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 carried out at the electron and plasma beam facilities within Work Package 3, Task 3 of the EURO-LABS project. The Task includes the KIT-ALFA facilities (KARA and FLUTE), INFN-LNF (BTF and SPARC-LAB), CEA (LPA-UHI100), and UKRI (CLARA). Due to technical issues affecting three of the six facilities, approximately 50% of the planned Access Units (AU) have been delivered to date. This figure is expected to increase, as there remains the possibility that some of the affected facilities will resume operation before the end of the project in August 2026. The document describes the projects conducted at each facility so far, highlighting their impact on the relevant research domains and selected key results. Ongoing and planned activities foreseen through the end of the project are also outlined. Finally, an overall assessment of the TA experience within the EURO-LABS framework is presented.

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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

This deliverable reports on the implementation and outcomes of Task 3.3 under EURO-LABS, which provides Transnational Access (TA) to electron and plasma beam testing research infrastructures across participating laboratories. The objective of the task is to enable external research teams to access high-quality electron and plasma beam test and facilities required for the development, validation, and qualification of advanced accelerator R&D and novel particle detector technologies.

Since the start of the project, access was successfully delivered in accordance with the Description of Action (DoA), with strong demand from the international user community. Technical issues encountered in some facilities reduced the amount of TA projects and the AU delivered, nevertheless in the active faciliteis the allocated AUs were implemented efficiently, supporting multiple experimental campaigns and a broad range of detector R&D activities. The facilities provided stable beam conditions, specialised irradiation environments, and technical support necessary for high-precision detector characterisation and radiation hardness studies.

The supported activities contributed to the validation of novel detector prototypes, improvements in timing and spatial resolution performance, radiation tolerance assessments, and optimisation of readout and integration systems. The programme also strengthened collaboration between European laboratories and external user groups, facilitating knowledge exchange and training of early-career researchers.

Overall, Task 3.3 is progressing well and highlights the strategic importance of coordinated transnational access to electron and plasma beam installations. While not all objectives have been fully achieved yet, they are expected to be met by the end of the project. Continued support under a successor framework will be essential to sustain technological innovation and maintain European leadership in this domain.

1 Introduction

This task group four RIs located in different countries across Europe, comprising six installations that provide electron beams over a wide energy energy range, intensity, and bunch length, as well as laser-driven or plasma accelerated low-energy electron beams. A brief description of the facilities is provided below.

KIT-ALFA (KARA & FLUTE facilities) - Germany
The Karlsruhe Institute of Technology (KIT) is a research university in the Helmholtz Association. KIT aligns its research fields with the long-term challenges of society to develop sustainable solutions. The focus is on energy, mobility, and information. KIT hosts the Accelerator Technology Platform (ATP), which combines accelerator-relevant infrastructures, technologies, and research in a unique way, taking advantage of the widespread expertise of KIT institutes to advance accelerator science and technology. The AcceLerator test FAcilities in the KIT Acc. Technology Platform ATP (ALFA), in the KIT Acc. Technology Platform ATP, offers for TA projects the electron-based, ultra-short-pulse terahertz source Far-infrared Linac and Test Experiment (FLUTE) and the electron storage ring Karlsruhe Research Accelerator of the KIT synchrotron radiation source (KARA).

FLUTE serves as an accelerator test facility for a variety of accelerator physics studies, generating pico- down to femto-second long electron bunches of 5 up to 41 MeV (planned up to 90 MeV), also providing coherent radiation in ultra-short, very intense, light pulses spanning the terahertz and far-infrared spectral range and beyond. Due to the flexibility of KARA and FLUTE, the parameter space is too large for a parameter scan for each measurement. KIT-Institute for Beam Physics and Technology (KIT-IBPT) operates the accelerators and provides technical and IT support, in addition, pursuing R&D in the fields of superconducting insertion devices, advanced beam diagnostics, and dynamics of picosecond and femtosecond electron and photon beams.

KARA is a 2.5 GeV electron storage ring, a platform for development and testing of new beam and acceleration technologies, pooling research of new accelerator concepts and development of new detectors. KIT operated KARA for more than 20 years, serving a variety of experiments with synchrotron radiation in the areas of condensed matter, nano- and micro-technologies, actinide research, environmental research and further application fields. In 2015, the KIT executive committee decided that KIT-IBPT also operates KARA as a test facility for accelerator and detector research with electrons and photons. Since few years, KIT no longer offers free access to users, but access to collaboration partners.

As part of the service improvements within EURO-LABS, KIT developed an integrated simulation and measurement framework for facilities with huge amounts of data and complex dependencies, like accelerator facilities, so that users and operators can prepare, plan, perform and evaluate experiments more efficiently. This measurement framework has been tested at KIT on the accelerator test facilities ALFA.

INFN-LNF (BTF, SPARC-LAB facilities) - Italy
The Frascati National Laboratories (LNF) of the Italian Institute for Nuclear Physics contributes to this task through two electron-beam user facilities: the Beam Test Facility at INFN-LNF (BTF), which utilizes extracted electron and positron beams from the

DAΦNE collider injector complex to serve two test areas BTF-1 and BTF-2, and the SPARC-Lab, a high-brightness photoinjector laboratory dedicated to advanced accelerator research and applications.

CEA-LIDYL (LPA-UHI100 facility) - France

The CEA Paris-Saclay is a research Institute located in the Plateau de Saclay (France). The CEA-LIDYL laboratory activities are focused on laser-matter interactions from physical up to chemical aspects. The research programs are extended from simple molecular systems to biomolecular ones up to plasmas. The UHI100 laser facility is the most intense laser system at the laboratory, which already provides Transnational Access (TA) to several of its facilities through the LASERLAB-Europe programme. UHI100 is mostly used by the Physics at High Intensity (PHI) group to study laser-matter interaction at ultra-high intensity. Topics of research mostly concern generation and applications of laser-driven particle sources and attosecond intense XUV beams.

The **LPA-UHI100 facility** consists of the UHI100 laser which delivers 100 TW at 10 Hz with 25 fs pulse duration and one experimental radiation protected area where a laser-driven electron source is available for internal and external users. The short pulse duration, ultra-high contrast and intensity together with radiation-protected experimental area, fully equipped for ultrahigh intensity experiments under vacuum make this facility unique. A geographic move from CEA-Saclay to CEA-Orme des Merisiers (a few kilometres away) has given the opportunity to optimise and redesign a new experimental area with 2 experimental chambers available, offering the possibility to use two high intensity beams in the same chamber. Available diagnostics include Thomson parabola for ion detection, magnetic spectrometer, ICT for electronic charge characterisation, and CCD cameras for spatial characterisation of the particle beams. The LPA UHI100 installation is now accessible by the EURO-LABS users.

The LPA-UHI100 installation provides an electron beam line operating from 75 to 100 MeV, and an experimental area dedicated to laser-driven electron acceleration studies in plasma media. The radioprotection has been specifically dimensioned for electron acceleration and the survey is insured by radioprotection service from CEA. The LPA-UHI100 is equipped with control and diagnostics of the laser beam crucial to control the electron beam properties such as a deformable mirror linked to a wavefront sensor to optimise the spatial profile of the laser, and a set of different focusing parabola for various range of intensities. Two types of gas target can be provided, a gas jet and a variable length gas cell. A magnetic spectrometer is available for electron spectrum characterization. EURO-LABS users can test new concepts or diagnostics using LPA-UHI100.

As part of the service improvements within EURO-LABS, LPA-UHI100 has implemented an additional turbopump system to the experimental chamber where laser-driven electron source is produced to increase the repetition rate of the facility, originally limited to 0,03Hz. If the target, at the begining of the project, was to reach 1Hz, this was not possible as the Nuclear Safety Authority has restricted the electron source delivery repetition rate to 0,3Hz. The maximum that has been reached at the moment is 0,12Hz. We plan to add , thanks to reallocation budget in the last phase of the project, additional fast valves to purge the gas pipes between consecutive gas delivery, and then to be able to shoot at higher repetition rate into the experimental vacuum chamber. This should be in place for the first beam time scheduled for June 2026.

STFC Daresbury (CLARA facility) - UK
Compact Linear Accelerator for Research and Applications (CLARA), located at the STFC Daresbury Laboratory in the UK, is a high performance, modular injector facility capable of delivering a highly stable, highly customisable, short pulse, high quality electron beam to a series of test enclosures. The principal aim of CLARA is to test advanced free electron laser (FEL) schemes, which can later be implemented on existing and future short wavelength FELs. CLARA will facilitate research into the underlying beam dynamics and accelerator technology sub-system challenges in photoinjector, RF acceleration, timing and synchronisation, beam diagnostics, accelerator controls and feedback processes. Electrons are accelerated using three 4-metre-long, 3 gigahertz RF accelerating cavities to an energy of 250 MeV. In addition, the Full Energy Beam Exploitation (FEBE) beamline on CLARA features a 120 terawatt ultra-short-pulse laser, enabling unique experiments that combine high-powered lasers with bright electron beams to probe novel accelerator concepts.

1.1 Purpose and Scope of the Document

This report provides an overview of the activities carried out to meet the commitments defined in DoA and the MS17 [6] 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. The facilities in KIT and LNF, successfully delivered the planned AUs and, in some cases, exceeded the number of TA projects originally foreseen, thereby fully meeting — and in part surpassing — the agreed commitments. At the same time, the facilities at UK and CEA were up until recently unable to host users due to technical issues and delays and they expect this last year of the project to receive their first TA projects and users. The document therefore presents a balanced account of both the challenges encountered and 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 4, 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 KIT-ALFA Facilities

Since the start of the project in September 2022 through the end of 2025, KIT has delivered overall more AUs and TA projects than originally planned, with different outcomes across its two participating facilities. The larger ALFA facility, the KARA synchrotron, has remained fully functional, continuously operational, and consistently available to users. Consequently, significantly more AUs than foreseen were provided, and additional access is planned until the end of the project, profiting from the recent resource reallocation within the project. The ALFA linear accelerator FLUTE experienced delays due to the late delivery of a new electron source and technical issues with the klystron in a new modulator. Despite these challenges, TA experiments at FLUTE have been successfully conducted since the end of 2025, covering a large fraction of the initially planned activities.

Table 1 summarizes the TA projects and AUs delivered in the KIT facilities at the time of writing of this report. In total, 120 AU were delivered at FLUTE out of 330 AU planned (36.4%), and 843 AU were delivered at KARA so far out of 880 AU planned (96%). The KIT internal website https://www.ibpt.kit.edu/project_EURO_LABS.php was set up for marketing purposes for EURO-LABS and TA at the beginning of the EURO-LABS project.

Table 1: KIT-ALFA: summary of completed TA Projects. The number of users corresponds only to those directly involved and received TA funds.

Project ID	Title	AU	No. Users	PI origin
FLUTE-01-SRR	Novel compact transverse deflecting system (Compact-TDS: ISSR and TSR) for longitudinal electron bunch diagnostics at FLUTE	120	8	CH
KARA-01-FCC-hh, KARA-03-FCC-hh	Photo-stimulated desorption measurements for future accelerators in BESTEX at KARA:FCC-hh beam-screen prototype no.5 with sawtooth profile, no. 6 with a-C coating)	220 480	8	CERN
KARA-04-μBunching	Advanced control of the μ-bunching instability	24	13	FR

Project ID	Title	AU	No. Users	PI origin
KARA-05-RDP	Resonant Depolarisation studies at KARA for FCC-ee	42	8	AT
KARA-06-BBB	Beam stabilization and handling experiments with KARA bunch-by-bunch feedback (BBB) system; collaboration with I.FAST, WP7.2 and beyond	12	25	JP
KARA-07-BBA	Parallel Beam Based Alignment (BBA) and BBA of individual magnets at KARA for FCC-ee	12	88	JP
KARA-08-BBA	Beam Based Alignment (BBA) at electron energies between 2.2 and 2.5 GeV at KARA: experiments in collaboration with I.FAST, WP7.2 and beyond	25	25	FR
KARA-09-BESTEC	Photon-stimulated electron emission analysis of Cu beam screens for LHC and functional a-C coatings for electron cloud mitigation in BESTEC at KARA	25	8	CERN

2.1.1 KIT-2025-FLUTE-01–SRR

Project description:
Recently, in collaboration with Paul-Scherrer-Institute PSI, and University Bern, both CH, and Karlsruhe Institute of Technology KIT, Germany, a novel compact transverse deflecting system (**Compact-TDS**) for longitudinal electron bunch diagnostics has been installed and commissioned at the linear accelerator test facility FLUTE at the KIT. The Compact-TDS employs intrinsically synchronized terahertz (THz) pulses generated by the photo-injector laser system to streak the electron bunches, enabling the reconstruction of the longitudinal phase space. The electric field of the THz pulse is enhanced by one of two resonator structures installed into the vacuum chamber of PSI integrated into the FLUTE facility: an Inverse Split-Ring Resonator (ISRR) delivered by Univ Bern) and a Tilted-Slit Resonator (TSR) designed by KIT, providing the potential for femtosecond-level temporal resolution. The experimental setup is shown schematically in Fig. 1.

