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OPERATIONAL IMPROVEMENTS AND UPGRADES OF THE CLEAR USER FACILITY

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Abstract

The CERN Linear Accelerator for Research (CLEAR) at CERN is a user facility providing a 200 MeV electron beam for accelerator R&D and irradiation studies, including medical applications. In this paper we will outline the most recent improvements in CLEAR operation and beam control and delivery, and describe the upgrades under way, giving an update of their current status. These upgrades include a new front-end for the laser system which will enable an highly flexible time structure, better stability and higher repetition rates, and the implementation of a second beam line which will provide additional testing capability and whose optics has been designed to match user requirements. Finally, we will discuss the proposed future experimental program of the facility, particularly in view of the novel capabilities provided by the upgrades.

INTRODUCTION

The CLEAR facility offers a diverse array of electron beams with customisable parameters [1–4], as detailed in Table 1. An overview of the time structure and charge parameters achievable at CLEAR, depicted in Fig. 1, along with a schematic layout of the beamline shown in Fig. 2.

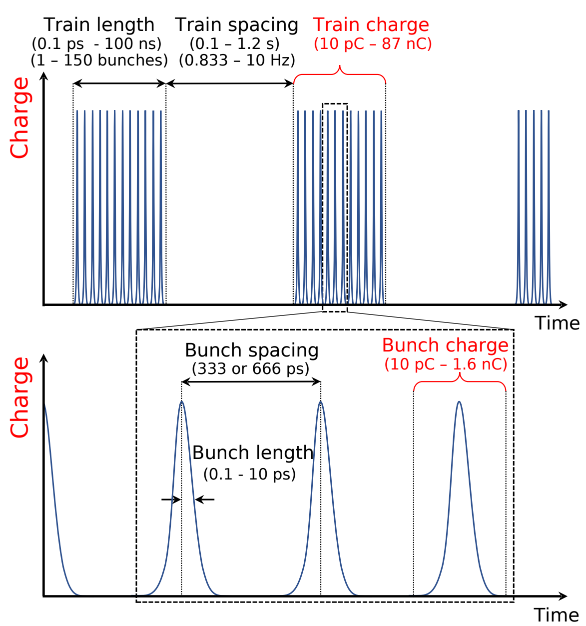

Figure 1: CLEAR beam time structure and charge parameters at the end of the beam line in 2024.

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Table 1: CLEAR Beam Parameters in 2024

Parameter	Value
Beam Energy	30 – 220 MeV
Beam Energy Spread	< 0.2% rms (< 1 MeV FWHM)
Bunch length RMS	0.1 – 10 ps
Bunch frequency	1.5 or 3.0 GHz
Bunch charge	0.005 – 1.6 nC
Norm. emittance	1 – 20 μm
Bunches per pulse	1 – 150
Max. pulse charge	87 nC
Repetition rate	0.8333 – 10 Hz

CLEAR operates independently from CERN's proton machines, enabling operation during the LHC's extended shutdowns and upgrades. Offering remarkable flexibility, the accelerator typically undergoes weekly experiment installations on Monday mornings and runs for 8 to 12 hours per day, five days a week, tailored to user demands. In 2023, CLEAR ran for 37 weeks and the beam availability was 96.7% (40 hours of fatal failure for 1209 hours of beam). In 2024, 35 experiments are planned in 39 weeks of beam. The approval of the CERN Medium Term Plan in September 2020 earmarked funding for extended CLEAR operation, subsequently endorsed by CERN management until the end of 2025.

CLEAR provides two distinct in-air test areas: VESPER (Very energetic Electron facility for Space Planetary Exploration missions in harsh Radiative environments), primarily utilised for electronics radiation hardness tests, and the In-Air Test Area offering greater flexibility for various experimental needs. Both areas have been utilised for medical applications studies such as Very High Energy Electron (VHEE) radiotherapy at Ultra High Dose Rate (UHDR), looking for the FLASH effect [5], beam instrumentation, diagnostics studies and electronics component irradiation, among others.

Notably, VESPER has played a role in testing and validating components for the ESA's JUpiter ICy moons Explorer (JUICE) mission, successfully launched in April 2023 [6–9]. It is expected to reach Jupiter in July 2031 after four gravity assists and eight years of travel. Additionally, CLEAR features in-vacuum test areas tailored for specific experiments, including studies on novel accelerator technologies such as plasma lenses and advancements in beam instrumentation [10, 11].

