

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

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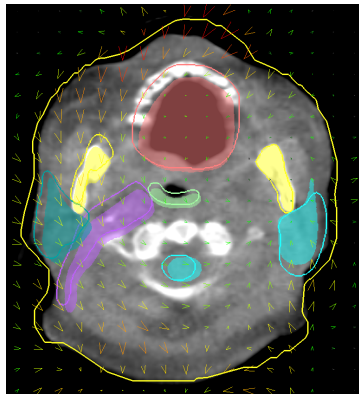
# Motivation

## Problem:

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

## Potential solution:

- **Adaptive therapy would correct inter-fractional geometry changes**, allowing margin reduction
- **Head and neck cases** are candidates to benefit from the technique



**Fig:** Head and neck patient geometry changes. The arrows represent a vector field.

# The need for adaptive proton therapy

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

- Reduced margins  $\rightarrow$  sensitive to errors
- Coverage deteriorates:

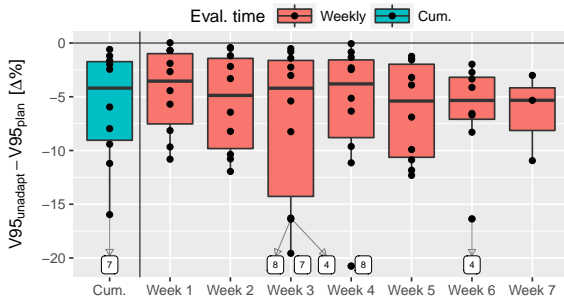


Fig: V95 in CTV decreases

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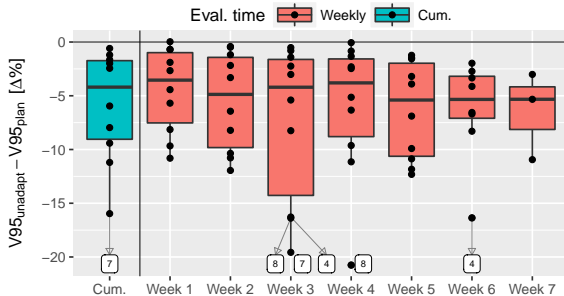


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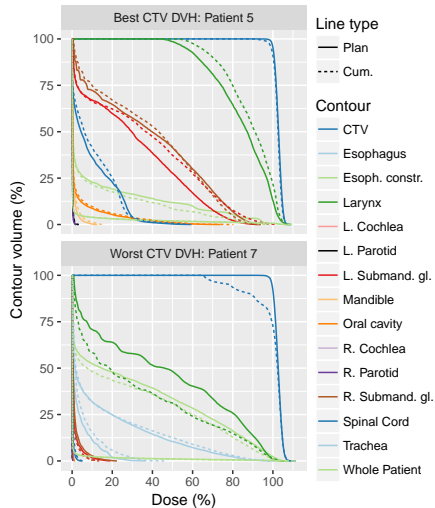


Fig: DVHs after full treatment

# 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

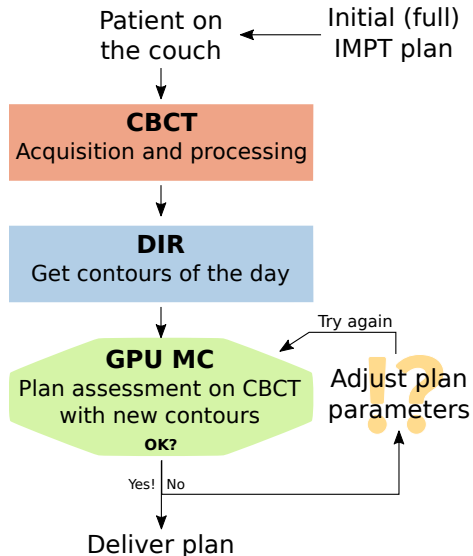
Rigid and deformable (DIR), GPU B-spline

