Range Uncertainties in Proton Therapy

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RADIATION ONCOLOGY

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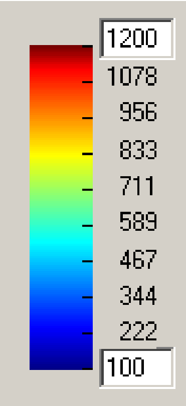
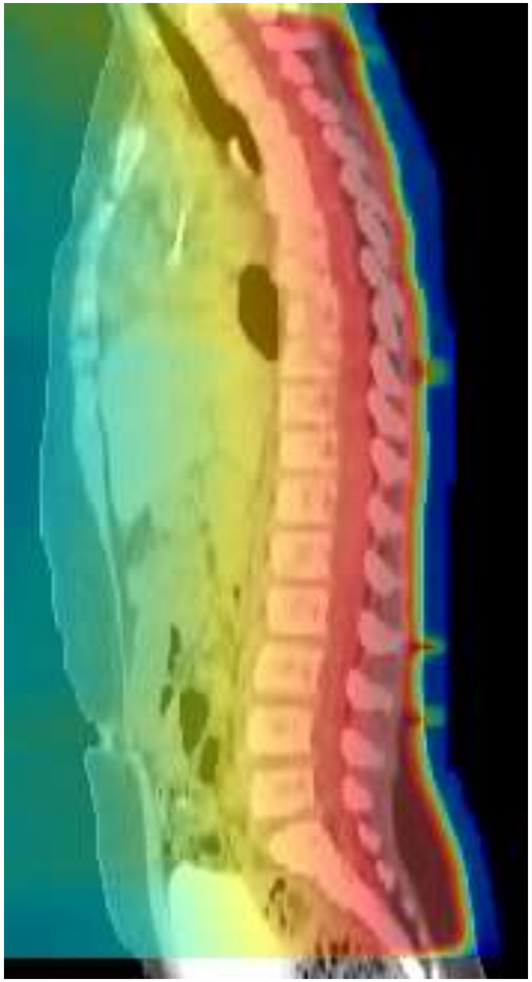
Proton Beam Range

Medulloblastoma

Protons

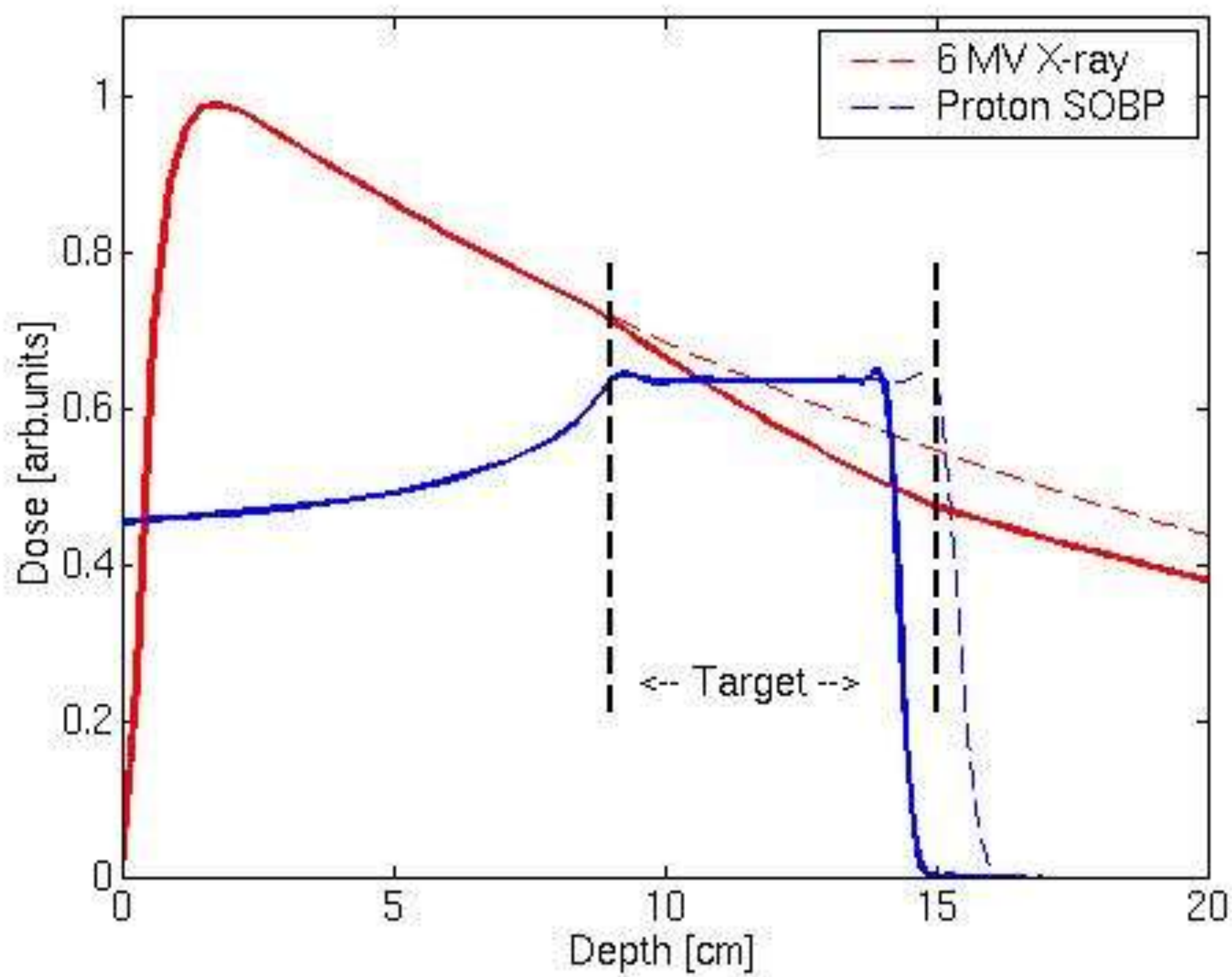


Photons



Proton Beam Range Uncertainty

The difference compared to photon therapy: range uncertainties

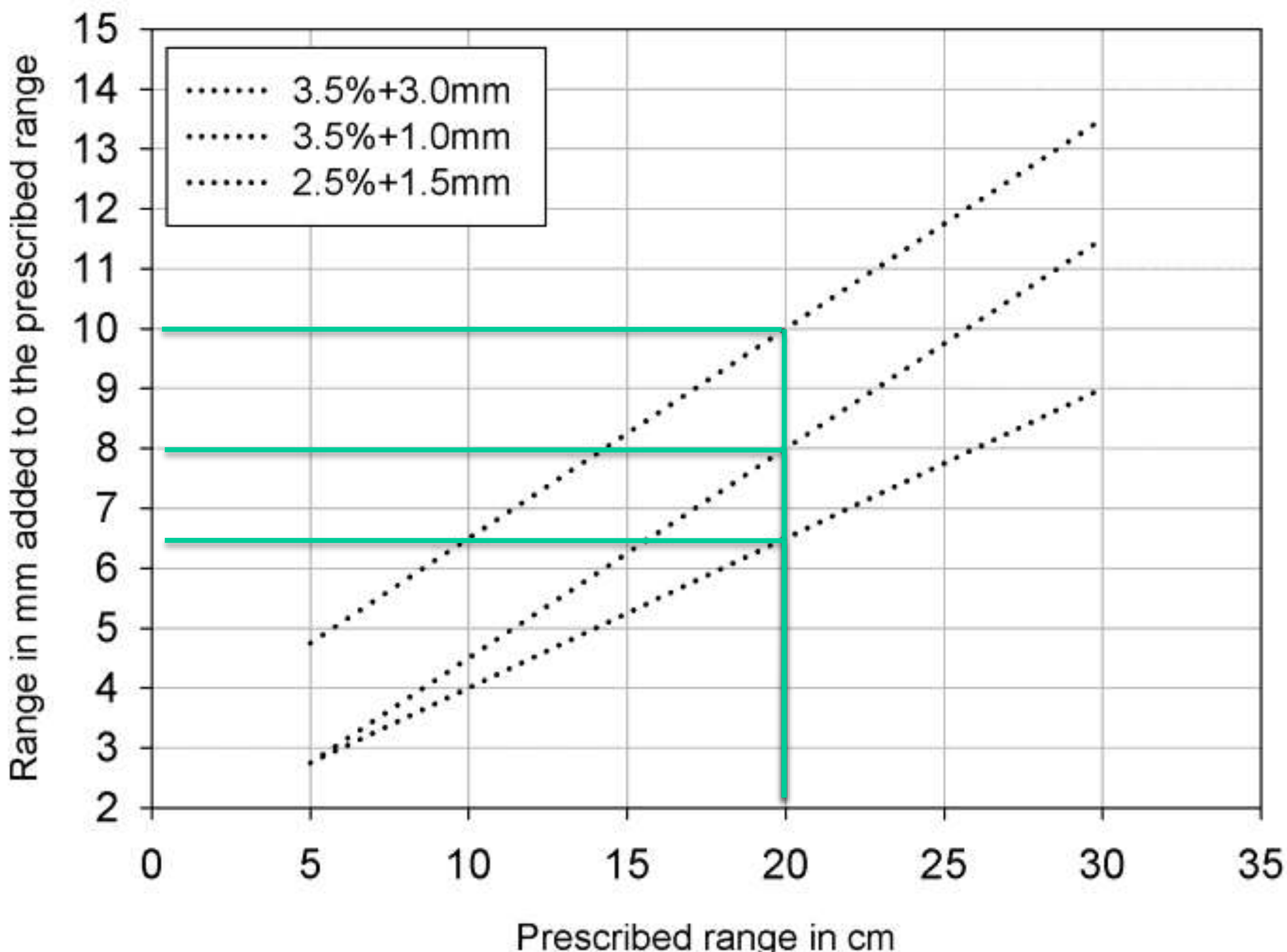


Proton Beam Range Uncertainty

In proton therapy, generic homogeneous PTV margin recipes are typically not sufficient !

