EURO-LABS

European Laboratories for Accelerator Based Science

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Deliverable Report

WP3- Access to RI for Accelerator R&D

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Abstract

This document reports on the progress of the Transnational Access (TA) activities at the CERN CERN Linear Electron Accelerator for Research (CLEAR) facility and Institute of Nuclear Chemistry and Technology (INCT) RAPID, conducted within Work Package 3, Task 4 of the EURO-LABS project. The projects carried out at the facility to date are described, together with their impact on the relevant research domains and selected highlights of the results obtained. In addition, the ongoing and planned projects foreseen up to the end of the project in August 2026 are outlined. Finally, an evaluation of the TA experience within the EURO-LABS framework is presented.

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EURO-LABS Consortium, 2026

For more information on EURO-LABS, its partners and contributors please see:

https://web.infn.it/EURO-LABS

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Delivery Slip

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Executive Summary

Within the EURO-LABS project, Work Package 3 (WP3) provides Transnational Access (TA) to key European Research Infrastructures dedicated to accelerator research and development. Task 3.4 focuses specifically on access to state-of-the-art electron beam facilities for applications-oriented research, strengthening the integration between accelerator physics, radiation science, materials research, environmental technologies, and medical applications.

This deliverable reports on the progress achieved in the implementation of TA activities at the two participating infrastructures:

the **INCT–RAPID** facility at the Institute of Nuclear Chemistry and Technology (Warsaw, Poland), and

the **CLEAR** facility at CERN (Geneva, Switzerland), based on the CERN Linear Electron Accelerator for Research.

Both facilities have provided reliable, high-quality access to external user teams, delivering Access Units (AUs) in line with the commitments defined in the Description of Action (DoA) and subsequent project milestones. The infrastructures have operated smoothly, offering not only beam time but also comprehensive scientific, technical, and dosimetric support, ensuring that users could effectively carry out ambitious experimental programmes.

At INCT–RAPID, TA activities have demonstrated the versatility and societal relevance of electron beam technologies. Projects span a broad range of domains, including: radiation chemistry and biochemistry, advanced polymer processing and nanogel design for drug delivery, sustainable materials and composite development, food safety and functionalisation, agricultural resilience and mutation breeding, and environmental applications such as greenhouse gas conversion.

At CERN, the CLEAR facility has provided highly flexible electron beams (up to 200 MeV) and expert support to a wide community of users working at the interface of accelerator physics, detector development, beam instrumentation, medical physics, and fundamental science. TA projects have addressed: beam diagnostics and monitoring for next-generation accelerators, electro-optical bunch profile measurements, Cherenkov-based detection systems, ultra-high dose rate (UHDR) and VHEE FLASH radiotherapy instrumentation, beam shaping and dual-scattering systems for uniform irradiation, and exploratory studies in fundamental electron dynamics.

CLEAR's versatility in beam parameters, rapid reconfiguration capability, and accessible experimental areas have enabled proof-of-principle demonstrations, prototype validation under realistic beam conditions, and the first experimental verification of novel concepts. Several projects have already resulted in peer-reviewed publications and doctoral theses, confirming the scientific impact of the access provided.

Overall, the progress achieved within Task 3.4 demonstrates that both participating infrastructures are effectively delivering high-quality Transnational Access, fostering cross-border collaboration, and enabling cutting-edge research with tangible scientific, technological, and societal impact. The remaining project period will further consolidate

these results, complete ongoing experiments, and exploit the available Access Units up to the conclusion of EURO-LABS in August 2026.

1 Introduction

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 3.4 provide state-of-the-art electron beams for R&D and applications, in particular for novel medical physics. In the task 3.4, there are two facilities providing access to accelerator infrastructure:

INCT-RAPID - the Centre for Radiation Research and Technologies (RAPID) facility located at the Institute of Nuclear Chemistry and Technology (INCT) in Warsaw-PL, and

CERN-CLEAR - the CERN Linear Electron Accelerator for Research (CLEAR) user facility located at CERN - CH.

INCT-RAPID - Poland
The RAPID infrastructure provides advanced irradiation and radiation-chemistry research capabilities using electron accelerators. TA activites within EURO-LABS includes projects carried out using: 1) LAE-10 linear electron accelerator with a nanosecond pulse radiolysis UV/VIS detection system, enabling detailed studies of transient chemical species and reaction kinetics relevant to chemistry and biochemistry; 2) high-power electron beam accelerators such as the ELEKTRONIKA 10-15 for sterilisation, polymer modification, and microbial decontamination, 3) ILU-6 accelerator (0.15–2 MeV, up to 20 kW) supporting experimental and demonstration work on gases, liquids, and solids, including environmental applications. Complementary facilities, gamma irradiation cells, dosimetry laboratory, electron spin resonance spectroscopy, and extensive material characterization equipment, provide comprehensive support for multidisciplinary research and technology development.

CERN-CLEAR - CH
The CERN Linear Electron Accelerator for Research (CLEAR) is an electron test facility aimed at developing instruments and components for existing and future accelerators, testing novel concepts as plasma and THz acceleration, investigating medical applications of electron beams including dosimetry and FLASH radiotherapy, studying radiation hardness of electronics for aerospace and high energy applications, and training the next generations of accelerator physicists. CLEAR is composed by a versatile 200 MeV electron linac coupled to a 20 m experimental beamline, and it is operated at CERN as a multi-purpose user facility.

1.1 Purpose and Scope of the Document

This report provides an overview of the activities carried out to meet the commitments defined in Description of Action (DoA) and the MS17 [1] document at the beginning of the project, particularly with regard to the provision of TA to user teams. It summarizes the access opportunities offered, the level of implementation achieved across the participating facilities, and the support provided to external users. Both facilities participating in Task 3.4 have been running smoothly since the start of EURO-LABS delivering Access Units (AU)s meeting the agreed commitments. The document presents the progress achieved in fulfilling our TA commitments.

1.2 Structure of the Document

This document is organised as follows. Section 1, the present section, outlines the content and structure of the report. Section 2 describes the TA projects carried out at each facility, including their main highlights, key results, and impact on the field. The deliverable concludes with Section 3, which summarizes the main outcomes and perspectives.

2 TA Activities

This section describes the TA projects conducted at each facility, highlighting their main results and impact on the field.

2.1 The Institute of Nuclear Chemistry and Technology (INCT) - RAPID infrastructure

INCT is playing a leading role in demonstrating versatile applications of electron beam technologies. Within EURO-LABS, a wide range of projects were completed using the INCT-RAPID e-beam infrastructure. These projects demonstrate the potential of electron accelerators to support innovation for a better life. The wide range of projects implemented within EURO-LABS demonstrates the unique flexibility of electron beam facilities in coping with the most pressing challenges.

Table 1 summarizes the TA projects and AUs delivered in the INCT-RAPDID facility at the time of writing of this report. In total, 375 AU were delivered out of 600 AU planned (55%). Note that the project IDs correspond to the submission date of the proposals, whereas the experiments were conducted later depending on beam availability and the facility's overall schedule constraints.

Table 1: INCT-RAPID: summary of completed TA Projects.

