# *High performance computing enabled proton optimization*

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# *High performance computing enabled proton optimization*

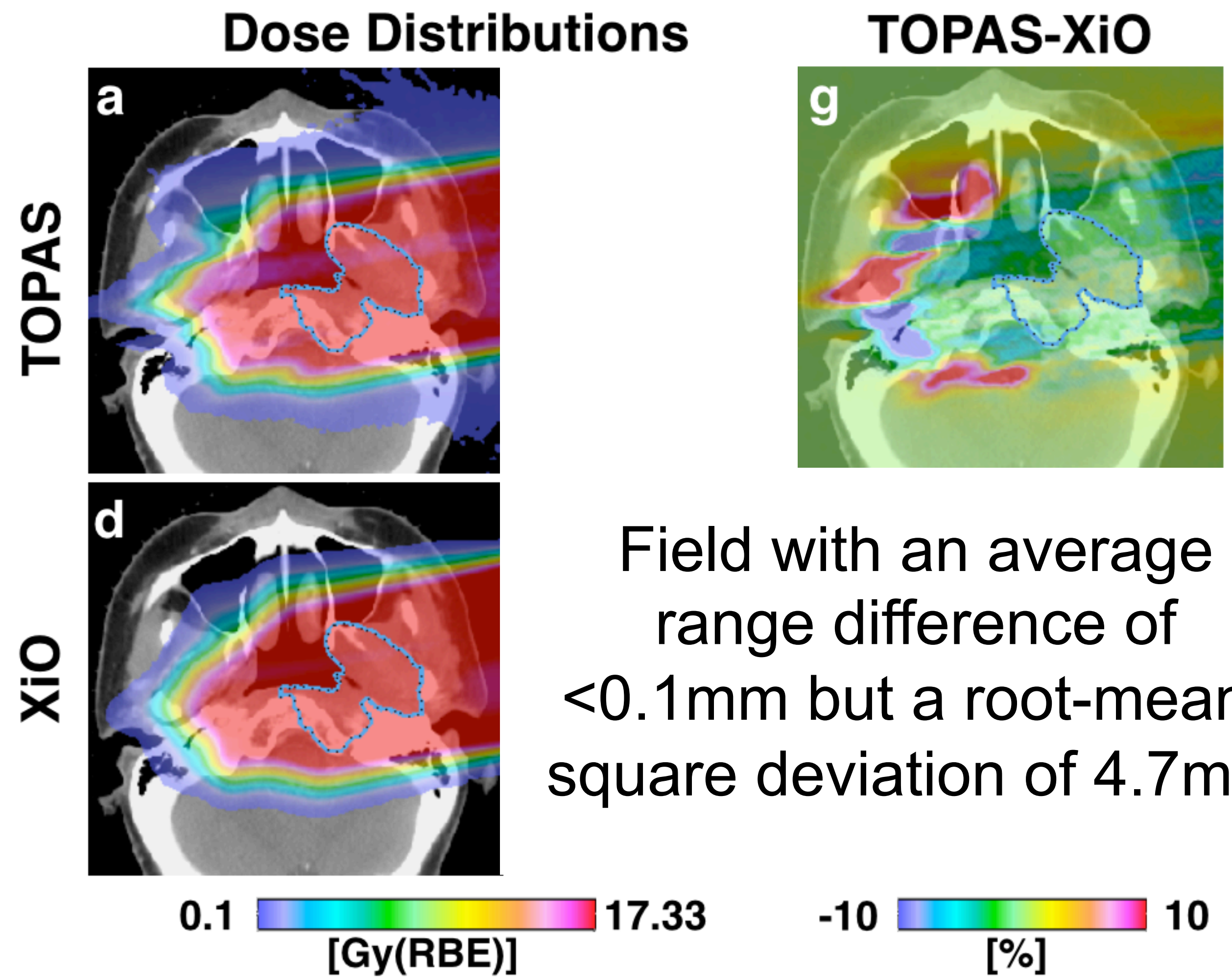
- Why is high performance computing more significant in proton therapy as compared to photon therapy?

Examples:

- 4D planning
- Robust optimization
- Biological optimization

Why is high performance computing more significant in proton therapy as compared to photon therapy?

