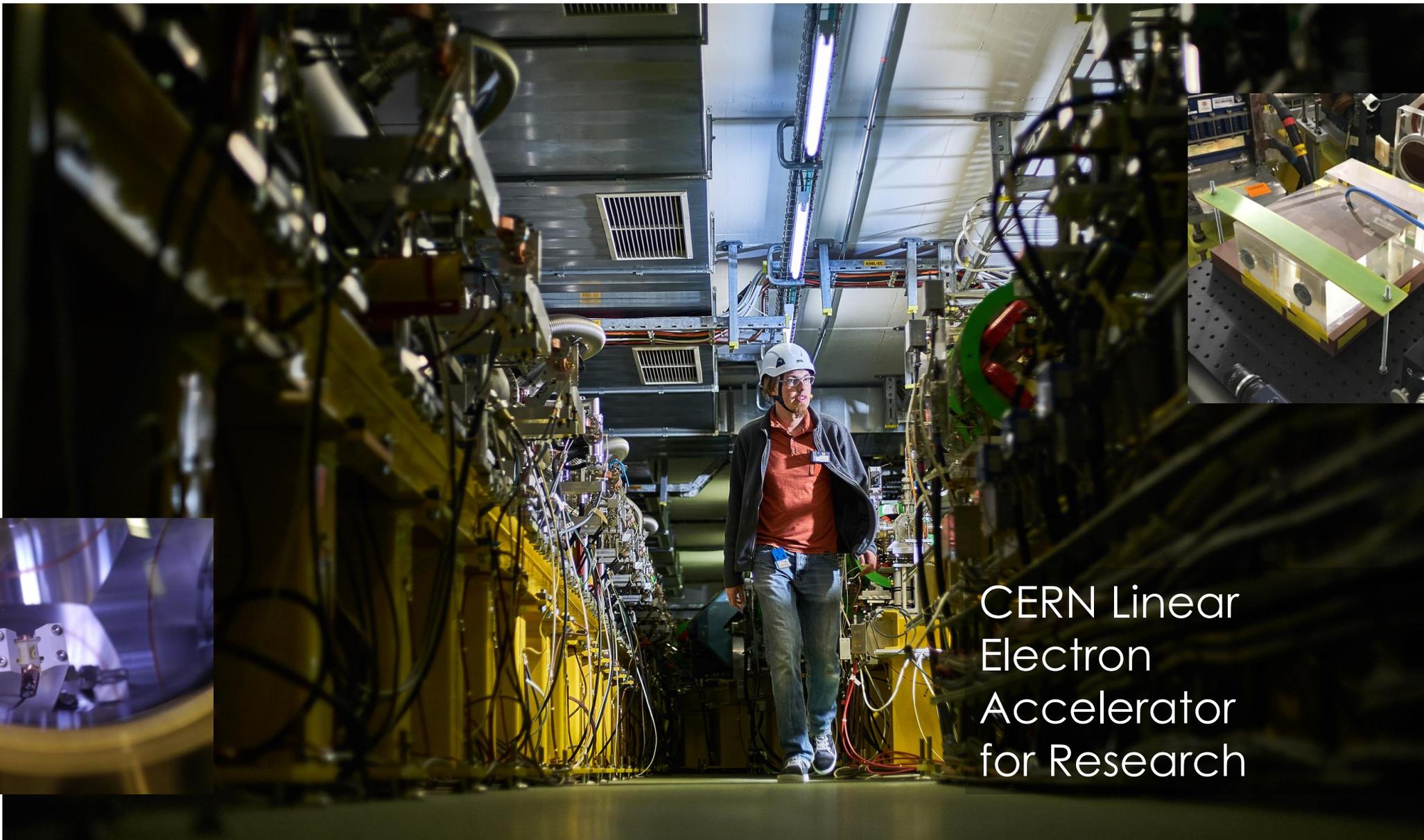
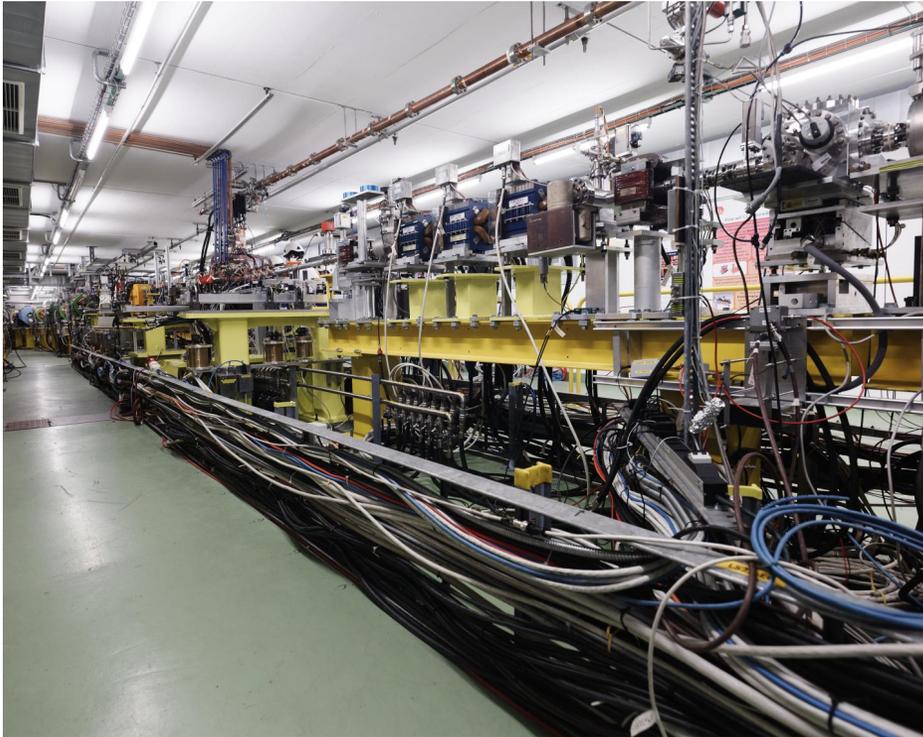


R. Corsini  
for the  
CLEAR team



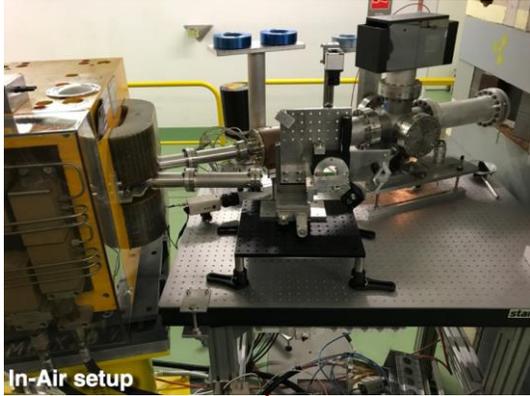
CERN Linear  
Electron  
Accelerator  
for Research



CLEAR is a versatile 200 MeV electron linac + a 20 m experimental beamline, operated at CERN as a multi-purpose user facility.

## Scientific and strategic goals:

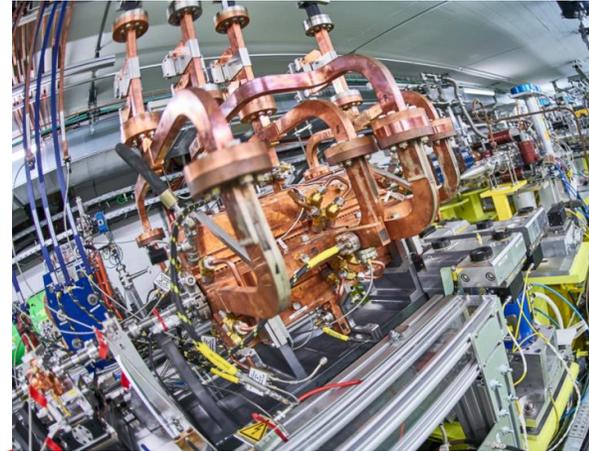
- Providing a test facility at CERN with high **availability**, easy **access** and **high quality e- beams**.
  - Performing **R&D** on **accelerator components**, including **beam instrumentation** prototyping and **high gradient RF** technology
  - Providing an **irradiation facility** with high-energy electrons, e.g. for testing electronic components in collaboration with **ESA** or for medical purposes (**VHEE/FLASH**)
  - 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.