Project ID	PI origin	Title	AU [h]
RAPID-2023-1	Ruder Bośkovic Institute, Croatia	Crosslinking of self-assambled fatty acids on copper by electron beam irradiation	25
RAPID-2023-2	ICP, Univ. Paris Saclay, France	One-electron oxida/on of S-adenosyl methionine	25
RAPID-2023-3	National Centre of Nuclear Sciences and Technologies CNSTN, Tunisia	Effect of ionizing irradiation on dried fruits	15
RAPID-2023-4	ICP, Univ. Paris Saclay, France	One-electron oxida/on of S-adenosyl methionine	15
RAPID-2023-5	University of Palermo	Irradiation engineering of biopolymer-based formulation for wound management and targeted drug delivery devices	50
RAPID-2023-6	Instituto Superior Técnico, Universidade de Lisboa, Portugal	Bioactivity of irradiated foods by low energy e-beam	25

Project ID	PI origin	Title	AU
RAPID-2023-7	Institute of Chemical Physics, University of Latvia	Influence of 10 MeV accelerated electrons on structure and properties of sheep wool fibres as a potential component for preparation of polymer-based composite materials	25
RAPID-2024-8	Ruder Bośkovic Institute, Croatia	Face masks recycling with the use of radiation technologies.	5
RAPID-2024-9	National Centre of NuclearSciences and Technologies CNSTN, Tunisia	Low energy elecytron beam irradiation of plant based animal feed	25
RAPID-2025-10	National Centre of NuclearSciences and Technologies CNSTN, Tunisia	Converting carbon dioxide (CO_2) and methane (CH_4) into Syngas using Electron beam Irradiation	50
RAPID-2025-11	University of Palermo	Electron Beam Irradiation for Polymer Crosslinking and Advanced Nanogel Design for Drug Delivery and Theranostics approaches	50
RAPID-2025-12	Center of Biotechnology of Borj Cedria, Tunisia	Enhancing Barley Resilience to Abiotic Stresses via Physical Mutagenesis for Sustainable Agriculture	50
RAPID-2025-14	Institute of Chemical Physics of the Faculty of Science and Technology of the University of Latvia (Riga, Latvia)	Electron nuclear double resonance spectra measurements for biphasic Li4SiO4-Li2TiO3 ceramics after exposure to 10 MeV accelerated electrons	15

2.1.1 EURO-LABS-RAPID-2023-01

Project Title: Crosslinking of self-assembled fatty acids on copper by electron beam irradiation

Aim of the project : The project was focused on studying the conditions for crosslinking fatty acids on metals using electron beams and grafting vitamin E on the developed polymer coatings.

Project summary: Polymer nanocoatings based on fatty acids have a great potential for biomedical applications. Such coatings can slow down the dissolution of metal-based implants, and fatty acids are biocompatible since they degrade into low-toxic products that are not harmful to the human body. Radiation-induced crosslinking is homogeneous, fast, can be carried out at room temperature without use of solvents, initiators and/or catalysts. If crosslinking is performed using ionizing irradiation the process is clean, and if the doses used are 25 kGy or higher the coatings are simultaneously crosslinked and sterilized (see Fig. 1). Nevertheless, their crosslinking has been studied and demonstrated only under gamma irradiation conditions, while for commercial applications crosslinking under electron beam technology could be more suitable due to technological parameters such as high dose rate and short irradiation time, or possibility of irradiation at low temperature.

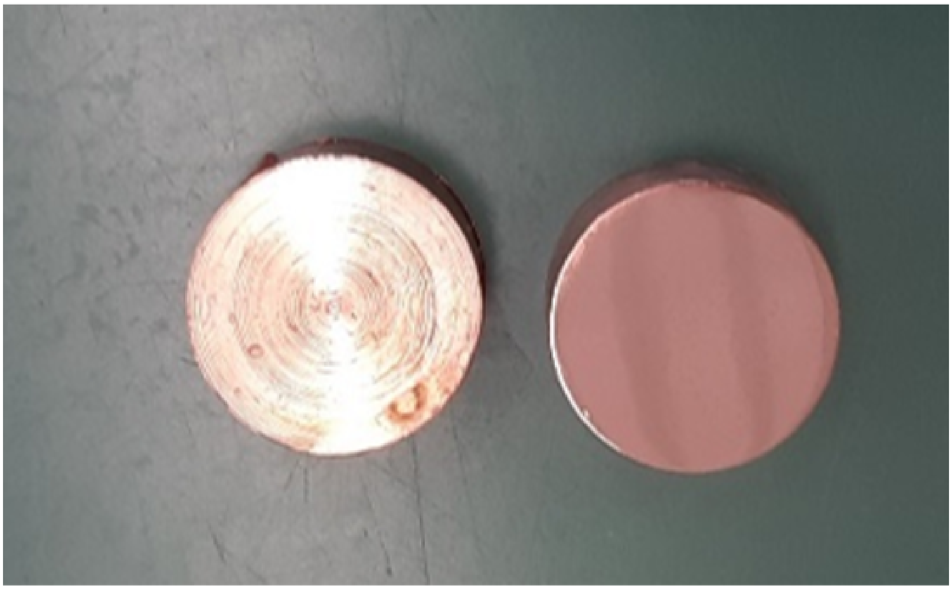

Figure 1: Copper disc with self-assembled fatty acids layer cross-linked with electron beam - project EURO-LABS-RAPID-2023-1.

Results: This study investigated how thin organic layers of self-assembled fatty acids respond to electron irradiation. By inducing crosslinking within these films, researchers demonstrated new pathways for creating robust, chemically resistant coatings on metallic surfaces. These findings open possibilities for protective layers in biochemistry, microelectronics, corrosion protection, and catalytic interfaces.

Publications:

- K. Marušić, E. Pezic, H. Bach-Rojecky, U. Gryczka, M. Walo. Optimizing Polymer Coatings for Implants and Drug Delivery: Gamma vs. EBeam Irradiation. Third International Conference on Applications of Radiation Science and Technology (ICARST-2025). Book of abstracts. IAEA-CN-332/183
- Bach-Rojecky, Helena; Mirosavljević, Marija; Kralj, Damir; Marušić, Katarina, Enhancing hydrophobicity through radiation crosslinking of stearic acid monolayers on calcium carbonate. 19th European Student Colloid Conference, Bordeaux, France, 24.06.2024-27.06.2024,

Abstracts accepted for the Second International Conference on Accelerators for Research and Innovation 22–26 June 2026, IAEA, Vienna, Austria

- E. Pezić, U. Gryczka, M. Walo, K. Marušić, radiation-curing of organic monolayers on metals: low- and high-energy electron beams versus gamma irradiation, oral presentation;
- H. Biljanić, U. Gryczka, M. Walo, K. Marušić. Electron beam-induced surface engineering of calcium carbonate for enhanced performance in polymer composites, poster presentation

Article submitted for publication:

- H. Biljanić, M. Mirosavljević, U. Gryczka, M. Walo, D. Kralj, K. Marušić, Role of Oxygen in Radiation Crosslinking of Stearic Acid on Calcium Carbonate for Polymer Filler Optimization, MDPI Polymers journal (https://www.mdpi.com/journal/polymers)

2.1.2 EURO-LABS-RAPID-2023-02 and EURO-LABS-RAPID-2023-04

Project title: One-Electron Oxidation of S-Adenosyl Methionine (SAM)

Aim of the project: The project aim to elucidate the mechanism of this oxidation of S-Adenosyl Methionine (SAM)and identify the transients involved.

S adenosyl methionine (SAM) is a very important biological compound resulting of the addition of a DNA nucleoside, adenosine, and an amino acid, methionine. it is a key metabolite involved in reactions of transmethylation and transsulfuration. In oxidative stress, it can be oxidized by reactive oxygen species such as OH radicals, while in the course of its biological action, it is reduced.

The project is a part of the study on the oxidation of sulfur containing peptides and identifying the final products.

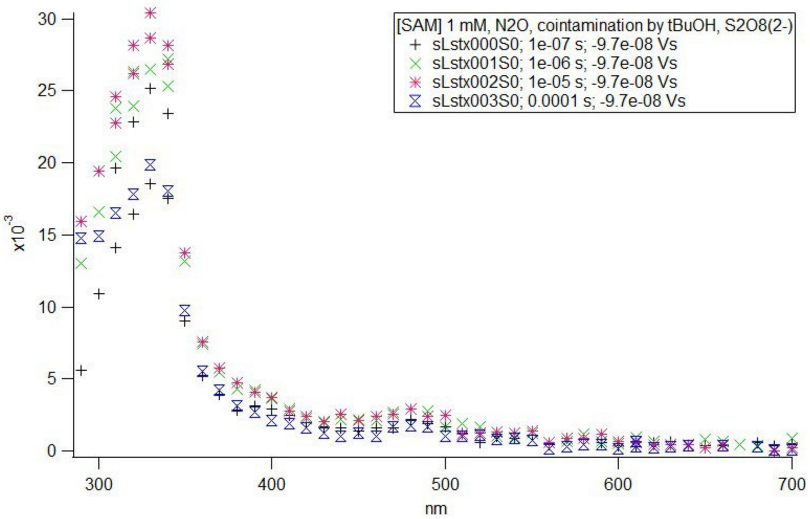

Figure 2: Absorption spectra of SAM formed by oxidization by OH radicals - project EURO-LABS-RAPID-2023-4

Results: Performed in two separate project cycles, this fundamental chemistry study explored how electron-induced oxidation affects the structure and reactivity of SAM—an essential biological methyl donor. It was found that, the adenosine moiety of SAM is oxidized while methionine moiety remains intact. The rate constant of reactions of OH radical with methionine is higher than that of adenosine. Understanding these mechanisms is crucial for radiation biochemistry, radioprotection research, and modeling radiation effects in living systems (see Fig. 2).