Proton Beam Range Uncertainty

Applied range uncertainty margins for non-moving targets



H. Paganetti: Phys. Med. Biol. 57, R99-R117 (2012)

Proton Beam Range Uncertainty

Range uncertainties sometimes limit our ability to exploit the end of range

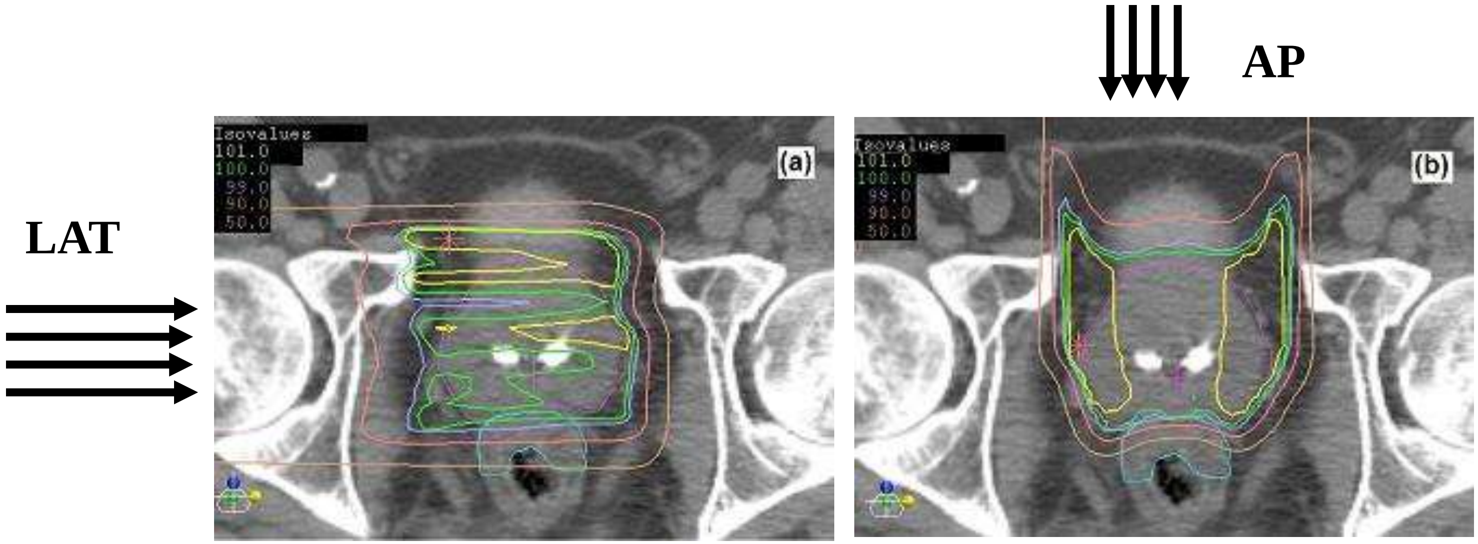
Example: Prostate treatments

Protons and Prostate Treatments

Current technique: Lateral fields
Use lateral penumbra (10 mm, 50-95%) to spare rectum
(penumbra not better than 15 MV photon fields)

Why not AP fields?

Use much sharper distal penumbra (~ 4 mm, 50-95%)

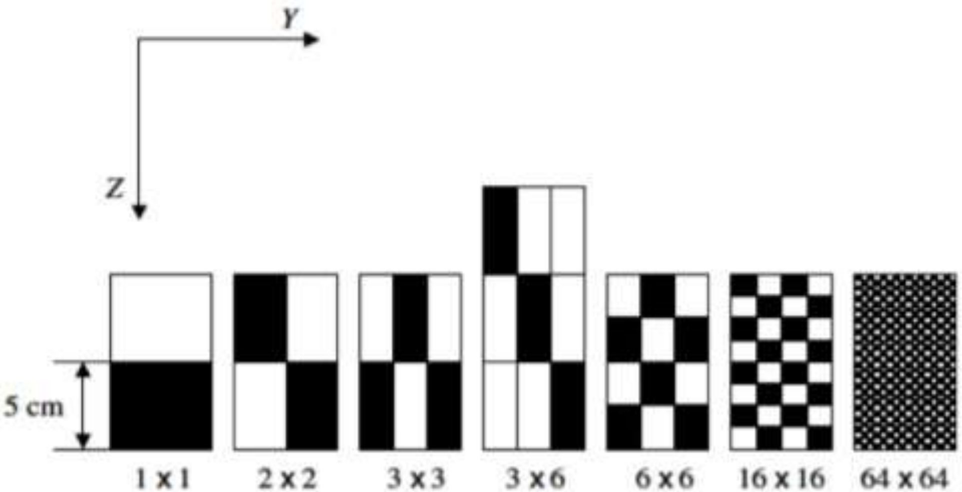


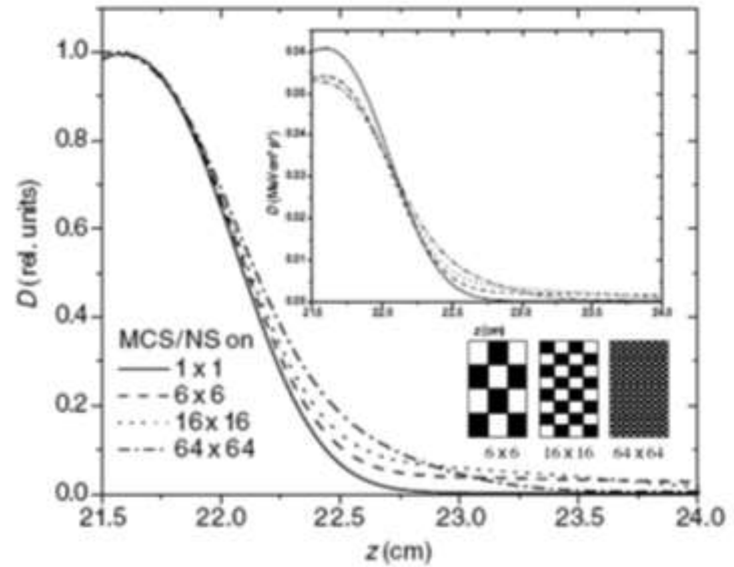
Range uncertainty margins for non-moving targets

Source of range uncertainty in the patient	Range uncertainty
Independent of dose calculation:	
Measurement uncertainty in water for commissioning	± 0.3 mm
Compensator design	± 0.2 mm
Beam reproducibility	± 0.2 mm
Patient setup	± 0.7 mm
Dose calculation:	
Biology (always positive)	+ 0.8 %
CT imaging and calibration	± 0.5 %
CT conversion to tissue (excluding I-values)	± 0.5 %
CT grid size	± 0.3 %
Mean excitation energies (I-values) in tissue	± 1.5 %
Range degradation; complex inhomogeneities	- 0.7 %
Range degradation; local lateral inhomogeneities *	± 2.5 %
Total (excluding *)	**2.7% + 1.2 mm**
Total	**4.6% + 1.2 mm**

