Radiotherapy Treatment Planning: Forward & Inverse Planning

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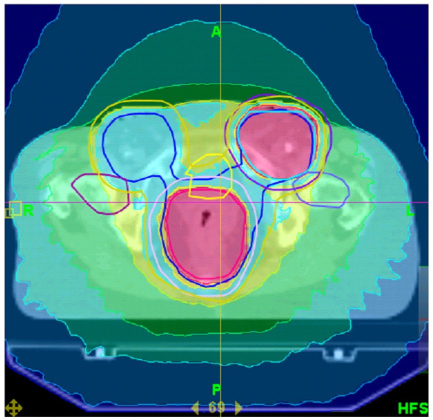
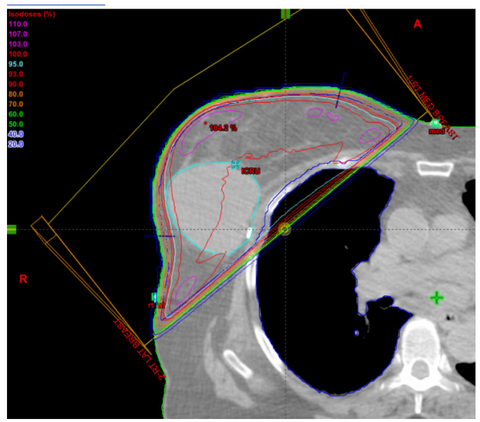
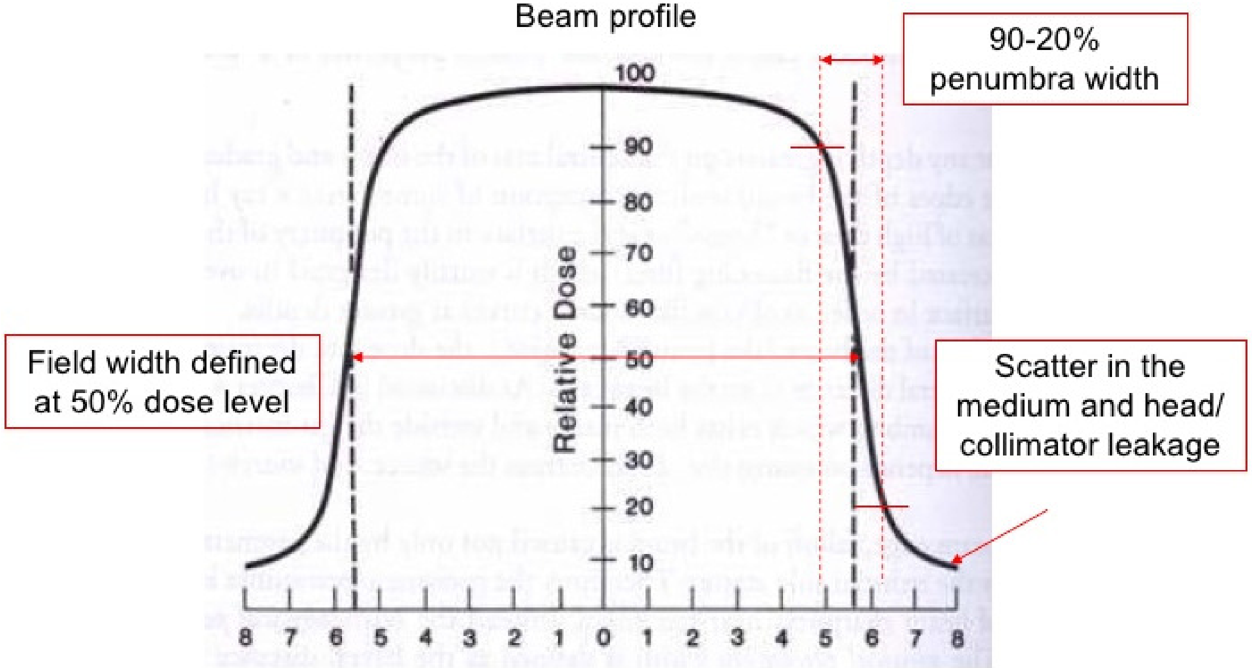
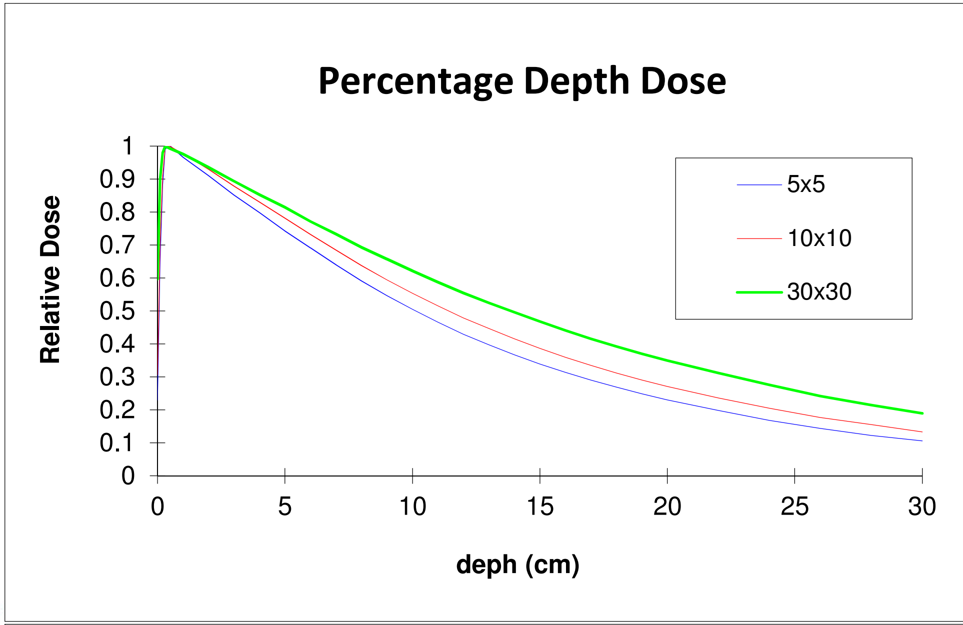
Lectures 3: Autumn 2019

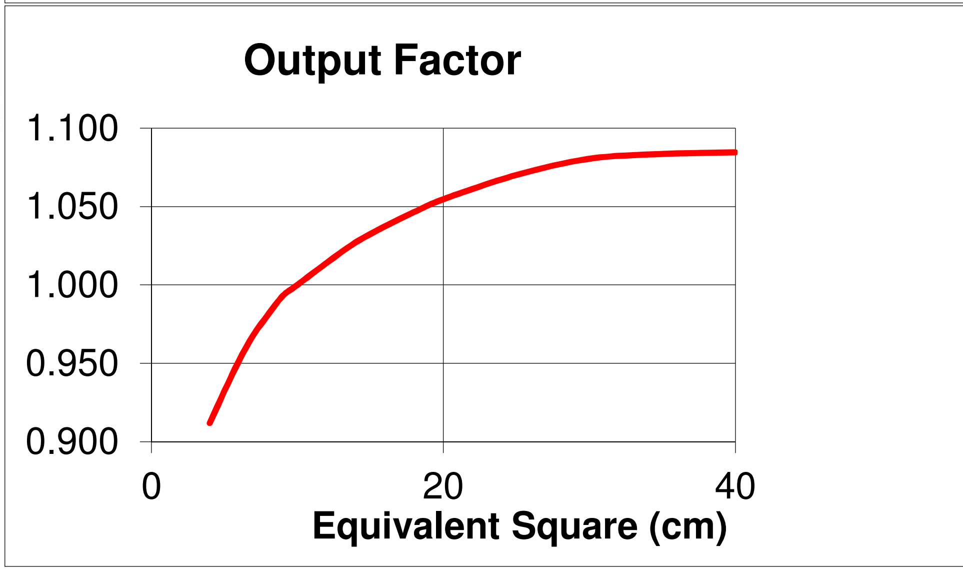




Beam Properties







Monitor Unit calculation

Typical linac calibration: 1MU = 1cGy (100 SAD, 10x10, dmax)

$$MU = \frac{\text{prescribed dose (cGy)}}{OF \times TMR \times WF}$$

where OF, TMR and WF can be found from tabulated data for a given **square** field size; for arbitrary field sizes the size of the equivalent square field (ESQ) can be calculated from:

ESQ = 4 * Area /Perimeter

Today’s Goals

1. How to create a forward planned treatment (“3D-CRT”)
   i. Parameters that affect 3D-CRT planning (Beam energy, direction, shape, “weight” and fluence modification)
2. How to create an inverse planned treatment (“IMRT”)
   i. Difference between objectives and constraints
   ii. Understand the optimisation process
   iii. Methods to “guide” the optimisation, e.g. dummy structures, weight and rank
3. Understand how to read Dose Volume Histograms to evaluate plan

Forward planning

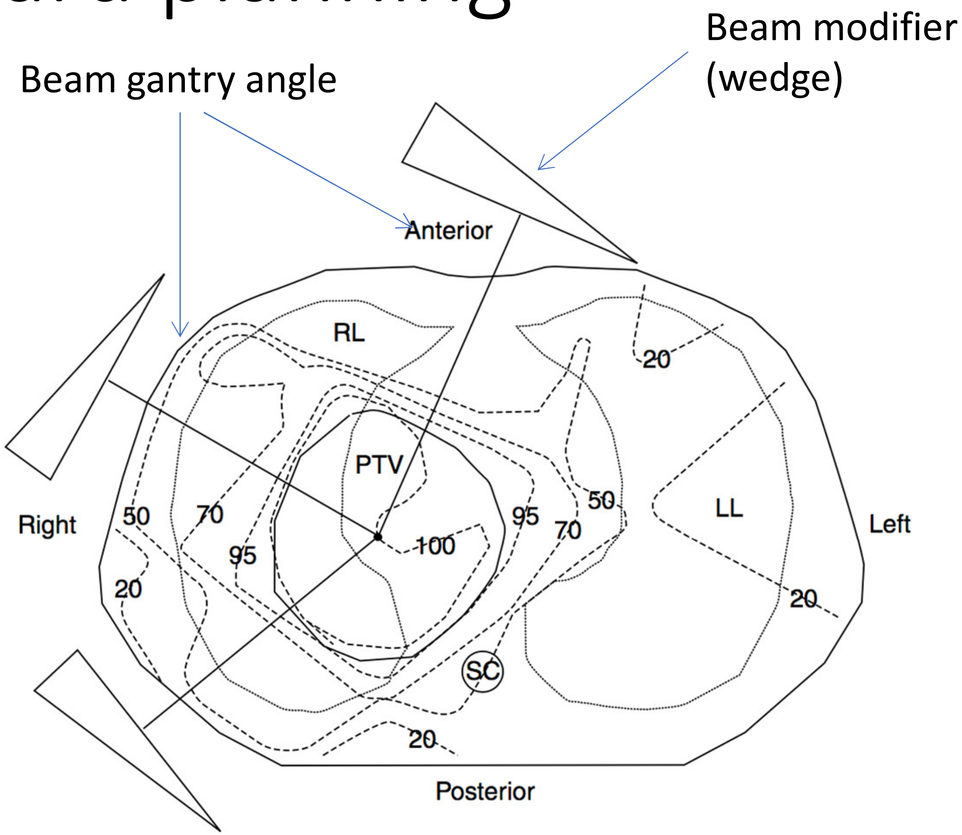
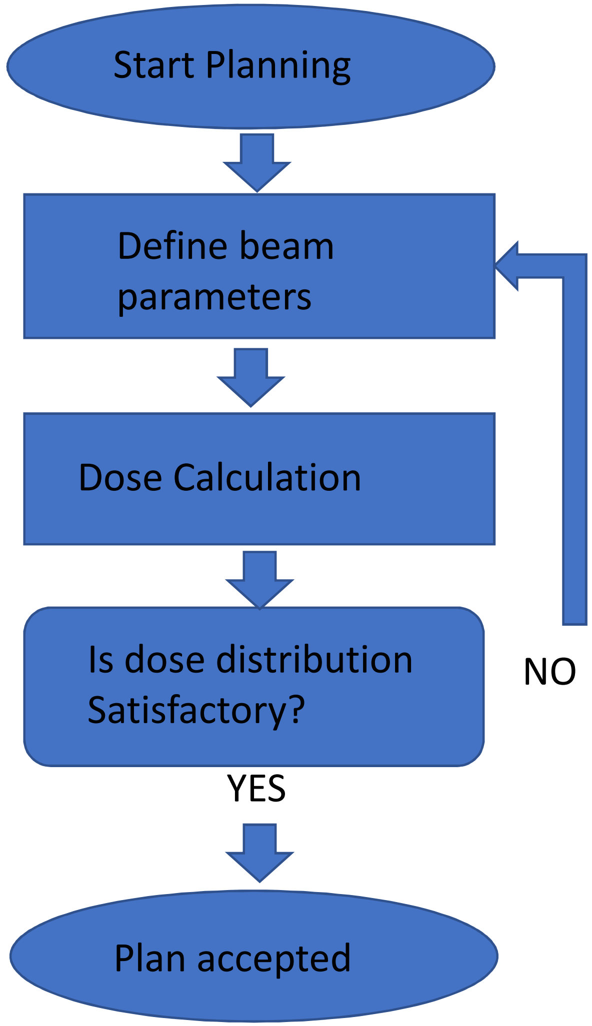


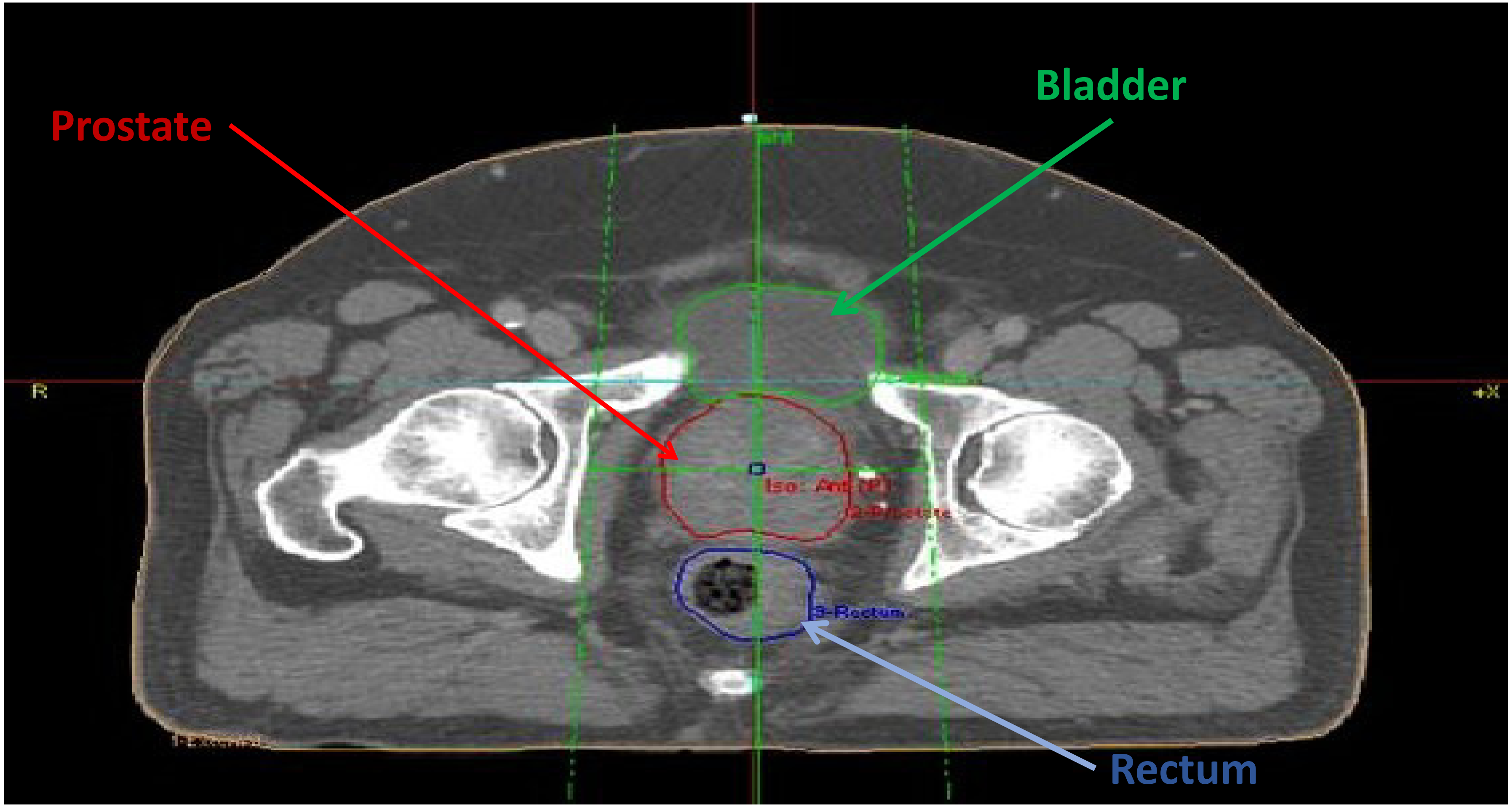
FIGURE 33.6
6 MV three-beam dose distribution normalised to 100 at the isocentre, for the treatment of a right bronchial tumour (PTV). The beams are arranged to avoid the contra-lateral lung and to keep dose to the spinal cord (SC) below tolerance. RL indicates the right lung and LL the left lung.



