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HEIDELBERG UNIVERSITY HOSPITAL

New developments in photon RT: Advanced treatment machines

HIRO Heidelberg Institute for Radiation Oncology
National Center for Radiation Research in Oncology Heidelberg
supported by:
German Cancer Research Center (DKFZ)
Heidelberg University Hospital
Heidelberg Ion-Beam Therapy Center (HIT)
Medical Faculty Heidelberg

DKTK German Cancer Consortium

Upright radiotherapy with photons

Grace solution from Leo Cancer Care:

- Upright patient positioning system
- CT scanner
- 6MV FFF Linac, 1200 MU/min

Potential benefits from the Linac perspective:

- Easier access to components
- MLC is easier to control, does not need to rotate
- Radiation protection is easier

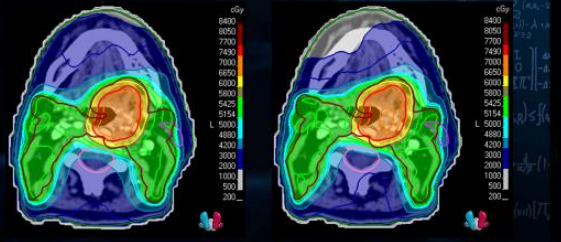
By courtesy of Dean Willems, Leo Cancer Care

System is not approved for Sale, presented for research purposes only

Machine characteristics influence treatment planning

UPRIGHT ARC PLANNING - PHOTONS

Comparison to conventional LINAC 1(2)



Chair: Ruby
1 arc
High-speed MLC
Fixed collimator angle

Conventional LINAC
3 arcs
Dual-layer MLC, moderate speed
Variable collimator angle

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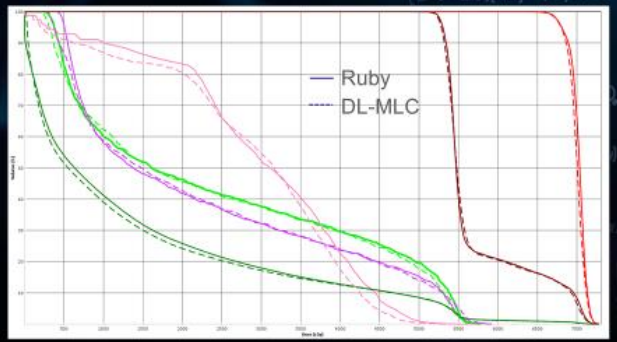
UPRIGHT ARC PLANNING - PHOTONS

Comparison to conventional LINAC 2(2)

Plan	Rotational speed	MLC speed	Objective	MU	Delivery time
Ruby 1 arc	6 deg/s	10 cm/s	587	700	95 s
DL-MLC 3 arcs (varied collimators)	12 deg/s	5 cm/s	560	606	91 s



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RaySearch Laboratories

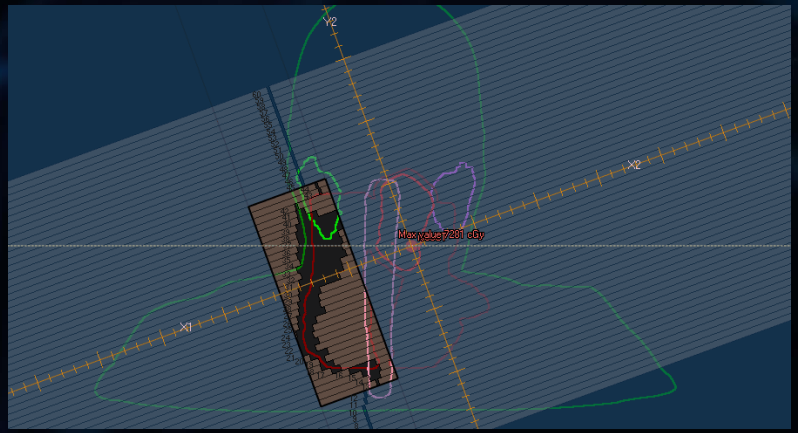
By courtesy of Erik Engwall, Raysearch Laboratories

By courtesy of Erik Engwall, Raysearch Laboratories

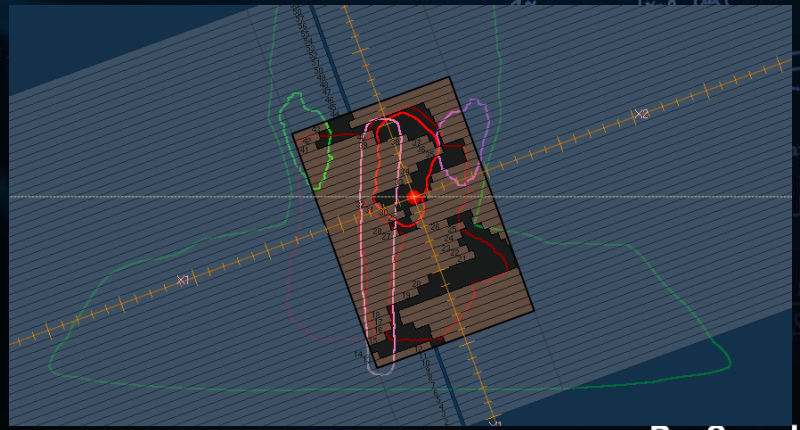
UPRIGHT ARC PLANNING - PHOTONS

Benefit of high MLC leaf speed

Plan	Rotational speed	MLC speed	Objective	MU	Delivery time
Ruby 1 arc (sliding window)	6 deg/s	10 cm/s	587	700	95 s
Ruby 1 arc (sliding window)	6 deg/s	3.5 cm/s	617	700	279 s
Ruby 1 arc (non sliding window)	6 deg/s	3.5 cm/s	929	713	62 s



