IMAGE GUIDANCE AND REGISTRATION – PARTICULAR CHALLENGES IN CASE OF RE-IRRADIATION

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CONFLICTS OF INTEREST

- Financial and technical support from Elekta AB under research agreements

- NKI-AvL is part of the Elekta Atlantic MR-linac Research Consortium

https://mrrt.elekta.com/

OUTLINE

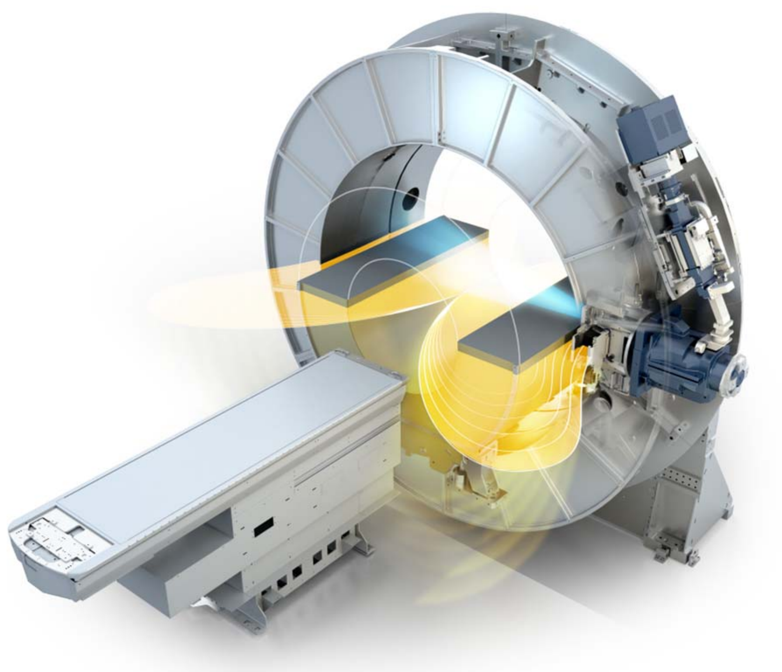
THE FUTURE IS NOW – MRI-GUIDED RADIOTHERAPY

THE WORKING HORSE – CBCT-GUIDED RADIOTHERAPY

DOSE ACCUMULATION – READY FOR CLINICAL USE?

IMAGE REGISTRATION – CHALLENGES AND OPPORTUNITIES

ELEKTA UNITY MR-LINAC



- 1.5 T Philips magnet
- 7 MV linac
- 22x56 cm2 treatment field
- Real-time cine-MR imaging
- MLC based on Agility design

Photo courtesy: Elekta AB

ELEKTA UNITY MR-LINAC AT NKI-AVL

INSTALLATION

- May 2016

INITIAL RESEARCH PHASE

- Phantom measurements
- Volunteer imaging
- Patient volunteer imaging

FINAL UPGRADE

- June-August 2018

Elekta Unity
Celebrating **CE mark**

ELEKTA UNITY MR-LINAC AT NKI-AVL

First patient treated TODAY
(September 6th, 2018)

MR-LINAC AT NKI

Clinical focus

- Prostate cancer
- Rectal cancer
- *Oligometastases (especially liver)*

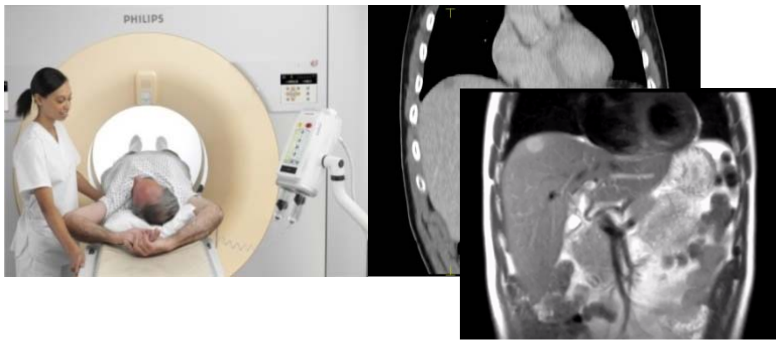
Technical focus

- EPID dosimetry
- *Practical 4D solutions*
- Quantitative imaging

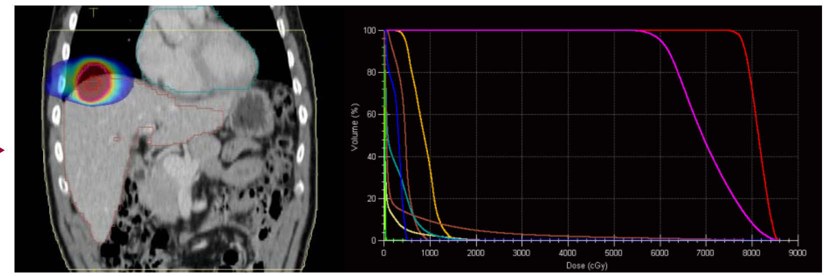
NKI'S LIVER RT WORKFLOW FOR THE MR-LINAC

PRE-TREATMENT IMAGING

4D-CT + 4D-MRI



TREATMENT PLANNING



DAILY IMAGING

4D-MRI

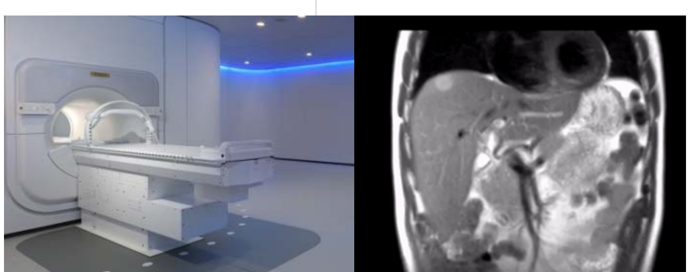
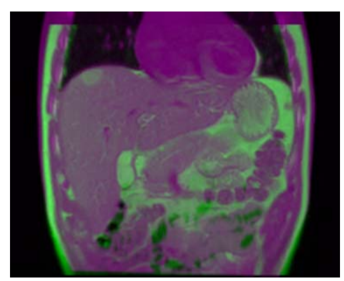


