MONTE CARLO STUDY OF THE OPTIMIZATION OF THE MINIBEAM COLLIMATORS IN PROTON MINIBEAM RADIATION THERAPY

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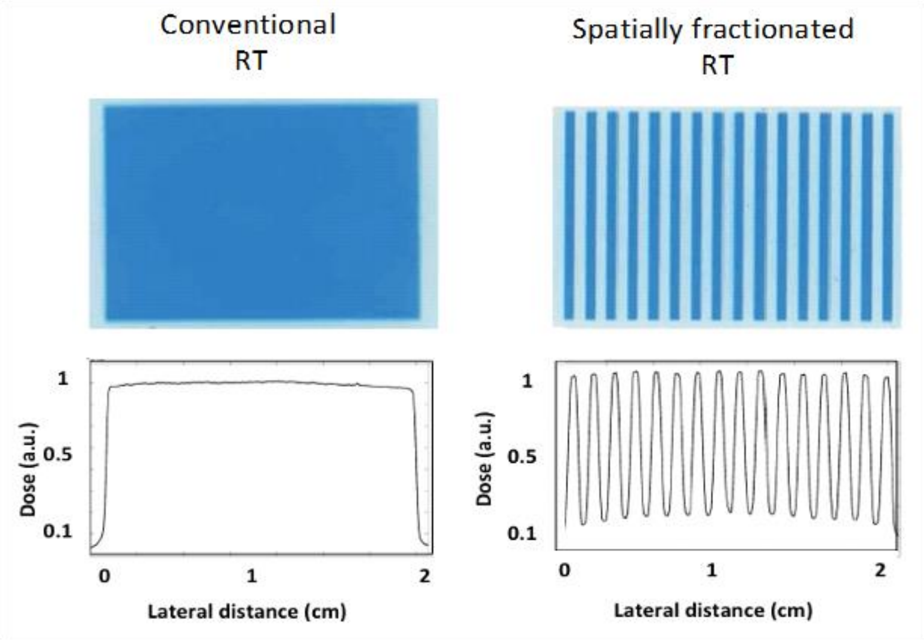
INTRODUCTION

AIM: optimizing the minibeam generation in a new radiotherapy approach called **proton-minibeam radiation therapy (pMBRT)**

↓

- Once of the current RT challenges: RT limited by the tolerance doses of normal tissues
- MBRT: Use of a spatial fractionation of the dose & submillimetric field sizes. MBRT has showed increase the tolerance of healthy tissue.
- Pioneer project that offers an optimized way of using protons for therapy.
- Application field: pediatric oncology and treatment of very radioresistant tumors.
- The technique is being technically implemented at Proton Therapy Center Orsay

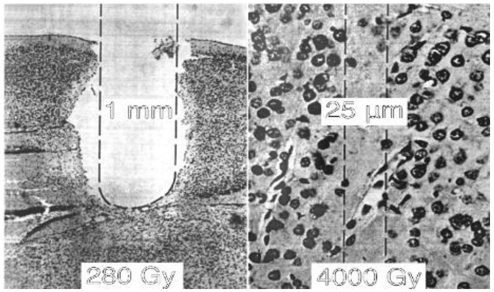
METHOD: **Minibeam Radiation Therapy**



- Submillimetric field sizes (25 to 700 µm)
- Interbeam separation (400 to 3500 µm)
- Dose profiles: pattern of peaks and valleys

Spatial fractionation

Instead of homogeneous distributions
→ gain in healthy tissue recovery & increase of tolerances [1,2]



Dose-volume effects

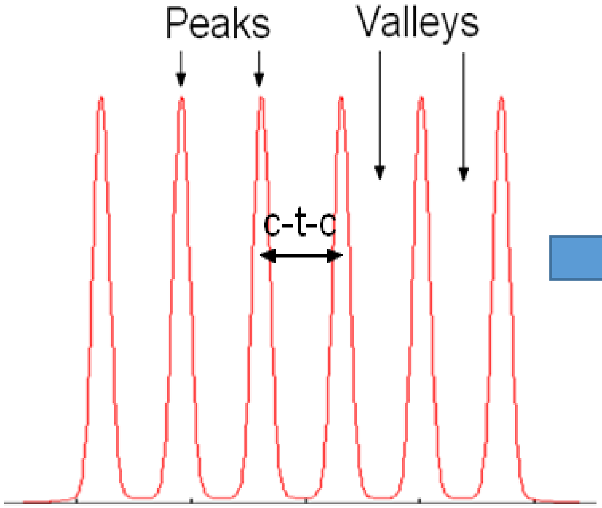
The smaller the field size is, the higher the tolerance
→ exponential increase of healthy tissue tolerances [3]

