DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

Frascati, February 18, 2003

Note: **BTF-1**

DAFNE Beam Test Facility Upgrade Proposal

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Introduction

During year 2002 the DAFNE Beam Test Facility (BTF) has been successfully commissioned. In the fall of the same year, the first users started taking data exploiting the beam extracted from the DAFNE injection system, down to the BTF experimental hall.

The BTF performance and the first user experience are fully described elsewhere [1]. The availability of the facility was limited by the main DAFNE experiments, KLOE and DEAR. The KLOE detector is able to take data also during the injection of the beam, practically leaving no time for BTF operation. During DEAR (FINUDA from 2003 on) operation the available duty cycle for the BTF is ≈ 50%.

The limitations imposed by the main experiments, as well as the growing interest for the facility pushed us to study a modification of the beam line in order to improve the operation duty cycle.

BTF Operation

The present layout of the BTF beam transfer line is shown in Fig. 1.

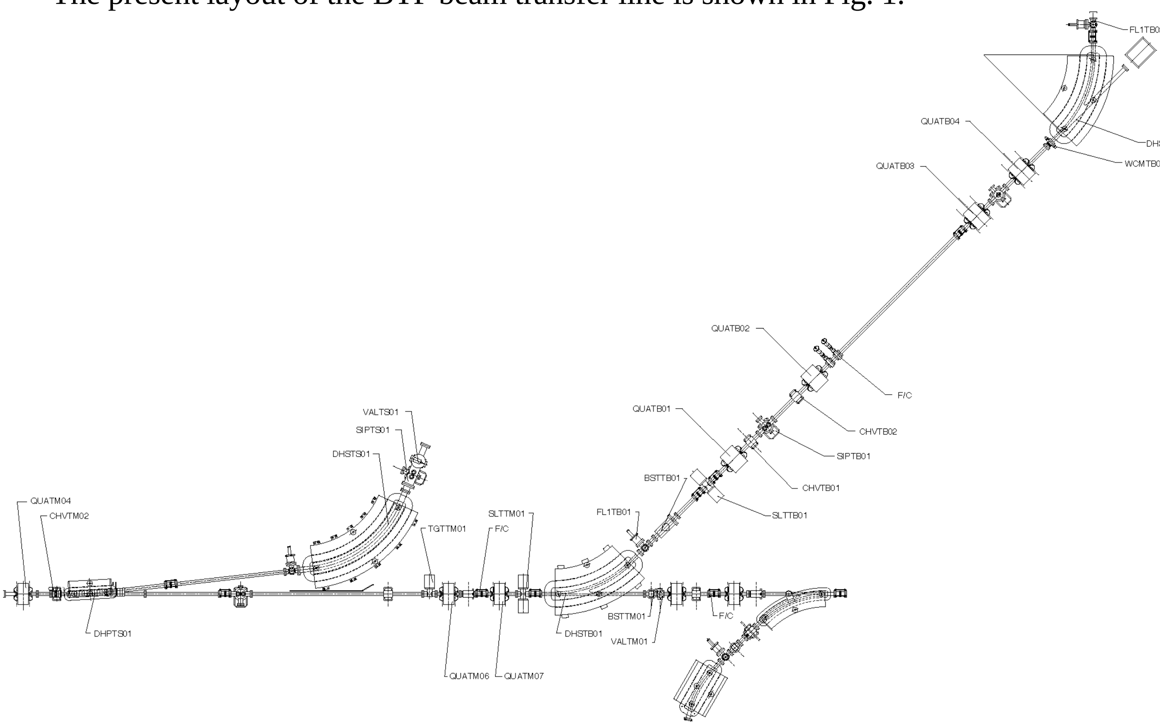

Figure 1: Beam Test Facility layout

The electron/positron beam produced by the LINAC [3] is stacked and damped in the Accumulator. It is then extracted at a rate between 1 and 2 Hz. and injected in the DAFNE Main Rings. The overall time required to fill both DAFNE Main Rings and set the line for the next refill consists of the following steps:

- electron injection: 2÷4 minutes
- switch LINAC system and beam transfer line to positron injection: 4 minutes
- positron injection: 2÷4 minutes
- switch LINAC system and beam transfer line to electron injection: 4 minutes

The whole procedure, in principle, takes ≈ 15 minutes. Most of the time is spent to change the polarity of the field in the full iron yokes of the dipoles and quadrupoles in the transfer line, while the LINAC system can be switched between positron and electron configurations in less then 1 minute.

