ADVOCACY FOR A DEDICATED 70 MEV PROTON THERAPY FACILITY

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Abstract

Since 1998 we treated more then 1500 patients with eye tumours at the HZB cyclotron with a 68 MeV proton beam.

The 5 years follow up shows a tumour control rate of more then 96%. The combination of a CT/MRT based planning and excellent physical beam conditions like 2 nA in the scattered proton beam, a 0.94 mm distal dose falloff and a dose penumbra of 2.1 mm offers the opportunity to keep side effects on a lowest level.

However all new medical proton facilities are equipped with accelerators delivering beams of 230 MeV and more. While this is needed for deep seated tumours, a lot of physical and medical compromises have to be accepted for the treatment of shallow seated tumours like eye melanomas.

Hence, we suggest a 70 MeV proton therapy facility. It should be equipped with a horizontal beam line and can have optionally a vertical line for more complicated cases under anaesthetics or for biological experiments. By the use of PBO-Lab and MCNPX beam line concepts and a radio-protecting architecture are designed.

MOTIVATION

Experiences from Berlin

Treatment of ocular melanomas at our cyclotron started in 1998. Since then, more than 1500 patients have been treated. In the past years, the number of patients per year increased to more than 200 [1]. The therapy planning and treatment system includes, among others:

- CT and/or MRI-based modelling and planning with the tool OCTOPUS [2,3] (see fig. 1)
- digital image guided patient positioning using TREAT [4]
- use of retractors to avoid irradiation of the eye lids

By far the most of the indications were uveal melanomas, followed by iris melanomas. The subgroup of large uveal melanomas increased. In order to prevent toxic reactions due to the inactivated tumour mass, the irradiation is followed by surgical removal of the tumour (endoresection or transscleral resection) [5]. Peculiar cases were the treatments of small children under anaesthesia, as they were not able to cooperate in the positioning process: Two children (5 and 7 months old) with retinonablastomas and a 5 year old child with an osteoma were treated.

The protons are accelerated by a 5 MV van-de-Graaff generator in combination with a k132 isochronous cyclotron giving a quasi DC, 68 ± 0.3 MeV proton beam. Regarding the depth dose profile, a distal falloff 90 - 10% of 0.94 mm is achieved. A simple single scattering technique provides a beam diameter of 40 mm with a penumbra of 80 - 20% of 2.1 mm.

All required therapeutic beam intensities can be delivered from the cyclotron with a dose rate of at least 15 Gy/min.

Side effects could be minimized due to the properties of our proton beam. The sharp distal dose falloff is often crucial for preventing high dose irradiation of sensitive structures essential for sight (optic nerve, papilla, macula). Furthermore, the sharp lateral penumbra and sharp distal falloff enabled us to spare the bones of the children’s skull completely in a frontal irradiation approach.

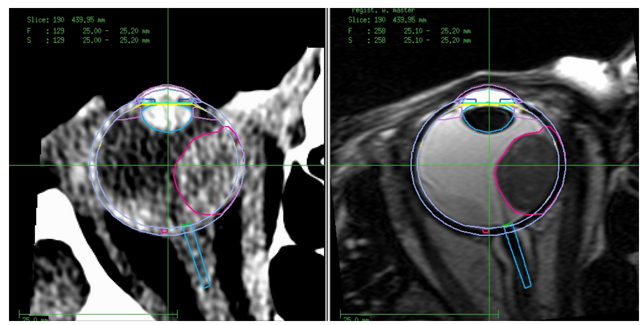

Figure 1a: CT (left) and MRI (right) slice of a right eye with delineated eye ball and lens (blue), papilla (green) on top of optic nerve (cyan), macula (magenta), and tumour (red). These slices are used for treatment planning.

