LINAC-BTF ACTIVITY REPORT 2020

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1 Experimental activities, beam time and outreach

The LINAC-BTF group, during 2020, was mainly involved in this chapters:

- Recover first line of BTF from vacuum fault for PADME run
- Build a second beam-line and experimental hall
- DAFNE run (up to Feb. 2020)
- Experimental runs (July 2020-Dec. 2020)
- E-rad project (from June 2020)
- Maintenance and consolidation of the LINAC

The pandemic emergency had interrupted machine operation from March 2020 up to May 2020. In this period, only logistics, software upgrade and maintenance operations took place, coordinated with the LNF safety service and allowed by the national legislation for the pandemic status. This event required a reschedule of the activities to be ready for the activities, executed in the remaining part of the year.

2 Introduction

The Beam-Test Facility (BTF) is an infrastructure mainly dedicated to the development and testing of particle detectors, providing electron or positron beams with tuneable energy from 30 MeV to 800 MeV, while the intensity (multiplicity) can be varied from 10^{10} particles/pulse, down to a single particle per pulse in a Poisson stochastic regime. The facility is successfully running with an average of 200 beam days/year, 25-30 experimental groups, 150-200 users booking since 2004 apart from a few minor stops. It is commonly booked for several applications ranging from detector development, characterization and calibration, to beam-diagnostics testing. Less frequently, BTF hosted high-intensity runs for electrons and neutrons photo-production irradiation purposes, high-intensity studies of electro-magnetic phenomena, photon-beam testing, and fixed-target experiments. Starting from the second half of 2017 the Beam-Test Facility (BTF) of the Frascati accelerator complex DAFNE was the object of two topics:

- a fixed target experiment with permanent installation, PADME,
- and a major upgrade, with the main purpose of splitting the existing beam-line and adding a second experimental hall for user activities.

Since 2017, a good portion of the activities was devoted to the PADME experiment beamtime, in 2018 its commissioning and installation, starting in April. In the meantime the BTF group develop and prepare the doubling line project and its installation, stopping the user activities until June 2019. The commissioning of the BTF beam for the PADME experiment occurred in July 2018, at the end of the PADME technical commissioning. The BTF started delivering secondary

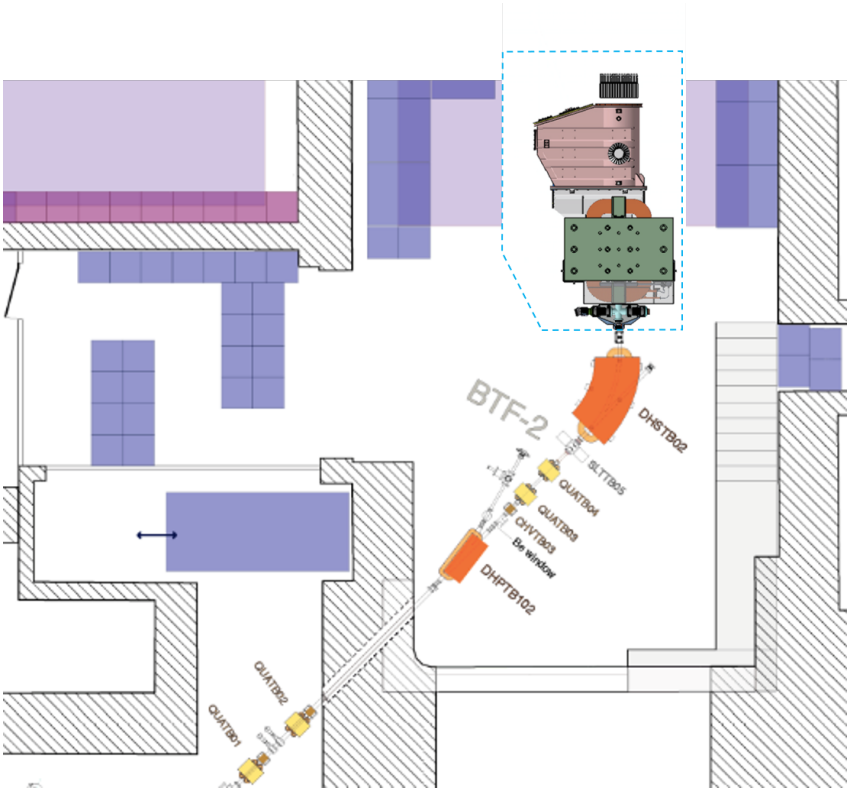

Figure 1: The DAFNE Beam-Test Facility (BTF), PADME experiment position and the second beam line for 2019 users beamtime call

positron beam in September 2018 for the first PADME run, achieved in March 2019. After the DAFNE duties with SIDDHARTINO run and achieved the BTF 2019 users call, the LINAC had been turned to new PADME parameters, with a lower beam energy demand and the duty to improve gamma background on PADME detectors, thus using a conditioned primary positron beam from LINAC. The PADME technical run started on the firsts of July 2019.