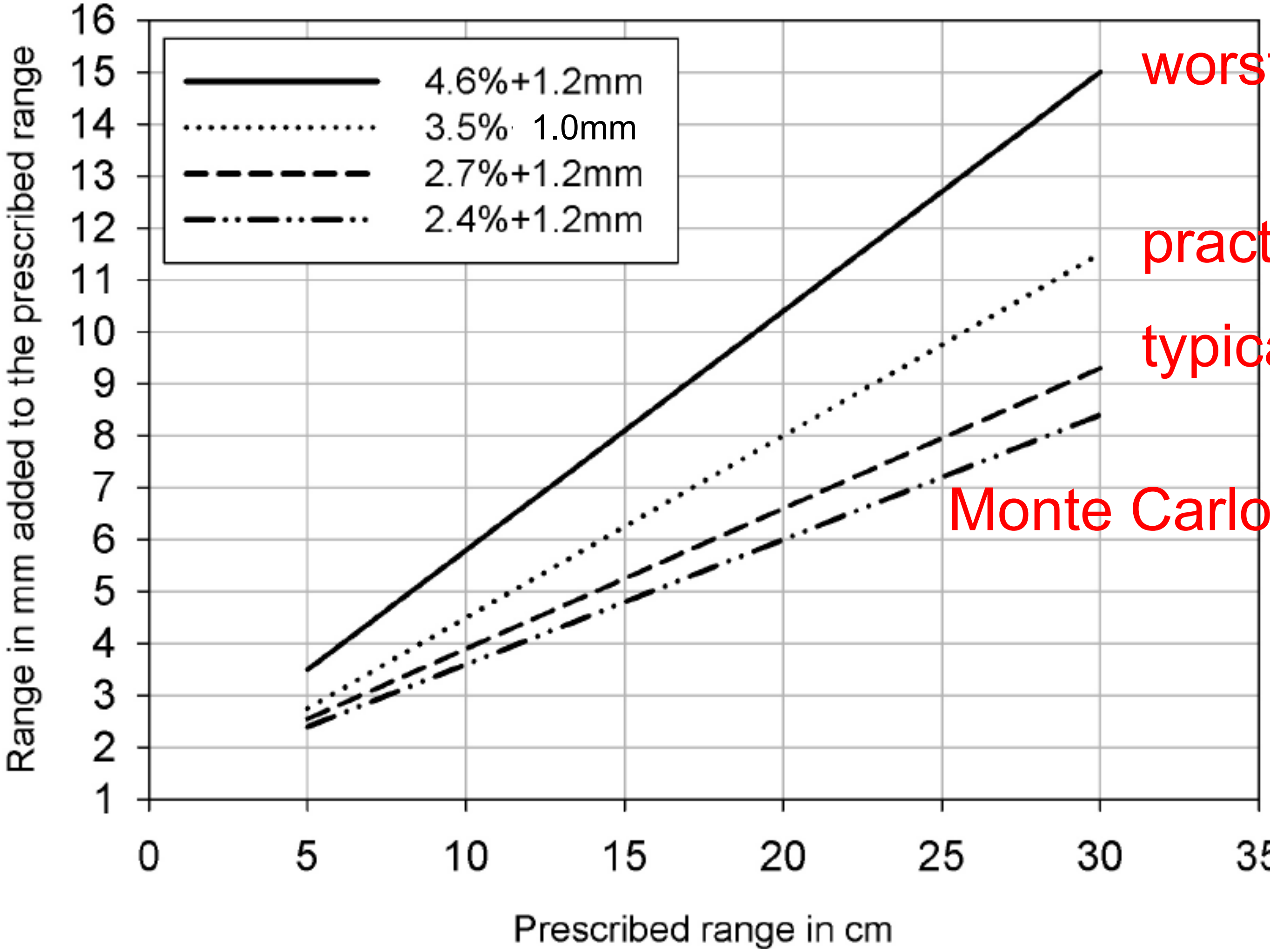
# Dose calculation uncertainties in proton therapy

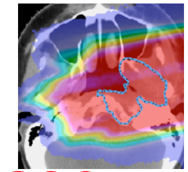



Field with an average range difference of <0.1mm but a root-mean-square deviation of 4.7mm

