Intensity Modulated Radiation Therapy

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Goal of IMRT

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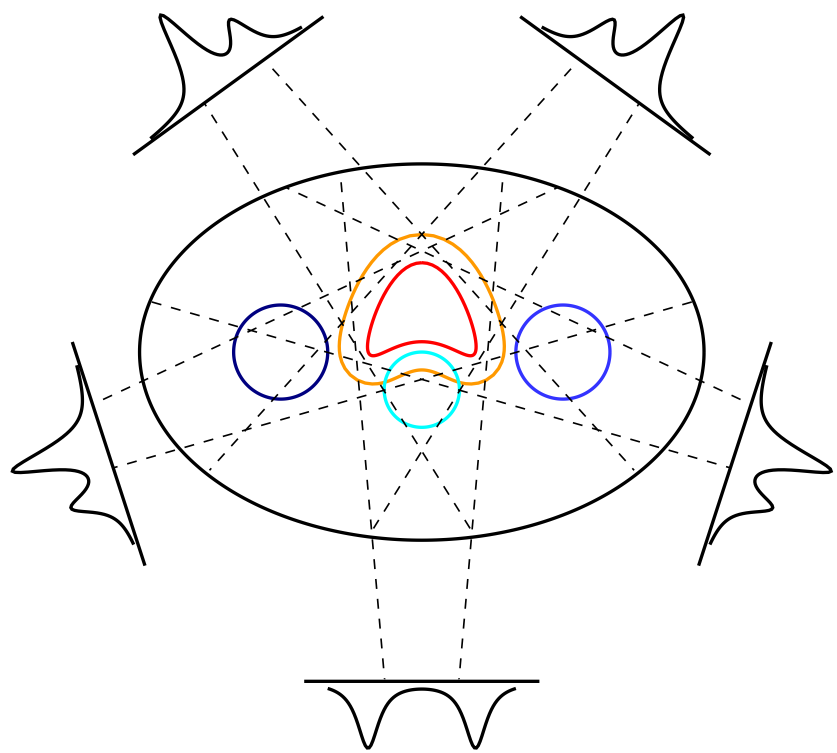
Dose escalation on target

and/or

Dose reduction on healthy tissues

by

Greater control over dose distribution in patient by intensity modulation



Goal of IMRT

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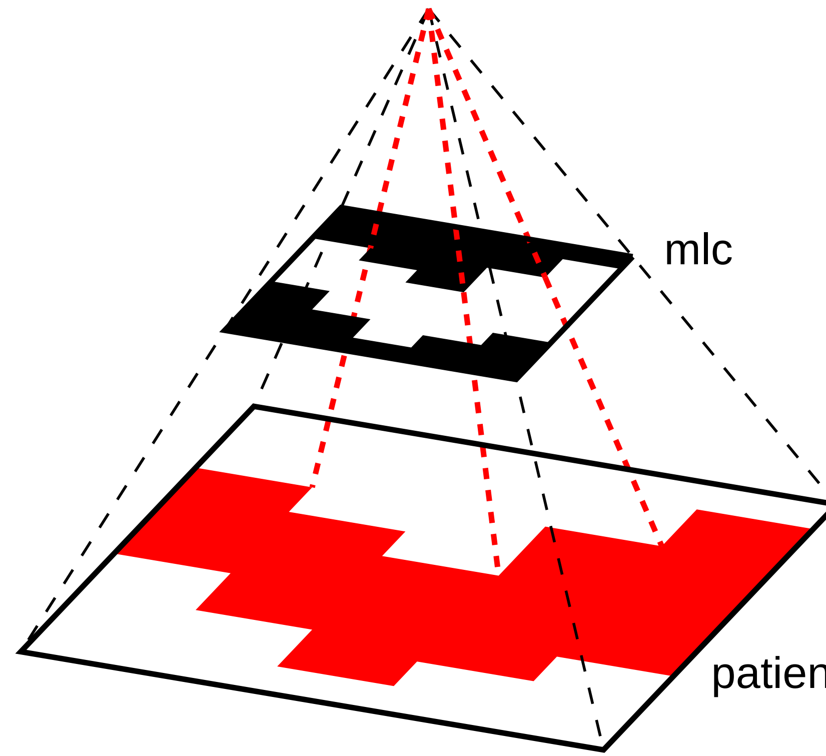
Main questions

- Q: Which intensity modulation?

  A: Inverse planning and optimization

- Q: Realization of intensity modulation?

  A: Multileaf collimator



Inverse planning and optimization

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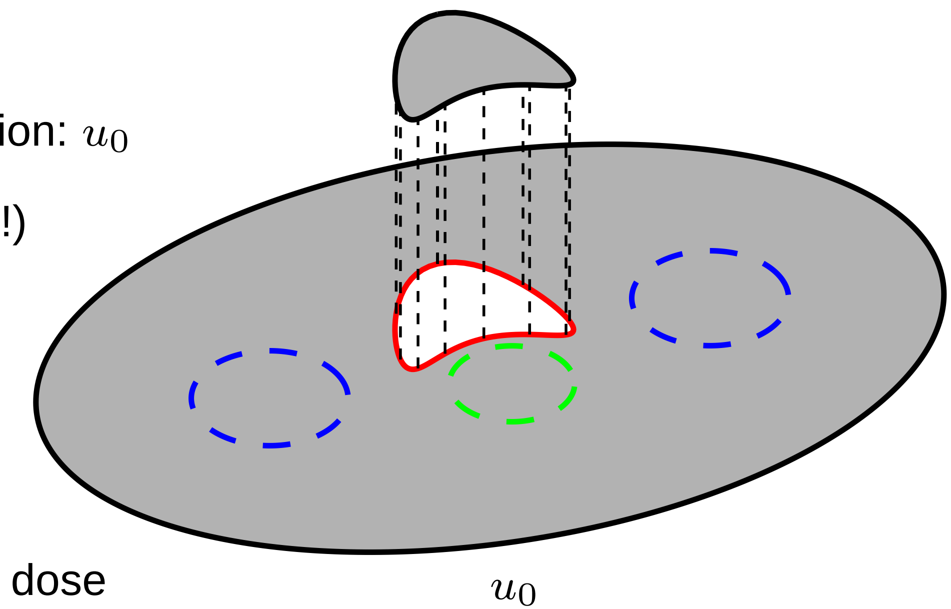
Forward planning: beam parameters $\longrightarrow$ dose-distribution

Inverse planning: dose-distribution $\longrightarrow$ beam parameters

(beam parameters: # of beams, energy, modality, beam angle, wedge angle, ...)

Which dose-distribution? Ideal dose-distribution: u_0

Inverse planning for u_0: negative intensities (!)



Alternative: optimization based on criteria for dose

Dose-volume histogram

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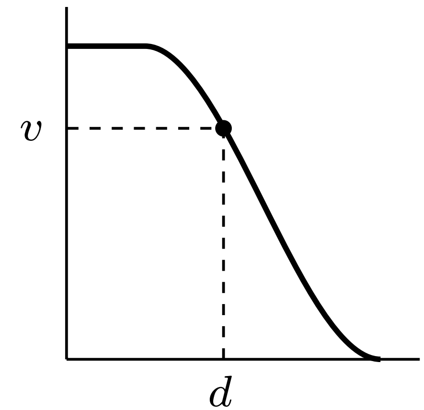
W is a part of the patient, tumor or critical organ

$f_W(d)$ is (rel.) volume of W receiving dose d or higher

graph of f_W is called dose-volume histogram (DVH) of W



Point (d, v) on graph of f_W means

volume v of W receives dose d or higher

Definition of f_W:

$u : V \to \mathbb{R}_+$ is dose-distribution on irradiated part $V \subset \mathbb{R}^3$ of the patient

$W \subset V$ is a region in V, a tumor or a critical organ, $|W|$is the volume of W

