COMMISIONING OF A NEW BEAMLINE FOR MEDICAL RESEARCH AND RADIATION HARDNESS TESTING

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Abstract

The HZB cyclotron accelerator complex provides 68 MeV protons for therapy and related research. The main accelerator is an isochronous sector cyclotron served by two injectors. The treatment room is fixed according to the regulatory agencies and the adjoining experimental station is often overbooked with users for radiation hardness test and dosimetry. To widen the irradiation possibilities, we built up a new beamline for medical research with minibeams and a second target station is prepared for radiation hardness experiments. The setup, possibilities and commissioning for these stations will be presented.

INTRODUCTION

The HZB cyclotron is an isochronous sector cyclotron served by two injectors: a 6 MV single-ended Van-de-Graaff or a 2 MV Tandetron [1,2]. The Tandetron is the standard injector for proton therapy of ocular tumours while the Van-de-Graaff provides also other ion species and permits more sophisticated time structures. The accelerator is available for experiments for three days per month. Until recently, only one experimental station just beside the treatment room was available (Fig. 1).

The increased variety of the experiments lead to beamtime losses due to the necessary changes in the experimental set-up and its proximity to the treatment/patient room in terms of radiation safety. Hence, it became essential to install new target stations. According to the users request, two different target stations were planned:

MiniBEE

This beamline is dedicated for Spatial Fractionated Proton Beam Therapy and will be equipped with a SARRP (small animal radiation research platform) [3,4]. This is a joint project between the HZB and the Universität der Bundeswehr München. The goal are proton beams of different energies with a FWHM of 100 µm and an intensity between 1 pA to 1 nA.

InOperando

This target station will be used for irradiation of solar cells with up to 10^{12} protons/(cm^{2}s). The solar cells will be under operation with parallel illumination of a sun simulator. The sun simulator will provide a spectrum which is typical for space (AM0). For this, a dedicated target station is required which permits a homogeneous irradiation of the solar cells with protons and a parallel irradiation with a sun simulator without with a calibrated AM-0 spectrum.

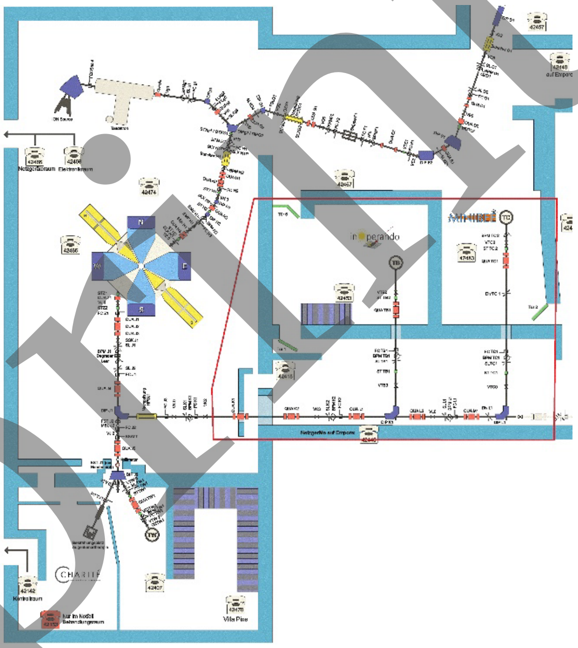

Figure 1: Layout of the HZB cyclotron with Tandetron injector, the Van-de-Graff being not shown here. The treatment room with the adjoining experimental station is at the bottom left. The red line marks the installation of the new beamlines.

BEAMLINES

Figure 2: Optical alignment of the dipoles and triplets using theodolites.

