Physics Uncertainty Issues for Prostate and Lung Cancers

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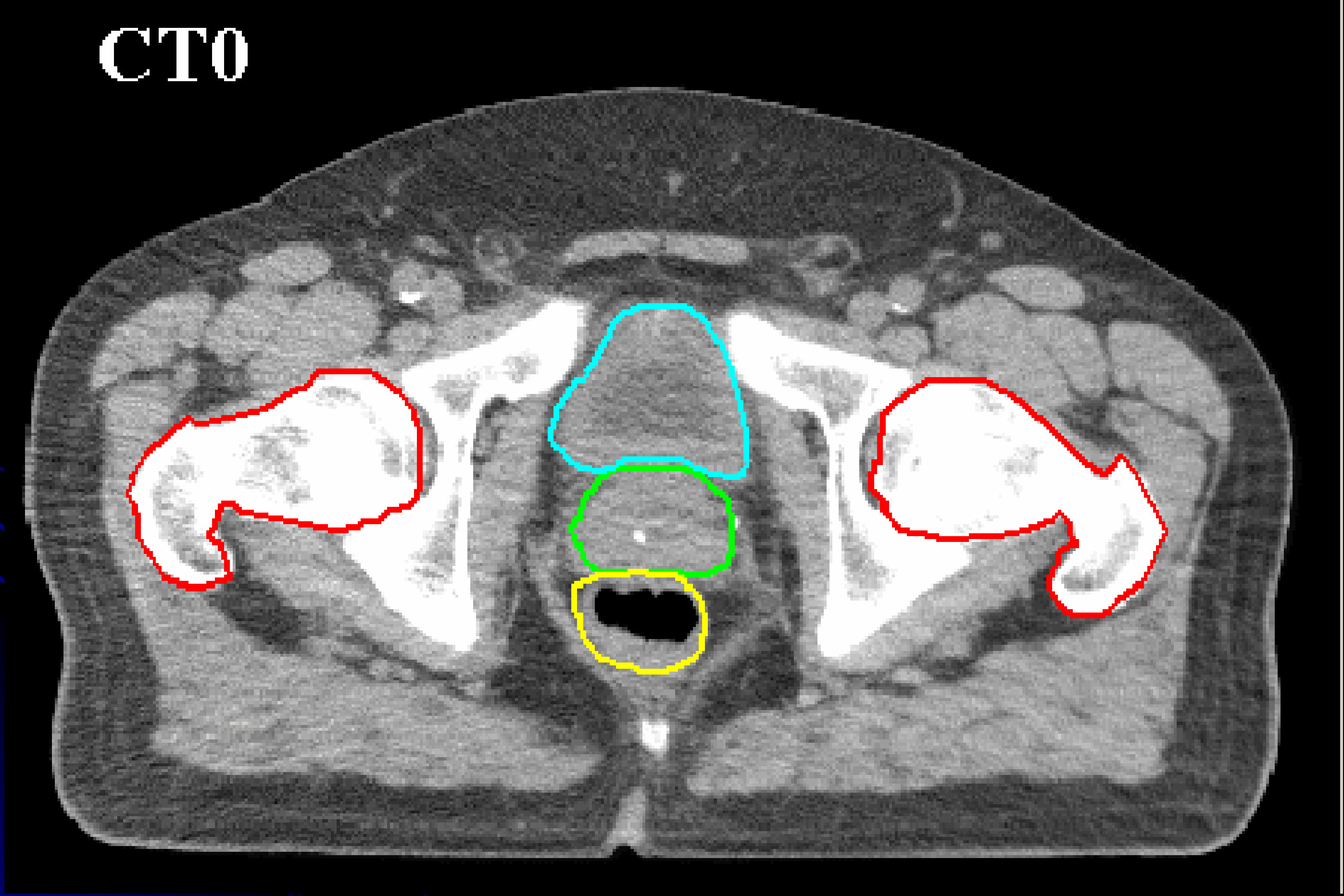
Outline

- Review physics-related issues in proton therapy of prostate and lung cancers
- Discuss strategies and challenges for handling motion issue

Potential Factors Affecting Prostate Treatment

- Target Motion (Prostate and SVs)
  - Inter-fractional rigid movement
    - Bony registration
    - Soft tissue target registration
  - Inter-fractional deformation
  - Intra-fractional motion
- Variations in Nearby Structures
  - Rectum filling
  - Bladder filling
  - Femoral heads

Inter-fractional Variations



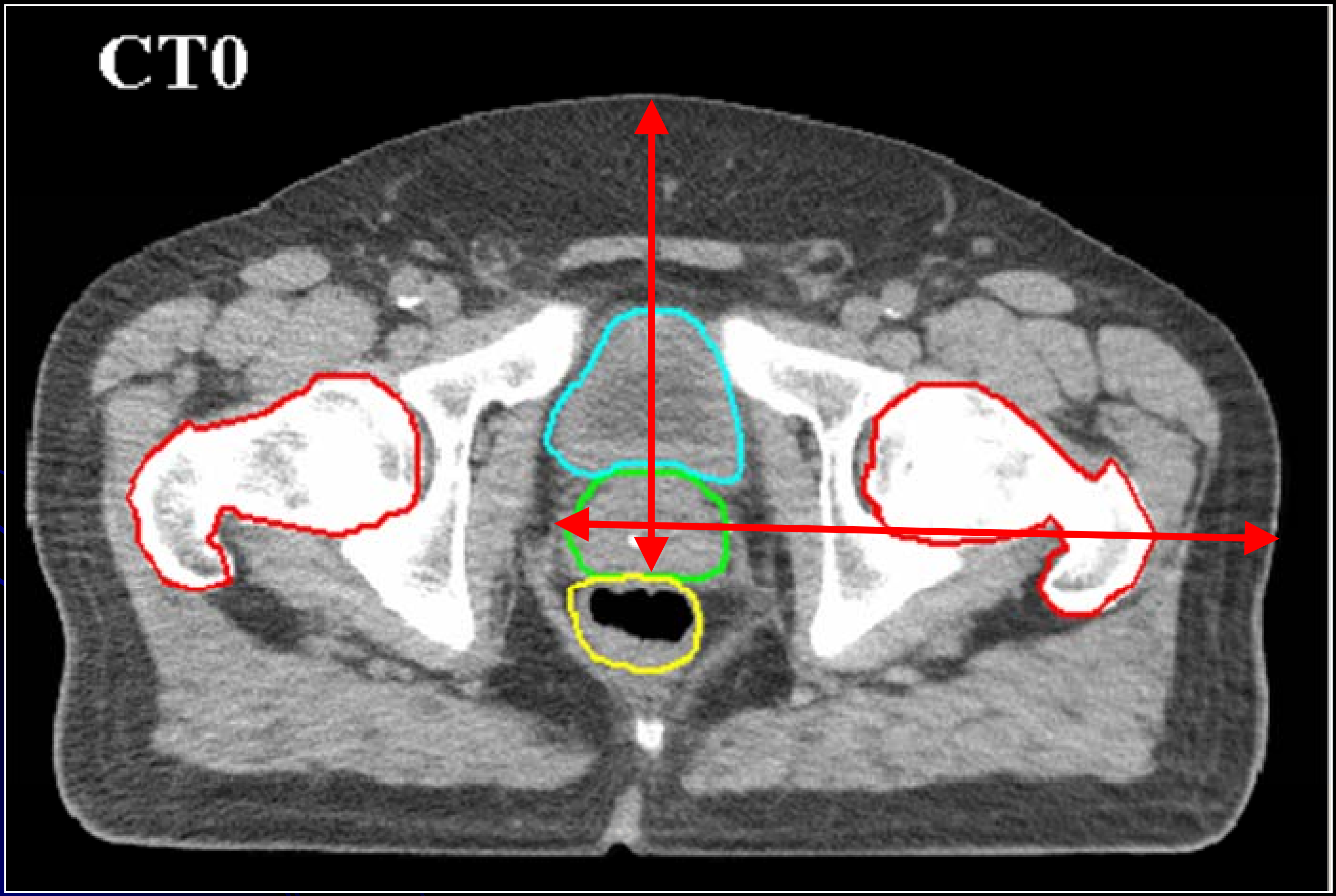
Planning contours mapped to 24 in-room CTs

MDACC

Inter-fractional Variations

Simulation CT is a snapshot of patient's anatomy!

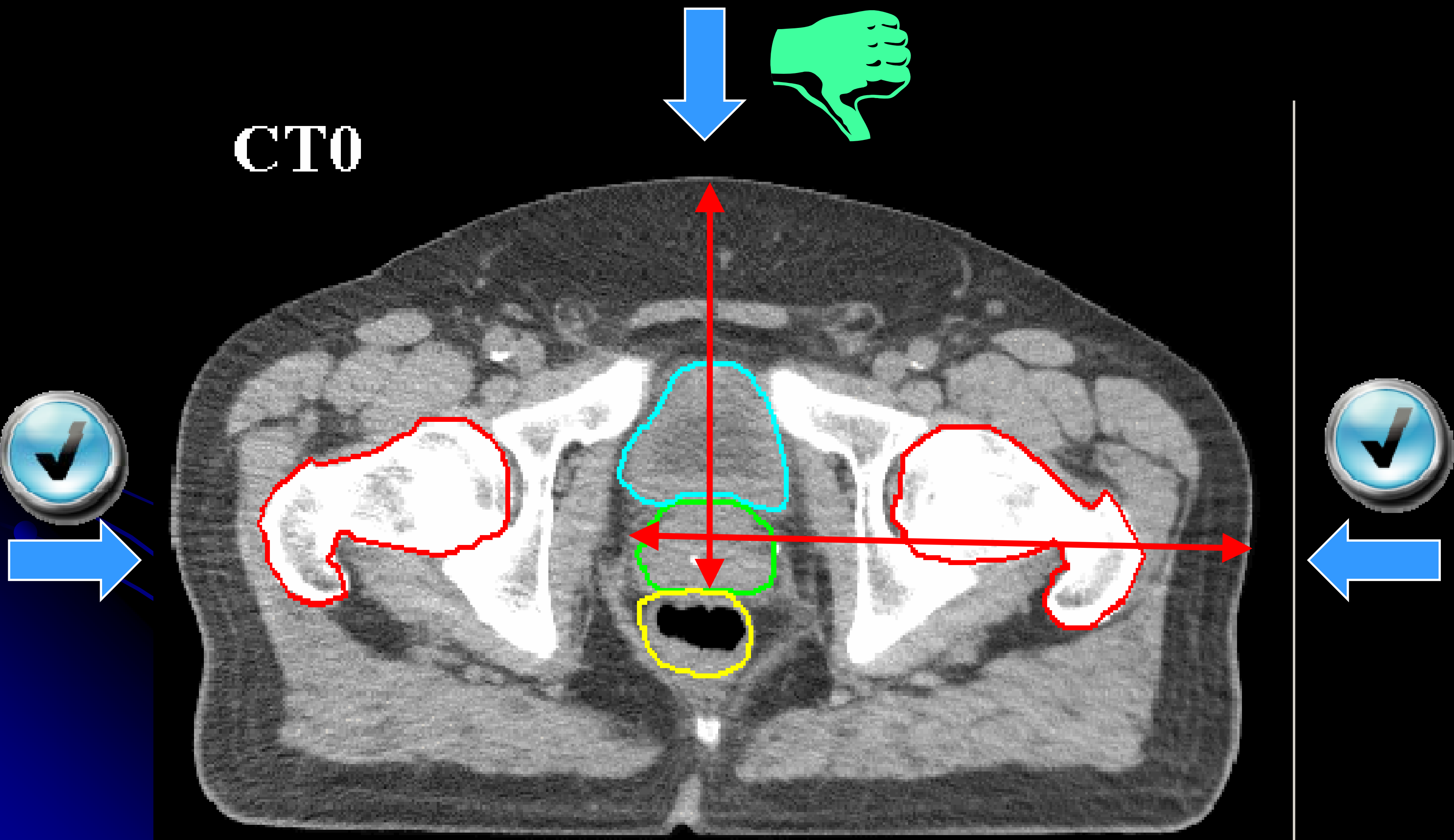
Planning CT



Planning contours mapped to 24 in-room CTs

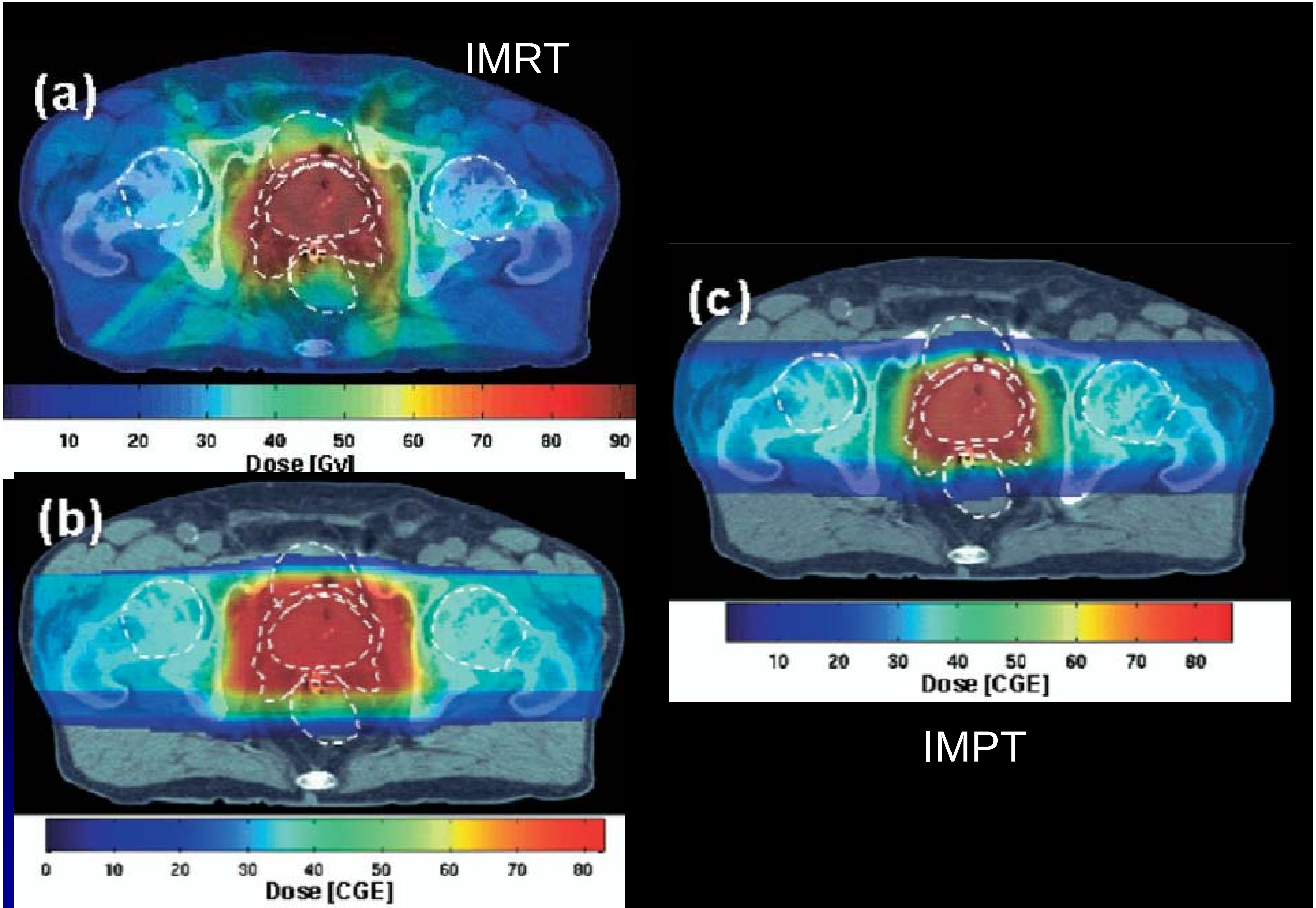
Inter-fractional Variations

Simulation CT is a snapshot of patient's anatomy!