[1] Y. Prezado *et al., J. Synchrotron Radiat.* **19** 60-65 (2012)

[2] P. Deman *et al., Int. J. Radiat. Oncol. Biol. Phys.* **82** 693-700 (2012)

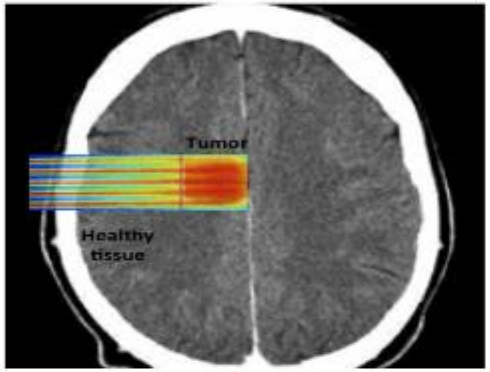
[3] Zeman et al., Science (1959)

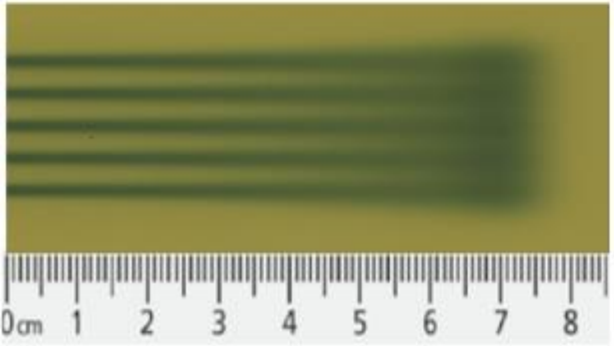
METHOD: **proton MiniBeam Radiation Therapy (pMBRT)**



$$PVDR = \frac{D_{\text{peak}}}{D_{\text{valley}}}$$

PVDR has to be as high as possible, while low valley doses are required in order to ensure the preservation of normal tissue





- Gain in healthy tissue recovery & increase of tolerances
- Spatial fraction of the dose in the normal tissue beyond the Bragg peak
- Quasi-homogeneous dose distribution at the Bragg peak location due to multiple Coulomb scattering in depth
- Potential gain in Therapeutic Index

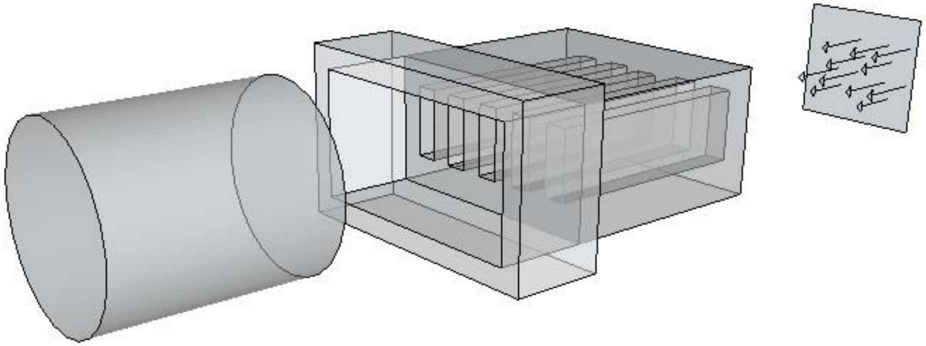
Prezado and G. Fois, *Med. Phys*. **40** 031712 (8pp.) (2013)

RESULTS: **Monte Carlo Simulations**

- Monte Carlo simulations (**GATE v7.1**) were used as a method to evaluate the dose distributions of pMBRT irradiations in several configurations of mechanical collimation.

