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A. Bolsi, D. C. Weber, T. Lomax and the CPT team Paul Scherrer Institut

Current and future strategies developed at Paul Scherrer Institute

ICTR 2016, 15th-19th February 2016, Geneva

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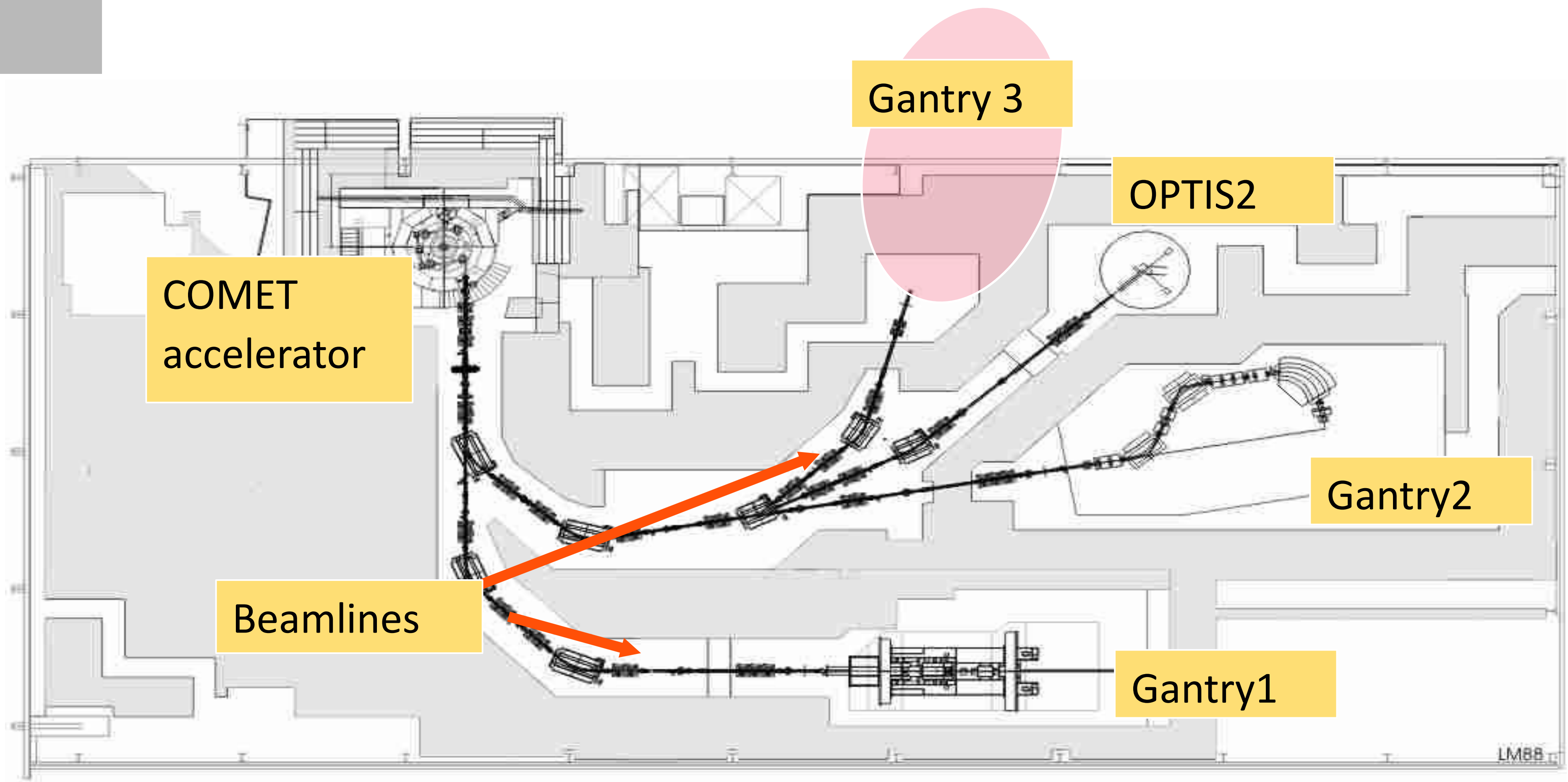
Overview

- Facilities at PSI
- Line scanning
- Treatments of moving targets
- Daily Adaptive Proton Therapy (DAPT)
- Dose calculation from log files
- Advanced imaging

Facility at PSI



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Facility at PSI

Gantry1 (1996, 1093 pts)

OPTIS (1984, 6691 pts)

Gantry2 (2013, 57 pts)

Gantry3 (2016)

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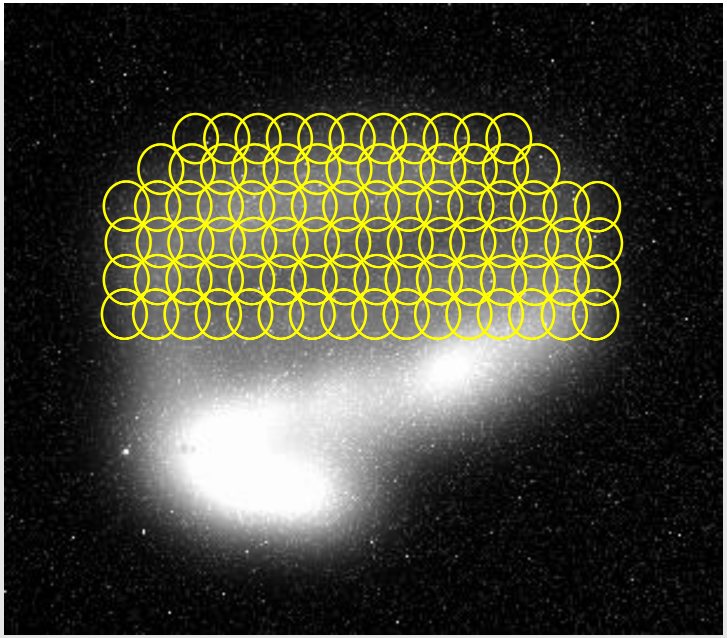
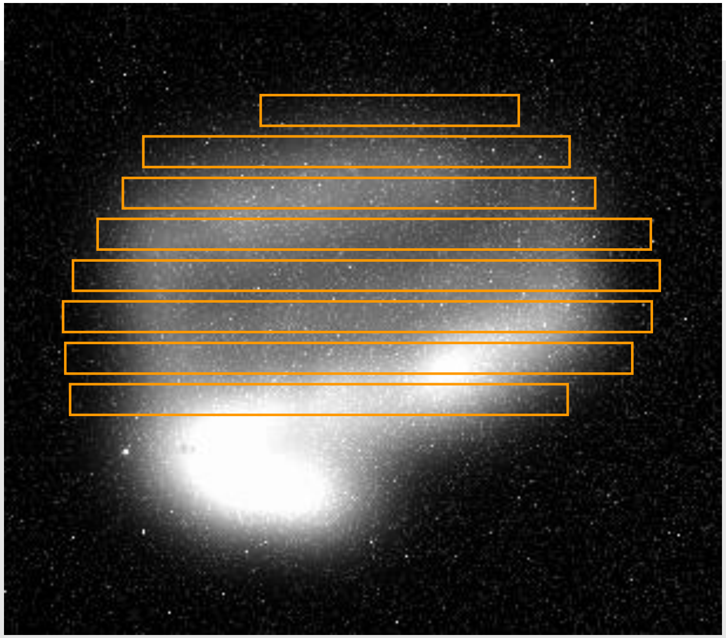
Advanced scanning