Planning contours mapped to 24 in-room CTs

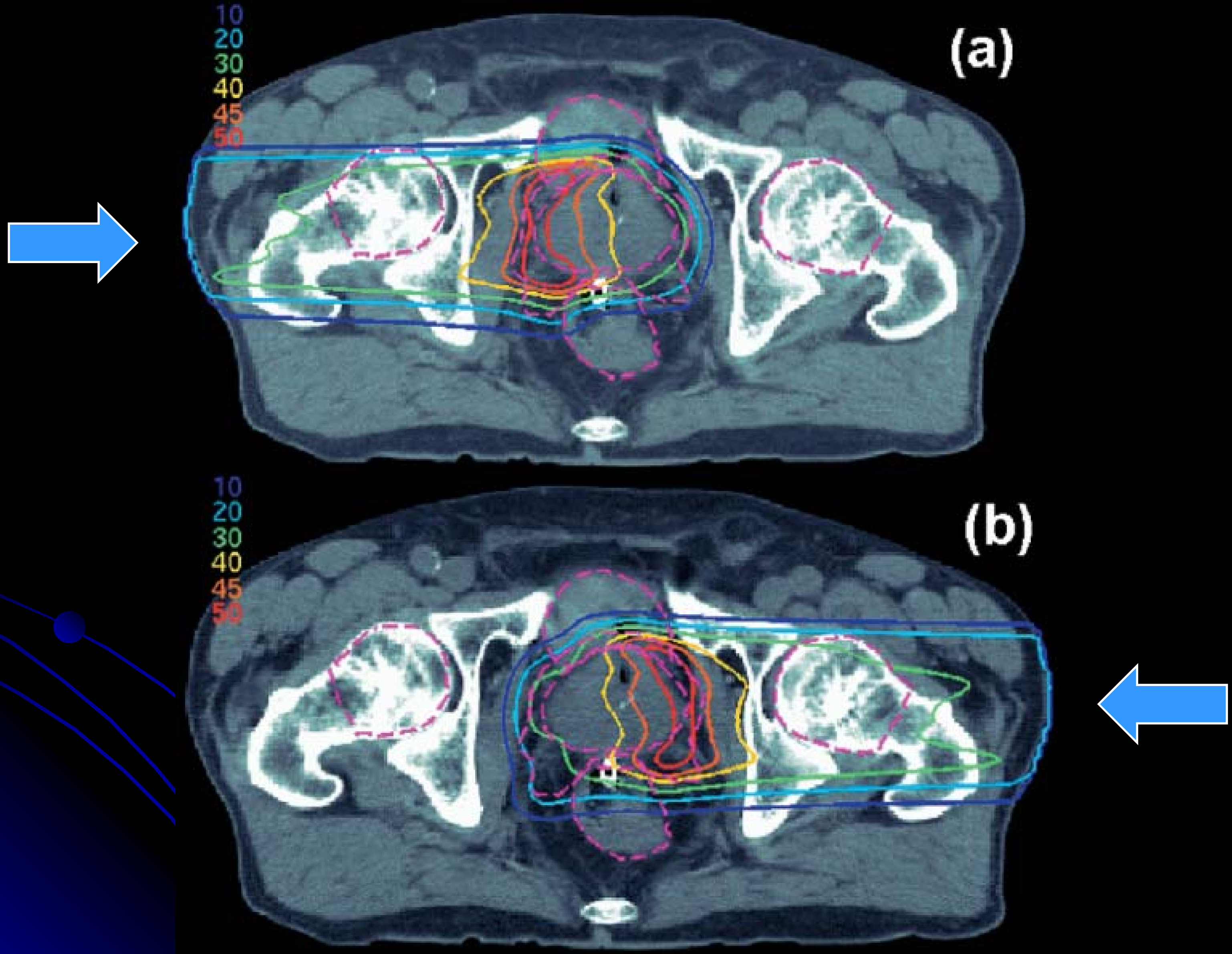
MDACC



Bi-lateral Proton

Trofimov et al. IJROBP 69(2): 444-453. (2007)

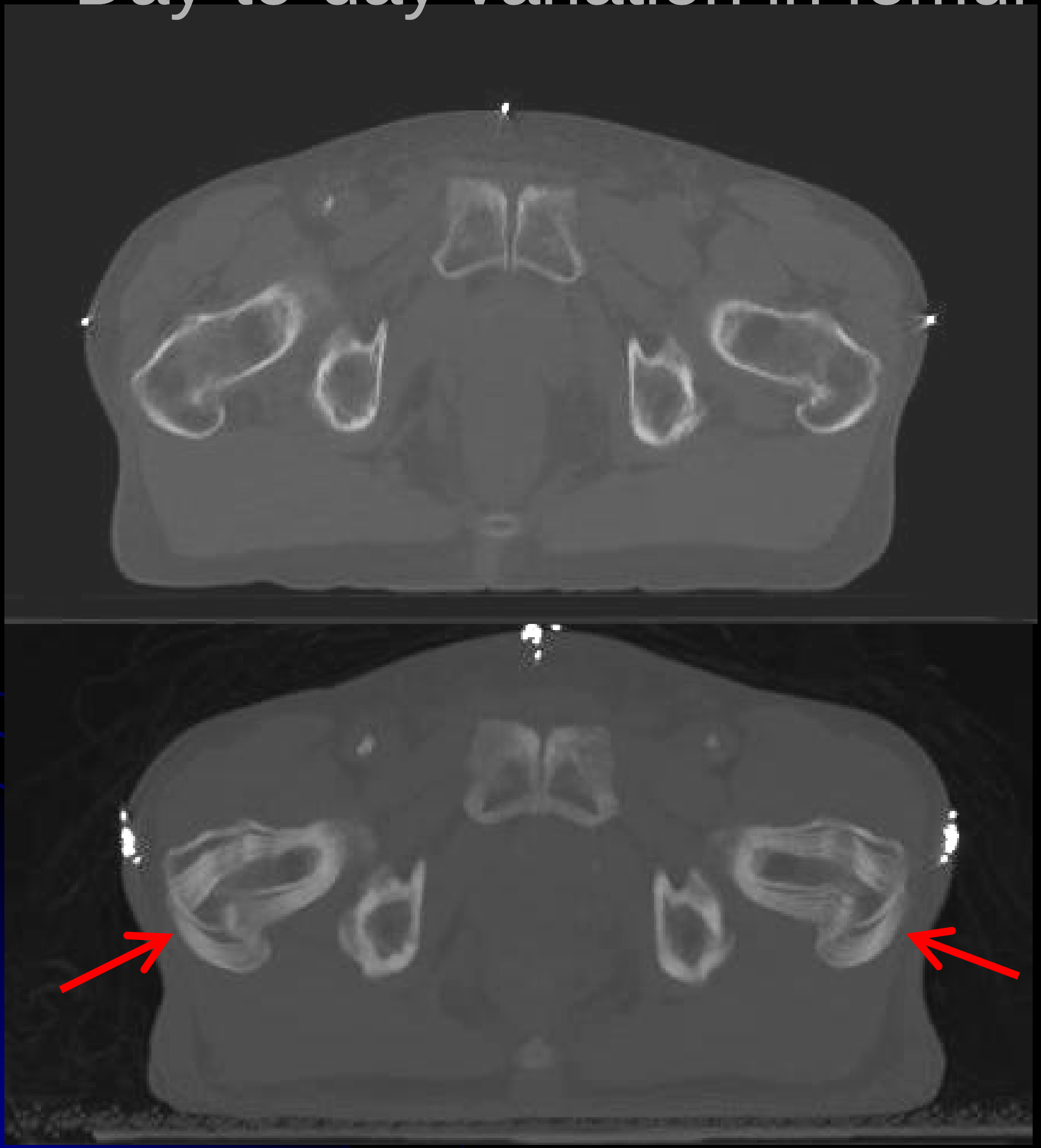
Robustness of IMPT for Multi-beam IMPT?



Trofimov et al. IJROBP 69(2): 444-453. (2007)

