UMC Utrecht

# MR-guided radiotherapy: Vision, status and research at the UMC Utrecht

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University Medical Center Utrecht

# About myself

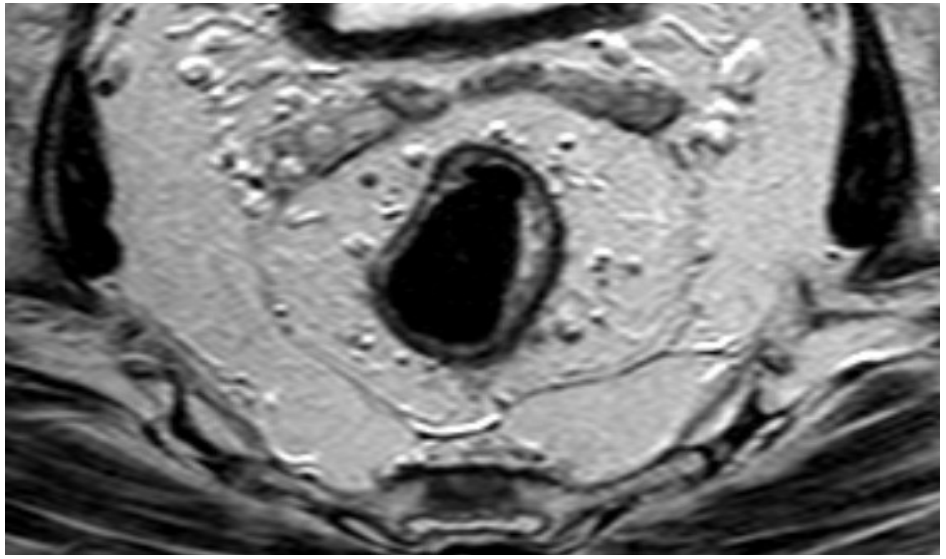

- Training
  - Medizintechnik TU Graz
  - PhD UMC Utrecht
- Clinical work
  - Software implementation (ART, IGRT)
  - Infrastructure maintainance (DICOM servers, workflows)
  - MRI (commissioning, QA, protocol development)
- Research
  - Starlit project 16M€
  - Fast MRI-acquisition
  - MLC tracking

# Topics

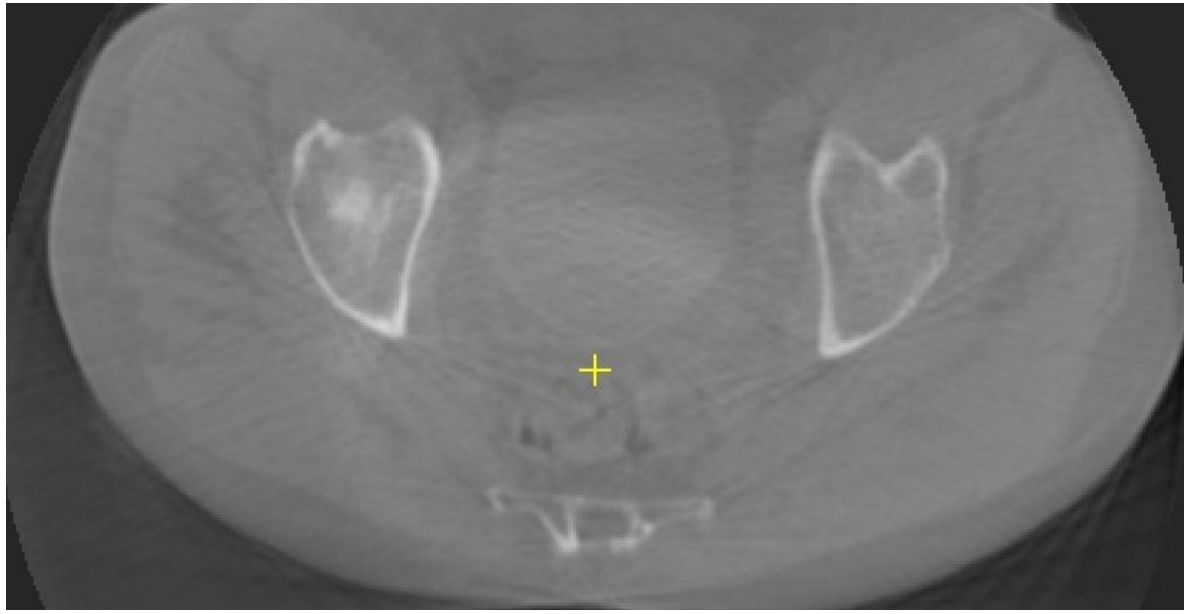
- Simultanous MRI /Why MRI-linac
- Image quality
- MRI-linac at the UMC Utrecht
- First clinical action of MRI-linac
- Research
  - Adaptive replanning
  - Online imaging
  - Real-time imaging
    - Latency
    - Geometric fidelity
  - **MLC tracking**

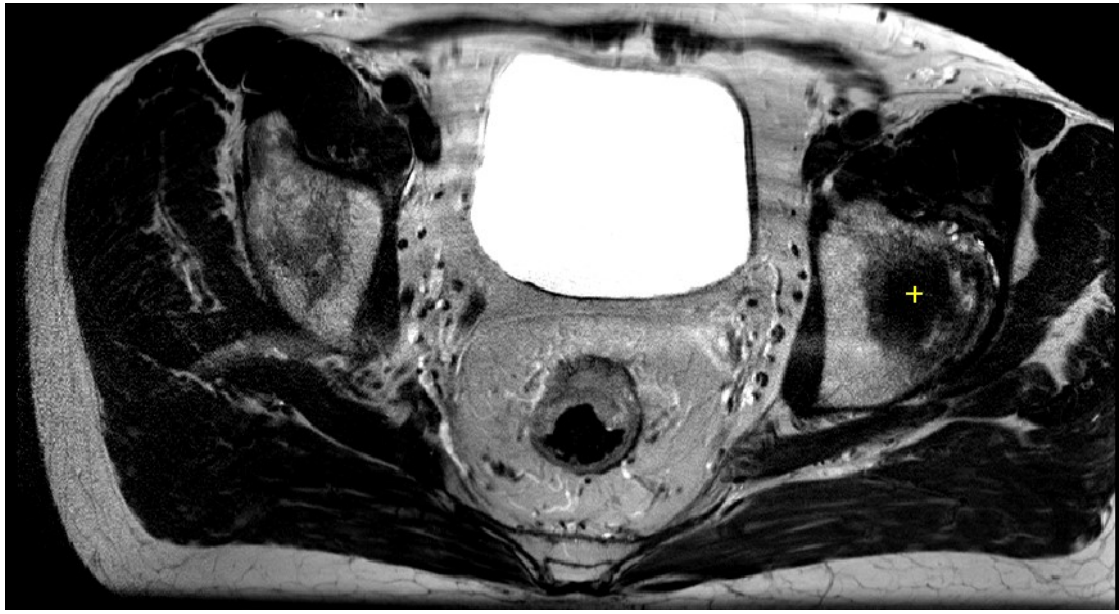
# Why online MRI-guidance?

- Image guidance
  - Solve anatomic uncertainty
  - Reduce the margins!
  - At the moment of radiation
  - With diagnostic image quality