*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)*



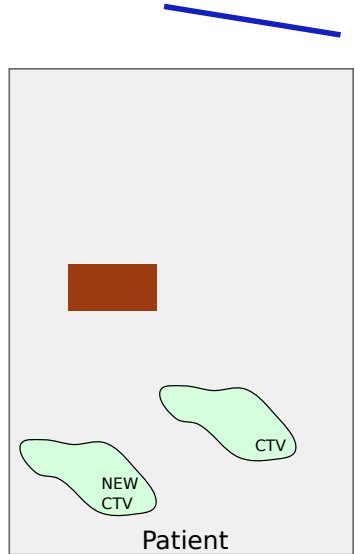
# Adaptation method

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

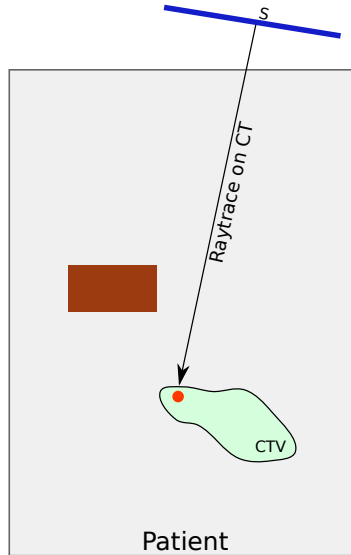
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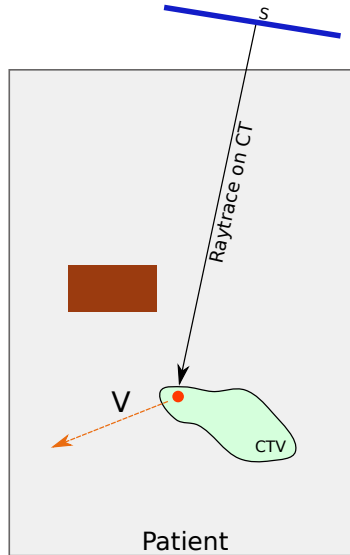




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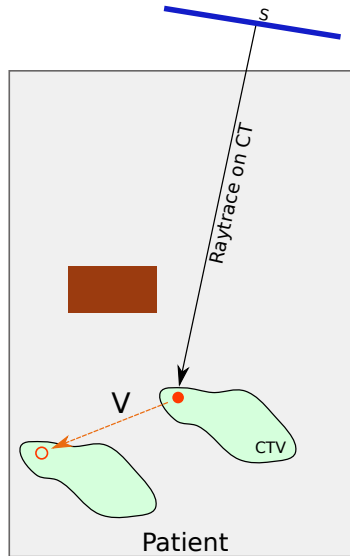
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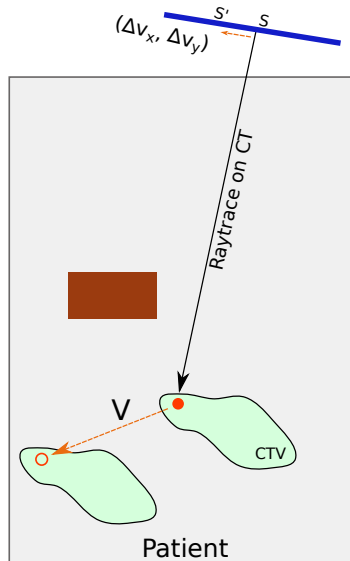
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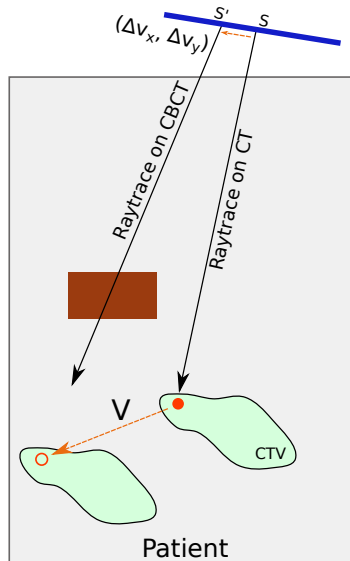
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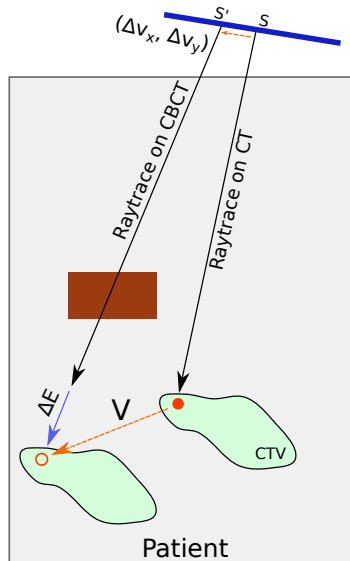
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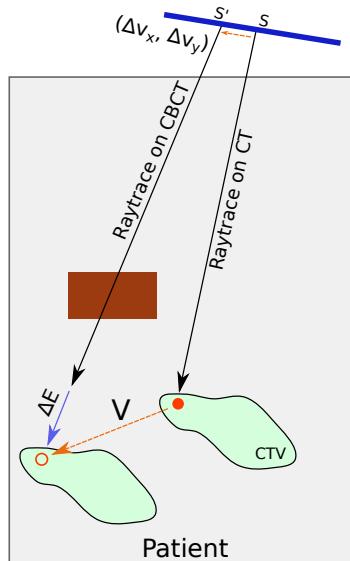


