BTF ACTIVITY REPORT 2024

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1 Introduction

The current status and development at the Beam Test Facility (BTF) are outlined, including contributions from various groups and projects. The BTF group, consisting of 3.2 FTE, supports external users as well as participants in the PADME experiment,contributing to ASIF-2 and EUROLABS projects. This includes managing, upgrading the BTF infrastructure and supporting own detector developments.
In 2024, the BTF maintained a high level of beam availability, with approximately 240 operational days for both external users and internal projects. Over 200 users benefited from beam access and received continuous support from the beamline scientists, available 24/7. During the same year, beam time was also allocated to the PADME/X17 test campaign, in preparation for the upcoming PADME/X17 technical and scientific run scheduled for 2025.
The booking software has reached a high level of maturity, enabling safe and straightforward access for all users. Variants of the software are currently being developed and adapted for use in other LNF facilities and INFN laboratories.
Both BTF experimental halls have been fully operational. In particular, BTFEH1 has undergone system upgrades to support PADME as well as two high-intensity projects related to FLASH-VHEE therapy. The FLASH-VHEE research community has expressed strong interest in the beam capabilities of BTFEH1, with two run slots already requested for the expected Q4 2025 call. Additionally, the BTFEH1 area has been requested for the FIREBALL@LNF experimental proposal. A talk and a Letter of Intent (LOI) has been submitted to the 68$^{\mathrm{th}}$ meeting [2] of the LNF Scientific Committee, following the talk "Unveiling the Physics of Relativistic Pair Plasma Jets in the Laboratory" with the related astrophysical scientific interests at the 67$^{\mathrm{th}}$ LNF Scientific Committee meeting [3].
The BTFEH2 area, primarily designated for external users, has been fully operational and has not experienced any significant faults during the 2024 user calls. This area has also been used for beam performance enhancements, particularly for a low-energy beam prototype associated with PSI-FCC related projects, as well as for the development of BTF detectors such as the Pulsed Ionization Chamber and BTF calorimeters.
The BTF team is actively involved in the EUROLABS Project, securing funding for 4 out of the 7 allocated weeks over the project's entire duration. Beginning in October 2024, BTF is also participating in the ASIF-2 Project, which focuses on integrating INFN facilities with ASI and space-related applications. Furthermore, a new collaborative effort has been initiated with the LNF Control Group to develop the LNF BTF/SPARC systems.
Starting in June 2024, following the DAΦNE shutdown, the LINAC operated in dedicated mode, exclusively serving BTF activities. A remarkable effort has been made by the LINAC group to restore to nominal power a nearly new Thales Klystron whose tube was contaminated by a vent caused by a main window crack in 2023.

2 Personnel

The BTF group consists on several key personnel and technicians:

- **BTF Group:** 3.2 FTEs including external, PADME, ASIF-2, and EUROLABS users.
- **Personnel:**
  - B. Buonomo (LINAC Head and BTF Technical Manager)
  - D. Di Giovenale (LINAC & BTF Staff)
  - C. Di Giulio (LINAC & BTF Staff)
  - E. Diociaiuti (BTF Staff)
  - L. Foggetta (BTF Scientific Manager & LINAC Staff)
  - C. Taruggi (PNRR TEX & BTF Staff)

3 Upgrades, Experiments, and Projects Summary

In 2024, BTF facility has act as a base for LNF and BTF-internal upgrades while maintaining its commitment to external users program, LNF experiments and BTF-involving projects:

- Most of the 2024 beam time (see Fig. 4.1) was devoted to **external user experiments** through three separate calls, completely fulfilled.
- **Booking software 11** for automated call and user management has been operational and extended to other INFN labs.
- Upgrades related to the **PADME experiment** were implemented, and dedicated beam time was allocated specifically for PADME operations.
- A **new experiment proposal, FIREBALL**, aims to secure dedicated BTF time in BT-FEH1 for astroparticle measurements in a laboratory environment, using both charged and quasi-neutral beams originating from primary and secondary sources within a plasma environment. A LOI was presented during the 68$^{\text{th}}$ LNF Scientific Committee.
- BTF participation in the **EUROLABS Project** has reached an advanced stage, with 4 out of 7 funded weeks already allocated and finalized.
- The **ASIF-2 Project**, launched in October 2024 by the Italian Space Agency (ASI) with ENEA, INFN and Università degli Studi di Milano Bicocca (UniMiB), builds upon the original ASIF initiative and focuses on studying the effects of space radiation on the durability of space-bound hardware and materials. The BTF is involved in the project through the development of capabilities for testing space applications, contributing to collaborative efforts across several institutions.
- Developments in the **Distributed Control System** (DCS) area included the integration of the EPIK8S/Phoebus package, developed by the LNF Control Service. A custom version for BTF was deployed, along with the implementation of a dedicated logbook and journal software available in the EPIK8S environment, OLOG, further enhancing the facility's data tracking capabilities.

- Upgraded vacuum and gas feeding layout: we have designed and installed new, high-quality vacuum exit windows made of aluminium. Additionally, BTFEH2 has been upgraded with a gas feeding system to better support the gaseous detector community. The upgrade also extended to BTFEH1, enhancing safety on the experimental side. As part of this effort, we refurbished the four existing gas lines, which had been inactive in recent years due to the practical suspension of external user activities.

- INFaN Network hosted in INFN-A still operates, with BTF at LNF continuing its coordination role in partnership with LNS.

4 2024 Executed Calendar

During 2024, the final run of the SIDDHARTA experiment continued through Q3, with DAΦNE injections providing enough beam availability for BTF, even though the injection scheme was LINAC/MR 25Hz/1-2Hz. The reduced spare pulse capabilities did not affect users' needs, except for a few hours of downtime.
The DAΦNE run schedule includes BTF open calls for external users in Q1-Q2, closed calls in Q3, and PADME engineering runs, which took place during a mixed call with external users' runs in Q4. This will be followed by LINAC building downtime throughout 2025:

1. January 29th, 2024: start of the external users' BTF1/BTF2 open call, running until June 3. This is scheduled for 2024 Q1-2 in pulse-sharing mode with DAΦNE, with activities planned until that date. LNF management reserved the option to extend this run in April/May.

2. The LNF management freed LINAC+BTF activities up to 15 July, so BTF continues with a closed call until that date for 2024 Q3.

3. July 15th, 2024: Start of the shutdown period due to LINAC maintenance on the fire extinguisher systems and a complete upgrade of the DAΦNE plant's Safety Access Control.

4. September 30th, 2024: restarting of BTF Q4 call beam time for external user, lasting until 20th December.

5. December 20th, 2024: start of the shutdown period. The LNF Technical Division will begin implementing solar panels on LNF rooftops, including the LINAC building and neighbouring structures. This will lead to a LINAC plant shutdown expected to last until March 15th, 2025, thus involving a BTF shutdown during the same period.

4.1 2024 BTF Beamtime for external users call

Details about beamtime for 2024 are provided:

- The Q1-Q2 and Q3 calls were fully booked and committed from startup to shutdown for external user. The Q4 mixed call includes 11 weeks, with 9 weeks of beam availability for non-BTF-related projects: 5 weeks for external users and 4 weeks for PADME engineering short run. The scheduling for the 2024 Q4 call had been fully completed, indeed is important to note that Q4 experienced significant overbooking, despite the slightly delayed opening of the call.

- For all the calls, no beam available days losses to report. The forecasted uptime for 2024 was 236 days, as estimated in 2023. The actual total beam availability days in 2024 were 232. The total activity days (including beam availability, setup changes, and maintenance) amounted to 290, with 75 days dedicated to facility shutdowns.

- All operations are conducted 24/7.
- Withdrawals from users were not affecting beam usage:

  - Two slots on Q3, no detector available, converted in beam study for EPICS test with beam, new detector developing (Gennarino, wide area TPX3, PIC), low energy beam study for PSI and LNL

  - One on Q4, no detector available, converted into other queued user

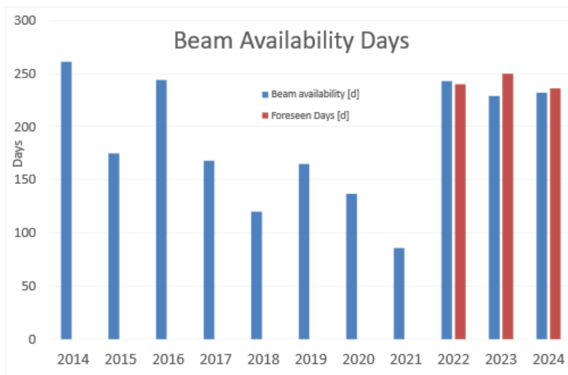


Figure 1: Last eleven years beam days availability

5 Upgrades, Maintenance and layout variation

Maintenance and testing have been minimized in Q4 to align with user needs and LINAC implementations. Some of the scheduled maintenance has been postponed to 2025, as the significant shutdown expected for to LINAC fluid maintenance and for LINAC building upkeep.

