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THE BEAM TEST FACILITY OF THE NATIONAL LABORATORIES OF FRASCATI

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Abstract

The Beam Test Facility (BTF) at the National Laboratories of Frascati (LNF) provides highly configurable positron/electron beams for different type of experiments. Extracted from the DAΦNE LINAC, the beam delivers up to 49 bunches/s, with 1 to 10^{10} particles/bunch. Secondary beams span 25–780 MeV (electrons) and up to 550 MeV (positrons). BTF includes two experimental halls: BTFEH1, suited for high-intensity and long-term experiments, and BTFEH2, optimized for lower intensities (up to 10^6 particles/s). Both halls feature remote-controlled movable tables, beam diagnostics, and essential services like laser alignment, networking, high-voltage support, and gas pipelines, ensuring comprehensive experimental capabilities and 24/7 user support. A notable strength of BTF lies in its user-friendly approach. Beam can easily be manipulated to meet users' specific needs, even during ongoing data collection. In this paper the upgrades concerning the development of a new control system based on Epik8s (EPICS on Kubernates) will be reported as well as the new improvement in beam dimension and energy loss concerning the substitution of the 500 µm BeO exit window with 120 µm Anticorodal one.

EXPERIMENTAL HALLS, BEAMS, AND USER

As a component of the DAΦNE accelerator complex [1], the INFN Laboratori Nazionali di Frascati (INFN-LNF) houses the Beam Test Facility [2] (BTF), a system of beam transfer lines and two experimental halls designed to transport electron or positron, primary or secondary beams to various hit points with the aid of beam diagnostics and High Energy Physics (HEP) experiment-focused services.

The LINAC [3] can operate at repetition rates up to 50 Hz and is capable of continuous 24/7 operation, delivering beams to the experimental halls. BTFEH1, offering over 30 m^2 of experimental area, typically receives conditioned, fixed-energy primary electron and positron beams. These beams have nominal energies of 510 MeV, with operational ranges from 160 (200) MeV to 780 (530) MeV for electrons (positrons), and an energy spread of approximately 0.5 % (depending on the selected energy). The pulse duration is typically 10 ns, extendable up to 320 ns, with emittance values of 1 (10) mm·mrad [4]. Beam intensities at the DUT point can reach up to 10^{10} particles/s, subject to radioprotection constraints.

Secondary beams are produced by directing the LINAC primary beam onto a variable-depth copper target (1.7–2.3 X_0), generating a continuous momentum distribution. These quasi-neutral, highly chromatic secondary beams are momentum and particle-type-selected using a 45-degree bending dipole and beam scrapers. The resulting beam intensity is energy dependent and significantly reduced compared to the primary beam. By adjusting the scraper positions, the beam multiplicity can be tuned down to the single-particle level across the full secondary energy range.

A summary of these different operational modes [5] and beam characteristics is reported in Fig. 1.

Parameters	BTF1 Time sharing		BTF1 Dedicated		BTF2 Time sharing	BTF2 Dedicated
	With Cu target	Without Cu target	With Cu target	Without Cu target	With Cu target	With Cu target
Particle Type (Dependance)	e^+ / e^- (User)	e^+ / e^- (DAΦNE status)	e^+ / e^- (User)		e^+ / e^- (User)	
Energy (MeV)	25–500	510	25–700 (e^-/e^+)	167–700 (e-) 250–550 (e+)	25–500	25–700
Best Energy Resolution at the experiment	0.5% at 500 MeV	0.5%/1%	0.5%	Energy dependent	1% at 500 MeV	
Repetition rate (Hz)	Variable from 1 to 49 (DAΦNE status)		1–49 (User)		Variable from 1 to 49 (DAΦNE status)	1–49 (User)
Pulse length (ns)	10		1.5–320 (User)		10	Expected 10-100
Intensity (particle/bunch)	1–10^5 (Energy dependent)	1 to 10^7 / 1×10^{10}	1–10^5 (Energy dependent)	1 to 10^{10}	1–10^4 (Energy dependent)	
Max int flux	1×10^{10} part./s				1×10^6 part./s	
Beam waist size(mm)	0.5–55 X / 0.35–25 Y (vacuum window dependent)				1x1	
Divergence (mrad)	Down to 0.5				Down to 0.5	

Figure 1: BTF beam characteristics.

Both experimental halls can receive secondary beams with minimal configuration differences. The beam spot size can be tuned to as small as 0.4 × 0.4 mm^2 using the final quadrupole doublet or easily reaching the desired users dimension. BTFEH2, with over 10 m^2 of experimental space, is primarily used for weekly-based user shifts and has operated without major faults during recent user calls. Although limited to beam currents of 10^6 particles/s, BTFEH2 has supported beam performance optimization, low-energy beam prototype development for FCC-related projects, and the testing of BTF-developed detectors such as the Pulsed Ionization Chamber and calorimeters [6]. In Fig. 2 the setup of the BTF experimental halls is reported.

