UPGRADE PLANS AND NEW TARGET STATIONS FOR THE HZB CYCLOTRON

A. Denker†[1], J. Bundesmann, A. Dittwald, G. Kourkafas,
Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany
[1]also at Berliner Hochschule für Technik, Berlin, Germany

Abstract

The HZB cyclotron provides protons for eye-tumor treatment in collaboration with the Charité – Universitätsmedizin Berlin. Parallel to therapy, there is an on-going research and development program for beam dosimetry and beam delivery. Furthermore, beam time is used for external users, e.g., the irradiation of geological samples or radiation hardness tests. In response of requests of our users, upgrade plans and new target stations are prepared.

INTRODUCTION

The layout of the accelerator facility is shown in Fig 1. A k=130 isochronous sector cyclotron is served by two injectors. The 2 MV Tandetron™ is mainly used for therapy. The 6 MV Van-de-Graaff permits adjustable time structures on the beam and a variety of ion species [1]. 83% of the beamtime is used for the therapy of ocular melanomas. So far, more than 4400 patients have been treated. 13% of the beam time is used for accelerator research and development as well as medical physics and dosimetry. 4% of the beamtime goes to external users, mainly for radiation hardness testing, quite often in combination with the use of our ^{60}Co source.

The facility has three target stations: the treatment room, an experimental station nearby [2], and an experimental station for higher intensities in the cyclotron vault. As the treatment room and the experimental station share one room from the radiation safety point of view, constraints with setting up experiments arose. Furthermore, the variety of experiments has increased, leading to a much larger number of different set-ups. Additionally, the users also asked for He beams, where the maximum energy now is 90 MeV. To overcome these issues, a further development of the accelerator complex is planned.

UPGRADE PLANS

Different Ion Species

In radiotherapy the potential benefits of protons, He, and C ions is discussed [3]. Hydrogen molecular ions (H_2^+) and He^{2+} ions with the same energy per mass unit have approximately the same range in tissue. Furthermore, they can be accelerated in the cyclotron as so-called cocktail beams. In first experiments [4] slight adjustments in the magnetic field of the cyclotron were needed beside a change in the RF frequency to switch from one ion species to the other. In the next tests, with isochronizing and centering the He^{2+} beam, H_2^+ could be extracted with an identical magnetic field setting, just changing the RF frequency by 0.72%. Passing the beam extraction window, the molecular H_2^+ ions break up into 22.5 MeV protons. The range and the spatial distribution at the experimental station have been measured with CMOS cameras. On the base of these experiments, we started a study for the design of a cyclotron being able to deliver 140 MeV H^{2+} and 280 MeV He_2^+ as a dedicated accelerator for ocular proton therapy.

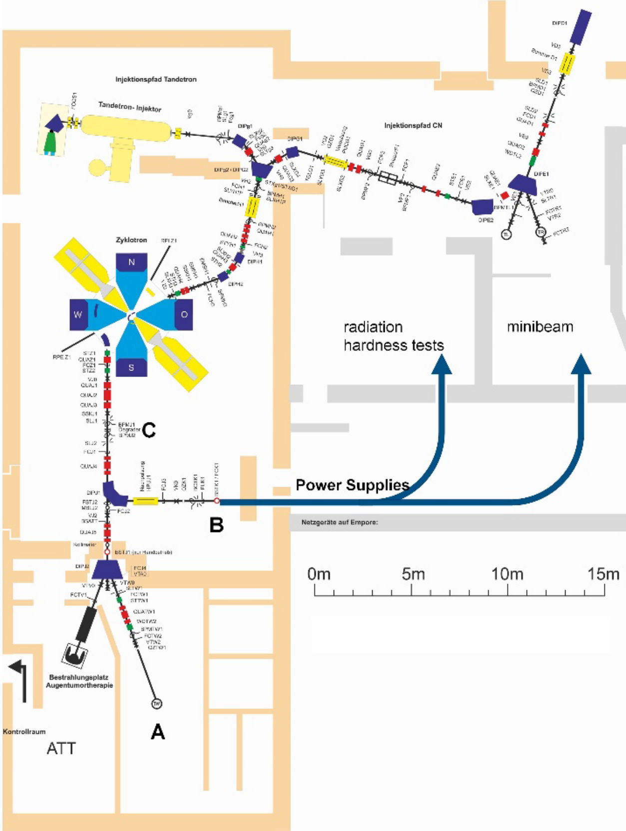

Figure 1: Layout of the accelerator facility. The vertical Van-de-Graaff sits on top of the dipole in the upper right corner indicated by a blue rectangle. Three experimental stations are available: the treatment room (ATT), one station nearby (A), and a station for higher intensities in the cyclotron vault (B). At C, a set-up for the installation of geological samples has been installed recently. The set-ups for dedicated radiation hardness tests and minibeams experiments are in the planning state. The blue arrows mark the planned beamline extensions.

