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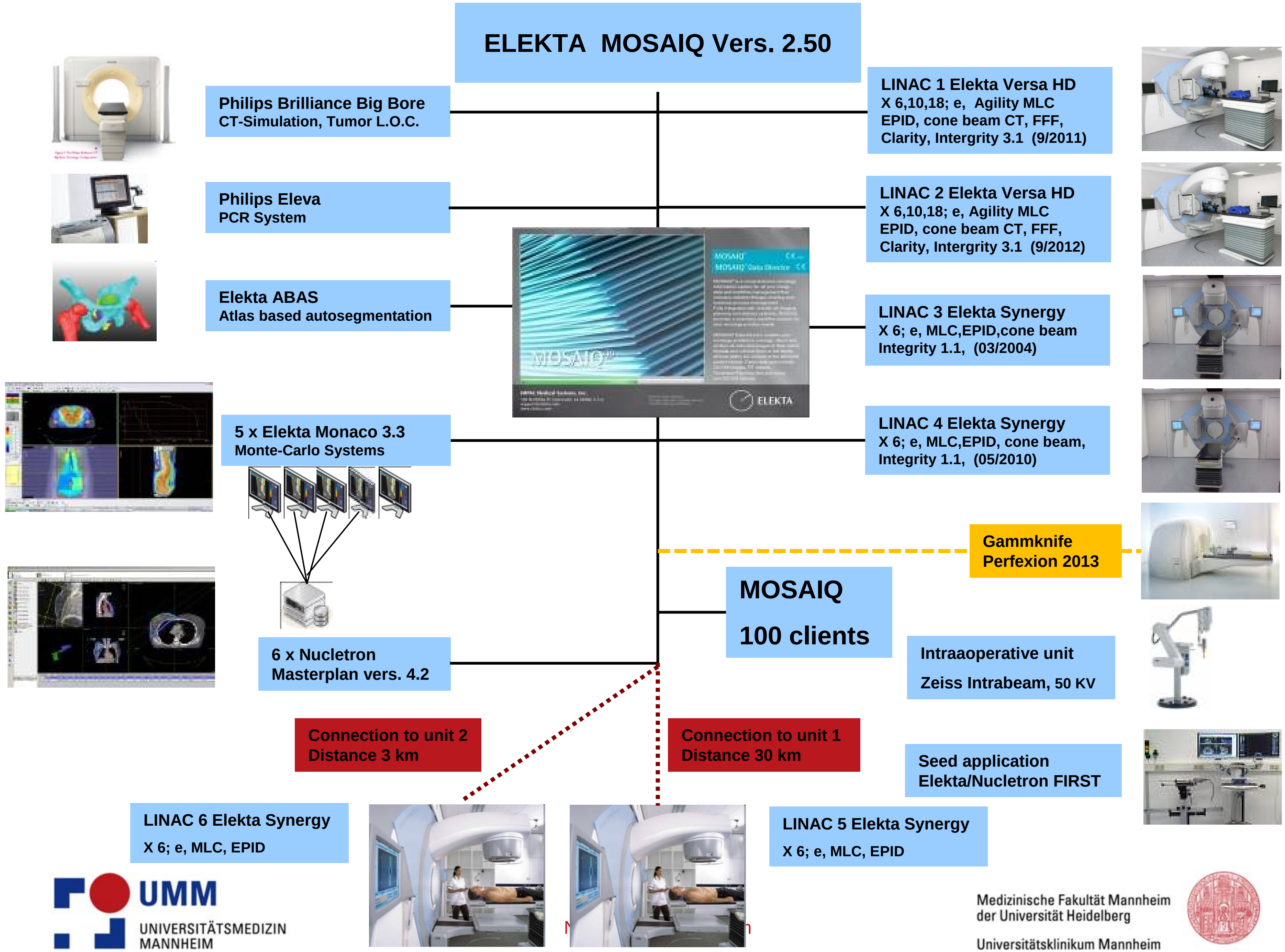
der Universität Heidelberg

Universitätsklinikum Mannheim

Nur noch moduliert?
Schnelle IMRT
mit Elekta Agility FFF

Frank Lohr, M.D.
Vice Chairman
University Medical Center Mannheim
Germany

Disclosures:
Research/Training Agreements with Elekta, IBA and CRAD


ELEKTA MOSAIQ Vers. 2.50
Philips Brilliance Big Bore
CT-Simulation, Tumor L.O.C.
Philips Eleva
PCR System
Elekta ABAS
Atlas based autosegmentation
5 x Elekta Monaco 3.3
Monte-Carlo Systems
6 x Nucletron
Masterplan vers. 4.2
LINAC 1 Elekta Versa HD
X 6,10,18; e, Agility MLC
EPID, cone beam CT, FFF,
Clarity, Intergrity 3.1 (9/2011)
LINAC 2 Elekta Versa HD
X 6,10,18; e, Agility MLC
EPID, cone beam CT, FFF,
Clarity, Intergrity 3.1 (9/2012)
LINAC 3 Elekta Synergy
X 6; e, MLC,EPID,cone beam
Integrity 1.1, (03/2004)
LINAC 4 Elekta Synergy
X 6; e, MLC,EPID, cone beam,
Integrity 1.1, (05/2010)
Gammknife
Perfexion 2013
MOSAIQ
100 clients
Intraaoperative unit
Zeiss Intrabeam, 50 KV
Seed application
Elekta/Nucletron FIRST
Connection to unit 2
Distance 3 km
Connection to unit 1
Distance 30 km
LINAC 6 Elekta Synergy
X 6; e, MLC, EPID
LINAC 5 Elekta Synergy
X 6; e, MLC, EPID
ELEKTA
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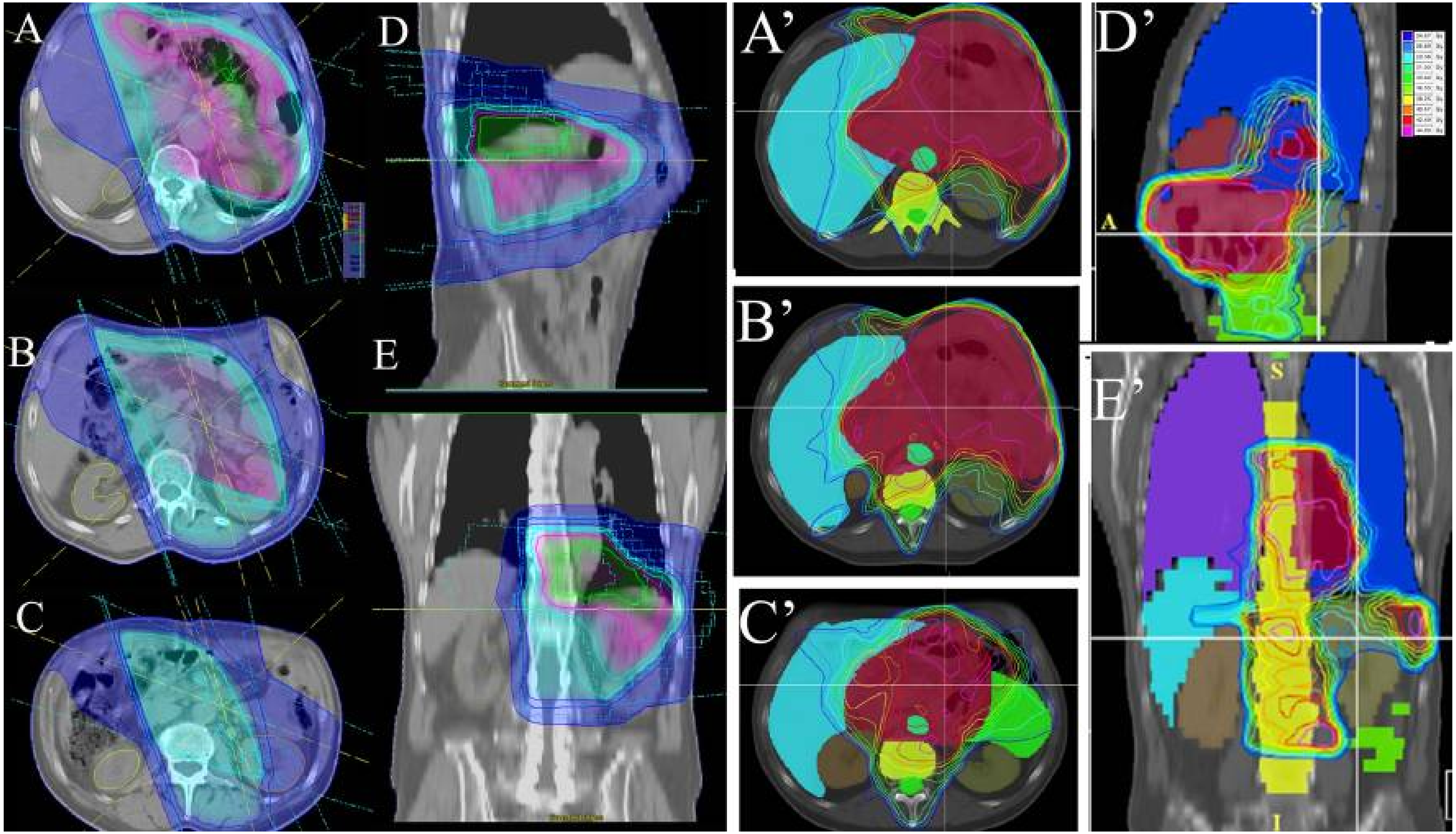
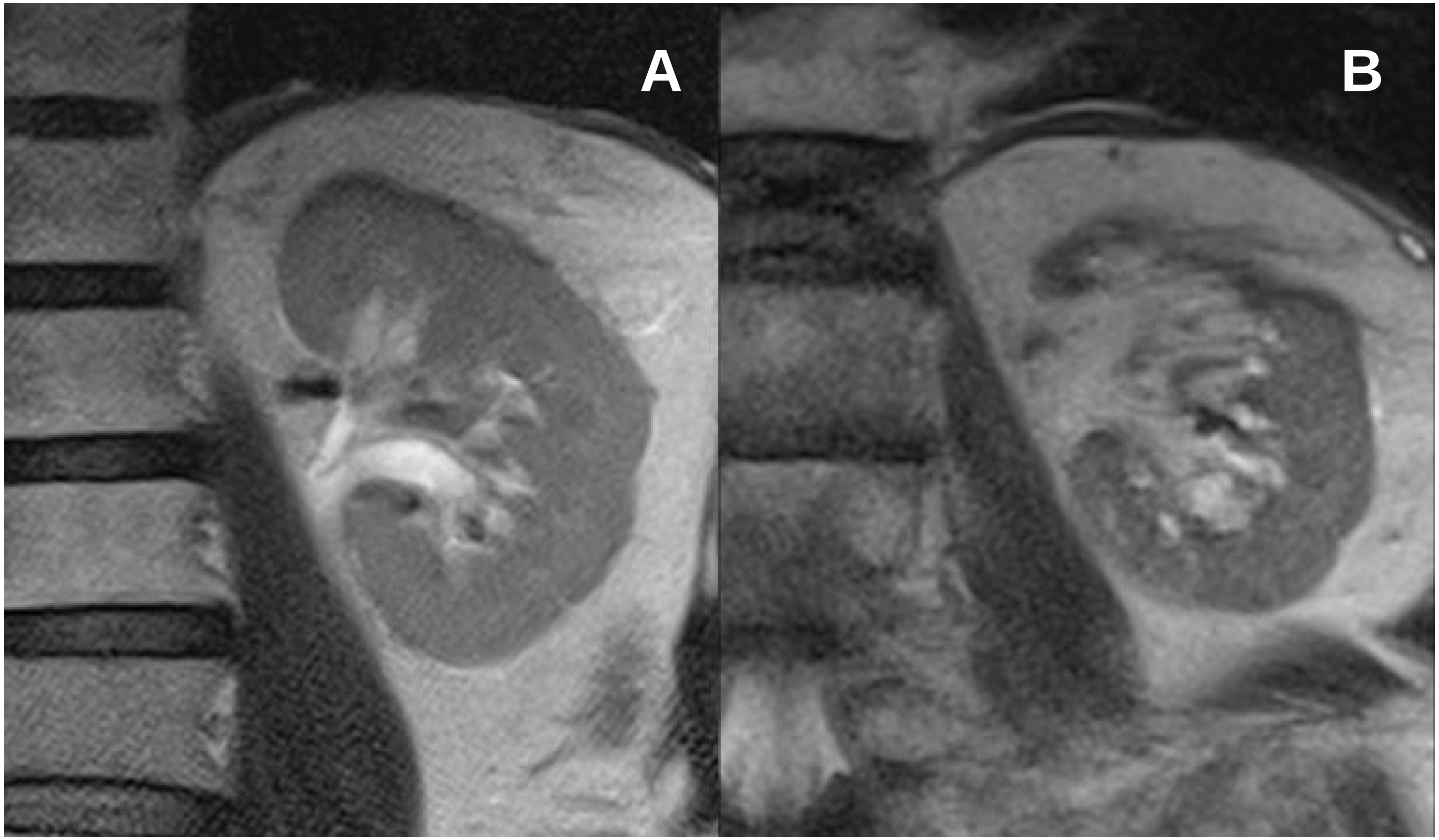
10J post full neck IMRT



	Right Kidney (Gy)							Left Kidney (Gy)						
	Median	Mean	D30	D60	Cranial part	Middle part	Caudal part	Median	Mean	D30	D60	Cranial part	Middle part	Caudal part
3DCRT-1	2.52	3.18	3.3	2.4	5	<5	<5	41.07	36.9	46.3	38.4	47.8	45.3	25.2
3DCRT-2	3.2	7.76	8.1	2.7	22.5	4.5	<4.5	25.8	22.95	27	18	45	42.7	36
IMRT-1	1.49	1.61	1.77	1.39	11	5	0	20.25	22.18	26.68	18.15	29	26	9
IMRT-2	14.77	16.12	17.4	13.8	13	8	4	23.84	23.28	27.7	21.2	26.8	18.5	13.5

T2w: (A) IMRT vs. (B) 3D

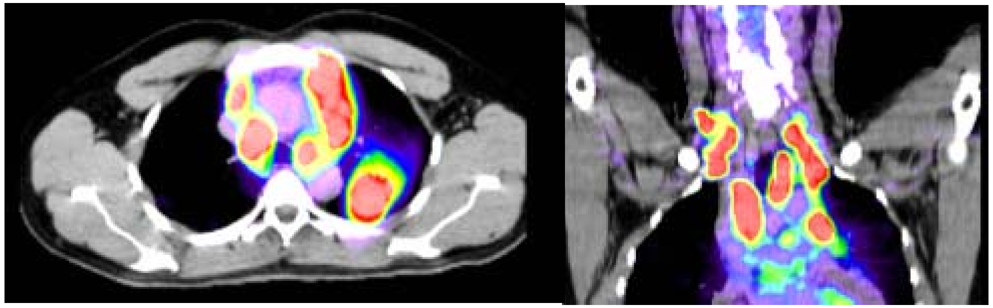


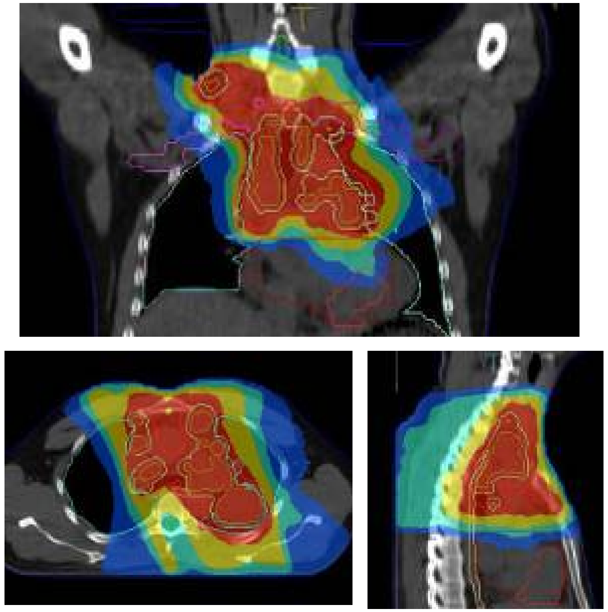
Haneder et al., SUON, 2012

Image Guided, PET-assisted Radiotherapy of Lung Cancer

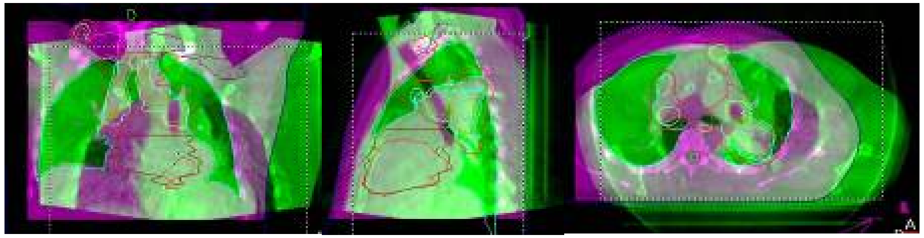
Target Volume Reduction and RT-Optimization for critical Tumor-to-Lung Ratio

1. CTV-Definition/Minimimization
based on functional Imaging (PET-CT)

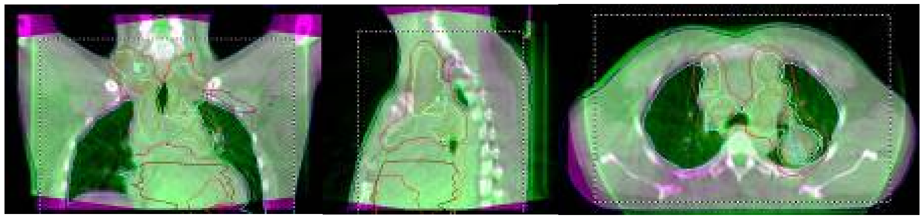




2. Treatment Planning as IMRT based on
Monte-Carlo Dose calculation



Suboptimal Positioning



Optimal Positioning

3. Image Guided Radiotherapy Treatment
with Cone-Beam-CT at Linac

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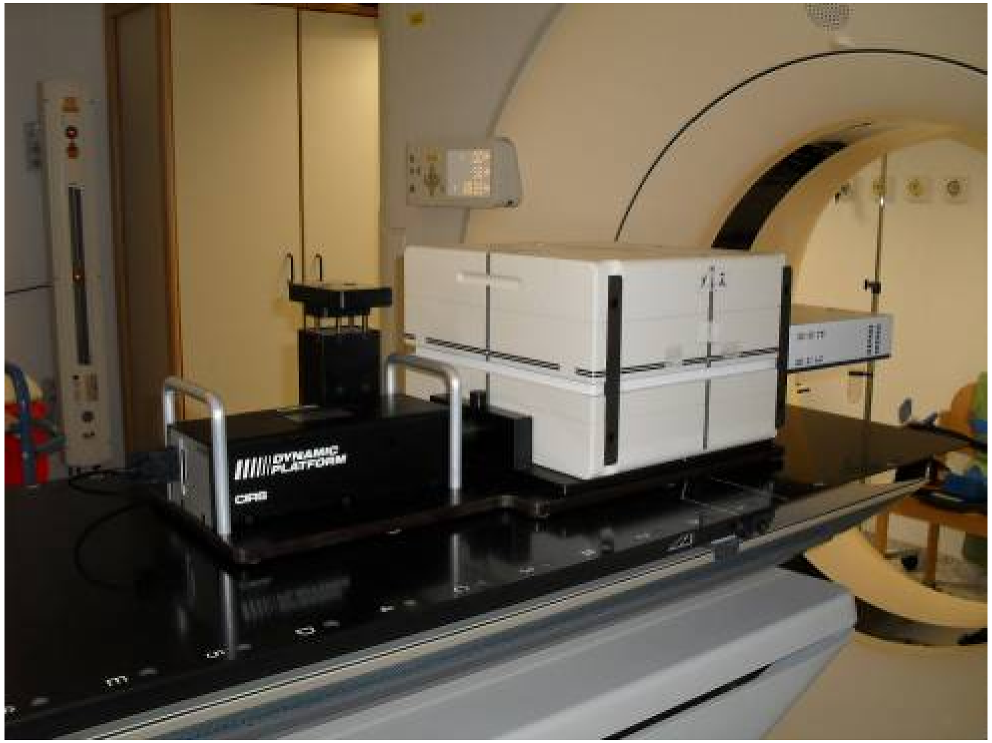
Fleckenstein et al., submitted

Measurement setup

- IBA Matrixx Evolution
- IBA Multicube
- CIRS dynamic platform model 008PL (accuracy 0.05mm)

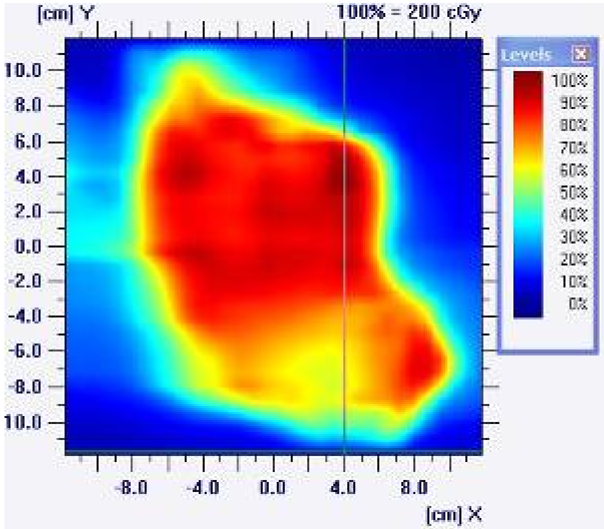
- VMAT plan generated in Monaco 2.0.3.beta



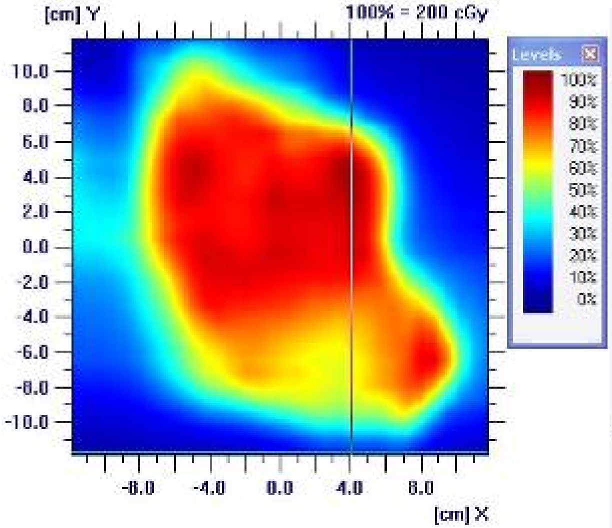
Fleckenstein et al., submitted

A=10mm, T=3.6s, cos4-motion trajectory

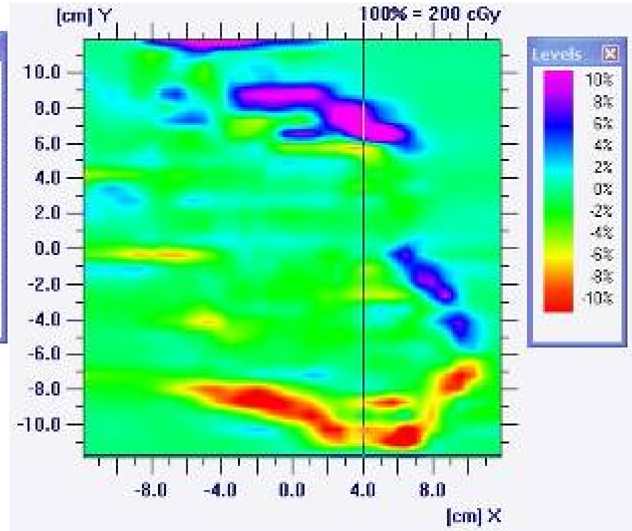
static case



with motion



difference map



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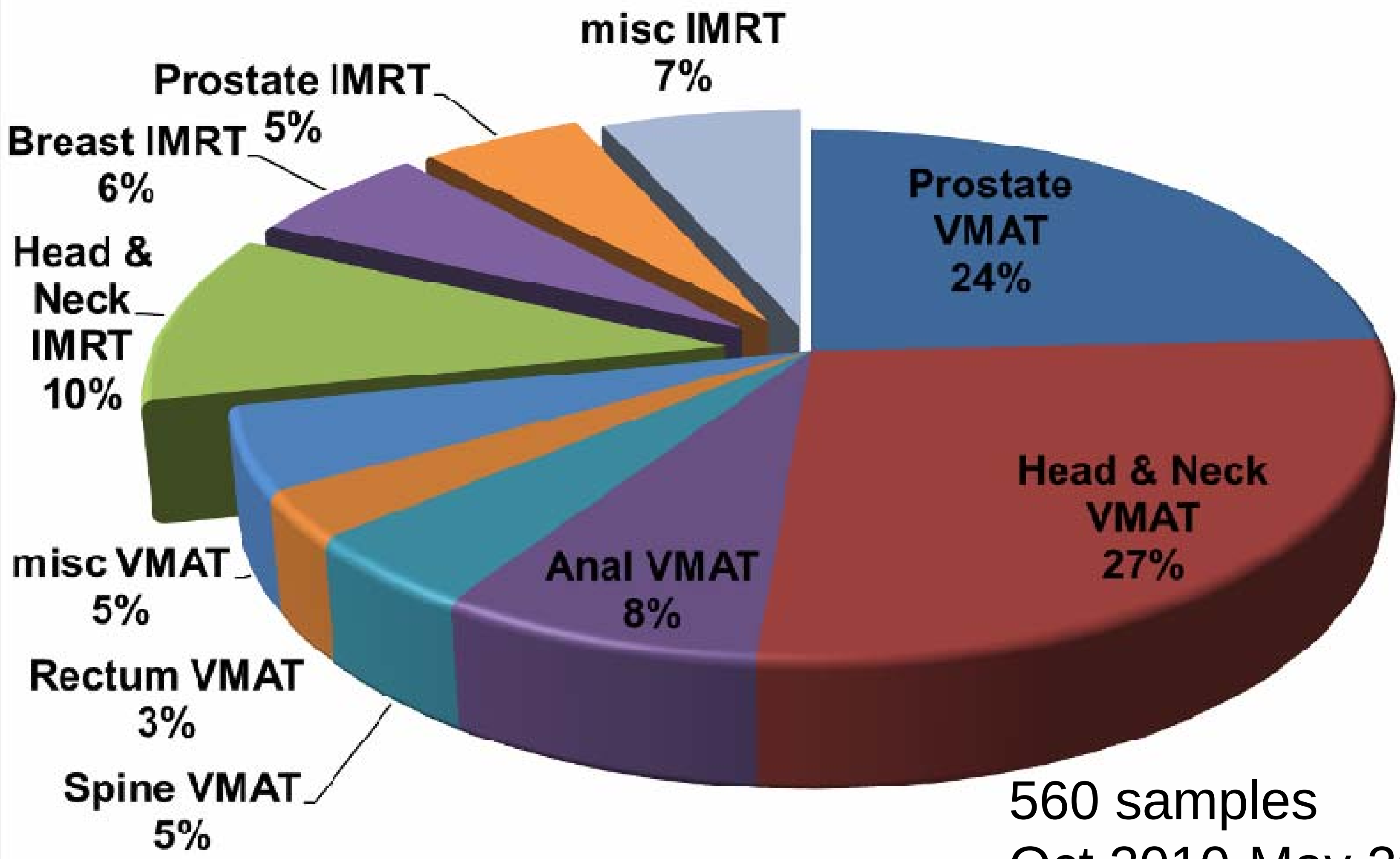
treatment plans by entities/modalities