Discrete spot scanning

- Switching off the beam after each spot
- Dead time per spot ~ 3ms

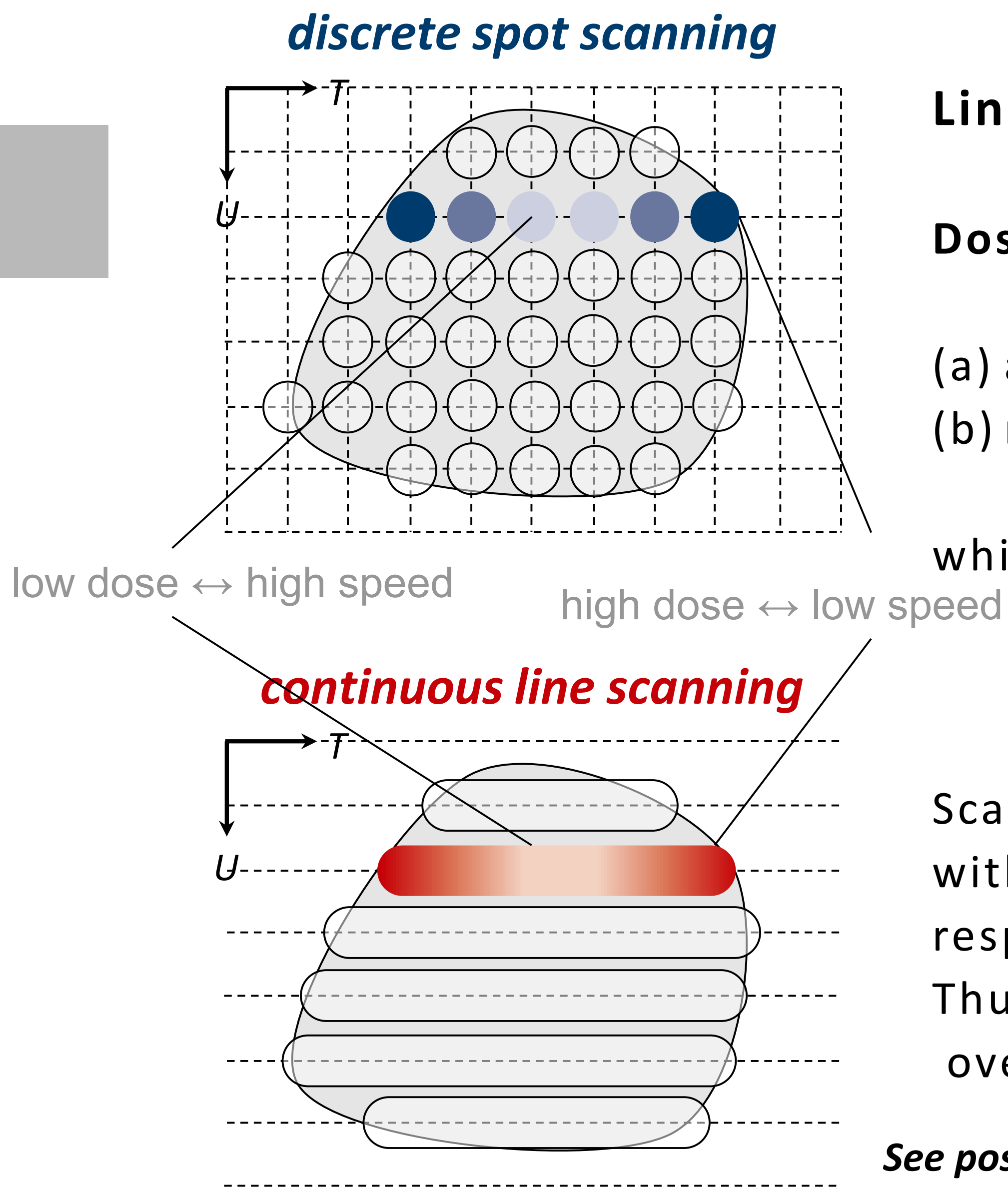
- Accurate dose delivery
- Discrete spot scanning is actual operation mode of Gantry 2

Continuous line scanning

- Paint lines of dose with continuous beam on

- For efficient and effective rescanning
- Operational in experimental mode, in development

Advanced scanning



Line scanning:

Dose modulation is achieved by

(a) adapting the scan speed *v* and
(b) modulating the beam current *I*

while scanning along straight lines

Scanner magnets can be controlled with high precision and short response time.
Thus, **speed modulation** is favorable over current modulation.

See poster: "Fast dose modulation in proton therapy with continuous line scanning" ,G. Klimpsi et al.

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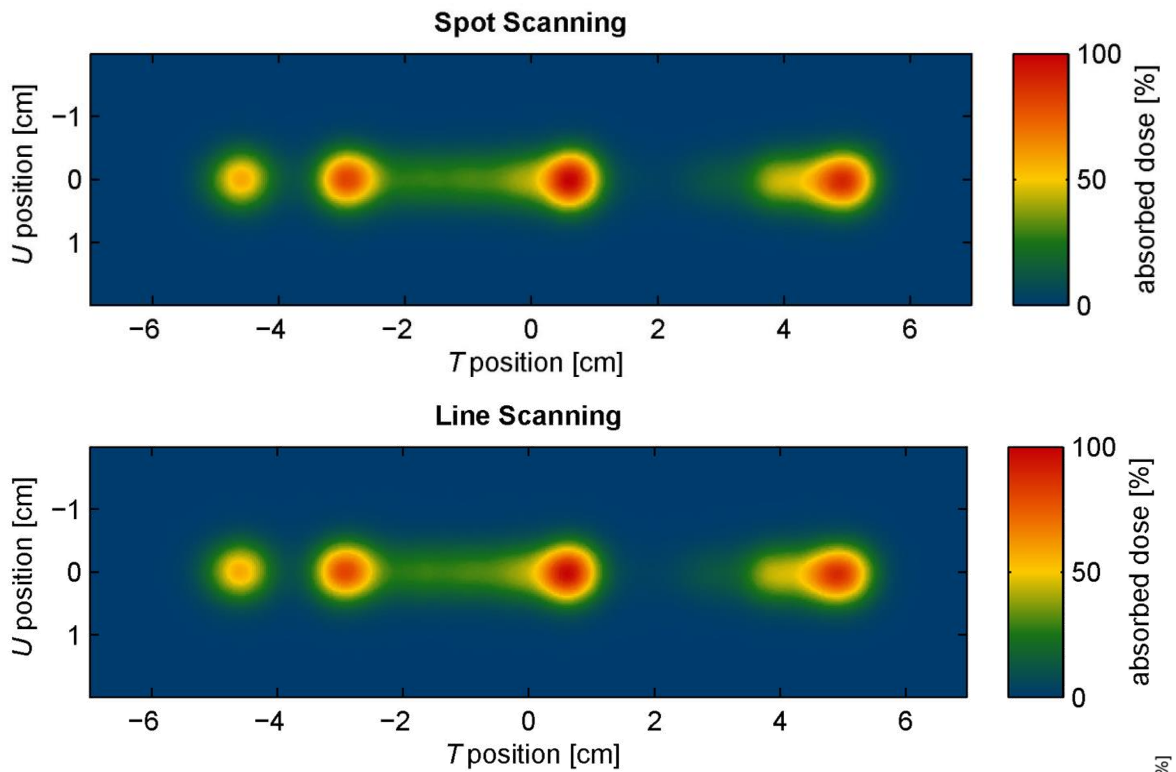
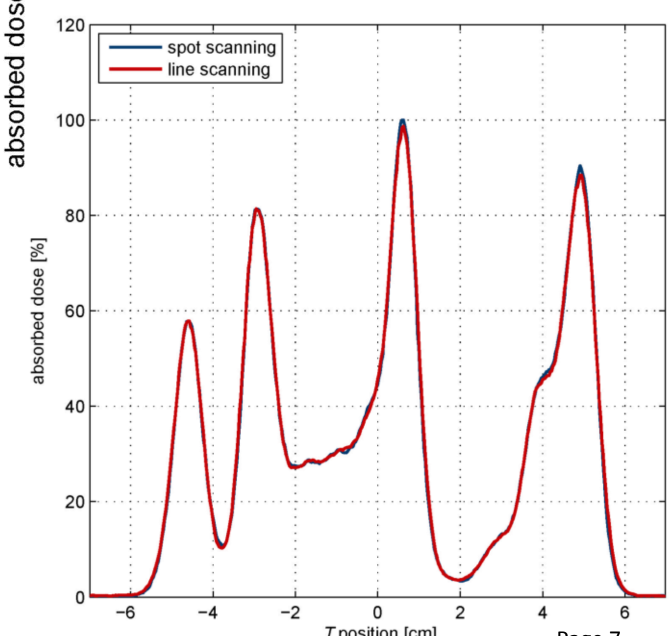
Advanced scanning



Highly modulated dose distribution delivered with spot scanning (top) and line scanning (bottom).