https://insidestory.iop.org/insidestory_flash1.html

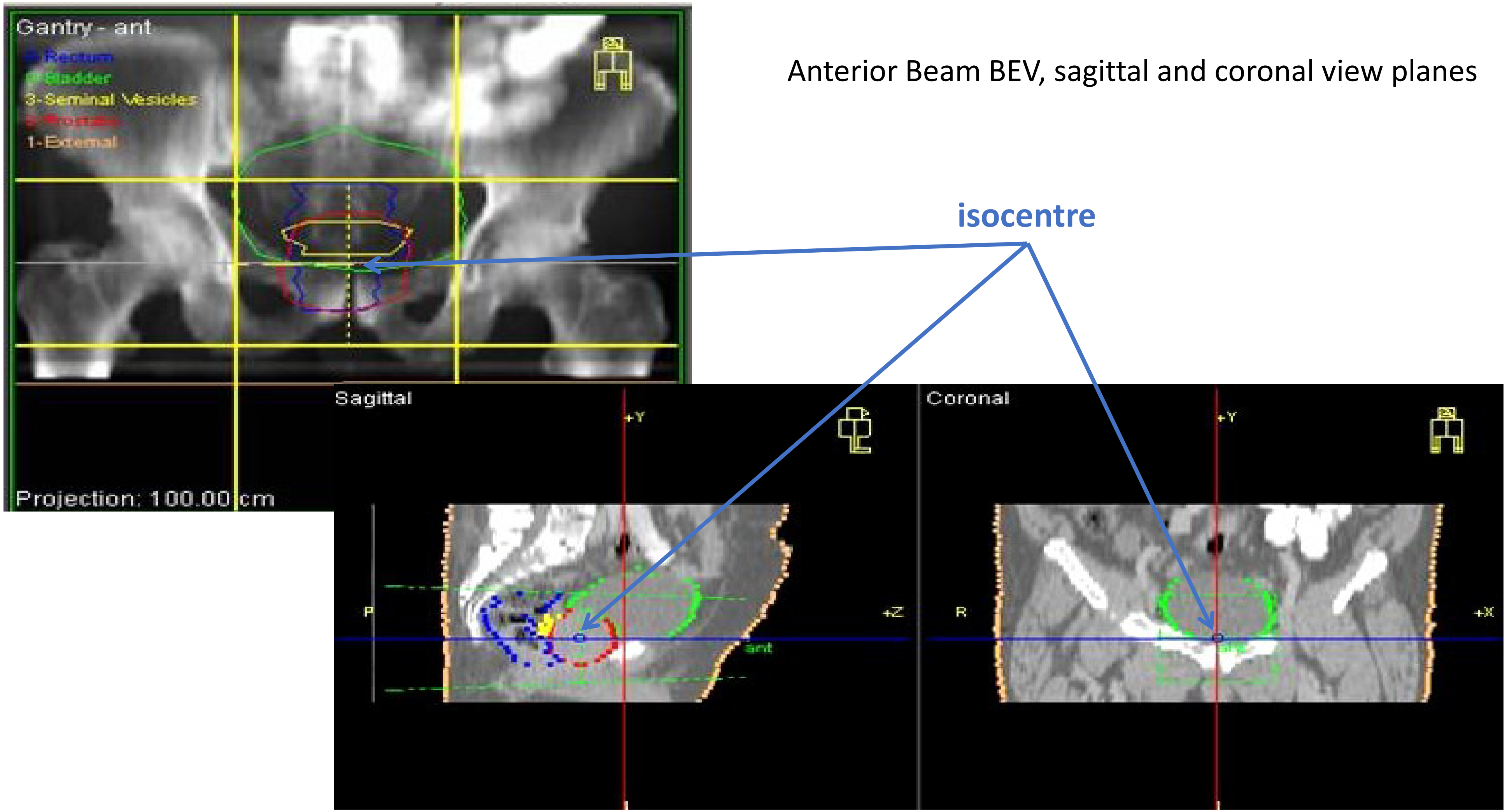
Step-by-step prostate plan

Place an anterior beam (Gantry at 0°) to the centre of prostate



Step-by-step prostate plan

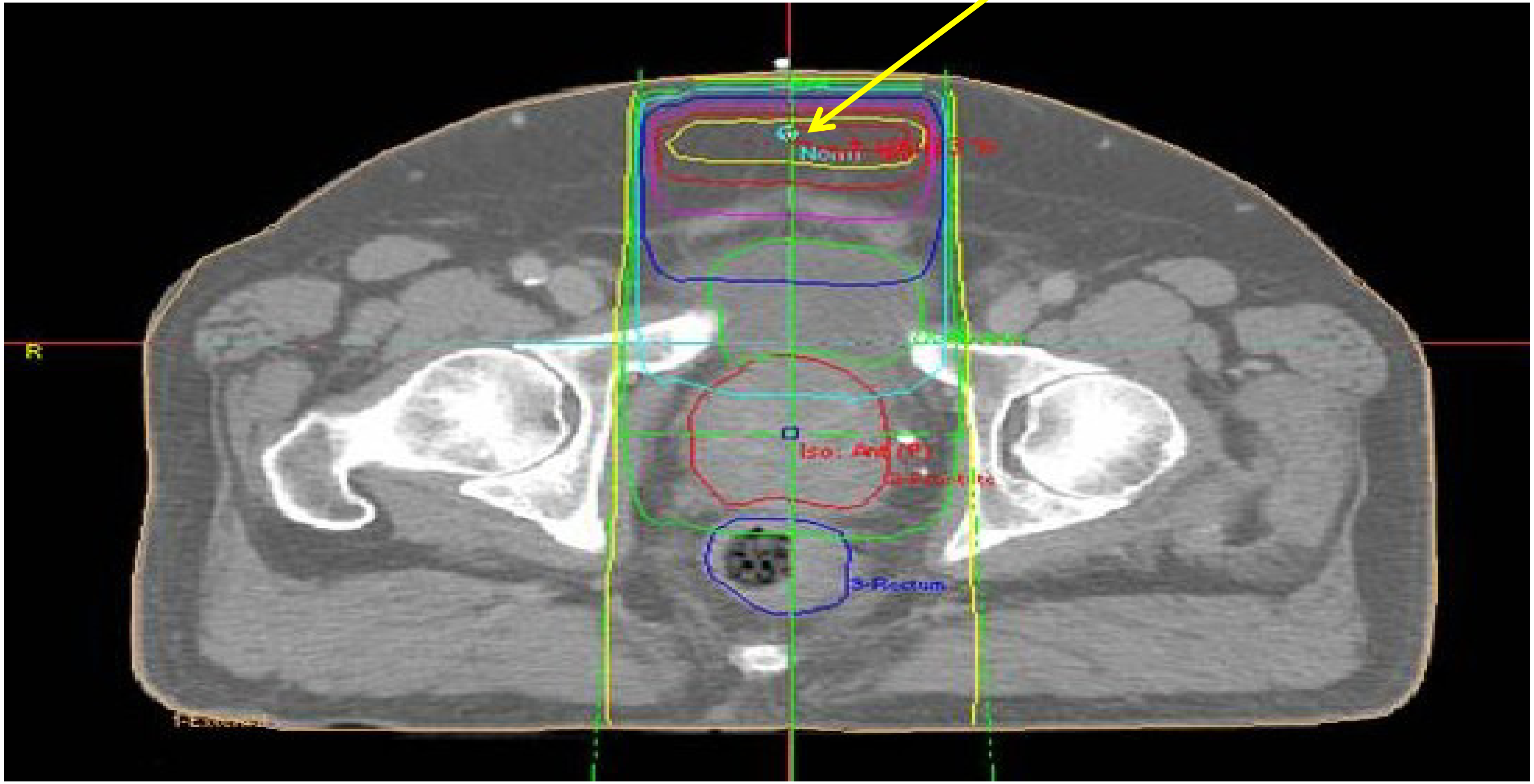
Anterior Beam BEV, sagittal and coronal view planes