At present, the experimental setup is located in the low-energy section of FLUTE, where the bunch length of electrons of about 5 MeV is primarily determined by the duration of the photoinjector laser pulse and is on the order of a few picoseconds. In previous mea-

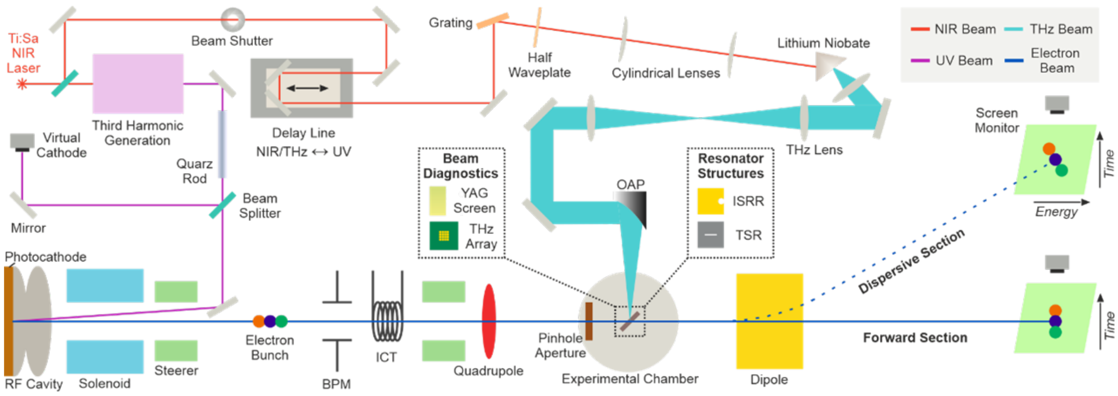

Figure 1: Sketch of the Compact-TDS experimental setup at KIT-ALFA-FLUTE: A Ti:Sa laser simultaneously drives electron bunch generation and THz pulse production, which is focused onto a field-enhancing resonator structure for THz streaking. The induced transverse modulation is observed on a downstream screen, while a dipole magnet enables simultaneous energy-resolved measurements in the dispersive section.

surements, bunch length diagnostics were successfully demonstrated using the available dispersive section of the beamline. Due to the linear energy-time correlation (chirp) within the bunch, the THz-induced oscillation can be imprinted onto the horizontally elongated beam profile by scanning the temporal overlap between the electron bunch and the THz pulse. In particular, for the TSR geometry, which exhibits a comparatively high quality factor, the THz field inside the slit can span several oscillation cycles. By fitting the resulting damped oscillation and determining the phase difference between the bunch head and tail, the bunch length can be extracted with an uncertainty of less than 100 fs.

However, the achievable temporal resolution of this phase-based method depends on the effective number of resolvable THz oscillation cycles contributing to the fit and improves approximately with the square root of this number in the high signal-to-noise regime. Consequently, a central objective of this measurement campaign was to maximize the number of usable oscillation cycles by increasing the scanning range and improving the experimental signal-to-noise ratio (SNR).

In a first step, the SNR was optimized through precise spatial alignment of the THz pulse with the resonator structure and by improving the transverse beam optics. A quadrupole magnet was used to increase the effective streaking strength. Subsequently, bunch length measurements were repeated in the dispersive section while recording the full THz ring down for both resonator geometries.

In a second phase of the experimental campaign, the electron bunch length was systematically reduced by shortening the photoinjector laser pulse. This was achieved by decreasing the length of the quartz rod employed at FLUTE in the laser light path towards the photo-injector's cathode for stretching the ultraviolet pulses after third-harmonic generation. As this modification changed the effective optical path length, the temporal overlap between the THz pulse and the electron bunch had to be re-established. The resulting measurements successfully verified the controlled reduction of the bunch length using the dispersive streaking technique.

Finally, within the remaining beam time, first exploratory single-shot THz streaking tests were performed. Owing to the limited signal-to-noise ratio, long exposure times and averaging over multiple bunches were required. Nevertheless, the underlying THz streaking technique is inherently single-shot capable, and future improvements in beam transmission, detection efficiency, and THz field strength are expected to enable single-bunch longitudinal diagnostics.

The experiments were prepared ahead of the experiments by KIT over several weeks and were carried out during a dedicated one-week beam time period, accompanied by close on-site collaboration and scientific exchange between the PSI and KIT teams; see Fig. 2

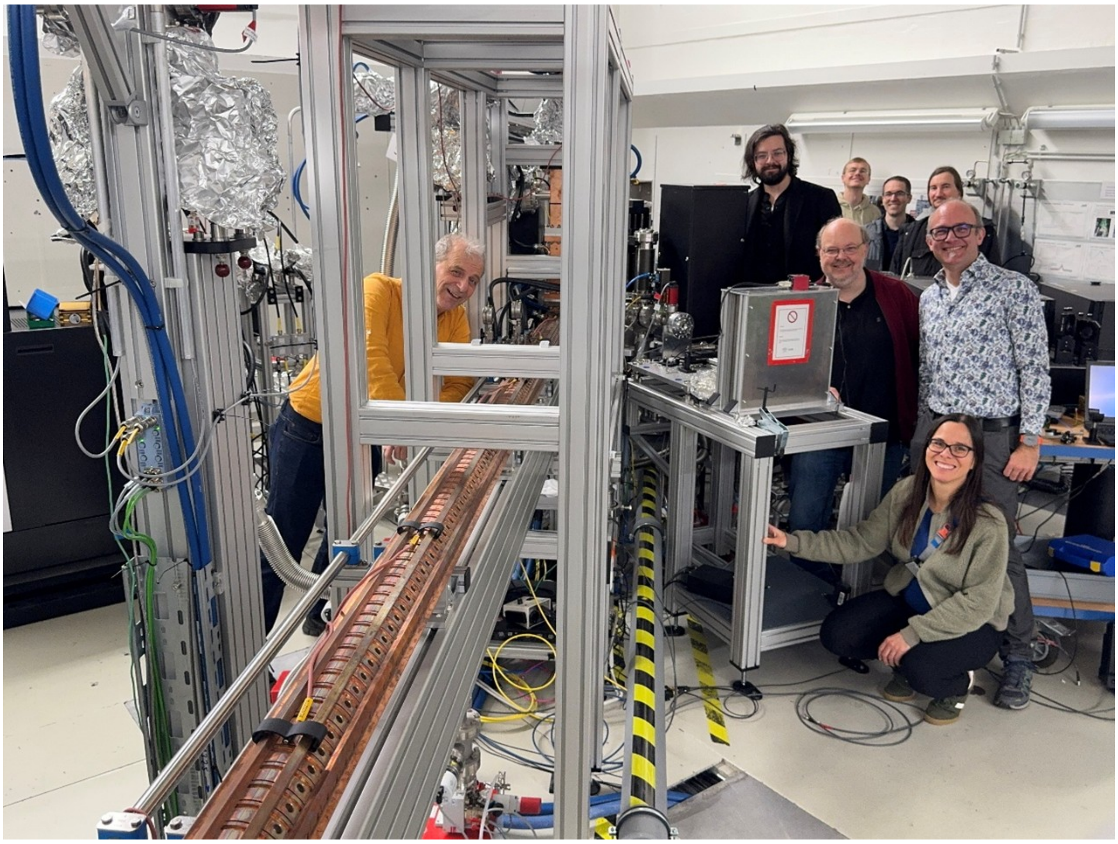

Figure 2: Group photo: PSI and KIT at the FLUTE of the KIT accelerator facilities: (from left to right: Micha Dehler (PSI), Gerard Lawler (PSI), Michael Nasse (KIT), Matthias Nabinger (KIT), Evan Ericson (PSI), Nicole Hiller (PSI), Rasmus Ischebeck (PSI), Sergei Glukhov (KIT))

Results:
The THz oscillation imprinted on the electron bunch in the dispersive section could be clearly measured, in particular for the TSR geometry, which yielded approximately ten resolvable oscillation cycles. Based on this, the bunch length was determined to be Δt = 2.4 ps with a temporal resolution of approximately 25 fs (see Fig. 3). In addition, the resonance frequency of the TSR structure was experimentally verified and found to be in good agreement with the simulation predictions ($f \approx 260\,\mathrm{GHz}$).

After replacing the quartz rod and reducing the pulse length of the photoinjector, the measurement was repeated, resulting in a reduced bunch length of approximately 1.8

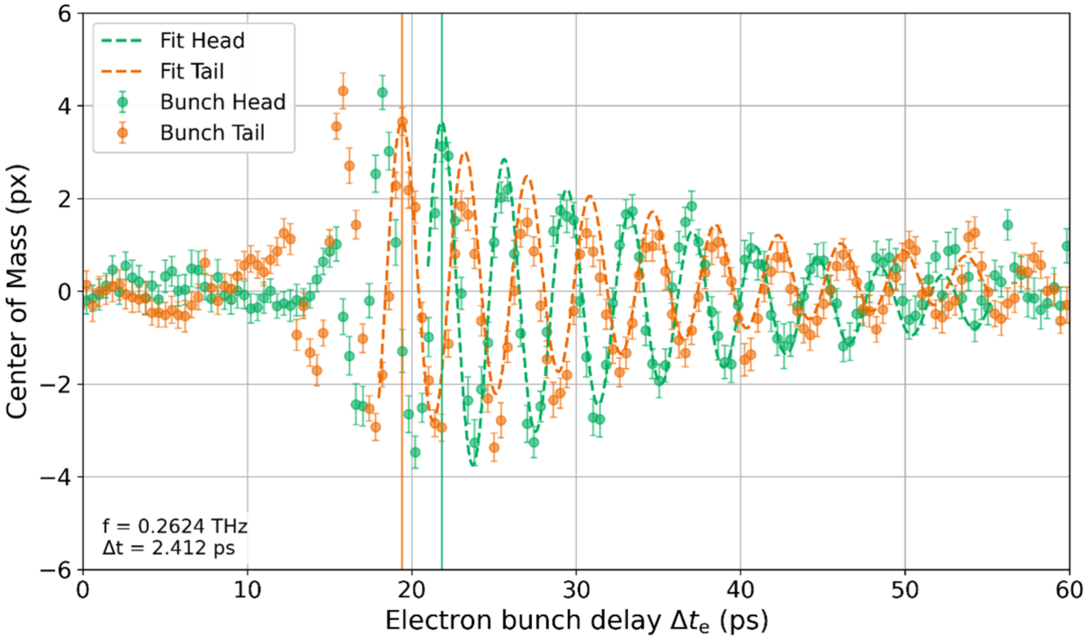

Figure 3: Electron bunch length measurement in the dispersive section of the KIT facility FLUTE. The graph shows the THz oscillation imprinted on the electron bunch while scanning the electron bunch delay for bunch head (green) and tail (orange). The bunch length can be deduced by the phase difference of the fit functions

ps. Notably, the bunch length reduction was directly observable, as the shorter bunch covered a smaller fraction of the THz oscillation compared to the 2.4 ps case (see Fig. 4).

Scientific value and impact in the field:

The results of this project co-funded by EURO-LABS Transnational Access confirm the impact of the presented measurements extending terahertz-based streaking diagnostics beyond the conventional zero-crossing approach typically applied to femtosecond electron bunches. By exploiting the multi-cycle THz ringdown in a dispersive beamline and extracting the bunch length from the phase difference between the bunch head and tail, the Compact-TDS introduces a complementary phase-resolved streaking concept. This enables the precise characterization of picosecond-scale bunches with femtosecond-level resolution, demonstrating the versatility of THz-driven deflectors across a broad range of beam regimes.

Moreover, the successful operation of a compact THz-based transverse deflecting system represents a natural technological progression from RF- to THz-frequency beam manipulation. Owing to the higher achievable field gradients, intrinsic laser synchronization, and reduced footprint, such systems offer a promising pathway toward compact, high-resolution beam diagnostics that may ultimately complement or replace conventional RF-based structures as these approach fundamental limits in size and timing precision.

The demonstrated capabilities are particularly relevant for research areas requiring precise longitudinal beam control, including ultrafast electron diffraction, free-electron laser development, and advanced accelerator concepts. In these fields, compact, high-resolution

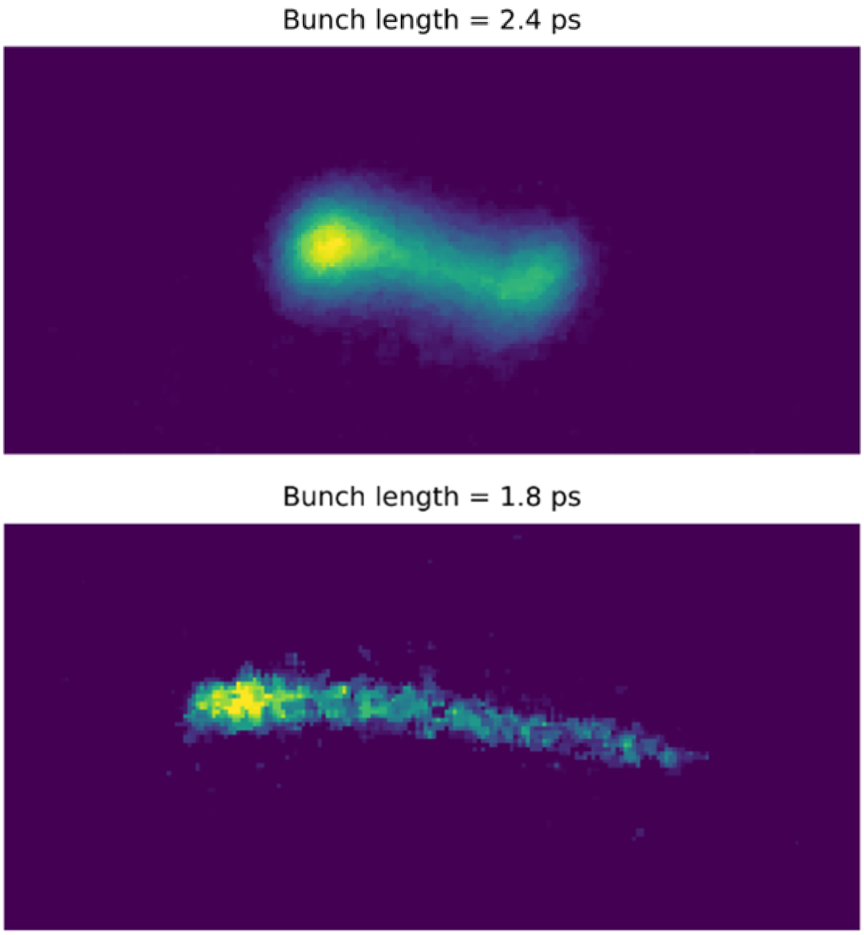

Figure 4: THz oscillation imprinted on the electron bunch detected at the KIT accelerator test facility FLUTE. Shown are screen images of the electron bunch in the dispersive section of the KIT facility FLUTE in an exemplary case of temporal overlap between THz and electron bunch, for the case of a 2.5ps bunch (top) and for 1.8ps bunch (bottom). Due to the linear chirp, the horizontal axis corresponds not only to energy, but also time. Therefore, the longer bunch length covers a larger fraction of the THz sine (more than half the period length) than the shortened case.

diagnostics are essential for optimizing beam quality and enabling next-generation ultrafast experiments.

