Promises and Perils of Proton Radiotherapy

Uncertainty Issues for non-moving Targets

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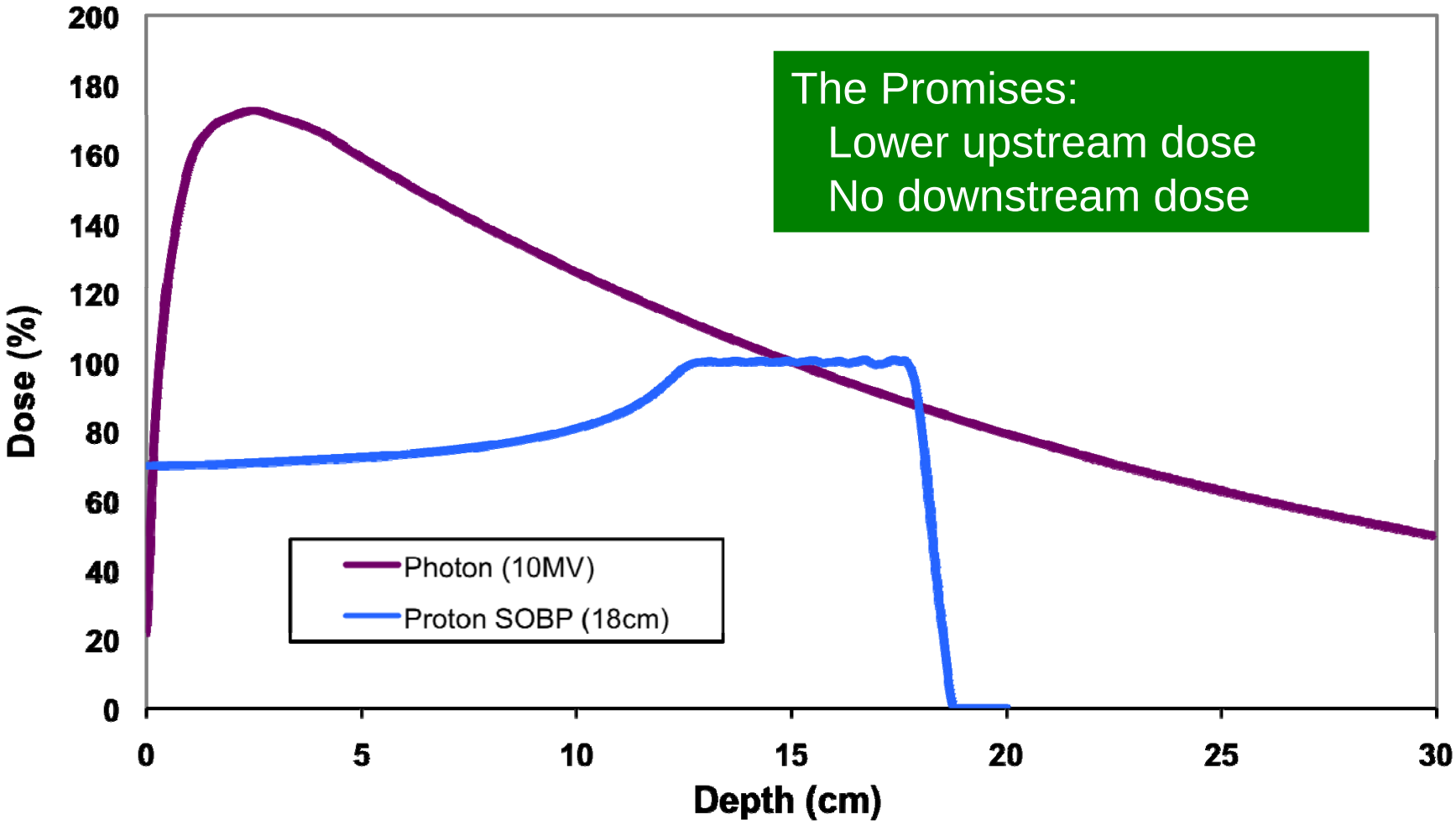
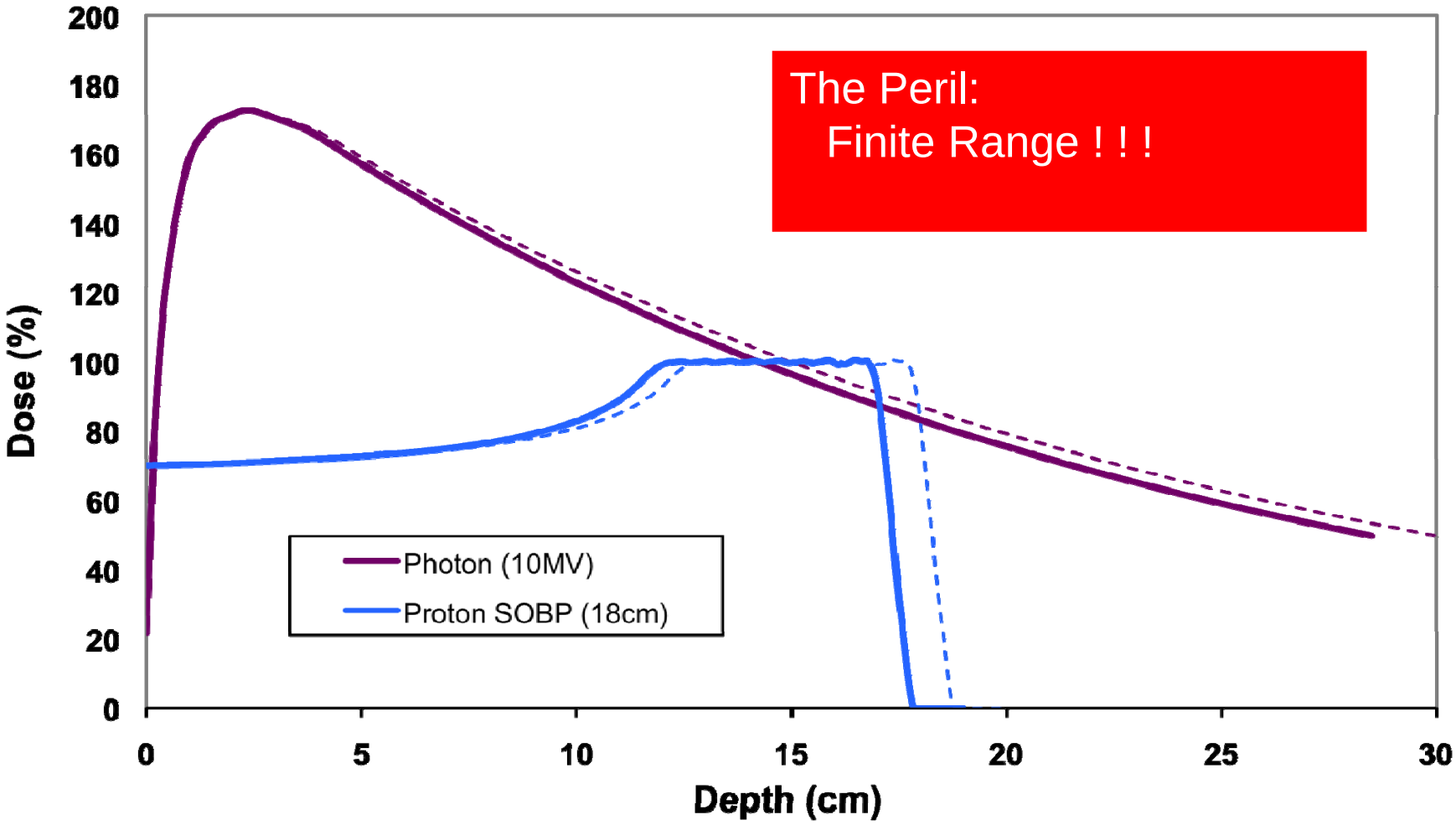
HARVARD MEDICAL SCHOOL

The promises



The perils


The Peril:
Finite Range ! ! !
Photon (10MV)
Proton SOBP (18cm)
Dose (%)
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200
0
5
10
15
20
25
30