Step-by-step prostate plan

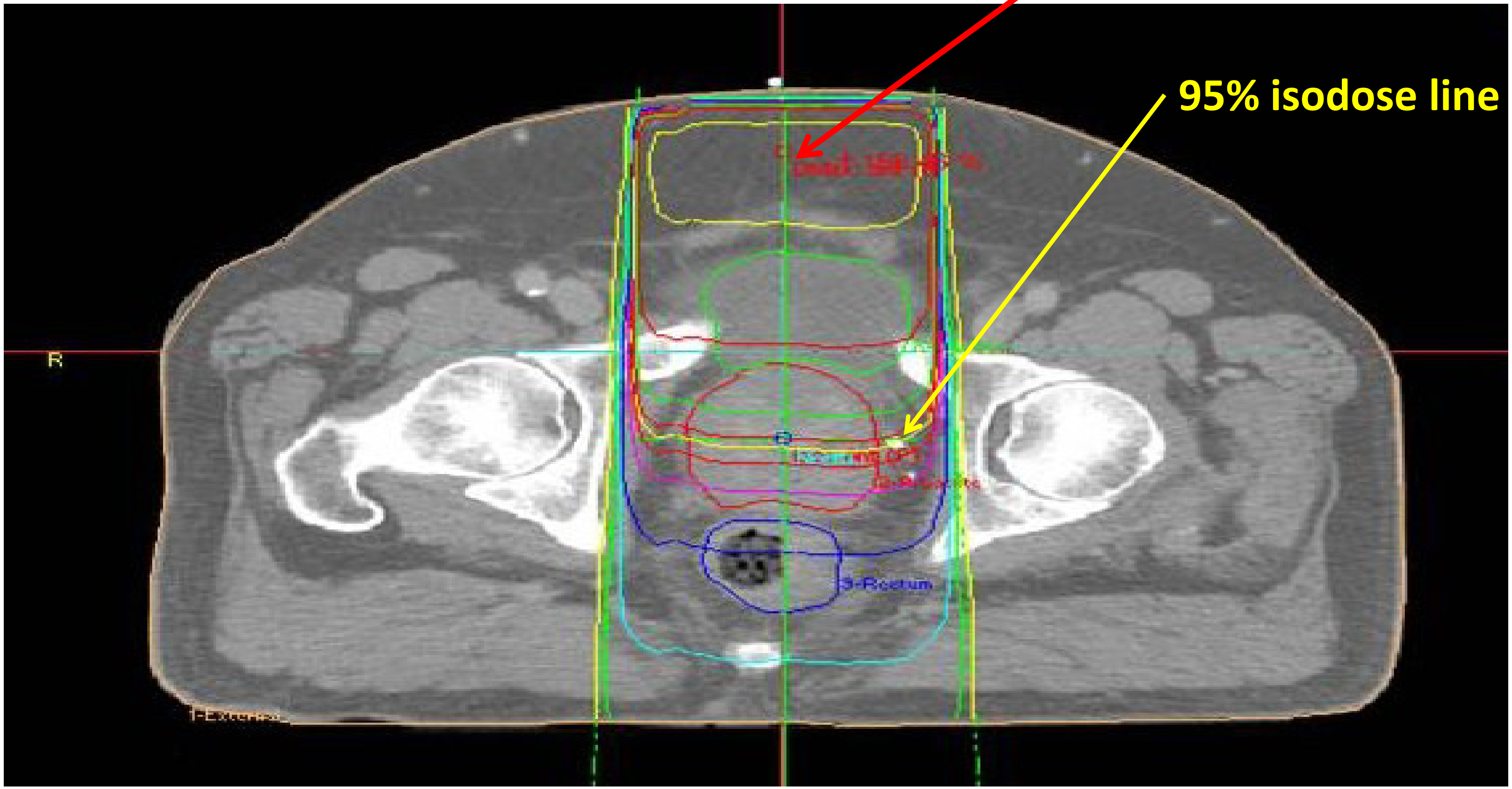
Dmax

Anterior Beam dose, normalised at d $_{max}$



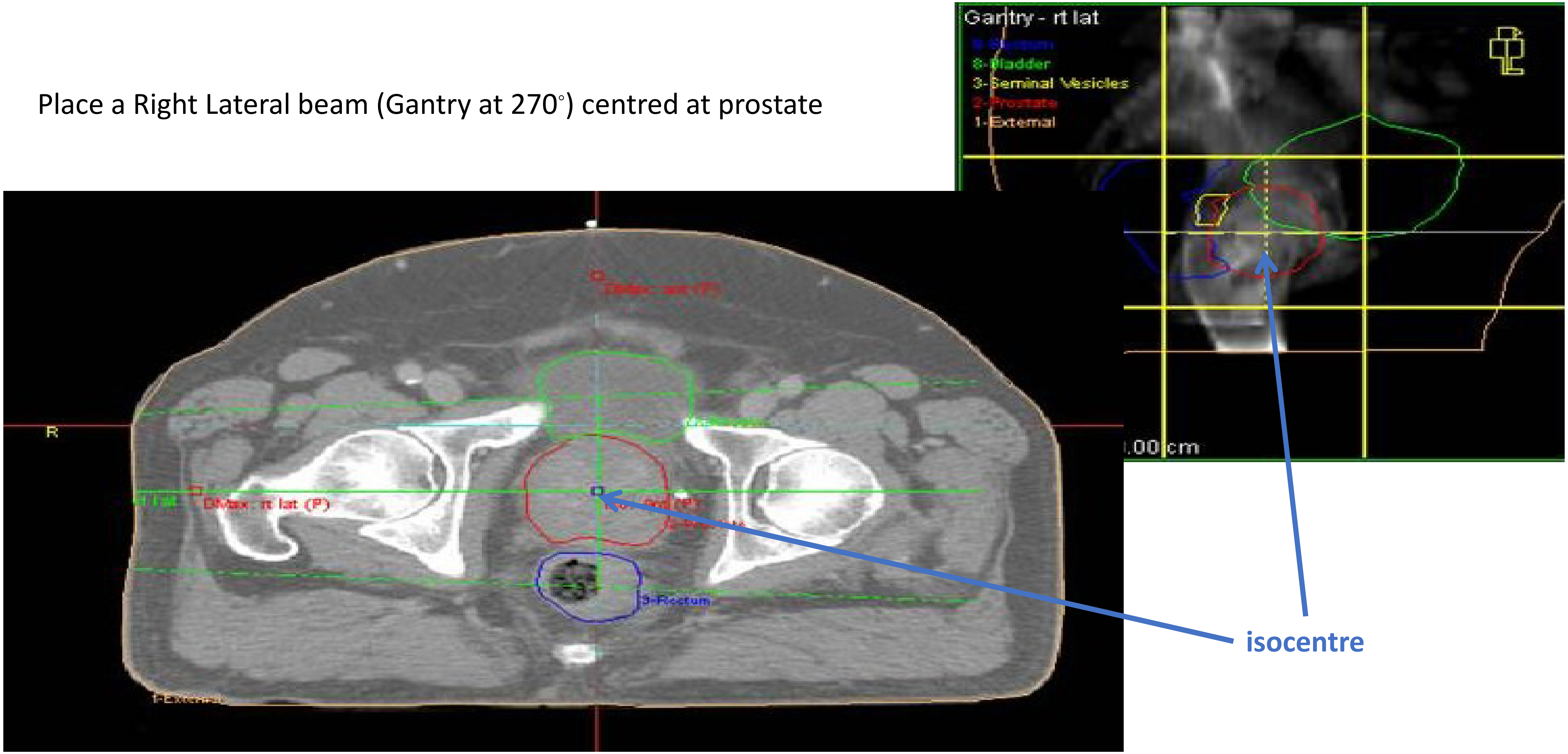
Step-by-step prostate plan

Anterior Beam dose, normalised at isocentre



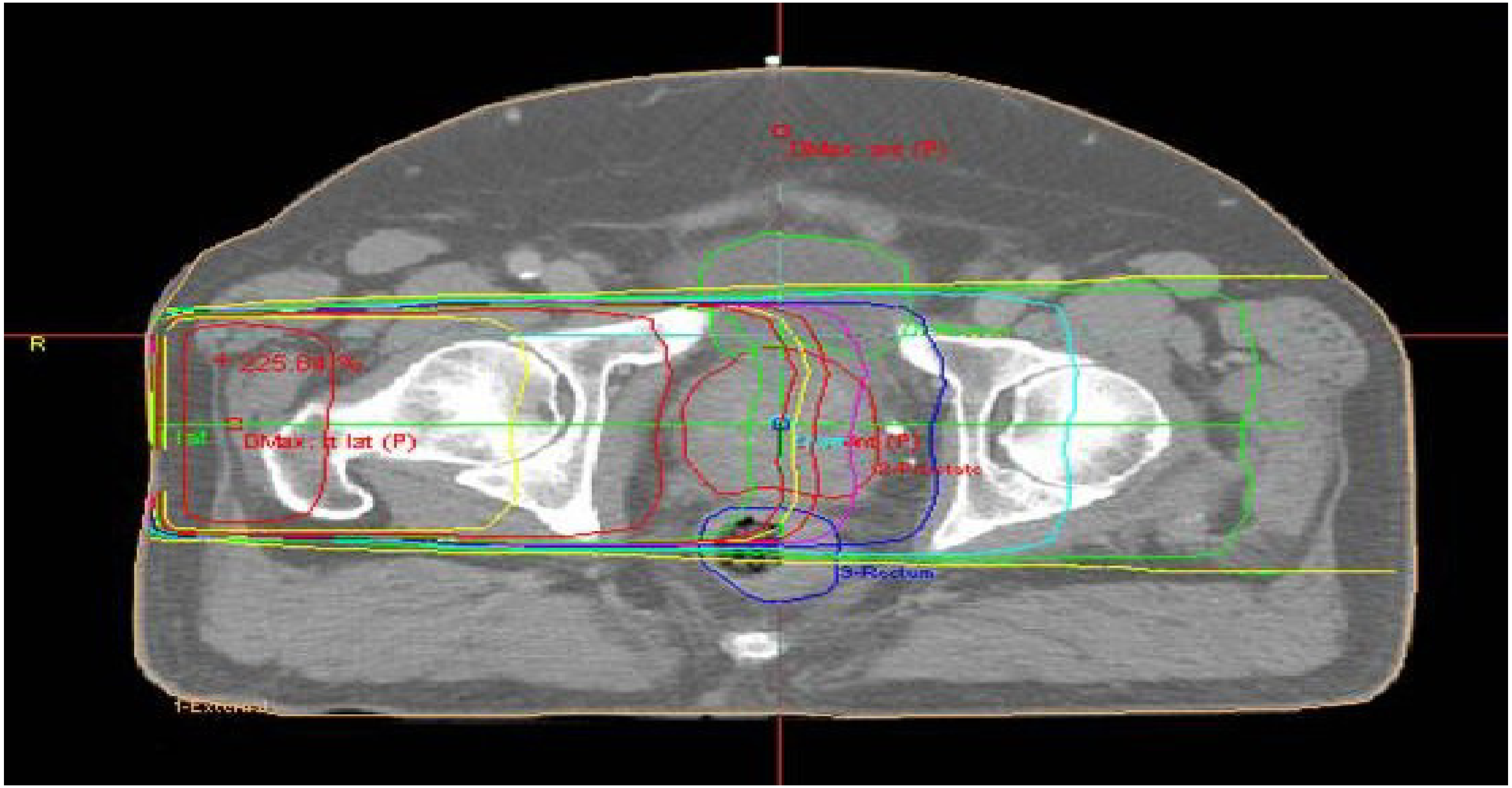
Step-by-step prostate plan

Place a Right Lateral beam (Gantry at 270°) centred at prostate



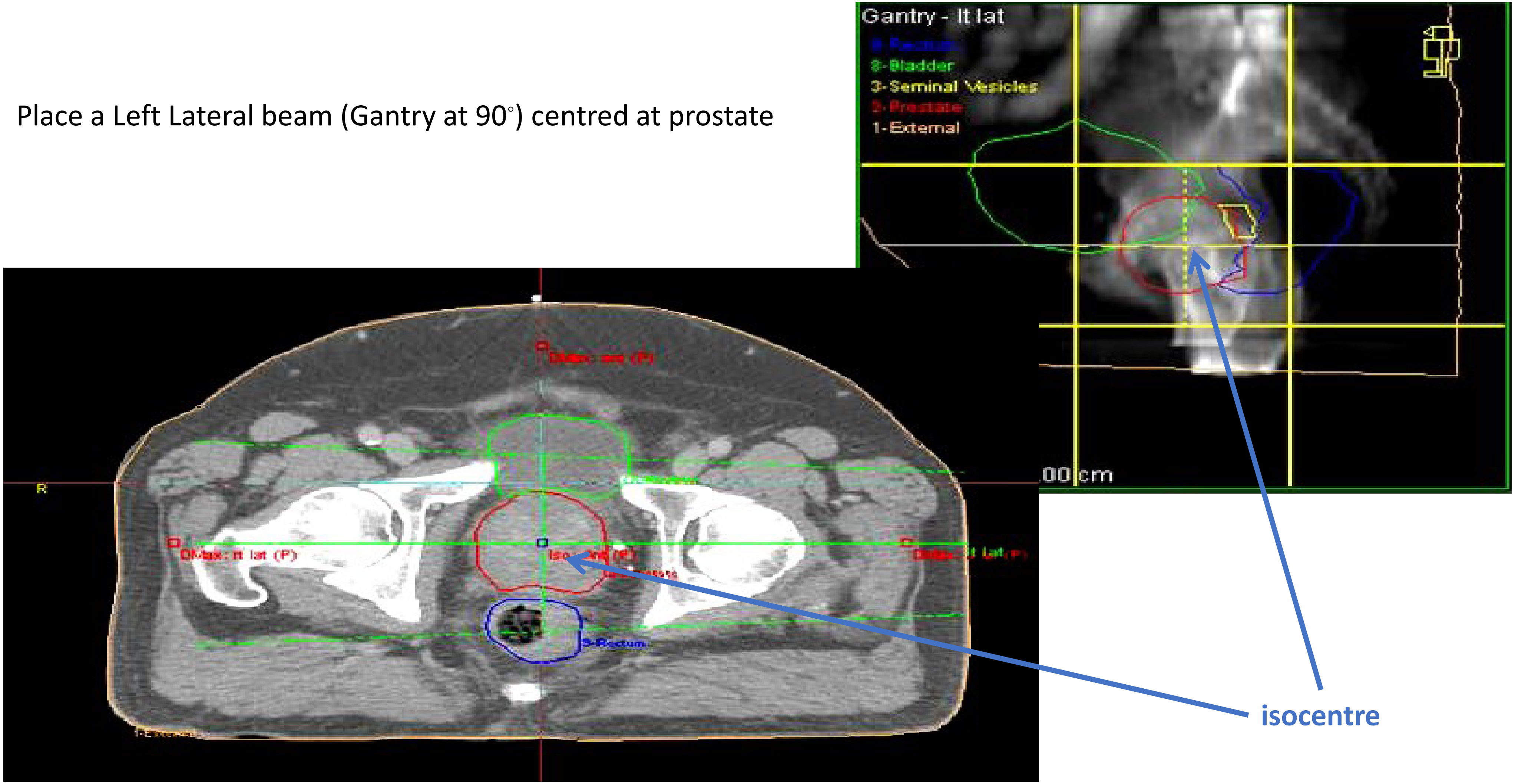
Step-by-step prostate plan

Normalise Right Lateral Beam dose at isocentre



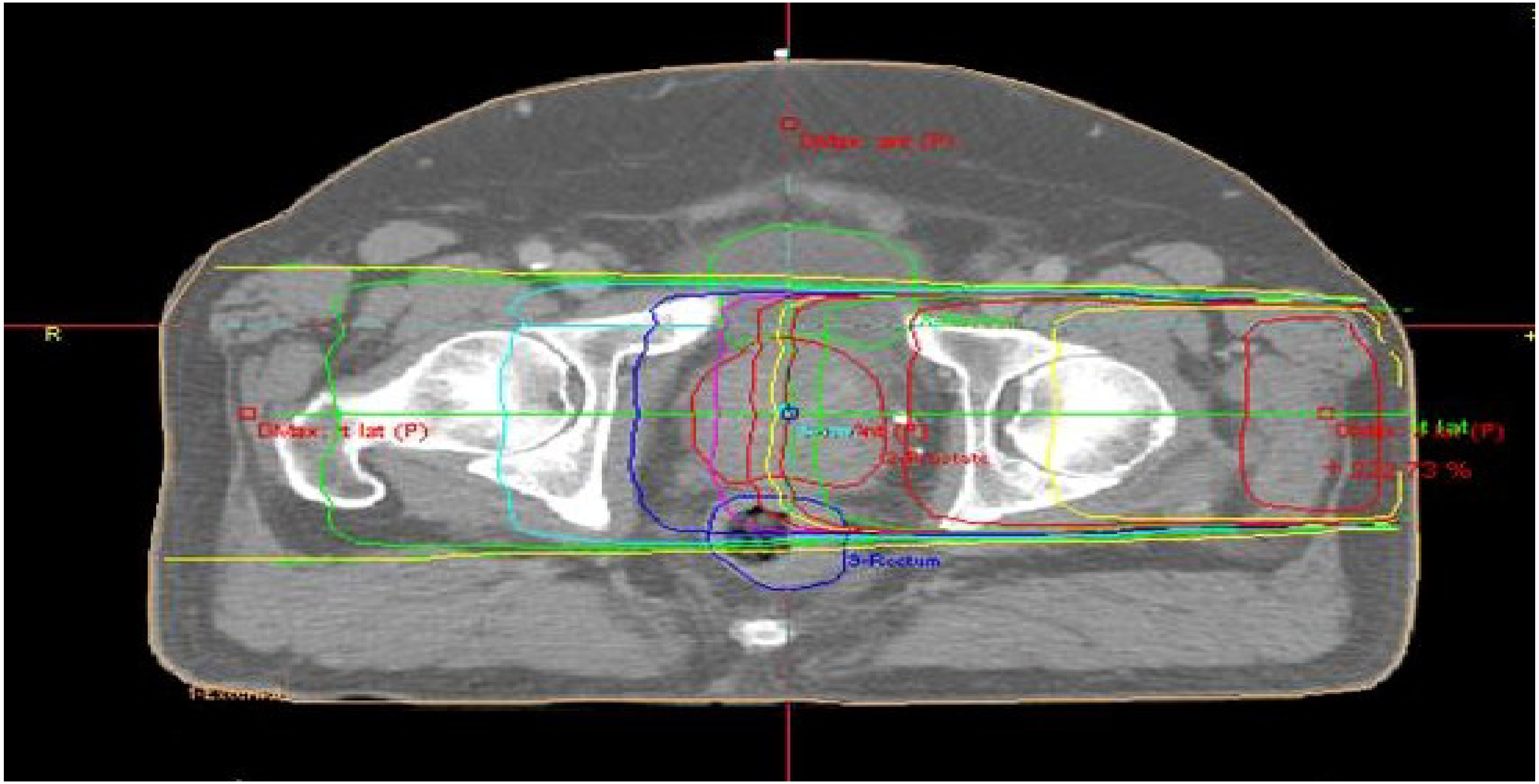
Step-by-step prostate plan

Place a Left Lateral beam (Gantry at 90°) centred at prostate



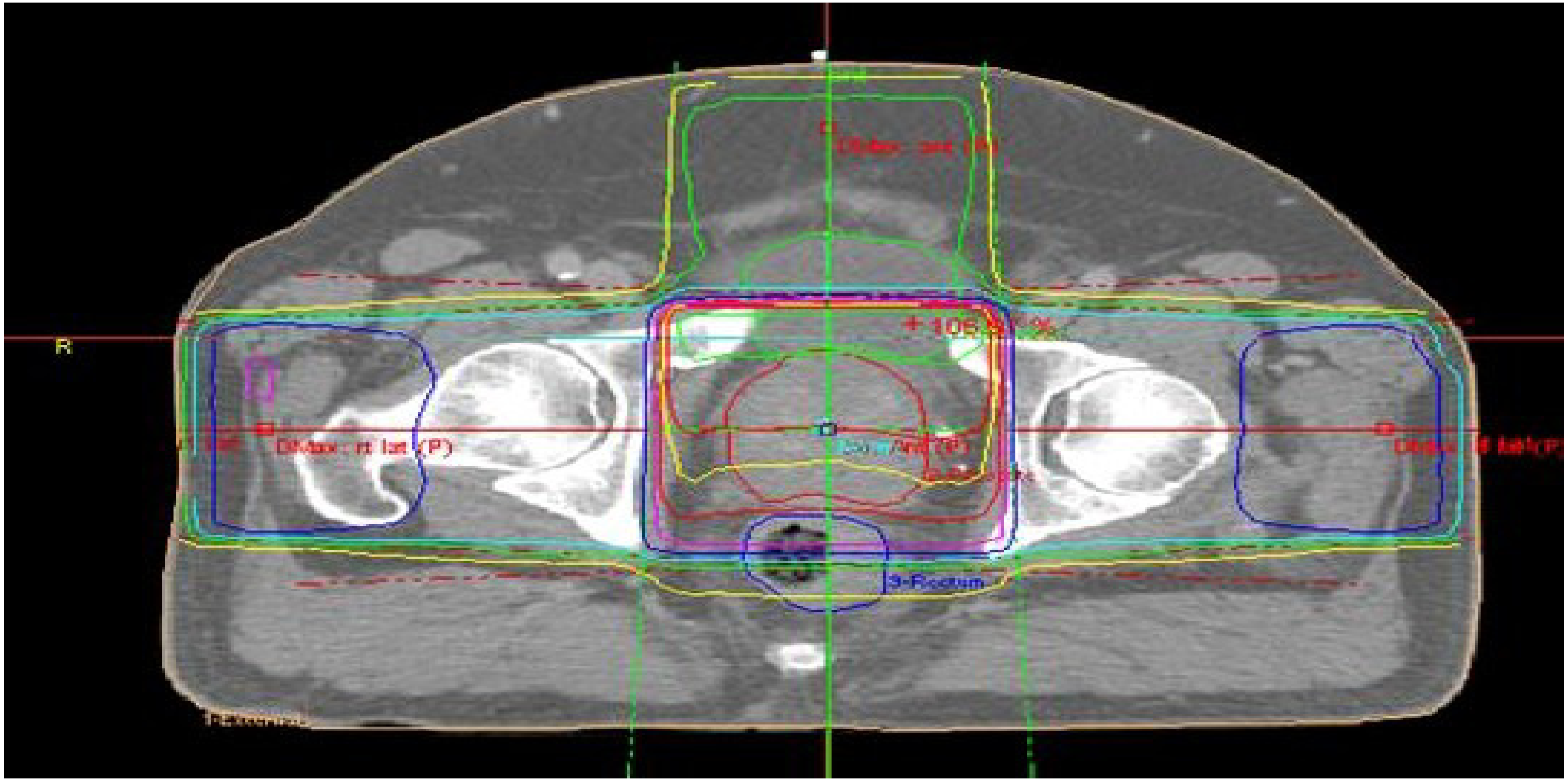
Step-by-step prostate plan

Normalise Left Lateral Beam dose at isocentre