560 samples
Oct 2010-May 2011

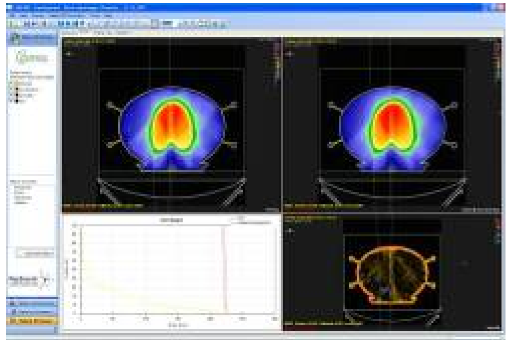
QA for VMAT

Boggula et al, submitted

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

IBA Multicube

- <u>Recent additions:</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

- IBA Compass

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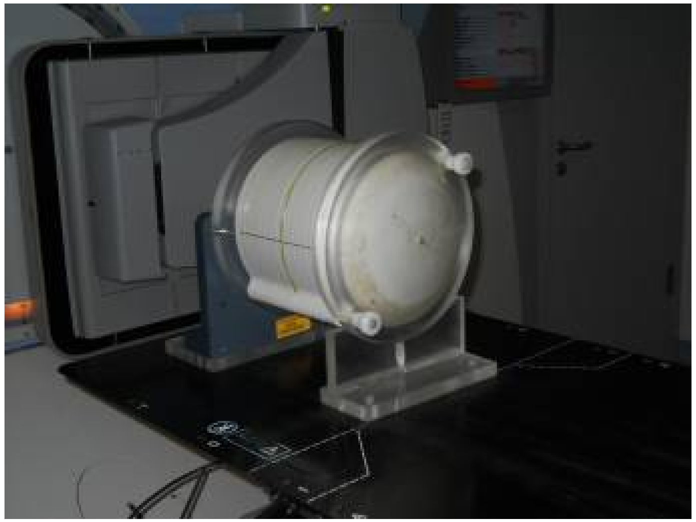
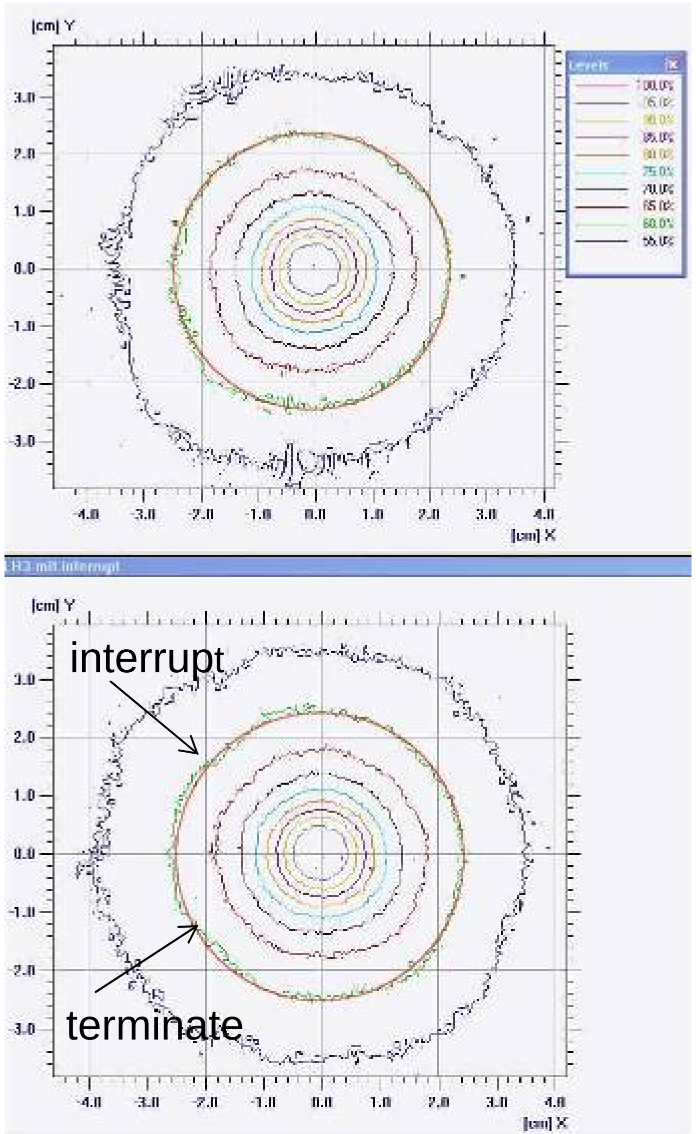
off-axis-target test

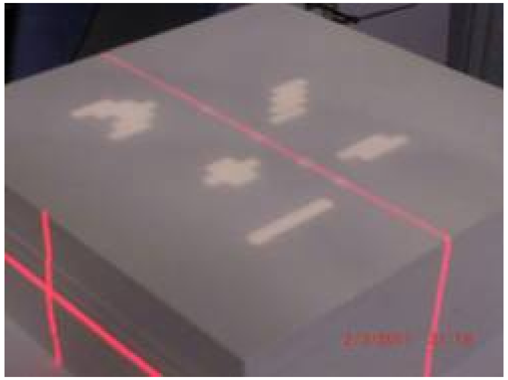
test 3: MLC and Gantry synchronization

modulated VMAT arc, which delivers dose to a PTV 8 cm from isocenter (16 cm x 1 cm field)

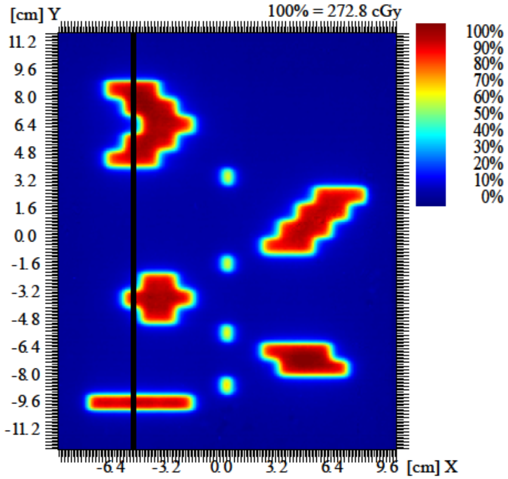




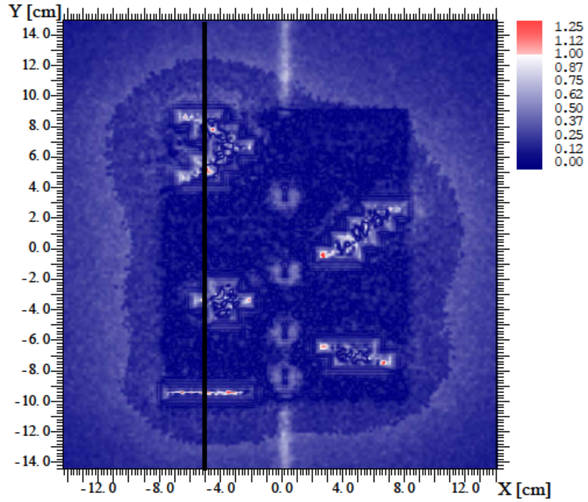
irregular MLC shaped field



measurement setup



film measurement



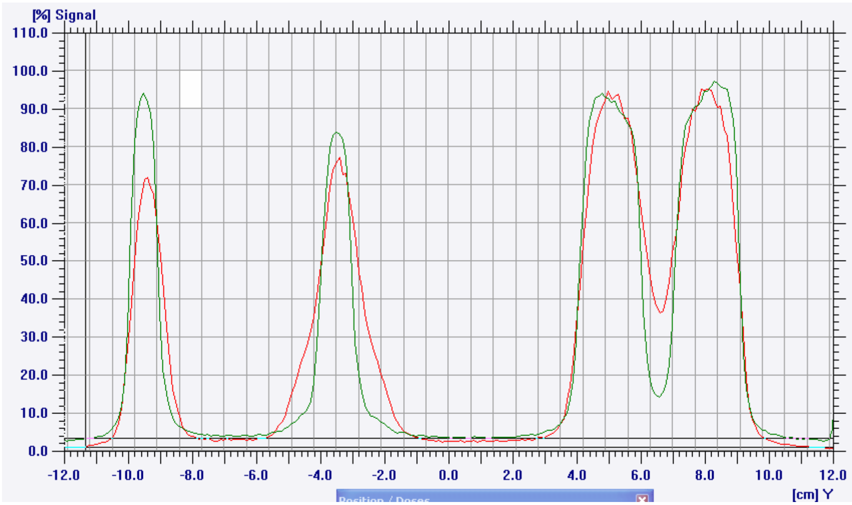
Gamma map (3%,3mm)

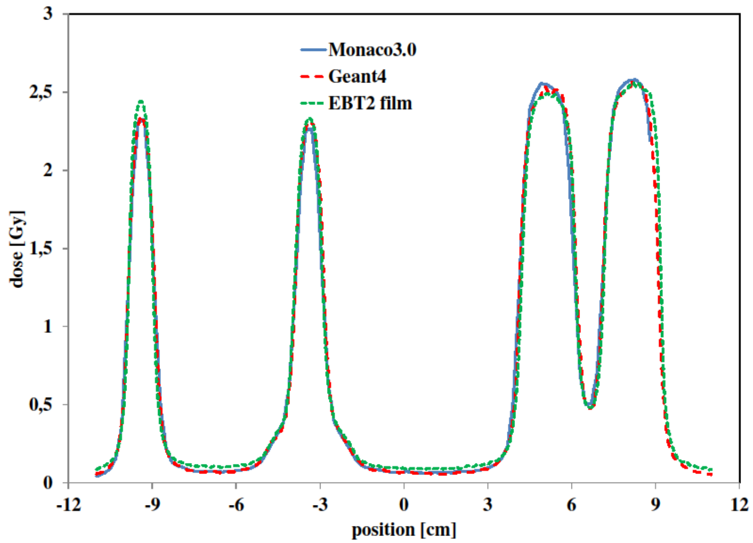
σ_{Monaco} = 0.5 %, σ_{Geant4} = 1.3 % on a 2 mm dose grid

γ (3 %, 3 mm) in the ROI_{10} :

- 97.3 % for film measurement against Monaco
- 99.0 % for film measurement against Geant4 and
- 99.4 % Monaco against Geant4
-

irregular MLC shaped field





profiles with
initial Monaco® head model

profiles with
adjusted Monaco® head model

Fleckenstein et al., submitted

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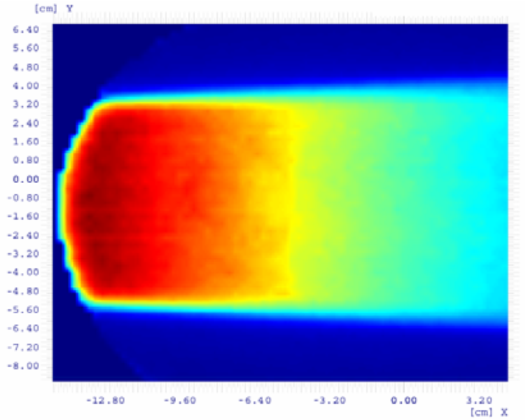
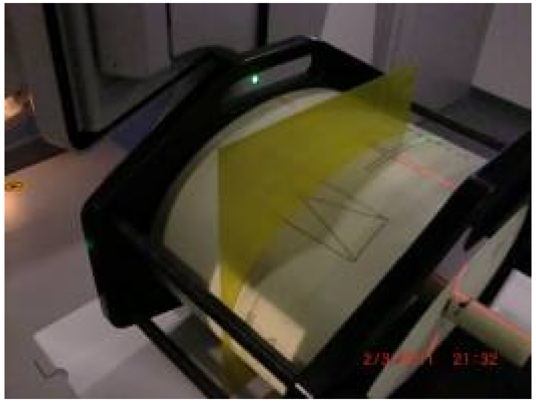
Fleckenstein et al., submitted

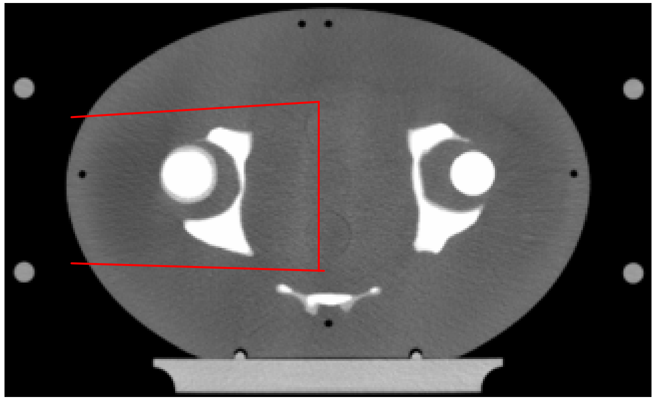
Dose to water – dose to medium conversion



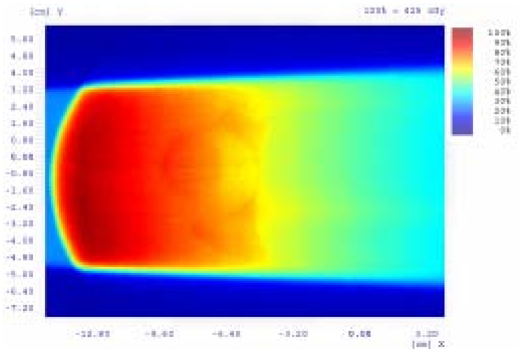
film measurement



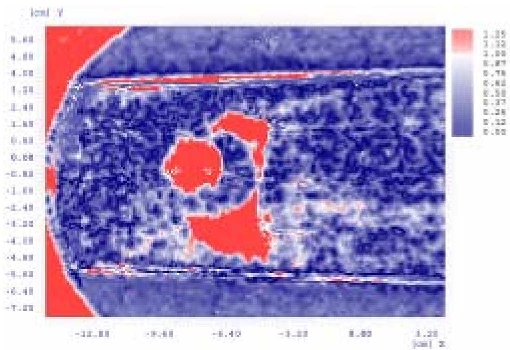
setup



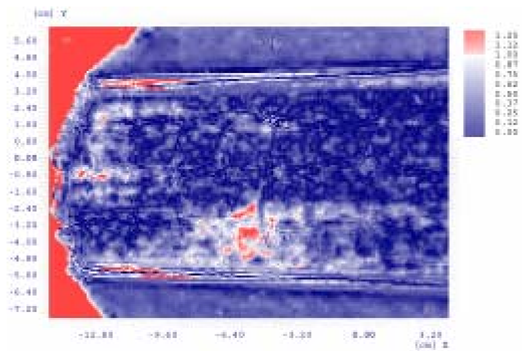
CT-slice



Monaco dose slice



global gamma (3%,3mm)



dm-dw corrected gamma (3%,3mm)

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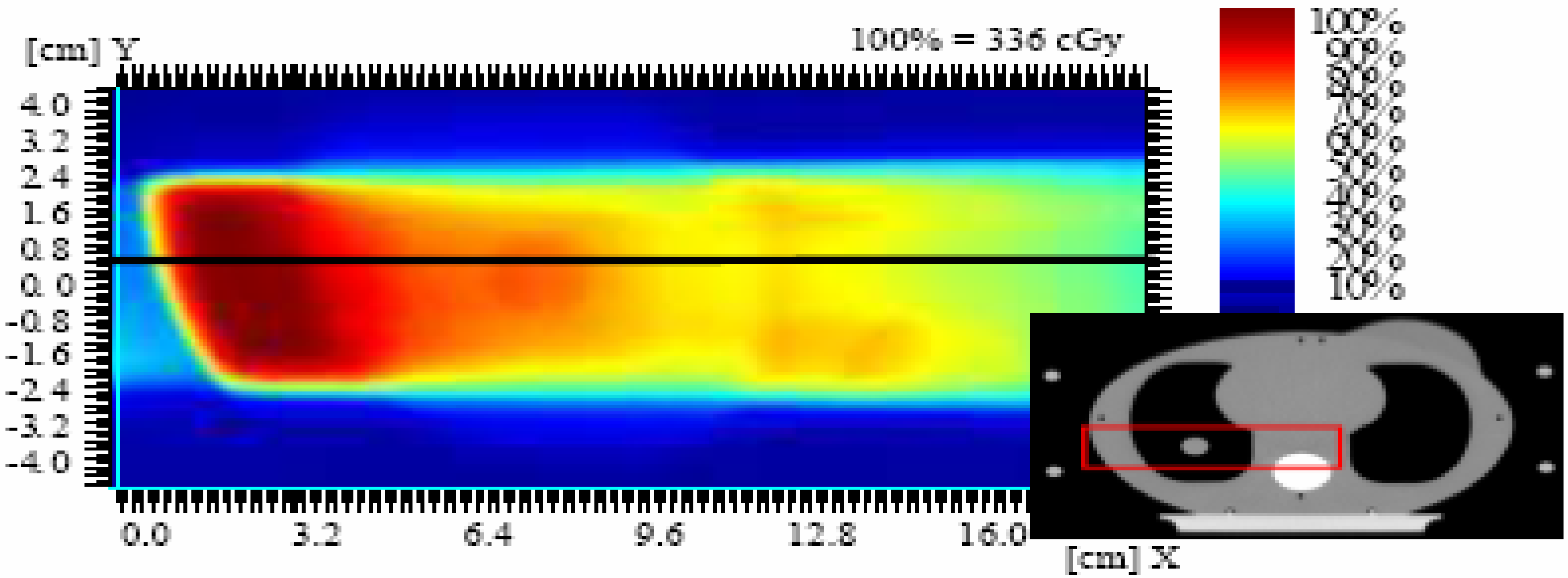
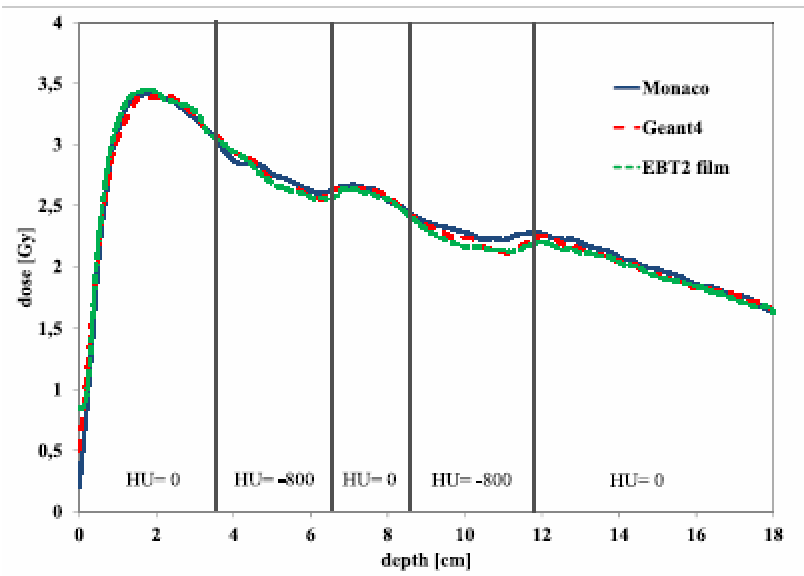
Fleckenstein et al., Z Med Phys, 2013





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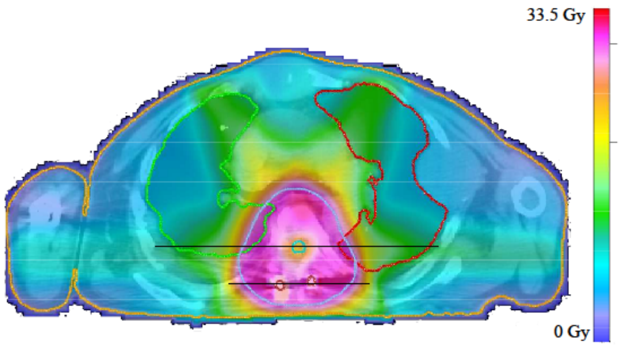
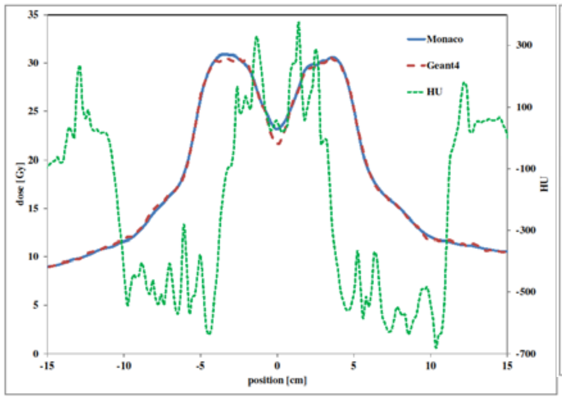
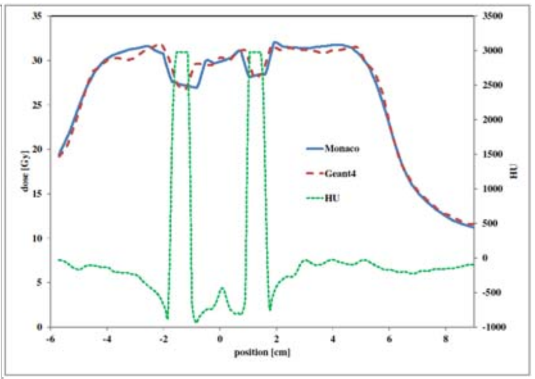
Fleckenstein et al., Z Med Phys, 2013

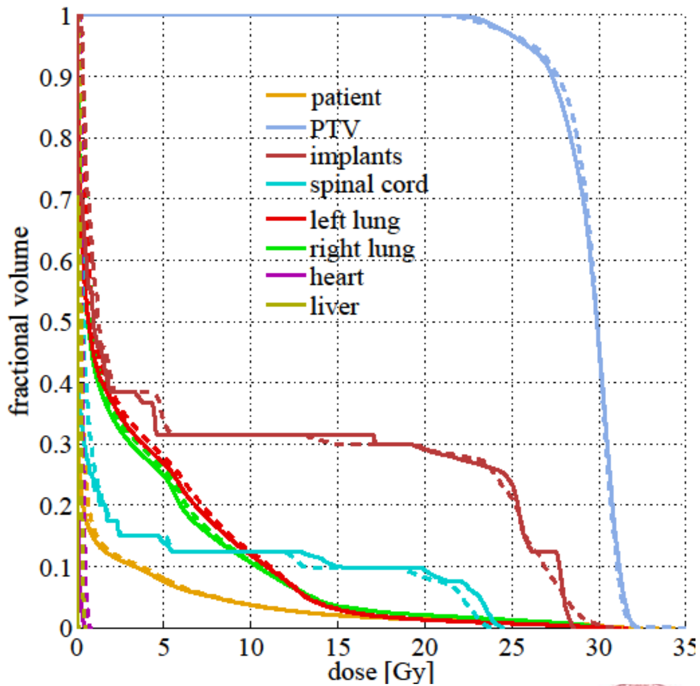
Monaco ® vs. Geant4
patient with metallic implants



mean deviation of the organs at risk:
(0.7 ± 0.3) % of D_{50}(PTV)
σ_{Monaco} = 0.4 %, σ_{Geant4} = 1.6 %







