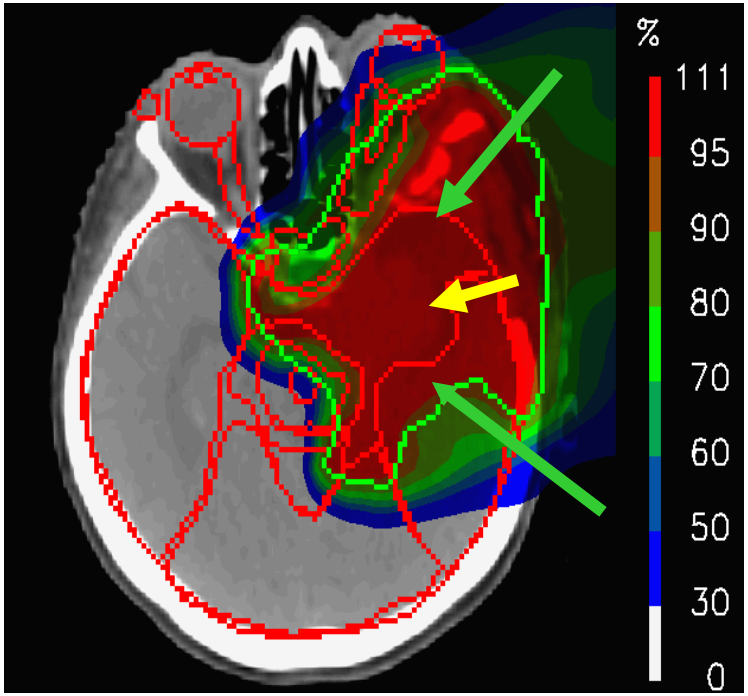
PAUL SCHERRER INSTITUT

Tony Lomax : Head of Medical Physics: Paul Scherrer Institute, Switzerland

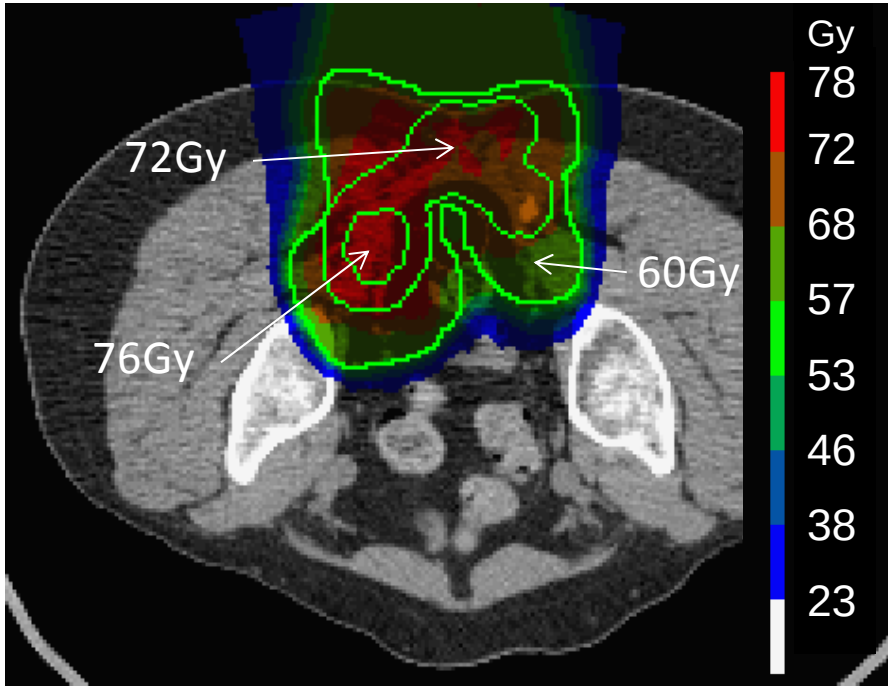
Myths and realities of range uncertainty in proton therapy

PPRIG – 2nd October 2016

Simply put – protons stop…



Meningioma (3 fields)

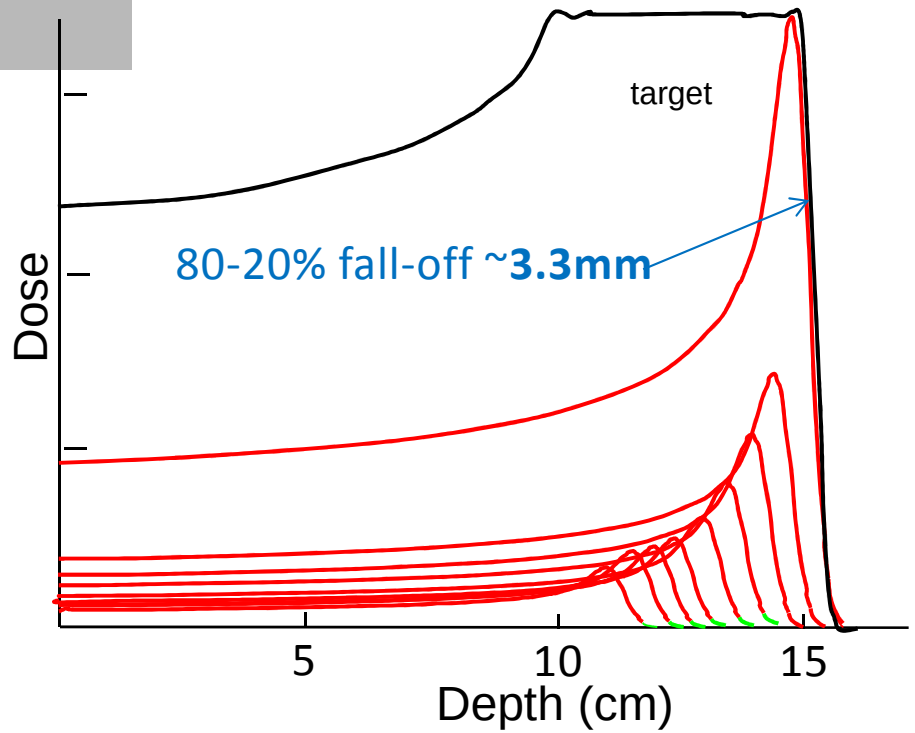


Sacral chordoma
(2 fields)

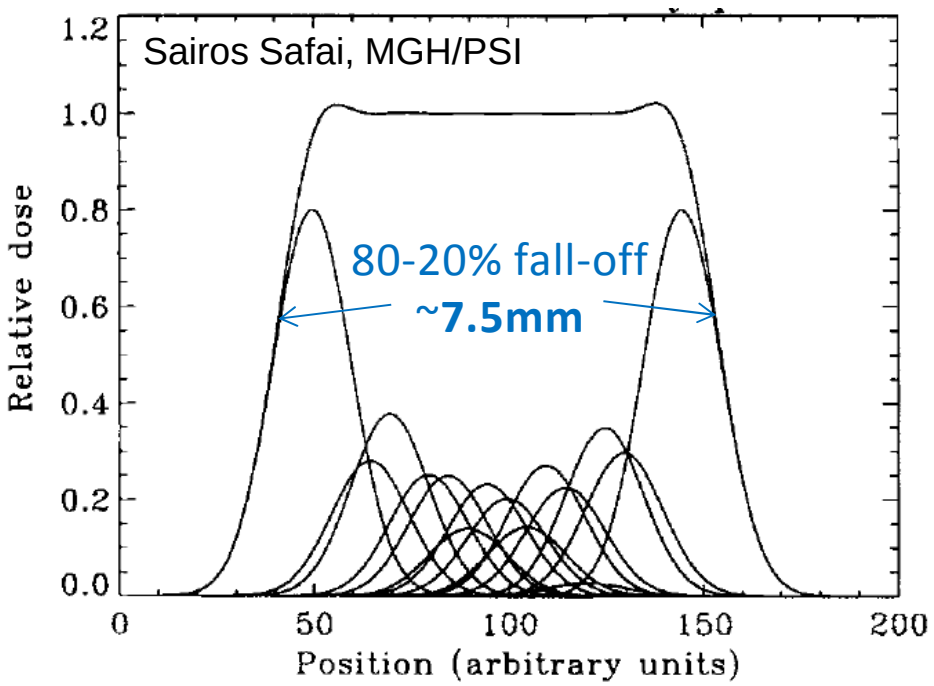
The advantage of proton therapy

Not only do they stop, but they stop sharply.

Distal fall-off at 15cm depth



Lateral fall-off at 15cm depth

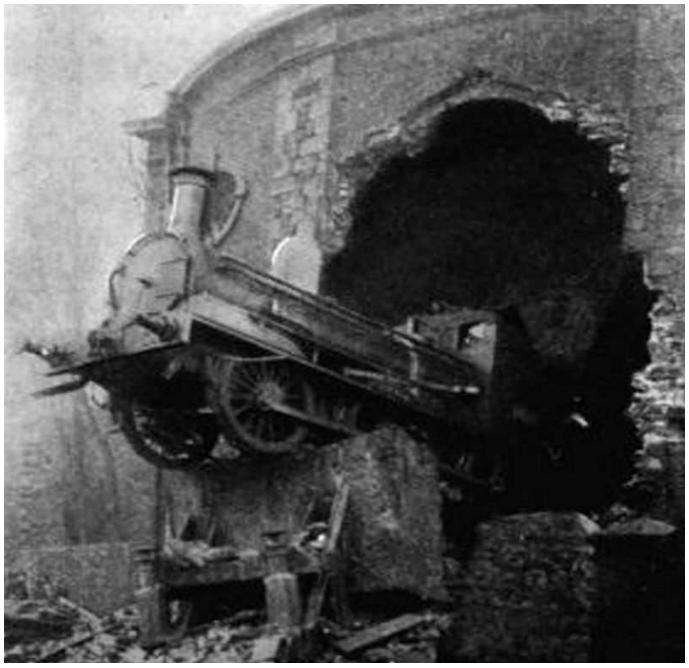


Thus, in theory, we can have sharper dose gradients using the distal edge than if we use the lateral edge.

