Monte Carlo simulations of microbeam radiation therapy with carbon ions for an interleaved irradiation geometry.

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OUTLINE

- Introduction to Microbeam Radiation Therapy (MRT);

- Monte Carlo simulations for MRT with heavy ions

  ↳ *Brain tumors in rabbits;*

- Conclusions.

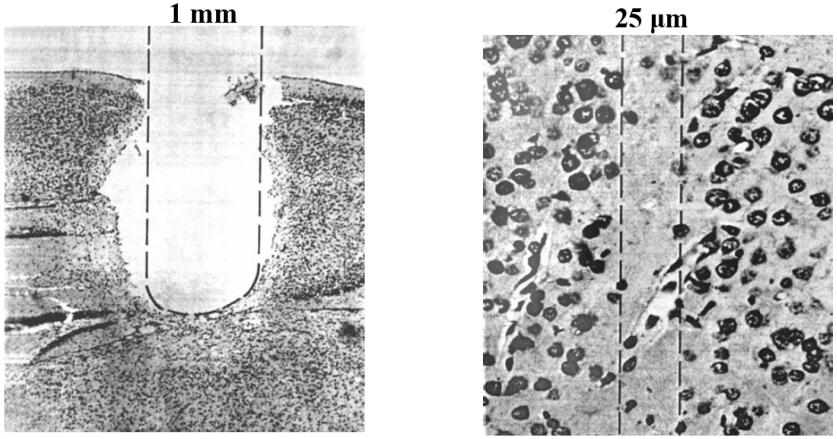
MRT → Microbeam Radiation Therapy
is an innovative technique carried out using an array of highly intense parallel microbeams

Microbeams are obtained using a colimator
Typical dimensions:

- ~ 25 - 300 μm wide,
- ~ 100 - 600 μm center-to-center (c-t-c) distance

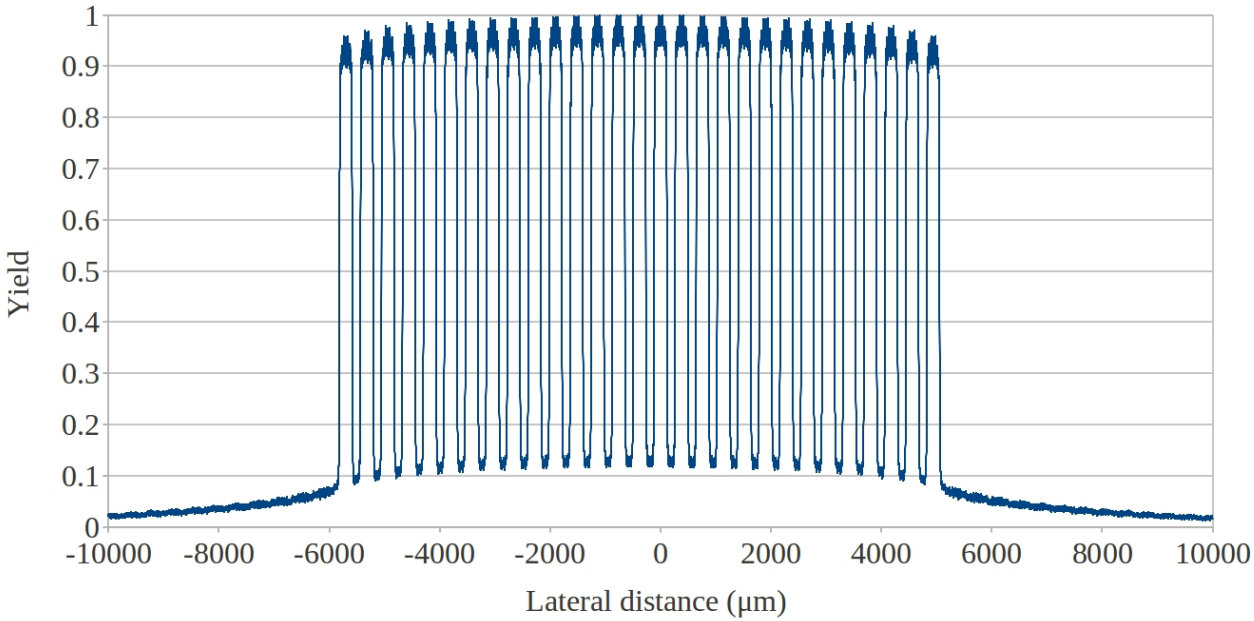
→Microbeams' tissue-sparing effect

The effectiveness of MRT is related to the ability of normal tissues to tolerate a very high radiation dose in small volumes.



