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THE FRASCATI BEAM TEST FACILITY NEW LINE: FROM DESIGN TO BEAM COMMISSIONING

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Abstract

The request of beam time for long-time experiments and contemporary the need to provide beam time to the detector developers community, drive the INFN to invest in the commissioning of a new beam line test facility. In this work we describe the necessary steps followed from the design to the commissioning of the new beam line in the Frascati Beam Test Facility.

INTRODUCTION

In the development of the detectors for the high energy physics (HEP) and astro-particles physics, the test beam and irradiation facilities are the key enabling infrastructures.

From 2005 the Beam-Test Facility (BTF) of the DAΦNE accelerator complex in the Frascati laboratory of the Italian National Institute of Nuclear Physics (INFN) has gained an important role in the European infrastructures devoted to the development and testing of particle detectors [1–3].

The presented proposal in 2016 aimed at improving the performance of the facility extending the range of application for the LINAC beam extracted to the BTF lines, in the directions of hosting fundamental physics long term experiments [4] and providing electron irradiation also for industrial users.

To achieve this, it was requested to double the BTF beamlines, in order to cope with the significant increase of users due to the much wider range of applications.

The original BTF line is in operation since 2002 [5, 6], and from 2004 operates in opportunistic mode [7] during the running of the DAΦNE electron-positron collider. The full LINAC beam can also be extracted towards the BTF line without being intercepted by the target (within the 3×10^{10} particles/s limit established radio-protection rules for the current shielding configuration).

In the next paragraphs the steps from the Conceptual Design Report presented in 2016 [8] to the commissioning of the new line are described. The issues necessary to be discussed for the reconstruction of the first line of the BTF (BTF1) for a long term experiment and the processing difficulties of the commissioning of the second line of BTF (BTF2) are described.

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THE DESIGN OF THE NEW BTF LINE

The main requirements from the users concerning the detector testing beam-test activities can be easily summarized:

- Good quality beam, in particular from the point of view of beam size, divergence and background, down to the low end of the BTF energy range, i.e., few tens of MeV. This requirement is particularly difficult to match if the setup is in air, downstream of the exit window.
- Extending the energy range towards higher energies: tracking and efficiency studies suffer from the Coulomb scattering of electrons, which scales as 1/p. Higher energies are also very useful for extending the range for the calibration of calorimeters.

The Beam-Test Facility (BTF) is an extraction and transport line, to produce electrons or positrons in a wide range of intensity, energy, beam spot dimensions and divergence, starting from the primary beam of the DAΦNE LINAC. The LINAC accelerate 50 pulses/s, one transported in the spectrometer, the other can be either transported to a small ring for emittance damping (and from there injected into the 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 degree bending 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 30 MeV up to almost the primary beam energy) and spread (typically better than 1 percent at higher energy, depending on the collimators settings). The beam is then transported to the experimental hall and focused 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.

The original idea for the new layout consists in a beam-splitting dipole, wrapped around a double-exit pipe, that can drive beam pulses from the upstream BTF beam-line alternatively to the two new lines [9]. 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 ("BTF 1"), also profiting of the existing concrete block-house, while the second will transport the beam, with three additional dipoles, in the area previously used as BTF control room ("BTF 2"), with few civil engineering work. A complete optimization of the new lines optics has been performed, in order to define the

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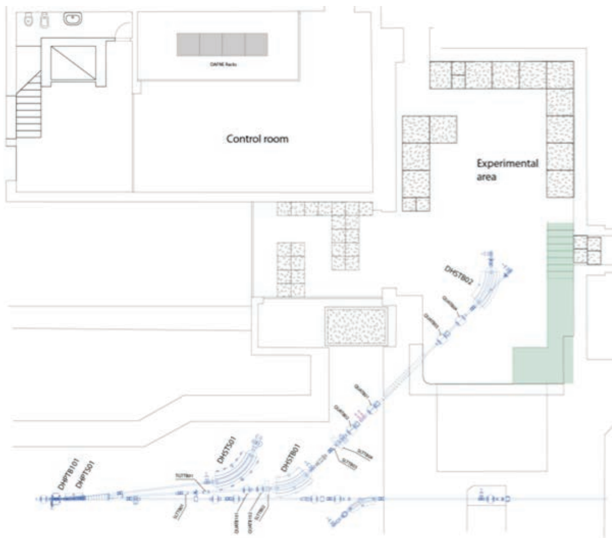