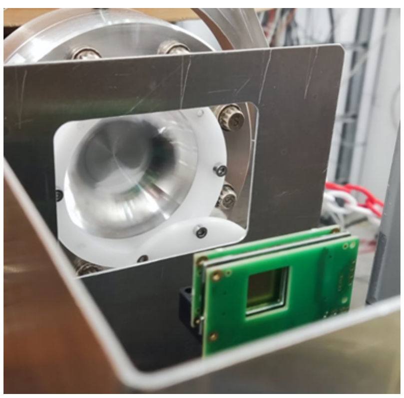
- BTFEH2 mains power line layout upgrade, scheduled for July-August, has been completed and was ready for Q4 beam time. A dedicated mains line for users has been implemented to reduce noise interference that was apparently originating from the users' side, affecting BTF instrumentation. This work, carried out by the Electrical Plant Service, was completed during the summer shutdown with no impact on user activities.
- The BTFEH1 crane has been restored and is now operational for the planned PADME and BTF logistics operations. The delay in overhauling the crane was due to the tight schedule for Q1-Q3 calls and the lack of scheduled crane usage, despite its potential need in Q4 for PADME operations. This work was completed by an external company.
- The BTFEH2 Gas Feeding system was designed in 2023 to support the integration of BTF with the gaseous detector community, expanding its scientific impact. It was installed in the past month to be ready for use in user runs requiring gaseous detector feeding. Due to restrictions in the BTF Experimental area, the BTFEH2 gas facility cannot replicate the BTFEH1 setup, where four different gas-type pipelines were previously installed.
  The new BTFEH2 gas delivery installation includes the typical setup with two inert gas pipelines (such as Nitrogen, Argon, or related inert mixtures), each equipped with first- and second-stage regulators, safety pressure switches, and a hypoxia sensor, all connected to the existing BTF gas safety systems. This work was carried out during a week when an external

user withdrew, ensuring that there was no impact on user beam time. The gas feeding facility was deployed by an external company.

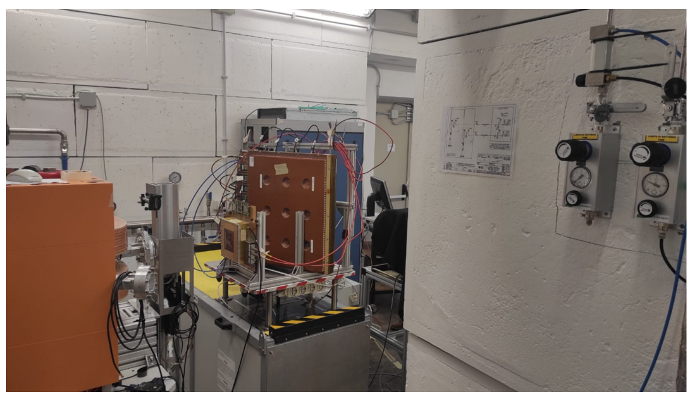
- In 2023, the BTFEH2 exit window was designed with a semi-spherical configuration to facilitate beam setup operations by reducing multiple scattering and secondary particle emissions. BTF, in collaboration with Valerio Lollo (LNF Vacuum Service), developed a specific design to address the reduced mechanical resistance of aluminum when low thicknesses over a round area are subjected to pressure differentials and vent cycles.
  Using specialized tools and machining procedures, we were able to achieve approximately 100 µm of flatness over a one-inch square area, significantly improving performance. Reliability tests were conducted during BTF user operations, which involved 20 cycles of venting from 1 atm to low vacuum, followed by abrupt venting and fast pumping (less than a second). The measured leak rate was approximately 1.8×10^{-8} mbar l s^{-1}.

- LINAC and SPP Services upgraded the fire extinguisher in the Modulator hall. This upgrade has been performed in the 2024 summer shutdown to lower beam availability impact as possible the BTF operation in Q4

- LINAC group upgraded the interlocked area access safety system for the whole DAΦNE area



(a) The new Vacuum Exit window



(b) Newly installed gas feeding in BTFEH2

Figure 2: BTFEH2 upgrades for vacuum system and gas feeding

- The BTFEH1 vacuum layout setup variation has been implemented in the BTF1-BEND line, at the end of the DHSTB002 magnet, upstream of the PADME target holder vacuum bellows. This upgrade involves adding a remotely controlled gating valve to achieve independent vacuum in the PADME TMP-pumped vessel, separate from the BTF ionic-pumped line. The motivation is to speed up BTF test beam uptime for PADME/X17 beam development in the BTF1-STRAIGHT line, during the long pumping period needed by PADME vessel to reach a suitable vacuum level. Additionally, the ionic pump associated with the BTF1-STRAIGHT line has been overhauled through a hot-degassing cleaning and pumping procedure to restore the correct vacuum pumping rate, which had decreased over the previous months. This reduction in pumping efficiency was likely caused by the previous PADME run, during which the average vacuum level remained around 1×10^{-7}mbar. The cleaning procedure was effective, though the vacuum level was not fully restored, achieving a value of 8×10^{-9}mbar. The LNF Vacuum Group, which carried out all these activities, also disassembled and reassembled the PADME cross and related components (such as the target, actuators, etc.) before linking them to the BTF1-BEND line.

- The BTFEH1 gas system revamp for PADME has been developed in preparation for the planned TPC installation within the PADME/X17 layout. Although this TPC will operate with inert gases, the mixture includes approximately 2% isobutane. To mitigate the risk of leaks resulting in potentially hazardous concentrations, a dedicated explosive-gas sensor has been installed in the TPC area. This sensor has been integrated into BTF's recently upgraded gas safety system, which already includes several other gas detectors added in recent years. In addition, all four gas pipelines, along with their safety valves, regulation stages, and associated safety systems, have been overhauled and certified. This ensures readiness for any potential changes in the gas layout required by the experiment.
- LINAC fire extinguisher upgrade completed.
- DAΦNE area access safety system upgraded.
- A remarkable effort has been made by the LINAC group to restore to nominal power a nearly new Thales Klystron whose tube was contaminated by a vent caused by a main window crack in 2023. The old LINAC Klystron-B exausted unit was overhauled with this in-house re-manufactured one, developed by the LINAC and Vacuum Service teams. After restoring the safety nitrogen filling with the nominal tube's vacuum via an external pumping line and then applying a soldered bypass to the pinch-off pumping line, the Klystron was installed and conditioned from scratch to nominal output power. Throughout 2024, stable operations have been assured by this procedure, saving 200k EUR in costs.

5.1 Maintenance and upgrades foreseen in 2025

Upcoming maintenance activities include:

- A 100 kW mains power line upgrade for BTFEH1 has been planned by the Electrical Plant Services of the LNF Technical Division. This upgrade increases electrical capacity to support future experiments and services in the BTFEH1 area.
- Vacuum layout upgrades at the end-of-line windows have been planned to implement a sequence from upstream to downstream: a remotely controlled gating valve, a compact pre-vacuum pumping line, and exit windows. This configuration will simplify operations for setting up and linking users' vacuum chambers. This work will be executed by Vacuum Services of the LNF Accelerator Division.
- The aforementioned upgrade has been started via adding BTF-Bend vs PADME gating valve. This layout implies a variation in the vacuum PLC layout that hosts the controlled vacuum pumps status read-back, the gating valves status readouts and actions, and the vacuum gauges related safety actions. The necessary improvements have been scheduled in the 2025 shutdown periods. As discussed, the same implementation will be applied to the BTF2 line in the BTFEH2 area, so the required PLC supervisor software and cabling have to be upgraded to get the full remote control and action link for the vacuum actuators. This work will be executed by Electrical Plant Services of the LNF Technical Division.
- BTF secondary fluid plant maintenance is needed for overhauling the flow meter of the BTF1 and BTF2 lines. Furthermore, an upgrade to the air conditioning systems for both all has been proposed, ensuring backup units, available for both the experimental halls in case of failures in the existing systems. This work will be executed by the Fluids Plant Services of the LNF Technical Division.

6 BTF Users and Activities

6.1 User Statistics

The BTF has hosted a significant number of users and activities over the years. 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 ($\sim$ 20%), dedicated PADME operations ($\sim$ 10%), irradiation-focused external users ($\sim$ 7%). The setup changes or maintenance periods to prepare for subsequent experiments are $\sim$ 20%, meanwhile the annual scheduled shutdown accounted for 20% of the total number of days.

