in partnership with

The Institute of Cancer Research

Cancer Research UK

The Royal Marsden NHS Foundation Trust

Treatment Planning and Optimisation of Hadron Therapy

U.Oelfke

Division of Radiotherapy & Imaging

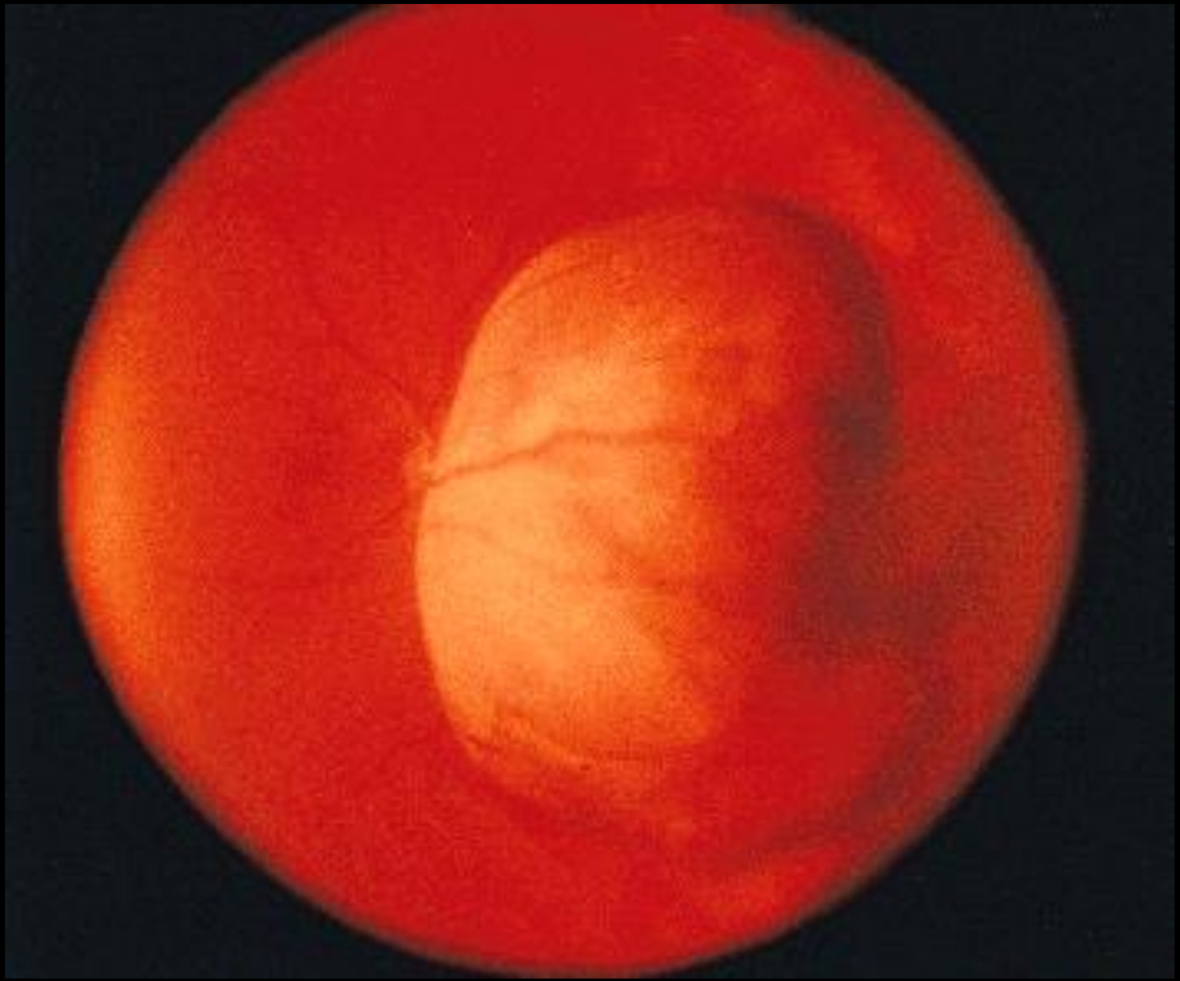
Making the discoveries that defeat cancer

„Planning is bringing the future into the present so that you can do something about it now“ Lakein Quotes

„Prediction is very difficult, especially about the future“ Niels Bohr

„Wise“ Planning: Inclusion of Uncertainties

Protontherapy of ocular tumors

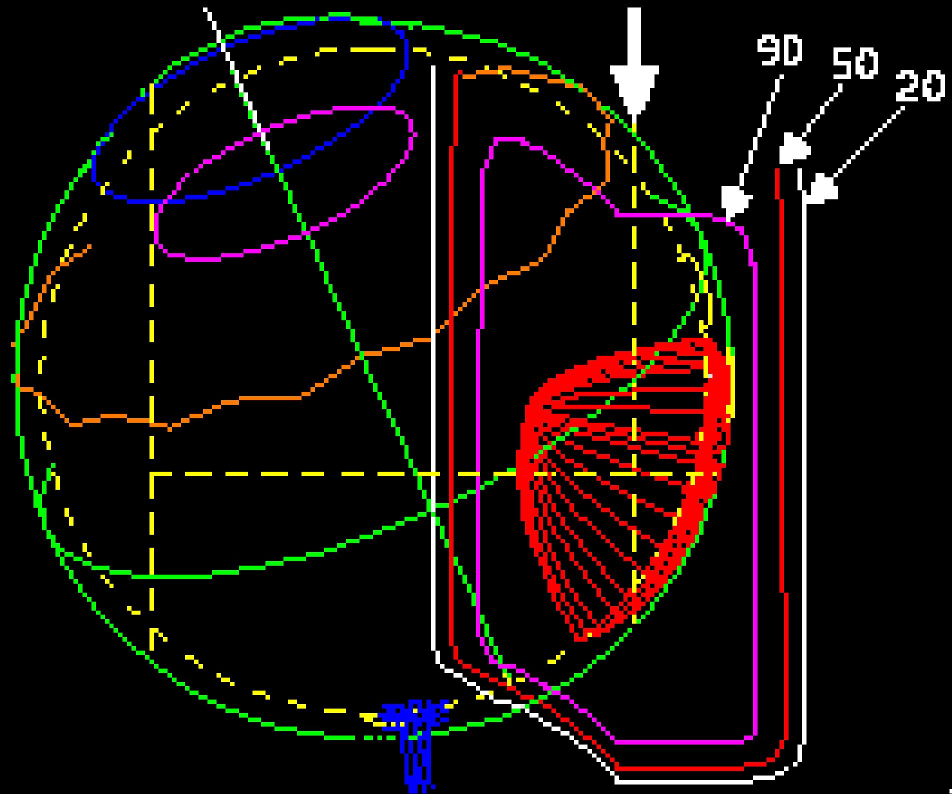


Fundus-View (E. Egger PSI)

Localistaion of tumor

Localisation vai tantalum clips(E. Egger PSI)

EYEPLAN



A. Kacperek, M. Sheen, Clatterbridge

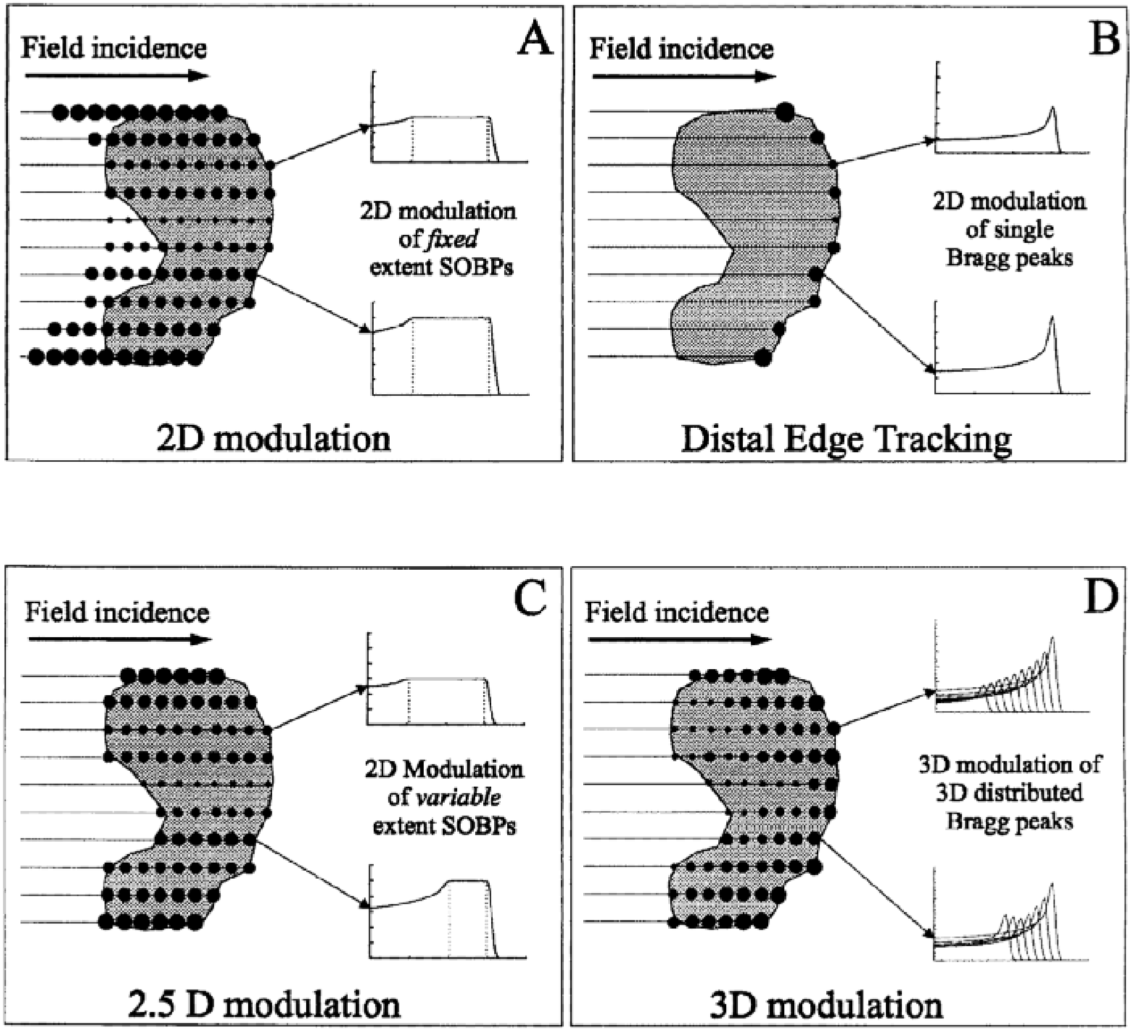
Challenges

- Number of degrees of freedom
  - proton energies
  - fluence weight

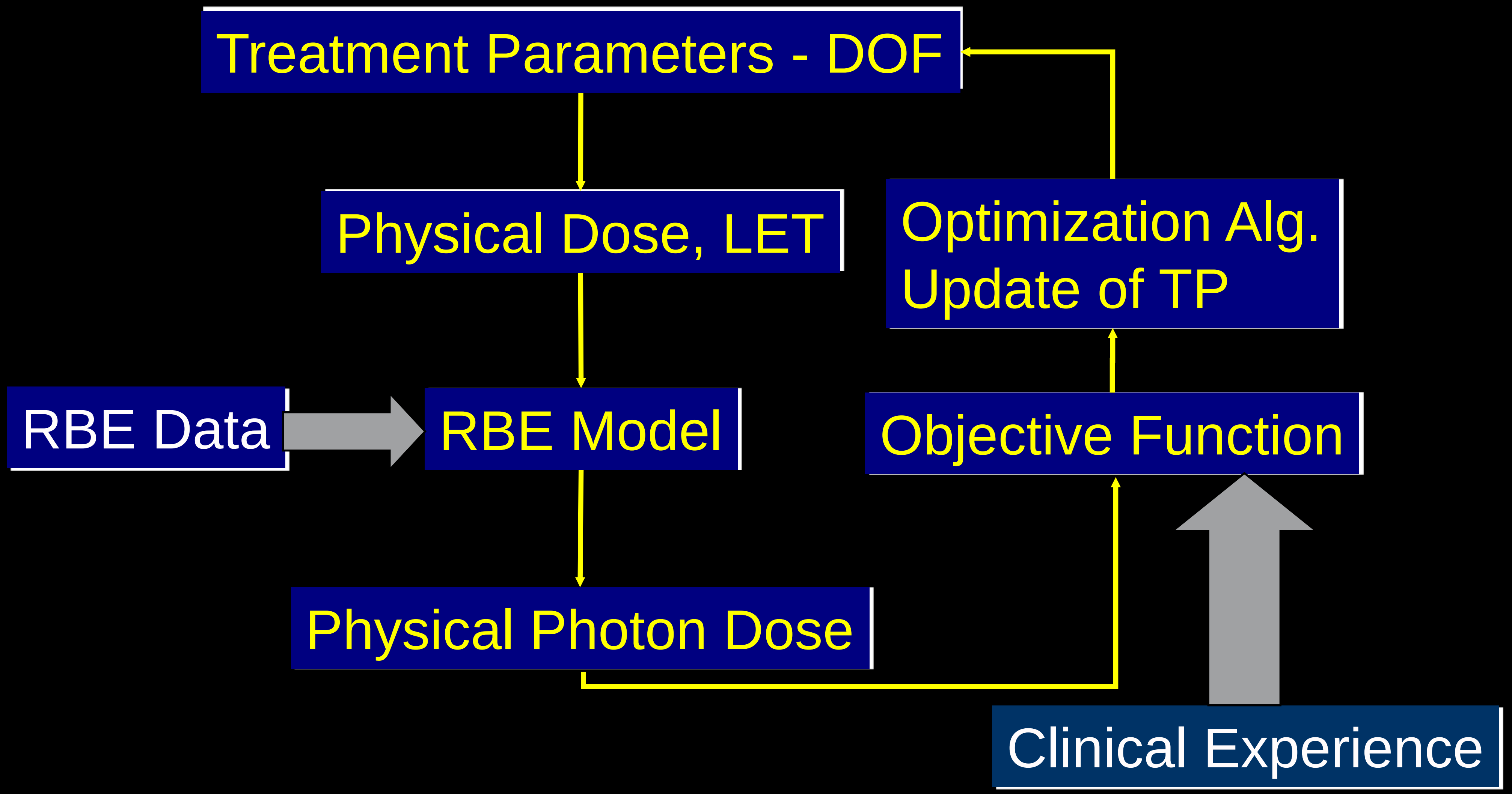
- ‘Biology’ ?

