Organ motion: clinical practice

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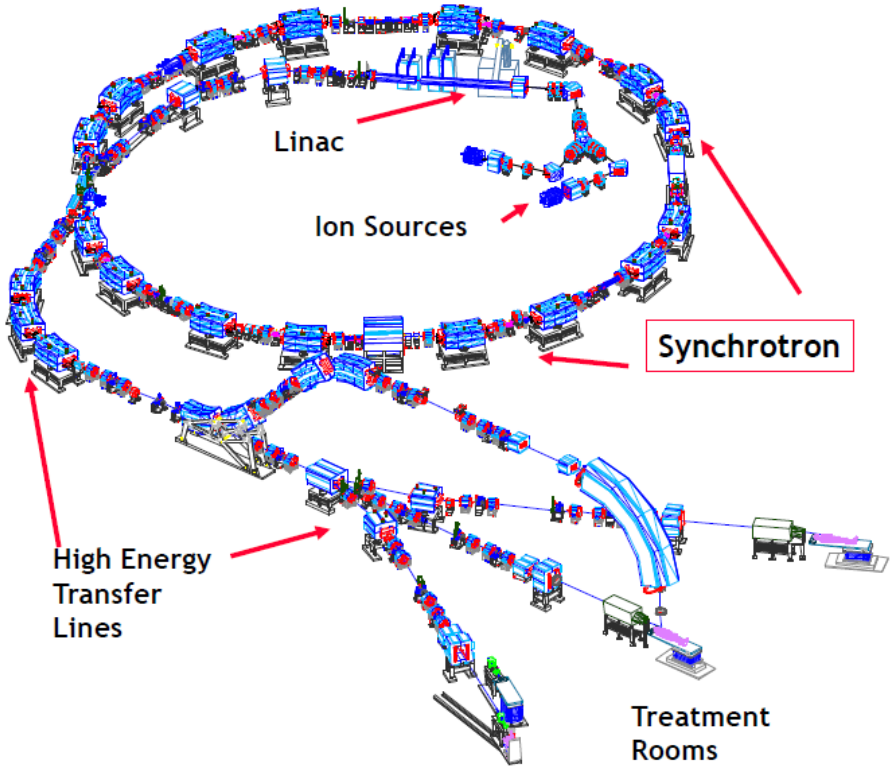
ENLIGHT
ANNUAL MEETING
CAEN, FRANCE | JULY 1-3, 2019

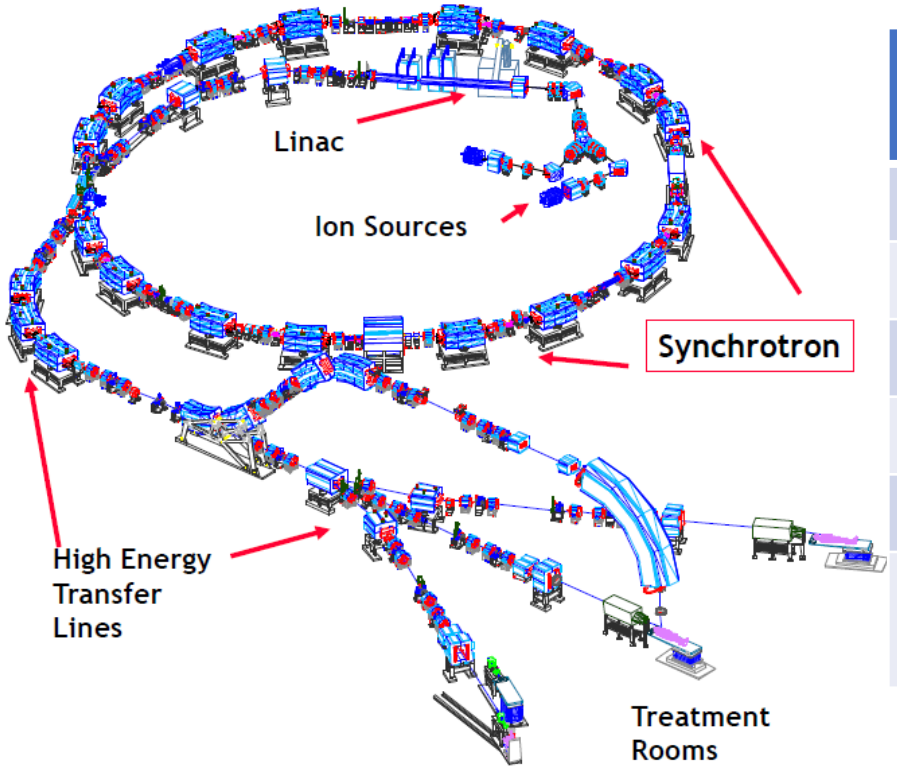
CNAO: fixed beam lines (h&n, pelvis, abdomen, eye,..)



✓2 lateral treatment rooms → fixed horizontal beam line

✓central room → horizontal and vertical fixed beam lines

CNAO: fixed beam lines (h&n, pelvis, abdomen, eye,..)



Number of treatments with gating @ CNAO: *september 2014 to january 2019*	
TOT	115
Upper abdomen	46
Thoracic, spine	48
Chest	21
Tumor type: pancreatic adenocarcinoma, HCC, sarcomas	

✓2 lateral treatment rooms → fixed horizontal beam line

✓central room → horizontal and vertical fixed beam lines

This talk:

- Upper abdomen moving targets.
- Pencil-beam scanning carbon ion RT plans, optimized with Siemens Syngo TPS, delivered with gating + rescanning.

Workflow

4D imaging

- Mask -> abdominal & thoracic compression
- 4DCT -> phase-based reconstruction
- External pressure sensor (ANZAI)

Planning

- ITV within gating window
- Plan optimization on 0% Exp CT with strategies to consider intra-fraction motion.
- Plan recalculation on expected gate limits CTs.
- Plan recalculation on re-evaluative CT the same day of treatment

In-room imaging

Delivery

- Gating at 0%Exp
- Layer-rescanning 5 times

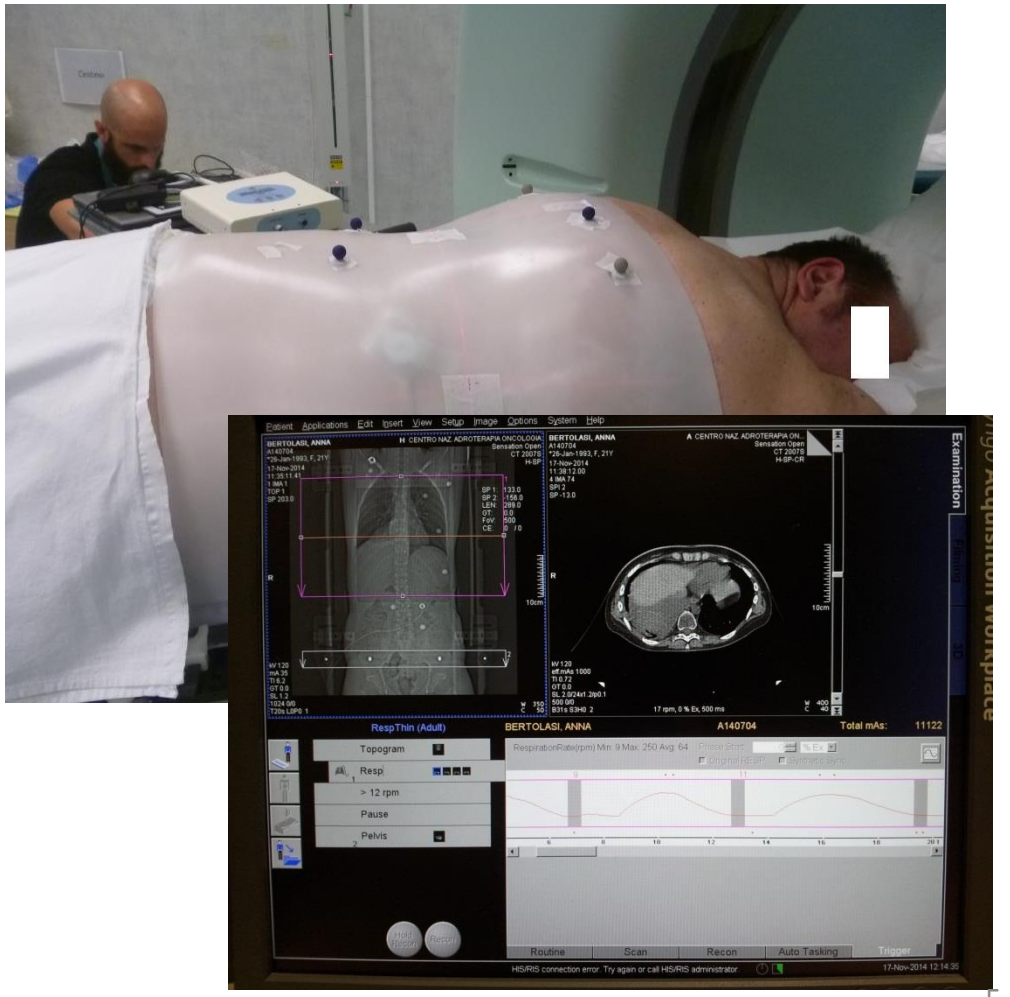
Re-evaluative imaging

- Plan recalculation on 4DCT
- Replanning (?)

4D imaging | Planning | In-room imaging | Delivery | Re-evaluative imaging

Characteristics:

- Mask -> abdominal & thoracic compression
  - 30%Ex: (0.3±0.2) cm, range (0.0 - 0.9)cm;
  - 30%In: (0.4±0.3) cm, range (0.0 – 1.0) cm;
- Supine and prone position
  - think at beam geometry (multiple ports)
  - consider multiple plans
- External pressure sensor (ANZAI) -> phase-based reconstruction
- 4DCT + 4DCT with MDC for organs delineation
- 5 (10) phases reconstructed (motion amplitude dependent: 0%EX, ±30%, ±50%, ±70%, 90%IN)



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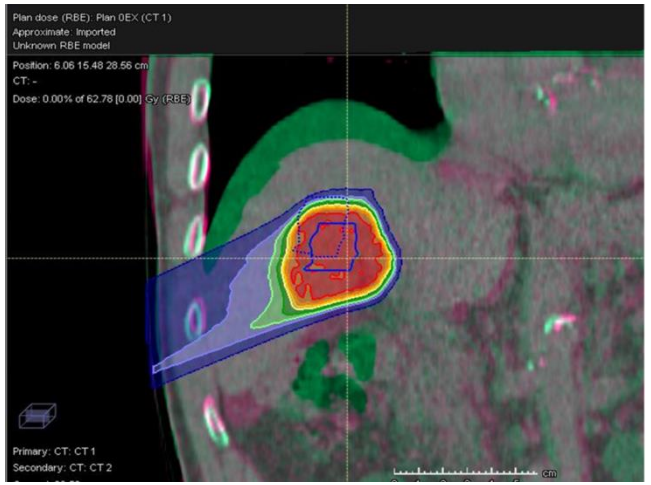
- External pressure sensor (ANZAI) -> phase-based reconstruction
- 4DCT + 4DCT with MDC for organs delineation
- 5 (10) phases reconstructed (motion amplitude dependent: 0%EX, ±20%, ±30%, ±50%, 90%IN)

Limits:

- Patient setup uncertainties
- Time consuming: n contouring + n plans + n re-evaluative
  Trust deformable registration
- Trust correlation between surrogate and internal motion
- 4DCT describes an average breathing during acquisition of apprx. 1 min

Limits: patient setup uncertainties

Hepatocellular Carcinoma
Planning (red) vs pre-treatment (green)0% EX CT
NOT treated



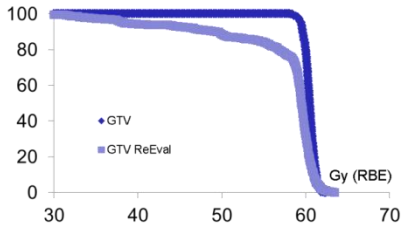
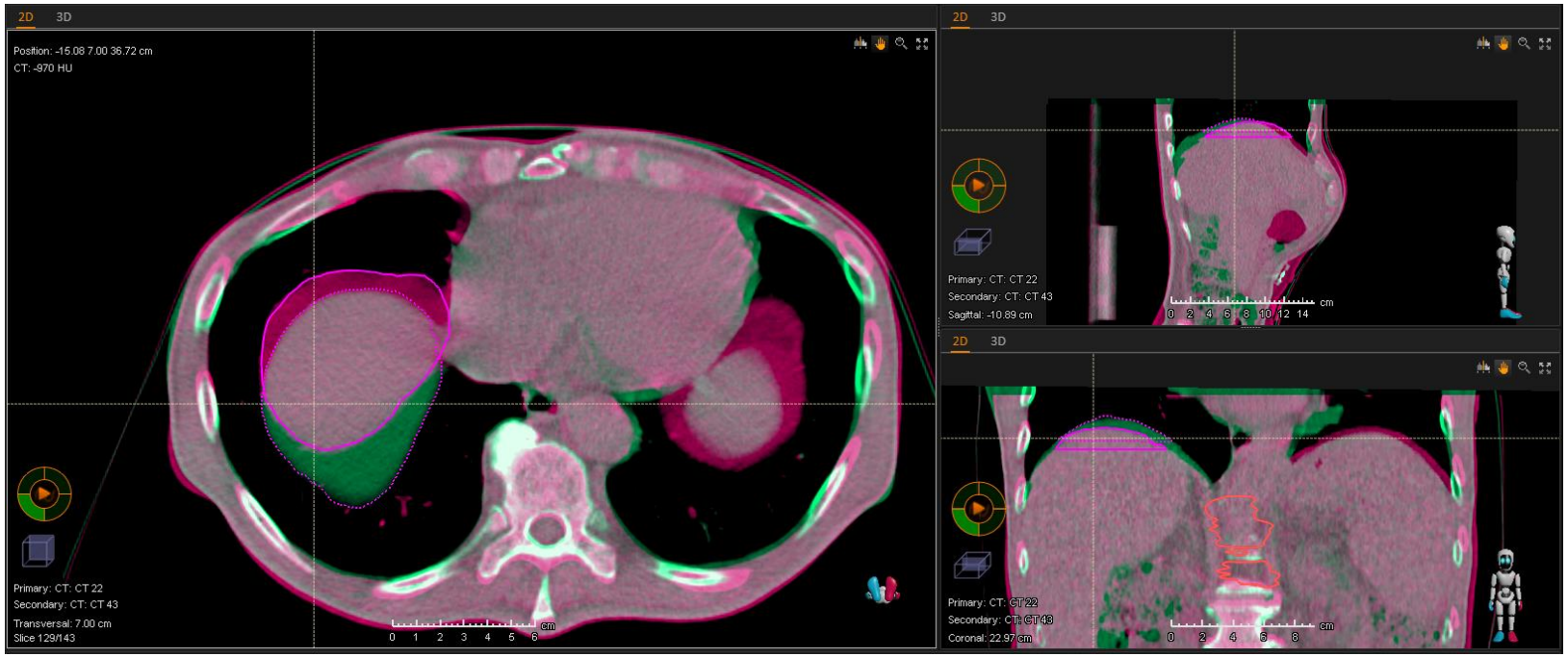


Figure 1. HCC patient. Clinical carbon ion plan optimized on GTV (blue contour) on planning CT at 0EX phase (red). Re-evaluative pre-treatment CT at corresponding phase is registered on it (green) and GTV is warped (dotted blue line), Treatment within the selected breathing range could not be guaranteed in this case, given this difference at full expiration phase. GTV DVHs for plan (*blue*) vs recalc. (*light blue*) is provided.