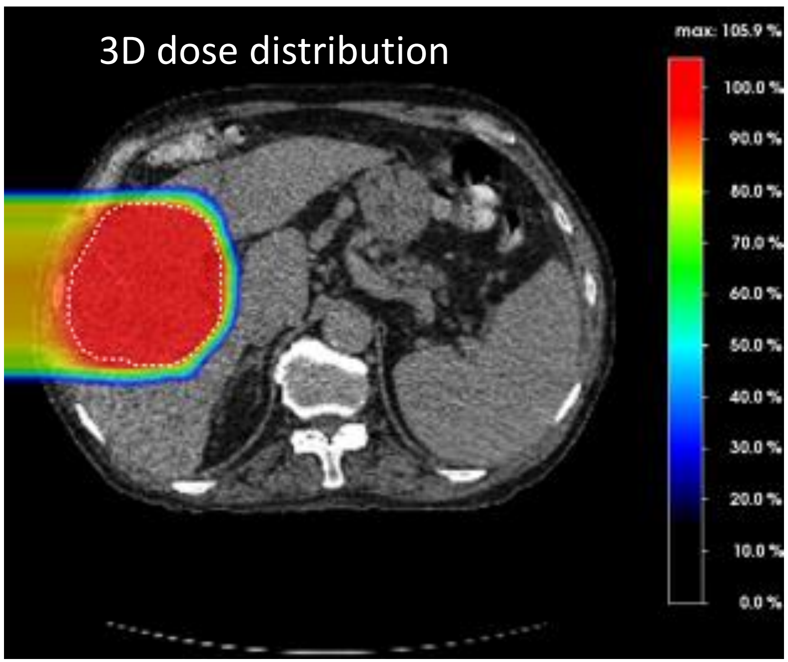
See poster: "Fast dose modulation in proton therapy with continuous line scanning" G. Klimpsi et al.

4D treatments

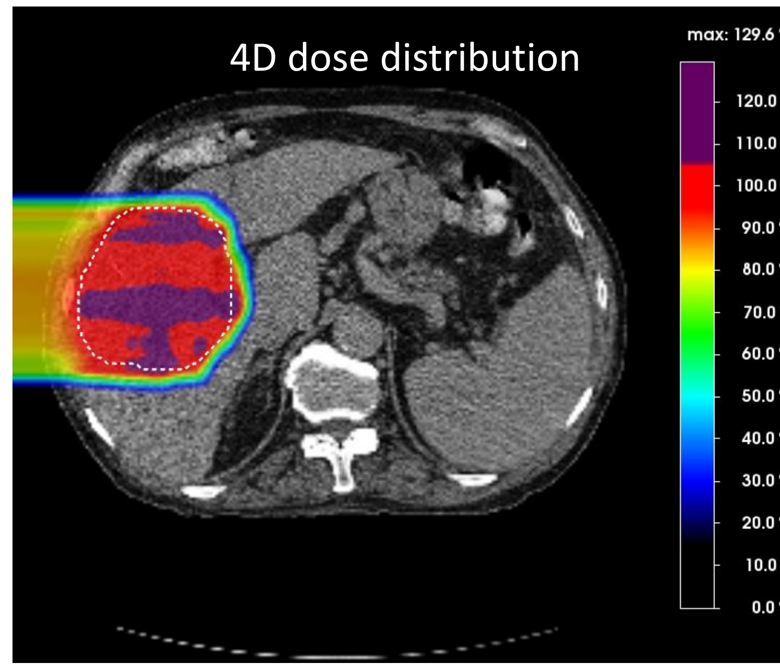
Interplay effect

It is due to beam scanning combined with target motion

Static case



~6mm S-I motion



Boye et al, Med. Phys. 40, 0617021:11, 2013

4D treatments

Motion mitigation techniques

- Margins
- Rescanning
- Breath hold / motion restriction
- Gating
- Tracking

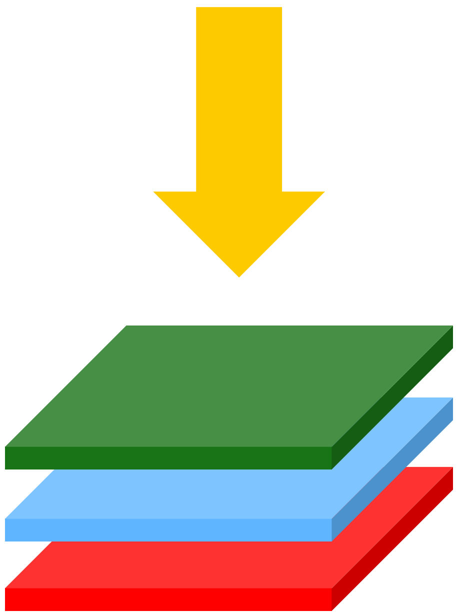
Reducing the anatomy motion in respect to the treatment beam