### In-air test stand

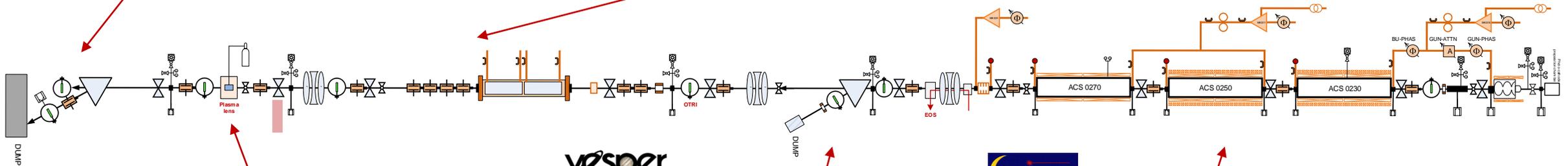
Testing ground for beam diagnostics R&D and THz radiation studies

Irradiation for medical and other applications

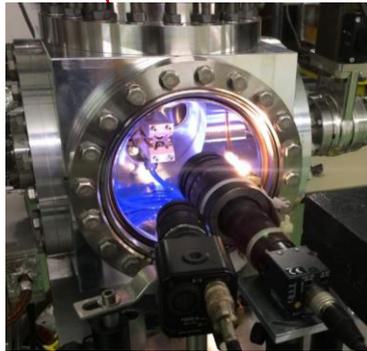


### CLIC Test-Stand

High-gradient and linear colliders R&D



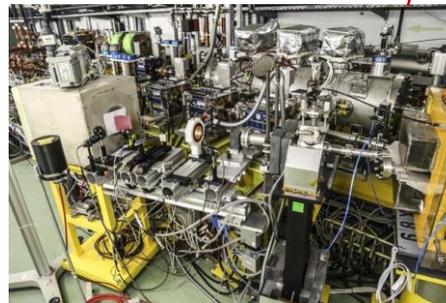
### The Plasma Lens Experiment



Novel concepts of plasma-based focusing and acceleration



### VESPER



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



### CALITES electron linac

Flexible accelerator providing 200 MeV electron beams to all CLEAR users

Extended parameter range and performances since 2017

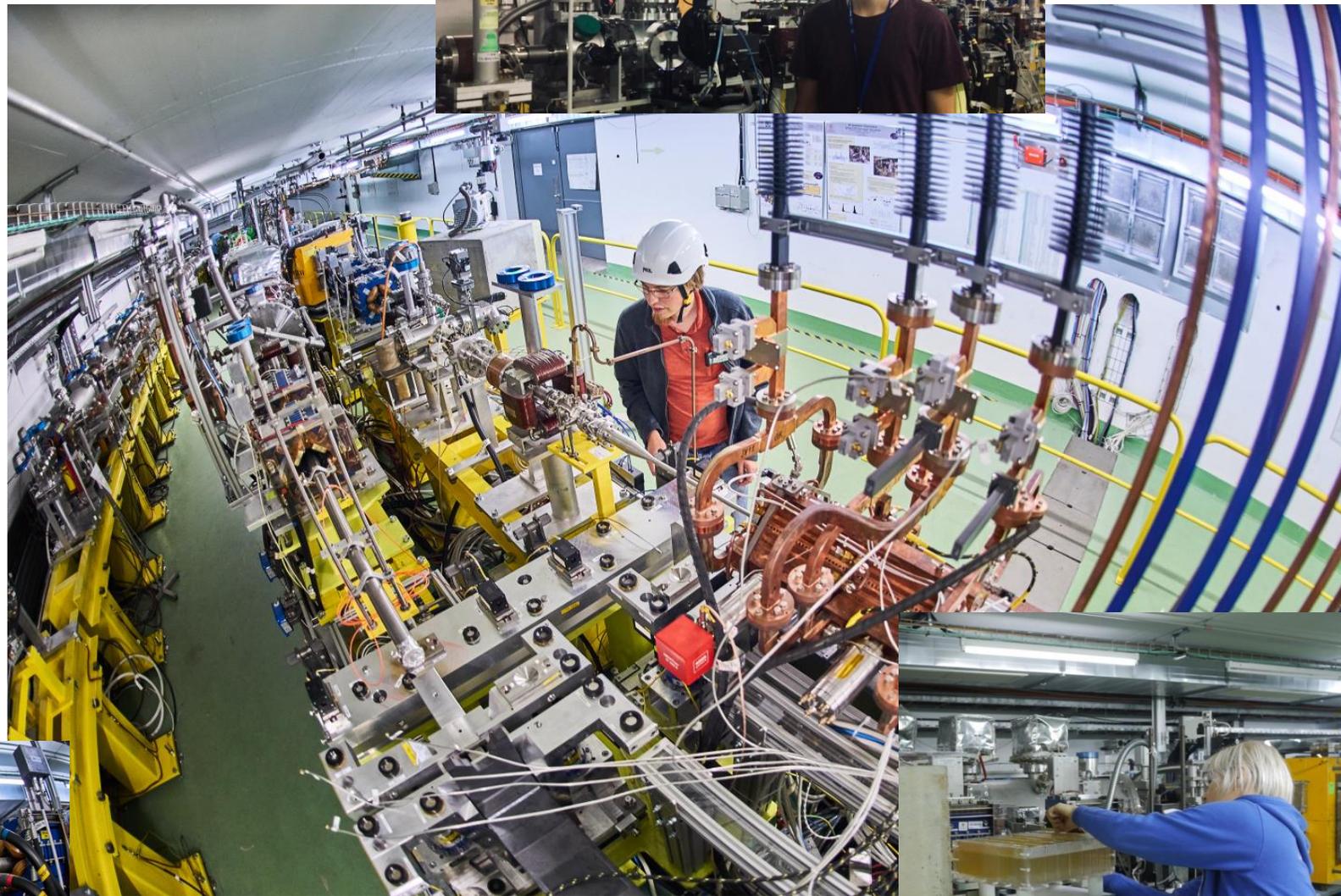
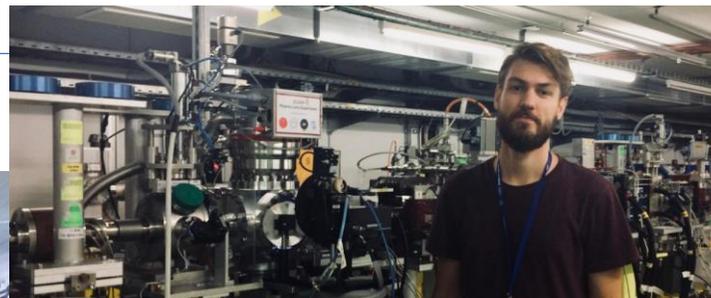
- Short bunches
- High charge
- Large energy range
- Stability, beam sizes,...

Beam parameter	Range
Energy	30 – 230 MeV
Energy Spread	< 0.2 % rms (< 1 MeV FWHM)
Bunch Length	0.1 ps – 10 ps rms
Bunch Charge	5 pC – 3 nC
Number of bunches per pulse	1 to ~150
Maximum total pulse charge	80 nC
Normalized emittances	3 $\mu\text{m}$ to 30 $\mu\text{m}$ (bunch charge dependent)
Repetition rate	0.8 to 10 Hz
Bunch spacing	1.5 GHz or 3 GHz

Start with beam **August 2017**

- 19 weeks of operation in 2017
- 36 weeks in 2018
- 38 weeks in 2019
- 34 weeks in 2020
- 35 weeks in 2021
- 37 weeks in 2022

Due to Covid-19 related measures, 2020  
2021 activities were impacted, and mainly  
limited to CERN users



The CLEAR Scientific Board (CSB) met on 1/2/23 in order to review the achievements of the 2022 CLEAR run, take stock of the proposals for beamtime in the 2023 run, and examine options for future running of the facility.

Presentations and background information can be found at <https://indico.cern.ch/event/1246404/>.

A brief summary of findings and recommendations is presented in the following.