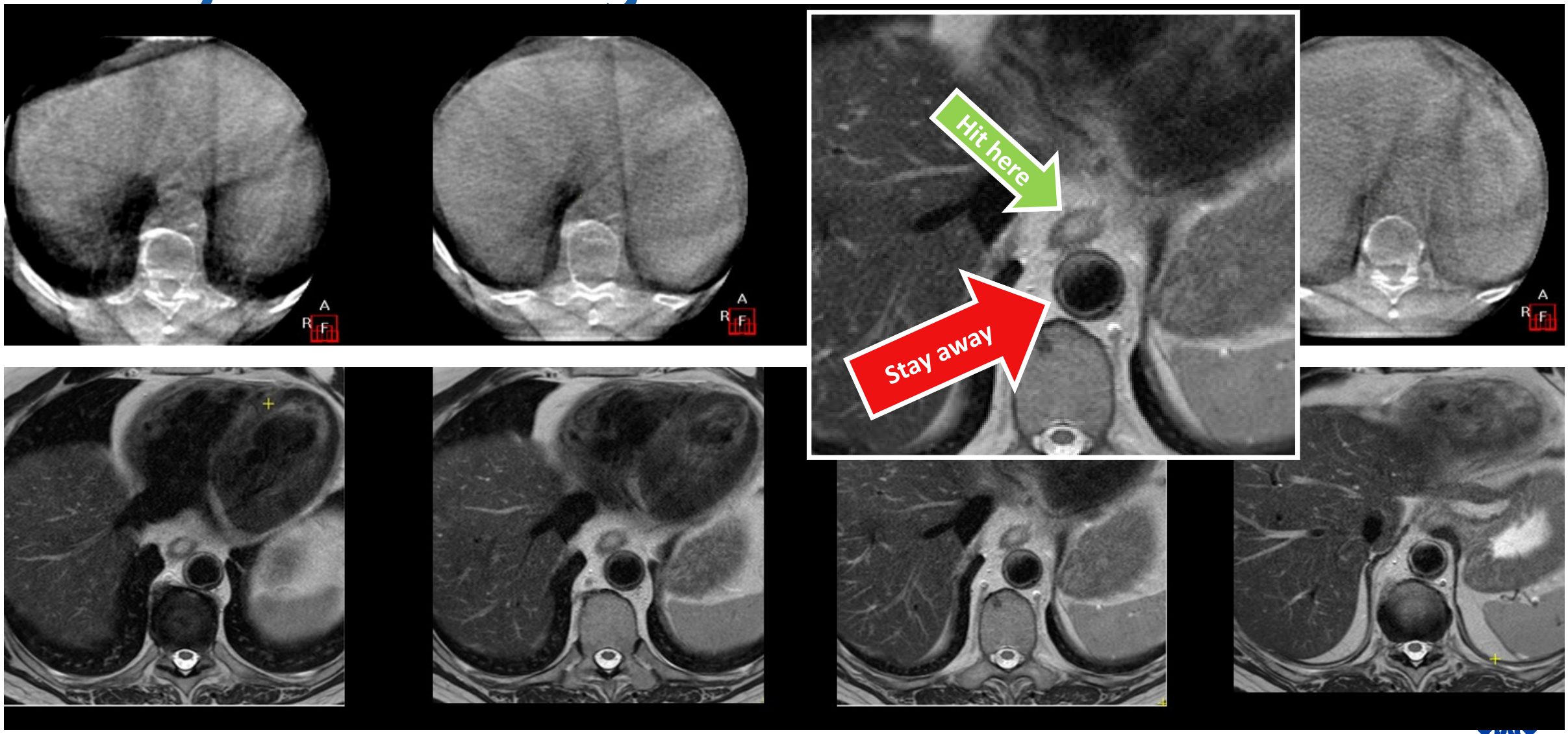


$T_2$ Weighted MRI of rectum, Courtesy Martijn Intven





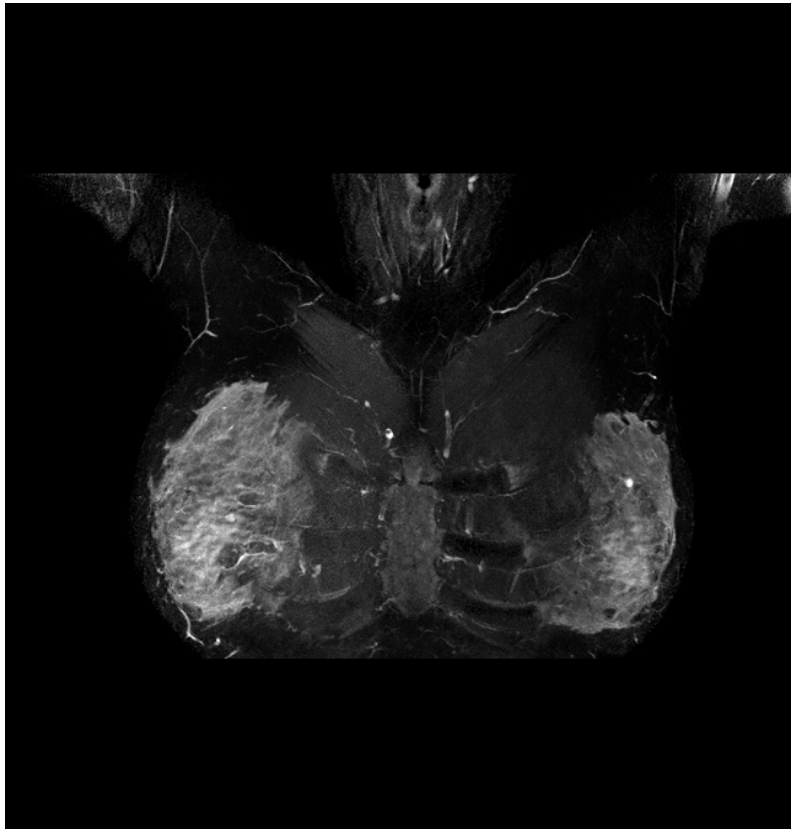
# Why online MRI-guidance?



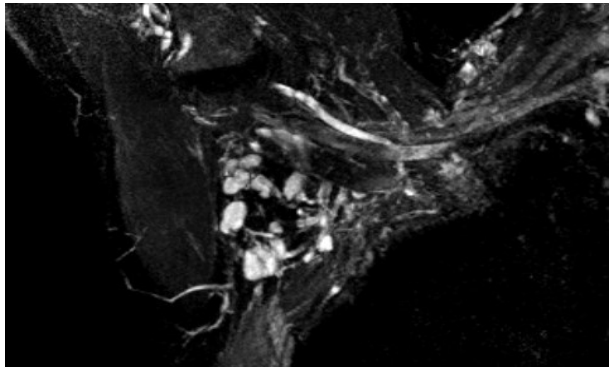

esophageal cancer, courtesy: Gert Meijer

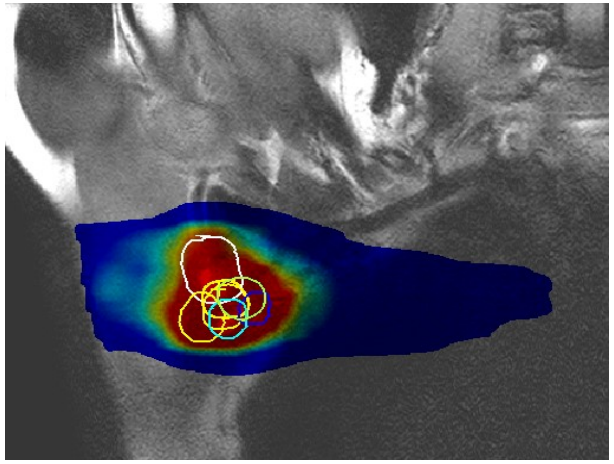
# Why online MRI-guidance?

3D $T_2$-TSE

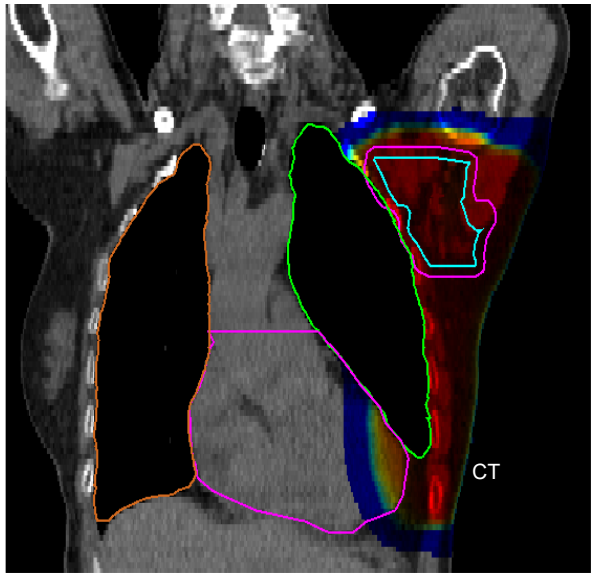


2D $T_2$-TSE





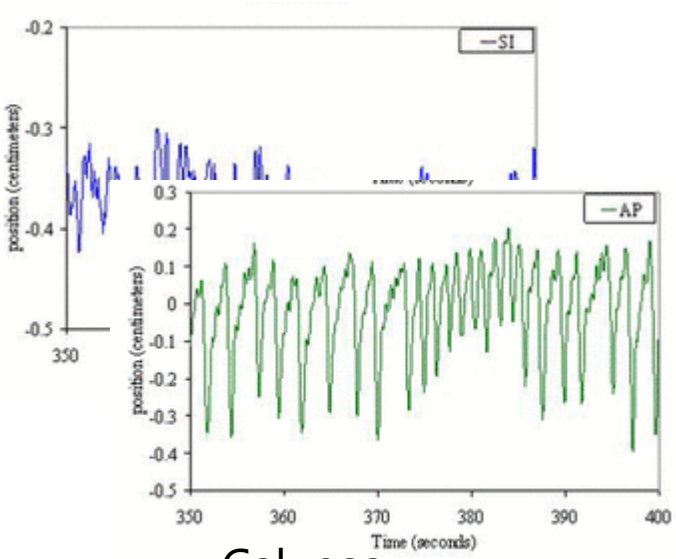
Irradiating individual lymph nodes



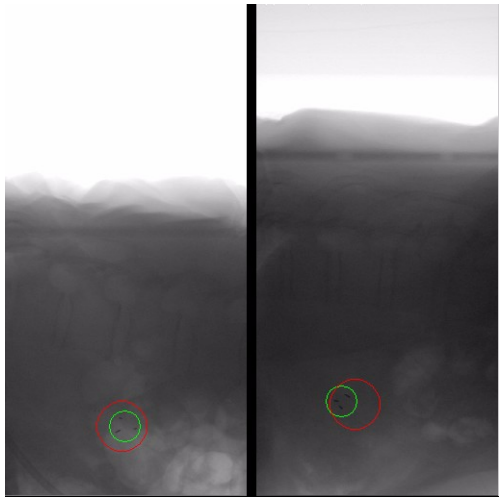

Lymph node visualization, courtesy Tristan van Heijst

# Why online MRI-guidance?

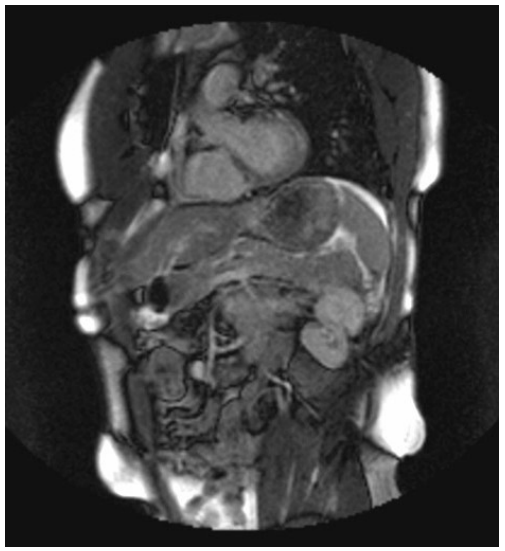
- Solve uncertainty due to motion
  - Resolve and visualize motion
  - Discrimination of target and surroundings
  - Independent of linac position

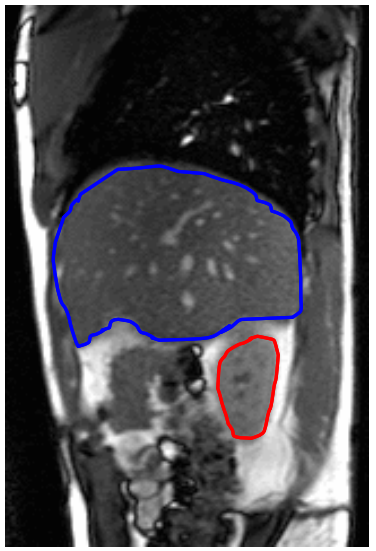



Calypso



Projektionen

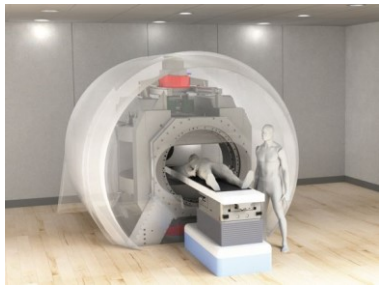


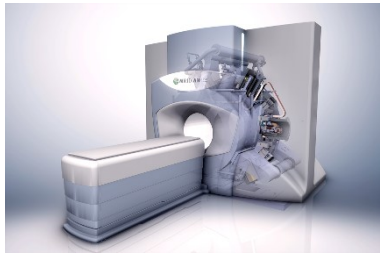


ONLINE MRI

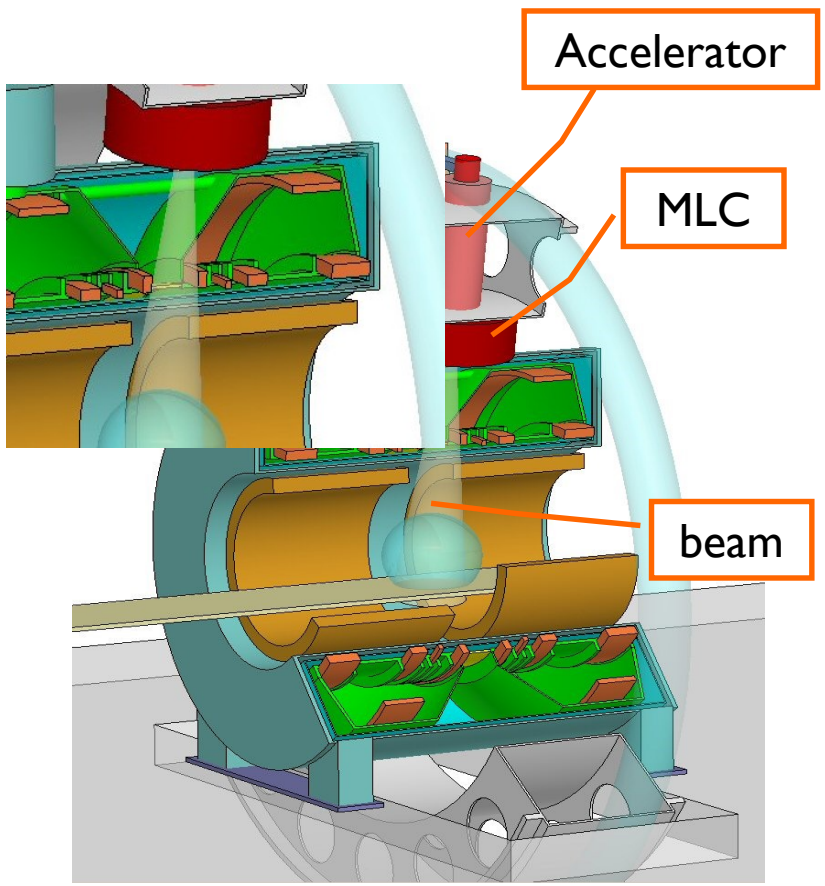
# MRI-guidance research and developments

