PAUL SCHERRER INSTITUT

PSI

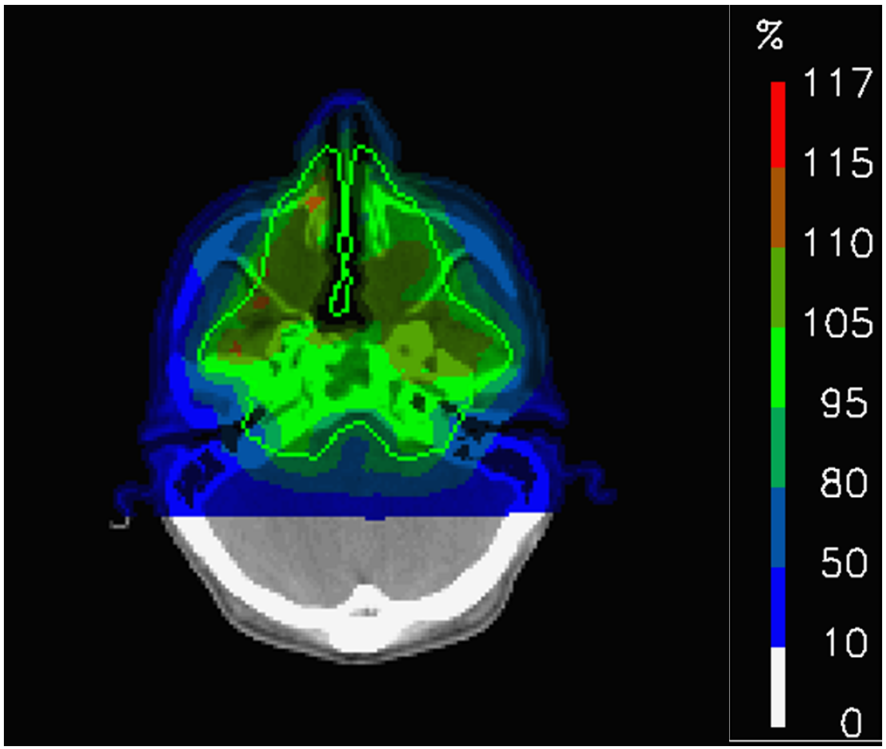
To promote excellency in patient care and innovative proton treatment

Paul Scherrer Institut
A.Bolsi

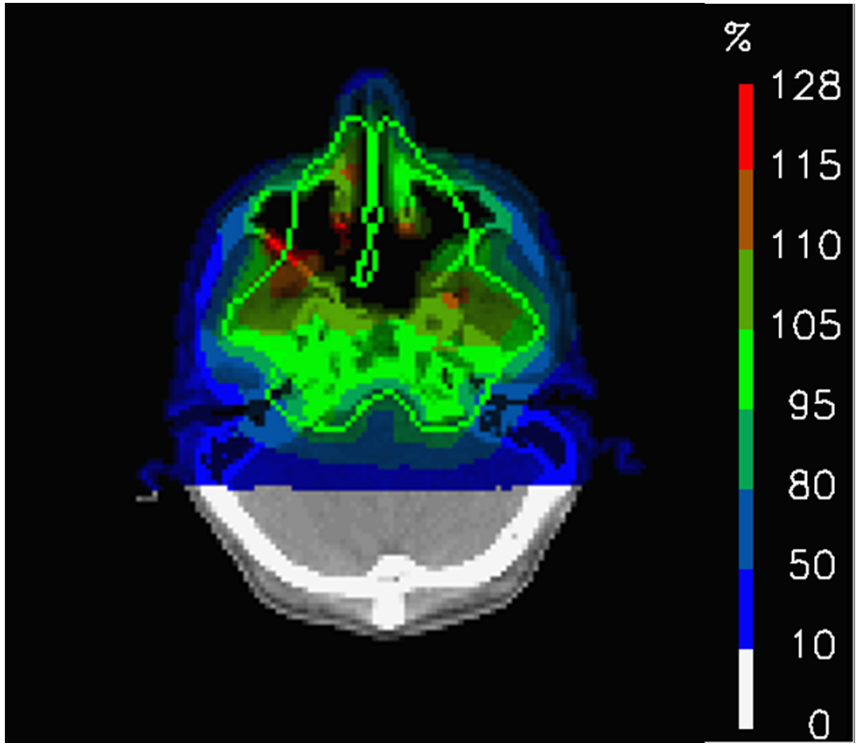
Uncertainties in the clinical practice

Introduction

Nominal



Delivered on a **single** fraction



There are different kind of uncertainties:

a) Density uncertainties

b) Range uncertainties

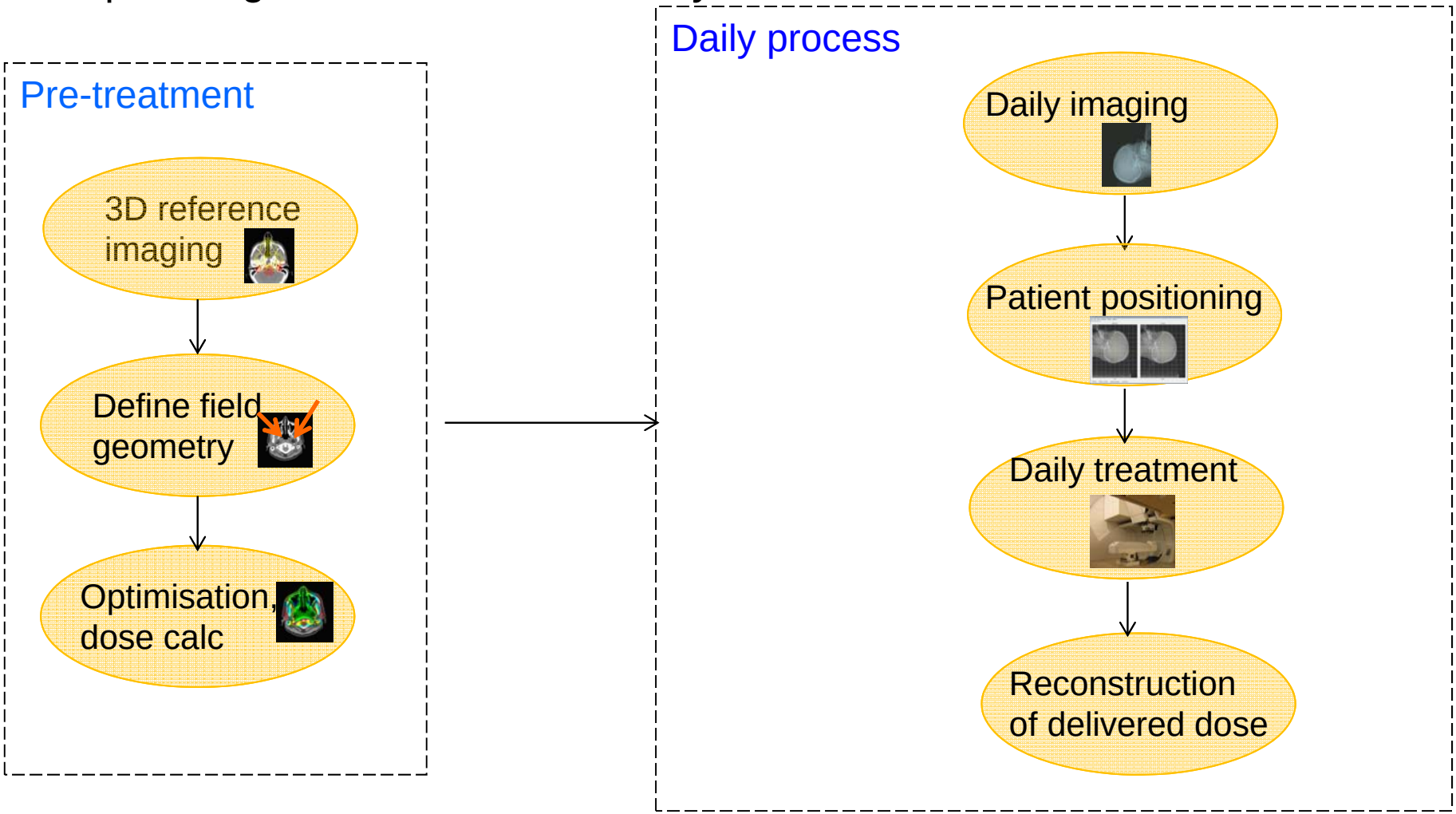
c) Set up uncertainties

d) RBE

e) Beam delivery

Introduction

They can appear in different step of the entire radiotherapy workflow: from planning CT to the dose delivery.



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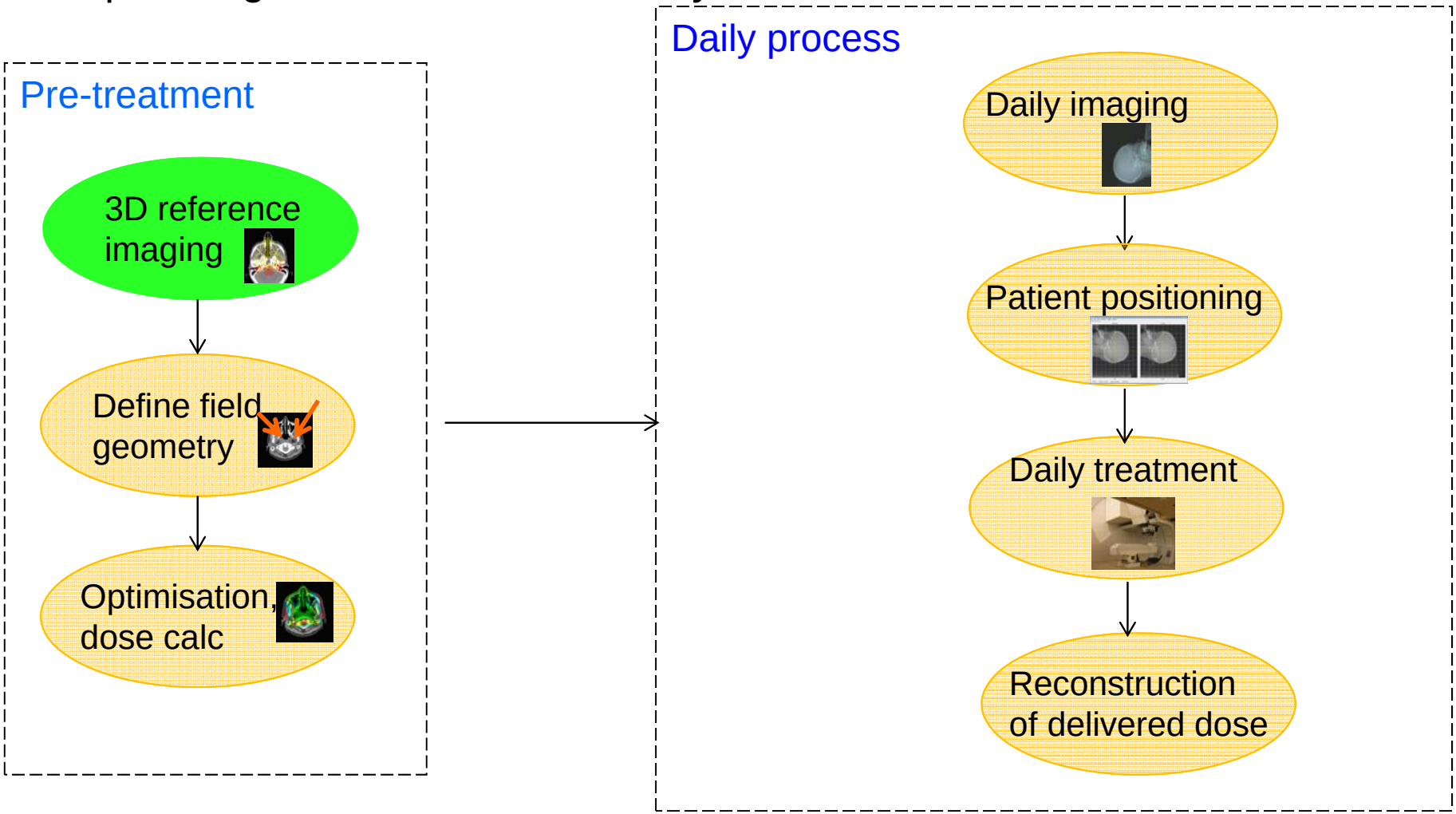
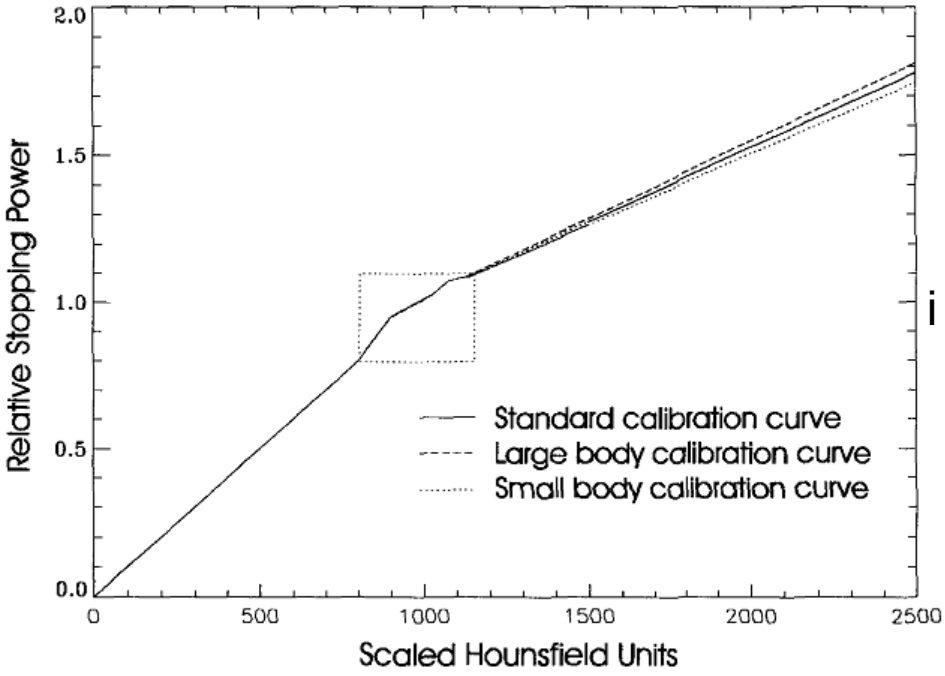
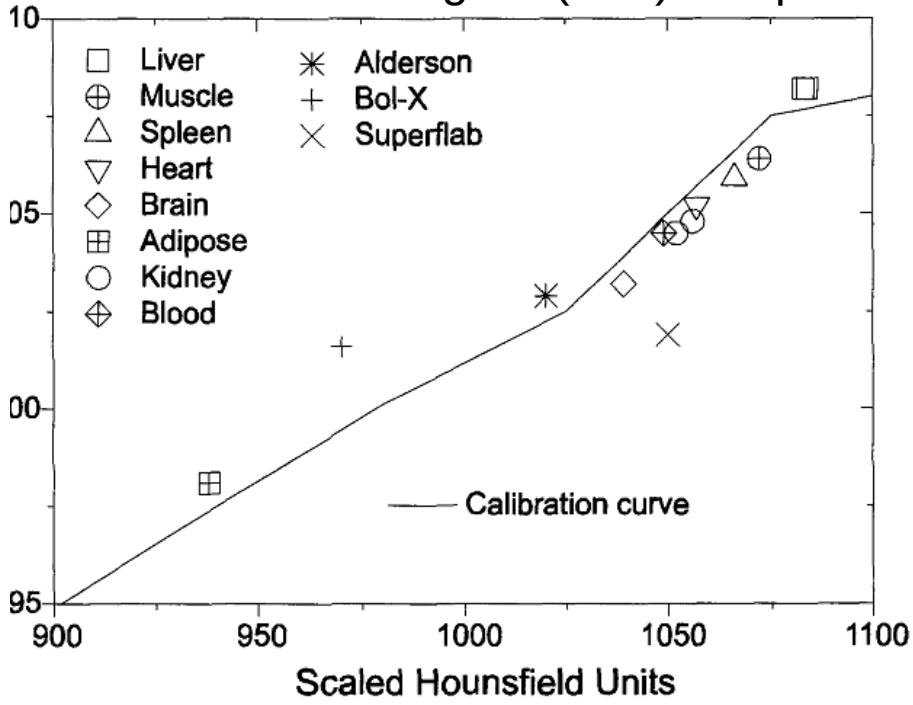


