



Modern Treatment Planning





INTRODUCTION

Treatment planning is the process of determining the most appropriate way to irradiate the patient

- Choosing an appropriate patient positioning and immobilisation method so that treatments will be reproducible;
- Identifying the shape and the location of the tumor and of the neighbouring organs at risk;
- Selecting a suitable beam arrangement;
- Evaluating the resulting dose distribution;
- Calculating the treatment machine setting to deliver the required absolute dose.





Target Definition





TARGET DEFINITION: Gross tumor volume

Radiotherapy is a **local** treatment
(which is complementary to systemic treatments)

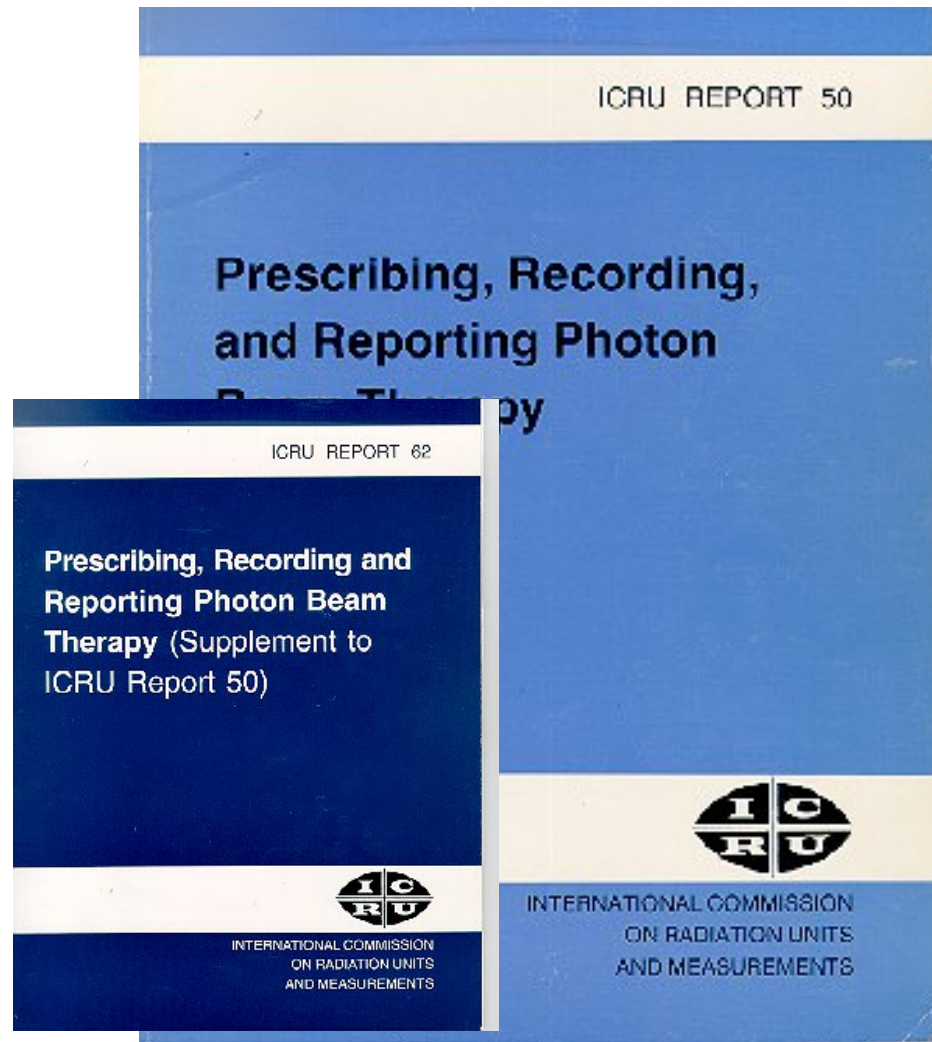
Therefore it is an essential part of the
TP-process to:

- (a) Define the tumor
- (b) Define organs at risk (OAR)



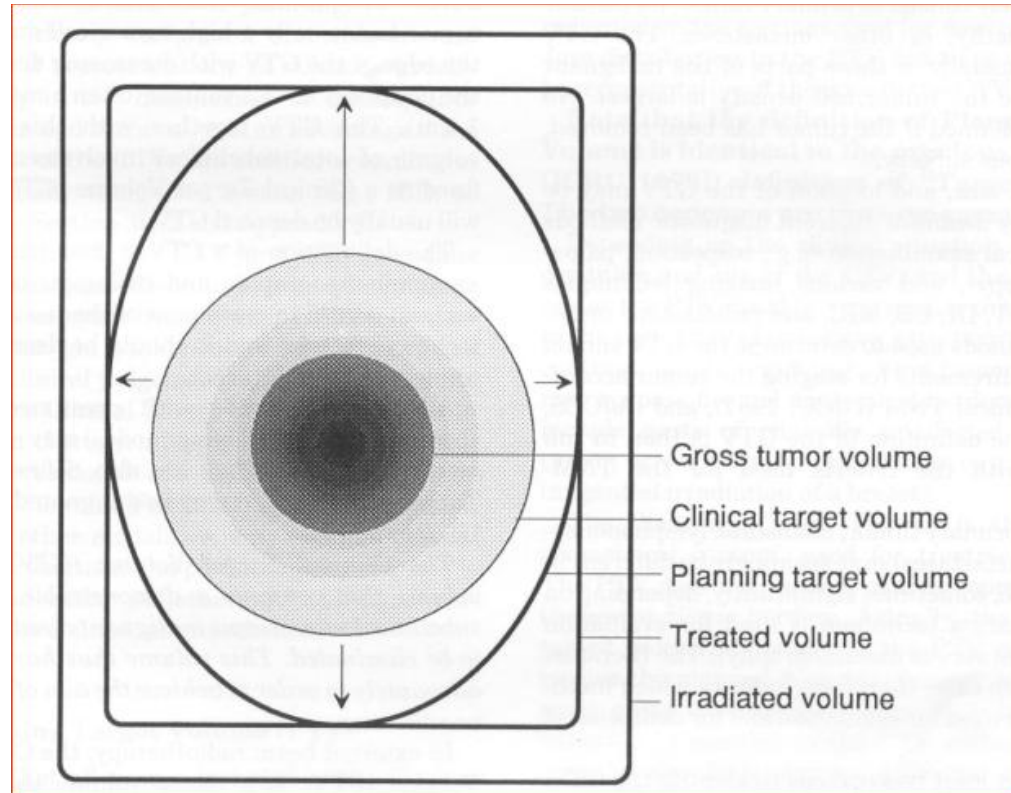
RECOMMENDATIONS BY THE ICRU

- **International Commission on Radiation Units and Measurements**
- **ICRU reports provide guidance on prescribing, recording and reporting**



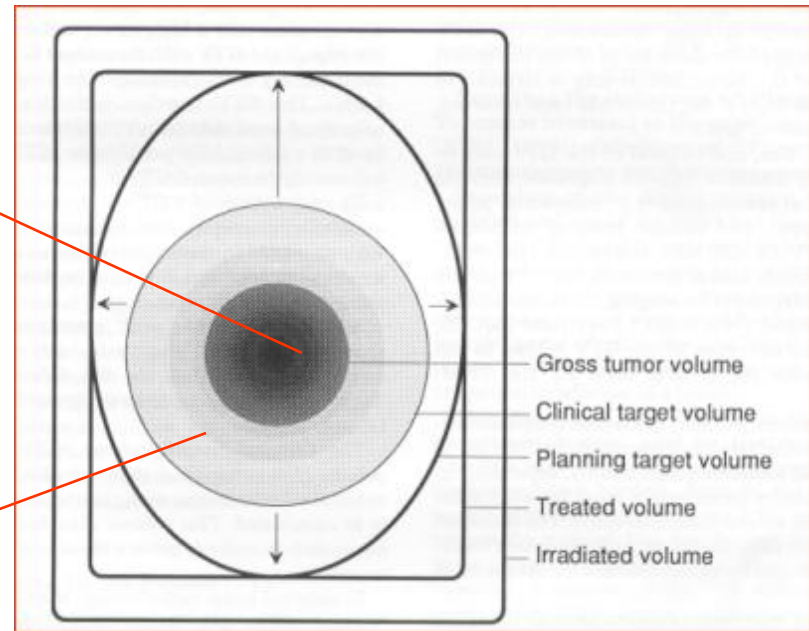
TUMOR RELATED TERMS

■ ICRU report 50



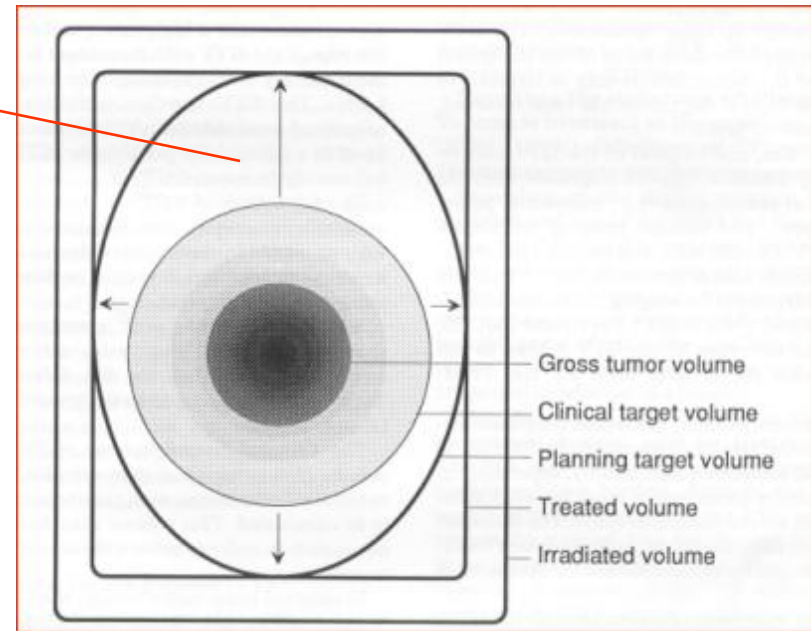
TUMOR RELATED TERMS

- Gross Tumour Volume (GTV) = clinically demonstrated tumour
- Clinical Target Volume (CTV) = GTV + extension for microscopic malignant disease



TUMOR RELATED TERMS

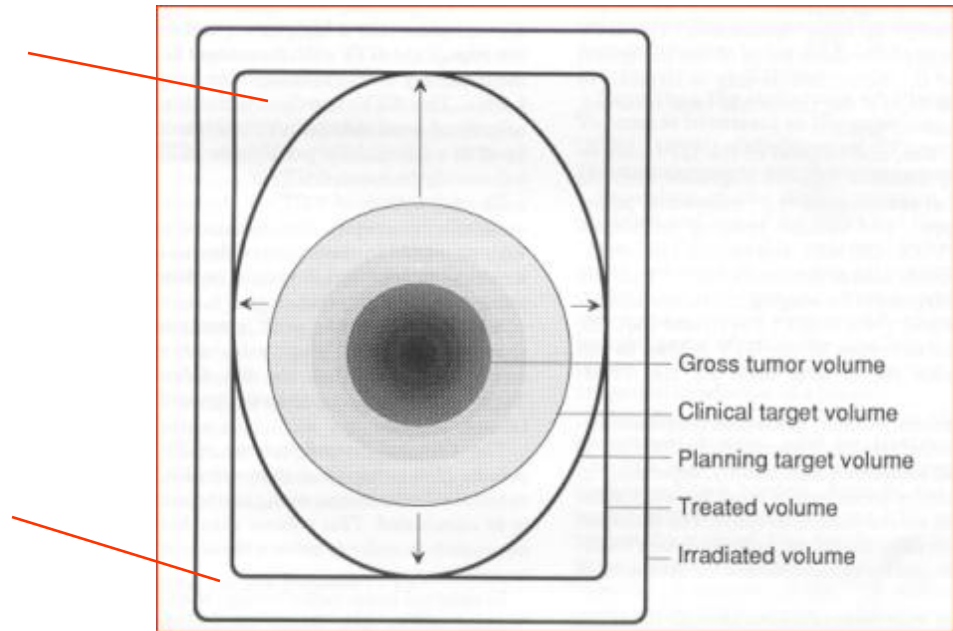
Planning Target Volume (PTV) = volume planned to be treated = CTV + margin for set-up uncertainties and potential of organ movement



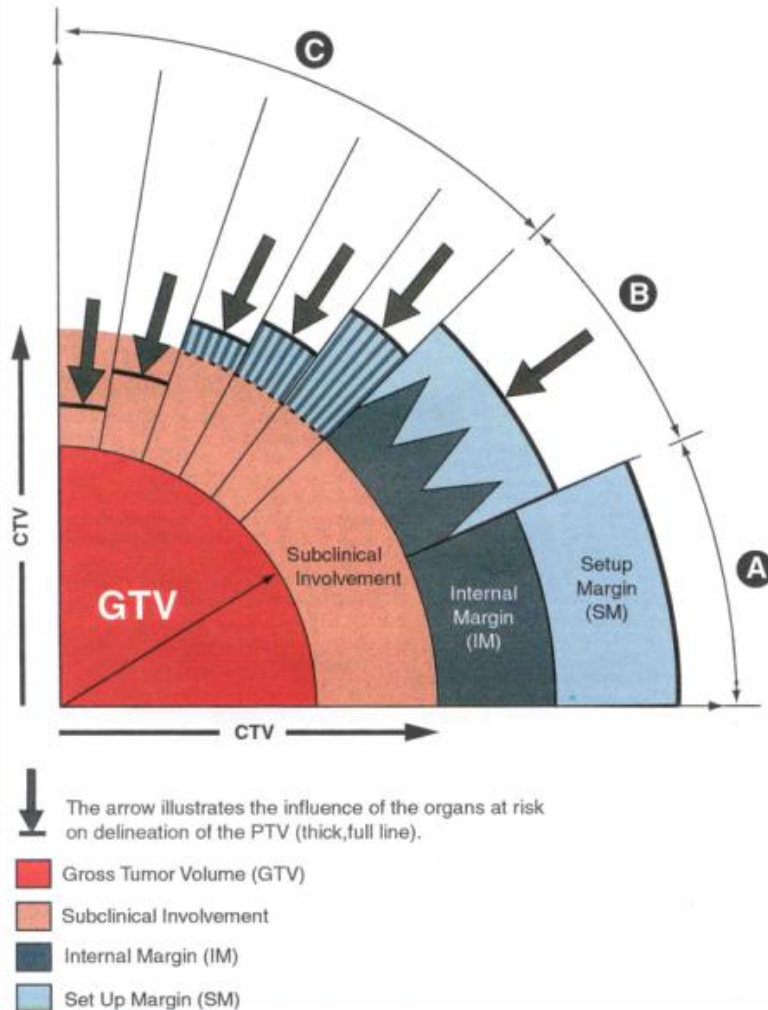
TUMOR RELATED TERMS

Treated Volume =
volume that receives
dose considered
adequate for clinical
objective

Irradiated volume =
dose considered not
negligible for normal
tissues



DEFINITIONS FROM ICRU 62



The concept of margins was expanded on by ICRU report 62

- Internal margin = due to organ motion
- Set-up margin

The two are often combined as independent uncertainties

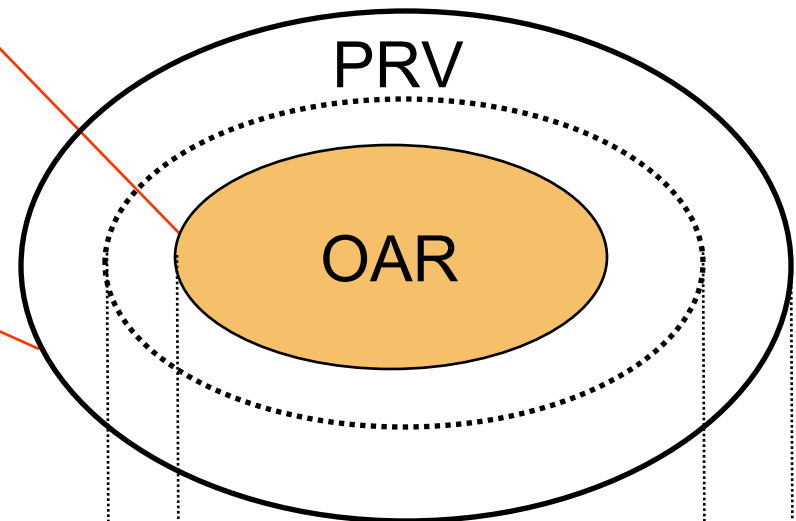
NORMAL TISSUE RELATED TERMS

▪ **Organ at risk (OAR)** = any organ of normal tissue which might be impacted by radiation dose

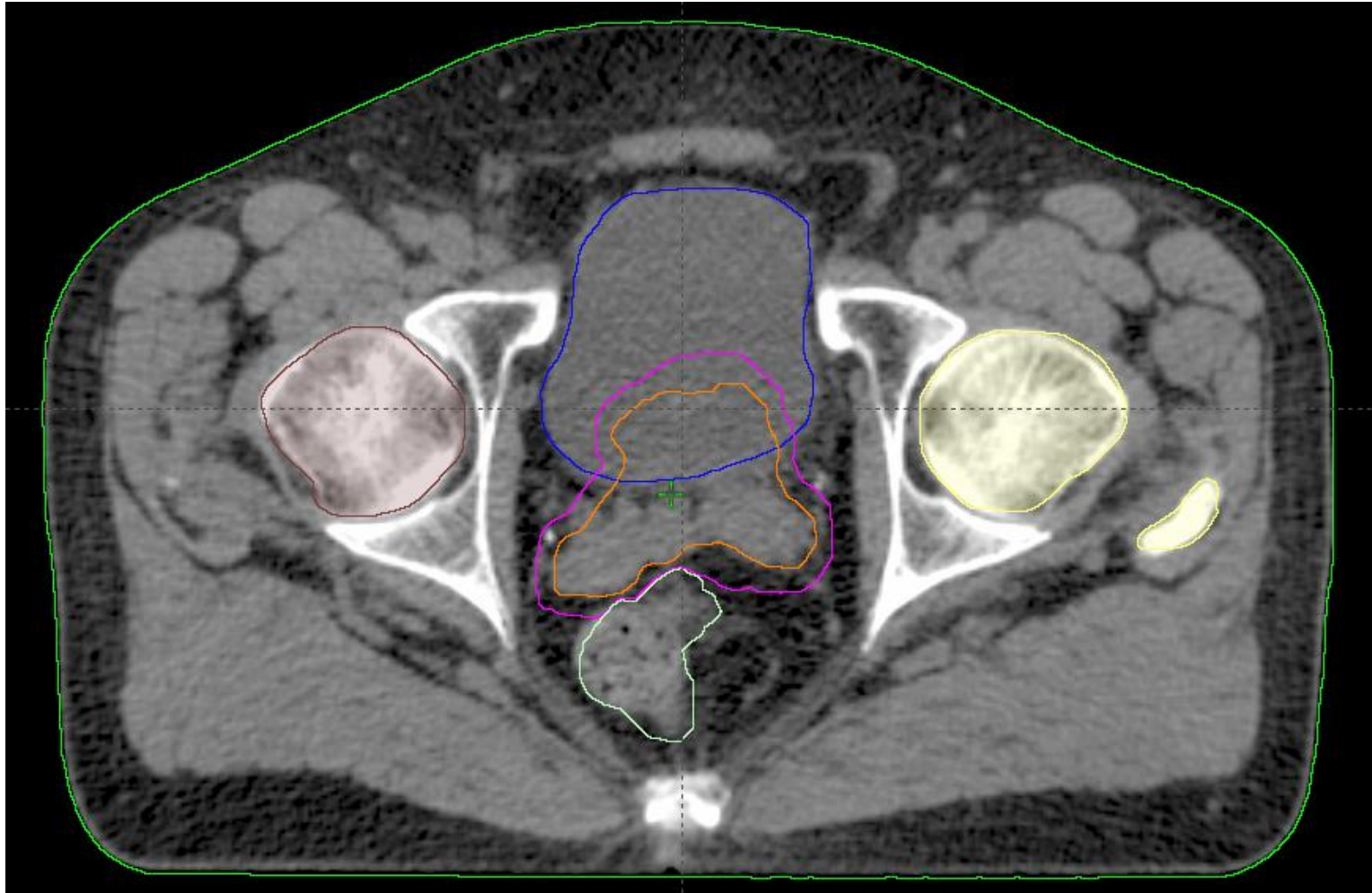
▪ **Planning risk volume (PRV)** =
 $OAR + IM + SM$

▪ **IM** = margin for expected physiological movements and size variation

▪ **SM** = margin for uncertainties in patient positioning and beam alignment



TARGET DELINEATION - EXAMPLE



INTRODUCTION: Patient data acquisition

First step in the TPS process. It is required for three different purposes:

- To assess the position and extent of the target volume in relation to the other anatomical structures, particularly the organs at risk;
- To acquire the data required for accurate computation of the dose distribution (shape and composition of the body);
- To acquire the information necessary for the accurate set up of the patient (landmarks, reference structures, ...);



PATIENT DATA ACQUISITION: COMPUTER TOMOGRAPHY

- Enormous technical breakthrough:

From 2-dim projections CT computes a property of the patient at every point within the the 3D space
(resolution < 1 mm)

- Measured property:

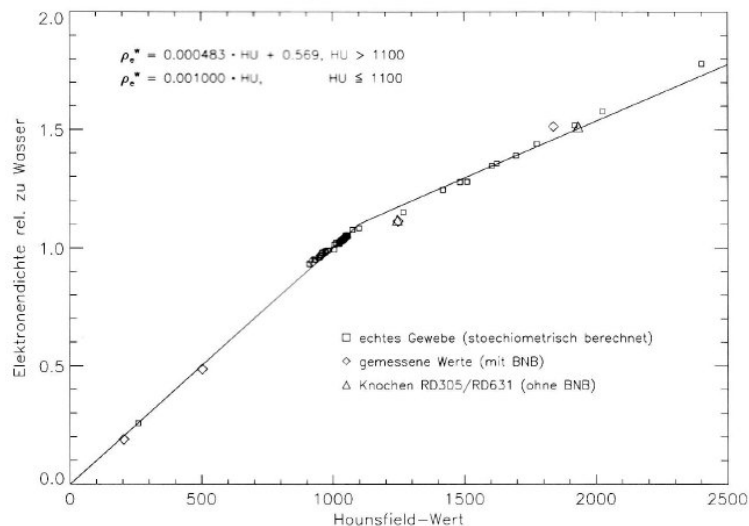
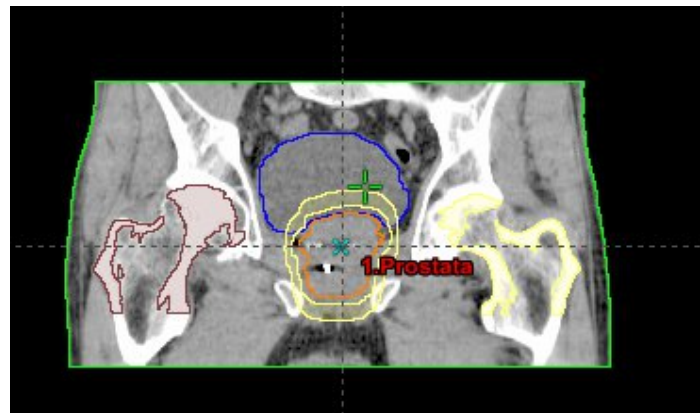
Linear x-ray absorption coefficient of the tissue relative to that of water (expressed in Hounsfield units)



COMPUTER TOMOGRAPHY FOR TREATMENT PLANNING

Definition of targets and OARs

Basis for dose calculation
Tissue heterogeneities are considered quantitatively.
Problem: CT numbers measured at kV energies, patient treated at MV energies!





