UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

Prime Esperienze con Versa HD – Velocità, Versatilità e Precisione

Frank Lohr, M.D.

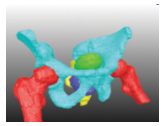
With the Help of Lennart Jahnke, Jens Fleckenstein, Florian Stileler, Volker Steil

(I)
Department overview

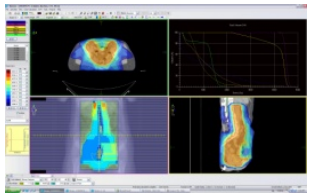
ELEKTA MOSAIQ Vers. 2.5

Philips Brilliance Big Bore
CT-Simulation, Tumor L.O.C.

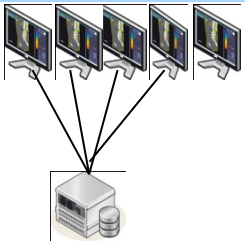
Philips Eleva
PCR System

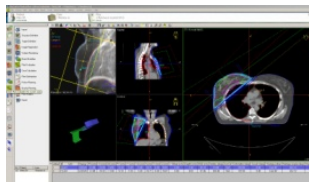


Elekta ABAS
Atlas based autosegmentation



5 x Elekta Monaco 3.3
Monte-Carlo Systems





6 x Nucletron
Masterplan vers. 4.3

LINAC 1 Elekta Versa HD
X 6,10,18; e, Agility MLC
EPID, cone beam CT, FFF,
Clarity, Intergrity 3.1

LINAC 2 Versa HD
X 6,10,18; e, Agility MLC EPID,
cone beam CT, FFF, Clarity,
Intergrity 3.1

LINAC 3 Elekta Synergy
X 6; e, MLC,EPID,cone beam
Integrity 1.1

LINAC 4 Elekta Synergy
X 6; e, MLC,EPID, cone beam,
Integrity 1.1

Gammknife
Perfexion 2013

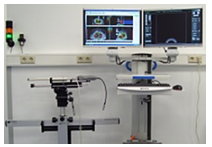
MOSAIQ
100 clients

Intraoperative unit
Zeiss Intrabeam, 50 kV

Connection to unit 2
Distance 3 km

Connection to unit 1
Distance 30 km

Seed application
Elekta/Nucletron FIRST



LINAC 6 Elekta Synergy
X 6; e, MLC, EPID

LINAC 5 Elekta Synergy
X 6; e, MLC, EPID

UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

Clinic statistics

Staff

22	MD´s (attending + residents)
12	Full licensed physicist
6	PhD-students
17	Radiographers
35	Researchers

Treatment

2300 patients per year,

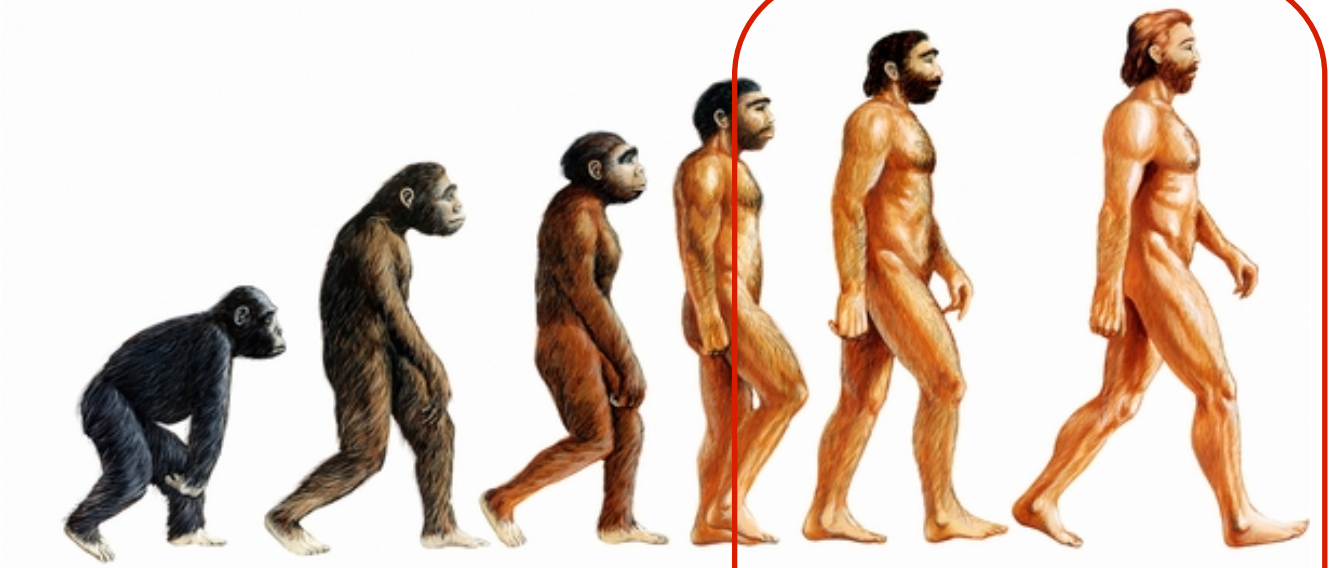
~1500 IMRT / VMAT Series per year,

~100 kV cone beam CT´s per day ~50 MV EPIDS per day

Film- and paperless since 2006

(II)
Evolution of Elekta Radiotherapy

The evolution of radiotherapy



- Cobalt
- Linac
- Linac
  - MLC
  - IMRT
- Desktop
  - MLC
  - IMRT
  - IGRT
  - Monaco 1.0
- Integrity 1.1
  - MLCi2
  - IMRT
  - IGRT
  - VMAT
  - Monaco 2.04

MLCi2

Integrity 1.1 e.g.

Continuously Variable Dose rate (CVDR)

Interdigitation for MLCi2

VMAT QA prescriptions

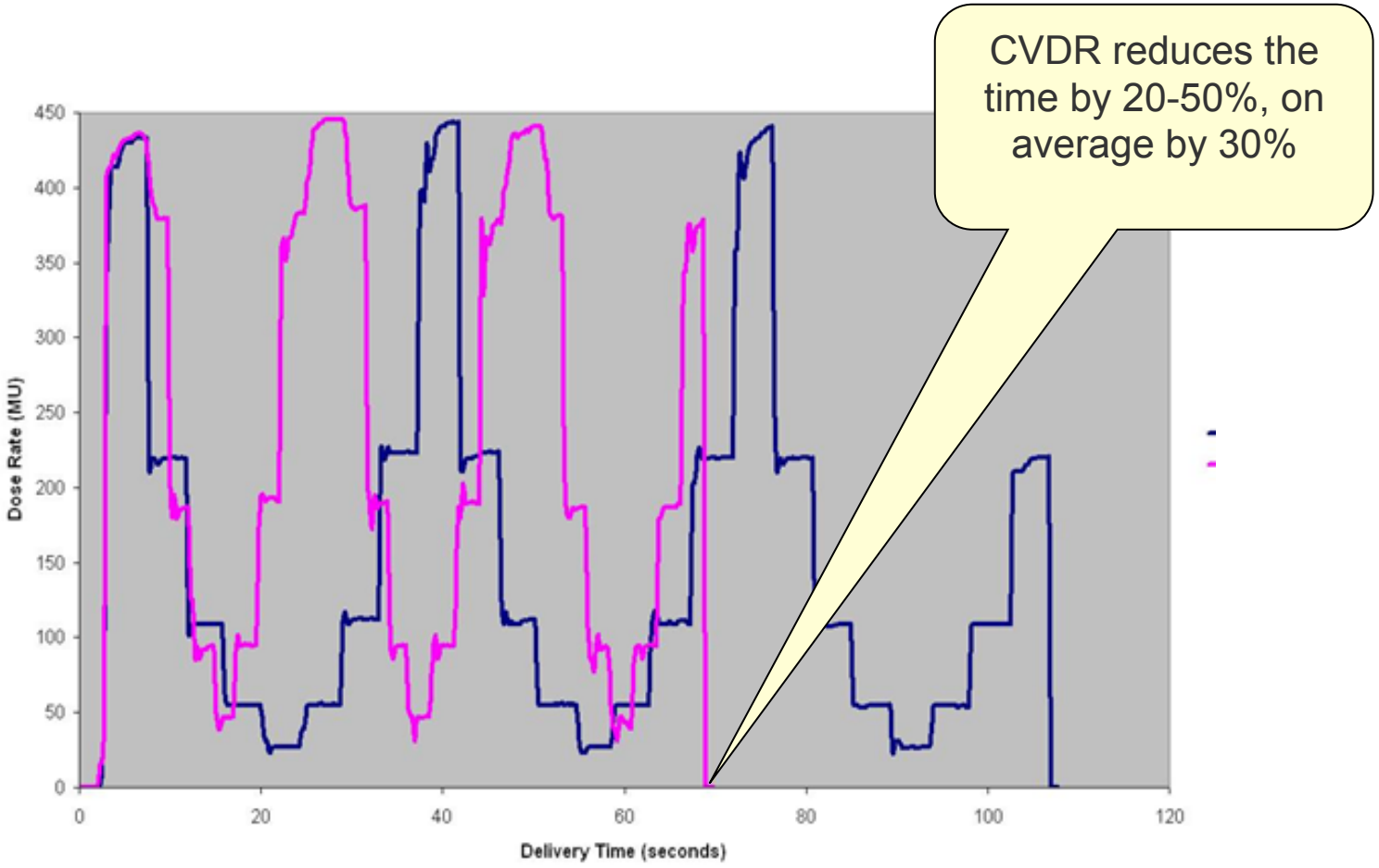
Improvements regarding Service Diagnostics

IntelliMax (support for remote support)

*By courtesy, Elekta

What is Integrity?

Advantages of Continuously Variable Dose rate (CVDR) ?



One clinical hour at a Linac

Elekta Synergy Platform + Desktop 7 + MLCi 2

Action	Patient	Time	Description	MU's	Fx Dose	Treatment Time	Total
finish treatment	Patient A	8:08					~34 min
finish IGRT	Patient B	8:20	2x MV Images (IView)	4.0 MU			
finish treatment	Patient B	8:29	6X StepNShoot 100CPs	401.4 MU	1.8 Gy	~9 min	
finish treatment	Patient C	8:38	6X StepNShoot 68CPs	637.7 MU	2.0 Gy	~7 min	
finish treatment	Patient D	8:46	6X StepNShoot 46CPs	531.3 MU	2.0 Gy	~7 min	
finish IGRT	Patient E	8:52	1x MV Images (IView)	2.0 MU			
finish treatment	Patient E	9:03	6X StepNShoot 150CPs	721.0 MU	2.0 Gy	~11 min	

Elekta Synergy + Integrety 1.1 + MLCi 2

Action	Patient	Time	Description	MU's	Fx Dose	Treatment Time	Total
finish treatment	Patient A	11:22					~26 min
finish IGRT	Patient B	11:35	cone beam CT (XVI)				
finish treatment	Patient B	11:43	6X StepNShoot 82CPs	614.6 MU	1.8 Gy	~8 min	
finish IGRT	Patient C	11:51	cone beam CT (XVI)				
finish treatment	Patient C	11:56	6X VMAT 205CPs	670.5 MU	2.0 Gy	~5 min	
finish IGRT	Patient D	12:06	cone beam CT (XVI)				
finish treatment	Patient D	12:13	6X VMAT 181CPs	1357.0 MU	2.0 Gy	~7 min	
finish IGRT	Patient E	12:22	cone beam CT (XVI)				
finish treatment	Patient E	12:26	6X VMAT 191CPs	479.7 MU	1.8 Gy	~6 min	

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				avf	Out

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

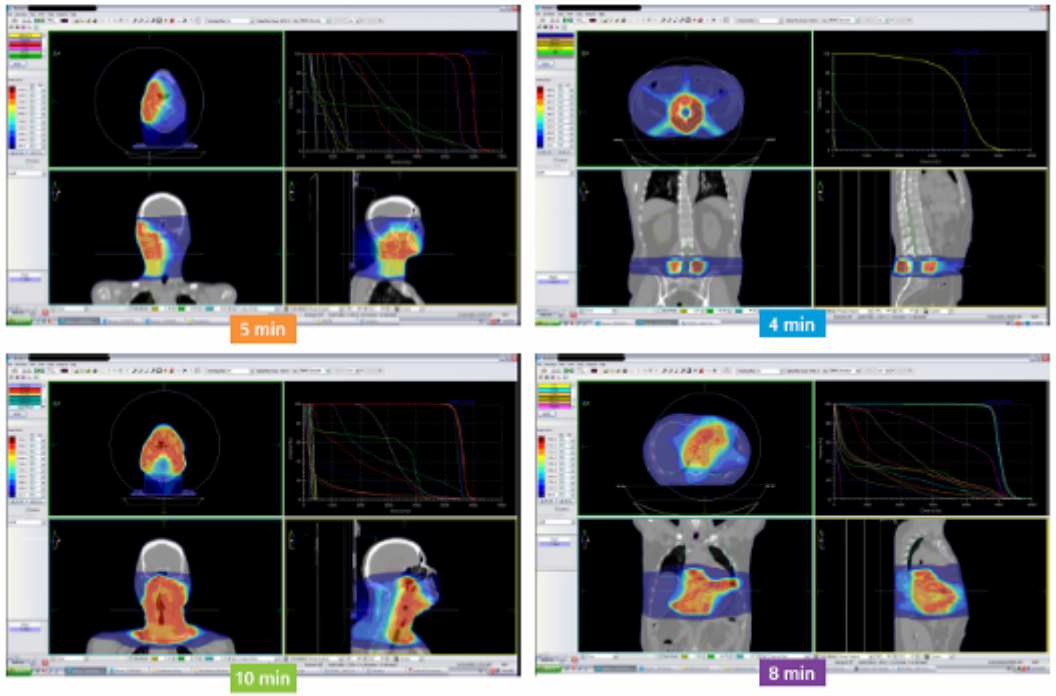
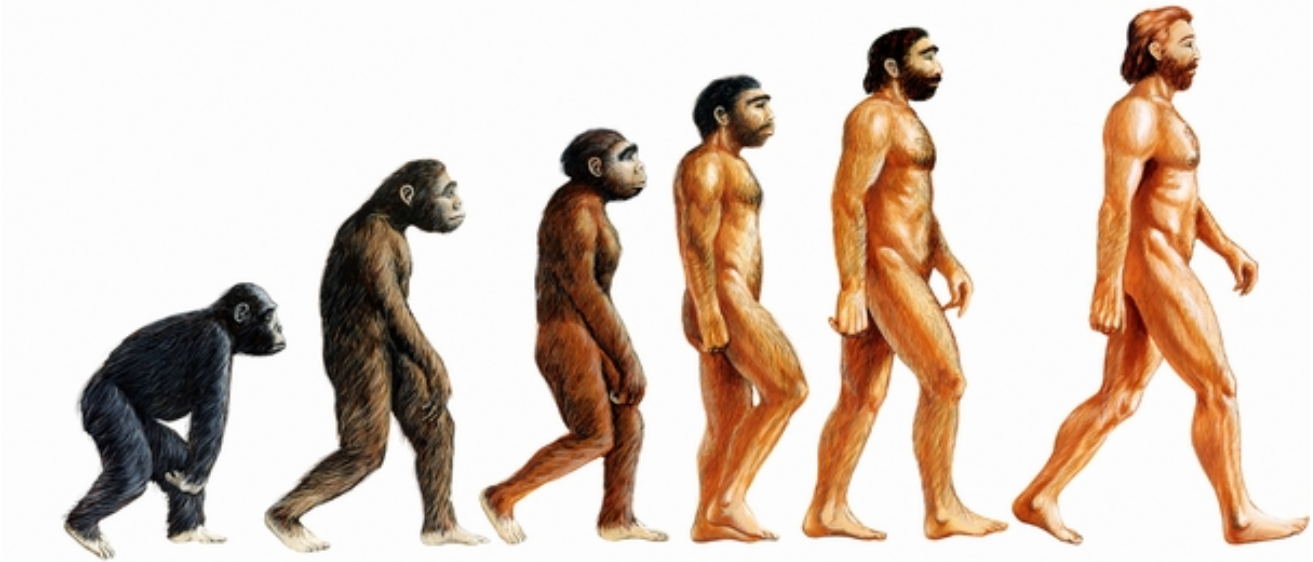


Figure 5. One hour routine treatment. Patient logistics vs. treatment time (IGRT + VMAT): 50% / 50%. Beam-on times between 2 and 7 minutes.

Limitations for treatment speed

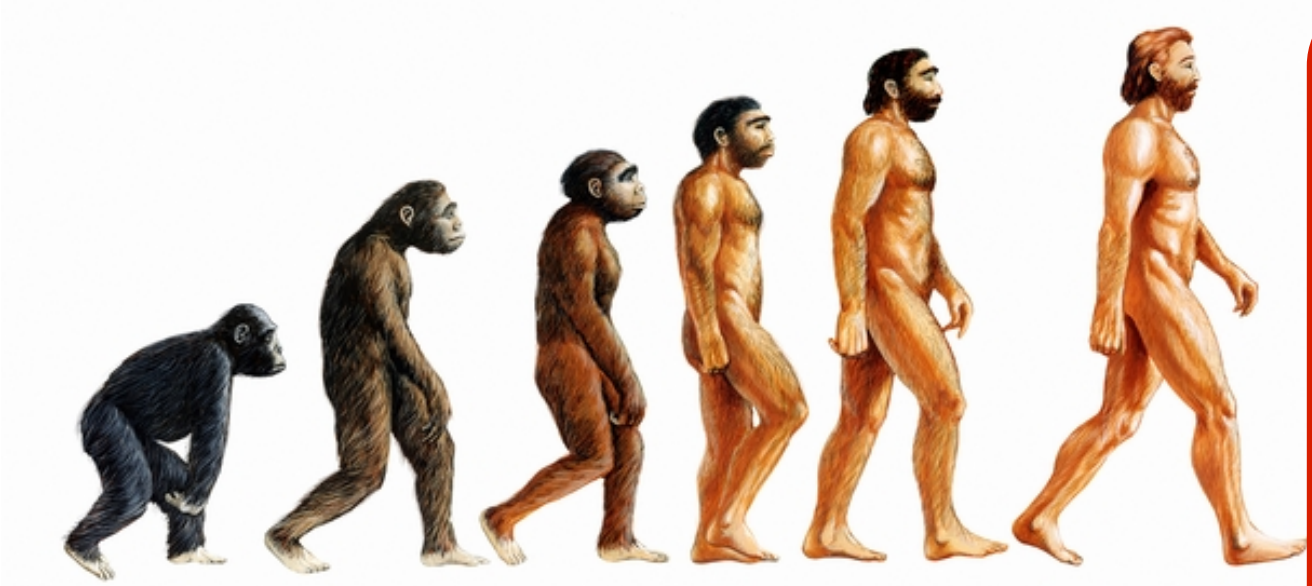
- Gantry speed
  - for safety reasons limited to 1 rpm
- Leaf speed
  - max. 2cm/sec with the MLC2i
- Dose rate
  - ~ 6 Gy/min

The evolution of radiotherapy



- Cobalt
- Linac
- Linac
  - MLC
  - IMRT
- Desktop
  - MLC
  - IMRT
  - IGRT
  - Monaco 1.0
- Integrity 1.1
  - MLCi2
  - IMRT
  - IGRT
  - VMAT
  - Monaco 2.04

The evolution of radiotherapy – the next generation



- Cobalt
- Linac
- Linac
  - MLC
  - IMRT
- Desktop
  - MLC
  - IMRT
  - IGRT
  - Monaco 1.0
- Integrity 1.1
  - MLCi2
  - IMRT
  - IGRT
  - VMAT
  - Monaco 2.04
- Integrity 3.1
  - Agility
  - IGRT
  - VMAT
  - Monaco 3.3
  - Mosaiq 2.5

Agility

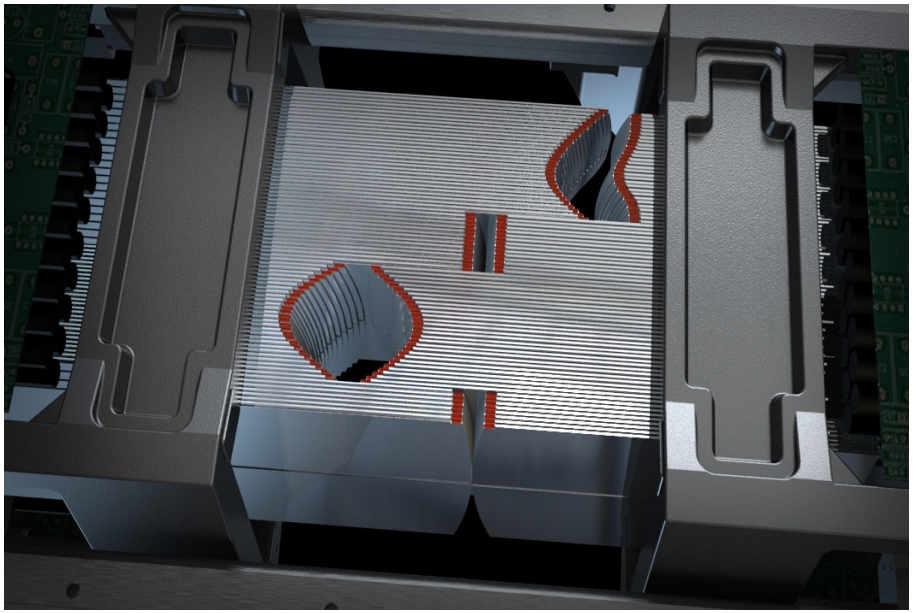
- 160 leaves x 5 mm width in ISO, 40x40 field

- Interdigitation

- Leaf speed up to 6.5 cm/ sec

- Leakage/ transmission < 0.5%

- Smoother and more precise modulation

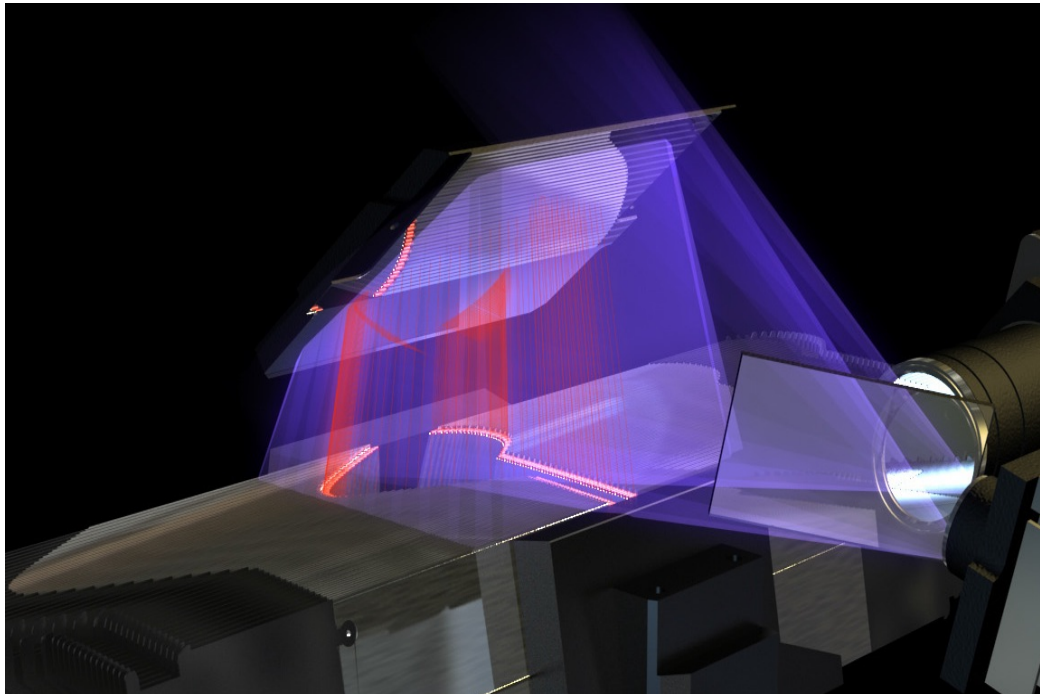


MLC	Nr.of leafs	Leaf width isocenter	overtravel	Leaf speed	Leaf nominal height
Agility	160	0,5 cm	15 cm	0-3,5cm/sec up to 6,5 cm/sec * *Combined with leaf guide	9 cm
MLC2i	80	1,0 cm	12,5 cm	0-2,0 cm/sec.	8,2 cm

*By courtesy of Elekta

MLC Rubicon-System

- MLC-reflectors replaced by ruby tips
- Ultraviolet light from an LED source produces infrared fluorescence when it falls on the ruby tips of the multileaf collimator leaves
- Infrared fluorescence detected by infrared camera



*By courtesy of Elekta

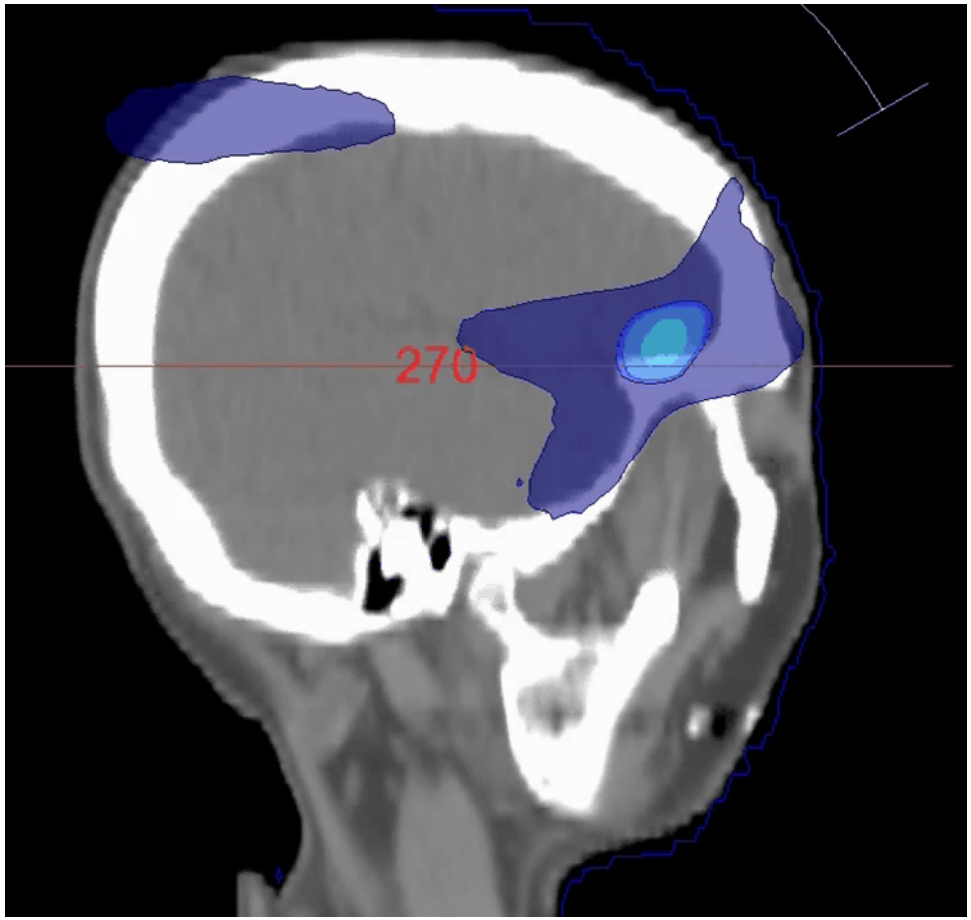
(III)
Monaco 3.3 treatment planning

Monaco 3.3 treatment planning

- Cost function based biological and physical optimization
- TEMPLATES
- Two step optimization (optimal fluence then segmentation)
- Margin concepts to avoid help structures
- Virtual Head Model
- Monte Carlo dose engine
- Segmentation with sliding window that fits the Agility head

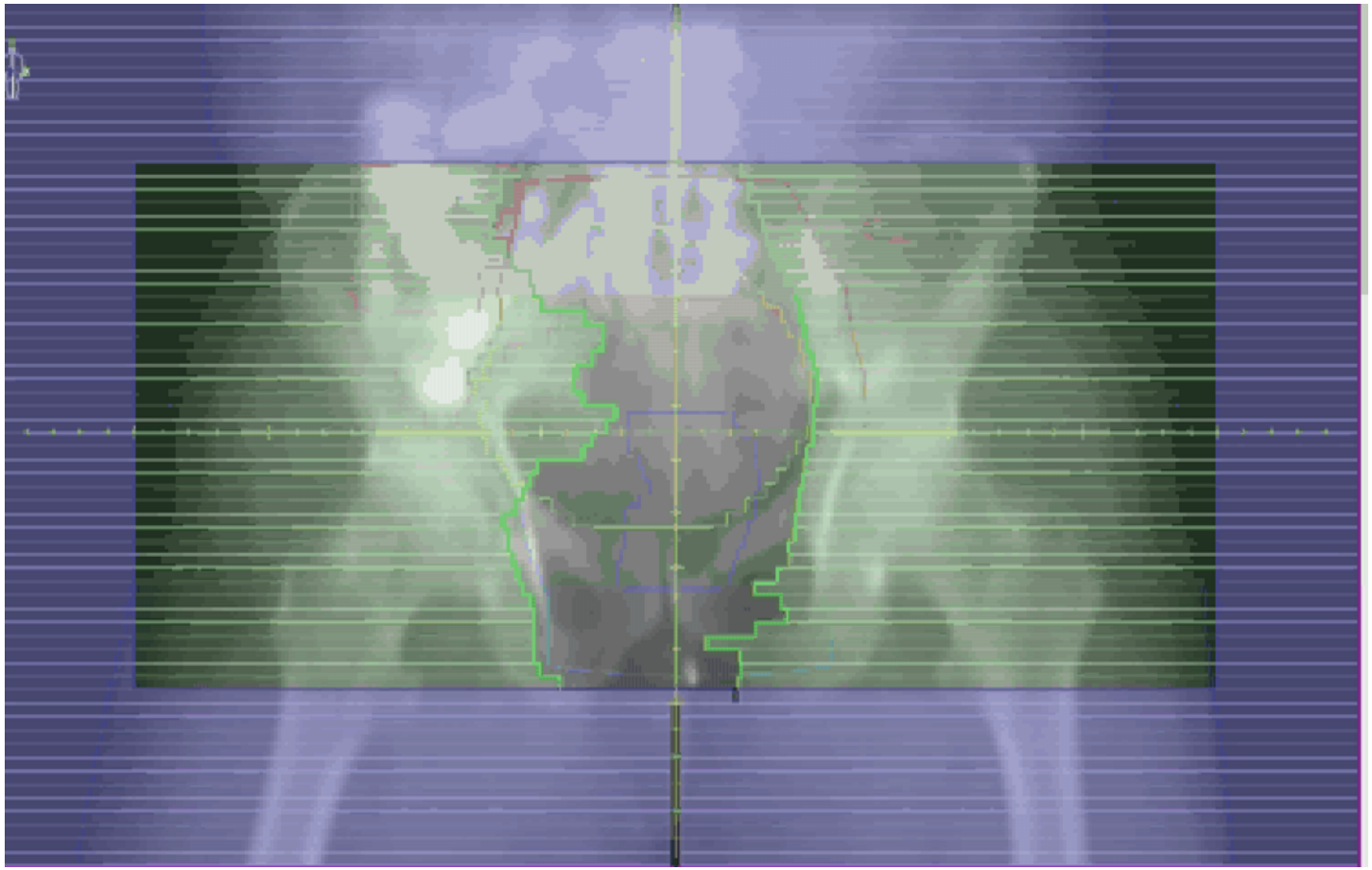
Agility and Monaco 3.3

- Small lesions
- Dedicated Micro MLC not needed anymore
- One solution for all our planning needs



