CLEAR REVIEW REPORT

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Charge to the review

On Wednesday 29th May, a review of the CLEAR user facility was held at CERN, with the aim to provide input to the CERN management about a possible extension of the facility operation beyond the presently approved date of end 2025, as recommended by the CLEAR Scientific Board in February this year. The agenda of the review and the material presented can be found at the following link: https://indico.cern.ch/event/1418402/ . This report has been compiled by the committee members following the specific charge to the review given as follows:

1. The continued operation of the CLEAR facility beyond 2025 is scientifically justified based on the input provided by the CLEAR Scientific Board?

2. The current levels of resources, both in terms of workforce and material budget, are sufficient for ensuring the efficient operation of the facility?

3. The recommendations from the 2021 review have been effectively implemented.

4. The proposed consolidation and upgrade plans meet the following criteria:

- Are they necessary for providing the required beams and reliability for researchers working in areas aligned with the global CERN strategy?
- Are they adequately covered in terms of both workforce and budget?
- Are they in alignment with CLEAR's potential strategic role in providing a testbed for the construction of a future e+e- collider at CERN?

Executive summary

We commend the CLEAR team for achievement of both excellent operational efficiency and outstanding support for user experiments. 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. Moreover, the committee is impressed with the quality of the presentations and the open discussion during the review and would like to thank the organiser and the speakers.

Based on material presented, on the discussions at the review, on the report of the previous review and other literature provided, the committee is fully convinced that continued operation of CLEAR beyond 2025 is scientifically justified.

The current level of resources of about 800kCHF/year is just sufficient to provide an efficient operation of the facility. Nevertheless, in 2027/28 two key staffs in BE-ABP will become unavailable (retirement and contract extension not yet granted) and succession planning to guarantee a smooth transition of personnel in BE-ABP avoiding any loss of expertise should be put in place.

The committee is pleased to report that the recommendations of the previous review have been generally followed, commensurate with the available resources, and would like to congratulate the CLEAR team for the thorough follow-up.

The committee also agrees that the proposed consolidation and upgrade plans for the laser, the second beam line and the Radio Frequency System are necessary to satisfy the needs of the users and they are aligned with the future potential role of CLEAR as a test bed for a future lepton collider. The current consolidation and upgrade plans will be adequately covered in terms of personnel and material budget if the 2 key staffs becoming unavailable in 2027 are replaced/continued as needed for operating the facility and the sum requested of 700kCHF for the consolidation of the RF system is granted. The committee strongly supports these requests that are deemed reasonable.

Additionally, the committee makes the following recommendations:

Recommendation 1: the committee recommends that the CLEAR team be centrally engaged in discussions and planning of electron test facilities for a future Higgs factory at CERN. The committee encourages CLEAR management to investigate with FCC-ee management the future needs, synergies and opportunities, for both accelerator and experiment developments. This interaction should be used also to plan for possible changes and upgrades of the facility on top of the ones already planned.

Recommendation 2: the committee recommends, in view of the approval of the AWAKE run2c/d in the MTP 2024, to provide an updated planning of the beam tests to be carried out with the new injector in CTF2 before its transfer to AWAKE. The committee recommends as well to launch a survey within the CLEAR user community to assess the relevance and the importance of providing beam tests at lower beam energy. This shall support, or not, the need for a dedicated second source to be operated under the umbrella of CLEAR. In this context, an estimation of the additional budget needed to operate a second injector shall also be provided.

Recommendation 3: the committee encourages the CLEAR team to develop automated tools that could reduce the time and the support needed by the users for accessing and analysing the data. These automated tools should be developed using standards and frameworks supported in ATS.

Detailed Report

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 technical support and operation team is lean, and comprises 3.9 CERN staffs (APT 2024) plus contributions from temporary manpower of 2 fellows/year and 3 students and part-time associates, amounting to about 9 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 CLEAR Scientific Board (CSB). A final decision on implementation and scheduling of the request is made by the CLEAR Technical Board.

Since operations started in 2017 a total of 138 beamtime requests have been received and 116 experiments have been supported, originating from 29 user groups that include 44 external collaborating institutes. The scientific output includes 23 journal papers, 36 conference papers, at least 12 PhD theses, and 17 ‘outreach’ articles.