### **CLEAR Scientific Board:**

Giovanni ANELLI (CERN)

Hans BRAUN (PSI)

Philip BURROWS (JAI/Oxford U.) *chair*

Roberto CORSINI (CERN) *ex officio*

Ilias EFTHYMIPOULOS (CERN)

Angeles FAUS-GOLFE (CNRS/In2p3-Orsay)

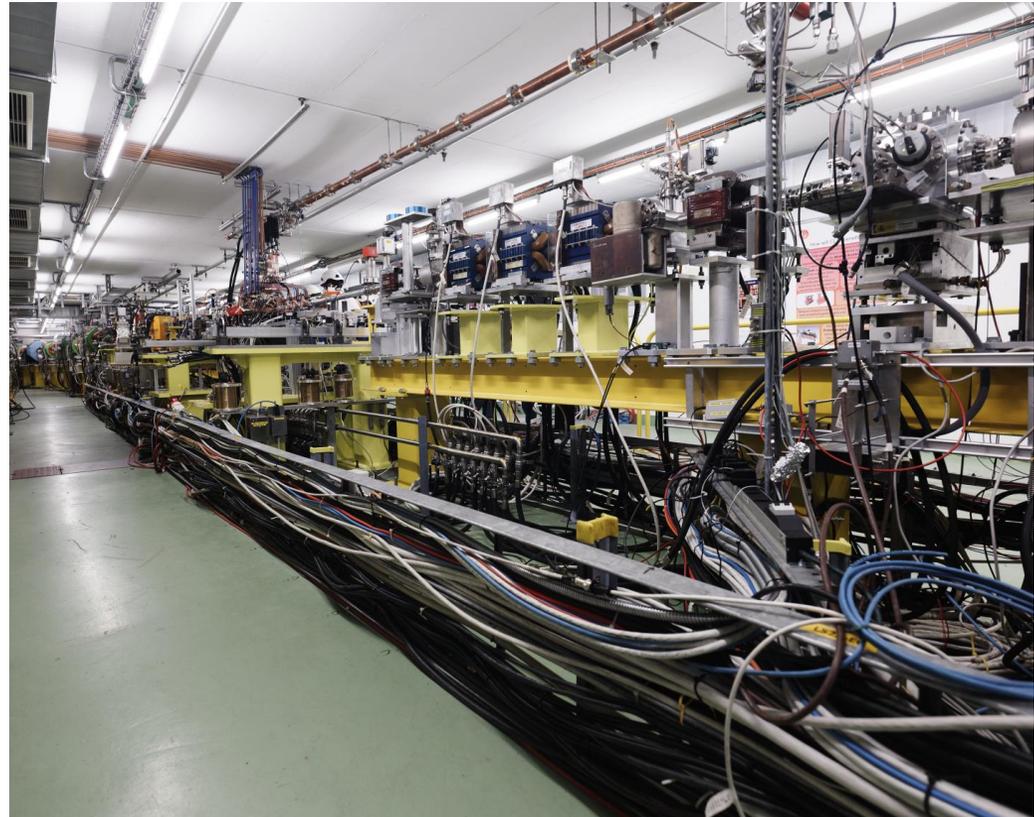
Massimo FERRARIO (INFN-LNF)

Eugenia HATZIANGELI (CERN)

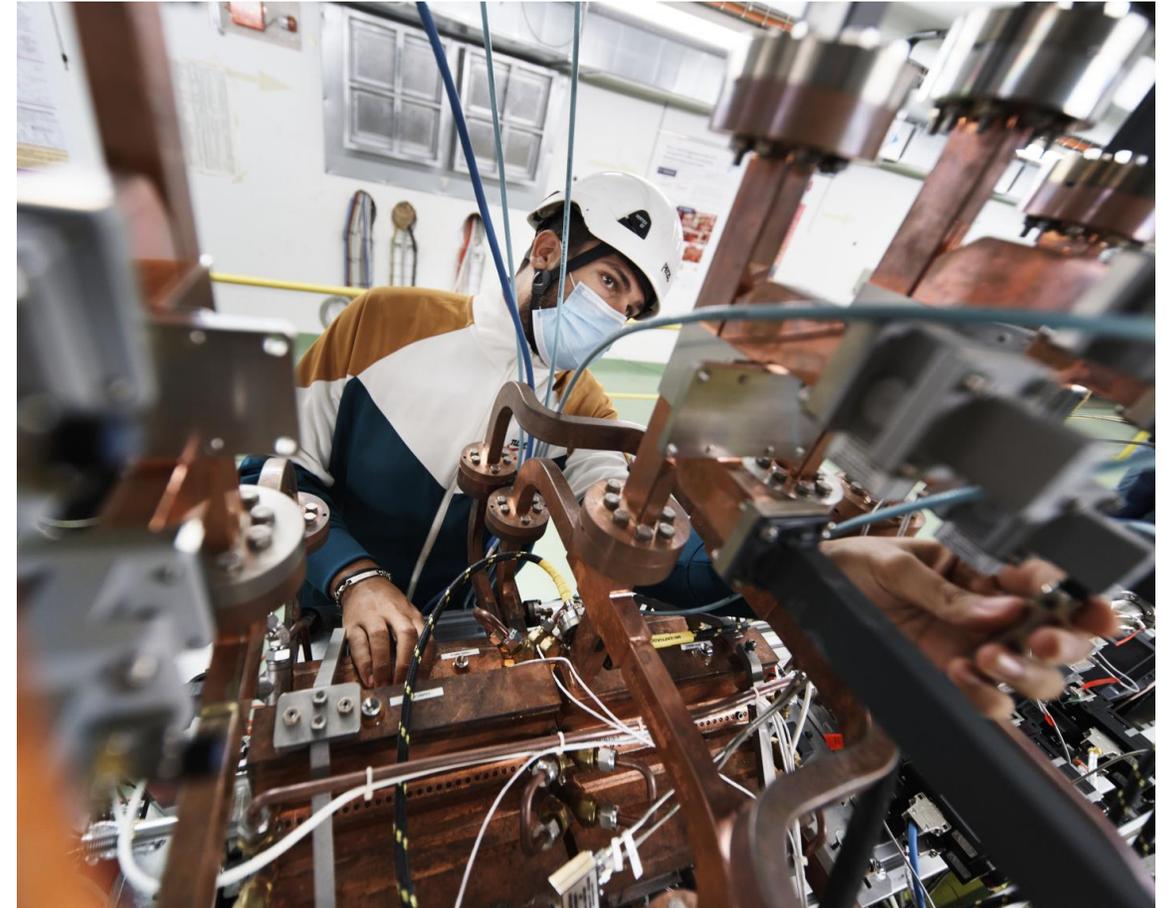
Giuseppe LERNER (CERN)

Steinar STAPNES (CERN)

Marie-Catherine VOZENIN (UNIL/CHUV)



