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BEAM PROPERTIES AT THE EXPERIMENTAL TARGET STATION OF THE PROTON THERAPY IN BERLIN

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Abstract

Beside the therapy station for ocular tumours, we have an experimental area for irradiations with protons and other ions either in air or in vacuum. The beam spot can be focused to a diameter of 1 mm in air. For larger homogeneous irradiated areas, we can use beam scanning with up to10 nA spot current. If scanning is not possible due to experimental needs, scattering foils are used.

For protons, the energy can be set to a mono-energetic beam of 68 MeV or to spread-out Bragg peaks with a mechanical range shifter. Very quick energy changes are achieved by absorber plates to reduce the energy.

THE EXPERIMENTAL AREA

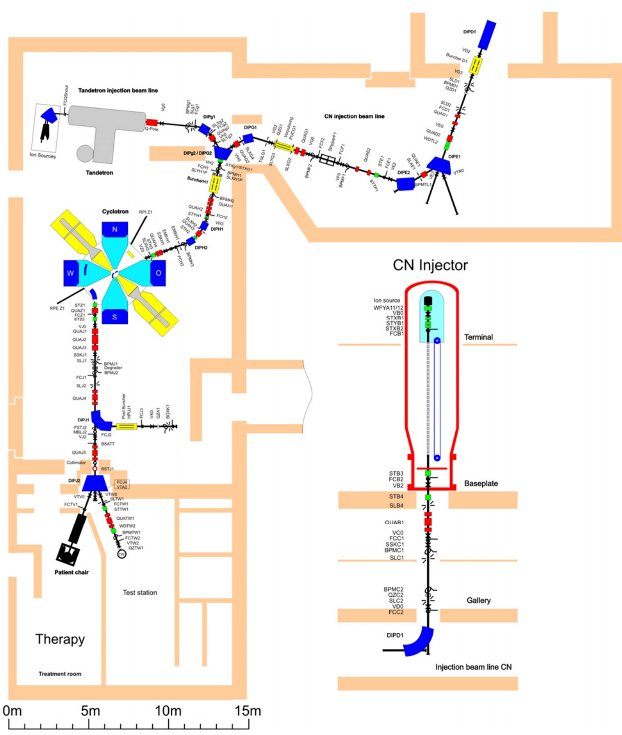

Figure 1: Layout of the accelerators and target stations.

The experimental area is located just beside the installation for the treatment of ocular tumours (Fig. 1). Thus, the beam as used for therapy can be brought to the target station in short time by switching the last dipole magnet in the beamline. The standard therapy beam is a quasi-DC 68 MeV proton beam with a beam size of 40 mm in diameter and a very homogenous beam profile (see Fig. 5). The beamline in the experimental area also permits to focus the beam down to a diameter of 1 mm.

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As from beam time to beam time slight changes in the settings of the beam line were needed to obtain the same beam position on target, the beam line settings were recalculated: Instead of a focal point between two quadrupole triplets the beam is now kept parallel at this position. With this setting, only tiny adjustments are needed on the last elements in the beamline to compensate slight differences when extracting the beam from the cyclotron.

Different settings for experiments are possible: The beam can be extracted in air via a thin Kapton foil and the samples to be irradiated are mounted on a xy table with a stroke of 50 cm and a positioning precision of 0.1 mm. The maximum weight for the samples is 50 kg. Large and sensitive objects can be irradiated: The largest sample was a painting with a size of 1 m × 1.4 m. Behind the xy table is a 2 m long optical bench. This is used mainly for irradiations in vacuum in order to avoid scattering of the beam in air.

The samples are aligned on the beam line axis with the help of an adjusted Laser system. The proton intensity is measured on-line using an ionisation chamber of PTW Freiburg. Radiation safety limits the quasi-DC proton beam intensity to about 10 nA in the experimental area. For most experiments this is largely sufficient.

BEAM SIZE ADAPTATION

The two-dimensional distribution of the beam is measured using a CCD camera with an x-ray converter foil (Sensicam QE from PCOAG). The resolution of the camera is 50 μm per pixel. For a quick determination of the beam spot, films are used.

Widening of the Beam Using a Scanning System

For higher proton intensities and passive irradiations a scanning system may be used. The scanning system consists of two scanners: a 21 cm long y-scanner, 5 cm distance, and a 21 cm long x-scanner. Settings of the power supplies for the scanning system is done with a LabView code.