H. Paganetti: Phys. Med. Biol. 57, R99-R107 (2012)

Range degradation Type I

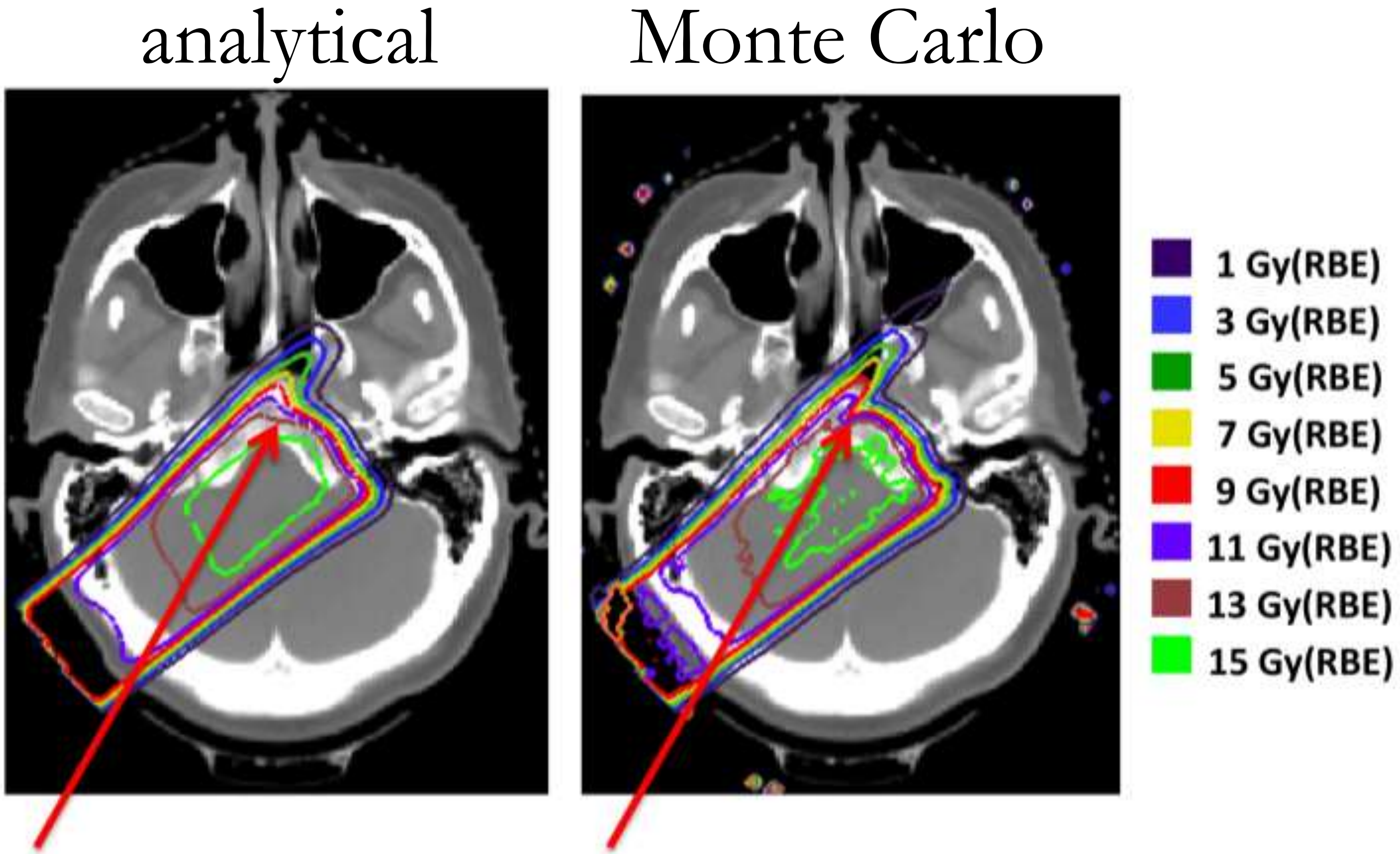




(Sawakuchi *et al.*, 2008)

Proton Beam Range Uncertainty

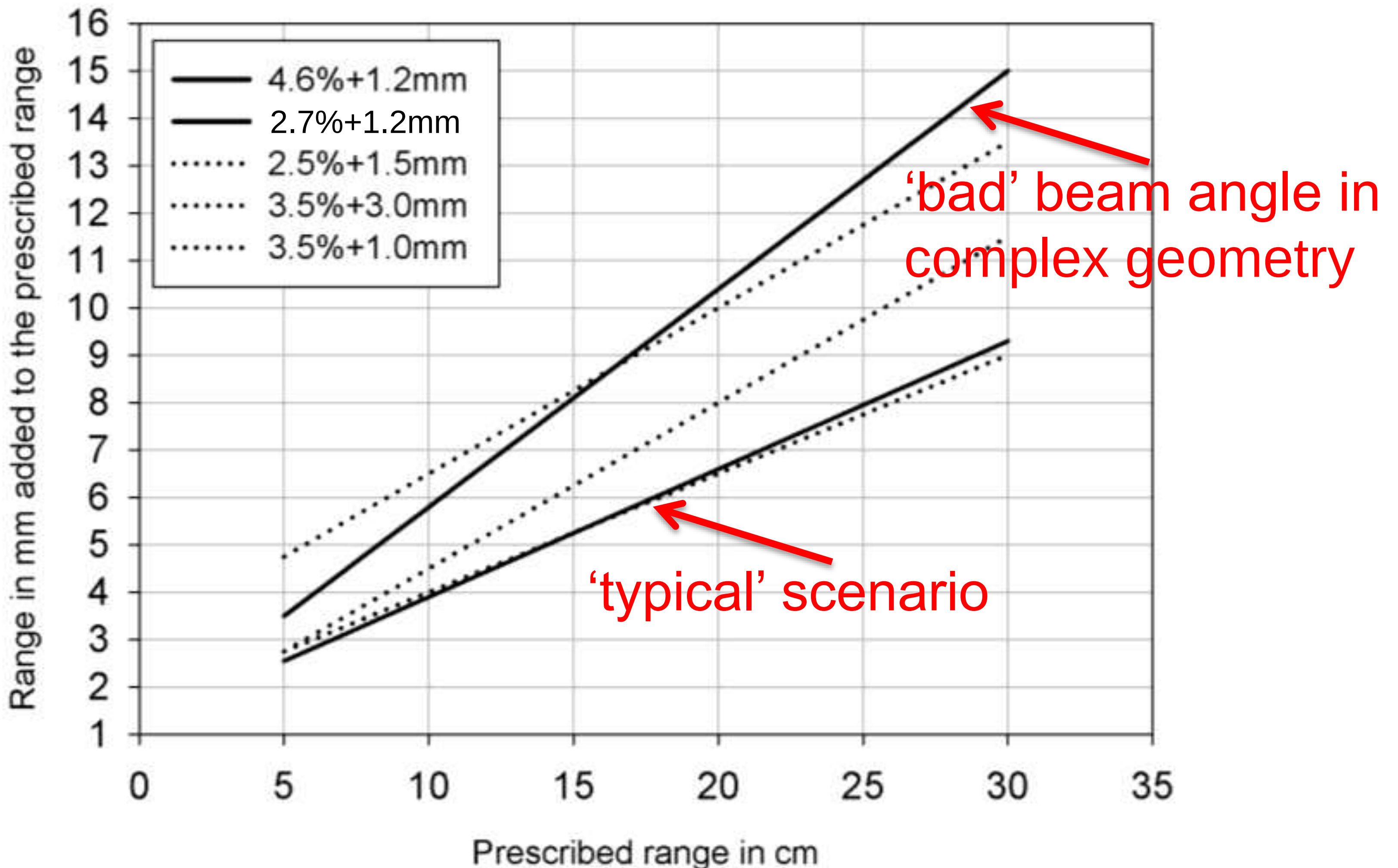
Range degradation Type II



(Paganetti *et al.*, 2008)

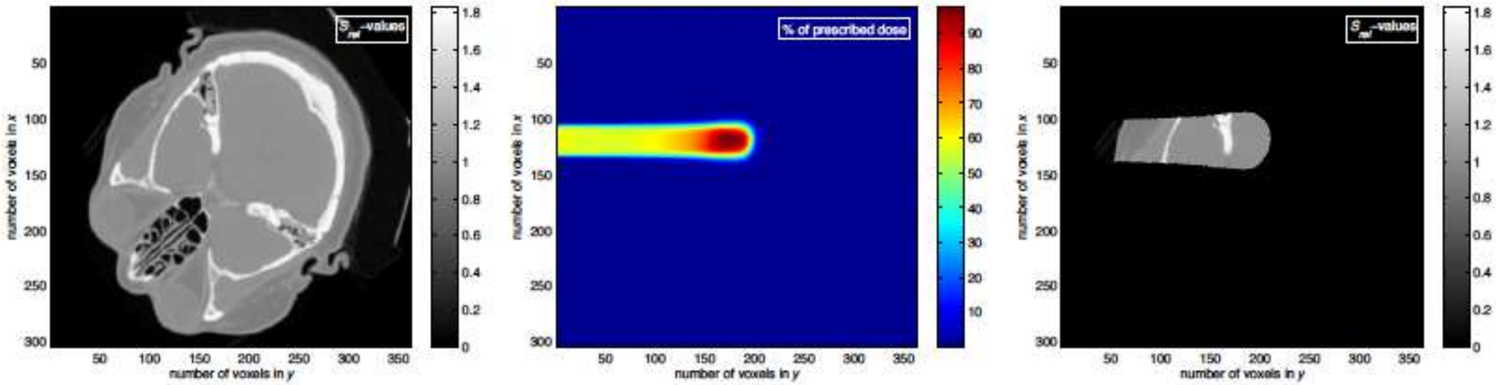
Proton Beam Range Uncertainty

Range uncertainty margins for non-moving targets



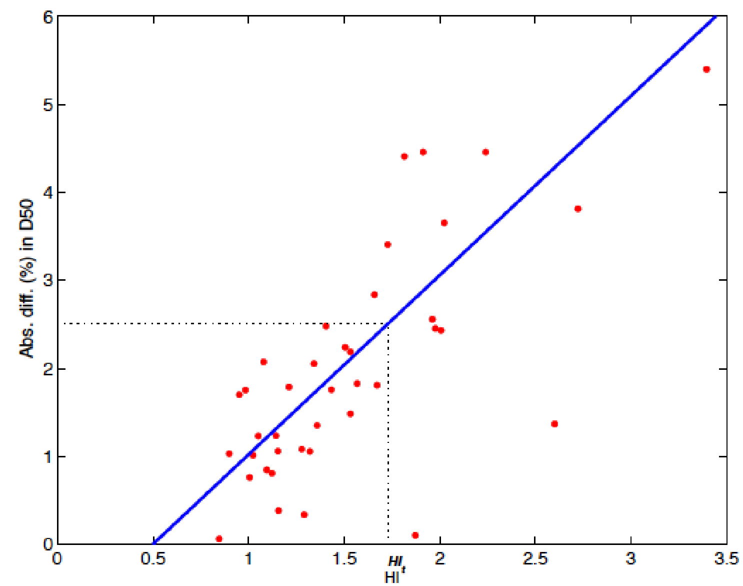
H. Paganetti: Phys. Med. Biol. 57, R99-R117 (2012)

