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# Possible upgrades of the DAFNE Beam-Test Facility (BTF)

P.Valente[1], B. Buonomo[2], L. Foggetta[2]

[1] *INFN Sezione di Roma, P.le Aldo Moro, 2 – 00185 Roma, Italy*
[2] *INFN LNF, Via Enrico Fermi, 40 – 00044 Frascati (Roma), Italy*

## Abstract

The BTF (Beam-Test Facility) is a transfer line using the electron or positron beam of the DAΦNE LINAC. The particle beams can be attenuated, energy-selected and collimated for a wide range of energy and intensity. The beam parameters can be tuned to match the needs of each users, mainly in the field of HEP detector testing, but also dedicated studies of electromagnetic interaction. The BTF has been operational for more than 10 years, mainly in "parasitic" mode to the operation of the DAΦNE collider, delivering beams for an average of more than 220 days/year.

The potential of the BTF facility can be further enlarged following different lines of development, which are briefly discussed in this paper: improvement of the environmental shielding for high-intensity applications; extension of the beam bunch time-width; addition of new collimators to reduce beams divergence and background at low intensity; doubling of the beam extraction system and transport line; improvement of the tagged photon source; increase of the maximum energy from 750/550 MeV (for electrons/positrons) to about 1 GeV/750 MeV respectively; improvement of a neutron line using the photo-production target; improvement of the beam diagnostics, mainly based on particle detectors, and the develop of a new BTF sub-system controls.

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# 1 – INTRODUCTION

## 1.1 – Brief description of the facility

The BTF (Beam-Test Facility) is part of the DAΦNE accelerator complex and is composed by an extraction line, a selectable target for secondary beam production and energy selection, through a pulsed 3° dipole and a 42° DC dipole magnet, three quadrupole doublets, a collimator system, in a ≈20 m long transport line. A second (45°) dipole magnet allows delivering beam from two alternative exits, delivering electrons or positrons in a 100 m$^2$ experimental hall. It is alternatively possible to transport the full LINAC primary beam without the insertion of the copper target. A schematic view of the transfer line at the end of the LINAC and of the BTF facility is shown in Fig. 1.1.

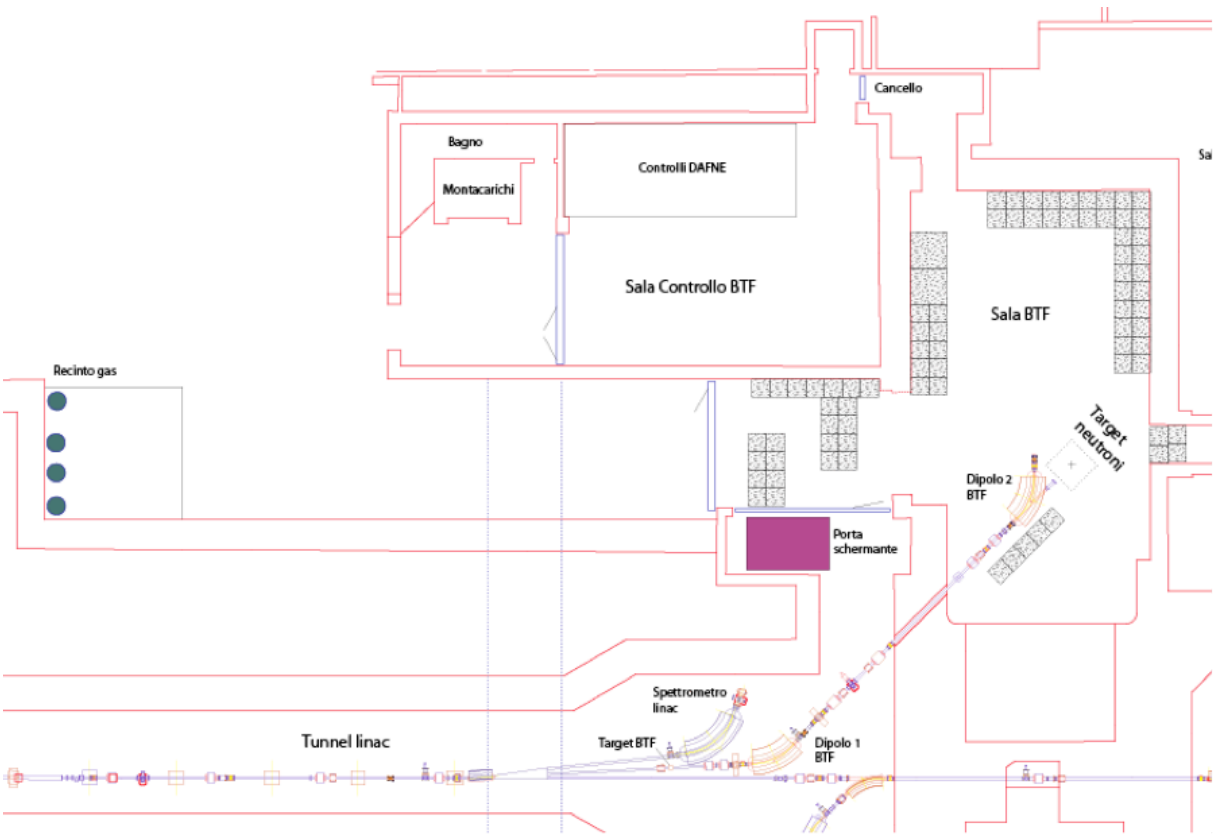


**FIG. 1.1** – Schematic view of the Beam-Test Facility extraction system from the LINAC, transfer line and experimental hall.

The BTF has been commissioned in year 2002[1)] and has been delivering beam to experiments and detector tests almost continuously since 2003.

In year 2003-2004 the possibility of producing and tagging Bremsstrahlung photons from a silicon micro-strip active target plus silicon micro-strip energy tagger detector has been added. Since 2008 a project (n@BTF) for the feasibility study of a photo-production neutron source using the full BTF electron beam is going on successfully.

The diagnostics of the facility has been continuously updated[2)], and the flexibility of the BTF beam parameters has been improved: e.g. not only the beam intensity, momentum, position and spot size can be monitored and adjusted, but also the beam bunch time-width can be produced with a duration of 1.4 and 10 ns.

**1.2 – Motivation: the impact of the facility**

In the last 10 years of operation, the DAΦNE Beam-Test Facility has delivered an average of 220 beam-days/year, providing access to a large number of experimental teams (see Fig. 1.2). The facility usually allocates slots of 1 week, Monday to Monday, and operates 24/7. More complex experimental setups of course required much longer beam-periods, up to the approximately five months of total allocation for the AGILE satellite pay-load calibration in 2005 (beam was not delivered 100% of this period, however).

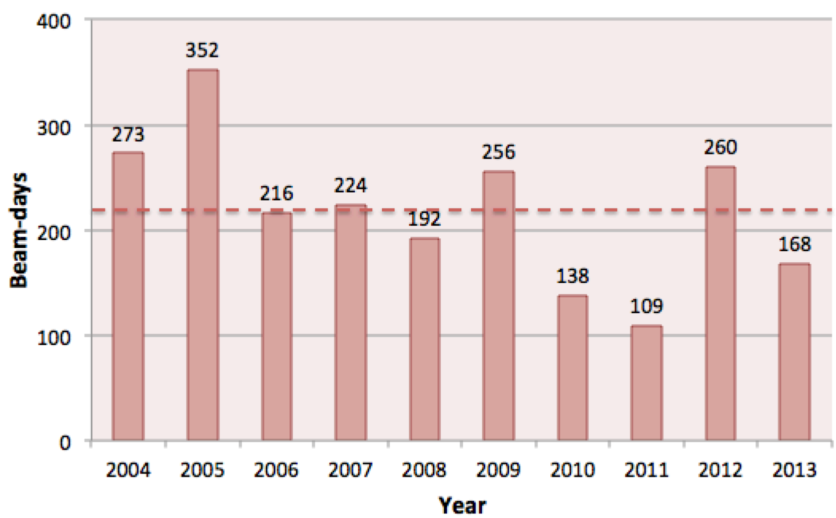


**FIG. 1.2** – Access to the BTF in the last 10 years of operation (beam-days, users sharing the beam are counted twice).

More than 250 shifts were allocated in the 10 years period, for an average duration of about 8 days (due to the great majority of 1 week shifts). Occasionally, two teams were present together, profiting of the possibility of using the same beam (in these cases one of the two applications has to be light enough, to minimize interactions with the beam).

A large fraction of the tests required electron or positron beam, with a 10% of allocation for the tagged-photon beam and a few shift dedicated to neutron production (due to the fact the neutron source is still under developing and test).

Approximately the 75% of the beam-time has been delivered in parallel to the operation of the DAΦNE collider, thanks to the possibility of selecting individual bunches in the 25 Hz or 50 Hz time-structure of the LINAC beam. While one bunch per second is driven on a magnetic spectrometer for the monitoring of the LINAC energy, the remaining 24 or 49 bunches/s can be either all extracted to the BTF line, or – during the injections to the DAΦNE collider – only the portion of pulses not delivered to the damping ring (some more details are given in section 3). This is possible thanks to the three-way exit line of the LINAC, served by two pulsed magnets, selecting either the spectrometer or the BTF line.