3 Recover the BTF line 1

At the end of July itself, a vacuum vent event occurred during the accomplishment of a vacuum window position change, asked from PADME to improve the positron-photon background. This event stopped the operations since it involved both of the two lines causing their almost complete dismantle. The event restoring and the subsequent refurbishing had stopped the further hall activities for the rest of 2019. In the mean time, the BTF team continued the development of the BTF upgrade project up to the single elements commissioning. At the end of 2019 and begin 2020 thanks to the coordinate efforts of the Accelerator Division Services and LNF Safety, FIS-MEL, Technical ad Administrative Departments, was implemented a temporary recovery of the BTF line 1 for PADME run that, accordingly the pandemic situation, started in July 2020, delaying the second line installation at the end of this specific run.

4 BTF doubling line project

The aim of this project is the realization of the splitting of the existing Frascati beam-test facility (BTF) into two branches (so-called BTF1 and BTF2), allowing to run two different beam-lines. The project entailed a new design on the final part of the previous beamline splitted for serving two different experimental (further called BTFEH1, the existing area, and BTFEH2, the newer one) areas and thus creating a new experimental hall, the related shielding, a new control room and the improving principal LNF-LINAC features, extending LINAC lifetime.

This is realized by sharing the beam from the LINAC employing a pulsed 15° dipole (<100 ms ramp, DHPTB102) and a two-way vacuum pipe, on two new beam-lines, with a second set of beam diagnostics for the monitoring of the beam intensity, of the spot size and position. The design of the two beam-lines, the project of all-new elements, the improvement of the vacuum, power, cooling and conditioning systems, as well as the modifications to the building has been completed in-house by the Frascati staff. During 2019, due to the technical stop of the PADME experiment, the overall activity upgrade and to permit a reduced user run, the first sections of the BTF2 line was fitted in the existing experimental area, using the first part of the second beamline, downstream of the new DHPTB102, a fast ramping magnet used for steering beam away from BTF1 line, used for PADME injections [1)]. During both of these activities, PADME run and user beam time, the BTF maintained the previous standard, granting access to various services available at the LNF $DA\Phi NE$ accelerator complex, such as power supply, networking, gas system, DAQ, high voltage, vacuum, alignment, magnetic fields, user assistance and shifters.

In the new configuration, the beam-line is split into two branches immediately after entering the BTFEH1, in order to share the available beam pulses between two different experimental setups; the final part of the existing beam-line is also slightly modified:

- The BTF-1 is dedicated to medium and long-term (more than few weeks, up to several months) installations or high-intensity applications requiring the extraction of the full LINAC beam, and essentially replicates the existing beam-line, downstream of the splitting magnet DHPTB102.
- The BTF-2 is intended instead for short-term (from one to few weeks) beam-tests, mainly at medium and low beam intensity, and stems from the DHPTB102 pulsed 15° dipole.

The final design of the new beam-lines has been carefully optimized to get the required beam parameters on both branches, in particular, around millimetric beam spot size and less than 1 mrad beam divergence at 500MeV. The main characteristics of the new beam-lines are fully described in [2)]. The upgrade activities in 2020 were continued following pandemic restrictions, getting all the needed items at the end of June and preparing halls and services to be ready for the BTF2 installation, immediately started at the end of the PADME run after an experimental run with a 2019 delayed user.