Beam Distribution Measurements

For the measurements of the two-dimensional beam distribution in the treatment room a CCD camera with a weight of about 20 kg is used. For easier handling, a new

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† denker@helmholtz-berlin.de

camera with a 3D printed housing and a weight of about 2 kg was developed and built. A CMOS sensor (FLIR) observes the light created by a scintillator foil (PERLUX GG1) which is mirrored by a metallized Kapton foil. The readout of the camera is performed by a LabVIEW code which also permits display and analysis of the data (see Fig. 2). When using the scattering foil about 8 m upstream of the experimental station, a very homogenous beam profile with a diameter of 40 mm can be achieved. This profile can be modified by inserting apertures to the desired beam area. Using a scattering foil 3 m upstream of the experiment, the intensity varies from 80% to 100% over 25 mm in y. This is sufficient for quite a large number of experiments and has the benefit of smaller beam losses. The use of this camera also facilitates the area determination of irregularly formed beam shapes.

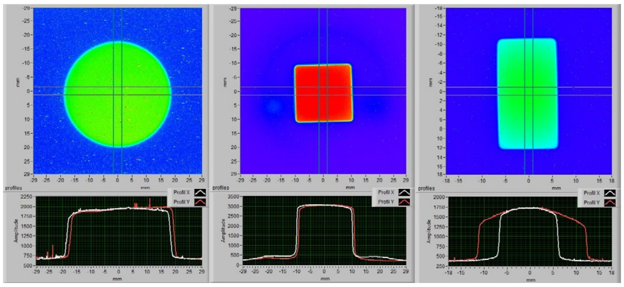

Figure 2: Two-dimensional beam distribution of 68 MeV protons for various experiments displayed in false colours and the corresponding profiles in the lower part of the picture. From left to right: beam widened to 40 mm diameter with a scattering foil 8 m upstream of the camera; same scattering but with an inserted rectangular 10 mm aperture; widened with a scattering foil 2 m upstream of the camera.

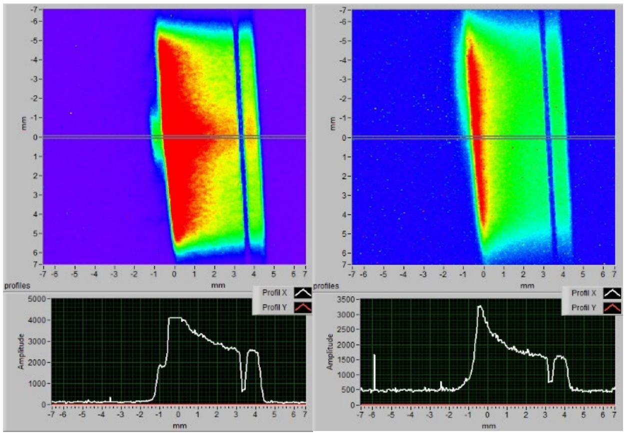

Figure 3: Range verification of 90 MeV He2+ (left) and 22.5 MeV protons (right), the particle beam coming from the right. The white line in the lower part represents the depth profile. The dip in this line marks the real beginning of the range, the intensity peak on its right side is due to reflections in the plexiglass wedges. The high energy transfer of He led to saturation effects at the end of the range.

For the range verification of the ions a depth profile camera has been developed [5,6]. The scintillator foil is installed between two plexiglass wedges with a density of 1.156 g/cm^3 having an angle of 15° with respect to the beam. The dimensions of this camera system are identical to the dimensions of the 2D camera; thus, a quick exchange is possible. Figure 3 shows the results obtained with the above-mentioned cocktail beam. The 90 MeV He beam has a larger electronic dE/dx ($9.602 \cdot 10^{-02}$ MeV/(cm^{2}mg)) than the 22.5 MeV proton beam ($2.406 \cdot 10^{-02}$ MeV/(cm^{2}mg)), which reflects in the intensity of the camera images: At the end of the range of the He beam saturation effects in the camera occur. Depending on the beam intensity, the exposure time is 2 s or less.

Many experiments require different energies within one experimental run. This is achieved by inserting degrader plates, as a change in the setting of the cyclotron with approximately six hours is too long. The depth profile camera permits a very quick determination of the range at the position of the samples to be irradiated. SRIM calculations [7] yield 4.59 mm and 4.48 mm respectively in plexiglass. The observed difference in Fig. 3 is due to energy loss in the scattering foil, extraction foil, air path. Range uncertainties, especially when slowing down to low energies, due to uncertainties in density and/or thickness of the absorber plates are avoided.