$W_d = \{x \in W \mid u(x) \geq d\}$ is the part of W receiving dose d or higher

$f_W : \mathbb{R}_+ \to [0, 1]$ is the relative volume of W receiving dose d or higher

$$f_W(d) = \frac{1}{|W|} \int_{W_d} 1 \, dx$$

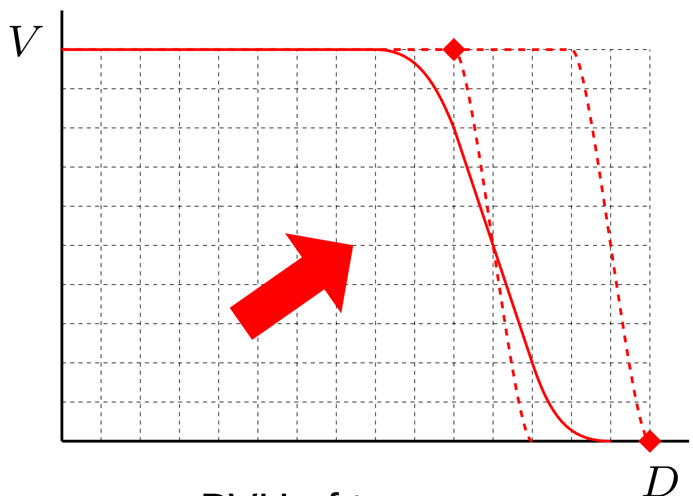
Optimization and object function

Dose criteria: points in dose-volume diagram (from clinical trials)

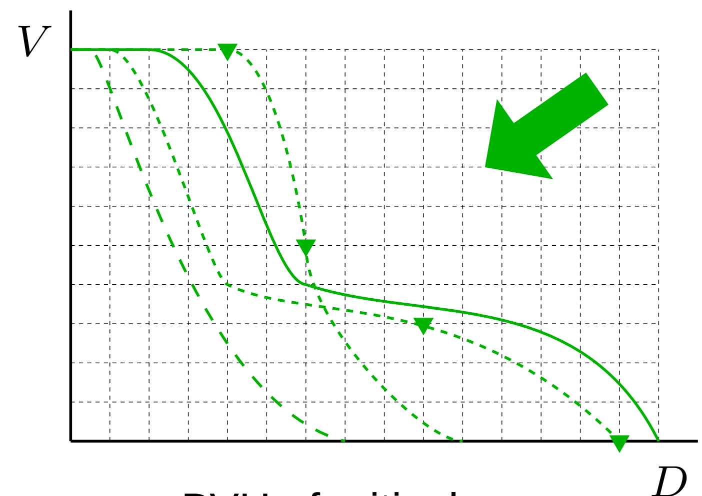
Object function measures (one-sided) distance from dose-volume points

Example, y beam parameters:

$$F(y) = \alpha F_T(y) + \beta F_O(y), \quad \alpha, \beta \;\text{ weights}$$



DVH of tumor



DVH of critical organ

Beam parameters in optimization: weights of beamlets in discrete intensity distribution

all other parameters (# of beams, energy, modality, ...) are fixed

Realization of IMRT

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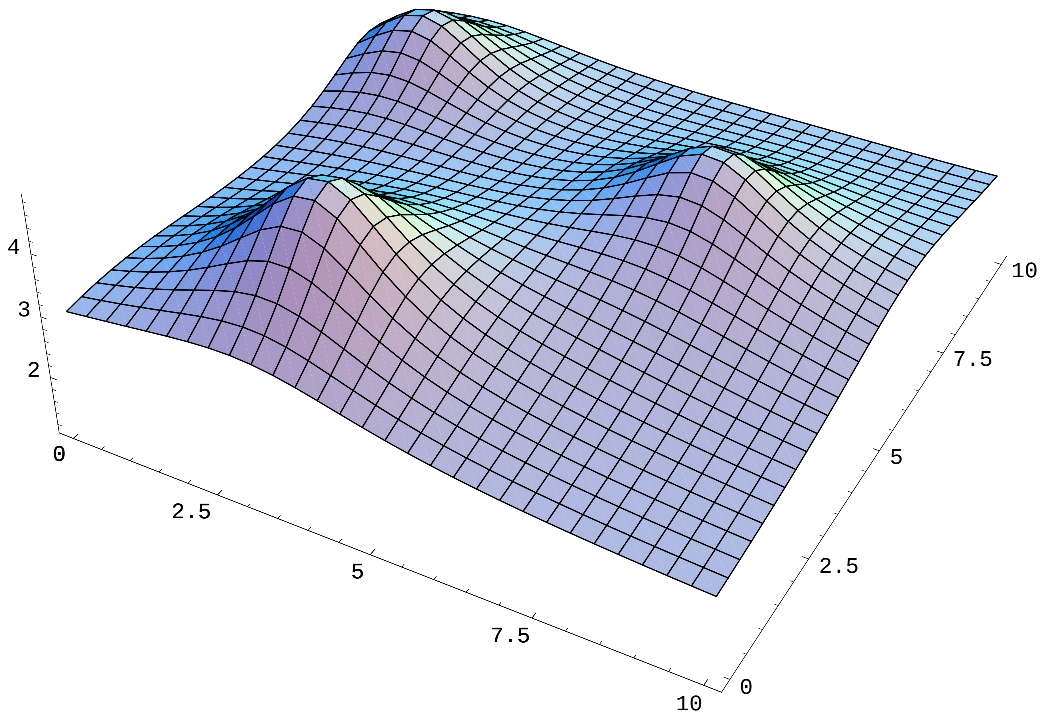
Intensity distribution for each beam (by optimization), for example



Q: How to realize?

