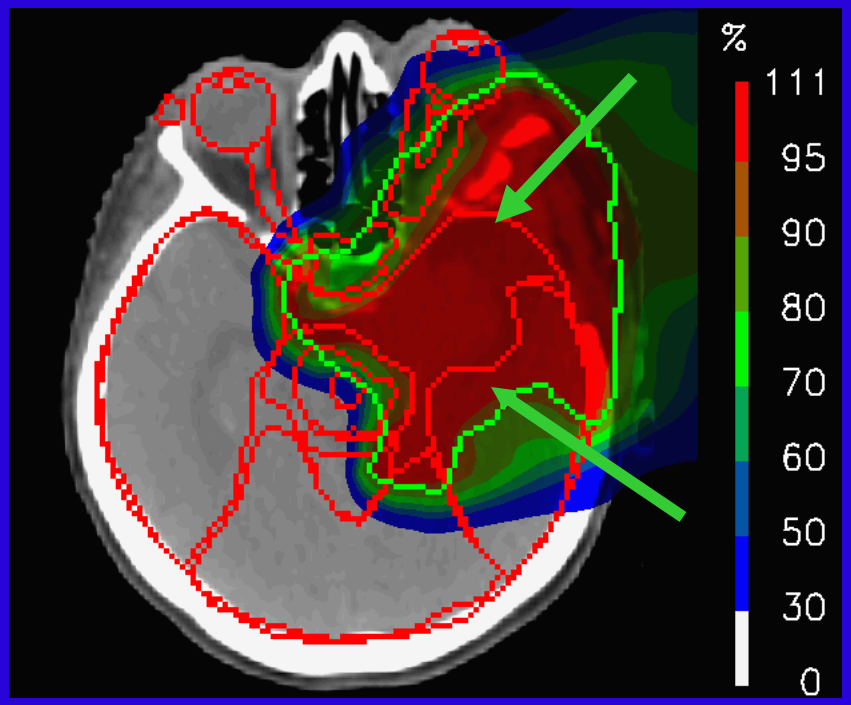
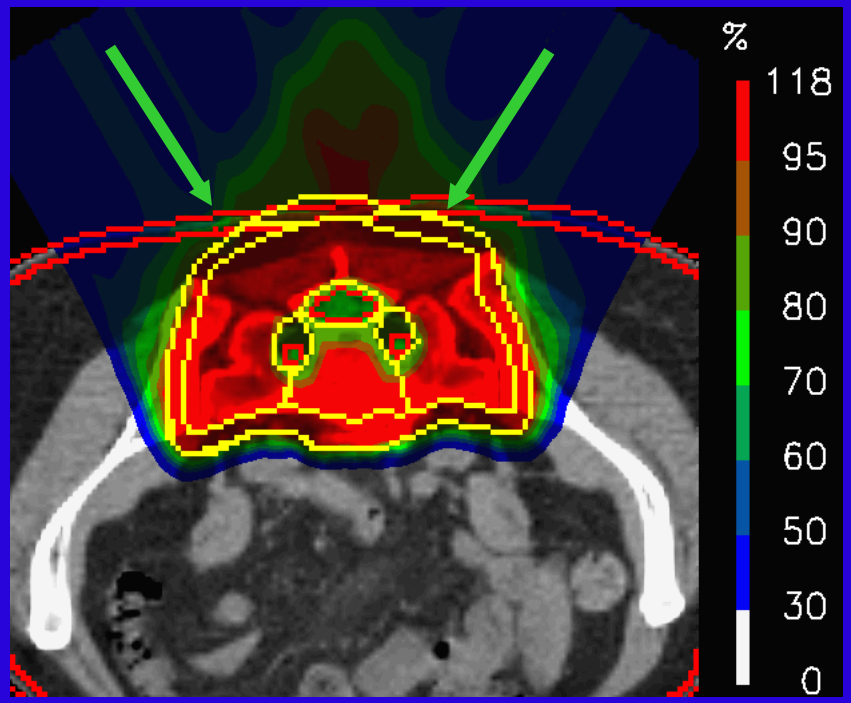
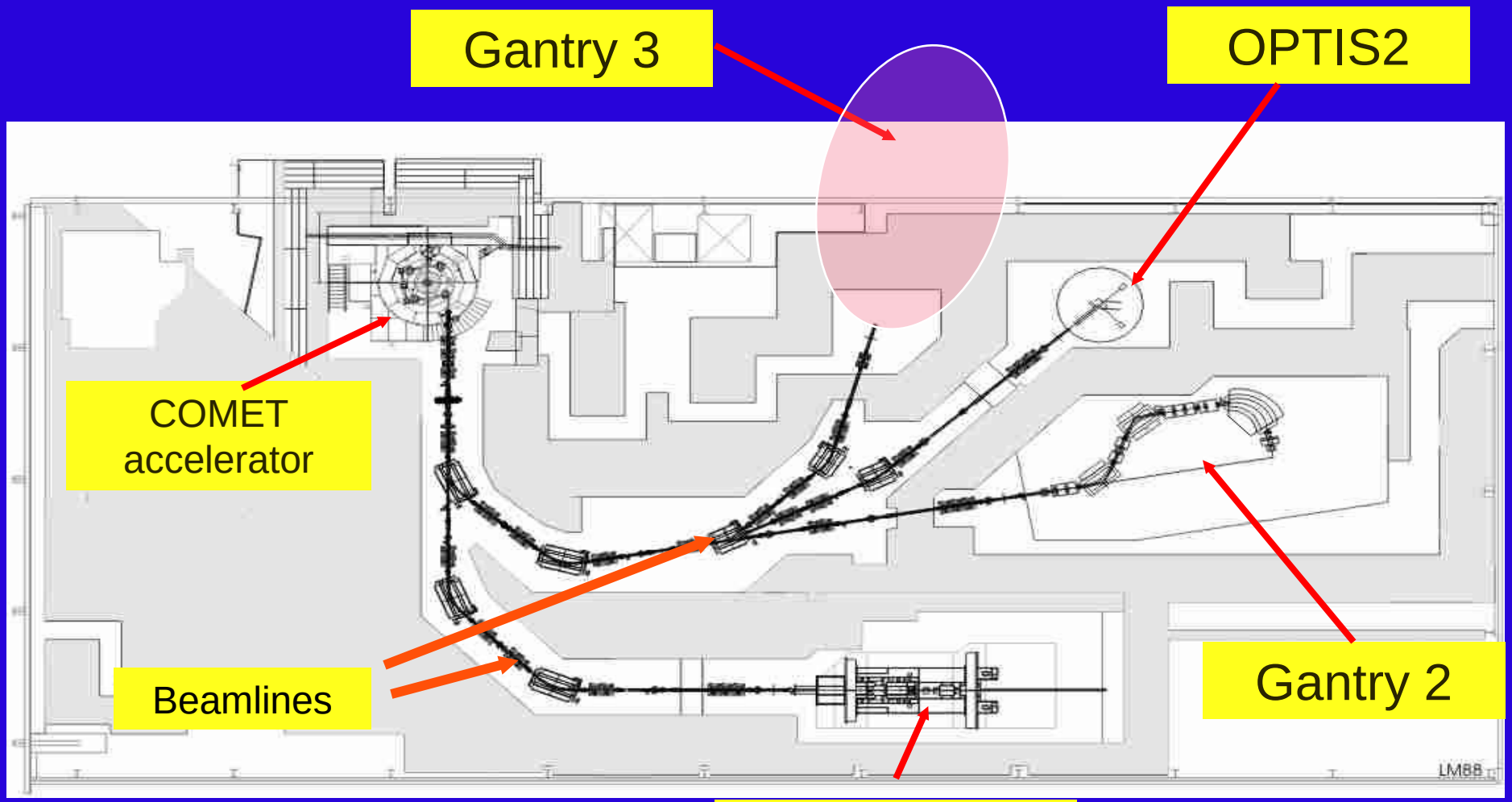
The clinical importance of gantries in particle therapy.



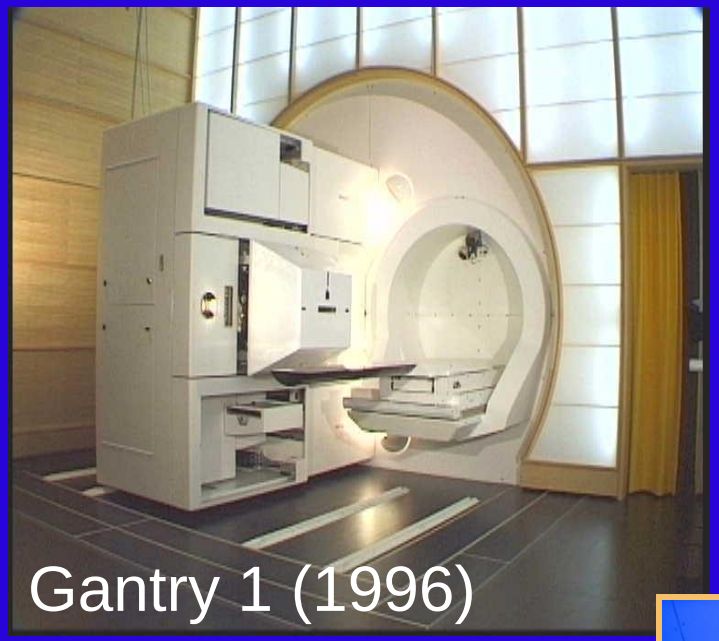


Tony Lomax
Centre for Proton Therapy, Paul Scherrer Institute, Switzerland
and
Department of Physics, ETH Zurich, Switzerland