During BTF operation, the high current LINAC beam is attenuated by a variable radiation length target (TTGTM01) and collimated by a slit system (SLTTM01). A DC dipole (DHSTB01) bends the attenuated beam towards the BTF experimental hall: this dipole must be off during injection into the DAFNE Main Rings.

The time to set the line, including the standardization of the two full iron dipoles of the BTF, which can be partially performed during the injection and switching procedure of the DAFNE Main Rings, is ≈ 1.5 minutes. Actually, injection during DEAR operation requires 15÷18 minutes, leaving about half of the overall time available for the operation of the BTF (see Fig. 2). In the case of KLOE data taking, which is not inhibited during injection, the time distance between successive fillings is less than 10 minutes, leaving practically no time available for the BTF.

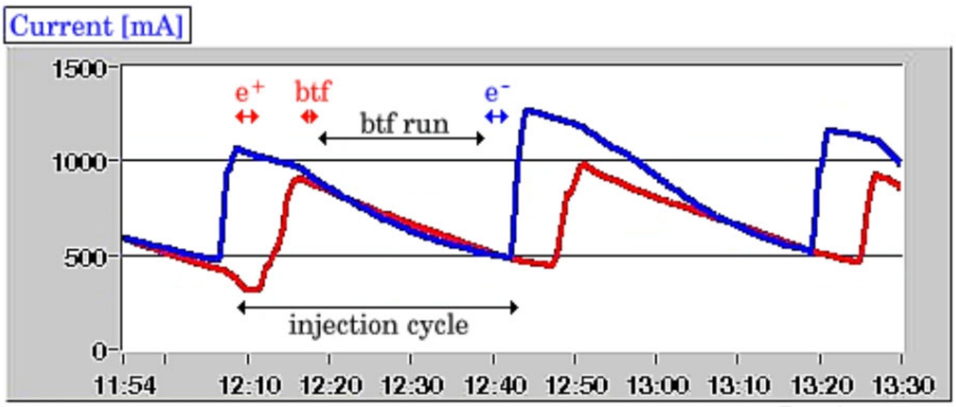

Figure 2: Example of a typical BTF run during DEAR operation. Two injection cycles are shown, an average of 22 minutes is available for the BTF.

New Layout Proposal

An almost complete separation between the DAFNE transfer lines to the Main Rings and the BTF channel will allow to operate in the BTF scheme with the only limitations of the LINAC switching time between the two beams and the time spent for filling the Main Rings. The new schematic layout is shown in Fig. 3.

