

A MULTI-LEAF FARADAY CUP ESPECIALLY FOR PROTON THERAPY OF OCULAR TUMORS

C. Kunert[#], J. Bundesmann, T. Damerow, A. Denker, Helmholtz-Zentrum Berlin, Germany
A. Weber, Charité Universitätsmedizin Berlin, Germany

Abstract

For tumor therapy with protons it is crucial to know the beam range with a high accuracy. The Multi-leaf Faraday Cup (MLFC) offers a quick and precise range or energy measurement. To adapt the principle of a MLFC to the eye tumor therapy requirements is a challenging task, due to the necessary accuracy in the sub mm regime. The first prototype has 42 channels; each consists of a 10 μm copper foil, connected to an ammeter, next to a 25 μm Kapton foil. An incoming proton beam creates a current of some pA in a certain channel with respect to its energy.

MOTIVATION

The eye tumor therapy benefits from the radiation therapy with protons in a lot of cases. Since 1998 the University Hospital Charité Berlin provides together with the Helmholtz-Zentrum Berlin (HZB) a treatment facility using the HZB isochronous cyclotron [1]. The main benefit of proton beams in tumor therapy is the determined range in tissue in contrast to the commonly used photon radiation. Additionally the protons create the highest dose just before stopping. This depth dose curve is called Bragg peak and an example is shown in fig. 1.

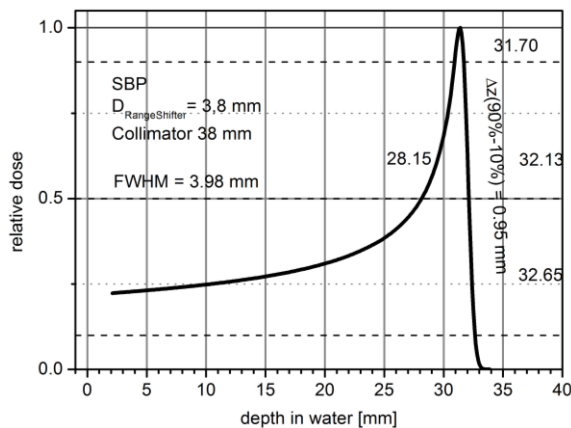


Figure 1: Typical Single Bragg Peak (SBP) of the HZB cyclotron

With such proton beams are very well determined radiation fields achievable, the dose can be delivered mainly to the tumor tissue, and critical tissues, which are highly sensitive to radiation, can be spared. In our case this leads to a tumor control of 96% after 5 years and in most cases the eyesight can be conserved.

The eye contains several critical structures in its small volume of 6-7 cm^3 , e.g. the optical nerve or the macula. Fig. 2 shows a typical planned dose distribution for a

melanoma located near the optical nerve. The positioning of the radiation field is crucial for the successful therapy with low side effects. Due to the small structures in the eye compared to other organs the necessary precision is in the sub mm regime. Therefore the positioning of the patients has to be done very precisely and the range of the proton beam has to be known with a resolution of 0.1 mm or better.

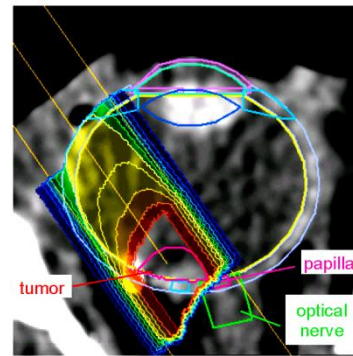


Figure 2: Planned radiation field with marked critical structures and the tumor.

Due to necessary quality checks, a range measurement has to be done in every therapy and after unexpected shut downs, e.g. an accidental shut-down due to instabilities in the power supply network. Thus, it would be a great advance to perform the necessary quality check in a short time to keep the therapy interruption as short as possible.