Femur Rotation

Day-to-day variation in femur position

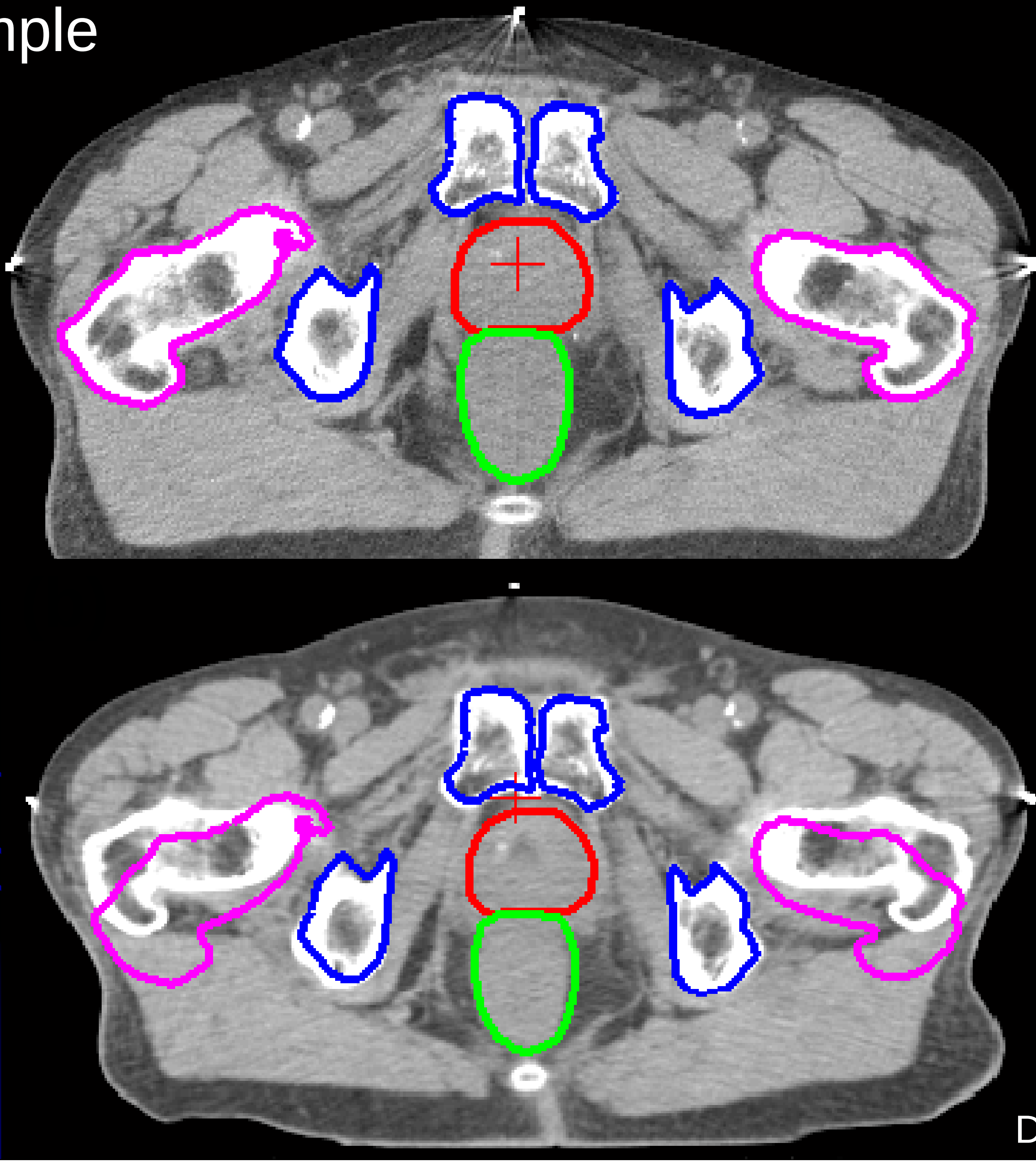


Planning CT

Anatomy over 20 CT imaging sessions

P. Park/MDACC

One Example



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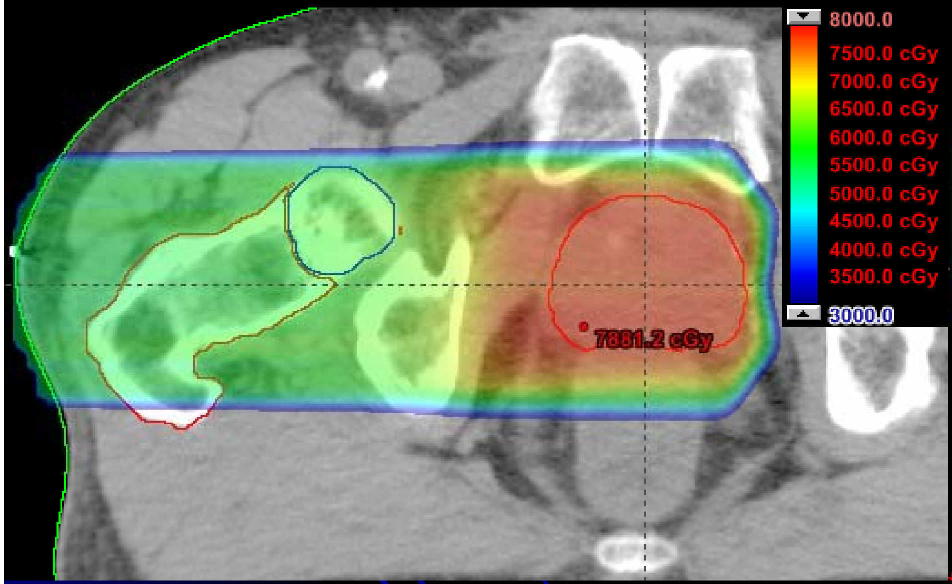
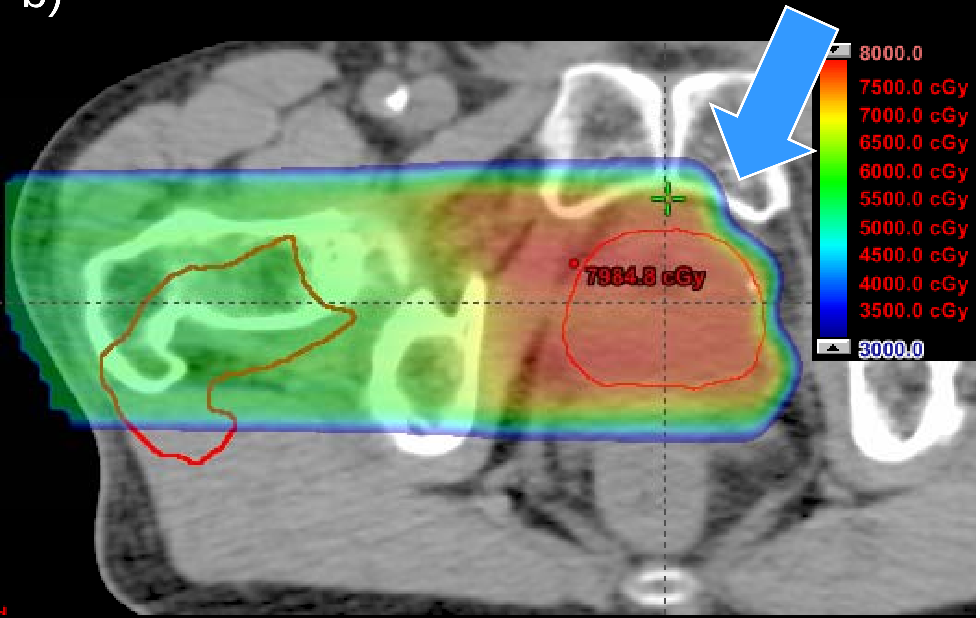
Proton Distal Dose Variations Due to Femur Rotation

a)



Original Plan

b)



Daily CT

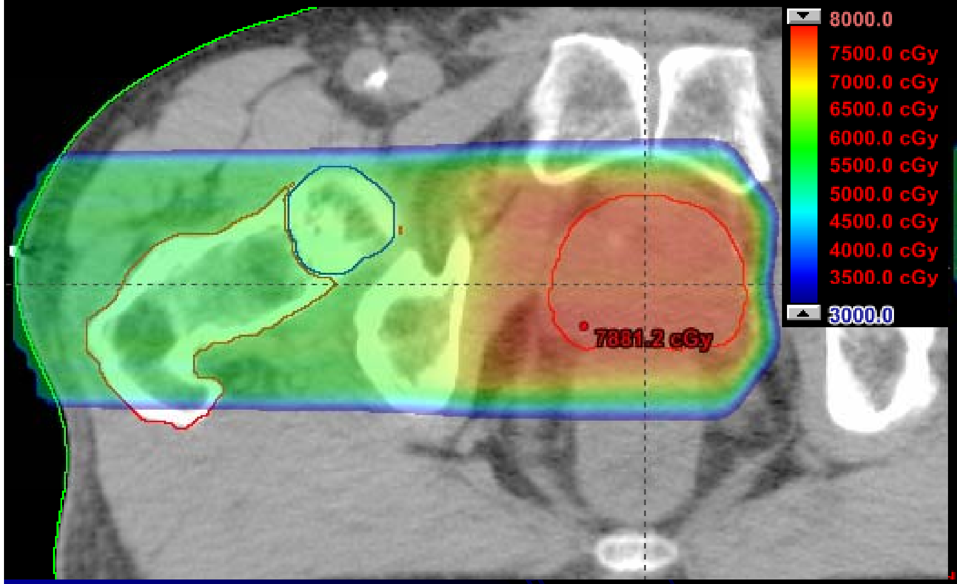
Melancon/MDACC

Can CBCT/CT-on-Rails based IGRT help?

Direct alignment of soft tissue target (the prostate)

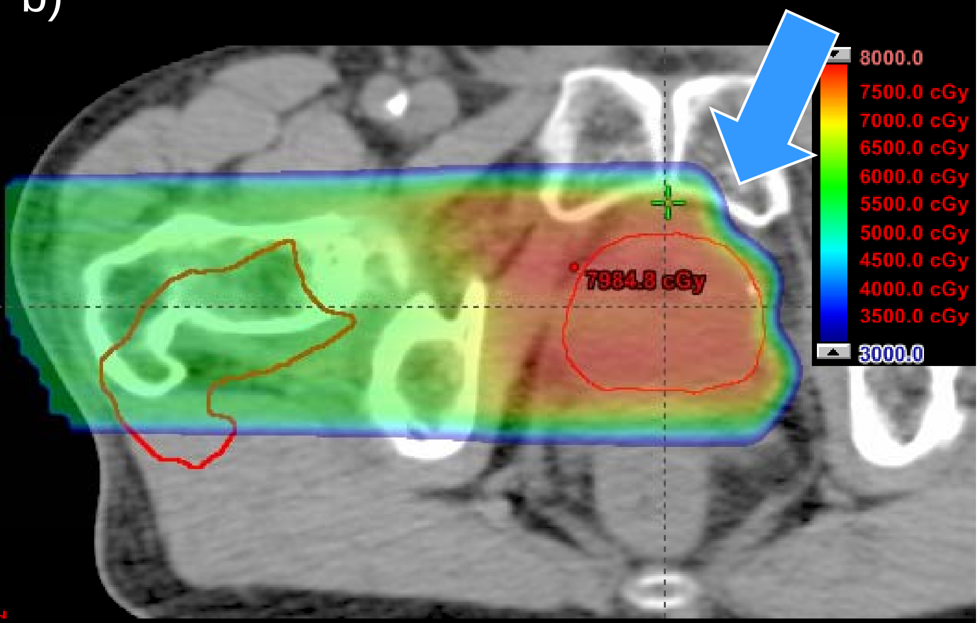
- Not entirely
  - IGRT ensures the position of the prostate
  - It will not guarantee normal tissue outside the target
    - Relative motion of the target relative to bony structures: the compensator can be off if bone is not aligned

a)



Original Plan

b)



Daily CT

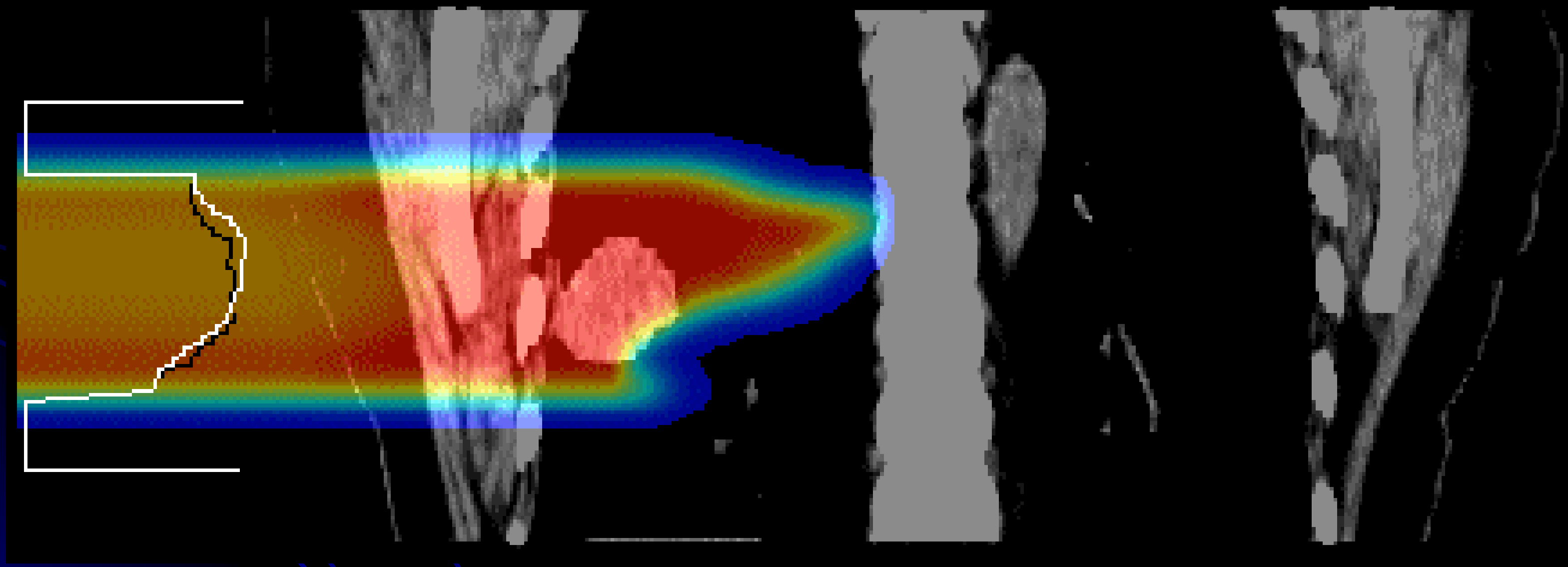
Immobilization is important for proton therapy!

Summary of Challenges in Prostate Proton Therapy

1. Uncertainties:
   - CT numbers and stopping powers ratios,
   - Inter-fractional changes of normal tissues in the beam path,
   - Intra-fractional organ motion,
2. Strategies
   - Optimization of beam angle selection
   - Better immobilization techniques
     - Leg position
     - Rectal balloon

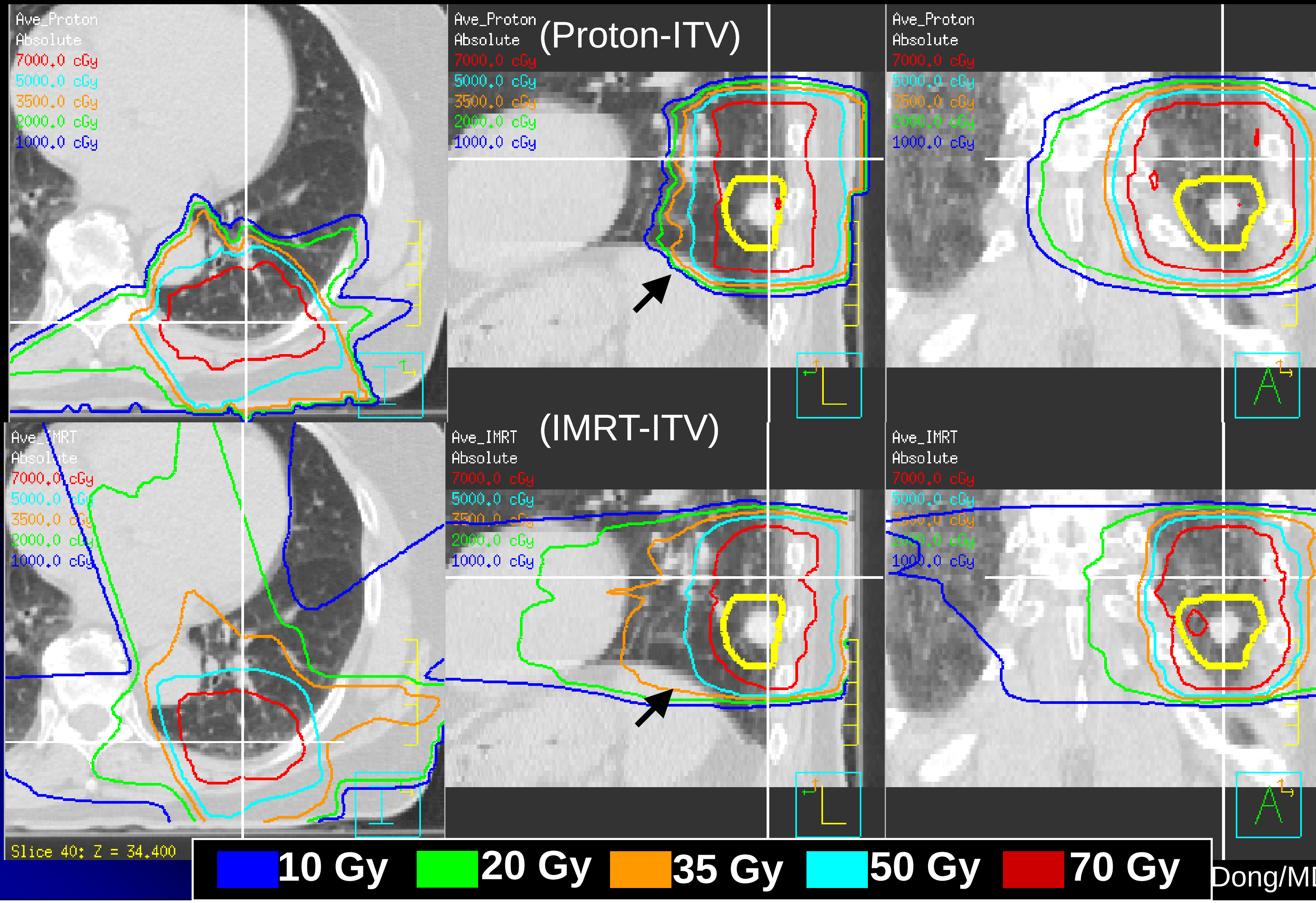
Factors Affecting Proton Therapy of Lung Cancer