5 The PADME runs

The BTF-1 is routinely operational since September 2018, apart from the stop described in the previous chapter. The PADME RUN 1 ended the 1^{st} March 2019. During the PADME RUN1, the collaboration needed more than 550 MeV positrons beam whose main parameters were: 25000 positron per bunch, flat distributed, in a minimum of 250ns beam bunch length and less than 2x2 mm. At the end of the RUN1, during beam setup trials was clear that the PADME detectors probably gain a better signal to background ratio if the positrons beam will be produced in the LINAC positron converter target and not as a secondary beam by the BTF target, close to the BTF Hall 1 area and source of secondary unwanted photons. So we implemented a new way of

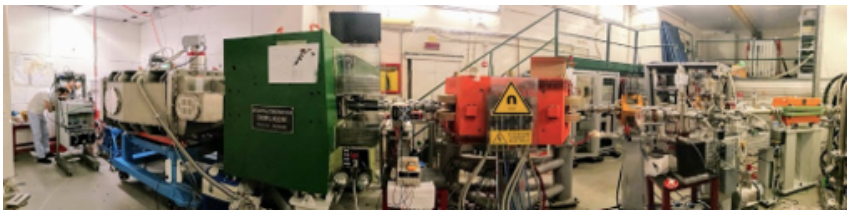

Figure 2: The DAFNE Beam-Test Facility (BTF), an overview of the 2019 layout: PADME vacuum chamber and detectors on the left, BTF2 line on the right

transport primary long beam with a limited energy spread by tuning LINAC modulator and gun timing parameters for primary positrons beam.

The positrons primary beam produced by the LINAC has an energy of 490 MeV, lower respect the energy required by the PADME experiment, but could have easily more than the 25000 positrons distributed in the 250 ns pulse length requested. This LINAC-BTF operations procedure and parameters were structured to reduce the radiation damage of the active elements, controls of the collimators and other plastic elements, as the safety mylar window, in the transfer line near the BTF target, hardly interested during the PADME RUN1. This duty was accomplished by lowering at minimum the gun emitted current (i.e. under the sensitivity of BPMs), letting few essential diagnostics elements in range to detect primary beam data.

During RUN1, attention was towards the vacuum window that divided the dynamic vacuum of PADME (that is at the level of (10^{-7} mbar) from the vacuum of the transfer line(10^{-10} mbar). This septum was identified by the experiment as a possible source of Bremsstrahlung interaction in a good portion of the impinging beam, leading to an increase of the beam energy spread at low energy, thus leading to beam undesired interactions with vacuum pipes after and in the middle of the DHSTB002 final steering. Accordingly to PADME experiment experts, the vacuum window was replaced in a new place, in LINAC tunnel upstream final scrapers (SLTB003 and SLTB004), with full pipe aperture and made by a single 0.125mm MYLAR foil. PADME needed a technical run (Tech-RUN2) to test their upgraded detectors and to investigate the new primary positrons conditioned beam from the BTF beamline. This technical run lasted from 3^{rd} July to the 8^{th} of August 2020 where BTF delivered $1,04E+12$ positrons on target (PoT), with a dedicated spot of a few squared millimeter area selected by PADME experts matching the PADME target hit requirements. In accordance to the PADME experts, the beam centroid energy was $431 \pm 1\%$ lowered from the maximum transportable in these conditions, formerly around 460MeV, due to the vacuum faults in the RF waveguide distribution from the klystron powered by modulator C, thus balancing a lower faults rate, faults not fully recoverable in the PADME assigned time slot.

At the end of this technical run, PADME reported that these two main improvements (conditioned primary beam and Mylar window) were crucial to minimize the secondary photon background. In the summer vacation, our group performed the needed overhauling of the exhausted LINAC elements and start new conditioning set to increase emitted power leading to an increased pulse time and energy beam centroid. These two parameters were pushed up to 330ns pulse length and 440 MeV but PADME preferred to remain to the well-studied Tech-RUN2 beam parameters for scientific and technical reasons. The scientific run, RUN2, injected PoTs starting on the 14^{th} September up to 3^{rd} December 2020 where BTF delivered $6.64E+12$ PoT, within a new dedicated spot of few squared millimeter area selected by PADME experts harmonizing again new PADME target requirements. The remaining parameters, as discussed earlier, were the same as the Tech-RUN2.