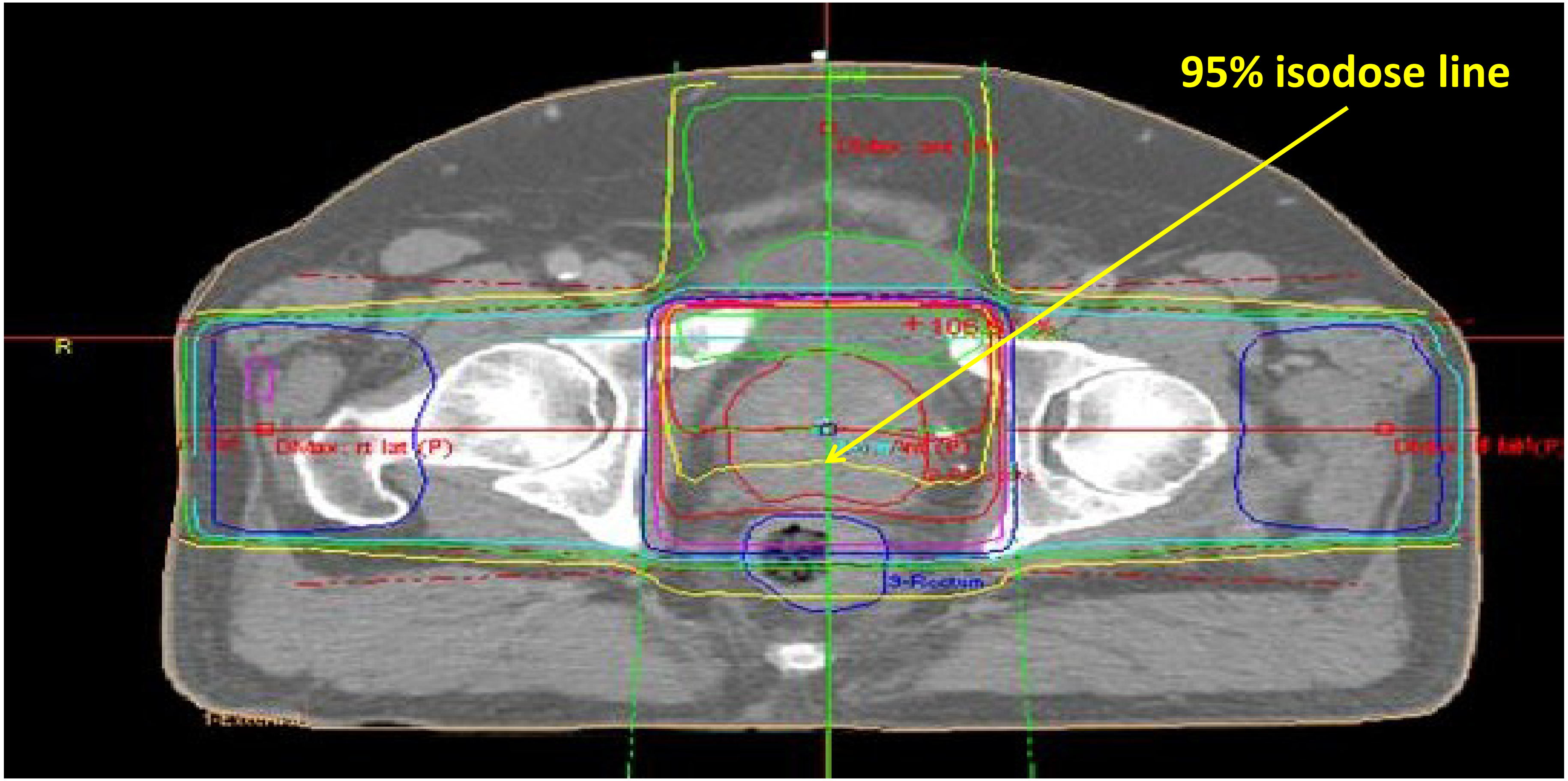
Step-by-step prostate plan

Add dose from all beams



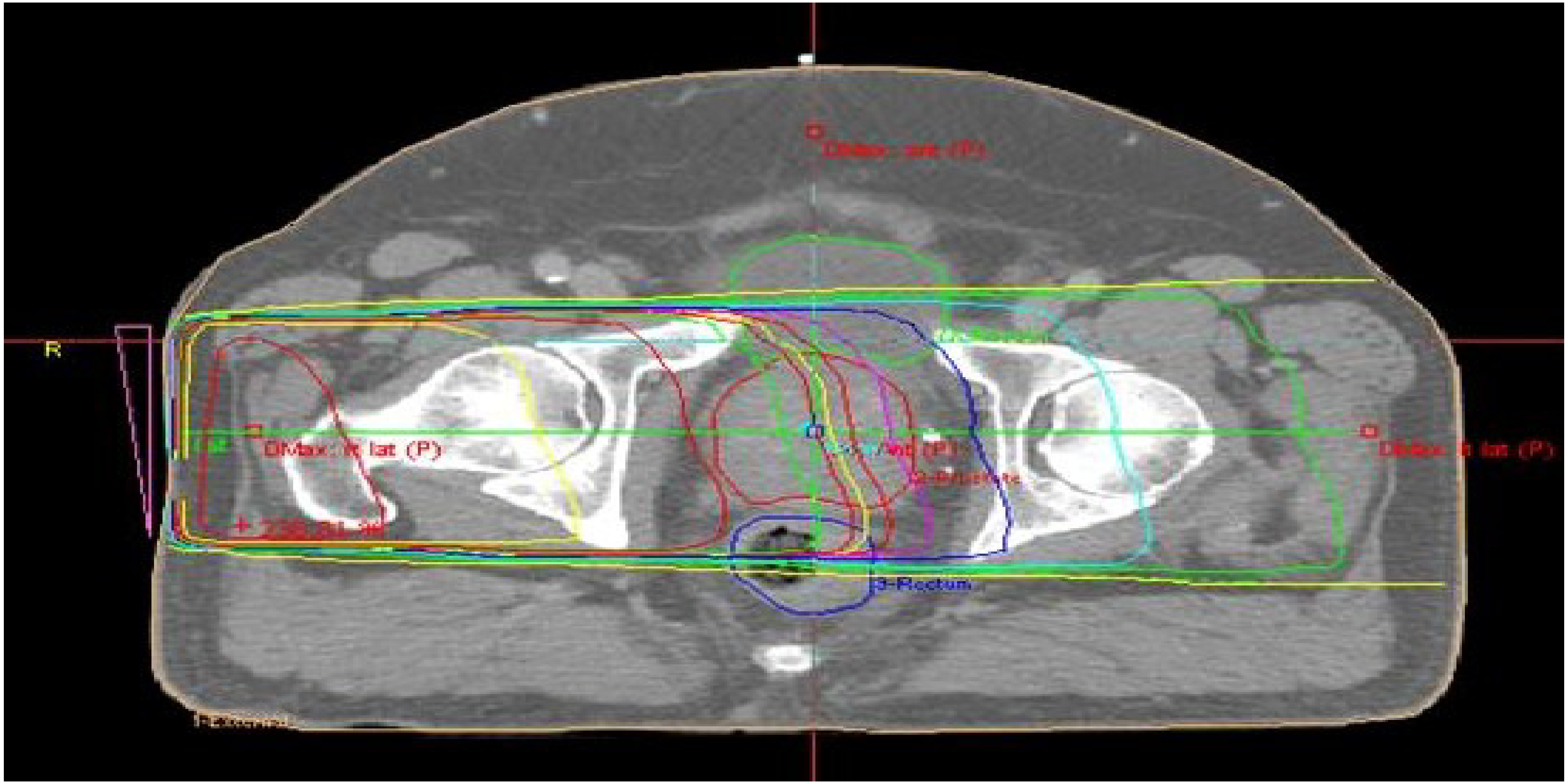
Step-by-step prostate plan

Add dose from all beams



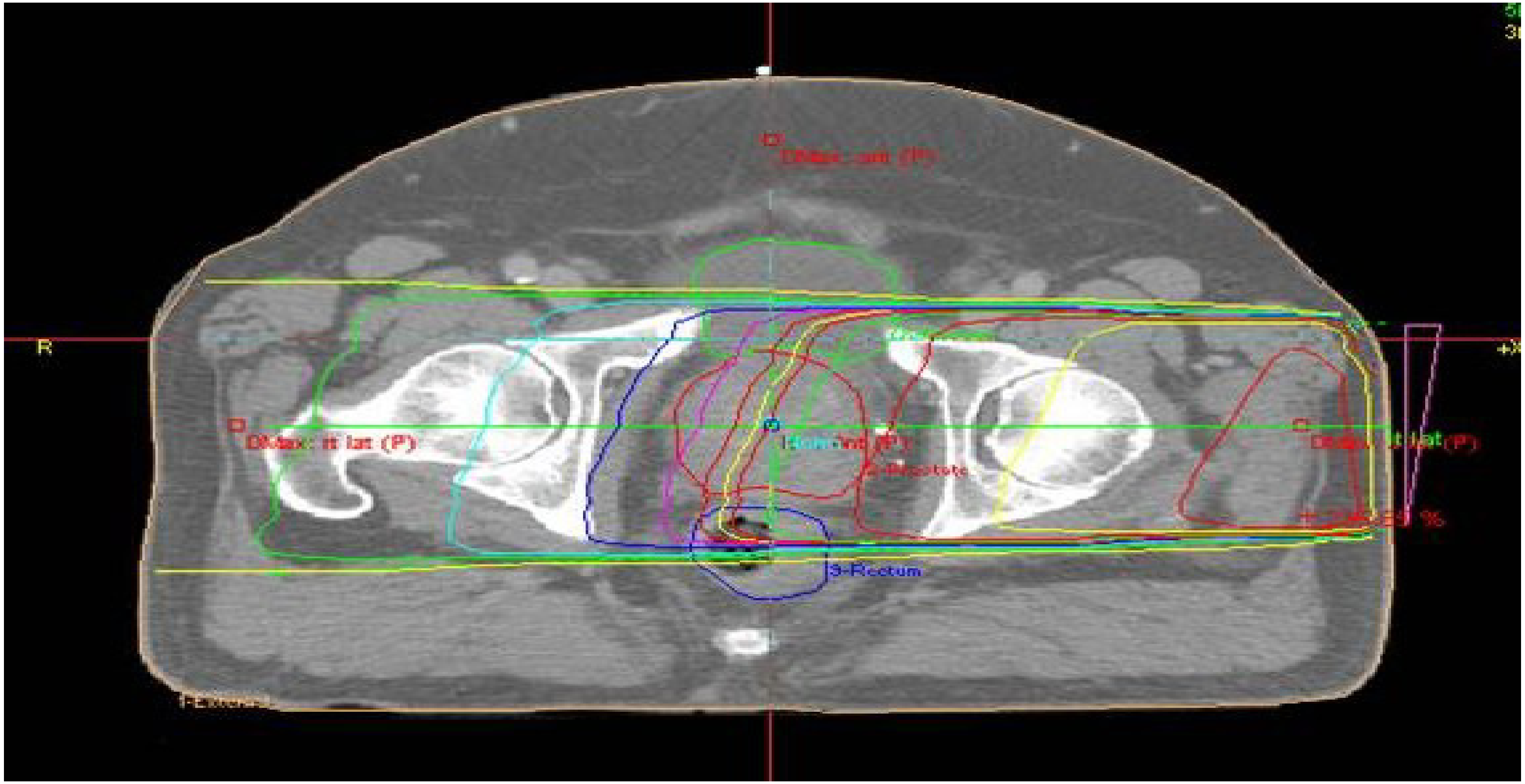
Step-by-step prostate plan

Add a wedge to the Right Lateral Beam



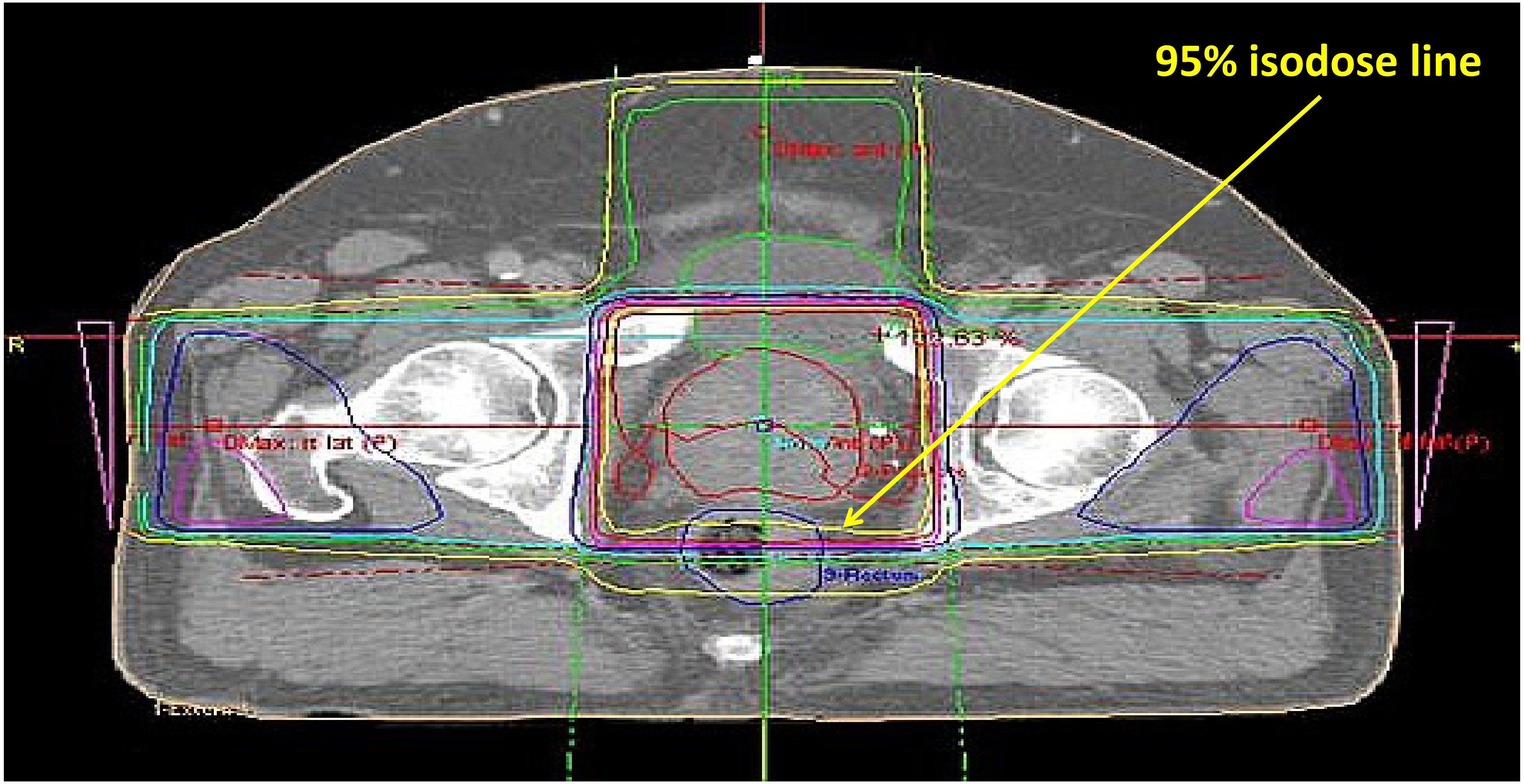
Step-by-step prostate plan

Add a wedge to the Left Lateral Beam



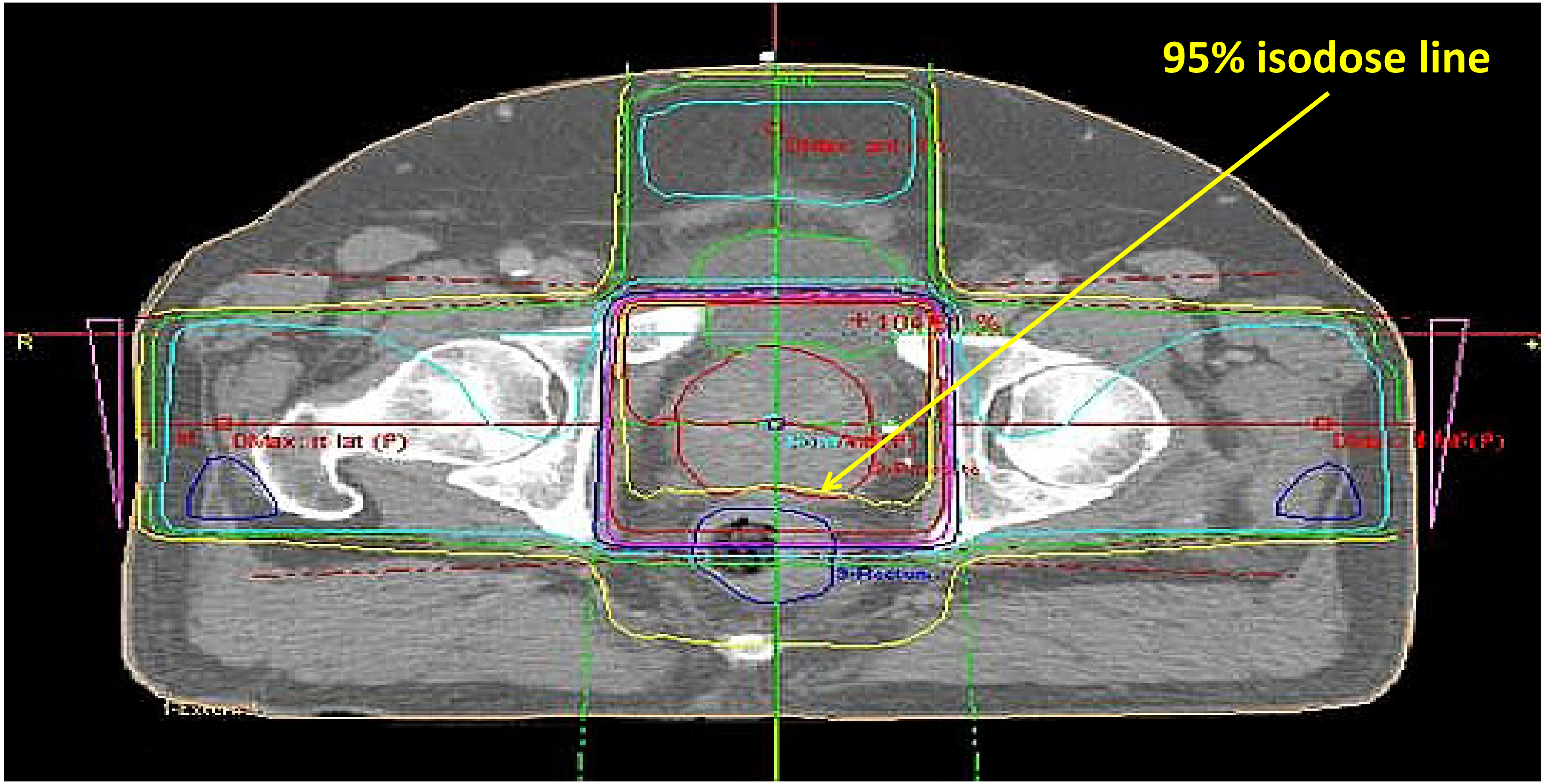
Step-by-step prostate plan

Dose addition of all beams, normalised at isocentre



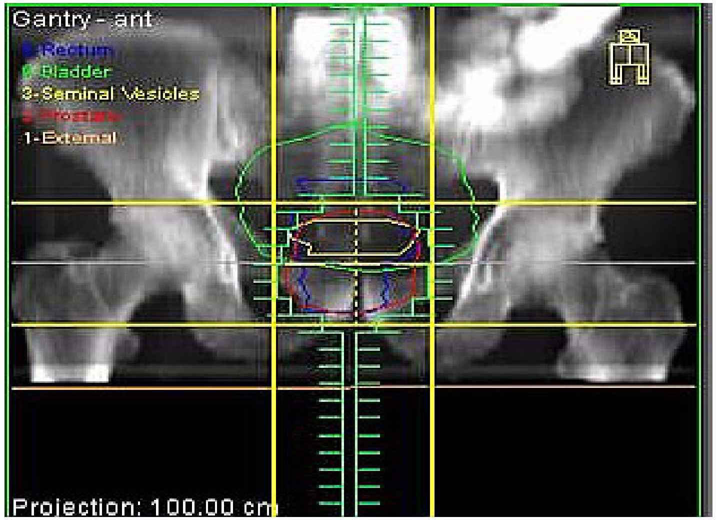
Step-by-step prostate plan

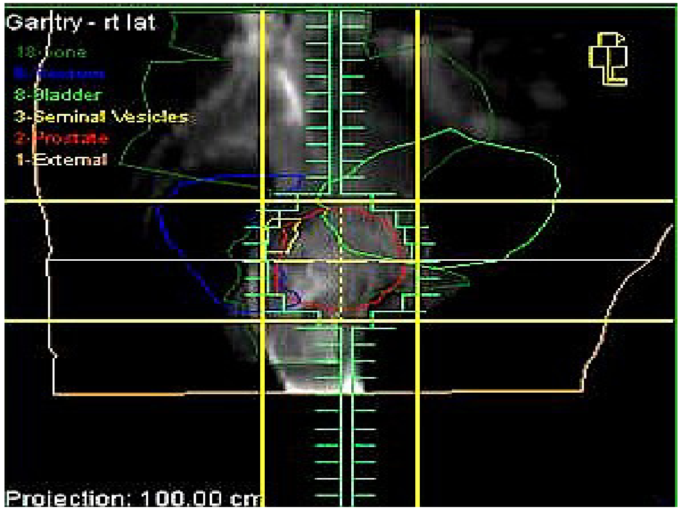
Dose addition of all beams, weights adjusted to improve confirmity