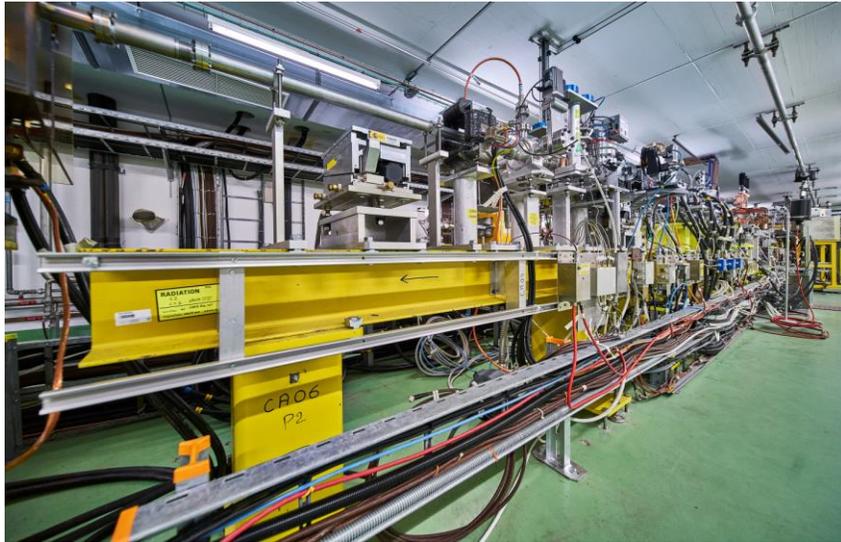
09:15	→ 09:30	<b>Introduction</b> Speaker: Roberto Corsini (CERN)	🕒 15m
09:30	→ 09:50	<b>CLEAR Facility Status and 2022 Experimental Program</b> Speaker: Pierre Korysko (University of Oxford (GB))	🕒 20m
09:50	→ 10:00	<b>Discussion</b>	🕒 10m
10:00	→ 10:20	<b>Outlook on the Experimental Program of 2023</b> Speaker: Wilfrid Farabolini (CERN)	🕒 20m
10:20	→ 10:30	<b>Discussion</b>	🕒 10m
10:30	→ 11:00	<b>Coffe Break</b>	
11:00	→ 11:15	<b>Review of Beam Diagnostics R &amp; D</b> Speaker: Stefano Mazzoni (CERN)	🕒 15m
11:15	→ 11:25	<b>Discussion</b>	🕒 10m
11:25	→ 11:40	<b>Review of Medical Application Studies</b> Speaker: Alexander Malyzhenkov (CERN)	🕒 15m
11:40	→ 11:50	<b>Discussion</b>	🕒 10m
11:50	→ 12:10	<b>CLEAR Perspectives beyond 2023</b> Speaker: Roberto Corsini (CERN)	🕒 20m
12:10	→ 12:30	<b>Discussion and Closing of Open Session</b>	🕒 20m
12:30	→ 13:30	<b>Lunch</b>	
13:30	→ 14:45	<b>Visit to CLEAR</b>	🕒
14:45	→ 15:45	<b>Scientific Board Closed Session</b>	
15:45	→ 16:05	<b>Coffee Break</b>	
16:05	→ 17:00	<b>Scientific Board Closed Session</b>	



This meeting was focused on the specific charge:

- Review and assess the [past CLEAR experimental programme](#), with particular focus on the one executed [last year](#).
- Review the [2023 experimental program](#), as defined by the user proposals received so far and the extrapolation of past experiments, and give recommendations on most relevant directions or activities to be followed.
- Make suggestions on the best ways to [handle priorities](#) and [optimize beam time allocation](#).

It would be also appreciated an initial assessment on [consolidation and upgrade plans](#) and potential [evolution](#) of the facility activities.



- 20 Experiments
- About 15 User Groups internal/external
- More than 13 external collaborating institutes
- Beam from March 1<sup>st</sup> to December 12<sup>th</sup> (with 3 weeks summer stop)
- 37 weeks of operation (early shutdown!)

## Beam Diagnostics R&D

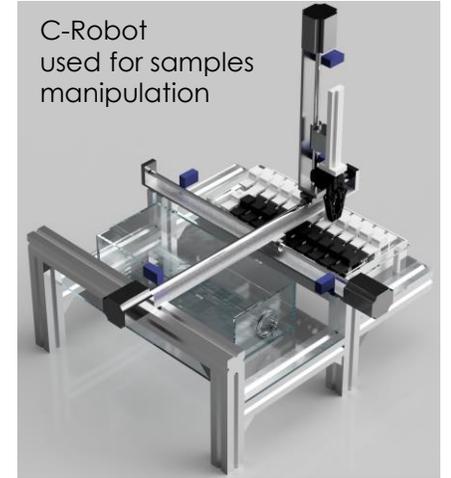


Cherenkov Diffraction Radiation studies (beam position and bunch length monitors)



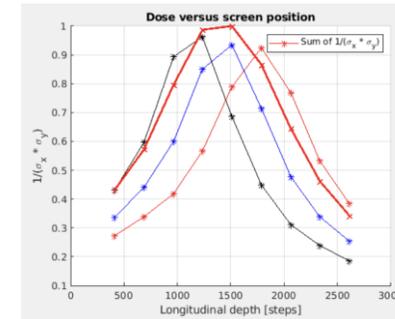
CLIC high resolution BPMs

## Medical Applications

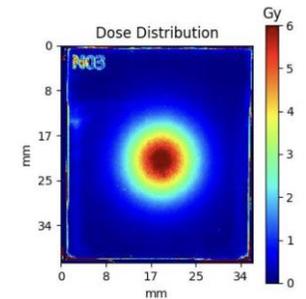


C-Robot used for samples manipulation

Beam Profiler detector for the LUXE experiment



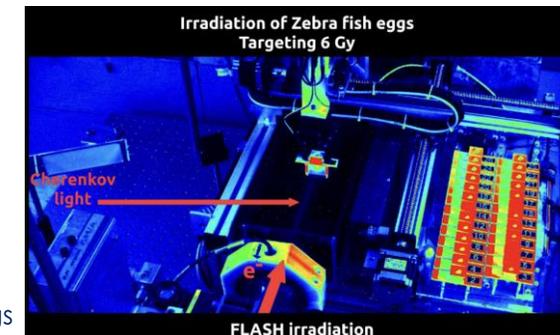
Use of focused beams for Radiotherapy (localized dose deposition)



Ultra-High Dose Rate (FLASH) dosimetry: Films, Alanin, Fibers...

Chemistry and Biology FLASH experiments

H<sub>2</sub>O<sub>2</sub> production – Plasmids – Zebra Fish Eggs



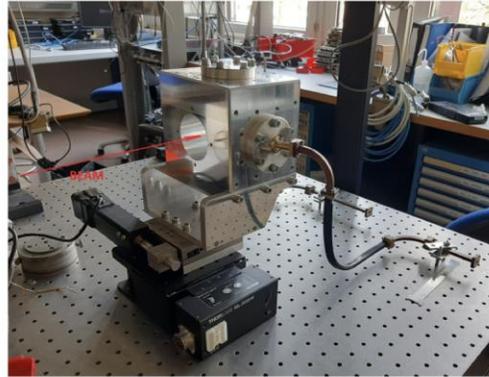
Irradiation of Zebra fish eggs Targeting 6 Gy

In 2022 more than **20 user experiments** were served during **37 weeks** of operation. Scientists from 15 institutes, in addition to CERN, benefitted from beamtime, which led directly to 18 conference papers, 5 journal papers, experimental data for 7 PhD theses, and numerous presentations. It should also be noted that CLEAR is an important facility for training and outreach. In 2022 20 CERN tours and visits (including ‘VIP’s as well as journalists, companies, and artists) were hosted; CLEAR was mentioned in 5 international press articles as well as 4 internal CERN articles; students attending the Joint Universities Accelerator School (JUAS) spent a training week operating the facility.

- **Finding 1:** User experiments capitalize on the unique CLEAR capabilities and address a **broad range of accelerator-based science** that spans advanced accelerator technology development, beam diagnostics, beam-based therapy and medical applications, and irradiation.
- **Finding 2:** The CSB commends the CLEAR operations team for delivering the **excellent scientific programme and efficient operation of the facility**. Access to beamtime for users is managed very efficiently and smoothly so as to maximize the overall scientific output. **The CSB notes that the team is very lean.**
- **Finding 3:** The CSB notes that, in addition to delivery of its main scientific mission, CLEAR represents an important CERN facility for **training and outreach**.

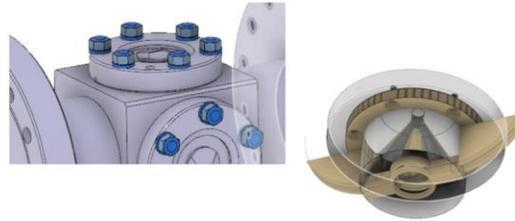
## Longitudinal profile ChDR / EO tests

- Test of vacuum ChDR pickups for longitudinal profile measurement with ns / tens of ps resolution
- Detection scheme using 20 – 40 GHz electro-optical modulators and 780/1550 nm laser at CLEAR. Other EM probes to test
- Proof of principle at CLEAR, then tests in HRM. Long term study for FCC



## Test of LHC EO buttons (CERN/RHUL)

- Beam validation of a technology being developed in collaboration with RHUL for HL-LHC
- Using fiber-coupled electro-optical waveguide coupled to a 50 Ohms terminated electrostatic button



## Recent Publications

- A. Curcio et al, "Diffractive shadowing of coherent polarization radiation", Phys. Lett. A **391**, 127135 (2021)
- A. Curcio et al, "Noninvasive bunch length measurements exploiting Cherenkov diffraction radiation", PRAB **23** (2020)
- A. Curcio et al. "Beam-based sub-THz source at the CERN linac electron accelerator for research facility", PRAB **22** (2019)
- R. Kieffer et al, "Experimental Observation of "Shadowing" in Optical Transition Radiation", Phys. Rev. Lett. **120** (2018)
- Yearly reporting to conferences (IBIC, IPAC, LCWS, ...)

