Online plan adaptation of head and neck IMPT treatments based on cone beam CT imaging and GPU Monte Carlo simulations

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Motivation

Problem:

- Proton therapy is **sensitive to geometry**
- Robust optimization cannot account for all scenarios
- **Smaller margins:** better plans

Problem and potential solution:

- **Adaptive therapy could allow margin reduction** by correcting inter-fractional geometry changes and mispositioning
- **Head and neck patients** are candidates to benefit from the technique

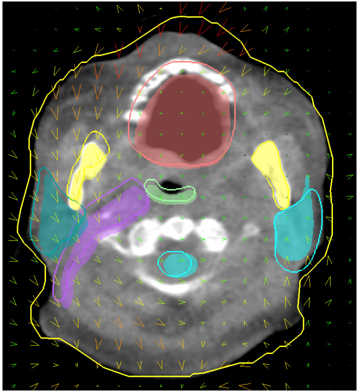

Fig: Head and neck patient geometry changes. Green: original CT. Red: CBCT. The arrows represent a vector field, the arrow color is a representation of their length.

The need for adaptive proton therapy

10 head & neck patients planned **without CTV margins**, evaluated at 60 weeks:

- Reduced margins → sensitive to errors
- Coverage deteriorates:

Fig: V95 in CTV decreases

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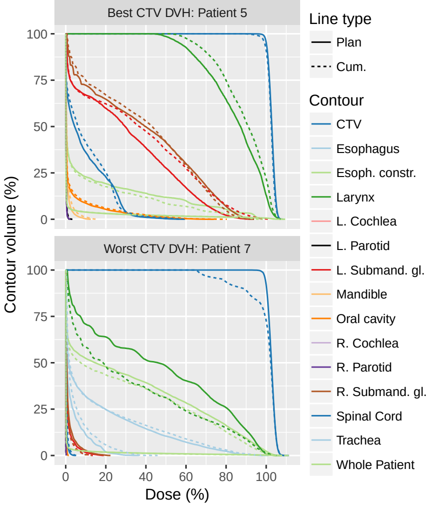


Fig: DVHs after full treatment

Adaptive proton therapy ingredients: the framework

Cone Beam CT (CBCT)

A priori CT-based scatter correction WEPL error $< 2\%$ in head cases.

Park et al., Med Phys. 2015;42(8), Kim et al., Phys Med Bio. 2017;62(1)

Image Registration: Plastimatch

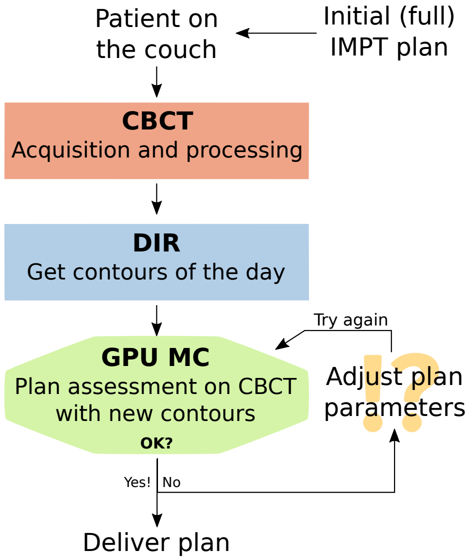
Rigid and deformable (DIR), GPU B-spline

Shackleford et al., Phys Med Biol. 2010;55(21)

Fast GPU MC: gPMC

Accurate calculation engine developed with UT Southwestern.

