

# A MULTI-LEAF FARADAY CUP ESPECIALLY FOR THE THERAPY OF OCULAR TUMORS WITH PROTONS

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## Abstract

For tumor therapy with protons it is crucial to know the beam range with high accuracy. The Multi-leaf Faraday Cup (MLFC) offers a quick and precise range and energy measurement. Our MLFC is adapted to the eye tumor therapy requirements and has 47 channels; each consists of a 10 μm copper foil (connected to an ammeter) next to a 25 μm Kapton™ foil. A system of absorbers has been constructed to achieve an energy range of 30 MeV to 70 MeV for the measurements. First results and characteristics are presented in this work.

## MOTIVATION

The Helmholtz-Zentrum Berlin (HZB) and the University Hospital Charité Berlin provide together a facility for treating eye tumors with proton radiation using the HZB isochronous cyclotron facility [1]. The main benefit of proton beams in tumor therapy is the determined range in tissue in contrast to the commonly used photon radiation. Furthermore protons create the highest dose just before stopping. This depth dose curve is called Bragg curve (SBP) and the HZB SBP is shown in Fig. 1.

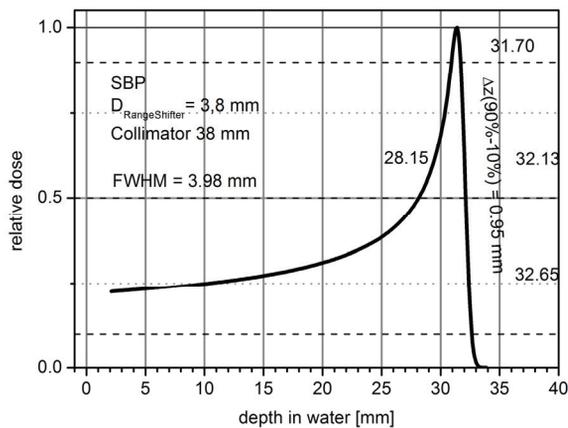


Figure 1: Typical Single Bragg Peak (SBP) of the HZB cyclotron used for the therapy with a distal dose fall off below 1 mm H<sub>2</sub>O (one of the sharpest worldwide) and an energy of approx. 62 MeV at the isocenter.

Such proton beams achieve very well determined radiation fields. Thus, 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.

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The eye is a rather small organ of 6-7 cm<sup>3</sup> and contains several critical structures, e.g. the optical nerve or the macula. Fig. 2 shows a typical dose distribution for a melanoma located near the optical nerve. To achieve a successful treatment with the side effects as low as possible, the positioning of the radiation field is crucial. Therefore the necessary precision of the positioning of the patient, the beam and the location of the tumor is in the sub mm regime.



Figure 2: Planned radiation field with marked tumor (1) and the critical structures lens (2) and optic nerve (3).

So, especially the quality checks measurements done before and during the therapy have to fulfill high standards. Additionally, the quality checks consume a lot of time and therefore it makes always sense to improve the tools used for measurements concerning the beam properties.

## MULTI-LEAF FARADAY CUP (MLFC)

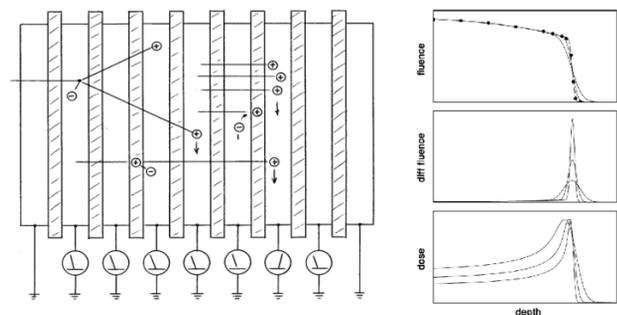


Figure 3: Principle of a MLFC and the comparison (top to bottom) of the fluence, differential fluence (range) and the Bragg curve as a function of depth for protons of the same energy, but a different energy spread [2], [3].

A MLFC is a stack of alternating conductor and insulator sheets (Fig. 3). Each conductor is connected to

an ammeter. Incoming protons stop in a certain sheet and due to the additional positive charge electrons are pulled from the ground potential to the sheet. By measuring the resulting currents the range (differential fluence) of the proton beam in matter can be measured relatively fast.

By defining the foil size and number an MLFC can be set to the eye tumor therapy requirements. To achieve a native resolution in water of approx. 100  $\mu\text{m}$  our MLFC consist of 10  $\mu\text{m}$  thick copper foils, which equals approx. 50  $\mu\text{m}$   $\text{H}_2\text{O}$ . As insulator we use Kapton™ foils of 25  $\mu\text{m}$  thickness, which corresponds to approx. 32  $\mu\text{m}$   $\text{H}_2\text{O}$ .

