A proposal of a novel method for eye cancer treatment with Proscan.

by Urs Rohrer (PSI), issued on September 7, 2001

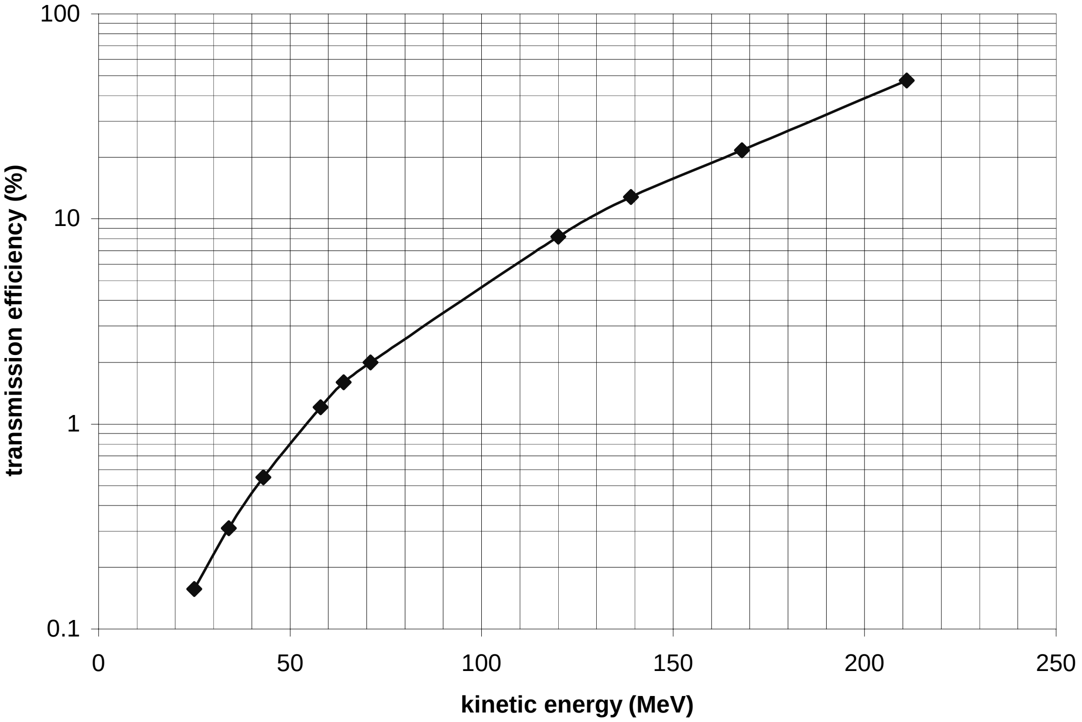
1. Introduction

For future cancer treatments with Gantry-2 of the Proscan project a dynamic method has been proposed by Eros Pedroni. This method requires the possibility for a fast (50 ms for 1 energy step), simultaneous and correlated variation of the fields of all magnets in the beam line together with the thickness of the degrader at the exit of the cyclotron in order to modulate the energy of the proton beam entering Gantry-2. This new design would help to avoid the usage of a range shifter in front of the patient. Table 1 and Fig.1 are showing some parameters characterizing the energy dependence of the Proscan proton beams.

Table 1: ***E****=kinetic energy,* ***p****=momentum,* ***dC****=degrader length (graphite),* ***Trans****=transmission*

E (MeV)	p (MeV/c)	dC (cm)	Trans(%)
71	372	18.75	2.0
120	485	15.0	8.2
139	530	13.0	12.8
168	586	10.0	21.6
211	664	5.0	47.3
250	729	0.0	100.0

Fig. 1: *Transmission efficiency as function of kinetic energy (values from table 1 & 2). All slits are fully open. The inner beam tube diameter is assumed to be 90 mm.*



One can see, that the beam momentum (all magnetic fields are scaled with this parameter) is only varying by a factor of 2 for the kinetic energy ranging from 70 to 250 MeV. The graphite degrader thickness has to be varied between zero and 19 cm.

2. The new idea.

By expanding the kinetic energy range of the beam line to the Optis area down to about 25 MeV (p=218 MeV/c), the fast energy modulation of the beam line could be used for the eye cancer treatment with the Proscan project. Instead of producing the SOBP (spread-out Bragg peak) with a rotating absorber of variable thickness, the momentum of the beam could be modulated with an additional degrader of variable thickness between 0 and 2.5 cm and a corresponding variation of the field of all magnets of the beam line into the Optis area. The modulation frequency achievable with this new method could be as high as about **1 Hz** (but much smaller than with the rotating wheel, which is about 100 Hz). Table 2 shows the relevant parameters for this extended energy range. The beam in front of the Optis chair would have to be made parallel (see Fig. 2) and with a collimation system with an inner diameter of 30 mm (transmission = 20 %) a relatively homogenous field with less than ±3 % variation could be produced (see Fig. 3 and Fig. 4).