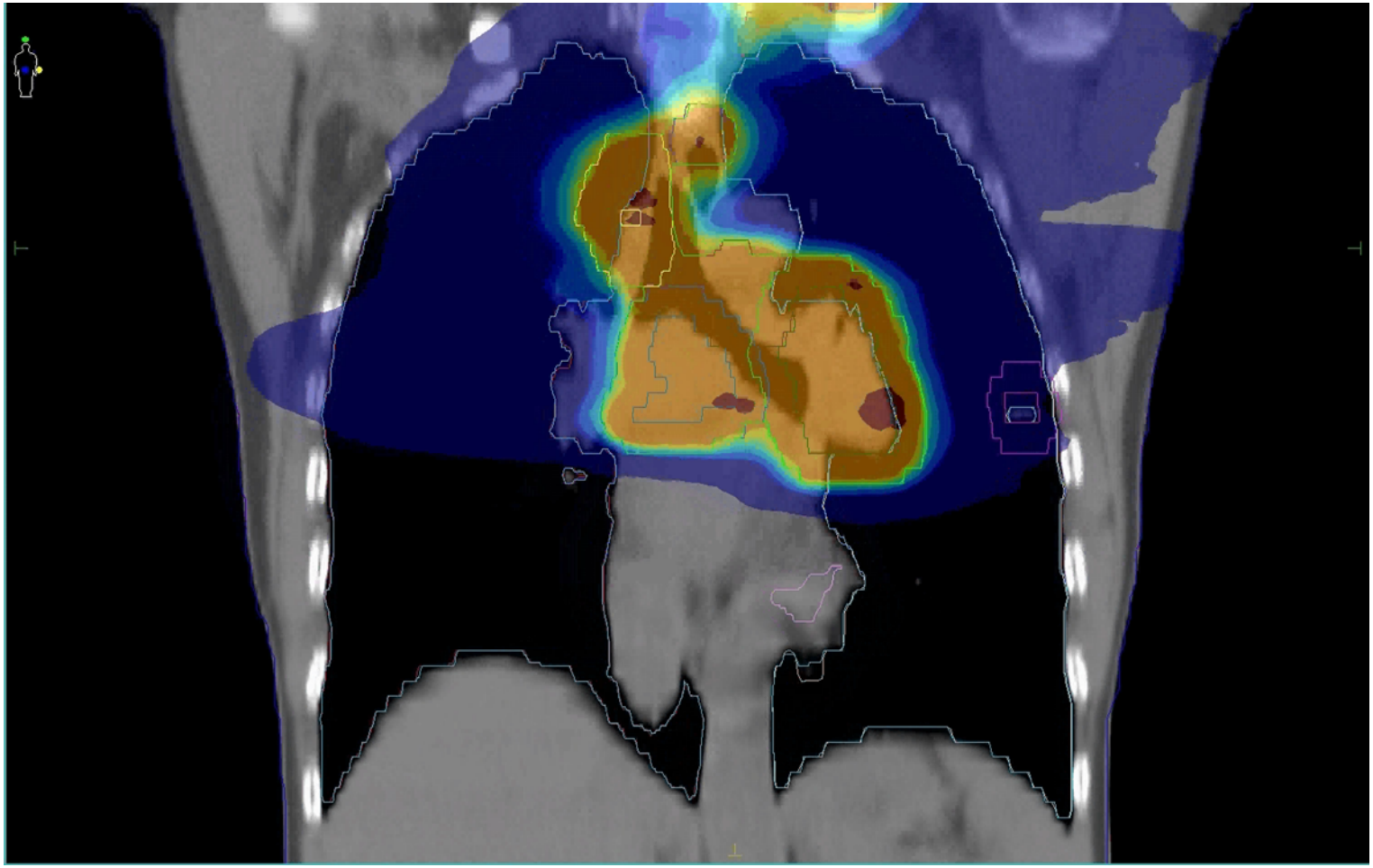
Moving leaf bank and Monaco

Moving leaf bank in Agility and in Monaco … full speed if all the leafs are moving in the same direction



Biased dose in planning

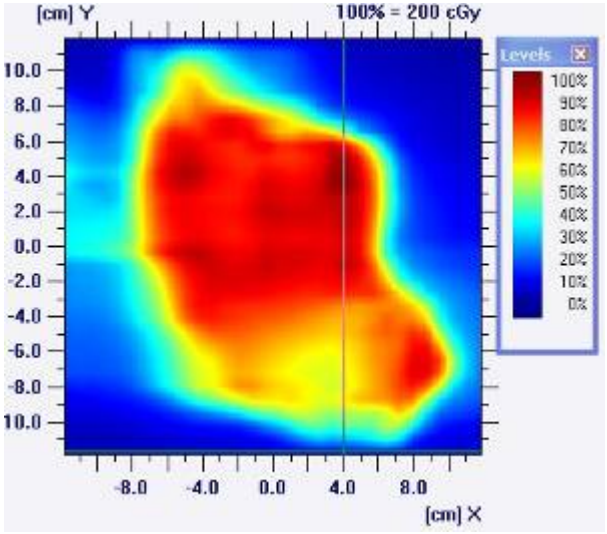
Optimization takes into account previously given doses…



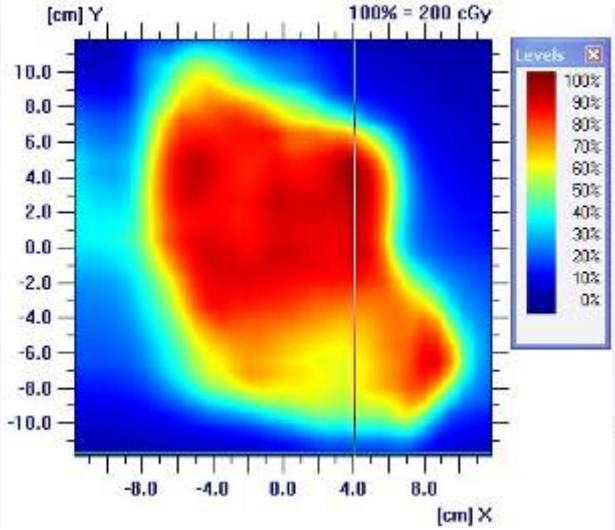
Fleckenstein et al., submitted

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

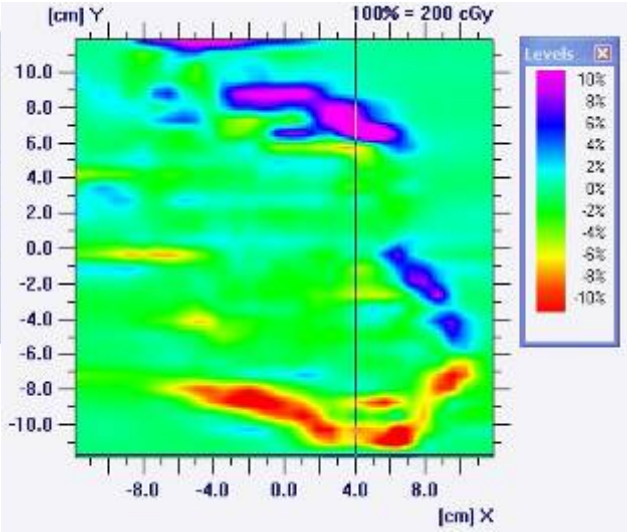
static case



with motion



difference map

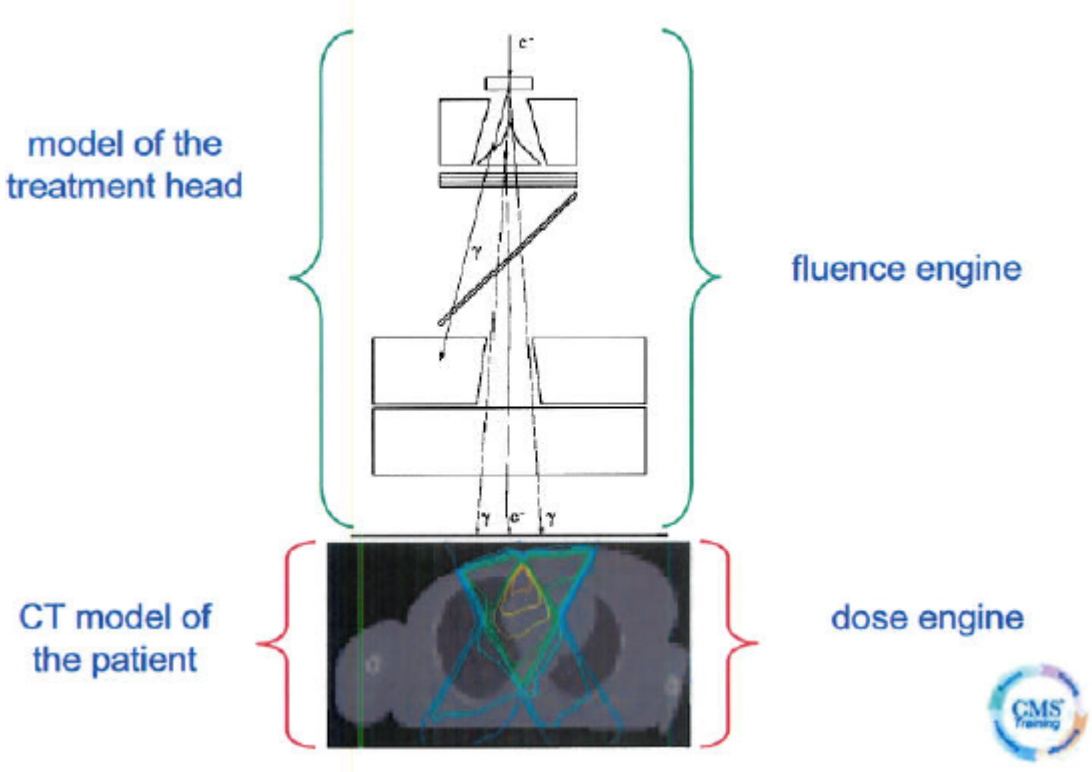


UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

Monaco dose calculation modules

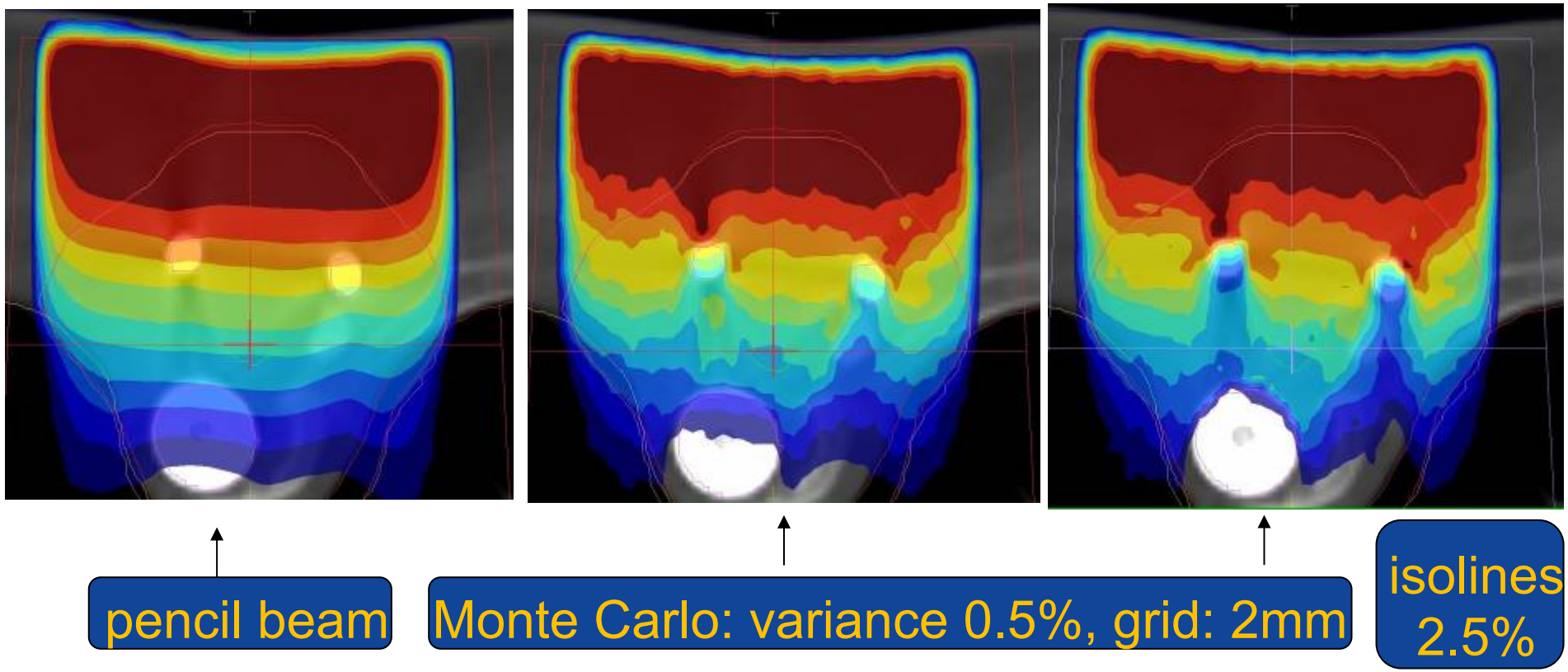


Virtual fluence model
vs.
full treatment head simulation

Pencil beam
and
Monte Carlo algorithm

ρ_e(HU) and ω_i (HU)

Hounsfield Unit conversion: metallic implants

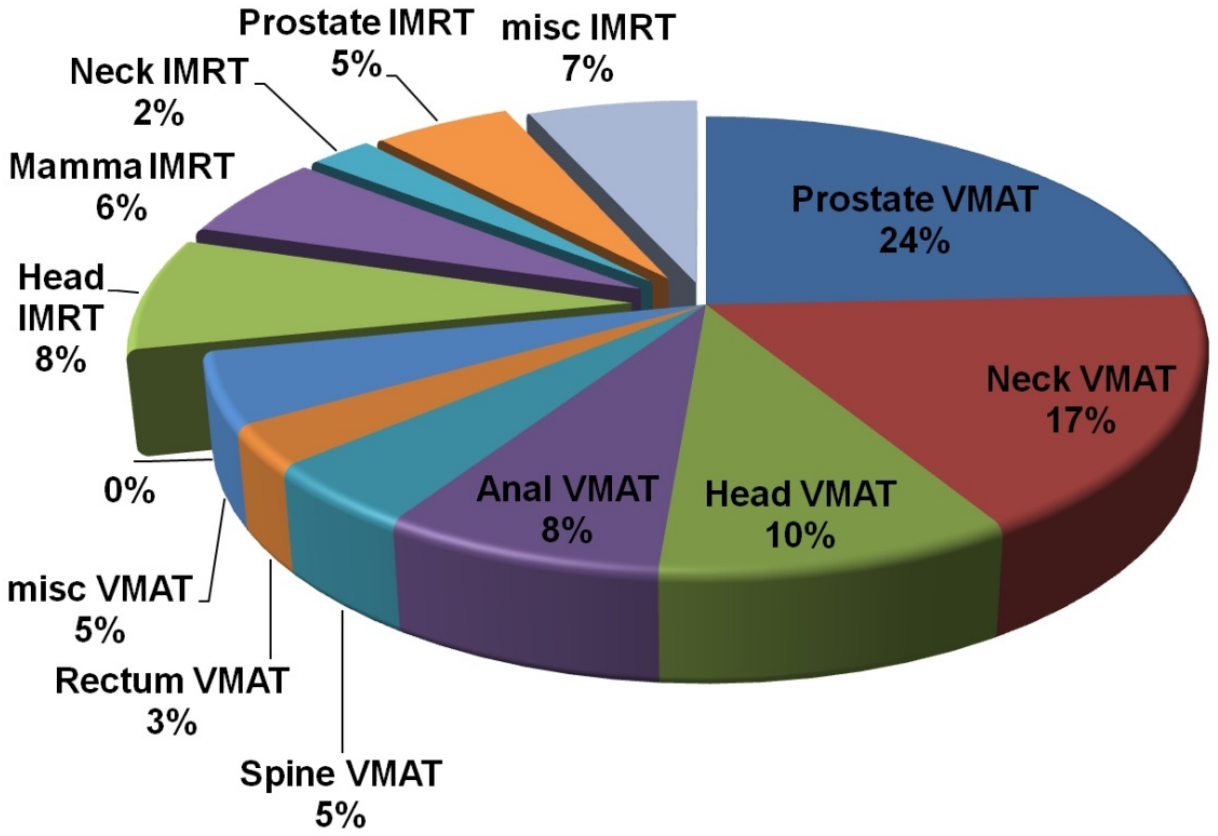


- contouring implants, which are in the PTV, improves the target DVH and enhances the optimization convergence probability
- relative electron density of titanium implants: 3.73
- use clear and fill options for CT reconstruction artifacts

Fleckenstein et al., Z Med Phys, 2013

Monaco 3.3 at Mannheim University Hospital

About 80% of all treatments are intensity modulated techniques



Limitations for treatment speed

- Gantry speed
  - for safety reasons limited to 1 rpm
- Leaf speed
  - max. 2cm/sec with the MLC2i
- Dose rate
  - ~ 6 Gy/min

One clinical hour at a Linac

Elekta Synergy + Integrity 1.1 + MLCi 2

Action	Patient	Time	Description	MU's	Fx Dose	Treatment Time	Total
finish treatment	Patient A	11:22					~26 min
finish IGRT	Patient B	11:35	cone beam CT (XVI)				
finish treatment	Patient B	11:43	6X StepNShoot 82CPs	614.6 MU	1.8 Gy	~8 min	
finish IGRT	Patient C	11:51	cone beam CT (XVI)				
finish treatment	Patient C	11:56	6X VMAT 205CPs	670.5 MU	2.0 Gy	~5 min	
finish IGRT	Patient D	12:06	cone beam CT (XVI)				
finish treatment	Patient D	12:13	6X VMAT 181CPs	1357.0 MU	2.0 Gy	~7 min	
finish IGRT	Patient E	12:22	cone beam CT (XVI)				
finish treatment	Patient E	12:26	6X VMAT 191CPs	479.7 MU	1.8 Gy	~6 min	

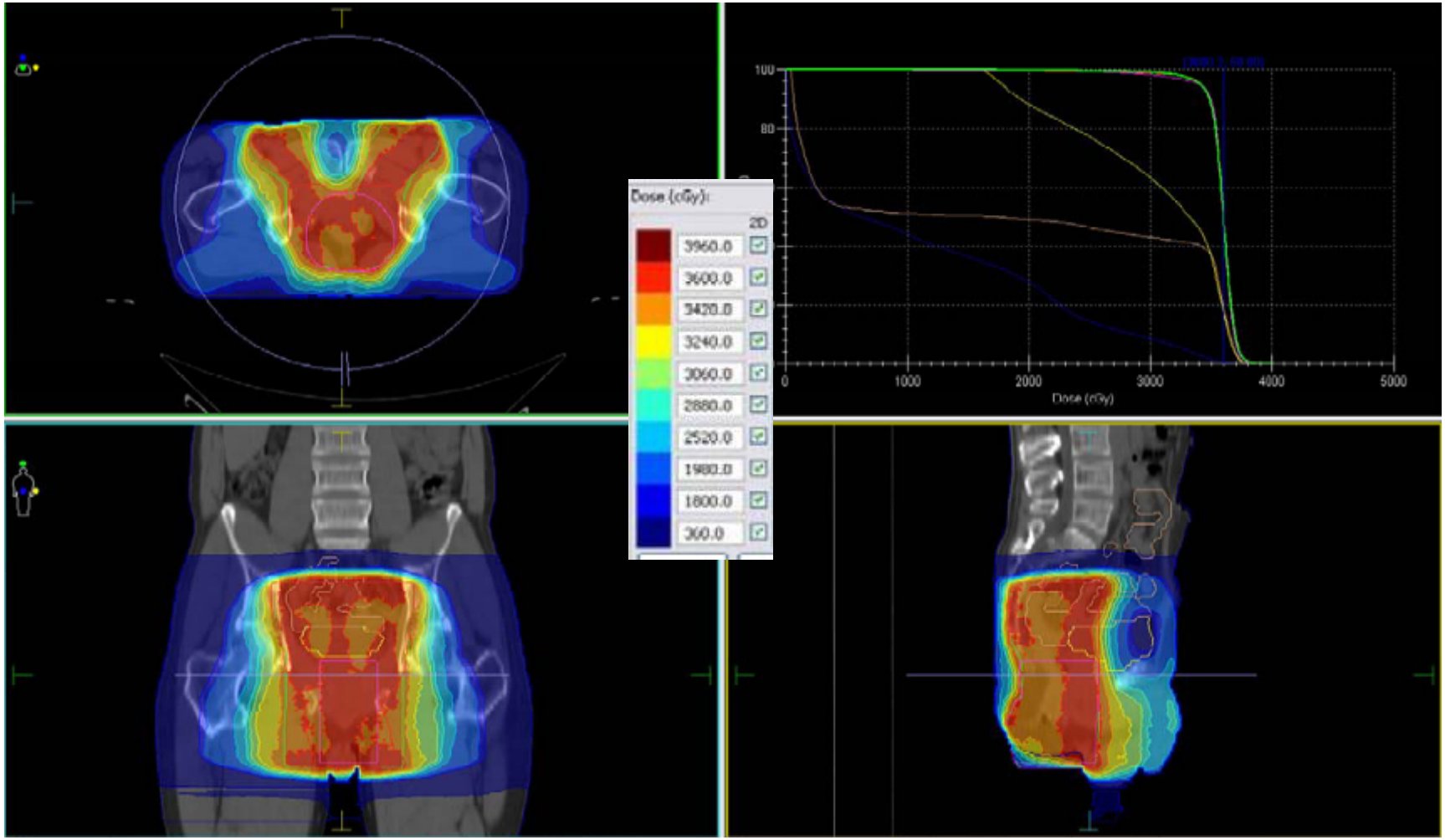
Versa HD + Integrity 3.1 + Agility

Action	Patient	Time	Description	MU's	Fx Dose	Treatment Time	Total
finish treatment	Patient A	10:15					~28 min
finish treatment	Patient B	10:22	10X VMAT 206CPs	424.8 MU	1.8 Gy	~4 min	
finish IGRT	Patient C	10:30	cone beam CT (XVI)				
finish IGRT	Patient C	10:32	2x MV Images (IView)	4.0 MU			
finish treatment	Patient C	10:37	10X VMAT 128CPs	491.2 MU	1.8 Gy	~5 min	
finish IGRT	Patient D	10:45	cone beam CT (XVI)				
finish treatment	Patient D	10:48	10X VMAT 189CPs	826.8 MU	2.0 Gy	~7 min	
finish IGRT	Patient E	10:55	cone beam CT (XVI)				
finish treatment	Patient E	11:00	10X DMLC 96CPs	670.2 MU	2.0 Gy	~5 min	
finish IGRT	Patient F	11:09	cone beam CT (XVI)				
finish treatment	Patient F	11:16	6X DMLC 165CPs	597.2 MU	2.0 Gy	~7 min	

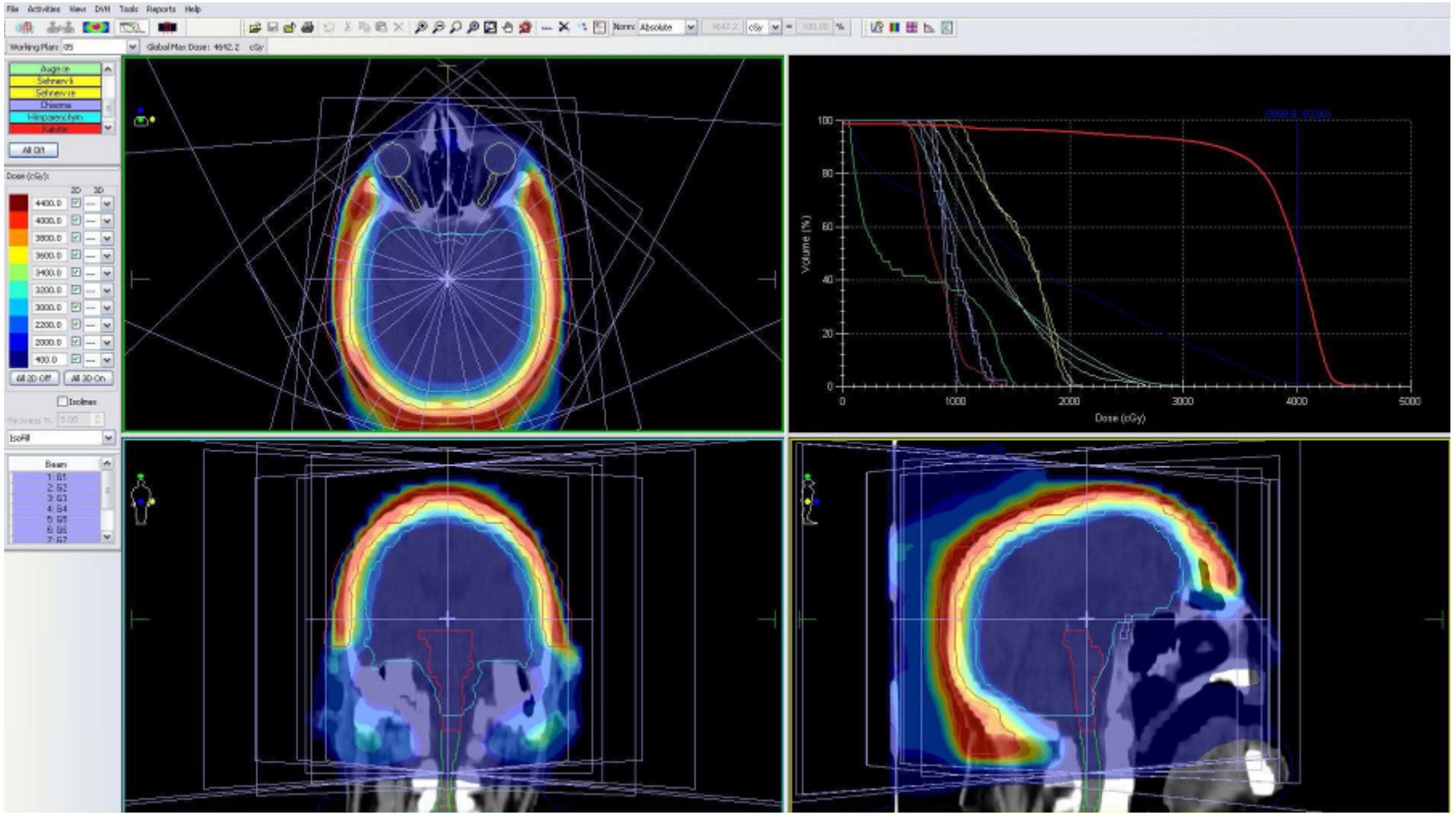
Limitations for treatment speed

- Gantry speed
  - for safety reasons limited to 1 rpm
- Leaf speed
  - max. 6.5 cm/sec with the Agility
- Dose rate
  - ~ 6 Gy/min