Pancreatic adenocarcinoma
Planning CT 0%EX (Dec 22, Magenta)
Re-evaluative CT 0%ex (Jan 15, Green)

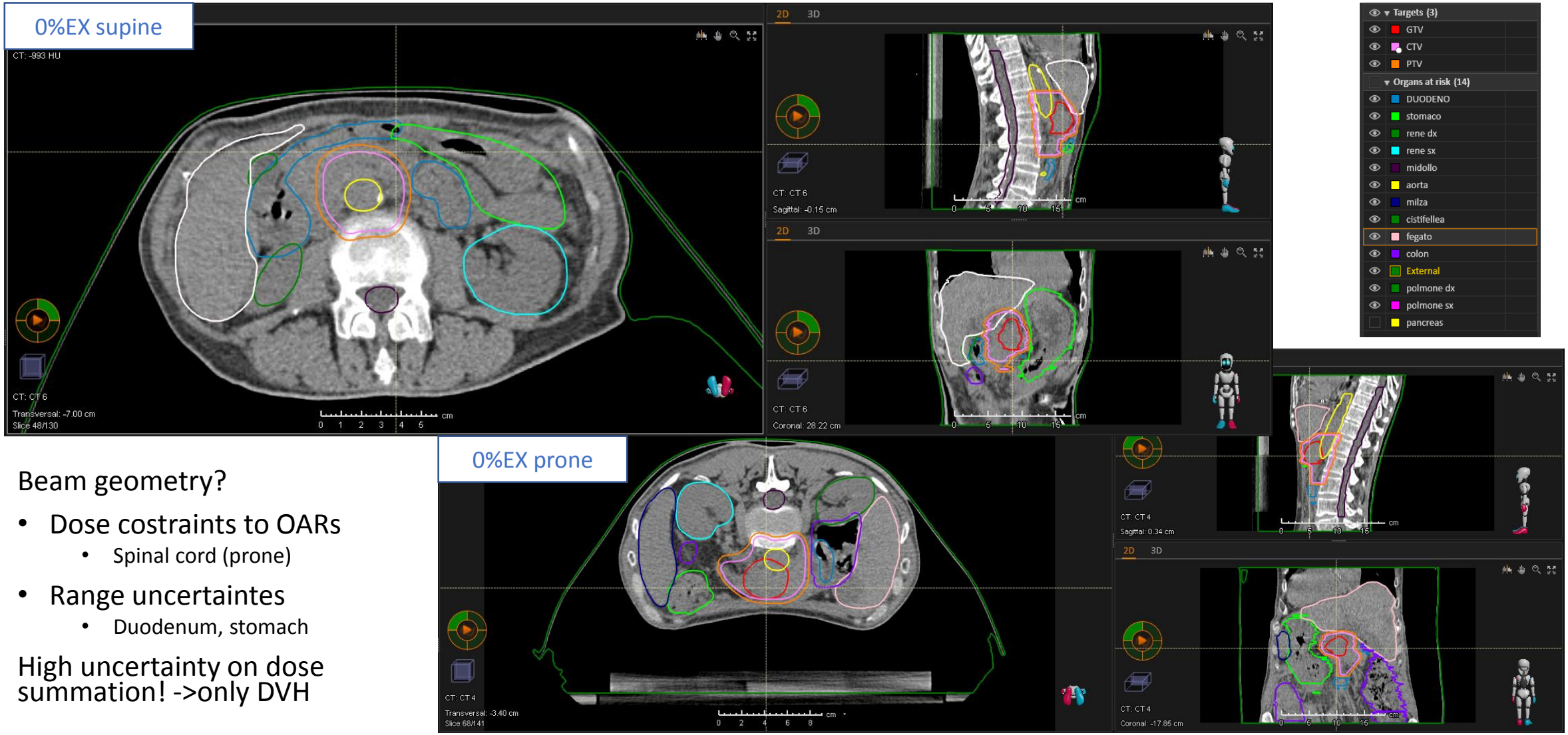
X [cm]	y[cm]	z[cm]	3D[cm]
-0.4	0.5	-1.2	1.35

Planning CT acquired 1 day after the mask preparation?



Limits: multiple setups

Pancreatic adenocarcinoma, C-ion, 57.6 Gy(RBE) 12fr/4.8Gy(RBE), 9fr supine + 3 fr prone, IMPT



Beam geometry?

- Dose costraints to OARs
  - Spinal cord (prone)
- Range uncertaintes
  - Duodenum, stomach

High uncertainty on dose summation! ->only DVH

Multiple setups

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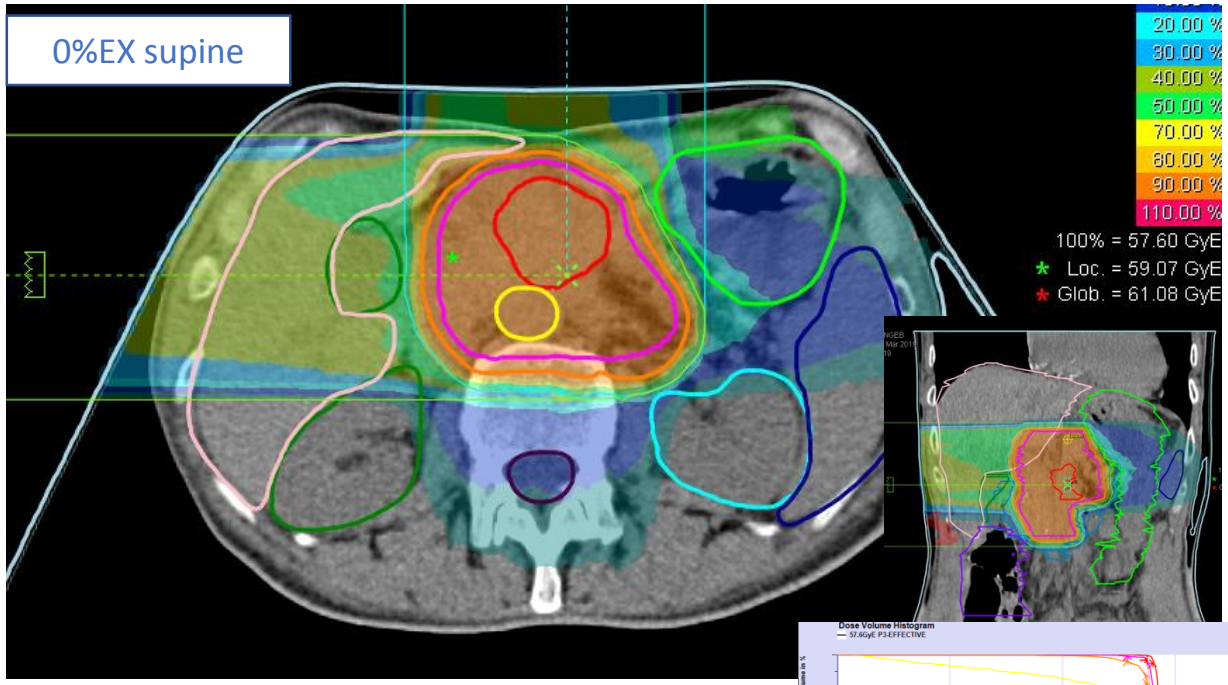

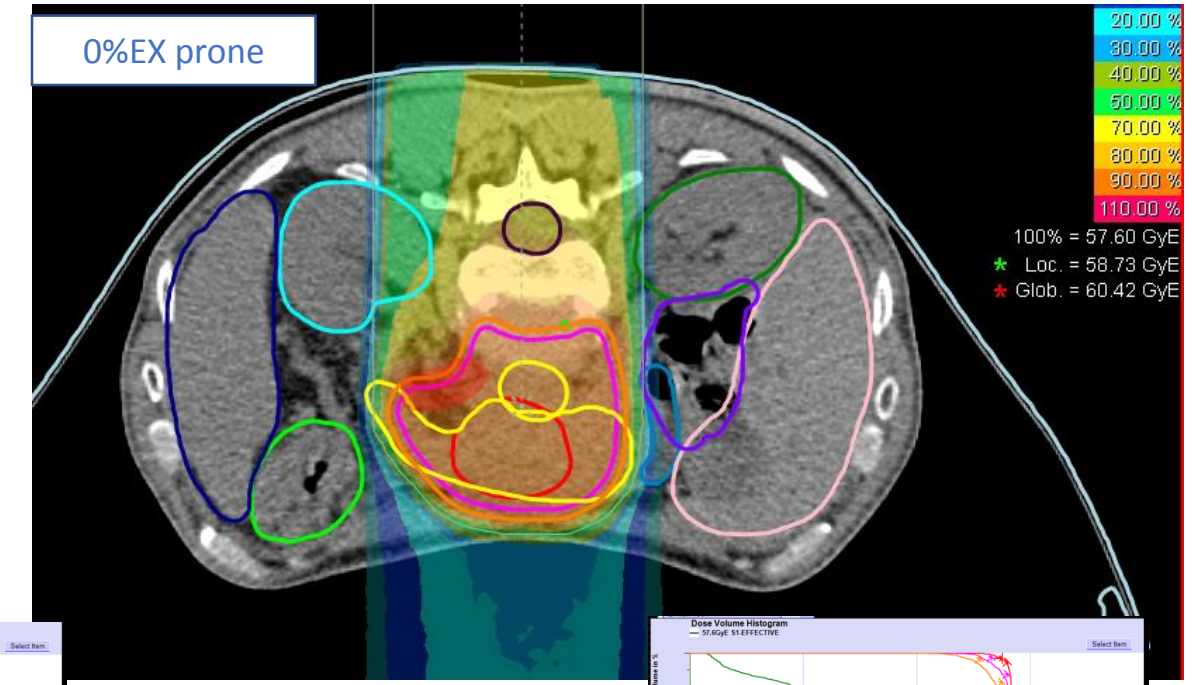

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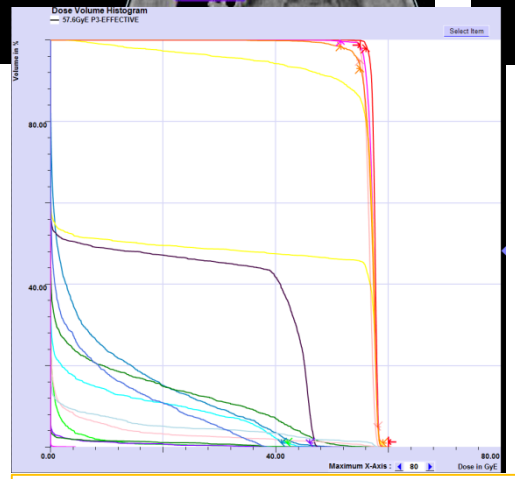
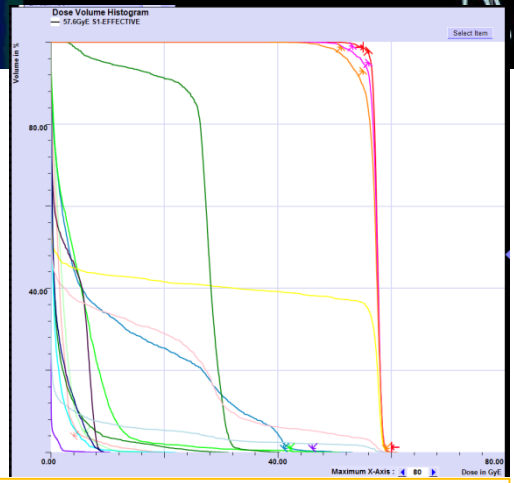


Respect on OARs dose costraints on single plans

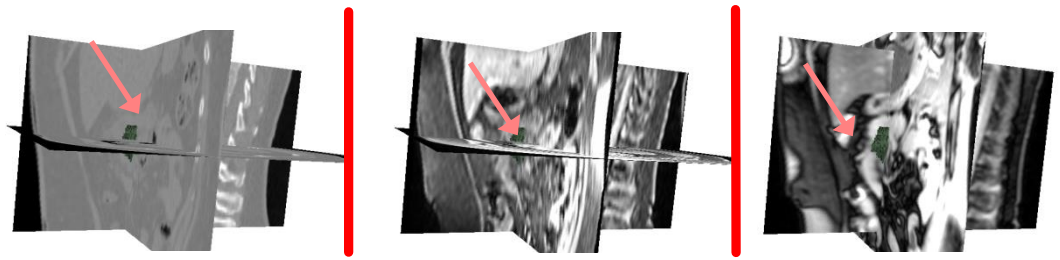


9 fr + 3 fr

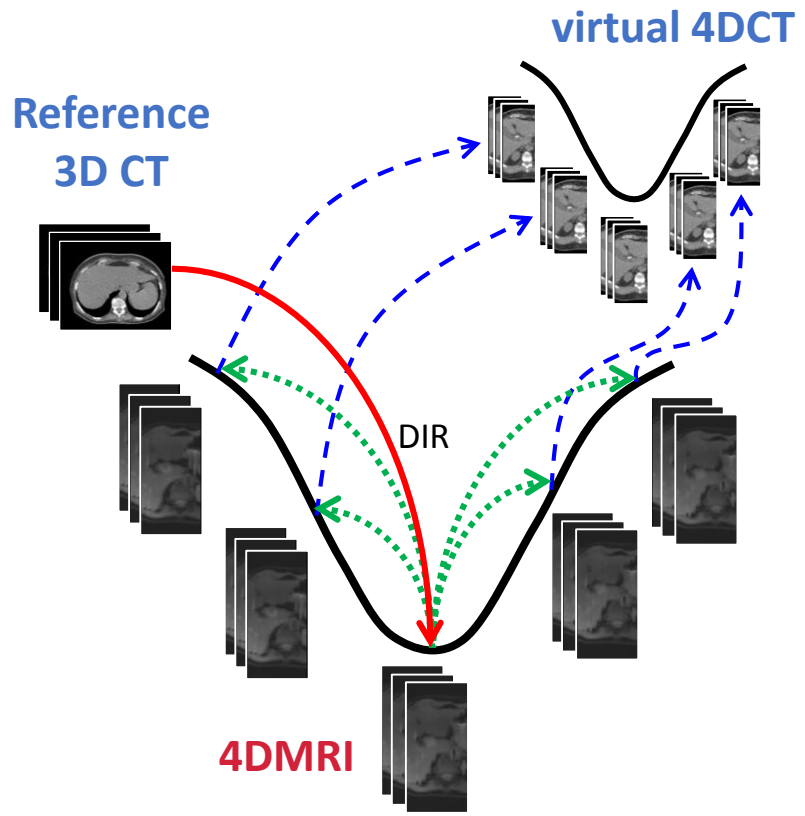
Average respiratory cycle
Virtual 4DCT from 4D MRI

CartCasLab @ POLITECNICO MILANO 1863
Computer Aided RadioTherapy & Computer Aided Surgery

