



Accuracy in Radiation Therapy: Current Achievements, Future Solutions

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Princess Margaret Hospital
University Health Network



accelerated
education program
putting innovation to work

IGRT

Radiation Medicine Program
Princess Margaret Hospital

Acknowledgements

Physics

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Radiation Therapy

Cynthia Eccles
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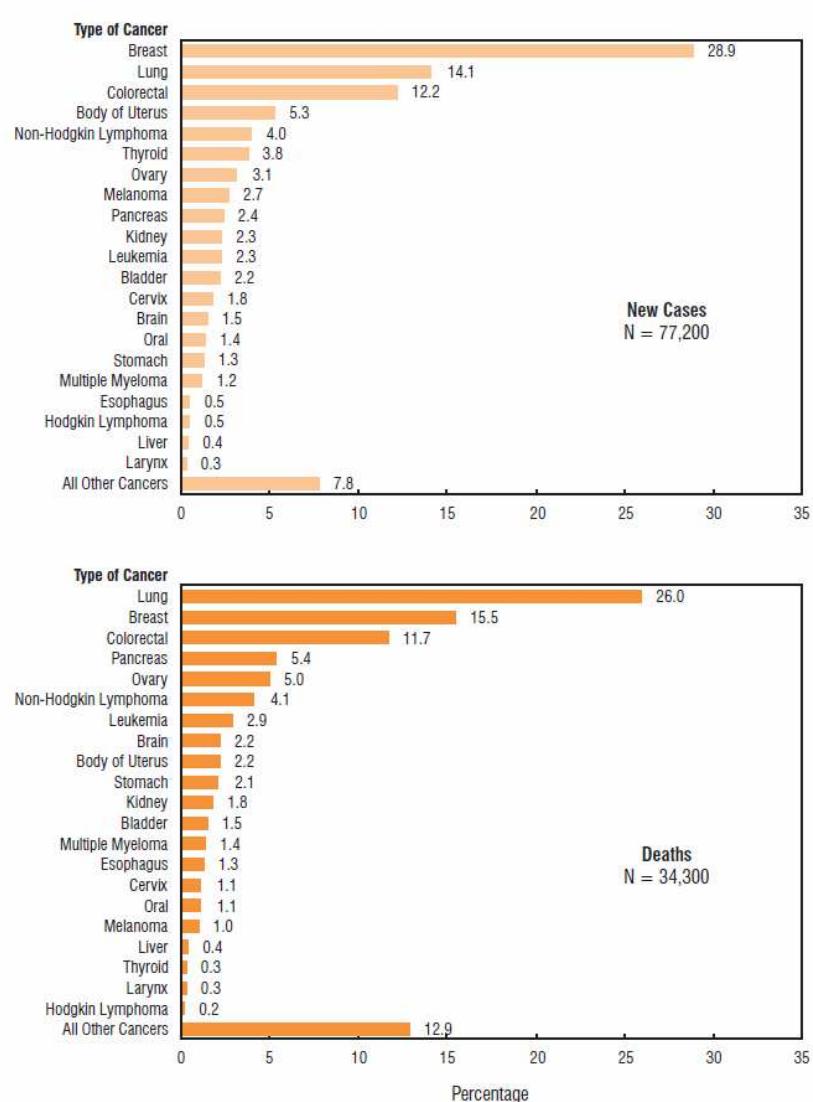
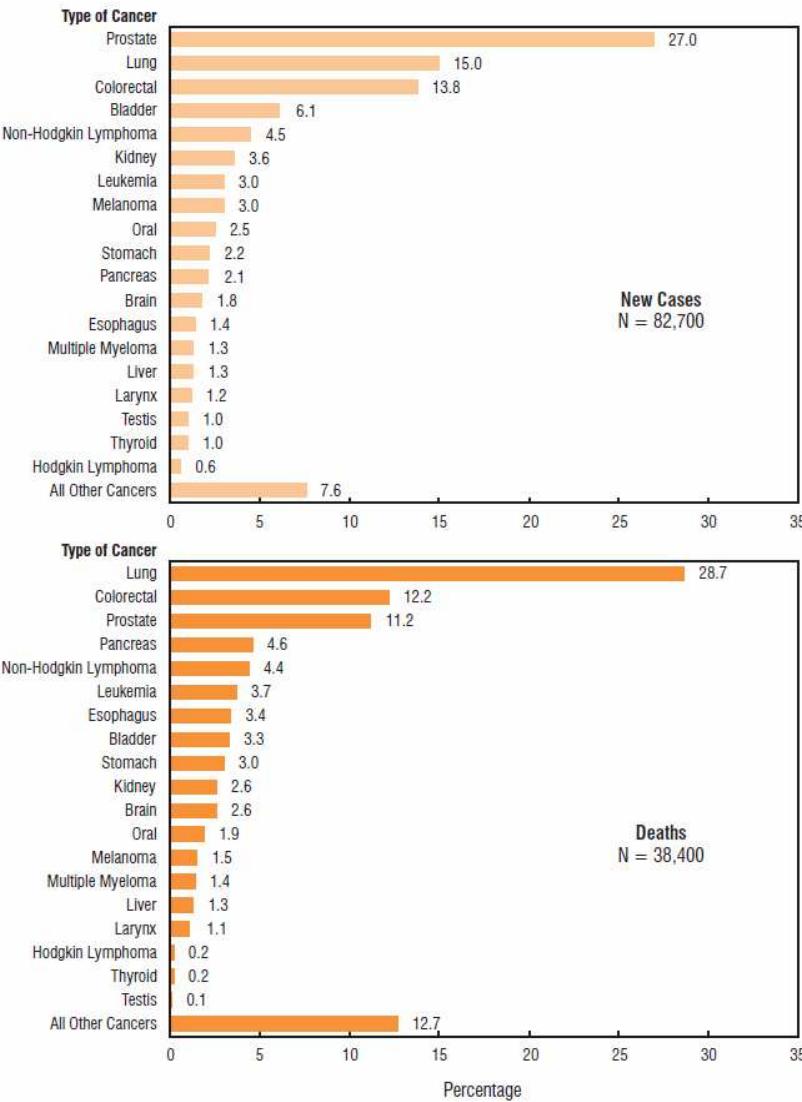
McMaster

Tamas Terlaky
Yuriy Zinchenko

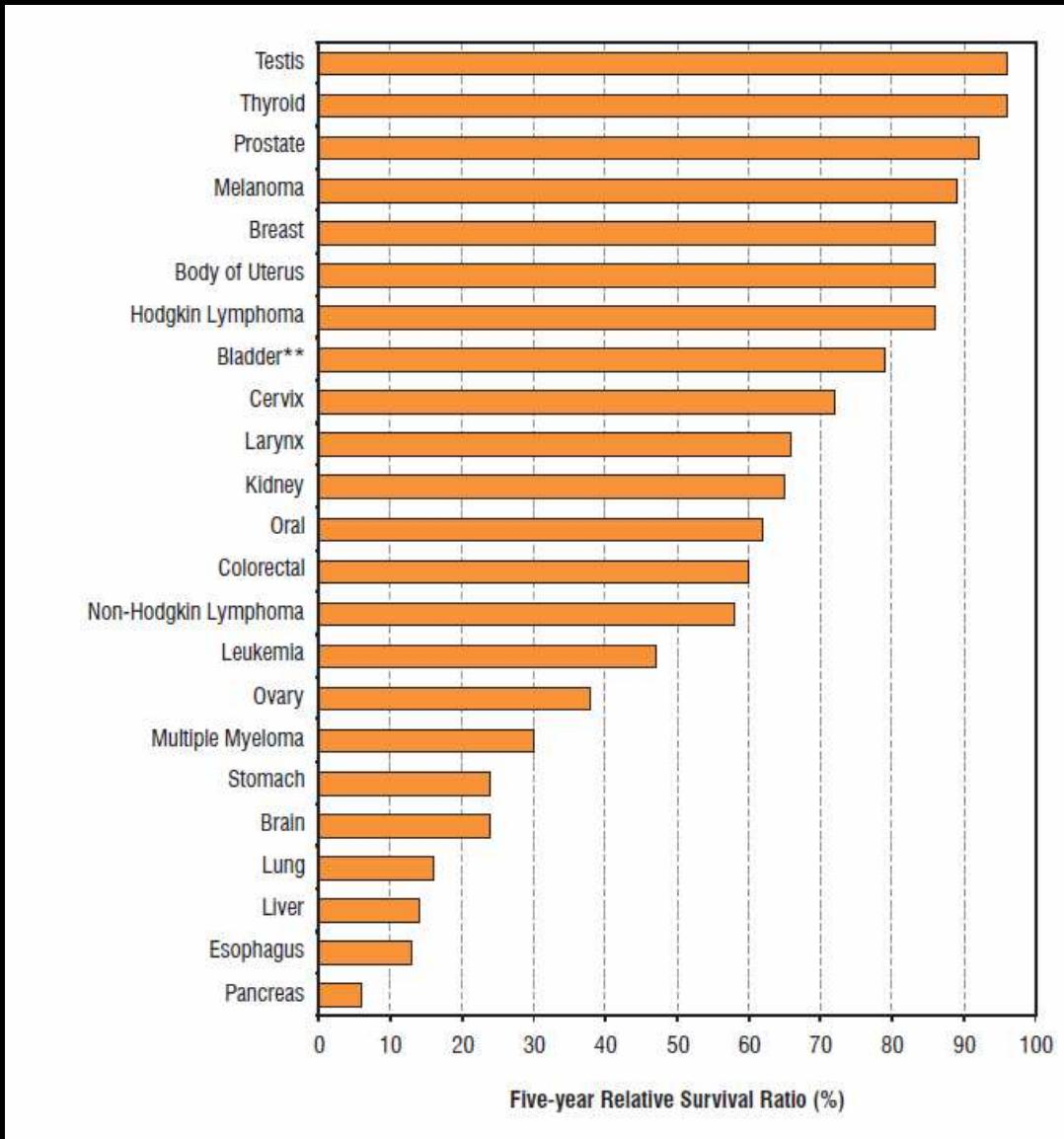
Outline

- Radiation therapy
- State of the art technologies
 - IMRT
 - IGRT
- Accuracy
 - Magnitude of problem
 - Solutions to problem