Anal Cancer



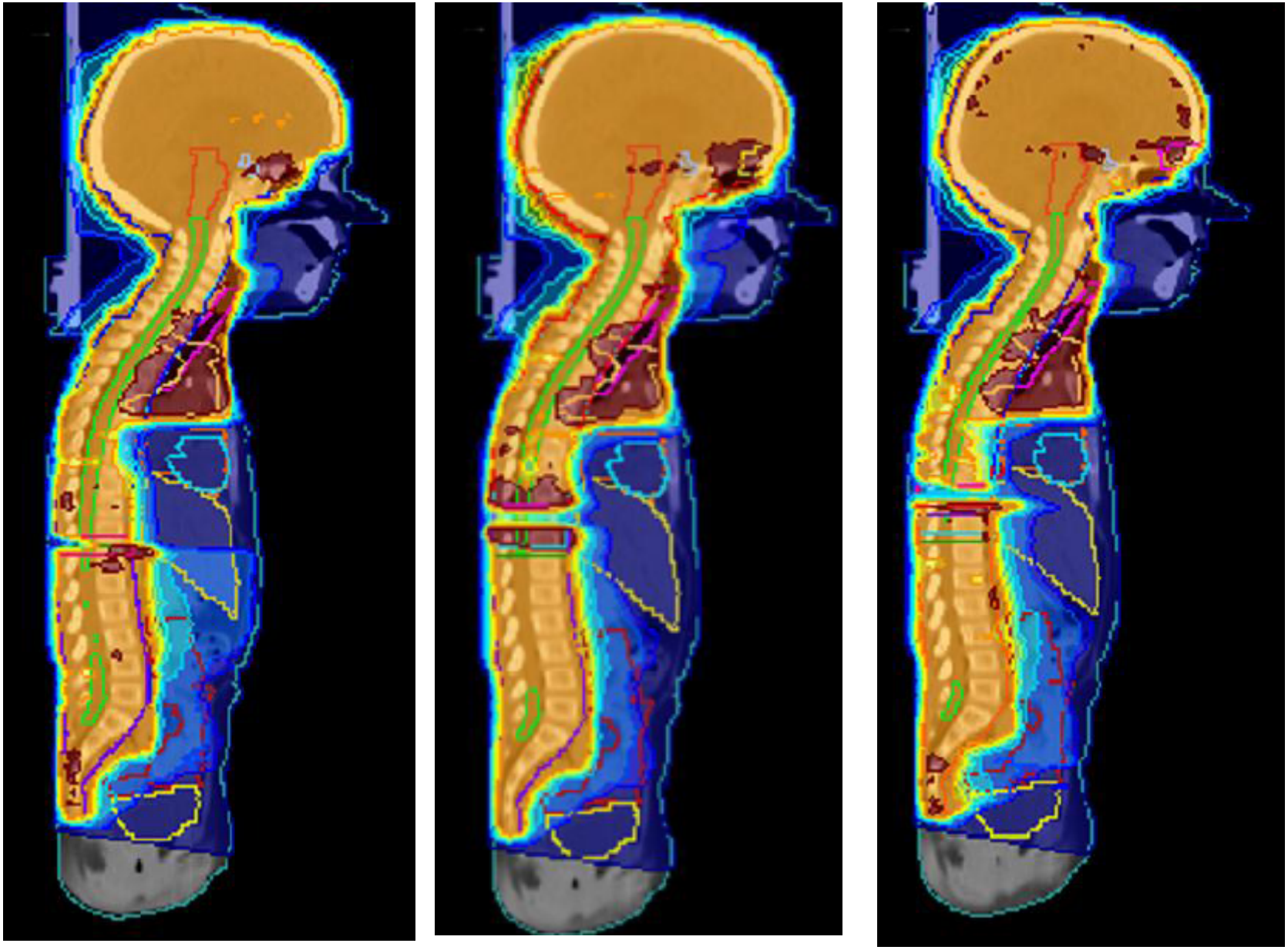
640 MU
BOT 8 min



UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

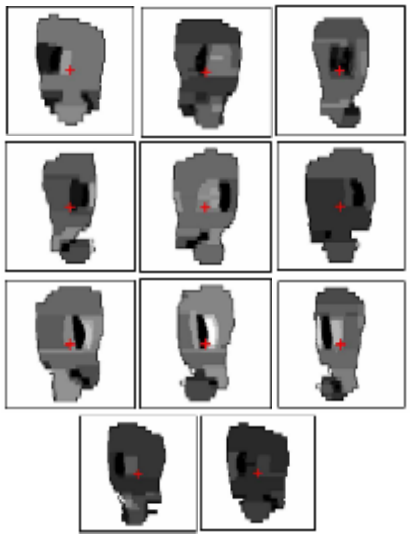


UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

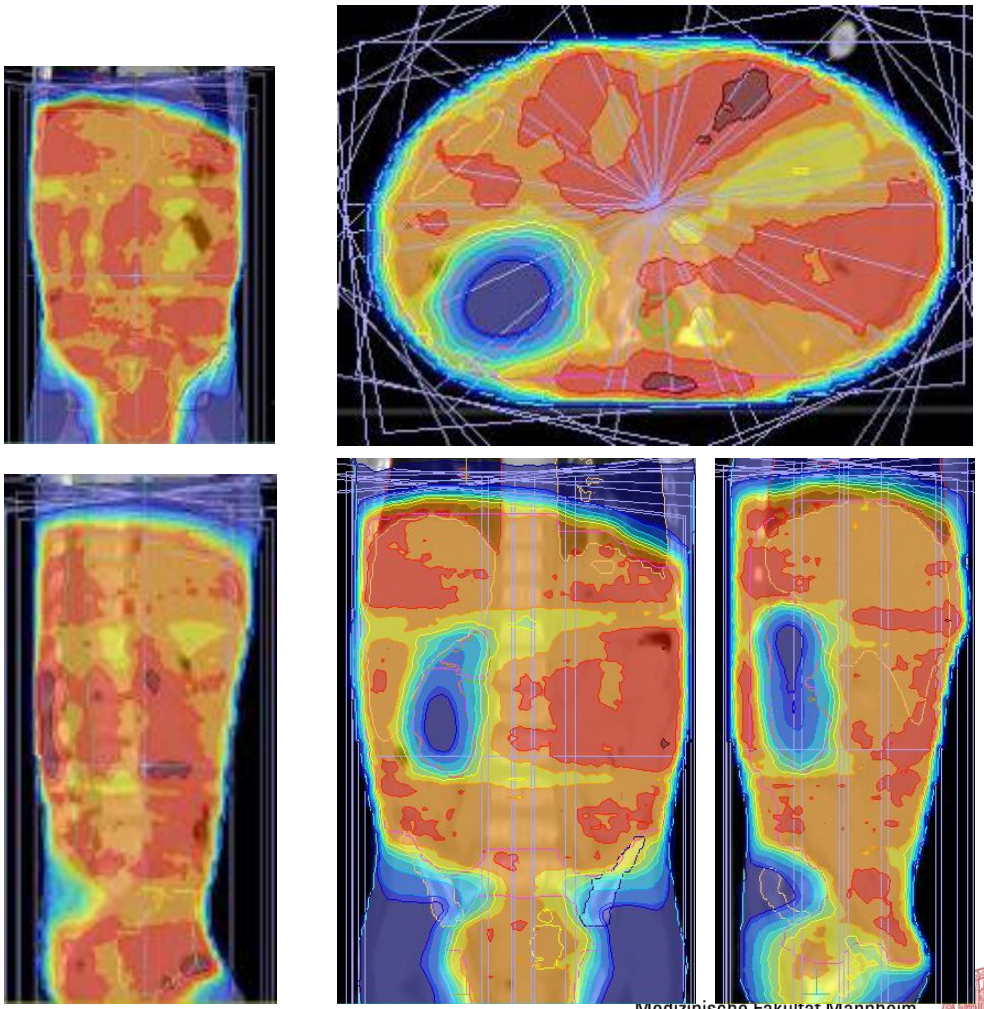
Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

Step-and-Shoot IMRT



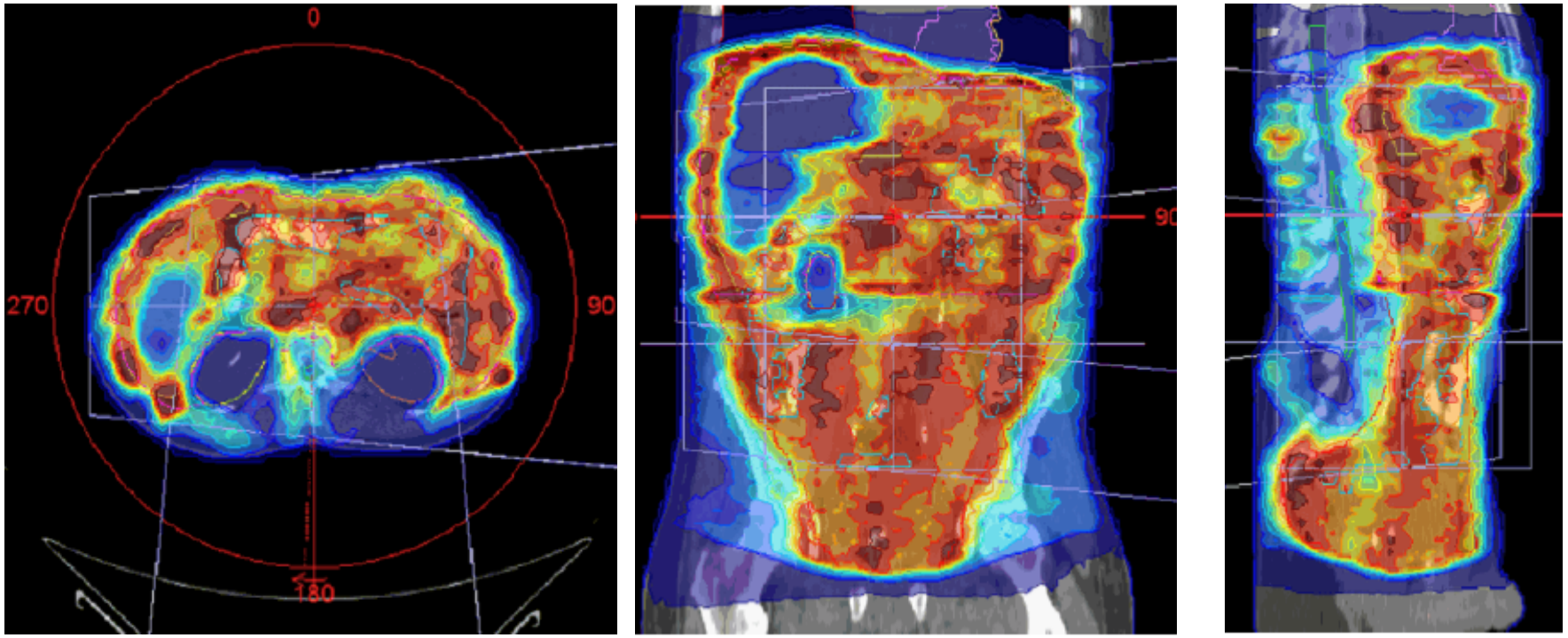
695 MU/1.5 Gy
92 Segments
T= 13 min



UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

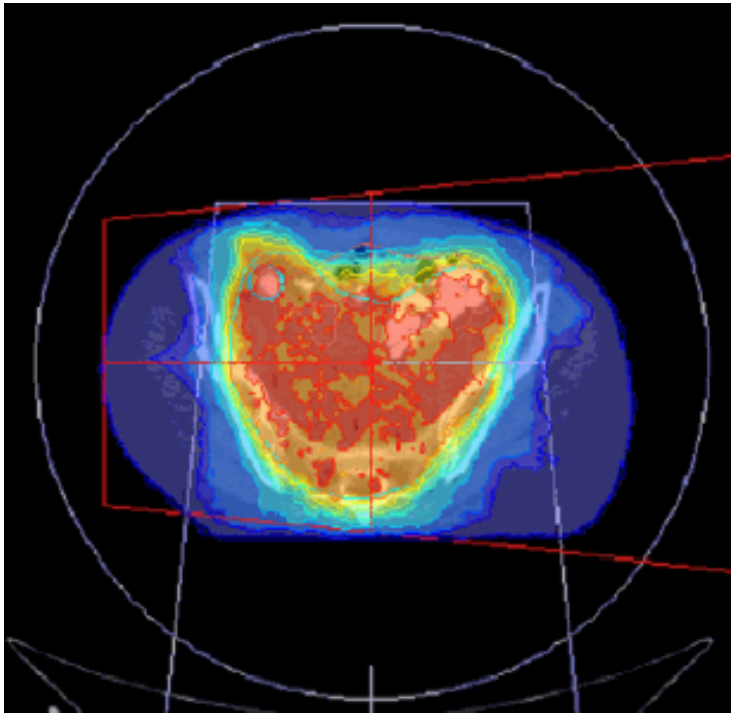
Universitätsklinikum Mannheim

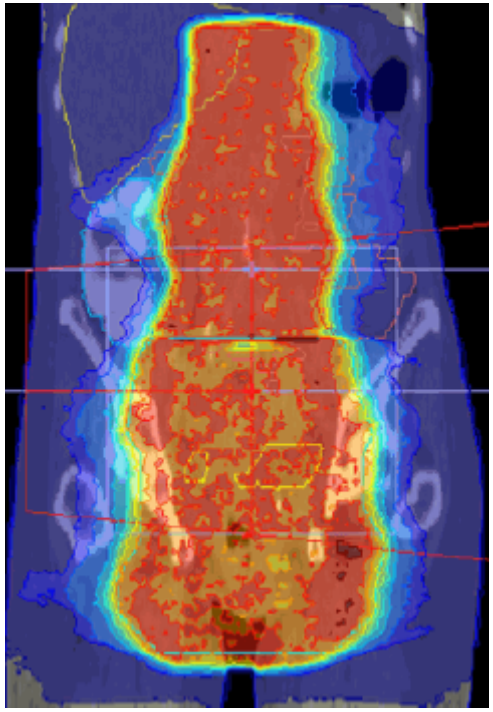


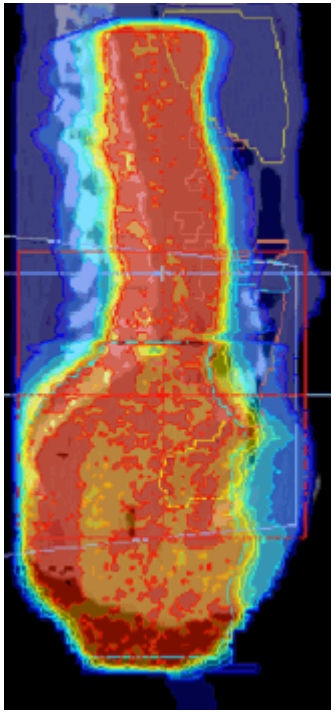
Peritoneal PNET

Two arcs, Two isocenters, 2740 MU/1.5 Gy

First CT to last beam off: ~20 min (2 CTs, 2 Arcs)







Anal Cancer

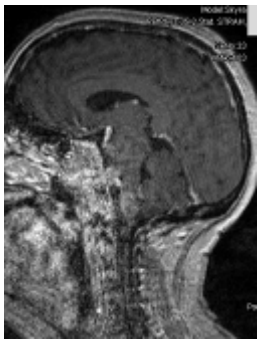
Two arcs, Two isocenters, 1403 MU/1.8 Gy

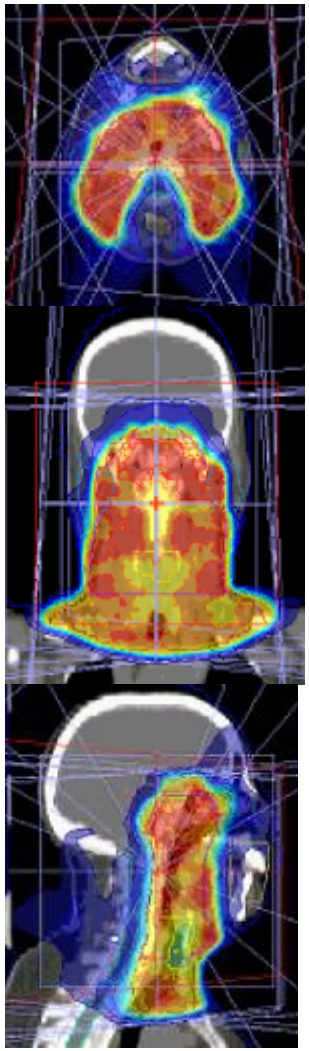
First CT to last beam off: <20 min (2 CTs, 2 Arcs)

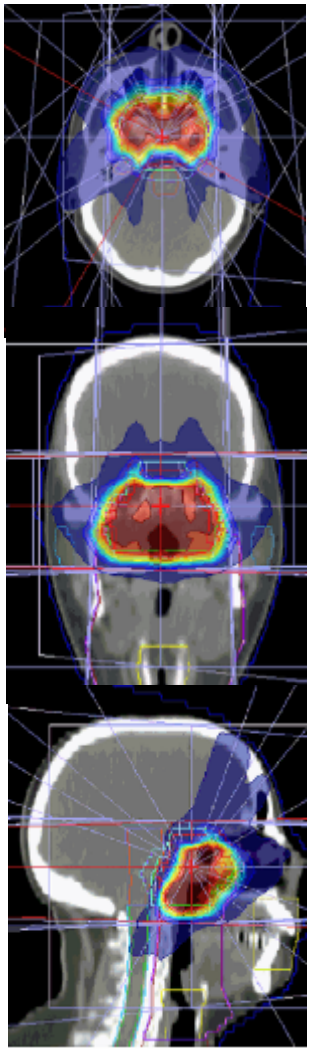
NPC

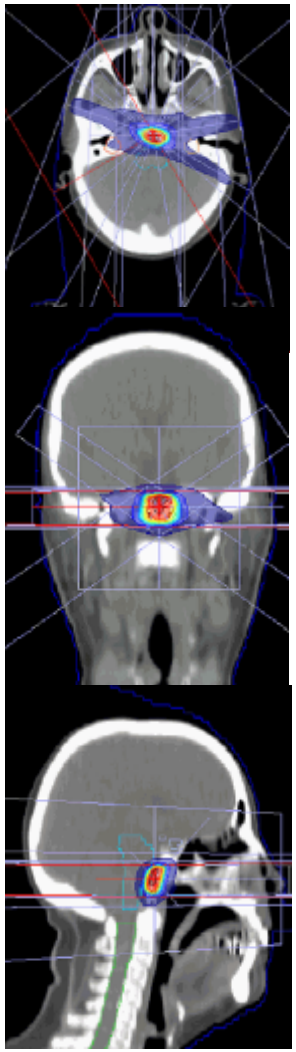
Treatment Sequence

before

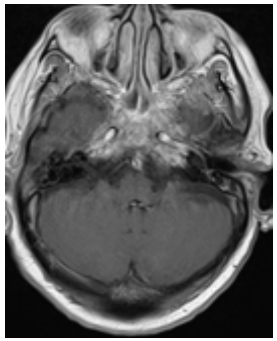


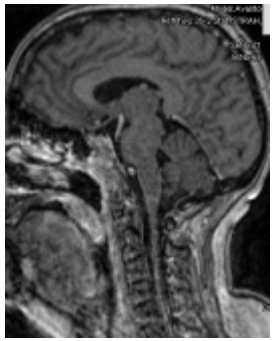






after

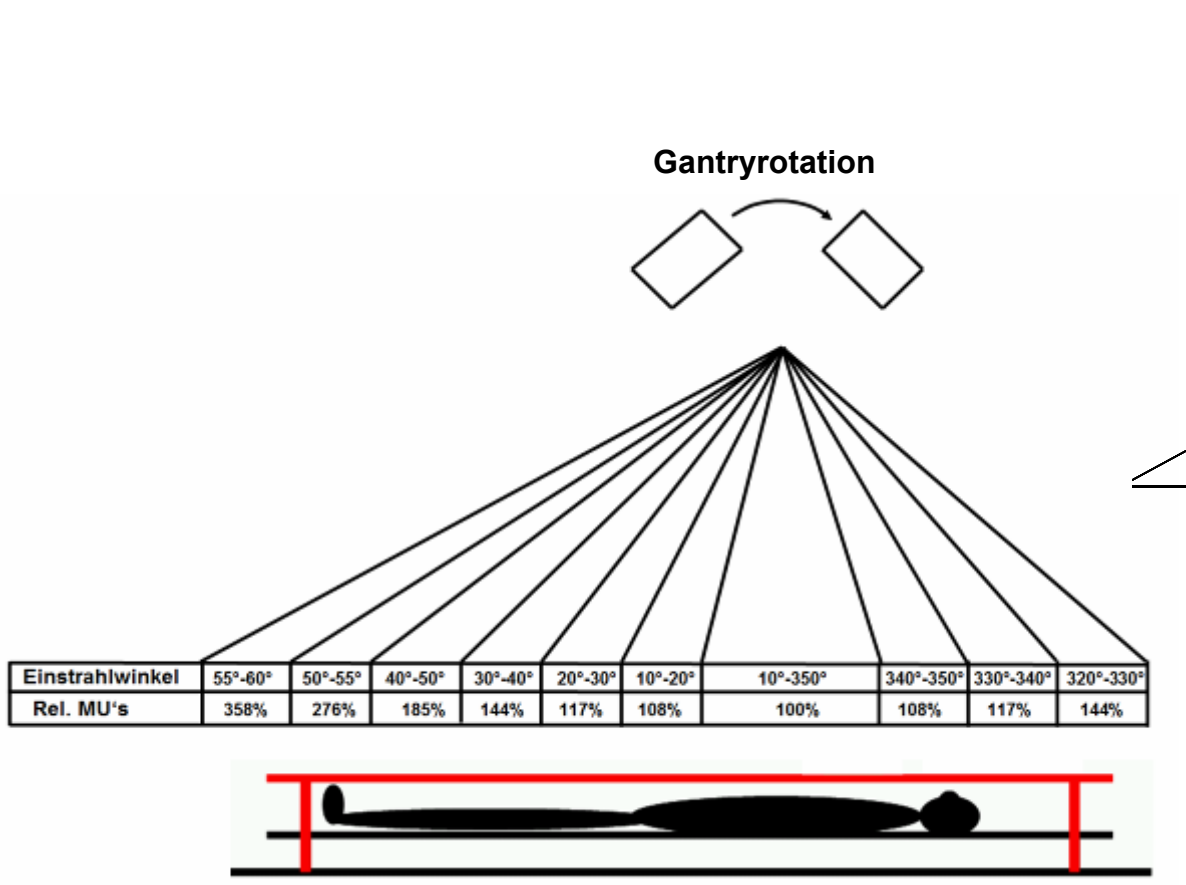




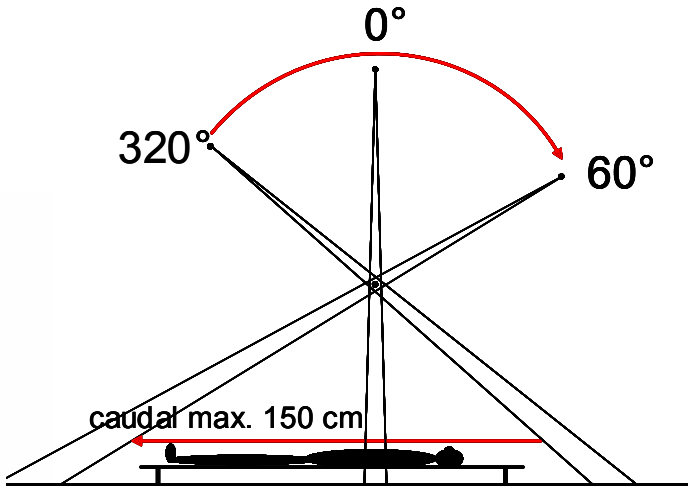
Longitudinal VMAT TBI

Jahnke et al., Radiother Oncol, 2014

Unterteilung eines kontinuierlichen Bestrahlungsbogens von 320° bis 60° mit 10 Kontrollpunkten (Feldgröße 10x40cm)



Einstrahlwinkel	55°-60°	50°-55°	40°-50°	30°-40°	20°-30°	10°-20°	10°-350°	340°-350°	330°-340°	320°-330°
Rel. MU's	358%	276%	185%	144%	117%	108%	100%	108%	117%	144%



Clinical experiences with FFF treatment delivery

Jens Fleckenstein, Ph.D.
University Medicine Mannheim, Germany

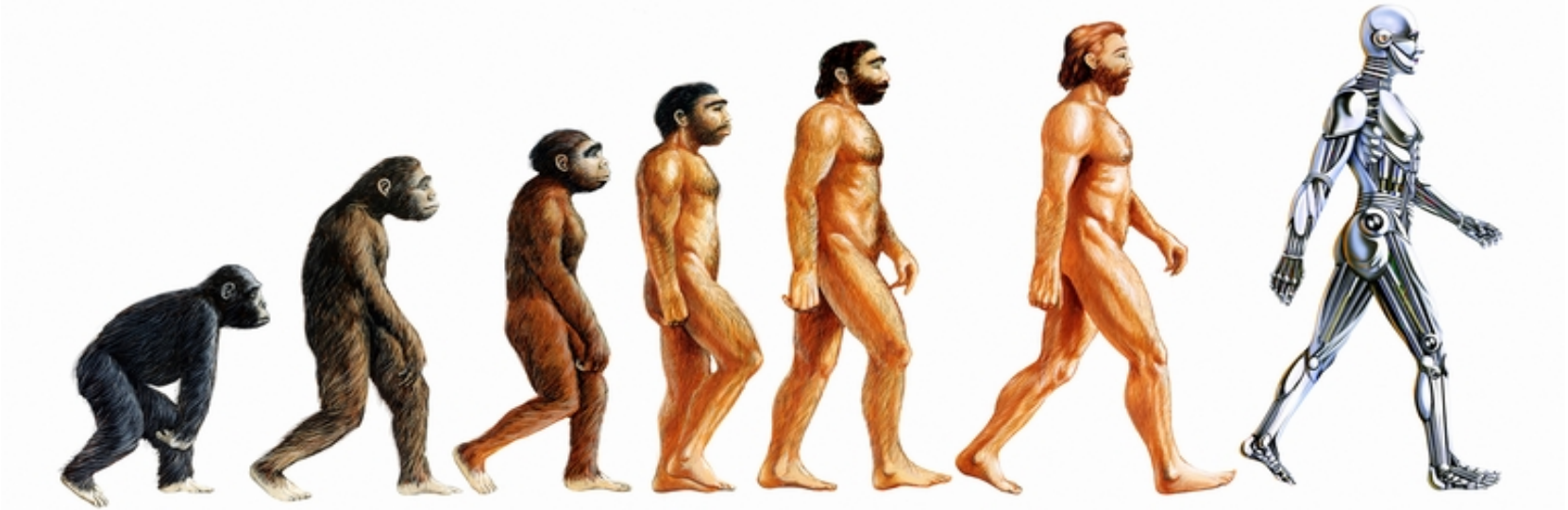
UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

(IV)
Overview

The evolution of radiotherapy – the next generation



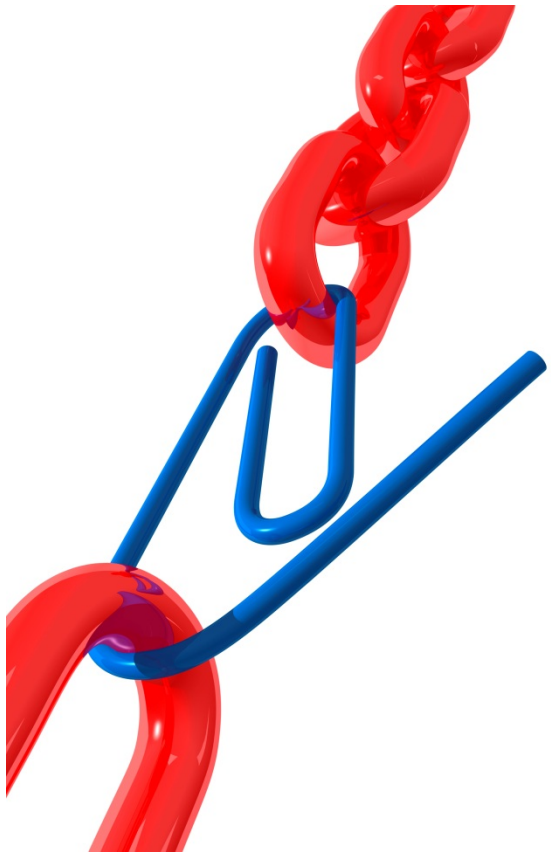
- Cobalt
- Linac
- Linac
  - MLC
  - IMRT
- Desktop
  - MLC
  - IMRT
  - IGRT
  - Monaco 1.0
- Integrity 1.1
  - MLCi2
  - IMRT
  - IGRT
  - VMAT
  - Monaco 2.04
- Integrity 3.1
  - IGRT
    - XVI,
    - Clarity,
    - ABC
  - VMAT/ dMLC
  - Monaco 3.3
  - Mosaiq 2.5
  - Versa HD

Treatment chain

- **Philips Brillinace CT** Big Bore – 16 stripe
- **Monaco 3.3** to use the full capability of the moving leaf banks
- **Mosaiq 2.5** to deliver FFF
- **Integrity 3.1** to deliver FFF beams

- **Agility MLC** to get high leaf speeds
- **DMLC/ VMAT** to be fast and conformal
- **FFF** to achieve high dose rates

- **IGRT (XVI, Symmetry, Clarity)** to position accurately
- **Patient immobilization (ABC)**
- A fast and reliable **QA** method



