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DELIVERABLE REPORT

WP3 – REPORT ON THE SERVICE IMPROVEMENTS FOR ELECTRON AND PLASMA BEAMS

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Abstract:

The present document reports on the service improvements planned for the RI Facilities participating to Task 3.3 and Task 3.4 of EURO-LABS Work Package 3 related to Electron and Plasma beam Facilities and Applications. Service improvements were planned for the KIT-ALFA (FLUTE and KARA), LPA-UHI100, and CERN/CLEAR facilities. In all cases, the planned activities are well advanced and will be completed and put in operation within the project's duration in 2026.

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	Name	Partner	Date
Authored by	Anthony Gleeson [Task 3.3 Leader] Urszula Gryczka [Task 3.4 Leader]	STFC-UKRI INCT	01/07/2025
Edited by	Saeid Masoumi, Robert Ruprecht, Patrick Schreiber, Marcel Schuh [KIT] Sandrine Dobosz Dufrénoy [LPA-UHI100] Roberto Corsini [CLEAR]	KIT CEA CERN	25/08/2025
Reviewed by	I. Efthymiopoulos [WP3 coordinator]	CERN	28/08/2025
Approved by	A. Navin [Scientific coordinator]	GANIL	30/08/2025

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Executive summary

The RI Facilities participating in Task 3.3 and Task 3.4 of Work Package 3 of EURO-LABS provide Transnational Access (TA) to users, enabling advanced R&D on present and future accelerators through state-of-the-art Electron and Plasma beams.

Service improvements were planned for the KIT-ALFA (FLUTE and KARA), and LPA-UHI100 facilities, aimed at enhancing the performance capabilities of the provided beams, as well as facilitating access and strengthening user support during their visits to the facilities for their experiments. In both cases, the planned activities are well advanced, will be completed, and put into operation within the project's duration in 2026.

The CLEAR planned service improvements aim to enhance the quality of measurements and the data acquisition process in areas critical to a large portion of users, and increase the number of users who can access the facility per unit time. In particular, this last objective is to be obtained by installing and putting into operation a second beam line, basically doubling the available locations for in-vacuum and in-air user experiments. The details of the status, budget, and schedule are presented.

The document presents the work carried out, together with a brief of resource usage and scheduling.

1 INTRODUCTION

EURO-LABS is a network of 33 research and academic institutions (25 beneficiaries and 8 associated partners) from 18 European and non-EU countries, involving 47 Research Infrastructures within the Nuclear physics, Accelerators and Detectors pillars. In this large network, EURO-LABS will ensure diversity and actively support researchers from different nationalities, gender, age, and variety of professional expertise.

Within EURO-LABS the Work-Package 3 (WP3) provides Transnational Access (TA) to Research Infrastructures for Accelerator R&D, with the RI Facilities participating in Task 3.3 focused on state-of-the-art electron and plasma beams, as test beds for advanced R&D on present and future accelerators. The RI Facilities in Task 3.4 provide state-of-the-art electron beams for R&D and applications, in particular for novel medical physics.

Service Improvements (SI) were planned for the KIT-ALFA (FLUTE and KARA), CEA/LIDYL LPA-UHI100, and CERN CLEAR facilities.

For KIT-ALFA, the SI encompasses the creation of a meta-database of measurements, linking numerous accelerator parameters to corresponding data sets. This database provides users access to the accelerator operation parameters, including metadata in FAIR format. Beyond servicing as a logging and reference tool, it also enables, in combination with the developed tools, the simulation of planned experiments prior to execution, thereby saving valuable setup time at the accelerator. This allows users to optimally perform their experiments, spending their time directly on measurements.

For the CEA/LIDYL-LPA-UHI100 facility, the SI involves the installation of an additional pumping system in the target chamber to boost the repetition rate of the laser-plasma accelerator from 0.03Hz to 1Hz. This is a challenging modification, but it would offer a significant advantage to operations and to the user experiments.

One of the main issues in the CLEAR facility is the fast turnaround between experiments (typically one experiment per week, with sometimes up to four experiments sharing beam time in the same week). Since experiments often have very different requirements and cannot share the same experimental space or setup, while several of them may be repeated a few times during a year, frequent mounting/demounting of experiments is needed, together with the repetition of beam setup procedures. A new beam line, branching out from the existing one, is under construction and will provide more areas available for experimental set-up, increasing the number of experiments which can run in parallel, and allowing for less frequent mounting/demounting of hardware. The new line will also provide more flexibility in the beam parameters that can be delivered to users (e.g., smaller or larger beam size in the in-air test stand). In parallel with this main improvement, upgrades of several data acquisition and beam diagnostics systems to be deployed on both lines are also ongoing, and will be fully operational in 2026 before the end of the project.