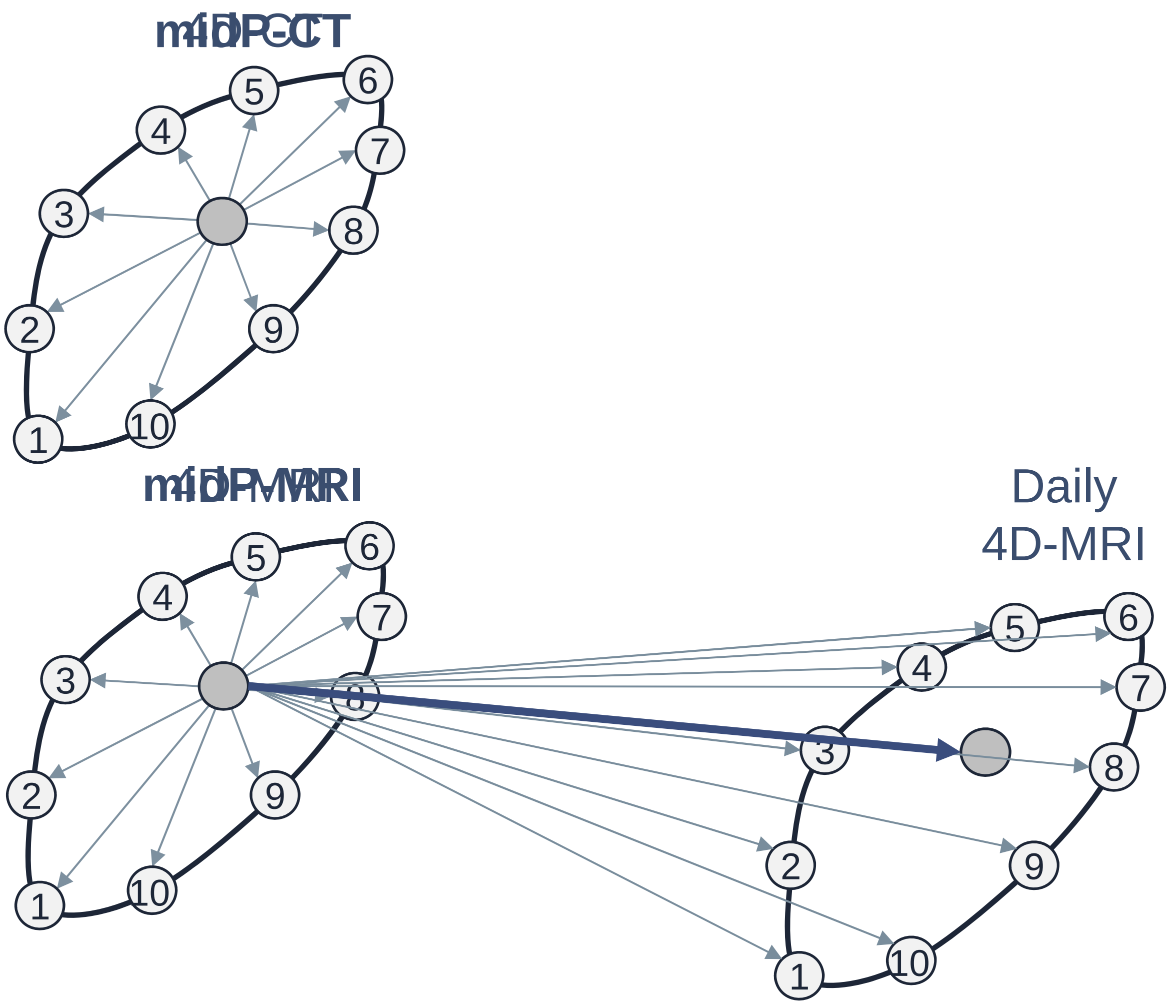
IMAGE REGISTRATION & PLAN ADAPTATION



TREATMENT DELIVERY

MID-POSITION STRATEGY ON THE MR-LINAC

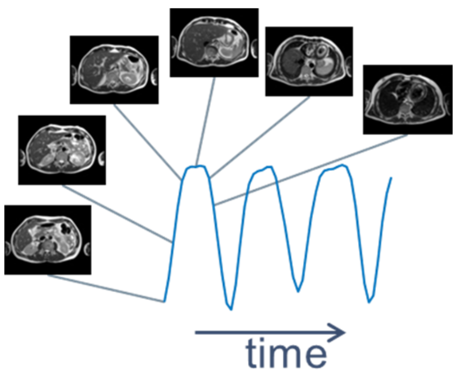
Simulation	Pre-beam

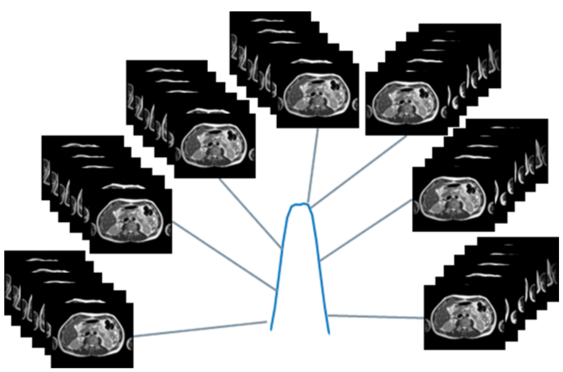


Simple Dose Shift

SELF-GATED 4D-MRI

2D SEQUENCE





DATA ACQUISITION

Data from arbitrary respiratory phases

↓

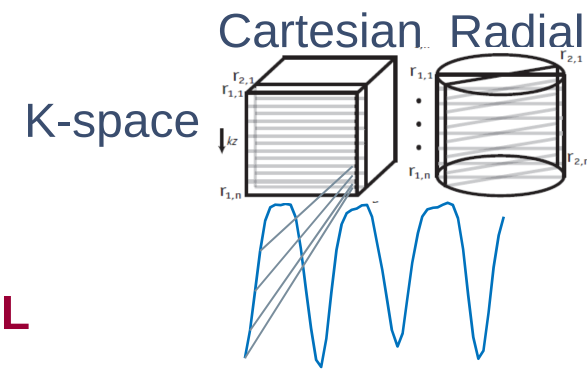
RESPIRATORY SIGNAL

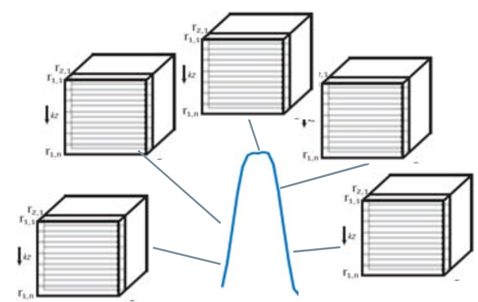
↓

DATA SORTING

To amplitude or phase

3D SEQUENCE



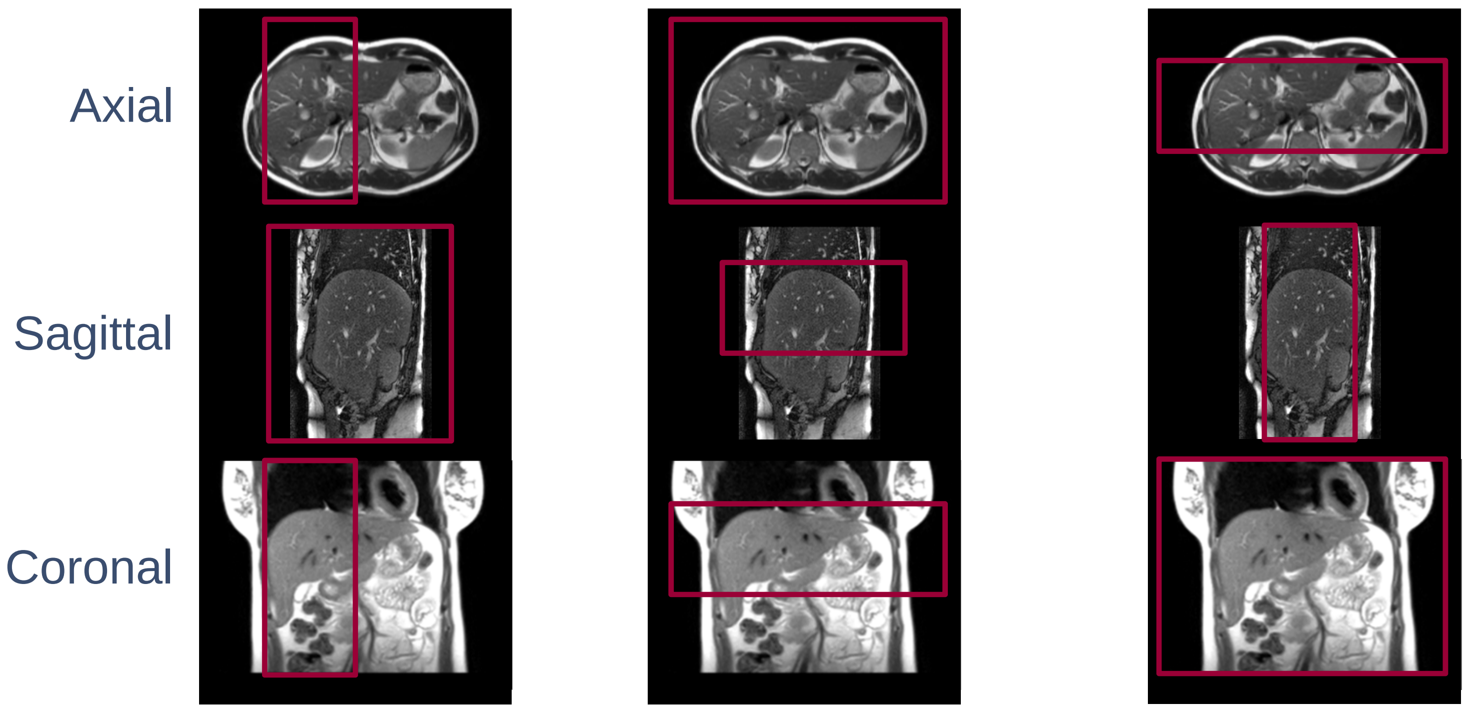


4D-MRI ACQUISITION: 2D VS 3D

Acquisition	2D	3D
SNR (spatial resolution)	-	+
Acquisition / reconstruction time	~minutes (3-15min)	<minute ~hours / dedicated reconstruction server
Pulse sequences	Standard	Tailored
Contrasts	T1 or T2 - weighted	T1-weighted

2D-BASED 4D-MRI

2D Orientation	Sagittal	Axial	Coronal
CC-motion	In-plane	Out-of-plane	In-plane
FOV coverage / acquisition time	-	+	+



FOV: 25 slices of 5mm, Acq time: ~4min

AXIAL/CORONAL 4D-MRI

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4D-MRI

Retrospective self-sorted 4D-MRI for the liver

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Respiratory motion
4D-MRI
MRI-guidance
Liver
MR-Linac
Self-gating

A B S T R A C T

Purpose: Daily MRI-guidance
this study was to develop a 4
reconstruction time <5 min,
Materials and Methods: Ima
sequence, repeated a variabl
the data by computing corr
phases and missing data wer
unteers. The SsS, image quali
assessed as a function of th
with liver metastasis on the
Results: SsS was in good ag
0.4 ± 0.6% to 37.1 ± 6.6% for
The RMSD of quantified m
>10 dynamics.
Conclusion: For 30 dynamics
in the validation experiment

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Clinical Investigation

A Self-Sorting Coronal 4D-MRI Method for Daily Image Guidance of Liver Lesions on an MR-LINAC

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RESULTS: SELF-SORTING SIGNAL ANALYSIS

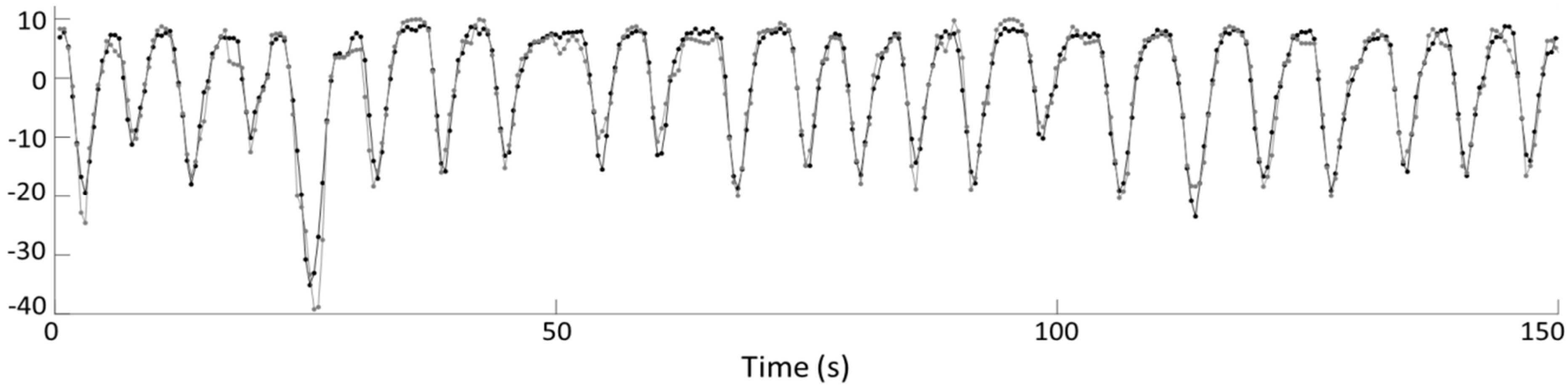
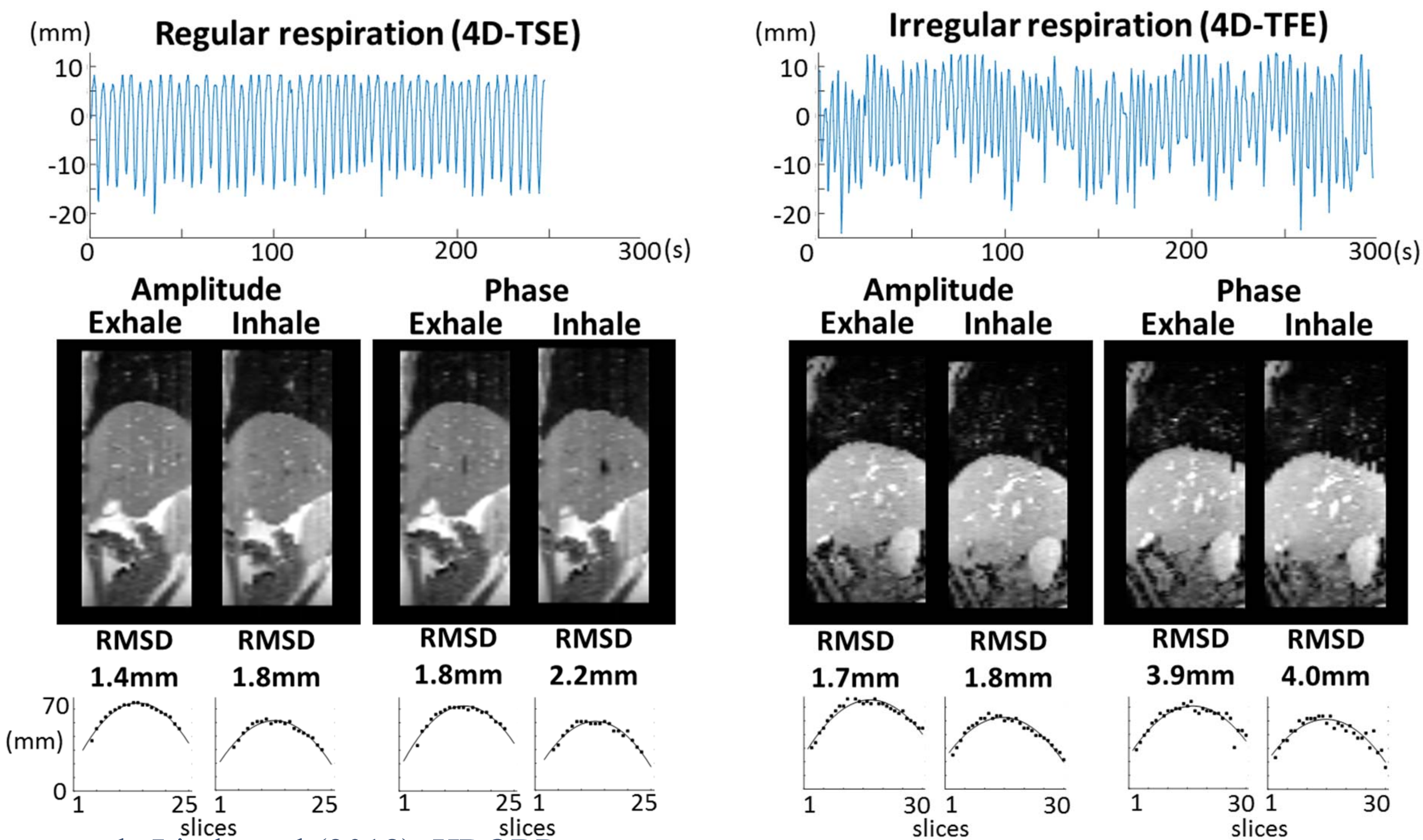