- Geometrical Uncertainties ?

Scanning: Dose Application Techniques



Inverse Planing: Optimization Loop



The framework of biological optimization

Physical optimization hadron therapy

Dose constraints

DVH constraints

….

Biological Optimization

Biological effect: E

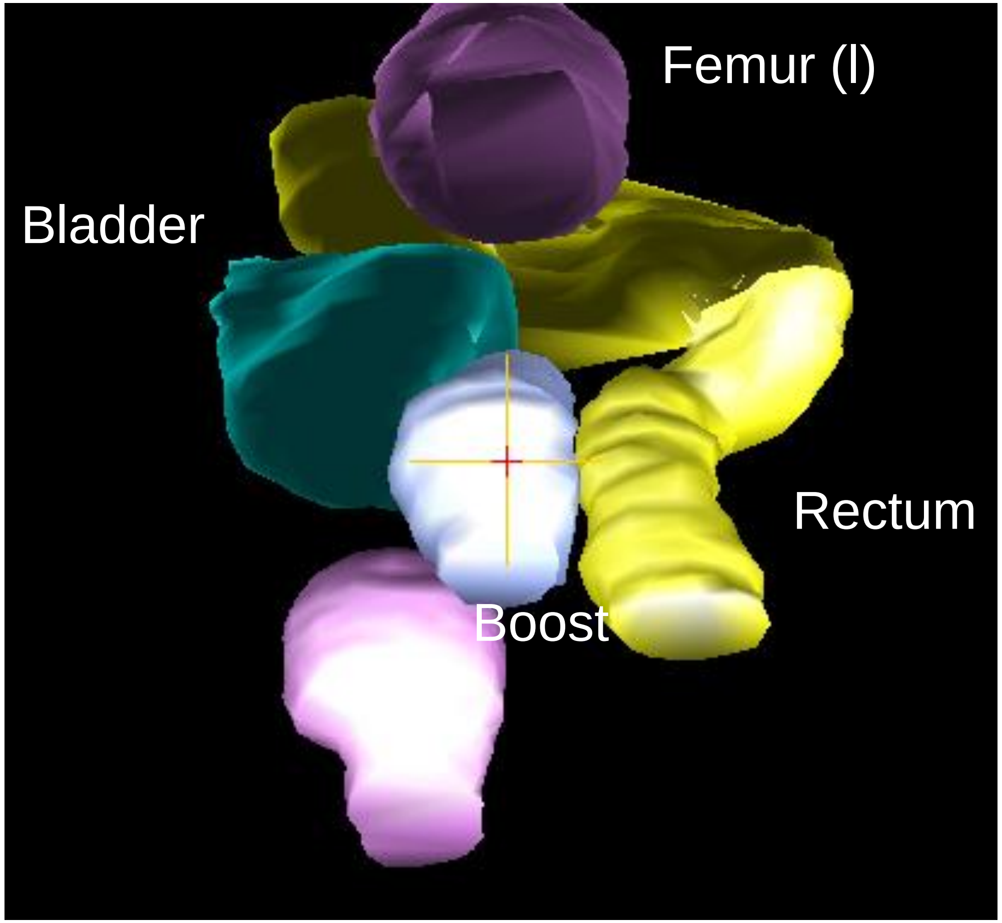
Two main components

Macroscopic model for the dose dependence of E

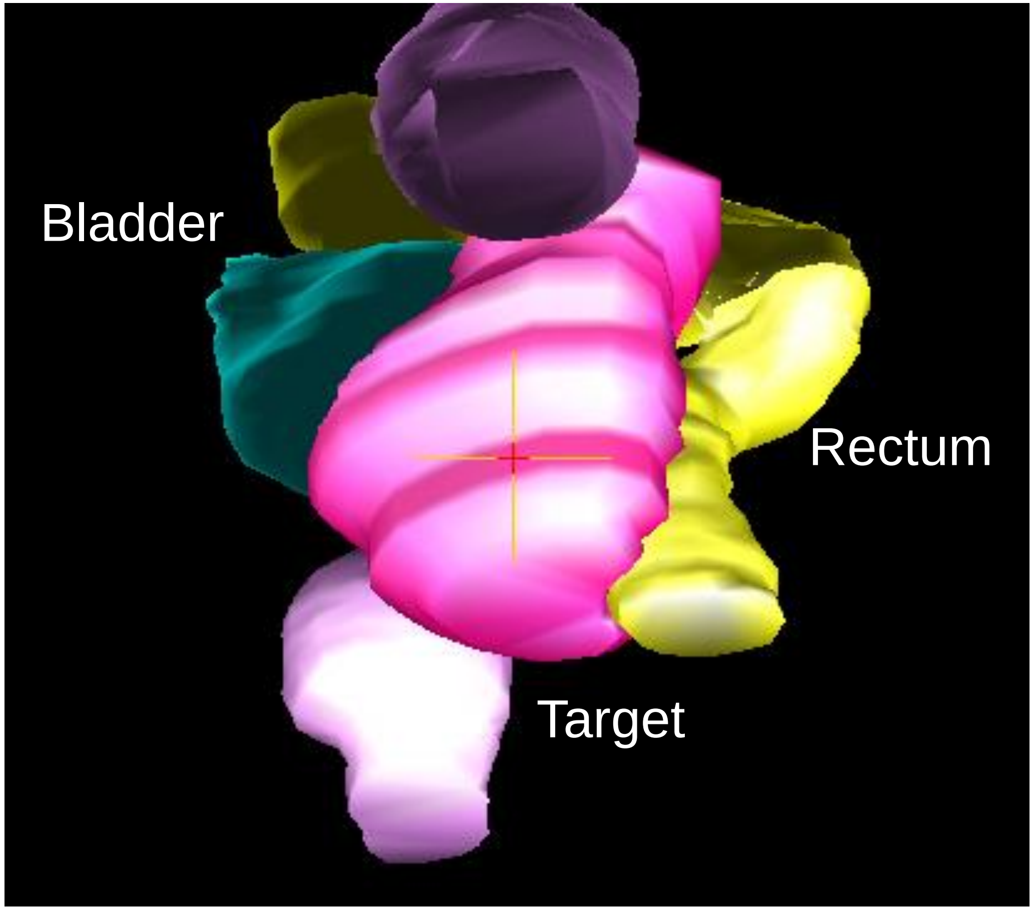
Microscopic model describing the dependence of E on intrinisic radiation quality only

$$E = \alpha D + \beta D^2$$

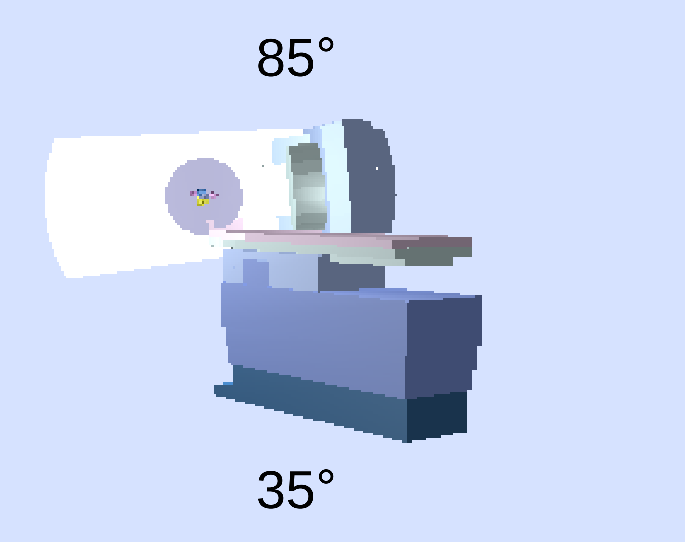
Prostate Ca: Anatomical Geometry (1)



Prostate Ca: Anatomical Geometry (2)