Radiation Therapy

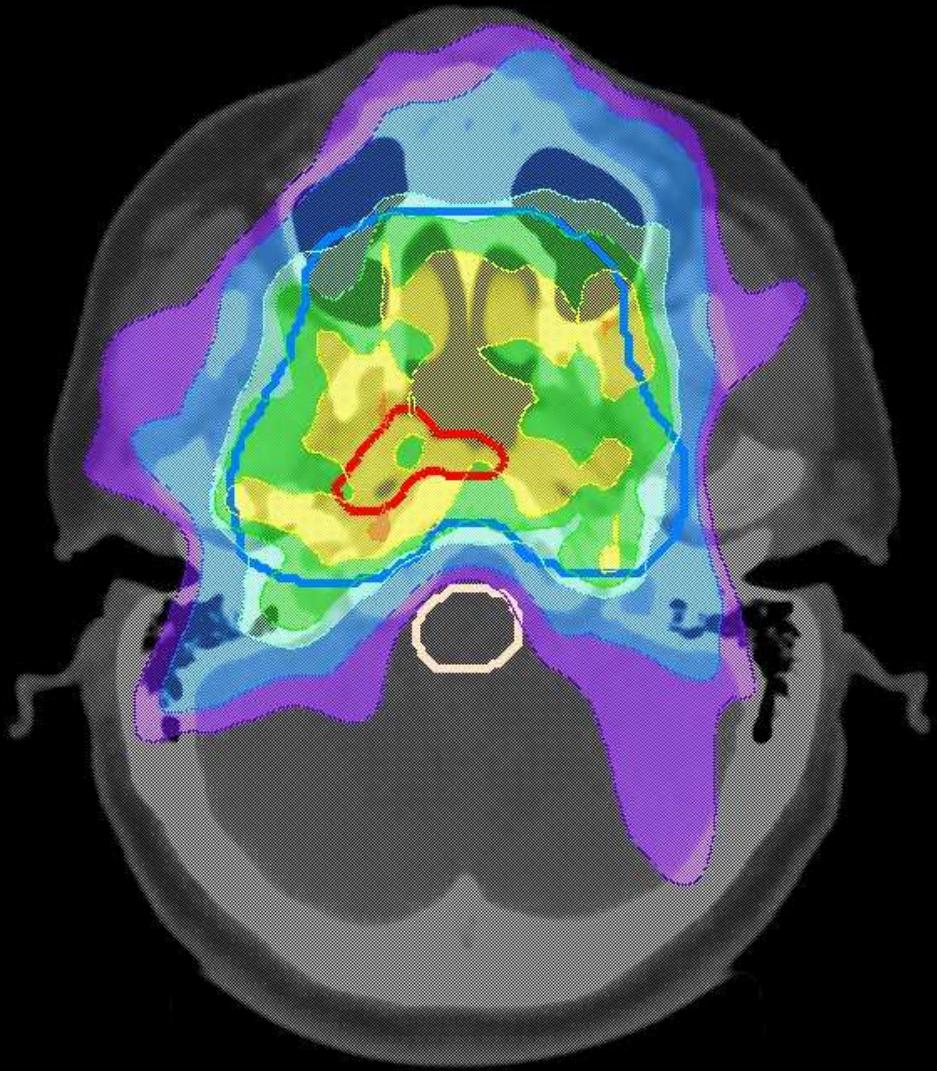


Radiation Therapy



Radiation Therapy

- Goal
 - High dose to tumour volume
 - Low dose to surrounding healthy tissue



Linear Accelerator



Multileaf Collimator

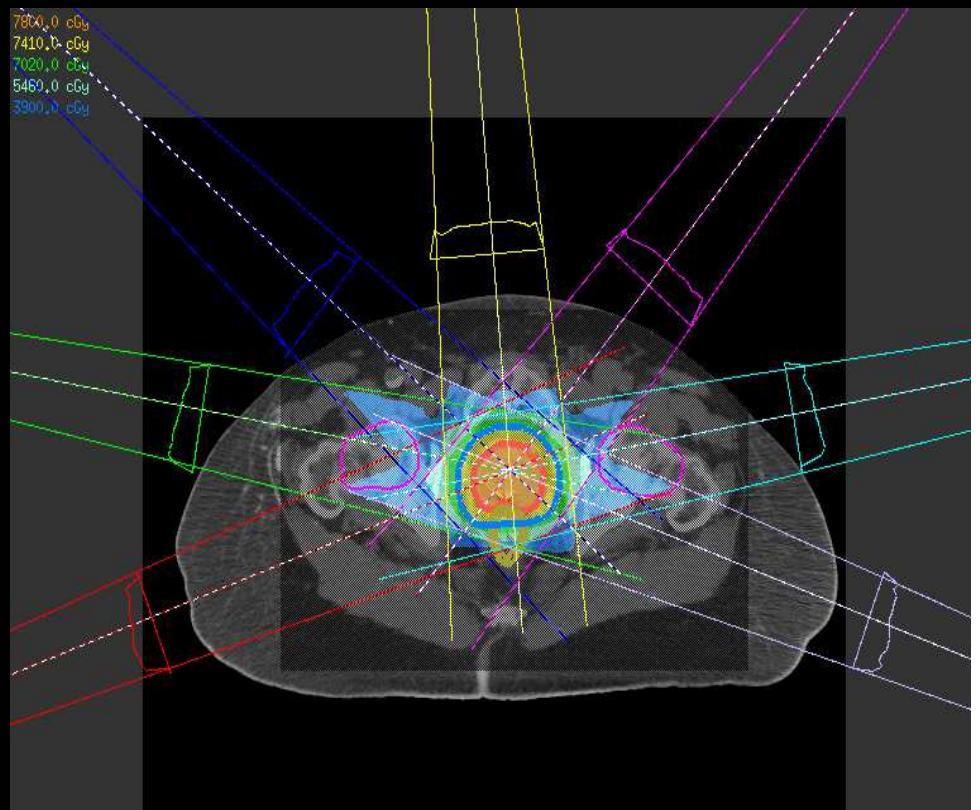


Outline

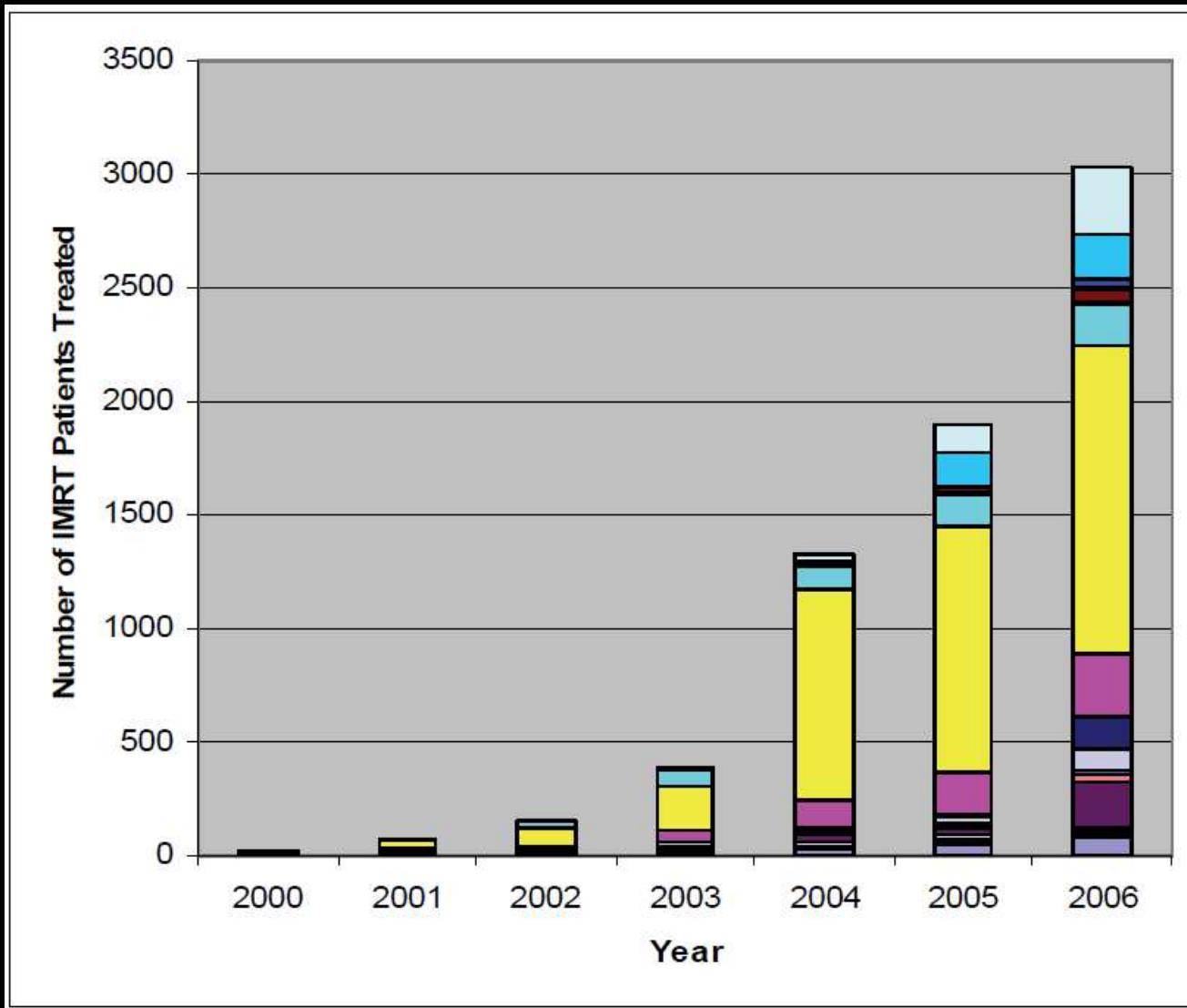
- Radiation Therapy
- State of the art technologies
 - IMRT
 - IGRT
- Accuracy
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Intensity Modulated Radiation Therapy (IMRT)

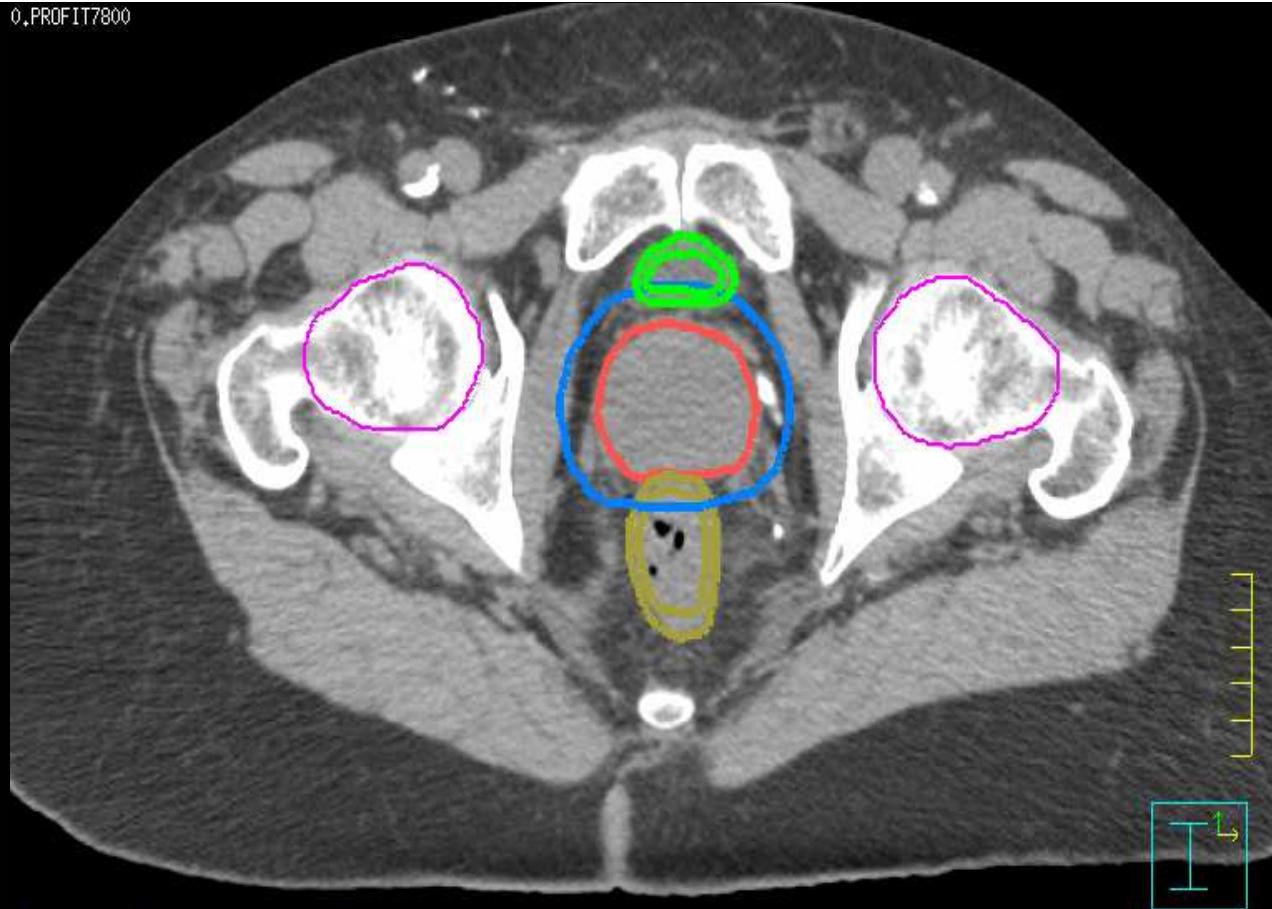
- Varies x-ray fluence across the treatment field
- Optimized assignment of non-uniform intensities to tiny subdivisions of beams



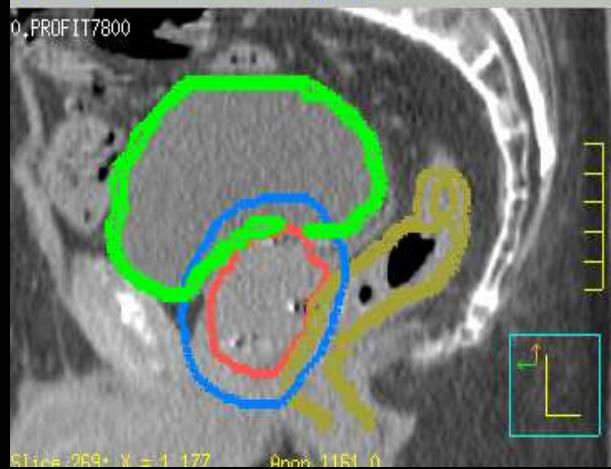
Intensity Modulated Radiation Therapy (IMRT)



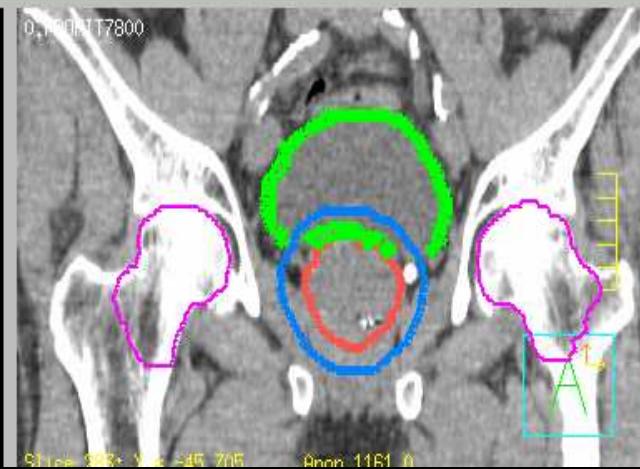
0_Profit7800



Slice 80; Z = -2,000 Anon_1161_0



Slice 289; Y = 1,177 Anon_1161_0



Slice 289; Y = -45,705 Anon_1161_0

IMRT Parameters

Trial 0.PROFIT7800

Optimization

Conversion

Beam



Optimization Type

Allow jaw motion/
Split beam?

RPO250

DMPO

Yes

RAO280

DMPO

Yes

RAO310

DMPO

Yes

RAO355

DMPO

Yes

LA040

DMPO

Yes

Max iterations 30

Convolution dose iteration 10

Stopping tolerance 1e-06

Apply tumor overlap fraction?

 Yes NoMLC delivery? Yes No

Minimum segment MUs 4

DMPO Settings

Maximum number of segments

68

Compute final dose? Yes No

Delivery Constraints

Beam Splitting

Minimum segment area

3

cm²

Overlap distance

2

cm

Leaf/jaw overlap

0.5

cm

Dismiss

Machine

EV05

Copy Machine Defaults

Help

Inverse Planning

File
Options
Utilities
Display

 Optimize
 Convert

Patient: ICRU Prostate Example,
Plan: Plan_5
Rev: R02.P01.D02

0.PROFIT78
 Help

Max Iterations
Current Iteration
Parameters

IMRT Parameters...
Reset Beams

Start Optimization
Stop Optimization

Beam
Dose Status
Opening Density Matrix

RPO250
Uncomputed

RAO280
Uncomputed

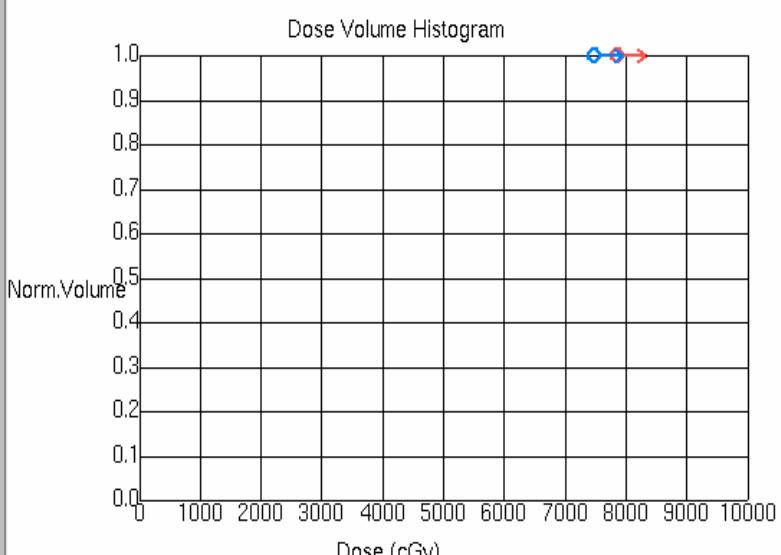
RAO310
Uncomputed

RAO355
Uncomputed

LAO40
Uncomputed

Dose Volume Histogram
Viewing Window

Dose Volume Histogram



Dose Normalized Absolute
Volume Normalized Absolute
Plan Eval...