For example, in 2023 27 user experiments were performed during 38 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 beamtime was deployed in the proportions: roughly 1/3 medical-related, 1/3 beam instrumentation, and 1/3 comprising

irradiation, particle-detector testing, advanced acceleration, training and machine development. A similar number of operation weeks is planned in 2024. At the time of the meeting the beamtime is essentially already fully subscribed.

CLEAR is also an important facility for training and outreach. Students attending the Joint Universities Accelerator School (JUAS) spent a training week operating the facility. 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 31 CERN tours and visits (including 'VIP's as well as journalists, companies, and artists) were hosted, and CLEAR was mentioned in 2 international press articles as well as 3 internal CERN articles.

Near-term improvements to CLEAR 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 in 2025.

The CLEAR laser systems have been identified as a potential source of failure and downtime. A new Electro-Optical (EO) comb front-end is foreseen to increase the time structure flexibility, increase the repetition rate, and generally improve the reliability.

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.

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.

The continued operation of the CLEAR facility beyond 2025 is scientifically justified based on the input provided by the CLEAR Scientific Board?

Beyond 2025

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 facility. Considering a programme of user experiments beyond 2025, priorities will certainly 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 FCC-ee.
- 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 Inverse Compton Scattering (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.
- Training and EU projects, with CLEAR being recognized as a valuable infrastructure in projects such as EURO-LABS.

In addition, 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 FCC-ee 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 future e+e- collider.

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 e+e- collider. Operation of CLEAR would maintain, and potentially enhance, the essential electron-beam expertise and capability at CERN which will be needed for construction of the future e+e- collider.

The current levels of resources, both in terms of workforce and material budget, are sufficient for ensuring the efficient operation of the facility?

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 technical support and operation team is lean and comprises staffs at a level of 3.9 FTE/year distributed in 6 different groups. The operation of CLEAR is relying as well on 2 FTE/y for Fellows/Graduates and 3 FTE/y for associates and Ph.D students. Over the period 2017-2023, the average yearly material-to-personnel budget amounts at around 550kCHF. This brings the total operational budget for CLEAR including material and consumables at a level of roughly 800kCHF/year. This number is very well in line with the estimation made in 2016 when the facility was initially proposed.

At the moment the current level of resources is barely sufficient to provide an efficient operation of the facility. Nevertheless, the main concern in ensuring an efficient operation facility in the future is linked to the future unavailability in the coming years of the two staff in BE-ABP who are in charge of the operation of the facility. The committee urges to put in place a succession planning to guarantee a smooth transition of personnel in BE-ABP avoiding any loss of expertise.

The recommendations from the 2021 review have been effectively implemented.

The recommendations made during the 2021 review (in italics) and the actions taken by the CLEAR team are listed below:

1. <u>User demand and role of the Scientific Committee:</u>
    a. *While it is important to respond rapidly to user requests and to maintain machine development and training opportunities, long-term experiments involving external users or demanding extensive support should be more closely followed-up by the Scientific Committee. The Scientific Committee could be included in the formal process of evaluation and approval of the beam-time request in EDMS.*

- A call for experimental proposals is made every year during the Year End Technical Stop (YETS), the collected proposals are evaluated and ranked by the CSB by February. Flexibility to accept additional proposals during the run is kept and also in this case a formal process of approval, involving the CSB members, has been implemented in EDMS.

b. *Evaluate the user needs requiring the installation of the new injector in CLEAR in time for a possible operation in 2023-2025.*
   - There was no strong demand for two-beam experiments that would justify the installation of the new injector in CLEAR. Instead, it is proposed to make use of the new injector to provide a new low-energy beamline in its present commissioning location in CTF2.