THE MLFC

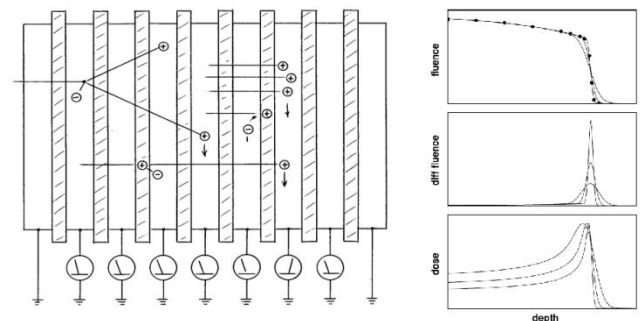


Figure 3: Principle of a MLFC and the comparison (top to bottom) of the fluence, differential fluence (range) and the Bragg peak as a function of depth [2], [3].

One idea for a quick and precise range measurement is a Multi-Leaf Faraday Cup. This is a stack of alternating conductor and insulator plates (fig. 3). Each conductor is connected to the ground potential via an ammeter. Incoming protons stop in a certain plate and this additional positive charge creates a current by pulling

electrons from the ground. Thus the differential fluence (range) of a proton beam can be measured relatively fast.

By determining the foil size and number an MLFC can be set to the eye tumor therapy requirements. In our case copper was chosen for the conductor material with a thickness of 10 μm , which equals approx. 50 μm H_2O equivalent. As insulator we use Kapton foils of 25 μm thickness, which corresponds to approx. 32 μm H_2O . We want to reach a native resolution better than 100 μm water equivalent in the range measurement.

Additionally, the MLFC is a tool to check the beam energy for radiation hardness tests (RHT). For RHT different energies are requested for the devices under test. In these cases the beam is degraded with a calculated amount of aluminum to achieve the requested energy.

SIMULATIONS

To dump a 68 MeV beam 6.75 mm copper is necessary. So, over 600 foils would be needed to dump the whole beam in the MLFC. To confine the efforts for the current measurement electronics, the number of channels should be kept low. Therefore simulations were conducted with MCNPX 2.6 to investigate how many copper foils are necessary to cover at least the Gaussian range peak in one measurement and to estimate the expected ratio of incoming beam to measured current in one foil. The simulations included the end of the nozzle, a chamber with the 50 copper foils covered by Kapton of 25 μm , 50 μm or 75 μm thickness and in front of the chamber a preabsorber of 315 mm acrylic glass. The simulated proton beam had a Gaussian energy distribution with the center around 68 MeV comparable to our real beam. The charge deposition in each copper foil was simulated. As shown in fig. 4, 50 foils are enough and the signal in the center of the peak is 3.5-4% of the incident proton beam.

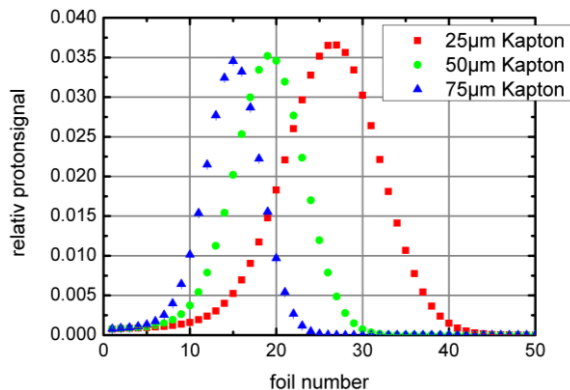


Figure 4: Simulated charge deposition in 10 μm copper foils for different Kapton foils and a 315 mm preabsorber.

EXPERIMENTAL SETUP

To measure the range peak in the MLFC the beam has to be degraded with a preabsorber in front of the MLFC. For the first setup with three foils a variable preabsorber has to be used to shift the peak over foils. By changing the thickness of the preabsorber the range of the proton beam can be changed and the end of the proton beam

could be driven over the foils step by step. At the treatment room this is done with the range shifter (see fig. 6), which is also used for the therapy. The range shifter has a fixed position in the beam line. Another range shifting tool is the double wedge made of acrylic glass. These are two wedges with their oblique sides in front of each other, but one is movable and a defined thickness can be determined. The double wedge can be located directly in front of the nozzle. Thus with the wedge the proton loss due to scattering is lower.