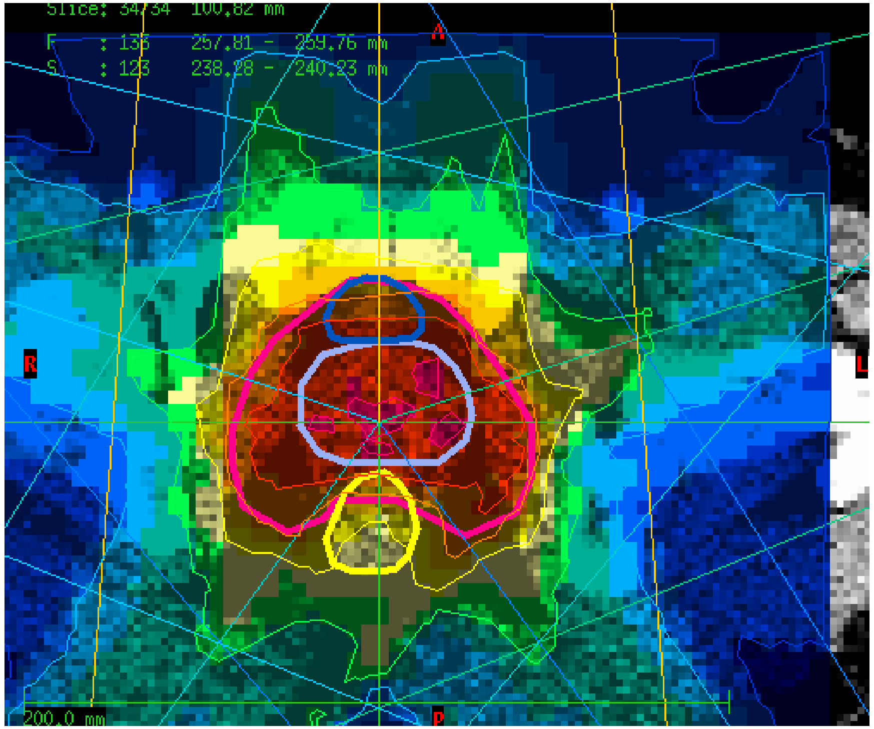


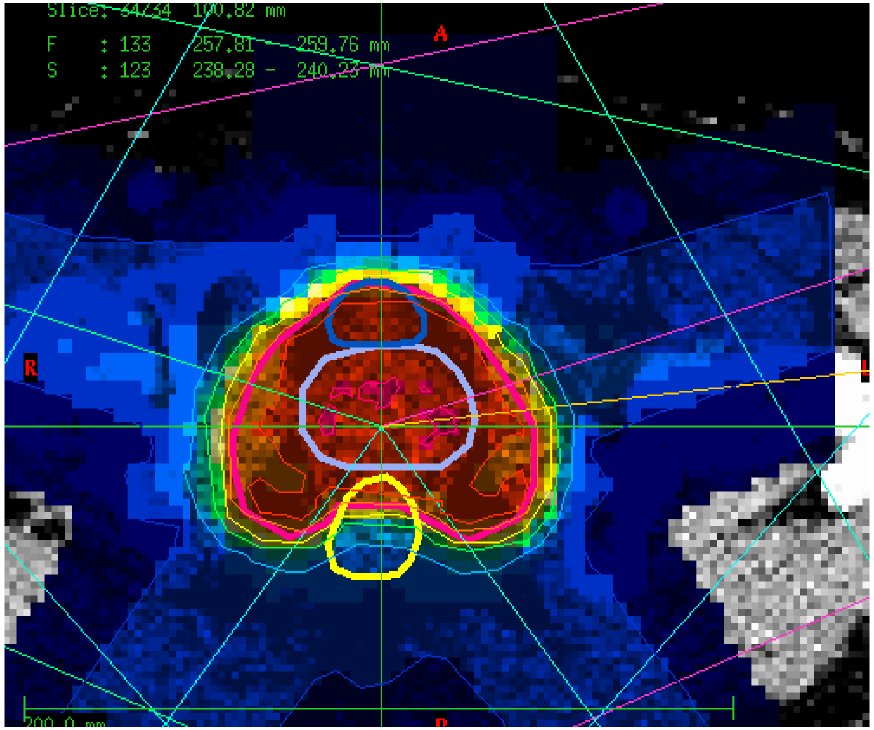
BEV



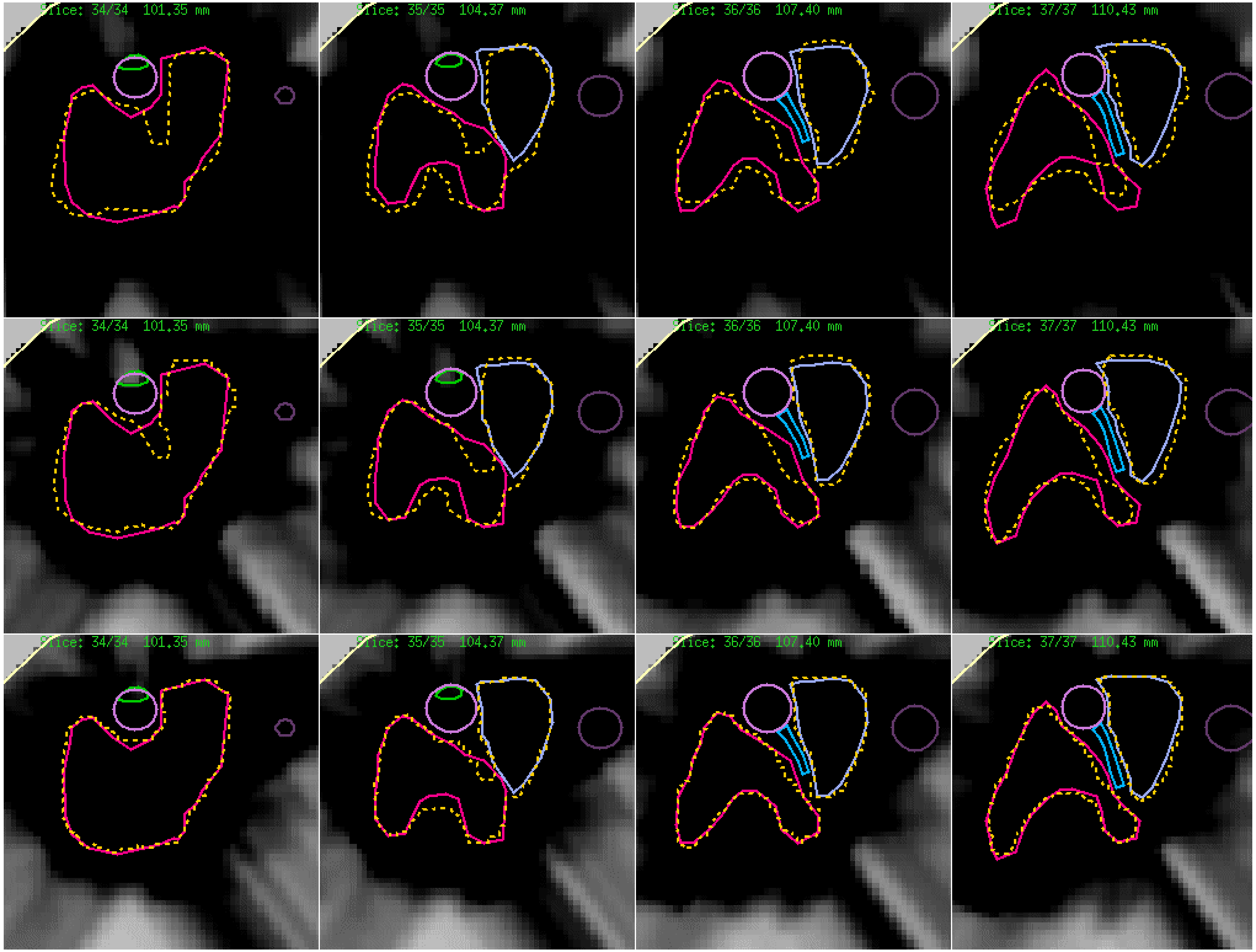
Photons vs. DET protons

Reduction of integral dose and lower dose levels





Conformal Avoidance: Photons – Protons – C12



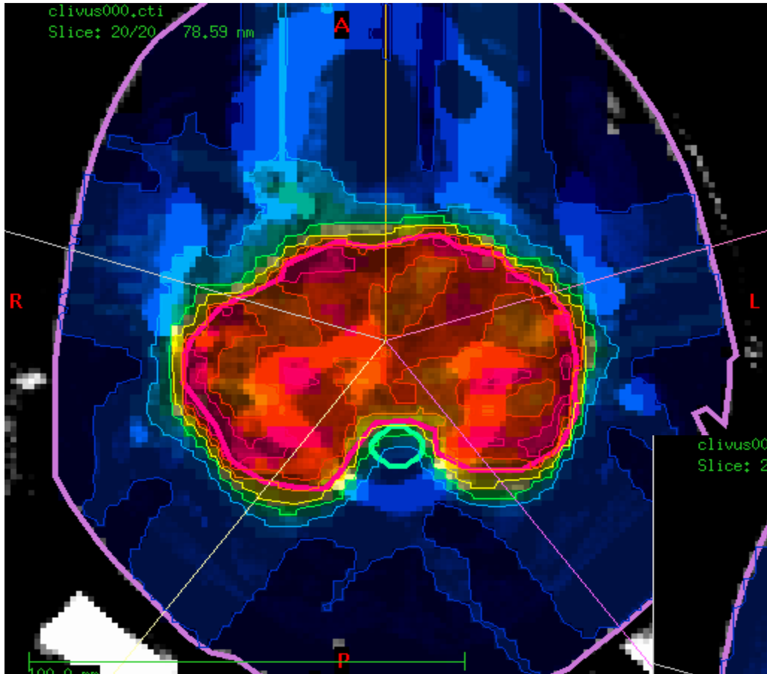
Photons

Protons

C12

U.Oelfke, Dissertation, 2001

DET with „normal“ (dose) optimization

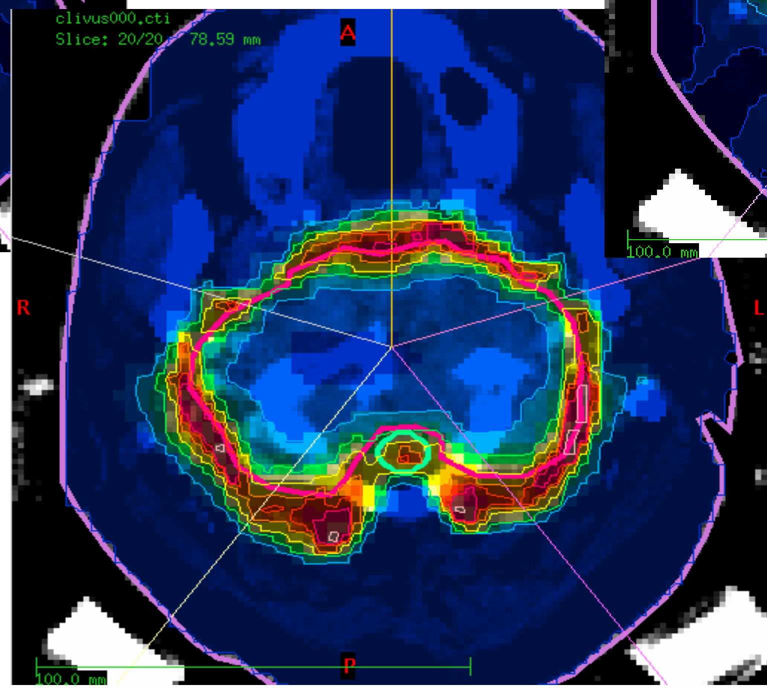


dose

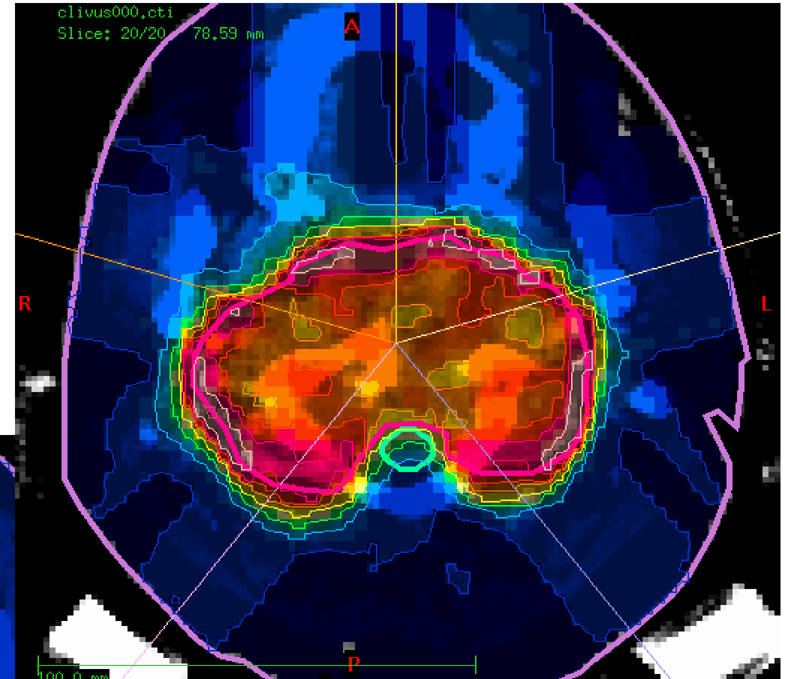
KonRad

patient with clivus chordoma

5 beams, DET

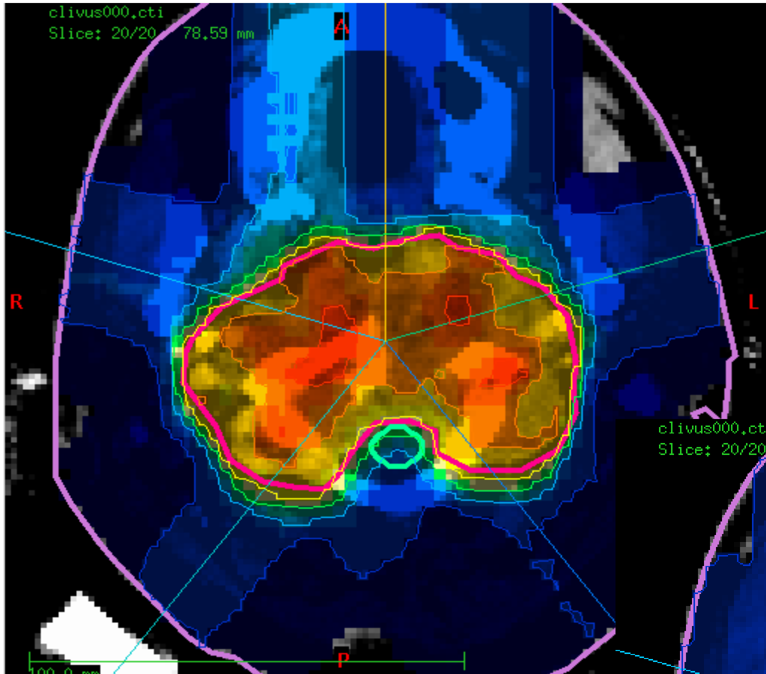


