THE FRASCATI LINAC BEAM-TEST FACILITY (BTF) PERFORMANCE AND UPGRADES*

B. Buonomo, C. Di Giulio, L. G. Foggetta†, INFN – Laboratori Nazionali di Frascati, Via Enrico Fermi 40, I-00044 Frascati (Rome), Italy.
P. Valente, INFN – Sezione di Roma, P.le Aldo Moro 2, I-00185 Rome, Italy.

Abstract

In the last 11 years the Beam Test Facility (BTF) of the Frascati DAFNE accelerator has gained an important role in the development of particle detectors development. Electron and positron beams can be extracted to a dedicated transfer line, where a target plus a dipole and collimator system can attenuate and momentum-select secondary particles.

The BTF can thus provide a wide range of beam parameters: energy (from about 50 to 750/540 MeV for electrons/positrons), charge (up to 10^{10} particles/bunch) and pulse length (1.5-40 ns), with a maximum repetition rate of 50 Hz.

Beam spot and divergence can be adjusted, down to sub-mm and 2 mrad. Photons can be produced on a target, and energy-tagged inside a dipole by Silicon micro-strip detectors. A shielded Tungsten target is used for neutron production: about $8\cdot 10^{-7}$/primary, 1 MeV neutrons are produced.

In addition to these activities, a dedicated particle physics experiment (PADME) has been recently approved for running at the BTF, with an intermediate intensity positron beam.

In order to cope with the increasing beam requests, an upgrade program of the facility has been proposed, along three main lines: consolidation of the DAFNE LINAC, in order to guarantee stable operation in the longer term; upgrade of the maximum beam energy to 1 GeV; doubling of the existing beam-line and experimental hall.

BTF LINE DESCRIPTION AND PRESENT PERFORMANCE

The Beam-Test Facility (BTF) of the INFN Frascati Laboratories is an extraction and transport line, optimized for the production of electrons and positrons in a wide range of intensity, energy, beam spot dimensions and divergence, starting from the primary beam of the DAFNE LINAC. Each of the 50 pulses/s accelerated by the LINAC can be either driven to a small ring for emittance damping (and from there injected into the DAFNE collider rings), or to the BTF line, by means of pulsed dipoles.

A variable depth target (from 1.7 to 2.3 X_0) spreads the momentum distribution of the incoming beam, then secondary electrons (or positrons) are momentum selected by means of a 45° dipole and collimators (in the horizontal plane). The beam intensity is thus greatly reduced, depending on the chosen secondary beam energy central value (from about 50 MeV up to almost the primary beam energy) and spread (typically better than 1%, depending on the collimators settings) [1].

The beam is then transported to the experimental hall and focussed by means of two quadrupole FODO doublets. The layout of the beam selection and transport line is shown in Fig. 1, together with the shielded experimental area.

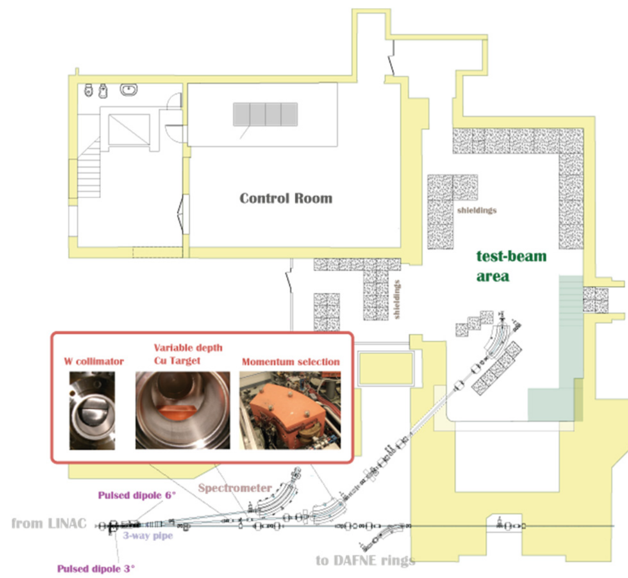

Figure 1: Layout of the BTF line and area, in the inset pictures of (from the left): Tungsten collimators pair, Copper beam-attenuating target, energy-selecting dipole magnet.