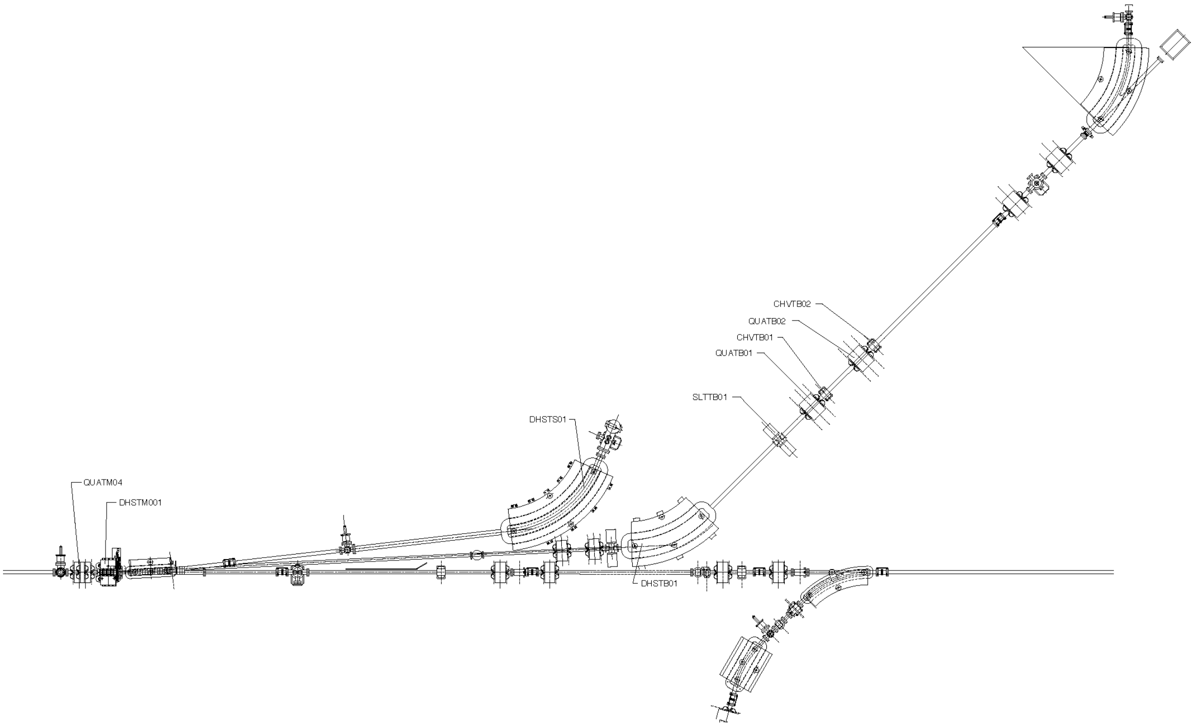

Figure 3: Beam Test Facility upgraded layout

A new small fast cycling DC dipole (DHSTM01) with laminated core and bending angle of 3° is introduced before the pulsed magnet (DHPTS01) used for the LINAC beam energy measurement [3]. This magnet will have the same cross-section, lamination thickness (0.35 mm), but half magnetic length, of the existing DHPTS01. A new dedicated power supply allowing a fast ramping and d.c. operation will power this 3° deflecting dipoles. A completely independent line, equipped with all the BTF elements (variable degrader, quadrupoles, dipoles, slits) is introduced at a nominal angle of 3° with respect to the main channel. The position of DHPTS01 is moved downstream the original position, in order to leave enough space for the new dipole. DHSTB01is removed from the main channel, and bends now the beam by 42° instead of the original 45° (its modification is discussed in the following paragraph). Both full iron dipoles DHSTB01 and DHSTB02 are always on, thus avoiding the long time necessary for their standardization.

During beam injection down to accumulator and Main Rings, DHSTM01 bend is off, and the beam follows the standard timing sequence and injection scheme; one LINAC bunch per second out of the available 50 is bent by 6° by the pulsed magnet DHPTS01 to the HODOSCOPE, for energy measurement. The remaining bunches follow the standard path to the Accumulator and Main Rings.

In BTF operation, DHSTM01 is switched on and the beam is driven into the new transfer line at 3° with respect to the main DAFNE transfer line. The pulsed magnet DHPTS01 kicks one LINAC bunch per second by the additional 3° necessary to reach the HODOSCOPE system.