Qin et al., Phys Med Biol. 2016;61(20)



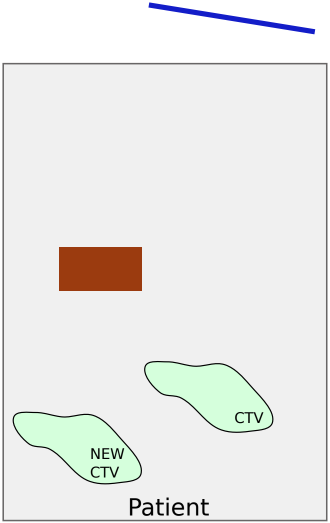
Adaptation method

Consists of 2 steps:

1. Geometrical adaptation: Move individual spots following a deformation vector field and correct energies
2. Weight tuning: Adjust the weight of the spots if necessary

Geometrical adaptation

Per spot $s_i = (x_0, y_0, E_0)$:



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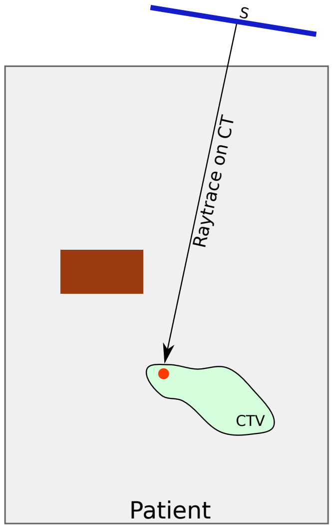
Per spot $s_i = (x_0, y_0, E_0)$:

1: **Raytrace** s_i in CT (r_i)



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Per spot $s_i = (x_0, y_0, E_0)$:

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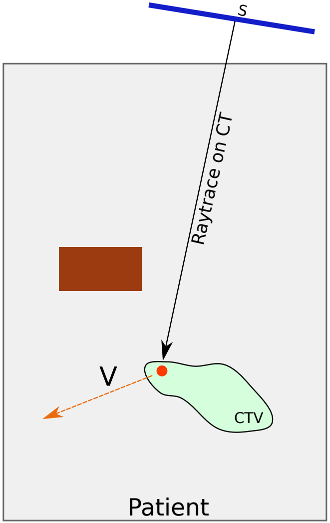
2: **Probe** VF at r_i coords: v_i



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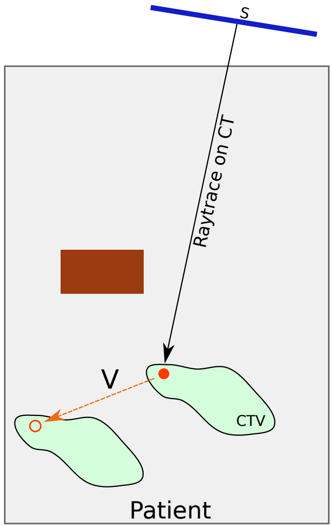

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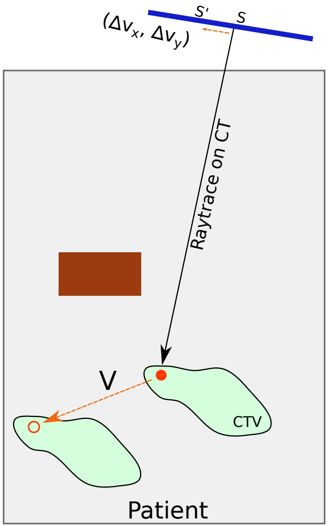
4: **Apply** v_i **to** s $\rightarrow$ $s'_i = (x_0 + \Delta v_x, y_0 + \Delta v_y, E_0)_i$



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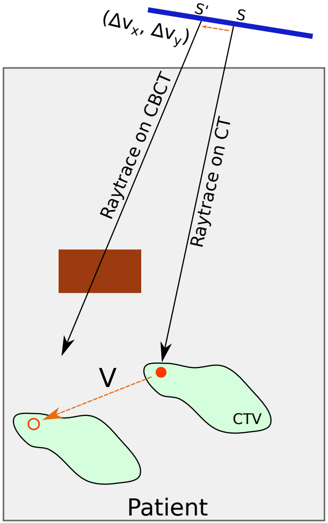
5: **Raytrace** s_i' in CBCT



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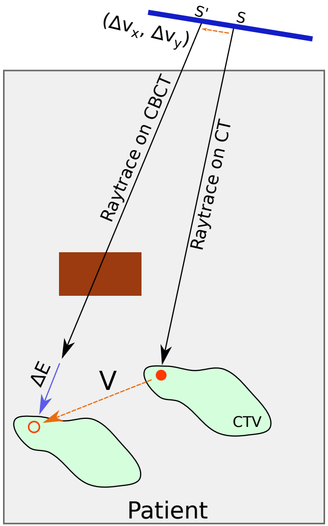