2 KIT-ALFA(KARA – FLUTE) – GE

2.1 SERVICE IMPROVEMENTS

ALFA (**AcceLerator Facilities)** is the name of the accelerator facilities as part of KIT's cross-institutional ATP (Accelerator Technology Platform). The main ALFA accelerator facilities are the linear accelerator-based FLUTE (compact Far-infrared Linear accelerator and Test Experiment) and the electron storage ring KARA (KArlsruhe Research Accelerator). ALFA offers a range of operational modes, as well as diagnostic devices with high data throughput. These diagnostic sensor networks are capable of taking synchronized data from different detector systems which enables new beam diagnostic methods and detailed beam dynamic analysis. For the analysis, the knowledge of all machine settings at the same time of the data is essential.

Due to the flexibility of KARA and FLUTE the parameter space is too large for a parameter scan for each measurement. Hence, it is essential to implement a metadata database, e.g., based on an RDM (Research Data Management) software (like Kadi4mat) to collect all parameter settings and link them to the dataset. This would enable the combination of data from different measurements in the data analysis. With this tool, users can utilize other measurements carried out in the past. The careful preparation and planning of experiments are essential to make use of the expensive beam time at accelerator test facilities. An integrated simulation and measurement framework will enable the preparation of experiments in greater detail, allowing for more automated measurements and data analysis. With the availability of the measurement meta database, planned experiments at KARA and FLUTE could be simulated in advance to identify the optimum settings, thus gaining beam time from setting-up and going faster to the actual measurements.

As part of the EURO-LABS funded service improvements, KIT has developed an integrated simulation and measurement framework for facilities with large amounts of data and complex dependencies, such as accelerator facilities, so that users and operators can prepare, plan, perform, and evaluate experiments more efficiently. The aim was to implement an integrated simulation and measurement framework within two years at ALFA, enabling testing at the KIT facilities KARA and FLUTE. Other research institutions or even companies, including those outside of accelerator research, could take over the development of this integrated simulation and measurement framework and adapt it for their applications.

Details on the activities

Identification of relevant metadata: Metadata for each measurement and simulation type is systematically collected, categorized, and aligned with FAIR principles to ensure consistency and reusability across facilities.

Implementation of metadata schemas: Schemas for simulation and measurement metadata are implemented to enable structured validation, interoperability, and integration with existing Research Data Management (RDM) services and tools. As the RDM software has been successfully deployed, the infrastructure for storing both data and metadata is now in place.

Data-flow documentation: Documentation of the desired data flow for automated transfer from measurement to permanent storage, including metadata

Evaluation of existing tools: Evaluation of existing simulation and measurement tools as well as existing frameworks for integrations.

Simulation framework: Implementation of a framework that allows the integration of simulation codes into the control system, including an example integration.

Measurement Framework: Implementation of a framework that allows the integration of measurement devices into the control system, including an example integration.

Simulation and Measurement Framework Documentation: Documentation of the frameworks for simulation and measurements.

Unified Access Framework: Implementation and documentation of a framework for unified access across measurement files and simulation results, including an example integration.

Documentation of Access Framework: Documentation of the framework for unified access to measurement and simulation data

2.2 STATUS

Data Management Framework Activities at KIT

KIT evaluated three research data management platforms—B2SHARE, RADAR, and Kadi4Mat. Each platform was assessed for capabilities in data storage, accessibility, metadata management, and integration with existing infrastructure. As a result of this evaluation, Kadi4Mat was selected as the Research Data Management (RDM) solution. It has been integrated into the KIT-IBPT institute's IT infrastructure and connected to the Large-Scale Data Facility (LSDF), the central storage system for large research data at the Karlsruhe Institute of Technology (KIT).

As security and compatibility with institutional infrastructure were key priorities throughout development, the system is now fully deployed within the institute's internal network and accessible at https://kadi.ibpt.kit.edu. Datasets can be uploaded to Kadi4Mat regardless of whether they originate from KARA or FLUTE, since it supports a variety of different measurement types. For testing, KIT utilized archived data from KARA experiments stored in the institute's IBPTSRDATA network storage. We are on the way to testing during user experiments at KARA, followed by testing in upcoming FLUTE experiments with friendly users. Feedback from these tests will guide final refinements ahead of broader deployment.