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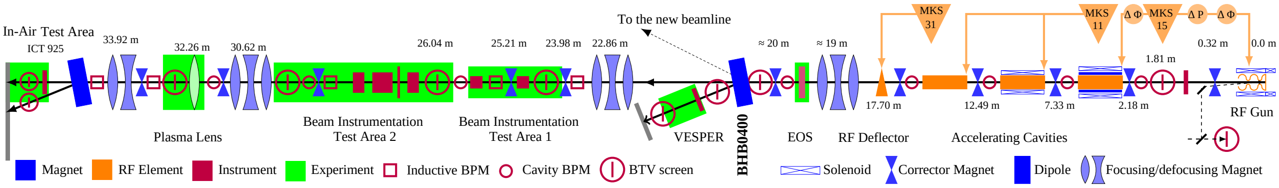

Figure 2: CLEAR beam line in 2024. Note that the electron beam travels from right to left.

OPERATIONAL UPGRADES

During the 2023/2024 period several upgrades were done to the CLEAR beamline:

A dual-scattering system in poly-lactic acid and aluminium was developed using TOPAS Monte-Carlo simulations. Studies to test the success of the scattering systems in providing beam magnification and uniformity were done in CLEAR. Measurements of beam intensity and dose profile were carried out with a YAG scintillating screen and EBT-3 Gafchromic films respectively. A generalised super-Gaussian function was used to the model the final beam, and comparisons were made with the simulations used for the design. A rendered image of the scatterer and beam shapes is shown in Fig. 3. This system is now used to deliver the same dose on the whole sample in a precise and controlled way [12].

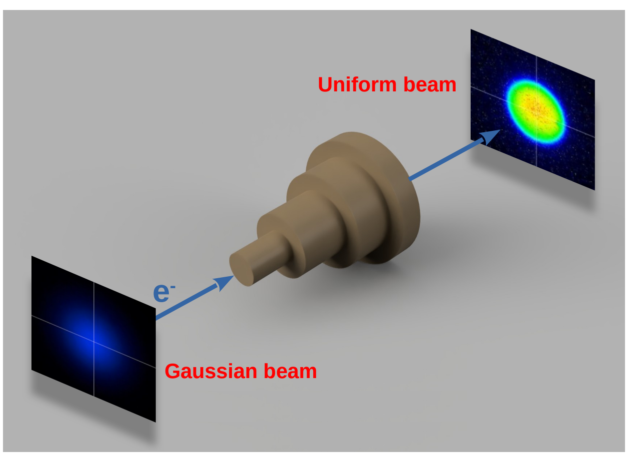

Figure 3: Rendered image of the conical shape scatterer and beam profiles.

A 10 mm beam collimator was designed, built and installed on the final In-Air Test Area. When inserted, coupled with the conical the dual-scattering foil, a 10 mm flat beam can be easily obtained for irradiations.

Three experiments were installed in-vacuum in the now called Beam Instrumentation (BI) test area: a FCCee Bunch Length Monitor using the Coherent Cherenkov Diffraction Radiation, FCCee Broad Band Pickups and Compact LInear Collider (CLIC) Cavity-Beam Position Monitors (C-BPMs).

The CLEAR photocathode has been rejuvenated. A thin layer of Cs_2Te was deposited by evaporation on the cathode surface in order to restore the desired quantum efficiency. After the treatment, a bunch charge of 2 nC has become achievable.

The vacuum system was updated and consolidated, offering higher reliability and a better vacuum level in several locations along the beam line.

A robotic system called the C-Robot was used for all 2023/2024 medical application experiments [5, 13, 14]. Developed by the CLEAR team, this system is specifically engineered to facilitate the irradiation of a wide array of samples for medical purposes. Consisting of three linear stages for precise movement along the X, Y, and Z axes, the system is equipped with six limit switches (two per axis), a 3D printed grabber, and a mounted-camera system featuring a dynamic filter. Additionally, it incorporates two tanks – one serving as a storage reservoir and the other integrated into the electron beam. The system enables the manipulation of up to 32 distinct 3D-printed holders within the electron beam, each capable of accommodating an Eppendorf tube containing samples. Notably, a novel dedicated holder featuring a YAG screen has been developed. Positioned post-screen is a mirror angled at 45° relative to the electron beam, facilitating precise measurement of beam parameters. Leveraging a camera mounted on the C-Robot, the system enables the measurement of beam position and size in both air and water across various positions within the beam area.

Additionally, a new robot, the C-Robot 2.0 has been designed and built by members of the CLEAR team and sent to PITZ, the DESY photo-injector test facility for reverse engineering studies. This robot will then be installed on the in-air test stand of the new CLEAR beamline for medical applications. It is an upgraded version of the C-Robot: it can hold up to 48 samples in its storage area, it is 3 times faster and more accurate. Rendered images of the C-Robot 2.0 is shown in Fig. 4.