Availability and Flexibility

The facility can operate essentially in two different modes: "parasitic", when the DAFNE collider is operating and only LINAC bunches not injected into the rings are available; "dedicated", when the collider is not operating and all LINAC bunches are available for the beam-test. Considering the frequency of electron and positron injections for DAFNE and the number of available bunches, an average of 20 pulses/s is delivered for BTF operation.

The facility has been steadily operating since 2004, with an average of more than 200 beam-days/year, and 25 user groups/year. Beam time is generally allotted in one week shifts (Monday to Monday, 24/7 operation). A small fraction of the shifts have been dedicated to:

- production of tagged photons, by means of a dedicated active Bremsstrahlung target and energy-tagging system, made up of Silicon micro-strip detectors [2];
- electro-production of neutrons on a Tungsten target, shielded by an optimized assembly of polyethylene and Lead [3].

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Table 1: BTF Beam Main Parameters Achieved in the Different Operation Modes

Parameter	"Parasitic" mode		Dedicated mode	
	With target	**Without target**	**With target**	**Without target**
Electrons or positrons	selectable at BTF	depending on DAFNE injection	selectable at BTF	selectable at LINAC
Energy (MeV)	30-500	510	30-700	250-750 (e-) 250-550 (e+)
Energy spread	1% at 500 MeV	0.5%	1% at 500 MeV	0.5-1%
Intensity	$1\text{-}10^5$	$10^7\text{-}1.5\times10^{10}$	$1\text{-}10^5$	$10^3\text{-}3\times10^{10}$
Pulse length	10 ns		1.5-40 ns	
Repetition rate	10-49 particles/s (depending on DAFNE injection)		1-49 particles/s	

By using the horizontal and vertical collimators, the beam intensity can be tuned from several thousands down to "single" electrons per pulse, i.e. producing a Poisson distribution with a given average multiplicity, that is the preferred operations mode for the characterization and calibration of particle detectors [4].

The main parameters achieved in the two different operation modes, with and without attenuating the beam with the BTF target, are reported in Table 1.

DAQ, Diagnostics, and Services

We have implemented a number of diagnostics detectors, both for intensity and beam spot monitoring, in the full range of intensities (from the full LINAC beam down to single particle). A wide range of services are available in the experimental hall (shown in Fig. 3), such as gas, vacuum, networking, low and high voltage supplies, trigger and timing, etc. [5].

Data from the Silicon micro-strip [6], FitPIX [7] and GEM TPC detectors [8] are made available to the users thanks to a new software framework based on MEMCACHED [9].

FitPIX is a Silicon, 55 μm pitch, 256×256 pixels detector (14×14 mm^2 active area). A typical beam spot imaged at the reference energy of 450 MeV is shown in Fig. 2: a transverse size of the order of $\sigma_{x,y}$=0.4 mm has been achieved after optics and collimators optimization, mainly limited by the multiple scattering on the thin (500 microns) Beryllium window at the exit of the vacuum beam-pipe. However a beam spot of σ=5 mm was still achieved for an optimized 30 MeV electron beam.

The angular divergence is of the order of few mrad, strongly depending on the focussing and on the beam energy, and again the effect of the exit window is not negligible.

Further details on the high resolution transverse diagnostics can be found in these proceedings [10].

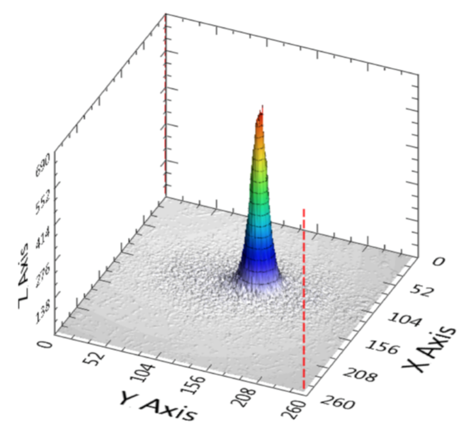

Figure 2: Typical 450 MeV electron beam imaged with the FitPIX detector (1 pixel=55 μm).