LET

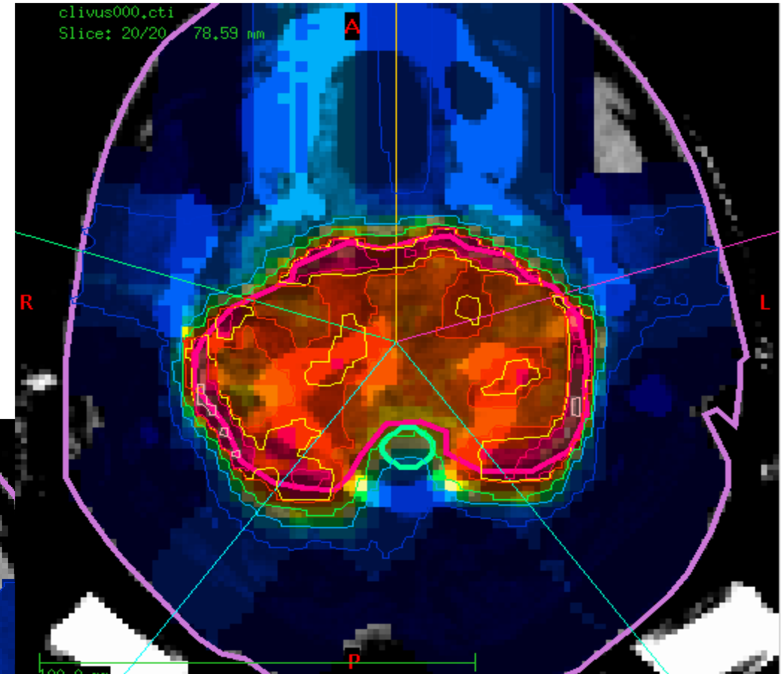


RBE · dose

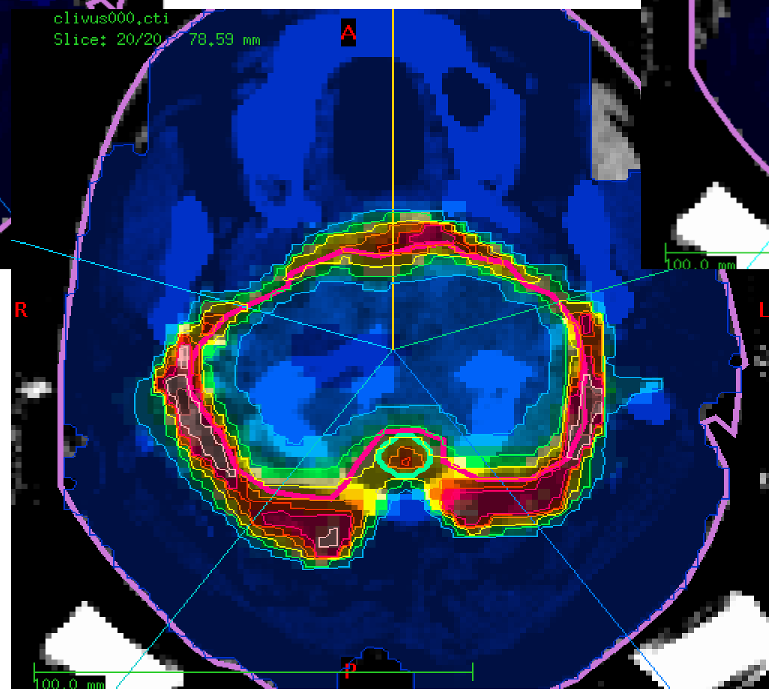
DET with „biological“ optimization



dose

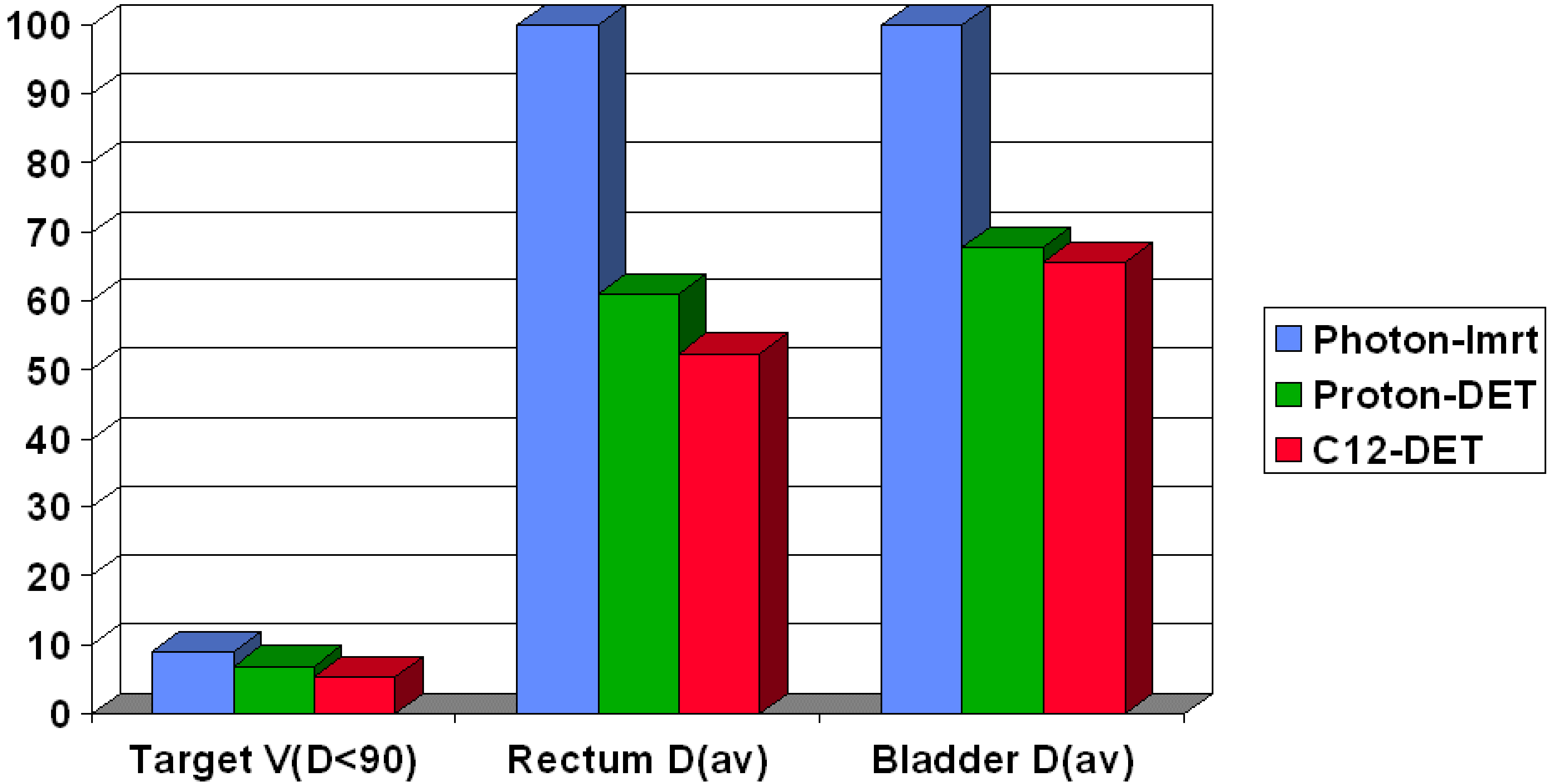


RBE · dose



LET

Prostate Ca: Different Modalities



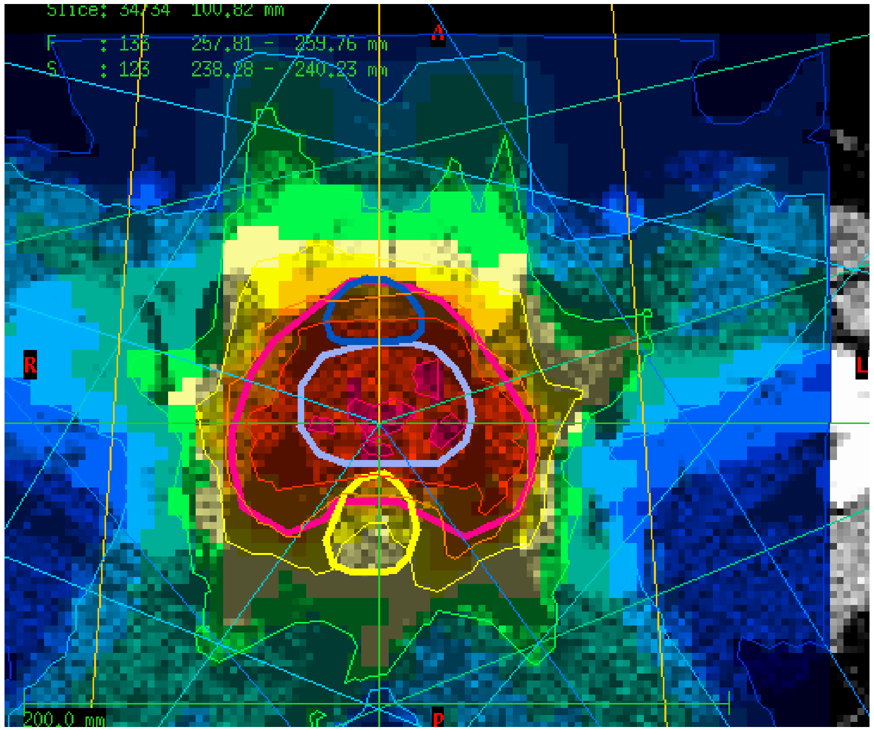
U.Oelfke, Dissertation, 2001

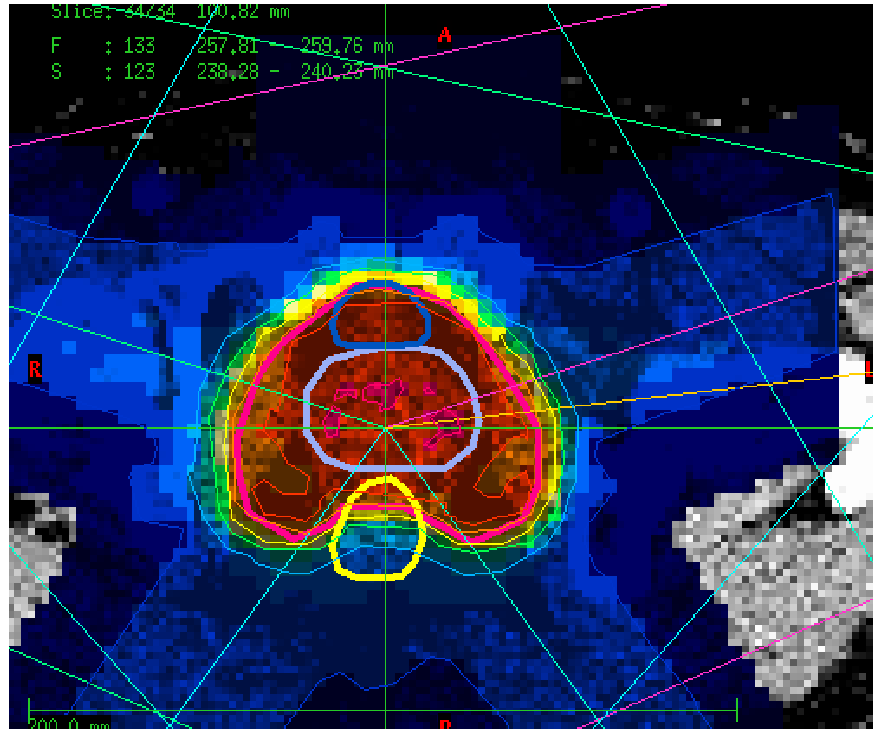
Projected advantages of hadron therapy

- Reduced integral dose
- Enhanced dose conformity
- Enhanced radiobiological properties
  - Intrinsic ‚biological' power
  - Less sensitive to uncertainties of the micro environment