Free breathing treatment



Tsunashima/MDACC

Proton vs. IMRT (motion effect to dose distribution)



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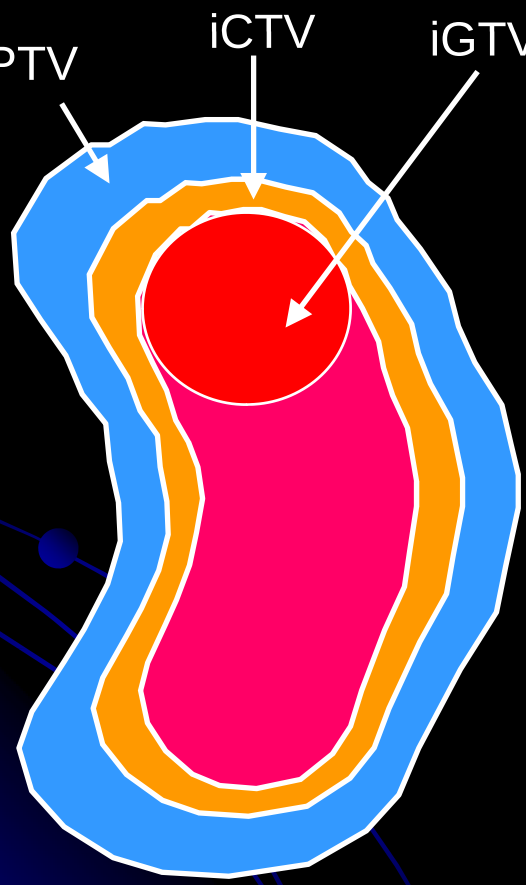
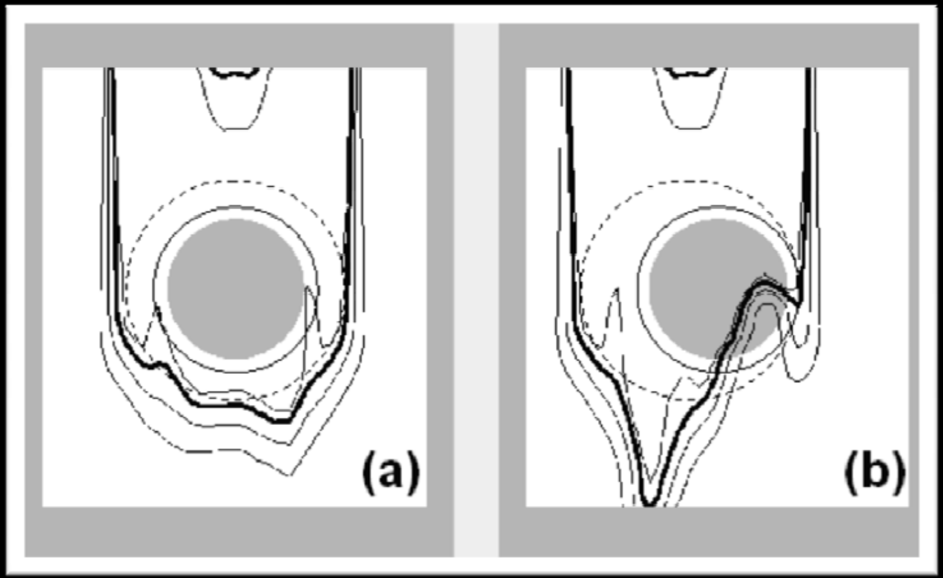
PTV Concept will not work



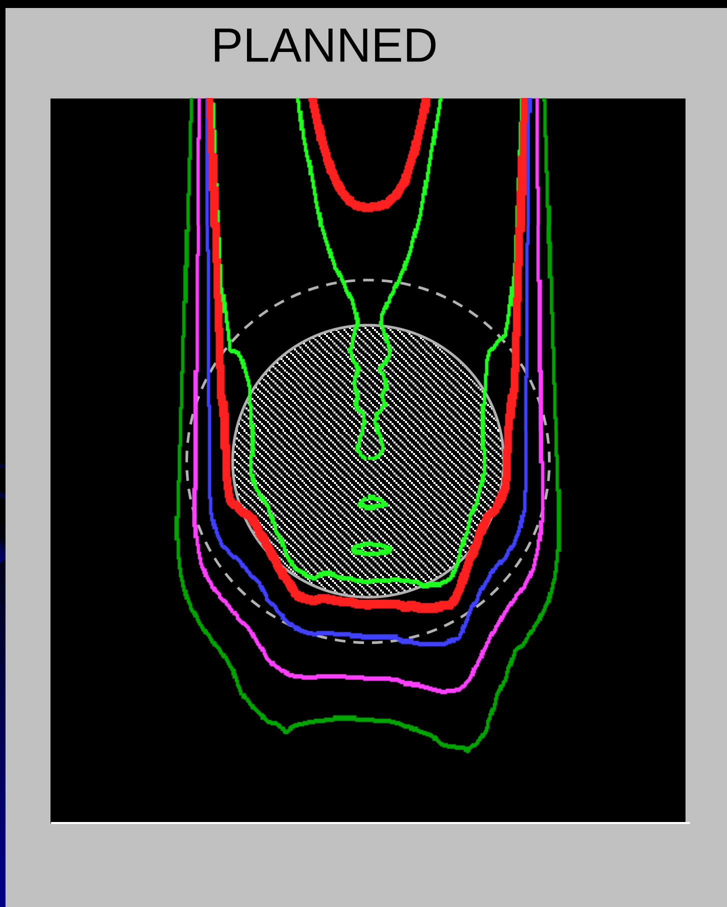
ICRU 62



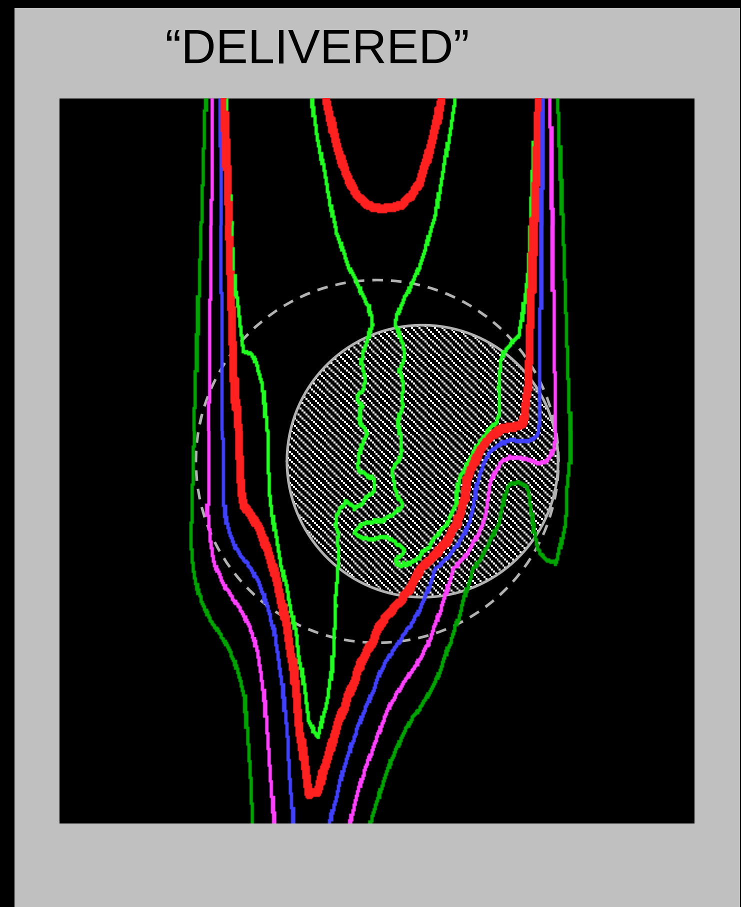
Proton Therapy

Effect of aperture expansion

RC smear: 0 mm
AP margin: 0 mm
Setup error: 0 mm
Tumor motion: 0 mm



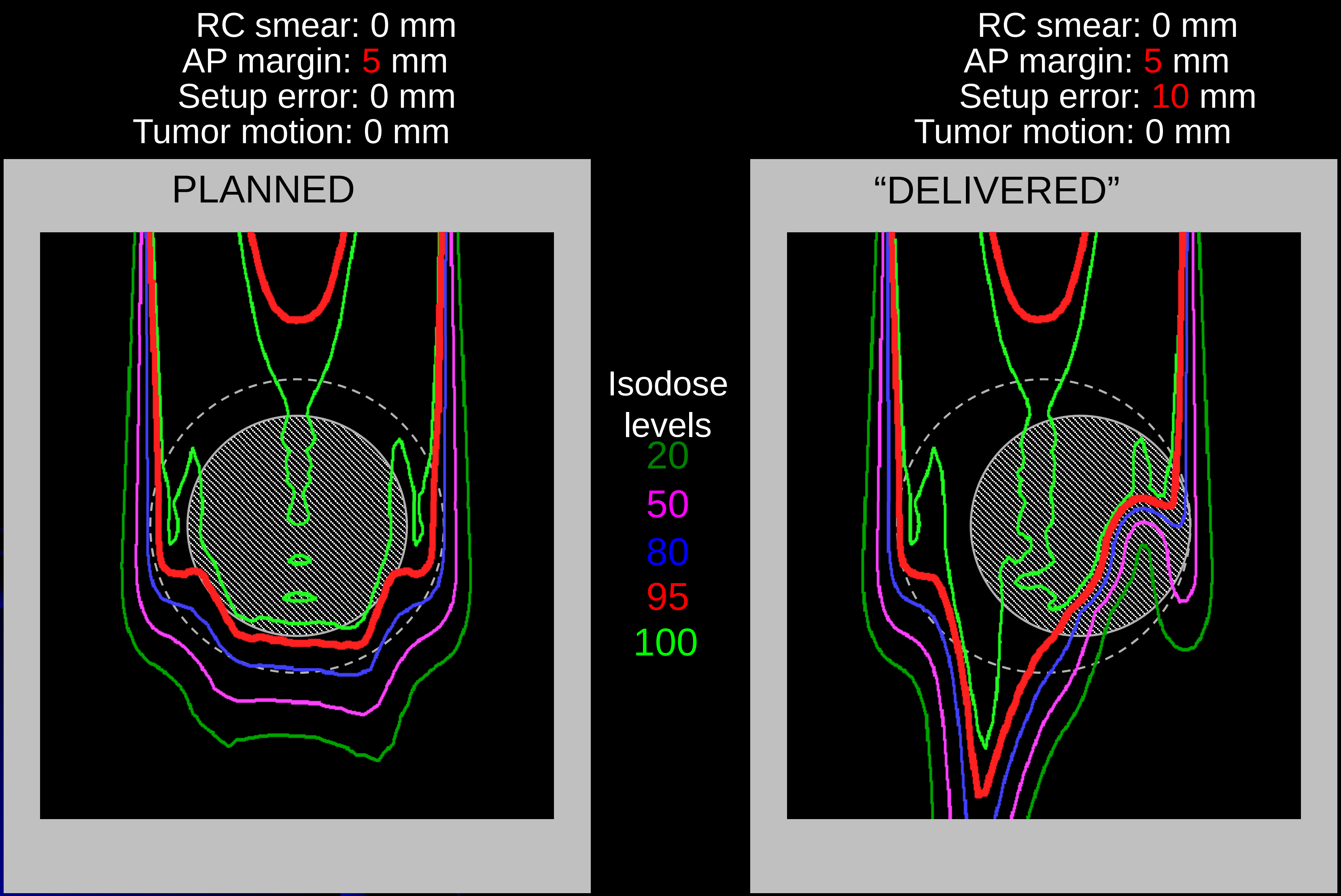
RC smear: 0 mm
AP margin: 0 mm
Setup error: 10 mm
Tumor motion: 0 mm



Isodose levels
20
50
80
95
100

Courtesy of Martijn Engelsman (MGH)

Effect of aperture expansion



Courtesy of Martijn Engelsman (MGH)