Designing a treatment plan

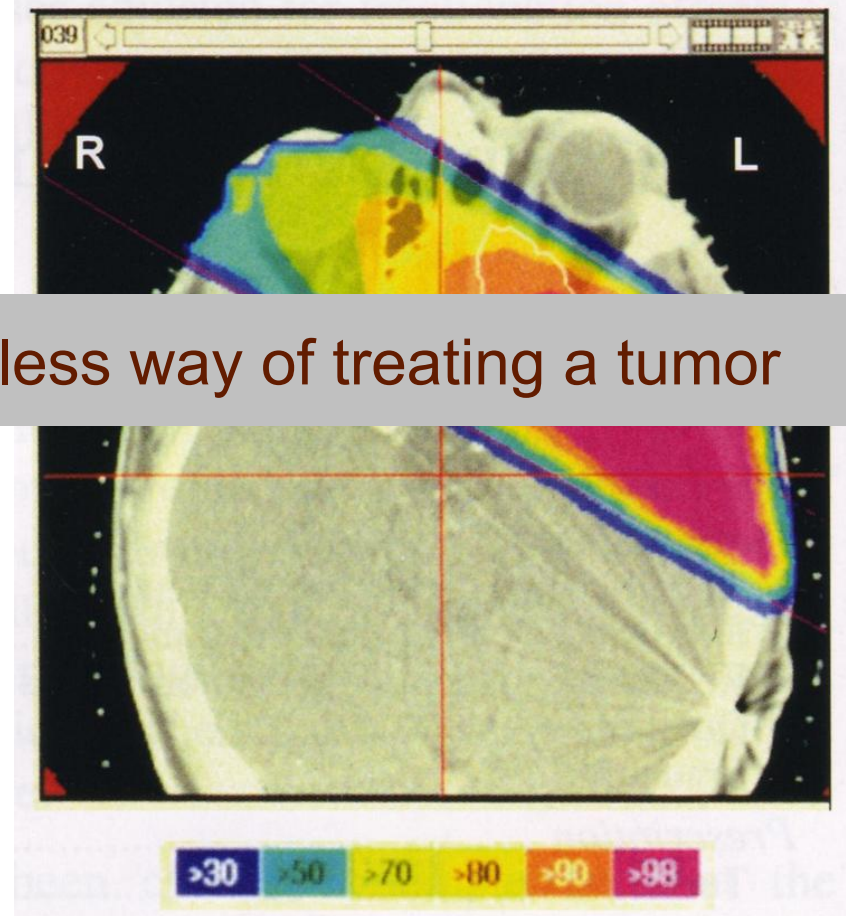


INTRODUCTION

Application of one treatment beam to a patient:

- Proximal dose is higher than tumor dose
- Beam exits through the eye

Hopeless way of treating a tumor





INTRODUCTION

Solution:

- Tumor cannot be treated using ONE single photon beam
- Use multiple cross-firing beams that concentrate dose within the target
- A **treatment plan** is the *set* of cross-firing beams and their *weights*



REQUIREMENTS ON THE OVERALL TREATMENT

The clinician must specify the:

- Fractionation scheme
- Prescription dose

	Physician's Intent
Prescription ID	1.1
Predecessor ID	
Status	Reviewed
Patient Orientation	
Volume (Site)	Breast, Left
Treatment Type	3D-Planung
Energy Mode	
Depth	
Prescribed %	
Prescribed Dose / Fraction [Gy]	2.000
Planned Dose / Fraction [Gy]	
Planned No. Fractions	30
Fractions per Week	5
Fractions per Day	1
Delivered Dose to Date [Gy]	+
Delivered No. Fractions to Date	
Remaining Dose [Gy]	+
Remaining No. Fractions	
Planned Total Dose [Gy]	= 60.000
Note	1.Serie bis 50 Gy, dann Boost bis 60 Gy
Entered By	kati
Entered Date	28.01.2008 11:24:28
Reviewed By	kschneider
Reviewed Date	28.01.2008 15:09:58
Create Plan...	Create Plan...
Treat Approved By	
Treat Approved Date	

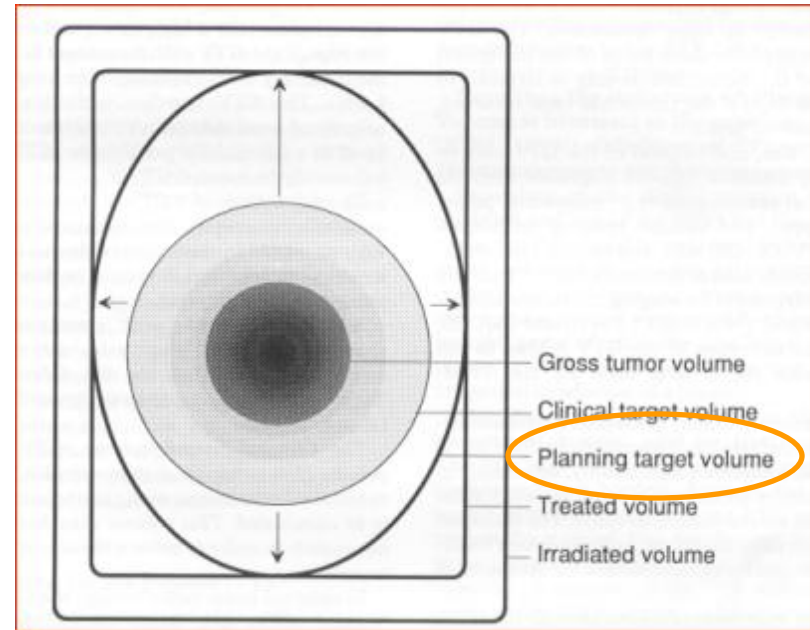


REQUIREMENTS REGARDING THE TUMOR

Tumor dose is prescribed to the PTV:

- Point-Dose prescription
- Dose homogeneity

ICRU recommendations:
 $95\% < Dose_{pres} < 107\%$



REQUIREMENTS REGARDING THE NORMAL TISSUES (OAR)

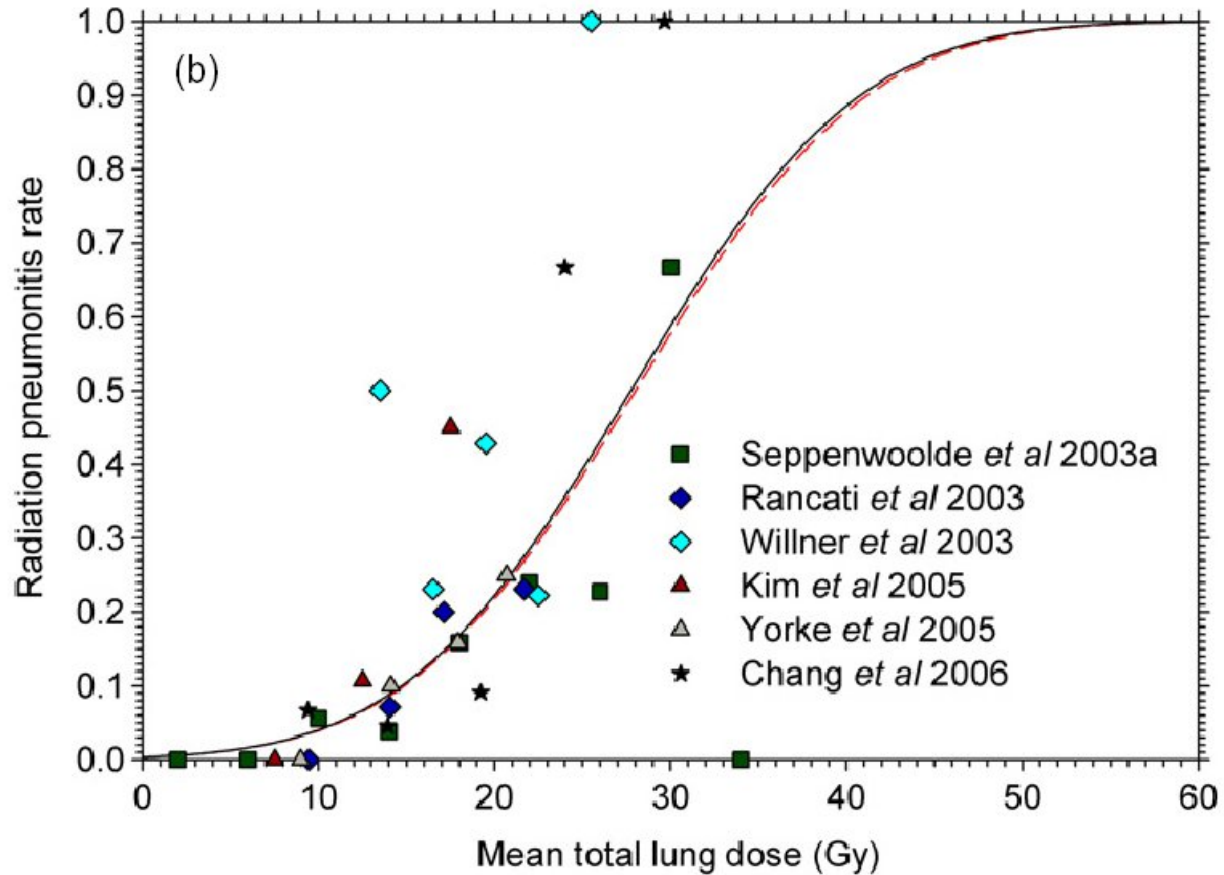
Requirements on OARs are stated as constraints:

- Constraints on dose and volume
“no more than 1/3 of the kidney may receive more than 60 Gy”
- Biological constraints
“the normal tissue complication probability (NTCP) for pneumonitis of the lung should not exceed 1 %”
- Constraints on dose fraction
“the maximum dose per fraction delivered to the optic nerve may not exceed 1.5 Gy”



REQUIREMENTS REGARDING THE NORMAL TISSUES (OAR)

Radiation pneumonitis as a function of mean lung dose



TRADEOFFS

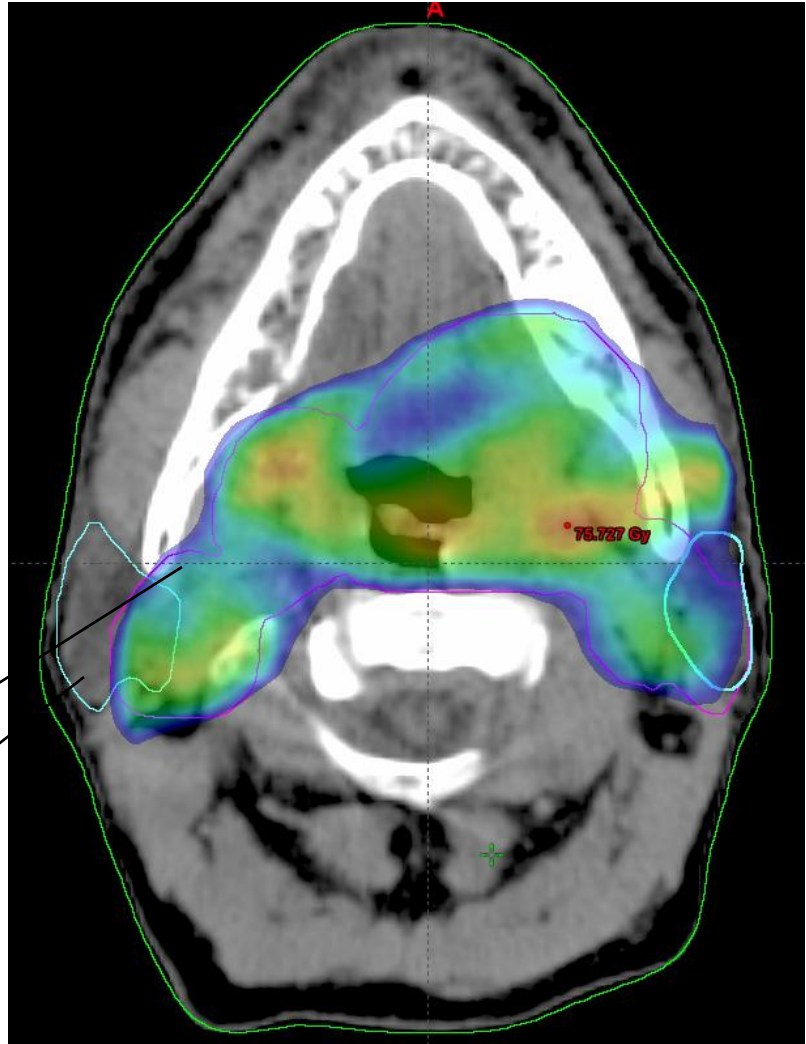
Usually no treatment approach can meet all planning aims.



This will result in tradeoffs amongst target volume and normal tissue aims.

Example:

- treatment of the total PTV up to 70 Gy
- sparing of parotis (mean 26 Gy)





REPRESENTATION OF DOSE

One cannot discuss the design of a treatment plan until having discussed the tools for inspecting one.

The dose distribution includes:

- The dose from a plan in all 3D-directions
- Anatomical information from one or more imaging studies
- Anatomical information from structure delineation

..... and including variations of these data in time





PRELIMINARIES OF TREATMENT PLANNING

We have been taken care of:

- Imaging studies
- Volumes of interest
- We know how a single photon beam is constructed
- We know how to display dose distributions

..... Let's start





APPROACHES OF TREATMENT PLANNING

Manual planning:

- Plan is iteratively improved
- Review of a large number of computed parameters (“expert inspection”)
- Subjective process

Computer-driven planning:

- Decision about the quality of a plan is made by the computer
- Usually used in intensity-modulated radiotherapy





PLANNING BY HAND

Partial list of variables to optimize plan:

- type of therapy
- type of radiation
- the location of the patient the tumor and OARs
- the number of beams
- the angulation and aiming point of each beam
- the shape of each beam
- the weight and intensity profile of each beam

The choice of these variables is the heart of the planning process





PLANNING BY HAND

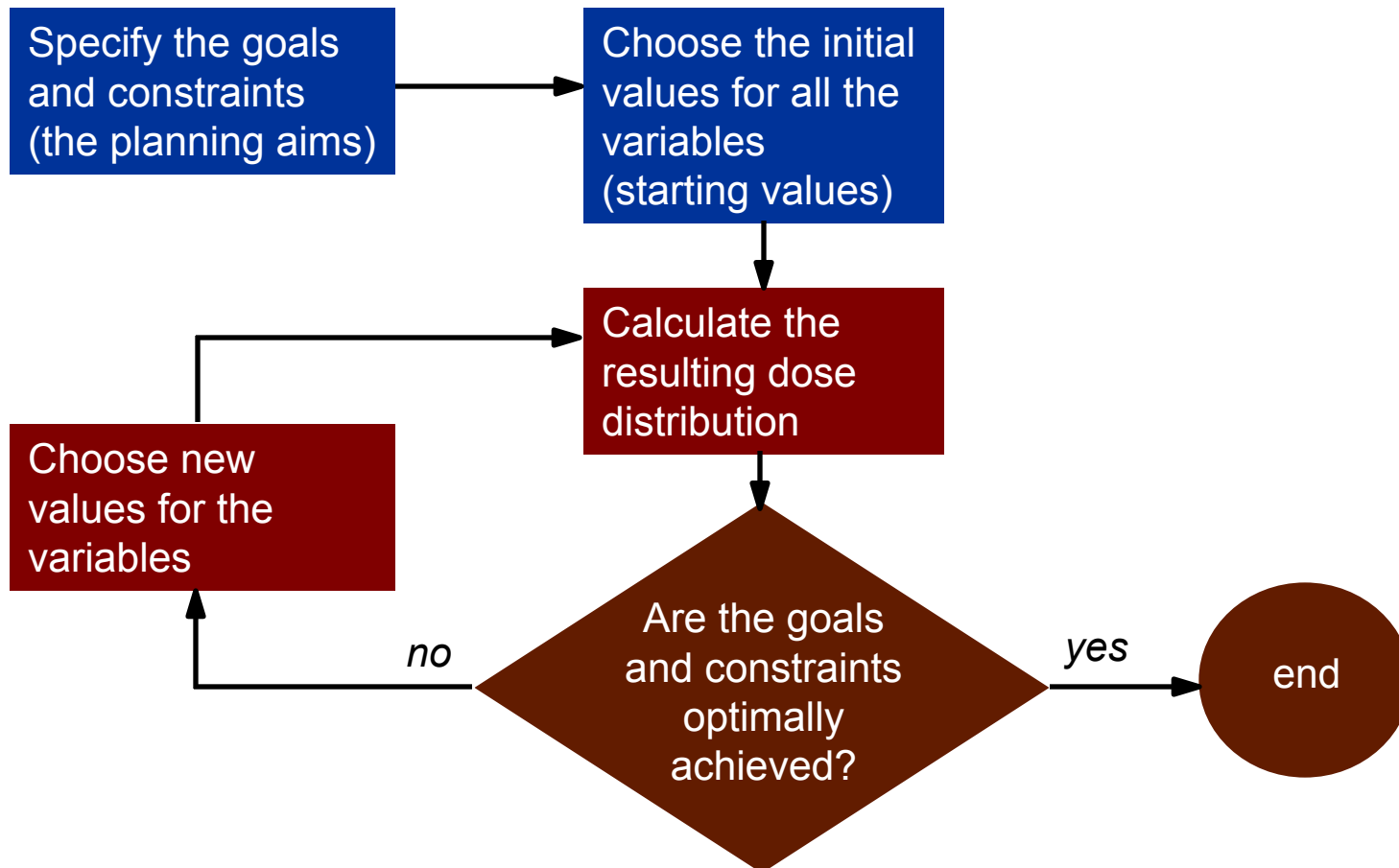
On what is the choice of plan variables based on?

- Plans used previously for similar cases
- Rules of thumb as how to set combinations of plan parameter
- Fast calculation engine to calculate interactively the dose distribution
- Display of that dose distribution
- Calculation of dose statistics
- Iteration of the process to arrive at the best plan
- **EXPERIENCE**



PLANNING BY HAND

Flow chart for manual planning:





CHOICE OF RADIATION MODALITY AND BEAM ENERGY

	<i>advantages</i>	<i>disadvantages</i>
photons	<ul style="list-style-type: none">• widely available• good skin sparing	<ul style="list-style-type: none">• higher entrance dose than tumor dose• high dose through patient up to exit surface
electrons	<ul style="list-style-type: none">• finite penetration, thus sparing tissues distal to the target volume• very slight skin sparing	<ul style="list-style-type: none">• broad penumbra due to scattering• only suitable for quite shallow targets due to shallow fall-off of the distal dose at higher energies
protons	<ul style="list-style-type: none">• virtually no dose distal to the target volume• somewhat reduced entrance dose proximal to the target	<ul style="list-style-type: none">• management of inhomogeneities is not trivial• penumbra becomes substantial at large depth• no skin sparing• limited availability



CHOICE OF BEAM DIRECTION

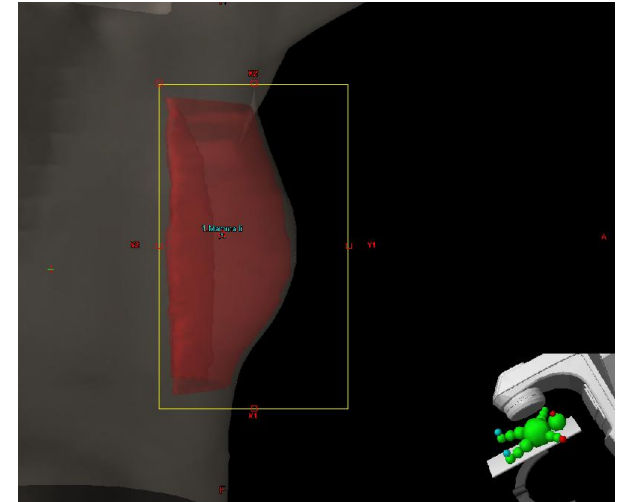
Useful approach for direction selection:

Beams-Eye-View (BEV):

- Perspective view of the patient's delineated anatomy as seen from the viewpoint of the radiation source
- Change in beam direction changes display
- Shows the spatial relationship between target and the delineated anatomy

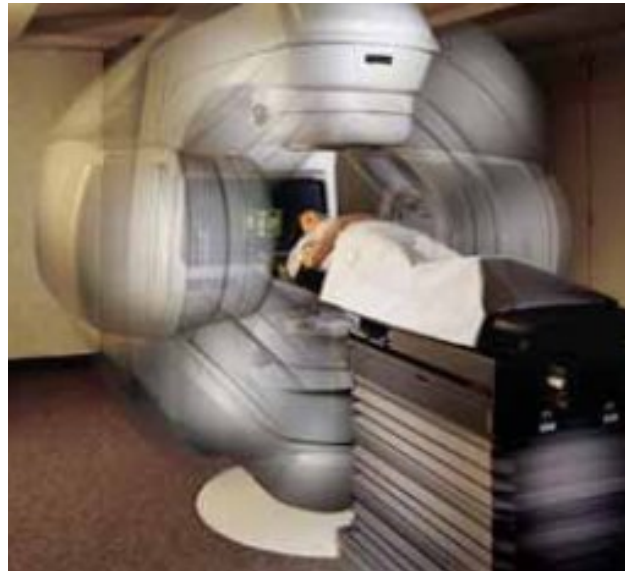


turn gantry



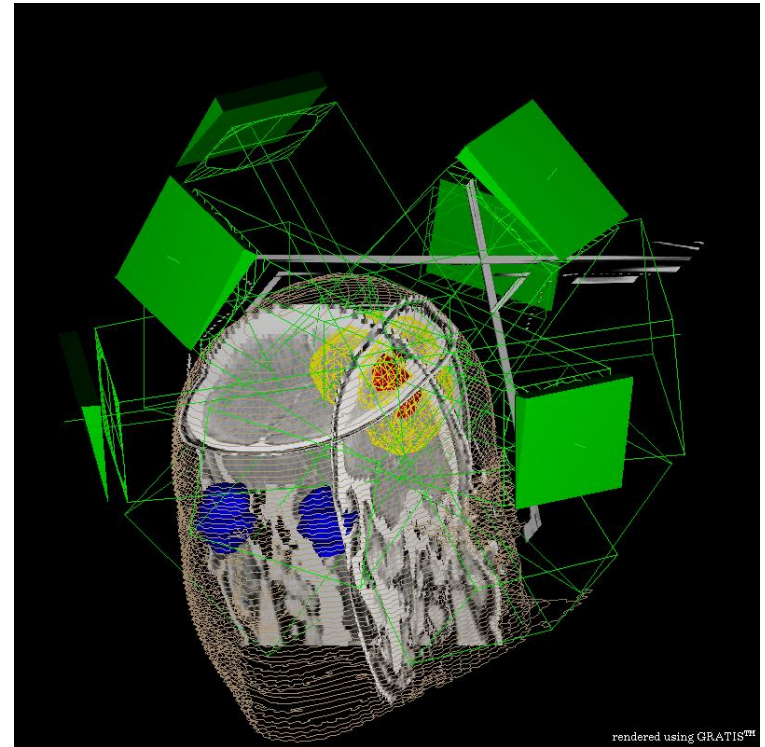
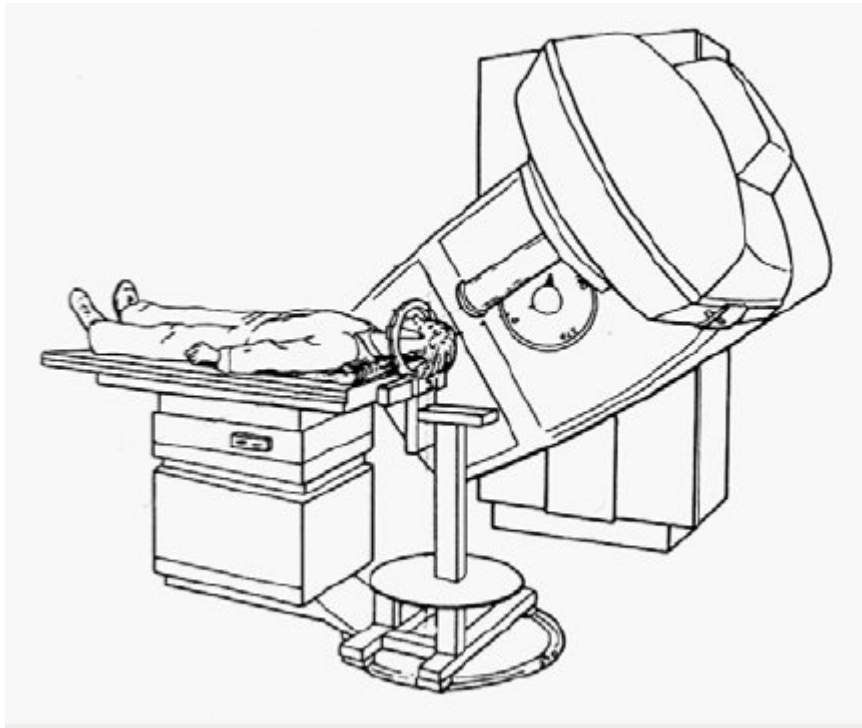
CHOICE OF BEAM DIRECTION