Table 2: ***E***=*kinetic energy,* ***δp/p***=*momentum spread,* ***rH2O***=*range in water,* ***trans***=*transmission efficiency,* ***dC***=*degrader length (graphite).*

E(MeV)	δp/p (2σ,%)	rH2O (cm)	trans (%)	dC (cm)
64	±1.35	3.5	1.6	19.22
58	±1.35	2.9	1.21	19.61
43	±1.35	1.7	0.55	20.48
34	±1.35	1.2	0.31	20.93
25	±1.35	0.65	0.157	21.32

Fig. 2: Envelopes of the 71 MeV parallel beam into the Optis area. At z=33.5 m a collimator is positioned, which cuts off the non-flat part (80 %) of the beam.

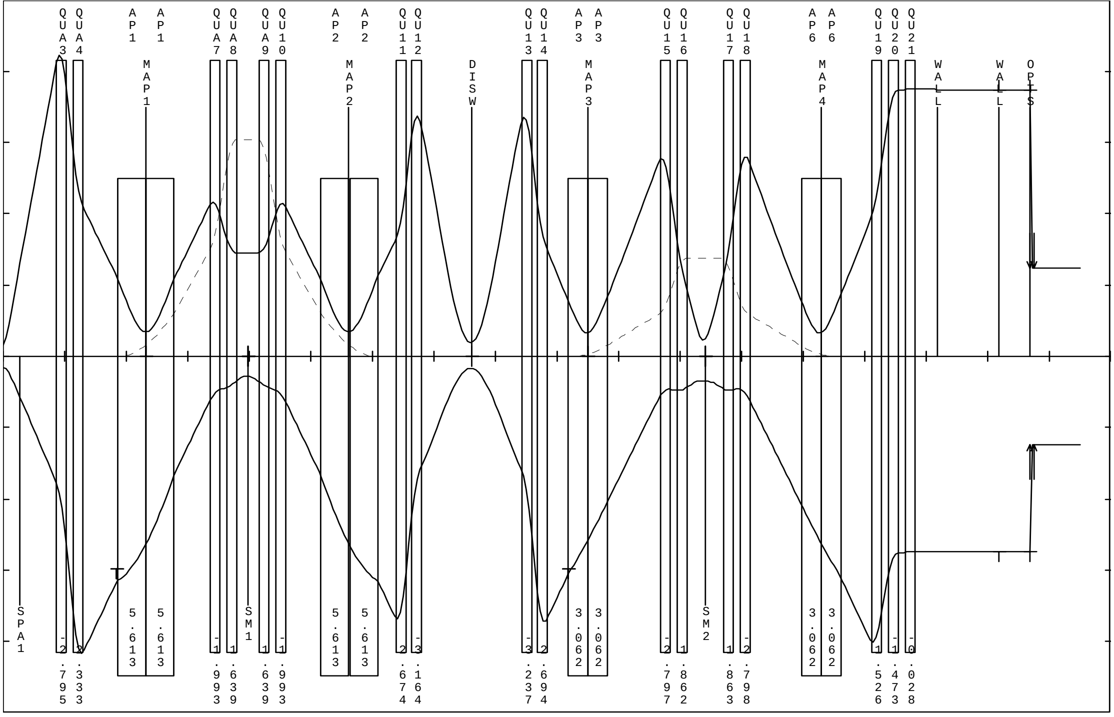


Fig.3: Radial distributions of the parallel beam at the Optis location before and after the collimator (r=15 mm). A linear rise of the distribution means a homogenous and constant proton distribution per unit cross section area. The transmission through the collimator of 30 mm diameter is around 20 %.