Highlights of results:
A compact terahertz-driven transverse (Compact-TDS) deflecting system was successfully commissioned at FLUTE, one of the KIT AcceLerator FAcilities ALFA. This Compact-TDS system enables high-resolution longitudinal electron bunch diagnostics. Using a novel phase-resolved multi-cycle THz streaking approach in a dispersive beamline, picosecond-scale bunch lengths were measured with femtosecond-level temporal resolution and systematically verified for two different bunch durations. This demonstrates the Compact-TDS as a quantitative and versatile diagnostic tool for high-resolution longitudinal electron beam characterization.

Publications:
The preparations for the Compact-TDS experiments were presented in the poster session

at the EURO-LABS 3rd Annual Meeting [10]. Until now, no results from these EURO-LABS–FLUTE experiments have been presented, as the measurements were taken recently and are still undergoing final evaluation. Future publications will acknowledge the EU-funded EURO-LABS project in accordance with the TA agreement.

Contribution to the evaluation of the TA at KIT:
Feedback from PSI team: The TA at KIT provided a highly productive framework for the development of the Compact-TDS diagnostics at FLUTE. In particular, the close scientific exchange of our PSI scientists with KIT operators and KIT scientists proved extremely valuable for optimizing the THz streaking technique, from experimental alignment strategies to data analysis approaches. The collaborative environment significantly enhanced both the efficiency of the beam time and the overall quality of the experimental results.

Planning for further experiment:
No further FLUTE experiments are currently planned within the timeframe of the EU project EURO-LABS because of the 2026 beginning installation of the new accelerator facility cSTART (compact STorage ring for Accelerator Research and Technology), which will use FLUTE as a source for research on the storage of electron bunches in the fs-range. We would very much welcome an EU-funded follow-up project to EURO-LABS that once again offers Transnational Access TA, as we would like to use EU funding for FLUTE experiments from 2027/28 onward.

2.1.2 KIT-KARA-01-FCC-hh-BS & KIT-KARA-03-FCC-hh-BS

Project description
CERN is operating the BEam Screen Test bench EXperiment (BESTEX) at one beam line of KARA at KIT. In the past, it had been utilized to measure photon reflection [3] and photon-induced desorption [4] of prototype beam screens and vacuum chambers in development of the technical solutions for the future circular collider (FCC) with its configurations for electron-positron collision and hadron-hadron collision. Furthermore, materials, geometrical structures, and coatings can be qualified under synchrotron light irradiation to extract relevant vacuum parameters for the operation of such geometries in particle accelerators.

Particle accelerators and colliders must cope with a large amount of synchrotron radiation (SR) power being deposited on the vacuum chamber walls. This has several effects that may be detrimental to the machine operation, such as Photo-Stimulated Desorption (PSD) increasing the pressure, and large heat loads that must be accounted for in the machine design.

The BESTEX at the KIT KARA was used to measure the heat load and photon-stimulated desorption for several beam screen and vacuum chamber prototypes. The results of this study are critical for the design of future high-energy hadron colliders such as FCC-hh. KARA has a comparable spectrum as the FCC-hh configuration for a future possible hadron collider at CERN.

During the project phases, the FCC-hh beam-screen prototype no. 5 (**KARA-01**) with Cu sawtooth profile and the new beam-screen prototype no. 6 (**KARA-03**) with amorphous carbon coating (a-C) and a titanium interlayer were characterized. Amorphous carbon is a stable and inert material, deposited via sputtering techniques onto the internal wall of a circular tube (carried out at CERN). It is the base technology at CERN for electron cloud mitigation. The main feature of interest of a-C is its extremely low secondary-electron yield, which is required to avoid the electron-cloud instability in accelerators with positively charged beams. The study of these prototype samples aimed at studying the outgassing properties under irradiation with KARA's synchrotron radiation dipole fan.

Results

After bakeout, the two beam screen prototypes were exposed to KARA synchrotron radiation while cooled with LN2 and the desorption of species from their surfaces was continuously monitored in the vacuum system with a residual gas analyzer and installed pressure gauges. Figs. 5 and 6 summarize the desorption of different species from the surfaces in dependence on the accumulated photon dose. In the initial phase, there is a clear increment of the desorption, which then drops after reaching doses between 1020 and 1021 ph/m, depending on the surface roughness and material. Table 2 includes the ratio of the main species that are still released after conditioning with doses above 1022 ph/m.

Prototype	No.5 (KARA-01)	No.6 (KARA-03)
H_2	85.8 %	82.3 %
CH_4	1.8 %	2.7 %
CO	8.3 %	6.1 %
CO_2	4.1 %	8.8 %

Table 2: Relative desorption yield of the main species for photon doses > 1022 ph/m for both prototypes: No.5 (KARA-01) with Cu sawtooth profile, No.6 (KARA-03) with a-C coating.

As expected, the main contribution to outgassing and increased pressure is caused by H2 release. The a-C/Ti thin film, which exhibits of 10 higher H2 release, also reaches the peak desorption only at higher doses [2]. These quantities must be considered when designing the related vacuum system, defining pumping strategies and vacuum control systems. The PSD characteristic can be well implemented in existing simulation tools such as MOLFLOW and will improve the design of the FCC vacuum system.

Scientific value and impact in the field

The PSD characterization performed resulted in quantitative material parameters that define the desorption behavior of surfaces in vacuum under synchrotron light irradiation. For the development of future high-energy hadron colliders, such as the FCC-hh, knowledge of the influences of material selection, surface geometry (such as a sawtooth profile), and coating technologies (such as a-C coating) are of great importance for designing the vacuum system of new machines and to develop a strategy for the necessary pumping and control system considering the experimental results that model desorption behavior with beam. Together with the studies on reaction of the materials under electron irradiation, which are easier to measure and do not need a synchrotron light source

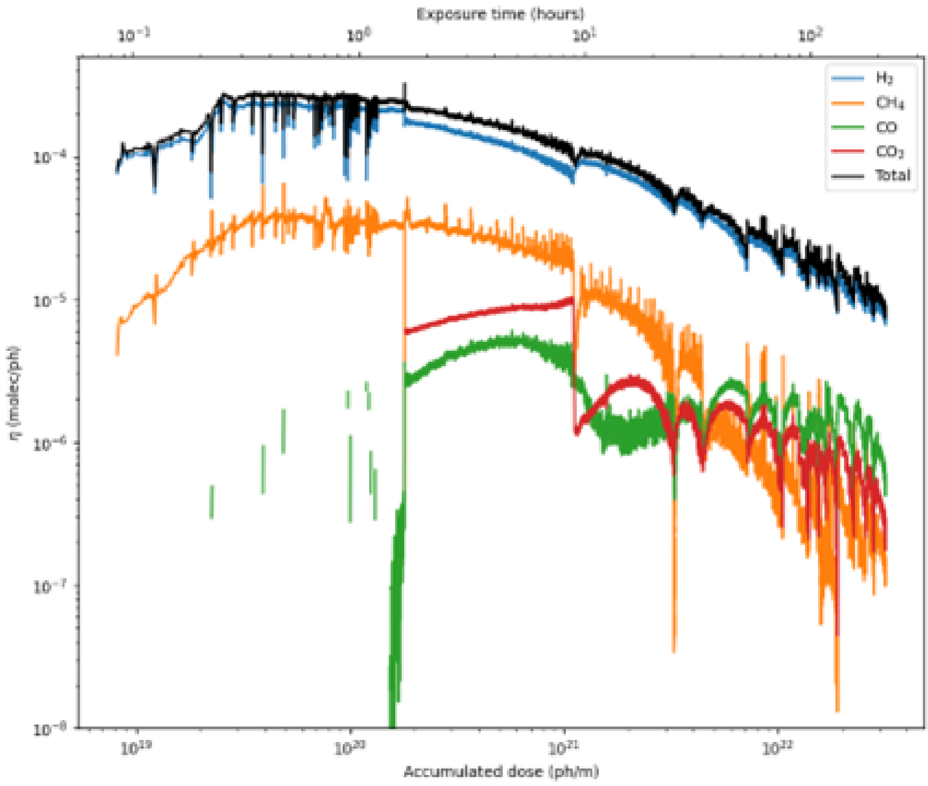

Figure 5: Photo-Stimulated Desorption (PSD) of different species from the surface of the prototype sample in dependence of accumulated photon dose.

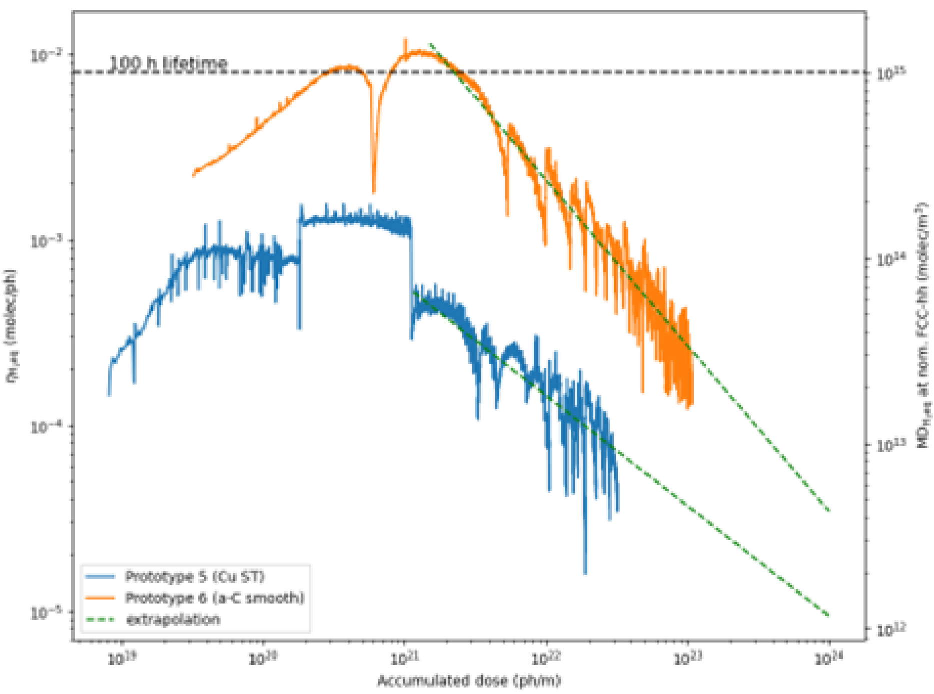

Figure 6: Photo-Stimulated Desorption (PSD) of H_2 molecules from the surfaces of the two prototypes in dependence of accumulated photon dose.

for the experiments, the dynamic pressure behavior during operation can be modeled and predicted for the complex geometries of the future particle accelerators.

Highlights of results
The photon-induced desorption of Cu with sawtooth profile and amorphous carbon coated beam screens was characterized using the KARA electron storage ring of the KIT synchrotron light source, which has a spectrum compatible with that of the FCC-hh configuration for a future possible hadron collider at CERN. The experiments allowed to qualify materials, geometrical structures and new thin film technologies for the future beam screens and to extract quantitative material parameters for the desorption behavior under exposure to photons in the keV range, which will be used as database in model calculations.

Contribution to the evaluation of the TA at KIT
Feedback from the CERN team: The KARA team at KIT is very helpful in the preparation of the experiments by supporting our installations with manpower and technical support during the installation of the new vacuum chamber by the vacuum team. They were very supportive and flexible, also allowing remotely discussed interventions to fix small problems while the CERN operators were remote at CERN. The facility itself allows for the BESTEX experiment a very good match of experimental synchrotron light conditions to characterize PEY at different photon energies as well as to perform photon-induced desorption studies. The offered operation time slots during the machine physics run were very helpful in allowing dedicated runs for the BESTEX calibration and the good availability of the beam. The planning and coordination of activities, experiments, and interventions is very smooth.

Publications
The experimental results were reported in CERN internal meetigns, FCC project weeks, and published articles:

- P. L. Henriksen, The beam screen test-bench experiment (BESTEX), TE-VSC seminar, CERN, 2024, https://indico.cern.ch/event/1372159/contributions/5769244/attachments/2803557/4892350/BESTEX_seminar_2024_02.pdf
- P. Lindquist Henriksen, M. Ady, R. Kersevan, Recent developments in surface conditioning measurements and vacuum simulations, FCC Week 2023, London, 2023, https://indico.cern.ch/event/1202105/contributions/5380087/

Planning for further experiment
A further PSD campaign is envisaged for the FCC-ee type vacuum chamber. Unfortunately, this system cannot be delivered and installed before the KARA summer in 2026 due to delays in the assembly technology development for laser welding of the Cu geometry for the FCC-ee type vacuum chamber. Therefore, these TA experiments cannot be finished before the end of the EURO-LABS project.