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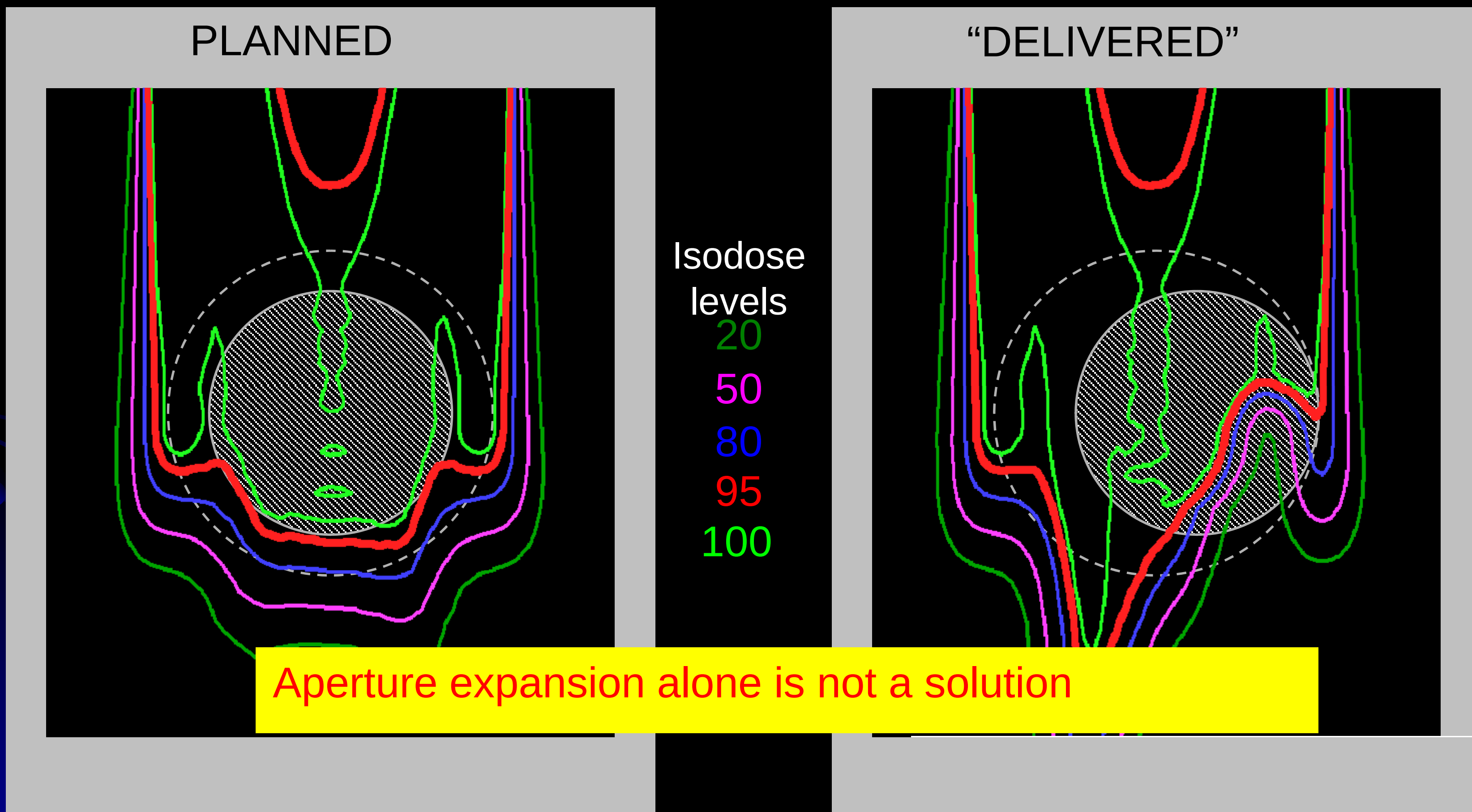
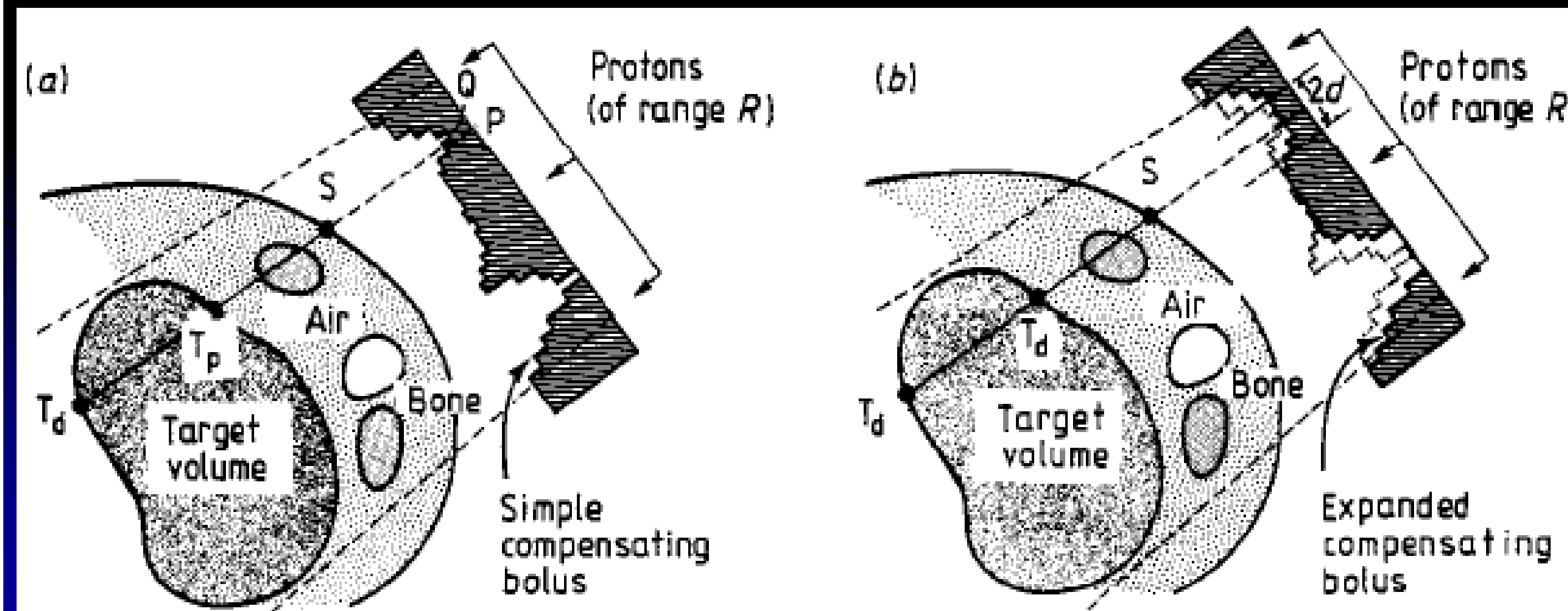


Courtesy of Martijn Engelsman (MGH)

Effect of range compensator smearing to ensure target coverage

- The bolus thickness at point P, as calculated by the ‘simple’ technique, is replaced by the thinnest bolus thickness calculated anywhere within ±d of the point P

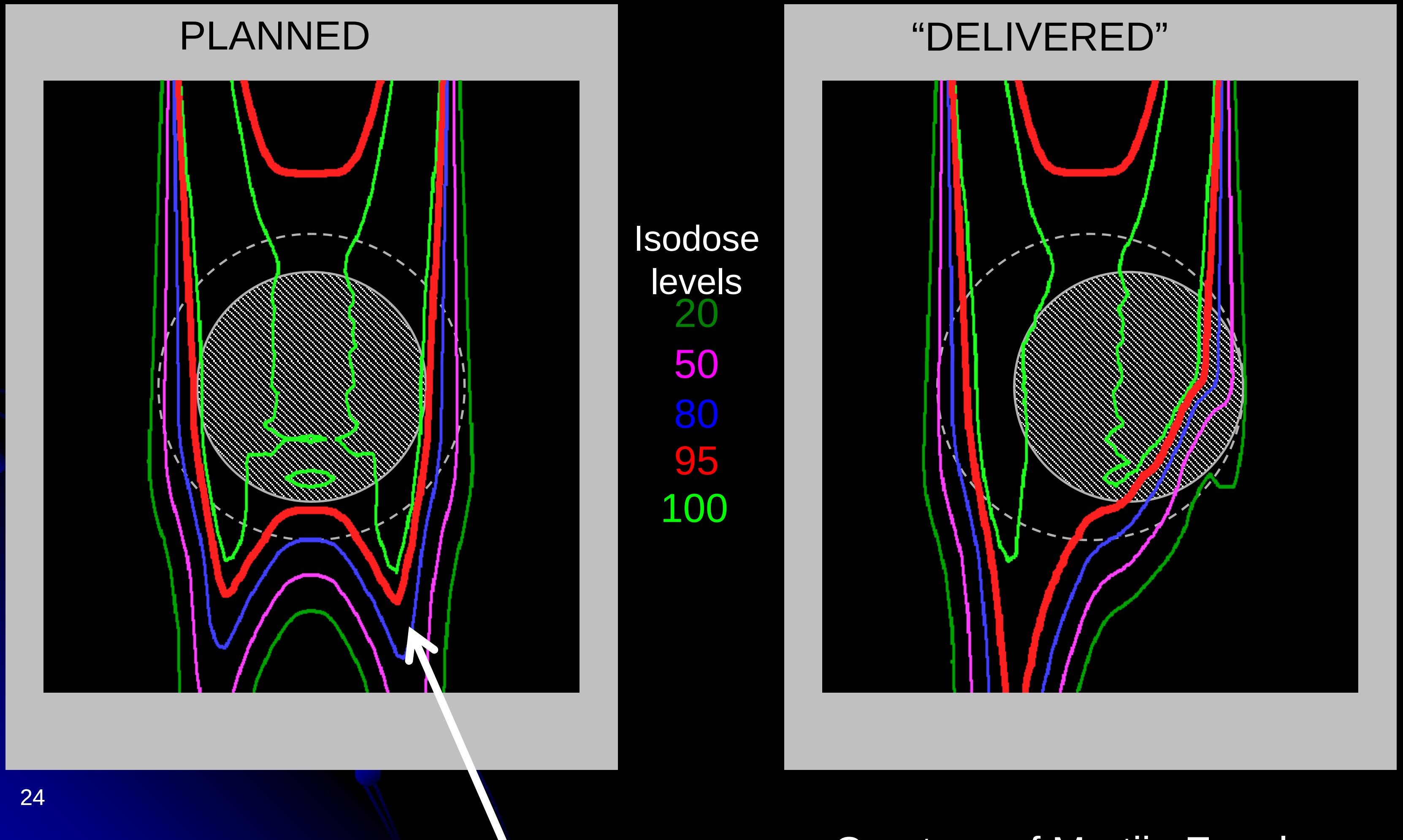


Urie, et al Phys. Med. Biol., 1983.

Effect of range compensator smearing

RC smear: 5 mm
AP margin: 0 mm
Setup error: 0 mm
Tumor motion: 0 mm

RC smear: 5 mm
AP margin: 0 mm
Setup error: 10 mm
Tumor motion: 0 mm



Courtesy of Martijn Engelsman (MGH)

Effect of range compensator smearing

RC smear: 10 mm
AP margin: 0 mm
Setup error: 0 mm
Tumor motion: 0 mm

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AP margin: 0 mm
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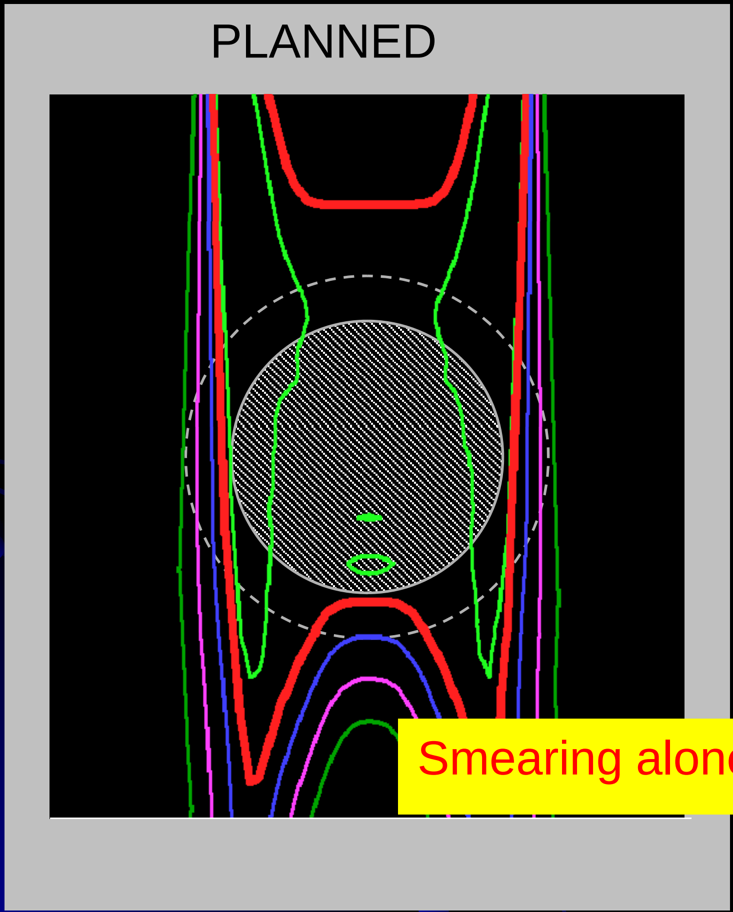
Tumor motion: 0 mm



Isodose levels
20
50
80
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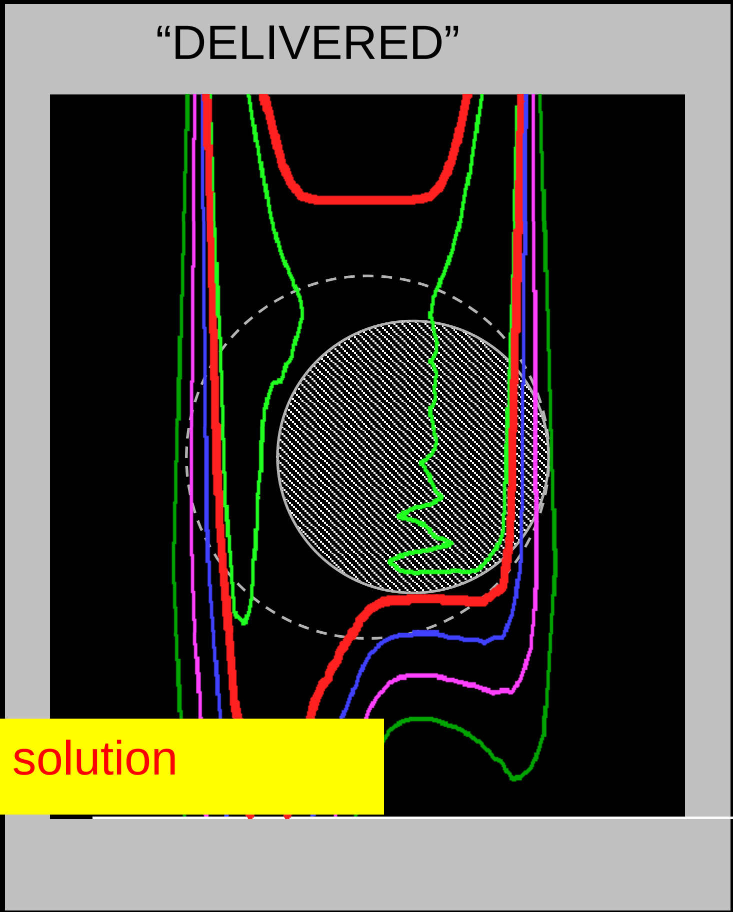
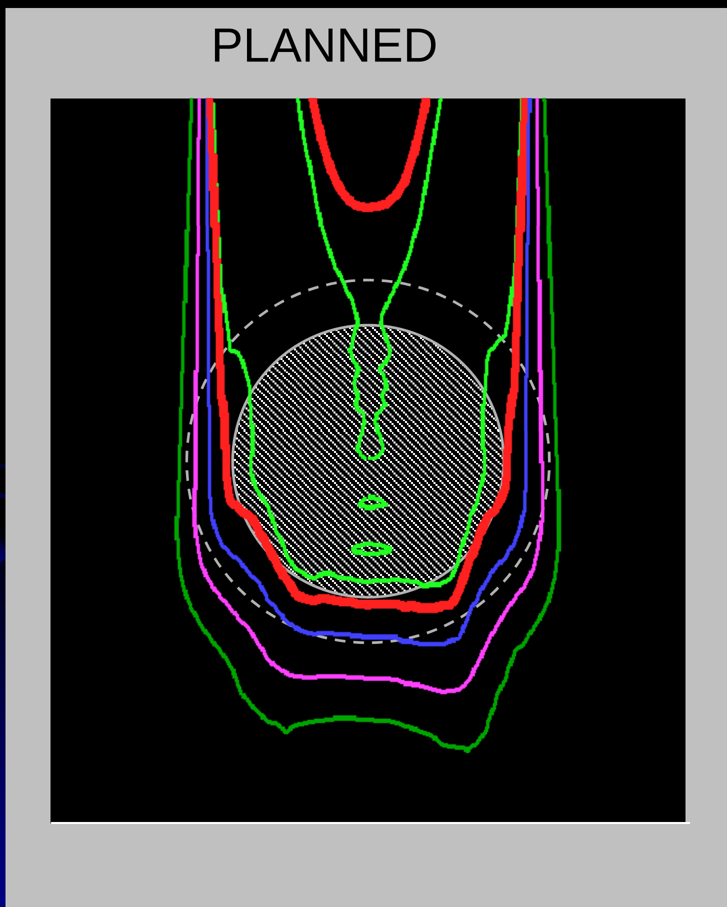


