VMAT Mannheim

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Und

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VMAT – Current status in Mannheim

- **ERGO++** delivered in Sept. 2007, current version 1.7.2, DMS 2.6.2
  - Class solutions of treatment of pelvis, prostata and spinal cords developed

- **Desktop 7.01** installed in April 2008 (nonclinical version)
- **Mosaiq 1.5** installation in September 2008 (for VMAT delivery)

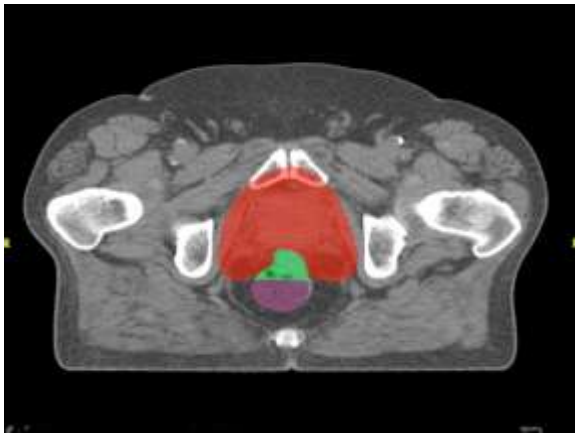
- **Desktop 7.01** installed in December 2008 (clinical version)
- **Mosaiq 1.6** installation in December 2008 (clinical Version for VMAT delivery)
- **Mosaiq 2.0** installation in August 2009
- **Integrity** Clinical Release pending
- **MLCi2** Installation Pending

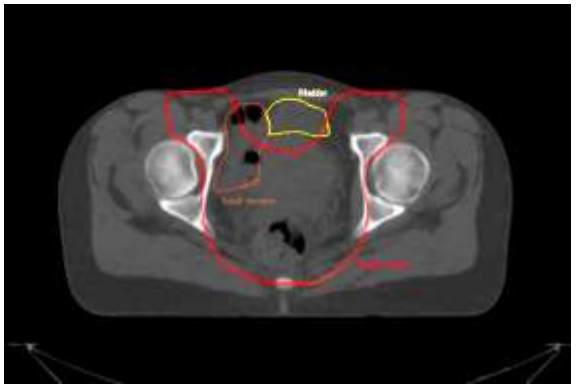
- First Patient treated clinically in December 2008 based on ERGO++

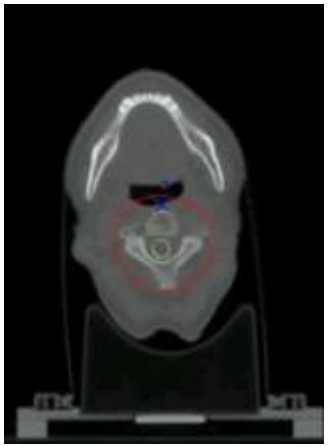
- **MONACO** clinical for step and shoot IMRT since July 2009 (post 1y Hyperion)
- **MONACO VMAT** clinical since 29.1.2010

Plan comparisons - Material and Methods

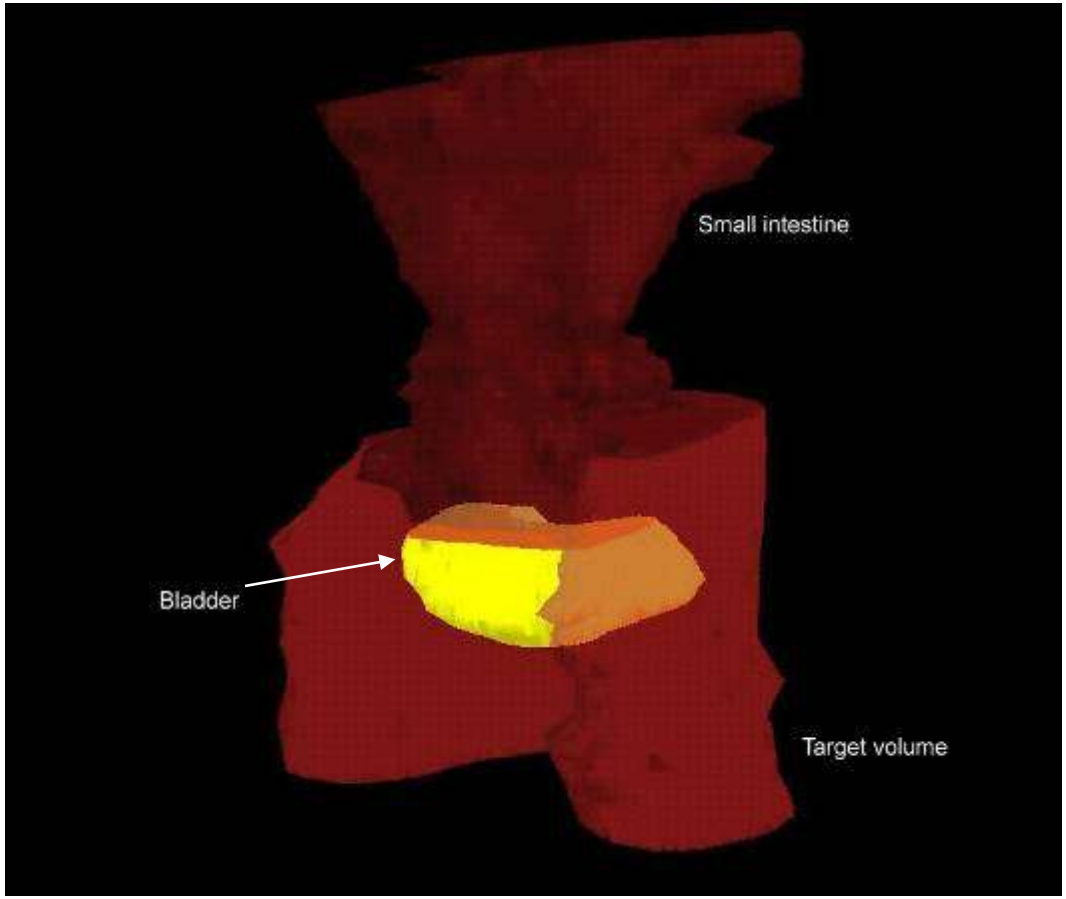
- Anal, prostate and paraspinal cases
- Treatment techniques plan comparison:
  - MLC based IMRT
  - Sequential Tomotherapy
  - 3D conformal radiation therapy (anal cases)
  - **VMAT**
- Material
  - Elekta Synergy 6MV (2x40 leaves / 1cm)
  - NOMOS Multivane Collimator (MIMiC / 1cm)
- Treatment planning systems (TPS)
  - VMAT → ERGO++ 1.7.1
  - IMRT → Hyperion 2.2.5.i (XVMC / PB)
  - MIMiC → CORVUS 6.3 (Pencil Beam)
  - 3D → Masterplan 3.0 SP1





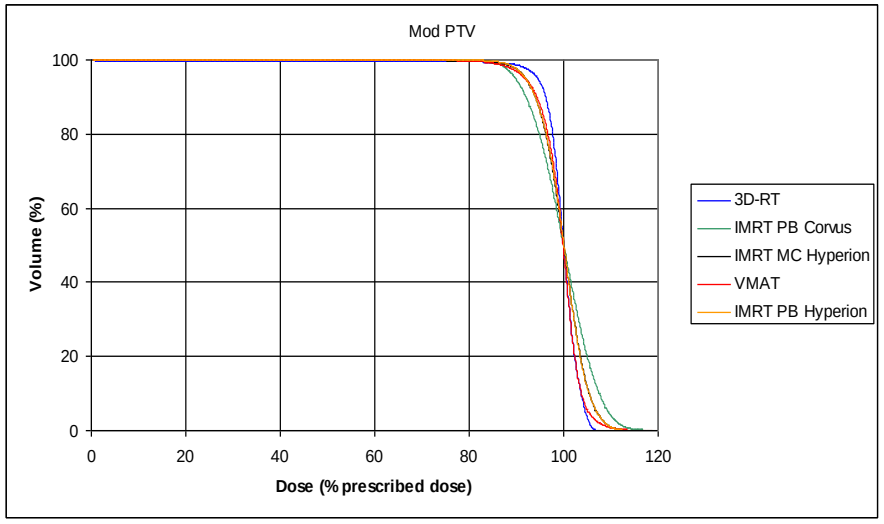


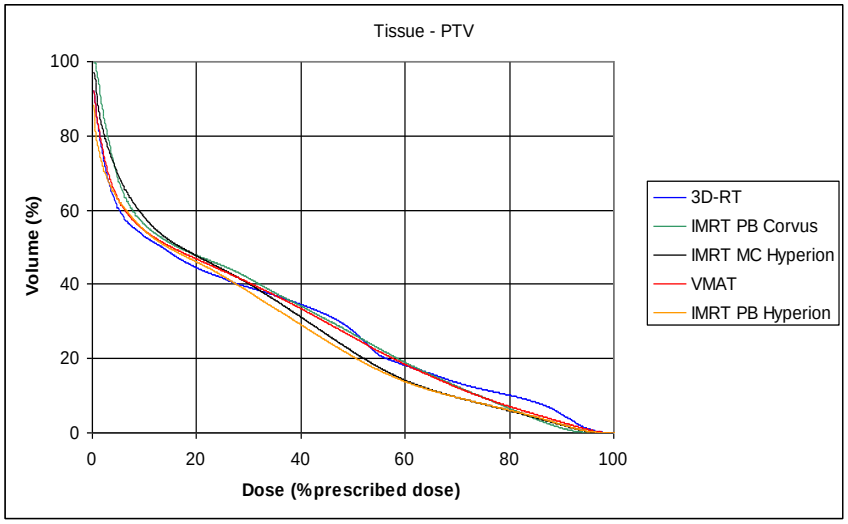
Anal Cancer

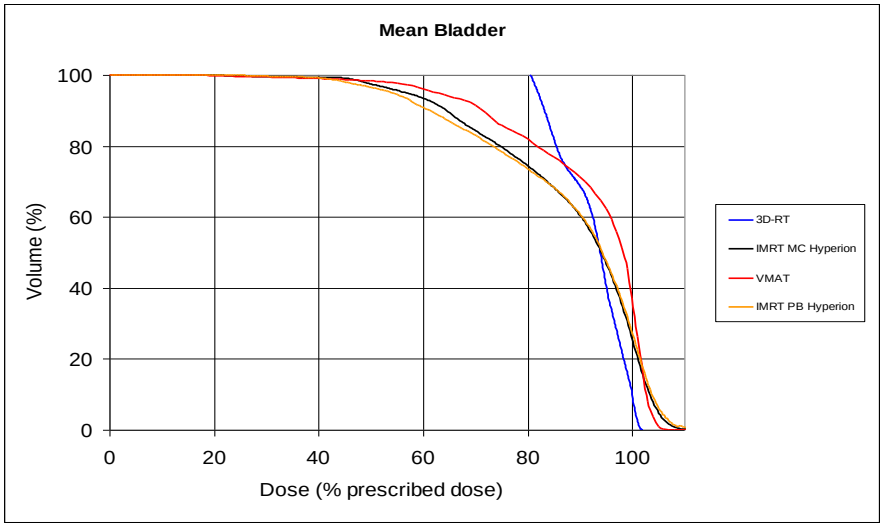


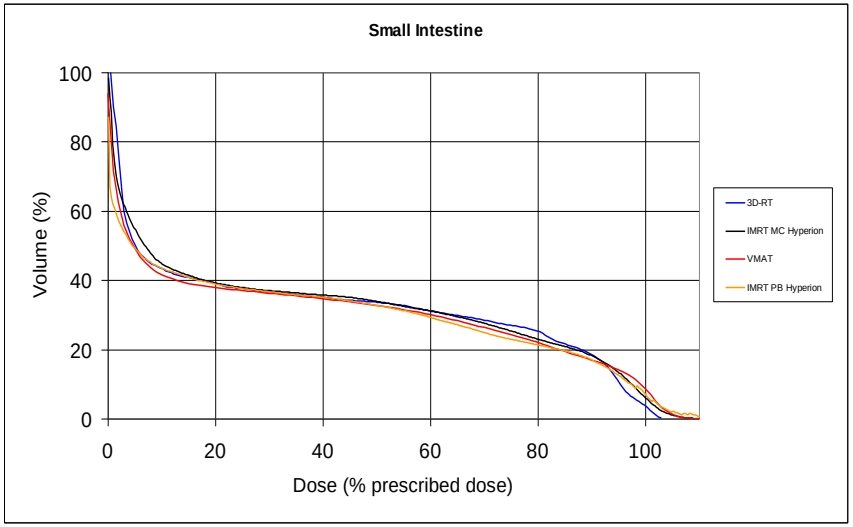
Stieler et al., Radiation Oncology, 2009

Anal Cancer – DVH's



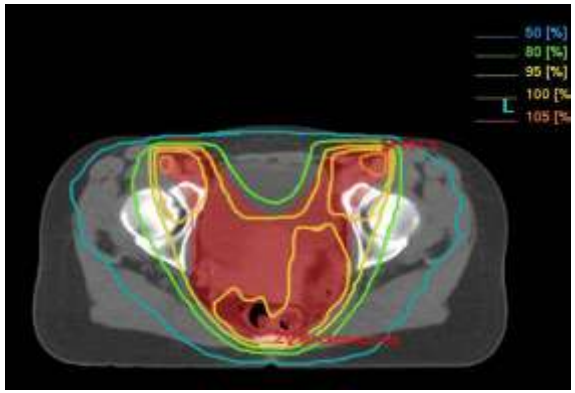




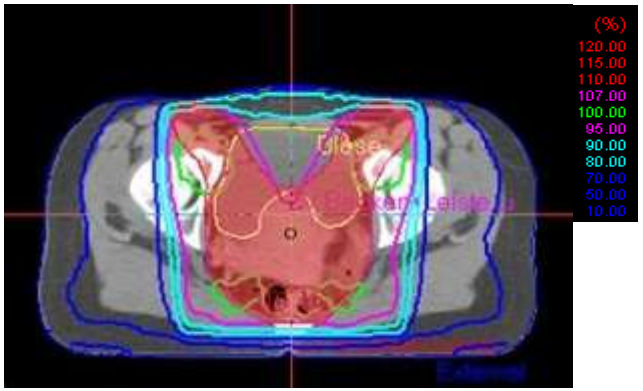


Stieler et al., Radiation Oncology, 2009

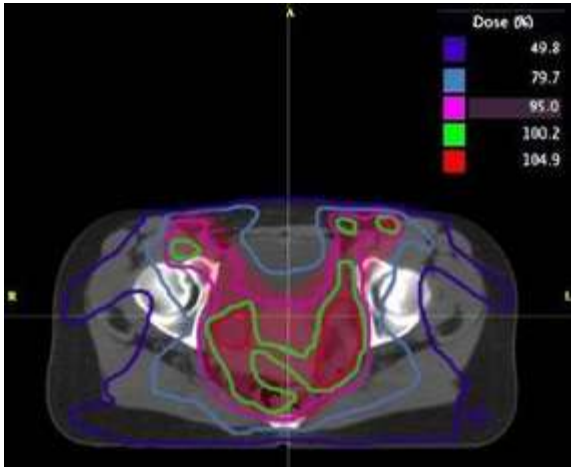
Anal Cancer – Different TPS



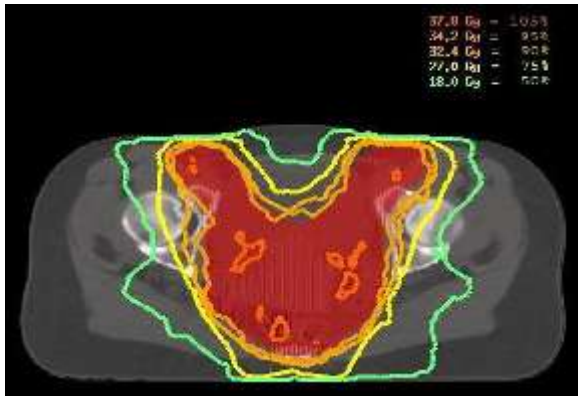
VMAT 2 Rot: ERGO++



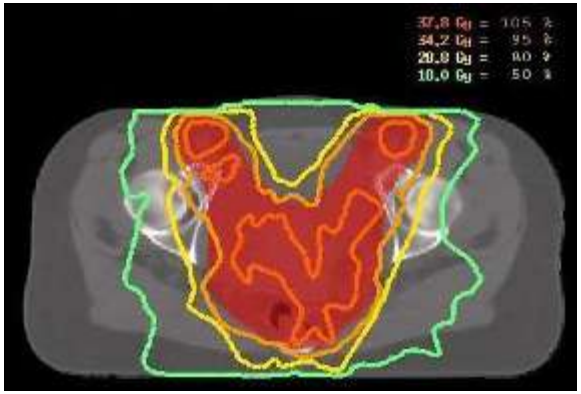
3D-RT: Masterplan



IMRT PB: Corvus



IMRT PB: Hyperion



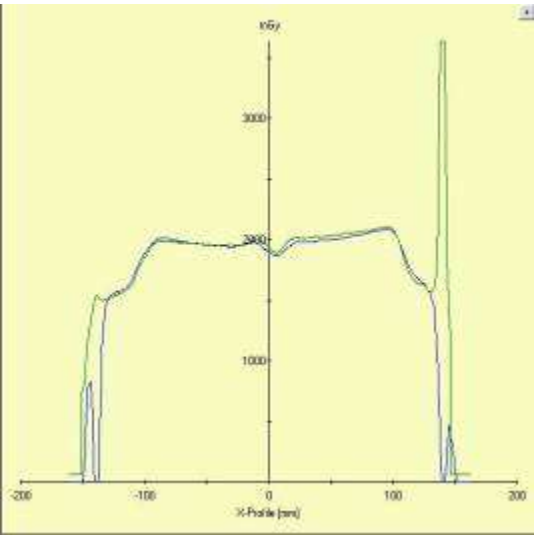
IMRT MC: Hyperion

Stieler et al., Radiation Oncology, 2009

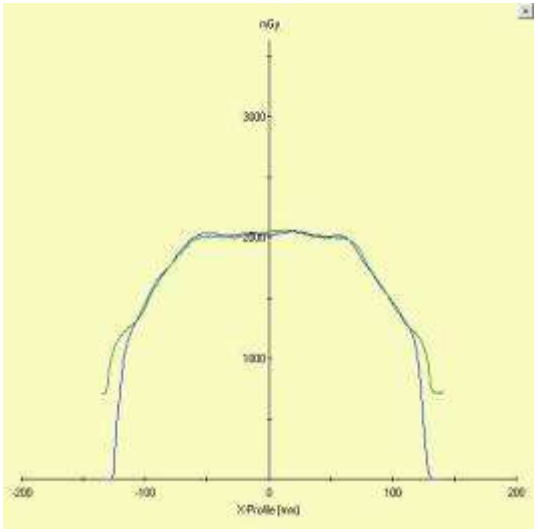
Anal Cancer – Results

	3D-CRT	VMAT '2 Rot'	IMRT (MC Hyperion)	IMRT (PB Hyperion)	IMRT (PB Corvus)
Homogeneity index (HI 36)	**1.06±0.02**	**1.11±0.02**	**1.11±0.08**	**1.10±0.02**	**1.15±0.03**
Conformality index	**2.00±0.16**	**1.39±0.09**	**1.30±0.02**	**1.26±0.05**	**1.33±0.21**
Monitor Units	**225±11**	**268±19**	**748±193**	**477±84**	**1260±172**
Mean Treatment Time (without positioning)	**3 Min 40**	**4 Min 50**	**10 Min 10**	**9 Min 30**	**9 Min 35**
$V_{\text{Tissue 10\% PD}}$	10739 cm³ ≡ 48.8%	10463 cm³ ≡ 47.6%	10806 cm³ ≡ 48.1%	10347 cm³ ≡ 46.0%	10591 cm³ ≡ 47.5%
$V_{\text{Tissue 30\% PD}}$	8187 cm³ ≡ 37.3 %	7674 cm³ ≡ 34.9 %	7593 cm³ ≡ 33.8%	7199 cm³ ≡ 32.0%	7874 cm³ ≡ 35.3%
$V_{\text{Tissue 50\% PD}}$	6052 cm³ ≡ 27.6 %	5089 cm³ ≡ 23.1%	4203 cm³ ≡ 18.7%	3971 cm³ ≡ 17.7%	5186 cm³ ≡ 23.2%
$V_{\text{Tissue 70\% PD}}$	3428 cm³ ≡ 15.6 %	2734 cm³ ≡ 12.4 %	1939 cm³ ≡ 8.6%	1933 cm³ ≡ 8.6%	2612 cm³ ≡ 11.7%
$V_{\text{Tissue 95\% PD}}$	982 cm³ ≡ 4.5 %	208 cm³ ≡ 0.9 %	14 cm³ ≡ 0.0%	0 cm³ ≡ 0.0%	53 cm³ ≡ 0.2%
$D_{\text{95\% Vol Tissue}}$	1.97 Gy ≡ 5.46%	0.75 Gy ≡ 2.09%	0.35 Gy ≡ 0.98%	0.31 Gy ≡ 0.85%	0.52 Gy ≡ 1.45%
$D_{\text{95\% Vol PTV}}$	34.09Gy ≡ 94.7%	33.84 Gy ≡ 94%	33.05 Gy ≡ 91.8%	32.95 Gy ≡ 91.54%	32.33 Gy ≡ 89.8%

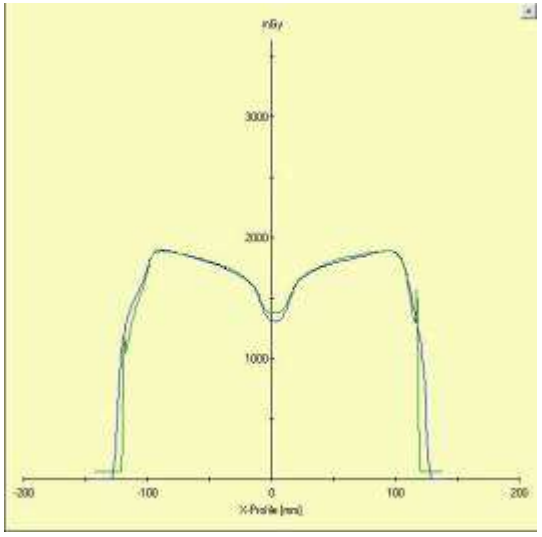
Wolff et al., Strahlenther Onkol, submitted



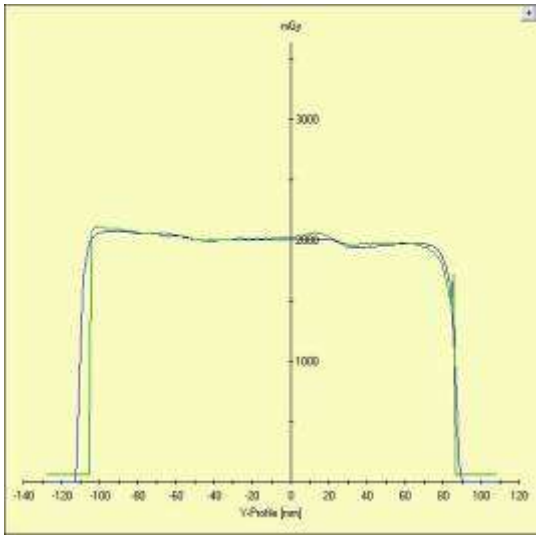
Coronal profile



Coronal profile



Coronal profile throught bulges

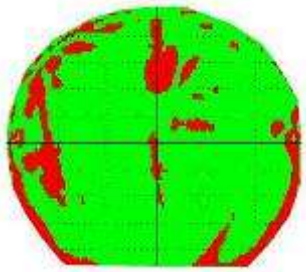


AP profile throught bulges

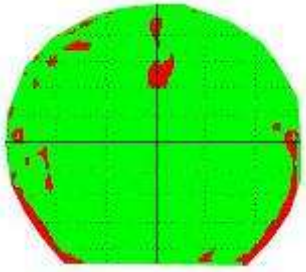
γ-Index / Absolute Analysis

Exemplary γ-Index

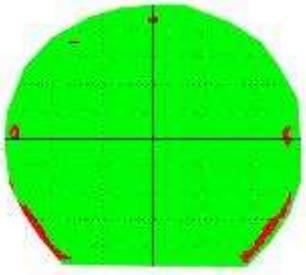
γ-Index 1% / 1 mm



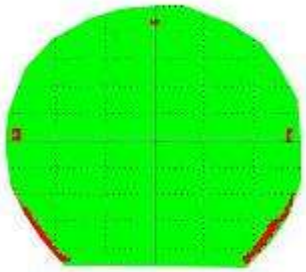
γ-Index 2% / 2 mm



γ-Index 3% / 3 mm



γ-Index 5% / 5 mm



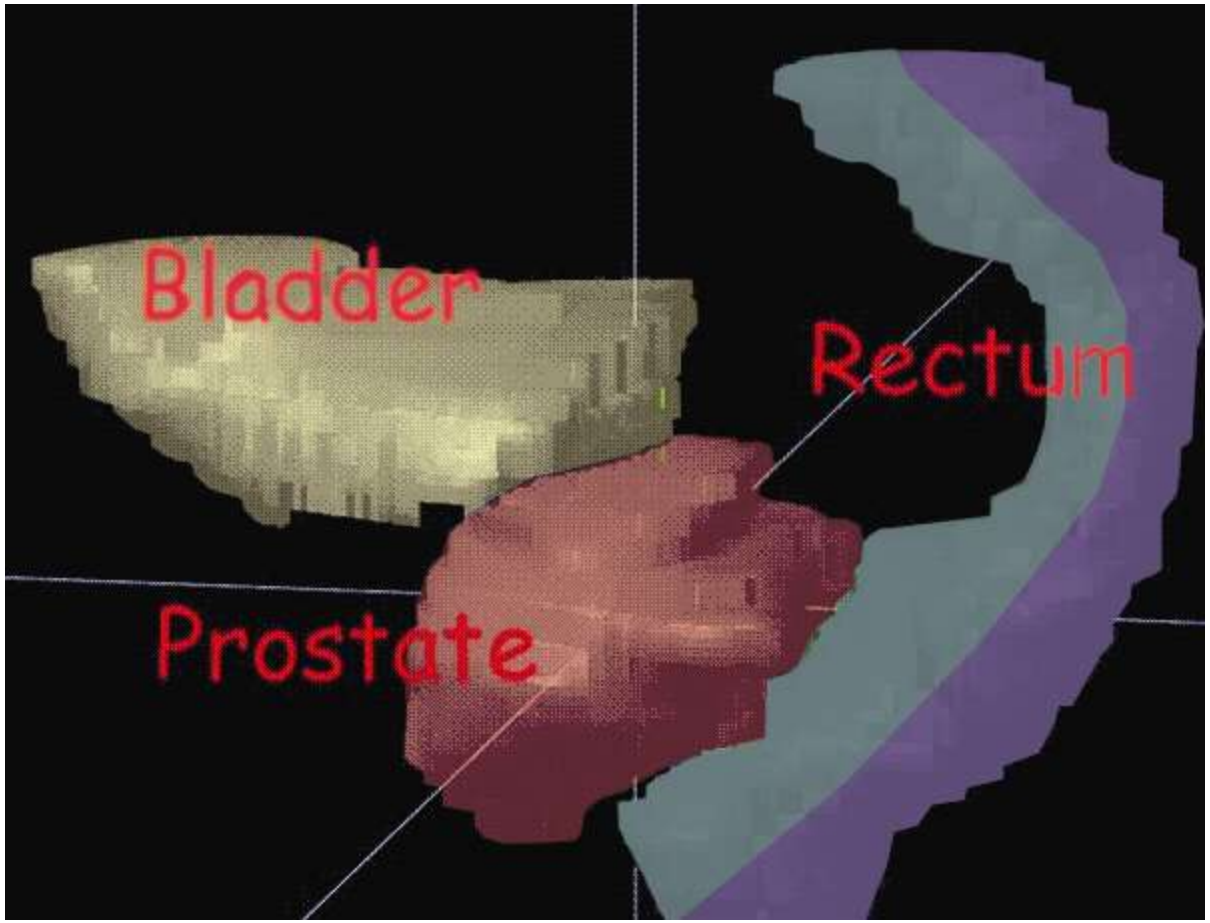
γ-Index 10% / 5 mm

Numerical γ-Index (pass criteria over all cases)

γ-Index 1% / 1mm: 42.8 ± 10.9%
γ-Index 2% / 2mm: 74.5 ± 9.3%
γ-Index 3% / 3mm: 90.2 ± 4.9%
γ-Index 5% / 5mm: 99.1 ± 0.7%
γ-Index 5% / 10mm: 100 ± 0.0% (set a default)