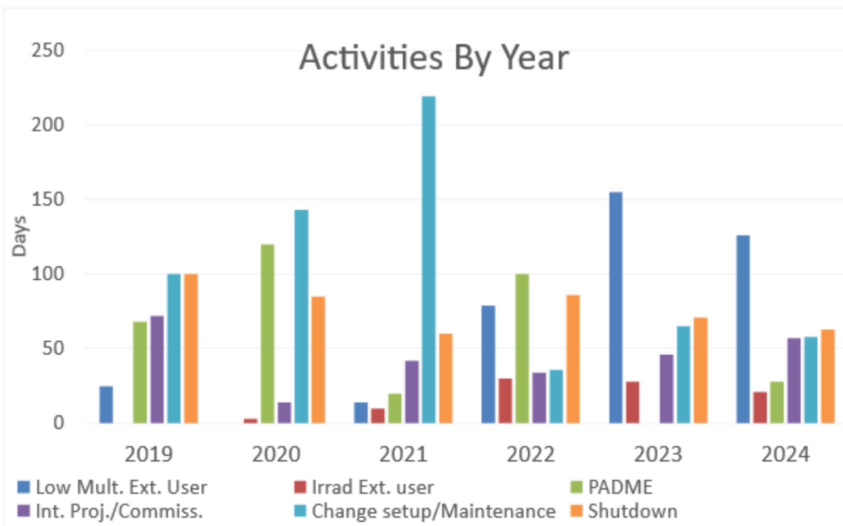
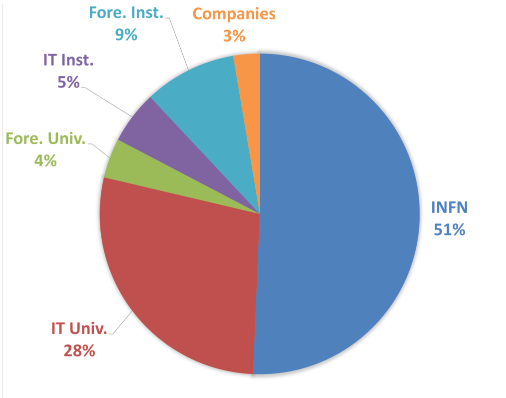


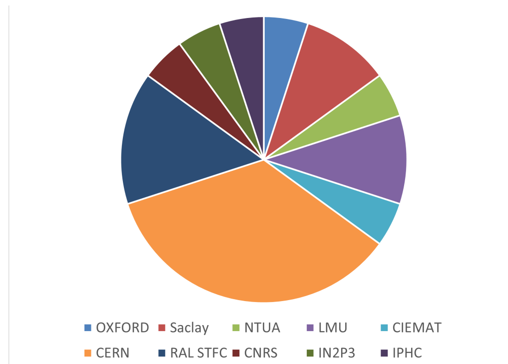
Figure 3: Last five years activities fractions

6.2 Involved Institutions

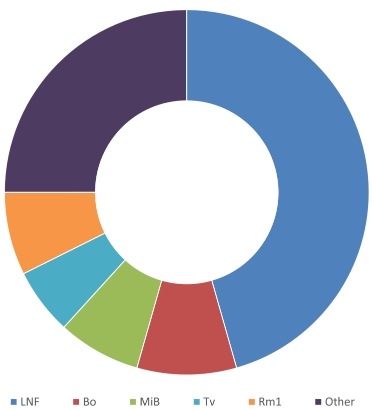
- The majority of users (Fig.4a) are from INFN (Fig.4c, 51%), followed by Italian universities (Fig.4d, 28%), foreign institutions (Fig.4b, 9%), Italian institutions (5%), foreign universities (Fig.4b, 4%), and companies (3%).
- There is good regional equalization between Italian institutions, with increased prevalence of non-Italian universities in respect of the previous year.



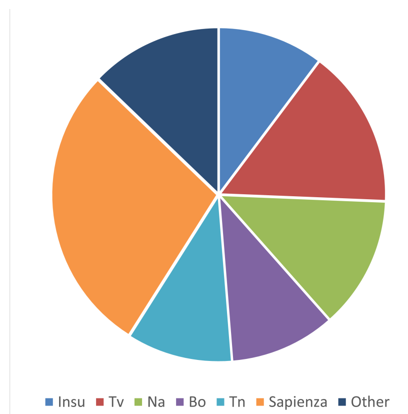
(a) Overall distribution of the team member institutions



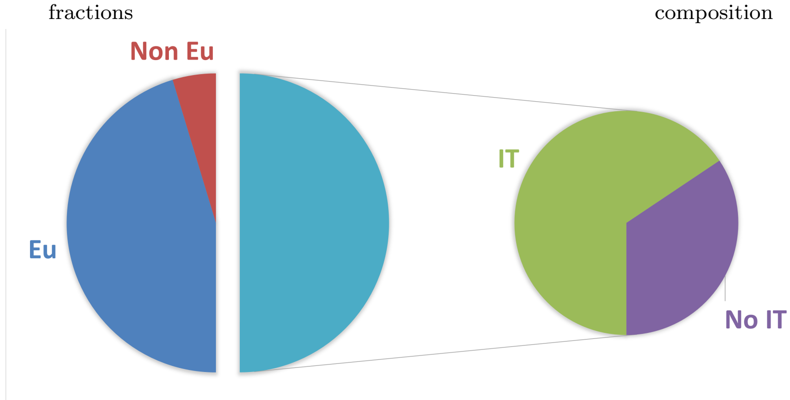
(b) Foreign institutions and universities involved in BTF activities



(c) Particular view on the involved INFN sections fractions



(d) Particular view on the Italian university team composition



(e) Overall fractions of regional distribution, no INFN

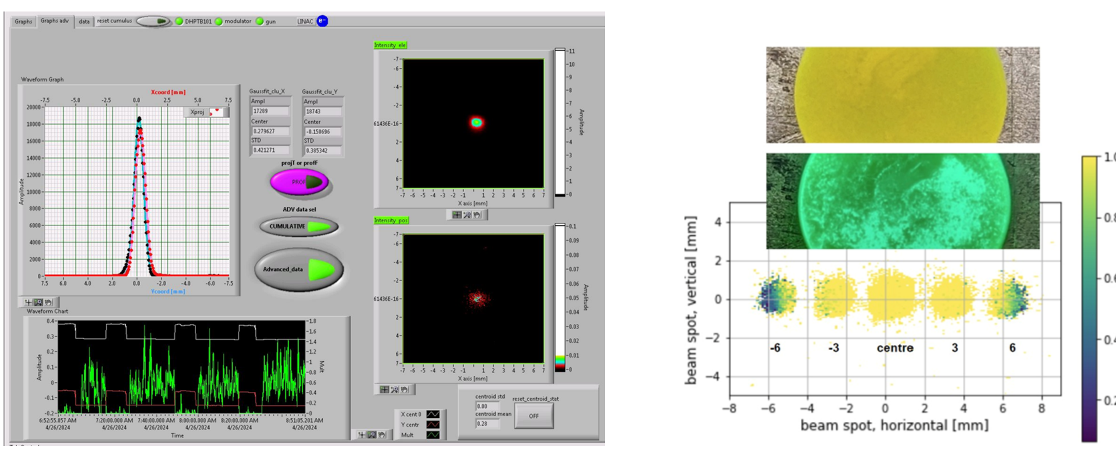
Figure 4: Statistics plot for the teams and related institutions origin, from 2022

7 Experimental Highlights

7.1 BTF single particle pencil beam, long time stability

The experiment (Nano Composite Scintillator developing - HEP Physics) by M. Soldani (LNF-INFN) et al., aims to develop fine-sampling, large-volume calorimeters for next-generation experiments using innovative scintillating materials made from perovskite or chalcogenide nanocrystals in a plastic matrix to create a nanocomposite scintillator. This experiment utilized the BTF beam for sub-mm spatial sensitivity reconstruction of detectors, with the beam also providing tomography of the device under test. Additionally, since the beam setup remained the same throughout the entire run, the experiment team leveraged the long-term stability of the BTF beam, with single-particle operation over H24:

- 450 MeV, single particle (Poisson constant = 0.8), secondary electrons
- 5 days, single beam set measure, only remote trolley table movement, no steering
- More than 600k events selected in a single particle mod
- Experiment DAQ takes around 3×10^6 total events – 15 hall entrances with full dipoles cycling



(a) BTF 5-days-long cumulative beam plot on BTF Pixel detector

(b) Cristal tomography, area sensitivity performed by Fig.5a

Figure 5: BTF pencil beam stability during NANOCAL run, courtesy of M. Soldani

7.2 BTF secondary bunched structure for detector timing

In the NOVA – MPC Development - HEP Physics experiment, T. Spadaro (LNF-INFN), V. Vagnoni (INFN-Bo), and colleagues developed a new generation MCP detector with an innovative anode design, achieving impressive light prompt response and timing sensitivity on the order of 10 ps. In addition to its primary function, the detector performed an important measurement of the LINAC bunching structure with a single particle using an off-energy secondary beam. The results demonstrated the feasibility of using the bunching structure for timing purposes.