2.1.3 KIT-2023-KARA-04–Micro-Bunching

Project description This project aimed at observing, understanding, and controlling ultra-fast self-organization of relativistic electron bunches in accelerator facilities. A central goal was to master the emission of giant pulses of terahertz (THz) Coherent Synchrotron Radiation (CSR) that occurs concomitantly in synchrotron radiation facilities and thus to propose new THz sources. Another intermediate and major milestone ass the improvement of novel ultra-fast observation tools. The project included investigations at KARA, the electron storage ring of the KIT synchrotron light source. KARA is one of the only experiments in the world that can "probe" directly the shape of relativistic electron bunches in a storage ring facility. We attempted to transfer techniques of chaos control (feedback control of periodic orbits) for achieving stable THz CSR emission at KARA, that we already had tried successfully at the synchrotron SOLEIL, to compare the results between the machines and also with theory. At KARA we had in principle the possibility to observe the evolution of the longitudinal bunch profile using the existing electro-optical near-field setup in real time.

When electron bunches in storage rings are compressed longitudinally (so called low-alpha mode) they emit strongly in the THz regime. This is potentially very useful for a variety of user experiments ranging from biological, medical, to material science. However, this high compression also leads to the so-called microbunching instability, which in turn leads to a very unstable emission of THz radiation rendering such accelerator modes useless for experiments.

Results During these experiments we implemented an advanced feedback control loop from chaos control theory on a fast FPGA board that controls the amplitude of one of the two main radiofrequency (RF) cavities in the electron storage ring KARA at KIT (see reference 1). The goal was to stabilize at a high level the CSR emission of THz power and therefore to control the microbunching instability. We used fast Schottky diodes at the IR2 beamline at KARA to measure the THz power in real time using the high-speed data acquisition board KAPTURE. We also measured the bunch length using a streak camera in parallel. For this experiment, the cavity needs to be operated at zero-crossing, in contrast to the normal off-crest mode used for acceleration for KARA user operation. Therefore, We did scans to find the zero-crossing configuration. We also scanned to find the optimal feedback parameters for each beam current. To avoid unplanned beam loss due to unstable regimes of the feedback during these scans we implemented a fast interlock system based on BPM signals.

Scientific value and impact in the field

The experiments on micro-bunching at KARA, the storage ring of the KIT light source, aimed at observing, understanding, and controlling ultra-fast self-organization of relativistic electron bunches in accelerator facilities.

Highlights of results

The experiments on micro-bunching at KARA, the storage ring of the KIT light source, contributes to observing, understanding, and controlling ultra-fast self-organization of relativistic electron bunches in accelerator facilities. A central goal was to master the emission of giant pulses of terahertz (THz) Coherent Synchrotron Radiation (CSR) that occurs concomitantly in synchrotron radiation facilities and thus to propose new THz sources. Another intermediate and major milestone was the improvement of novel ultra-fast observation tools. KARA is one of the only experiments in the world that can "probe" directly the shape of relativistic electron bunches in a storage ring facility.

2.1.4 KIT-KARA-05–Resonant-Depolarization

Project description
FCC-ee precision physics measurements demand an accurate and precise determination of the center-of-mass collision energy, which can be obtained from the beam energies. Since the depolarizing frequency is directly proportional to the beam energy, one promising way to determine this energy is to depolarize transversely polarized bunches. This is also known as the Resonant depolarization (RDP) technique. RDP has long been implemented at KARA, where the resonant frequency is determined by the resulting change in the Touschek-lifetime. Performing a RDP measurement campaign with numerous scan settings and bunch configurations allows us to explore how this technique could be applied at the FCC-ee and, in particular, the sensitivity to various parameters, such as depolarizer scan speed and scan velocity.

Most measurements were performed at a nominal beam energy of 2.5 GeV, where the KARA ring is well set up and corrected with the DBA lattice for the KIT light source user operation. Typically, the depolarizer frequency is swept from 1.705 to 1.735 MHz over 650 s and a change in the local loss rate is observed. The depolarizing frequency, at which the loss rate changes, gives the spin tune can be converted to an equivalent beam energy. The depolarization frequency has been found to be around 1.7139 MHz, with an equivalent beam energy of roughly 2.48 GeV.

Complementary optics measurements, based on turn-by-turn measurements, have been performed. For these optics measurements, a total beam current of about 60 mA was stored, spread over roughly 30 bunches, and thus under conditions similar to those for the RDP scans.

Results:
Optics studies:
The relative error of the β-function with respect to the model, known as β-beating, is inferred using the so-called β from the amplitude method. Although this technique would be spoiled by BPM calibration errors, a rather low rms β-beating of 1.1 % horizontally and 0.5 % vertically is measured, which is shown in Fig. 7.

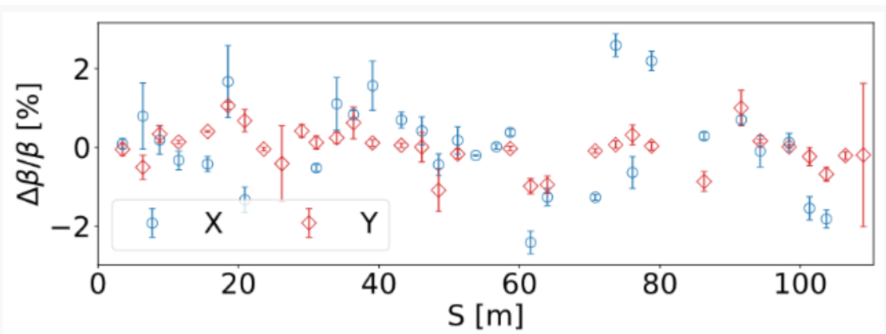

Figure 7: Measured relative error of the β-function with respect to the model at top energy.

To obtain the off-momentum optics the RF-frequency was shifted by roughly ± 15 kHz, resulting in a relative momentum offset of $\mp 3 \times 10^{-3}$. An rms dispersion error of 40 mm horizontally and 12 mm vertically was measured. In, the majority of BPMs observe a lower horizontal dispersion than predicted by the model, especially in sector 3 (between $S = 55$ and 82.5 m)

RDP scans:
The measured loss rates as a function of E are fitted to

$$F(E) = F_0 + \frac{h}{2}\,\mathrm{erf}((E - E_0)a) + bE + cE^2\,. \tag{1}$$

where the fit parameter E_0 corresponds to the center of the step and, hence, to the inferred beam energy. For the fitting, we used the Python function *curve_fit*, available from the *scipy* package [11], which implements a nonlinear least-squares method based on the Levenberg-Marquardt algorithm. The parameters a, b, c, h and F_0 are also determined by this fit, including the respective errors.

To investigate in detail the dependence on the scan velocity and direction, an automated measurement campaign was executed. During a long night of 16 h, numerous scans were performed and recorded, with a scan range extending from 1705 to 1725 kHz, corresponding to an energy range of 2.4795 to 2.4830 GeV.

The loss rates from these two scans are shown in the top and bottom pictures of Fig. 8, respectively. Notably, the scan towards higher frequencies yields a significantly steeper change of loss counts than the scan in the other direction, which hints towards a negative energy drift.

An automated scan on 16 h has endorsed this energy drift. After 16 h, the measured beam energy was 0.8 MeV lower than at the beginning of the measurement. This trend of decreasing beam energy is consistent with all RDP scans in both scanning directions and for scan durations ranging from 100 to 600 s. During these scans, the RF frequency was constant. Therefore, a likely source of the observed energy drift is a slow increase in the ring circumference because of warm-up and thermal expansion after the machine is restarted.

Scientific value and impact in the field
Reasonable agreement with the available optics models was found. At maximum energy a low rms β-beating of less than 1.1 % was measured, along with a horizontal and vertical spurious rms dispersion of 40 and 12 mm, respectively, with the highest errors in sector 3. Therefore,machine understanding has been advanced, which opens the way for further studies on the storage ring.

Regarding the RDP scans, the hypothesis that both directions must be scanned for the FCC-ee has been endorsed by measurements performed at KARA.

Highlights of results
Optics measurements based on turn-by-turn data have been acquired, analyzed, and compared to the model values, where, in general, a good agreement has been found. Several resonant depolarization scans have been acquired with varying scan duration and direction to measure the average beam energy over a 16 h campaign. During that measurement, a drift of -50 keV/h was observed. Furthermore, performed measurements strengthen the assumption that for the Future Circular electron-positron Collider scans must also be performed in both scan directions.

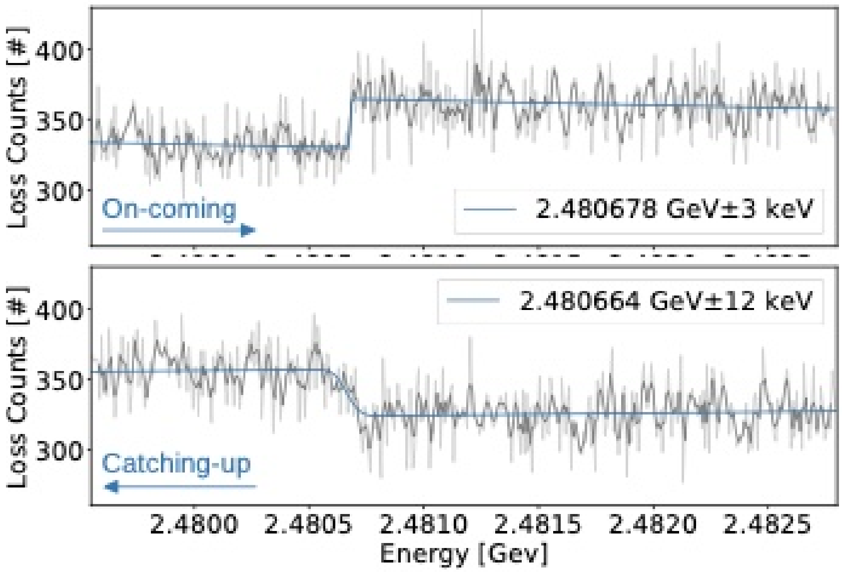

Figure 8: Scan results for increasing (top) and decreasing depolarizer frequency (bottom) with the respective fit results shown. The different shape of the fitted function is consistent with a downward drift in beam energy.

Contribution to the evaluation of the TA at KIT:
The application process has been straightforward. Data sharing among facilities has been excellent. Measurements and analysis has strengthened the collaboration and knowledge exchange between CERN and KIT.

Publications:
The results were presented at IPAC 2024 contributions.

- J. Keintzel *et al.*, "Investigations in turn-by-turn optics measurements at KARA", in *Proc. IPAC'24*, Nashville, TN, USA, May 2024, pp. 1294–1298, doi:10.18429/JACoW-IPAC2024-TUPG33.
- J. Keintzel *et al.*, "Probing FCC-ee energy calibration through resonant depolarization at KARA", in *Proc. IPAC'24*, Nashville, TN, USA, May 2024, pp. 2516–2520. doi:10.18429/JACoW-IPAC2024-WEPR20.

Planning for further experiment
Recently, RDP scans for KARA have been simulated using xSuite. However, since during measurements a vertical kick of 1.7 µrad over roughly 800 million turns has been applied, this kick has been scaled to maintain the same resonance strength over a shorter scan duration. In future measurements, it could be aimed to reproduce this condition in order to allow for an easier comparison between simulated and measured RDP scan.

2.1.5 KIT-2024-KARA-06–BBB-feedback–I.FAST

Project description
Bunch-by-bunch (BBB) feedback systems are indispensable to realise ultra-low emittance rings by which the electron beams can reach high-quality states for application to

synchrotron radiation light sources and colliders.

This project was a joint experimental campaign following the I.FAST workshop on BBB feedback systems, in which several experts on BBB systems from around the world participated. The experiment included three topics related to the BBB systems, carried out with real electron beams at the KARA storage ring of the KIT light source and the booster synchrotron by operating the BBB systems installed into each accelerator.

The KARA storage ring (0.5 – 2.5 GeV) and the booster synchrotron (53 – 500 MeV) have the same BBB system. Therefore, we conducted experiments related to the BBB system with both accelerators. We performed the following three experiments. The plans A and B was for the KARA storage ring, and the plan C was for the booster synchrotron:

1. Vertical emittance/beam-size control
   The aim of the experiment was to manipulate the vertical beam size by exciting the betatron oscillation with the BBB system to improve the Touschek beam lifetime. Nowadays, the top-up operation, in which beams are regularly injected to maintain the stored beam current in storage rings, is widely applied in light sources and colliders. The beam lifetime, however, remains a relevant issue for operating accelerator complexes. This is much more relevant for accelerators without the top-up operation option, such as the KARA storage ring. In the case that the BBB system excites the betatron oscillation with sinusoidal wave signals whose frequency corresponds to the betatron frequency, the beam oscillates with a simple dipole oscillation, with the center of mass of the beam oscillating without a change in the beam size. In this experiment, the BBB system was driven by a band-limited white noise signal to avoid a simple dipole oscillation while controlling the beam size. The experiment was carried out in the KARA storage ring with 2.5 GeV operation. Figure 1 shows typical results for the spatial beam profile under white-noise excitation with a bandwidth of 800 kHz. As shown in the figures, the vertical beam size increased under noise excitation. Figure 2, which summarizes the vertical beam size during the experiment, clearly shows its increase. This suggests the ability to control the vertical beam with the BBB system, which can be easily activated or deactivated without causing orbit disturbance or hysteresis. This point should be emphasized to clarify the distinction from conventional methods for controlling the vertical beam size with skew quadrupole magnets. This method is easy to apply to other storage ring facilities and has other applications, such as improving the beam injection rate by mitigating the Touschek beam loss effect.