But stopping can be dangerous if we don't know where…

Getting it right…

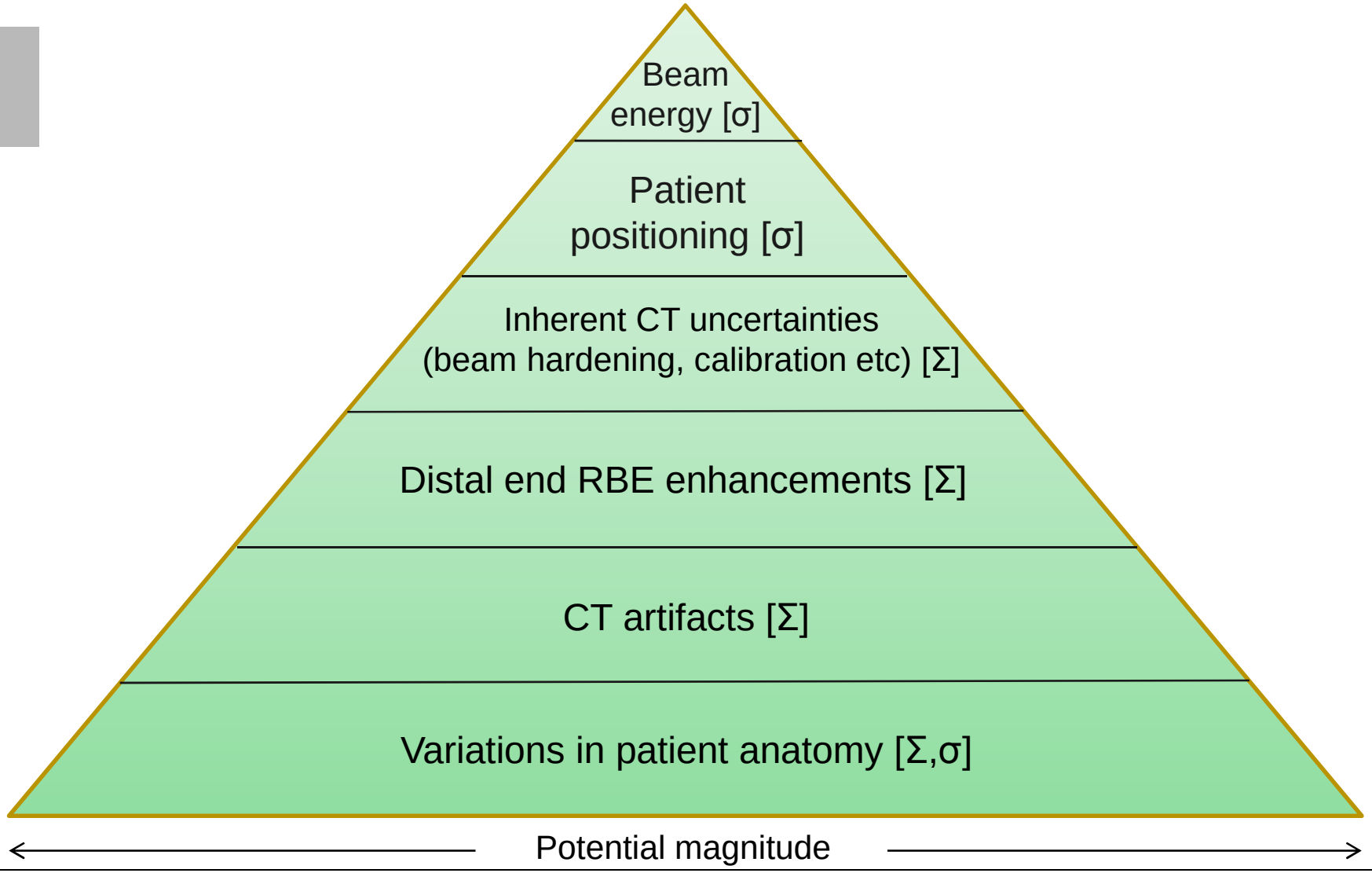
Getting it wrong…



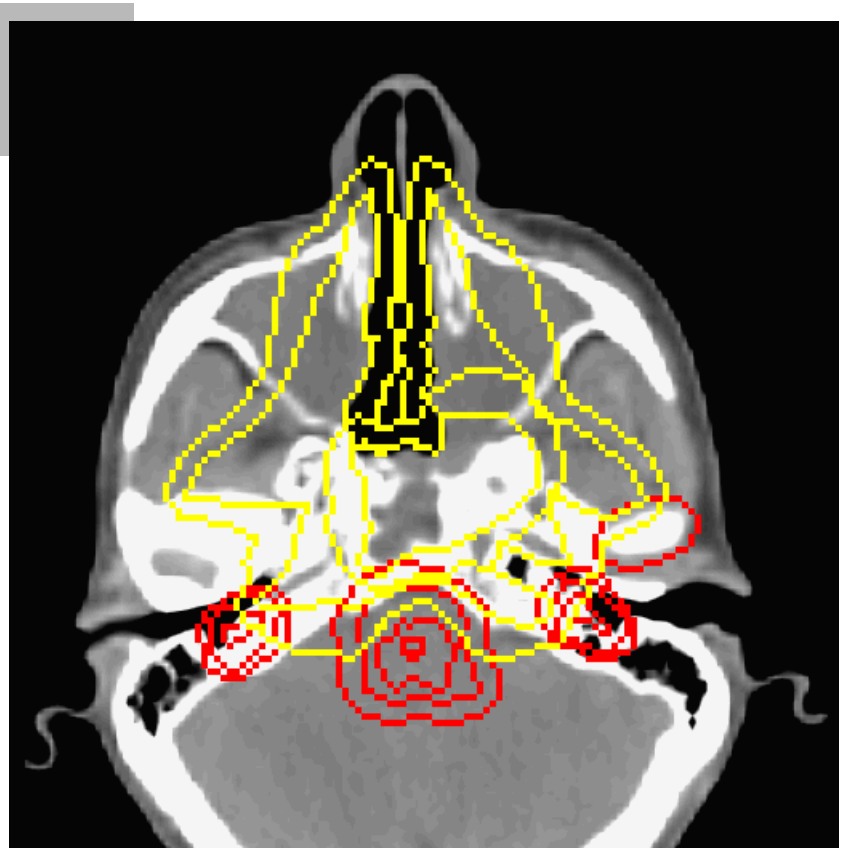
The problem of range uncertainty

Range uncertainty

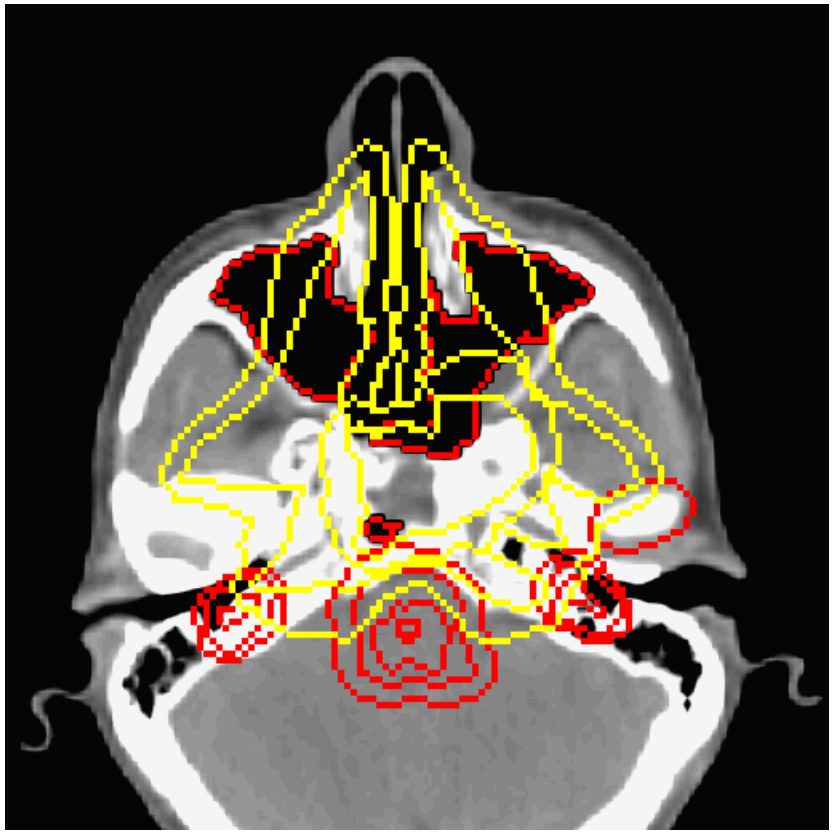
What makes range ‘uncertain’?



Examples of range uncertainty 1 – cavity filling



Planning CT

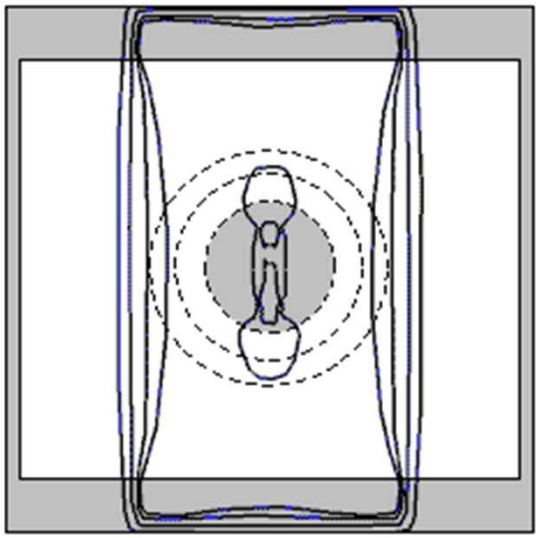


Repeat CT after 2 weeks

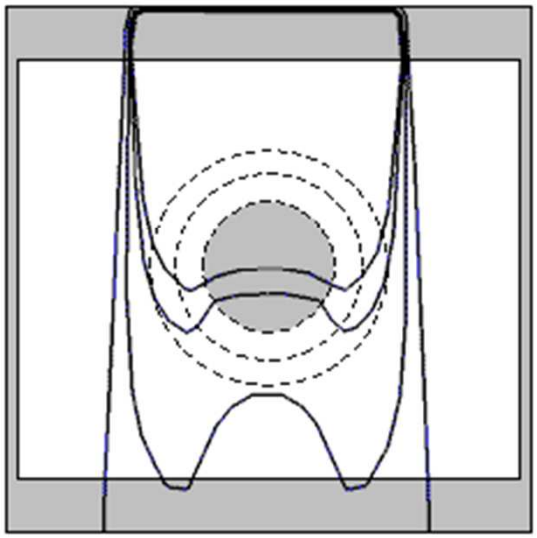
Unavoidable range changes of centimeters…

Examples of range uncertainty 2 - motion

Parallel opposed photons



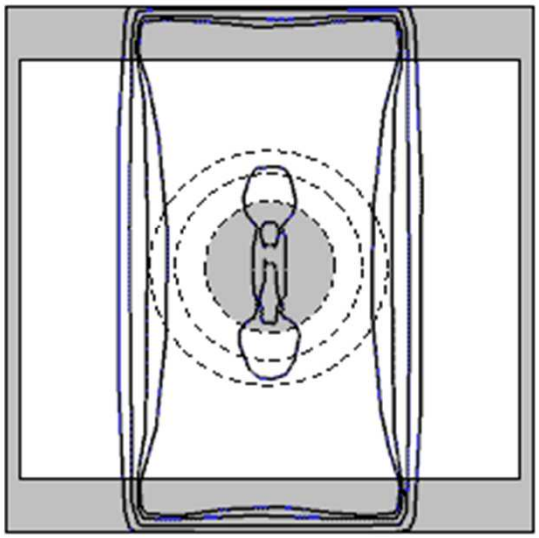
Single field photons



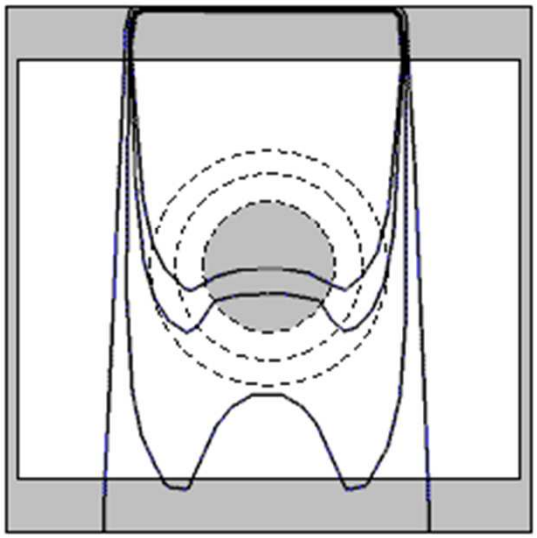
Martijn Engelsmann, MGH (now at HollandPTC)