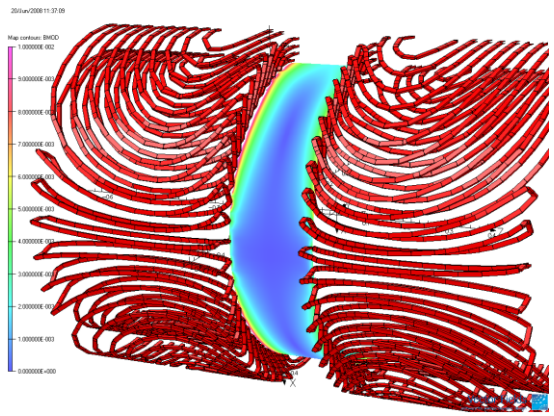
- Utrecht, The Netherlands
  - 1.5 T MRI, 7 MV linac
  - www.elekta.com/mr-linac
- Edmonton, Canada
  - 0.5 T MRI, 6 MV linac
  - www.magnettx.com
- Viewray, Cleveland, USA (www.viewray.com)
  - 0.35 T MRI, 3 Co sources or 6 MV linac (Feb 2014)
  - Clinical since 2014
- Australia MR linac project, Sydney (www.sydney.edu.au)
  - 1.0 T MRI, 6 MV linac

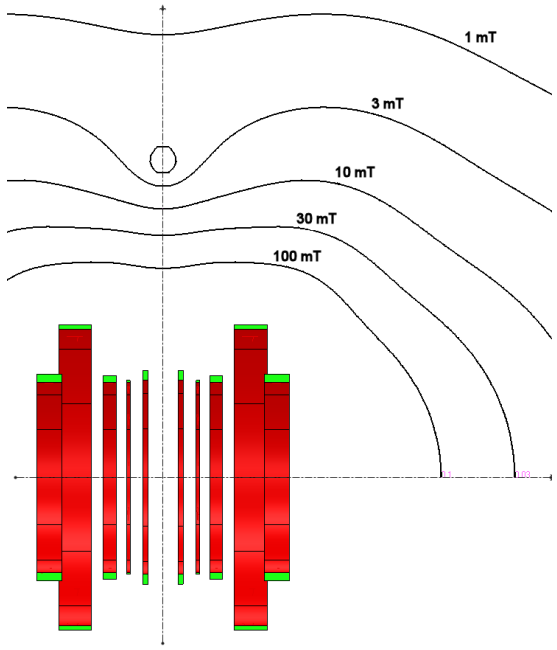




# MRI-linac design at the UMC Utrecht



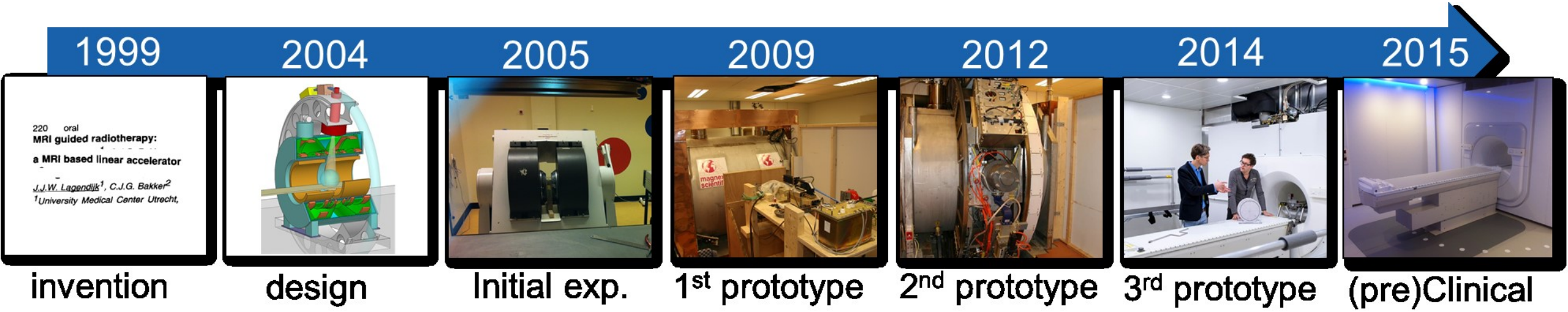



- Bore design
  - High field strength
  - Diagnostic image quality
  - Good field homogeneity
- Radiation transparency
  - Coil gap
  - Uniform gamma attenuation in cryostat
  - Split gradient coil
- Active shielding
  - 0T zone

J Overweg et al 2009 Proc. Intl. Soc. Mag. Reson. Med. 17

# MRI-linac design at the UMC Utrecht


# MRI-linac at the UMC Utrecht




More recent:

- Upgrade to CE-configuration
- Set-to-work
- Finished in July 2018
- First patient in pre-CE state

Lagendijk and Bakker, MRI guided radiotherapy - A MRI based linear accelerator
Radiotherapy and Oncology Volume 56, Supplement 1, September 2000, 220 (ESTRO 19)

# First patient on the MRL: “First in Man”

- Aim:
  - D
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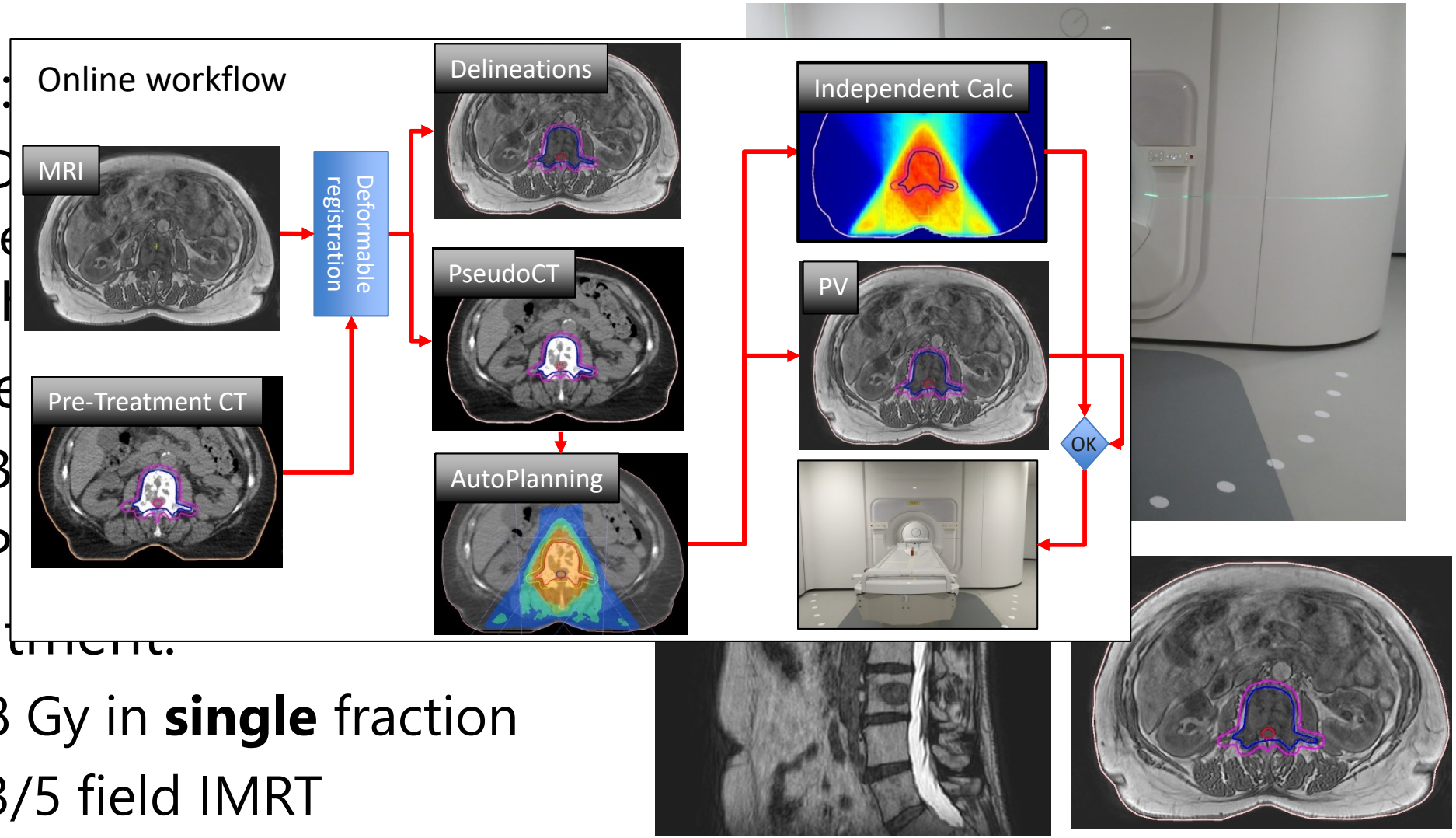
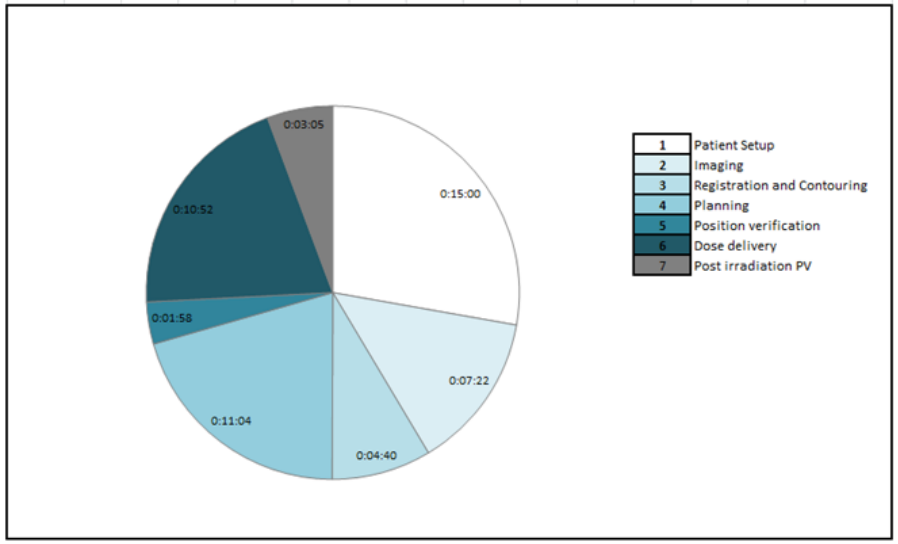
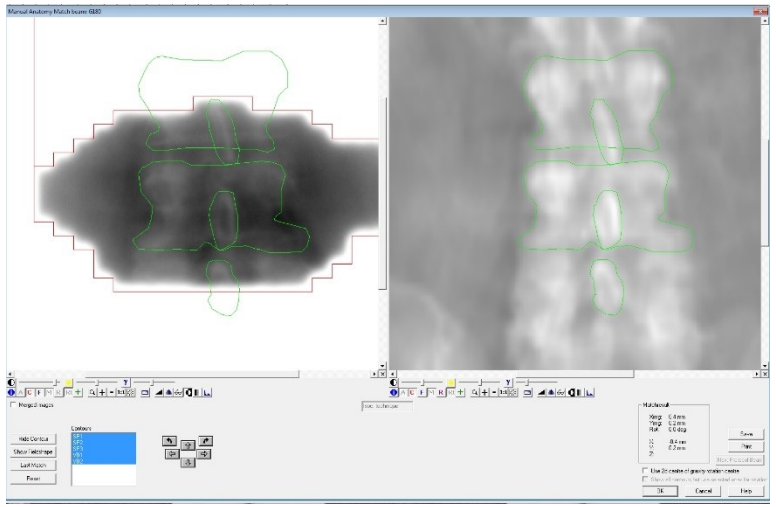
- Patie
  - B
  - P
- Treatment:
  - 8 Gy in **single** fraction
  - 3/5 field IMRT