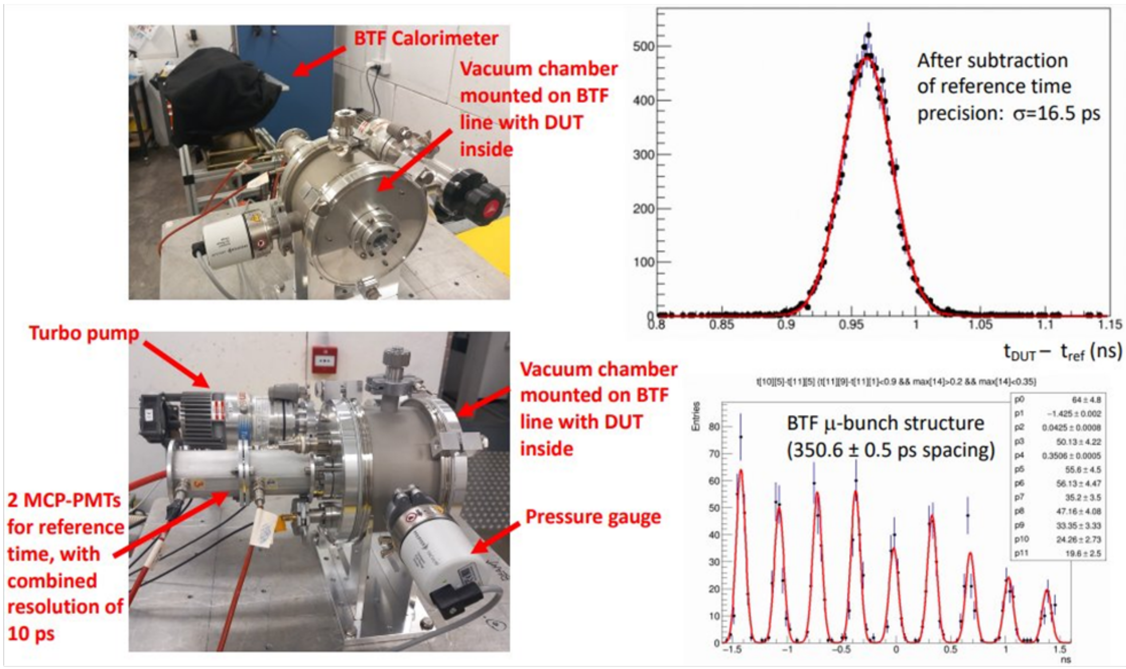
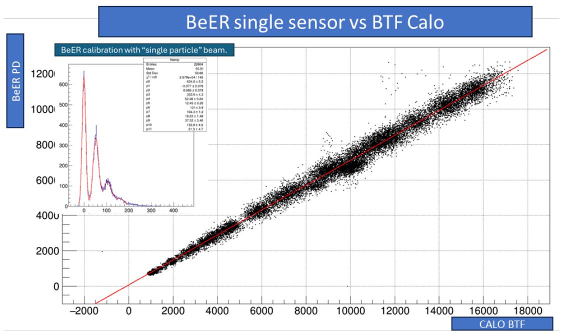


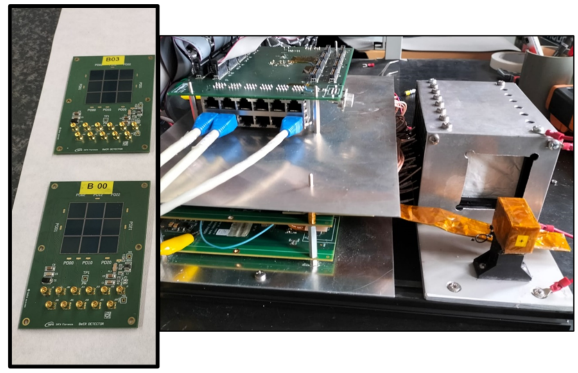
Figure 6: Identification of BTF secondary single particle beam bunched structure operated by NOVA team, courtesy of T. Spadaro adn V. Vagnoni

7.3 BTF secondary beam multiplicity scan

In the BeER (Beam-monitor with Extreme Range) - Photo Diodes Development - an HEP Physics experiment, P. L. Pacini (FI-INFN), N. Mori (FI-INFN), and colleagues developed a detector consisting of six layers, each containing 3×3 blind Excelitas VTH2110 Photo Diodes (PD) with an active area of $1\,\text{cm}^2$. These silicon PIN diodes are used as ionization detectors, providing an easy-to-use online monitor for high-energy nuclei (e.g., SPS ions) and high-multiplicity (BTF electron) beams. The system is designed for seamless integration into user DAQs to provide event-by-event charge (or particle count) information. The BTF beam operated at 302 MeV, with secondary electrons ranging from a single-particle regime to 2×10^4 electrons per shot. The large dynamic range was confirmed with high-multiplicity runs using BTF Lead Glass Calorimeter. The BeER detector is capable of counting fairly less 20k electrons, beginning from the single-particle regime (Fig. 7).



(a) BTF multiplicity scan in comparison with the BeER setup, in the left top corner is zoomed the single sparticle regime starting scan



(b) Setup used by the BeER team, Fig.7a

Figure 7: BTF multiplicity scan capabilities, courtesy of P. L. Pacini and N. Mori

7.4 Low Energy Beam

Some new proposals needs high flux, low energy secondary BTF beam in BTFEH2 for exploiting new HEP detector, expecially from the collaborator of FCC-PCUBE experiment where the detector capabilities needs electron beams in the range of 25−100 MeV. The beam setup choiches was to optimize maximum multiplicity vs best transverse dimensions (i.e. best high flux) while maintaining a gaussian shape and beam waist compatible with two detector position: at 20 cm (named short focus) from exit windows and 1 m away (named long focus), typical user setup installation points depending of user detector layout. In order to overcome BTF Fitpix transverse dimension (1.4×1.4 cm^2) we also used the new QUAD TPX3 Hybrid (with 100 μma Si absorber thickness) with the Katherine readout, developed in collaboration with ENEA N-TOF group.

Energy [MeV]	**Multiplicity [k#]**	σ_x **[mm]**	σ_x **[mm]**
100	6	2.8	2.8
75	5.5	4.2	3.8
50	5	5.5	6.5
40	2.5	8.4	7.3

Table 1: Secondary electron, long focus setup

Energy [MeV]	**Multiplicity [k#]**	σ_x **[mm]**	σ_x **[mm]**
100	30	3.2	2.3
75	18	3.2	2.3
50	5	2.3	1.7
50	0.002	1.2	1.5
40	1	2.5	2.4
30	2	4.3	5.3
13	0.006	4.0	6.0

Table 2: Secondary electron, short focus setup

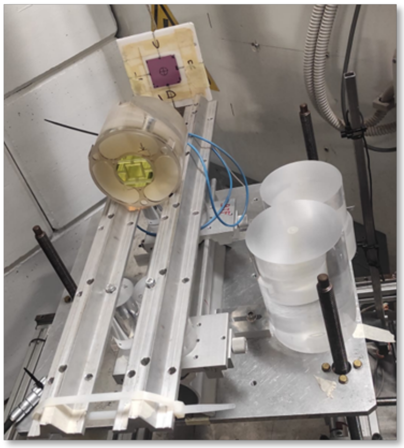
7.5 FLASH-VHEE

The FLASH effect in radiotherapy offers therapeutic advantages by sparing healthy tissues while maintaining treatment efficacy. Experimental verification can primarily be performed *in vivo* using low-energy (4−7 MeV) electrons, delivering doses in <100 ms at rates exceeding 40 Gy/s. However, further basic research and advanced technological solutions are needed, particularly for Very High Energy Electron (VHEE) beam irradiation, which aims to treat deep-seated tumors with electron with energies ranging from 50 to 200 MeV. This could lead to a paradigm shift in radiotherapy, with evidence suggesting the potential application of the FLASH effect in future VHEE FLASH LINAC systems.
BTF aims to contribute to this area by addressing the scientific needs related to detector development, both for beam diagnostics and dose measurement. In 2024, additional run time has been allocated for:

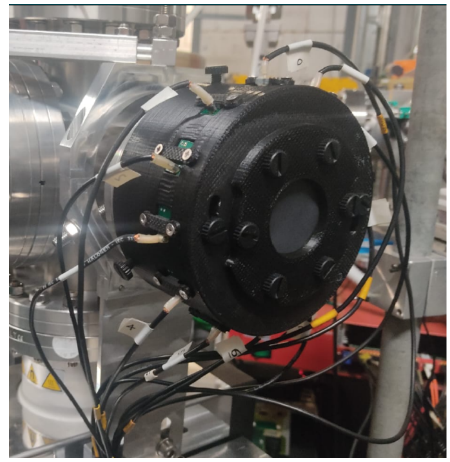
- Control Imaging Systems - MORSEPET - M.G. Bisogni et al. (Uni-Pisa) developed a novel method for verifying the dose delivered to tissue or a phantom by a VHEE beam. This method is based on detecting the Bremsstrahlung radiation emitted by the beam as it passes through the tissue/phantom. The team used a BTF 150 MeV electron secondary beam, with a multiplicity of around 1000, to generate an electromagnetic shower over an EJ212 plastic scintillator foil positioned parallel to the beam direction (see Figure 8c. A cooled CCD camera was used to collect the emitted blue light. The team also demonstrated the feasibility of *in vivo* dose measurement in a phantom irradiated with a VHEE beam, using a secondary 150 MeV, 80 MeV beam by using its setup scrolling longitudinally a hollow PMMA phantom.