The system supports a variety of metadata schemas to accommodate diverse experimental setups. Moreover, automation features are available to reduce manual metadata entry, using Python libraries and the Kadi-Apy tool. Finally, our deployed RDM infrastructure is ready to accept data and metadata from other accelerator facilities.

Simulation and Measurement Framework Activities at KIT

Several existing projects on measurement and simulation framework have been evaluated such as BlueSky for example. It has been concluded that for the required use-case, they are not suitable in terms of simplicity of implementation and integration into the control system. Therefore, a Measurement and Simulation Framework has been implemented at KIT that allows implementation of simulations and measurements that are integrated in the control system without extensive knowledge over the intricacies of the control system itself.

The integration exposes control variables as well as result variables via the control system. Each integration comes with auto generated panels that can be integrated in the standard control interface for operators easing adoption of newly built tools. The control over how the measurement or simulation is integrated into the control system has been refined recently, allowing a more fine-grained configuration. Several use cases have been implemented using this measurement framework. Among them are a centralized chromaticity measurement, energy measurement using resonant spin depolarization, dispersion and beta function measurement. All these benefits from having a central interface accessible from anywhere in the machine network.

Some of the implemented measurements were implemented by physicists without extensive knowledge of the control system, proving that the framework can be used as intended. Furthermore, some measurements have already been used and even been implemented by a user group in the framework of **Transnational Access** within the European project EUROLABS.

An optics simulation has been implemented and integrated into the control system.

This simulation serves two purposes: the live display and calculation of optics functions in sync with the real accelerator, including chromaticity, and the estimation of effects on the machine without actually modifying it. Both features use the same interface as the actual accelerator making it possible to move from one to the other quickly. KIT also joined the Python accelerator middle layer efforts (https://github.com/python-accelerator-middle-layer), which is part of LEAPS (League of European Accelerator-based Photon Sources), to benefit from the joint efforts.

For camera image processing, multiple open-source tools and frameworks have been evaluated, and areaDetector (https://areadetector.github.io/areaDetector) has been chosen as the most suitable. A unified framework for camera image processing has therefore been implemented based on areaDetector, allowing a shared interface between KARA and FLUTE. This framework enables easy switching between users across the two accelerators, offering high performance and maintainability.

Unified Access Framework at KIT

To access simulation as well as measurements, the standard control system interface was chosen. This allows unified access to configure simulations/measurements as well as access to the results in a familiar way. To this end, for the simulations as well as the measurements, panels have been built that work with the CSS (Control System Studio) GUI used for general interactions with the control system.

Furthermore, for long term preservation, the results of measurements done with the measurement framework are automatically saved including metadata in hdf5 files, that contain a pre-defined structure. This allows easy adaptation of analysis scripts.

2.3 USE OF RESOURCES

Budget planning

The EC contribution up to the end of the EURO-LABS project amounts to 150,000 €, the additional budget for development and testing being borne by KIT.

Initially, the project proposal foresaw outsourcing the development work for the Service Improvement. However, after further consideration, an in-house solution was preferred, with the task assigned to a KIT scientist experienced in data management at ALFA. An additional advantage of this solution is that it ensures long-term support and preserves the know-how within the laboratory. This approach required a transfer of funds within the Project, which both the PO and the GB approved.

Schedule

The timeline for the KIT activities was:

1. Identify relevant metadata (60d)
2. Implement data structure (30d)
3. Data-flow documentation (35d)
4. Evaluation of existing tools (60d)
5. Simulation framework (85d)
6. Measurement Framework (85d)
7. Simulation and Measurement Framework Documentation (30d)
8. Unified Access Framework (75d)
9. Documentation of Access Framework (15d)

Some of the activities were carried out in parallel and in a flexible sequence. The proposed service improvements were expected to be developed in the first two years of the project EURO-LABS to be operational from M30.

The data management service is fully developed and evaluated using existing archived KIT data. It is now ready to accept measurement data directly from control system operators or scripts via the API (Application Programming Interface) for user experiments. Furthermore, the measurement framework has already been used and implemented by a user group exploiting Transnational Access within EURO-LABS.

KIT invested EU-funded 13.3 PM (116.264€ full costs) for service improvements until M36.