10 cm/s leaf speed
Sliding window segments



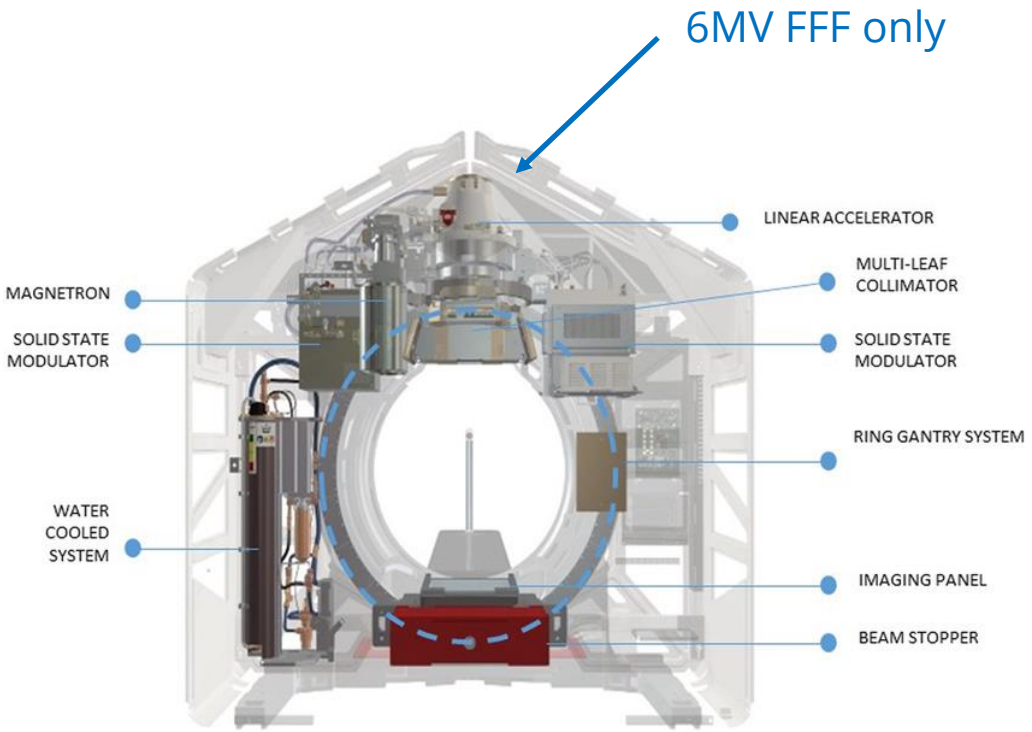
3.5 cm/s leaf speed
“Step-and-shoot” segments

RaySearch Laboratories

Advanced photon treatment machines

Example: Varian Halcyon

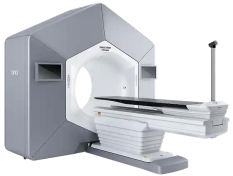
www.varian.com

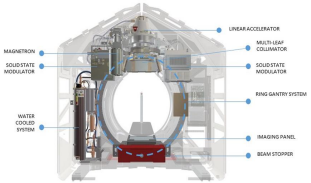


Cozzi L et al., Technology in Cancer Research and Treatment, Volume 17, 2018.

Compact photon treatment machines

Here: double stack MLC





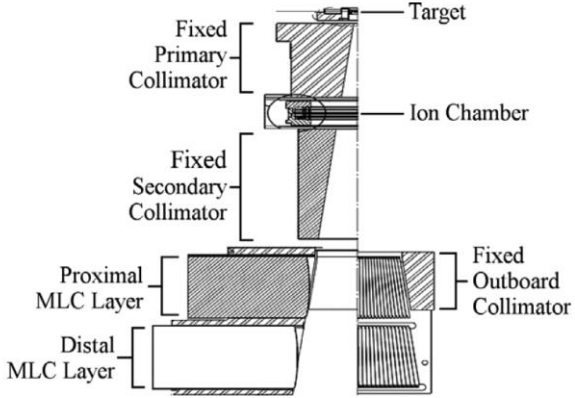


FIG. 1. Schematic drawing of the Halcyon™ head assembly.[18] The primary and secondary collimators are fixed in place, and are not movable jaws. Shown are the positions of the proximal (upper) and distal (lower) MLC layers, with the bottom left displaying the leaf side view, and the bottom right illustrating the leaf end view.

TABLE 1 Comparison of the Varian Halcyon™ MLC system[17,18] to the widely used Varian Millennium™ 120-leaf MLC system.[19,20]

Characteristics	Halcyon™ MLC	Millennium™ 120-leaf MLC
MLC Configuration		
Layers	Dual-layer	Single-layer
Beam shaping technique	Proximal and distal MLCs with 0.5 cm offset (no jaws)	MLC and jaws
Number of leaves	114 (29/bank on proximal, 28/bank on distal)	120 (60/bank)
Maximum field size	28 cm × 28 cm	40 cm × 40 cm
Direction of motion	Transverse	Transverse
Physical properties		
Leaf end shape	Rounded	Rounded
Leaf end radius	23.4 cm	8.0 cm
Leaf height	7.7 cm	6.5 cm
Leaf width (at isocenter)	1 cm	Pairs 1 & 40: 1.4 cm Pairs 2–10 and 51–59: 1 cm All others: 0.5 cm
Nominal 6MV-FFF transmission	Single-layer: 0.47% Dual-layer: 0.01%	1.36%
MLC motion		
Leaf end position accuracy	1 mm	1 mm
Leaf velocity	5.0 cm/s	2.5 cm/s
Leaf acceleration	200 cm/s/s	50 cm/s/s
Position detection mechanism	Primary: Motor encoder Secondary: Soft pots	Primary: Motor encoder Secondary: Soft pots
Overtravel across central axis	14 cm	15 cm

Lim TY et al., Characterization of the Halcyon TM multileaf collimator system, JACMP 2019; 20:4: 106–114

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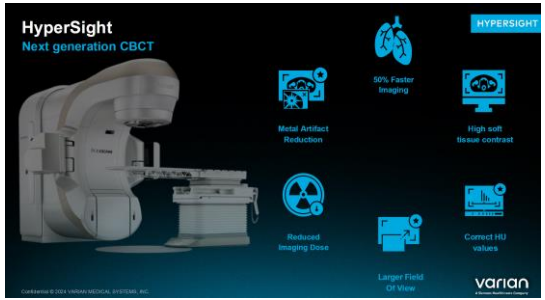
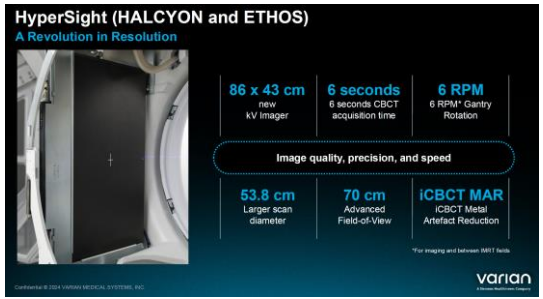
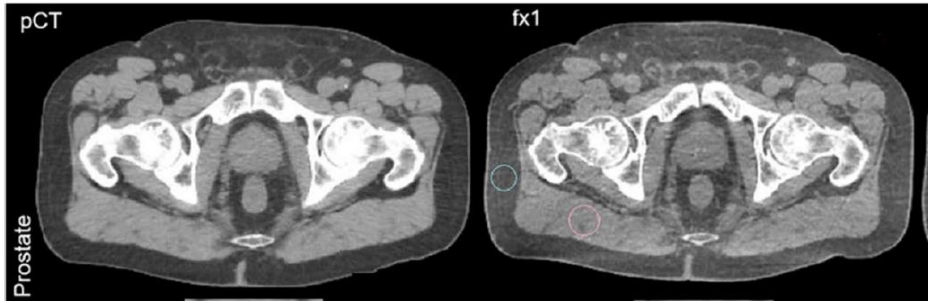
Advanced integrated imaging

→ Superior onboard image quality is necessary for (online) adaptive treatments

Example: Varian HyperSight







Schmidt et al. Radiation Oncology (2025) 20:153
https://doi.org/10.1186/s13014-025-02730-8