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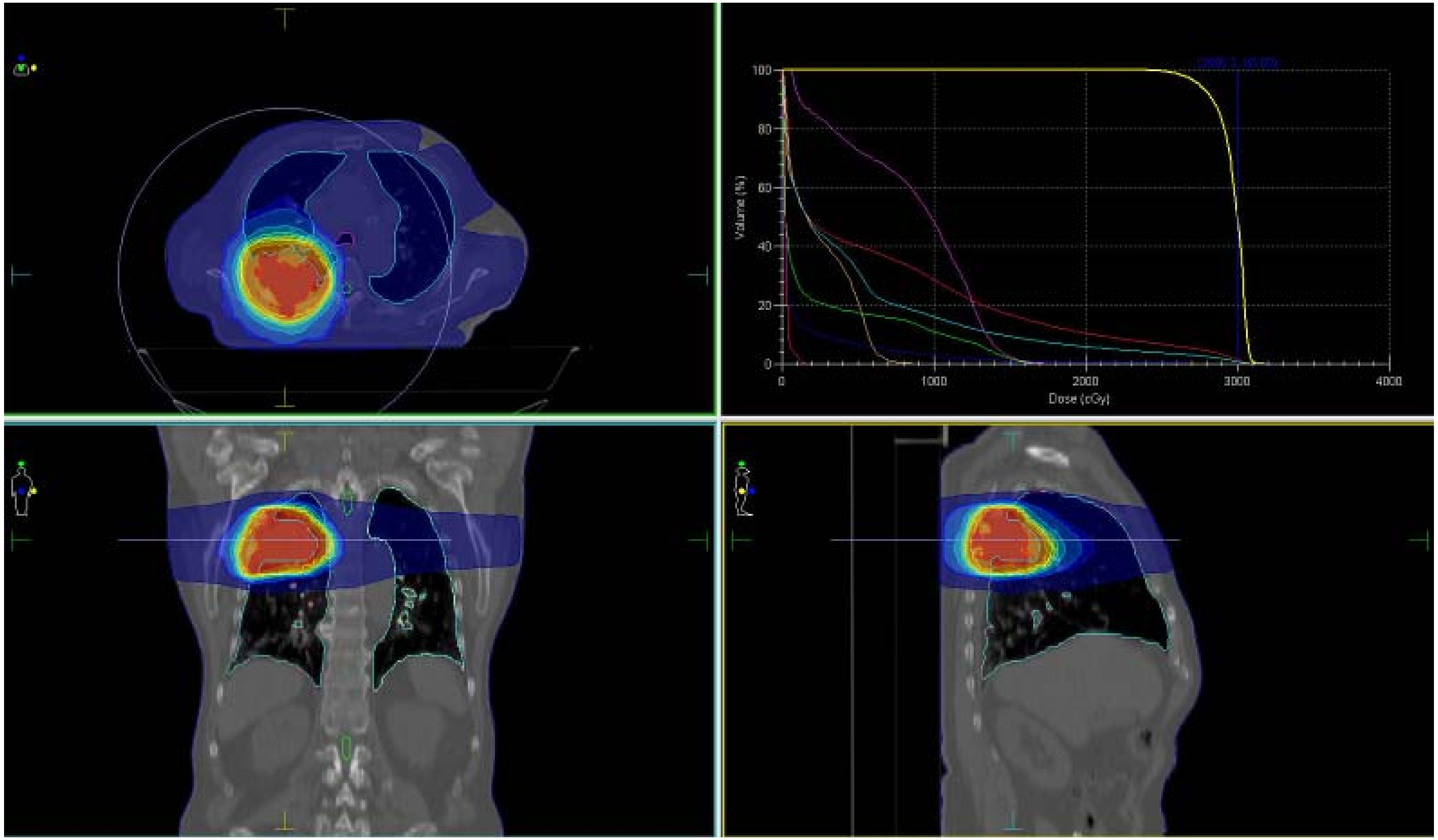
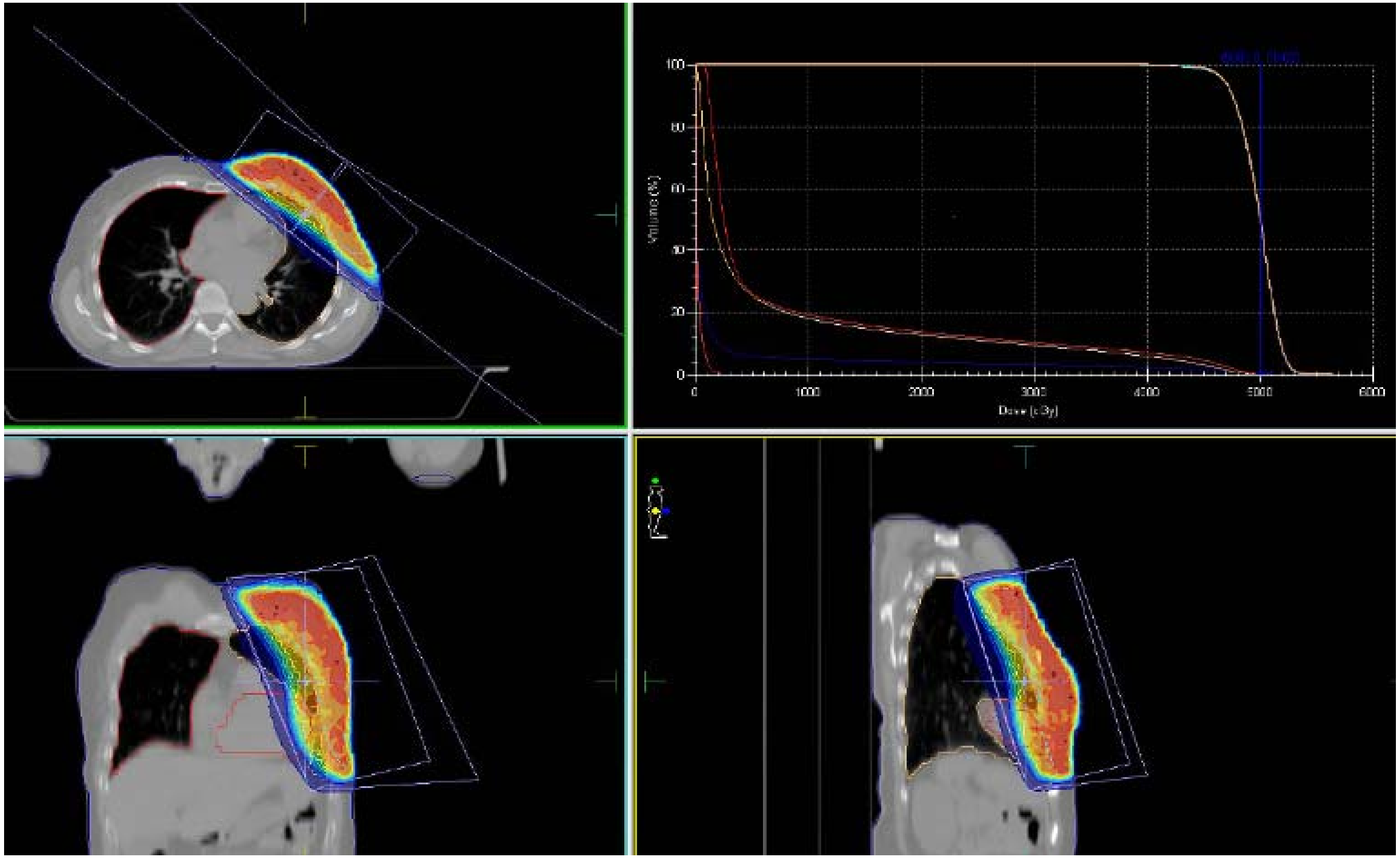
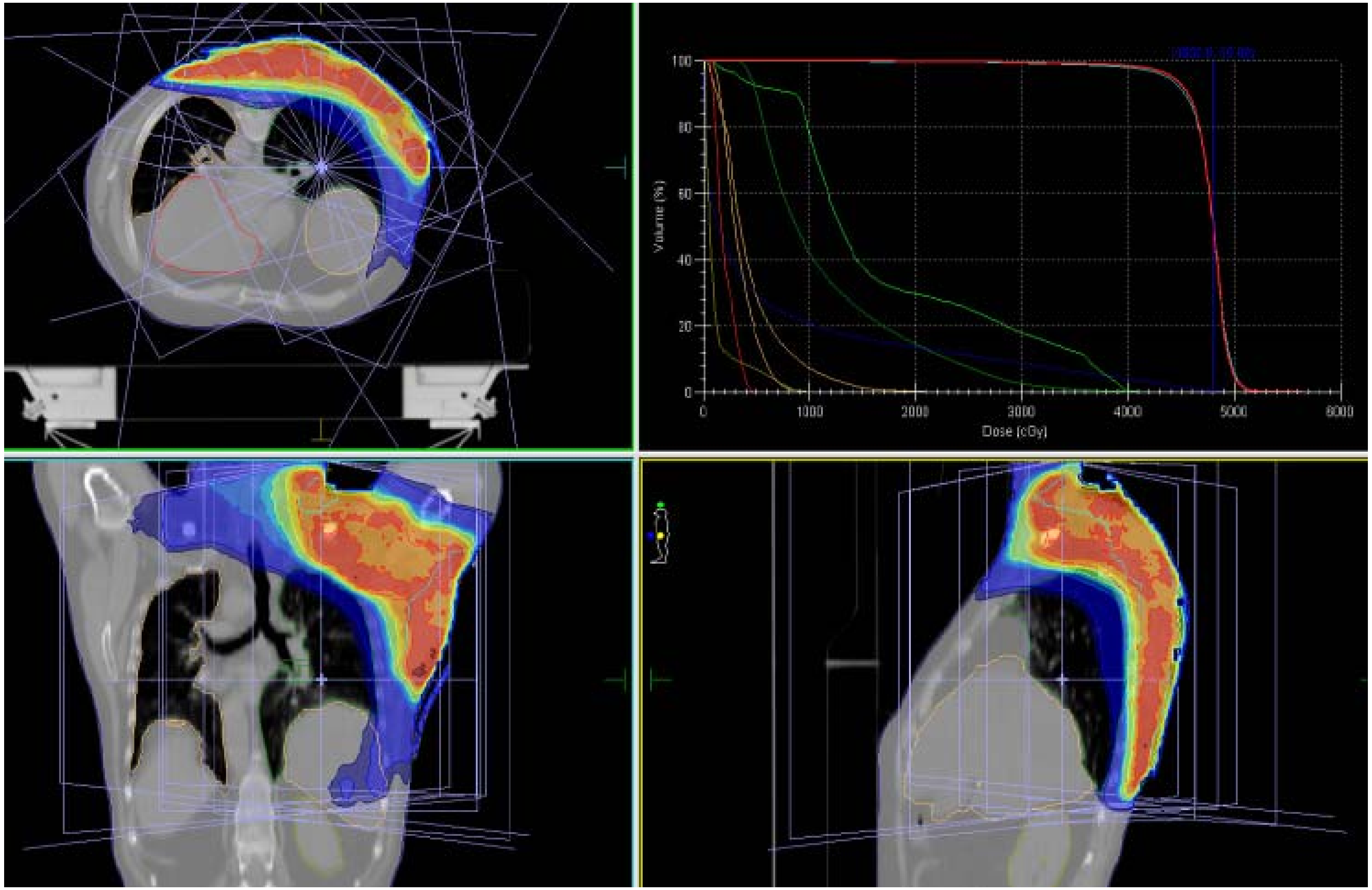
Lung Tumor boost



Breast will in a bit be exclusively tangential IMRT

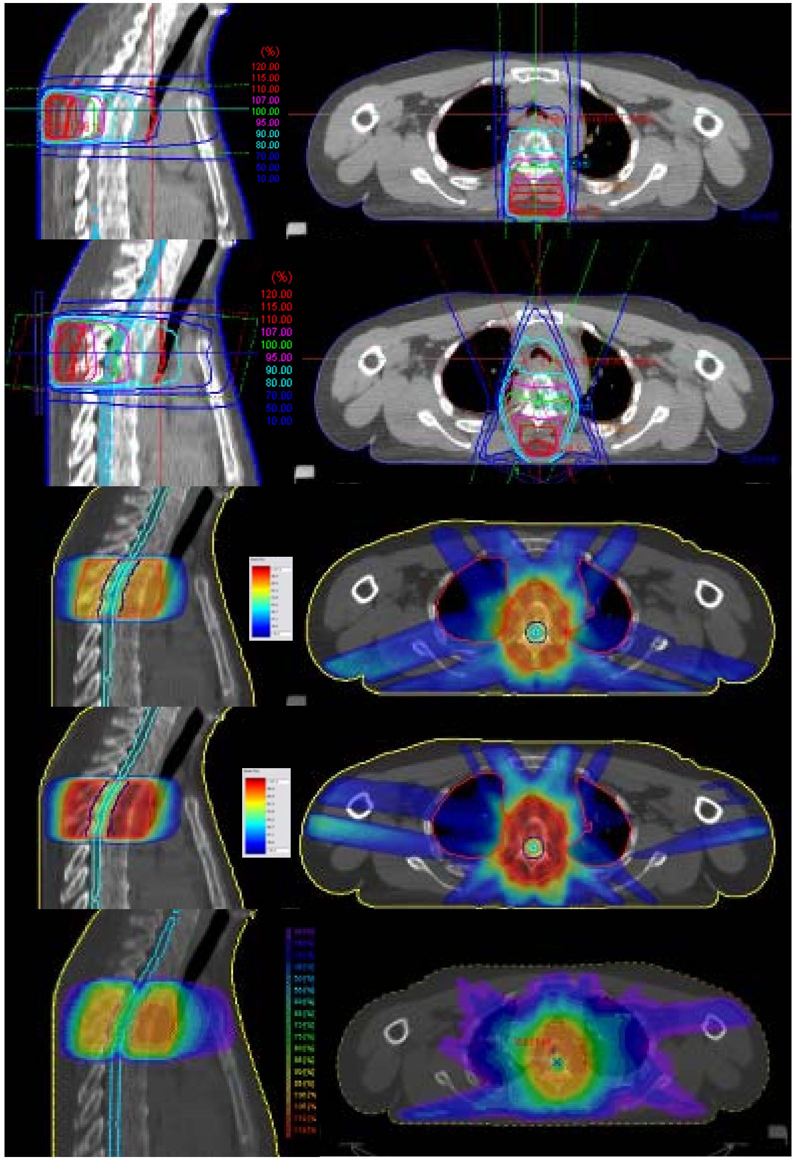


Cutaneous Melanoma Metastases



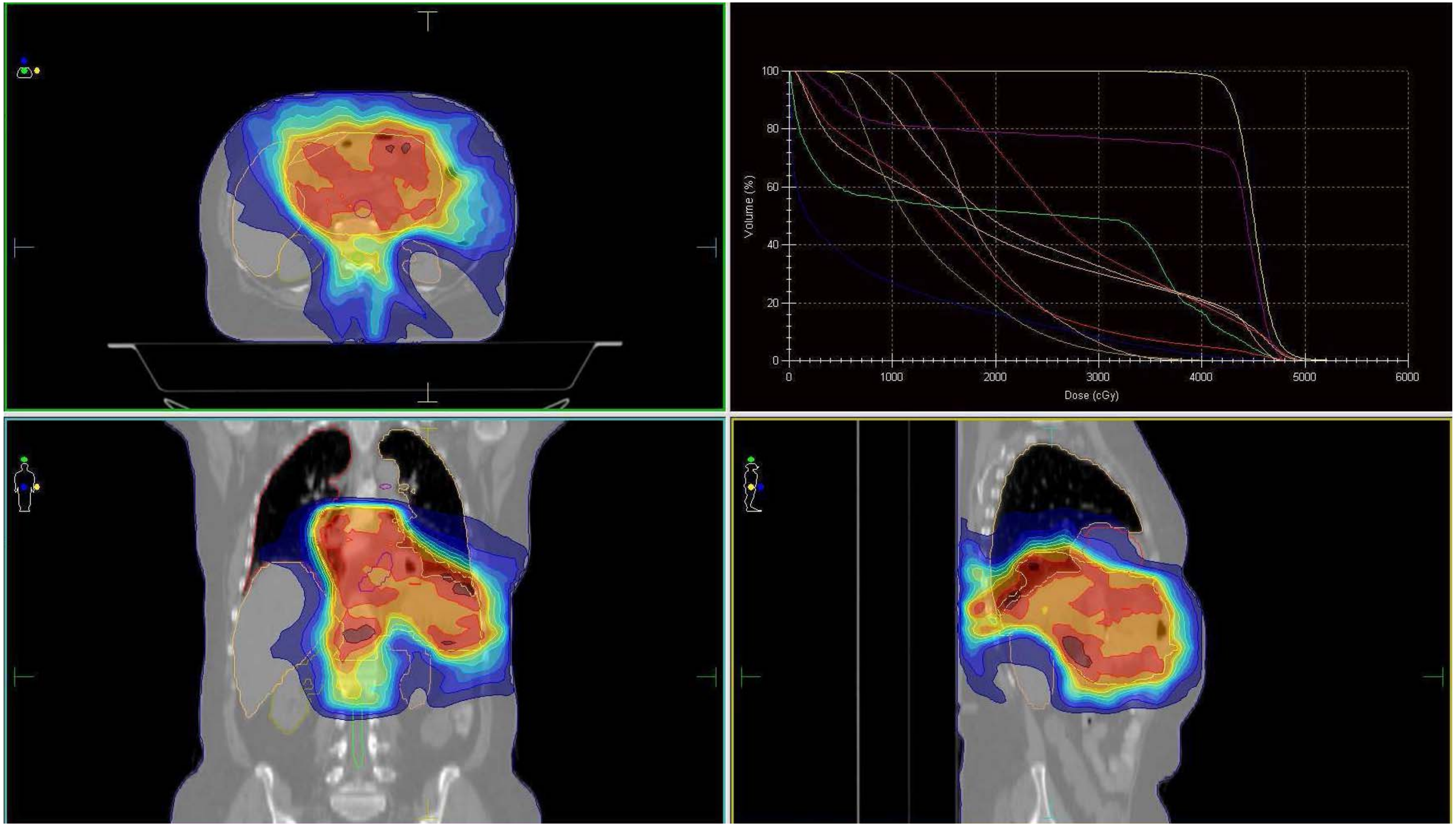
VMAT for Reirradiation of Paraspinal Tumors