The proton therapy facility at PSI

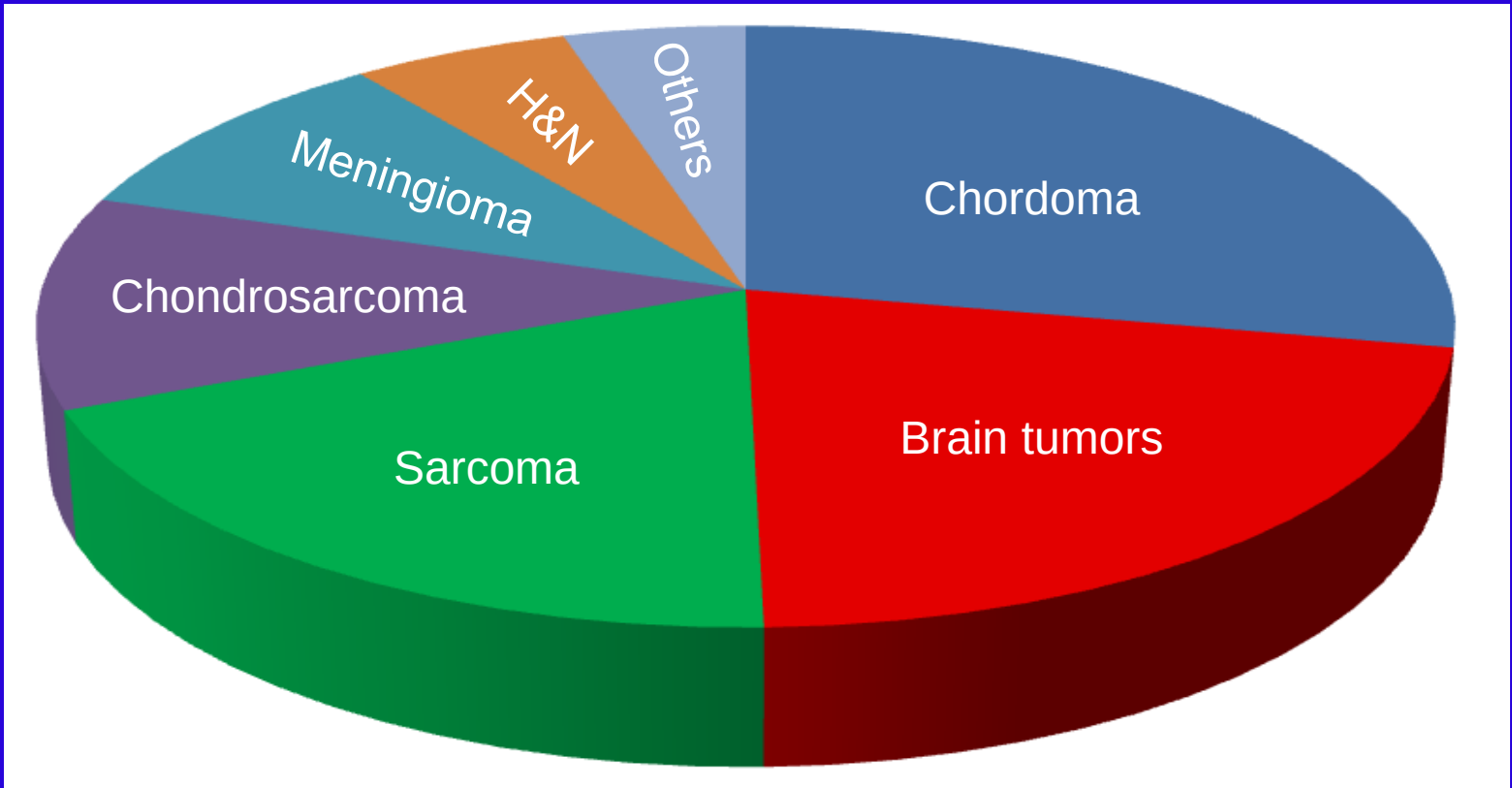


Proton gantries at PSI…



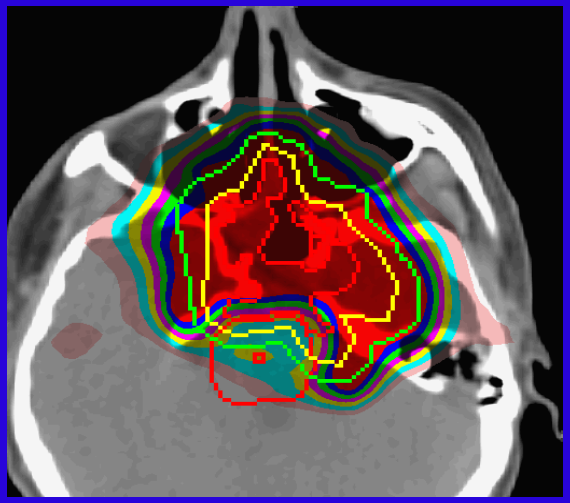
Treatment of deep seated tumours

Gantries 1 and 2

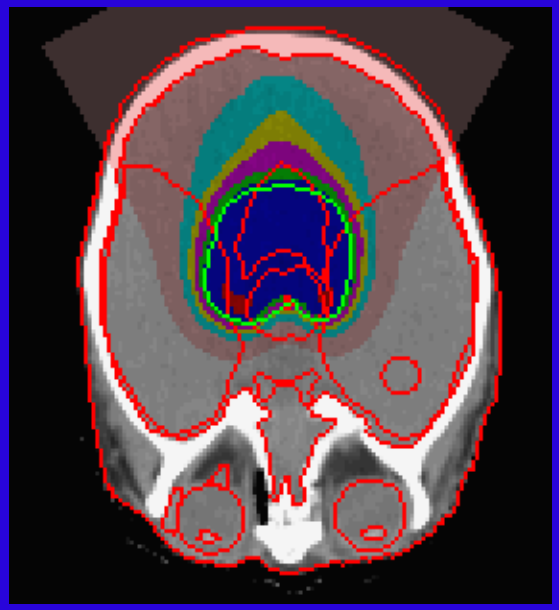


~1100 patients treated, ~400 of them children

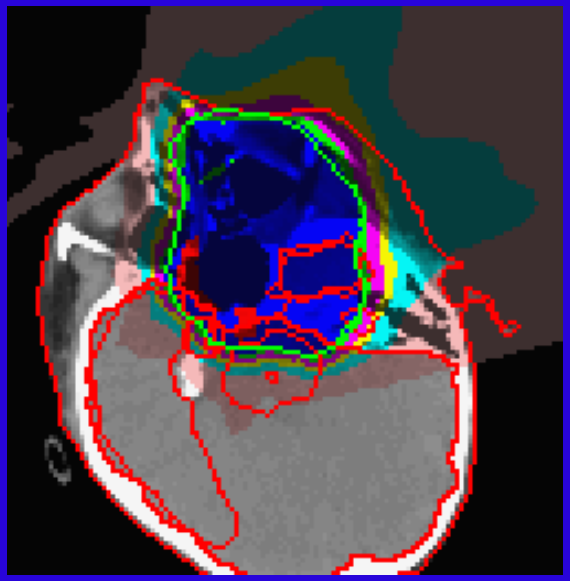
Proton therapy at PSI



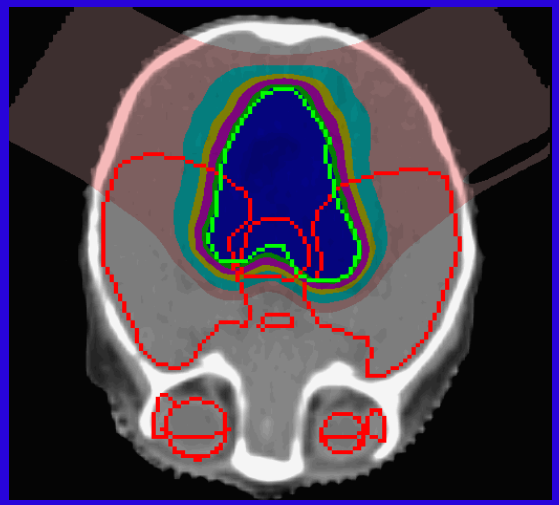
Skull base chordomas
222 Patients
5y Local control: 80%



Ependymomas
50 Patients
5y Local control: 78%

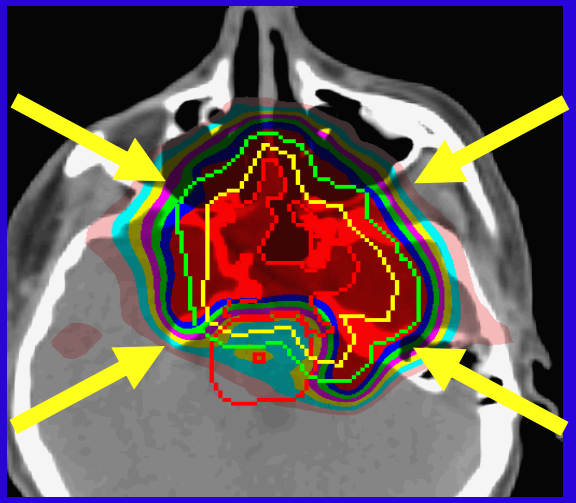


Parameningeal Rhaddomyosarcomas
31 Patients
5y Local control: 73%

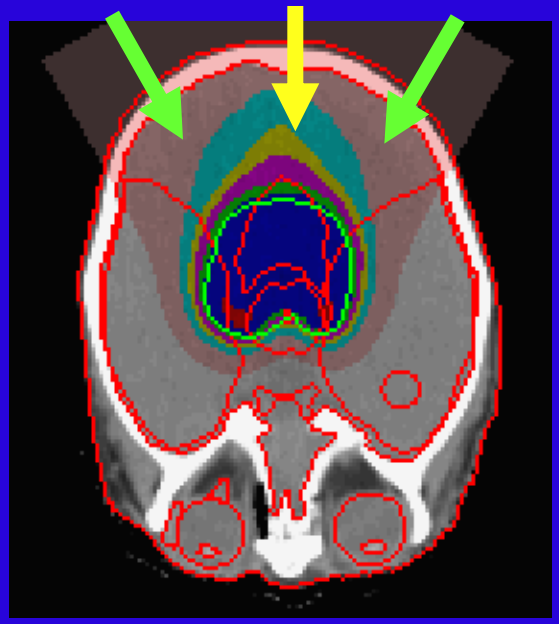


Atypical Teratoid/Rhabdoid
15 Patients
2y Local control: 66%

The flexibility of a gantry has been exploited for all…



Skull base chordomas
222 Patients
5y Local control: 80%



Ependymomas
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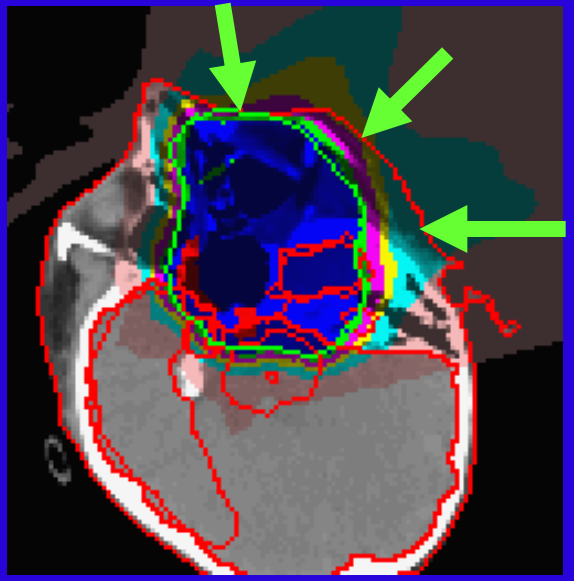

Parameningeal Rhaddomyosarcomas
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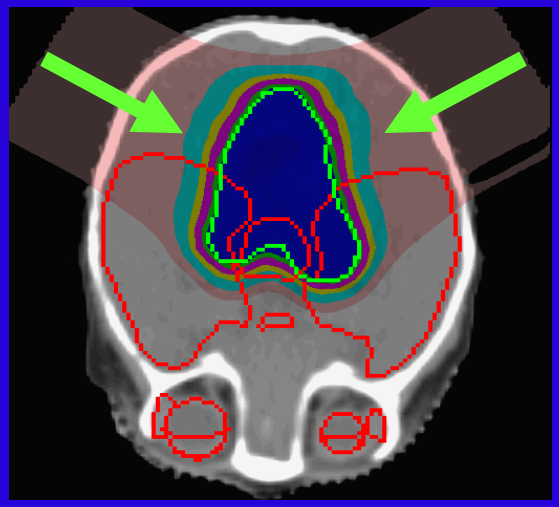
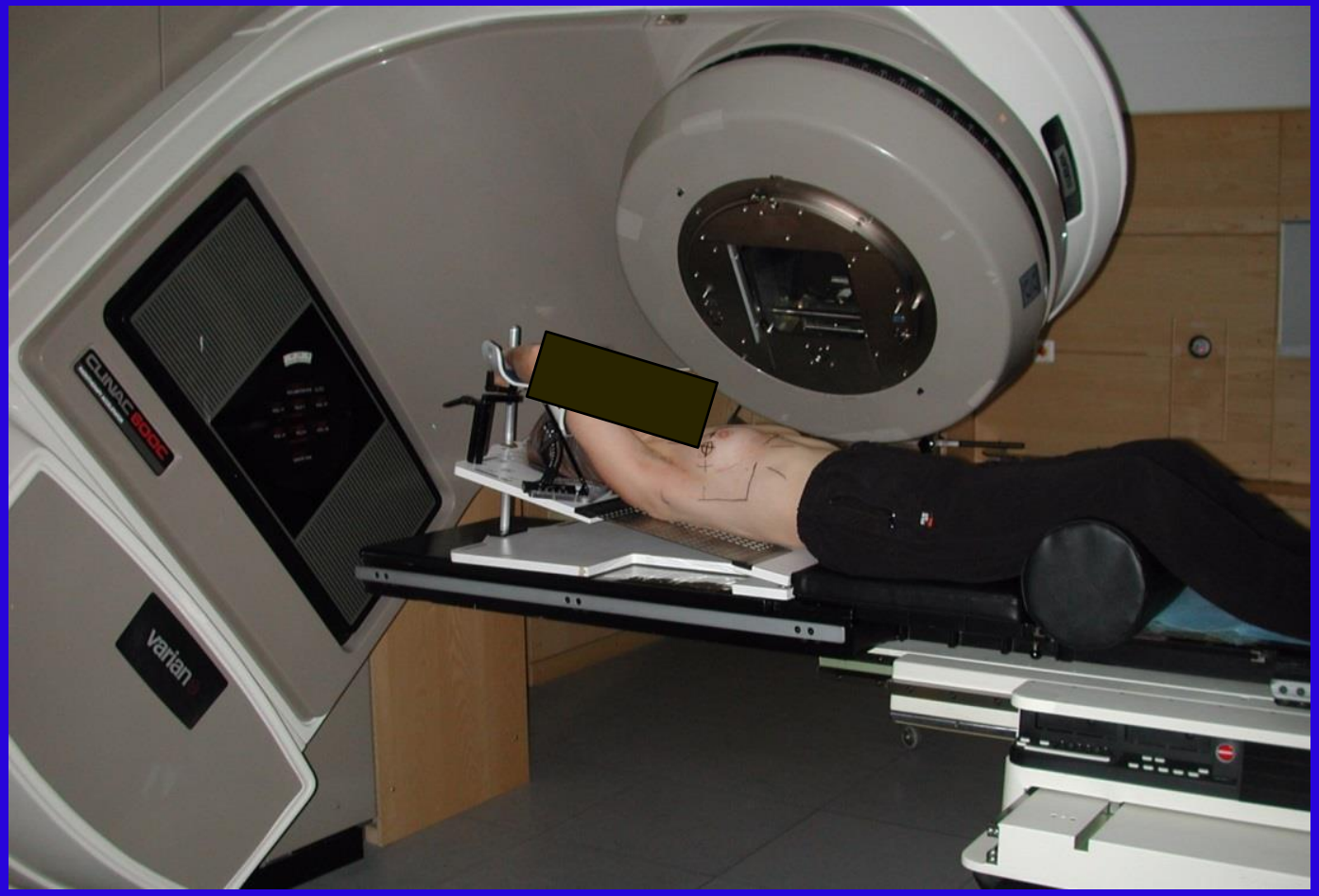