- Frequently the geometry of the target and the OARs will suggest a particular approach
- Not all beams can avoid all OARs; particular OARs are included in one or more beams: dose < constraints
- Linacs rotate around a central point: *isocenter*
- beam lies in a plane perpendicular to the axis of the gantry's rotation



CHOICE OF BEAM DIRECTION NON-COPLANAR BEAMS

- Patient couch can rotate around the isocenter
- Is rarely used for geometrical reasons (patient is a “cylinder”)
- Mostly used in head and neck treatments





DESIGN OF FIELD SHAPE

Goal:

- Cover the entire CTV
- Do this with adequate margins (PTV) to take care of patient and organ motion, setup errors and penumbra
- Avoid OARs or minimize volume of OARs that is covered by the beam

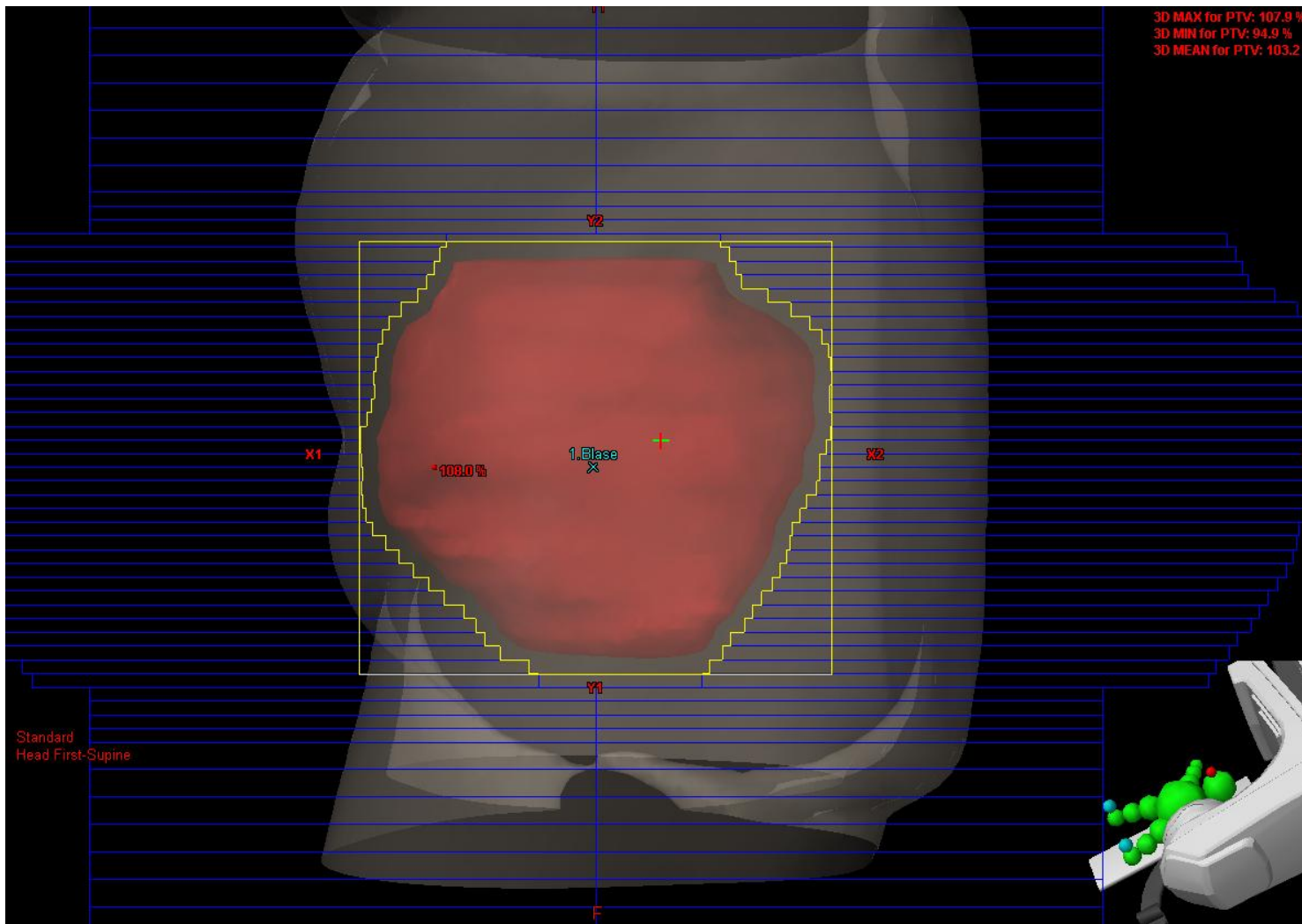
Use Beams-Eye-View (BEV):

- Setting the collimator
- Setting the jaws (size of the rectangular field)
- Design of blocks or MLC-settings





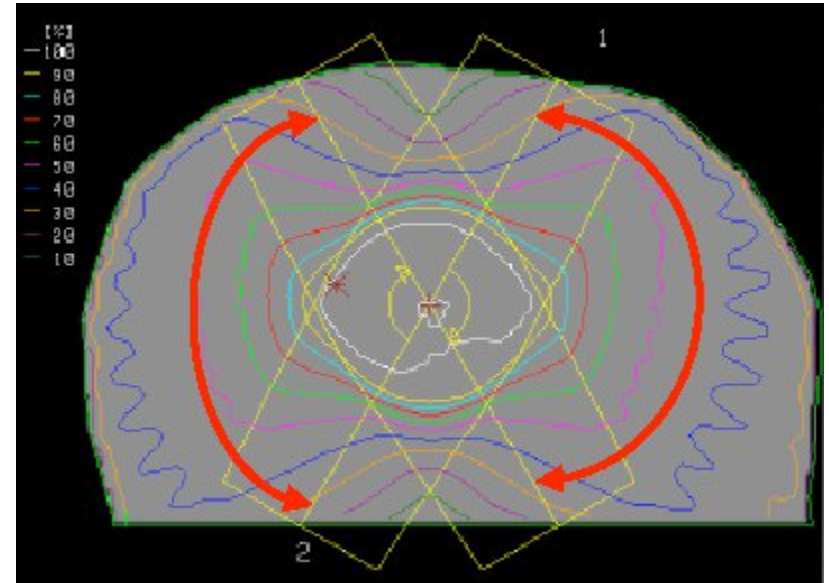
DESIGN OF FIELD SHAPE



NUMBER OF BEAMS

Generally the choice of number of beams depends on the patient's individual geometry!

- Arc therapy: rotating the beam around the patient
- Fixed beams:
 - Rarely use one beam, except for superficial tumor
 - Two parallel-opposed beams give a high dose outside the target volume
 - Typically between 3 and 7 beams are chosen

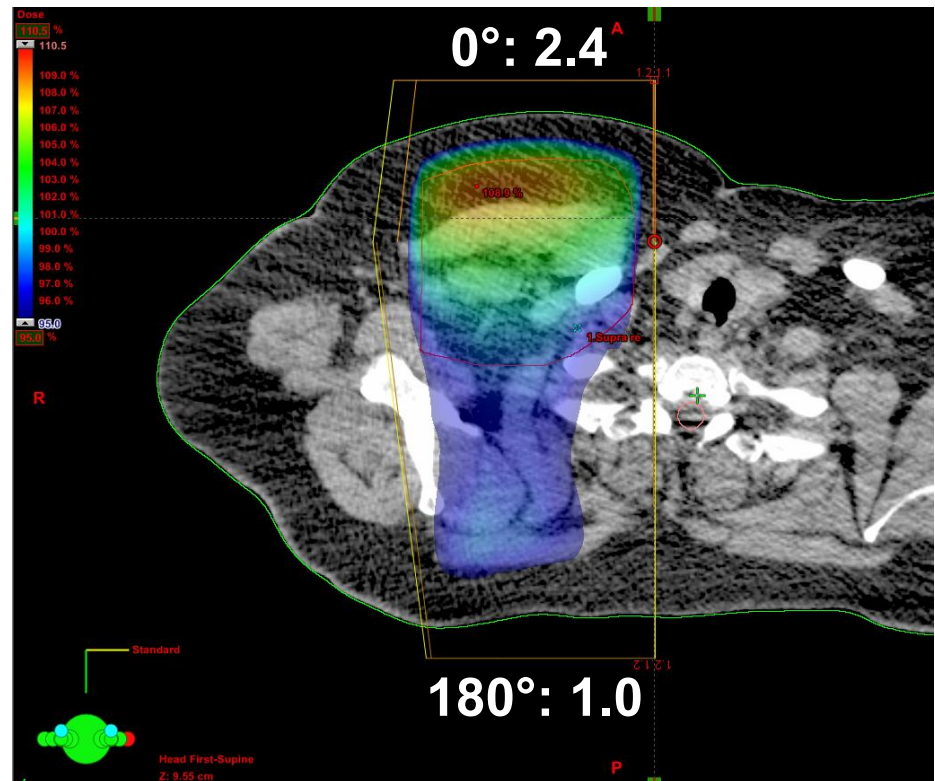


DETERMINATION OF BEAM WEIGHTS

Not all beams
need to be equally weighted = need to deliver the same
dose to the PTV

How is the weighting
decided?

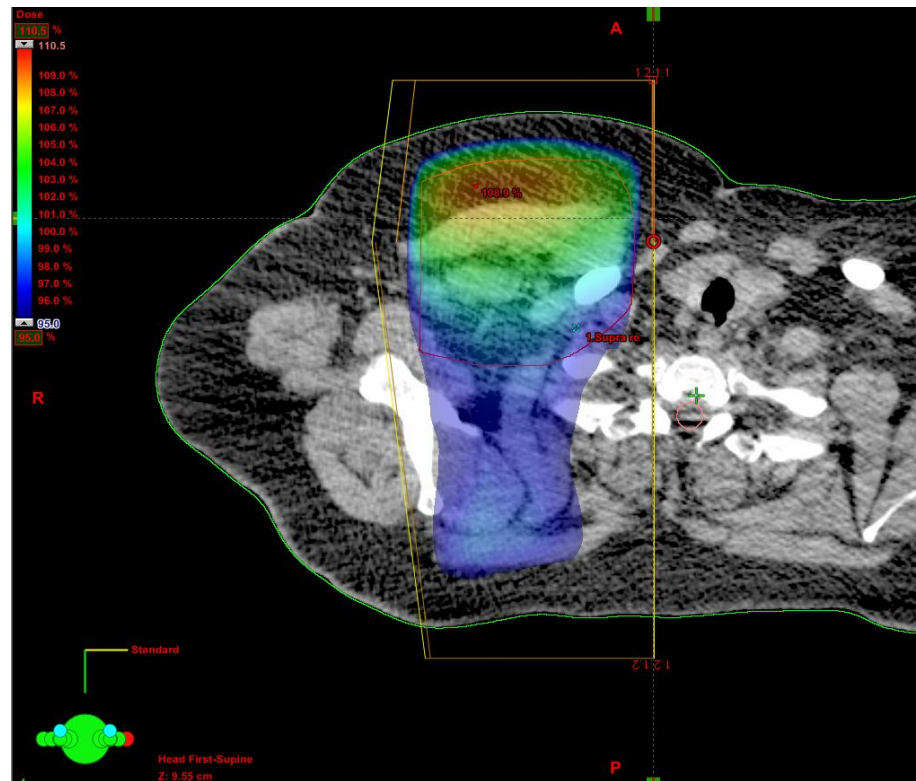
- Experience
- Trial and error
- expert judgement
- Rules of thumb



CENTRAL TENET OF TREATMENT PLANNING

Planner are disposal engineers!

- The planner's job is to decide how to dispose of the dose that must inevitably be delivered outside the target volume





INTEGRAL DOSE

- Dose outside the target volume is a *toxic* substance
- Integral dose is a measure of how much toxic material is involved
- Integral dose is the measure of *total energy* deposited in the patient outside the target volume
- Integral dose does directly correspond to tissue damage

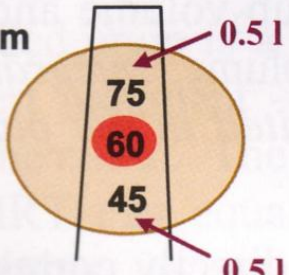
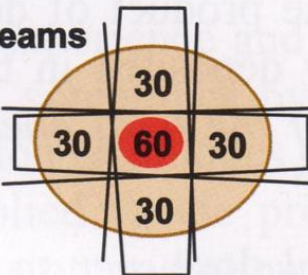
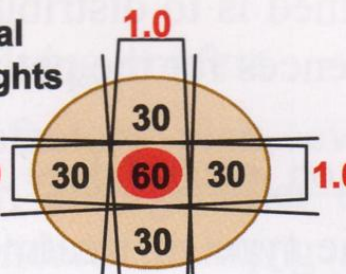
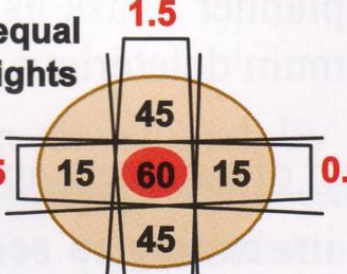
$$I = S (D_i \times m_i)$$

Volume outside
target



IMPACT OF TREATMENT APPROACHES ON INTEGRAL DOSE

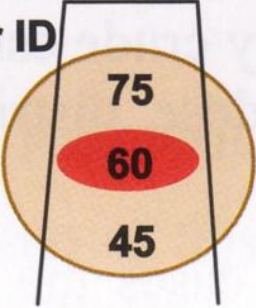
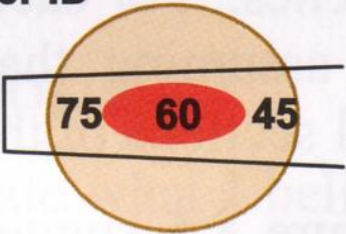
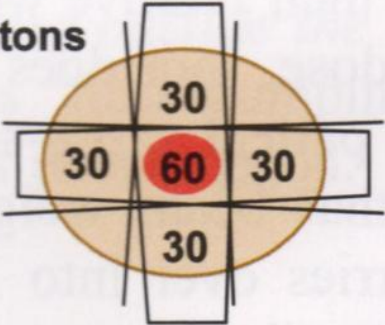
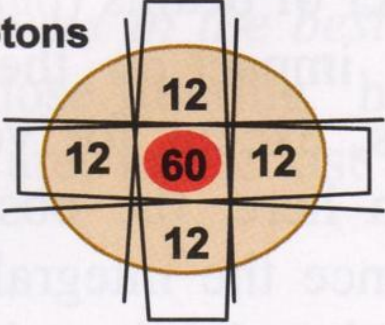
Less integral dose is better for the patient

<p>(a) number of beams</p>	<p>1 beam</p>  <p>$ID = 75 \times 0.5 + 45 \times 0.5 = 60 \text{ Gy.l}$</p>	<p>4 beams</p>  <p>$ID = 4 \times 30 \times 0.5 = 60 \text{ Gy.l}$</p>
<p>(b) beam weights</p>	<p>equal weights</p>  <p>$ID = 4 \times 30 \times 0.5 = 60 \text{ Gy.l}$</p>	<p>unequal weights</p>  <p>$ID = 2 \times 45 \times 0.5 + 2 \times 15 \times 0.5 = 60 \text{ Gy.l}$</p>

In many cases treatment technique has little impact on integral dose



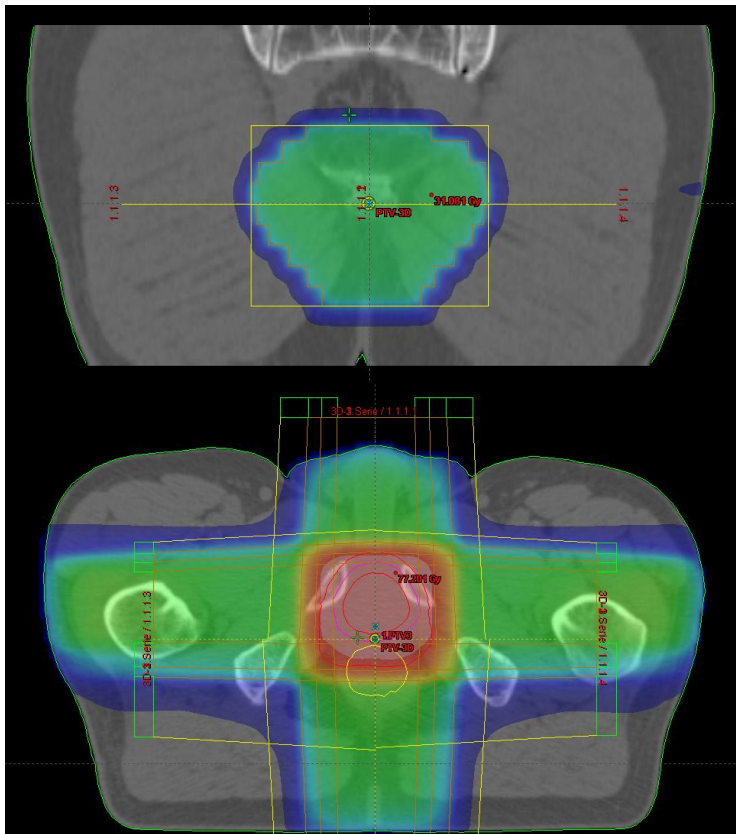
IMPACT OF TREATMENT APPROACHES ON INTEGRAL DOSE

<p>(c)</p> <p>target volume shape non-spherical</p>	<p>higher ID</p>  <p>$ID = 75 \times 0.6 + 45 \times 0.6 = 72 \text{ Gy.l}$</p>	<p>lower ID</p>  <p>$ID = 75 \times 0.4 + 45 \times 0.4 = 48 \text{ Gy.l}$</p>
<p>(d)</p> <p>modality</p>	<p>photons</p>  <p>$ID = 4 \times 30 \times 0.5 = 60 \text{ Gy.l}$</p>	<p>protons</p>  <p>$ID = 4 \times 12 \times 0.5 = 24 \text{ Gy.l}$</p>

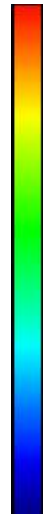
Target shape and radiation modality have biggest impact on integral dose

A LOT TO A LITTLE OR A LITTLE TO A LOT?

Conformal 3D irradiation

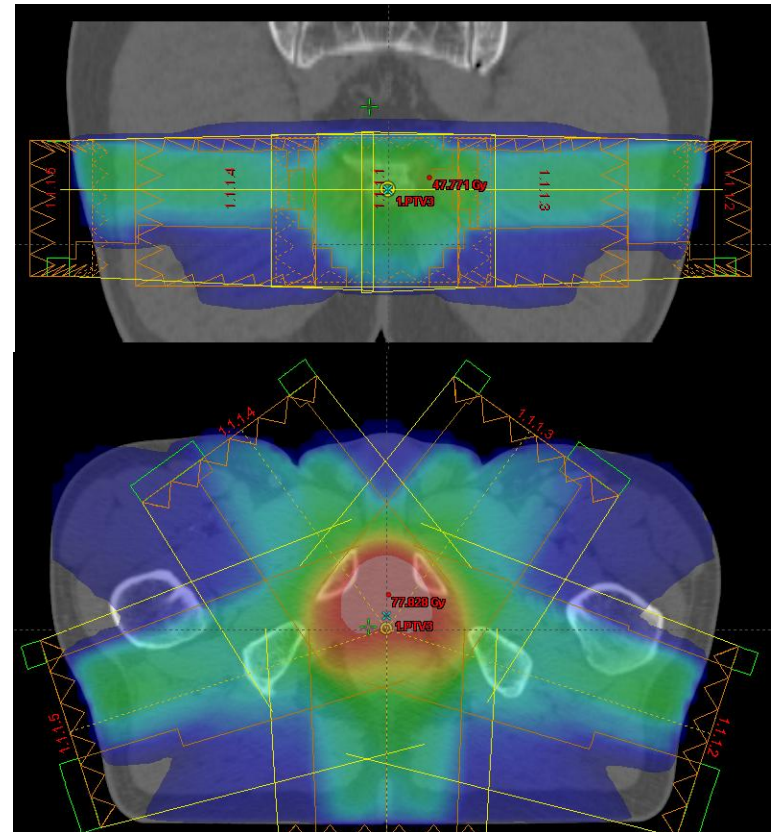


72 Gy



4 Gy

IMRT



Integral dose is approximately constant



A LOT TO A LITTLE OR A LITTLE TO A LOT?

**High dose to a modest volum
or
Low dose to a larger volum**

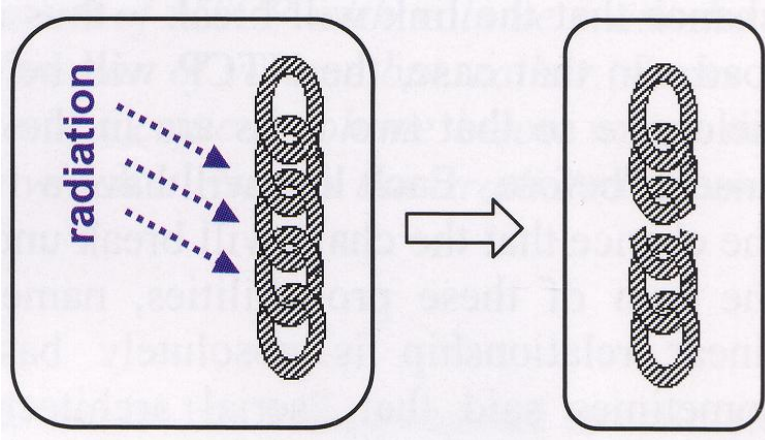
There is no definite answer to this question

Influence of tissue architecture!



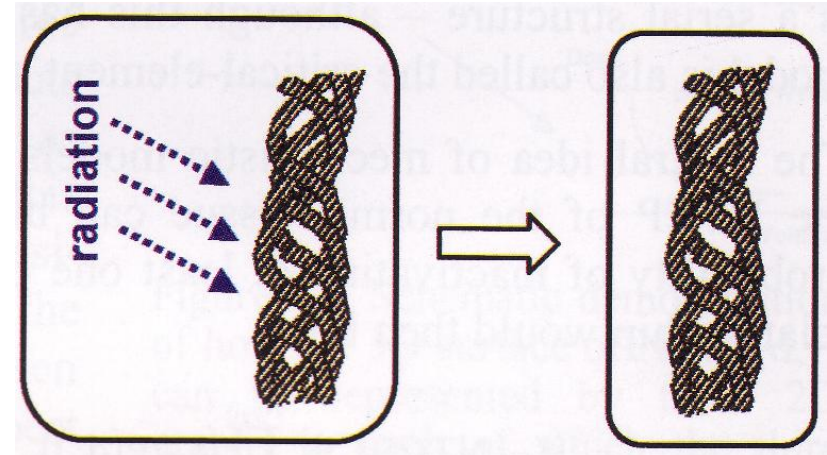
THE INFLUENCE OF TISSUE ARCHITECTURE

serial architecture



only one functional sub-unit (FSU) is sufficient to cause loss of function of the organ

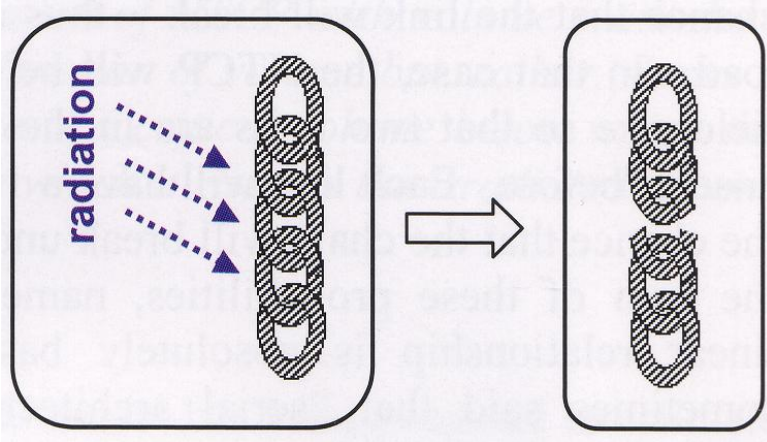
parallel architecture



normal tissue is responsible for. Function is lost, when a critical number of FSUs is lost.