Table1: Image-based self-sorting signal vs navigator signal results

ImS vs NavS		
Correlation	0.95 – 0.97	(range)
RMSD (mm)	1.39 – 2.13	(range)
Time difference inhale positons (s)	0.06 ± 0.13	(mean ± SD)
Bin difference for amplitude-binning	0.41 ± 0.64	(mean ± SD)
Bin difference for phase-binning	0.23 ± 0.47	(mean ± SD)

van de Lindt et al (2018), IJROBP

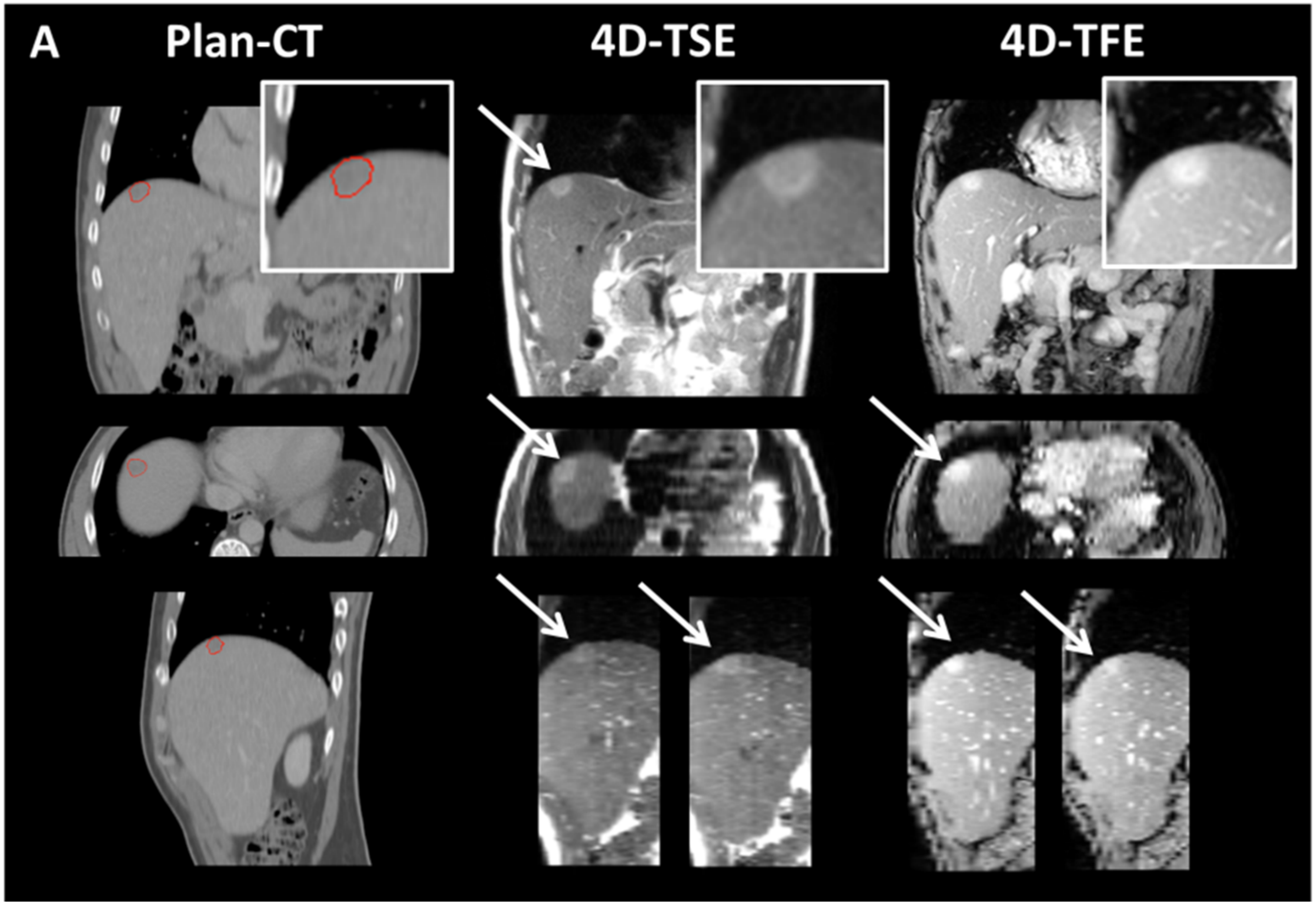
RESULTS: AMPLITUDE VS PHASE SORTING



van de Lindt et al (2018), IJROBP

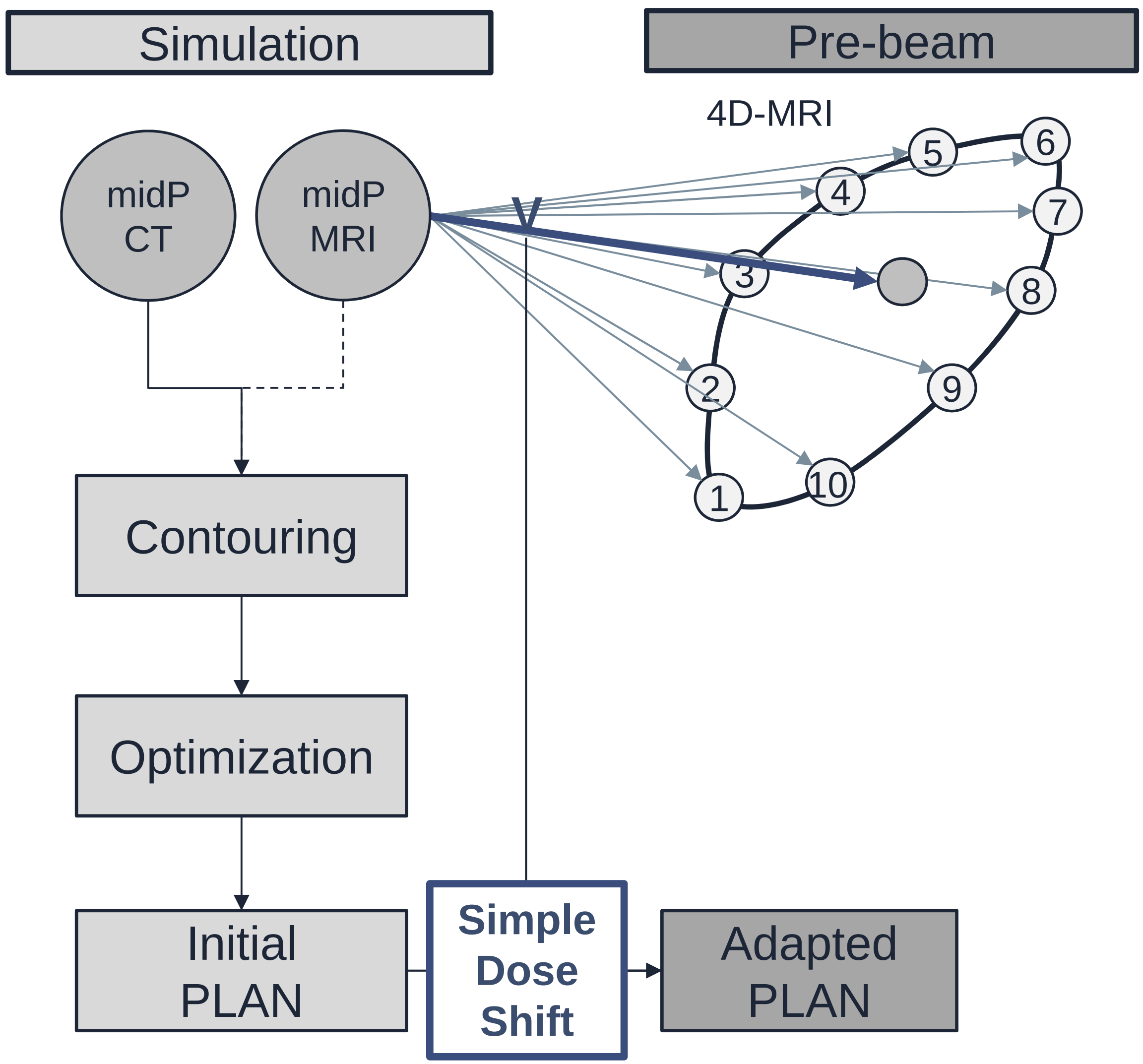
RESULTS: TUMOR VISIBILITY

Lesion: 15mm



van de Lindt et al (2018), IJROBP

MR-LINAC: DAILY PLAN ADAPTATION IS A MUST



MATERIALS & METHODS: EXPERIMENTAL VALIDATION

4D-MRI[1]

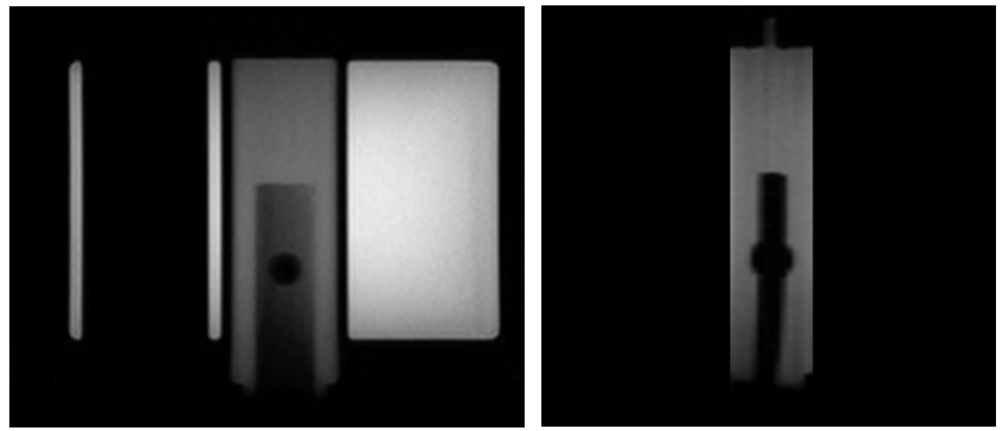
- Unity MR-Linac
- Coronal multi-2D TSE

TREATMENT PLANNING

- Monaco v5.19
- 10-beam step-and-shoot IMRT
- 3x20 Gy

PHANTOM MOTION

- Periodic CC motion
  - A =15 mm
  - T=4 s
- CC baseline shifts
  - 0, 5, 10 and 15 mm



[1] *TN van de Lindt et al., IJROBP., 2018*

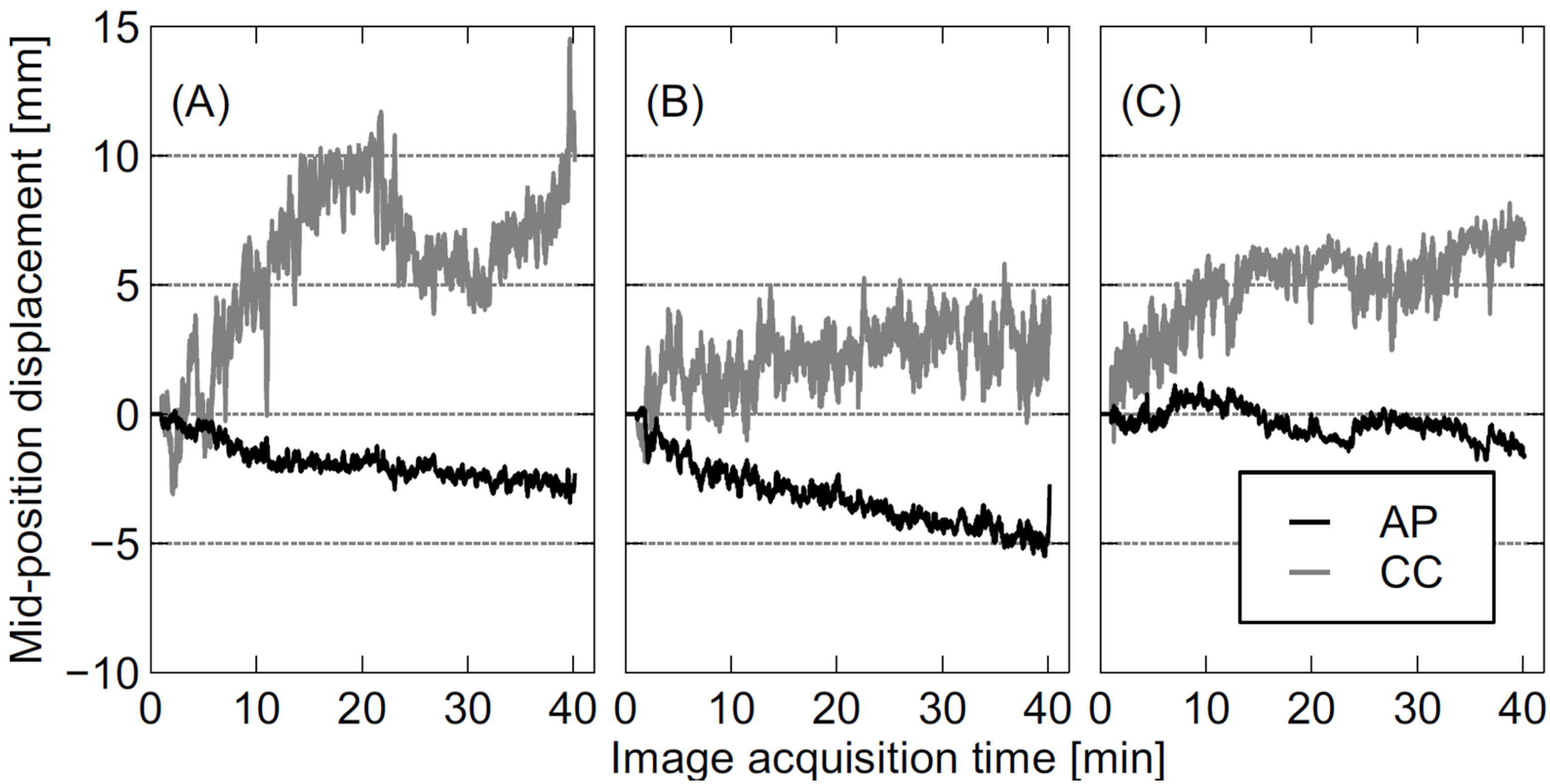
RESULTS

GEOMETRIC AND DOSIMETRIC RESULTS

	EPID		MRI	Film	
Baseline shift (mm)	MidP (mm)	Cine (mm)	4D (mm)	Residual CC-shift (mm)	γ pass rate (%)
5	5.0	5.3	3.8	1.6 – 1.8	86 – 91
10	9.8	10.6	10.0	0.2 – 0.8	97 – 99
15	15.0	15.5	14.3	-0.1 – 0.8	93 – 99
Δ Mean±SD	0.1±0.1	-0.5±0.1	0.6±0.6	0.8±0.8	94±5