Examples of range uncertainty 3 - motion

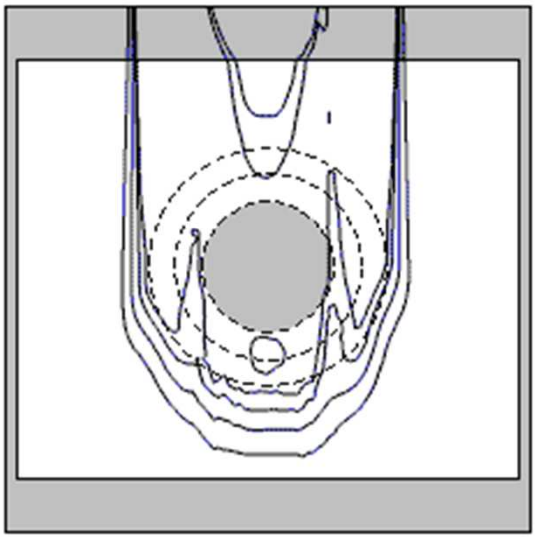
Parallel opposed photons



Single field photons



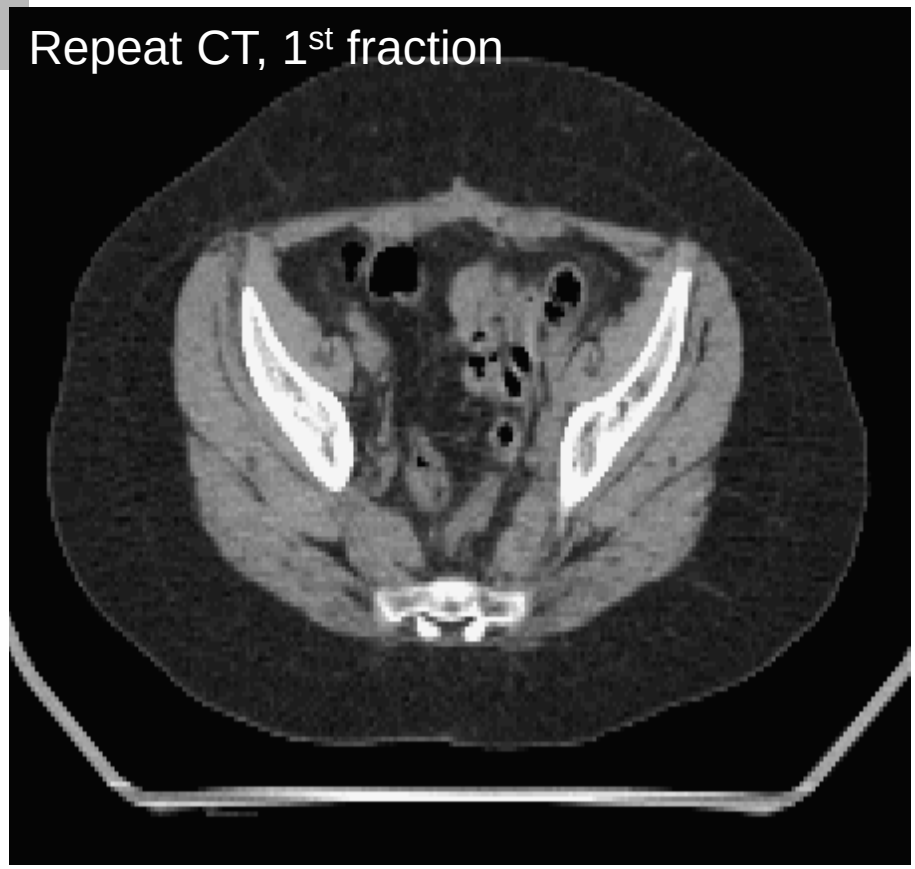
Single field protons

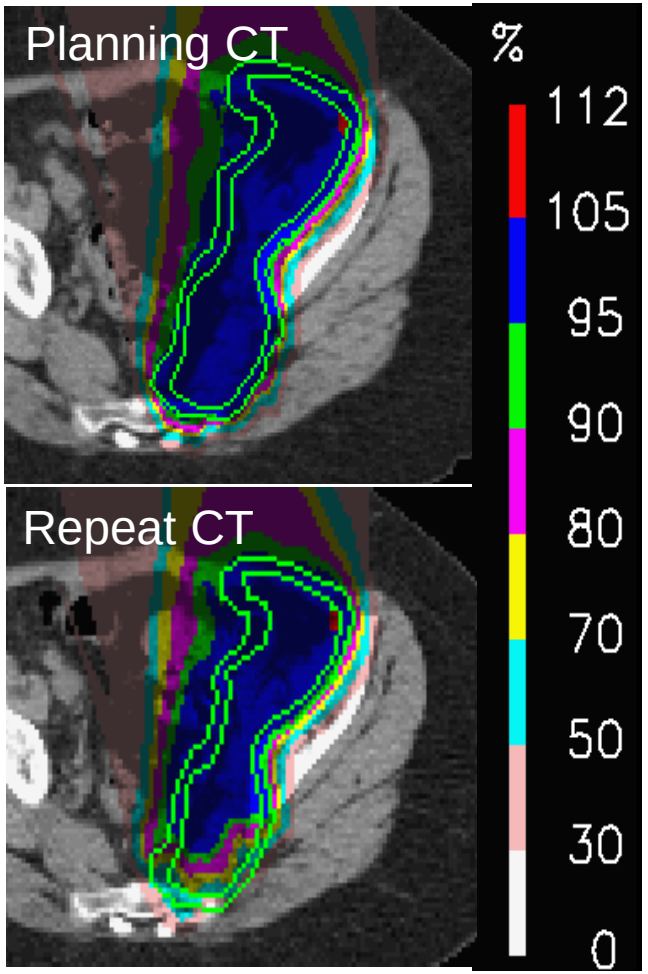


Martijn Engelsmann, MGH (now at HollandPTC)

Why is range uncertainty a problem?

1. (Partial) target misses…



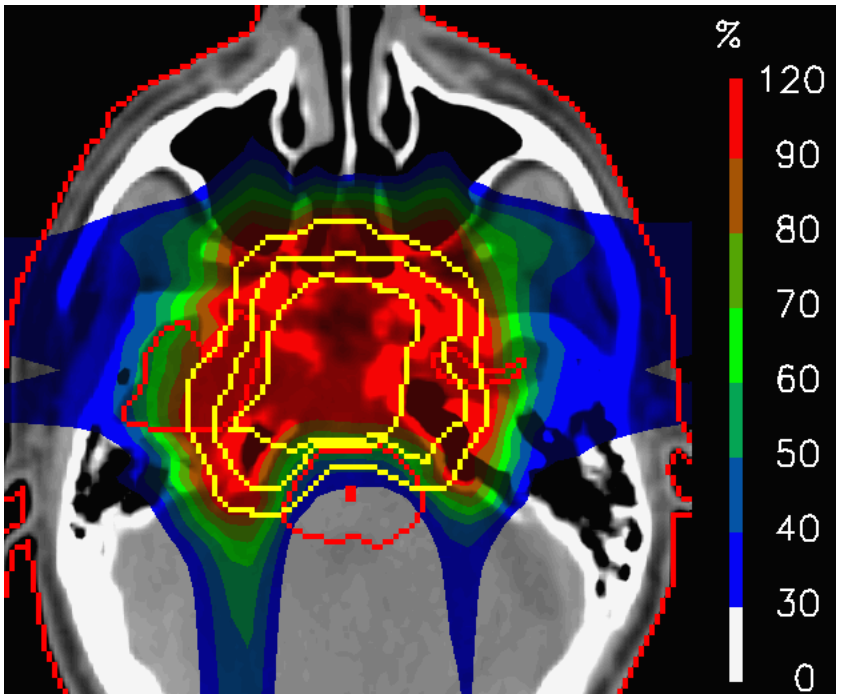


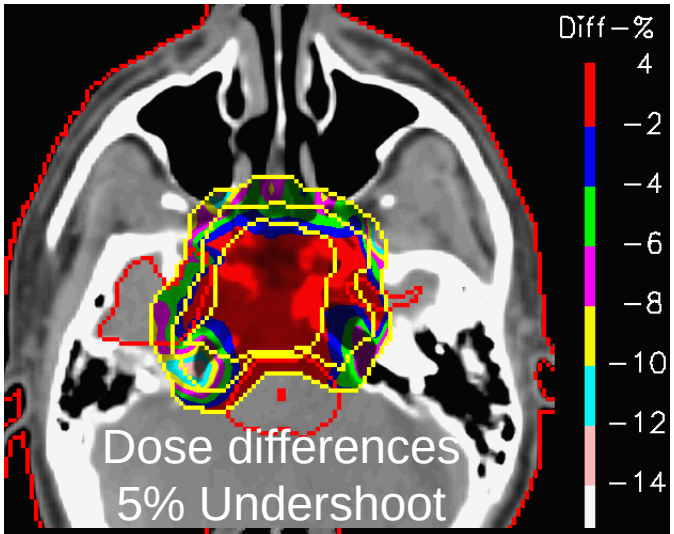
Francesca Albertini and Alessandra Bolsi (PSI)

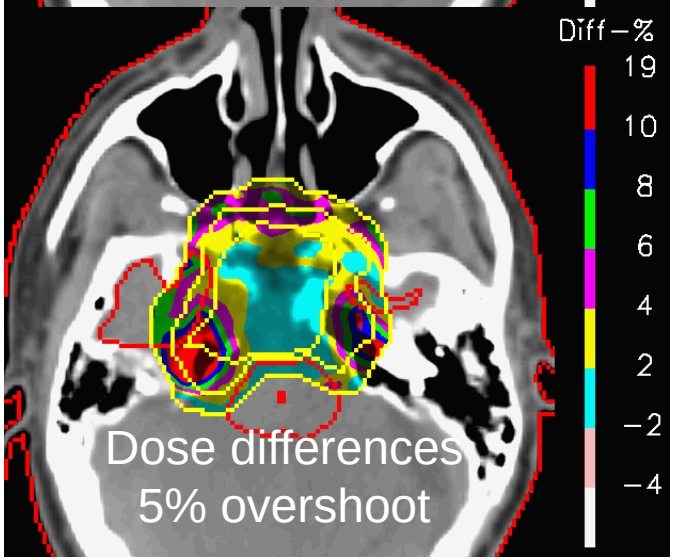
Why is range uncertainty a problem?

2. Unplanned cold and hot spots…

3 field IMPT plan



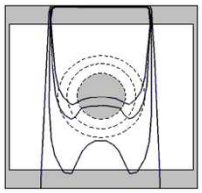


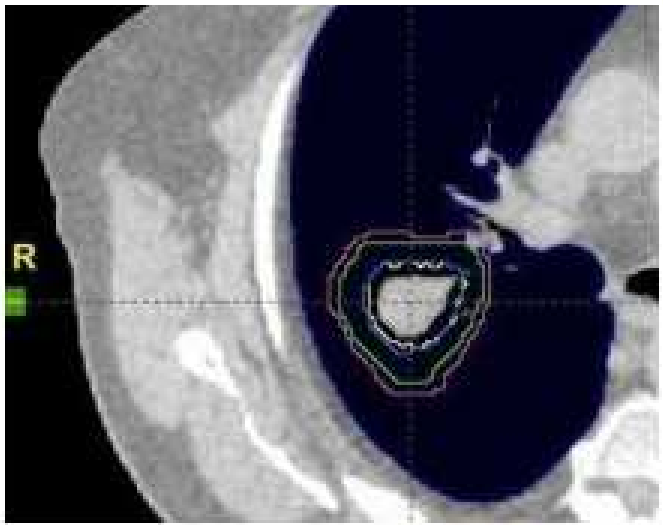


Lomax AJ (2007) in 'Proton and charged particle Radiotherapy', Lippincott, Williams and Wilkins

Why is range uncertainty a problem?

3. Enlarged volumes to ensure target coverage under conditions of motion

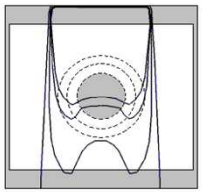


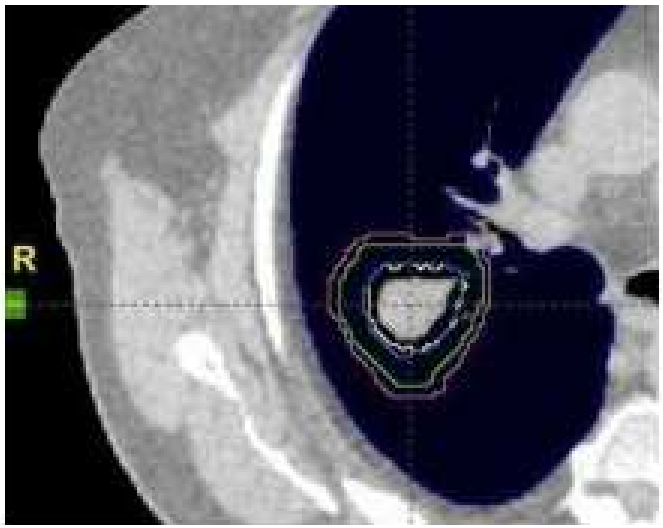


Motion compensated volumes for photons

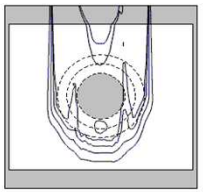
Why is range uncertainty a problem?