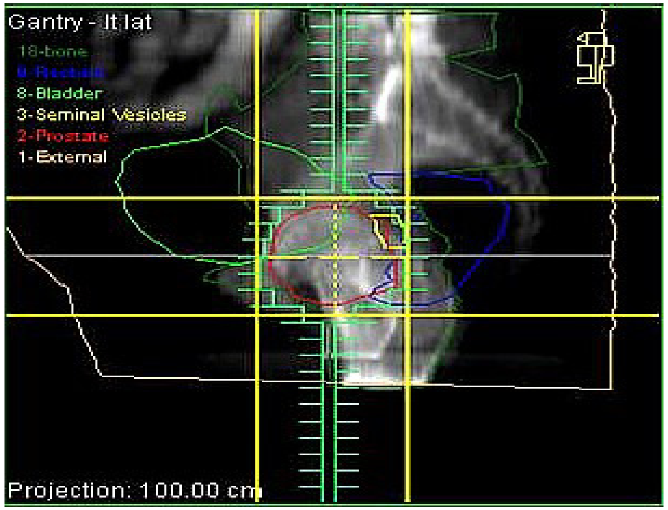


Step-by-step prostate plan

Conform Beams’ MLCs to the shape of the prostate

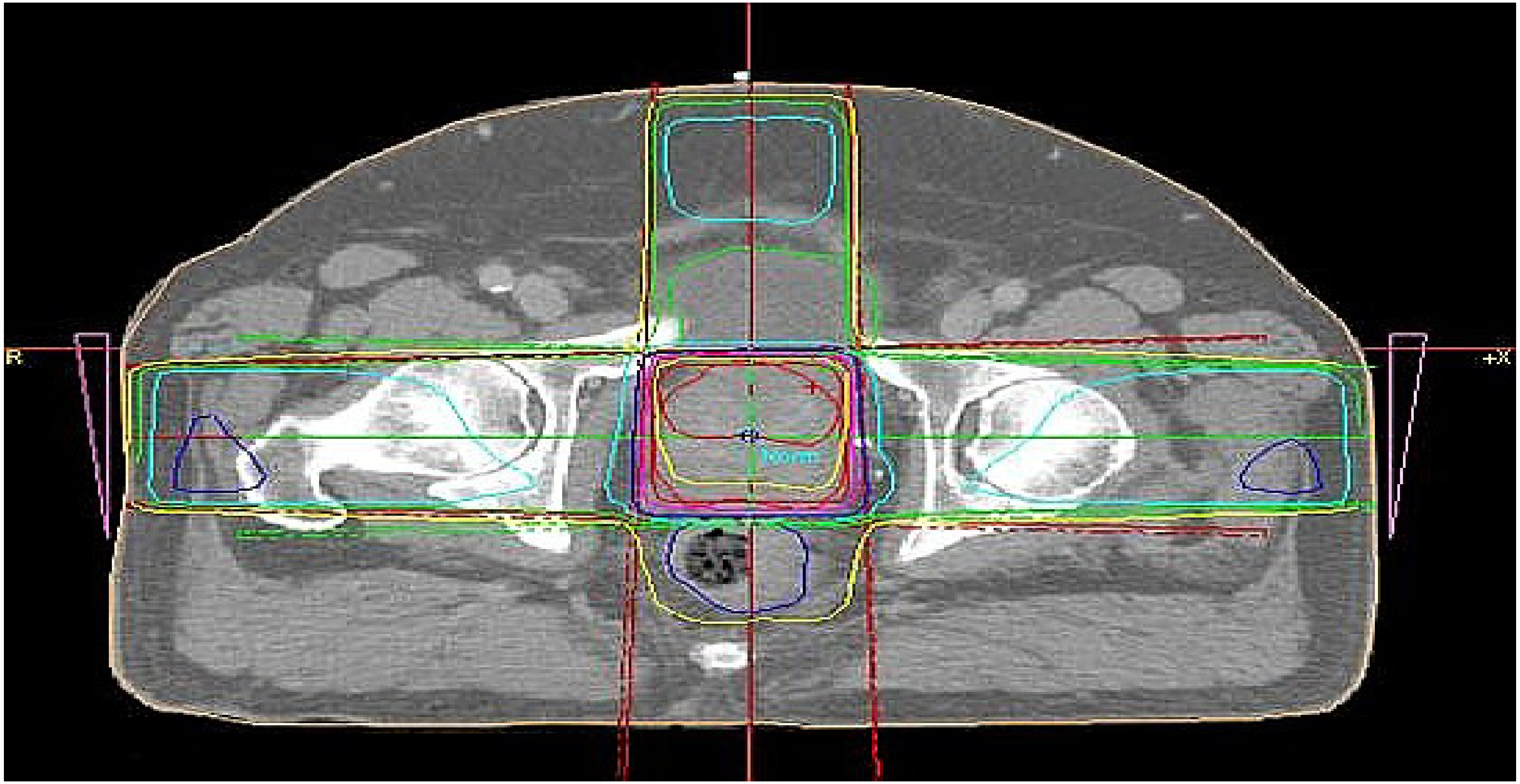






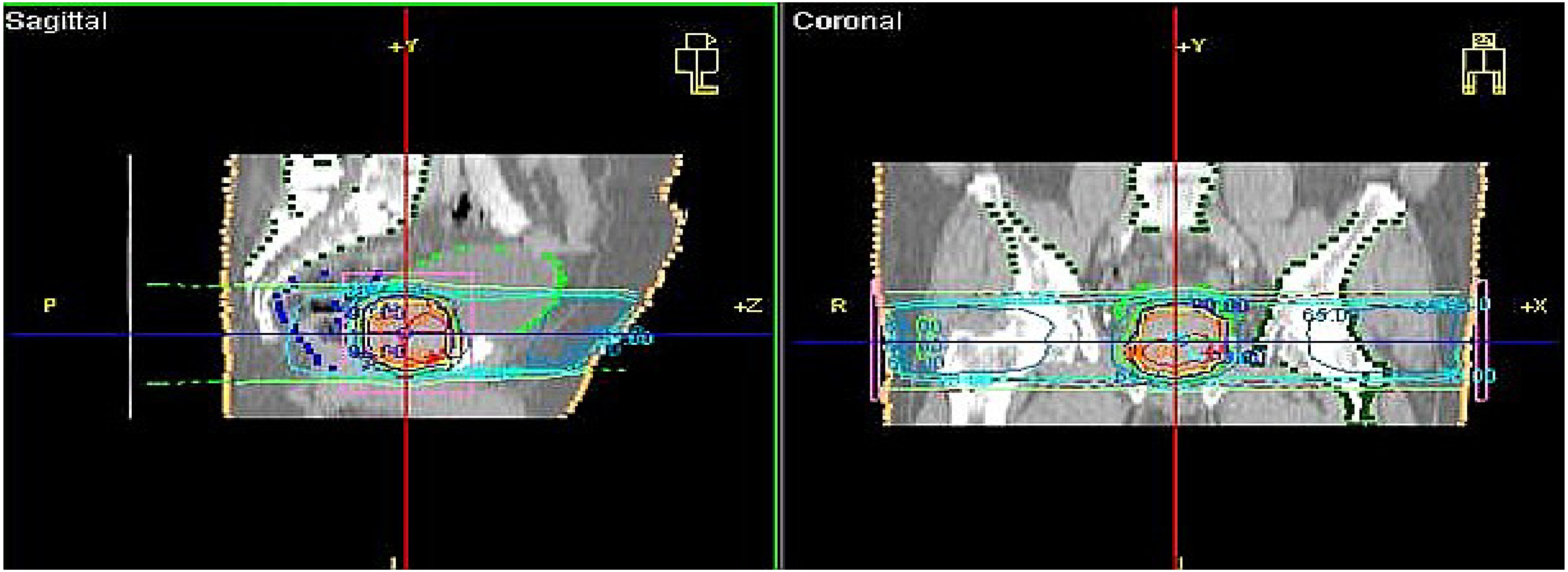
Step-by-step prostate plan

Dose addition of wedged beams with MLCs

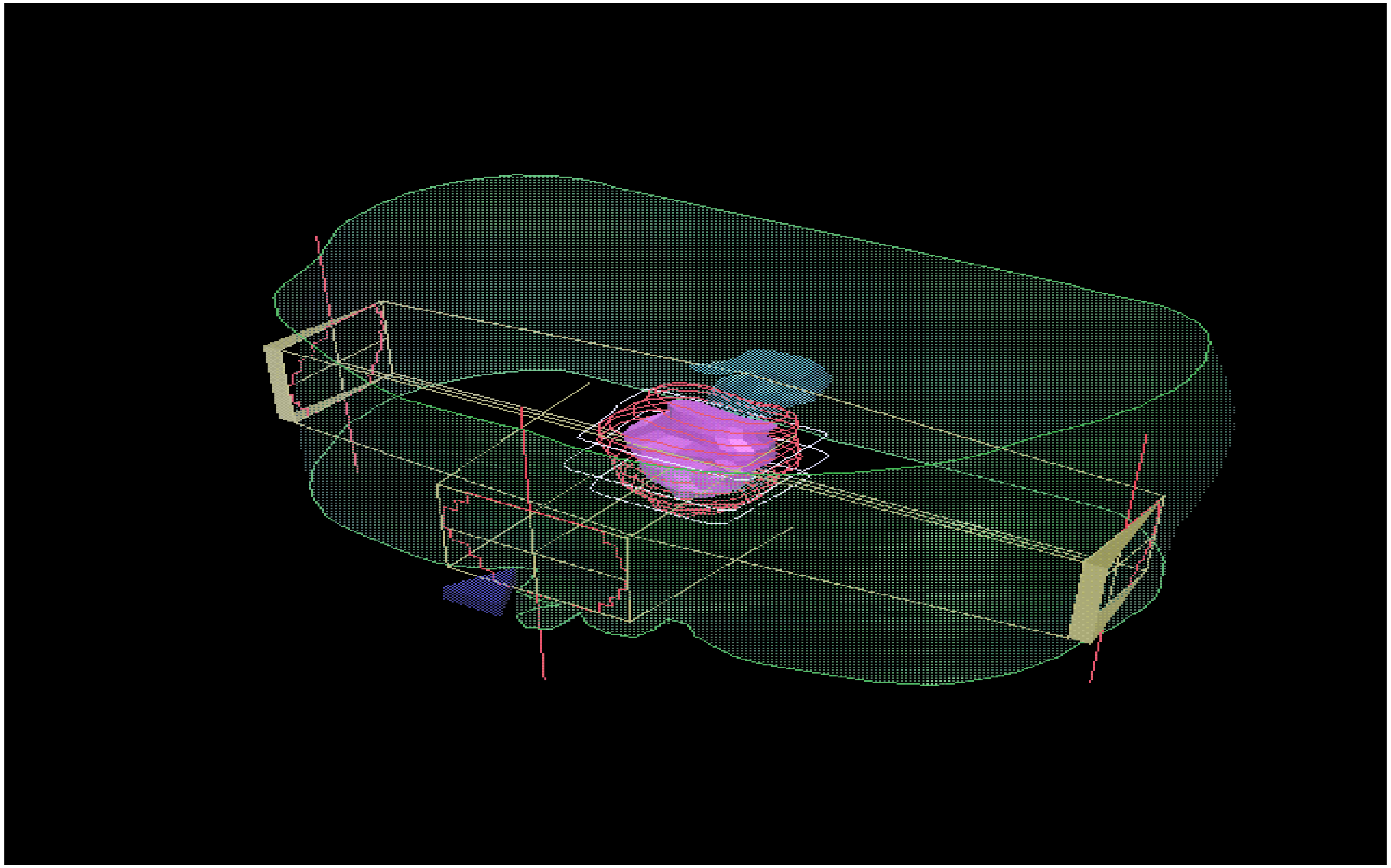


Step-by-step prostate plan

Dose addition of wedged beams with MLC, other planes



3-D Visualisation



Forward planning steps summary

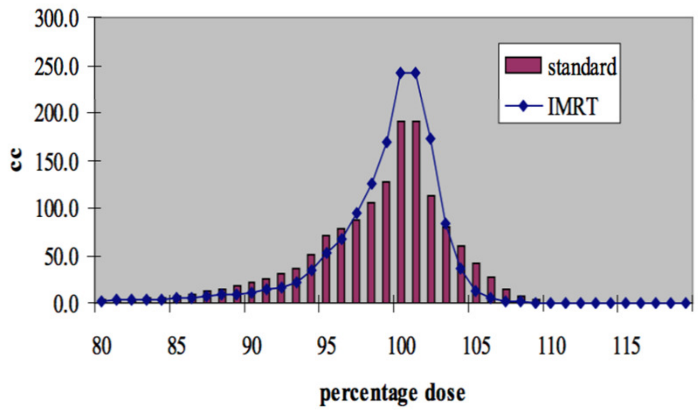
- Choose energy
- Choose beam direction
- Normalise beam
- Repeat; other beams directions
- Cover PTV
- Change collimator angle (optional)
- Add wedges (optional)
- Make uniform the dose distribution to PTV
- Optimise beam weighting
- Conform beam to shape (MLCs)
- Minimise dose to OARs and remaining healthy tissue (body)

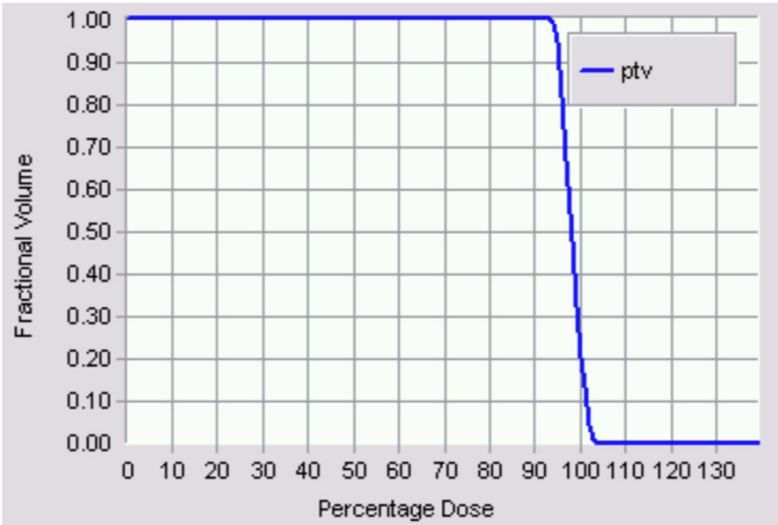
Forward planning; critique?

