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Dose enhancement studies in Microbeam Radiation Therapy: Geant4 simulations and experimental results

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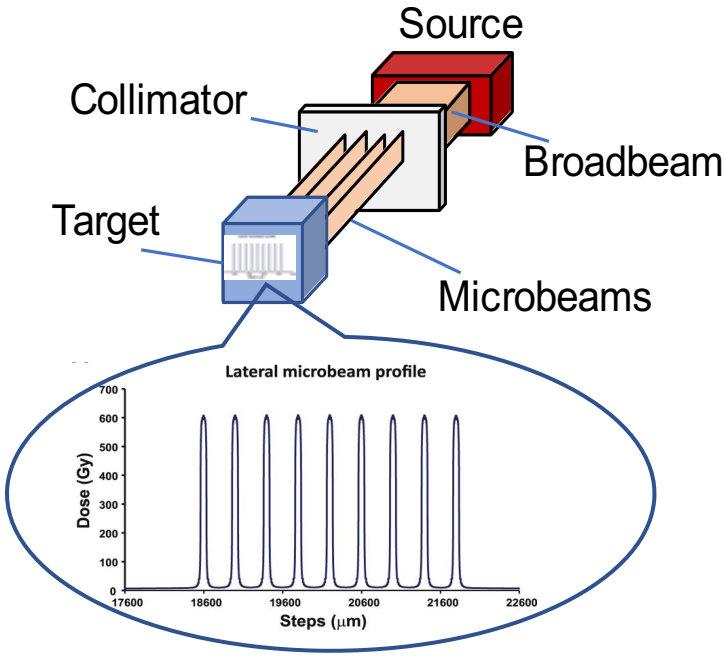
MRT

- Preclinical technique that may improve tumour control with less normal tissue damage than conventional RT

- MRT uses a spatially fractionated array of narrow microplanar X-ray beam, typically 50 μm wide and with a separation of 400 μm c-t-c

- High dose rate is important to limit the motion of the irradiated target

- At the ESRF: ~14000 Gy/s; Typical irradiation: 600 Gy (exposure ~100 ms vs 70 Gy split into daily doses of 2 Gy in conventional RT)

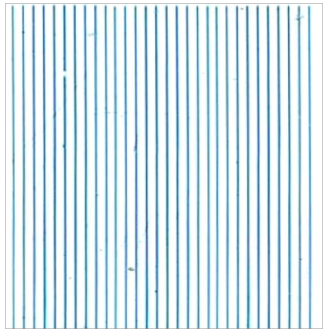


MRT: What is so special?

- Lower energies
- High doses -> No need for temporal fractionation
- The response of tumour tissue to MRT is different to normal tissue response
- The response of tumour and normal tissue to MRT is different compared to conventional BB RT

Relatively low dose
Long exposures
Divergent beams

vs



Very high x-ray dose
Very short exposure
Parallel beams

MRT: barriers?

- Synchrotrons: too big, too expensive, too complex for clinical environment
- How to compare the radiobiological effects of MRT with conventional BB therapy
- Finding the optimal therapeutic strategy

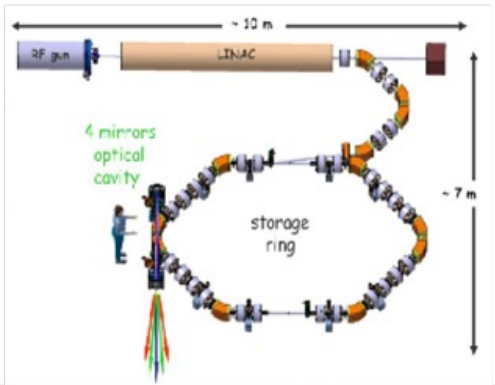
Alternative sources

- Inverse Compton compact sources are available in Europe
- Lower dose rate (10^{13} vs 10^{18} ph/s)

