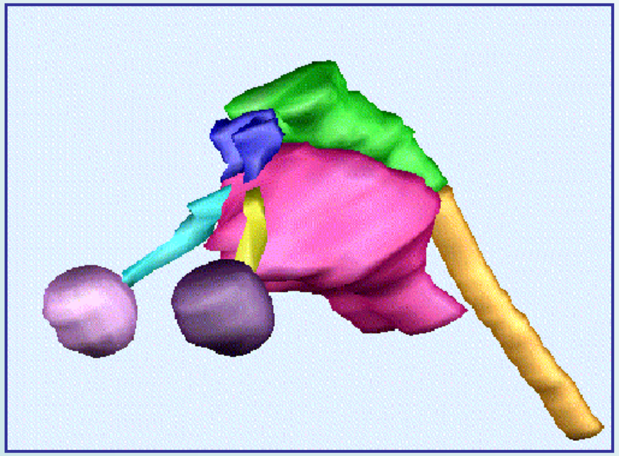
IMPT with Carbon Ions



PTCOG 48, Heidelberg, 28.09.-03.10.2009

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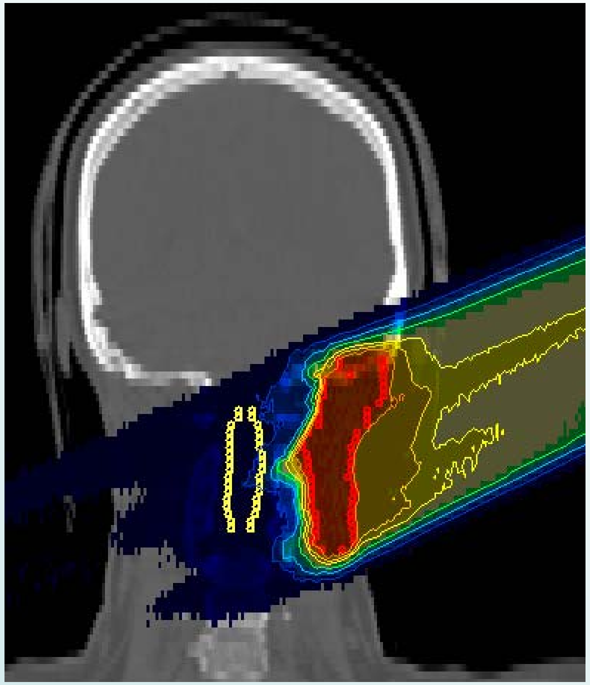
Setting the stage

„Planning with protons/ions is a real pleasure!“ (A. Mazal)

Already for a single field…

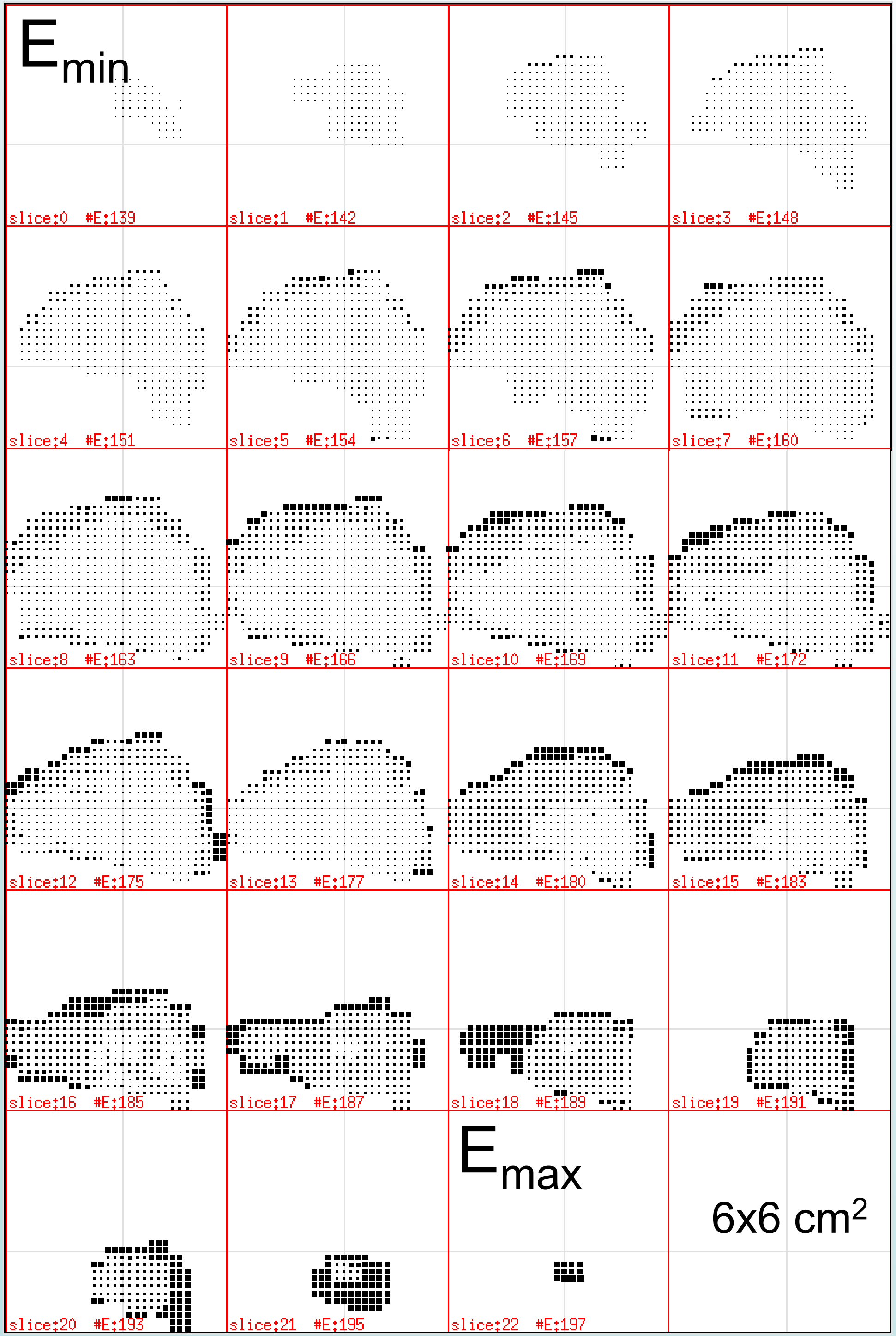


Basis also for multiple fields:

SBO: Single Beam Optimization (A. Lomax: SFUD)

→ Individual dose optimization of each field

SBO – Scanspot Distribution



Single field of a two beam prostate plan with SBO, i.e. homogeneous dose of individual fields

23 energy slices

pixel size $\propto$ part. Number

- **Already fluence modulated RT**

  → „Ion IMRT“

a-ha!

Setting the stage cont´d

SBO: Single Beam Optimization (A. Lomax: SFUD)
→ Individual dose optimization of each field

´easy´
~unique solution

SBO is fine!

However, let‘s explore

the full potential of ion beam scanning

IMPT: Intensity Modulated Particle Therapy
→ Simultaneous dose optimization of all fields

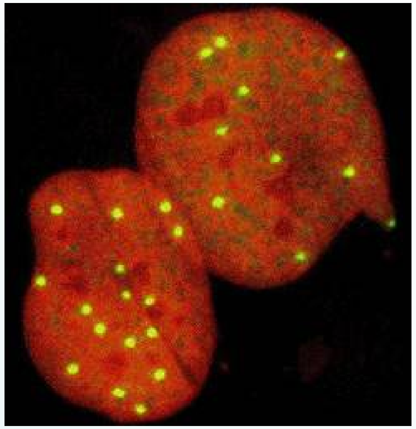
´easy´ as well
degeneracy**!!!**

Outline

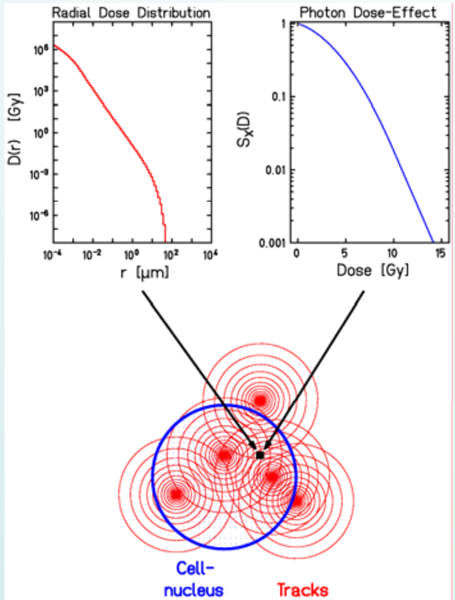
- What‘s so special about Carbon Ion IMPT?
- Clinical implementation of IMPT at GSI
  - IMPT at GSI
  - Robustness of IMPT plans
- Dose modulation of IMPT fields
- IMPT at HIT
- Summary & Outlook

Carbon Ion IMPT

The difference to proton IMPT? → BIOLOGY!



