AK IMRT

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Optimierung der Protonentherapie mit KonRad

Dr. Jan J. Wilkens

Abteilung Medizinische Physik in der Strahlentherapie

E-Mail: j.wilkens@dkfz.de

dkfz. GERMAN CANCER RESEARCH CENTER IN THE HELMHOLTZ ASSOCIATION

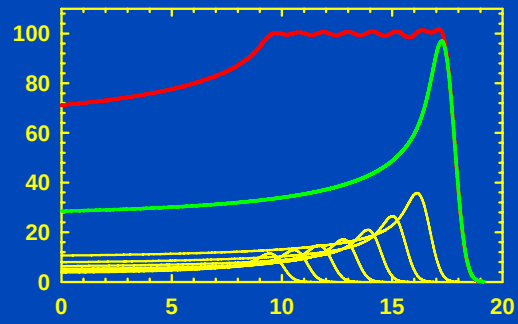
Introduction to proton therapy

Physical properties (dose distribution) allow for a better spatial conformation of the dose to the target

Proton beam delivery:

- passive technique:
  - scattering foil, broad beams

    energy modulation: SOBP's



- active technique:
  - scanning of narrow beams

    energy and fluence modulation: SOBP's or IMPT

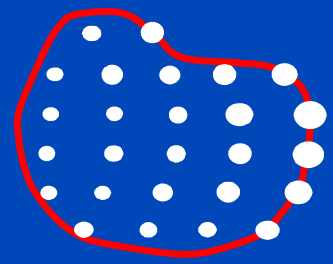
Definition of IMPT

- SOBP's:
  - homogeneous dose in target for every field
- IMPT:
  - multifield technique
  - each field delivers an inhomogeneous dose to the target
  - superposition of all fields yields desired dose distribution
  - scanning alone is not necessarily IMPT!
- IMPT needs inverse planning / optimization

Inverse planning for IMPT

1. Select beam directions

2. Find spot positions



3. Optimize spot weights
   find best set {w} of spot weights that minimizes the objective function

$$F_T = \sum_{i \in T} (D_i(\{w\}) - \bar{D})^2$$

4. Evaluate plan

Inverse planning for IMPT

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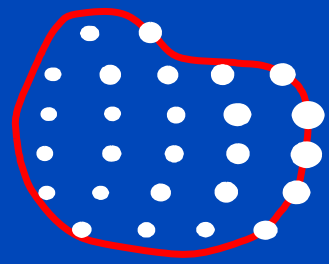

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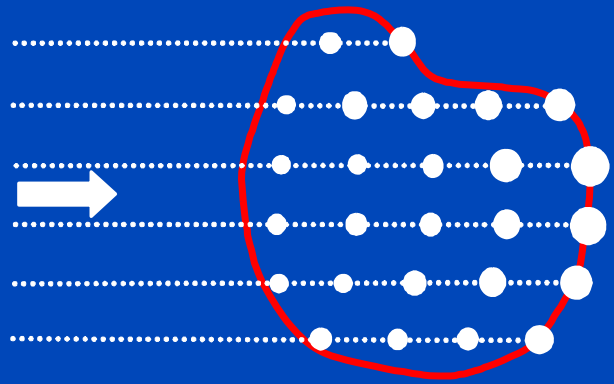
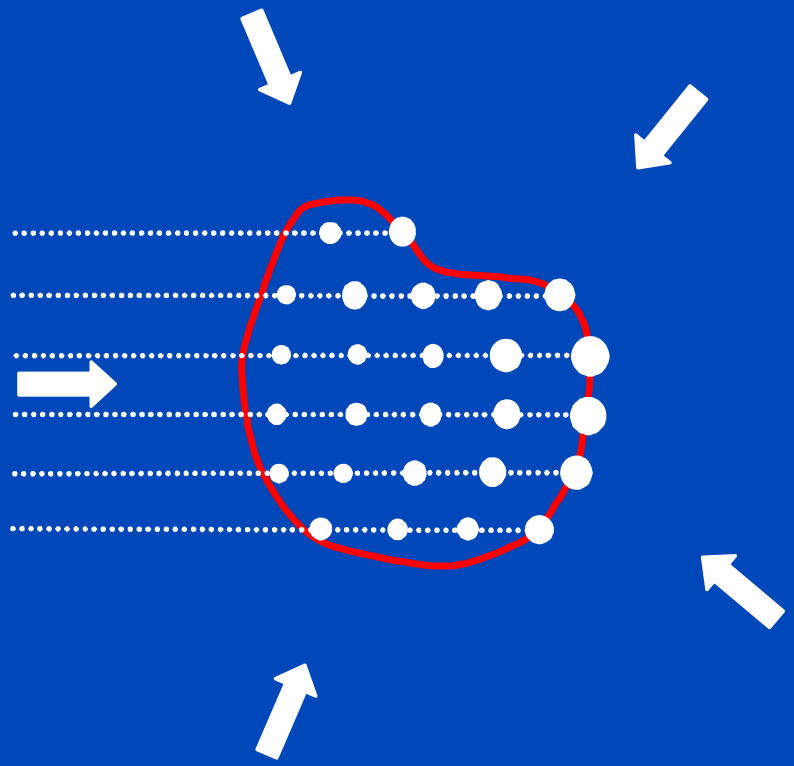
Spot positions in IMPT