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Spot adaptation:  $(\Delta v_x, \Delta v_y, \Delta E)_i$



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Four strategies constraining the geometrical adaptation:

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



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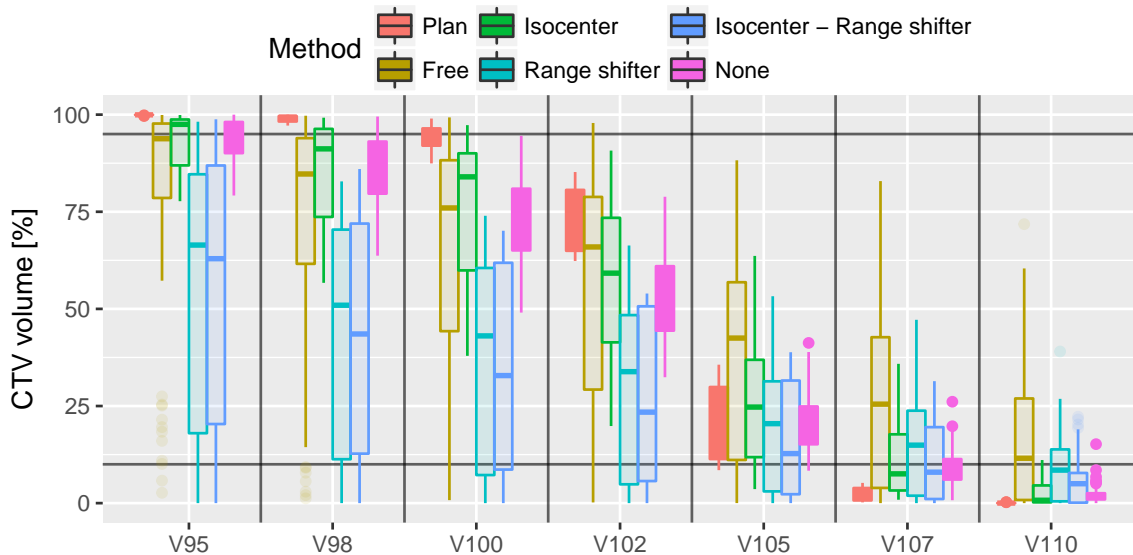
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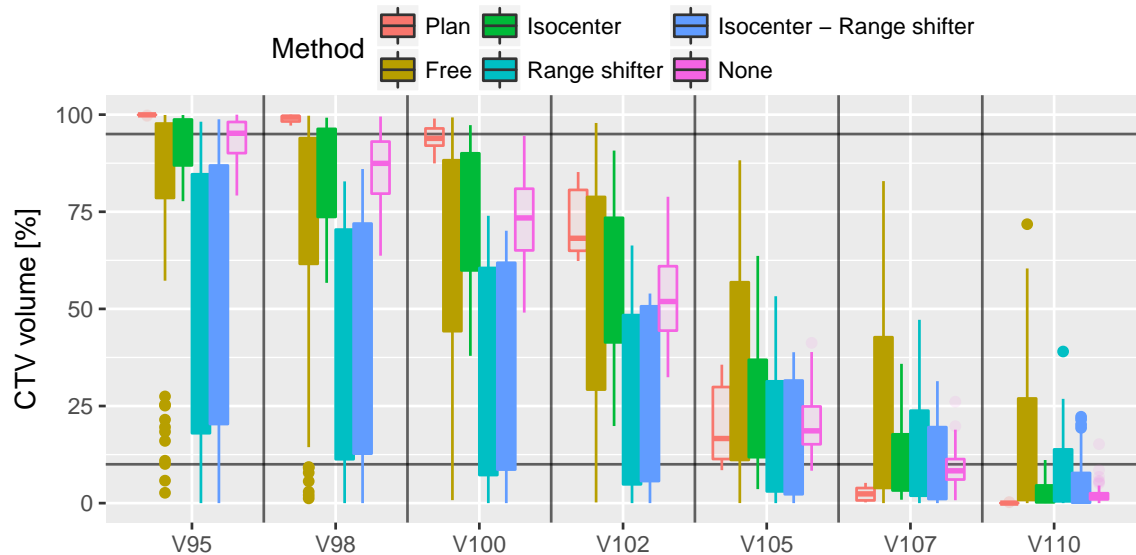
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- 6 **Tune set weights** to fill the remaining dose and spare OARs