The facility maintained a high level of beam availability, with approximately 240 operational days dedicated to both external and internal users. More than 200 users accessed the beamlines, receiving continuous support from beamline scientists. 2025 has been dedicated to the data taking of the PADME/X-17 experiment [7], and three weeks of external user activities are planned for December 2025. The BTF hosted a significant number of users and activities over the years (see Fig. 3). In 2024, the typical user team had an average shift duration of 6.5 days and involved around 7 participants per team.

BTF hall activities in 2024 are categorized as follows: low-multiplicity external users (43 %), internal (LNF) projects and commissioning beam time (~20 %), dedicated PADME

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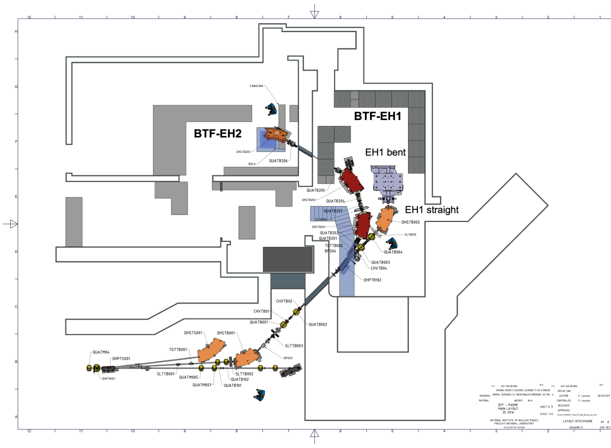

Figure 2: Layout of the BTF line and area.

operations (~10 %), high intensity irradiation-focused external users (~7 %) [8]. The setup changes or maintenance periods to prepare for subsequent experiments are ~20 %, meanwhile, the annual scheduled shutdown accounted for 20 % of the total number of days.

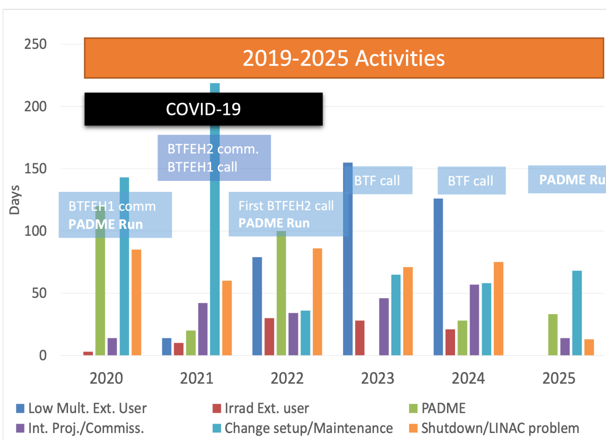

Figure 3: Last six years activities fractions.

BTF INFRASTRUCTURE AND TECHNICAL SERVICES

The BTF provides a comprehensive and user-oriented infrastructure designed to support a wide range of experimental needs. It includes high-speed 1 Gb networking capabilities with DHCP auto-endpoints and live diagnostics accessible via LabView®, Grafana, and EPICS user dashboards and their local retrieving via MemCached and EPICS services.

The data acquisition and control systems feature VME and NIM electronics, QDC and TDC modules, digital delays, and triggered imaging systems based on the EPIK8s platform, which also enables online data analysis. A rich software ecosystem supports detector integration through C, C++, and Python libraries and APIs, facilitating the development and deployment of user readout DAQ integrated with BTF live diagnostics. The facility offers a full range of technical services, including:

- Power supplies, crates, and electronic boards;
- Mechanical infrastructure such as remotely controlled trolley tables, sliders, and mounting kits;
- Vacuum systems and gas pipelines equipped with safety interlocks;
- General utilities: logistics, electrical power, compressed air, and fluid systems;
- Triggering systems: digital delay lines, particle-type latching, and finger triggering.

UPGRADE ON THE VACUUM WINDOWS

A novel spherical-disk beam window design has been developed at LNF by the Vacuum Group in collaboration with the BTF staff. The window, milled from bulk aluminum, offers enhanced mechanical robustness and reduced stress concentrations when compared with conventional brazed or planar foil windows, such as the 50 µm-thick titanium windows currently employed on the BTF straight line. Two geometrical configurations—single- and double-sided spherical caps—were fabricated and subjected to rigorous testing, including 50 rapid venting cycles. Both variants demonstrated excellent mechanical stability while significantly mitigating beam scattering effects. Experimental characterization at 25 MeV further revealed a reduction of approximately 35 % in the transverse beam dimension – as shown in Fig. 4 – underscoring the potential of this design for improved beam quality and operational reliability.