Spot positions in IMPT



"full 3D modulation"

DET vs. 3D modulation

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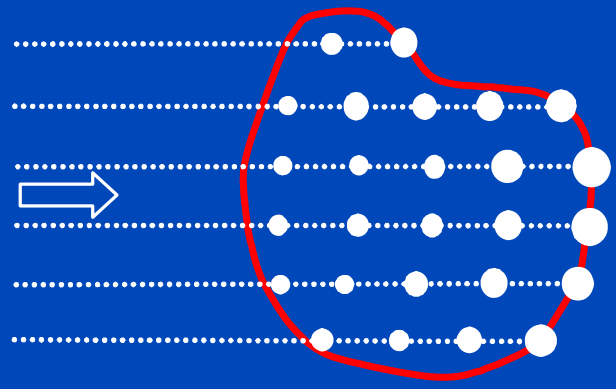
distal edge tracking

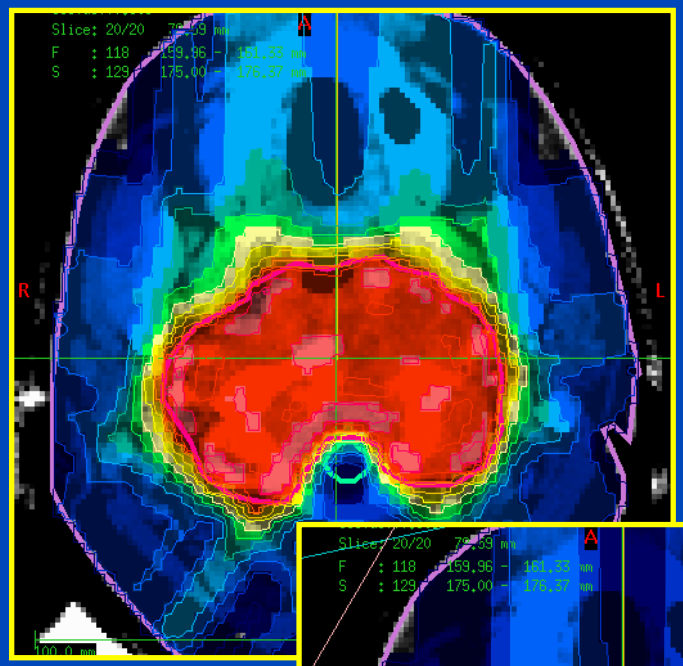
+ fast optimization
+ fast delivery
+ reduced integral dose

3D modulation



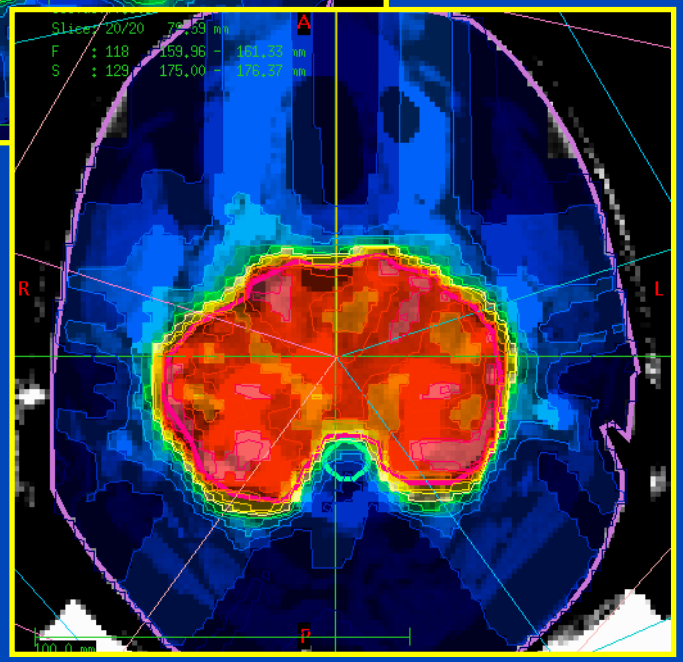
+ more degrees of freedom
+ less uncertainties
+ less fields
+ better biol. properties