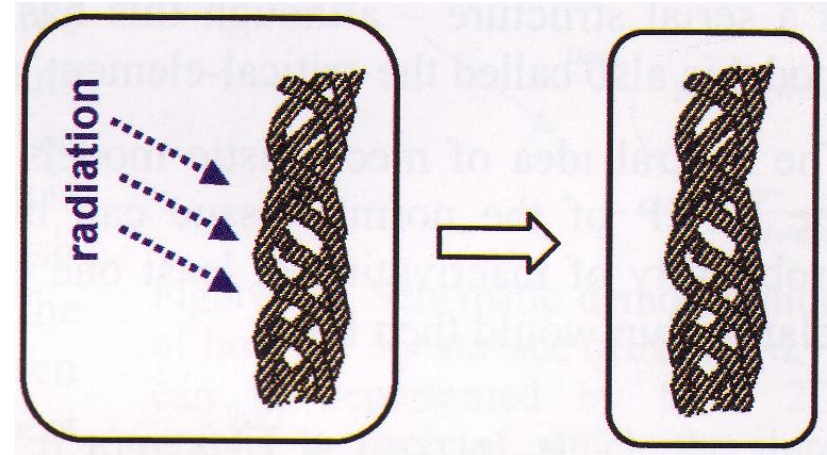
THE INFLUENCE OF TISSUE ARCHITECTURE

serial architecture



Strategy
A little to a lot

parallel architecture



Strategy
A lot to a little



Intensity Modulated Radio Therapy IMRT





INTRODUCTION

So far we have implicitly assumed that each radiation field is near uniform over its cross section

- 20 years ago Cormack, Brahme and Pedroni had the idea to use non-uniform fields
- Using mathematical techniques, an irradiation scheme using non-uniform beams could be found, which limit dose to normal tissues while delivering the desired dose to the target

Motivation from CT reconstruction:

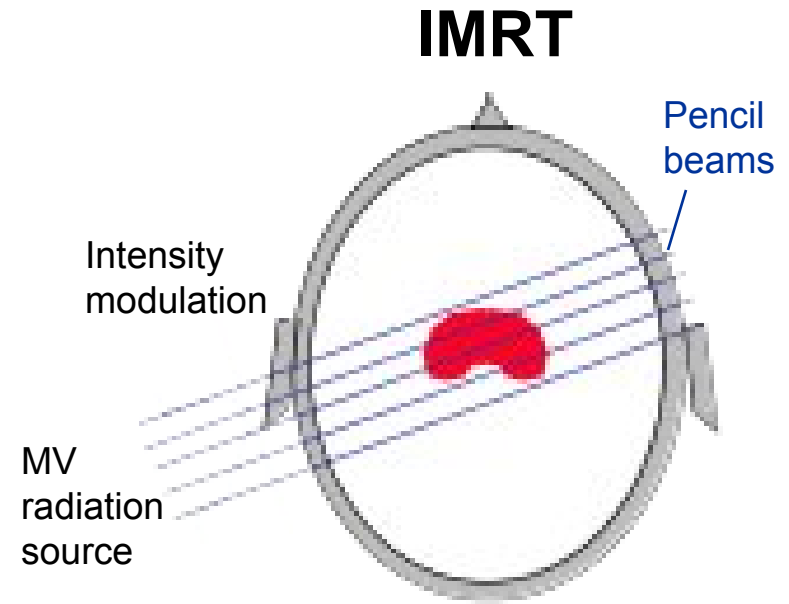
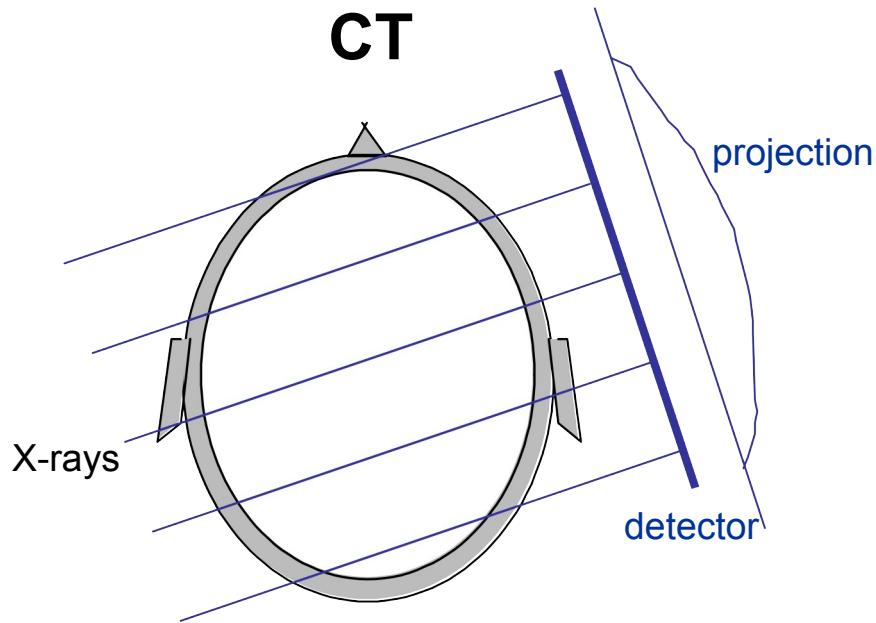
From the intensity reduction of x-rays traversing an object one can deduce the internal structure of the object.



INVERTING COMPUTER TOMOGRAPHY

Calculation of *intensities* (*pencil beam weights*) that pass through the object and deliver dose

- Highly non-uniform individual fields
- Problem: negative intensities



INVERTING COMPUTER TOMOGRAPHY

Image Reconstruction (Backprojection)

Density Distribution of the Tissue

x-ray Projection (CT-Scanner)

Backprojection

Set of 2D Slice Images

IM Radiotherapy (Projection)

Prescribed 3D Dose Distributions

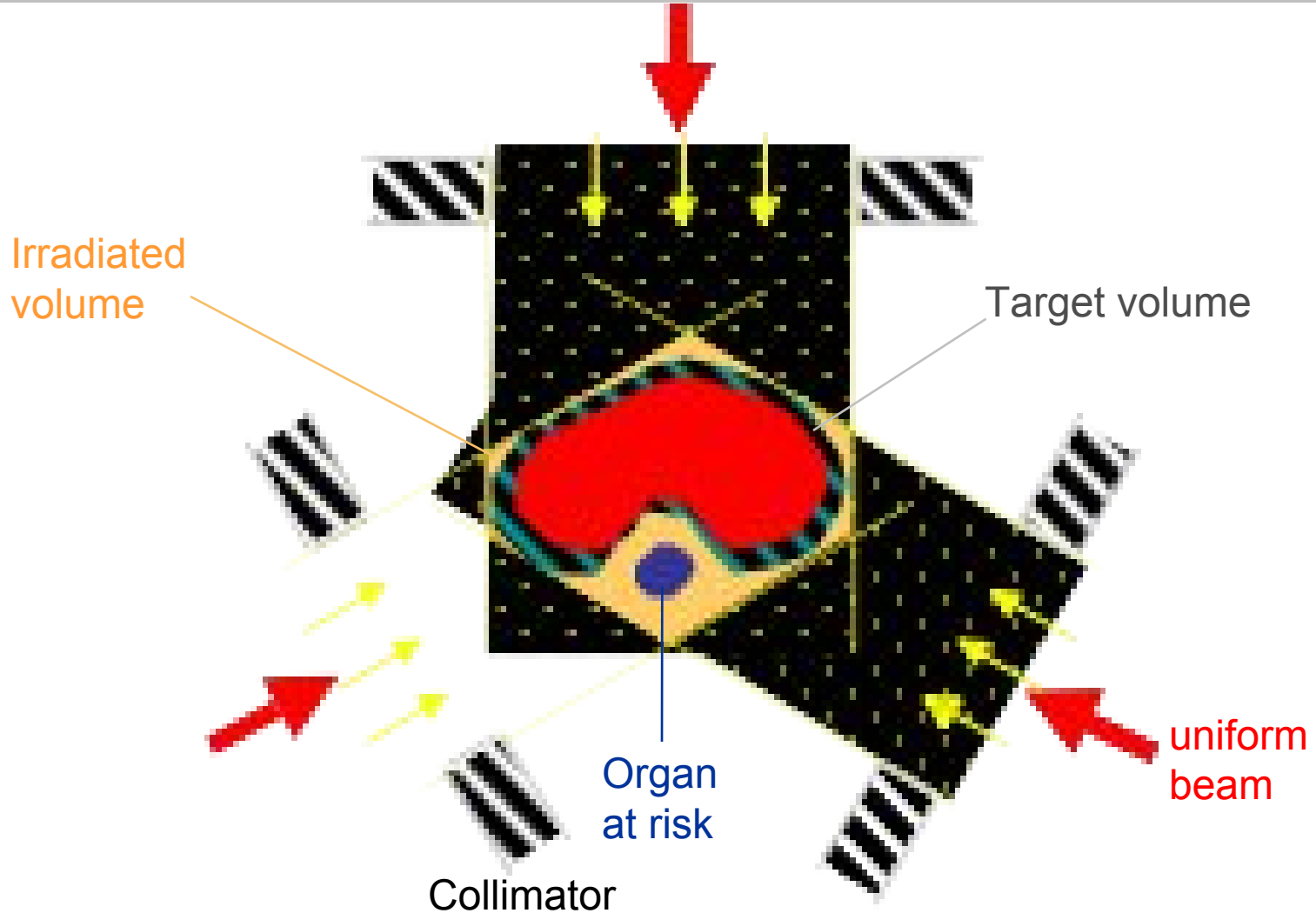
Projection (Computer)

IMRT with Projections

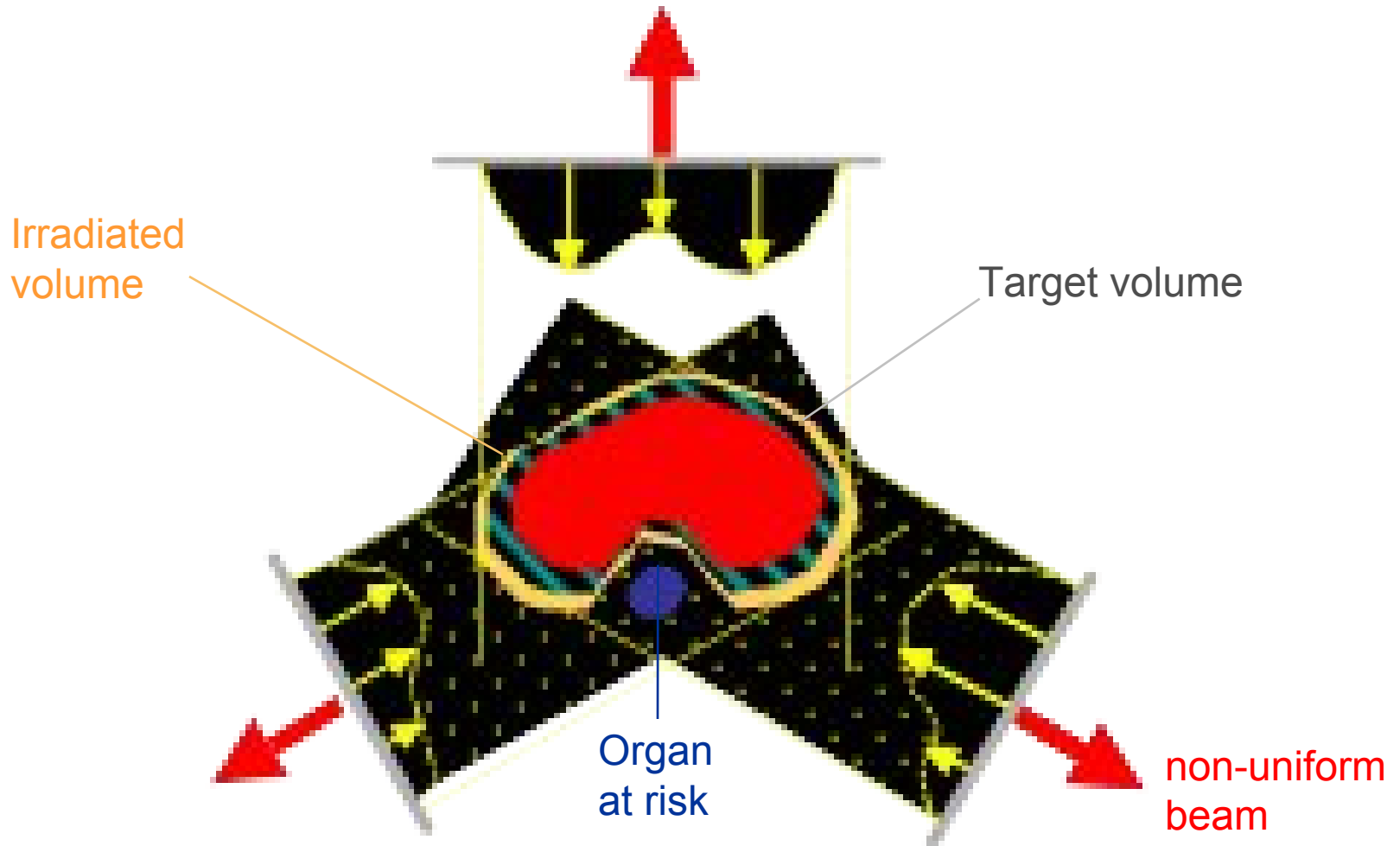
Dose Distribution



UNIFORM-INTENSITY RADIOTHERAPY CONVEX DOSE DISTRIBUTIONS

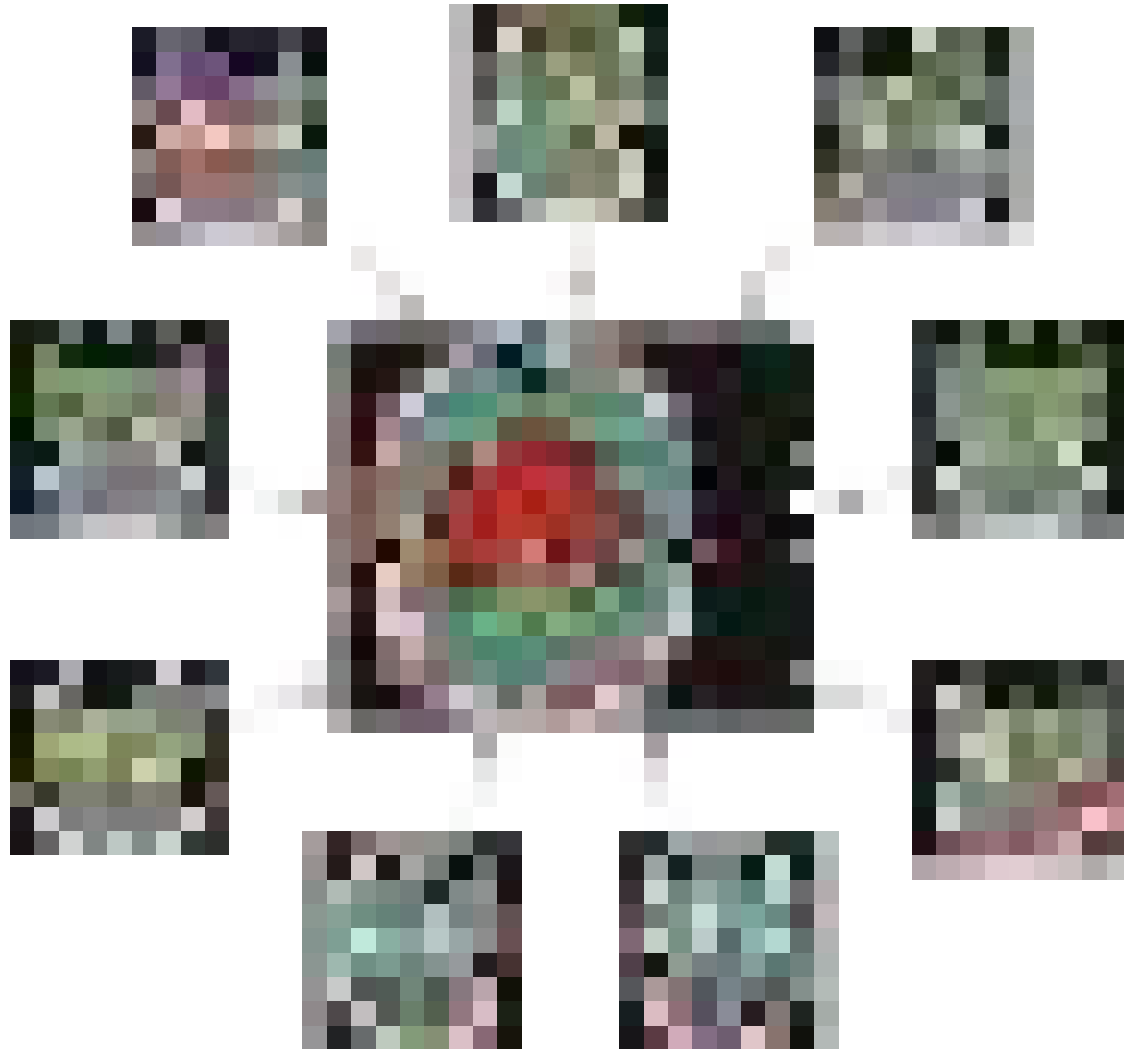


NON-UNIFORM-INTENSITY RADIOTHERAPY CONCAVE DOSE DISTRIBUTIONS





IMRT OF NASOPHARYNGEAL CANCER



ADVANTAGES OF IMRT

Creation of concave dose distributions:

- Sparing of selected normal tissues
(*conformal avoidance*)

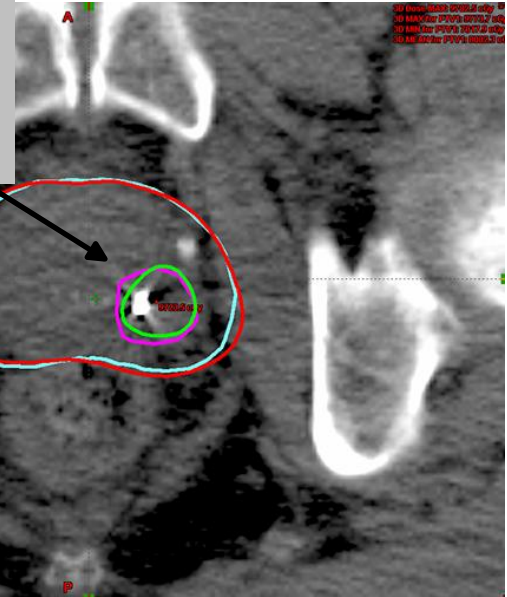
Delivery of non-uniform dose distributions to the target:

- Two different target volumes one nested inside the other (*integrated boost*)
- delivering additional dose to sub-regions of the target because they contain more resistant cells
(*dose painting*)
- deliver a reduced dose to sub-regions of the target volume because a critical volume runs through it
(*dose painting*)

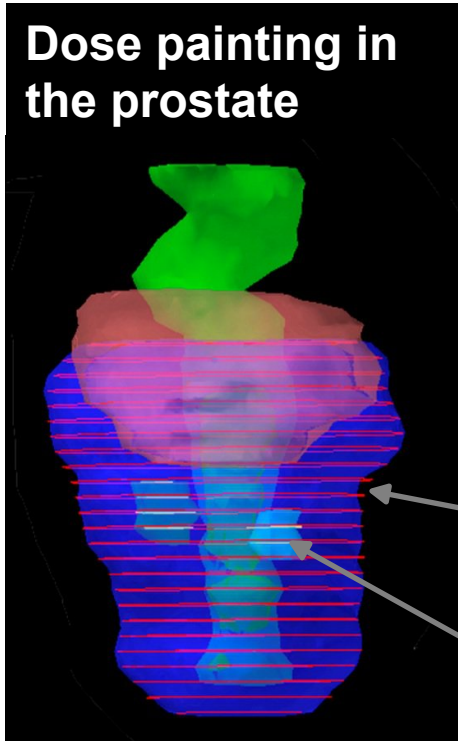


DOSE PAINTING IN TARGET SUBREGIONS

Definition of target in the target by increased Gadolinium uptake in MRI



Dose painting in the prostate

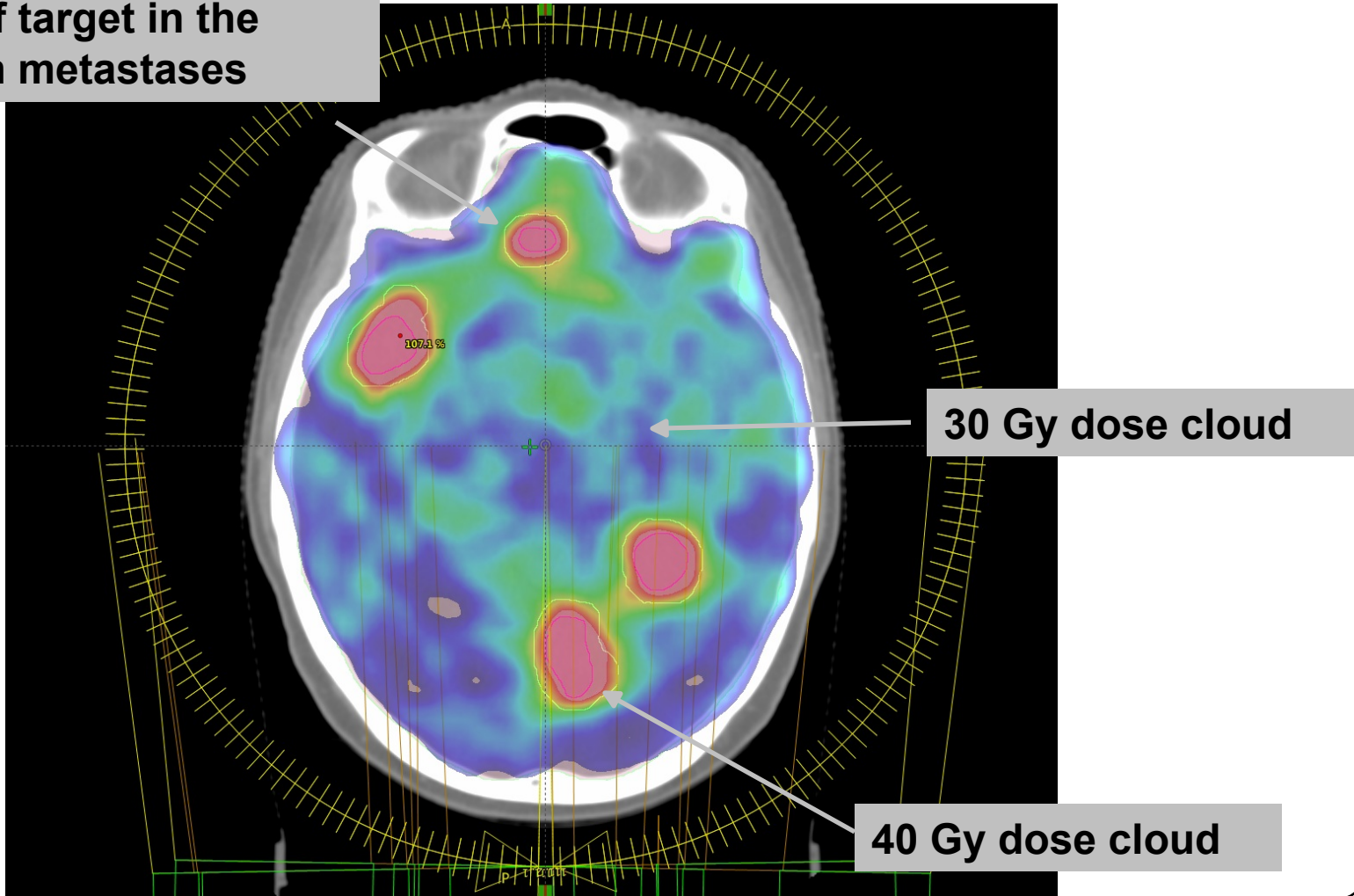


75.6 Gy dose cloud

94.5 Gy dose cloud

DOSE PAINTING IN THE BRAIN

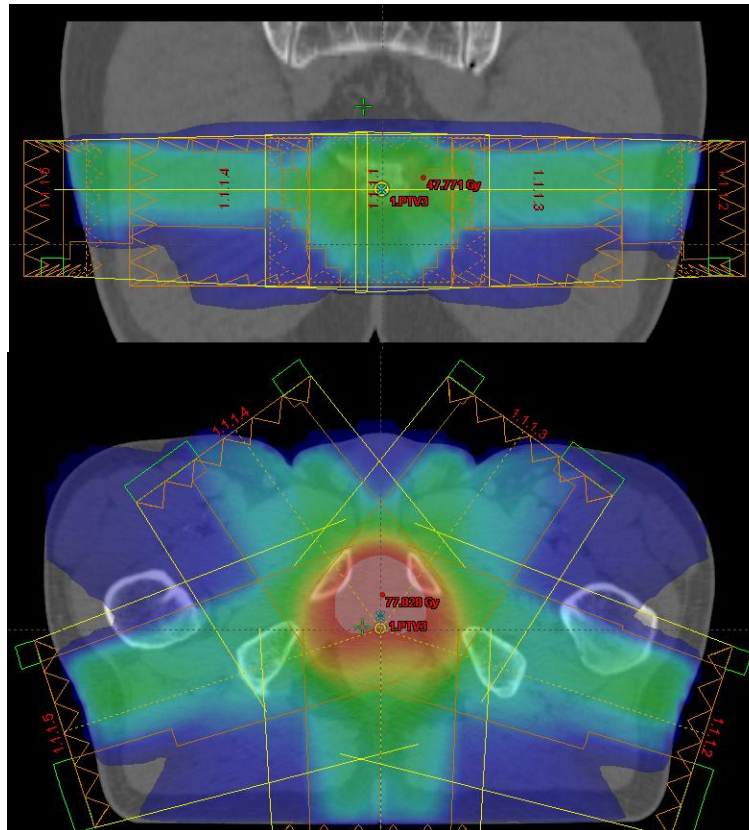
Definition of target in the target: brain metastases