From the point of view of electron/positron beam parameters, the full range of the BTF has been exploited. LINAC delivers electron or positron beam for refilling DAΦNE rings: in case of primary beam transport, once having set up the BTF line, only one of the two kinds of primaries could be delivered to BTF hall. When the BTF is set up for operating with the secondary beam, the particle delivered to BTF hall are independent from the sign of LINAC primaries. In both cases, the LINAC energy is fixed at 510 MeV for the normal operation of the collider.

Concerning the beam intensity we can distinguish three regimes:

- **Secondary beam, single particle** - a Poissonian distribution with a given average multiplicity is delivered. It covers approximately the 50% of the users requirements, mainly for detector testing purposes. The primary beam is attenuated by the BTF (variable-depth, copper) target, and collimated both before and after the energy-selecting and extracting dipole, thus allowing a very fine tuning of the beam intensity, once having selected the required energy up to the maximum primary energy. The selection of three different target depths (1.7, 2.0 or 2.3 radiation lengths), allows a further tuning of the secondary beam intensity in the low and intermediate energy range, as shown in the graph in Fig. 1.3.

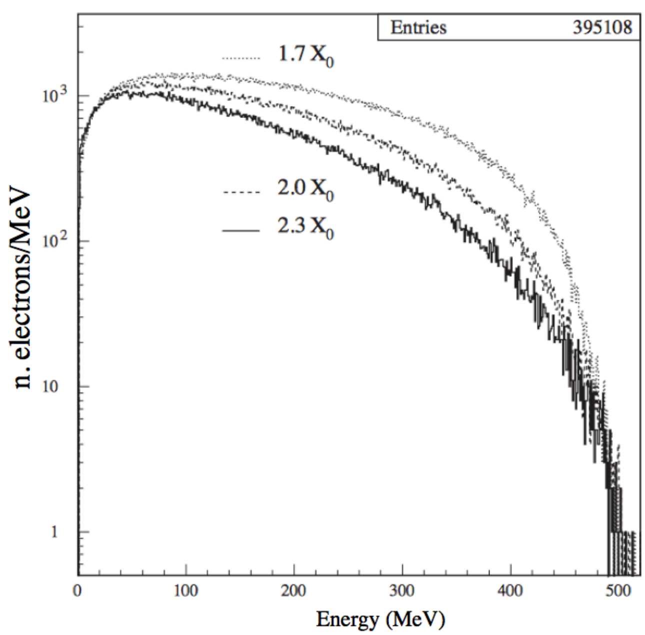


**FIG. 1.3** – Number of electrons emerging from the attenuating target (with an angular cut of 4 mrad) for $10^8$ primary electrons[1].

- **Secondary beam, intermediate intensity** - ranging from hundreds to hundred thousand particles per bunch, requiring the attenuation of the LINAC beam with the BTF target, while selecting an energy lower than the primary one and opening wide the collimators. The maximum beam intensity with the attenuating target can be estimated considering $2\times10^{10}$ primary electrons and 1% momentum acceptance to be $<2\times10^5$ electrons/bunch on the peak of the energy distribution of Fig. 3, around 100 MeV, without taking into account the transport efficiency and the strong reduction attainable with the upstream tungsten collimators.

- **Primary beam, high intensity** - when extracting the full LINAC beam (i.e. without interposing the copper target), the beam is also focused and steered according to the user needs. The collimation system allows adjusting the intensity from $10^7$ up to the nominal values ($10^{10}$ electron/bunch, $10^9$ positrons/bunch).

Naturally, the "parasitic" operation mode of the BTF implies two main limitations: one related to the intensity of the beam, the second on the maximum delivered energy. The former occurs during the positron phase of the LINAC: the primary beam intensity is lower when the LINAC delivers positrons, due to the efficiency of the positron production. The second limitation is on the maximum energy, fixed to 510 MeV during the operation of the DAΦNE collider (which is a symmetric phi-factory, running at 1,02 GeV center of mass energy). In a dedicated LINAC+BTF mode, the energy of LINAC primary beam could be tuned ranging from 300MeV to 750 MeV.

This very wide range of operating parameters allowed exploiting the BTF beam for a large number of applications, mainly - of course - in the field of high-energy physics.

Indeed, at least one half of the users have used the facility for **detector-testing** purposes, covering almost all the possible detection techniques:

- **Calorimeters**: homogenous (NaI,CsI, PbWO, LYSO, YAP: Belle-II, CMS, KLOE-2, Linear collider); sampling (Mu2E, KLOE, AMS, LUMI, Linear collider, Mambo, NA62, MICE, …);

- **Gas detectors**: GEM/Micromegas (LHCb, ATLAS, UA9, Siddharta, KLOE-2, Siddharta), drift chamber/tubes (Super-B, MEG, TPS), RPC (Linear collider);

- **Silicon detectors**: microstrip (AGILE, Insubria), pixel (ALICE, MIMOSA, Linear collider);

- **Scintillating/Fluorescence detectors**: MEG, neutron detection, fiber-trackers (MEG, BES-III, Plasmon-X), AIRFLY (Auger);

- **Cerenkov detectors**: RICH (LHCb, JLAB12), threshold (UA9)

- **Nuclear emulsion**: OPERA.

In addition, experiments looking at specific **beam-induced effects** were carried on at the BTF:

- **Beam diagnostics**: fluorescence flag, WCM diagnostics calibration, emittance measurement (pepper pot)

- **Thermo-acoustic effect**: RAP (gravitational wave detection)
- **Beam-induced radiation**: C-SPEED, AMY (microwave yield measurement)
- **Crystal-channeling** and parametric radiation emission.

Practically all the major HEP experimental groups operating in Italian community have accessed at least once the BTF facility. The teams can be grouped essentially in three classes:

- International HEP **large or very large collaborations**, such as ATLAS, CMS, ATLAS, ALICE, LHCb, typically from one sub-detector community, representing approximately 25% of the users;
- **Intermediate-size** HEP/nuclear/astroparticle international collaborations, like KLOE, NA62, MEG, UA9, AGILE, Auger, JLAB experiments, and many others, representing more than 50% of the cases;
- **Smaller groups**, generally for detector/electronics/diagnostics studies not directly related to a large experiment, for the remaining percentage.

Due to the large fraction of teams coming from international collaborations, a good participation of non-Italian groups was constantly registered in these years, at the level of 30% of the users, mainly from EU countries (but also a good fraction from Russia). This was also facilitated by the inclusion of the BTF as a facility in the Trans-national Access to Research Infrastructure program of the Hadron Physics projects, in the FP6 and FP7 European Programs. The average funding under these programs can be estimated in 150 man-days/year and 15-20 travels. In this case, after approval from the BTF Users Committee, the projects are further evaluated by the Hadron Physics international Users Selection Panel.

An estimate of the scientific impact of the facility can be represented by the number of papers based on data collected with the BTF beam. Limiting to the cases in which the use of the facility is specifically cited or acknowledged, an average of 15 publications/year can be identified.

This very long experience represents a good guidance in trying to provide a better and wider support to scientific community, in particular the HEP field and particle detectors R&D. We have identified three different aspects for the improvement of the facility:

- better beam parameters: in terms of higher intensity, higher energy, better momentum resolution and beam size, tuning of the time structure, etc.;
- wider beam-access: calling for more lines, photon and neutron production, etc., and improved efficiency;
- better control and monitoring of the beam parameters.

In the following sections a menu of different upgrades and improvements of the facility are briefly presented.

## 2 – SHIELDING UPGRADE

The BTF experimental space is located inside the LNF building originally designed as experimental hall for pion experiments (it was indeed named “Sala pioni”, Fig. 2.1) of the LEALE project[3)], produced by the LINAC of ADONE (the accelerator system operational in Frascati from 1967 up to 1993): a 375 MeV electron (positron) beam of 150 mA (1 mA), up to 4 μs long pulses at 3-250 Hz, produced bremsstrahlung striking on a thin tungsten radiator, pions were then produced by photo-production on a graphite target (a 10 mm diameter, 50 mm long cylinder). A double 70° sector magnet energy loss spectrometer was used to measure pion momentum[3)].