2. Resources for continued operation:
   a. *An updated manpower plan for continued CLEAR operation in the future addressing the expected departures (e.g., safety) should be presented and approved by the ATS management. Possible synergies with cathode development and production for other electron guns operated at CERN should be identified. The responsibility for the configuration management for the CTF/CLEAR area should be defined.*
      - The manpower plan has been updated and personnel departures have been addressed with a new staff (on limited duration contract) joining the CLEAR team and with the nomination of a safety officer. Synergies (notably with AWAKE) on cathode development and production are exploited. Configuration management for CLEAR could not be addressed due to lack of resources.
   b. *CLEAR offers unique opportunities for a wide external user community. In case that would grow to a level requiring significant extension of the facility it might be judicious to seek external funding (which might include, inter alia, contributions from industrial partners). The proposal of applying for EU transnational access (RADNEXT, ARIES) should also be pursued.*
      - External (EU) funding to support users and limited infrastructure improvements has been obtained (EURO-LABS) together with budget and manpower contributions from different collaborating institutions and universities. An additional funding opportunity with the Swiss National Science Foundation is being pursued.
3. Safety:
   a. *The safety aspects have been adequately assessed but need to be followed up timely. We encourage to pay particular attention to the safety documentation considering the involvement of external users in the experiments. A clarification on the framework of operation of the CLEAR facility might be required.*
      - Safety officers are involved in the formal approval process of new experiments and RP is present at CLEAR weekly operation meetings. Safety documentation is available and updated whenever infrastructure changes are occurring.
   b. *A replacement for the Facility Safety Officer should be identified (see also recommendation 2).*
      - See above.
4. Improvements:
   a. *Tools to generate automatic entries in the logbook for short faults are available and could be tested in CLEAR. This could facilitate the use of AFT.*
      - The generation of automatic logbook entries could not be implemented due to lack of manpower. An effort has been made towards a more systematic documentation in the logbook and in weekly reports.
   b. *The correlation between measured beam parameters and dosimetry should be investigated in collaboration with the users as this could be beneficial for medical applications and irradiation to electronics.*

- This has been the subject of a PhD thesis. An on-line application provides dosimetry data based on beam measurements.

5. Upgrades
   a. *Based on the user needs assess the configuration and the resources required for installation of the new injector in CLEAR.*
      - No use case for a two-beam set-up has been evidenced.
   b. *Conduct a quantitative analysis of the needs of the communities using CLEAR to see if the need of a second beam line is justified; if so, conduct a quantitative analysis of the impact of the installation of a second beam line on machine availability and experiment turn-around time and assess the required resources for construction, installation and operation.*
      - At present, operation over extended hours is necessary to accommodate the user requests. The installation of the second beamline would allow to avoid de-installation and reinstallation of experiments between two consecutive measurements that typically are interleaved by a few days to allow preliminary data analysis. This would reduce the CLEAR manpower effort required for the experiment set-up and therefore no additional resources for the operation of the additional line are expected to be necessary. The design of the second beamline has been completed and resources needed for its construction and installation have been granted. The implementation of the second beam line has been approved by the ATS management. Installation will take place during the next YETS and commissioning is planned for spring 2025.

From the above we conclude that **the recommendations of the previous review have been generally followed, compatibly with the available resources, and we congratulate the CLEAR team for the thorough follow-up.**

The proposed consolidation and upgrade plans meet the following criteria:

- Are they necessary for providing the required beams and reliability for researchers working in areas aligned with the global CERN strategy?

- Are they adequately covered in terms of both workforce and budget?

- Are they in alignment with CLEAR's potential strategic role in providing a testbed for the construction of a future e+e- collider at CERN?

The proposed consolidation and upgrade plan includes the laser system, a second beamline, the Radio Frequency systems refurbishing and a second injector.

Upgrade and consolidation of the laser system. Operation of the CLEAR laser system requires consolidation to improve stability. At the same time the introduction of the EO frequency combs will allow for increased flexibility and fully programmable system that can also simulate FCC-ee electron bunch

structure. This is done in synergy with developments for Gamma Factory Proof-of-Principle experiment at SPS and Compton polarimeter for FCC-ee. About 90% of the components for this upgrade are already in house. This work is currently being performed and remains within the CLEAR operational budget envelope.

A **second beam line** has been studied and is currently being implemented, recuperating hardware from CTF3 facility. It would ease operation and improve the global efficiency of the facility being able to manage several experimental setups in parallel. With the second beamline, which is presently under preparation, the efficiency of experiment preparation and execution time will be greatly enhanced, thus providing more capacity and opportunities for users. The second beam line will also provide a variability of the beam size in a broader range thus accommodating more user requests.