2. Commissioning test searching for common procedures
   The aim of this experiment was to look for common procedures for commissioning bunch-by-bunch feedback systems. There are now several bunch-by-bunch feedback systems in operation around the world, and to operate with good performance, they need to be periodically adjusted by changing internal parameters. However, commissioning is currently carried out in different ways at different institutes. As mentioned above, this experiment formed part of an international joint experimental campaign following the I.FAST workshop on BBB feedback systems. This workshop brought together the main developers of BBB systems from around the world. This provided the first opportunity for them to meet in

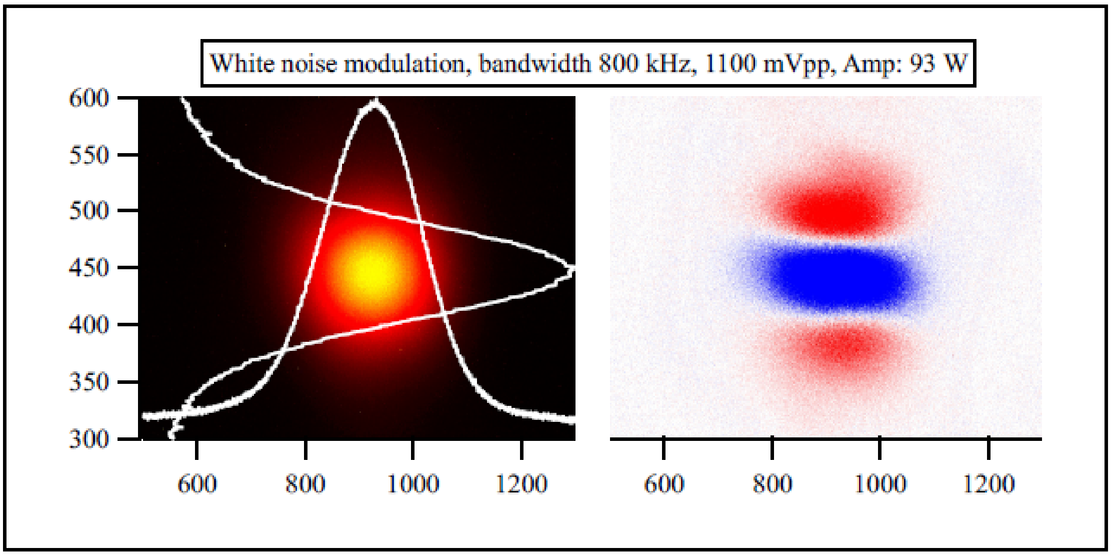

Figure 9: Transverse beam profile under white noise excitation with the BBB feedback system at KARA. The image on the left shows the spatial beam profile observed by synchrotron radiation. The image on the right shows the same beam profile minus the unperturbed beam profile. The two vertical red sections illustrate the vertical beam expansion caused by the noise excitation of the BBB system.

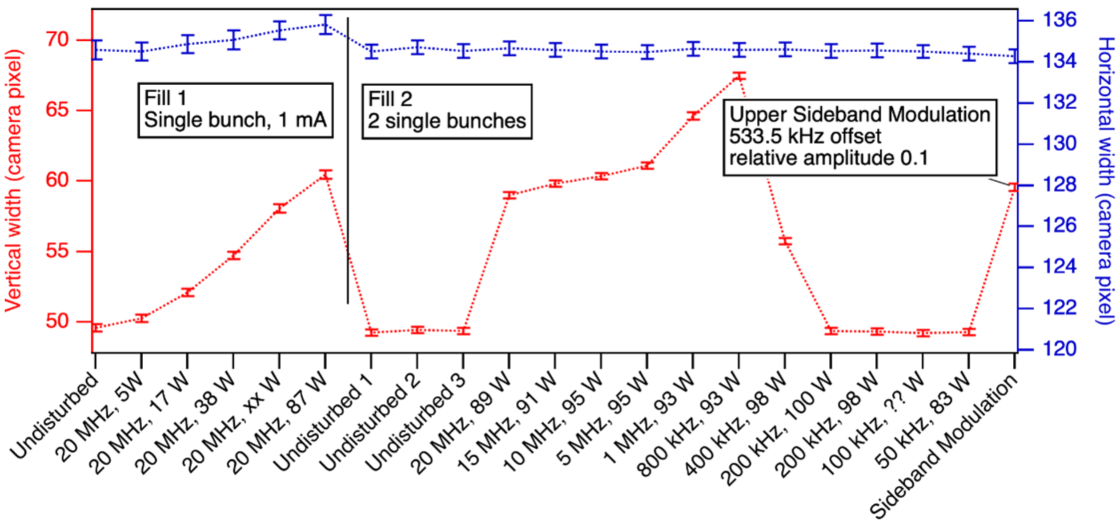

Figure 10: Horizontal and vertical beam size during the KARA experiment. The red curve shows the change in the vertical beam size, which peaks at the noise bandwidth, with a power of 800 kHz and 93 W. That corresponds to the condition in the Figure above.

person, and they discussed commissioning methods by operating the real BBB system. The experiment and test were carried out in parallel with the systematic experiment on vertical beam size manipulation, in consultation with BBB specialists. The participants concluded that there was a need to share common commissioning methods for BBB systems, and that further discussions and information sharing are the next relevant steps.

3. Test for longitudinal kicks at booster synchrotron The aim of this experiment was to give a longitudinal kick to the beam circulating in the booster synchrotron using the BBB feedback system. The BBB feedback system has been installed in the KARA booster, and the transverse kick test has been carried out with the strip-line kicker so far. The strip-line kicker is normally used to kick the beam transversely. However, it can be used to longitudinally kick the beam if the relative phase between the difference strip lines is properly adjusted. The experiment was carried out as the first attempt and commissioning to longitudinally kick the booster beam, with advice and support from BBB system specialists. After several trials and errors, we confirmed that the booster beam was kicked longitudinally, demonstrating the feasibility of integrating the longitudinal BBB system based on the strip-line kickers. The longitudinal feedback system is normally composed of a radio-frequency accelerating cavity (RF cavity) designed for use as a feedback system. However, this experiment showed the feasibility of conducting longitudinal feedback not with RF cavities but with strip-line kickers. Note that strip-line kickers are among the most widely used beam instruments and are easy to integrate into accelerator systems.

Results The experiment took place as an international joint experiment and immediately after the I.FAST workshop on BBB feedback systems. Due to the arrangement, the workshop participants discussed the experimental plans during the workshop. This strongly motivated international networking in this research field and led to several intriguing results, such as vertical beam size control with BBB systems.

Scientific value and impact in the field
This joint experimental campaign at KARA for 2 days strengthened the international networks of experts on bunch-by-bunch feedback systems and on injectors. These experiments led to the next step, such as longitudinal manipulation of the beams to improve quality of the booster beam.

Highlights of results
Between the I.FAST workshop on bunch-by-bunch feedback systems and the I.FAST workshop on injectors, a joint experimental campaign took place at the Karlsruhe Institute of technology (KIT) in collaboration with partners of I.FAST 7.2 and the EU project EURO-LABS, where the workshop participants conducted hands-on experiments with the Karlsruhe Re- search Accelerator (KARA), a 2.5 GeV electron storage ring of the KIT light source, and its bunch-by-bunch feedback system as well as in the 500 MeV Booster.

Contribution to the evaluation of the TA at KIT
Feedback from I.FAST project: KIT is an established host for international workshops including hands-on experimental campaigns. As mentioned, this experiment was carried out as an international joint project that immediately followed the I.FAST workshop on BBB feedback systems. Due to proper arrangement and combination, the experiment took place in a highly cultivated and motivated environment. Moreover, the experiment yielded intriguing results that warrant further in-depth research with a scope of application to daily accelerator operations and R&D. From this point of view, the experiment had enough and sufficient contribution to the research area of accelerator physics and technology. Additionally, we would like to stress that the combination of the topical

workshop and the experiment aimed at those topics worked quite well, and we hope that this style could be adopted for further experiments carried out within the EURO-Labs project framework.

Publications
The results of the project were presented:

- A. Mochihashi: Networking Activities for he I.FAST Project in the High-Brightness Accelerator for Light Sources; 15th International Particle Accelerator Conference IPAC24, Nashville, TN; ISBN: 978-3-95450-247-9 ; ISSN: 2673-5490 ; doi:10.18429/JACoW-IPAC2024-TUPG34
- T. Nakamura, "Bunch-by-bunch feedback system review", Proceedings of the 13th International Beam Instrumentation Conference (Beijing, China, September 2024) 235-240. doi:10.18429/JACoW-IBIC2024-WECI1
- I.FAST workshop 2024 on Bunch-by-Bunch Feedback Systems and Related Beam Dynamics, in Scientific Program: doi:https://indico.kit.edu/event/3742/program

Planning for further experiment
I.FAST realized in 2025 a second Workshop including a hands-on experimental campaign at KARA, see KIT-KARA-08 below.

2.1.6 KIT-KARA-07-BBA-FCCee

Project description
The Future electron-positron Circular Collider (FCC-ee) is a circular electron-positron collider proposedwith a circumference of about 91 km within the framework of the FCC Design Study. The accelerator is being designed to operate from 45.6 GeV to 182.5 GeV to allow the production of Z-bosons with and without associated Higgs-bosons, as well as the pair production of W-bosons and top-quarks. The accelerator aims for a luminosity of up to 1.44×10^{36} $\mathrm{cm^{-2}\,s^{-1}}$ at 45.6 GeV, which sets strict boundaries on the accelerator optics and thus on alignment tolerances of all lattice elements.

The desired mechanical alignment tolerances for these elements are in the range of 100 µm to 150 µm. However, in order to achieve the ambitious design goals, a few µm (10-20 µm) relative alignment of quadrupoles and sextupoles is required. To achieve this, corrector magnets are foreseen to steer the beam towards the magnetic centre, known as Beam-based Alignment (BBA). The BBA has to be executed for at least 1870 quadrupoles and 630 sextupoles, therefore, the average time required to determine the individual magnetic offset is a key parameter for the selection of the BBA method in addition to the accuracy. The development of a concept for the BBA at FCC-ee is currently based on simulations, but should be supported by proof-of-principle tests on existing machines.

The KArlsruhe Research Accelerator (KARA) test facility is an electron storage ring that enables both parallel BBA and the BBA of individual magnets. Within a magnet family, all magnets are connected in series, so that the strength of all magnets in the family is changed simultaneously during modulation. Furthermore, an additional power supply, connectable to each quadrupole individually, and a separately powered sextupole, also allows the BBA to be studied of individual magnets.

Both techniques were compared to verify the results from classical and parallel BBA with other BBA measurements at KARA using the Matlab Middle Layer BBA, and compared to simulations. The measurement data are used to improve the closed orbit measurements by matching model and BPM data, and finally allow conclusions for FCC on time requirements and accuracy of the BBA approaches.

Results

Quadrupole BBA

Several beam tests were performed at the KIT accelerator test facility KARA with beam currents between 50 mA and 60 mA distributed equally over approximately 135 bunches and a beam energy of 2.5 GeV. All quadrupoles are pre-cycled to reduce magnet hysteresis. For the individual quadrupole BBA, the current was changed by ± 5 A at each quadrupole individually. For the parallel BBA, the current was changed by ± 1 A to ± 1.5 A for all 8 quadrupoles in a family. We note, that the set and read-back values for the quadrupole currents could differ by up to a few tens of mA, which is not considered further here.

The variants of the individual BBA used differ only slightly in the selection of the correctors for the orbit changes and the evaluation methodology used. In the individual BBA, the strength of a quadrupole is varied, and the resulting orbit changes can be clearly attributed to the changed kick at the location of the magnet [9]. The parallel BBA follows a similar idea, but the strength of several magnets is varied simultaneously. The observed closed orbit change is due to altered kicks at all varied quadrupoles. Therefore, an orbit response matrix is used to separate the individual contributions [5]. The further procedure is analogous to the individual BBA.

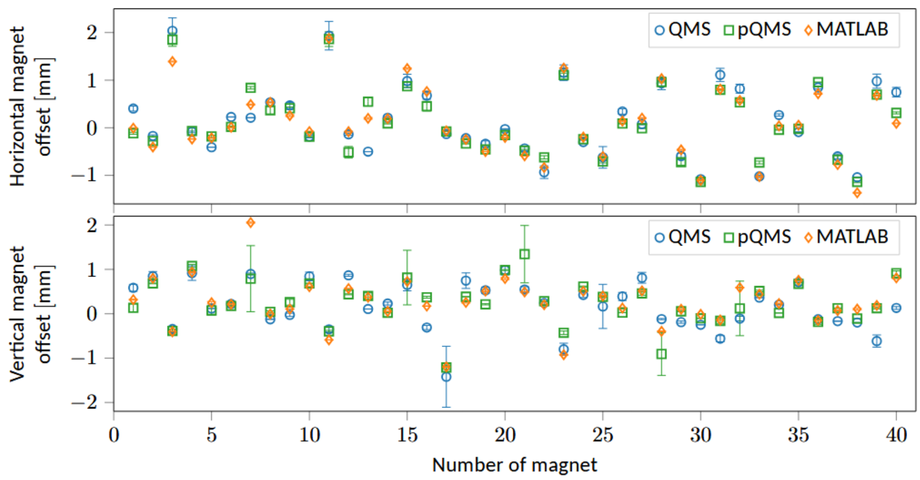

Figure 11: Estimated magnet offsets with respect to closest BPM using linear (blue), rms (orange) and parallel BBA (green).

Both beam tests and complementary optics measurements based on turn-by-turn BPM data have been performed with and without sextupoles. The measured natural chromaticity is -12.94 $\pm$ 0.16 in the horizontal and -7.50 $\pm$ 0.07 in the vertical plane. Using the sextupoles, the chromaticity is trimmed to -0.18 $\pm$ 0.05 in the horizontal and 0.76 $\pm$ 0.11 in the vertical plane. The β-beating is in the range of ± 12 % in the horizontal and ± 20 % for 90 % of BPMs in the vertical plane. A significantly larger β-beating of $\pm 40\,\%$ and $\pm 30\,\%$, respectively, occurs during operation with natural chromaticity. Since the accelerator model is adapted to the optics with activated sextupoles, the deviations are attributed to the reduced feed-down effects from the sextupoles. Changes in the chromaticity and tune are observed during the BBA tests, but it is not fully understood whether these are caused by the BBA, as significant tune drifts are also observed during operation without changing settings. The measurement results obtained are shown in Fig.11 and are comparable with earlier measurements [1].