Inherent CT uncertainties: calibration from HU to RPSP

Stoichiometric calibration (PSI)[1]



Validation with biological (cow) samples[2]



~1% range uncertainties through soft tissues, ~2% through bone
~1.5mm range uncertainty in brain, ~3.5mm for prostate (lateral beams)

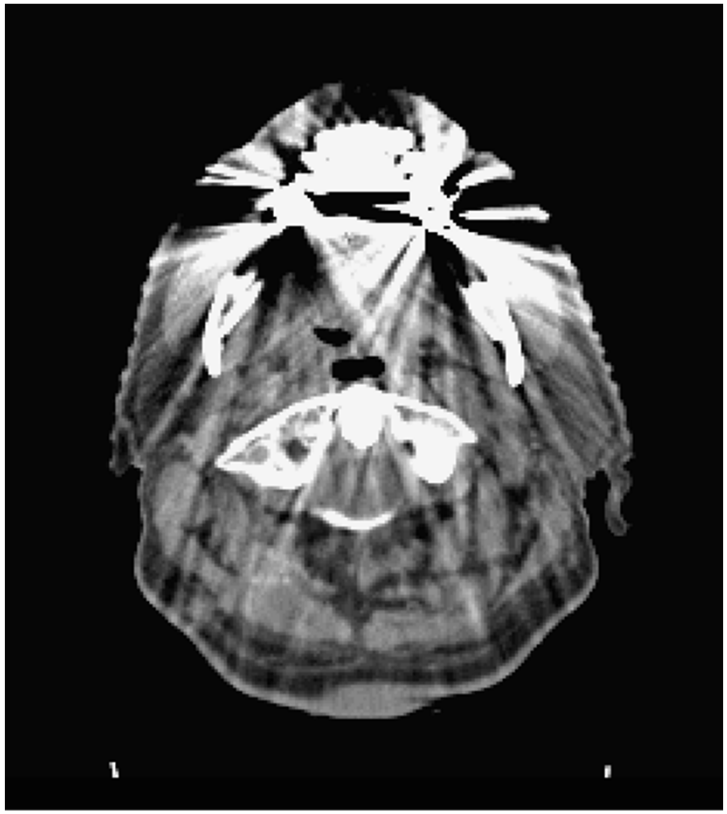
[1]Schneider et al. 1996, [2]Schaffner and Pedroni 1998

Planning CT

CT artifacts can compromise CT data quality

Artefacts along the spinal cord due to titanium implants

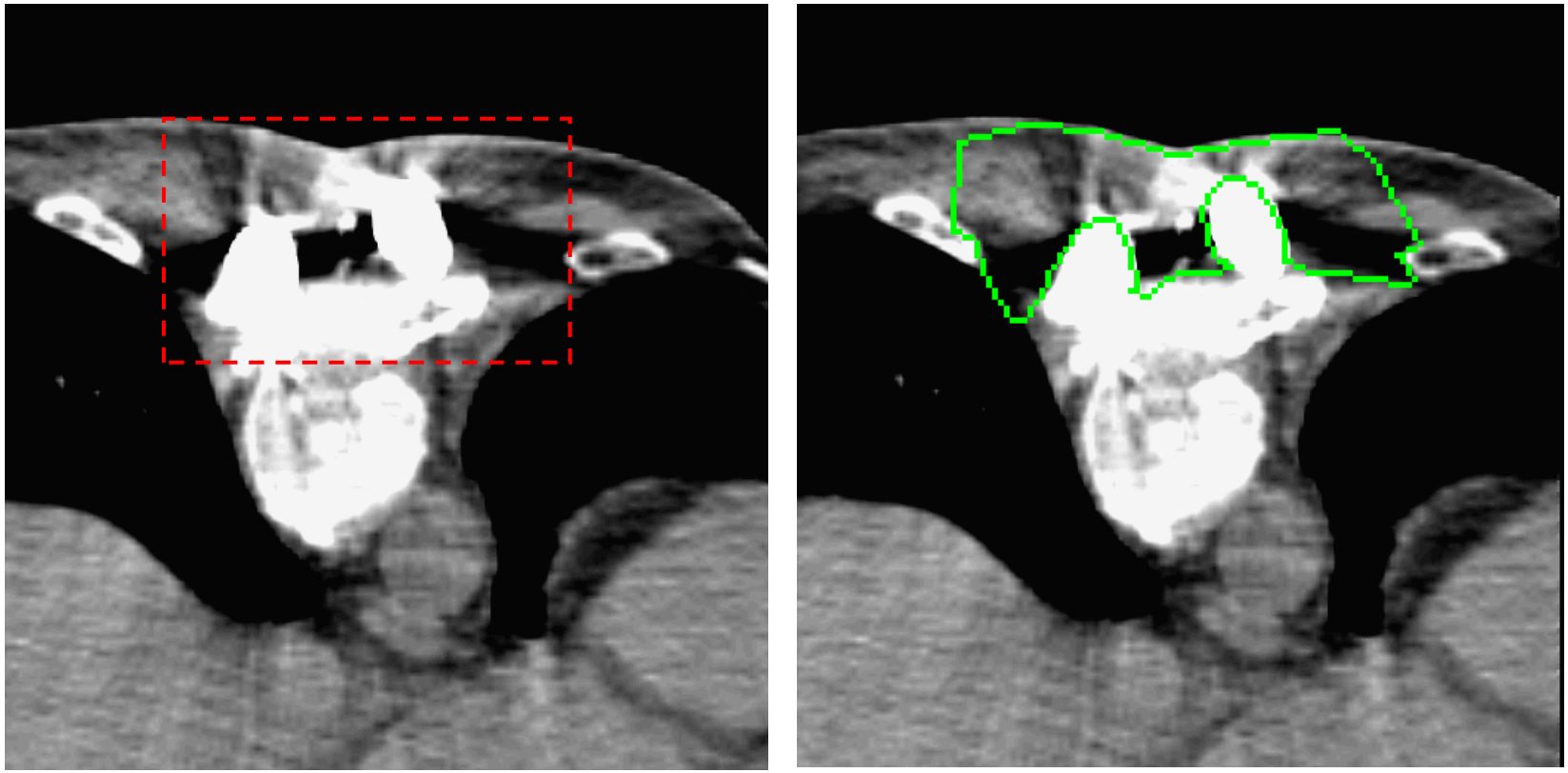
Artefacts due to metal implants in the Teeth (normally not titanium)



Planning CT

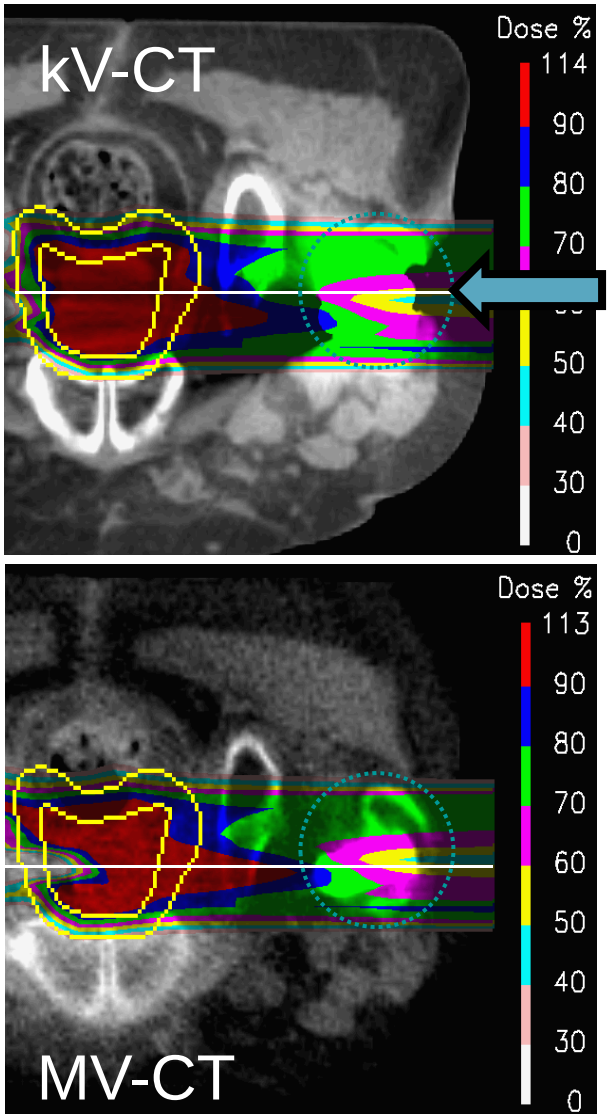
CT artifacts : how we can deal with them

CT data set with artefacts → Manual delineation of the soft tissue areas, HU substituted

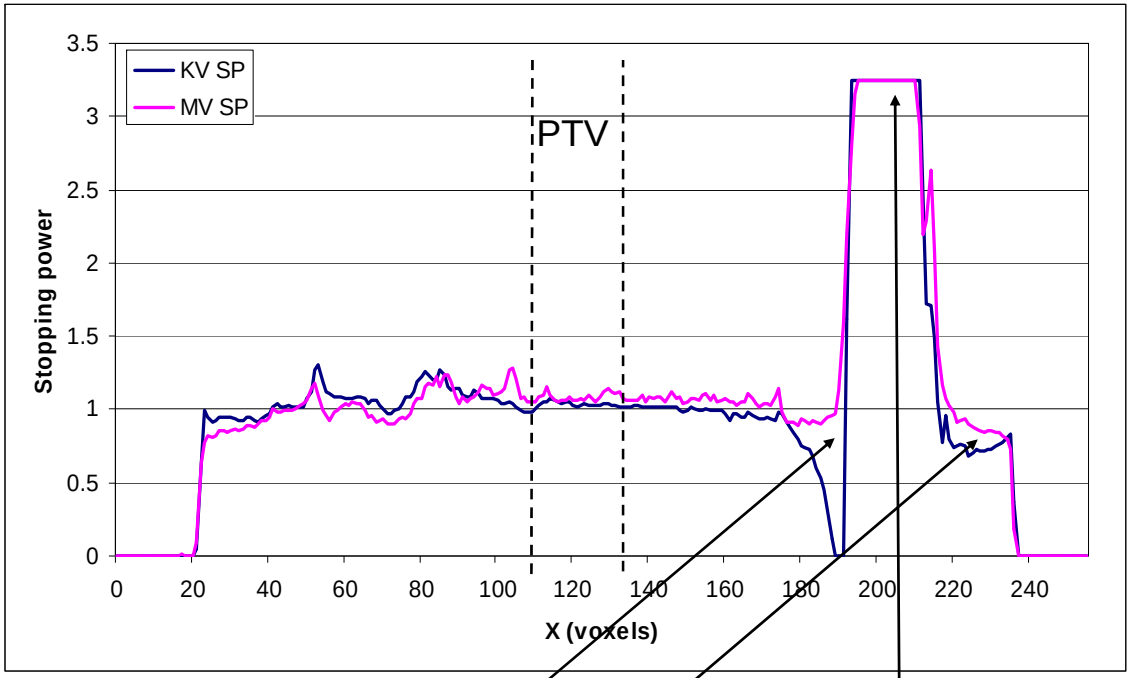


Additionally: beam hardening effect, noise and resolution.
Planning CT errors: they are systematic and contribute to range uncertainties.