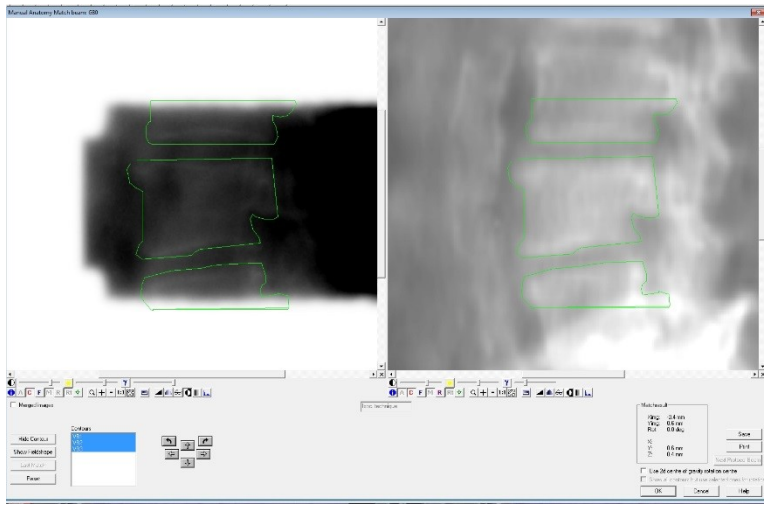



*Raaymakers et al. PMB. 2017;62(23):41-50*

# First in Man: Summary





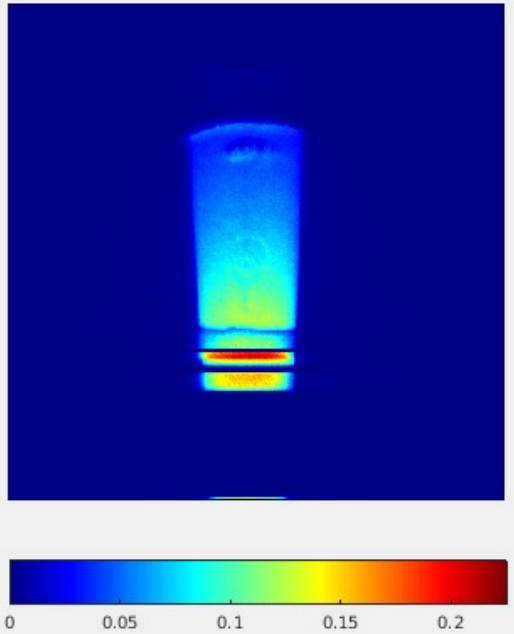
- Total time **54 minutes** for entire procedure
  - 15 min patient set-up
  - 7 min preparation MRI
  - 4 min registration and contour validation
  - 11 min planning
  - 10 min delivery and beam-on MRI

- Bone match using EPID and pseudo CT DRR
- Theraview software
- Displacement vector (3D): 0.3 mm

# First in Man: Dose reconstruction

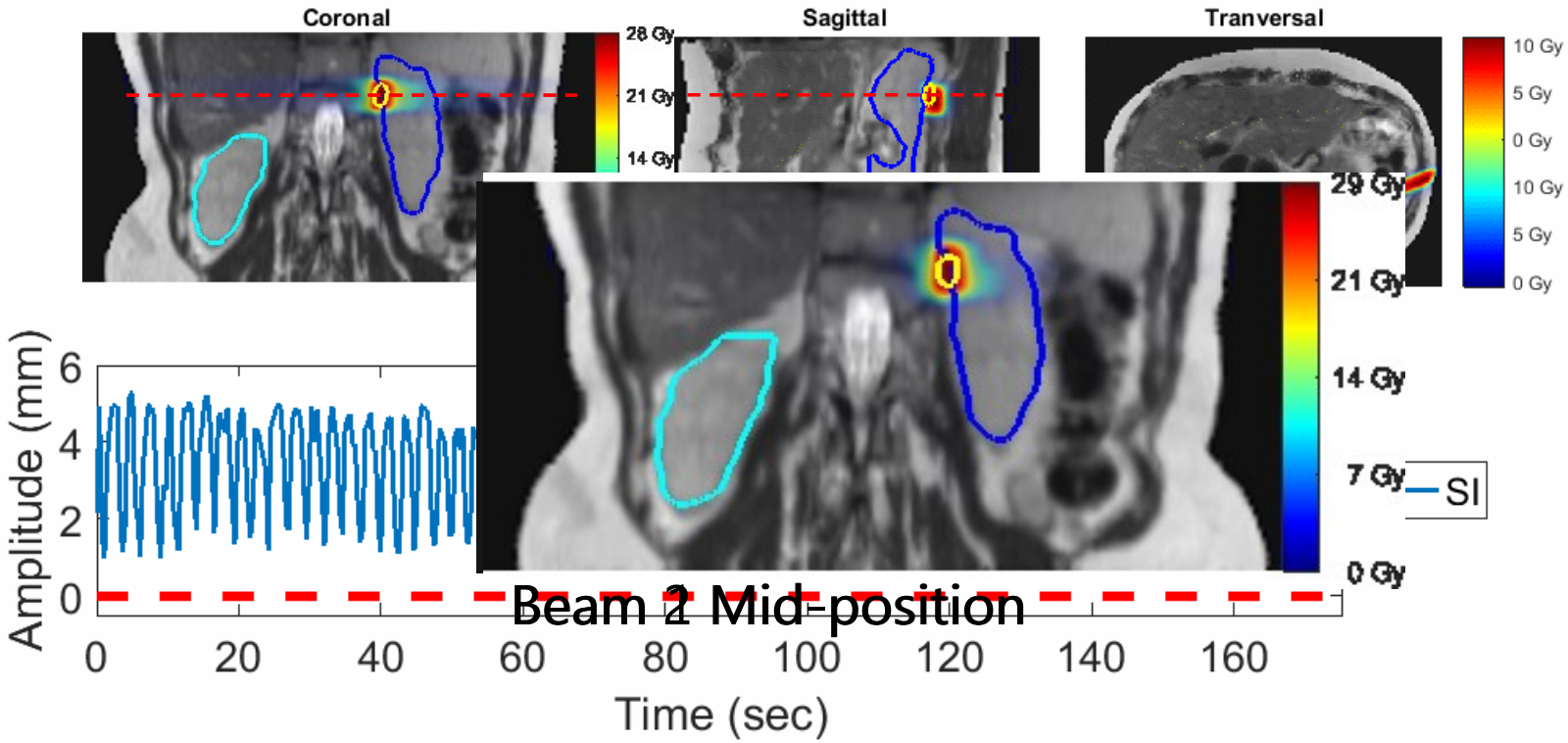
- Independent (geometry, state) 3D MR imager

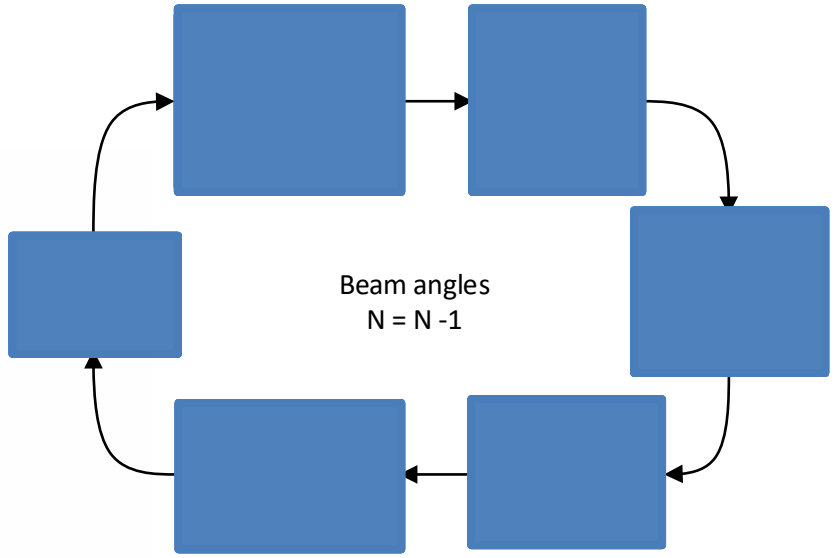
- Time-stamped MRI data + time-stamped linac geometry
- Forward dose calculation
- First live dose reconstruction
- Dose validation

