SABINA
Source of Advanced Beam Imaging for Novel Applications
2025 Activity Report

L. Sabbatini, I. Balossino
on behalf of the SABINA team

1 Introduction

SABINA (Source of Advanced Beam Imaging for Novel Applications) is the new THz and mid-infrared (MIR) Free-Electron Laser under installation at the SPARC_LAB facility of INFN-LNF.It is designed to generate high-intensity, short-pulse radiation with tunable polarization in the THz-MIR spectral range, addressing the so-called THz gap. The accelerator will provide 30–100 MeV electron beams to drive a Self-Amplified Spontaneous Emission (SASE) process through three APPLE-X undulators, producing quasi-monochromatic radiation between 3 and 30 THz with milliJoule-level pulse energies and picosecond durations. The radiation will be delivered to a dedicated user station for applications in materials science and biology, fostering scientific, technological and industrial researc. A comprehensive machine-consolidation program has been implemented to enhance stability and reliability, enabling future external user access. By combining intense broadband THz pulses with a 250 TW laser, SABINA will open new experimental regimes in nonlinear THz optics, ultrafast dynamics, and high-field magneto-spectroscopy, strengthening SPARC_LAB 's role as a national hub for ultrafast science.

Originally funded by the Lazio Region (POR-FESR) and then supported by the PNRR Rome Technopole initiative, the project entered a key implementation phase in 2025, marking the transition from design to implementation. During this period, the electron beam line has been fully installed and is undergoing final validation. The commissioning phase with first beam is scheduled for early 2026. These activities will validate beam transport, assess undulator performance, and enable the initial THz measurements while the radiation transport line is expected to be completed and installed within 2026.

2 Description

The SABINA beamline originates from the photoinjector of SPARC_LAB downstream of the dogleg section and includes all components required by beam-dynamics design, such as magnets, diagnostics, vacuum components, and mechanical supports to ensure proper beam performance. The photon source is a chain of three APPLE-X undulators (1.3 m length, 55 mm period) designed and built by KYMA S.p.A. with a compact lightweight structure (fig.2). Each module underwent detailed magnetic characterization before installation, followed by additional stability tests at LNF in collaboration with ENEA using distributed Fiber Bragg Grating sensors to measure structural strain.

After passing through the undulators, electrons and radiation are separated by a mirror: the electrons are directed to the dump, while the radiation is transported outside the bunker over a 15 m optical beamline. The dedicated user hutch, located in LNF building n.7, hosts a 5 T cryostat and a synchronized femtosecond laser system, enabling advanced experiments such as THz/MIR pump–VIS/UV probe and THz-pump/THz-probe studies. Between the production bunker and the user area, an underground room houses an intermediate diagnostic station.

(a) SPARC_LAB and FLAME bunker (b) THz beamline

Figure 1: *Panoramic views of the SPARC_LAB infrastructures*

3 2025 Activities

During the year, all beamline components were installed, completing the preparation of the machine for full electron transport from the gun to the beam dump. These activities involved multiple Accelerator Division services (Vacuum, Electrical Engineering, Mechanical Engineering, Electronics and Diagnostics, Control Systems, and Laser) as well as Technical Division services (Fluid and Electrical Systems). In parallel, significant progress was made on the THz beamline. The vacuum chambers hosting the focusing and steering mirrors were designed together with their mechanical supports. The first two chambers were delivered to LNF, and the first (M1) was installed (fig.**??**). The remaining four are under design review. All activities were coordinated with ongoing SPARC_LAB operations, including EuAPS installations, solenoid commissioning, gun recommissioning after cathode replacement, and regular experimental programs. Coordination was ensured through weekly technical and scientific meetings and continuous updates of the GANTT schedule.

3.1 Mechanical Engineering and Vacuum Services Activities

Following the completion of the dogleg design and preparatory floor work in 2024, 2025 focused on the installation and optimization of mechanical supports and components, including diagnostics, vacuum chambers, magnets, and shielding. Custom 3D-printed supports were developed for the undulator vacuum pipes to ensure precise positioning. High-precision alignment of beamline elements was performed using a laser tracker, both before and after installation of vacuum pipes and ancillary systems. Additional mechanical interventions included the design and installation of a certified retractable ladder between the SABINA and adjacent undulator lines, along with continuous updates of the CAD layout.

Vacuum activities concentrated on installing pipes and valves for the undulator and the full beamline, including the Y-shaped chamber connecting the dogleg to the beam dump. Leak tests validated the system. For the THz line, M1 was installed after testing and cleaning; M2 was delivered and tested, but not installed yet, while the remaining chambers are under procurement and design refinement in collaboration with Sapienza Università di Roma.

3.2 Electronics and Diagnostics, Electrical Engineering, Control Systems, and Laser

Diagnostics activities included installation and integration of cavity BPMs, cabling, and implementation of the flags for beam profile and imaging.

Magnetic elements were prepared, cabled, tested, and integrated with cooling and interlock systems, with full validation of operability. Support was also provided for undulator characterization, installation, and control integration.

Control system development progressed in parallel with the implementation of the new EPICS-on-Kubernetes (EPIK8S) framework, enabling integration of all beamline elements into the updated architecture.

A dedicated laser system was installed at the Y-shaped chamber to support precise alignment of the THz mirror line, validated in collaboration with the alignment team.

3.3 Fluid and Electrical Systems

Fluid services implemented the temperature-controlled water cooling for seven magnetic elements and restored the compressed air system for vacuum valves. Moreover, an environmental control system has been designed and will be implemented for both the user facility and the diagnostic hutch in order to guarantee stable temperature and humidity conditions, thus preserving beam quality.

Electrical activities focused on grounding, interlock verification, and system-wide validation in coordination with magnet and fluid services to ensure safe and stable operation.