2.1.3 EURO-LABS-RAPID-2023-03

Project title: Effect of ionizing irradiation on dried fruits

Aim of the project: The main objective of the project was the assessment of the effect of low Energy Electron Beam LEEB (< 350 keV) on naturally occurring microorganisms in dried tomatoes and red chili pepper and the evaluation of their nutritional properties.

Several outbreaks occurred after the consumption of contaminated dried tomatoes and red chili pepper by pathogenic microorganisms. Ionizing irradiation was suggested as an efficient and promising treatment for foodborne pathogens inactivation along with the preservation of nutritional values and organoleptic properties of these products. For this purpose, doses ranging between 3 to 10 kGy were applied and the affect on organoleptic and nutritional properties of dried tomatoes and red chili pepper before and after treatment was also evaluated.

Results: This study examined how low-dose electron irradiation affects microbial load, quality parameters, and shelf life of dried fruits. It shows that that applications irradiation of red chili pepper resulted in effective reduction of microbial load (see Fig. 3). Such applications contribute to safer food supply chains and reduced post-harvest losses—priorities for global and European food markets.

Figure 3: Chilli pepper used for dose verification for irradiation with electron beam of energy 330 keV - EURO-LABS-RAPID-2023-3

Publications:

- Faten RAHMANI , Habiba KOUKI, Moktar HAMDI, Souhir BOUAZIZI , Mohamed Amine KHAMMASSI, Widad ZERNADJI, Sylwester BULKA, Urszula

GRYCZKA, Fatma HMAIED. Implementation of Low energy e beam for dried vegetable treatment: effect on microbial and physicochemical qualities of dried red chili pepper (*Capsicum annuum L.*). Innovative Food Science and Emerging Technologies, Volume 101, Article number 103954, 2025, DOI: 10.1016/j.ifset.2025.103954.

2.1.4 EURO-LABS-RAPID-2023-05

Project title: Irradiation engineering of biopolymer-based formulation for wound management and targeted drug delivery devices

Aim of the project: The project aims to produce new hydrogel formulations for wound healing and polymeric nanoparticles as substrates for therapeutic and diagnostic (theranostic) nanodevices.

For the new hydrogel wound dressings, a mixture of synthetic polymers and polysaccharides with intrinsic antioxidant/anti-inflammatory properties was developed. Irradiation plays a key role in this approach, as it can perform several functions: cross-linking of the synthetic polymer to improve the mechanical performance of the hydrogel films, partial degradation of the polysaccharide with generation of bioactive oligosaccharides, and sterilisation of the final product. For the development of therapeutic nanoparticles by irradiating aqueous solutions of biocompatible polymers, irradiation conditions will be sought that can lead to relatively monodisperse nanoparticles in the 5-50 nm range. In addition, simultaneous grafting of functional monomers capable of directing the nanocarrier to target tissues and cells and immobilising radioactive ions will be sought.

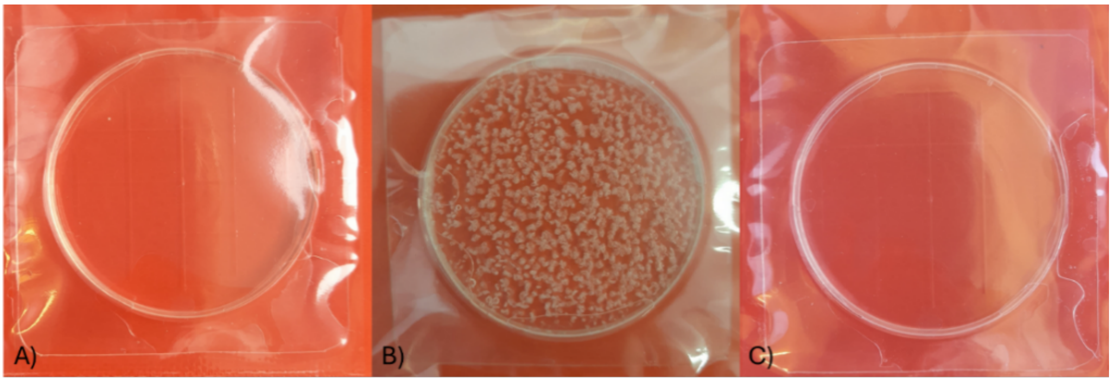

Figure 4: A) Sample before irradiation; B) after one pass under the EB at a dose of 28 kGy; C) after two days after irradiation - project EURO-LABS-RAPID-2023-5

Results: Electron beams provide a reagent-free method to form nanogels with controlled size, stability, and drug-loading properties. The properties of the irradiated samples produced at INCT were assessed through rheological, mechanical, swelling/erosion tests, thermogravimetric analysis, scanning electron microscopy (SEM) to evaluate their suitability for wound healing applications (see Fig. 4). The results support future developments in targeted drug delivery and theranostic systems, demonstrating the strategic value of e-beam processing for next-generation biomedical materials.

2.1.5 EURO-LABS-RAPID-2023-06

Project title: Bioactivity of irradiated foods by low energy e-beam

Aim of the project: The overall objective of the project was to evaluate the potential of the low energy e-beam (<350 keV) irradiation treatment on the enhancement of food bioactivity.

Low energy e-beam irradiation could represent an important in-line processing food technology, which could contribute to its quality improvement (potential food functionalization) and safety requirements, allowing food irradiation to reach more broad markets. Previous studies have indicated that the treatment by gamma radiation and high-energy e-beam is able to preserve or improve the bioactivity of food products, highlighting irradiation potential as a food functionalization process. The bioactivity (e.g. antioxidant activity, antimicrobial activity) of the extracts from non-irradiated and irradiated food products with low energy electron beam was evaluated.

Results: Irradiation of food samples, namely avocados, rosemary and cherry tomatoes using low energy electron beams (2 - 10 kGy) were performed, followed by the extraction of bioactive compounds and the assessment of bioactvities. The dosimetric characteristics of the LEEB irradiations were evaluated using B3 Radiochromic film. Researchers evaluated whether low-energy e-beam treatment alters the nutritional, functional, or antioxidant properties of food products. The findings help refine irradiation protocols to maintain or enhance food quality while ensuring safety.

2.1.6 EURO-LABS-RAPID-2023-07

Project title: Influence of 10 MeV accelerated electrons on structure and properties of sheep wool fibres as a potential component for preparation of polymer-based composite materials

Aim of the project: The project aim to investigate the use of high-energy (10 MeV) electrons to modify the structure of natural wool fibres, improving their compatibility with polymer matrices

Sheep wool is a natural, renewable, cheap, easy obtainable, sustainable, and biodegradable material. Since only sheep wool fibers of defined quality are utilized in the textile industry, unprocessed fibers often regrettably become waste. Therefore, such wool fibers are a topical problem for sheep breeding industry. Among the possible applications of the sheep wool fibers is their modification and implementation in composites or filtrating systems. The ionizing radiation has been used for modification of polymeric materials and wool therefore, it is proposed to apply it for treatment of wool and wool-polymer composites.

Results: In the framework of this project, two types of the irradiation were performed. The first irradiation experiment was dedicated to the sheep wool and sheep wool composite samples, while the second irradiation experiment was focused on measurements of Electron Paramagnetic Resonance (EPR) spectra of non-irradiated and irradiated sheep wool fibers (see Fig. 5). Within the frames of the project, the sheep wool samples as well as sheep wool – polymer composites were irradiated with 10 MeV accelerated electrons up to absorbed doses of 25, 50, 100, 250 and 500 kGy. It was observed, that unirradiated wool samples contain low content of free radicals. Irradiation with 10 MeV accelerated electrons causes the formation of unstable radicals (28 kGy sample was measured immediately after irradiation) and stable radicals (50, 100 and 500 kGy samples were measured approximately one day after irradiation). This work contributes to developing sustainable composite materials that combine renewable raw materials with advanced performance characteristics—an approach particularly relevant to European green technologies and bio-based industries.