Zeman et al, Radiat Res 15, 496,1961

The resulting dose distribution is a sequence of peaks and valleys, where the valleys come from the superposition of the tails of the dose distribution from the individual microbeams.



Example of dose distribution produced by a microbeam array.

The dose in the 'valley' should be below the tolerance limit of the tissue.

An important characteristic of this dose distribution is the so-called "Peak to Valley Dose Ratio"(PVDR), defined as the ratio between the peak dose and the valley dose.

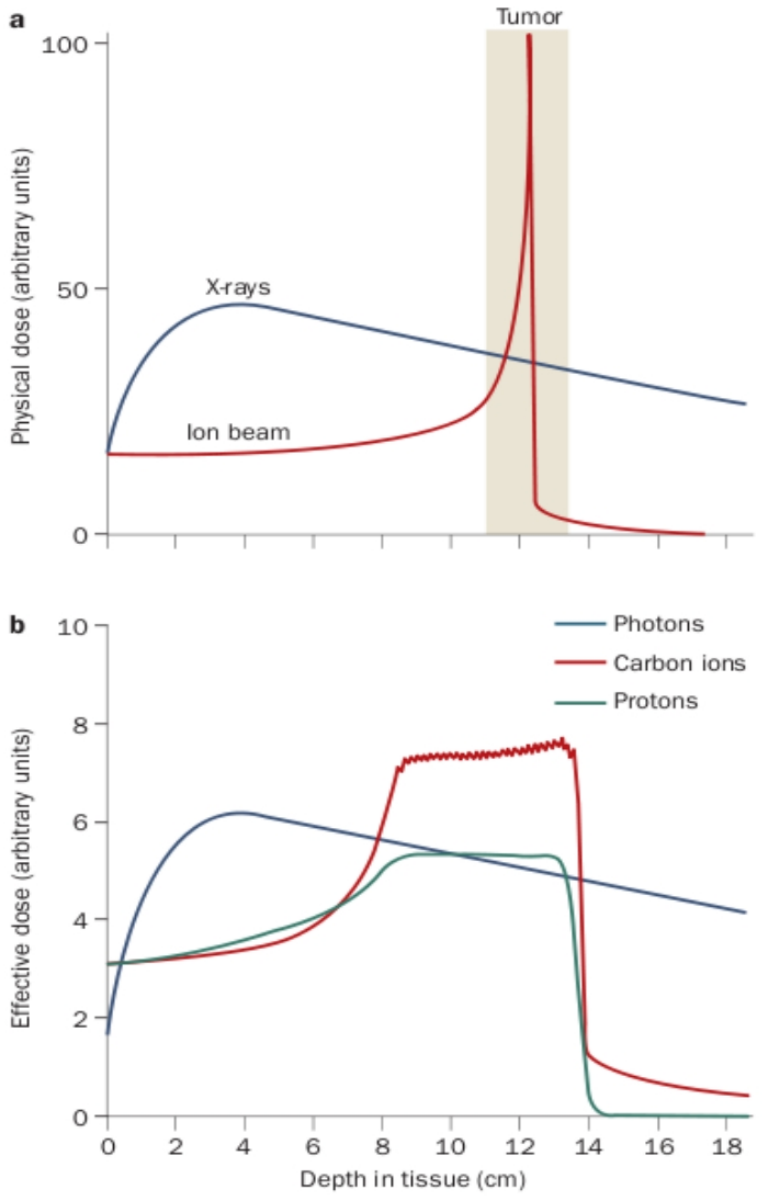
By contrast with x-rays, which are attenuated by the body and show an exponential decrease in the radiation dose with increasing tissue depth, charged particles deposit little energy at the body's entrance and instead deposit most of their energy just before they come to stop in tissue

→ BRAGG PEAK

Since the Bragg peak for particles of a given energy is very narrow, beams of different energies have to be superimposed to produce a

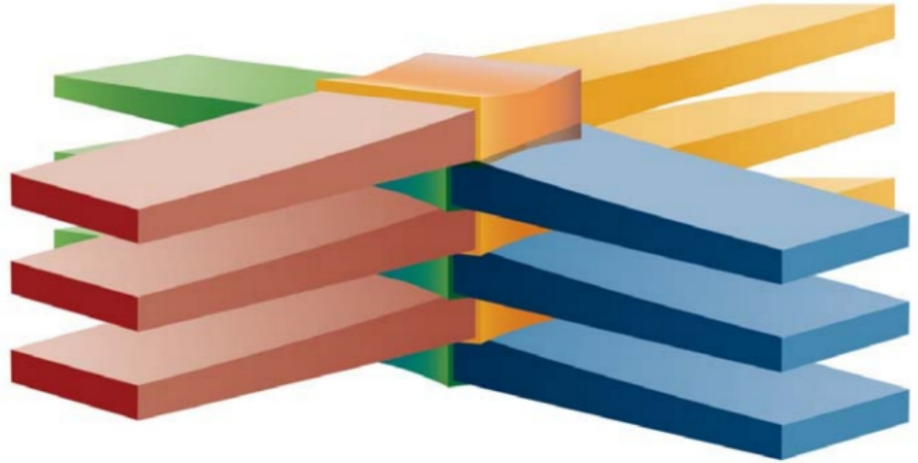
→ spread-out Bragg peak (SOBP)