The required switching time between BTF and injection configurations comes now only from ramping the two magnets DHSTM01 and DHPTS01 to the different values, and has been estimated to be less than 10 seconds. A possible scheme of operation, taking into account the upgrade of the LINAC repetition rate from the present 25 Hz to 50 Hz, is the following:

- e+ Injection into Accumulator and DAFNE Main Rings: 60 sec at 120 bunches
- LINAC switch to e^- and BTF magnet ramp up: 40 sec
- BTF operation
- Switch of the Accumulator and Main Rings transfer line to e-
- BTF magnets ramp down: 10 sec
- e- Injection into Accumulator and DAFNE Main Rings: 60 sec at 120 bunches
- BTF magnets ramp up: 10 sec
- BTF operation
- Switch of the Accumulator and Main Rings transfer line to e+
- LINAC switch to e+ and BTF magnets ramp down: 40 sec

In this conservative estimate the offtime for the BTF is less than 4 minutes per each complete refill of the collider with two beams. In the standard KLOE operation during the last year, the number of refills per day did not exceed 80: with the upgraded channel the BTF up time can therefore reach 80% during KLOE and 90% during FINUDA operation. We would also remark that a fully separated channel will make BTF operation much more reliable.

Parameters of the energy analyzing dipole in the modified channel

The new layout of the BTF channel (see Fig. 3) is designed with the aim of minimizing the modifications to the existing beam line. In particular, the position of the long straight section downstream the first bending magnet DHSTB01 remains the same, although its length is slightly reduced. Therefore, the sum of the bending angles of DHSTM01 and DHSTB01 must still be 45°, as in the former layout. Being 3° the angle to the beam given by DHSTM01, DHSTB01 must deflect it by 42° instead of 45°.

In order to investigate the effects of this different bending angle on the optical and geometric parameters of the beam line, a computer code realized for the analysis of the magnetic measurements performed on the dipoles of the DAFNE accelerator complex [3] has been modified to cope with the measurements performed at ANSALDO on DHSTB01. The program propagates the trajectory of a particle of given energy and given initial conditions through a map of measured field values by integrating the equation of motion under the effect of the Lorentz force. Being the field fixed by the current in the magnet during the measurement, the energy of the particle is changed until the overall deflection, including the effect of fringing fields, is equal to its required value. The current required at a different energy while maintaining the deflection constant can be then calculated by interpolating the field versus current behavior around the nominal values. Table 1 shows the nominal parameters of the magnet in the original version and those in the upgraded one.

Table 1 - DHSTB01 parameters

	Original	Upgrade
Bending angle (deg)	45	42
Nominal energy (MeV)	799.03	799.03
Beam energy (MeV)	798.42	798.42
Excitation current (A)	586	533
Field at magnet center (T)	1.547	1.449
Nominal bending radius (m)	1.723	1.839
Angle at entrance (deg)	0	1.5
Angle at exit (deg)	0	1.5
Distance at magnet center (mm)	-1.29	-10.15
Trajectory shortening (mm)	-0.93	-5.25

Figure 4 is a representation of the tracking program output. The plot shows the distance between the nominal trajectory inside the dipole and that found by the integration. The ideal trajectory is defined as a straight line extending at a distance where the fringing field of the dipole vanishes, a circle with the nominal bending radius and nominal bending angle and a second straight line tangent to the end of the circle with the same length of the first one. The actual path followed by the particle feels the influence of the fringing fields and it is bent towards the inside of the ideal trajectory before the region of the ideal magnet, where the field is represented as a square function with the nominal field inside the circle and zero outside. The consequence is an overall shortening of the beam trajectory that reduces the field integral: the beam energy corresponding to the desired deflection is therefore smaller than the nominal one, as shown in Table 1.