Dose distributions for scanning techniques



full 3D modulation

- patient with clivus chordoma
- 5 coplanar fields

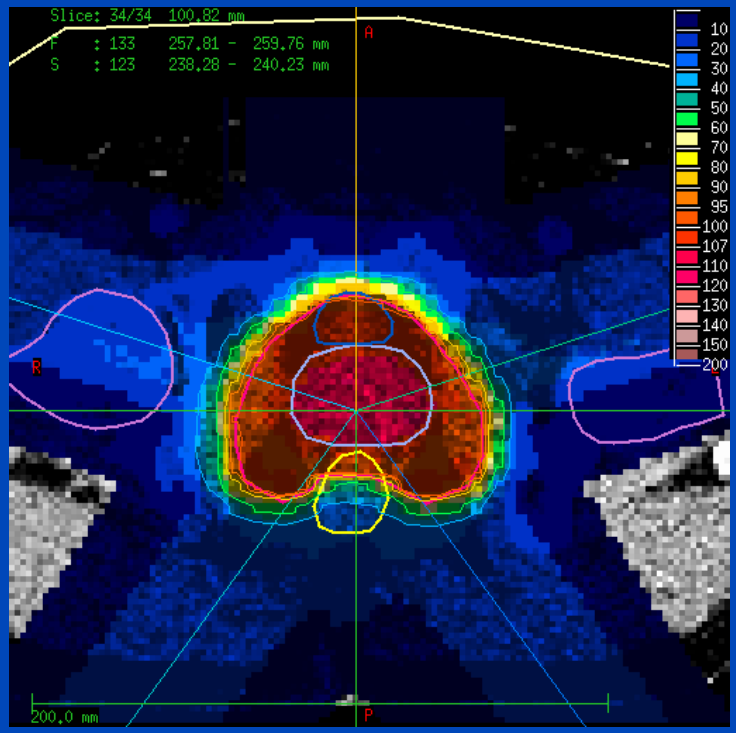


dose

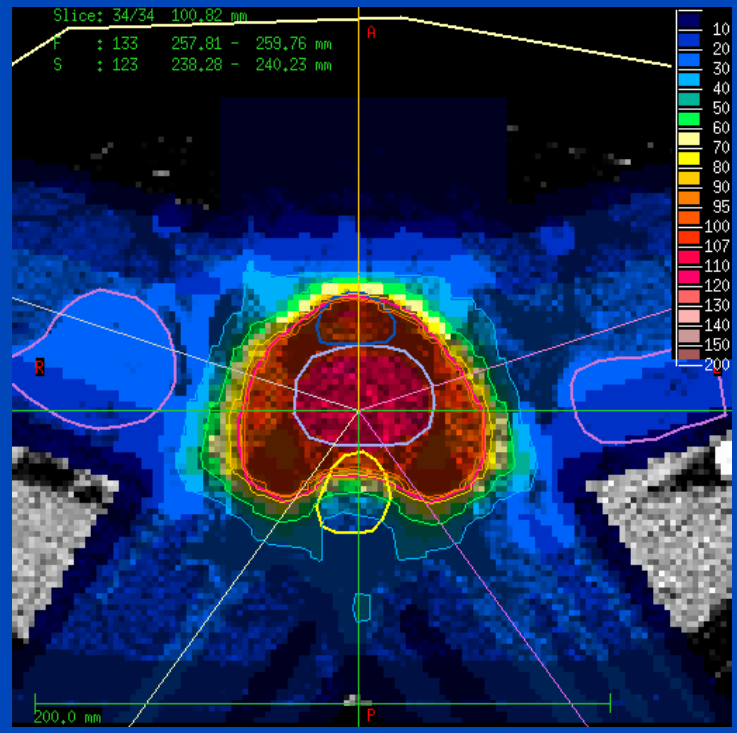
distal edge tracking

Dose distributions for scanning techniques

DET



3D



All plans normalized to median dose in target volume

Comparison of IMPT with IMRT

Fair comparisons should use the same planning platform!