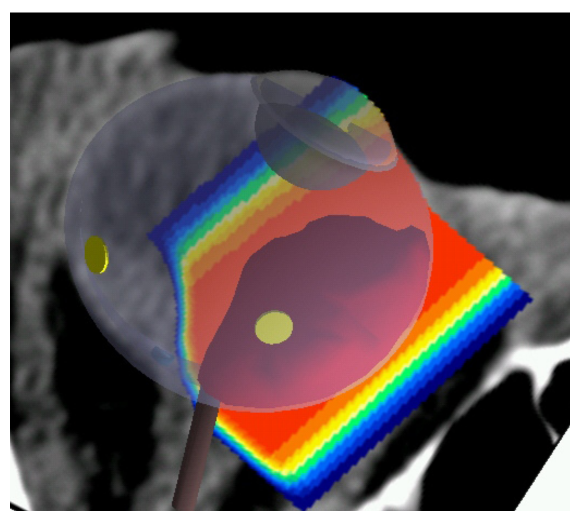

Figure 1b: Dose distribution calculated with OCTOPUS.

New Facilities

So far, 60000 patients have been treated with protons, among them more than 17000 with ocular tumours. Since 1990, an increase of medical proton facilities replacing therapy units at research facilities is observed world-wide. End of July 2010, the particle therapy co-operative group

(PTCOG) lists 19 new facilities under construction [6]. However, the 11 projects building cyclotrons are equipped with an accelerator delivering at least 230 MeV.

Hence, for the treatment of ocular melanomas, they all need to degrade the proton beam to the desired energy of about 70 MeV. The resulting large energy spread or very low beam intensity means that ocular tumour therapy has to accept compromises regarding side effects or requires an extremely sophisticated beam shaping technique as at the Paul Scherrer Institute new eye facility OPTIS2 [7]. A dedicated facility would provide a proton beam with the desired properties and allow a patient workflow taking into account the special needs of eye patients.

A 70 MeV DEDICATED FACILITY

The requirement for an accelerator dedicated for eye tumour therapy is the provision of a quasi-DC beam with the following properties:

- energy of extracted beam: 72 MeV
- intensity of extracted beam ~ 100 nA
- $dE/E \leq 0.4\%$
- half beam extent, x, y: 2 mm • 4 mm
- half beam divergence x' • y': 4 mrad • 3 mrad

With these properties, it is possible to provide a sharp distal falloff and a sharp penumbra (see below). 72 MeV have been chosen as this energy will allow the treatment of all ocular tumours, even in the case of optic nerve infiltration.

A small cyclotron would fulfil these needs well, with the benefit of comparable low costs.

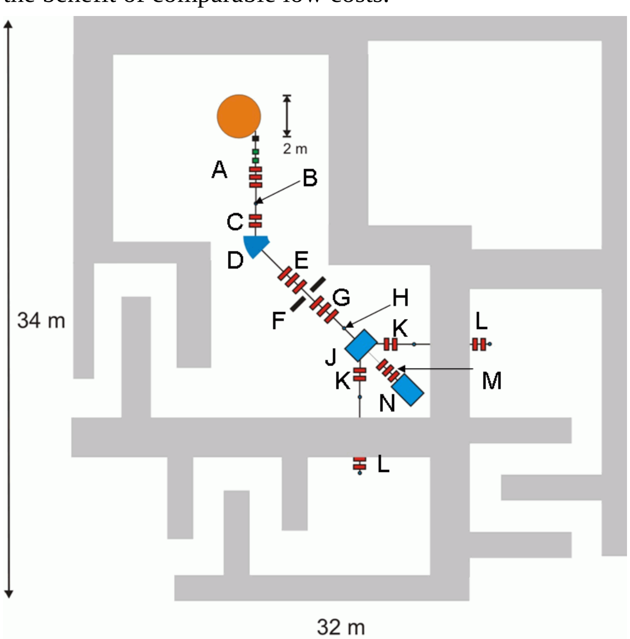

Figure 2: Layout of the proposed facility. An energy selections system permits the definition of energy as well as energy spread. Two horizontal beam lines and one vertical line are suggested. For details see text.