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For the sake of sustainability, beam line material was reused as much as possible. In 2009 quadrupole triplets and 90° bending magnets were donated to CERN for an extension of ISOLDE. However, this extension was realised in a different way and CERN sent the items back to HZB (Fig. 2). All the water-cooling hoses were replaced and the coil connections redone. From the Maier-Leibnitz-Laboratorium (MLL) in Munich [5], we could get 12 magnet power supplies. Albeit these devices were more than 30 years old, they were repairable as the schematics were still available from the producer (FUG, now XP Power [6,7]). They were refurbished: new fans were installed, rectifier and capacitors tested, the output verified, and a standardized 15-pin remote connection installed. The calibration was renewed and an electronic interface developed, which implements digital switching on/off, interlocks, analogue set-, and readback values (Fig. 3). Some minor electrical faults were repaired like broken Thyristor in the pre-regulation and faulty transistors in the fine regulation. In contrast to modern highly integrated power supplies this was possible to be done in house. The power supplies deliver 50 V/80 A (FUG NTN 2800M-35) and 50 V/120 A (FUG NTN 4200-35) with a stability in the range of 50 ppm over eight hours, while the quadrupoles take a maximum of 35 V and 65 A.

Figure 3: Refurbished FUG power supplies with new developed interlock interface to the Beckhoff-PLC.

For eight slit units the old unipolar stepper motors from SLOW SYNC were replaced by bipolar Sanmotion stepper motors [8]. The feedback was changed from the mechanical CAMAC-encoder with a resolution of 0.04 mm to a geared 10-turn potentiometer with a resolution of 0.01 mm. The slits and the Faraday cups (FC) now consist of 40 mm thick Al99 to reduce neutron production, as the old versions were made of copper with a tantalum inlet. The FCs were integrated into the existing digital multiplexer system [9].

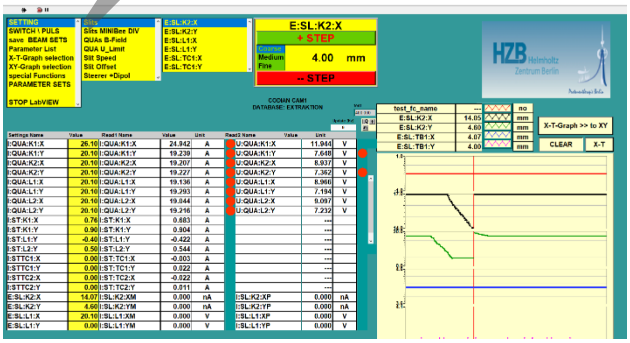
The 2 m thick wall between the cyclotron vault and the next room was opened and the elements installed according to the results of beam line calculations carried out using PBOLab [10] and BDSIM[4,11]. The aim is a telescopic beam transport. The alignment was checked with optical theodolites (Fig. 2). The precision of the height measurements performed with an surveyor's optical level is ±0.02 mm and the differences between nominal and measured values is below ±0.1 mm.

As the beamline is extended beyond the existing radiation safety area, four more local dose monitors were installed and connected to a safety system. The beam distribution path is cleared by a patrol and locked. Only after this procedure the Faraday Cup, serving as beam dump in the vault upstream, can be opened.

For observation of the beam spot in various locations in the beamline, a new optical beam profile monitor (BPM) with thin scintillators was developed [12].

CONTROL SYSTEM

The control system of the cyclotron magnets and the beamlines in the cyclotron vault and treatment room are based on VSystems and CAMAC interfaces. As CAMAC modules are now obsolete and the EPICS community is striving, the extension of the control system to the new beamline is done in EPICS. The new beamlines were equipped with a combination of programmable logical controllers (PLC) from Beckhoff using the communication protocol of automation device specification (ADS) interface to EPICS. The goal is to use existing hardware in stock for the control of valves, faraday cups and steerer power supplies by the Beckhoff-PLCs. Following the safety philosophy of the cyclotron, all interlocks for safety are hard wired, not implemented in software. For the motion of the aperture slits, the control of the quadrupole power supplies and steerers, faraday cups and optical beam profile monitors the Beckhoff-PLCs are addressed over ETHERCAT. These values are then transferred to EPICS-PV via the ADS-interface. In collaboration with Cosylab [13] these software modules and IOCs were developed. The GUI was created in LabVIEW (Fig. 4), because a similar solution is used on the low-level RF-control for the cyclotron [14]: The EPICS-PVs are transported over channel access. The LabVIEW-GUI is using CA-Lab [15] for accessing the EPICS-PVs.