- Time & efficiency
- Difficulty
- Keeping track of parameters vis-à-vis Dose Distribution
- Dose distribution shape limitations & OAR sparing

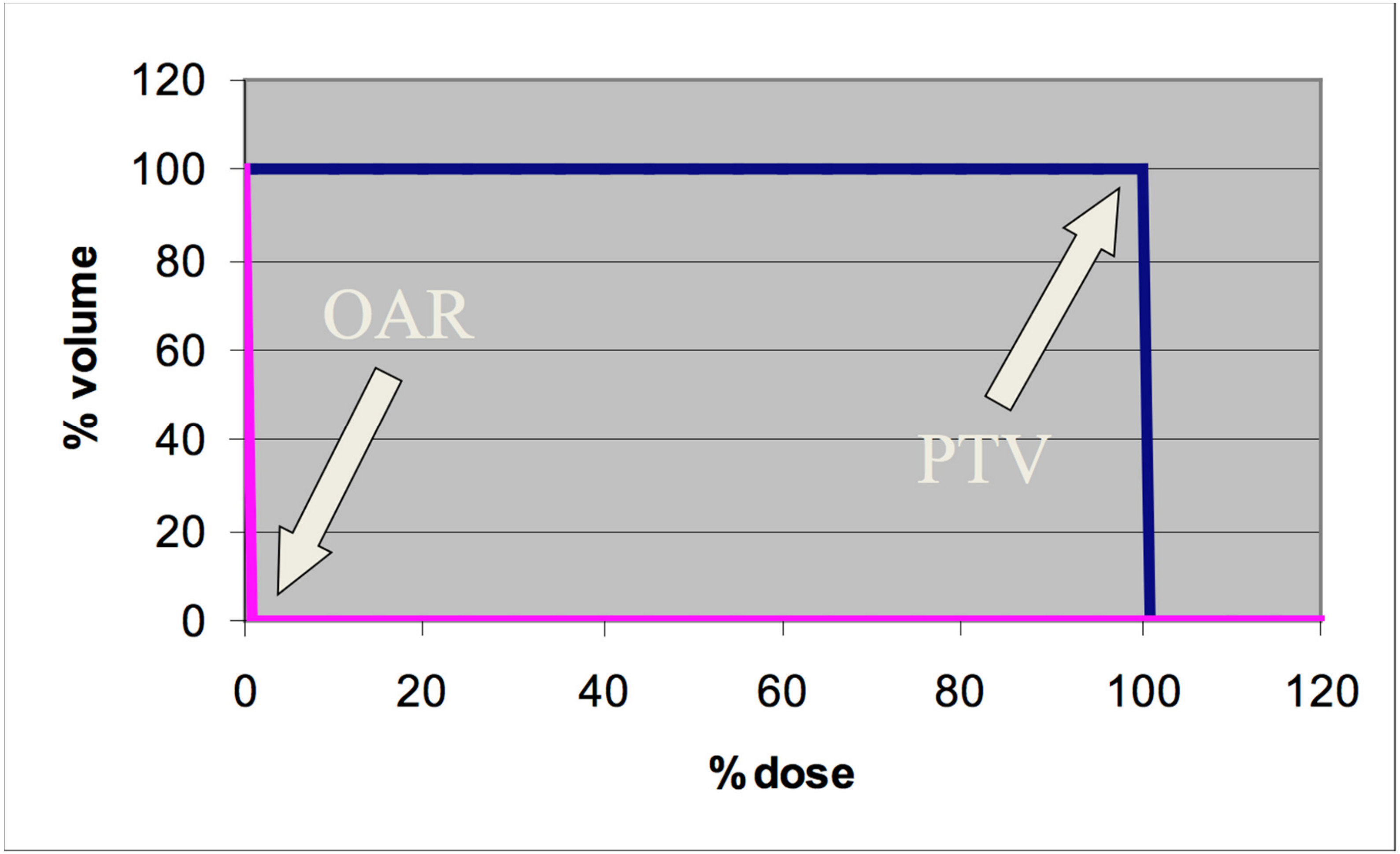
Dose-Volume Histograms

- A **histogram** that displays the amount of **dose** is received by a certain **volume** of a particular “structure” (target or OAR)
- Dose or volume can be displayed in either absolute (e.g. Gy, cc) or relative (%) units
- Differential or cumulative plots

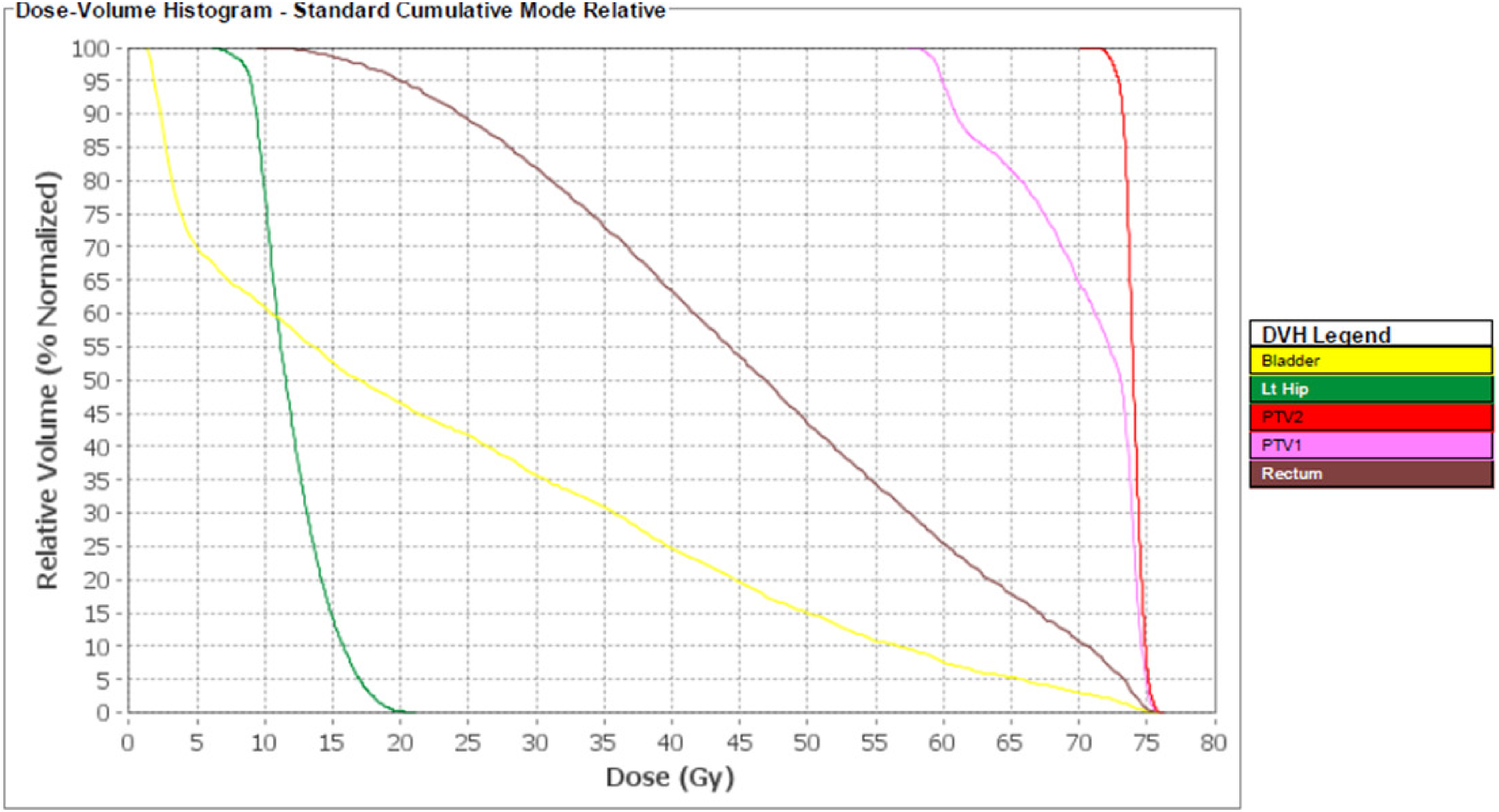




Perfect world DVH



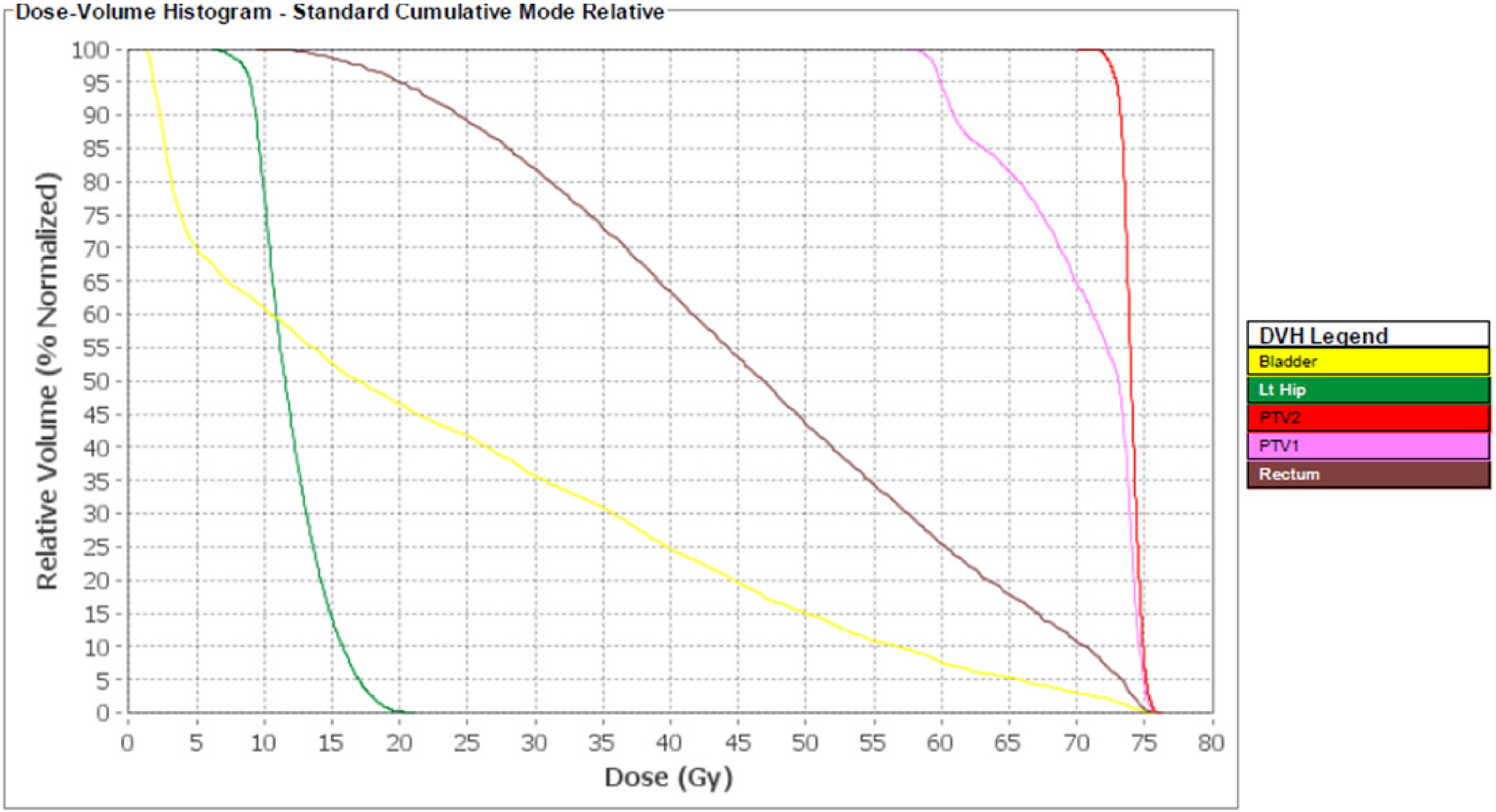
Real life DVH example – prostate plan



DVH Example – info “mining”

- What is the max dose received by Lt Hip?
- What is the mean dose to the bladder?
- What dose was received by 30% of the rectum?
- What do you think was the prescription dose to PTV2?
- What is the max dose received by PTV2?
- If the prescription to PTV2 was 74Gy, what is the percentage max dose PTV2 receives?
- Is this plan acceptable?

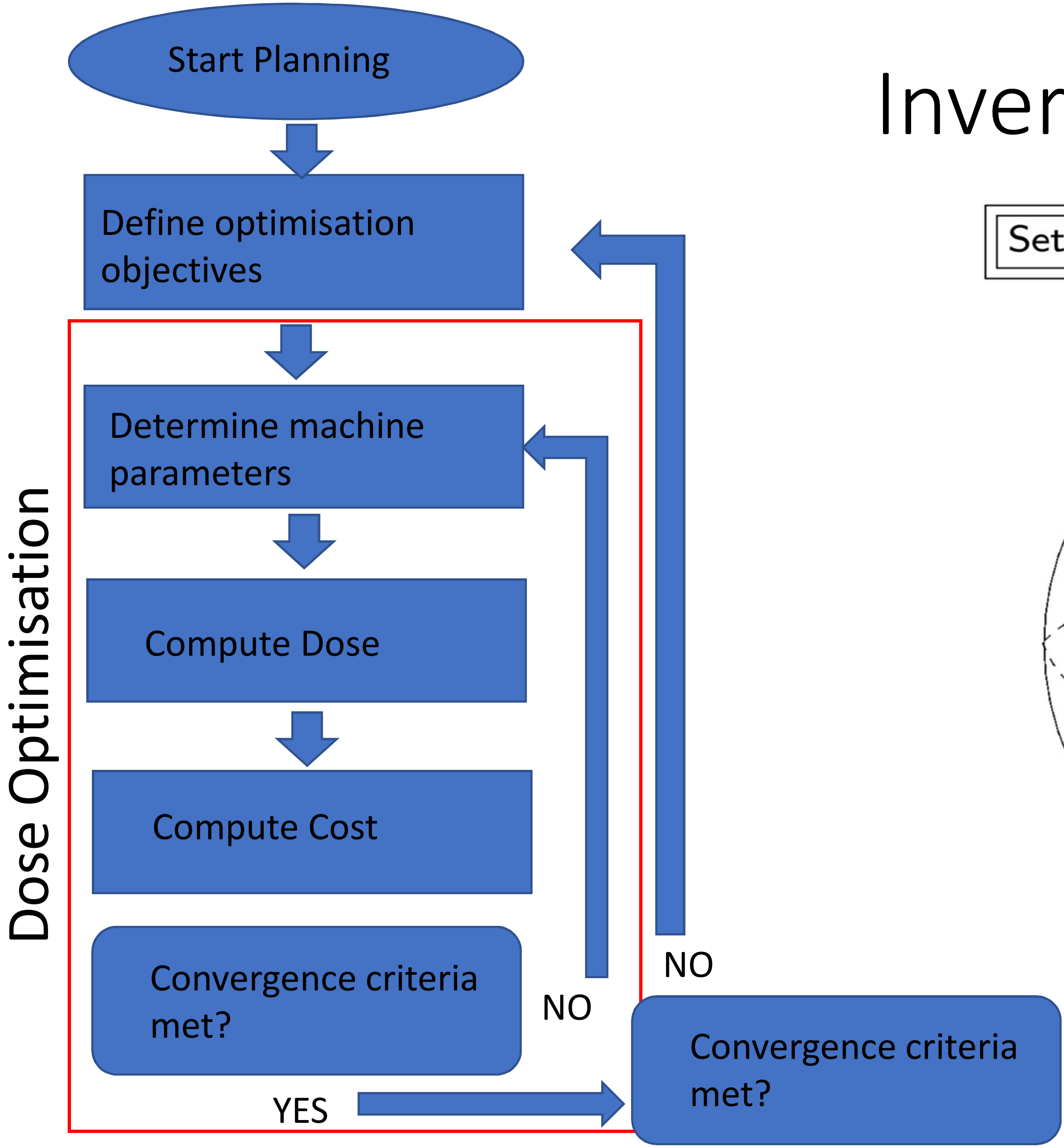
Real life DVH example – prostate plan

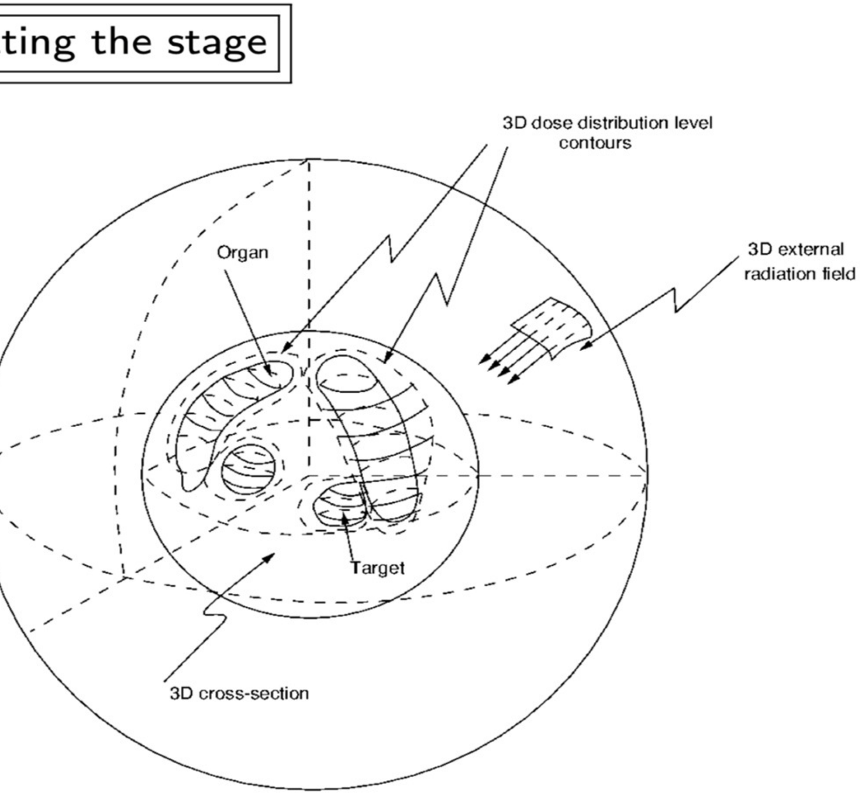


DVH Examples

- What is the max dose received by Lt Hip? Ans = 20Gy
- What is the mean dose to the bladder? Ans = 17Gy
- What dose was received by 30% of the rectum? Ans = 57Gy
- What do you think was the prescription dose to PTV1? Ans = 74Gy
- What is the max dose received by PTV2? Ans = 76Gy
- If the prescription to PTV2 was 74Gy, what is the percentage max dose PTV2 receives? Ans = 103%
- Is this plan acceptable? Yes; PTV dose between 95% - 107%, OAR constraints within tolerance…

Inverse Optimisation





Inverse Optimisation

Start Planning

↓

Define optimisation objectives

Dose Optimisation

↓

Determine machine parameters

↓

Compute Dose

↓

Compute Cost

Convergence criteria met?