Range and Hetereogeneities



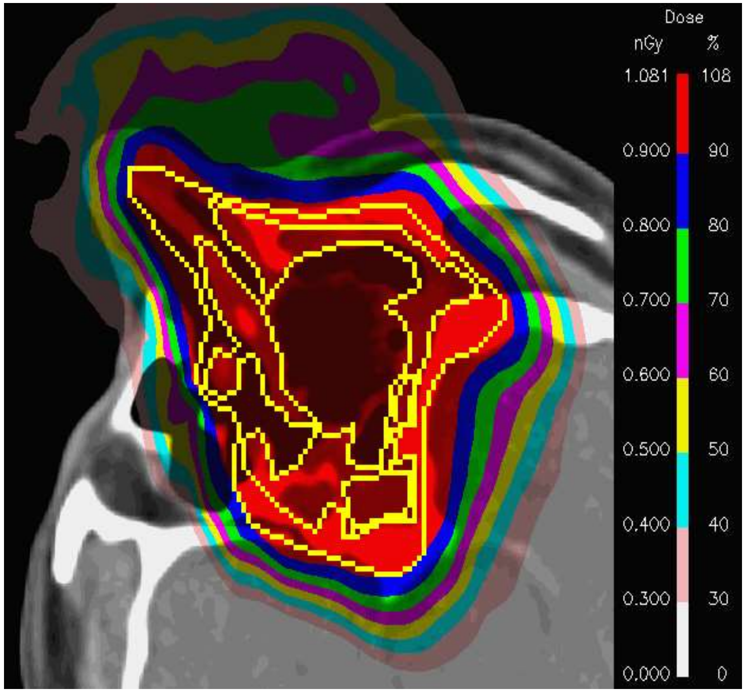
(a)CT isocenter slice (b)Dose cube isocenter slice (c)Sampling voxels

Heterogeneity Index based on patient geometry relative to pencil kernel

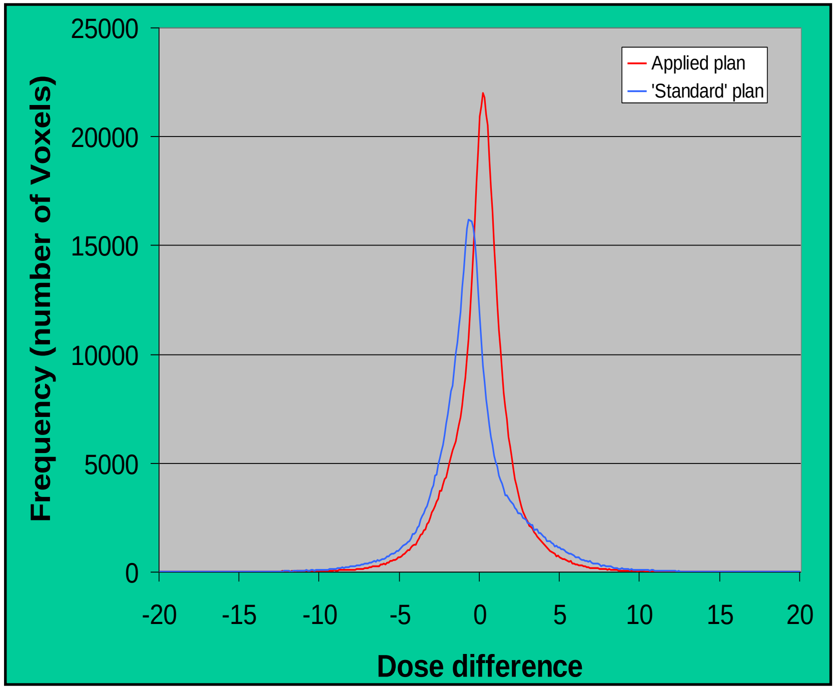


M. Bueno, H. Paganetti, M.A. Duch, J. Schuemann: An algorithm to assess the need for clinical Monte Carlo dose calculation for small proton therapy fields. Med Phys 2013

Avoiding density heterogeneities



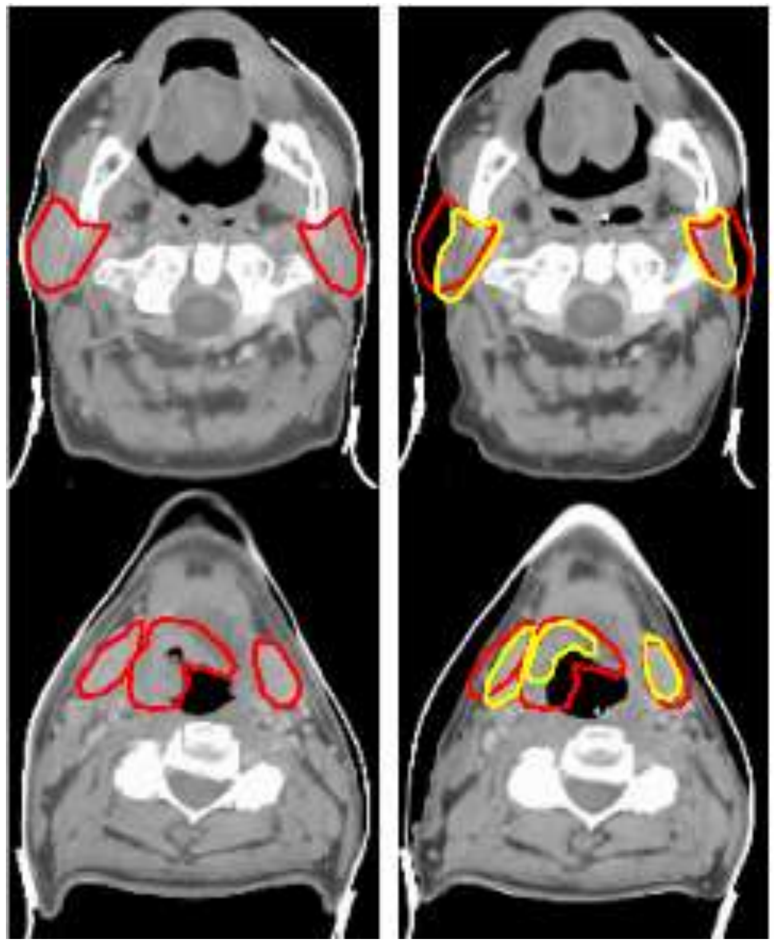
Field	Applied plan			'Standard' plan		
	Gantry angle	Table angle	Density heterogeneity index	Gantry angle	Table angle	Density heterogeneity index
1	-45	-90	20.4	-90	-120	28.2
2	-10	0	12.9	-90	-60	30.2
3	-120	-120	12.7	60	0	26.2



In addition(!): patient geometry changes

Example: Intra-fractional geometry changes

Before RT After RT



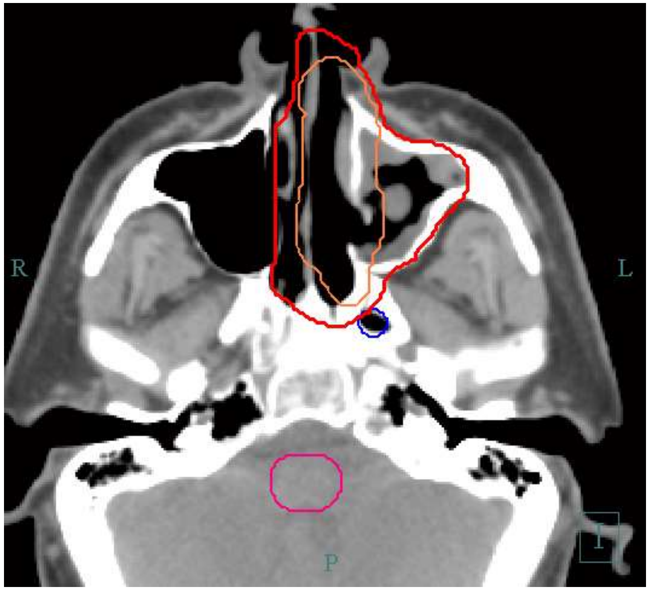
- Parotid glands

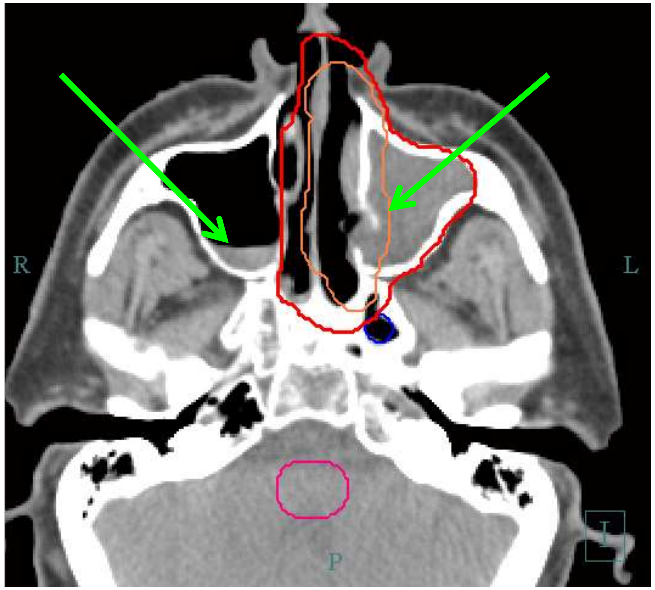
- Subm.glands
- Tumor

E. M. Vasques Osorio *et al.*
IJROBP 70: 875-82

In addition(!): patient geometry changes

- Patient weight gain / loss
- Filling up of sinuses
- (Sub-clinical) pneumonia
- Wet hair / gel / hairspray