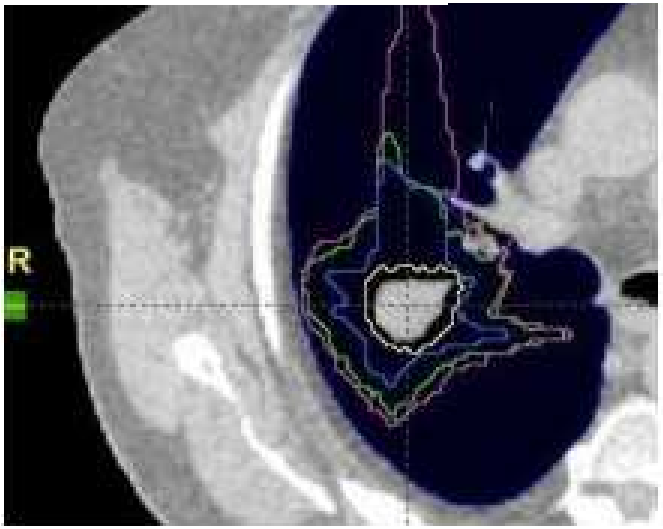
3. Enlarged volumes to ensure target coverage under conditions of motion





Motion compensated volumes for photons



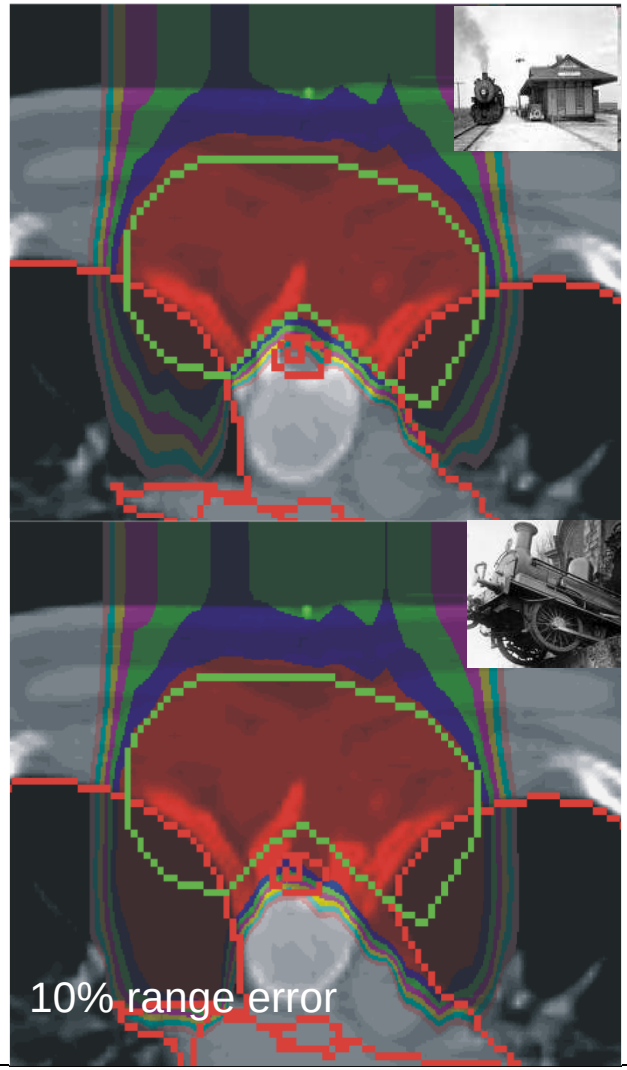


Motion compensated volumes for protons

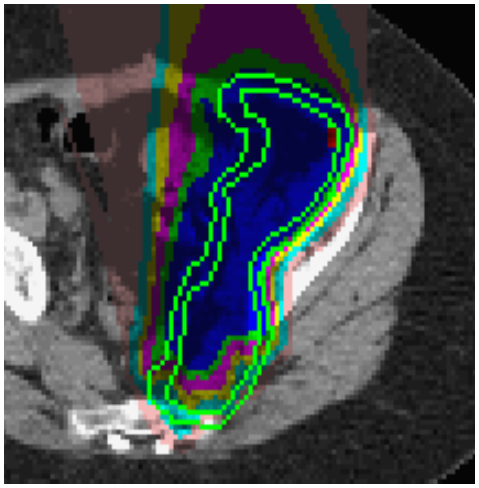
4. Overdosing (distal) critical structures

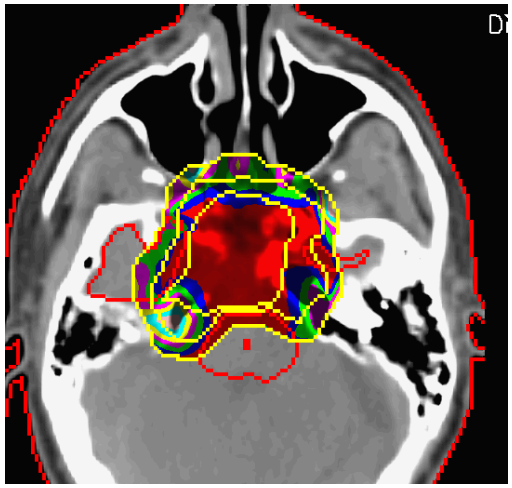
The sharpest gradient is only sharp….

…if it stops in the right place

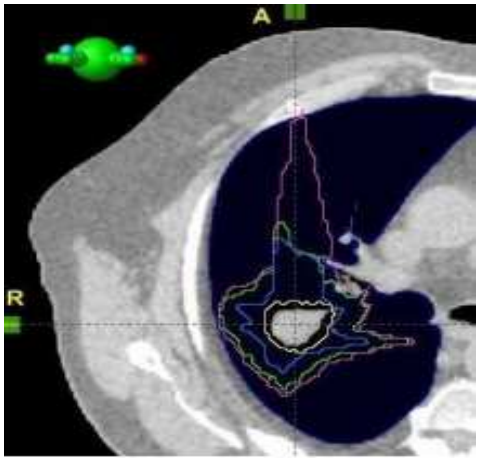


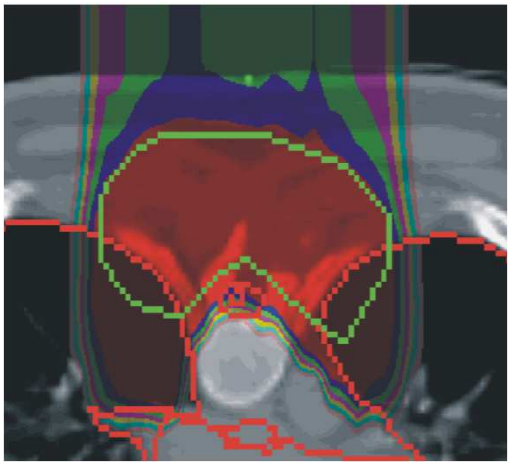
The problem of range uncertainty





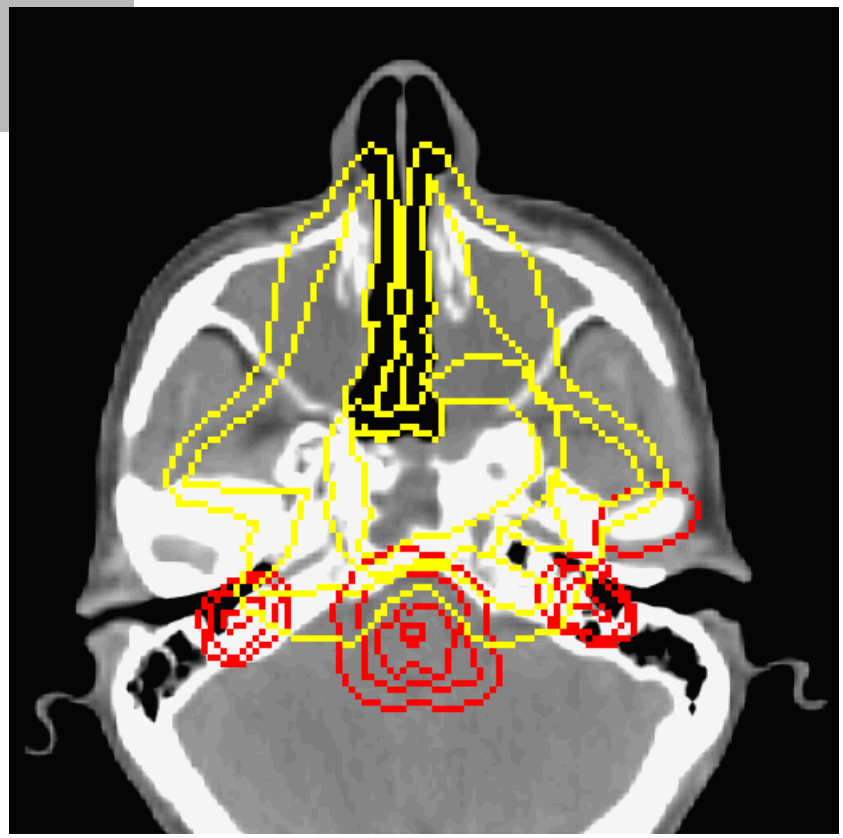
But are things always really as bad as they seem?



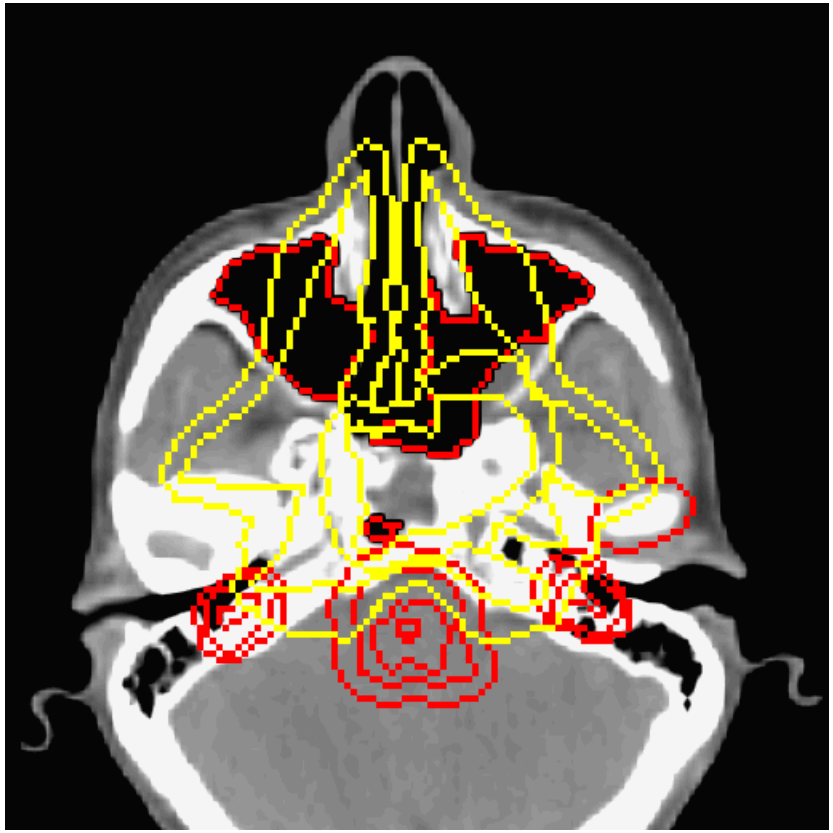


Things might not be as bad as they seem…

Remember this?