Further refinements are planned before wider introduction by the end of the EURO-LABS project, for which up to 12 PM (about 110 k€) will be invested additionally.

2.4 FEEDBACK FROM OPERATIONS

Data Management Framework Activities at KIT

The data management service was tested using a selected set of archived datasets from the KIT-IBPT institute, originating from previously completed KARA experiments. This phase provided early feedback on functionality, integration, and usability in real experimental settings. A variety of dataset sizes were used for testing, ranging from 2 GB to 500 GB. The results showed that Kadi4Mat is stable and performs well during data uploads.

Furthermore, Kadi4Mat's configuration was fine-tuned to reduce upload times. For instance, uploading a dataset of approximately 26 GB initially took 27 minutes, but after optimization, the time was reduced to 15 minutes—representing a significant improvement of around 44%. In addition to the web user interface, the Kadi-Apy tool was used to test data uploads. The evaluation showed an average improvement of approximately 23% in upload performance. Based on decisions made during our regular bi-weekly meetings, LSDF was preferred over S3 for data storage due to its superior maintenance and backup capabilities. Additionally, we evaluated the upload speed for both storage systems and found that LSDF consistently outperforms S3.

Measurement Framework Activities at KIT

The Measurement Framework at KIT has been used during several user proposals, e.g. the Transnational Access proposal EURO-LABS-KIT-2024-KARA-07_TA, for BBA (Beam Based Alignment) for FCCee, realised in November 2024. Further measurement scripts have been developed utilizing the existing Framework by the users. These will be integrated the in the Measurement Framework to enrich the available tools for future measurements.

3 CEA/LIDYL-LPA-UHI100 – FR

3.1 IMPROVEMENTS

The LPA-UHI100 facility delivers electron source in the 100MeV range, issued from laser-plasma acceleration mechanism. The maximum repetition rate of the source is directly linked to the repetition rate of the laser itself. Most of the laser-driven electron source are generated from Ti:Sapphire laser system, delivering from few to 100's of TW power. The maximum repetition rate of such laser system is generally around 10 Hz, but the electron source doesn't often exploit this property as it requires a specifically designed target coupled to very demanding pumping system. Increasing the frequency of the electron source is a big issue, in particular for medical applications or even for material testing.

The improvement proposal is to boost the pumping system of the interaction chamber hosting the acceleration process to work at 1Hz (instead of 0,03Hz which is our actual rep. rate) (see Figure 1).

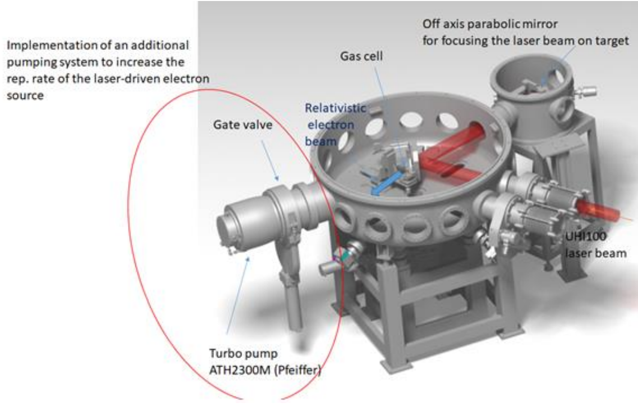

Figure 1: left: view of the radioprotected experimental room for electron source acceleration- © L. Godart/CEA , right: sketch of a part of the service improvements (increase of the pumping speed to increase the repetition rate

This will offer new possibilities for data accumulation and could attract more users to the facility. Additionally, this is the least costly solution before replacing the driving laser with a higher-frequency system, while maintaining the same level of power. If the addition of one new turbo pump to the existing system is insufficient to achieve the 1 Hz repetition rate, we plan to design and implement a differential pumping system. The last point to take care to is the loss of reflectivity of the last compressor grating (meaning degradation of the electron acceleration process) due to a potential carbon burns that can be due to pollution of the vacuum chambers combined to the high repetition rate. To overcome this problem, we investigate a new solution consisting of implementing a system that deliver oxygen leakage during shots in the compressor chamber to avoid the carbon deposition on gratings.