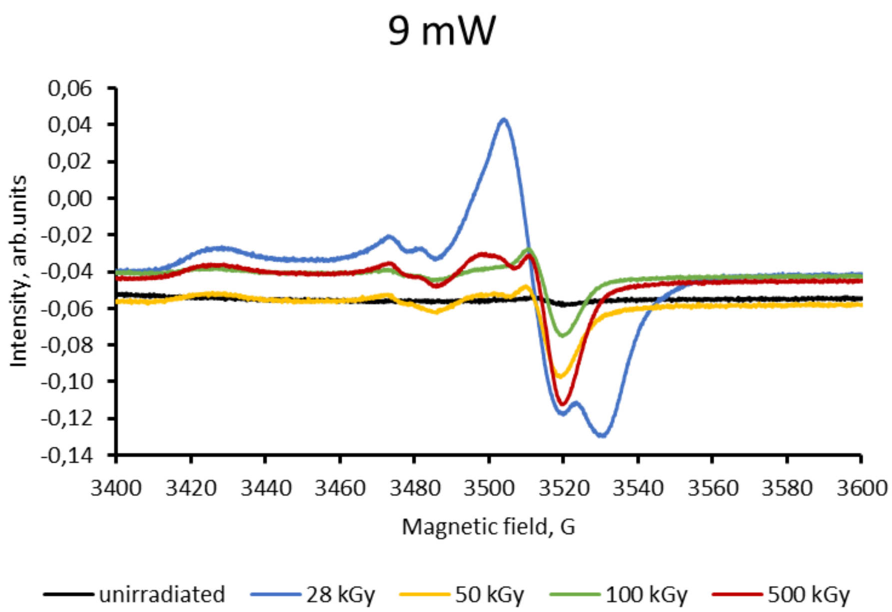

Figure 5: EPR spectra of unirradiated and accelerated electron irradiated sheep wool fibers - project EURO-LABS-RAPID-2023-7

2.1.7 EURO-LABS-RAPID-2024-08

Project title: Face masks recycling with the use of radiation technologies

Aim of the project: The project aimed to investigate the use of electron irradiation to sterilize and modify the properties of SFMs.

Plastic waste management presents a significant environmental challenge, with an estimated 70% of all plastic becoming waste and only a small fraction being recycled due to high processing costs and complex separation procedures. This project proposes an innovative approach to recycling polymer plastic waste, particularly used surgical face masks (SFM) made of polypropylene, by leveraging radiation technology for sterilization and material modification. Recent research has shown that incorporating shredded SFMs into recycled concrete aggregate can enhance the strength and stiffness of road construction materials, offering a promising solution for reducing plastic waste.

Results: The samples of face masks were irradiated with doses of 25 and 50 kGy, at 3 different dose rates, namely 100, 1000, and 10000 kGy/h. These results will be compared with the results previously obtained in our gamma-irradiation facility. The masks were irradiated in order to sterilize them and modify the properties of the polypropylene fibers which make up the masks. The irradiated masks aimed to be mixed with bitumen, and the resulting composite material. This approach aims to provide a sustainable, environmentally friendly method for recycling plastic waste, reducing landfill impact, and improving road construction materials.

2.1.8 EURO-LABS-RAPID-2023-09

Project title: Low energy electron beam irradiation of plant based animal feed

Aim of the project: The main objective of the project was the assessment of the effect of low energy electron beam LEEB (< 350 keV) on naturally occurring microorganisms in different type livestock feed and the evaluation of their nutritional properties.

Animals and zoonotic diseases occurred after the consumption of contaminated products by pathogenic microorganisms. Ionizing irradiation was suggested as an efficient and promising treatment for foodborne pathogens inactivation along with the preservation of nutritional values considering animal welfare. For this purpose, doses ranging between 3 to 10 kGy were applied using electron beams of energy below 350 keV selected based on structure of treated feed type and estimated penetration range of electrons. Microbial and nutritional properties of concentrated feed for livestock before and after treatment were evaluated.

Results: The samples tested within the project were: The samples of livestock feed used in this study are: corn, barley and commercial livestock feed. Microbiological analysis of irradiated samples was performed in the laboratory of Microbiology and molecular biology in the CNSTN. Samples were analysed for naturally occurring microorganisms including Total aerobic plate count, Total coliforms, Fecal coliforms, *Clostridium perfringens*, *Staphylococcus* spp., yeasts and moulds. Microbial analyses are carried out before and after ionizing treatment, in accordance with standardized methods to determine the energy of electrons and dose needed for effective elimination of microbial contamination.

2.1.9 EURO-LABS-RAPID-2023-10

Project title: Converting carbon dioxide CO_2 and methane CH_4 into Syngas using Electron beam Irradiation

Aim of the project: The project aim to investigate the use of electron beam to mitigate the emissions of greenhouse gases

Rising greenhouse gas (GHG) levels, particularly CO_2, are accelerating climate change, resulting in severe environmental impacts such as global warming and ocean acidification. This project seeks to mitigate these emissions by harnessing ionizing radiation to facilitate the methane dry reforming (MDR) process, which converts CO_2 and CH_4 into syngas ($CO + H_2$) a vital industrial feedstockthrough radiolytic reactions. While gamma-ray irradiation has successfully demonstrated this process at ambient temperature, it faces certain limitations. Electron beam (EB) irradiation, with its higher energy efficiency over shorter durations, presents a promising alternative. The project investigated the effects of low-dose EB irradiation on CH_4 and CO_2 mixtures in both gaseous and aqueous phases to optimize hydrogen production. Key irradiation parameters such as gas composition, dose, dose rate, catalyst addition, and mixture ratios will be systematically explored to enhance H_2 yield. Gas Chromatography (GC) was used as the primary analytical tool to monitor reaction progress and quantify hydrogen production.

Results: The goal of this project was to investigate the effects of EB irradiation on CH_4 and CO_2 mixtures in both gaseous and aqueous phases to optimize hydrogen/Acetic Acid production. Key irradiation parameters such as gas composition, dose, dose rate, and mixture ratios will be systematically explored to enhance H_2/ CH_3COOH yield. The prepared mixtures were irradiated using the Elektronika 10/10 linear accelerator. Irradiation was performed at different dose rates of 5, 10, 20, and 25 kGy/pass, with total doses ranging from 10 to 100 kGy. For CO_2/CH_4 mixture, preliminary GC analysis indicates the formation of H_2. For irradiation of liquids the preliminary results indicate that the CH3COO- concentration increases with the irradiation dose and reaches its highest value when the gas mixture contains 60% CH_4 and 40% CO_2.

2.1.10 EURO-LABS-RAPID-2023-11

Project title: Electron Beam Irradiation for Polymer Crosslinking and Advanced Nanogel Design for Drug Delivery and Theranostics approaches

Aim of the project: This study seeks to develop novel nanocarrier formulations through e-beam irradiation of an amphiphilic polymer that forms micelles in water.

The goal was to simultaneously crosslink the hydrophilic chain, which forms the shell, while degrading the hydrophobic core to obtain a hydrogel micro-/nano-shell. Various irradiation parameters were investigated to achieve the desired structural properties, thereby enhancing the capture volume and colloidal stability of the carriers in aqueous solutions. Particle size distribution was be tested on site to identify the most promising irradiation conditions. Another aspect of this study was focused on developing theranostic nanoparticles for nuclear medicine. These nanoparticles were also synthesized through electron beam irradiation of polymer and advanced monomer aqueous solutions. This approach aims to create as-born sterile and biocompatible nanogels with functional groups capable of binding chelating agents and targeting agents, offering sustainable and customizable solutions for precision medicine.

Results: The interaction of radiation with aqueous polymer solutions allows for precise control over the formation of polymer networks, enabling tuning of chemical properties and dimentions by adjusting polymer and monomer concentration, radiation dose, and medium conditions (e.g., pH). Furthermore, another experiment was carried out that investigates the formation of hollow hydrogel nanostructures from PVP-PLA diblock copolymer micelles using dual-effect irradiation, in a process that simultaneously induces crosslinking of the hydrophilic PVP shell and degradation of the hydrophobic PLA core, in order to determine an increased stability of self-assembled micelles. Ionizing radiation (e-beam) was used as a clean and effective initiator to induce crosslinking and polymerization, avoiding the need for chemical initiators. This methodology is essential for producing biocompatible hydrogels suitable for biomedical and environmental applications.