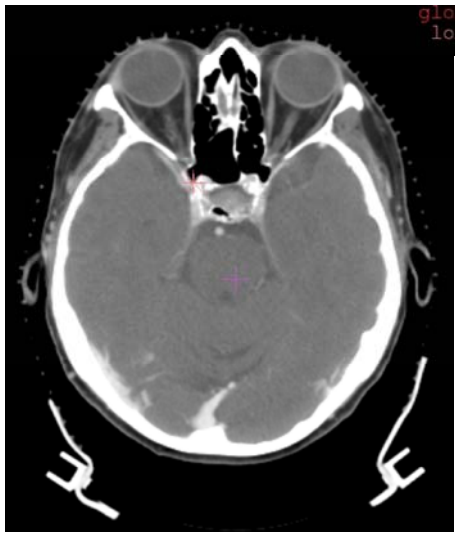
Proton Mindset

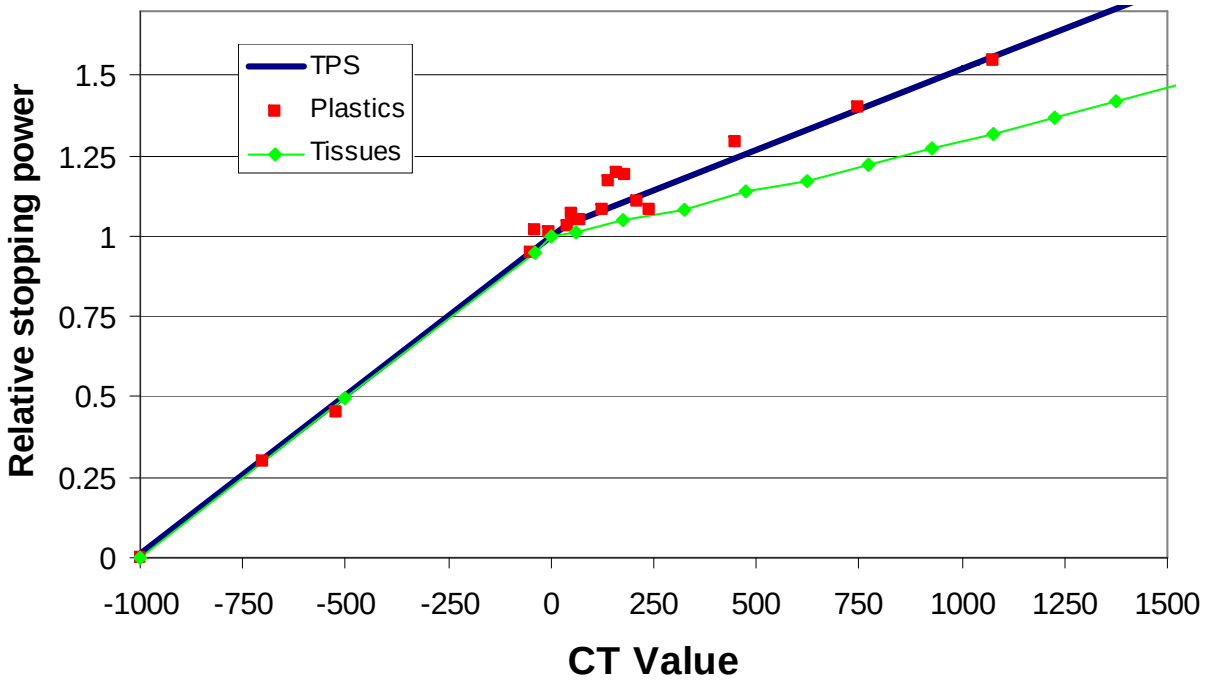
CT-scan

Hounsfield units conversion

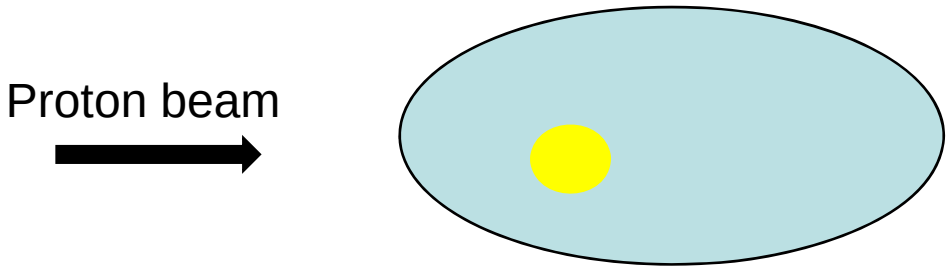
Photons → Electron Density

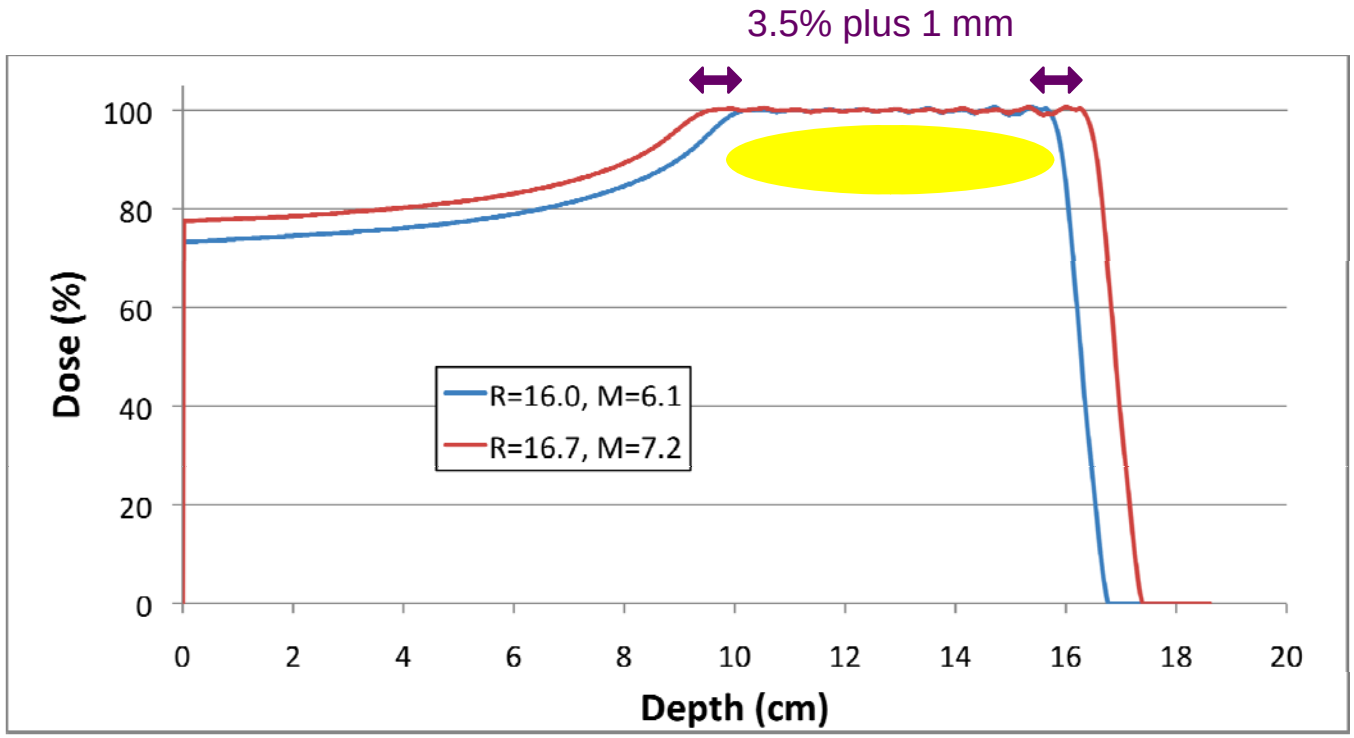
Protons → Proton stopping power



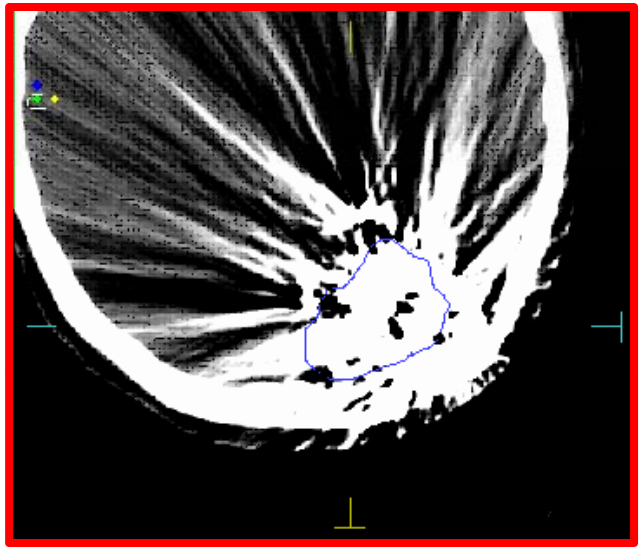


3.5% plus 1 mm

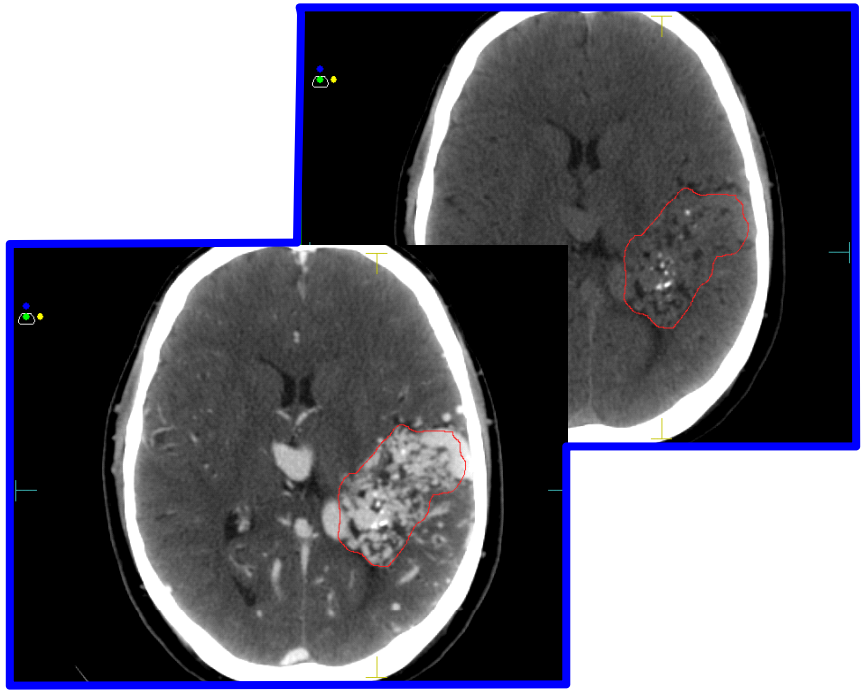

Proton beam


3.5% plus 1 mm
Dose (%)
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20
Depth (cm)
R=16.0, M=6.1
R=16.7, M=7.2