Single field trough the metal implant: extreme case



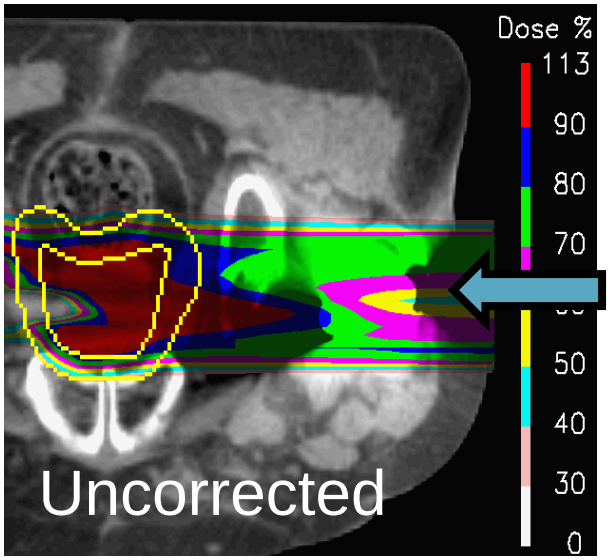
Stopping power profiles

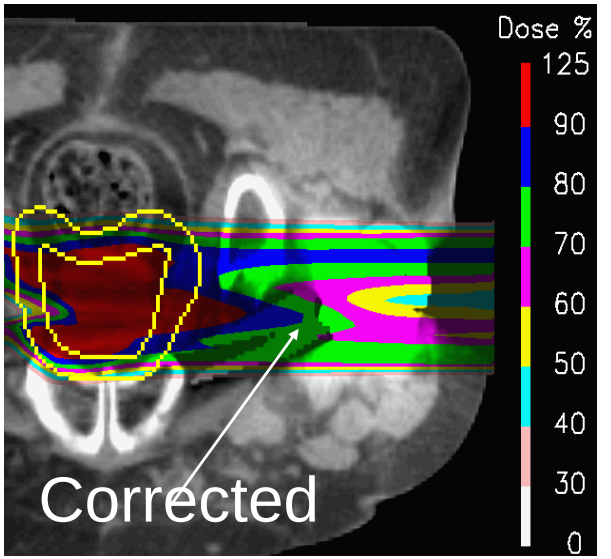


kV-CT artifacts

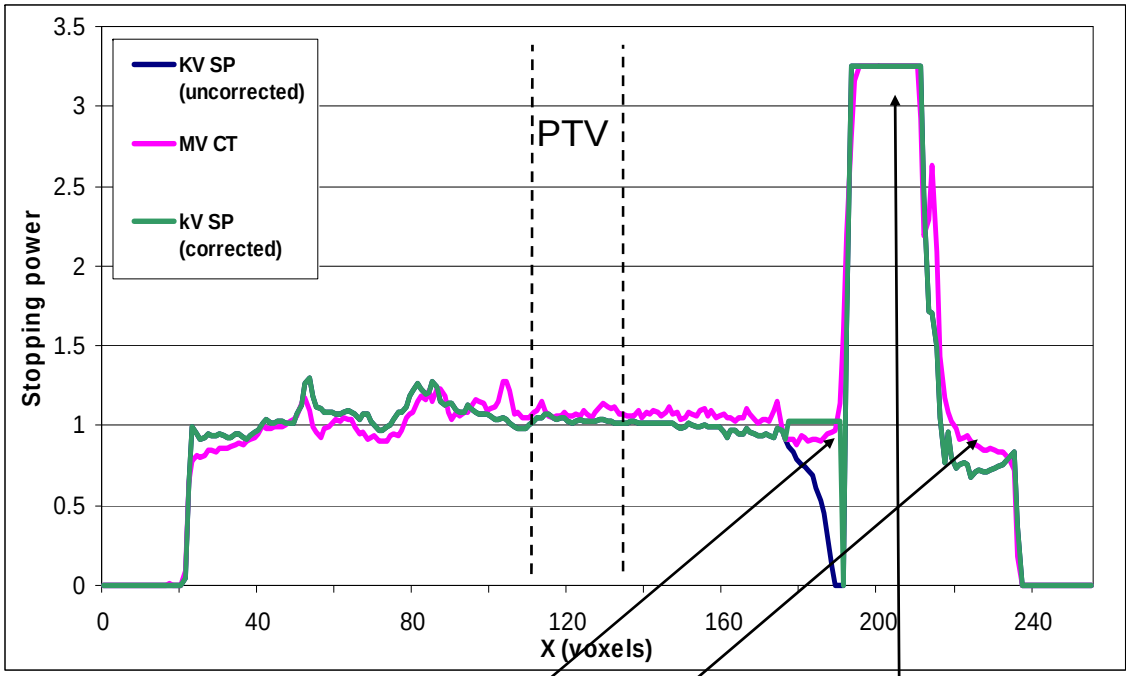
Prosthesis

Single field trough the metal implant: extreme case





Stopping power profiles

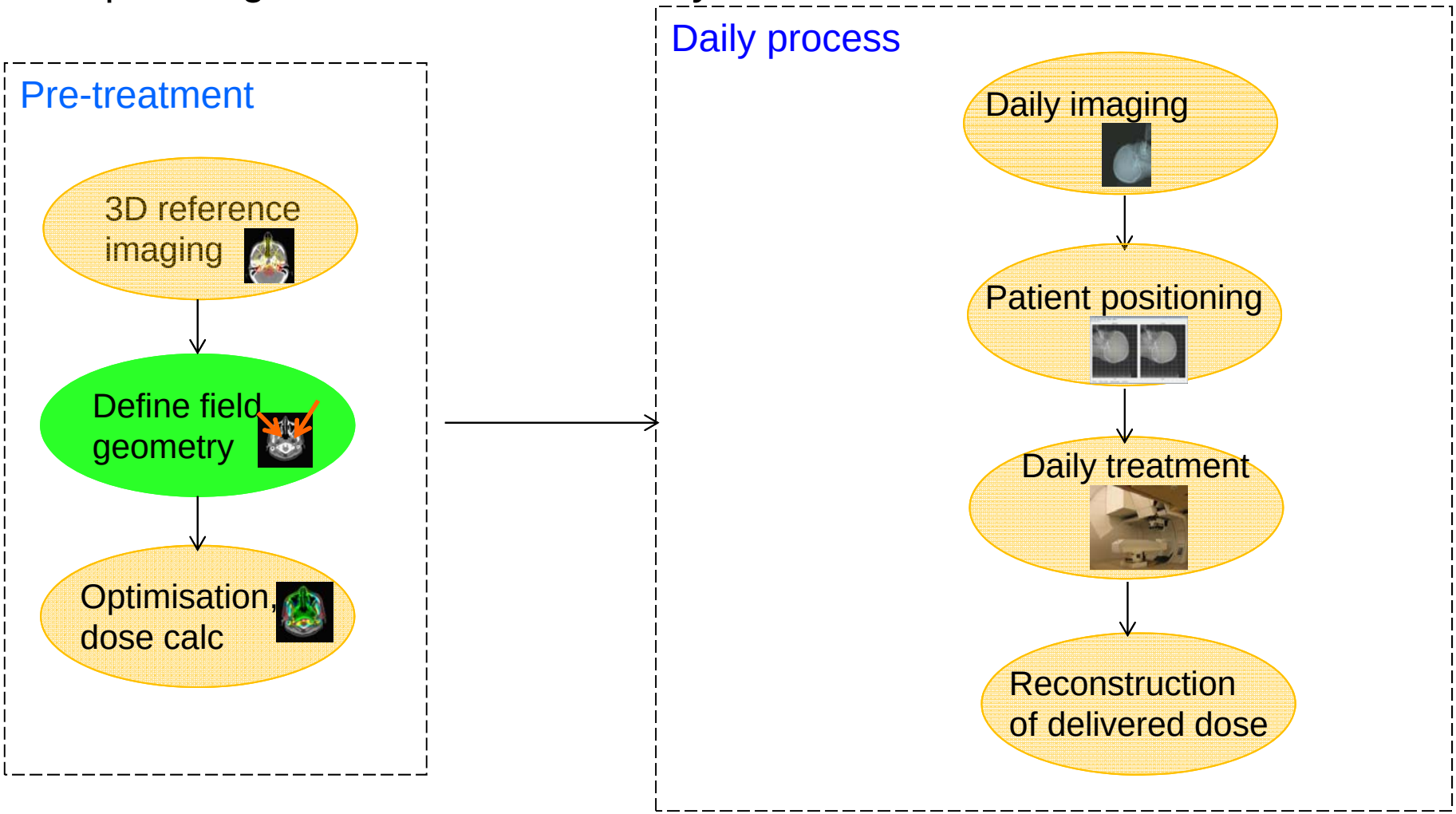


kV-CT artifacts

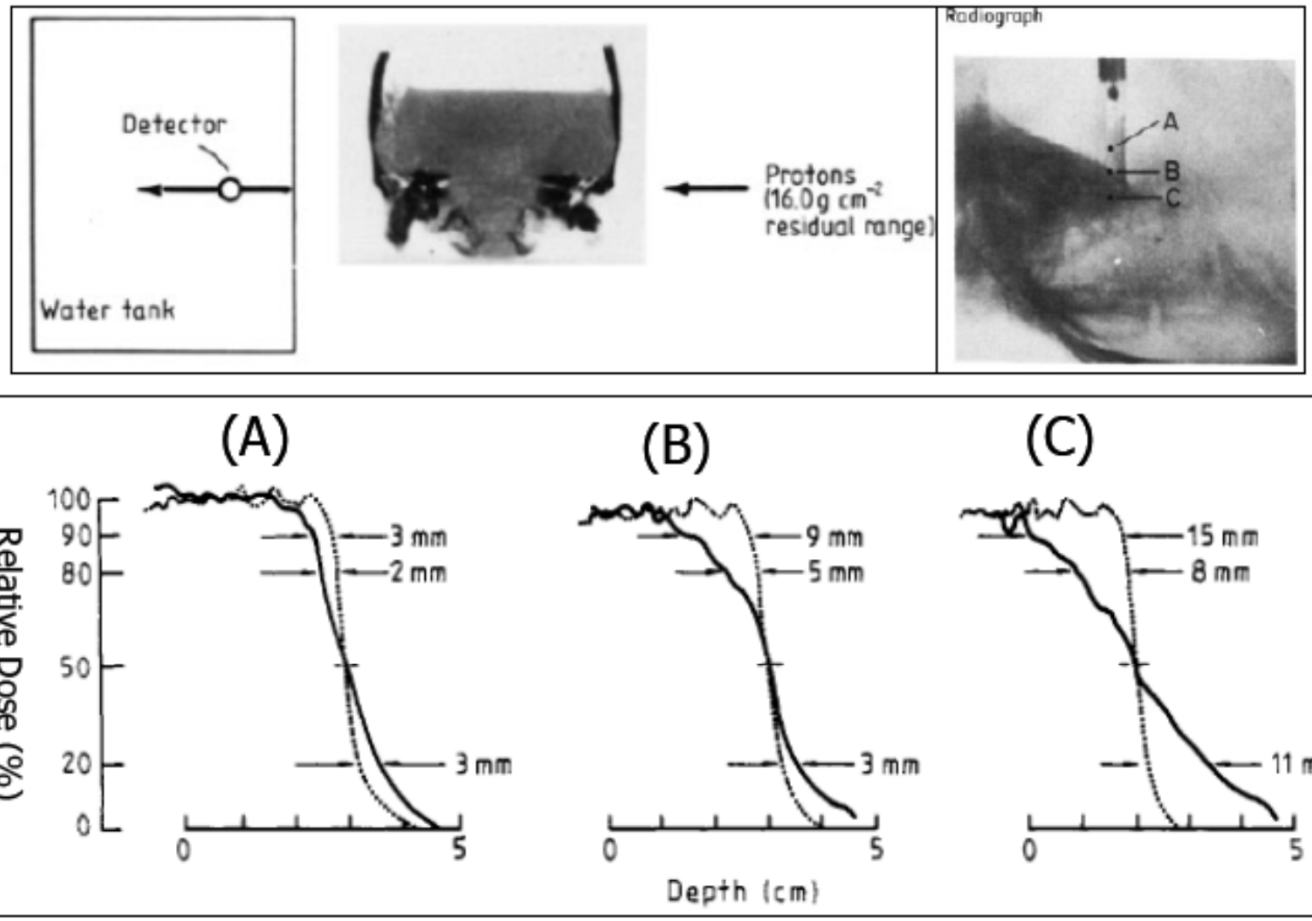
Prosthesis

Introduction

They can appear in different step of the entire radiotherapy workflow: from planning CT to the dose delivery.



Density heterogeneities: degradation of the Bragg peak shape

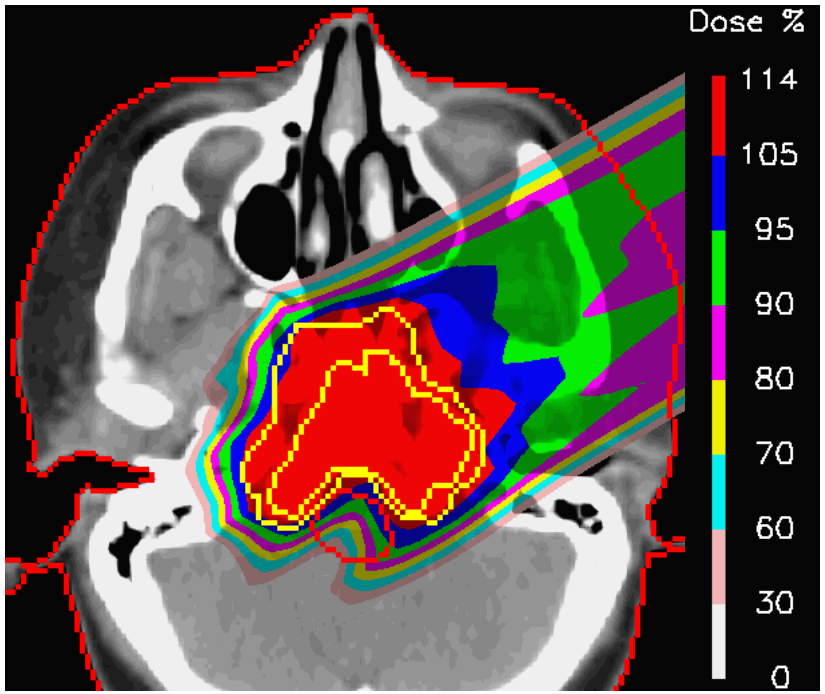


Protons Through Base of Skull: 90 to 20% fall of increases from 6 to 32 mm

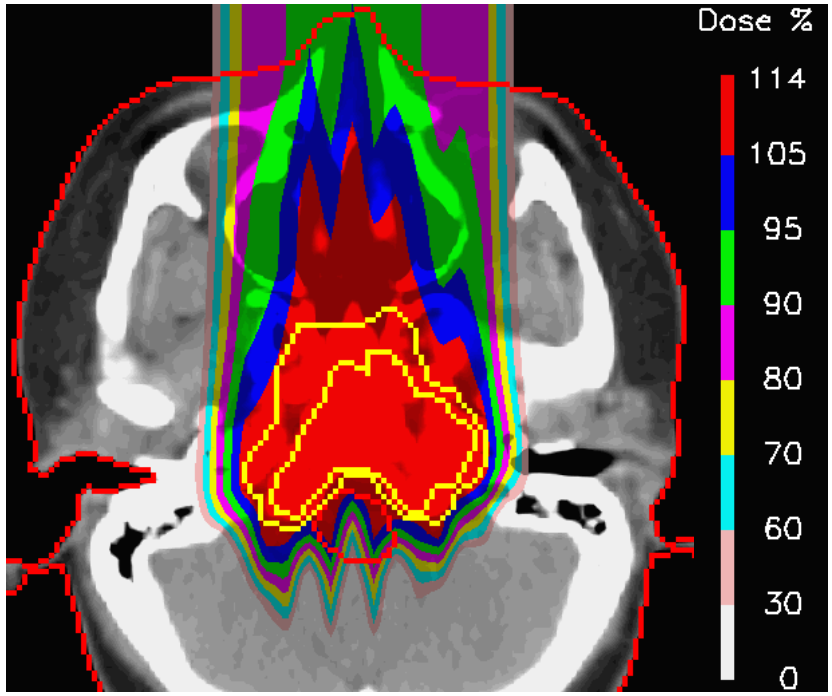
Urie et al, PMB, 1986, 31;1-15

Planning

Example field through relatively homogenous anatomy



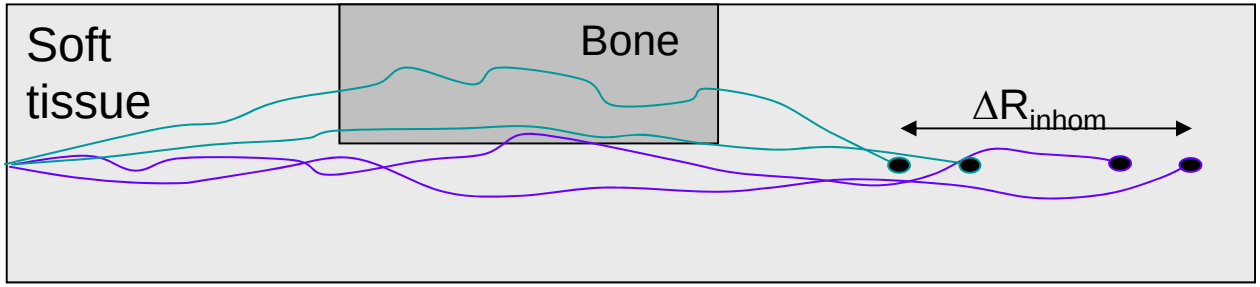
Example field through very inhomogenous anatomy