Using dose enhancement to increase the dose rate

2 m

10 - 20 m



150 m

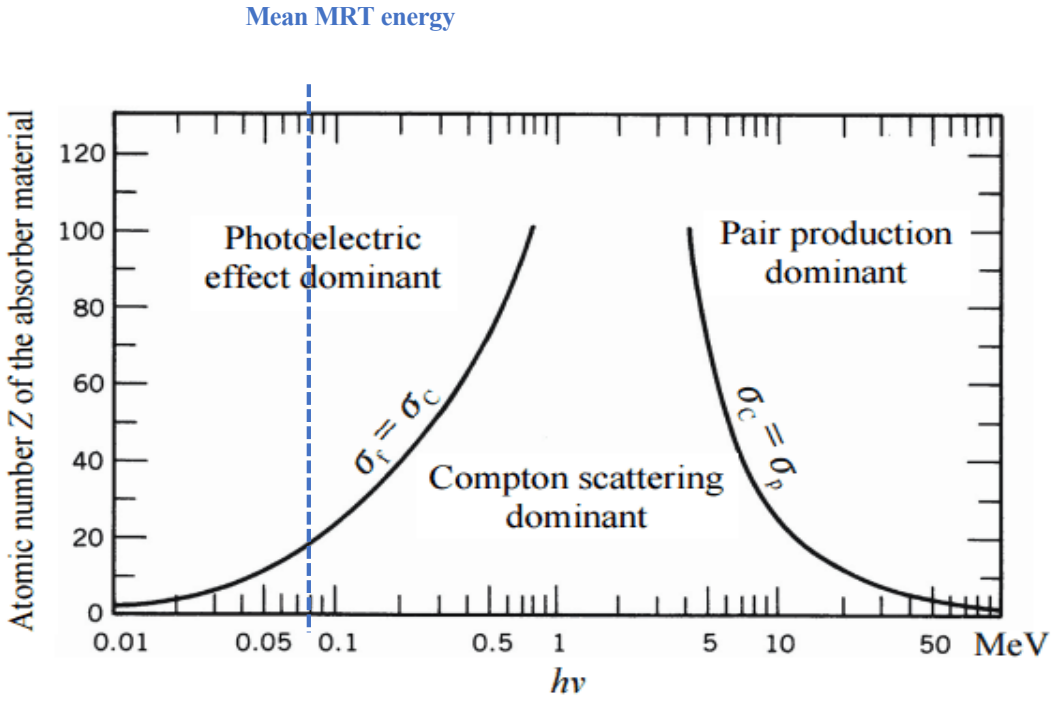
Source	Clinical Linac	Compton Source	Synchrotron
Number of patients per day	30	To be determined	2
Cost	2 M£	10-20 M£	>250 M£
Availbility	3 -10 per radiotherapy centre	Potentially 1 per hospital	3 in Europe

Combination of X-rays with dose enhancers

- Dose enhancers are high-Z compounds that can be selectively accumulated within the tumour prior to irradiation
- The probability of photoelectric interaction increases significantly for the energy range of the MRT spectrum