- Certified dosimetry in FLASH regime – DIAMONDS for VHEE - M. Marinelli, G. Rinati(Uni-Roma TV) L. Giuliani (Uni-Roma Sapienza) et al., conducted dose measurements at high energy in the FLASH regime using synthetic diamond-based Schottky diodes operated at zero bias voltage. In this experiment (see Figure 8a), BTF provided a custom-designed flag holder (designed with T. Napolitano, LNF-SPCM) to trigger BTF cameras on Nd:YAG flags in an optical lock-in regime, combining BTF ICT measurements with spatial reconstruction. The 510 MeV electron primary beam was used for shot-by-shot dose measurement, reproducing the electromagnetic shower dose release in PMMA at varying depths. This approach allowed for a comparison of diamond-based active dose measurements with EBT3 GAFCHROMIC film, marking the first trial of diamond dose detectors in the low-energy regime.

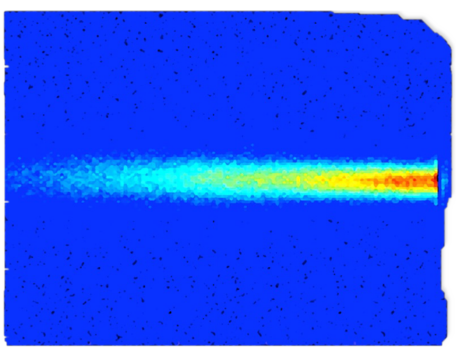
- New beam charge measurement in air – FLASHDC - A. Trigilio (LNF), M. Marafini (CREF) et al. This experiment aims to measure pulsed beam charge and centroid position by means of SiPM array in a cylindrical darkroom. This readout is calibrated to read-out part of the fluorescence spectrum emission in air induced by the passage of 510 MeV primary electron beam. Because of the static installation of the setup, the centroid measurement was performed by steering the beam inside the detector itself. The charge measurements have been compared with those of the BTF ICT's, with single pulse charge tuning from 10 pC (lower ICT sensitivity range) up to around 1 nC range. In this explored range, the team's detector exhibits an upper saturation, while BTF is not ready to measure below the lower ICT sensitivity levels. Despite the reduced measurement range, the experiment demonstrated the detector's performances in terms of linearity, centroid sensitivity and the understanding of the detector's capabilities [1]. The BTF team is already involved in developing a detector that could exploit a more extended range of primary intensity tuning.



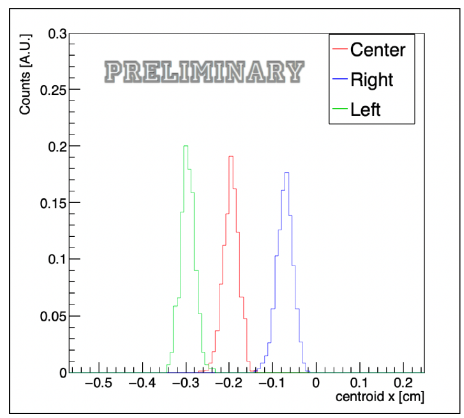
(a) Setup for DIAMOND for VHEE, where the BTF Flag holder refactoring is visible on the cylindrical PMMA block.



(b) Setup installed in BTF exit flange for FLASHDC experiment



(c) MORSEPET Single shot electromagnetic shower, courtesy of M. G. Bisogni



(d) Reconstructed BTF beam centroid position with FLASH DC setup, courtesy of M. Marafini

Figure 8: FLASH-VHEE related experiment conducted in BTF halls

8 Dissemination and Contributions

Throughout the year, significant progresses were made in educational and outreach initiatives, largely driven by the efforts of E. Diociaiuti and D. Di Giovenale. The activities included a diverse range of events targeting various groups, from school professors and PhD students to primary and lower secondary school students. Notably, the LNF guided tour and lab events saw the highest engagement, with 1125 and 1720 participants, respectively. This comprehensive approach not only highlights the dedication to fostering educational growth but also underscores the commitment to community engagement.

Event Type	Target	Participants
Professional Tutoring	Secondary School professors	50
PhD Tutoring	PhD Student	22
Undergraduate Tutoring	Post-High school University student BTF user	22
LNF guided tour	University and Secondary school	1125
PCTO	Last year of Secondary school	30
Childhood guided tour Tutoring at school	Primary and Middle school	357
Laboratory events	IDWS,Open Day, Inspyre, (...)	1720

Table 3: List of outreach activities carried out by the BTF team

BTF congratulates S. Bertelli and her team [5] for their dedicated efforts in accelerating the dissemination of scientific knowledge both within Italy and internationally. We are grateful to be able to participate in this tremendous achievement.

8.1 Selected Publications Citing BTF

Moreover, around 20 papers citing BTF were published between January and November 2024, with positive feedback from users. A selection of the publication can be found in the following subsection.

- Cantone, C., et al. "Research and Development Status for an Innovative Crystal Calorimeter for the Future Muon Collider." IEEE Transactions on Nuclear Science 71.5 (2024): 1116-1123.
- Gargiulo, R., et al. "Development of a sub-mm particle tracking detector based on a plastic scintillator with SiPM charge sharing." Journal of Instrumentation 19.12 (2024): T12006.
- Chiti, M., et al. "Photon and neutron dose evaluation at the Beam Test Facility of the INFN-National Laboratory of Frascati." Radiation Measurements 176 (2024): 107216.
- Bertelli, S., et al. "Design and performance of the front-end electronics of the charged particle detectors of PADME experiment." Journal of Instrumentation 19.01 (2024): C01051.
- Cantone, C., et al. "Crilin: a semi-homogeneous crystal calorimeter for the muon collider." (2024).
- Bertelli, S., et al. "Characterization of the PADME positron beam for the X17 measurement." Journal of High Energy Physics 2024.8 (2024): 1-23.
- Cantone, C., et al. "Developing an alternative calorimeter solution for the future Muon Collider: The Crilin design." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 1069 (2024): 169973.
- Avoni, G., et al. "Development of a sapphire microstrip detector for gamma beam monitoring." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 1068 (2024): 169752.
- Bertelli, S., et al. "Beam diagnostics with silicon pixel detector array at PADME experiment." Journal of Instrumentation 19.01 (2024): C01016.

- Antonelli, A., et al. (2024). Development of nanocomposite scintillators for use in high-energy physics. Nuclear Instruments and Methods in Physics Research Section A.
- Testa, Marianna, et al. "Direct detection of minimum ionizing charged particles in a perovskite single crystal detector with single particle sensitivity." Nanoscale 16.27 (2024): 12918-12922.
- Mancini, M. "Searching for X17 using resonant production at PADME." IL NUOVO CIMENTO 100.254 (2024): 47.
- Bertelli, S., et al. "Design and performance of the front-end electronics of the charged particle detectors of PADME experiment." Journal of Instrumentation 19.01 (2024): C01051.

9 ASIF-2 Project

The ASIF (Advanced Space Infrastructure for Radiation Testing) project, developed by the Italian Space Agency (ASI), focuses on studying the impact of space radiation on performance and the lifespan of hardware and materials used in space environments. This initiative involves various institutions engaged in scientific and technological research relevant to the space community.
The project is framed within the context of the New Space Economy (NSE), which is expected to reach a valuation of $1 trillion by the 2030s. This economy includes over 130 space agencies, 150 research centres, and more than 10,000 companies globally. In Italy, the NSE reflects trends in upstream, midstream, and downstream sectors, supported by a robust knowledge and education system.
Space radiation can cause various effects on electronic components, including:

- Total Ionizing Dose (TID)
- Total Non-Ionizing Dose (TNID)
- Displacement Damage (DD)
- Single Event Effects (SEE)

These effects can lead to cumulative long-term degradation, non-ionizing damage, and bit flips from single energetic particles. Mitigation strategies include shielding, specific rad-hard designs, and Radiation Hardness Assurance (RHA), which involves iterative design and testing methodologies. In order to discriminate the best mitigating actions, ground irradiation tests in representative environments are needed with scientific support.

The ASIF-2 related commitment includes:

- Calibration activities of space detectors with electron beams, exploiting the specific temporal and energetic properties of the BTF.
- Feasibility study of irradiation campaigns and radiation damage measurement with electron beams on space components (electronics and sensors).
- Maintenance and updating of the test facility and systems for measuring the intensity and fluence of test beam particles

9.1 ASIF-2 Project Partnership

ASIF-2 is a coordinated approach to create a national network supporting customers and scientific research on radiation hardness assessment for space projects. It leverages top-notch research labs and irradiation facilities, shared strategic vision from ASI, ENEA, INFN, and Università degli Studi di Milano Bicocca (UniMiB), and dedicated professionals.