3.2 STATUS

We have installed a fully refurbished turbomolecular pump (Alcatel 1600M – max 39000 rpm) on the experimental chamber used for electron beam generation. This addition significantly enhances the pumping capacity, which was previously handled by an Alcatel 1300M (max. 34000 rpm). Initially, we were able to operate at a repetition rate of just 0.03 Hz. However, with the recent installation and after finally receiving authorization from ASNR(Autorité de Sûreté Nucleaire et de Radioprotection), the Nuclear Safety Authority in France, an approval we had been awaiting since the start of the EUROLABS project, we have entered the debugging phase of the facility. During this phase started in March 2025, we had to face a stop of three months due to a problem on the cooling system of the laser (April – end of June).

The first tests indicate that we can operate the facility at a repetition rate of 0.1Hz using Hydrogen to generate a good quality electron beam. Even if it's a notable improvement, we have not yet reached our final goal of 1Hz. The maximum repetition rate allowed for the facility, as imposed by ASNR, is 0.3 Hz. This now constitutes the new operational limit for the platform. One potential path forward, depending on the quality requirements of future experiments, is to use nitrogen instead of hydrogen. This would increase the charge but may degrade beam quality in terms of divergence and stability. As nitrogen is easier to pump, this could allow us to increase the repetition rate. These tests are expected to be conducted before the end of the year.

We also encountered a technical issue with the pump, which required disconnecting it and sending it to the vendor for inspection and repair. The pump has since been returned and will be reinstalled in October for complementary tests with a different gas.

Another critical aspect of laser-driven facilities is the gradual loss of reflectivity in the optical compressor, particularly on the last grating optic. This degradation occurs as impurities from the vacuum chambers along the laser transport line are partially burned onto the final grating. Over time, this reduces laser reflectivity and, consequently, the efficiency of electron beam generation. We have started to explore the solution of implementing a depollution system based on plasma production inside the compressor, trapping the burned impurities and cleaning the last grating component.

We plan to acquire a GV10X system from the IBSS Group, distributed by Milexia. Although we have already received a quotation for €26,000, CEA procurement regulations require us to obtain additional offers before proceeding with the purchase. If all goes as expected, the system should be implemented by the end of the year. Further testing will then be carried out to determine the optimal operating parameters.

The solution initially budgeted for was a less attractive, though functional, system that required adaptations to operate on the new facility and involved significant cleaning time. By contrast, the GV10X system offers a much more efficient approach, reducing the time needed for this operation. Its adoption became a promising option after a visit to our collaborator's DRACO 150TW and PW laser facility at Helmholtz-Zentrum Dresden-Rossendorf (Germany) in 2024, where its effectiveness was successfully demonstrated.

3.3 USE OF RESOURCES

Budget and work plan

Planning	Budget	Tasks
April 2023	5k€ /4,5k€ (spent)	overall maintenance, and cleaning – maintenance (refurbishment) of a turbo pump ATH2300M by Pfeiffer, that has been given to our team (reorganization and retirement…) + associated gate valve requested to isolate from the generation chamber (fast opening of the generation chamber)
October 2023	2,5k€ (planned and spent)	implementation of a pressure regulator to remotely operate the gas for electron generation – Bronkhorst system
October 2023	6,2k€ (spent)	the target as been fixed to 0,3 Hz max by ASNR, Nuclear Safety Authority. Computer server for automatic saving of the recorded diagnostics – for automation, analysis, data storage

April 2025	0,9k€ (spent)	repair of the turbo pump ATH1600M and controller after few tests (connection problems between pump and controller)
December 2025		implementation of a cleaning system on the compressor to preserve the reflectivity of the overall ensemble and guarantee the efficiency of laser-driven particle source generation.

The last point as not yet been implemented. Recently, a more sophisticated solution has been identified for cleaning the final gating of the compressor, compared to the one originally envisaged. However it requires a significantly higher budget than the 5k€ initially planned: the quotation we received in July 2025 amounts to 26k€.

This system will reduce the time required to clean the compressor optics, a procedure that is mandatory after a given number of laser shots – still to be determined, as the facility remains in the debugging phase. In our previous system, cleaning was needed every 4,000-5,000 shots at 0.03Hz. Increasing the repetition rate will shorten the interval between cleaning operations. Implementing this improvement is therefore essential to secure beam time on the facility without excessive downtime for cleaning.

The total overall expenses will be 14k€ over 22k€ granted for service improvements, as the expenses have been made after the beginning of the project. The total expenses that have been made corresponds to 22k€.

3.4 FEEDBACK FROM OPERATIONS

We were not ready to operate the facility as the ASNR authorization came late. We have a first TA proposal that will be submitted in September, pending the finalization of technical details. The pressure regulator has been implemented for the first tests and the repetition rate, in operation, is 0.1Hz at that time.