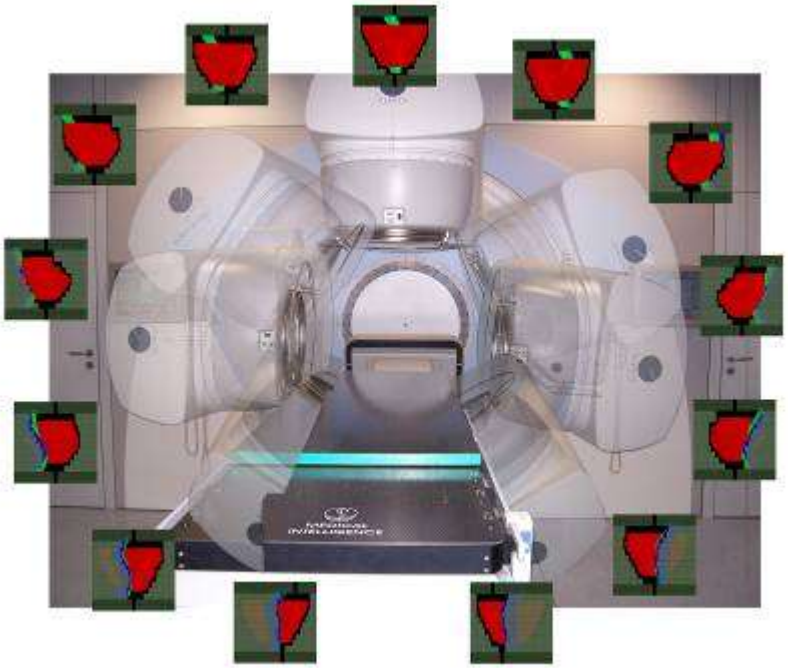
Absolute Dose of Ion Chamber D_{mean} = 1.84 ± 2.06 % (max: +4.0% min: -2.4%)

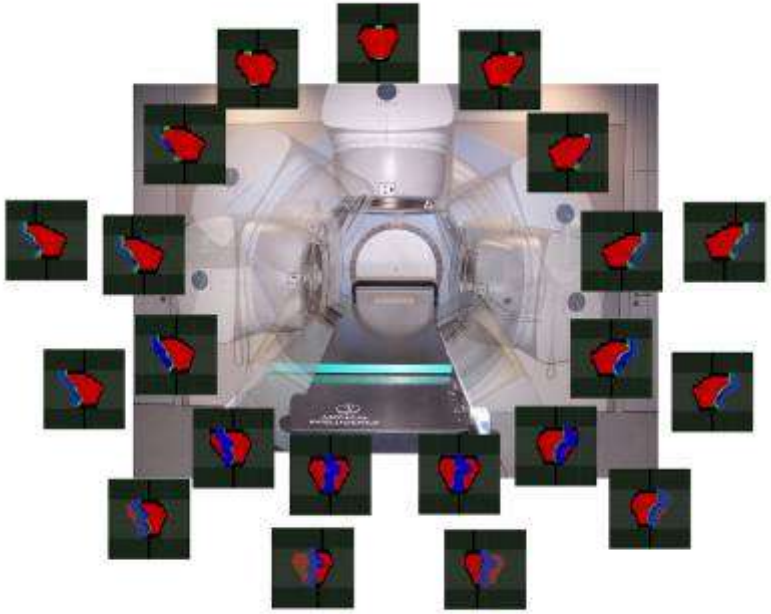
Prostate Cancer



Wolff et al., Radiother Oncol, 2009

Prostata carzinoma – VMAT rotation strategies





VMAT 1 Rot:

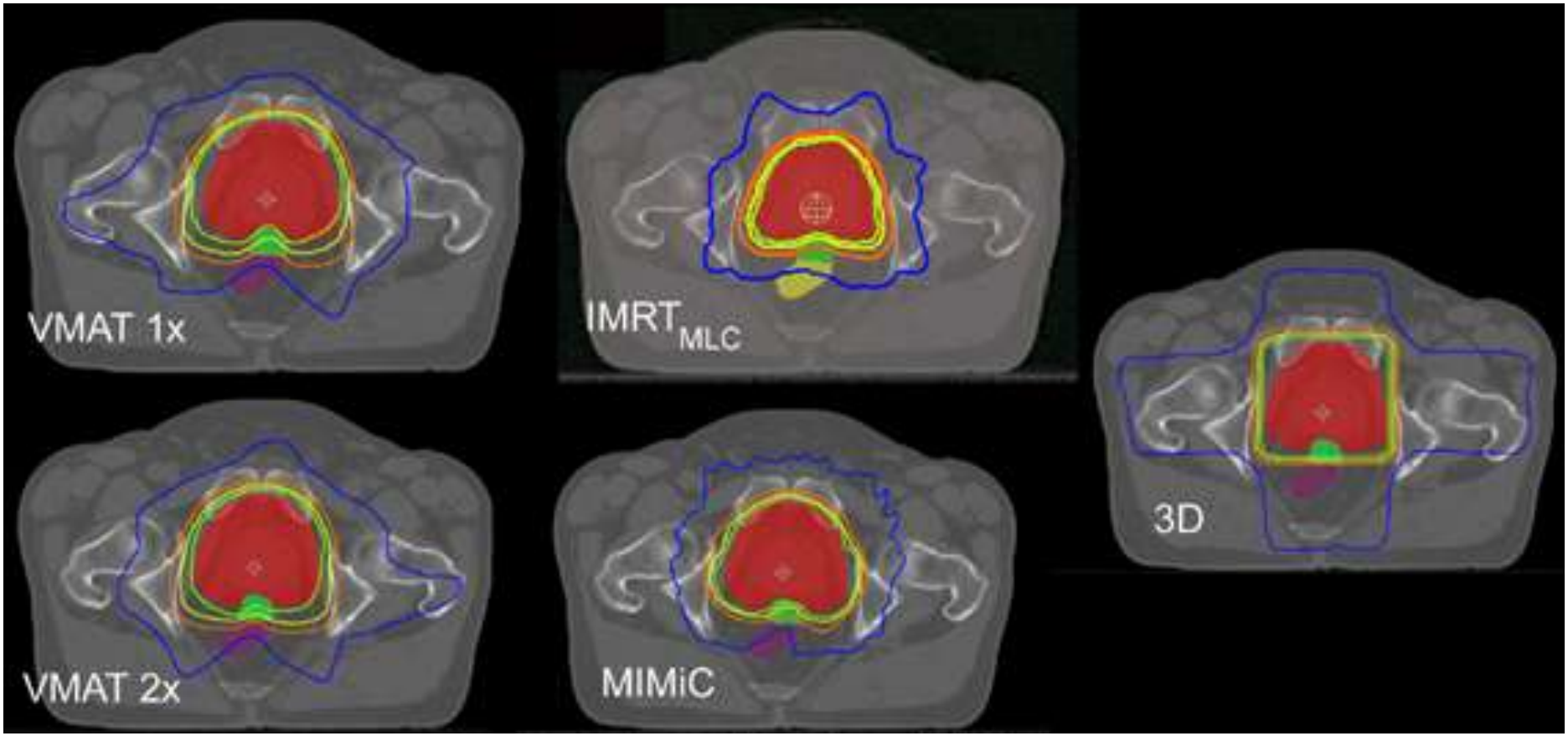
- 1x 360° rotation with shielded OAR in front of target

VMAT 1,5 Rot.

- 1x360° rotation on target
- 2x100° rotation on target with shielded OAR

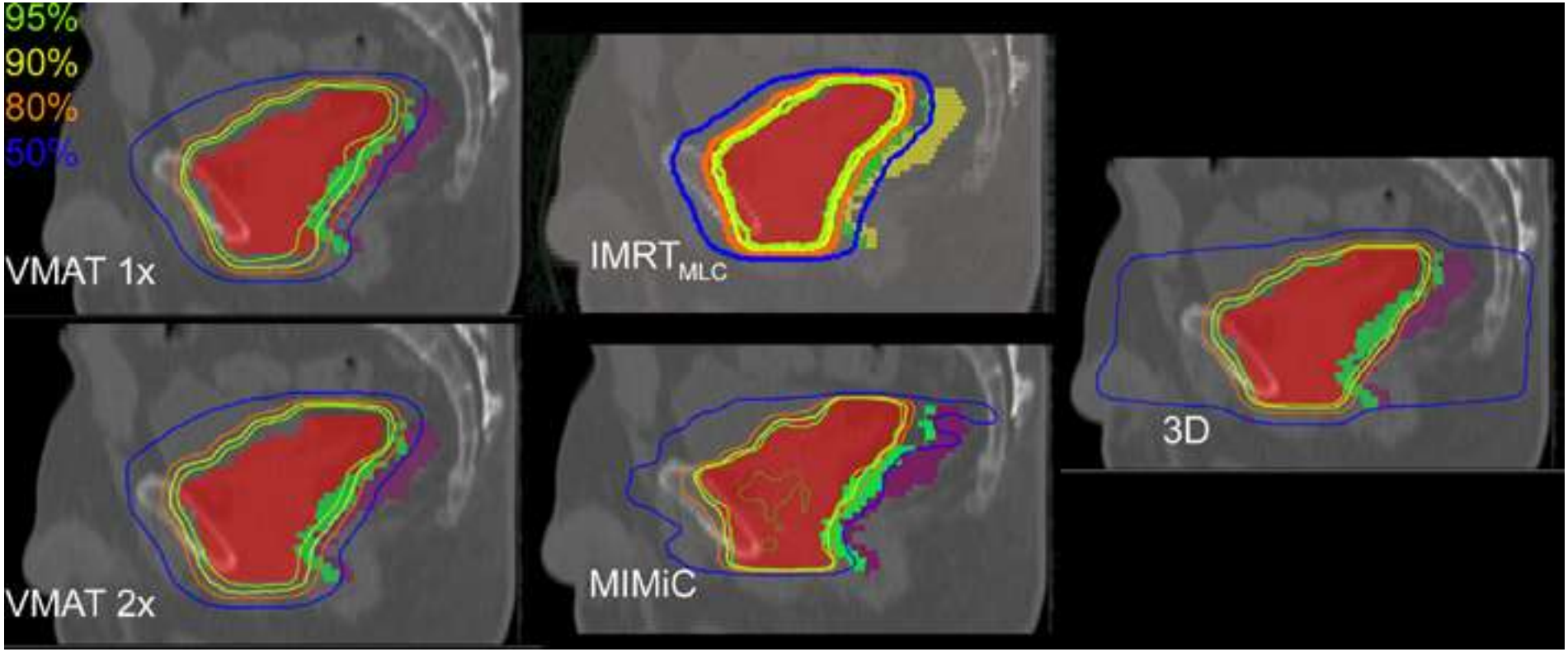
Wolff et al., Radiother Oncol, 2009

Axial dose distribution



Wolff et al., Radiother Oncol, 2009

Sagittal dose distributions



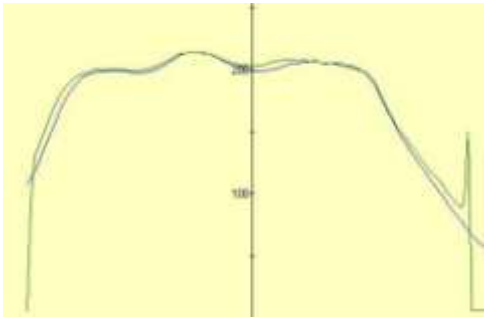
Wolff et al., Radiother Oncol, 2009

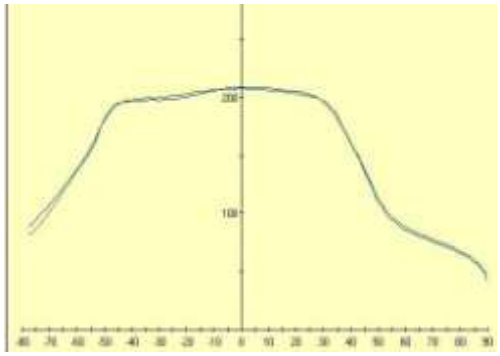
Prostate Cancer

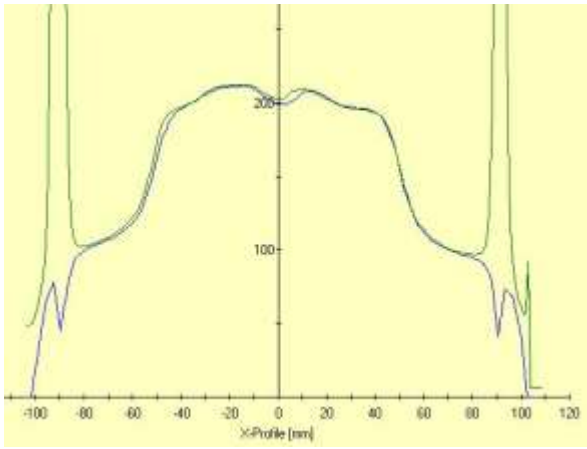
		VMAT 1x	VMAT 2x	$IMRT_{MLC}$	MIMiC	3D
$D_{mean\ Target}$	[Gy]	75.97 ± 0.07	75.93 ± 0.06	75.73 ± 0.14	75.89 ± 0.3	76 ± 0.03
$D_{99\%\ Target}$	[Gy]	69.62 ± 0.84	69.74 ± 1.0	66.46 ± 1.9	66.13 ± 5.4	71.02 ± 0.58
$D_{95\%\ Target}$	[Gy]	71.59 ± 0.53	71.70 ± 0.63	70.51 ± 0.91	69.79 ± 3.52	73.42 ± 0.37
$D_{mean\ Rectum\ post}$	[Gy]	38.57 ± 2.38	38.75 ± 2.39	34.89 ± 1.81	31.85 ± 2.12	55.43 ± 6.28
$D_{mean\ Rectum\ ant}$	[Gy]	61.59 ± 4.41	60.29 ± 3.34	53.99 ± 3.24	50.69 ± 3.29	66.33 ± 5.96
$V_{tissue\ 70\%}$	[cm^3]	505 ± 83	482 ± 29	284 ± 40	337 ± 73	414 ± 35
$V_{tissue\ 50\%}$	[cm^3]	1231 ± 177	1155 ± 91	933 ± 172	869 ± 154	1993 ± 551
$V_{tissue\ 30\%}$	[cm^3]	3438 ± 494	3340 ± 507	3414 ± 732	2819 ± 630	3061 ± 619
$V_{tissue\ 10\%}$	[cm^3]	6729 ± 1364	6703 ± 1407	5746 ± 1294	6341 ± 1905	4506 ± 956
TTT	[min]	1.8 ± 0.1	3.7 ± 0.2	6 ± 1	12 ± 2	2.5 ± 0.1
MU		386 ± 29	371 ± 34	544 ± 56	2714 ± 697	252 ± 8
$CI_{RTOGmod}$		1.51 ± 0.16	1.45 ± 0.14	1.23 ± 0.16	1.5 ± 0.23	1.46 ± 0.06
HI		1.11 ± 0.03	1.09 ± 0.03	1.1 ± 0.02	1.19 ± 0.07	1.04 ± 0.01

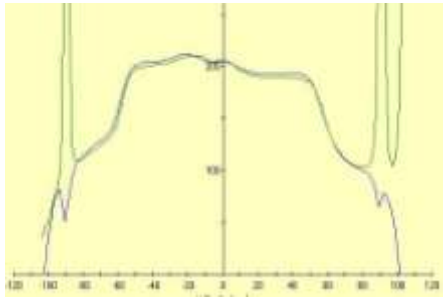
Wolff et al., Strahlenther Onkol, submitted

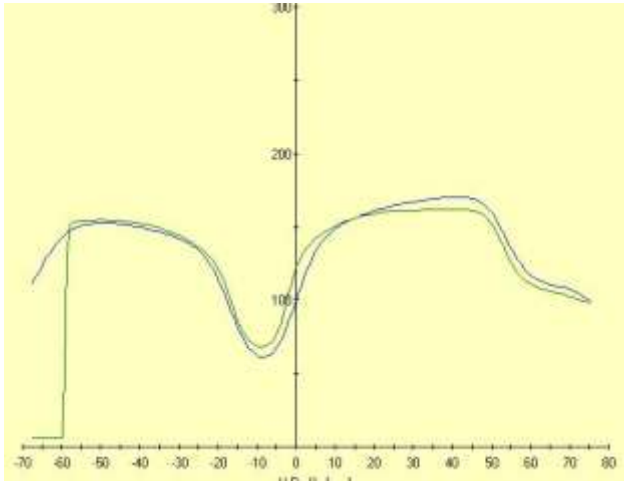
QA measurements - profiles

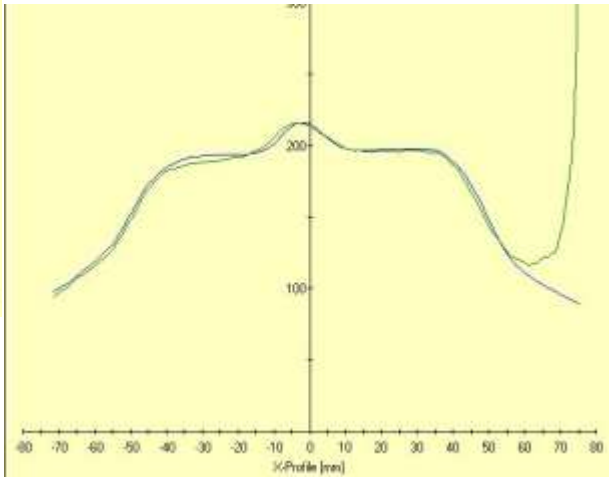


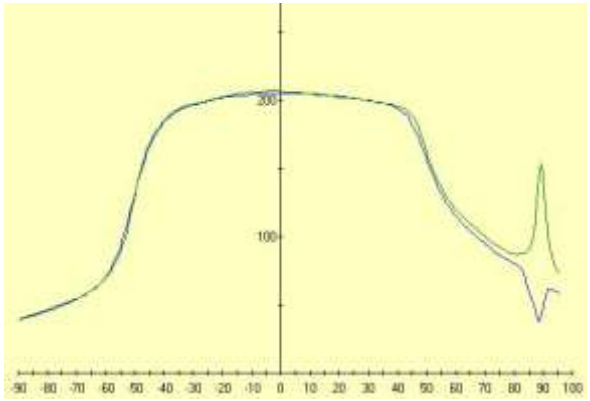




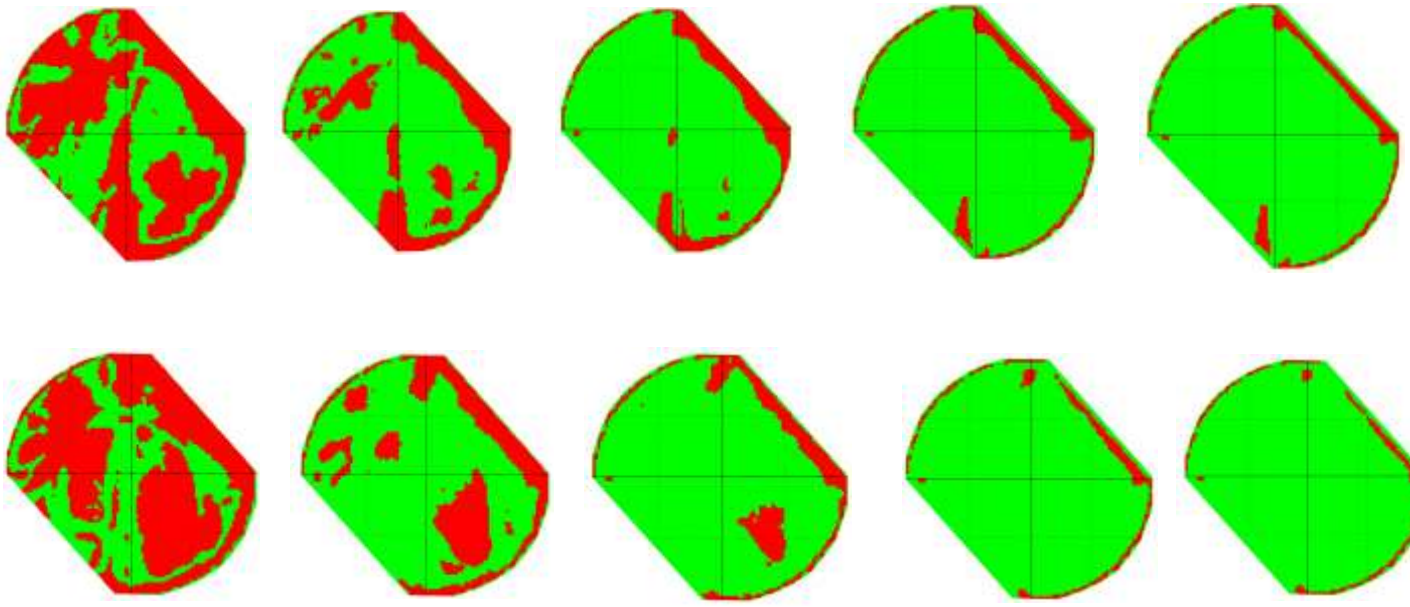








Wolff et al., Strahlenther Onkol, submitted



1 rot.

1,5 rot.

γ-Index: 1% / 1mm | 2% / 2mm | 3% / 3mm | 5% / 5mm | 10% / 5mm

was calculated for each plan , here exemplary for pat 8

Wolff et al., Strahlenther Onkol, submitted

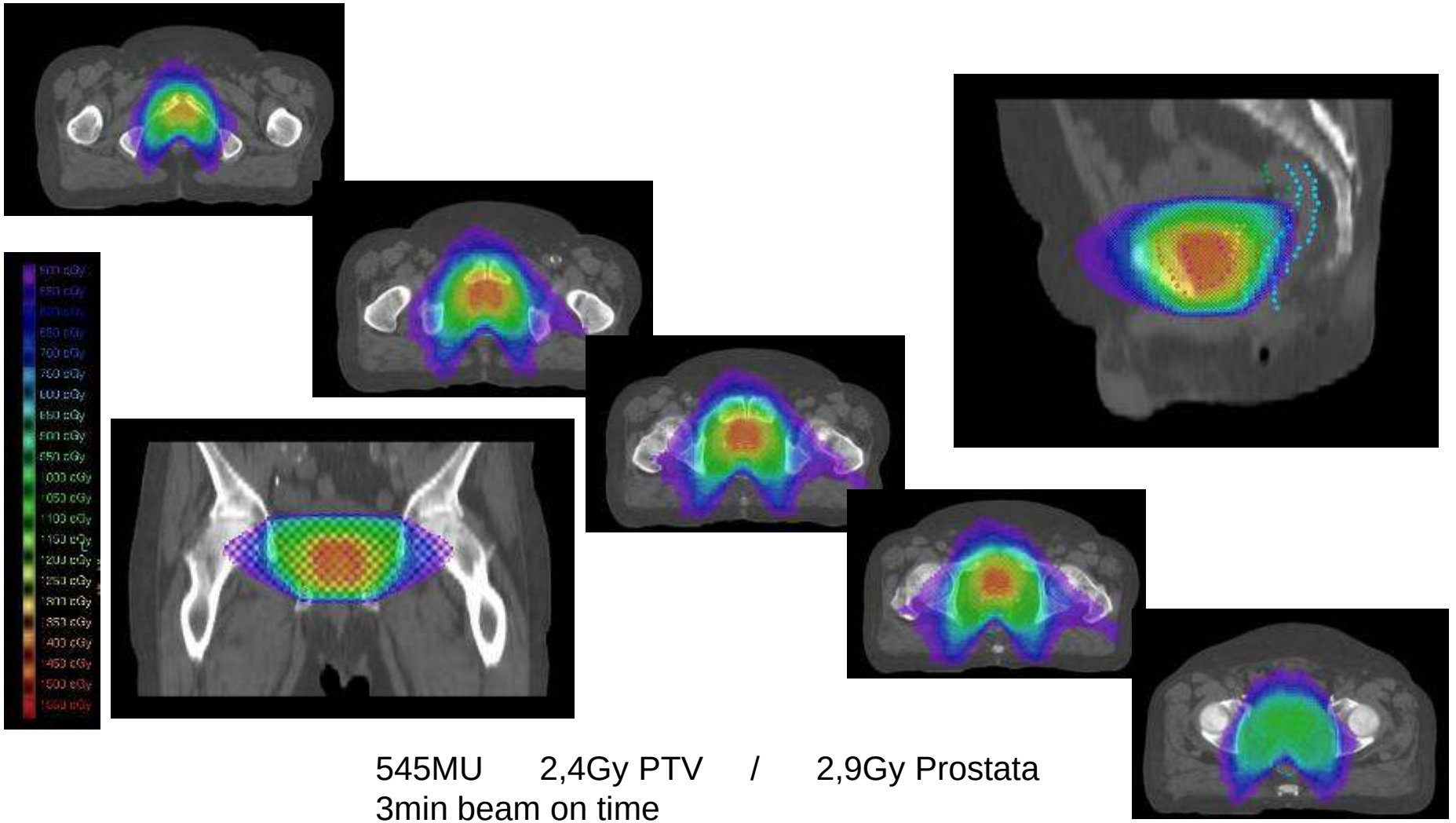
Results of the measurements

- absolute dose of ion chamber Δ_{mean} = 1,64%±1,14 (max: +3,7% min: -1,25%)
- good relative agreement between measured and calculated in film measurements
- Mean pass criteria for γ-Index:

1% / 1mm	40,9% ± 8,7		pass pixel (green)
2% / 2mm	69,3% ± 10,4		pass pixel (green)
3% / 3mm	84,8% ±	8,0	pass pixel (green)
5% / 5mm	97,2% ±	2,7	pass pixel (green)
10% / 5mm	is set to 100%		

Wolff et al., Radiother Oncol, 2009

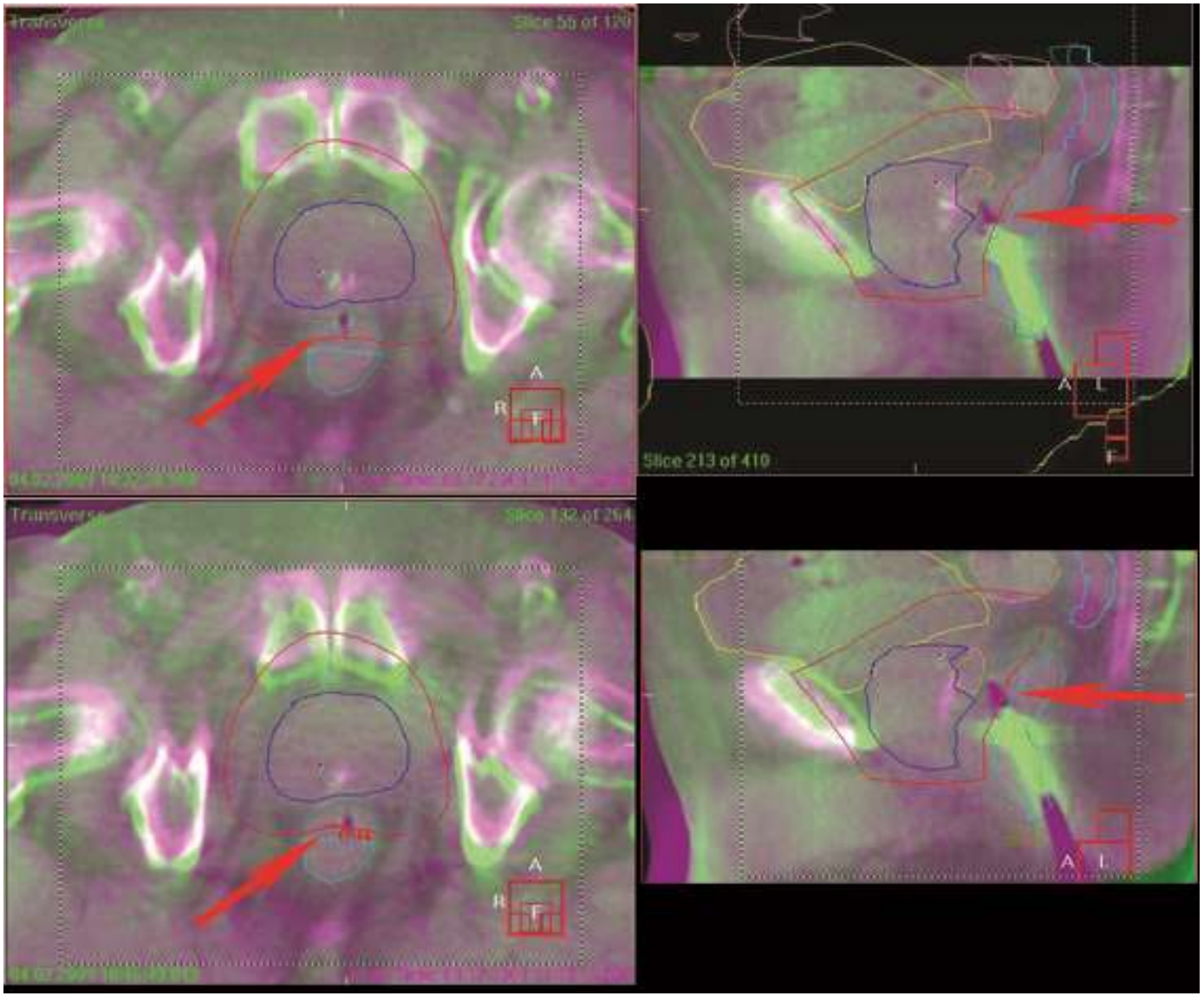
Second clinical patient
with 2 rotations