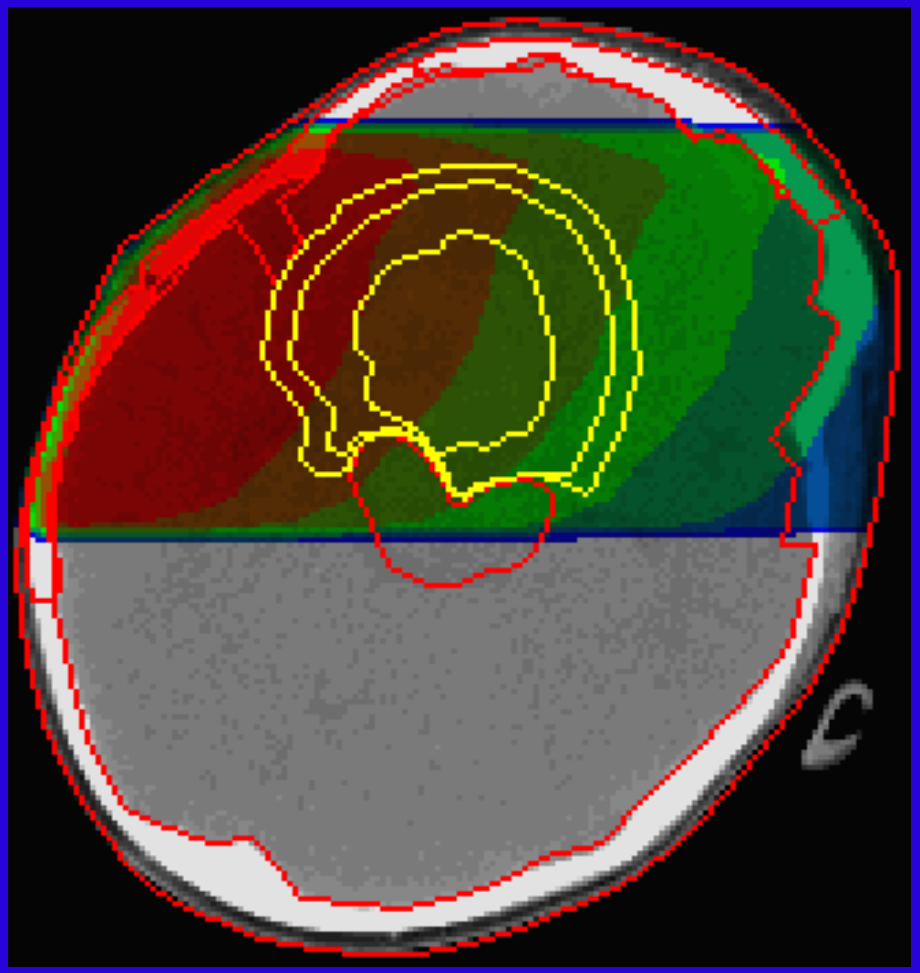
Atypical Teratoid/Rhabdoid
15 Patients
2y Local control: 66%

Gantries in conventional radiotherapy…



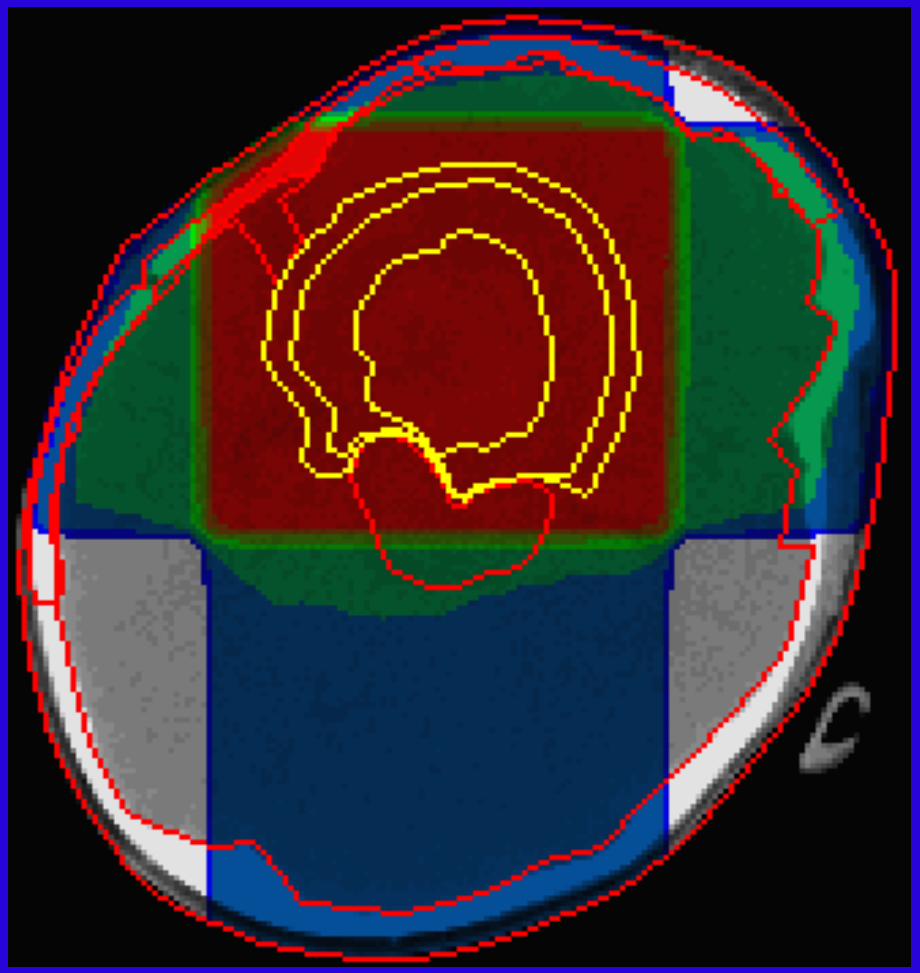
The need for gantries – photons.

A single field 6Mv photon plan



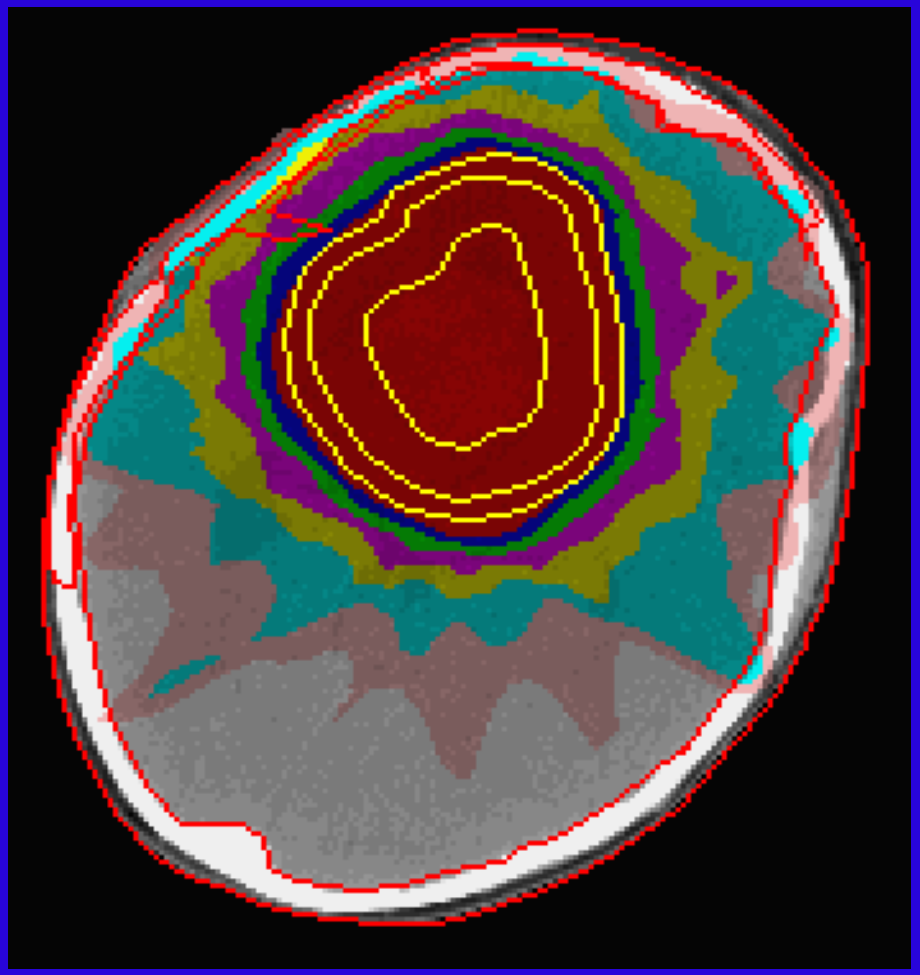
The need for gantries – photons.

A four-field 6Mv photon plan



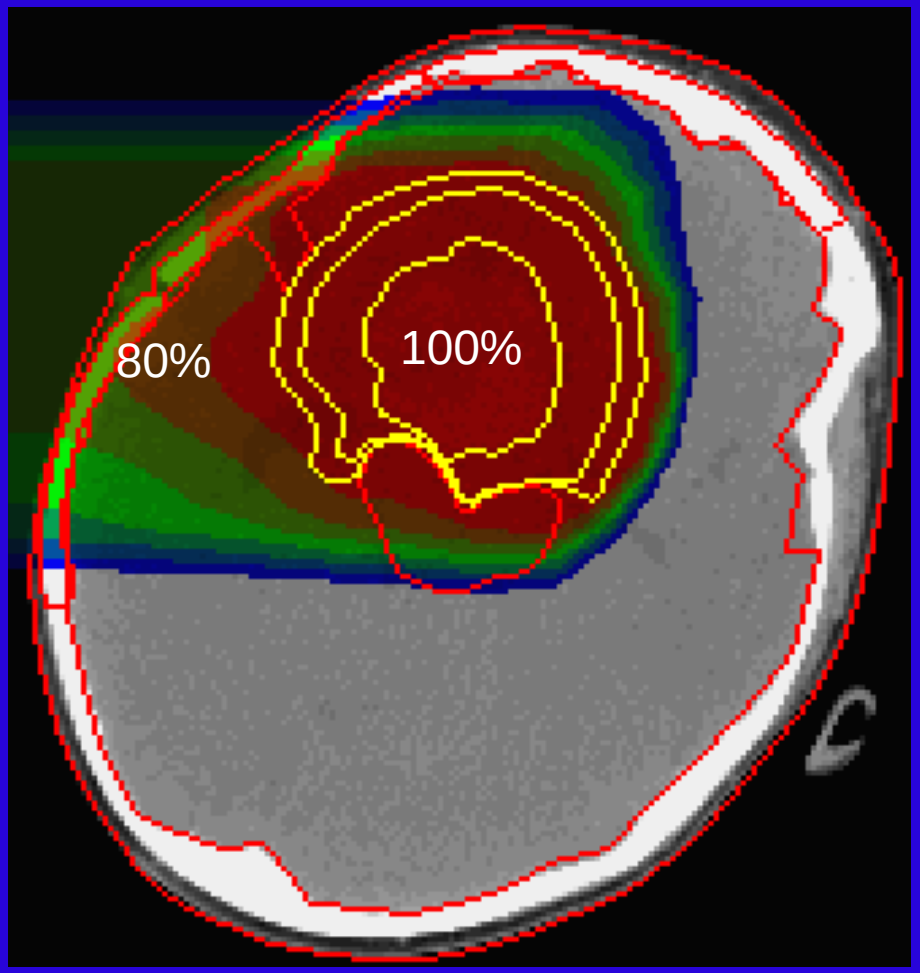
The need for gantries – photons.

A nine-field, 6MV IMRT photon plan



The need for gantries – protons?

A single PBS proton field



Why do we need gantries for proton therapy?.

- To be flexible
- To be safe
- To deliver multiple, angularly spaced fields

Be flexible...

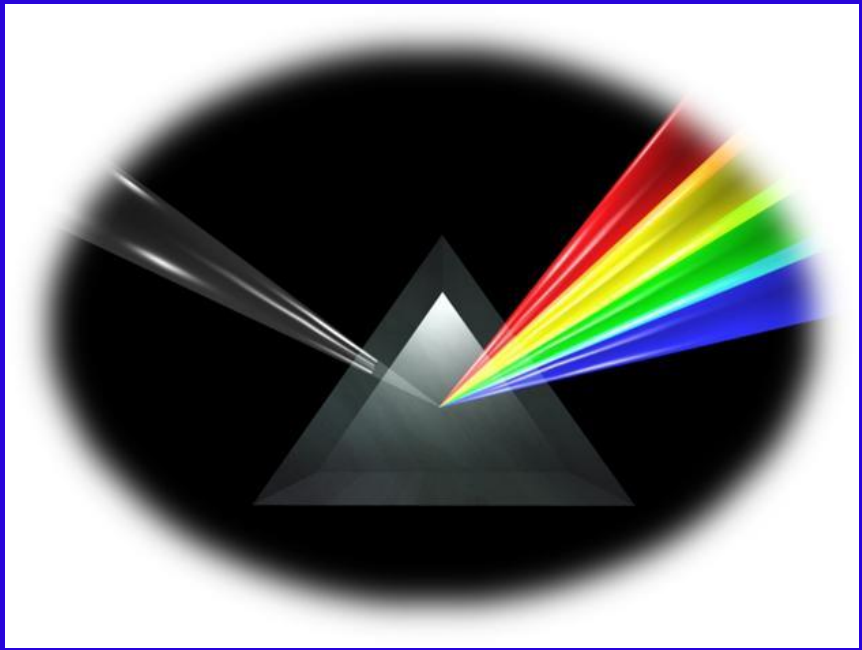
Proton therapy facilities are generally designed for life times of up to 25 years. This leads to a number of questions.

1. Do we know what indications we will be treating in 5, 10 15 years time?
2. Can we base our designs on current proton indications when these account for only 1% of all radiotherapy patients?
3. Do we know what new developments will come along in delivery and imaging in this time?
4. How do we keep abreast of new developments should they occur?