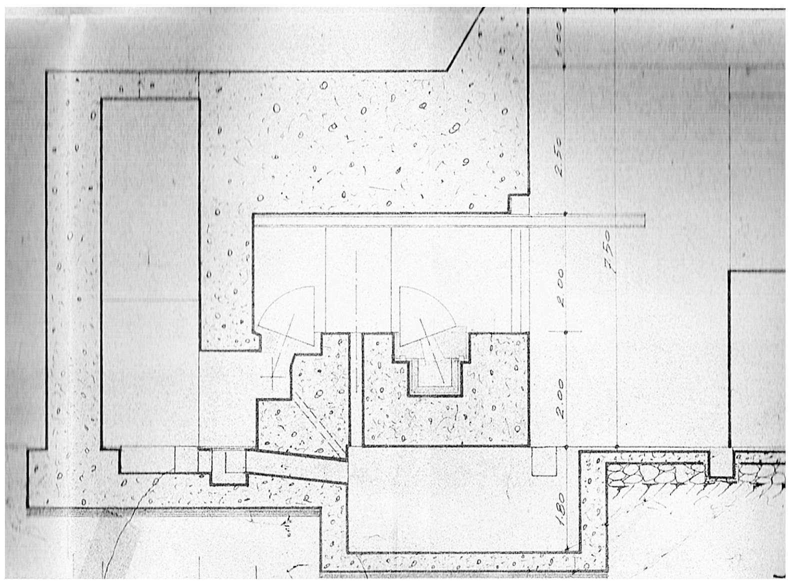

**FIG. 2.1** – Section of the former “Sala pioni” of the ADONE-LEALE project.

The building, presently dubbed with the number 54 (Fig. 2.2), has walls made by 50 cm of concrete, constituting adequate shielding for low intensity electron/positron beams, which is the operation of the BTF with the attenuating target. On the contrary, in order to drive the full DAΦNE LINAC inside the BTF hall, more shielding was required. For this purpose, concrete blocks (1×1×1 $m^3$ and 0.5×0.5×0.5 $m^3$) have been used to increase the thickness of the lateral walls to 150 cm, up to a height of 4.25 m (the total height of the hall is 7.5 m), as shown in Figg. 2.3 and 2.4.

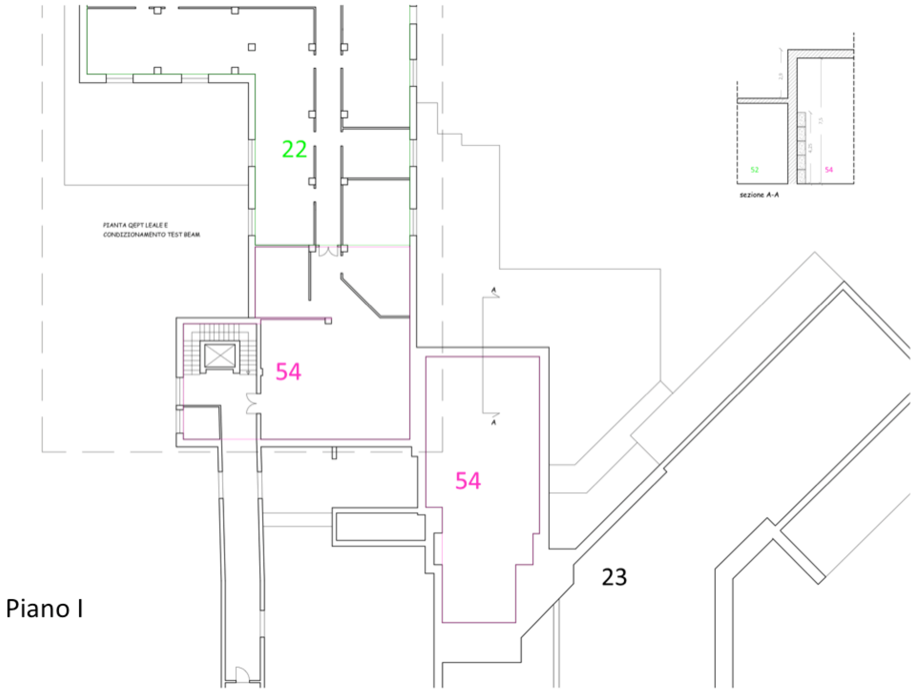


**FIG. 2.2** – Present plan of the BTF and nearby buildings (First floor).

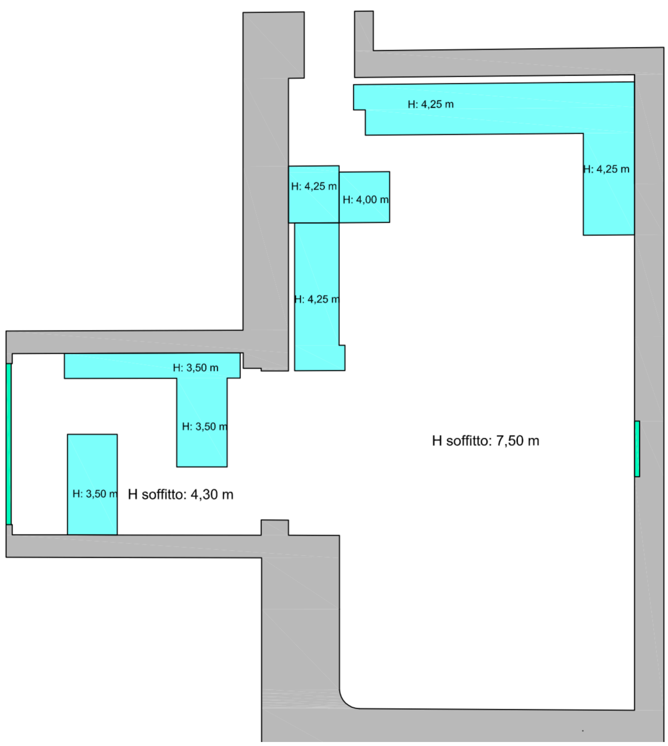


**FIG. 2.3** – Plan of the present configuration of the shielding with the 4.25 m wall made of concrete blocks.

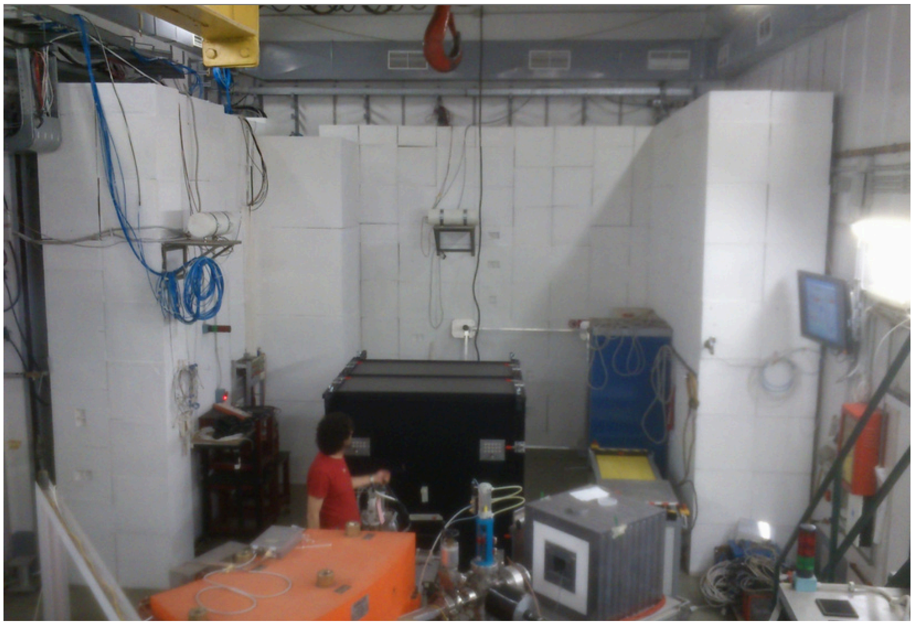

**FIG. 2.4 –** Present configuration of the BTF hall.

Provided that the irradiated material is surrounded in all directions by 15 cm of lead plus the mentioned 150 cm of concrete, the BTF hall is authorized for a beam of $3{\times}10^{10}$ electrons/second[4)].

In order to simplify high-intensity operations, we foresee to further shield the portion of the experimental hall towards the nearby building 52 (hosting the power supplies of the DAΦNE damping ring magnets), providing additional concrete in the top part of the hall (above 4.25 m), presently not covered by the 100 cm blocks. Unfortunately, the presence of a 25 tons crane in the BTF hall does not allow the simple solution of increasing the height of the concrete blocks wall up to the hall ceiling, due to the interference with the rails

A possible solution is then to build a concrete roof at an intermediate height, covering that portion of the experimental room at a lower height (compatible with the use of the crane). This can be realized by using concrete pre-fabricated beams, to be laid onto the lateral block-wall, once having strengthened the structure, e.g. with a steel support frame. This would be a solution similar to what has been designed and built for the shielding roof of the FLAME bunker (see Fig. 2.5).

In particular, T-shaped concrete beams can be used in order to reduce "cracks", providing a total concrete thickness of 1 m. Pre-fabricated beams of total length of 5-6 m can be built and safely sustained by the approximately 1 m lateral columns, for example with an headroom of 3 m (or even 3.25 m), in order to reproduce the present lateral shielding configuration (see schematic section in Fig. 2.6).