ROI
Type
Constrain
Target cGy
% Volume
% Variation
Weight
Objective Value
a
gEUD

 Redo Spread
 CTV
 50

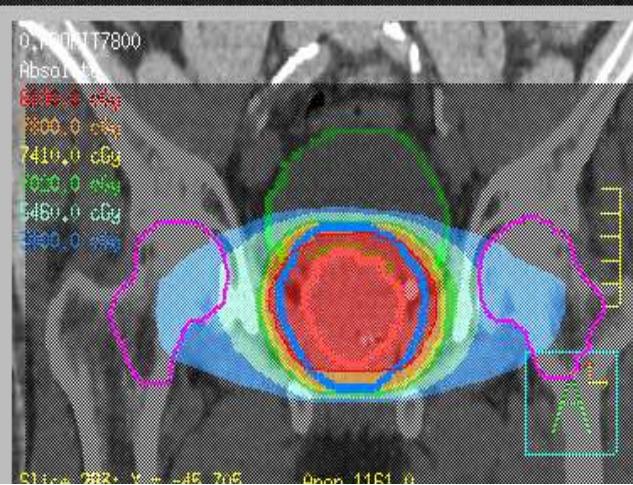
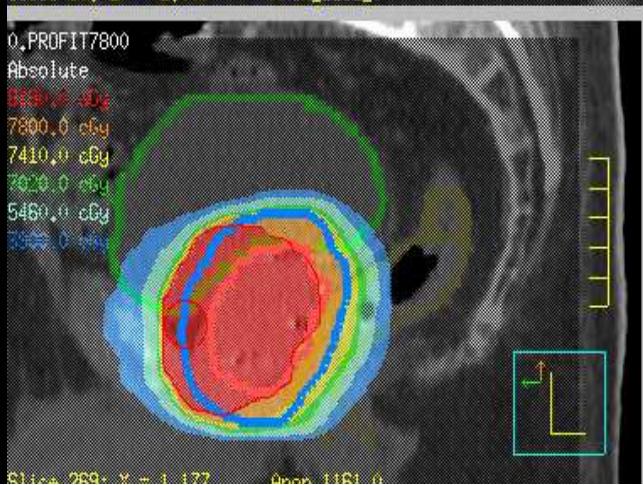
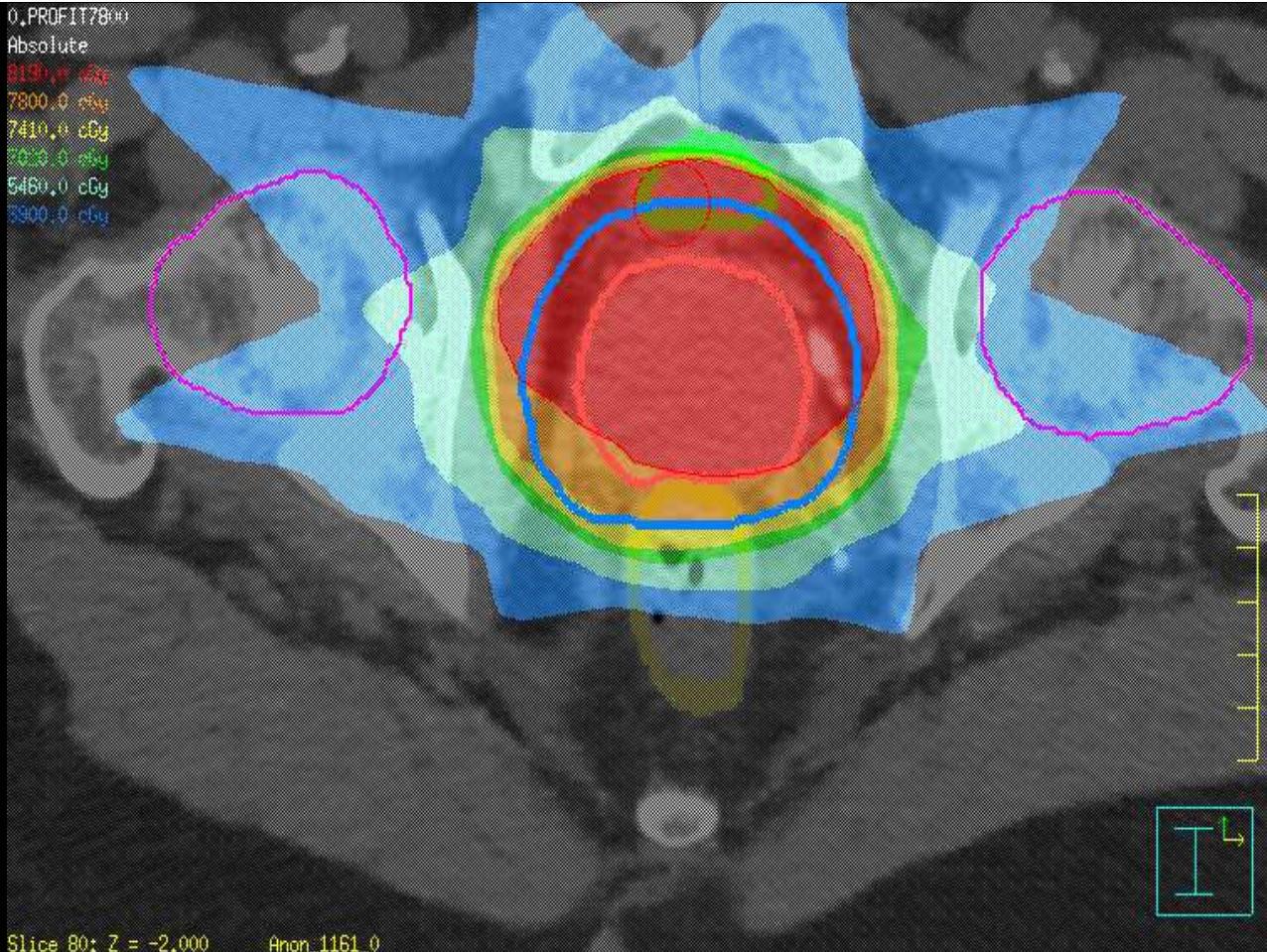
Add Objective
 RingPTV
 50

Delete Objective

--

Sort Objectives

Composite objective value: Recompute Values



Plan Evaluation

File Options Utilities Display

Patient: ICRU Prostate Example,,
Plan: Plan_5 Rev: R02.P01.D02

Trials

Display Trial Line Type

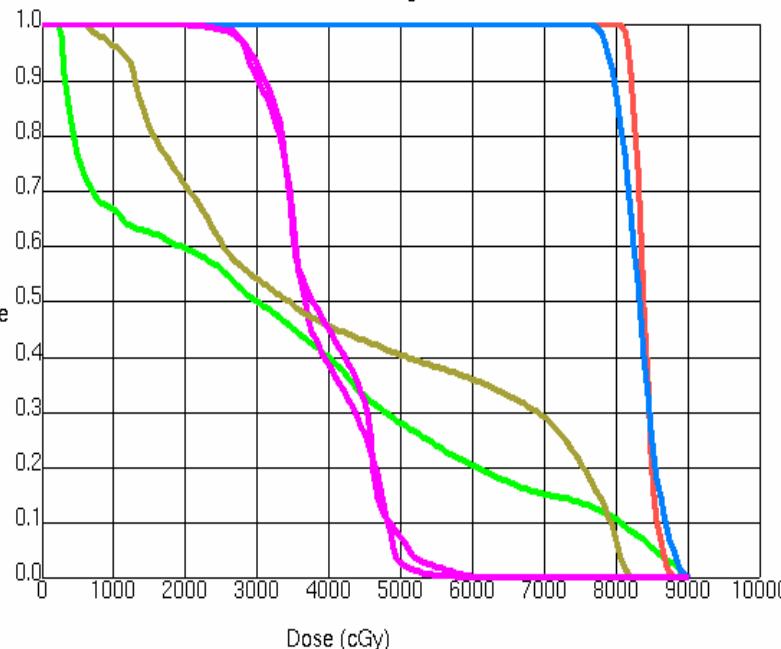
- | | | |
|-------------------------------------|--------------|---------------|
| <input checked="" type="checkbox"/> | 0.PROFIT7800 | X-Thick Solid |
| <input type="checkbox"/> | 1.Trial_1 | Thin Solid |

ROIs

Display ROI a

- | | | |
|-------------------------------------|--------------------|----|
| <input checked="" type="checkbox"/> | CTV | I1 |
| <input checked="" type="checkbox"/> | BladderWall | I1 |
| <input checked="" type="checkbox"/> | RectumWall | I1 |
| <input checked="" type="checkbox"/> | RightFemur | I1 |
| <input checked="" type="checkbox"/> | LeftFemur | I1 |
| <input checked="" type="checkbox"/> | PTV | I1 |
| <input type="checkbox"/> | RingPTV | I1 |
| <input type="checkbox"/> | Avoid | I1 |
| <input type="checkbox"/> | Dosegrid | I1 |
| <input type="checkbox"/> | BladderWall_INTERP | I1 |

Dose Volume Histogram



DVH Calculation

- Cumulative
- Differential

Dose Axis Display

- Normalized Dose
- Absolute Dose
- Auto-Compute Max
- Specify Max Dose

Volume Axis Display

- Normalized Volume
- Absolute Volume

Tabular DVH...

ROI Statistics

Line Type	ROI	Trial	Min.	Max.	Mean	Std. Dev.	% Outside Grid	% > Max	Generalized EUD
<input type="checkbox"/>	BladderWall	0.PROFIT7800	233.9	9003.0	3367.7	2796.3	0.00 %	0.00 %	3366.34
<input checked="" type="checkbox"/>	CTV	0.PROFIT7800	7993.7	8831.3	8392.0	136.2	0.00 %	0.00 %	8392.46
<input checked="" type="checkbox"/>	LeftFemur	0.PROFIT7800	1870.9	5806.3	3858.6	679.1	0.00 %	0.00 %	3858.27
<input checked="" type="checkbox"/>	PTV	0.PROFIT7800	7521.6	9019.2	8322.9	268.4	0.00 %	0.00 %	8324.05
<input type="checkbox"/>	RectumWall	0.PROFIT7800	624.9	8254.6	4267.8	2642.3	0.00 %	0.00 %	4270.48
<input type="checkbox"/>	RightFemur	0.PROFIT7800	1541.6	5992.6	3939.1	729.4	0.00 %	0.00 %	3939

Inverse Planning

File **Options** **Utilities** **Display**

Patient: ICRU Prostate Example, ,
Plan: Plan_5 **Rev:** R02.P01.D02

0.PROFIT78

 **Help**

Max Iterations

Current Iteration

Parameters

IMRT Parameters... **Reset Beams**

Start Optimization **Stop Optimization**

Beam Dose Status

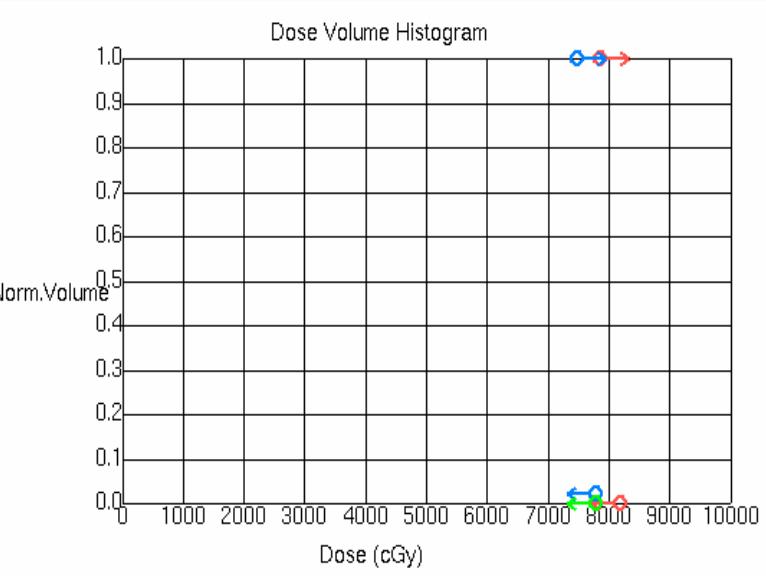
RPO250	Uncomputed
RAO280	Uncomputed
RAO310	Uncomputed
RAO355	Uncomputed
LAO40	Uncomputed

Opening Density Matrix



Dose Volume Histogram **Viewing Window**

Dose Volume Histogram



Norm. Volume

Dose (cGy)