	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

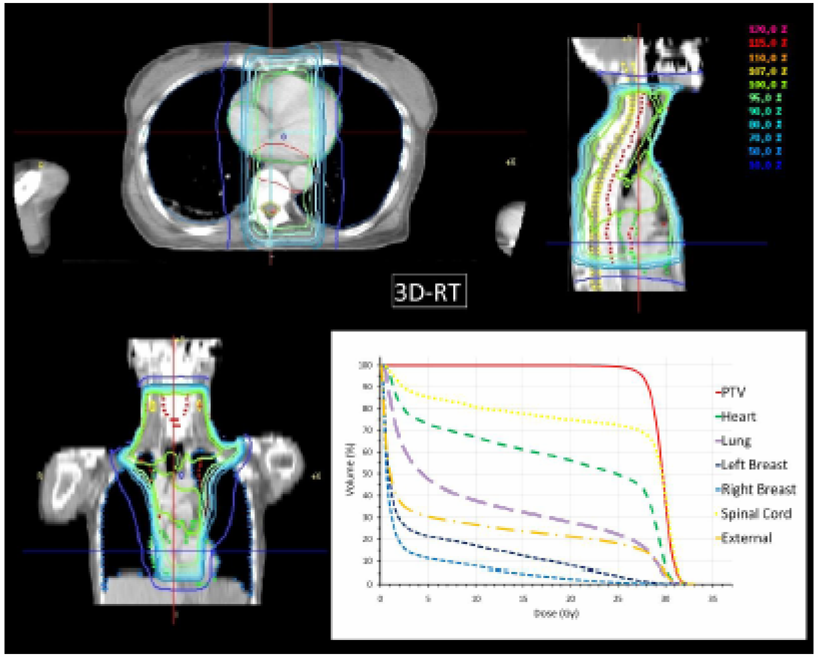


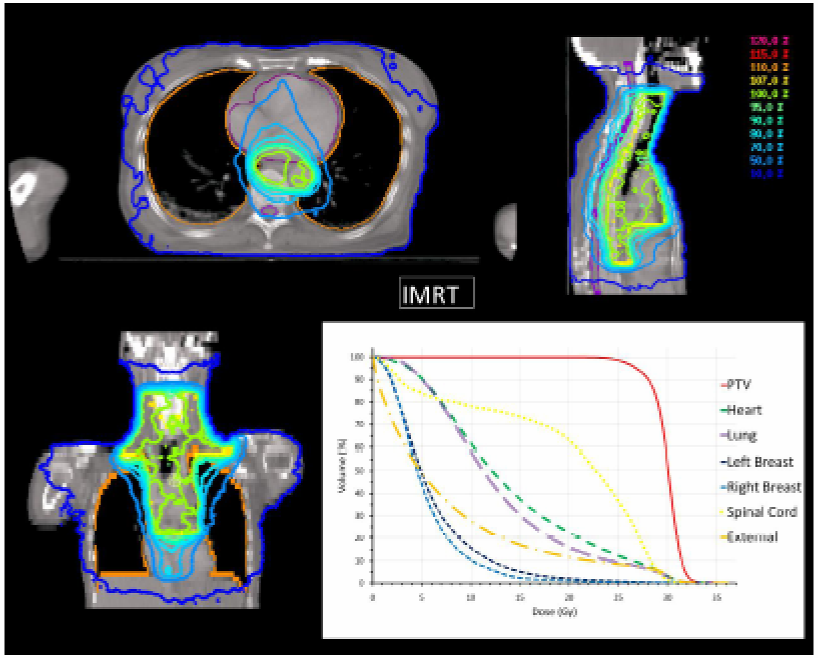
Stieler et al. SUON, 2011

Gastric Cancer



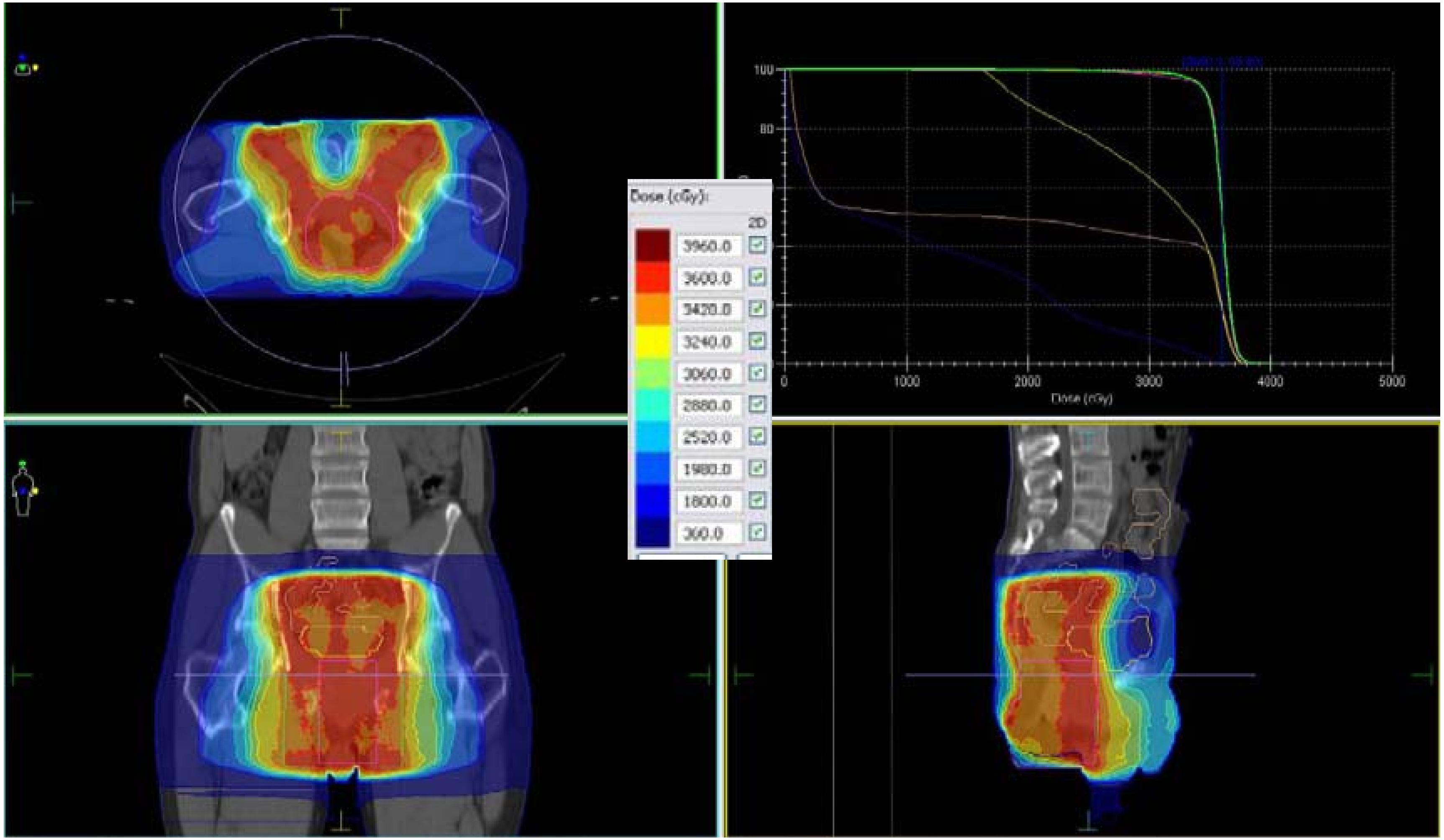
Hodgkin's Disease



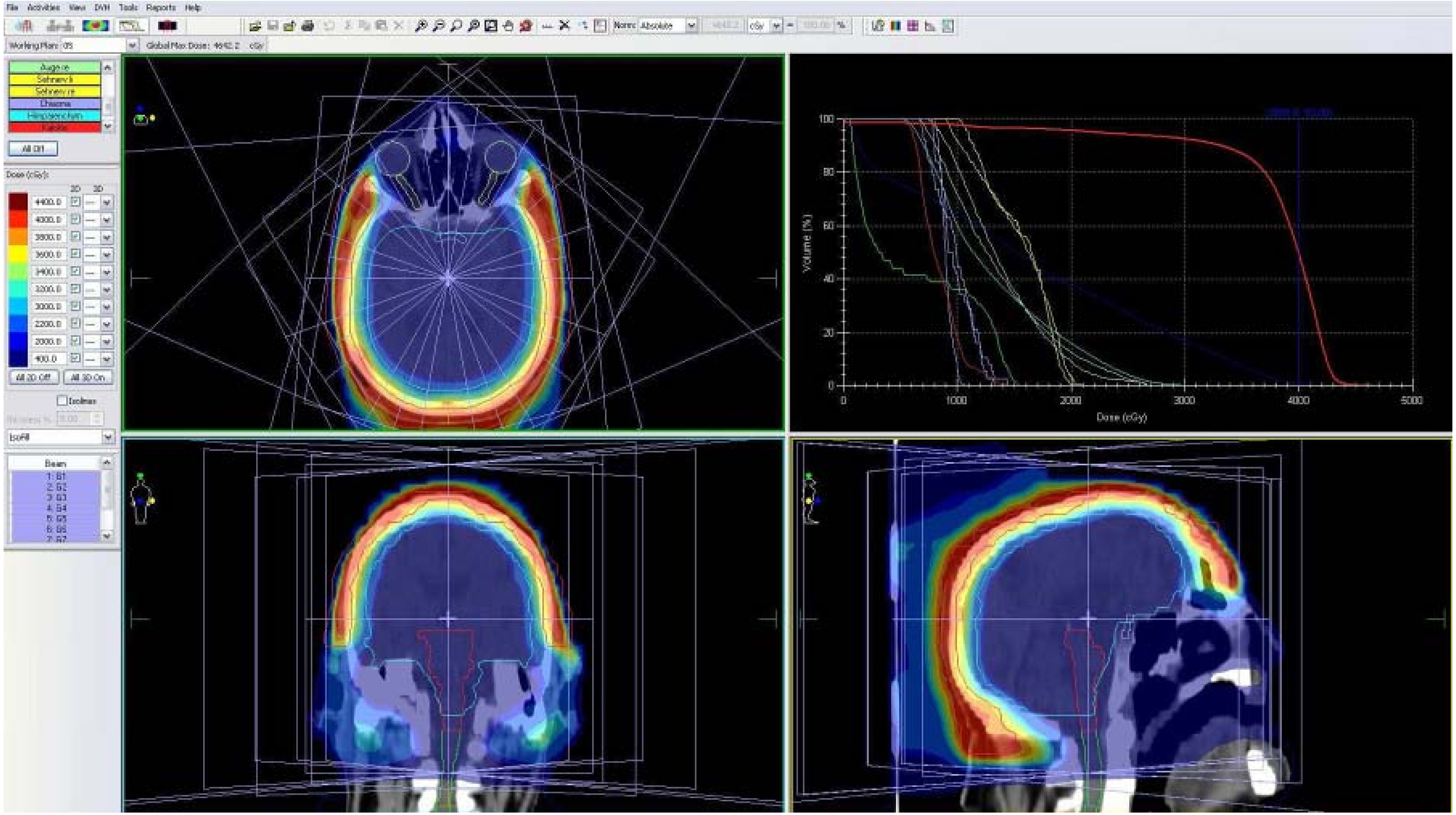


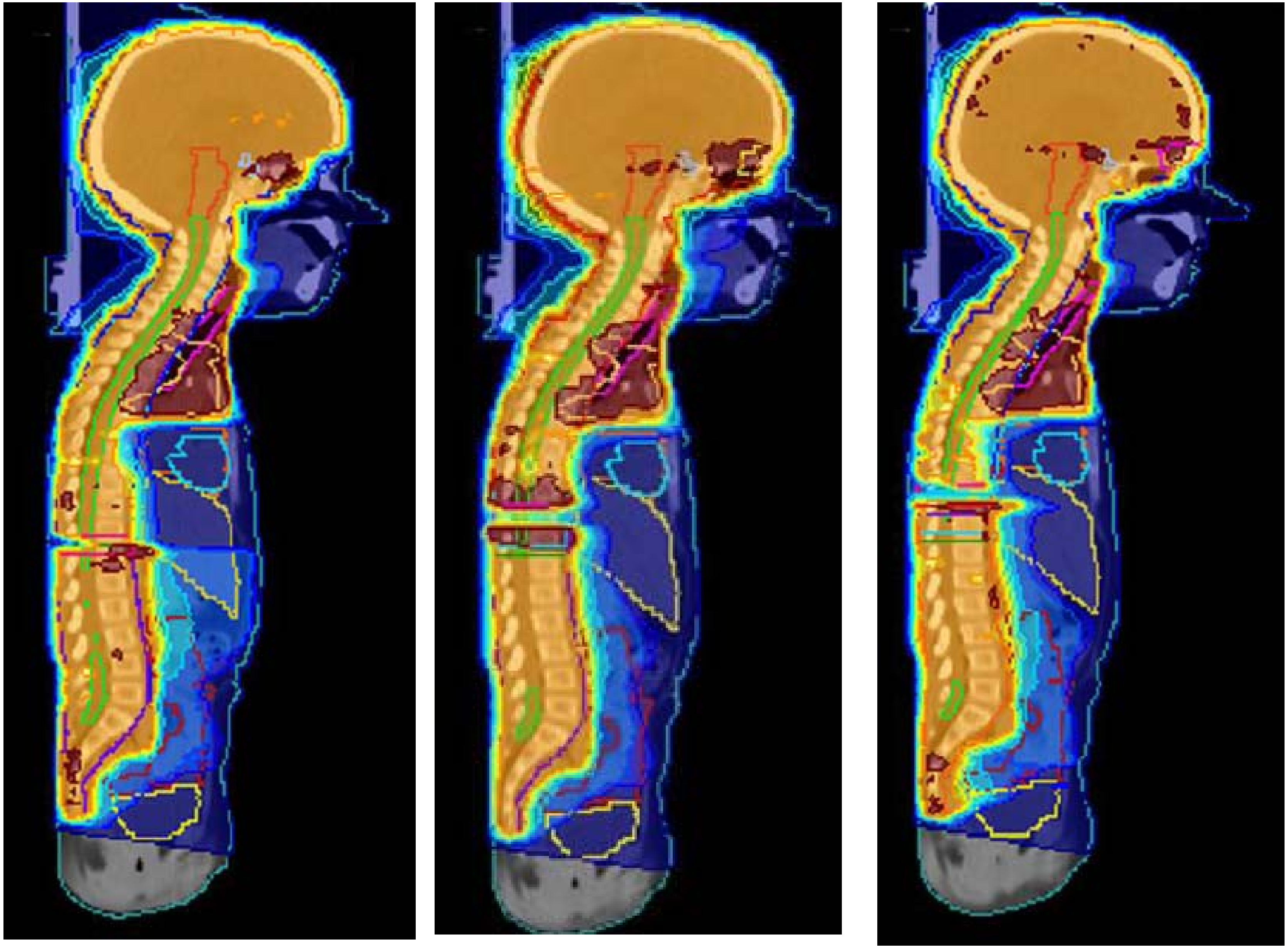
Koeck et al., IJROBP, 2012

Anal Cancer

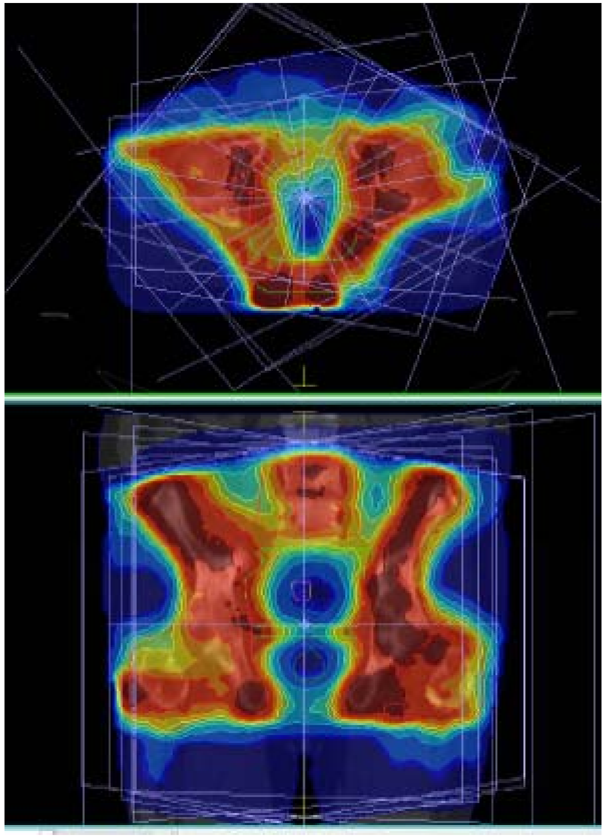


640 MU
BOT 8 min

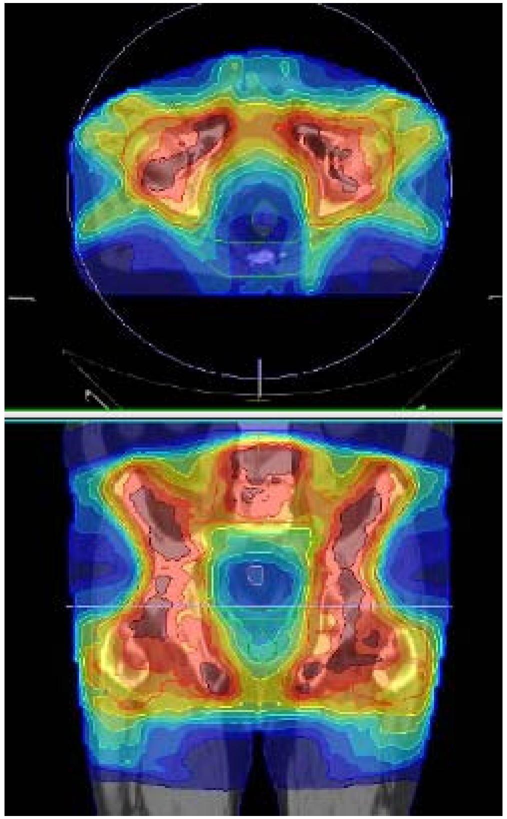




Static Gantry IMRT



VMAT



LB4
07.09.2010

#	Patient	ID1	Time (beam on + imaging)	Crs	Txd-Field	Mode	MU	Wdg MU	Dose	Wdg-Appl	Comp-FDA*	Block-Oth	V&R	I/O
100	Patient A	AAA	12:47	1	CT	X CT	0.0		0 cGy				vp	Out
101	Patient B	BBB	12:52	1	10ROT	6X VMAT 104C P	444.1	0.0	200 cGy				vf	Out
	Patient B	BBB	13:02	7	CT	X CT	0.0		0 cGy				vp	Out
102	Patient C	CCC	13:06	7	4ROT1	6X VMAT 91CP	848.1	0.0	200 cGy				vf	Out
	Patient C	CCC	13:13	1	CT	X CT	0.0		0 cGy				vp	Out
103	Patient D	DDD	13:23	1	2ROT1	6X VMAT 192C P	662.9	0.0	200 cGy				vf	Out
	Patient D	DDD	13:39	1	CT	X CT	0.0		0 cGy				vp	Out
104	Patient E	EEE	13:47	1	2ROT1	6X VMAT 189C P	775.3	0.0	200 cGy				ovf	Out

27 min. total treatment time, including cone beam CT and imaging.

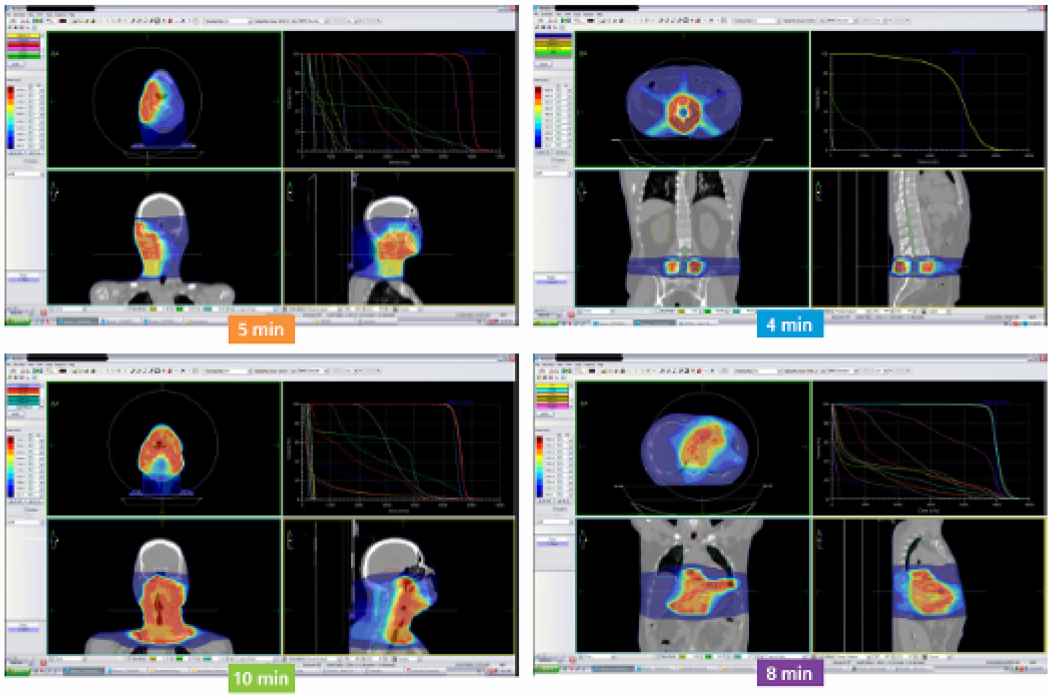


Figure 5. One hour routine treatment. Patient logistics vs. treatment time (IGRT + VMAT): 50% / 50%. Beam-on times between 2 and 7 minutes.

Clinical Commissioning of the new Elekta Agility

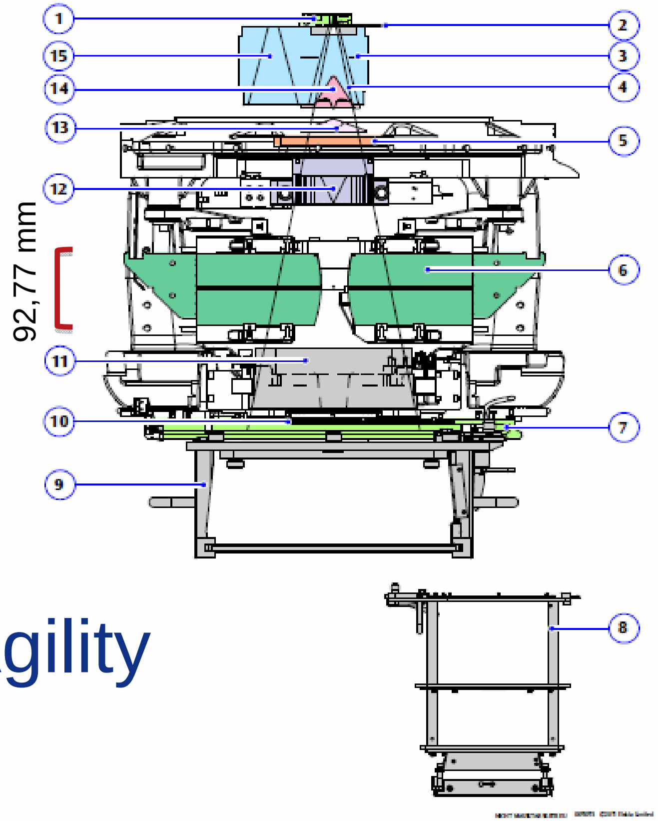
Dipl.Phys. MSc. Flavia Molina

Klinik für Strahlentherapie und Radioonkologie
Universitätsklinikum Mannheim
Medizinische Fakultät Mannheim
Direktor: Prof.Dr.F.Wenz

Properties of Agility

Lamellenzahl	160
Leaf width at Isocenter	5 mm
Maximum Field size	40 x 40 cm²
Minimum Field size	0,5 x 0,5 cm²
Maximum Leaf Speed	6,5 cm/s
Diaphragm-Speedt	9 cm/s
Transmission	< 0,5%
Interdigitation	possible

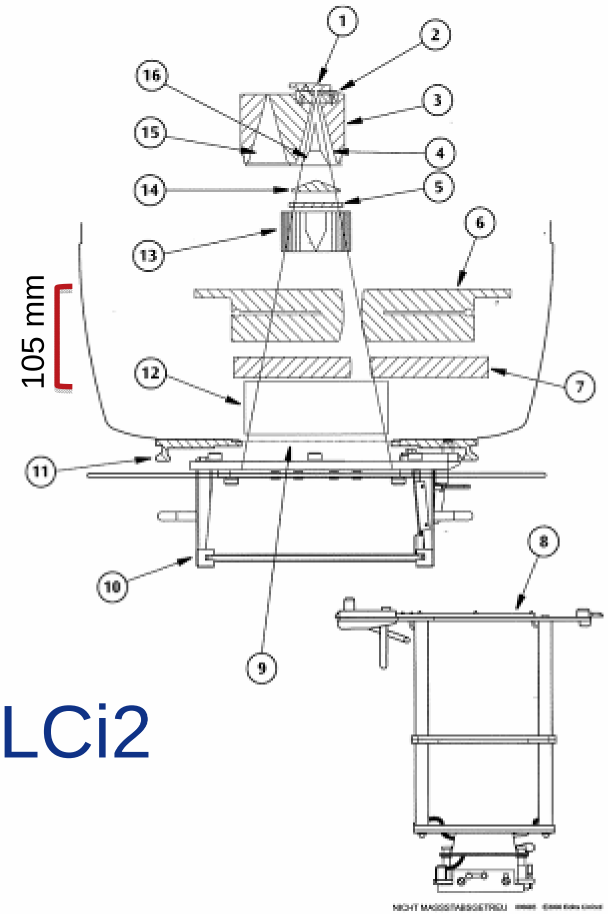
Modes of



Agility

Abbildung 11.1 Schematische Darstellung des Agility-Blendensystems (IEC 61217)

(1) Targetblock
(2) Primärer Feldausgleichsfilter
(3) Primärkollimator
(4) Port 1
(5) Ionisationskammer
(6) MLC-Leaves
~~(7) Zubehörring~~
~~(8) Elektronenapplikator~~
(9) Satellitenträger
(10) Mylar®-Fadenkreuzfolie
(11) Y-Blenden
(12) Motorisierter Keilfilter (mit Rückstreuplatte)
(13) Sekundärer Filter
(14) Differentialfilter
(15) Port 2

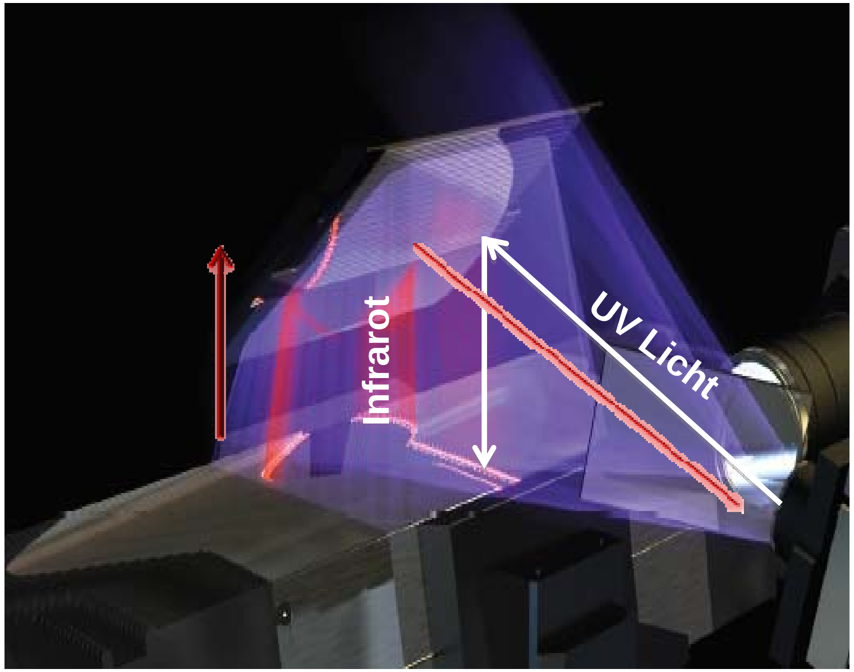


MLCi2

Abbildung 13.1 Schematische Darstellung von MLCi und MLCi2 (IEC 61217)

(1) Targetblock
(2) Primärer Feldausgleichsfilter
(3) Primärkollimator
(4) Port 1
(5) Ionisationskammer
(6) MLC-Leaves
(7) X-Backup-Blenden (Sekundärkollimatoren)
(8) Elektronenapplikator
(9) Mylar®-Fadenkreuzfolie
(10) Satellitenträger
(11) Zubehörring
(12) Y-Blenden (Sekundärkollimatoren)
(13) Motorisierter Keilfilter (mit Rückstreuplatte)
(14) Sekundärer Filter
(15) Port 2
(16) Differentialfilter

MLC Rubicon-System

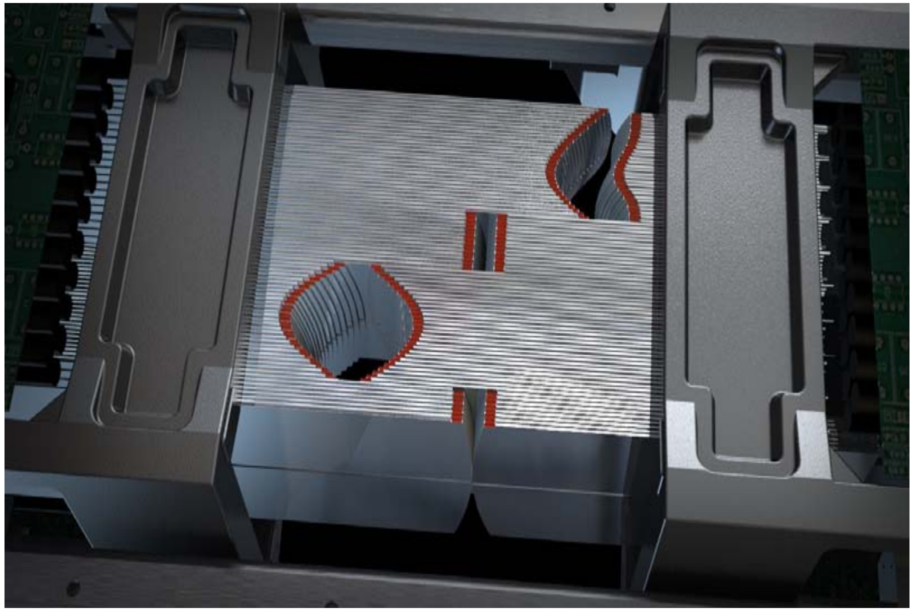


Leafspeed

- 160 Leaves x 5 mm at Isozentrum,
 über das gesamte 40x40 Feld.

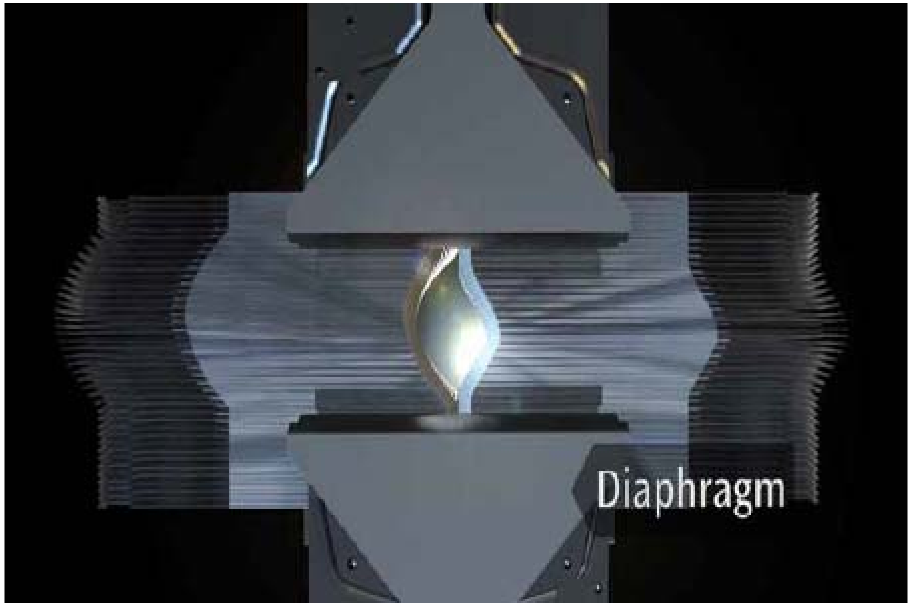
- Interdigitation and Island Shapes

- Maximum Leafspeed 6.5cm/s



Transmission

- Leakage < 0,5% over the whole field



Agility Kommissionierung I

1 Linac delivered in Mai 2012

Installation june/july 2012

Integrity 3.0

XVI R 4.5

IViewGT

Mosaiq 2.4.1

- **Photon Energy**
  - **6MV**
  - **10MV**
  - **18MV**

Elektron Energy:

- 6MeV

- 8 MeV

- 10 MeV

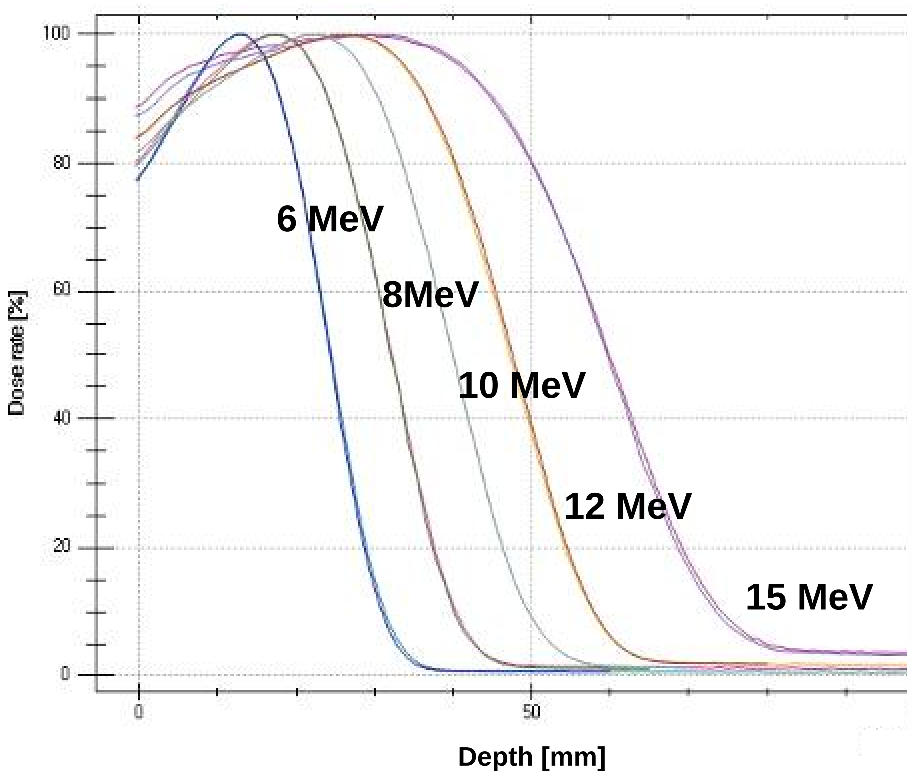
- 12 MeV

- 15 MeV

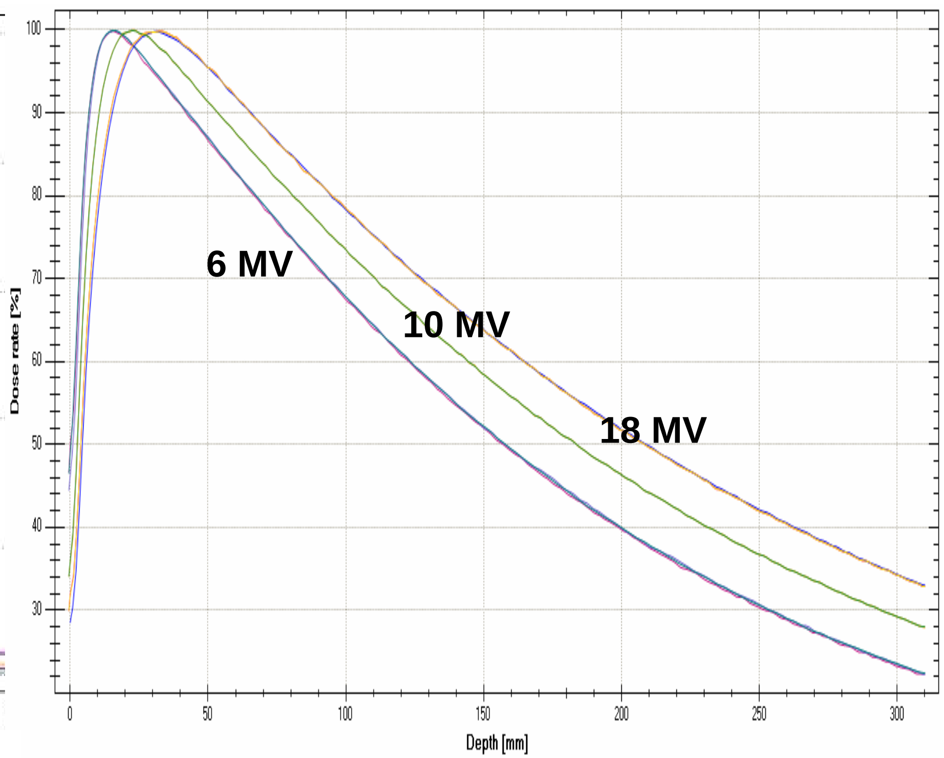
Filter free for Research since Oktober 2012

TDK Agility and MLCi2

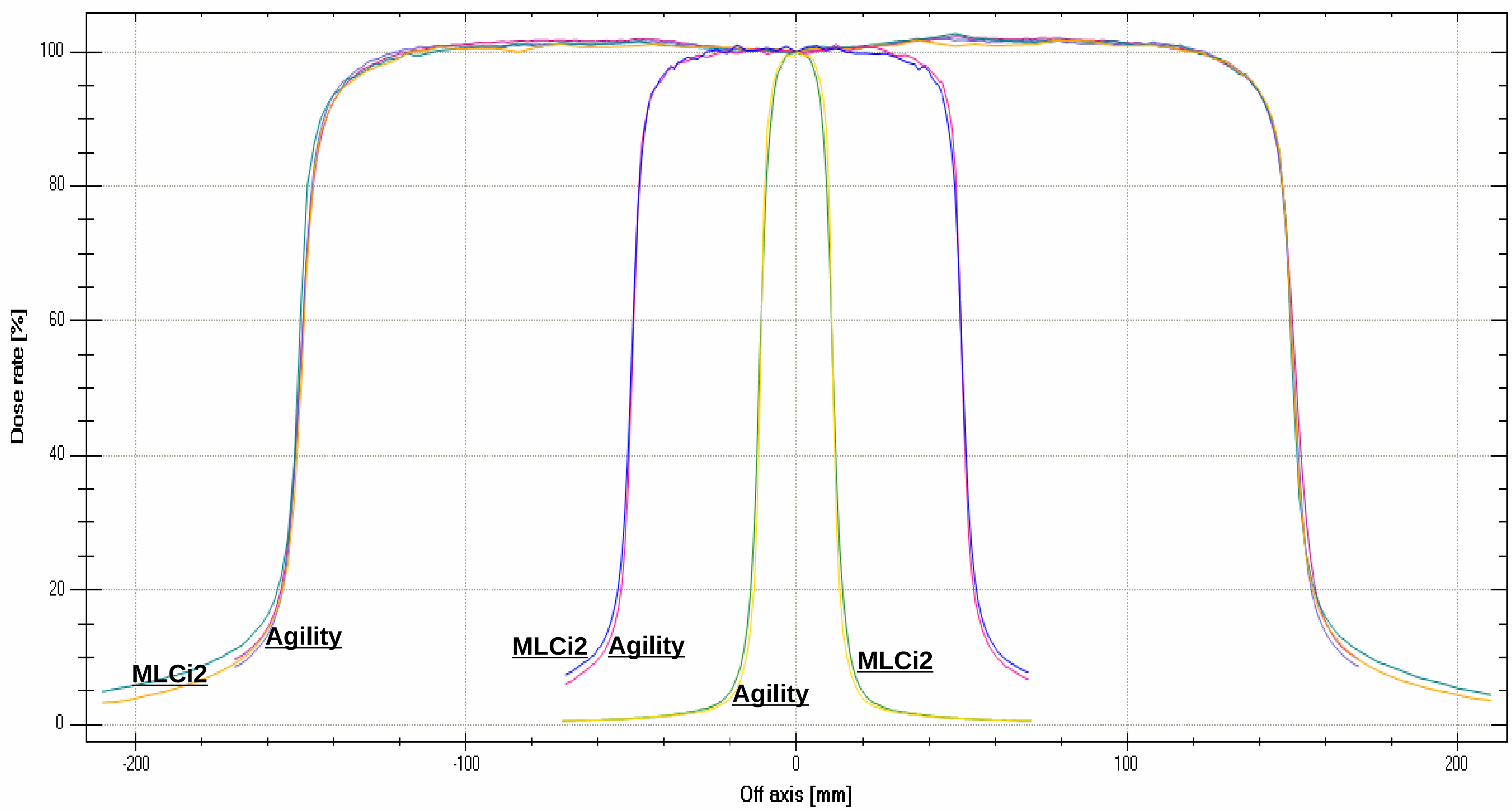
Elektronen



Photonen



In- Cross Plane Agility und MLCi2



Flattening filter free (FFF) with Monaco 3.3

F. Stieler, Ph.D.
V. Steil, F. Lohr, M.D.

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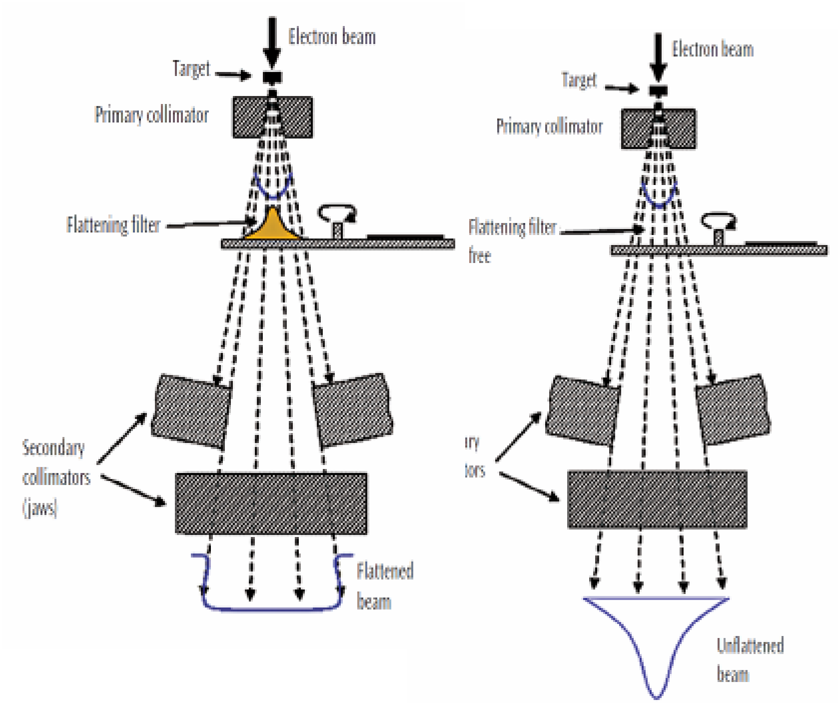
Universitätsklinikum Mannheim