**FIG. 2.5 –** The FLAME bunker shielding roof realized with T-shaped concrete beams.

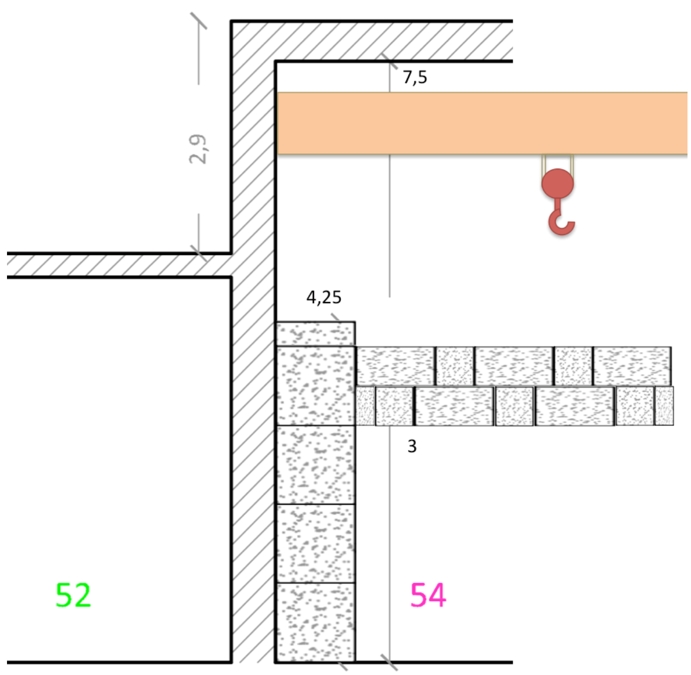


**FIG. 2.6 –** Possible partial coverage of the BTF hall (building n. 54) towards the damping ring power supply building (n. 52) with a headroom of 3 meters and 1 m high concrete beams (T-shaped), of total length 5.5 m (4.75 m free span). The roof will have a total width of about 4 m and a thickness of 1 m. Lateral sustaining columns of 1 m concrete blocks not shown.

As a result, the downstream part of the BTF experimental hall would be constituted by a "block-house" of 1 m concrete, closed on three sides and on the top. In order to keep the "chicane" protecting the entrance of the BTF hall, the simplest solution is to add two more columns of 1 m side concrete blocks (3 m high), aside of the existing one. Lowering the wall on the opposite side of the hall also to 3 m, would then constitute the two columns supporting the roof. The additional 1 m blocks would limit the useful opening of the "block-house" to 4.75 m, thus limiting the length of the pre-fabricated concrete beams to 5.5/6 m. A schematic view of the new concrete walls and roof is shown in Fig. 2.7. In order to leave a 80 cm wide access to the hall, a 3 m lintel will be needed to cover the access opening.

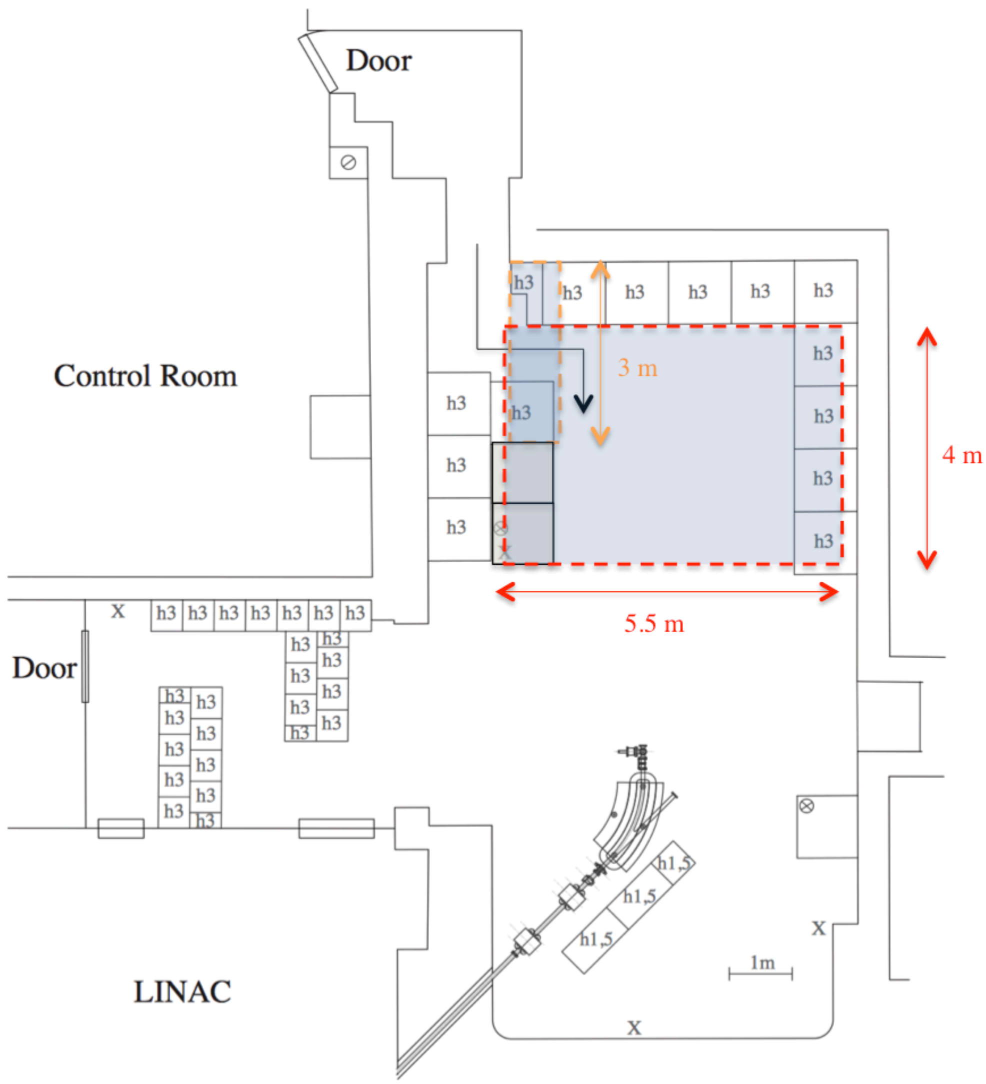


**FIG. 2.7** – Possible partial coverage of the BTF hall with a concrete roof of total length 5.5 m (4.75 m free span) and a total width of about 4 m.

## 3 – EXTENSION OF THE BEAM PULSE DURATION

The DAΦNE LINAC beam is produced by a thermo-ionic triode gun (maximum 150 kV, 12 A) with a typical pulse (applied to the grid controlling the electron flow) of rectangular shape and 10 ns duration, optimized for the injection of the accelerated beam in the DAΦNE damping ring (and from there, to the main rings).

The resulting LINAC beam is then approximately 10 ns long, with a 2856 MHz structure given by the S-band accelerating structures. Thanks to a recent upgrade of the pulser system, the LINAC gun can deliver beam bunches with a time duration ranging from 1.4 up to 40 ns in 0.5 ns steps.
The resulting time structure is shown, as example, in Fig. 3.1

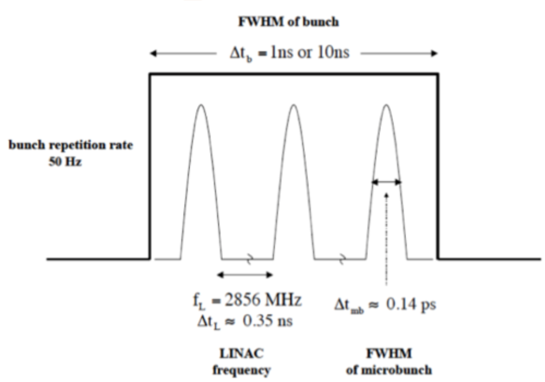


**FIG. 3.1** – LINAC micro-bunch time structure.

A longer pulse duration can be very interesting for high intensity. A notable example of this kind of requirement are electron fixed target experiments for the search of light bosons in a "hidden" sector. An interest for such kind of experiments has been recently expressed also in the Frascati laboratories[5)].

The possibility of distributing electrons/positrons over a wide time window (of the order of 100 or 200 ns) would be also very interesting for detector testing purposes, since that would correspond to an interesting range for the equivalent rate of particles.

In order to accelerate bunches much longer than 40 ns, equal to the maximum overlapping time of the present four modulator SLED flat-top pulse, different use of the pulse compression system is under investigation.

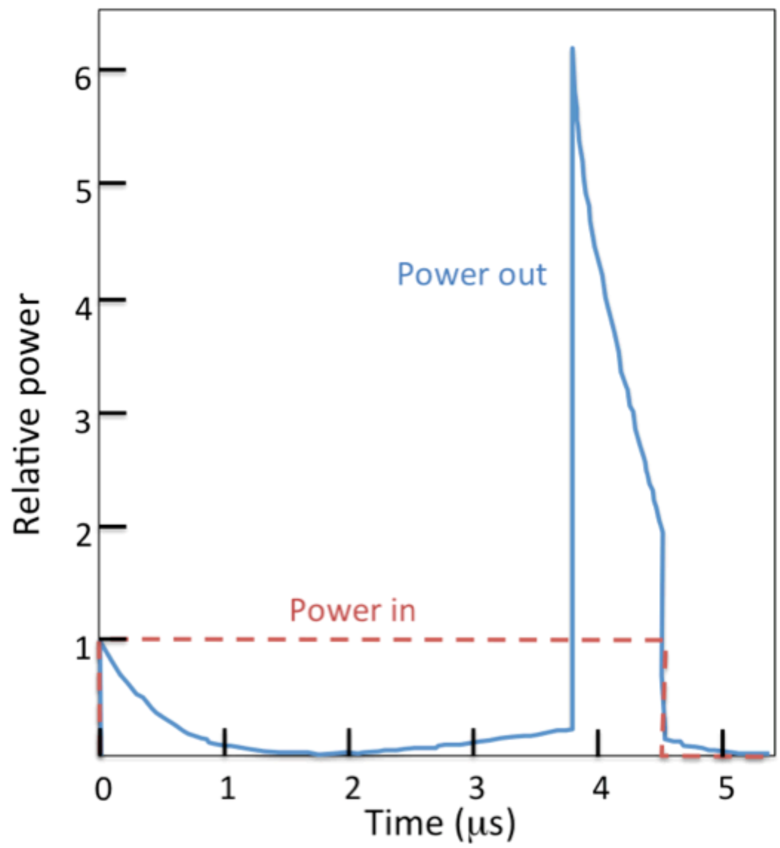


**FIG. 3.2** – Input power to and output power from the SLED microwave network as a function of time[6)].

This would require not only a new gun pulsing system, but also a careful tuning of the phases in order to keep at an acceptable level the energy spread due to the fall-down of the RF power out of the SLED and the beam transport.