- RBE weighted dose optimization for all fields simultaneously!
  - the depth modulation varies for every point in the field
  - consider particle spectrum (fragments!) in every point in 3D
  - detailed biological modeling necessary (LEM model)
  - optimization of absolute value of dose and particle numbers (cf. „Biological Treatment Planning“, T. Elsässer, Tuesday)



- Time and memory consuming dose optimization!
  - RBE weighted dose
  - Multiplication of beam spots / ndof

- Clinical treatment planning
  1) **Phys. absorbed dose**
     derive suitable plan and optimization parameters, help-contours, …
  2) **RBE weighted dose**
     apply parameters found in 1)

~minutes calc. time

~hours…

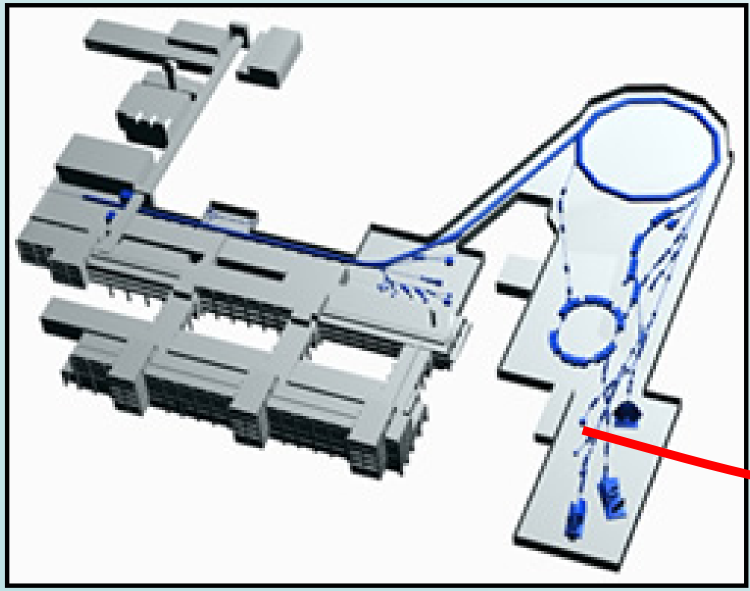
Clinical Treatment Planning Systems:
TRiP98BEAM (GSI), *syngo* PT Planning (Siemens)

Ion beam IMPT

- IMPT – also SBO – requires few fields only
  - Advantage of active depth dose modulation
  - Plan application time ~ number of fields
  - Reliable ion count and position measurement during beam application
    → lower limit ~5.000 carbon ions per beam spot, corresp. to ~10 mGy (peak)
  - GSI experience: **two fields** sufficient in most cases, **max. 3 fields**

Pilot Project at GSI: ^{12}C Beam Scanning

GSI: Gesellschaft für Schwerionenforschung, Darmstadt



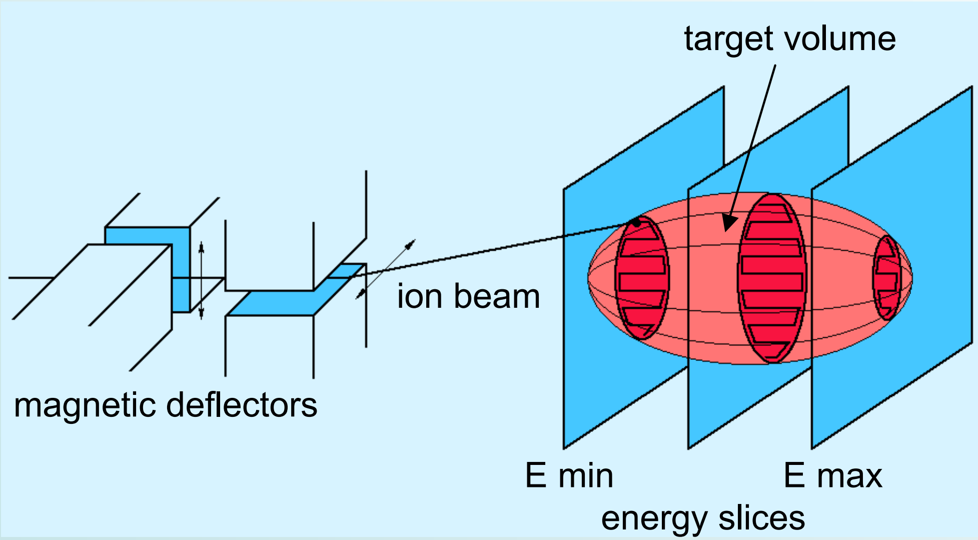
Basic research facility

Fixed beam line

Beam line

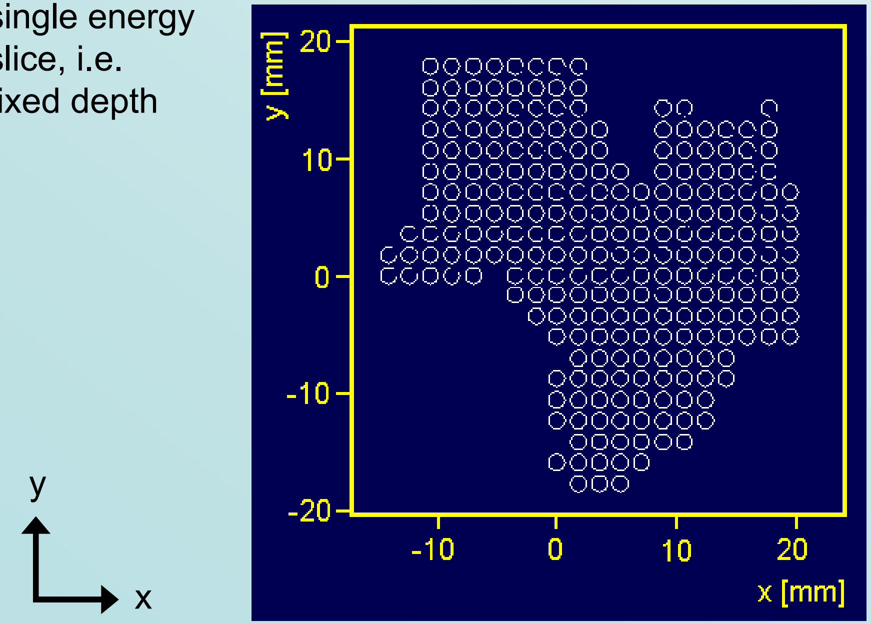
- **Carbon ion radiation therapy 1997-2008**
- **3 treatment periods of 4 weeks per year**
- **In total 437 patients treated**

Carbon ion therapy at GSI



- Raster scanning system with active energy variation
- Typical treatment plan
  - energy steps ≈ 3 mm depth
  - transverse raster size 2..3 mm

single energy slice, i.e. fixed depth



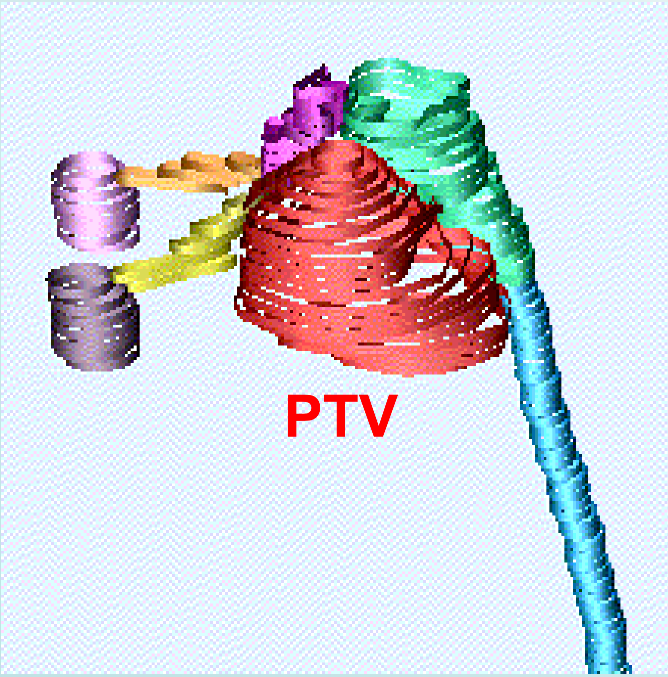
Up to ~50.000 raster points / field

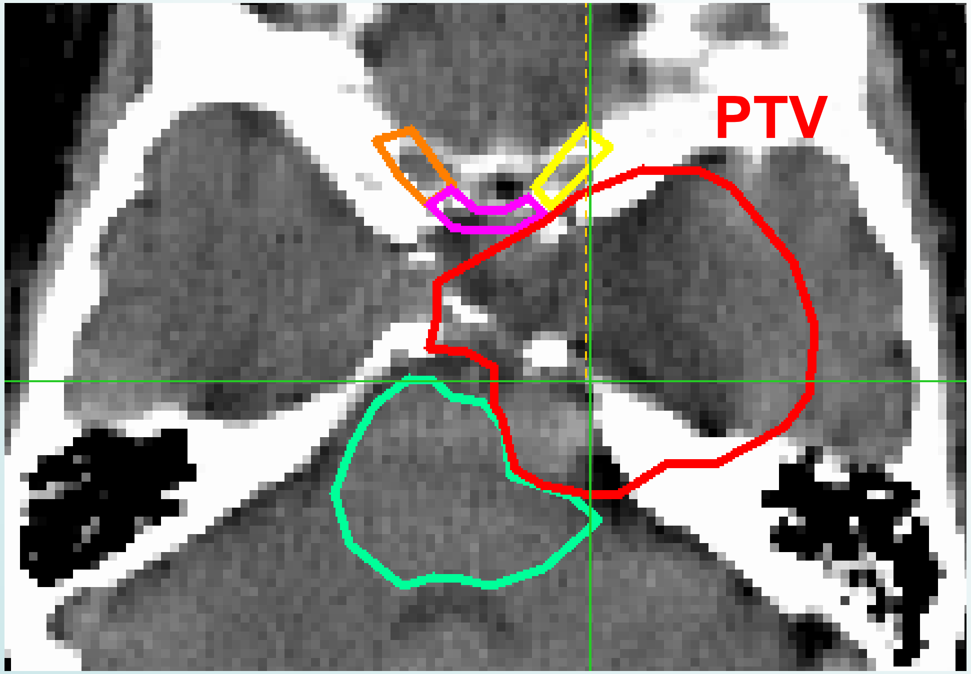
→ **Dose optimization to derive number of particles for each raster point:**

TRiP treatment planning software

Typical indications

- Deep seated tumours at the skull base (Chordoma, Chondrosarcoma)
- Surrounded by brainstem, chiasma, optical nerves, …