Smearing alone is not a solution

Courtesy of Martijn Engelsman (MGH)

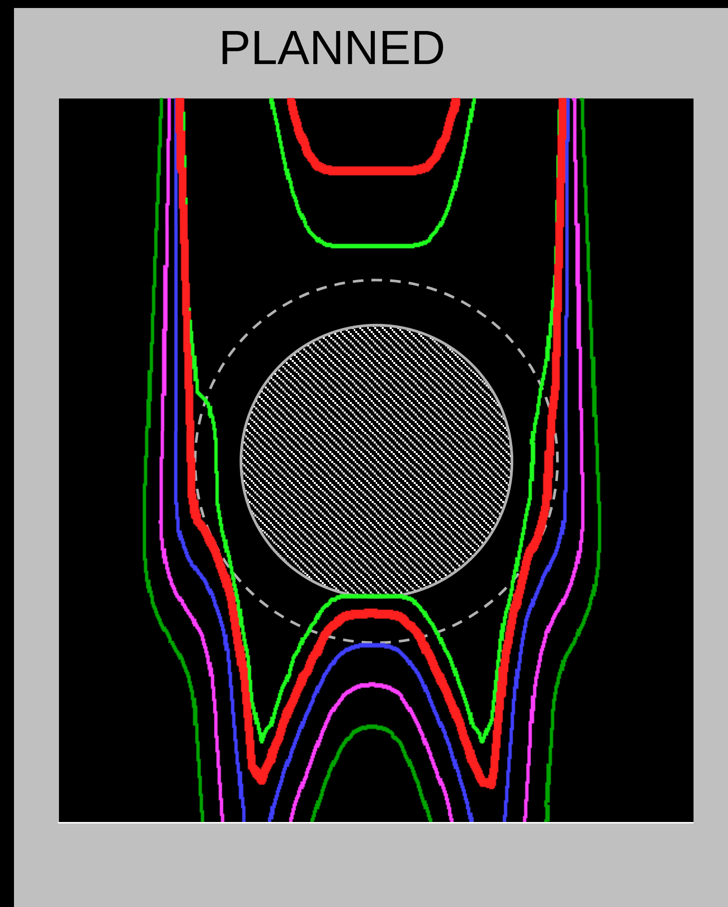
Compensator Smearing and Aperture Expansion

RC smear: 0 mm
AP margin: 0 mm
Setup error: 0 mm
Tumor motion: 0 mm



Isodose levels
20
50
80
95
100

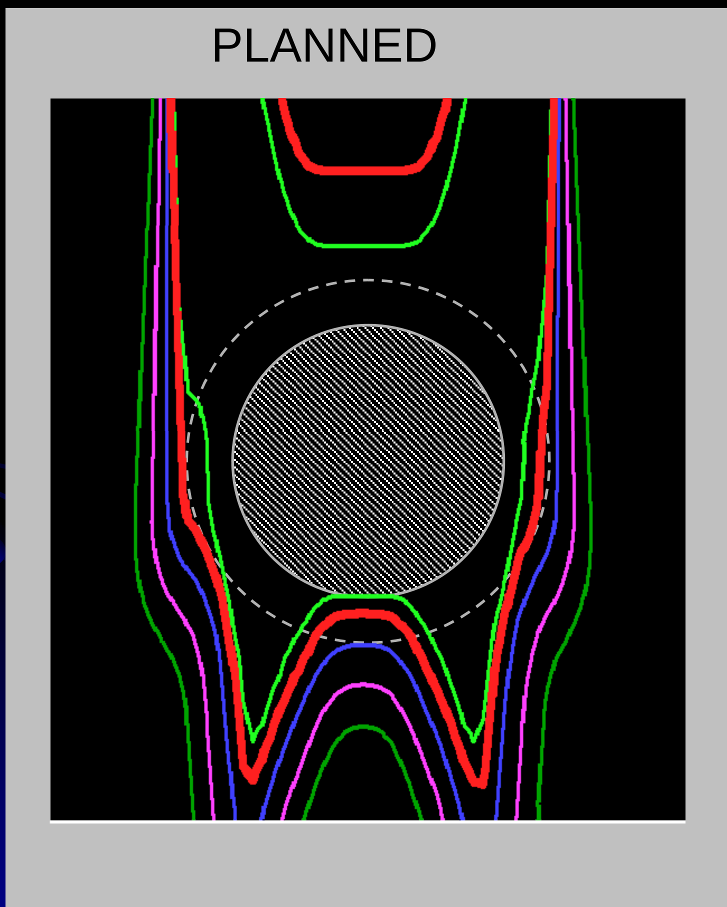
RC smear: 7.5 mm
AP margin: 7.5 mm
Setup error: 0 mm
Tumor motion: 0 mm



Courtesy of Martijn Engelsman (MGH)

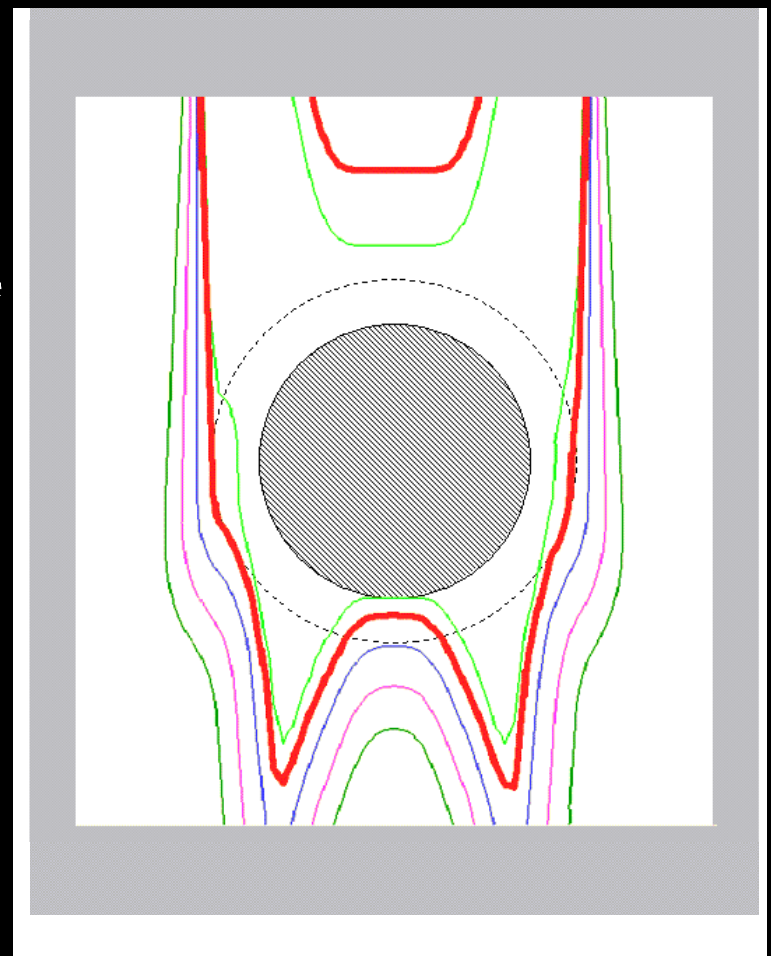
Compensator Smearing and Aperture Expansion

RC smear: 7.5 mm
AP margin: 7.5 mm
Setup error: 0 mm
Tumor motion: 0 mm



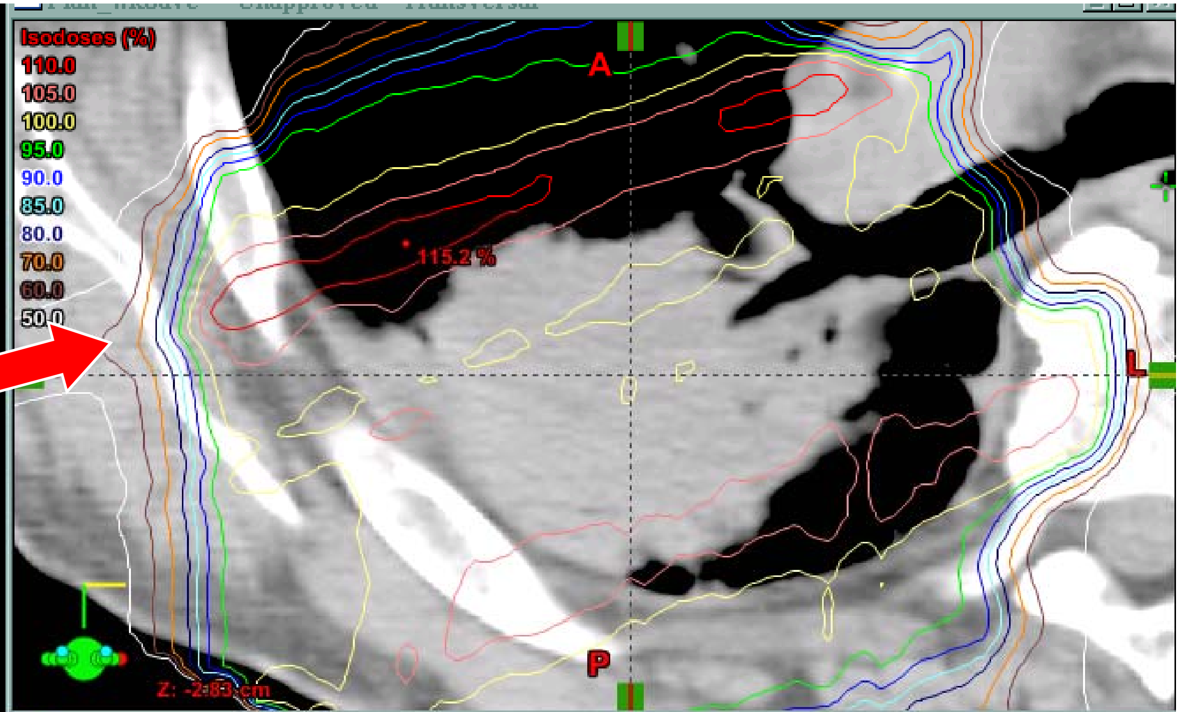
Isodose levels
20
50
80
95
100

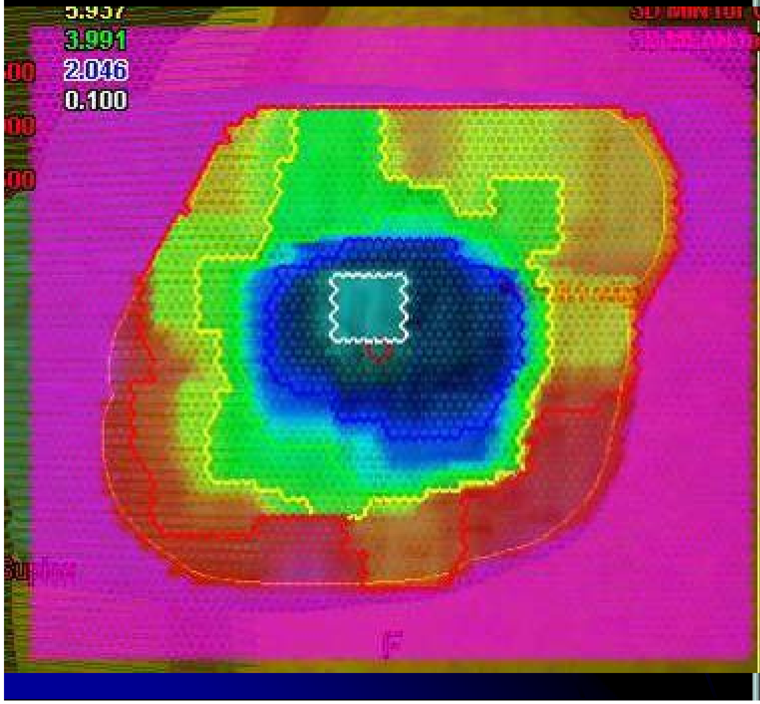
RC smear: 7.5 mm
AP margin: 7.5 mm
Setup error: 5 mm

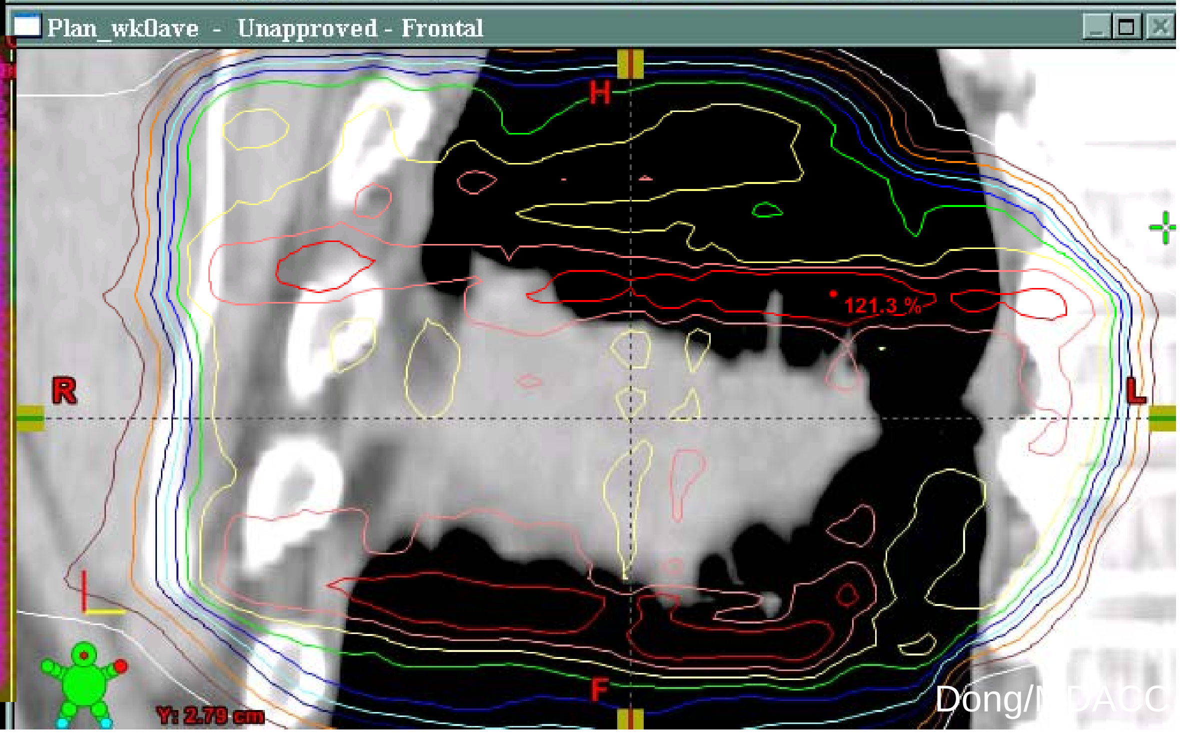


Courtesy of Martijn Engelsman (MGH)

How to evaluate a plan in the presence of anticipated motion?