Figure 3: View of the BTF experimental hall showing the last part of the beam transport line, from the left: vacuum valve, quadrupole doublet (yellow), 45° beam switching magnet (orange), lead/polyethylene shielding box for neutron production target.

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BTF UPGRADES

The increasing number of requests for beam has motivated a wide program of consolidation and improvement of the facility [11], along three main directions: consolidation of the LINAC infrastructure, in order to guarantee a stable operation in the longer term; upgrade of the LINAC energy, in order to increase the facility capability (especially for the almost unique extracted positron beam); doubling of the BTF beam-lines, in order to increase the access capability, coping with the significant increase of users.

LINAC Consolidation

The Frascati LINAC is a 60 m long, S-band (2856 MHz), travelling wave, constant gradient linear accelerator modelled on the SLAC design. The 16 accelerating sections are fed by four RF power stations composed by line modulators powering 45 MWp klystrons with SLED compression.

The most critical parts of the LINAC sub-systems, are the modulators, and in particular their control and safety interlocks. Even though maintenance activities in the last years concerned mainly the RF stations, still a number of critical components are the original parts installed more than 20 years ago [12]. In order to carry on a complete refurbishing of the modulators a test RF station has to be built for the qualification and test of the new systems.

Energy Upgrade

In the present configuration a 15 m drift space is present between the end of the LINAC and the switch-yard driving the beam towards the DAFNE rings or the BTF line. This gives the opportunity of adding at least four SLAC-type accelerating sections, made up of 86 disk-loaded cells for a length of 3.05 m.

A fifth RF station, identical to the existing ones, with a 45 MWp klystron and a SLED pulse compressor, feeding the four new sections would allow increasing the final energy of at least 260 MeV, allowing to reach about 1 GeV for electrons and 800 MeV for positrons. The upgraded RF distribution layout is shown in Fig. 4.

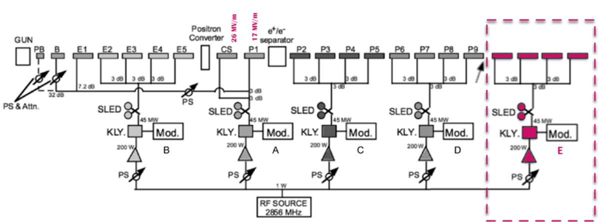

Figure 4: Proposed layout of the RF distribution for the upgraded LINAC.

A higher accelerating field (of at least 50%) can be achieved doubling the number of new RF stations, allowing to reach an energy gain of 90 MeV in the additional four accelerating sections.

Beam-line Doubling and Extended Pulse

Recently the PADME experiment for the search of new fundamental forces, in particular of a vector (dark photon) or axial-like mediator, has been approved, aiming at a sensitivity of $\varepsilon=10^{-3}$ for the coupling, in a mass range up to 24 MeV/c^2, using the annihilation of about 10^{13}, 550 MeV positrons on a thin target [13-15].

In order to host for a few years a long-term installation with the size and complexity of a full-fledged high-energy physics experiment, without severely limiting the use of the beam-test, a second beam-line has to be realized.

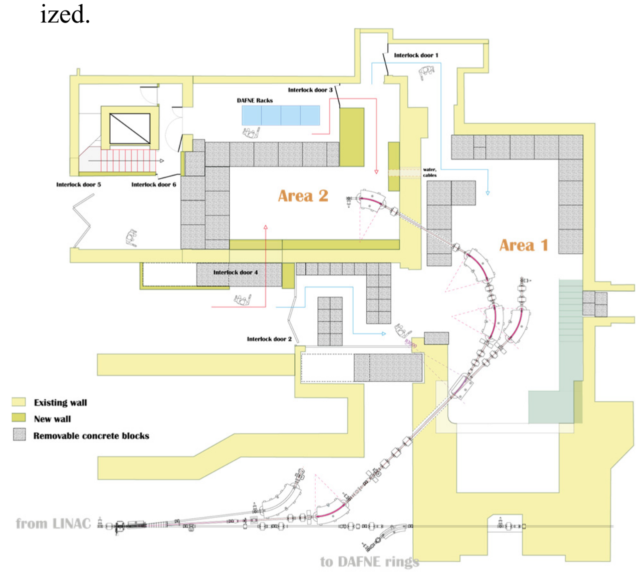

Figure 5: The new BTF lines and the modified layout of the building for hosting two separated experimental areas.