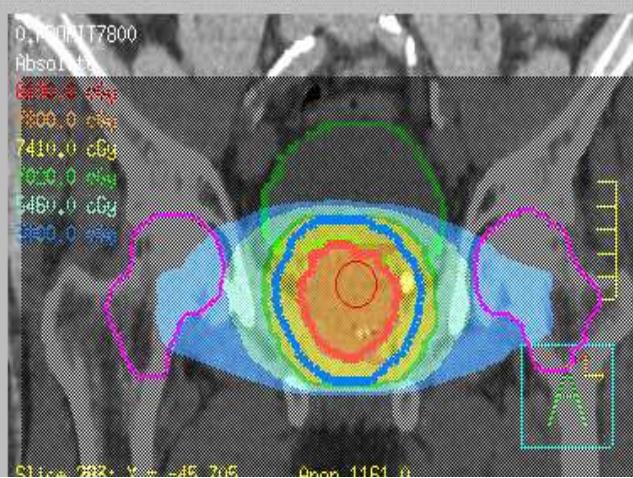
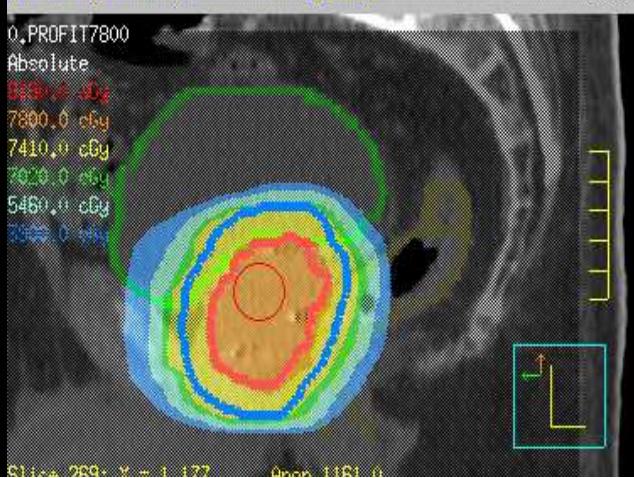
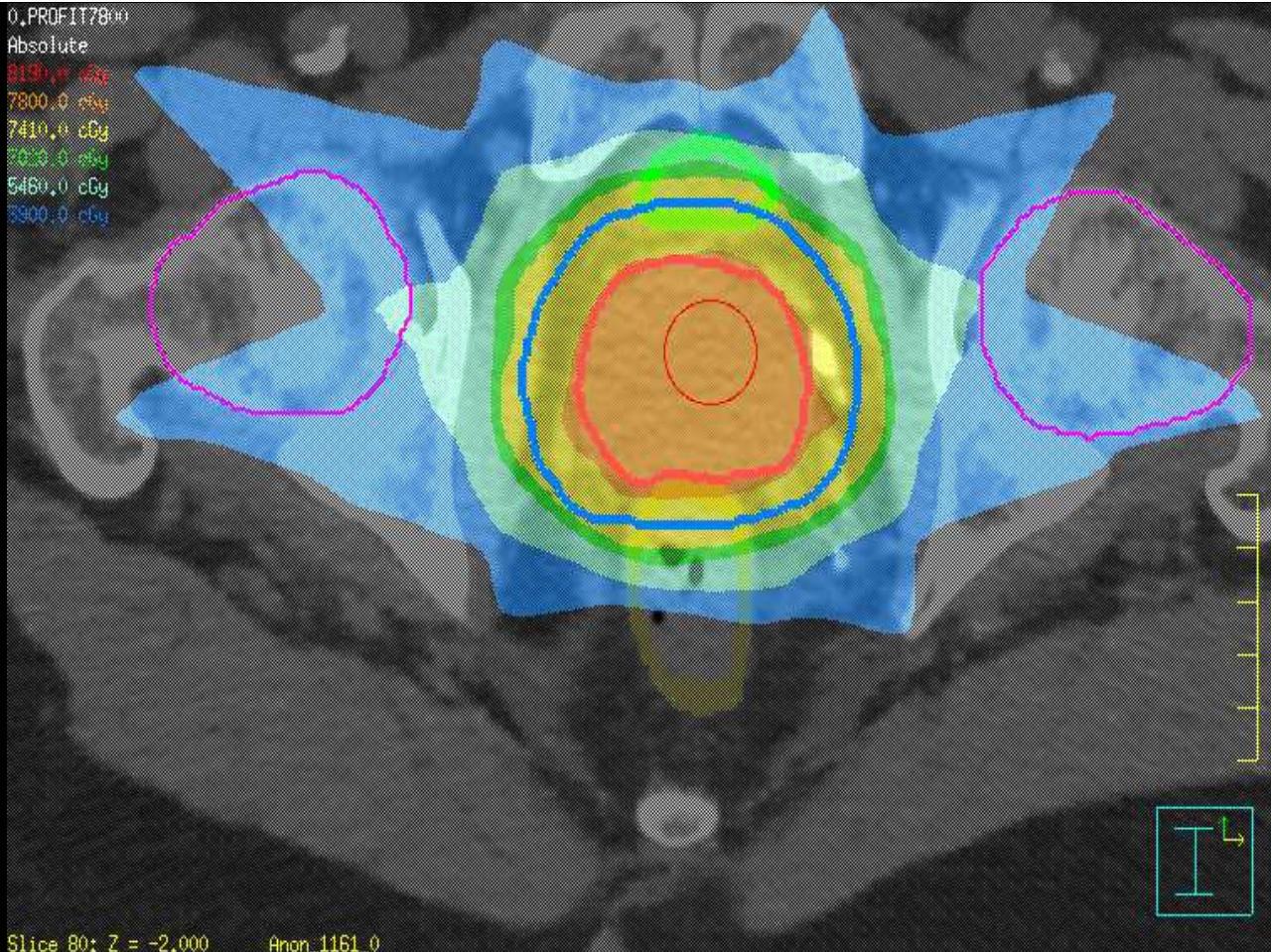
Dose ◇ Normalized ◆ Absolute Volume ◆ Normalized ◇ Absolute

Plan Eval...

 **Add Objective**
Delete Objective
Sort Objectives

ROI	Type	Constrain	Target cGy	% Volume	% Variation	Weight	Objective Value	a	gEUD
◆ CTV	Min Dose	<input type="checkbox"/>	7865	50	--				
◆ RingPTV	Min Dose	<input type="checkbox"/>	7475	50	--				
◆ CTV	Max Dose	<input type="checkbox"/>	8190	38	--				
◆ RingPTV	Max DVH	<input type="checkbox"/>	7800	38	--				
◆ BladderWall	Max Dose	<input type="checkbox"/>	7800	1	--				

Composite objective value: **Recompute Values**



Plan Evaluation

File Options Utilities Display

Patient: ICRU Prostate Example,,
Plan: Plan_5 Rev: R02.P01.D02

Trials

Display Trial Line Type

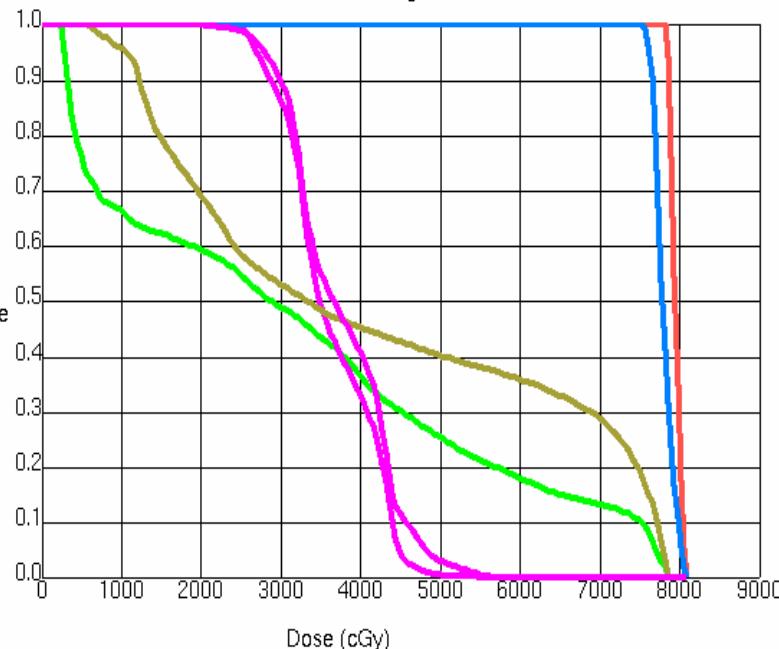
- | | | |
|-------------------------------------|--------------|---------------|
| <input checked="" type="checkbox"/> | 0.PROFIT7800 | X-Thick Solid |
| <input type="checkbox"/> | 1.Trial_1 | Thin Solid |

ROIs

Display ROI a

- | | | |
|-------------------------------------|--------------------|---|
| <input checked="" type="checkbox"/> | CTV | 1 |
| <input checked="" type="checkbox"/> | BladderWall | 1 |
| <input checked="" type="checkbox"/> | RectumWall | 1 |
| <input checked="" type="checkbox"/> | RightFemur | 1 |
| <input checked="" type="checkbox"/> | LeftFemur | 1 |
| <input checked="" type="checkbox"/> | PTV | 1 |
| <input type="checkbox"/> | RingPTV | 1 |
| <input type="checkbox"/> | Avoid | 1 |
| <input type="checkbox"/> | Dosegrid | 1 |
| <input type="checkbox"/> | BladderWall_INTERP | 1 |

Dose Volume Histogram



DVH Calculation

- Cumulative
- Differential

Dose Axis Display

- Normalized Dose
- Absolute Dose
- Auto-Compute Max
- Specify Max Dose

Volume Axis Display

- Normalized Volume
- Absolute Volume

Tabular DVH...

ROI Statistics

Line Type	ROI	Trial	Min.	Max.	Mean	Std. Dev.	% Outside Grid	% > Max	Generalized EUD
<input type="checkbox"/>	BladderWall	0.PROFIT7800	222.6	7877.5	3150.8	2554.6	0.00 %	0.00 %	3149.43
<input checked="" type="checkbox"/>	CTV	0.PROFIT7800	7784.9	8094.7	7945.7	64.6	0.00 %	0.00 %	7947.08
<input checked="" type="checkbox"/>	LeftFemur	0.PROFIT7800	1758.3	5479.9	3619.5	588.4	0.00 %	0.00 %	3619.18
<input checked="" type="checkbox"/>	PTV	0.PROFIT7800	7471.9	8094.7	7797.0	121.5	0.00 %	0.00 %	7798.13
<input type="checkbox"/>	RectumWall	0.PROFIT7800	591.9	7874.3	4174.1	2621.7	0.00 %	0.00 %	4176.72
<input type="checkbox"/>	RightFemur	0.PROFIT7800	1500.0	5626.9	3746.8	660.9	0.00 %	0.00 %	3746.87

Inverse Planning

File
Options
Utilities
Display

Patient: ICRU Prostate Example,
Plan: Plan_5
Rev: R02.P01.D02

0.PROFIT78

Max Iterations: 30
Current Iteration: 0
Parameters: 0

IMRT Parameters...
Reset Beams

Start Optimization
Stop Optimization

Beam
Dose Status
Opening Density Matrix

RPO250
Uncomputed

RAO280
Uncomputed

RAO310
Uncomputed

RAO355
Uncomputed

LAO40
Uncomputed

Dose Volume Histogram
Viewing Window

Dose Volume Histogram

Norm. Volume
Dose (cGy)

Dose ◇ Normalized
Absolute
Volume ◇ Normalized
Absolute

Plan Eval...

ROI
Type
Constrain
Target cGy
% Volume
% Variation
Weight
Objective Value
a
gEUD

RingPTV
Min Dose

7475
50
--

CTV
Max Dose

8190
38
--

RingPTV
Max DVH

7800
38
--

BladderWall
Max Dose

7800
1
--

RectumWall
Max EUD

3800
1
--

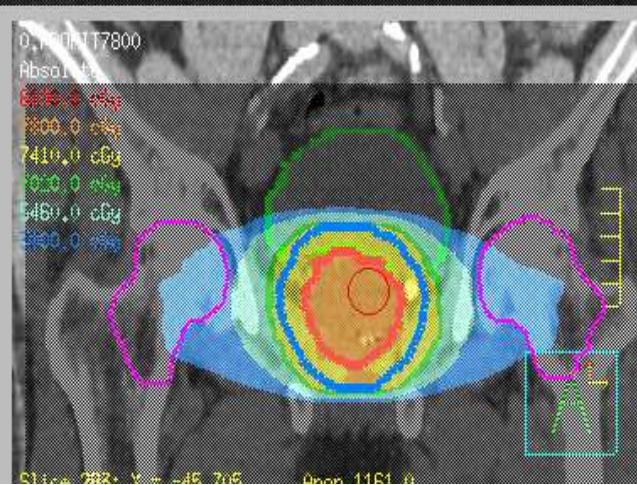
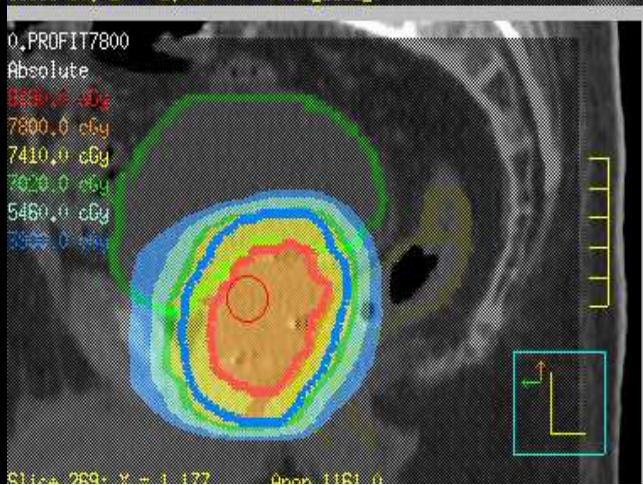
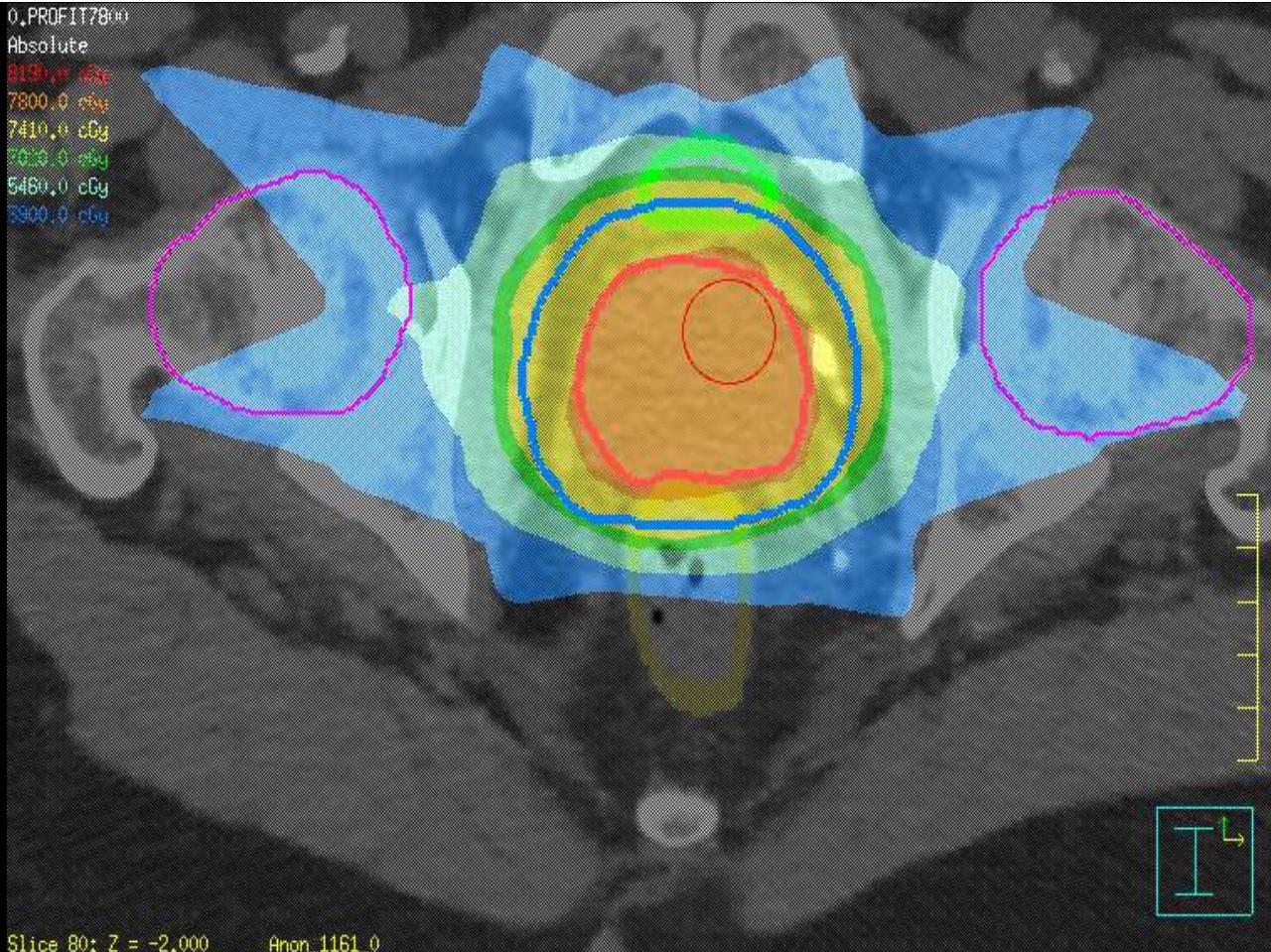
RightFemur
Max Dose