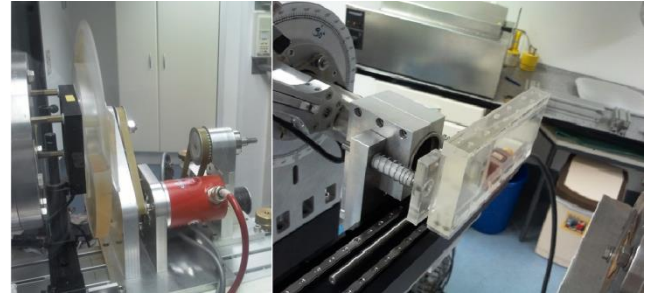


Figure 6: Left: the range shifter, right: double wedge with the end of the nozzle. The beam comes from the left side.

The first current measurements were conducted with three 617 Programmable Electrometers from Keithley. Thus the first setup was limited to three foils. Later, we used the “Rabbit Box” from iThemba Labs, South Africa, which can measure electrical currents in up to 48 channels simultaneously, but has a higher noise in the low pA regime than the electrometers from Keithley.

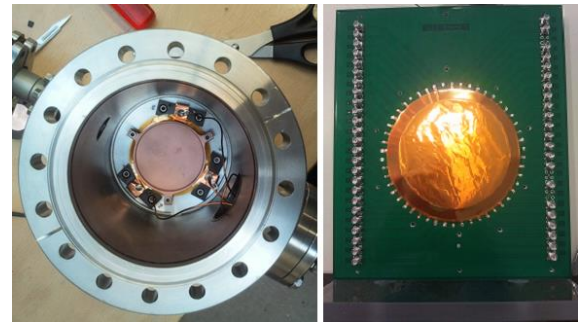


Figure 5: The open vacuum chamber with three copper foils with a diameter of approx. 4 cm (left), setup with 42 copper foils with a diameter of 10 cm (right).

The actual setup is basically a board with a hole of 10cm in the middle and 50 spots in a circle of 12cm diameter, where the copper foils can be soldered on (fig. 5). Each spot has a 50 Ω impedance connection to a SMA connector. Despite careful soldering, in some channels dark currents of up to 1nA were observed and only 42 connections are usable. On top a 2.45 mm thick Aluminum plate is mounted for pressing on the foils and for shielding. For the connection to the Rabbit Box, we use special low noise cables.

RESULTS & FIRST APPLICATIONS

Fig. 7 shows the result of a measurement with the three foil setup. The chamber was evacuated but in the first two

foils a high noise is present, as can be seen in the large y-error bars corresponding to the standard deviation. This is explained by the use of rather long BNC-cables (10 m) for the connection to the electrometers to keep them far away from the nozzle during irradiation.

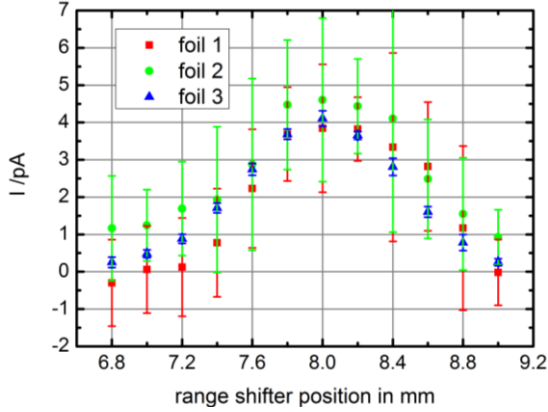


Figure 7: Measured current for each foil for different positions of the range shifter for the chamber setup. Foil 1 saw the beam first.

The main issue is the low current. By the conducted simulations (fig. 4) it was found that the expected signal in the foils is approx. 4% of the incoming proton current at the maximum height of the range curve. The therapy beam current is below 100 pA per cm² of beam field, the expected signal is around 4 pA per cm². In fact the ratio of approx. 4% was validated in the first setups. Therefore it is important to keep the dark current as low as possible.