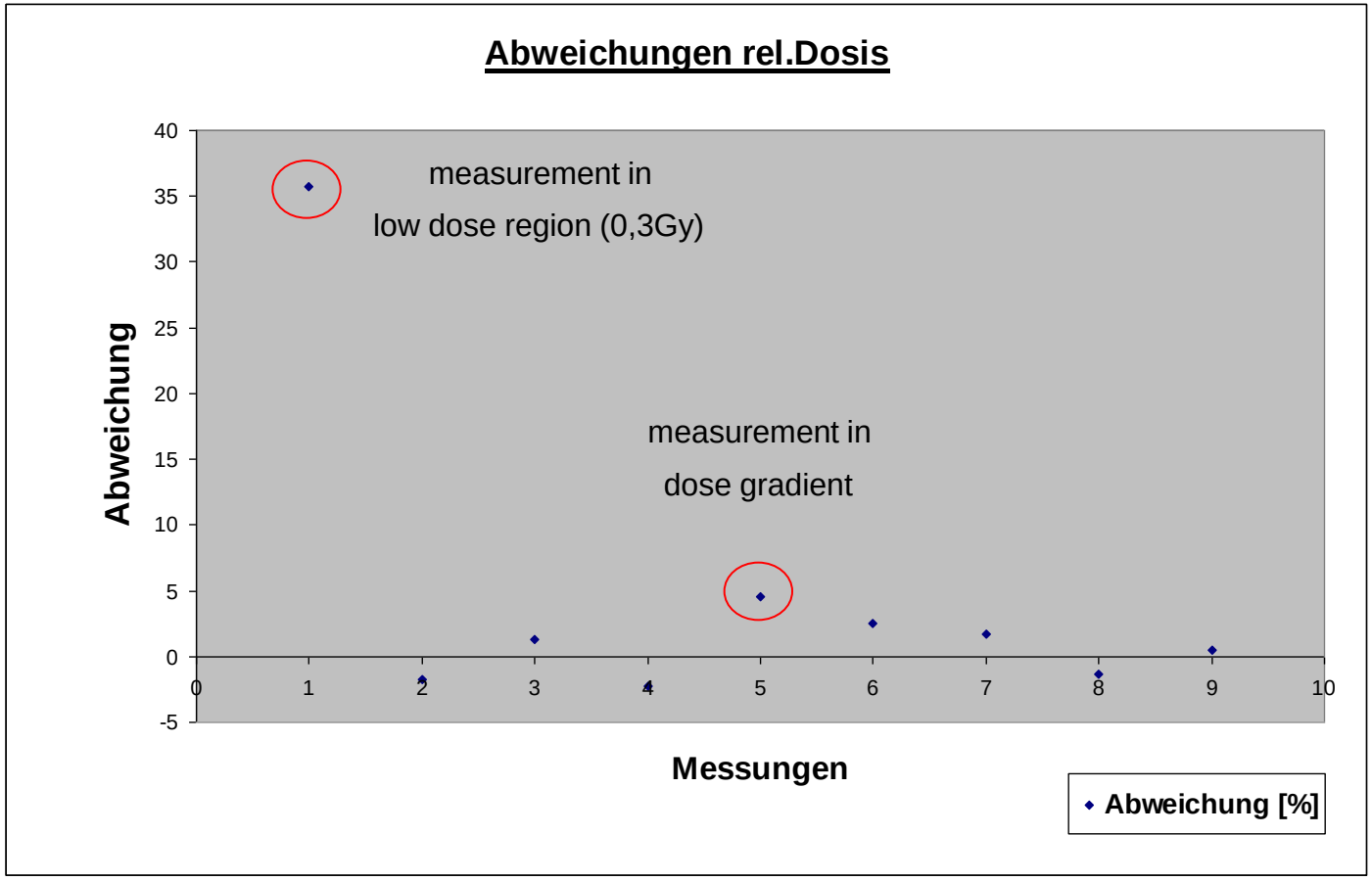
545MU 2,4Gy PTV / 2,9Gy Prostata
3min beam on time

Wolff et al., Strahlenther Onkol, submitted

In vivo dosimetry

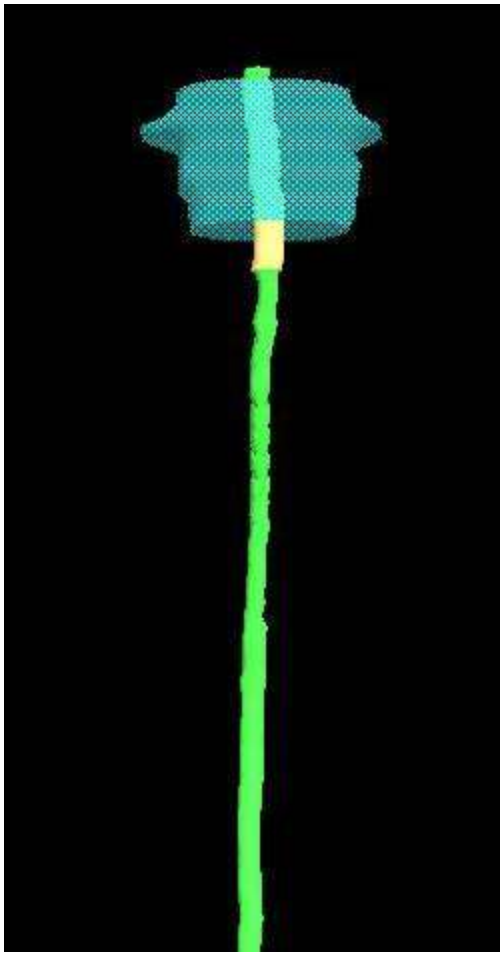


In vivo dosimetry



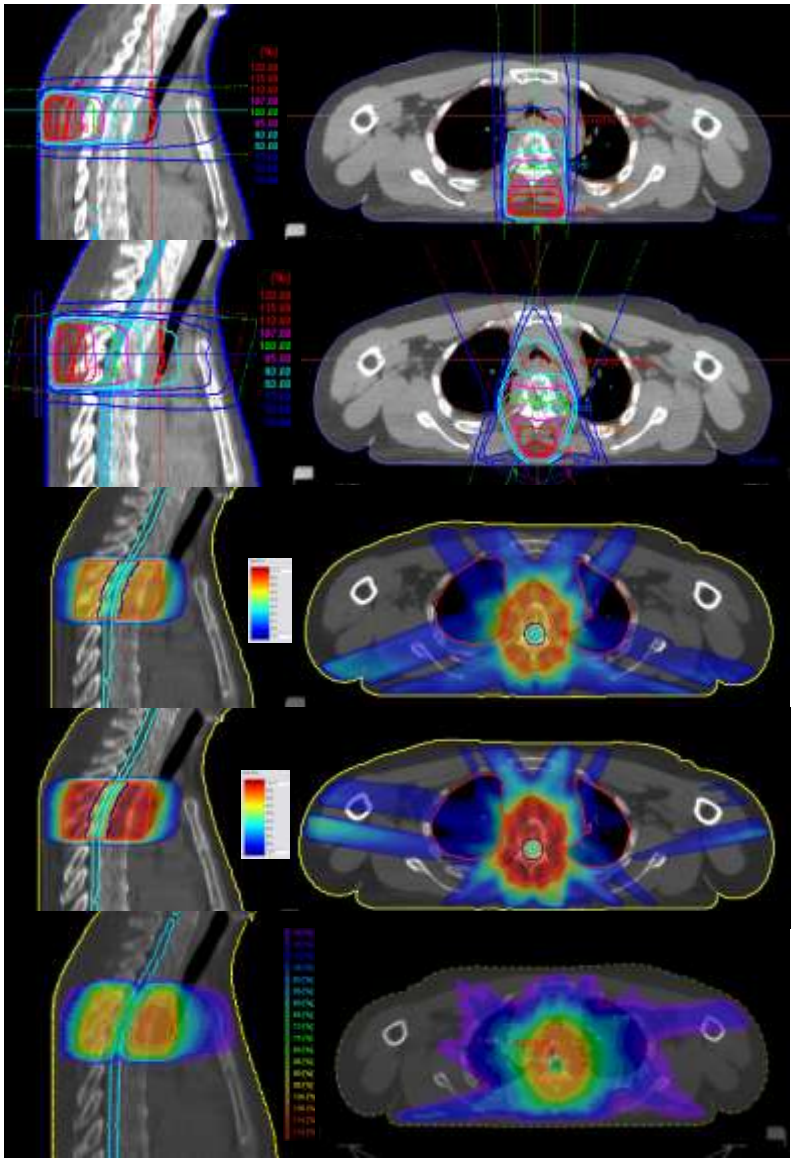
9 measurements in first patient in the high dose region:
All <2.5% (except 2) deviation from calculation

Paraspinal Cancer



VMAT for Reirradiation of Paraspinal Tumors

	3D-PA	3D-Wedge	IMRT 5B	IMRT 7B	VMAT
HI40	-	-	1.18±0.07	1.17±0.06	1.14±0.07
CI	-	-	1.74±0.32	1.85±0.21	1.96±0.36
MU	240±21	553±136	844±133	877 ±102	785±92
Time	25±2 sec	88±7 sec	348±72 sec	472±82 sec	289±69 sec
$C_{95\%PD}$	0% / 47.92±9.89%	0% / 55.33±1.93%	82.59±4.56%	81.22±4.37%	81.28±4.25%
SC_{PTV}	26.11±0.33Gy	25.98±0.06Gy	26.91±0.93Gy	25.67±1.55Gy	23.54±2.35Gy

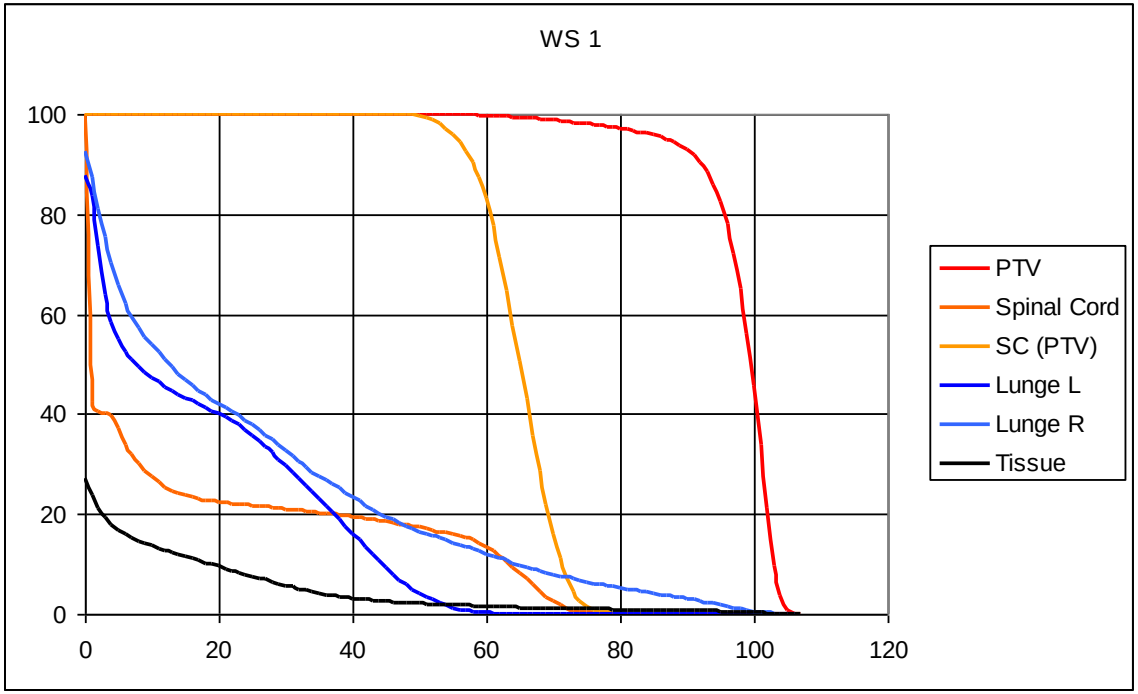


Stieler et al. submitted

Stieler et al., submitted

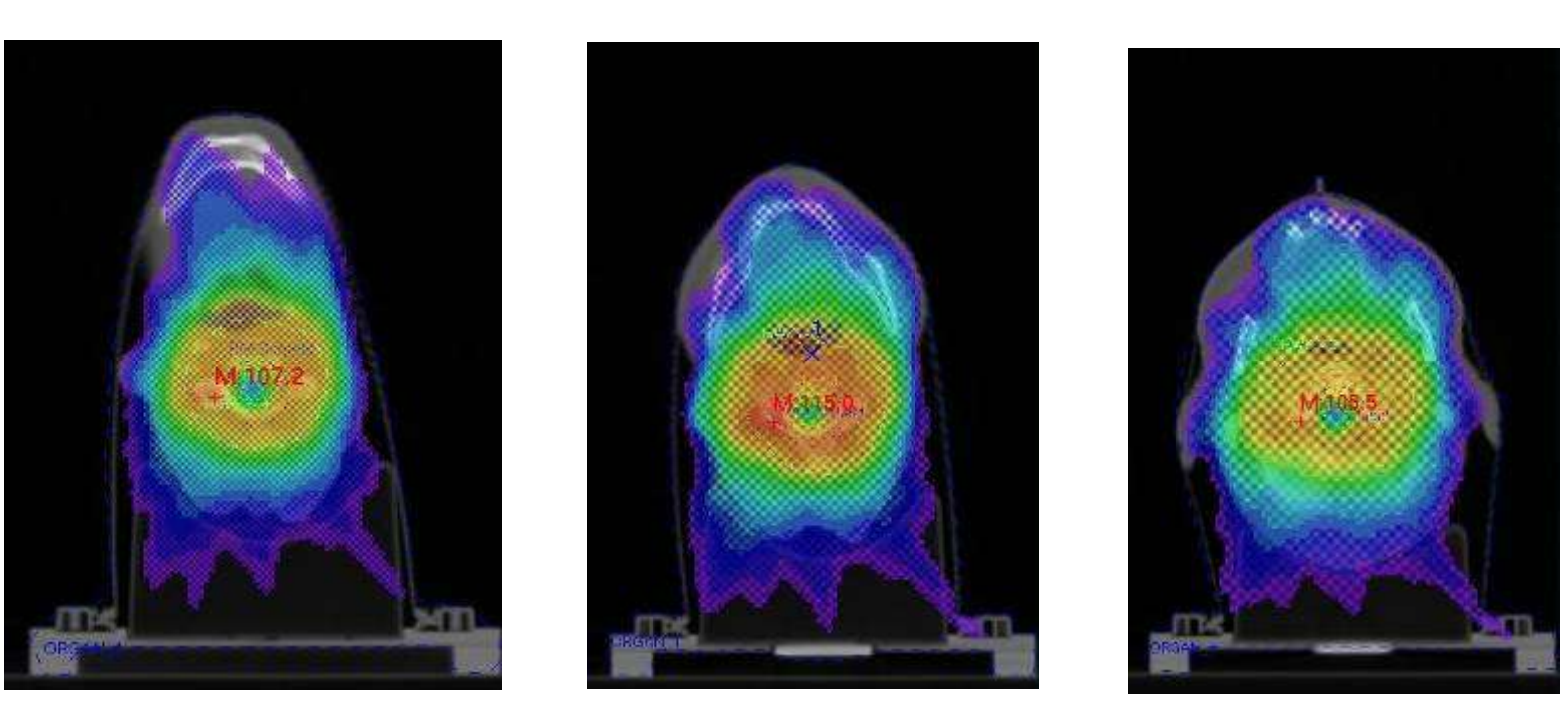
Research: Spinal cord with 2 rotations

Monitor Units	823
Median Dose Spinal Cord	3.2 Gy
Maximal Dose Spinal Cord	30.8 Gy
Median Dose Spinal Cord (PTV)	26 Gy
Maximal Dose Spinal Cord (PTV)	31.6 Gy



Stieler et al., submitted

Clinical: Spinal cord with 2 rotations



- First clinical spinal cord patient with VMAT
- Delivery time: 3 minutes 10 seconds
- MU: 597 (2Gy fraction dose)
- QA with EDR2 films / ion chamber:
    - Absolute deviation: +0.19%

Monaco VMAT

IMRT TPS Monaco

Options:

- XVMC calculation for real dose distribution (dose-to-medium)
  - Voxel based
  - Gantry head is „black box“
  - New clinical prescriptions to OAR have to be implemented

- Biological Optimization
  - Is model-based (development through evidence-based trends on cell responses to radiation)
  - Use of Equivalent Uniform Dose (EUD)
  - Multiple cost function
    - e.g. for serial/parallel organs

- Powerful Sequencer
  - Lower number of Segments and MU

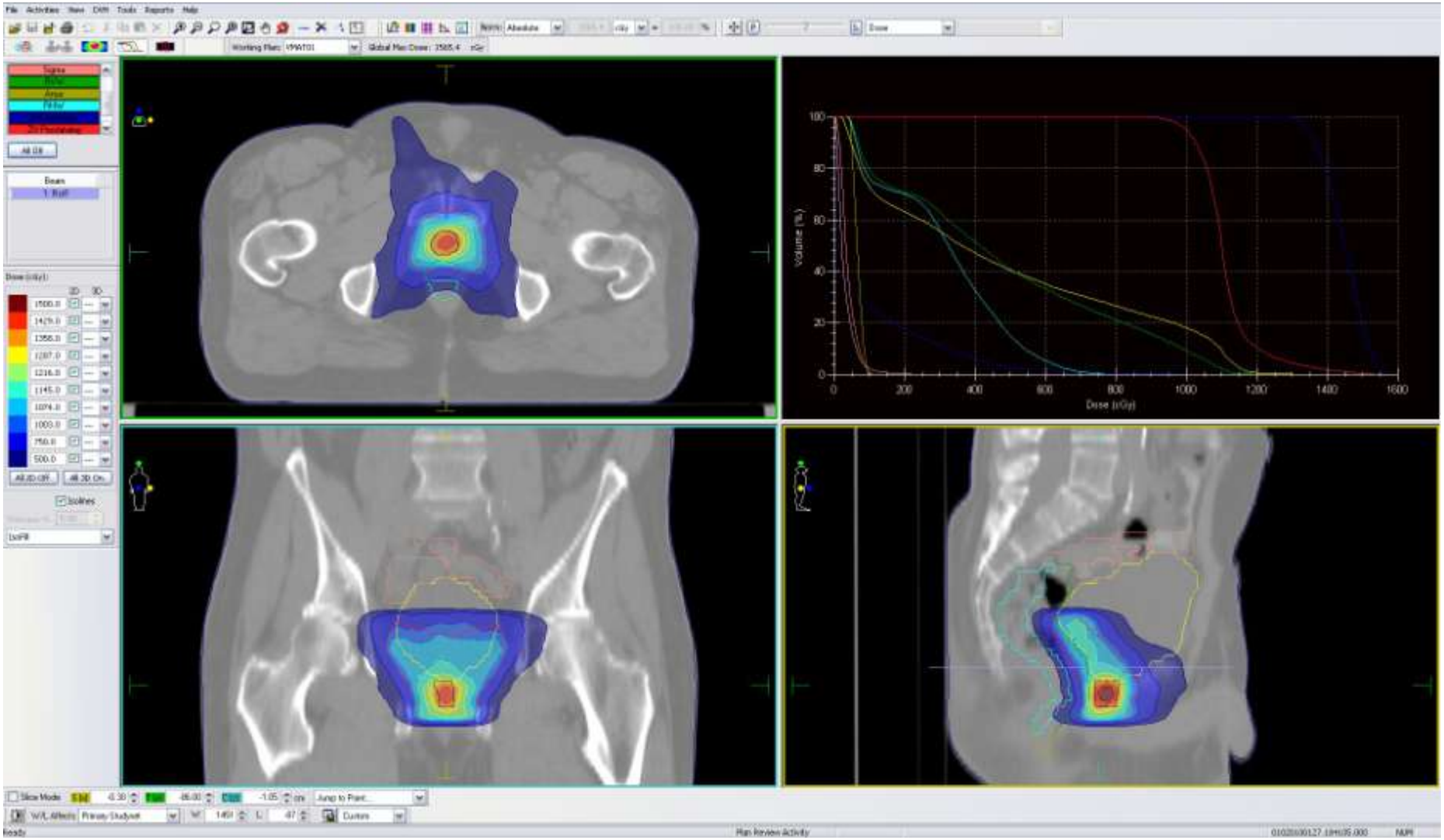
	Type	Applied To	Biological Parameter	Isoconstraint	Reference Dose	Description
Poisson Cell Kill	Objective	Target	Cell Sensitivity	EUD / Rx Dose	Prescription (Gy)	Biological Cost Function
Serial Complication Model	Constraint or Secondary Objective	OAR	Power Law Exponent (k)		EUD (Gy)	Biological Cost Function
Parallel Complication Model	Constraint or Secondary Objective	OAR	Power Law Exponent (k)	Mean Organ Damage (%)	Reference Dose	Biological Equivalent of Overdose Volume Constraint
Quadratic Overdose	Constraint	Target / OAR		RMS Dose Excess (Gy)	Maximum Dose (Gy)	Physical Constraint
Quadratic Underdosage	Constraint	Target		RMS Dose Deficit (Gy)	Maximum Dose (Gy)	Physical Constraint
Maximum Dose	Constraint	Target / OAR			Maximum Dose (Gy)	Physical Constraint
Overdose Volume Constraint (DVH)	Constraint or Secondary Objective	OAR		% Volume > Threshold Dose (%)	Threshold Dose (Gy)	Physical DVH Constraint for OAR
Underdose Volume Constraint (DVH)	Constraint	Target		% Volume < Threshold Dose (%)	Threshold Dose (Gy)	Physical DVH Constraint for Target

Monaco VMAT

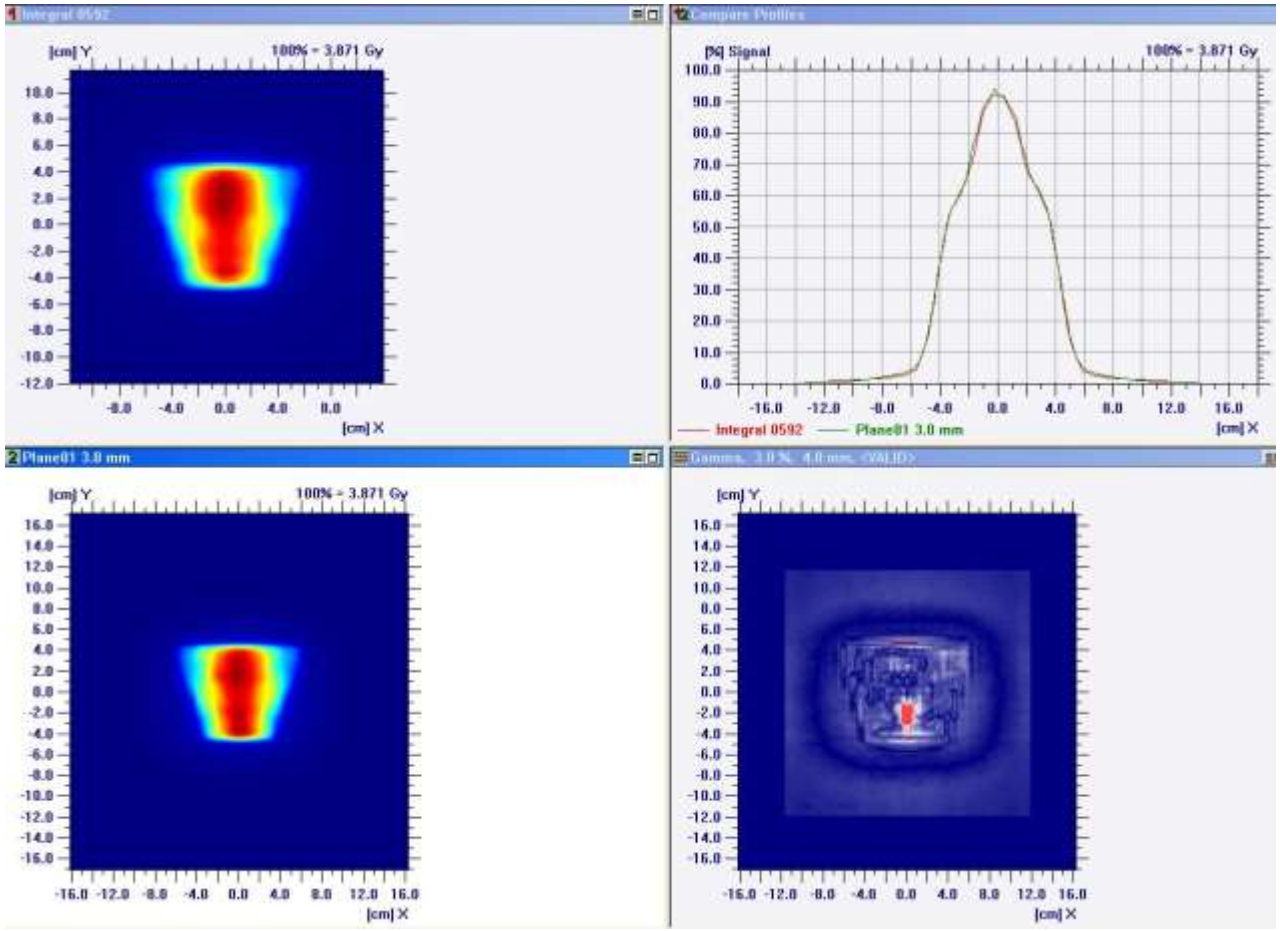
First treated Monaco VMAT patient in Mannheim

VMAT Prostate

- PTV 11Gy with integrated boost up to 15Gy
  - (after previous conformal RT 60Gy without integrated boost → cummulative dose = 70/75Gy)
- Rectum posterior: 50% volume received less than 50% PD
- Single rotation
- Treatment time: 4 minutes 20 seconds
  - Estimated treatment time with Integrity: ~3 minutes
  - Integrity and MLCi 2: ~2.5 minutes
- 724 monitor units