Figure 1: The BTF layout until 2017.

new beam elements requirements, both using G4beamline and MADX [10]. The original idea of a fast magnet for a 45 degree bending angle was excluded, so the design was changed for a fast 15 degree dipole magnet and a new design of the facility is shown in Fig. 2. The new magnetic line to

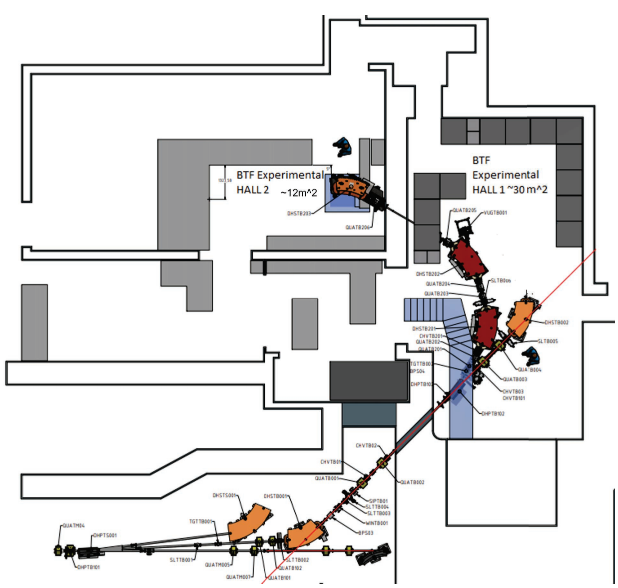

Figure 2: The BTF2 new layout.

transport the beam in the BTF2 experimental hall after the 15 degree pulsed magnet consists by 6 quadrupoles two 45 degree bending magnet and one 35 degree magnet.

THE NECESSARY STEPS FROM THE DESIGN TO THE COMMISSIONING

The budget The financial aspect of the project was shown in the conceptual design report presented in 2016. After review of the INFN Machine Advisory Committee the budget for all the project was available from March 2018.

The law authorizations All the requested legislation steps for start a new activity in the building 54 of the laboratory was submitted to the relative authorities and government agencies to obtain the permission. The agencies that request clarification on the environment aspect of the activity receive the answers in the request time thanks to the effort coordinated effort of the Safety Division, Technical Division, Radio-Protection Division, Administrative Division and Accelerator Division of the Laboratory.

The civil engineering activities After a first step where the general requirements from the Technical Division was collected related to the, building, cooling systems, power supplies, electrical and interlock systems, a continue feedback loop with the designer of the Accelerator Division was necessary, to produce the right actions to mitigate the risks that could present this upgrade project in a 50 year old building with a lack of documentation of the status of the building and auxiliary system.

The building 54 of the laboratory was modified for adding the new radio-protection shielding for the BTF2, a new entrance was realized and the building was modified to receive all the auxiliary systems as the new electric distribution and the required cooling system distribution for the magnets elements with their interlocks and for the experimental area. A new room of the roof of the BTF2 for the power supplies was prepared considering all the necessary auxiliary systems (network, cooling, controls). The new control room of BTF, far away 60 m from the experimental halls, was prepared in 2018 with all the auxiliary systems to accommodate the users.

The design and commissioning of the magnetic elements During the design phase was evident that the main constrain for the installation of the new BTF line was the space limitation. The Magnetic Service of the Accelerator Division has collected the requirement for a 20 T/m magnetic fields for the six quadrupoles and the requirements for the different dipoles, the fast pulse dipoles, the 2 H-type bending dipoles and the last 35 degree C-type bending dipole. The Magnetic Service has provided the Magnetic design to the Mechanical Engineering Service of the Accelerator Division that has produced the mechanical design for the bids. All the magnets delivered are characterized with their power supplies by the Magnet Service in the new measurement magnet area. More details on the magnetic elements are in [11].