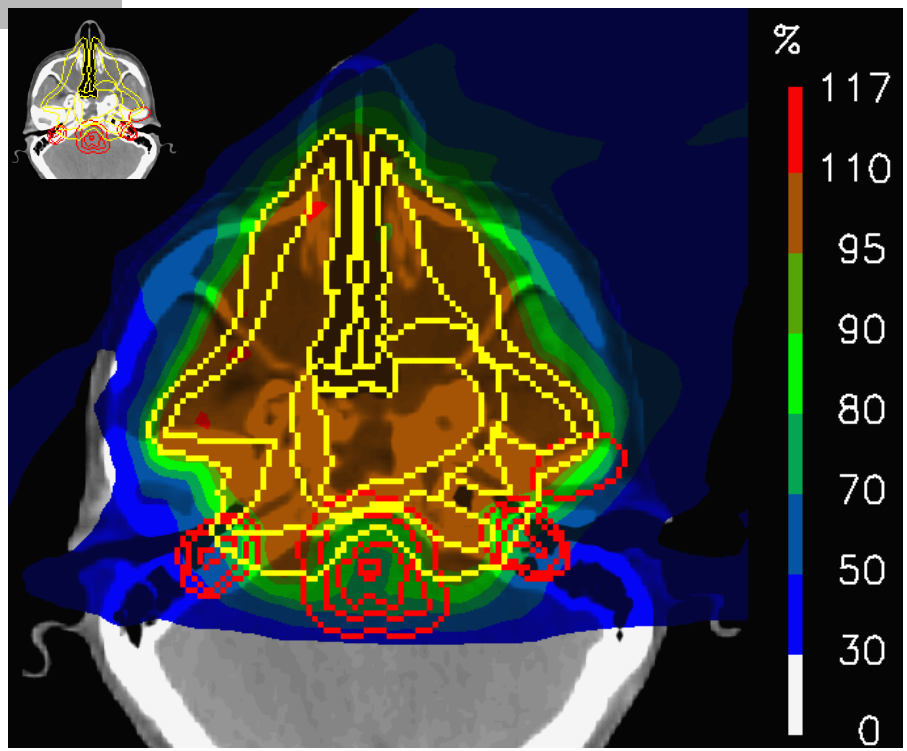


Planning CT

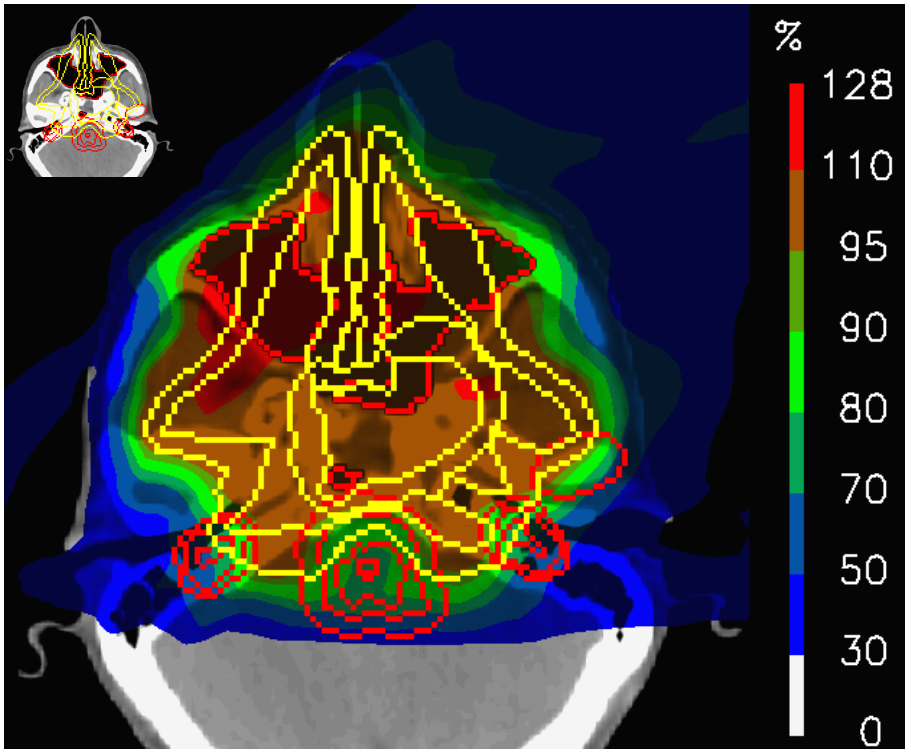


Repeat CT after 2 weeks

Estimating the consequences of extreme anatomical changes

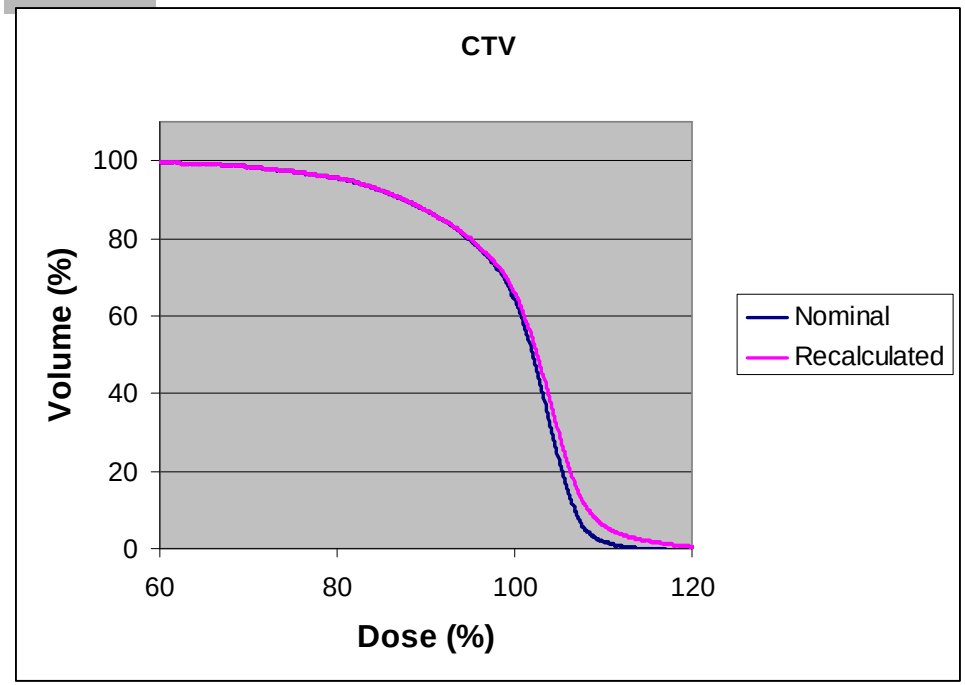


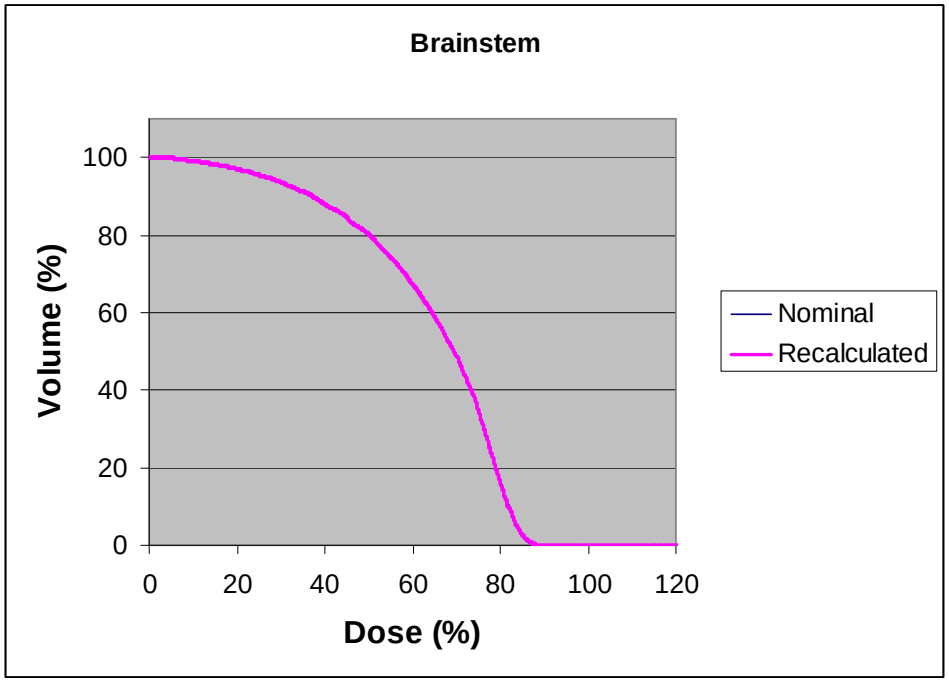
Nominal plan



Recalculated plan

Estimating the consequences of extreme anatomical changes





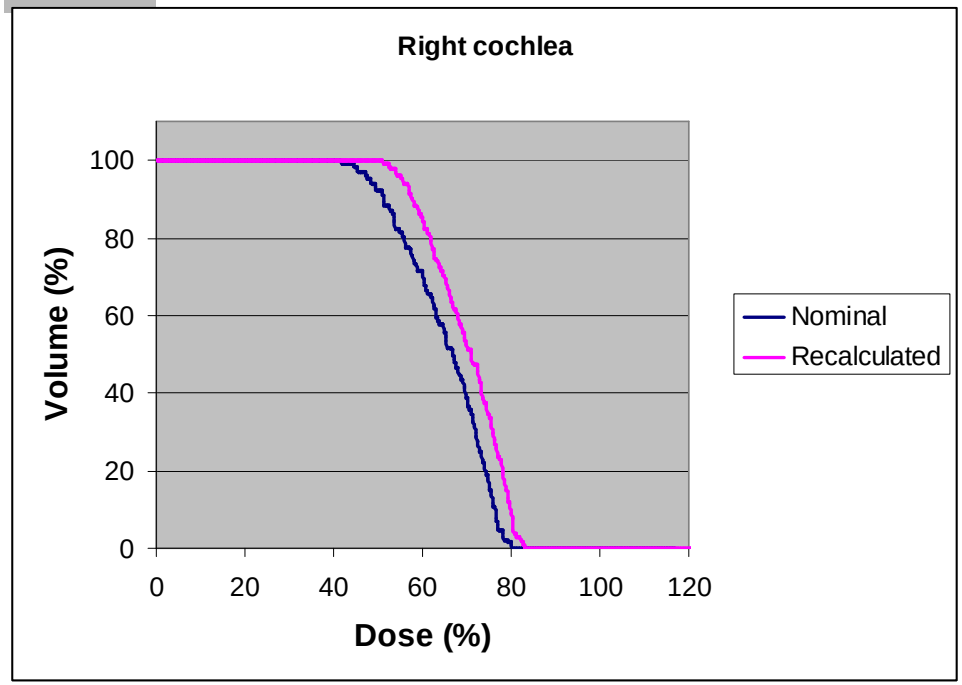
Change in mean dose: +0.7%

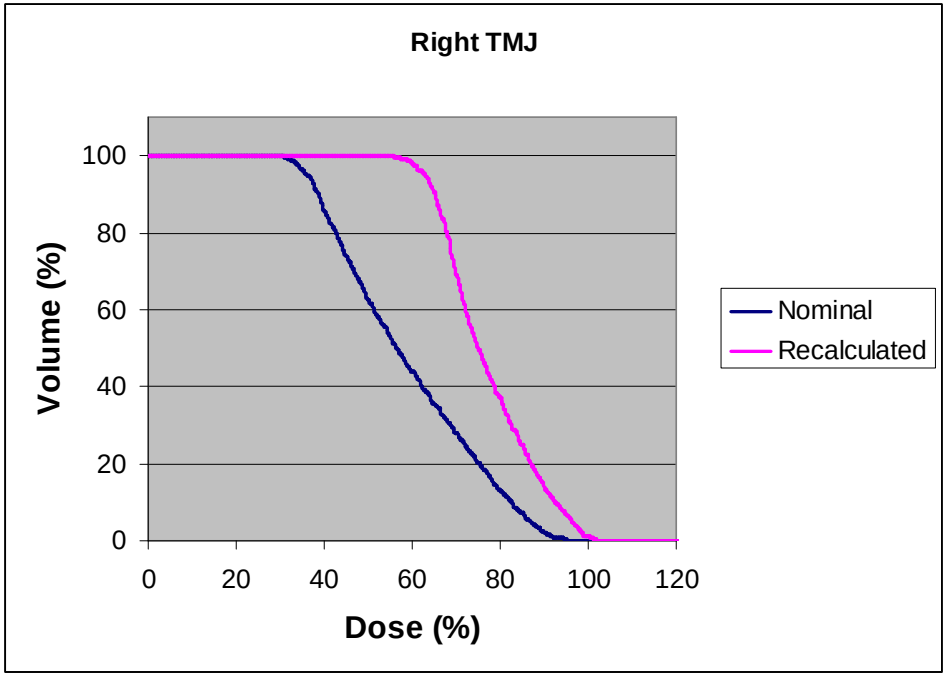
Change in max dose: +7.6%