FFF Development Work

The FFF pilot sites are
Middlesbrough, UK
Leeds, UK
Mannheim, Germany
Leeuwarden, Netherlands

The following sites were a part of the consortium
National Physics Laboratory, UK
Vienna, Austria
Birmingham, UK
NKI-AVL, Netherlands
Leeds, UK
Leeuwarden, Netherlands

Flattening filter free (FFF) mode



- FFF increases the dose rate for 6MV ~16 Gy/min, 10 MV ~22 Gy/min

- FFF beams have less variation of off-axis beam hardening

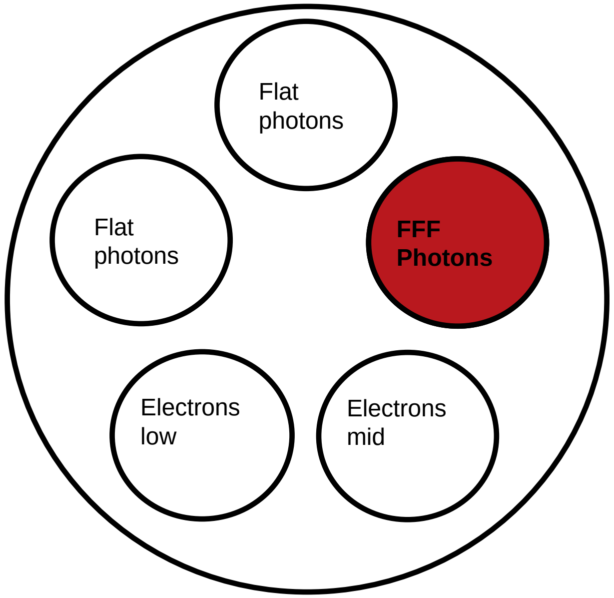
- FFF has less photon head scatter

- FFF has less leakage outside of beam collimation

*By courtesy of, Elekta Crawley

FFF Mannheim machine setup

Photonen (MV)	FF	FFF
X06	√	√
X10	√	√
X18	√	Ø
Elektronen (MeV)		
Low 04,06,08	√	√
Mid 10,12,15	√	√
High 18,20,22	Ø	Ø



FFF - Clinical application chain

Treatmentplanning

Monaco Version 3.3

Linear accelerator

Versa HD (Agility, Integrity vers. 3.1, FFF)

OIS System

Mosaiq Version 2.5

Limitations for Modulation in General

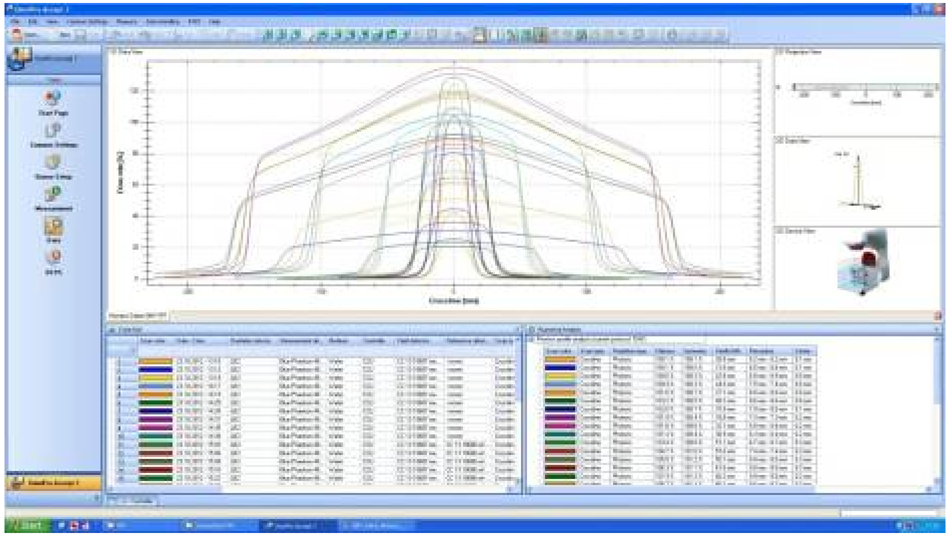
- Gantryspeed
    - Due to patient safety 1 rpm

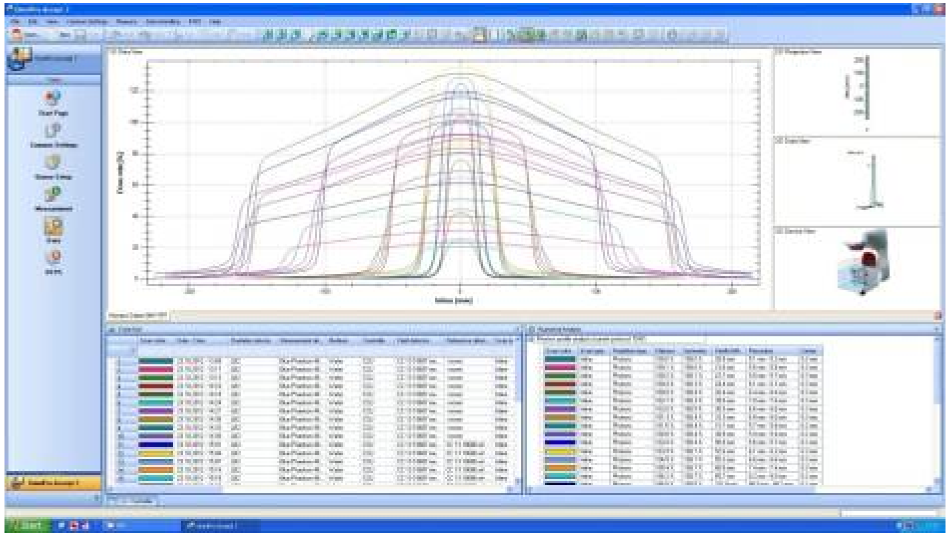
- Leafspeed
    - Agility MLC ~3 times faster than MLC2i

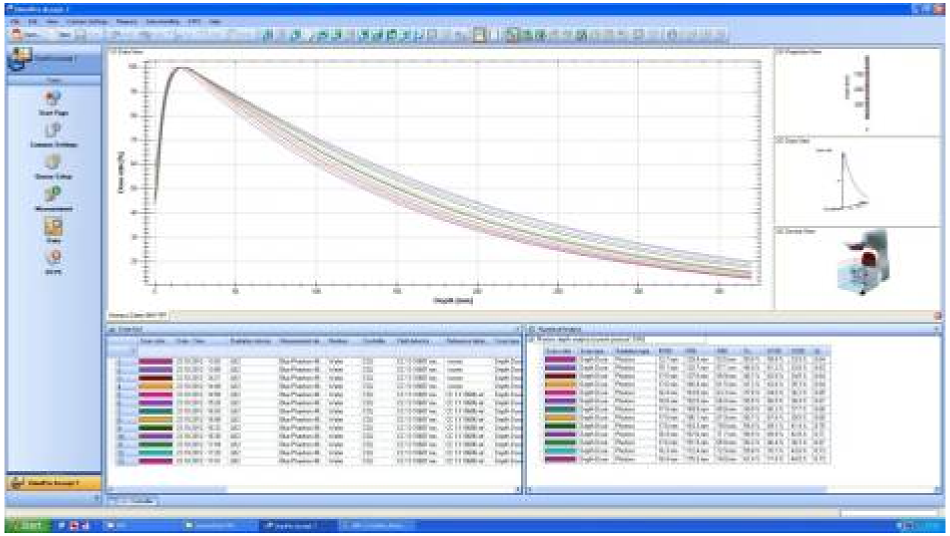
- Doserate
    - conventional ~ 6 Gy/min

MLC	Nr.of leafs	Leaf width isocenter	overtravel	Leaf speed	Leaf nominal height
Agility	160	0,5 cm	15 cm	0-3,5cm/sec up to 6,5 cm/sec * *Combined with leaf guide	9 cm
MLC2i	80	1,0 cm	12,5 cm	0-2,0 cm/sec.	8,2 cm

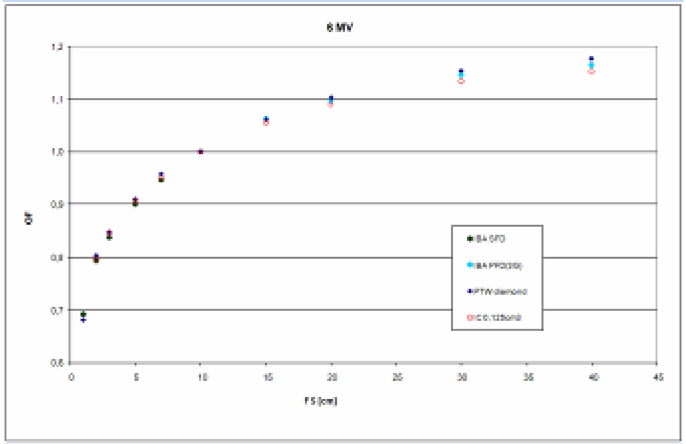
FFF – Basic data for Monaco 3.3, e.g.6 MV

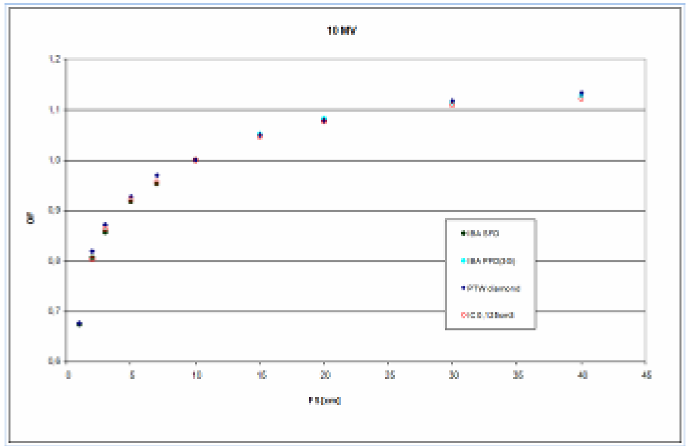






FF / FFF – Validation output factors
Monaco 3.3 vers. Measurements 6 /10 MV

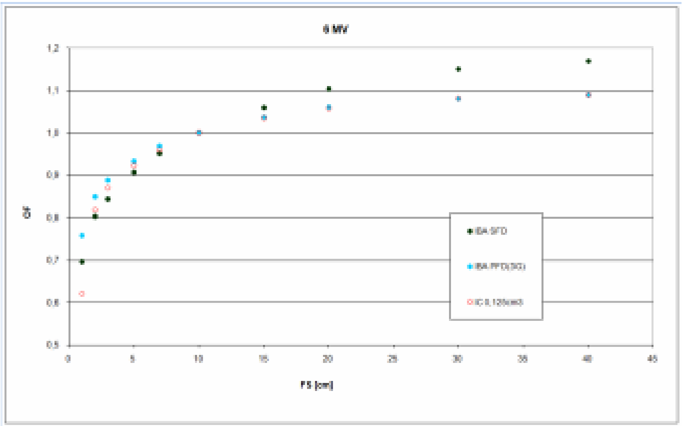


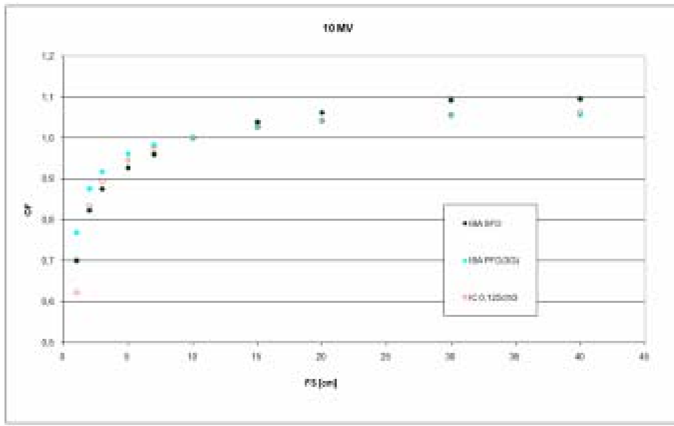


FF - mode

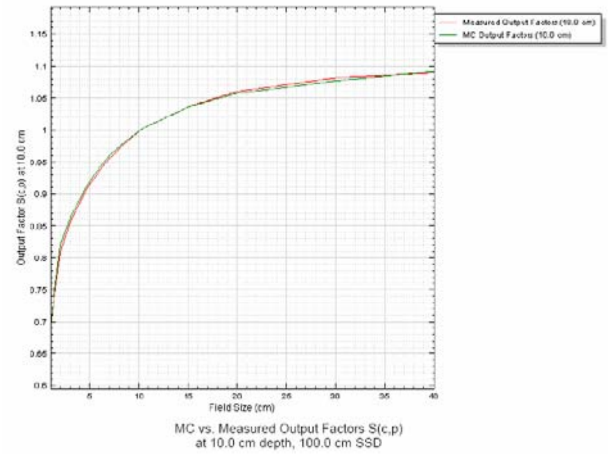
- IBA SFD
- IBA PFD(3G)
- PTW diamond
- IC 0,125cm3

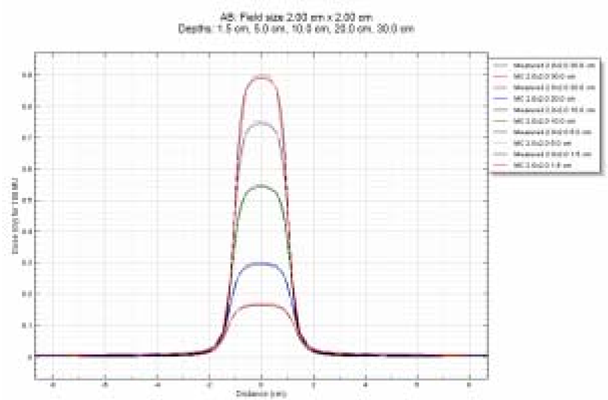
FFF - mode

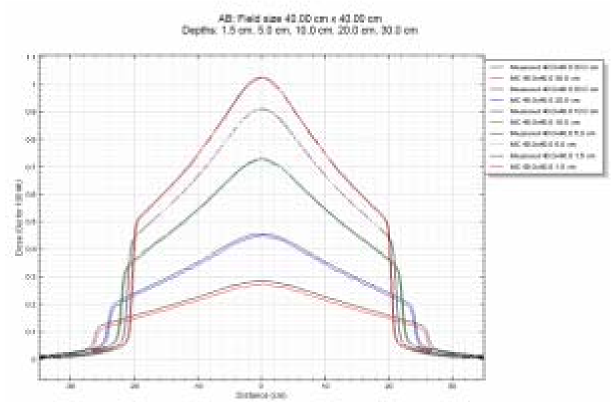


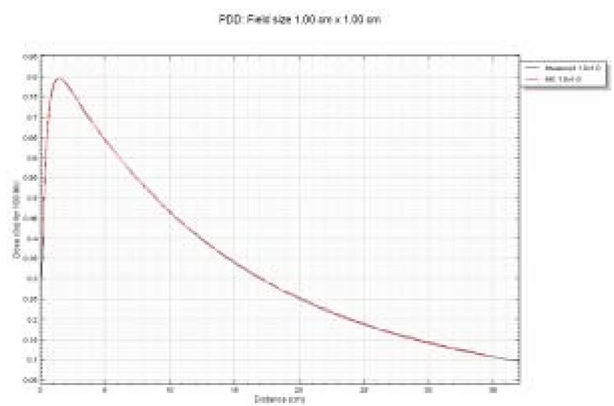


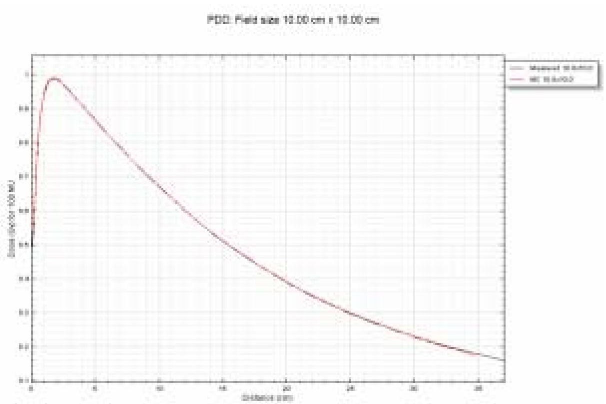
FFF – Validation measured vers. calculated data e.g. 6 MV

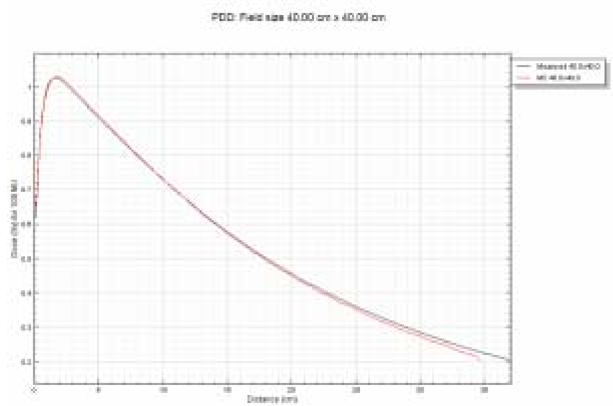












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Wang, IJROBP, 2012

Surface Dose

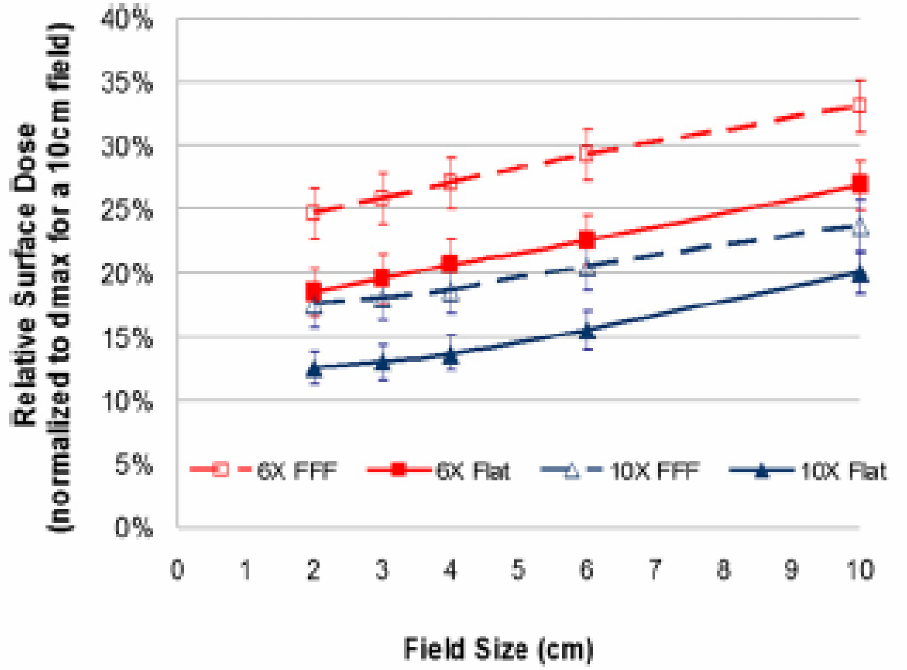

Fig. 1. Relative surface dose (D_0/D_{max}) increases linearly with the field size (~1%/cm^2) for both 6X and 10X flat and FFF photon beams (error bar = standard deviation). The surface output factors for field sizes 2 × 2 ~ 10 × 10 cm^2 show 6X FFF > 6X Flat > 10X FFF > 10X Flat, which have zero-field-size surface doses of 22.8%, 16.4%, 15.7%, and 10.2%, respectively. FFF = flattening filter-free.

Peripheral Dose

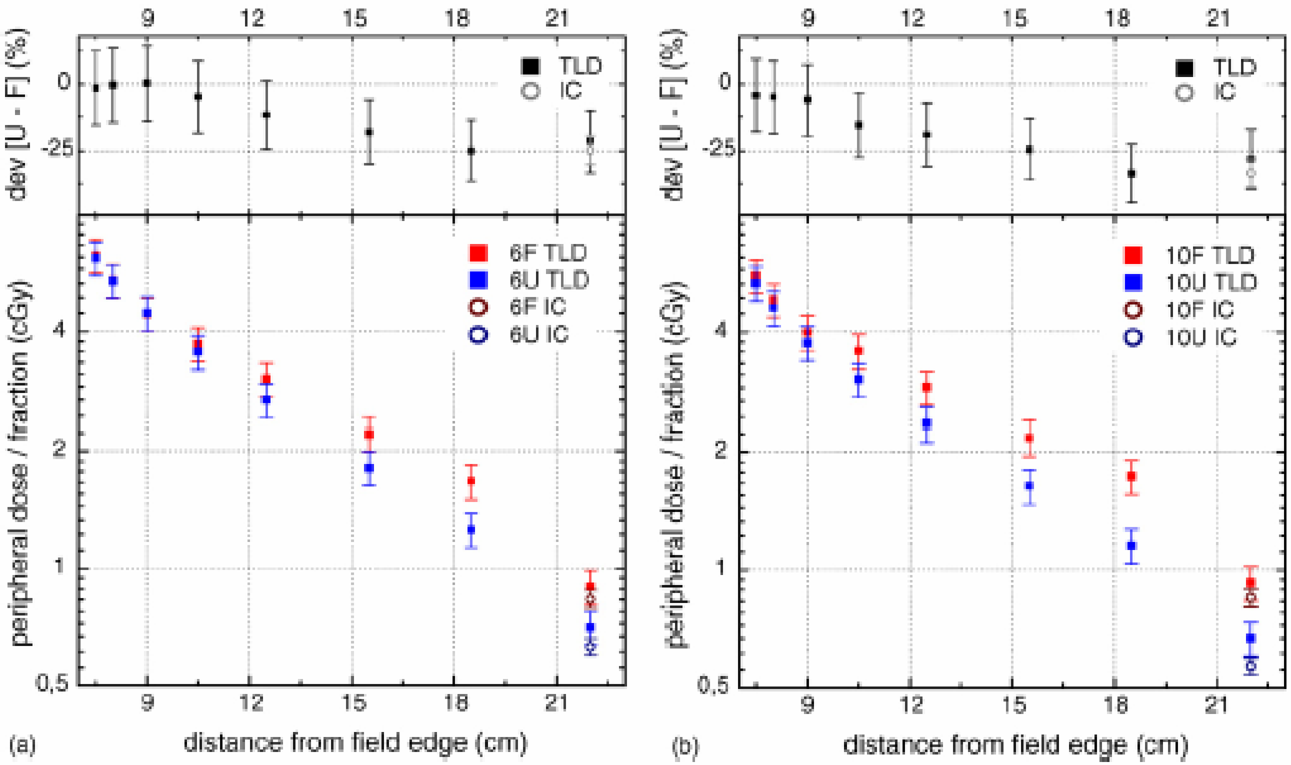

Figure 5. Results of peripheral dose measurements (in the isocentric plane) as a function of the distance from the field edge for the lung SBRT plans with a) 6 and b) 10 MV flattened and unflattened beams. The relative percentage reduction in peripheral dose (dev [U - F]) achieved by using FFF beams when compared to FF beams is indicated in gray in the top part of the figure.

Kragl et al., Z Med Phys, 2011

Peripheral Dose

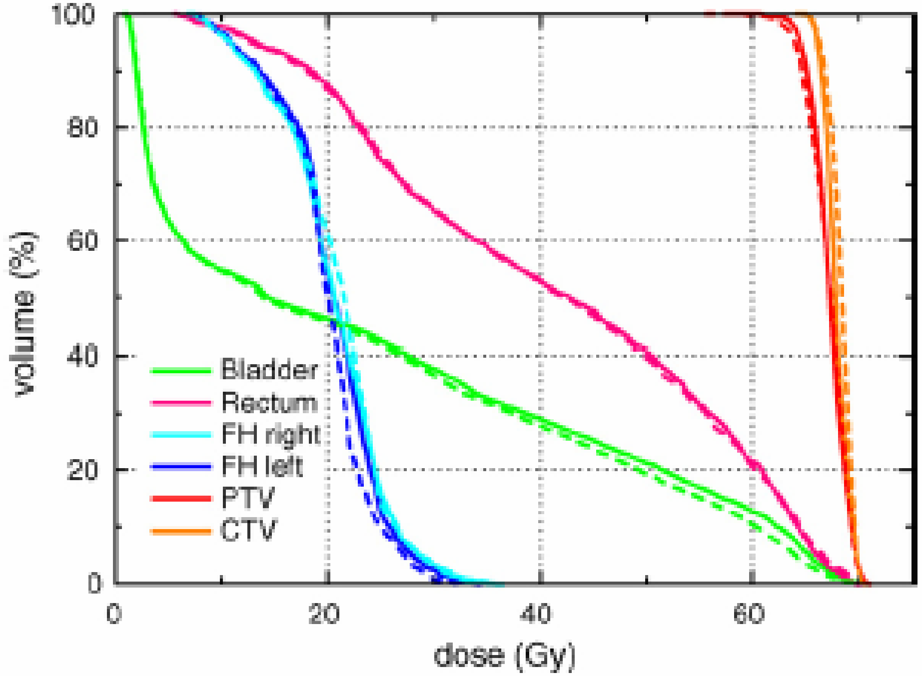

Figure 4. Comparison of DVHs for the prostate IMRT case using FF (solid lines) and FFF beams (dashed lines). The plans were normalized in order to result in the same mean dose to the PTV.