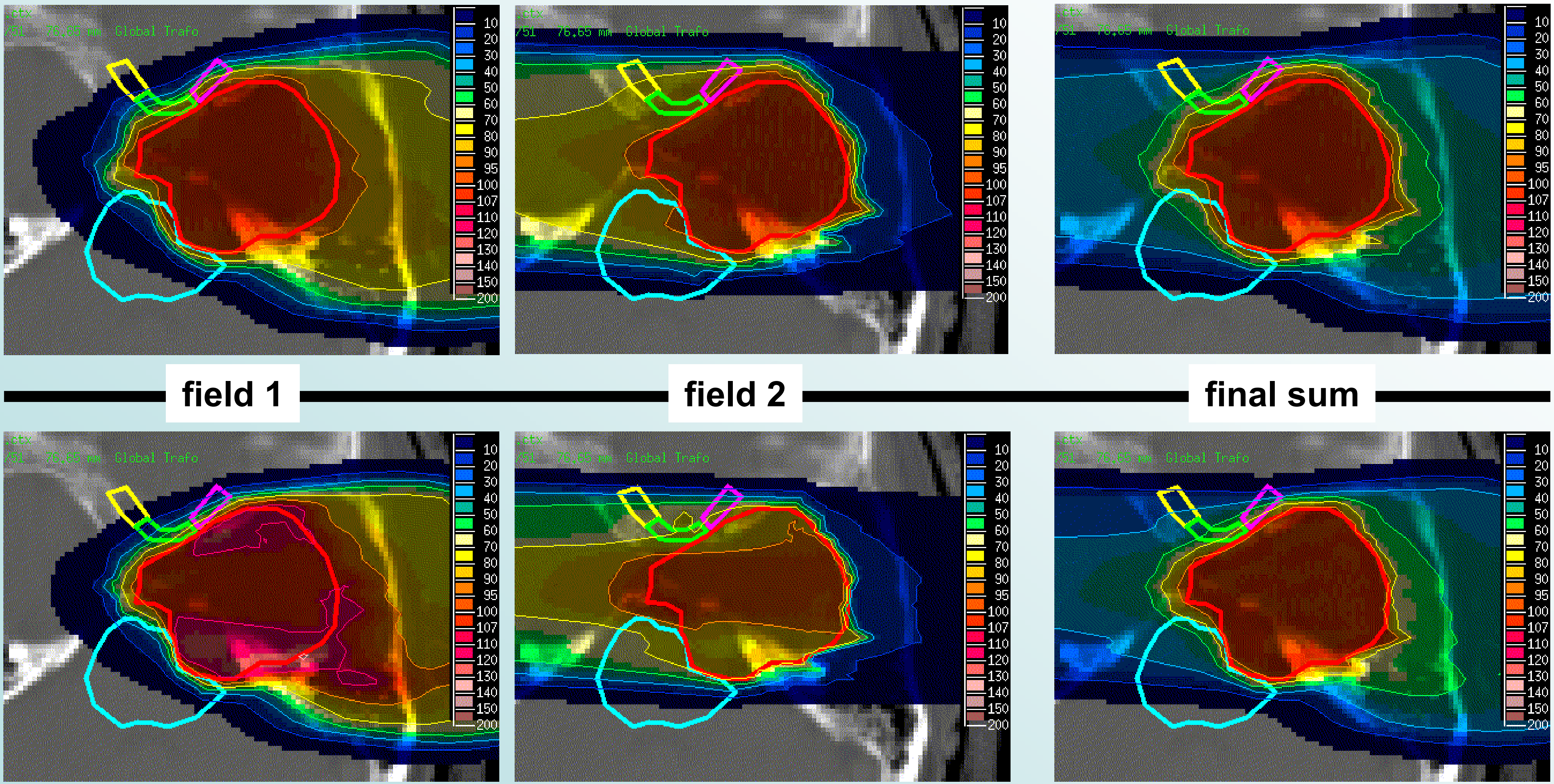


Treatment: Two lateral fields (horizontal beam line)

From SBO to IMPT

Individual single field dose opt.

SBO

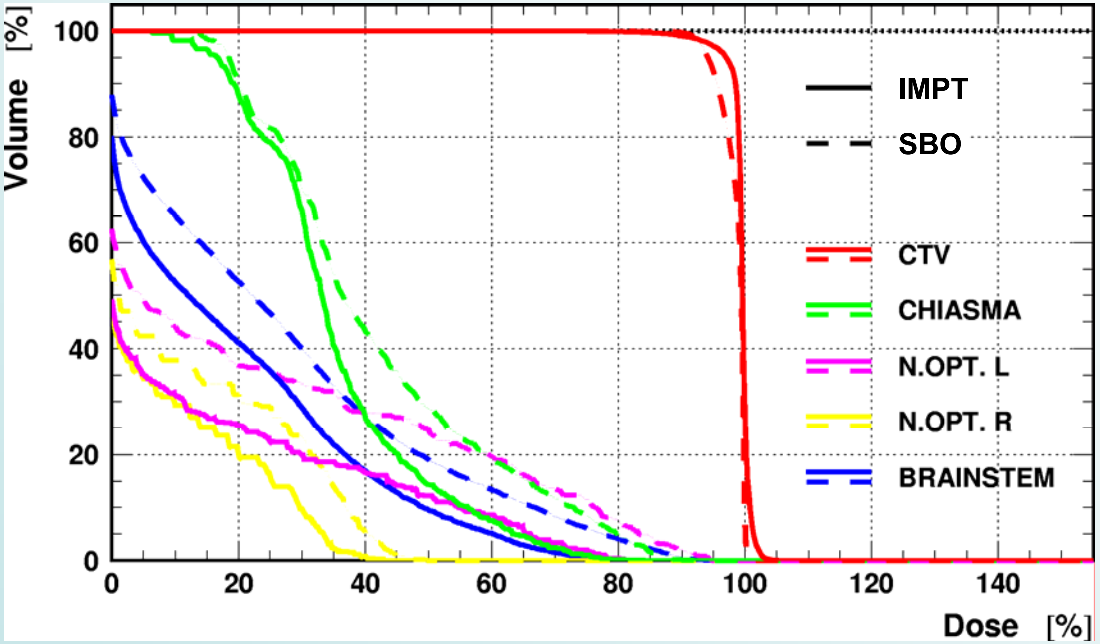


Simultaneous multiple field dose opt.

IMPT

IMPT – Dose volume evaluation

Comparison of IMPT with SBO:

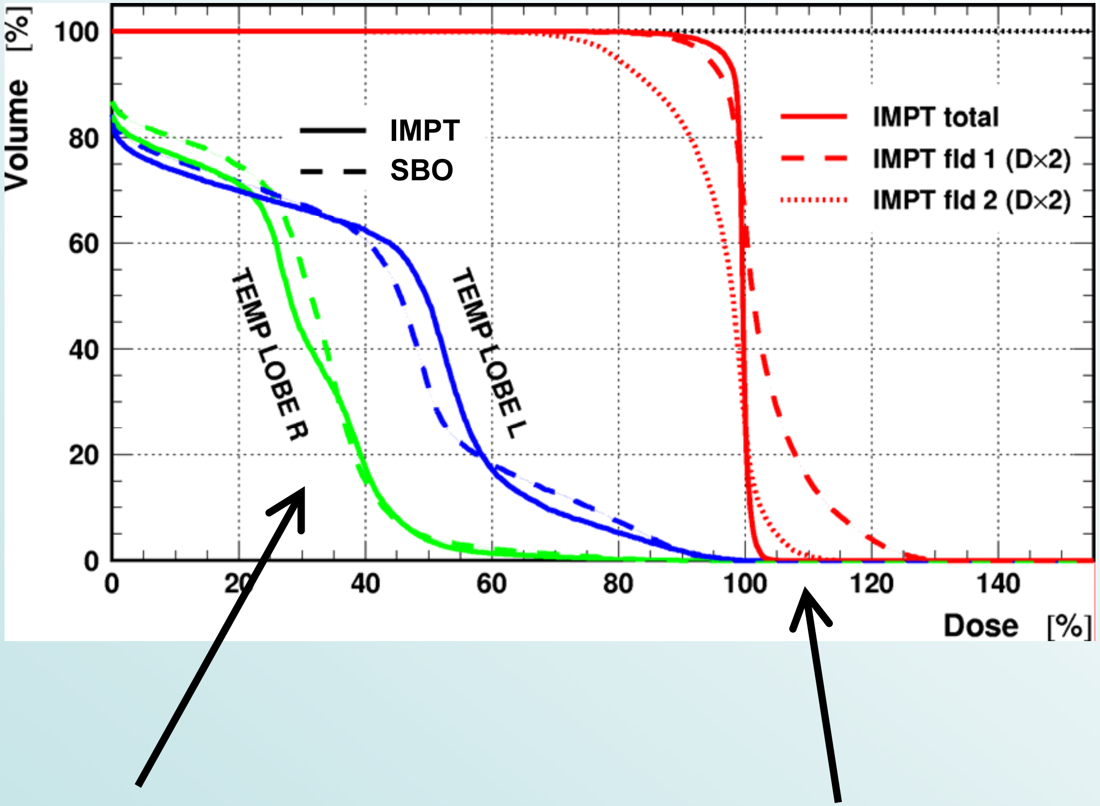


IMPT – **TARGET:** increased dose conformity, improved homogeneity
OARs: significantly improved sparing

Especially for convex/concave target/OAR situations of high curvature,
e.g. spinal cord, optical nerves