- dose calculation grid
- planning objectives
- optimization algorithm
- …

research version of KonRad @ DKFZ:
multi-modality planning tool

KonRad Inverse Planning v2.2.15 - DEMONSTRATION PRODUCT - NOT FOR CLINICAL USE

Plan Output

Patient ID: clivus
Patient Name: test,test
Image Series: clivus000

Plan ID:
Plan #: 160
#Beams: 5 #Fractions: 1
INHO: ON
Linac: PRIMUS2,
Energy: 6.00 MV
MLC: TOSHIBA2
Mode: STEP

Image
Previous Next
Zoom + Zoom -
50 200
Window center Window width
Update each 5. iteration (fast)
Overlap Priority Image

Display
Organ Parameters DVH
CT (sagittal/frontal) Fluence
DVH (complete) Show sum of dose cubes

Setup
Sequencer Isodoses Normalization
Margining

Status
objective (relative diff.)
10.00
1.00
0.10
50 60 70 80 90 100 110 120
Rel Abs Org Last diff. [%] 0.2123

Optimization
Reset Start Stop

Transverse
CT/000/20
A
clivus
test,test
February 06, 2006
(0/-0)
(288/0)
(72/0)
R
L
(216/0)
(144/0)
50 mm
Max (slice): 69.21 Gy
58.70 Gy
Z: 78.58 mm
P

Dose-Volume-Histogram
Volume [%]
Sequencer: OFF
100
80
60
40
20
TARGET
PATIENTCONTOUR
BRAINSTEM
20 40 60 80
DVH (unnormalized) with exclusive volumes
Dose [Gy]

Organ Parameters

VOI	On/ off	Overlap Priority	Organ Type	Max Dose	Penalty	Min Dose	Penalty	DVH Points
[1] Target								
TARGET		1	1 2 3	61.0	10.0	58.0	100.0	
[2] Organs at risk								
PATIENTCONTOUR		---	1 2 3	60.0	1.0	0.0	0.0	
BRAINSTEM		2	1 2 3	10.0	1.0	0.0	0.0	
[3] Unclassified								
RIGHTEYE		---	1 2 3	1.0	1.0	0.0	0.0	
LEFTEYE		---	1 2 3	1.0	1.0	0.0	0.0	
LEFTOPTICNERVE		---	1 2 3	1.0	1.0	0.0	0.0	
RIGHTOPTICNERVE		---	1 2 3	1.0	1.0	0.0	0.0	

Accept Cancel

Status

Research version of KonRad

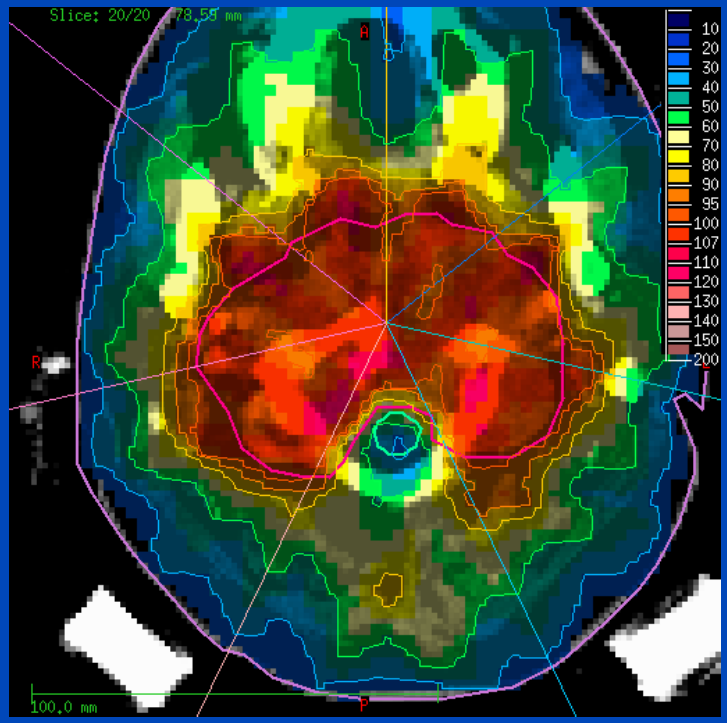
Modules in KonRad:

- radiation types
  - photons, electrons, protons, carbon ions
- dose calculation
  - pencil beam, 2D-PB, superposition, Monte Carlo, …
- optimization engines
  - gradient / Newton; L-BFGS
- biological optimization
  - RBE for protons and carbon ions

Nill S, Bortfeld T, Oelfke U (2004) "Inverse planning of intensity modulated proton therapy" *Z Med Phys* **14**(1) 35-40