NO → Determine machine parameters

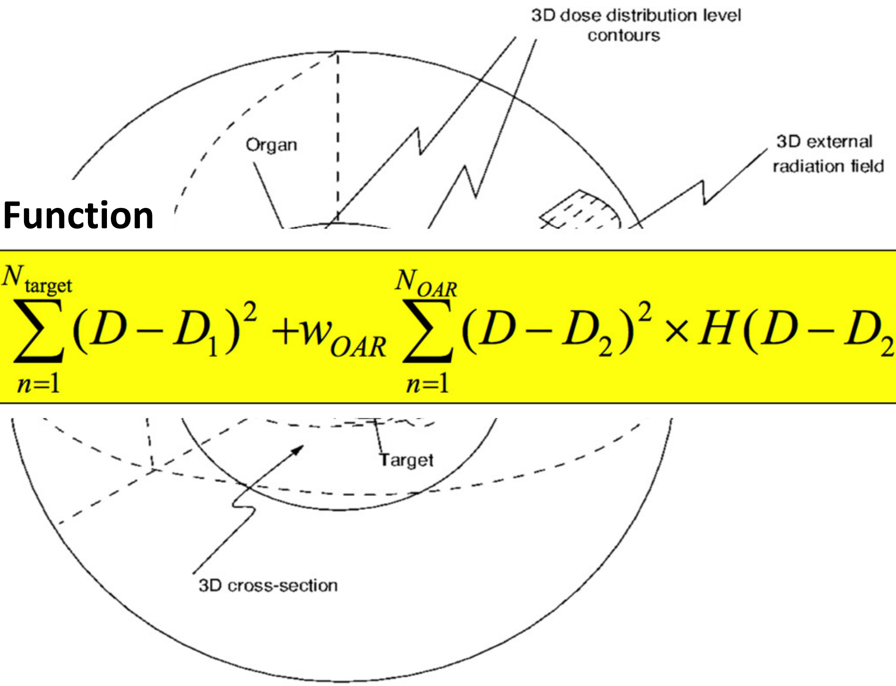
YES →

Convergence criteria met?

NO → Define optimisation objectives

YES → Plan accepted

Setting the stage

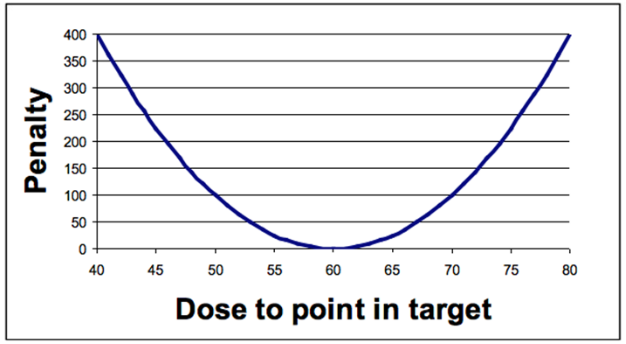


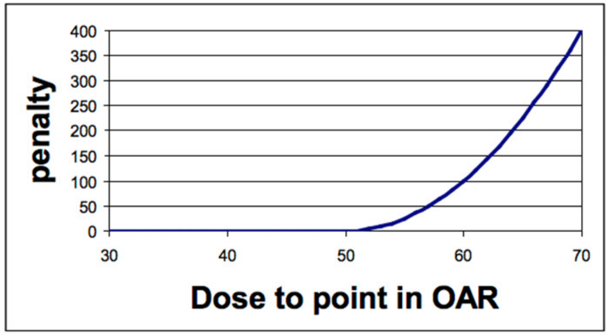
Optimisation Function

$$OF = w_{\text{target}} \sum_{n=1}^{N_{\text{target}}} (D - D_1)^2 + w_{OAR} \sum_{n=1}^{N_{OAR}} (D - D_2)^2 \times H(D - D_2)$$

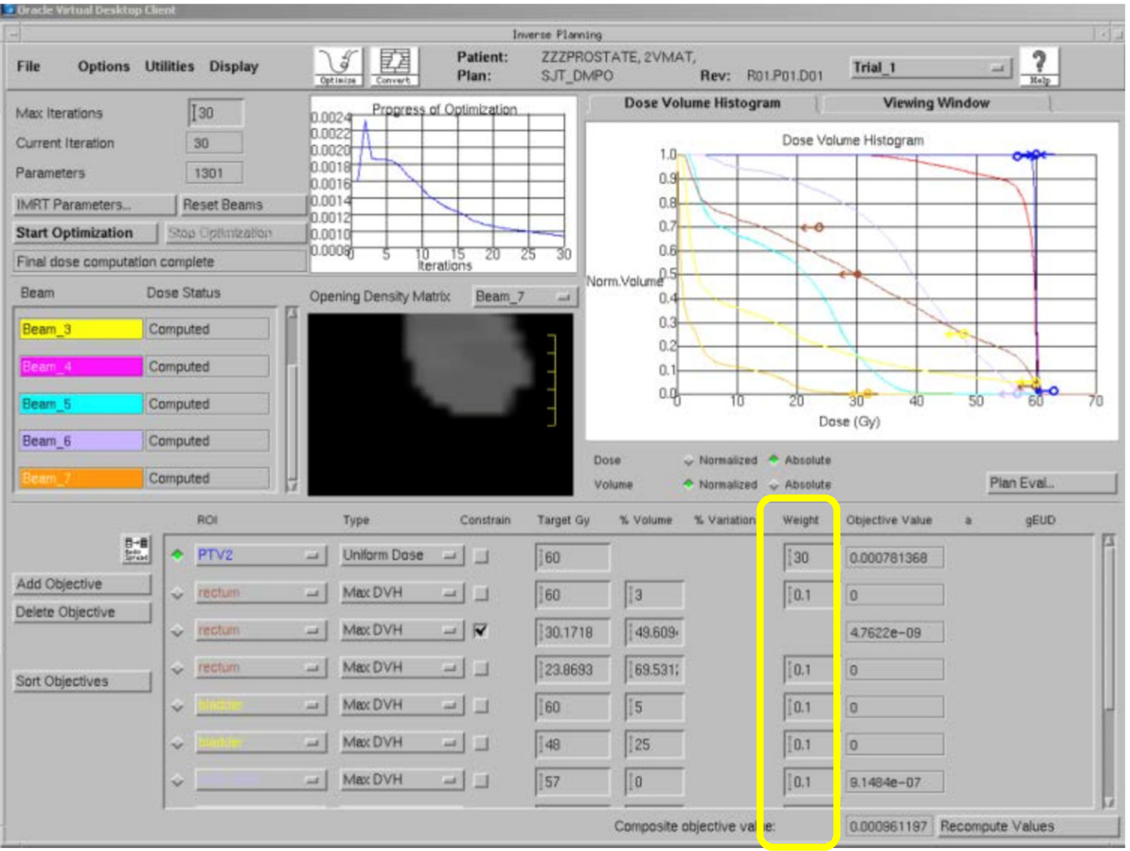
$$OF = w_{\text{target}} \sum_{n=1}^{N_{\text{target}}} (D - D_1)^2 + w_{OAR} \sum_{n=1}^{N_{OAR}} (D - D_2)^2 \times H(D - D_2)$$

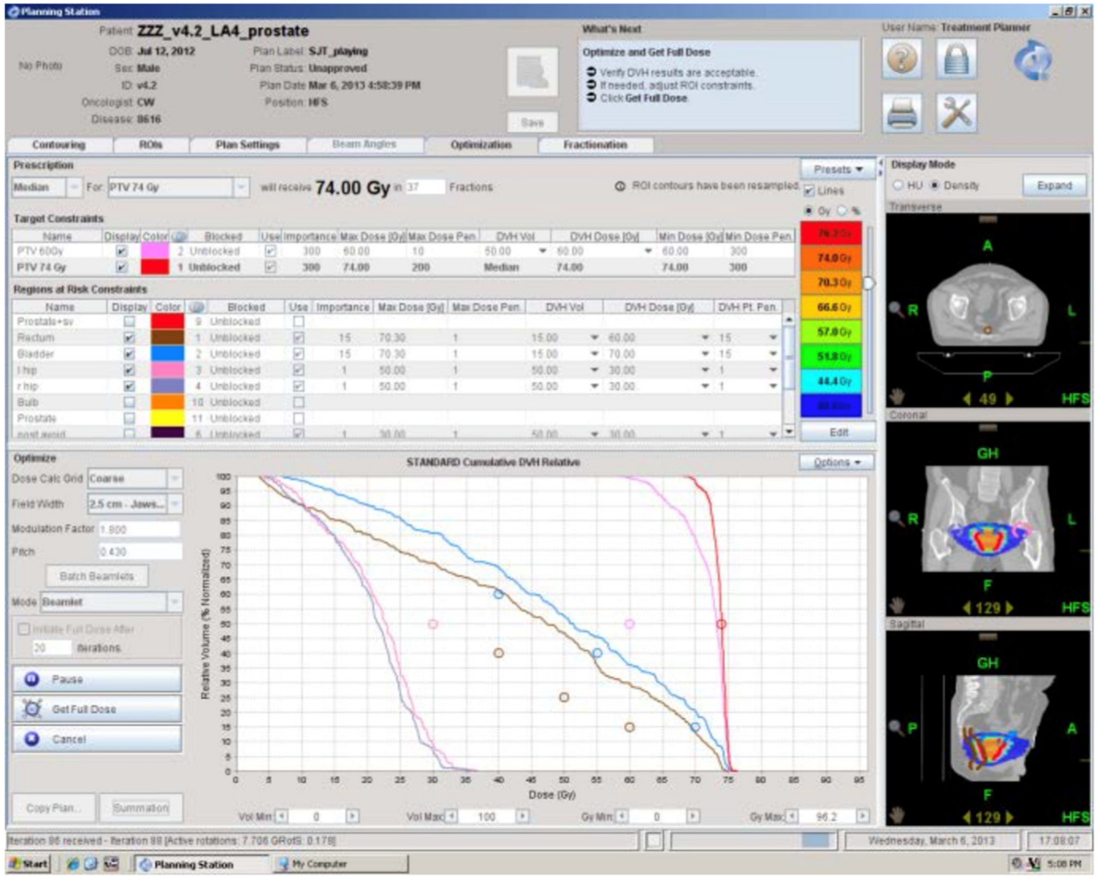
- Take the difference between what you've got and what you want, square it, and add it up for all points in the target volume.
- Multiply by an arbitrary weight (also known as importance)
- Do the same for the organs at risk. The H function is a function that gives 1 for positive input, zero for negative input.
- The choice of weights will affect how important each organ is (see next slide)
- Other mathematical functions are available in some planning systems. This one (the quadratic function) is the original and simplest.





Inverse planning; “talking” to the optimiser





Parameters affecting optimisation

Weight

Also known as **Importance** or **Priority**; controls the general strength of a particular objective

Power

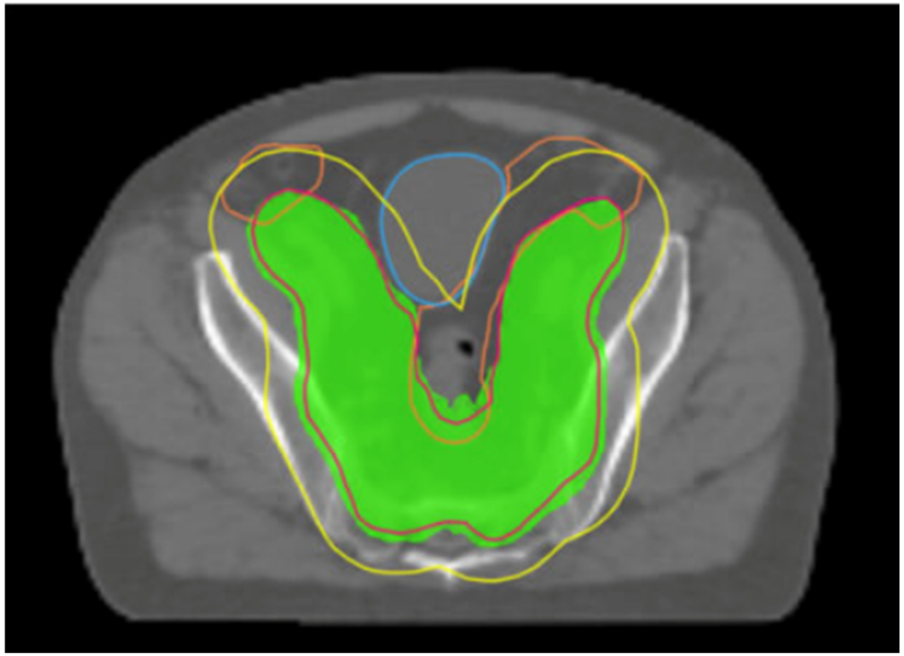
As above; Increasing power will increase the strength of the objective

Priority

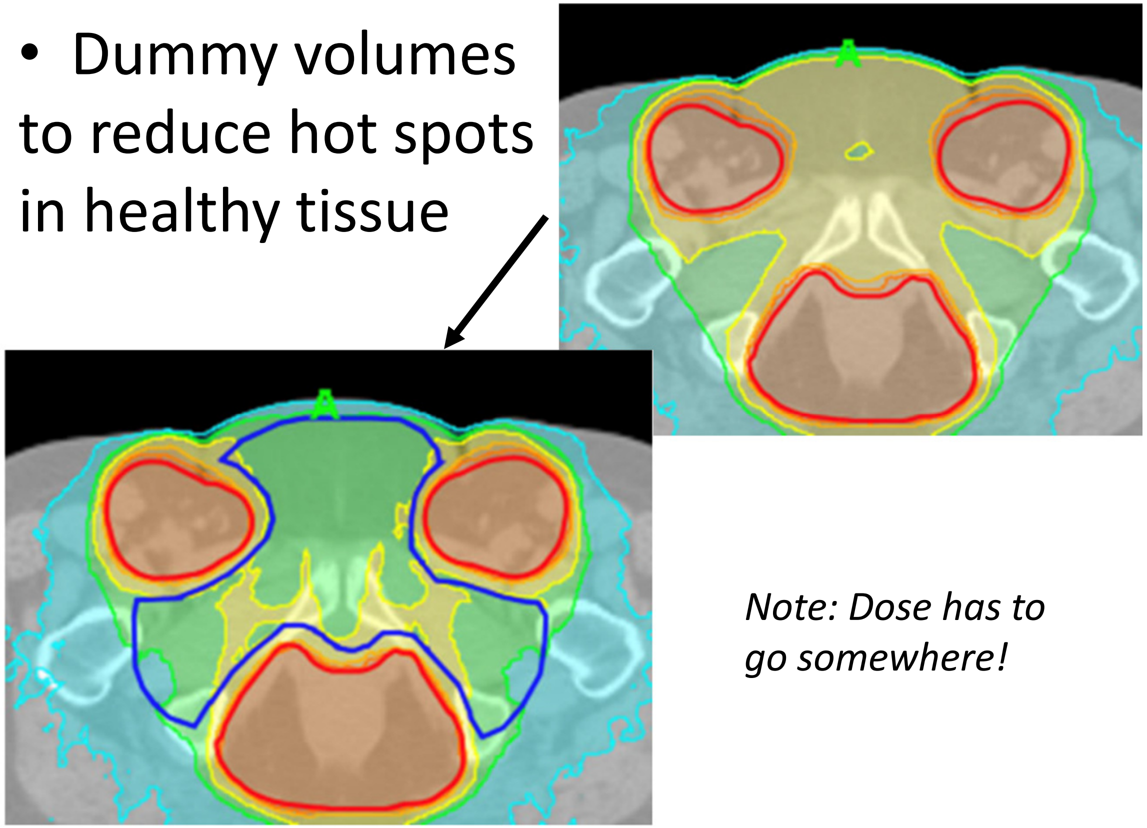
Also known as **Rank, Overlap Priority, Weight;** This determines which organ “owns” voxels in overlap regions.