Change in mean dose: +0.0%

Change in max dose: +0.1%

Estimating the consequences of extreme anatomical changes





Change in mean dose: +4.6%

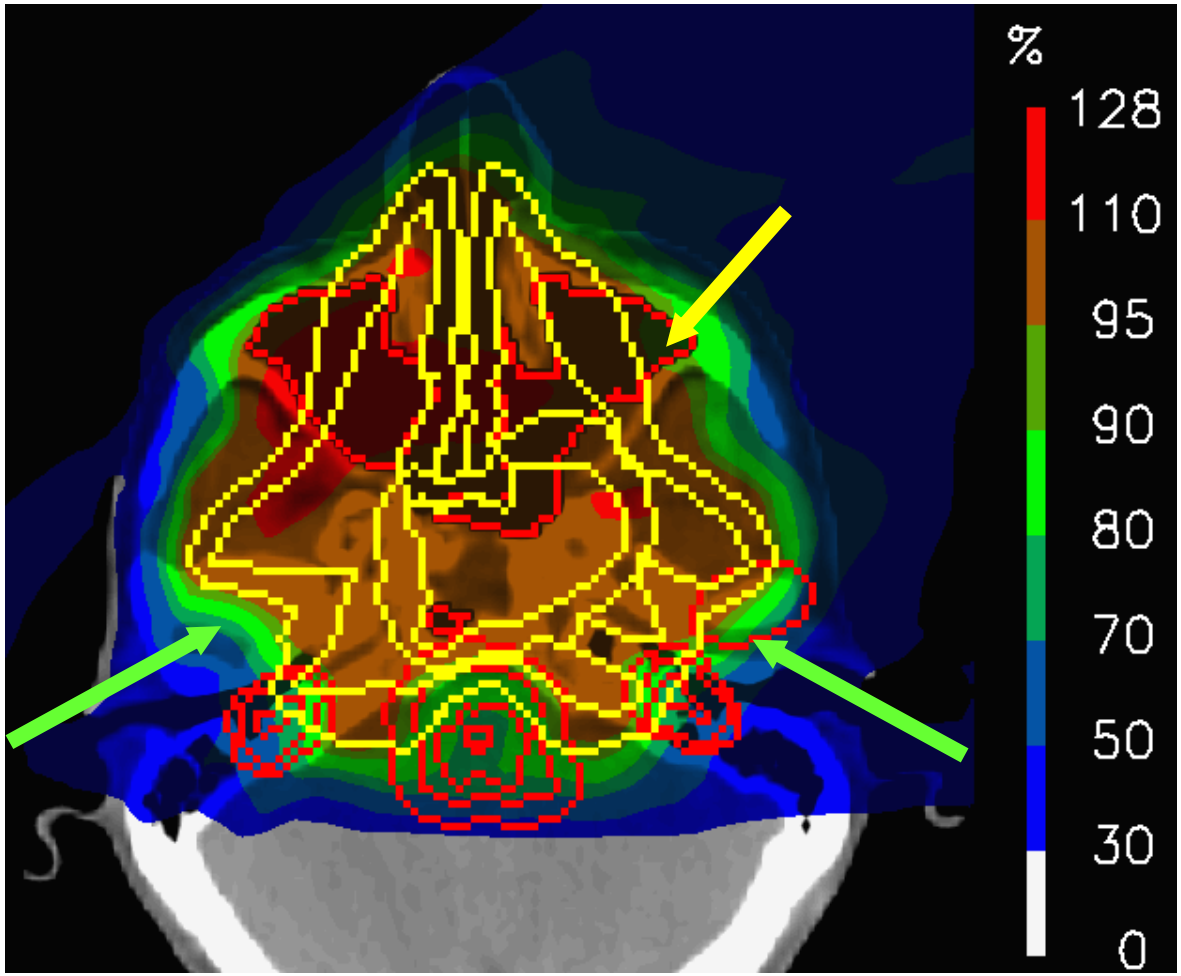
Change in max dose: +3%

Change in mean dose: +18.3%

Change in max dose: +6.5%

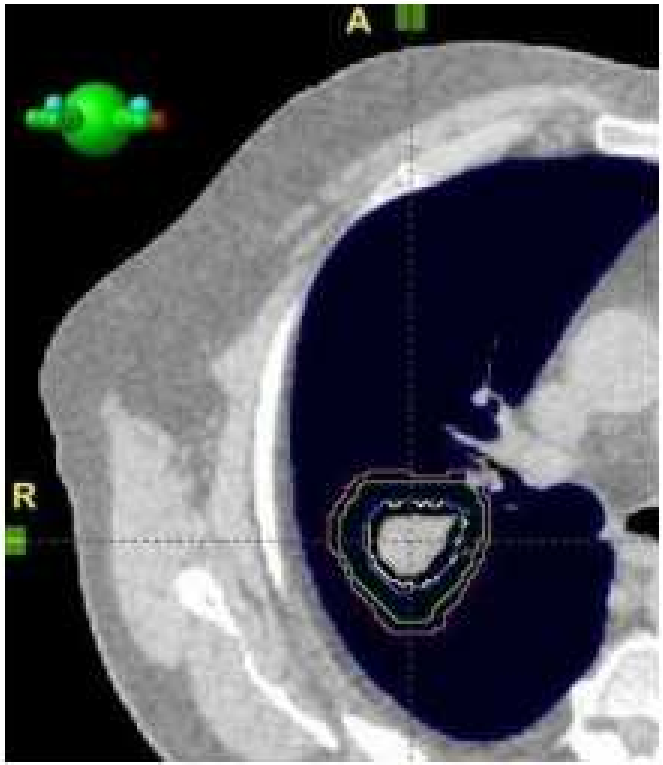
But things might not be as bad as they seem…

(Partially) robust planning

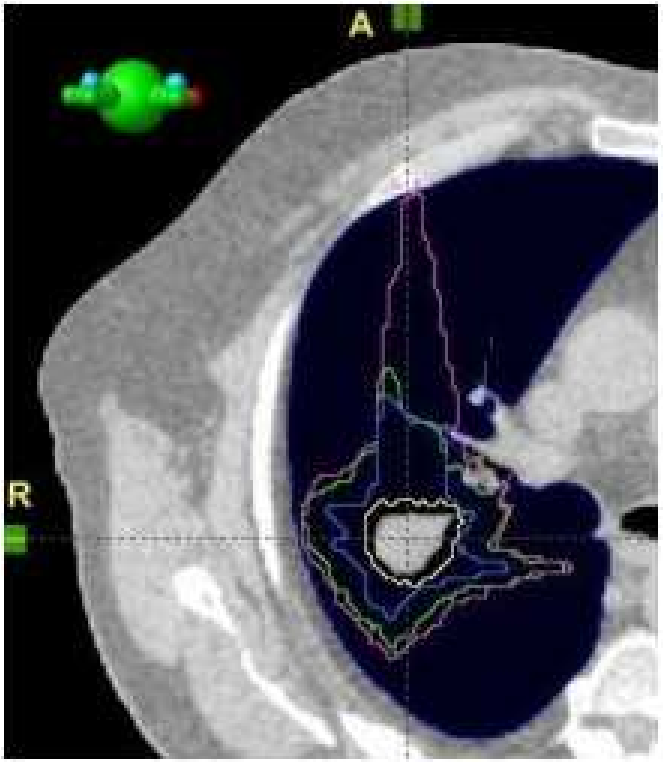


But things might not be as bad as they seem…

And what about this?