Volume (%)
Dose (cGy)
0
20
40
60
80
100
200
400
600
800
1000
1200
1400
1600

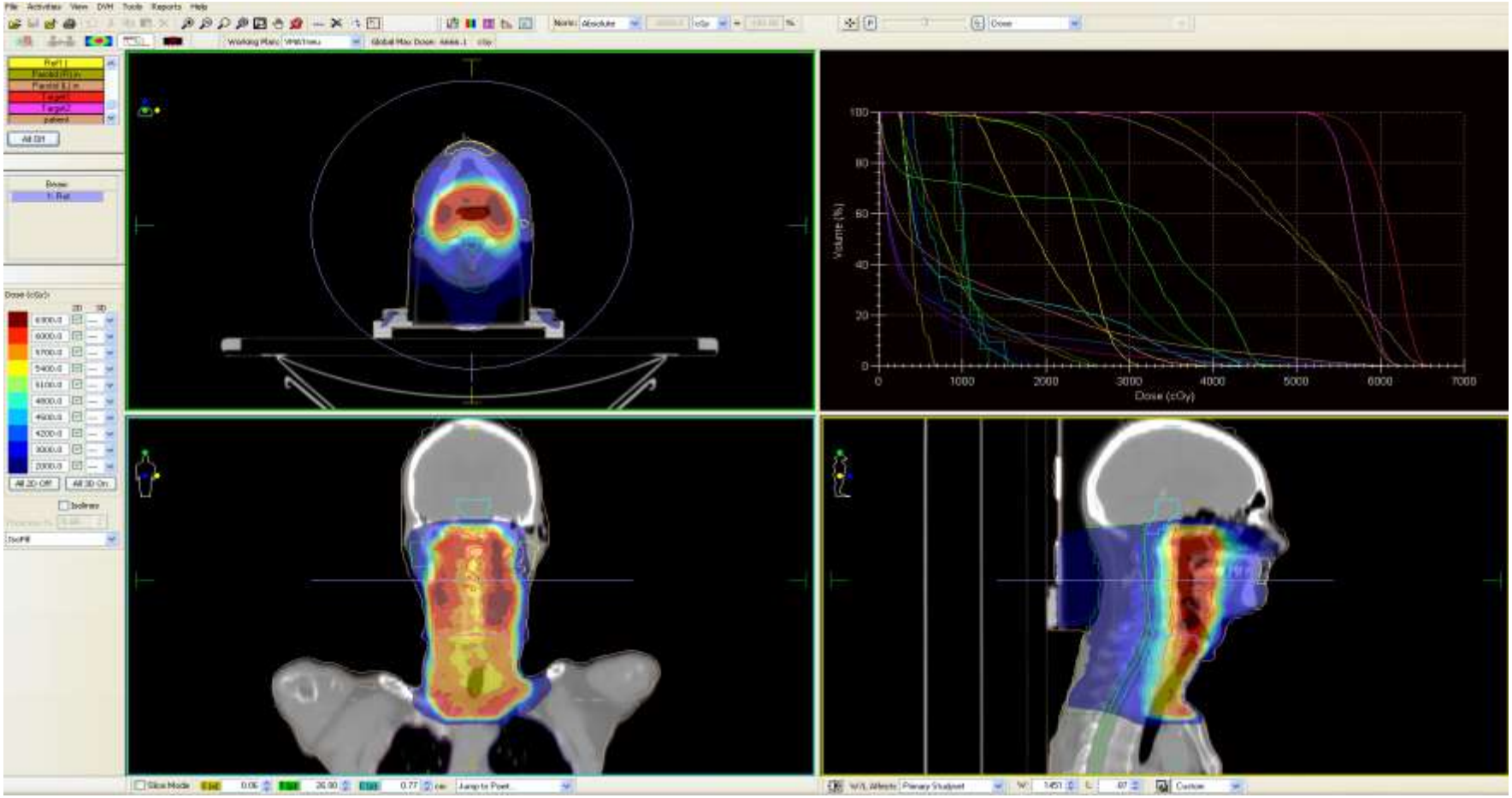
QA with IBA Matrixx and gantry holder

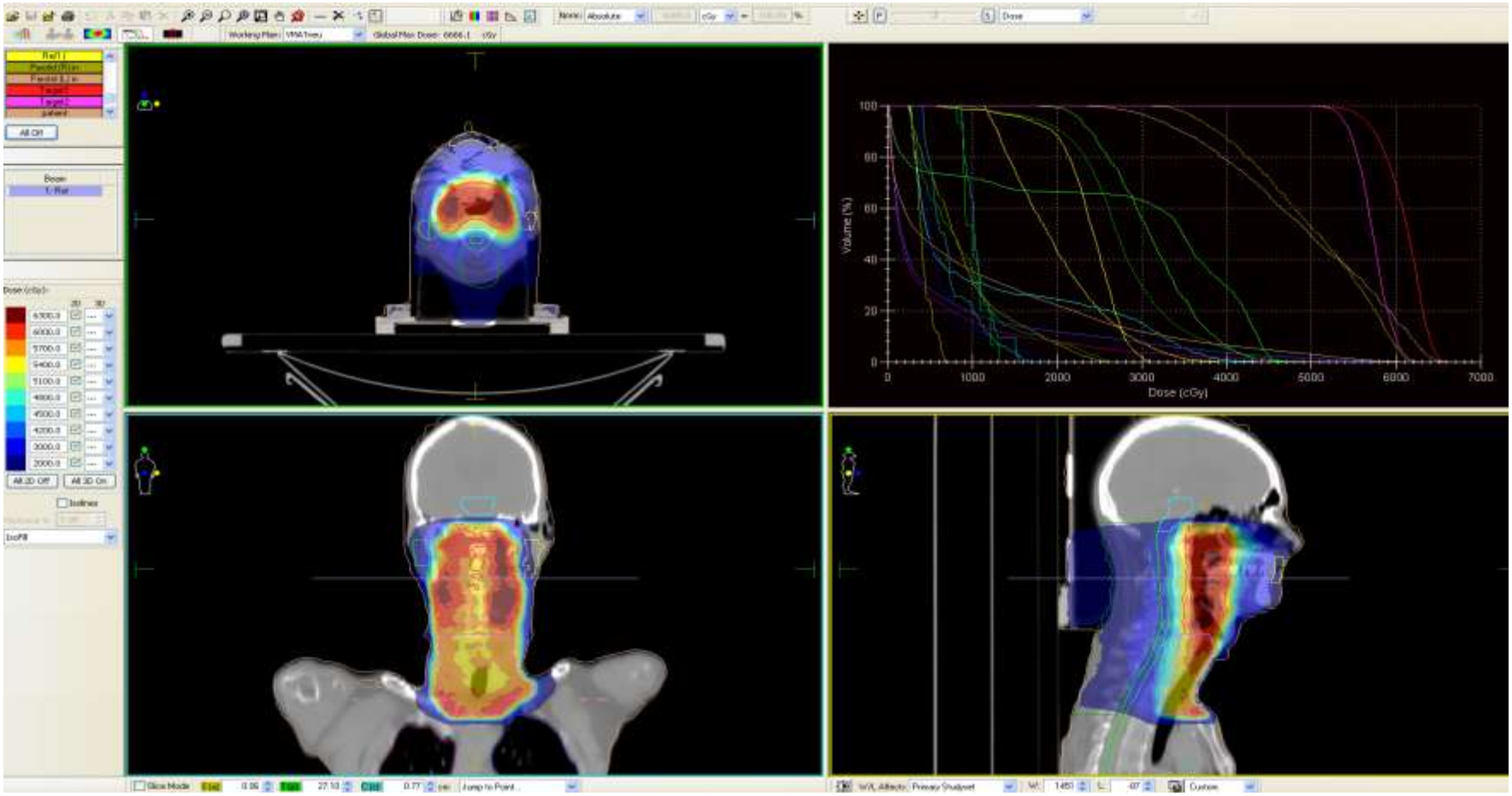


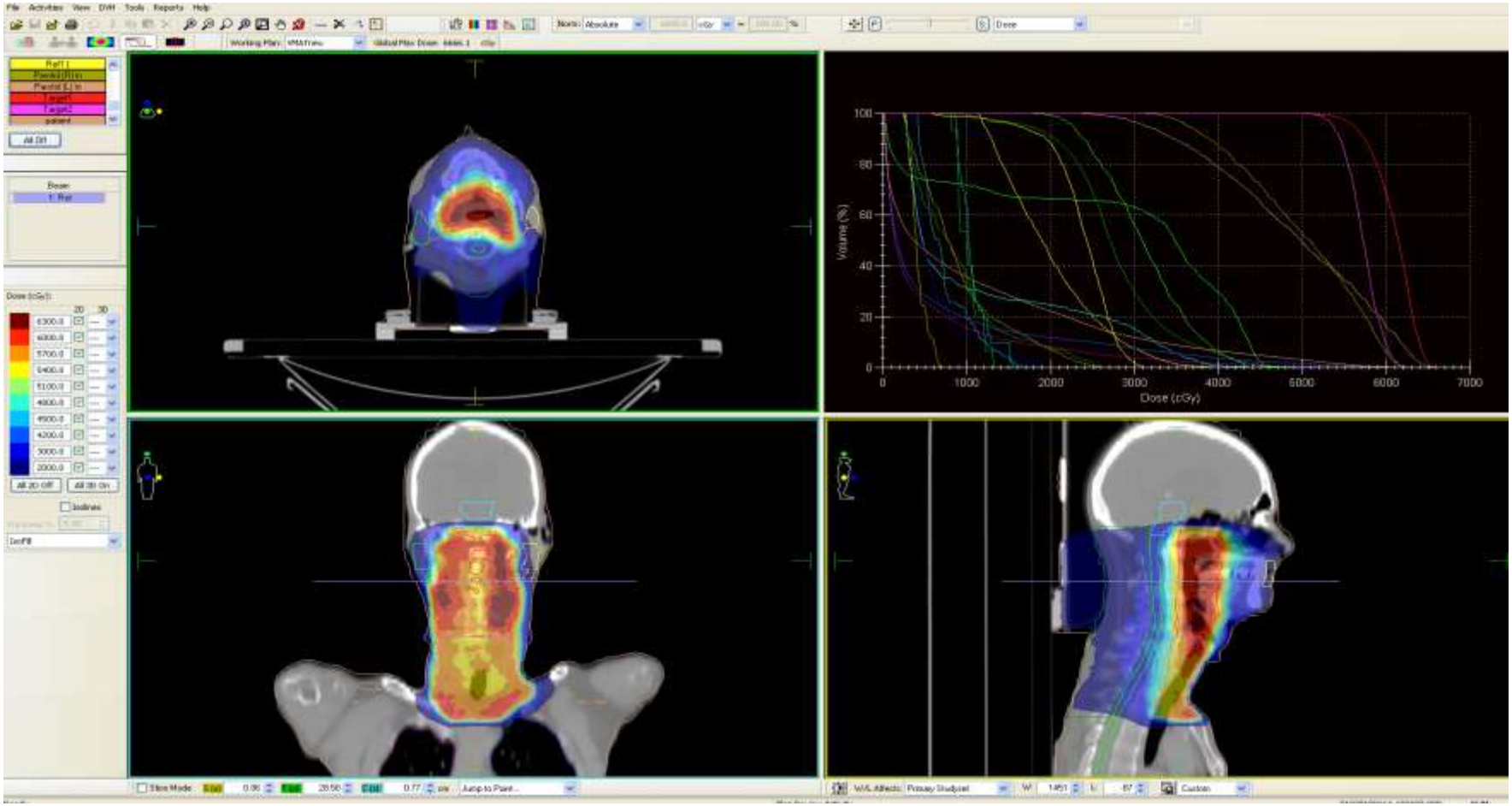
Gamma 3%-4mm:
99.4% pass

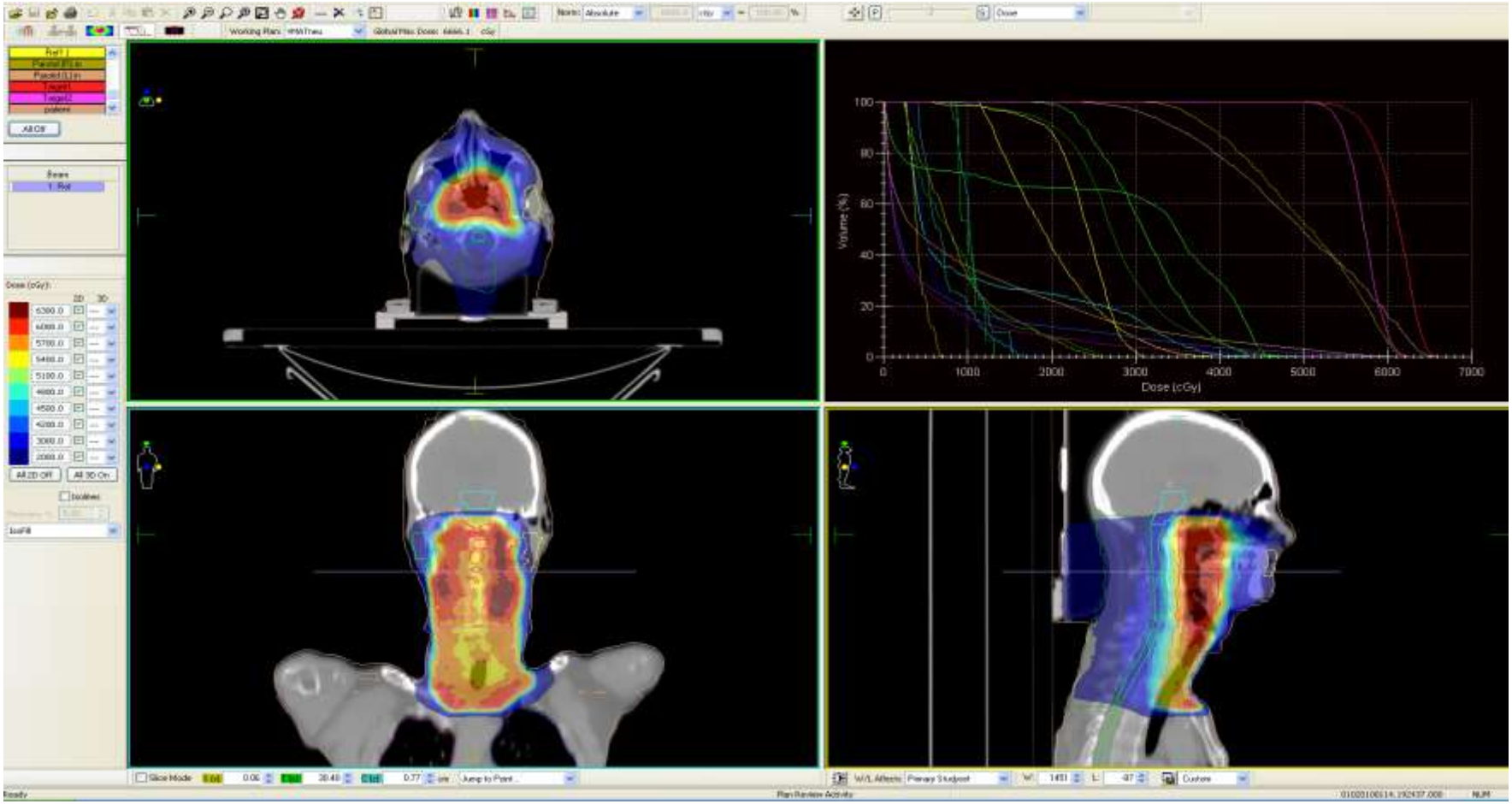

V
M
A
T
M
O
N
A
C
O
29. Januar 2010
MONACO

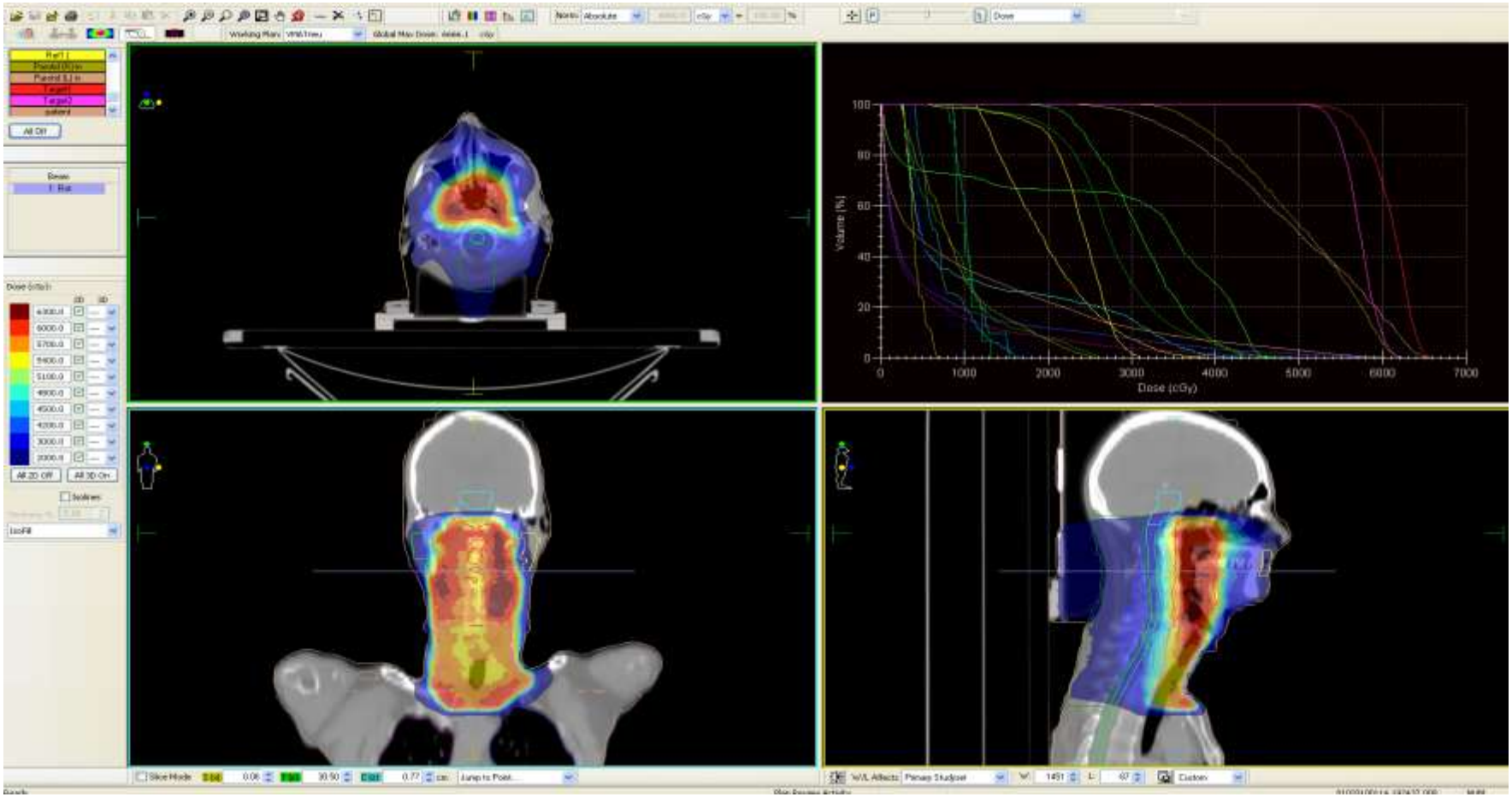
H&N

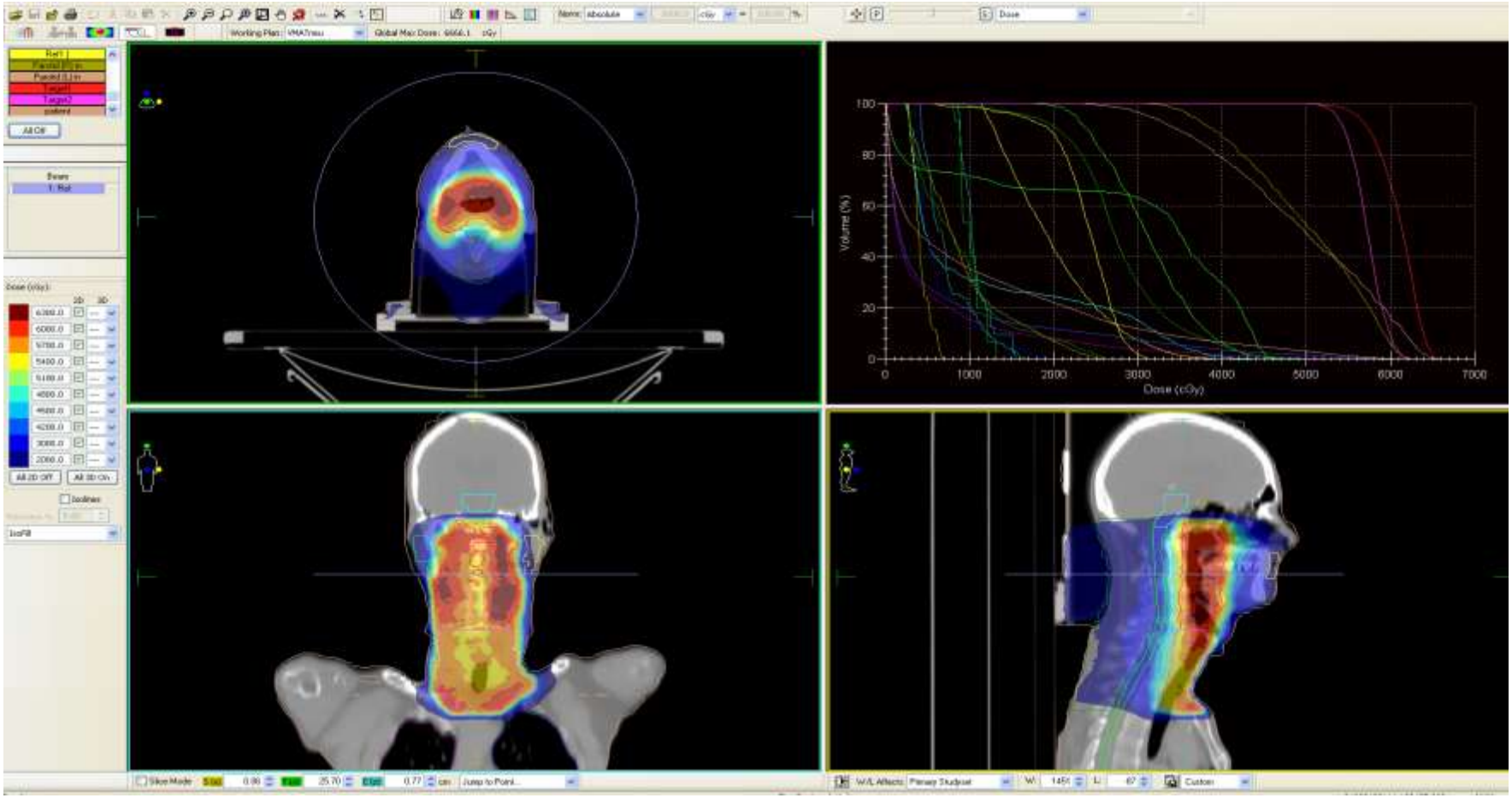

Volume (%)
Dose (cGy)
0
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
100

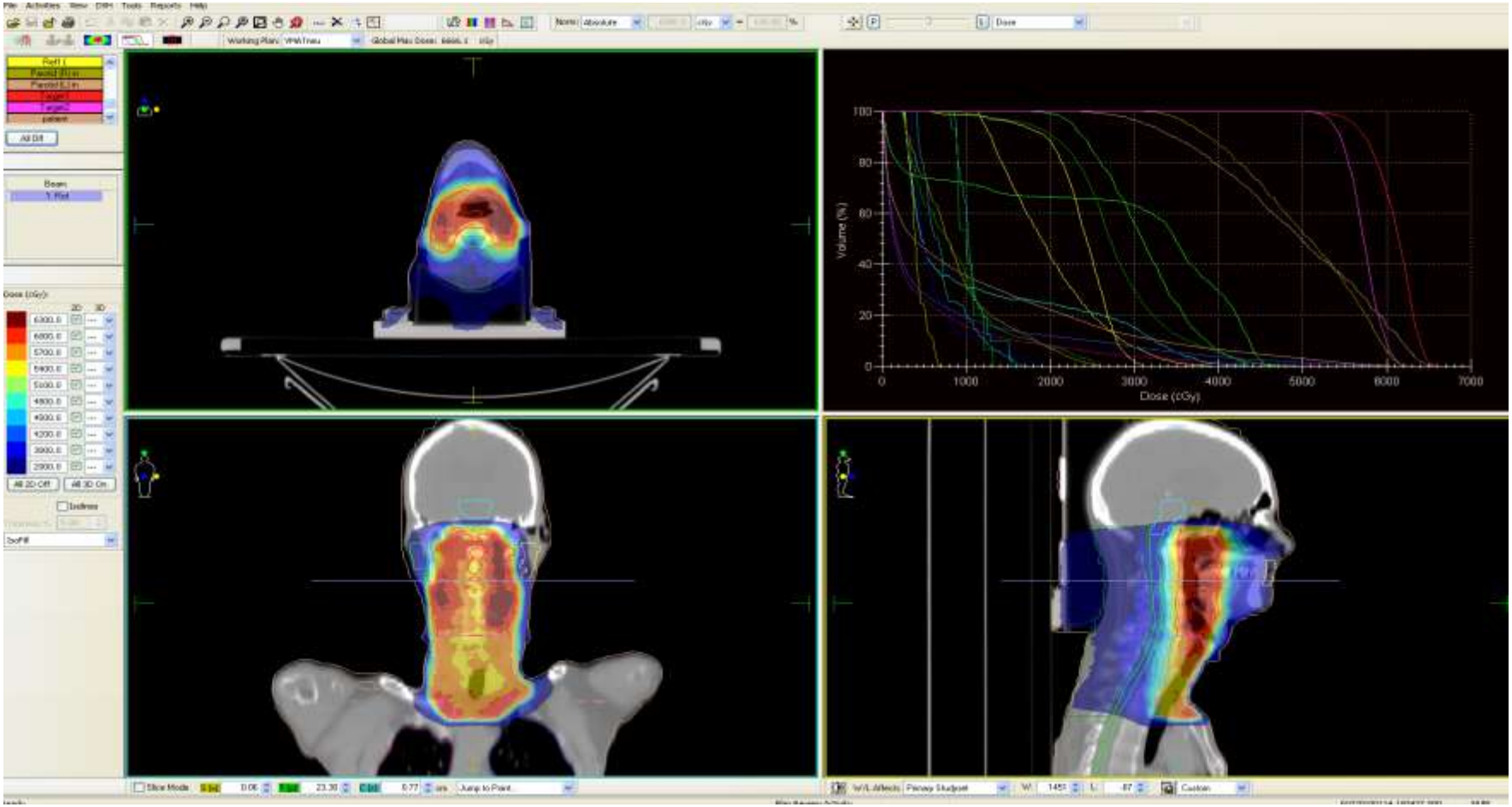

All Off
All 3D Off
All 3D On
Volume (%)
Dose (cGy)
0
20
40
60
80
100
1000
2000
3000
4000
5000
6000
7000