- ESRF spectrum ranges from 30 to 600 keV, with a peak energy at 80 keV

- Iodine Z= 53
- Gadolinium Z=71

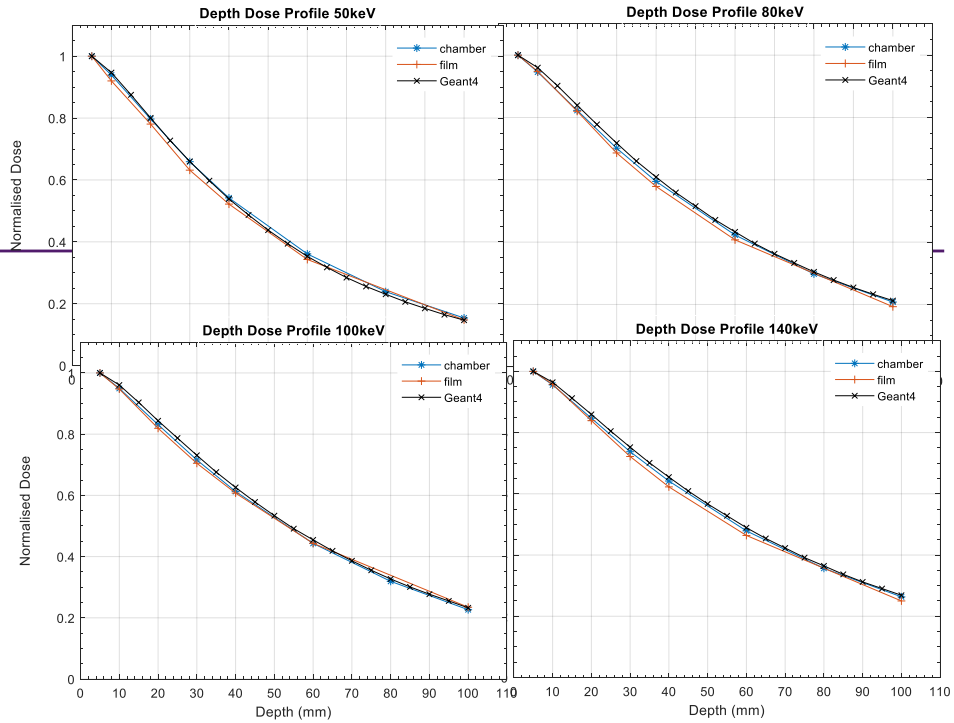


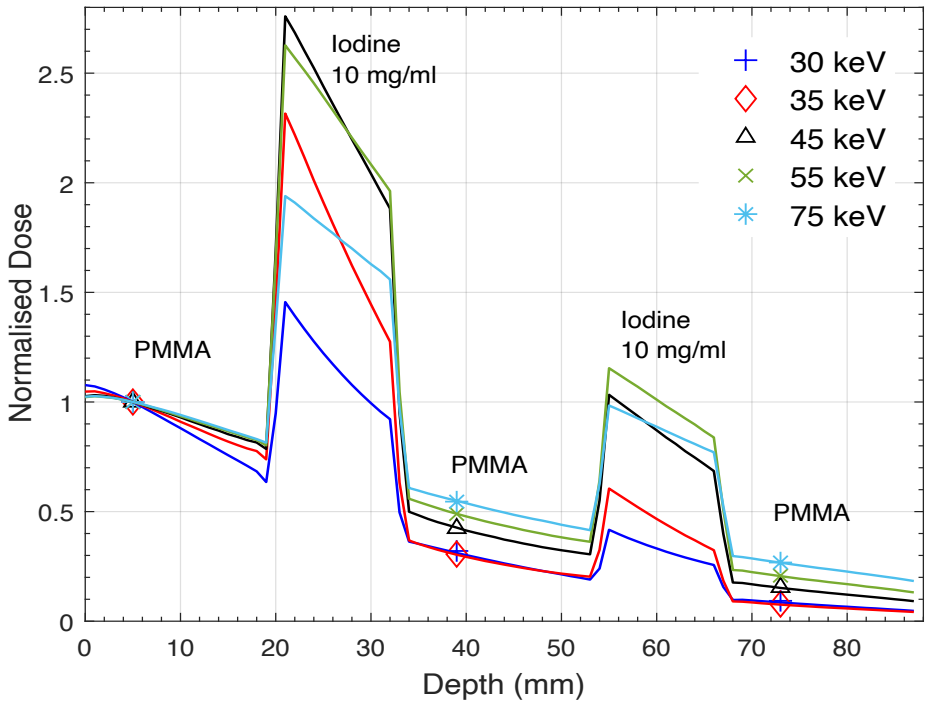
Dose enhancement

- Quantitative dosimetry for MRT has proven to be very challenging

- We have shown that I and Gd based compounds – standard injectable medical imaging radiocontrast agents – can be used with BB to enhance the dose deposition to the tissue by increasing the density of ejected electrons