3.4 THz Beamline and User Area

The THz transport line was designed to preserve beam quality and optimize focusing. M1 has been installed, while M2 is available but not yet mounted due to potential temporary configurations. M3 is in production, and the remaining chambers (4, 5 and diagnostic) are undergoing designs verifications. The user area design is ongoing, with instrumentation tests planned for the first half of 2026 and further procurement to follow.

3.5 Beam Dynamics and Commissioning Preparation

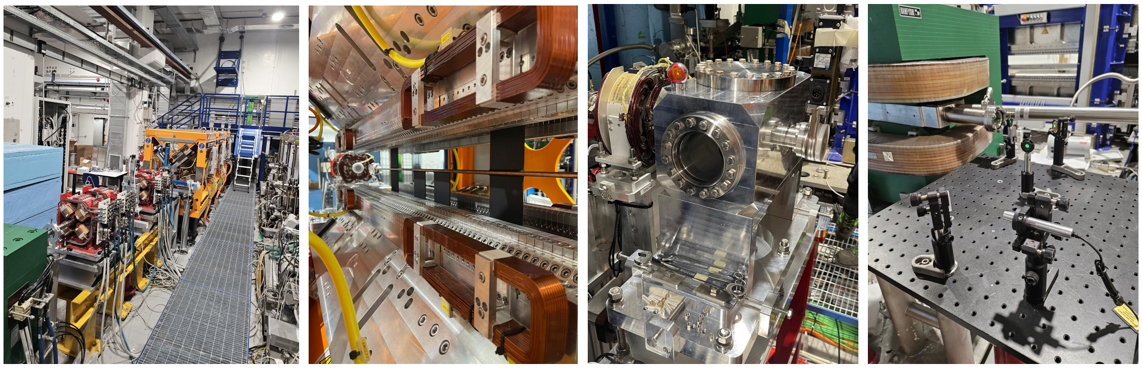
Commissioning preparation included defining operational procedures and reference beam parameters (75 pC, on-crest acceleration, 100 MeV). Beam transport configurations were defined, nominal matching optics established, and diagnostics preliminarily tested.

Beam-based alignment to verify magnetic elements, and transport through the undulator was commissioned with open gap conditions, following BPM validation, trajectory feedback tests. Measurement campaigns for the optimization of the Twiss parameters and emittance are planned as a second phase, and finally initial gap-closure trials will begin.

3.6 Management and Coordination

Project activities were continuously monitored through updated GANTT charts and a shared Confluence workspace, ensuring coordination with other collaborators within the experimental bunker.

Outreach efforts included website updates (SABINA website) and conference participation to strengthen the visibility and integration of the THz and user facility within the broader scientific community.



(a) Straight dogleg part (b) Undulators detail (c) M1 alignment (d) Laser system

Figure 2: *Representative images of the work performed on the SABINA dogleg*

4 Ongoing activities in 2026

Electron beam commissioning is planned for the first half of 2026 within the SPARC_LAB scientific program and will include full beam transport through the dogleg and the evaluation of undulator performance in different configurations. To support early tests, a temporary setup will be installed immediately downstream of the undulators to allow initial observation of THz radiation while the permanent photon-transport system is still under completion. These activities will verify beam optics, stability, and transmission efficiency, and will compare experimental results with simulations at different beam energies.

In 2025, SABINA was proposed and accepted as a node of the IR2TECH research infrastructure network of Rome Technopole, the research ecosystem of the Lazio Region funded by PNRR (https://infrastrutture.rometechnopole.it/it), which increased institutional and media attention to the project.

The initiative also involves doctoral research activities: a PhD project titled "Analysis and Control of Beam Optics for the Optimization of SABINA FEL Performance" contributes directly to commissioning through advanced simulation, control tools, and performance optimization. This work supports both technical development—such as beam injection optimization, automated diagnostics integration, and studies of microbunching effects—and high-level training in accelerator physics and next-generation FEL technologies within an international research environment.

5 List of conference talks by LNF authors in year 2025

In 2025, the SABINA beamline — together with its applications and installation work — has been presented at several conferences:

1. I. Balossino on behalf of the working group, Undulator developments for the Frascati FEL user facilities, Insertion Devices for Future Light Sources Workshop (ID25), satellite event of IPAC25, Taiwan, 31 May–1 June 2025.

2. I. Balossino on behalf of the working group, SABINA-THz: l'infrastruttura per utenti con radiazione THz prodotta da fascio di elettroni, SIF Congresso Nazionale, Palermo, Italy, 22–26 September 2025. Mention as best communication in the section "Fisica applicata, acceleratori e beni culturali".

3. I. Balossino on behalf of the working group, From concept to commissioning: SABINA – A 3–30 THz/IR FEL user facility at SPARC-LAB, FELs of Europe, Topical Workshop on Selected Problems in FEL Physics: from Soft X-rays to THz, Grado, Italy, 24–26 September 2025.

4. L. Giannessi, Internal seminar, SPARC, 16 January.

5. I. Balossino on behalf of the working group, Advancing SABINA: installation, commissioning plan and early THz diagnostics, TeraDays 2026, Milan, Italy, 29–30 January 2026. Abstract submitted and accepted.

6. I. Balossino on behalf of the working group, SABINA FIRST SIGHTS: The user facility with THz-MIR polarized radiation provided by a Free Electron Laser at its first electron beam run, IPAC 2026. Abstract submitted and accepted.

6 Acknowledgment

The current status achieved by SABINA, which experienced rapid progress throughout 2025, is the result of the work of the involved LNF personnel, first and foremost the DA and DT services, to whom we express our deepest gratitude. The project has also benefited from the THz expertise of the Sapienza TeraHertz group, the FEL expertise of colleagues from ENEA, and the valuable support of collaborators from other INFN divisions.

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