2.1.11 EURO-LABS-RAPID-2023-12

Project title: Enhancing Barley Resilience to Abiotic Stresses via Physical Mutagenesis for Sustainable Agriculture

Aim of the project: Electron-beam irradiation was used with a dual purpose: to induce genetic variability in barley seeds for stress-response improvement and to enhance the conservation of barley and wheat grains and flours. Seven calibrated electron-beam doses were applied to barley seeds and to barley and wheat grains and flours to support both mutation induction and conservation improvement. All treatments were fully replicated and will enable downstream screening for stress-responsive mutants and evaluation of irradiation effects on grain and flour preservation.

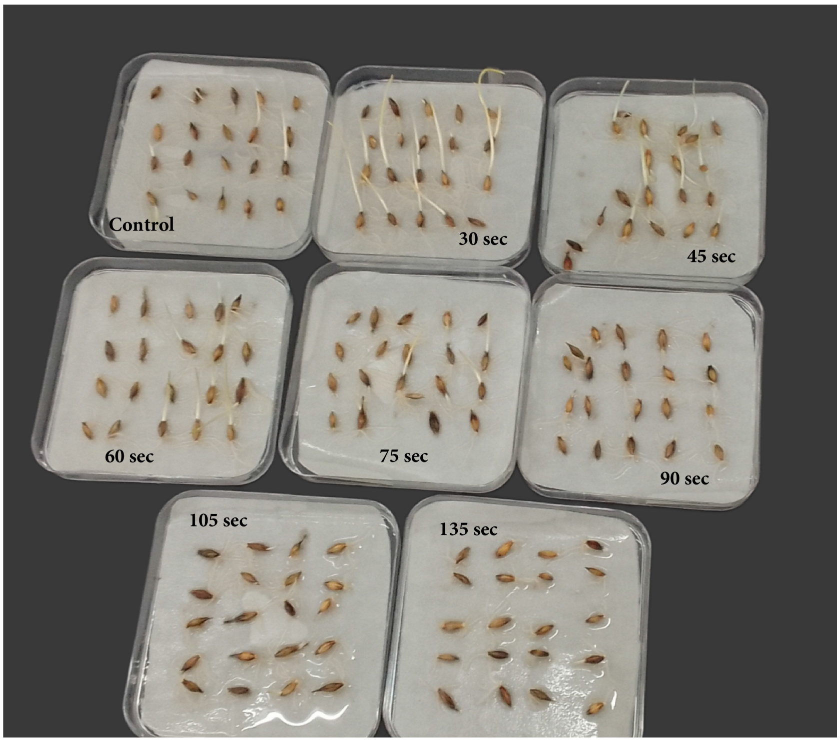

Figure 6: Appearance of irradiated barley seed germination under 250 mM NaCl after 8 days for different irradiation durations - project EURO-LABS-RAPID-2025-12

Results: Screening of irradiated seeds across all irradiation durations (30, 45, 60, 75, 90, 105, and 135 seconds) was performed using a germination test with three independent replicates of 20 seeds each (n = 60 (see Fig. 6). Non-irradiated seeds were included as controls. Seeds were germinated under salt stress conditions (250 mM NaCl) for 8 days (see Fig. 7).

2.1.12 EURO-LABS-RAPID-2023-14

Project title: Electron nuclear double resonance spectra measurements for biphasic Li_4SiO_4-Li_2TiO_3 ceramics after exposure to 10 MeV accelerated electrons

Aim of the project: The objective of this project is to measure electron nuclear double resonance (ENDOR) spectra of biphasic Li_4SiO_4-Li_2TiO_3 ceramics after exposure to 10

Figure 7: Effect of mutation treatment of electron beam irradiation depending on duration of irradiation on hypocotyl length in barley seedlings grown under 250 mM NaCl - project EURO-LABS-RAPID-2025-12

MeV accelerated electrons.

Advanced ceramic breeder (ACB) pebbles, primarily composed of lithium orthosilicate Li_4SiO_4 with lithium metatitanate (Li_2TiO_3) as a second phase, are being developed and tested worldwide as potential materials for tritium breeding in thermonuclear fusion reactors. The objective of this project is to measure electron nuclear double resonance (ENDOR) spectra of biphasic Li_4SiO_4-Li_2TiO_3 ceramics after exposure to 10 MeV accelerated electrons. ENDOR spectroscopy is a powerful and widely used magnetic resonance technique that combines aspects of electron paramagnetic resonance (EPR) and nuclear magnetic resonance (NMR). It is particularly effective for the study of local nuclear surroundings of radiation-induced defect centres with paramagnetic properties (electron spin $S \neq 0$). In this project, the following materials were characterised using EPR spectroscopy after irradiation using accelerated electrons (up to about 500 kGy absorbed dose, room temperature, air):

1. two-phase Li_4SiO_4-Li_2TiO_3 powder;
2. Li_4SiO_4 powder with additions of Ti^{4+} ions;
3. Li_2TiO_3 powder with additions of Si^{4+} ions;
4. single-phase Li_4SiO_4 powder;
5. single-phase Li_2TiO_3 powder.

On the basis of the obtained results of EPR spectroscopy, irradiated samples exhibiting suitable spectral intensity will be selected for further characterisation using ENDOR spectroscopy. This project offers valuable insights into the nature, structure, and properties of paramagnetic radiation-induced defect centres in the ACB pebbles, supporting the development of tritium breeding materials for future thermonuclear fusion reactors.

Based on these observations, irradiation durations of **35 and 45 s** appear suitable for future experiments, while a shorter exposure (**15 s**) could be tested to further investigate potential stimulatory or hormetic responses at low irradiation doses.

2.2 The CERN CLEAR infrastructure

Within EURO-LABS, CLEAR has supported a broad portfolio of scientific and technological projects, highlighting the adaptability of electron beam facilities to diverse research domains. These activities underline the strategic importance of accelerator-based technologies in addressing key societal and technological challenges, while also contributing to the training of the next generation of accelerator scientists and engineers.

Table 2 summarizes the TA projects and AUs delivered in the CERN-CLEAR facility at the time of writing of this report. In total, 476 AU were delivered out of 1200 AU planned (36.4%).

Table 2: CERN-CLEAR: summary of completed TA Projects.

Project ID	PI origin	Title	AU [h]
CLEAR-LUXE	INFN, Italy	Development and testing of a beam profile detector for the LUXE experiment	88
CLEAR-FOM-UHDR	Oxford University, UK	Fibre-optic Monitor for UHDR Real-time Dosimetry for VHEE FLASH Radiotherapy	80
CLEAR-KIT	Karlsruhe Institute of Technology (KIT), Germany	Tests of prototype EO monitor for FCC-ee on beam	40
CLEAR-LUCID	INFN Bologna, Italy	Study of Cherenkov light production and absorption in quartz fibers	40
CLEAR-ECOL	IJCLab Paris, CNRS, France	Study of resonance of the electron internal clock	68
CLEAR-DSS	Oxford University, UK	Dual-Scattering System to provide uniform beams for irradiations and conformal VHEE FLASH studies	80
CLEAR-AI	Universitá di Roma La Sapienza, Italy	Reinforcement Learning studies	40
CLEAR-CLEAR-THZ	Paul Scherrer Institute (PSI), Switzerland	THz radiation studies	40

2.2.1

EURO-LABS-CERN-2023-CLEAR-LUXE

Project title: Development and testing of a beam profile detector for the Laser Und XFEL Experiment (LUXE).

Aim of the project: The experimental goals were to develop and test with beam a beam profile detector for the proposed LUXE experiment.

Project summary: The activity carried out at CERN focused on the Beam Profiler (BP) of the LUXE experiment. LUXE has been proposed at the XFEL.EU facility at DESY (Hamburg) and aims to study Strong-Field QED (SFQED) by colliding a 16.5 GeV electron beam from XFEL with an ultra-high-power laser (40–300 TW). This interaction reaches electromagnetic field strengths close to the Schwinger limit ($\simeq 1.3 \times 10^{18}$ V/m) within a micrometric focal region. In this regime, key SFQED effects are expected, including spontaneous electron–positron pair production from vacuum and modification of the Compton spectrum due to effective mass increase from vacuum polarization. LUXE will operate in two modes:

- e–laser mode: direct interaction between the electron beam and the laser.
- γ–laser mode: interaction between high-energy photons and the laser.