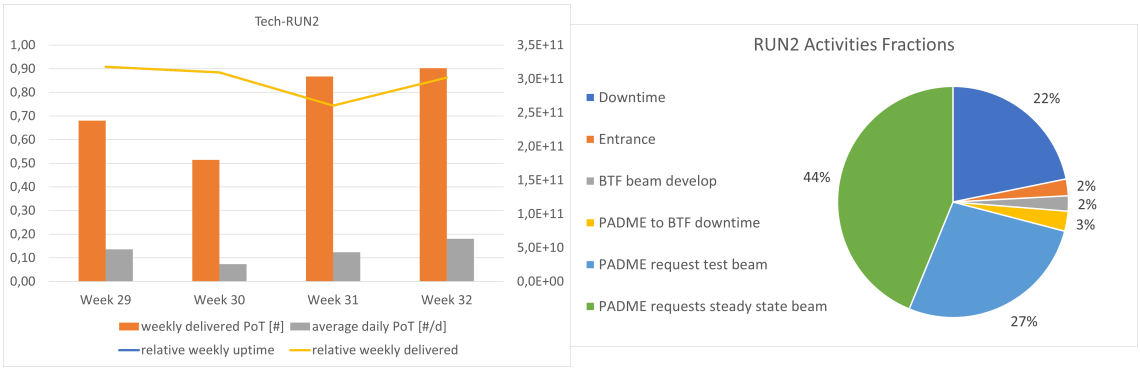

Figure 3: The injected PoTs on the left, the BTF fractional activities on the right, for the Tech-RUN2

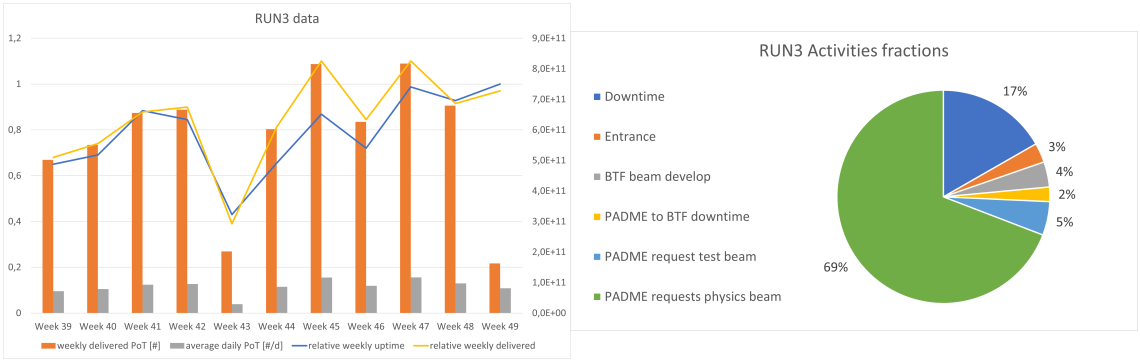

Figure 4: The injected PoTs on the left, the BTF fractional activities on the right, for RUN2

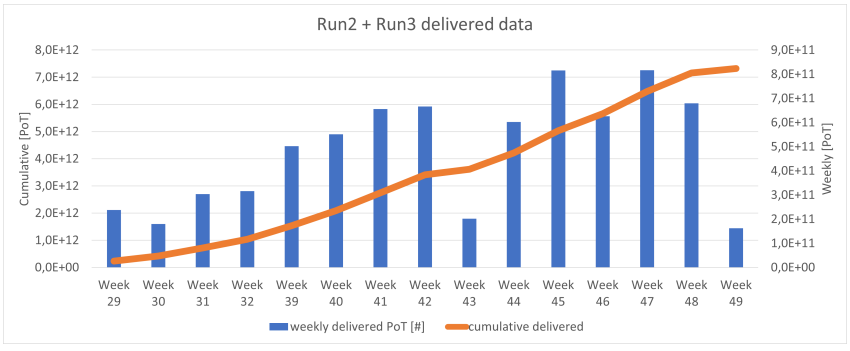

Figure 5: The overall data for PADME Tech-RUN2 and RUN2

6 e-RAD project

The general aim of the project is the use of electron sources, available at the INFN-LNF to measure the behavior and resistance of electronic components intended to be subjected to radiation in the aerospace environment. The values and results acquired with these measurements will be compared with homologous measurements performed with photons to define comparative resistance thresholds and related indicators. The first setup of the lower energy beam ever reached with this LINAC for the eRAD project is around 165MeV was done at the end of 2020, immediately after the PADME RUN2. The LINAC setup was deeply changed from the DAFNE one to obtain this energy with a primary electron beam with enough pulse charge that fulfills the irradiation test requirements: the last four sections of the LINAC were put in antiphase with respect to the previous ones for reducing beam spread and energy centroid. The project will continue in 2021 and 2022 with dedicated beam time to be assigned exclusively, out of DAFNE and users beam time. The project was funded by a regional fund [3].