Photons vs. DET protons

Reduction of integral dose and lower dose levels

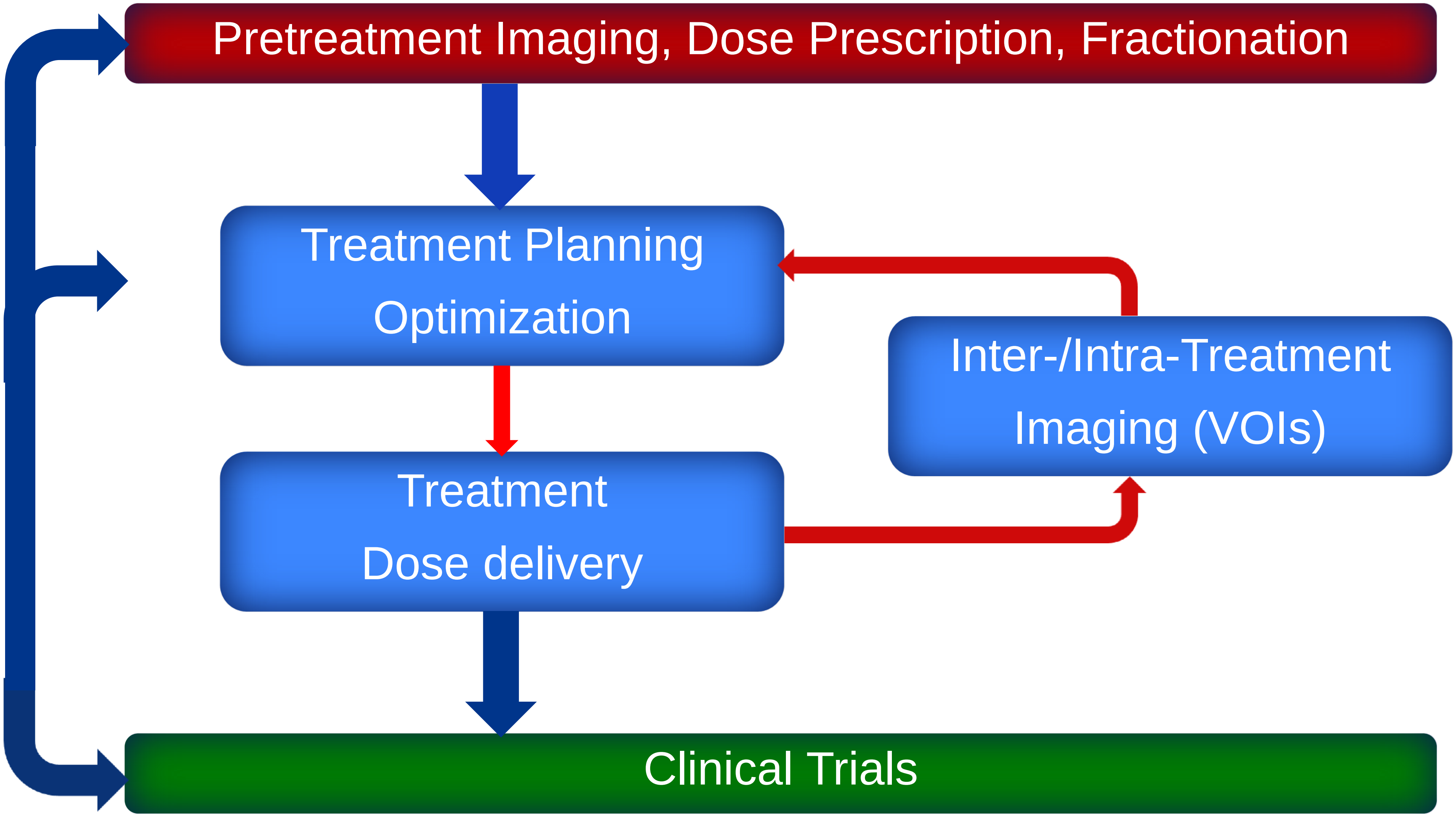




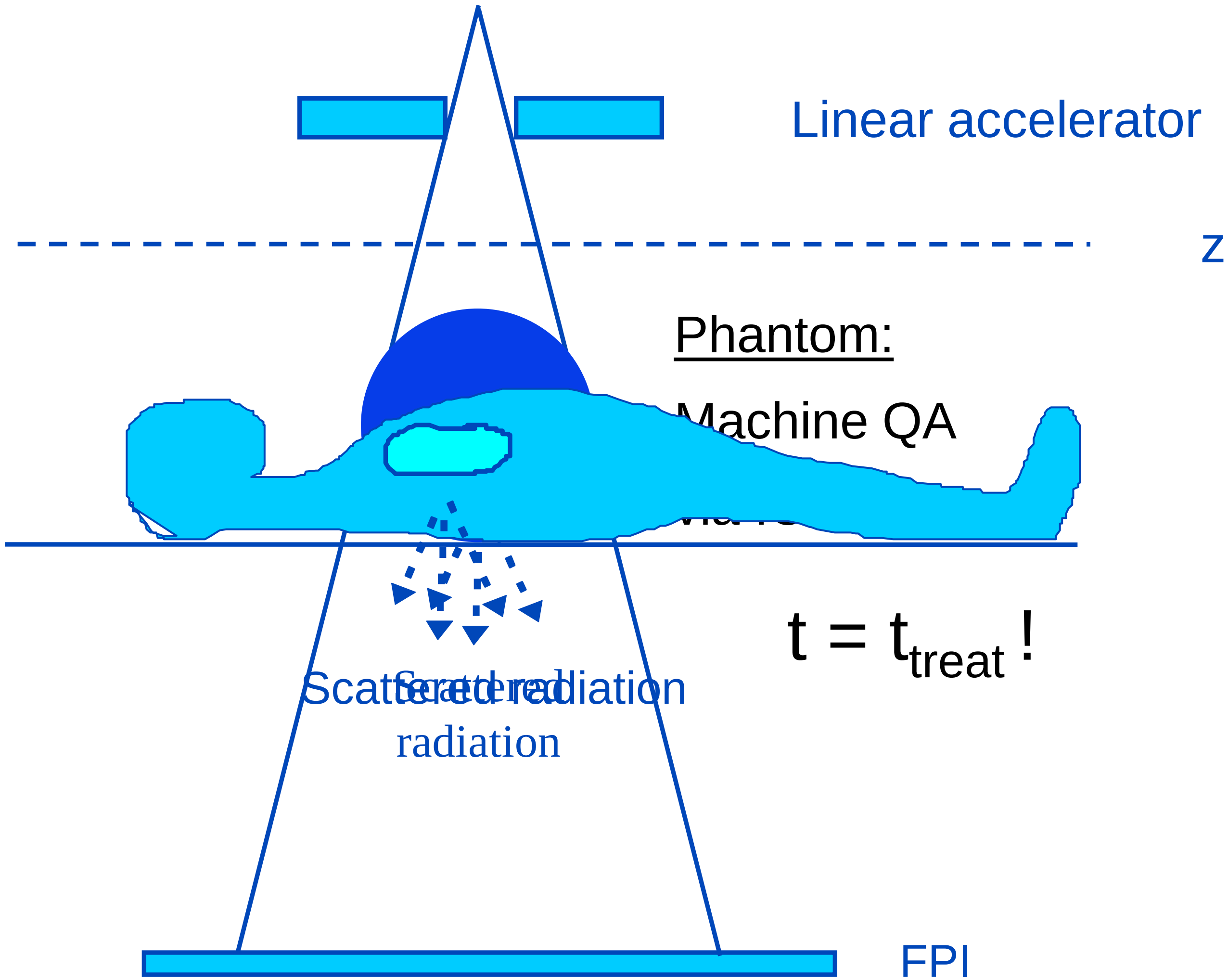
However, that is the ‚ideal world' !
What about a ‚real' patient?

U.Oelfke, Dissertation, 2001

IGRT/ART: The geometry loop



Focus our attention to the main uncertainty



What do we need for ‚patient' calibration ?

Depth dose curve:

e-density (x)

Ionization potential (x)

Local energy spectrum (x) (Straggling)

Nuclear absorption cross section (x)

Z/A (x)

?

Lateral Scattering:

Coulomb Interaction with nuclei, screened by electrons

Moliere Theory

How do we verify the ‚patient' calibration ?

PET activation studies ….

Proton radiography ….

Proton CT ….

?

Lets start with a daily CT and good image guidance…

Geometrical uncertainties

- Target delineation uncertainties
- Calibration of ‚actual‘ patient images to particle stopping powers
    - HU vs. e densities
    - HU vs. I potential

⇒ Uncertainties for range, energy,

Geometrical uncertainties

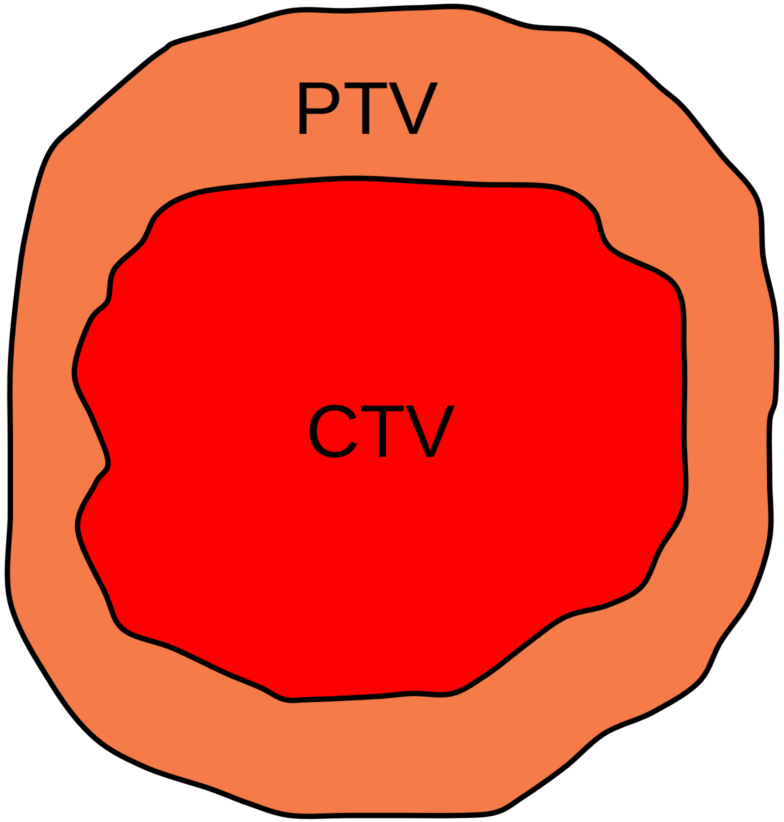
- Partial volume effects in imaging

→ Straggling uncertainties

- Setup uncertainties

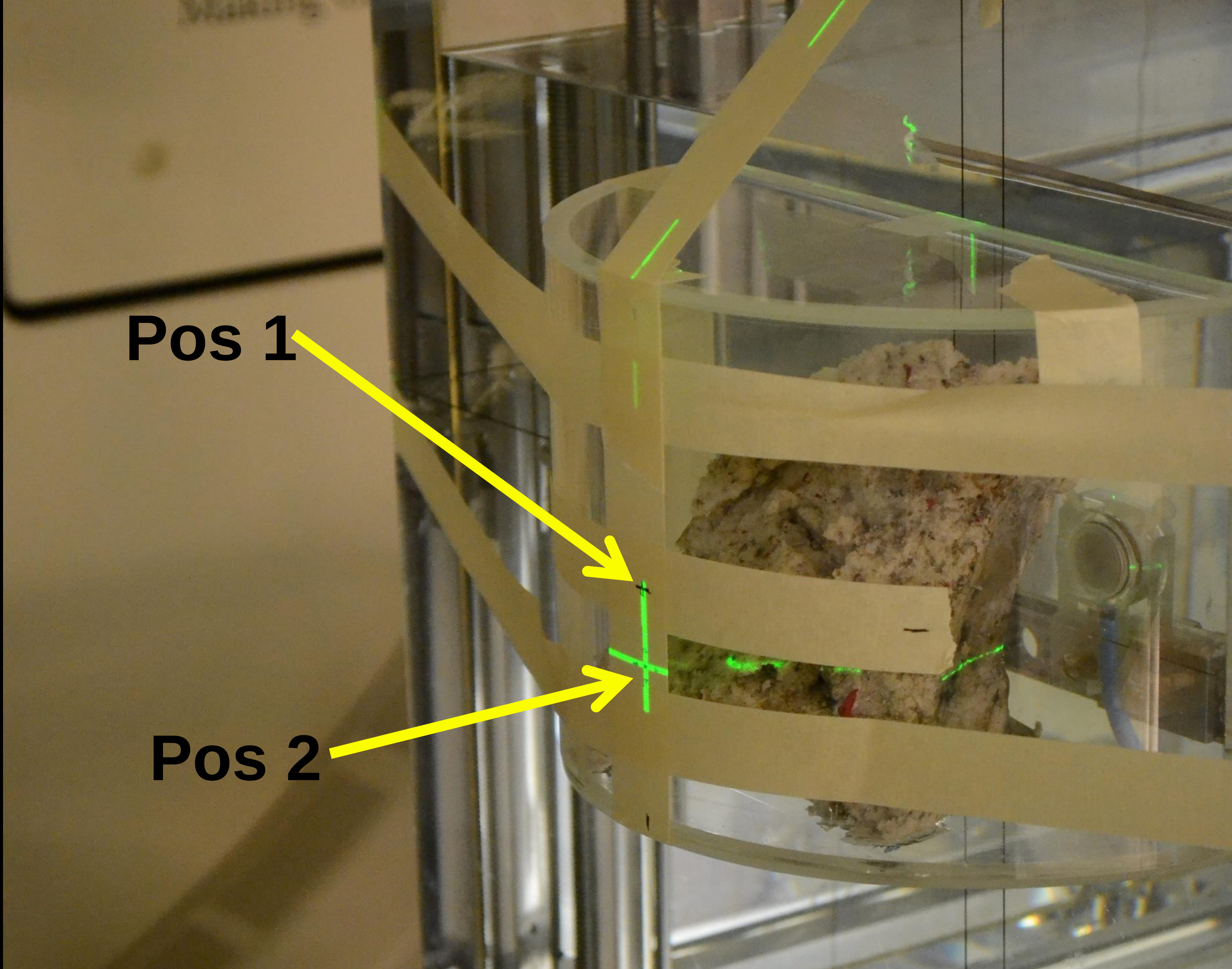
- Organ motion, deformations

Extra margins for protons ….