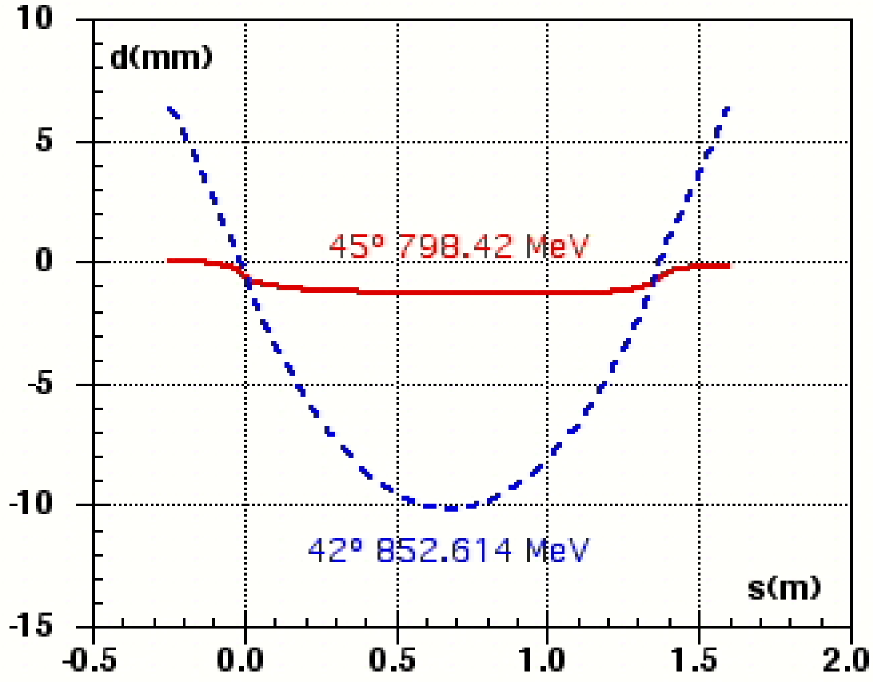

Figure 4 - Distance between calculated and nominal trajectory in DHSTB01.
Full line = original bending angle of 45°
Dotted line = upgrade bending angle of 42°

In order to understand better the difference, it is important to define the nominal energy correctly. In fact, the relation between the field integral in a dipole and the corresponding beam deflection is:

$$\alpha\ (\mathrm{rad}) = 0.2998 \int B(T)dl(m) / E(GeV)$$

where the constant is the velocity of light scaled to practical units. The nominal energy in Table 1 is calculated by taking the field integral over the nominal trajectory, while the beam energy comes from the field integral over the trajectory followed by the particle.

The field map measured at ANSALDO consists of 5 longitudinal scans in steps of 2.82 mrad (corresponding to 4.86 mm on the nominal trajectory), the central one along a circle of the nominal bending radius and the others with bending radii larger and smaller by 2.5 and 5 cm, with the same center of curvature. The field at the different tracking points has been obtained by means of a parabolic interpolation between the nearest measured points.

Figure 4 shows the result of the calculation for the nominal case compared with the corresponding one in the geometry required for the upgrade. In this case the dipole will be positioned symmetrically with respect to the input and output straight sections, and its field will be reduced to reach a final deflection of 42°. Each straight section will therefore form an angle of 1.5° with respect to the perpendicular to the dipole endfaces. This situation is schematically represented in Fig. 4 where the dotted line shows the distance between the nominal and calculated trajectories in the upgraded case: the beam energy corresponding to the required deflection of 42° is 852.61 MeV at the nominal excitation current of 586A, corresponding to the measured points in the field map.

Figure 5 shows the behaviour of the field at the magnet center as a function of the excitation current.