Schuemann J et al. Phys. Med. Biol. 2014

# Dose calculation uncertainties in proton therapy



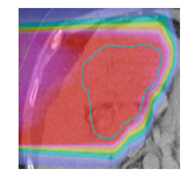



worst case

practice

typical case

Monte Carlo



H. Paganetti: Phys. Med. Biol. 57: R99-R117 (2012)

# Monte Carlo tools in proton therapy

# Monte Carlo tools in proton therapy

The TOPAS Monte Carlo system (for proton therapy) is distributed by non-profit **TOPAS MC Inc.**

## topasmc.org

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TOPAS

Welcome to TOPAS MC Inc., a non-profit organization created to support and extend the TOPAS Tool for Particle Simulation.

Geant 4
Proud user of the Geant4 Simulation Toolkit

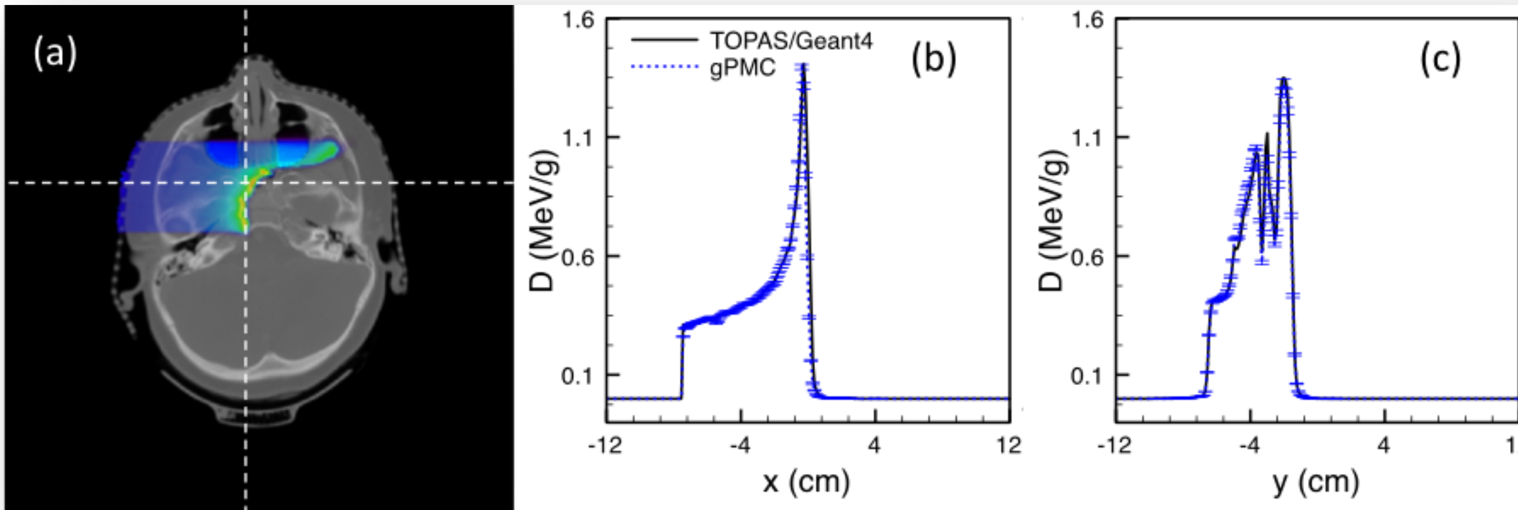
TOPAS wraps and extends the Geant4 Simulation Toolkit to make advanced Monte Carlo simulation of all forms of radiotherapy easier to use for medical physicists. TOPAS can model x-ray and particle therapy treatment heads, model a patient geometry based on CT images, score dose, fluence, etc., save and replay a phase space, provides advanced graphics, and is fully four-dimensional (4D) to handle variations in beam delivery and patient geometry during treatment. TOPAS users configure pre-built components (such as nozzles, patient geometry, dosimetry and imaging components) to simulate a wide

# Monte Carlo tools in proton therapy

**gPMC**

UT SOUTHWESTERN MEDICAL CENTER

MGH 1811




| | Source Energy (MeV) | <σ/D> (%) | $P_\gamma$ (1mm/1%)(%) | $P_\gamma$ (2mm/2%)(%) | T (sec) |
|---|---|---|---|---|---|
| Inhomogeneous phantom | 100 | 0.9 | 99.9 | 99.9 | 9.44 |
| Patient | 100 | 1.0 | 95.1 | 99.9 | 10.08 |