The MLFC is a tool to check the beam energy in general and we want to use it for radiation hardness tests (RHT), too. 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. Typical maximal energies used for eye tumor therapy are between 60 MeV and 70 MeV. For the RHT it is common to use energies down to 30 MeV. This sets the required energy limits for our MLFC to a range from 30 MeV to 70 MeV.

## SETUP

The protons are extracted from the cyclotron at 68 MeV and are decelerated until they reach the eye of the patient in the treatment room to approx. 62 MeV, due to adaptations of the beam to each patient.

To dump the whole 68 MeV beam in the MLFC 6.75 mm of copper are necessary, or more than 600 foils in our case. But the first 500 or more would only decelerate the beam and the interesting peak of the differential fluence (see Fig. 3) would be located in the last foils.

Simulations were conducted [4] to investigate how many copper foils are necessary to cover at least the Gaussian shaped differential fluence peak (DFP or range peak) in one measurement. As a result less than 50 channels (one channel is the combination of a Kapton™ foil in front of a copper foil behind) are enough to cover the whole peak, if there is a degrader in front of the foil stack to decelerate the beam to an energy that the beams stops in the foil stack, which means below 19 MeV.

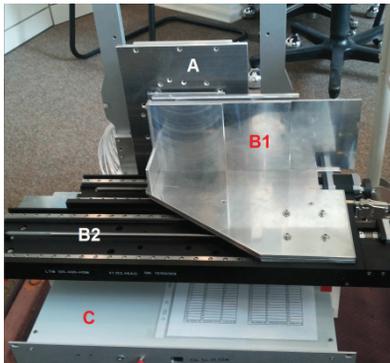


Figure 4: Setup with the absorber system (stair B1, moveable table B2), the MLFC stack (A) and the Rabbitbox (C).

Because the MLFC should be able to measure different energies, a particular absorber system had to be developed and constructed (see Fig. 4). This system has to fulfill that beam energies can be measured without knowing the energy in advance.

The absorber system consists of two main parts, a stair and a double wedge, both made out of Aluminum with a purity of 99.5 %. Both are mounted on moveable tables in front of the MLFC stack. The stair has three steps (S1-S3), each 4 mm thick (S1=12.06 $\pm$ 0.01 mm, S2=7.98 $\pm$ 0.01 mm, S3=4.05 $\pm$ 0.005 mm). The stair can be moved entirely out of the beam (S4=0 mm). The double wedge has an adjustable thickness range from 3.14 $\pm$ 0.09 mm to 6.30 $\pm$ 0.13 mm.

The actual MLFC-Stack, shown in Fig. 5, consists of 48 foils sets slightly pressed between a 7 mm thick copperplate in the back, which works as a beam dump, and a 0.2 mm thick Aluminum sheet in the front. Each copper foil is connected to the Rabbitbox, an ammeter with 48 channels for simultaneous measurements from iTHEMBA labs, South Africa. Each copper foil is soldered onto an especially designed board, which connects (50  $\Omega$  impedance) the foils via SMA couplings and low-noise cables to the Rabbitbox. The copper foil of the last channel lies directly on top of the beam dump so a direct readout of the beam dump signal is achieved.

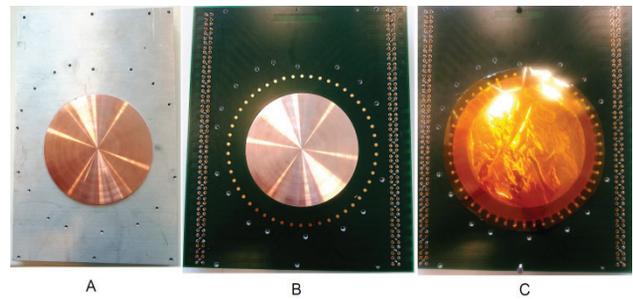


Figure 5: A: Back plate of the MLFC with beam dump, B: Board on top of the back plate, C: Copper foils soldered onto the board with Kapton™ foils in between.

The copper foils have a diameter of 10 cm and the Kapton™ foils have a diameter of 12 cm. The active area of the MLFC is a circular area with a diameter of 10 cm.

For controlling and analysis a LabVIEW™ program was written. This program includes an automatic search for the correct position of the absorber system to have the range peak in the MLFC stack and a measurement procedure with an analysis of the measured data.

During this procedure the currents in every channel are measured several times and a previous measured background value for each channel is subtracted. The mean value of each channel is saved and a Gaussian fit, weighted with the standard deviation of the mean values, is done. The fit can be done in units of channels, energy or water range. The outputs are the fit data as well as typical values like the center, standard deviation and amplitude of the Gaussian curve and their errors.

## RESULTS

Fig. 6 shows a typical result of a measurement. As expected it shows a Gaussian shaped curve which do not go to zero in the first foils, due to protons that stops earlier via nuclear interactions. In the last channel (48) is the dump signal. The error bars are different, because every channel has a different noise. Additionally, the first one has the biggest noise due to the worst shielding (only the 0.3 mm Al plate), every following channel is shielded by the channels in front of it. The second channel seems to be broken.