Sextupoles are switched off for the linear BBA with the aim of reducing non-linear effects in the optics, while the sextupoles are switched on for the rms BBA. The reproducibility of rms BBA, is in the range from $30\,\mu\text{m}$ to $40\,\mu\text{m}$ for the vertical and horizontal planes, respectively, and is calculated based on earlier offset estimates measured after the shut-down in summer 2024. The offsets determined with the two individual and the parallel BBA approaches are shown in Figure 11 and show rms deviations from $240\,\mu\text{m}$ to $350\,\mu\text{m}$ between the different measurement results.

Parallel BBA was performed with sextupoles turned off and on. A total of 5 measurements were carried out with the sextupoles switched off. All measurements agree with a rms error of $(13.2 \pm 1.9)\,\mu\text{m}$ in the horizontal and $(137 \pm 12)\,\mu\text{m}$ in the vertical plane. We note that increasing the amplitude of the corrector strength and the associated position changes reduces the deviations and measurement uncertainties in the vertical plane for the subsequent measurements. To validate the reproducibility, parallel BBA is performed with activated sextupoles in different fills. While the reproducibility with activated sextupoles is within $35\,\mu\text{m}$ to $50\,\mu\text{m}$ in the horizontal and vertical planes respectively, local outliers up to $0.7\,\text{mm}$ in horizontal and $1.3\,\text{mm}$ in vertical are observed, as shown in Figure 12. To find the best settings for parallel BBA parameter scans are

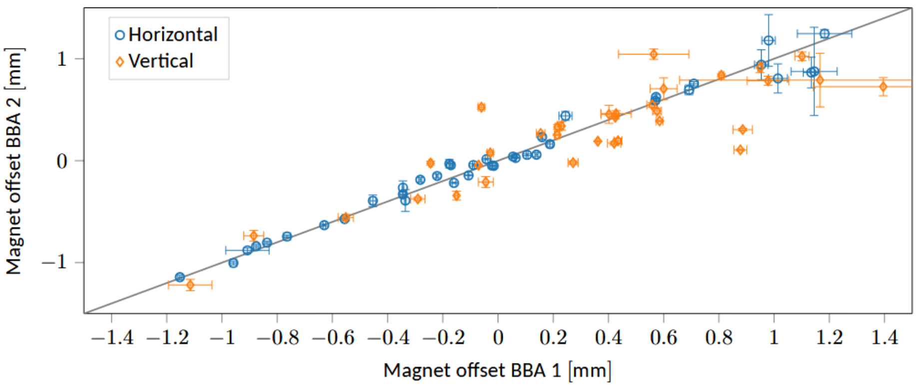

Figure 12: Reproducibility of estimated horizontal (blue) and vertical (orange) offsets with two parallel BBA measurements with activated sextupoles (BBA 2) and deactivated sextupoles (BBA 1).

performed. It is found that the amplitude of the quadrupole current change has little impact on the accuracy of the BBA. However, large effects are observed with variations of the orbit changes using the amplitude and the relative signs of the corrector strength changes. The same selection of orbit correctors, two for the horizontal and two for the vertical plane, was used for all offset measurements with the parallel BBA. For further optimisations, different orbit correctors could be selected, as large offset deviations and uncertainties occur with the same magnets, regardless of the choice of the parameter values mentioned. Comparing parallel BBA results with and without sextupoles, the rms error is 57.3 µm horizontally and 263 µm vertically.

Comparing individual with parallel techniques shows an rms deviation of 174 µm and 334 µm for rms BBA (with sextupoles) or 281 µm and 358 µm for the newly implemented linear BBA (without sextupoles). However, local outliers, showing deviations of up to 1.3 mm occur, the origin of which remains to be investigated. One reason for the different results could stem from using simulated orbit response matrices based on an accelerator model. Future studies could aim to reduce discrepancies between the machine and the model using measurements. The improved model could also improve the parallel BBA technique by providing a response matrix which fits better to the accelerator.

Sextupole BBA

A similar, parallel approach was used for the sextupole BBA. Since the eight sextupoles of each family are powered in series, only parallel BBA techniques are applicable. The uncertainties for position determination with the parallel sextupole BBA are about one order of magnitude greater than those of the parallel quadrupole BBA. The dipole kick from the magnet depends quadratically on the offset between the magnetic centre and the particle beam. Due to the quadratic dependence, the kick strength experienced by a beam with a 1 mm offset is only about 3 % of the dipole strength experienced by a beam with the same offset in the quadrupole. This proportion increases with increasing offset, but for the position deviations possible in the accelerator, the deflection caused by a quadrupole is many times stronger than that caused by a sextupole. The relative changes in sextupole strength during beam-based alignment are about an order of magnitude greater, but this and the shorter magnets are not sufficient to compensate for these differences in kick strengths. This could explain the larger uncertainties and increased number of outliers compared to the quadrupole version. It is noted that sextupole BBA is performed for the first time at KARA, and results are consistent.

KARA features an individually powered sextupole, which is not part of the original magnet optics and is therefore not used during normal operation. It was used for individual sextupole BBA experiments. In the horizontal plane, an approach based on induced orbit shifts was used. In the vertical plane, two different approaches were tested. One approach is based on the induced orbit shifts, and the other uses the change of the betatron coupling strength $|C^-|$. In contrast to position-based measurement, the coupling strength depends linearly and not quadratically on the offset. The coupling strength is determined on the basis of the TbT BPM data using the ratio of the heights of the tune peaks in the spectrum and the difference between the two fractional tunes using the data of every BPM. For the vertical plane, the results agree well. Measurements in the change of coupling strength yield a lower measurement error.

Scientific value and impact in the field

The differing results of the quadrupole BBA approaches led to a more detailed examination and consideration of systematic sources of error caused by beam angle and BPM placement. The large distances between the quadrupole and the next BPM, up to a focus length of the quadrupole, result in high sensitivity to changes in beam angle. Different selections of orbit correctors for beam position variation lead to differing results. The influence of the beam angle on the result is supported by the accompanying simulation results. An experimental verification is not feasible due to a lack of suitable diagnostics.

Although the BBA approach considered for FCC cannot be tested on KARA, the experiments, particularly those relating to accuracy and reproducibility in comparison with other machines, allow estimates to be made for FCC-ee. Measurements have contributed to a better understanding of systematic sources of error, which are minimized by a favorably chosen design in FCC-ee to reach the target BBA accuracy of 10 µm to 20 µm.

Two different approaches, one orbit-based and one coupling-based, for individual sextupole BBA were compared using an individual powered sextupole. This initial experiment showed consistent results for the vertical magnetic offset. Based on this, the coupling-based approach for FCC-ee will be pursued further.

Highlights of results
Parallel BBA with different parameters was tested at KARA for the first time and the results were compared using two slightly different individual methods, which differed in the choice of corrector for orbit variation and evaluation methodology. Individual and parallel approaches show similar reproducibility, but the results are not compatible with each other. Simulations on Quadrupole BBA suggest that beam angles in combination with large distances between the BPM and the quadrupole are the cause.

Sextupol BBA was also tested for the first time, both individually and in parallel. The offset between an individually powered Sextupol and BPM was determined based on coupling and orbit shift. Both methods yielded compatible results.

Contribution to the evaluation of the TA at KIT
The planning of the beam time went smoothly, as did the application process. KIT worked very well in the preparation phase by replacing two power supplies for the measurements: for the BBA, the unipolar power supply was replaced by a dipolar power supply; on the individual sextupole, the power supply was replaced by a more powerful one to allow for greater variation in sextupole strength. During beam time, the operators provided excellent support with injection, beam adjustment, and measurement systems for the measurements and experiment preparation, as well as with problems with a fuse in the quadrupole power supply. The measurements worked well; only for the turn-by-turn measurements would a fully synchronized measurement have been helpful.

Publications
The results were presented at IPAC 2025 in Taipei and published via the Light peer review process. The publication was therefore published once in the Proceedings and once in the Conference Series by IOP.

Planning for further experiment
Further measurements in the form of verification of the causes for the deviations between the quadrupole BBA measurements and testing of further approaches for the sextupole BBA are not possible with the now available diagnostics.

2.1.7 KIT-2025-KARA-08–Experiment-I.FAST

Project description
KARA-Experiments of the I.FAST community and beyond:

For future synchrotrons storing ultra-low emittance beams, the stability of the accelerator is of paramount importance in order to exploit the properties of the high-quality beams. To achieve these high beam qualities, high demands are placed on the accelerator components and their positioning, their manufacturing tolerances and stability. The Innovation Fostering in Accelerator Science and Technology (I.FAST) workshop on 'Stability of storage ring-based light sources,' which preceded the measurement period, already dealt with various aspects from beam position stability to the magnets and associated power supplies to the infrastructure around the accelerator. The measurement time offers an excellent opportunity to study parts of the topics discussed directly on a storage ring.

The KArlsruhe Research Accelerator (KARA) test facility is an electron storage ring that enables diverse testing options. A recently implemented parallel Beam-Based Alignment (BBA) allows the offsets between the magnetic centre of the next quadrupole and the centre of the next BPM to be determined quickly. The parallel BBA uses two corrector magnets to vary the closed orbit at all quadrupoles of a family and changes the magnetic strength of all quadrupoles of a family. Compared to the BBA of individual magnets, the relative changes in the gradient field strength must be lower for beam stability when modulating the magnetic strength of the entire quadrupole family. These small changes in the magnetic field strength cause much weaker hysteresis effects. Due to this, a pre-cycle before the BBA can be avoided. The simultaneous offset determination for several magnets and the non-essential pre-cycle can significantly speed up the BBA process and reduce the time required from around two hours to less than ten minutes. This fast approach offers new measurement opportunities like BBA measurements with lower energies, where the beam lifetime is much shorter, or to study thermal effects.

In addition to the BBA, there are numerous other possibilities for measurements. In addition to measuring the position of the particle beam using BPM, synchrotron light monitors, and beamlines, this also includes diagnostics for optics measurements and beam dynamics analyses. At this point, recurring measurements of tune, chromaticity, beta function, and electron energy would also be suitable. Overall, numerous measurement methods and options are available and can be used according to the interests of the workshop participants. The BBA and some optics measurements are firmly planned.

Results

The BBA was carried out at 2.5 GeV, but also at slightly lower energies of 2.2 GeV or 2.3 GeV. The optics were approximately the same for these energies, so no relevant differences in the orbit response matrices used for the offset reconstruction were expected. These two lower energies are interesting for more energy-saving accelerator operation. Due to the lower electron energy and the resulting lower synchrotron radiation power, one of the two klystrons is sufficient for operation, which can significantly reduce power consumption of the accelerator. In addition to the particle energy, the bunch charge or beam current is relevant for many processes in beam dynamics. The beam current is also relevant for wake fields and heating due to resistive losses caused by the real parts of the impedance. For this reason, these features were also varied for the experiments.

Scientific value and impact in the field:

The hands-on experiments on BBA at KARA integrated in the I.FAST workshop engage the participants of the workshop to be onside, strengthened the I.FAST networking activities and beyond far above the BBA community.

Highlights of results
The hands-on experiments on BBA at KARA integrated in the I.FAST workshop engage the participants of the workshop to be onside, strengthened the I.FAST networking activities and beyond far above the BBA community. Different strategies of Beam Based Alignment (BBA) was carried out at KARA, the storage ring of the KIT light source and accelerator test facility at 2.5 GeV (user operation), but also at slightly lower energies of 2.2 GeV and 2.3 GeV with no relevant differences in the orbit response matrices used for the offset reconstruction. Due to the lower energy, one of the two klystrons is sufficient for operation, which significantly reduced power consumption of the accelerator.

Contribution to the evaluation of the TA at KIT
KIT is an established host for international workshops including hands-on experimental campaigns.

Planning for further experiment:
I.FAST has been completed, therefore, no further experiments are planned.

2.1.8 KIT-KARA-09–PEY-for-LHC

Project description
CERN is operating the BESTEX experiment at one beam line of KARA at KIT. In the past, it had been utilized to measure photon reflection [7] and photon-induced desorption [8] of prototype beam screens (BS) and vacuum chambers in the development of technical solutions for the future circular collider (FCC) with its configurations for electron-positron collision and hadron-hadron collision. Furthermore, materials, geometrical structures, and coatings can be qualified under synchrotron light irradiation to extract relevant vacuum parameters for the operation of such geometries in particle accelerators.

The infrastructure and design of hadron particle accelerators and colliders must handle certain detrimental effects that originate from or are influenced by photon-induced effects. Another example is the emission of electrons generated by impacting synchrotron radiation, which can in the worst case, when resonating with the proton beam, contribute to the build-up of electron clouds that then lead to heat loads to the cryogenic system. The intensity of the high-luminosity LHC beam necessitates the application of functional amorphous carbon (a-C) coatings inside the beam screens of the LHC magnets. A campaign is foreseen for a-C coating of the magnets in the straight sections with 150 nm of Ti and 100 nm of carbon during LHCs long shutdown 3 (LS3), while CERN is currently developing a process to coat 7 km of beam screens of the LHC arcs in LS3 with a very thin (10-20 nm) coating of a-C for electron cloud mitigation. While the characterization of secondary electron yield of such functionalized surfaces is established on a lab-scale, the evaluation of the Photoelectron Yield (PEY) requires a synchrotron source. This project aims at comparing the PEY of these two types of function coatings for electron cloud mitigation with the standard Cu surfaces that are currently installed in the LHC. The material parameters obtained will allow us to strengthen the modeling of electron cloud effects in the LHC and quantitatively validate that the functional a-C films are capable of limiting the electron density in the high-luminosity LHC era from 2030.