UPDATES IN THE CONTROL SYSTEM

The BTF played a pivotal role in the development of the !CHAOS (Control system based on Highly Abstracted and Open Structure) [9] control system, which has been in use since 2011. Building upon this foundation, a new standard, EPIK8s, has been introduced to address the evolving needs of advanced projects such as EUPRAXIA and SS-RIP. This new standard, based on EPICS, incorporates significant advancements in system management technologies, including containerization, orchestration (e.g., Kubernetes), and cloud-based solutions.

The transition of the LNF accelerators complexes control system to EPICS represents a strategic shift driven by both practical and technical considerations. The primary reason for this change is the lack of resources to continue developing the existing custom control system (CS). Additionally, LNF is facing a surge of new projects, the most prominent being EUPRAXIA, which necessitates a scalable and robust control infrastructure.

EPIK8S is currently undergoing testing at BTF for critical subsystems, including magnets, scrapers and triggered cameras (flags). In addition to these tests, new developments have been initiated to meet specific BTF requirements. These include the control of high-voltage (HV) crates, the integration of PTU sensors, and the creation of channels to connect LabVIEW systems with EPIK8S using JSON-based protocols.

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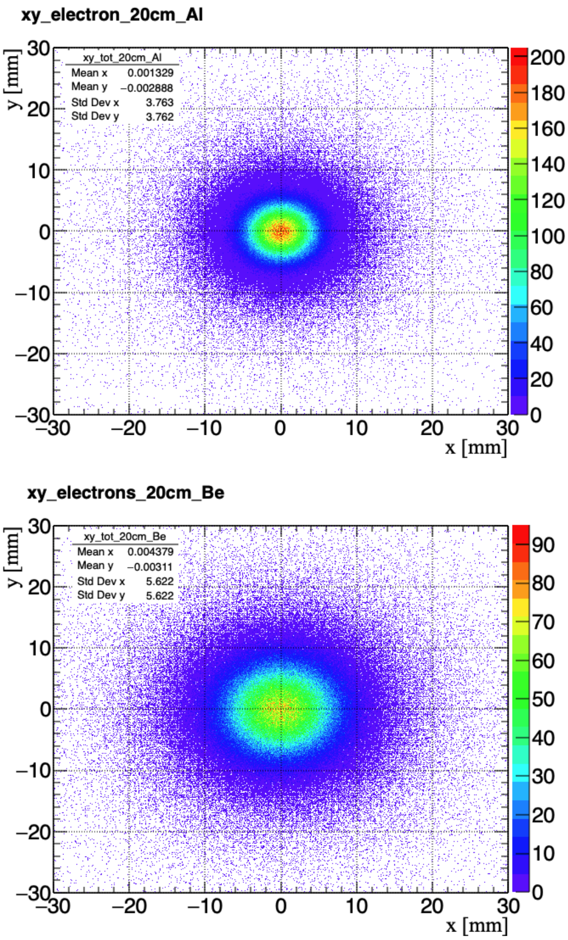

Figure 4: Simulated transverse beam at 20 cm from the exit window in Antocorodal (Left) and Berillium oxide (Right).

This innovative approach combines the flexibility and scalability of EPICS with cutting-edge technologies, providing a robust framework for the implementation of distributed control systems for future projects.

Moreover, a recent enhancement to the facility's infrastructure is the implementation of OLOG (Online Logbook) [10], a system that allows users and operators to record beam conditions, experimental configurations, and observational data in a structured, searchable database. OLOG supports image attachments, time-stamped entries, and metadata tagging, thereby improving collaboration and ensuring full traceability of experimental sessions. These features significantly strengthen reproducibility and operational efficiency, making OLOG an essential tool for both users and facility staff.

CONCLUSION

The BTF at the National Laboratories of Frascati stands as a critical resource for external users, offering highly configurable electron and positron (e^+/e^-) beams tailored for the development and characterization of advanced detectors. The facility's capability to deliver beams with multiplicities ranging from a single particle per bunch to 10^{10} particles per bunch, coupled with a maximum energy of 780 MeV for electrons and 530 MeV for positrons, makes it uniquely versatile. A key strength of the BTF is the flexibility of its beam parameters, which can be adjusted in real-time, even during data acquisition, enabling users to optimize beam configurations dynamically. The facility is organized into two experimental halls and three beamlines, with one beamline currently available to users. This operational beamline is equipped with a remotely controlled table for experimental setups, comprehensive beam diagnostics, and a range of ancillary services, further enhancing the user experience. Looking ahead, the BTF continues to be an indispensable tool for the scientific community, driving advancements in particle detector technologies and experimental methodologies. Its features and user-focused design underline its role as a leading facility for beam testing and research.

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