- Multi-slice acquisition of sagittal images during free-breathing (TrueFISP sequence, resolution: 1.33x1.33x5mm)
- 4DMRI retrospective sorting (Meschini et al. Phys Med 2019;58:107-13)
- 6 pancreas + 2 liver patients treated with gated carbon ion therapy
- 18 4DMRI overall (repeated acquisition during the same scan and/or after ~1 week)



CT and GTV (0% exhale) | **MRI and GTV** | **2D CINE MRI and GTV**



[submitted manuscript]

Purpose: **robust** and **conformal** treatment plan

- Targets and OARs delineated on all phases: use of DIR?
- ITV within gating window (0% to ± 30% exp)
- Plan optimization on 0% Exp:
  - Beam geometry: avoid surfaces which moves perpendicular to beam axis;
  - Consider possible inter-fraction motion;
- Plan recalculation on different phases:
  - ± 30% exp: estimated gating window limits
  - 100% in: worst-case scenario
- Pre-treatment recalculation (same day)

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Clinical case:

Pericardial leiomyosarcoma

Carbon ion – 64Gy (RBE), 16fr/ 4 Gy(RBE)

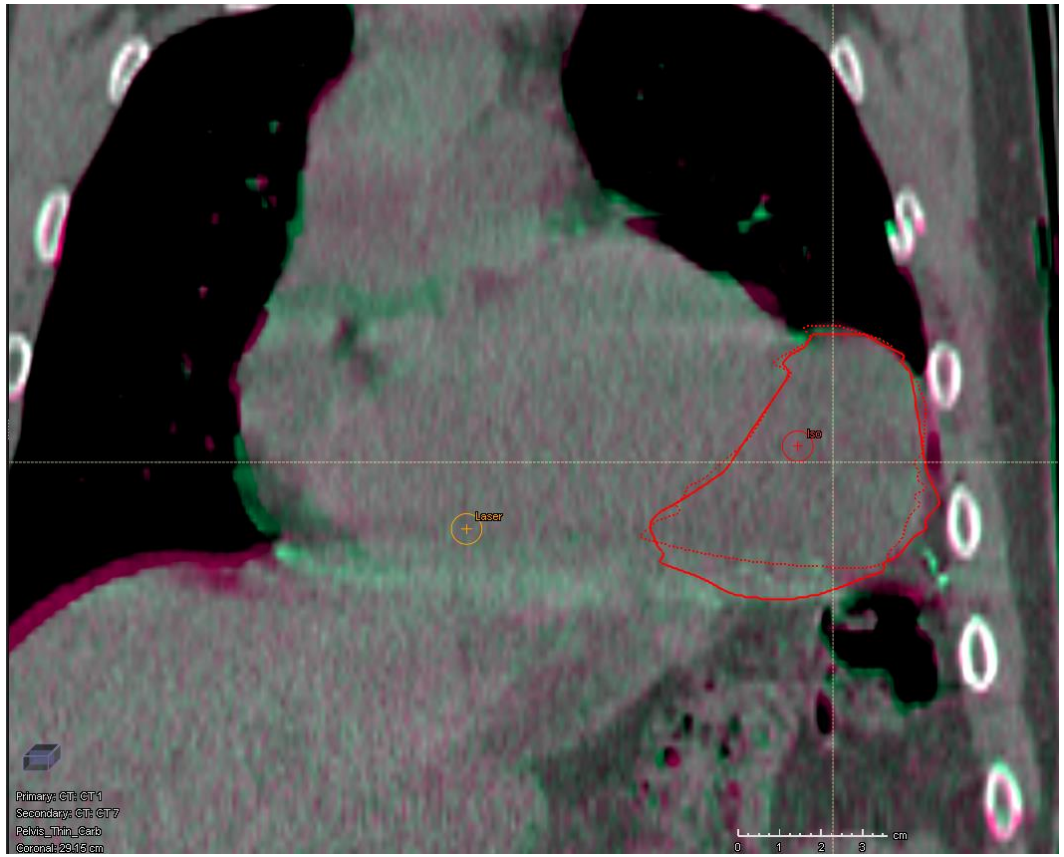
Datasets

Respiratory-gated 4DCT (10 phases)

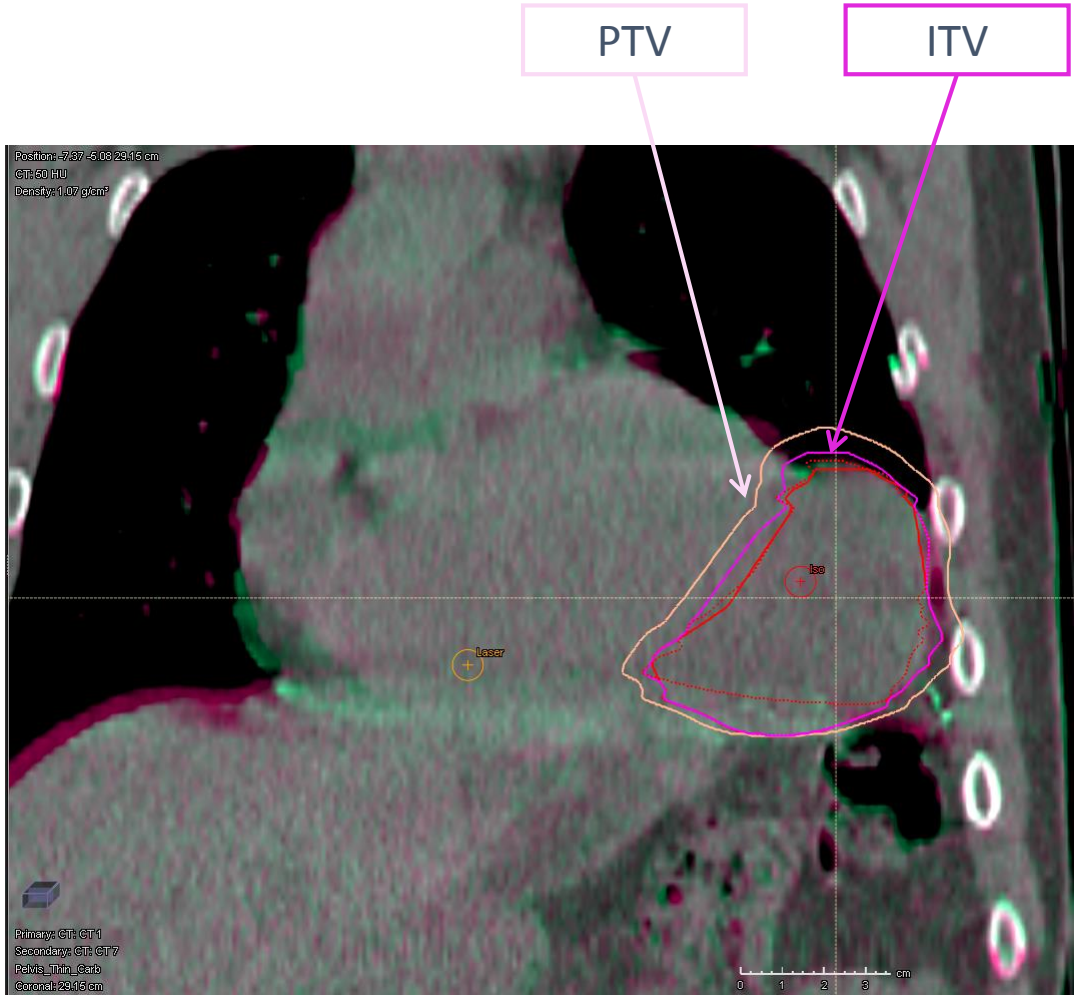
Cardiac-gated 4DMRI (external source)

Robust & conformal planning

Define the target



GTV 0%EX (green)
GTV 30%EX (magenta)
GTV 30%IN

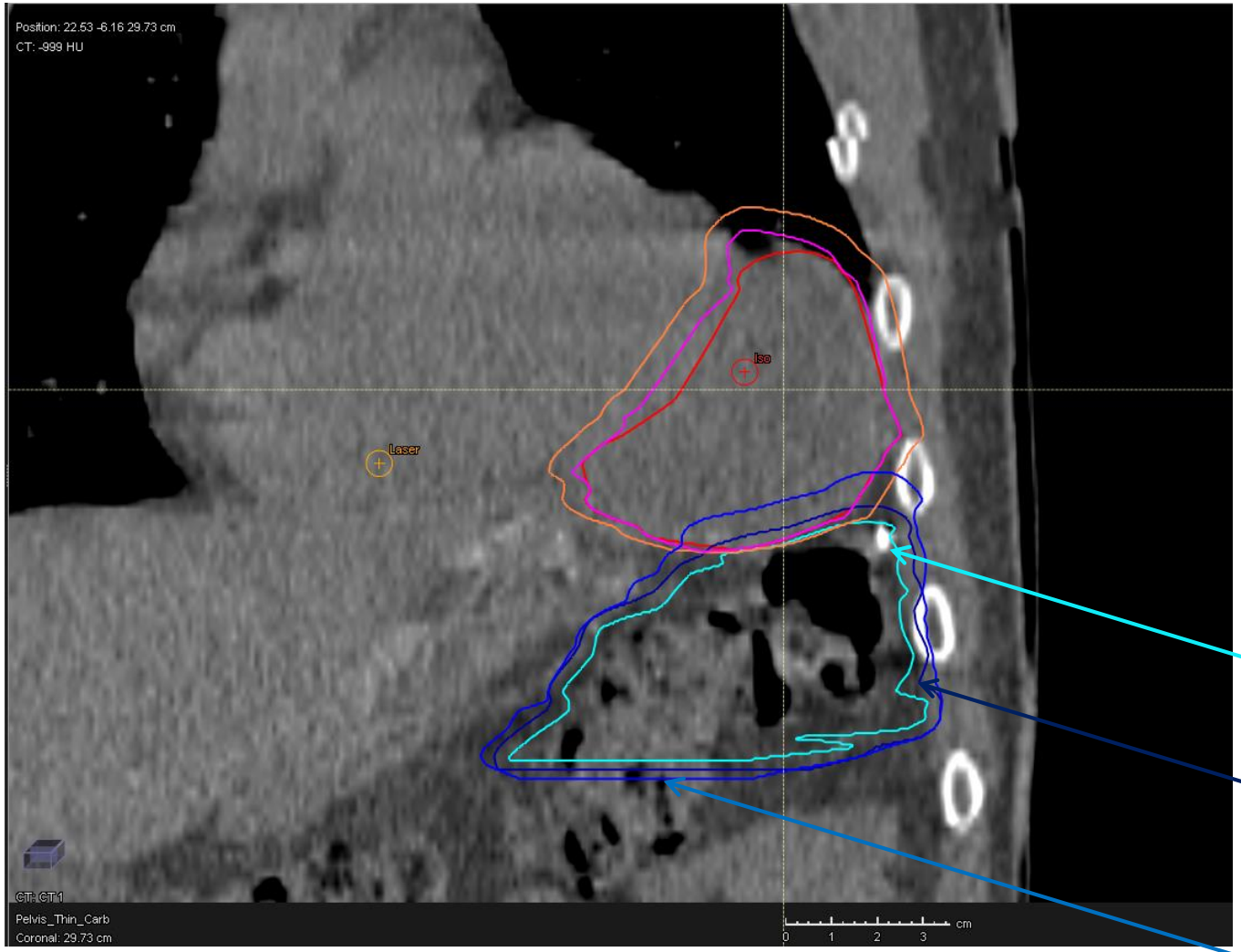


ITV= GTV (0%EX)+ GTV(30%IN)+GTV (30%EX)
ITV manually adjusted considering 4DMRI

PTV = ITV + 5mm

Robust & conformal planning

OARs



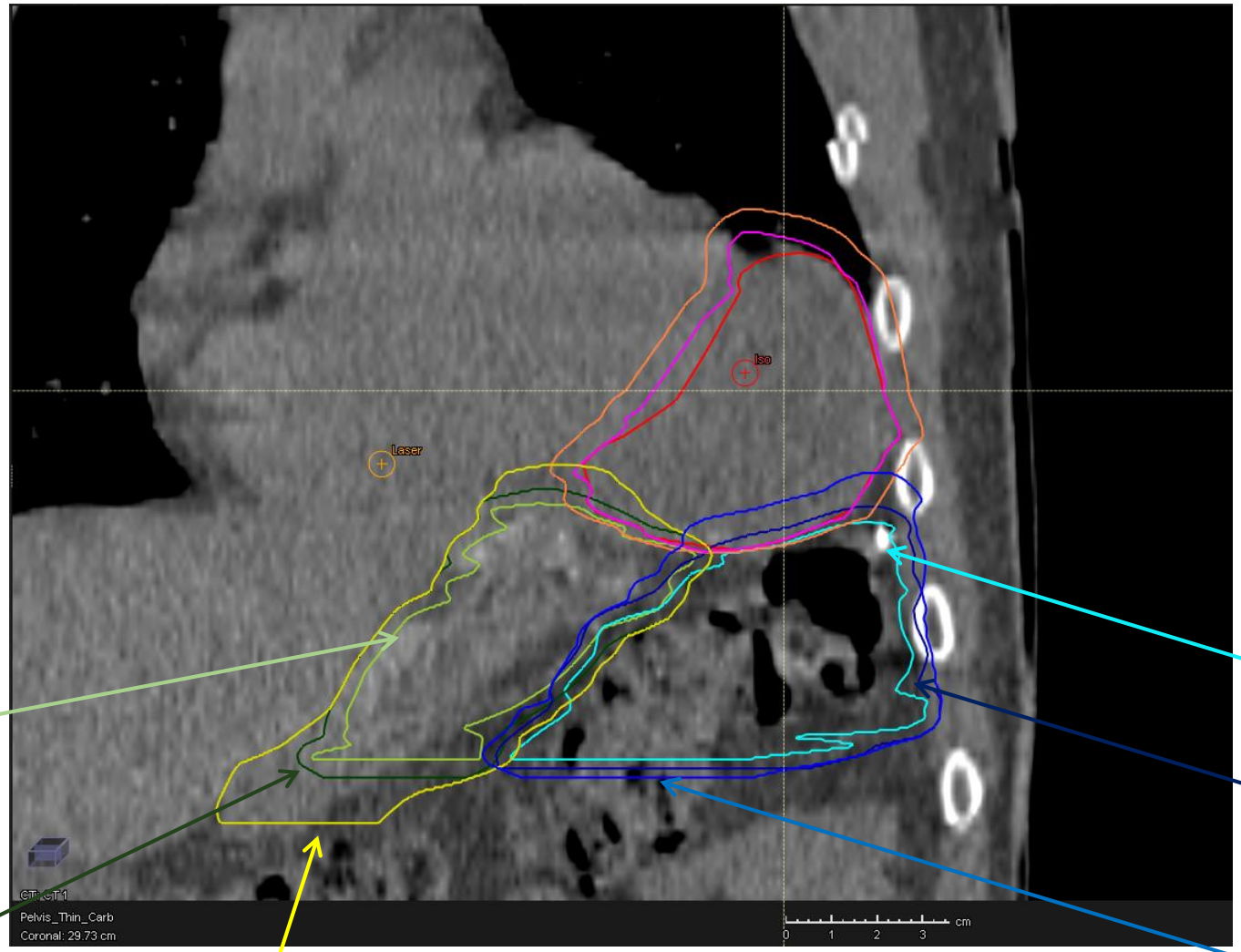
Colon

ITV

PRV of ITVs
(ITV + 3 mm)