Jia X; Schuemann J; Paganetti H and Jiang SB: GPU-based fast Monte Carlo dose calculation for proton therapy. Physics in Medicine and Biology 2012 57: 7783-7798

# 4D planning

# 4D treatment assessment using 4D-MC

Treatment planning (ASTROID)

↓

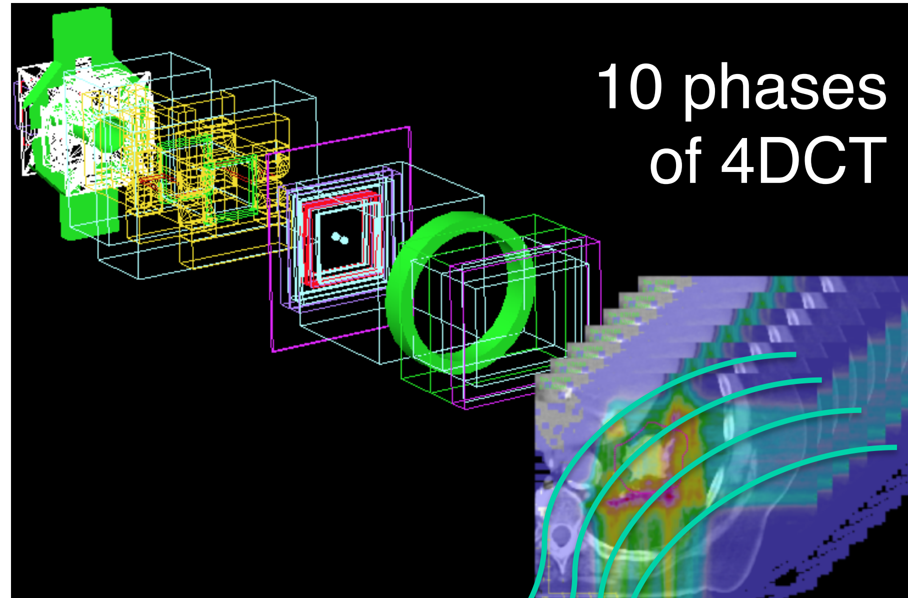
MC on 10 4DCT phases sorting beam spots according to the delivery time structure

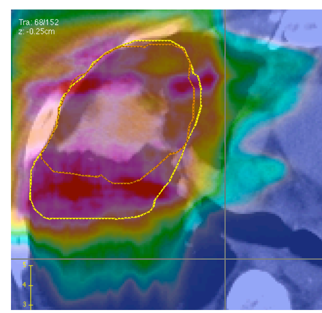
↓

plastimatch

↓

Dose distribution on reference phase (4D)