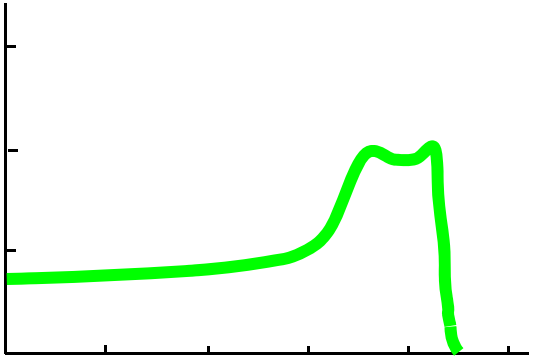


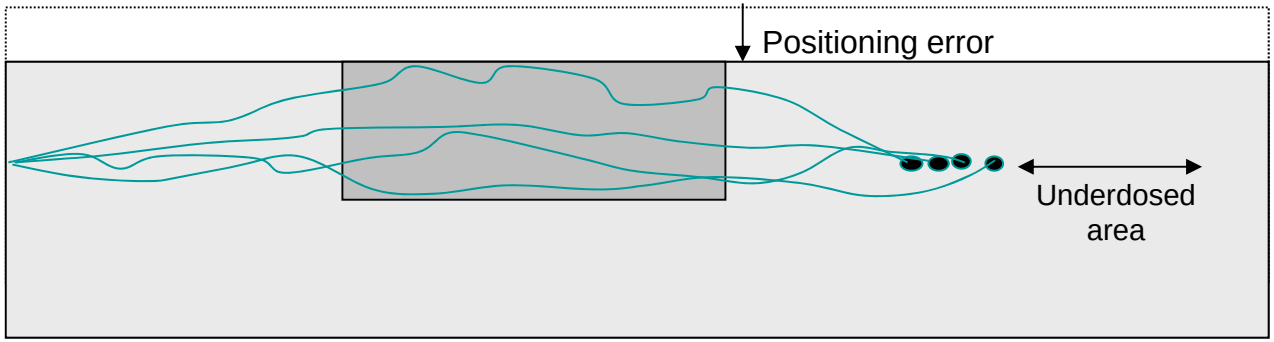
Lomax PMB 2008a

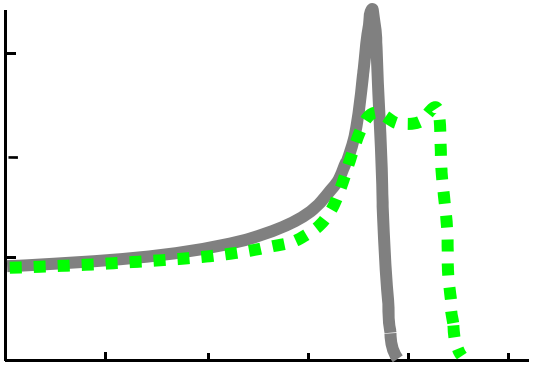
Planning

When planning it is important to select field directions which go trough the minimum possible in-homogeneities.
They play also a role when we come to the positioning process

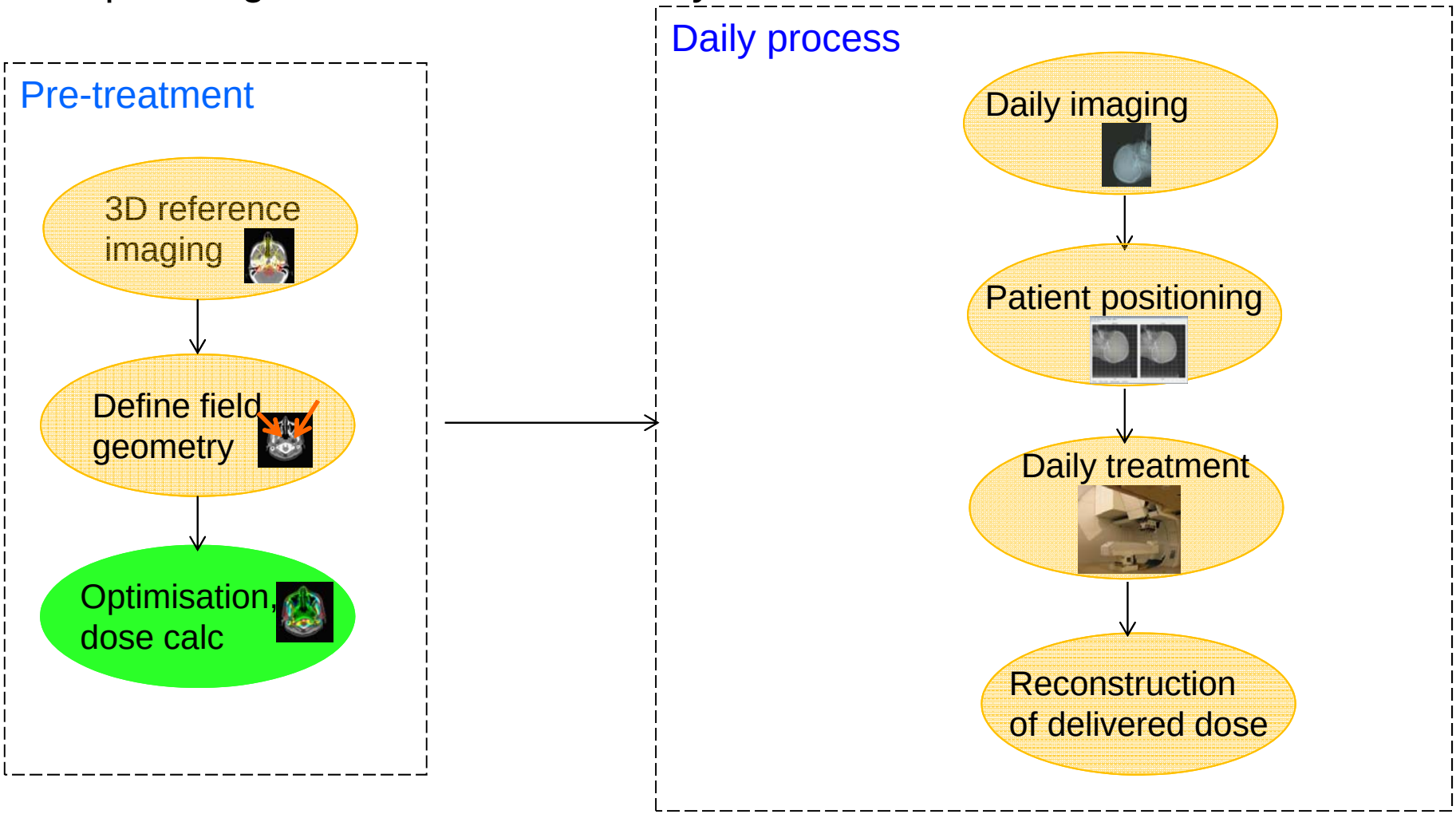






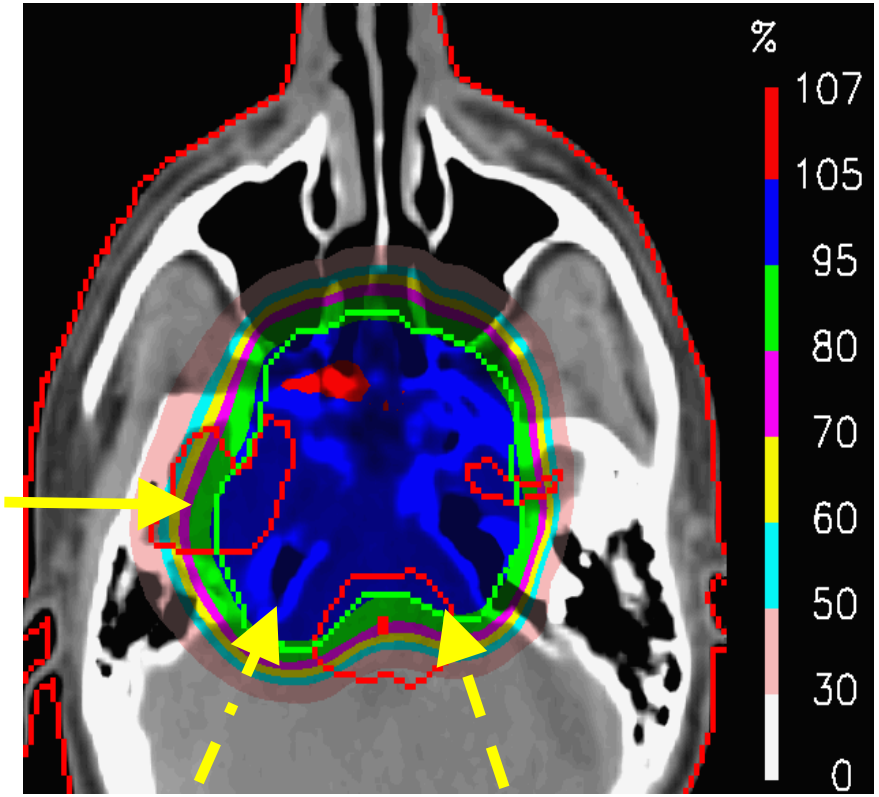


They can appear in different step of the entire radiotherapy workflow: from planning CT to the dose delivery.

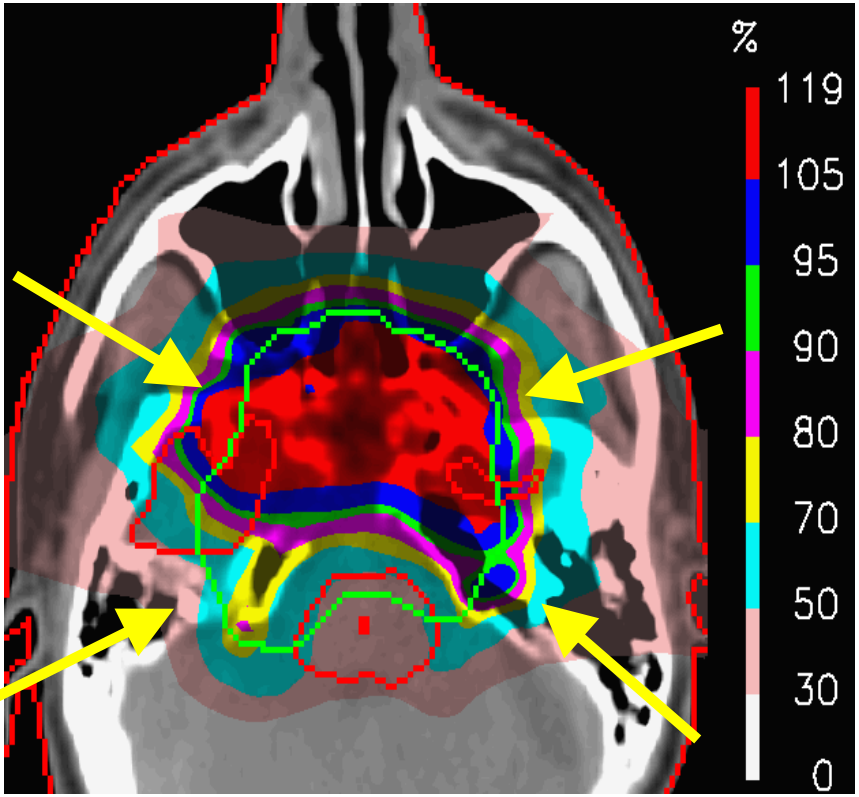


SFUD vs IMPT plans

SFUD



IMPT

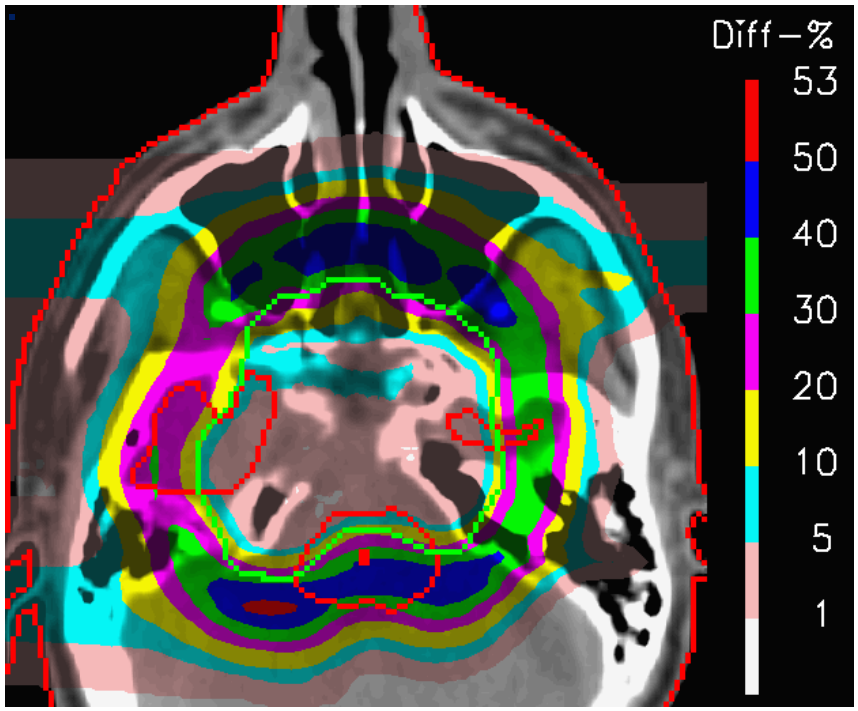


SFUD plans are generally more robust than the IMPT plans (highly in-homogeneous individual dose distribution are ‘patched’ inside the target volume)