The Beam Screen Treatment (BST) project at CERN aims at reducing the heat load on the cryogenic system by modifying the inner surface of the BS with a thin (10-20 nm) layer of amorphous carbon, which shall lower the secondary electron yield (SEY) of the surface and hence mitigate the electron cloud. The treatment must also be effective with respect to the PEY, which shall be tested at KARA. The critical energy of LHC is much lower than for KARA (44 eV instead of 6.3 keV) and a suitable selection of the low energy tail of the KARA synchrotron radiation was obtained by setting the entrance slits on the experiment. SynRad simulations have validated that this approach is feasible, and the beam positions and the photon spectrum can be selected precisely. Four electrically separated samples (dimensions 200 × 20 mm2, three with different a-C coatings, one uncoated degreased Cu) were installed in December 2025 in the BESTEX vacuum chamber on a beam screen of LHC dimensions.

Results

The commissioning of the new experiment was performed at KARA by 2.5 GeV electron energy starting with very low beam current on the 2nd and 23rd of January 2026 in a dedicated experimental procedure validating the slit and sample alignment/positions to measure the emitted electrons (see Fig. 13). One technical problem on the biasing of one of the four samples required another vacuum intervention: the reference Cu sample could not be evaluated. This problem was fixed to restart measurements with another low-intensity test run on 12.02.2026 and then followed 2.5 GeV user operation beam current by continuous data acquisition to apply the required synchrotron light doses.

As a preliminary result, Fig. 14 shows the correlation between initial desorption (PSD) upon exposure and the measured photocurrent for three different PEY samples for possible LHC beam screens tested in BESTEX at KARA at KIT. A clear difference can be identified and a direct start of conditioning was observed.

Scientific value and impact in the field

The ongoing experiments will deliver a comparative assessment of the PEY of copper surfaces during interaction with synchrotron radiation at photon energies generated in proton accelerators, i.e. the LHC, to qualify the amorphous carbon coating for electron cloud mitigation (mainly optimized for secondary electron yield) has no detrimental effect on the PEY. Furthermore, material parameters are obtained

Highlights of results

The Photoelectron Yield of LHC type beam screen inner surfaces (pure Cu surfaces with or without surface functionalization with amorphous carbon layers) is characterized at grazing incidence at the critical synchrotron light energy of the LHC (40 eV) to compare the electron emission of the different conditions, measure the related material parameters required to improve electron cloud simulations and to qualify recently developed thin film coatings that are meant to mitigate electron cloud limitations in the Hi-LUMI LHC operation era.

Contribution to the evaluation of the TA at KIT

The KIT team at KARA is very helpful in the preparation of the experiments by support-

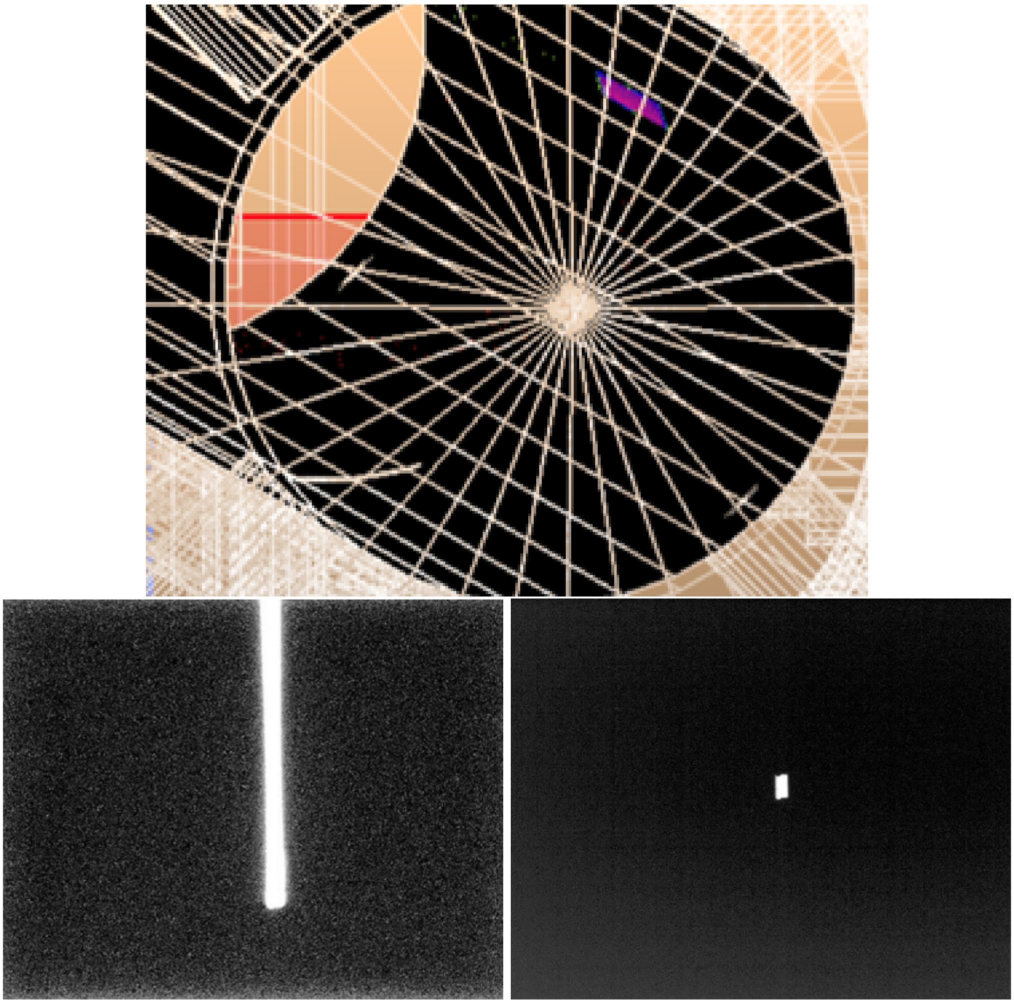

Figure 13: Result of the SynRad simulation for selection of a truncated photon beam with 50 eV maximum photon energy and defined sample position (top). Fluorescent screen images of full (bottom-left) and truncated (bottom-right) synchrotron beam for the selection of the right spectral range for (Photoelectron Yield) PEY experiments according to the SynRad simulations.

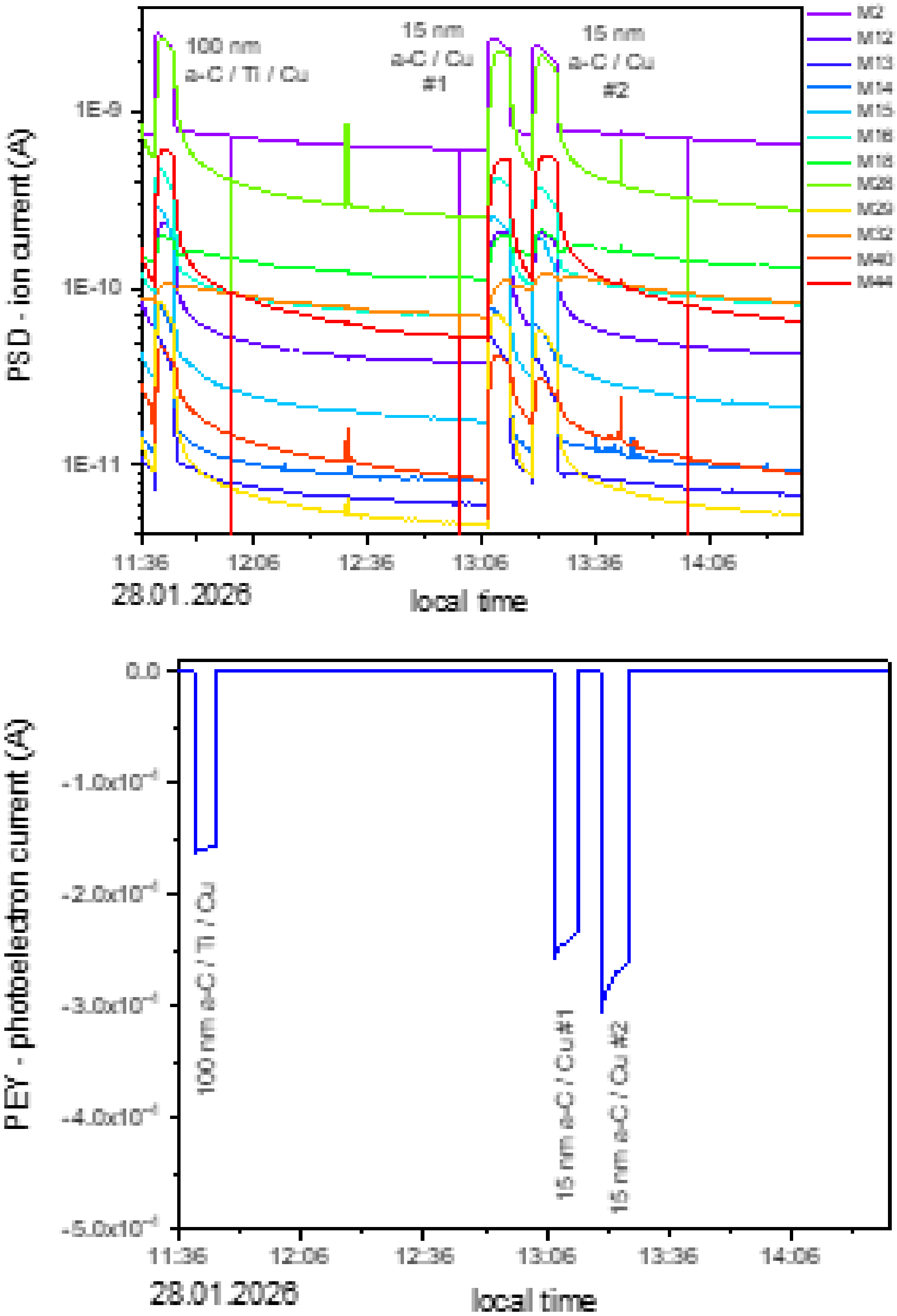

Figure 14: Photon-induced desorption (top) and photoelectron current (bottom) during irradiation of 3 (out of 4) samples installed in the BESTEX system in KARA at KIT. An immediate conditioning is observed.

ing our installations with manpower and technical support during the installation of the new vacuum chamber by the vacuum team. They were very supportive and flexible, also allowing remotely discussed interventions to fix small problems while the remote operators were at CERN. The facility itself allows for the BESTEX experiment a very good match of experimental synchrotron light conditions to characterize PEY at different photon energies as well as to perform photon-induced desorption studies. Very helpful were available time slots during machine physics runs to allow dedicated runs for calibration of the BESTEX experiment after modification to a PEY measurement. The planning and coordination of activities, experiments, and interventions is very smooth.

Publications
The PEY measurements have just begun, and we hope to submit the results to a journal after summer 2026.

Planning for further experiment
The chamber with the 4 test PSD samples was installed in December 2025, commissioned in January 2026, and the actual data acquisition has started from 16.02.2026. We will profit from ”User Operation” at KARA (2.5 GeV electron energy) to evaluate the conditioning of the samples upon light exposure to characterize the changes in PEY during operation. This experiment will continue at least until the end of April and potentially beyond, depending on the conditioning behavior (up to KARA summer break) to thoroughly characterize the transformation of the surface and the related change in electron emission. A further PSD campaign is envisaged for the FCC-ee-type vacuum chamber. Unfortunately, this system cannot be installed before the KARA summer break due to delays in the development of the assembly technology for laser welding of the Cu geometry. Therefore, these further experiments cannot be realized before the end of the EURO-LABS project.

2.2 INFN-LNF BTF & SPARC-LAB Facilities

As mentioned above, INFN-LNF participates in EURO-LABS with two facilities: BTF and SPARC-LAB.

The BTF facility has been running smoothly, serving a wide user community in terms of research fields and geographical distribution (national and international). This report presents the TA activities within the EURO-LABS program at the LNF□INFN Beam Test Facility (BTF) between 2023 and 2025, where six experimental campaigns were realized, each aimed at validating new detector technologies (Micromegas, Timepix3, multichannel control systems, etc.) and delivering concrete performance data for future high□energy physics experiments.

Contrary to BTF, the operation of SPARC-LAB was limited due to an ongoing consolidation and upgrade program aimed at preparing a new facility for FEL radiation production in the THz range, as well as the conversion of the experimental hall into a leading facility for plasma accelerator R&D within the EuPRAXIA project, which is currently being pursued with the highest priority. The combination of these two major activities left essentially no availability to accommodate Transnational Access (TA) slots. As a result, the laboratory’s contribution to EURO-LABS was redirected toward supporting users at the Beam Test Facility (BTF).

Table 3 summarizes the TA projects and AUs delivered in the BTF facilities at the time of writing of this report. In total, 1512 AU were delivered at BTF more than the 1176 AU planned, covering part of the AU of SPARC-LAB. The sections that follow detail the scientific value, the measured outcomes, and the associated publications and collaborations that stemmed from the EURO-LABS support.

Table 3: LNF-BTF: summary of completed TA projects. The users listed refer to the direct participants who received financial support.

Project ID	Title	AU	PI origin	No of Users[1]
BTF-01-MM-TPC	Micro-Megas TPC	168	IT	9
BTF-02-MICROGASTRACK	Study of novel segmented micropattern gas detectors for tracking and beam measurements	336	BU	2
BTF-03-CALOBEAMPIX	Cross calibration of pixelized and calorimetric measurements of beam multiplicity and geometry	168	BU	7
BTF-04-CoMOMDeMPE	Detector Control System for Managing Physics Experiment	336	BU	8
BTF-05-PIXSTREAM	Test, performance, calibration and synchronization of silicon pixel detectors regarding of beam multiplicity, geometry and energy	336	BU	7
BTF-06-Pcube_DIAG_TEST	PSI-Pcube diagnosties chamber prototype (view-screen & scintillator-fiber) to be experimentally characterized as a function of the charge/energy of the BTF e^-/e^+ beam	168	BU	8

2.2.1 BTF-01-MicroMegas TPC

Project description
The MM TCP project was aiming at testing a MM chamber with an enlarged drift region up to 5 cm in order to profit from its TPC tracking performances.