Finally, detuning or by-passing the SLED cavities would allow to set a gun pulse practically as long as the klystron RF power pulse, but of course this would also result in a reduction in available energy and demands consistent work on the LINAC RF system.

**4 – SMALL DIVERGENCE BEAM**

The present collimation system of the BTF is composed by two couples of tungsten slits, two horizontal and two vertical, which are used to control the momentum spread of the selected beam and to tune the beam intensity, respectively. Of course, those slits also allow improving the definition of the BTF beam spot, which is generally of the order of 2-3 mm (rms) in both the coordinates, while the divergence is of the order of 2 mrad, corresponding to a beam emittance of the order of 4 mm·mrad.

In Fig. 4.1, for example, the effect of the collimators defining a 3×2 $mm^2$ rectangle, is clearly visible (the beam is imaged by a Medipix silicon pixel detector). Those values are obviously referred to the non-attenuated beam (i.e. without the target).

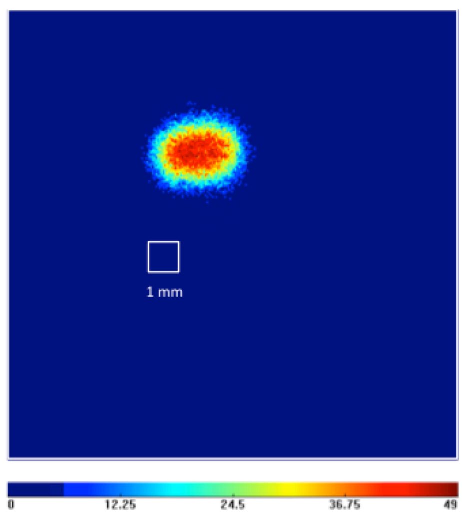


**FIG. 4.1 –** Electron beam spot at 500 MeV.

For some experiment it would be desirable to have a quasi-parallel beam, i.e. a very small divergence beam. This is very difficult to obtain with the current collimators, since they are quite far from the beam exit and upstream of the last four focussing quadrupoles. In order to get a very low divergence beam a dedicated collimator, of appropriate shape, inserted in the beam pipe in last portion of the BTF transport line, would be needed. Using a high-Z material should allow to keep the length of the collimator small, thus allowing to have a simple movement for the insertion/extraction from the beam-line.

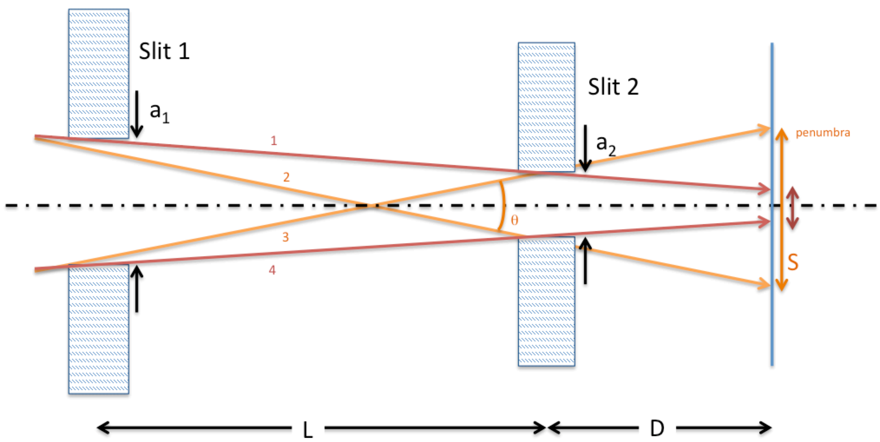


**FIG. 4.2** – Two slits collimation.

Referring to the simplified picture shown in Fig. 4.2, two slits placed at relative distance L and a distance from the "target" D, with apertures $a_1$ and $a_2$ will define a maximum beam spot of size:

$$S = (a_1 + a_2)(L + D)/L - a_1$$

While for the angle θ:

$$tg(\theta/2) = (a_1+a_2)/L$$

Quite naturally, small θ values, i.e. a quasi parallel beam can be obtained either having very small aperture ($a_1+a_2$) or a large distance L between the slits.

However, since the acceptance of such a system is $(a_1a_2)/L$, the requirement of small θ can be optimized by displacing the two slit systems, increasing L with respect to decreasing the apertures $a_1$ and $a_2$.

In order to optimize the background, this scheme can be modified by using a downstream thick absorber, e.g. a full high-Z cylinder, with a few selectable holes, used together with the existing *x-y* scapers. This solution would have the benefit of keeping L>>D, while keeping the last collimator not too close to the user "target" spot, thus reducing the background induced by the collimator itself.

E.g. considering apertures of the order of $a_1=a_2=1$ mm, a distance between the existing slits and the new absorber of L=7 m, and D=3 m, we can reach a divergence of order 0.3 mrad (to be compared with a RMS multiple scattering angle of about 1.1 mrad for 1 m of air at 500 MeV) and a penumbra S≈2 mm.

**5 – DOUBLING OF THE BEAM LINE**

In original beam-test project the LINAC beam was extracted to the BTF line by a large DC bending magnet – the same 45° dipole used for the energy selection – so that the time needed for the ramping up and down was severely limiting the duty cycle of the facility. Morever, the attenuating target has to be inserted directly in the transfer line from the LINAC end to the damping ring (and from there to the main rings), with a potential interference with the normal DAΦNE operations in case of errors or failures of the stepper motors.

With the upgrade performed in 2004, the BTF line has been much better separated from the injection into DAΦNE, thanks to the realization of a three-way switchyard, made by a 3° pulsed dipole magnet (DHRTB101) and to the 6° pulsed dipole magnet (DHPTS01, already used to drive a single pulse to the spectrometer line), giving the possibility of choosing to which of three separated lines drive each individual bunch delivered by the LINAC (see Fig. 5.1):

- Both fast dipole and pulsed dipole **off**, angle=**0°**: the beam continues straight to the damping ring where the bunch can be injected;
- Pulsed dipole DHRTB101 **on**, pulsed dipole DHPTS01 **off**, angle=**3°**: those bunches are extracted to the BTF line, where they can be attenuated by the target and energy selected or directly transported to the experimental hall by a 42° bending;
- Pulsed dipole DHPTS01 **on**, angle=**6°**: a single bunch is driven to the magnetic spectrometer for the energy measurement (a 45° bending magnet followed by a metallic strip detector).

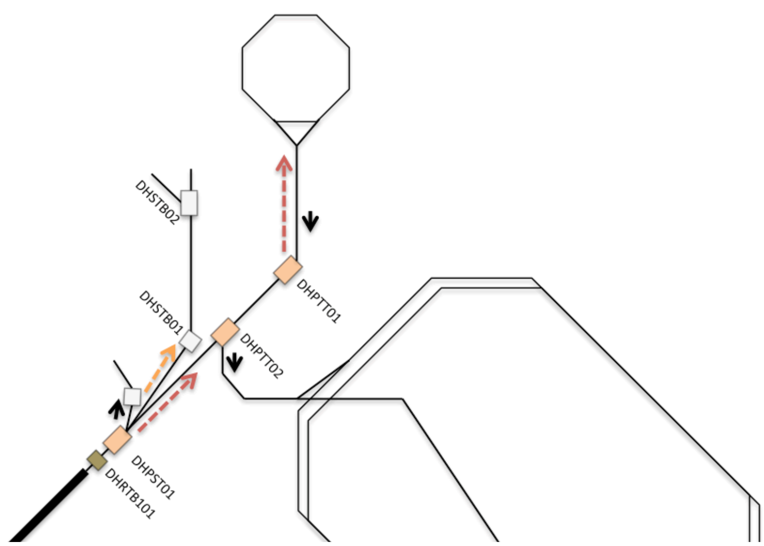


**FIG. 5.1** – Three pulsed magnet are used for energy measurement (DHPST01), injection to the damping ring and extraction (single turn) from the damping ring to the main rings (DHPTT01 and DHPTT02). In addition, a dipole (DHRTB101) is used to deviate bunches to the BTF line.