Radiation Oncology

RESEARCH Open Access

Advanced HyperSight™ imaging for patients with adaptive SBRT of prostate cancer: a longitudinal analysis of tissue demarcation

Ralf Schmidt[1,2], Thanh Nguyen[1], Alicia S. Bicu[1,2], Paula Cvachovec[1], Victor Siefert[1,2], Miriam Eckl[1], Marvin Willam[1], Matthias F. Froelich[3], Stefan O. Schoenberg[3], Michael Ehmann[1,2], Daniel Buergy[1,2], Sven Clausen[1], Jens Fleckenstein[1], Frank A. Giordano[1,2,4], Judit Boda-Heggemann[1,2] and Constantin Dreher[1,2,4,5*]

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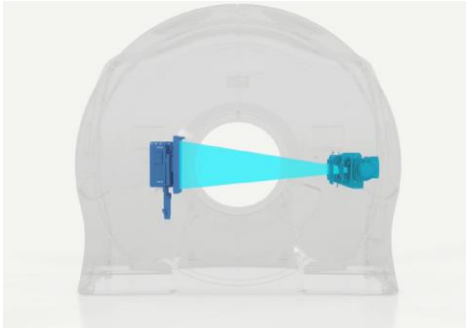
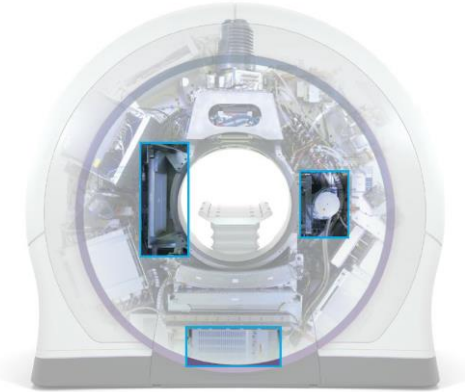
Advanced integrated imaging

Example: Accury Radixact Tomotherapy

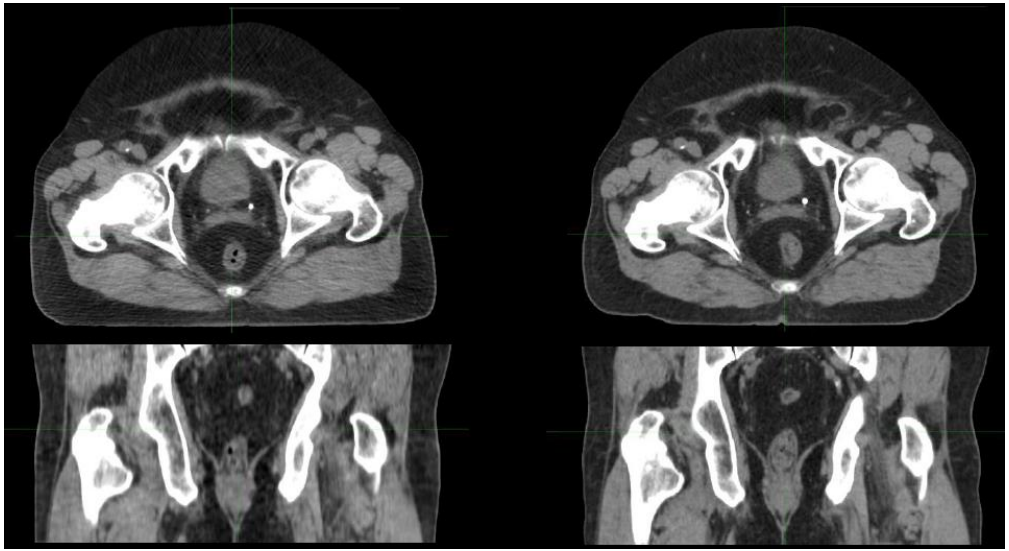




Helical kVCT up to 135cm length, 50cm FOV

Relatively fine beam (1-2cm)

Which is which?



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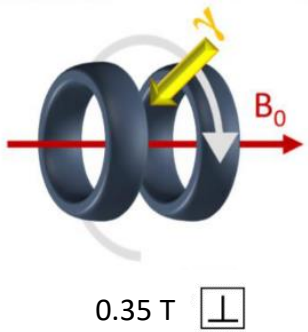
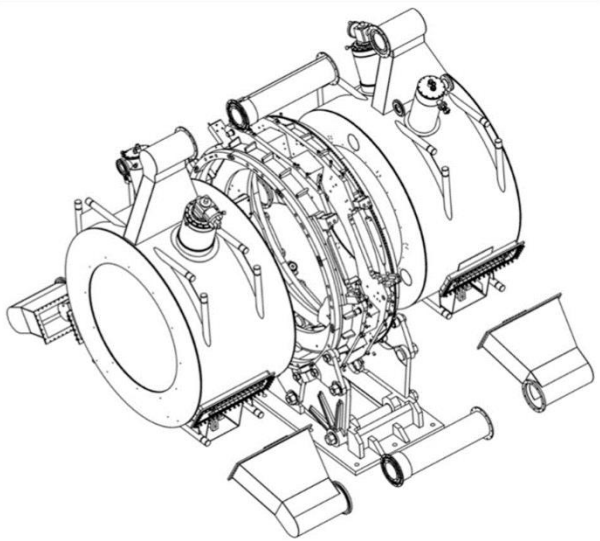
Advanced integrated imaging

Example: MR-Linac





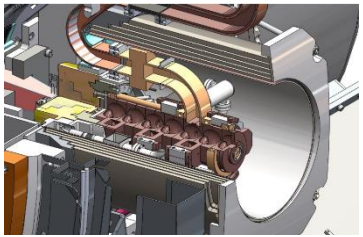
- split, superconducting 0.35 T magnet (double-donut)
- magnet halves are mechanically and thermally connected
- circular radiation gantry in 28cm gap between magnet halves
- 70cm bore, 50cm max. FOV

Gantry design: shielding buckets

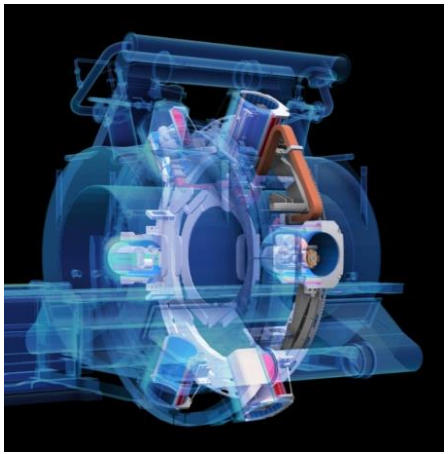
- Shielding buckets: combination of steel + mu-metal for magnetic shielding and carbon fiber + copper for RF shielding