Gamma analysis: 3%/2mm

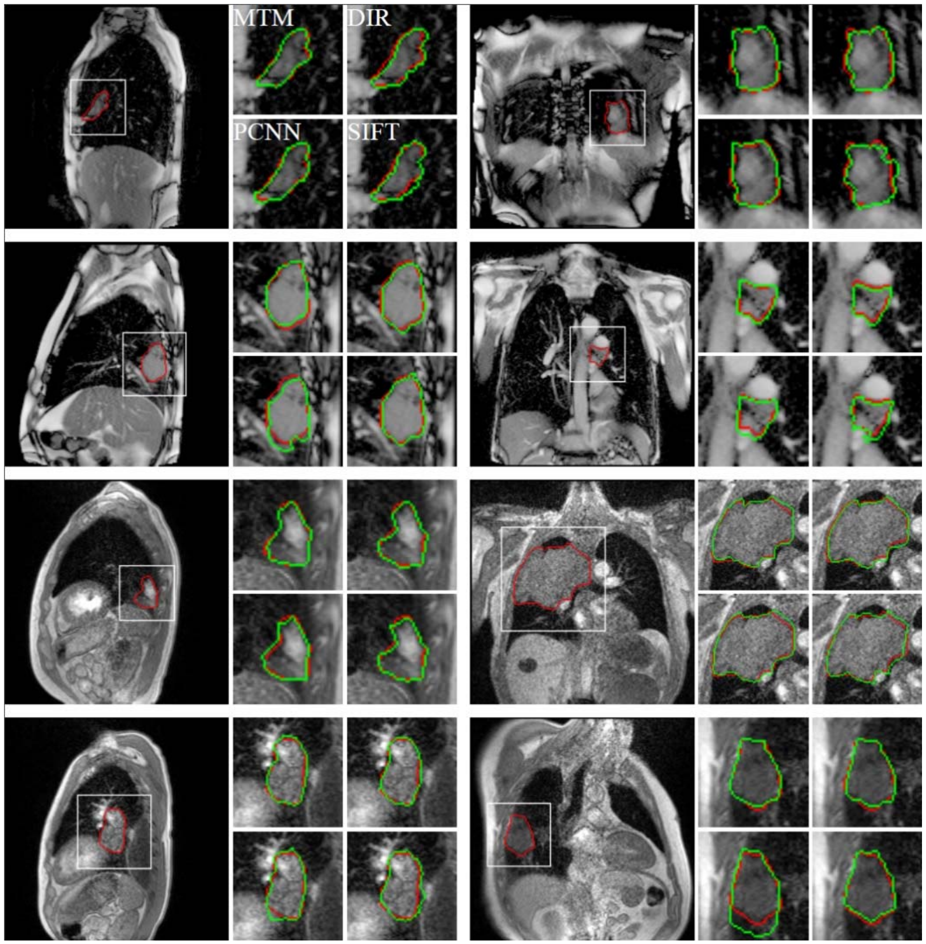
NEXT FRONTIER: REAL-TIME ADAPTATIONS



Motion variability not captured by 4d imaging

Fast et al (2018), IJROBP

CINE MRI + AUTO-CONTOURING



- 6 patients
- 22 image series: sequence (bSSFE vs GRE) + image orientation
- Dice: 0.92 (median)
- Centroid distance: 1.5 mm (median)
- Multi-template matching (MTM) and deformable image registration (DIR) performed best

Fast & Eiben et al (2017), R&O

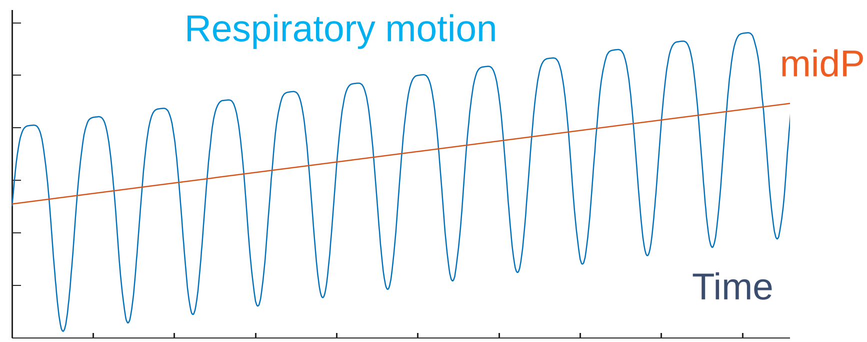
TUMOUR TRAILING

REGULAR MOTION

- High-frequency motion components
- Accounted for in mid-position planning strategy

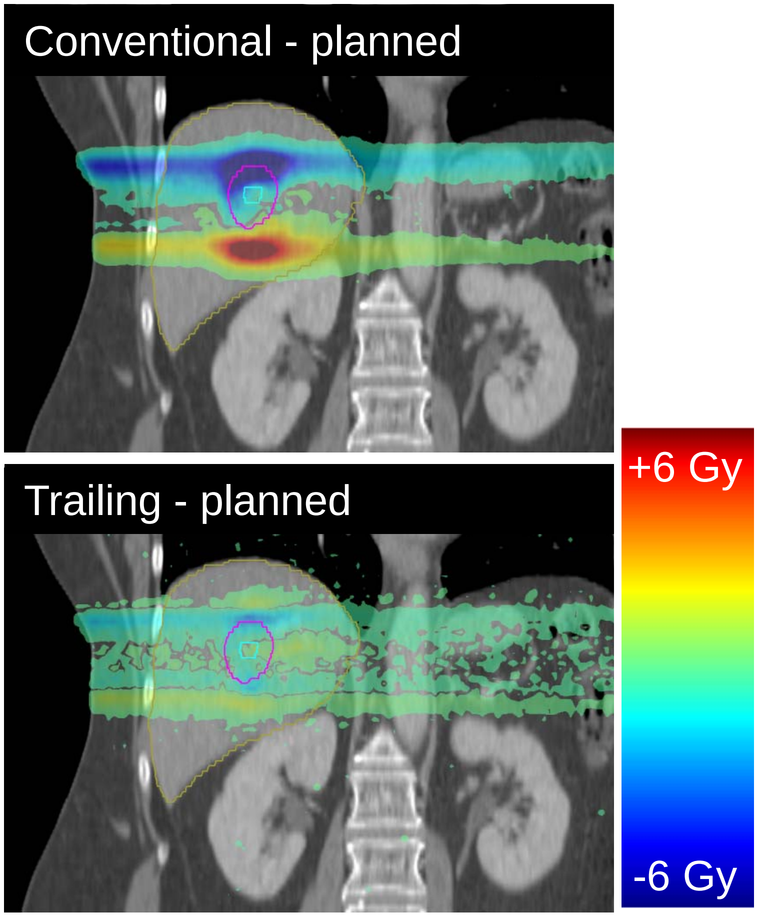
IRREGULAR MOTION

- Low frequency motion components (slow baseline drifts)
- Following mid-position changes during treatment → Tumour trailing[#]



[#]Trofimov et al (2008), Med. Phys. 35 / George et al (2008), Med. Phys. 35

MR-LINAC: FEASIBILITY OF TRAILING



- 3x20 Gy liver SBRT
- Simulated delivery to midP CT (full consideration of interplay)
- Baseline drift: 0.5 mm/min (CC) & 0.25 mm/min (AP)
- *Isocentre-shift* ‡ dose reconstrucion
- Trailing vs Conventional vs Planned