The maximum LINAC repetition rate is 50 Hz, but more often in the last years, it is set at 25 Hz in the standard DAΦNE operation. The injection in the main rings is performed at repeated sequences of 0.5, 1 or 2 Hz. In each sequence, the injection is performed by driving a definite number *n* of consecutive LINAC bunches in the accumulator ring and wait the accumulator beam to damp down to its equilibrium energy spread and emittance. The last part of the sequence is composed of the extraction of the beam from the accumulator and the delivering to the main ring. This is accomplished during the LINAC shot to the spectrometer. The unused LINAC shots are delivered to the BTF line if needed. If non injection is operated in DAΦNE, 24 or 49 bunches are delivered (if needed) to the BTF line and one to the spectrometer.

The BTF line downstream to the energy selecting 42° dipole (DHSTB01) is similar to the one already foreseen in the original design of the beam-test[8)]: the beam is transported by a transfer line – that includes six quadrupoles for focussing – in the BTF hall, where a two-way beam pipe inside a second 45° dipole magnet (DHSTB02, with the same characteristics of DHSTB01, see Fig. 5.3) either delivers the beam parallel to the long side of the hall, or let it go straight (along the diagonal of the hall), as shown in Fig. 5.4.

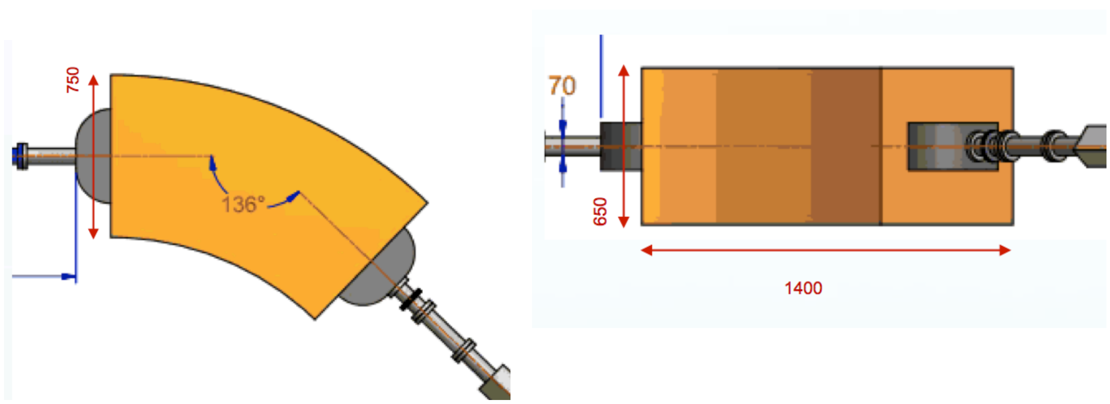


**FIG. 5.3** – The "orange" dipoles, the two twin magnets DHSTB01 and DHSTB02 sharing the same characteristics, can bend up to 800 MeV/c particles by 45°.

Each line is equipped with: remote gate valve, ionic pumping system, remote vacuum readout system, remote insertion of beryllium oxide or YAG:Ce flag readout via CCD camera, beam charge monitor, 0.5 mm beryllium thick window exit and an overall vacuum security system. The straight line is presently used for high intensity applications in neutron photo-production (N@BTF) whose the target is hosted inside its shielding, placed at the exit of the line. Other beam positioning/monitoring detector are GEM trackers, fiber hodoscope, Silicon pixel and neutron counters; a remotely-controlled trolley – onto which the device under test is usually placed – is positioned in front of this exit.

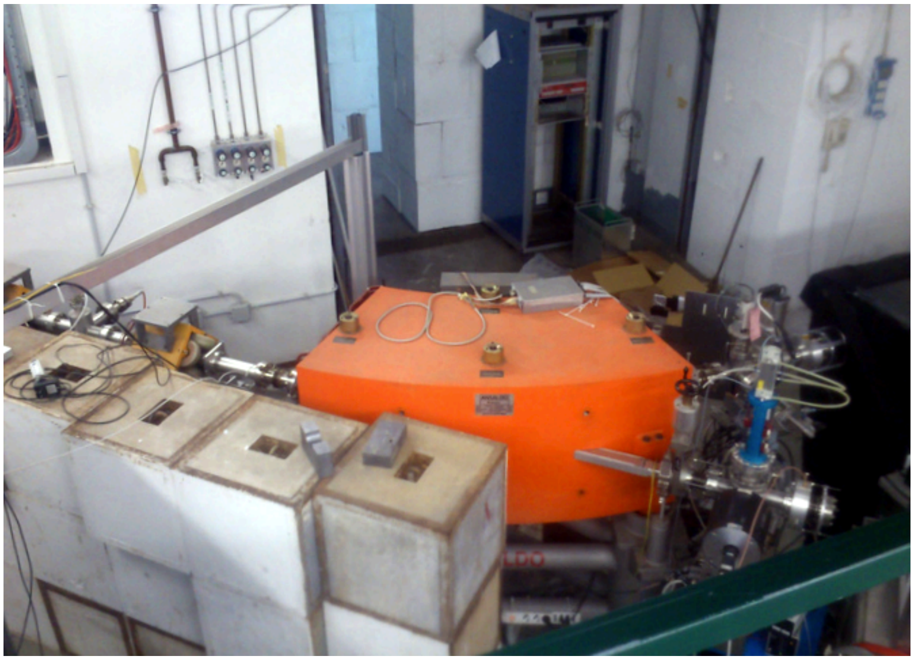

**FIG. 5.4** – The DHSTB02 “orange” dipole either lets the beam going straight (towards the right bottom corner of the picture) or drives particles at 45° with respect to the extraction line (towards the right side of the picture).

The basic idea is to change the arrangement of the BTF transfer and exit lines, in order to add a dipole (possible a pulsed magnet, capable of selecting individual bunches in the sequence), for driving the beam to two alternative, separated lines, with the purpose of running two different experiments in parallel. One of the simplest solutions is shown in Fig. 17:

- A dipole selects two alternative lines (e.g. at 22.5°) one with respect to the other;
- The first “straight” line (field **off**), allows to use the “lower” part of the experimental hall, and will profit of the focussing and collimation of the BTF transfer line upstream in the LINAC tunnel, right after the attenuating target. This line could also host a renewed version of the photon tagging (see section 6).

- The second "bending" line (field **on**), can host a further focussing (e.g. a triplet of quadrupoles) and another dipole magnet for further splitting of the beam. This second line would also be the most suitable one for high intensity application, since it will drive the beam in the "upper" part of the hall, that can be further shielded with a concrete ceiling (on top of the lateral block-walls, see section 2). This scheme is shown in Fig. 5.5.

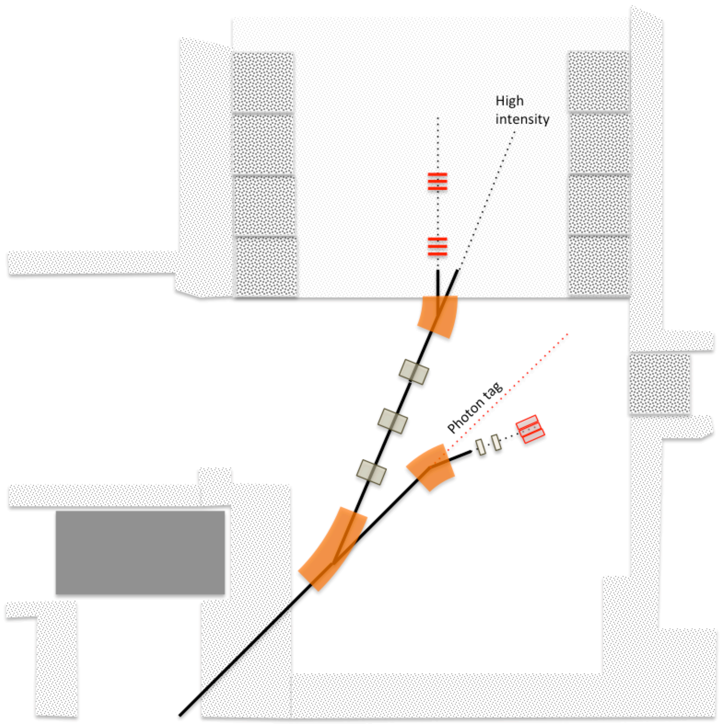


**FIG. 5.5** – A possible scheme for the splitting in two beam-lines.

Another possibility, requiring two larger DC dipole magnets, and also some civil engineering, would be to use the "left" side of the BTF hall, e.g. the portion of the room running parallel to the LINAC tunnel, by bending the beam (including the pulsed magnet) of an angle >135° (see Fig. 5.6). In addition, for compensating the dispersion, an additional quadrupole doublet has to be arranged in the line, e.g. in between two DC dipoles of about 60° (if the first dipole gives a bending of at least 22.5°).