A: Discretization of space and dose and segmentation

Realization of IMRT

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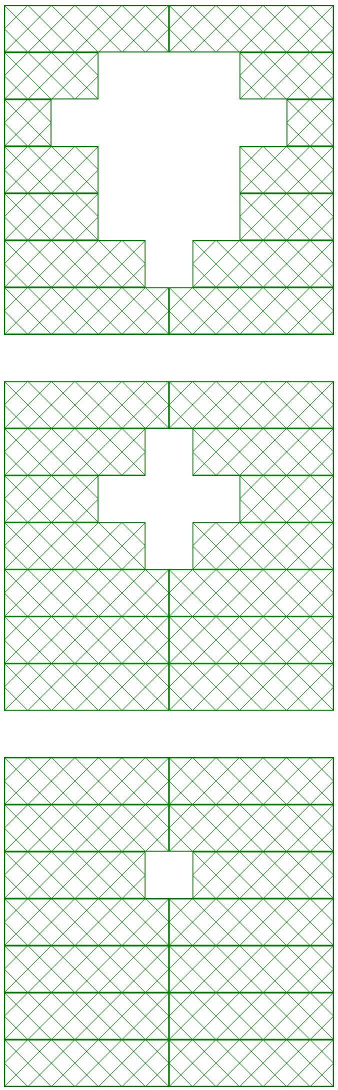
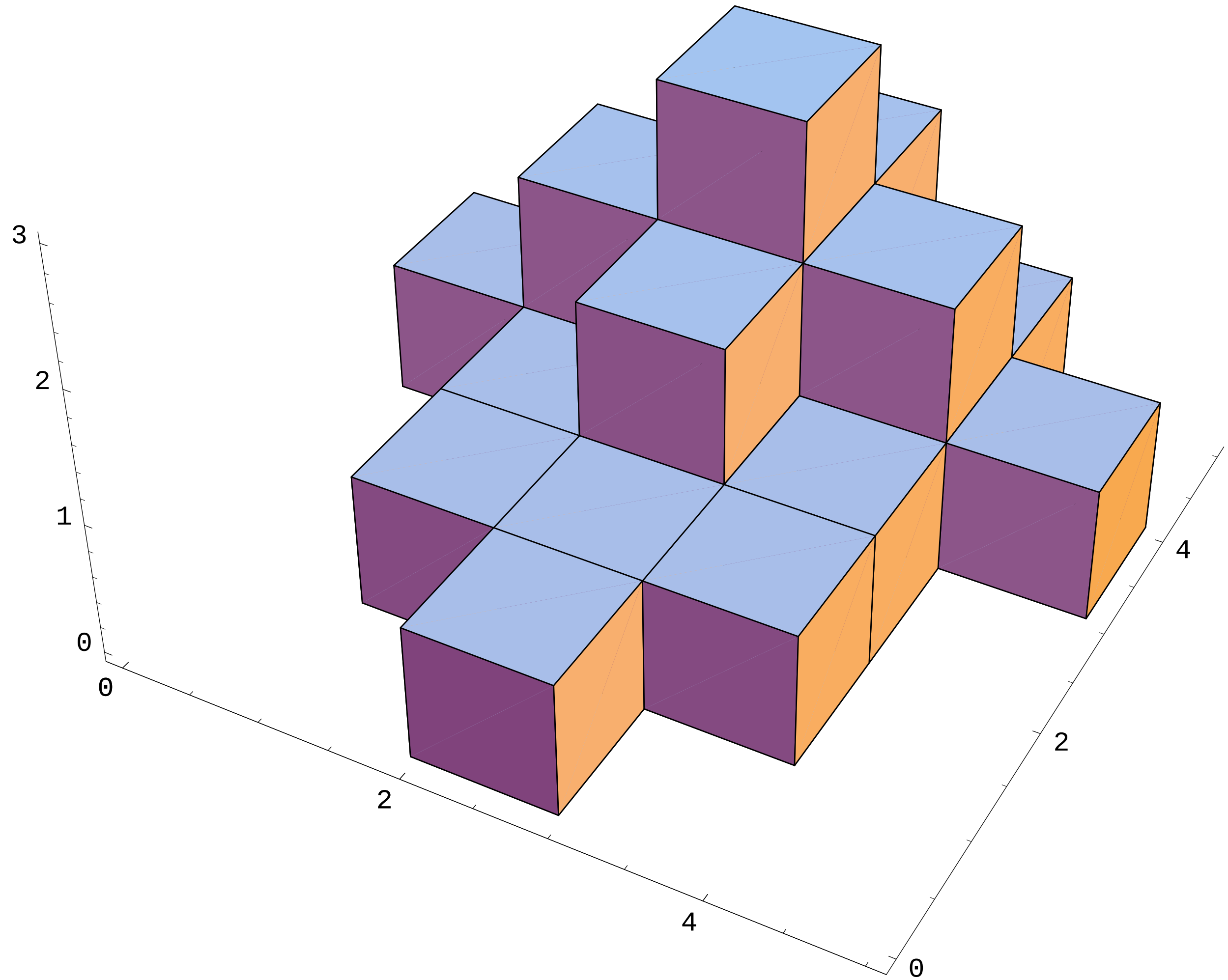
Segmentation: "adding" beams with different leaf settings



Three segments



Intensity distribution

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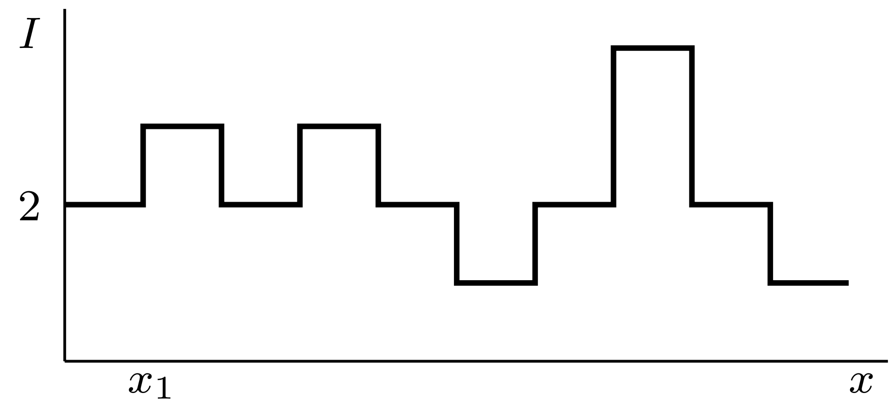
Discretized intensity distribution

	16	25	
	24	31	

← single row corresponding to one leaf pair

Desired intensity profile I for one row $\longrightarrow$



Find: leaf positions as function of (discrete) time

Here: time as function of leaf position

But: intensity $\propto$ monitor units $\propto$ time

So: intensity as function of leaf position

$I_L(x_i)$ intensity left leaf at x_i

$I_R(x_i)$ intensity right leaf at x_i

Realization of IMRT

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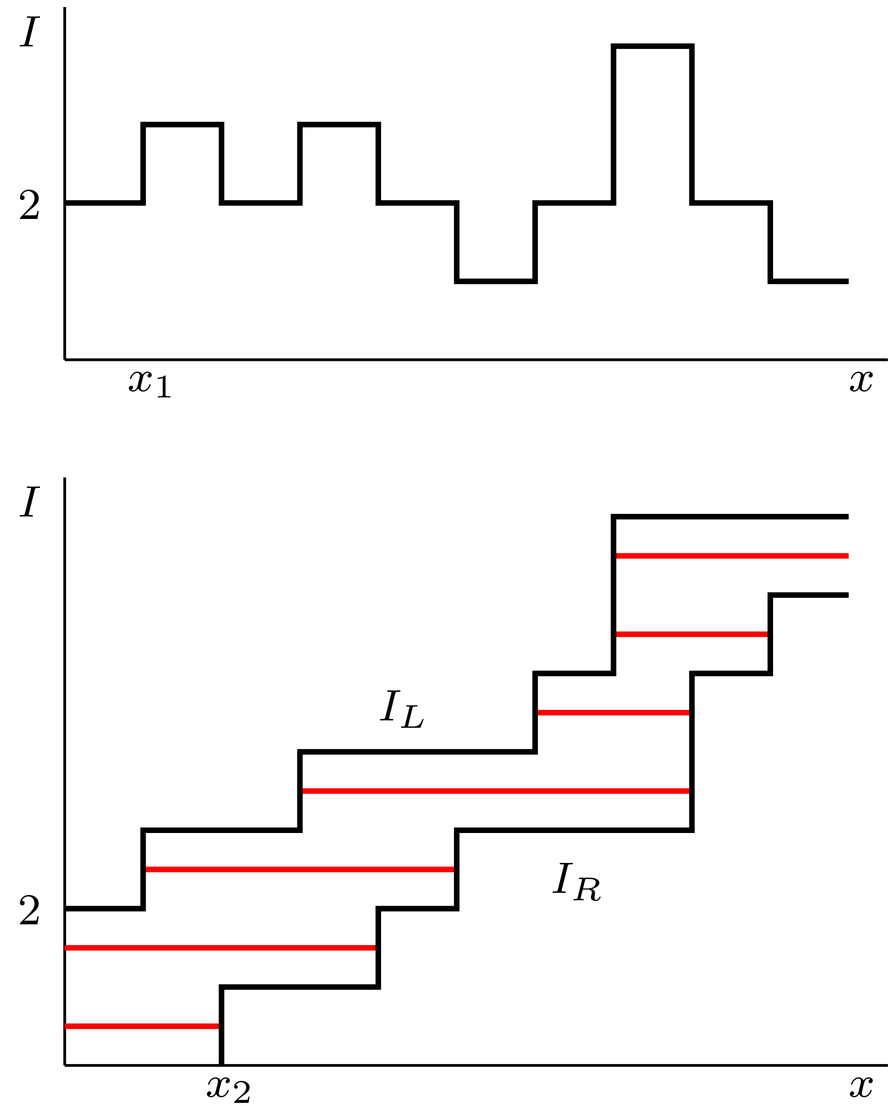
$I_L(x_i)$ intensity left leaf at x_i

$I_R(x_i)$ intensity right leaf at x_i



Solve the following problem

Find I_L and I_R satisfying:

1) $I_L(x_i)$ and $I_R(x_i)$ non-decreasing

2) $I_L(x_i) - I_R(x_i) = I(x_i)$

Solution is not unique, so minimize:

treatment time or equiv

monitor units or equiv

$\max_i I_L(x_i)$

Global description of algorithm K see [3]:

uni-directional segmentation, left to right

if I increases, I_L is increased,

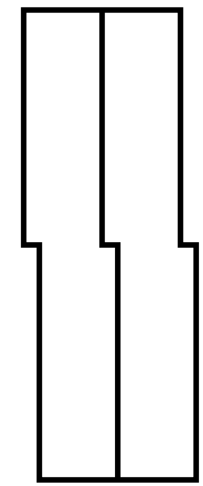
if I decreases, I_R is increased

Realization of IMRT

Recently published algorithms (2004) Q (see [5]) and K (see [4]), examples of segmentation for three intensity distributions (from [4])

Q		K	
MU	Segs	MU	Segs
520	26	220	11
1660	78	440	22
990	75	310	30

different solutions ...



tongue-and-groove
to avoid leakage

Comments

- Errors
  discretization of space and dose
  tails or penumbras
  tongue-and-groove

- Linac restrictions
  minimal distance of opposing leafs for pairs and neighbours
  minimal monitor units

- QA restrictions
  minimal area of segment
  minimal number of neighbouring open leaf pairs

Example

Optimization using anatomical segments, limited IMRT at UMCG

- Set dose-volume criteria for tumor regions and critical organs
- Fix energy (6 MV), modality (photons), # of beams (21), beam angles (...), segments based on patient anatomy
- Optimize weights of 21 segments

Anatomical segments

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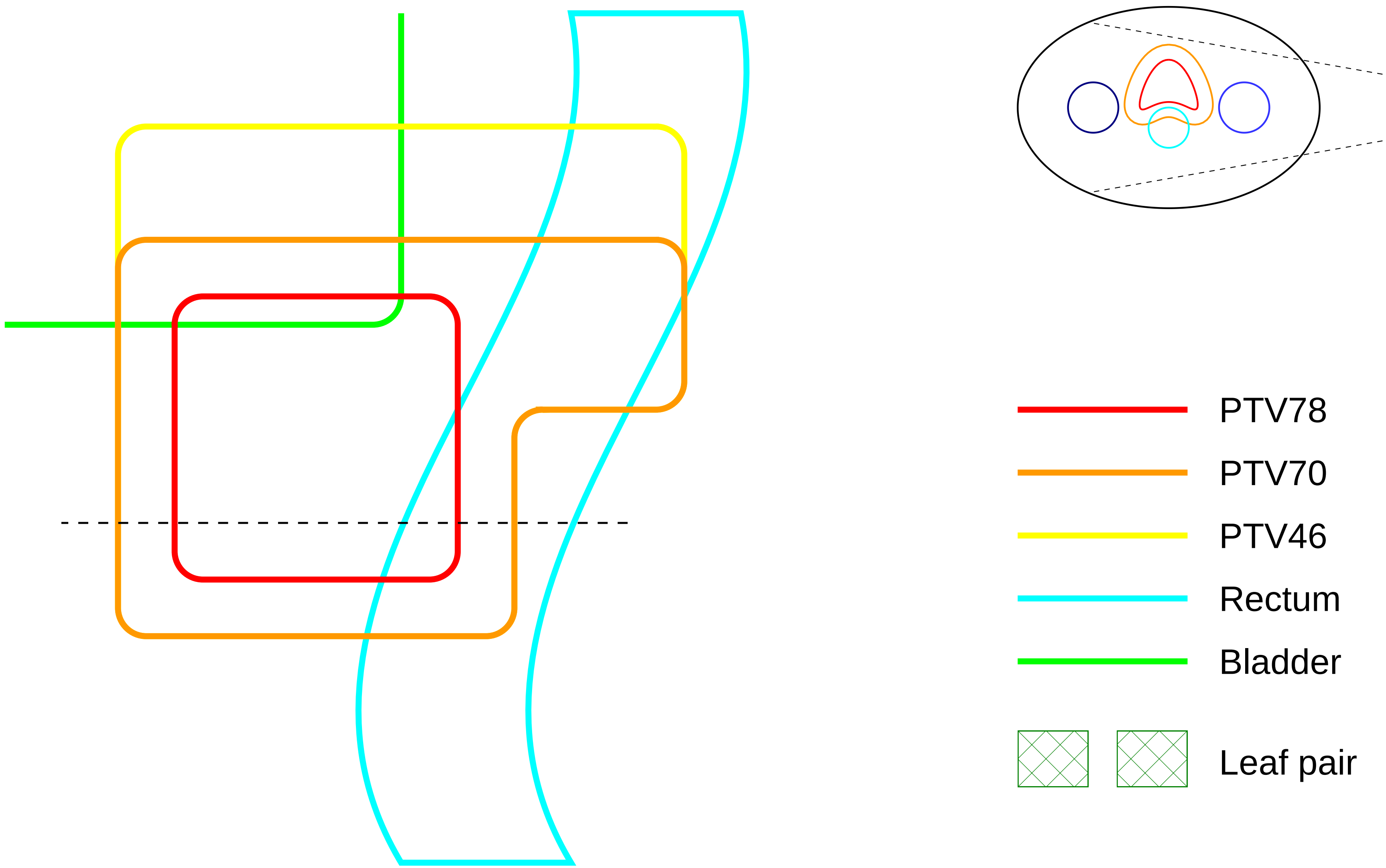
Beam's eye view of lateral beam



Anatomical segments

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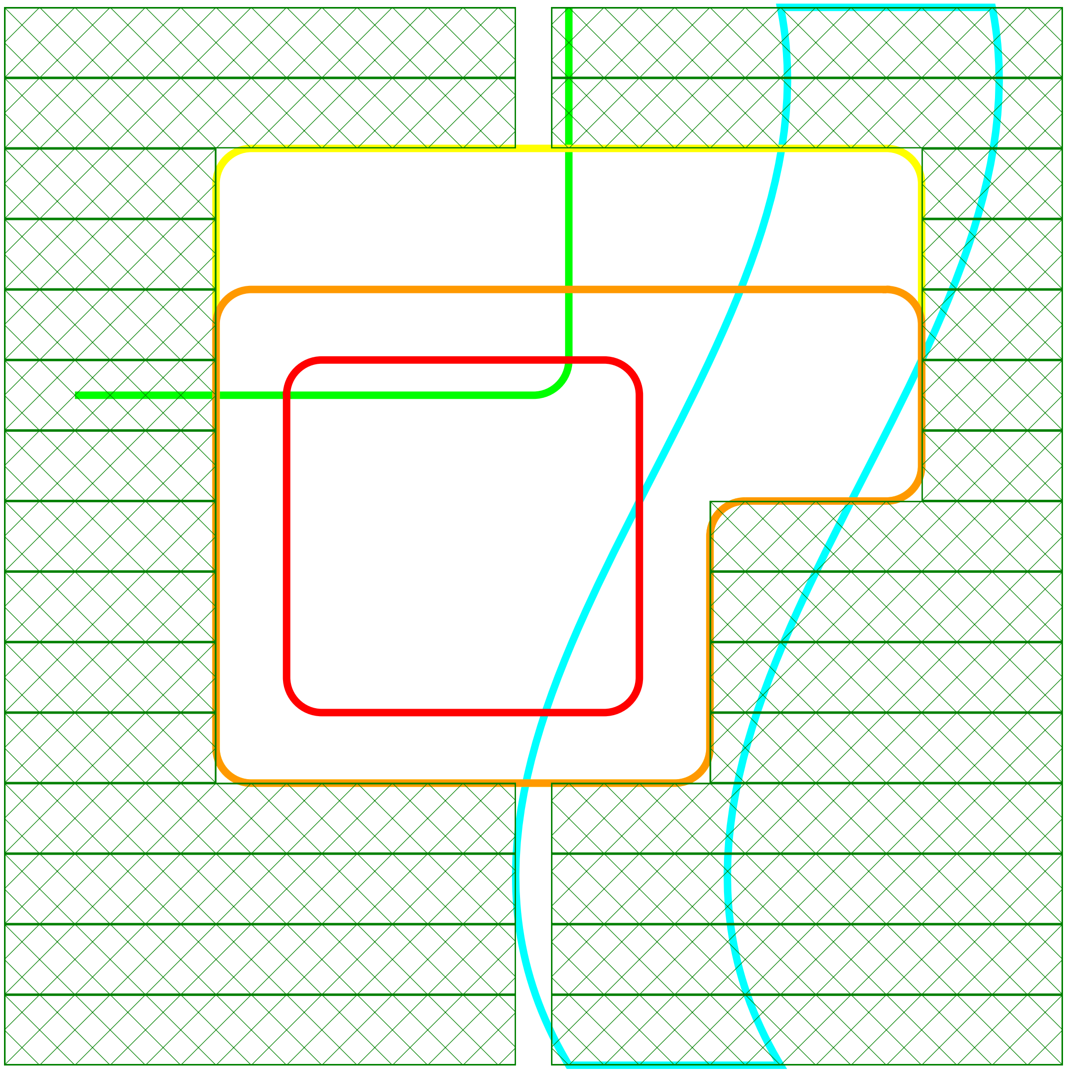
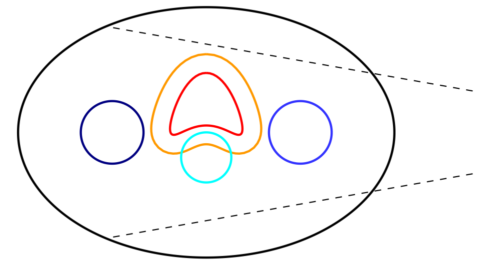
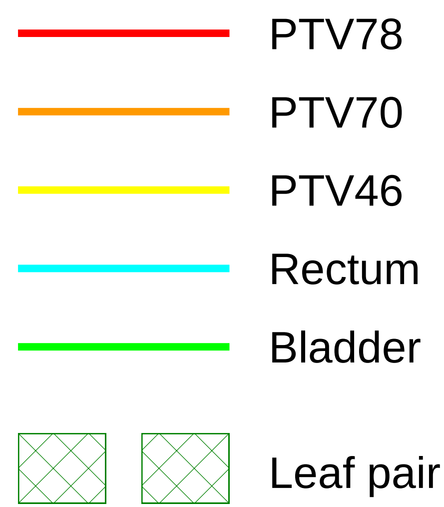
Beam’s eye view of lateral beam, segment 1