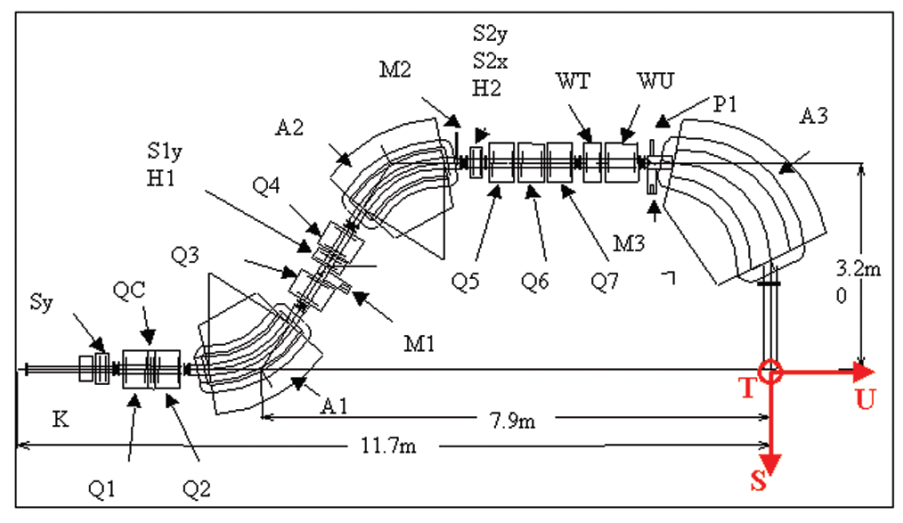
So the best approach is to invest in flexibility, and flexibility means gantries…

Be safe…

E.g. Beam optics of the beamline and gantry provide safety



Prism



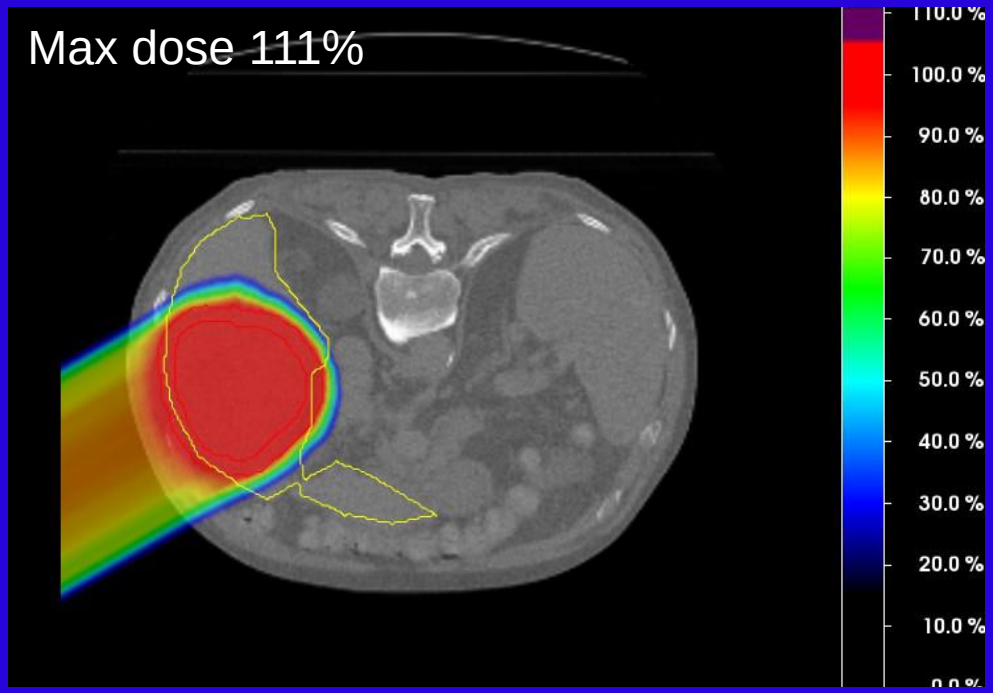
The proton ‘Prism’

Deliver multiple fields…

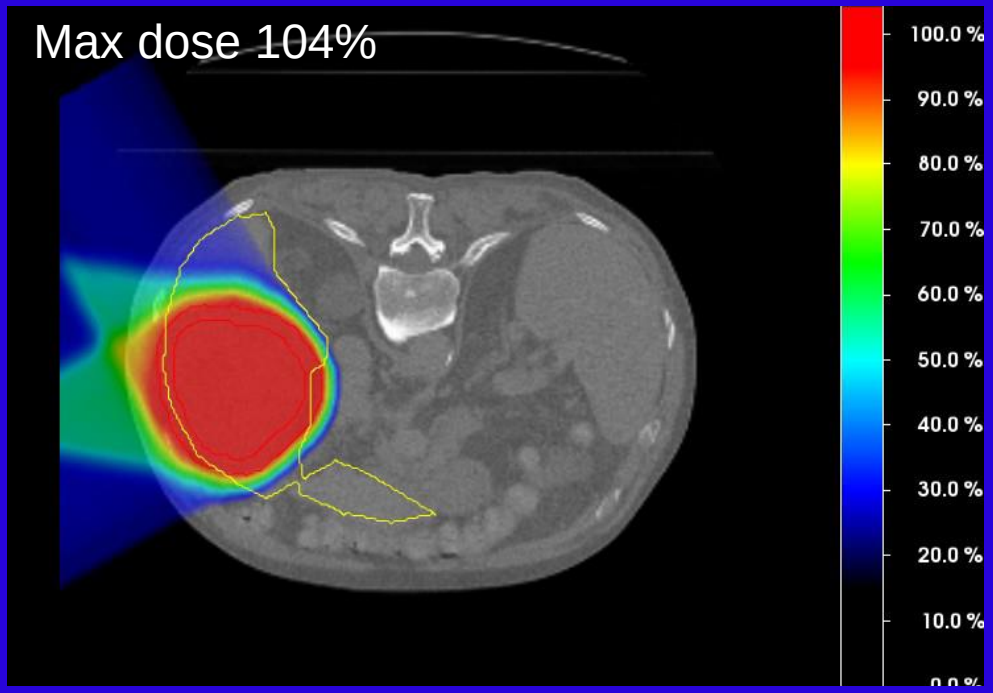
- For dose homogeneity and conformity
- For plan robustness
- For improved delivery accuracy

Multiple fields improve dose homogeneity

PBS proton plans to a liver tumour



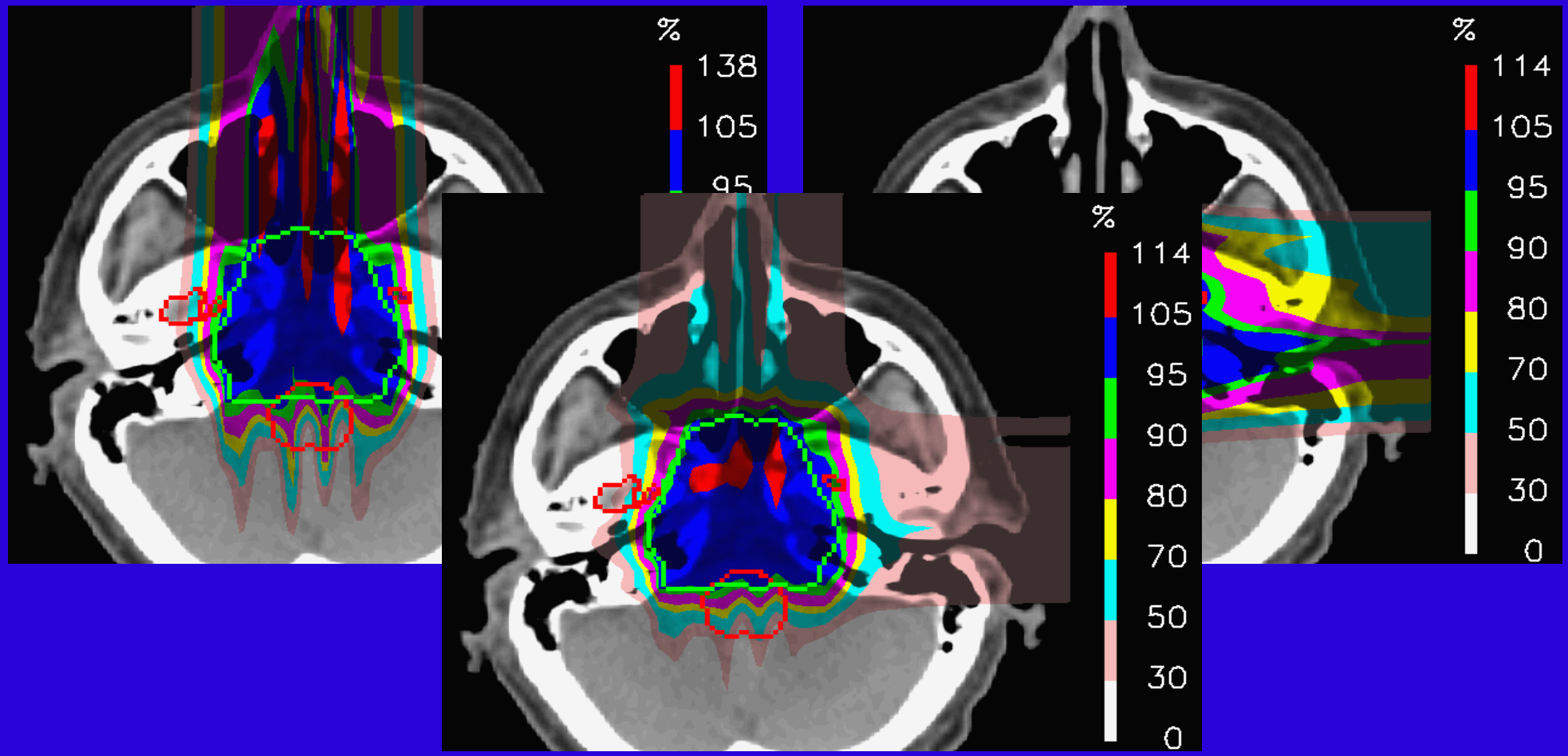
Single field plan



Three field plan

Knopf et al, Phys. Med. Biol. 56 (2011) 7257-7271

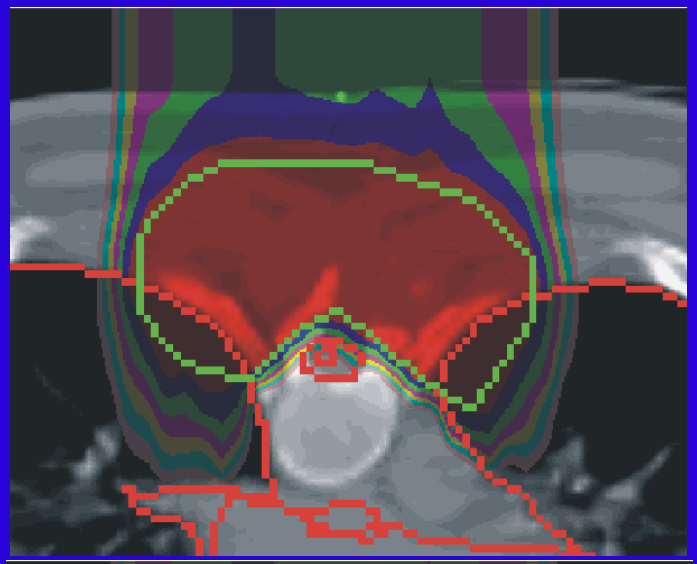
Multiple fields improve dose conformity



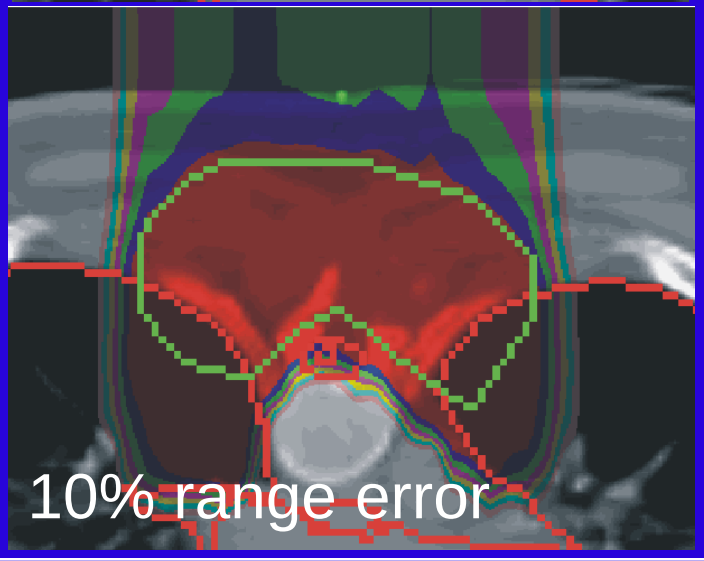
Lomax et al 2015, AAPM summer school, Colorado Springs