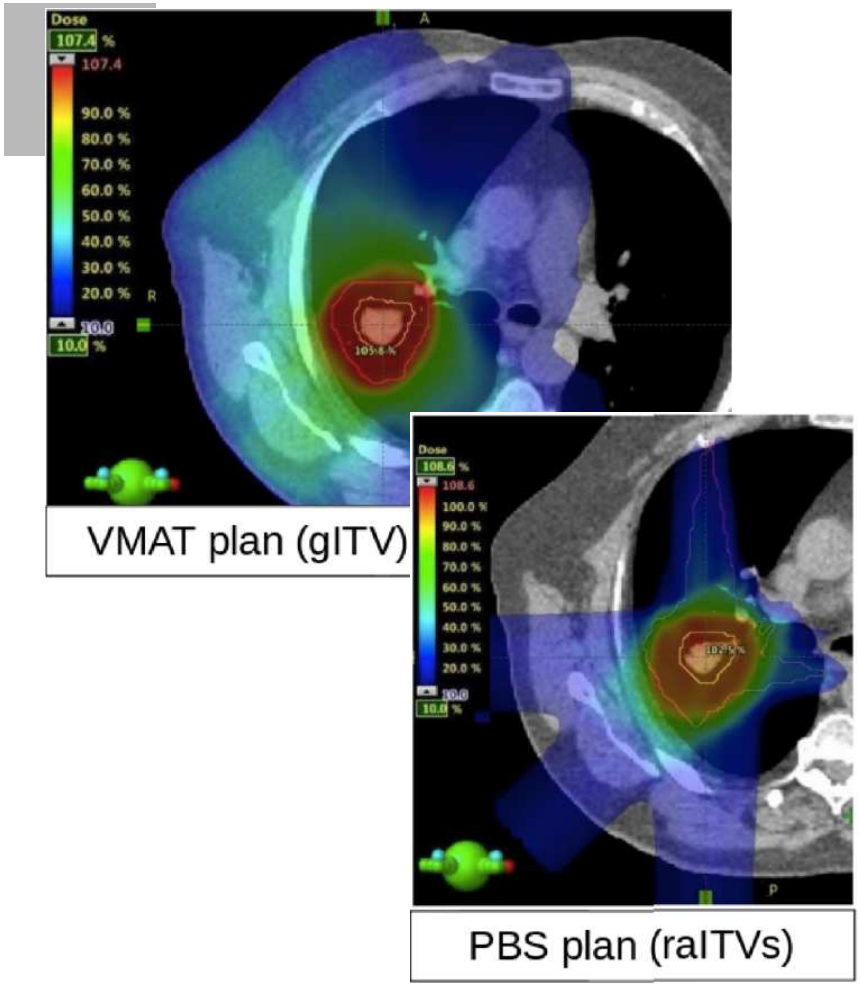
Motion compensated volumes for photons

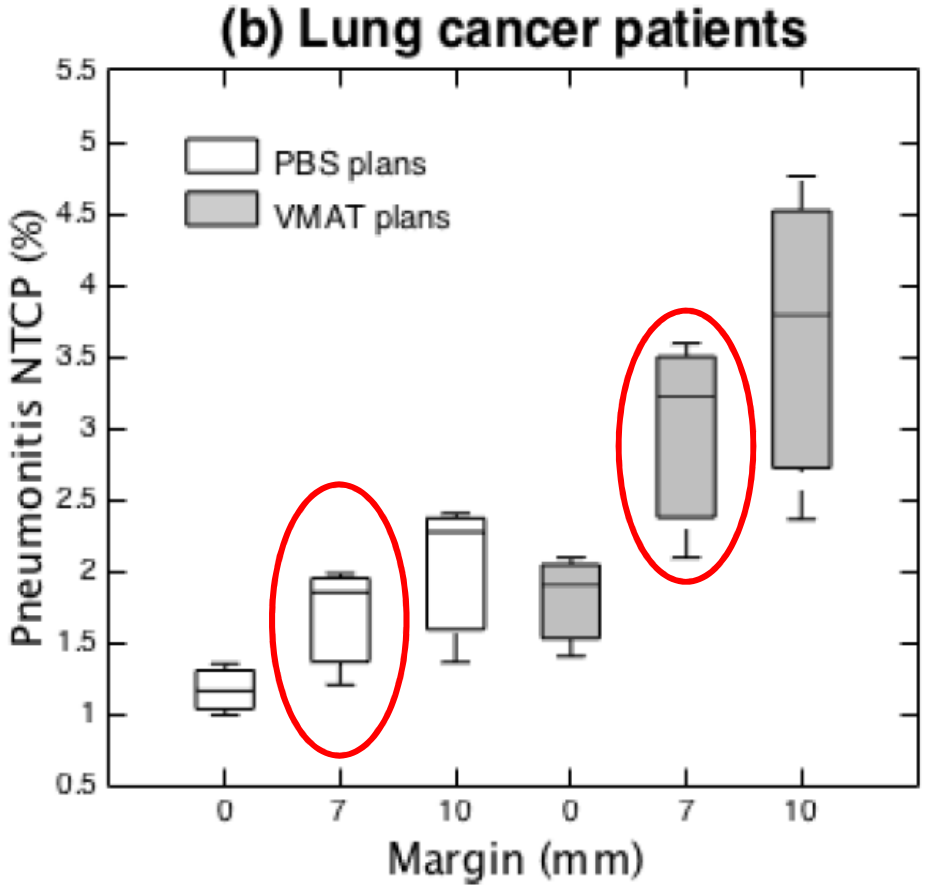


Motion compensated volumes for protons

But things might not be as bad as they seem…

Photons vs. protons with motion compensated volumes

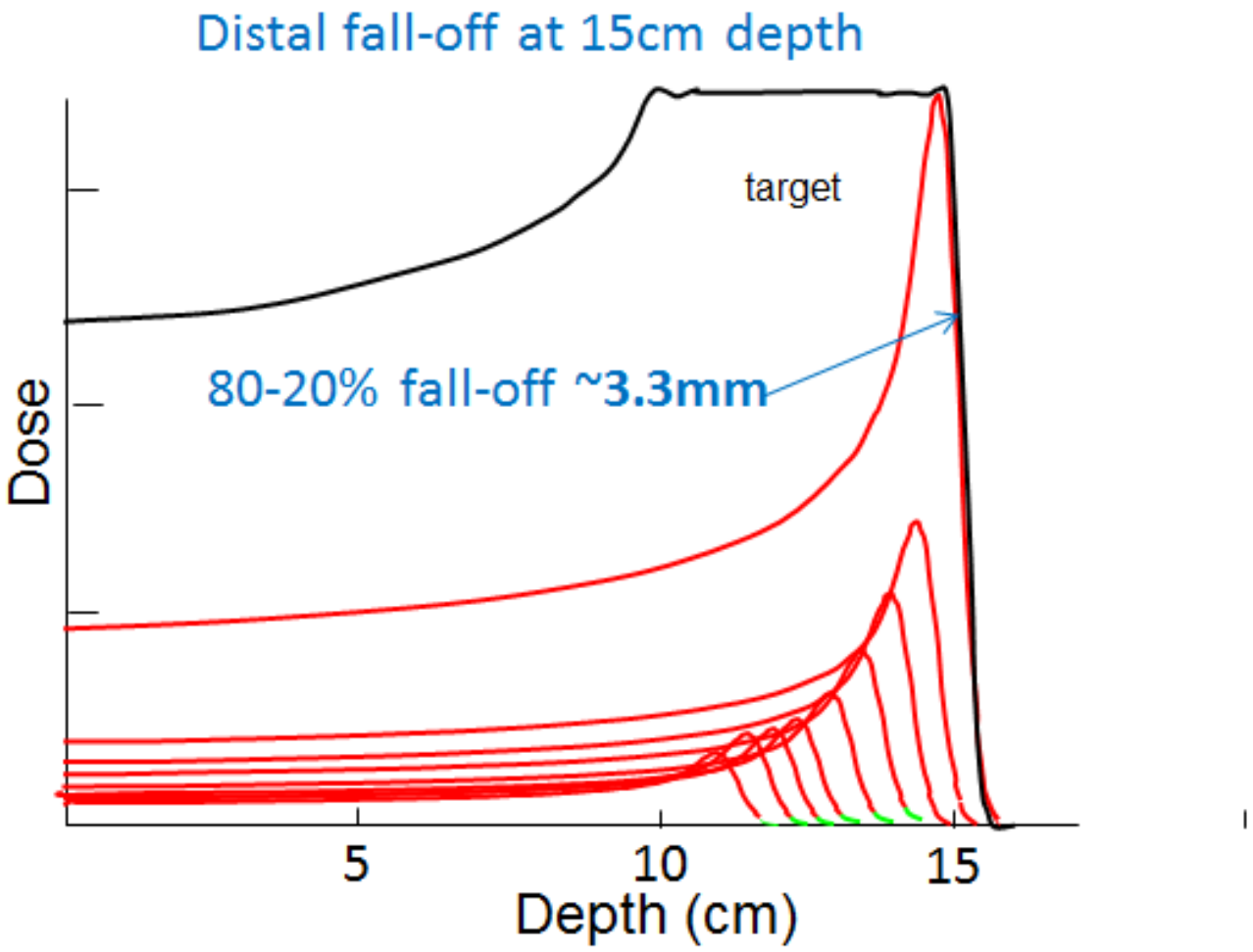




Bernatowicz et al 2016, Submitted to Strahl. Ther., Oct 2016

… and what about the ‚sharpest' gradient?

The Bragg peak and the SOBP in water

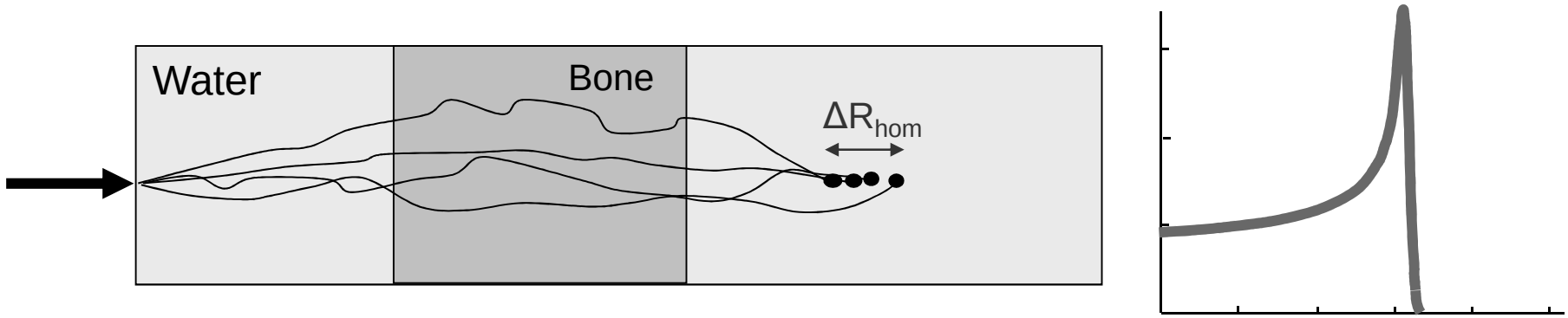


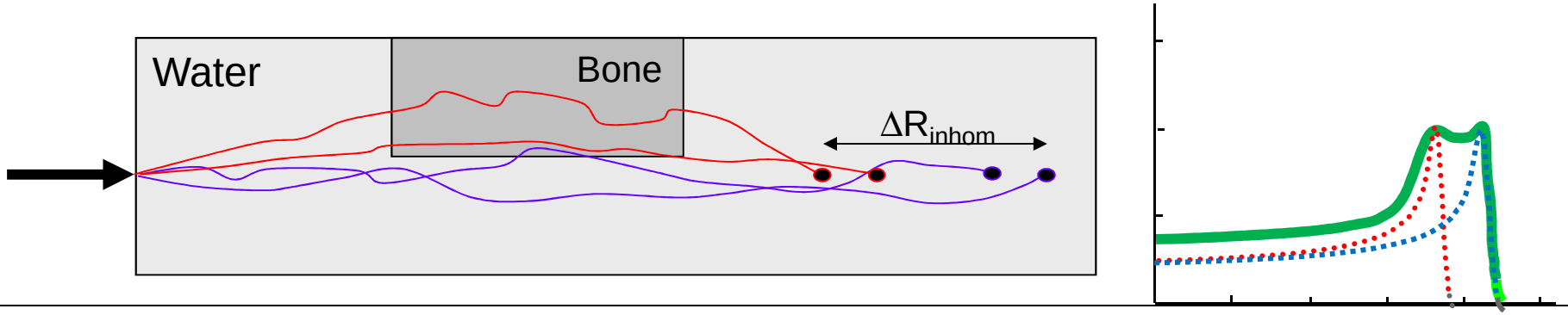
… and what about the ‚sharpest' gradient?

But real patients are not water….