Layout of the Beam Lines

Fig. 2 depicts the layout of the beam lines. Two horizontal beam lines, with identical properties, permit preparation of the patients in one room, while the other room is used for treatment or physics experiments. It is possible to treat anesthetized children on a horizontal beam line. However, the handling of anesthetized children would be much easier on a dedicated vertical beam line would. In addition, this room may be used for irradiation of cell cultures.

Calculations for the beam lines have been performed using TRANSPORT within the PBO-Lab Package [8] and Graphics TURTLE [9].

After the cyclotron, the beam is first focused on a slit system (A,B). An energy selection system, consisting of a quadrupole doublet (C), a 45° dipole(D), two quadrupole triplets (E,G) with the energy slits (F) in between, allows the definition of the energy as well as the energy spread.

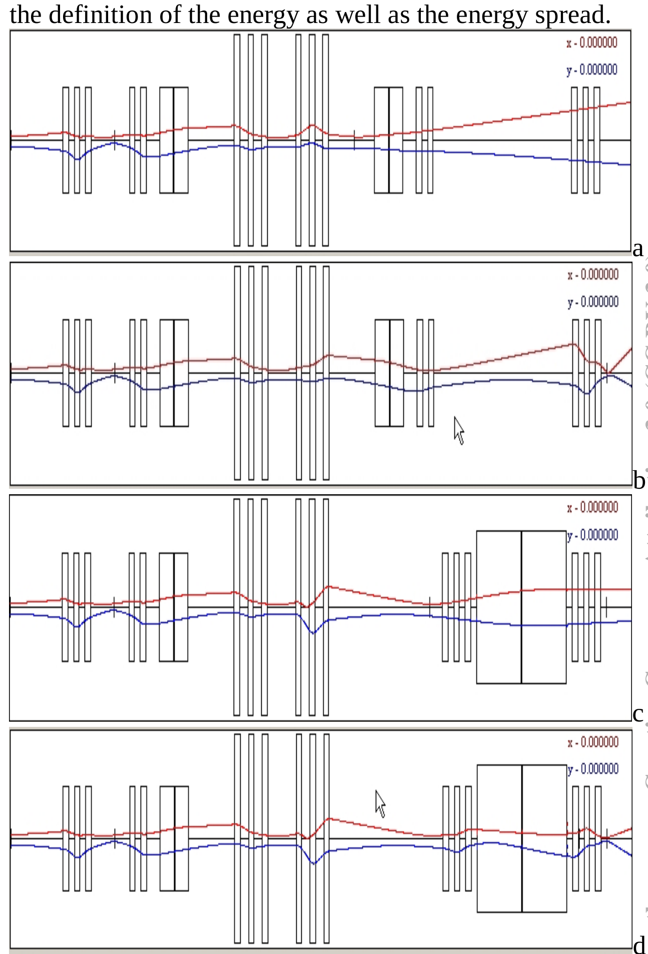

Figure 3: Beam envelopes for the beam lines, from top to bottom: horizontal line: broad beam, sharp beam, vertical line: broad beam, sharp beam.

At this point, the energy spread is reduced to 0.2% in order to provide a distal falloff of less than 1 mm in the therapy rooms, which is close to the physical limit. The advantage of this layout compared to a mere energy shift by using a range shifter is that the energy spread and thus the width of the Bragg peak are kept small. This is of interest for the treatment of tumours lying close to sensitive structures, e.g. macula, papilla, and optic nerve. The dipole K switches between the two horizontal rooms, while dipole N transfers the beam to the vertical room.

For all beam lines, two different ways of focusing are foreseen:

- focusing on a simple scattering foil after the energy selection system (fig. 3a, 3b): Two foils will be necessary on different positions (H): one for the horizontal lines, one for the vertical line. The last active quadrupole will then be the quadrupole G, focusing on a 50 µm Ta scattering foil. This proven technique will provide a beam spot of at least 40 mm at the isocentre (see fig. 4).
- sharp focus in the treatment room. Thus, the penumbra 80 - 20% is reduced from 2.0 to 1.5 mm. In this case, the quadrupoles K and L are active.