This code also corrects for influences of the scanning frequency on the current of the power supplies and for the geometric differences due to the fact that the scanners are in different positions on the beam axis. To define the irradiation field, the user can choose between various functions, repetition rates, and distances of the scan lines. The user also has to define the shape of the beam spot, which was determined using a quartz, a film or the CCD camera. The dose distribution for the chosen parameters is then simulated and visualised. Figure 2 shows in the top row two different shapes of a focused beam. Identical settings

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of the scanners would lead to different homogeneities of the simulated dose distribution.

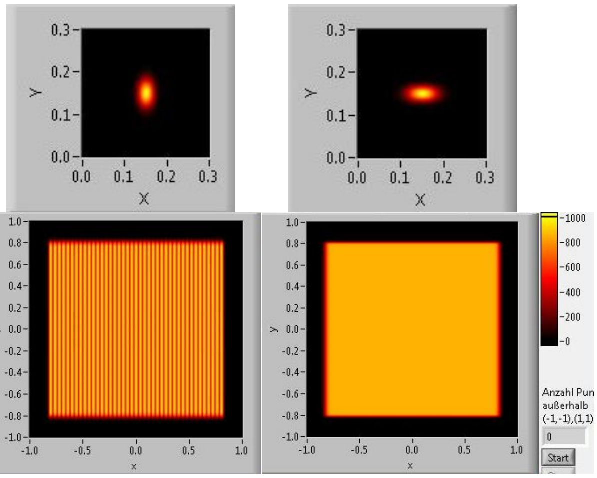

Figure 2: The top row shows two different beam spots used for scanning. The simulated dose distribution for identical settings of the scanner is shown in the lower row.

Using the scanning system together with an aperture, homogenous dose distributions with sharp lateral fall-offs can be produced. In the example shown in Fig. 3 the dose varies less than 5% over the 20 mm of the aperture width.

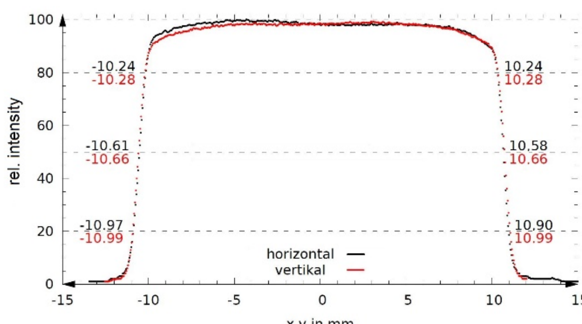

Figure 3: Line scan in x and y of a scanned irradiation field with a quadratic aperture having 20 mm edge length [1].

Besides rectangular or quadratic irradiation fields, irregular fields can be created (Fig. 4). The field size is about 30 mm x 30 mm at the position of the xy table. The maximum size depends on the position of the sample with respect to the scanning system.

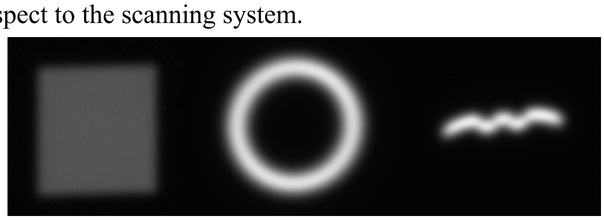

Figure 4: CCD images of the proton beam using the scanning system. Rectangular, circular or irregular shapes are feasible.

However, for devices which are actively tested, the beam size has to be adapted in a different way to avoid interplay effects when the proton beam scans over the internal structures of the devices.

Widening of the Beam by Scattering Foils

For the therapy of ocular melanomas the beam is widened by a 50 µm thick Ta-foil about 8 m upstream of the isocentre. About 90% of the extracted proton beam is thus lost, but the result is a very homogenous distribution (see Fig. 5).

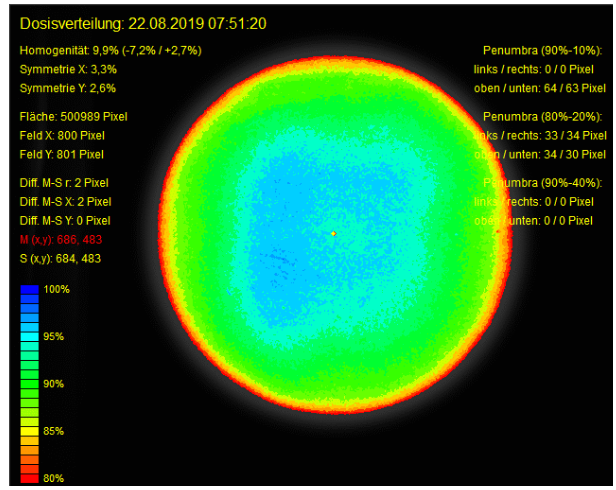

Figure 5: CCD image in false colours of the proton beam using the scattering foil upstream, showing a very homogenous dose distribution.