DISADVANTAGES OF IMRT

It is not possible to spare all the OARs

- Dose has to be deposited somewhere (integral dose)



INVERSE PLANNING OF IMRT

Specify the desired
dose distribution



Calculate the treatment
variables which would
lead to the desired
dose distribution



end

Straightforward scheme, but with
problems:

- Negative intensities
- When negative intensities are set to zero there is no room for balancing conflicting goals (TCP – NTCP)



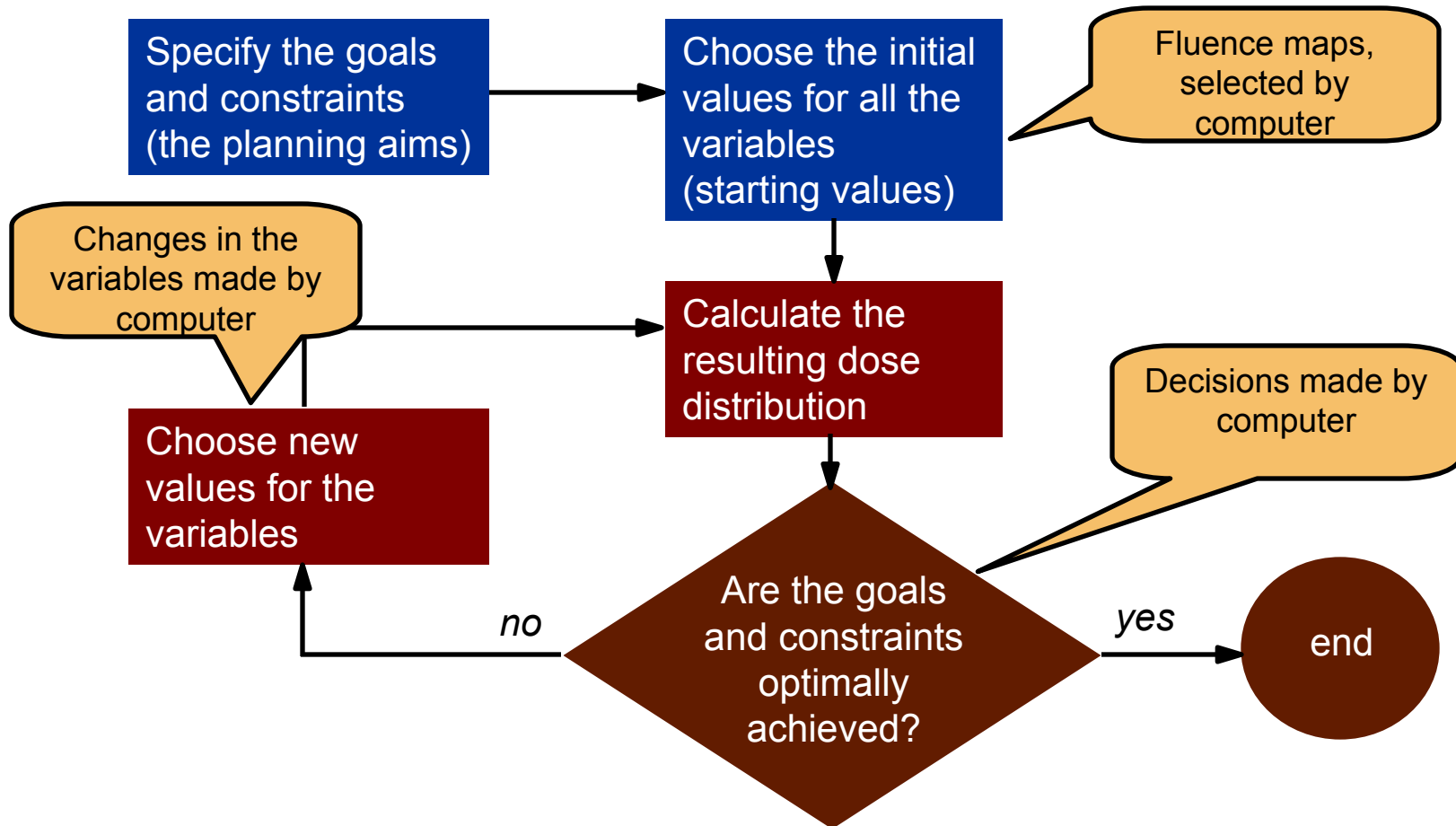
Inverse planning is not used in clinical
practice



Forward planning of IMRT

FORWARD PLANNING OF IMRT

Flow chart for forward IMRT planning:





FORWARD PLANNING OF IMRT

Two main aspects of planning IMRT:

- Establishing a method for computing a numerical *score*, expressing how well the goals were achieved (assign a numerical value to rank plans)
- Conducting a *search* through the space of treatment variables to locate the set of values of those variables that gives the best score (6000 variables with 10^{13} choices)





What is usually not included in the score

- Type of radiation
- Energy of radiation
- Number and direction of beams
- Table rotation (IMRT is usual coplanar)





What is usually included in the score

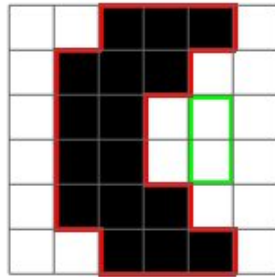
Tumor response:

- The difference between the minimum (mean) target dose and the prescribed dose
- The dose exceeded by 95% of the target volume (cold spots)
- The dose exceeded in 5% of the target volume (hot spots)

Morbidity for each organ at risk:

- The difference between the maximum (mean) OAR dose and its constraint dose
- The difference between the volume of the OAR which receives more than a dose D and the corresponding volume constraint
- integral dose





Red: Target

Green: Organ at risk

Objective Function:

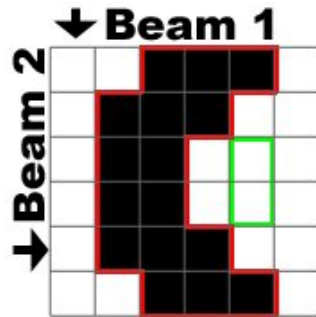
Mean squared deviation between actual and prescribed dose in the target

Constraint:

Dose in organ at risk $< 50\%$, positive intensities

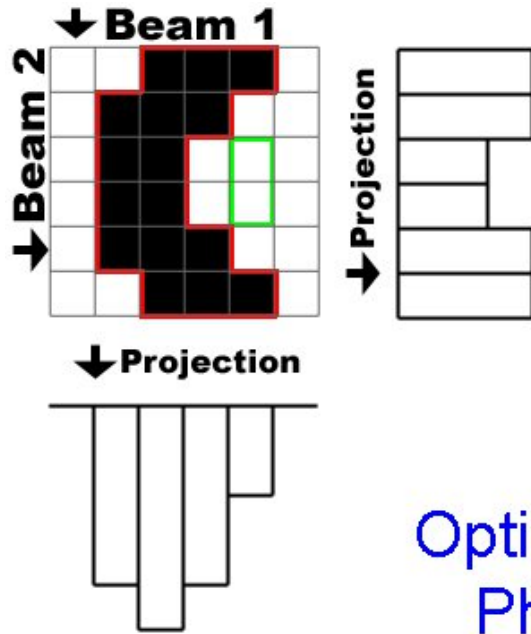
Optimization Phase 1



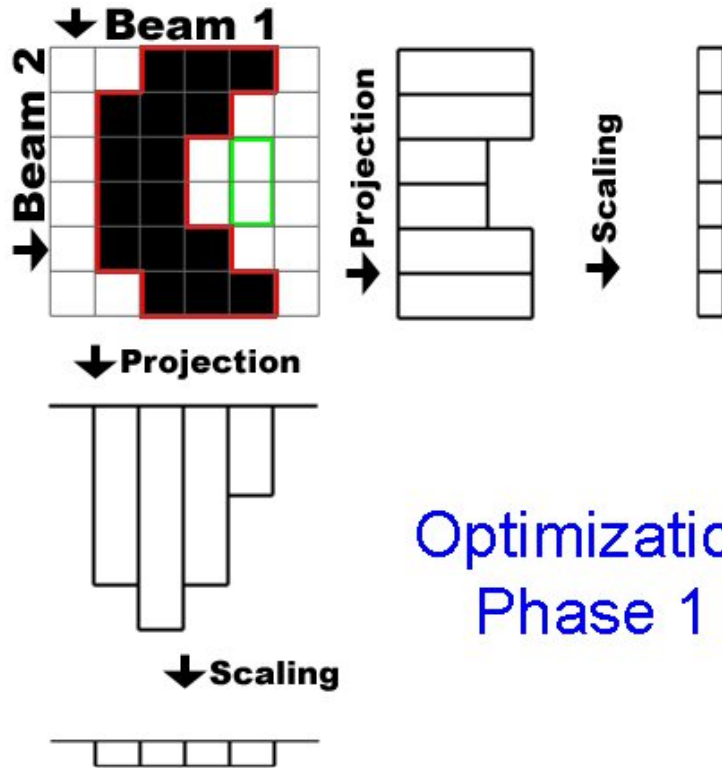


Optimization Phase 1



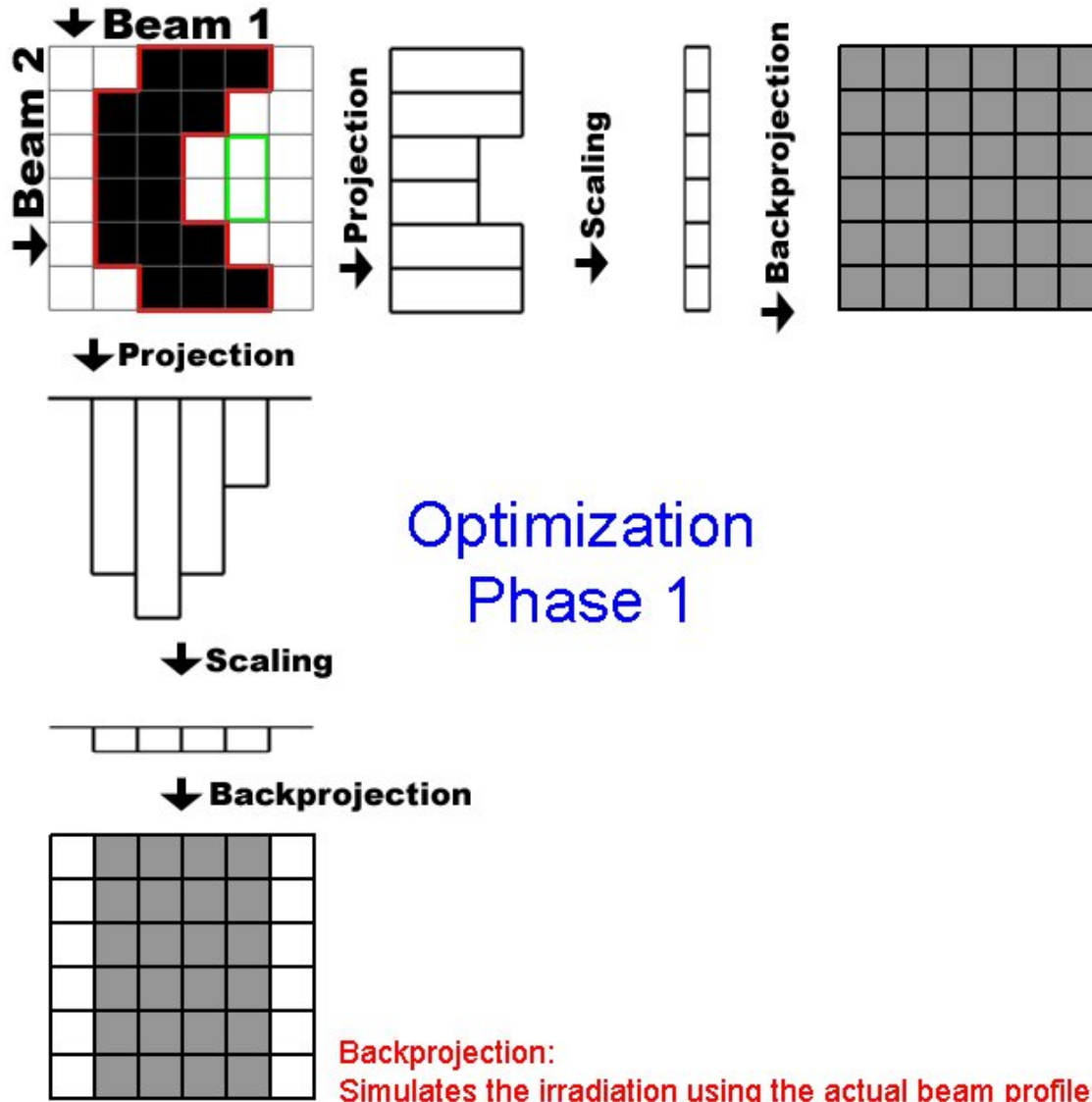


Projection: Summation of the dose values along the beam direction



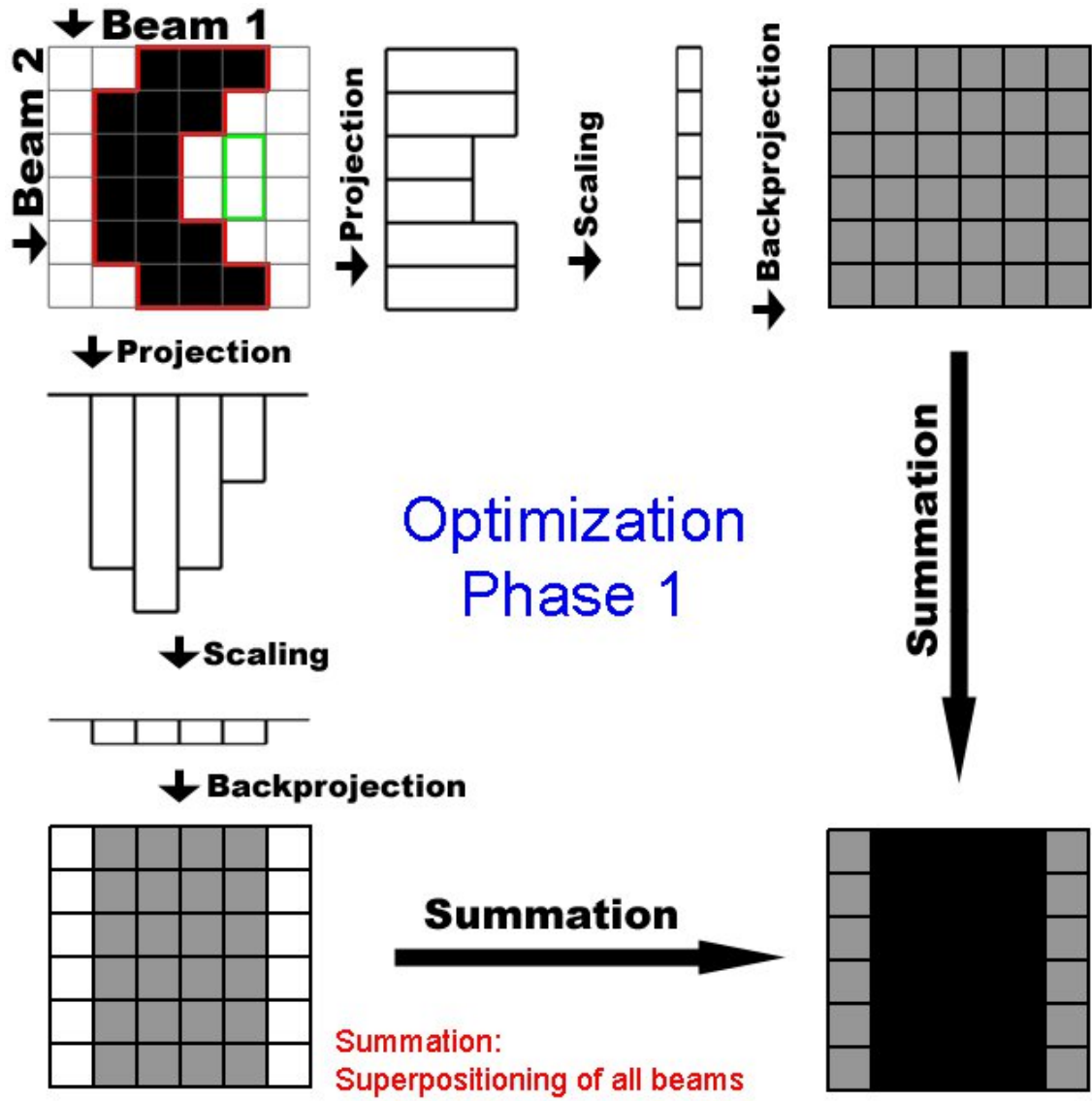
Optimization Phase 1

Scaling: Division by number of contributing dose elements and by number of beams

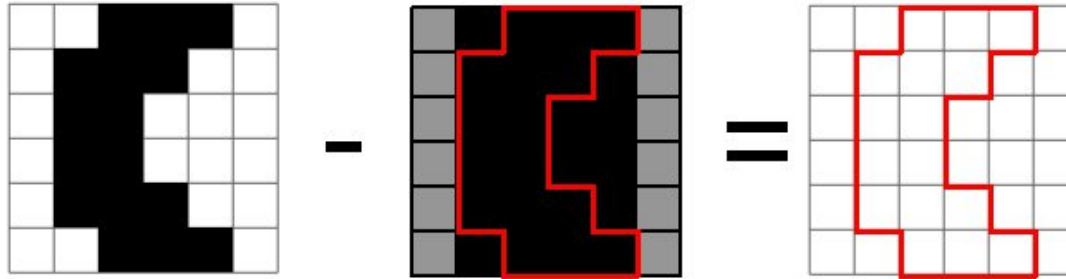


Optimization Phase 1

Backprojection:
Simulates the irradiation using the actual beam profiles

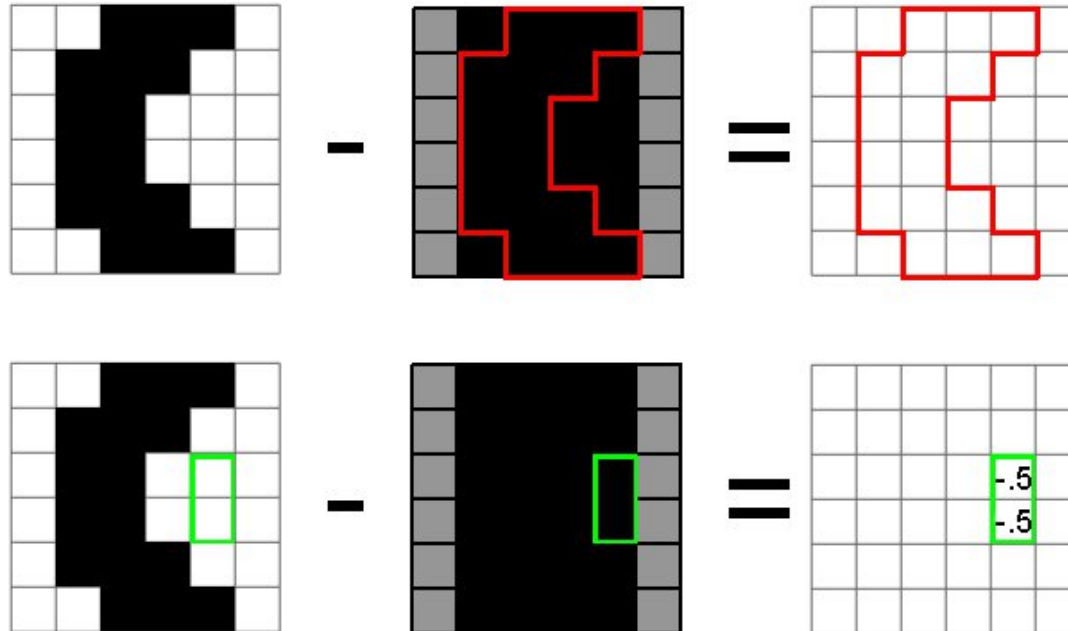


Evaluation Phase 1



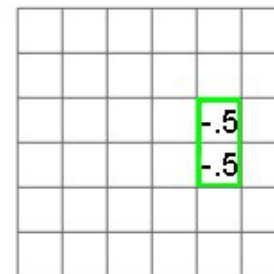
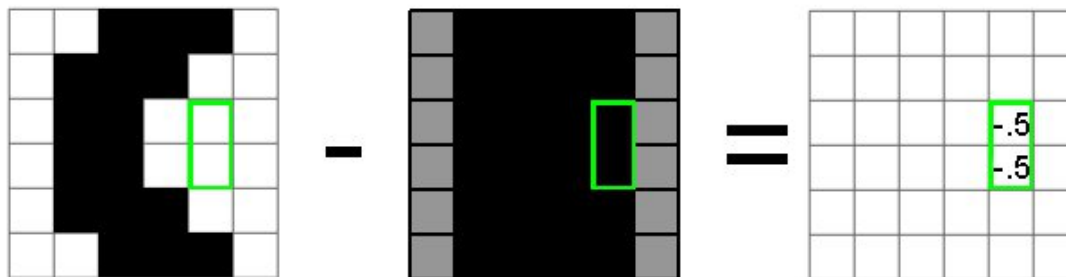
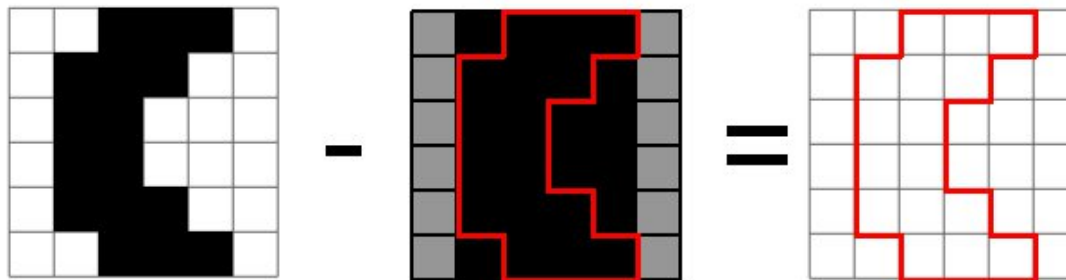
Comparing prescribed and realized dose in the target volume.
In this case there is no difference, therefore no correction necessary.