Robust & conformal planning

OARs



Stomach

ITV

PRV of ITVs
(ITV + 3 mm)

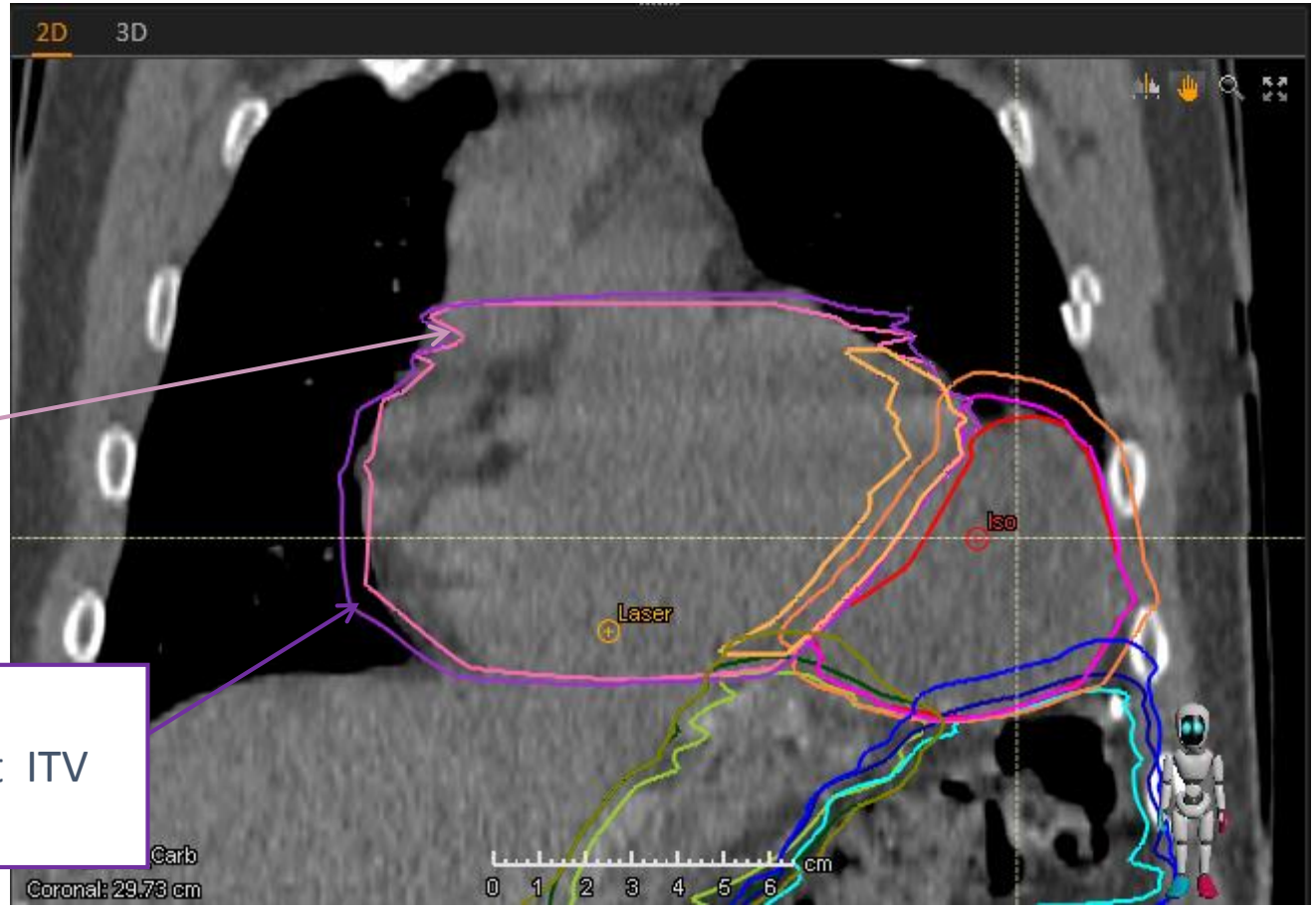
Colon

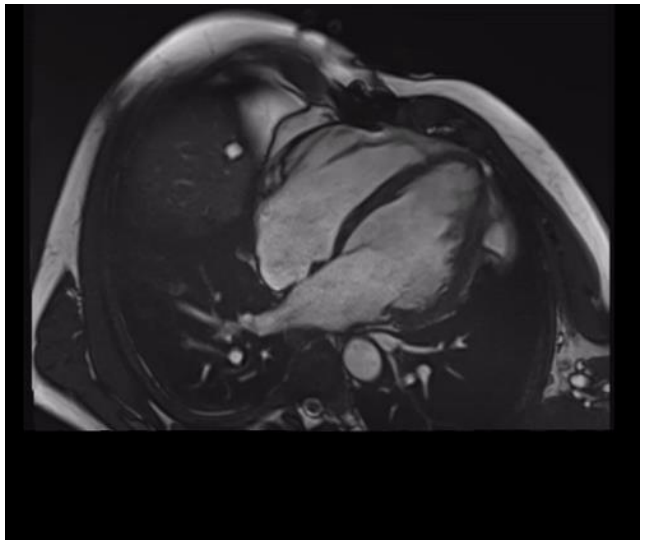
ITV

PRV of ITVs
(ITV + 3 mm)

Robust & conformal planning

OARs





Heart: evaluate motion from external cardiac MRI -> SI and LL directions (3 mm).
Heart ITV not used for plan optimization, only cardiac wall contour.

Robust & conformal planning

Plan optimization

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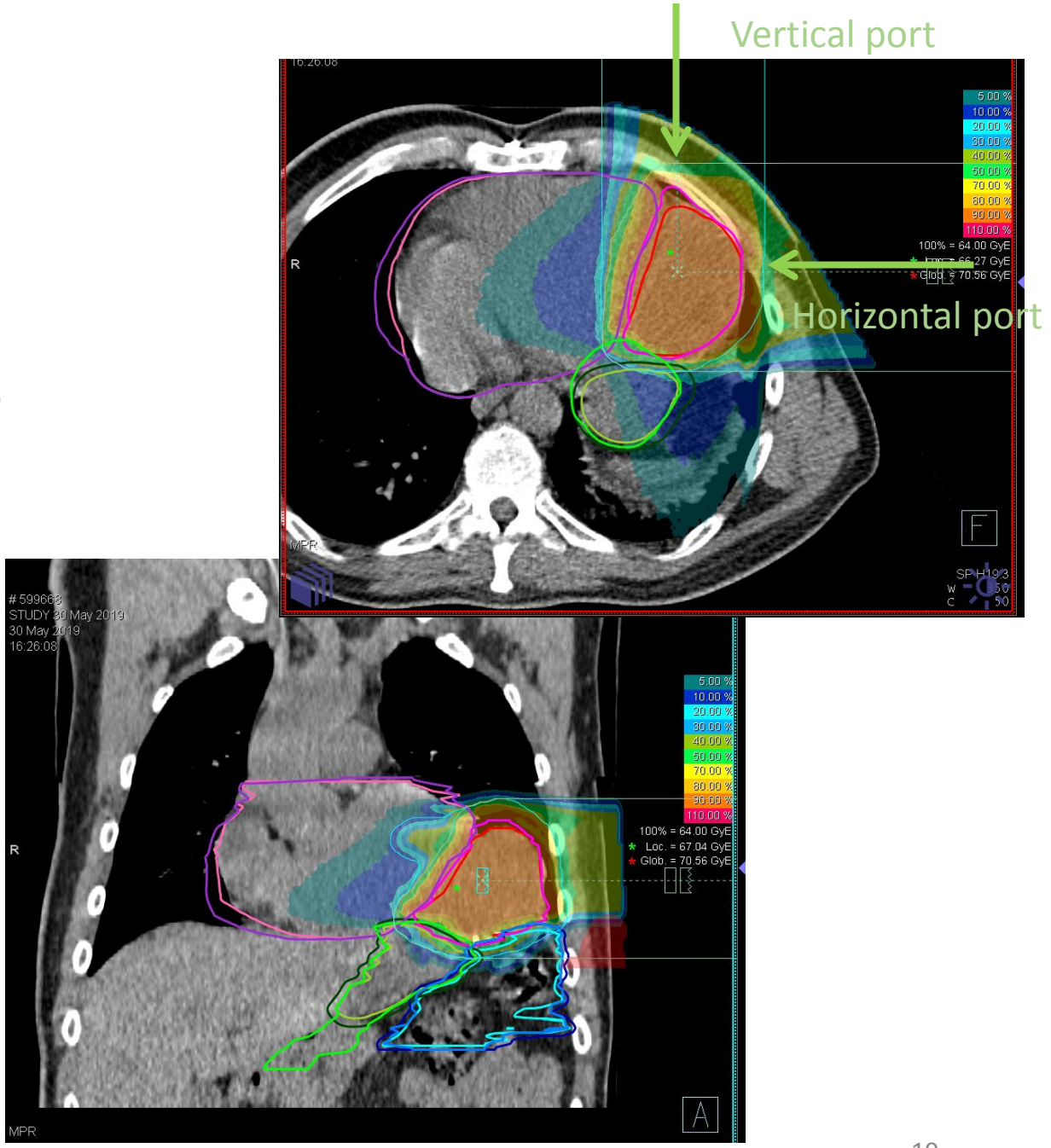

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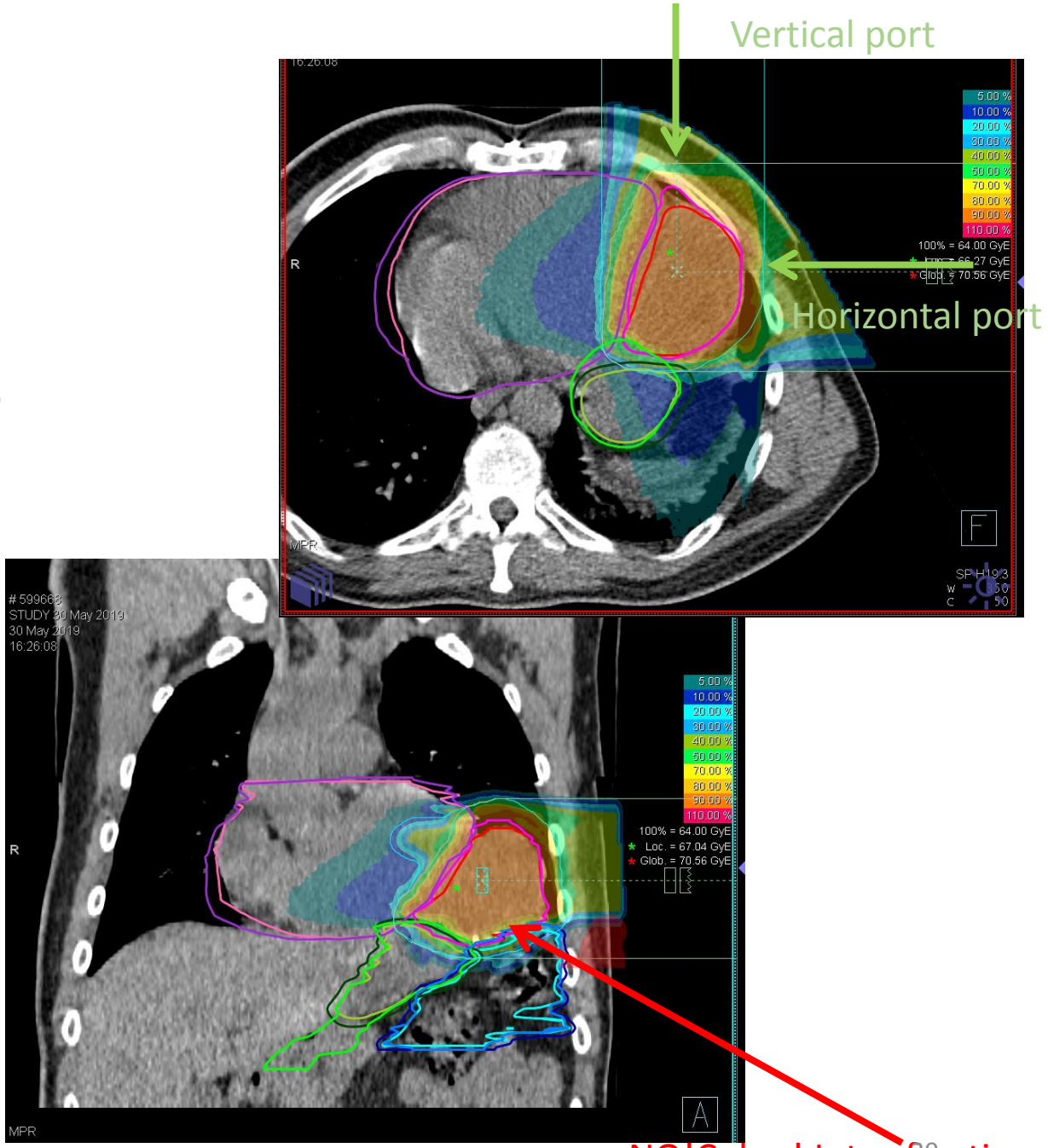