Current status Versa HD in Mannheim

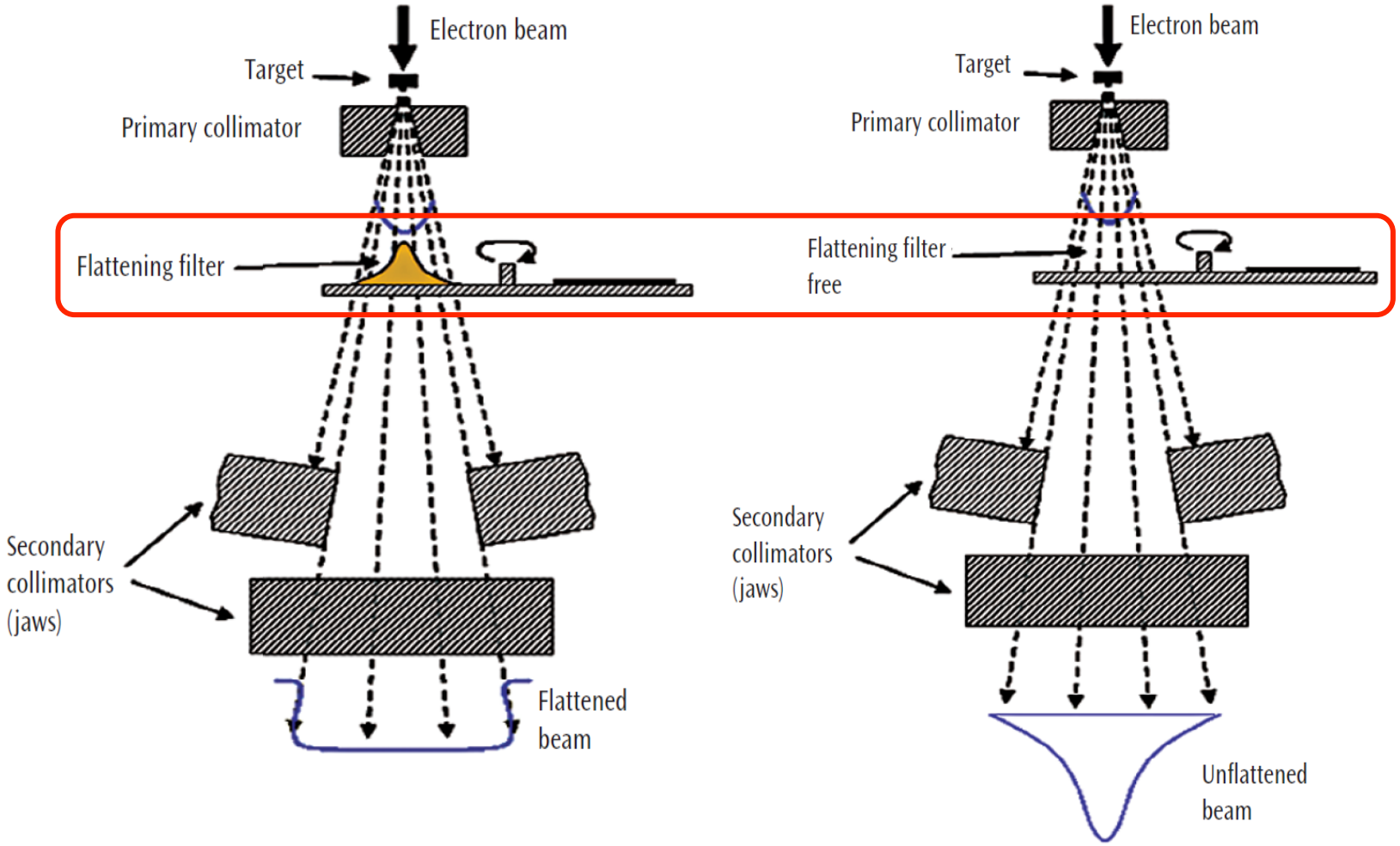
- Nov. 2012: machine commissioning finished, validation report received
- Mar. 13th: first patient treated with FFF
- Jul. 22-26: matching second Versa HD
- Until Aug. 1st: 38 patients treated with FFF
- Hypo-fractionated ($D_{fx} \geq 5$ Gy) treatments performed:
  - Brain metastases,
  - Lung,
  - Liver,
  - Adrenal glands

Limitations for treatment delivery time

- Gantry speed
  - for safety reasons limited to 1 rpm
- Leaf/ Jaw speed
  - max. 6.5 cm/s with Agility MLC
- Dose rate Versa HD
  - FF mode: ~ 6 Gy/min (600 MU/min)
  - FFF mode: ~ 15 Gy/min (1500 MU/min) for 6 MV
    ~ 24 Gy/min (2400 MU/min) for 10 MV

(V)
Versa HD FFF beam

Flattening filter free (FFF) treatment head



UMM UNIVERSITÄTSMEDIZIN MANNHEIM

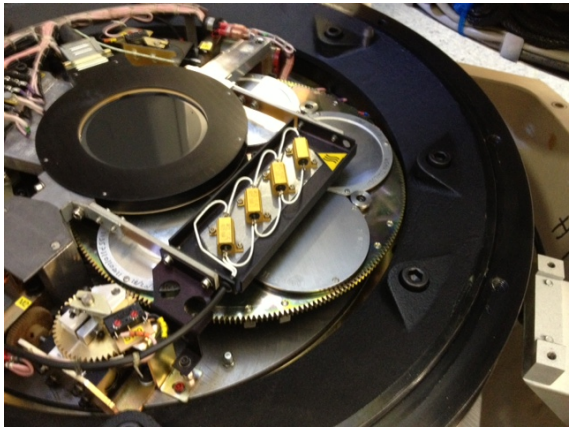
By courtesy of Eva Hrbackova, Elekta Crawley

Medizinische Fakultät Mannheim der Universität Heidelberg

Universitätsklinikum Mannheim

Filter setup Mannheim

	flat	FFF
photons - potential in (MV)		
6	√	√
10	√	√
18	√	Ø
electrons - energy in (MeV)		
low: 4, 6, 8	√	√
mid: 10, 12, 15	√	√
high: 18, 20, 22	Ø	Ø

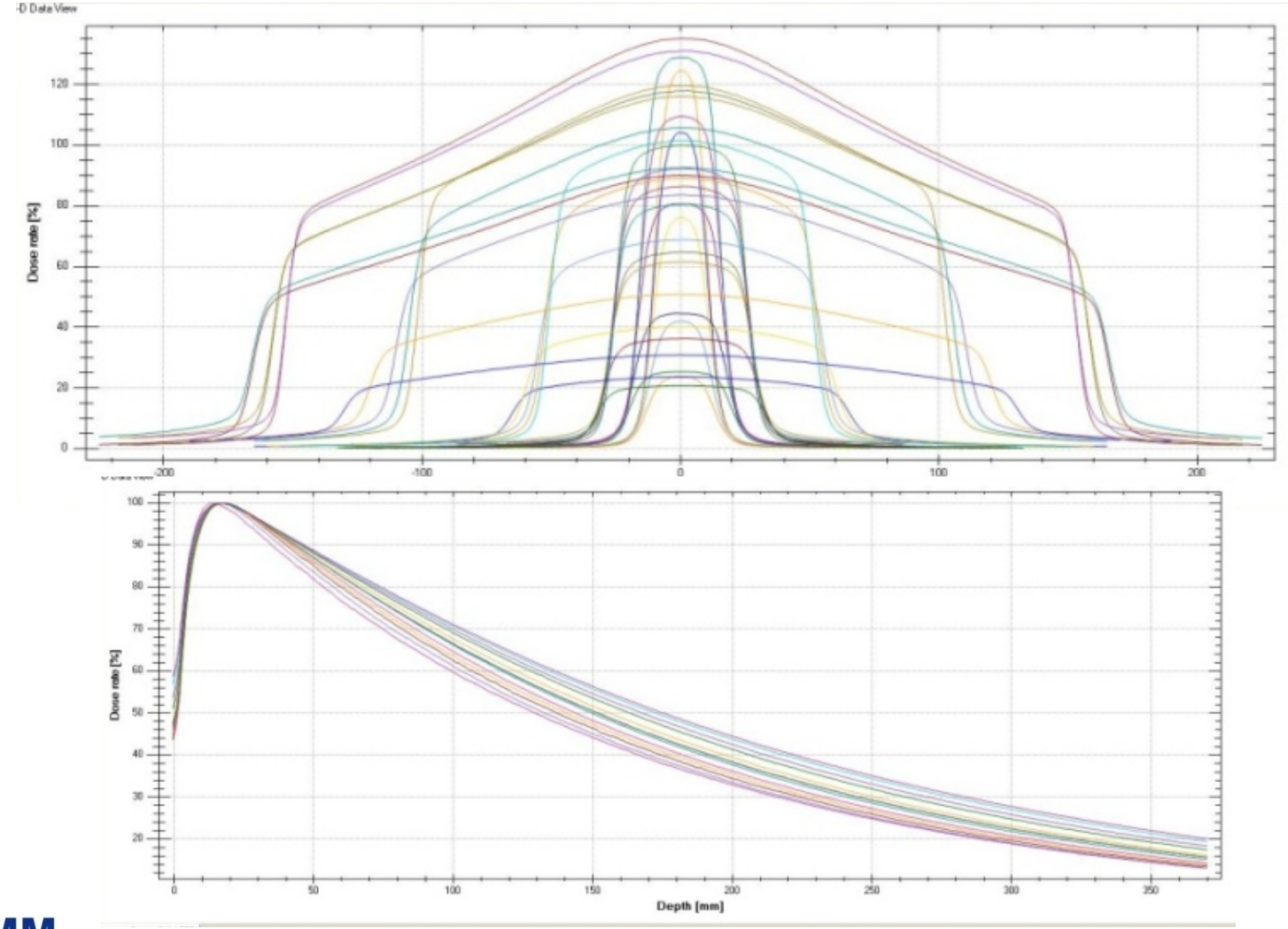


UMM
UNIVERSITÄTSMEDIZIN MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

beam data requirements for Monaco 3.3, FFF , 6 MV

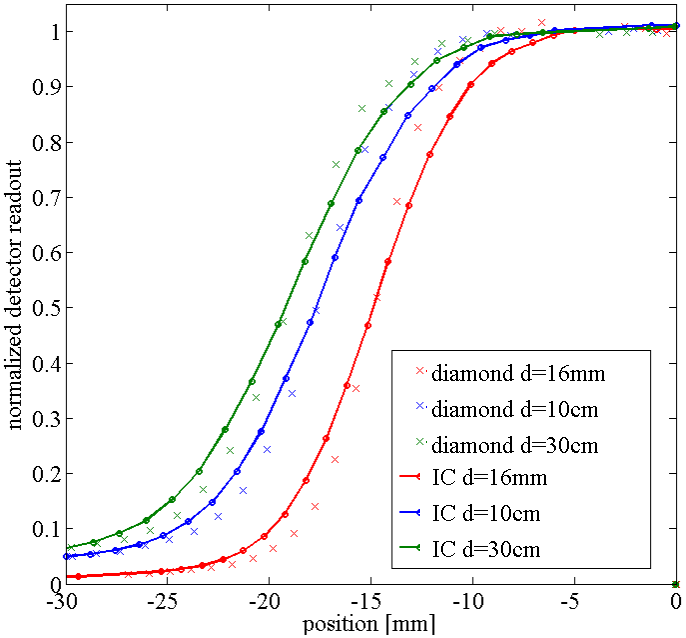


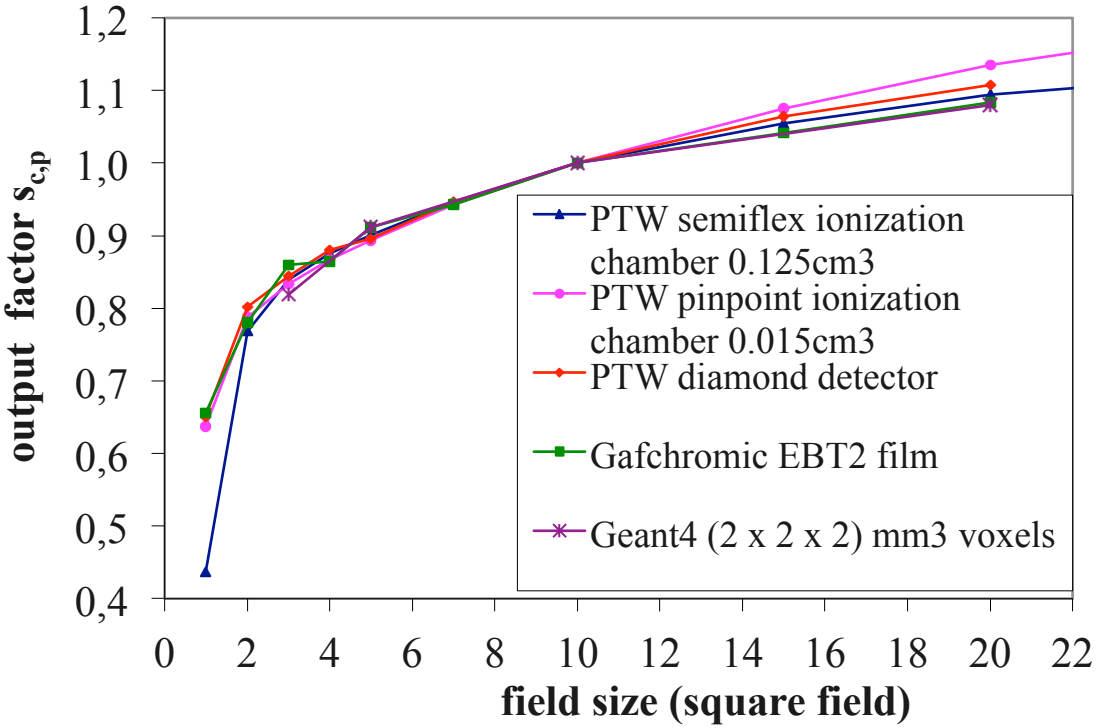
UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

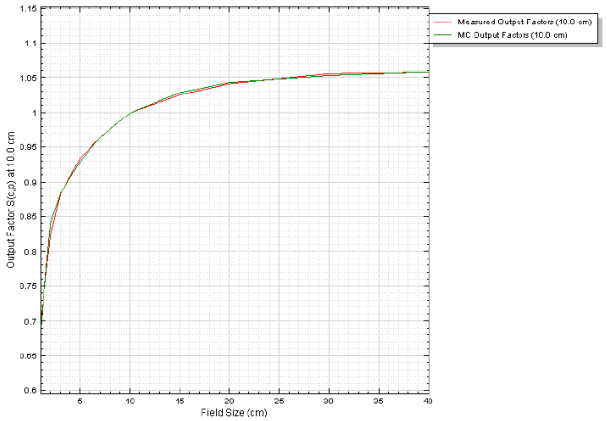
accurate profile/ head scatter measurements



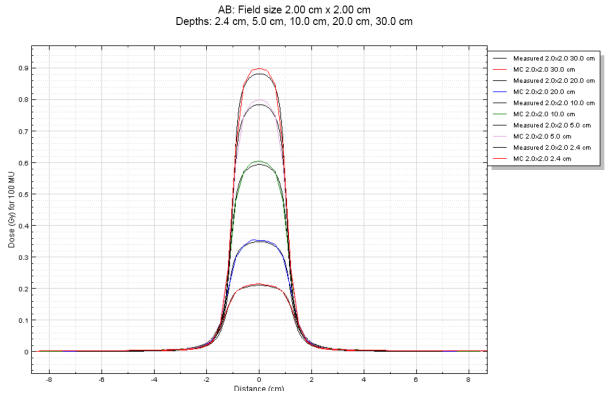


- (3 × 3) cm² quadratic fields (A-B direction)
- VMAT with interdigitating leafs: smaller segments accurate measurements for equivalent field sizes FS< (3 × 3) cm²
- use diamond or diode detector for FS< 3 cm

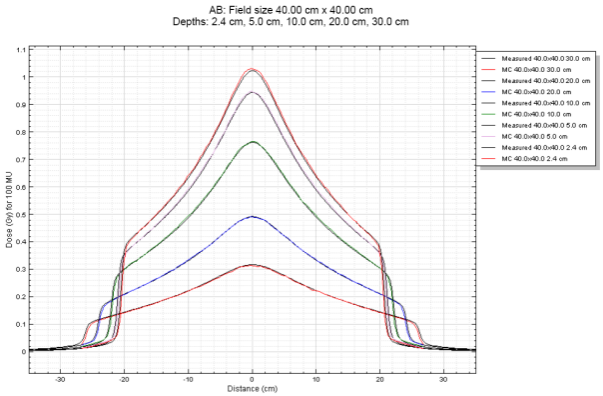
Monaco Virtual Energy Fluence model - FFF 10 MV



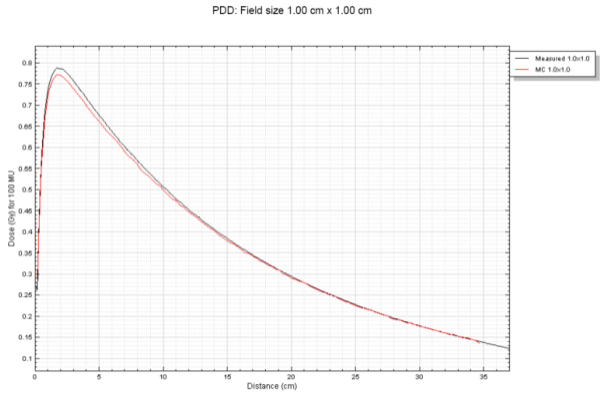
$s_{c,p}$



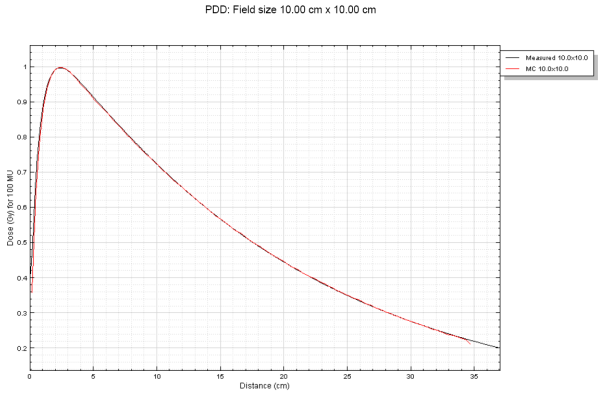
(2×2) cm² field



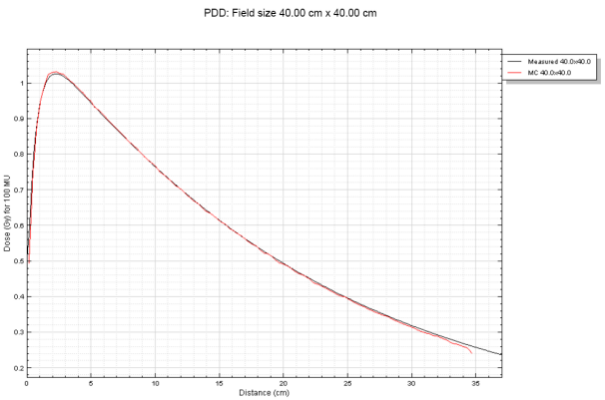
(40×40) cm² field



PDD (1×1) cm²



PDD (10×10) cm²



PDD (40×40) cm²

UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

Versa HD – LINAC matching – lateral profiles

		10 cm x 10 cm						30 cm x 30 cm						40 cm x 40 cm					
		Monaco		Linac 1		Linac 2		Monaco		Linac 1		Linac 2		Monaco		Linac 1		Linac 2	
Measurement point distance																			
0.2	G-T axis	98.0	97.7	99.1	99.3	99.4	99.2	89.9	90.4	95.2	95.1	95.2	95.3	85.3	86.1	92.3	92.1	92.4	92.6
	A-B axis	97.4	98.4	99.2	99.1	99.2	99.2	90.7	90.3	95.1	94.7	95.3	95.3	85.8	85.9	92.2	91.7	91.9	92.1
0.5	G-T axis	91.6	91.3	95.1	95.4	95.6	95.1	70.0	69.8	80.0	79.9	80.2	80.2	61.4	61.3	72.5	72.5	72.6	72.8
	A-B axis	91.5	91.5	95.2	94.9	95.0	95.1	69.7	70.1	79.9	79.4	80.2	80.2	61.2	61.0	72.4	72.1	72.2	72.4
0.8	G-T axis	81.2	80.9	87.3	87.7	88.0	87.1	54.0	53.2	64.8	64.8	64.8	64.9	44.6	44.8	56.2	56.1	56.1	56.3
	A-B axis	81.6	81.3	87.2	86.9	86.8	87.2	53.5	53.1	64.8	64.5	64.9	64.9	44.9	44.9	56.2	55.9	55.8	56.2

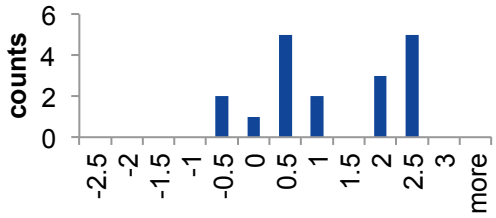
10 MV

measured mean values									
0.2	G-T axis	97.9	99.2	99.3	90.2	95.1	95.3	85.7	92.2	92.5
	A-B axis	97.9	99.2	99.2	90.5	94.9	95.3	85.9	92.0	92.0
0.5	G-T axis	91.5	95.3	95.3	69.9	79.9	80.2	61.4	72.5	72.7
	A-B axis	91.5	95.0	95.1	69.9	79.6	80.2	61.1	72.2	72.3
0.8	G-T axis	81.1	87.5	87.5	53.6	64.8	64.9	44.7	56.1	56.2
	A-B axis	81.5	87.0	87.0	53.3	64.7	64.9	44.9	56.0	56.0

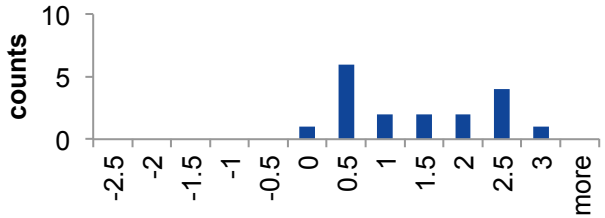
references from Elekta customer acceptance test (CAT)				
0.2	98.4	90	84.9	
0.5	91.4	67.9	59	
0.8	81.1	51.5	42.4	
tolerance (±%)	3	3	3	

deviation from CAT in (%)										
0.2	G-T axis	-0.6	0.1	0.2	0.2	0.5	0.7	0.8	1.1	1.4
	A-B axis	-0.5	0.1	0.1	0.5	0.3	0.7	0.9	0.8	0.9
0.5	G-T axis	0.0	0.3	0.4	2.0	1.7	2.0	2.3	2.2	2.4
	A-B axis	0.1	0.1	0.1	2.0	1.4	2.0	2.1	1.9	2.0
0.8	G-T axis	0.0	0.4	0.4	2.1	2.2	2.3	2.3	2.5	2.6
	A-B axis	0.3	-0.1	-0.1	1.8	2.1	2.3	2.5	2.4	2.4

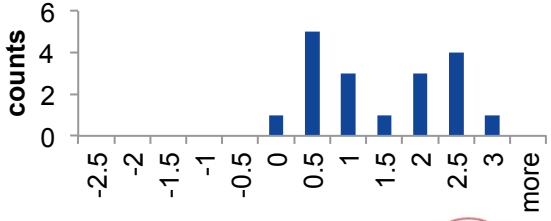
Monaco TPS



LINAC 1



LINAC 2



UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

(VI)
Patient collective

Patient collective

	ID	Modality	fx	dose in (Gy)	CPs/segs	MU	beams/rots	energy
head	1	VMAT	1	16	180	5217	4	6
		VMAT	1	16	176	7620	4	6
	2	VMAT	1	16	112	4326	3	6
	3	VMAT	1	22	32	3089	8	6
	4	VMAT	1	16	66	2245	2	6
	5	VMAT	1	22	66	3206	2	6
	6	VMAT	1	16	89	2439	2	6
	7	VMAT	1	16	66	2353	2	6
	9	VMAT	1	16	90	2094	2	6
	11	VMAT	2	20	69	1395	1	6
	12	VMAT	1	16	54	1992	2	6
	13	VMAT	1	16	66	3971	2	6
		VMAT	1	16	65	4390	2	6
	14	VMAT	1	22	54	3101	2	6
	15	VMAT	3	5	89	974	2	6
	16	VMAT	1	22	71	4022	2	6
		VMAT	1	22	144	6058	4	6
	17	DMLC	1	22	70	8850	10	6
	18	DMLC	1	16	172	4201	8	6
	19	DMLC	1	22	32	3667	8	6
	20	DMLC	5	5	29	757	9	6
	21	DMLC	1	16	36	2236	10	6
	22	DMLC	1	16	66	3833	11	6
		DMLC	1	22	72	6700	12	6
		DMLC	1	13	54	2326	11	6
	23	VMAT	1	20	228	2206	3	6
	24	VMAT	1	20	87	2017	3	6

	ID	Modality	fx	dose in (Gy)	CPs/segs	MU	beams/rots	energy
liver	25	DMLC	5	5	42	1554	7	10
pelvis	26	DMLC	1	5	81	1402	9	10
		VMAT	4	5	182	2007	1	10
lung ABC	27	DMLC	12	5	27	947	7	10
	28	DMLC	4	12	166	3803	1	10
	29	DMLC	5	12	32	2260	8	10
	30	DMLC	5	12	45	2336	9	10
	31	DMLC	12	5	23	820	7	10
		DMLC	12	5	28	983	7	10
	32	DMLC	5	12	28	2365	7	10
	33	DMLC	5	12	27	2300	7	10
	34	DMLC	5	12	32	1873	8	10
		DMLC	5	12	32	1861	8	10
	35	VMAT	12	5	45	979	4	10
		VMAT	12	5	44	972	4	10
	36	VMAT	5	10	66	1294	1	10
	37	VMAT	12	5	191	1830	1	10
	38	VMAT	5	12	67	1847	1	10

One clinical hour at a Linac

Synergy + Agility + Integrity 3.1

Action	Patient	Time	Description	MUs	Fx Dose	Treatment Time	Total
finished treatment	Patient A	10:15					~28 min
finished treatment	Patient B	10:22	10X VMAT 206CPs	424.8 MU	1.8 Gy	~4 min	
finished IGRT	Patient C	10:30	cone beam CT (XVI)				
finished IGRT	Patient C	10:32	2× MV Images (IView)	4.0 MU			
finished treatment	Patient C	10:37	10X VMAT 128 CPs	491.2 MU	1.8 Gy	~5 min	
finished IGRT	Patient D	10:45	cone beam CT (XVI)				
finished treatment	Patient D	10:48	10X VMAT 189 CPs	826.8 MU	2.0 Gy	~7 min	
finished IGRT	Patient E	10:55	cone beam CT (XVI)				
finished treatment	Patient E	11:00	10X DMLC 96 CPs	670.2 MU	2.0 Gy	~5 min	
finished IGRT	Patient F	11:09	cone beam CT (XVI)				
finished treatment	Patient F	11:16	6X DMLC 165 CPs	597.2 MU	2.0 Gy	~7 min	

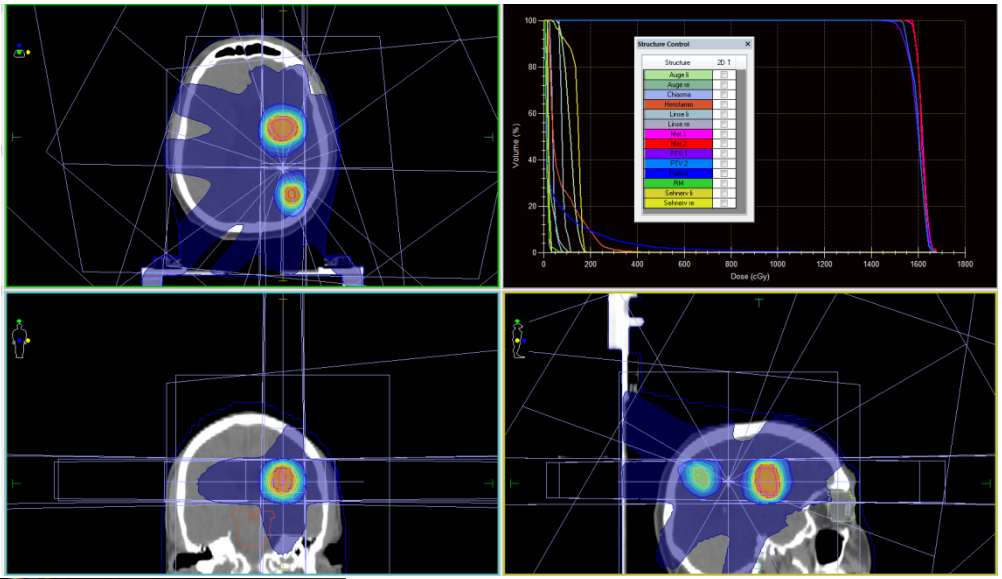
Versa HD + Integrity 3.1

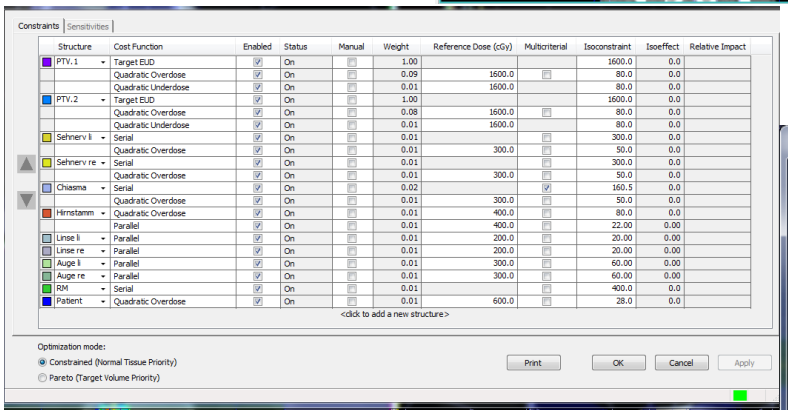
Action	Patient	Time	Description	MUs	Fx Dose	Treatment Time	Total
finished treatment	Patient G	12:18					~29 min
finished IGRT	Patient H	12:25	cone beam CT (XVI)				
finished treatment	Patient H	12:33	10X FFF DMLC 40 CPs ABC	2,260.1 MU	12.0 Gy	~8 min	
finished IGRT	Patient I	12:42	cone beam CT (XVI)				
finished treatment	Patient I	12:51	6X FFF DMLC 37 CPs	757.6 MU	5.0 Gy	~9 min	
finished IGRT	Patient J	13:04	cone beam CT (XVI)				
finished treatment	Patient J	13:07	10X VMAT 219 CPs	644.6 MU	2.0 Gy	~3 min	
finished IGRT	Patient K	13:17	cone beam CT (XVI)				
finished IGRT	Patient K	13:19	2x MV Images (IView)	4.0 MU			
finished treatment	Patient K	13:28	6X DMLC 149 CPs	584.4 MU	1.8 Gy	~9 min	