‡Poulsen et al (2012), Med. Phys. / Fast et al (2018), IJROBP

MR-LINAC: TRAILING PROOF-OF-PRINCIPLE

Motion monitoring

- Sagittal b-FFE cine-MRI
- 1x1x10 mm^3
- 3 Hz

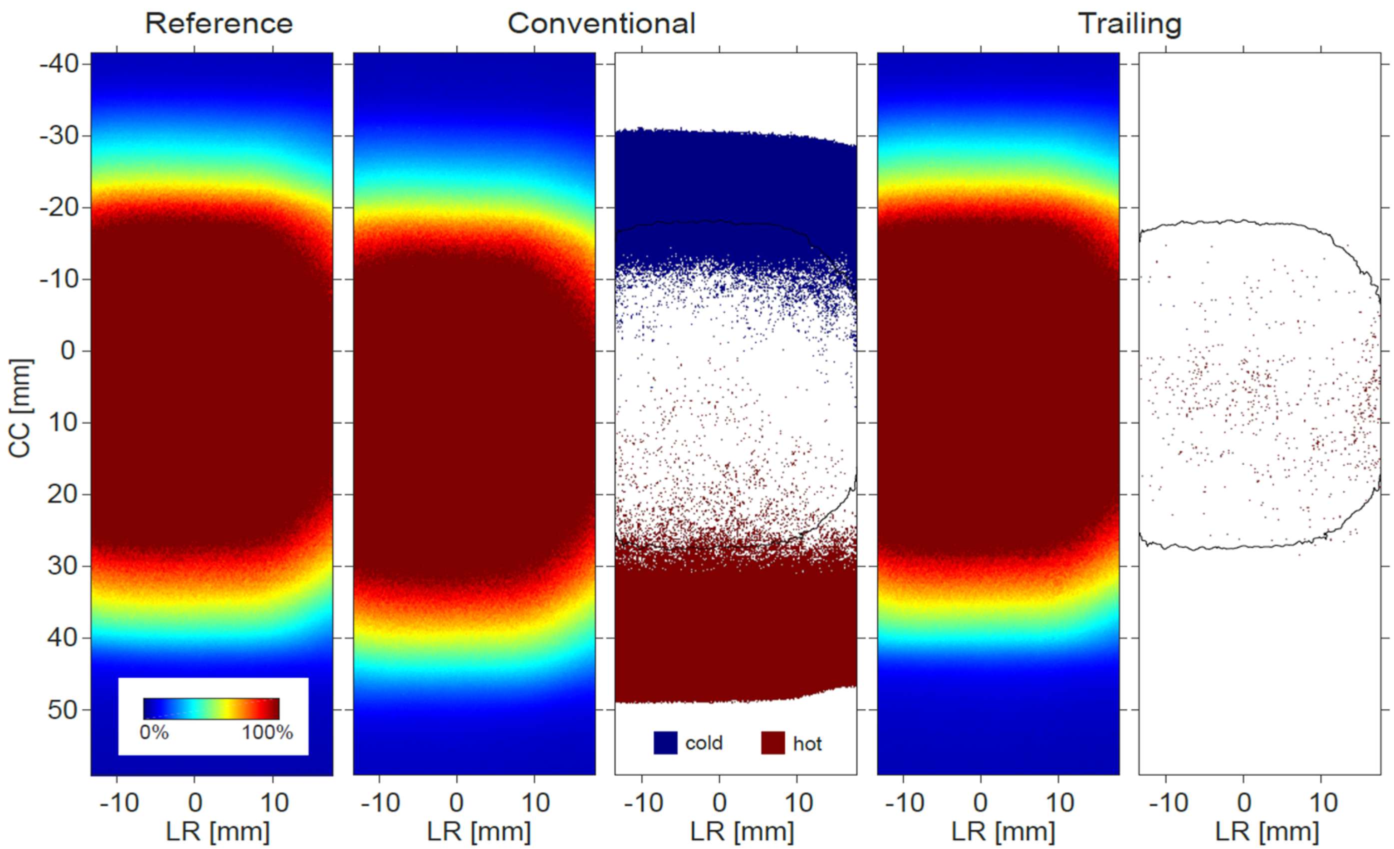
Plan adaptation

- Triggers for motion ≥1 mm
- Adapts MLC to target in beam's-eye-view

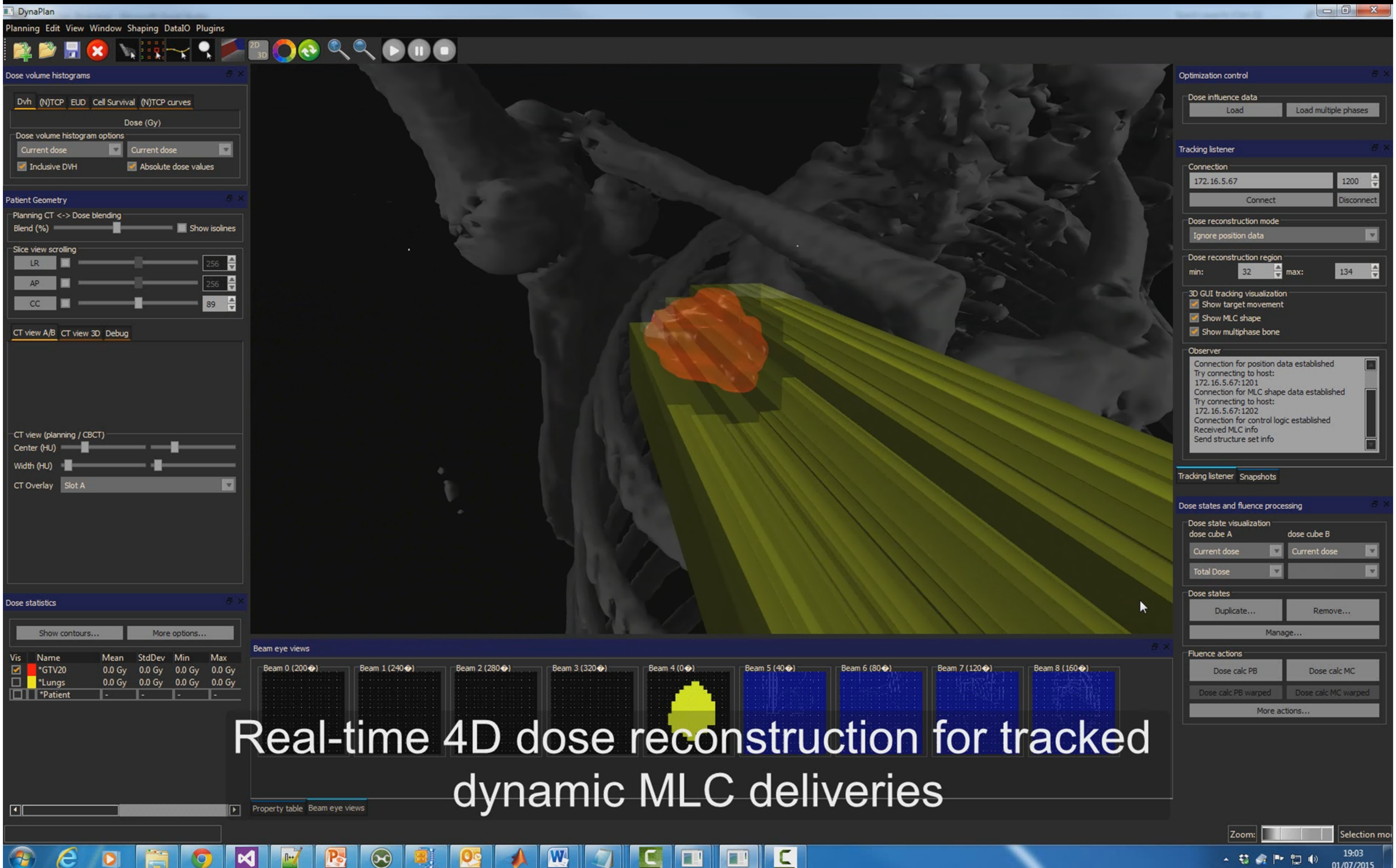
Trailing

- Starts with initial plan
- Pauses linac when needed
- Transfers adapted plan via iCom interface

RESULTS: DOSE AND GAMMA-DISTRIBUTION



Gamma analysis: 3%/2mm



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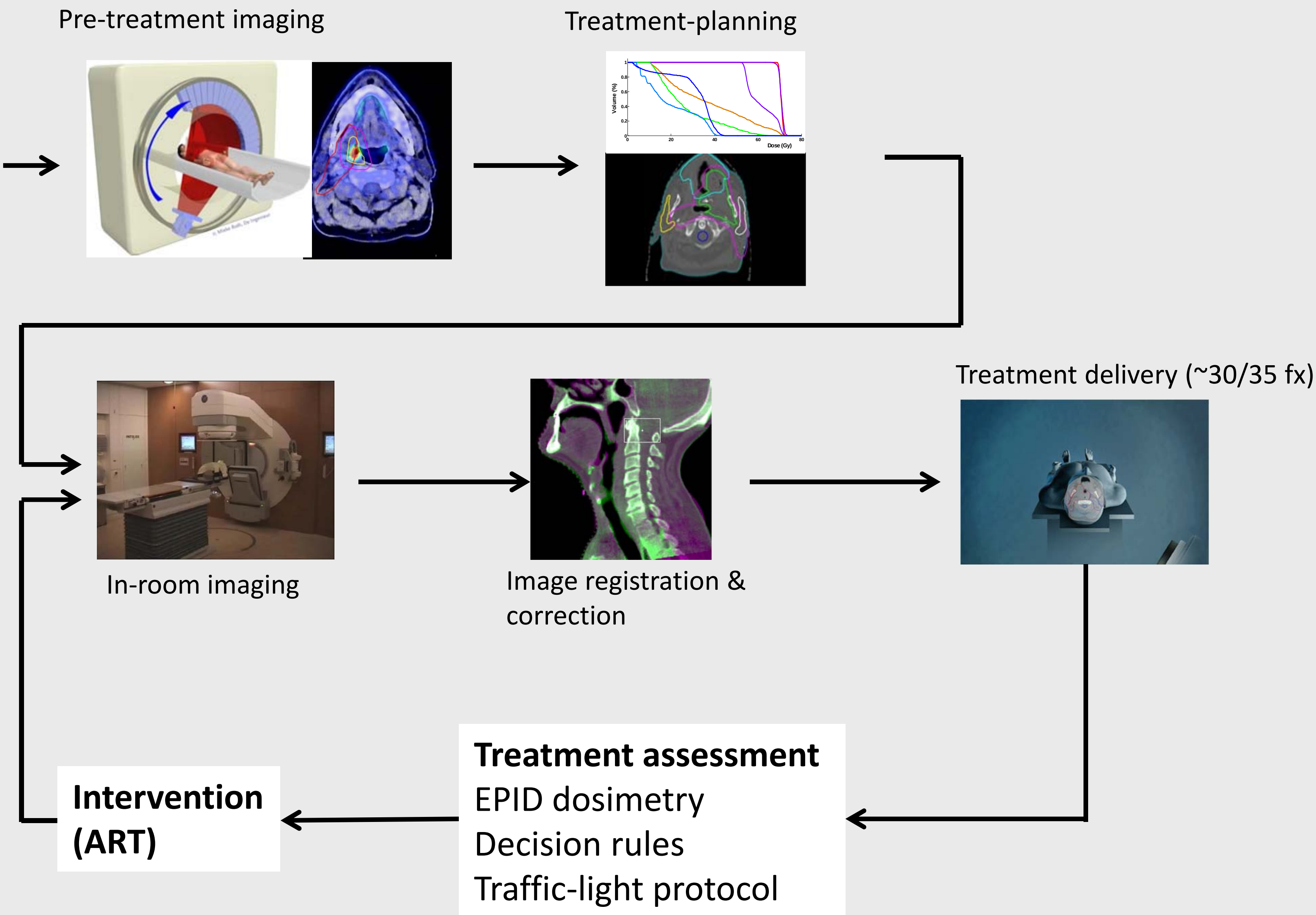
The (adaptive) Radiotherapy Process



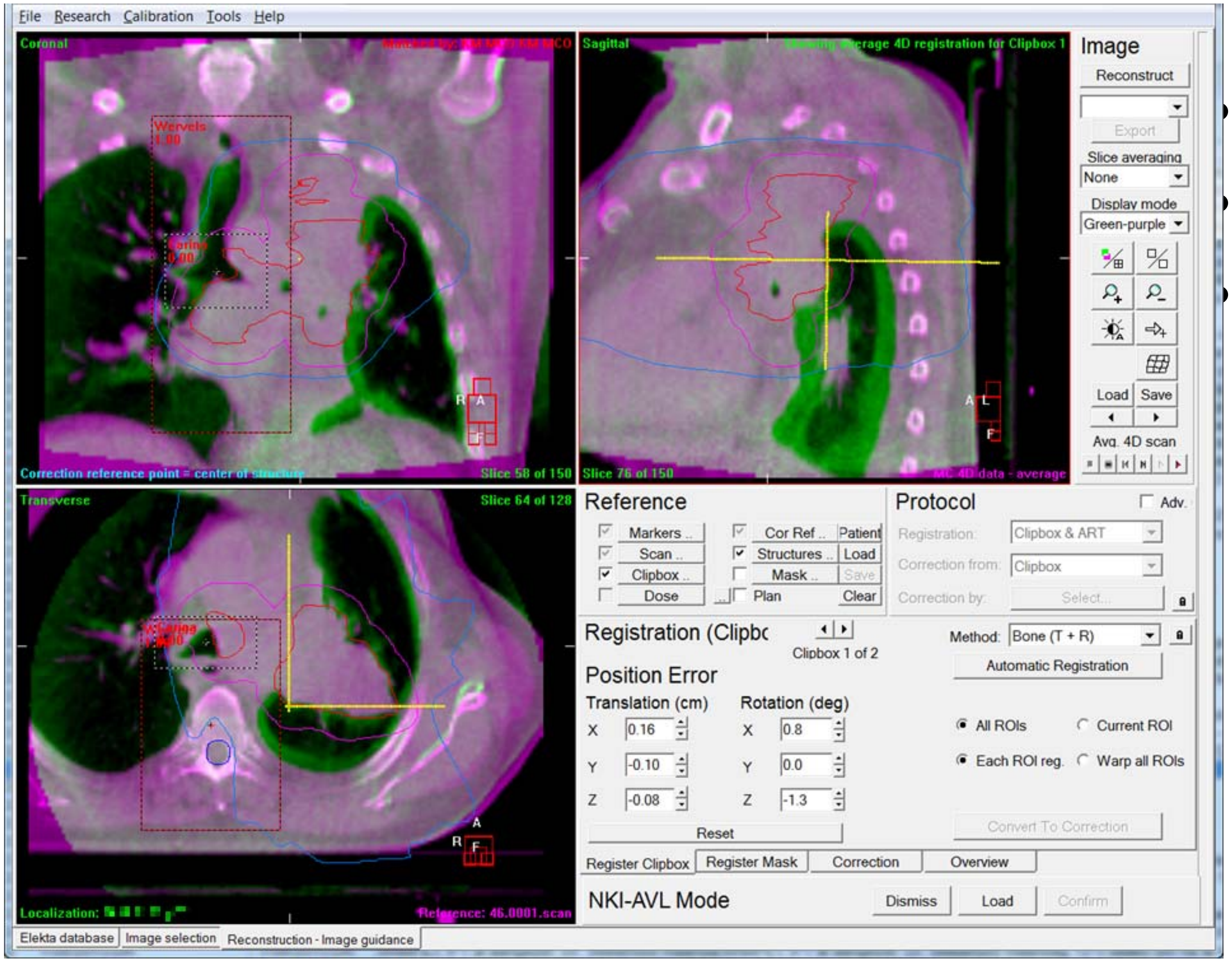
Introduction – current practice

- EPID: *traffic-light* for dose differences with planned
  >> but what does it mean in the anatomy?