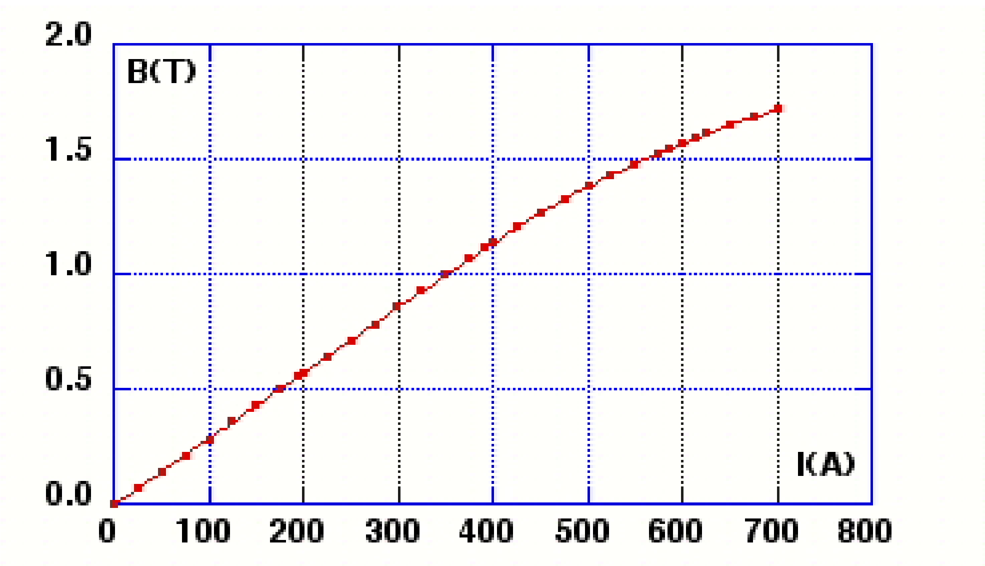

Figure 5 - Excitation curve of DHSTB01

The behaviour is linear up to ≈ 400 A, and the corresponding equation is:

$$B\ (T) = 0.002716 + 0.0028446\ I\ (A)$$

while above 400 A one must use a parabolic interpolation:

$$B\ (T) = -0.29593 + 0.0045459\ I\ (A) - 2.38678\times10^{-6}\ I^{2}\ (A)$$

Under the assumption that the field integral scales as the field at the magnet center, which is correct below 400 A and reasonable above, it is possible to find the current at which the particle with the beam energy in Table 1 is deflected by 42° by solving the corresponding second order equation and, eventually, to prepare a calibration table relating beam energy to excitation current for the new deflecting angle of 42°.

From Fig. 4 one can observe that the displacement of the beam path from the center of the magnet pole is ≈1 cm. This displacement can easily be tolerated because the specified good field region for the magnet is ± 2 cm.

The small angle at the entrance and exit of the dipole introduces also a small effect on the beam focusing. It can be represented in the lattice model with two thin lens quadrupoles, focusing in the horizontal plane, each with an integrated gradient of 0.0142 T at the nominal energy. The bending radius of the magnet, in the lattice model, should be increased to 1.839 m as well.

Optics

An example of transport optics for the new BTF channel, matched to the present DAFNE settings and without the introduction of the beam degrader TGMTT01 is shown in Fig. 6. However, in the new beam line a long drift from the new magnet DHSTM01 up to the first two BTF quadrupoles is required by the horizontal encumbrance of the quadrupoles inside the DAFNE transfer line (see Fig. 3); as a consequence, the flexibility of the matching to the BTF is somewhat decreased, in the sense that it is not easy to match any configuration of the matching quadrupoles upstream DHSTM01 (see Fig. 6). The wide range of matching conditions can be reestablished by properly modifying the excitation currents of the first quadrupoles in the DAFNE transfer line downstream DHSTB01.