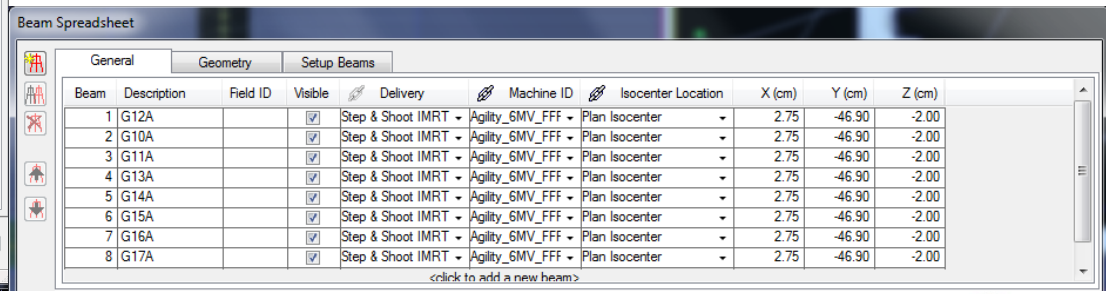
(VI.a)
Brain treatments

2 brain metastases, D= (1×16) Gy treatment planning

Stieler et al., Radiother Oncol, 2013







UMM UNIVERSITÄTSMEDIZIN MANNHEIM

Medizinische Fakultät Mannheim der Universität Heidelberg

Universitätsklinikum Mannheim

2 brain metastases, D= (1×16) Gy documentation

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)	150.0	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

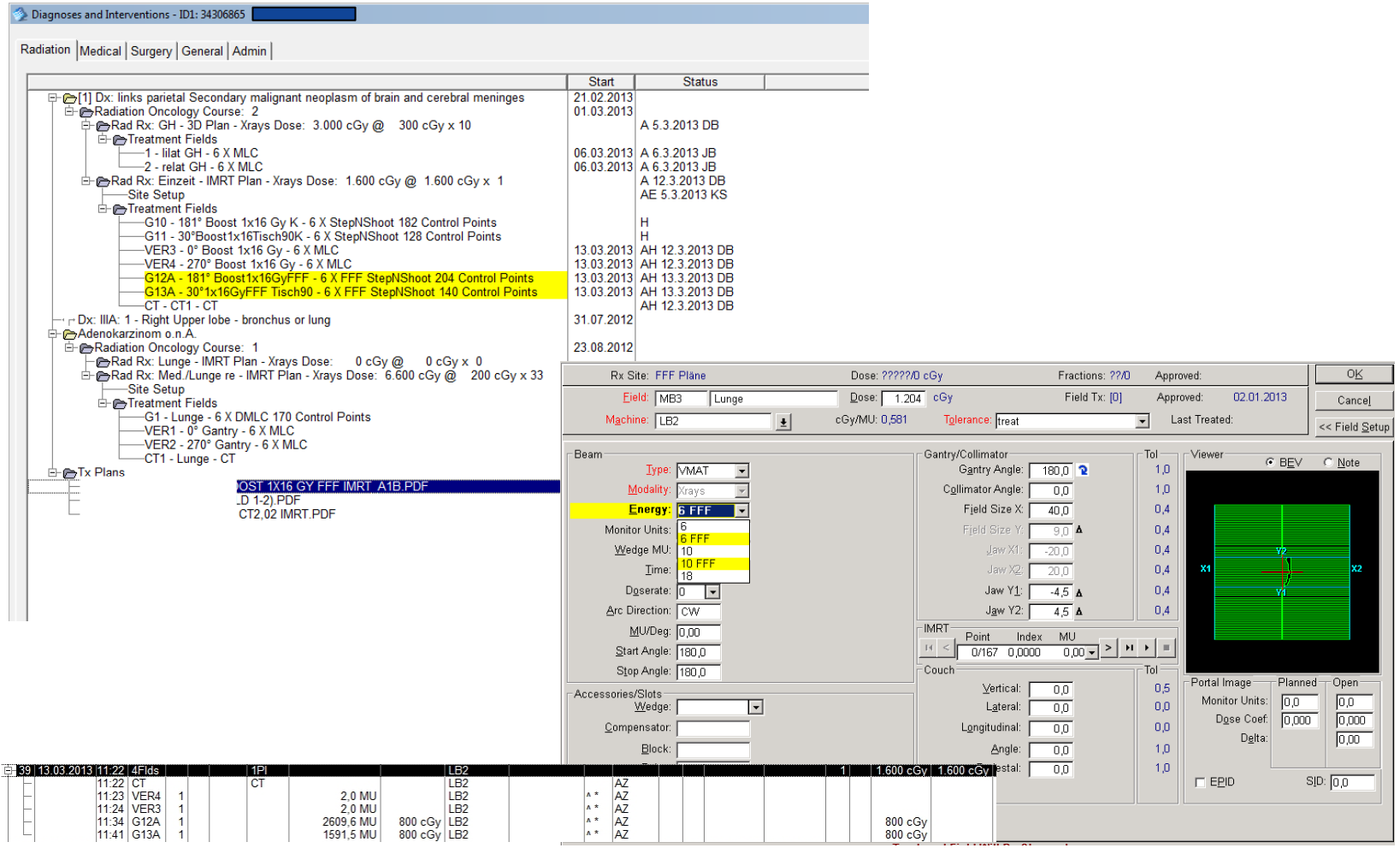
Whole procedure including CBCT and verification:

T= 19 min

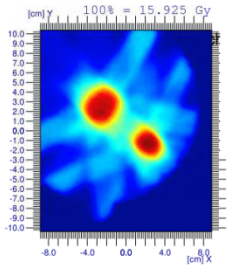
treatment time for 8 beams, 172 CP, 4.2k MU, 2 table angles:

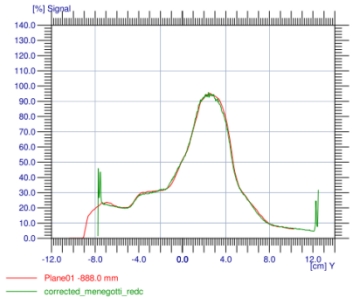
T= 7 min

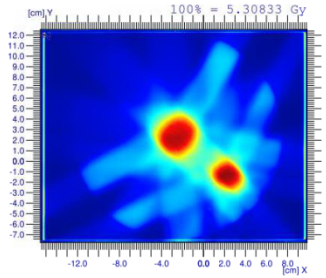
2 brain metastases, D= (1×16) Gy documentation

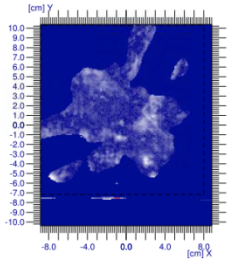


2 brain metastases, D= (1×16) Gy quality assurance









Intensity modulated radiosurgery of brain metastases with flattening filter-free beams

	Treatment technique	Treatment time (min)	Monitor units (MU)	
			Single Metastases	Multiple Metastases
IMRT	Agility FF	9:49±0:59	3501±523	4636±372
	Versa HD	5:06±0:23	3364±406	4534±642
VMAT	Agility FF	8:32±2:21	3333±867	4284±249
	Versa HD	4:18±1:07	3275±950	4635±583

	Treatment technique	Conformity index CI		Homogeneity index HI		GI_{Low}		GI_{High}	
		S.M.	M.M.	S.M.	M.M.	S.M.	M.M.	S.M.	M.M.
IMRT	Agility FF	0.67± 0.02	0.66± 0.03	1.08± 0.01	1.08± 0.02	2.65± 0.22	3.39± 0.41	3.23± 0.63	3.27± 0.24
	Versa HD	0.66± 0.04	0.64± 0.03	1.08± 0.01	1.10± 0.02	2.61± 0.18	3.36± 0.67	3.16± 0.58	3.03± 0.67
VMAT	Agility FF	0.75± 0.04	0.74± 0.02	1.05± 0.01	1.06± 0.01	2.79± 0.17	2.95± 0.23	3.23± 0.43	3.45± 0.41
	Versa HD	0.72± 0.05	0.70± 0.04	1.07± 0.02	1.06± 0.01	2.81± 0.16	3.03± 0.31	3.29± 0.35	3.66± 0.55

Stieler et al., Radiother Oncol, 2013

Courtesy of F. Stieler

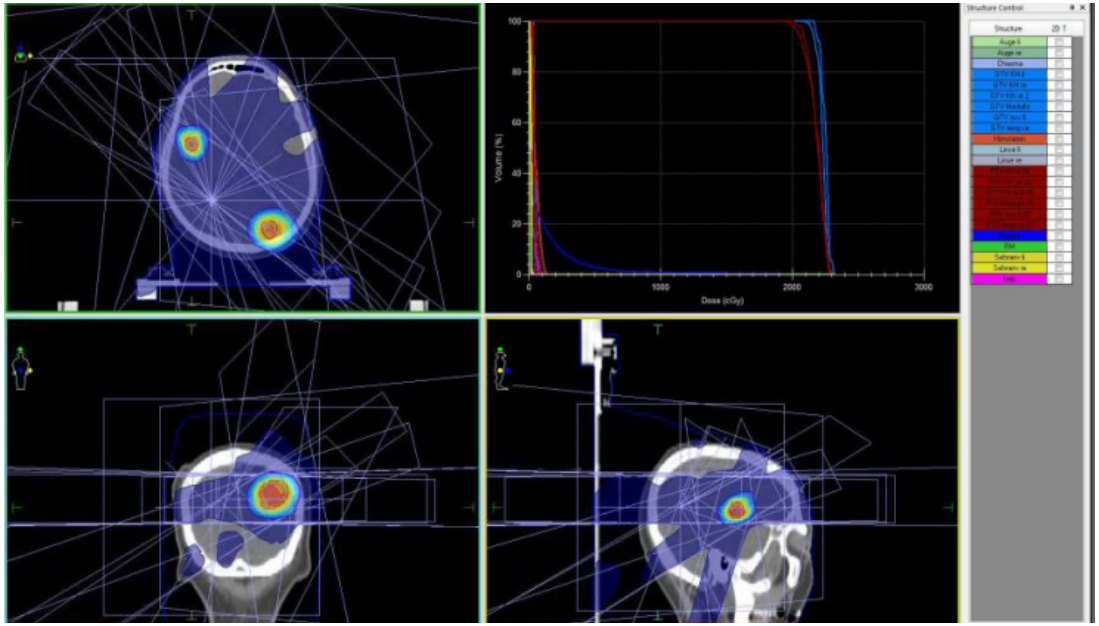
UMM UNIVERSITÄTSMEDIZIN MANNHEIM

Medizinische Fakultät Mannheim der Universität Heidelberg

Universitätsklinikum Mannheim

2 mets, D= (1×22) Gy, T= 18 min (beam on)
12 beams, 4 table angles, 6.7k MU

Stieler et al., Radiother Oncol, 2013



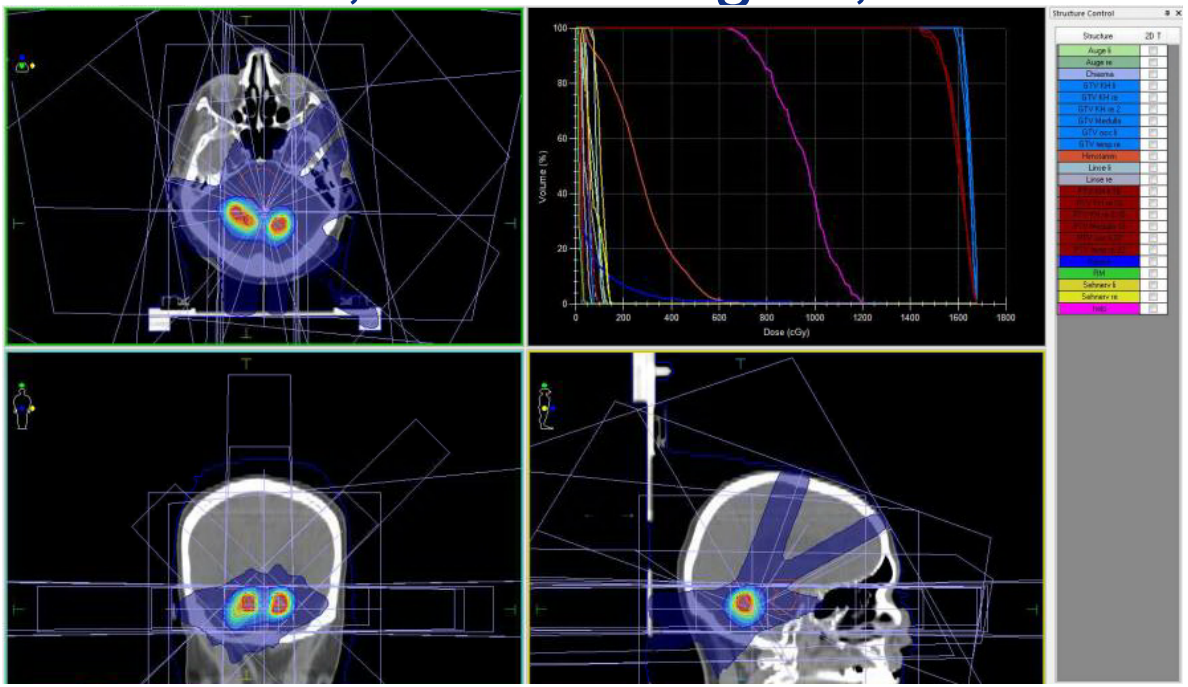
Beam #	Description	Machine ID	Energy	Gantry	Coll.	Couch	Isocenter X	Isocenter Y	Isocenter Z	# of Segs	MU/fx
1	G21	Agility_6MV_FFF	6 (FFF)	260.0	0.0	0.0	-3.00	18.50	-4.00	6	595.84
2	G22	Agility_6MV_FFF	6 (FFF)	288.0	0.0	0.0	-3.00	18.50	-4.00	6	591.78
3	G23	Agility_6MV_FFF	6 (FFF)	0.0	0.0	0.0	-3.00	18.50	-4.00	6	603.19
4	G24	Agility_6MV_FFF	6 (FFF)	40.0	0.0	0.0	-3.00	18.50	-4.00	6	593.15
5	G25	Agility_6MV_FFF	6 (FFF)	72.0	0.0	0.0	-3.00	18.50	-4.00	6	588.75
6	G26	Agility_6MV_FFF	6 (FFF)	130.0	0.0	0.0	-3.00	18.50	-4.00	6	556.97
7	G27	Agility_6MV_FFF	6 (FFF)	30.0	120.0	90.0	-3.00	18.50	-4.00	6	573.16
8	G28	Agility_6MV_FFF	6 (FFF)	70.0	120.0	90.0	-3.00	18.50	-4.00	6	554.75
9	G29	Agility_6MV_FFF	6 (FFF)	35.0	150.0	45.0	-3.00	18.50	-4.00	6	542.85
10	G30	Agility_6MV_FFF	6 (FFF)	65.0	150.0	45.0	-3.00	18.50	-4.00	6	582.11
11	G31	Agility_6MV_FFF	6 (FFF)	295.0	120.0	315.0	-3.00	18.50	-4.00	6	344.00
12	G32	Agility_6MV_FFF	6 (FFF)	325.0	120.0	315.0	-3.00	18.50	-4.00	6	573.58
13	VER5	Agility_6MV_Int	6	0.0	0.0	0.0	-3.00	18.50	-4.00	0	0.00
14	VER6	Agility_6MV_Int	6	270.0	0.0	0.0	-3.00	18.50	-4.00	0	0.00
									Total:	72	6700.14

Normalization

Prescription (cGy): 2200.0 # of Fractions: 1 (2,200.00 cGy/fx)

2 mets, D= (1×16) Gy, T= 12 min (beam on)
12 beams, 4 table angles, 3.6k MU

Stieler et al., Radiother Oncol, 2013



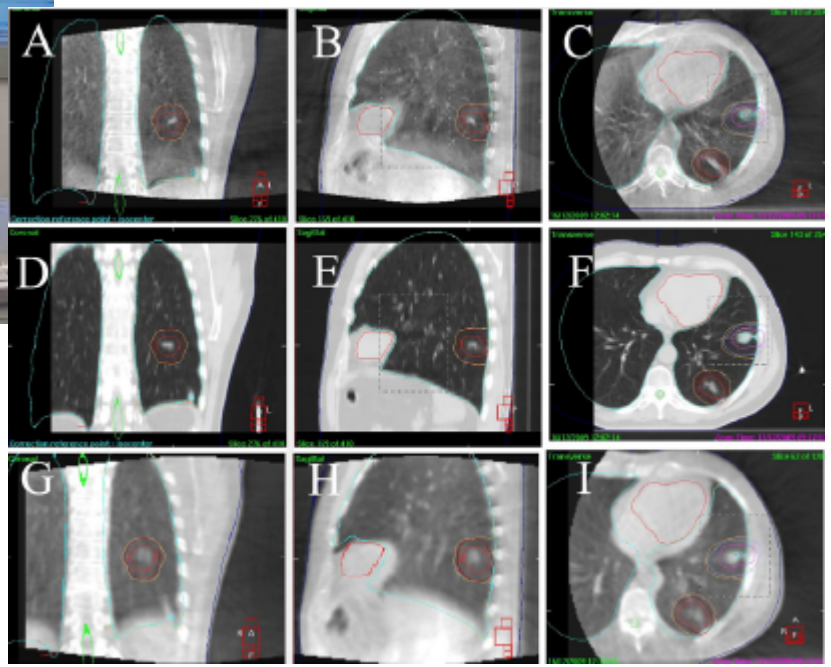
Beam #	Description	Machine ID	Energy	Gantry	Coll.	Couch	Isocenter X	Y	Z	# of Segs	MU/fx
1	G2	Agility_6MV_FFF	6 (FFF)	181.0	0.0	0.0	0.00	14.00	-3.00	6	581.44
2	G5	Agility_6MV_FFF	6 (FFF)	260.0	0.0	0.0	0.00	14.00	-3.00	6	224.07
3	G1	Agility_6MV_FFF	6 (FFF)	288.0	0.0	0.0	0.00	14.00	-3.00	6	370.88
4	G8	Agility_6MV_FFF	6 (FFF)	40.0	0.0	0.0	0.00	14.00	-3.00	6	366.08
5	G3	Agility_6MV_FFF	6 (FFF)	72.0	0.0	0.0	0.00	14.00	-3.00	6	128.10
6	G4	Agility_6MV_FFF	6 (FFF)	130.0	0.0	0.0	0.00	14.00	-3.00	6	201.05
7	G6	Agility_6MV_FFF	6 (FFF)	30.0	0.0	90.0	0.00	14.00	-3.00	6	373.11
8	G7	Agility_6MV_FFF	6 (FFF)	70.0	0.0	90.0	0.00	14.00	-3.00	6	463.03
9	G9	Agility_6MV_FFF	6 (FFF)	35.0	0.0	45.0	0.00	14.00	-3.00	6	383.68
10	G10	Agility_6MV_FFF	6 (FFF)	65.0	0.0	45.0	0.00	14.00	-3.00	6	374.08
11	G12	Agility_6MV_FFF	6 (FFF)	295.0	0.0	315.0	0.00	14.00	-3.00	6	367.35
13	VER1	Agility_6MV_Int	6	0.0	0.0	0.0	0.00	14.00	-3.00	0	0.00
14	VER2	Agility_6MV_Int	6	270.0	0.0	0.0	0.00	14.00	-3.00	0	0.00
									Total:	66	3832.87

Normalization

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

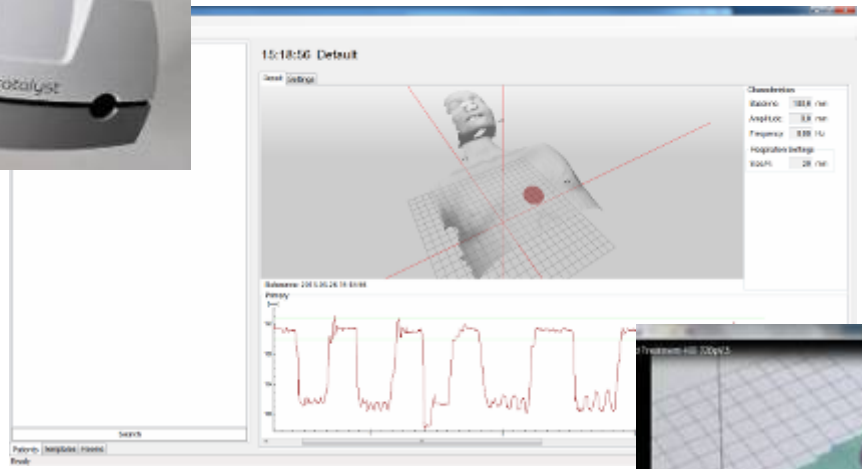
(VI.b)
Lung treatments

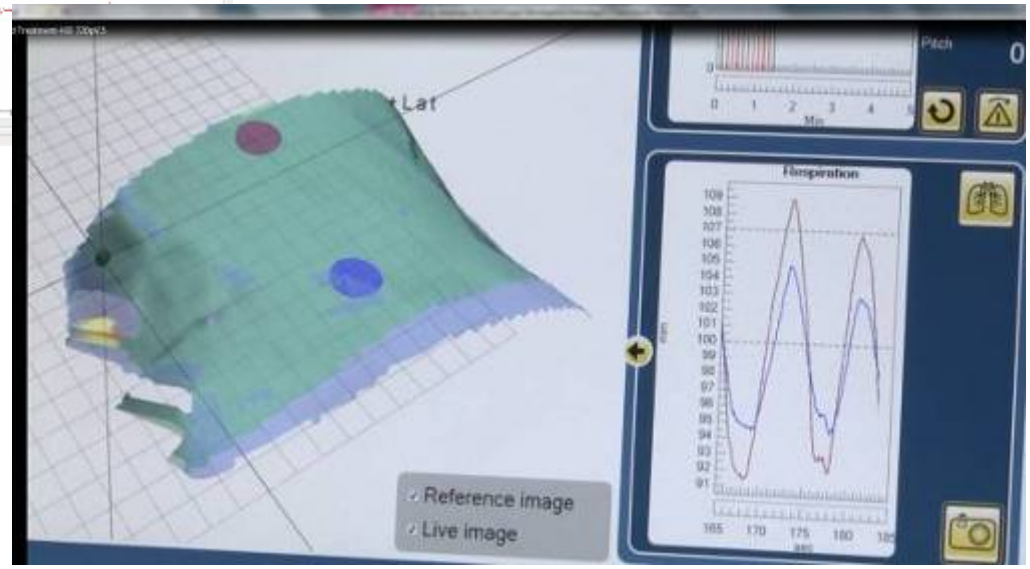
Clinical Setup:
1. Flow-Based Breath Hold Triggering



Boda-Heggemann et al,
Radiother Oncol, 2011

Clinical Setup:
2. Surface-based Surveillance





Stieler et al.,
Strahlentherapie, 2012

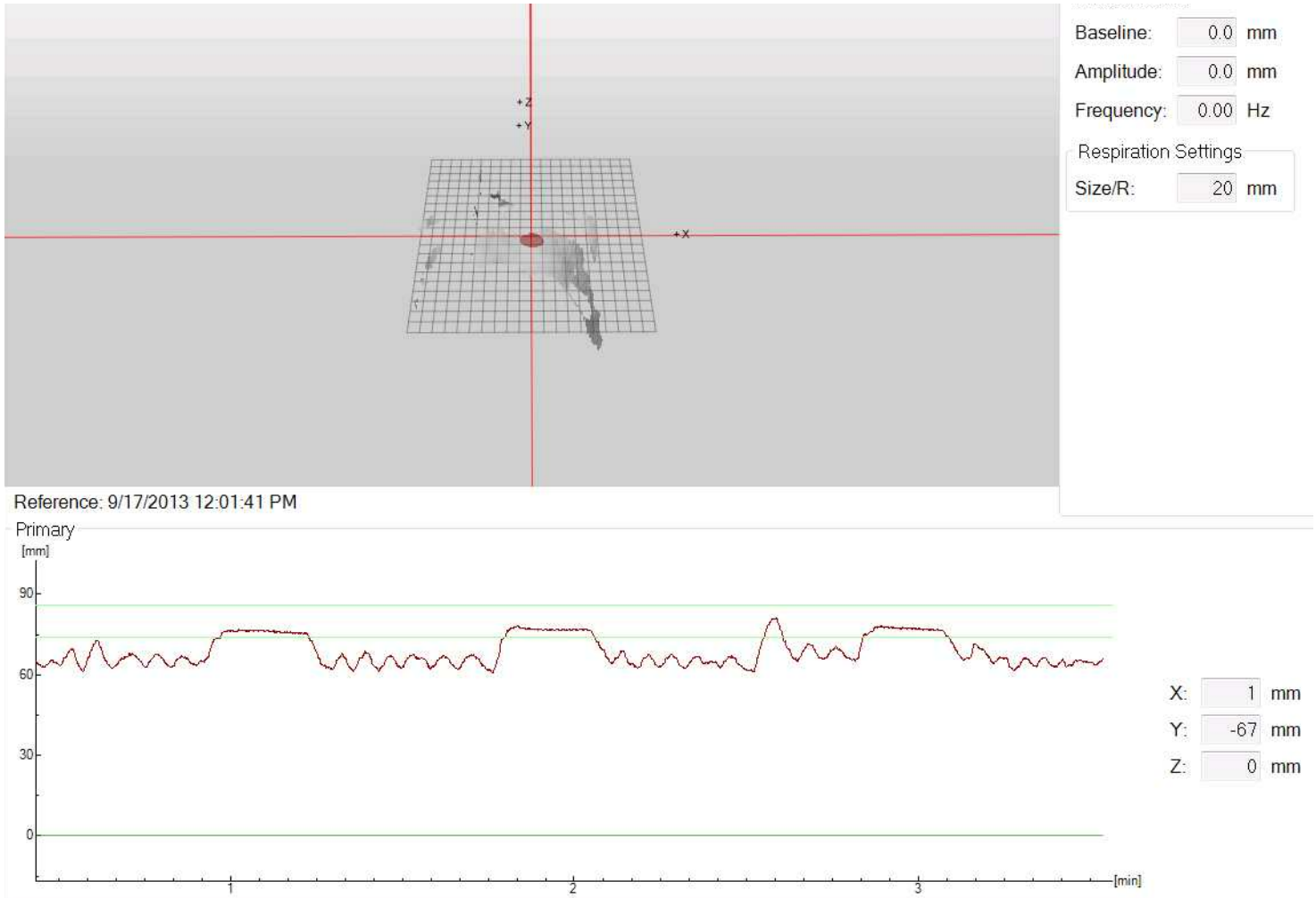
Stieler et al.,
Strahlentherapie, 2013

UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

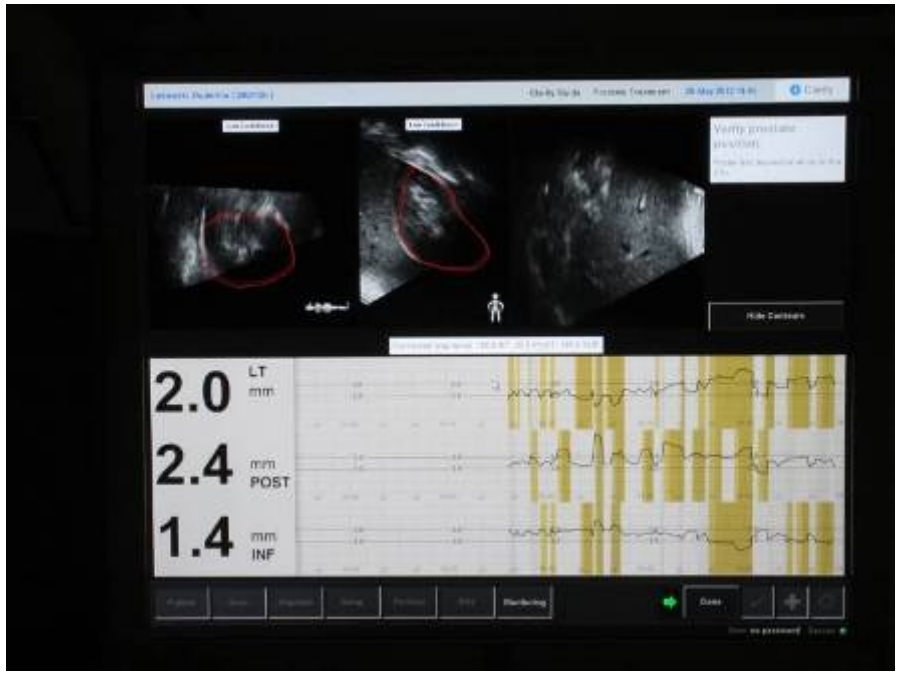
Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

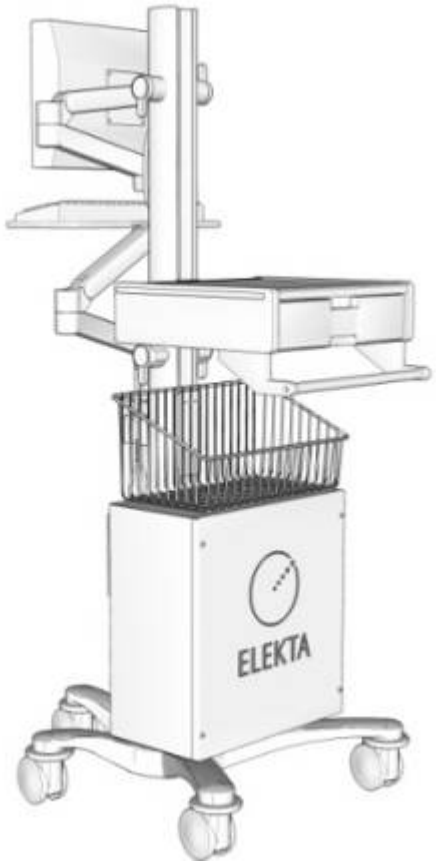
Breath hold surveillance

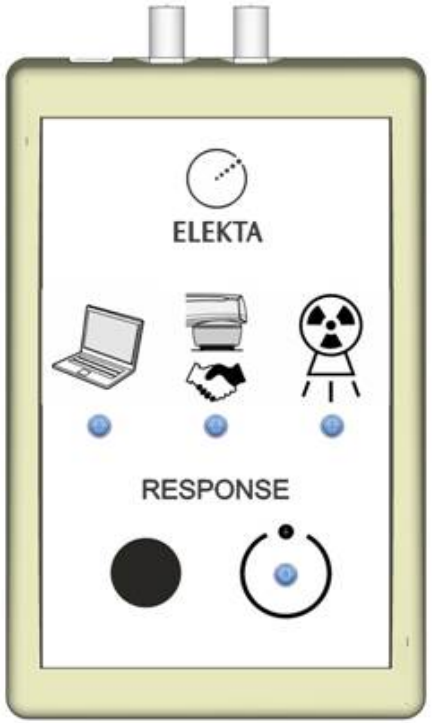


Clinical Setup:
3. Direct Liver Tracking



Clinical Setup:
Flow-Based Breath Hold Triggering

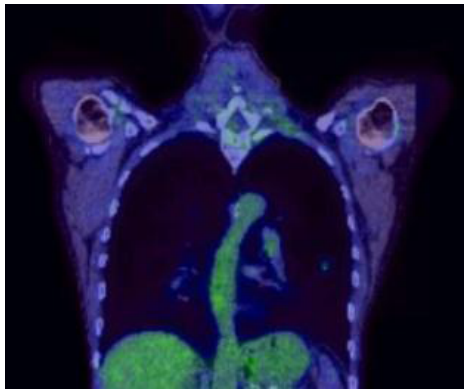




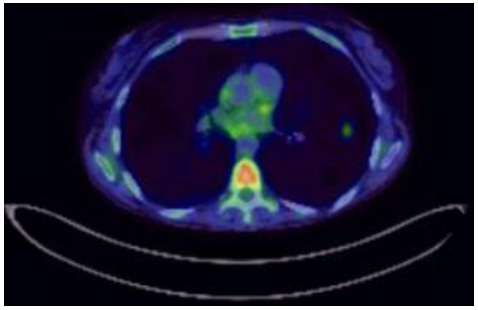
“Intensity Modulated, Volume-Image Guided SABR (Stereotactic Ablative Radiotherapy) can be applied in a 15-min treatment slot”