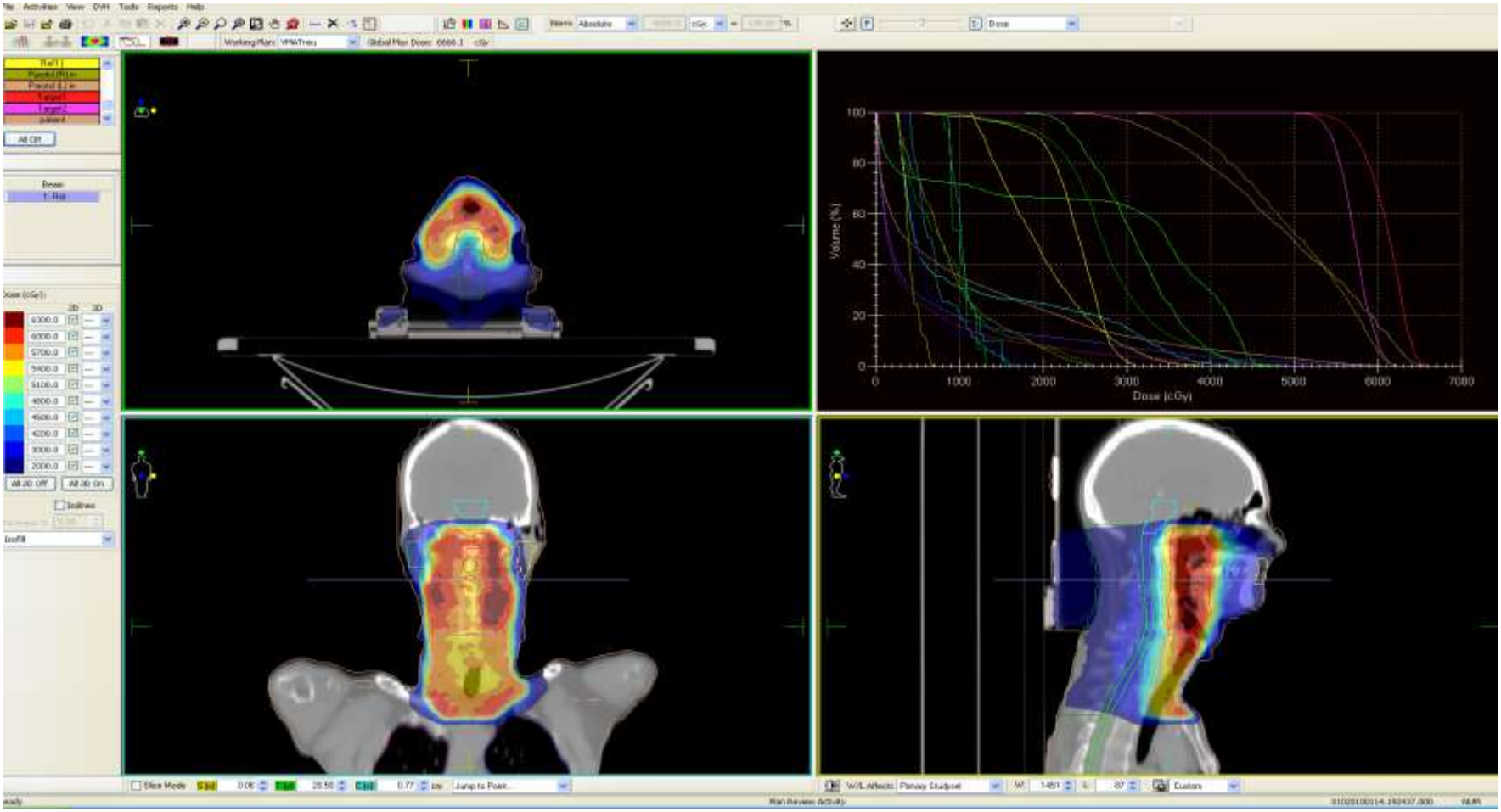

100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

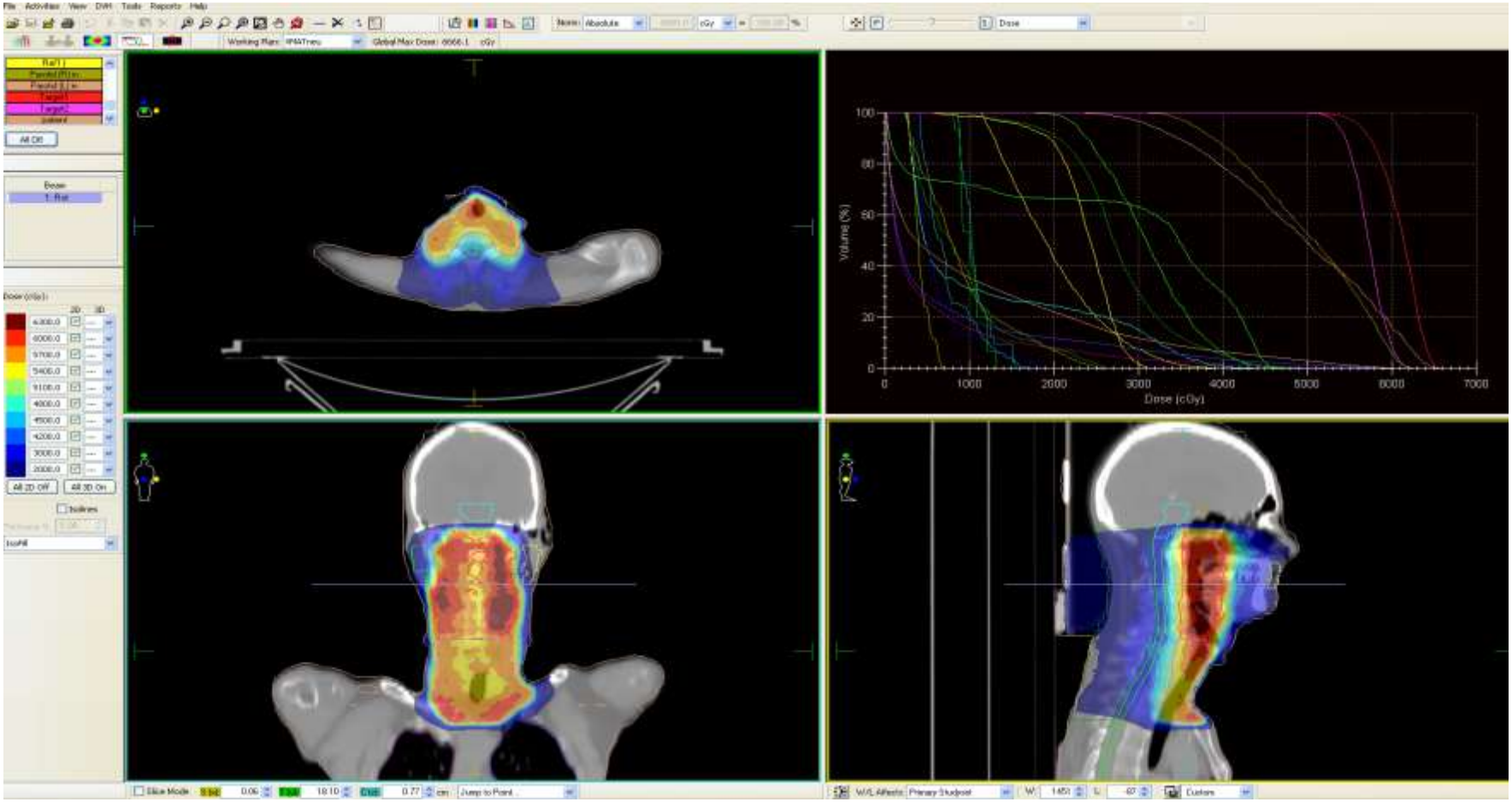

100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

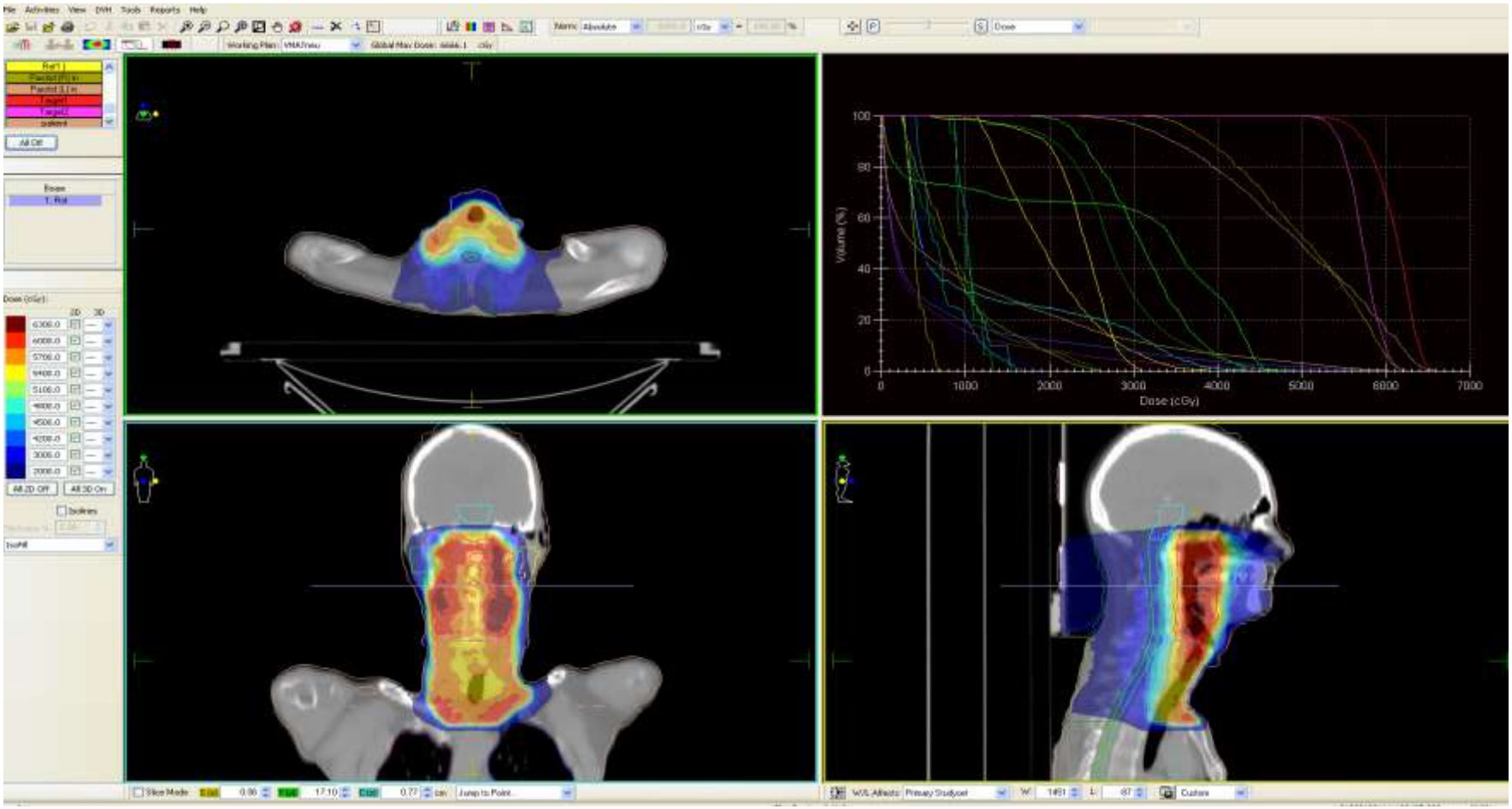

100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

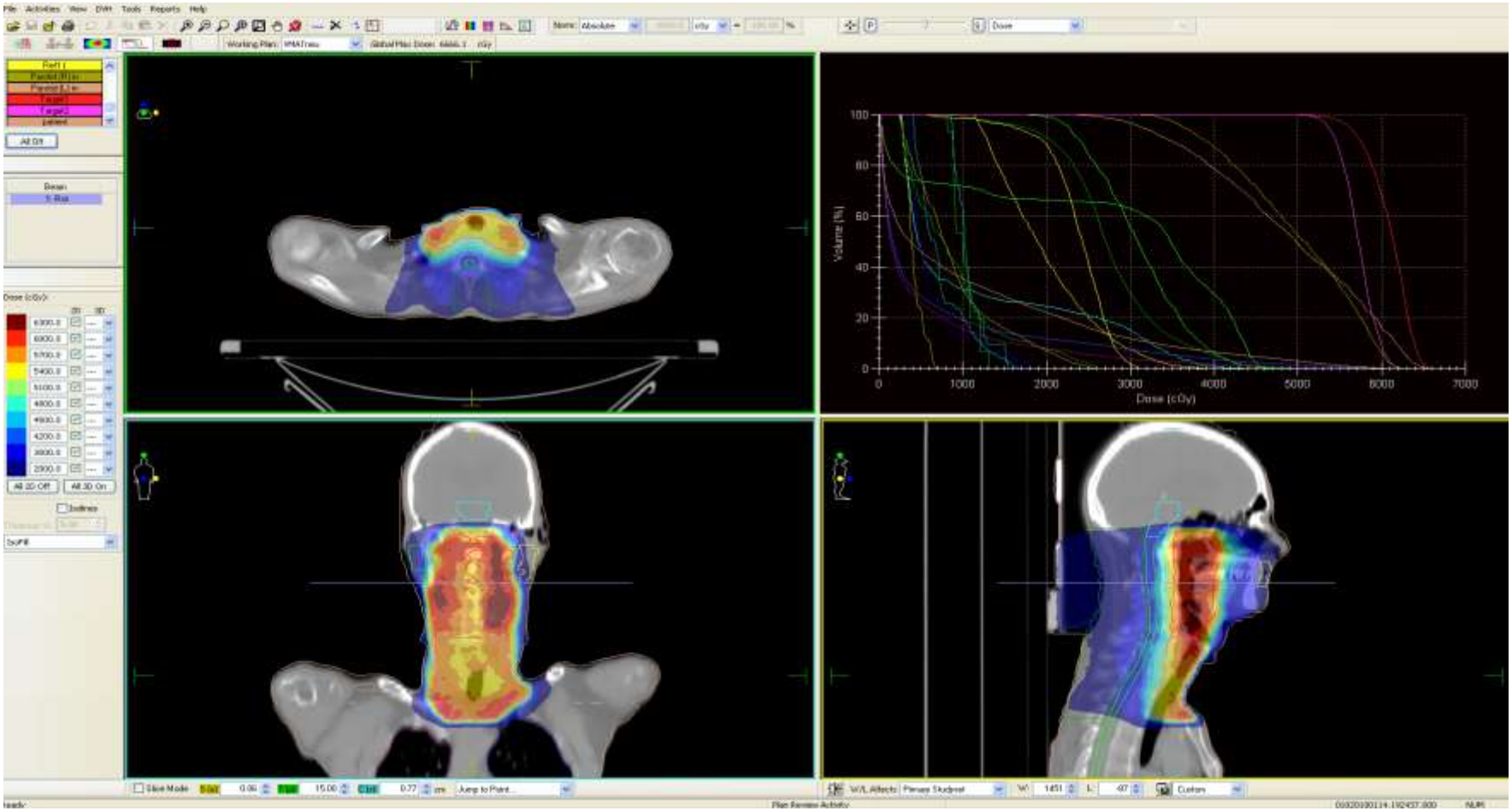

100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

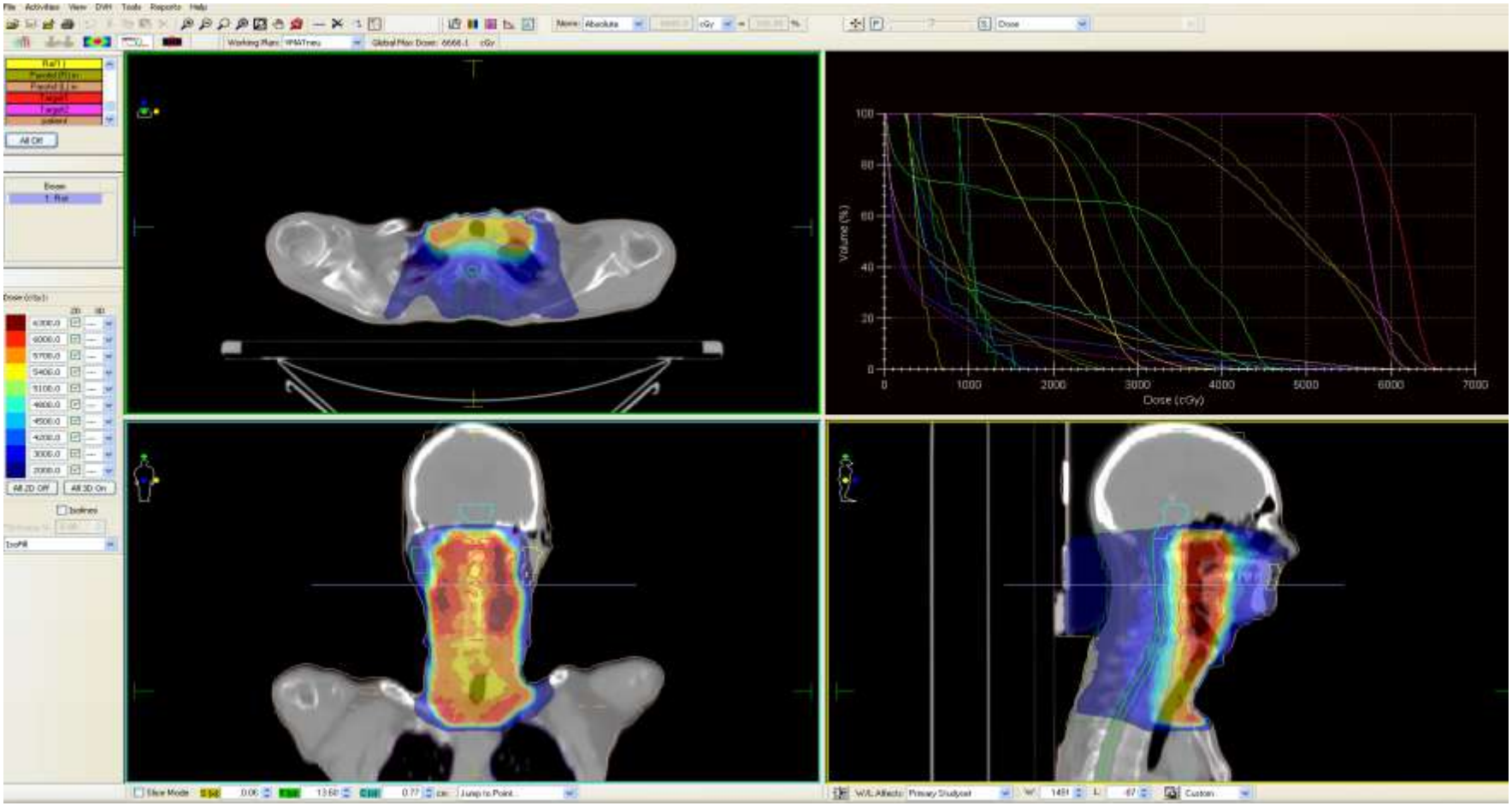

Volume (%)
Dose (cGy)
0
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
100


Volume (%)
Dose (cGy)
0
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
100

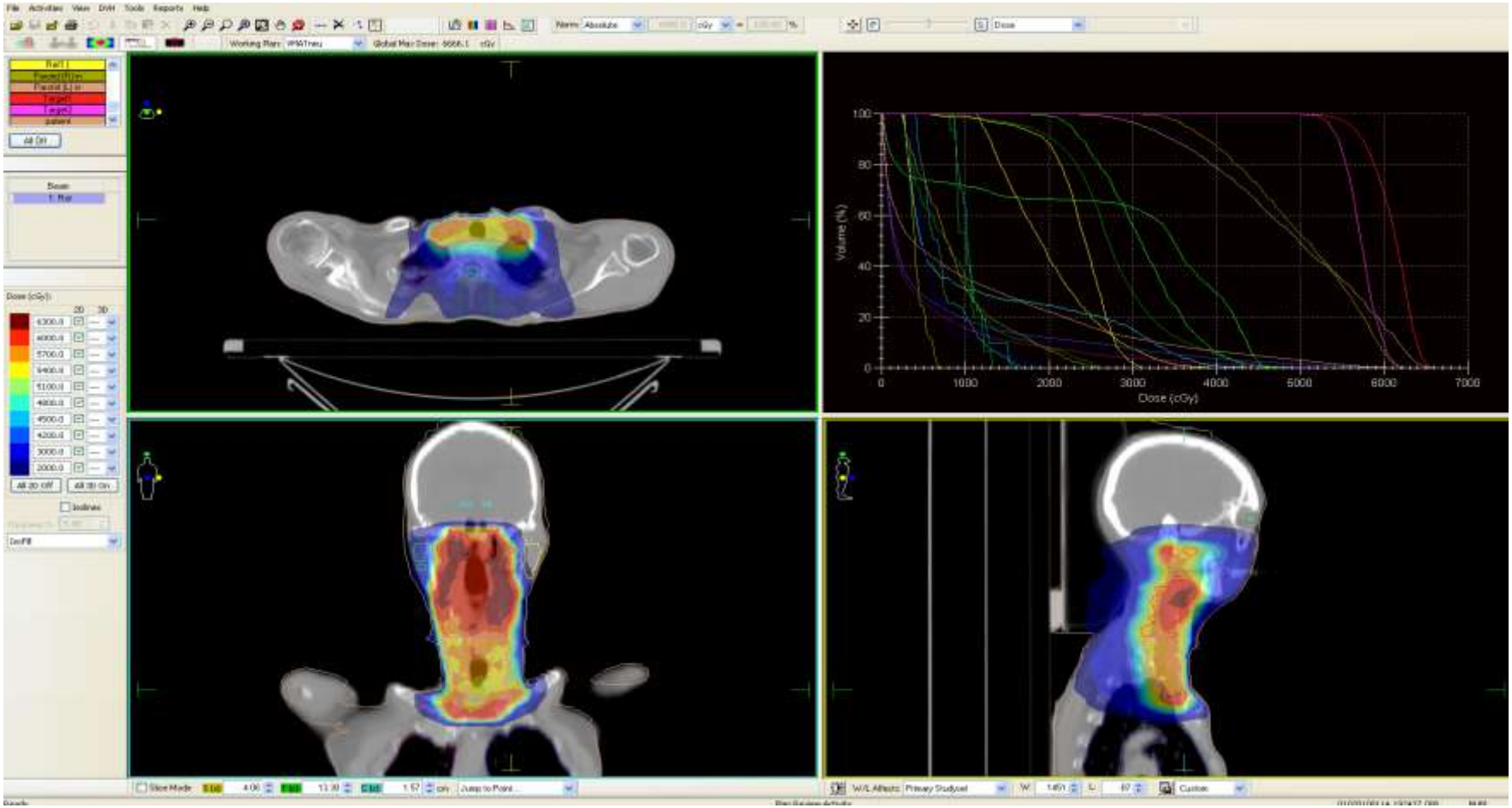

Volume (%)
Dose (cGy)
0
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
100