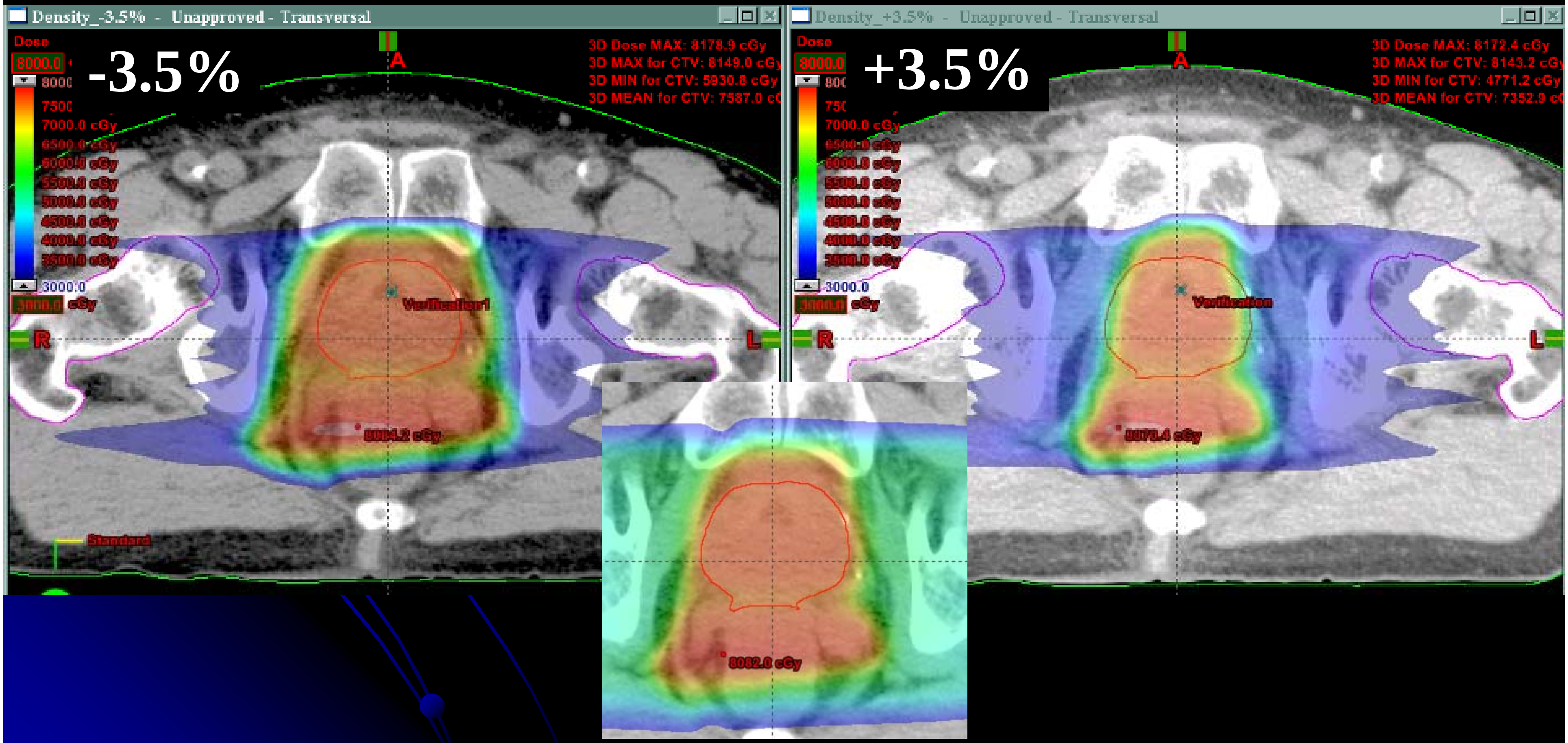






CT Number uncertainties have a significant impact on proton dose distributions

But commonly it's not visible on proton plans

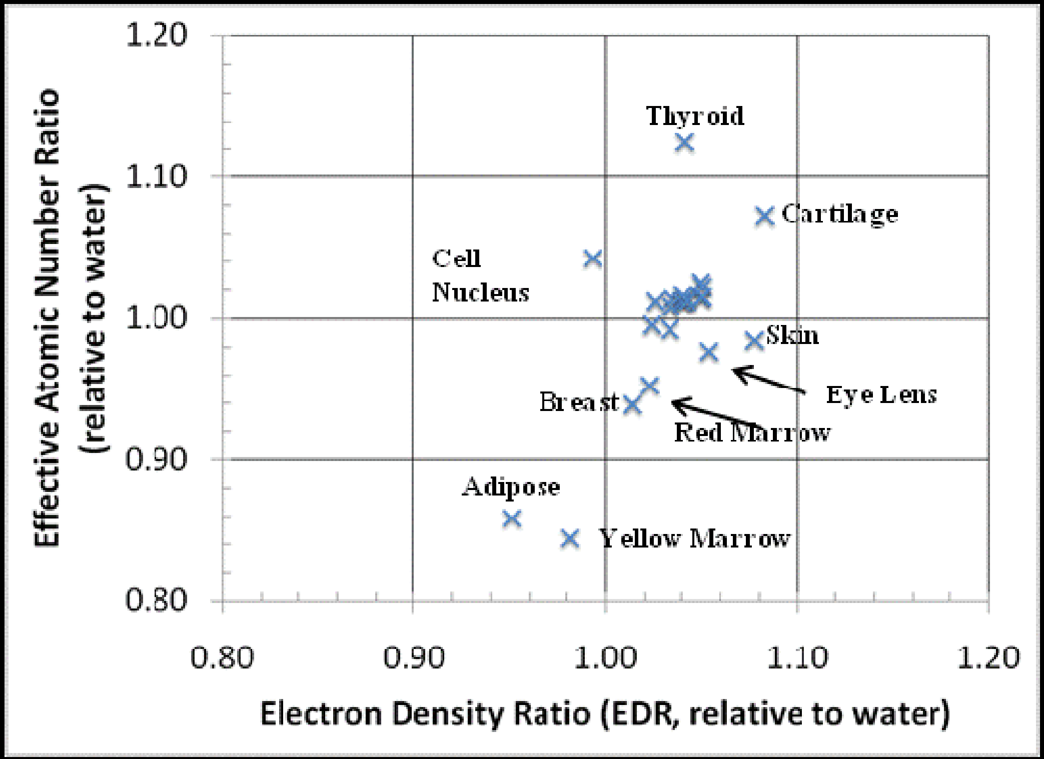


0% uncertainty

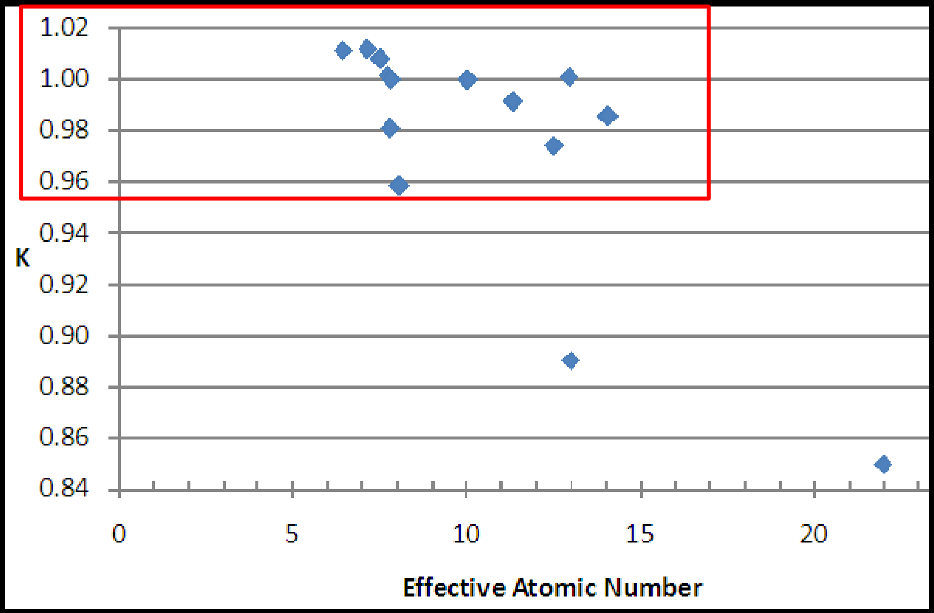
Dong/MDACC

Scatter plot of various human biological tissues listed in ICRU Report 44 and ICRP Report 23

Human biological tissues have different electron density ratios (HUs) and effective atomic numbers

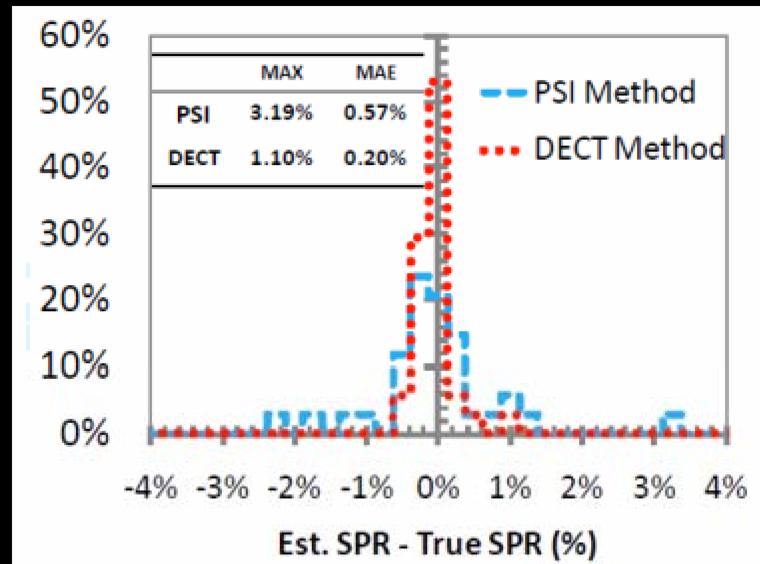


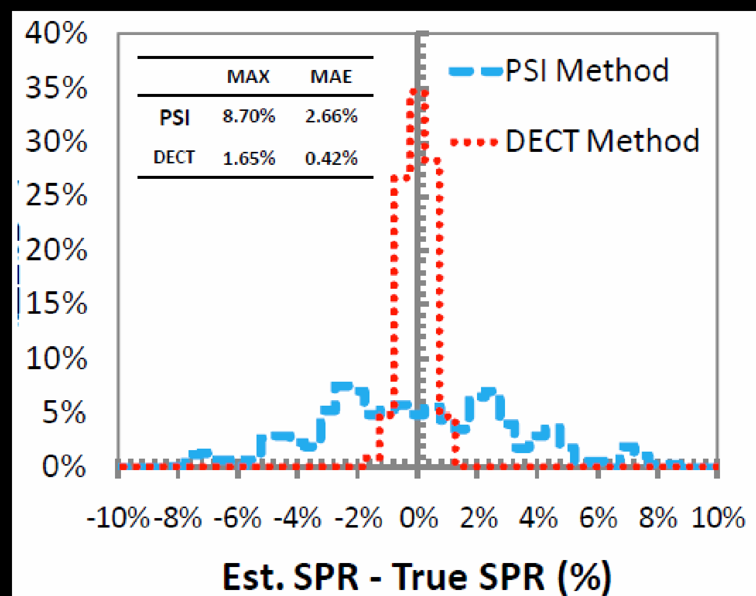
Proton Stopping-Power-Ratio depends on the effective atomic numbers (~ 3 - 4 % uncertainties)



Improving CT number Accuracy

- High Energy CT imaging to reduce metal artifacts
- Dual-energy CT imaging to characterize material compositions
  - Electron density
  - Effective atomic number





Challenges in planning moving target

- 4D dose calculation
  - Accumulating dose distributions voxel-by-voxel and phase-by-phase
    - Require deformable image registration and re-computing plans for each breathing phase using 4D CT
- 4D treatment plan optimization
  - Automatically adjust distal margin, aperture, compensator smearing parameters to satisfy target coverage and normal tissue sparing
- 4D treatment plan evaluation

None of these are currently available in a commercial product!