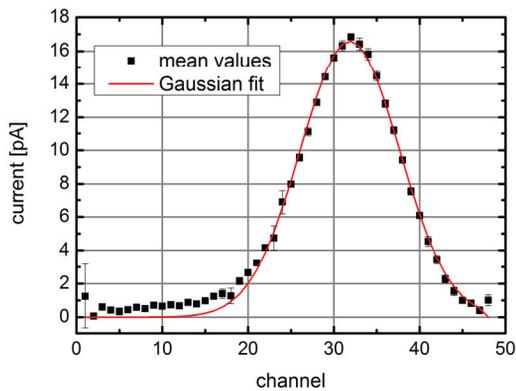


Figure 6: Example of a measurement (274 pA beam with 67.59 MeV) in units of channels and the Gaussian fit done by LabVIEW™. The error bars represent the standard deviation of the mean values in each channel.

The beam extracted from the cyclotron goes through a 50 μm Tantalum foil for scattering and an 80 μm Kapton™ nozzle window. In the treatment room the beam passes also an air path and a few devices for measurements and beam shaping. With one device it is possible to vary the range of the protons in precise steps of 10 μm H<sub>2</sub>O. This was used to investigate the relative resolution for the MLFC shown in Fig. 7.

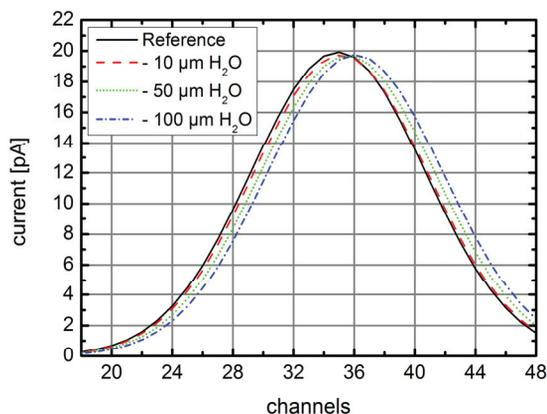


Figure 7: Result of measurements for the relative energy resolution. Each fit curve is based on data measured with a bit less water equivalent material in the beam path.

In Fig. 7 the dotted (green) and dash-dotted (blue) curve can be clearly separated from the reference. In contrast the dashed (red) one is too close to the reference.

Differences in the proton range below 50 μm cannot be clearly separated because they are in the same order as the fitting error (see table. 1).

Table 1: Results of the Relative Resolution Test

| Range difference        | Center of the fit | Error of the fit |
|-------------------------|-------------------|------------------|
| 0 (Reference)           | 35.0              | 0.26             |
| -10 μm H <sub>2</sub> O | 35.1              | 0.25             |
| -50 μm H <sub>2</sub> O | 35.5              | 0.28             |

To check the energies used for RHT two programs, based on stopping power tables, are used to calculate the expected energy at the target room out of the extraction energy of 68.63±0.1 MeV (measured by varying the current in a dipole magnet) and degraded by the scattering foil, the nozzle window, Aluminum degraders (0, 8 mm, 14 mm) to achieve the requested energy and the air path to the MLFC. One program is “SRIM” [5], a standard program in physics to calculate ion ranges and the other program is “lookup” [6] a tool to plan beam lines of proton therapy facilities. The results are shown in table 2.

Table 2: Results of Energy Check for Radiation Hardness Tests (RHT) for the Extraction Energy of 68.63 MeV.

| Requested energy | Nominal energy 1* | Nominal energy 2** | Measured energy |
|------------------|-------------------|--------------------|-----------------|
| 30 MeV           | 30.66 MeV         | 30.87 MeV          | 31.02 MeV       |
| 50 MeV           | 49.28 MeV         | 49.34 MeV          | 49.29 MeV       |
| 68 MeV           | 67.71 MeV         | 67.68 MeV          | 67.59 MeV       |

\*calculated with SRIM [5], \*\*calculated with lookup [6]

## OUTLOOK

The energies in table 2 are in good agreement, but there are still discrepancies in absolute range measurements of the order of 0.1 mm H<sub>2</sub>O compared to measurements with a water phantom. One reason could be small variations in the foil thicknesses, which will be tested by experiments.

A LabVIEW™ program was written, which uses an analytical model for Bragg curve calculation [7] to calculate a Bragg curve out of the values for the center and standard deviation in units of water range measured by the MLFC. But some improvements have to be done for a quick comparison with a Bragg curve measured in a water phantom. Furthermore it is planned to investigate whether it is possible to measure even Spread-Out Bragg Peaks, which would make a further developed MLFC a more powerful tool for the therapy.

## ACKNOWLEDGMENT

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