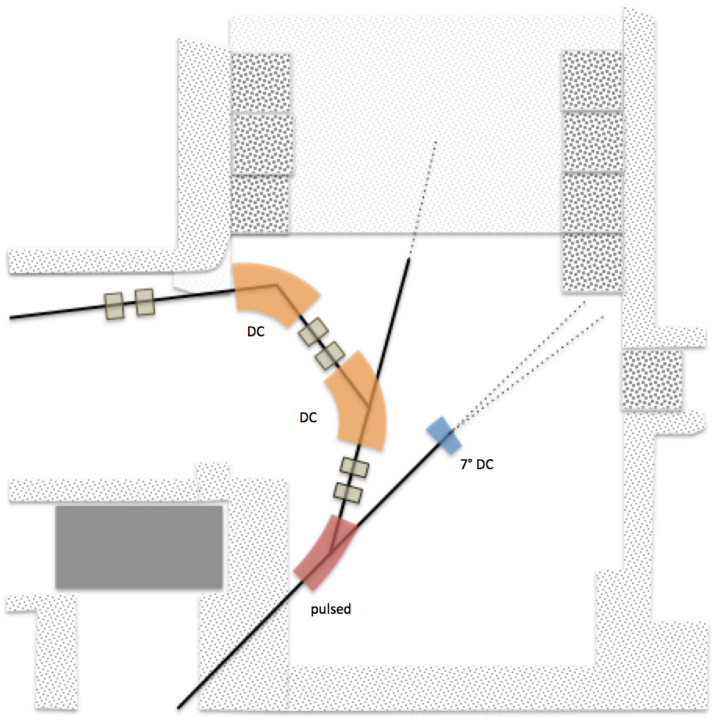


**FIG. 5.6 –** An alternative layout for the splitting of the BTF line.

The resulting configuration would offer the advantage of a better use of the available surface, but should be further investigated, because of the limited space available and the limitation on the maximum field/bending radius of the dipoles.
The area where the new line would be directed has to be rearranged, since it is now occupied essentially by the "chicane" made by concrete blocks shielding the door towards the access road (parallel to the LINAC tunnel, left part of see Fig. 1).

The available space could be enlarged in a relatively simple way, by covering the area just outside the door on the access road with a concrete roof. One side of this area is protected by the groundwork of the LINAC tunnel, while on the opposite side (towards the present BTF control room) the wall should be reinforced with shielding blocks.

## 6 – NEW TAGGED PHOTON SOURCE

The present BTF tagged photon source is constituted by two elements:

- an active target for the production of Bremsstrahlung photons from the (attenuated) electron beam, made by two couples of x-y Silicon micro-strip detector planes;
- a series of 10 modules of silicon micro-strip detectors, placed in the inside of the final dipole magnet gap, for the measurement of the radiating electron lost energy.

Depending on the energy lost by the electron radiating a Bremsstrahlung photon, different strips in the tagging modules is fired; the photon energy can be reconstructed by using the measured direction of the electron inside the active target (see Fig. 6.1).

The active target planes are made of two couples of 0.380 mm thick silicon micro-strip detectors, 8.9×8.9 $cm^2$, with a pitch of 0.23 mm, placed in a dark aluminium box, at 15 mm distance, on a movable rail in a gap inside the vacuum pipe upstream of the final dipole (DHSTB02). Presently the gap is the vacuum pipe is not there, and it is replaced by a bellow.

The tagging modules are made of 2 cm high detectors, 384 strips each, with pitch 0.300 in the central region of the module, and 0.600 mm in the outer parts.

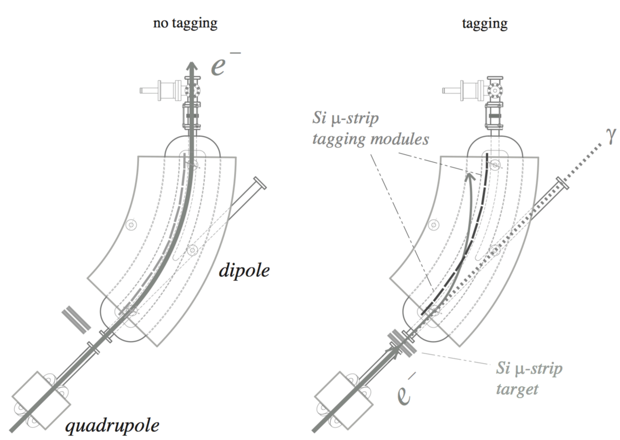


**FIG. 6.1** – Present tagged photon source of the BTF.

This system, successfully built, installed and commissioned, has been extensively used for the calibration of the AGILE satellite pay-load, has the following characteristics:

- The photon energy is reconstructed position of the hit in the tagging modules, but this relation is highly non-linear;
- A single electron track has to cross, for a given event (i.e. BTF bunch), the active target, in order to correctly reconstruct the direction and entrance position inside the magnetic field; in addition a cut on the track reconstruction quality has to be performed;
- In the active target the photon production occurs by Bremsstralhung in one of the four Silicon planes;

- The position of the hit is estimated by the centroid of a reconstructed cluster of neighbouring strips, so that the efficiency is further reduced by the requirement of having just one single clean cluster in the tagging system; indeed, it is possible to also retain multi-clusters events, in which only a photon has been actually produced;

However, it also suffers from some limitations:

- The effect of diverging electrons, due to combined effect of multiple scattering in the target and the non-negligible divergence of the electron beam;
- The best of photon detection is when single electron per bunch is delivered. It is not optimized with the Poissonian distribution of the secondary beam in the low multiplicity operation
- The loss of good photon events, due to the limited active (vertical) area of the tagging modules, of only 2 cm since they have to fit inside the magnet gap;
- The loss of good photon events due to the showering of the electron after the radiation when crossing the vacuum chamber walls, with a resulting complex pattern of hits inside the tagging modules causing the rejection of the event.
- The non-linear relative spread of the tagged photon energy, giving an approximately $1/E(\gamma)$ behaviour, ranging from 40% at $E(\gamma)$=40 MeV and 2% at $E(\gamma)$=420 MeV;
- The overall complexity of the acquisition and reconstruction system (in total composed by 5736 channels)

Many of these issues can be solved or mitigated by re-designing the tagging system without the main fundamental limitation that has driven the concept of the original BTF system, i.e. the re-use of the last dipole magnet (DHSTB002), and the need of placing the tagging detectors outside of the curved beam pipe inside the gap of the same magnet.
The principle of design can be listed as follows:

- The magnet should be designed for the purpose, with open-yoke geometry (C-shaped) in order to put the tagging detectors in vacuum;
- Indeed, the tagging detectors, and possibly also the radiating target, have to be in vacuum, in order to reduce the multiple scattering;
- The tagging detectors have to be placed in the focal surface in order to reduce the effect of the divergence;
- The total deflection angle should be optimized both from the point of view of the achievable resolution and of avoiding spurious hits on the tagging detectors;
- Due to the 1/E behaviour of the Bremsstrahlung probability, the acceptance has to be the highest possible towards the lower part of the spectrum;
- The depth of the target has to be optimized in order to have a ≈1 radiating electron per bunch;
- The granularity of the tagging detectors has to be optimized with respect to the final energy

resolution.

A possible configuration of the analysing magnet and the relative focal plane detector is shown in Fig. 6.2, for a set of typical parameters: distance of the Bremsstrahlung source between 20 and 50 cm, magnetic field maximum strength 1.5 T, 45° sector magnet with bending radius 1.5 m. The trajectories for divergent, monochromatic electrons of different momentum have been calculated following the method of Tajima[10].

The benefit of placing a segmented detector in the focal plane and the possibility of having it in vacuum, allows to relax the requirements on the detector resolution. In the simple example shown in Fig. 6.2 the almost linear range of electron momentum 300 MeV/c wide, giving a photon energy between 60 MeV and 360 MeV, corresponds to a spatial span of about 50 cm. In order to have a resolution comparable to the uncertainty due to residual dispersion and misalignment, a resolution still at the level of 2% at 60 MeV can be achieved with a detector with granularity of 5 mm, with relatively simple readout of the order ≈100 channels.

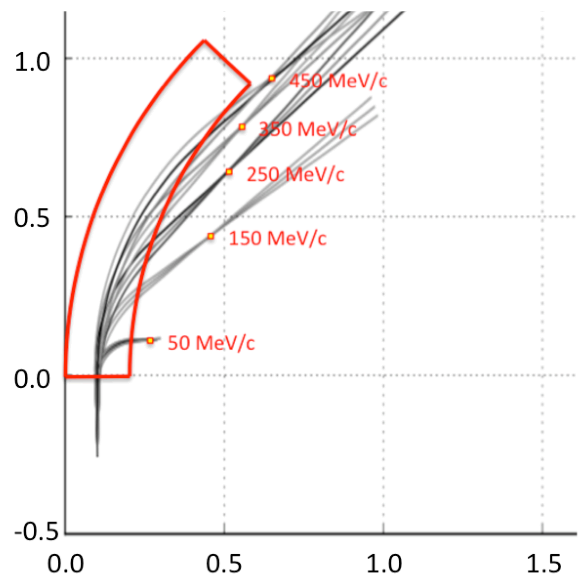


**FIG. 6.2** – A possible configuration of the analysing dipole magnet (a 45° sector magnet) and calculation of the focal plane.