Holds true as well for IMPT compared to field patching and ramp techniques

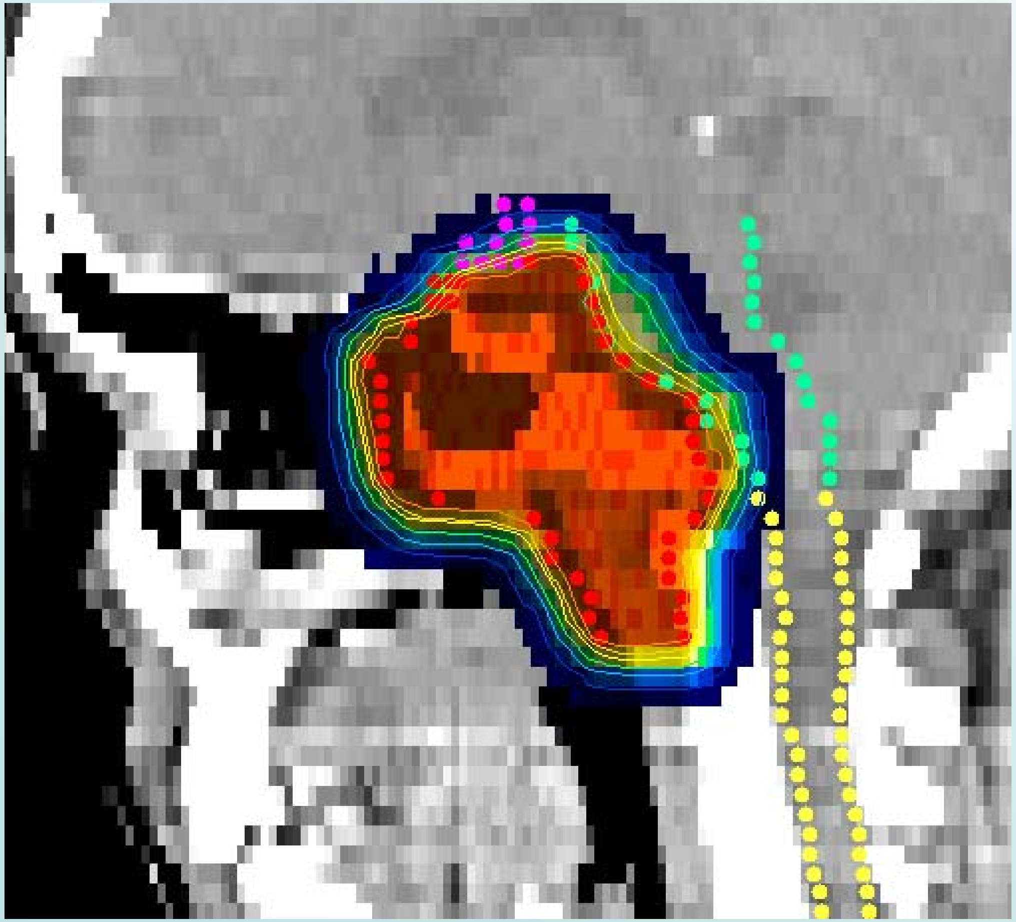
IMPT – plan evaluation

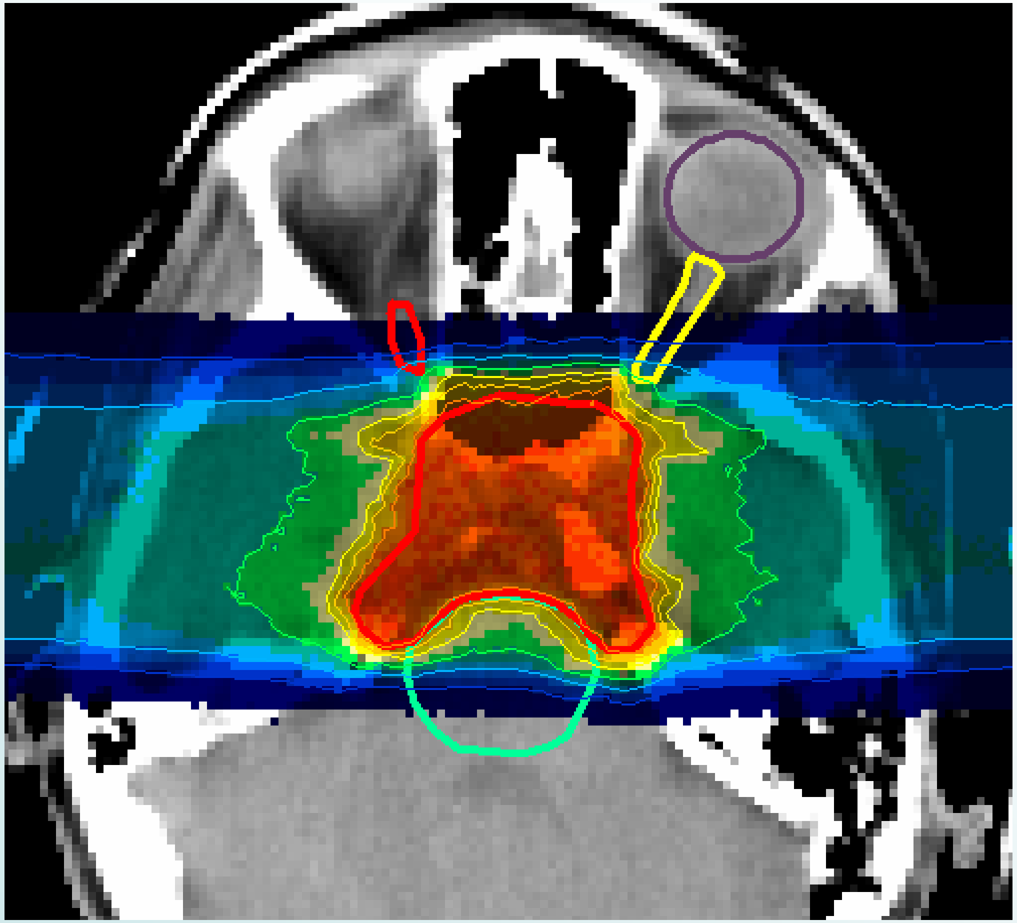


- Improvements / no disadvantages for normal tissue, not considered during dose optimization
- **Only moderate dose modulations between fields!**

IMPT – dose shaping (1)