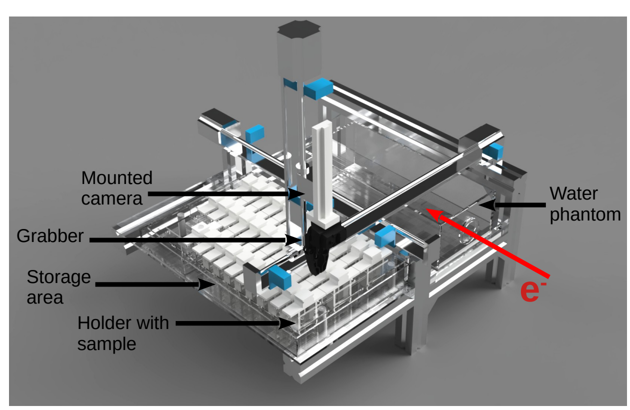

Figure 4: Rendered image of the C-Robot 2.0.

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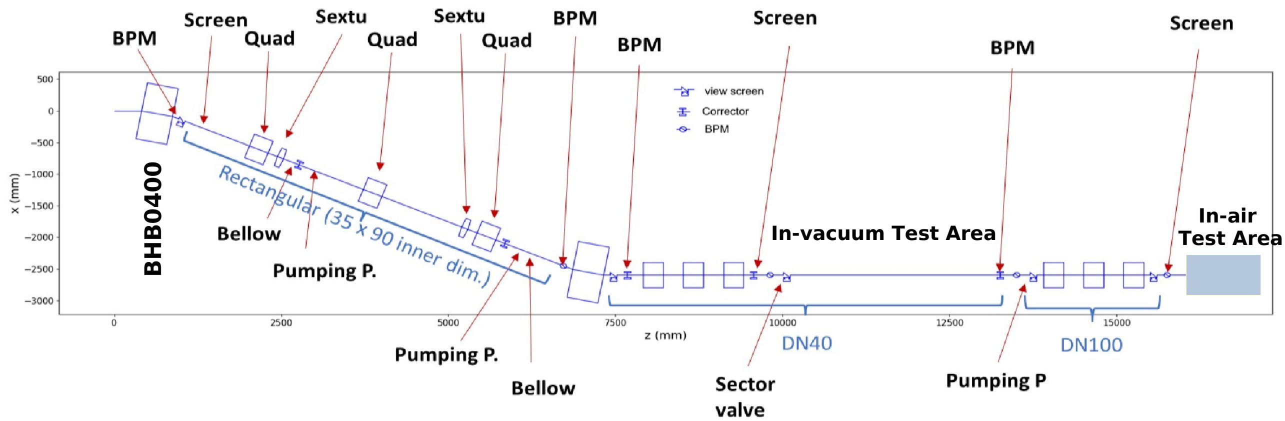

Figure 5: Schematic of the CLEAR second beamline. The beam travels from left to right.

A new electron source, which includes a photoinjector and an X-band accelerating structure, is currently being commissioned in stages in the former CTF2 area, near the CLEAR hall. This effort is a collaboration between CLIC, AWAKE, and CLEAR. The current plan supports using the new source after commissioning and before its installation in AWAKE as an independent beamline at its existing CTF2 location, integrating it into the CLEAR user facility. These improvements and consolidations will allow CLEAR to support a modest increase in user experiments, keeping pace with the growing demand from its user community.

CLEAR PHOTO-CATHODE LASER UPGRADES

Despite a 99.6% availability in 2023, the CLEAR laser systems have been identified as a potential source of failures and downtime. To address this, a new Electro-Optical (EO) comb front-end is planned to enhance time structure flexibility, increase the repetition rate, and generally improve reliability. The implementation of EO frequency combs will enable a fully programmable system capable of simulating the electron bunch structure of the FCC-ee. This development is being carried out in synergy with the Gamma Factory Proof-of-Principle experiment at SPS and the Compton polarimeter for FCC-ee. Approximately 90% of the components needed for this upgrade are already in house. This new system will be able to generate sophisticated beam time patterns, thus permitting novel experiments. In particular, studies on new accelerating methods and developments for time-resolved diagnostics will profit from these capabilities.