## Optical BLM tests (CERN)

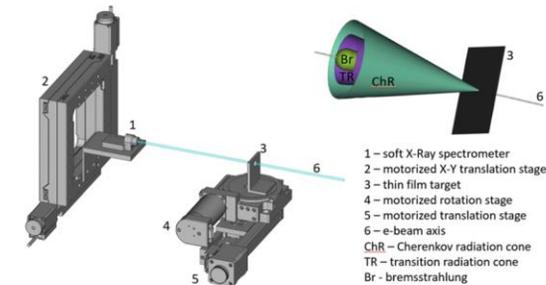
- Test of new optical BLM. Loss signal: Cherenkov Radiation produced in fibres.
- 2020: measurement of ChR as a function of angle to benchmark simulations
- 2021: improved read-out electronics and new sensors (SiPM, PMT, PD) test with low intensity bunches / trains
- Complement to BL tests in SPS



## R&D

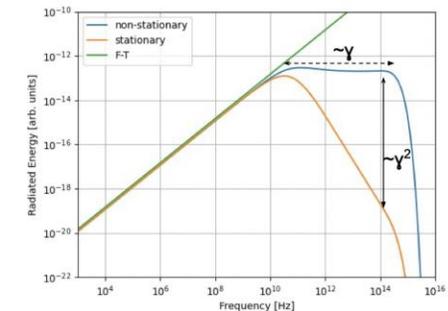
### X-ray Cherenkov test (Belgorod)

- Study of ChR in soft X-rays regime.
- Absolute light yield and angular distribution as a function target angle
- Preparation affected by COVID. Foreseen 2<sup>nd</sup> half of 2021



### Validation of ChDR theoretical model (CERN)

- Models for ChDR still not fully validated. Basic tests to measure ChDR spectrum in the range 100-300 GHz
- Verification needed for applications to high energy beams (FCC)
- Radiation produced by dielectric conical target, tests in Summer 2021

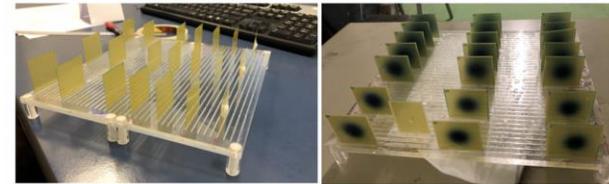


Calibration of operational medical dosimeters – nonlinear effects with high-dose short pulses

Verification of FLASH effect using biological dosimeters

Experimental verification of dose deposition profiles in water phantoms

Demonstration of “Bragg-like peak” deposition with focused beams



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

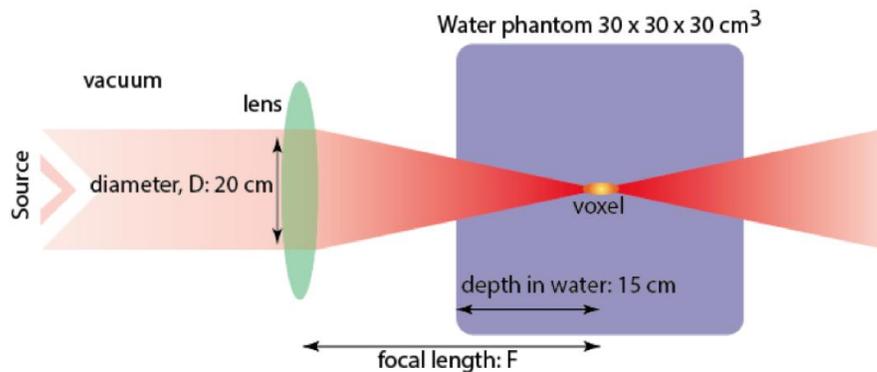


Calorimeter and ROOS chamber, Nat. Phys. Lab. UK (A. Subiel et al.)

High dose rate dosimetry



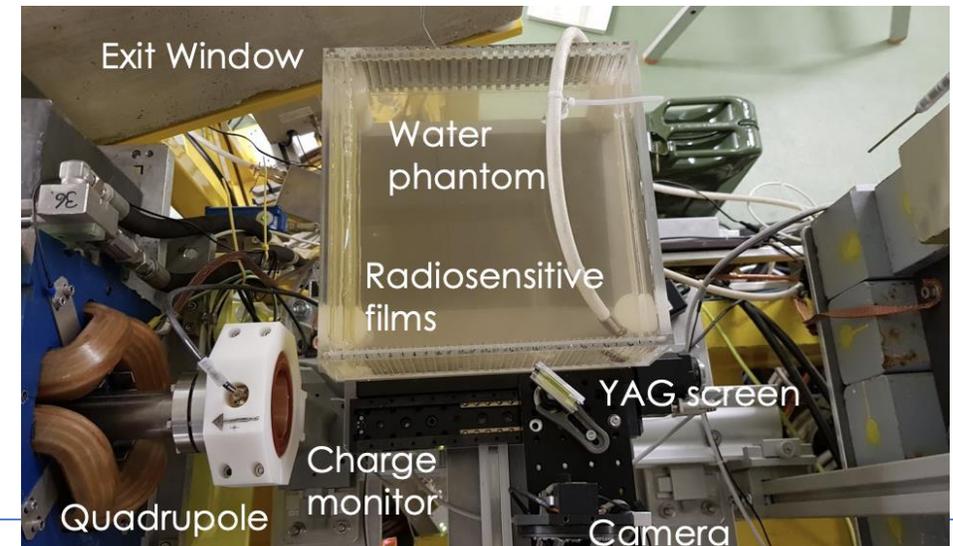
Advance Markus chambers and SRS Array, Oldenburg University and PTW (B. Poppe, D. Poppinga et al.)



**Aim:**

Focus the beam on the tumour to minimize the dose on the nearby healthy tissues

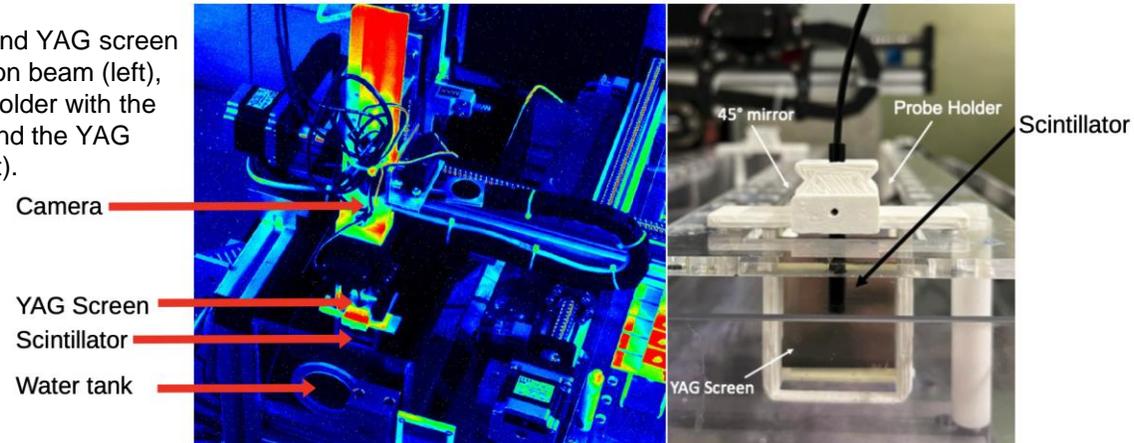
Strathclyde and Manchester



In 2022 several user experiments with a focus on beam diagnostics were performed. The other main area of activity was linked to medical applications (VHEE-FLASH radiotherapy studies).