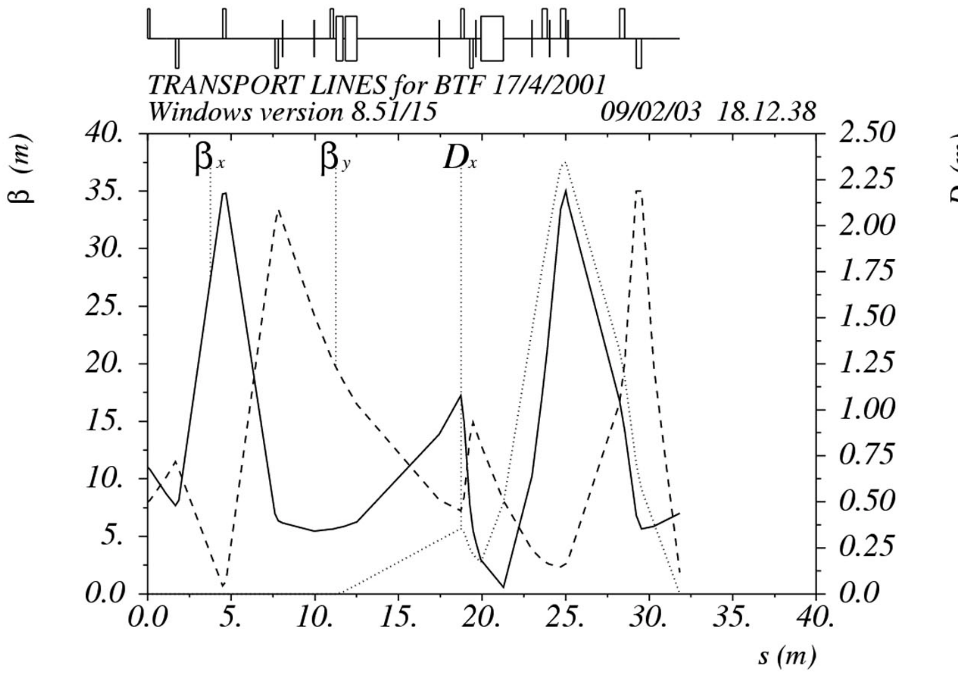

Figure 6: New layout optics without the beam degrader TGMTT01

When the degrader TGMTT01 in inserted in the BTF TL, the initial conditions are affected by the extremely large divergence introduced by the target, which translates in an increase of the effective emittance by several orders of magnitude and to a low value of both the horizontal and vertical beta-functions which describe the envelope of the beam in the line. The optical functions along the channel are shown in Fig. 7, while the corresponding beam envelopes are given in Fig. 8.

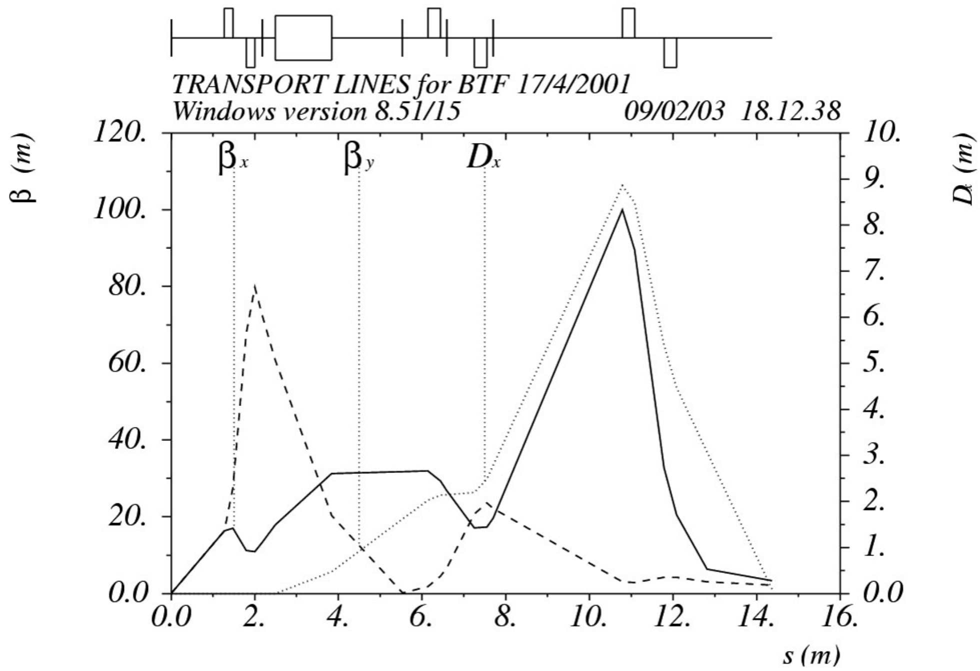

Figure 7: New BTF optical functions downstream the TGMTT01 degrader inserted in the channel