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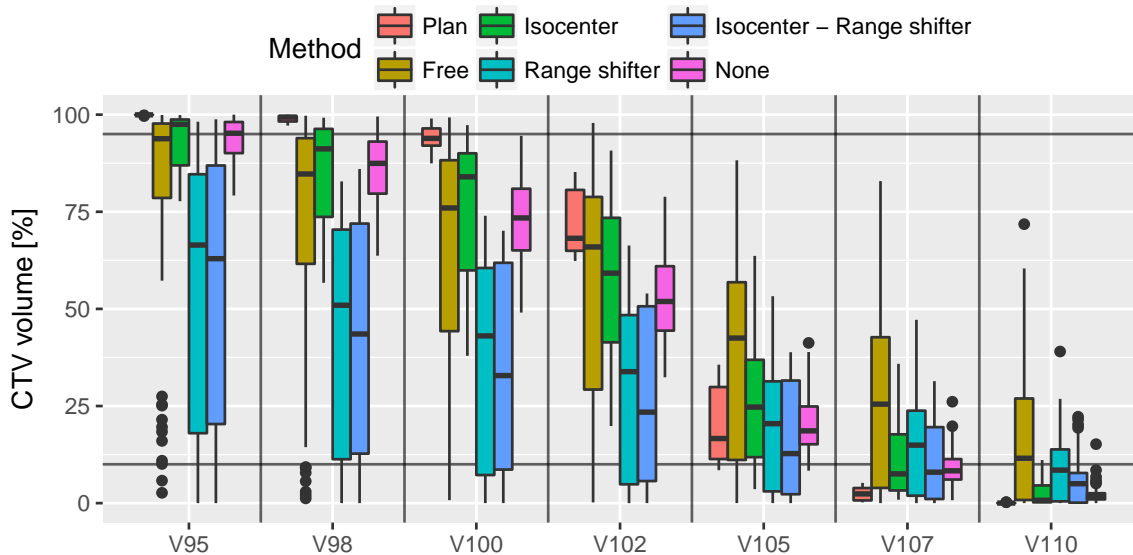