The design and commissioning of the vacuum elements The requirement to adapt the BTF1 for long term experiment and the needs to remove all the Beryllium windows, drive the development of a safety system to protect the LINAC vacuum from the accidentally events that could happening during the installation of experience in both BTF lines.

The vacuum system has been designed by the Vacuum Service of the Accelerator Division in order to allow the

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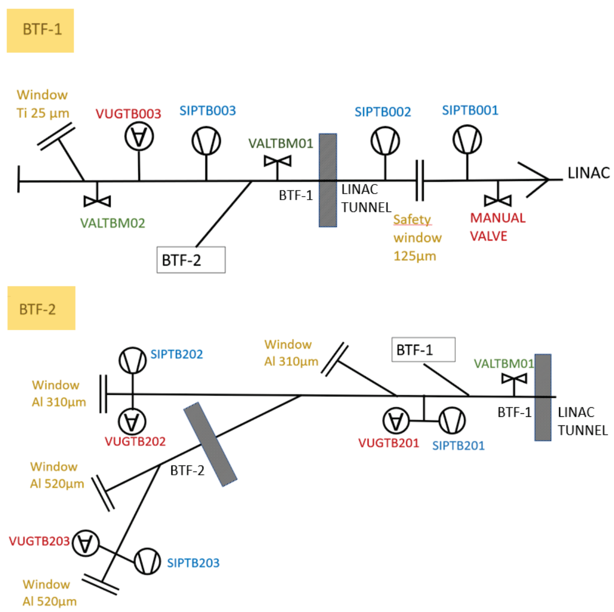

Figure 3: The BTF Vacuum system layout.

installation of elements in the transfer line without exposing the LINAC vacuum to risks. It is compose by fast valves, vacuum measurement systems, pumping devices, collimators for beam manipulation, beam stopper for safety procedure, thin Mylar windows for vacuum LINAC separation and thin Titanium (25 um) and Aluminium windows at the end of the lines as shown in Fig. 3.

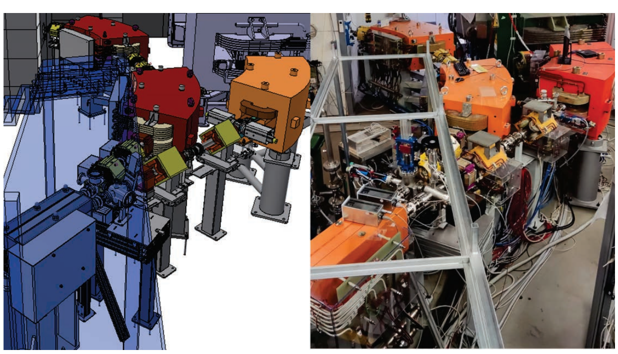

Figure 4: On the left the 3D design and on the right the commissioned BTF line.

The design and commissioning of the mechanics elements Most of the magnets and auxiliary mechanics system drawings are produced by the Mechanical Service of the Accelerator Division. They produce different 3D mapping of the BTF areas to reduce the installation time and the risk of the interference during the installation of all the elements as shown in in Fig. 4. Thanks to this method a detailed schedule of the activities has provided the tools to optimize the resources.

The radio protection system The radio-protection Service has followed all the procedure for the authorizations and

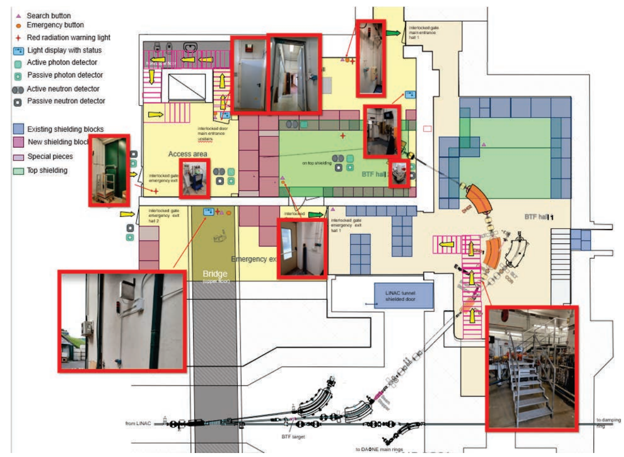

Figure 5: The layout of the BTF2 safety system.

provides the guidelines for the search procedure of the BTF2 area. The installation of the safety system for the BTF2 is shown in Fig. 5. Thanks to their support the beam commissioning of the new line is ongoing. The radio-protection limit for BTF2 is 10^6 particle/s with an energy of 730 MeV.

