

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

S. Seidel*, C. Kunert¹, J. Bundesmann, T. Damerow, A. Denker, Helmholtz-Zentrum Berlin, Germany
 A. Weber, Charité Universitätsmedizin Berlin, Germany
¹former Helmholtz-Zentrum Berlin, Germany

Abstract

For radiation therapy with protons knowing the beam range with high accuracy is crucial. The Multi-leaf Faraday Cup (MLFC) allows a quick and precise range measurement of the full radiation field in air. In the field of eye tumor therapy an accuracy in the submillimeter regime is required. We present an MLFC with 47 channels which can be read out simultaneously. Each channel consists of a 10 μm copper foil, connected to an ammeter, next to a 25 μm kapton foil. An automated preabsorber system allows range measurements in different energy regions. The achievable relative resolution of 50 μm in water meets the desired accuracy for eye tumor therapy. Furthermore it is possible to gain information about the dose distribution in water for quality assurance measurements.

MOTIVATION

Over the past years radiation therapy with protons has become a very important tool in cancer treatment. Since 1998 a collaboration of the Charité Universitätsmedizin and the Helmholtz-Zentrum Berlin (HZB) provides a treatment facility for eye cancer. Ocular tumors especially benefit from the superior dose distribution of protons. This distribution known as the Bragg-Peak provides the highest dose just before the end of the finite range in tissue (see Fig. 1).

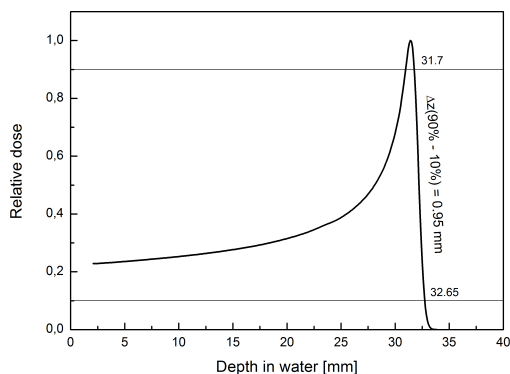


Figure 1: Typical single Bragg Peak (SBP) of the HZB cyclotron with 0.95 mm distal dose fall off (90 - 10 %).

That way it is possible to deliver the maximum dose only to the target volume and spare critical tissues highly sensitive to radiation. At our facility this leads to a local tumor control of 96 % after 5 years. The human eye is a very small organ (with a volume of 6 – 7 cm^3) and contains of several critical structures crucial for the sight, e.g. the optical nerve or the

macula. When treating melanomas located close to those structures a very precise positioning of the target volume and a precise knowledge of the proton range is required.

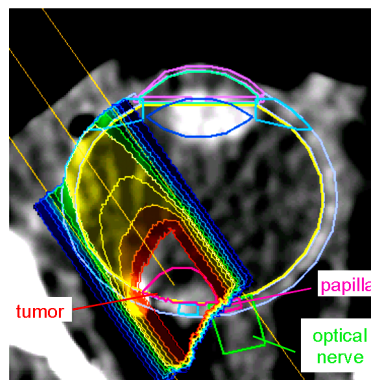


Figure 2: Planned radiation field with marked critical structures and the tumor.

At our facility we achieve a distal dose fall off (the distance between 90 and 10 percent of the maximum dose) of less than 1 mm (Fig. 1). This is also a reason why the range measurement needs to be accomplished with a resolution of 0.1 mm. During quality assurance this is usually done by measuring the dose distribution in a water phantom. The measurements are very time consuming and therefore it would be a great advantage to use a device which enables quick and precise range measurements.

METHODS AND MATERIAL

MLFC

A Multi-Leaf Faraday Cup (MLFC) is a well-suited device for a quick and precise range measurement. It is a stack of alternating conductor and insulator plates. Each conducting plate is connected to ground potential via an ammeter. Incoming protons stop in a certain plate and add positive charges which create a current by pulling electrons from the ground. Thus the differential fluence (and therefore the range) of a proton beam can be measured.

By determining the needed plate thickness and number a MLFC can be set to meet the eye tumor therapy requirements. It furthermore enables measurements of the full radiation field in air.

Our device consists of 47 copper foils with a thickness of 10 μm , which equals approx. 50 μm water equivalent. As insulator we use Kapton foils of 25 μm thickness corresponding to approx. 32 μm water.

* sophie.seidel@helmholtz-berlin.de

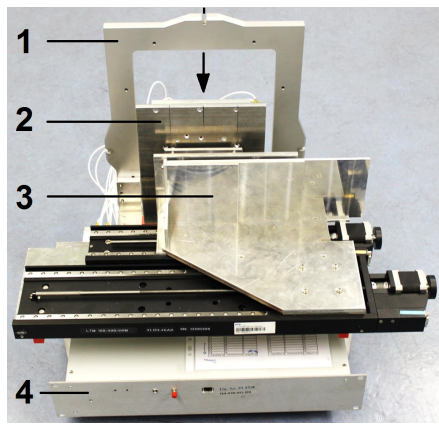


Figure 3: Final setup of our MLFC. The holder (1), the MLFC itself (2), the preabsorbing system (3) and the electronics (4). The beam direction is shown by the arrow.