Boda-Heggemann et al.,
Radiother Oncol, 2013

- Flattening-filter-free FFF 10 MV Versa HD
- intensity modulated Monaco dMLC plan
- Active breathing coordinator ABC
- image-guidance XVI, EPID



Transversal and coronal PET-CT images of the patient



UMM UNIVERSITÄTSMEDIZIN MANNHEIM

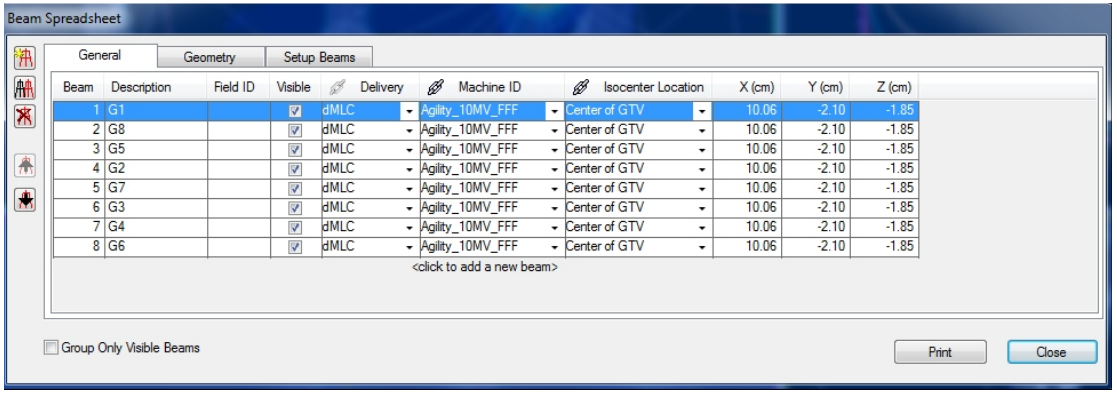
Courtesy of J. Boda Hegemann

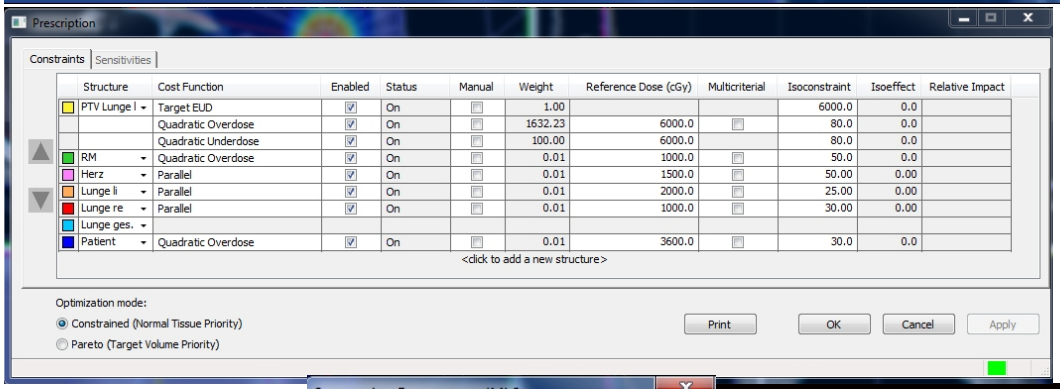
Medizinische Fakultät Mannheim der Universität Heidelberg

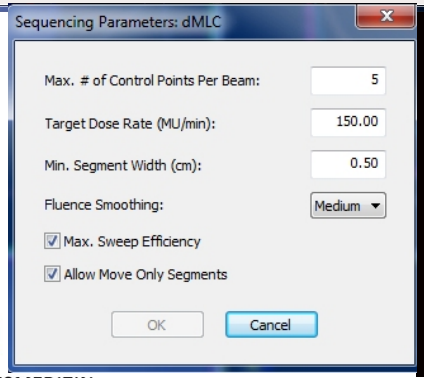
Universitätsklinikum Mannheim

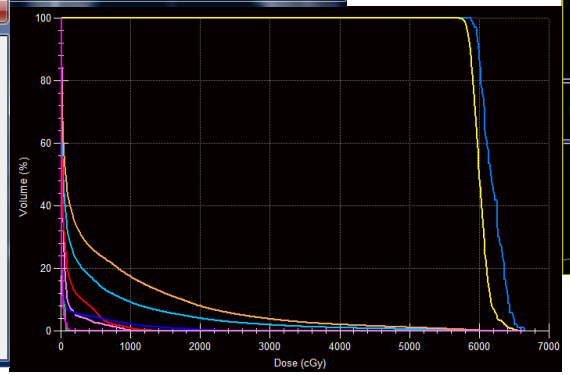
SABR (Stereotactic Ablative Radiotherapy)

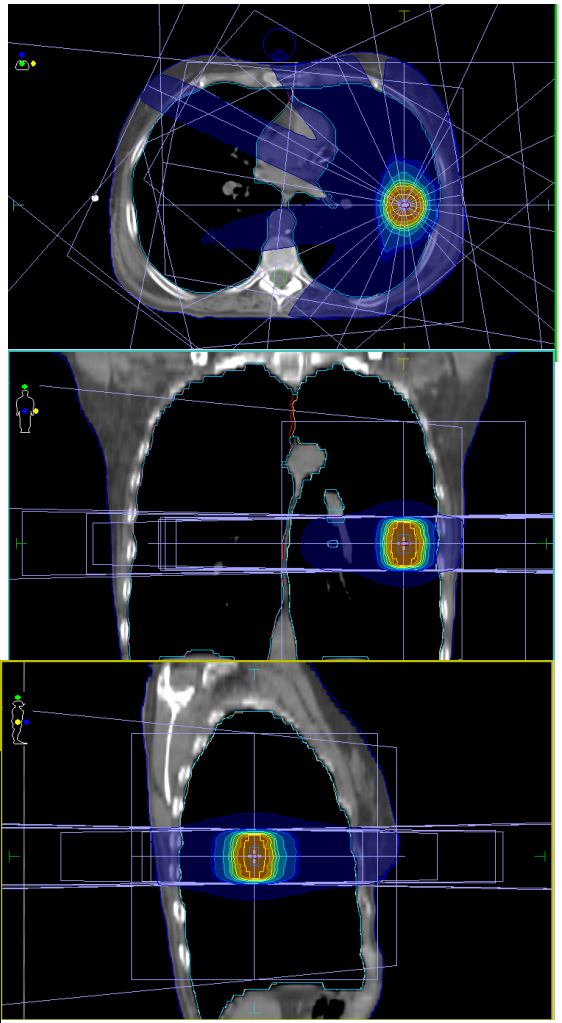
Treatment planning











UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

SABR (Stereotactic Ablative Radiotherapy)

documentation

First fraction setup time incl. ABC/ CBCT and EPID: T= 30 min
treatment time: T= 8 min (8 beams, 2.3k MU)

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				1PI			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			

UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

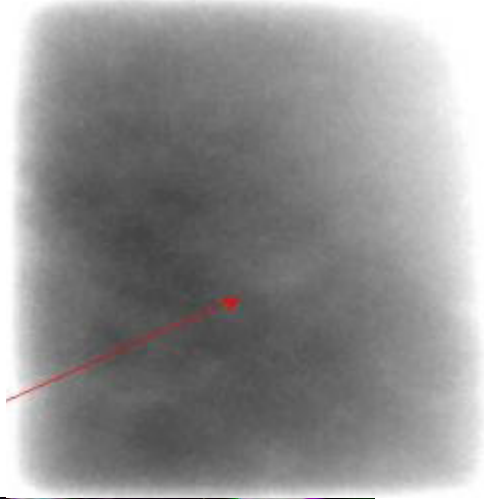
Medizinische Fakultät Mannheim
der Universität Heidelberg

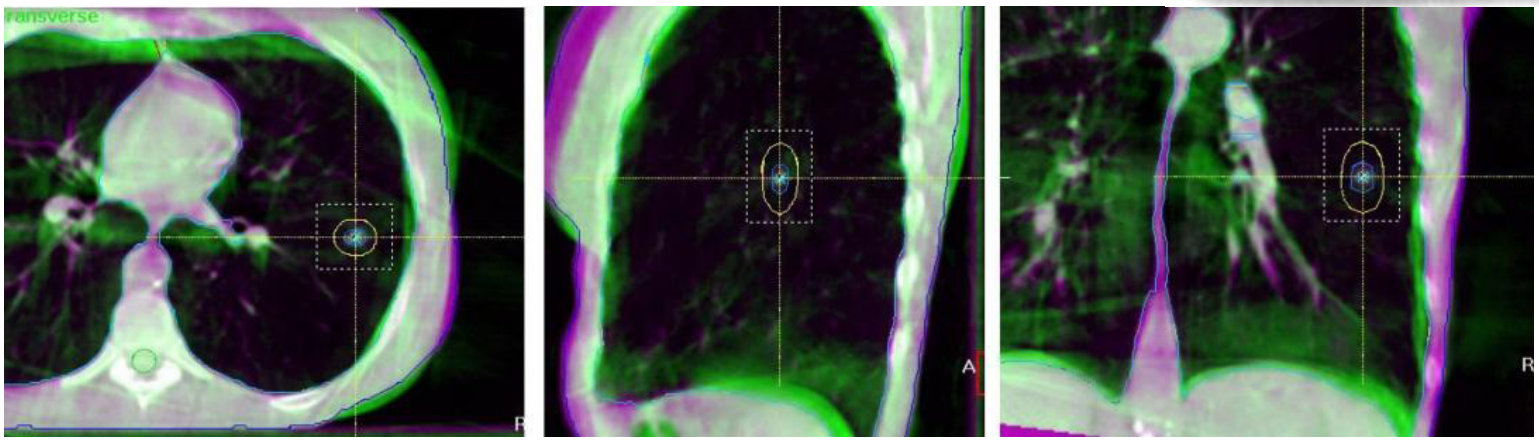
Universitätsklinikum Mannheim

SABR (Stereotactic Ablative Radiotherapy)

Image guidance

Iview (EPID)
MV-verification image

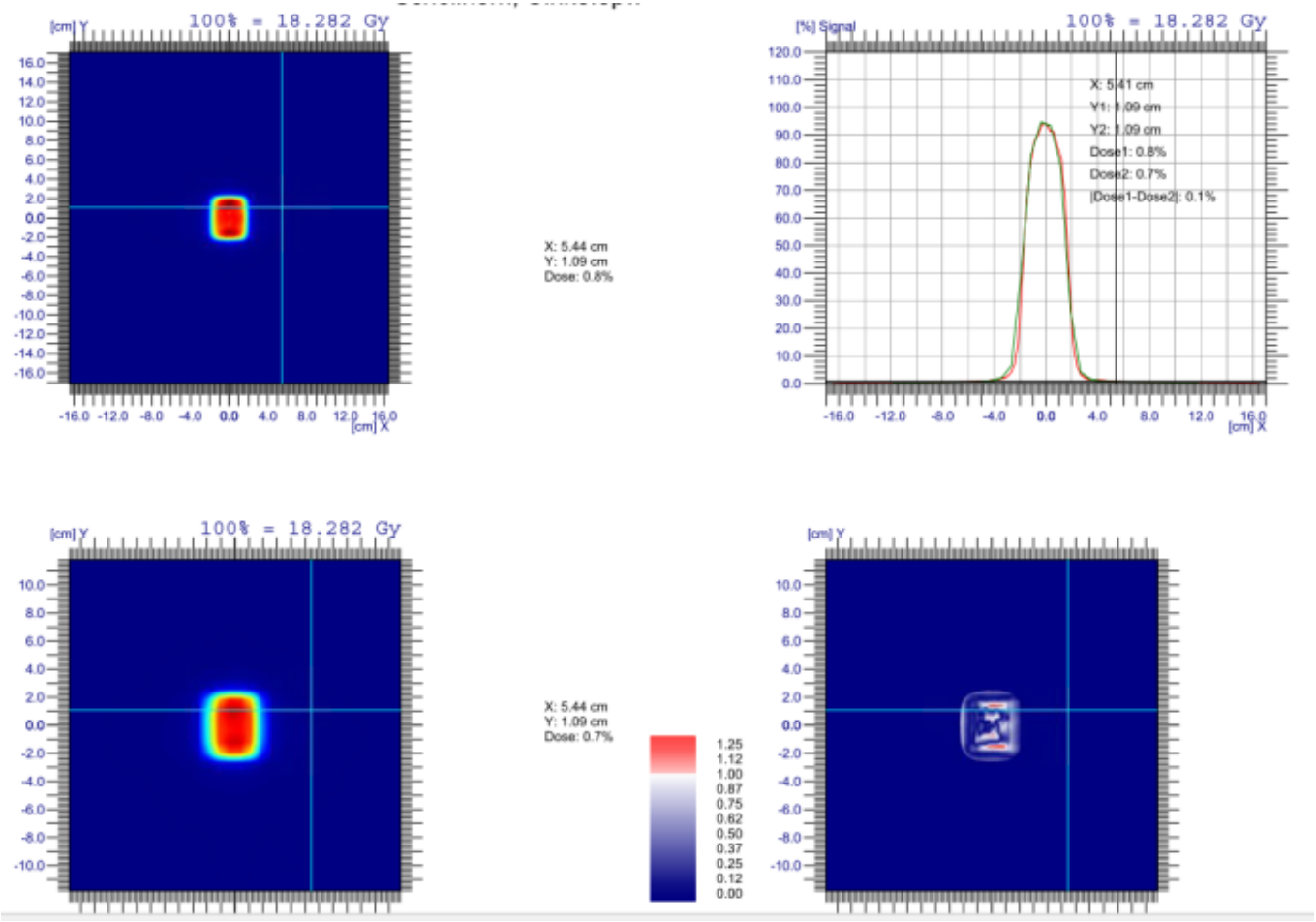




Transversal, sagittal and coronal CBCT (XVI) images

SABR (Stereotactic Ablative Radiotherapy)

Quality assurance



UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

2nd lung hypofractionated FFF treatment

D= (5×12) Gy
total treatment time including CBCT: T= 18 min
treatment time (beam on): T= 6 min
2.2k MU in 9 dMLC beams

Setup Information

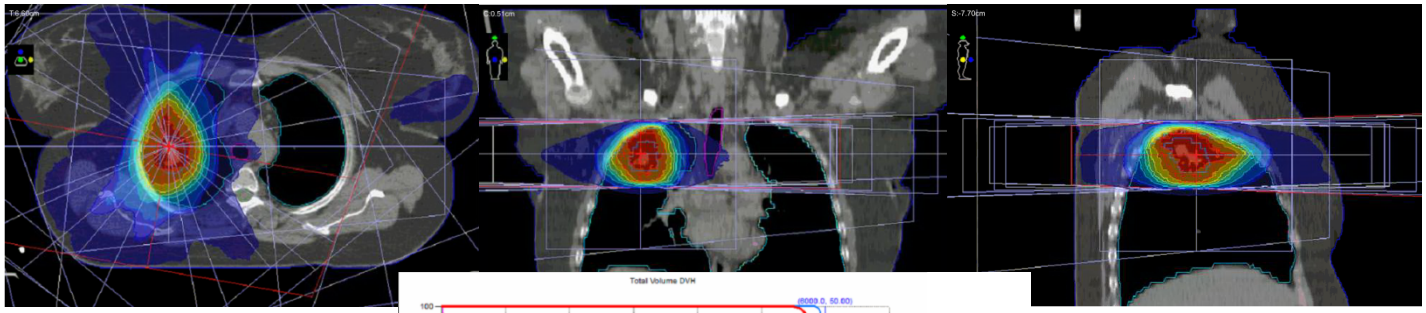
Scan Reference Coordinates (cm): No Scan Reference Point has been selected

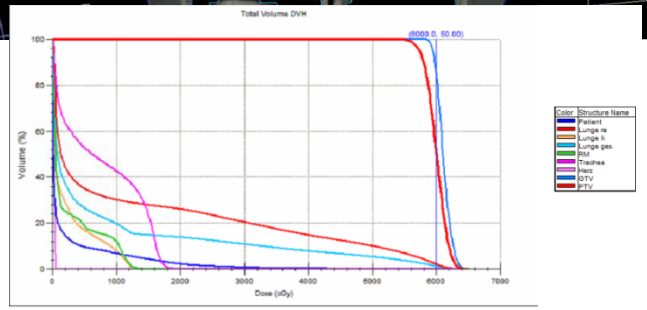
Beam #	Description	Machine ID	Energy	Gantry	Coll.	Couch	Isocenter X	Isocenter Y	Isocenter Z	# of Segs	MU/fx
1	G1	Agility_10MV_FFF	10 (FFF)	190.0	0.0	0.0	-7.70	6.60	0.51	5	256.81
2	G8	Agility_10MV_FFF	10 (FFF)	220.0	0.0	0.0	-7.70	6.60	0.51	5	252.64
3	G9	Agility_10MV_FFF	10 (FFF)	250.0	0.0	0.0	-7.70	6.60	0.51	5	320.61
4	G5	Agility_10MV_FFF	10 (FFF)	295.0	0.0	0.0	-7.70	6.60	0.51	5	171.90
5	G2	Agility_10MV_FFF	10 (FFF)	335.0	0.0	0.0	-7.70	6.60	0.51	5	344.46
6	G7	Agility_10MV_FFF	10 (FFF)	0.0	0.0	0.0	-7.70	6.60	0.51	5	231.78
7	G3	Agility_10MV_FFF	10 (FFF)	30.0	0.0	0.0	-7.70	6.60	0.51	5	342.59
8	G8	Agility_10MV_FFF	10 (FFF)	80.0	0.0	0.0	-7.70	6.60	0.51	5	191.79
9	G6	Agility_10MV_FFF	10 (FFF)	140.0	0.0	0.0	-7.70	6.60	0.51	5	222.98
10	VER1	Agility_10MV_FFF	10 (FFF)	0.0	0.0	0.0	-7.70	6.60	0.51	0	0.00
11	VER2	Agility_10MV_FFF	10 (FFF)	90.0	0.0	0.0	-7.70	6.60	0.51	0	0.00
									Total:	45	2335.57

4	15.04.2013	12:21	9Flds				1Pl			LB2				4	10	1.200 cGy
		12:21	CT1				CT			LB2			AZ			
		12:22	G1	4	10			256,9 MU	133 cGy	LB2			AZ			133 cGy
		12:22	G10	4	10			252,7 MU	133 cGy	LB2			AZ			133 cGy
		12:23	G9	4	10			320,6 MU	133 cGy	LB2			AZ			133 cGy
		12:24	G5	4	10			171,9 MU	133 cGy	LB2			AZ			133 cGy
		12:25	G2	4	10			344,5 MU	133 cGy	LB2			AZ			133 cGy
		12:25	G7	4	10			231,9 MU	133 cGy	LB2			AZ			133 cGy
		12:26	G3	4	10			342,7 MU	133 cGy	LB2			AZ			133 cGy
		12:27	G8	4	10			191,8 MU	133 cGy	LB2			AZ			133 cGy
		12:28	G6	4	10			223,1 MU	136 cGy	LB2			AZ			136 cGy

Normalization

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



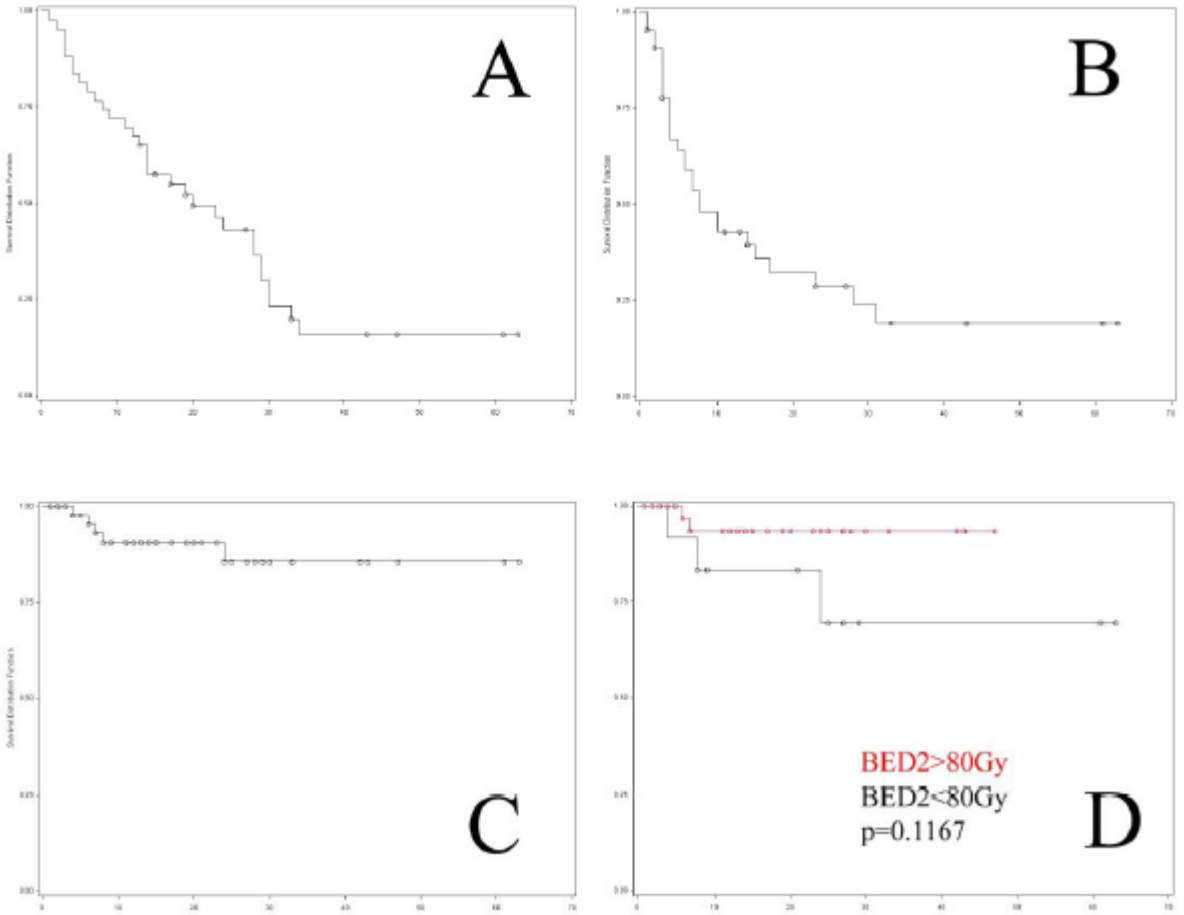


UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

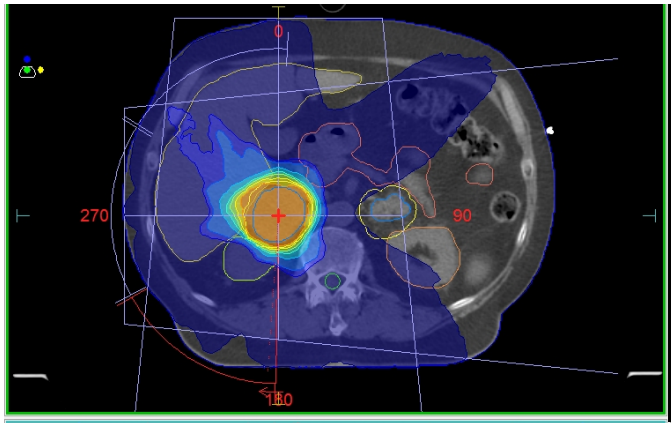
Clinical Results Image Guided BH-Lung SABR

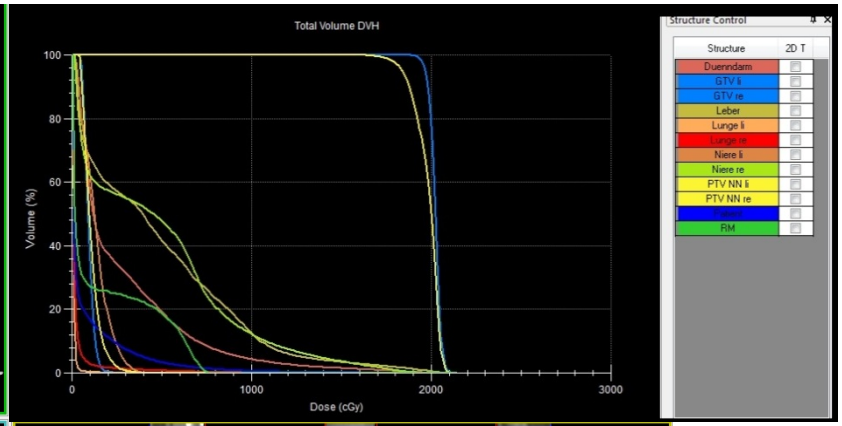


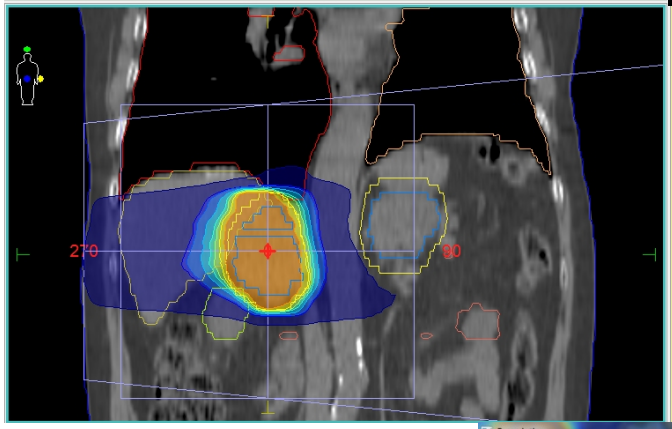
Boda-Heggemann et al., submitted

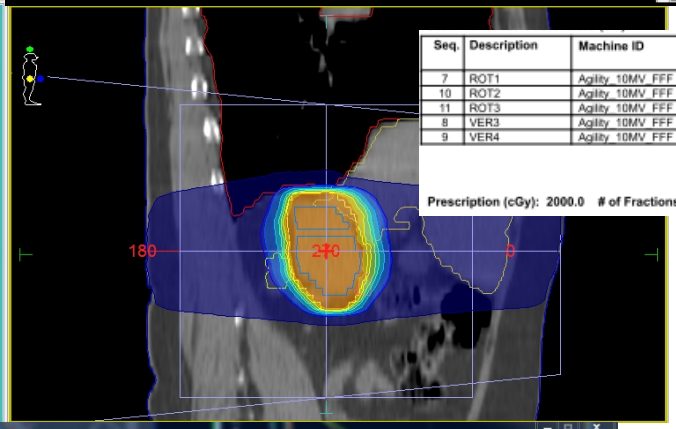
(VI.c)
Treatment of adrenal glands

Right adrenal gland
3×60°partial VMAT arcs, D= (4×5) Gy





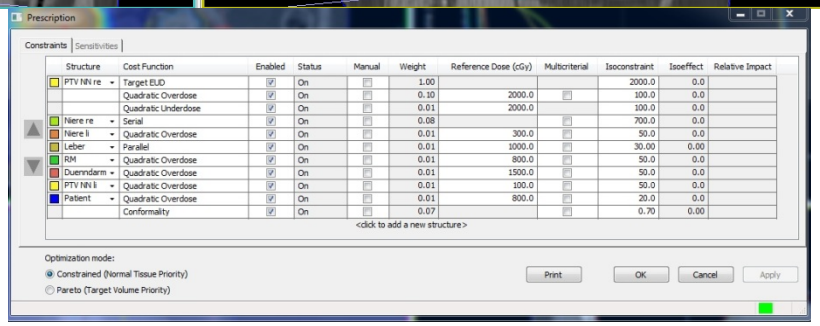




Seq.	Description	Machine ID	Energy	Gantry	Coll.	Couch	Isocenter X	Isocenter Y	Isocenter Z	# of Segs	MU/fx
7	ROT1	Agility_10MV_FFF	10 (FFF)	181.0/60.0	0.0	0.0	-4.68	-140.70	-0.85	13	295.37
10	ROT2	Agility_10MV_FFF	10 (FFF)	242.0/60.0	0.0	0.0	-4.68	-140.70	-0.85	14	287.95
11	ROT3	Agility_10MV_FFF	10 (FFF)	303.0/60.0	0.0	0.0	-4.68	-140.70	-0.85	15	356.32
8	VER3	Agility_10MV_FFF	10 (FFF)	0.0	0.0	0.0	-4.68	-140.70	-0.85	0	0.00
9	VER4	Agility_10MV_FFF	10 (FFF)	270.0	0.0	0.0	-4.68	-140.70	-0.85	0	0.00
									Total:	42	939.64