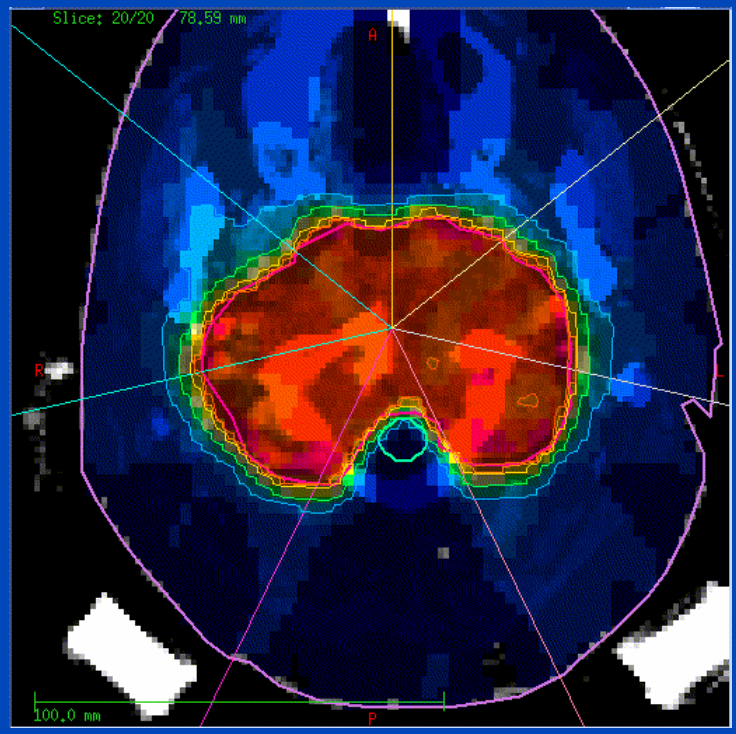
Comparison of IMRT with IMPT

Photon IMRT



Integral dose [a.u.]: 1.0

IMPT



0.438

Photon IMRT vs. DET / 3D protons

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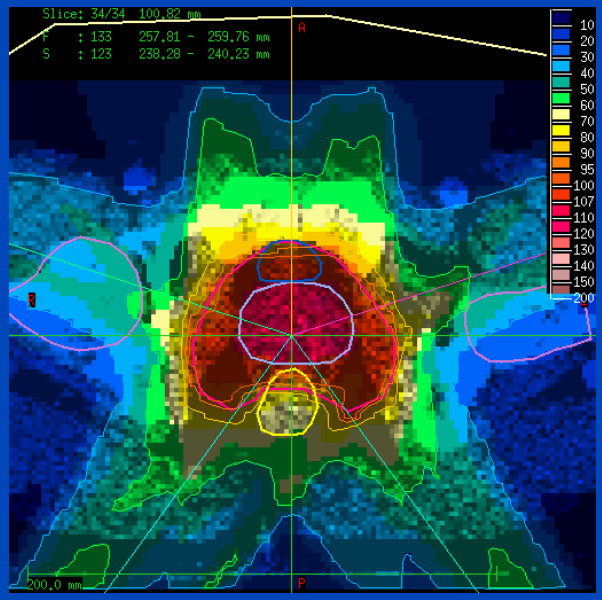
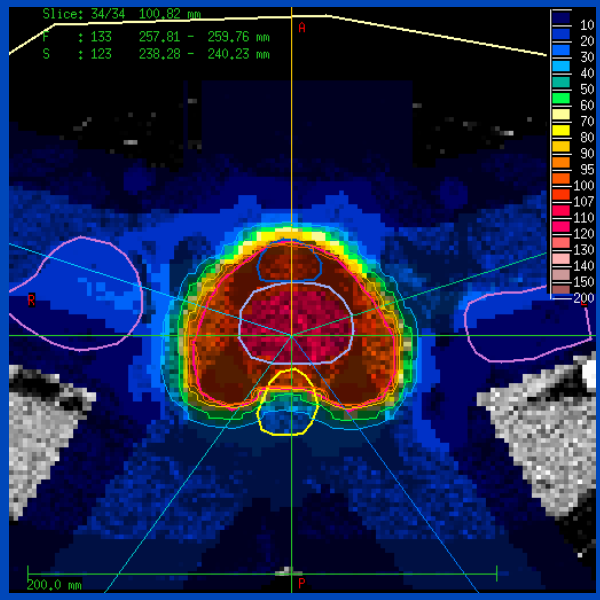
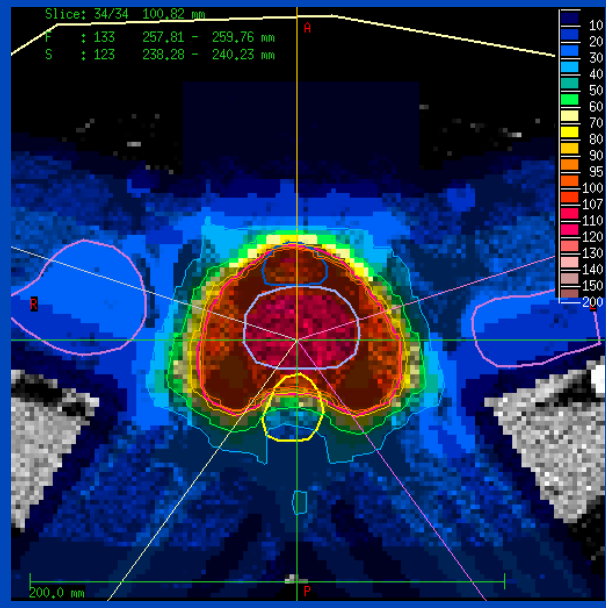
Photon IMRT	DET	3D
		