CLEAR SECOND BEAMLINE

Upcoming improvements to CLEAR include the addition of a second beamline. This will allow for the creation of more testing areas, both in-air and in-vacuum, minimizing the need for frequent mounting and dismounting of experiments and diagnostics equipment. As a result, beam time and operational flexibility will increase, enabling the parallel execution of 'non-compatible' experiments within the same day or week with quick turnaround times. This enhancement also expands the range of beam parameters, such as enabling larger beam sizes and stronger focusing thanks to a larger chamber size, a magnetic chicane and sextupole magnets. The design of the second beamline has been completed and resources needed for its installation and construction have been granted. The implementation of the second beam line has been approved. A schematic of the CLEAR second beam line in shown in Fig. 5. The installation will take place during in winter 2024/2025 and commissioning is planned for spring 2025.

CONCLUSION

As CLEAR embarks on its eighth year of operation, the experimental parameter range accessible to users has steadily expanded, surpassing even the capabilities of 2023. This broadened beam parameter range positions CLEAR as an attractive facility for conducting experiments with VHEE for UHDR studies, among other applications. Notably, enhancements include increased pulse charge and improved beam stability. Additionally, new tools and instruments, such as beam scatterers, collimators, sample holders, and optical fibers for real-time dosimetry, have been installed to facilitate a diverse range of experiments. Comprehensive documentation, including pictures, presentations, and publications for all CLEAR experiments, is available on the dedicated CLEAR Experiments web page [15].

Looking ahead, CLEAR aims to further enhance its flexibility, accessibility, and achievable beam parameters. Future plans for CLEAR include the upgrade of the photo-cathode laser, the installation of a second beamline, partly dedicated to medical applications, in order to accommodate growing demands in that field and the upgrade of the Radio Frequency (RF) systems (low level RF, klystrons and modulators consolidation). Moreover, a second electron beam source has been developed in a nearby CTF2 experimental hall, offering additional opportunities for beam testing and research at lower energies.

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REFERENCES

[1] CLEAR: http://clear.web.cern.ch/

[2] K. N. Sjobak *et al.*, "Status of the CLEAR electron beam user facility at CERN", in *Proc. IPAC'19*, Melbourne, Australia, May 2019. doi:10.18429/JACoW-IPAC2019-MOPTS054

[3] R. Corsini *et al.*, "First experiments at the CLEAR user facility", in *Proc. IPAC'18*, Vancouver, BC, Canada, 2018. doi:10.18429/JACoW-IPAC2018-THPMF014

[4] D. Gamba *et al.*, "The CLEAR user facility at CERN", *Nucl. Instr. Meth. Phys. Res. A*, vol. 909, p. 480, Nov. 2018. doi:10.1016/j.nima.2017.11.080

[5] P. Korysko *et al.*, "VHEE and ultra high dose rate radiotherapy studies in the CLEAR user facility", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 5063–5066. doi:10.18429/JACoW-IPAC2023-THPM078

[6] M. Tali *et al.*, "Mechanisms of electron-induced single-event upsets in medical and experimental linacs", *IEEE Trans. Nucl. Sci.*, vol. 65, no. 8, pp. 1715–1723, Aug. 2018.

[7] A. Coronetti *et al.*, "SEU characterization of commercial and custom-designed SRAMs based on 90 nm technology and below", presented at 2020 IEEE Radiation Effects Data Workshop (in conjunction with 2020 NSREC), 2020, pp. 1–8. doi:10.1109/REDW51883.2020.9325822

[8] A. Coronetti, "R2E activities at CLEAR", presented at the CLEAR review 2021. https://indico.cern.ch/event/1015632/contributions/4262430/

[9] M. Tali *et al.*, "Mechanisms of electron-induced single-event latchup", *IEEE Trans. on Nucl. Sci.*, vol. 66, no. 1, pp. 437–443, Jan. 2019.

[10] C. A. Lindstrøm *et al.*, "Emittance preservation in an aberration-free active plasma lens", *Phys. Rev. Lett.*, vol. 121, no. 19, p. 194801, Nov. 2018.

[11] C. Pakuza *et al.*, "Electron beam studies on a beam position monitor based on Cherenkov diffraction radiation", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 4806–4809. doi:10.18429/JACoW-IPAC2023-THPL146

[12] C. Robertson *et al.*, "Dual-scattering foil installation at CLEAR", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 5059–5062. doi:10.18429/JACoW-IPAC2023-THPM073

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

[14] C-Robot Gibtlab Repository: https://gitlab.cern.ch/CLEAR/arduino4d_robot/

[15] List of CLEAR Experiments: https://pkorysko.web.cern.ch/CLEAR/Table/CLEAR_experiments.html