Electronics

To cover the whole radiation field we use a board with a 10 cm hole in the middle and 50 spots in a circle of 12 cm diameter, where the copper foils are soldered onto (Fig. 4). Each spot has a 50 Ω impedance connection to the "Rabbit Box" from iThemba Labs, South Africa, we use. This "Rabbit Box" consists of 48 channels which can measure electrical currents simultaneously. Therefore our final device consists of 47 copper foils and one channel for the current in the beam dump. The expected signal is in the range of pA which makes the use of special low noise cables necessary.

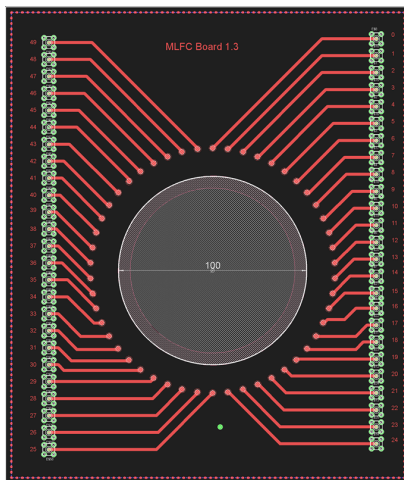


Figure 4: Schematic representation of our board with 50 spots for soldering the copper foils onto.

Preabsorber System

The whole setup is mounted onto a special holder to attach it to the treatment chair in front of the beam line in the treatment room. To measure the proton range in different energy regions (e.g. for radiation hardness testing) we use a special preabsorbing system which can vary the absorber

thickness automatically. It consists of a stair with 4 steps from 0 mm to 12 mm aluminium and a double wedge for fine adjustment from 3 mm to 6 mm aluminium. This enables continuous measurements in an energy range between 30 MeV and 70 MeV. An especially for this purpose developed program varies the preabsorber automatically until the whole beam is stopped between the first and the last foil.

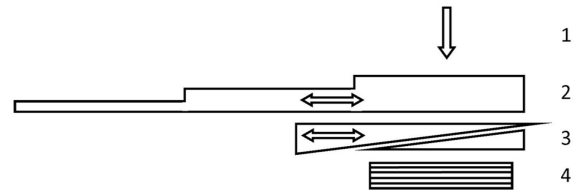


Figure 5: Schematic representation of the preabsorbing system with the beam direction (1), the stairs with 4 steps (2), the double wedge (3) and the MLFC (4).

RESULTS AND APPLICATIONS

The typical result of a measurement with our MLFC is shown in Figure 6. The preabsorber was set to 16.68 mm aluminium and the measurement was done with a beam current of 500 pA. The value of the maximum signal is within the expected range of approx. 5 % of the incoming current. The curve has an almost Gaussian shape. Therefore a Gaussian fit has been performed to determine the expected value and the variance of the differential fluence of the beam. In this particular case the expected value corresponds to an energy of 67.6 MeV. This agrees very well with the calculated value [3] of 67.3 MeV taking into account the extraction energy of the cyclotron (68 MeV) and the energy loss due to the scatter foil, the nozzle and air.

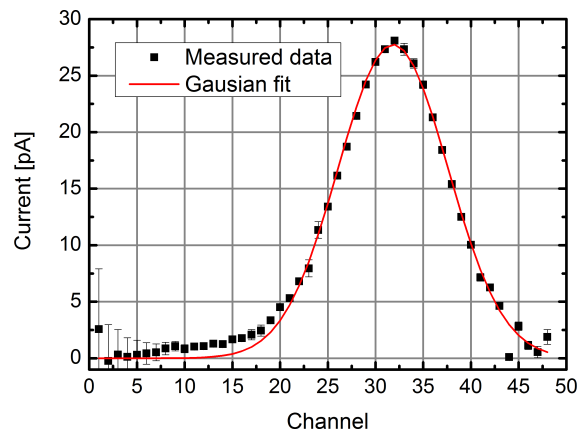


Figure 6: Typical measurement of the 68 MeV therapy beam at 500 pA with 16.68 mm aluminium as preabsorber. A Gaussian fit reveals the center being at foil 32 which corresponds to an energy of 67.6 MeV.

The relative resolution of our device is found to be 50 μm proton range in water [1] which is even more precise than the required 100 μm for eye tumor therapy.

Apart from measuring the proton range and energy of the beam, knowing the actual dose distribution in water is crucial for the quality assurance in medical physics. Since the measured signal only corresponds to the differential fluence of the protons, some calculations have to be made. It is possible to find an analytical model of the Bragg curves for therapy beams with energies up to 200 MeV [2]. The required expected value of the proton range and its variance can be obtained using our MLFC. Therefore we are able to gain information about the shape of the Bragg Peak in water. Figure 7 shows the expected result of measuring a Spread out Bragg Peak with an MLFC. The received signal is a superposition of the signals for each single energy peak.