The photons will be produced either via electron conversion on a tungsten target or by inverse Compton scattering upstream of the main interaction point. The experiment will achieve the highest electromagnetic field intensity ever produced in a macroscopic laboratory volume and will:

- Probe non-perturbative electron–photon and photon–photon interactions.
- Study the transition from perturbative to non-perturbative QED.
- Enable searches for beyond-Standard-Model particles coupling to photons via SFQED processes.

LUXE received CD1 approval from DESY at the end of 2022. For both operation modes, precise monitoring of the downstream high-energy gamma-ray beam profile is essential, in particular the classical non-linearity parameter ξ. This parameter, proportional to the laser electric field and inversely proportional to its frequency, is a key indicator of proximity to the Schwinger regime. To first approximation, ξ can be inferred from the ratio of the beam profile widths parallel and perpendicular to the laser polarization direction.

In the e–laser configuration, the Beam Profiler (BP) is expected to detect about 10^9 photons per bunch crossing (at 1 Hz), with a minimum beam width of 0.3 mm. These conditions require a detector with high radiation tolerance, fine granularity, and minimal material budget. The proposed BP consists of two orthogonal strip detectors forming a single station. Each sensor has a 2×2 cm^2 active area, 150 μm thickness, and 100 μm strip pitch. Sapphire was selected as the sensor material due to its excellent radiation hardness and proven performance in beam monitoring at FLASH, XFEL, and CMS (LHC).

Results: Initial irradiation tests were performed at CLEAR in winter 2022, validating a full BP demonstrator (sensor plus readout electronics). Despite limited beam time and schedule constraints, these campaigns were crucial to evaluate detector performance under intense electron irradiation and to characterize the electronic noise of the complete readout chain. Beam tests were done in 2024 and 2025, with the aim to complete the validation of the fully instrumented demonstrator. The primary objective was to confirm its reconstruction performance under realistic operating conditions. Secondary goals included measuring the charge collection efficiency as a function of sensor bulk temperature and assess the response after heavy irradiation of the final strip-detector version. The goals were largely achieved, in particular the profile reconstruction was satisfactory for the bunch charges expected in LUXE (while at higher charges the device showed a limitation due to a polarization effect) and the collection efficiency loss as a function of the total received dose could be assessed, and confirmed to be within acceptable limits for LUXE expected operating conditions.

Publication:

- G. Avoni et al, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 1068, 2024

2.2.2 EURO-LABS-CERN-2023-CLEAR-FOM-UHDR

Project title: Fibre-optic Monitor for UHDR Real-time Dosimetry for VHEE FLASH Radiotherapy

Aim of the project: The experimental goals were to develop, test and characterise an Ultra-High Dose Rate (UHDR) beam profile and dose monitor for Very High Energy Electron (VHEE) beams using an array of optical fibres. The potential application aimed is fast dosimetry for radiotherapy in the FLASH regime.

Project summary: Current conventional radiotherapy linacs use transmission ionisation chambers as beam monitors, but these saturate in the ultrahigh dose rate (UHDR) conditions required for FLASH. Therefore an alternative technology needs to be developed in order to facility the clinical translation of VHEE FLASH radiotherapy. A beam profile monitor, consisting of an array of silica optical fibres attached to a photodetector which measure the Cherenkov radiation generated by the electrons as they pass through the silica fibre, was developed. The response of these fibres was then characterised dosimetrically to passive dosimeters in water and in air such as radiochromic films.

Results: Initial tests and measurements were performed on a horizontal array of 28 fused silica fibres (30 cm in length) to measure the response linearity to dose-per-pulse (with EBT-XD films in water), and beam profile (vertical projection) measurements. The beam time in October 2023 was intended to test a new setup using shorter cut fibres and to measure the homogeneity of the response of the individual fibres. The beam time in November 2023 was used to obtain data on the response linearity and beam profile measurements (vertical projection) with the improved setup and with an improved spatial resolution of 0.5 mm with both a Gaussian pencil beam and a dual-scattered uniform beam.

Overall the experimental aims were achieved. Initial plans did involve the possibility of testing 2 x fibre arrays (one in horizontal and one in vertical) during the November beam time, however due to limitations with the number of fibres available, the homogeneity of the fibre response and diameter and with spatial limitations at the in-air test stand it was decided to just test one fibre array (see Fig. 8) These initial measurements consisted of scanning a small, round beam of 1 nC over the fibres in the array, either by scanning the beam directly or by moving the assembly with a vertical linear stage.

Response linearity measurements were done using an increasing number of bunches per train and recording the response of the fibres to 3 single shots per dose-per-pulse, with a single shot also taken with an EBT-XD film at a depth of 100 mm in water. Profile comparison measurements were taken with both YAG and film in-air with the fibres in and out (to observe the effect of the fibres on the beam), with charges of 0.5 nC, 1 nC and 10 nC, showing good agreement.

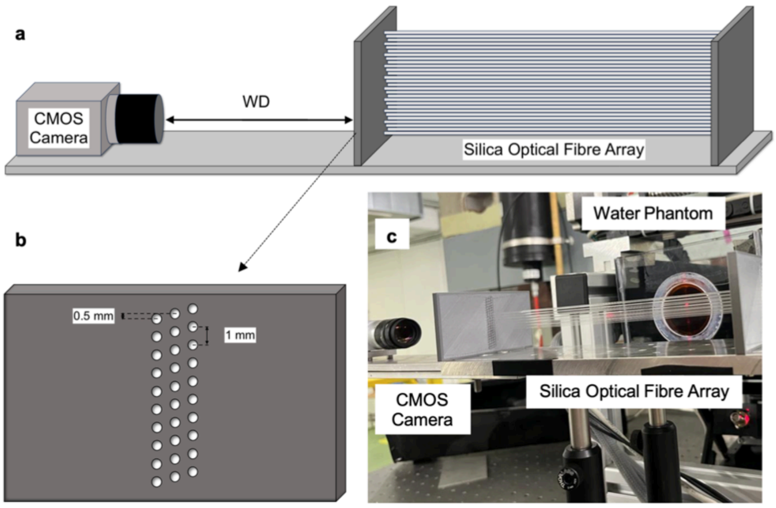

Figure 8: a) Schematic of the assembly with the CMOS cameras and silica fibre array, where the working distance (WD) between the edge of the lens and the fibres is 105 mm. b)Schematic of 3D printed fibre support displaying the vertical arrangement of the silica fibres. c) Photograph of the fibre array, consisting of 24 fused silica fibres, installed in the in-air test stand at the CLEAR facility.

Publications:

- Joseph J Bateman et al 2024 Phys. Med. Biol. 69 085006
- Bateman, J. J. (2024). VHEE dosimetry in a FLASH: ultrahigh dose rate dosimetry and real-time beam monitoring for very high energy electron FLASH radiotherapy [PhD thesis]. University of Oxford.

2.2.3 EURO-LABS-CERN-2023-CLEAR-KIT

Project title: Tests of prototype EO monitor for FCC-ee on beam

Aim of the project: first proof-of-principle of a novel design for a longitudinal bunch profile monitor for FCC-ee using electro-optical spectral decoding (EOSD).

Project summary: Within the EU feasibility study Future Circular Collider Innovation Study (FCCIS), a new electro-optical (EO) bunch length monitor is being developed for the beam parameters of FCC-ee. For FCC-ee, a bunch-by-bunch diagnostic delivering sub-ps resolution with full machine coverage on a timescale of minutes is required, as outlined in the Conceptual Design Report. The EO technique is a promising candidate for meeting these specifications. The proposed system builds on experience gained at KIT's KARA storage ring, where an EO near-field monitor provides turn-by-turn longitudinal bunch profile measurements. CLEAR provides an ideal test environment for first prototype validation. Its in-air experimental area allows straightforward installation and access to the EO crystal without opening vacuum chambers. Under CLEAR beam conditions, modulation of a synchronized laser pulse by the electron beam has been successfully observed, providing a first proof-of-principle and enabling further optimisation of the setup.