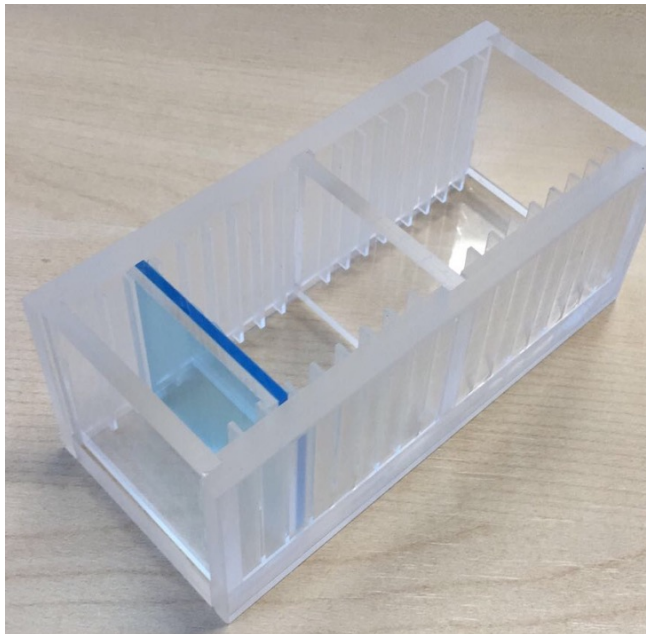
Very good agreement of Geant4 and experimental results for BB





Challenges in experimental dosimetry

- Will the dose pattern be preserved in depth?
- How do we validate our models?
- Gafchromic films disintegrate in liquids
- Two different Gafchromic films are needed to measure peaks and valleys



Results 1 – Lateral dose profiles

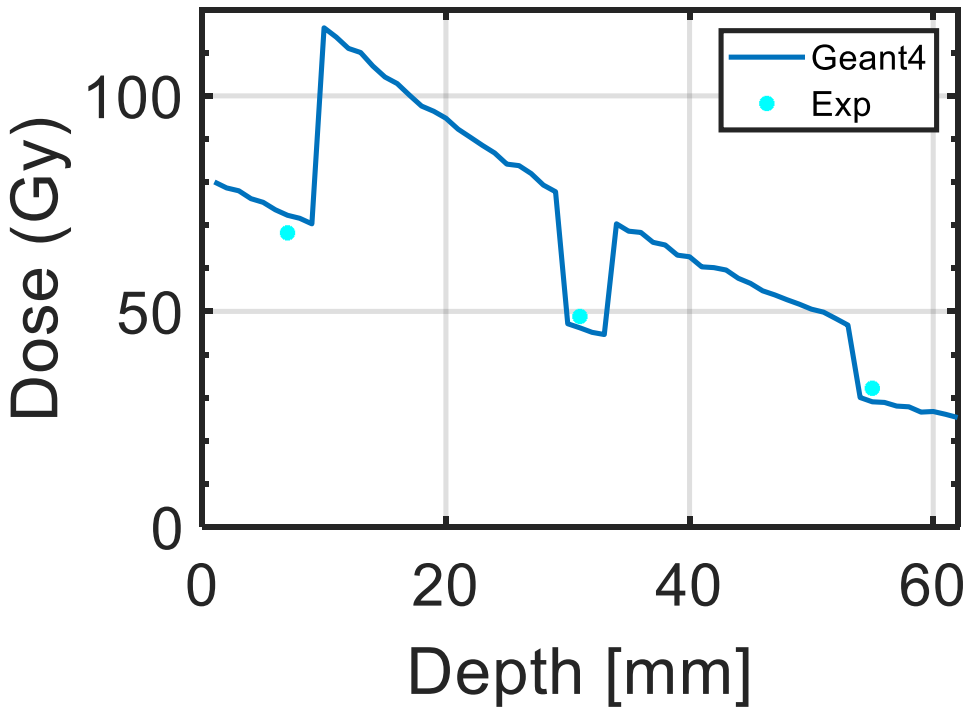


Figure 1. Comparison of experimental and simulated percentage depth dose profiles, results are within 5%.