Chordoma at the skull base: (15+5) Fx á 3 GyE

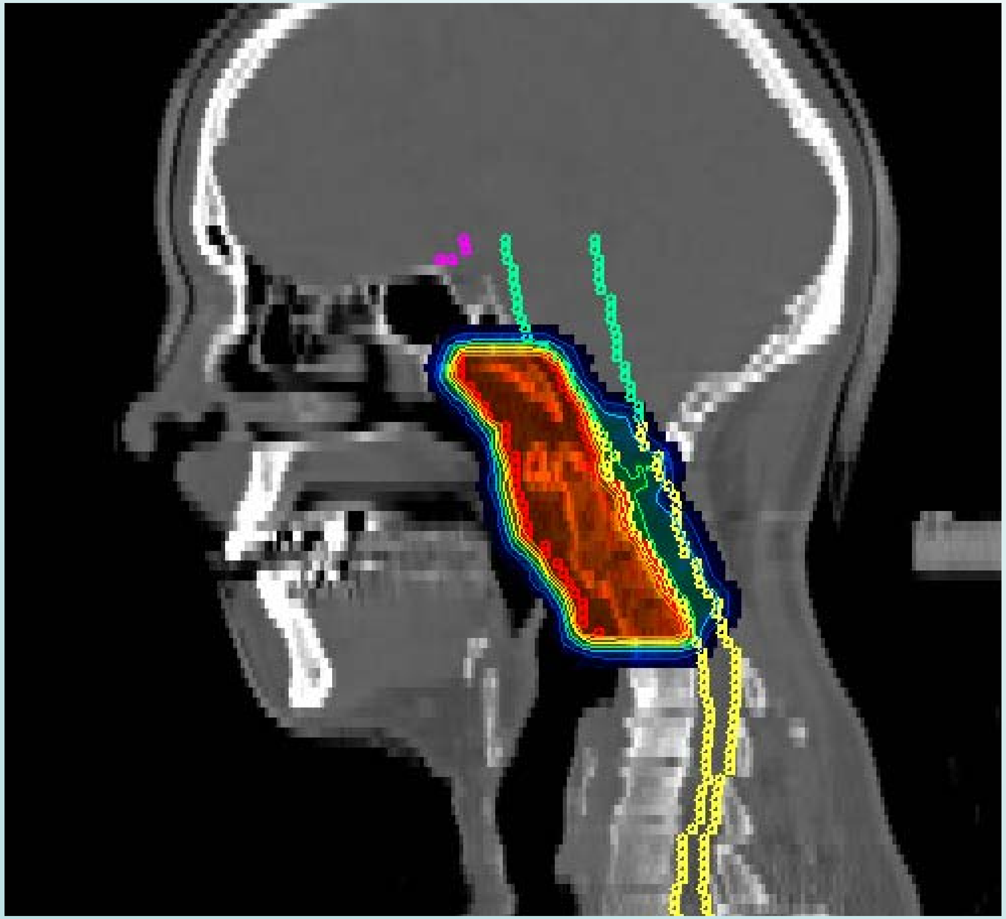


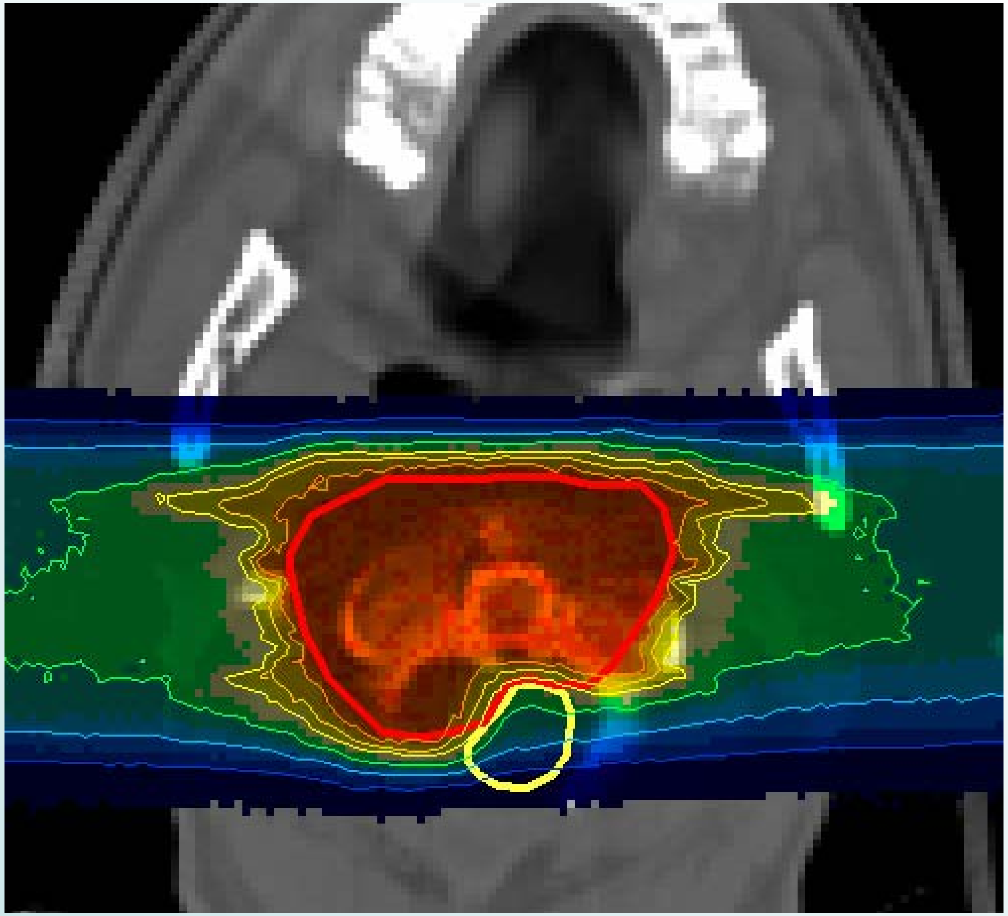


- Shaping the 90% isodose to the PTV wrapping around the brain stem
  ➔ IMPT makes use of increased ndof to obtain optimal shaping

IMPT – dose shaping (2)

Chordom at skull base down to C2, 1995 photon RT with 56 Gy
15 Fx á 3 GyE, myelon < 30 GyE





- Maximize target coverage while respecting myelon dose constraint

Clinical implementation of IMPT

… to explore the full potential of ion radiation therapy
… to improve the efficiency of treatment planning

- ✓ TRiP98BEAM dose optimization – numerical methods
- ✓ Biological verification of multiple field dose optimization

A. Gemmel et al *Phys. Med. Biol.* **53** 6991-7012, 2008

- ✓ Suitable dose optimization parameters
- ✓ Feasibility using the GSI raster scanner
- ✓ Real patient plan dose verification measurements

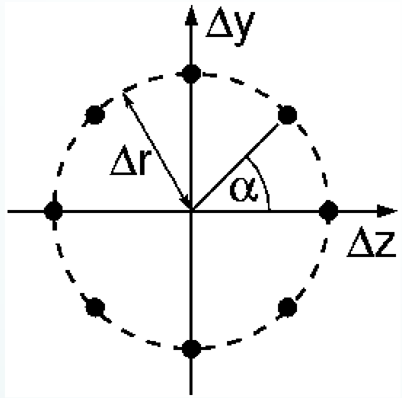
Major concern:
Fields of inhomogeneous dose distributions complement one another
→ sensitive to patient positioning issues and ion range uncertainties

- **Robustness of IMPT plans concerning**
  - **a) positioning uncertainties**
  - **b) ion range uncertainties**

compare IMPT with SBO

a) Robustness of IMPT plans concerning positioning uncertainties

Displace target point and re-calculate the dose distribution using the origial treatment plan

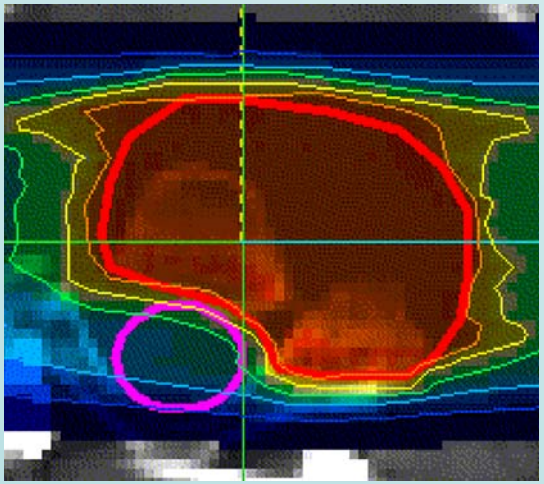


Here: Shifts perpendicular to beam direction (x)
Δr = 1-2mm, α = 0, 45, 90, …, 315°

Compare: ~2mm accuracy by head mask fixation
~1mm due to orthogonal radiographs before each fx

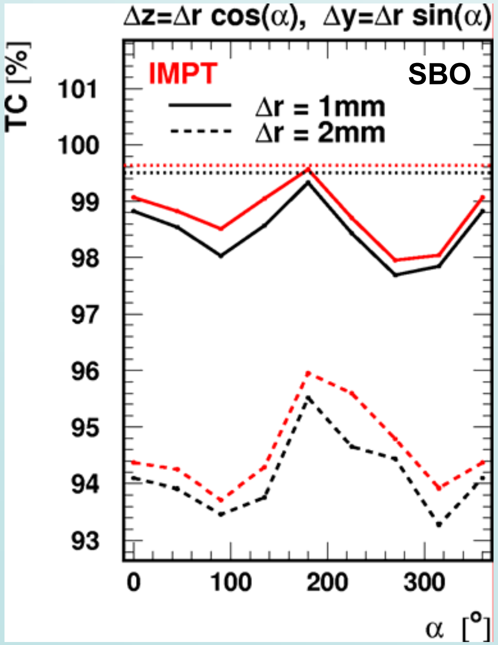
Example:

PTV

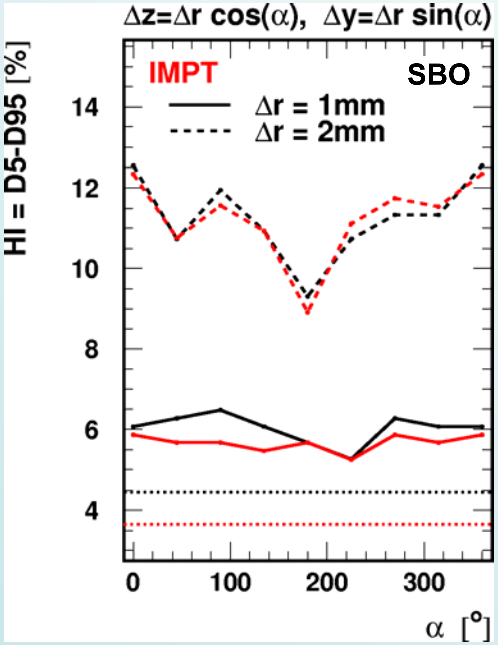


Spinal Cord

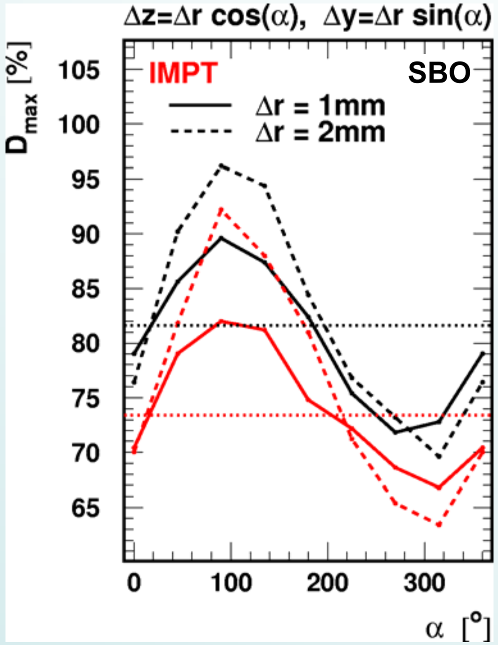
Target Coverage



Target Homogeneity



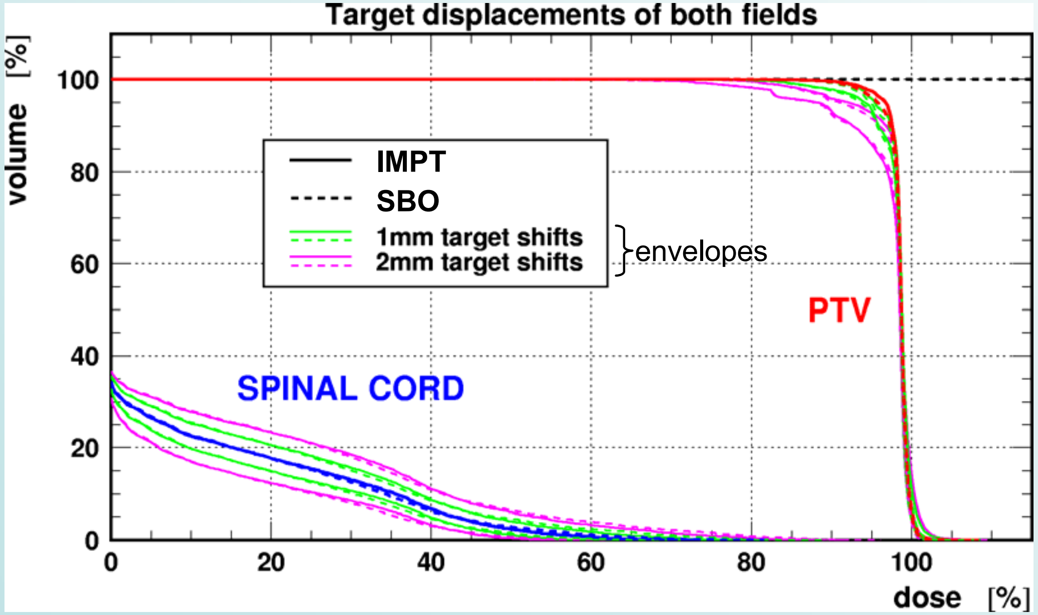
Spinal Cord D_{max}



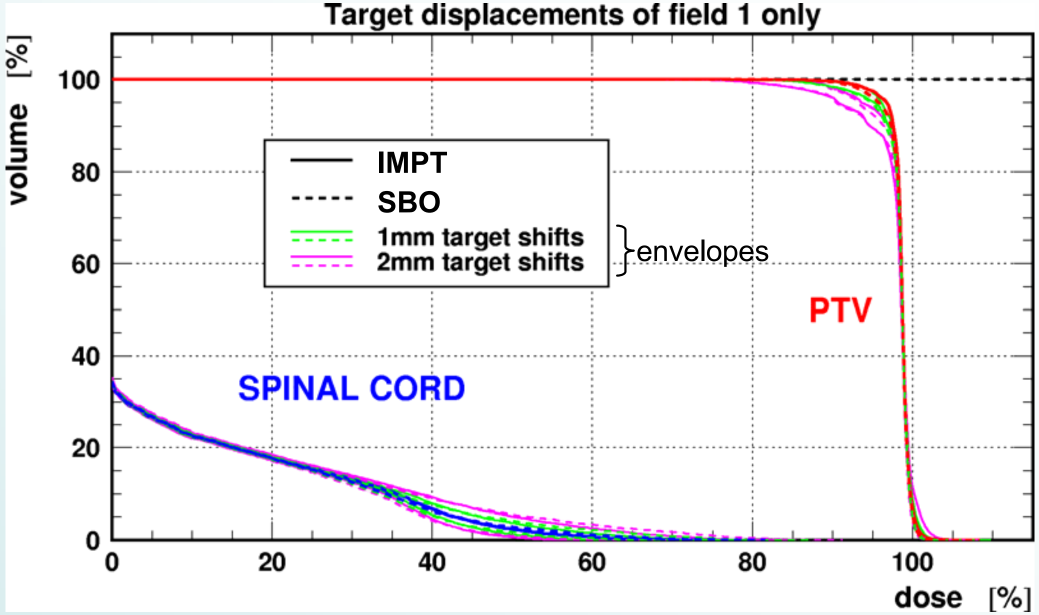
→ at worst, originally beneficial IMPT plan gets as critical as SBO plan

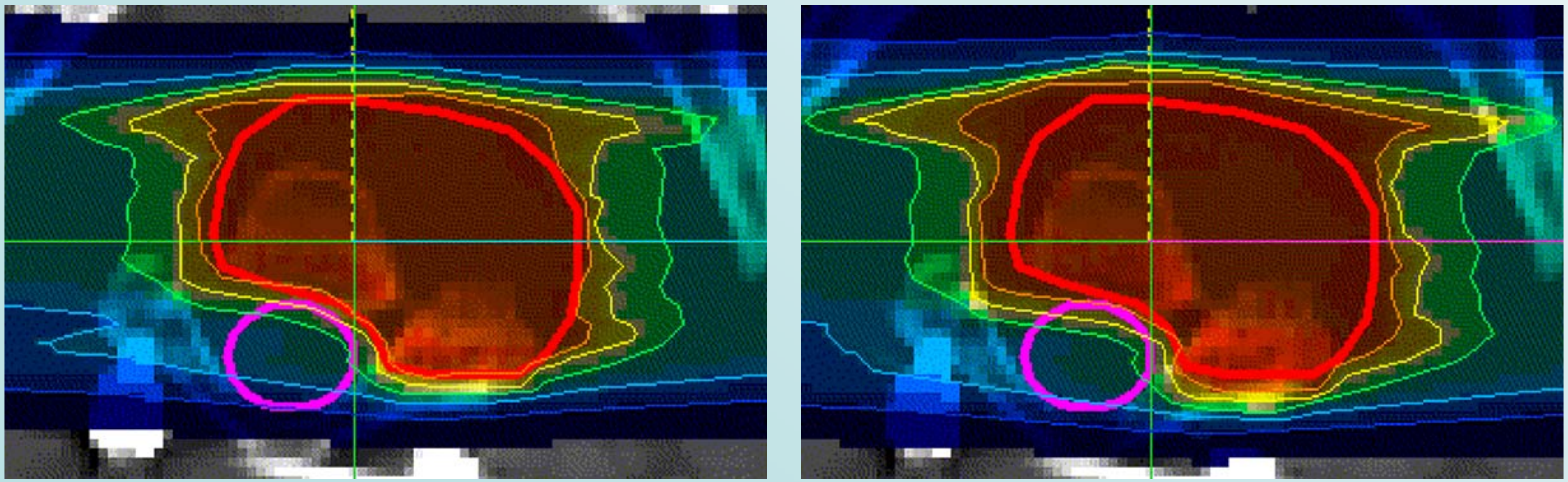
a) Robustness of IMPT plans concerning positioning uncertainties cont'd

inter-fractional movement



intra-fractional movement





IMPT

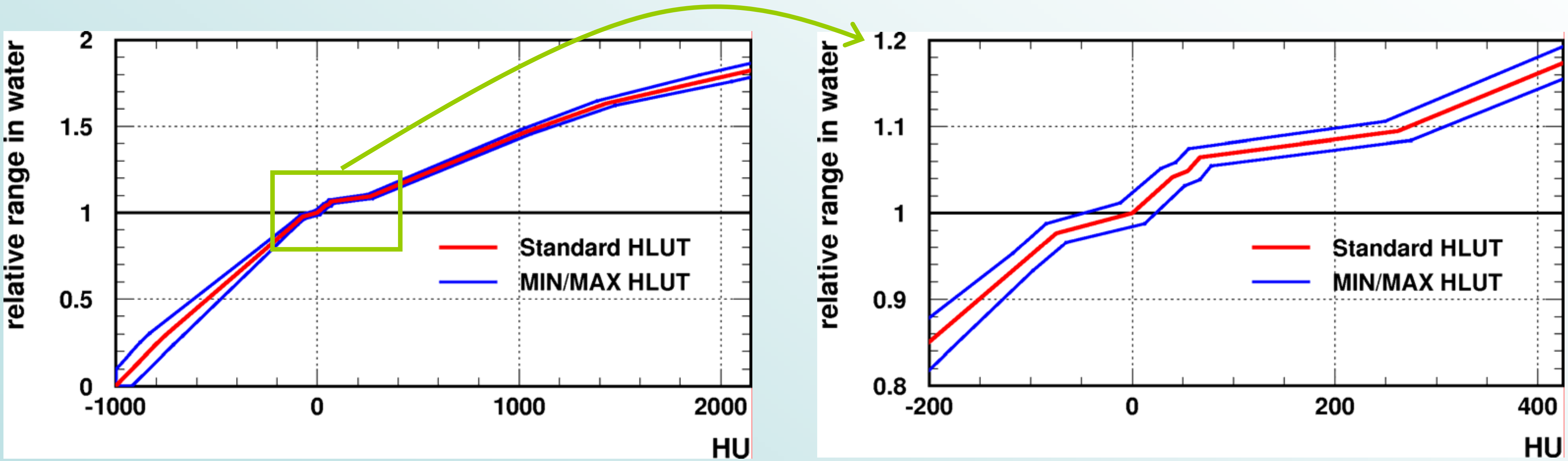
left: orig. plan

right: „worst case" maximum dose of all 2mm target point displacements

b) Robustness of IMPT plans concerning range uncertainties

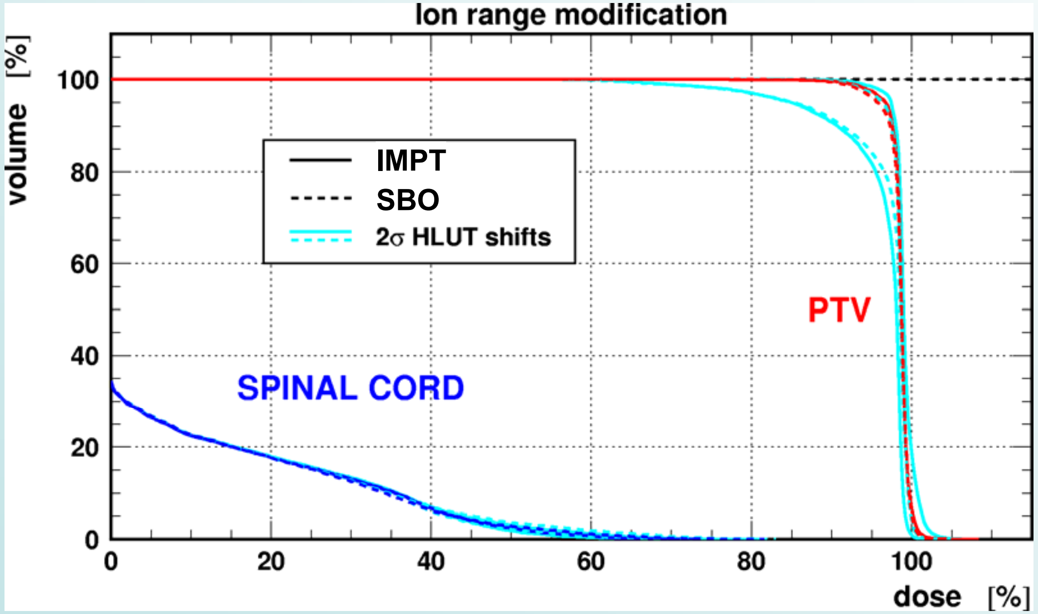
Modify CT calibration HLUT (HU ↔ relative range in water), about 2% in soft tissue
3% in lung and bone

According to investigations on CT and ion range measurements, S. Qamhiyeh, PhD thesis, Univ. of Heidelberg, 2007



- Simulates improper knowledge on HLUT and e.g.
  weight loss of patient
  influence of metal implants
  …