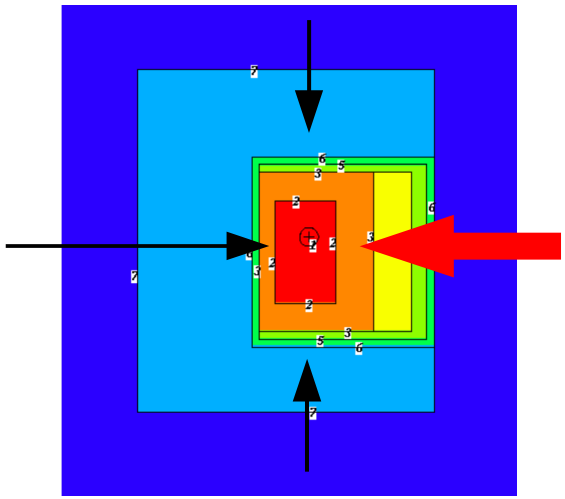
that covers the whole tumor.



Durante and Loeffler Nat. Rev. Clin. Oncol. 7, 37–43 (2010)

Interleaved Carbon Minibeams is a new method that employs arrays of parallel, thin planes of carbon beams in a geometry that produces a solid radiation field in the tumor.
The arrays of microbeams come from 4 different directions and interleaved in the tumor volume.





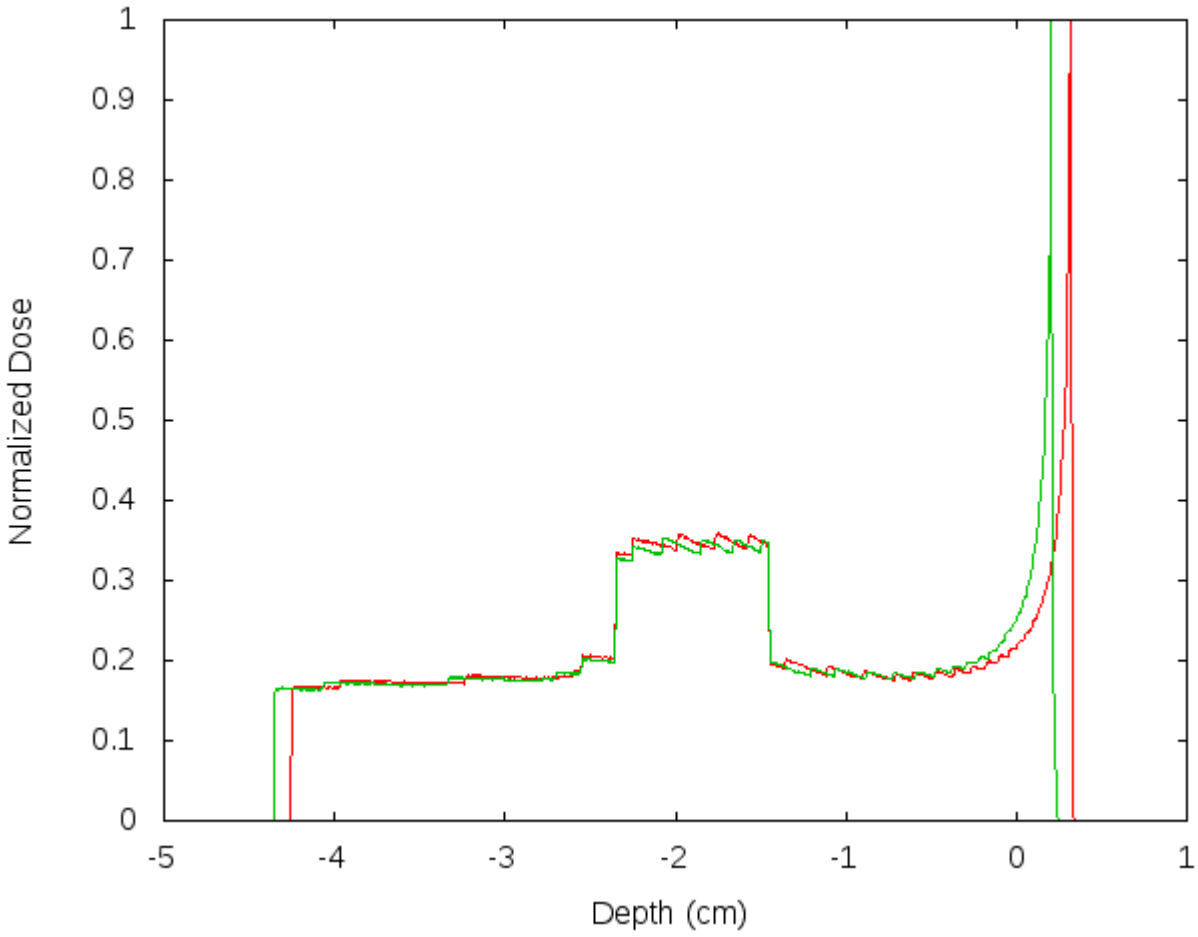
Simplified input geometry of the rabbit head