- CTV: Volume in the patient
  - prescribed dose
- PTV: Volume in beam coordinates
  - no dose necessary
  - ‚dose-victim‘ of CTV
- PTV – CTV = Margin
  ‘probabilistic concept’

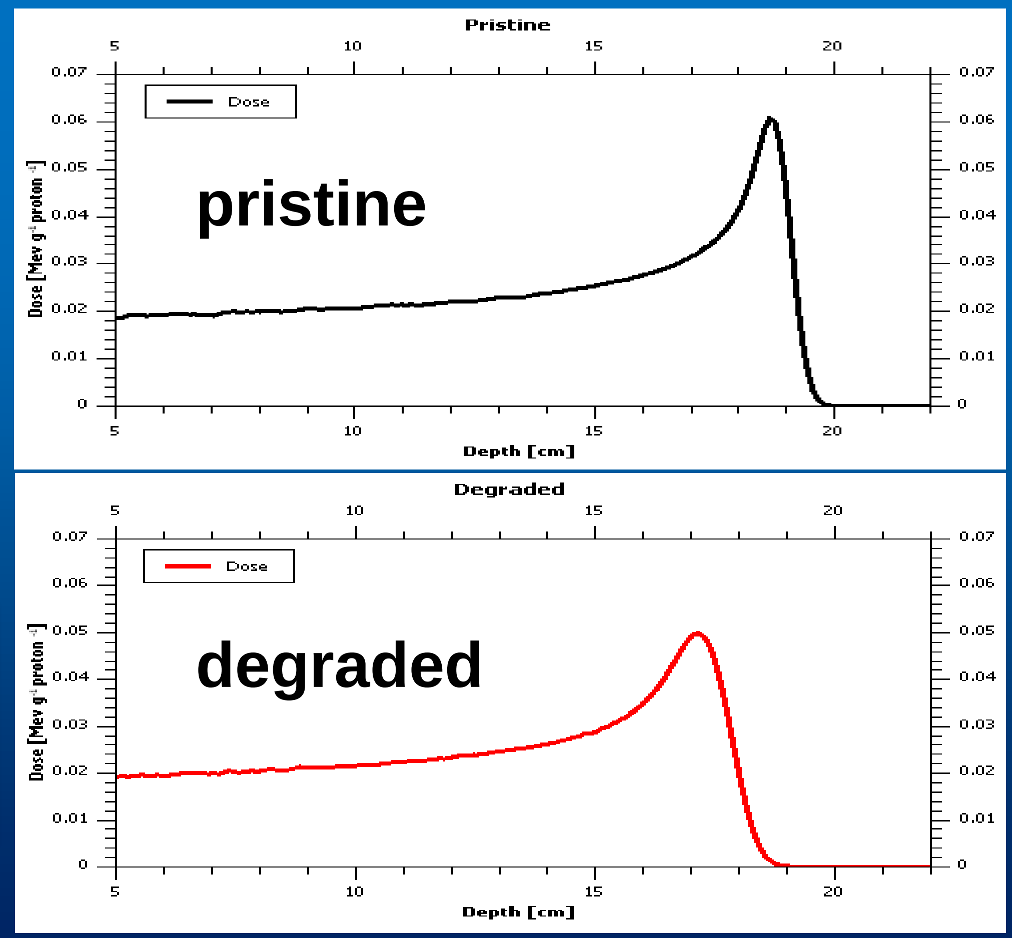
Example: Imaging related straggling uncertainties


Pos 1
Pos 2

Distal edge degradation

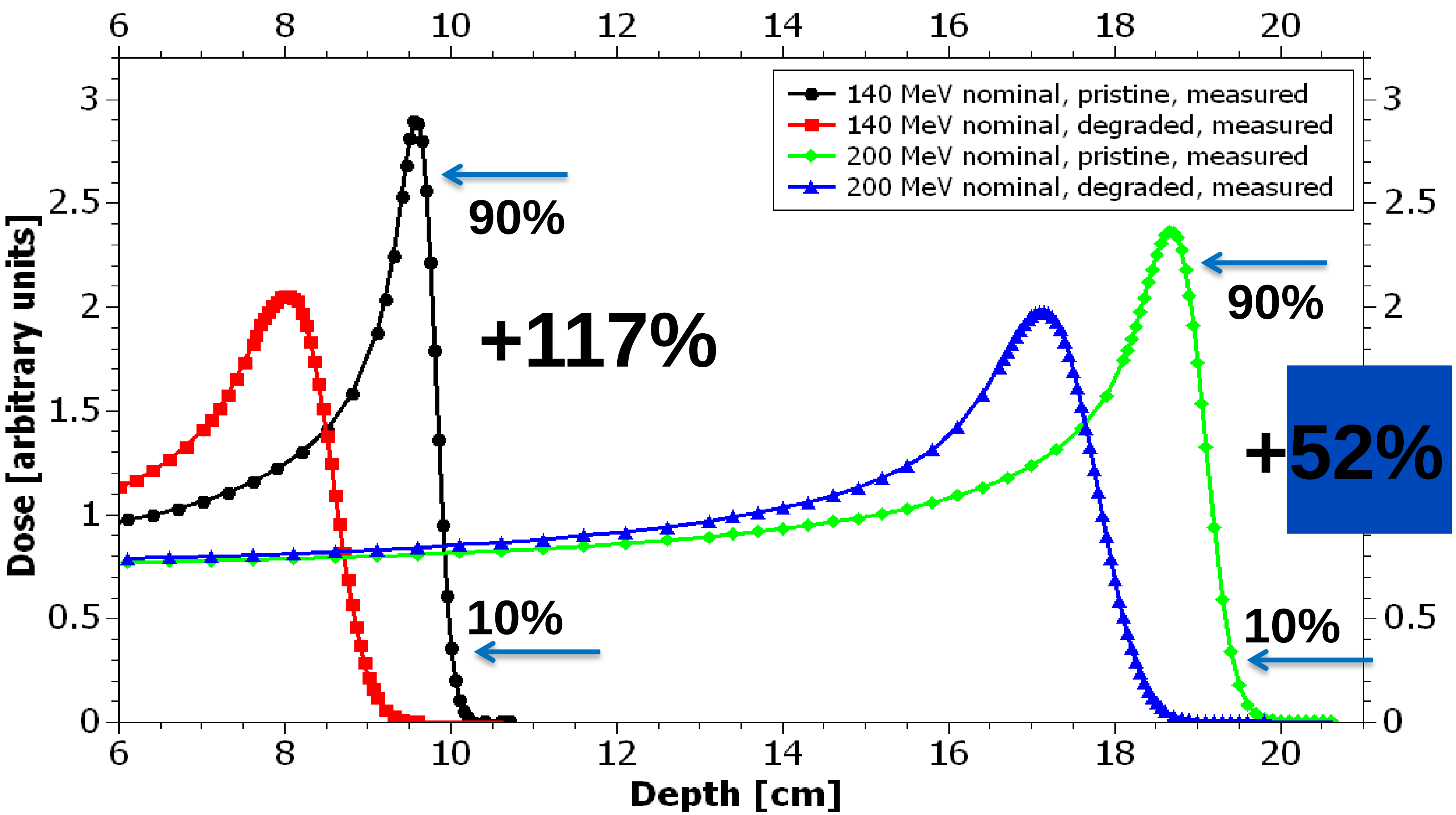
Proton Beam

Lung tissue



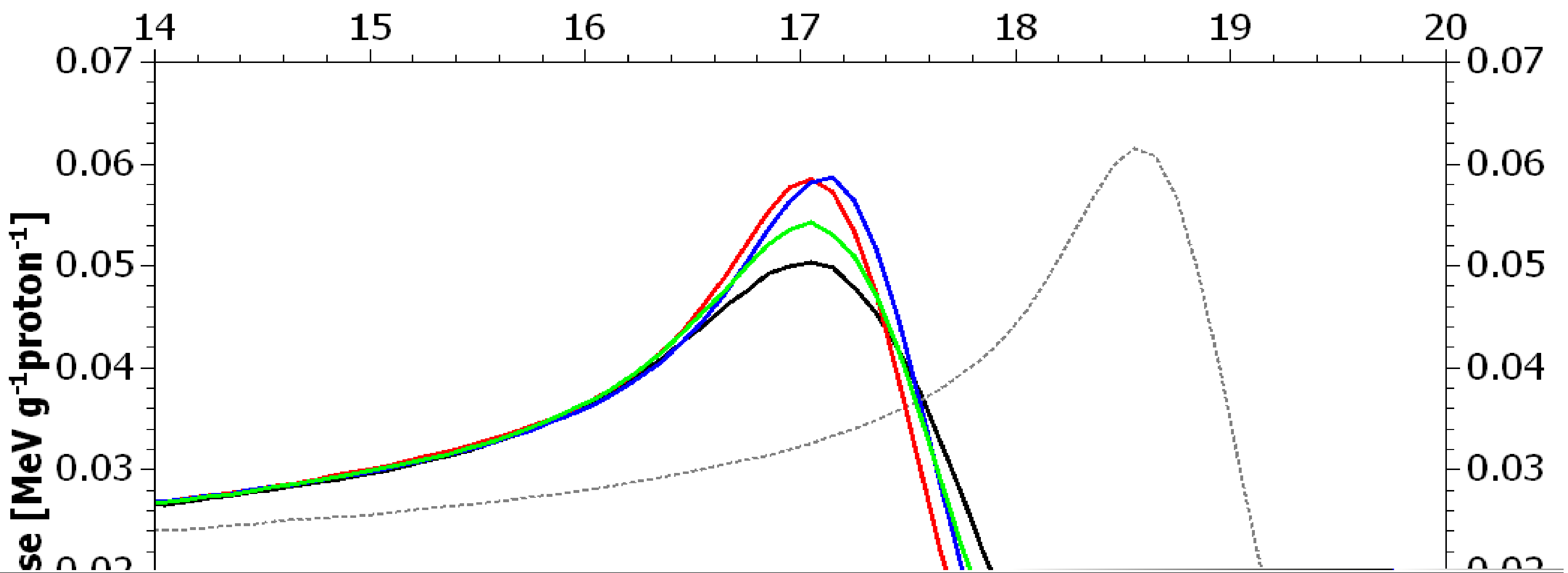
Dose to water

Experimental Results



Phantom leads to **degradation** of Bragg peak

Influence of CT imaging



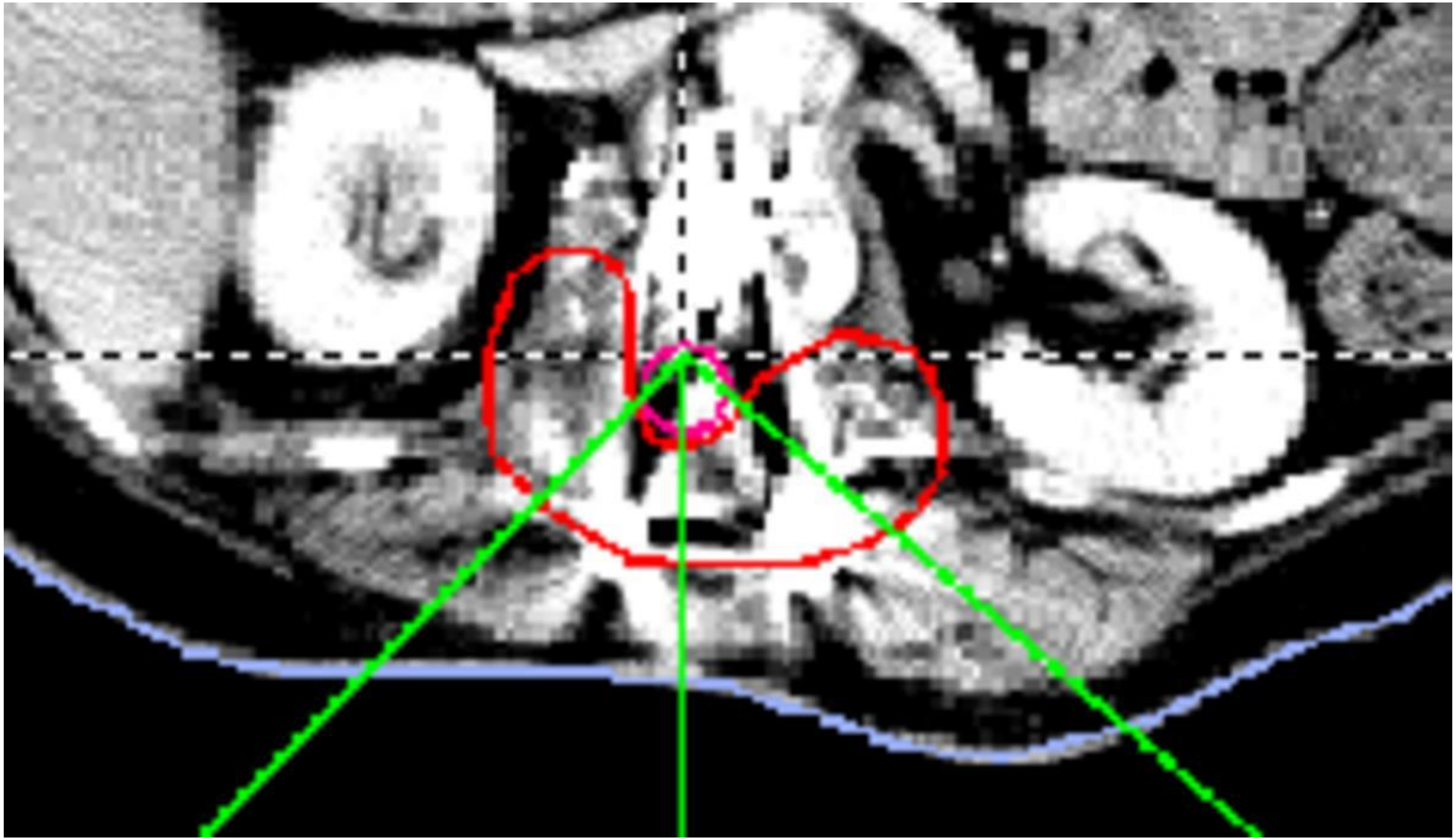
[redacted]