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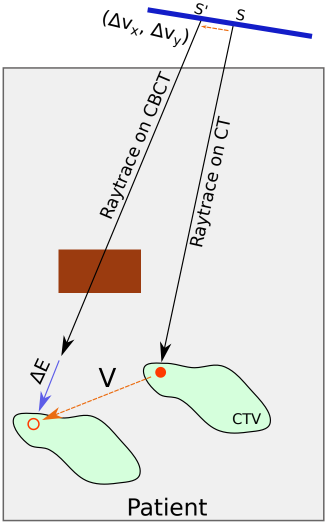
Spot adaptation: $(\Delta v_x, \Delta v_y, \Delta E)_i$



Geometrical adaptation

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Four strategies constraining the geometrical adaptation:

- Free: No constrains shifts
- Isocenter shift: Average VF in CTV
- Range shifter: Average energy shift
- Iso. + range: Average VF and energy shifts

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6. **Tune set weights** to fill the remaining dose and spare OARs with original objectives/constraints

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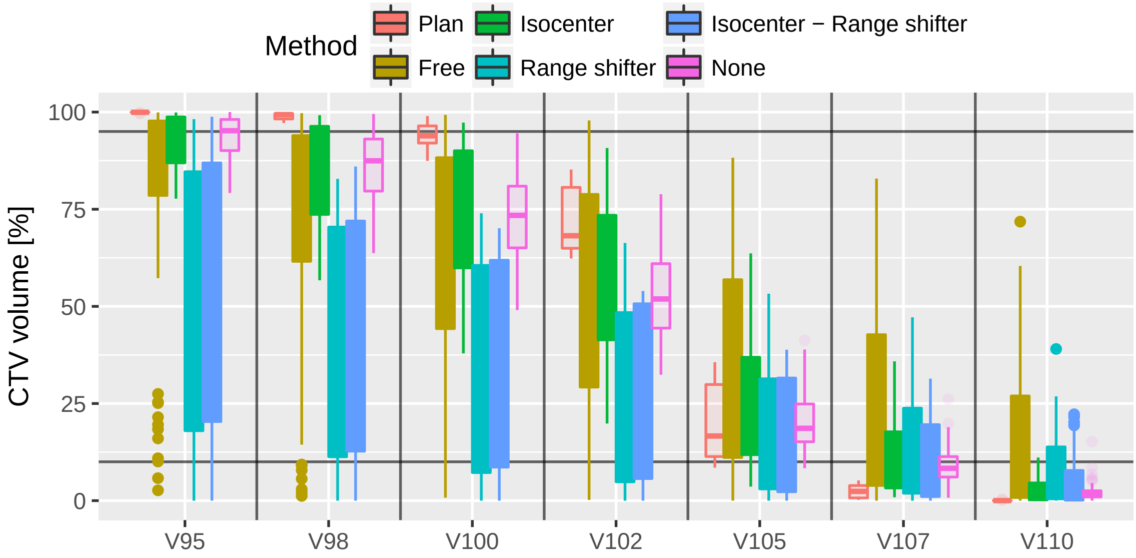