The ASIF network includes several facilities across Italy, each contributing to different aspects of radiation testing:

- Calliope: ENEA γ-irradiation facility at Casaccia, used for Total Ionizing Dose (TID) testing.
- FNG (Frascati Neutron Generator): ENEA, Frascati, this facility is used for Displacement Damage (DD) testing with neutrons.
- Tapiro Reactor: ENEA reactor at Casaccia, providing fast neutron irradiation for DD testing.
- Triga RC-1 Reactor: ENEA reactor at Casaccia, used for thermal neutron irradiation for DD testing.
- TOP-IMPLART: ENEA proton irradiation facility, used for TID testing with protons.
- REX: ENEA low energy electron irradiation facility in Frascati, used for TID and TNID testing.
- **BTF-LNF**: This facility provides a high-duty-cycle electron beam with a bunched structure, suitable for Total Ionizing Dose (TID) and Total Non-Ionizing Dose (TNID) testing. The BTF is known for its advanced electron beam capabilities, essential for simulating space radiation environments and testing the resilience of electronic components.
- Laboratori Nazionali del Sud (LNS): LNS specializes in high-intensity ion and proton beams. This facility is used for both TID and SEE testing.
- TIFPA (Trento Institute for Fundamental Physics and Applications): TIFPA provides stable proton beams, originally developed for medical therapy, now adapted for space radiation testing. The proton beams at TIFPA are used for TID and SEE testing.
- UniMiB University: Collaborating with INFN on various aspects of the project, including web portal management and dose simulators. This collaboration ensures that the ASIF project benefits from cutting-edge research and technological advancements in radiation testing.

These facilities provide a comprehensive infrastructure for conducting irradiation tests and studies, ensuring that the ASIF project can achieve its ambitious goals of enhancing the resilience and reliability of space technologies.

From ASIF-2, BTF received funding of 83k for personnel, 32k for infrastructure.
ASIF-2 will continue for the next two years, with annual meetings and reviews.

10 New DCS Development - EPIK8S

BTF has played a crucial role in the development of !CHAOS, a system that has been in use since 2011. The latest DCS standard being implemented is EPIK8s ("EPICS on Kubernetes"), which is also designed for the DCS implementations of EUPRAXIA and ELI-NP. This system is based on EPICS but integrates significant advancements in cutting-edge technologies for systems management, including containerization and orchestration, even in cloud environments. The user tools have evolved from those developed for !CHAOS, offering enhanced functionality and an improved user experience.

10.1 EPIK8S LNF Framework

EPIK8s is a framework designed to facilitate the deployment and management of EPICS (Experimental Physics and Industrial Control System) on Kubernetes clusters. It offers scalability and flexibility, allowing it to scale easily across facilities and support large, distributed systems. The framework simplifies deployment through ArgoCD, reducing manual setup time, and enhances fault tolerance with automatic restarts and dynamic service reallocation, ensuring consistent system uptime. Containers provide isolated, resource-efficient environments that improve performance. EPIK8s establishes a common platform, streamlining collaboration between research institutes.
Currently, the deployment of infrastructure and computing capabilities has been assigned to the SICR and SATC Services of the Lab. The development of the new IT infrastructure project, which will replace the current test area, is still ongoing and is scheduled for installation in 2025.

10.2 EPIK8s and other upgrades in BTF

EPIK8s supports the control of various components such as magnets, motors (scrapers), and triggered cameras (flags). Additionally, specific developments have been tailored to BTF's needs, including HV crate control, PTU sensors, and the integration of LABVIEW with EPIK8s channels via JSON exchange. The contributions of A. D'Uffizi, R. Esposito, F. Galletti, R. Gargana, and A. Michelotti have been instrumental in these advancements.
In addition to the EPIK8s controls, additional Python-based tools have been developed like PyFitPix, PyStatus, and PyGenny, which manage BTF detectors and subsystems in terms of data collection and visualization.
While the system has been refactored to better suit BTF's requirements and new features have been introduced, the full migration is still in progress. Maintaining compatibility with existing data files remains a priority, and efforts are underway to enable access to older datasets.

10.2.1 Magnets, Scrapers, and Cameras

The Process Variables (PVs) of the main BTF subservices have significantly improved the implementation of the BTF setup and its automation, allowing a simplified user setup selection. In the two experimental Hall, the status of temperature, humidity, and pressure is read from a PHT sensor, transmitted as JSON to Memcached, and then forwarded from Memcached to the corresponding PVs. Similarly, vacuum status is handled by LabVIEW producers that send data to Memcached, which is subsequently transferred to PVs.

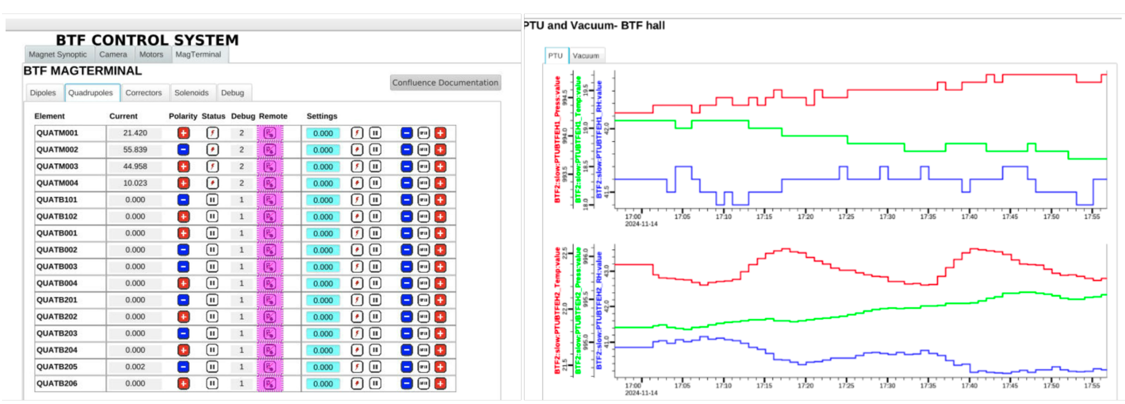


Figure 9: Phoebus interface for magnet control (left) and status of PHT and vacuum (right)

10.2.2 Power Supplies

The EPICS IOCs are implemented directly by CAEN, enabling full monitoring and control of all boards and channels. The system visualizes the relevant PVs over time, offering a comprehensive view of power supply status and performance.

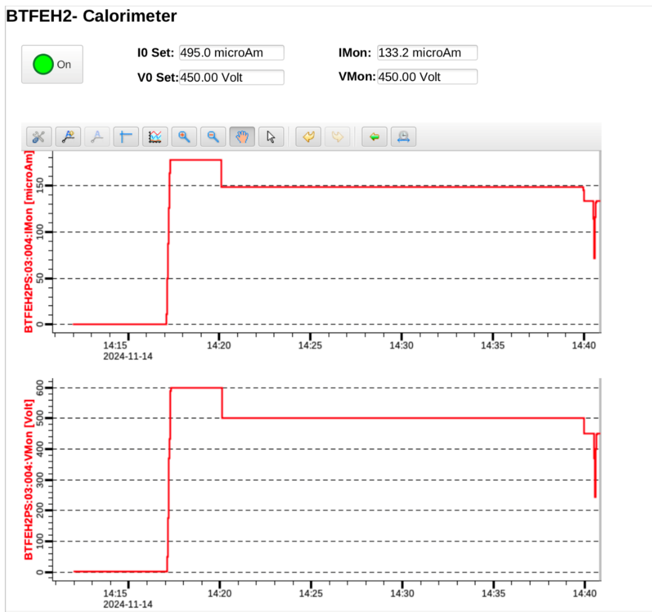


Figure 10: Phoebus interface for CAEN HV power supply control

10.2.3 Genny and PyFitPix

PyFitPix reads pixel data from Memcached, similar to the LabVIEW interface, and enables the saving of ROOT files containing pixel data, timestamps, and other relevant information. This tool has proven particularly useful for users, as it allows them to save ROOT files for later analysis. Moreover, a Python-based GUI has also been developed to display the charge deposited in the 9 crystals of “Genny”, a BTF calorimeter used to study particle multiplicity in low-energy regimes, where the lead-glass detector is no longer effective. This tool retrieves data from Memcached, generates ROOT files, and provides online monitoring of the channel statuses, offering users real-time insights into the beam status.