Anatomical segments

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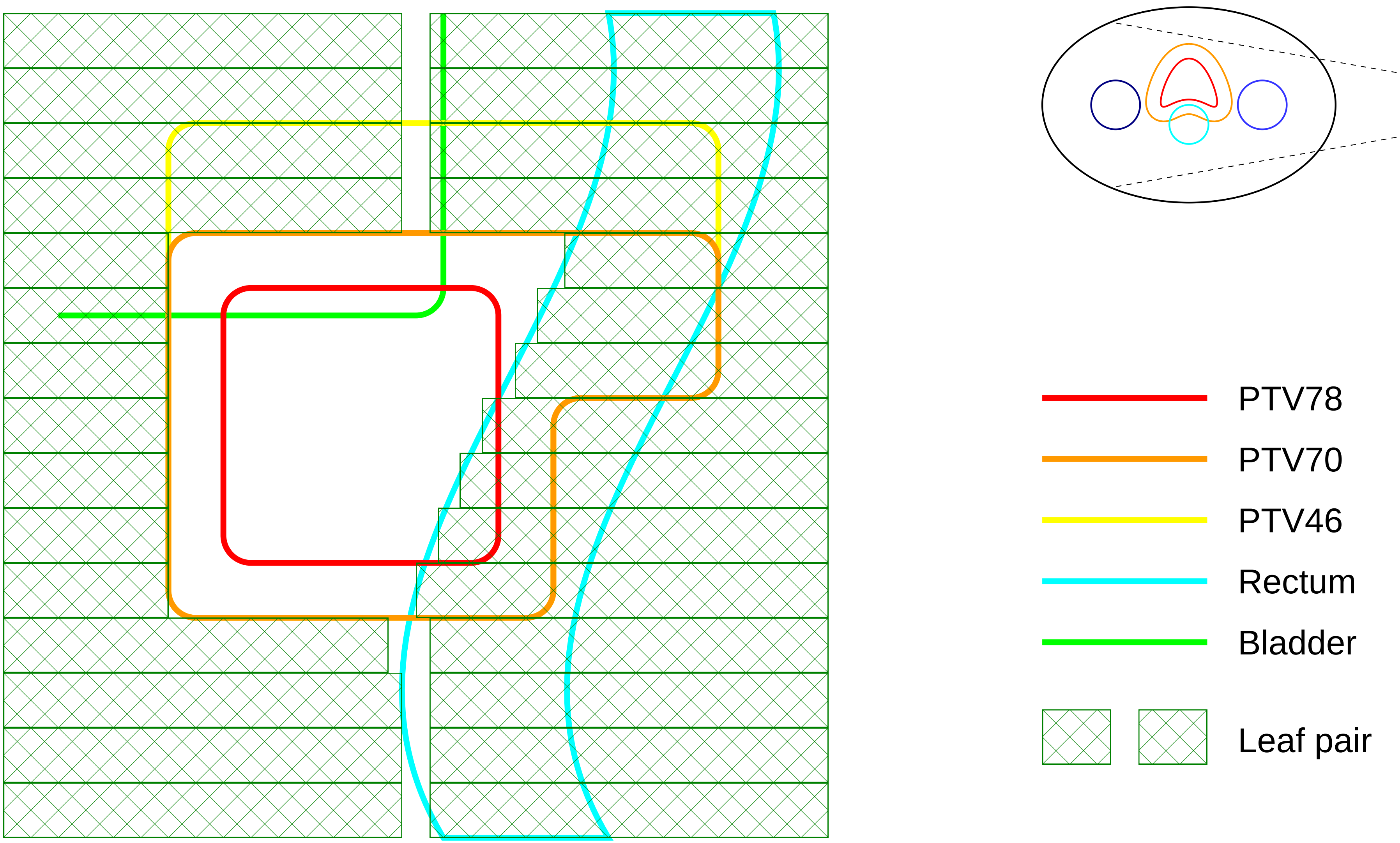
Beam’s eye view of lateral beam, segment 2