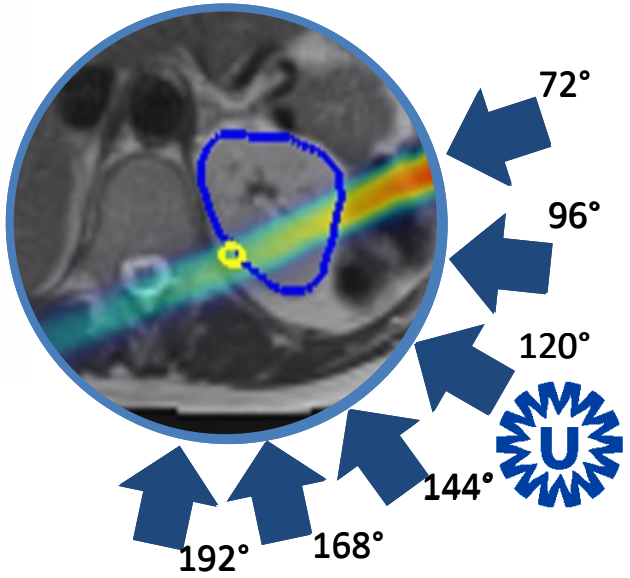



M Glitzner *et al* 2015 *Phys. Med. Biol.* **60** 8869

# Research: Adaptive replanning per beam

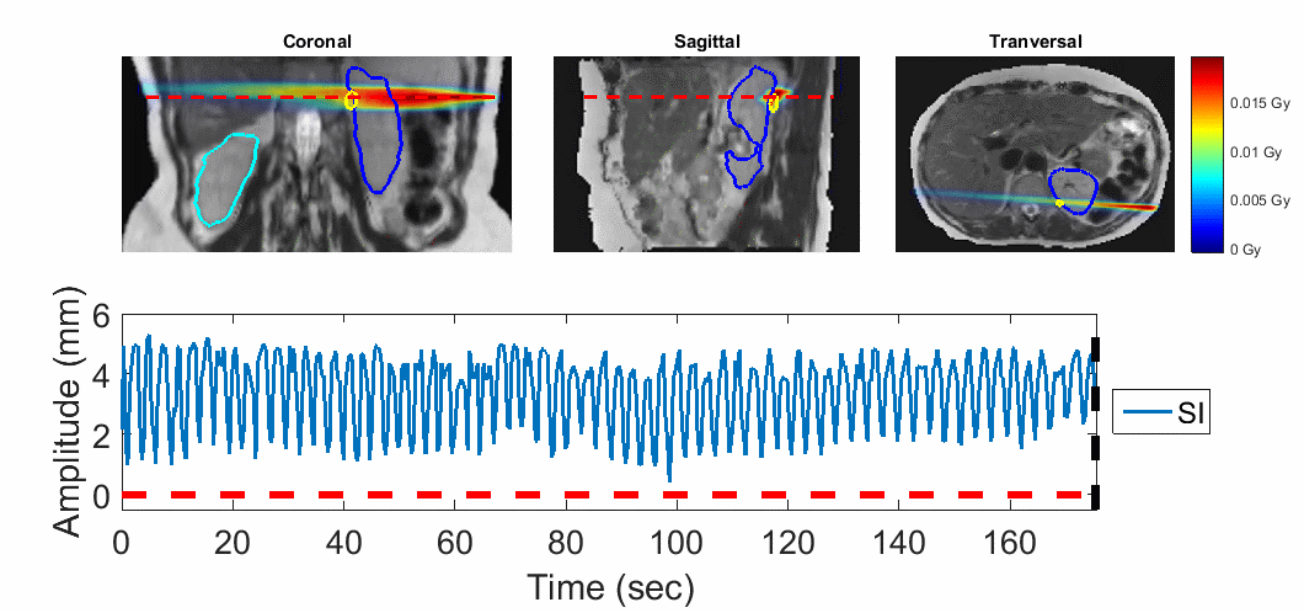


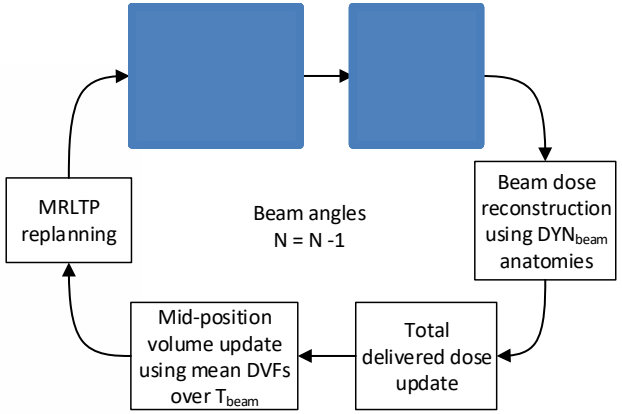



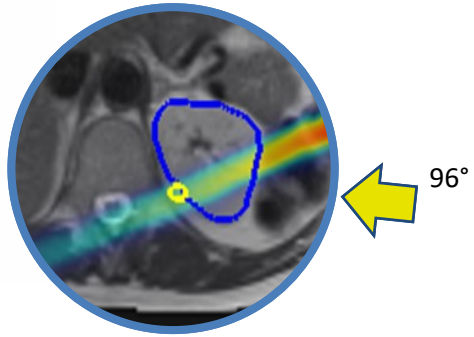




Kontaxis et. al 2017 PMB 62 7233

# Inter-beam replanning regime

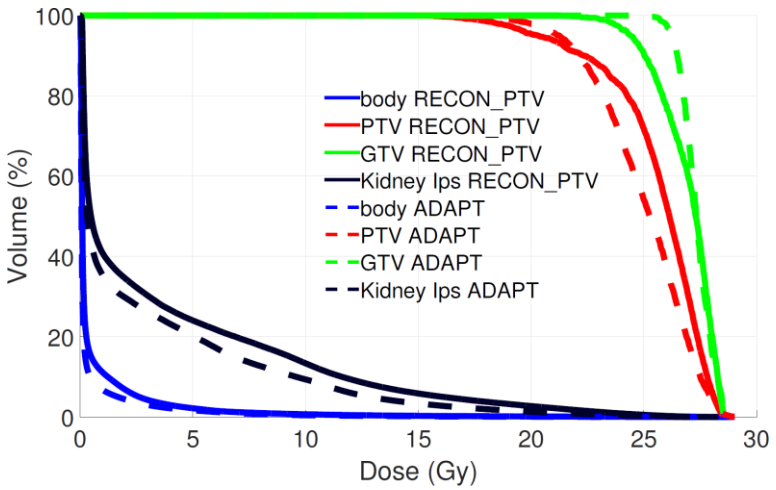


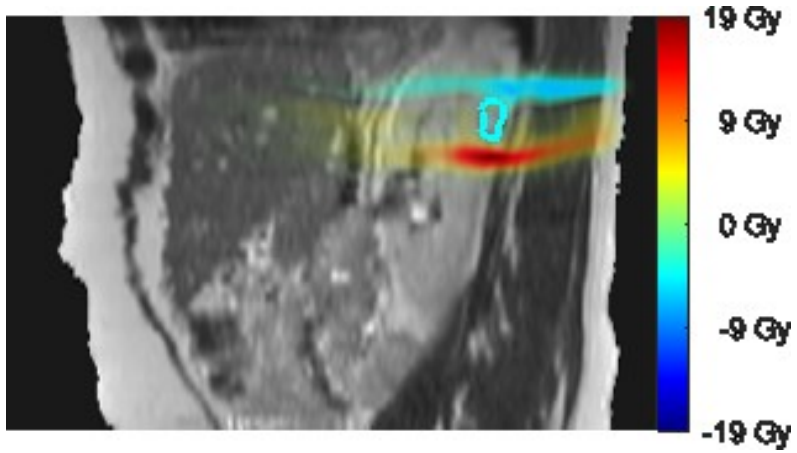



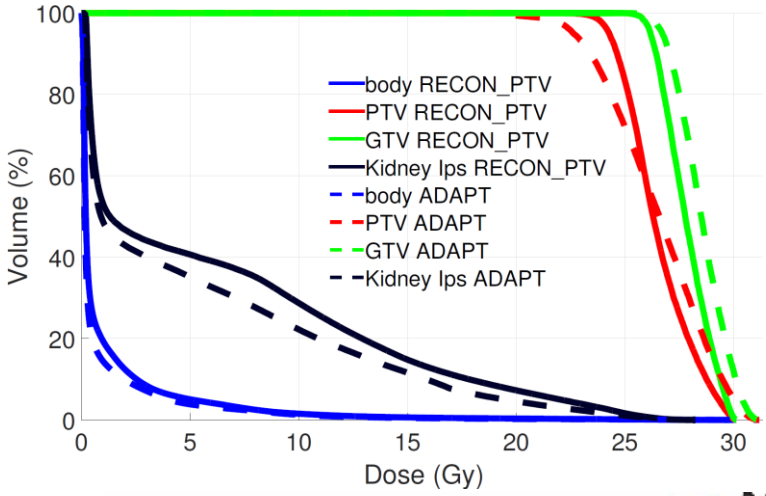

Kontaxis et al. PMB 2017

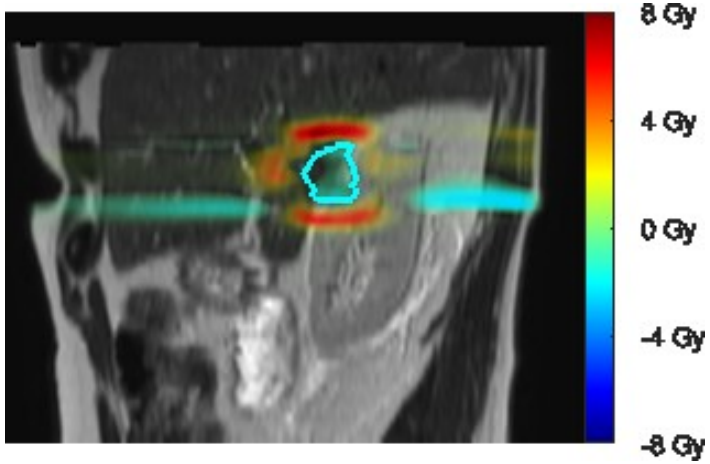
# Baseline drift correction and margin reduction




Recon_PTV - Adaptive



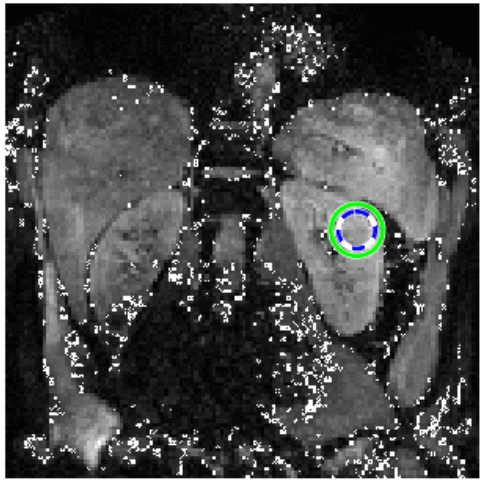

Recon_PTV - Adaptive

Kontaxis et. al 2017 PMB 62 7233

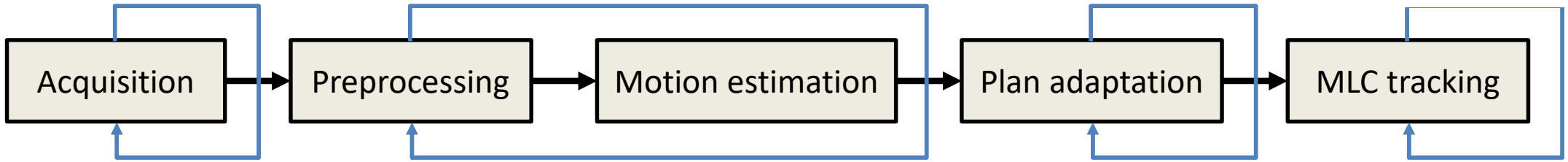
# MR-linac therapy guidance: real time, MRI-guided MLC-tracking