Settings Name	Value	Read1 Name	Value	Unit	Read2 Name	Value	Unit
I:QUA:K1:X	26.10	I:QUA:K1:X	24.942	A	U:QUA:K1:X	11.944	V
I:QUA:K1:Y	20.10	I:QUA:K1:Y	19.239	A	U:QUA:K1:Y	7.648	V
I:QUA:K2:X	20.10	I:QUA:K2:X	19.207	A	U:QUA:K2:X	8.937	V
I:QUA:K2:Y	20.10	I:QUA:K2:Y	19.227	A	U:QUA:K2:Y	7.362	V
I:QUA:L1:X	20.10	I:QUA:L1:X	19.136	A	U:QUA:L1:X	8.966	V
I:QUA:L1:Y	20.10	I:QUA:L1:Y	19.293	A	U:QUA:L1:Y	7.194	V
I:QUA:L2:X	20.10	I:QUA:L2:X	19.044	A	U:QUA:L2:X	9.097	V
I:QUA:L2:Y	20.10	I:QUA:L2:Y	19.216	A	U:QUA:L2:Y	7.232	V
I:ST:K1:X	0.76	I:ST:K1:X	0.683	A		---	
I:ST:K1:Y	0.90	I:ST:K1:Y	0.904	A		---	
I:ST:L1:Y	-0.40	I:ST:L1:Y	-0.422	A		---	
I:ST:L2:Y	0.50	I:ST:L2:Y	0.544	A		---	
I:STTC1:X	0.00	I:ST:TC1:X	-0.003	A		---	
I:STTC1:Y	0.00	I:ST:TC1:Y	0.022	A		---	
I:STTC2:X	0.00	I:ST:TC2:X	-0.022	A		---	
I:STTC2:Y	0.00	I:ST:TC2:Y	0.011	A		---	
E:SL:K2:X	14.07	I:SL:K2:XM	0.000	nA	I:SL:K2:XP	0.000	nA
E:SL:K2:Y	4.60	I:SL:K2:YM	0.000	nA	I:SL:K2:YP	0.000	nA
E:SL:L1:X	20.10	I:SL:L1:XM	0.000	V	I:SL:L1:XP	0.000	V
E:SL:L1:Y	0.00	I:SL:L1:YM	0.000	V	I:SL:L1:YP	0.000	V

test_fc_name	---	no
E:SL:K2:X	14.05	mm
E:SL:K2:Y	4.60	mm
E:SL:TB1:X	4.07	mm
E:SL:TB1:Y	4.00	mm

Figure 4: Screenshot of the special LabVIEW GUI for the new beamlines.

COMMISIONING MEASUREMENTS

Until 2006, the cyclotron was mainly used for heavy ions. Protons were only used in the vault containing the treatment room and the experimental station. Therefore, the commissioning measurements were also used to check the radiation levels in adjacent rooms. During these measurements it turned out that the openings from the climatization were not sufficiently shielded. Furthermore, the inOperando experiment must be shifted as the ceiling thickness in the cave is not sufficient for the required proton beam intensities and blocking access to all adjacent rooms is not desired.

By default, injection into the cyclotron is done with a DC beam from the Tandetron, which leads to multi-turn extraction. This results in a larger energy spread compared to single-turn extraction: 0.2% instead of 0.1%. Furthermore, there are several beams in different heights visible on the optical BPM (Fig. 5, left). For this reason, the slits after the first double focusing magnet are set to the same values as used for heavy ions with single turn extraction. The quadrupoles were set to the pre-calculated values and both the transmission as well as the 2D images of the beam were monitored.

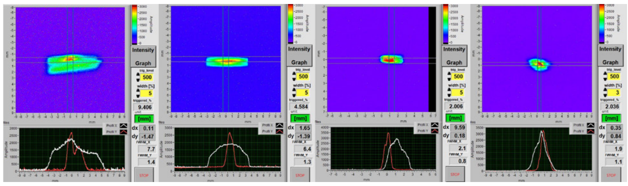


Figure 5: Screenshots from the optical BPMs along the beamline. From left to right: after the first dipole, between first and second dipole, before the third dipole, in front of the experimental station.