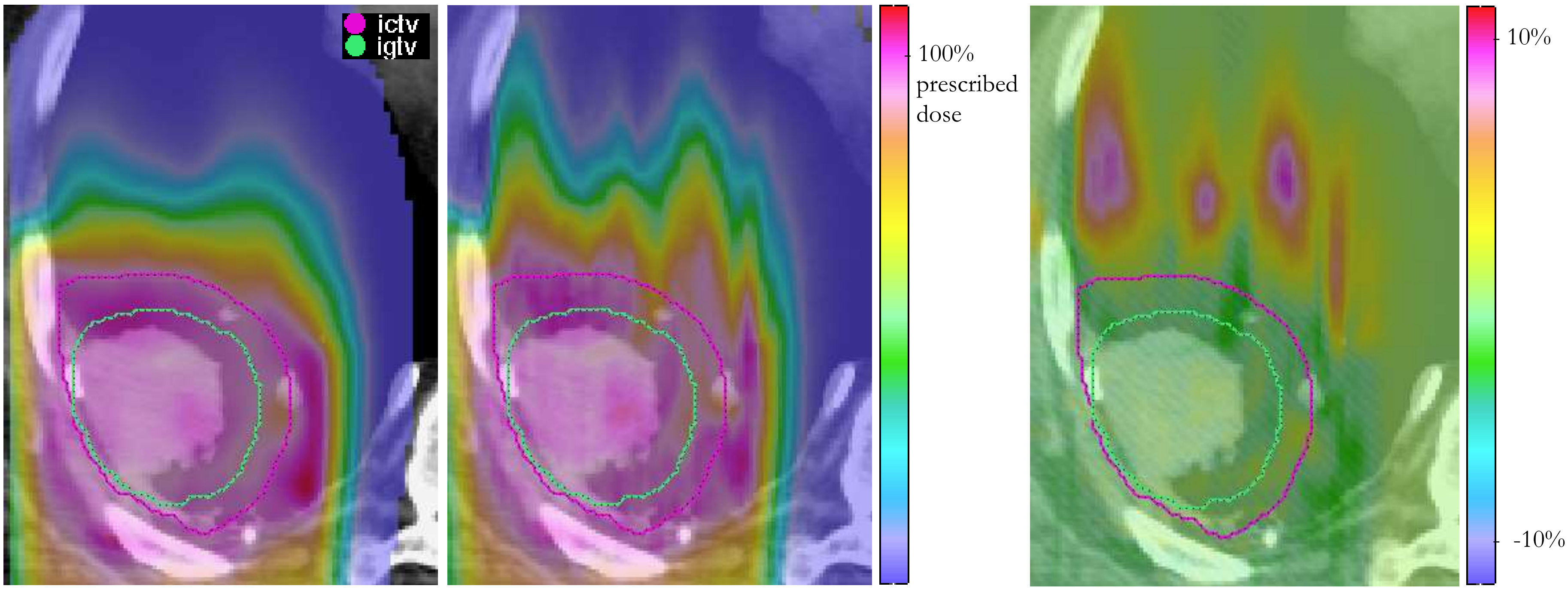


Proton Beam Range Uncertainty

Lung

- Dose fall-off often in lung tissue (density ~0.25-0.3)
  -> range differences magnified by factor 3-4

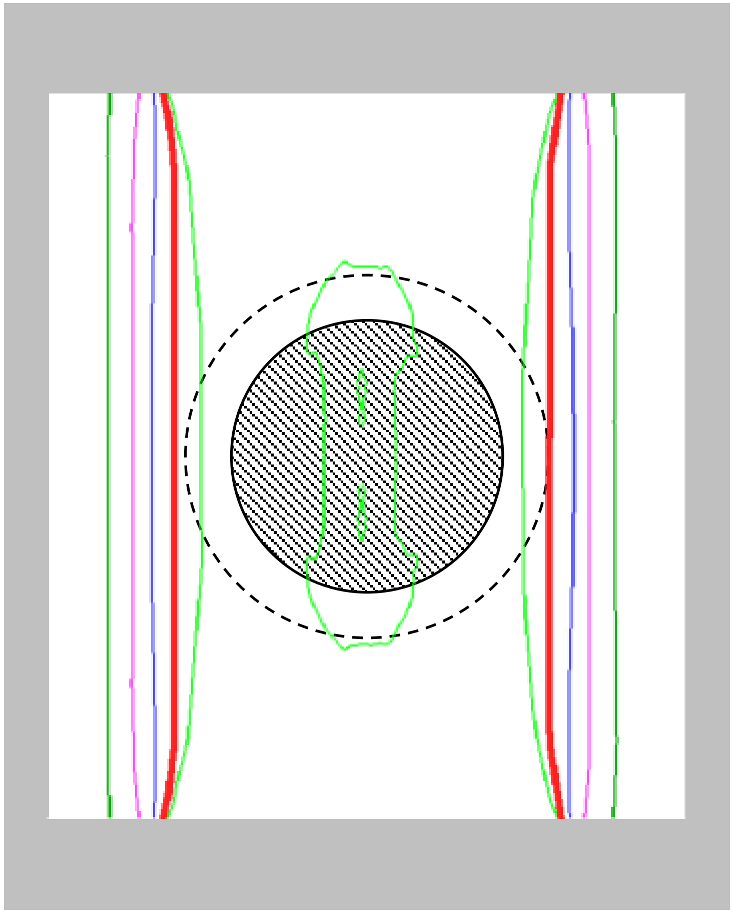
Pencil Beam Monte Carlo Difference



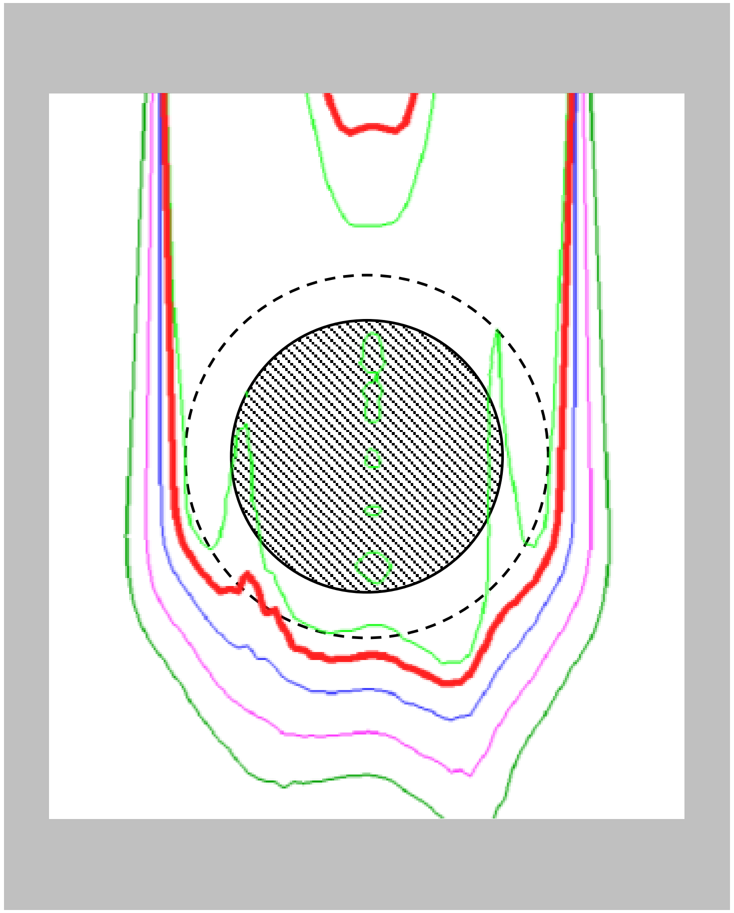
Motion

Isodose levels
20
50
80
95
100

Photons



Protons



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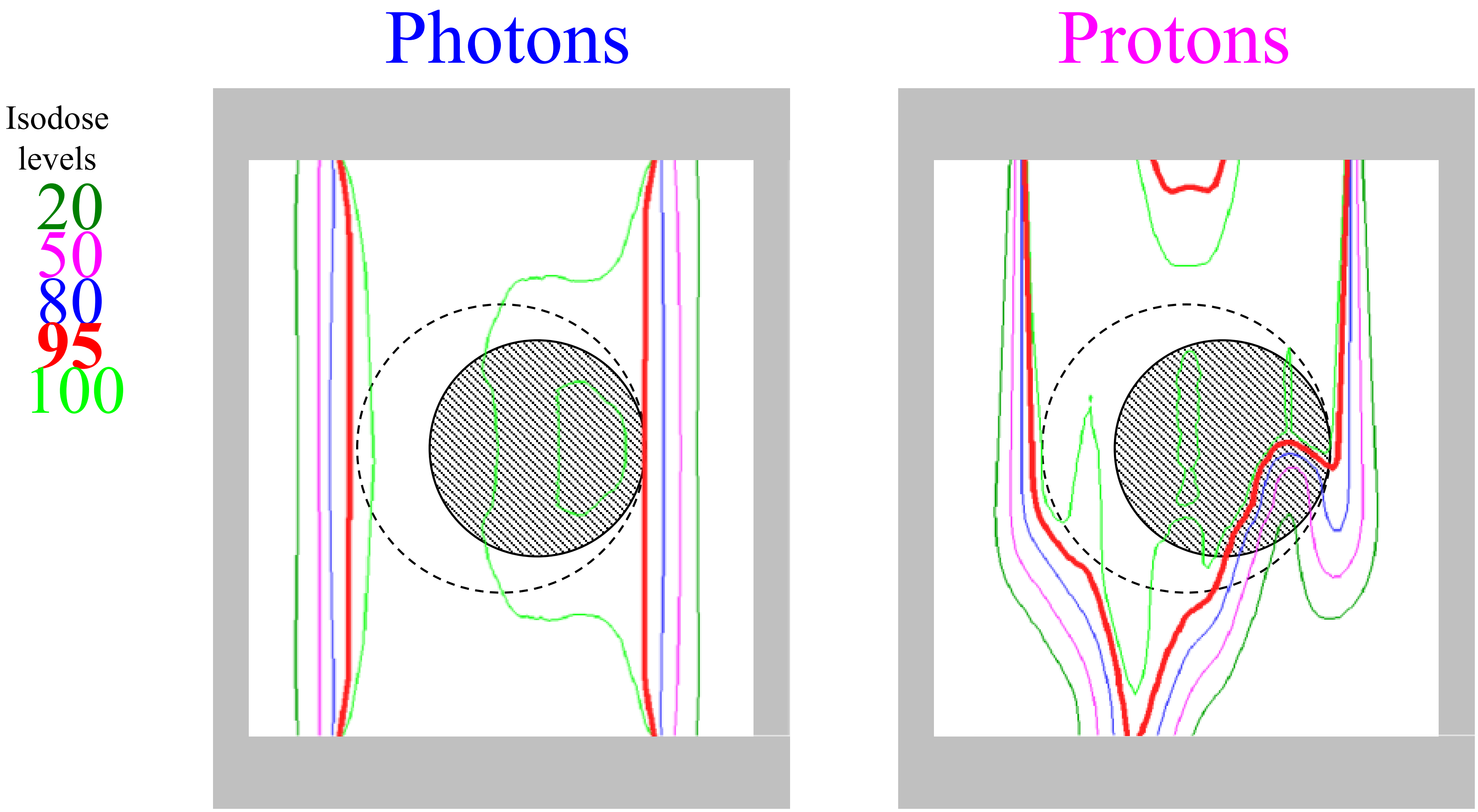
Motion