- Response (tracking) quality
  - Image fidelity
    - geometric accuracy
    - Target/OAR
    - Surrogate
  - Temporal quality
    - **real-time**

# MR-linac therapy guidance: real time, MRI-guided MLC-tracking

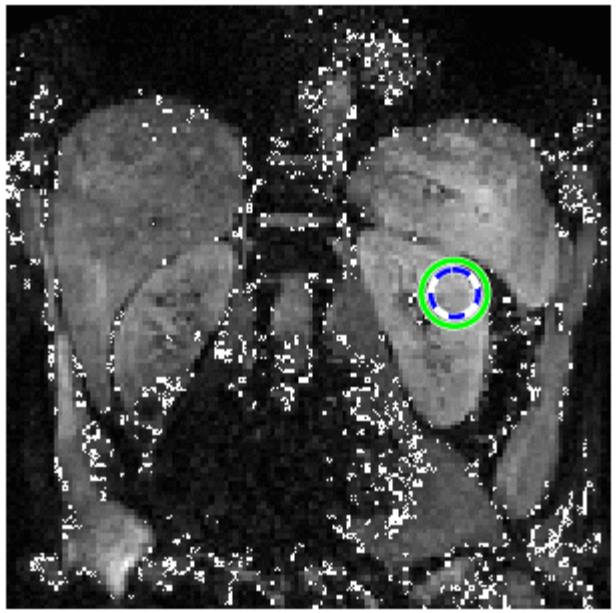


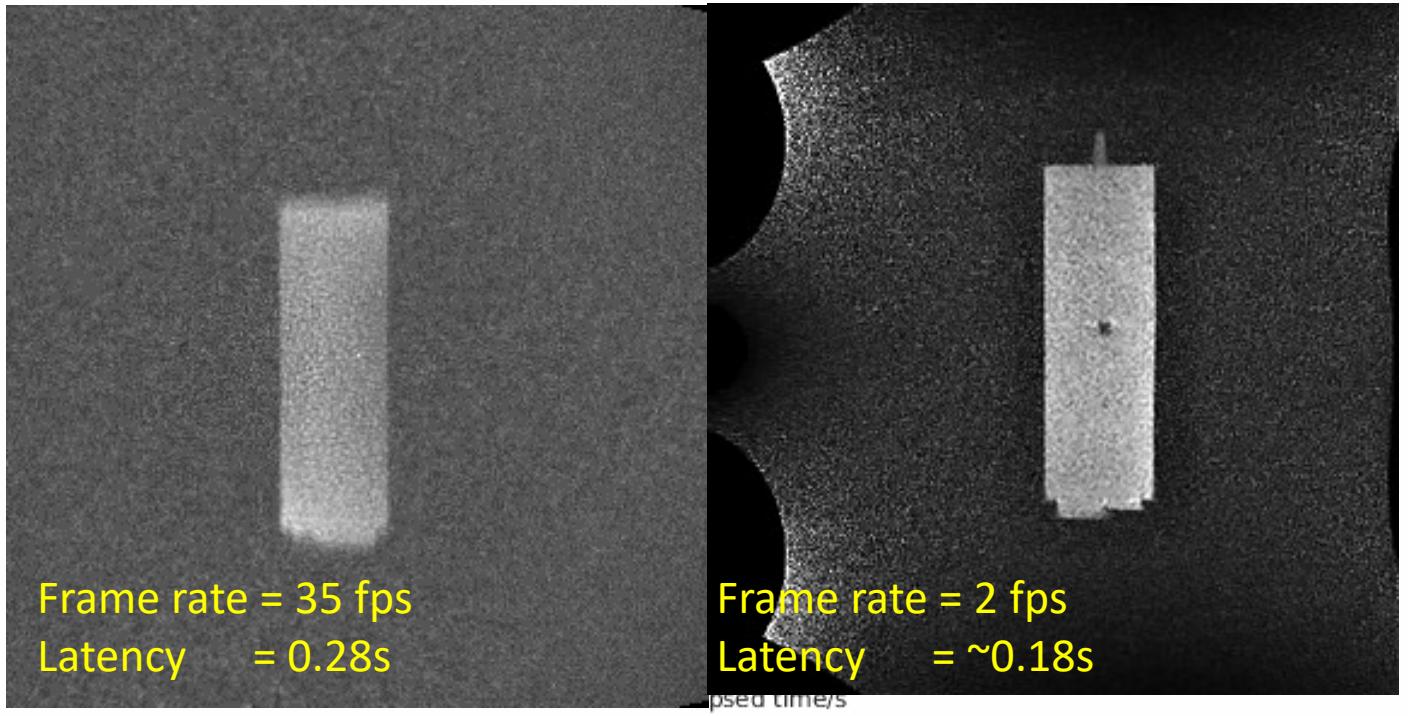
- A typical day of an real-time MRI-linac system
  - Take an image (⌛)
  - Process the image (⌛)
  - Estimate motion in the image (⌛)
  - Process motion into a suitable adaptation (⌛) (segment shift)
  - Apply adaptation as long as it is suitable (⌛)
  - Be done fast and start all over …



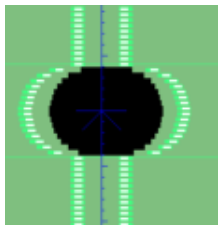
# MR-linac therapy guidance: Imaging latency

Object in MRI
physical object






Physical motion → MRI → Image → Framerate, Latency → Apply tracking position → Update rate, Latency



# MRI-latency: How long does the image acquisition take…

- ‘Normal sensors’ Integration time + readout

- Special sensors, i.e. DSLR

- MRI sensors

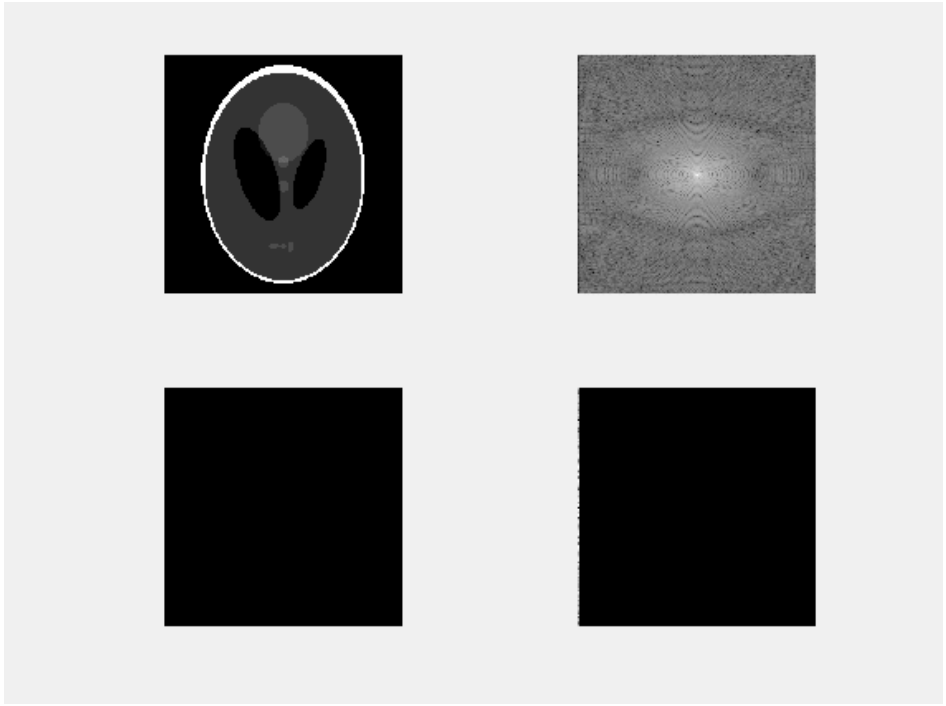
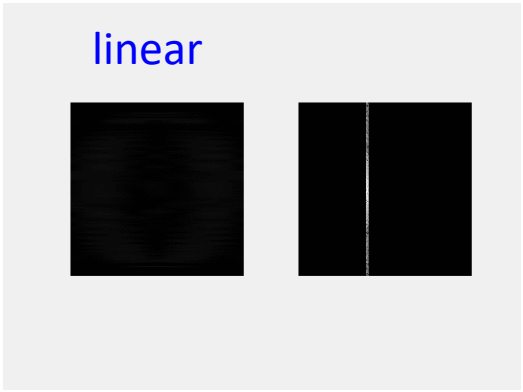


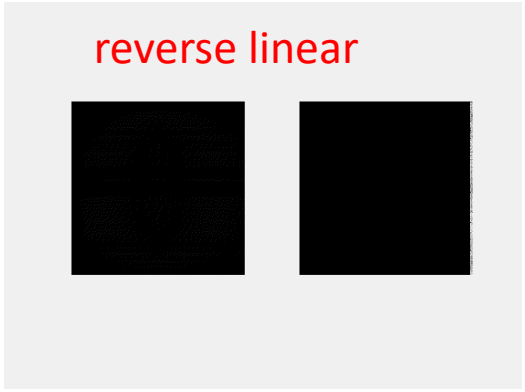
Image source: https://www.premiumbeat.com/blog/3-tips-for-dealing-with-rolling-shutter/