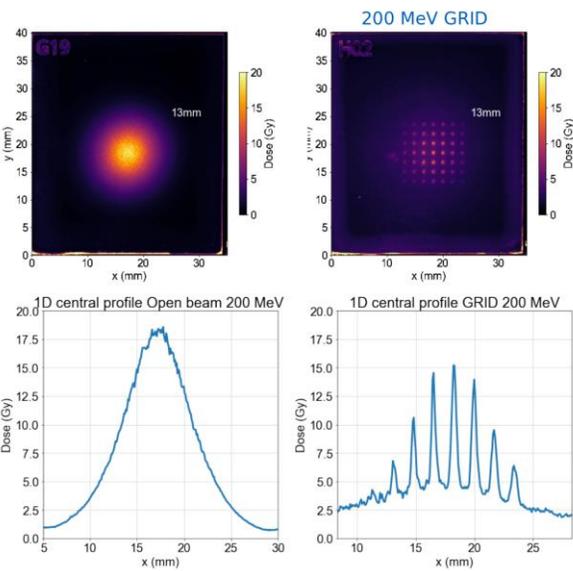
- **Finding 4:** The beam diagnostics experiments **are well in line with two of the key strategic goals** of CLEAR, namely “Performing R&D on accelerator components” and “Providing a training infrastructure for the next generation of accelerator scientists and engineers”.
- **Finding 5:** The beam instrumentation techniques tested at CLEAR have many challenges in common with methods developed at FEL facilities in and outside the CERN member states; **scientific exchanges between the respective user groups and FEL instrumentation groups**, through workshops and conferences, would be beneficial.
- **Finding 6:** CLEAR is currently a **unique facility** for addressing topical issues for medical applications via a range of user experiments.

Scintillator and YAG screen in the electron beam (left), 3D printed holder with the scintillator and the YAG screen (right).



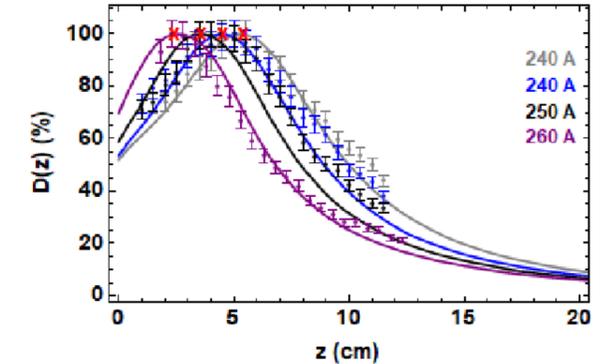
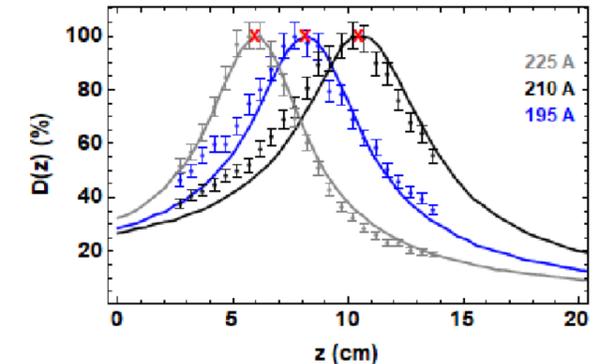
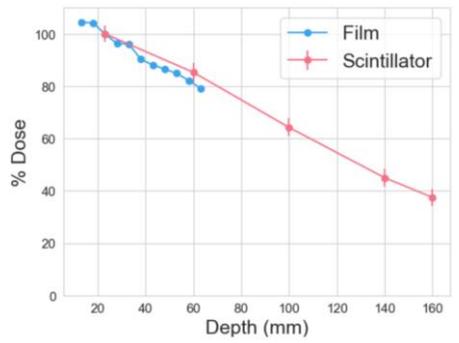
Camera  
YAG Screen  
Scintillator  
Water tank

45° mirror  
Probe Holder  
Scintillator  
YAG Screen



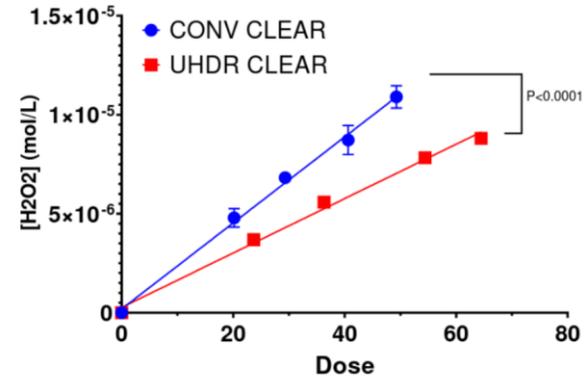
Plastic scintillator dosimetry and Spatially-Fractionated Radiotherapy (SFRT) using a tungsten collimator

(Victoria University)



Peak dose deposition by focusing, in air (top) and in water (bottom)

Manchester University

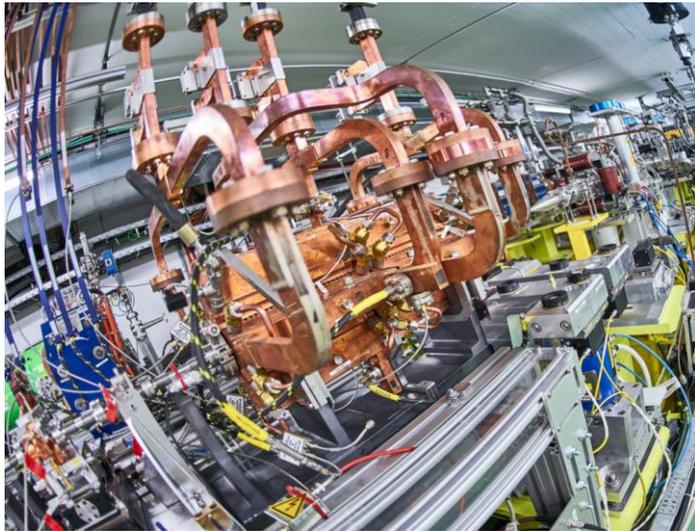


Chemistry experiment comparing effects with conventional and Ultra-High Dose Rate irradiation

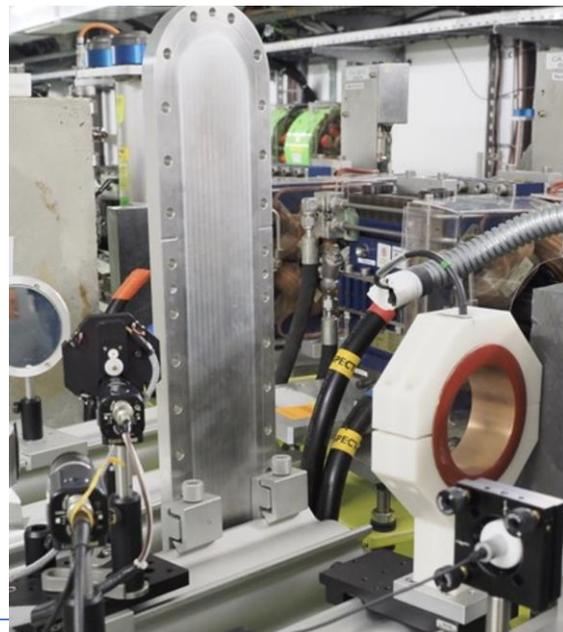
(CHUV)

In earlier years, though not in 2022, dedicated experiments related to CLIC, plasma wakefield acceleration (including AWAKE), and THz-based acceleration were performed.

- **Finding 7:** The CSB encourages groups working on these topics to **resume relevant activities at CLEAR** and reinforce their links and synergies with AWAKE and EUPRAXIA in areas of R&D of common interest.