Normalization

Prescription (cGy): 2000.0 # of Fractions: 4 (500.00 cGy/fx)

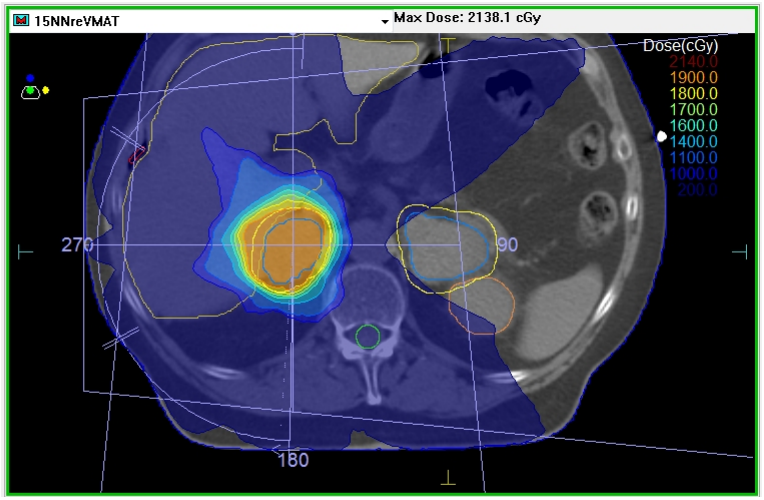


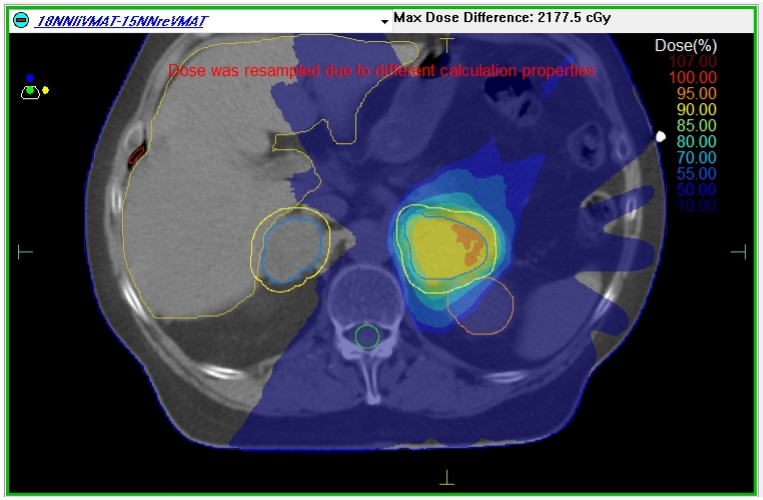
UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

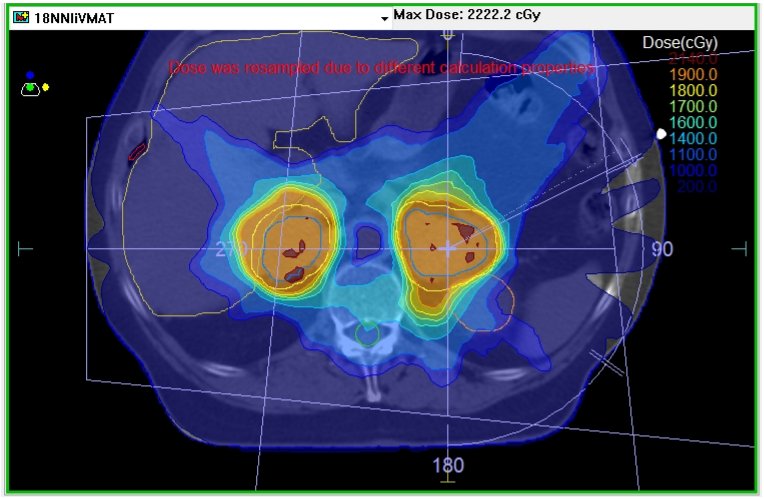
Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

Sum plan adrenal glands
D= (4×5) Gy, T= 3 min







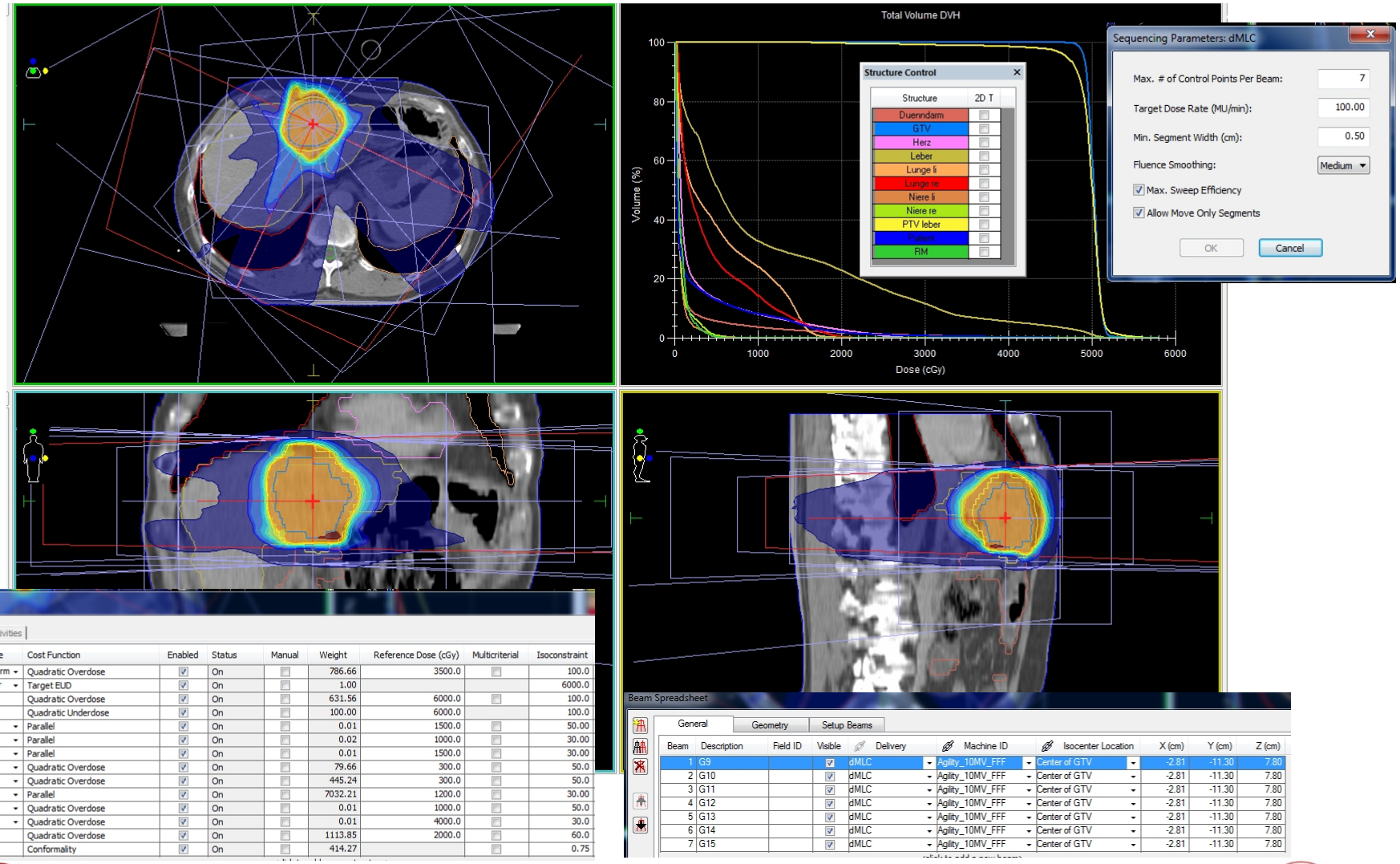
UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

(VI.d)
Liver treatment

7 fields dMLC, 10 MV
T= 6 min, D= (10×5) Gy



Clinical Results Liver

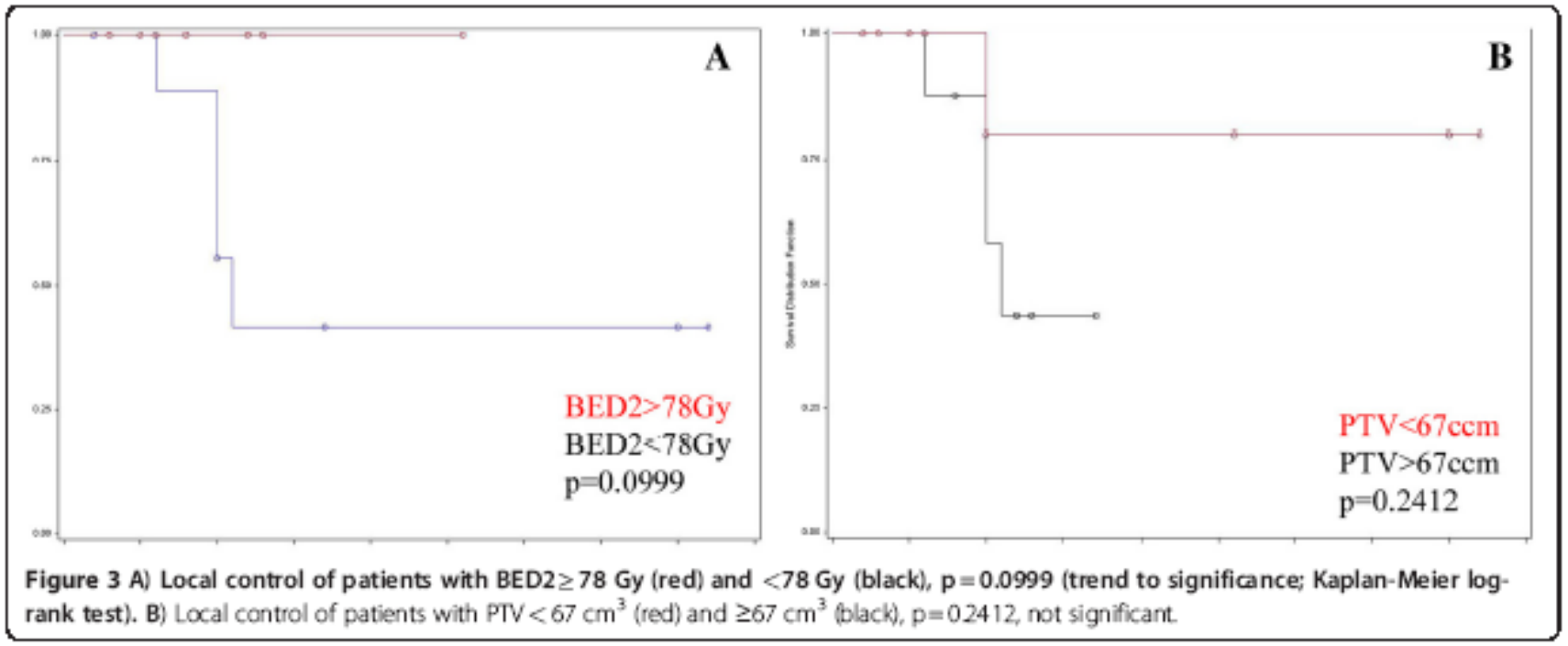
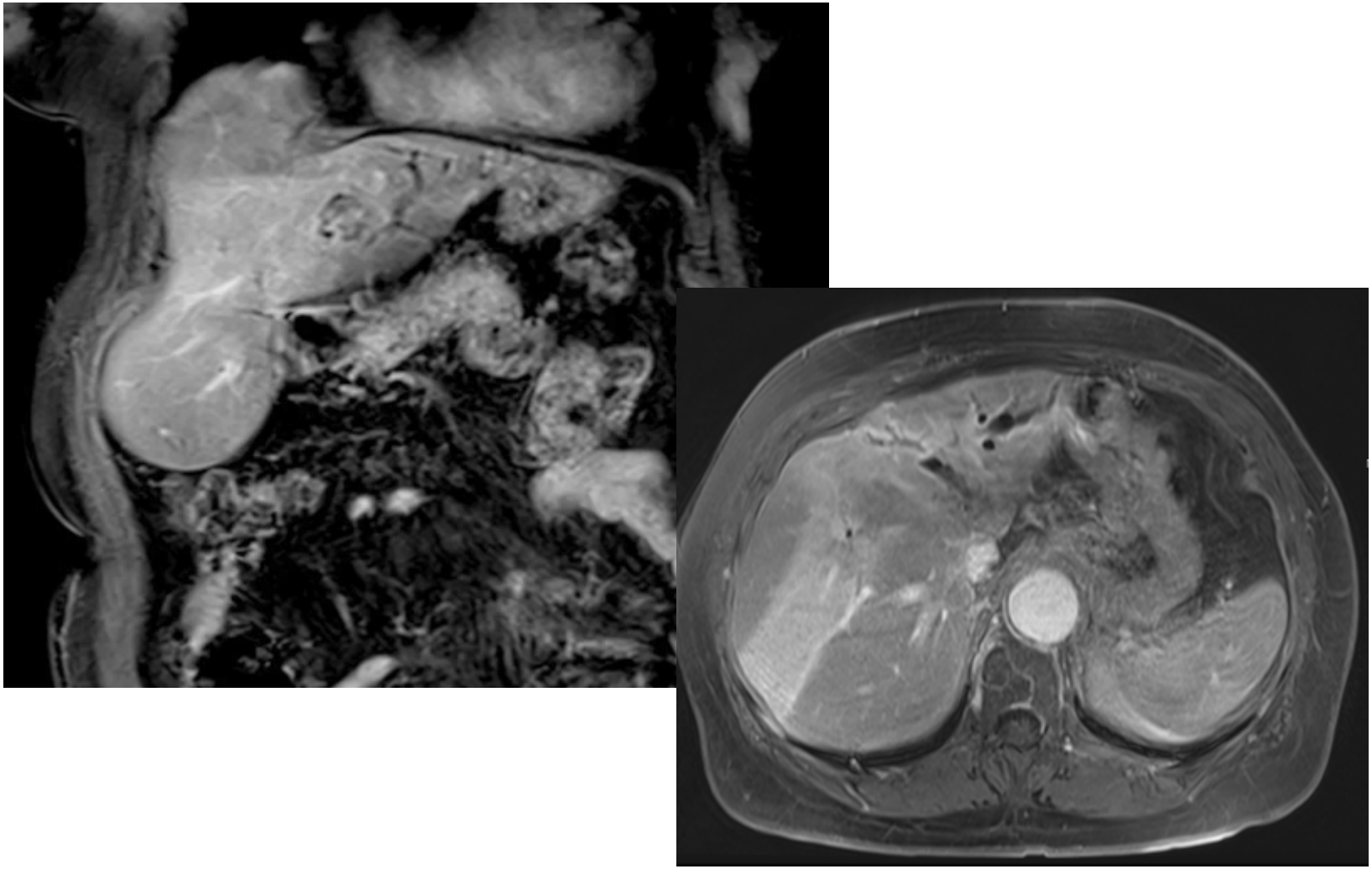


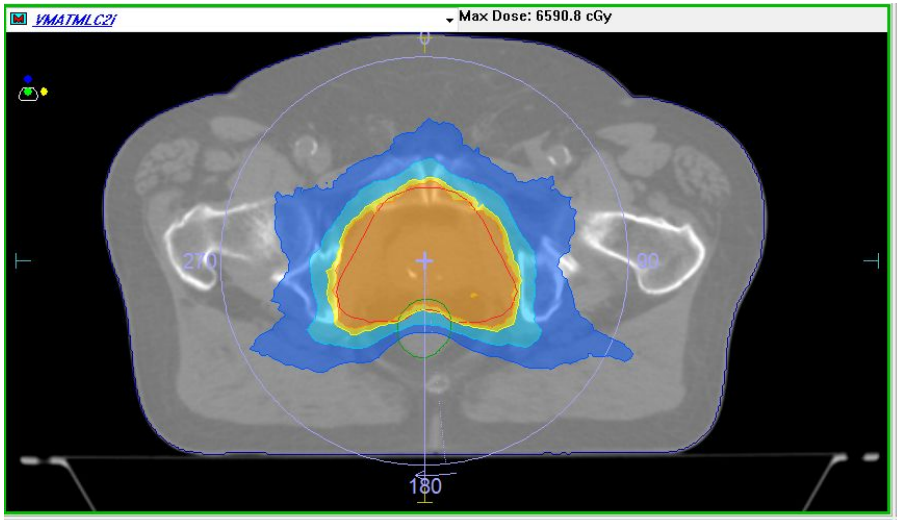
Figure 3 A) Local control of patients with BED2 ≥ 78 Gy (red) and <78 Gy (black), p = 0.0999 (trend to significance; Kaplan-Meier log-rank test). B) Local control of patients with PTV < 67 cm^3 (red) and ≥67 cm^3 (black), p = 0.2412, not significant.

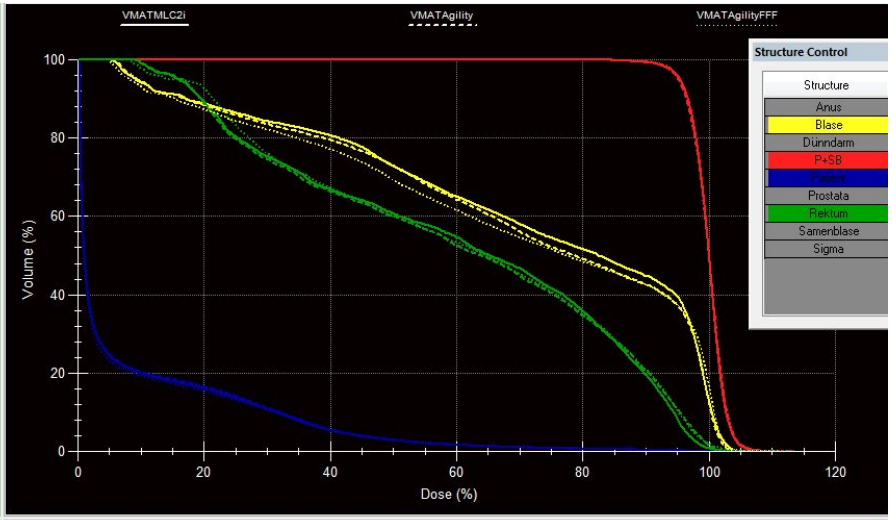
Boda-Heggemann et al., Rad Onc, 2012

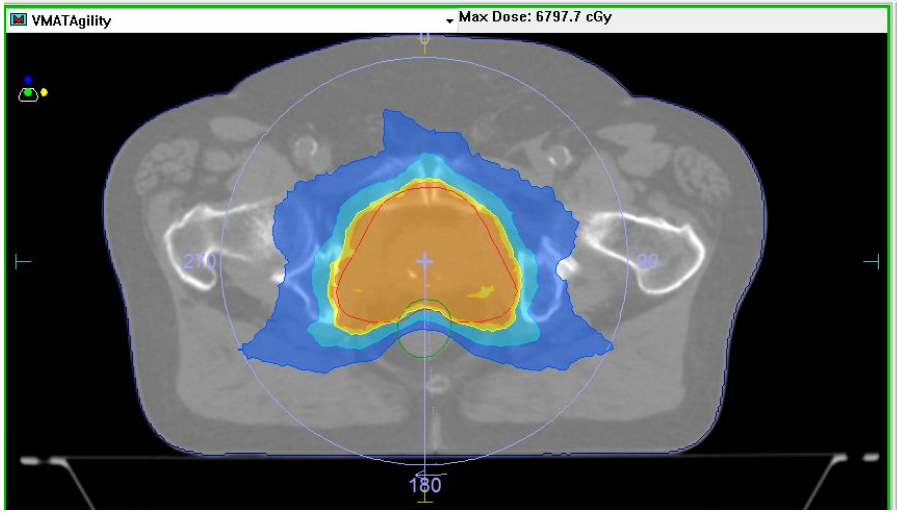


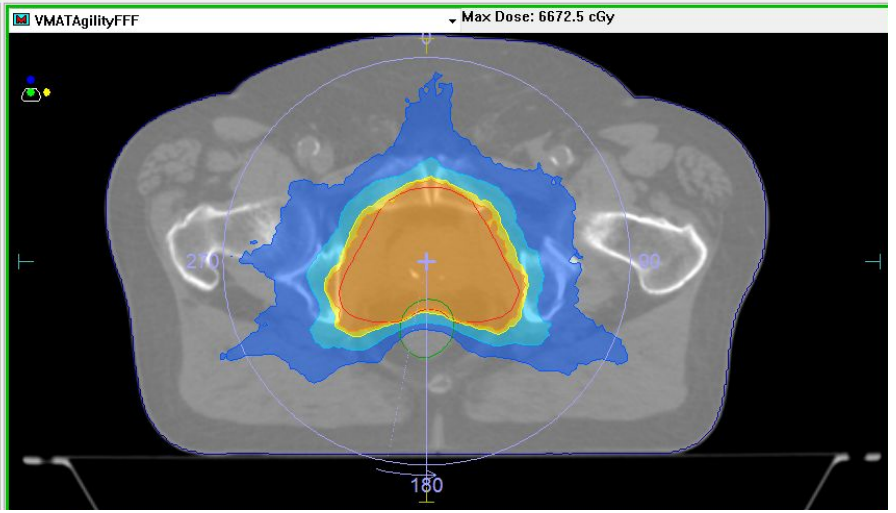
(VII)
Comparison of
MLCi2 – Agility - Versa HD
treatment times

Prostate
moderately complex, D= (30×2) Gy, 1 VMAT arc



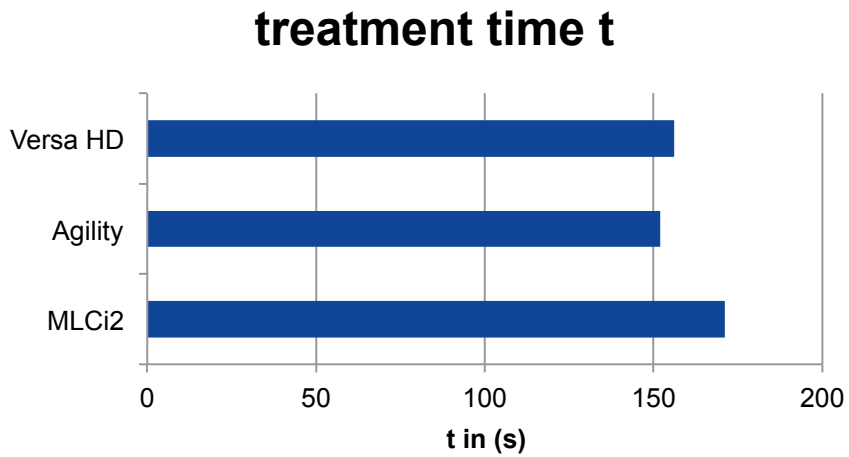




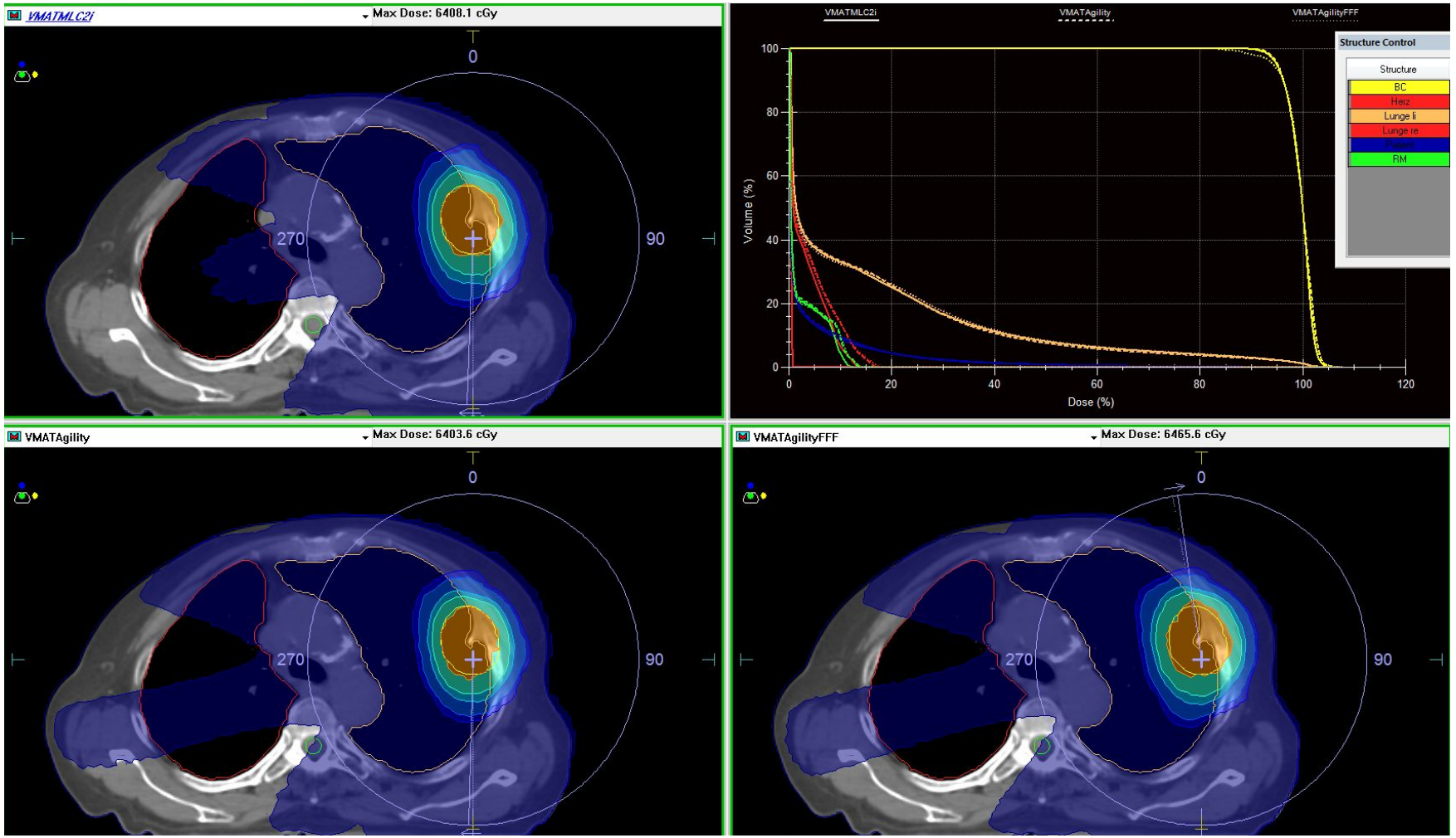


Prostate
moderately complex, D= (30×2) Gy, 1 VMAT arc

PROSTATE	MLCi2 Monaco 3.3	Agility Monaco 3.3	Versa HD Monaco 3.3
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
beam-on time per fraction	171 s	152 sec	156 s
number of MU's delivered	789	762	915



Lung
moderately complex, D= (5 ×12) Gy, 1 VMAT arc



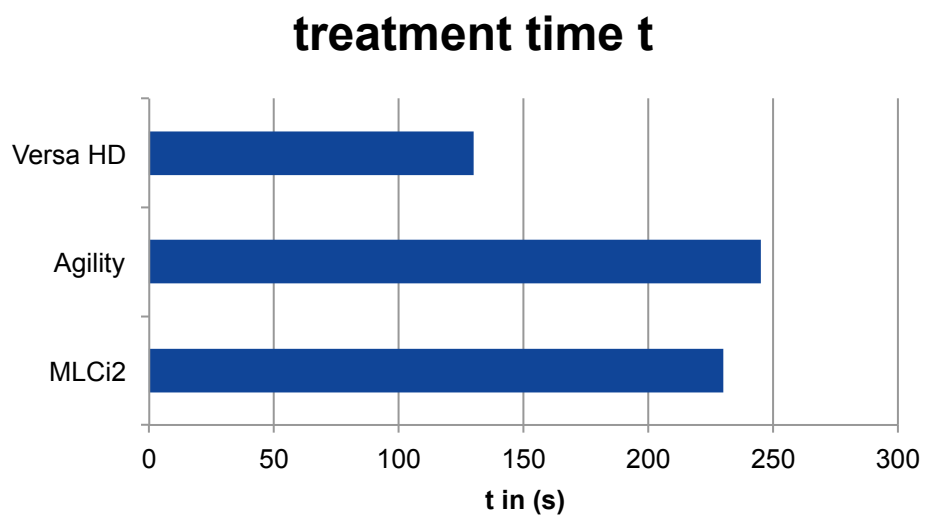
UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