CT artifacts

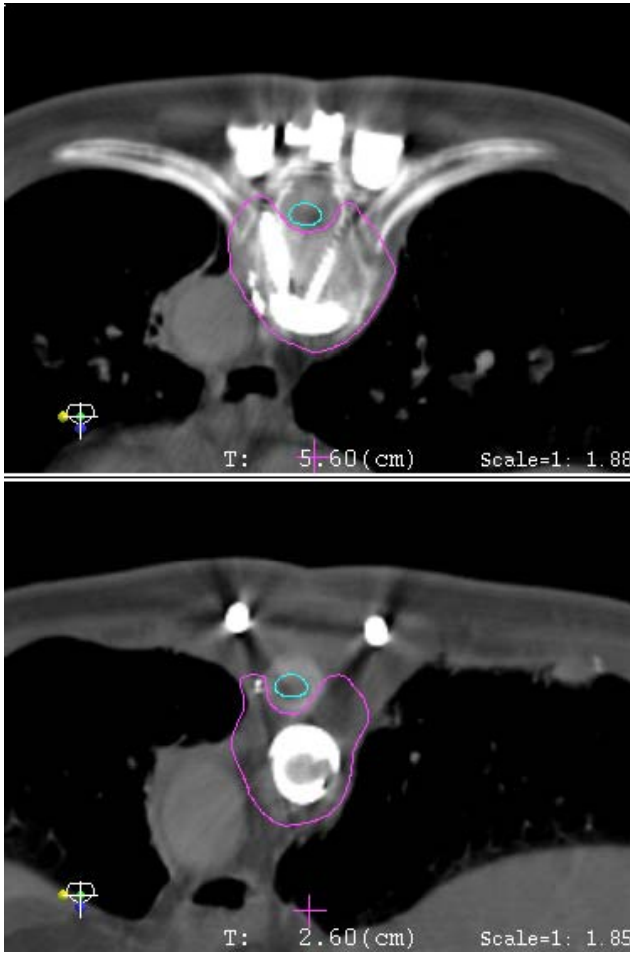


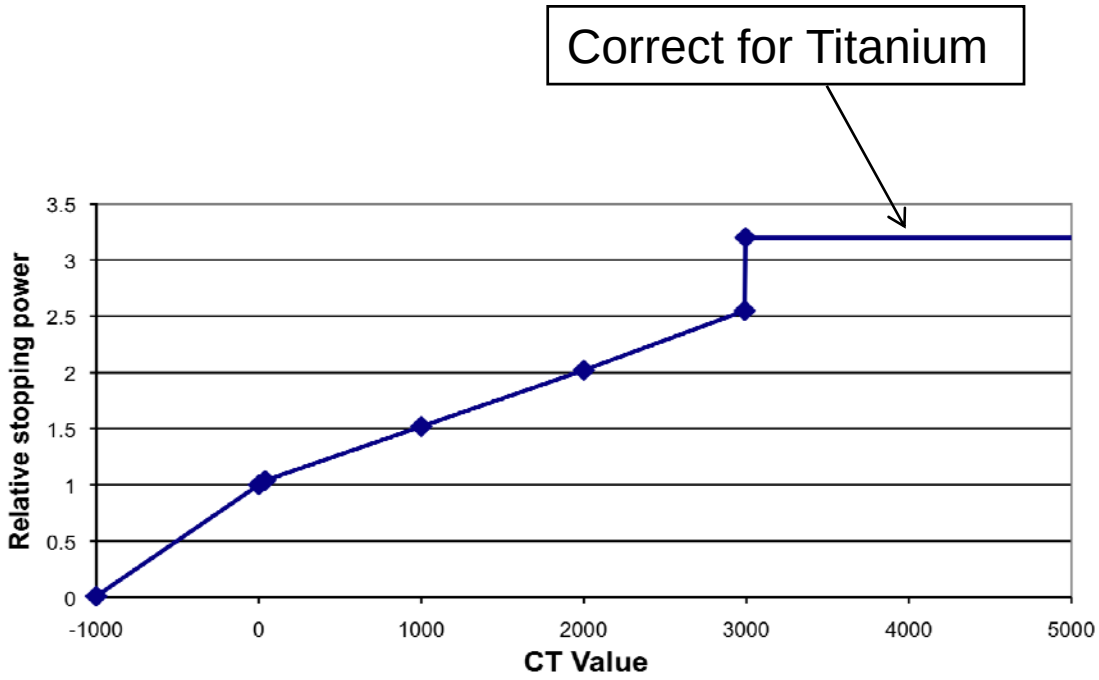
High-density streak artifacts
➔ Density override



Contrast / Onyx glue
➔ Multiple CT-scans
➔ Density override

Patient hardware



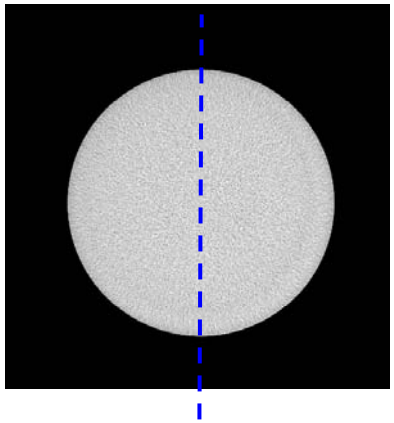


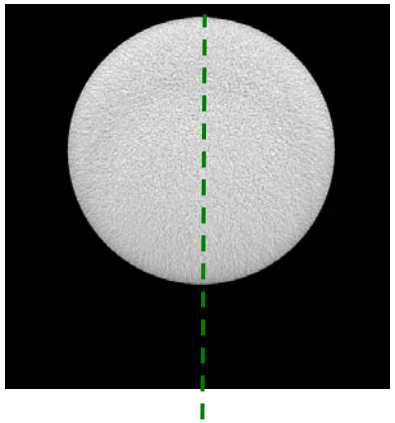
CT reconstruction circle

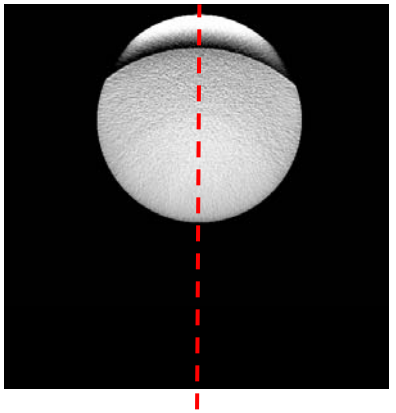
Centered
FOV = 50 cm

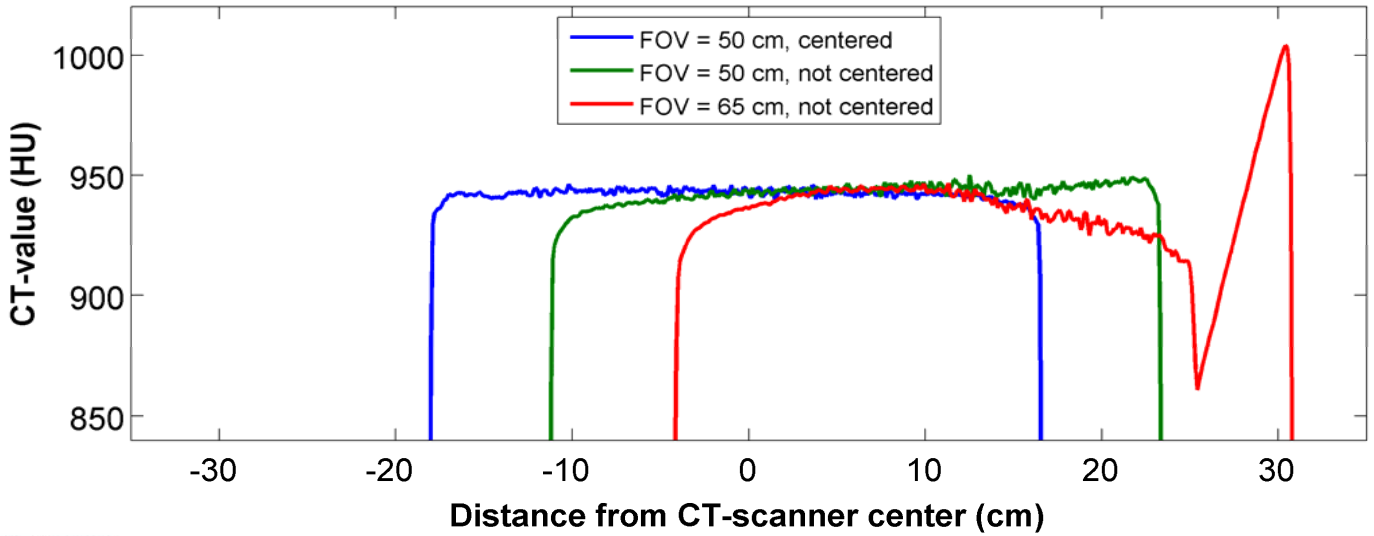
Not centered
FOV = 50 cm

Not centered
FOV = 65 cm









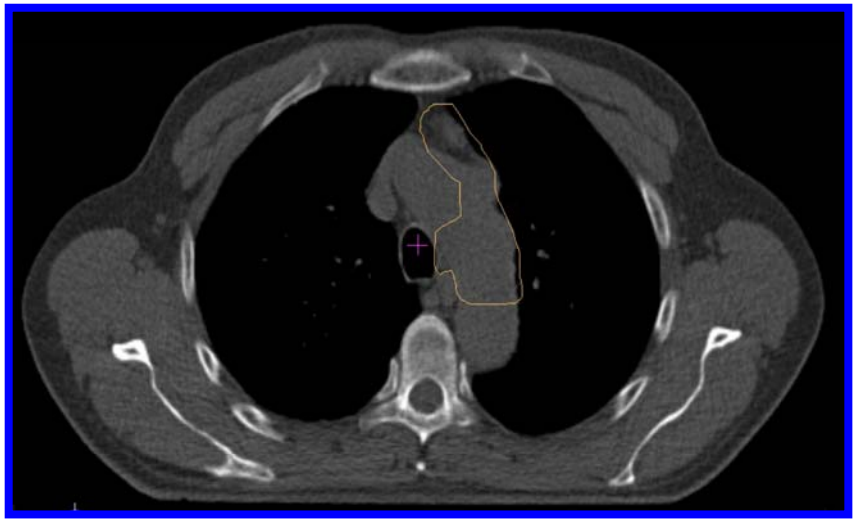
Prostate example

- Consider re-scanning for treatment planning
- Consider prescribing a diet

Lung example

Arm position
- Limits beam directions
- Reproducible setup?

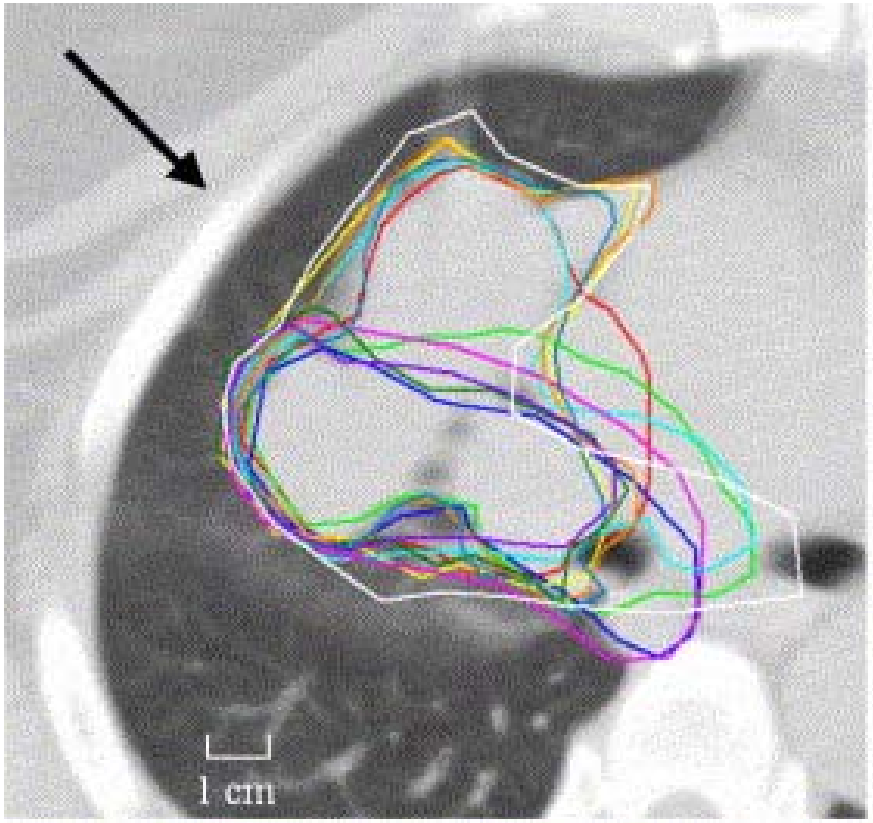
AP and PA fields
- Skim density surface
- With smearing ➔ exit dose