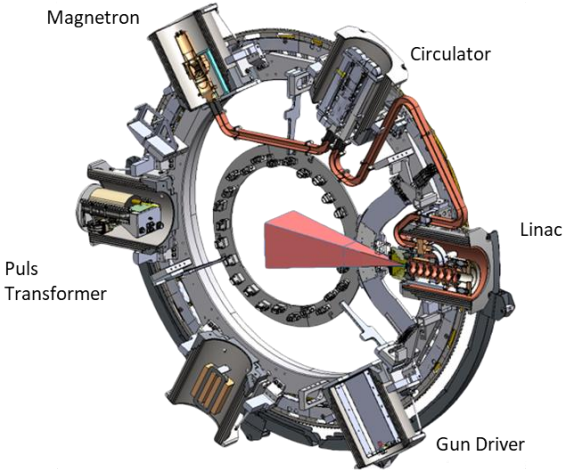
→ Linac is shielded from the B_0-Field

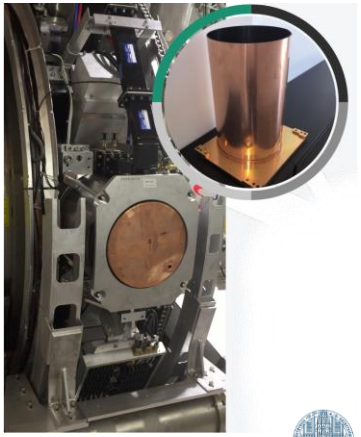
→ MR is shielded from electromagnetic noise



- Imaging is limited to static gantry and MLC







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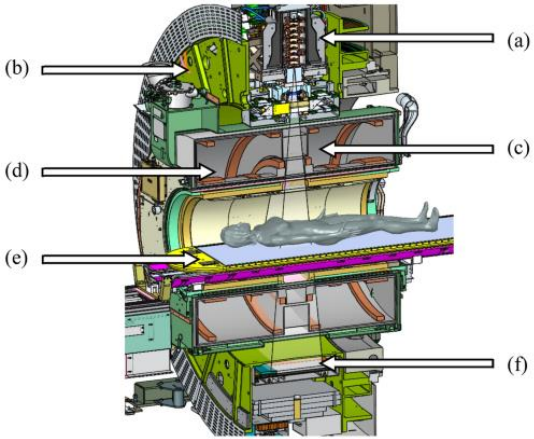
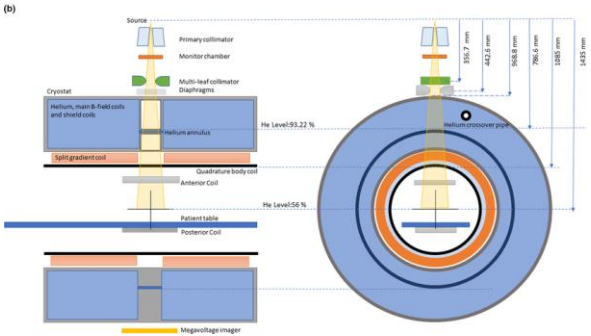
Elekta Unity MR-Linac

- 1.5 T transverse magnetic fiels
- Only one magnet/cryostat
- Linac gantry around the cryostat (greater distance)
- Complete RF shielding between linac components and MRI



Shoobridge and Baines, Phys End Sci Med 2022, DOI:10.21203/rs.3.rs-368526/v1



Roberts DA et al., Med Phys 2021, DOI: 10.1002/mp.14764

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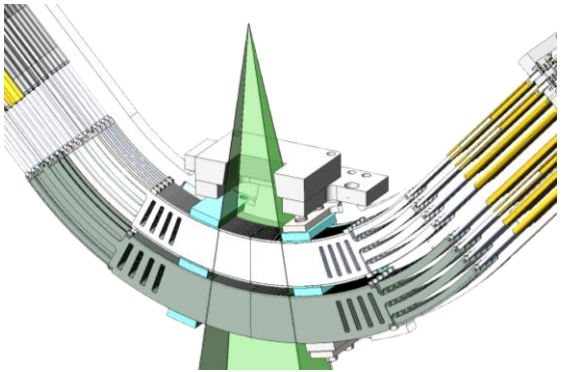
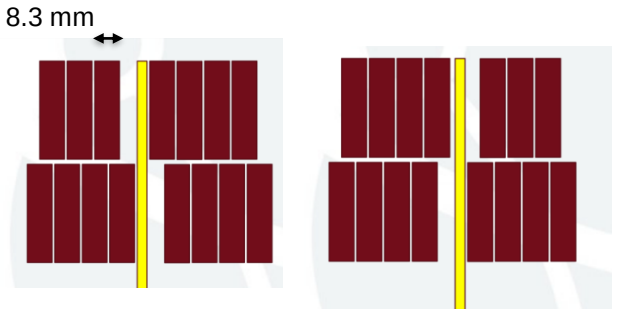
RT system: Linac and MLC

- 6MV FFF Linac with 600 MU/min @90cm SAD



- double stack, double focus MLC, 138 tungsten-alloy leaves
- max. Fieldsize 27.4 x 24.1 cm^2, min. Fieldsize 2 x 4.15 mm^2
- no additional jaws

- Physical leaf width = 8.3mm @ isocentric plane
- Both stacks are shifted by half a leaf width