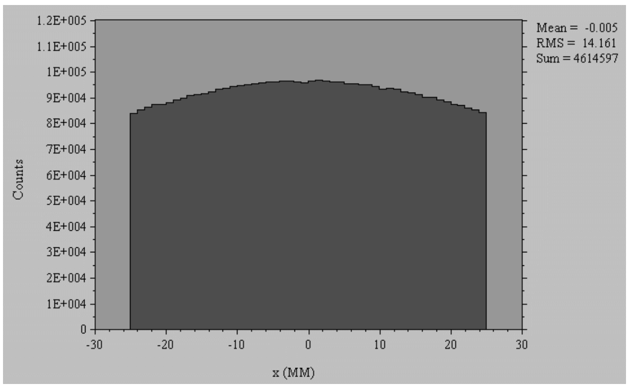

Figure 4: Turtle histogram of the horizontal broad beam behind the exit window. The beam intensity is sufficiently homogenous over more than 40 mm diameter.

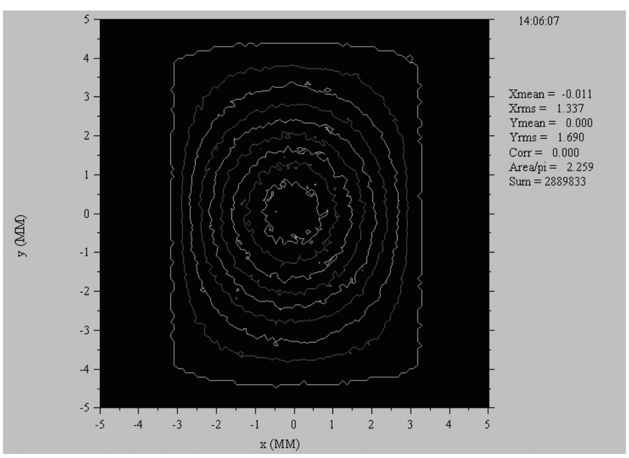

Figure 5: Turtle histogram of the horizontal sharp beam providing a well-defined beam spot in the treatment room.

For further neutron dose calculations, the transmission of the protons has been evaluated, assuming an extraction efficiency of 80%, hence, an extracted beam intensity of 100 nA. The resulting beam intensities are listed in table 1. For the sharp focusing, higher beam intensities are achievable in the rooms, which may be useful for experiments. First estimations of the neutron dose have been performed and used in the layout of the walls and mazes of the facility. More exhaustive calculations using FLUKA as well as MCNPX will be used for a detailed design.

Table 1: Transmission of the proton beam for the different focusing versions.

Place	Broad Beam	Sharp Beam
cyclotron exit	100 nA	100 nA
collimator 1 m behind exit	60 nA	60 nA
energy slits	30 nA	30 nA
collimator behind scattering foil	6.5 nA	
beam in treatment room	2.5 nA	30 nA

SUMMARY AND PERSPECTIVES

From our experience, the treatment of ocular melanomas requires special features from the accelerator, like matching energy and energy spread, as well as sufficient intensity. The positioning process is time consuming, and not well predictable, as it requests active cooperation of the patient, thus restricting the workflow in the overall patient throughput. Albeit it is possible to treat children under anaesthesia at a horizontal line, a vertical beam line would ease the process.

This proposal for a dedicated 70 MeV proton therapy facility for ocular melanomas is based upon our experiences gathered in more than 10 years of treatment. The achievable distal falloff, close to the physical limit, and sharp penumbra provide best therapeutic potential for patients with ocular tumours.

Detailed calculations of the neutron doses are in progress.

In Germany we see a definite necessity for a single low energy facility which guarantees the excellence of proton therapy for the need of 80 million people.

ACKNOWLEDGEMENTS

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