EuAPS – WP2 Activity Report 2025 (LNF)

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1 EuAPS at LNF: Overview and Objectives

The EuAPS (EuPRAXIA Advanced Photon Source) project is embedded within the broader framework of the European EuPRAXIA project, which is already included in the ESFRI Roadmap. EuPRAXIA foresees the establishment of a distributed European user facility providing advanced radiation sources (FEL, betatron, positrons) driven by electron beams accelerated through plasma-based technologies.

EuAPS involves the participation of INFN as the lead institution, with contributions from the Frascati National Laboratories (LNF), the Southern National Laboratories (LNS), and the INFN Milan Division. The co-proposing institutions include CNR, with its branches in Pisa, Montelibretti (Rome), and Potenza, as well as the University of Rome Tor Vergata.

EuAPS aims to achieve several of the scientific objectives outlined in the EuPRAXIA Technical Design Report (TDR), contributing to the realization of a distributed user facility designed to grant research groups access to advanced radiation sources.

These infrastructures include:

- A plasma-based betatron source for the production of partially coherent soft X-rays (Frascati National Laboratories)
- A high-average-power, high-repetition-rate laser system (CNR-INO, Pisa)
- A high-power laser system (Southern National Laboratories, Catania)

The University of Tor Vergata, CNR-ISM (Rome), and CNR-ISM (Potenza) are responsible for diagnostics, X-ray beam manipulation systems, and the experimental chambers dedicated to user activities. The INFN Milan unit carries out key theoretical and simulation studies aimed at the design and optimization of the betatron source.

The project has been funded with €22,350,588.00

All infrastructures must be completed and operational by April 2026, with a guaranteed operational lifetime of at least 10 years, consistent with the long-term objectives of the EuPRAXIA project.

2 Progress in 2025

As the lead institution, INFN has been directly involved in two of the four Work Packages. At the Frascati National Laboratories, activities focused primarily on:

WP1 – Project Management (A. Falone resp.)

WP2 – Installation and commissioning of the Betatron Source Infrastructure (A. Cianchi - Univ. Tor Vergata, resp.)

Careful planning of activities, continuous interaction with suppliers to monitor component delivery schedules, and coordination with several laboratory services proved crucial in developing and progressively refining a timeline and human resource allocation compatible with the original project deadline of November 30, 2025.

During the first half of 2025, the INFN governance, considering procurement procedures across several PNRR projects at risk of not meeting their deadlines, initiated discussions with the Italian Ministry of University and Research (MUR). This process resulted in the publication of an official circular on July 31, 2025, extending all PNRR projects to April 30, 2026.

This extension allowed the project to address technical issues that had emerged over time and to redefine the work plan accordingly.

The intensive installation phase required the involvement of a significant portion of laboratory personnel. Key activities included:

- Installation of vacuum components at FLAME and within the SPARC bunker
- System alignment procedures
- Installation of diagnostics and mirrors
- Cabling and integration activities

These operations required close collaboration among multiple technical services. Effective coordination and optimization efforts enabled steady and consistent progress throughout the installation phase.

Delays were experienced in the upgrade of the laser system due to technical and logistical issues encountered by the supplier. These delays impacted the initial schedule; however, the project extension to April 30, 2026, will allow full recovery of the timeline.

2.1 Infrastructure areas and installation status

During 2025, the WP2 activities progressed along three complementary installation areas associated with the FLAME laser facility and the final EuAPS beamline integration:

- **Paradise**: is the laser distribution area where the main FLAME laser beam is routed after amplification. In this zone, the beam can either be compressed and directed toward the FLAME experimental bunker or transported in an uncompressed state along an alternative beamline toward the SPARC bunker. Paradise therefore functions as the switching and conditioning point that enables flexible delivery of the laser to different experimental areas.
- **Inferno**: the FLAME bunker area dedicated to the R&D of the betatron radiation source, where the laser and diagnostics can be tested.
- **SPARC**: the final installation location for the EuAPS betatron source on the beamline, where the system will be integrated with the final infrastructure and services.

Figure 1 shows the current status of the three areas.

2.2 Gas-jet test stand and repetition-rate tests

A dedicated **Gasjet** test stand was used to qualify the supersonic helium gas-jet operation and the associated vacuum/extraction concept, in view of high-repetition-rate operation. The test stand reproduces the interaction chamber (IC) and the extraction system (ES) layout, including turbomolecular pumps on the IC and a Roots-based extraction line above the jet for efficient helium removal.

The key outcomes of the experimental campaign (Deliverable 2.2.2) are summarised as follows:

(a) Paradise (FLAME, above bunker/outside clean room).

(b) Inferno (FLAME bunker, WP2 R&D area).

(c) SPARC (final installation location).

Figure 1: WP2 installation areas used during 2025 for integration, R&D and final deployment of the betatron source.

- With helium backing pressure between 40–70 bar, pulsed injection at 1 Hz and a valve opening time of 3 ms, the pressure in the transition pipe (TP) remained well below the reference limit of 1.5×10^{-3} mbar, reaching 2.7×10^{-4} mbar at 70 bar, with 7.9×10^{-4} mbar measured in the IC.
- Increasing repetition rate at 70 bar (3 ms opening time), the TP pressure stayed at the few 10^{-4} mbar level up to 2 Hz, and remained below 10^{-3} mbar at 5 Hz (8.2×10^{-4} mbar in TP), demonstrating suitability for operation up to 5 Hz.
- The extraction system plays a critical role in maintaining stable operation; tests varying the number of Roots pumps showed limited degradation when reducing from three to one pump (TP pressure from 2.7×10^{-4} to 3.5×10^{-4} mbar at 70 bar and 1 Hz), while removing the extraction pumping entirely led to pressures in the 10^{-2} mbar range and unstable turbomolecular pump operation.