## 7 – ENERGY UPGRADE TO 1 GEV

The potential of the BTF would be enlarged by extending the energy range, both at lower energy and on the high energy side. In particular, the reduced multiple scattering and the possibility of improving the beam quality – both from the spot size and the divergence/collimation point of view – would enrich the possibilities for detector testing. Of course, extending the energy range would also be desirable from the point of view of detector calibration for HEP or also for astro-particle applications. Finally, raising the energy in the GeV range, would increase the yield of a possible neutron/hadron photo-production source, also extending the fast neutron spectrum in a region more interesting for detector qualification e.g. at the luminosity upgraded LHC.

The DAΦNE LINAC is a S-band, SLAC-type accelerating structure, using four 45 MW sledded klystrons as RF sources, capable of routinely deliver 85 mA of positrons (up to 100 mA) and 350 mA of electrons, with a 1.5 mm·mrad emittance and 1 mm spot size (electrons at the positron converter). The schematic layout is shown in Fig. 7.1

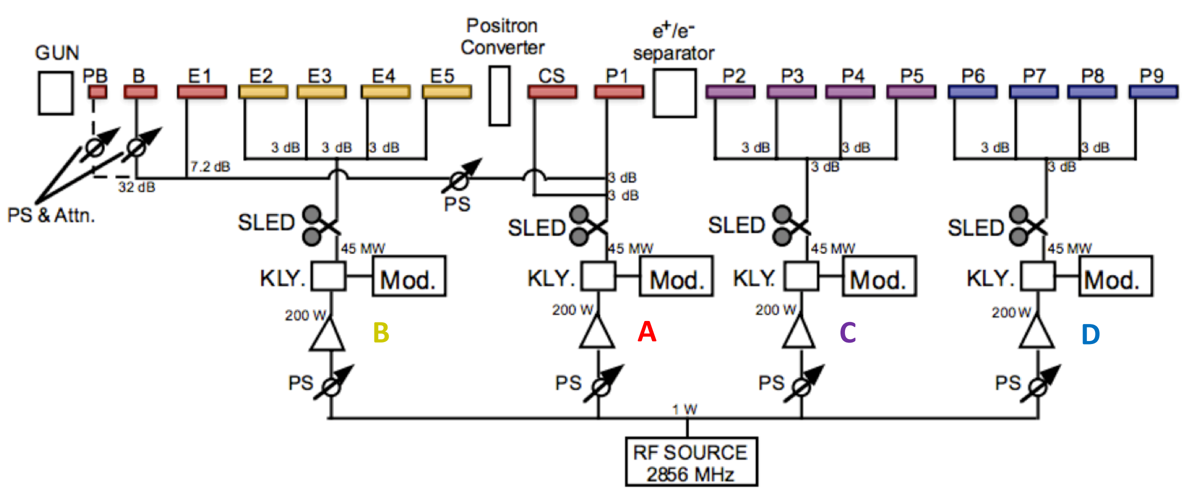


**FIG. 7.1** – Present DAΦNE LINAC scheme.

The possibility of doubling the energy has been studied in the past[11)], starting from the consideration that two parts can be distinguished: the accelerating sections, occupying a portion of the LINAC tunnel approximately 60 m long, and a drift section, before the three-way derivation described in 5: one towards the spectrometer for energy measurement, one to the BTF line, and one towards the damping ring and main rings.

The accelerator sections can be divided in four groups, each served by one of the four RF power stations with the aim of bringing electrons/positrons up to 510 MeV, for injection in the DAΦNE main rings, but in principle capable of reaching a design maximum energy of 750 MeV/550 MeV for electrons/positrons. During BTF dedicated operation with electrons, approximately a maximum energy of about 720 MeV has been achieved.

In the context of this work, we consider an even simpler hypothesis, of adding at least one power station, composed by a klystron, a modulator and a SLED. Considering a 45 MW klystron feeding four 3 meters long sections, the maximum energy should be increased by at least 240 MeV (20 MV/m), but higher energies can be reached by using an higher power klystron.

## 8 – NEUTRON LINE

In the recent years the n@BTF project has assessed the possibility of producing neutrons by impinging the DA$\Phi$NE LINAC electron beam on a high-Z target. Detailed measurement[12)] of the neutron spectrum followed the optimization, design and building of the Tungsten target and of the Lead/Polyethylene shielding box. The simulated and measured neutron spectrum, characterized by an evaporation spectrum peaked at about 1 MeV, is shown in Fig. 8.1.

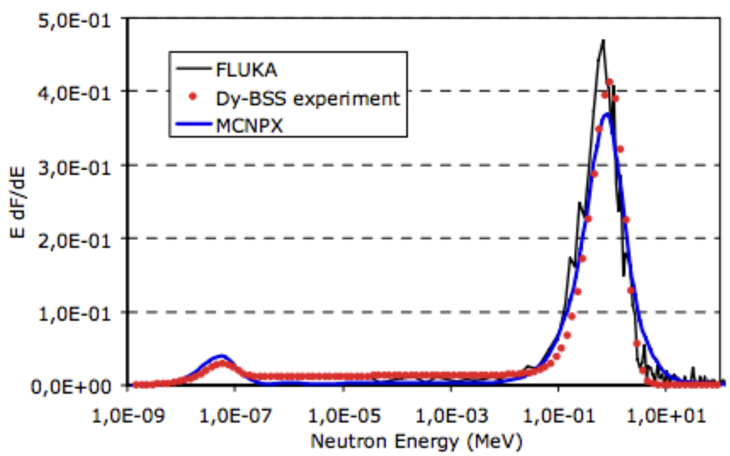


**FIG. 8.1** – Un-moderated neutron spectrum from the BTF target (simulated and measured).

Mainly two aspects of the present source can be improved, in order to enlarge the use of the neutron beam: the total neutron yield, and the produced neutron spectrum.

### 8.1 – Increasing the neutron yield

The present configuration of the neutron source at BTF – as designed, built and commissioned thanks to the n@BTF project – is limited by two main factors: the maximum electron beam power delivered by the LINAC, and the target plus shielding configuration, which has been optimized taking into account a certain number of limitations, mainly due to cost or simplicity of construction and operation.

- Increasing the electron beam power delivered to the target. Upgrades of the shielding of the area and of the safety equipment should be performed in order to drive the full LINAC beam current.

- Improving the target station. One simple possibility would be to replace the target, optimized starting from the choice of Tungsten as material, with a Uranium one. Another possibility is to use a Berillium reflector and optimizing the target geometry, further optimizing the neutron extraction lines.

Presently, the BTF hall is enabled by the national authorities for a maximum intensity of $3\times10^{10}$ electrons/s, but the typical operation is between one and two orders of magnitude below. Instead the maximum charge per bunch that can be delivered at full LINAC power is of the order of $2.2\times10^{10}$. Of course the shielding of the BTF hall must be improved in order to get a new authorization, e.g. starting from the preliminary project sketched in section 2.

**8.2 – Moderating the neutron spectrum**

The fast neutron spectrum produced at the BTF, peaked around 1 MeV (as shown in Fig. 8.1), can be shifted towards thermal energies with a moderator setup. This would greatly enlarge the potential use of a low-intensity source like n@BTF, since it would allow to have a metrological characterization; this would qualify it as neutron detector calibration facility.

The simplest moderator system would be realized with an optimized depth of water: already with about 10 cm of water the thermal spectrum is populated, with a loss of the total fluence of about one order of magnitude, but of course more sophisticated moderating schemes can be studied, as for example pioneered by the prototypal ETHERNES (Extended Thermal Neutron Source) facility within the NEURAPID project[13)].

Enlarging the available space allowing time-of-flight applications at low neutron intensities, such as neutron resonant capture analysis (NRCA), would also be beneficial, even though the neutron flux decrease quickly with the distance from the production target ($1/r^2$). Considering a maximum distance from the neutron source of about 5 m, resonances in the range 1-20 eV may be effectively recognized (e.g. Au, Sb, Ag, Cu).

## 9 – DIAGNOSTICS, CONTROL AND OTHER IMPROVEMENTS

One of aspects emerging from the users experience at the BTF is the need of storing the beam parameters, generally measured and controlled by the BTF DAQ and control system, on a event-by-event basis. This can be done in two ways:

- in **hardware**: by locking the user acquisition system, generally driven by the main beam trigger (connected to LINAC timing system, so precisely timed with the particles arrival), to the BTF systems. This solution has two great disadvantages:
    - It needs the splitting of the analog signals, in order to keep the possibility of monitoring the beam with the usual BTF tools, degrading the signal to noise ratio.
    - It can sum the dead-times of the two DAQ systems, and can generate a dead-lock, stopping the data logging;
- in **software**: by time-stamping each event and aggregating the two data-streams, profiting of the relatively low maximum rate at the BTF (50 Hz). This method needs of course to notify the exact format and meaning of the BTF recorded information and needs to rely on a time reference with a jitter much better than 20 ms.

A possible improvement in this context would be to provide an easily accessible, standardized software interface to the BTF data, in order to be used by any user group to synchronize with our data.

A preliminary project, in collaboration with the team of the !CHAOS project has been recently started. In the November 2013 the control on the BTF magnet power supplies and beam steering/focusing was already positively performed using the !CHAOS DCS; this collaboration still goes on.

**10 – ACKNOWLEDGEMENTS**

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