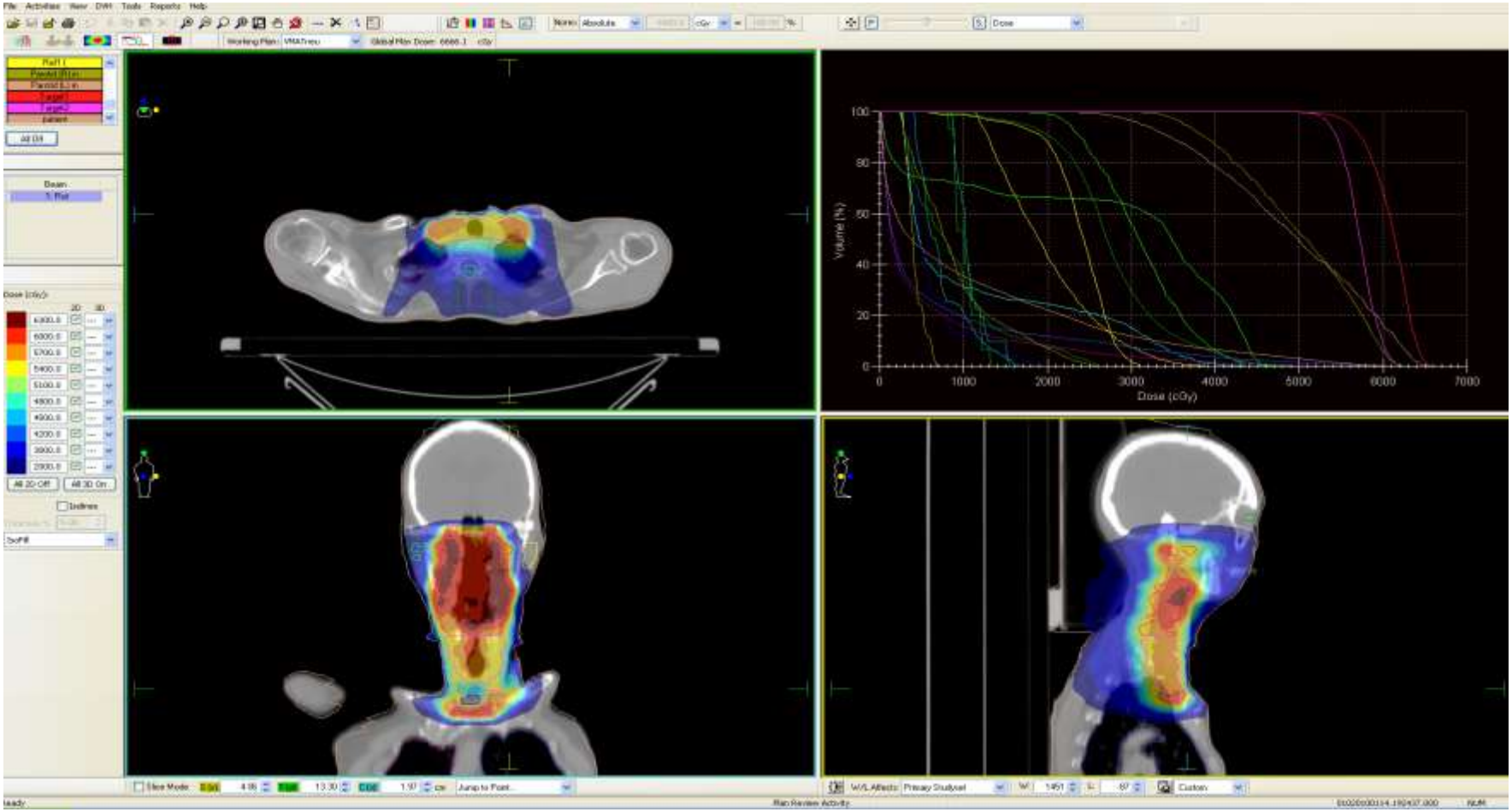

Volume (%)
Dose (cGy)
0
20
40
60
80
100
1000
2000
3000
4000
5000
6000
7000

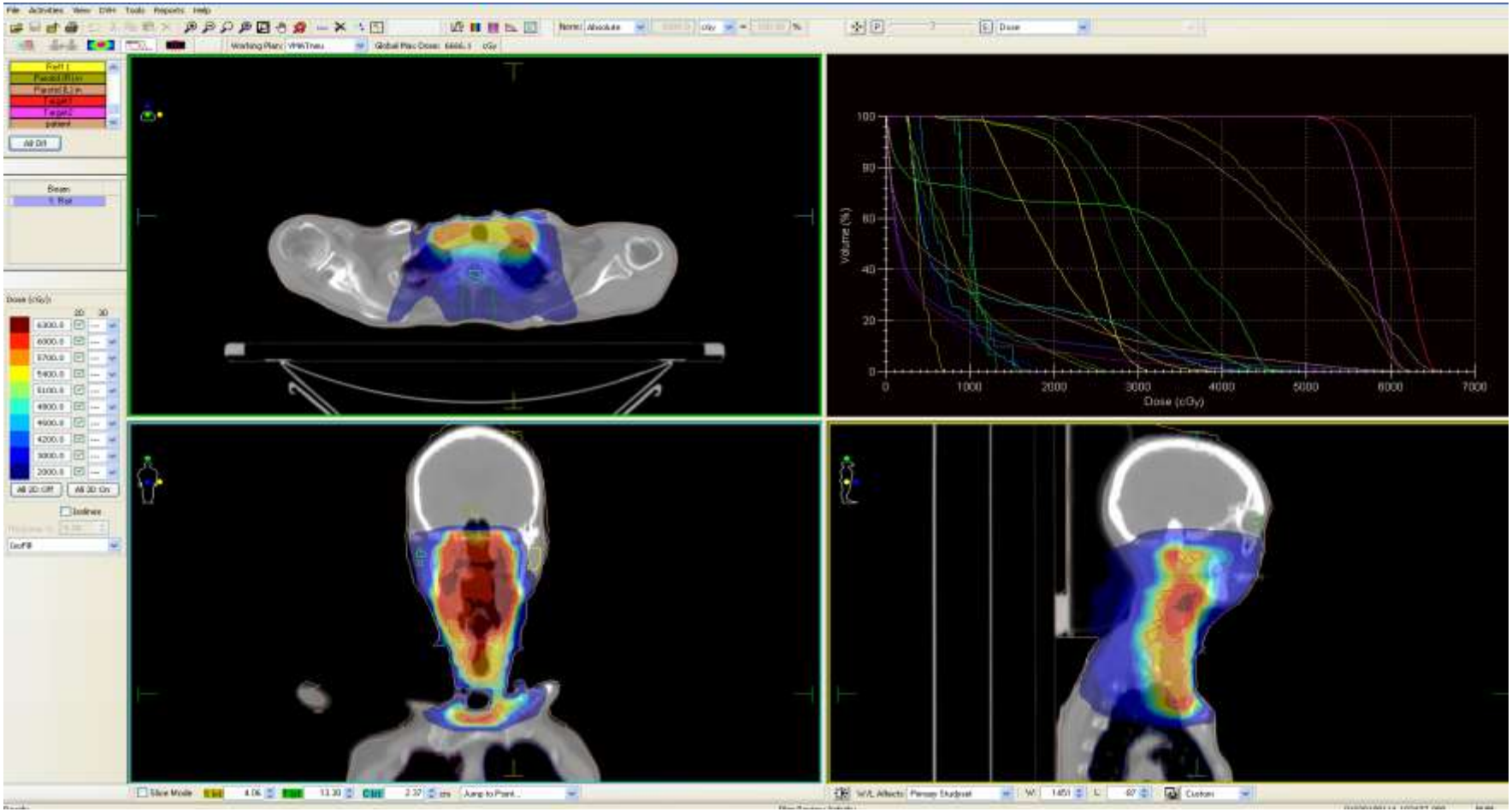

100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

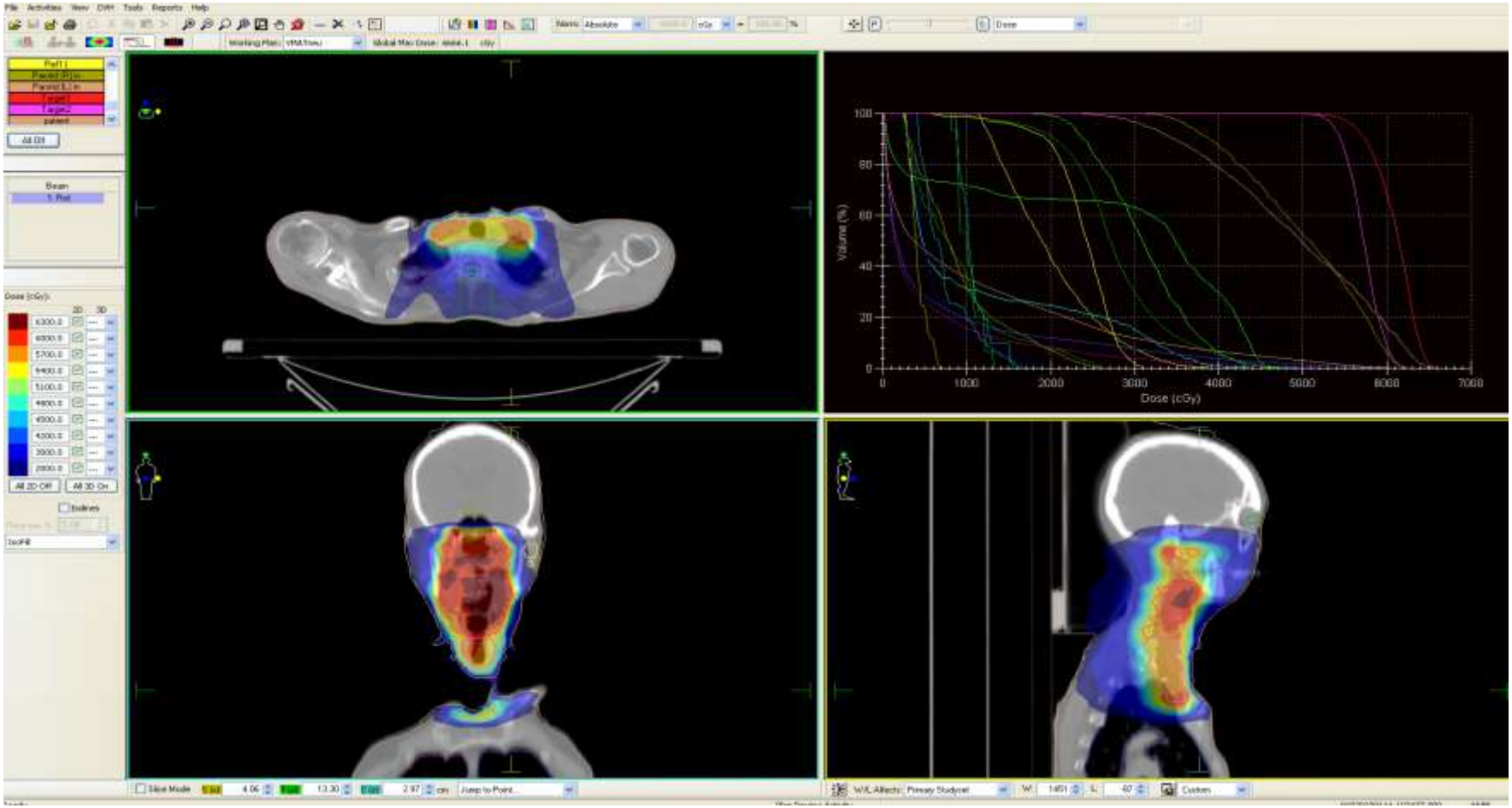

100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

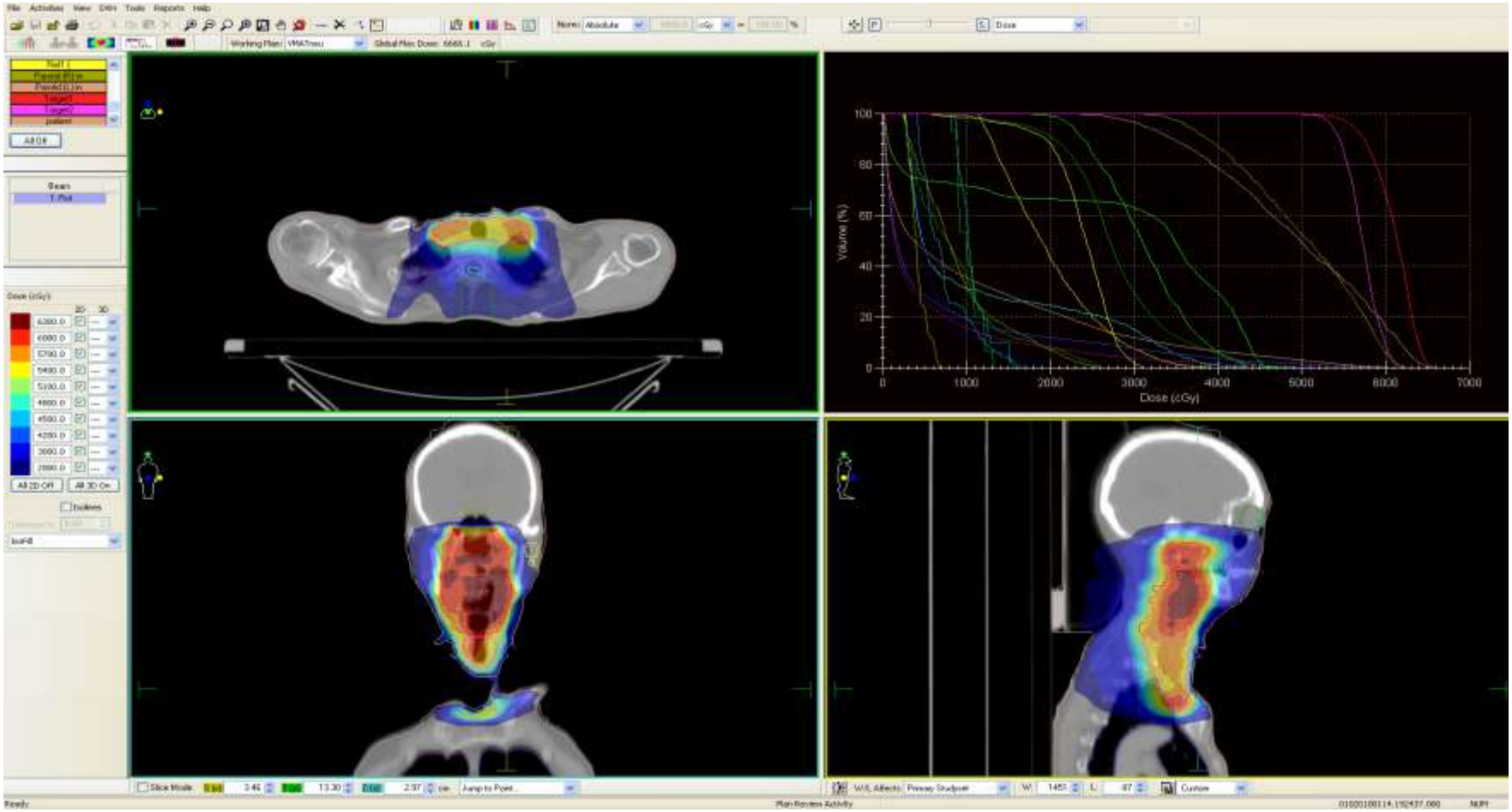

Volume (%)
Dose (cGy)
0
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
100

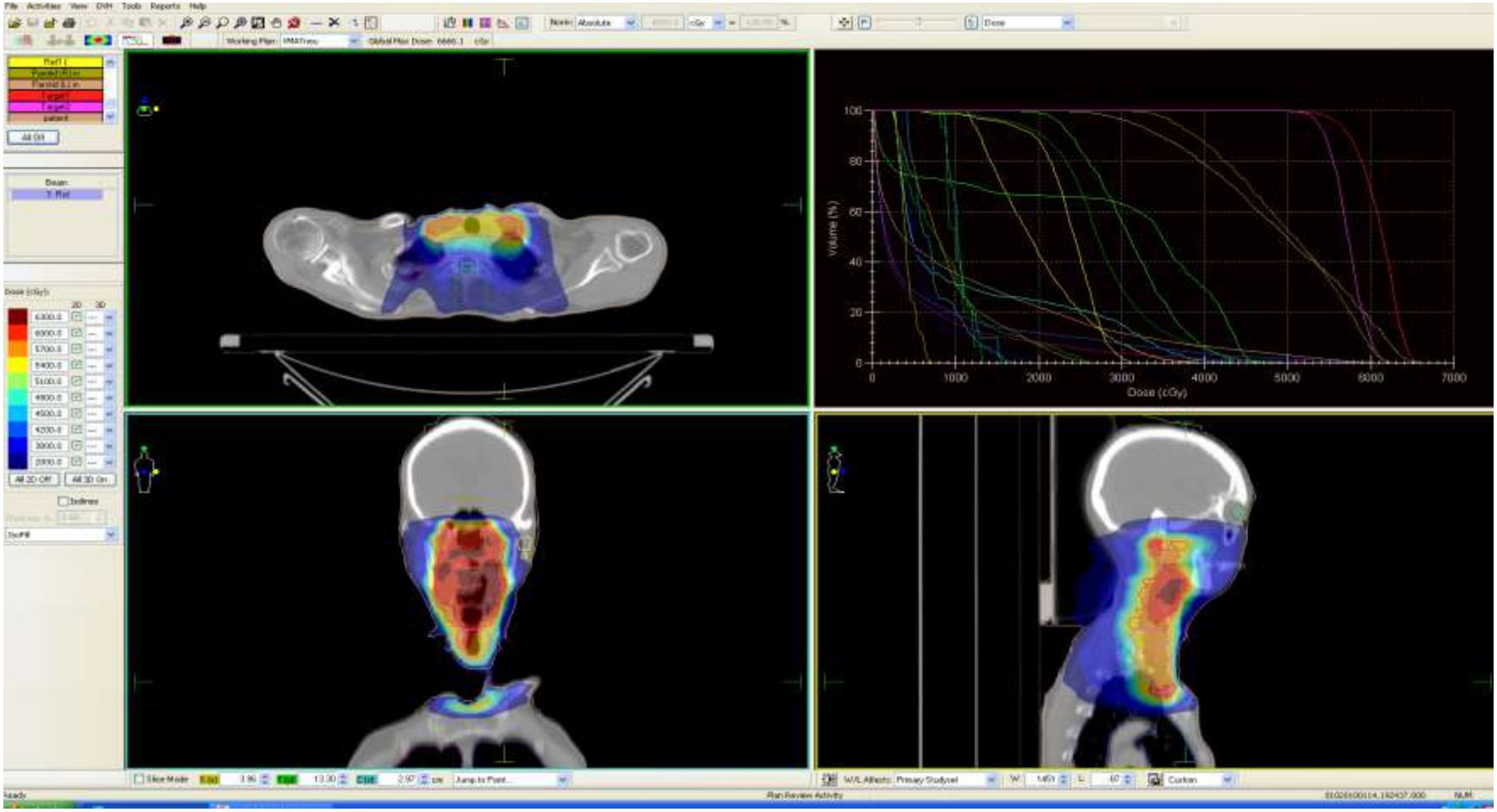

100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

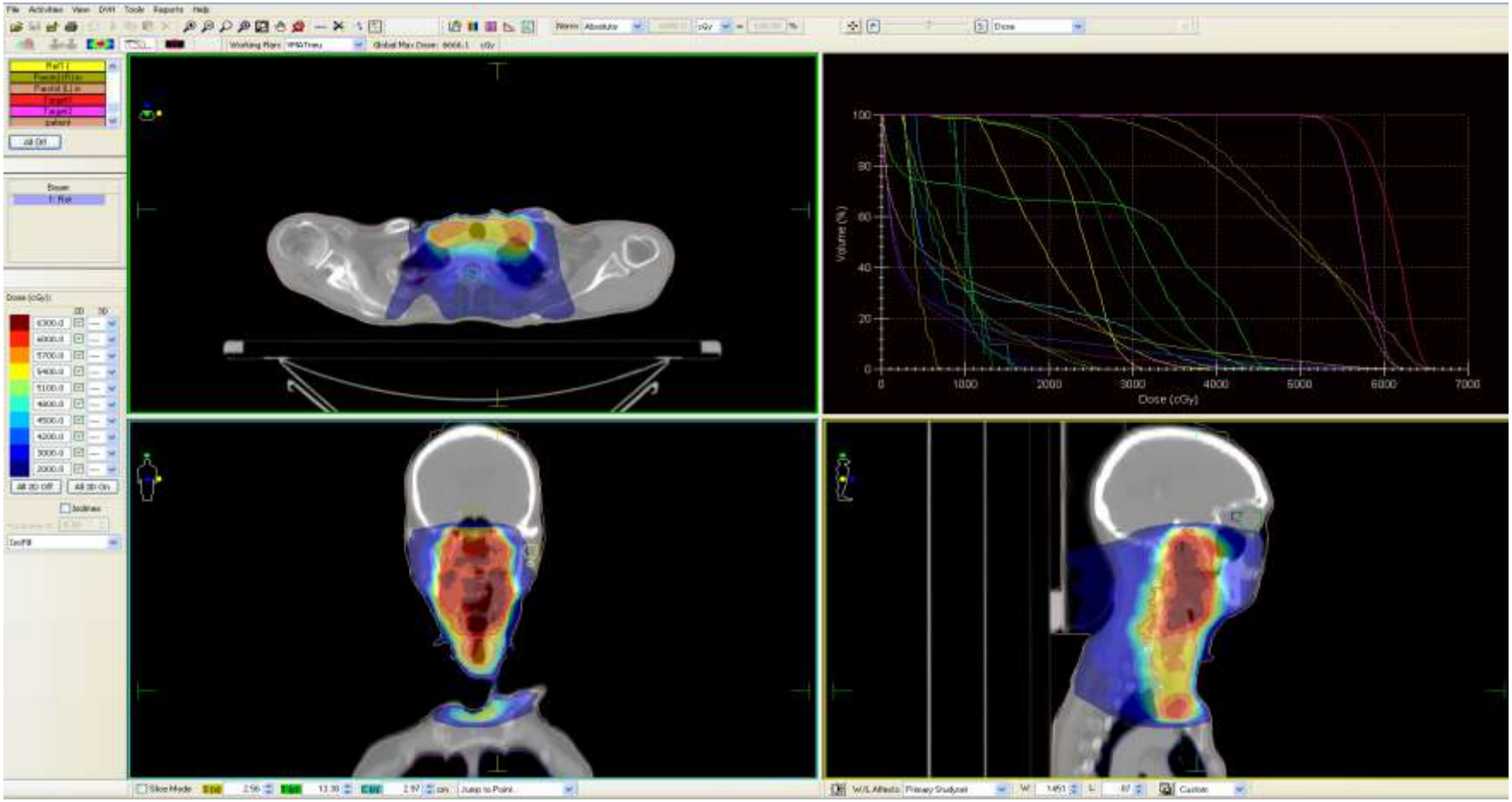

Volume (%)
Dose (cGy)
0
20
40
60
80
100
1000
2000
3000
4000
5000
6000
7000

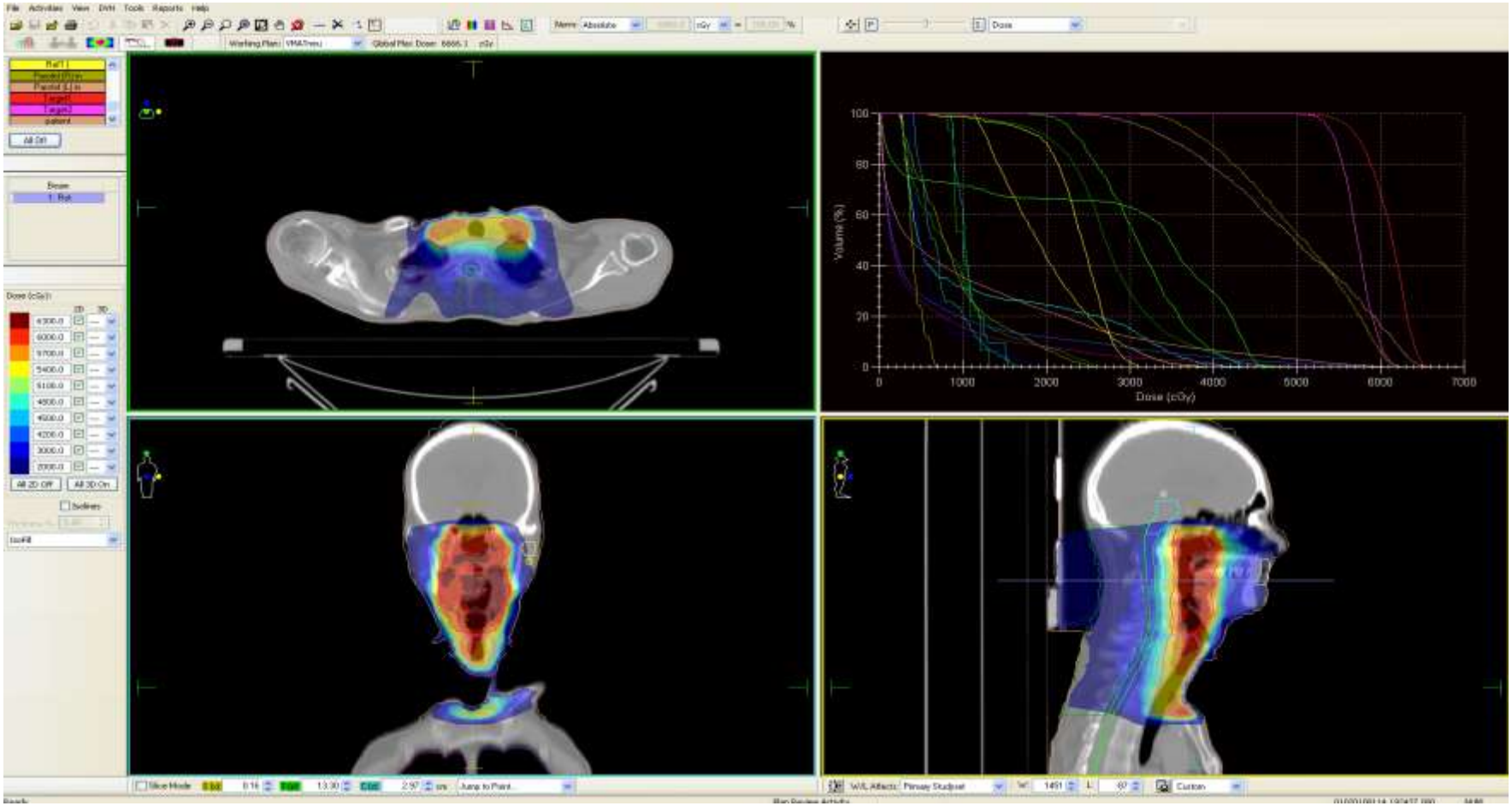

100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

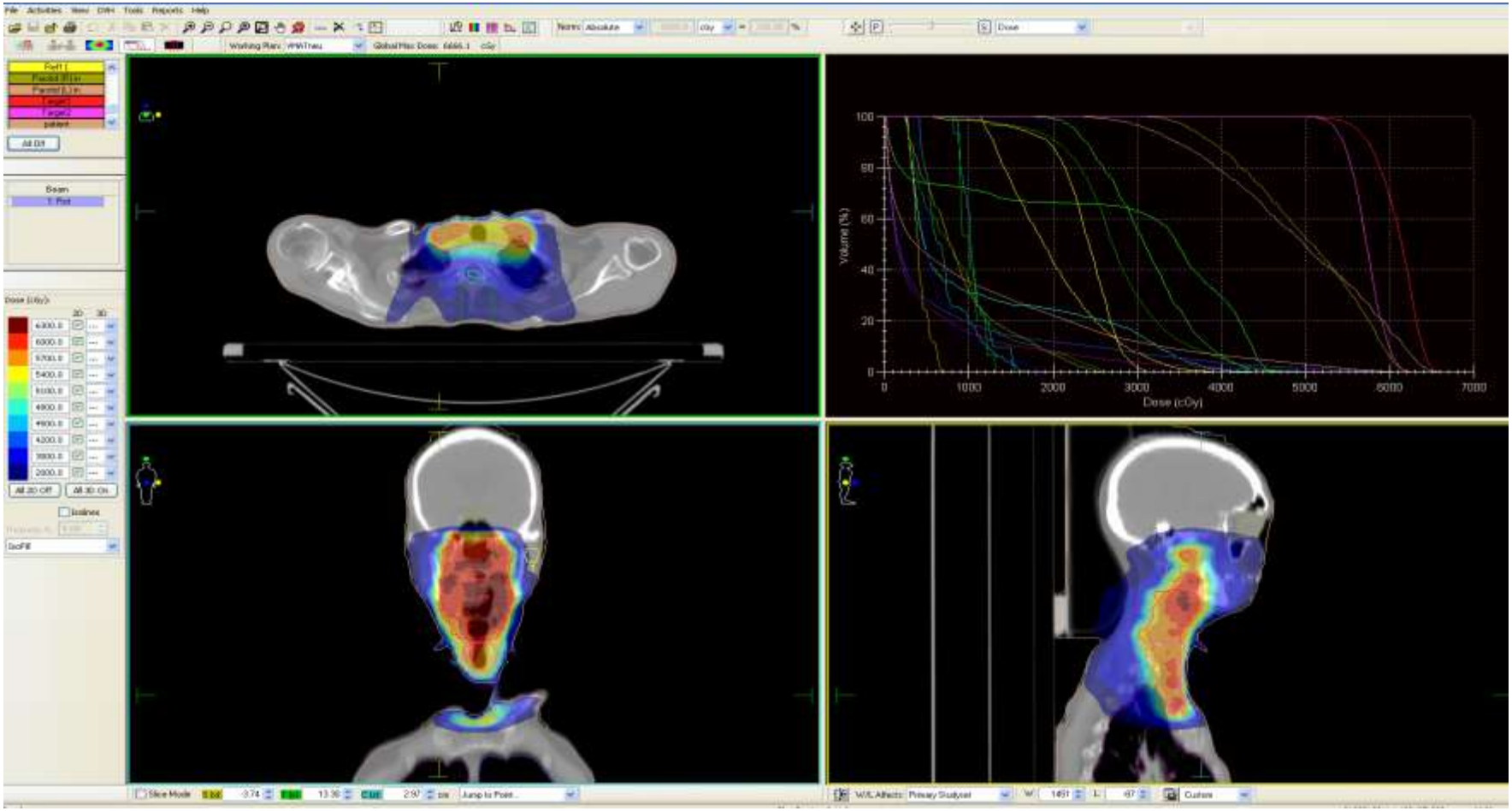

100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

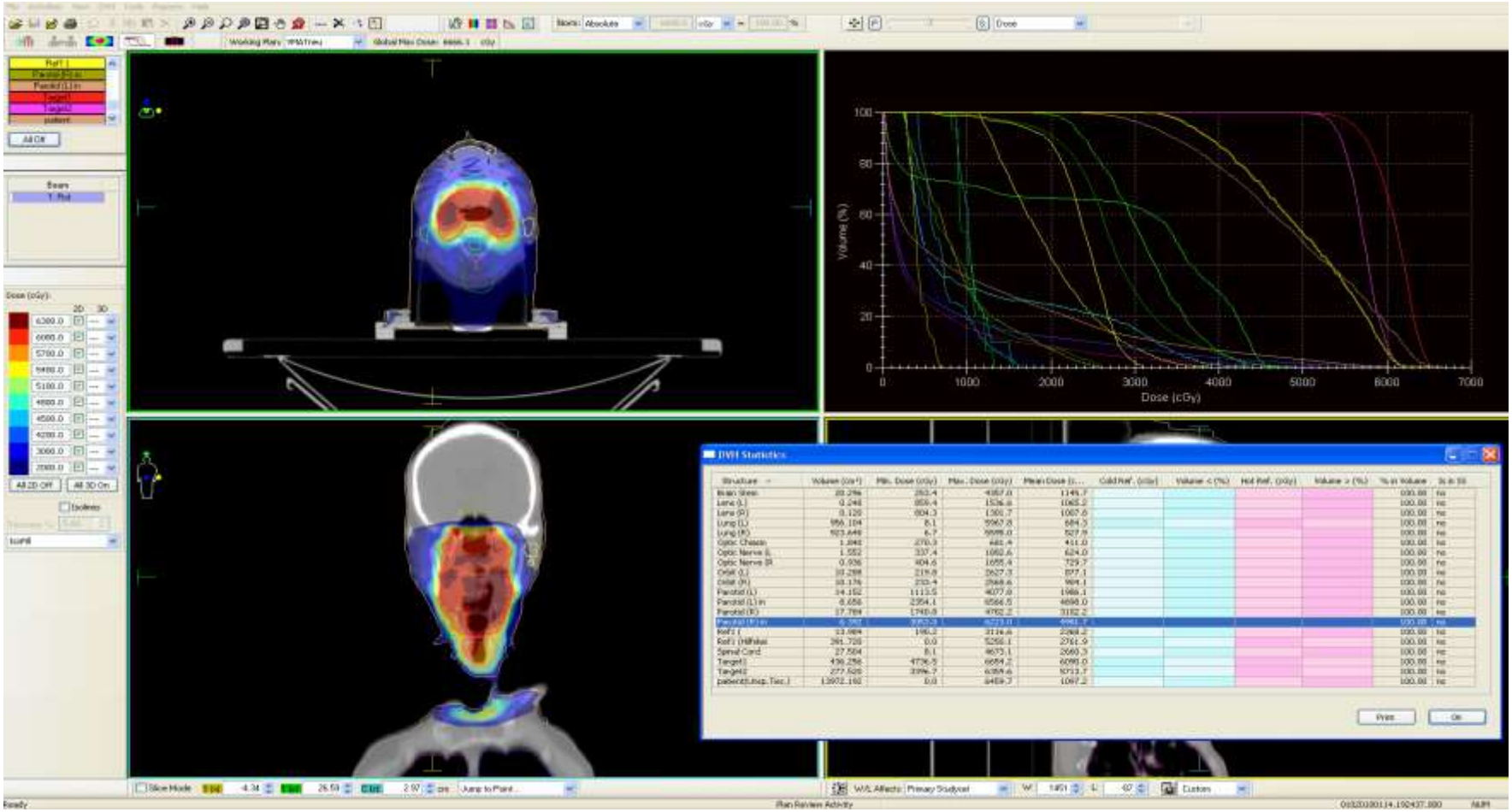

Volume (%)
Dose (cGy)
0
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
100

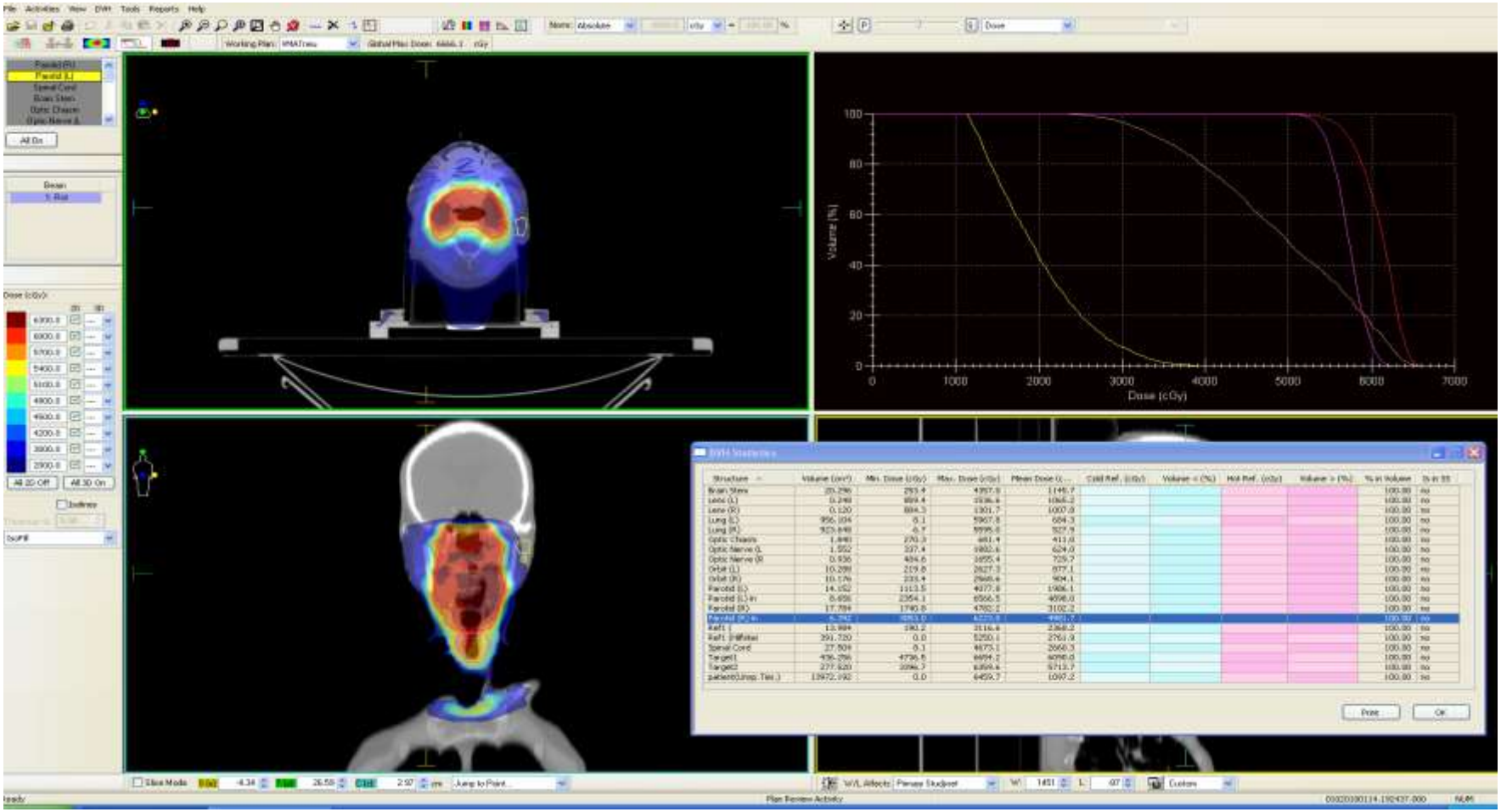

100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)