Evaluation Phase 1

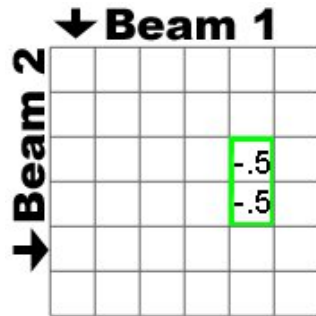


Same for the organ at risk: Here the difference is -0.5.

Evaluation Phase 1

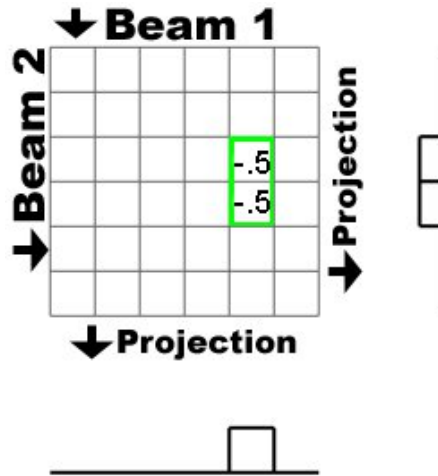


Resulting correction matrix.



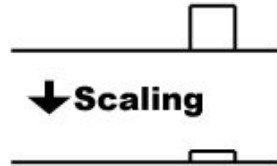
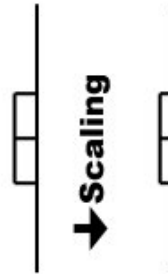
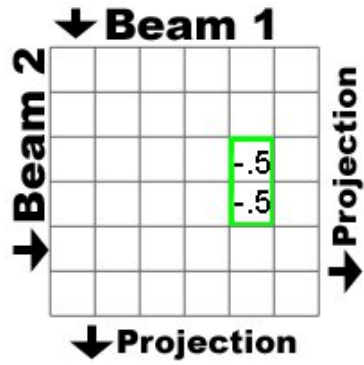
Optimization Phase 2





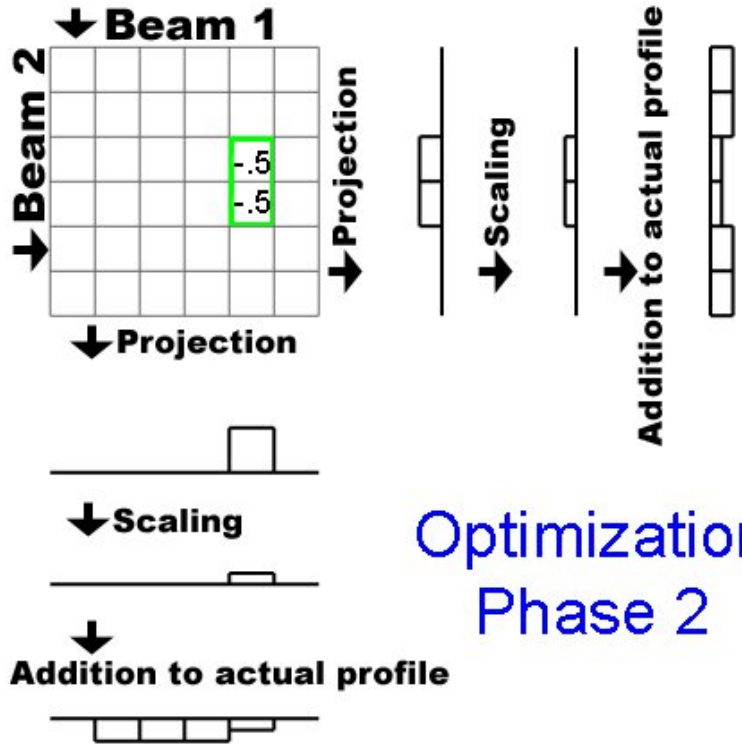
Optimization Phase 2

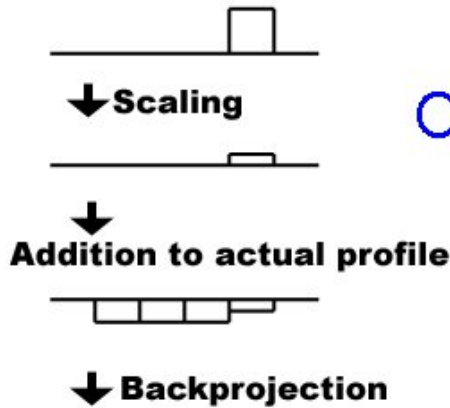
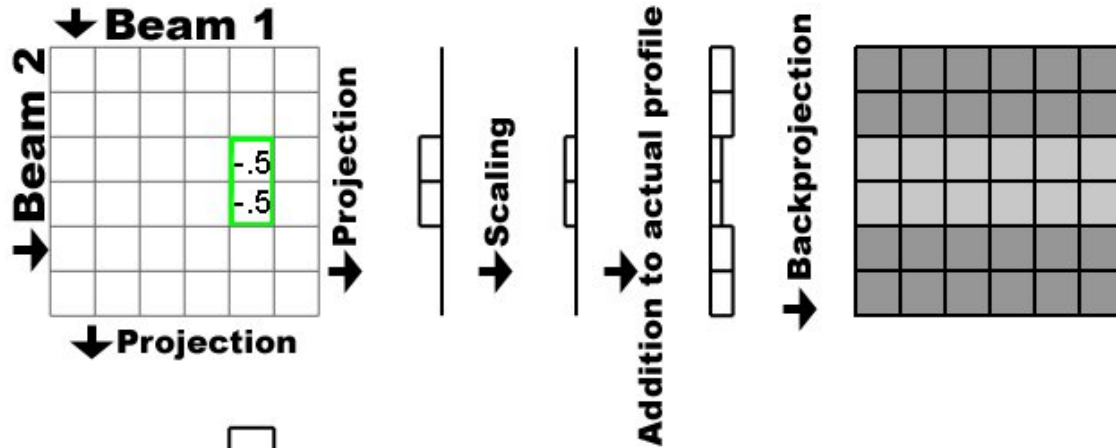




Optimization Phase 2

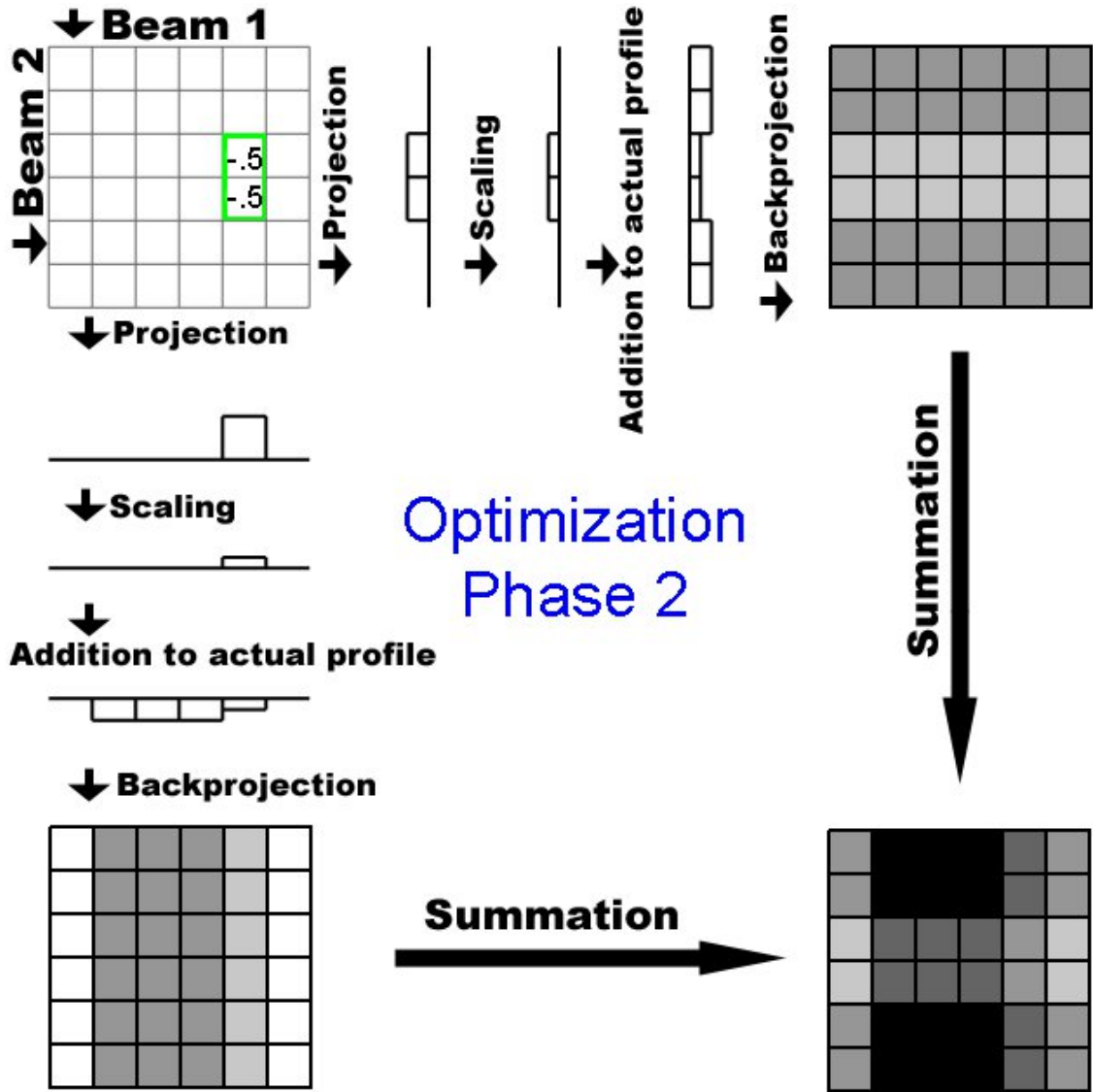






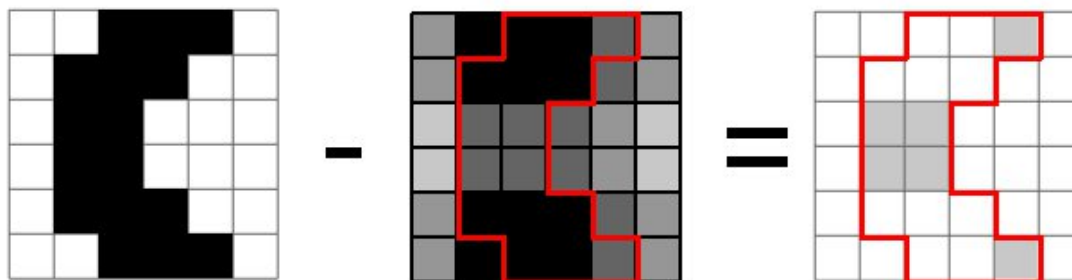
Optimization Phase 2



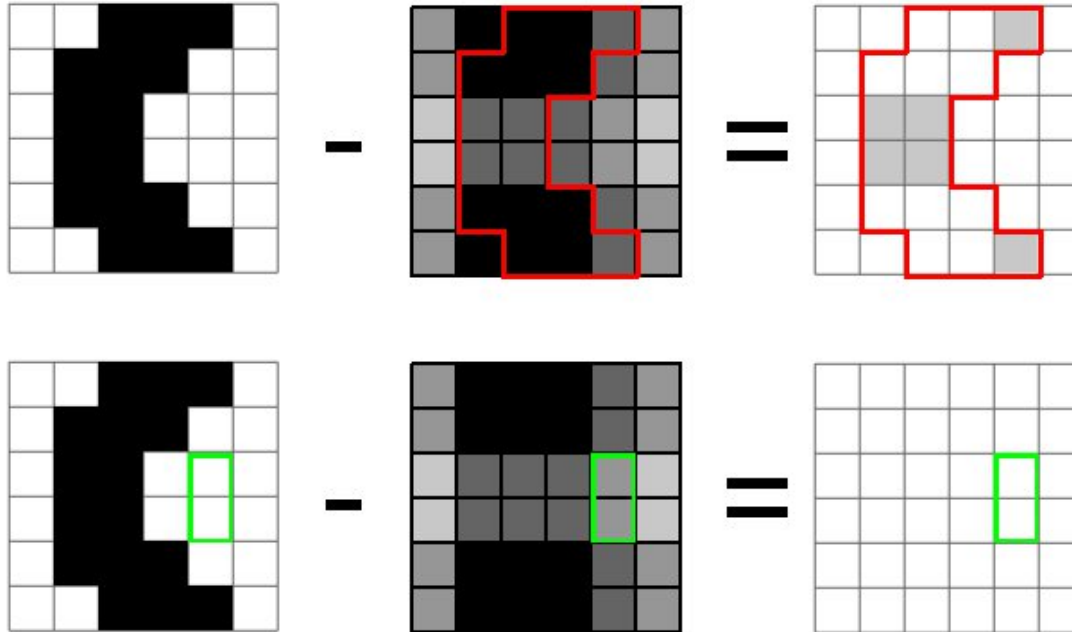


Optimization Phase 2

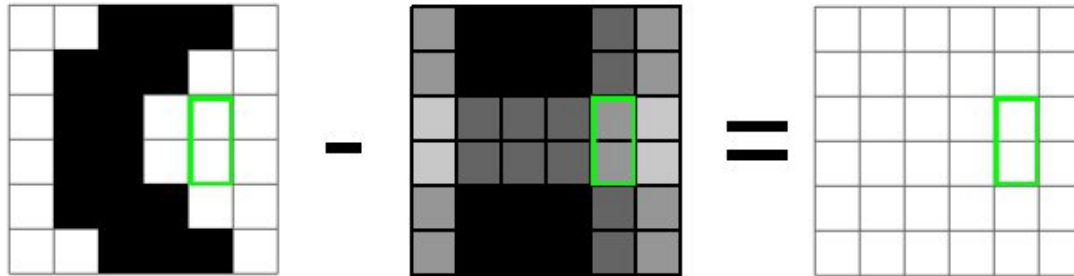
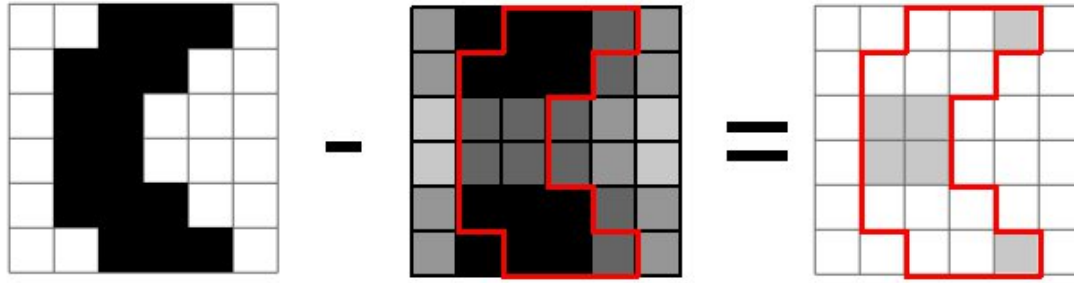
Evaluation Phase 2



Evaluation Phase 2



Evaluation Phase 2





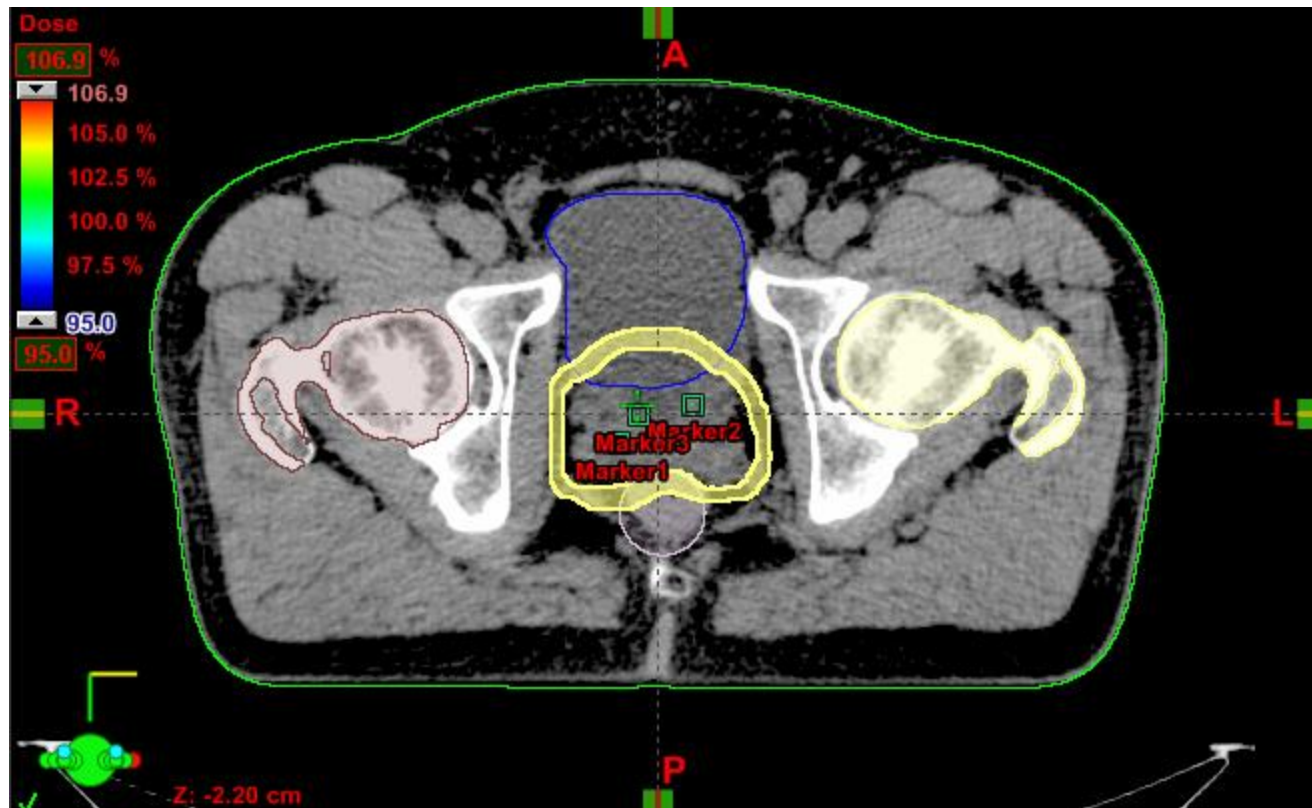
Optimization Phase 3

Repeat the steps of evaluation and optimization
until an acceptable treatment plan is found.



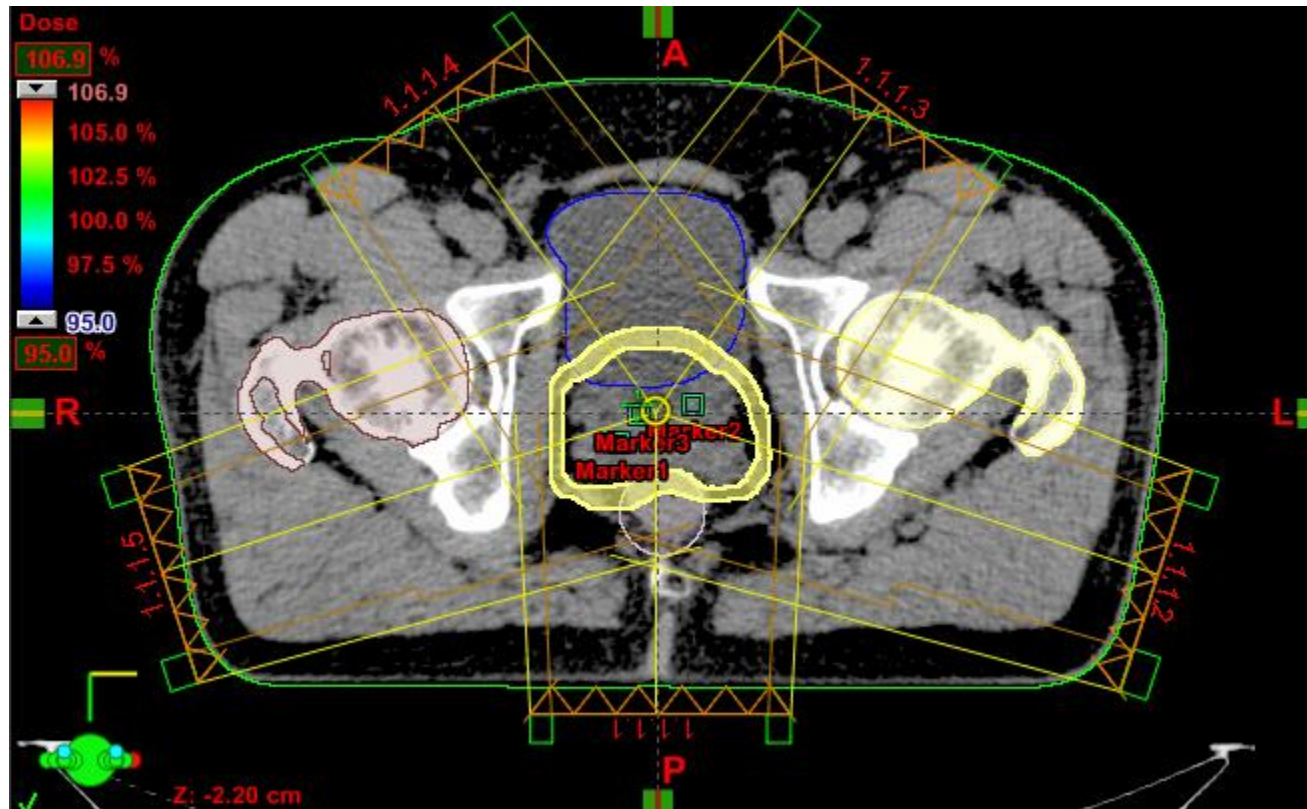
OPTIMIZATION: example prostate

Imaging and Contouring



OPTIMIZATION: example prostate

Field definition





Optimization

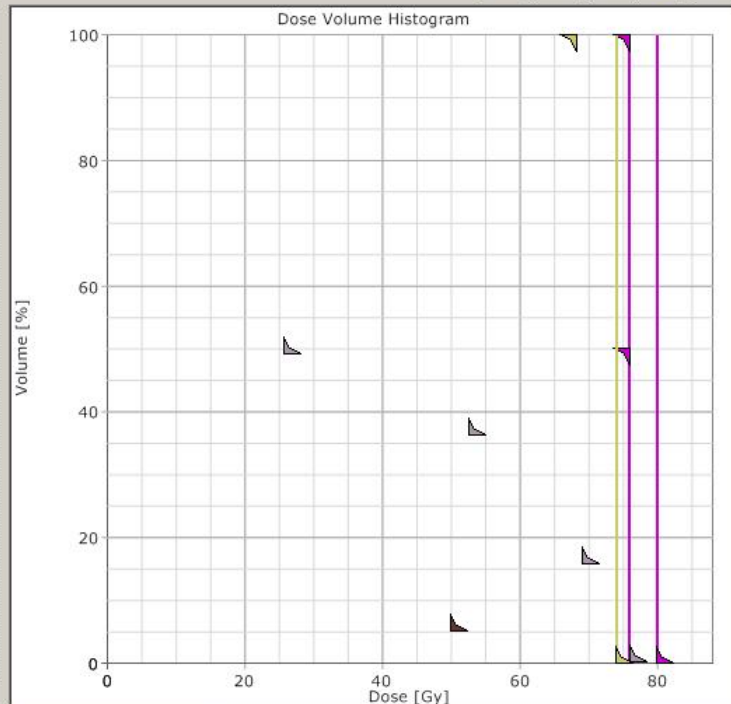
Structures and Objectives

Use Normal Tissue Objective

Priority: 150

Normal Tissue Objective Parameters...