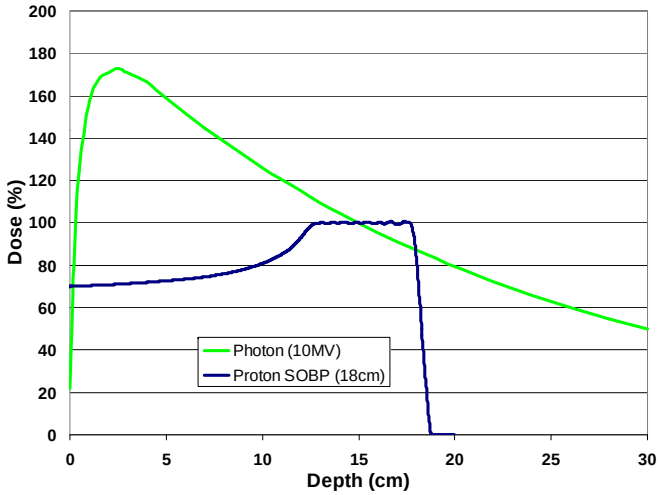
Proton Mindset

Target Delineation

Target delineation



Steenbakkers et al.
Radiother Oncol.
2005; 77:182-90

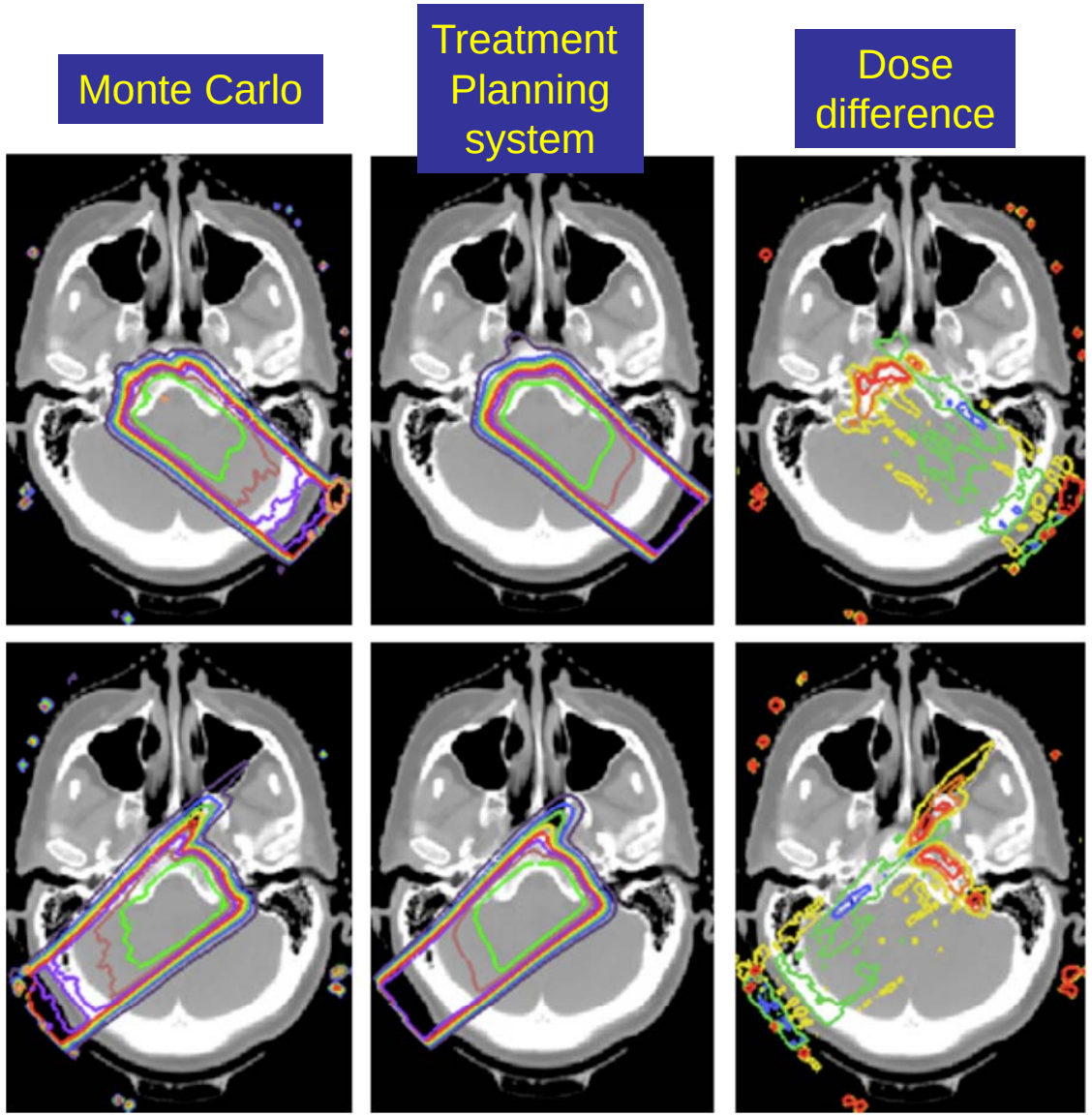


- Protons: Reduced proximal and zero distal dose
- Treatment day field combination dependent