NEW TARGET STATIONS

For the installation of new target stations, the beam line has to be prolonged from the cyclotron vault into the area where the power supplies are installed.

The high intensity target station (B in Fig. 1) will be changed to a removable system. Thus, the beamline can be prolonged. The power supplies of the dipoles and quadrupoles installed in the area Power Supplies (Fig. 1) are moved to the floor above.

The beam focal point in front of the first dipole downstream the cyclotron, indicated as a blue arc, is the starting point. For each beamline, one double focusing 90° magnet is foreseen, which will compensate the energy dispersion created by the first 90° dipole in the cyclotron vault. In between, pairs of quadrupoles provide a telescopic beam transport. Thus, achromaticity is achieved at the focal point after the second dipole. The rest of the beamline then depends on the experimental needs.

Radiation Hardness Tests

Radiation hardness tests with protons are often performed after total ionizing doses (TID) tests at the ^{60}Co source, which provides dose rates between 1 Gy/h to 100 Gy/h in a 3 m times 4 m irradiation room.

In response to requests of our users, a new target station for radiation hardness tests with particles, especially the irradiation of solar cells, is planned. The properties of this station should be similar to the existing set-up: the particle beam will be extracted from the vacuum of the beam line via a Kapton foil into ambient atmosphere. Either a broad beam, at least 40 mm in diameter can be used or the beam size will be adapted to the device under test with slits or apertures (see Fig. 2). Typical applied proton number will be 10^4 p/cm^2 to 10^{11} p/cm^2 within 15 minutes. For high proton fluences (e.g. 10^{13} p/cm²) the installation of a wobbling system is foreseen to reduce the beam losses due to widening the beam via a scattering system. The incoming proton beam will be monitored by a transmission ionization chamber.

There is more room available at this new target station. Thus, besides the possibility of operating the devices under test during the irradiation, additional measuring opportunities are possible:

- in-situ luminescence measurements.
- solar simulator to measure the response of solar cells during the irradiation.
- possibility to install a vacuum chamber.

Due to the installation in a separated room, the radiation hardness tests can be prepared while the area of the treatment room is in use for patients.

Minibeam Experiments

In collaboration with the Universität der Bundeswehr München the installation of a preclinical proton minibeam radiotherapy facility for small animal irradiation is foreseen. Beamline calculations for the design of the beamline are ongoing [8]. After the focal point, a special quadrupole will reduce the beam size. These first calculations look very promising, that the required small beam size can be achieved.

Geological Samples

One additional target station has already been implemented: For the irradiation of geological samples, a new experimental setup was realized in the beamline directly after the cyclotron (C in Fig. 1). At this position, a retractable and movable sample holder with a vacuum lock system is installed, allowing sample changes without interfering with the beam line vacuum. Up to 60 samples with a size of 1 cm by 1.5 cm can be mounted. Hence, a stack of geological samples can be irradiated with high intensities. The goal of this experiment is the synthesis of ^{3}He for ^{4}He/^{3}He thermochronology. In first tests it could be shown that a uniform beam distribution over the sample size and thus a uniform ^{3}He production could be achieved [9,10].

CONCLUSION

It could be confirmed experimentally that a switching from He2+ ions to protons with a velocity of 22.5 MeV/u could be achieved without any changes in the magnetic field of the cyclotron. Thus, the adjustment time was shortened to 15 min. This could be even shortened further, if we could change the RF frequency during its operation, which is at the moment not feasible.

The distribution of the proton beam in x and y as well as in z can be measured quickly with two cameras. One is providing a two-dimensional image of the beam at the position of samples to be irradiated. The other shows the penetration of the beam in (times 1.156 water equivalent) plexiglass and thus permits the determination of the energy of the particles. As the camera is mounted at the position of the devices under test or the samples to be irradiated, the effects of the scattering foil, beam exit foil, degraders, transmission ionization chambers are taking into account. The same applies to the depth-profile camera.

The separation of the experiments into different rooms will permit in the future a parallel use leading to a more efficient use of the beam time. The experimental station nearby the treatment position will mainly be used for medical physics and dosimetry. For the medical physicists and radiation oncologists this station is within comfortable reach. Radiation hardness tests will be able to set up and test their experiment without constraints due to necessary changes of experiments and patient operations. Furthermore, the experimental opportunities are enhanced, as there will be much more space around the irradiation station available.

The set-up of the minibeam station will open up new experimental opportunities.

For geological samples with the goal of thermochronology a station has been set up and will be now conveyed into routine operation.

Last but not least we started to investigate the possibilities of a design for a dedicated 70 MeV/u cyclotron providing both He and ions.

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