7 LINAC Activities

The S-band linear accelerator was built to be the electron and positron source is now also being used to support the DAFNE accelerator complex and the Beam Test Facility (BTF) out of the standard way of operations. The existing klystron modulator in the Linac uses a 50 Hz high voltage power supply and adopts a traditional L-C resonant charging scheme. The original design of the TITAN BETA system for the FRASCATI linac employed a conventional DC high-voltage power supply based on a full-wave bridge diode assembly and a resonant charging circuit. The main component of high voltage charging power consists of a 3- phase variable phase control (SCR), a high voltage step-up transformer, a rectifier assembly and a charging inductance. After more than twenty years' operation, some components are no longer in good condition and circuit failure occurred often. The stability of the output high voltage is not satisfying especially when the AC line voltage fluctuations: one of the possible ends of this class of events is the circuit breaker trips caused by arcing at the load side during the 'On' state (before the recovery) of the thyratron. This problem is attributable to the DC high-voltage power supply, which sees the arcing as a short circuit. If an inverter power supply is used as an HV generator, it will just meet the demands and makes the overall system size smaller with a new generation modular implementation, improving the reliability of the highly demanded LINAC switching power scheme for the repeated production of positrons and electrons. With extensive field-tests, the modulator's high-voltage charging system has been redesigned to use a constant-current, high-frequency inverter power supply (EMI-303), which has 30 kJ/sec charging capability. in January 2020 the modulator D it's upgraded in the final configuration with the power supply in the modulator cabinet.

In 2020 different activities were implemented:

- New klystrons in modulator C;
- Linac online diagnostics;
- Modulator PFN and thyratron simulation;
- Linac maintenance;
- new vacuum pumps for klystron C RF distribution.

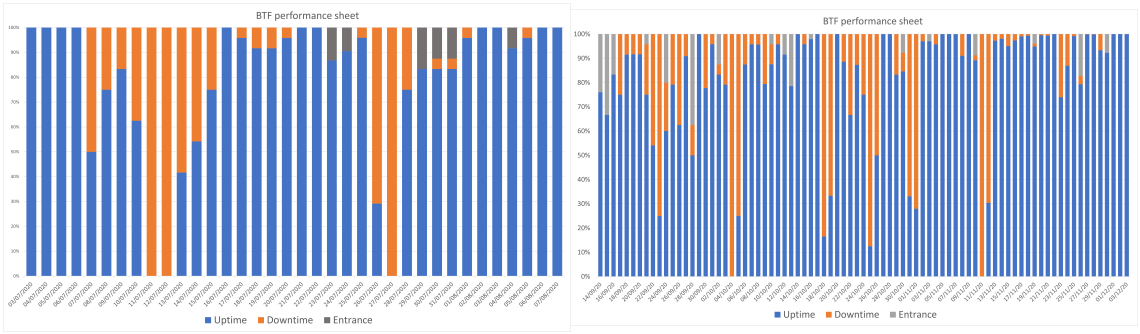

Figure 6: The performances of LINAC during the PADME Run2 and Run3

7.1 LINAC Setup change for PADME

In February 2020 a fault in the Variac of the filament power supply of klystron on modulator C was the clue that the klystron must be substituted after 11 years, for a short circuit of the klystron filament. The new klystron was installed and in 3 days thus the LINAC restarted to produce electrons and positrons for DAFNE.

Unfortunately after 1 month of operations, this new klystron had vacuum faults due to faulty installed elements that led the Klystron repaired by the factory.

The installation of the second new klystron was done few days again before the pandemic lockdown and the conditioning procedure was interrupted by the lockdown itself. The conditioning restarted in June 2020 but vacuum activities in the RF waveguide between the klystron and the SLED took a long time to be conditioned and they were the principal source of LINAC downtime. The maximum outputted power from the plant was 27 MW that reduced the maximum beam energy reachable, up to around 430MeV for positrons beam with a bunch length spanning from 250ns up to 320ns.

7.2 LINAC Online status

During the pandemic period, the activities of the LINAC-BTF staff were dedicated to implementing visualization tools for LINAC faults and the monitoring of all the elements under LINAC control system: vacuum, RF, HV, magnets, sections temperature. This allowed online monitoring of the LINAC status and a dedicated interface was developed for the klystron installed in modulator C for conditioning. In figure 7 a screenshot of the monitoring of klystron powered by modulator C during conditioning.