Volume (%)
Dose (cGy)
0
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
100


100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)


Volume (%)
Dose (cGy)
0
20
40
60
80
100
1000
2000
3000
4000
5000
6000
7000

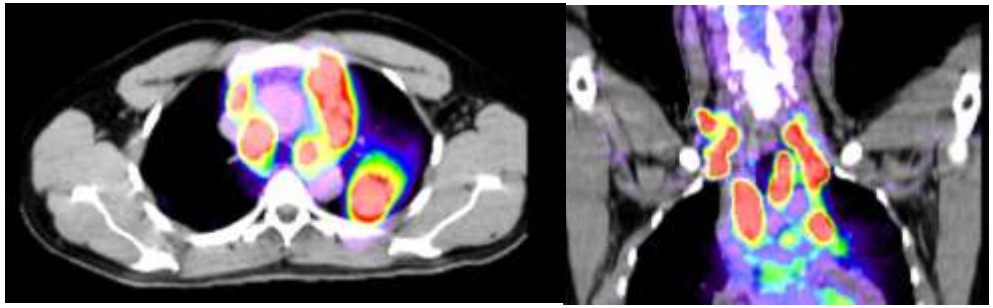

Volume (%)
Dose (cGy)
DVH Statistics

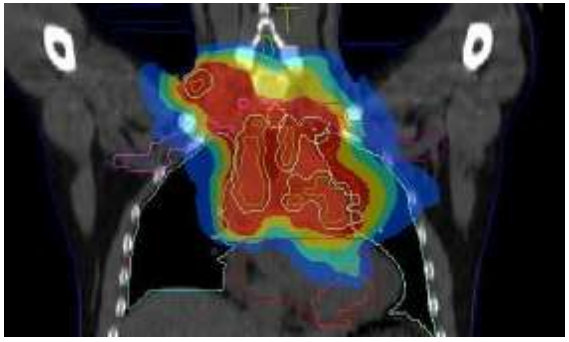

100
80
60
40
20
0
Volume [%]
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

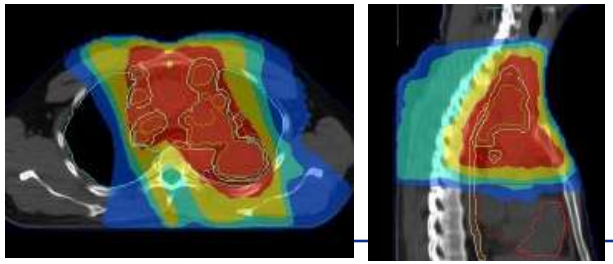
Bildgesteuerte, PET-gestützte Strahlentherapie beim Lungenkarzinom

Zielvolumenminimierung und Bestrahlungsoptimierung bei ungünstigem Tumor-zu-Lungenvolumenverhältnis

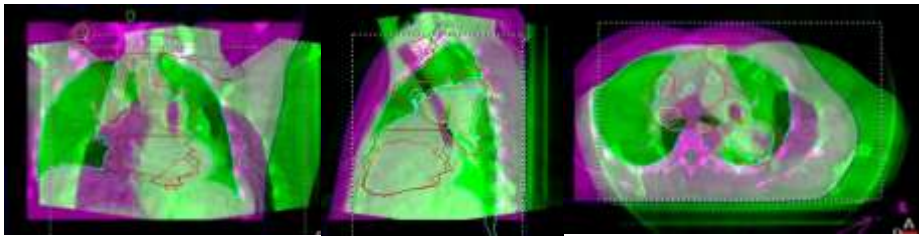
1. Zielvolumendefinition/Minimierung auf Basis von funktioneller Bildgebung (PET-CT)



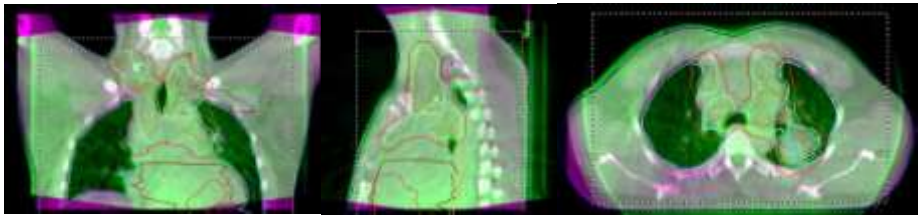




2. Bestrahlungsplanung als IMRT auf Basis einer Monte-Carlo Dosisberechnung



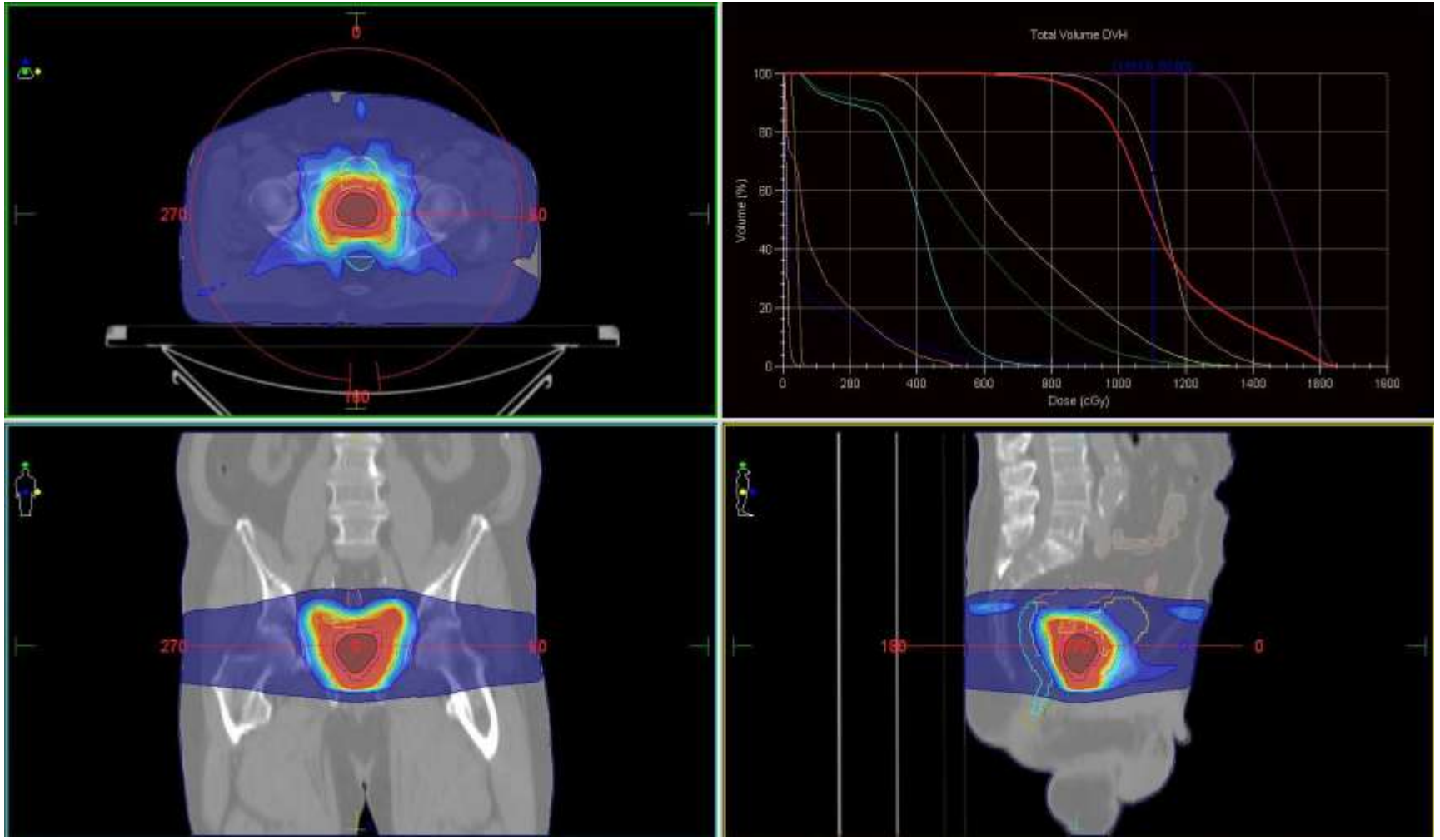
Unzureichende Positionierung

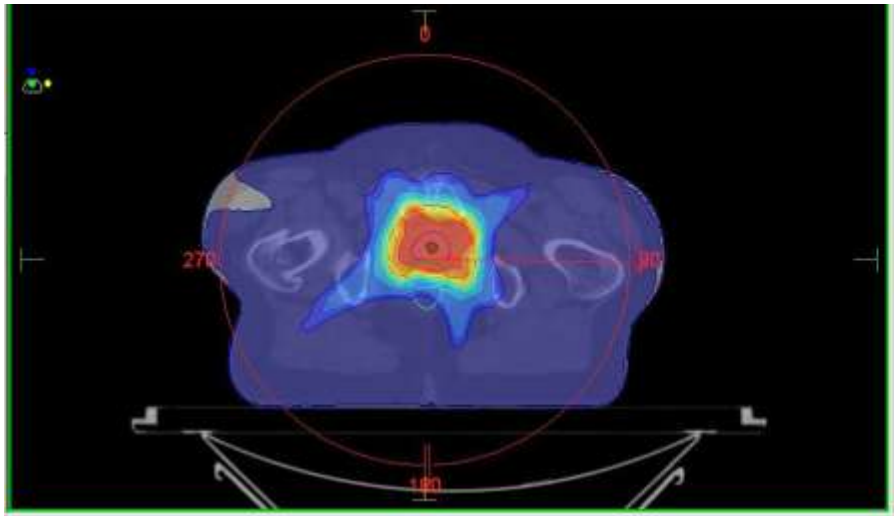


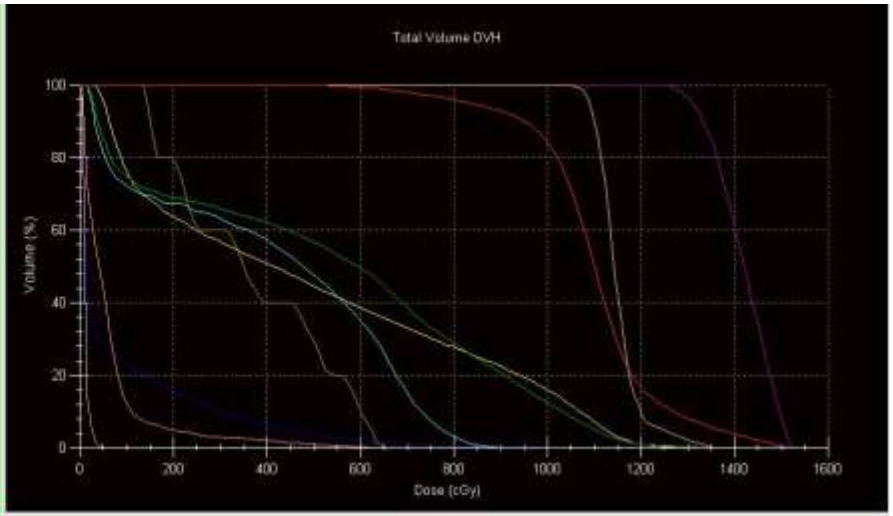
Optimale Positionierung

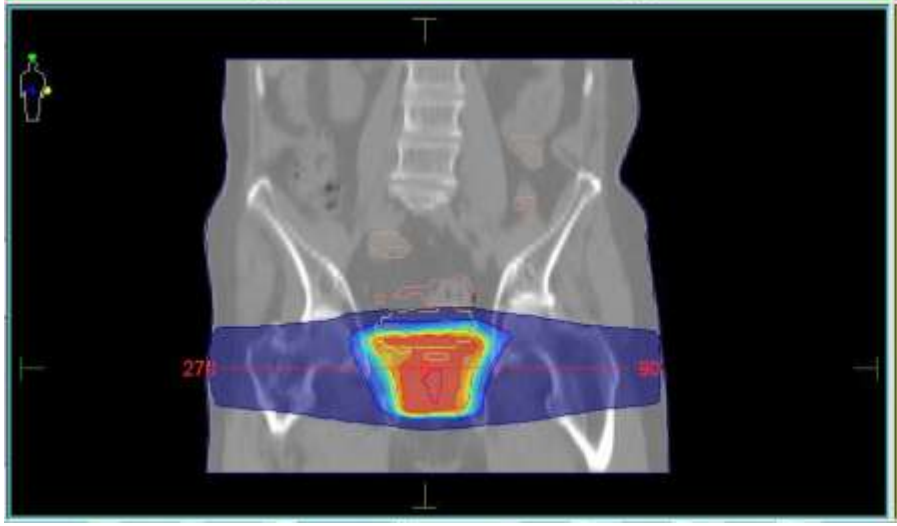
3. Bildgesteuerte Bestrahlung mittels Cone-Beam-CT am Beschleuniger

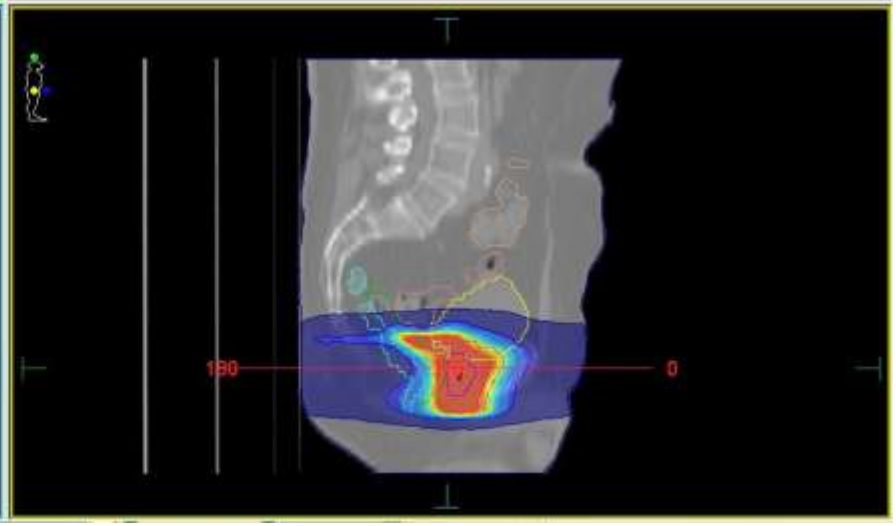
Prostata


0
270
90
180
Total Volume DVH
Volume (%)
Dose (cGy)
0
200
400
600
800
1000
1200
1400
1600
1800
100
80
60
40
20
0
270
90
180
0

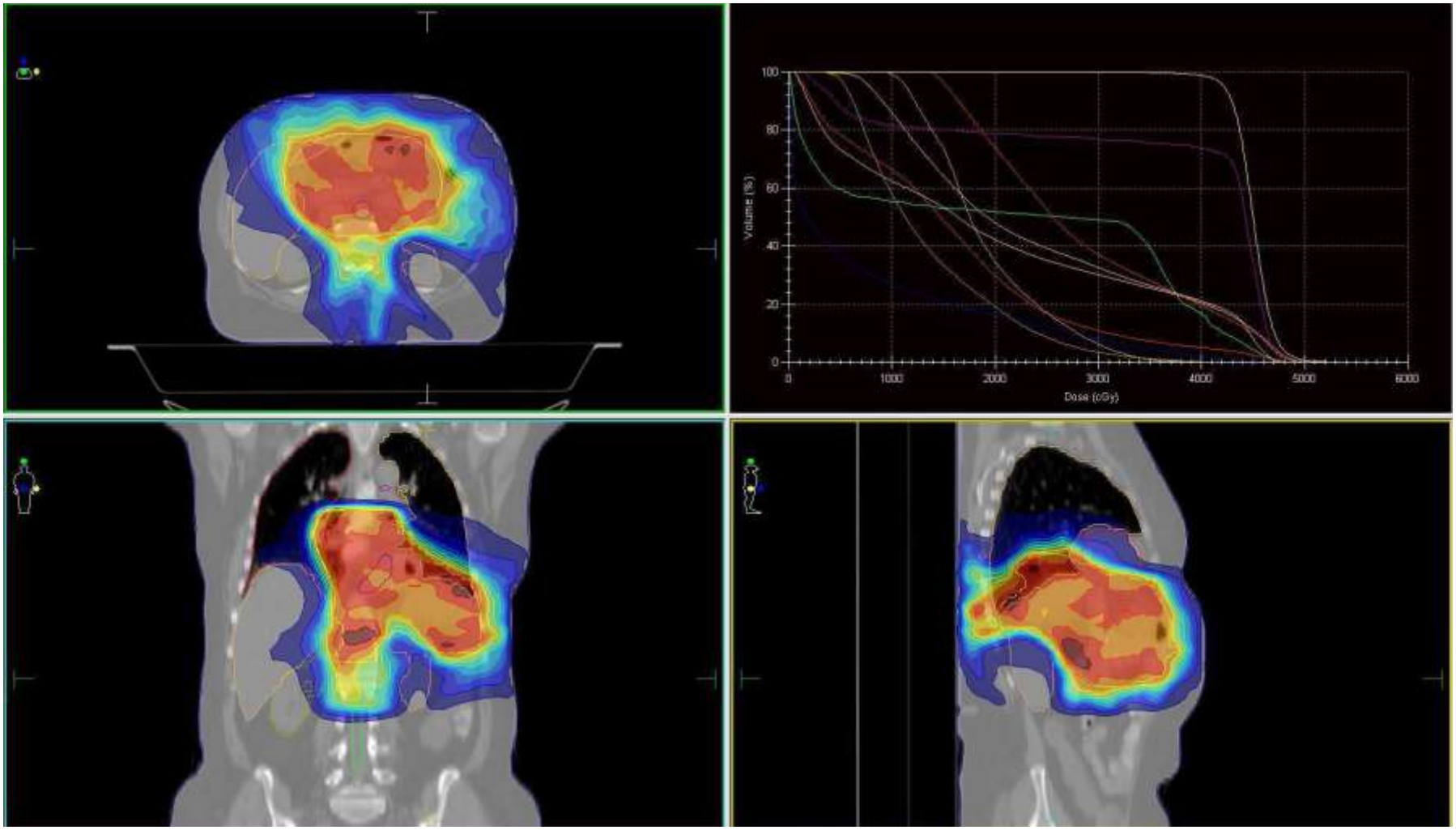

0
270
90
180


Total Volume DVH
Volume (%)
Dose (cGy)
100
80
60
40
20
0
0
200
400
600
800
1000
1200
1400
1600


270
90


180
0

Magen


100
80
60
40
20
0
Volume (%)
0
1000
2000
3000
4000
5000
6000
Dose (cGy)

Bildgesteuerte, PET-gestützte Strahlentherapie beim Lungenkarzinom

Zielvolumenminimierung und Bestrahlungsoptimierung bei ungünstigem Tumor-zu-Lungenvolumenverhältnis

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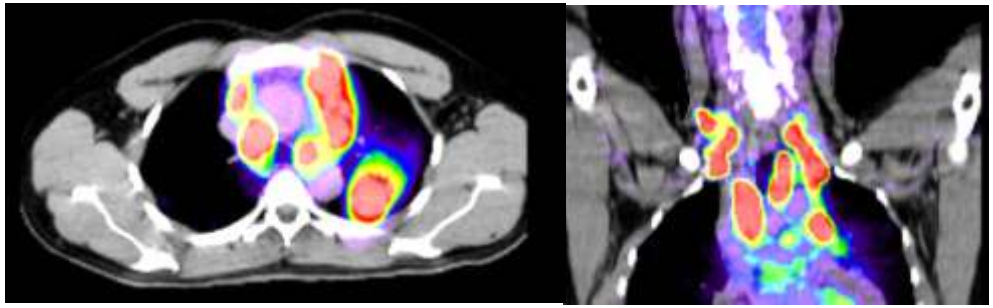
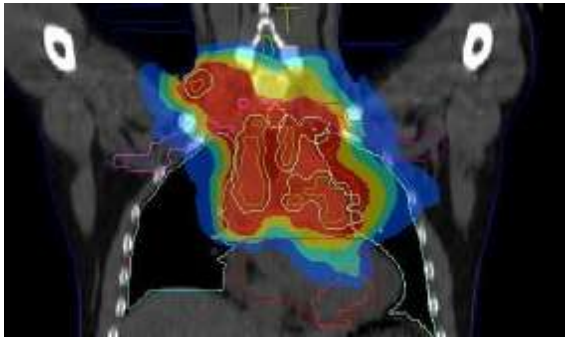
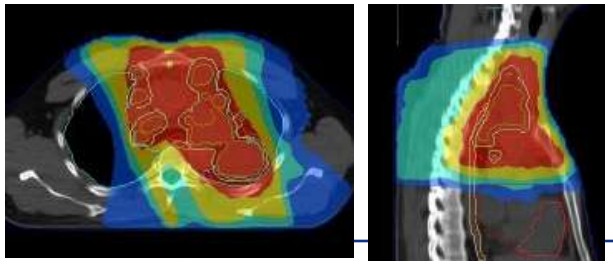
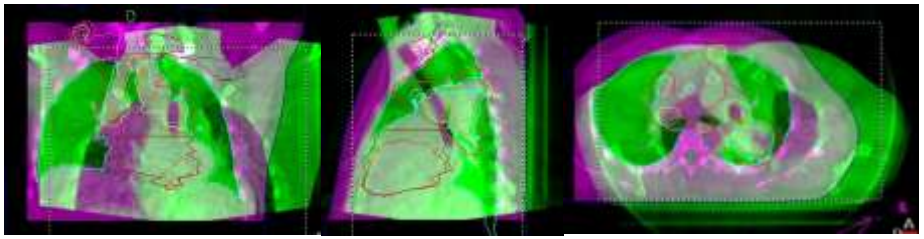


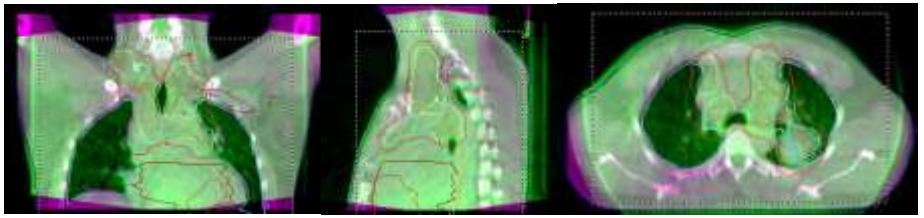




2. Bestrahlungsplanung als IMRT auf Basis einer Monte-Carlo Dosisberechnung

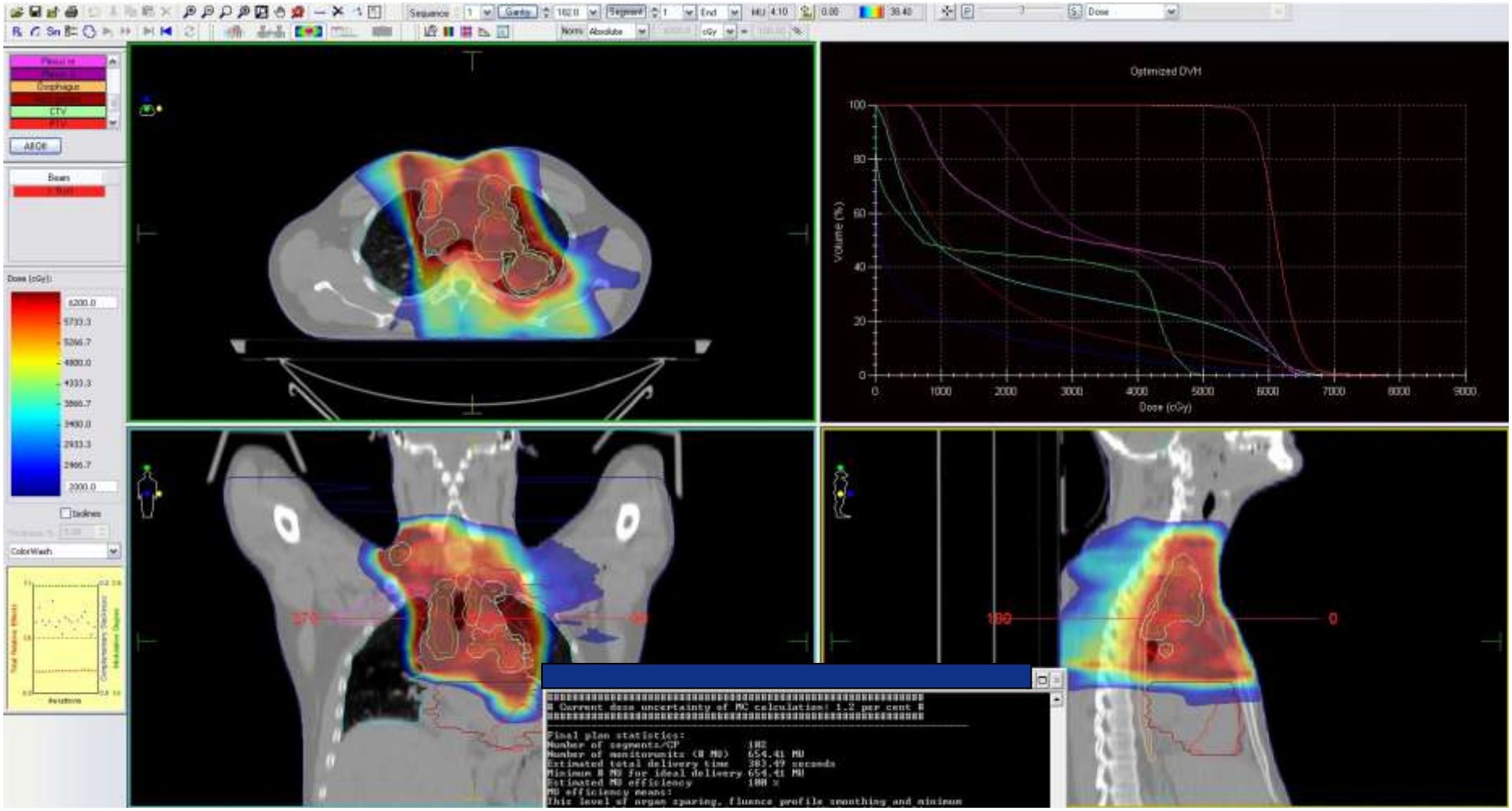


Unzureichende Positionierung



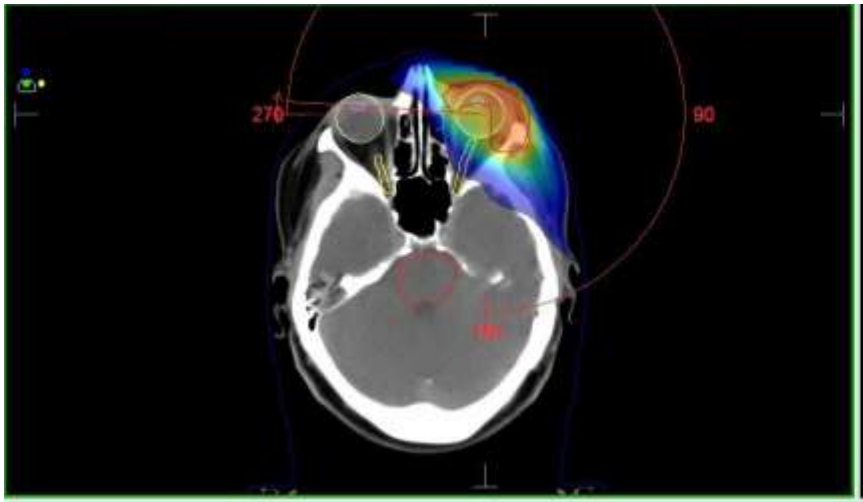
Optimale Positionierung

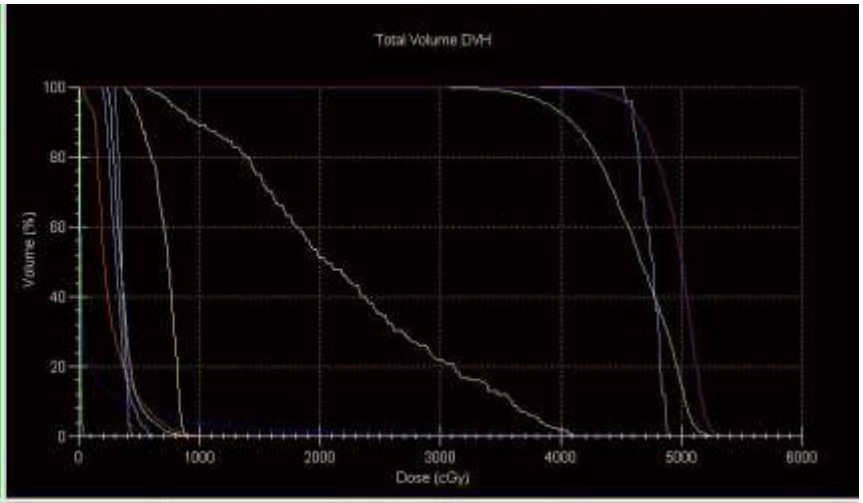
3. Bildgesteuerte Bestrahlung mittels Cone-Beam-CT am Beschleuniger

