CLEAR SCIENTIFIC BOARD REPORT
8/3/24

The CLEAR Scientific Board (CSB) met on 16/2/24 in order to review the achievements of the 2023 CLEAR run, take stock of the proposals for beamtime in the 2024 run, and examine options for near- and medium-term future running of the facility. Presentations and background information can be found at https://indico.cern.ch/event/1374893/. A brief summary of findings and recommendations is presented below.

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1. Introduction

CLEAR is a ‘standalone’ facility which started operations in August 2017 and it has since been serving a growing number of users annually. In a typical year 30-40 weeks of beam operation are provided between March and December (with a short summer stop), usually via 2 shifts per day, 5 days per week. The operation team is lean, and comprises 1 staff, 1 fellow, 1 associate, plus contributions from some PhD students and part-time associates, amounting to about 3.5 FTE/year in total. The material budget is roughly 800kChF/year.

User requests are made formally via a beamtime request form, and typically there follows a productive discussion between the proponents and the CLEAR team so as to better understand, define, and serve the user requirements. An EDMS infrastructure has been set up to allow convenient review of requests by the CSB. A final decision on implementation and scheduling of the request is made by the CLEAR Technical Board.

Internal CERN reviews of CLEAR were held in 2019 and 2021 and operation is currently approved (and in the MTP) through to the end of 2025. A further CERN review is planned for April 2024, with one of its main objectives being the evaluation of the scope and benefits of CLEAR operations in the next 5-year period 2026-2030.

2. Scientific accomplishments of 2023 beam operations

In 2023 27 user experiments were performed during 37 weeks of operation, amounting to 153 days of beamtime (including machine development); the beam uptime was an impressive 97%. Scientists from 18 user groups from 13 institutes, in addition to CERN, benefitted from beamtime. The scientific output included 10 conference papers, 8 journal papers, experimental data for 13 PhD theses, and numerous presentations. It should also be noted that CLEAR is an important facility for training and outreach. In 2023 31 CERN tours and visits (including ‘VIP’s as well as journalists, companies, and artists) were hosted; CLEAR was mentioned in 2 international press articles as well as 3 internal CERN articles. As in previous years students attending the Joint Universities Accelerator School (JUAS) spent a training week operating the facility.

Finding 1: We commend the CLEAR team for achievement of both excellent operational efficiency and outstanding support for user experiments in 2023. The resulting scientific papers, PhD theses, training sessions, and facility visits are testament to the impressive output and impact of CLEAR. That this was achieved with very modest resources is all the more commendable. CLEAR is a great asset to CERN.

We comment briefly below on the main areas of scientific activity advanced in the 2023 run.

Beam diagnostics experiments

In 2023 ten experiments on beam diagnostics were performed using 62 beam days in total, representing a doubling of the activities in this area compared with the five experiments in 2022. The table below lists the experiments, together with the lead institutes and, where applicable, the target of the activity.

Experiment	Institute or Company	Target of activity
AWAKE scintillation screen	University College London	AWAKE
3D Diamond Detectors	University of Kansas	
MicroBPM	CERN	CERN IIRAD
Broad Band pickups	PSI	P3 experiment, FCC-ee e+ prod.
FCC Cerenkov bunch length monitor	CERN	FCC
CLIC Cavity Beam Position Monitors	Royal Holloway, University of London	CLIC
EO Bunch Profile Monitor for FCC-ee	KIT	FCC-ee
Emittance measurement with OTR light	Liverpool University	
Beam Profile Monitor for LUXE	INFN Bologna	LUXE experiment DESY/Eu-XFEL
High frequency Wall Current Monitor	Bergoz	

Finding 2: It is striking that the majority of the beam diagnostic experiments have clear target applications, thus emphasizing the importance of CLEAR as a test-bed for critical beam instrumentation for both existing and future accelerator facilities and/or experiments.

Medical-application experiments

The medical-application experiments were one of the main activities at CLEAR, with growing demand and representing a total of roughly 14 weeks of beamtime. The ‘C-Robot’, which allows the precise control of samples for multiple irradiations, was used in most of the experiments. In addition, a new C-Robot v2.0 was built for the new CLEAR beamline (see below) which is particularly adapted for medical applications with very flexible optics. (This development is so successful that the robot will be replicated at the PITZ facility at DESY-Zeuthen).

Experiments in 2023 were mainly focused on Very High Energy electron (VHEE) beams targeted at understanding better the ‘FLASH’ effect, aimed at minimizing the dose and the damage to healthy tissue, including investigations of new dosimetry methods. Experiments can be broadly classified as:

1. Dosimetry studies with various methods: real-time dosimetry with thin scintillating screen, Ultra High Dose Rate (UHDR) using radio-chromic films, optical fiber dosimetry (Oxford Univ.) and combination of real-time and high spatial resolution by using scintillators and optical fibers.
2. Irradiation methods and dose delivery modalities, where the experiments planned were on minimizing the damage on healthy tissues by improving strong focusing, minimizing dose and damage by reducing scattering, and studying dose values using GRID collimators. Irradiation methods: VHEE focusing (Manchester Univ.), impact of scatterers (Oxford Univ.) or collimators (spatial fractionation) (UVic), and
3. FLASH effect studies via: chemical, plasmid irradiation, in vivo radiobiology (UVic, EPFL) or bio dosimeters (CHUV).