5500
1
--

LeftFemur
Max Dose

5500
1
--

Composite objective value:
--
Recompute Values



Plan Evaluation

File Options Utilities Display

Patient: ICRU Prostate Example,,
Plan: Plan_5 Rev: R02.P01.D02

Help

Trials

Display Trial Line Type

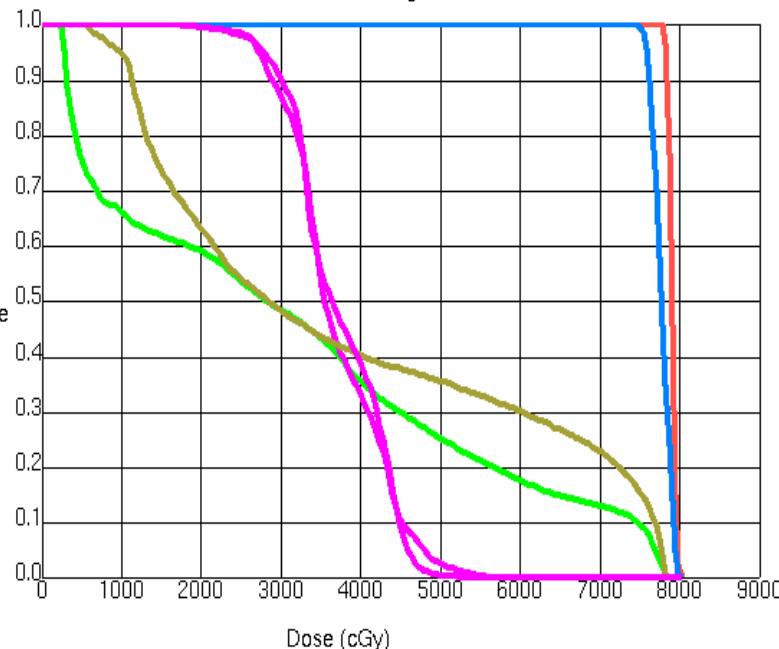
- 0.PROFIT7800 X-Thick Solid
- 1.Trial_1 Thin Solid

ROIs

Display ROI a

- CTV 1
- BladderWall 1
- RectumWall 1
- RightFemur 1
- LeftFemur 1
- PTV 1
- RingPTV 1
- Avoid 1
- Dosegrid 1
- BladderWall_INTERP 1

Dose Volume Histogram



DVH Calculation

- Cumulative
- Differential

Dose Axis Display

- Normalized Dose
- Absolute Dose
- Auto-Compute Max
- Specify Max Dose

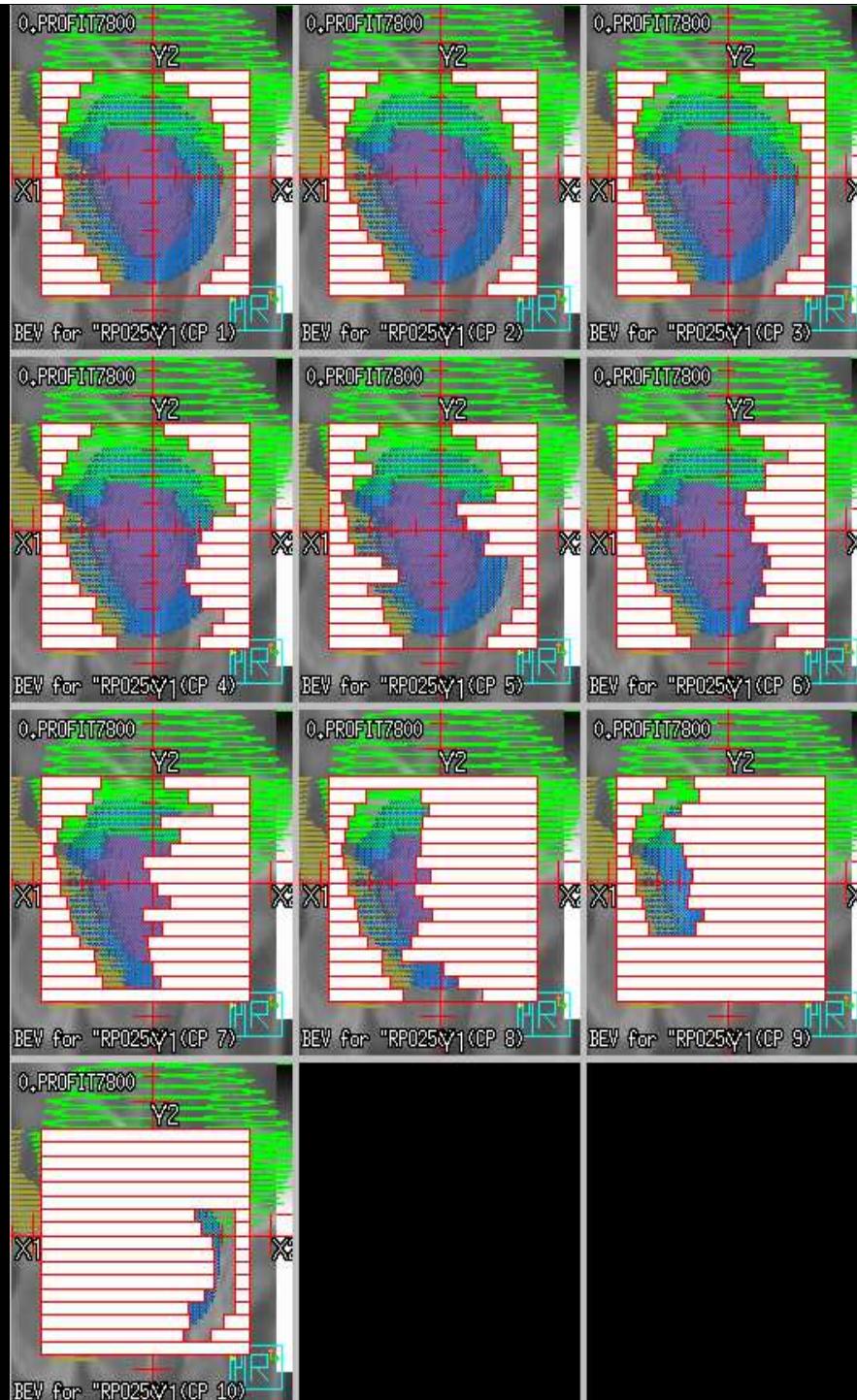
Volume Axis Display

- Normalized Volume
- Absolute Volume

Tabular DVH...

ROI Statistics

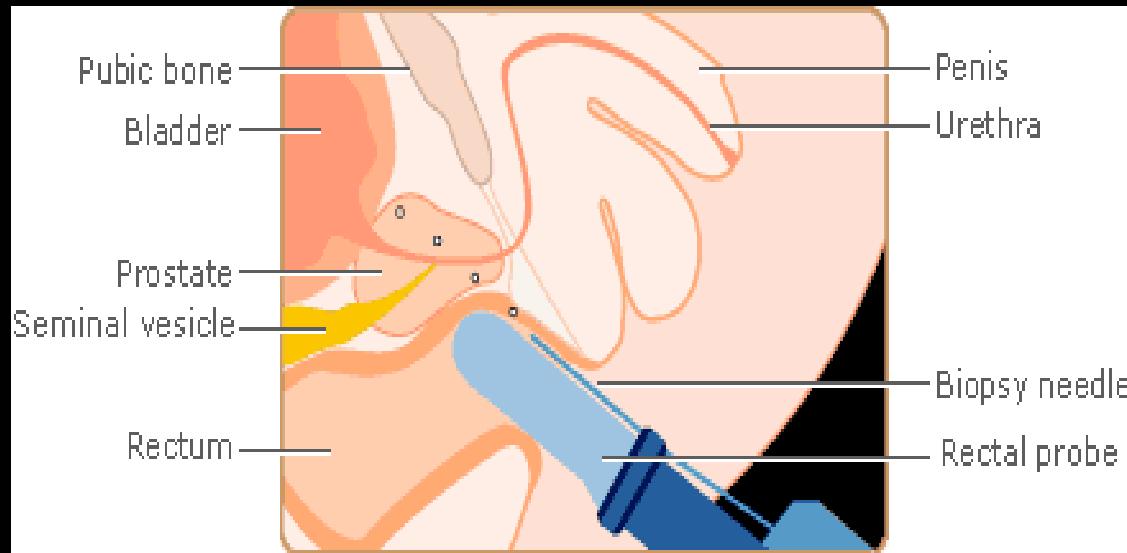
Line Type	ROI	Trial	Min.	Max.	Mean	Std. Dev.	% Outside Grid	% > Max	Generalized EUD
<input checked="" type="checkbox"/>	BladderWall	0.PROFIT7800	223.3	7852.8	3125.1	2544.6	0.00 %	0.00 %	3124.12
<input checked="" type="checkbox"/>	CTV	0.PROFIT7800	7759.1	8026.3	7900.4	43.7	0.00 %	0.00 %	7901.57
<input checked="" type="checkbox"/>	LeftFemur	0.PROFIT7800	1473.8	5212.4	3667.0	601.8	0.00 %	0.00 %	3667.16
<input checked="" type="checkbox"/>	PTV	0.PROFIT7800	7362.1	8026.3	7770.9	112.2	0.00 %	0.00 %	7772.46
<input checked="" type="checkbox"/>	RectumWall	0.PROFIT7800	567.6	7862.3	3828.6	2573.3	0.00 %	0.00 %	3830.16
<input checked="" type="checkbox"/>	RightFemur	0.PROFIT7800	1355.2	5587.4	3740.7	646.3	0.00 %	0.00 %	3740.88