Kragl et al., Z Med Phys, 2011

Commissioning FFF with Monaco 3.3 and Agility

F. Stieler
J. Fleckenstein

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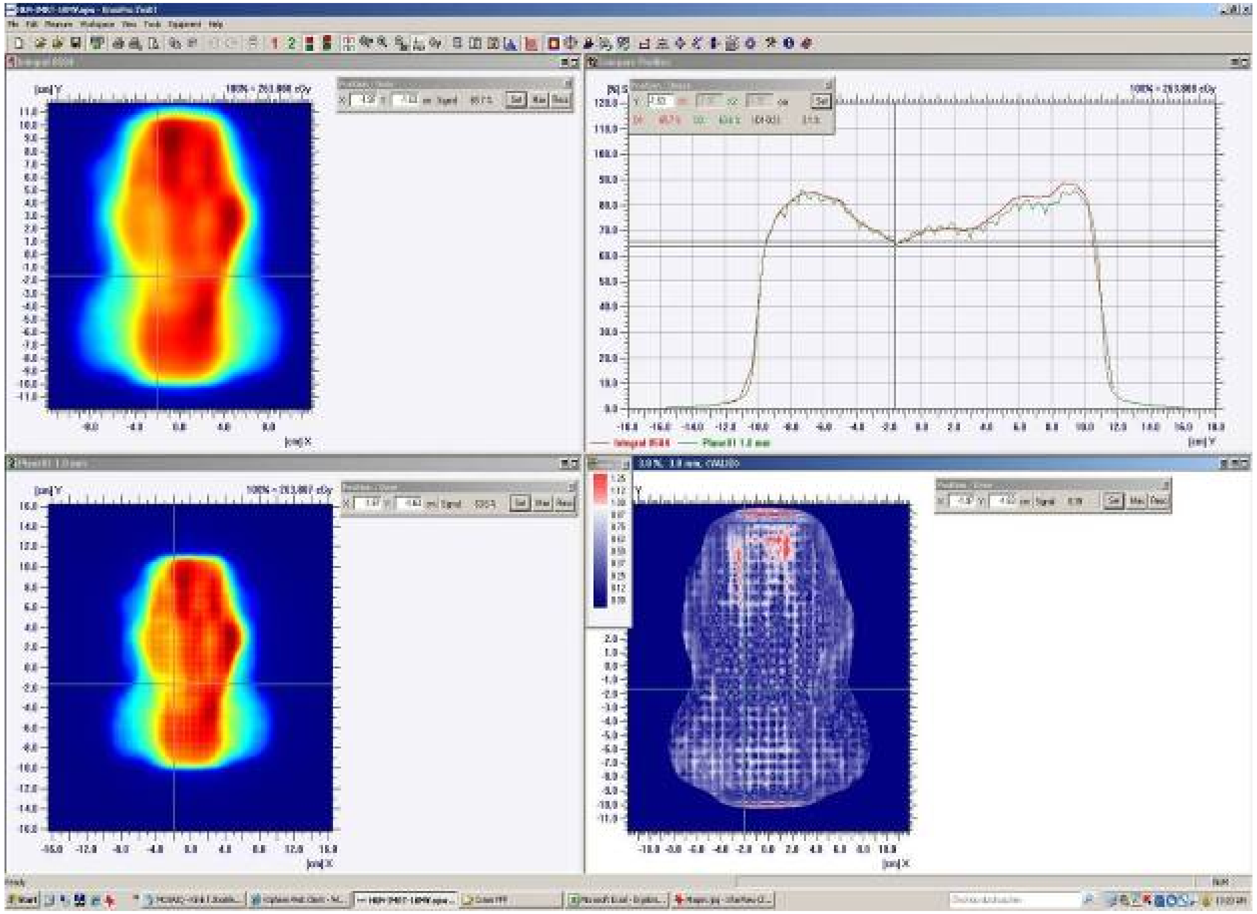
Larger volume Head & Neck
6MV FFF – IMRT 9 Beams- 2Gy

Gamma 33:
97,95%

Gamma 55:
99,99%

collapsed

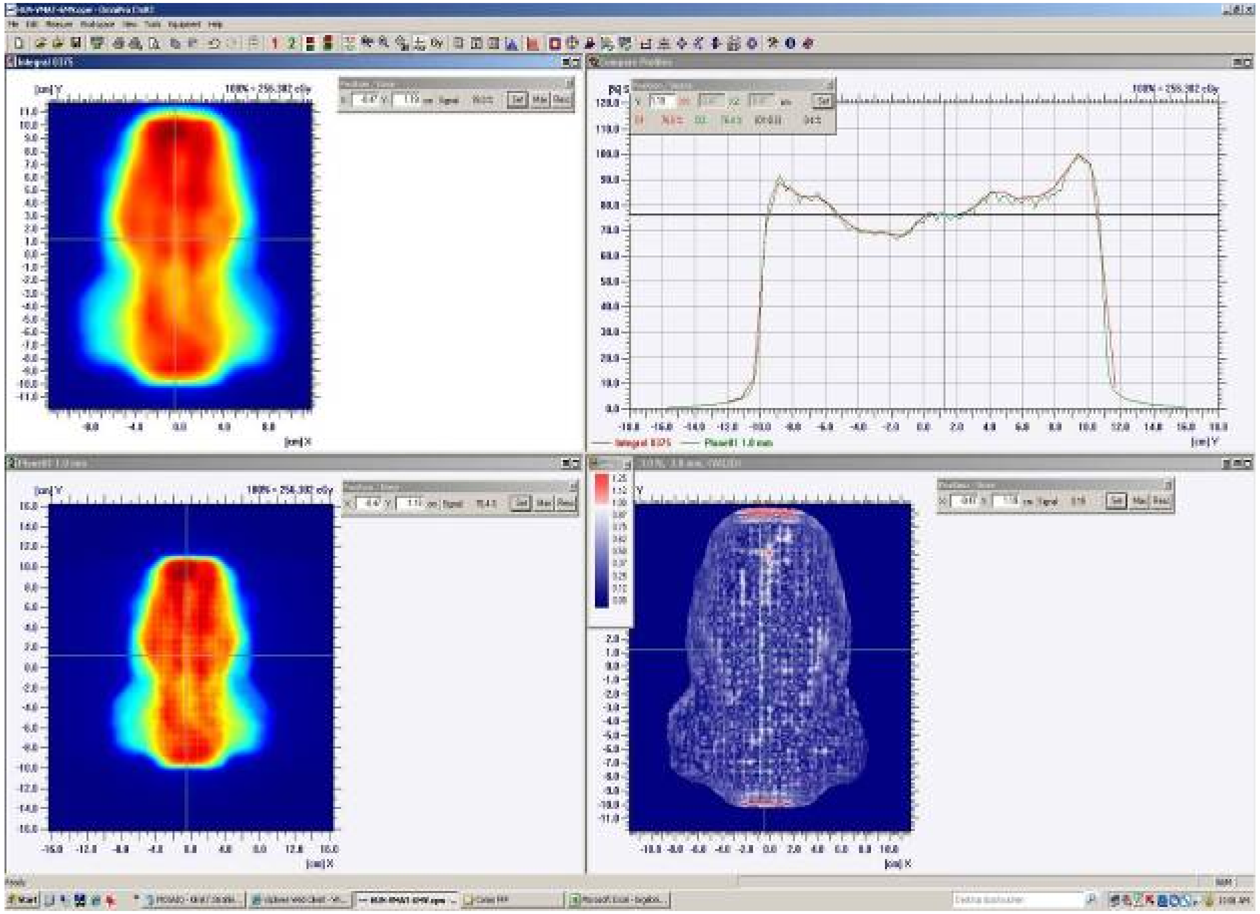


Larger volume
Head & Neck 6MV FFF – VMAT 2 Arcs – 2Gy

Gamma 33:
98,99%

Gamma 55:
99,91%

collapsed



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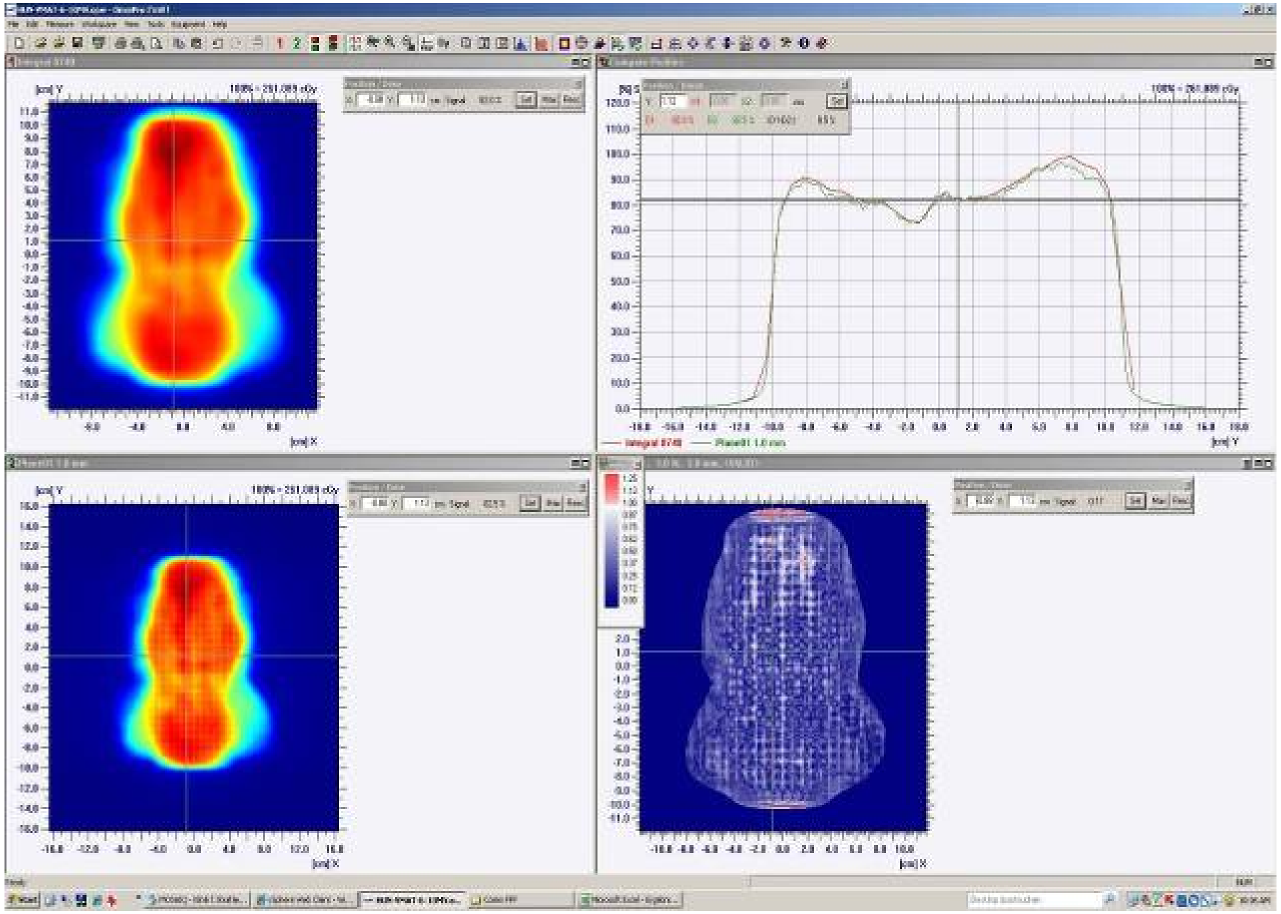
Larger volume
Head und Neck – 6&10MV FFF – VMAT 2 Arc – 2Gy

Gamma 33:
99,19%

Gamma 55:
99,98%

collapsed

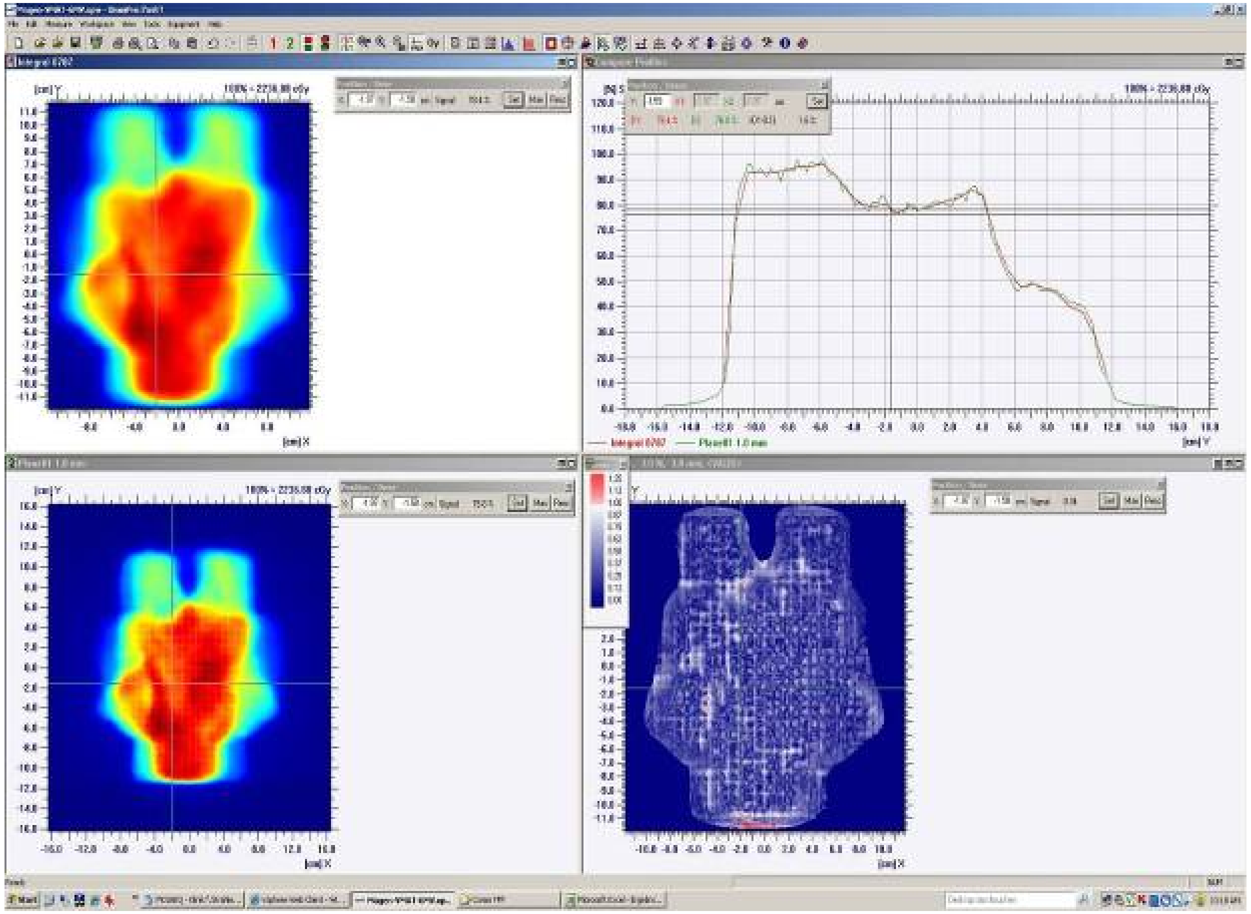


Larger volume stomach
6 MV FFF – VMAT 2Arcs – 15Gy

Gamma 33:
99,48%

Gamma 55:
100%

collapsed



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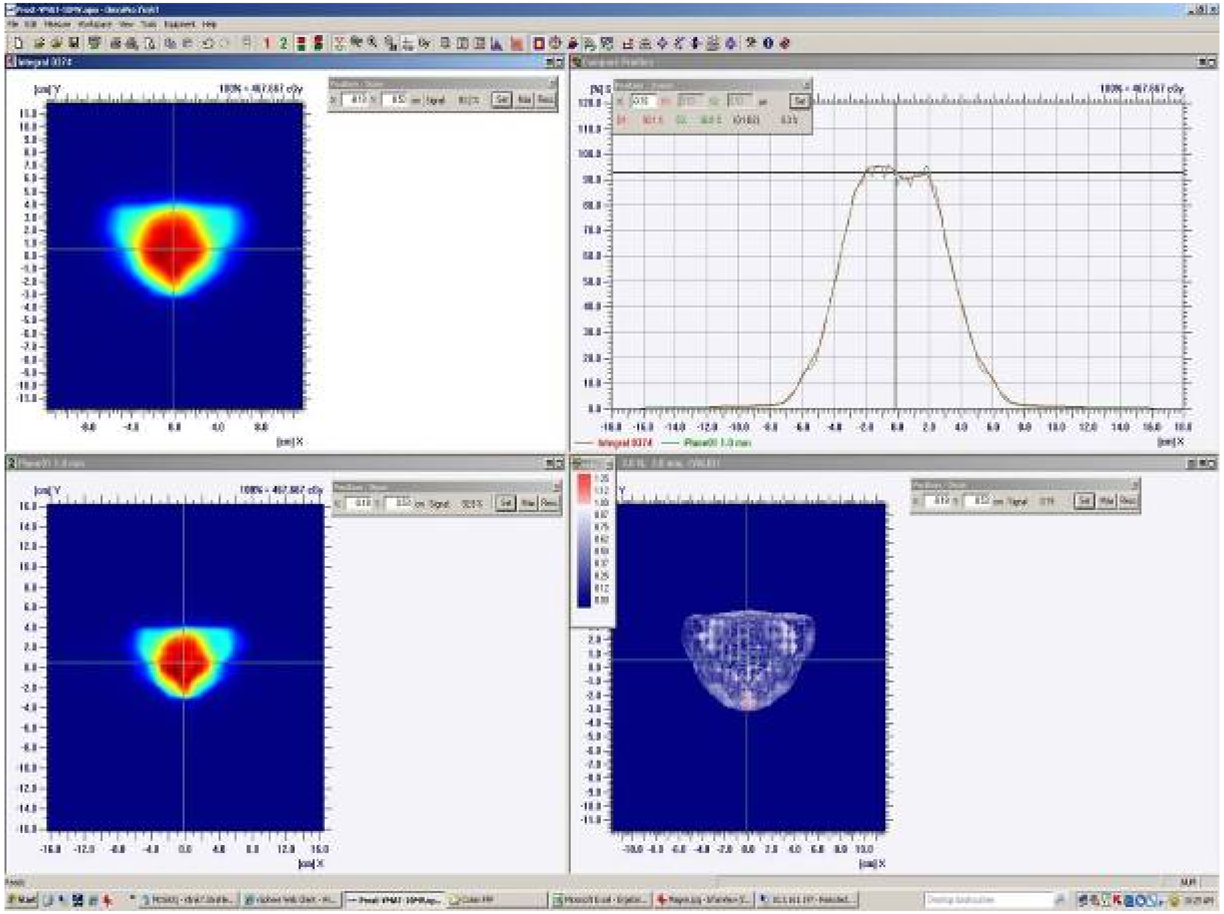
Midsize volume Prostate with integrated boost 10MV FFF – VMAT 2Arcs -2,5Gy

Gamma 33:
99,17%

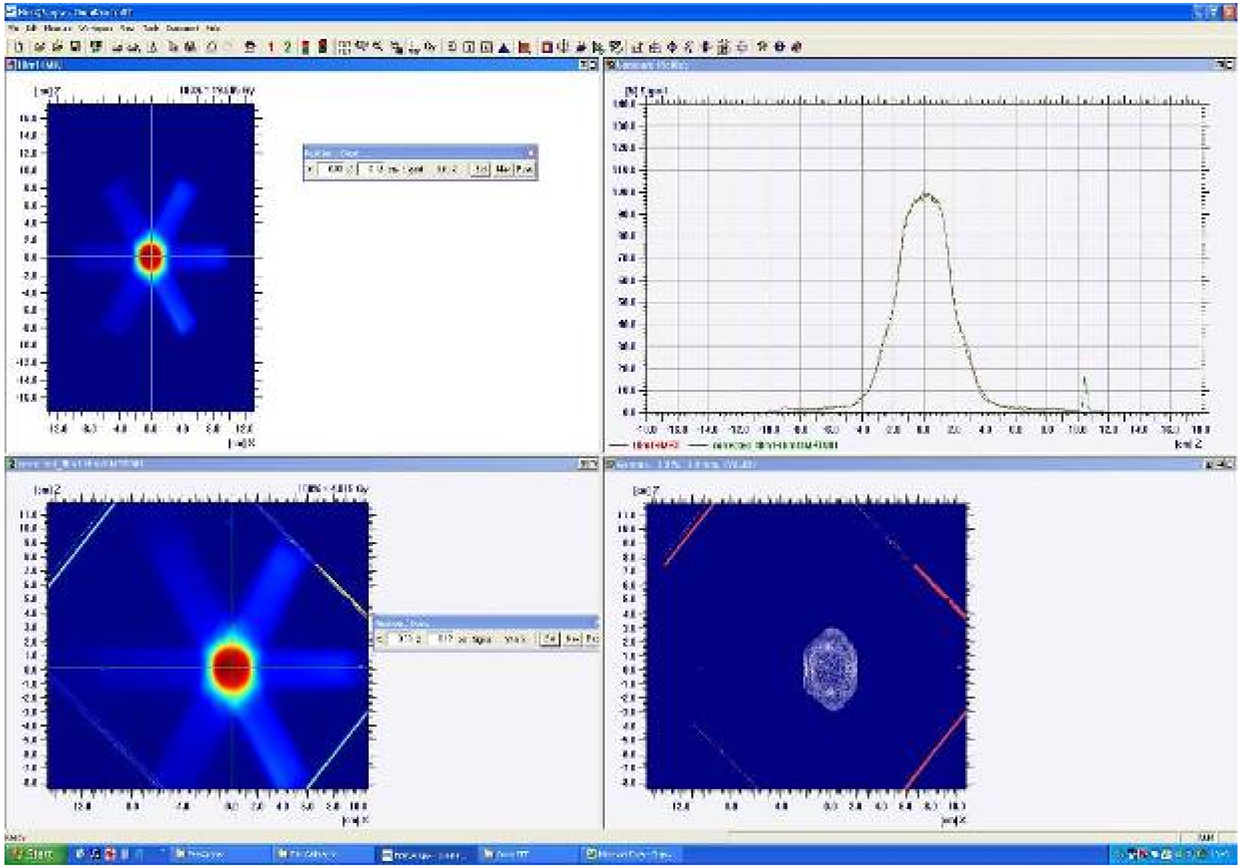
Gamma 55:
100%

collapsed



Small volume Brain 1 – 6 MV FFF – IMRT vs VMAT (noncoplanar)

Gamma 33:
99,86%
Gamma 55:
100%
Kammer:
-1.1%



Flattening filter free (FFF) with Monaco 3.3

Preclincal Examples

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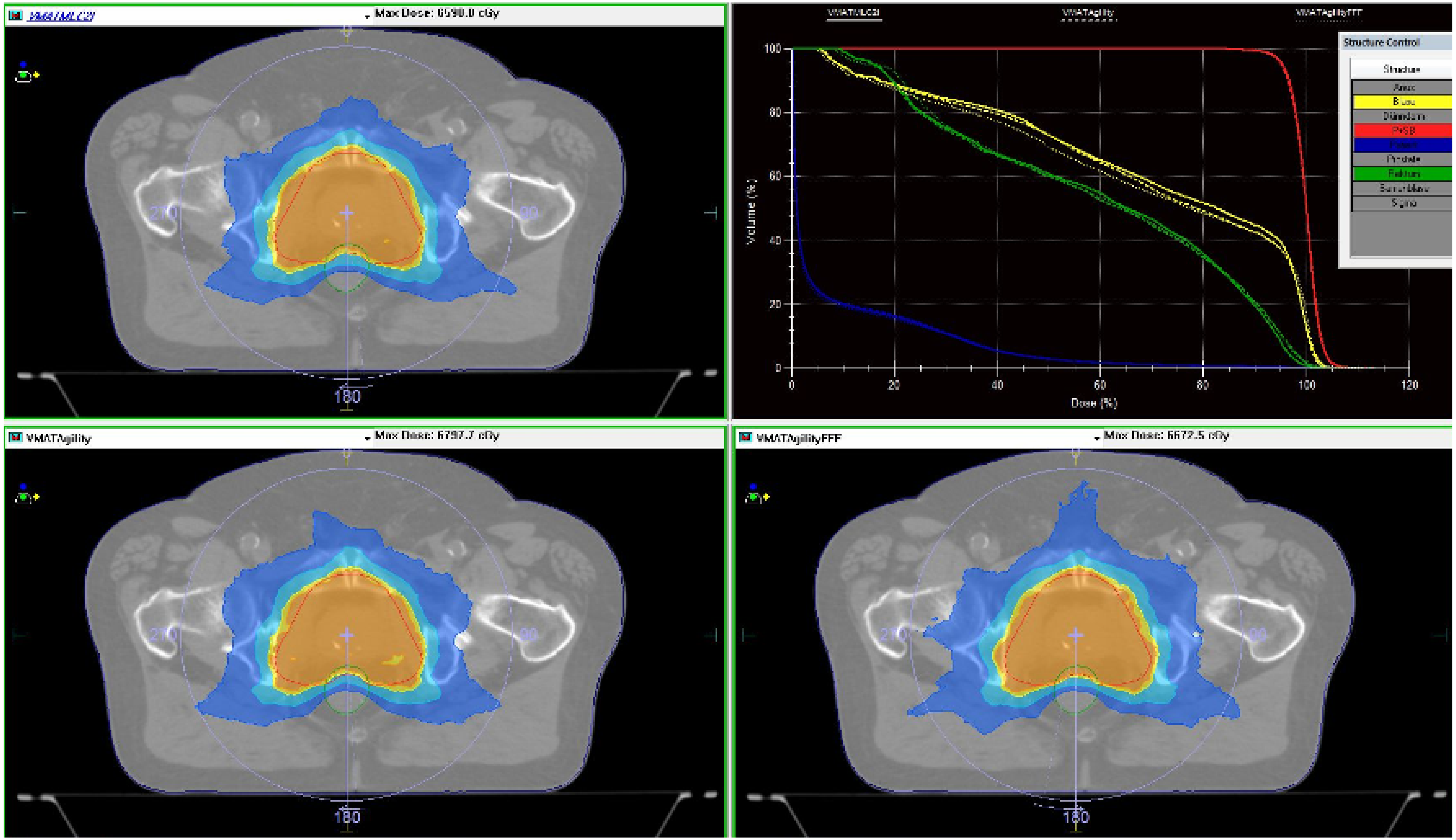
Prostate – moderately complex, low fraction dose

PROSTATE	MLCi2 Monaco 3.3	Agility Monaco 3.3	Agility + FFF Monaco 3.3
PTV prescription	mean 60 Gy	mean 60 Gy	mean 60 Gy
Homogenity index	1.09	1.09	1.09
OAR Rectum, mean dose	35.8Gy	35.6	35.96 Gy
OAR Bladder, mean dose	42.3 Gy	41.7	40.95 Gy
number of fractions	30	30	30
beam-on time per fraction	171 sec	152 sec	156 sec
number of MU's delivered	789	762	915
total number of segments	2 Rotations	2 Rotations	2 Rotations