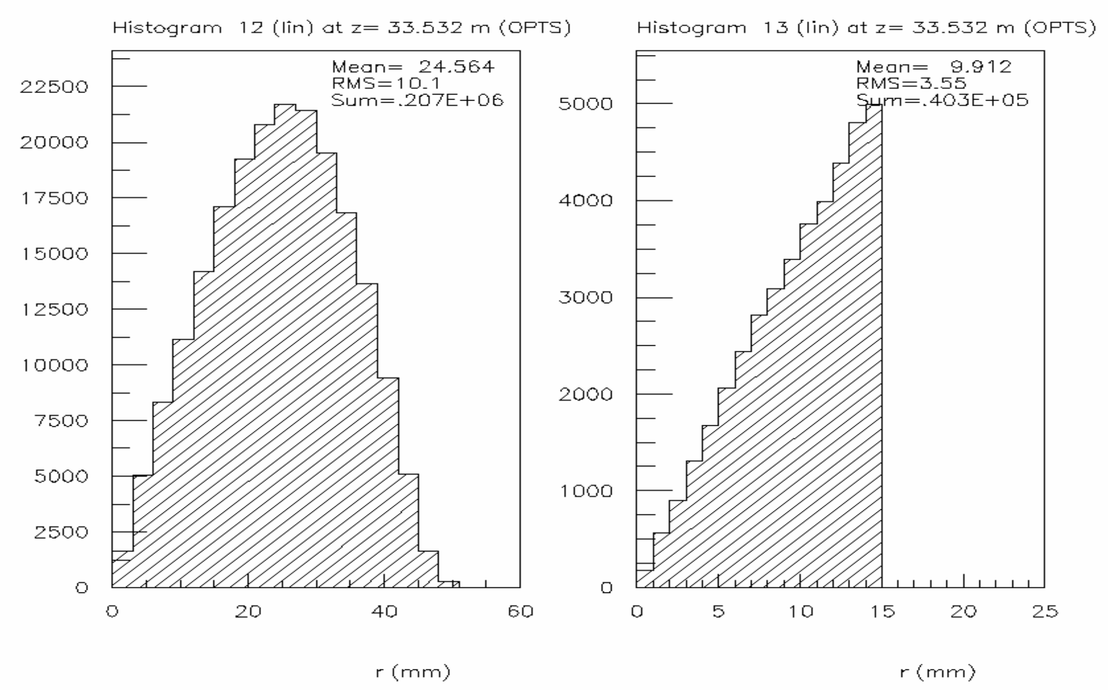
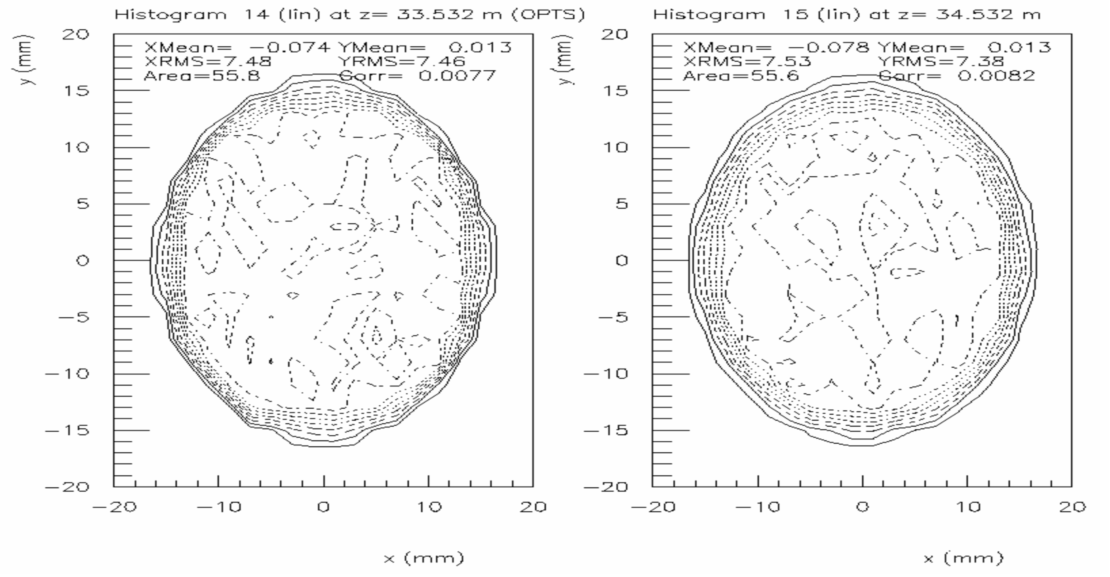


Fig. 4: x/y distribution of the proton beam after the collimator and 1 m further downstream. The almost perfect parallel structure of the beam is well demonstrated with this figure.



3. Some dose rate considerations.

With formula 1 the proton current density i in nA $/cm^2$ at the location of the eye treatment may be computed. (I_0 is the proton current in front of the degrader, t_{bl} is the beam line transmission efficiency taken from Fig. 1, t_{col} is the transmission of the circular collimator at the Optis location and r is the radius of this collimator.

$$i = \frac{I_0 \cdot t_{bl} \cdot t_{col}}{\pi \cdot r^2} \quad [nA / cm^2] \qquad (1)$$

For 500 nA initial current and a 70 MeV degraded beam and with a collimator radius of 15 mm the current density at the location of Optis *i* is 500 • 0.02 • 0.2 / 7.07 = 0.28 nA $/cm^2$. With formula 2 (E_{kin} is the kinetic energy, *i* the current density from formula 1 and r_{H_2O} the range of the protons in water) the average dose rate dr_m in water in units of Gy/s (1 Gy = 1 Joule/kg) may be computed:

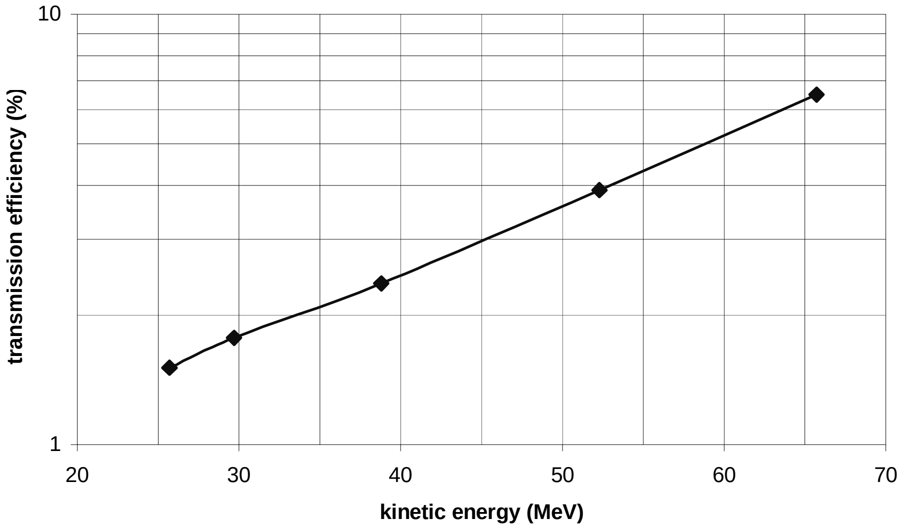
$$dr_m = \frac{E_{kin}[MeV] \cdot i\,[nA/cm^2]}{r_{H_2O}\,[cm]} \quad [Gy/s] \qquad (2)$$

With the above current density *i* of 0.28 for 70 MeV we get 70.0 • 0.28 / 4.0 = 4.9 Gy/s average dose rate dr_m. Because the ratio of the dose rate at the Bragg peak and the average dose rate for 70 MeV is about 3:1, we get an effective dose rate at the Bragg peak of about 15 Gy/s, which is much more than the 1 Gy/s considered as being sufficient for treatments with the present Optis apparatus at the 70 MeV Philips Cyclotron (Injector-1).

4. Some remarks concerning the range modulation.

Table 2 and Fig.1 are showing, that for the new method the transmission efficiency between 64 and 25 MeV is dropping by a factor of 10, whereas with the present Optis apparatus this factor is only around 4 (see Fig. 5). This is due to the fact, that with the new method the momentum bandwidth is limited by the bending magnets dispersion to ±1.35 % (see table 2), whereas with the present Optis apparatus there is no dispersion between the modulator and the eye. For an energy of 25 MeV produced with a 0.6 mm thick lead scatterer and a 12 mm thick aluminium absorber, the 2σ-momentum spread is ±6.5 % (This is probably advantageous for getting a smooth SOPB more easily).

Fig. 5: Simulated transmission efficiency of the present Optis apparatus used together with the 70 MeV Philips Cyclotron. As modulator aluminium has been used for computing the attenuation of the transmission efficiency. A 0.6 mm thick lead foil serves as a primary scatterer.



5. Discussion.

a) As already mentioned, the modulation frequency cannot be increased beyond 1 Hz. Therefore, if a treatment with a typical duration of 15 sec has to be interrupted – because the patient is moving his eyes – the position of the degrader has to be remembered in order to continue the treatment at this position once the patient is ok again.
b) This method is sensitive to low frequency beam fluctuations (<<10 Hz) during the treatment, whereas the traditional method is more sensitive to high frequency beam fluctuations (>>10 Hz).
c) Because of the narrower momentum spread and the steeper intensity fall-off at energies below 60 MeV, it might be more difficult to compose a smooth and flat SOBP than with the traditional method.
d) New instruments for the dose distribution verification have to be built, because the present ones rely on a fast range modulation frequency (~100Hz).
e) The presented method has no rotating parts anymore in the patient room and the neutron background may be much smaller than with the traditional method used at the Injector-1. (Only less than 10 nA are entering the patient's room instead of 60 nA.)
f) For patient-safety reason the degrader has to be divided into two parts. A variable wedge (0.5-2.5 cm graphite) has to be placed in front of a fixed plate of about 19 cm thick graphite. This has also the advantage of less mass, which has to be accelerated forth and back during the energy modulation. This degrader combination has to be rapidly exchangeable with the degrader needed for the Gantry treatments
g) Because this method is novel, it first has to be tested with real beam before one should embark on it. This means one first has to investigate the difficulties to set-up some parallel beam at different energies and to test the homogeneity of the parallel beam-field and verify the transmission efficiency curve for different proton energies.