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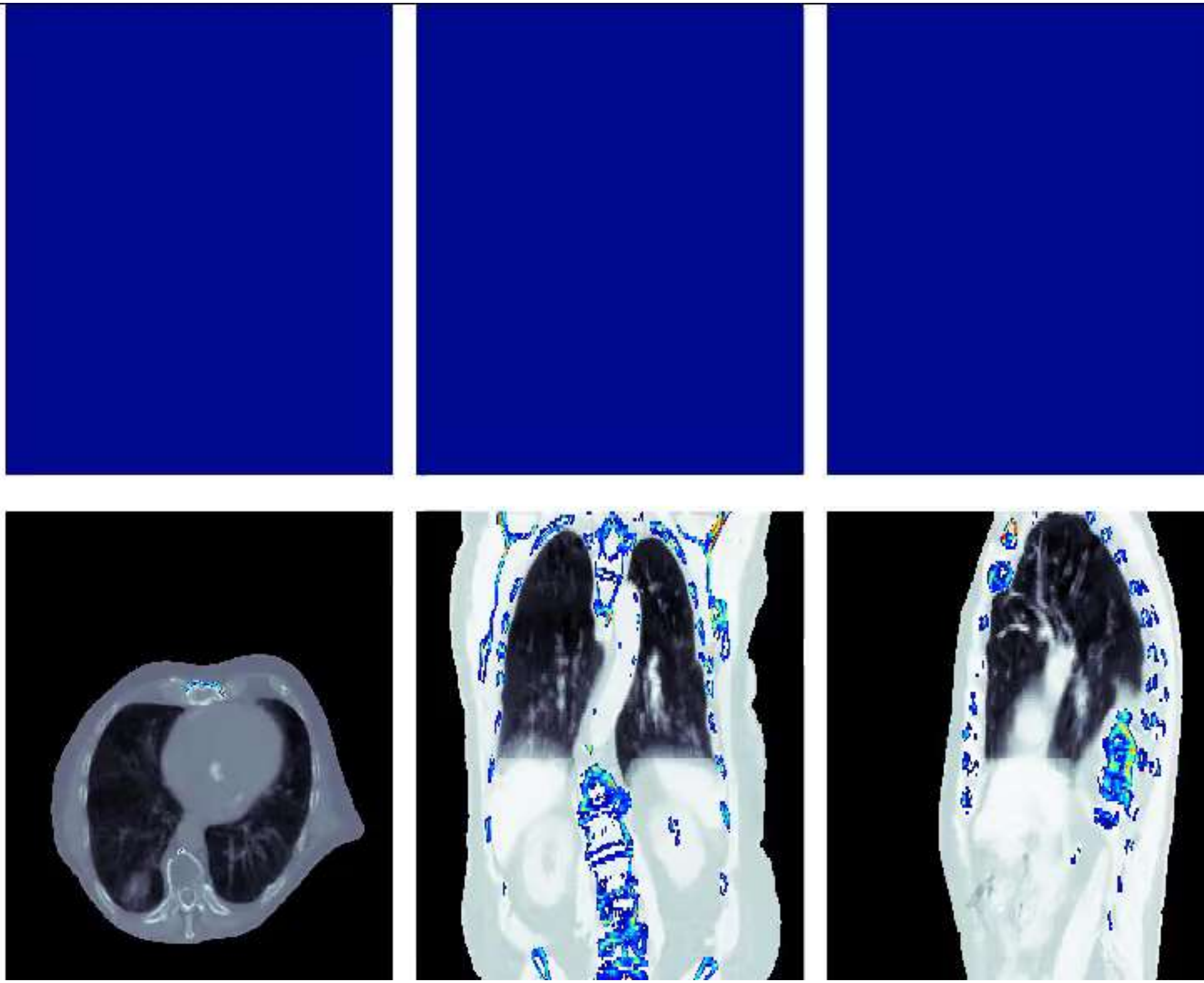
Motion

Transversal	Coronal	Sagittal



dose delivered over time

cumulative dose

Addressing range uncertainties

Source of range uncertainty in the patient	Range uncertainty	Monte Carlo dose calculation
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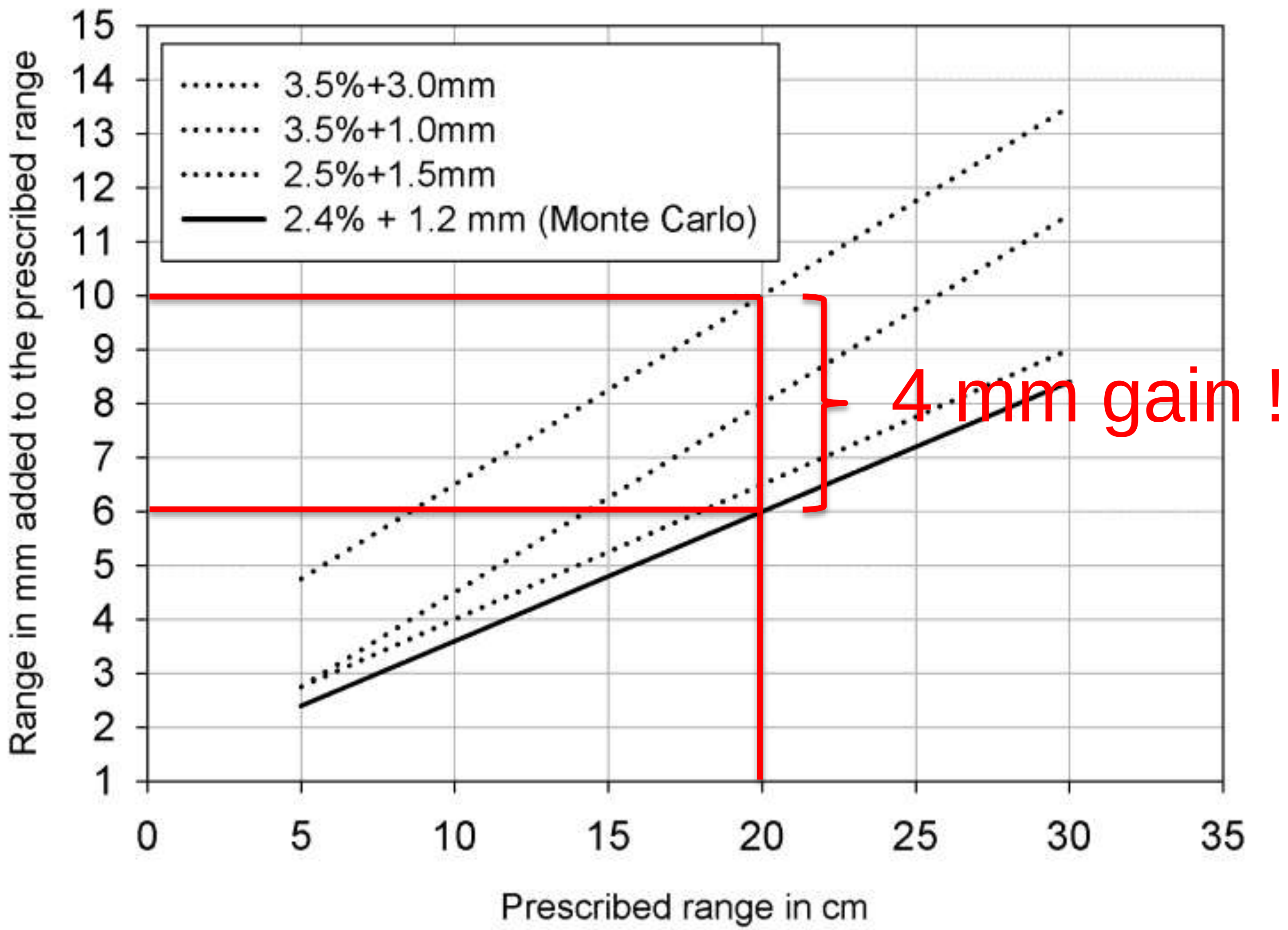
H. Paganetti: Range uncertainties in proton beam therapy and the impact of Monte Carlo simulations
Phys. Med. Biol. 57: R99-R117 (2012)

Addressing range uncertainties



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Addressing range uncertainties

DiscoveryNews. ... would fly a Humvee.