Integral dose [a.u.]: 1.0	0.40	0.46

Comparison of IMPT and IMRT

dkfz.

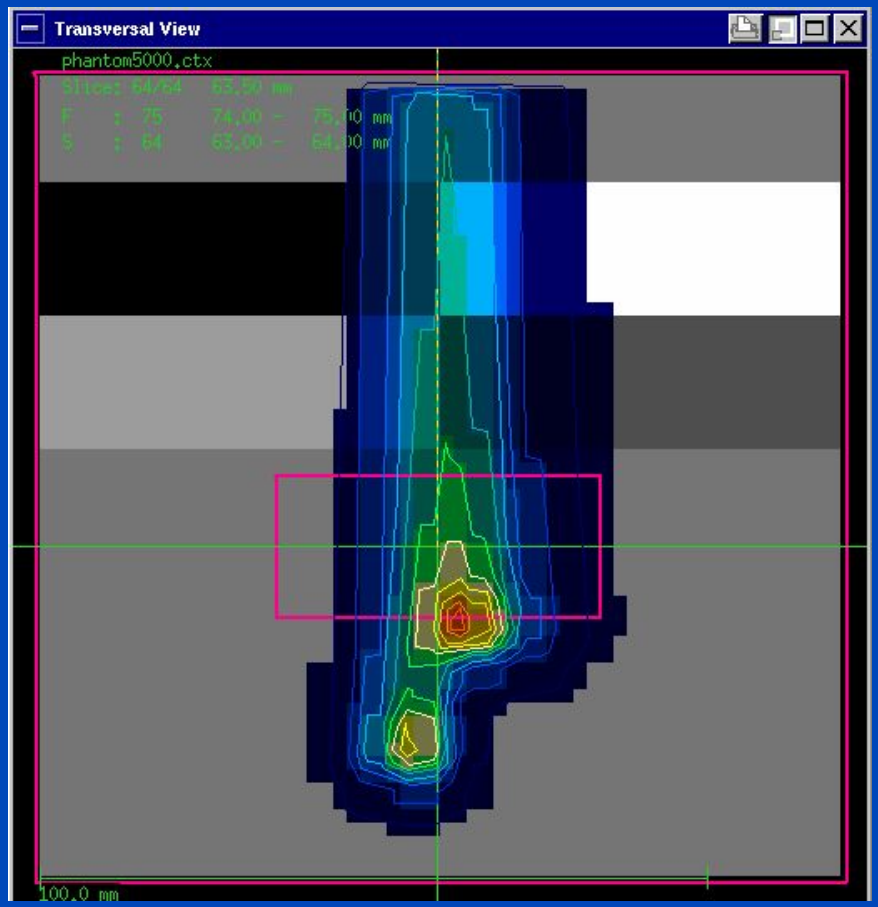
Results for IMPT:

- No significant improvement for the target dose distribution compared to photon IMRT
- Significant reduction of the mean dose for the organs at risk
- Significant reduction by a factor 2-3 for the integral dose

- For deep seated tumors: lateral penumbra for protons similar to photons!