CLIC High gradient accelerating structure



AWAKE spectrometer calibration



Cherenkov BPMs for AWAKE

Plasma Lens



Helium

Argon

Roughly 40 weeks of beamtime operations are planned in 2023. To date a total of 32 ‘requests’ had been identified. A number of requests are for follow-on experiments from previous years, and two are carried forward from 2022 (due to the earlier-than-planned CLEAR shutdown). The requests originate from teams led by user institutes (18), CERN (12), and companies (2). The requests can be categorised as: beam diagnostics (13), medical applications (13), accelerator technology development (5), and irradiation (1). Many requests comprise multiple beam operation periods and/or experimental setups; however, a number of the requested experiments can be performed in parallel. A provisional analysis yields a total of 182 ‘beam days’ including 87 (medical), 65 (diagnostics), and 29 (accelerator development), not including time for preparation/set up or machine development. A detailed run schedule will be prepared but it already seems clear that the in-hand requests can be expected largely to fill the available beamtime.

- **Finding 8:** Based on the 2022 and earlier runs, the SB has full confidence that the CLEAR management will attempt to schedule the requests so as to optimise the use of the beamtime and maximise the scientific outcomes.

- **Recommendation 1:** The CSB recommends that a **second call for 2023 beamtime requests** be advertised promptly, with a definite deadline. Should this result in a serious over-subscription for the planned beamtime the SB recommends that proposals be evaluated on their merits (see below) and prioritised accordingly. The SB recognises that late requests can (inevitably) occur and recommends that they may be given consideration, subject to the constraints defined by the available beamtime and machine setup.
- **Recommendation 2:** The CSB recommends that in the evaluation of beamtime requests the **following criteria** (not listed hierarchically) be taken into account:
  - Scientific/technical excellence of the proposed research.
  - Capitalisation on the unique capabilities of CLEAR.
  - Compatibility with the beam parameters and machine setup possible at CLEAR.
  - Direct support of CERN's scientific mission, including (where applicable) strategic partnerships with other institutes.
  - Support (where applicable) for Trans-National Access (TNA) to CLEAR.
  - Enhancement of stewardship of electron beamline expertise at CERN.
  - Training of personnel, notably early-career researchers.

The CSB affirms its readiness to provide, where desirable, rapid feedback on beamtime requests.

- **Recommendation 3:** The CSB recommends that an **appropriate number of machine-development days** be scheduled so as to maintain and enhance the CLEAR capabilities for serving current and future users.
- **Recommendation 4:** The CSB recommends that efforts be made to **increase modestly the size of the operation team** for 2023, so as to widen the expertise pool and avoid excessive load on operators. One possibility is to seek additional involvement of associates from collaborating institutes that engage in the user experiments.

Beam restarted as planned, February 27<sup>th</sup>. Activities so far:

- Beam re-commissioning
- JUAS practical days

MDs on

- Automatic dispersion-free steering (A. Aksoy)
- Uniform beam distribution (A. Malyzenkhov – L. Dyks)

Completion of last year program:

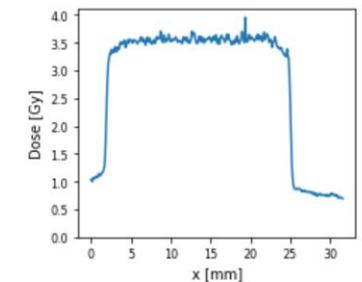
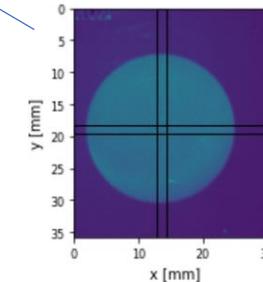
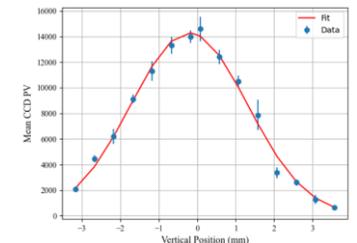
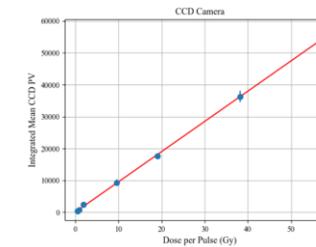
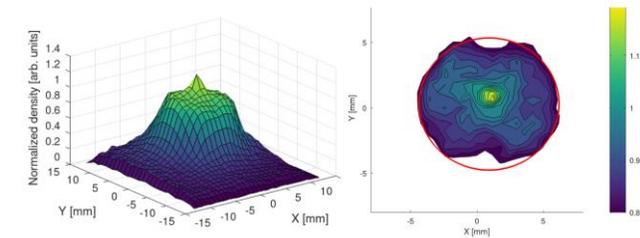
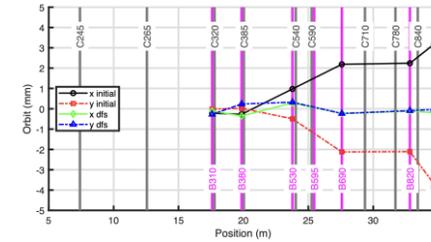
- LUXE detector (INFN Padua)
- Neutron production (CERN RP group)

Initial tests on:

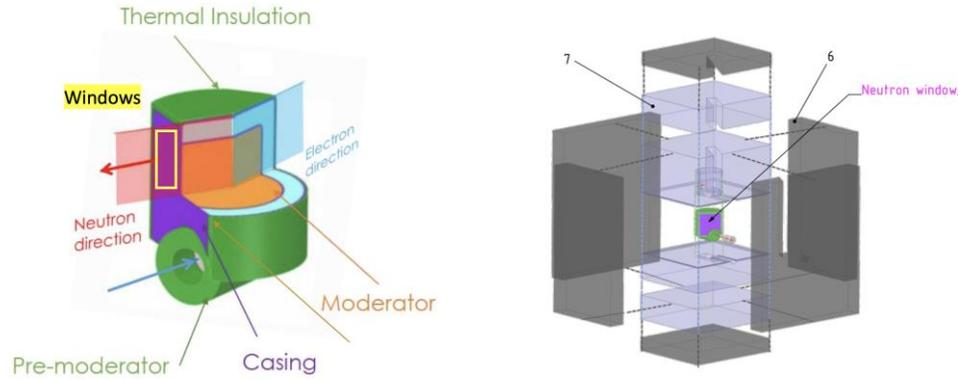
- Scintillator fibers real time dosimetry (J. Bateman – Oxford)
- Uniform beam by double scatterer + collimator (C. Robertson (Oxford))
- Passive dosimetry, real time dosimetry with beam diags (V. Rieker – CERN)
- Beam Current Transformer (Bergoz)

Ongoing & coming:

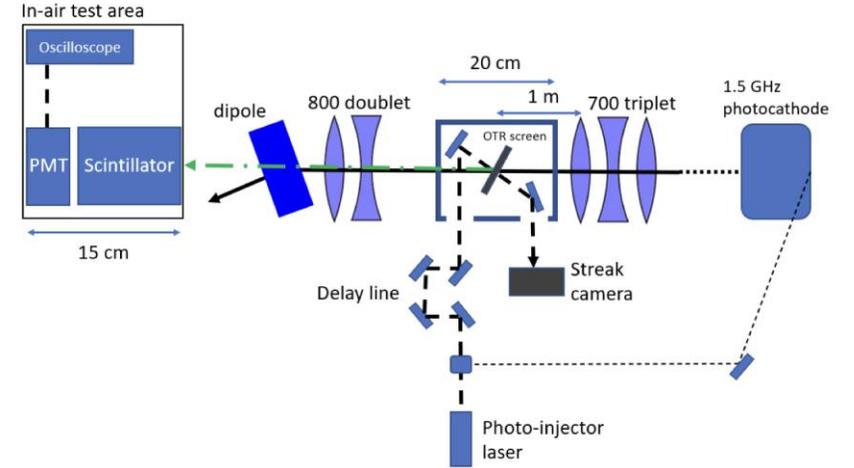
- Experiment on Plasmid irradiation (Manchester U.)
- Chemistry and Biology - zebra fish eggs (CHUV)
- ...