4 CLEAR – CERN

4.1 IMPROVEMENTS

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 user experiments, reducing the need for frequent mounting and dismounting of experimental set-ups 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 at the end-of-line experimental station which will also have improved handling/measurement hardware.

The beam line reuses many hardware components (magnets, power supplies, girders, vacuum and diagnostics equipment…) already existing at CERN and recuperated by a previous facility, CTF3, no longer operational. This allowed for a relatively low cost (last estimation is about 200 kCHF) for such an installation. Most of the required budget is coming from CLEAR/CERN operational budget. The contribution from EUROLABS are in large part used to properly equip the new user areas. The items charged on the EURO-LABS budget include a beam current measurement device (ICT), a wide-band wall current transformer (WCT) to measure the beam time structure, (especially important for medical application users), an optical table, vacuum and optical components, beam screens and associated cameras, two vacuum chambers for the two new beam line dipoles, plus drawing office work. Additional items still to be purchased using EURO-LABS funds include 1) an ionization chamber for real-time dosimetry, 2) some ADC and timing modules and other acquisition and data handling hardware.

4.2 STATUS

The new beam line was fully approved by CERN management in June 2023 and the beam line design was completed at beginning 2024 (see Figure 2). Several components of the beam line have been installed in the winter shut-down 2024-2025, and the installation is being completed in August-September 2025 (see Figure 3). All supports, magnets, power supplies are in place and connected, as well as most of the vacuum equipment and the diagnostics. On the critical path are the two new dipole chambers, whose construction was launched before summer. Hardware and beam commissioning are planned before the end of 2025. Completion of the construction and commissioning of the new beamline will be crucial to support the CLEAR extended programme beyond 2025, since it will provide more flexibility to cope with the increasing beamtime demands and will enlarge the technical portfolio of the CLEAR facility.

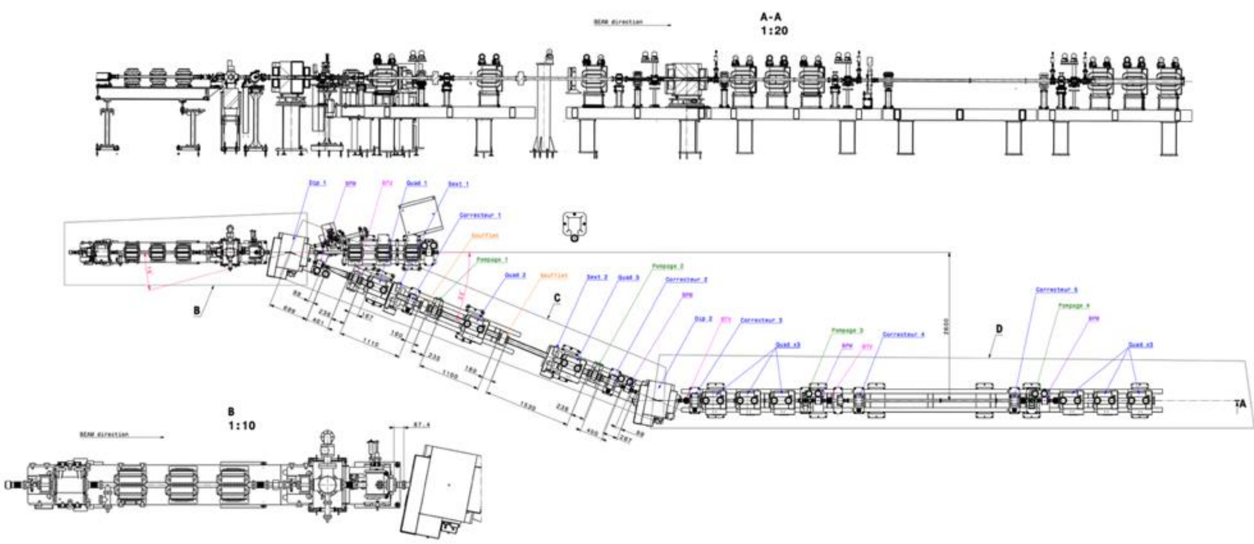

Figure 2: Layout of the new CLEAR beam line.