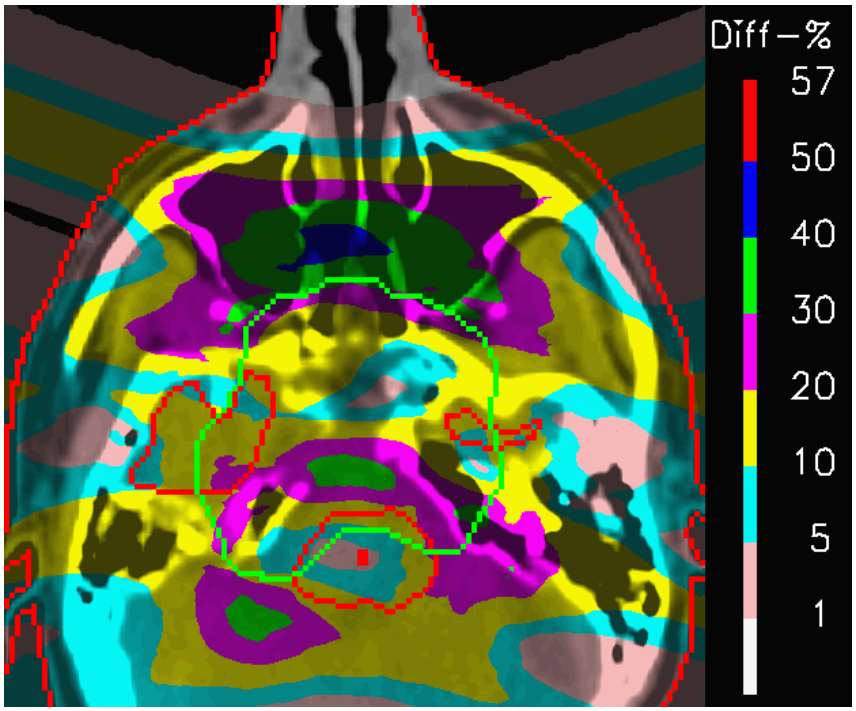
Evaluating uncertainties: max to min dose distributions

This indicates the maximum differences (~ error bars) expected in the plan due to set up errors (Albertini F. et al. Phys Med Biol. 2011)

SFUD



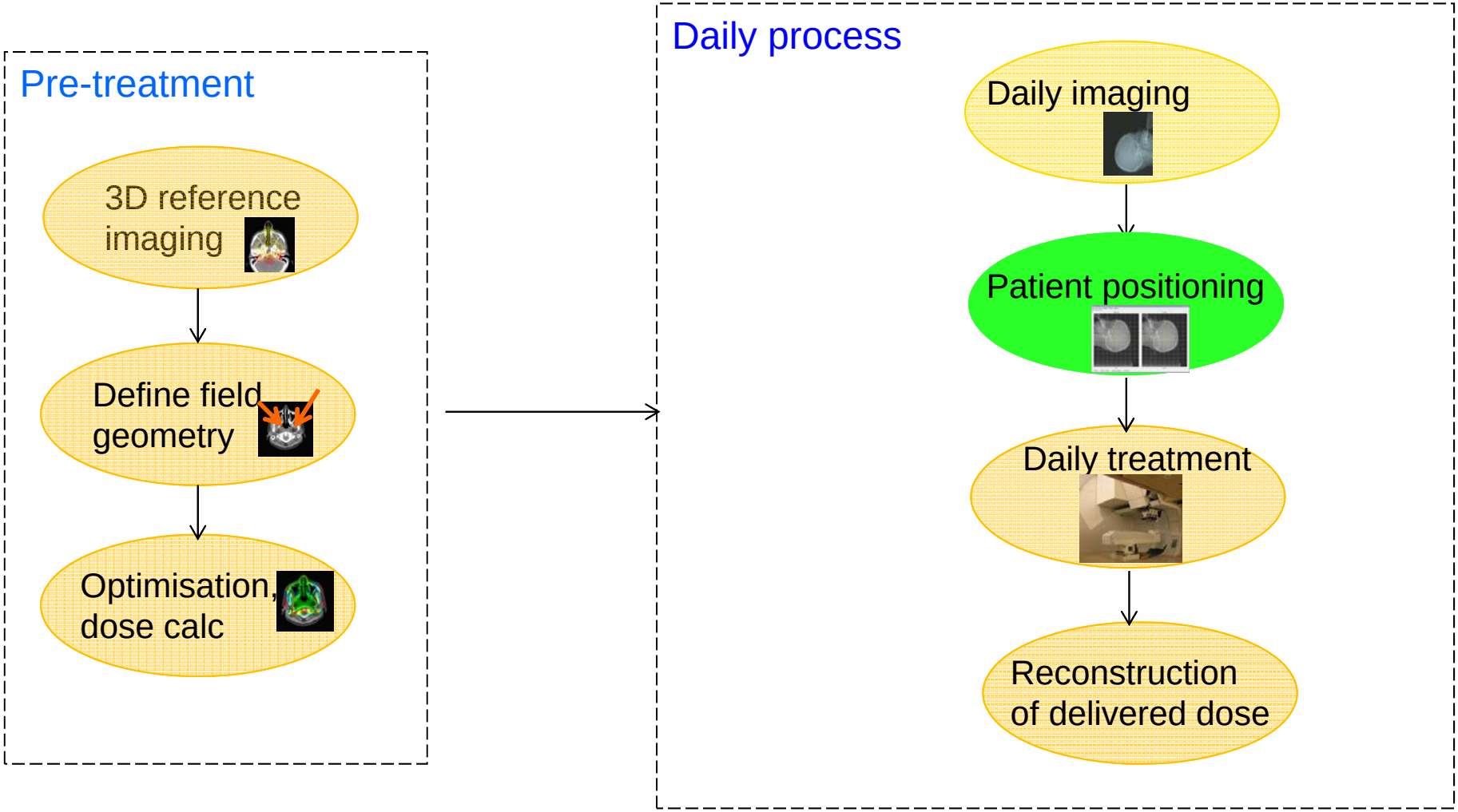
IMPT



- SFUD more robust than IMPT in the target
- IMPT plan more robust for brainstem
- Margins increase robustness for SFUD, but not necessarly for IMPT.

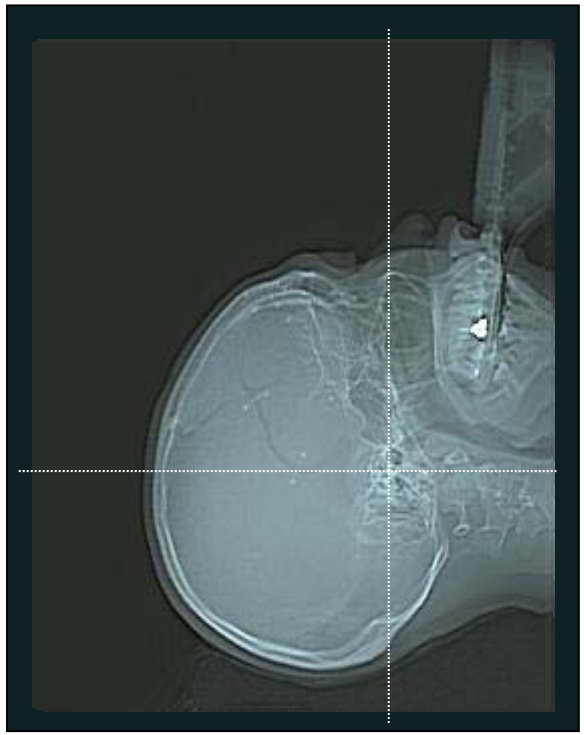
Lowe et al "Incorporating the effect of fractionation in evaluating the robustness of proton plans to set-up uncertainties"

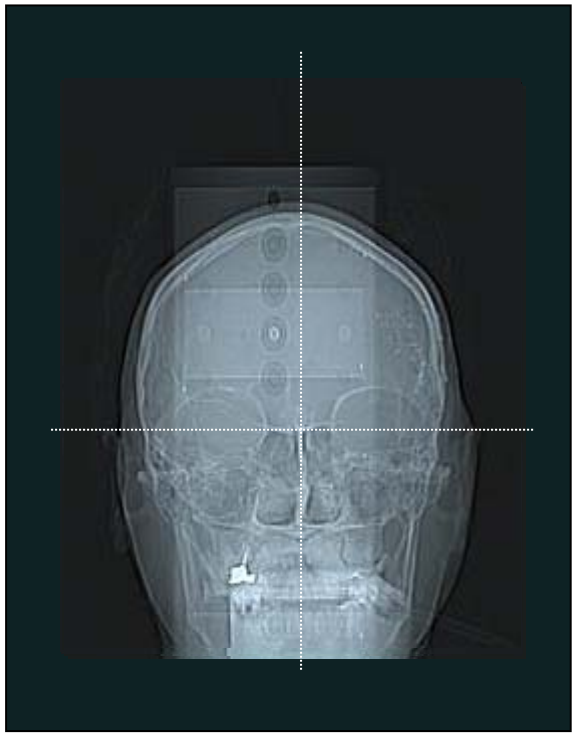
They can appear in different step of the entire radiotherapy workflow: from planning CT to the dose delivery.