- IGRT: Decision rules & *traffic-light* protocol
  >> we see deformations, what does it mean?
  - Dual registration Lung
  - Multi-clipbox HNC

- Ad hoc assessment: editing the pCT for weightloss/deformations in Pinnacle …

Example lung

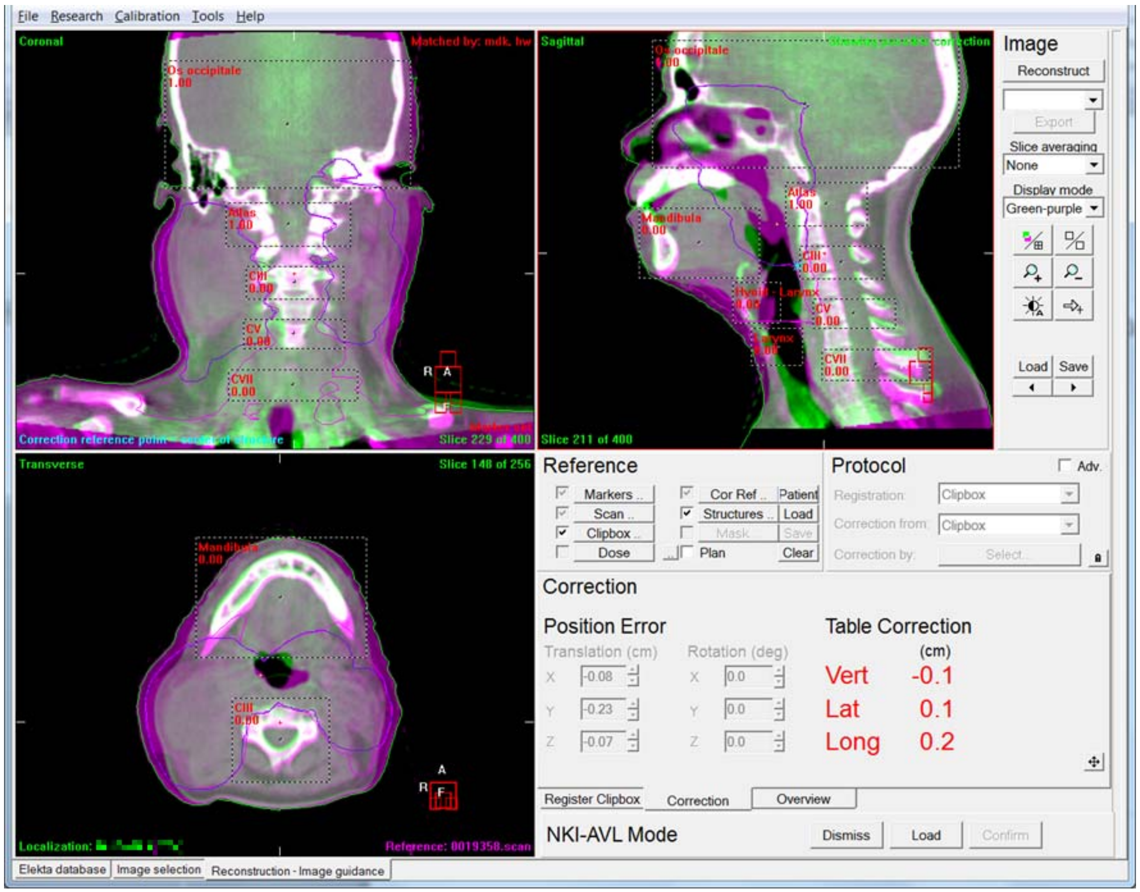


- Lung Cancer
- 60 Gy, 30 fxs
- Previously irradiated:

cord dose < 20 Gy

NTD (a/b=2)

Example HNC



- Nasopharynx
- SIB 70 Gy, 35 fxs
- Large PTV
- Many OARs:
  N. Opticus, Chiasm, Brainstem
- mROI with weights 1/0

What these examples show

Mental exercise…

- Isodose lines: is that what we delivered?
- Deformations: how does that change CTV/OAR dose?
- History: Systematic? Random? Trend?
- Timing: How much can we still gain with replanning?
- Upon replanning: what about dose already delivered?

→ We see geometry, we must think dose…

>> HEADACHE!

Alternative: dose accumulation

alternative: dose accumulation

compute the total delivered dose
in the patient while accounting for
dosimetrical and geometrical discrepancies

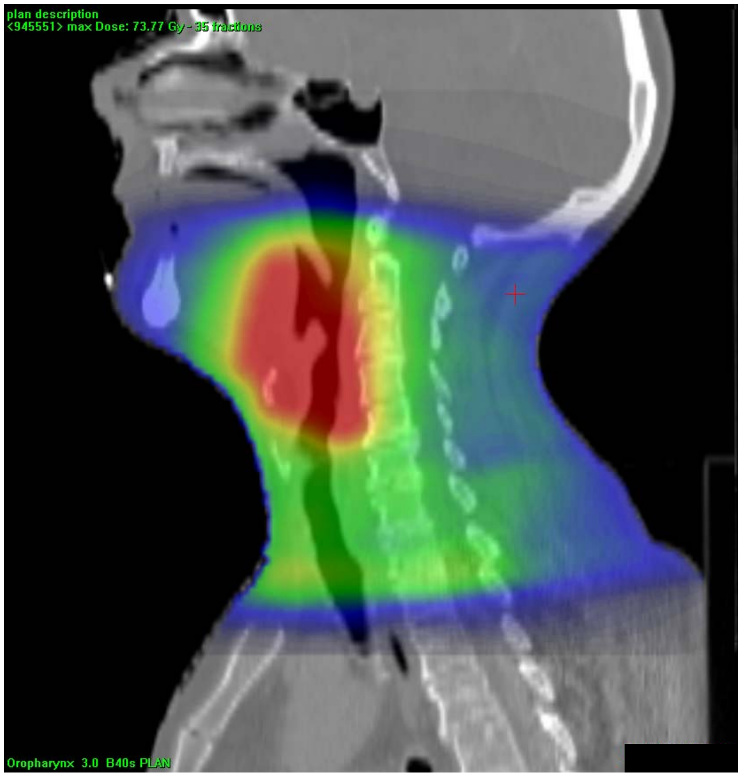
2 important steps:

- Dose distribution delivered is different than planned

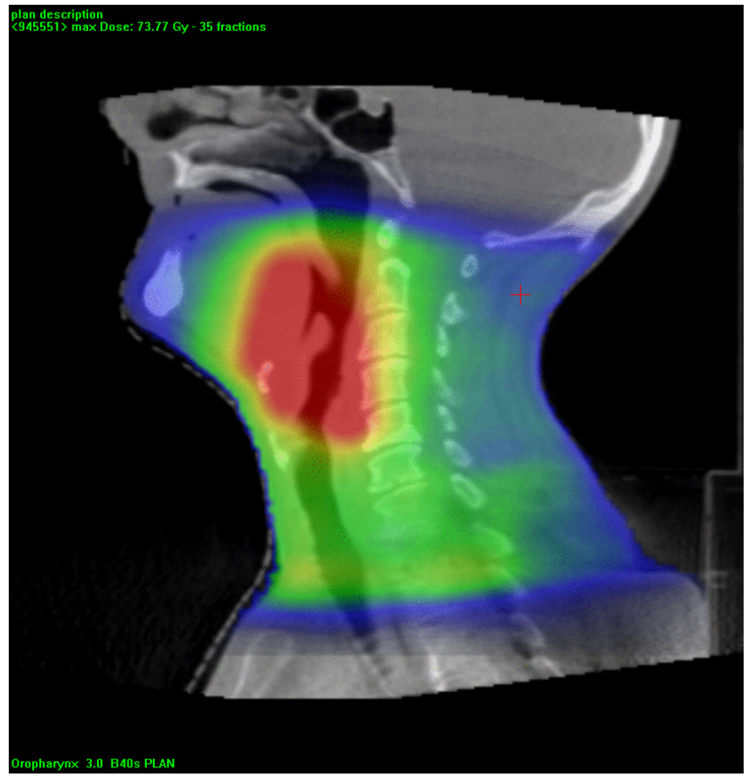
- Dose ends up at different location than planned