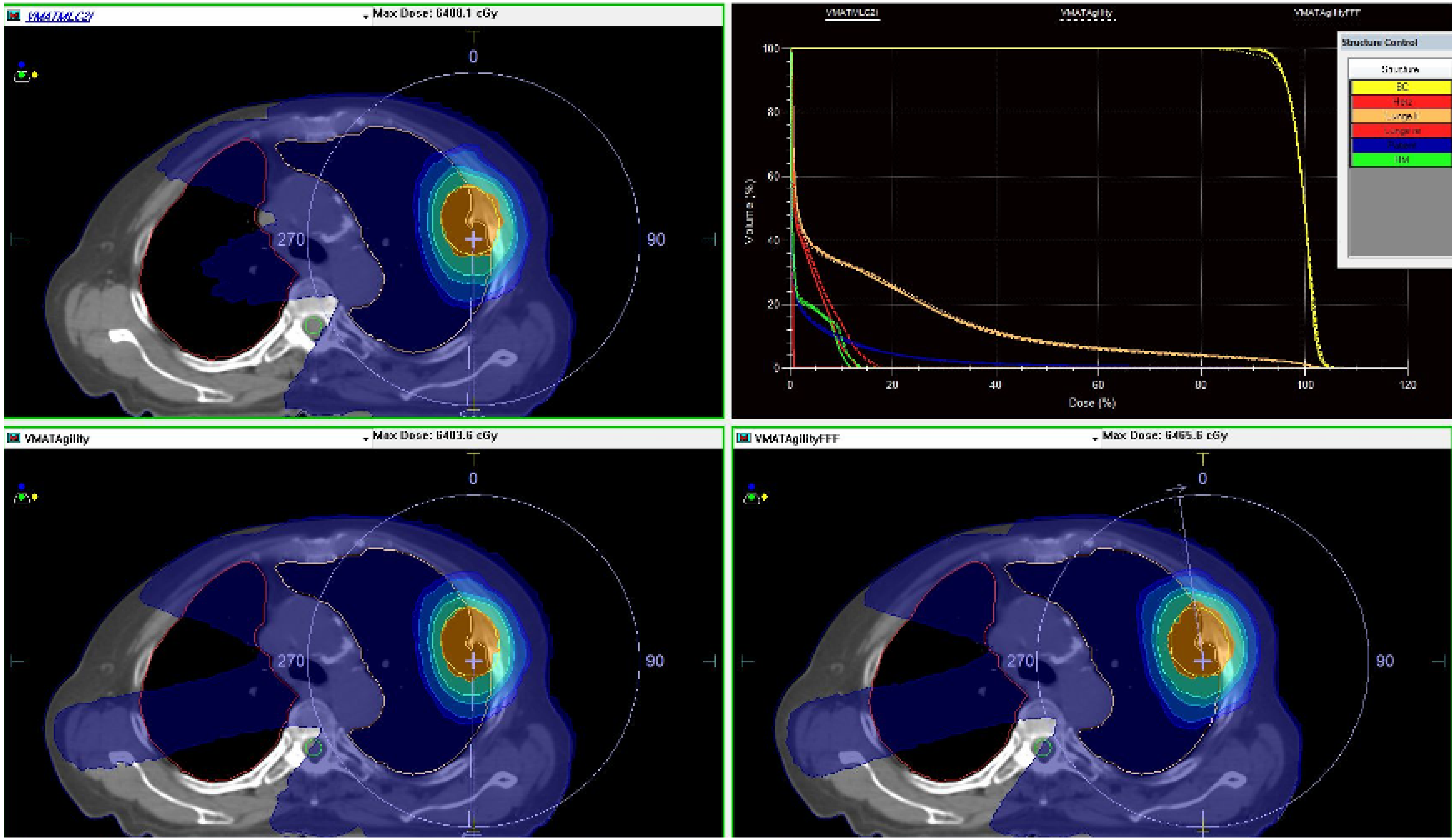
Dose distribution screenshots, DVH



Lung - moderately complex, high fraction dose

LUNG	MLCi2 Monaco 3.3	Agility Monaco 3.3	Agility + FFF Monaco 3.3
PTV prescription	60 Gy	60 Gy	60 Gy
Homogeneity Index	1.09	1.09	1.09
OAR Lung left, mean dose	8.25 Gy	8.13 Gy	8.35 Gy
OAR Lung right, mean dose	1.80 Gy	2.2 Gy	2.15 Gy
OAR Heart, Mean dose	0.18 Gy	0.17 Gy	0.17 Gy
number of fractions	5	5	5
beam-on time per fraction	230 sec	245 sec	130 sec
number of MU's delivered	2014	1997	2281
total number of segments	1 Rotation	1 Rotation	1 Rotation

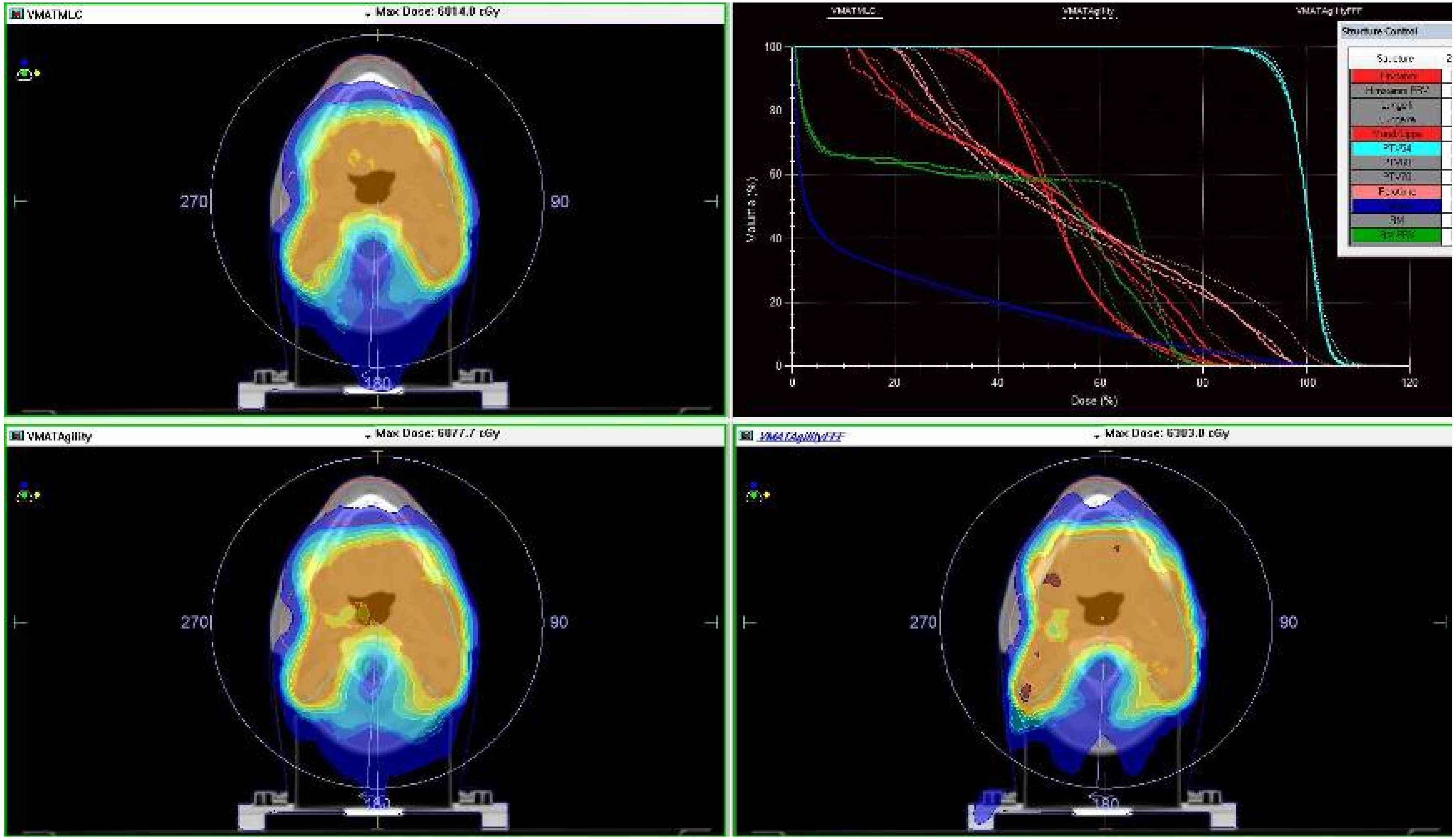
Dose distribution screenshots, DVH



Head & Neck - highly complex,low fraction dose

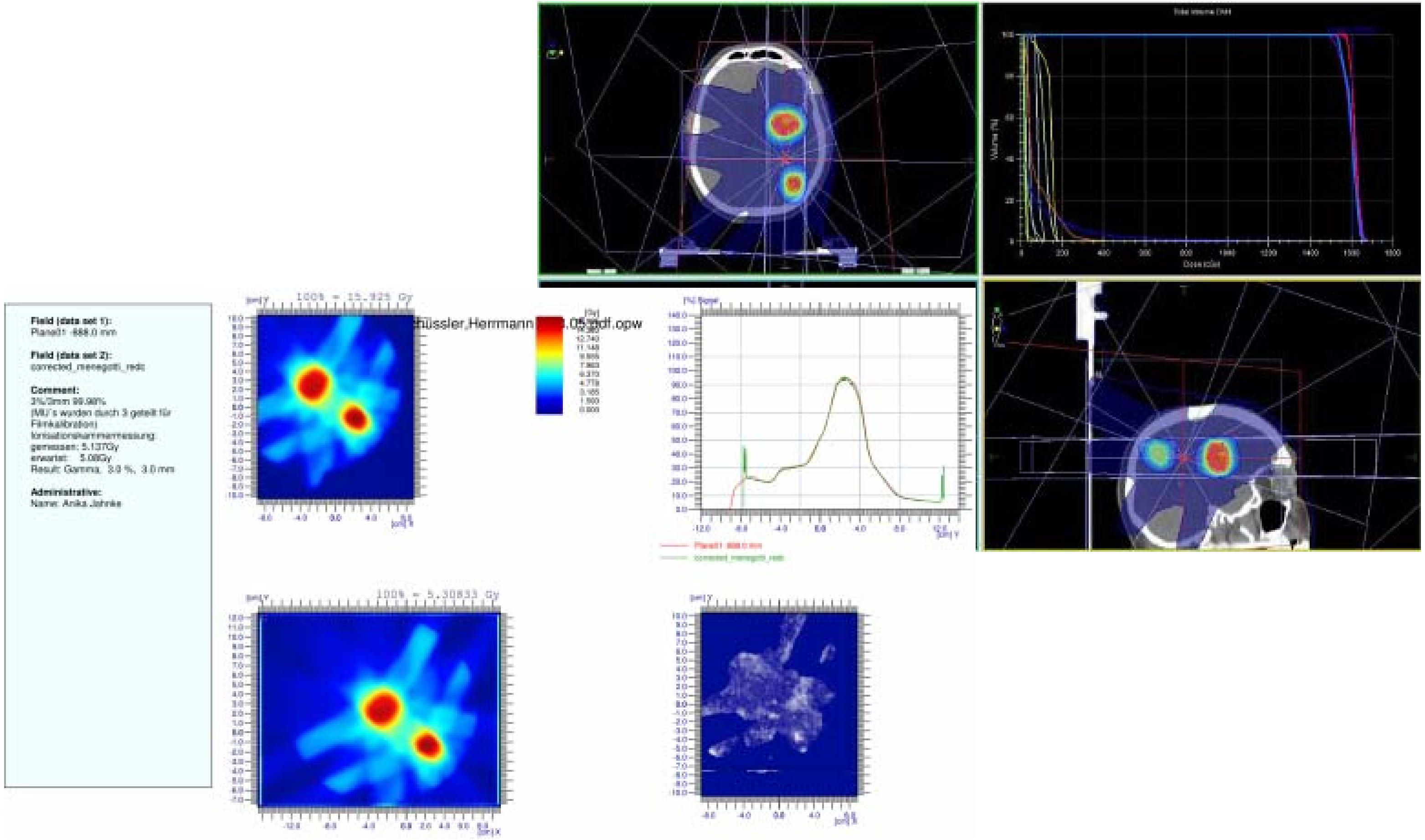
Head and neck	MLCi2 Monaco 3.3	Agility Monaco 3.3	Agility + FFF Monaco 3.3
PTV prescription	54 Gy	54 Gy	54 Gy
Homogeneity Index	1.12	1.14	1.13
OAR Parotis, mean dose	29.79 Gy	28.86 Gy	30.91 Gy
OAR Spinal Cord, max dose	44.33 Gy	42.40 Gy	44.62 Gy
OAR Lips, Mean dose	27.99 Gy	28.01 Gy	30.82 Gy
OAR Brain stem, mean dose	28.32 Gy	26.94 Gy	29.46 Gy
number of fractions	30	30	30
beam-on time per fraction	293 sec	182 sec	169 sec
number of MU's delivered	635	633	1123
total number of segments	2 Rotation	2 Rotation	2 Rotation

Dose distribution screenshots, DVH




1 st

Our first FFF treatment
2 metastases 16 Gy each, one fraction



Our first FFF treatment

Plan Information

Studyset ID: CT3 **# of Slices:** 163 **Pixel Size:** 0.07 **Scan Orientation:** HFS

Treatment Position: HEAD IN

Setup Information

Scan Reference Coordinates (cm): No Scan Reference Point has been selected

Beam #	Description	Machine ID	Energy	Gantry	Coll.	Couch	Isocenter X	Y	Z	# of Segs	MU/fx
1	G12A	Agility_6MV_FFF	6 (FFF)	181.0	0.0	0.0	2.75	-46.90	-2.00	11	296.79
2	G10A	Agility_6MV_FFF	6 (FFF)	220.0	0.0	0.0	2.75	-46.90	-2.00	19	522.46
3	G11A	Agility_6MV_FFF	6 (FFF)	288.0	0.0	0.0	2.75	-46.90	-2.00	21	621.86
4	G13A	Agility_6MV_FFF	6 (FFF)	72.0	0.0	0.0	2.75	-46.90	-2.00	28	676.61
5	G14A	Agility_6MV_FFF	6 (FFF)	144.0	0.0	0.0	2.75	-46.90	-2.00	23	491.76
6	G15A	Agility_6MV_FFF	6 (FFF)	30.0	0.0	90.0	2.75	-46.90	-2.00	22	461.56
7	G16A	Agility_6MV_FFF	6 (FFF)	70.0	0.0	90.0	2.75	-46.90	-2.00	24	688.53
8	G17A	Agility_6MV_FFF	6 (FFF)	160.0	0.0	90.0	2.75	-46.90	-2.00	24	441.39
9	VER3A	Agility_6MV_Int	6	0.0	0.0	0.0	2.75	-46.90	-2.00	0	0.00
10	Ver4A	Agility_6MV_Int	6	270.0	0.0	0.0	2.75	-46.90	-2.00	0	0.00
									Total:	172	4200.96

Normalization

Prescription (cGy): 1600.0 **# of Fractions:** 1 (1,600.00 cGy/fx)

100.00 % of 1600.0 cGy to cover 50.00 % of PTV.1

Dose Calculation

Grid Spacing (cm): 0.20

# of Calculation Points: 5906752

Assigned CTtoED File: DICOM3.BrillianceBigC

Algorithm: Monte Carlo Photon
Calculate Dose to: Medium

MC Std Dev per Plan: 1.00

Max Dose in Plan (cGy): 1674.7

Max Dose Location (cm): X = 1.95 Y = -46.90 Z = 1.40

Delivery Mode: Step & Shoot IMRT

Whole procedure
Incl.CBCT and verification 19 min.
treatment time (beam on) 7 min.

			p / Field			Meterset	Dose	Machine	Notes T S P F D C	Sts	By	Rx:GH Fx	ED	Dly	Cum	Rx:Einzeit Fx	ED	Dly	Cum
								LB3											
								LB3											
								LB3											
								LB4											
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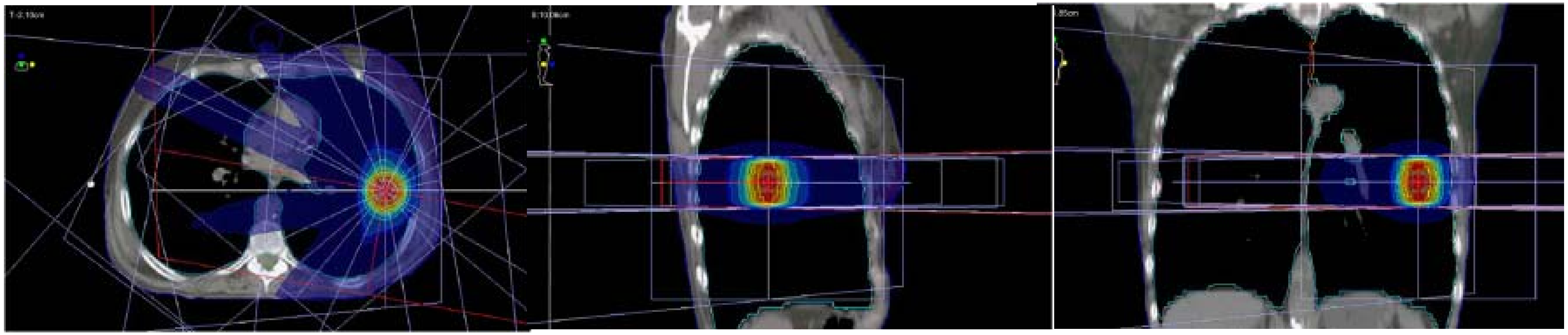
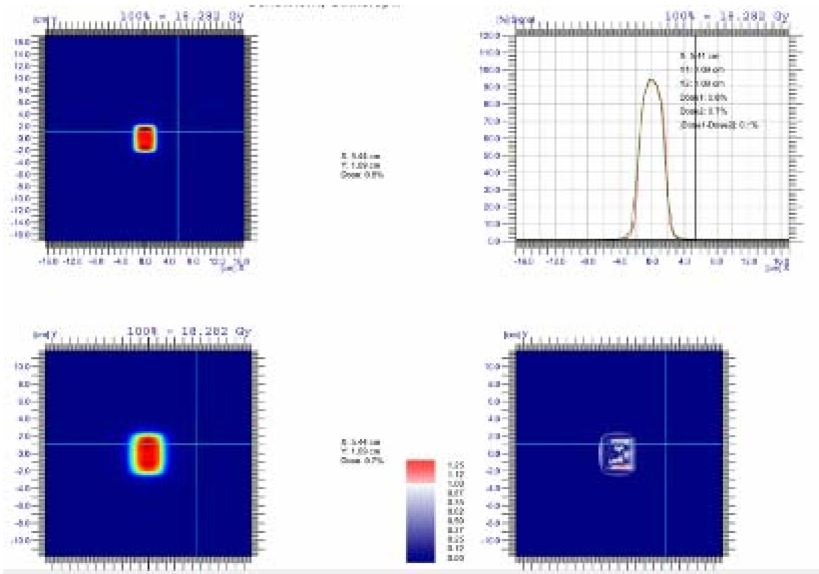
								LB4											
								LB3											
								LB2				1		300 cGy	300 cGy				
								LB2											
								LB2				2	1	300 cGy	600 cGy				
QA		18:02	2Flds					LB2											
36	08.03.2013	10:54	2Flds					LB2				3	2	300 cGy	900 cGy				
37	11.03.2013	14:18	2Flds					LB2				4	5	300 cGy	1.200 cGy				
38	12.03.2013	14:59	2Flds					LB2				5	6	300 cGy	1.500 cGy				
39	13.03.2013	11:22	4Flds		1PI			LB2								1		1.600 cGy	1.600 cGy
		11:22	CT		CT			LB2			AZ								
		11:23	VER4	1		2,0 MU		LB2		^ *	AZ								
		11:24	VER3	1		2,0 MU		LB2		^ *	AZ								
		11:34	G12A	1		2609,6 MU	800 cGy	LB2		^ *	AZ							800 cGy	
		11:41	G13A	1		1591,5 MU	800 cGy	LB2		^ *	AZ							800 cGy	
40	14.03.2013	7:44	2Flds					LB2				6	8	300 cGy	1.800 cGy				
QA		9:46	1Fld					LB2											
41	15.03.2013	7:44	2Flds					LB2				7	9	300 cGy	2.100 cGy				
42	18.03.2013	7:44	2Flds					LB2				8	12	300 cGy	2.400 cGy				

First Lung hypofractionated FFF treatment
Fraction dose 12 Gy





First Lung hypofractionated FFF treatment
Fraction dose 12 Gy

Whole procedure
incl. CBCT and verification 30 min.
treatment time (beam on) 8 min.

Plan Information

Studyset ID: CT1 **# of Slices:** 88 **Pixel Size:** 0.12 **Scan Orientation:** HFS

Treatment Position: HEAD IN

Setup Information

Scan Reference Coordinates (cm): No Scan Reference Point has been selected

Beam #	Description	Machine ID	Energy	Gantry	Coll.	Couch	Isocenter X	Isocenter Y	Isocenter Z	# of Segs	MU/fx
1	G1	Agility_10MV_FFF	10 (FFF)	190.0	0.0	0.0	10.06	-2.10	-1.85	4	325.68
2	G8	Agility_10MV_FFF	10 (FFF)	220.0	0.0	0.0	10.06	-2.10	-1.85	4	286.03
3	G5	Agility_10MV_FFF	10 (FFF)	295.0	0.0	0.0	10.06	-2.10	-1.85	4	253.22
4	G2	Agility_10MV_FFF	10 (FFF)	335.0	0.0	0.0	10.06	-2.10	-1.85	4	236.79
5	G7	Agility_10MV_FFF	10 (FFF)	0.0	0.0	0.0	10.06	-2.10	-1.85	4	280.43
6	G3	Agility_10MV_FFF	10 (FFF)	30.0	0.0	0.0	10.06	-2.10	-1.85	4	237.69
7	G4	Agility_10MV_FFF	10 (FFF)	80.0	0.0	0.0	10.06	-2.10	-1.85	4	341.93
8	G6	Agility_10MV_FFF	10 (FFF)	140.0	0.0	0.0	10.06	-2.10	-1.85	4	298.01
9	VER1	Agility_6MV_Int	6	0.0	0.0	0.0	10.06	-2.10	-1.85	0	0.00
10	VER2	Agility_6MV_Int	6	90.0	0.0	0.0	10.06	-2.10	-1.85	0	0.00
									Total:	32	2259.77

Normalization

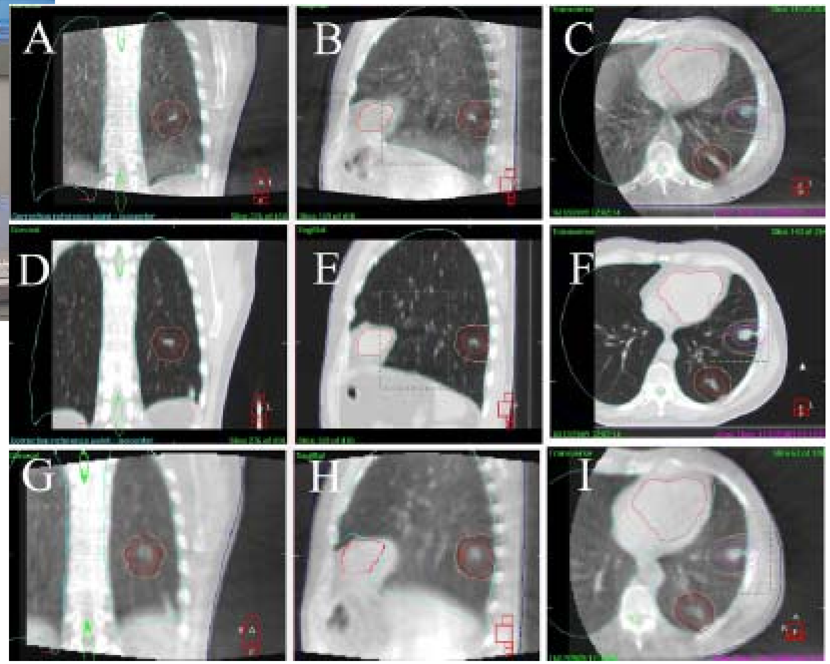
Prescription (cGy): 6000.0 # of Fractions: 5 (1,200.00 cGy/fx)

Rad Rx: Lungenmetastase FFF - IMRT Plan - Xrays Dose: 6.000 cGy @ 1.200 cGy		A 26.3.2013 SM
Site Setup		AE 22.3.2013 KS
Treatment Fields		
G1 - 190° Lunge ABC FFF - 10 X FFF DMLC 5 Control Points	26.03.2013	A 26.3.2013 SM
G8 - 220° Lunge ABC FFF - 10 X FFF DMLC 5 Control Points	26.03.2013	A 26.3.2013 SM
G5 - 295° Lunge ABC FFF - 10 X FFF DMLC 5 Control Points	26.03.2013	A 26.3.2013 SM
G2 - 335° Lunge ABC FFF - 10 X FFF DMLC 5 Control Points	26.03.2013	A 26.3.2013 SM
G7 - 0° Lunge ABC FFF - 10 X FFF DMLC 5 Control Points	26.03.2013	A 26.3.2013 SM
G3 - 30° Lunge ABC FFF - 10 X FFF DMLC 5 Control Points	26.03.2013	A 26.3.2013 SM
G4 - 80° Lunge ABC FFF - 10 X FFF DMLC 5 Control Points	26.03.2013	A 26.3.2013 SM
G6 - 140° Lunge ABC FFF - 10 X FFF DMLC 5 Control Points	26.03.2013	A 26.3.2013 SM
VER1 - 0° Lunge ABC FFF - 6 X MLC	26.03.2013	A 26.3.2013 SM
VER2 - 90° Lunge ABC FFF - 6 X MLC	26.03.2013	A 26.3.2013 SM
CT1 - FFF - CT		A 25.3.2013 KH
EPID - 0° - 10 X FFF	26.03.2013	A 26.3.2013 SM

62	26.03.2013	11:46	11Fld		1Pl			LB2				1	1.200 cGy	1.200 cGy
		11:46	CT1		CT			LB2		+	Sv/Sv			
		11:53	VER2	1		2,0 MU		LB2	^		Sv			
		11:54	VER1	2		4,0 MU		LB2	^	+	Sv			
		12:01	EPID	2		10,1 MU		LB2	^	+	Sv/Sv			
		12:05	G7	1		280,4 MU	150 cGy	LB2	^		Sv		150 cGy	
		12:06	G3	1		237,7 MU	150 cGy	LB2	^		Sv		150 cGy	
		12:07	G4	1		341,9 MU	150 cGy	LB2	^		Sv		150 cGy	
		12:08	G6	1		298,0 MU	150 cGy	LB2	^		Sv		150 cGy	
		12:10	G1	1		325,7 MU	150 cGy	LB2	^		Sv		150 cGy	
		12:11	G8	1		286,0 MU	150 cGy	LB2	^		Sv		150 cGy	
		12:12	G5	1		253,3 MU	150 cGy	LB2	^		Sv		150 cGy	
		12:13	G2	1		236,8 MU	150 cGy	LB2	^		Sv		150 cGy	