Interestingly, the beam was far too low in front of the experimental room of MiniBEE. The position could not be corrected with the steerers directly after the cyclotron. Additional steerers were therefore installed in the beamline between the dipoles. The settings of the steerers confirmed the suspicion from former operation of the last dipole with heavy ions: the height markers of this 90° bending magnet in the beamline are faulty. Finally, the magnet was adjusted mechanically until the beam was on axis.

CONCLUSION

The beam line for MiniBEE is fully functional until the last Faraday Cup before the experiment. The transmission in the beamline is 100% for 68 MeV protons. As a result of the radiation level measurements the shielding between the rooms was improved. The inOperando beamline must be moved to a position downstream of the third dipole for maintaining access to adjacent rooms. Measurements on the beam profile after the third quadrupole are therefore necessary.

The next steps will be to send the beam in the experimental area, in order to obtain dose levels and beam shapes required for the MINIBEE project. Furthermore, beam settings and profiles for different energies will be determined. The experiments are scheduled for May and Jun 2026.

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REFERENCES

[1] A. Denker *et al.*, "Status of the HZB Cyclotron", in. *Proc. CYCLOTRONS'22,* Beijing, China, Oct. 2022, pp. 159-162, 2022. doi:10.18429/JACoW-CYCLOTRONS2022-WEAO04

[2] HVEC, `https://www.highvolteng.com/index_en.html`

[3] A. Rousseti *et al.*, "Preclinical proton minibeam radiotherapy facility for small animal irradiation", in *Proc. IPAC'23,* Venice, Italy, May 2023, pp. 4522-4524. doi:10.18429/JACoW-IPAC2023-THPL043

[4] A. Rousseti *et al.*, "Current status of MINIBEE: minibeam beamline for preclinical experiments on spatial fractionation in the FLASH regime", in *Proc. IPAC'24,* Nashville, USA, May 2024, pp. 3663-3666. doi:10.18429/JACoW-IPAC2024-THPR62

[5] Maier-Leibnitz-Laboratorium (MLL), `https://www.mll-muenchen.de/tandem/index.html`

[6] FUG, now XP Power , `https://www.xppower.com/storage/portals/0/pdfs/SF_NTN2K8.pdf`

[7] FUG, now XP Power, `https://www.xppower.com/storage/portals/0/pdfs/SF_NTN4K2.pdf`

[8] *SANMOTION, `https://publish.sanyodenki.com/library/books/SANMOTION_F2_E/book/data/SANMOTION_F2_E.pdf`

[9] J. Bundesmann *et al.:* "Upgrading the Beam Diagnostic of the HZB-Cyclotron from an Analogue to a new Digital Platform" in *Proc. Cyclotrons'22*, Beijing, China, Oct. 2022, pp. 228-230, 2022. doi:10.18429/JACoW-CYCLOTRONS2022-WEPO011

[10] G. H. Gillespie, "The Particle Beam Optics Laboratory: Enhancing the Scientific Productivity of the Accelerator Community" in *Proc. EPAC'02*, Paris, France, Jun. 2002, pp. 1628-1630 `https://proceedings.jacow.org/e02/PAPERS/WEPRI040.pdf`

[11] L. J. Nevay *et al.*, "BDSIM: An Accelerator Tracking Code with Particle-Matter Interactions", *Comput. Phys. Commun.*, vol. 252, p. 107200, 2020. doi:10.1016/j.cpc.2020.107200

[12] A. Denker *et al.*, "Development of an Optical Beam Profile Monitor for the HZB Cyclotron", presented at the 17th International Particle Accelerator Conf. (IPAC'26), Deauville, France, May 2026 paper THP4046, this conference.

[13] Cosylab `https://cosylab.com/`

[14] T. Fanselow et al., "Operational Experience in the Treatment of Ocular Melanomas with a New Digital Low-level RF Control System" in *Proc. Cyclotrons'19*, Cape Town, Sep. 2019, South Africa, pp. 162-165, 2019. doi:10.18429/JACoW-Cyclotrons2019-TUP007

[15] CA Lab: `https://www.helmholtz-berlin.de/zentrum/organisation/it/calab/index_en.html`