First checks with the Rabbit Box showed offset currents of about ± 60 pA. A measurement with and without the beam was done to subtract the offset.

Without any preabsorber the MLFC could measure proton energies from approx. 22 MeV – 29 MeV. This corresponds to the first and the last foil. Due to the Aluminum plate on top of the foils, lower energies are not reachable, but such low energies are not interesting either. By adding a particular preabsorber, higher proton energies can be measured.

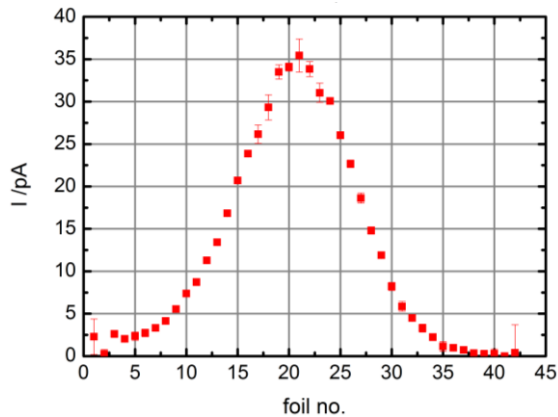


Figure 8: First measurement of the 68 MeV beam at 700 pA with a 27.23 mm preabsorber of acrylic glass. The center is at foil 21, this corresponds to 67.6 MeV.

Fig. 8 shows the measurement of the beam, which is extracted from the cyclotron with approx. 68 MeV. Then the beam passes through 50 μ m scatter foil of Tantalum and the nozzle window of 50 μ m Kapton. In front of the MLFC is an acrylic glass plate of 27.23 mm. The center of the Gaussian peak corresponds to 67.6 MeV. So, the beam energy of the cyclotron is verified.

Also, RHT measurements are done at the HZB cyclotron and these measurements need different beam energies. Thus, measurements with the MLFC for checking the real beam energy against the calculation with SRIM [4] were recently conducted and tab. 1 shows the results. The calculation started with 68 MeV protons and calculated their energy after passing through the scatter foil (50 μ m Ta), the nozzle (80 μ m Kapton), the degrader stack of Aluminum in the particular thickness and air (24 cm minus the thickness of the absorber stack). The MLFC stood at the same position as the tested devices and the measured energy corresponds to the center of the each range peak for each measurement.

Table 1: Results of energy check for radiation hardness tests (RHT).

Requested energy	Nominal energy*	Measured energy
30 MeV	29.8 MeV	30.8 MeV
50 MeV	48.7 MeV	49.2 MeV
68 MeV	67.3 MeV	67.6 MeV

*as calculated with SRIM [4]

The MLFC measurement is in good agreement with the calculation. So, the MLFC offers a quick verification of the needed energies for RHT.

OUTLOOK

Further measurements for the MLFC characterization and tests of especially developed amplifiers are planned. Automated measurements require special preabsorbers and a software tool. Additionally an analytical model for Bragg peak calculations out of particular range values [5] will be tested concerning its accuracy.

ACKNOWLEDGMENT

Our sincere thanks go to iThemba Labs, South Africa, for the possibility to use their Rabbit Box and their support.

REFERENCES

- [1] A. Denker et al., “Eye Tumor Therapy in Berlin,” Proceedings of IPAC’10, Kyoto, May 2010, MOPEA002, p. 64 (2010); <http://www.JACoW.org>
- [2] B. Gottschalk, “BGtalks: Multi-Layer Faraday Cup” (2007)
- [3] B. Gottschalk; “On the Characterization of Spread-Out Bragg Peaks and the Definition of ‘Depth’ and ‘Modulation’” (2004)
- [4] “SRIM-the Stopping and Range of Ions in Matter”, software packages for calculating stopping power and range of ions in matter, <http://www.srim.org>
- [5] T. Bortfeld, “An analytical approximation of the Bragg curve for therapeutic proton beams,” Med.Phys. 24, 2024 (1997).