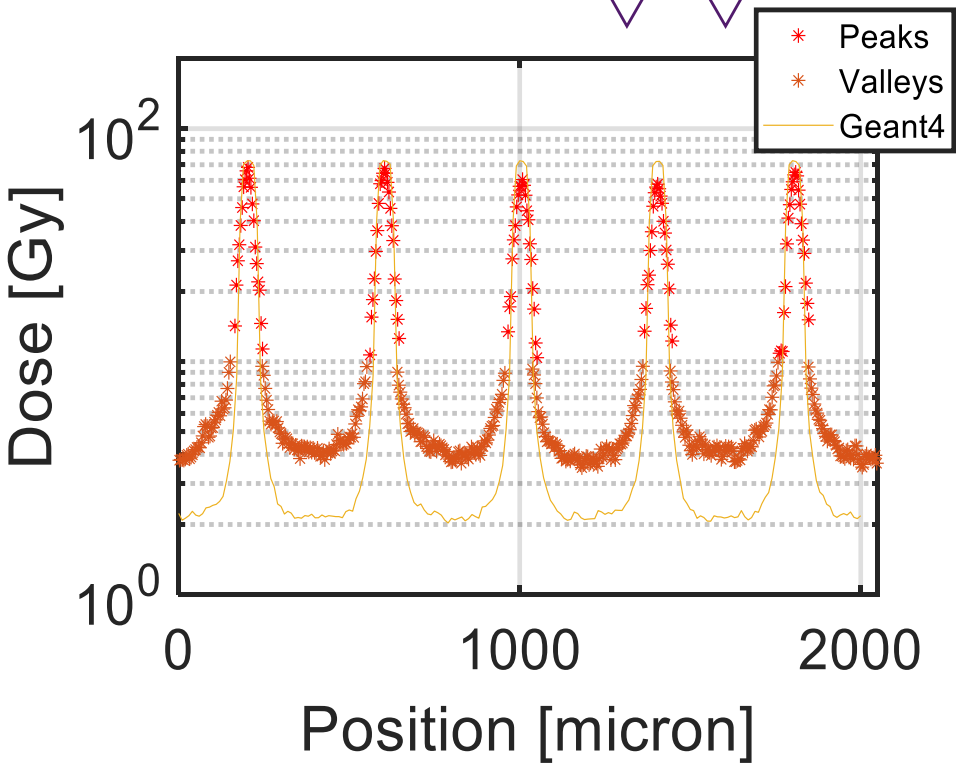


Figure 2. Comparison of experimental and simulated microbeams spatial distribution for Gadolinium (concentration 10 mg/ml). Discrepancy in the valley dose needs more investigation.

Results 2 - PVDRs

Simulated PVDRs are higher: underestimation of the valley dose.

Gd10

PVDR GEANT4	
1st slit	34.3632
2nd slit	23.0602
3rd slit	22.0395
PVDR FILM	
1st slit	30.2016
2nd slit	25.5061
3rd slit	26.5436

Gd20

PVDR GEANT4	
1st slit	34.8568
2nd slit	21.4302
3rd slit	21.0198
PVDR FILM	
1st slit	38.8174
2nd slit	19.9242
3rd slit	29.5482

I10

PVDR GEANT4	
1st slit	33.0758
2nd slit	23.0652
3rd slit	22.0291
PVDR FILM	
1st slit	22.4975
2nd slit	14.4451
3rd slit	21.4693

I20

PVDR GEANT4	
1st slit	32.4171
2nd slit	21.7707
3rd slit	22.4906
PVDR FILM	
1st slit	23.8433
2nd slit	19.1179
3rd slit	22.2972

Conclusions and future steps

- Geant4 looks promising for dose deposition calculations of broad beams at low energies
- When it comes to microbeams, there is an underestimation of the valley dose with respect to experimental data that needs further investigation
- Gel dosimetry, first experiments at compact sources, different dose enhancers, different concentrations

- **Thanks to:**
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Thank you for your attention!!!