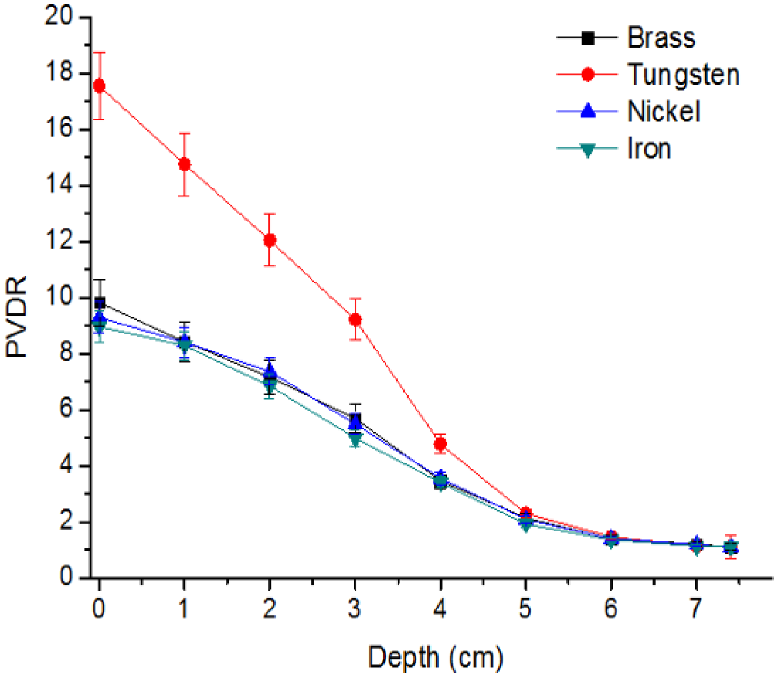
- **Assessed**: the peak and valley depth dose curves, PVDR values, penumbras, and secondary neutron contributions as a function of depth.

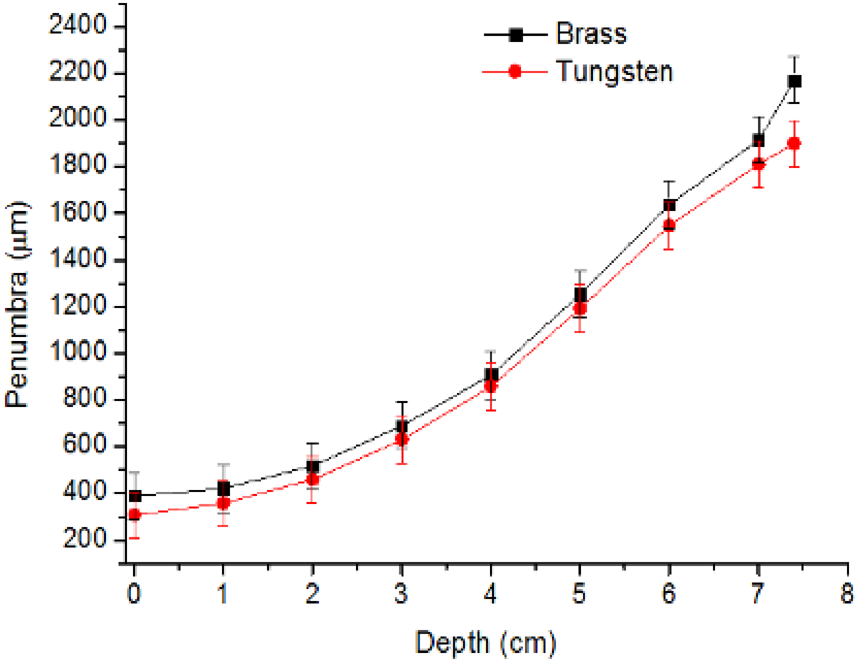
Initial configuration:



- 100 MeV proton beams
- 5 multislit collimator (400 µm microslit width, 3200 µm c-t-c)
- 5 cm collimator thickness
- 7 cm phantom-collimator distance

MONTE CARLO SIMULATIONS: **Collimator material**



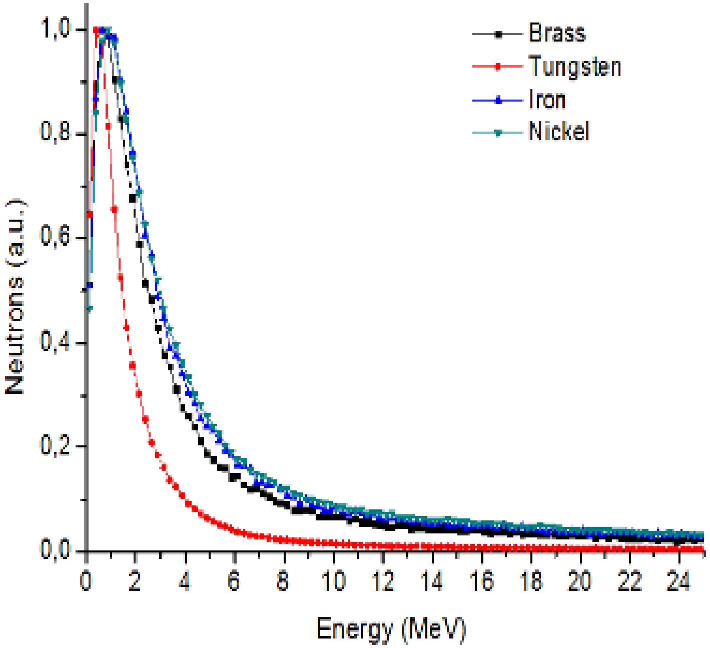


- PVDR@W values ~ double other collimators
- Gain in penumbra values: narrower than in conventional radiosurgery (> 2.5 mm) → it helps in normal tissue sparing