Structure	Type	Volume [cc]	Points	Resolution [mm]	Priority
BODY		19869	196232	4.50	
Blase		517	17243	3.00	
	Upper	50.0	55.0		100
	Upper	15.0	75.0		100
	Upper	35.0	70.0		100
CTV		64	2131	3.00	
PTV3		120	4009	3.00	
	Upper	0.0	80.0		100
	Lower	100.0	76.0		150
	Lower	50.0	76.0		100
Rektum		36	32221	1.00	
	Upper	26.8	64.9		50
li Femurkopf		137	4567	3.00	
	Upper	5.0	50.0		100
p-PTV		118	13288	2.00	
	Upper	0.0	74.0		100
	Lower	99.9	68.4		120
re Femurkopf		131	4354	3.00	
	Upper	5.0	50.0		100
virt rect		71	64027	1.00	
	Upper	49.1	25.7		100
	Upper	36.3	52.6		100
	Upper	15.7	69.1		150
	Upper	0.0	76.0		200



Add Upper Objective Add Lower Objective Delete

	MLC	Method	X Smooth	Y Smooth	Minimize Dose	Fixed Jaws	Field Weight
1.1.1.1	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.2	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000
1.1.1.3	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.4	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.5	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000

Base dose plan: Select...

Max time (min): 100

Max iterations: 1000



Optimize

OK Cancel Apply

View with interpolation
 Use color



Optimization

Structures and Objectives

Use Normal Tissue Objective

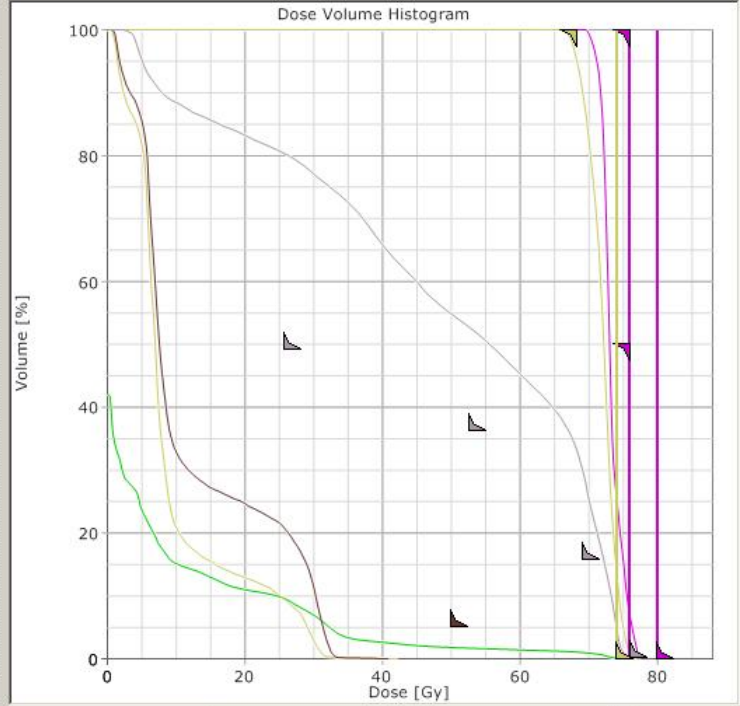
Priority:

Normal Tissue Objective Parameters...

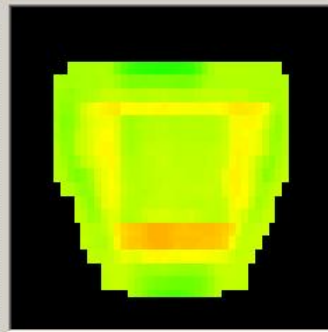
Structure	Type	Volume [cc]	Points	Resolution [mm]	Priority
BODY		19869	307530	4.50	
Blase		517	26838	3.00	
	Upper	50.0	55.0		100
	Upper	15.0	75.0		100
	Upper	35.0	70.0		100
CTV		64	4344	3.00	
PTV3		120	7582	3.00	
	Upper	0.0	80.0		100
	Lower	100.0	76.0		150
	Lower	50.0	76.0		100
Rektum		36	35133	1.00	
	Upper	26.8	64.9		50
li Femurkopf		137	13985	3.00	
	Upper	5.0	50.0		100
p-PTV		118	16575	2.00	
	Upper	0.0	74.0		100
	Lower	99.9	68.4		120
re Femurkopf		131	14535	3.00	
	Upper	5.0	50.0		100
virt rect		71	70223	1.00	
	Upper	49.1	25.7		100
	Upper	36.3	52.6		100
	Upper	15.7	69.1		150
	Upper	0.0	76.0		200

Add Upper Objective Add Lower Objective Delete

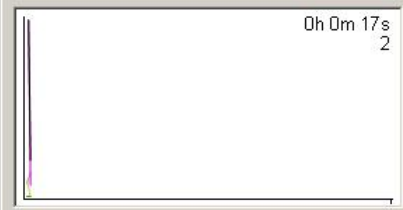
	MLC	Method	X Smooth	Y Smooth	Minimize Dose	Fixed Jaws	Field Weight
1.1.1.1	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.2	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000
1.1.1.3	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.4	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.5	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000



Base dose plan: Select...



Max time (min):
 Max iterations:



0h 0m 17s
2
Continue
OK Cancel Apply

View with interpolation
 Use color

Optimization

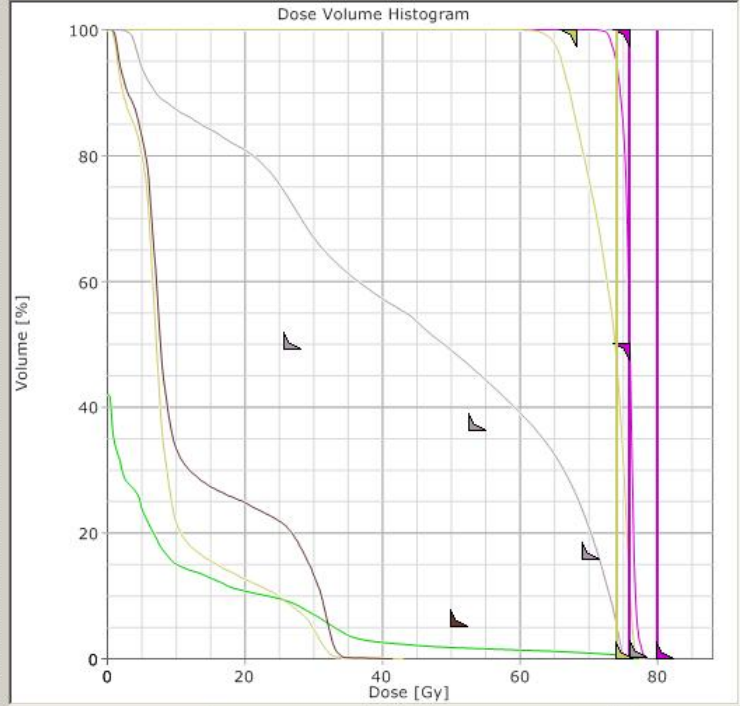
Structures and Objectives

Use Normal Tissue Objective Priority: Normal Tissue Objective Parameters...

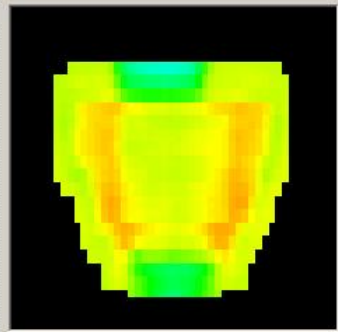
Structure	Type	Volume [cc]	Points	Resolution [mm]
BODY		19869	307530	4.50
Blase		517	26838	3.00
	Upper	50.0	55.0	100
	Upper	15.0	75.0	100
	Upper	35.0	70.0	100
CTV		64	4344	3.00
PTV3		120	7582	3.00
	Upper	0.0	80.0	100
	Lower	100.0	76.0	150
	Lower	50.0	76.0	100
Rektum		36	35133	1.00
	Upper	26.8	64.9	50
li Femurkopf		137	13985	3.00
	Upper	5.0	50.0	100
p-PTV		118	16575	2.00
	Upper	0.0	74.0	100
	Lower	99.9	68.4	120
re Femurkopf		131	14535	3.00
	Upper	5.0	50.0	100
virt rect		71	70223	1.00
	Upper	49.1	25.7	100
	Upper	36.3	52.6	100
	Upper	15.7	69.1	150
	Upper	0.0	76.0	200

Add Upper Objective Add Lower Objective Delete

	MLC	Method	X Smooth	Y Smooth	Minimize Dose	Fixed Jaws	Field Weight
1.1.1.1	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.2	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000
1.1.1.3	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.4	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.5	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000



Base dose plan: Select...



Max time (min):
 Max iterations:



Continue
 OK Cancel Apply

View with interpolation
 Use color

Optimization

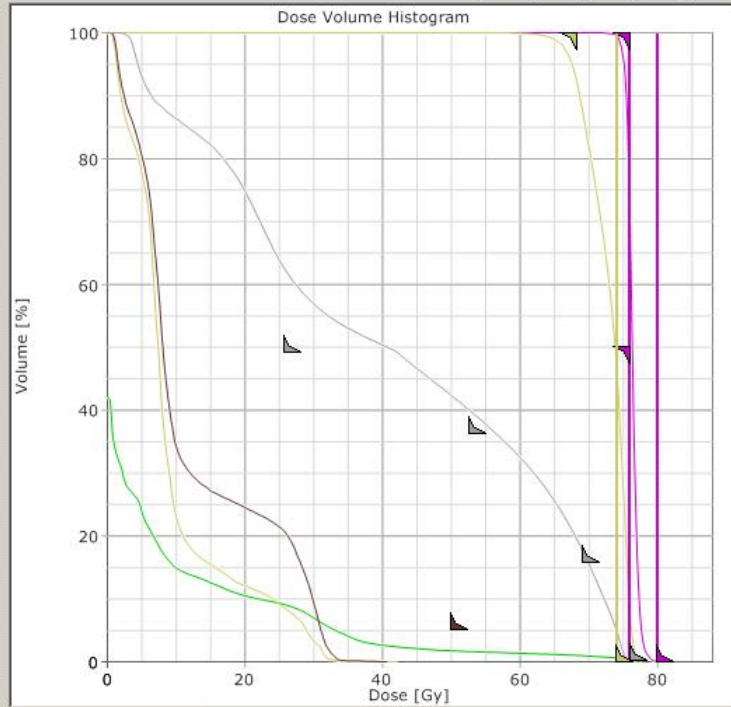
Structures and Objectives

Use Normal Tissue Objective

Priority:

Normal Tissue Objective Parameters...

Structure	Type	Volume [cc]	Points	Resolution [mm]
BODY		19869	307530	4.50
Blase		517	26838	3.00
	Upper	50.0	55.0	100
	Upper	15.0	75.0	100
	Upper	35.0	70.0	100
CTV		64	4344	3.00
PTV3		120	7582	3.00
	Upper	0.0	80.0	100
	Lower	100.0	76.0	150
	Lower	50.0	76.0	100
Rektum		36	35133	1.00
	Upper	26.8	64.9	50
li Femurkopf		137	13985	3.00
	Upper	5.0	50.0	100
p-PTV		118	16575	2.00
	Upper	0.0	74.0	100
	Lower	99.9	68.4	120
re Femurkopf		131	14535	3.00
	Upper	5.0	50.0	100
virt rect		71	70223	1.00
	Upper	49.1	25.7	100
	Upper	36.3	52.6	100
	Upper	15.7	69.1	150
	Upper	0.0	76.0	200



Add Upper Objective

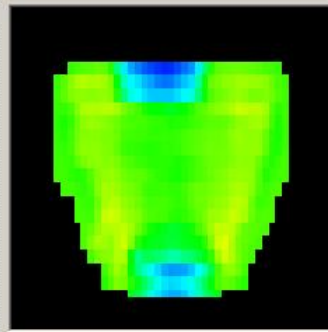
Add Lower Objective

Delete

	MLC	Method	X Smooth	Y Smooth	Minimize Dose	Fixed Jaws	Field Weight
1.1.1.1	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.2	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000
1.1.1.3	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.4	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.5	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000

Base dose plan:

Select...



Max time (min):

Max iterations:

0h 0m 33s
7



Continue

OK

Cancel

Apply

View with interpolation
 Use color



Optimization

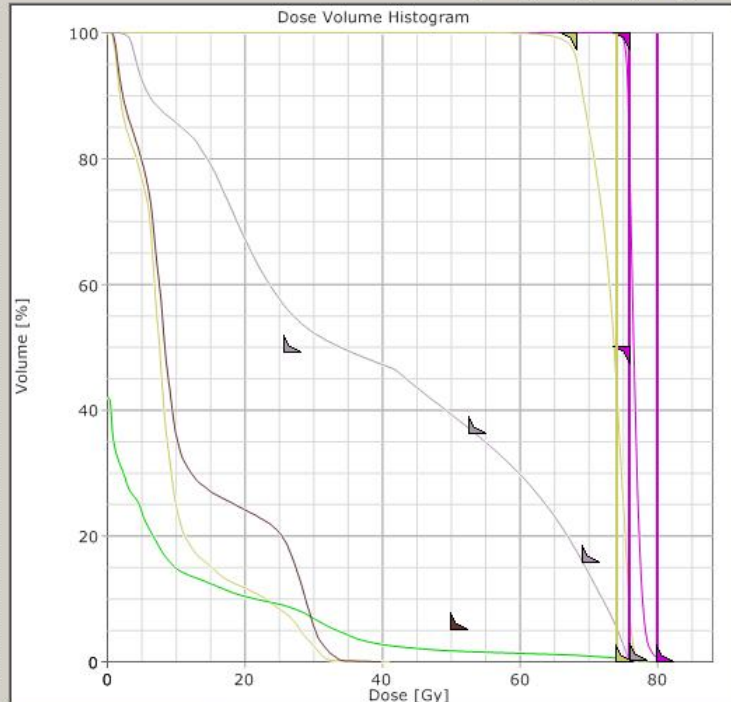
Structures and Objectives

Use Normal Tissue Objective

Priority:

Normal Tissue Objective Parameters...

Structure	Type	Volume [cc]	Points	Resolution [mm]
BODY		19869	307530	4.50
Blase		517	26838	3.00
	Upper	50.0	55.0	100
	Upper	15.0	75.0	100
	Upper	35.0	70.0	100
CTV		64	4344	3.00
PTV3		120	7582	3.00
	Upper	0.0	80.0	100
	Lower	100.0	76.0	150
	Lower	50.0	76.0	100
Rektum		36	35133	1.00
	Upper	26.8	64.9	50
li Femurkopf		137	13985	3.00
	Upper	5.0	50.0	100
p-PTV		118	16575	2.00
	Upper	0.0	74.0	100
	Lower	99.9	68.4	120
re Femurkopf		131	14535	3.00
	Upper	5.0	50.0	100
virt rect		71	70223	1.00
	Upper	49.1	25.7	100
	Upper	36.3	52.6	100
	Upper	15.7	69.1	150
	Upper	0.0	76.0	200



Add Upper Objective

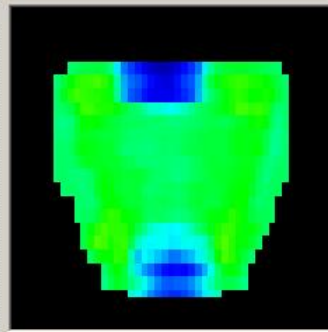
Add Lower Objective

Delete

	MLC	Method	X Smooth	Y Smooth	Minimize Dose	Fixed Jaws	Field Weight
1.1.1.1	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.2	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000
1.1.1.3	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.4	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.5	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000

Base dose plan:

Select...



Max time (min):

Max iterations:

0h 0m 40s
10



Continue

View with interpolation
 Use color

OK Cancel Apply

Optimization

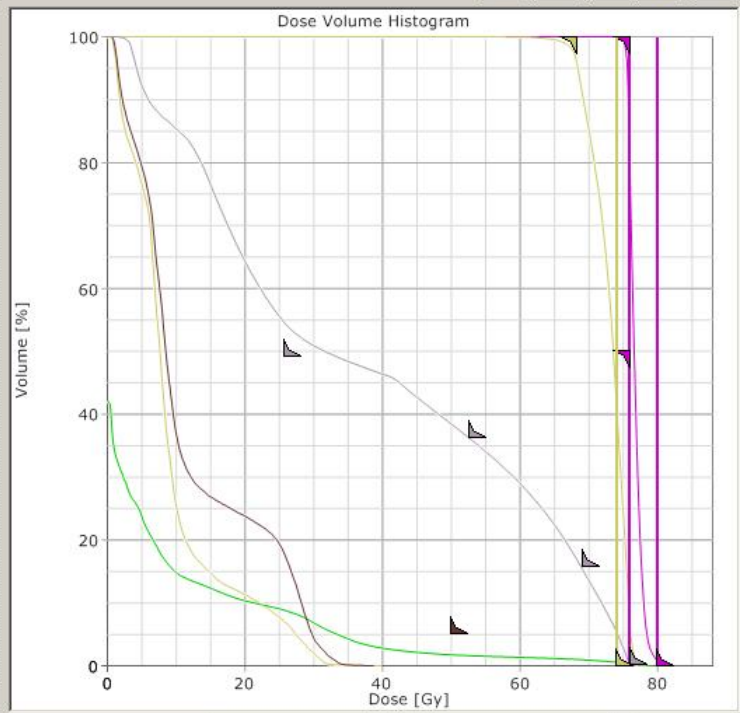
Structures and Objectives

Use Normal Tissue Objective

Priority:

Normal Tissue Objective Parameters...

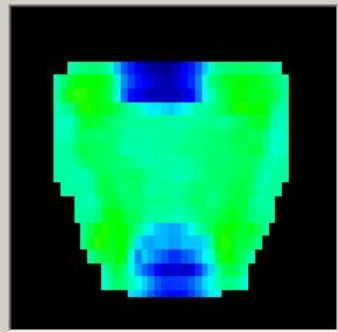
Structure	Type	Volume [cc]	Points	Resolution [mm]
BODY		19869	307530	4.50
Blase		517	26838	3.00
	Upper	50.0	55.0	100
	Upper	15.0	75.0	100
	Upper	35.0	70.0	100
CTV		64	4344	3.00
PTV3		120	7582	3.00
	Upper	0.0	80.0	100
	Lower	100.0	76.0	150
	Lower	50.0	76.0	100
Rektum		36	35133	1.00
	Upper	26.8	64.9	50
li Femurkopf		137	13985	3.00
	Upper	5.0	50.0	100
p-PTV		118	16575	2.00
	Upper	0.0	74.0	100
	Lower	99.9	68.4	120
re Femurkopf		131	14535	3.00
	Upper	5.0	50.0	100
virt rect		71	70223	1.00
	Upper	49.1	25.7	100
	Upper	36.3	52.6	100
	Upper	15.7	69.1	150
	Upper	0.0	76.0	200



Add Upper Objective Add Lower Objective Delete

	MLC	Method	X Smooth	Y Smooth	Minimize Dose	Fixed Jaws	Field Weight
1.1.1.1	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.2	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000
1.1.1.3	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.4	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.5	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000

Base dose plan: Select...



Max time (min):
 Max iterations:

Optimizing 0h 0m 39s
 10

Stop
 OK Cancel Apply

View with interpolation
 Use color

Optimization

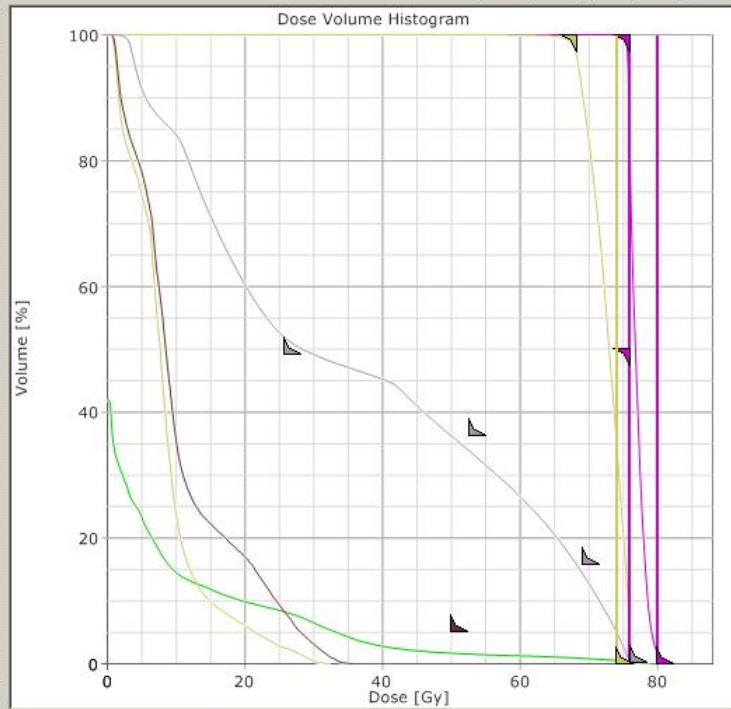
Structures and Objectives

Use Normal Tissue Objective

Priority:

Normal Tissue Objective Parameters...

Structure	Type	Volume [cc]	Points	Resolution [mm]
BODY		19869	307530	4.50
Blase		517	26838	3.00
	Upper	50.0	55.0	100
	Upper	15.0	75.0	100
	Upper	35.0	70.0	100
CTV		64	4344	3.00
PTV3		120	7582	3.00
	Upper	0.0	80.0	100
	Lower	100.0	76.0	150
	Lower	50.0	76.0	100
Rektum		36	35133	1.00
	Upper	26.8	64.9	50
li Femurkopf		137	13985	3.00
	Upper	5.0	50.0	100
p-PTV		118	16575	2.00
	Upper	0.0	74.0	100
	Lower	99.9	68.4	120
re Femurkopf		131	14535	3.00
	Upper	5.0	50.0	100
virt rect		71	70223	1.00
	Upper	49.1	25.7	100
	Upper	36.3	52.6	100
	Upper	15.7	69.1	150
	Upper	0.0	76.0	200



Add Upper Objective

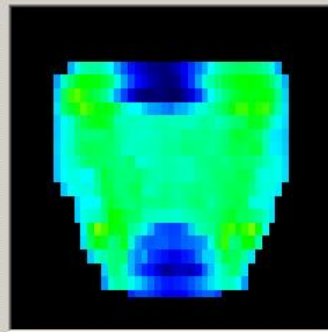
Add Lower Objective

Delete

	MLC	Method	X Smooth	Y Smooth	Minimize Dose	Fixed Jaws	Field Weight
1.1.1.1	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.2	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000
1.1.1.3	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.4	Millennium 120	Beamlet	40	30	0	<input type="checkbox"/>	1.000
1.1.1.5	Millennium 120	Beamlet	50	50	0	<input type="checkbox"/>	1.000

Base dose plan:

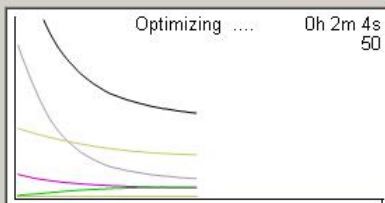
Select...