Radio Frequency systems (including timing system) the Low Level RF would need consolidation in the coming years. It would require both hardware development and personnel support (Grads) and there are synergies with the work needed for AWAKE and FCC-ee that need yet to be explored. Some consolidation for klystrons and modulators is also needed. The total amount of money needed for the RF consolidation includes 300kCHF for refurbishing /repairing high power RF components, 300k for Low Level RF and 400kCHF for graduate support (M to P). Some 400kCHF can be absorbed by the CLEAR operation budget but this would mean running some risk of not being able to maintain a proper operation support. This upgrade/consolidation is necessary to guarantee even the present performance.

A **new injector** in CTF2 is currently under commissioning as part of the AWAKE run2c/d program. It provides lower beam energies and has raised some interests for beam tests in the CLEAR user community.

The CLEAR program, though moderate in budget and resource needs, is and will be important for the global CERN strategy for three main reasons:

- As a testbed for advanced beam instrumentation and, it allows testing and commissioning of instrument prototypes for ongoing and future CERN facilities. There are numerous examples from past CLEAR runs with tests for CLIC, AWAKE, and FCC-ee-related instrument developments.
- As a platform for accelerator applications beyond particle physics it demonstrates the usefulness of CERN technology developments for society.
- It is an excellent program for the training of future accelerator and instrumentation experts from the CERN member state universities.

The new gun laser system presently under development will provide much more flexibility 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 has so far achieved excellent results with rather limited resources. In particular, the manpower for operation is barely sufficient, and the situation will certainly not get any better in the coming years.

The point to be addressed to guarantee future operation are the following :

a) The Radio Frequency systems will need extra resources, both in terms of personnel and material budget;
b) The operation largely relies on temporary personnel, paid by M to P, which leads to issues with continuity and transfer of knowledge between people and competes with the material budget required for operation and upgrades; a marginal increase in the material budget would ease the situation;
c) 2 key staffs (one retirement and one extension not yet agreed and partially supported with external funds) will become unavailable in 2027/2028. it is essential for the future of CLEAR that they are replaced/extended and that a proper succession planning, in line with the medium-term plans of the organisation to strengthen high energy lepton collider studies, is worked on as soon as possible.

In conclusion, the current consolidation and upgrade plans will be adequately covered in terms of personnel and material budget only if the 3 above mentioned challenges will be resolved.

CLEAR was born from a CLIC test facility, and therefore naturally has the potential to become relevant for FCC-ee too, based on the experience accumulated by the facility managers and physicists, the hardware developed and tested in view of CLIC, the know-how achieved in the operation of the only complex at CERN dedicated to bunched electron beams.

The studies linked to FCC-ee have not yet reached the maturity to require a dedicated test facility, which however could become necessary soon, as detailed study cases are not defined yet but they are quickly taking shape. The foundations in CLEAR as testbed also for FCC-ee are there and they should be used, as already started for the first test campaigns relevant for FCC-ee, mainly on beam instrumentation.

In this sense it would be appropriate to explore what potential requests for FCC-ee could materialize in the short term. Testing the front-end for the electron source and studying positron target damage by irradiation, proposed during the review, certainly constitute excellent examples. Today the facility offers for FCC-ee a source for coherent radiation studies for longitudinal beam diagnostic development. CLEAR could become a key player in providing test beams in the period 2026-2030 during which the LS3 at CERN for the LHC injector chain, the EAST and the North Area will also coincide with similar periods in other laboratories.

The facility also presents a unique opportunity for the training of students and researchers, both for learning accelerator physics, as well as machine operation, specifically on lepton beams. This is also thanks to the fact that the facility is not connected to the LHC injector chain, offering a flexible and evolutionary modus operandi, which lends itself also to the development of new techniques prior deployment elsewhere. An example could be those linked to artificial intelligence for control systems that could be tested at CLEAR.

In this sense, the CLEAR exploitation is aligned with CERN's future needs for the next collider, being the only facility with the capability to provide or develop test beams for lepton colliders as well as a training centre also for the next generation of machine physicists, engineers and technicians who will contributed to the construction and operation of the next lepton collider.