Small Animal CT scanner → **improvement** due to **less volume averaging**

Better Image Guidance

Robust Therapy Planning

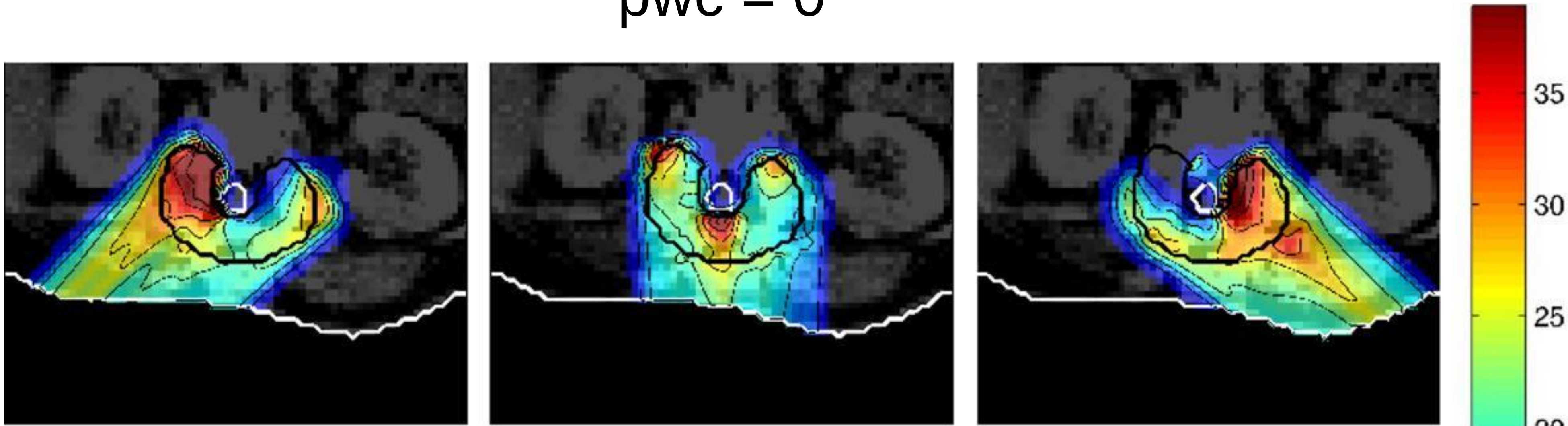
Example: 3 copl. IMPT beams



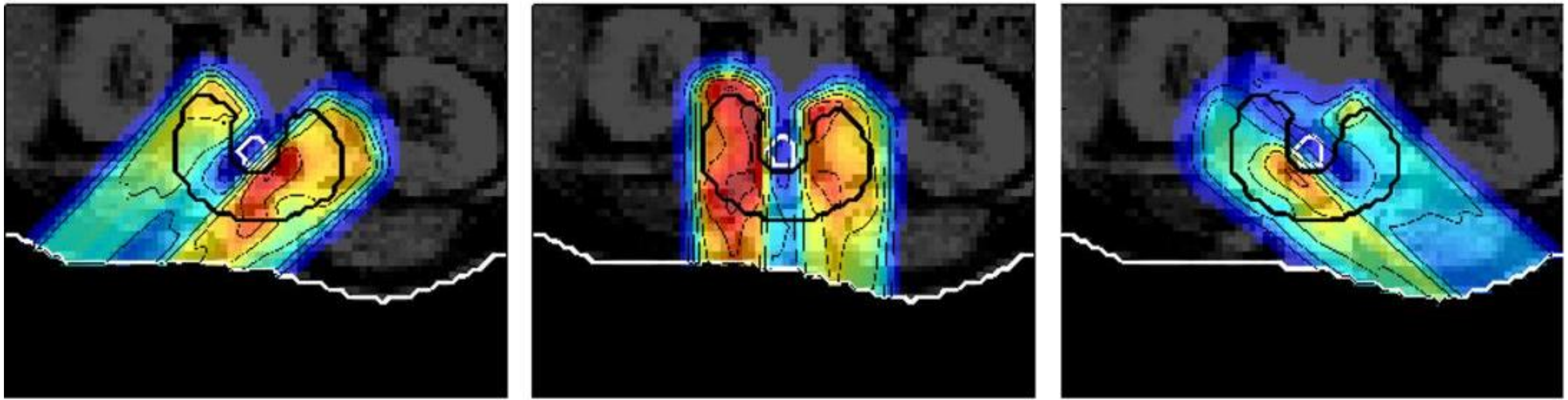
Range uncertainty: 5 mm

Range uncertainty: 5 mm – Distal Margin

pwc = 0



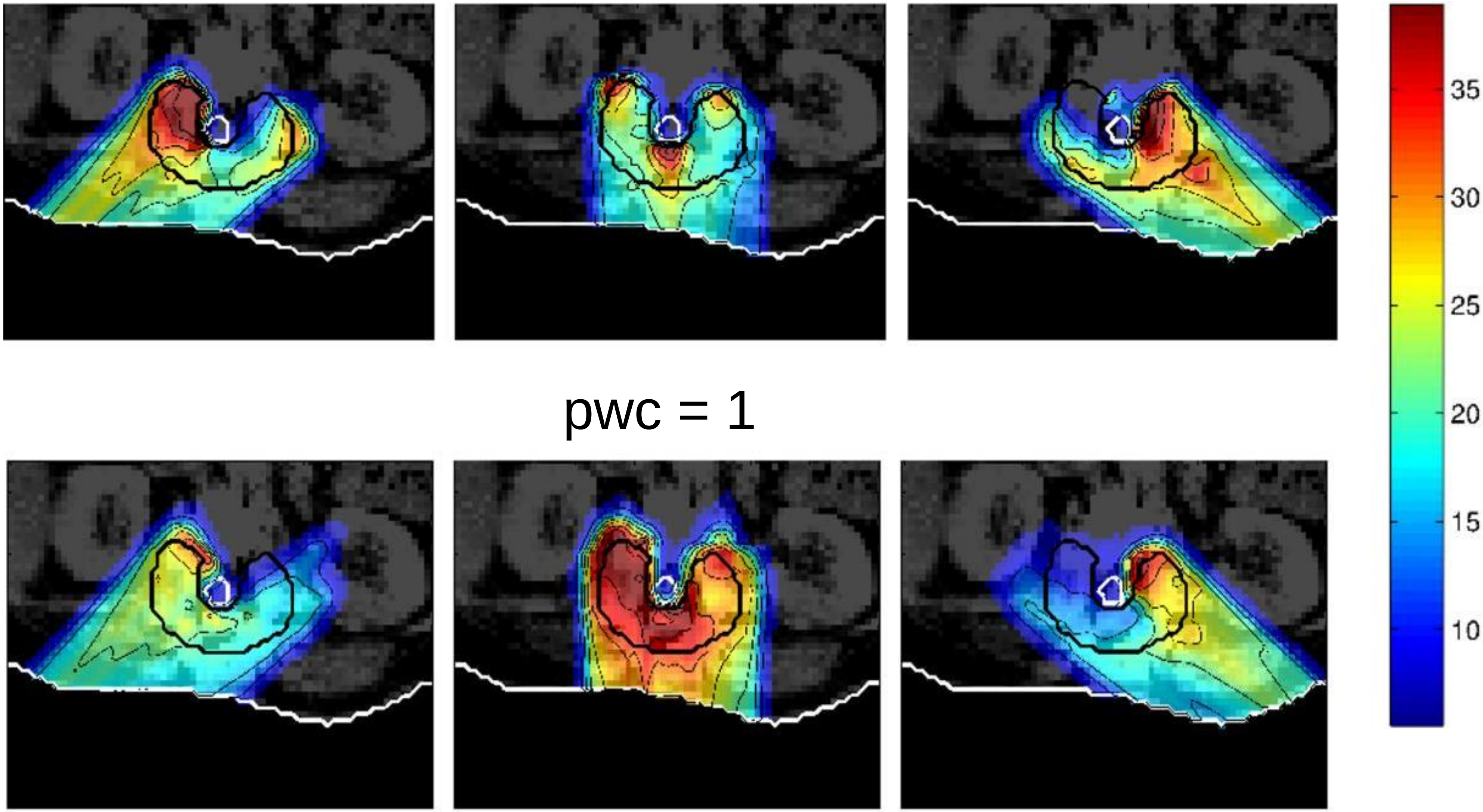
pwc = 1



Setup uncertainties 2 mm – Lateral Margins

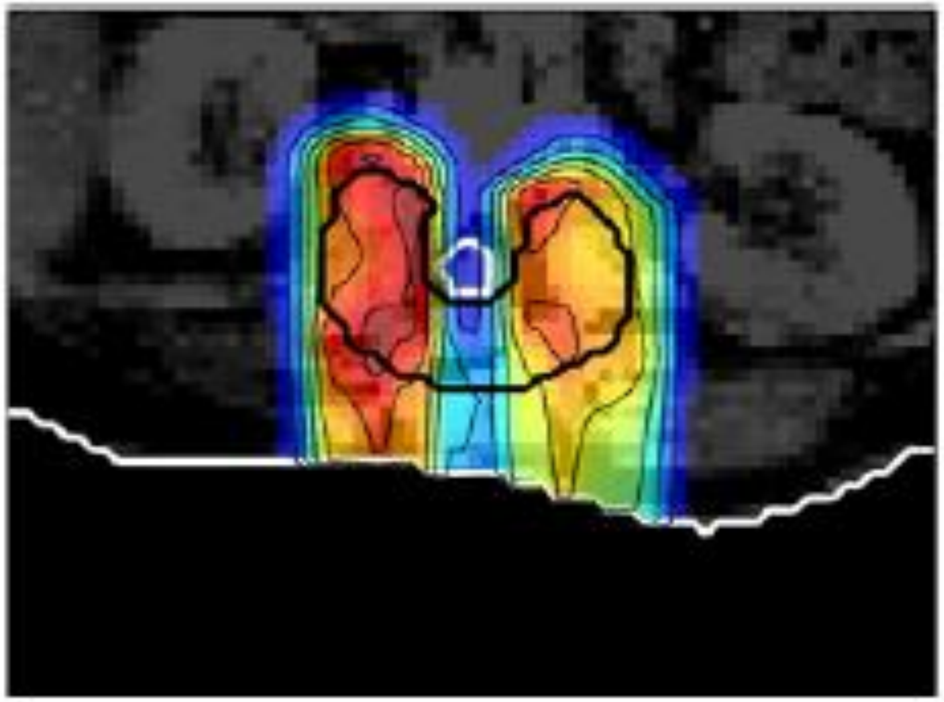
pwc = 0

pwc = 1



Range vs. Setup Uncertainties

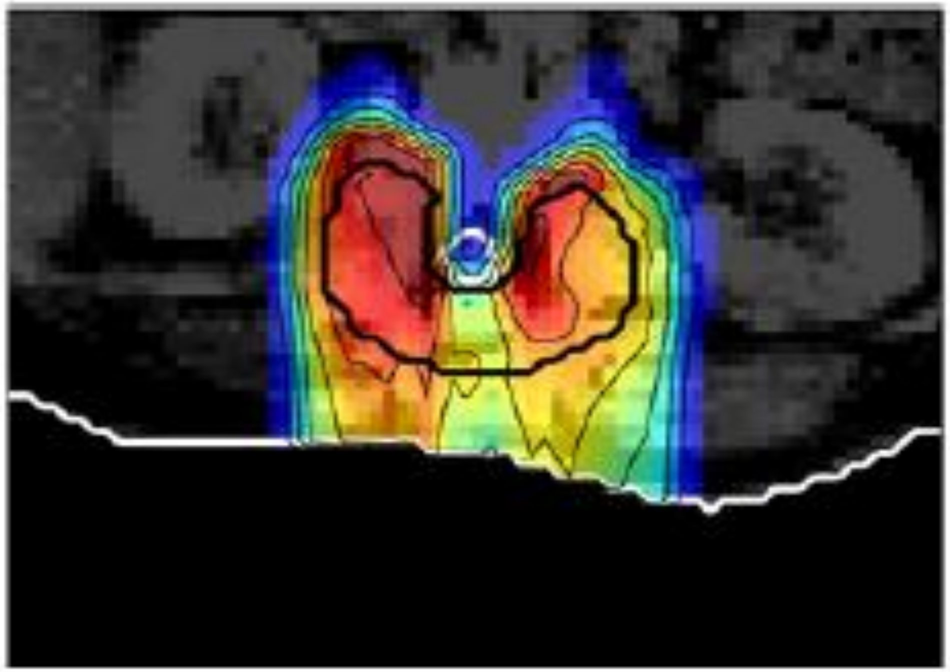
Range: 5 mm



Setup: 0 mm

Range vs. Setup Uncertainties

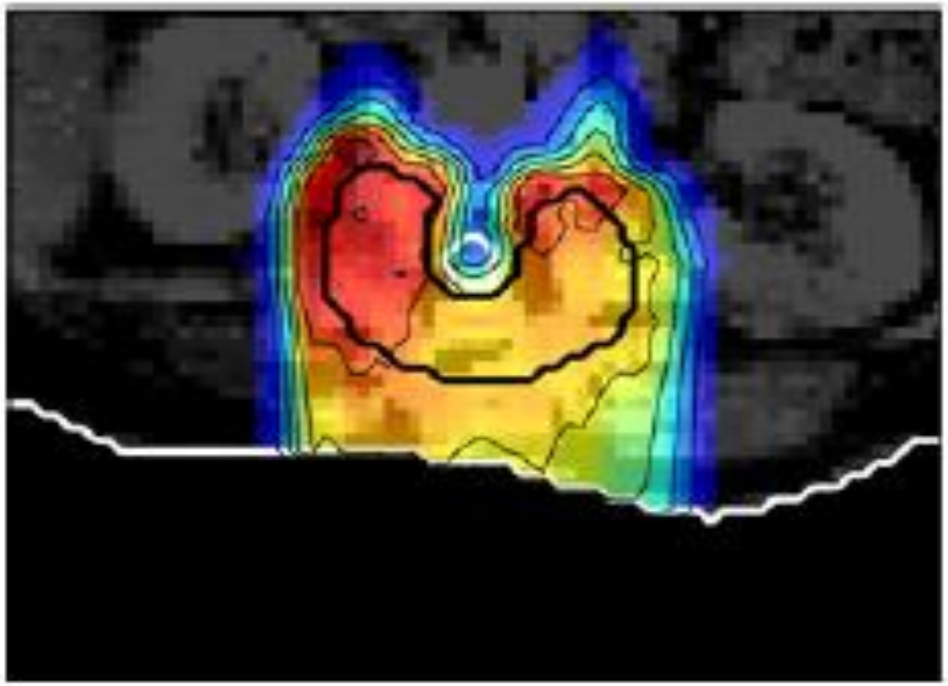
Range: 5 mm



Setup: 2 mm

Range vs. Setup Uncertainties

Range: 5 mm

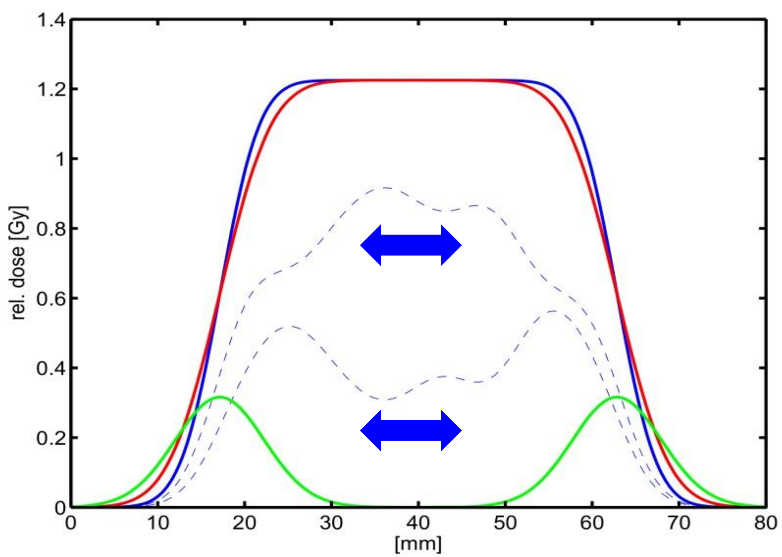


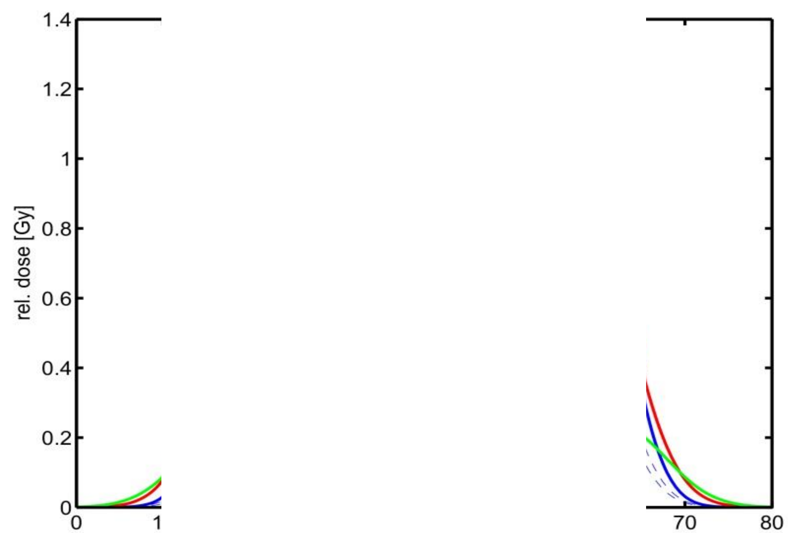
Setup: 5 mm

Correlation of uncertaities