Multiple fields improve plan robustness – Range uncertainty

A single field plan to a thoracic spinal tumour…

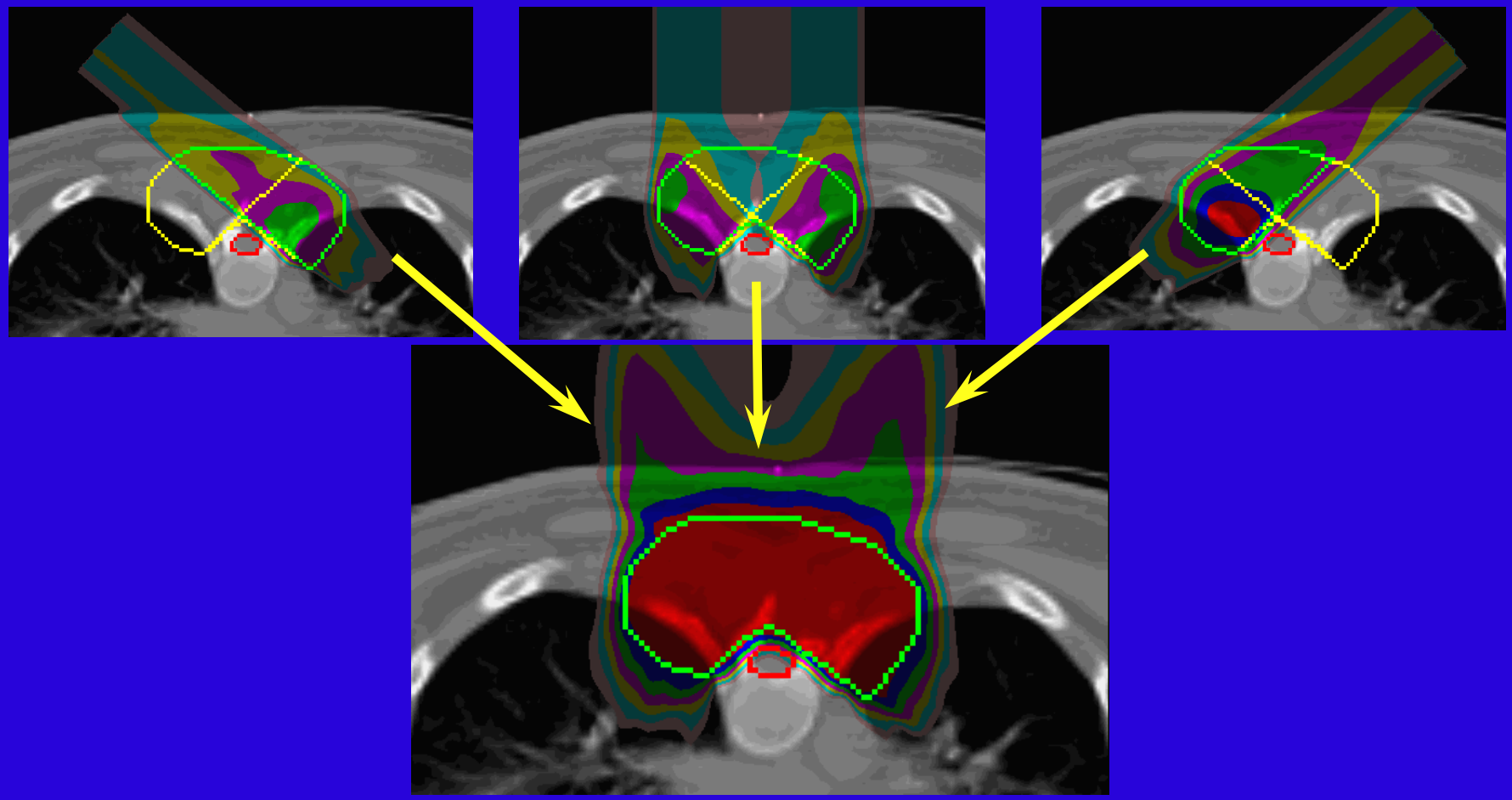


The dose that could be applied if proton range is wrong by 10%!