Simulation parameters: beam width 300 μm
600 μm ctc distance

Bragg peak's displacement keeping the same beam's energy

→ 150 MeV/u

is obtained adding 1mm filter.

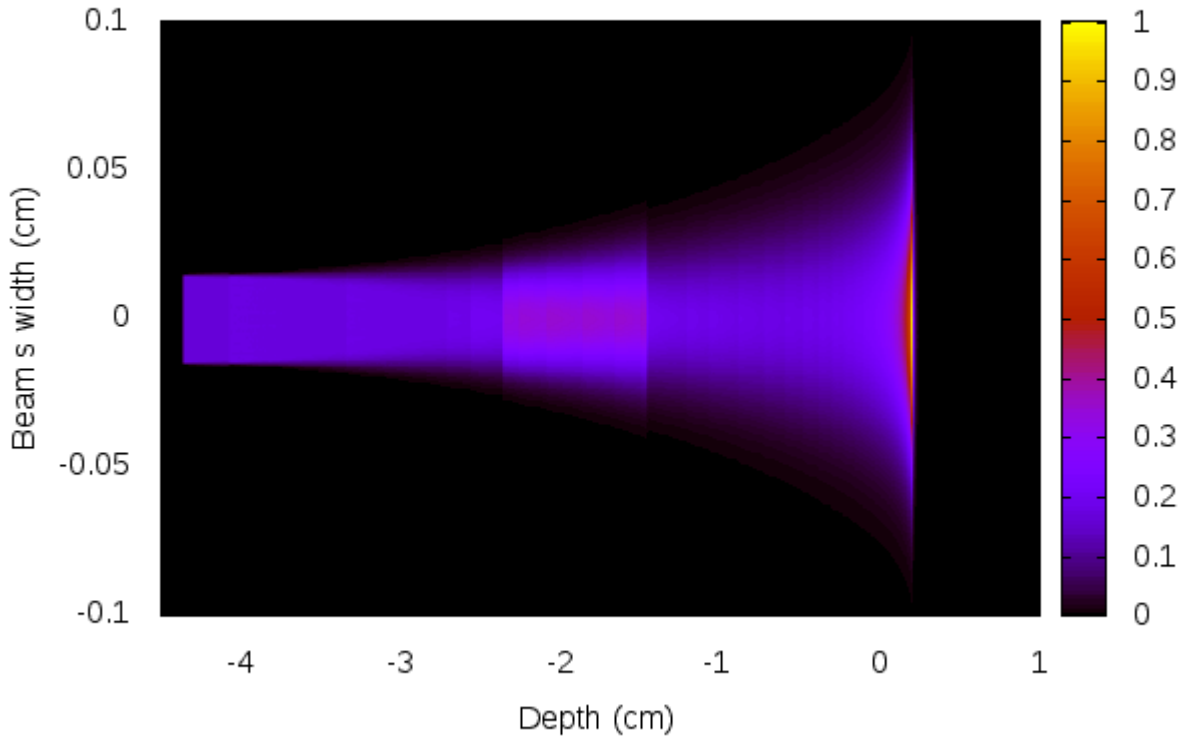