MONTE CARLO SIMULATIONS: **Neutron contribution**

Material	Multislit Collimators(%)	Conventional Collimator (%)
Brass	14.7 ± 0.4	11.5 ± 0.2
Tungsten	39.6 ± 0.9	30.78 ± 0.14
Iron	13.5 ± 0.3	10.6 ± 0.3
Nickel	9.4 ± 0.3	7.4 ± 0.2

- Tungsten delivers the highest secondary neutron yield
- pMBRT delivers a lightly higher secondary neutron yield than conventional collimators (2x2cm^2)



D$_{neutron}$ for all depths are

< 0.00016% & 0.0003% of D$_{peak}$

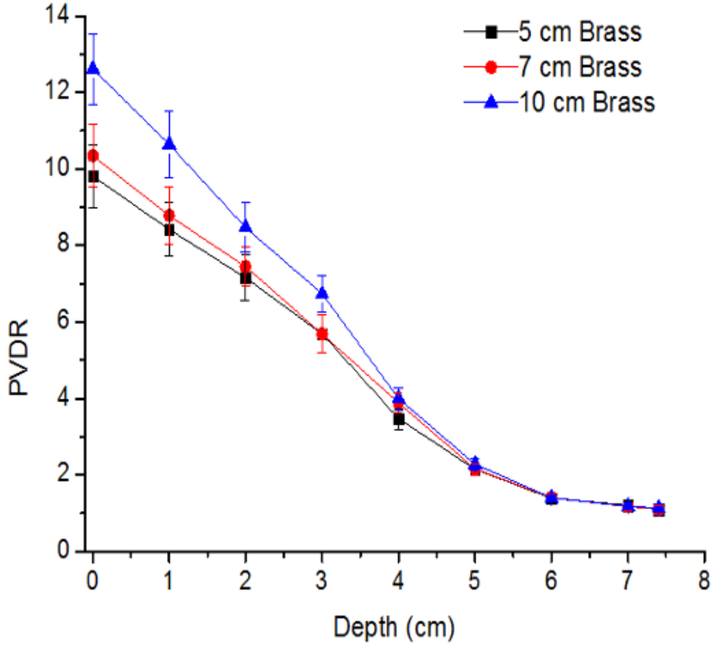
< 0.0014% & 0.005% of D$_{valley}$

by using the Brass & W collimators

Biological neutron doses in the phantom (patient) will still be less than 1% of total absorbed dose in the worst case (entrance).

MONTE CARLO SIMULATIONS:

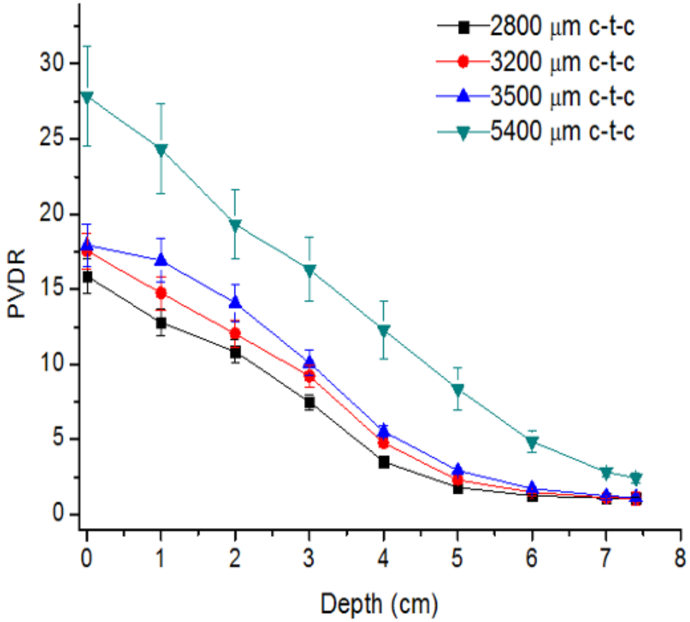
Collimator thickness



if ↑ collimator thickness: ↑ gain PVDR, but ↓ output factor

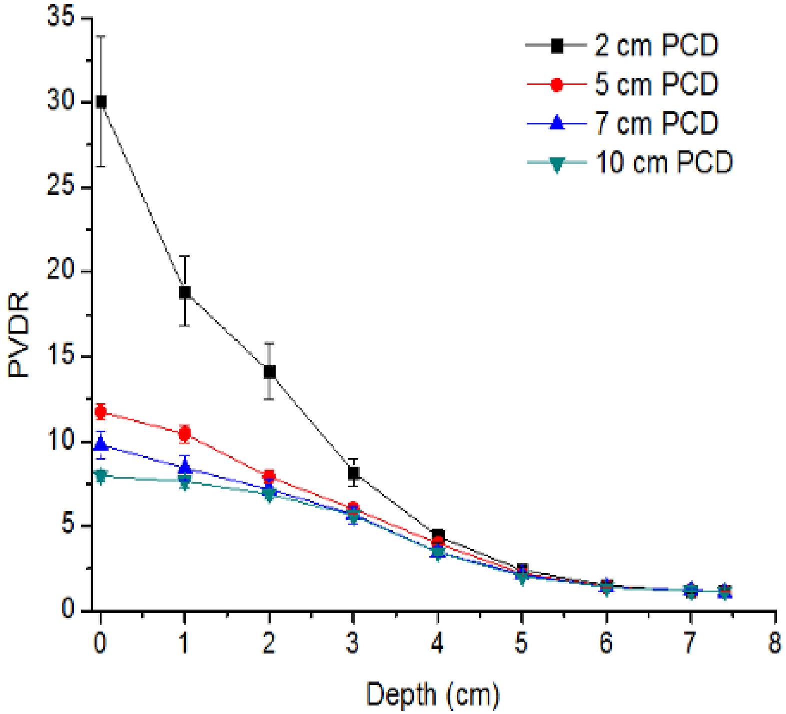
→ the number of neutrons produced in the collimator will increase by 25% to deposit the same peak dose

center-to-center distance



if ↑ c-t-c distance: ↑ gain PVDR, but ↓ the homogenization in the target → the use of larger c-t-c significantly increases the PVDR, but to obtain a homogeneous dose in the target the interlacing of two orthogonal arrays would be required

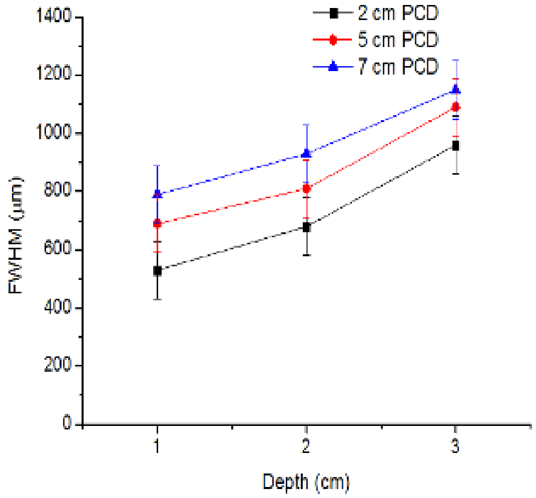
MONTE CARLO SIMULATIONS: **phantom-collimator distance**



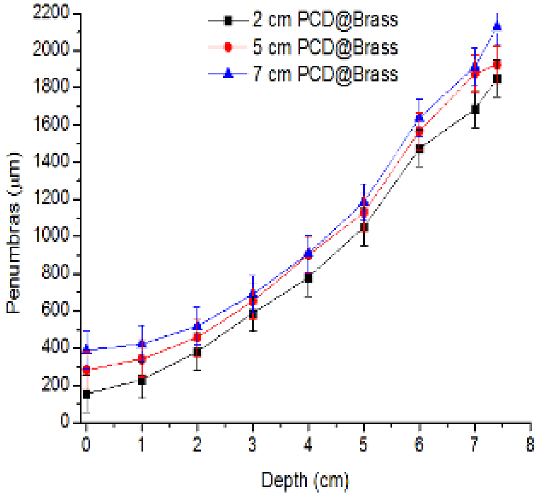
If ↓ PCD distance:

- ↓FWHM & ↑PVDR
- ↑Neutron dose, e.g. reducing PCD distance from 7 to 2 cm increases the neutron dose in the surface by a factor of 7.

Full width at half maximum @ Brass



Penumbras @ Brass



CONCLUSIONS

- Tungsten and brass offer the best compromise among the materials evaluated.
- Tungsten multislit provides the highest PVDR and lowest penumbra but it significantly increases the neutron production in the collimator, although the biological doses in the phantom remain below 1%.
- The PVDR are lower for the brass, but it is more advantageous in terms of neutron contamination, manufacturing cost and microetching.
- The aforementioned results will be used to guide the manufacture of optimized collimators for the next pre-clinical studies.

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