Max time (min):

Max iterations:

Optimizing 0h 2m 4s 50



Stop

View with interpolation
 Use color

OK

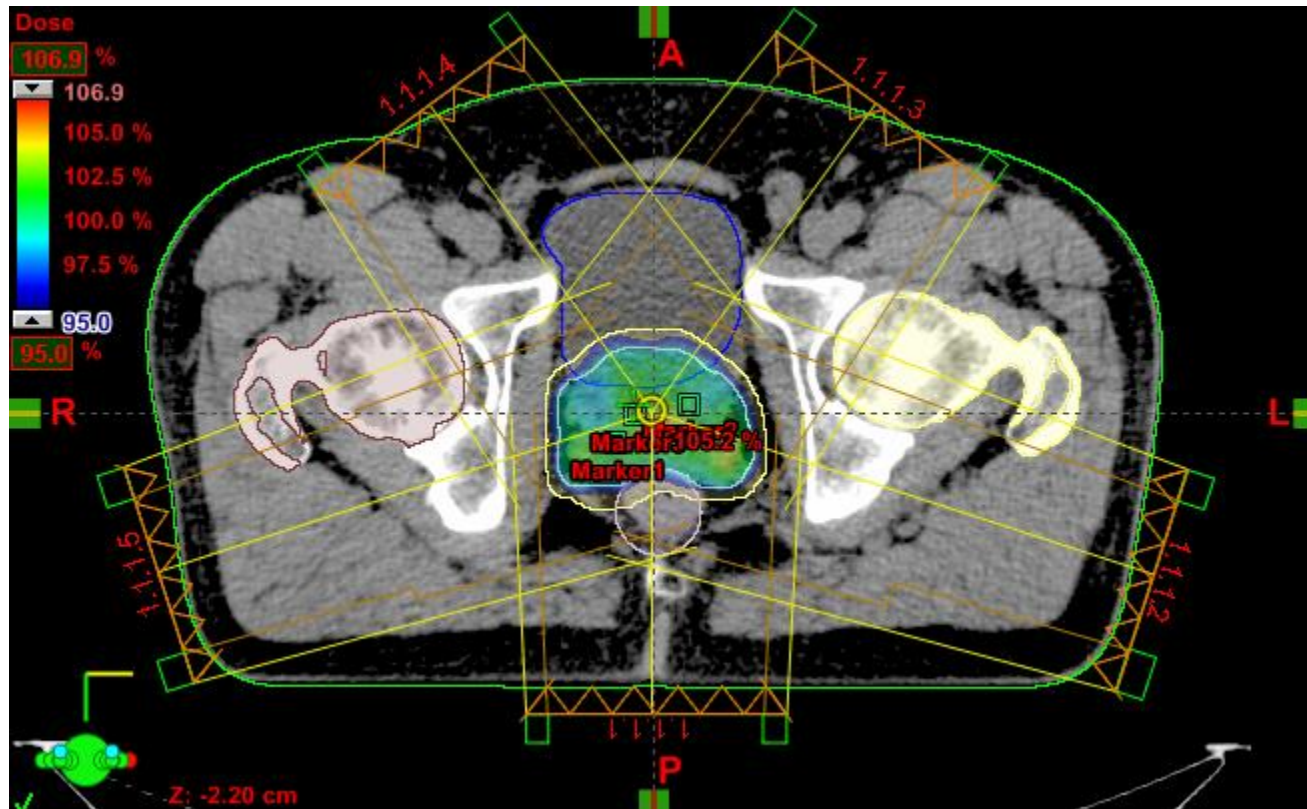
Cancel

Apply

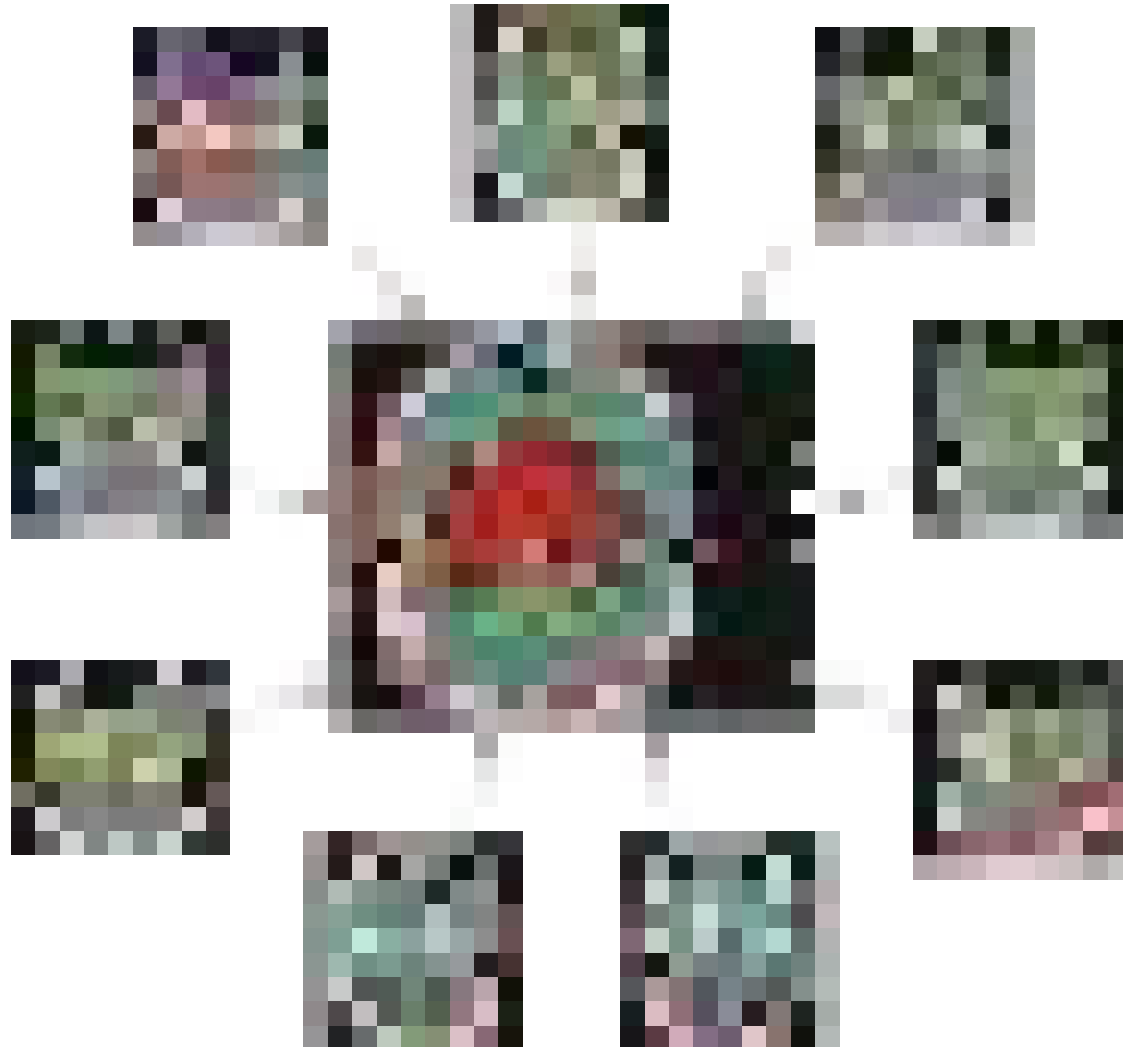


OPTIMIZATION: example prostate

Prescribed dose

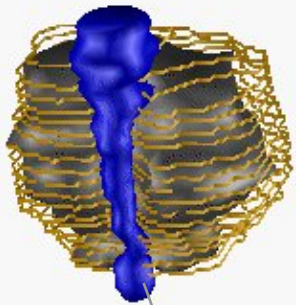


IMRT dose distribution: head and neck

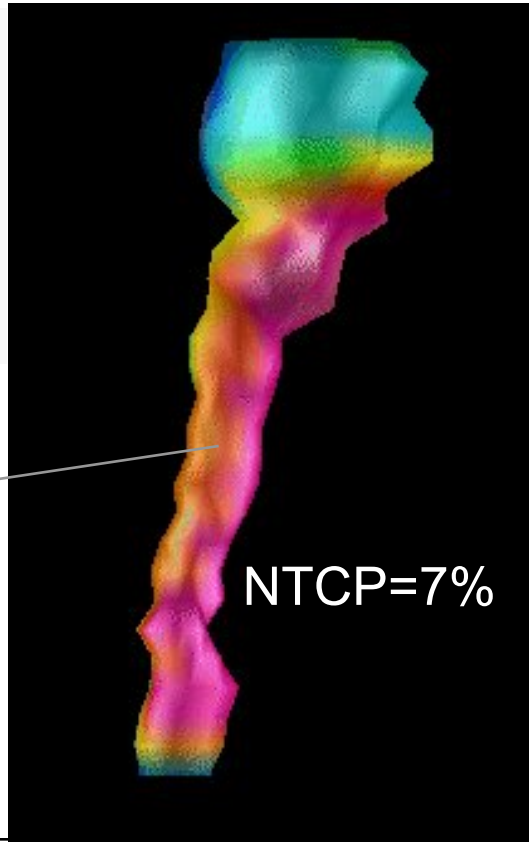


IMRT dose distribution: head and neck

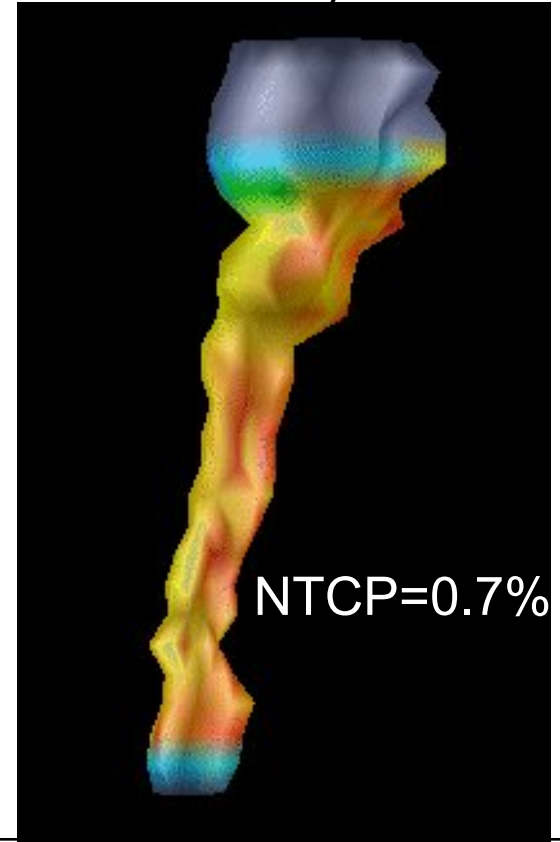
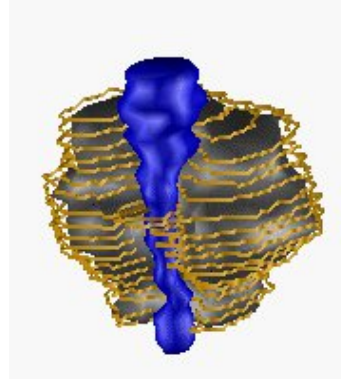
3D-conformal
(4 fields)



Brain stem



IMRT
(9 fields)

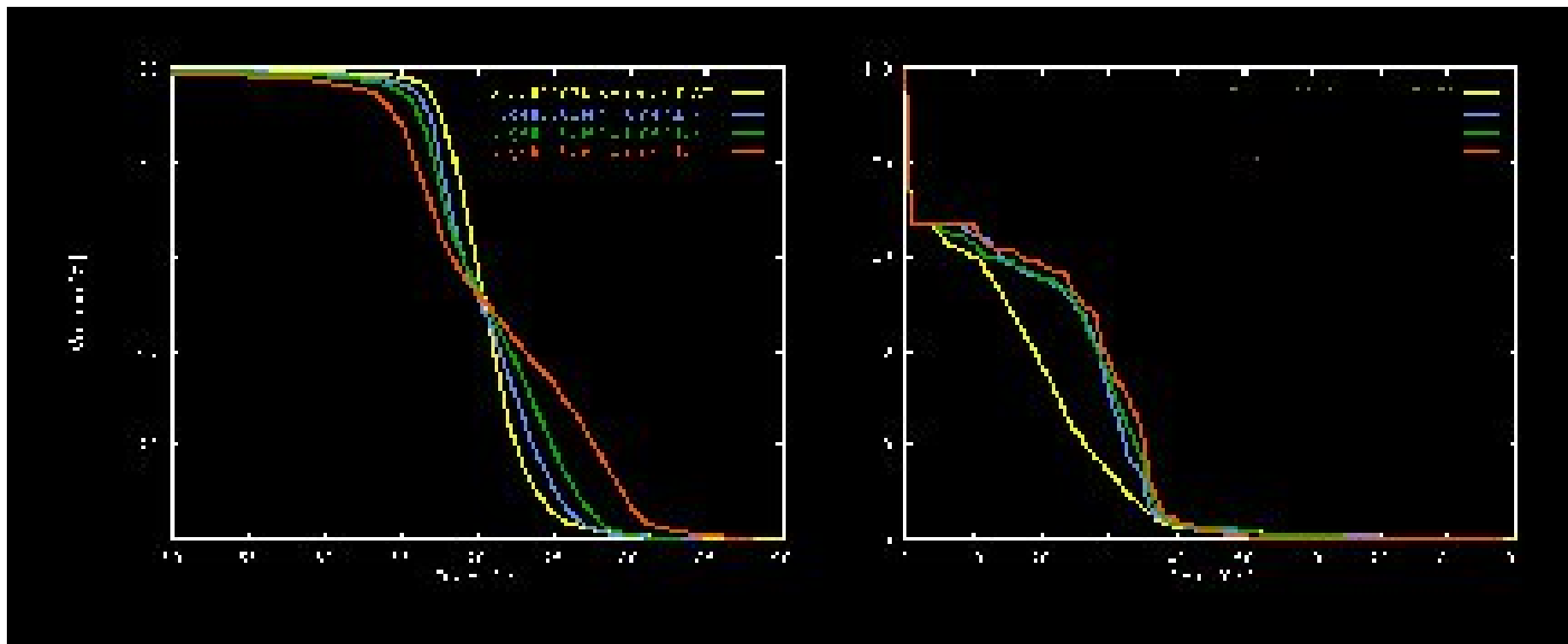


IMRT: number of beams

Example chordoma

Target

Brainstem





IMRT: number of beams

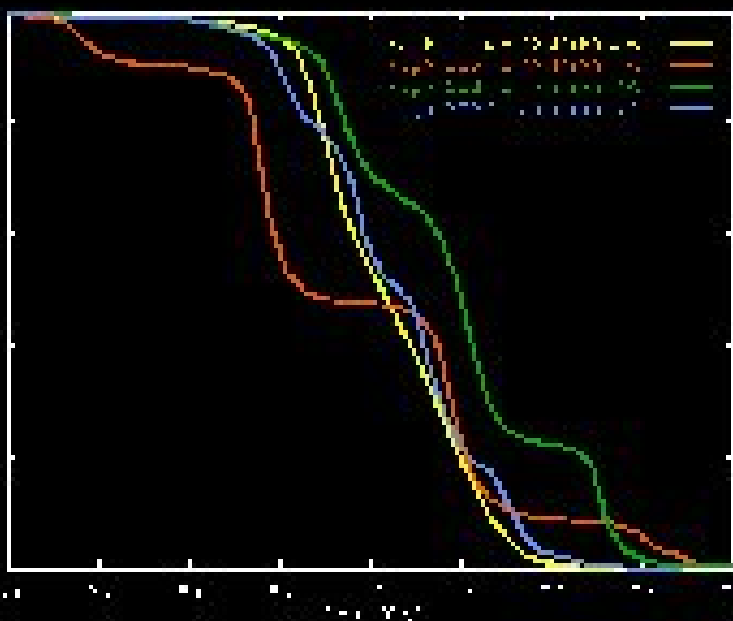
- Relatively few coplanar beams necessary (<10)
- Beams may be evenly spaced in $[0, 360^\circ]$
- For less than 5-6 beams, orientations must be optimized
- Generally no conformation possible with less than 4 beams



IMRT: number of intensity levels

Example chordoma

Target



Brainstem





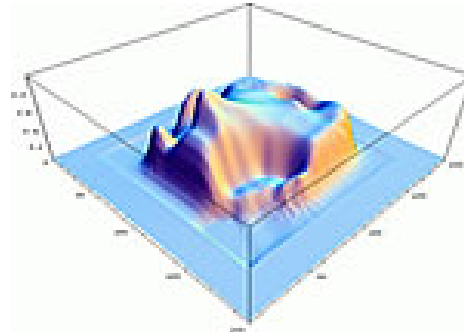
IMRT: number of intensity levels

- About 5 intensity levels per beam are generally sufficient
- This means about 7-8 subfields per beam
- This means about 50-60 subfields in total



REALISATION OF INTENSITY MODULATION

Calculated intensity map:

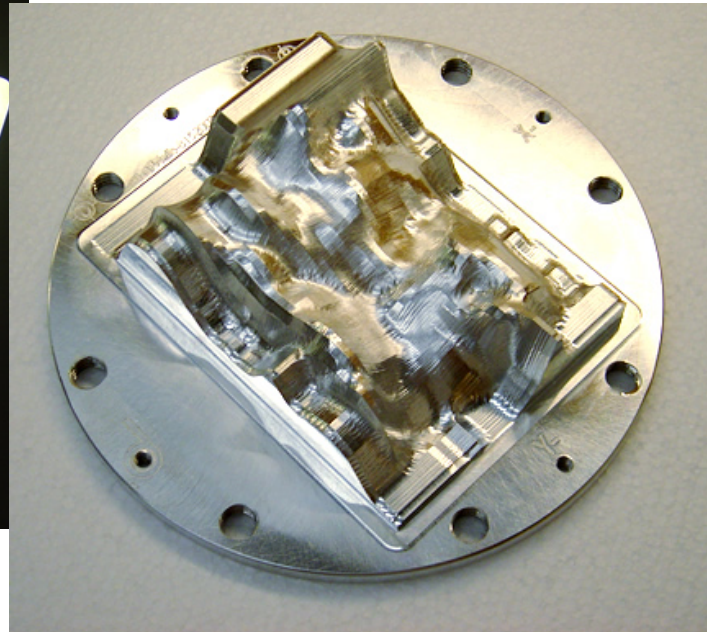
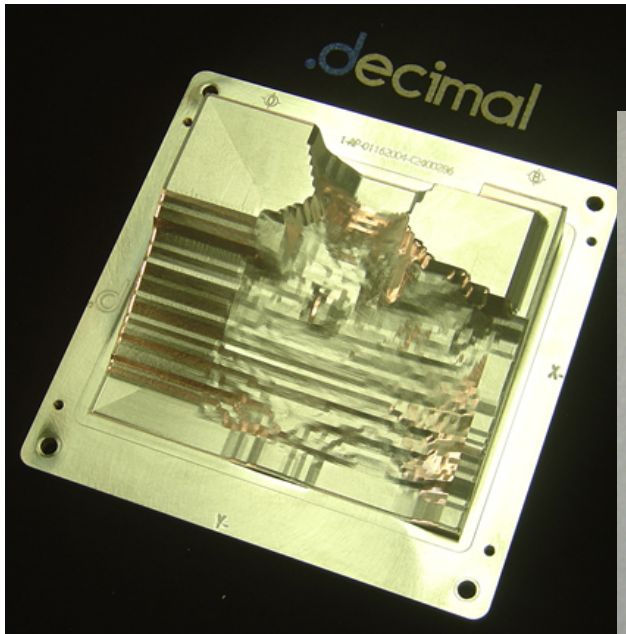
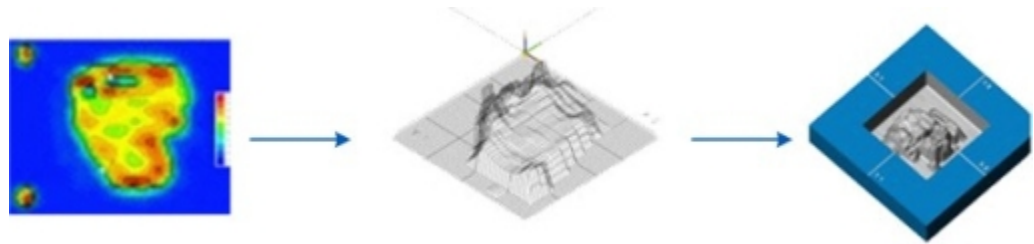


Practical realisation:

- Metal compensator
- Multiple-static fields: step-and-shoot technique
- Dynamic multi leaf collimator: DMLC
- (Tomotherapy)
- (Swept pencil beams: Cyberknife etc.)

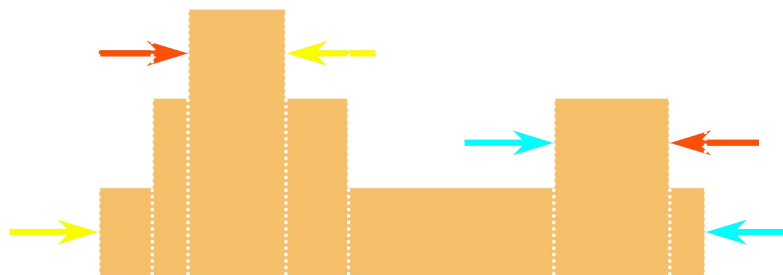
INTENSITY MODULATION: metal compensator

- Patient specific
- Beam specific

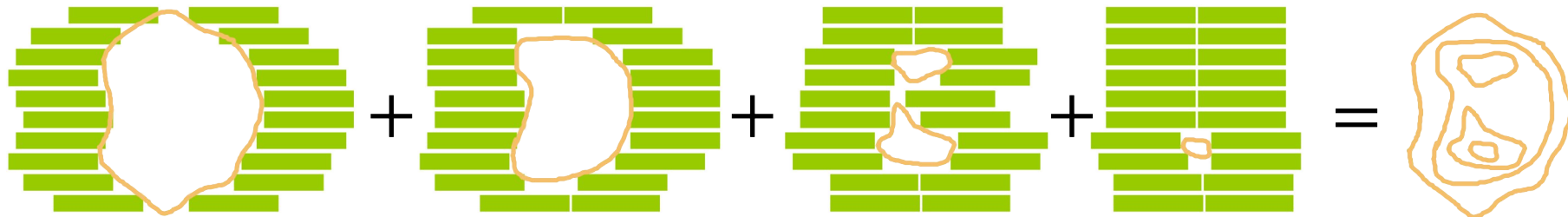
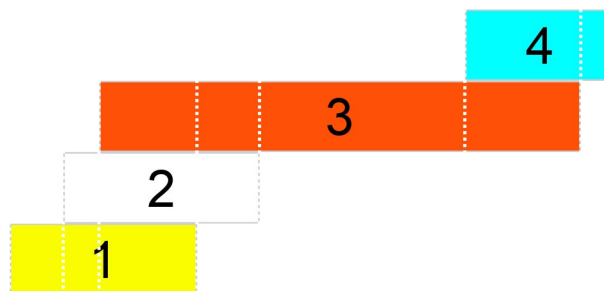


INTENSITY MODULATION: step and shoot

IM-profile



Combination of single fields



INTENSITY MODULATION: DMLC