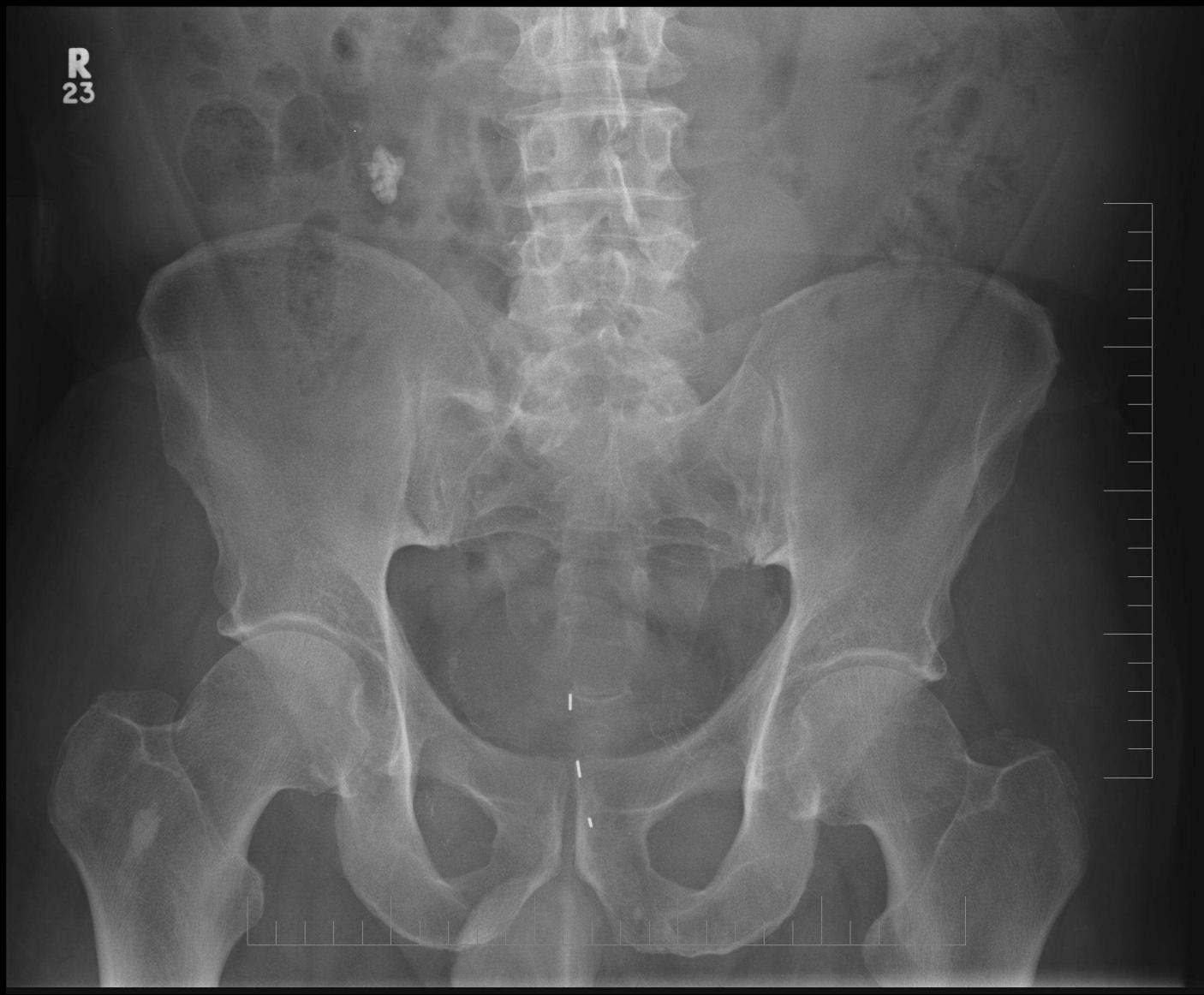
Outline

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 - Solutions to problem

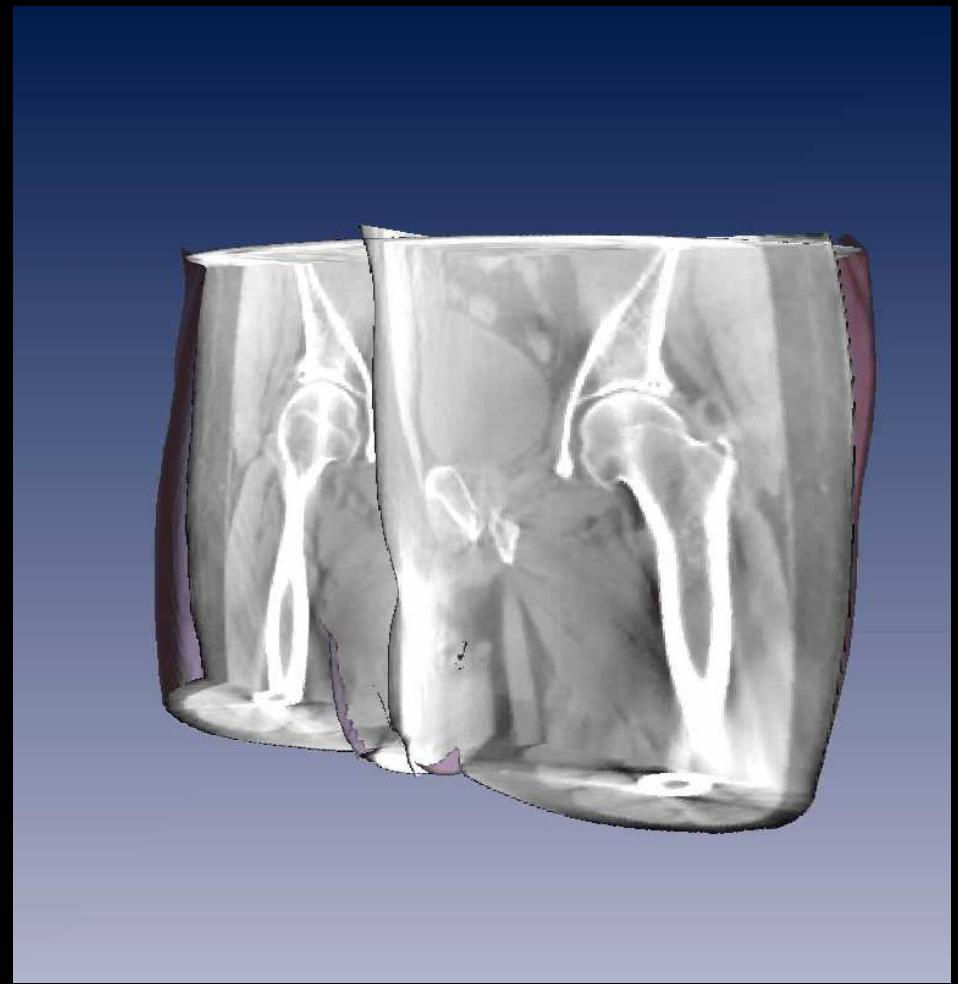
Prostate Fiducial Markers



Prostate Fiducial Markers



Cone-Beam CT



Cone-Beam CT

CBCT Markers	R/L	A/P	S/I
	$\sigma = 0.6, 1.3, 1.3$		
	$\Sigma = 0.4, 1.0, 1.0$		

CBCT Soft Tissue	R/L	A/P	S/I
	$\sigma = 0.9, 2.2, 2.3$		
	$\Sigma = 0.5, 2.2, 1.2$		

CBCT for Fiducial Guidance: 0.5 cGy @ 2cm, 0.3 cGy @ 15cm



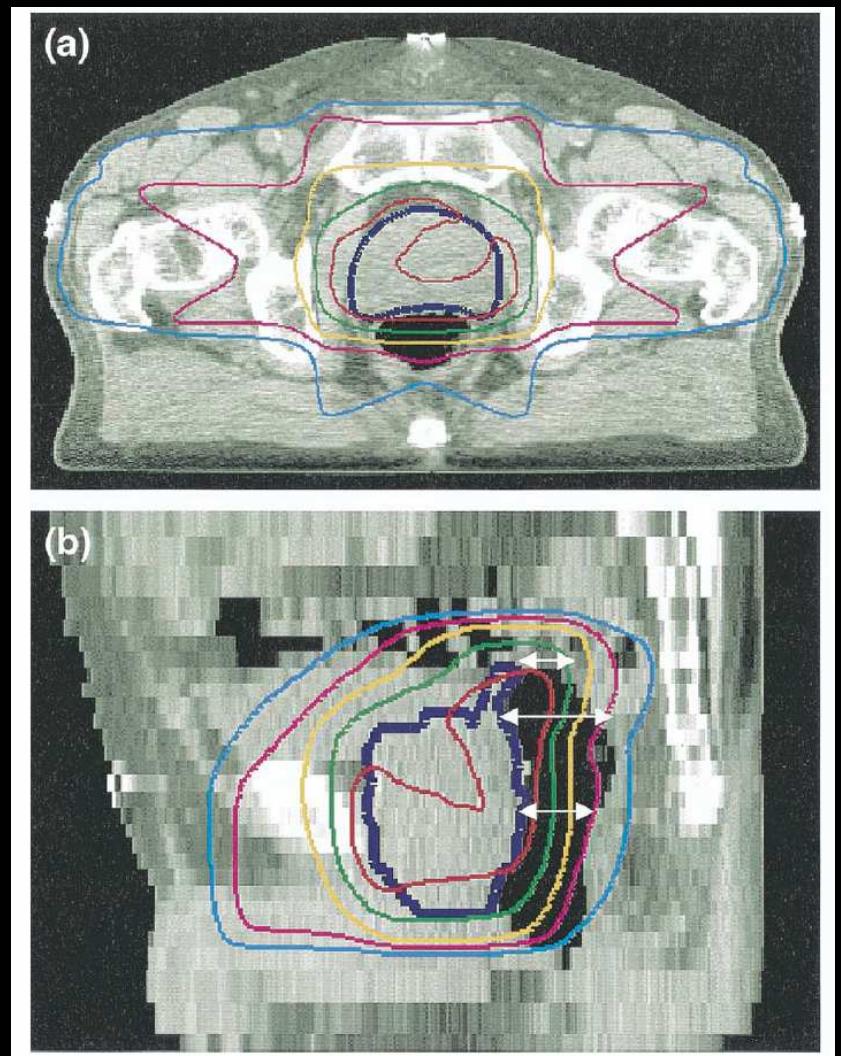
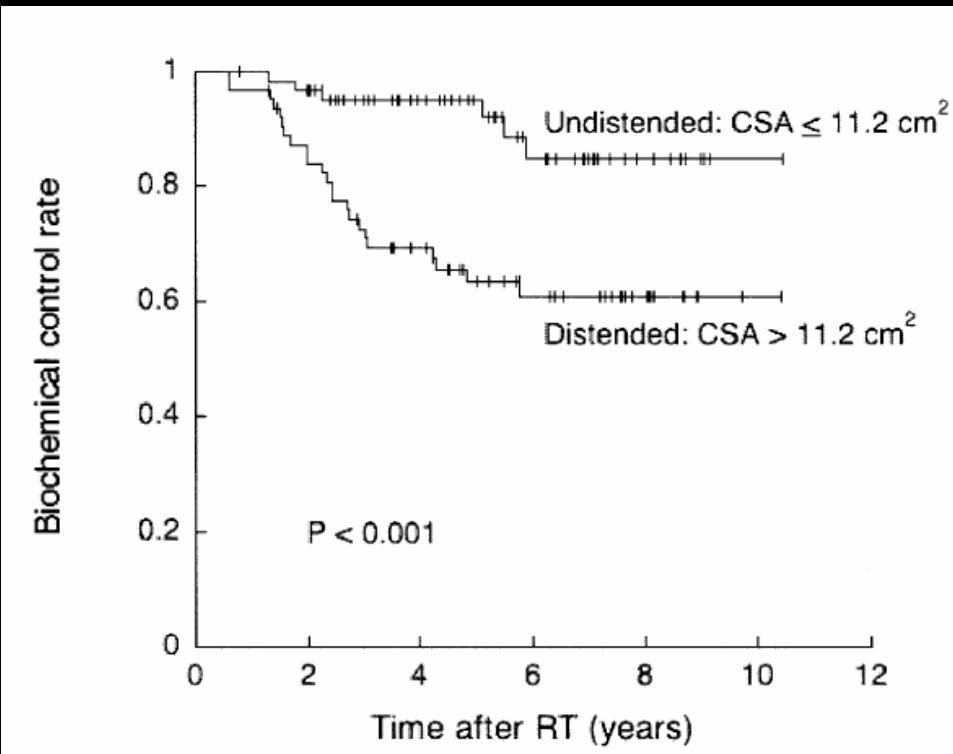
CBCT for Soft Tissue Guidance: 3.1 cGy @ 2cm, 1.8 cGy @ 15cm



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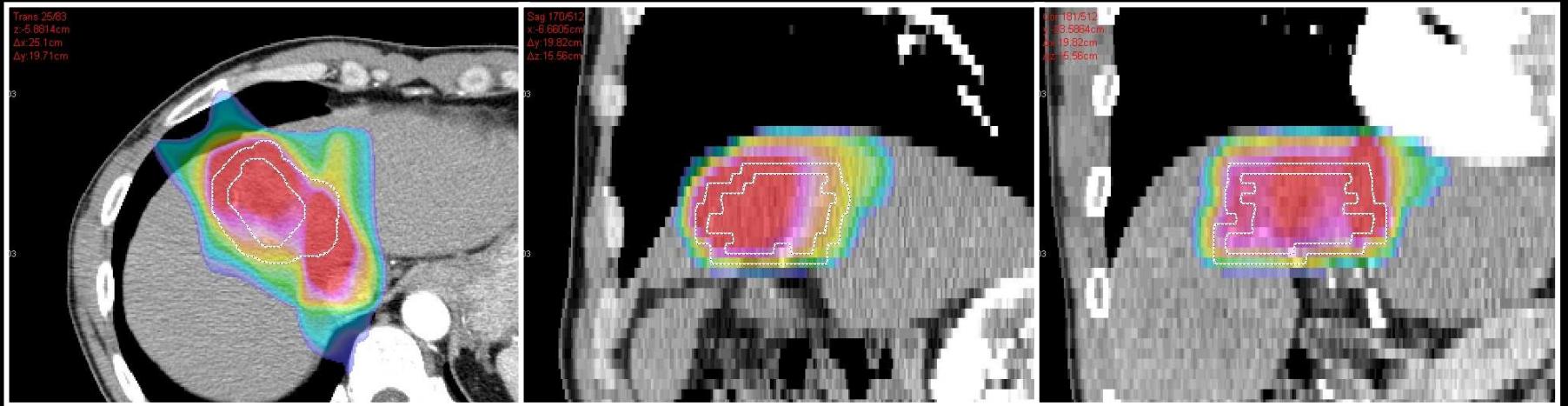
Impact of Systematic Errors



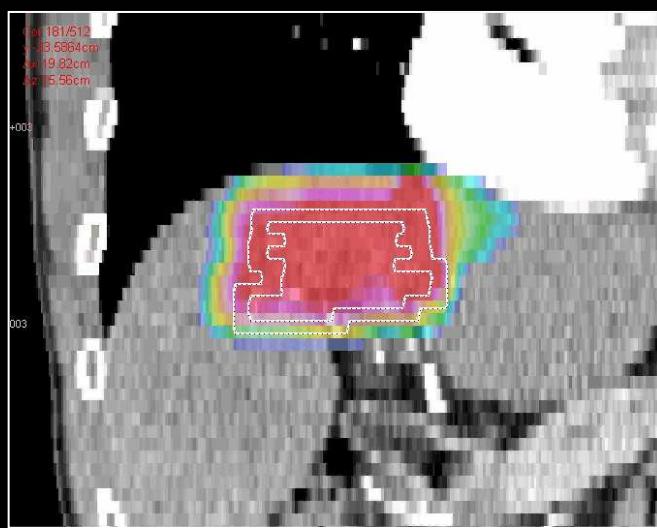
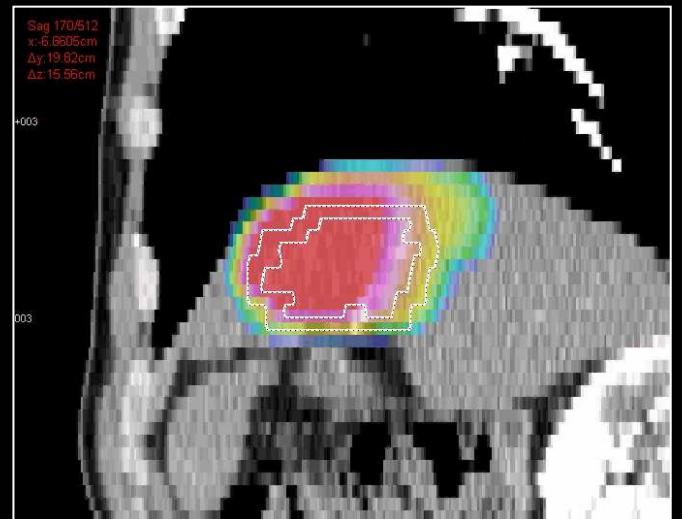
SBRT Liver Case Study