WHERE and WHEN is my image formation

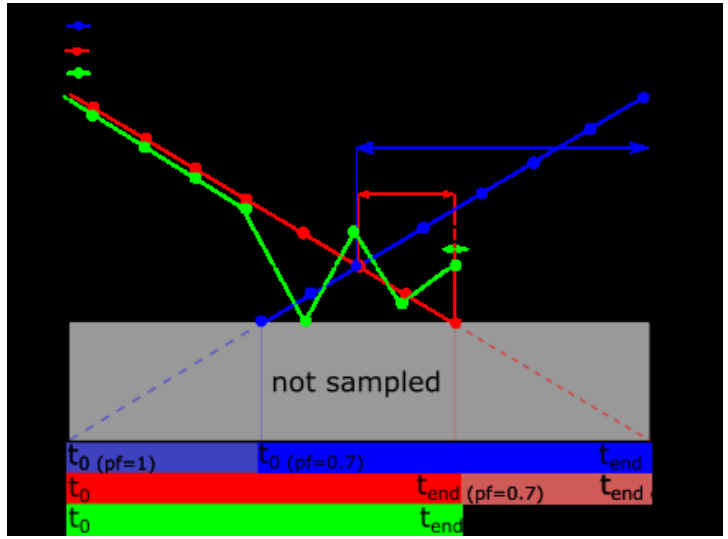
# MRI latency analysis

- Hypothesis: High sensitivity of k-space-based read-out to trajectory





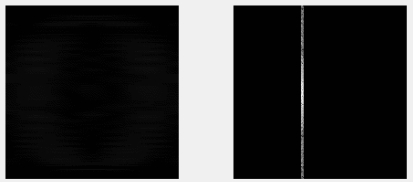



- Acceleration using partial sampling/partial *Fourier*

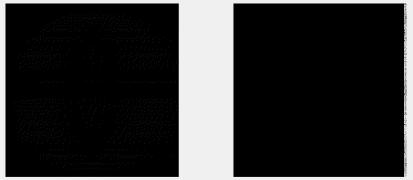
*P. Borman et al., in revision*

# MRI latency analysis: Cartesian results

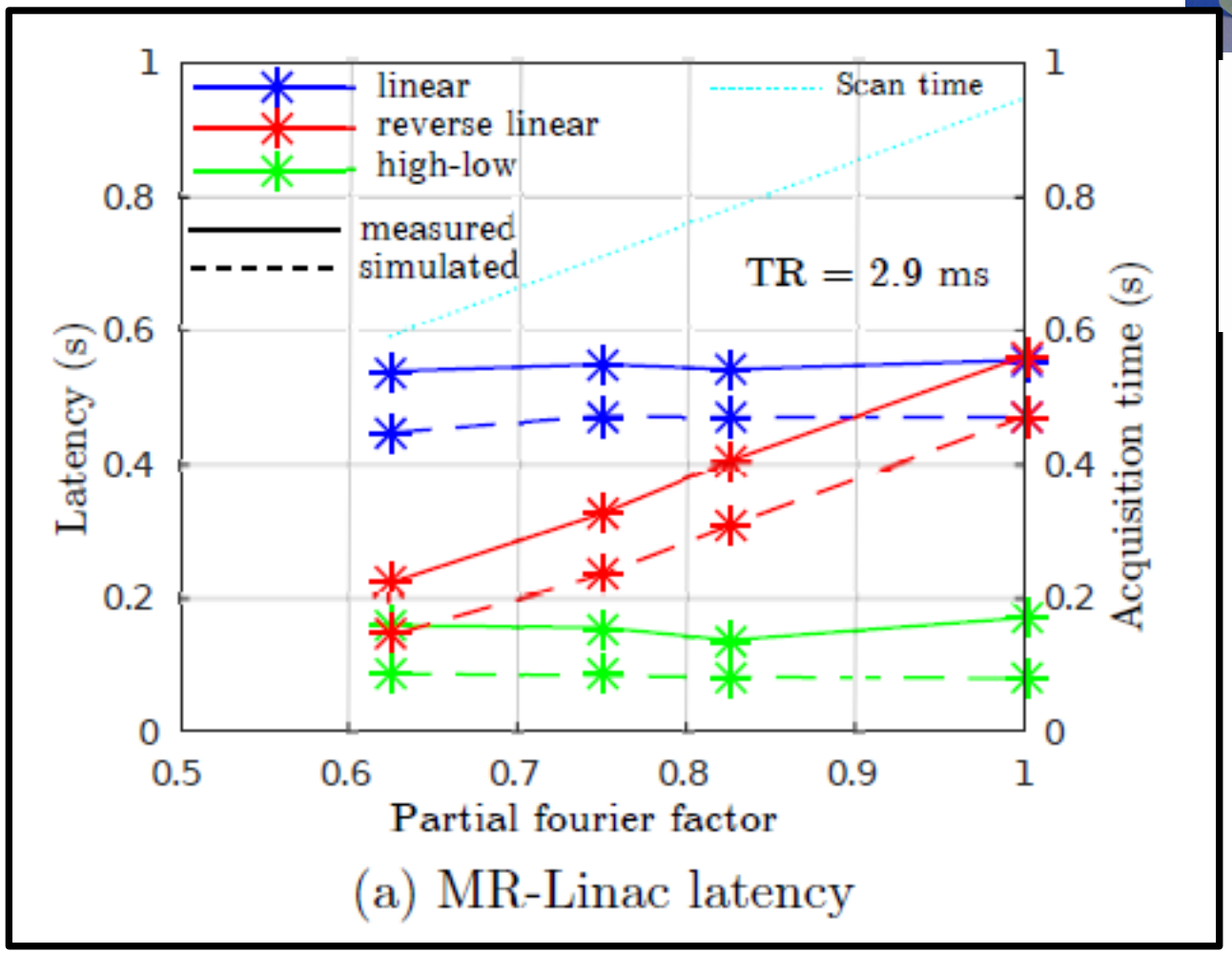
linear



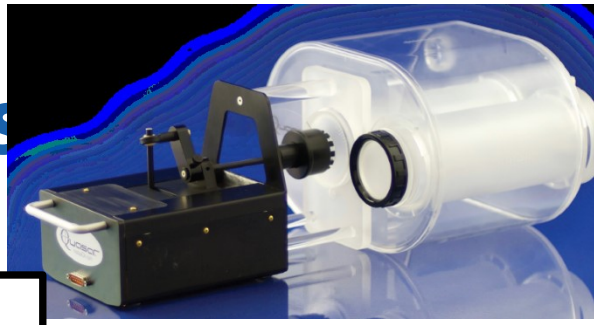
reverse linear

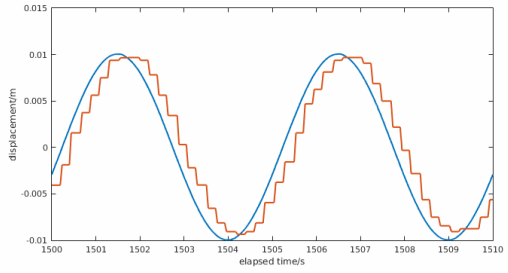


high-low

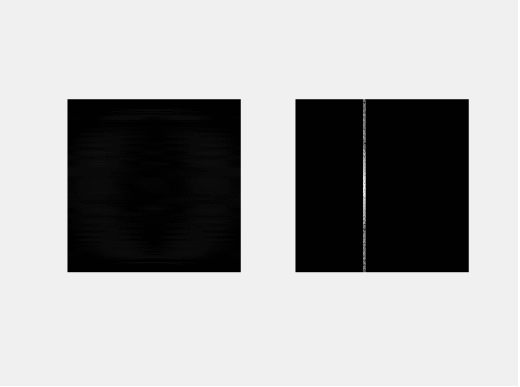


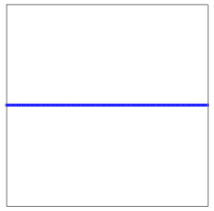
(a) MR-Linac latency



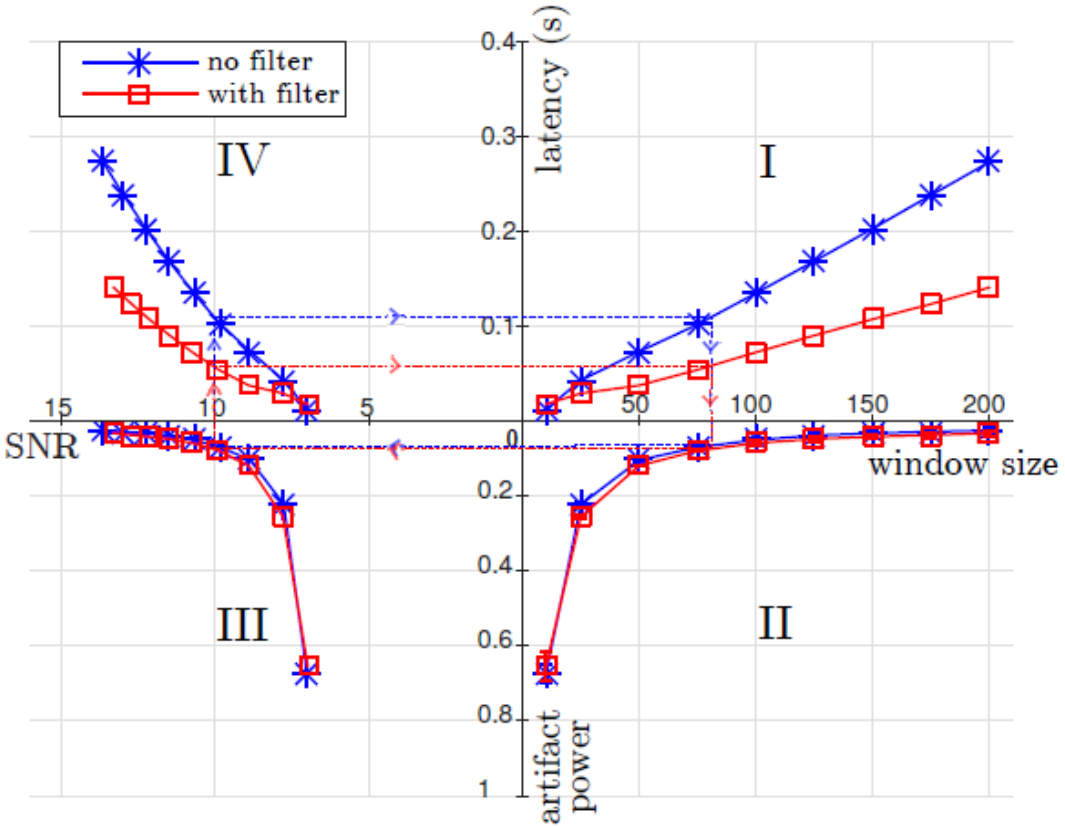


# MRI latency analysis con'd: Radial results

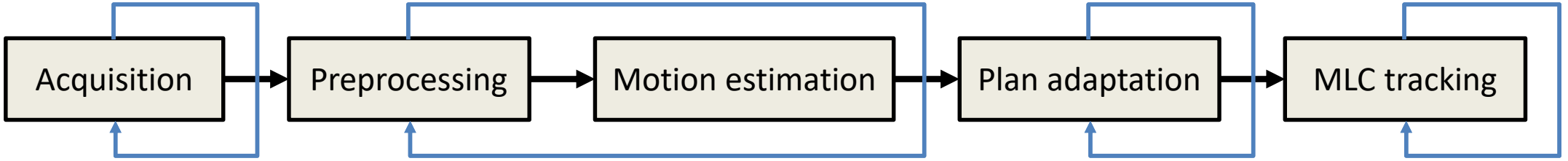




- Generally, $\Delta T = t_{acquisition}/2$
- Golden angle sampling:
  - Temporal weighting filter penalizes importance of "old spokes"
  - Signal processing can reduce latency about 50%, $T = t_{acquisition}/4$