- and their combinations…

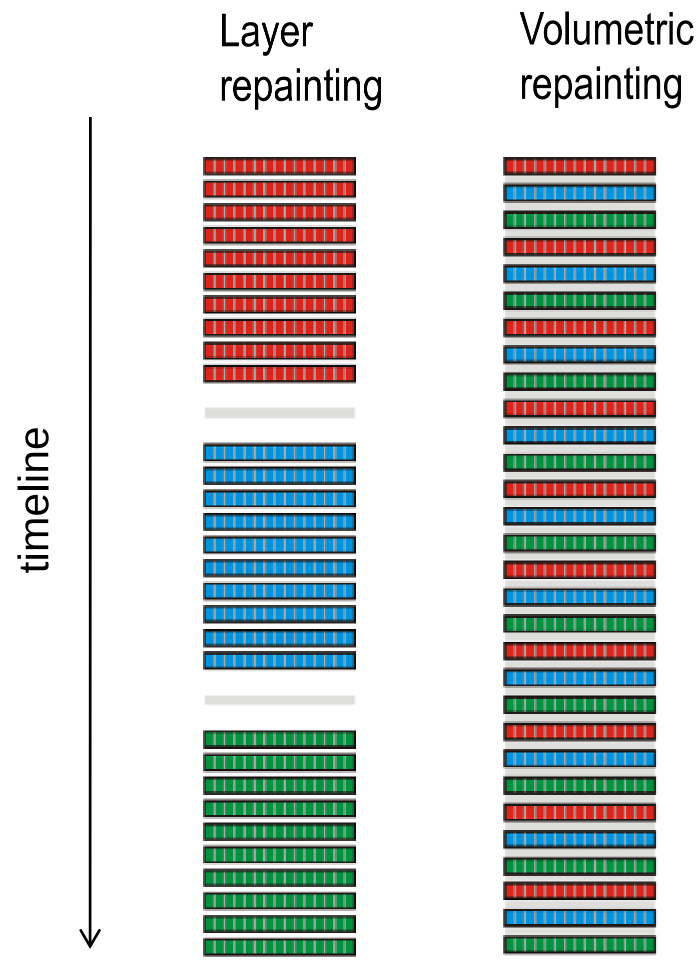
Increasing complexity

4D treatments

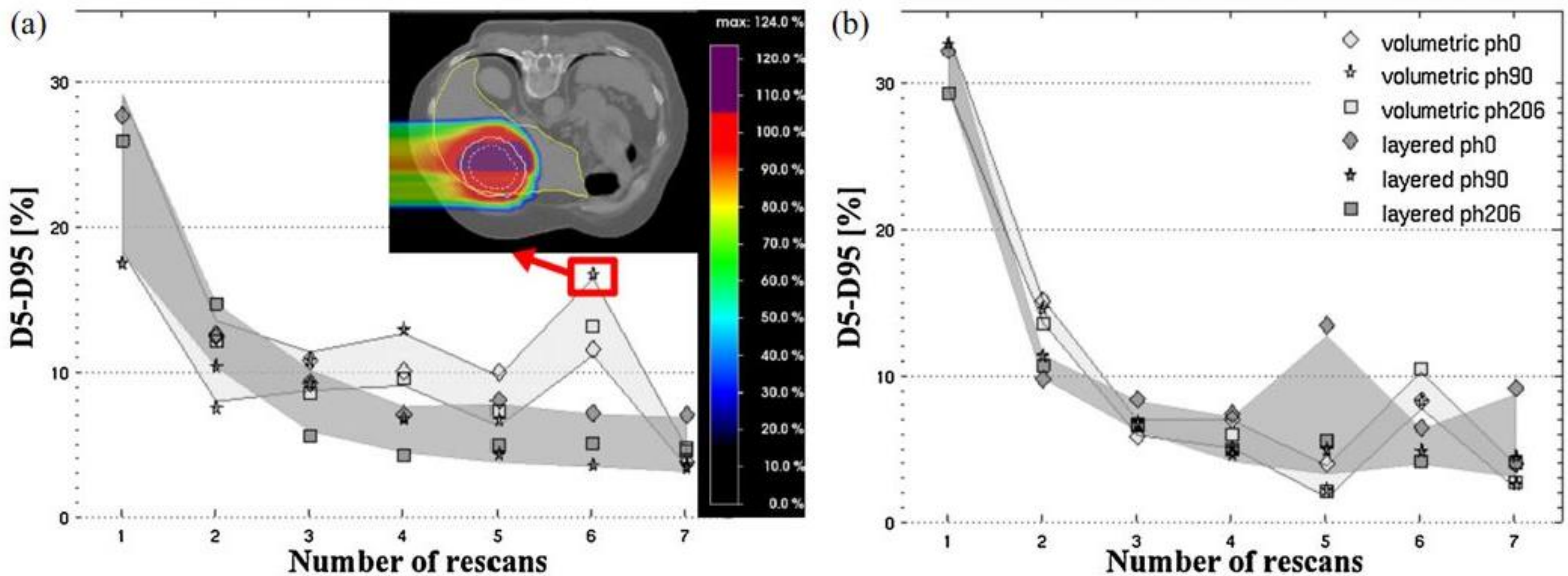
Volumetric vs layered rescanning



Iso energy layers



4D treatments



Bernatowicz et al, PMB 58 (2013) 7905-7920

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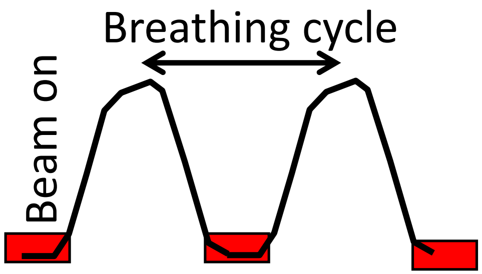
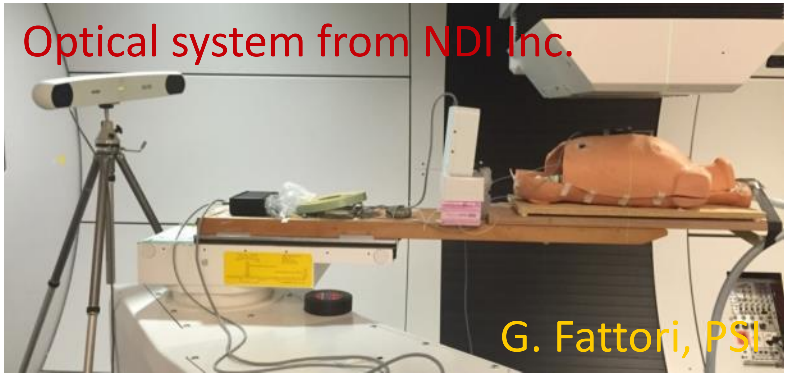
4D treatments

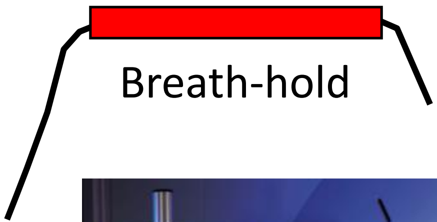
Beam gating



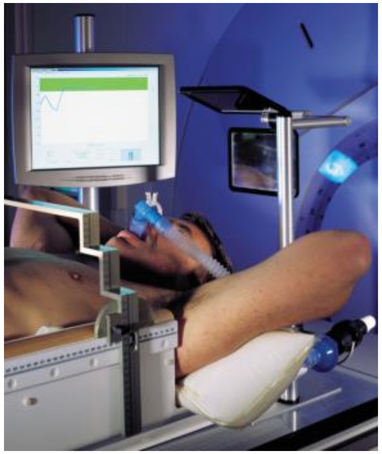
- Breathing cycle is monitored (externally)
- Irradiation only during defined window (e.g. exhale phase)
- Longer treatments
- Interaction with dose delivery



Breath-hold



- Patient actively hold his breath
- Irradiation only during breath-hold window



Benefit:

- Dose application in quasi-static condition
- 4D problem is reduced to 3D (planning / verification)
- Efficient irradiations

- Attractive for line scanning: Entirely treating a small volume < 10s

→ Both techniques are established in conventional therapy ←

4D treatments

4D treatment planning and verification

- Treatment planning as if a static case
  - **Average CT** generated from a 4DCT as the reference CT

- **4D dose calculation engine**
  - It combines the time structure of 4DCT with the time structure of delivery of all spots
  - It calculates the dose distribution taking into account the interplay of the two dynamic processes

Delivery on a **moving platform** in addition to the standard patient specific verification

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Daily Adaptive Proton Therapy

Anatomical and positioning uncertainties

They can have severe effects on proton dose distributions

Density changes will affect the ranges

Robust plans should avoid paths trough the cavities

Planning CT (cavity full)

2 weeks later (cavity empty)

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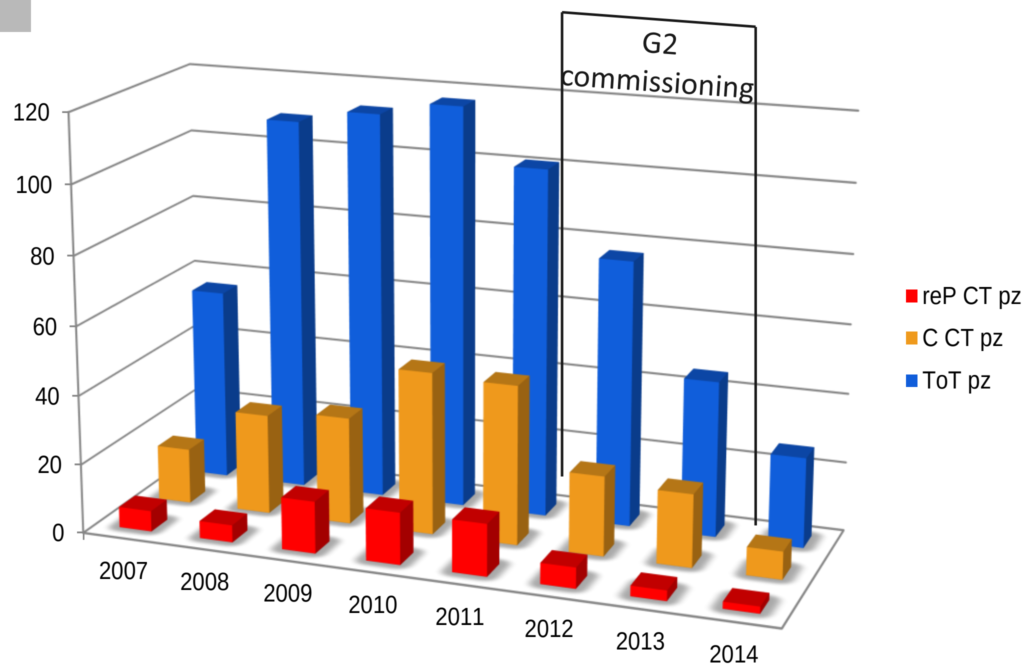
Daily Adaptive Proton Therapy



644 patients treated at PSI since 2007

- 221(34%) had repeat CT's for monitoring anatomical change
- 67 (10%) were re-planned at least once due to anatomical changes*