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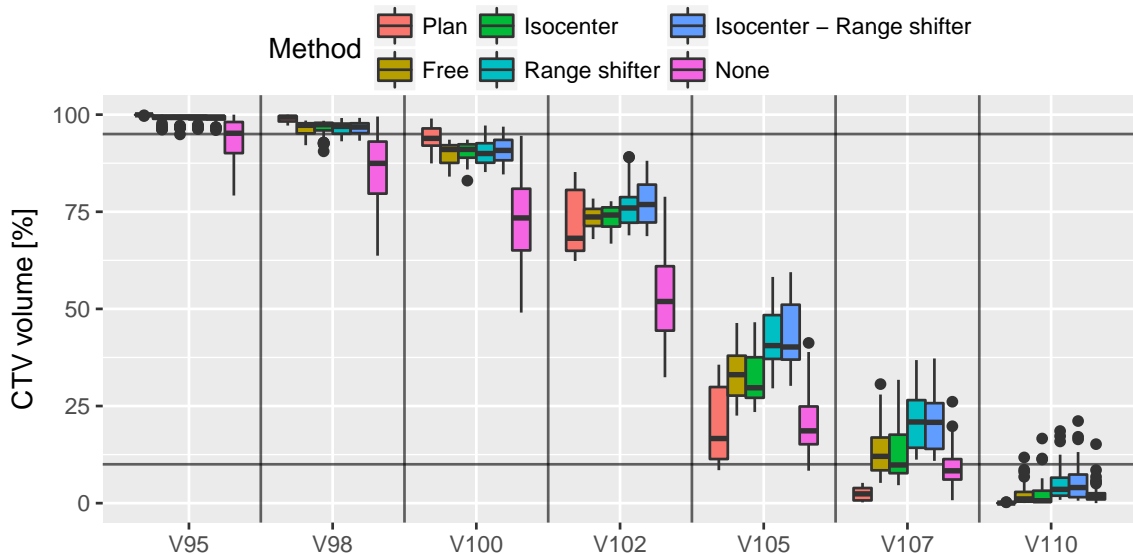




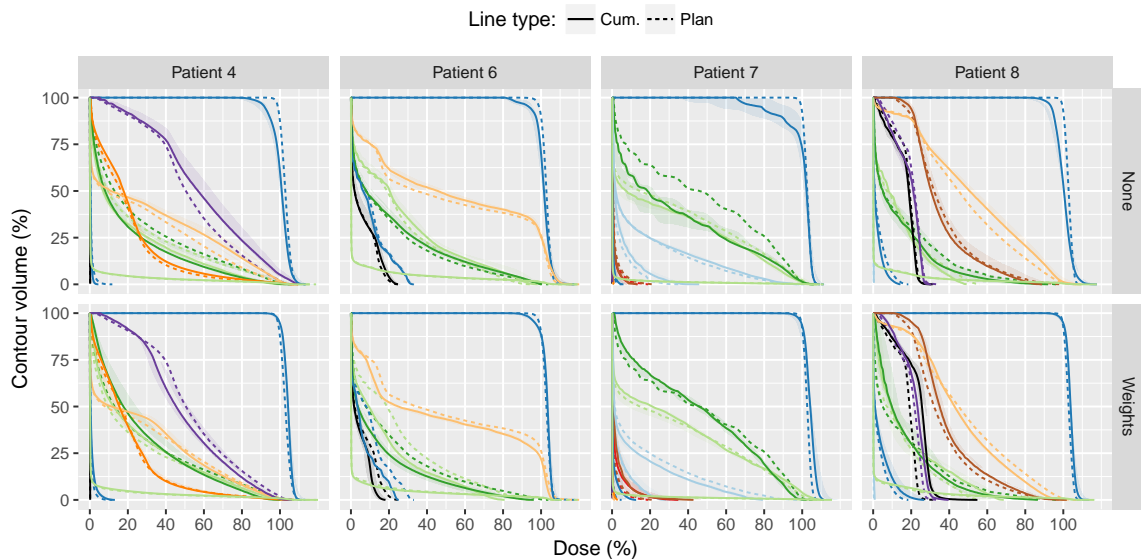
# Results: all geometrical adaptations (no weight tuning)



# Results: all geometrical adaptations + weight tuning



# Results with free geometrical adaptation + weight tuning



# Timing and conclusions

Timing, timing, timing!!

<i>(seconds)</i>	Minimum	Average	Maximum	Expected
Geometrical adapt.	11.7	<b>16.9</b>	26.57	~ 1 – 5
gPMC validation	115.6	<b>261.9</b>	419.2	~ 30
Weight tuning	12.0	<b>44.8</b>	198.0	~ 5 – 120
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Conclusions:

- If adaptation is needed, weight tuning is generally 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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