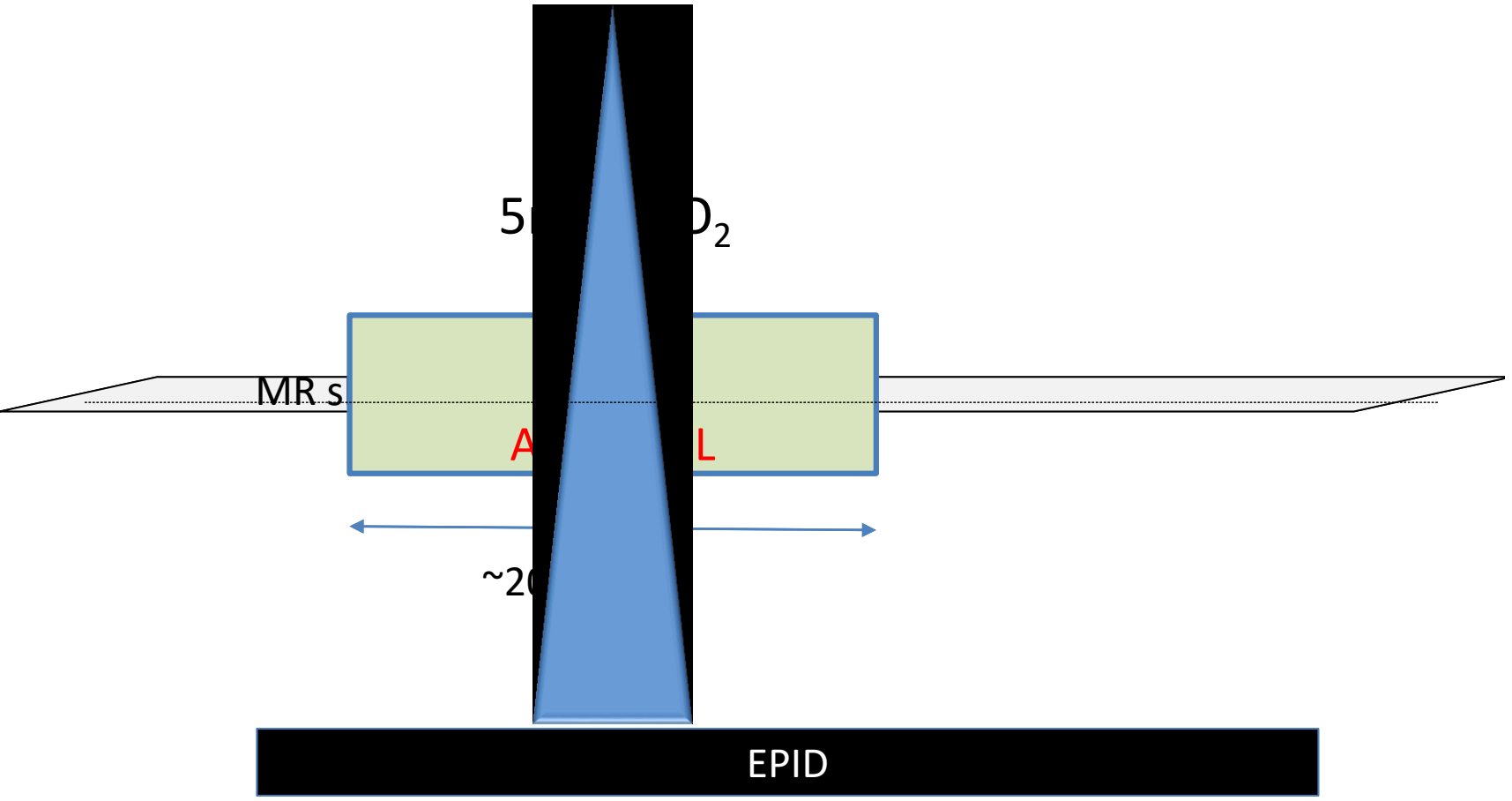


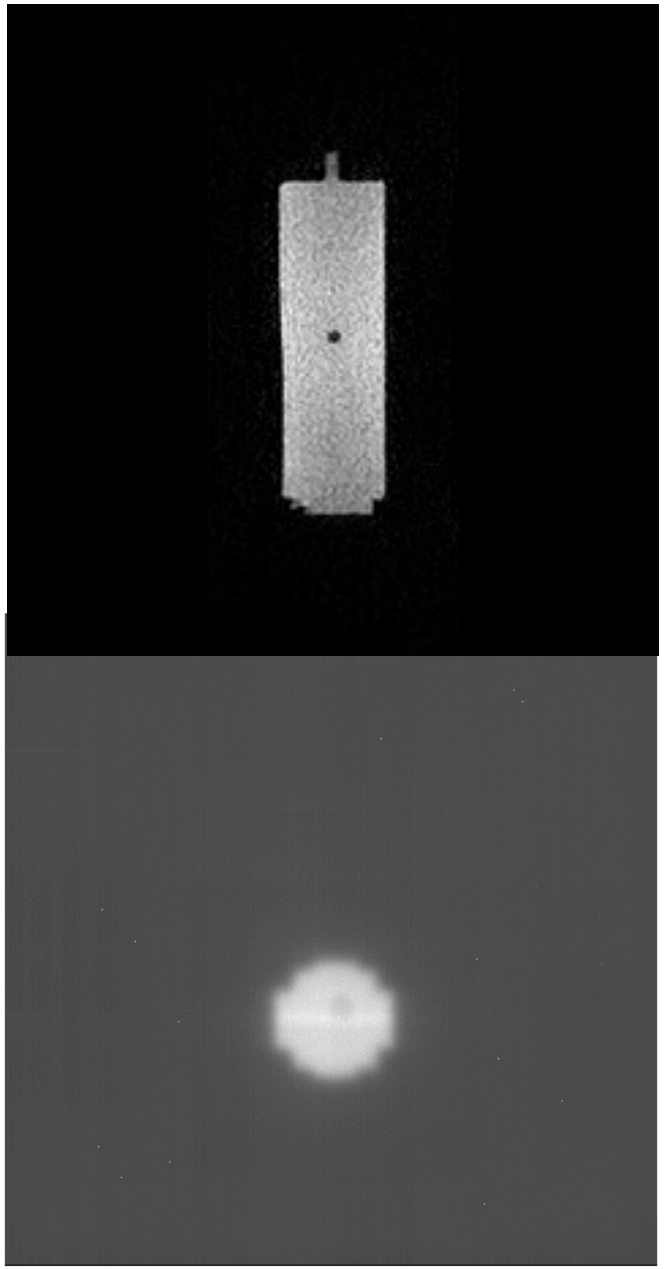
# Latency summary



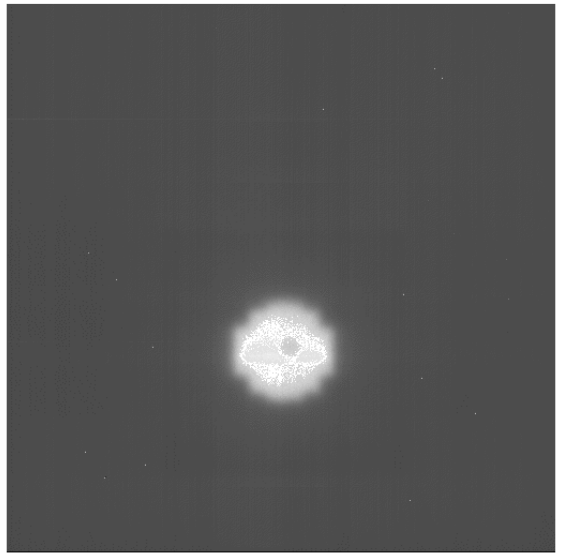

- Runtime estimation
  - Acquisition: 180ms – 550ms + image age!
  - Preprocessing + motion estimation: ~80ms
  - Plan adaptation (simple tracking, gating): 5ms
  - MLC tracking: ~30ms

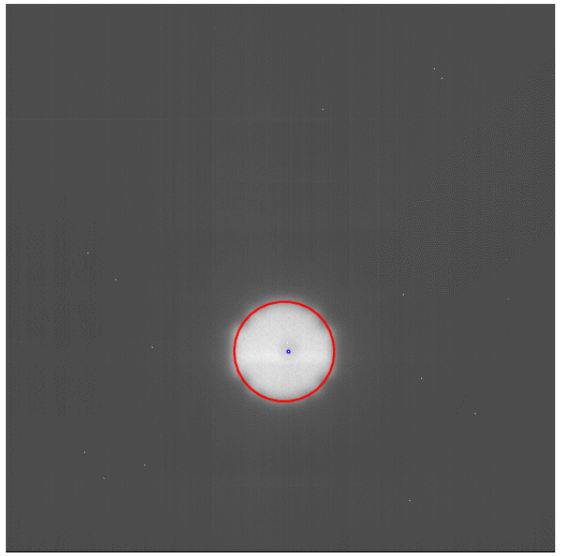
# The proof of the pudding: MLC tracking on the MRI linac

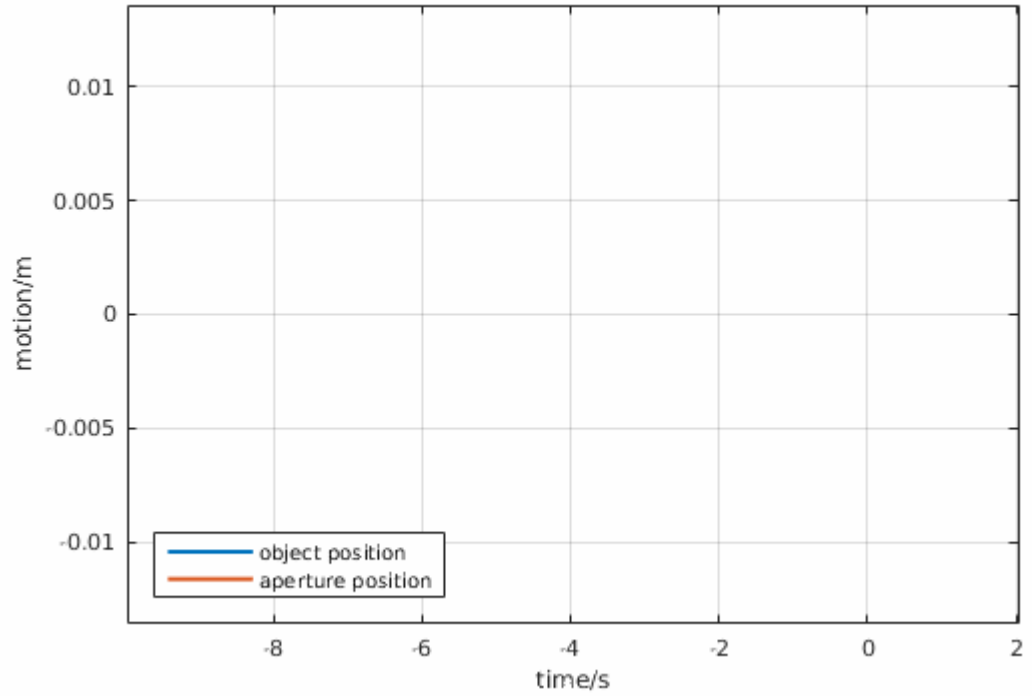


# **Experiments:** MRI-guided position feedback








| Estimated latency | 10Hz | 41.94 |
|---|---|---|
| | 5Hz | 127.11 |

# MRI-guidance at UMC Utrecht

- Prototype phase finished
  - Clinical proof of concept
  - Beam & plan QA
- CE clearance in due time (July 2018)
- Strong research line
  - Real-time imaging and MLC tracking
  - Adaptive replanning
- See what you treat