- Two lateral dose profiles form a homogeneous dose in the nominal case
- The uncertainty depends on the correlation assumption

Perfect correlation





Nominal dose

Sub beams

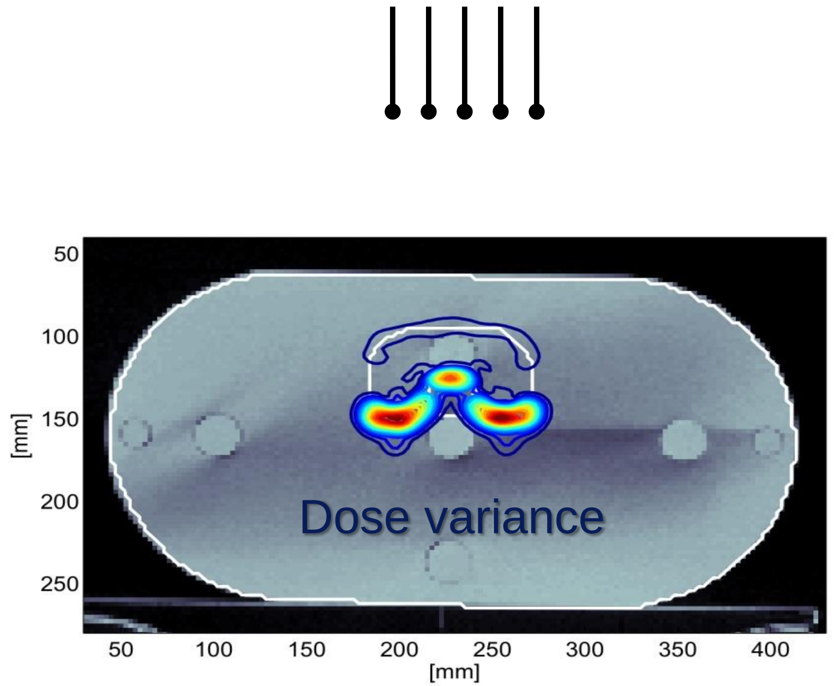
Expectation value

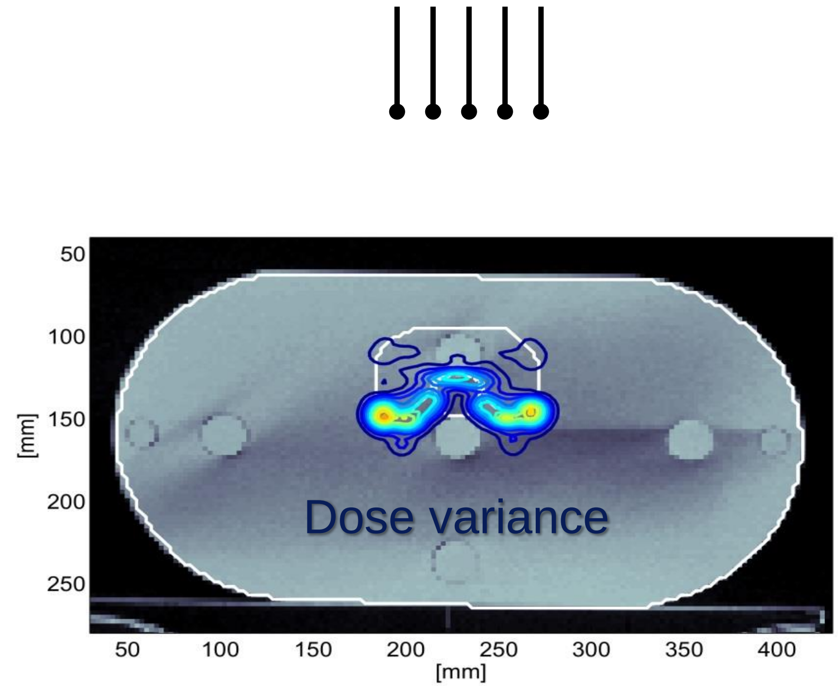
Standard deviation

- One anterior proton beam forms a homogeneous dose in the target volume
- The uncertainty depends on the correlation assumption

Range errors of entire beam correlated

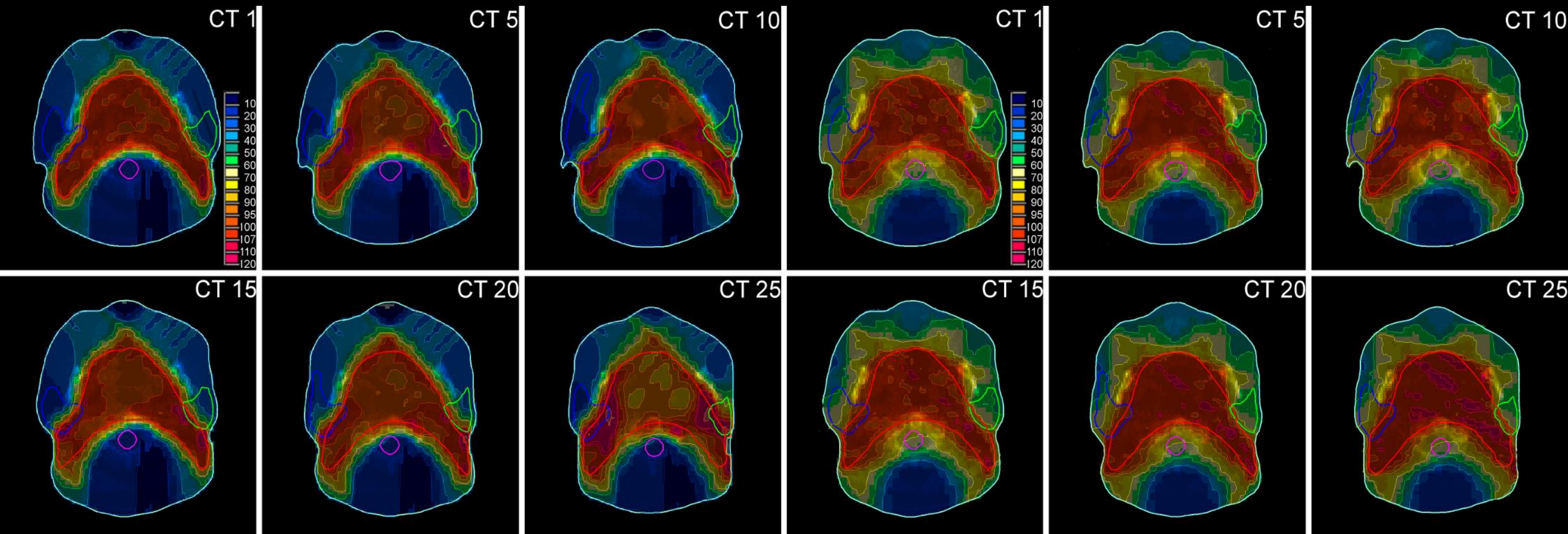
Range errors of pencil beams impinging at different lateral positions uncorrelated





Treatment planning is a central issue to exploiting the physical advantages of PT.

So lots of things still have to be done ….



CT 1
CT 5
CT 10
CT 1
CT 5
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CT 15
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