Three main advantages of the MRI in an MRL

1. Soft-tissue based positioning

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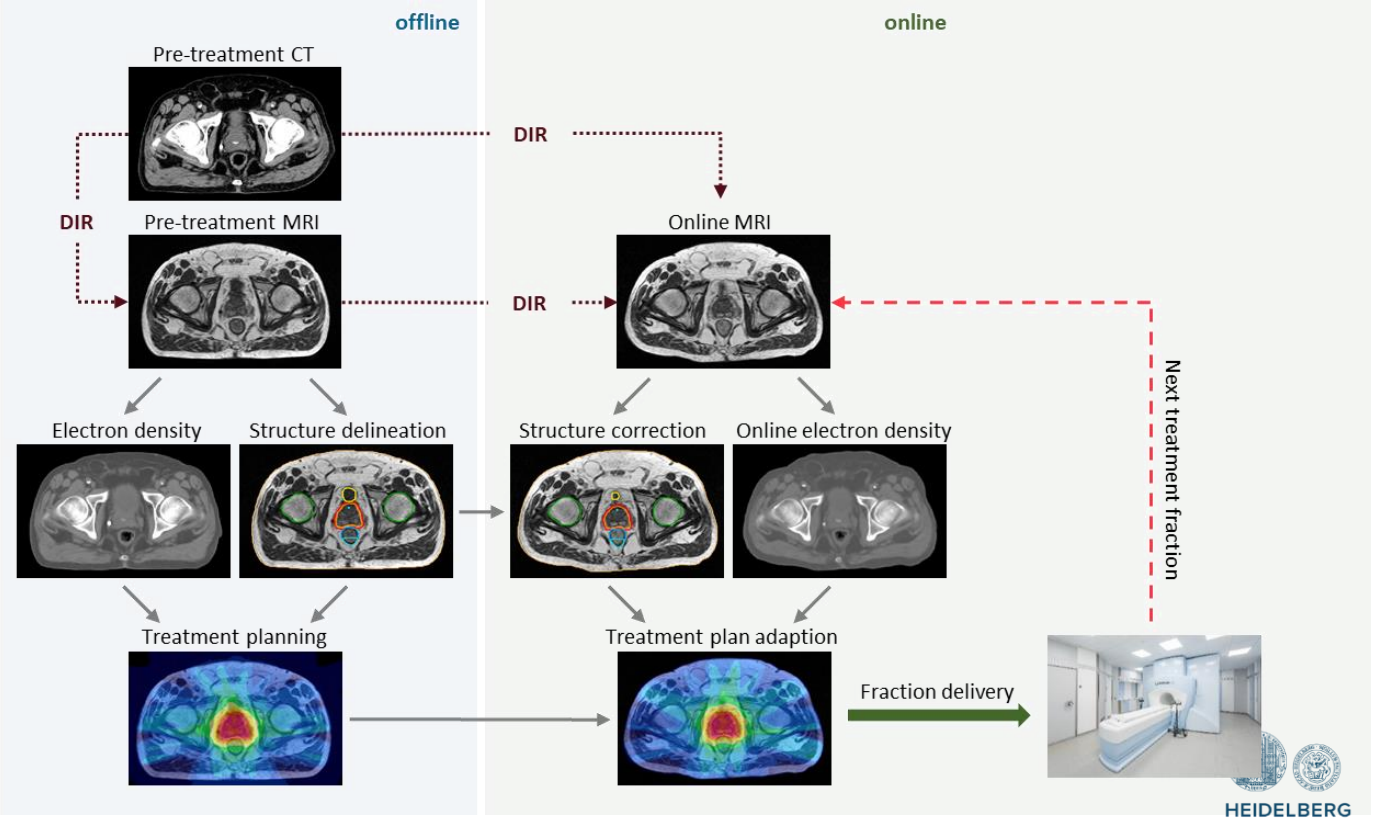
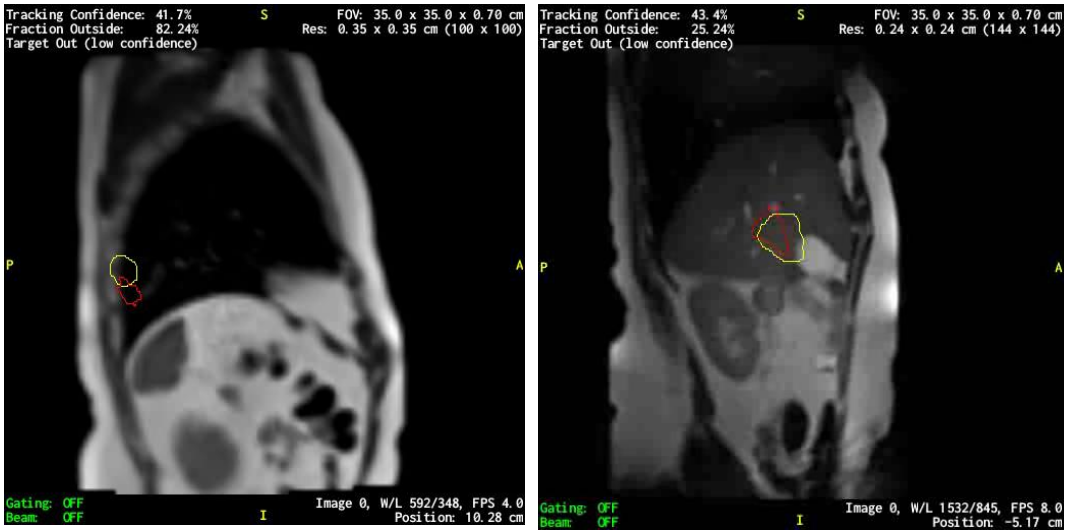
Three main advantages of the MRI in an MRL

2. Online adaptation



Three main advantages of the MRI in an MRL

3. Real-time imaging and beam control



Three main advantages of the MRI in an MRL

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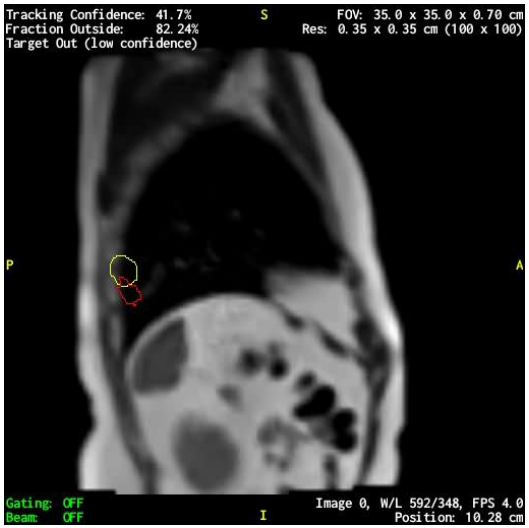