* Turn around time ~2-3 days

Placidi et al PTCOG 2015

T. Lomax

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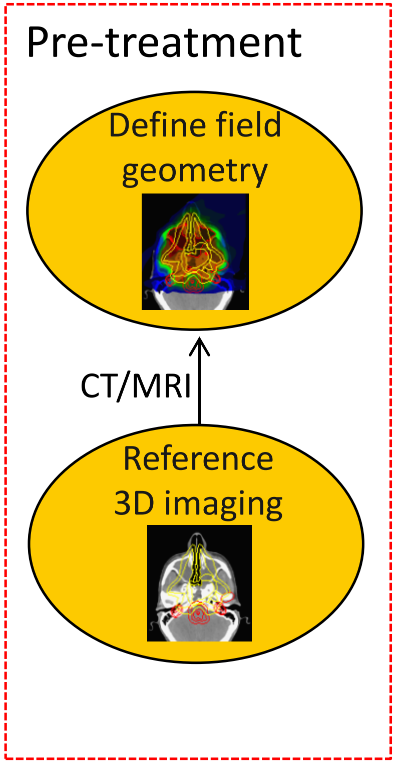
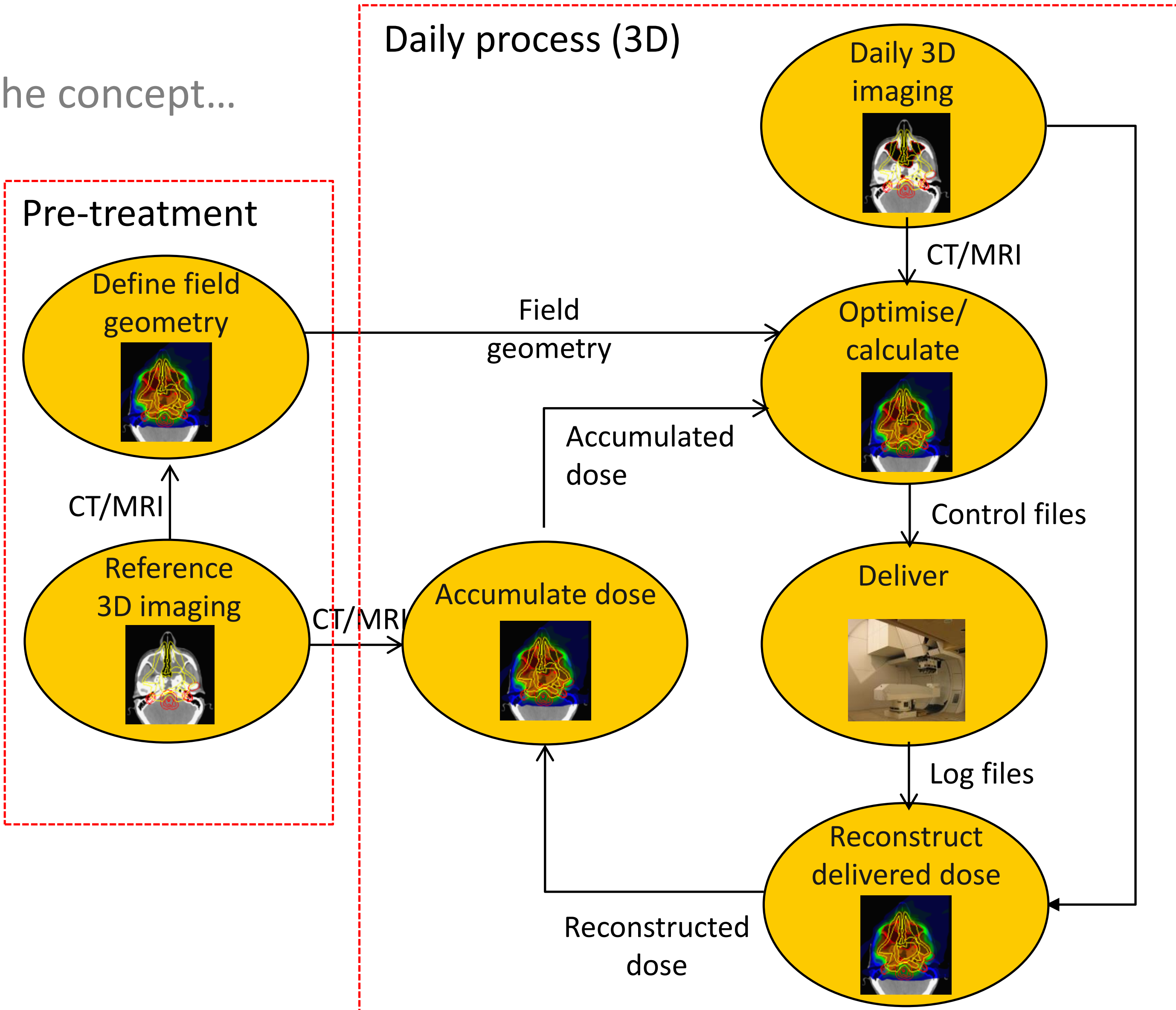
Daily Adaptive Proton Therapy

The concept…



Daily Adaptive Proton Therapy

The concept…

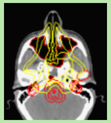


Daily Adaptive Proton Therapy

What is needed

Daily process (3D)

Daily 3D imaging

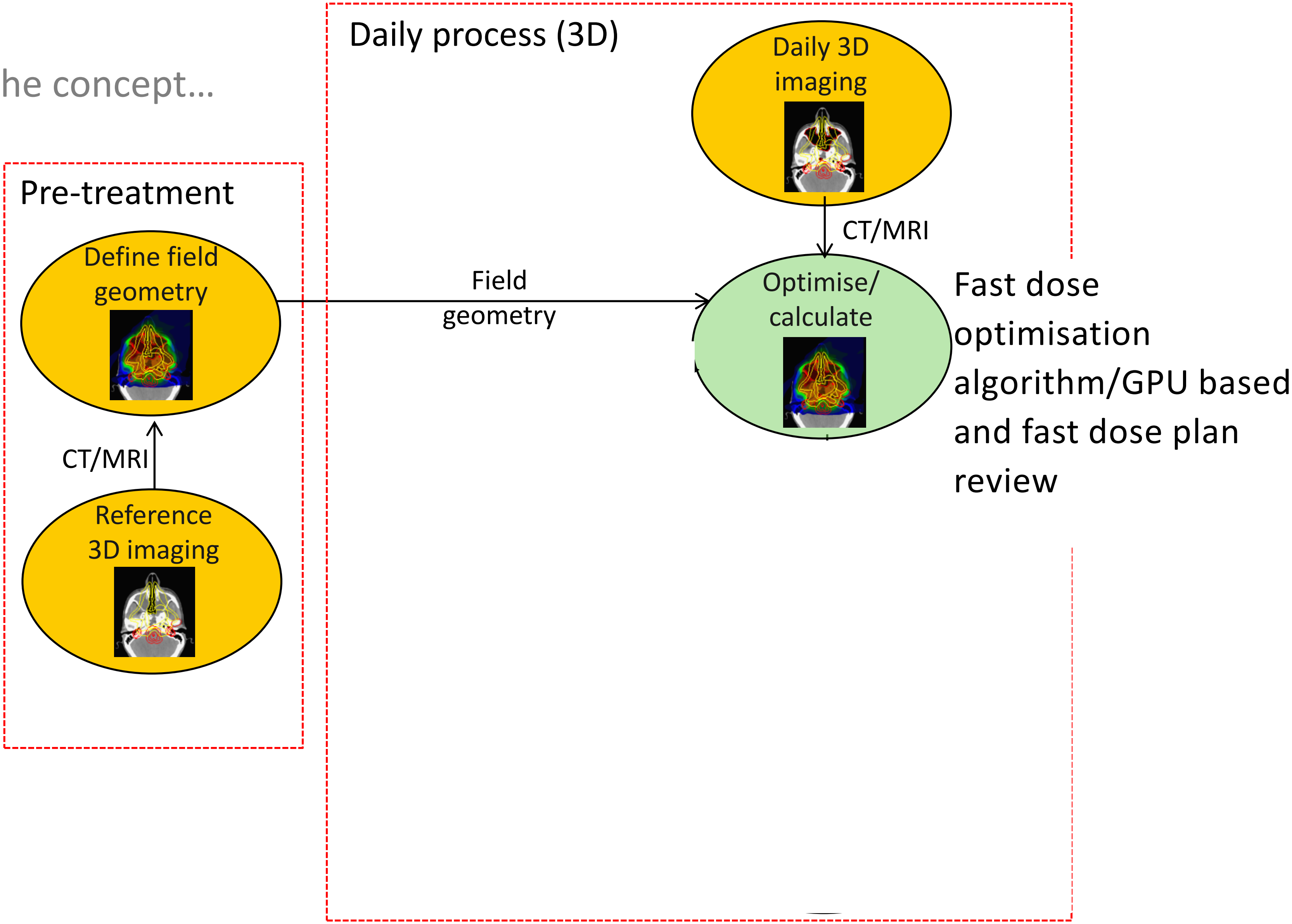


Daily imaging option in-room:

here both positioning and delivery can take place

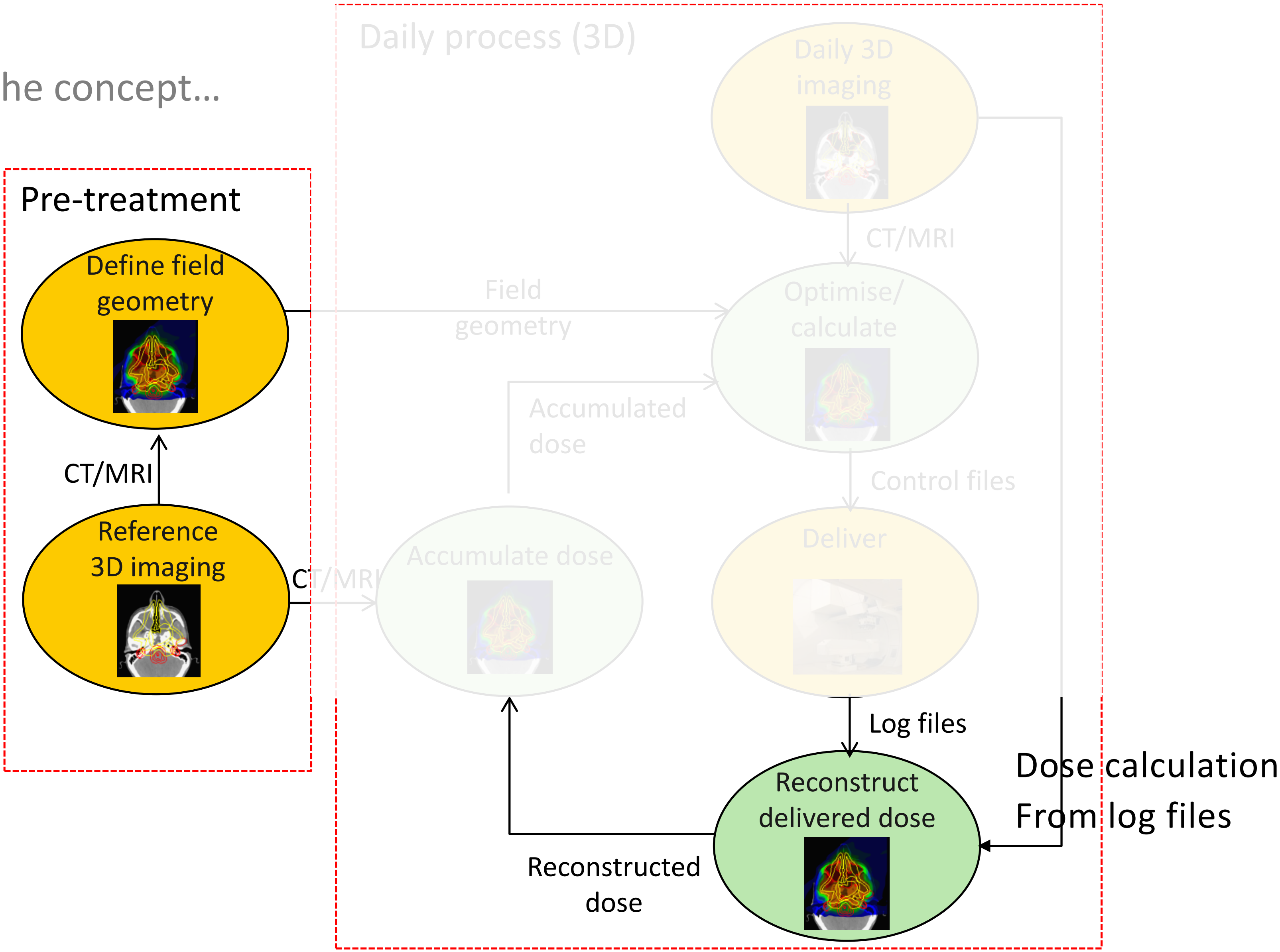
Daily Adaptive Proton Therapy

The concept…



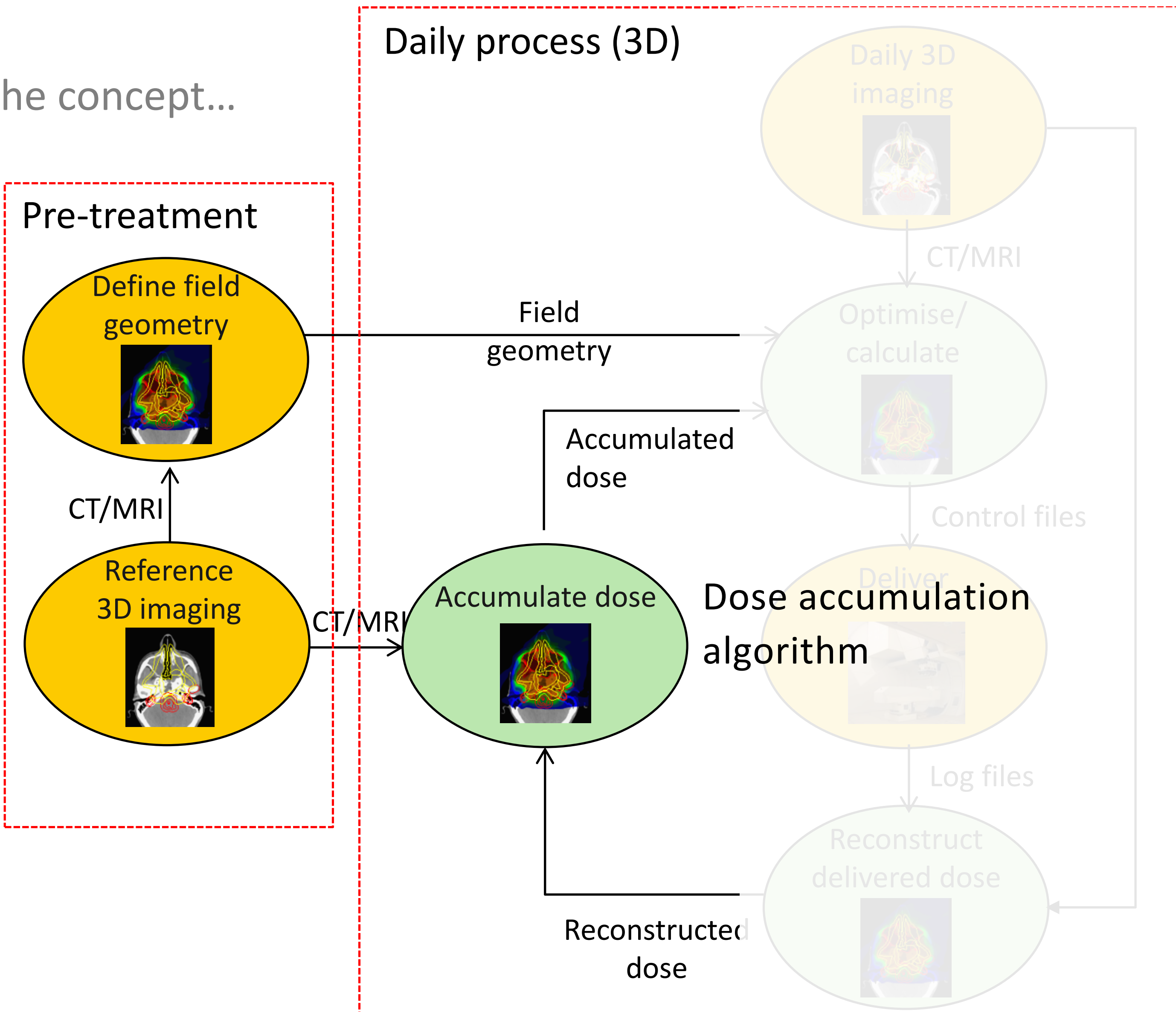
Daily Adaptive Proton Therapy

The concept…



Daily Adaptive Proton Therapy

The concept…



Independent dose calculation from log files

The dose can be calculated from log files which record all the significant delivery parameters of a steering files

Significant parameters for the dose reconstruction:

- Monitor units per spot
- Spot position
- Couch position and angle
- Gantry angle

Independent dose calculations for commissioning, quality assurance and dose reconstruction of PBS proton therapy
G. Meier et al. Phys Med Biol 60 (2015)

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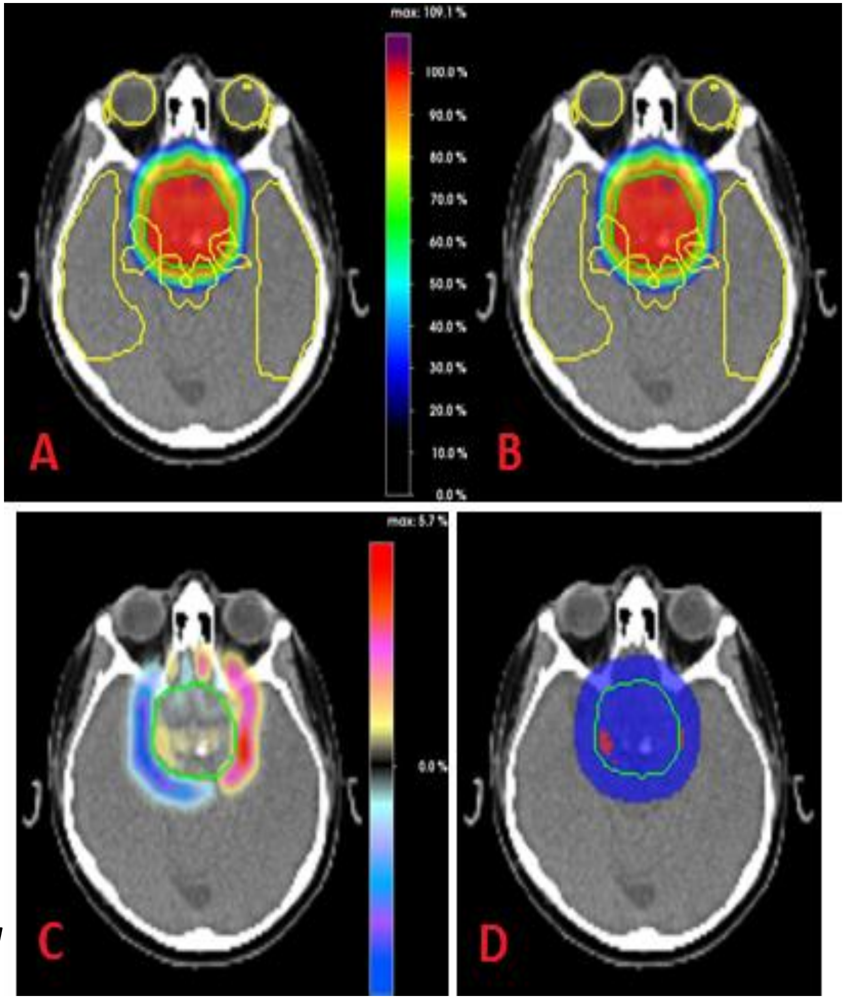
Log files dose calculation