Dose accumulation

Step 1: Dose distribution delivered is different than planned



Planned dose in pCT



planned/recalculated dose in CBCT

Dose accumulation

Step 2: Dose ends up at different location than planned

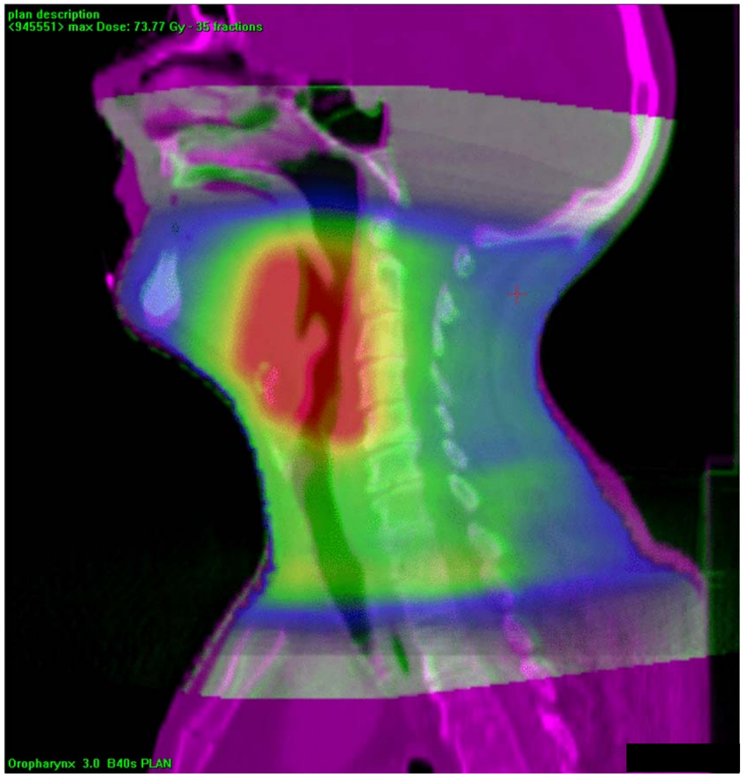
Deformation & anatomy differences

CBCT warping

Dose accumulation

Step 2: Dose ends up at different location than planned

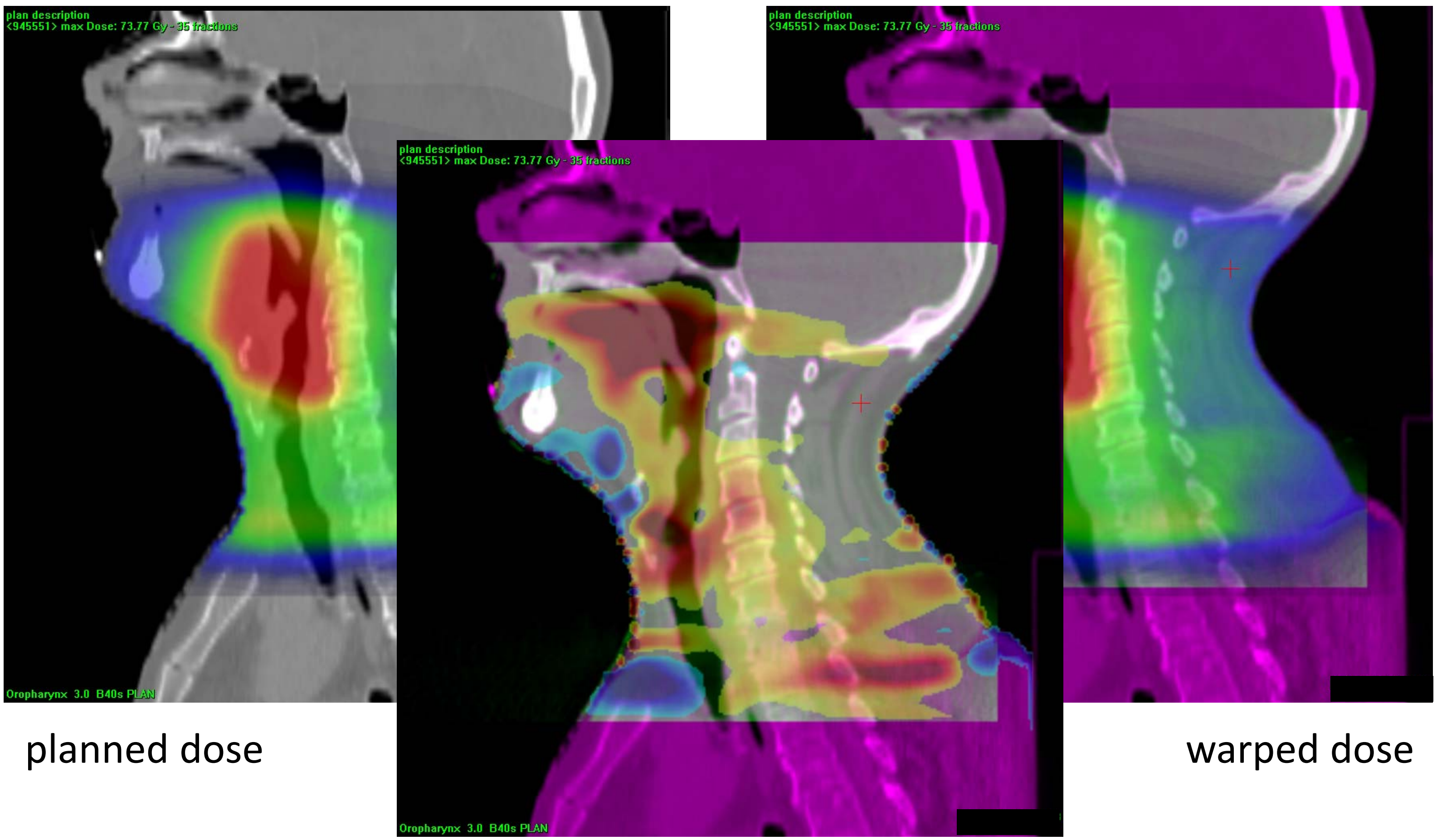
Deformation & anatomy differences



dose warping

Dose accumulation

After dose warping: common reference

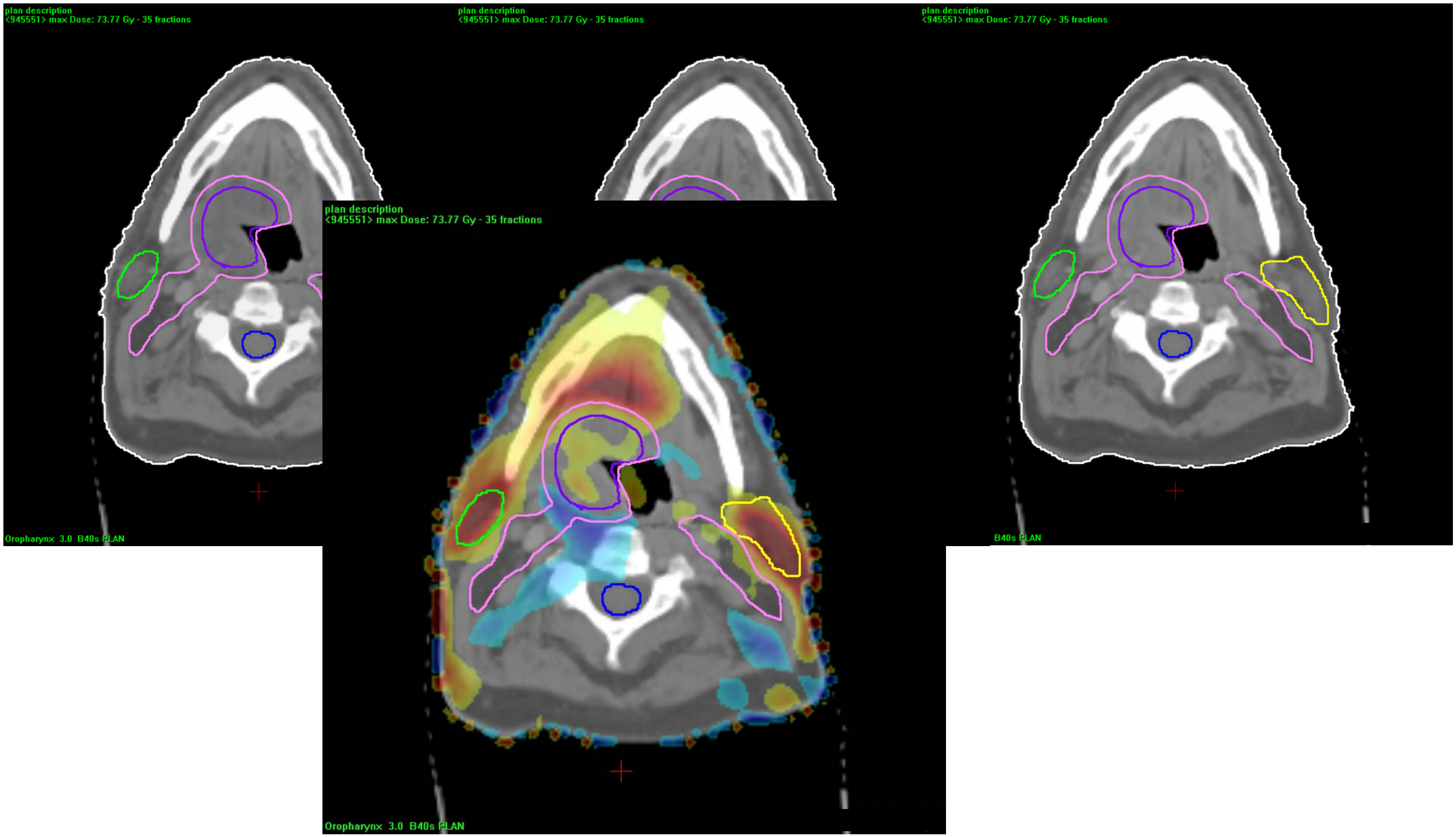


planned dose

warped dose

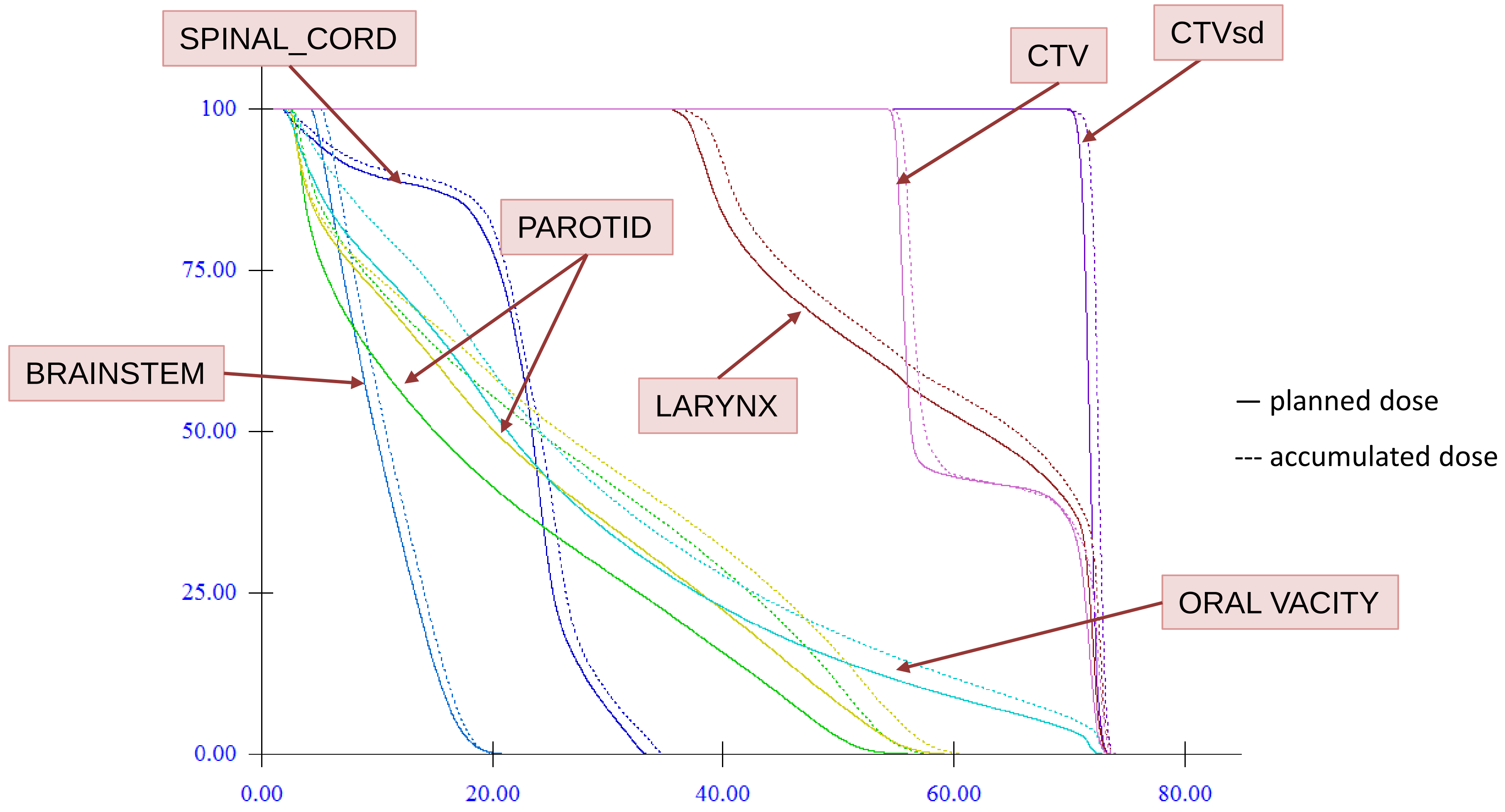
Dose accumulation

Planned dose | Accumulated dose | Difference dose



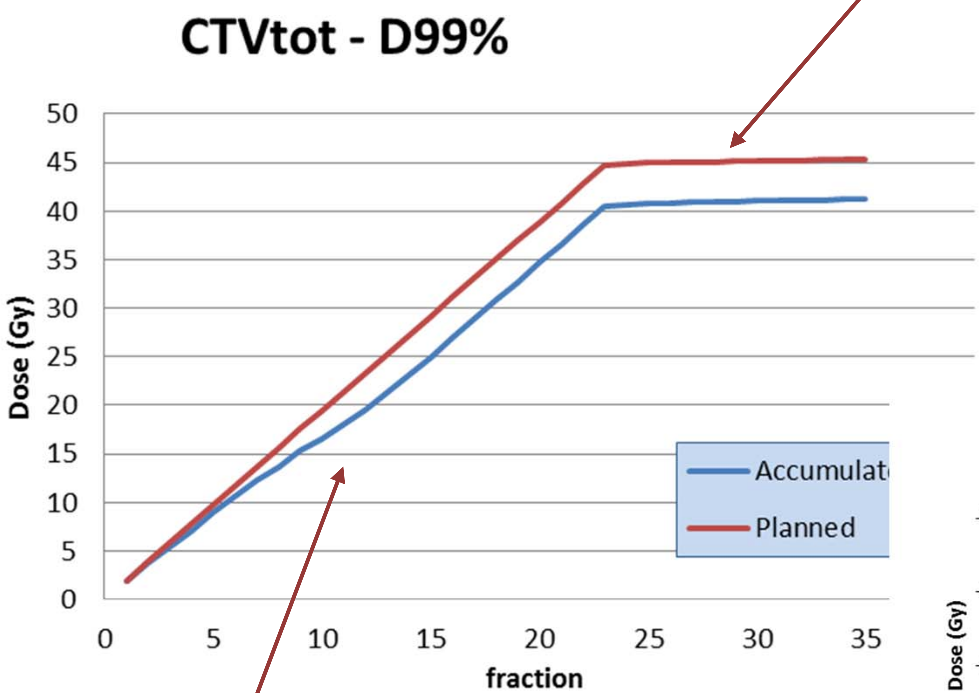
Dose accumulation: DVH differences

DVH: accumulated dose vs planned dose