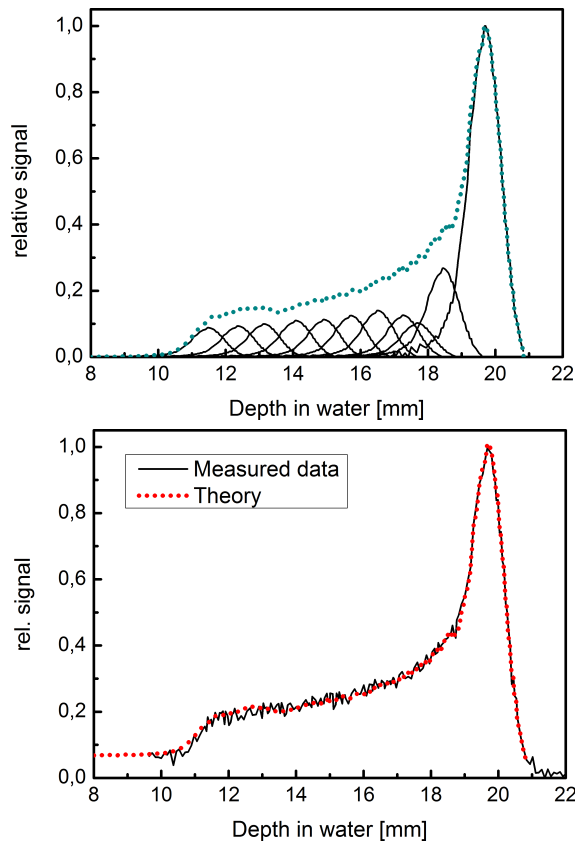


Figure 7: Measurement of a SOBP with the MLFC as a superposition of different monoenergetic beams (upper figure). Comparison between the expected curve and the measured data (lower figure).

Using an ionization chamber has the disadvantage of being very time consuming since every value has to be acquired separately. Depending on the range and modulation this could take up to 10 minutes while the MLFC allows a fast measurement of several data points simultaneously in less than 3 minutes.

Figure 7 also shows the good agreement between the expected shape of the curve and the actual measurement. Figure 8 shows the results of two measurements performed with

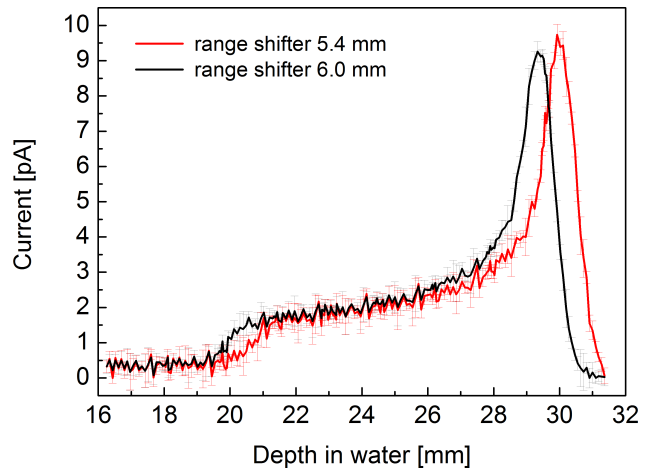


Figure 8: Comparison between the correct preabsorber of 6.0 mm (black curve) and the wrong preabsorber of 5.4 mm (red curve)

our MLFC which could be typically done for quality assurance before each patient treatment. One curve was acquired using the correct preabsorber of 6.0 mm acrylic glass for that particular patient and the other one was measured using the wrong range shifter position of 5.4 mm. The differences are clearly visible and confirm the achievable submillimeter precision of our device.

CONCLUSION

Our MLFC allows quick and precise proton range and energy measurement in different energy regions. With a resolution of 100 μm and a relative resolution of 50 μm in water it not only meets the requirements for eye tumor therapy but it exceeds them. Furthermore in the context of quality assurance for radiation therapy, measurements of SOBP in water are possible to verify the accuracy of the range shifter position and modulation with high precision.

ACKNOWLEDGMENT

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

REFERENCES

- [1] C. Kunert, "A Multi-Leaf Faraday Cup especially for proton therapy of ocular tumors", in *Proc. 5th International Particle Accelerator Conference (IPAC'14)*, Dresden, Germany, June 2014, paper WEPRO082, pp. 2149-2152.
- [2] T. Bortfeld, "An analytical approximation of the Bragg curve for therapeutic proton beams", *Med. Phys.*, vol. 24, pp. 2024-2033, 1997.
- [3] "SRIM-the Stopping and Range of ions in Matter", software packages for calculation stopping power and range of ions in matter, <http://www.srim.org>