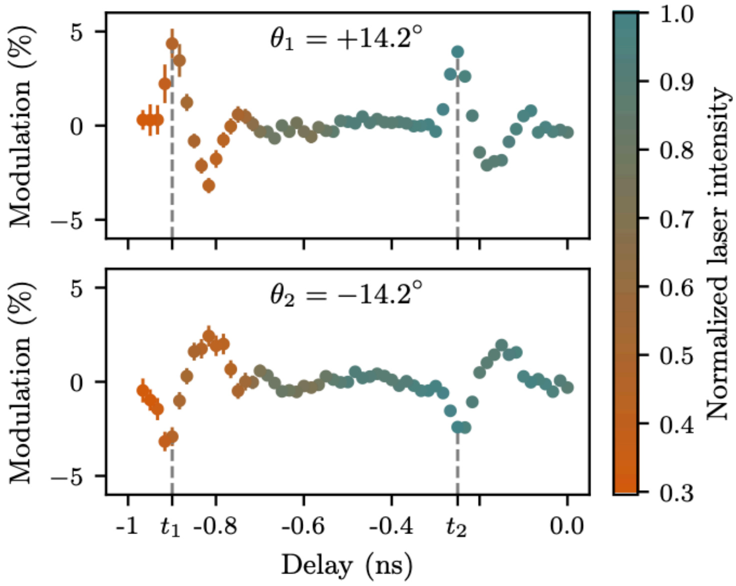

Figure 9: Electro-optical sampling of two electron bunches, taken at different angles of the half wavelength waveplate with opposite sign. Every data point is the mean value over 100 shots, with the standard error of the mean indicated as error bar. The marker color indicates the absolute laser intensity, which changed during the scan of the optical delay stage due to non-optimal alignment.

The EO monitor consists of a compact optical assembly with fibre input and dual fibre outputs, mounted on a movable stage to adjust the crystal–beam distance. A chirped laser pulse is transported via optical fibres to the crystal. When an electron bunch passes nearby, its Coulomb field induces birefringence in the crystal (Pockels effect), modulating the laser polarisation proportionally to the longitudinal charge distribution. This polarisation modulation is converted into intensity modulation using waveplates and a polarising beam splitter.

The encoded pulse is returned via fibre to the CLEAR streak laboratory, where the existing Toptica FemtoFiber Pro NIR laser infrastructure and fibre links are available. Spectral analysis is performed with a grating-based spectrometer and ultra-fast line camera or alternatively with a fast photodiode and oscilloscope. The custom DAQ system is operated in collaboration with the CERN BI group.

Results: Measurements were carried out both in 2023 and 2024 on an improved setup. Initial results showed a weak EOS signal, just above the noise level, while in the second campaign the the signal-to-noise ratio was substantially improved. Eventually, a scan resulted in clear EOS signals of two consecutive bunches, which successfully demonstrated the feasibility of the novel crystal holder design (see Fig. 9).

Publication:

- M. Reissig et al, in Proc. IPAC'25, Taipei, Taiwan, pp. 3125-3128

2.2.4 EURO-LABS-CERN-2023-CLEAR-LUCID

Project title: Study of Cherenkov light production and absorption in quartz fibers

Aim of the project: The aim of the experiment was to study the Cherenkov light production and absorption in quartz fibers as a function of the beam angle and the absorbed dose. In addition to being an interesting scientific topic in itself, the data are meant to be used to introduce correction factors to the ATLAS luminosity measurement.

Project summary: Bundles of fibers were exposed to the beam, held by a rotating support structure using a step-motor so that the output could be measured as a function of the incident angle. A bundle of 3 different quartz fibers, has been exposed to the electron beam so that Cherenkov light is produced in the interaction. The light is readout by photomultipliers positioned at one end of the fibers. The fibers are held in a support structure that can rotate using a remote controller so that a section of the fiber can be hit at different angles and the signal can be measured as a function of this angle. In addition, two out of the three fibers had been previously irradiated in a gamma facility. The beam was aimed at different distances from the PMTs, in order to study the impact of the irradiation on the light transmission.

Results: The measurements were mostly successful, although some experimental difficulties allowed to draw only partial conclusions. The system allowed ± 85 deg rotations. Vertical and horizontal scans were taken.

The goals were partially achieved, since the dependence of the produced/detected light from the angle was measured in some angular ranges, but a full-range measurement was inaccurate. The vertical scans revealed the absorption of light in irradiated sectors of one of the fibers. This effect was measured. In the other fibers, experimental issues stopped us from getting a reliable measurement.

2.2.5 EURO-LABS-CERN-2023-CLEAR-ECOL

Project title: Study of resonance of the electron internal clock

Aim of the project: The ultimate goal is to study a resonant effect that occurs when electrons are channeled in a crystal. In such a study is paramount to control with a high accuracy the energy of single electrons. This can in principle be achieved with collimators that will select only a few electrons on a defined orbit through a magnetic field.

Project summary: The experiment consisted in the test of a collimation system capable to reduce the multiplicity of the beam and, with very small apertures, constrain the trajectory of the electrons. Once the trajectory of the electron is well constrained changes in dipole settings allow to vary the energy of the particle selected by a few keV (within the initial beam energy spread). The tests requested in 2024 were a first attempt to achieve ultra-low multiplicity at CLEAR in VESPER using collimators.

This was attempted by inserting 3 collimators with holes around a dipole magnet and trying to align them.

Results: During the test it was possible to send the beam through each collimator separately but the multiplicity became too low to confirm that the 3 collimators were correctly aligned and the beam sent through them.

Data analysis shows that the multiplicity was successfully reduced below 1 electron per shot, however the spectrum indicates that there was some scattering and the energy of the particles was degraded. The collimators were installed on UHV linear translations the first two days. However, during pumping a leak was detected on the linear translation of the last collimator, so it was decided to operate this collimator in air. It was later observed that one collimator was titled, so it was necessary to break the vacuum to remove this tilt.

The pixels detector and the calorimeter were also installed and tested.

2.2.6 EURO-LABS-CERN-2023-CLEAR-DSS

Project title: Dual-Scattering System to provide uniform beams for irradiations and conformal VHEE FLASH studies

Aim of the project: A dual scattering system, composed by a thin flat scatterer and a thicker shaped one, can be used to alter the transverse distribution of an electron beam such to obtain a flat profile, useful for uniform irradiation of samples and - together with a collimator - to obtain conformity for VHEE FLASH Radiotherapy. The goal of this project was to study the dependence of the uniformity on the initial beam, and the evolution of the flattened beam in a water phantom. The dose deposition in this phantom was also investigated, along with the component of the dose arising from secondary particle production in the scattering system.

Project summary: Goals of this experiment were to verify and characterise the vacuum-dual scattering system at CLEAR, which had been previously installed and had some experiments carried out upon as CLEAR MD. The key aim was to ensure parameters to provide a reliable and consistent flat beam for future operation in water, and study the evolution of the beam profile and dose with depth. Additionally, the ratio between the charge measured downstream of the collimator and the flat-top dose required study. Twiss parameters of any setups was also desired for improved comparisons with MC simulations in TOPAS. Finally, the secondary dose component of the scattered beam was of interest for general operation as well as for MC comparisons once again.

The CLEAR dual-scattering system composed of a PEEK Gaussian scatterer and 1st uniform aluminium foil scatterer was installed in two vacuum chambers in the experimental beamline. Further installations were done for the numerous radiochromic films (EBT-3 and EBT-XD) which were used during the experiment. Some work was carried out to optimise cameras for operation and measurements of experiment. It was found that the steel stem used for mounting of 2nd scatterer may have intruded on the uniform dose and intensity profiles slightly. This has since been rectified by the CLEAR operation team before a second measurement campaign.