The same foil can be used for the experimental target area, providing a beam diameter of 50 mm. The irradiation area is set using a pair of slits in x and y for rectangular samples or adequate apertures are used for round samples. This reduces activation of the samples. However, for small devices needing high proton intensities the beam losses and activation of slits or apertures are not negligible. In addition, for radiation hardness tests variations of the beam homogeneity of 10% are acceptable.

For this reason, a second scattering system (Fig. 6) was installed in the beamline 1 m upstream of the target position. Using SRIM [2], the required foil thickness for various beam diameters have been estimated, making simplifications on the start parameters of the beam on the foil. The foils were mounted on a moving mechanism. A quartz on the moving mechanism allows to check the size and position of the proton beam.

Figure 6: Adjustment unit for positioning of the foils on the beam line axis (a), moving mechanism with three different foils and a ruby quartz.

The beam size for the different scattering foils was measured using the CCD camera (see Fig. 7). Using the software Image – ProPlus an intensity profile from the grey values of the images was calculated and compared to the estimations by SRIM (Table 1).

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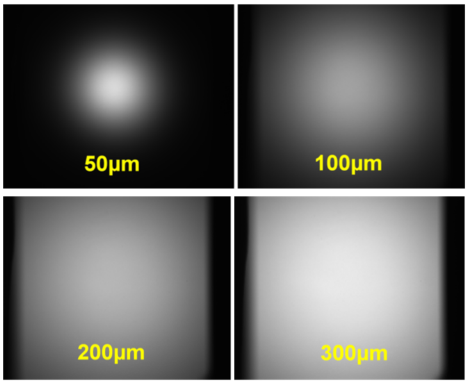

Figure 7: CCD images of the full beam spot using different scattering foils. For 200 µm and 300 µm thickness, the overall beam spot is larger than the entrance aperture of the CCD camera.

Typical dimensions of solar cell samples or electronic components are less than 20 mm in one direction. Thus, the 100 µm foil together with a corresponding aperture is used to confine the irradiation field to 20 mm in diameter. The transmission using an aperture was measured and is 35%. For this beam size the gain in intensity is about a factor 20 compared to the scattering system 8 m upstream.

Table 1: Comparison of the Beam Diameter with Intensity Variations of 80% to 100%. The Error for the Diameter is Estimated to be About ±1 mm

Foil Thickness	Diameter (SRIM)	Diameter (measured)
50 µm	9 mm	10 mm
100 µm	14 mm	20 mm
200 µm	22 mm	31 mm
300 µm	28 mm	40 mm

ENERGY VARIATION

Our standard beam is the 68 MeV proton beam used for therapy. A change of the setting of the accelerators in order to achieve a different energy takes at least 4 hours, mainly due to the ramping time of the main magnets of the cyclotron. In most cases, especially for radiation hardness tests, a mono-energetic beam is not necessary. Thus, for quick changes in energy, aluminium plates of different thicknesses are introduced in the beam path. The final energy is determined with a special Multi-Leaf Faraday cup [3].

EXAMPLES

Radiation Hardness Tests

The experimental area is used mainly for dosimetry and radiation hardness tests. Besides experiments for the German Space Agency DLR, solar cells [4, 5] for space applications are irradiated. These require comparable high proton doses of 10^{11}-10^{13} protons/cm², while the irradiation time should not exceed an hour. Depending on the experimental needs, JV-curves are acquisitioned or the proton induced currents is measured in-situ.

PIXE and PIGE

Small beam spot sizes and intensities are needed for material analysis with Proton Induced X-ray Emission (PIXE) and Proton Induced γ-ray Emission (PIGE) [6]. Especially for light elements in a heavy matrix, PIXE provides information of the material composition close to the surface, while PIGE yields information from larger depths. For a good lateral resolution, the beam diameter is focused to 1 mm. The proton beam intensities are below 0.1 pA. Silver coins from the Münzkabinett (museum for coins and medals) in Berlin have been investigated [7].

CONCLUSION

The experimental area is a flexible, versatile room which permits the irradiation of sensitive and large objects. The beam intensity is varied between 10^3 protons/sec up to 10^{10} protons/sec. The time structure of the beam ranges from a quasi-DC beam, where the cyclotron frequency defines the repetition rate, over pulse trains to single pulses. The possible beam size ranges from 1 mm up to 50 mm in diameter. Very homogenous dose distributions can be provided employing either the scanning system or the scattering foil used for therapy. Using the second scattering system, 10^{13} protons/cm² can be applied within less than one hour with acceptable losses in homogeneity.

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