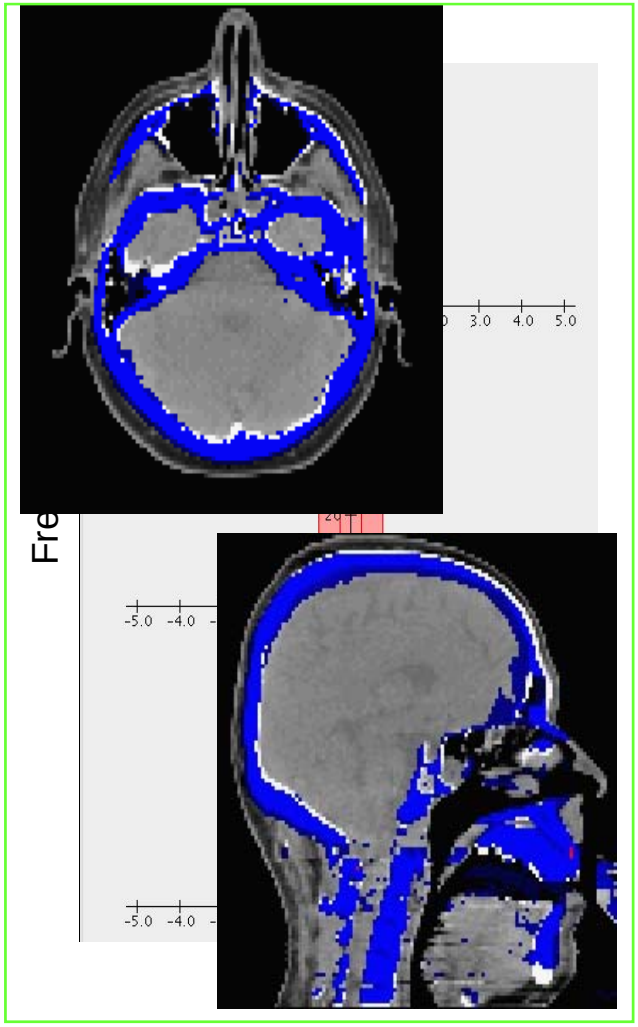


Patient positioning

Daily positioning protocol significantly reduce patient misplacement





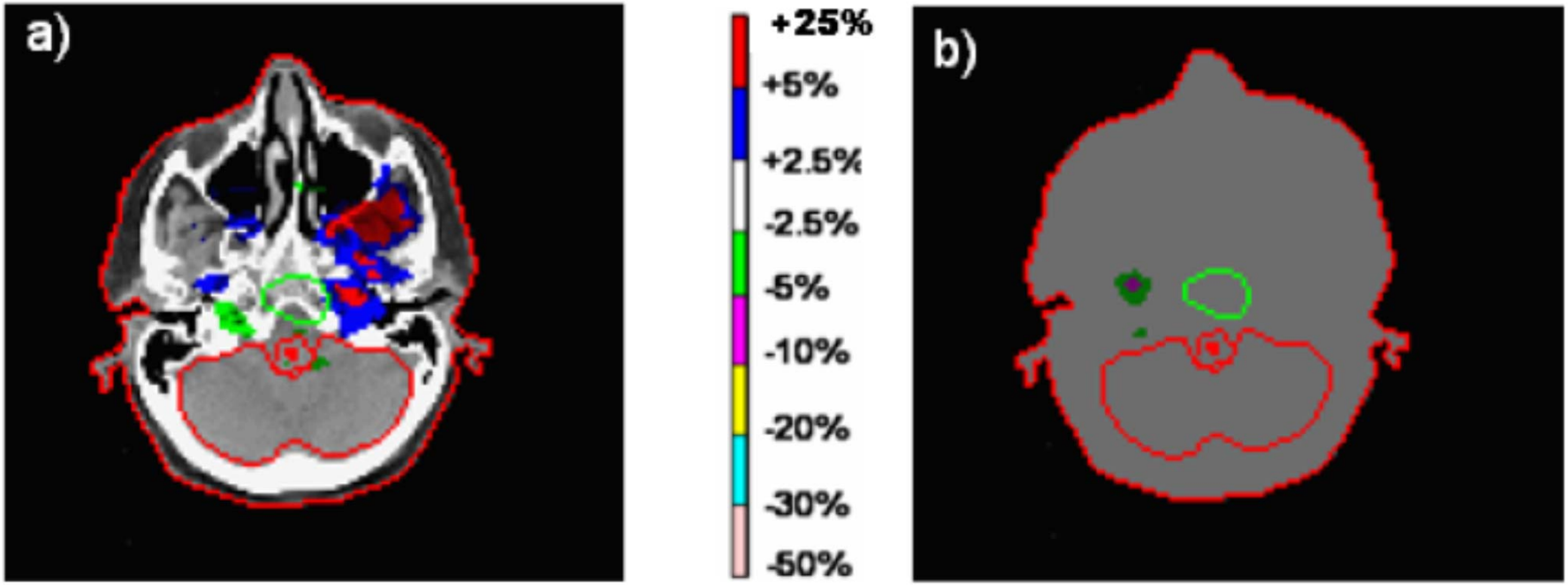


Planning

Set up errors combined with density heterogeneities

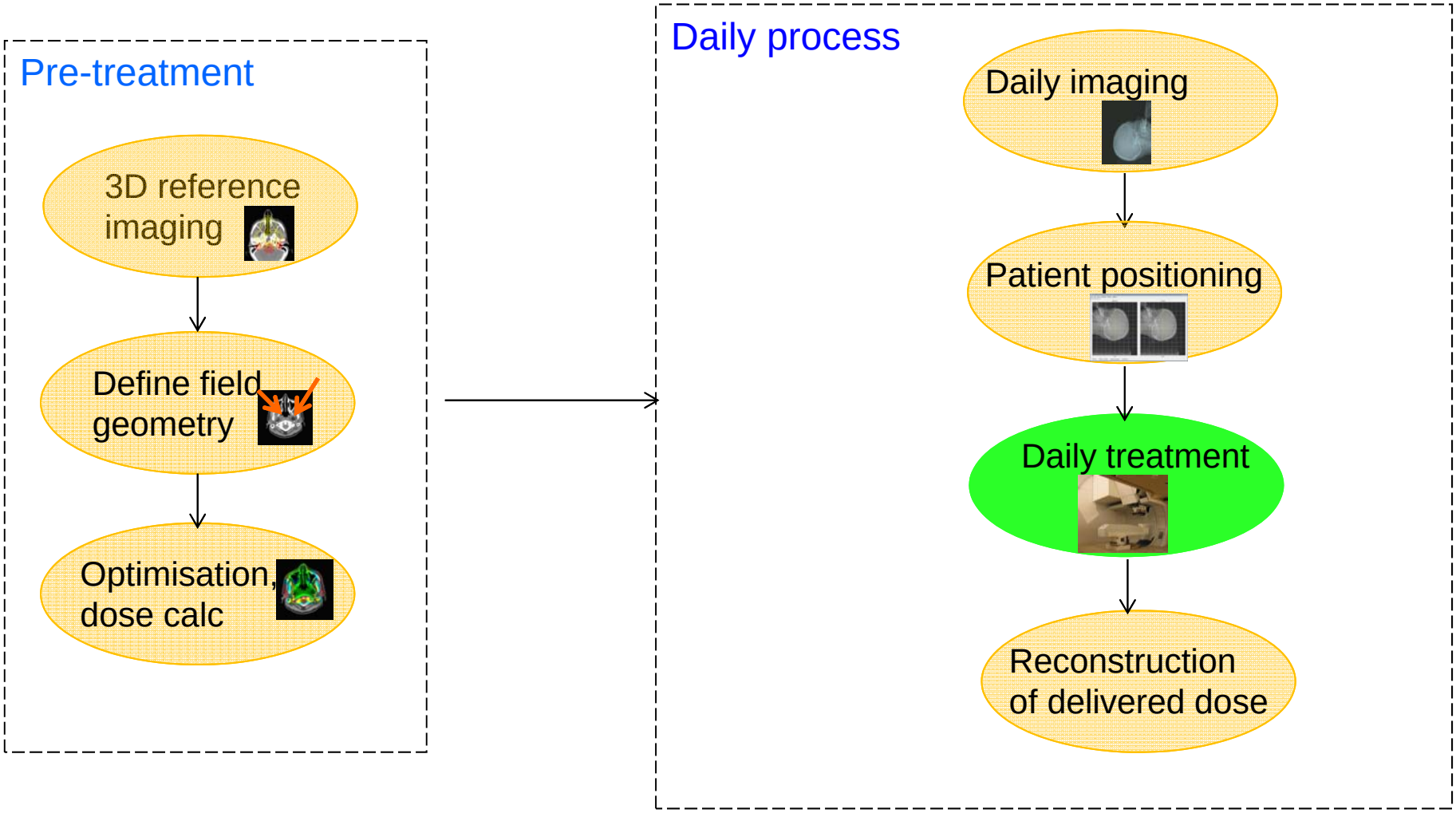
patient geometry

“water equivalent” patient



Even after image guided re-positioning, density heterogeneities can somewhat degrade the delivered dose due to residual positioning errors

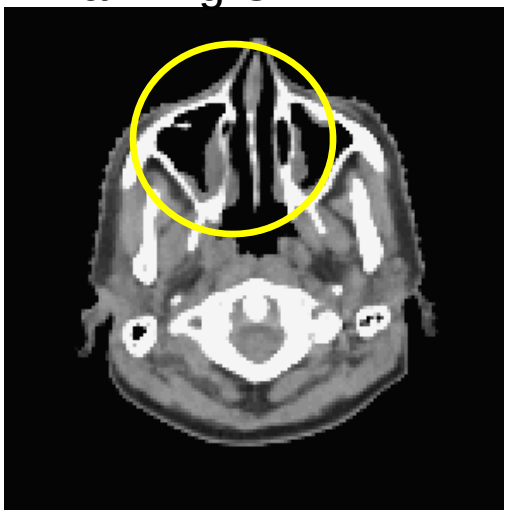
They can appear in different step of the entire radiotherapy workflow: from planning CT to the dose delivery.



Daily treatment

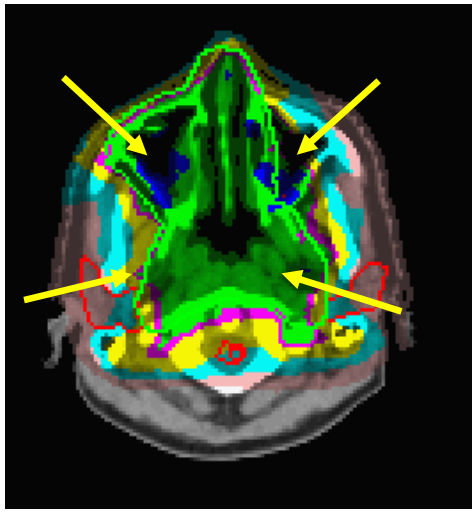
Nasal cavity fillings

Planning CT



Repeated CT

Nominal dose distribution

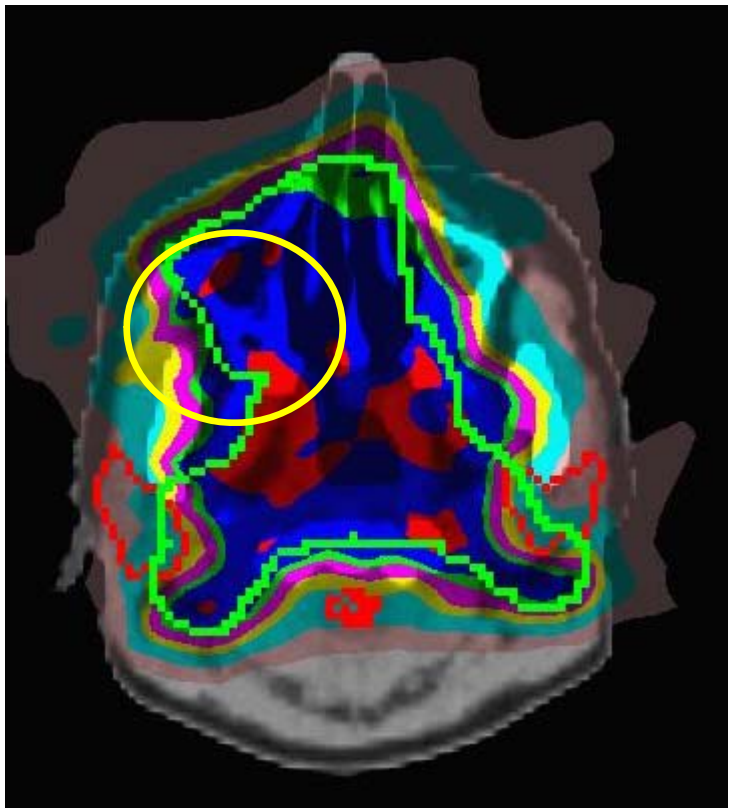


Every week the repeated CT slices acquired showed a significant different changing in the cavity fillings, with consequences on the delivered dose distributions.

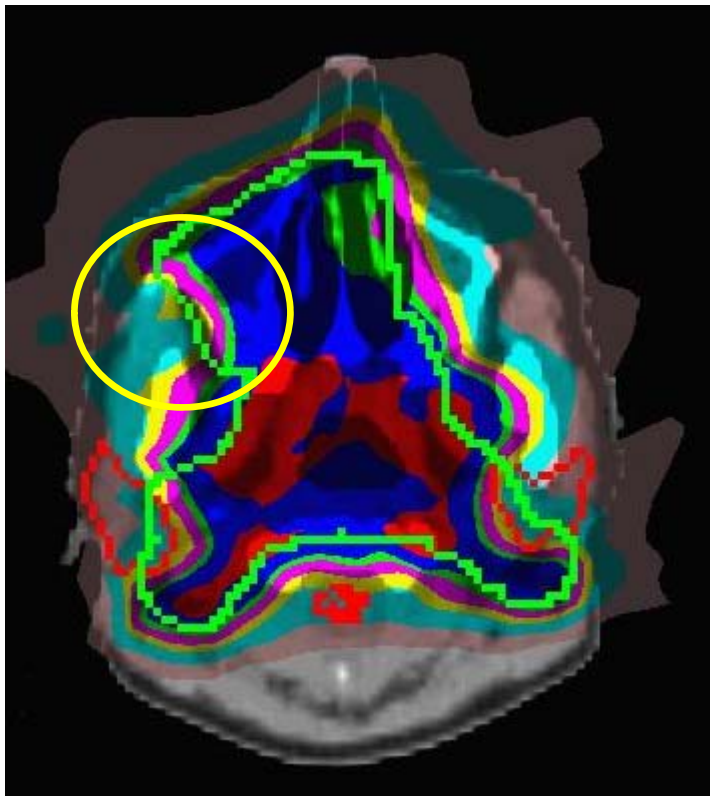
Daily treatment

Nasal cavity fillings

Nominal dose distribution (CTV in green, spinal cord in red)



Recalculated dose distribution

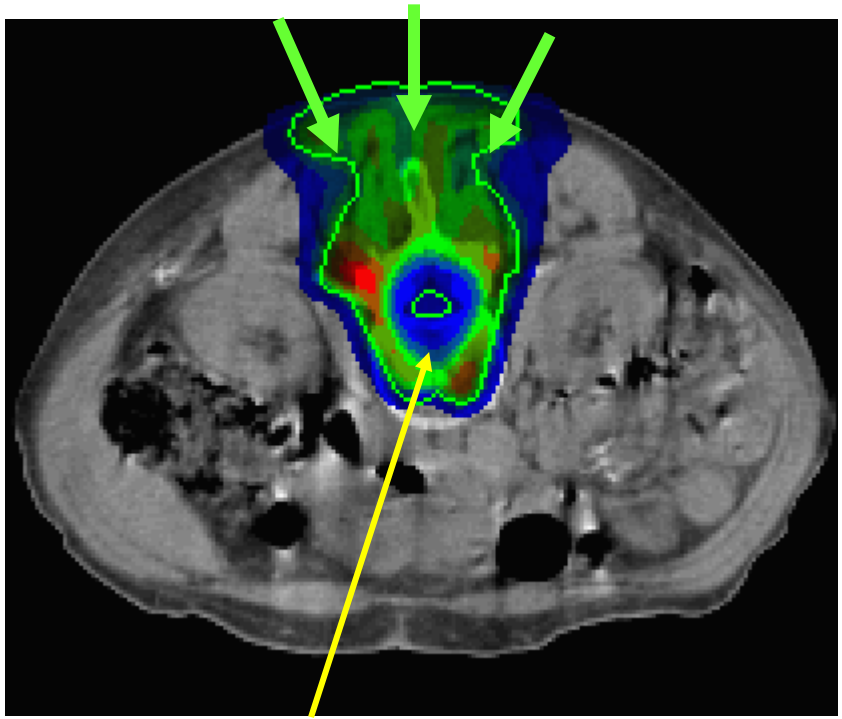


Placidi et al. "The effect of anatomical changes on PBS proton dose distributions: a retrospective review of 951 patients treated at PSI"

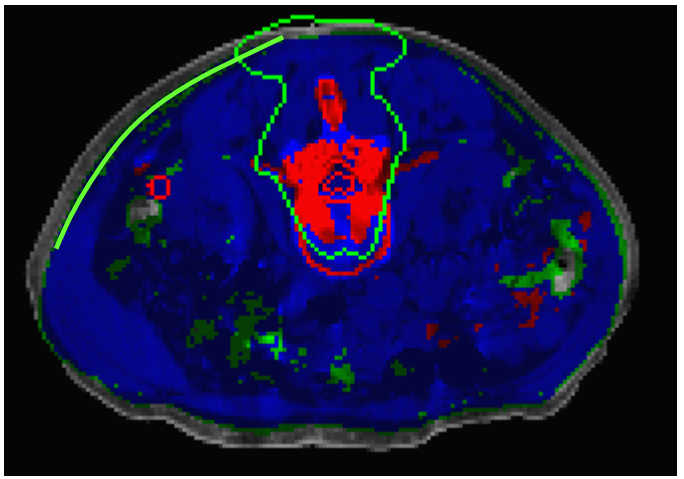
During treatment

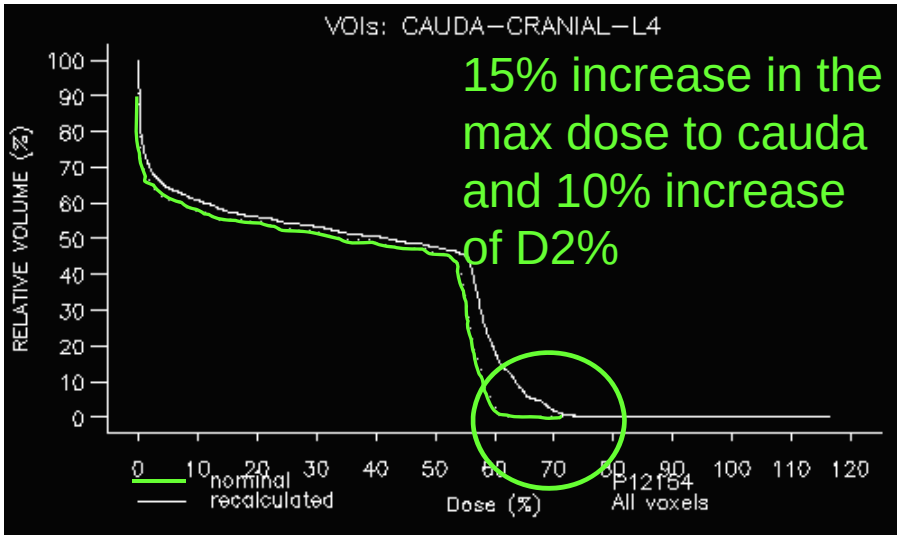
Weight changes

3 fields IMPT plan, pt lost 1.5 kg.