Proton Mindset

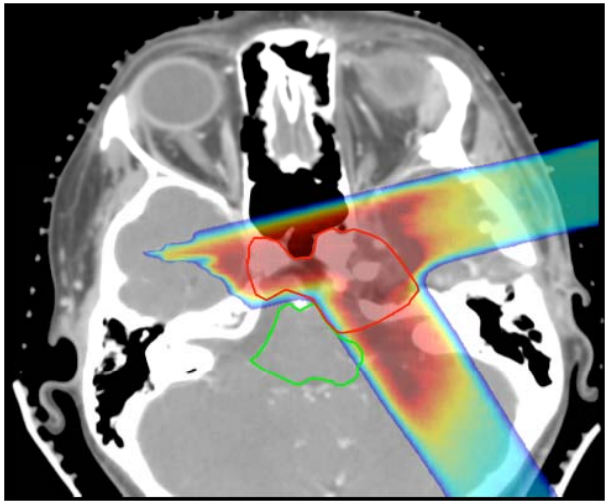
Dose Calculation

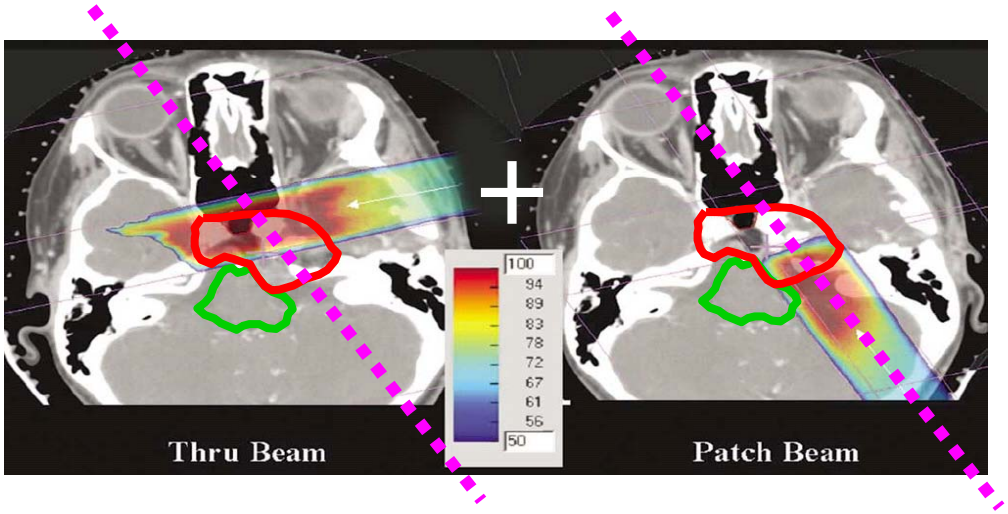
Pencil beam vs Monte-Carlo

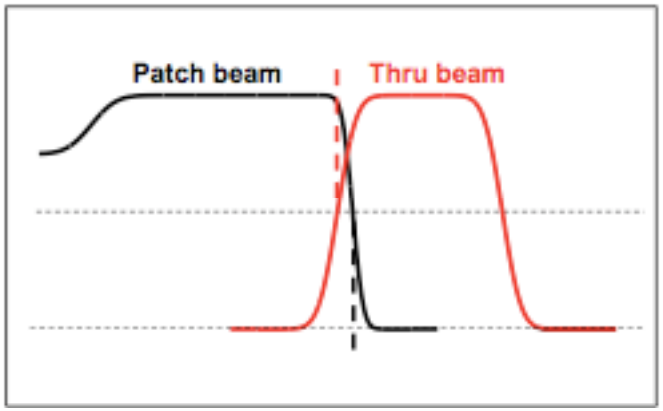


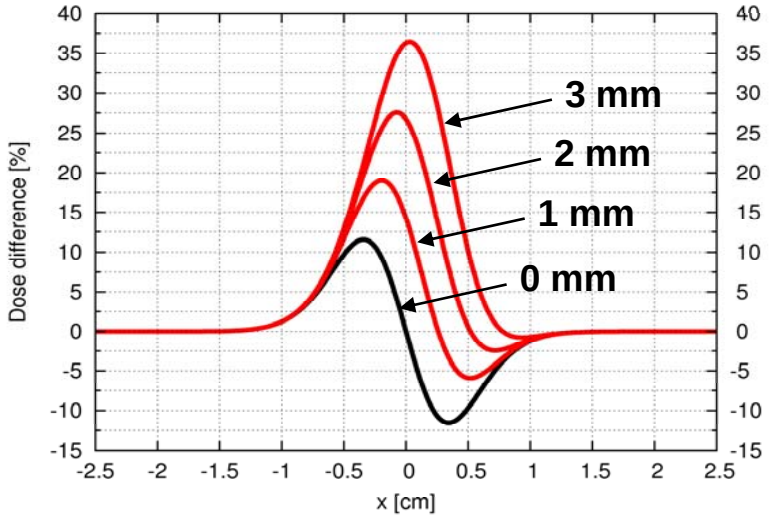
H. Paganetti *et al.*

Patching

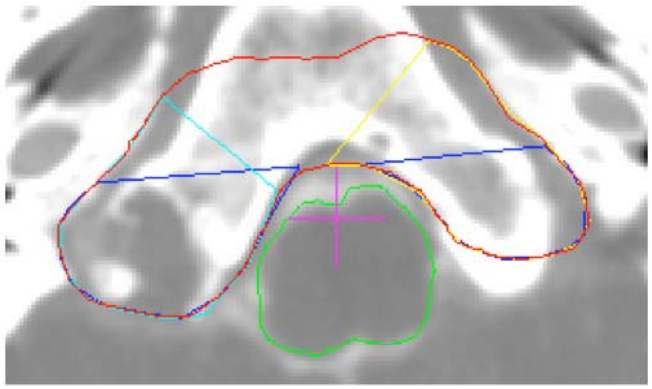


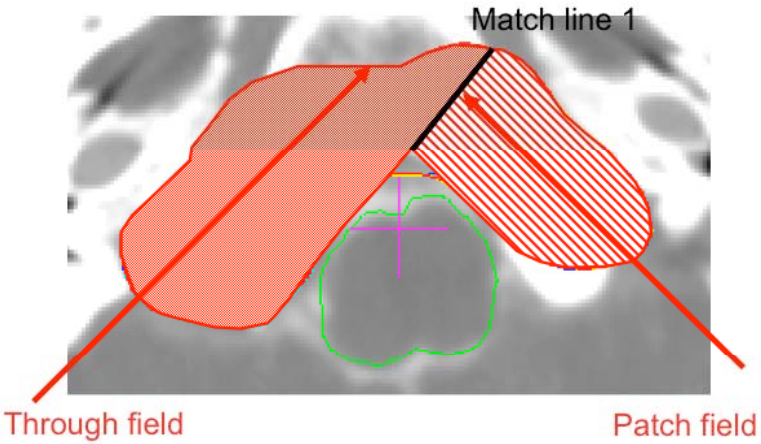

100
94
89
83
78
72
67
61
56
50
Thru Beam
Patch Beam

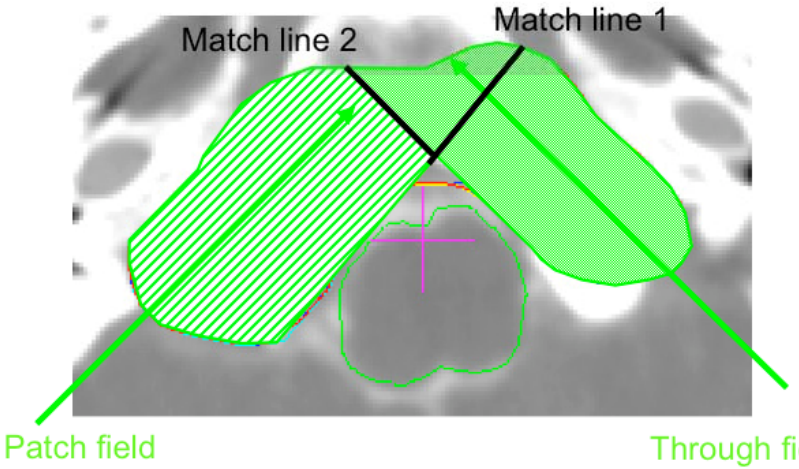

Patch beam
Thru beam

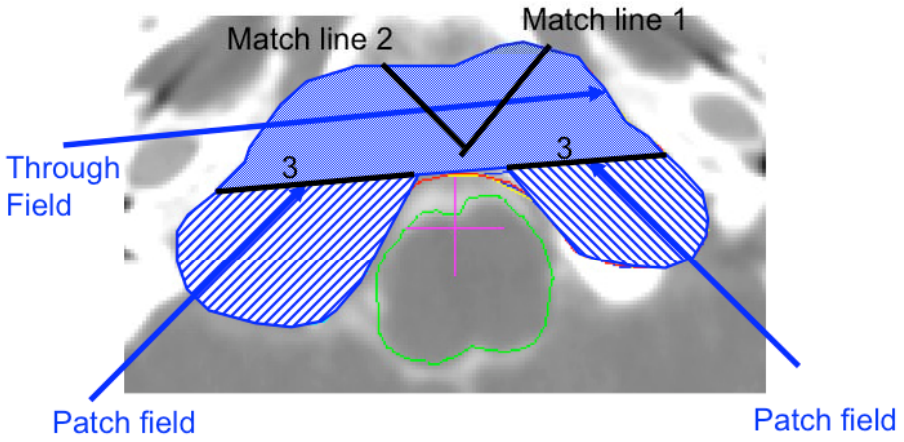

Dose difference [%]
x [cm]
3 mm
2 mm
1 mm
0 mm

Patching: multiple match lines





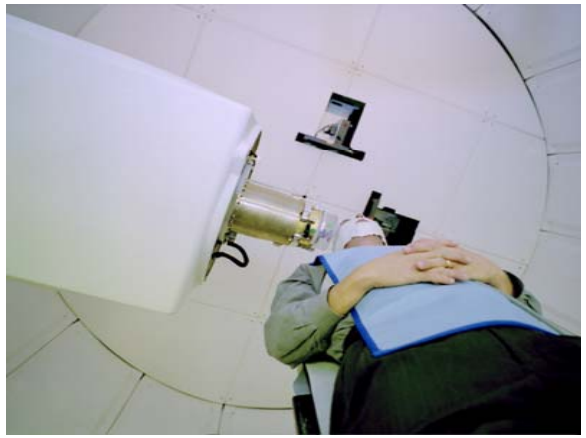


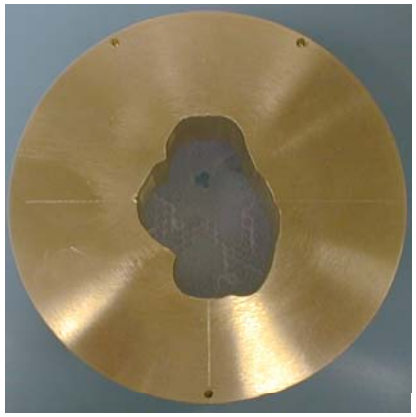


Proton Mindset

Patient Alignment

Hardware proximity



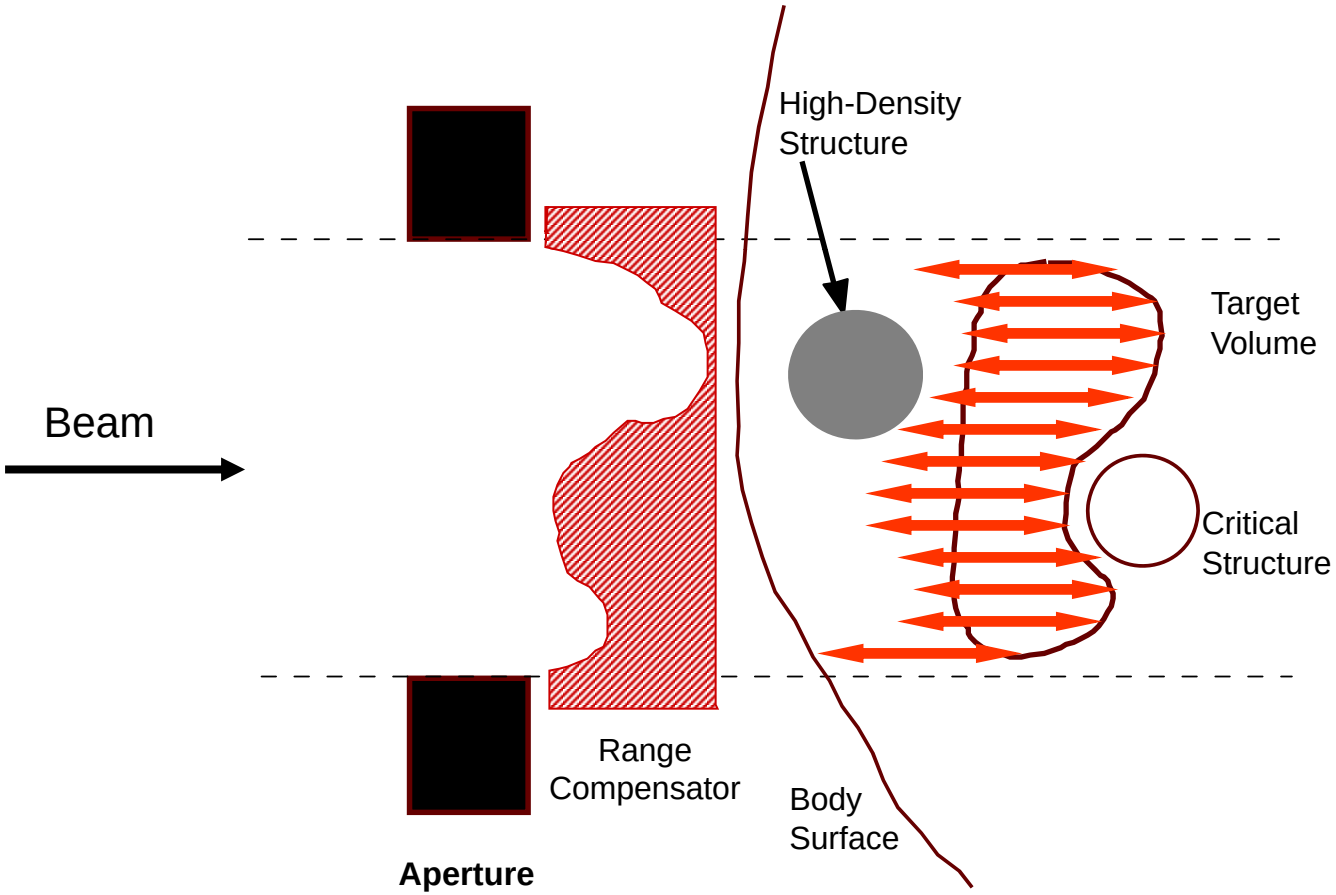


Airgap larger then planned:

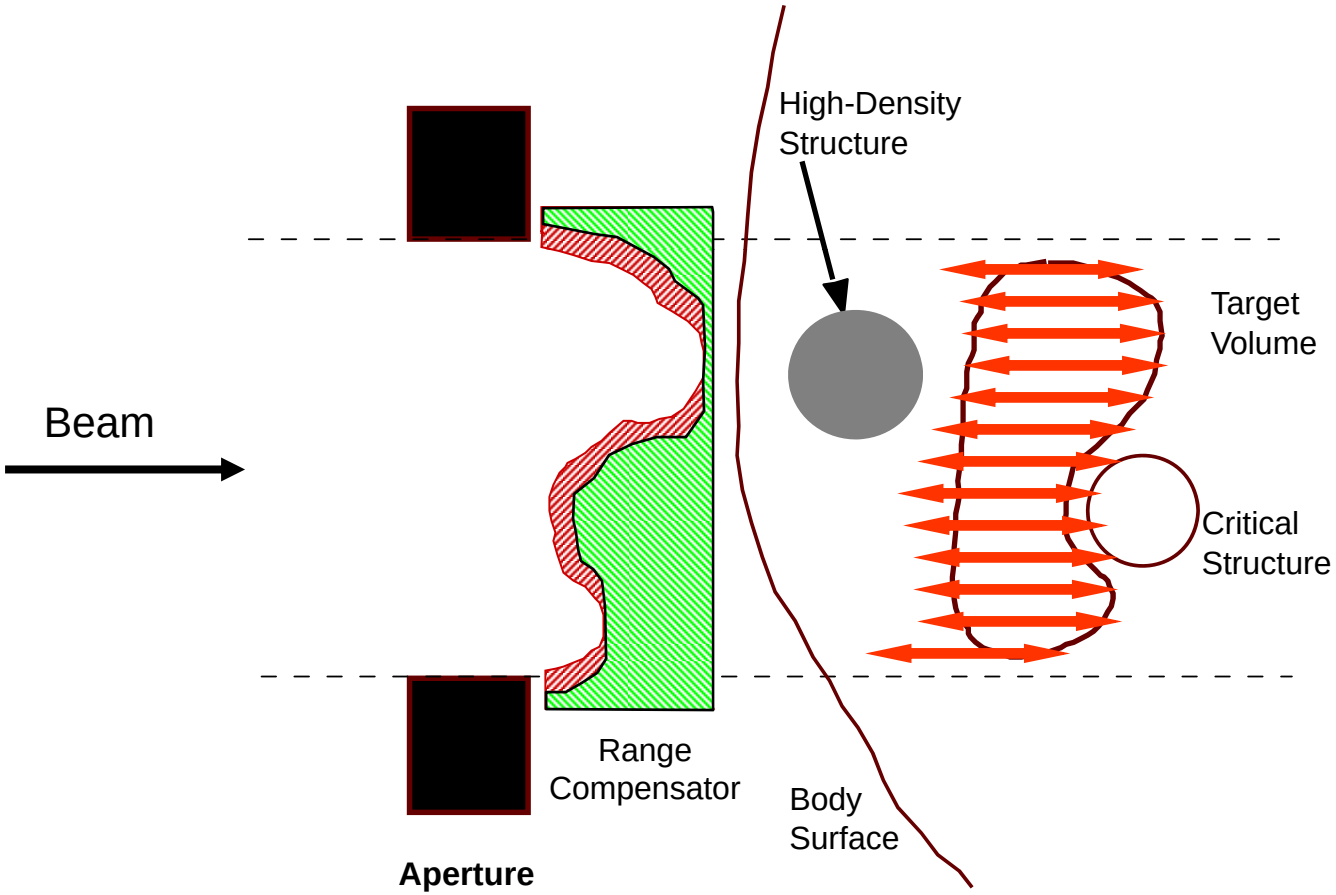
- Increased aperture projection
- Increased penumbra due to scatter in Range Compensator

Dosimetrist training / understanding

Smearing for setup errors



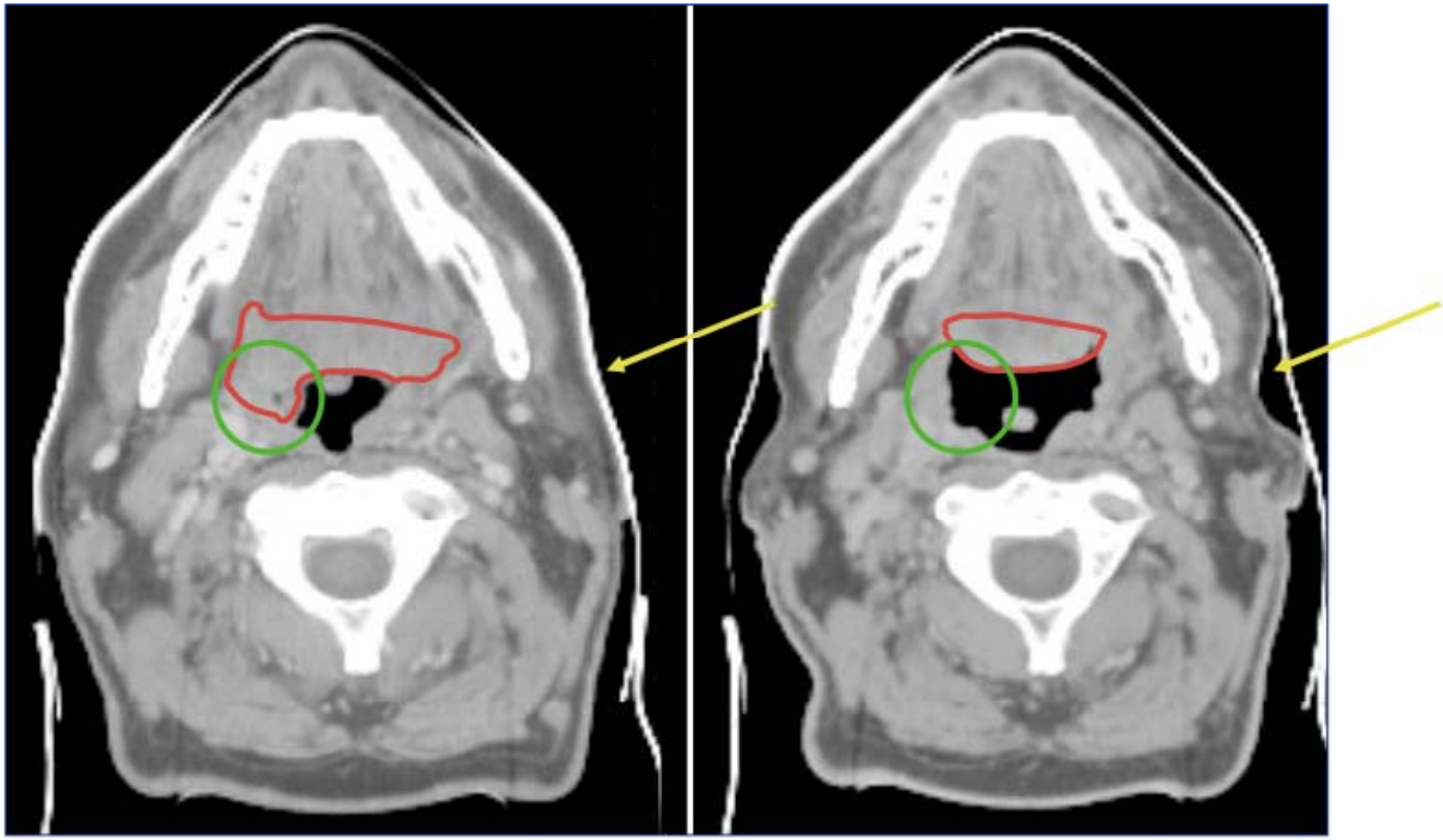
Smearing for setup errors



Setup verification

- Any “photon” approach can be a proton approach, e.g.
  - Orthogonal X-rays + DRRs
  - Ultrasound
  - AlignRT
- Conebeam CT
  - Full 3D patient alignment
  - Observe density changes