Multiple fields improve plan robustness – Range uncertainty

The applied plan



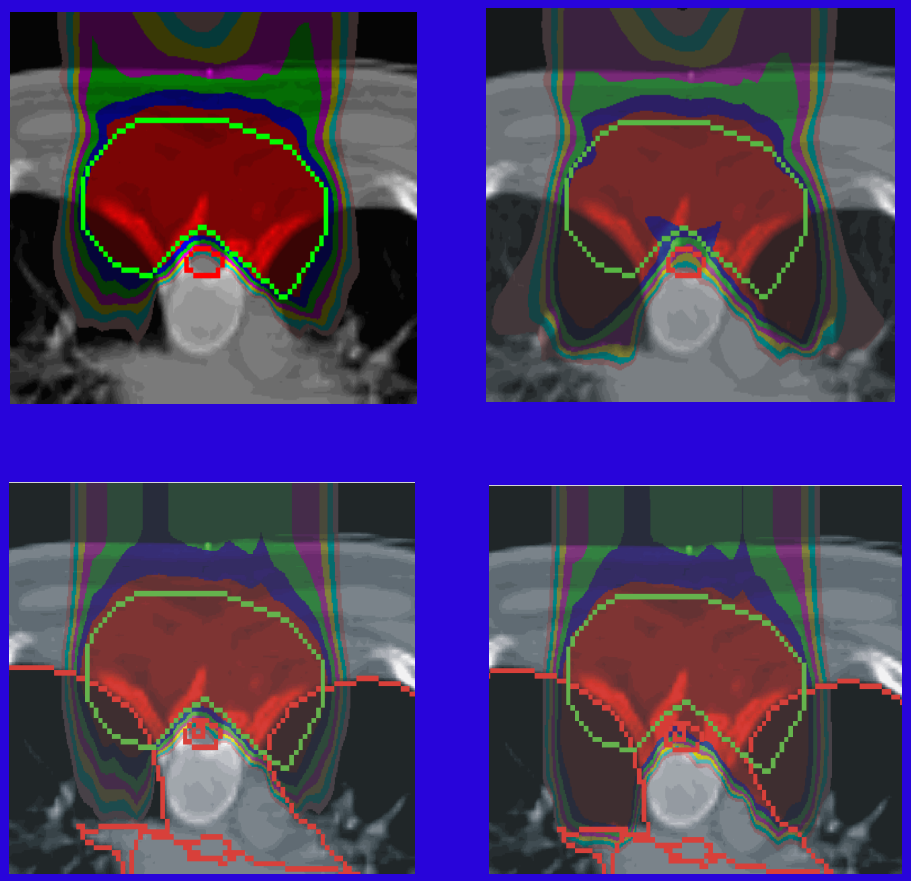
Lomax et al 2001, Med. Phys. 28:317-324

Multiple fields improve plan robustness – Range uncertainty

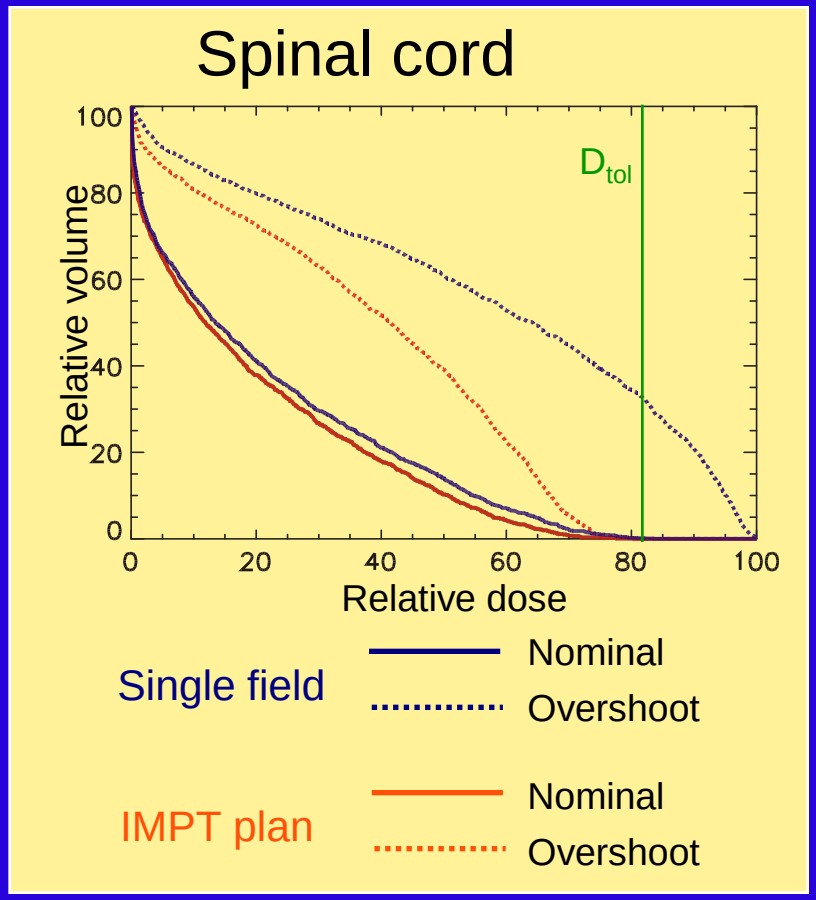
Nominal | 10% overshoot

IMPT

Single field



DVH analysis



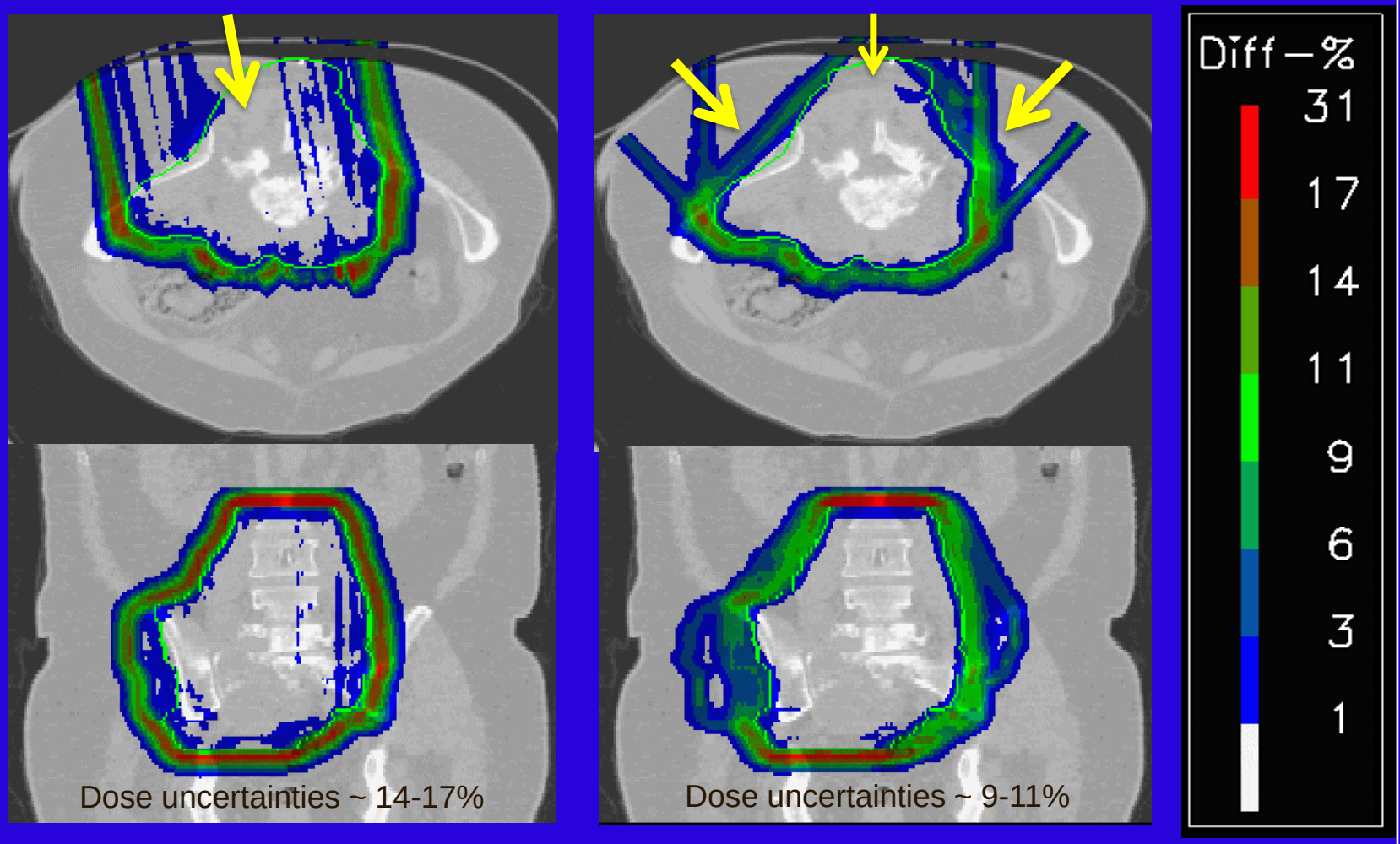
Lomax et al 2001, Med. Phys. 28:317-324

Multiple fields improve plan robustness – Set-up uncertainty

Dose error bars for fractionated positioning errors

$\sigma_{85\%}$ = 3.3mm

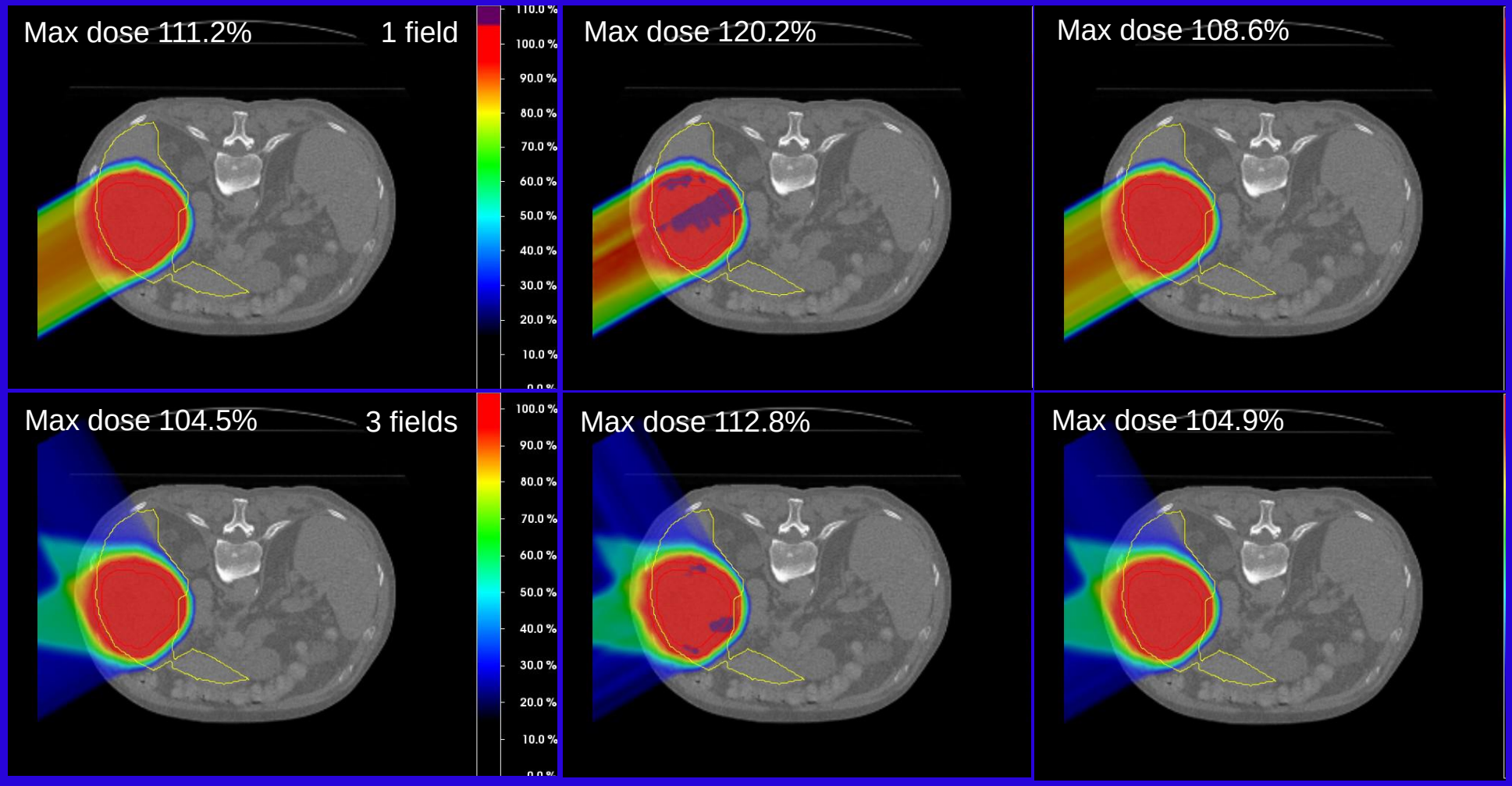
Fractions = 23



Albertini et al 2011 PMB 56:4399-4413, Lowe et al 2015 PTCOG54 and manuscript in preparation

Multiple fields improve plan robustness – Motion

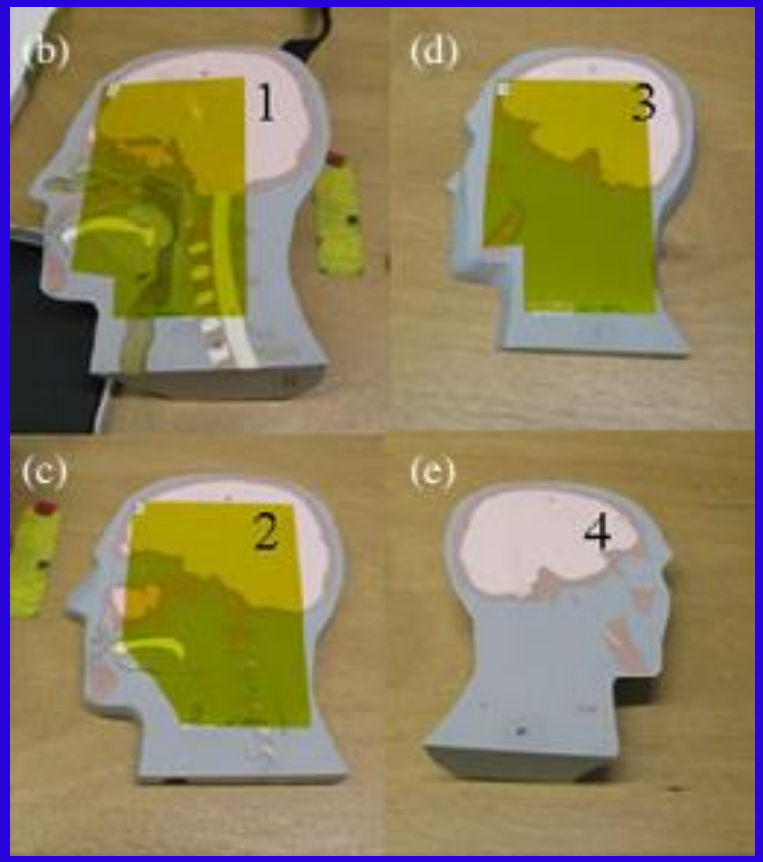
Static | 6mm S-I motion | 4 x re-scanning

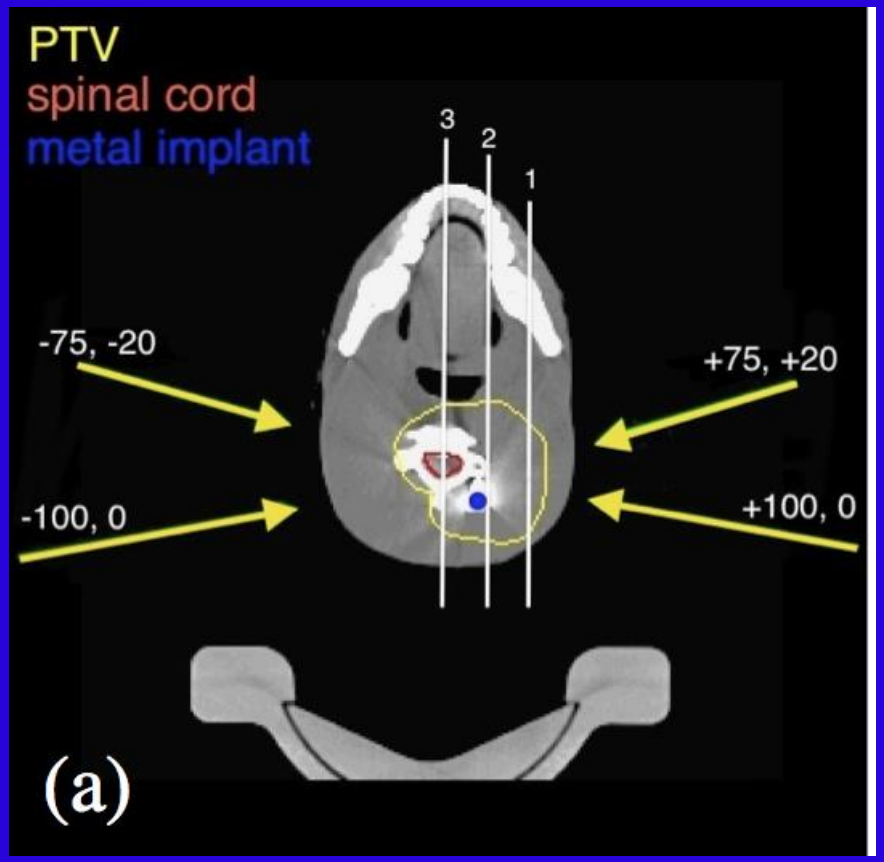


Knopf et al, Phys. Med. Biol. 56 (2011) 7257-7271

Multiple fields improve plan robustness – Delivery accuracy

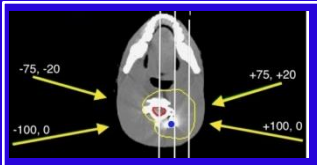
An experimental verification of dose accuracy of PBS proton therapy in the presence of metal artefacts



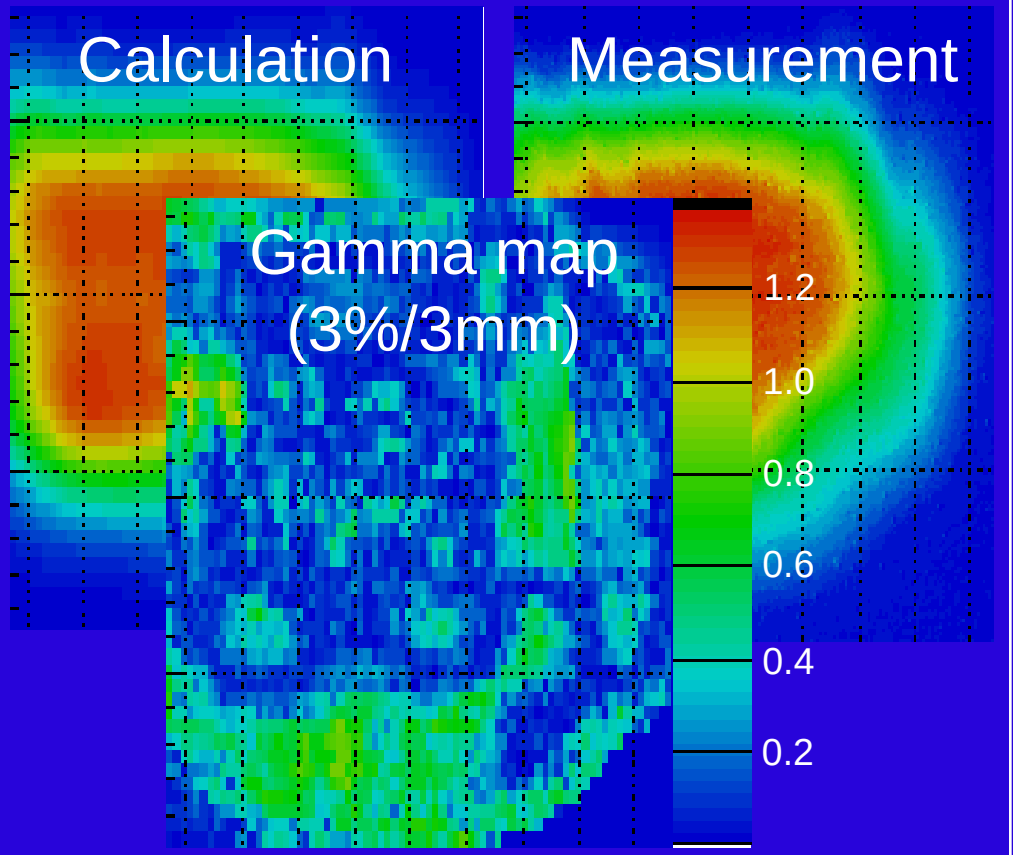


Dietlicher et al 2014 PMB 59:7181-7194

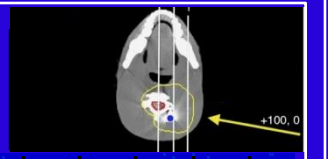
Multiple fields improve plan robustness – Delivery accuracy