Anatomical segments

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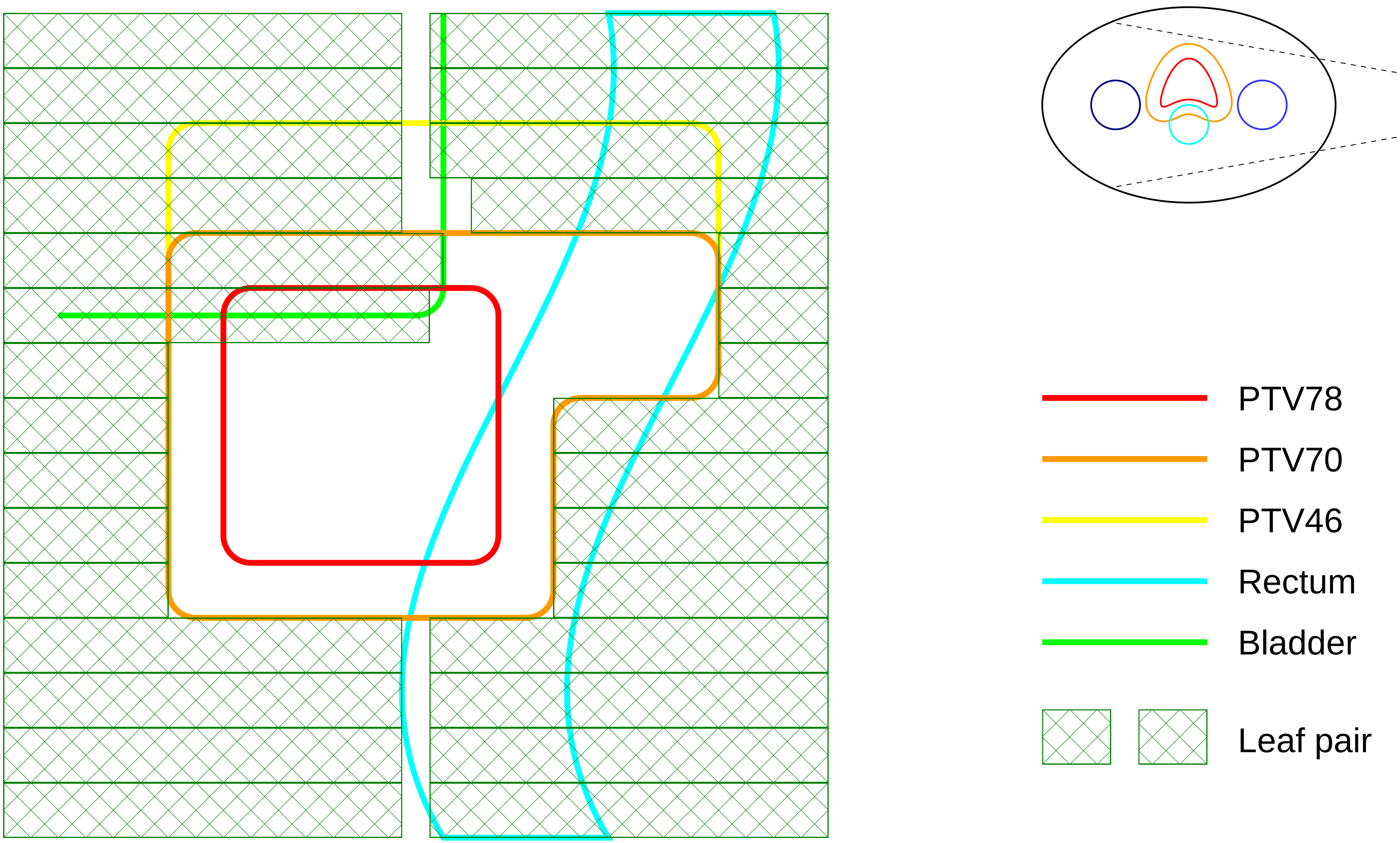
Beam's eye view of lateral beam, segment 3



Anatomical segments

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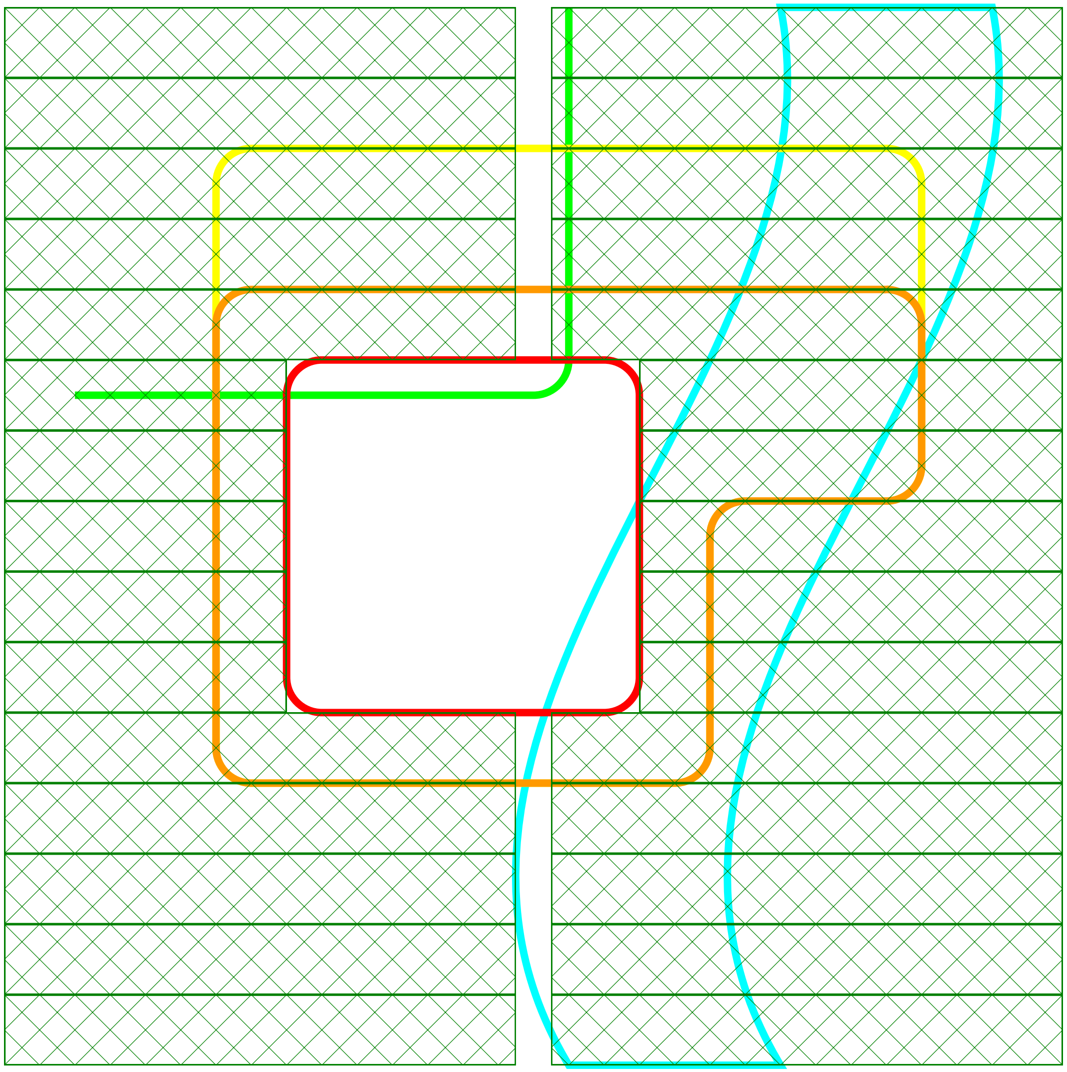
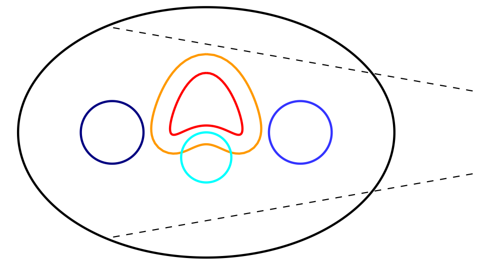
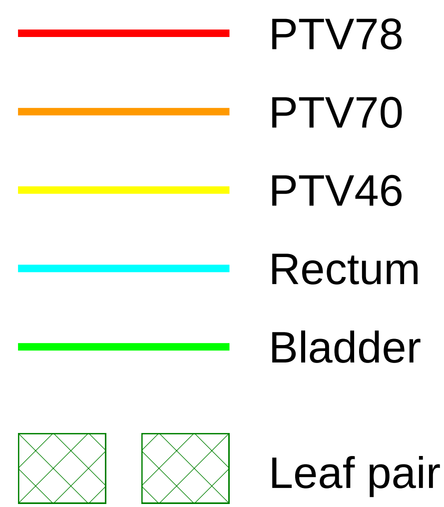
Beam's eye view of lateral beam, segment 4