2-D visualization of a carbon minibeam

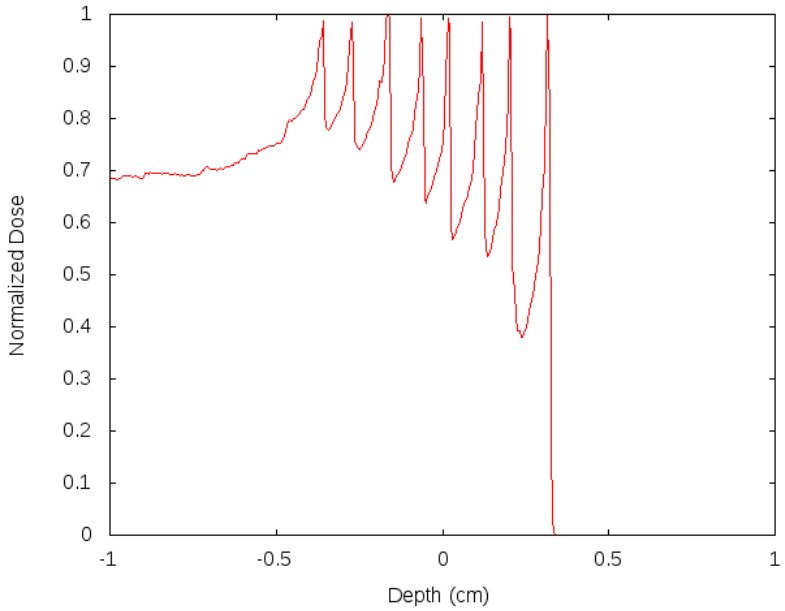
→ 150 MeV/u

At the Bragg peak a big widening of the beam is obtained