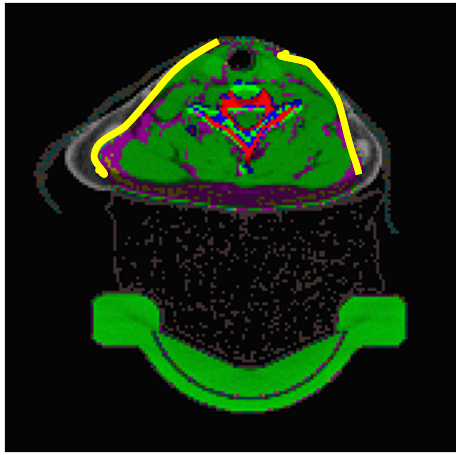
Cauda equina, included in the PTV was spared





During treatment

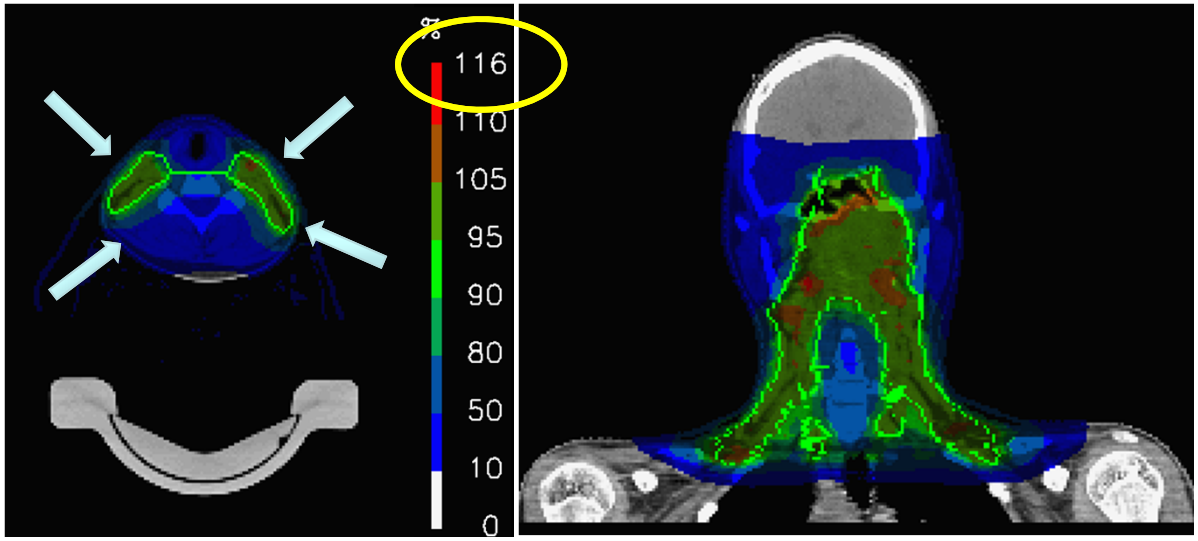
Volume shrinkage (neck lymph nodes)



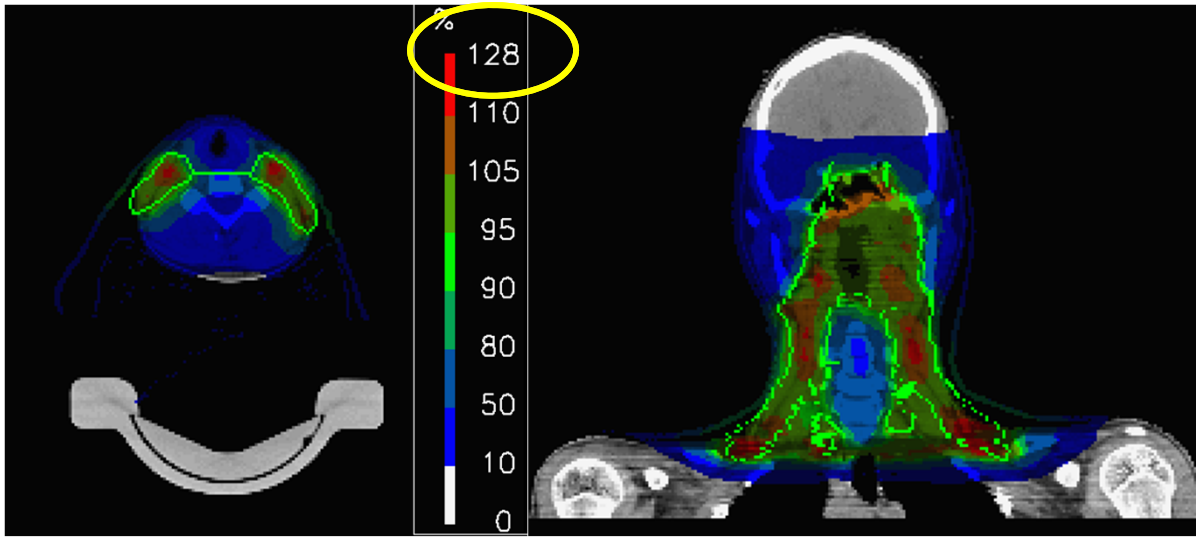
Node shrinkage of about 1 cm;
It was detected during the course of treatment.

Replanning was done due to the overdosage

Nominal



Recalculated



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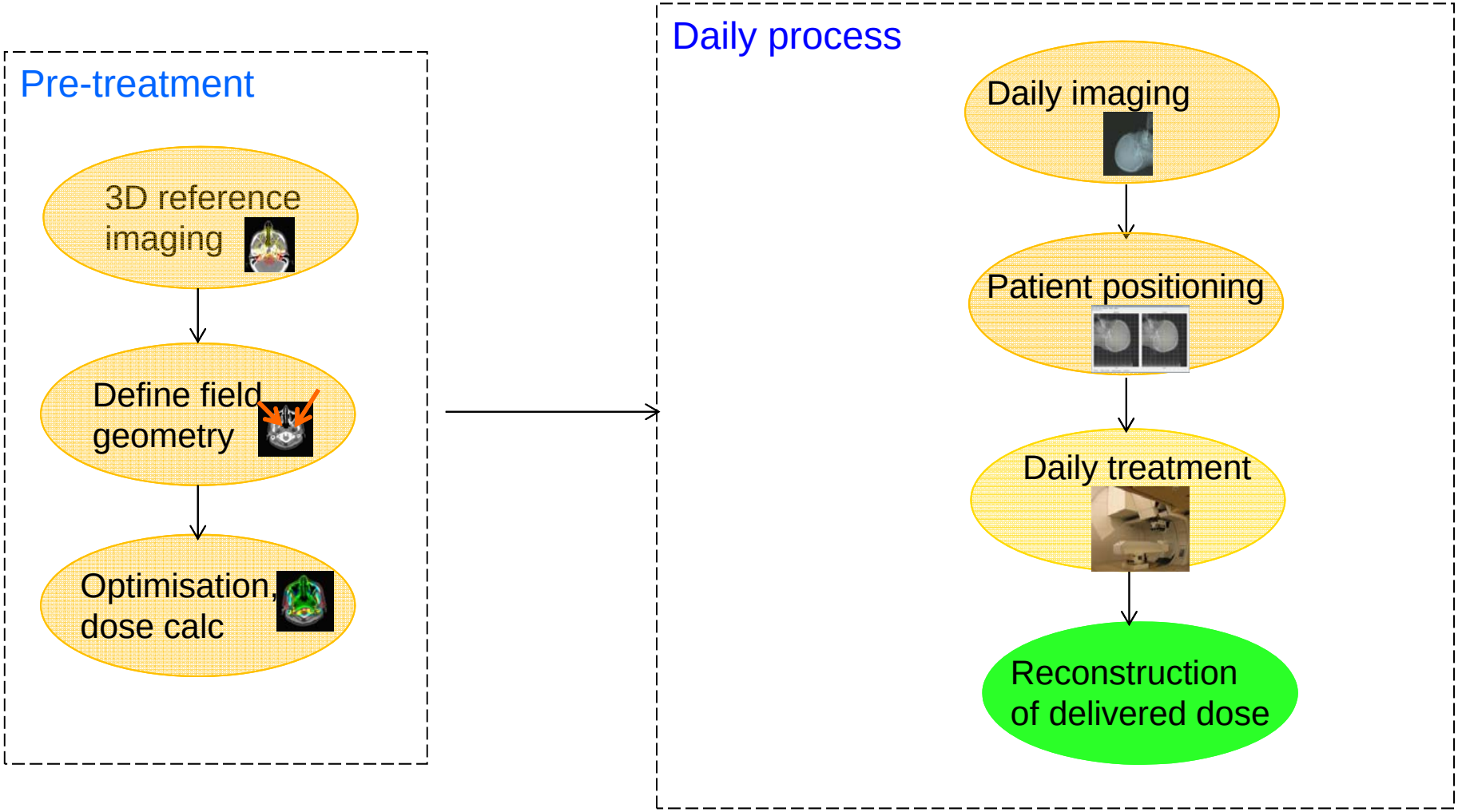
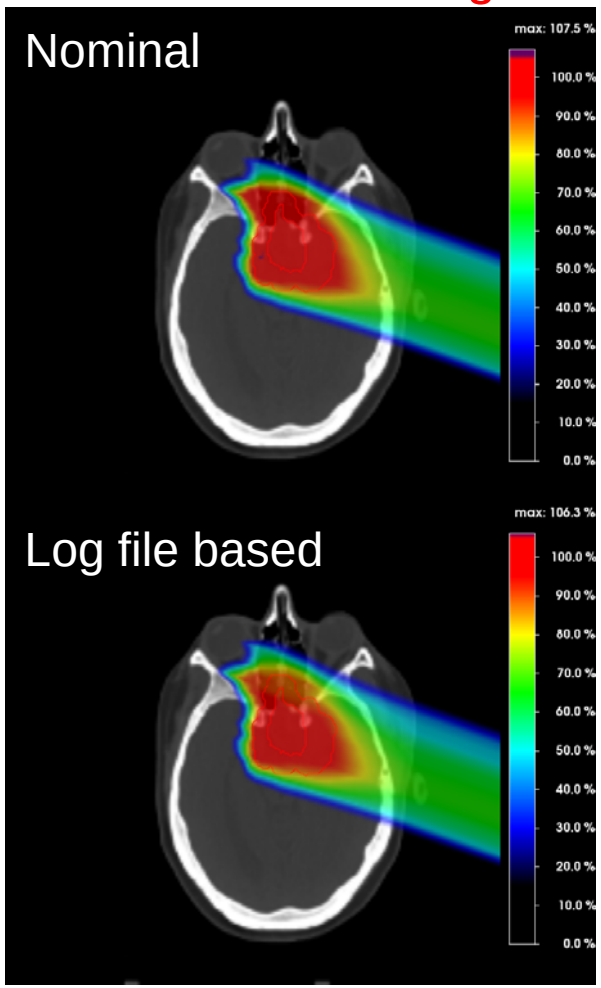
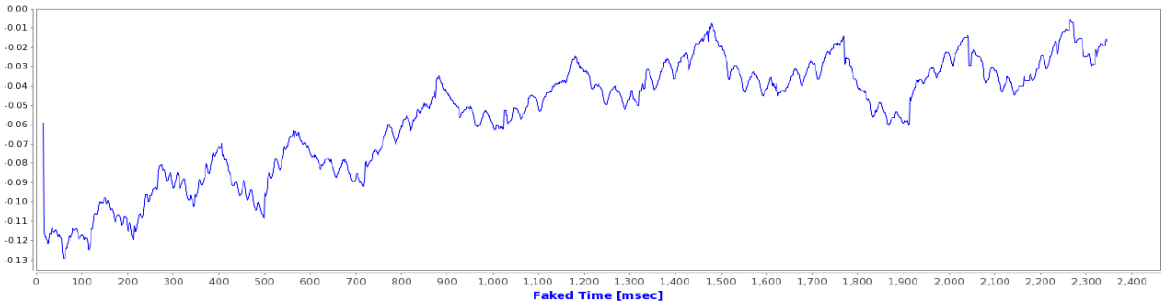


Delivered dose

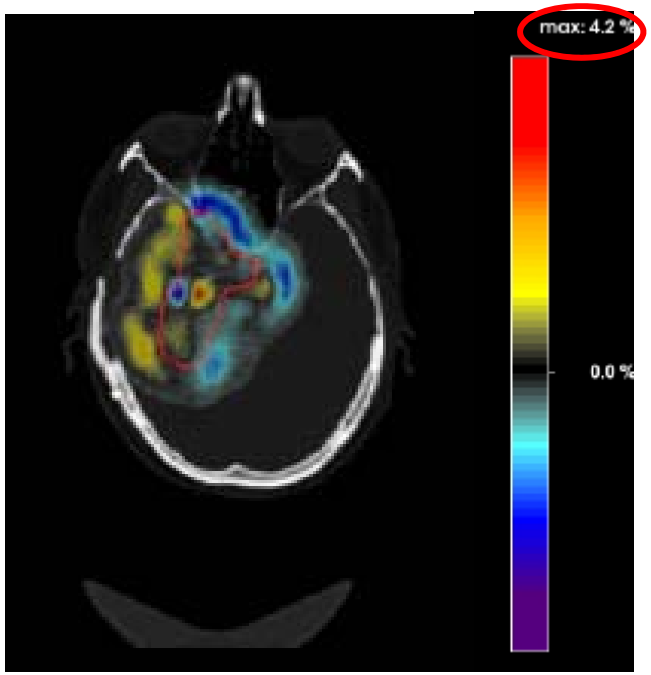
Calculation from log files



U position dynamic correction (teaching) [cm]



Meier G. et al. Independent dose calculations for commissioning, quality assurance and dose reconstruction of PBS proton therapy. Phys Med. Biol 2015 Apr 7; 60(7): 2819-36



Scandurra et el.“Is what we plan what we actually deliver? Using machine log-files to analyse delivery of 20 clinical PBS plans on PSI Gantry 2”. Poster at PTCOG 54

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Dealing with uncertainties

Different ways to deal with the (range and set up) uncertainties:

1. patient monitoring
   (detect range differences as soon as possible
   ideally daily)

2. adaptive therapy
   (adapt the plan, as soon as possible
   ideally daily)

3. robust planning
   (reduce a-priori the impact of range uncertainties)

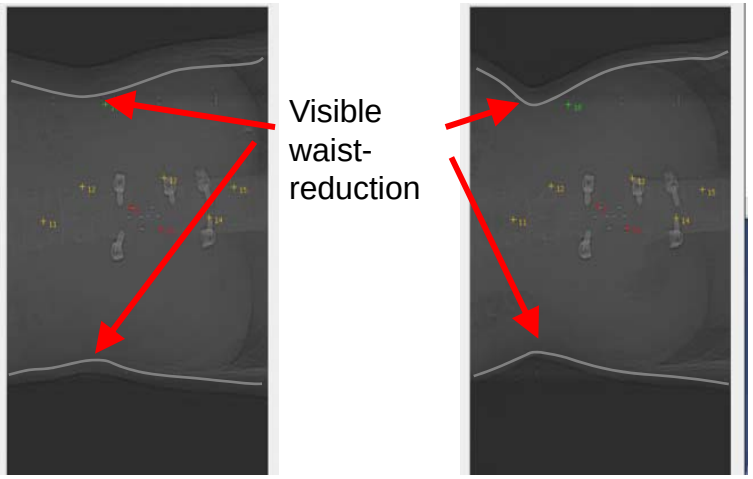
Dealing with uncertainties

1. Patient monitoring (daily or regularly)

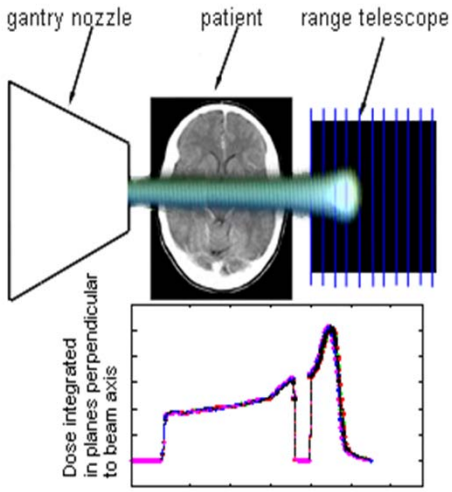
Daily X-ray (BEV)