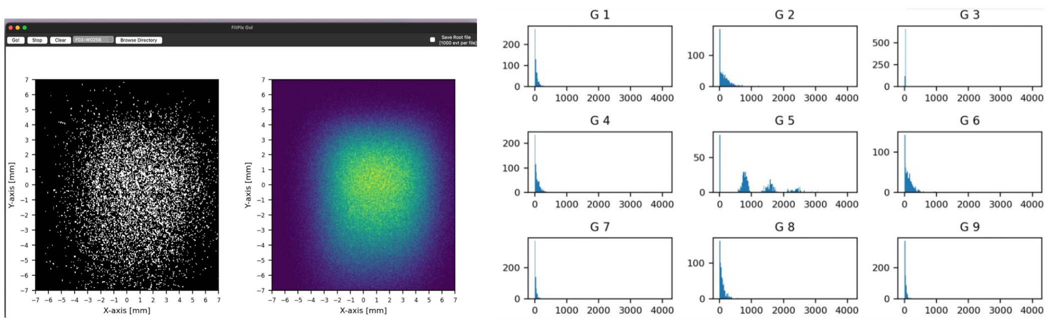


Figure 11: Left :Image of the pyFitPix Gui, allowing centroid visualization and data saving in ROOT format. Right: Image of the Data visualization of pyGenny. The beam was firing the central crystal of the matrix with low multiplicity

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10.2.4 PyStatus and Grafana

PyStatus reads LINAC status from Memcached, including details on particle delivery, mod ON/OFF, and gun ON/OFF status. All significant archived PVs are displayed in Grafana, continuing the hybrid development to include all BTF control services for users.

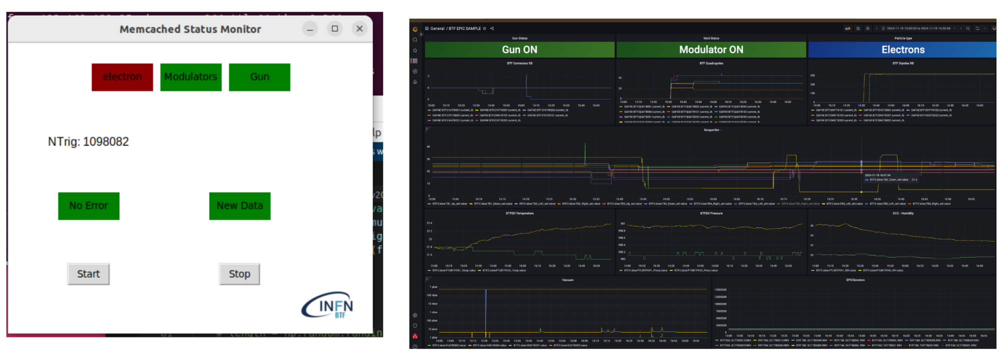


Figure 12: Left:Image of the GUI used to visualize the status of the LINAC and BTF and play a sound alert. Right:Screen on the new Grafana page

10.3 OLOG

Starting in the second half of 2024, the OLOG electronic logbook was integrated into the BTF with the support of the SICR and Control Service. Based on feedback from the BTF team, the system has been gradually adapted to meet the facility's specific operational needs. By the end of the year, this collaboration resulted in the deployment of a customized version of the service, featuring INFN-wide LDAP-based authentication..
The logbook now interfaces with the EPIK8s control system, allowing for the automatic saving and retrieval of magnet and scraper configurations. OLOG is accessible both via a web browser and directly through the Phoebus control interface. Further developments and service improvements are expected to continue throughout 2025, including OAuth2 plus OIDC based authentication.

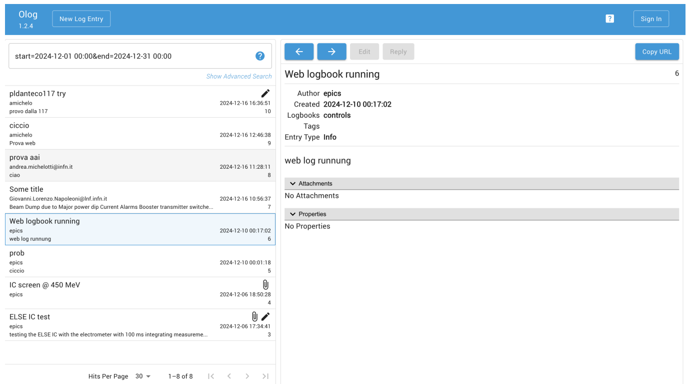


Figure 13: First test of OLOG web interfaces performed in December 2024

11 Booking Management Software

The BTF booking management software [4] is based on an automated approval workflow that manages external user calls, internal and external activity bookings, and the process from experiment proposal submission to territorial access. It is integrated with the INFN authentication and authorization infrastructure (INFN-AAI). The system handles weekly, last-minute shifts, withdrawals, and re-bookings through a strategic workflow, supporting over 400 users with automated shift management. It has completed more than 100 bookings for BTF development.
Some other INFN facilities used or intend to use the three different software versions (Fig. 14, even if the typical developing time for a new one (based on the existing three) is around three person-month in full customization from design to initial development, then test-debug phase.
Five forks were established. The features related to each of them can be found in Fig. 14.

- INFN-LNF BTF
  - More than three years of continuous developing, internal activities, and external users for call or fast booking
  - Almost two years of continuous operation with users
- INFN-LNF DAΦNE-L Facility
  - Released a few months ago, internal activities and external users for call or fast booking, with sample-mailing capabilities
  - Final approval state
- INFN-LNF PLC/UTA remote control
  - Released two years ago, for Conference room booking related automation control
  - Developed for LNF Technical Division, yet to be evaluated
- INFN-LABEC
  - Released a few months ago, internal booking management
  - Collaboration born on INFaN 12)

- INFN-LNF FISMEL7
  - In final developing, for radioactive source managing

Where t

Facility Booking Software version	User Type	Booking type	Workflow type	Auth Management workflow	Calendar management	User Management	Reports and Documents Management	Booking period
BTF	External, internal, (GODIVA LoA2)	• External user Call • On demand	BTF like	• Secretariat • Management	Users' selection, management allocation	Secretariat explicit approval (automatic role creation for new no-INFN users, dynamic)	In the call proposals	Weekly
DAFNE Light	External, internal, (GODIVA LoA1 LoA2)	• External user Call, • On demand, • Sample mailing (no team)	BTF like extended	• Management • Beamline scientist • PAC	Management allocation	Implicit (no automatic role creation, user already associated)	At experiment ends	Daily/Weekly
LABEC	Internal (GODIVA LoA2)	Internal Management	Linear	Management	Management allocation	None	At experiment ends	Daily
FISMEL	Internal (GODIVA LoA2)	Internal User	Linear	Management	Users' selection	Internal (GODIVA LoA2)	At experiment ends	Open up to 30 days

Figure 14: The feature schema of the different Booking software versions currently in operation.

The workflow for each fork is complex, handling short-request bookings, long-call settlements, and rebooking, as well as sample mail-in bookings. The new GUI features a modern UI design and technologies, providing each user with a personal space to find and upload documents, proposals, and manage the various phases of the territorial access workflow to the facility infrastructure, ensuring the safe execution of experiment-related activities.
In 2024, a new version of the GUI was developed, incorporating all the listed capabilities and providing dynamic representation for different management levels.

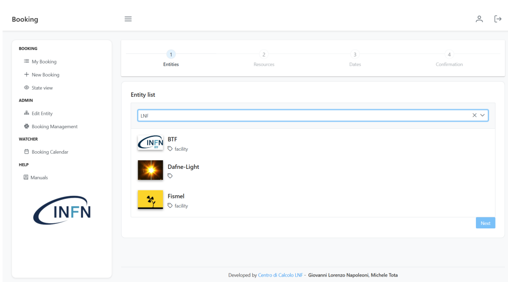
The Booking Software is continuously being developed by G. L. Napoleoni (LNF Computing Center, lead developer), R. Orrú, M. Tota, and G. Papalino, in collaboration with the BTF group and the LNF Secretariats:

- AD-Secretariats (M.R. Ferrazza, G. Vinicola, V. Rosicarelli)
- Personnel-Secretariats (G. Dalla Vecchia, F. Triolo, L. Occidente, A. Mininni)

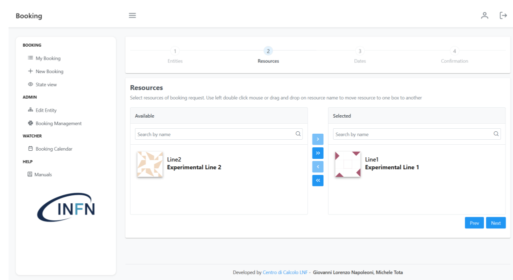
12 Irradiation National Facility Network - INFaN

The proposal was initiated within the INFN-A [6] environment to establish an internal INFN network connecting irradiation facilities dedicated to external users. This proposal is based on a shared vision of abstraction and synergy among the various scientific, technological, and technical management experiences of irradiation facilities across the national territory, all under the management of INFN. Its objectives are:

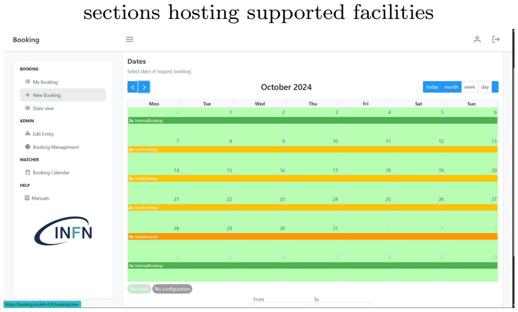
- **Internal network**: Establish an internal network within INFN to facilitate the exchange of scientific, technological, technical, and infrastructure resources between irradiation facilities for mutual operational benefit.