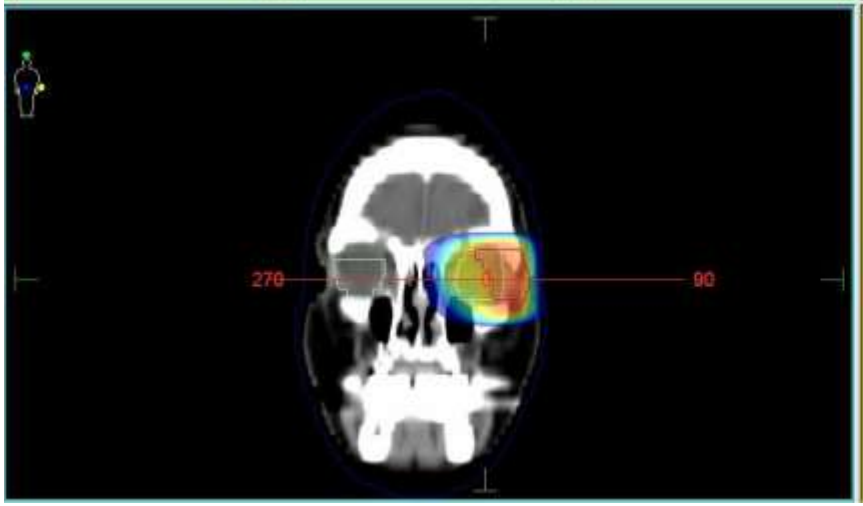

Optimized DVH
Volume (%)
Dose (cGy)
Final plan statistics:
Number of segments/CP 182
Number of monitorunits (8 MU) 654.41 MU
Estimated total delivery time 383.49 seconds
Minimum 8 MU for ideal delivery 654.41 MU
Estimated MU efficiency 100 %
MU efficiency means:
This level of organ sparing, fluence profile smoothing and minimum

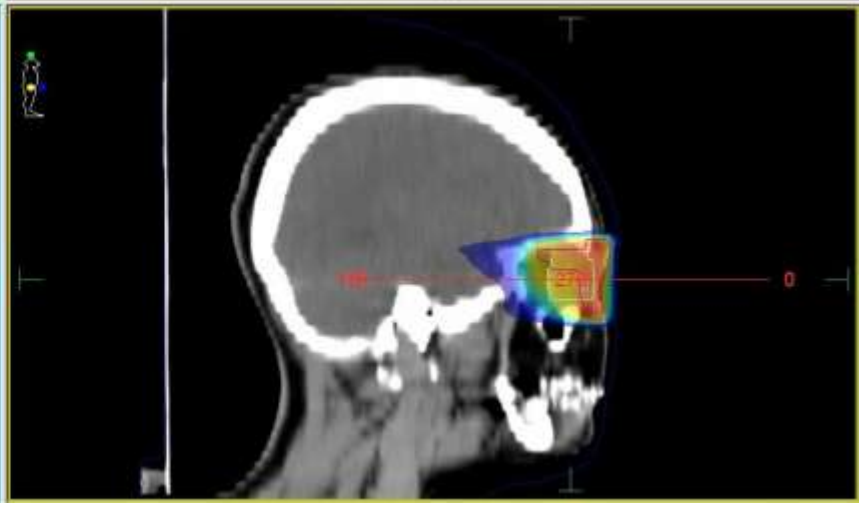
VMAT

Augenlid


270
90


Total Volume DVH
Volume (%)
100
80
60
40
20
0
0
1000
2000
3000
4000
5000
6000
Dose (cGy)


270
90

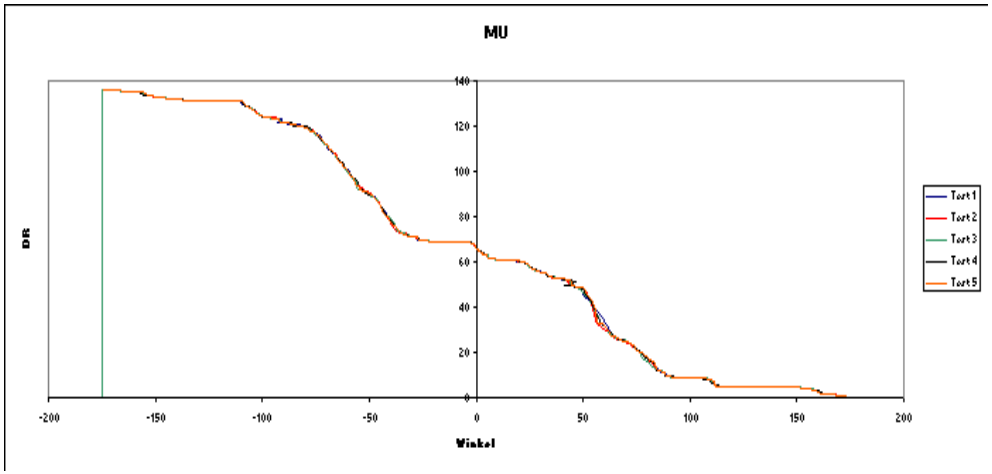

0

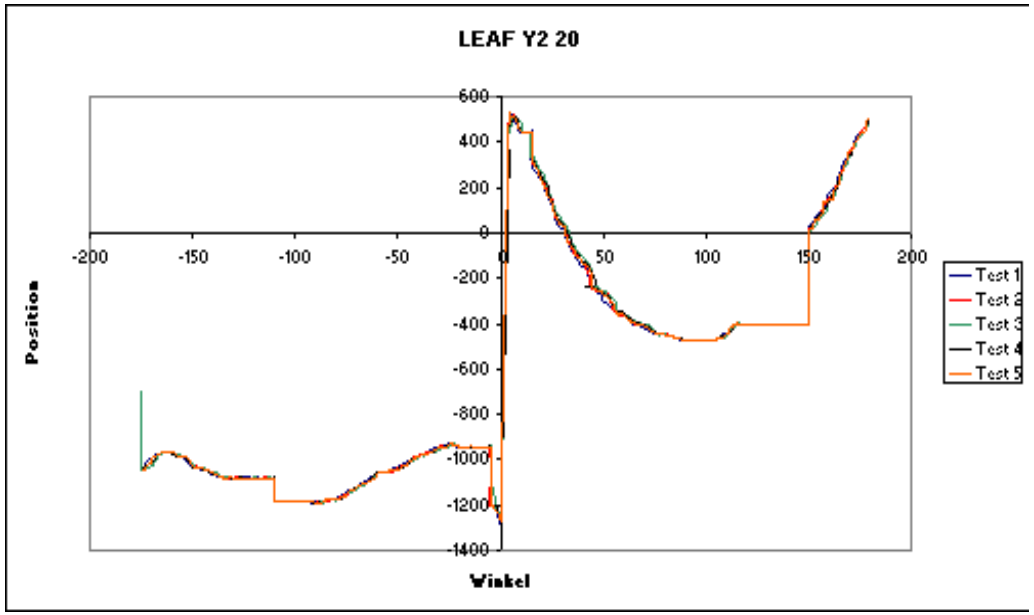
QA for VMAT

Linac tests for VMAT

MU Check

Add up MU per gantry angle

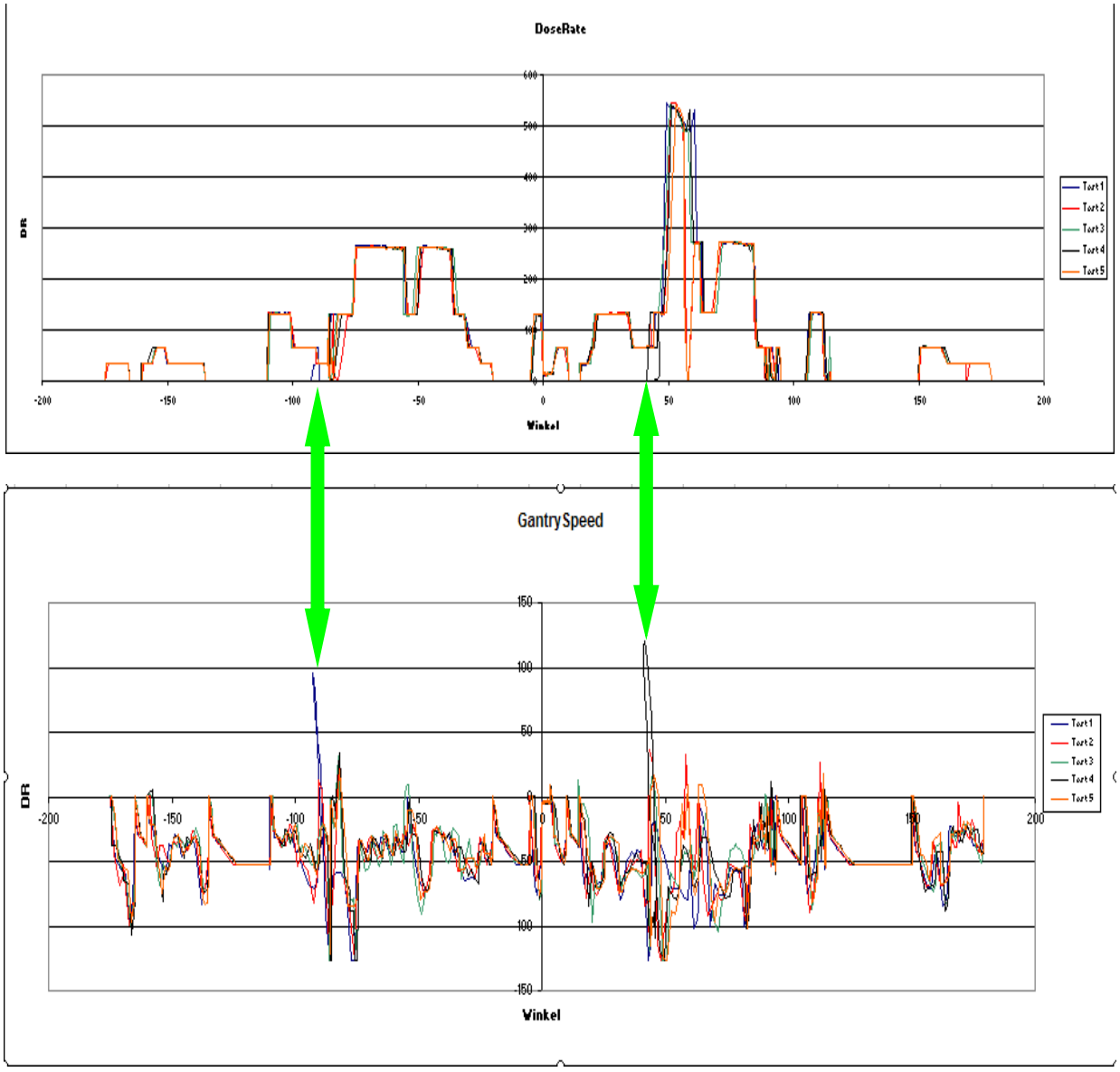




MLC Check

Leaf position per gantry angle

Linac tests for VMAT



Dynamic Dose Rate Check

Dose rate per gantry angle

Gantry Speed Check

Gantry Speed per gantry angle

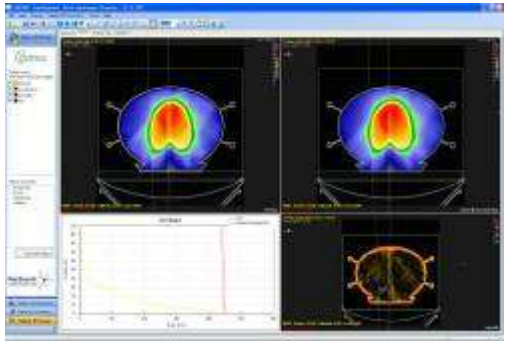
QA for VMAT

Boggula et al, submitted

- So far
  - Extended Linac QA according DIN 6847-5
  - Full patient plan verification using EDR2 film and ion chambers
  - In vivo dosimetry during patient delivery for prostate cancer

IBA Multicube

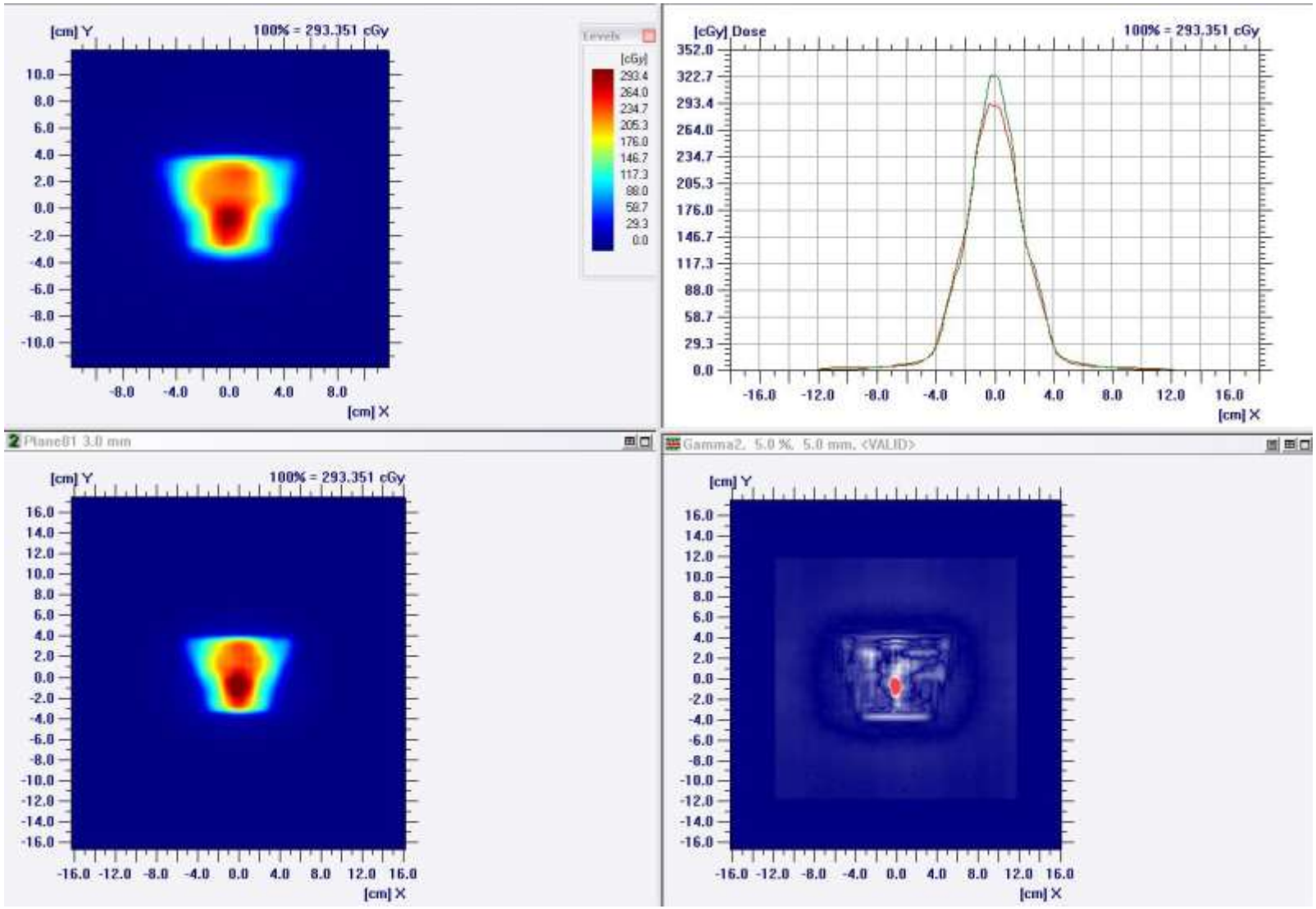
- <u>Future:</u>
  - IBA MatriXX 2D-arry detector for patient plan verification
    - MatriXX Evolution with gantry angle sensor and multicube phantom (Comparison of measurement to TPS)

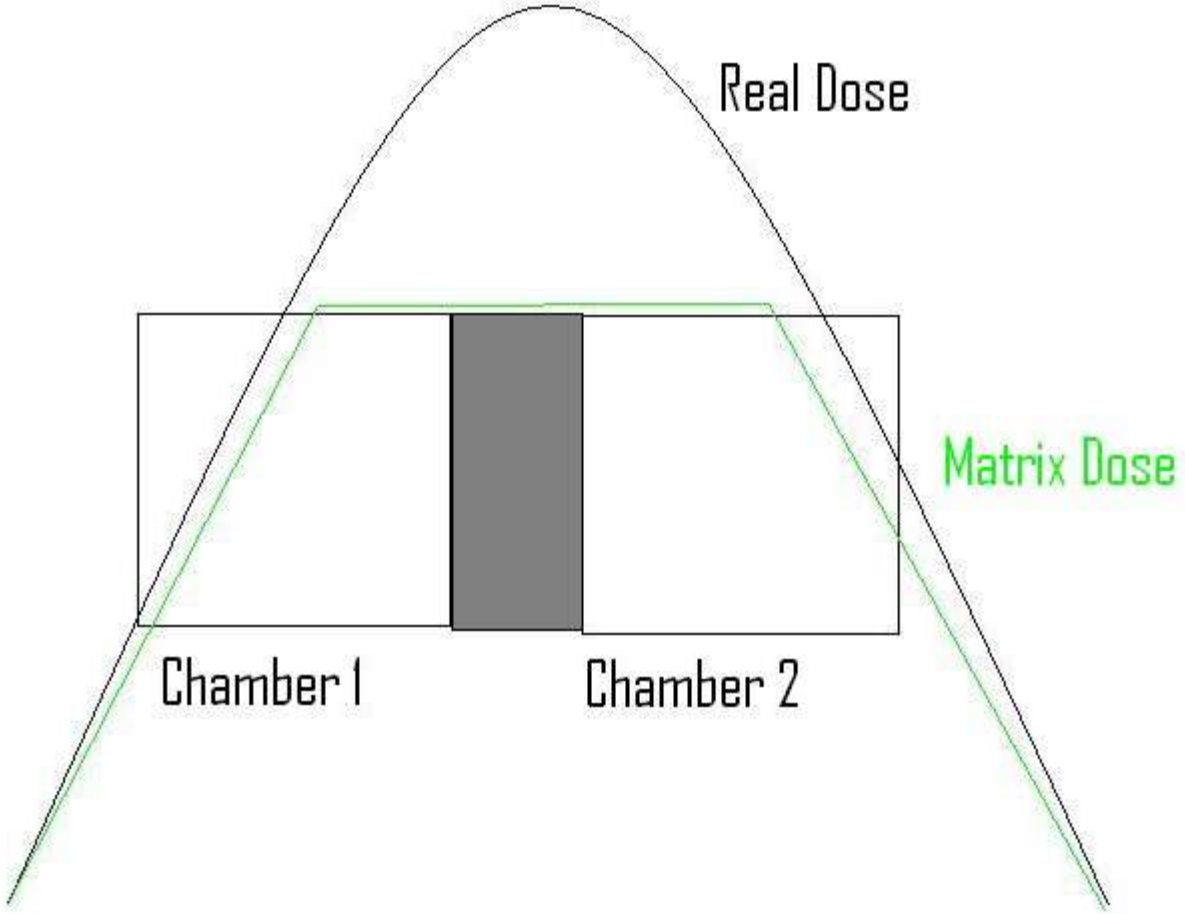


IBA Compass

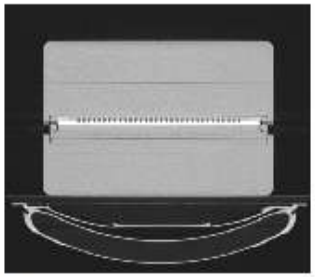
    - MatriXX Evolution with gantry holder and Compass software (independent TPS using measured fluences)
  - IBA transmision detector for online plan verification

IBA transmision detector

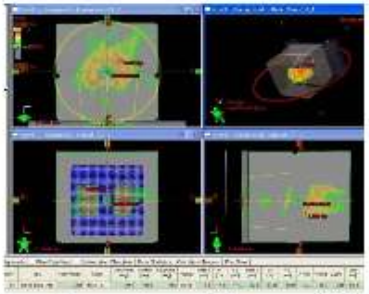

[cm] Y
100% = 293.351 cGy
Levels
[cGy]
293.4
264.0
234.7
205.3
176.0
146.7
117.3
88.0
58.7
29.3
0.0
[cm] X
[cGy] Dose
352.0
322.7
Plane81 3.0 mm
Gamma2, 5.0 %, 5.0 mm, <VALID>


Real Dose
Matrix Dose
Chamber 1
Chamber 2

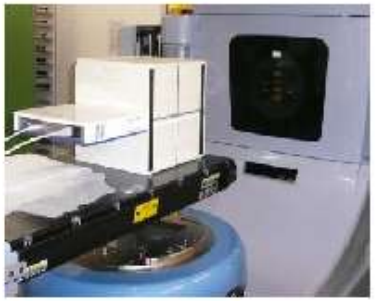
Treatment Plan QA: Typical workflow



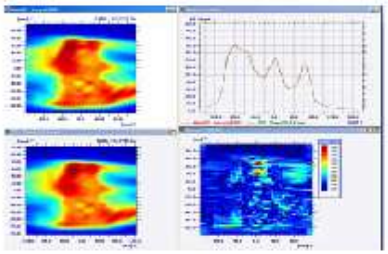
1.- CT: acquire images



2.- Create Plans (TPS)

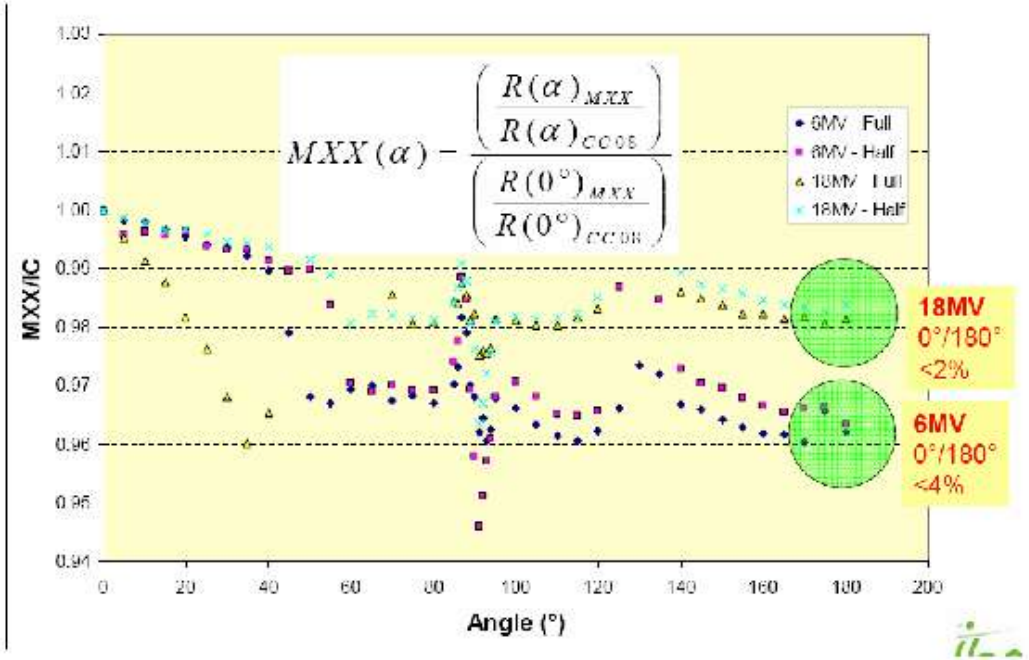


3.- Deliver planned treatment

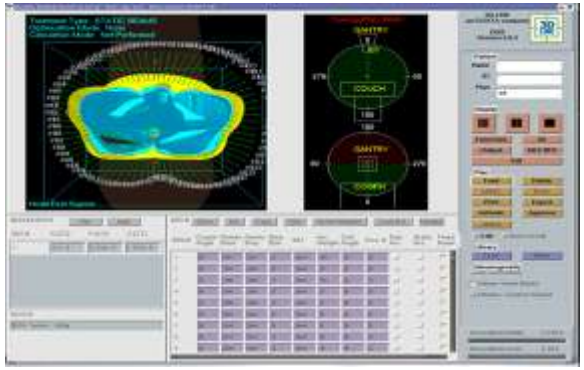


4.- Evaluate Plan vs Measurements

MatriXX - Residual angular dependence

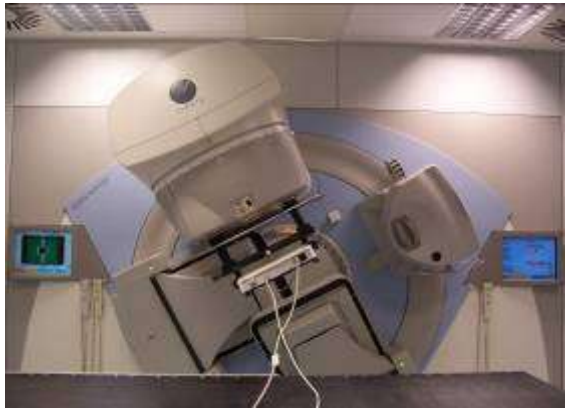


Dose Reconstruction - COMPASS



ERGO++

DICOM

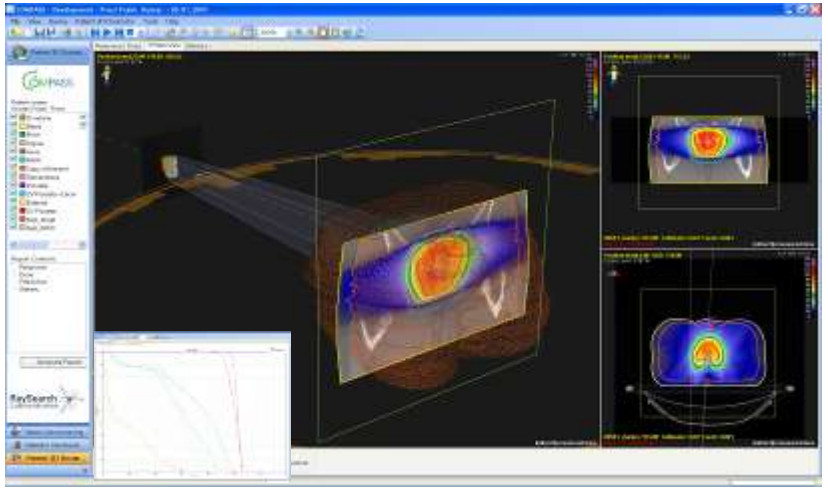


Linac + COMPASS setup

DICOM

Fluence

COMPASS



Reconstructs the dose based on delivered fluence

Thank you for your attention

and don‘t rotate too fast ☺