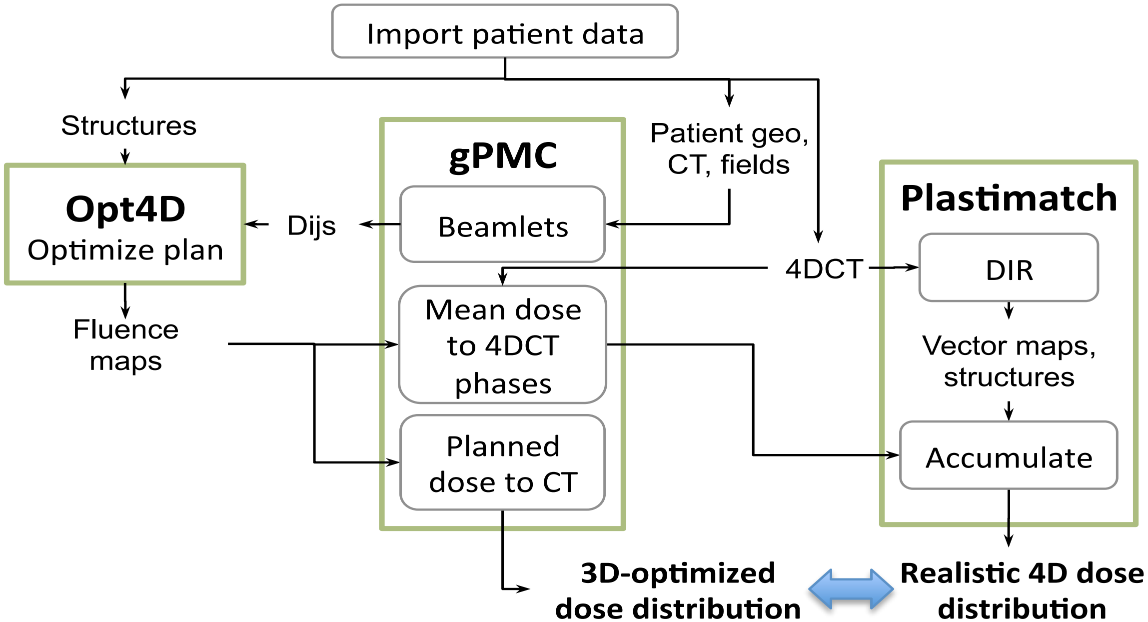


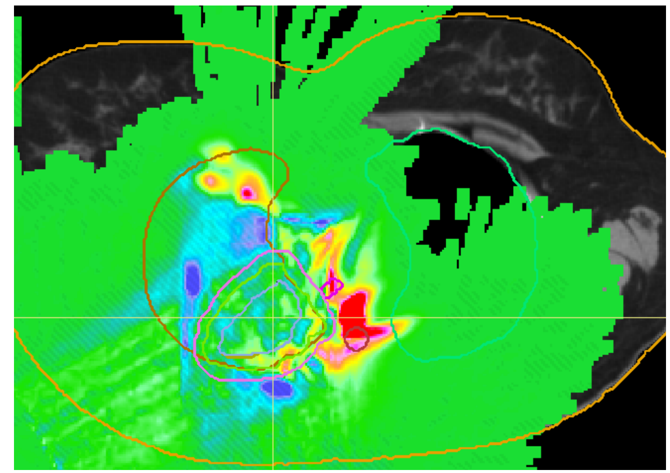
transform the resulting 10 dose distributions back to a reference phase ($T_{50}$)

Grassberger; Dowdell; Shackleford; Sharp; Choi; Willers; Paganetti: Motion interplay as a function of patient parameters and spot size in spot scanning proton therapy for lung cancer. International Journal of Radiation Oncology, Biology, Physics 2013 86: 380-386

# 4D treatment assessment using 4D-MC




Framework flow chart showing the optimization engine (Opt4D), the GPU MC code (gPMC) and the DIR code (Plastimatch).



Example of the dose difference of the static plan and the 4D simulation.

# 4D treatment assessment using 4D-MC

**Performance**

4D plan simulation with GPU MC:

~ 5 minutes

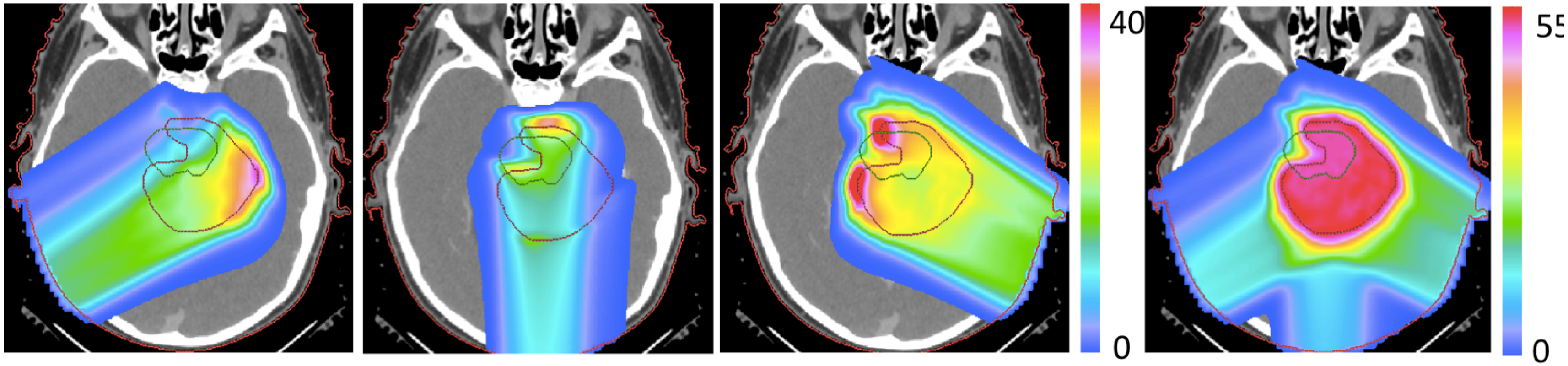
Total process, including DIR of the 4DCT phases to the reference phase:

~10 minutes

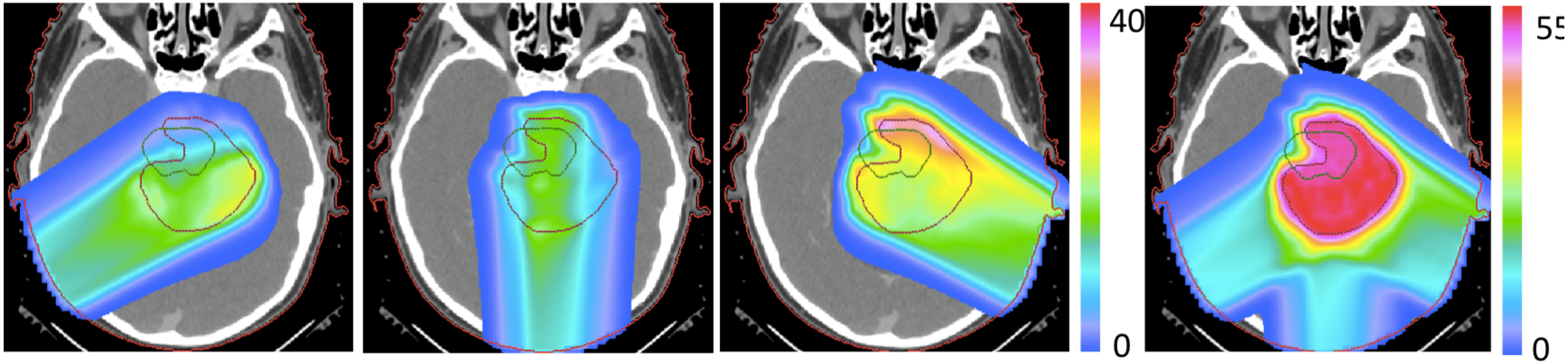
Per patient on one GPU (NVIDIA Tesla K40C)

# Robust optimization

# Robust optimization




(a) conventional IMPT plan




(b) robustly optimized IMPT plan

# Robust optimization

Efficiency considerations:

Assuming field with 1000 spots per field.
Assuming $10^6$ particles per spot:

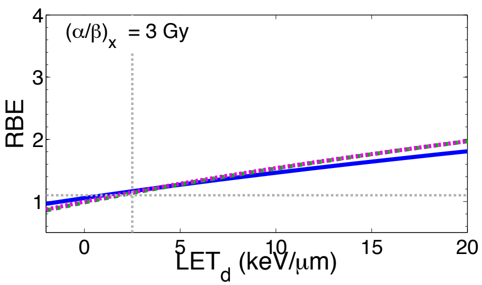
- 1st spot: 15 sec. (includes loading of CT)
- subsequent spots: 2 sec.

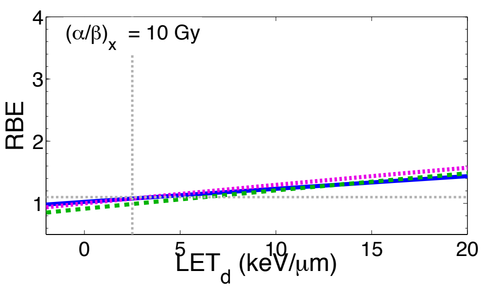
Field: ~30 min. times number of error scenarios