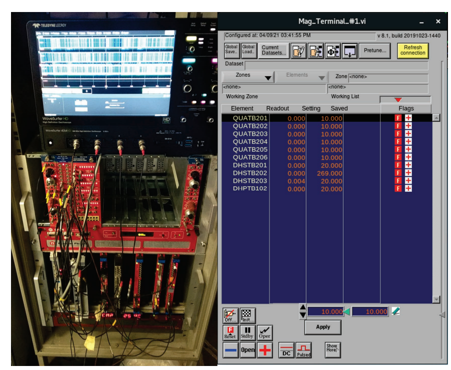

Figure 6: On the left the new BTF2 DAQ system under test, on the right the controls of the new magnets implemented in DCS.

The control system As shown in Fig. 6, all the new magnetic elements power supplies controls are implemented into the DAΦNE Control System (DCS) [12] thanks to the support of the Control Service of the Accelerator division, and a BTF2 Data Acquisition System based on SIS3153 Ethernet-VMEbus interface was developed, installed and tested as shown in Fig. 6 during the test phase, where the SCALER, QDCs, PIO, TDCs and the Timing Unit are visible on the left.

THE FIRST BEAM COMMISSIONING IN BTF2

Driven by simulations and thanks to the possibility to check the beam at the straight exit of each dipole in the new transfer line, the first beam was transported at the exit of the new line in few working hours. The diagnostic used for this

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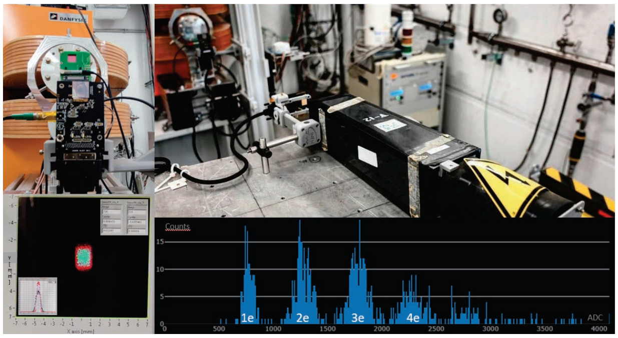

Figure 7: On the left high the pixel detectors low the cumulative distribution, on the right the lead glass calorimeter and low the particle count identification by the ADC counts (thanks to !CHAOS [13] integration of BTF DAQ).

test is a silicon pixel detector for details see [14–18] and a lead glass calorimiter as shown in Fig. 7.

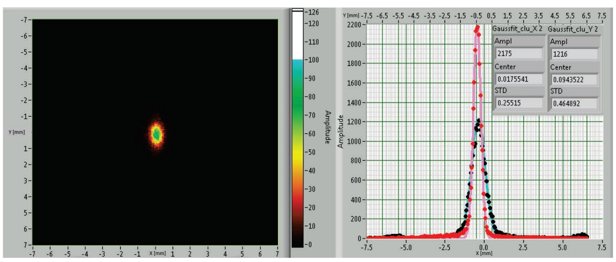
Figure 8: On the left the beam spot accumulated for about 2000 bunches with single particle detected by silicon pixel detector, on the right the Gaussian fit of the cumulative distribution ($\sigma_x = 0.25$ mm, $\sigma_y = 0.46$ mm).

After few days of optimization of the line parameters we obtain the best focused beam at the exit of the BTF2 for a 450 MeV electron beam bunch with single particle for bunch is shown in Fig. 8.