a) Nominal TPS dose of treatment field

b) Log-file-calculated treatment field as delivered on the day

c) Dose difference distribution of the two fields (logfile - TPS)

d) 3Dgamma calculation with red voxels failing the criteria of 1% and 2mm



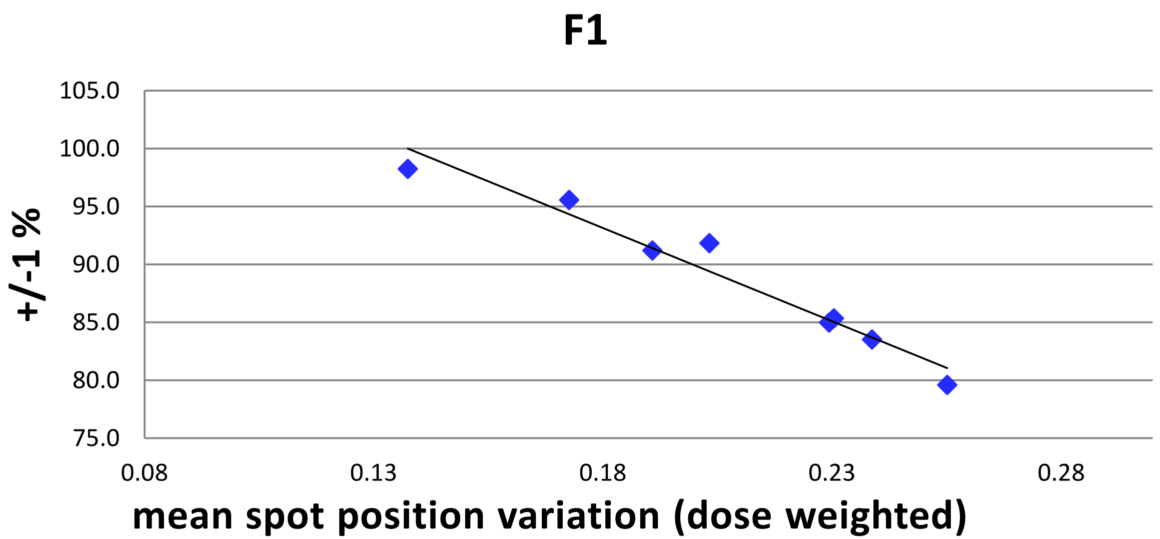
Assessing the quality of proton PBS treatment delivery using machine log files: comprehensive analysis of clinical treatments delivered at PSI Gantry 2.

Scandurra D. et al., Phys Med Biol.61(3), 2016

Log files dose calculation

The differences between TPS and from log files dose distributions can be due to:

- Interlocks
- Unusually large spot position deviations
- Skipped spots
- Other issues with accelerators/beam line set up..



M. Peroni

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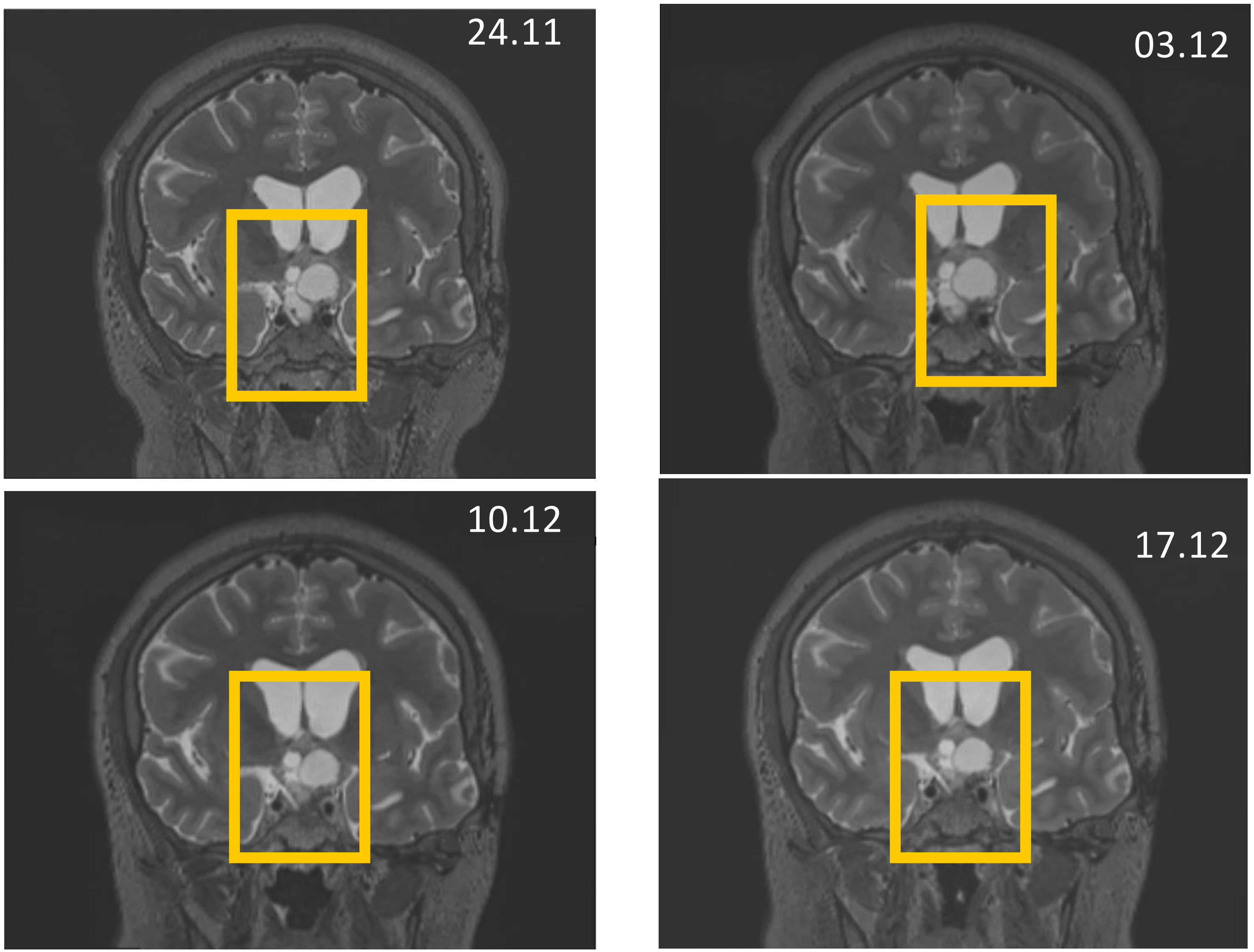
Advanced imaging - MRI