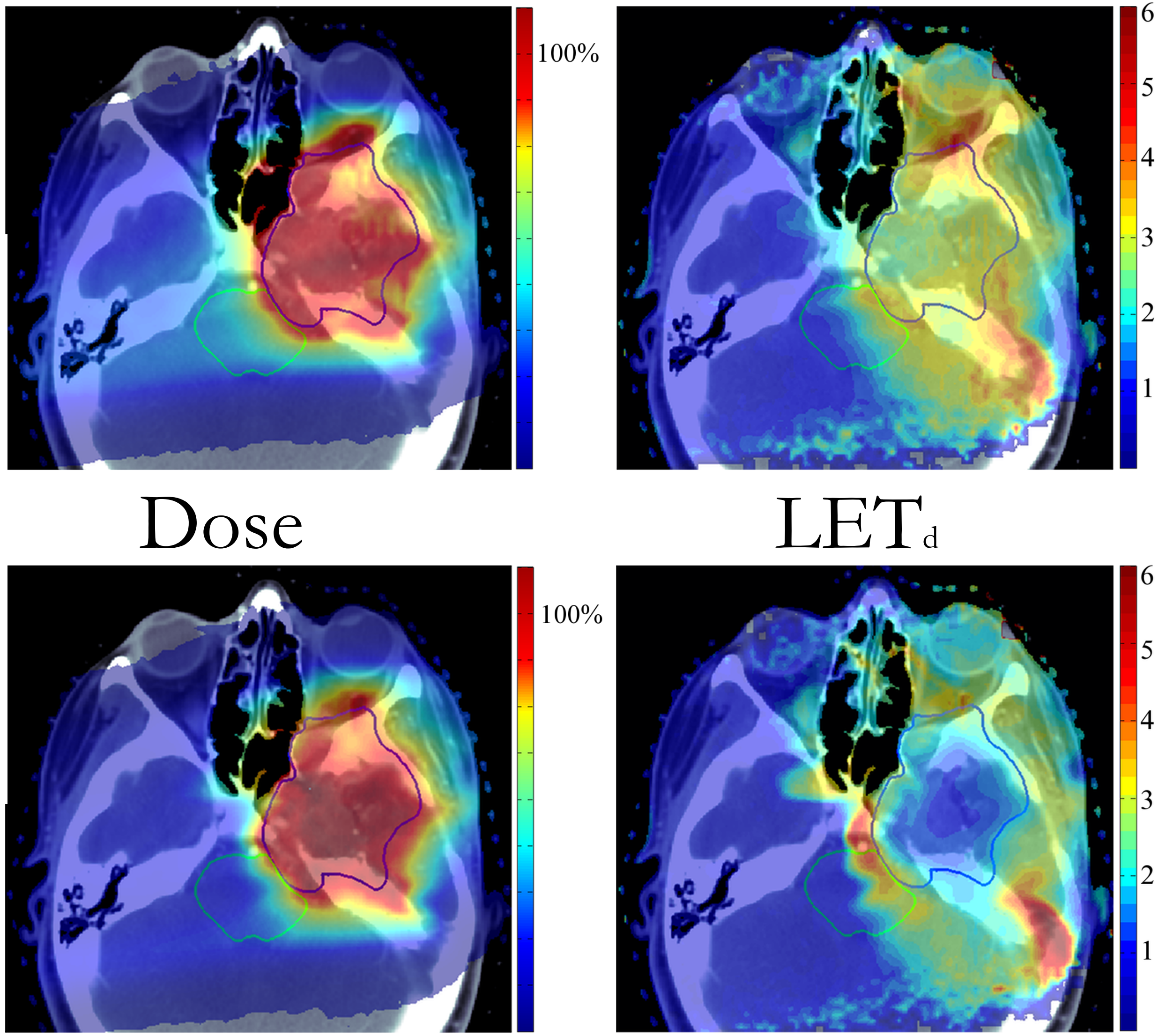
# Biological optimization

# Biological optimization

PLAN 1




PLAN 2

Grassberger C. et al. Int J Radiat Oncol Biol Phys 2011 80: 1559-1566

# Efficiency considerations:

Assuming field with 1000 spots per field.
Assuming $10^6$ particles per spot:

- 1st spot: 15 sec. (includes loading of CT)
- subsequent spots: 2 sec.

Field: ~30 min. (includes dose and LET)

# Conclusions

- Monte Carlo dose calculation techniques have a potential larger clinical impact in proton therapy than in photon therapy.

- Monte Carlo calculations are needed for

- Accurate dose calculation for planning and treatment assessment
- Studying patient specific four-dimensional treatment planning
- Accurate robust optimization strategies
- Biological treatment optimization