Anatomical segments, old plan

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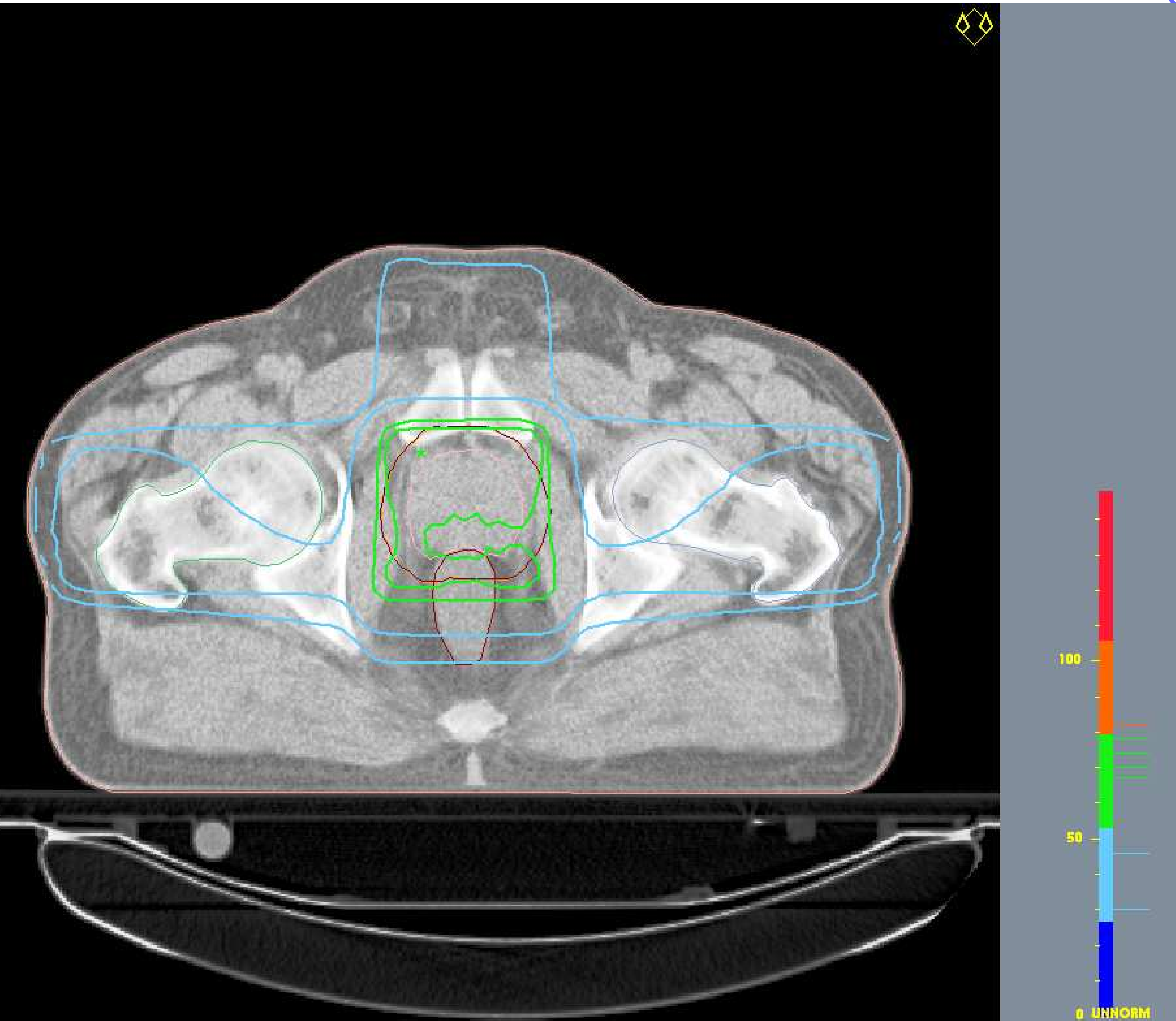

Anatomical segments, new plan

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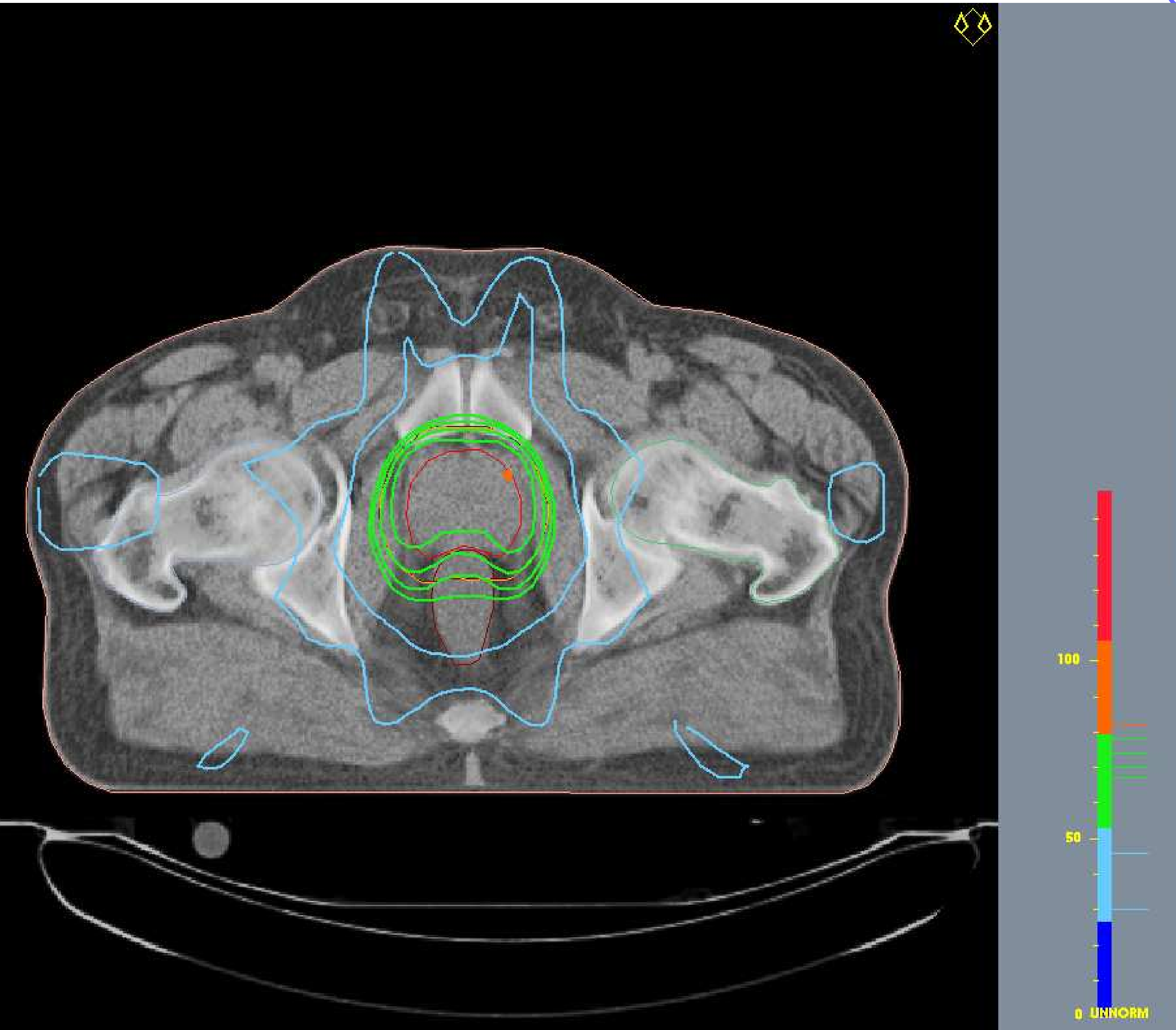