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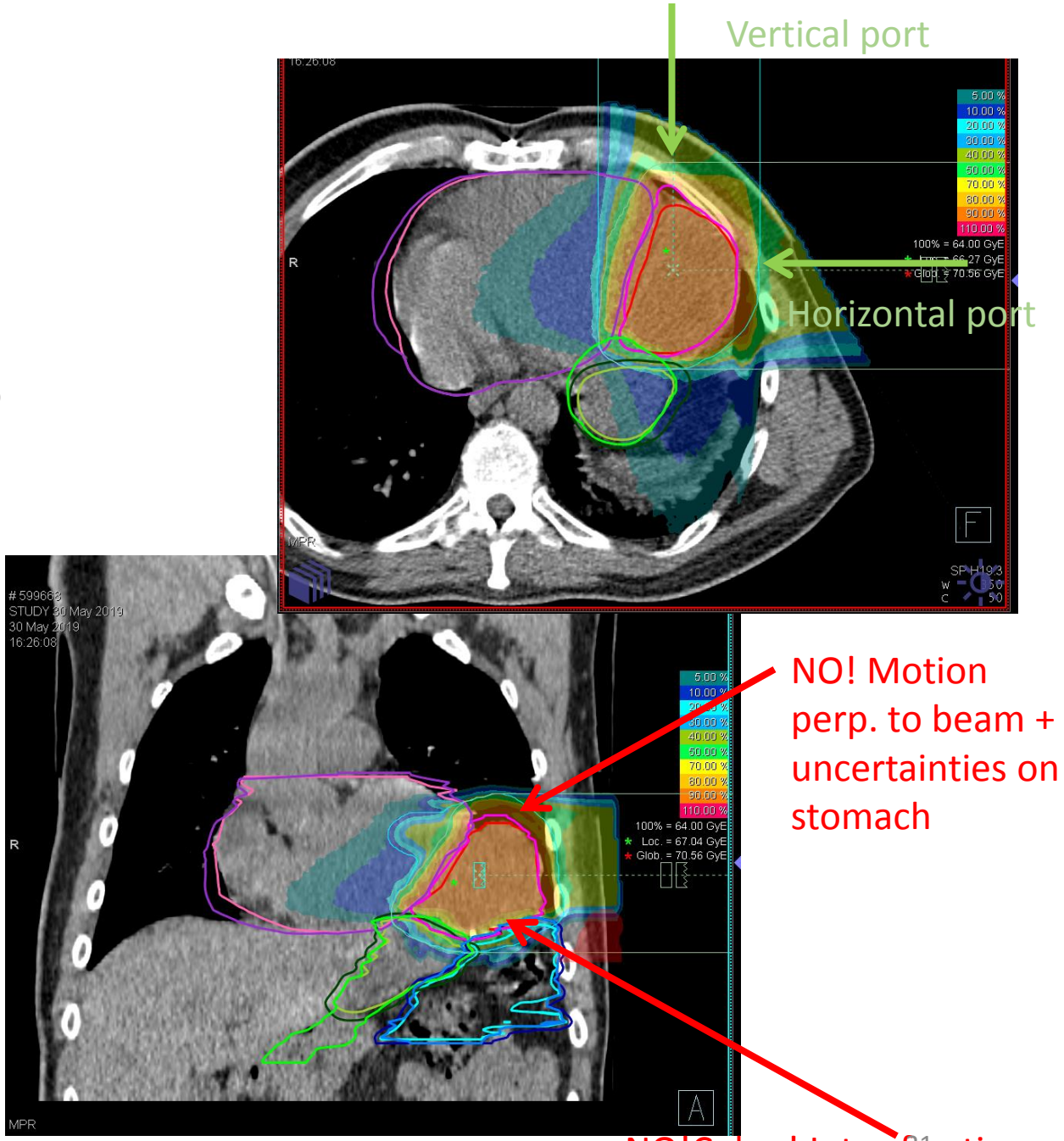

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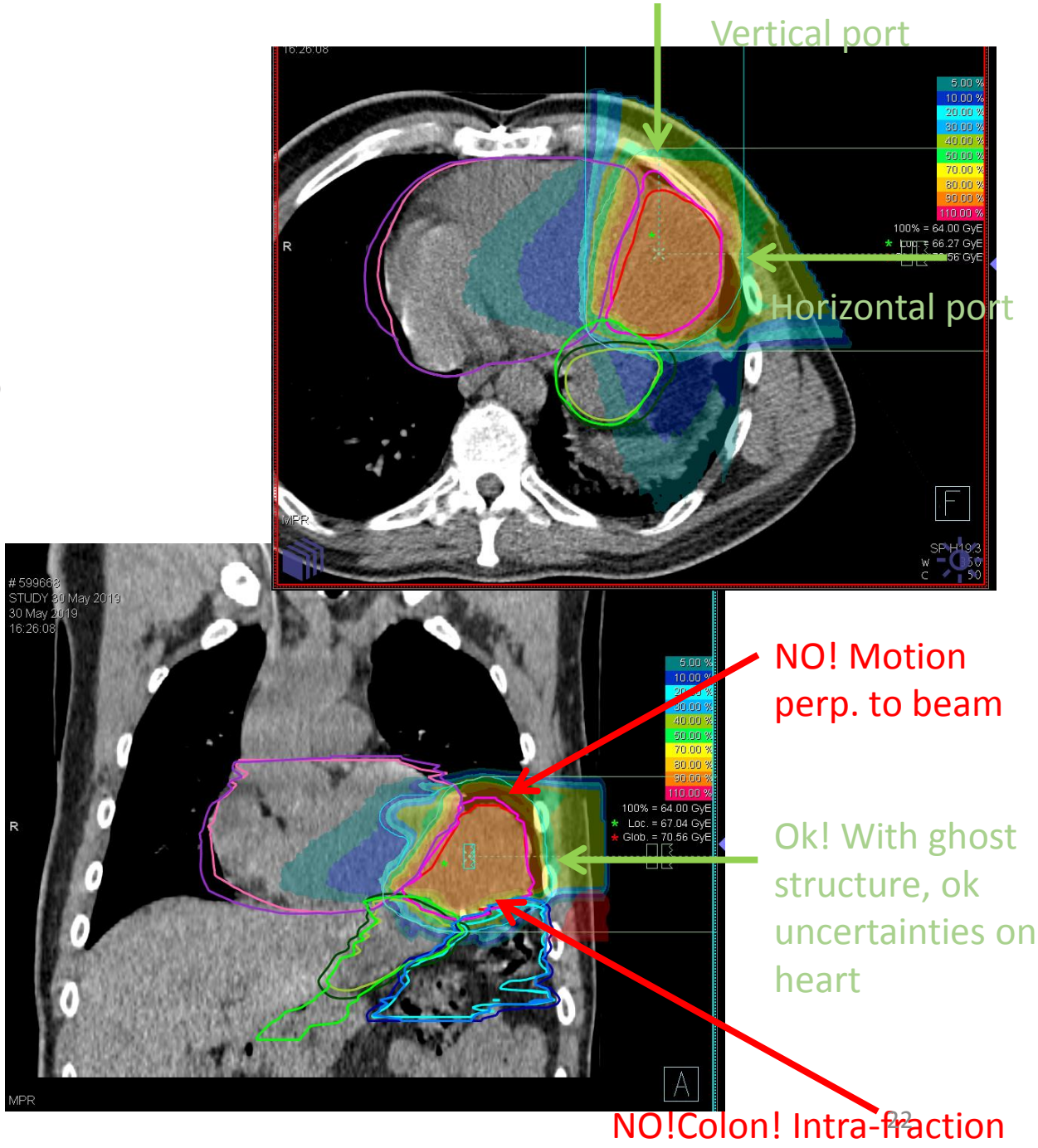

Robust & conformal planning

Plan Recalculation

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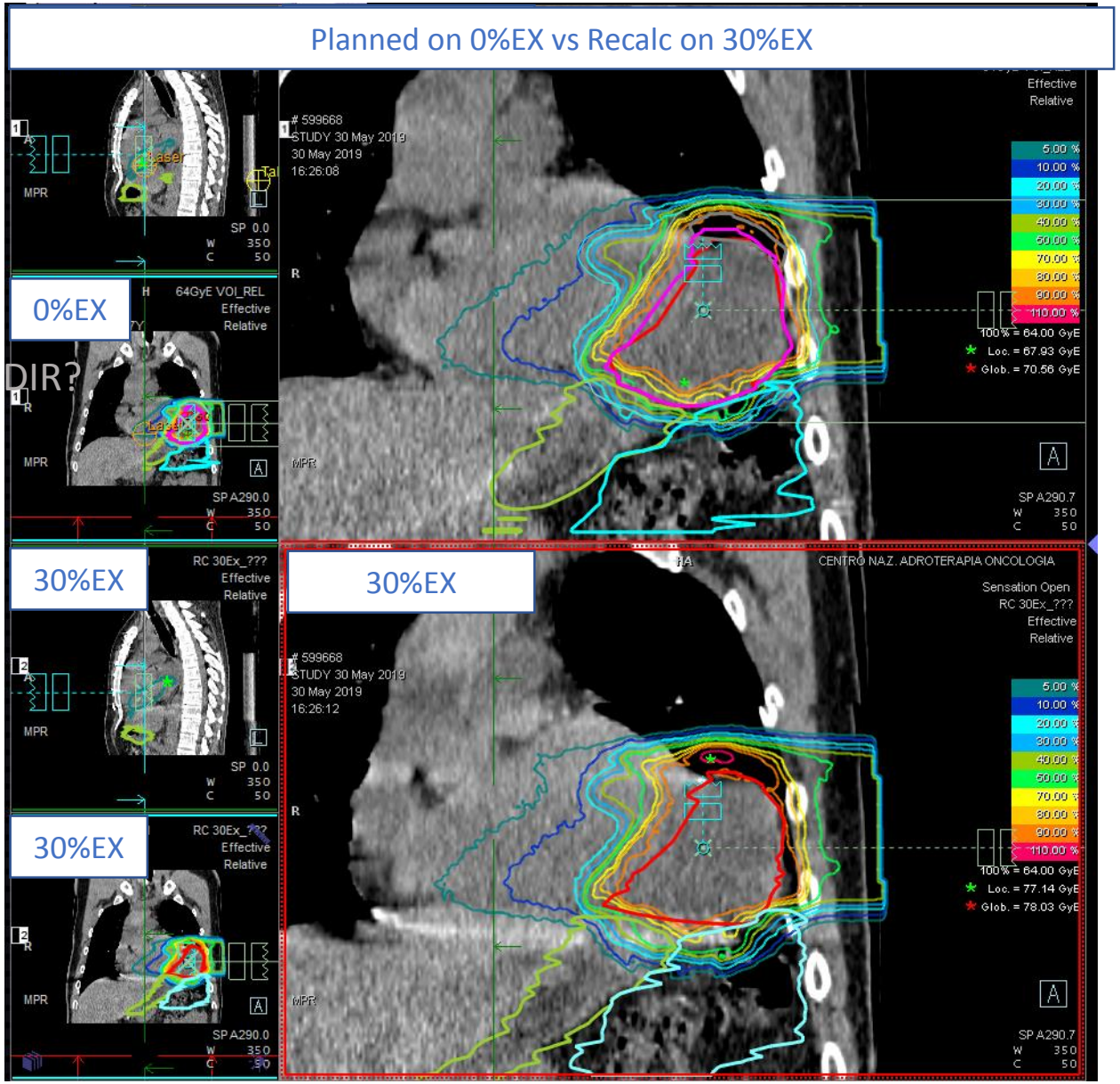

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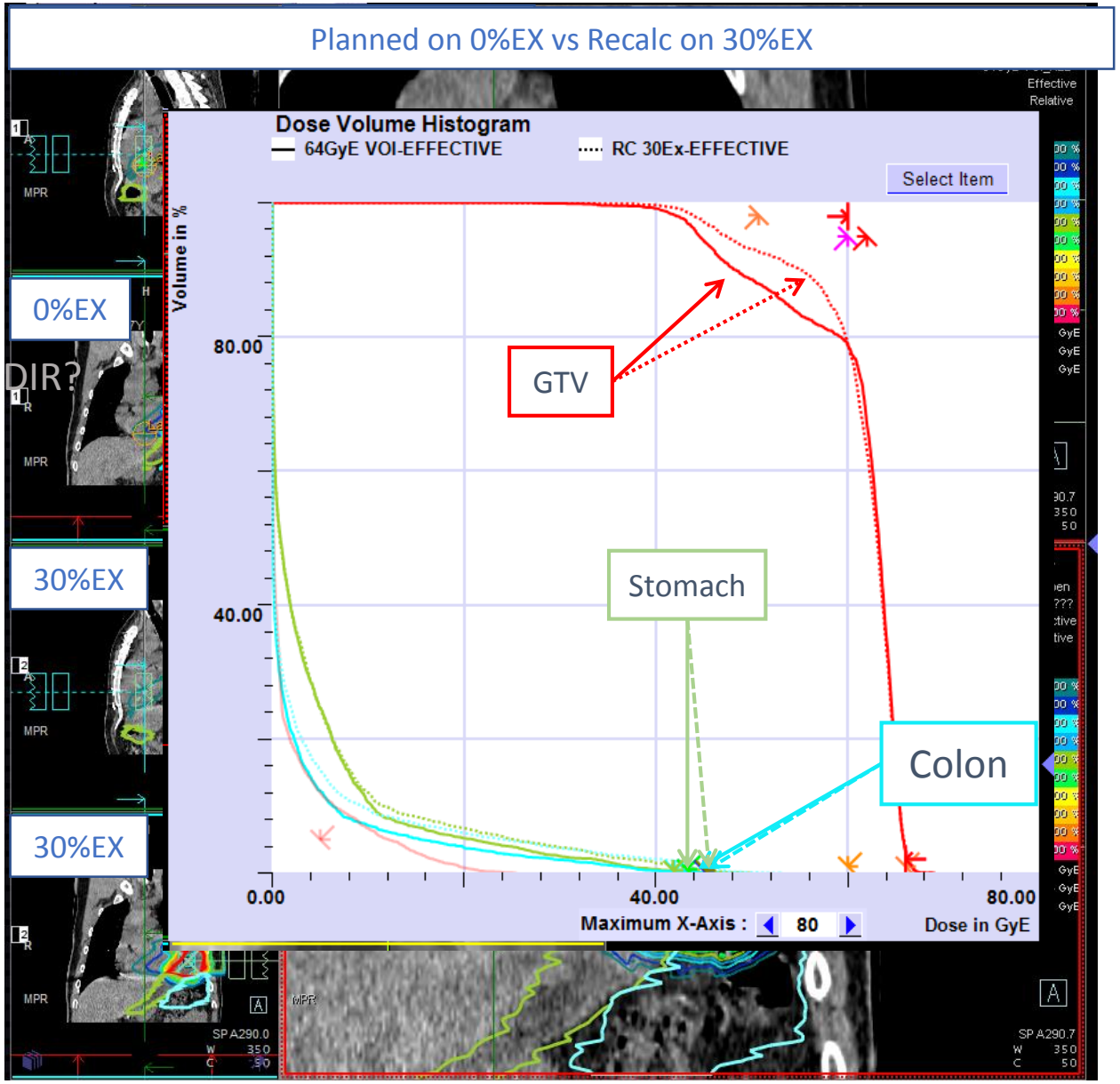