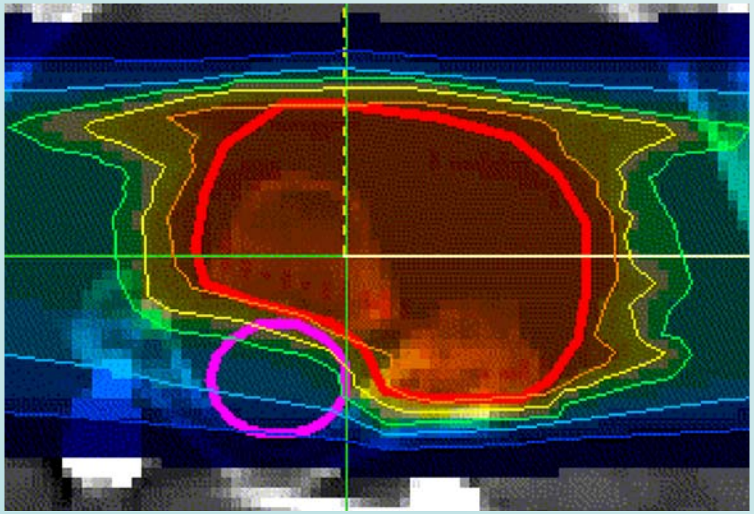
b) Robustness of IMPT plans concerning range uncertainties cont'd



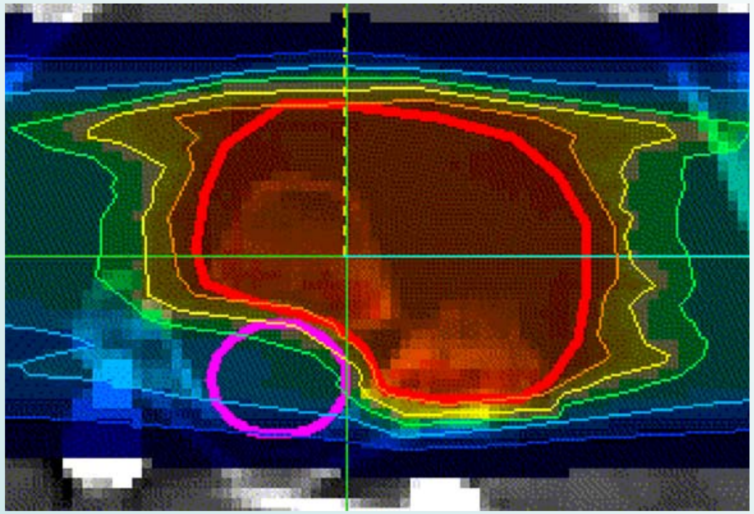
MAX HLUT: shorter ion range
target underdose

MIN HLUT: larger ion range
~ no effect on TC
OAR may suffer

SBO:



IMPT:



SBO and IMPT plans re-calculated using MIN HLUT → **IMPT plan superior**

Robustness of IMPT plans

General conclusions

... based on investigations of many (>20) different treatment plans and considering all directions for displacements and rotations:

Compared to SBO carbon ion treatment plans
(homogeneous dose distributions of individual fields)

- IMPT plans are superior
- at worst, originally beneficial IMPT plans get as critical as SBO plans

Note: IMPT restricted to moderate dose modulation of single fields

SBO	**50/50**	
IMPT	**< ~70/30**	(< 60/40 for larger vol.) → **close to SBO**

Summary: IMPT at GSI

Carbon ion IMPT for skull base tumors

- **yields convincing results**
  - increased TARGET conformity, improved sparing of OARs
  - feasibility (raster scanner, dosimetry, …)
  - enhanced robustness of treatment plan application
- **entered clinical routine at GSI**
  - ~30 patients treated with carbon ion IMPT plans at GSI since 2007

Dose modulation of IMPT fields

- **Moderate dose variations between fields** (<~70/30)
  - Complement of fields with moderate dose gradients within target volume
    ➔ plan robustness concerning positioning uncertainties is predominantly driven by tissue heterogeneities

  - **Already significant dose distribution improvements**
  - **Still save enough for reliable plan application to patient**

- **Strong dose variations** (up to 100/0)
  - Even better dose distributions (central plan)
  - Fields with steep dose gradients within target volume
  - Robustness may decrease → requires careful checks!

  - **Weigh up dose distribution vs. application reliability**

➔ May need some discussion and dedicated analysis…

Plan robustness

Robustness of plan application is an issue for **both SBO and IMPT plans!**

- **Position and range uncertainties** - weighting „good“/„bad“ beam spots
  - Consider lateral tissue heterogeneities
    - Port homogeneity index PHI (Ammazzalorso et al, Thursday talk)
    - Homogeneity index H (Pflugfelder et al.)
    - …
  - and range uncertainties
    - Risk adapted plan optimization (Unkelbach et al.)
    - …

- **Beam angle configuration**
  - Beam angle optimization considering plan robustness
    - Input: „good“/“bad“ beam spots
  - Beam angle optimization considering plan quality
    - Simultaneous optimization of beam angle and dose (and robustness)

  → Especially useful for gantry!

Many tools are just evolving, to be evaluated and optimized…

Plan evaluation – not only for IMPT

Treatment planning systems should provide

definitely

- Display beam dose distributions
  - Dose gradients of complementing fields
- Display scan spot distribution
  - Connectivity of scan spots
  - Range of particle numbers → estimated beam-on time

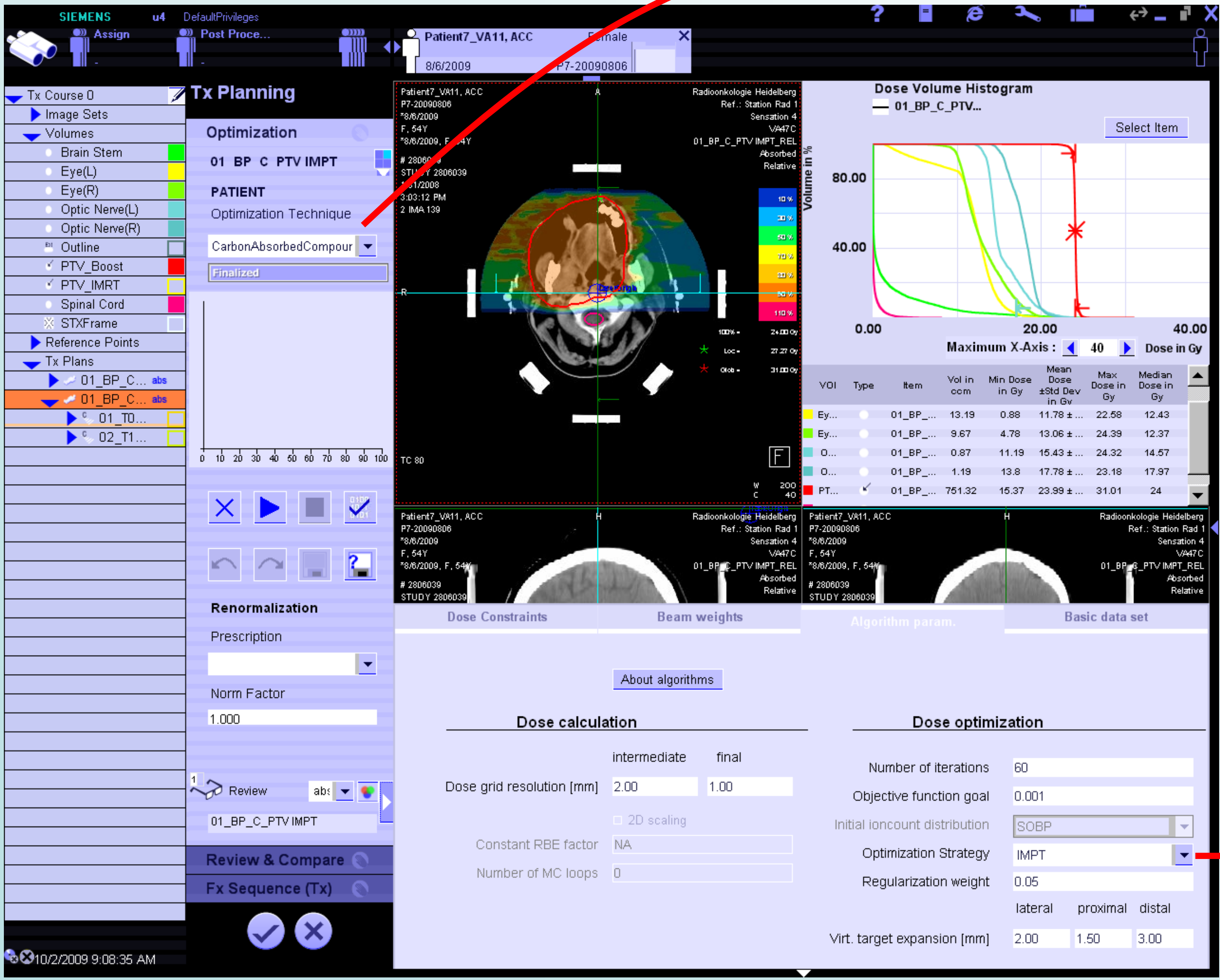
if possible

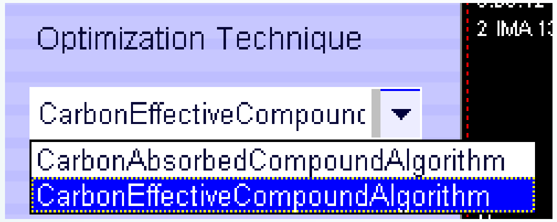
- Lateral heterogeneity measures
- Position & range variations to access plan robustness
  - Efficient summaries, e.g. worst case min./max. dose for all systematic shifts/rots
  - Still access to single events/effects

Further concepts?