Risk adapted planning

Risk adapted inverse planning

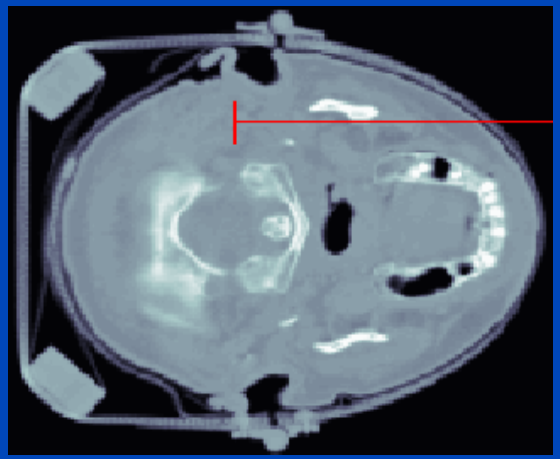


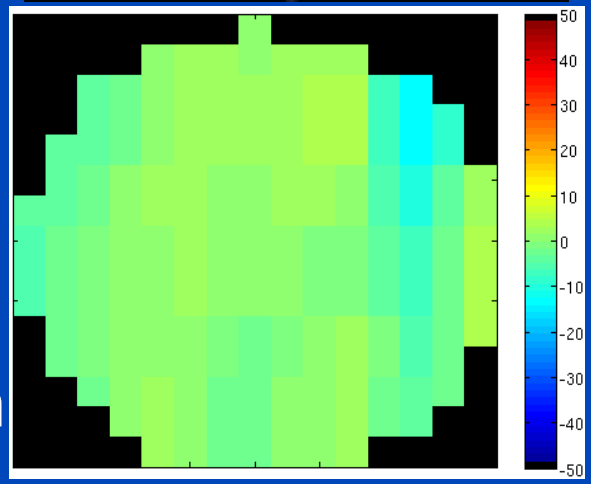
Tissue inhomogeneities

- degradation of the Bragg peak if beam spot is parallel to an interface
- cause problems for dose calculation
- very sensitive to motion and set-up errors

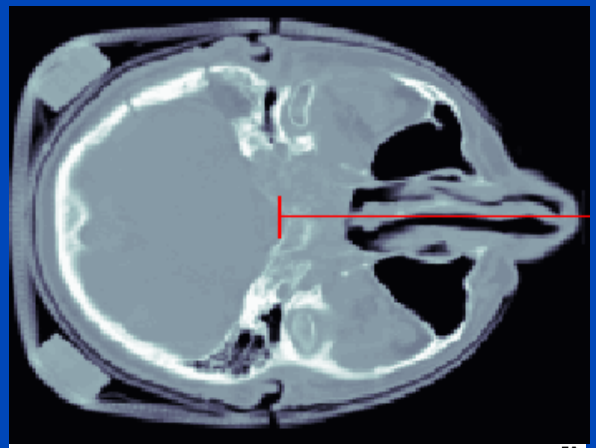
⇨ do not use such spots!