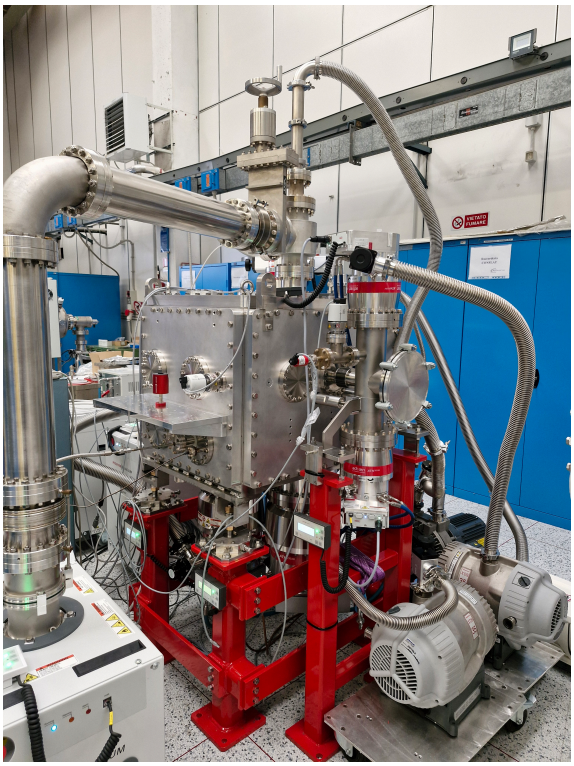

Figure 2: Gasjet test stand used for vacuum and repetition-rate tests of the supersonic helium jet and extraction system.

2.3 Characterisation chamber hardware

In parallel, the hardware for the betatron beam characterisation line was finalised (Deliverable 2.4.3), adopting a modular vacuum system based on imaging techniques. The set-up is structured in three sections that can be operated jointly or independently, to keep diagnostic tools as close as possible to the source while preserving flexibility:

- a *double-slit chamber* at the exit of the source for current readout and coarse beam-size control;
- a *main diagnostic chamber* with a remotely actuated tool holder to insert scintillating screens (YAG:Ce), a Faraday cup and a mirror for visible imaging (EM-CCD);
- a *filter chamber* followed by an X-ray CCD camera stage, enabling spectral characterisation in single-photon-counting mode with remotely selectable filters.

The overall design includes a dedicated frame and alignment strategy (laser-based references and fine adjustment screws) to support different configurations (one, two, or three diagnostic modules online) and to adapt the observation distance to the expected beam divergence.

2.4 Annual meeting

In June 2025, the first EuAPS Annual Meeting was successfully held, organized by the Southern National Laboratories. The event gathered approximately 40 participants, including personnel

from partner institutions and external experts, who presented potential ideas and proposals to become future users of the facilities under construction.

The meeting agenda is available at:

`https://agenda.infn.it/event/46260/overview`

The presentations covered: general overview of the EuAPS project for external users, status updates on key Work Packages, progress in plasma-based X-ray sources and diagnostics. A scientific sessions on: X-ray Phase Contrast Tomography for life sciences, radiobiological applications of laser-driven beams and high-repetition-rate laser technologies. The external contributions included experiences from other research infrastructures, such as capillary discharge activities at ELI-Beamlines and developments in high-repetition-rate laser-driven electron acceleration, highlighting broader scientific and technological synergies. The meeting served both as a scientific forum and a coordination platform, strengthening collaborations, sharing results, and aligning strategies toward the construction and operational planning of the advanced photon and particle sources envisioned by the EuPRAXIA roadmap.

2.5 Financial report progress

Throughout the year, each equipment delivery was accompanied by the corresponding invoices. As a result, INFN's reported expenditure profile in 2025 increased significantly, rising from less than €0.5 million to over €11 million as of November 30, 2025.

Given the bi-monthly reporting structure, expenses incurred in December 2025 will be reported at the end of January 2026.

INFN received a total funding allocation of €14,935,838.00. The remaining amount to be reported mainly concerns final payments related to above-threshold procurement procedures, which alone account for approximately 25% of the residual budget.

3 List of Conference Talks by LNF Authors in 2025

Laser-Plasma Accelerators Workshop 2025, Ischia, Italy
"Preliminary Study of the X-ray Betatron Radiation Source in the EuAPS Project"
Poster, Student Grant — F. Stocchi

16th International Particle Accelerator Conference (IPAC 2025), Taipei, Taiwan
"Initial characterization of a laser-driven betatron radiation source in the EuAPS project"
Poster, Student Grant — F. Stocchi

High Precision X-ray Measurements 2025, Frascati, Italy
"Betatron X-ray Radiation in the EuPRAXIA Advanced Photon Source Project"
Invited Talk — F. Stocchi

7th European Advanced Accelerator Conference (EAAC 2025), Isola d'Elba, Italy
"Characterization of Secondary Radiation from LWFA in the EuAPS Project"
Poster, Student Grant — F. Stocchi

SILS Conference 2025
"New ultrafast photon source for user application at LNF: from THz to x-ray"
Talk — F. Villa