Dose “sculpturing”

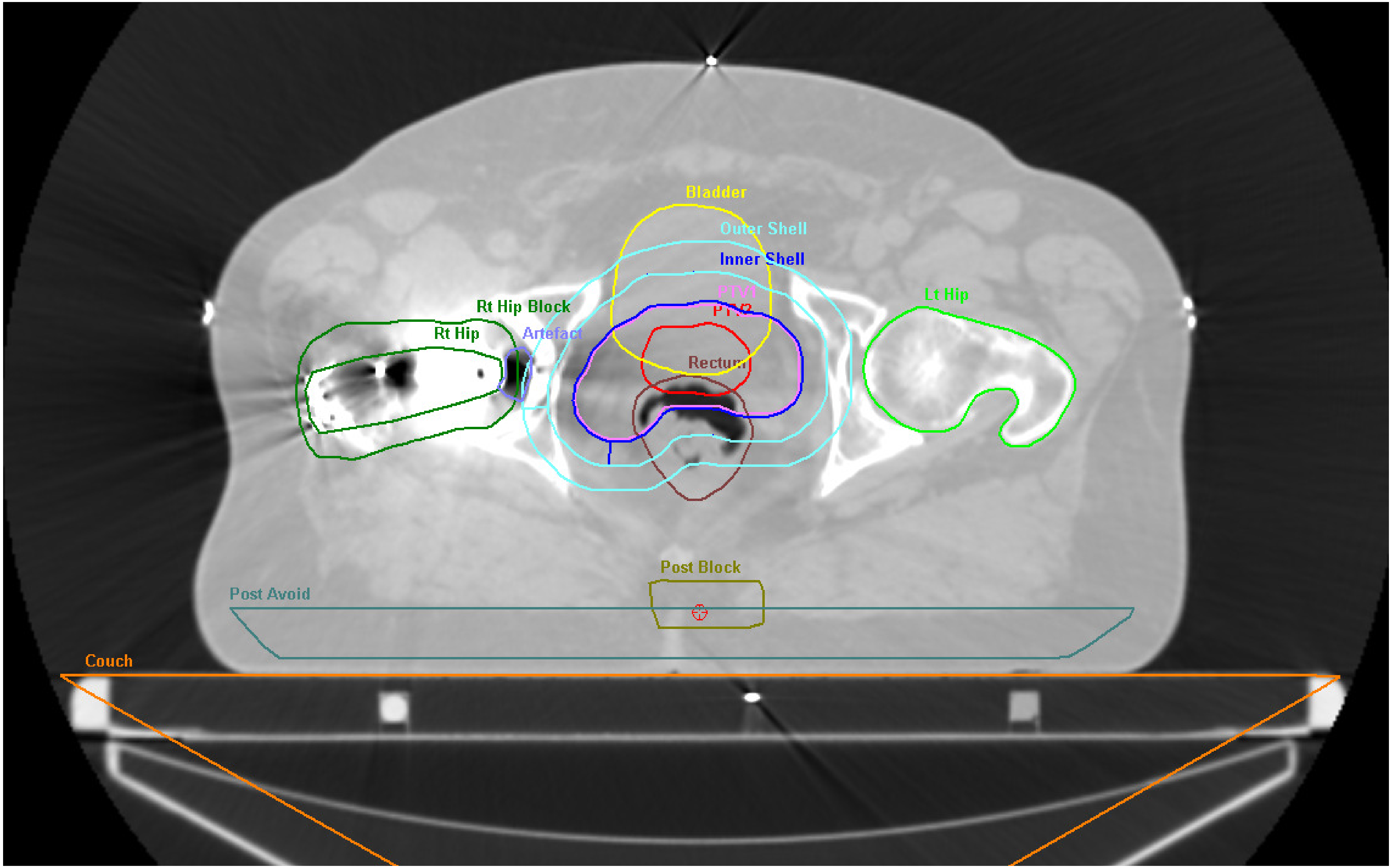
- “Rings” or transition volumes to increase dose gradient around PTV

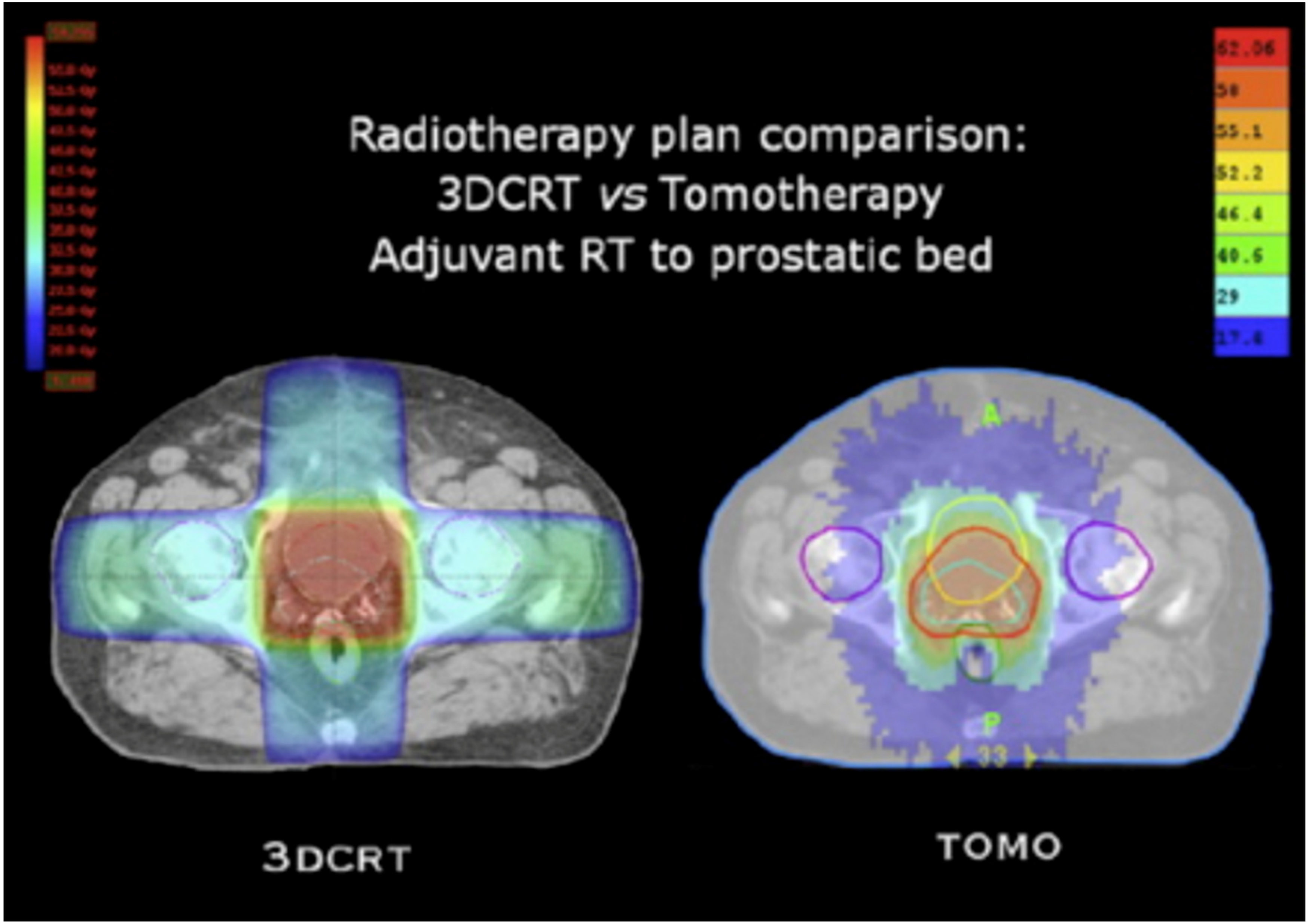


- Dummy volumes to reduce hot spots in healthy tissue

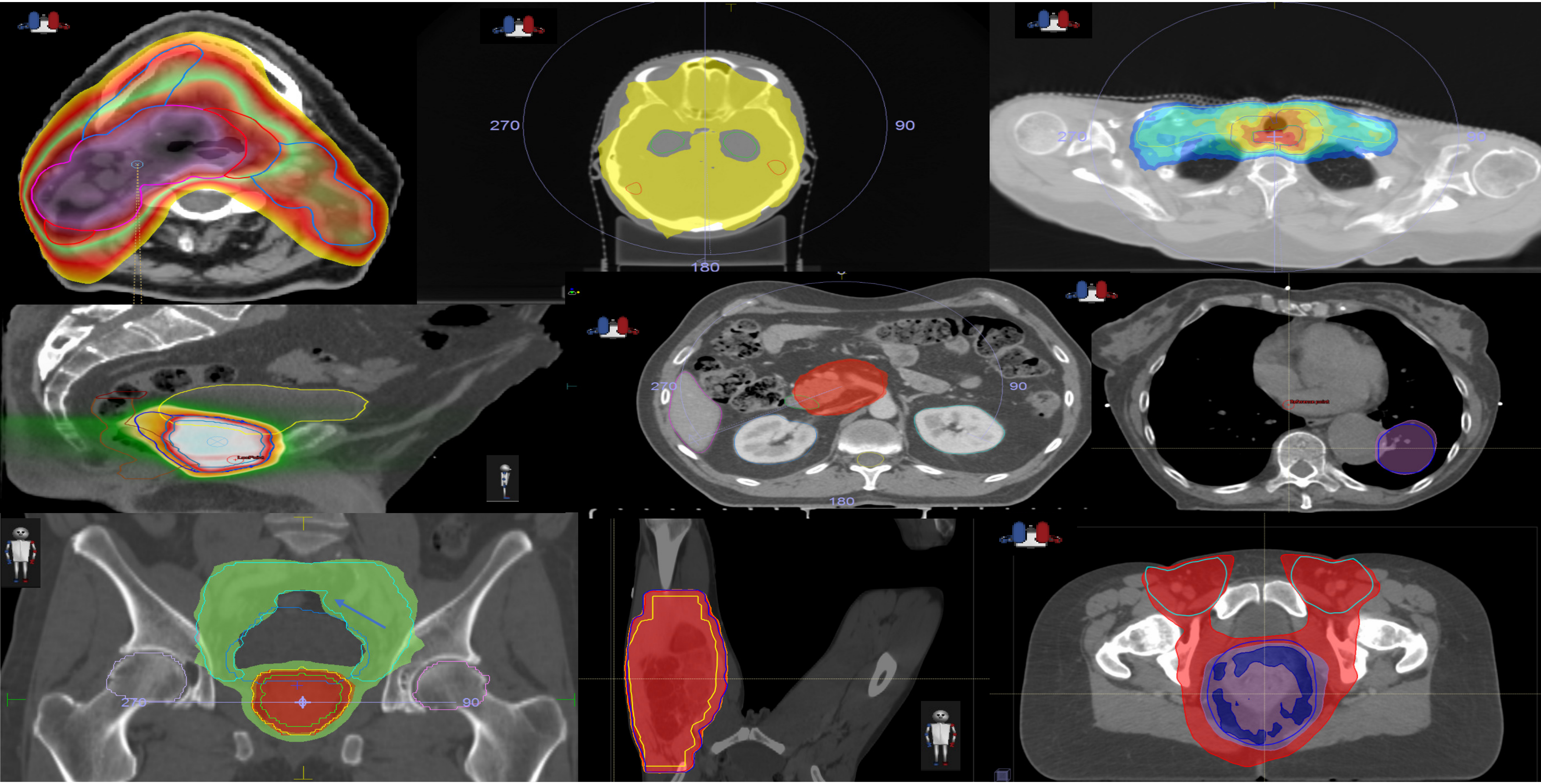


Note: Dose has to go somewhere!

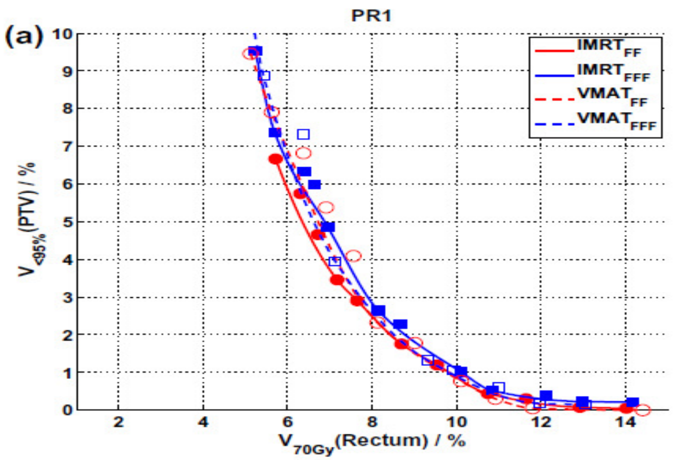

Bladder
Outer Shell
Inner Shell
PTV1
PTV2
Rt Hip Block
Rt Hip
Artefact
Lt Hip
Rectum
Post Block
Post Avoid
Couch

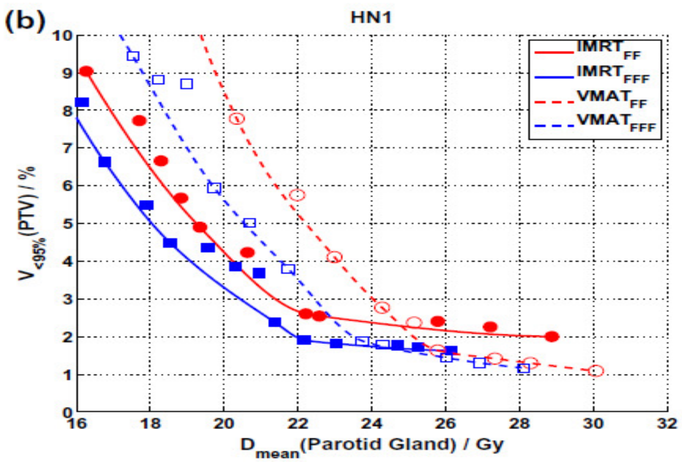

Radiotherapy plan comparison:
3DCRT *vs* Tomotherapy
Adjuvant RT to prostatic bed
62.06
58
55.1
52.2
46.4
40.6
29
A
P
3DCRT
TOMO

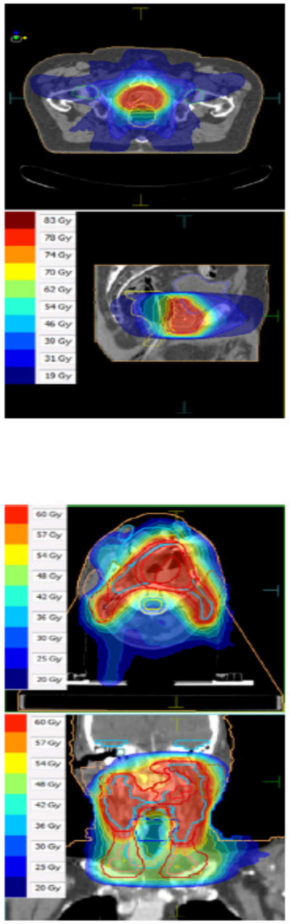
VMAT plan galery



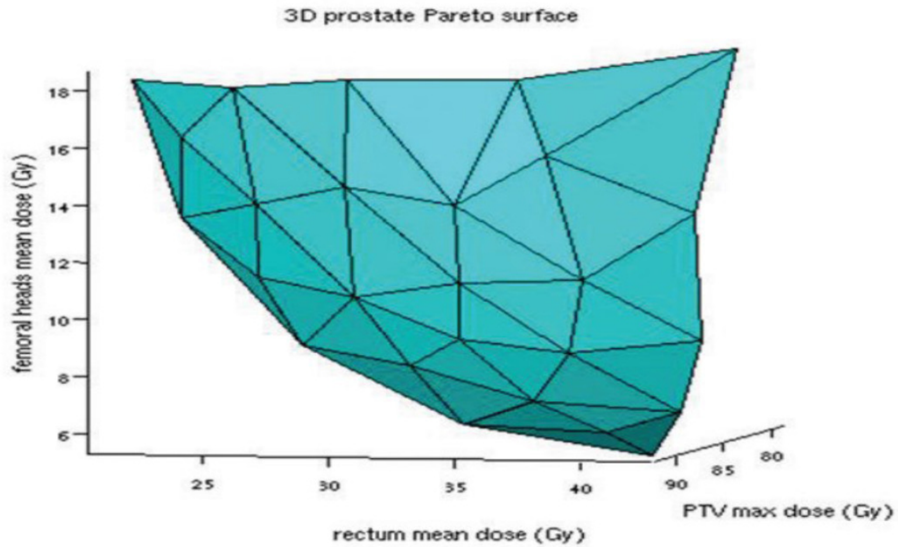
Plan Optimality (?)







W. Lechner, Radiotherapy and Oncology 109 (2013) 437–441



Definition: Pareto optimality describes a state of affairs in which resources are distributed such that it is not possible to improve a single individual without also causing at least one other individual to become worse off than before the change.
Source: Wikipedia

Summary

- Radiotherapy treatments are either Forward (typically used for 3D-CRT) or Inverse (IMRT) planned.
- Forward plans; all treatment delivery related parameters (e.g. number of beams, energy, gantry & collimator angles, MLC position, wedges, weights) are set **by the planner** and the dose is then calculated by the TPS.
- The plan is reviewed and its quality assessed by the corresponding DVHs (Nb: always keep an eye on the 3D dose distribution…)
- The process is repeated until all treatment goals (for PTV and OAR) are met.
- Inverse plans; only number of beams and directions (IMRT) or first & last gantry angle (VMAT) as well as beam energy are defined.
- Treatment objectives (as per clinical protocol) are defined for target(s) and OARs
- The dose is calculated by the TPS for various delivery conditions (e.g. MLCs shapes & dose per gantry angle)
- An **objective function** measures how far the planned dose differs from the treatment objectives
- The process is repeated **iteratively** until the objective function's value *is minimised*.
- The plan is reviewed and its quality assessed by the corresponding DVHs (Nb: always keep an eye on the 3D dose distribution…)
- Experience makes a good planner (and a bit of artistic flare…)

Thank you

Clinical protocol example – IMRiS trial (UCLH)

PTV volume	Pre-op Cases	Post-op Cases	
	Dose to PlanPTV_5000	Dose to PlanPTV_6000/PlanPTV_6600	Dose to PlanPTV_5220/PlanPTV_5350
98%	>90%	>90%	>90%
95%	>95%	>95%	>95%
50% (median) or mean of volume	100%	100%	100% ± 1Gy
<5%	>105%	>105%	Avoid hotspots
<2%	>107%	>107%	Avoid hotspots

OAR	Dose constraint
Mandatory	
Normal tissue limb corridor [68]	$V_{20Gy} < 50\%$
BrachialPlexus [69]	Mean dose < 60 Gy Max dose (D0.1cc) < 65 Gy
Optimal	
Weight-bearing bone – bone in treatment field [68]	$V_{50Gy} \leq 50\%$
Weight-bearing bone – whole bone [16]	Mean dose ≤ 40Gy $V_{40Gy} \leq 64\%$
FemoralHeadNeck [70]	Mean dose <40Gy
Joint [68]	$V_{50Gy} < 50\%$