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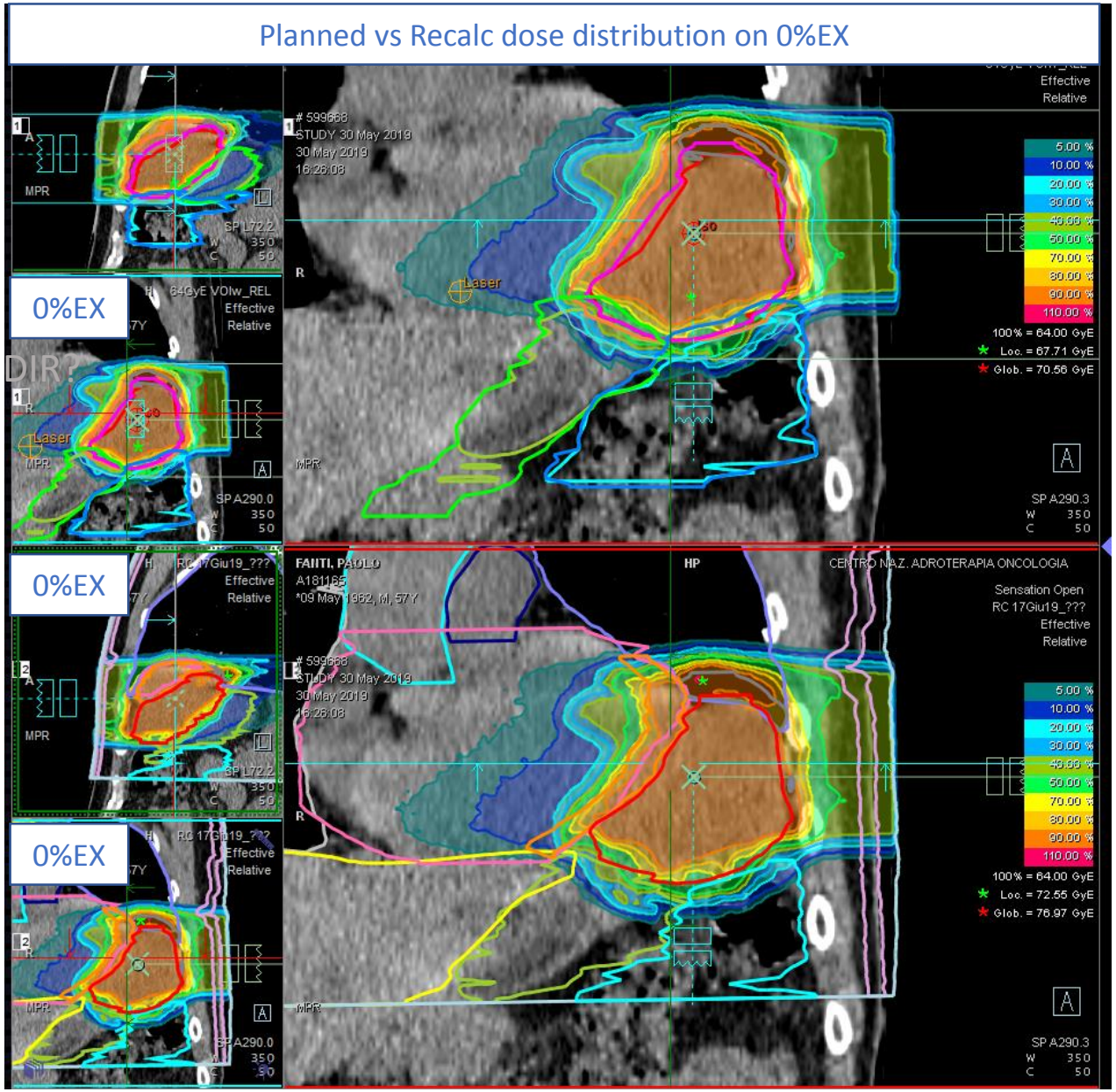

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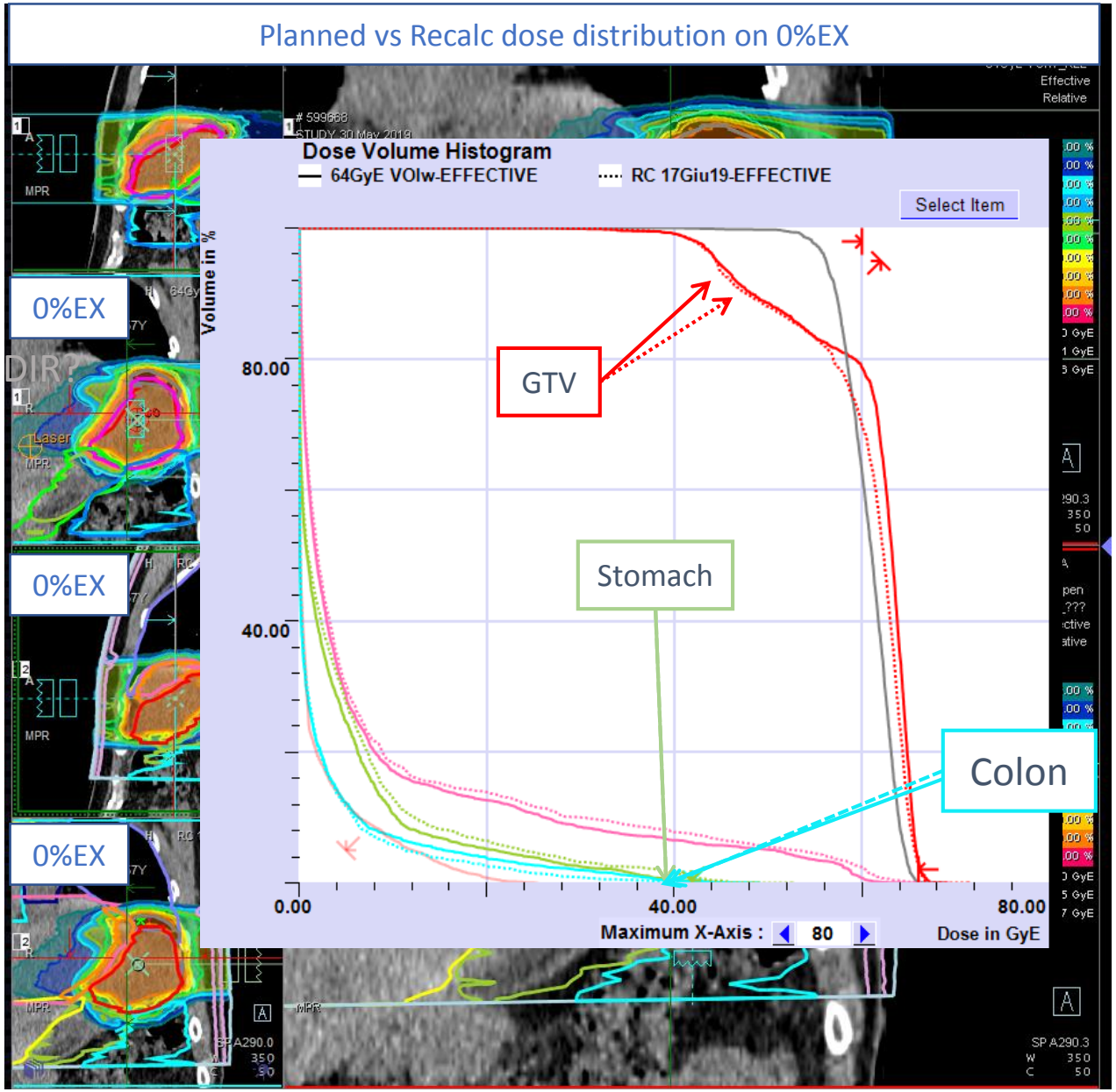

Robust & conformal planning

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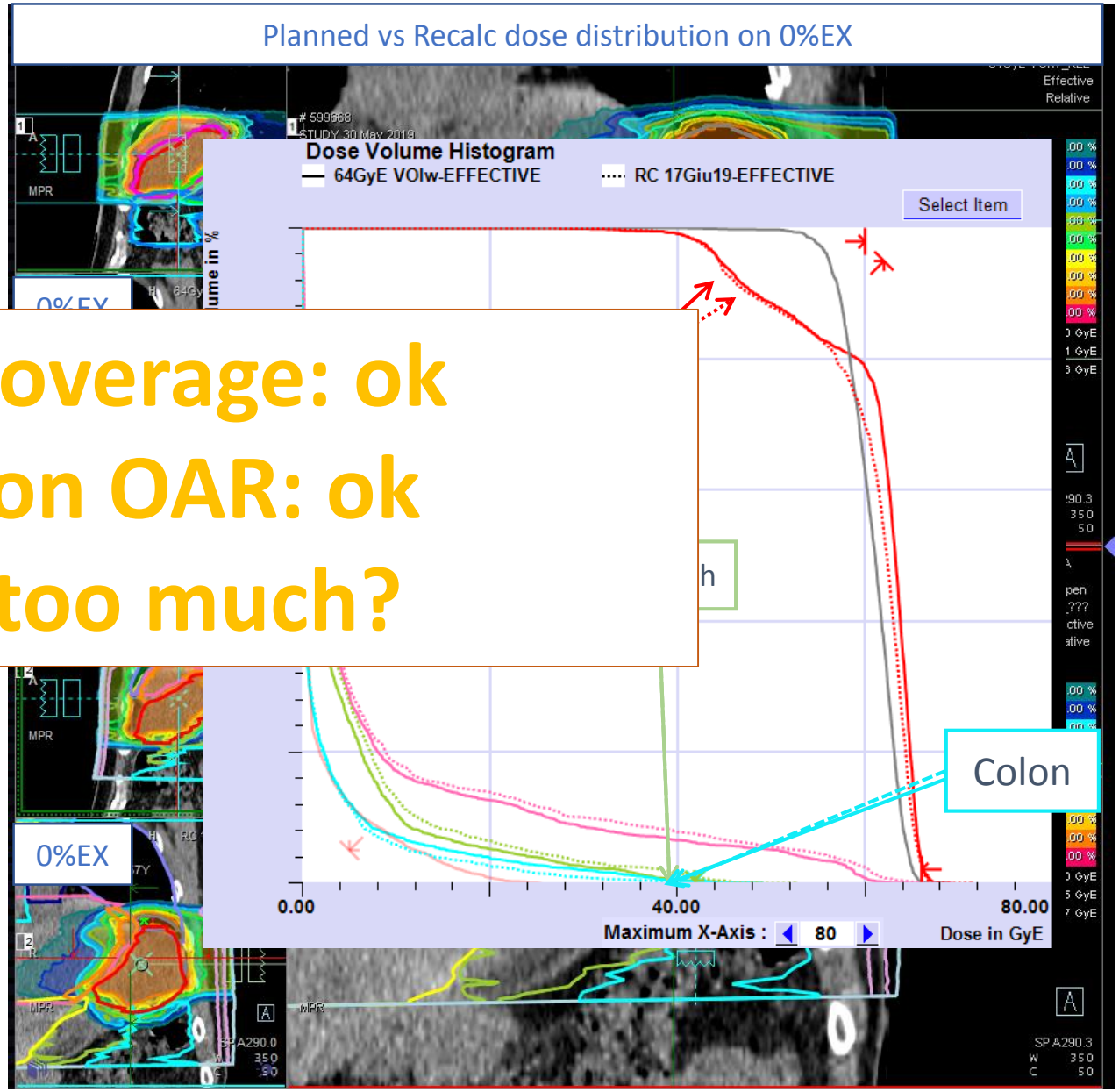
Target coverage: ok

Safety on OAR: ok

Is this too much?

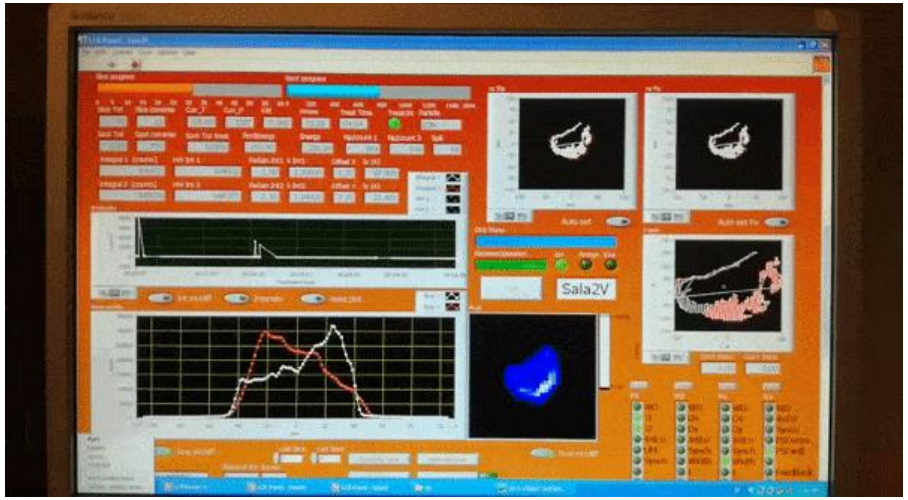


4D imaging | Planning | In-room imaging | **Delivery** | Re-evaluative imaging

Delivery: gating + layer rescanning

- Gating at end-exhale phase.
  - Adjustable flat-top time + spill extraction synchronized with gate on
  - gate window ≈ 1 s

- 5-times layer rescanning
  - *5* is a compromise:
    - same number of minimum n° particles per spot as a standard plan, for each rescan
    - more rescans -> higher threshold -> less conformal dose
  - Fractionation helps vs interplay effect



Commissioning of the 4-D treatment delivery system for organ motion management in synchrotron-based scanning ion beams

Mario Ciocca [a,*], Alfredo Mirandola [a], Silvia Molinelli [a], Stefania Russo [a], Edoardo Mastella [a], Alessandro Vai [a], Andrea Mairani [a], Giuseppe Magro [a], Andrea Pella [a], Marco Donetti [a], Francesca Valvo [a], Piero Fossati [a,b], Guido Baroni [a,c]

Physica Medica, 2016

Treatment duration: simple stats

9 patients, 27 irradiated fields

Average treat. time ≈ 9 min -> gating + rescanning

average QA time ≈ 5 min -> only rescanning

$$\frac{\text{Treat Time}}{\text{QA Time}} \approx 2.3$$

- Monitor treatment on daily imaging (CBCT, etc.) and/ or re-evaluative 4DCT;

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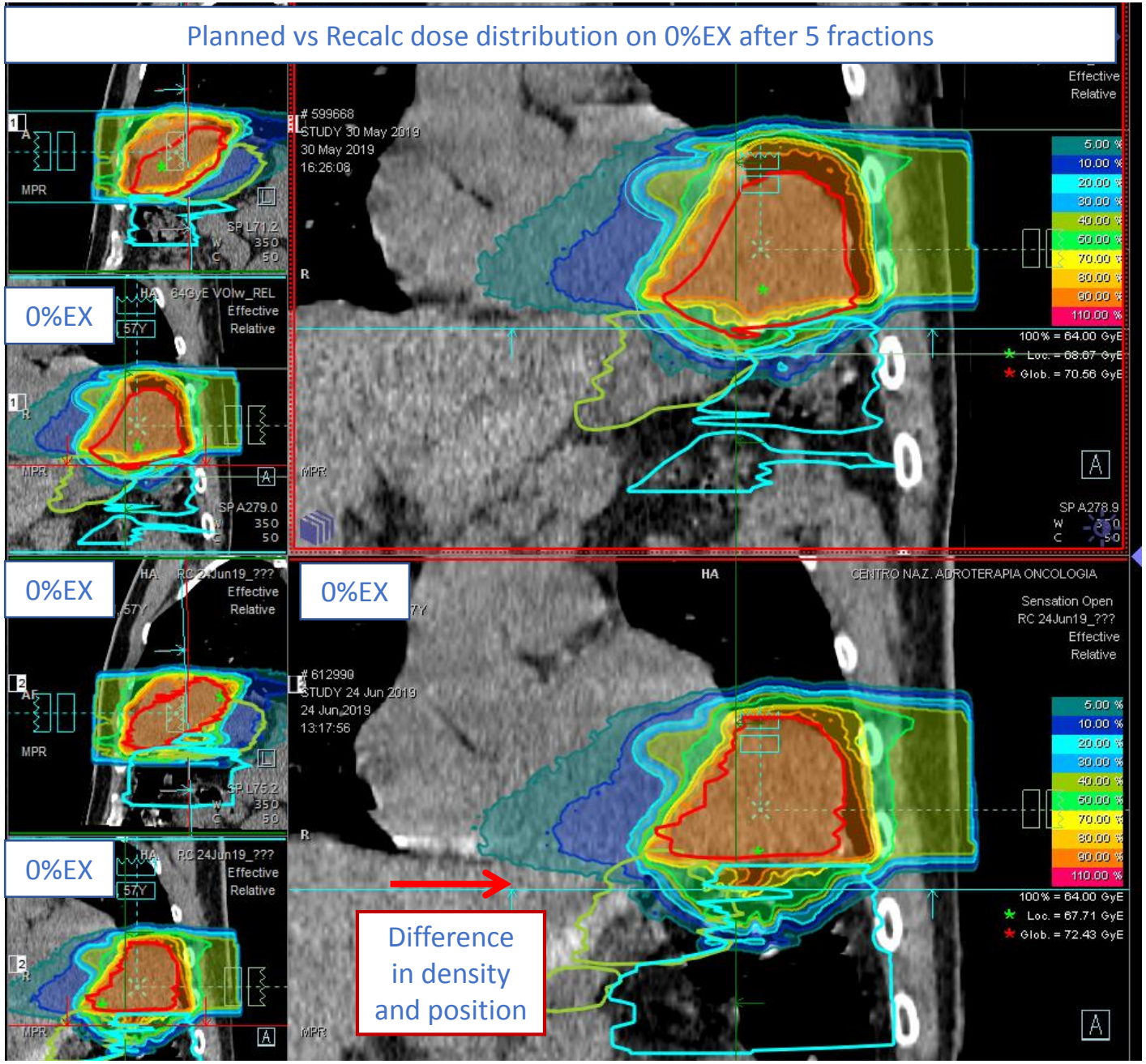
Re-evaluative 4DCT on the 2° week