The idea for the new layout is schematically shown in Fig. 5: a beam-splitting dipole, wrapped around a double-exit pipe, can drive beam pulses from the upstream BTF beam-line alternatively to the two new lines. In case, the dipole can be connected to a pulsed power supply for a fast switch between the two lines.

The first line drives the beam in the existing experimental hall (“Area 1” in the picture), also profiting of the existing concrete block-house, while the second will transport the beam, with three additional dipoles, in the area presently used as BTF control room (“Area 2”), with minor civil engineering work.

A complete optimization of the new lines optics has been performed, in order to define the new beam elements requirements, both using G4-beamline and MAD-X [16], as shown in Fig. 6-7.

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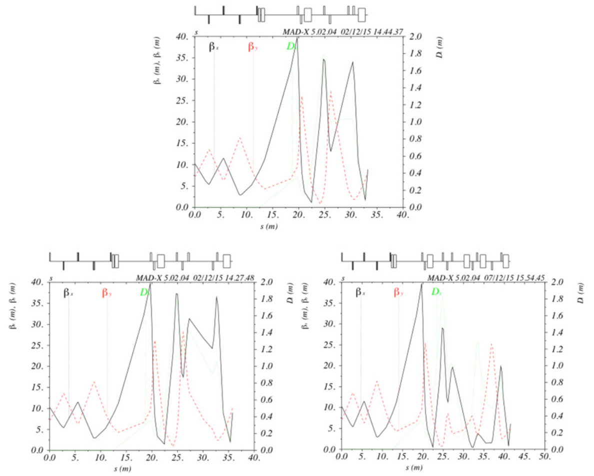

Figure 6: MAD-X results for the β function and dispersion of the present BTF (top) and for the new lines "1" and "2" (bottom left and right respectively).

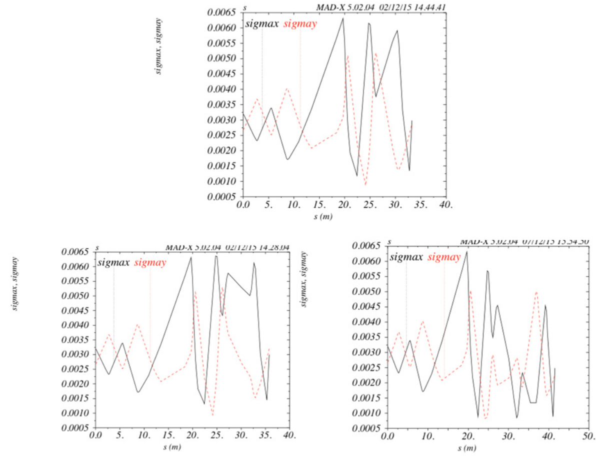

Figure 7: MAD-X results for the envelope (σ_x and σ_y) of the present BTF (top), and for the new lines "1" and "2" (bottom left and right respectively).

The PADME experiment sensitivity is essentially limited by the pile-up probability in the calorimeter [17], thus imposing a limit on the number of positrons in the beam. It would be then useful to further extend the range of the LINAC beam pulse length beyond the 40 ns presently achieved.

In order to do that, an upgrade program for the LINAC thermo-ionic gun is under way, aiming at extending the beam pulse up to a few hundreds of ns, while keeping the energy spread under control.

CONCLUSIONS

The continuous improvement of the performances and services of the BTF facility has produced an increased number of beam requests, mainly from the detector development community.

Recently PADME, a fixed-target experiment, aiming at exploring light dark matter models with the BTF positron beam, has been approved, thus posing further requirements both in terms of beam parameters and enlargement of the infrastructure. This has been one of the main drives of the BTF upgrade program.

ACKNOWLEDGEMENT

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