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Discovery News > Space News > Particle Physicists Learn Cancer-Fighting Tricks

PARTICLE PHYSICISTS LEARN CANCER-FIGHTING TRICKS

Analysis by Jennifer Ouellette
Wed Nov 9, 2011 02:56 PM ET
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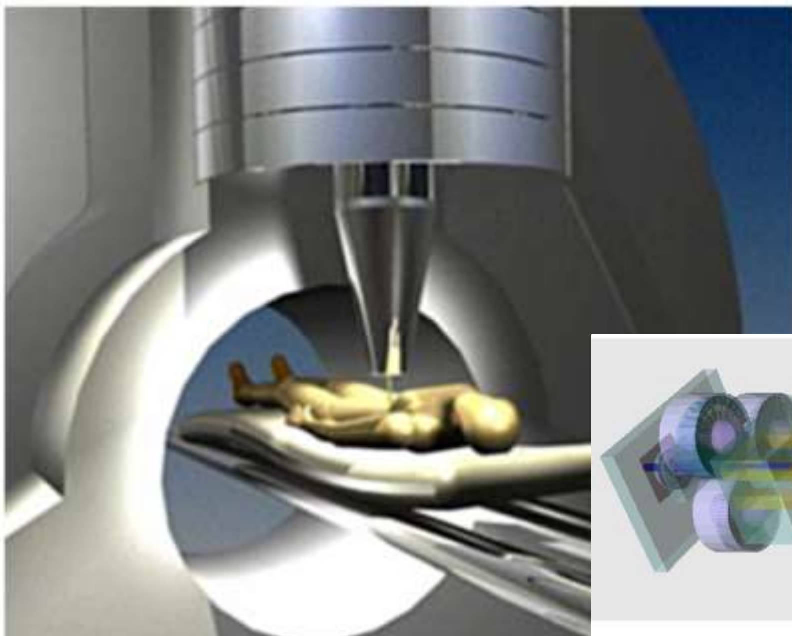
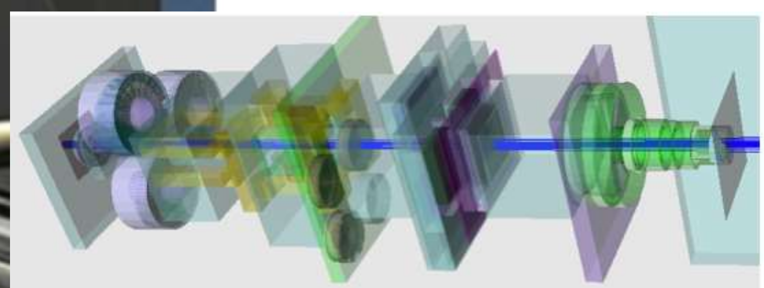




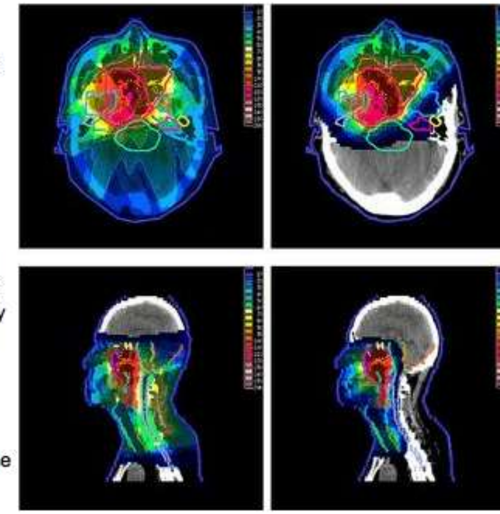
Over the last few decades, particle physicists have developed all kinds of useful simulation tools to help them predict the behavior of subatomic particles interacting with matter, with valuable applications in medical

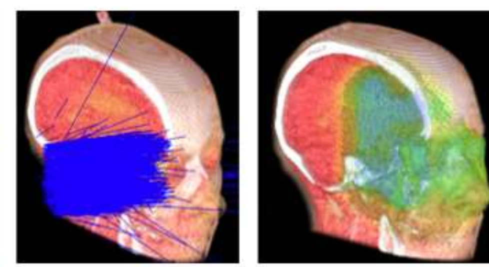
ANALYSIS: Particle Physics Can Help Fight Cancer

Proton therapy works on similar principles. Wilson first suggested in 1946 that the energetic protons produced at the Harvard Cyclotron Laboratory might be an effective cancer treatment. The very first treatments were performed at particle accelerators originally built for physics research: Berkeley Radiation Laboratory in 1954, and Uppsala in Sweden in 1951.

So proton therapy has been around for about 50 years, generally reserved for the most complicated cancers, such as tumors in the head, eyes, or neck that have not yet spread to distant areas of the body -- locations where collateral damage to surrounding tissue could have serious consequences.

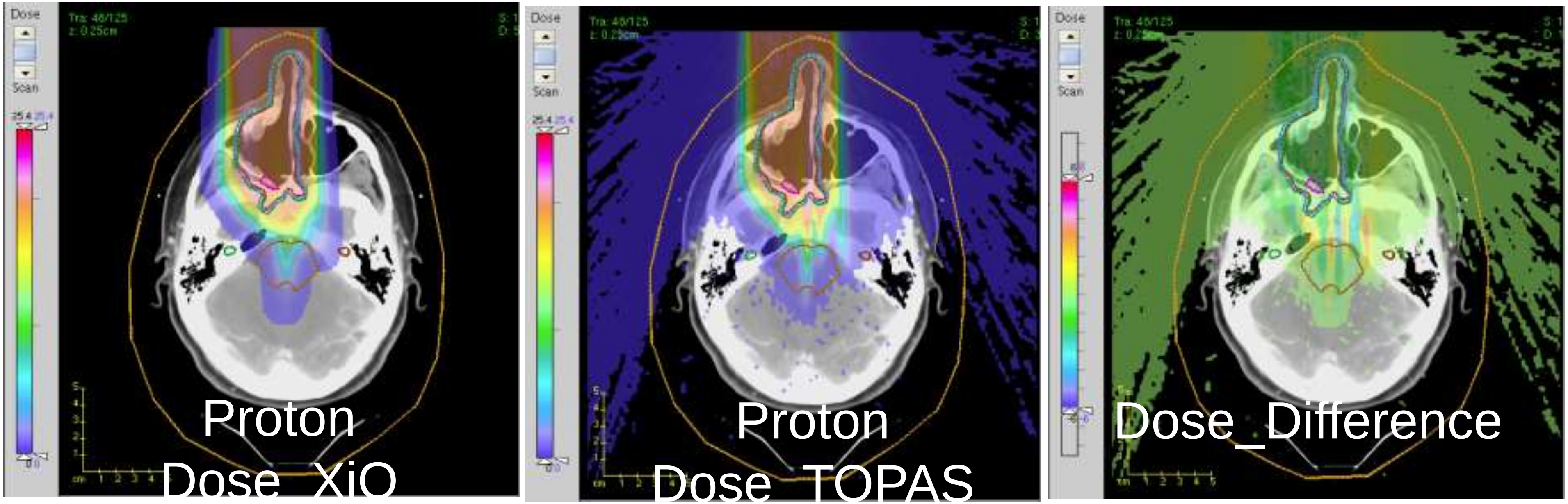
That's because proton therapy offers fewer side effects. In conventional x-ray therapy, the x-rays travel through the body and deliver radiation to all the tissues along the way to the actual tumor. To cut down on the damage to healthy tissue, doctors usually limit the dose delivered to the tumor.

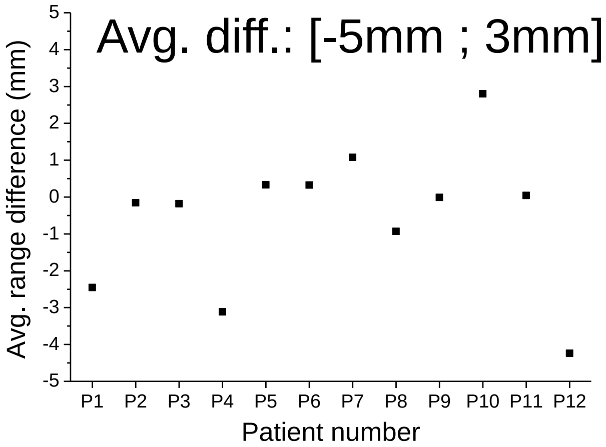


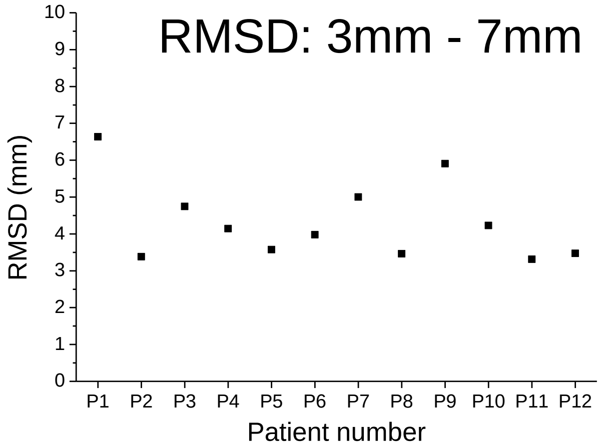


Addressing range uncertainties

Head & Neck Patient







Addressing range uncertainties

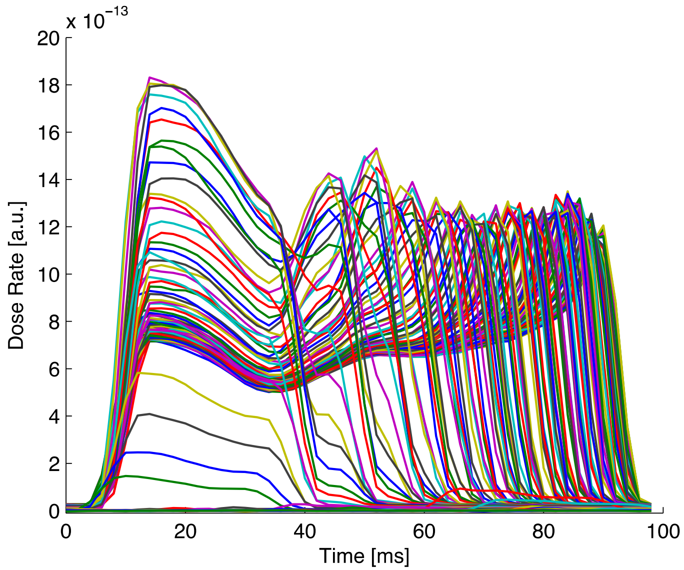
1 Balloon with detector array embedded on the surface