Pericardial leiomyosarcoma
Carbon ion – 64Gy (RBE), 16fr/ 4 Gy(RBE)



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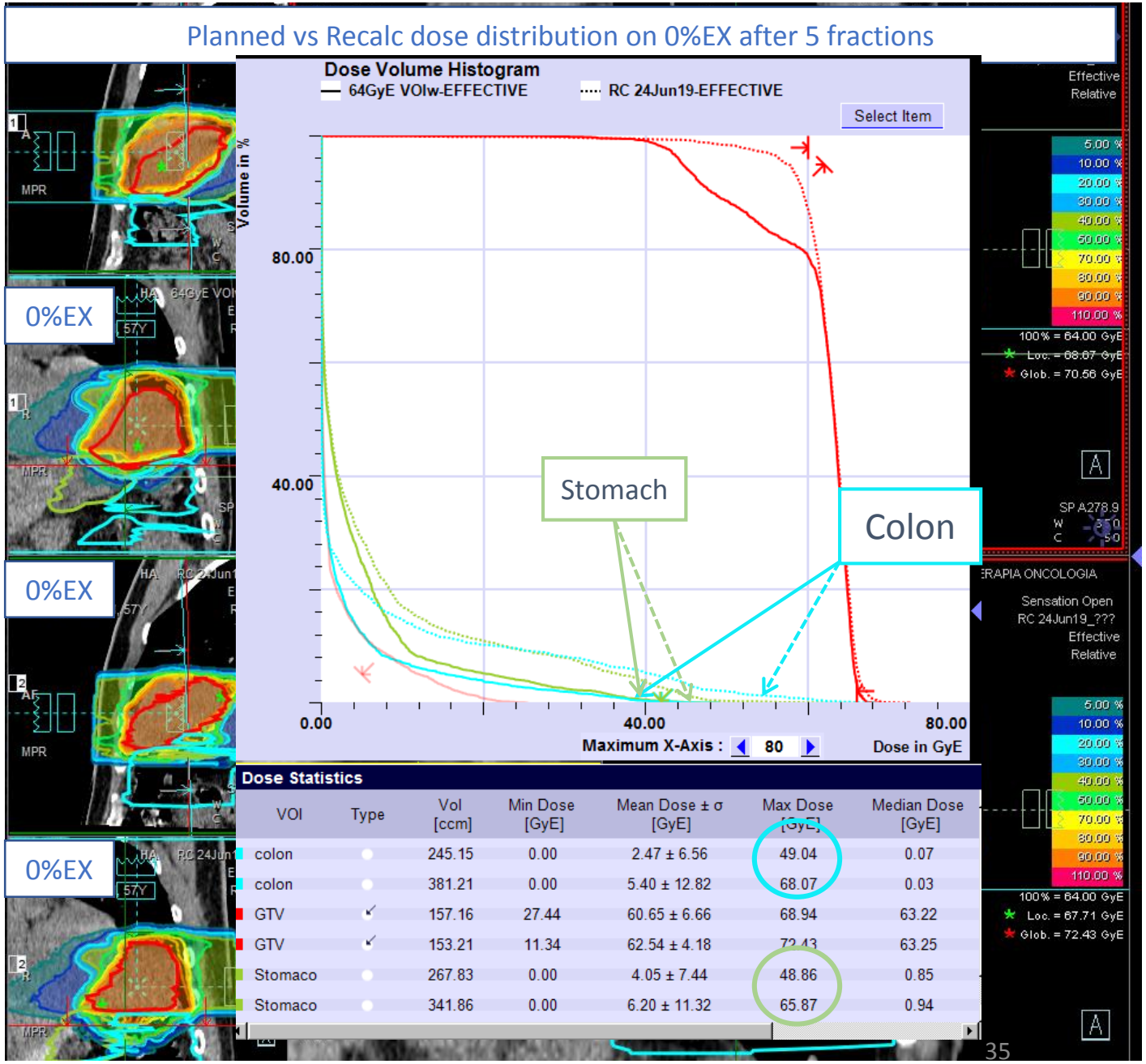


- Monitor treatmer
  imaging (CBCT, et
  or re-evaluative 4

Re-evaluative 4D

Pericardial leiomyo

Carbon ion – 64Gy (RBE), 16fr/ 4 Gy(RBE)

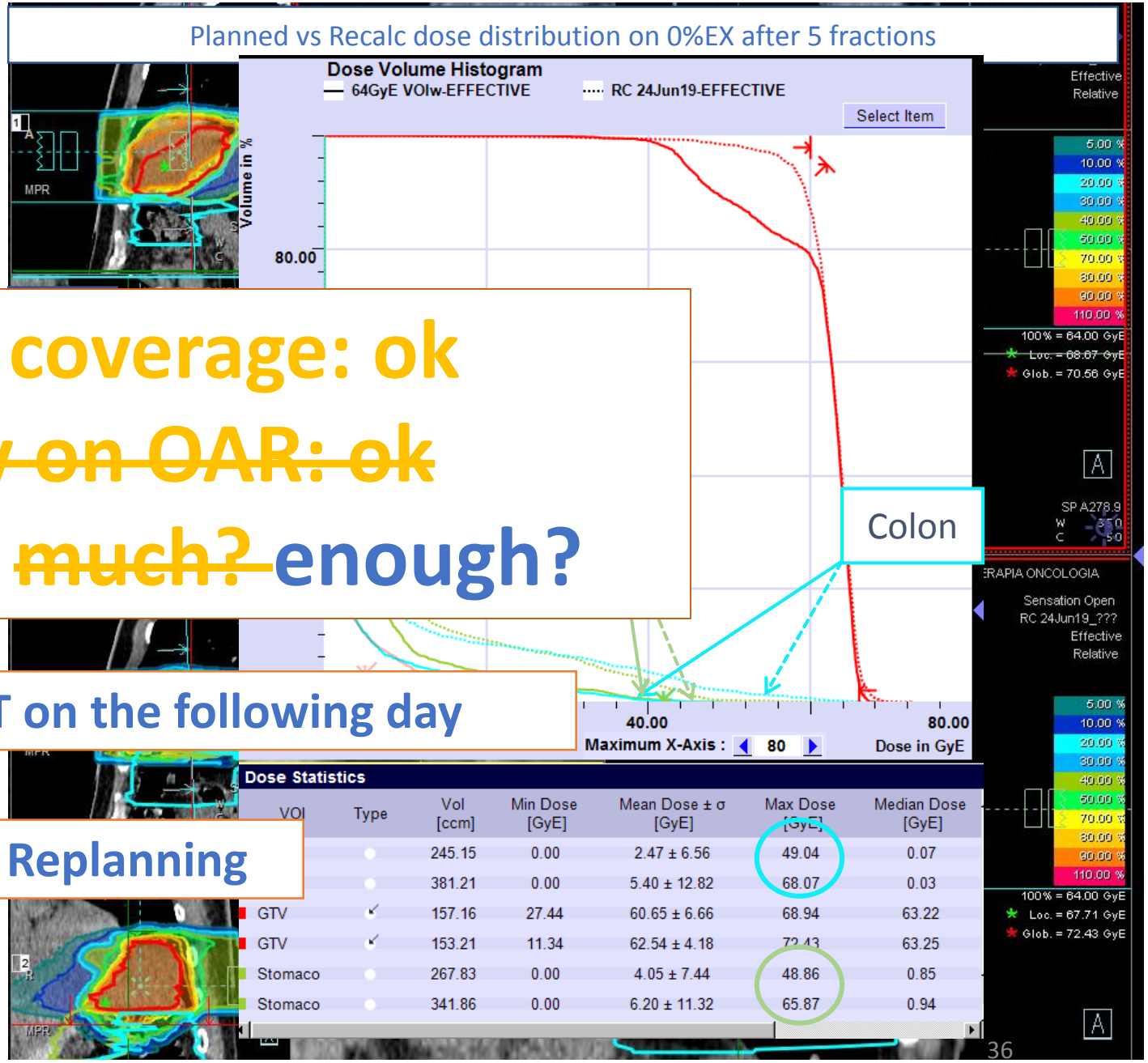
Target coverage: ok

~~Safety on OAR: ok~~

Is this too ~~much?~~ enough?

New 4DCT on the following day

Replanning



Under development (1): robust planning

Commercial TPS with tools for **robust planning**:

- with protons (Raystation, Eclipse...)
- with carbon ions (Raystation v.8b)

The TPS simulates scenarios of setup and range uncertaintes, or organ motion as represented by a 4D set, and optimize a robust plan.

Under development (1): robust planning

Commercial TPS with tools for **robust planning**:

- with protons (Raystation, Eclipse...)
- with carbon ions (Raystation v.8b)

The TPS simulates scenarios of setup and range uncertaintes, or organ motion as represented by a 4D set, and optimize a robust plan.

Minimax optimization for handling range and setup uncertainties in proton therapy

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Methods: Dose contributions for a number of range and setup errors are calculated and a minimax optimization is performed. The minimax optimization aims at minimizing the penalty of the worst case scenario. Any optimization function from conventional treatment planning can be utilized by the method. By considering only scenarios that are physically realizable, the unnecessary conser-

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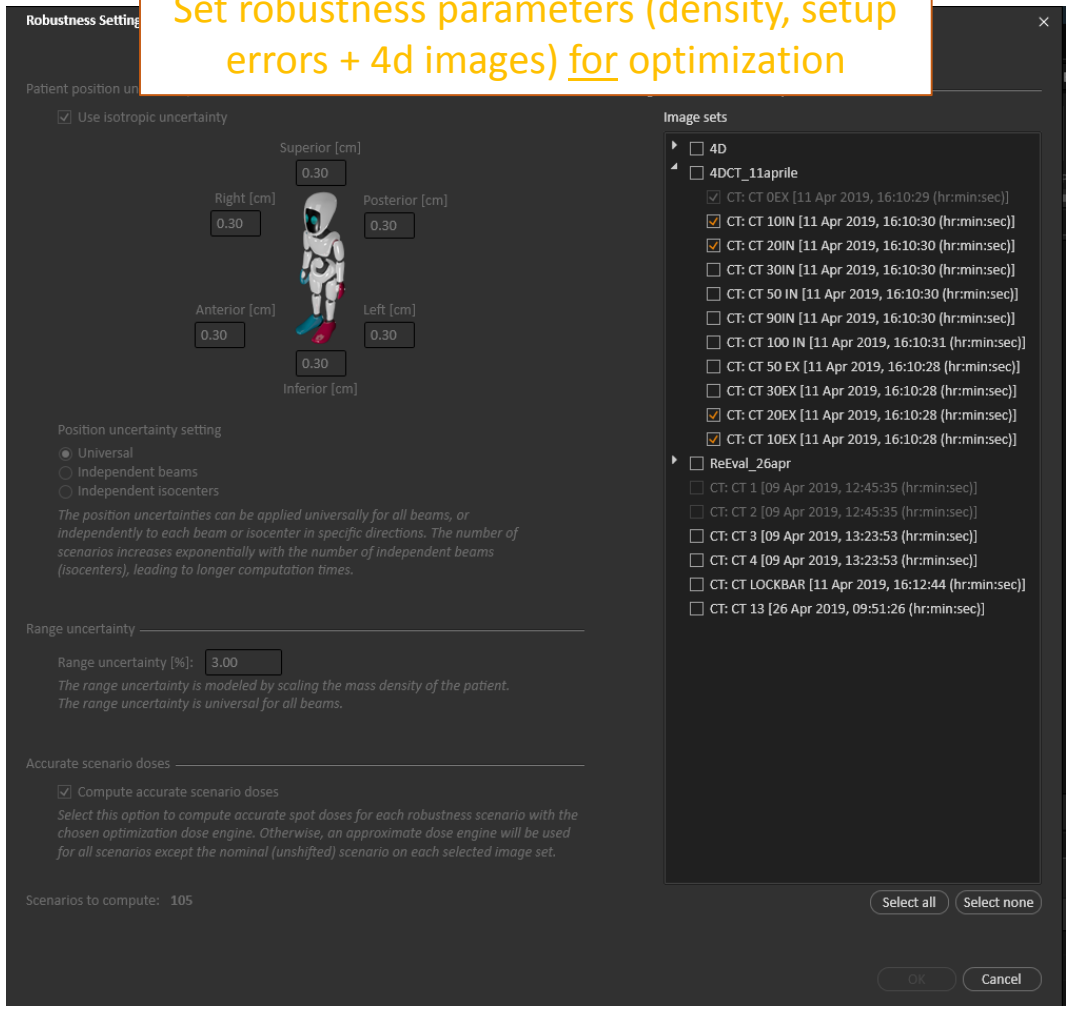
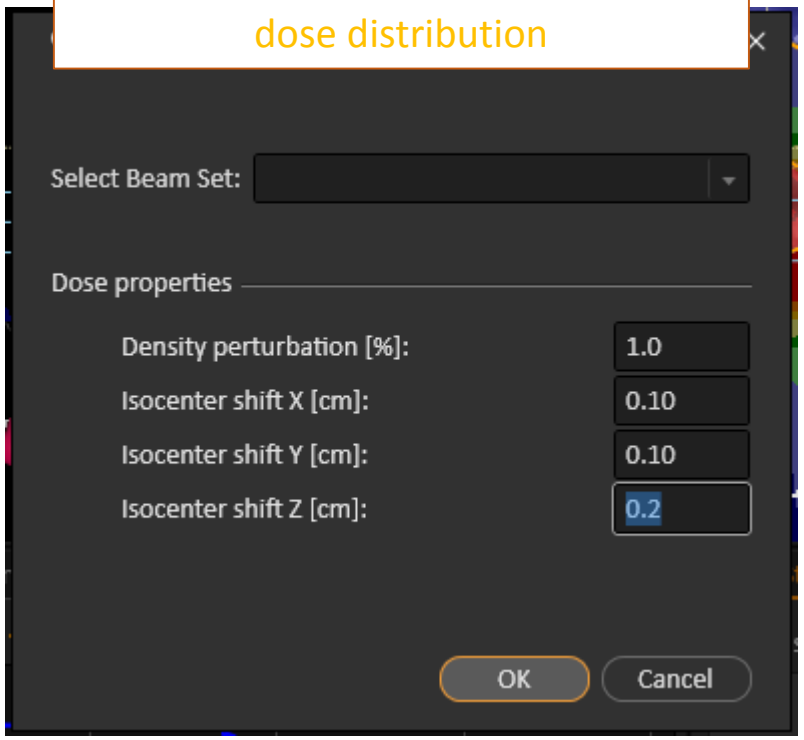
Under development (1): robust planning