7.3 Modulator Simulation

In the same period, part of the LINAC-BTF staff developed a simulation of the LINAC modulator pulse starting from the measurement done before the lockdown and in collaboration with CERN experts. This allows us to produce a simulation in time-domain of the modulator under different tunable parameters, comparing its output with previous measurements as shown in figure 8 .

7.4 Linac Maintenance

During the PADME run in July 2020, different faults reduce the uptime for the experiment. Different faults on the SRC charging systems and in the same period on the diode on the 3 phase

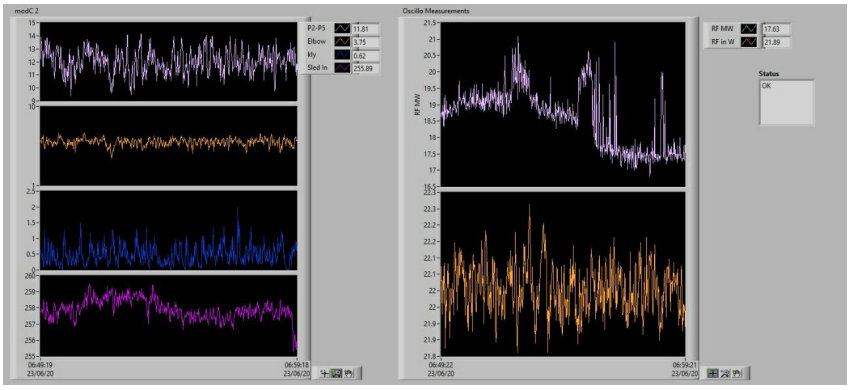

Figure 7: A screenshot of the monitoring of klystron powered by modulator C during conditioning.

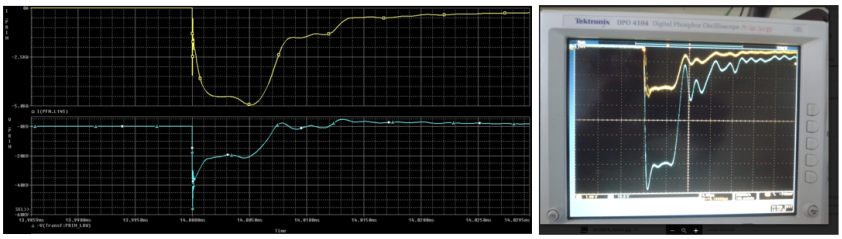

Figure 8: Simulations and measurements of the primary current (blue) and voltage(yellow) of the modulator.

of the HVPS power supply requested a study on the main power done by the Electric Service of the Technical Division.

In September and October 2020, some faults related to the thyratron trigger chassis and to the thyratron power supply on modulator C were fixed changing the elements necessary to restart the operation. These faults suggested the need for more maintenance periods for the aged subsections of the LINAC.

7.5 New Vacuum pumps on RF klystron C distribution

Before the PADME RUN2, was necessary to substitute (September 2020) a pump installed in the ModC Klystron RF waveguides and in the SLED section, as the online diagnostics in August suggested rescheduling the substitution of these LINAC ion pumps. Furthermore, in October 2020, a vacuum leak in the same ModC klystron RF waveguide was identified and fixed by the accelerator division vacuum service.

In accordance with the Vacuum Service we scheduled in December 2020 to substitute all the ions pumps on the remaining klystron C RF network and sections.

7.6 Outreach

Beam Line for Student 2020 is a CERN competition where teams of high-school students propose a scientific experiment with the possibility to perform in a beamline owing to a BL4S collaboration site. BTF was selected for its past contributions for the BL4S project but unfortunately this year, our participation as beamline site had to be canceled in autumn '19 and moved in the future, due to the delay in implementing the second beamline. We have continued our support in the BL4S competition as projects referee.

7.7 Acknowledgements

BTF staff warmly thank all the Lab people belonging to Acceleration and Technical divisions, FISMEL, RSPP, Administration for their incredible and brave support in this hard-to-live(and work) pandemic period.

References

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2. Bruno Buonomo, Claudio Di Giulio, Luca Foggetta, and Paolo Valente. Studies of the doubling of the Frascati Beam-Test Facility (BTF) line. Technical Report AIDA-2020-NOTE-2016-002, CERN, Geneva, Apr 2016.

3. eRAD is a project co-founded by Regione Lazio with the Progetti Strategici 2019 public call, within POS-FESR 2014-2020 program. https://www.laerospazio.enea.it/. Online.