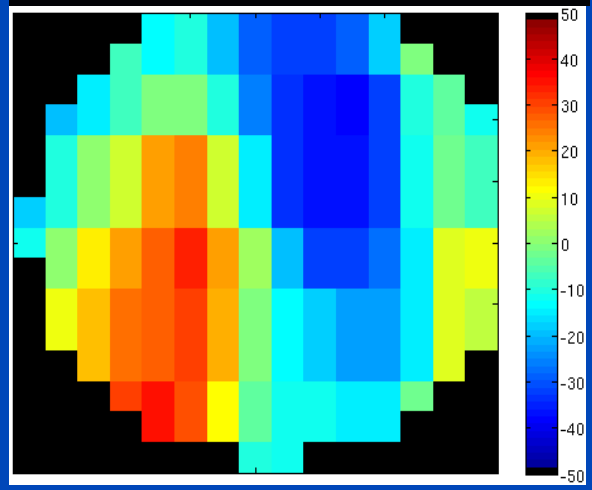
Heterogeneity index H





H=2.3mm



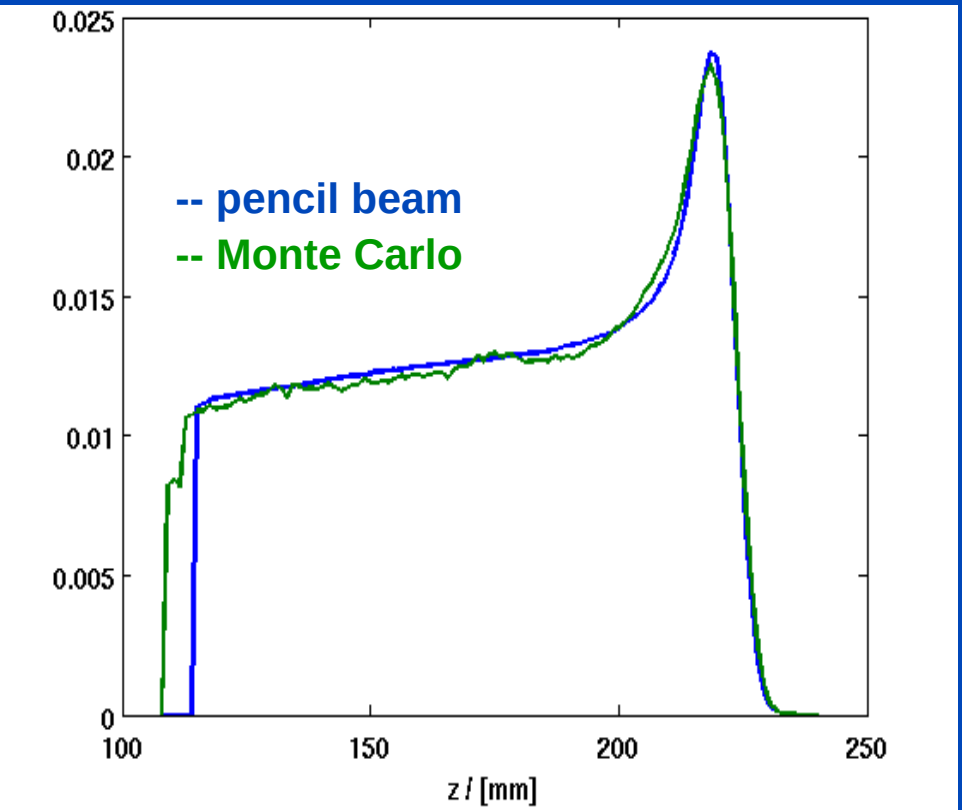


H=24.1mm

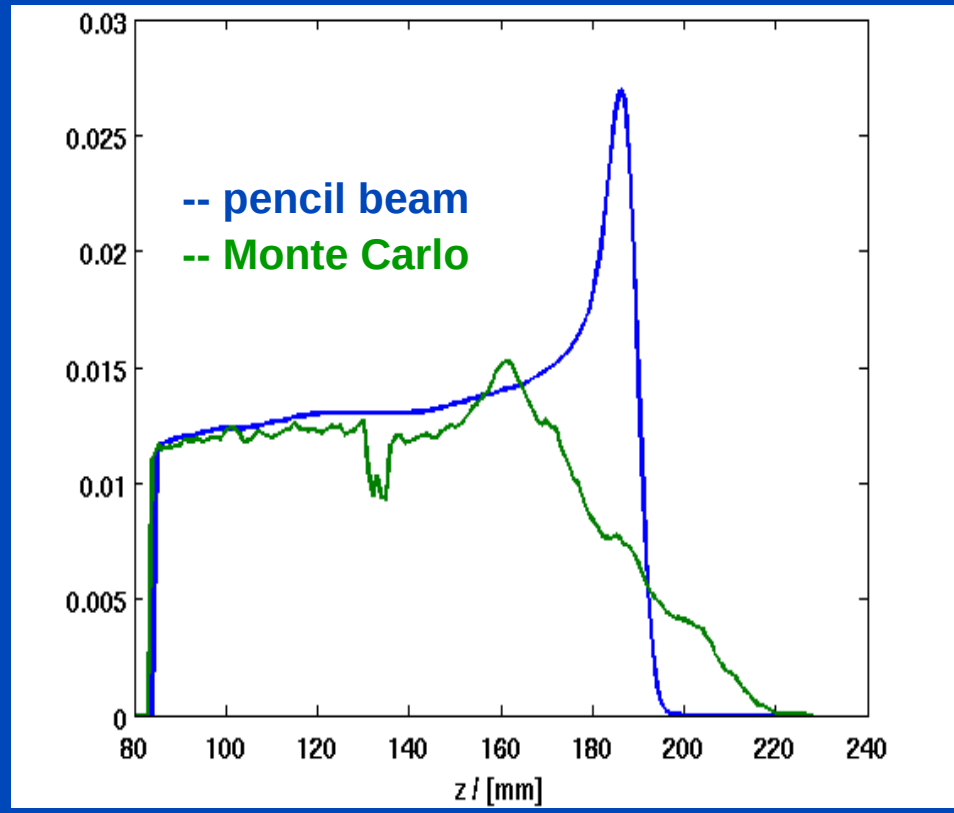
Pflugfelder D., J.J. Wilkens, H. Szymanowski and U. Oelfke (2007) "Quantifying lateral tissue heterogeneities in hadron therapy" *Med. Phys.* 34(4) 1506-1513

Example for small / large H:

H=2.3mm



H=24.1mm



spots with large H can be penalized in the optimization!

Acknowledgements

Thanks to:

- Simeon Nill
- Uwe Oelfke
- Daniel Pflugfelder
- Hanitra Szymanowski

- our clinical partners

- Siemens Medical Solutions