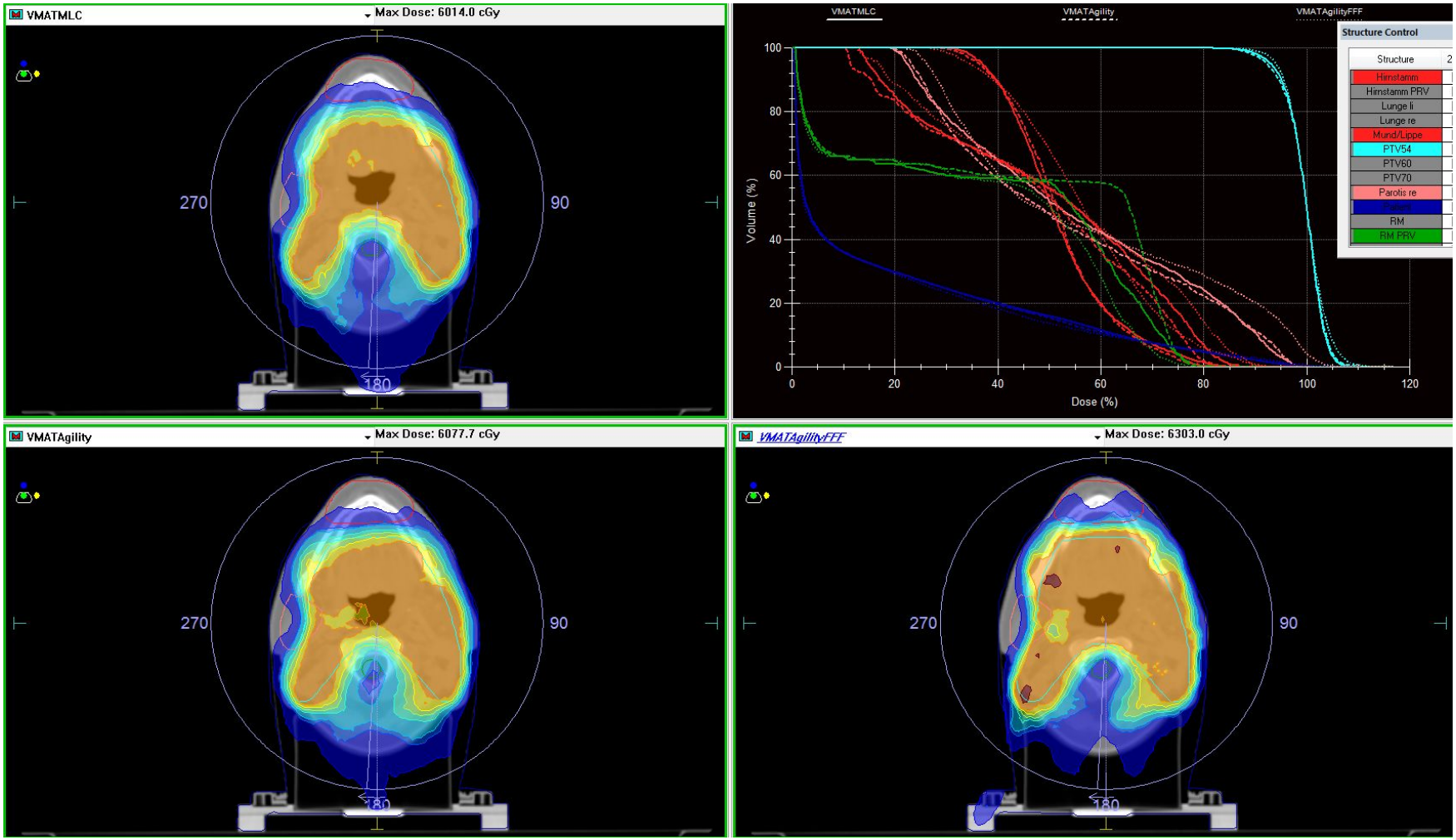
Universitätsklinikum Mannheim

Lung
moderately complex, D= (5 ×12) Gy, 1 VMAT arc

LUNG	MLCi2 Monaco 3.3	Agility Monaco 3.3	Versa HD Monaco 3.3
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
beam-on time per fraction	230 s	245 s	130 s
number of MU's delivered	2014	1997	2281

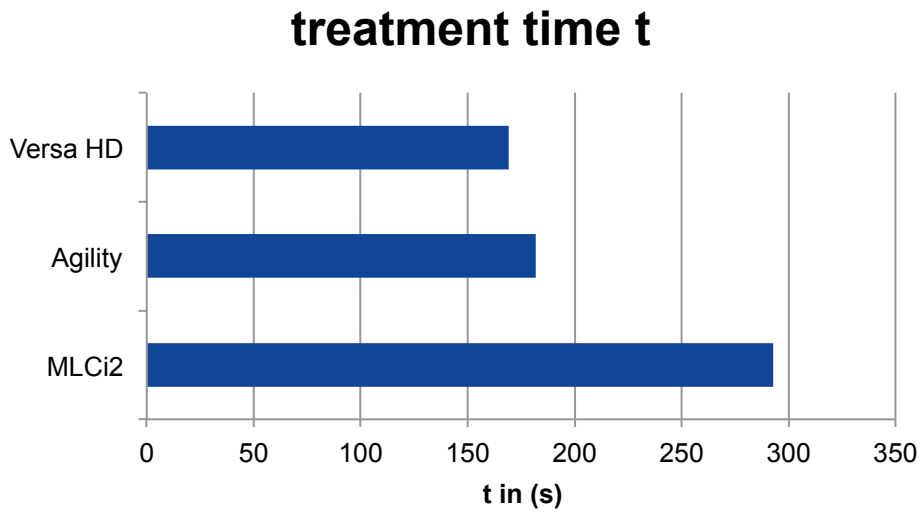


Head & Neck
complex segmentation, D= (30 ×1.8) Gy, 2 VMAT arcs



Head & Neck
highly complex, D= (30 ×1.8) Gy, 2 VMAT arcs

Head and neck	MLCi2 Monaco 3.3	Agility Monaco 3.3	Versa HD Monaco 3.3
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
beam-on time per fraction	293 s	182 s	169 s
number of MU's delivered	635	633	1123

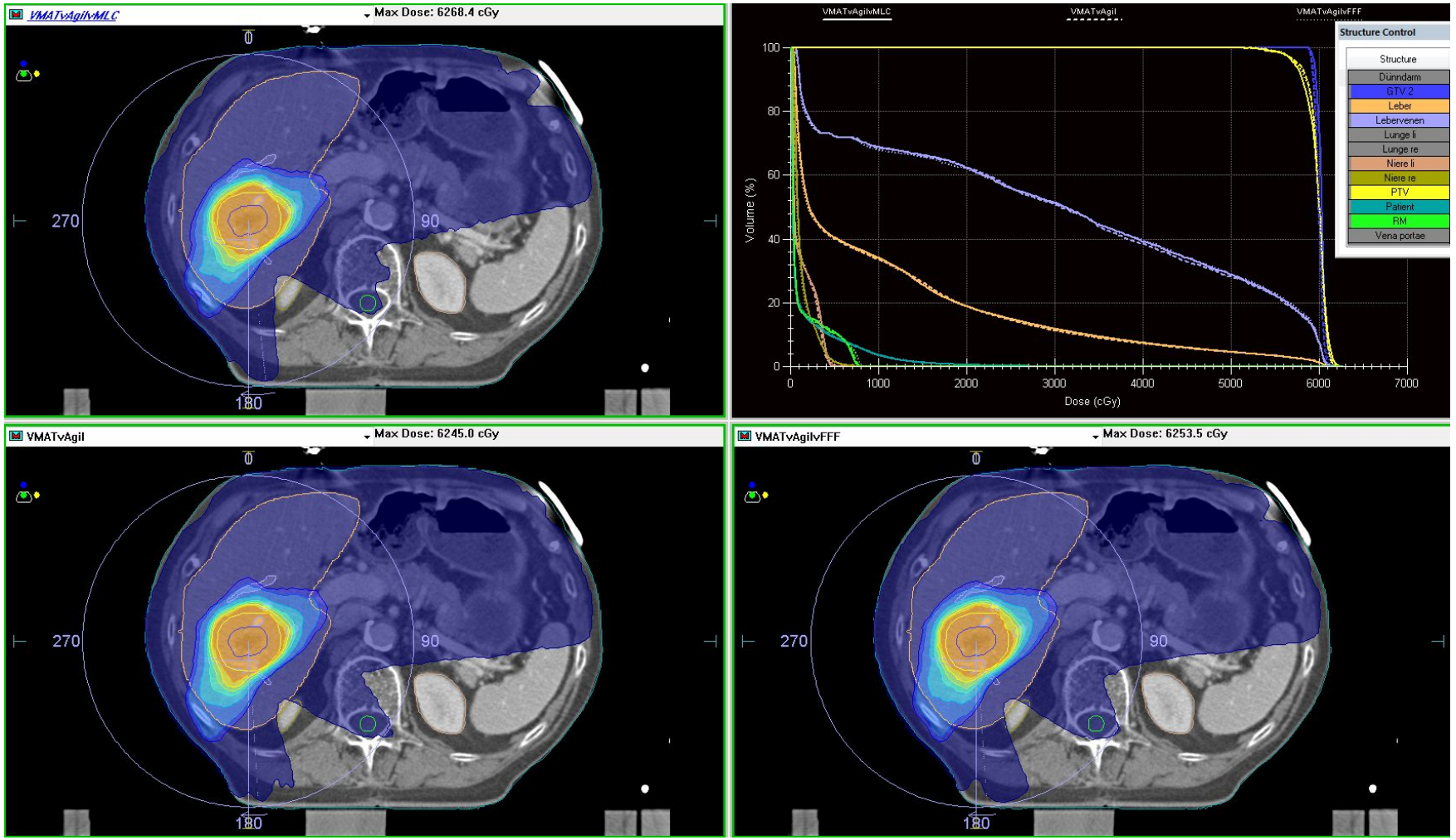


UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

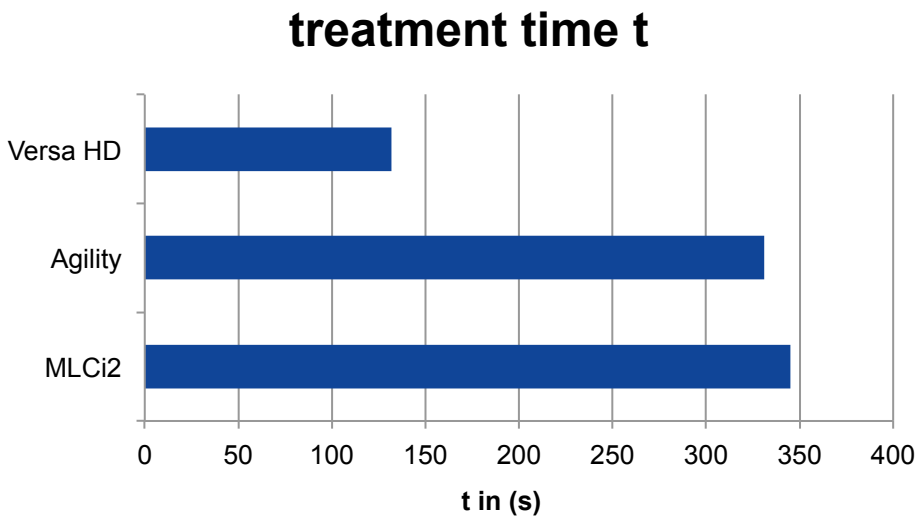
Universitätsklinikum Mannheim

Liver
moderately complex, D= (5 ×12) Gy, 1 VMAT arc



Liver
moderately complex, D= (5 ×12) Gy, 1 VMAT arc

LIVER	MLCi2 Monaco 3.3	Agility Monaco 3.3	Versa HD Monaco 3.3
Homogeneity index	1.07	1.06	1.06
OAR Liver, mean dose	10.57 Gy	10.46 Gy	10.44 Gy
OAR Kidney, max dose	8.63 Gy	8.15 Gy	8.13 Gy
OAR Spinal Cord, max dose	7.82 Gy	7.91 Gy	8.20 Gy
beam-on time per fraction	345 s	331 s	132 s
number of MU's delivered	2494	2710	2733



UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

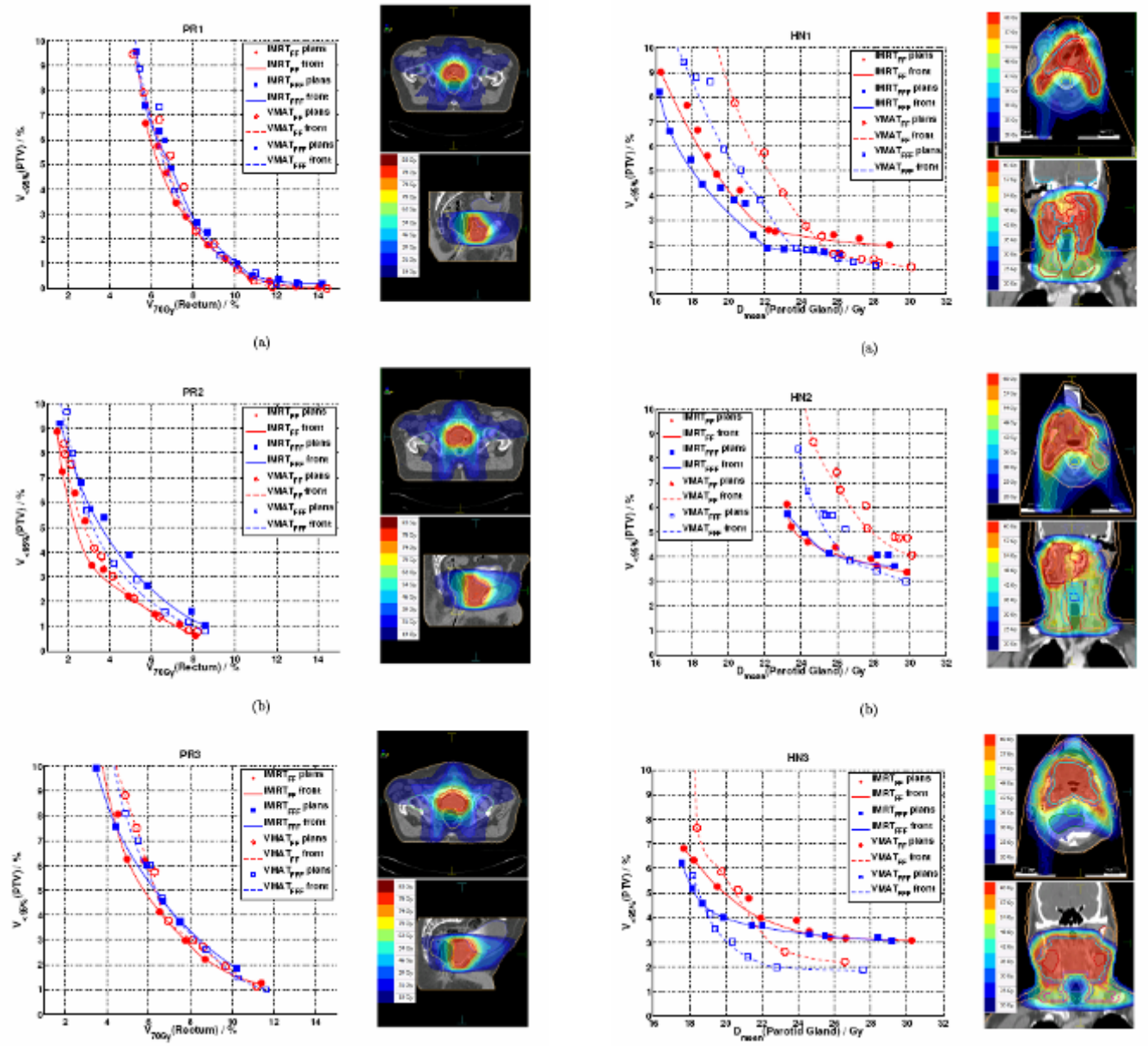
Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

Evaluation of treatment plan quality of IMRT and VMAT with and without flattening filter using Pareto optimal fronts

Lechner et al., submitted

Courtesy AKH Vienna



UMM
UNIVERSITÄTSMEDIZIN MANNHEIM

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

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

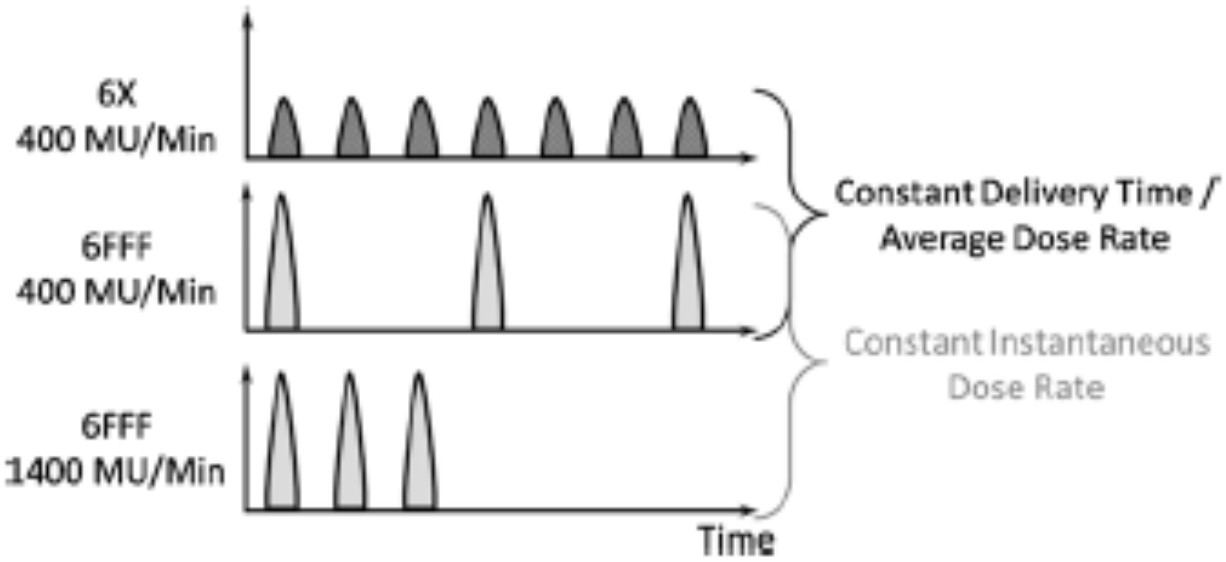


Figure 1. Schematic illustrating the different dose-per-pulse and pulse repetition frequencies of the x-ray fields used in this study.

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)

Positive Studies

Lohse, R&O, 2011

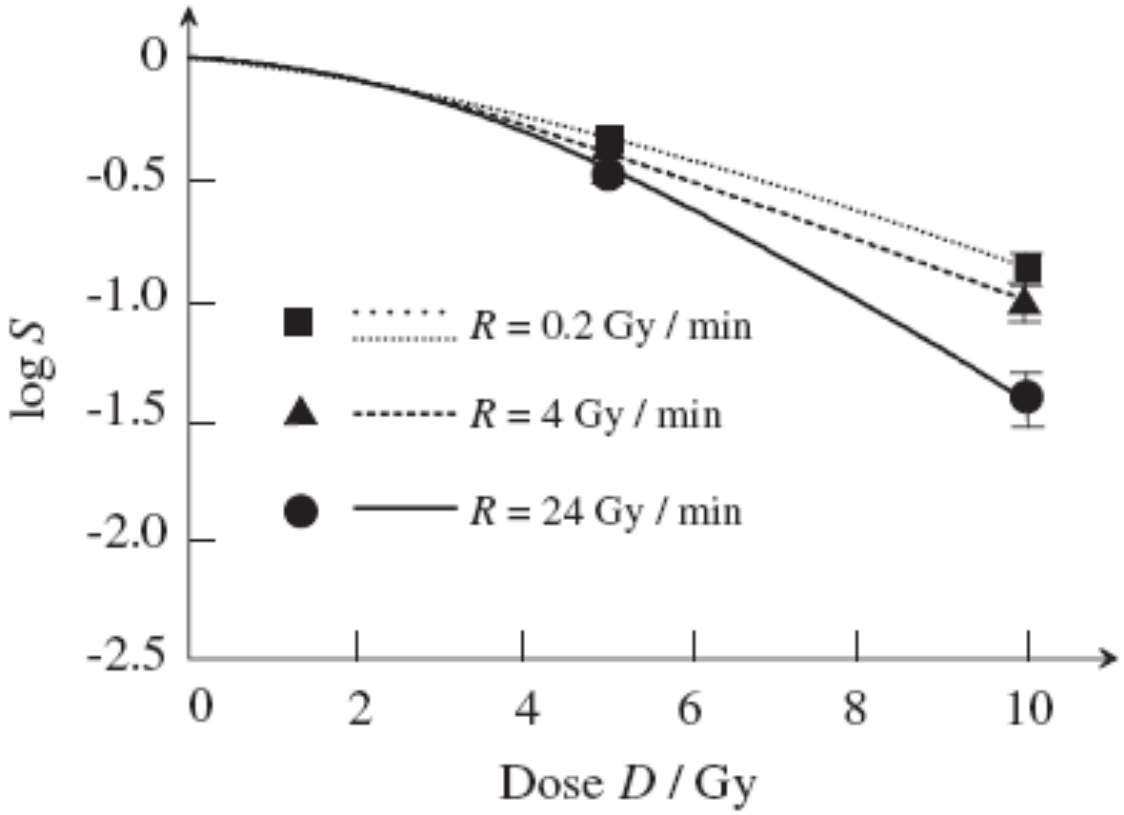


Fig. 4. Surviving fraction of T98G-glioblastoma cells at different dose rates. For 24 Gy/min, the Γ-LQ-model can fit the experimental data with $\alpha = 0.03\ \mathrm{Gy}^{-1}$, $\beta = 0.04\ \mathrm{Gy}^{-2}$ and $\gamma = 0.556\ \mathrm{min}^{-1}$; for 4 Gy/min, γ has to be adapted to $0.361\ \mathrm{min}^{-1}$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

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

Lohse, R&O, 2011

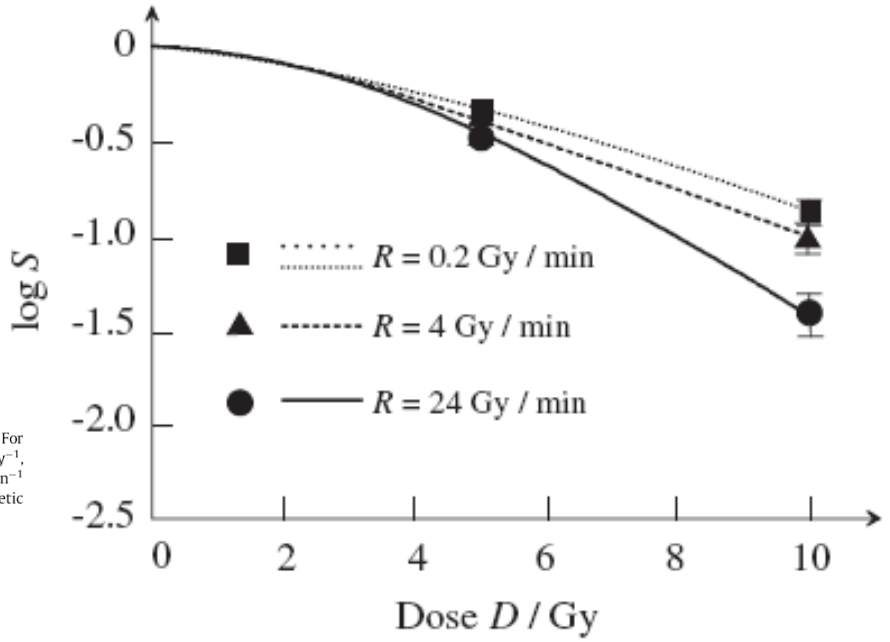


Fig. 4. Surviving fraction of T98G-glioblastoma cells at different dose rates. For 24 Gy/min, the Γ-LQ-model can fit the experimental data with $\alpha = 0.03\ Gy^{-1}$, $\beta = 0.04\ Gy^{-2}$ and $\gamma = 0.556\ min^{-1}$; for 4 Gy/min, γ has to be adapted to $0.361\ min^{-1}$ and for $R = 0.2$ Gy/min,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

VS.

Verbakel, Acta Oncol, 2013

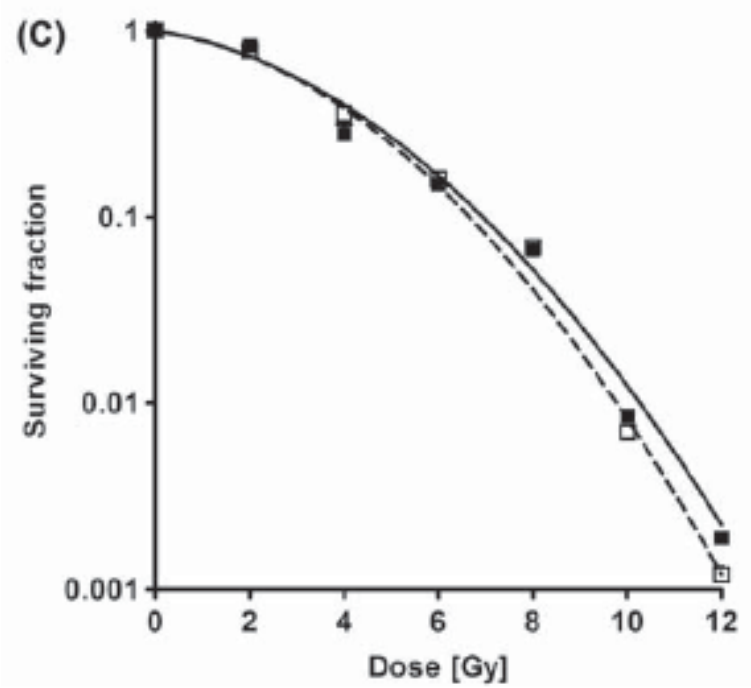


Figure 3. Normalized cell survival curves for SW 1573 (A), D384 (B) and T98 (C) cells. Error bars represent the standard error of the
mean (n 3). Open squares FF, Closed squares FFF.

UMM
UNIVERSITÄTSMEDIZIN
MANNHEIM

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

Klinikum rechts der Isar
Technische Universität München

Munich-Centre for Advanced Photonics
www.munich-photonics.de

Radiation biology of laser induced protons and heavy ions

PD Dr. Thomas Schmid
Department Radiotherapy and Radiooncology

Preconference – 37 Years of Radiation Research

March 07, 2013

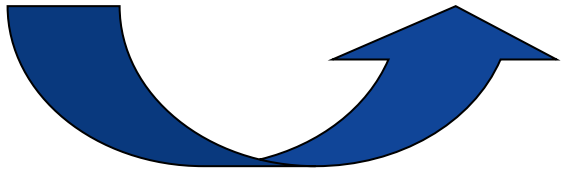
Pulsed character of laser-accelerated protons

“conventional“ proton therapy

2 Gy in 100ms (=10^{-1} s)
per cell / tissue voxel

laser-based proton therapy

2 Gy in 1ns (=10^{-9} s)
per cell / tissue voxel



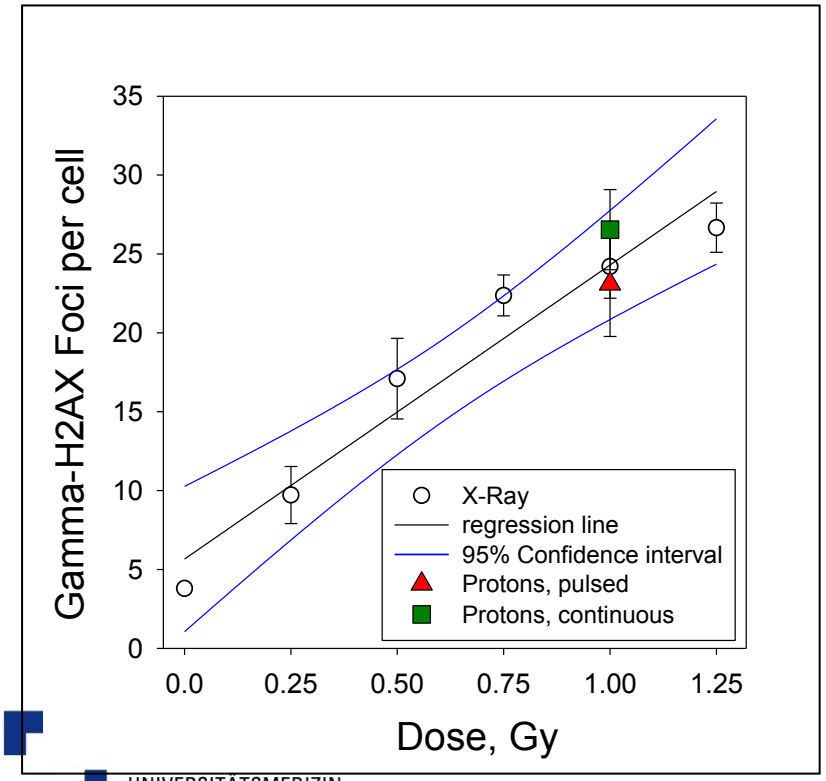
factor 10^8

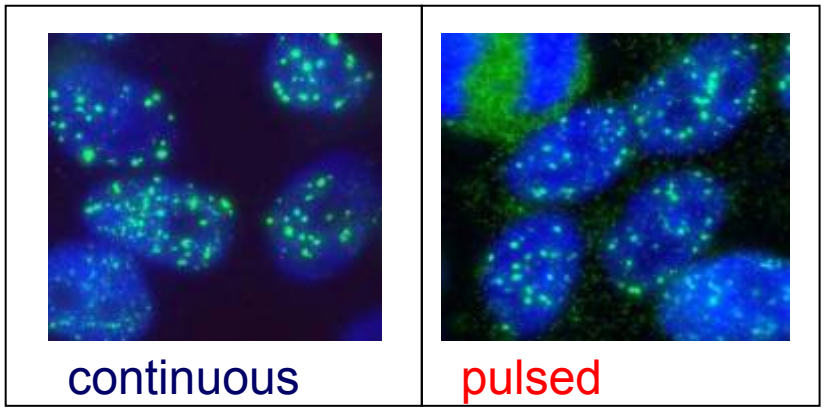
Is this difference in dose-rate of biological relevance?

Factor 10^8 corresponds to an application of a 3 year event in only 1 second

γ-H2AX-foci in HeLa cells / repair of DNA DSBs

20 MeV protons (tandem accelerator)
1 Gy (single dose)





	continuous (1 Gy in 100 ms)	**pulsed** (1 Gy in 1 ns)
Foci per cell	26.54 ± 2.54	23.29 ± 2.04
RBE	1.13 ± 0.21	0.96 ± 0.18

Take home messages - Versa HD

- Better modulation in shorter treatment times
  - higher conformity/ homogeneity – 160 MLC leaves
  - higher leaf speed
  - higher dose rates can be achieved with FFF
- Where do we see this clinically
  - Agility speed improvements can be seen for many treatment sites and fractionation schemes
  - The advantage of higher dose rates from FFF can mainly be seen for moderately complex plans with fraction doses D> 5 Gy
- Quality assurance
  - An extensive measuring/ validation of base data and commissioning phase is necessary
  - individual pre-treatment plan verification recommended

Grazie per l‘attenzione