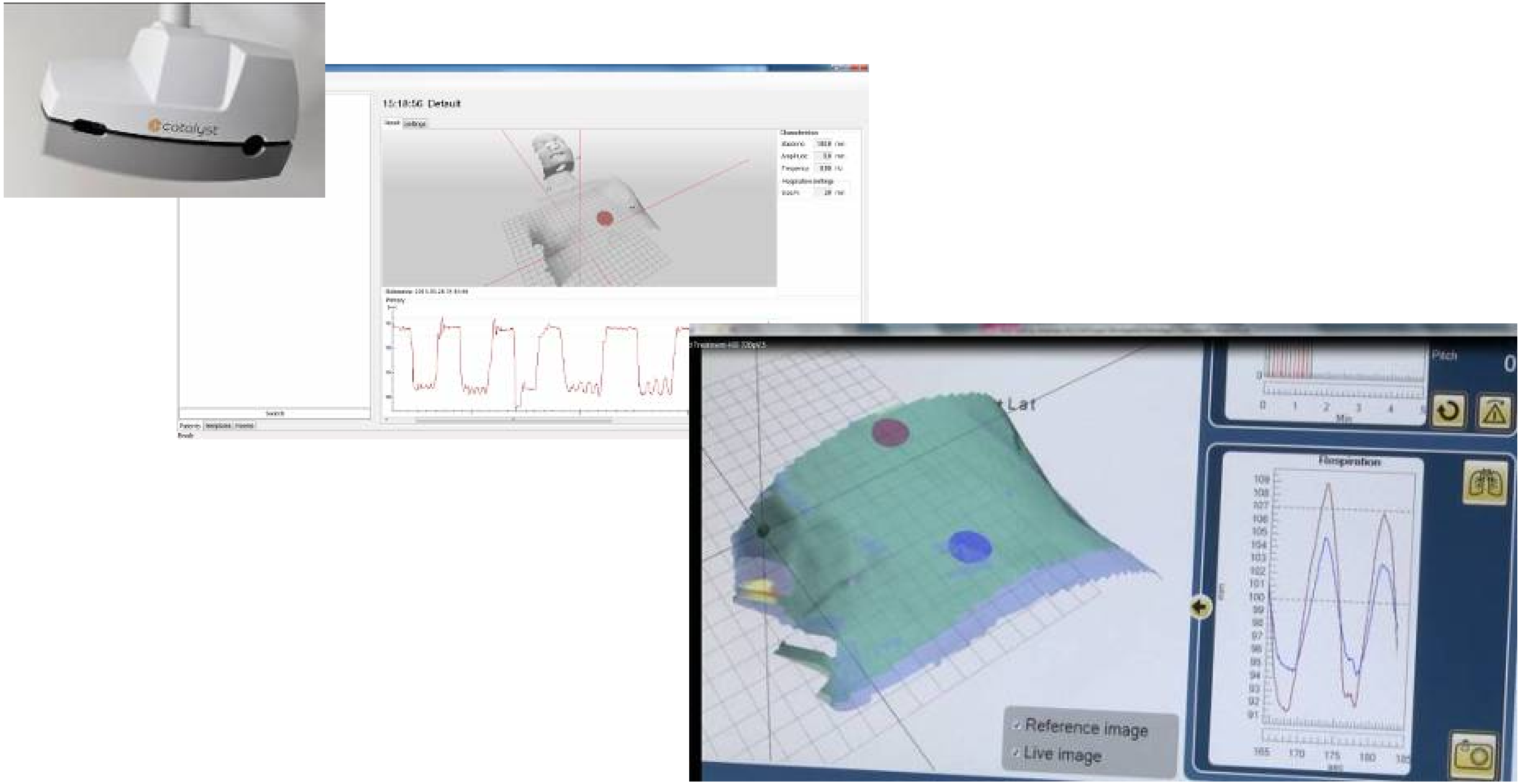
Breath Hold / Gating

Clinical Setup:
1. Flow-Based Breath Hold Triggering

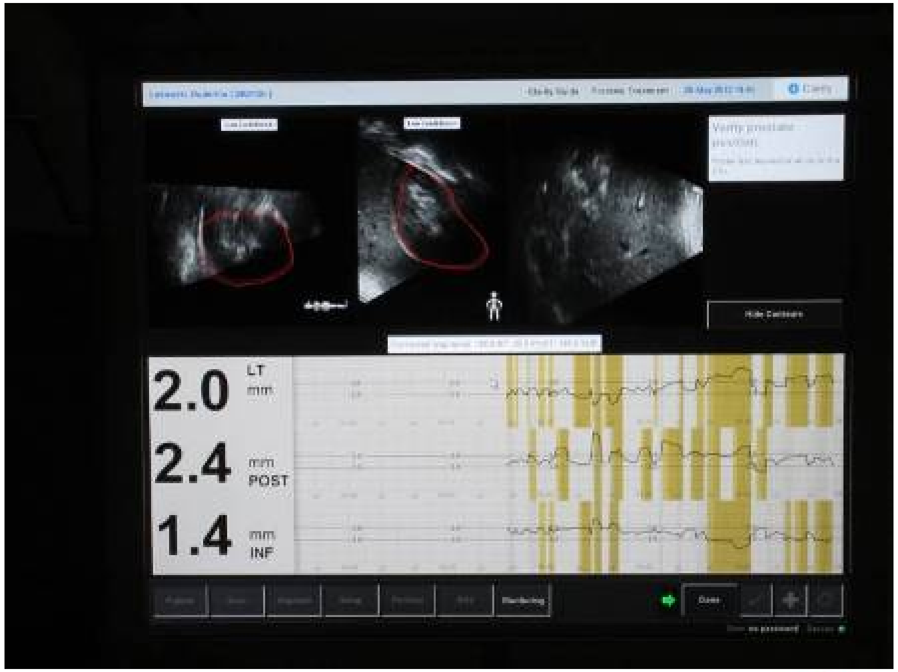


Boda-Heggemann et al,
Radiother Oncol, 2011

Clinical Setup:
2. Surface-based Surveillance

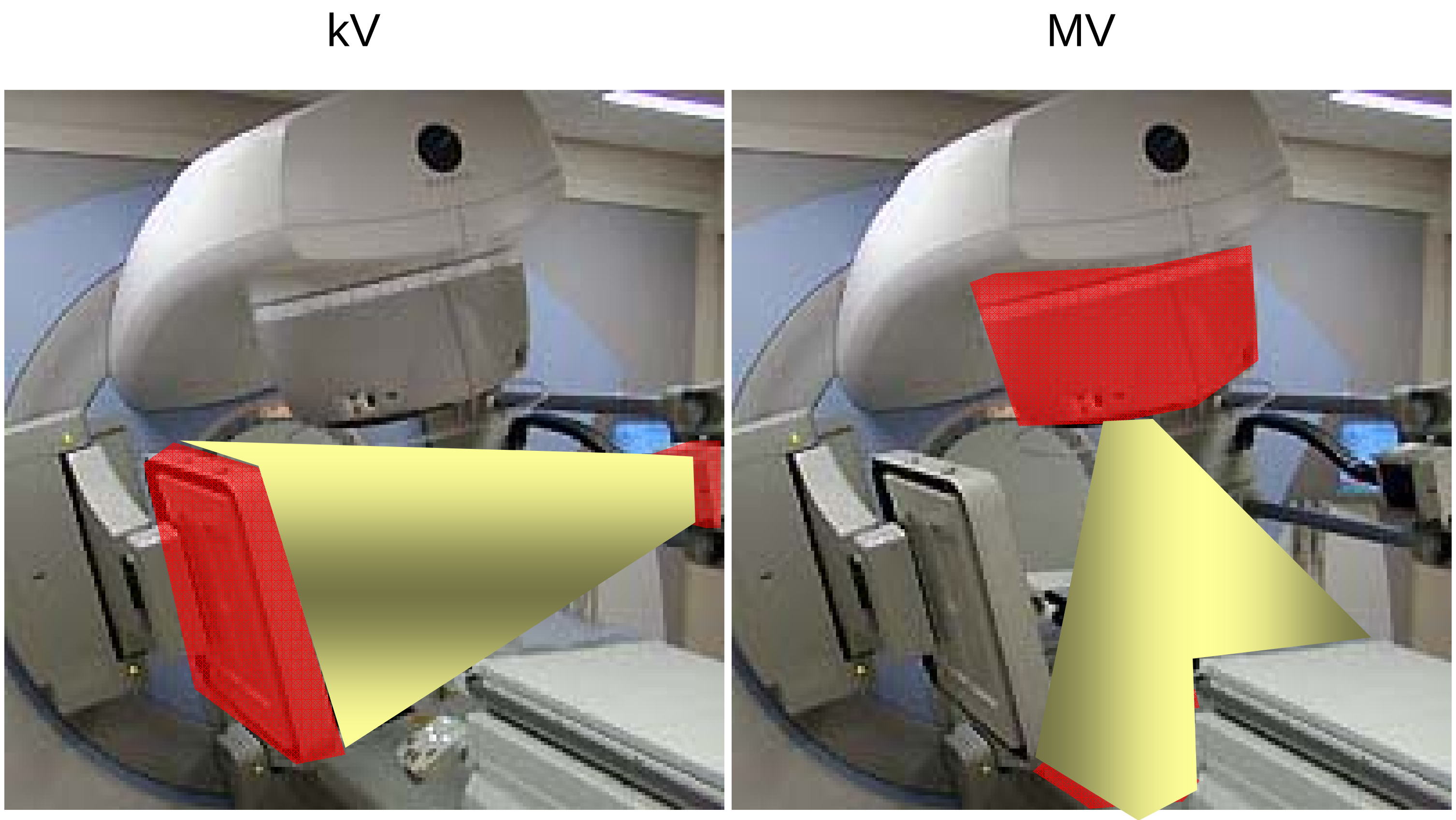


Clinical Setup:
3. Direct Liver Tracking



Fast CBCT

Ansatz kV+MV-Rekonstruktion



http://www.elekta.com/healthcare_international_beaumont_work_results_breakthrough.php

kV-MV imaging workflow

Workflow Automation for ultrafast Kilovoltage Megavoltage Cone Beam CT

Blessing et al., ESTRO, 2013

Physics 1: Imaging in radiotherapy: Technical developments. 20/04/13, 10:30 to 11:30.

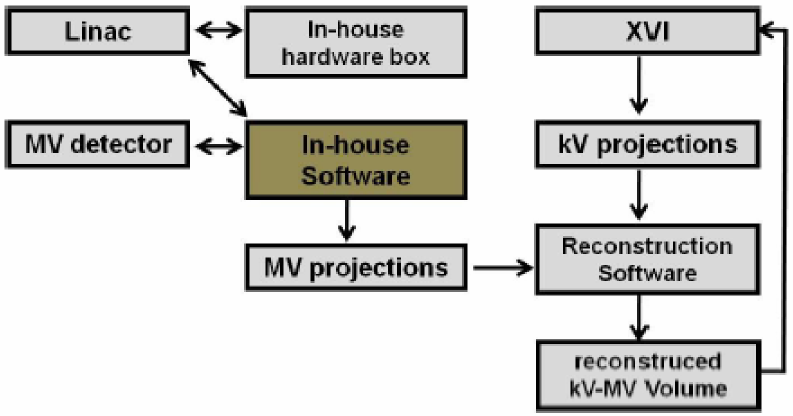


Table 1

workflow	duration (manual)	duration (automated)
prepare Linac for kV-MV mode	~1/2 hour (connect hardware box, reconnect cables in kV and MV detector control board)	~1 sec (turn key switch)
Login kV and MV service mode	~10 sec	~10 sec
prepare XVI for Volume imaging	~10 sec	~10 sec
logout, login MV	~10 sec	~10 sec
load MV beam	~10 sec	~10 sec
set relevant Linac parameters I	~30 sec (manual changes in MV service mode)	~1 sec (in-house software waits for confirmation, press enter)
start and interrupt MV beam	~10 sec	~5 sec
set relevant Linac parameters II	~30 sec (manual changes in MV service mode)	~1 sec (in-house software waits for confirmation, press enter)
start kV	~10 sec	~1 sec
start MV	~10 sec	~1 sec
rotate Gantry, start MV readout	~10 sec	~15 sec
angle mapping	~10 min (analyse images, find initial projection)	0 sec (software output: angle list for MV projection)
reconstruction	~10 sec	~10 sec
total:	**roughly 10 min +1/2 hour preparation**	**roughly 1 min**

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Dose Rate effects in Photon and Particle treatments - Are high dose rates problematic?

Dose Rate? Pulse Rate??? Dose per Pulse????

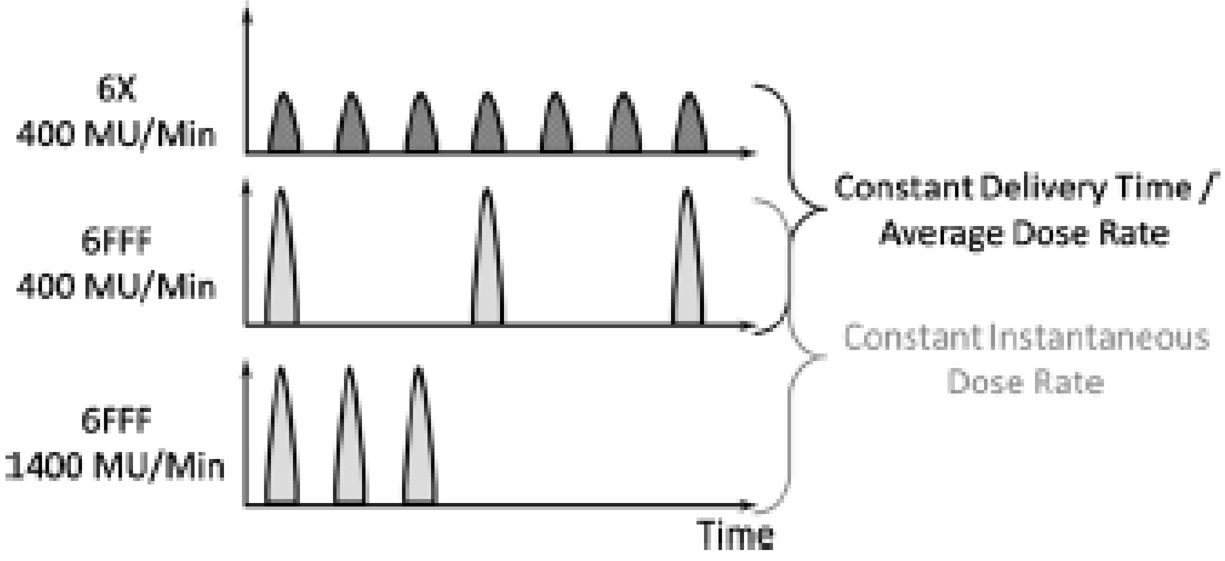

Figure 1. Schematic illustrating the different dose-per-pulse and pulse repetition frequencies of the x-ray fields used in this study.

King et al., PMB, 2013

Negative Studies

Michaels, Rad Res, 1978 (OER, field emitting device)
Ling, IJROBP, 1985 (OER)
Steel et al., 1990 (cell lines, 0,25-90 cGy/min)
"There was little evidence of a dose-rate effect above 2 cGy/min but significant sparing was seen at lower dose rates"

Zackrisson, Acta Oncol, 1991 (cell lines, HDR e-, 24000Gy/min)
Soerensen, R&O, 2011 (cell lines, diff. DR/pulse)
Verbakel, Acta Oncol, 2013 (cell lines, moving strip)
King, PMB, 2013 (cell lines, mesh buildup)

Reviews bei
Ling, R&O, 2010
Wilson, Br J Radiol, 2012 (Oxygen depletion)

Negative Studies

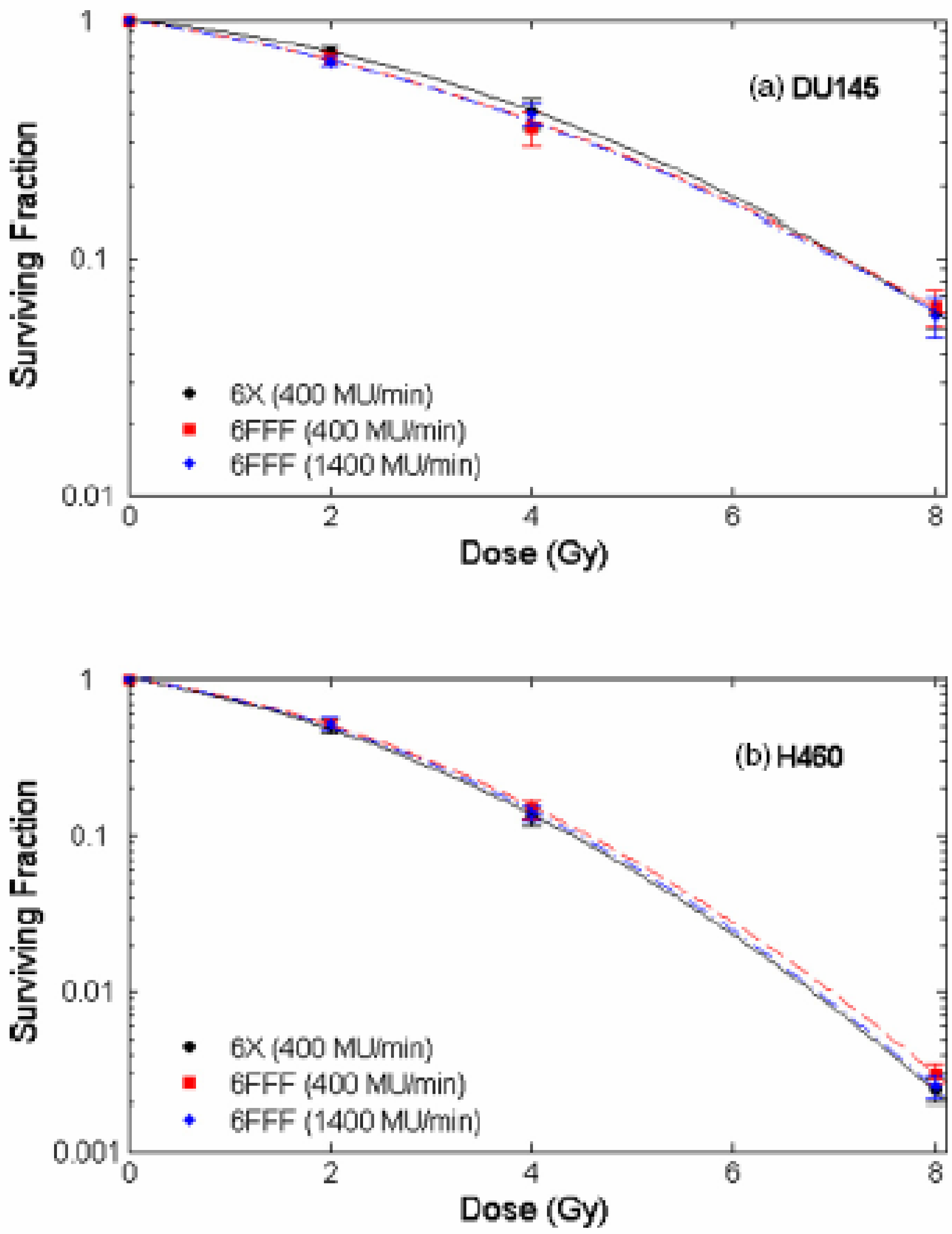

Figure 4. Cell survival plots following exposure to flat 6 MV radiation fields with different average or instantaneous dose-rates for (a) DU145 and (b) H460 cell lines. Error bars represent ± standard error of each data set. Lines represent the results of linear–quadratic fits to the data.

Table 2. Results of linear–quadratic curve fitting analysis (with ± standard error of the mean) for cells exposed to different average or instantaneous dose-rates.

Treatment modality	DU145		H460	
(MU dose-rate)	α	β	α	β
6X (400 MU min^{-1})	0.09 ± 0.03	0.03 ± 0.01	0.24 ± 0.19	0.06 ± 0.03
6FFF (400 MU min^{-1})	0.14 ± 0.13	0.03 ± 0.02	0.21 ± 0.11	0.07 ± 0.02
6FFF(1400 MU min^{-1})	0.14 ± 0.15	0.03 ± 0.06	0.21 ± 0.16	0.07 ± 0.03

King et al., PMB, 2013

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Positive Studies

Lohse, R&O, 2011

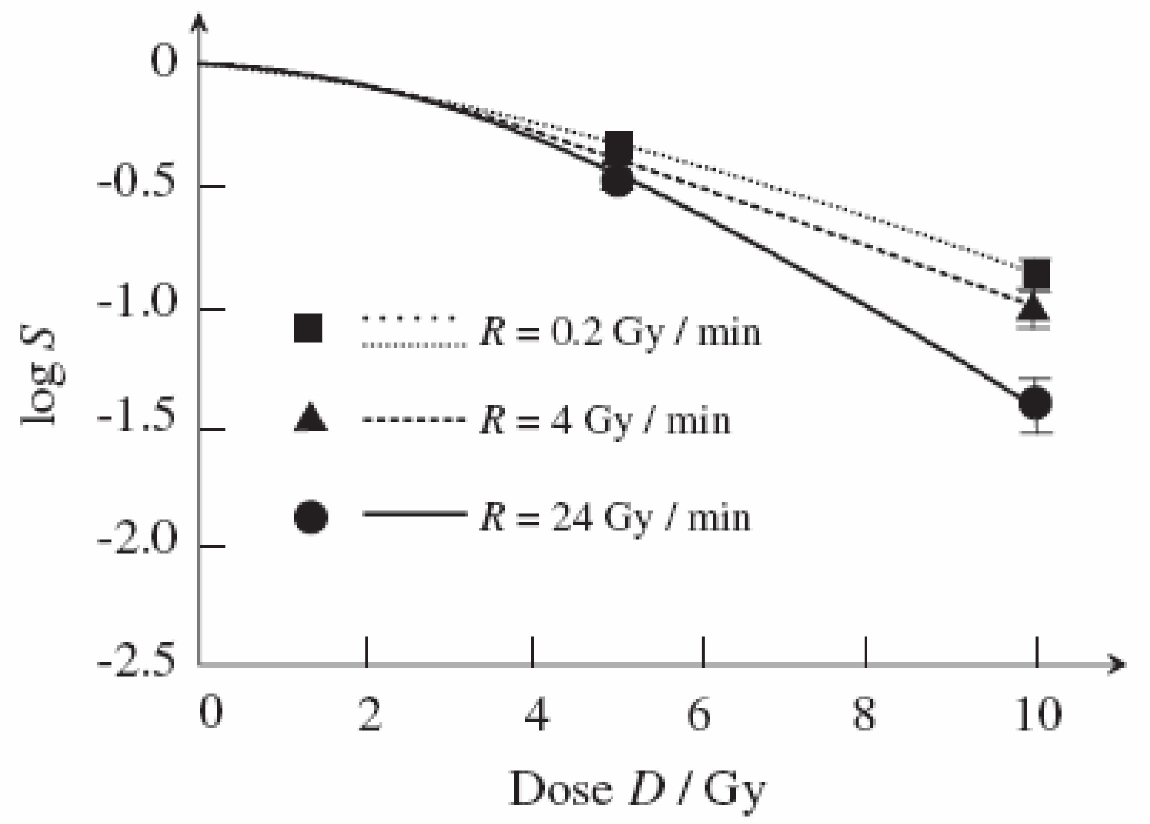
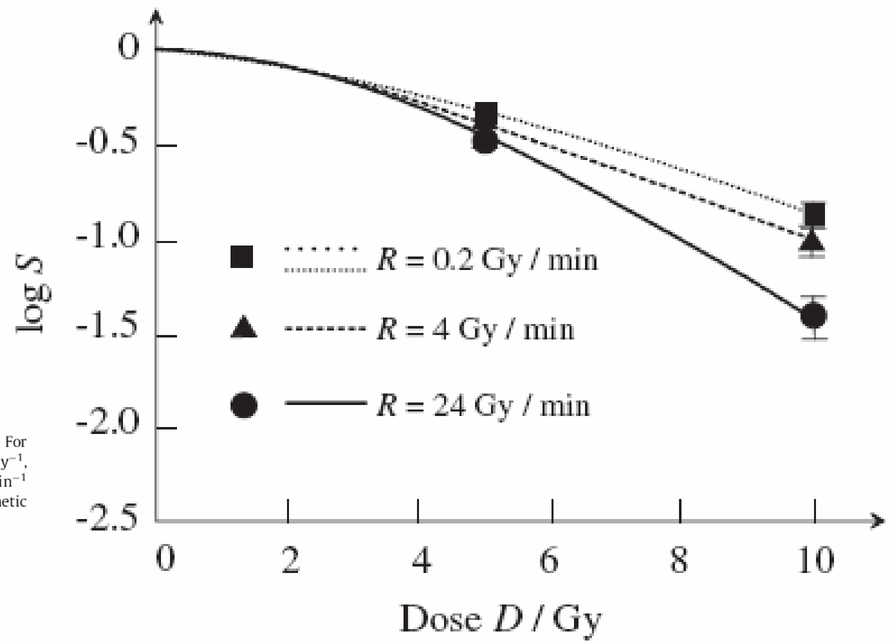


Fig. 4. Surviving fraction of T98G-glioblastoma cells at different dose rates. For 24 Gy/min, the Γ-LQ-model can fit the experimental data with $\alpha = 0.03\ Gy^{-1}$, $\beta = 0.04\ Gy^{-2}$ and $\gamma = 0.556\ min^{-1}$; for 4 Gy/min, γ has to be adapted to $0.361\ min^{-1}$ and for $R = 0.2$ Gy/min, a good fit can only be achieved by adapting the kinetic constant to $\gamma = 0.0313\ min^{-1}$.

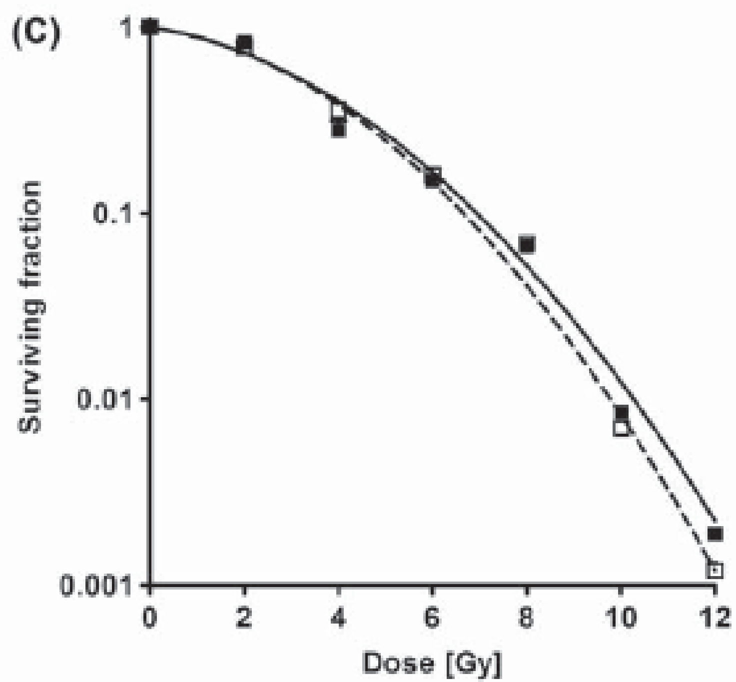
But: Disparate Results for same cell line (T98 Glioma)



Lohse, R&O, 2011

Fig. 4. Surviving fraction of T98G-glioblastoma cells at different dose rates. For 24 Gy/min, the Γ-LQ-model can fit the experimental data with $\alpha = 0.03\ Gy^{-1}$, $\beta = 0.04\ Gy^{-2}$ and $\gamma = 0.556\ min^{-1}$; for 4 Gy/min, γ has to be adapted to $0.361\ min^{-1}$ and for $R = 0.2$ Gy/min, a good fit can only be achieved by adapting the kinetic constant to $\gamma = 0.0313\ min^{-1}$.

VS.



Verbakel, Acta Oncol, 2013

Figure 3. Normalized cell survival curves for SW 1573 (A), D384 (B) and T98 (C) cells. Error bars represent the standard error of the
mean (n 3). Open squares FF, Closed squares FFF.

Synopsis

Low dose rates

-> Loss of effect

Intermediate dose rates (covering the spectrum of what is currently possible with FFF Linacs (overall and per pulse)

->No effect

Ultra-high Dose rates

(not relevant for photons, possibly for laser pulsed particles)

-> Oxygen Depletion

Courtesy M. Alber/F. Stieler