Finding 3: CLEAR is a unique facility for addressing the FLASH effect in radiotherapy with VHEE, which has brought an increase in requests in this field. The selection of experiments in 2023 (and those proposed for 2024) are strategically chosen to help progress studies of the FLASH effect towards clinical use. The new tools, C-Robot v2 and the new beamline with flexible optics, which will become available in 2025, demonstrate the degree of effort put into the facility to better serve the medical user community.

Advanced accelerator technology experiments

Several experiments relevant to the field of advanced accelerator technology, including beam manipulation and beam diagnostics (see above), were performed during the 2023 CLEAR operation. Of particular note are:

- A plasma lens test has been performed, in the framework of the fruitful collaboration with Oslo University, investigating the “double-plane optical beam enlargement without scattering” and tests of “non-linear plasma lens device concept”.
- Advanced beam manipulation and diagnostics tests have been performed with possible application to advanced accelerators, in particular uniform beam generation and novel emittance measurement.
- A scintillation screen in support of the AWAKE facility program has been tested.

Finding 4: CLEAR is an ideal machine for implementing and testing advanced accelerator components. Strengthening the collaboration with AWAKE will certainly be of mutual interest, in particular concerning the foreseen new AWAKE photoinjector.

Recommendation 1: More visibility should be given to the CLEAR capabilities for tests of advanced acceleration concepts in order to attract more users from other broad international collaborations such as EuPRAXIA.

Irradiation experiments

During 2023, a test setup at the THz station was used for the first time for the irradiation of cables in the scope of the CARE project at CERN. A high-intensity beam (30 nC/train) was directed on a 15 cm long Al target, previously characterized by the R2E team during 2021 and 2022. The beam was optimized to obtain the highest possible energy, and the lowest possible energy spread, while keeping the high intensity (achieving energies in the range between 170 and 205 MeV). In total, 3 cables were irradiated, reaching approximately 100 kGy, 200 kGy, and 400 kGy. The first irradiation lasted around a half-day, the second lasted one day, and the third lasted two days. The level of dose that was reached during the campaign is remarkably high considering the short duration of the test (around 200 kGy/day).

Finding 5: This experience suggests that the CLEAR accelerator may be productively used in future to perform similar irradiations. One aspect to be considered is Radiation Protection (RP): when operating at high beam intensities and for several hours, the activation of the area is non-negligible, requiring ideally at least one night of cooldown before access.

KT aspects

CLEAR is also an interesting facility for industrial partners. In 2023 some tests were conducted by the company Bergoz Instrumentation on an improved beam current transformer. Another important knowledge transfer aspect of CLEAR comes from the scientific results (publications, presentations at conferences, PhD theses) and from the use of CLEAR as a training facility for students, including the Joint Universities Accelerator School.

Transnational access aspects

CLEAR is an active participant in the EURO-LABS project, providing Transnational Access (TA) support to its users. Additionally, EURO-LABS allocates funds to CLEAR for targeted facility improvements aimed at benefiting its users, and CLEAR will be one of the three CERN facilities to offer hands-on training courses. In 2023, the inaugural year of the project, the CLEAR team actively promoted the TA opportunities within the user community; as a result, a total of 6 TA project requests were satisfied in 2023 and 250 access units were delivered out of the 1200 committed total over 4 years. While the startup was gradual, there are promising indications for improvement in the coming years. Regarding the service enhancements, progress has been made in utilizing project funds for the design work of the new C-robot and the development of the new beamline design.

Finding 6: Although the TA projects started gradually, the rate improved significantly towards the end of the year.

3. Scope of beamtime requests for 2024 operations

A similar number of weeks of beamtime operation are planned in 2024. At the time of the meeting 28 requests had been identified, amounting to roughly 153 days of beamtime (before schedule optimisation). 12 requests (55 beam days) are for medical experiments, 10 requests (62 beam days) are for beam instrumentation experiments, and 4 requests (30 beam days) are for accelerator development/physics experiments; 6 beam days are planned for education/training for JUAS and EURO-LABS. Of the total of 28 requests, 14 are for follow-on experiments to those performed in 2023. The planned medical application in 2024 are mainly focusing in exploring dose and dose rate parameters for both healthy and cancerous cells, using VHEE beams.

Finding 7: 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 in 2024. If user demand continues to increase, a tighter selection of experiments may be required in the future.