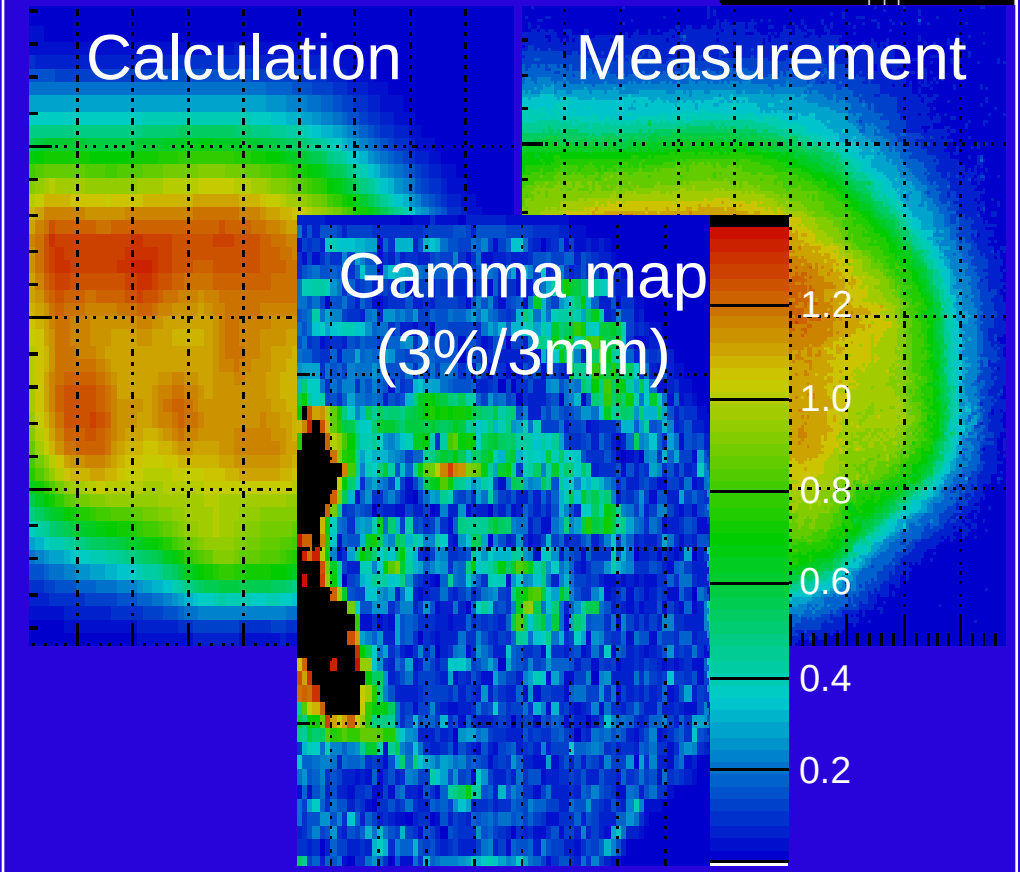


Full plan



Single field

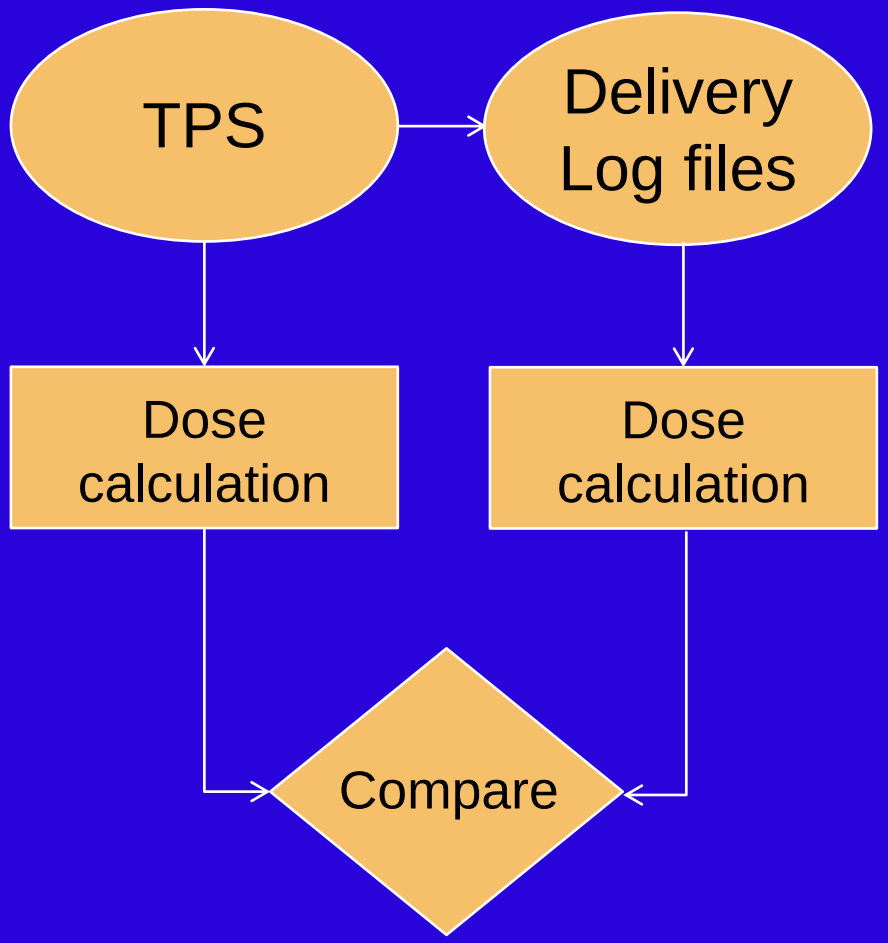


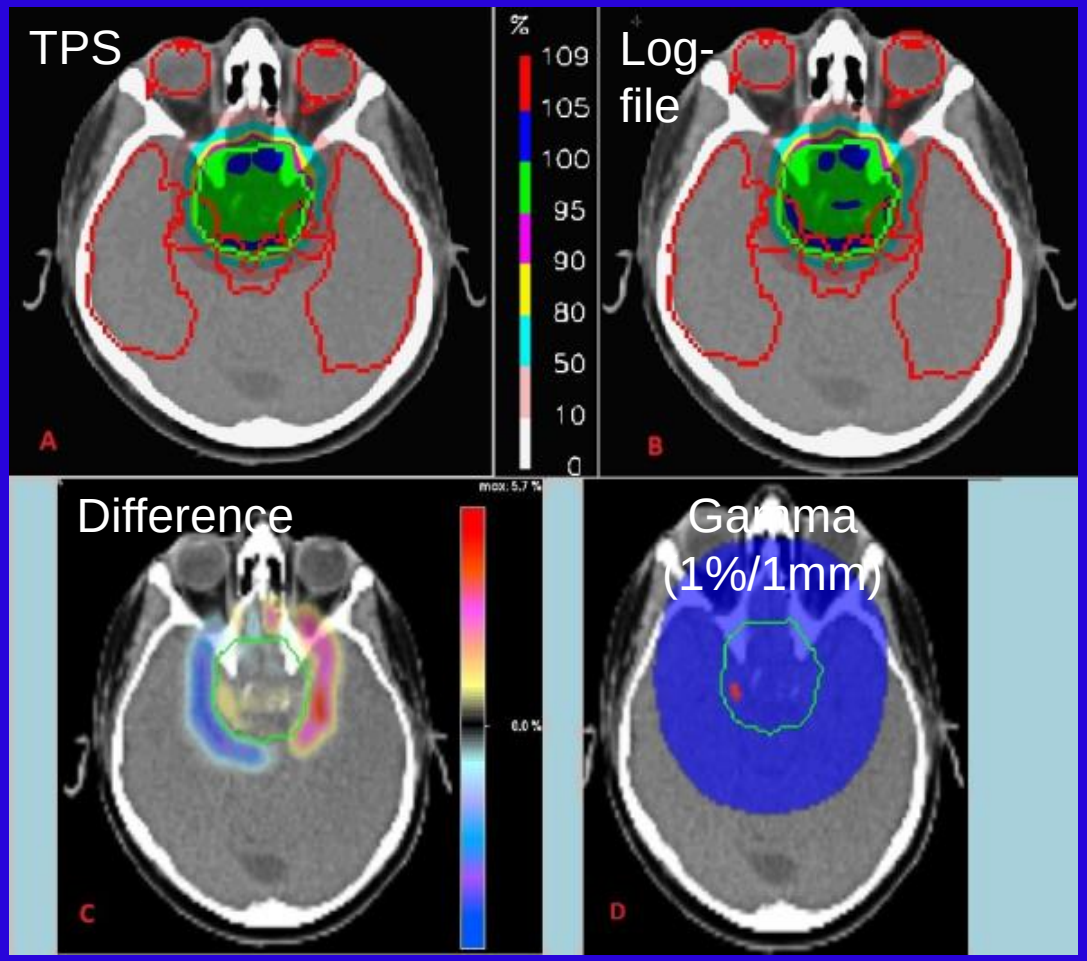


Dietlicher et al 2014 PMB 59:7181-7194

Multiple fields improve plan robustness – Delivery accuracy

Dose reconstruction from treatment log files



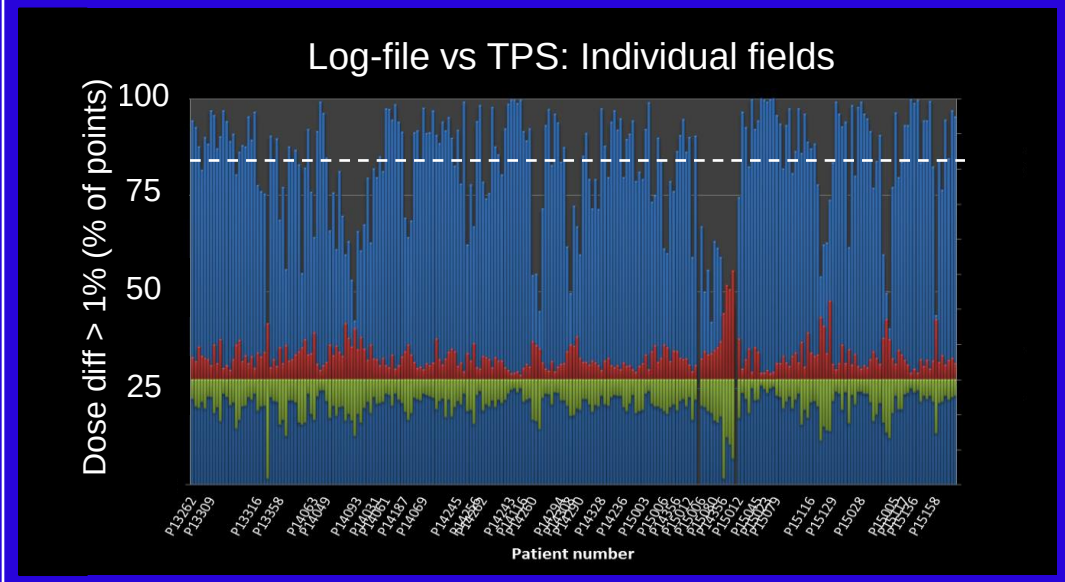


Meier et al 2015 PMB 60:2819-2836

Multiple fields improve plan robustness – Delivery accuracy

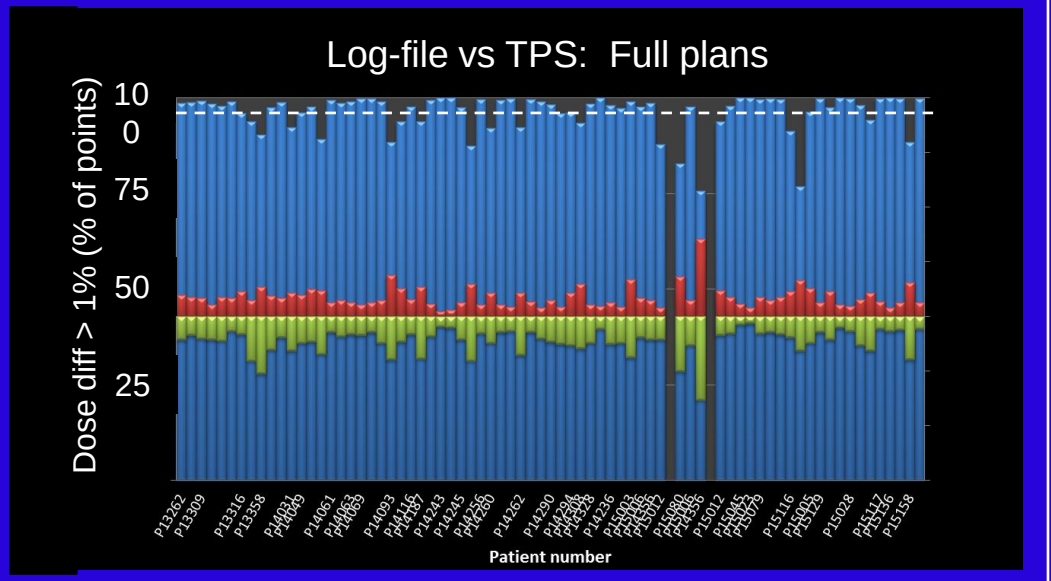
A comprehensive analysis of log-file dose calculations for 37 patients, 77 plans, 257 field)

Analysis per field



+/-1% agreement 82.3%

Analysis per plan (3.3 fields per plan)