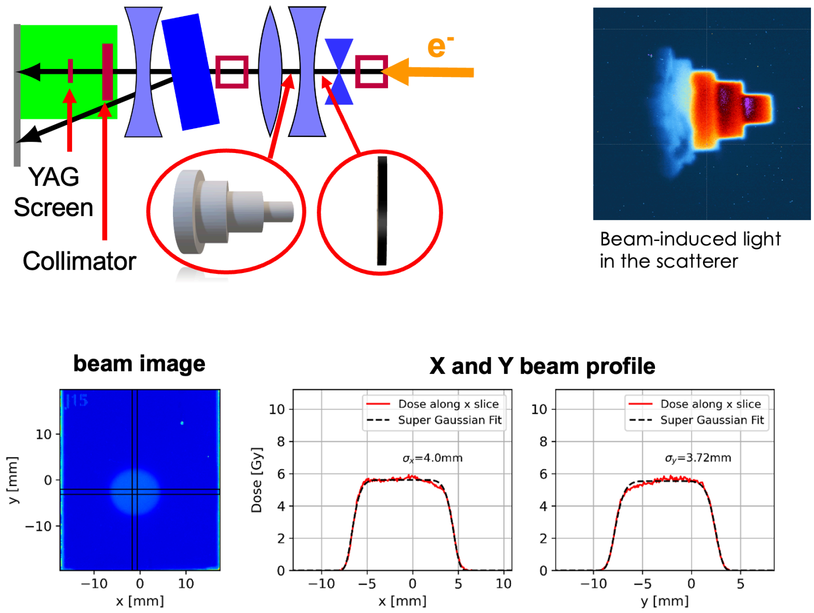

Figure 10: Schematic of the Double Scattering System as installed in CLEAR, and image of the beam induced Cherennkov light emission in the Gaussian scatterer (top). Image and profiles of the flattened beam at delivery (bottom).

Results: The profile and dose measurements gave excellent results and meet all the goals of this experiment. The results obtained are the first experimental demonstration of beam flattening with dual-scattering foils in the VHEE regime, confirmed with both profile measurements with a YAG screen and radiochromic EBT3 films. This showed that the dual-scattering method is capable of producing large beams with uniform components from VHEE beams with initially small and non-uniform transverse intensity distributions. In this study for production of beams with uniform components of 1–2 cm, the superficial dose contribution from Bremsstrahlung was minimal. The system has since been put routinely in operation in the CLEAR facility for irradiation of samples, both in the frame of VHEE/FLASH studies or for other kind of irradiation tests (see Fig. 10).

Publications:

- C. Robertson et al, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 1082, Part 1, 2026
- Robertson, C. 2024. "Homogeneous Dose Delivery for Very High Energy Electron Beams." PhD thesis, University of Oxford.

2.2.7 EURO-LABS-CERN-2023-CLEAR-AI

Project title: Reinforcement Learning (RL) studies

Aim of the project: The experiment aims to evaluate the CLEAR accelerator as a testbed for AI- driven automation in CERN's Efficient Particle Accelerator (EPA) project. Key objectives include acquiring signals through CERN's NXCALS infrastructure for data analysis and exploring machine learning applications for optimization. The results and techniques acquired can potentially be relevant for beam operation in any particle accelerator.

Project summary: Three key applications were targeted for investigation: optimizing beam orbit, optimizing beam transport and control beam size and shape, all to explore AI's potential in accelerator operations. The experiment involve extended data acquisition sessions and real-time analysis to assess outcomes and refine methodologies. The initial experimental period concentrated on beam orbit correction, using screen + camera systems as diagnostics. By the end, results have been numerically evaluated against operational requirements, aiming at the development of a user interface.

Results: The results demonstrated the effectiveness of the proposed RL-based correction method for the beam orbit. Fast convergence and stable learning behavior were observed for this task. After only a few tens of episodes, the agent learned to reliably correct random initial orbits in a single step,surpassing the reward threshold. This demonstrates not only the efficiency of training but also the agent's ability to generalize to varying machine conditions during deployment. Training convergence was typically achieved within approximately two hours of runtime, validating the robustness and practicality of the method for routine accelerator operation. An autonomous correction of beam trajectories was achieved within a few pulses, while respecting machine safety constraints and instrumentation limits. This resulted in a reproducible, software-in-the-loop system that progressively refined beam alignment over successive iterations, outperforming, for instance in speed, manual tuning and static correction algorithms. Beyond orbit steering, similar RL-based strategies could be adapted for targeting other beam properties, such as minimizing beam size, controlling beam shape, or maximizing transmission efficiency, but only limited initial tests were performed for these. Promising preliminary results have also been observed when applying similar techniques to quadrupole alignment tasks.

Publications:

- A. Gilardi *et al.*, Beam Energy Forecasting using Machine Learning at the CLEAR accelerator, in *Proc. IPAC'25*, Taipei, Taiwan, Jun. 2025, pp. 2747–2750, DO:doi:10.18429/JACoW-IPAC2025-THPM031

2.2.8 EURO-LABS-CERN-2023-CLEAR-THz

Project title: THz radiation studies

Aim of the project: Free-electron laser facilities demand versatile and inexpensive THz sources for pump- probe experiments. Smith-Purcell radiation provides a compact method to generate resonant and narrowband terahertz sources but is limited by its low radiation power. We propose a 3D terahertz emission-collection concept to boost the terahertz efficiency. Systematic simulations demonstrate that the 3D concept can improve the coherent radiation power by orders of magnitude compared with the conventional 2D collection concept. Most importantly, mechanical deformations are first proposed to be introduced to deformable dielectric materials to generate continuously tunable THz radiations from relativistic electrons. The proposed experiment aims to verify the dominance of the concept for a high-energy, tunable, and narrowband THz radiator. This work provides valuable insights into the development of high-power and tunable narrowband terahertz radiators.

Project summary: The primary goal was to detect and characterize coherent THz radiation generated by a 3D-printed helix dielectric structure (high-temperature PMMA) inserted into the CLEAR beamline. We aimed to:

- Identify the THz signal from single electron bunches.
- Construct the THz frequency spectrum using a Michelson interferometer.
- Study the dependence of THz signal strength on bunch charge, number of bunches, and bunch length.

Results: The experiment goals were successfully achieved. The THz signal was clearly identified, and we acquired autocorrelation traces and spectra. We also observed the expected trends under varied beam conditions.

3 Conclusions

At the RAPID facility, 13 projects had been completed by the end of February 2026, delivering a total of 375 AUs out of the 600 AUs originally planned. In addition to the ongoing and completed projects, four further projects have been approved or submitted, corresponding to an additional 150 hours and bringing the total allocated time to 525 hours.

Efforts and promotional activities are ongoing to encourage research teams from different countries to apply for access under the remaining available Access Units (AU). The activities foreseen through the end of the project in August 2026 include the application of low-energy electron beams (<350 keV), which are of particular importance for the potential commercialization of radiation technologies.

The projects implemented at INCT within the RAPID infrastructure demonstrated the broad applicability of electron-beam irradiation across materials science, chemistry, environmental technologies, agriculture, and biomedical research. A key contribution of the facility was the provision of irradiation under a range of electron-beam parameters, combined with comprehensive user support, particularly in the area of dosimetry and characterization of irradiation conditions. This ensured accurate dose delivery, reproducibility, and the overall reliability of experimental results.

These activities were essential for optimizing irradiation parameters, validating technological processes, and enabling a meaningful interpretation of the physicochemical and biological effects induced by ionizing radiation. The research carried out not only advanced the fundamental understanding of radiation-induced mechanisms but also supported the development of practical applications, including medical materials, food safety technologies, sustainable composites, and environmental solutions.

At the CERN-CLEAR facility, eight projects had been completed by the end of February 2026, delivering a total of 476 AUs out of the 1,200 AUs originally planned. The facility will remain operational until the end of the project, with two new experiments currently in the approval pipeline.

Despite numerous promotional activities — including announcements at meetings and workshops — aimed at encouraging research teams from different countries to apply for the offered TA access, limited external interest was observed, even though the facility itself is fully utilized for internal R&D activities. As outlined in the project proposal and Grant Agreement (GA), the unused TA budget will be reallocated to other facilities within WP3.

Nevertheless, the projects carried out are of high value and have produced significant scientific results across a variety of R&D areas.

References

[1] I. Efthymiopoulos et al. *MS17 – WP3 Facilities Ready to Receive TA Requests*. Tech. rep. EURO-LABS, 2024. url: https://web.infn.it/EURO-LABS/wp-content/uploads/2024/05/EURO-LABS_MS17_Report_v1.0-1.pdf.

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List of Abbreviations

AU	Access Units
CLEAR	CERN Linear Electron Accelerator for Research
DoA	Description of Action
EPA	Efficient Particle Accelerator
EPR	Electron Paramagnetic Resonance
INCT	Institute of Nuclear Chemistry and Technology
LUXE	Laser Und XFEL Experiment
RAPID	Centre for Radiation Research and Technologies
RL	Reinforcement Learning
TA	Transnational Access
UHDR	Ultra-High Dose Rate
VHEE	Very High Energy Electron