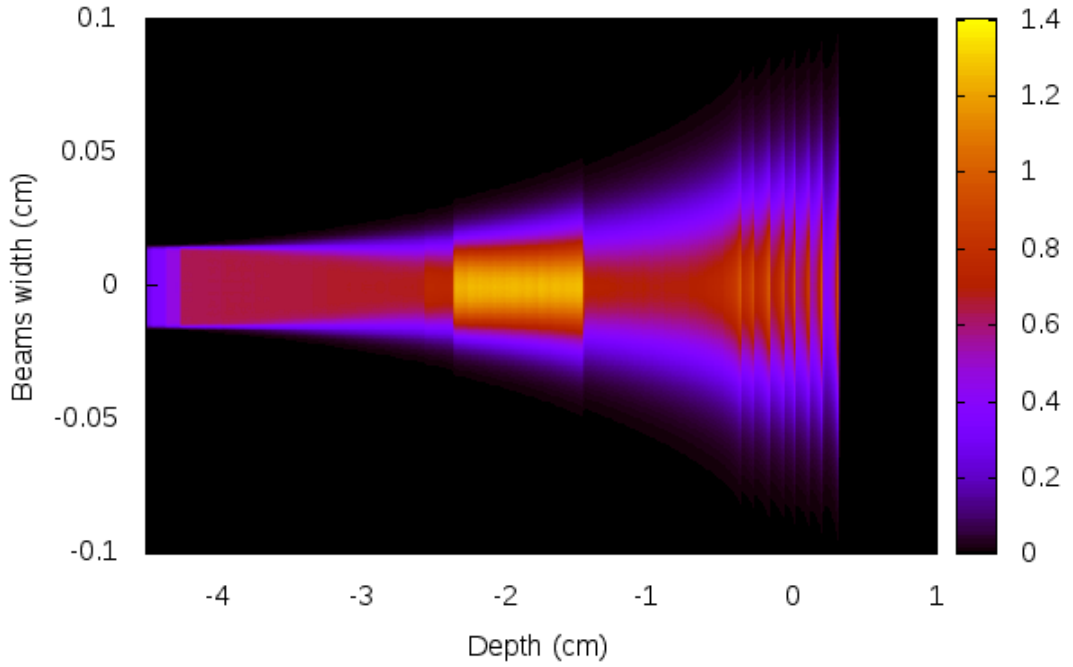
→ angular straggling



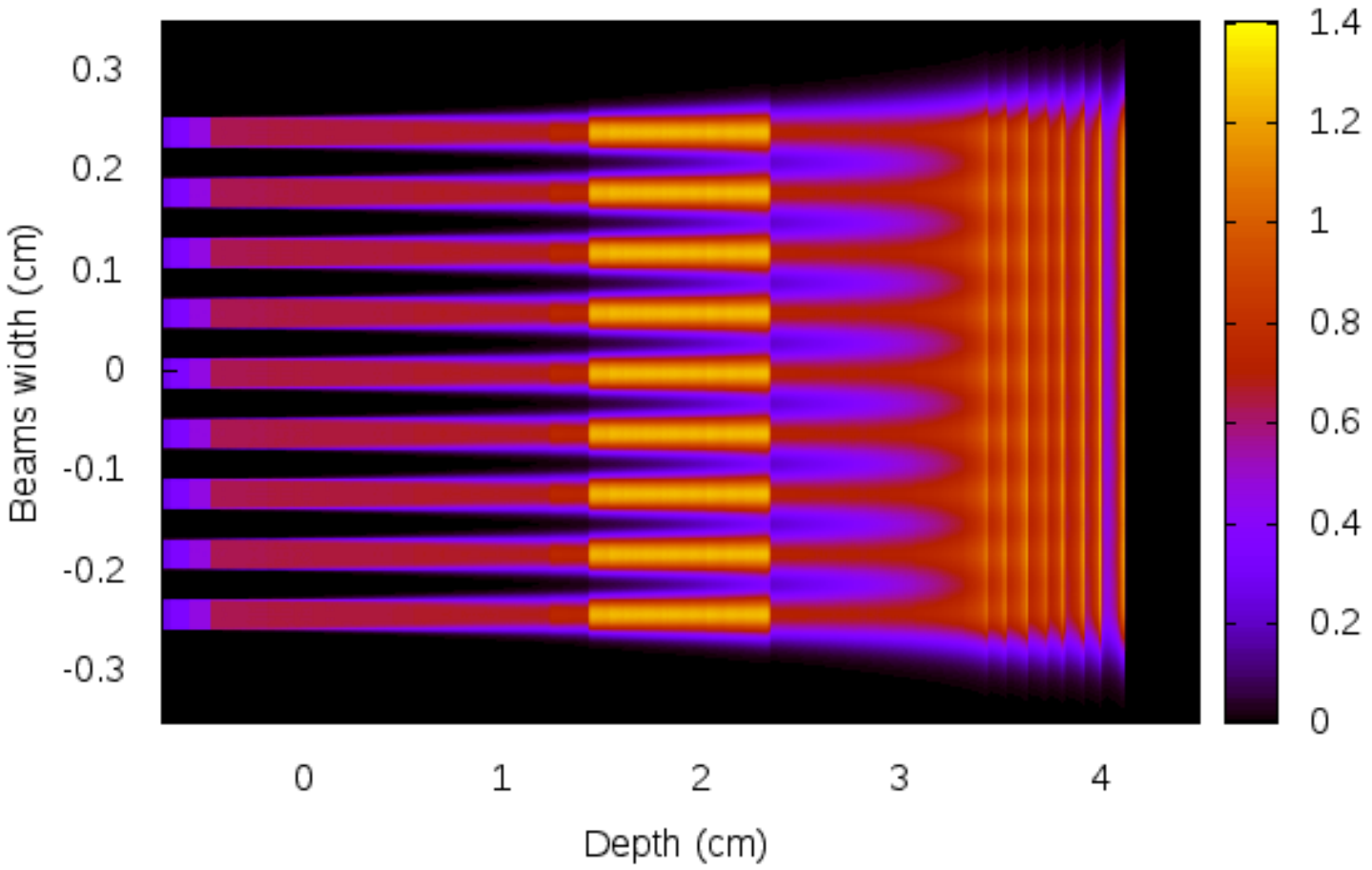
Spread Out Bragg Peak (SOBP) is obtained summing the distributions got for 7 filters (1mm each).