## Some other relevant experiments planned in 2023 (or beyond)

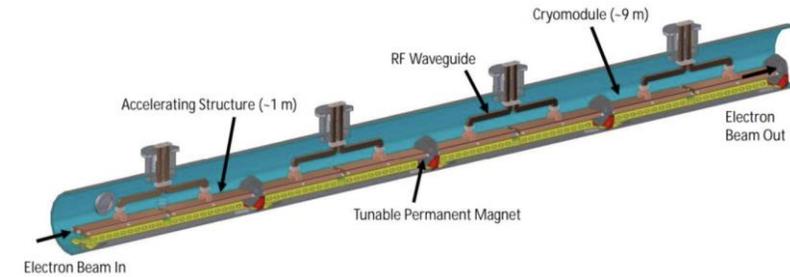
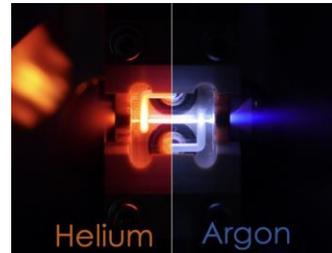
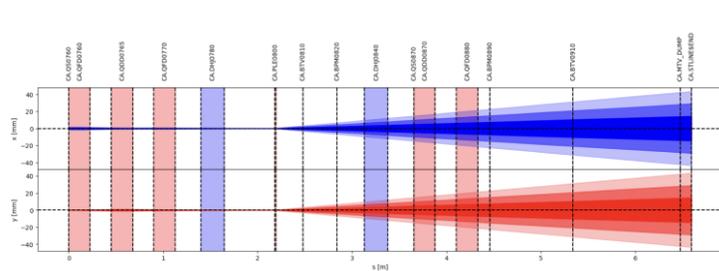


VULCAN Neutron target/moderator (DAES, CERN-KT)



Inverse Compton Scattering (V. Musat, A. Latina)

## Plasma Lens defocusing (Oslo U., K. Sjobaek)



CC3 module (SLAC, E. Nanni et al.)

The CLEAR operation is currently approved until end 2025. An internal CERN review is planned for 2023/2024, with one of its main objectives the evaluation of the future of the facility beyond 2025.

The user requests for experiments at CLEAR have expanded well beyond what was foreseen in the original proposal in 2016.

**First**, the external and internal user activities related to accelerator technology developments for existing and new accelerators, beam dynamics and diagnostics, irradiation campaigns, novel accelerator technologies, and training are largely in line with the ambitions and goals presented in the original proposal, and have been carried out successfully.

**Secondly**, the user community and requests for experiments related to medical studies and dosimetry development far exceed expectations, primarily driven by intense interest in VHEE and FLASH therapy.

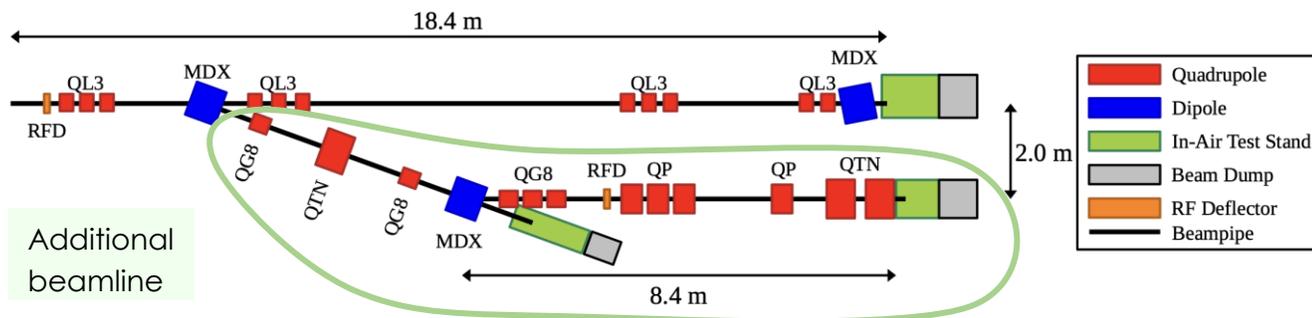
**Finally**, new ideas not fully developed in 2016, such as neutron production and an Inverse Compton Scattering (ICS) facility based on compact electron linacs, are foreseen to be tested and benchmarked at CLEAR in 2023-25.

- **Finding 9:** The CLEAR programme fulfils the promise and goals outlined in the original 2016 proposal across a wide range of R&D studies. The user community is significantly larger than original foreseen, notably in the areas of medical studies and dosimetry.

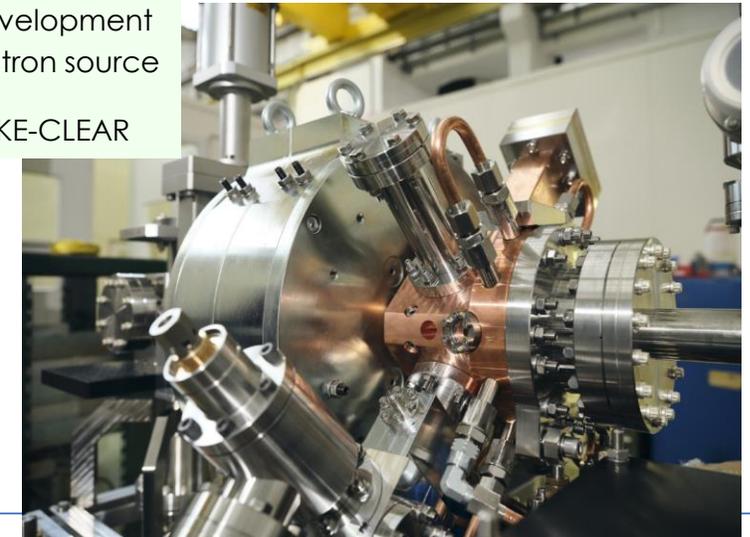
Two obvious possible extensions to the facility are being considered:

- 1) installation of an additional experimental beamline so as to increase user space, and
- 2) installation of a new e-source which would allow very flexible drive- and probe-beam experiments, which, if combined with an extra beamline, would provide enhanced beam capabilities for users. Such a source, based on an RF injector built by INFN-LNF in the framework of the CLIC collaboration combined with an X-band structure, is being assembled in CTF2. It could either be moved to CTF3 for a period, or become a standalone ~60-70 MeV facility with its own scientific programme, and/or a potential e-source for AWAKE at a later stage. CLIC, AWAKE and CLEAR are all contributing to development of this source.

- **Finding 10:** Several possibilities exist, and are already partly prepared, for extending the capabilities of the CLEAR facility. These expansions are not critical for the current programme as foreseen in 2023, but do represent opportunities for operations in 2024 and beyond.



Common development of novel electron source  
CLIC-AWAKE-CLEAR



One of the most critical factors in determining the future of CLEAR, beyond the science potential, user interest and training opportunities, is the strength and resource needs of its operational team. CLEAR users can already be supported by a EURO-LABS TNA. Such schemes, including training for students and technical and scientific personnel, as well as support for networks of small research facilities, are priorities in near-future EU programmes. R&D with relevance for EUPRAXIA, i.e. plasma lenses, could also be supported by EU programmes. Medical studies are high priority in EU and national research programmes. All of these, and more, are potential ways to increase external support of the facility.

- **Finding 11:** The operational team of CLEAR is already lean and at this stage, looking beyond 2025, in several important cases the availability of personnel is not completely secure.
- **Recommendation 5:** An upgrade strategy, with options, should be prepared during the coming year such that the potential extension of the CLEAR programme beyond 2025 can be evaluated, taking into account the potential offered by these upgrades.
- **Recommendation 6:** Strengthening the operational team with external resources, potentially linked to training of external personnel spending significant time in CLEAR, should be pursued with high priority. External resources, for example EU projects, can also in some case support more user projects, research and activities.
- **Recommendation 7:** Even if externally-supported projects have a high potential for growth, it is important that projects that are critical for on-going CERN priorities, for example instrumentation tests for HL-LHC, development of future particle physics technologies, as well as activities preparing CERN for a future electron-positron Higgs Factory facility, are supported with high priority.
- **Recommendation 8:** The potential for using CLEAR for studies related to accelerator sustainability (e.g. higher-efficiency RF systems, permanent magnets) should be further investigated and taken into account in future reviews of the facility.

# Thanks for your attention!

*Acknowledgements to the dream CLEAR team:*

*W. Farabolini, P. Korysko, A. Malyzhenkov, A. Aksoy, K.  
Sjobaek, L. Dyks, V. Rieker, J. Bateman, C. Robertson, L. Wroe,  
E. Granados, M. Martinez, S. Curt, D. Gamba, ...*