Set robustness parameters (density, setup errors + 4d images) for optimization

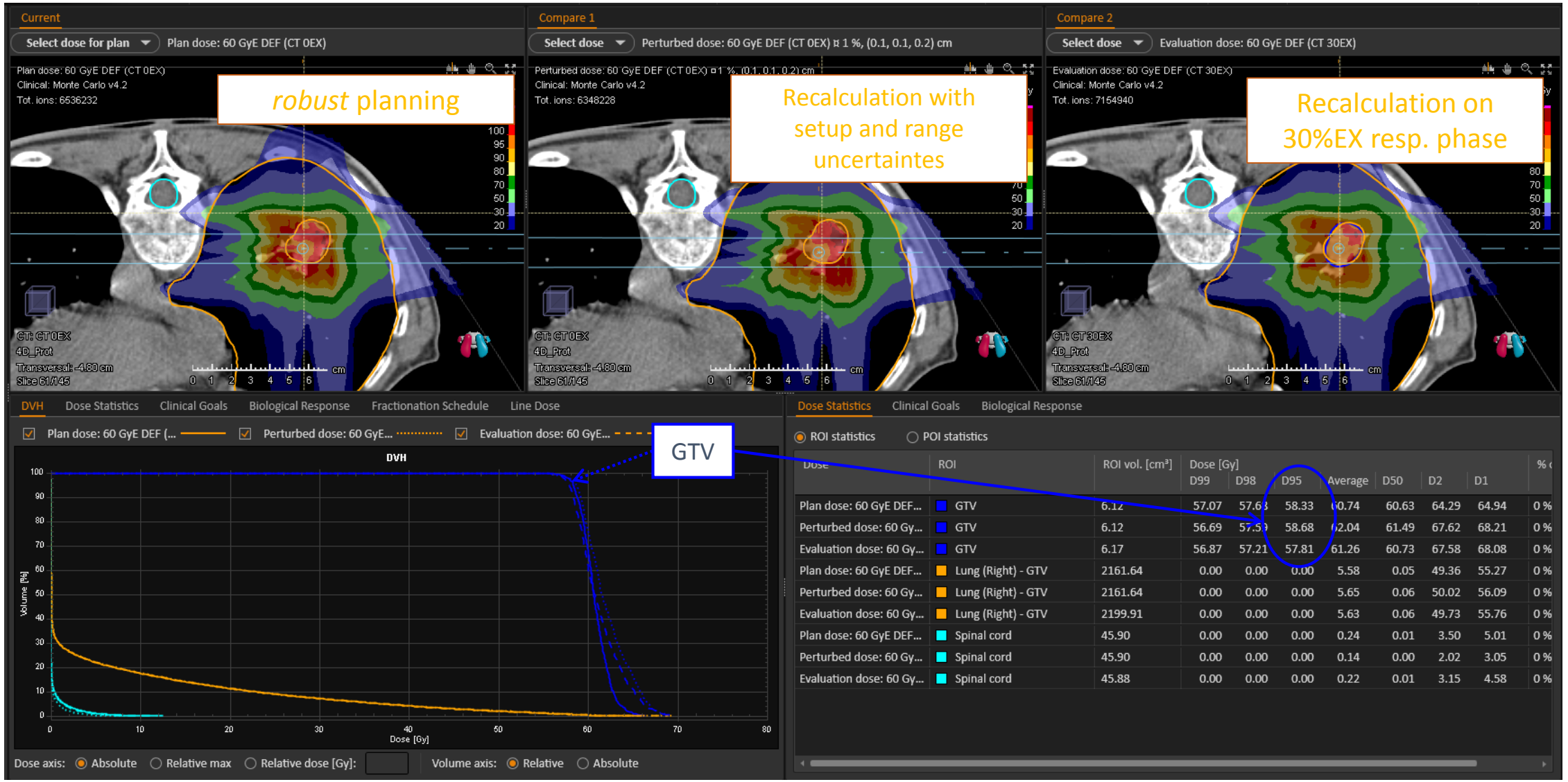


Evaluate robustness on calculated dose distribution



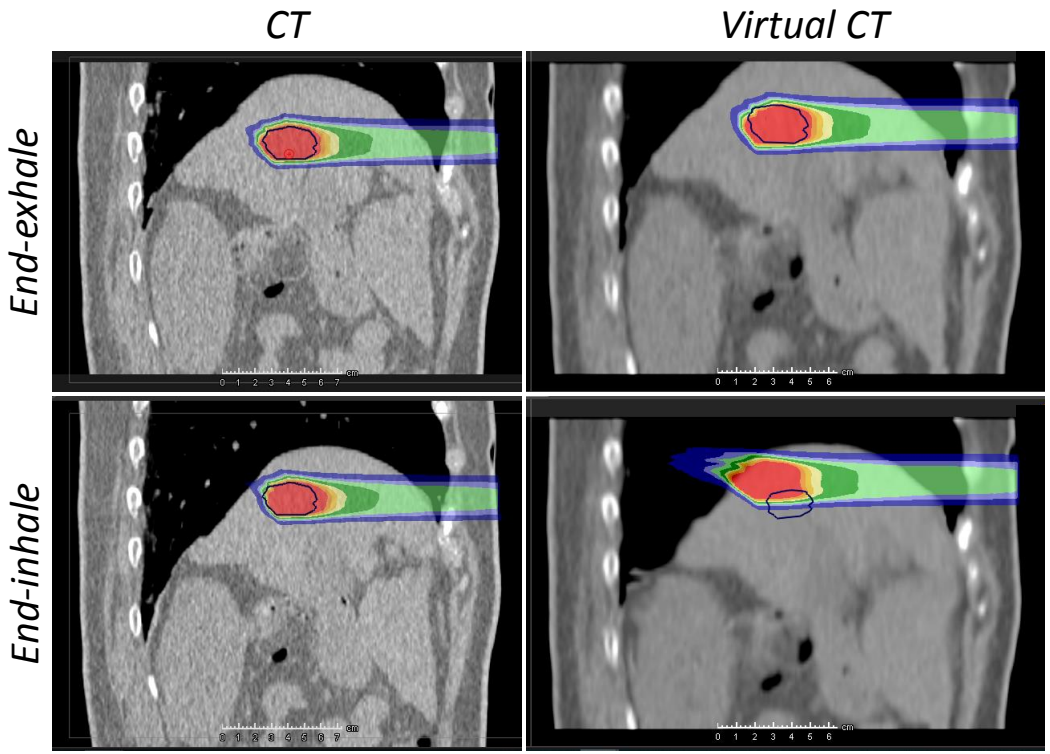
Robust planning

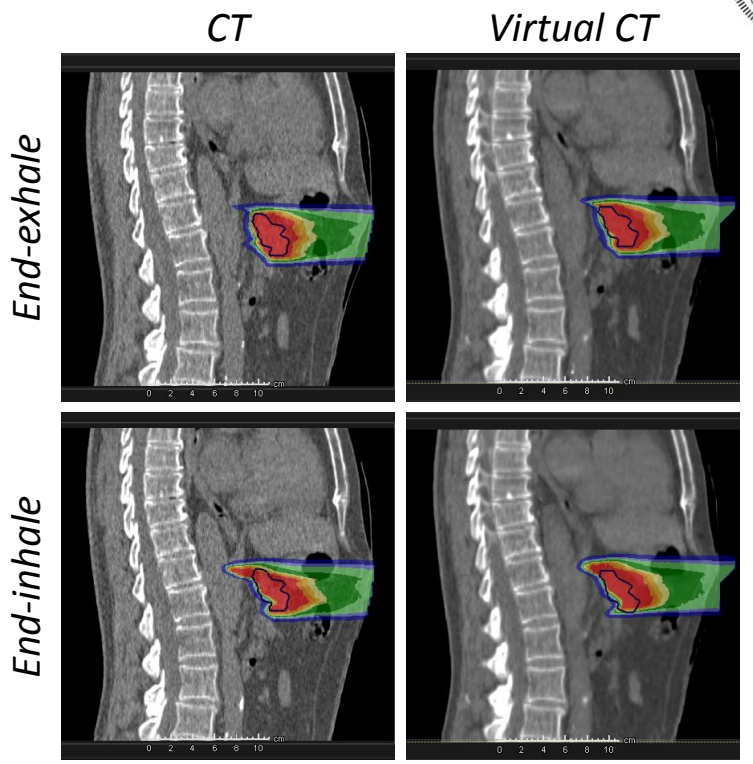
Lung adenocarcinoma, P, 60 Gy(RBE) 10fr/6Gy(RBE), IMPT



Dose	ROI	ROI vol. [cm³]	Dose [Gy] D99	D98	D95	Average	D50	D2	D1	%
Plan dose: 60 GyE DEF...	GTV	6.12	57.07	57.63	58.33	60.74	60.63	64.29	64.94	0 %
Perturbed dose: 60 Gy...	GTV	6.12	56.69	57.53	58.68	62.04	61.49	67.62	68.21	0 %
Evaluation dose: 60 Gy...	GTV	6.17	56.87	57.21	57.81	61.26	60.73	67.58	68.08	0 %
Plan dose: 60 GyE DEF...	Lung (Right) - GTV	2161.64	0.00	0.00	0.00	5.58	0.05	49.36	55.27	0 %
Perturbed dose: 60 Gy...	Lung (Right) - GTV	2161.64	0.00	0.00	0.00	5.65	0.06	50.02	56.09	0 %
Evaluation dose: 60 Gy...	Lung (Right) - GTV	2199.91	0.00	0.00	0.00	5.63	0.06	49.73	55.76	0 %
Plan dose: 60 GyE DEF...	Spinal cord	45.90	0.00	0.00	0.00	0.24	0.01	3.50	5.01	0 %
Perturbed dose: 60 Gy...	Spinal cord	45.90	0.00	0.00	0.00	0.14	0.00	2.02	3.05	0 %
Evaluation dose: 60 Gy...	Spinal cord	45.88	0.00	0.00	0.00	0.22	0.01	3.15	4.58	0 %

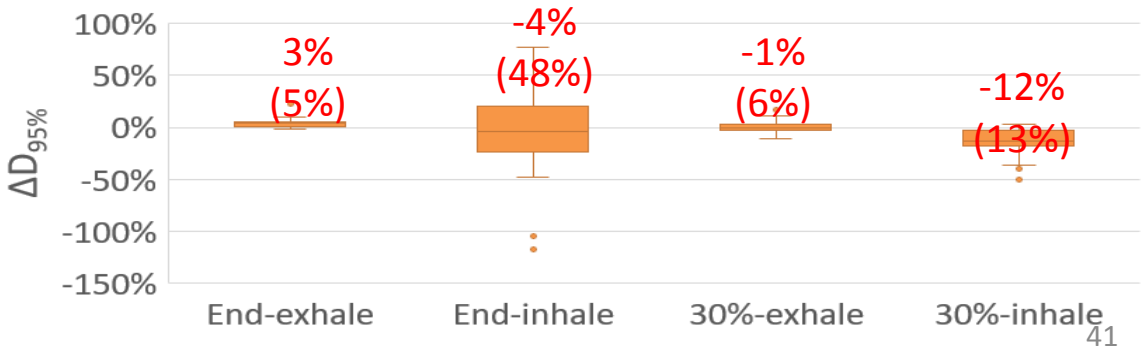
On development (2): use of MRI





CIRT plans optimized on end-exhale CT, recomputed on other phases and on virtual 4DCT

[submitted manuscript]



On development (3): delivered dose fraction estimation

The 4DD is the averaged sum of the doses calculated on all N (typically 10) individual phases of a 4D CT scan using the planned fluence without considering the time dependence of the delivery fluence. To calculate the 4DDD, details on the time dependence of the delivery fluence are considered together with changes in anatomy owing to respiratory motion (19, 20, 41). A

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Critical Review

Consensus Guidelines for Implementing Pencil-Beam Scanning Proton Therapy for Thoracic Malignancies on Behalf of the PTCOG Thoracic and Lymphoma Subcommittee

- From machine log-file: time point each spot is delivered at which geometric position;
- From gating system: which was the patient anatomy at the delivery of a particular spot

Retrospective evaluation of dose degradation per fraction

Four-Dimensional Patient Dose Reconstruction for Scanned Ion Beam Therapy of Moving Liver Tumors

Daniel Richter, PhD,*,† Nami Saito, PhD,* Naved Chaudhri, PhD,‡ Martin Härtig, MSc,§ Malte Ellerbrock, PhD,‡ Oliver Jäkel, PhD,‡,§ Stephanie E. Combs, MD,§ Daniel Habermehl, MD,§ Klaus Herfarth, MD,§ Marco Durante, PhD,*,† and Christoph Bert, PhD*,‖

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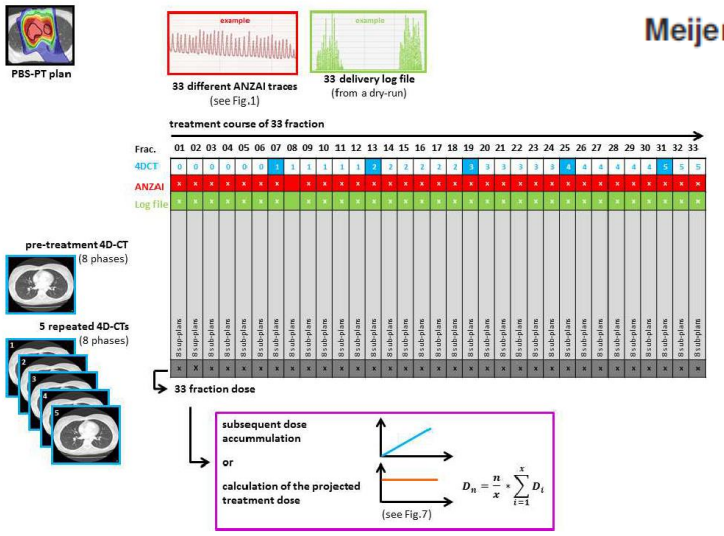
Log file-based dose reconstruction and accumulation for 4D adaptive pencil beam scanned proton therapy in a clinical treatment planning system: Implementation and proof-of-concept



Meijers *et al.*: Med. Phys. 46 (3), March 2019

tionality. For most realistic dose assessment, input data comprised the treatment delivery machine log files of 33 fractions and the patient's breathing patterns, which were acquired during treatment, as well as weekly acquired 4D-CT datasets taken throughout the treatment course. The precision of the 4D dose reconstruction methodology is experimentally validated using a dynamic CIRS thorax phantom.

Thanks!

…. and questions