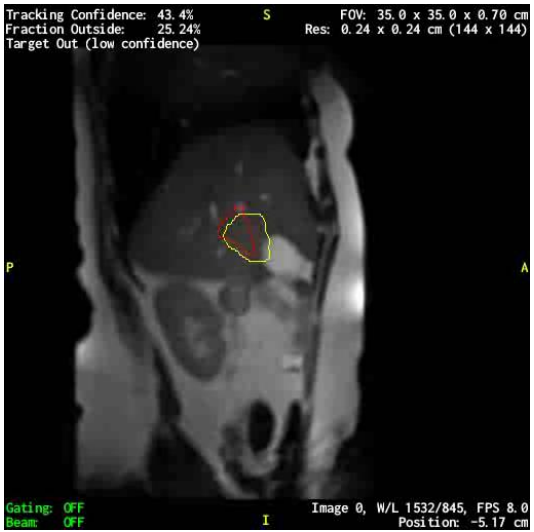

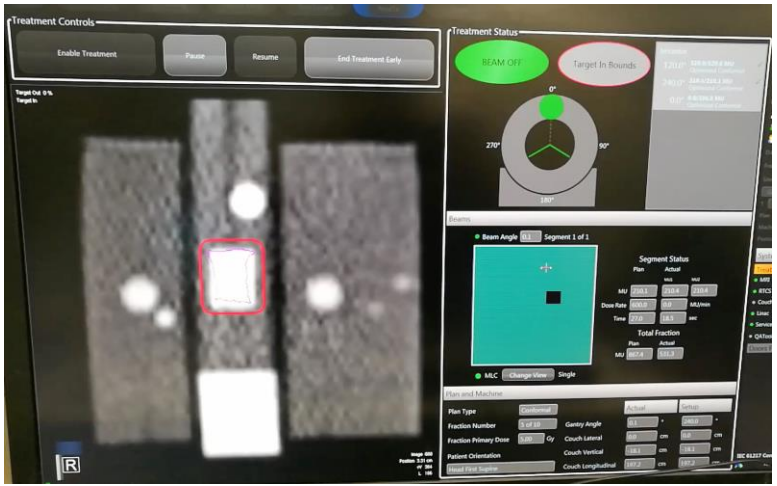

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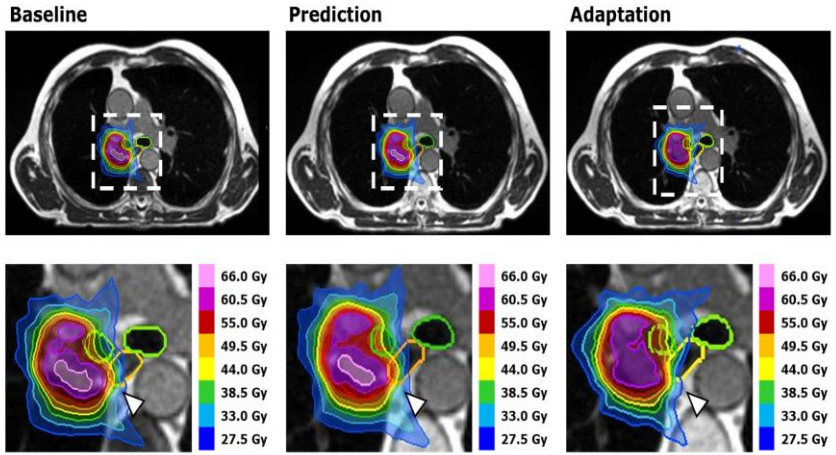
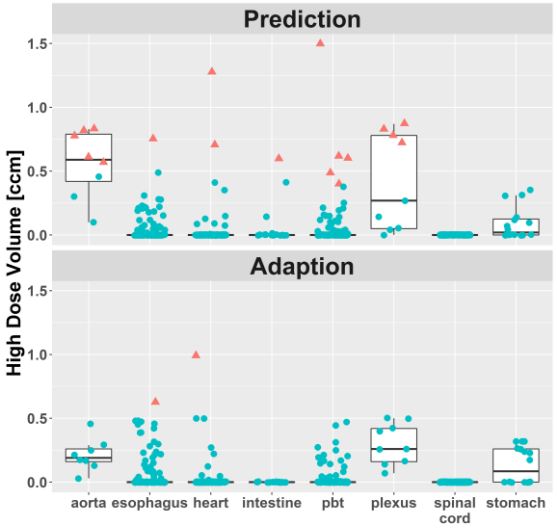
Potential of Pulmonary Adaptive MR-guided SBRT

- Daily adaptation: reduce OAR dose, increase target coverage
- OAR very close / margin reduction



Daily plan adapation is especially necessary:
In tumors with (PTV) contact to radiosensitive OARs
For safe dose escalation



OAR dose constraint violations:
> 90% of patients with PTV< 2mm distance to OAR

Regnery S, …, Hörner-Rieber J, Front Oncol 2022
Regnery,…Hörner-Rieber, Lung Cancer 2023

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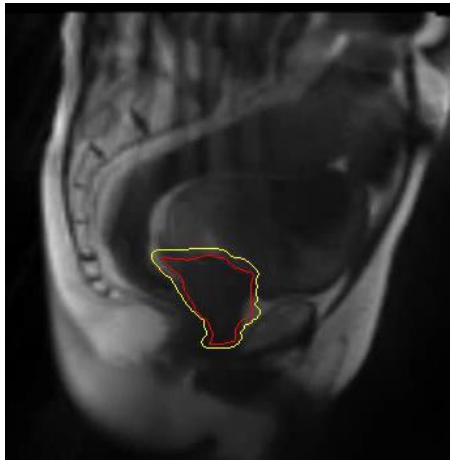
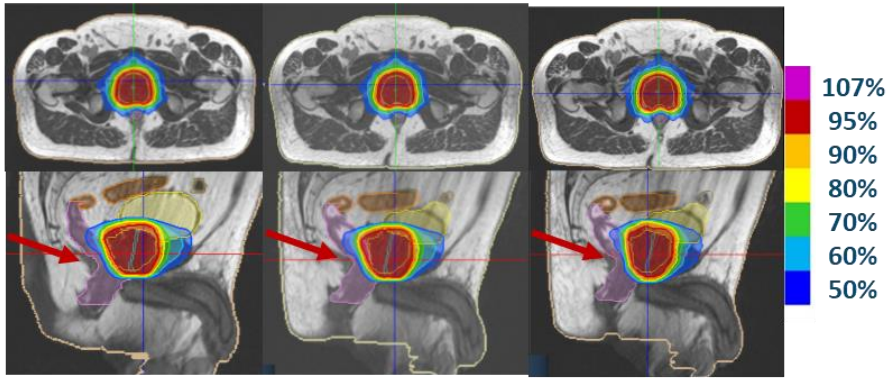
MRI-guided adaptive RT therapy for prostate

5 x 7,5 Gy, SIB with up to 5 x 8,0 Gy boost (mpMRI)

- → Daily adaptive RT enables hypofractionation
- → Daily adaptive RT enables margin reduction
- → MRI-based beam gating enables further margin reduction





Ristau,…Hörner-Rieber, Körber, Rad Oncol 2022
Fink et al., Front Oncol. 2024
Fink et al., ctRO 2024

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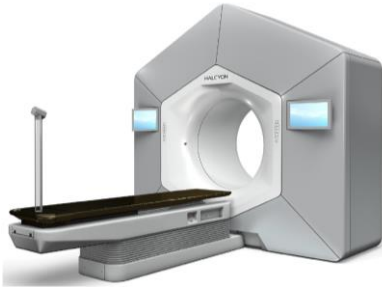
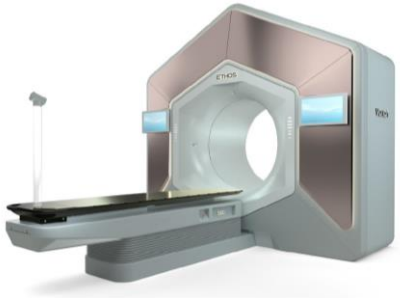
Advanced photon treatment machines

Dedicated Linacs for online adaptive





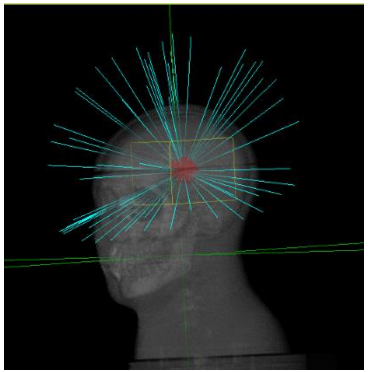
www.varian.com

www.elekta.com

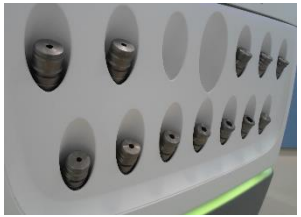
- → Linac hardware is the same
- → Integrated software solutions for online treatment plan adaptation
- → But: unfortunately, vendors lock down everything, no interfaces (HW and SW)