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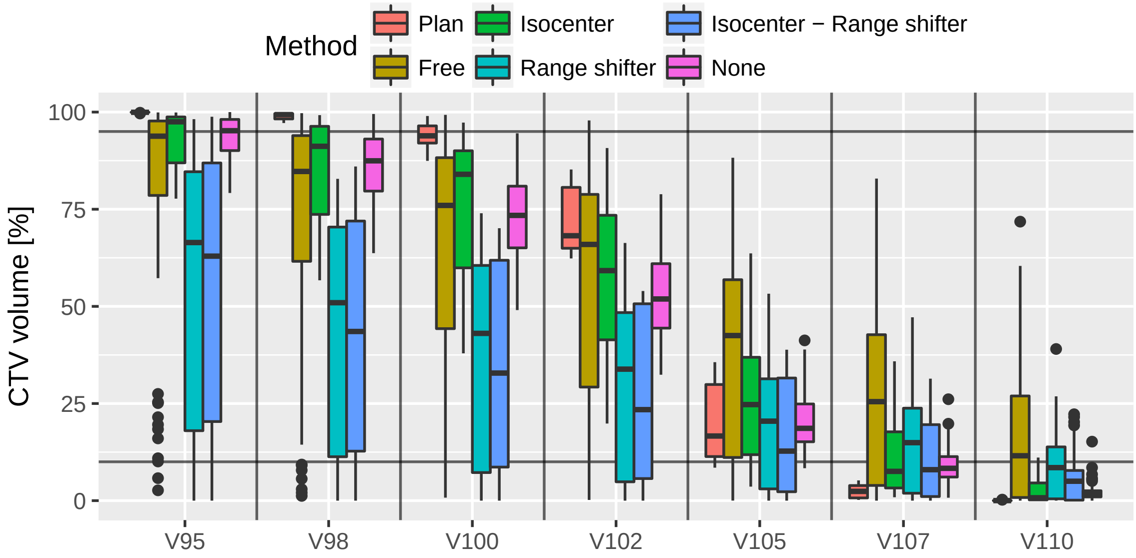
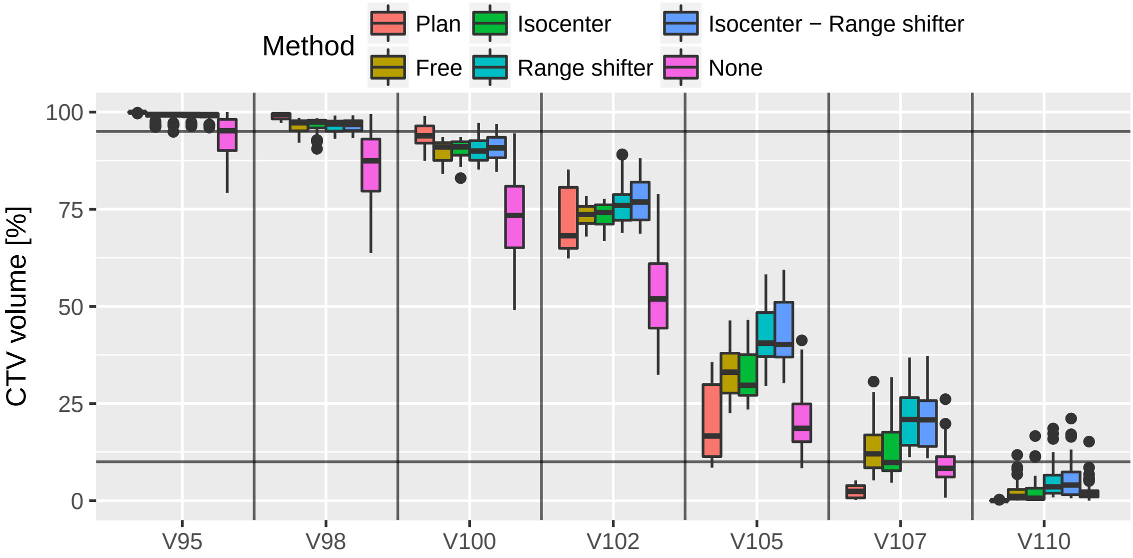
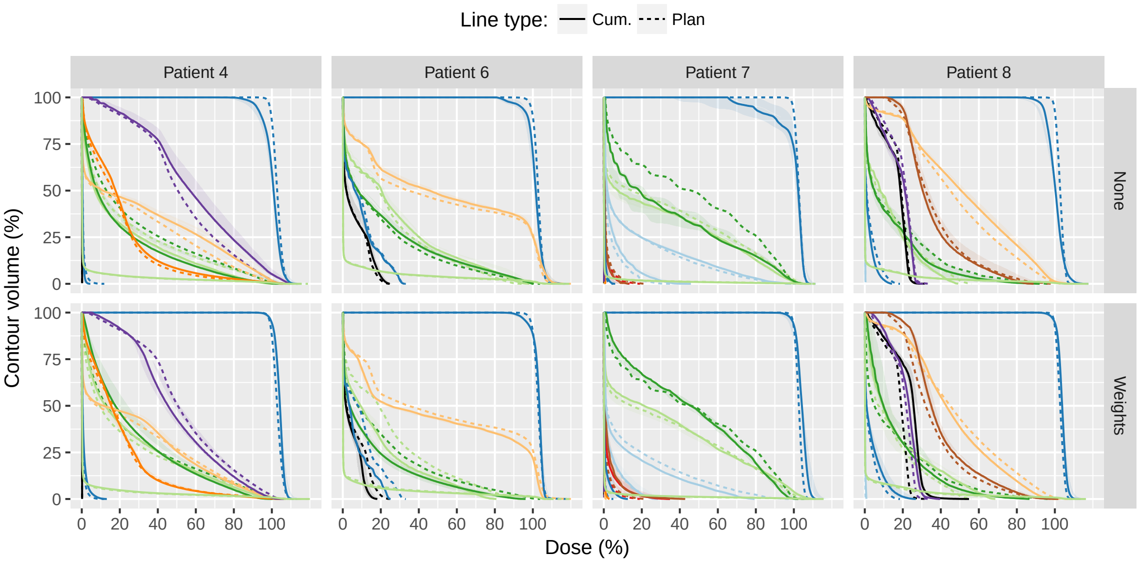