Shape changes of patient and tumor

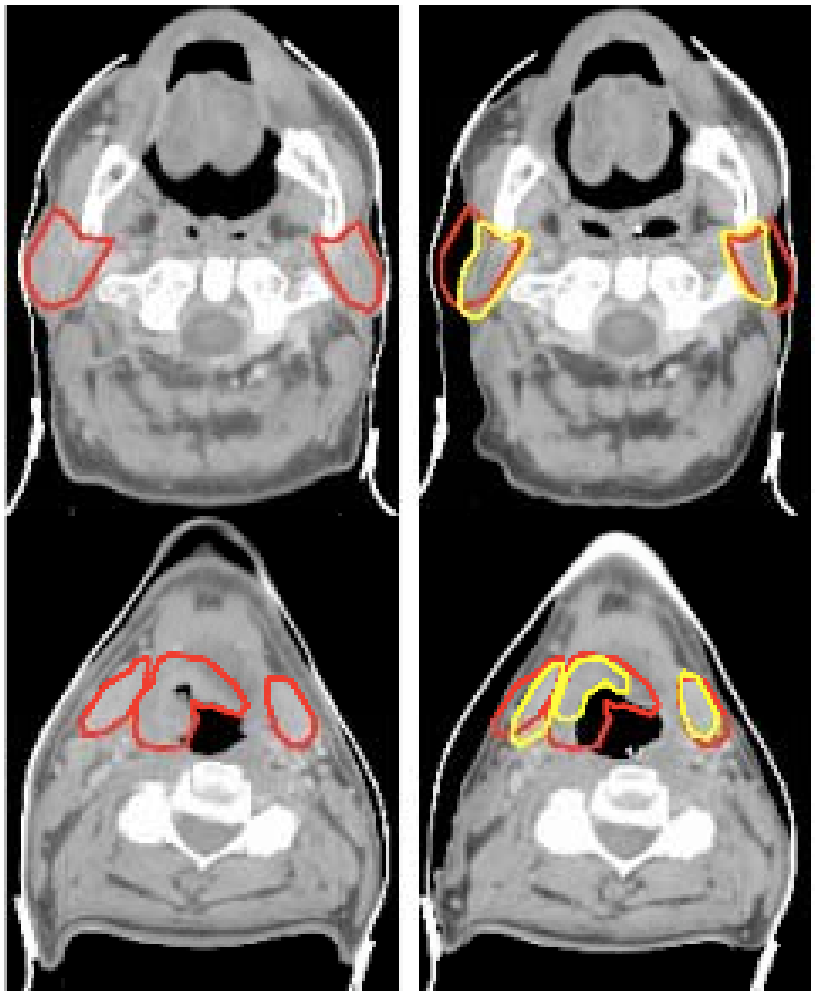


Mischa Hoogeman, Erasmus MC

Shape changes of patient and tumor

Before RT

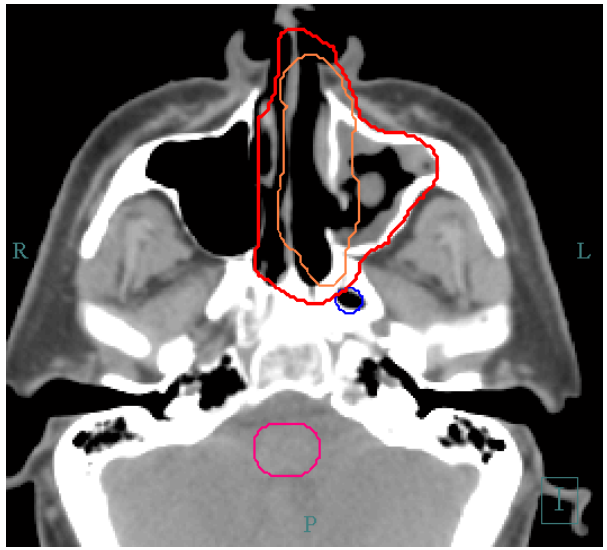
After RT

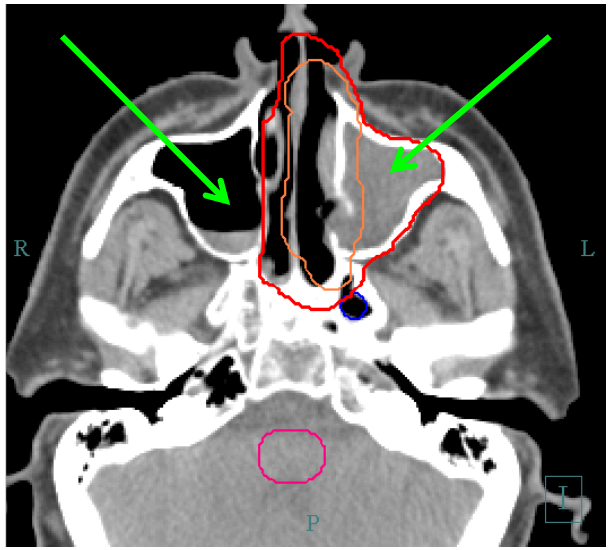


E. M. Vasques Osorio *et al.*
IJROBP 70: 875-82

Other density changes

- Patient weight gain / loss
- Filling up of sinuses
- (Sub-clinical) pneumonia
- Wet hair / gel / hairspray





Lei Dong, MDAH

“Catch” substantial density changes

- Measure patient weight
- AlignRT
- Tightness of immobilization device
- Physician follow-up
- Repeat CT-scanning
- Conebeam CT

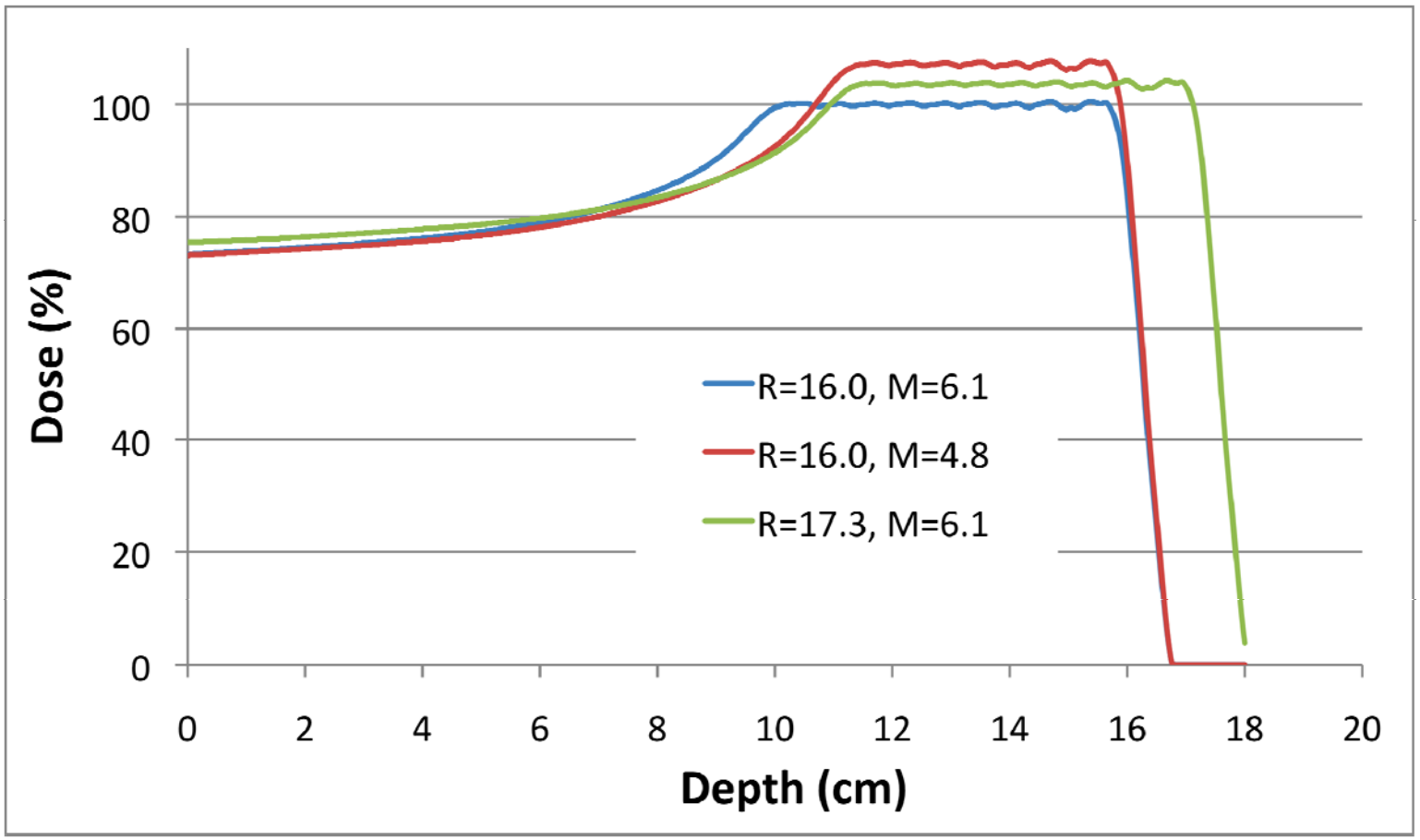
Currently: Unknown clinical importance

Proton Mindset

Dose Delivery

Double whammy

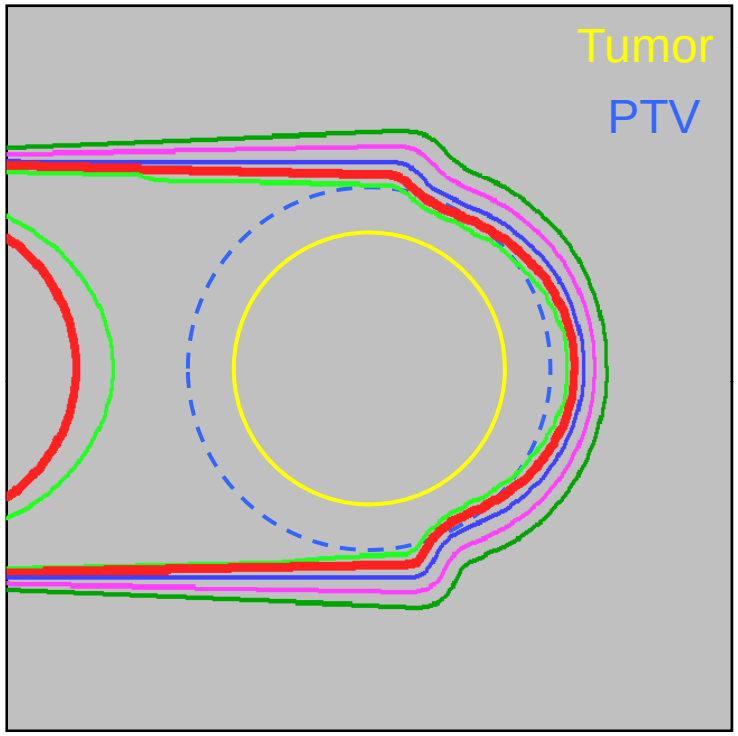
Same number of MU for each SOBP



Proton Mindset

Dose Evaluation

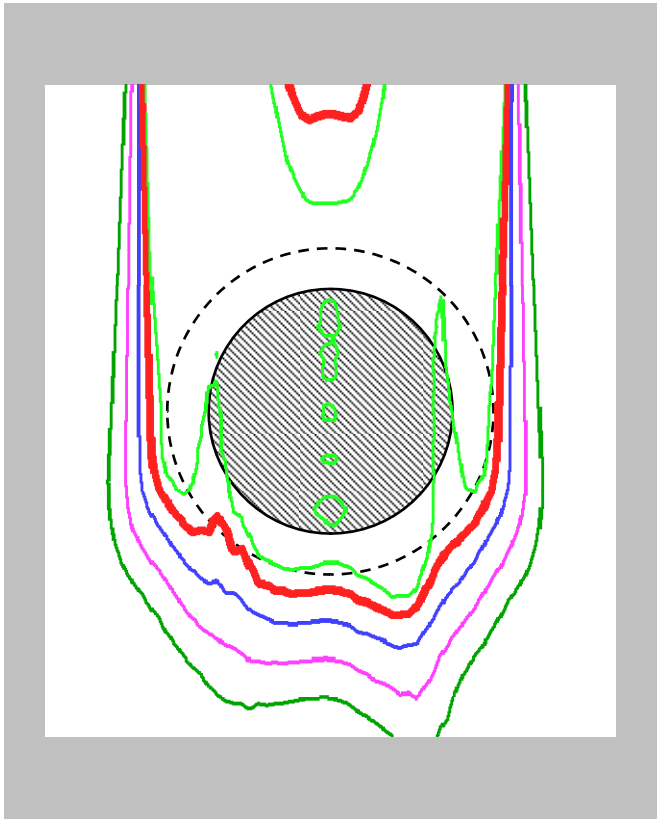
PTV in particle therapy



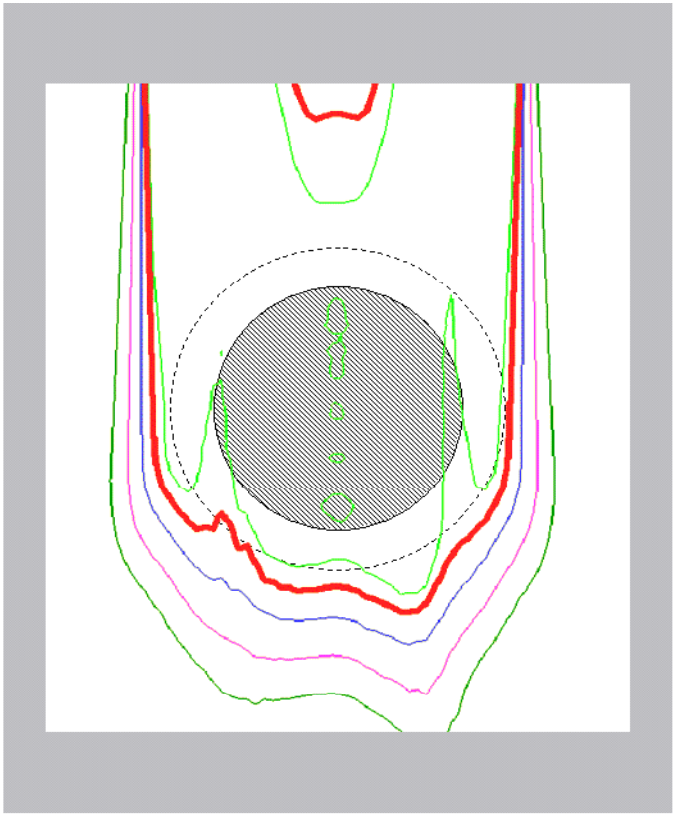
Distal margin not needed for setup errors