MRI for detecting anatomical changes during treatment

Cranio-pharingioma evolution during therapy



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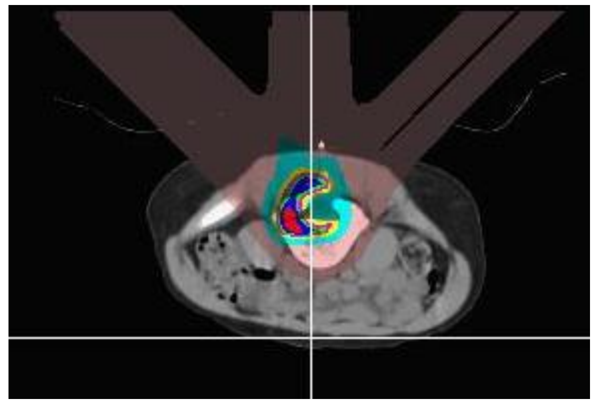
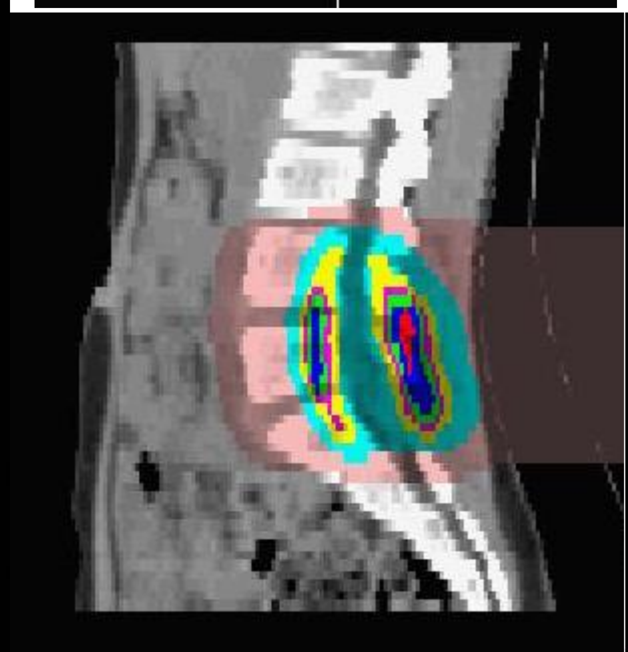
Advanced imaging - MRI

MRI for detecting anatomical changes after treatment

2010



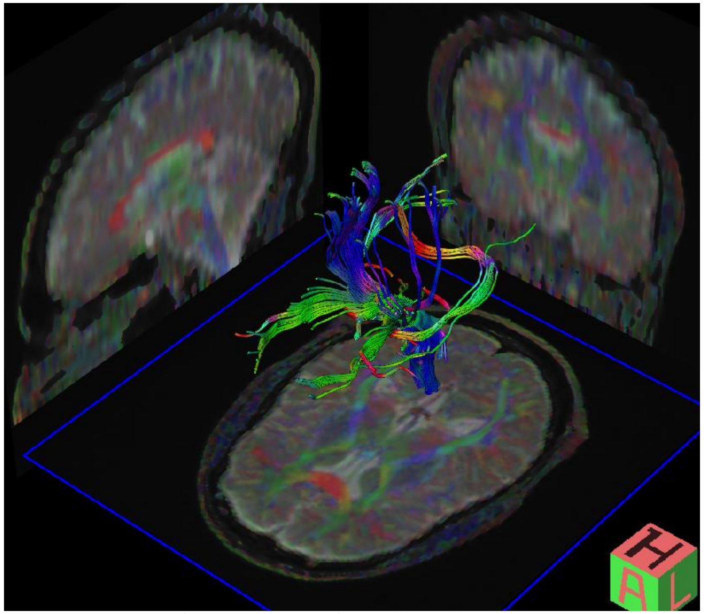


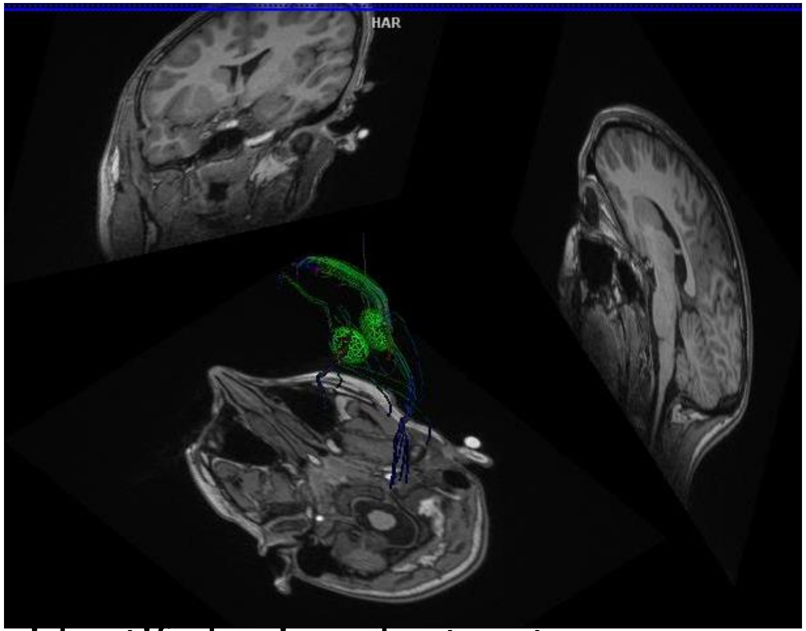
2014

Advanced imaging - MRI

Tumors are sitting next to functional areas (e.g. language or motor areas of cerebral cortex)

We want to treat the whole tumour volume...and with high dose





Using advanced MRI sequences, we can identify brain sub-structures. Therapy will be shaped on the sub-regions (e.g. identifying boosting areas or avoidance paths)

Advanced imaging – 4D treatments

4DCT is the gold standard for motion estimation

→ Only average breathing cycle

4DMRI: reconstruction of several breathing cycles

→ Not always artifact free

4DMRI: less artifacts as acquired in sagittal direction

→ Cannot really be used for daily motion evaluation

4DMRI: not to be used for planning

Are there alternatives?

4DMRI (radiation free)

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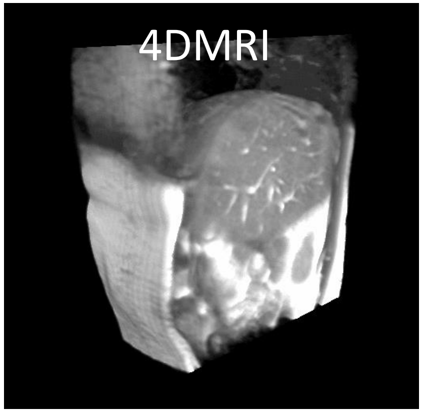
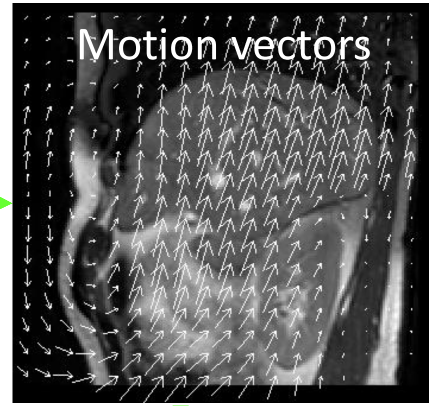
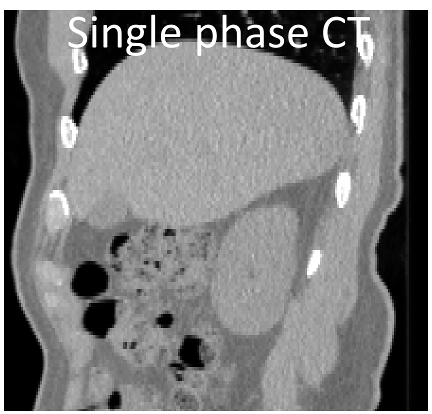
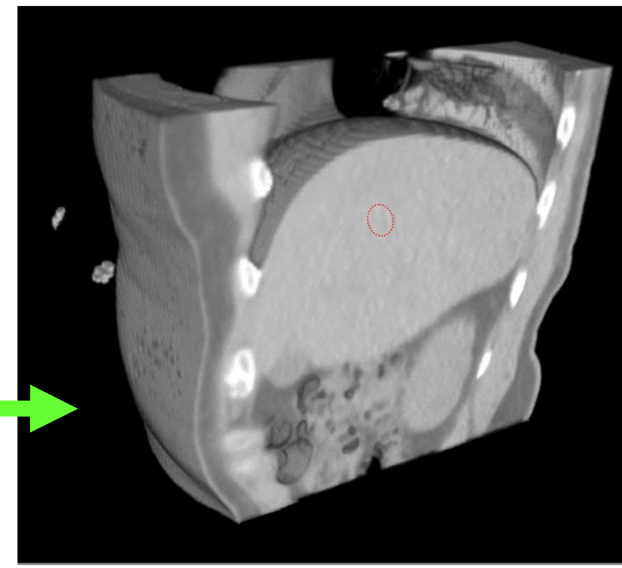
Advanced imaging – 4D MRI







Volumetric image deformation



4DCT(MRI)

Von Siebenthal M. et al, MICCAI 2005

Celicanin et al, Magn. Reson. Med 2015

My thanks go to

- D. Meer
- G. Klimpsi
- J. Hrbacek
- F. Albertini
- D. Scandurra
- M. Peroni
- T. Lomax
- D.C. Weber
- CPT team