Anatomical segments, old plan

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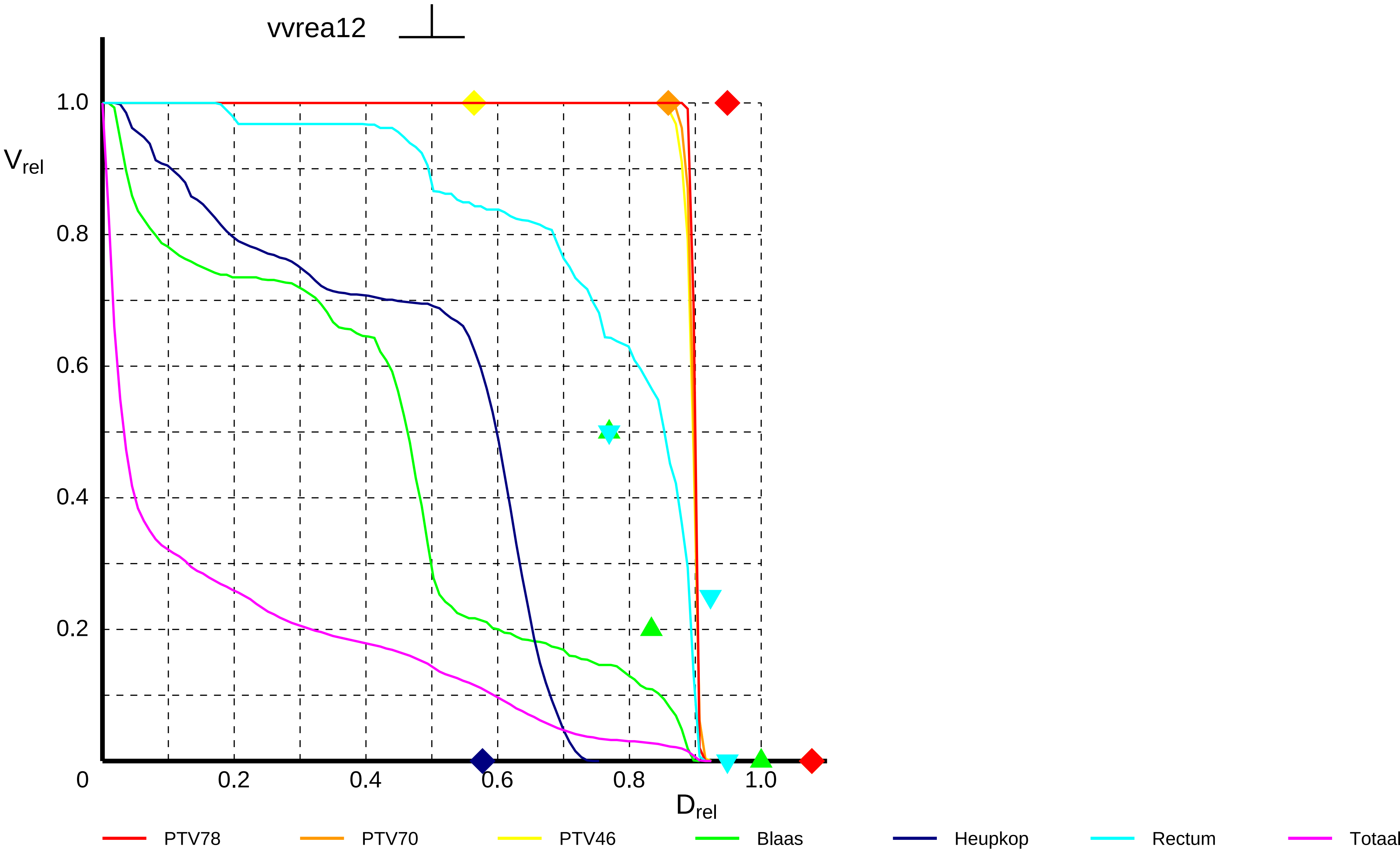

Anatomical segments, new plan

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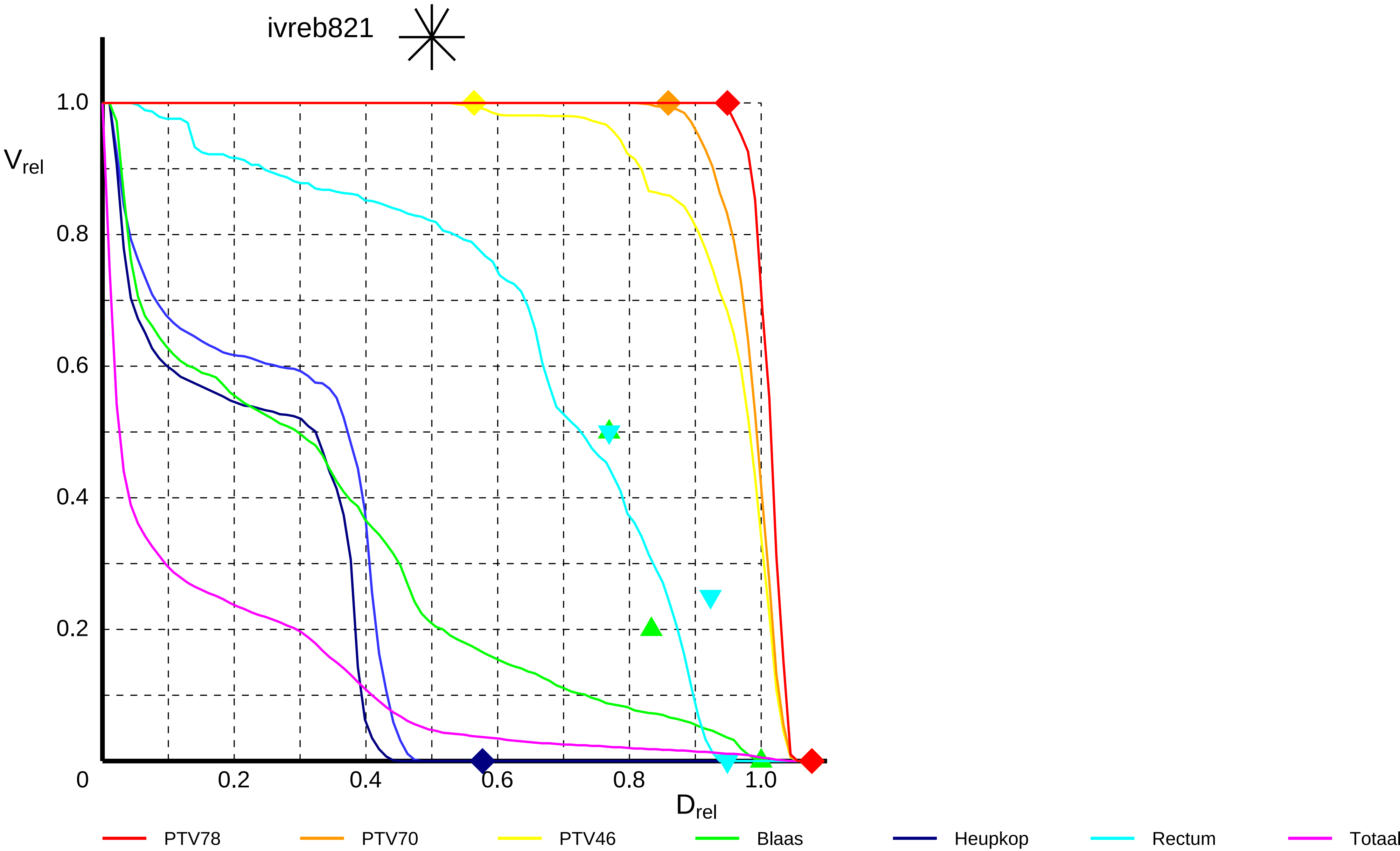

Conclusion

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For a large number of patients one can

- escalate dose on tumor regions and
- reduce dose on critical organs

applying (limited) IMRT using a multileaf collimator

Some issues to be resolved

- dose criteria for critical organs, object functions
- optimization w.r.t. all beam parameters, eg. beam angles
- finding an optimal segmentation method or direct optimization of leaf settings
- is a multileaf collimator really suited for intensity modulation?

  (interleaf leakage, tongue-and-groove underdosage, tails or penumbras, leaf collision avoidance, ...)

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[6] D.M. Shepard, M.C. Ferris, G.H. Olivera, T.R. Mackie, Optimizing the delivery of radiation therapy to cancer patients, SIAM Review *41(4)* (1999) pp. 721-744.

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[8] P. Xia, L.J. Verhey, Multileaf collimator leaf sequencing algorithm for intensity modulated beams with multiple static segments, Medical Physics, *25(8)* (1998) pp. 1424-1434.