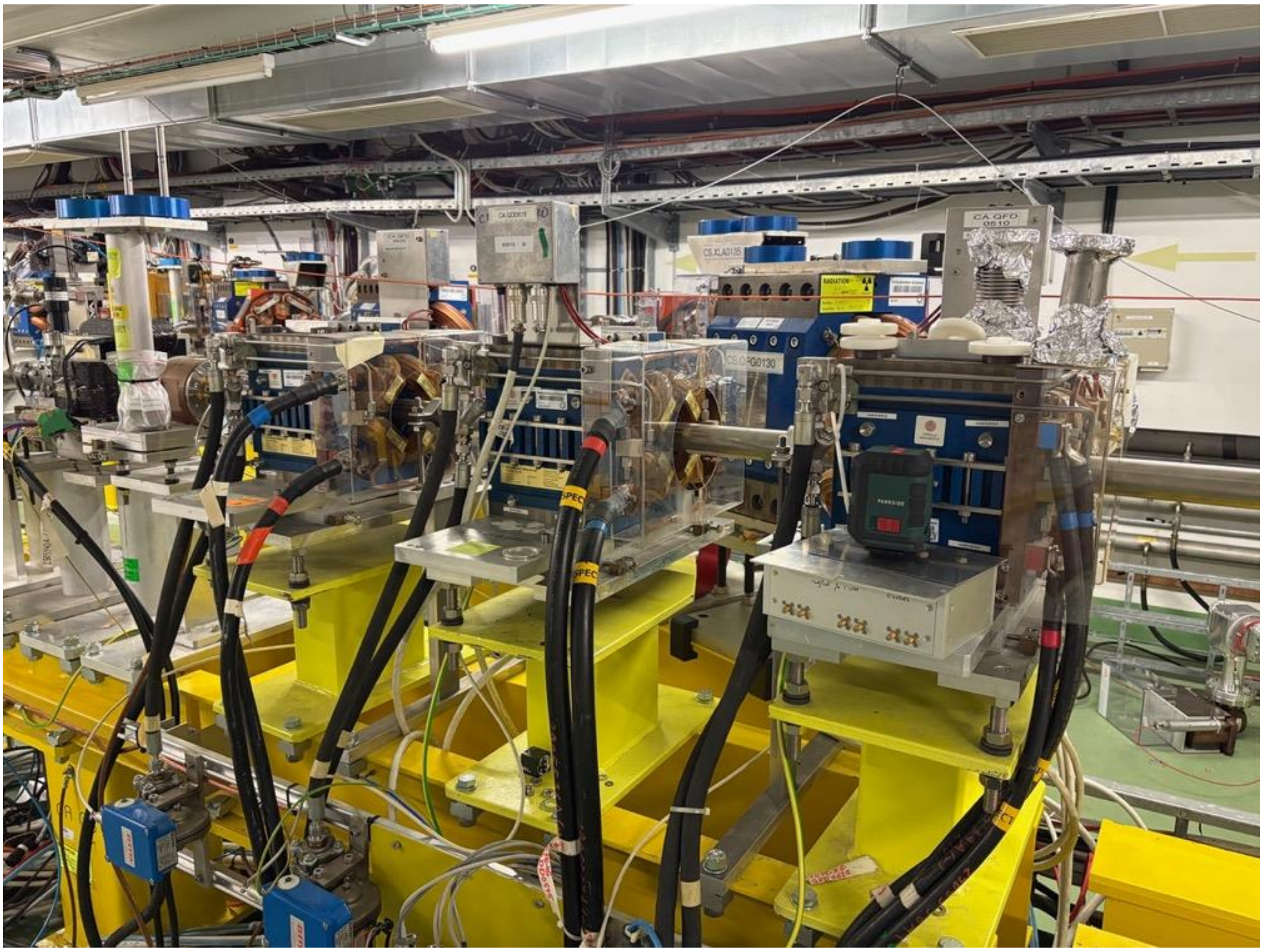

Figure 3: Photo of part of the new beam line (first quadrupole triplet), showing the present status of the installation, including vacuum chamber, electrical and water cooling connections and some beam diagnostics elements (BPMs).

4.3 USE OF RESOURCES

The budget from EURO-LABS has been committed so far for a total of 92 kCHF. The spending profile has been so far as follows: 1.8 kCHF in 2023, 30 kCHF in 2024 and 35 kCHF in 2025, for a total actually charged of 67 kCHF. All planned budget is expected to be spent within spring 2026.

4.4 FEEDBACK FROM OPERATIONS

The new beam line and other service improvements are foreseen to be fully operational at the restart of CLEAR beam operation in March 2026.