(a) Selection page of Bocking software, with INFN sections hosting supported facilities



(b) Next page of Fig.15a, with line display for selection of the selected facility



(c) Booking admin page, calendar view

(d) team leader view for checking team status

- **Generalized infrastructure with INFN national IT services**: Develop a generalized infrastructure based on national services, including information sharing, beam time calls, and access procedures for INFN irradiation facilities serving scientific and third-mission purposes, while respecting the usage norms and local practices of each facility, which will be integrated into an abstract IT infrastructure.
- **Common Funding**: Establish a fund to implement innovative and experimental operational solutions (e.g., detectors, hardware, and software infrastructure) for shared ownership and common use, as well as to support and sustain the network itself.

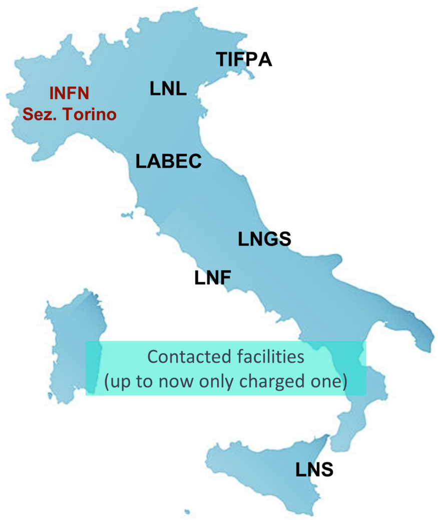
BTF plans to dedicate one or more weeks per year of each facility's machine time to INFaN activities, including detector tests, hardware tests, and control. We are currently working to establish all aspects of the infrastructure and apply it to the facilities participating in INFaN

12.1 An example: LABEC-LNF Collaboration

During the summer of 2024, a major fault in the cabinet mains caused burned components on the LABEC Control PLC. Since recovery from the manufacturer was not possible, LNF-LINAC Technicians (G. Piermarini and M. Ceccarelli) identified the problem and refurbished parts from discontinued products. In less than two weeks, the components were repaired and installed, with teams from both labs utilizing the INFaN network to facilitate contact between lab personnel and expertise.

13 FIREBALL@LNF

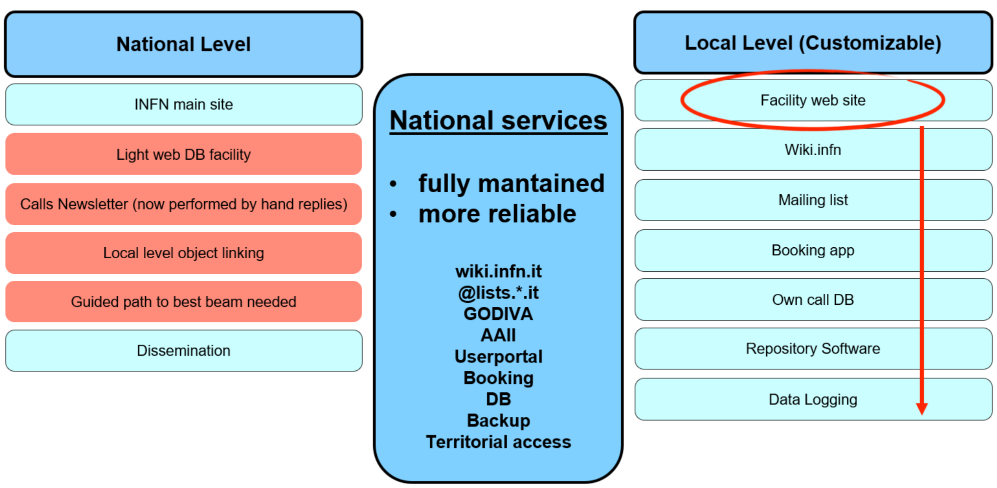
In 2023, the BTF group was contacted by the Oxford group (G. Gregori, R. Bingham) to explore the possibility of implementing a setup in BTFEH1 for conducting long-term experiments in the



(a) Regional distribution of the INFaN facilities

Key contacts	
INFN-LNF	Luca Foggetta
INFN-LNS	Giada Petringa
INFN-LNL	Luca Bellan
INFN-LNGS	Matthias Junker
INFN-FI	Mirko Massi & Massimo Chiari
INFN-TIFPA	Francesco Tommasino & Enrico Verroi
INFN-TO	Simona Giordanengo

(b) List of the refering people



(c) INFaN actions for a common IT layout

Figure 16: INFaN network specifications

field of astrophysical measurements in laboratory. The scientific case is based on the need to understand the complex interplay between relativistic particle beams, plasma instabilities, magnetic fields, and radiation production, which is crucial for explaining observations of gamma-ray bursts (GRBs), fast radio bursts (FRBs), and cosmic-ray acceleration. Telescopes are unable to resolve the microphysical processes involved, and computational modeling of the interplay between macro- and micro-scale processes necessitates the use of very costly simulations due to the wide variety of length scales involved.

To study the mechanisms behind particle acceleration and GRB formation in astrophysical environments, the collaboration proposes three experimental programs, with modular implementation across three phases. Each phase will involve data taking and setup over periods ranging from a few months to a year. The program is compatible with high-intensity operations for external users and will require design, procurement, and technician time from LNF.

In 2024, the BTF formed a large team to study the feasibility of the experiment resulting in a LOI presented to the 68th LNF Scientific Committee.
The collaboration is established with bi-monthly meetings, where both sides contribute to advancing the experiment proposal. The current areas of interest identified by LNF are:

- The SIDDHARTA group, following the activities of C.O. Curceanu in managing the collaboration and the detector area of FIREBALL measurement interests, especially in the X-ray and γ-ray range.
- LINAC, BTF, and the LNF Magnet Service (A. Vannozzi, A. Trigilio) have begun studies to develop a Flux Concentrator magnet aimed at optimizing the collection of quasi-neutral beam charge from a target, which is intended to shower the primary LINAC beam transported through BTFEH1, down to the DHSTB002 magnets
- FISMEL Service (A. Esposito, F. Chiarelli) is exploring the target design and the feasibility of the experiment from a radioprotection point of view, by developing a full BTFEH1 area in FLUKA [10] environment.
- The FLAME group (A. Ghigo, M.P. Anania) has offered the possibility of lending BTF a two-head high-power laser, which is currently decommissioned from the FLAME setup, to support the study of neutral/charged beams with high photon flux concurrent injection.
- The SPP Service (S. Vescovi, P. Ballerino) has been invited for studying the feasibility of the BTF installation required by FIREBALL, specifically focusing on the RF fields needed to generate plasma in two different cells downstream of the target.

The BTF related activity worked alongside different LNF seminars conducted by Prof. G. Gregori (Department of Physics, University of Oxford, UK) and R. Bingham (STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK and Department of Physics, University of Strathclyde, Glasgow, UK) then talk and the aforementioned Letter of Intent (LOI) submitted to the 68th meeting [2] of the LNF Scientific Committee, preceded by the talk "Unveiling the Physics of Relativistic Pair Plasma Jets in the Laboratory" with the related astrophysical scientific interests at the 67th LNF Scientific Committee meeting [3].

14 Acknowledgments

The results of the LINAC/BTF operations need to be shared with all LNF personnel involved, including DT and DA services, secretariats, and administrations, especially the DAΦNE operators. It is also beneficial to share knowledge about cutting-edge detector physics and technology with users, forwarding the users experience to the rest of the scientific community, far beyond HEP area. The primary function of the BTF is to enhance the experience of external users before, during and after the beam time itself. This is achieved through the relentless scientific consultancy work provided 24/7 by the highly skilled Beam Line Scientists who form the team. Their expertise has been repeatedly acknowledged by the users themselves, who owe a debt of gratitude for the profound dedication that sustains this facility.

Acknowledgments for EUROLABS Project

BTF is supported by the European Union's Horizon Europe Research and Innovation programme under Grant Agreement No 101057511 (EURO-LABS), that forward transnational access to the facility by foreign users.

Acknowledgments for ASIF-2 Project

BTF is supported by the ASI-INFN Cooperative Agreement 2024-21-HH.0 “ASIF - ASI Supported Irradiation Facilities, Sviluppo Operativo”, for develop the facility in space related application.

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3. R. Bingham et al., "Unveiling the Physics of Relativistic Pair Plasma Jets in the Laboratory" talk at 67$^{\text{th}}$ LNF Scientific Committee, Laboratori Nazionali di Frascati, May 27-28, 2024 https://agenda.infn.it/event/41331/timetable/?view=standard

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