Scientific value and impact on the field
The test was crucial to define the working point and to test a different gas mixture made of 88% Ar + 10% CO_2+ 2% C_4H_{10} (isobutane) and its performances. The test results were also used to improve the design of the PADME Micromegas tracker.

Results
The experiment was well-planned, executed smoothly, and achieved its goals, including testing a Micromegas type that had not been tested before. The combination of on-site and remote support, along with continuous monitoring of the system parameters, contributed to the overall success of the operation.

Highlights of results and publications
First results in the TPC mode have been analyzed and presented at the EURO-LABS 3rd Annual Meeting.

- M. Antonelli and others, Design and development of a double-gap MicroMegas detector with novel readout plane, EURO-LABS 3rd Annual Meeting, CERN, 2024,https://indico.cern.ch/event/1370378/contributions/

2.2.2 BTF-02-MICROGASTRACK

Project description
The MICROGASTRACK project was aiming at testing a Migromegas gas chamber with novel signal readout plane at variable high voltage

- successful operation of a large area double gap Micromegas
- data acquired in external trigger mode

Scientific value and impact on the field
Combining precise sub-millimeter tracking with beam monitoring capabilities in a single Micropattern gas detectors device is a state-of-the-art problem, which could be applicable to experiments where the residual primary beam inducing the interactions of physics interest is transported through the experimental setup.

Results
The experimental test was successful. Working parameters have been identified and detector usability and design have been verified.

Highlights of results and publications
A paper is in preparation:

- M. Antonelli and others, Design and development of a double-gap MicroMegas detector with novel readout plane, article in preparation, 2024,

2.2.3 BTF-03-CALOBEAMPIX

Project description
The CALOBEAMPIX project aims at setting a Timepix3 detector array to nominal operation and cross-calibrate it with a lead-glass calorimeter by means of electron/positron beams.

- Spatial scan of the Timepix-Leadglass combined system
- Threshold scan and calibration of Timepix
- HV scan and calibration of LeadGlass calorimeter

Scientific value and impact on the field:
Silicon pixel detectors are of utmost importance in the contemporary precision physics but their operation usually requires non-trivial expertise both in analog and digital electronics technology as well as data acquisition architectures.

In addition, the calibration and synchronization with other devices might be tricky due to the built-in data flow architecture in the ASIC.

Results
The cross-calibration of the Timepix-LeadGlass beam monitoring revealed the necessity to introduce a correction factor due to the energy absorption in the Timepix cooling frame. This factor was a result of the finite beam dimension coupled to the beam position in the Timepix.

The Timepix threshold was calibrated and was chosen to ensure a linear dependence between the beam intensity and the number of hits registered in the Timepix.

Highlights of results and publications
Talk was presented, and conference proceedings were prepared, sent for publication:

- K. Kostova and others, Calibration of the PADME beam monitoring calorimeter, PoS, COST Action COSMIC WISPers (CA21106), 2025

2.2.4 BTF-04-CoMOMDeMPE

Project descriptions
The CoMOMDeMPE project aims at developing and testing a computer system for the configuration management and control of physics experiments, as well as their various hardware management and data collection modules.

The system is able to store and apply configuration data to a number of hardware devices (e.g. most intelligent HV, NIM and VME crates, a large array of switches and other power control devices, several standard and custom power supplies, acquisition and trigger boards, etc.), maintain a structured description of multiple detector configurations, including complex interdependencies.

Scientific value and impact on the field
The project will enable the test and the validation of a common system able to provide comprehensive control and monitoring of various detector units. The planned system is

highly configurable and could be employed at various stages of test physics experiments within or beyond the scope of particle and accelerator physics.

Results
The platform was applied for the running physics experiment, implementing crucial detector monitoring parameters, like HV, temperature, etc.

- The developed platform was installed and bootstrapped at BTF-LNF and was tested with equipment, exposed to e-/e+ beam
- A configuration with hardware components and users with different permissions was tested and validated.

Highlights of results and publications
A paper is in preparation, at very advanced stage:

- S. Ivanov and others, Development and testing of a universal control and monitoring framework for multichannel detector systems, in preparation, to be submitted to JINST,2025

2.2.5 BTF-05-PIXSTREAM

Project description
The project aims at operating silicon pixel detectors possibly in continuous data stream mode, collecting events with $\mathcal{O}(ns)$ time resolution and at exploiting the acquired data for calibration of the bias and threshold of the individual pixels, for synchronization by an external trigger. Furthermore, the project aims at testing the operation of the new developed DAQ system for beam monitoring pixel detectors in data stream mode in a relevant environment, and the synchronization of the data flow with a global clock.

Scientific value and impact on the field
Silicon pixel detectors are of utmost importance in the contemporary precision physics. However, their operation usually requires non-trivial expertise both in analogue and digital electronics technology as well as data acquisition architectures, making the leap from bare bone hardware to a useful detector system rather lengthy. In addition, the calibration and synchronization with other devices might be tricky due to the built-in data flow architecture in the ASIC. The project is intended to address and improve the mentioned issues.

Results
The experimental test carried out at LNF BTF was successful and several important outcomes of general importance were achieved. The developed custom DAQ architecture to be applied both to Timepix and MIMOSA sensors reached these goals:

- Stable streaming mode data collection from Timepix, with ToA resolution of 1.56 ns
- Extraction of the beam parameters only with the Timepix acquired data
- MIMOSA testing postponed due to non-availability of the sensor
- Beam profile measured both in time and spatial domain, data collected for the study of spatial parameters estimation

- Identified flows in the Timepix operation, ML methods applied to cope with the missing data,
- no MIMOSA data analysed, a dedicated project expected

Highlights of results and publications
Apart from the presentations by EURO-LABS team members (amounting to more than 10) and the papers in preparations,

Two PhD theses submitted at Faculty of Physics, Sofia University relied directly on the developments and the output of the analysis of the data, taken within the EURO-LABS project:

- Svetoslav Ivanov, Investigation of the beam parameters for the search for new light particles, Faculty of Physics, Sofia University, 2026
- Simeon Ivanov, Development and evaluation of multichannel detector systems, Faculty of Physics, Sofia University, 2026

A member in two of the project teams (CALOBEAMPIX and PIXSTREAM) also participated in the Fourth Annual Meeting (FAME) of the EURO-LABS with a poster and was awarded as best poster with a subsequent oral presentation:

- K. Kostova, Detector studies and services development with BTF at INFN-LNF, EURO-LABS 4th Annual Meeting, Jožef Stefan Institute, Ljubljana, Slovenia, 2025, https://indico.cern.ch/event/1572254/overview

Evaluation of the TA at BTF
Feedback from Sofia University team: The EURO□LABS project gave to the Faculty of Physics at Sofia University access to the BTF at LNF□INFN, enabling participation in joint research initiatives (silicon pixel detectors, Cherenkov calorimeters, novel gaseous detectors, multichannel control systems). The possibility for direct testing of equipment with a real high energy particle beam helped the Faculty member to strengthen the group and attract new young researchers, eager to participate and perform the tests themselves.

2.2.6 BTF-06-Pcube

Project description
The general goal of the Pcube collaboration at SwissFEL (PSI) is to test a proof-of-principle demonstrator of high yield e+ source for FCC-ee injector. The Goal of the Pcube_DIAG_TEST project at BTF is to experimentally test a prototype of the Pcube diagnostics (scintillator screen+ scintillator fiber) with positron and electron beams of different charge and energy. In particular the calibration test of a view-screen set-up (scintillator screen+imaging camera) to characterize the transverse profile of e+/e- beams, and the calibration test of a scintillator fiber+PMT+ADC with the aim of characterizing the scintillator fiber response vs charge and energy of the e+/e- beams.

Scientific value and impact on the field
The positron source is a critical bottleneck and a fundamental prerequisite for the FCC-ee, as it must provide an unprecedented flux of particles to achieve the high-luminosity targets required for precision Higgs physics.

Results:
The Pcube diagnostics prototype was tested at the BTF with e+/e- beams of 300, 90 and 50 MeV and a variable charge with a maximum multiplicity per bunch ranging from 13000 to 7000 particles and a beam size (rms) of several mm. The results of the test of the Pcube scintillator screen were not conclusive and not quantitatively indicative of the expected design performance of the Pcube imaging set-up probably because of the low charge density per surface unit hitting the view-screen. The response of the scintillator fiber set-up showed instead high sensitivity to the e+/e- beams. Thanks to the BTF motorized table where the scintillator fiber was installed with a vertical orientation w.r.t. the charged beams, it was possible to sample and reconstruct the horizontal Gaussian distribution of the e+/e- beam as a function of the motor position. Preliminary analysis results of the scintillator fiber readout as a function of the different beam energy and charge confirmed the expected linearity of the scintillator response. A deeper analysis of the experimental data acquired during the BTF measurement session is ongoing for a more precise estimate of the calibration factors of the scintillator fiber.

Highlights of results and publications Presently, preliminary analysis results of the Pcube_DIAG_TEST experimental data have been presented only internally at PSI. In case of future publications and official communication of the experimental results obtained by the Pcube team at the BTF, the BTF colleagues will be included in the author list and the EURO-LABS support will be properly acknowledged.

2.3 CEA - LPA-UHI100 Facility

Since the beginning of the project, LPA-UHI100 has not been able to deliver the initially planned 640 AU. This situation is primarily due to significant delays encountered by CEA and the facility in obtaining authorization to operate from the Autorité de sûreté nucléaire (ASN).

A first temporary authorization was granted from early 2024 until August 2024, allowing operation of the laser-driven electron source in a degraded mode (maximum energy of 50 MeV, repetition rate of 1 shot per minute, and 15 pC per electron bunch). A second temporary authorization was issued in January 2025, extending the operating parameters to a maximum energy of 200 MeV, 300 pC per bunch, and a maximum repetition rate of 0.03 Hz.

In parallel, the facility faced a major technical issue affecting the laser water-cooling system. As a consequence, the laser — and therefore the laser-driven electron source — could not operate. A definitive technical solution was implemented following a three-month shutdown in 2025.

The facility has now been running reliably for several months and is ready to provide access to users. One proposal has already been submitted and accepted by the User Selection Panel (USP), with beam time scheduled for June 2026.

Planning for further experiments
LPA -UHI100 had to face a strong delay before being able to operate the laser-driven electron source due to administrative processes. Finally, the facility is running and will deliver 200 AU over the 640 originally planned. The beamtime is scheduled in june

2026. Proposal: LWFA shot-to-shot electron beam characterization with electro-optical sampling crystal for multi-staging. PI. F. Filippi, ENEA, Italy.

2.4 UKRI - CLARA Facility

Whilst accepted that CLARA would not be immediately available for TA users at the start of the EURO-LABS programme, it was envisaged that the facility would be available approximately one year into the programme. However, a number of significant technical delays and reconfigurations of the facility, coupled with changing priorities within the UK science sector has substantially lengthened the commissioning period. By the end of 2025 it had not been possible to host any external users, including TA, on the upgraded facility.

Planning for further experiments
Despite this, the forward outlook is positive. Whilst a full call for external users is unlikely in 2026, a period has been set aside in Q1 for user commissioning of the FEBE hutch by 'friendly' users (i.e. those willing to except that the facility is not yet fully commissioned and beamtime may be sub-optimal, or cancelled at short notice). A number of international users are in the process of preparing EURO-LABS applications to make use of the CLARA facility.

3 Summary

Task 3.3 successfully implemented transnational access to distributed beam facilities within the EURO-LABS framework. The task enabled external research teams to perform beam tests, irradiation campaigns, and laboratory, and beam-based performance characterisation required for advanced detector R&D.

Access provision followed the planned procedures for proposal evaluation, user selection, and infrastructure scheduling. The participating facilities delivered high-quality experimental conditions and technical assistance, ensuring safe and efficient execution of the supported campaigns. The interest and demand for access remained strong, confirming the critical role of these European infrastructures in R&D on present and future accelerators and detector qualification and development.

The experimental work supported under Task 3.3 addressed key technological challenges including precision beam characterization and monitoring, timing, spatial resolution, sensor optimisation, and system integration. The results contributed directly to ongoing detector upgrade programmes and future large-scale research infrastructures.

The task achieved to a large fraction its operational and scientific objectives, despite the technical issues encountered in some key facilities.

4 Conclusions

Task 3.3 has successfully delivered structured transnational access to advanced electron beam for accelerator and detector R&D research infrastructures, fully achieving the objectives defined in the project work plan. The facilities operated reliably and safely, supporting a diverse portfolio of acceelerator systems and detector R&D activities and enabling external user participation at a high technical level.

The programme strengthened European collaboration in instrumentation research, facilitated access to specialised beam and testing environments, and supported the development and qualification of next-generation detector technologies. The scientific and technological outputs confirm the importance of maintaining shared access mechanisms for distributed infrastructures.

The sustained user demand and the high quality of the outcomes demonstrate that transnational access to electron beam testing facilities remains essential for Europe's competitiveness in particle physics (accelerator and detector) instrumentation and related high-technology domains. Continued coordinated support beyond the current project framework is therefore strongly justified.

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List of Abbreviations

DoA	Description of Action
TA	Transnational Access
AU	Access Units
FLUTE	Far-infrared Linac and Test Experiment
KARA	Karlsruhe Research Accelerator of the KIT synchrotron radiation source
KIT-IBPT	KIT-Institute for Beam Physics and Technology
ALFA	AcceLerator test FAcilities in the KIT Acc. Technology Platform ATP
CLARA	Compact Linear Accelerator for Research and Applications
BTF	Beam Test Facility at INFN-LNF
TSR	Tilted-Slit Resonator
ISRR	Inverse Split-Ring Resonator
PSD	Photo-Stimulated Desorption
RDP	Resonant depolarization
BBA	Beam-based Alignment