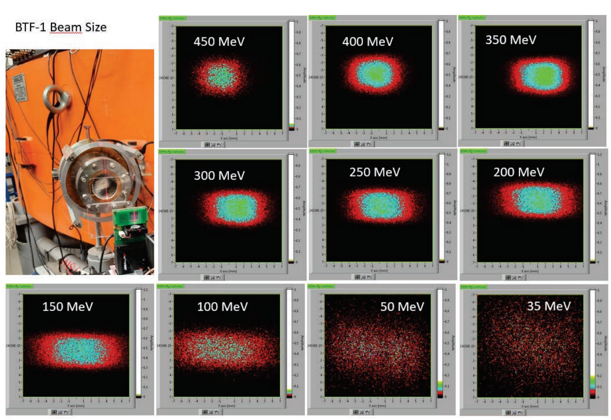

Figure 9: The BTF1 straight exit windows and the measured beam spot at various energy.

We test the possibility to transfer the beam between the two lines simply turning on and off the 15 degree pulsed magnet to find the best beam possible for the two lines. The

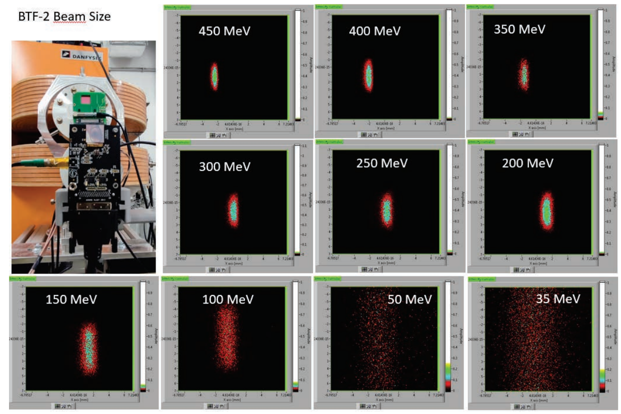

Figure 10: The BTF2 exit windows and the measured beam spot at various energy.

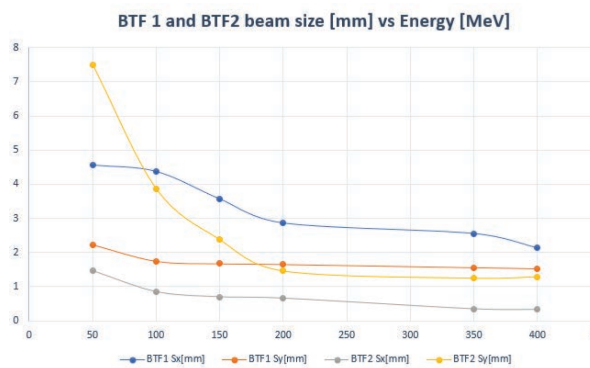

Figure 11: The plot of the measured BTF2 and BTF1 beam size vs Energy.

measurements of the beam spot with silicon pixel detector are shown for an energy range from 450 MeV to 35 MeV in Fig. 9 for BTF1 and Fig. 10 for BTF2.

For the BTF2 a pretune of the magnet provide the possibility to check the beam quality for different energy of electron, as shown in Fig. 11.

CONCLUSION

The commissioning of the BTF2 line will continue in the next months to scan all the possibility and to provides to the users the parameters of the facility. The call for the users is scheduled to be published at the begin of 2022.

REFERENCES

[1] A. Rocchi *et al.*, "Linearity and rate capability measurements of RPC with semi-insulating crystalline electrodes operating in avalanche mode," *J. Instrum*, vol. 15, no. 12, C12004, 2020. doi:10.1088/1748-0221/15/12/C12004

[2] V. C. Antochi *et al.*, "Performance of an optically read out time projection chamber with ultra-relativistic electrons," *Nucl. Instrum. Meth. A*, vol. 999, p. 165209, 2021. doi:10.1016/j.nima.2021.165209

[3] E. Diociaiuti, "Study of the Mu2e sensitivity to the $\mu^- \to e^+$ conversion process," Thesis, FNAL, USA. doi:10.2172/1605578

ISBN: 978-3-95450-230-1 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2021-MOPP05

[4] F. Oliva, "Performance of the charged particle detectors of the PADME experiment," *J. Instrum*, vol. 15, no. 06, C06017, 2020. doi:10.1088/1748-0221/15/06/C06017

[5] A. Ghigo and F. Sannibale, "Single electron operation mode in DAPHNE BTF," *Conf. Proc. C*, vol. 940627, pp. 2444-2446, 1995.