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

KT aspects

In 2024 the company Bergoz Instrumentation will continue tests on the beam current transformer. Another test will be done by the company DAES SA for the VULCAN project, which aims at developing a compact accelerator-driven neutron source for neutron diffraction applications. The project will be carried out by a consortium of Swiss and Danish SMEs: DAES, DTI, and Xnovo and is partially funded by the Eureka Eurostars program. A key component of the VULCAN instrument is the Target-Moderator-Reflector (TMR) system, where photoneutrons are produced by electron beam interaction with a high-Z target and are moderated using a combination of a room temperature pre-moderator and a cryogenic moderator. Experimental characterization of the TMR will be the main objective of the measurement campaign at CLEAR facility. One of the most interesting applications of VULCAN will be for material analysis of batteries and fast fuel cell development.

Transnational access aspects

CLEAR will continue the TA program for EURO-LABS in 2024 with the aim of catching up based on the progress from 2023. The facility is set to host an advanced hands-on training school in June.

Recommendation 2: The CLEAR team should continue to further increase the publicity of the TA possibilities within EURO-LABS to the user community. At the end of 2024, more than 50% of the declared access units for the facility need be delivered, leaving the remaining ones for 2025 and possibly 2026 the last year of the EURO-LABS project should the operation of CLEAR be extended.

4. Future operations

Near-term through 2025

Near-term improvements to the CLEAR facility include the introduction of a second beamline. This addition enables the creation of more areas for in-air and in-vacuum testing, reducing the need for frequent mounting and dismounting of experiments and diagnostics equipment. Consequently, it increases the available beam time and operational flexibility, allowing for the parallel execution of ‘non-compatible’ experiments within the same week or day, with a quick turnaround. This modification also broadens the beam parameter space, for

example allowing for larger beam sizes and stronger focusing. Commissioning is scheduled for late 2024 or early 2025.
The CLEAR laser systems have been identified as a potential source of failure and downtime. A new EO comb front-end is foreseen to increase the time structure flexibility, increase the repetition rate, and generally improve the reliability.

Finding 8: The second beamline and laser-system improvements will enhance reliability and flexibility for operations in 2024/25, and can be executed within the existing planned resource envelope.

A new electron source (comprising a photoinjector and an X-band accelerating structure) is currently being commissioned in stages in the former CTF2 area, adjacent to the CLEAR hall. This initiative is a collaborative effort involving CLIC, AWAKE, and CLEAR. Current plans favour its use after commissioning and before its installation in AWAKE as an independent beamline in the existing location (CTF2), and as an integral part of the CLEAR user facility.

Finding 9: While the timeline for AWAKE and any potential conflicts requires clarification, it is feasible to duplicate parts of the source with limited investment to avoid such conflicts.

Recommendation 3: CSB recommends that CERN support this approach towards upgrades, including CTF2. The committee encourages the CLEAR team to investigate the possibilities for utilisation of CTF2, define the necessary resources, and evaluate the user interest in CTF2 beyond the planned Inverse Compton Scattering (ICS) studies.

Finding 10: The CLEAR programme has yielded important scientific results, has a growing user community, and an exciting future programme in various key areas. The aforementioned improvements and consolidations will enable CLEAR to accommodate a modest increase in user experiments, aligning with the growth of its user community demand.

Beyond 2025

Finding 11: Considering a programme of user experiments beyond 2025, future priorities would likely include:

- Beam diagnostics R&D, which currently accounts for about 30% of total experiments and is roughly evenly divided between CERN and external users. It is reasonable to expect that demand for this will remain at least stable, or more likely increase due to demand from FCCee (see below).
- Priority for novel acceleration techniques (including plasma, THz, and X-band high-gradient technologies) will be maintained through long-term programmes supported as part of the LDG roadmap. This includes support for the plasma lens, ongoing assistance to AWAKE, and potentially a comprehensive ICS experiment.
- Medical applications are notably important and prominent. The next four to five years are crucial for fully establishing VHEE/FLASH therapy techniques, covering fundamental studies, time structure dependence, and optimization of parameters, as well as its supporting technologies, including beam delivery, dosimetry, and beam control. If extended, CLEAR will uniquely serve the VHEE/FLASH community for a number of years, playing a pivotal role in the field, including facilitating knowledge transfer to other laboratories equipped for animal testing.
- There is likely to be an overall increase in activities in other areas, such as irradiation, neutron production, beam testing of particle detectors and detector components, which will provide further demand.
- The role of training and EU projects, with CLEAR being recognized as a valuable infrastructure in projects such as EURO-LABS.

Completion of the construction and commissioning of the new beamline will be crucial to support an extended programme beyond 2025. This will provide more flexibility to cope with the increasing beamtime demands and will enlarge the technical portfolio of the CLEAR facility. Moreover, as preparations progress towards a future Higgs factory at CERN, there is growing consensus on the need for relevant electron-beam test facilities including, for example, prototypes of key system elements of the FCCee injector complex. If such future electron facilities are designed for versatile use, they could continue and expand the CLEAR programme, attracting a broad user community, in addition to serving as a foundational step towards a Higgs factory.

Finding 12: A CLEAR programme beyond 2025 could serve as a crucial step and bridge towards an electron-beam test facility based around developing key components required for a Higgs factory.

Recommendation 4: CSB recommends that the CLEAR team be centrally involved in discussion of electron test facilities for a future Higgs factory at CERN.

Acknowledgements

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