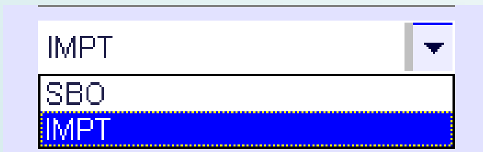
IMPT at HIT

syngo PT Planning (Siemens)





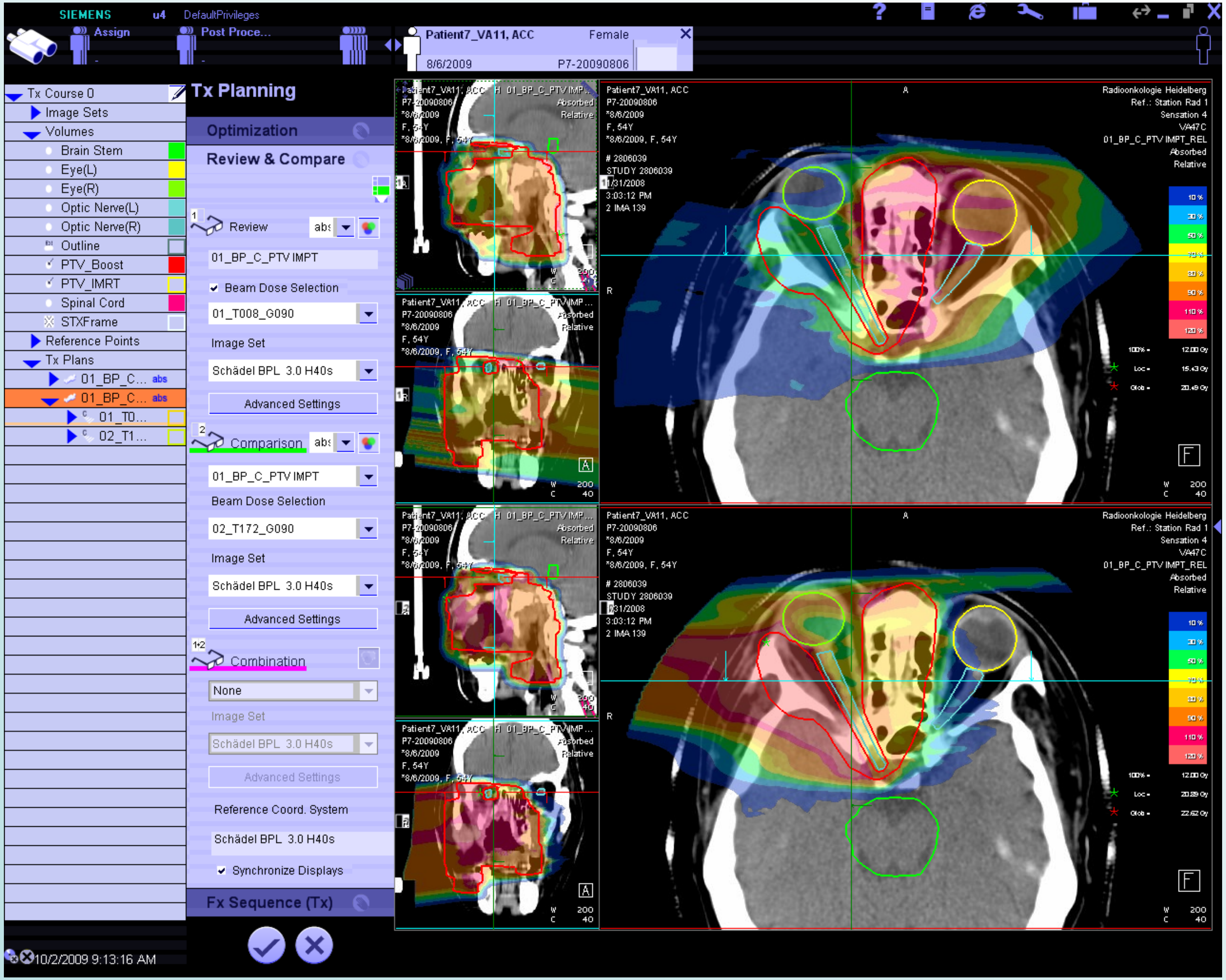
Optimization Strategy



IMPT for all ion species: p, 12C, …

IMPT evaluation at HIT (1)

Beam Dose Selection

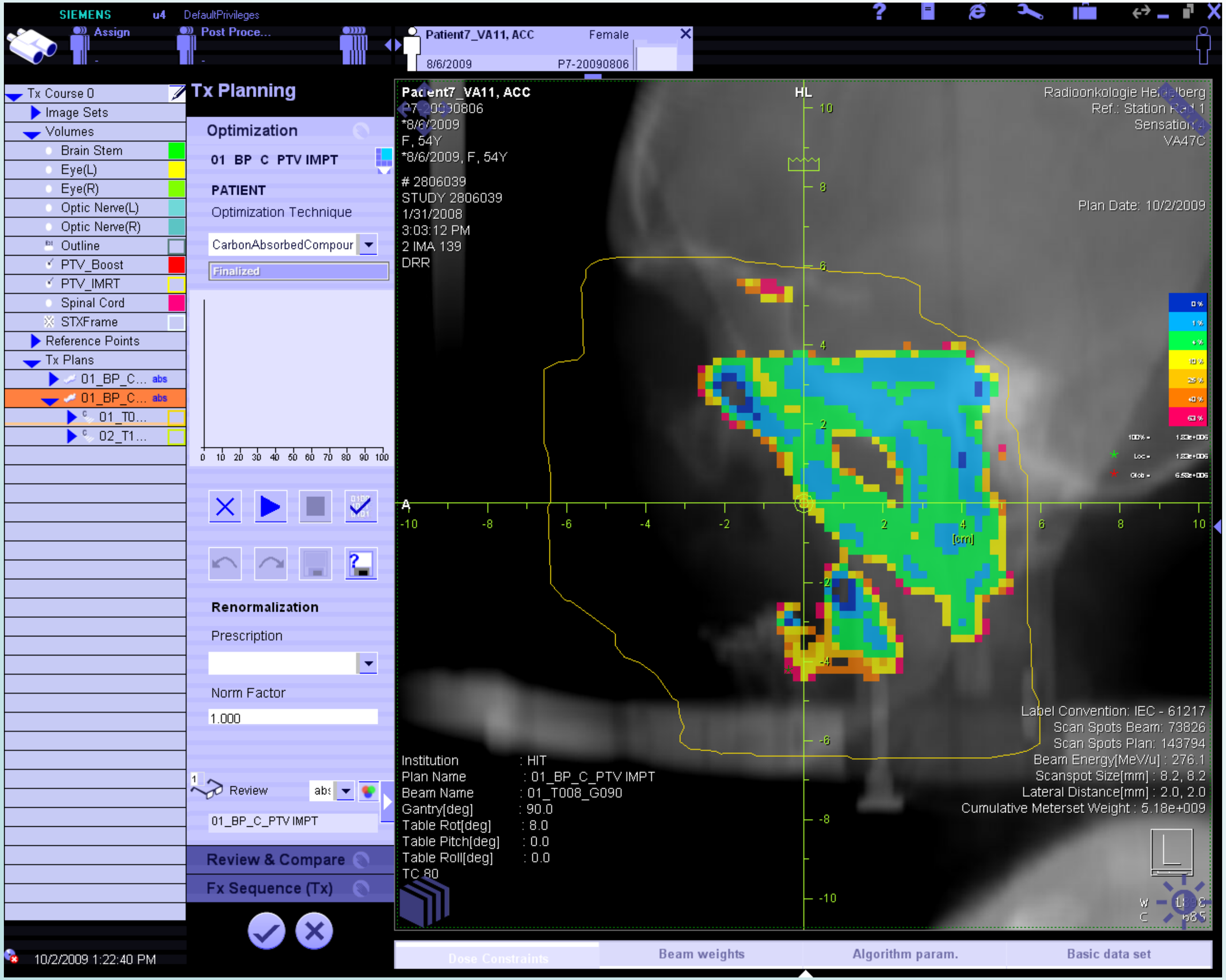


Field 1 (T=8°)

Field 2 (T=172°)

IMPT evaluation at HIT (2)

Beam Spot Distribution in BEV with underlaying DRR

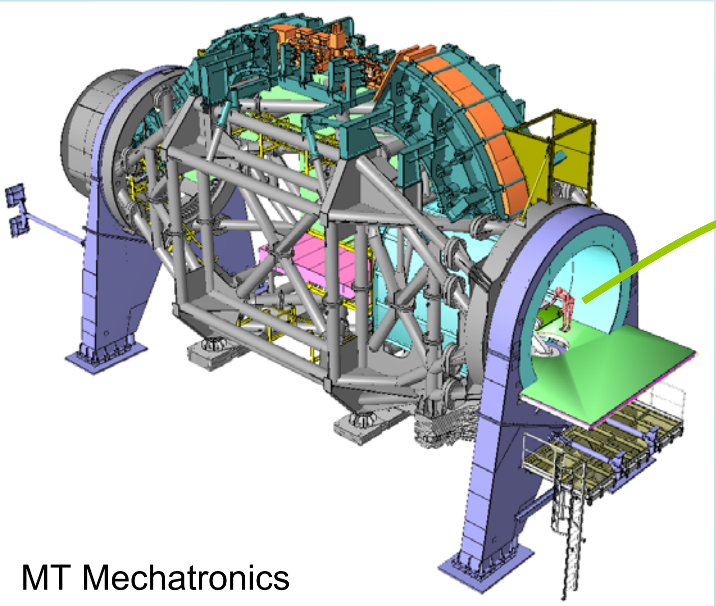


- Further analysis offline on scientific data platform (also for SBO!):
  e.g. **TRiP** to evaluate plan robustness concerning position and range uncertainties

IMPT – do we need a gantry?

Compare gantry with G=0° and/or G=45° fixed beams, in addition to G=90° horizontal fixed beam

- Question of gantry or not gantry is independent of IMPT/SBO
  - Beam angle selection is important and powerful
    GSI experience: Sometimes even 5° make a big difference
  - My opinion: Already convincing results with fixed beams,
    however, a gantry plan will do even better!
  - Finally: Judge by clinical results…



MT Mechatronics

Conclusion

IMPT with Carbon Ions

- Is very similar to proton IMPT – except for biology

IMPT

- Is in many aspects similar to SBO
- Improves the dose shaping
- Offers many flavours (degeneracy)
  - Moderate/strong dose modulation of complementing fields
  - Dependence on starting conditions
- Can influence the plan robustness
  - Position and range uncertainties
  - Beam application time
- Requires some attention

… and is a lot of fun!

Thank you for your attention!