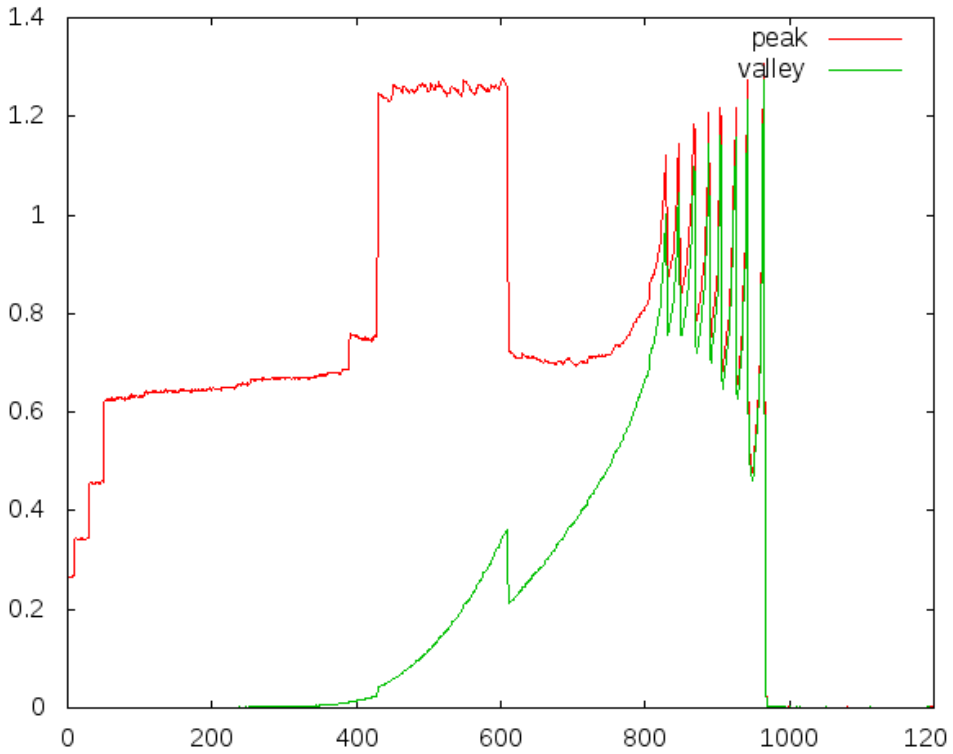


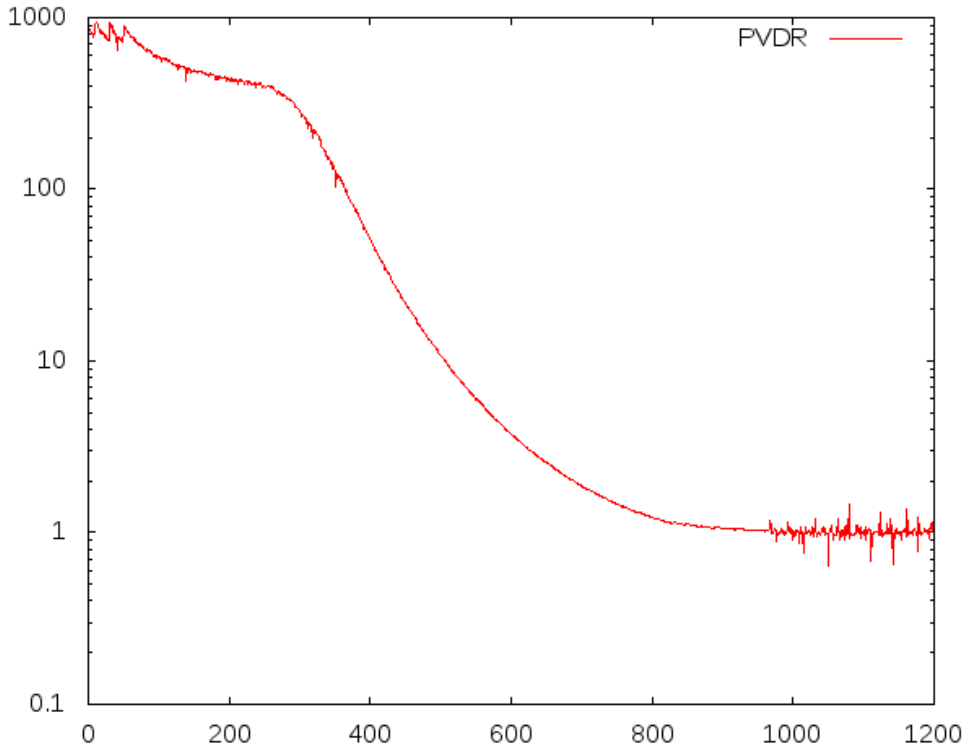
2-D visualization of the superposition for 7 beams (with filters)