- Six-fraction protocol
- Daily on-line imaging and active breathing control

GTV min 49 Gy, PTV min 29 Gy

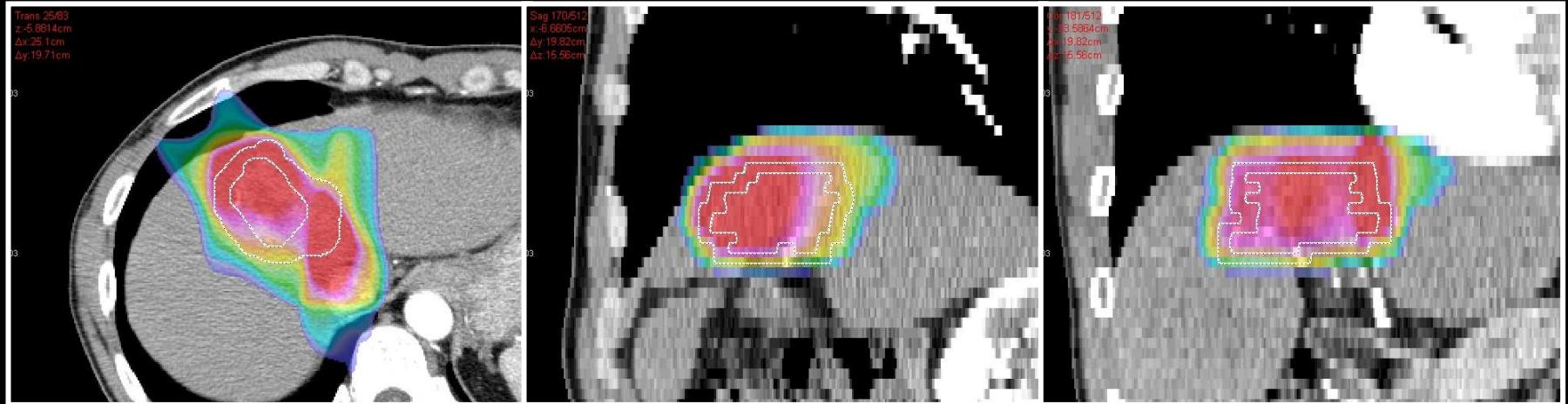


Liver - On-Line Correction

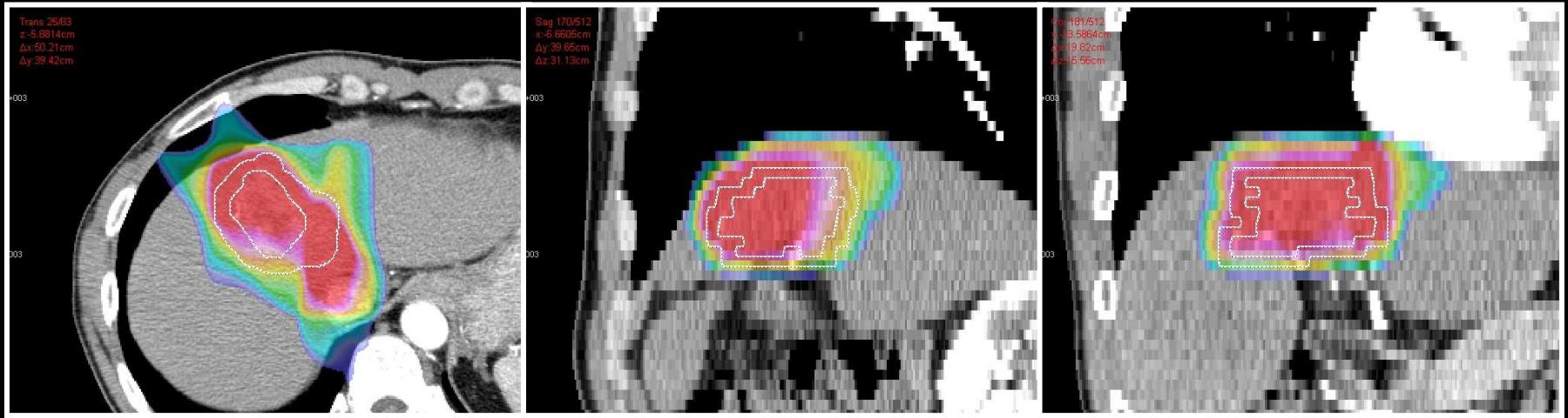


Liver - On-Line Correction

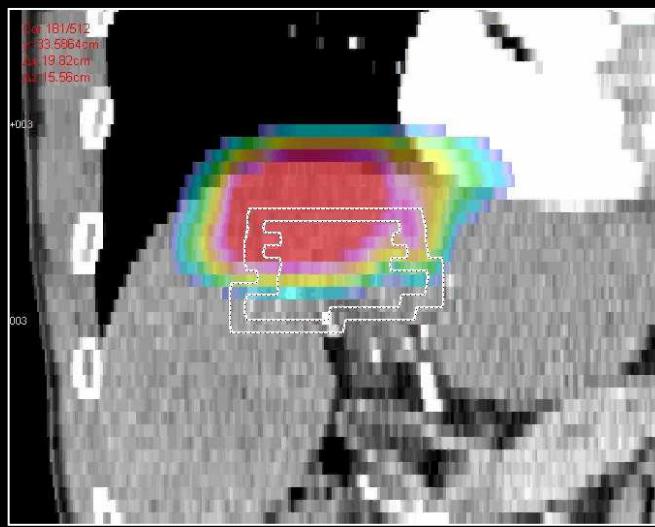
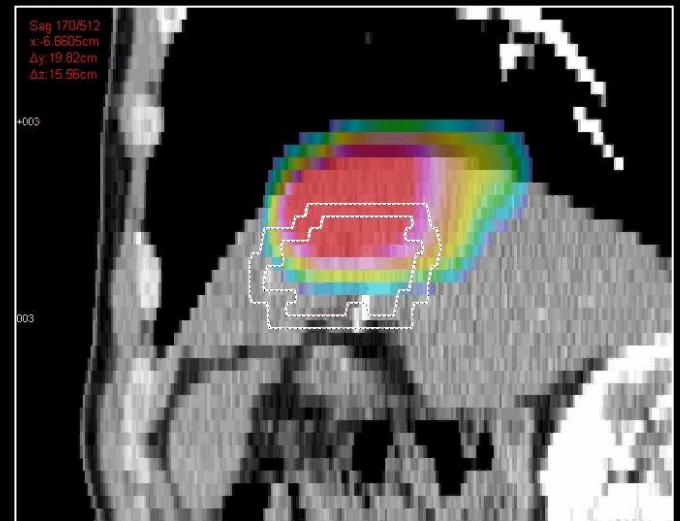
Planned - GTV min 49 Gy, PTV min 29 Gy



Delivered - GTV min 50 Gy

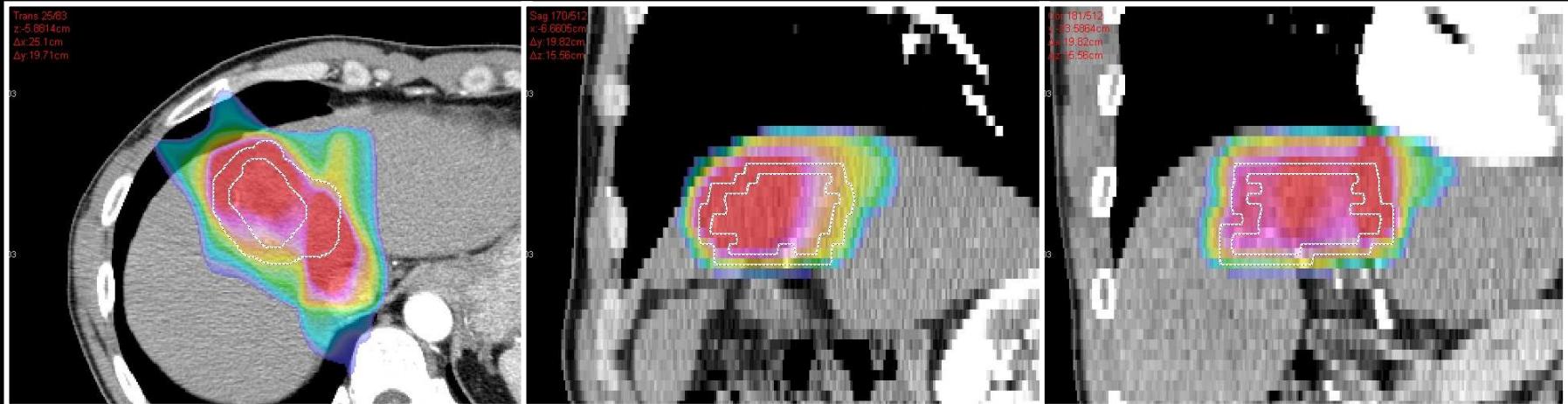


Liver - No Correction

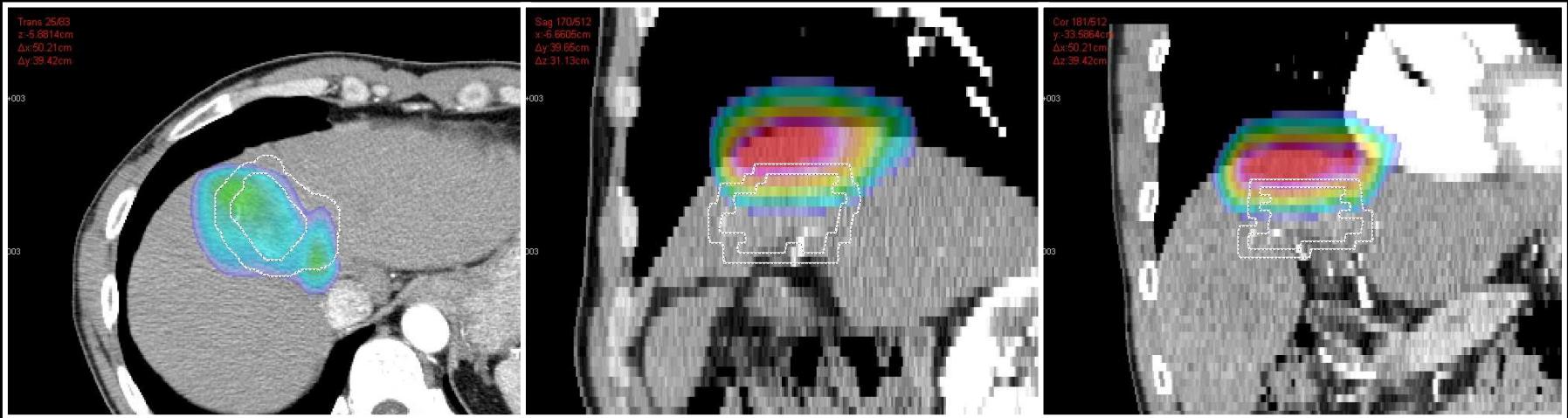


Liver - No Correction

Planned - GTV min 49 Gy, PTV min 29 Gy



Delivered - GTV min 16 Gy



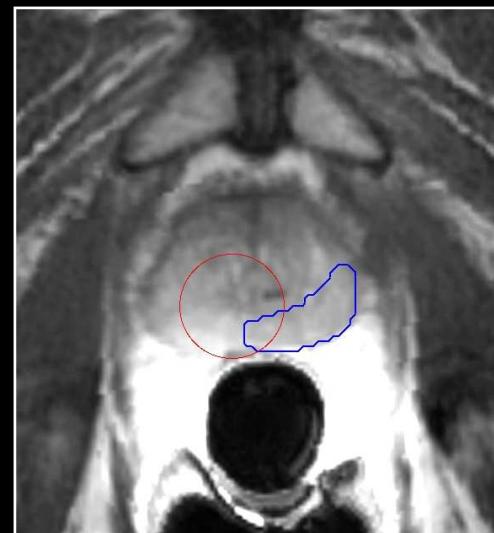
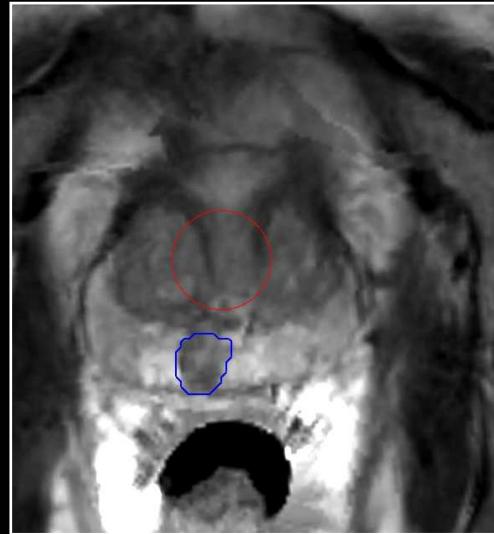
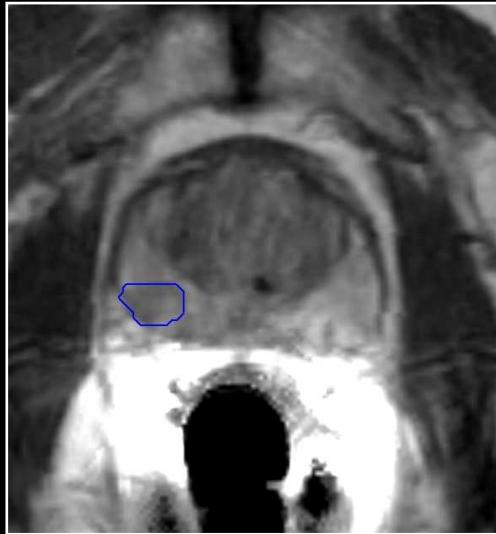
Outline

- Radiation Therapy
- State of the art technologies
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- Accuracy
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 - Solutions to problem

Solutions to Uncertainty

- Reduce
 - Better imaging for planning
 - Better imaging for treatment localization
- Anticipate
 - Margins
 - Robust optimization
 - Adapt