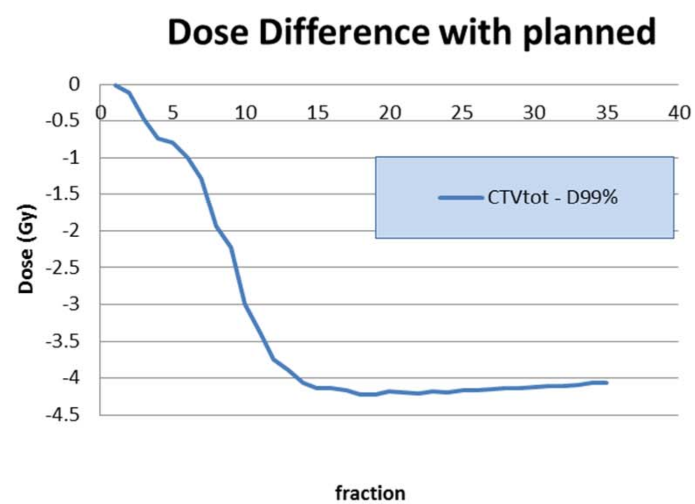


Challenges: prediction of final dose

Boost plan



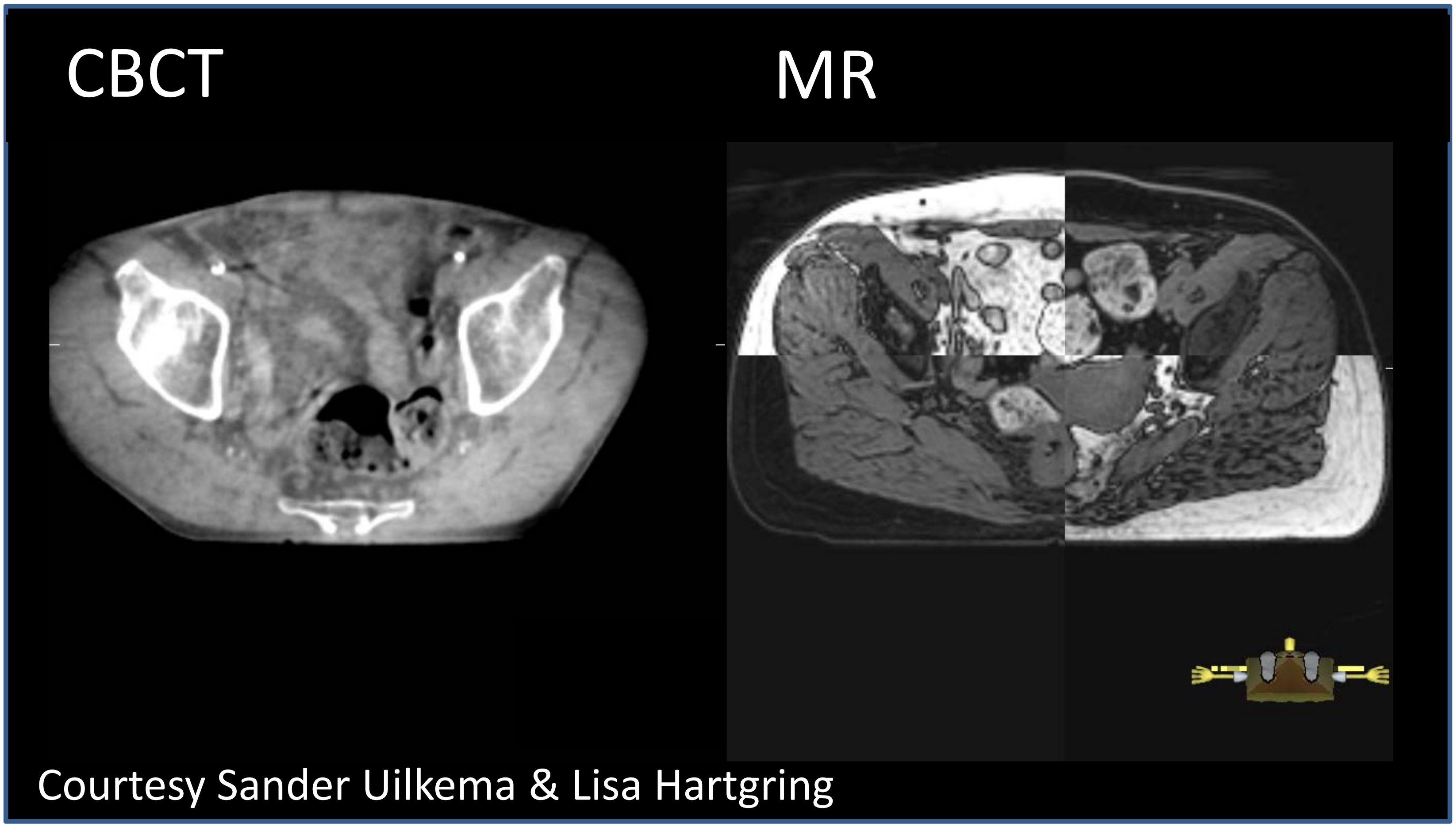
ART @ fx 14



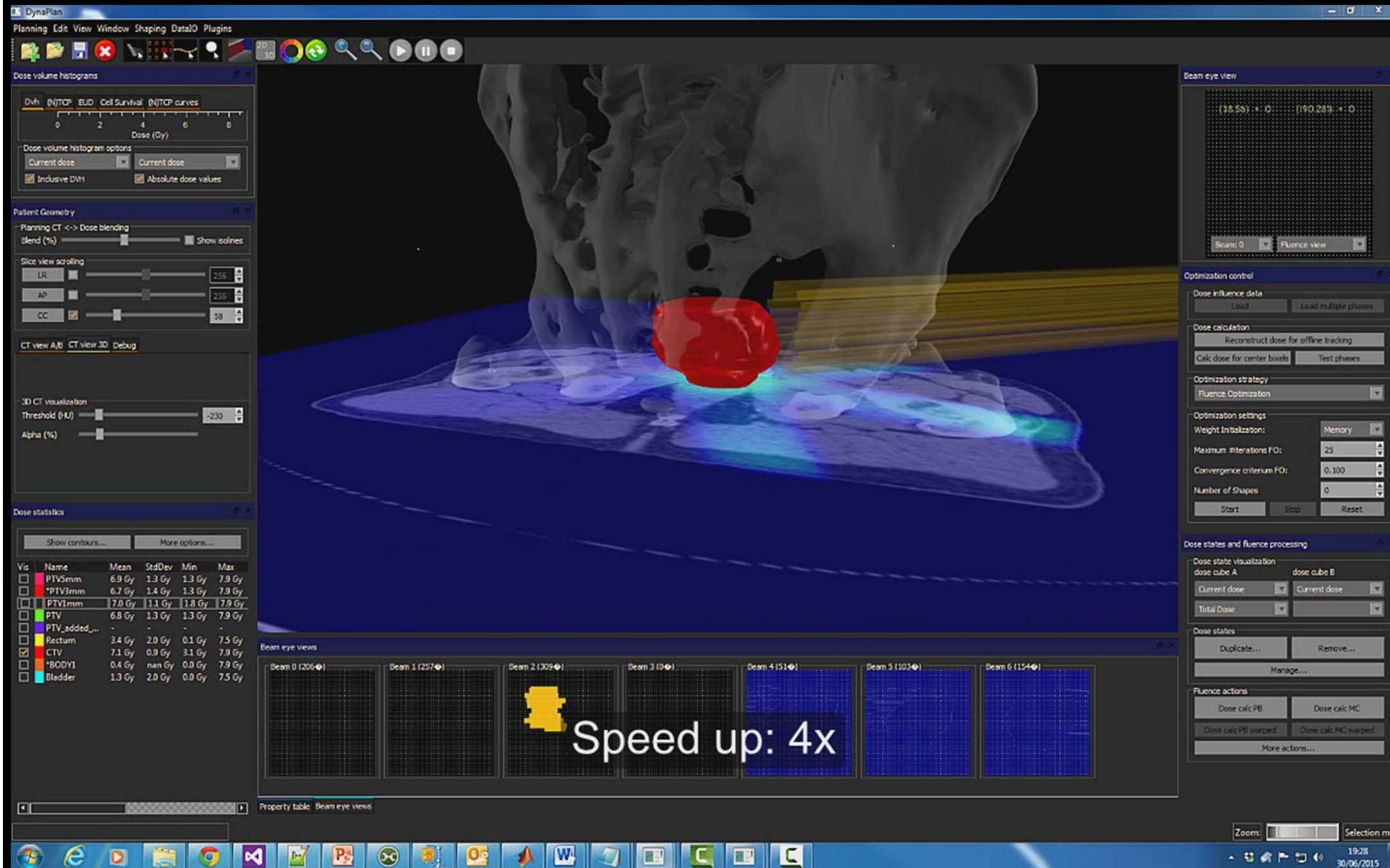
Challenges: DIR with limited Image Quality

- HNC: OK…
- Lung: WIP…

Example image quality rectum



Courtesy Sander Uilkema & Lisa Hartgring



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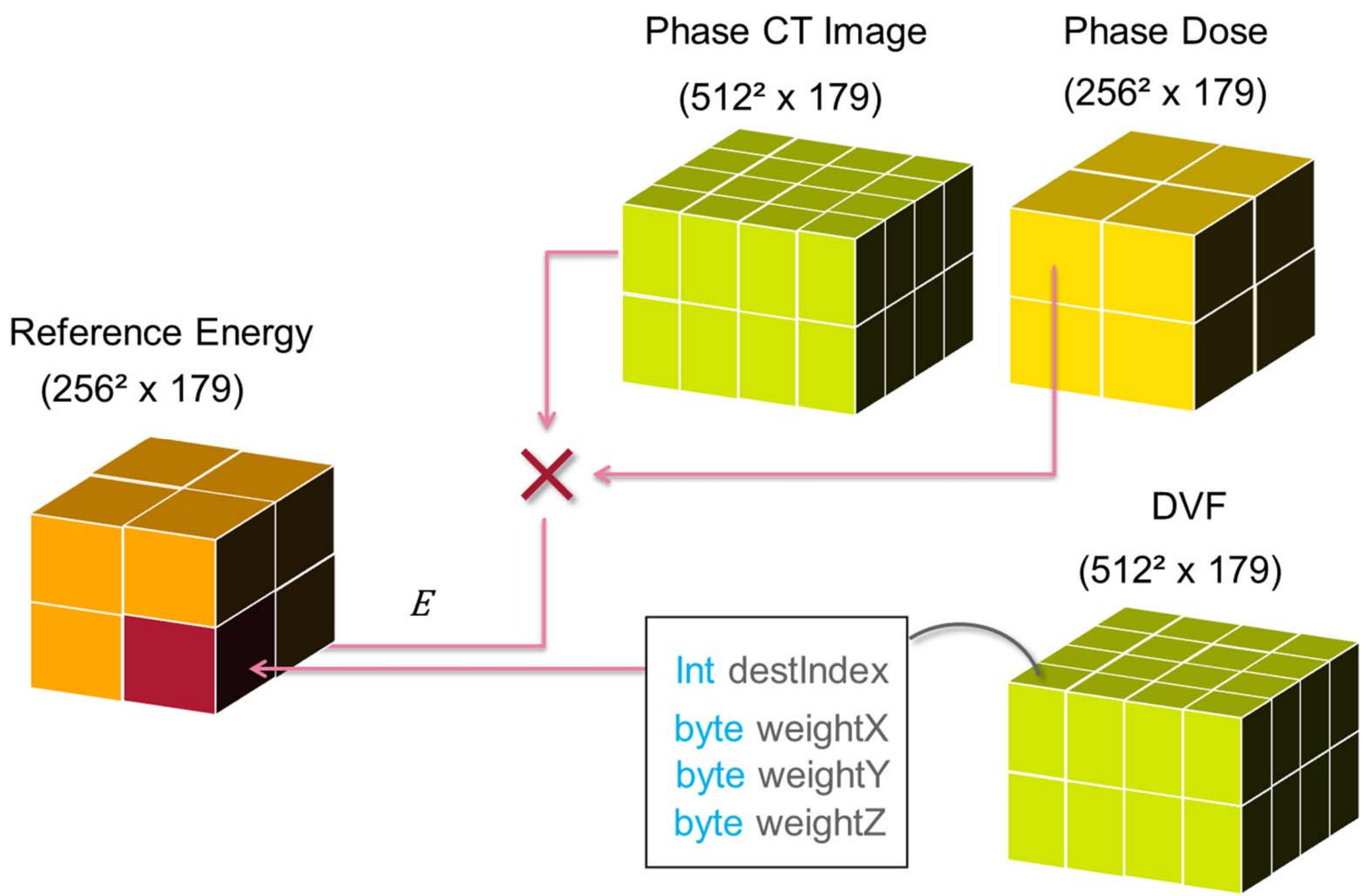
DOSE ACCUMULATION: ENERGY-MASS TRANSFER



Li et al. (2014), Med. Phys. / Ziegenhein et al (2018), Sci. Rep.

SUMMARY & OUTLOOK

- MRI-guidance provides excellent soft-tissue contrast
- Novel 4D-MRI radiotherapy solutions are being developed
- Margin reduction / active motion management will provide scope to allow for re-irradiations
- Away with the surrogate reality: start looking at dose in anatomy daily