PTV in particle therapy

Planned dose

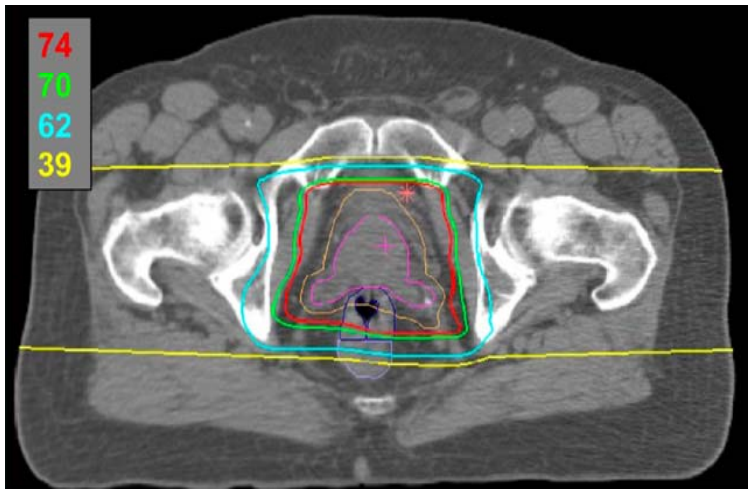


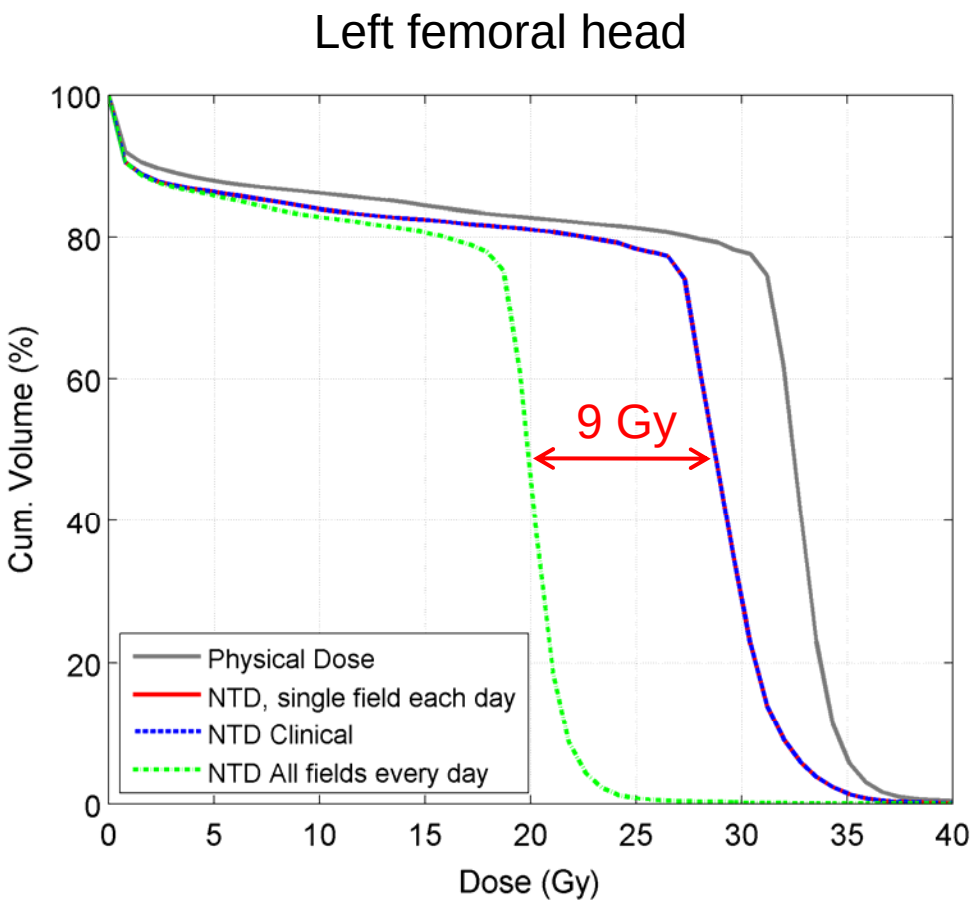
Delivered dose



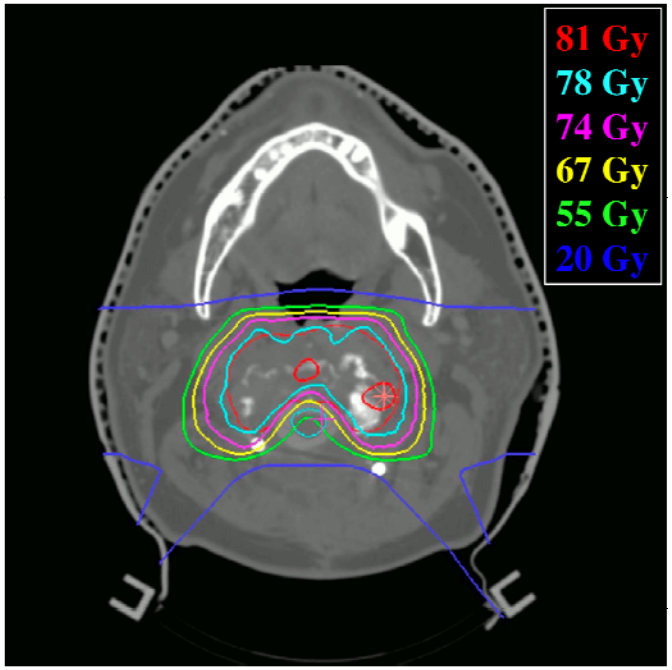
Please see Lei Dong's presentation for PTV for e.g. lung tumors

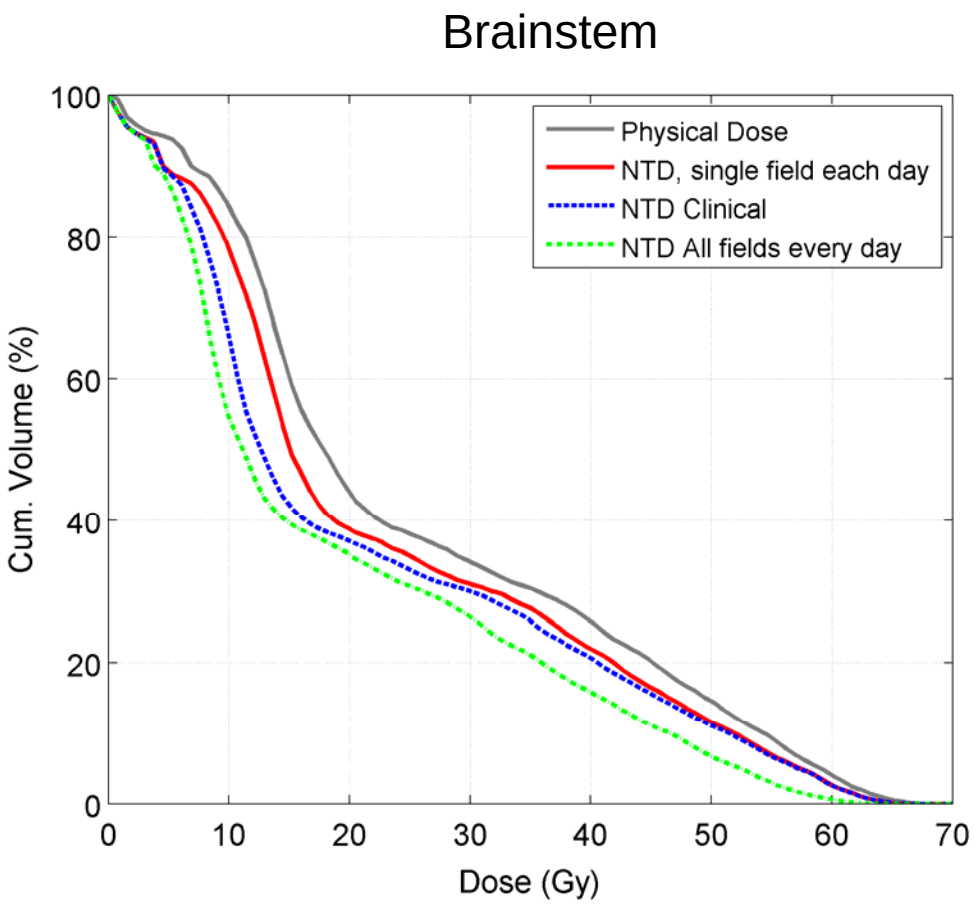
Batched field delivery: Prostate





Batched field delivery: Chordoma





Proton mindset necessary in:

- CT-scan
- Target delineation
- Dose calculation
- Patient alignment
- Dose delivery
- Dose evaluation

Ten year vision

- Acquire Proton CBCT prior to every fraction.
  - low dose
  - 3D / 4D proton stopping power information
  - Accurate patient alignment
- Automatically draw (progress) target volume and normal tissues
  - How about biological information?
- On-line plan re-optimization and then delivery
  - Pencil Beam Scanning is obviously required for this.

Conclusions

Think Density, Density, Density …

It's high time to accurately assess the effects of intra-treatment course density variations