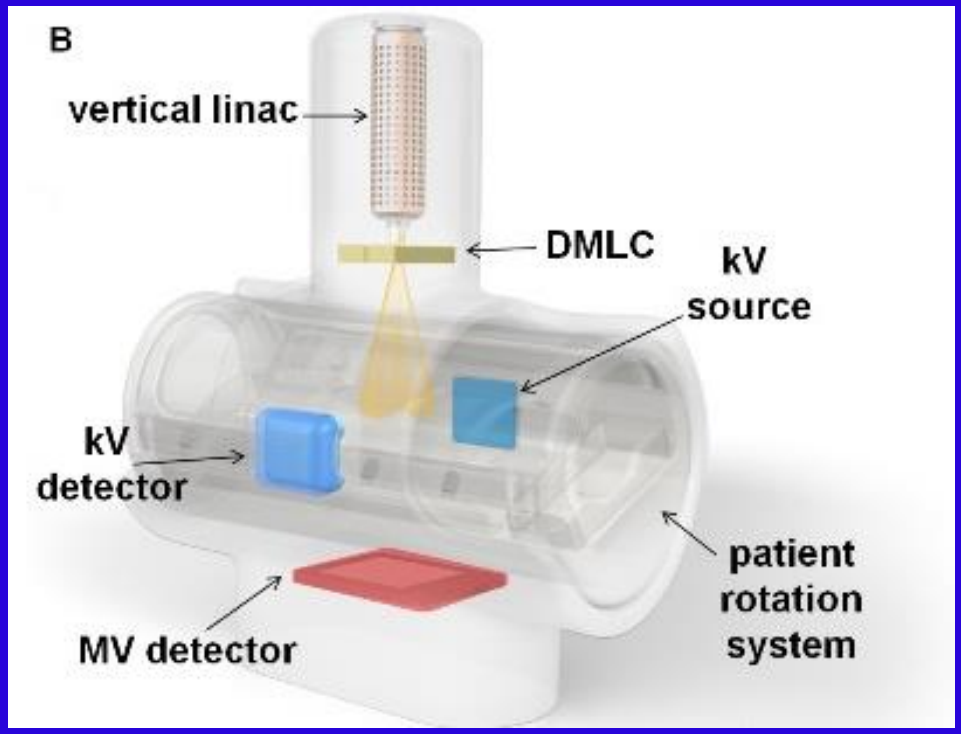


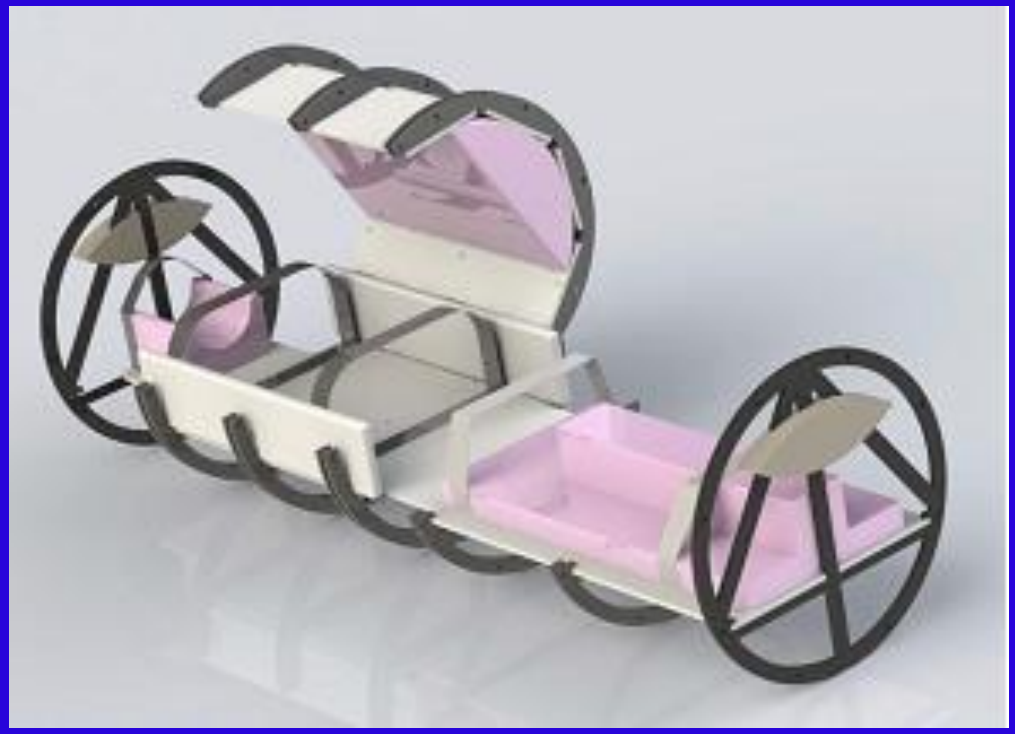
+/-1% agreement 96.4%

Scandura et al 2015 , Manuscript in preparation

Are there alternatives to a gantry?

Rotating the patient – the Nano-X system from Australia

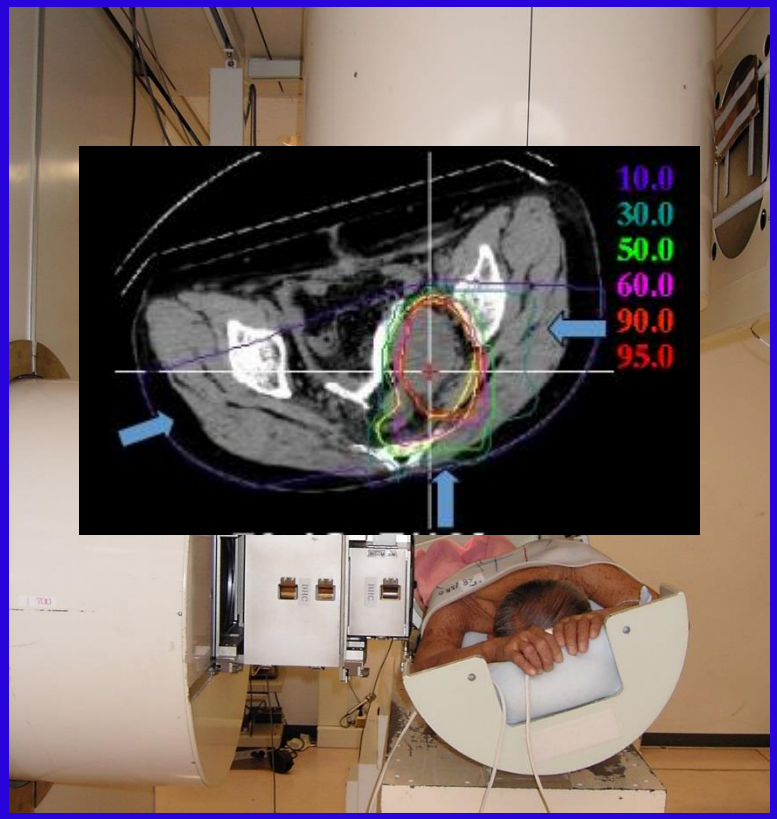


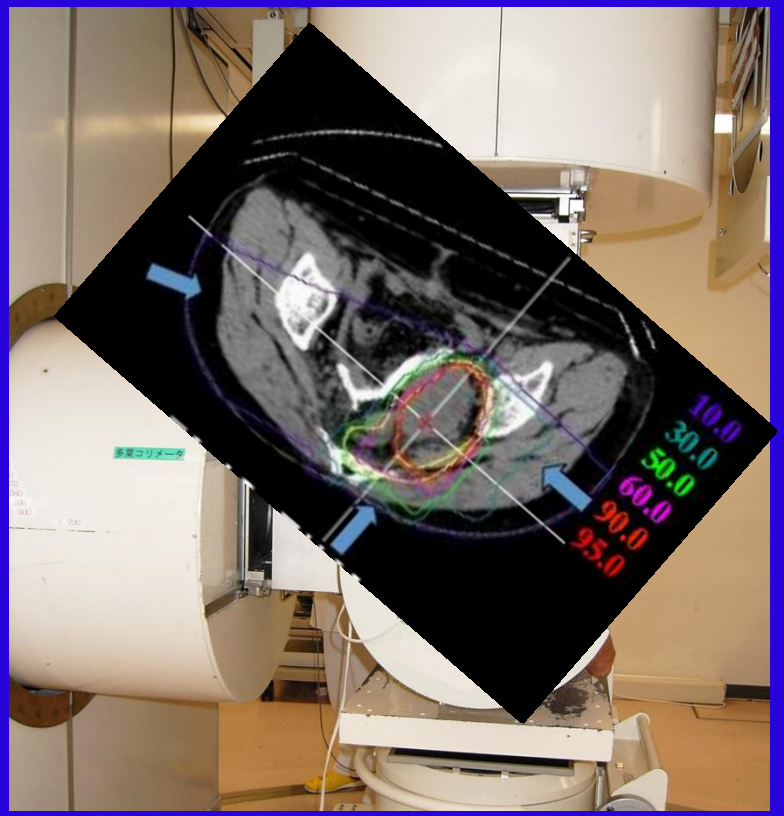


Paul Keall, University of Sydney, Australia

Are there alternatives to a gantry?

Rotating the patient – Carbon ion therapy on a fixed beam line

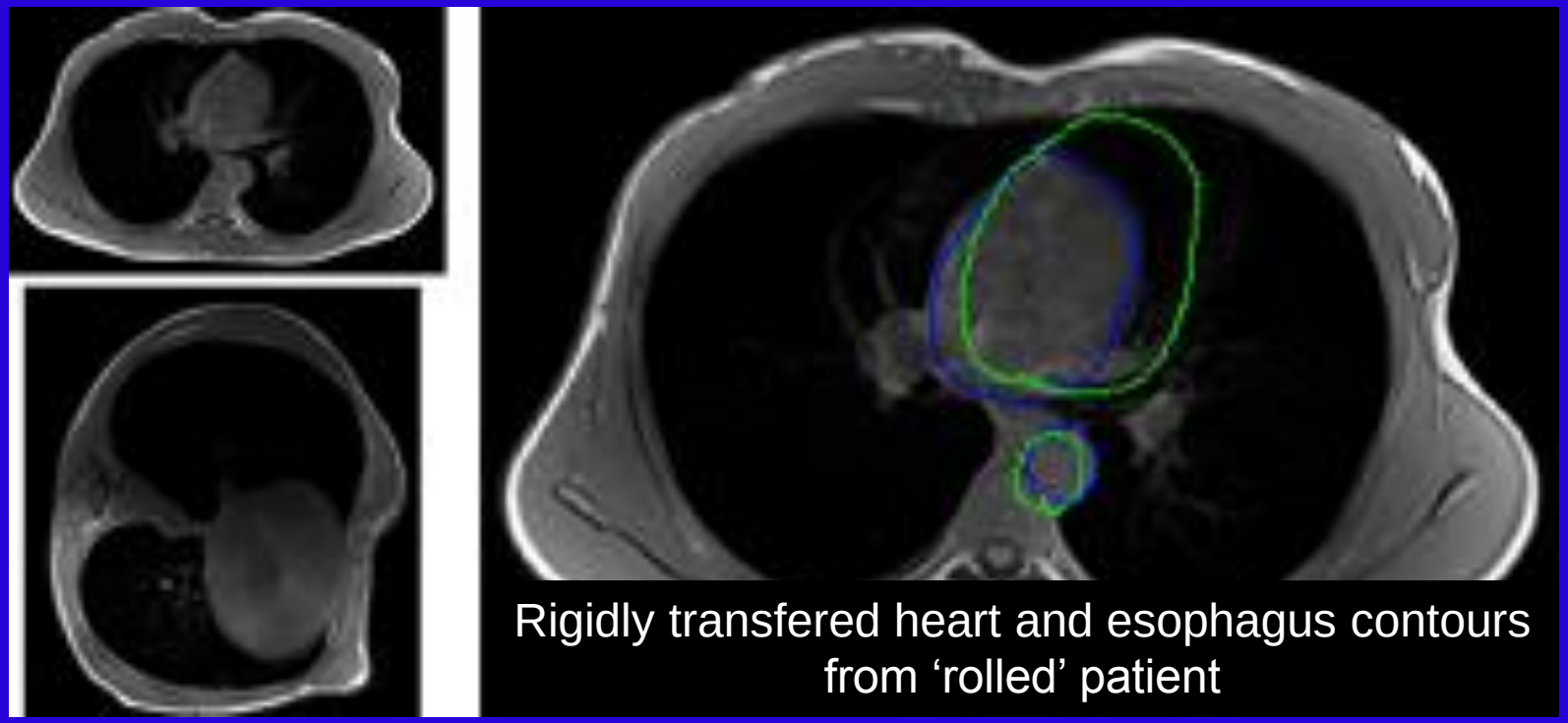




Hirohito Tsujii, NIRS, Japan

Are there alternatives to a gantry?

Rotating the patient – the problem of deformable anatomy



Rigidly transfered heart and esophagus contours from ‘rolled’ patient

B Whelan et al (University of Sydney):

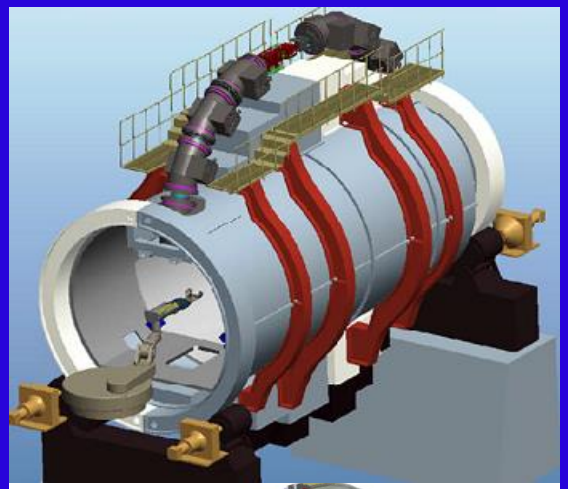
“…, based on these results we can report that deformation is expected to be both significant and complex.”

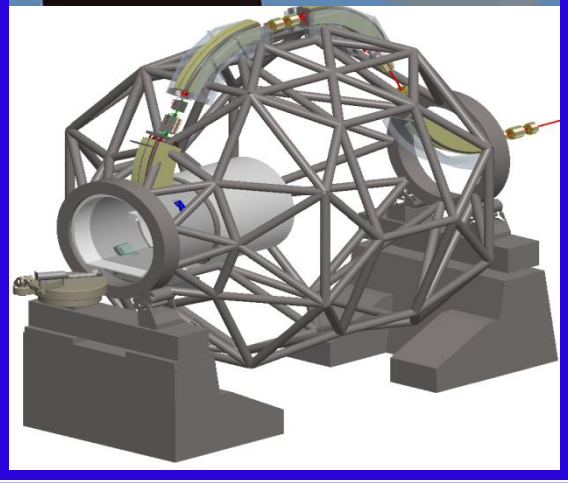
Are there alternatives to a gantry?

Apparently not always….

Koji Noda (NIRS) in 'Carbon Ion radiotherapy: Principles, Practices and treatment planning'. Edited by H Tsujii.

"… the patient is fixed in supine, prone, and often rolled positions by typically 10-20 degrees from the horizontal plane in order to achieve a better combination of beams. This situation often adds to the patient's load, complicates treatment planning, and makes precise positioning difficult. A rotating-gantry system will resolve many of these problems."





The rest of the world seems to agree as well…