Robotic Photon Radiotherapy: CyberKnife

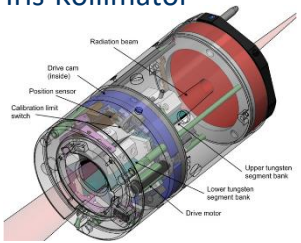
Orthogonal X-Ray



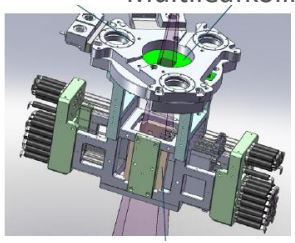
Rundkollimatoren



Iris-Kollimator

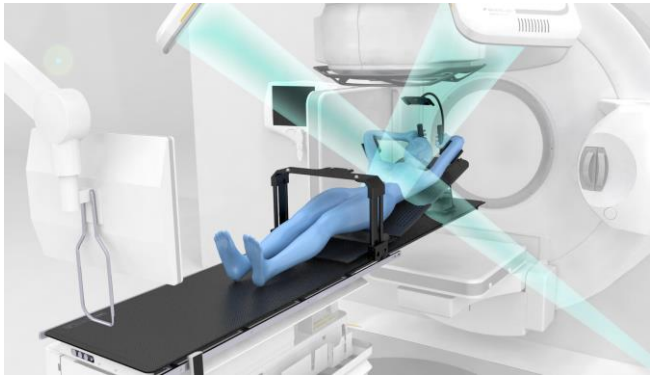


Multileafkollimator



Continuous, automated position correction based on 2D X-Ray imaging and automated image registration

Integrated motion management: also for standard linacs



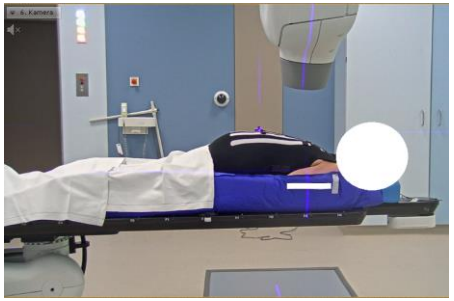
www.brainlab.com

But: 2D X-Ray imaging

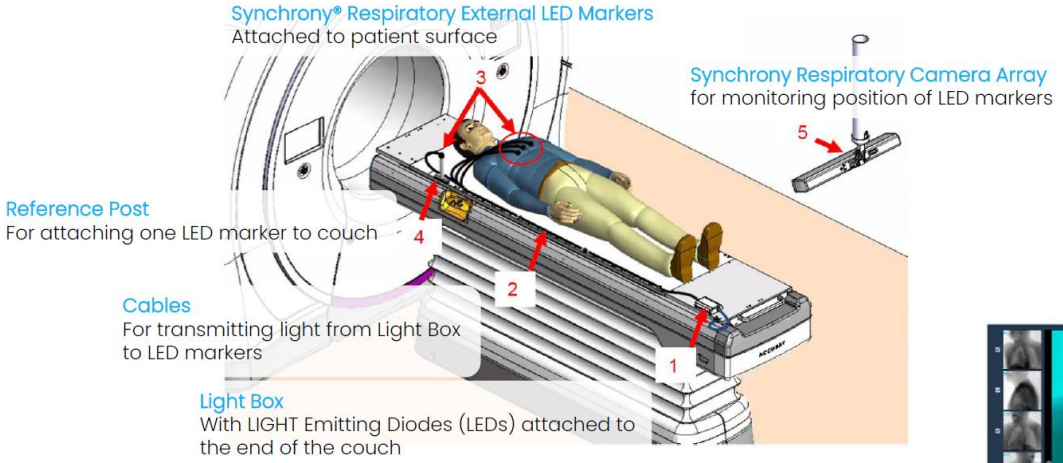
→ currently, if target is not visible in the X-ray image, gold marker implantation is needed

Motion management: tracking

- Breathing motion detection based on LED on patient chest
- Correlation with tumor position in X-ray image
- Prediction of the movement and online correction by the robot
- Re-assessment of the model by re-imaging



Motion management for tomotherapy



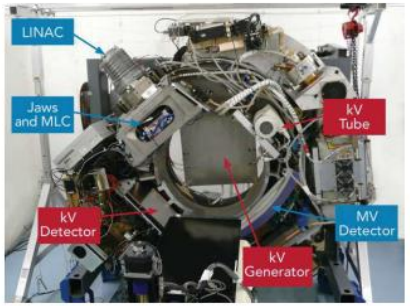


FIG. 1. A picture of the experimental tomotherapy system, highlighting the kV x-ray tube and detector mounted orthogonal to the MV beamline. The kV generator is mounted to a metal plate on the back side of the gantry.

Here: same principle like the Cyberkinfe system

If Tumor is not visible in the X-Ray image,

Gold markers (fiducials) need to be implanted

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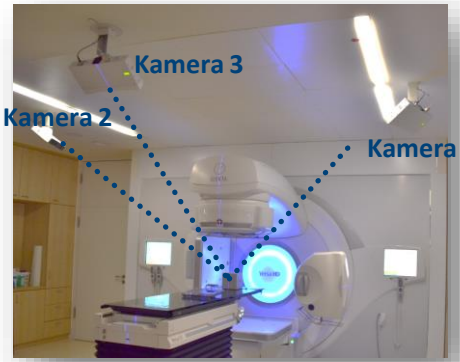
Surface Guidance

3D detection of the patient surface using optical cameras

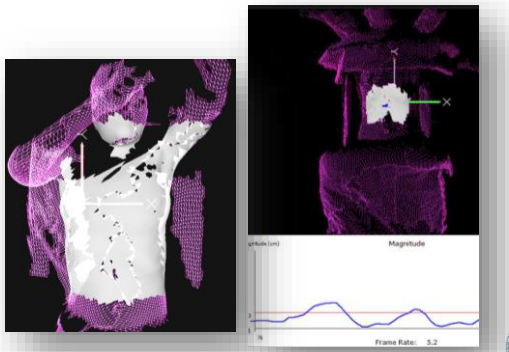


Main use:

Deep inspiration breathhold for breast irradiation

Improvement of patient positioning

Gating for thoracic treatments



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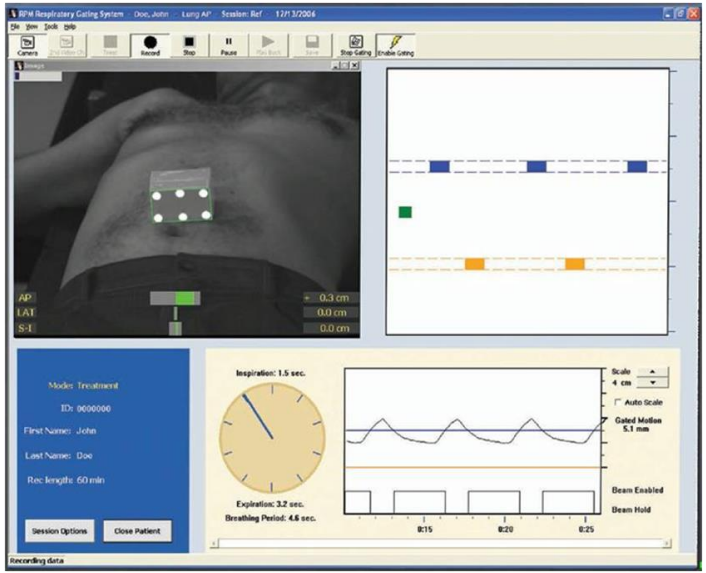
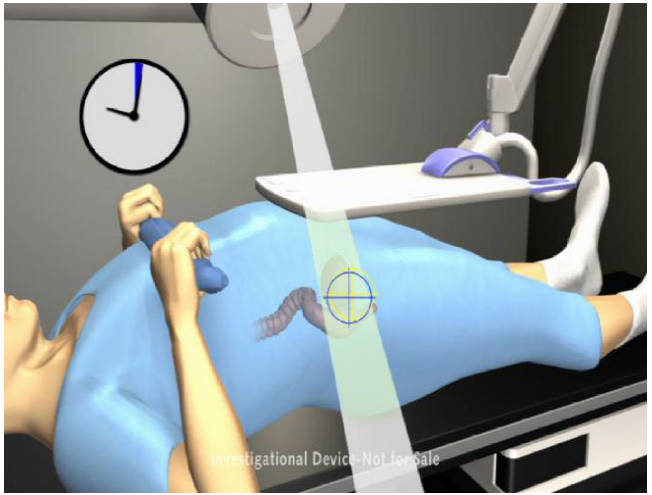
Other methods for gating





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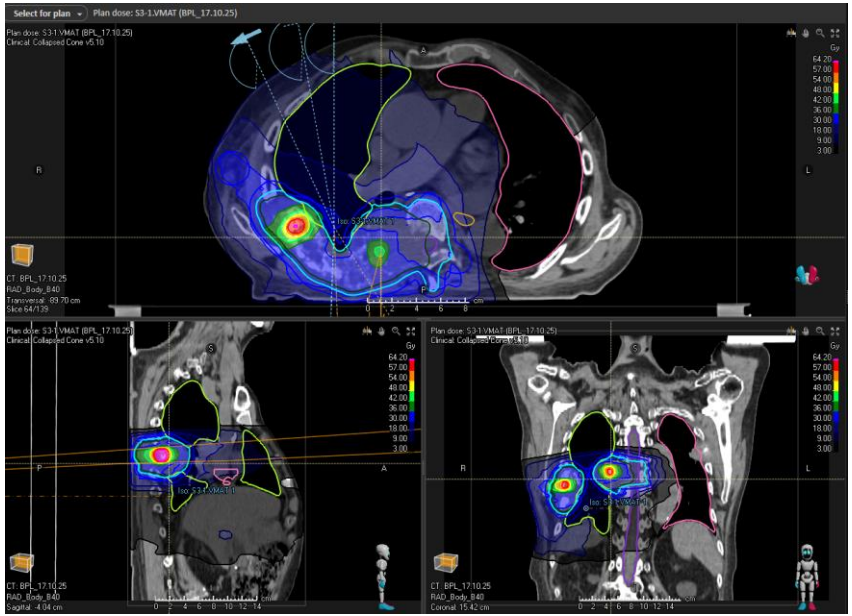
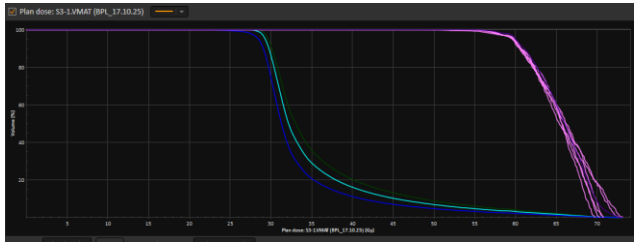
Advanced concepts can be carried out with standard linacs



Lattice therapy



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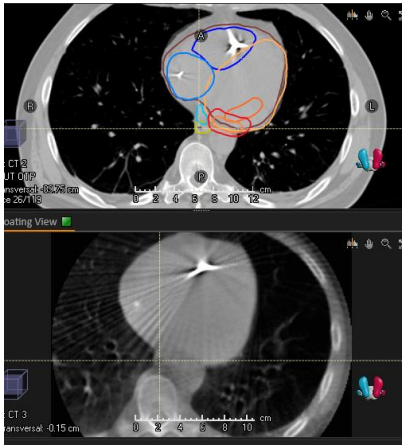
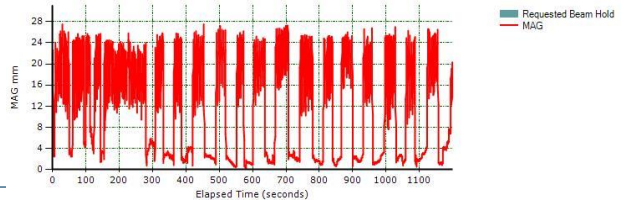
Advanced concepts can be carried out with standard linacs

Cardiac ablation for therapy-resistant ventricular tachycardia
24 Gy in one session
Here: treated in breathhold





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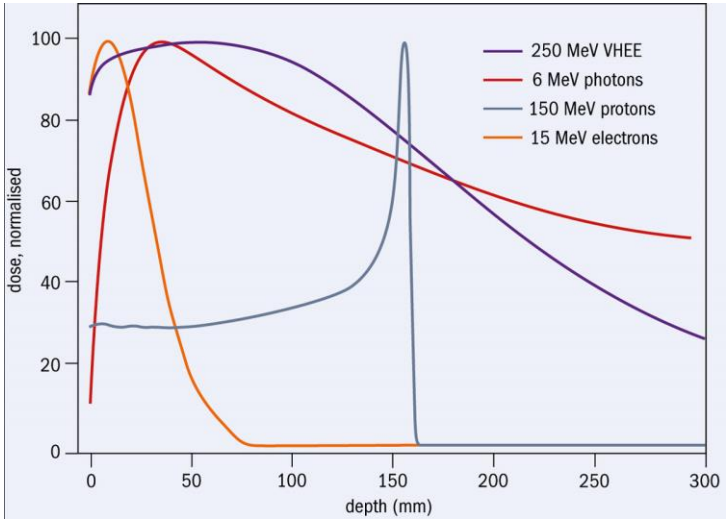
What I did not talk about

- Electron FLASH with standard Linacs
- Photon FLASH
- Very High Energy Electrons (VHEE)
  (w/wo FLASH)



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