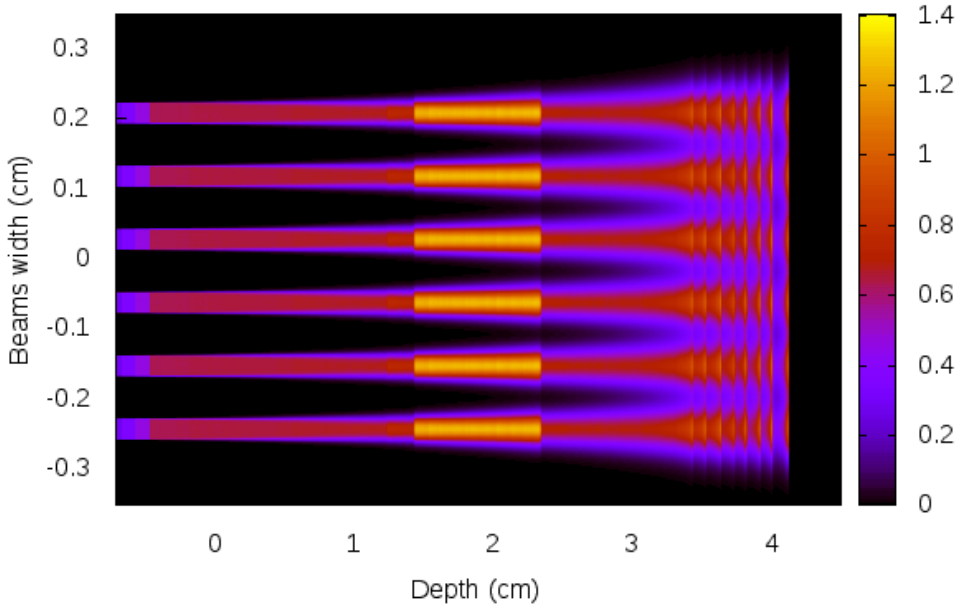


300 μm beam's width
600 μm c-t-c distance

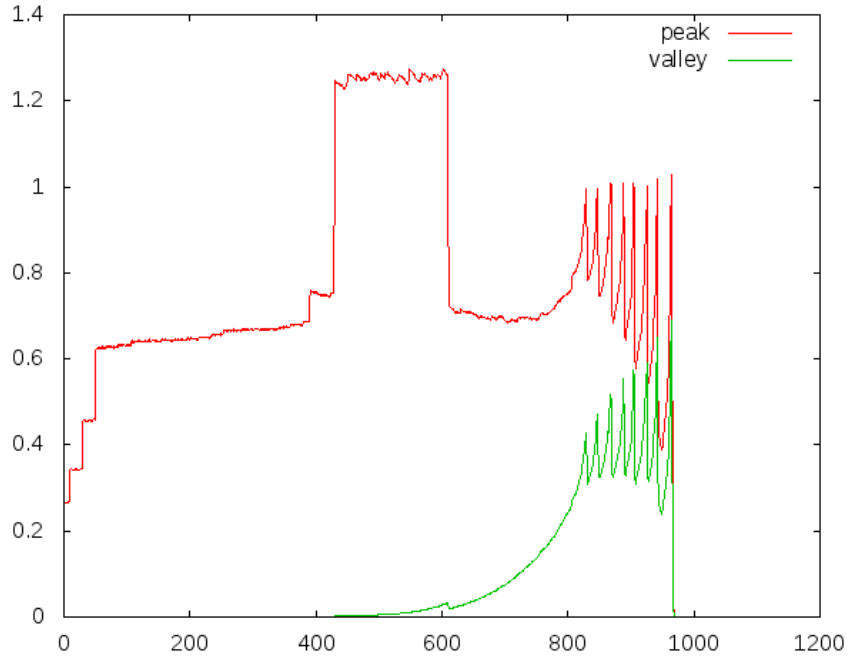


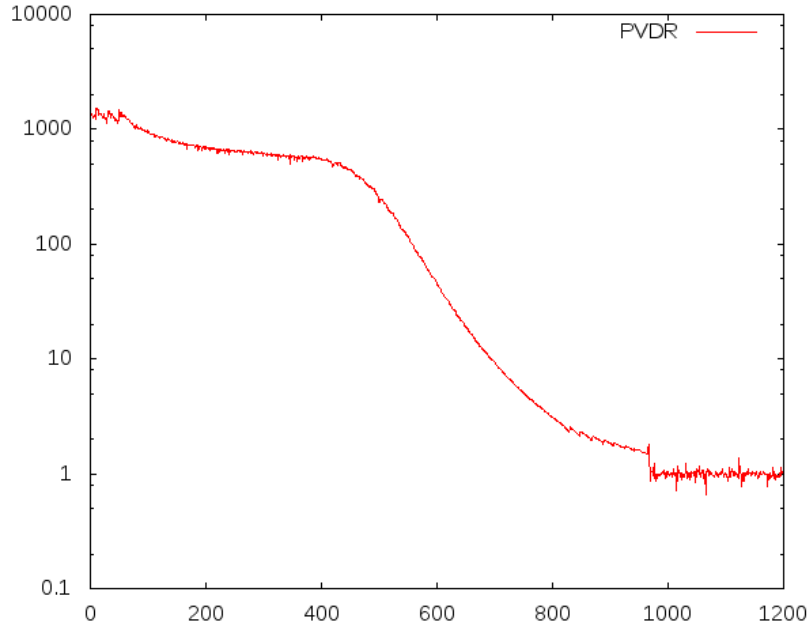

peak
valley
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
120


PVDR
1000
100
10
1
0.1
0
200
400
600
800
1000
1200



300 µm beam's width
900 µm c-t-c distance





Conclusions

Brain tumor in rabbits

My simulations produced information about the depth of the Bragg peak in the subject, its detailed dose distribution, and the beam broadening (angular straggling) along the beam's path. The simulation results were in agreement with our experimental findings.

- *My simulations are being used in a manuscript we are preparing for submission to the Proceedings of the National Academy of Sciences, USA.*

I will complete the simulation of the dose distribution on interlaced carbon microbeams by introducing the curve of the carbon's relative biological effectiveness (RBE) and re-design Bragg-peak spreading to produce a flat top for the photon-equivalent dose instead of the physical dose.