Reference scout

3d fraction



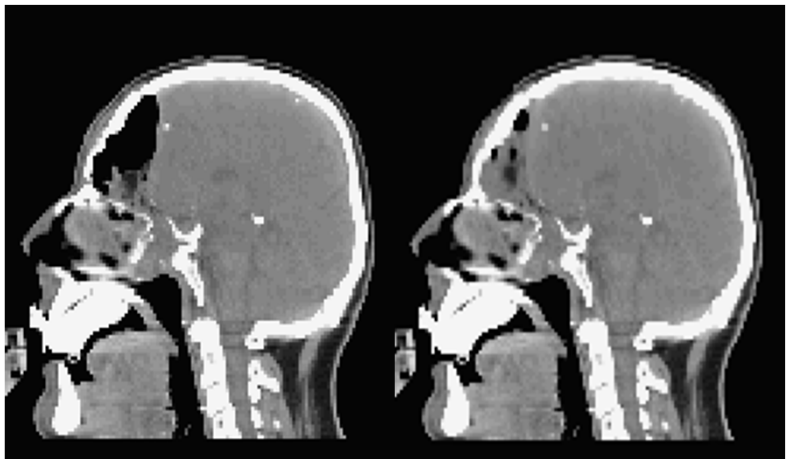
Range probe



Mumot M et al
PMB 2010

Control CT

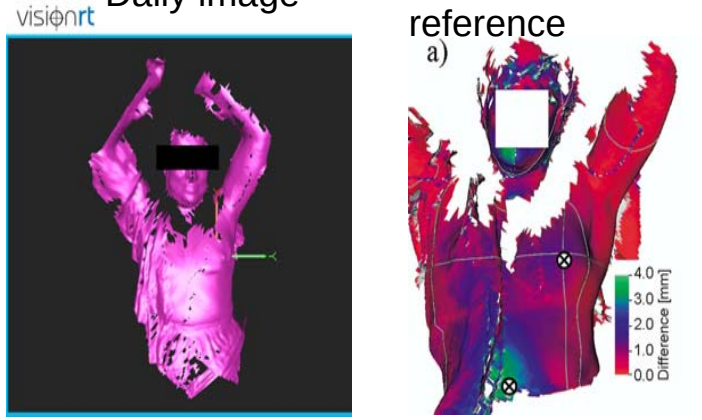
Planning CT control CT



Surface imaging

Daily image

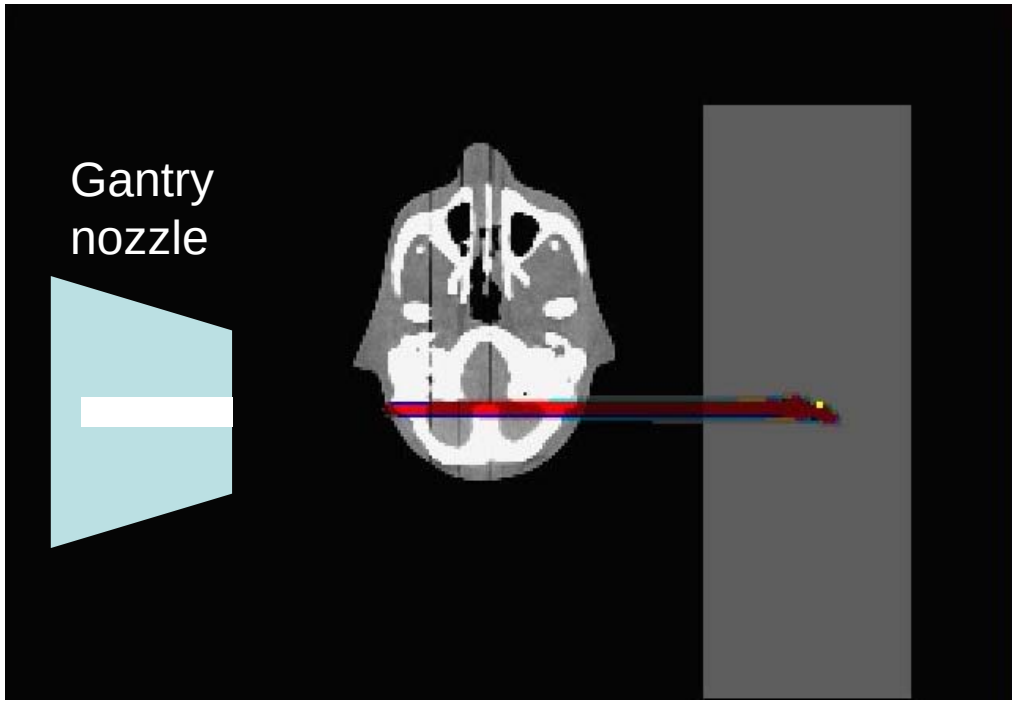
Difference from the reference



Christoph Bert et al IJROBP 2006

Dealing with uncertainties

1. Range probe



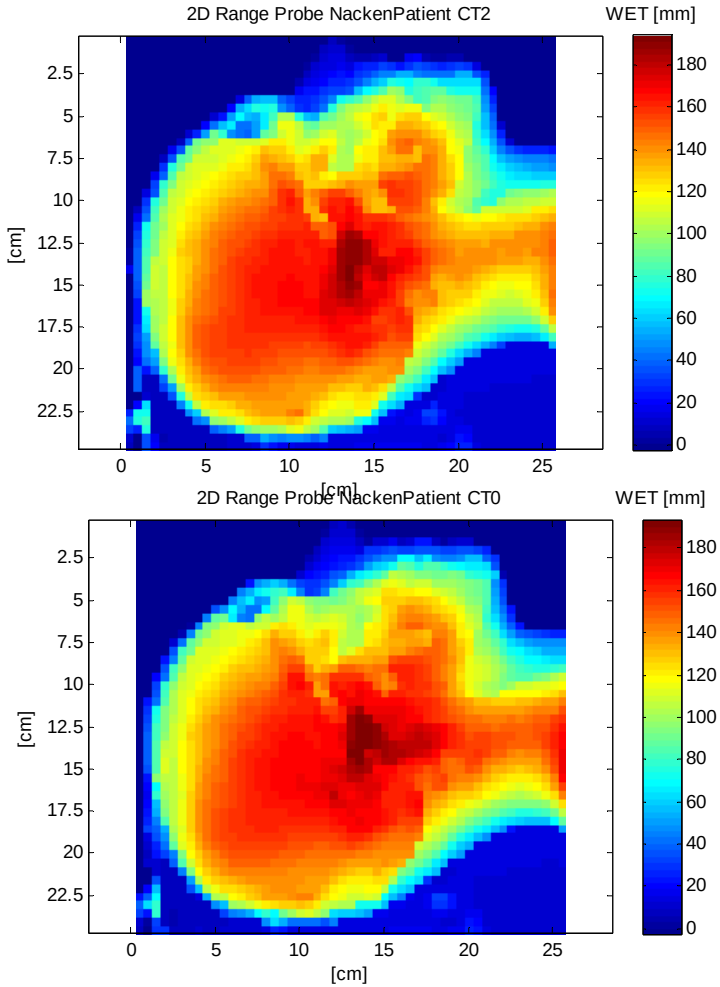
Single pencil beam with going trough the patient

residual range measured in the MLIC

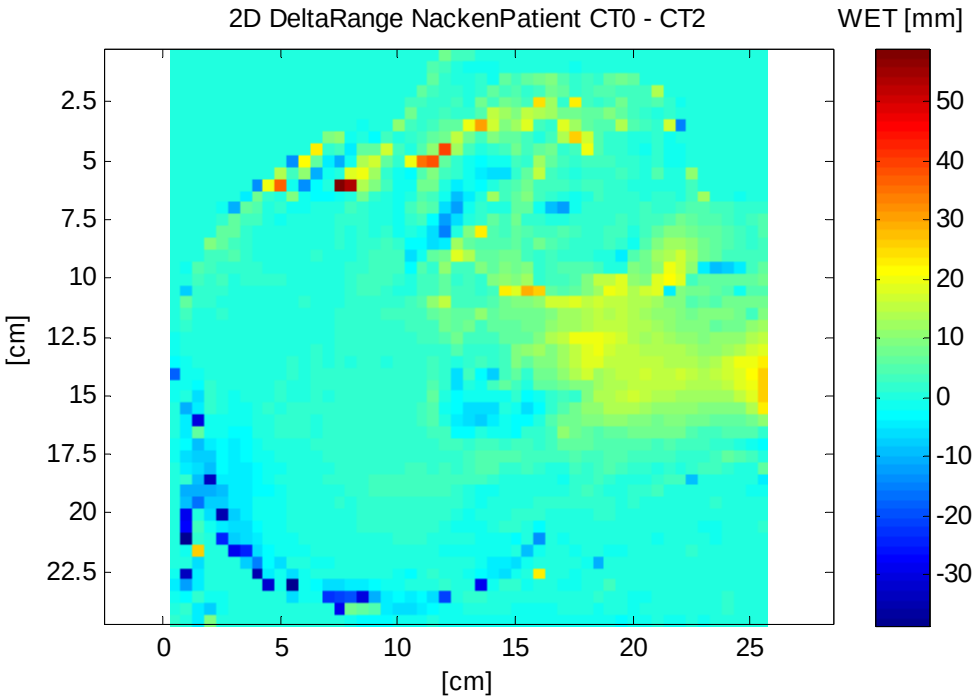
PhD work of Abdel Hammi (PSI)

1. Range probe 2D

2D RP 5x5mm spacing.



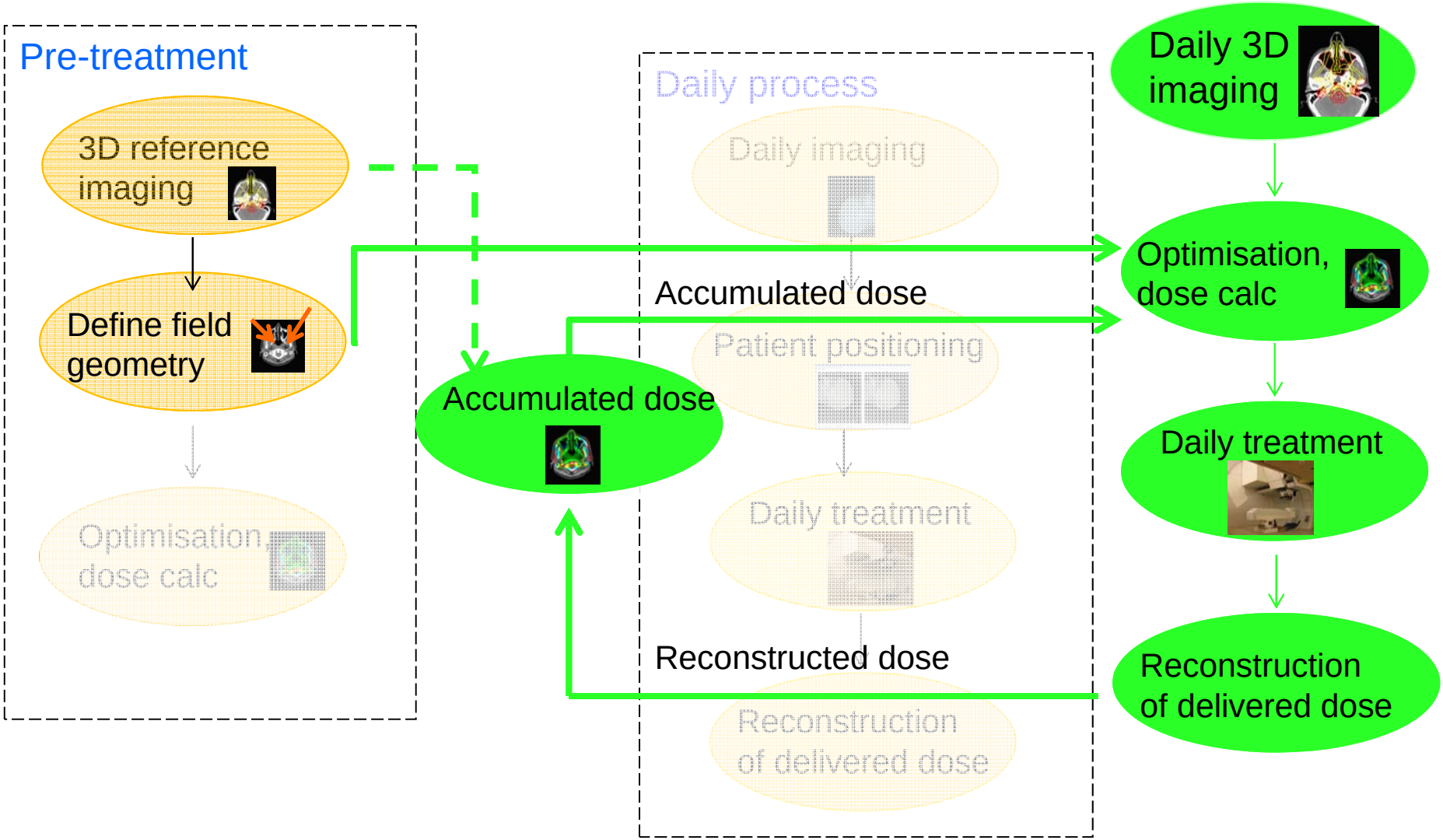
Residual positioning error and anatomical changes



PhD work of Abdel Hammi (PSI)

Dealing with uncertainties

2. Adaptive therapy



Courtesy of Tony Lomax

3. Robust planning

1. Careful selection of field incidences and planning techniques (as IMPT and SFUD)

1. Automatic incorporation of all the errors (range, set-up) in the optimization process (change of the cost-function)

Unkelbach J et al 2009 Med Phys. ; Unkelbach J et al 2007 PMB; Maleike, Flynn (Ex Raysearch)

3. Changing the optimization starting condition:

   a. manual selection of beam angles avoiding or penalizing path going through sensitive areas

   b. changing the initial beamlet fluences

Lomax A et al, 2001 Med Phys; Albertini F et al, 2010 PMB

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Summary

There are different kind of uncertainties (i.e. heterogeneities, positioning, range, delivery, RBE...)

They come into play during the entire workflow

Different possible solutions are based on:

a. Image guidance
b. Daily adaptive
c. Robust optimisation

The simplest and cheapest solution is based on:

Multiple fields with optimised directions

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Thank you!

..a special thank to Tony Lomax , Francesca Albertini and all my CPT colleagues

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Introduction

Uncertaities in the clinical practice:
Head and neck cases very challenging due to many concomitant problems:

-denti, artefatti, eterogeneneità patient positioning, shrinkage of the nodes…(satangunantan)
-Organ motion (slide di Tony..ma questo merita talk a parte)
-Referenze a poster di Dan e gabriel (eventuale slide su log file calculation)

Differenza di uncertainties in SFUD/IMPT!!!!!!
Sostituire range adaptive con plan adaptation

Immagine su artefatti denti, eventualemnte tagliare ancora una slide di Stefania.
Summary

Dynamically Adapted Radiotherapy (DART)

The concept…