Imaging for Planning



4D-CT

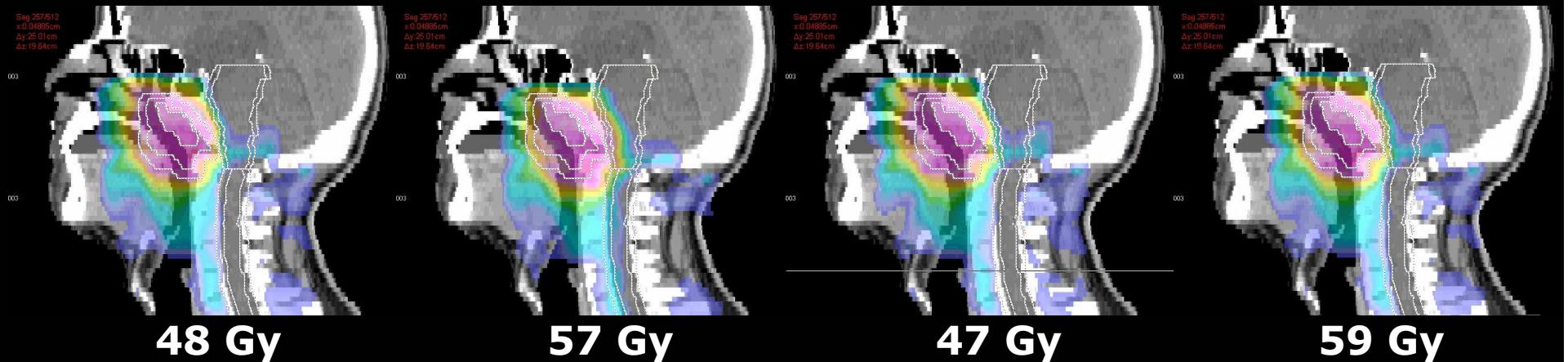




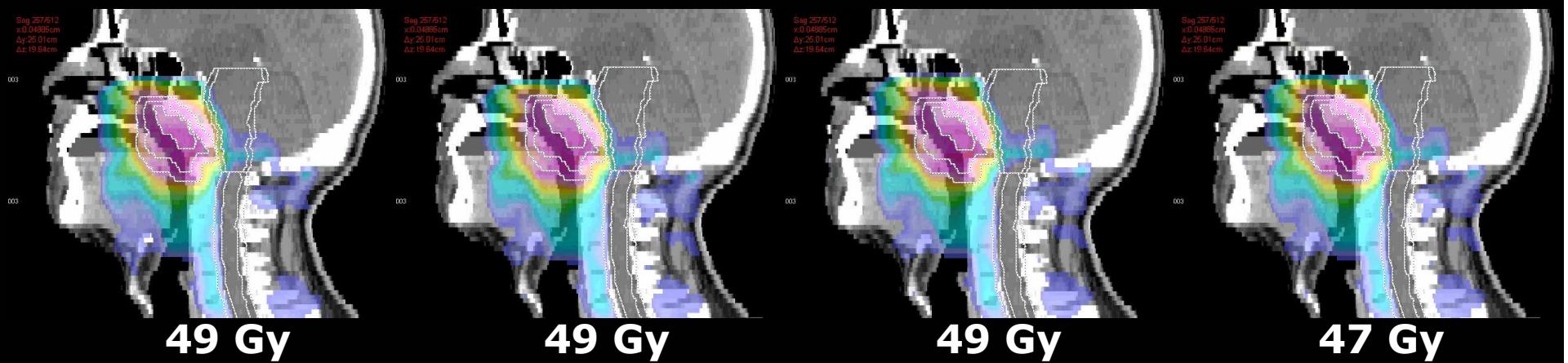
Nasopharynx

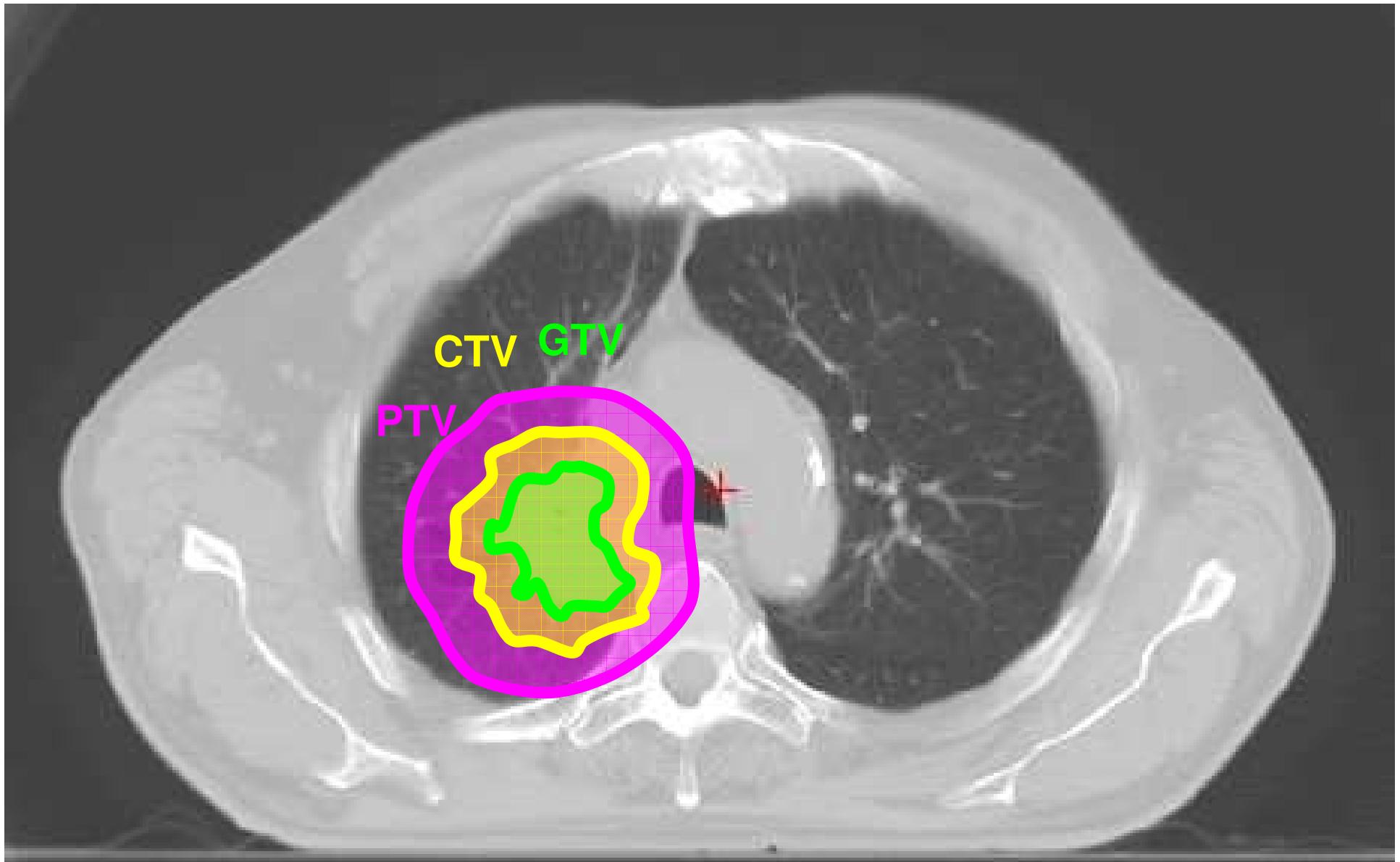
Princess Margaret Hospital

Uncorrected



Corrected





Gross Tumour Volume (GTV):

Clinical Target Volume (CTV):

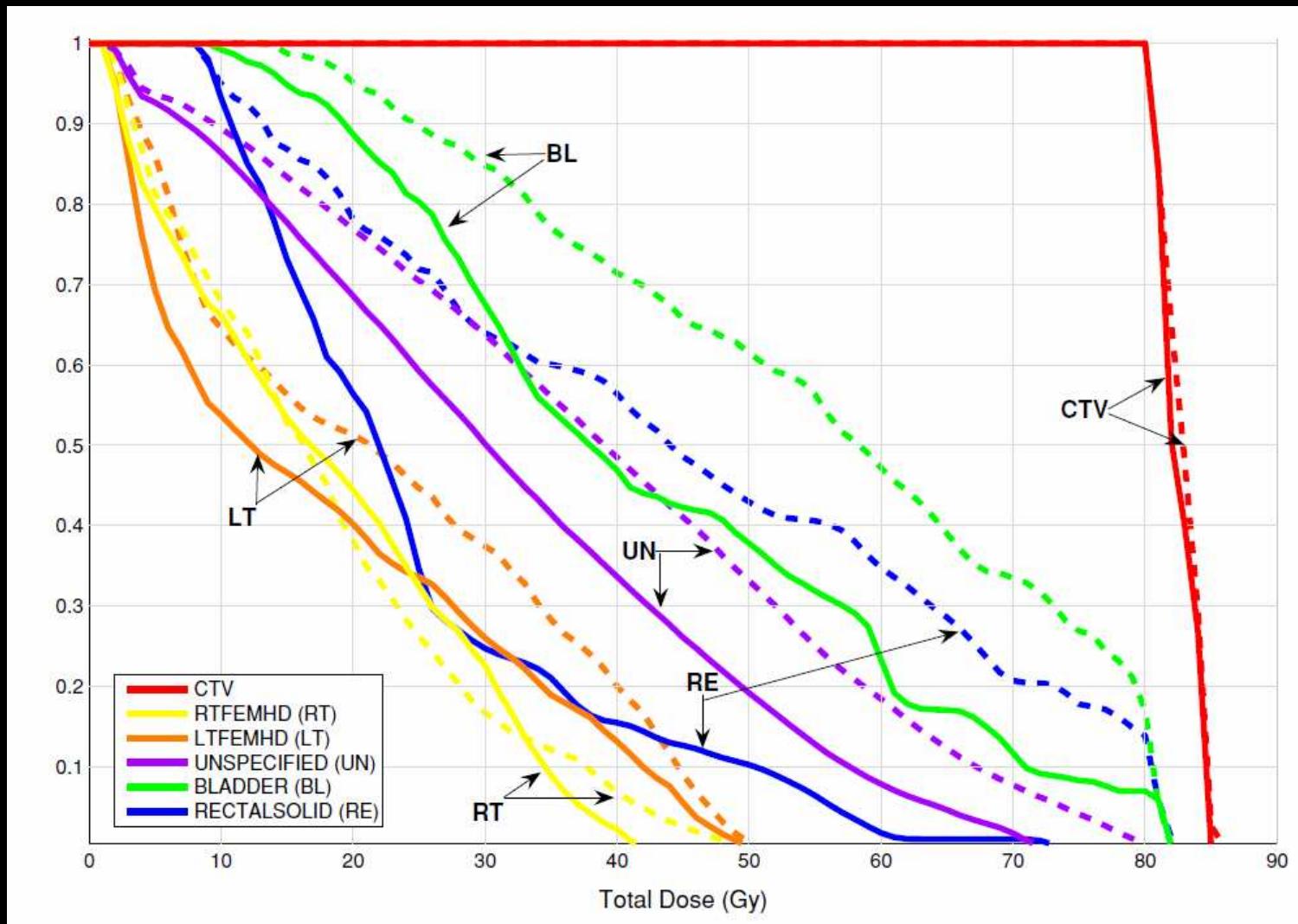
Planning Target Volume (PTV):

Tumour as seen on image

GTV + microscopic disease

CTV + geometric uncertainty

Robust Optimization

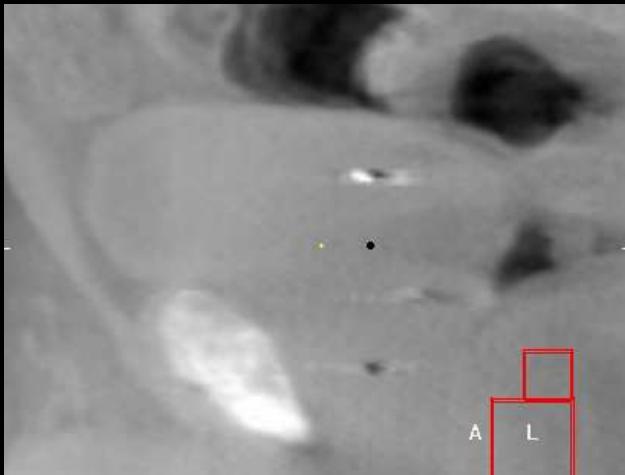


Chu et al, Phys Med Bio, 2005

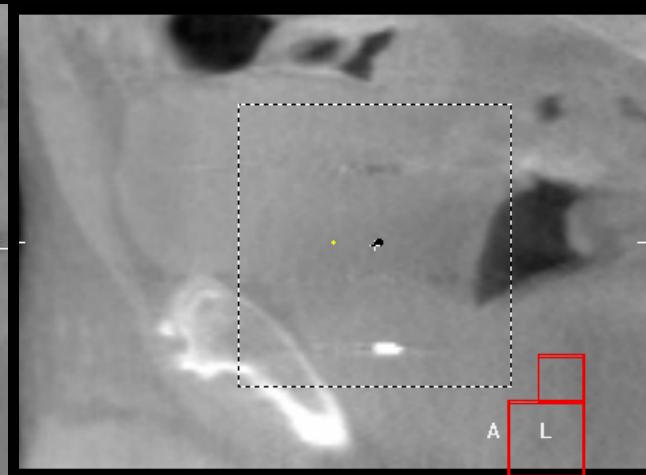
Adaptive



Plan



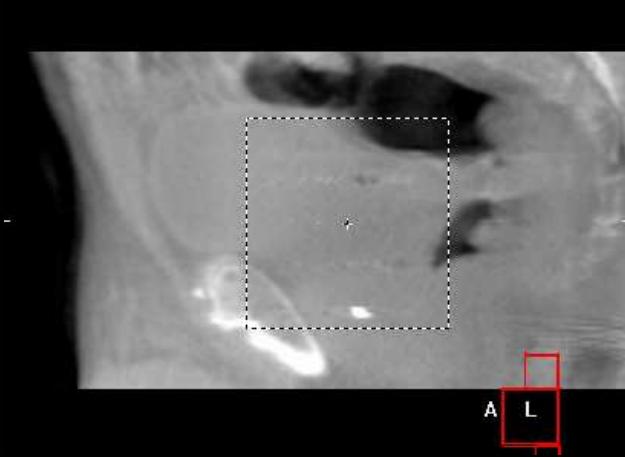
Fx 1



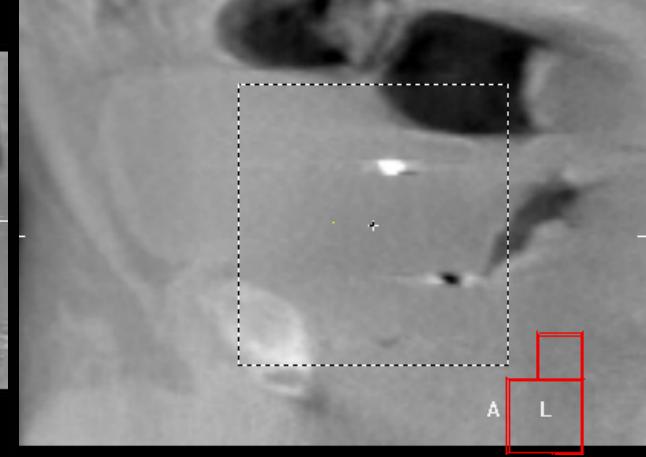
Fx 1 (Post-treatment)



Fx 2



Fx 3



Fx 4

Conclusions

- IMRT and IGRT are powerful new tools for radiation therapy
- Large uncertainties in treatment delivery result in poor treatment outcomes
- Quantitative margin design, robust optimization, and adaptive processes can reduce the impact of uncertainties