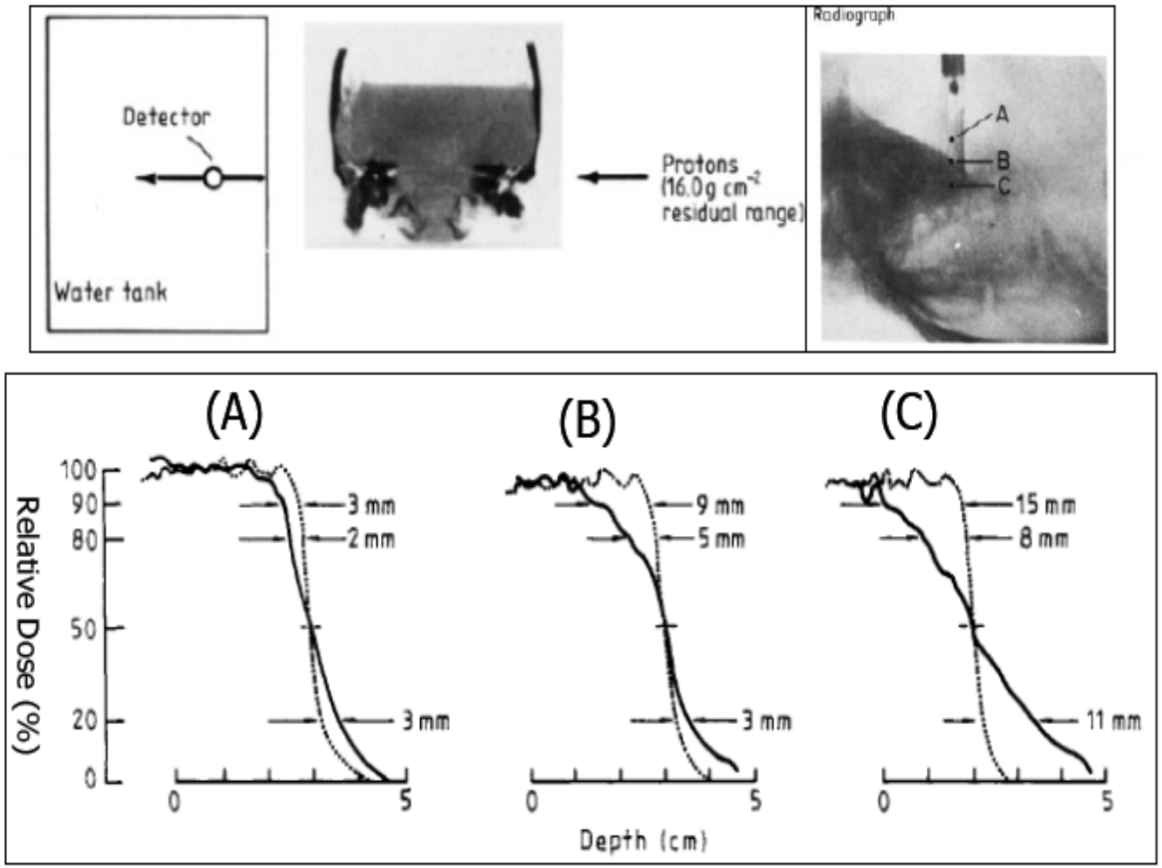
Density (range) effects on protons

Degradation of the Bragg peak





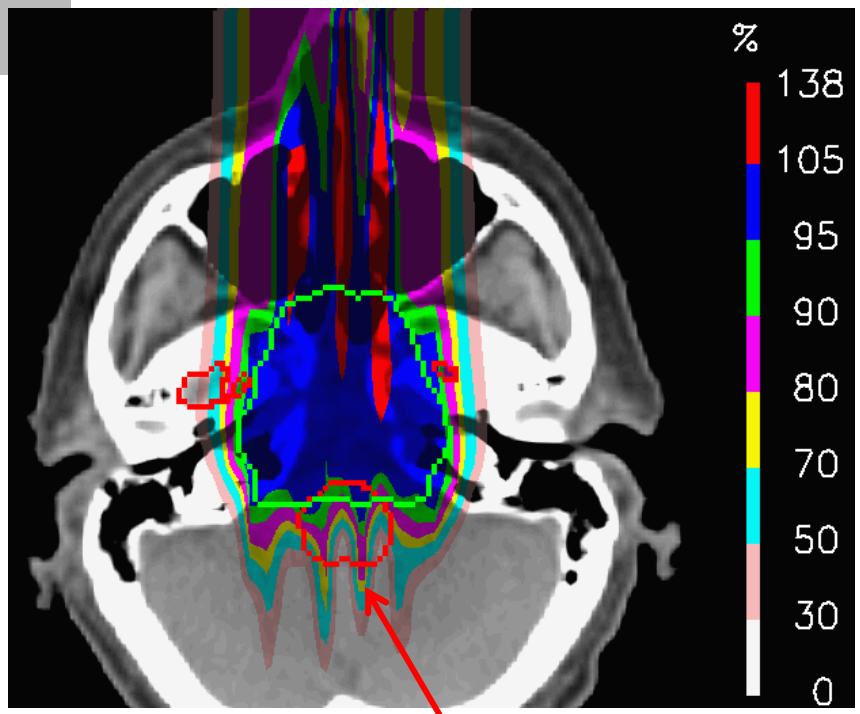
Density (range) effects on protons

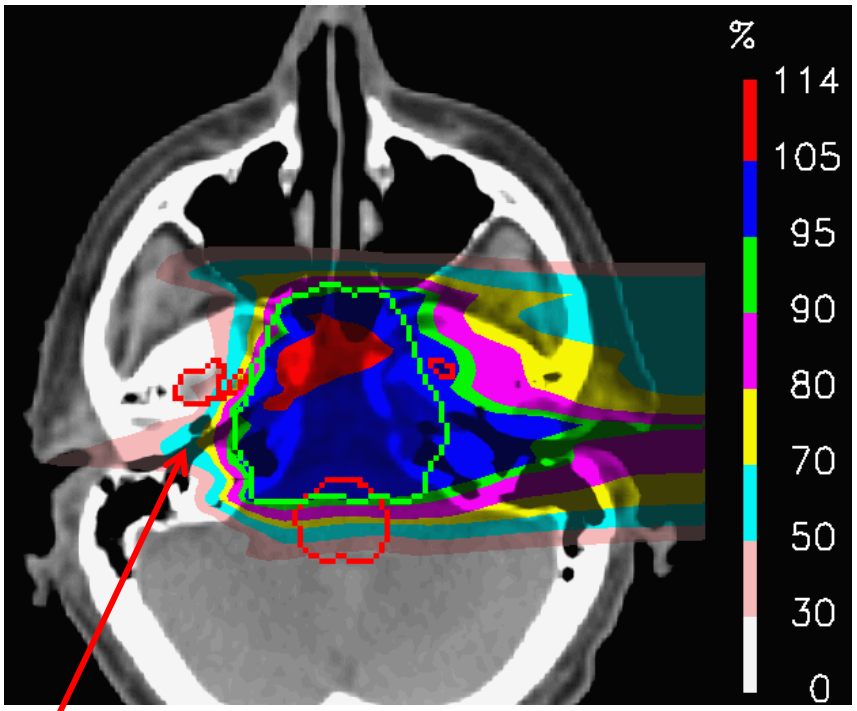


Protons Through Base of Skull: 90 to 20% fall of increases from 6 to 32 mm

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

Density (range) effects on protons



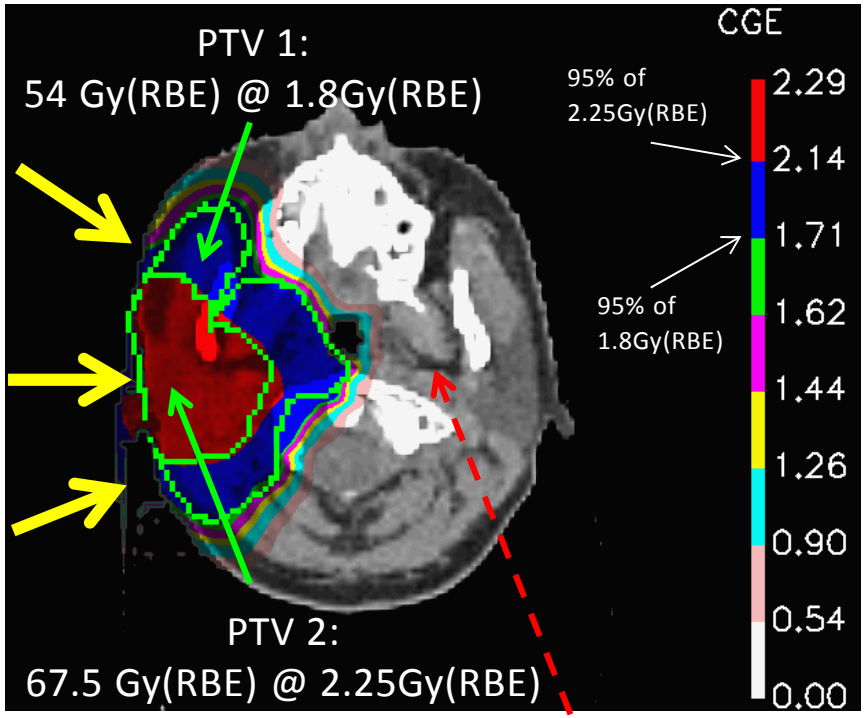


Often, in patient geometries,
there are no ‘sharp’ distal edges

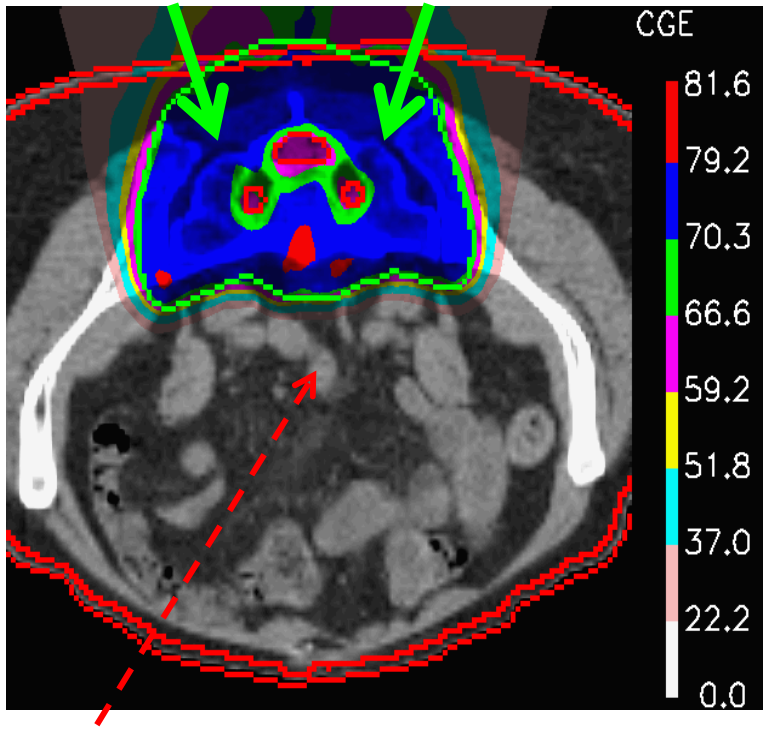
Not the ‚sharpest' gradient, but sharp enough…

However, we exploit the Bragg peak in every proton therapy treatment to significantly reduce doses to normal tissues

SIB treatment to a Parotid tumour



Large sacral chordoma



… and in many cases, the advantage will remain, even if there is a certain amount of range uncertainty.

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Myths and realities of range uncertainties

- We should certainly consider and understand the possible effects of range uncertainty
- But we shouldn't be paranoid about it
- Certainly, it is not good practice to stop a single field against a critical organ (e.g. spinal cord)
- But we can (and do!) use the stopping characteristics of protons to spare large volumes of normal tissue with almost every proton treatment we deliver
- Used carefully and sensibly, protons can be a very powerful, and safe, treatment modality <u>despite</u> range uncertainty

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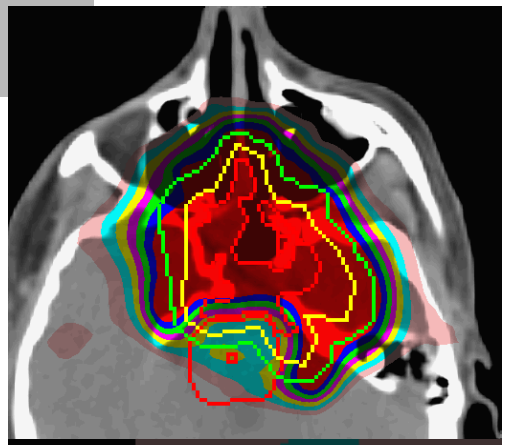
The bottom line…

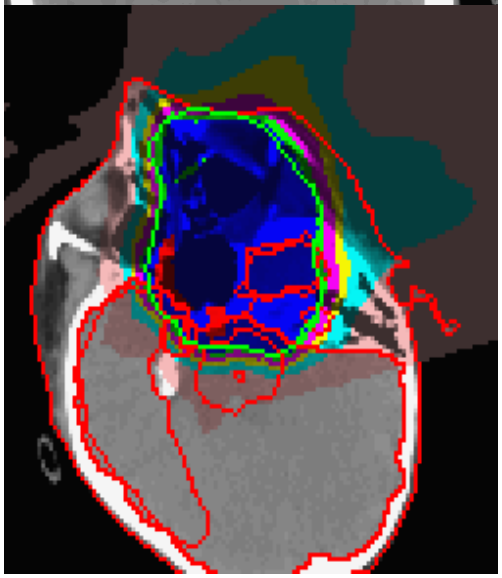
Although the Bragg peak maybe a two edged sword, one edge is still very much sharper than the other…



Skull base tumours

222 Patients

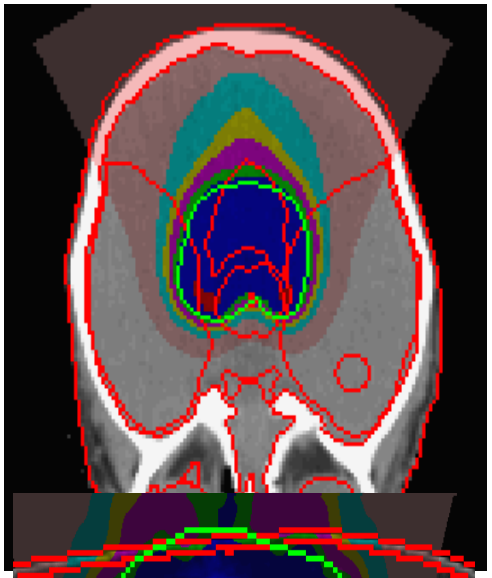
7y Local control: 80%



Parameningeal Rhaddomyosarcomas

31 Patients

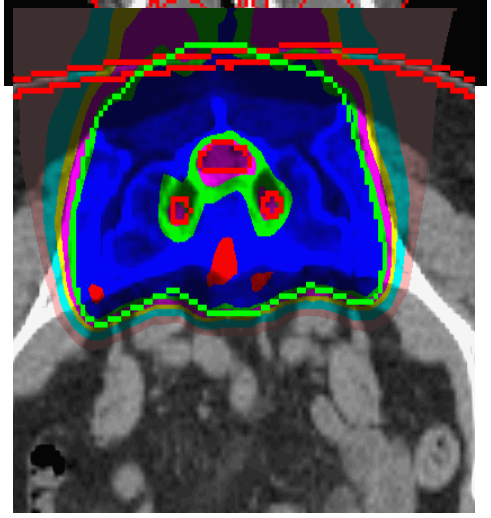
5y Local control: 73%



Ependymomas

50 Patients

5y Local control: 78%



Sacral chordomas

36 Patients

5y Local control: 66%