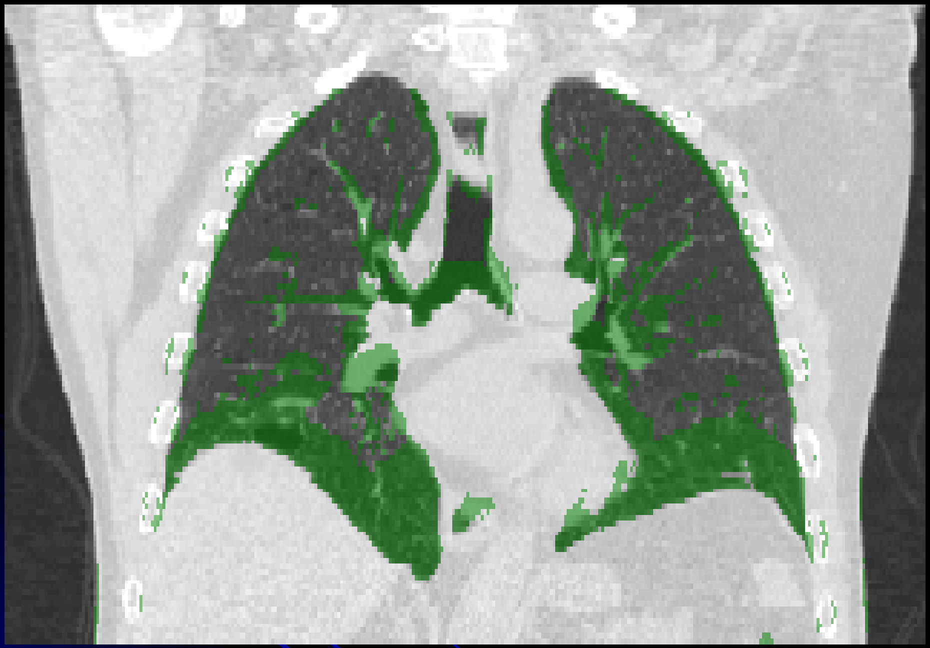
Proton Planning Guide for Non-Gated Treatment - A practical approach by MDACC and MGH

- Target delineation
  - ITVs delineated on a 4D CT set
- Dose calculation
  - Using the time-averaged CT based on the 4D CT set
  - Override iGTV with tissue density
    - A compromise to cover the moving target without altering TPS internal compensator design
- Planning
  - Evaluate DVHs using contours derived from Mid-ventilation CT
- Final Plan Summary
  - Copy the plan to Mid-ventilation CT without any density override
  - Report DVHs using lung volumes defined either for Mid-Ventilation or the Expiration phase

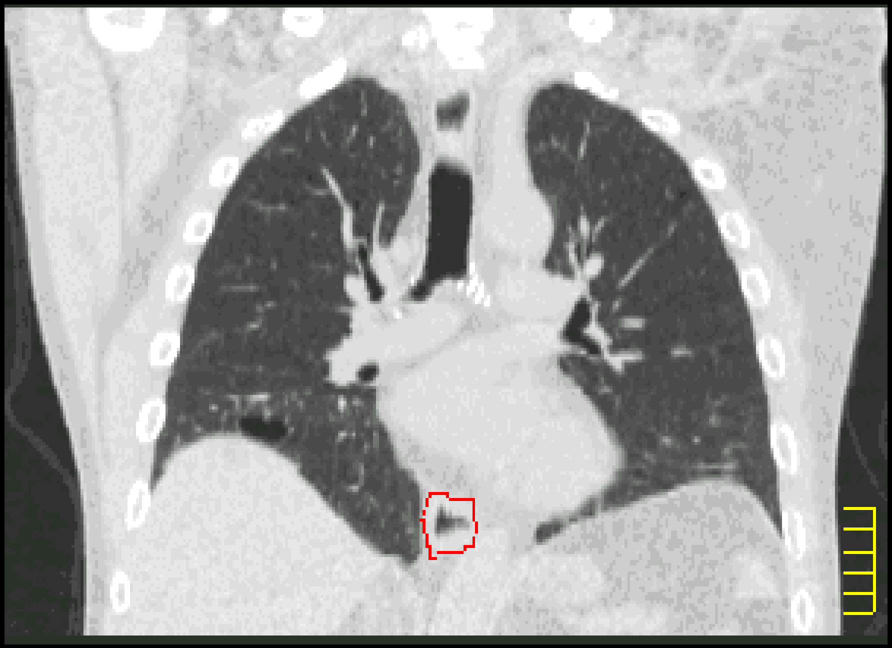
Special Situations

- If gated treatment is not used
  - Tumor near the diaphragm
    - The patient is not a good candidate for proton therapy if any beam can not avoid a portion of the diaphragm before entering the treatment target.
      - We don’t have a good solution!
- Stomach filling
  - If we cannot avoid the beam direction through the stomach, the patient is not a good case for proton therapy.

Esophagus cancer near GE junction

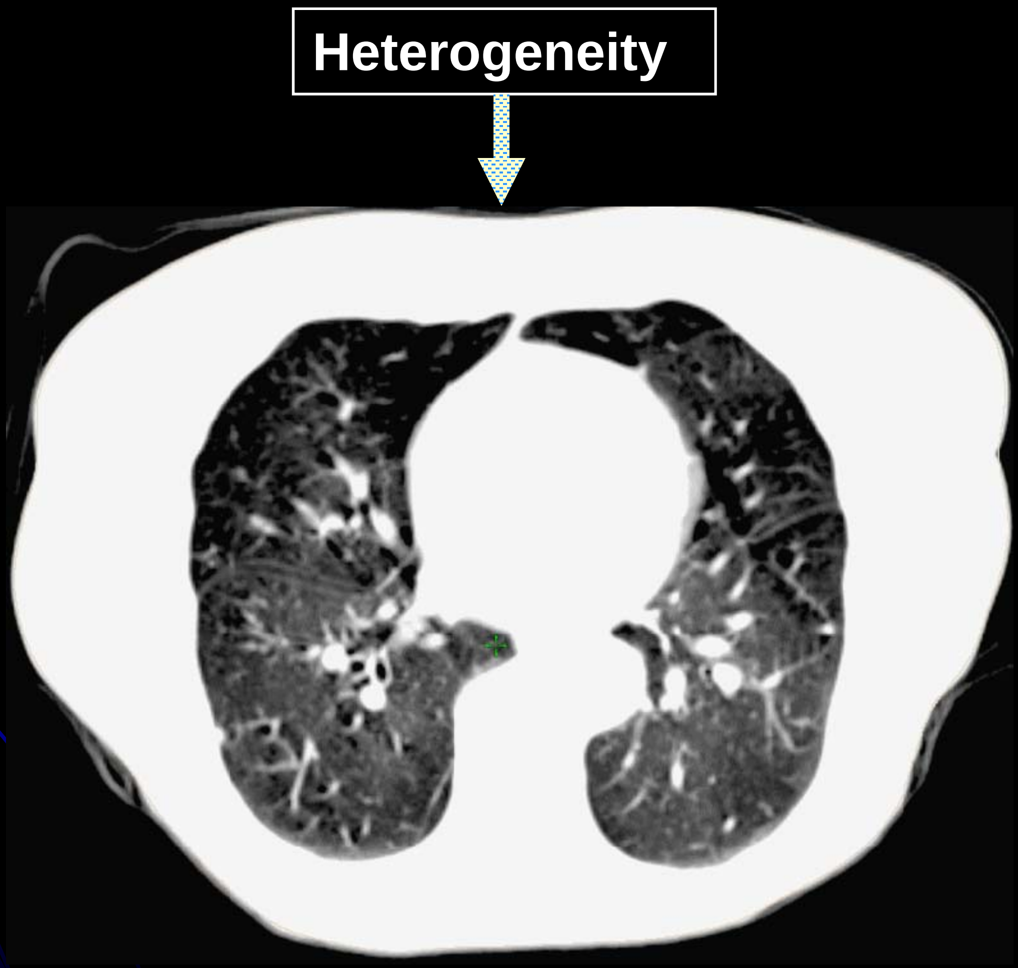


Green: density changes



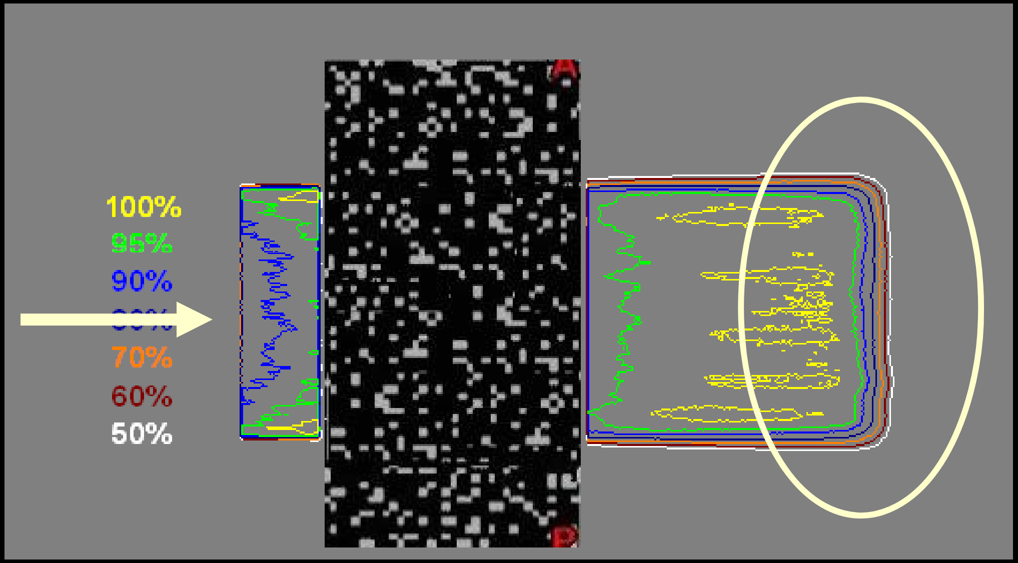
Red: GTV

More problems: Distal Edge Degradation Caused By Heterogeneities



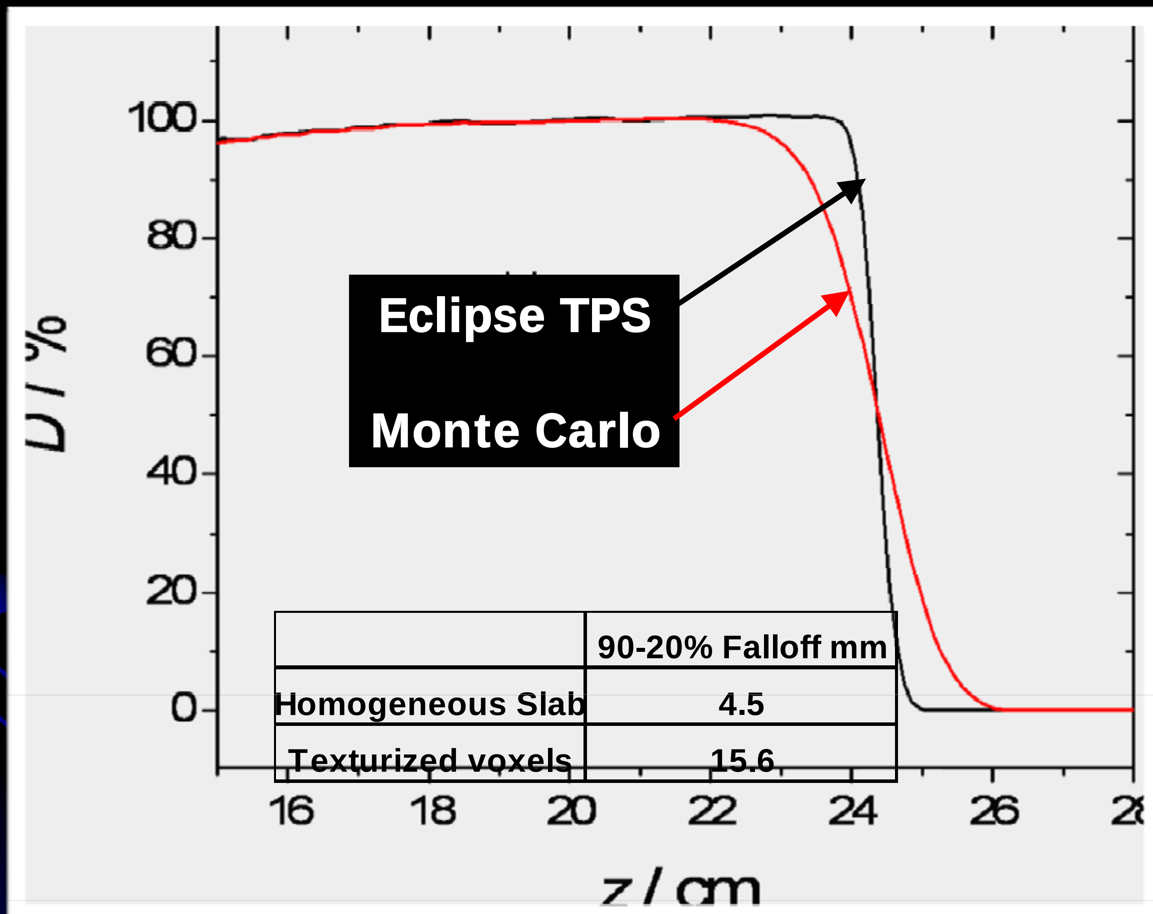
"Texturized" Lung Equivalent Material
Monte Carlo vs. TPS Dose Calculations

Simulations with Validated Monte Carlo



- **Texturized phantom: 3 × 3 × 3 mm^3 voxels**
- **Random 20% with unit density, rest air**
- **Average density = 0.2 gm/cc**

Range Degradation Through Lung Equivalent Material - Homogeneous vs. “Texturized”



	90-20% Falloff mm
Homogeneous Slab	4.5
Texturized voxels	15.6

Calculation Error!

Titt/MDACC

Summary of Physics Uncertainty Issues

- Proton beams are more sensitive to
  - Organ motion
  - Anatomy changes in the beam path
  - CT number accuracy
  - Treatment devices in the beam path (for example, the couch, immobilization devices)
- IGRT and motion management may help
- Proton plans are difficult to evaluate
- Many challenges remain due to practical reasons
  - Compromises may have to be made for routine practice
    - Use common sense!