Results: all geometrical adaptations + weight tuning



Results with free geometrical adaptation + weight tuning



Timing and conclusions

Timing, timing, timing!!

(seconds)	Minimum	Average	Maximum	Expected
Geometrical adapt.	11.7	**16.9**	26.57	$\sim 1-5$
gPMC validation	115.6	**261.9**	419.2	~ 30
Weight tuning	12.0	**44.8**	198.0	$\sim 5-120$
Total	-	**322.7**	-	$\sim \mathbf{60-120}$

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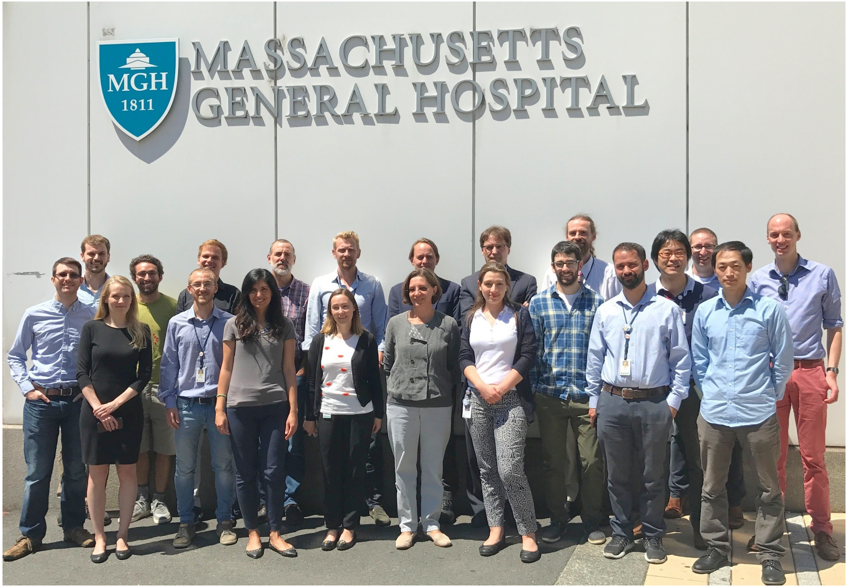
Conclusions:

- If adaptation is needed, weight tuning is necessary
- Tuning the **weight of a subset of spots** might be enough
- The algorithm has the potential to **be applicable online, pending hardware and parallelization**
- The algorithm might **allow further margin reduction**



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