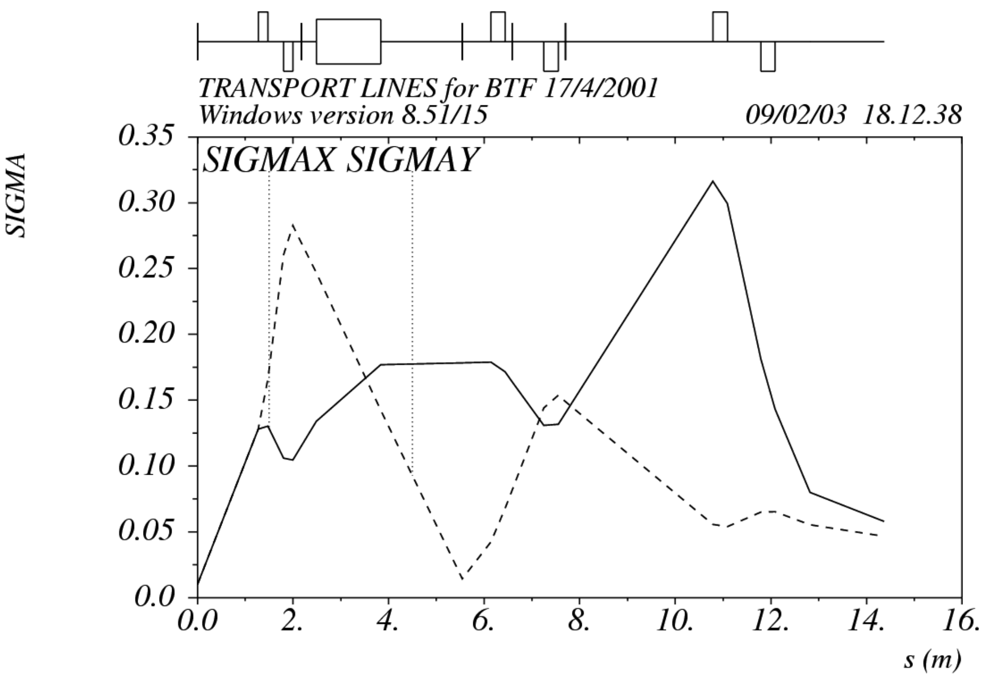

Figure 8: Beam sixes (in m) in the line following the TGMTT01 degrader

The beam sizes are calculated neglecting the effect of the slits used to select the energy of the particles. These slits reduce significantly the beam size in the horizontal plane, while in the vertical one the particles are collimated only by the vacuum chamber of the line. The expected spot size at the entrance of DHSTB02 is therefore of the order of few millimeters in the horizontal plane and few centimeters in the vertical one.

Conclusions

The upgrade proposal presented overcomes all present limitations imposed by KLOE operations, where no time at all is now left for beam delivering in the BTF test area, and strongly improving the duty-cycle during FINUDA operation from 50% up to 90%. The cost of the modification is limited essentially to the realization of the fast cycling DC dipole (with laminated core and related power supply) and of a new thin chamber in the pulsed dipole DHPTS01.

We estimate to start the construction of the new transfer line vacuum chambers and the DHSTM01 magnet at the end of the DAFNE shutdown, scheduled in May 2003.

The installation is expected to take place in January 2004, during the DAFNE cryogenic system maintenance.

References

[1] G. Mazzitelli, P. Valente “Commissioning of the DAFNE Beam Test Facility” LNF-03/003(P).

[2] R. Boni, S. Kulisnski, M. Preger, B. Spataro, M. Vescovi, G. Vignola “The Frascati Phi-Factory Injection System”. IEEE Particle Accelerator Conference, May 6-9, San Francisco, CA, USA. Pag 961-963.

[3 A. Battisti, B. Bolli, F. Iungo, F. Losciale, M. Paris, M. Preger, C. Sanelli, F. Sardone, F. Sgamma, M. Troiani, S. Vescovi "Measurements and tuning of DAFNE Accumulator dipoles" DAFNE Technical Note MM-9 (29/8/1995).