[6] A. Ghigo, G. Mazzitelli, F. Sannibale, P. Valente and G. Vignola, "Commissioning of the DAFNE beam test facility," *Nucl. Instrum. Meth. A*, vol. 515, pp. 524-542, 2003. doi:10.1016/j.nima.2003.07.017

[7] B. Buonomo, G. Mazzitelli and P. Valente, "Performance and upgrade of the DAFNE Beam Test Facility (BTF)," *IEEE Trans. Nucl. Sci.*, vol.52, pp. 824-829, 2005. doi:10.1109/TNS.2005.852704

[8] P. Valente *et al.*, "Linear Accelerator Test Facility at LNF: Conceptual Design Report," [arXiv:1603.05651 [physics.acc-ph]].

[9] B. Buonomo, C. Di Giulio, L. Foggetta and P. Valente, "The Frascati LINAC beam test facility performances and upgrades," *Nuovo Cim. C*, vol. 40, no. 1, 69, 2017. doi:10.1393/ncc/i2017-17069-6

[10] B. Buonomo, C. Di Giulio, L. Foggetta and P. Valente, "Studies of the doubling of the Frascati Beam-Test Facility (BTF) line", CERN, Geneva, Switzerland, Rep. AIDA-2020-NOTE-2016-002, 2016.

[11] L. Sabbatini *et al.*, "Fast Ramped Dipole and DC Quadrupoles Design for the Beam Test Facility Upgrade", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 3638–3640. doi:10.18429/JACoW-IPAC2018-THPAL011

[12] G. Di Pirro, C. Milardi, A. Stecchi, L. Trasatti, "DANTE: control system for DAΦNE based on Macintosh and LabVIEW", vol. 352, p. 455, Oct. 2002. doi:10.1016/0168-9002(94)91568-7

[13] A. Stecchi *et al.*, "!CHAOS General Status Report", in *Proc. 12th International Workshop on Personal Computers and Particle Accelerator Controls (PCaPAC'18)*, Hsinchu City, Taiwan, Oct. 2018, pp. 17–21. doi:10.18429/JACoW-PCaPAC2018-WEC5

[14] L. G. Foggetta, B. Buonomo and P. Valente, "Evolution of Diagnostics and Services of the DANE Beam Test Facility", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 904–906. doi:10.18429/JACoW-IPAC2015-MOPHA049

[15] B. Buonomo, C. Di Giulio, L. G. Foggetta and P. Valente, "The Frascati LINAC Beam-Test Facility (BTF) Performance and Upgrades", in *Proc. 5th Int. Beam Instrumentation Conf. (IBIC'16)*, Barcelona, Spain, Sep. 2016, pp. 395–398. doi:10.18429/JACoW-IBIC2016-TUPG29

[16] P. Valente, B. Buonomo, C. Di Giulio and L. G. Foggetta, "Frascati Beam-Test Facility (BTF) High Resolution Beam Spot Diagnostics", in *Proc. 5th Int. Beam Instrumentation Conf. (IBIC'16)*, Barcelona, Spain, Sep. 2016, pp. 221–224. doi:10.18429/JACoW-IBIC2016-MOPG65

[17] B. Buonomo, C. Di Giulio, L. G. Foggetta and P. Valente, "A Hardware and Software Overview on the New BTF Transverse Profile Monitor", in *Proc. 5th Int. Beam Instrumentation Conf. (IBIC'16)*, Barcelona, Spain, Sep. 2016, pp. 818–821. doi:10.18429/JACoW-IBIC2016-WEPG73

[18] P. Valente, B. Buonomo, C. Di Giulio and L. G. Foggetta, "DANE BTF Improvements of the Transverse Beam Diagnostics", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 250–252. doi:10.18429/JACoW-IPAC2017-MOPAB061