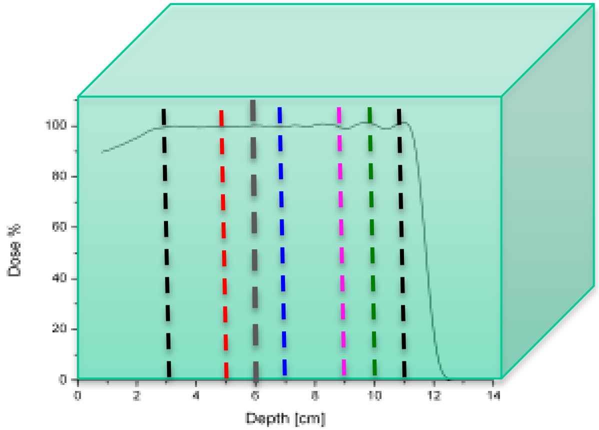
2 Deliver dose (< 1 cGy) for 500 ms using a few cm of extra beam range to cover dosimeters

3 Measure dose rate functions by a multi-channel electrometer

4 Match data (pattern matching) to determine WEPL at dosimeters and adjust beam range

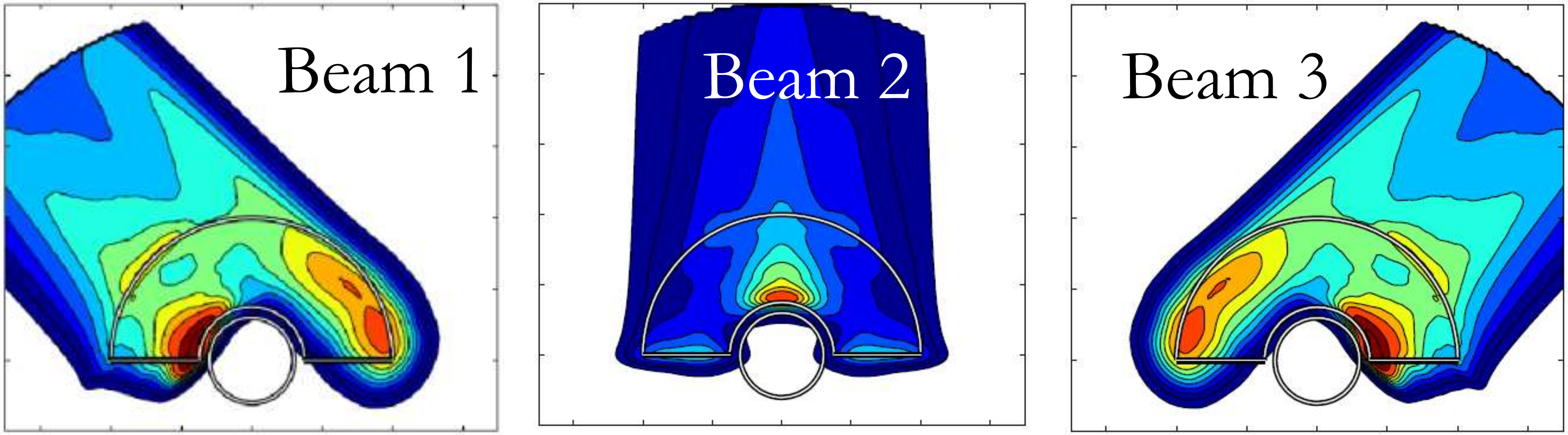
5 Commence treatment



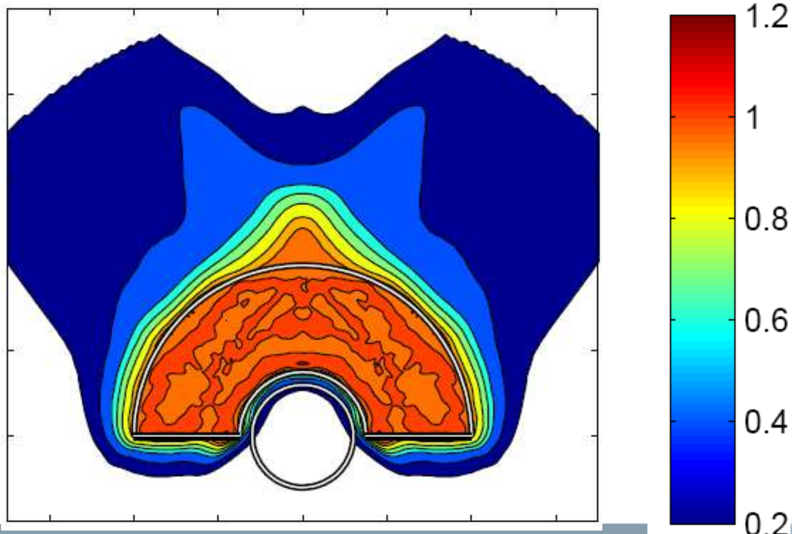


Addressing range uncertainties

Mitigating range uncertainties using robust planning in IMPT



Total dose:



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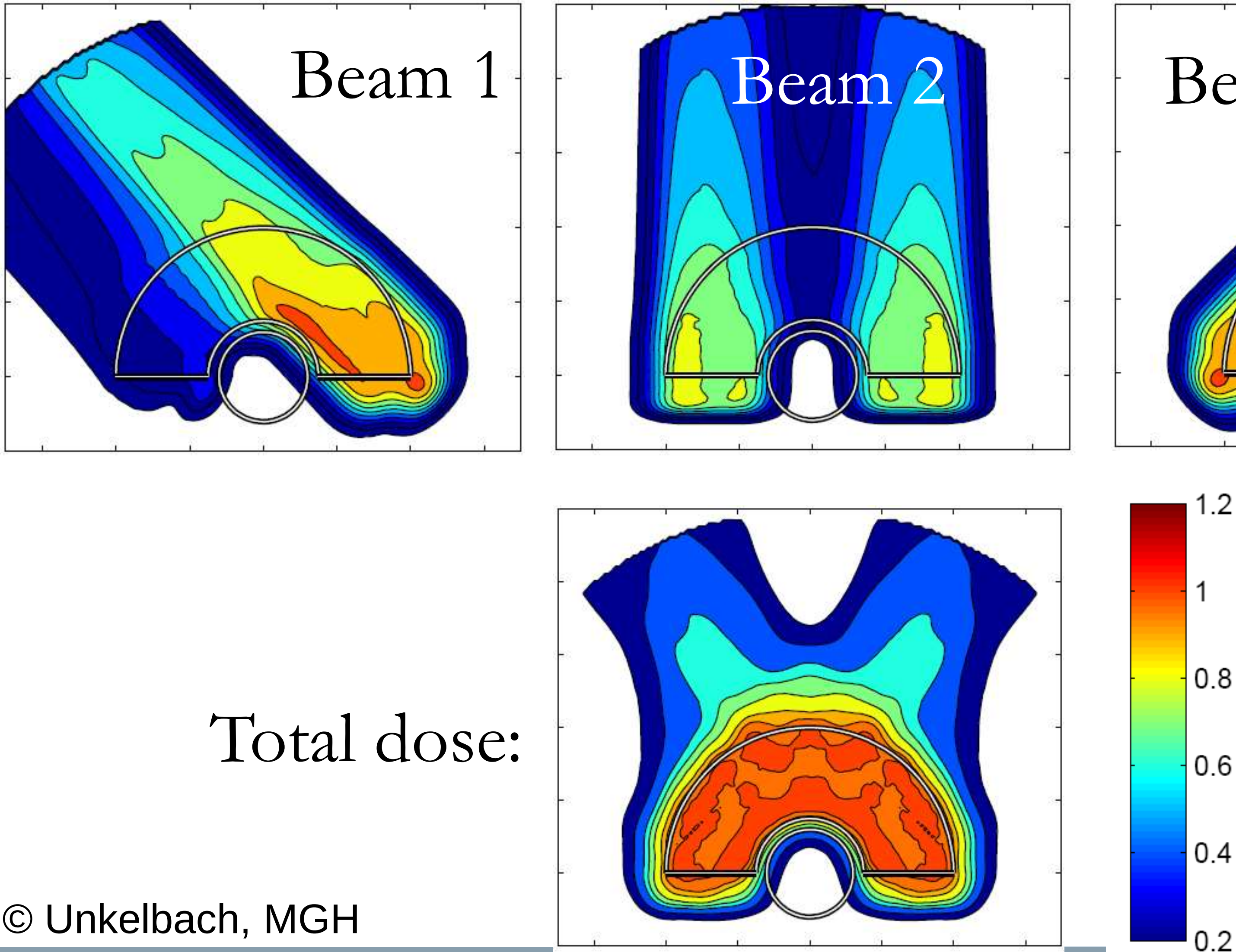
Addressing range uncertainties

Mitigating range uncertainties using robust planning in IMPT



Total dose:

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Conclusion

- Range uncertainties in proton therapy can be substantial (i.e. several mm)
- Advanced dose calculation only solves part of the problem
- Robust planning can mitigate the impact of range uncertainties
- Proton treatment planning needs to be done by experienced planners who understand the impact of range uncertainties
- For some sites (e.g. prostate) range uncertainties prevent us from exploiting the full potential of proton therapy
- In vivo range verification is highly desirable